pybdsim Documentation

Release 3.1.0

Royal Holloway

Apr 02, 2023

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pybdsim is a Python package to aid in the preparation, running and validation of BDSIM models.

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AUTHORSHIP

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CHAPTER

THREE

INSTALLATION

pybdsim is developed for Python 3. The developers use 3.8 to 3.11. It can be install through pip (with internet access):

```
pip install pybdsim
```

There are the following features that result in more dependencies being installed:

- *uproot* - includes uproot data loading
- *boost_histogram* - includes boost-histogram package for 4d histograms
- *cpymad* - allows usage of cpymad for converting models
- *pysad* - allows usage of pysad for converting models

These can be installed as:

```
pip install pybdsim[uproot]
```

or:

```
pip install pybdsim[uproot,boost_histogram,cpymad,pysad]
```

3.1 Requirements

ROOT and its python interface are required to load BDSIM output and also histogram files from rebdsim (the analysis tool). This cannot be found through pip but must be separately installed.

Note: When installing ROOT, make sure that ROOT is installed with the same python interpreter you intend to use the package through. Most systems have more than one Python.

Generally, the requirements for pybdsim are

- matplotlib >= 3.0
- numpy >= 1.14
- scipy
- fortranformat
- pymadx
- pymad8
- pytransport

These are all available through pip and will be automatically installed.

Optional:

- ROOT Python interface

3.2 Local Installation

Although on pip, for development purposes you may wish to use pybdsim from a copy of the source code. It is possible to clone the git repository and use pip to *point* at the local set of files, or generally install that set of files as a once off.

We have provided a simple Makefile in the main pybdsim directory that has a small set of ‘rules’ that should help with the relevant pip commands. pip is used even though pybdsim is found from the local set of files.

To install pybdsim, simply run `make install` from the root pybdsim directory.:

```
cd /my/path/to/repositories/
git clone http://bitbucket.org/jairhul/pybdsim
cd pybdsim
make install
```

Alternatively, run `make develop` from the same directory to ensure that any local changes are picked up.

CHAPTER

FOUR

BUILDING MODELS

pybdsim provides a series of classes that allows a BDSIM model to be built programmatically in Python and finally written out to BDSIM input syntax (‘gmad’).

4.1 Creating A Model

The `Machine` class provides the functionality to create a BDSIM model.

```
>>> a = pybdsim.Builder.Machine()
```

First, we construct an instance of the Machine class, then call various functions to add components to the beam line. As each one is added, it is appended to the sequence. There is one function for each beam line element in BDSIM. Each of these functions begins with “Add”. e.g.

```
>>> a.AddDrift("d1", length=0.1)
```

Each function has a different set of arguments depending on what is required for that element. (e.g. “k1” is required for a quadrupole). Every function takes a set of keyword arguments (‘kwargs’ - see *kwargs - Flexibility*) that will be added to the definition:

```
>>> a.AddDrift("d2", length=1.2, aper1=0.3, aper2=0.4, apertureType="rectangular")
```

No checking is done on these parameters and they are simply written out.

Extra definition objects (e.g. a field map definition) can be constructed and added to the machine so that they are written out with it.

```
>>> fm1 = pybdsim.Builder.Field("f1", magneticFile="../maps/QNL.dat")
>>> a.AddObject(fm1)
```

The arguments can generally be found by using a question mark on a function.:

```
>>> a.AddDrift?
Signature: a.AddDrift(name='dr', length=0.1, **kwargs)
Docstring: Add a drift to the beam line
File:      ~/physics/reps/pybdsim/Builder.py
Type:      instancemethod
```

4.2 Adding Options

No options are required to run the most basic BDSIM model. However, it is often advantageous to specify at least a few options such as the physics list and default aperture. To add options programmatically, there is an options class. This is instantiated and then 'setter' methods are used to set values of parameters. This options instance can then be associated with a machine instance. For example:

```
>>> o = pybdsim.Options.Options()
>>> o.SetPhysicsList('em hadronic decay muon hadronic_elastic')

>>> a = pybdsim.Builder.Machine()
>>> a.AddOptions(o)
```

The possible options can be seen by using tab complete in ipython:

```
>>> a.Set<tab>
```

Note: Only the most common options are currently implement. Please see *Feature Request* to request others.

4.3 Adding a Beam

A beam definition that specifies at least the particle type and total energy is required to run a BDSIM model. The machine class will provide a default such that the model will run 'out of the box', but is of course of interest to specify these options. To add a beam definition, there is a beam class. This is instantiated and then 'setter' methods are used to set values of parameters. this beam instance can then be associated with a machine instance. For example:

```
>>> b = pybdsim.Beam.Beam()
>>> b.SetDistributionType('reference')
>>> b.SetEnergy(25, 'GeV')
>>> b.SetParticleType('proton')

>>> a = pybdsim.Builder.Machine()
>>> a.AddBeam(b)
```

Note: More setter functions will dynamically appear based on the distribution type set.

4.4 Writing a Machine

Once completed, a machine can be written out to gmad files to be used as input for BDSIM. This is done as follows:

```
>>> a = pybdsim.Builder.Machine()
>>> a.Write('outputfilename')
```

4.5 Units

The user may supply units as strings that will be written to the gmad syntax as a Python tuple. For example:

```
>>> a = pybdsim.Builder.Machine()
>>> a.AddDrift('d1', (3.2, 'm'))
```

This will result in the following gmad syntax:

```
>>> print a[0]
d1: drift, l=3.2*m;
```

Note: There is no checking on the string supplied, so it is the users responsibility to supply a valid unit string that BDSIM will accept.

4.6 kwargs - Flexibility

'kwargs' are optional keyword arguments in Python. This allows the user to supply arbitrary options to a function that can be inspected inside the function as a dictionary. BDSIM gmad syntax to define an element generally follows the pattern:

```
name : type, parameter1=value, parameter2=value;
```

Many parameters can be added and this syntax is regularly extended. It would therefore be impractical to have every function with all the possible arguments. To solve this problem, the `**kwargs` argument allows the user to specify any option that will be passed along and written to file in the element definition as 'key=value'. For example:

```
>>> a = pybdsim.Builder.Machine()
>>> a.AddDrift('drift321', 3.2, aper1=5, aper2=4.5, apertureType="rectangular")
```

This will result in the following gmad syntax being written:

```
>>> print a[0]
drift321: drift, apertureType="rectangular", aper2=4.5, aper1=5, l=3.2;
```

Anywhere you see a function with the last argument as `**kwargs`, this feature can be used.

The arguments included in the function signatures are the minimum arguments required for functionality.

CHAPTER

FIVE

CONVERTING MODELS

pybdsim provdies converters to allow BDSIM models to prepared from optical descriptions of accelerators in other formats such as MADX and MAD8.

The following converters are provided and described here:

- MADX to BDSIM
  - *MadxTfs2Gmad*
  - *MadxTfs2GmadStrength*
- MAD8 to BDSIM
  - *Mad8Twiss2Gmad (using saved TWISS output)*
- Transport to BDSIM
  - *pytransport*
- BDSIM Primary Particle Conversion
  - *BDSIM Primaries To Others*

5.1 MadxTfs2Gmad

A MADX lattice can be easily converted to a BDSIM gmad input file using the supplied python utilities. This is achieved by

1. preparing a tfs file with madx containing all twiss table information
2. converting the tfs file to gmad using pybdsim

5.1.1 Preparing a Tfs File

The twiss file can be prepared by appending the following MADX syntax to the end of your MADX script:

```
select,flag=twiss, clear;
twiss,sequence=SEQUENCENAME, file=twiss.tfs;
```

where *SEQUENCENAME* is the name of the sequence in madx. By not specifying the output columns, a very large file is produced containing all possible columns. This is required to successfully convert the lattice. If the tfs file contains insufficient information, pybdsim will not be able to convert the model.

Note: The python utilities require "*.tfs*" suffix as the file type to work properly.

5.1.2 Converting the Tfs File

Once prepared, the Tfs file can be converted. The converter is used as follows:

```
>>> pybdsim.Convert.MadxTfs2Gmad('inputfile.tfs', 'latticev1')
```

The conversion returns three objects, which are the `pybdsim.Builder.Machine` instance as converted, a second *Machine* that isn't split by aperture and a list of any ommitted items by name.

```
>>> a,b,c = pybdsim.Convert.MadxTfs2Gmad('inputfile.tfs', 'latticev1')
```

where *latticev1* is the output name of the converted model. The converter has the ability to split items in the original TFS file if an aperture is specified somewhere inside that element - use for disjoint aperture definitions. If a directory is used in the output name, this will be created automatically, for example:

```
>>> a,o = pybdsim.Convert.MadxTfs2Gmad('inputfile.tfs', 'test/latticev1')
```

will create a directory *test* if it doesn't exist already.

There are a few options that provide useful functionality for conversion:

tfs	path to the input tfs file or pymadx.Data.Tfs instance
outputfilename	requested output file
startname	the name (exact string match) of the lattice element to start the machine at this can also be an integer index of the element sequence number in madx tfs.
stopname	the name (exact string match) of the lattice element to stop the machine at this can also be an integer index of the element sequence number in madx tfs.
stepsize	the slice step size. Default is 1, but -1 also useful for reversed line.
ignorezerolengthitems	nothing can be zero length in bdsim as real objects of course have some finite size. Markers, etc are acceptable but for large lattices this can slow things down. True allows to ignore these altogether, which doesn't affect the length of the machine.
samplers	can specify where to set samplers - options are None, 'all', or a list of names of elements (normal python list of strings). Note default 'all' will generate separate outputfilename_samplers.gmad with all the samplers which will be included in the main .gmad file - you can comment out the include to therefore exclude all samplers and retain the samplers file.
aperturedict	Aperture information. Can either be a dictionary of dictionaries with the the first key the exact name of the element and the daughter dictionary containing the relevant bdsim parameters as keys (must be valid bdsim syntax). Alternatively, this can be a pymadx.Aperture instance that will be queried.
aperlocalpositions	Dictionary of element indices to a list of pairs of the form (local_point, aperdict), for example (0.1, {"APER1": "CIRCULAR", "APER1": 0.4}). This kwarg is mutually exclusive with "aperturedict".
collimatordict	A dictionary of dictionaries with collimator information keys should be exact string match of element name in tfs file value should be dictionary with the following keys: "bdsim_material" - the material "angle" - rotation angle of collimator in radians "xsize" - x full width in metres "ysize" - y full width in metres
userdict	A python dictionary the user can supply with any additional information for that particular element. The dictionary should have keys matching the exact element name in the Tfs file and contain a dictionary itself with key, value pairs of parameters and values to be added to that particular element.
verbose	Print out lots of information when building the model.
beam	True | False - generate an input gauss Twiss beam based on the values of the twiss parameters at the beginning of the lattice (startname) NOTE - we thoroughly recommend checking these parameters and this functionality is only for partial convenience to have a model that works straight away.
flipmagnets	True | False - flip the sign of all k values for magnets - MADX currently tracks particles agnostic of the particle charge - BDSIM however, follows the definition strictly - positive k -> horizontal focussing for positive particles therefore, positive k -> vertical focussing for negative particles. Use this flag to flip the sign of all magnets.
usemadxaperture	True | False - use the aperture information in the TFS file if APER_1 and APER_2 columns exist. Will only set if they're non-zero. Supercedes kwargs *aperturedict* and *aperlocalpositions*.
defaultAperture	The default aperture model to assume if none is specified.
biases	Optional list of bias objects to be defined in own _bias.gmad file. These can then be attached either with allelementdict for all components or userdict for individual ones.
allelementdict	Dictionary of parameter/value pairs to be written to all components.
optionsDict	Optional dictionary of general options to be written to the bdsim model options.
linear	Only linear optical components
overwrite	Do not append an integer to the base file name if it already exists. Instead overwrite the files.
allNamesUnique	Treat every row in the TFS file/instance as a unique element. This makes it easier to edit individual components as they are guaranteed to appear only once in the entire resulting GMAD lattice.

The user may convert only part of the input model by specifying *startname* and *stopname*.

Generally speaking, extra information can be folded into the conversion via a user supplied dictionary with extra parameters for a particular element by name. For a given element, for example 'drift123', extra parameters can be speficied in a dictionary. This leads to a dictionary of dictionaries being supplied. This is a relatively simple structure the user may prepare from their own input format and converters in Python. For example:

```
>>> drift123dict = {'aper1':0.03, 'aper2':0.05, 'apertureType':'rectangular'}
>>> quaddict = {'magnetGeometryType':'polesfacetcrop}
>>> d = {'drift123':drift123dict, 'qf1x':quaddict}
>>> a,o = pybdsim.Convert.MadxTfs2Gmad('inputfile.tfs', 'latticev1', userdict=d)
```

5.1.3 Notes

1) The name must match the name given in the MADX file exactly.
2) Specific arguments may be given for aperture (*aperturedict*), or for collimation (*collimatordict*), which are used specifically for those purposes.
3) There are quite a few options and these are described in *pybdsim.Convert*.
4) The BDSIM-provided pymadx package is required for this conversion to work.
5) The converter will alter the names to remove forbidden characters in names in BDSIM such as '$' or '!'.

5.1.4 Preparation of a Small Section

For large accelerators, it is often required to model only a small part of the machine. We recommend generating a Tfs file for the full lattice by default and trimming as required. The pymadx.Data.Tfs class provides an easy interface for trimming lattices. The first argument to the pybdsim.Convert.MadxTfs2Gmad function can be either a string describing the file location or a pymadx.Data.Tfs instance. The following example trims a lattice to only the first 100 elements:

```
>>> a = pymadx.Data.Tfs("twiss_v5.2.tfs")
>>> b = a[:100]
>>> m,o = pybdsim.Convert.MadxTfs2Gmad(b, 'v5.2a')
```

5.2 MadxTfs2GmadStrength

This is a utility to prepare a strength file file from a Tfs file. The output gmad file may then be included in an existing BDSIM gmad model after the lattice definition which will update the strengths of all the magnets.

5.3 Mad8Twiss2Gmad (using saved TWISS output)

Note: This requires the https://bitbucket.org/jairhul/pymad8 package.

A MAD8 lattice can be easily converted to a BDSIM gmad input file using the supplied python utilities. This is achieved by

1. preparing twiss, envel, survey and structure tape files with mad8
2. echo variables in the mad8 job log (SIGPT, SIGT)
3. converting the tape files to gmad using pybdsim

5.3.1 Running mad8

The following variables need to be defined in the Mad8 job from a `BETA0`

```
EMITX     := 0.01e-6
EMITY     := 0.01e-6
BLENG     := 0.3e-3
ESPRD     := 0.1e-3
TALFX     := BETA0[alfx]
TALFY     := BETA0[alfy]
TBETX     := BETA0[betx]
TBETY     := BETA0[bety]
TGAMX     := (1+TALFX*TALFX)/TBETX
TGAMY     := (1+TALFY*TALFY)/TBETY
SIG11     := EMITX*TBETX
SIG21     := -EMITX*TALFX
SIG22     := EMITX*TGAMX
SIG33     := EMITY*TBETY
SIG43     := -EMITY*TALFY
SIG44     := EMITY*TGAMY
C21       := SIG21/SQRT(SIG11*SIG22)
C43       := SIG43/SQRT(SIG33*SIG44)
S0_I1.G1  : SIGMA0, SIGX=SQRT(SIG11), SIGPX=SQRT(SIG22), R21=C21, &
                    SIGY=SQRT(SIG33), SIGPY=SQRT(SIG44), R43=C43, &
                    SIGT=BLENG, SIGPT=ESPRD

VALUE, EMITX
VALUE, EMITY
VALUE, ESPRD
VALUE, BLENG
```

Creating the output files:

```
use, <latticename>
twiss, beta0=BETA0, save, tape=twiss_<latticename> , rtape=rmat_<latticename>
structure, filename=struct_<latticename>
envelope, sigma0=SIGMA0, save=envelope, tape=envel_<latticename>
```

Optionally the following files are required:

```
survey, tape=survey_<latticename>
```

Running mad8:

```
mad8s < <jobfilename> > <jobfilename>.log
```

5.3.2 Converting the Mad8 files

Two steps are required to create the model from the Mad8 files, first to create template files for the collimators and apertures from the Mad8, this is done by running the following commands

```
pybdsim.Convert.Mad8MakeCollimatorTemplate(<inputtwissfilename>,<collimatordbfilename>
↪)
pybdsim.Convert.Mad8MakeApertureTemplate(<inputtwissfilename>,<aperturedbfilename>)
```

Copy the <collimatordbfilename> to `collimator.dat` and <aperturedbfilename> to `apertures.dat` Once prepared, the Tape files can be converted. The converter is used as follows:

```
pybdsim.Convert.Mad8Twiss2Gmad(<inputtwissfilename>,<outputgamdfilename>)
```

5.4 pytransport

https://bitbucket.org/jairhul/pytransport is a separate utility to convert transport models into BDSIM ones.

5.5 BDSIM Primaries To Others

The particle coordinates recorded by BDSIM may be read from an output ROOT file and written to another format. This can be used for example to ensure the exact same coordinates are used in multiple BDSIM simulations, or to when comparing BDSIM to other tracking codes such as PTC. It can also be used for example to pass coordinates from one BDSIM simulation to another where a detailed simulation of a region of the machine may be desired without the need to simulate the preceding section of the machine.

For the conversion to PTC coordinate convension, it is assumed that PTC calculations are performed in 6D, and that the *TIME* flag in the *PTC_CREATE_LAYOUT* routine is false, meaning the fifth and sixth coordinates are $-pathlength$ and $\delta p = \frac{(p-p_0)}{p_0}$ respectively.

For all converters, a *start* number, *n* can be specified which converts from the nth particle onwards. The number of particles converted can be specified with the *ninrays* argument. For example, to convert particles 2 to 10 only, the arguments supplied would be `start=2, ninrays=9`.

5.5.1 BdsimPrimaries2Ptc

The primary BDSIM coordinates are converted to PTC format. The converter is used as follows:

```
>>> pybdsim.Convert.BdsimPrimaries2Ptc('output.root', 'inrays.dat')
```

5.5.2 BdsimSampler2Ptc

The BDSIM coordinates from a provided sampler name are converted to PTC format. The converter is used as follows:

```
>>> pybdsim.Convert.BdsimSampler2Ptc('output.root', 'inrays.dat','DR1')
```

This will convert the coordinates recorded in sampler *DR1*. Only the primary particles are converted.

5.5.3 BdsimPrimaries2BdsimUserFile

The primary BDSIM coordinates are converted to a BDSIM *userFile* format. The converter is used as follows:

```
>>> pybdsim.Convert.BdsimPrimaries2BdsimUserFile('output.root', 'inrays.dat')
```

5.5.4 BdsimSampler2BdsimUserFile

The BDSIM coordinates from a provided sampler name are converted to a BDSIM *userFile* format. The converter is used as follows:

```
>>> pybdsim.Convert.BdsimSampler2BdsimUserFile('output.root', 'inrays.dat','DR1')
```

The time coordinate recorded in the input file will be finite if the sampler being converted is not at the start of the machine. This function is intended to convert particles into a primary distribution, therefore the time coordinate must be centred around *t=0*. As the nominal time is not recorded, the mean time is subtracted from all particles. Note that at low particle numbers, statistical fluctuations may result in the mean time being significantly different from the nominal time.

5.5.5 BdsimPrimaries2Madx

The primary BDSIM coordinates are converted to madx format. The converter is used as follows:

```
>>> pybdsim.Convert.BdsimPrimaries2Madx('output.root', 'inrays.dat')
```

5.5.6 BdsimPrimaries2Mad8

The primary BDSIM coordinates are converted to mad8 format. The converter is used as follows:

```
>>> pybdsim.Convert.BdsimPrimaries2Mad8('output.root', 'inrays.dat')
```

CHAPTER

SIX

MODEL COMPARISON

Once a BDSIM model has been prepared from another model, it is of interest to validate it to ensure the model has been prepared correctly.

6.1 Preparing Optics with BDSIM

The BDSIM model should be run with a 'core' beam distribution - ie typically a Gaussian or Twiss Gaussian that will match the optics of the lattice. For a physics study one might use a halo, but this is unsuitable for optics validation.

To compare, a BDSIM model is run with samplers attached to each element. This records all of the particle coordinates at the end of each element. Once finished a separate program ('rebdsim') is used to calculate moments and optical functions from the distribution at each plane. This information can then be compared to an analytical description of the lattice such as that from MADX.

Note: It is important to open any apertures that are by design close to the beam such as collimators. A non-Gaussian distribution will affect the calculation of the optical parameters from the particle distribution.

6.1.1 Running BDSIM

We recommend the following settings:

- Collimators are opened to at least 6 sigma of the beam distribution at their location.
- The *stopSecondaries* and *stopTracks* options are turned on to prevents secondaries being simulated and recorded.
- The physics list is set to "" - an empty string. This leaves only magnetic field tracking so that if a particle does hit the accelerator it will pass through without scattering.
- Simulate between 1000 and 50000 particles (events).

Note: This procedure is only suited to comparing linear optical functions. If sextupoles or higher order magnets are present, these should be set to zero strength but must remain in the lattice. The pybdsim.Convert.MadxTfs2Gmad converter for example provides a boolean flag to convert the lattice with only linear optical components. The user may of course proceed with non-linear magnetic fields included but it is only useful to compare the sigma in each dimension to a similarly similuated distribution and not the Twiss parameters.

6.1.2 Analysing Optical Data

The *rebdsim* tool can be used with an input *analysisConfig.txt* that specifies *CalculateOpticalFunctions* to 1 or true in the header (see BDSIM manual). Or the specially prepared optics tool *rebdsimOptics* can be used to achieve the same outcome - we recommend this. In the terminal:

```
rebdsimOptics bdsimRawOutputFile.root optics.root
```

This may take a few minutes to process. This analyses the file from the BDSIM run called 'bdsimRawOutputFile.root' and produces another ROOT file called *optics.root* with a different structure. This output file contains only optical data.

6.2 Comparing to MADX

After preparing the optics from BDSIM, they may be compared to a MADX Tfs instance with the following command in Python (for example):

```
>>> pybdsim.Compare.MadxVsBDSIM('twiss_v5.2fs', 'optics.root')
```

This will produce a series of plots comparing the orbit, beam size, and linear optical functions.

The MADX twiss file (in tfs format) should contain all the possible columns in the Twiss Module table. This can be prepared in a similar way as we would do for converting to BDSIM GMAD syntax:

```
select,flag=twiss, clear;
twiss,sequence=SEQUENCENAME, file=twiss.tfs;
```

Note: The user should take care to ensure the emittance and energy spread (EX, EY, SIGE) are correctly specified in MADX for accurate comparison. The energy spread will contribute to the beam size in dispersive regions. The emittance will scale the beam size.

6.3 Comparing to MAD8

The comparison for MAD8 is exactly the same as MADX - please see above for further details. One difference is that both a TWISS and ENVELOPE file are required.:

```
>>> pybdsim.Compare.Mad8VsBDSIM('../mad8/TWISS_T4D', '../mad8/ENVEL_T4D', 'xfel_
↪optics.root')
```

6.4 Comparing to BDSIM

Two BDSIM optics files can also be compared with the following command:

```
>>> pybdsim.Compare.BDSIMVsBDSIM('optics1.root', 'optics2.root')
```

6.5 Comparing to PTC

BDSIM output can be compared to the PTC output from the PTC_TRACK routine available in MADX. The PTC output is written to a file typically named *trackone*, however it is necessary to convert this into a BDSIM-like ROOT output file. This can be easily accomplished with the *ptc2bdsim* tool, however the particle species and nominal momentum is required to correctly convert to the BDSIM coordinate convention. An example terminal command:

```
ptc2bdsim trackone ptc.root proton 0.9999
```

Once the ROOT file has been generated, the *rebdsimOptics* tool (see Analysing Optical Data) must be used to generate the ROOT file with the appropriate optical data. Finally, the two files can be compared with the following command:

```
>>> pybdsim.Compare.PTCVsBDSIM('ptc_optics.root', 'bdsim_optics.root')
```

6.6 Comparing to Transport

With the help of pytransport a TRANSPORT "FOR002" output file that has sigma matrices can be read and compared with BDSIM output:

```
>>> pybdsim.Compare.TransportVsBDSIM('FOR002.DAT', 'bdsim_optics.root')
```

CHAPTER SEVEN

DATA LOADING

Utilities to load BDSIM output data. This is intended for optical function plotting and small scale data extraction - not general analysis of BDSIM output.

7.1 Loading ROOT Data

pybdsim can load several different ROOT files produce by BDSIM, rebdsim, rebdsimCombine, bdskim, rebdsimOptics, rebdsimHistoMerge. In all cases, the same function is used but it may return a different pybdsim class representing the loaded data.

```
>>> d = pybdsim.Data.Load("mylovelyfile.root")
```

In the case of a *rebdsim* file, an instance of the pybdsim.Data.RebdsimFile class is returned (See *RebdsimFile*). In the case of a raw BDSIM output file, an instance of the BDSIM DataLoader analysis class is returned (even in Python).

Note: To load BDSIM raw data, the `<bdsim-install-dir>/bin/bdsim.sh` script must be sourced. This sets up environmental variables that ROOT requires to load our shared libraries in C++ with definitions of the layout of the files (i.e. the C++ classes). See also, *Manually Loading Raw Data* for a method to load the libraries yourself (normally automatic with `Load()`).

7.1.1 Load Just Histograms

It may be useful to load just the histograms on a computer with ROOT and pybdsim but without BDSIM and all the libraries. In this case, we can use the RebdsimFile class directly and flag that we should not try to load the BDSIM libraries. In this case, it can only interpret native ROOT objects such as histograms and not the other data in the file such as the beam line model (for plotting machine diagrams).

```
>>> import pybdsim
>>> d = pybdsim.Data.RebdsimFile("sample1.root", histogramsOnly=True)
>>> d.histogramspy
{'Event/PerEntryHistograms/PrimaryX': <pybdsim.Data.TH1 at 0x1549cef40>,
'Event/PerEntryHistograms/EventDuration': <pybdsim.Data.TH1 at 0x1549d1040>,
'Event/PerEntryHistograms/EnergySpectrum': <pybdsim.Data.TH1 at 0x1549e0df0>,
'Event/PerEntryHistograms/EnergyLossManual': <pybdsim.Data.TH1 at 0x15503adc0>,
'Event/PerEntryHistograms/TunnelLossManual': <pybdsim.Data.TH1 at 0x15503adf0>,
'Event/PerEntryHistograms/AperImpactXInRange': <pybdsim.Data.TH1 at 0x15503ae20>,
'Event/SimpleHistograms/PrimaryYSimple': <pybdsim.Data.TH1 at 0x15503ae50>,
'Event/MergedHistograms/PhitsHisto': <pybdsim.Data.TH1 at 0x15503ae80>,
'Event/MergedHistograms/PlossHisto': <pybdsim.Data.TH1 at 0x15503aeb0>,
'Event/MergedHistograms/ElossHisto': <pybdsim.Data.TH1 at 0x15503aee0>,
'Event/MergedHistograms/PhitsPEHisto': <pybdsim.Data.TH1 at 0x15503af10>,
```

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```
'Event/MergedHistograms/PlossPEHisto': <pybdsim.Data.TH1 at 0x15503af40>,
'Event/MergedHistograms/ElossPEHisto': <pybdsim.Data.TH1 at 0x15503af70>,
'Event/MergedHistograms/PFirstAIHisto': <pybdsim.Data.TH1 at 0x15503afa0>,
'Event/MergedHistograms/ElossTunnelHisto': <pybdsim.Data.TH1 at 0x15503afd0>,
'Event/MergedHistograms/ElossTunnelPEHisto': <pybdsim.Data.TH1 at 0x15503ad90>,
'Event/PerEntryHistograms/PrimaryXY': <pybdsim.Data.TH2 at 0x155043040>,
'Event/SimpleHistograms/PrimaryXYSimple': <pybdsim.Data.TH2 at 0x1550430a0>,
'Event/PerEntryHistograms/D2XYEnergy': <pybdsim.Data.TH3 at 0x1550430d0>}
```

7.2 Looping Over Raw ROOT Data

We can loop over the raw BDSIM data easily with pybdsim.

```
d = pybdsim.Data.Load("run1.root")
eventTree = d.GetEventTree()

for event in eventTree:
    # now we have event.<branchname>.<variable>
    print(event.Eloss.n)
```

We can also get an index with enumeration:

```
for i,event in eventTree:
    print(i, event.Eloss.n)
```

7.3 RebdsimFile

When a *rebdsim* output file is loaded, all histograms will be loaded into a dictionary with their path inside the root file (i.e. in various folders) as a key. All histograms are held in a member dictionary called *histograms*. Copies are also provided in *histograms1d*, *histograms2d* and *histograms3d*.

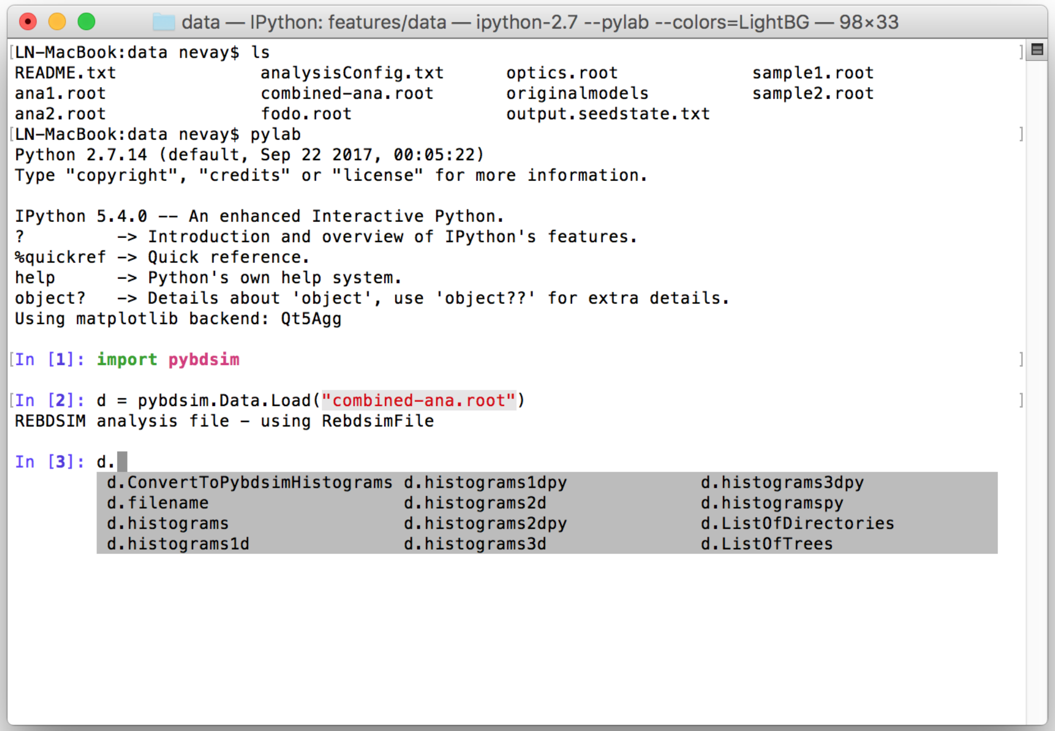
For convenience we provide wrappers for the raw ROOT histogram classes that provide easy access to the data in numpy format with simple matplotlib plotting called *pybdsim.Data.TH1*, *TH2* and *TH3*. Shown below is loading of the example output file *combined-ana.root* in *bdsim/examples/features/data*.

7.4 Histogram Plotting

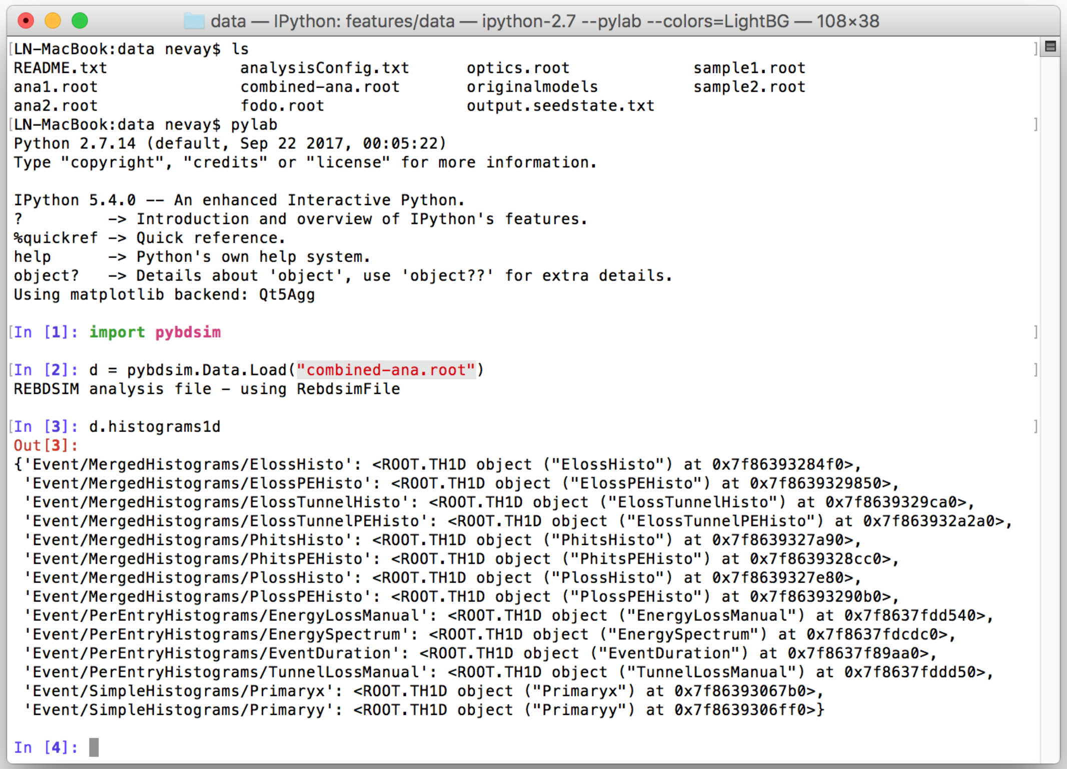
Loaded histograms that are wrapped in our pybdsim.Data.THX classes can be plotted:

```
>>> pybdsim.Plot.Histogram1D(d.histogramspy['Event/PerEntryHistograms/EnergyLossManual
→'])
```

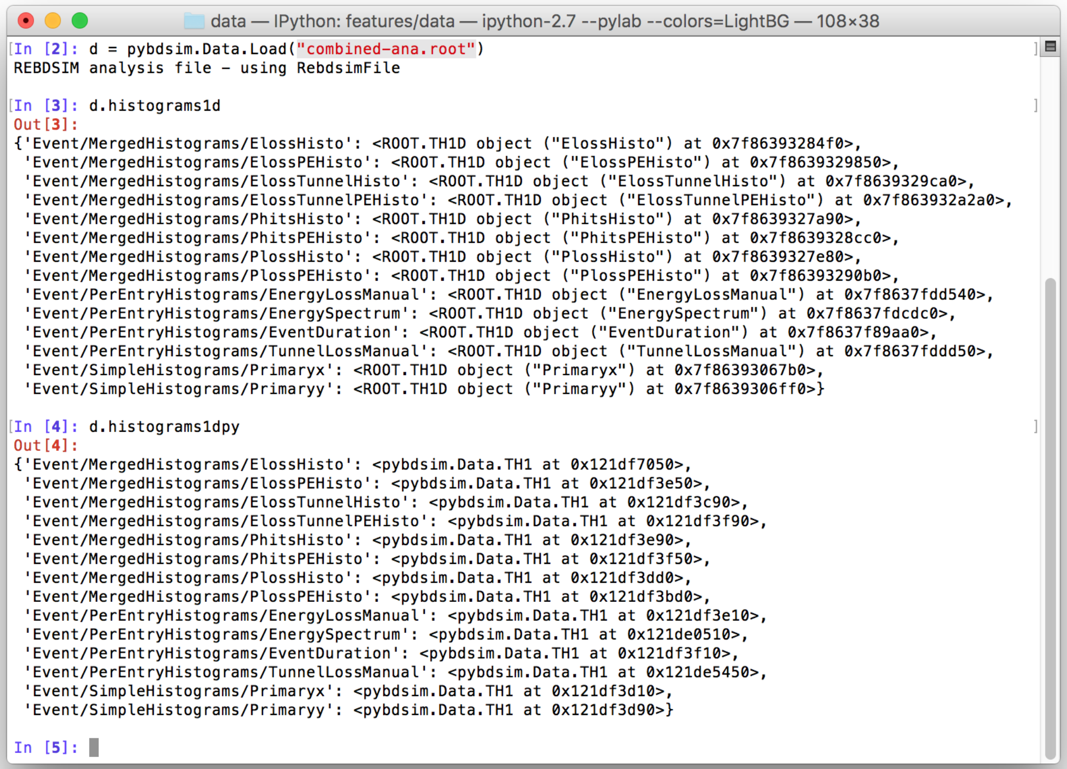
Note, the use of *d.histogramspy* for the wrapped set of histograms and not the raw ROOT histograms.


data — IPython: features/data — ipython-2.7 --pylab --colors=LightBG — 98×33

```
LN-MacBook:data nevay$ ls
README.txt              analysisConfig.txt      optics.root             sample1.root
ana1.root               combined-ana.root       originalmodels          sample2.root
ana2.root               fodo.root               output.seedstate.txt
LN-MacBook:data nevay$ pylab
Python 2.7.14 (default, Sep 22 2017, 00:05:22)
Type "copyright", "credits" or "license" for more information.

IPython 5.4.0 -- An enhanced Interactive Python.
?         -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help      -> Python's own help system.
object?   -> Details about 'object', use 'object??' for extra details.
Using matplotlib backend: Qt5Agg

In [1]: import pybdsim

In [2]: d = pybdsim.Data.Load("combined-ana.root")
REBDSIM analysis file - using RebdsimFile

In [3]: d.
         d.ConvertToPybdsimHistograms d.histograms1dpy            d.histograms3dpy
         d.filename                   d.histograms2d              d.histogramspy
         d.histograms                 d.histograms2dpy            d.ListOfDirectories
         d.histograms1d               d.histograms3d              d.ListOfTrees
```


data — IPython: features/data — ipython-2.7 --pylab --colors=LightBG — 108×38

```
LN-MacBook:data nevay$ ls
README.txt              analysisConfig.txt      optics.root             sample1.root
ana1.root               combined-ana.root       originalmodels          sample2.root
ana2.root               fodo.root               output.seedstate.txt
LN-MacBook:data nevay$ pylab
Python 2.7.14 (default, Sep 22 2017, 00:05:22)
Type "copyright", "credits" or "license" for more information.

IPython 5.4.0 -- An enhanced Interactive Python.
?         -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help      -> Python's own help system.
object?   -> Details about 'object', use 'object??' for extra details.
Using matplotlib backend: Qt5Agg

In [1]: import pybdsim

In [2]: d = pybdsim.Data.Load("combined-ana.root")
REBDSIM analysis file - using RebdsimFile

In [3]: d.histograms1d
Out[3]:
{'Event/MergedHistograms/ElossHisto': <ROOT.TH1D object ("ElossHisto") at 0x7f86393284f0>,
 'Event/MergedHistograms/ElossPEHisto': <ROOT.TH1D object ("ElossPEHisto") at 0x7f8639329850>,
 'Event/MergedHistograms/ElossTunnelHisto': <ROOT.TH1D object ("ElossTunnelHisto") at 0x7f8639329ca0>,
 'Event/MergedHistograms/ElossTunnelPEHisto': <ROOT.TH1D object ("ElossTunnelPEHisto") at 0x7f863932a2a0>,
 'Event/MergedHistograms/PhitsHisto': <ROOT.TH1D object ("PhitsHisto") at 0x7f8639327a90>,
 'Event/MergedHistograms/PhitsPEHisto': <ROOT.TH1D object ("PhitsPEHisto") at 0x7f8639328cc0>,
 'Event/MergedHistograms/PlossHisto': <ROOT.TH1D object ("PlossHisto") at 0x7f8639327e80>,
 'Event/MergedHistograms/PlossPEHisto': <ROOT.TH1D object ("PlossPEHisto") at 0x7f86393290b0>,
 'Event/PerEntryHistograms/EnergyLossManual': <ROOT.TH1D object ("EnergyLossManual") at 0x7f8637fdd540>,
 'Event/PerEntryHistograms/EnergySpectrum': <ROOT.TH1D object ("EnergySpectrum") at 0x7f8637fdcdc0>,
 'Event/PerEntryHistograms/EventDuration': <ROOT.TH1D object ("EventDuration") at 0x7f8637f89aa0>,
 'Event/PerEntryHistograms/TunnelLossManual': <ROOT.TH1D object ("TunnelLossManual") at 0x7f8637fddd50>,
 'Event/SimpleHistograms/Primaryx': <ROOT.TH1D object ("Primaryx") at 0x7f86393067b0>,
 'Event/SimpleHistograms/Primaryy': <ROOT.TH1D object ("Primaryy") at 0x7f8639306ff0>}

In [4]:
```


data — IPython: features/data — ipython-2.7 --pylab --colors=LightBG — 108×38

```
In [2]: d = pybdsim.Data.Load("combined-ana.root")
REBDSIM analysis file - using RebdsimFile

In [3]: d.histograms1d
Out[3]:
{'Event/MergedHistograms/ElossHisto': <ROOT.TH1D object ("ElossHisto") at 0x7f86393284f0>,
 'Event/MergedHistograms/ElossPEHisto': <ROOT.TH1D object ("ElossPEHisto") at 0x7f8639329850>,
 'Event/MergedHistograms/ElossTunnelHisto': <ROOT.TH1D object ("ElossTunnelHisto") at 0x7f8639329ca0>,
 'Event/MergedHistograms/ElossTunnelPEHisto': <ROOT.TH1D object ("ElossTunnelPEHisto") at 0x7f863932a2a0>,
 'Event/MergedHistograms/PhitsHisto': <ROOT.TH1D object ("PhitsHisto") at 0x7f8639327a90>,
 'Event/MergedHistograms/PhitsPEHisto': <ROOT.TH1D object ("PhitsPEHisto") at 0x7f8639328cc0>,
 'Event/MergedHistograms/PlossHisto': <ROOT.TH1D object ("PlossHisto") at 0x7f8639327e80>,
 'Event/MergedHistograms/PlossPEHisto': <ROOT.TH1D object ("PlossPEHisto") at 0x7f86393290b0>,
 'Event/PerEntryHistograms/EnergyLossManual': <ROOT.TH1D object ("EnergyLossManual") at 0x7f8637fdd540>,
 'Event/PerEntryHistograms/EnergySpectrum': <ROOT.TH1D object ("EnergySpectrum") at 0x7f8637fdcdc0>,
 'Event/PerEntryHistograms/EventDuration': <ROOT.TH1D object ("EventDuration") at 0x7f8637f89aa0>,
 'Event/PerEntryHistograms/TunnelLossManual': <ROOT.TH1D object ("TunnelLossManual") at 0x7f8637fddd50>,
 'Event/SimpleHistograms/Primaryx': <ROOT.TH1D object ("Primaryx") at 0x7f86393067b0>,
 'Event/SimpleHistograms/Primaryy': <ROOT.TH1D object ("Primaryy") at 0x7f8639306ff0>}

In [4]: d.histograms1dpy
Out[4]:
{'Event/MergedHistograms/ElossHisto': <pybdsim.Data.TH1 at 0x121df7050>,
 'Event/MergedHistograms/ElossPEHisto': <pybdsim.Data.TH1 at 0x121df3e50>,
 'Event/MergedHistograms/ElossTunnelHisto': <pybdsim.Data.TH1 at 0x121df3c90>,
 'Event/MergedHistograms/ElossTunnelPEHisto': <pybdsim.Data.TH1 at 0x121df3f90>,
 'Event/MergedHistograms/PhitsHisto': <pybdsim.Data.TH1 at 0x121df3e90>,
 'Event/MergedHistograms/PhitsPEHisto': <pybdsim.Data.TH1 at 0x121df3f50>,
 'Event/MergedHistograms/PlossHisto': <pybdsim.Data.TH1 at 0x121df3dd0>,
 'Event/MergedHistograms/PlossPEHisto': <pybdsim.Data.TH1 at 0x121df3bd0>,
 'Event/PerEntryHistograms/EnergyLossManual': <pybdsim.Data.TH1 at 0x121df3e10>,
 'Event/PerEntryHistograms/EnergySpectrum': <pybdsim.Data.TH1 at 0x121de0510>,
 'Event/PerEntryHistograms/EventDuration': <pybdsim.Data.TH1 at 0x121df3f10>,
 'Event/PerEntryHistograms/TunnelLossManual': <pybdsim.Data.TH1 at 0x121de5450>,
 'Event/SimpleHistograms/Primaryx': <pybdsim.Data.TH1 at 0x121df3d10>,
 'Event/SimpleHistograms/Primaryy': <pybdsim.Data.TH1 at 0x121df3d90>}

In [5]: 
```

7.5 ROOT Histogram Operations

Loaded histograms from a rebdsim file are both wrapped in our pybdsim.Data.THX classes for nice numpy arrays for easy plotting, but also we retain the original ROOT objects.

We can use the original ROOT objects to do many very useful things with the histogram, then wrap it again for plotting.

1) Get the ROOT histogram from the loaded file in pybdsim
2) Manipulate that ROOT object
3) Wrap it yourself in a pybdsim.Data.THX class
4) Plot using pybdsim.Plot.Histogram…

e.g.

```
>>> d = pybdsim.Data.Load("run1-ana.root") # a rebdsim output file
>>> h1 = d.histograms['Event'/PerEntryHistograms/EnergyLossBeamline']
>>> h1rebin = h1.Rebin(2, h1->GetName()+"_rebin2")
>>> h1rebinpy = pybdsim.Data.TH1(h1rebin)
>>> pybdsim.Plot.Histogram1D(h1rebinpy)
```

ROOT’s histograms provide many (many…) functions. You can see them all at the ROOT website (Look for “CERN ROOT TH1” in google) or TH2 or TH3:

- https://root.cern.ch/doc/master/classTH1.html
- https://root.cern.ch/doc/master/classTH2D.html
- https://root.cern.ch/doc/master/classTH3D.html

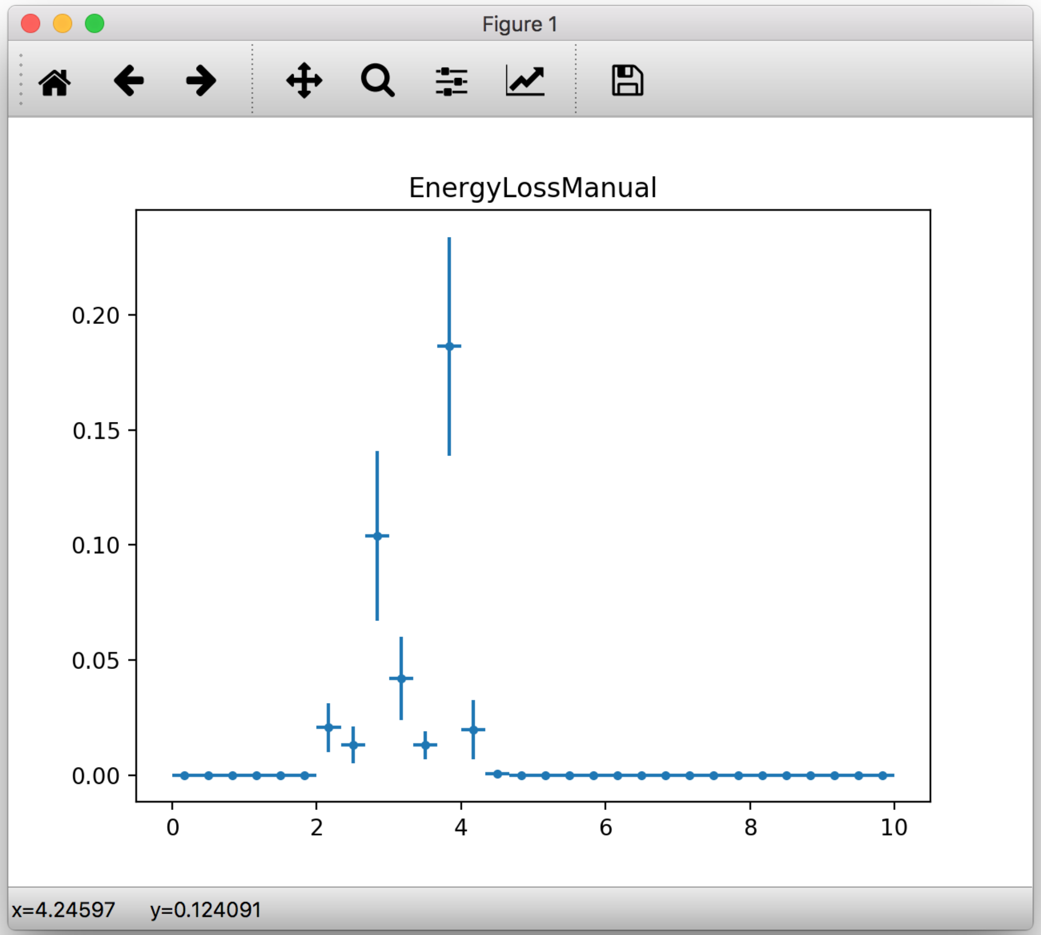


Figure 1
EnergyLossManual
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
x=4.24597 y=0.124091

TH1 is, perhaps nonintuitively, the base class for 2D and 3D histograms, so many functions are documented there. The 2D and 3D ones have some specialised methods.

Note: The integral and its error are nicely provided as members in pybdsim.Data.THXD. Also, you can use the pybdsim.Plot.Histogram… functions with a scaling parameter for the data.

Some useful functions assuming a histogram `h` of type TH1D or TH2D or TH3D in Python:

TH1

- `hnew = h.Rebin(N,h.GetName()+"_rebin"+str(N))` Join N bins into 1. e.g. Rebin(2) is merge 2 bins into 1.
- `h.Add(h2)` Changes `h` by adding h2 to it.
- `h.Add(h2, -1)` Changes `h` by subtracting h2 from it.
- `h.Divide(h2)` Change `h` to h divided by h2.
- `h.Multiply(h2)` Change `h` to h times h2.
- `h.Scale(number)` Change `h` to multiply every bin by 'number'.

TH2

- `hnew = h.Rebin2D(Nx, Ny, h.GetName()+"_rebin"+str(Nx)+str(Ny))` Join Nx bins in x and Ny bins in y into 1.
- `h.Scale(number)` Change `h` to multiply every bin by 'number'.
- `h.ProjectionX(h.GetName()+"_int_x", 0, -1, "e")` Integrate along the x dimension giving a 1D histogram in y.
- `h.ProjectionY(h.GetName()+"_int_y", 0, -1, "e")` Integrate along the y dimension giving a 1D histogram in y.

TH3

- `h.Scale(number)` Change `h` to multiply every bin by 'number'.
- `h2d = h.Project3D("yxe")` Integrate along z to give a TH2D x,y histogram and calculate errors ('e'). https://root.cern.ch/doc/v608/classTH3.html#a94dd0a21d42fd95756e906e7f50fa293

  e.g. a 3D scoring mesh in x,y,z has N bins z = 1. We 'project' (i.e. integrate) in z given the same answer (only function available in ROOT) to get a 2D xy histogram. We want the errors to be calculated too rather than be 0.

  ```
  >>> h3d_raw = d.histograms['Event/MergedHistograms/MyScoringMeshName']
  >>> h2d = h3d_raw.Project3D("yxe")
  >>> h2dpy = pybdsim.Data.TH2(h2d)
  >>> pybdsim.Plot.Histogram2D(h2dphy)
  ```

- `h1d = h.ProjectionZ()` Integrate x and y to give a 1D histogram in z.

  e.g. a 3D scoring mesh in x,y,z has only 1 bin in x and y, but N in Z. We use this function to reduce it to the 1D histogram it effectively is.

  ```
  >>> h3d_raw = d.histograms['Event/MergedHistograms/PhantomDose']
  >>> h1d = h3d_raw.ProjectionZ()
  >>> h1py = pybdsim.Data.TH1(h1d)
  >>> pybdsim.Plot.Histogram1D(h1py)
  ```

ROOT Jargon

- "Profile" histogram is an average in 1 dimension, not a 'profile' as per the real meaning of the word.
- "Projection" means integral.

7.6 Python Histogram Operations

Some of the above operations are provided in functions of *pybdsim.Data.TH2* and *pybdsim.Data.TH3* - the 'Python' versions in pybdsim.

See *pybdsim.Data module* and look for each of the classes there, where their functions are listed.

Some specifically for 3D histograms (i.e. often scoring meshes) are described below.

7.7 3D Scoring Histograms

When using scoring in BDSIM, 3D histograms are produced for 3D scoring meshes. In pybdsim, we have a few extra functions to help handle and inspect these. Plotting 3D is inherently difficult because it has to be viewed from multiple angles to be understood. A few small utility functions are provided to get individual slices and integrals along each dimension to save the user from the difficultly of using underlying ROOT histograms.

The functions are members of an instance of `pybdsim.Data.TH3`, the Python version of the histogram.

- `pybdsim.Data.TH3.IntegrateAlong1Dimension`
- `pybdsim.Data.TH3.IntegrateAlong2Dimensions`
- `pybdsim.Data.TH3.Slice2DXY`
- `pybdsim.Data.TH3.Slice2DXZ`
- `pybdsim.Data.TH3.Slice2DXY`

Examples:

```
h3d # assume an pybdsim.Data.TH3 instance
```

```
h2dx = h3d.IntegrateAlong1Dimension('x')  # return type pybdsim.Data.TH2
pybdsim.Plot.Histogram2D(h2dx)
```

```
for i in range(h3d.nbinsz):
    h2i = h3d.Slice2DXY(i)
    pybdsim.Plot.Histogram2D(h2i)
```

```
h1dz = h3d.IntegrateAlong2Dimension('z')
pybdsim.Plot.Histogram1D(h1dz)
```

Full documentation can be seen in the TH3 class documentation in the *pybdsim.Data module* documentation.

7.8 Manually Loading Raw Data

We can use ROOT direct if you prefer.

```
import ROOT
import pybdsim

pybdsim.Data.LoadROOTLibraries()
# this imports all of BDSIM's analysis classes and puts them inside ROOT

# we need to know the BDSIM C++ classes we want by name
d = ROOT.DataLoader("run1.root")
# now the same as pybdsim.Data.Load("run1.root")
```

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```
model = pybdsim.Data.GetModelForPlotting(d)
```

7.9 Sampler Data

Warning: This is a simplified way of loading sampler data that “flattens” the structure losing all concept of which coordinate belongs to which event. This is not recommend, and this may perhaps not be efficient, but it is occasionally useful. If you want to make a histogram, use rebdsim. Only with this will the error bars be correct.

Sampler data can be trivially extracted from a raw BDSIM output file

```
>>> import pybdsim
>>> d = pybdsim.Data.Load("output.root")
>>> primaries = pybdsim.Data.SamplerData(d)
```

The optional second argument to *SamplerData* can be either the index of the sampler as counting from 0 including the primaries, or the name of the sampler.

```
>>> fq15x = pybdsim.Data.SamplerData(d, fq15x)
>>> thirdAfterPrimares = pybdsim.Data.SamplerData(d, 3)
```

A near-duplicate class exists called *PhaseSpaceData* that can extract only the variables most interesting for tracking (‘x’,’xp’,’y’,’yp’,’z’,’zp’,’energy’,’t’).

```
>>> psd1 = pybdsim.Data.PhaseSpaceData(d)
>>> psd2 = pybdsim.Data.PhaseSpaceData(d, fq15x)
>>> psd3 = pybdsim.Data.PhaseSpaceData(d, 3)
```

CHAPTER

EIGHT

DATA LOADING USING UPROOT

Utilities to load BDSIM output data using *uproot*. It is intended for small-scale data extraction - not a general analysis of BDSIM output.

8.1 Loading ROOT Data

pybdsim can load several different ROOT files produced by BDSIM, rebdsim, rebdsimCombine, bdskim, rebdsimOptics, rebdsimHistoMerge. Depending on the type of the file, you can load the file using:

```
>>> bdsim_data = pybdsim.DataUproot.BDSimOutput("output.root")
>>> rebdsim_data = pybdsim.DataUproot.ReBDSimOutput("rebdsim_output.root")
>>> rebdsim_optics_data = pybdsim.DataUproot.ReBDSimOpticsOutput("rebdsim_optics_
→output.root")
```

Note: To use methods in this module, the user must run `BDSIM` with the option `uprootCompatible=1`.

8.1.1 Model

The model can be accessed from any file using one of these commands:

```
>>> model = bdsim_data.model.df
>>> model = rebdsim_data.model.df
>>> model = rebdsim_optics_data.model.df
>>> model = rebdsim_combine_data.model.df
```

It returns a *pandas.DataFrame* with the information of the model.

Note: The option `dontSplitSBends=1` should be used in `BDSIM` to have one entry for the sbend.

8.1.2 Samplers Data

Samplers data can be trivially extracted from a raw BDSIM output file

```
>>> import pybdsim
>>> d = pybdsim.DataUproot.BDSimOutput("output.root")
>>> samplers = d.event.samplers
```

`samplers` is a dictionary where keys are the name of the samplers and values are an instance of *pybdsim.DataUproot.BDSimOutput.Event.Sampler*. Data can be easily converted in a *pandas.DataFrame* using:

```
>>> samplers['sampler_name'].df
```

The primary beam can be extracted using the same procedure:

```
>>> primary_beam = d.event.primary
```

8.1.3 Optics Files

After loading the file using `pybdsim.DataUproot.ReBDSimOpticsOutput`, the optics of the line can be accessed using:

```
>>> optics = rebdsim_optics_data.optics
>>> results = optics.df
```

8.1.4 Histograms

After loading the file using `pybdsim.DataUproot.ReBDSimOutput`, histograms can be accessed using:

```
>>> histo = rebdsim_data.event.MergedHistograms.ElossHisto
>>> values = histo.values
>>> centers = histo.centers
>>> errors = histos.errors()
```

4D histograms are stored in a *boost histogram* and can be accessed using `histo.bh`. The methods to use to access the data (values, errors, centers) are the same as above. You can compute the Ambient dose H10 with a method that takes as input the conversion factor file for the particle:

```
>>>  h10 = histo.compute_h10("conversion_factor.dat")
```

The *conversion_factor* file is a table that contains the energy and the conversion factor for a given particle. This method returns a 3D histograms over the form *X, Y, Z, H10*.

Note: There is no filter in this method therefore, the user must specify a filter for a given particle (see BDSIM documentation).

CHAPTER

NINE

FIELD MAPS

The *pybdsim.Field* module has several functions and classes to help create, convert, and visualise BDSIM-format field maps easier. Various useful workflows are described below, but every function and class is documented in: *pybdsim.Field module*.

9.1 Loading

Existing BDSIM-format field maps can be loaded with:

```
fm = pybdsim.Field.Load("nameOfFieldMap.dat")
```

This will automatically detect the number of dimensions in the field map and load it into a numpy array inside a pybdsim class. The class is one of:

- `pybdsim.Field.Field1D`
- `pybdsim.Field.Field2D`
- `pybdsim.Field.Field3D`
- `pybdsim.Field.Field4D`

These all have member variables such as:

- `data` - the numpy array of the field map data
- `columns` - a list of column names
- `header` - a dictionary of all information in the header

9.2 Writing

Al of the pybdsim classes described in *Loading* (e.g. *Field3D*) have a method called `Write`. This will write out the instance of that class (i.e. that particular field map data) to a BDSIM-format field map file.

Therefore, these classes represent a a very good route for creation and conversion of field maps. The recommended strategy is to get the information *into* one of those classes then it can be written out to file, loaded, plotted with ease.

9.3 Creation

A field map can be created from scratch in Python from knowledge of a field, such as an equation. A numpy array of the right shape should be created, then an instance of `pybdsim.Field.Field[N]D` created (where N is one of (1,2,3,4).

Creating the array is entirely up to the user as this depends on how they get the information. However, a small example script is shown below here (in Python language):

```python
import numpy as np
import pybdsim

fx, fy, fz = 0.0, 1.0, 0.0
xmax = 30  # cm is the default units for bdsim field maps
ymax = 30
data = []
# loop over and build up 3d lists of lists of lists
for xi in [-xmax, xmax]:
   v = []
   for yi in [-ymax, ymax]:
       # here, fx,fy,fz could be from a function
       v.append([xi, yi, fx, fy, fz])
       data.append(v)

# convert to numpy array
data = np.array(data)

# construct a BDSIM format field object and write it out
f = pybdsim.Field.Field2D(data)

# optionally add some strings that will appear as comments at the
# start of the file
f.AddComment("I = 200A")
f.AddComment("Generated by fictional software v1.2.3")
f.Write("box-field-map.dat')
```

Note: BDSIM's default convention for a field map is to loop over the lowest dimension first, i.e. x. Therefore, the loop above is with x on the outside. See below for purposely handling the other order of looping.

Note: See *Importance of Order*.

This minimal example creates a 2D 'box' of 4 points in space each with the same field value of [0,1,0] (unit Y direction with magnitude 1). The box is $\pm 30cm$ in size. Units aren't used explicitly - just numbers - but the units of BDSIM field map files are cm and s.

Note: The file written out by the class at the end can be loaded again with `pybdsim.Field.Load` to get a (new) object with the same contents as the original Field2D instance.

The array should be structured to contain the coordinates and field components at each point. So for a 2D field map, this would be: (x, y, F_x, F_y, F_z). The array would then have 2 dimensions representing its structure. So if the field map had 10 points in x and 20 in y, it would ultimately be a numpy array with the shape `(10,20,5)`.

Generally, the `numpy.shape(array)` would look like:

- 1D: `(N_x, 4)`

- 2D: `(N_x, N_y, 5)`
- 3D: `(N_x, N_y, N_z, 6)`
- 4D: `(N_x, N_y, N_z, N_t, 7)`

Warning: A key check is looking at the field map, the higher dimension coordinates (e.g. Y, not X) should change first. So for a given X value we should see the Y values cycle through a range, then the X should increment then the Y values cycle again. If this is not the case, then the loop order of dimensions is backwards. You can use "loopOrder" in the header or rewrite the field map correctly.

9.3.1 Alternative Dimensions

In the case of alternative dimension (e.g. a 2D field map with *x* and *z* dimensions but no *y*), the construction is the same but we can label the dimensions differently. The dimensions must be in order (e.g. *x*, *y*, *z*, then *t* for whichever ones are used).

Example:

```
fm = pybdsim.Field.Field2D(arrayData, firstColumn='X', secondColumn='Z')
```

9.3.2 Alternative Loop Order

It is possible for BDSIM to read a file where the right-most coordinate column varies first. However, for each value, the coordinate columns must still be in x,y,z,t order left to right. Below is an example similar to above but writing out the file the other way (note the write function). This will also write the line `loopOrder> tzyx` in the header so BDSIM can load the field map equivalently.

```
import numpy as np
import pybdsim

fx, fy, fz = 0.0, 1.0, 0.0
xmax = 30  # cm is the default units for bdsim field maps
ymax = 30
data = []
# loop over and build up 3d lists of lists of lists
for yi in [-ymax, ymax]:
   v = []
   for xi in [-xmax, xmax]:
       # here, fx,fy,fz could be from a function
       # note, xi and yi coordinates must still be in that order for the value in the␣
↪array
       v.append([xi, yi, fx, fy, fz])
       data.append(v)

# convert to numpy array
data = np.array(data)

# construct a BDSIM format field object and write it out
# this will be written out in the BDSIM conventional looping order
f = pybdsim.Field.Field2D(data, flip=True)
f.Write("box-field-map.dat')
```

Below is a script included with bdsim (`bdsim/examples/features/maps_bdsim/Generate2DLoopOrder.py`) that shows 4 ways to write a field map with the same information. Ultimately, they convey the exact same field map to BDSIM although the file contents differ (2 sets of possible contents).

```python
import numpy as _np
import pybdsim

B = 2.0

# LOOP METHOD 1
data = []
# loop over and build up 3d lists of lists of lists
for x in [-1,0,1]:
    v = []
    for z in [3,4]:
        v.append([x, z, B*x, B*x*z, B*z])
    data.append(v)

# convert to numpy array
data = _np.array(data)

# we looped in x first as per bdsim, so we need only tell it that
# the 2nd column is Z and not Y
f = pybdsim.Field.Field2D(data, secondColumn='Z')
f.Write('2dexample_loopOrder_for_xz.dat')
# but we can purposively write it out the other loop way for testing purposes
# note the header keys are still the same apart from loopOrder> tzyx
f.Write('2dexample_loopOrder_for_xz_tzyx.dat', writeLoopOrderReversed=True)


# LOOP METHOD 2
data2 = []
# loop over other way - outer dimension first
# this isn't the bdsim way, but we may get a field map from some other source that's
# structured like this - so even if you're not creating it in a loop, it may have this
# structure already.
for z in [3,4]:
    v = []
    for x in [-1,0,1]:
        v.append([x, z, B*x, B*x*z, B*z]) # values must still be in xyzt order
    data2.append(v)

# convert to numpy array
data2 = _np.array(data2)

# array structure is z is outer dimension, then x - we need it the other way
# around, so we use flip=True when constructing the field instance
g = pybdsim.Field.Field2D(data2, flip=True, secondColumn='Z')
# this will write out a file identical to the very first one
g.Write('2dexample_loopOrder_for_zx.dat')
# this will write out a file identical to the second one
g.Write('2dexample_loopOrder_for_zx_tzyx.dat', writeLoopOrderReversed=True)
```

9.4 Visualisation and Plotting

To visualise a field map, it is possible to do so in BDSIM / Geant4. See the BDSIM manual for this information. This draws a selection of arrows in the 3D model and gives a rough indication that the field map is as intended.

An alternative way is to load the data in pybdsim in Python and plot it, either fully or in slices (for 3D or 4D maps).

Any library desired can be used in Python and the classes described above in *Loading* provide an excellent way to get a numpy array, that is ubiquitous in Python programming and libraries.

pybdsim provides a variety of small plotting functions mostly for 1D and 2D field maps using Matplotlib. These functions are inside the `pybdsim.Field` module and all start with `Plot`. A list is:

- `pybdsim.Field.Plot1DFxFyFz`
- `pybdsim.Field.Plot2D`
- `pybdsim.Field.Plot2DXY`
- `pybdsim.Field.Plot2DXYMagnitude`
- `pybdsim.Field.Plot2DXYConnectionOrder`
- `pybdsim.Field.Plot2DXYStream`
- `pybdsim.Field.Plot2DXYComponent`
- `pybdsim.Field.Plot2DXYFxFyFz`
- `pybdsim.Field.Plot2DXYBx`
- `pybdsim.Field.Plot2DXYBy`
- `pybdsim.Field.Plot2DXYBz`
- `pybdsim.Field.Plot3DXY`
- `pybdsim.Field.Plot3DXZ`

Warning: Plots that use arrows or stream plots do **not** depend on the order of the points so they cannot be relied upon to tell if the field map being prepared is in the correct order. Use *Plot2DXYMagnitude* or *Plot2DXYConnectionOrder* to verify the order of the points.

A (guaranteed) complete list can be found in *pybdsim.Field module*.

Each can be inspected (in IPython, which is recommended) with a question mark to see its description:

```
>>> import pybdsim
>>> pybdsim.Field.Plot2DXY?
Signature: pybdsim.Field.Plot2DXY(filename, scale=None)
Docstring:
Plot a bdsim field map file using the X,Y plane.

:param filename: name of field map file or object
:type filename: str, pybdsim.Field._Field.Field2D instance
:param scale: numerical scaling for quiver plot arrow lengths.
:type scale: float
>>>
```

9.5 Conversion

your data -> numpy array -> pybdsim.Field.FieldND(data) class

To convert a field map, you should first write a loader from your own format to the field map into a numpy array with a structure described in *Creation*. Then, this array can be *wrapped* in an instance of one of the pybdsim Field classes. This class can then be used to write out the field map in BDSIM's format. This would look something like:

```
def LoadMyFormatFieldMap(filename):
    # ... some implementation...
    # assume variable 'data' of type numpy.array
    return data

def Convert(inputfilename, outputfilename):
    d = LoadMyFormatFieldMap(inputfilename)
    # assume here it's a 2D field map... need to know which class to use
    bd = pybdsim.Field2D(d)
    bd.Write(outputfilename)
```

The source of a field map data should represent an equally spaced grid of points and provided in order, such that it can be converted easily to BDSIM's format with the various classes.

Note: See *Importance of Order*. Make sure to validate the order with plots before using in a simulation in BDSIM. You can also visualise the fields in BDSIM to check. It is recommended to do this with a single component before using in a bigger model.

9.6 Sorting Points

If the data points for the field map correspond to a rectilinear grid but are not provided in order (sometimes can happen from finite-element programs), you should ideally try to get a field map in order. Failing that, you can try to sort the data into an ordered array. An example implementation is given in `pybdsim.Field.SortUnorderedFieldMap2D`. Although, this is provided there is no guarantee the implementation will work depending on the numerical precision of the coordinates. It is still recommended to go back to the origin field program and get a correct grid of points.

9.7 Importance of Order

In a BDSIM field map file, the coordinates at each point are written but BDSIM itself does not use these. BDSIM reads the header information and loops over the data assuming the number of points specified in the header. Therefore if the data is provided in the wrong order the field map will appear scrambled in BDSIM. This can happen with hand-preparation and editing of files.

It is **recommended** to use the pybdsim.Field classes as these are guaranteed to write the data out correctly.

Plots that use arrows or stream plots do **not** depend on the order of the points so they cannot be relied upon to tell if the field map being prepared is in the correct order. Use *Plot2DXYMagnitude* or *Plot2DXYConnectionOrder* to verify the order of the points.

CHAPTER

TEN

UTILITY CLASSES

Various classes are provided for the construction of BDSIM input definitions. There are classes defined in `pybdsim.Builder` that allow writing of an object without any checks. Also, there are some specialised classes listed here that exist in `pybdsim` that include some checking and utility functions.

Once a class is constructed, converting to a string in Python will produce a string in BDSIM input syntax that can be written to a file.

10.1 General Classes

- `pybdsim.Builder.Aperture`
- `pybdsim.Builder.Atom`
- `pybdsim.Builder.BLM`
- `pybdsim.Builder.CavityModel`
- `pybdsim.Builder.Crystal`
- `pybdsim.Builder.Field`
- `pybdsim.Builder.Material`
- `pybdsim.Builder.Query`
- `pybdsim.Builder.Region`
- `pybdsim.Builder.SamplerPlacement`
- `pybdsim.Builder.Scorer`
- `pybdsim.Builder.ScorerMesh`
- `pybdsim.Builder.Tunnel`
- `pybdsim.Builder.XSecBias`

These all work in the same way. The are constructed with the first argument being a name, then paramter value pairs as keyword arguments ("kwargs"). e.g.

```
>>> a = pybdsim.Builder.Aperture('aperDef1', aper1=3, aper2=(2.5,'cm'))
>>> str(a)
    'aperDef1: aperture, aper1=3, aper2=2.5*cm;\n'
```

Acceptable types are int, float, str, list, tuple(number, str). In the case of a tuple (e.g. `()`), it should contain 2 items and the second is the units string.

An example with a list:

```
>>> sp = pybdsim.Builder.SamplerPlacement('z350mL',
                                          z=(350,'m'),
                                          shape="rectangular",
                                          aper1=(5,'m'),
                                          aper2=(5,'m'),
                                          partID=[13,-13])
>>> str(sp)
    'z350mL: samplerplacement, shape="rectangular", partID={13,-13}, aper1=5.0*m,␣
↪z=350.0*m, aper2=5.0*m;\n'
```

Note: The keyword arguments are not checked. One could write "bananas=5" and it would be used, but ultimately would have no meaning to BDSIM.

10.2 Specialised Classes

10.2.1 Beam.Beam

This beam class represents a beam definition in gmad syntax. The class has 'setter' functions that are added dynamically based on the distribution type selected.:

```
>>> b = pybdsim.Beam.Beam()
>>> b.SetParicleType("proton")
>>> b.SetDistributionType("reference")
```

10.2.2 Options.Options

This class provides the set of options for BDSIM. Please see *pybdsim.Options module* for more details.

10.2.3 XSecBias.XSecBias

This class provides the definition process biasing in BDSIM. Please see *pybdsim.XSecBias module* for more details.

CHAPTER ELEVEN

SUPPORT

All support issues can be submitted to our issue tracker

11.1 Feature Request

Feature requests or proposals can be submitted to the issue tracker - select the issue type as proposal or enhancement..

Please have a look at the existing list of proposals before submitting a new one.

CHAPTER

TWELVE

VERSION HISTORY

12.1 V3.1.0 - 2023 / 04 / 02

- Add the writing and reading of comment lines in field maps.
- Reduce print out when loading a field map.
- Clean imports in cpymad interface as well as in Convert functions.

12.2 V3.0.1 - 2023 / 03 / 22

- Fix import for pybdsim when ROOT is present but librebdsim etc. are not available through environmental variables, or findable. Would cause induce a classic ROOT segfault when importing pybdsim.
- Fix wrong exception being raised.
- Always write a comment string at the start of a BDSIM field map file to specify the units of the file.

12.3 V3.0.0 - 2023 / 03 / 19

- Restructure package into a declarative Python package where all source files are now in *src/pybdsim/*.
- The package now has a feature called *uproot* for the optional dependencies of uproot, pandas, and pint packages.
- Field classes no longer have `flip=True` as the default - it is now `False`. Please check any field maps created by scripts using these classes.

12.3.1 New Features

- Add a module to load BDSIM output file, included rebdsim files with uproot.
- Create a nice Python copy of the header information from any (re)bdsim file when loading with pybdsim using only Python types.
- New integration for 2D histograms along each axis to 1D histograms.
- New slices for 3D histograms as well as integrating along a dimension ('projection'). See *3D Scoring Histograms*.
- New ratio plot for 2x 1D histograms. See *pybdsim.Plot.Histogram1DRatio*.
- New loading and handling of 4D histograms (from BDSIM with Boost). They can now be loaded and handled similarly to 1,2,3D histograms. They are loaded automatically when loading a rebdsim file.

- pybdsim.Data.TH1,2,3 now have `xrange`, `yrange`, and `zrange` members where appropriate with a convenient tuple of the range in each dimension. They also have the member `integral` and `integralError` taken from their ROOT objects.
- Field plotting functions now tolerate Field class objects as well as filenames to make it easier to check field objects as you're making them.
- New field plotting for 2D field maps showing each component.
- New field reflection utility function *pybdsim.Field.MirrorDipoleQuadrant1* for 2D fields.
- New field plotting function *pybdsim.Field.Plot2DXYConnectionOrder* to see the order an array is written in. This can be used to validate any field manipulations.
- New field plotting function *pybdsim.Field.Plot1DFxFyFz* to see field components in 1D.
- Field loading automatically works for dimensions such as X, Z for 2D instead of X, Y now.
- Ability to load a rebdsim output file and only load the ROOT histograms without loading the BDSIM and rebdsim shared libraries, so it can be used on a separate computer with just ROOT.
- Added classes to Builder for all GMAD objects. New ones include *aperture*, *atom*, *blm*, *cavitymodel*, *crystal*, *field*, *material*, *newcolour*, *query*, *region*, *samplerplacement*, *scorer*, *tunnel*, *xsecbias*.

12.3.2 Bug Fixes

- pybdsim would throw an exception that librebdsim and libbdsimRootEvent could not be loaded and stop if the libraries had been already loaded separately outside pybdsim. This has been fixed by fixing the interpretation of the error codes from ROOT.
- Fix warning about "nonposy" in matplotlib version for log scales.
- Fix check in Run of if it's a ROOT file or not. Simplify it to use file extension.
- Tolerate no pytransport installation.
- Fix loading of aperture data from a BDSIM output file.
- Fix loading of model data.
- Fix aperture plots from a BDSIM output file.

12.3.3 General

- The Beam class now takes *distrType* and not *distrtype* so as to match BDSIM syntax and be less confusing.
- Updated out of date documentation.
- Better automatic ranges for Histogram1DMultiple plots by default.
- Better field loading in *pybdsim.Field.Load*. Returns the same Field object from pybdsim as you would write.

12.4 v2.4.0 - 2021 / 06 / 16

12.4.1 New Features

- Transform3D function in a Machine.
- Crystal, ScorerMesh and Placement also can be added to a Machine.
- Ability to insert and replace an element in a machine.

12.4.2 Bug Fixes

- Python 3.8+ warnings fixed.
- Add ROOT_INCLUDE_PATH to ROOT as newer versions don't do this automatically.
- Fixed vmin for 2D histogram plot.

12.5 v2.3.0 - 2020 / 12 / 15

12.5.1 New Features

- Convenience functions for pickling and un-pickling data in the Data module with optional compression.
- Generic loss map plot.

12.6 v2.2.0 - 2020 / 06 / 08

12.6.1 New Features

- Support for Python3.

12.7 v2.1 - 2019 / 04 / 20

12.7.1 New Featuers

- Optional flag of whether to write out the converted model with *pybdsim.Convert.MadxTfs2Gmad*.
- Machine builder now supports new bdsim jcol element.
- Machine diagram drawing can now start from any arbitrary S location.
- For loaded histograms (using *pybdsim.Data.TH1*, *TH2*, *TH3* classes, there are now functions *ErrorsToSTD()* and *ErrorsToErrorOnMean()* to easily convert between the different types of error - the default is error on the mean.
- New plotting function *pybdsim.Plot.Histogram2DErrors* to visualise 2D histogram errors.

12.7.2 General

- Return arguments of *pybdsim.Convert.MadxTfs2Gmad* is now just 2 items - machine and omitted items. Previously 3.

12.7.3 Bug Fixes

- Fix loading of Model tree from ROOT output given some recent collimation variables may have a different structure or type from the existing ones.
- In *pybdsim.Plot.Histogram2D*, the y log scale argument was "ylocscale" and is fixed to "yLogScale".

12.8 v2.0 - 2019 / 02 / 27

12.8.1 New Features

- Machine diagram plotting automatically from BDSIM output. Compatible with newer BDSIM output format.
- Support for thin R matrix, parallel transporter and thick R matrix in builder.
- Generate transfer matrix from tracking data from BDSIM for a single element.
- Control over legend location in standard energy deposition and loss plots.
- Utility function to write sampler data from BDSIM output to a user input file.
- Support for energy variation in the beam line in MAD8 conversion.

12.8.2 General

- Remove dependency of root_numpy. pybdsim now uses only standard ROOT interfaces.
- Update physics lists.

12.8.3 Bug Fixes

- Fix bug where calling pybdsim.Plot.PrimaryPhaseSpace with an output file name would result in an error as this argument was wrongly supplied to the number of bins argument.
- Fix for hidden scientific notation when using machine diagram.
- Fix TH1 TH2 TH3 histogram x,y,z highedge variables in histogram loading. These were the lowedge duplicated, which was wrong.
- Add missing variables from sampler data given changes in BDSIM.

12.9 v1.9 - 2018 / 08 / 24

12.9.1 General

- Significant new tests.
- Trajectory loading from BDSIM ROOT output.
- Plot trajectories.
- New padding function for 1D histogram to ensure lines in plots.
- New value replacement function for histograms to ensure continuous line in log plots.
- Control over aspect ration in default 2D histogram plots.
- New classes for each element in the Builder.
- Refactor of MadxTfs2Gmad to use new classes in Builder.

12.9.2 Bug Fixes

- Fix orientation of 2D histograms in plotting.
- Fix header information labels when writing field maps with reversed order.

12.10 v1.8 - 2018 / 06 / 23

12.10.1 General

- Setup requires pytest-runner.
- Introduction of testing.
- Removed line wrapping written to GMAD files in Builder.
- “PlotBdsimOptics” is now “BDSIMOptics” in the Plot module.
- New comparison plots for arbitrary inputs from different tracking codes.
- Prepare PTC coordinates from any BDSIM sampler.

12.10.2 Bug Fixes

- Fixes for “Optics” vs “optics” naming change in ROOT files.

12.11 v1.7 - 2018 / 06 / 30

12.11.1 General

- Can specify which dimension in Field class construction (i.e. ‘x’:’z’ instead of default ‘x’:’y’).

12.11.2 Bug Fixes

- ‘nx’ and ‘ny’ were written the wrong way around from a 2D field map in pybdsim.

12.12 v1.6 - 2018 / 05 / 23

12.12.1 Bug Fixes

- Fix machine diagram plotting from BDSIM survey.
- Fix machine diagram searching with right-click in plots.

12.13 v1.5 - 2018 / 05 / 17

12.13.1 New Features

- Function now public to create beam from Madx TFS file.
- Improved searching for BDSAsciiData class.
- Ability to easily write out beam class.
- Plot phase space from any sampler in a BDSIM output file.
- __version__ information in package.
- Get a column from data irrespective of case.
- Coded energy deposition plot. Use for example for labelling cyrogenic, warm and collimator losses.
- Improved Transport BDSIM comparison.
- Function to convert a line from a TFS file into a beam definition file.

12.13.2 Bug Fixes

- Fix library loading given changes to capitalisation in BDSIM.
- Beam class now supports all BDSIM beam definitions.
- Support all aperture shapes in Builder.
- Fixes for loading optics given changes to capitalisation and BDSAsciiData class usage.
- Fixes for collimator conversion from MADX.

12.14 v1.4 - 2018 / 10 / 04

12.14.1 New Features

- Full support for loading BDSIM output formats through ROOT.
- Extraction of data from ROOT histograms to numpy arrays.
- Simple histogram plotting from ROOT files.
- Loading of sampler data and simple extraction of phase space data.
- Line wrapping for elements with very long definitions.
- Comparison plots standardised.
- New BDSIM BDSIM comparison.
- New BDSIM Mad8 comparison.
- Support for changes to BDSIM data format variable renaming in V1.0

12.14.2 Bug Fixes

- Correct conversion of all dispersion component for Beam.
- Don’t write all multipole components if not needed.
- Fixed histogram plotting.
- Fixed conversion of coordinates in BDSIM2PtcInrays for subrelativistic particles.
- Fixed behaviour of fringe field *fint* and *fintx* behaviour from MADX.
- Fixed pole face angles given MADX writes out wrong angles.
- Fixed conversion of multipoles and other components for ‘linear’ flag in MadxTfs2Gmad.
- Fixed axis labels in field map plotting utilities.
- MADX BDSIM testing suite now works with subrelativistic particles.
- Many small fixes to conversion.

12.15 v1.3 - 2017 / 12 / 05

12.15.1 New Features

- GPL3 licence introduced.
- Compatibility with PIP install system.
- Manual.
- Testing suite.

CHAPTER

THIRTEEN

MODULE CONTENTS

This documentation is automatically generated by scanning all the source code. Parts may be incomplete.

pybdsim - python tool for BDSIM.

Module	Description
Builder	Create generic accelerators for BDSIM.
Compare	Comparison of optics between different codes.
Constants	Constants.
Convert	Convert other formats into gmad.
Data	Read the bdsim output formats.
DataUproot	Data loading with uproot instead of pyroot.
Field	Read and write BDSIM field format files.
Geant4	Dictionary that contains process and subprocess IDs
Gmad	Create bdsim input files - lattices & options.
ModelProcessing	Tools to process existing BDSIM models and generate other versions of them.
Optics	Optical calculation in development.
Options	Methods to generate bdsim options.
Plot	Some nice plots for data.
Run	Run BDSIM programatically.
Visualisation	Help locate objects in the BDSIM visualisation, requires a BDSIM survey file.
Writer	Write various objects from Builder.

Class	Description
Beam	A beam options dictionary with methods.
XSecBias	A cross-section biasing object.

13.1 pybdsim.Beam module

Module containing a similarly named Beam class for creating a BDSIM beam distribution programmatically.

class `pybdsim.Beam.`**`Beam`**(*particleType='e-'*, *energy=1.0*, *distrType='reference'*, **args*, ***kwargs*)

Bases: `dict`

`ReturnBeamString`()

`SetDistributionType`(*distrType='reference'*)

`SetE0`(*e0=1*, *unitsstring='GeV'*)

`SetEnergy`(*energy=1.0*, *unitsstring='GeV'*)

SetParticleType(*particleType='e-'*)

SetS0(*s0=0*, *unitsstring='m'*)

SetT0(*t0=0.0*, *unitsstring='s'*)

SetX0(*x0=0.0*, *unitsstring='m'*)

SetXP0(*xp0=0.0*)

SetY0(*y0=0.0*, *unitsstring='m'*)

SetYP0(*yp0=0.0*)

SetZ0(*z0=0.0*, *unitsstring='m'*)

SetZP0(*zp0=0.0*)

WriteToFile(*filename*)

13.2 pybdsim.Builder module

Builder

Build generic machines for bdsim. You can create a lattice using one of the predefined simple lattices or by adding many pieces together of your own design. Finally, output the gmad files required.

Classes: Element - beam line element that always has name,type and length Machine - a list of elements

class pybdsim.Builder.**Aperture**(*name*, ***kwargs*)

Bases: `GmadObject`

A crystal definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.**ApertureModel**(*apertureType='circular'*, *aper1=0.1*, *aper2=0*, *aper3=0*, *aper4=0*, *warningName=''*)

Bases: `dict`

A class that produces the aperture representation of an element. Only non-zero values are written for the aperture parameters. Includes parameter checking.

class pybdsim.Builder.**Atom**(*name*, ***kwargs*)

Bases: `GmadObject`

A atom definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.**BLM**(*name*, ***kwargs*)

Bases: `GmadObject`

A blmplacement definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.**CavityModel**(*name*, ***kwargs*)

Bases: `GmadObject`

A cavitymodel definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit `pybdsim.Builder.`**`CreateDipoleDriftRing`**`(`*filename*, *ncells=60*, *circumference=100.0*, *driftfraction=0.1*, *samplers='first'*`)`

Create a ring composed of dipoles and drifts filename ncells - number of cells, each containing 1 dipole and a drift circumference - in metres driftfraction - the fraction of drift in each cell (0.0 < driftfraction < 1.0) samplers - 'first', 'last' or 'all'

`pybdsim.Builder.`**`CreateDipoleFodoRing`**`(`*filename*, *ncells=60*, *circumference=200.0*, *ncellsToMake=None*, *samplers='first'*`)`

Create a ring composed of fodo cells with 2 dipoles per fodo cell.

filename ncells - number of fodo+dipole cells to create circumference - circumference of machine in metres ncellsToMake - number of cells to actually build for part of the machine (None = all) samplers - 'first','last' or 'all'

Hard coded to produce the following cell fractions: 50% dipoles 20% quadrupoles 30% beam pipe / drift

`pybdsim.Builder.`**`CreateDipoleRing`**`(`*filename*, *ndipoles=60*, *circumference=100.0*, *samplers='first'*`)`

Create a ring composed of only dipoles filename ncells - number of cells, each containing 1 dipole and a drift circumference - in metres samplers - 'first', 'last' or 'all'

`pybdsim.Builder.`**`CreateFodoLine`**`(`*filename*, *ncells=10*, *driftlength=4.0*, *magnetlength=1.0*, *samplers='all'*, ***kwargs*`)`

Create a FODO lattice with ncells.

ncells - number of fodo cells driftlength - length of drift segment in between magnets magnetlength - length of quadrupoles samplers - 'all','first' or 'last' kwargs - kwargs to supply to quadrupole constructor

`class` `pybdsim.Builder.`**`Crystal`**`(`*name*, ***kwargs*`)`

Bases: *`GmadObject`*

A crystal definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

`class` `pybdsim.Builder.`**`CrystalCol`**`(`*name*, *l*, *xsize*, *material*, ***kwargs*`)`

Bases: *`Element`*

`class` `pybdsim.Builder.`**`Decapole`**`(`*name*, *l*, *k4*, ***kwargs*`)`

Bases: *`Element`*

`class` `pybdsim.Builder.`**`Degrader`**`(`*name*, *l*, *nWedges*, *wedgeLength*, *degHeight*, *materialThickness=None*, *degraderOffset=None*, ***kwargs*`)`

Bases: *`Element`*

`class` `pybdsim.Builder.`**`Drift`**`(`*name*, *l*, ***kwargs*`)`

Bases: *`Element`*

`class` `pybdsim.Builder.`**`Dump`**`(`*name*, *l*, ***kwargs*`)`

Bases: *`Element`*

`class` `pybdsim.Builder.`**`ECol`**`(`*name*, *l*, *xsize*, *ysize*, ***kwargs*`)`

Bases: `_Col`

`class` `pybdsim.Builder.`**`Element`**`(`*name*, *category*, *isMultipole=False*, ***kwargs*`)`

Bases: *`ElementBase`*

Element - an element / item in an accelerator beamline. Very similar to a python dict(ionary) and has the advantage that built in printing or string conversion provides BDSIM syntax.

Element(name,type,**kwargs)

```
>>> a = Element("d1", "drift", l=1.3)
>>> b = Element("qx1f", "quadrupole", l=(0.4,'m'), k1=0.2, aper1=(0.223,'m'))
>>> print(b)
```

(continues on next page)

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```
qx1f: quadrupole, k1=0.2, l=0.4*m, aper1=0.223*m;
>>> str(c)
qx1f: quadrupole, k1=0.2, l=0.4*m, aper1=0.223*m\n;
```

A beam line element must ALWAYs have a name, and type. The keyword arguments are specific to the type and are up to the user to specify - these should match BDSIM GMAD syntax.

The value can be either a single string or number or a python tuple where the second entry must be a string (shown in second example). Without specified units, the parser assumes S.I. units.

An element may also be multiplied or divided. This will scale the length and angle appropriately.

```
>>> c = Element('sb1', 'sbend', l=(0.4,'m'), angle=0.2)
>>> d = c/2
>>> print(d)
sb1: sbend, l=0.2*m, angle=0.1;
```

This inherits and extends ElementBase that provides the basic dictionary capabilities. It adds the requirement of type / category (because 'type' is a protected keyword in python) as well as checking for valid BDSIM types.

`classmethod from_element`(*parent_element_name: str*, *isMultipole=False*, ***kwargs*)

`split`(*points*)

Split this element into len(points)+1 elements, with the correct lengths. This does not affect magnetic strengths, etc, which is left to derived classes where appropriate.

`class` `pybdsim.Builder.`**`ElementBase`**(*name*, *isMultipole=False*, ***kwargs*)

Bases: `MutableMapping`

A class that represents an element / item in an accelerator beamline. Printing or string conversion produces the BDSIM syntax.

This class provides the basic dict(ionary) inheritance and functionality and the representation that allows modification of existing parameters of an already declared item.

`keysextra`()

`class` `pybdsim.Builder.`**`ElementModifier`**(*name*, *isMultipole=False*, ***kwargs*)

Bases: *`ElementBase`*

A class to MODIFY an already defined element in a gmad file by appending an updated definition. Using this alone in BDSIM will result in an undefined type error. This class is particularly useful for creating a strength file.

# define an element >>> a = Element('qf1', 'quadrupole', l=0.3, k1=0.00345) >>> b = ElementModifier('qf1',k1=0.0245) >>> f = open('mylattice.gmad', 'w') >>> f.write(str(a)) >>> f.write(str(b)) >>> f.close()

cat mylattice.gmad qf1, quadrupole, l=0.3, k1=0.00345; qf1, k1=0.0245

This results in the quadrupole strength k1 in this example being changed to 0.0245.

`class` `pybdsim.Builder.`**`ExternalGeometry`**(*name*, *l*, *outerDiameter*, *geometryFile*, ***kwargs*)

Bases: *`Element`*

`class` `pybdsim.Builder.`**`Field`**(*name*, ***kwargs*)

Bases: *`GmadObject`*

A field definition. Any kwargs will be written as parameter=value. parameteter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.Gap(*name*, *l*, ***kwargs*)

Bases: `Element`

pybdsim.Builder.**GenerateSamplersFromBDSIMSurvey**(*surveyfile*, *outputfilename*, *excludesamplers=True*)

Create a gmad file with samplers for all the elements in a beamline as described by the survey outline from bdsim

bdsim –file=mylattice.gmad –outline=survey.dat –outline_type=survey

excludesamplers - bool - exclude any existing samplers

class pybdsim.Builder.GmadObject(*objecttype*, *name*, ***kwargs*)

Bases: `MutableMapping`

A gmad object does not have a length unlike every `Element` hence it needs its own class to produce its representation.

keysextra()

class pybdsim.Builder.HKicker(*name*, *hkick*, ***kwargs*)

Bases: `Element`

split(*points*)

Split this element into len(points)+1 elements, with the correct lengths. This does not affect magnetic strengths, etc, which is left to derived classes where appropriate.

class pybdsim.Builder.JCol(*name*, *l*, *xsize*, *ysize*, ***kwargs*)

Bases: `_Col`

class pybdsim.Builder.Kicker(*name*, *hkick*, *vkick*, ***kwargs*)

Bases: `Element`

split(*points*)

Split this element into len(points)+1 elements, with the correct lengths. This does not affect magnetic strengths, etc, which is left to derived classes where appropriate.

class pybdsim.Builder.Laser(*name*, *l*, *x*, *y*, *z*, *waveLength*, ***kwargs*)

Bases: `Element`

class pybdsim.Builder.Line(*name*, **args*)

Bases: `list`

A class that represents a `list` of `Elements`

Provides ability to print out the sequence or define all the components.

Example:

```
>>> d1 = Element("drift1", "drift", l=1.3)
>>> q1 = Element("q1", "quadrupole", l=0.4, k1=4.5)
>>> a = Line([d1,q1])
```

DefineConstituentElements()

Return a string that contains the lines required to define each element in the `Line`.

Example using predefined Elements name ‘d1’ and ‘q1’:

```
>>> l = Line([d1,q1])
>>> f = open("file.txt", "w")
>>> f.write(l.DefineConsituentElements())
>>> f.close()
```

class pybdsim.Builder.**Machine**(*verbose=False*, *sr=False*, *energy0=0.0*, *charge=-1.0*)

Bases: `object`

A class represents an accelerator lattice as a sequence of components. Member functions allow various lattice components to be append to the sequence of the machine. This class allows the user to programatically create a lattice and write the BDSIM gmad representation of it.

Example:

```
>>> a = Machine()
>>> a.AddDrift('mydrift', l=1.3)
>>> a.Write("lattice.gmad")
```

Example with Sychrotron rescaling:

```
>>> a = Machine(sr=True, energy0=250,charge=-1)
>>> a.AddDipole('sb1','sbend',length=1.0,angle=1e-5)
>>> a.AddDrift('dr1',length=1)
>>> a.AddDipole('sb2','sbend',length=1.0,angle=1e-5)
>>> a.AddDrift("dr2",length=1)
```

Caution: adding an element of the same name twice will result the element being added only to the sequence again and not being redefined - irrespective of if the parameters are different. If verbose is used (True), then a warning will be issued.

AddBLM(*name*, ***kwargs*)

AddBeam(*beam=None*)

Assign a beam instance to this machine. If no Beam instance is provided, a reference distribution is used.

AddBias(*biases*)

Add a Builder.XSecBias instance or iterable of instances to this machine.

AddCT(*name='ctscan'*, *length=1.0*, *dicomDataFile=''*, *dicomDataPath=''*, ***kwargs*)

AddCrystal(*name*, ***kwargs*)

AddCrystalCol(*name='cc'*, *length=0.01*, *xsize=0.001*, ***kwargs*)

AddDecapole(*name='dc'*, *length=0.1*, *k4=0.0*, ***kwargs*)

AddDegrader(*length=0.1*, *name='deg'*, *nWedges=1*, *wedgeLength=0.1*, *degHeight=0.1*, *materialThickness=None*, *degraderOffset=None*, ***kwargs*)

AddDipole(*category='sbend'*)

category - ‘sbend’ or ‘rbend’ - sector or rectangular bend

AddDrift(*name='dr'*, *length=0.1*, ***kwargs*)

Add a drift to the beam line

AddDump(*name='du'*, *length=0.1*, ***kwargs*)

AddECol(*name='ec'*, *length=0.1*, *xsize=0.1*, *ysize=0.1*, ***kwargs*)

AddElement(*name='el'*, *length=0.1*, *outerDiameter=1*, *geometryFile='geometry.gdml'*, ***kwargs*)

AddFodoCell(*basename*, *magnetlength*, *driftlength*, *kabs*, ***kwargs*)

basename - the basename for the fodo cell beam line elements magnetlength - length of magnets in metres driftlength - length of drift segment in metres kabs - the absolute value of the quadrupole strength - alternates between magnets

kwargs are other parameters for bdsim - ie material=’Fe’

AddFodoCellMultiple(*basename='fodo'*, *magnetlength=1.0*, *driftlength=4.0*, *kabs=0.2*, *ncells=2*, ***kwargs*)

AddFodoCellSplitDrift(*basename*, *magnetlength*, *driftlength*, *kabs*, *nsplits*, ***kwargs*)

basename - the basename for the fodo cell beam line elements magnetlength - length of magnets in metres driftlength - length of drift segment in metres kabs - the absolute value of the quadrupole strength - alternates between magnets nsplits - number of segments drift length is split into

Will add qf quadrupole of strength +kabs, then drift of l=driftlength split into nsplit segments followed by a qd quadrupole of strength -kabs and the same pattern of drift segments.

nsplits will be cast to an even integer for symmetry purposes.

kwargs are other parameters for bdsim - ie aper=0.2

AddFodoCellSplitDriftMultiple(*basename='fodo'*, *magnetlength=1.0*, *driftlength=4.0*, *kabs=0.2*, *nsplits=10*, *ncells=2*, ***kwargs*)

AddGap(*name='gp'*, *length=1.0*, ***kwargs*)

AddHKicker(*name='hk'*, *hkick=0.0*, ***kwargs*)

AddIncludePost(*include*)

Add the name of a file (str) that should be included in the main file after others.

AddIncludePre(*include*)

Add the name of a file (str) that should be included in the main file before others.

AddJCol(*name='jc'*, *length=0.1*, *xsize=0.1*, *ysize=0.1*, ***kwargs*)

AddKicker(*name='kk'*, *hkick=0.0*, *vkick=0.0*, ***kwargs*)

AddLaser(*length=0.1*, *name='lsr'*, *x=1*, *y=0*, *z=0*, *waveLength=5.32e-07*, ***kwargs*)

AddMarker(*name='mk'*)

AddMaterial(*materials*)

Add a Builder.Material instance or iterable of instances to this machine.

AddMuSpoiler(*name='mu'*, *length=0.1*, *b=0.0*, ***kwargs*)

AddMultipole(*name='mp'*, *length=0.1*, *knl=(0, 0)*, *ksl=(0, 0)*, ***kwargs*)

AddObject(*obj*)

Add an object or definition to be written to the model. An 'object' is a definition that isn't part of a sequence such as a Field, Crystal, or Placement. Anything that has a string representation can be added to the list.

For an iterable object, tuple, list, and dict are accepted. For a dict, the value (not the key) is added to the internal list without the key.

Objects: Aperture, Atom, BLM, CavityModel, Crystal, Field, Laser, Material, NewColour Placement, Query, Region, SamplerPlacement, Scorer, ScorerMesh, XSecBias.

AddOctupole(*name='oc'*, *length=0.1*, *k3=0.0*, ***kwargs*)

AddOptions(*options=None*)

Assign an options instance to this machine.

AddPlacement(*name*, ***kwargs*)

AddQuadrupole(*name='qd'*, *length=0.1*, *k1=0.0*, ***kwargs*)

AddRBend(*name='rb'*, *length=0.1*, *angle=None*, *b=None*, ***kwargs*)

`AddRCol`(*name='rc'*, *length=0.1*, *xsize=0.1*, *ysize=0.1*, ***kwargs*)

`AddRFCavity`(*name='arreff'*, *length=0.1*, *gradient=10*, ***kwargs*)

`AddRmat`(*name='rmat'*, *length=0.1*, *r11=1.0*, *r12=0*, *r13=0*, *r14=0*, *r21=0*, *r22=1.0*, *r23=0*, *r24=0*, *r31=0*, *r32=0*, *r33=1.0*, *r34=0*, *r41=0*, *r42=0*, *r43=0*, *r44=1.0*, ***kwargs*)

`AddSBend`(*name='sb'*, *length=0.1*, *angle=None*, *b=None*, ***kwargs*)

`AddSampler`(*names*)

`AddScorerMesh`(*name*, ***kwargs*)

`AddSextupole`(*name='sx'*, *length=0.1*, *k2=0.0*, ***kwargs*)

`AddShield`(*name='sh'*, *length=0.1*, ***kwargs*)

`AddSolenoid`(*name='sl'*, *length=0.1*, *ks=0.0*, ***kwargs*)

`AddTKicker`(*name='tk'*, *hkick=0.0*, *vkick=0.0*, ***kwargs*)

`AddTarget`(*name='trg'*, *length=0.1*, *material='Cu'*, ***kwargs*)

`AddThinMultipole`(*name='mp'*, *knl=(0, 0)*, *ksl=(0, 0)*, ***kwargs*)

`AddThinRmat`(*name='rmatthin'*, *r11=1.0*, *r12=0*, *r13=0*, *r14=0*, *r21=0*, *r22=1.0*, *r23=0*, *r24=0*, *r31=0*, *r32=0*, *r33=1.0*, *r34=0*, *r41=0*, *r42=0*, *r43=0*, *r44=1.0*, ***kwargs*)

`AddTransform3D`(*name='t3d'*, ***kwargs*)

`AddUndulator`(*name='un'*, *length=1.0*, *b=0*, *undulatorPeriod=0.1*, ***kwargs*)

`AddVKicker`(*name='vk'*, *vkick=0.0*, ***kwargs*)

`AddWireScanner`(*name='ws'*, *length=0.1*, *wireDiameter=0.001*, *wireLength=0.1*, ***kwargs*)

`Append`(*item*, *is_component=False*)

`GetIntegratedAngle`()

Get the cumulative angle of all the bends in the machine. This is therefore the difference in angle between the entrance and exit vectors. All angles are assumed to be in the horizontal plane so this will not be correct for rotated dipoles.

`GetIntegratedLength`()

Get the integrated length of all the components.

`GetNamesOfType`(*category*)

Returns a list of names of elements that are of the specified category.

`InsertAndReplace`(*newElement*, *sLocation*)

New element will be placed at the central s location.

`RegenerateLenInt`()

`ReplaceElementCategory`(*category*, *newcategory*)

Change category of all elements of a given category. All parameters of the element being changed will be preserved, please update with the UpdateCategoryParameter function.

`ReplaceWithElement`(*name*, *newelement*, *warnAboutLengthDifference=True*)

Replace an element in the machine with a new element object (one of the individual element pybdsim.Builder classes that inherit the Element class).

`SynchrotronRadiationRescale`()

Rescale all component strengths for SR

UpdateCategoryParameter(*category*, *parameter*, *value*)

Update parameter for all elements of a given category.

UpdateElement(*name*, *parameter*, *value*)

Update a parameter for a specified element name. Modifying element length will produce a warning. If a value for that parameter already exists, the value will be overwritten.

UpdateElements(*names*, *parameter*, *value*, *namelocation='all'*)

Update multiple elements. Supplied names can be a sequence type object containing a list of element names or a string where all elements with names containing that string will be updated. namelocation specifies if names string can be at the 'beginning', 'end', or anywhere ('all') in an elements name.

UpdateGlobalParameter(*parameter*, *value*)

Update parameter for all elements of a given category.

Write(*filename*, *verbose=False*, *overwrite=True*)

Write the machine to a series of gmad files.

kwargs: overwrite : Do not append an integer to the basefilename if already exists, instead overwrite existing files.

next()

class pybdsim.Builder.**Marker**(*name*)

Bases: *Element*

class pybdsim.Builder.**Material**(*name*, ***kwargs*)

Bases: *GmadObject*

A material definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.**MuSpoiler**(*name*, *l*, *B*, ***kwargs*)

Bases: *Element*

class pybdsim.Builder.**Multipole**(*name*, *l*, *knl*, *ksl*, ***kwargs*)

Bases: *Element*

split(*points*)

Split this element into len(points)+1 elements, with the correct lengths. This does not affect magnetic strengths, etc, which is left to derived classes where appropriate.

class pybdsim.Builder.**NewColour**(*name*, ***kwargs*)

Bases: *GmadObject*

A newcolour definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.**Octupole**(*name*, *l*, *k3*, ***kwargs*)

Bases: *Element*

class pybdsim.Builder.**Placement**(*name*, ***kwargs*)

Bases: *GmadObject*

A placement definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

pybdsim.Builder.**PrepareApertureModel**(*rowDictionary*, *default='circular'*, *warningName=''*)

class pybdsim.Builder.**Quadrupole**(*name*, *l*, *k1*, ***kwargs*)

Bases: *Element*

class pybdsim.Builder.Query(*name*, ***kwargs*)

Bases: `GmadObject`

A query definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.RBend(*name*, *l*, *angle=None*, *B=None*, ***kwargs*)

Bases: `_Dipole`

class pybdsim.Builder.RCol(*name*, *l*, *xsize*, *ysize*, ***kwargs*)

Bases: `_Col`

class pybdsim.Builder.RFCavity(*name*, *l*, *gradient*, ***kwargs*)

Bases: `Element`

class pybdsim.Builder.Region(*name*, ***kwargs*)

Bases: `GmadObject`

A region definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.Rmat(*name*, *l*, *r11*, *r12*, *r13*, *r14*, *r21*, *r22*, *r23*, *r24*, *r31*, *r32*, *r33*, *r34*, *r41*, *r42*, *r43*, *r44*, ***kwargs*)

Bases: `Element`

class pybdsim.Builder.SBend(*name*, *l*, *angle=None*, *B=None*, ***kwargs*)

Bases: `_Dipole`

class pybdsim.Builder.Sampler(*name*)

Bases: `object`

A sampler is unique in that it does not have a length unlike every `Element` hence it needs its own class to produce its representation.

class pybdsim.Builder.SamplerPlacement(*name*, ***kwargs*)

Bases: `GmadObject`

A samplerplacement definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.Scorer(*name*, ***kwargs*)

Bases: `GmadObject`

A scorer definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.ScorerMesh(*name*, ***kwargs*)

Bases: `GmadObject`

A scorermesh definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

class pybdsim.Builder.Sextupole(*name*, *l*, *k2*, ***kwargs*)

Bases: `Element`

class pybdsim.Builder.Shield(*name*, *l*, ***kwargs*)

Bases: `Element`

class pybdsim.Builder.Solenoid(*name*, *l*, *ks*, ***kwargs*)

Bases: `Element`

`pybdsim.Builder.`**`SuggestFodoK`**`(`*magnetlength*, *driftlength*`)`

returns k1 (float) value for matching into next quad in a FODO cell. f = 1/(k1 * magnetlength) = driftlength -> solve for k1

Note the convention in pybdsim.Builder is that the quadrupoles in the fodo cell are split in two. So this is in fact half the integrated k you need. This matches with the other functions in Builder.

`class pybdsim.Builder.`**`TKicker`**`(`*name*, *hkick*, *vkick*, ***kwargs*`)`

Bases: *`Element`*

`split``(`*points*`)`

Split this element into len(points)+1 elements, with the correct lengths. This does not affect magnetic strengths, etc, which is left to derived classes where appropriate.

`class pybdsim.Builder.`**`ThinMultipole`**`(`*name*, *knl=(0, 0)*, *ksl=(0, 0)*, ***kwargs*`)`

Bases: *`Element`*

`class pybdsim.Builder.`**`Transform3D`**`(`*name*, ***kwargs*`)`

Bases: *`Element`*

`class pybdsim.Builder.`**`Tunnel`**`(`*name*, ***kwargs*`)`

Bases: *`GmadObject`*

A tunnel definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

`class pybdsim.Builder.`**`Undulator`**`(`*name*, *l*, *b*, *undulatorPeriod*, ***kwargs*`)`

Bases: *`Element`*

`class pybdsim.Builder.`**`VKicker`**`(`*name*, *vkick*, ***kwargs*`)`

Bases: *`Element`*

`split``(`*points*`)`

Split this element into len(points)+1 elements, with the correct lengths. This does not affect magnetic strengths, etc, which is left to derived classes where appropriate.

`class pybdsim.Builder.`**`WireScanner`**`(`*name*, *l*, *wireDiameter*, *wireLength*, *material*, ***kwargs*`)`

Bases: *`Element`*

`class pybdsim.Builder.`**`XSecBias`**`(`*name*, ***kwargs*`)`

Bases: *`GmadObject`*

A xsecbias definition. Any kwargs will be written as parameter=value. parameter=(value,unit) -> parameter=value*unit

13.3 pybdsim.Compare

`pybdsim.Compare.`**`MadxVsBDSIM`**`(`*tfs*, *bdsim*, *survey=None*, *functions=None*, *postfunctions=None*, *figsize=(10, 5)*, *saveAll=True*, *outputFileName=None*`)`

Compares MadX and BDSIM optics variables. User must provide a tfsoptIn file or Tfsinstance and a BDSAscii file or instance.

Parameters	Description
tfs	Tfs file or pymadx.Data.Tfs instance.
bdsim	Optics root file (from rebdsimOptics or rebdsim).
survey	BDSIM model survey.
functions	Hook for users to add their functions that are called immediately prior to the addition of the plot. Use a lambda function to add functions with arguments. Can be a function or a list of functions.
figsize	Figure size for all figures - default is (12,5)

`pybdsim.Compare.`**`MadxVsBDSIMOrbit`**(*tfs*, *bds*, *survey=None*, *functions=None*, *postfunctions=None*, *figsize=(12, 5)*)

Plot both the BDSIM orbit and MADX orbit (mean x,y).

tfs - either file name or pymadx.Data.Tfs instance bds - filename or BDSAsciiData instance - rebdsimOrbit, rebdsimOptics output files

`pybdsim.Compare.`**`BDSIMVsBDSIM`**(*first*, *second*, *first_name=None*, *second_name=None*, *survey=None*, *saveAll=True*, *outputFileName=None*, ***kwargs*)

Display all the optical function plots for the two input optics files.

`pybdsim.Compare.`**`TransportVsBDSIM`**(*first*, *second*, *first_name=None*, *second_name=None*, *survey=None*, *saveAll=True*, *outputFileName=None*, ***kwargs*)

Display all the optical function plots for the two input optics files.

13.4 pybdsim.Constants module

`pybdsim.Constants.`**`GetPDGInd`**(*particlename*)

`pybdsim.Constants.`**`GetPDGName`**(*particleid*)

13.5 pybdsim.Convert

Module for various conversions.

`pybdsim.Convert.`**`BdsimPrimaries2Mad8`**(*inputfile*, *outfile*, *start=0*, *ninrays=-1*)

Takes .root file generated from a BDSIM run an an input and creates a MAD8 inrays file from the primary particle tree.

Parameters

- **`inputfile`** (*`str`*) – root format output from BDSIM run
- **`outfile`** (*`str`*) – filename for the inrays file
- **`start`** (*`int`*) – starting primary particle index
- **`ninrays`** (*`int`*) – total number of inrays to generate

`pybdsim.Convert.`**`BdsimPrimaries2Madx`**(*inputfile*, *outfile*, *start=0*, *ninrays=-1*)

Takes .root file generated from a BDSIM run an an input and creates a MADX inrays file from the primary particle tree.

Parameters

- **inputfile** (*str*) – root format output from BDSIM run
- **outfile** (*str*) – filename for the inrays file
- **start** (*int*) – starting primary particle index
- **ninrays** (*int*) – total number of inrays to generate, default is all available

`pybdsim.Convert.`**`BdsimPrimaries2Ptc`**(*inputfile*, *outfile=None*, *start=0*, *ninrays=-1*)

Takes .root file generated from a BDSIM run an an input and creates a PTC inrays file from the primary particle tree. If no output file name is given, it will be <inputfile>.madx (stripping off the .root).

Parameters

- **inputfile** (*str*) – root format output from BDSIM run
- **outfile** (*str*) – filename for the inrays file
- **start** (*int*) – starting primary particle index
- **ninrays** (*int*) – total number of inrays to generate (-1 means all)

`pybdsim.Convert.`**`MadxTfs2Gmad`**(*tfs*, *outputfilename*, *startname=None*, *stopname=None*, *stepsize=1*, *ignorezerolengthitems=True*, *samplers='all'*, *aperturedict={}*, *aperlocalpositions={}*, *collimatordict={}*, *userdict={}*, *partnamedict={}*, *verbose=False*, *beam=True*, *flipmagnets=None*, *usemadxaperture=False*, *defaultAperture='circular'*, *biases=None*, *allelementdict={}*, *optionsdict={}*, *beamparamsdict={}*, *linear=False*, *overwrite=True*, *write=True*, *allNamesUnique=False*, *namePrepend=''*)

MadxTfs2Gmad convert a madx twiss output file (.tfs) into a gmad tfs file for bdsim

Example:

```
>>> a,b = pybdsim.Convert.MadxTfs2Gmad('twiss.tfs', 'mymachine')
```

returns Machine, [omittedItems]

Returns two pybdsim.Builder.Machine instances. The first desired full conversion. The second is the raw conversion that's not split by aperture. Thirdly, a list of the names of the omitted items is returned.

tfs	path to the input tfs file or pymadx.Data.Tfs instance
outputfilename	requested output file
startname	the name (exact string match) of the lattice element to start the machine at this can also be an integer index of the element sequence number in madx tfs. This item is included in the lattice
stopname	the name (exact string match) of the lattice element to stop the machine at this can also be an integer index of the element sequence number in madx tfs. This item is not included
stepsize	the slice step size. Default is 1, but -1 also useful for reversed line.
ignorezerolengthitems	nothing can be zero length in bdsim as real objects of course have some finite size. Markers, etc are acceptable but for large lattices this can slow things down. True allows to ignore these altogether, which doesn't affect the length of the machine.
samplers	can specify where to set samplers - options are None, 'all', or a list of names of elements (normal python list of strings). Note default 'all' will generate separate outputfilename_samplers.gmad with all the samplers which will be included in the main .gmad file - you can comment out the include to therefore exclude all samplers and retain the samplers file.
aperturedict	Aperture information. Can either be a dictionary of dictionaries with the the first key the exact name of the element and the daughter dictionary containing the relevant bdsim parameters as keys (must be valid bdsim syntax). Alternatively, this can be a pymadx.Aperture instance that will be queried.
aperlocalpositions	Dictionary of element indices to local aperture definitions of the form {1: [(0.0, {"APERTYPE": "CIRCULAR", "APER1": 0.4}), (0.5, {"APERTYPE": "ELLIPSE", "APER1": 0.3, "APER2": 0.4}), …], 2: […], } This defines apertures in the element at index 1 starting with a CIRCULAR aper from 0.0m (i.e. the start) before changing to ELLIPSE 0.5m into the element, with possible further changes not displayed above. As the aperture definition in GMAD is tied inseparable from its aperture definition, and vice versa, this conversion function will automatically split the element at the provided local aperture points whilst retaining optical correctness. This kwarg is mutually exclusive with 'aperturedict'.
collimatordict	A dictionary of dictionaries with collimator information keys should be exact string match of element name in tfs file value should be dictionary with the following keys: 'bdsim_material' - the material 'angle' - rotation angle of collimator in radians 'xsize' - x full width in metres 'ysize' - y full width in metres
userdict	A python dictionary the user can supply with any additional information for that particular element. The dictionary should have keys matching the exact element name in the Tfs file and contain a dictionary itself with key, value pairs of parameters and values to be added to that particular element.
partnamedict	A python dictionary of dictionaries. The key is a

`pybdsim.Convert.`**`MadxTfs2GmadStrength`**`(`*input*, *outputfilename*, *existingmachine=None*, *verbose=False*, *flipmagnets=False*, *linear=False*, *allNamesUnique=False*, *ignoreZeroLengthItems=True*`)`

Use a MADX Tfs file containing full twiss information to generate a strength (only) BDSIM GMAD file to be used with an existing lattice.

existingmachine	either a list or dictionary with names of elements to prepare.
flipmagnet	similar behaviour to MAdxTfs2Gmad whether to flip k values for negatively charged particles.
linear	only use linear strengths, k2 and higher set to 0.

`pybdsim.Convert._MadxTfs2Gmad.`**`MadxTfs2Gmad`**`(`*tfs*, *outputfilename*, *startname=None*, *stopname=None*, *stepsize=1*, *ignorezerolengthitems=True*, *samplers='all'*, *aperturedict={}*, *aperlocalpositions={}*, *collimatordict={}*, *userdict={}*, *partnamedict={}*, *verbose=False*, *beam=True*, *flipmagnets=None*, *usemadxaperture=False*, *defaultAperture='circular'*, *biases=None*, *allelementdict={}*, *optionsdict={}*, *beamparamsdict={}*, *linear=False*, *overwrite=True*, *write=True*, *allNamesUnique=False*, *namePrepend=''*`)`

MadxTfs2Gmad convert a madx twiss output file (.tfs) into a gmad tfs file for bdsim

Example:

```
>>> a,b = pybdsim.Convert.MadxTfs2Gmad('twiss.tfs', 'mymachine')
```

returns Machine, [omittedItems]

Returns two pybdsim.Builder.Machine instances. The first desired full conversion. The second is the raw conversion that's not split by aperture. Thirdly, a list of the names of the omitted items is returned.

tfs	path to the input tfs file or pymadx.Data.Tfs instance
outputfilename	requested output file
startname	the name (exact string match) of the lattice element to start the machine at this can also be an integer index of the element sequence number in madx tfs. This item is included in the lattice
stopname	the name (exact string match) of the lattice element to stop the machine at this can also be an integer index of the element sequence number in madx tfs. This item is not included
stepsize	the slice step size. Default is 1, but -1 also useful for reversed line.
ignorezerolengthitems	nothing can be zero length in bdsim as real objects of course have some finite size. Markers, etc are acceptable but for large lattices this can slow things down. True allows to ignore these altogether, which doesn't affect the length of the machine.
samplers	can specify where to set samplers - options are None, 'all', or a list of names of elements (normal python list of strings). Note default 'all' will generate separate outputfilename_samplers.gmad with all the samplers which will be included in the main .gmad file - you can comment out the include to therefore exclude all samplers and retain the samplers file.
aperturedict	Aperture information. Can either be a dictionary of dictionaries with the the first key the exact name of the element and the daughter dictionary containing the relevant bdsim parameters as keys (must be valid bdsim syntax). Alternatively, this can be a pymadx.Aperture instance that will be queried.
aperlocalpositions	Dictionary of element indices to local aperture definitions of the form {1: [(0.0, {"APERTYPE": "CIRCULAR", "APER1": 0.4}), (0.5, {"APERTYPE": "ELLIPSE", "APER1": 0.3, "APER2": 0.4}), …], 2: […], } This defines apertures in the element at index 1 starting with a CIRCULAR aper from 0.0m (i.e. the start) before changing to ELLIPSE 0.5m into the element, with possible further changes not displayed above. As the aperture definition in GMAD is tied inseparable from its aperture definition, and vice versa, this conversion function will automatically split the element at the provided local aperture points whilst retaining optical correctness. This kwarg is mutually exclusive with 'aperturedict'.
collimatordict	A dictionary of dictionaries with collimator information keys should be exact string match of element name in tfs file value should be dictionary with the following keys: 'bdsim_material' - the material 'angle' - rotation angle of collimator in radians 'xsize' - x full width in metres 'ysize' - y full width in metres
userdict	A python dictionary the user can supply with any additional information for that particular element. The dictionary should have keys matching the exact element name in the Tfs file and the dictionary itself with key, value pairs of parameters and values to be added to that particular element.
partnamedict	A python dictionary of dictionaries. The key is a

`pybdsim.Convert._MadxTfs2Gmad.`**`MadxTfs2GmadBeam`**(*tfs*, *startname=None*, *verbose=False*, *extraParamsDict={}*)

Takes a pymadx.Data.Tfs instance and extracts information from first line to create a BDSIM beam definition in a pybdsim.Beam object. Note that if kwarg startname is used, the optics are retrieved at the start of the element, i.e. you do not need to get the optics of the previous element, this function does that automatically.

Works for e+, e- and proton. Default emittance is 1e-9mrad if 1 in tfs file.

`pybdsim.Convert._MadxTfs2Gmad.`**`ZeroMissingRequiredColumns`**(*tfsinstance*)

Sets any missing required columns to zero. Warns user when doing so.

13.6 pybdsim.Data module

Output loading

Read bdsim output

Classes: Data - read various output files

`class` `pybdsim.Data.`**`ApertureInfo`**(*apertureType*, *aper1*, *aper2=0*, *aper3=0*, *aper4=0*, *offsetX=0*, *offsetY=0*)

Bases: `object`

Simple class to hold aperture parameters and extents.

`class` `pybdsim.Data.`**`BDSAsciiData`**(**args*, ***kwargs*)

Bases: `list`

General class representing simple 2 column data.

Inherits python list. It's a list of tuples with extra columns of 'name' and 'units'.

`ConcatenateMachine`(**args*)

Add 1 or more data instances to this one - suitable only for things that could be loaded by this class. Argument can be one or iterable. Either of str type or this class.

`Filter`(*booleanarray*)

Filter the data with a booleanarray. Where true, will return that event in the data.

Return type is BDSAsciiData

`GetColumn`(*columnstring*, *ignoreCase=False*)

Return a numpy array of the values in columnstring in order as they appear in the beamline

`GetItemTuple`(*index*)

Get a specific entry in the data as a tuple of values rather than a dictionary.

`IndexFromNearestS`(*S*)

return the index of the beamline element clostest to S

Only works if "SStart" column exists in data

`MatchValue`(*parametername*, *matchvalue*, *tolerance*)

This is used to filter the instance of the class based on matching a parameter withing a certain tolerance.

```
>>> a = pybdsim.Data.Load("myfile.txt")
>>> a.MatchValue("S",0.3,0.0004)
```

this will match the "S" variable in instance "a" to the value of 0.3 within +- 0.0004.

You can therefore used to match any parameter.

Return type is BDSAsciiData

NameFromNearestS(*S*)

ToDF()

Get this BDSAsciiData instance as a pandas.DataFrame instance.

class pybdsim.Data.**BDSBH4D**(*hist*, *extractData=True*)

Bases: `object`

Wrapper for a BDSBH instance. Converts to numpy data.

ErrorsToErrorOnMean()

Errors are by default the error on the mean. However, if you used ErrorsToSTD, you can convert back to error on the mean with this function, which divides by sqrt(N).

ErrorsToSTD()

Errors are by default the error on the mean. Call this function to multiply by sqrt(N) to convert to the standard deviation. Will automatically only apply itself once even if repeatedly called.

class pybdsim.Data.**BeamData**(*data*)

Bases: `object`

classmethod **FromROOTFile**(*path*)

class pybdsim.Data.**CavityInfo**(*rootInstance=None*)

Bases: `object`

Simple class to represent a cavity info instance. Construct from a root instance of the class.

class pybdsim.Data.**CollimatorInfo**(*rootInstance=None*)

Bases: `object`

Simple class to represent a collimator info instance. Construct from a root instance of the class.

pybdsim.Data.**CreateEmptyRebdsimFile**(*outputfilename*, *nOriginalEvents=1*)

Create an empty rebdsim format file with the layout of folders. Returns the ROOT.TFile object.

class pybdsim.Data.**EventInfoData**(*data*)

Bases: `object`

Extract data from the Info branch of the Event tree.

classmethod **FromROOTFile**(*path*)

class pybdsim.Data.**EventSummaryData**(*data*)

Bases: *EventInfoData*

Extract data from the Summary branch of the Event tree.

pybdsim.Data.**GetApertureExtent**(*apertureType*, *aper1=0*, *aper2=0*, *aper3=0*, *aper4=0*)

pybdsim.Data.**GetModelForPlotting**(*rootFile*, *beamlineIndex=0*)

Returns BDSAsciiData object with just the columns from the model for plotting.

pybdsim.Data.**GetNEventsInBDSIMFile**(*filename*)

Utility function to extract the number of events in a file quickly without fully loading it. Uses only ROOT to inspect the tree. Will raise an IOError exception if no Event tree is found. No check if it's a BDSIM format file or not.

class pybdsim.Data.**Header**(***kwargs*)

Bases: `object`

A simple Python version of a header in a (RE)BDSIM file for easy access to the data.

class pybdsim.Data.**Histogram1DSet**(*name=None*)

Bases: `object`

Basic histogram for a categorical axis with a dict / map as the storage.

This is completely agnostic of the type of the value used as the axis.

It is ultimately a python dict[key] = (value, sumWeightsSq) where 'key' is the 'x' used to file the histogram.

The bin errors can be accessed by calling Result() to return a dictionary of key : (value, error)

h = Histogram1DSet("PDG_ID") h.Fill(2212) h.Fill(-13)

Histograms can be merged with the += operator:

h2 = Histogram1DSet() h2.Fill(2212) h2.Fill(13)

h2 += h1

Fill(*x*, *weight=1.0*)

Flush()

Empy the bins and set the number of entries to 0.

Result()

return a dictionary of key : (value, error)

value is the bin value. error is calculated as sqrt(sum(weights^2)/n) for the sum of the weights squared in an individual bin.

ResultMean()

return a dictionary of key : (mean, error)

mean is the bin value / n error is calculated as sqrt(1/n * sum(weights^2)/n) for the sum of the weights squared in an individual bin.

SortByBin()

pybdsim.Data.**Load**(*filepath*)

Load the data with the appropriate loader.

ASCII file - returns BDSAsciiData instance. BDSIM file - uses ROOT, returns BDSIM DataLoader instance. REBDSIM file - uses ROOT, returns RebdsimFile instance.

pybdsim.Data.**LoadPickledObject**(*filename*)

Unpickle an object. If the name contains .pbz2 the bz2 library will be used as well to load the compressed pickled object.

pybdsim.Data.**LoadROOTLibraries**()

Load root libraries. Only works once to prevent errors.

pybdsim.Data.**LoadSDDSColumnsToDict**(*filename*)

Load columns from an SDDS file, e.g. twiss output.

filename - str - path to file

returns dict{columnname:1d numpy array}

class pybdsim.Data.**ModelData**(*data*)

Bases: `object`

A python versio of the data held in a Model tree in BDSIM output.

d = pybdsim.Data.Load("output.root") md = pybdsim.Data.ModelData(d)

Extracts this from a bdsim output file.

classmethod FromROOTFile(*path*)

GetApertureData(*removeZeroLength=False*, *removeZeroApertures=True*, *lengthTolerance=1e-06*)

return a list of aperture instances along with coordinates: l,s,x,y,apertures l - length of element s - curvilinear S coordinate at the *end* of the element x - horizontal extent y - vertical extent apertures = [ApertureInfo]

PrepareAxisAngleRotations()

class pybdsim.Data.**OptionsData**(*data*)

Bases: `object`

classmethod FromROOTFile(*path*)

pybdsim.Data.**PadHistogram1D**(*hist*, *padValue=1e-20*)

Pad a 1D histogram with padValue.

This adds an extra 'bin' to xwidths, xcentres, xlowedge, xhighedge, contents and errors with either pad value or a linearly interpolated step in the range (i.e. for xcentres).

returns a new pybdsim.Data.TH1 instance.

pybdsim.Data.**ParseSpectraName**(*hname*)

class pybdsim.Data.**PhaseSpaceData**(*data*, *samplerIndexOrName=0*)

Bases: `_SamplerData`

Pull phase space data from a loaded DataLoader instance of raw data for all events.

Extracts only: 'x','xp','y','yp','z','zp','energy','T'

Can either supply the sampler name or index as the optional second argument. The index is 0 counting including the primaries (ie +1 on the index in data.GetSamplerNames()). Examples:

```
>>> f = pybdsim.Data.Load("file.root")
>>> primaries = pybdsim.Data.PhaseSpaceData(f)
>>> samplerfd45 = pybdsim.Data.PhaseSpaceData(f, "samplerfd45")
>>> thirdAfterPrimaries = pybdsim.Data.PhaseSpaceData(f, 3)
```

pybdsim.Data.**PickleObject**(*ob*, *filename*, *compress=True*)

Write an object to a pickled file using Python pickle.

If compress is True, the bz2 package will be imported and used to compress the file.

class pybdsim.Data.**ROOTHist**(*hist*)

Bases: `object`

Base class for histogram wrappers.

ErrorsToErrorOnMean()

Errors are by default the error on the mean. However, if you used ErrorsToSTD, you can convert back to error on the mean with this function, which divides by sqrt(N).

ErrorsToSTD()

Errors are by default the error on the mean. Call this function to multiply by sqrt(N) to convert to the standard deviation. Will automatically only apply itself once even if repeatedly called.

class pybdsim.Data.**RebdsimFile**(*filename*, *convert=True*, *histogramsOnly=False*)

Bases: `object`

Class to represent data in rebdsim output file.

Parameters

- **filename** (*str*) – File to load
- **convert** (*bool*) – Whether to ROOT histograms to pybdsim ones as well

- **histogramsOnly** (*bool*) – If true, then don't load rebdsim libraries and only load histograms.

Contains histograms as root objects. Conversion function converts to pybdsim.Rebdsim.THX classes holding numpy data.

If optics data is present, this is loaded into self.Optics which is BDSAsciiData instance.

If convert=True (default), root histograms are automatically converted to classes provided here with numpy data.

If histogramsOnly is true, only the basic ROOT libraries are needed (i.e. import ROOT) and no Model data will be loaded - only ROOT histograms.

ConvertToPybdsimHistograms()

Convert all root histograms into numpy arrays.

GetModel()

GetModelTree()

ListOfDirectories()

List all directories inside the root file.

ListOfLeavesInTree(*tree*)

List all leaves in a tree.

ListOfTrees()

List all trees inside the root file.

pybdsim.Data.**ReplaceZeroWithMinimum**(*hist*, *value=1e-20*)

Replace zero values with given value. Useful for log plots.

For log plots we want a small but +ve number instead of 0 so the line is continuous on the plot. This is also required for padding to work for the edge of the lines.

Works for TH1, TH2, TH3.

returns a new instance of the pybdsim.Data.TH1, TH2 or TH3.

pybdsim.Data.**SDDSBuildParameterDicts**(*sddsColumnDict*)

Use first the LoadSDDSColumnsToDict on a parameters file. Then call this function to sort it into ElementName : {ParameterName:ParameterValue}. An extra key will be added that is KEYWORD for the ElementType in the inner dictionary.

class pybdsim.Data.**SamplerData**(*data*, *samplerIndexOrName=0*)

Bases: `_SamplerData`

Pull sampler data from a loaded DataLoader instance of raw data for all events.

Loads all data in a given sampler.

Can either supply the sampler name or index as the optional second argument. The index is 0 counting including the primaries (ie +1 on the index in data.GetSamplerNames()). Examples:

```
>>> f = pybdsim.Data.Load("file.root")
>>> primaries = pybdsim.Data.SamplerData(f)
>>> samplerfd45 = pybdsim.Data.SamplerData(f, "samplerfd45")
>>> thirdAfterPrimaries = pybdsim.Data.SamplerData(f, 3)
```

class pybdsim.Data.**Spectra**(*nameIn=None*)

Bases: `object`

append(*pdgid*, *hist*, *path*, *nameIn=None*)

class `pybdsim.Data.`**`TH1`**(*hist*, *extractData=True*)

Bases: *ROOTHist*

Wrapper for a ROOT TH1 instance. Converts to numpy data.

```
>>> h = file.Get("histogramName")
>>> hpy = TH1(h)
```

`Rebin`(*nBins*)

class `pybdsim.Data.`**`TH2`**(*hist*, *extractData=True*)

Bases: *TH1*

Wrapper for a ROOT TH2 instance. Converts to numpy data.

```
>>> h = file.Get("histogramName")
>>> hpy = TH2(h)
```

`IntegrateAlongX`()

Integrate along the x axis returning a TH1 in y.

`IntegrateAlongY`()

Integrate along the y axis returning a TH1 in x.

`Rebin`(*nBinsX*, *nBinsY=None*)

`SwapAxes`()

Swap X and Y for all members. Returns a new copy of the histogram.

class `pybdsim.Data.`**`TH3`**(*hist*, *extractData=True*)

Bases: *TH2*

Wrapper for a ROOT TH3 instance. Converts to numpy data.

```
>>> h = file.Get("histogramName")
>>> hpy = TH3(h)
```

`IntegateAlong1Dimension`(*dimension*)

Integrate along a dimension returning a new 2D histogram.

Parameters

`dimension` (*`str`*) – 'x', 'y' or 'z' dimension to integrate along

returns pybdsim.Data.TH2 instance.

If the projection is done in z, a 2D histogram of x,y is returned that is the sum of the bins along z. The errors are also calculated.

For 'x', the 2D histogram is z,y. For 'y', the 2D histogram is z,x. For 'z', the 2D hsitogram is x,y.

`IntegateAlong2Dimensions`(*resultDimension*)

Integrate along 2 dimensions returning a new 1D histogram along the result dimension

Parameters

`resultDimension` (*`str`*) – 'x', 'y' or 'z' dimension to produce 1D histogram along.

returns pybdsim.Data.TH1 instance.

`Slice2DXY`(*index*)

Extract a single 2D histogram from an index along the Z dimension.

Parameters

`index` (*`int`*) – index in z array of bins to extract, e.g. 0 -> nbinsz-1

Slice2DXZ(*index*)

Extract a single 2D histogram from an index along the Y dimension.

Parameters
index (*int*) – index in y array of bins to extract, e.g. 0 -> nbinsy-1

Slice2DZY(*index*)

Extract a single 2D histogram from an index along the X dimension.

Parameters
index (*int*) – index in x array of bins to extract, e.g. 0 -> nbinsx-1

pybdsim.Data.**TRotationToAxisAngle**(*trot*)

This will return a list of [Ax,Ay,Az,angle] from a ROOT.TRotation.

If not imported, it will return [0,0,0,0]

class pybdsim.Data.**TrajectoryData**(*dataLoader*, *eventNumber=0*)

Bases: object

Pull trajectory data from a loaded Dataloader instance of raw data

Loads all trajectory data in a event event

```
>>> f = pybdsim.Data.Load("file.root")
>>> trajectories = pybdsim.Data.TrajectoryData(f,0)
```

next()

pybdsim.Data.**WriteROOTHistogramsToDirectory**(*tfile*, *directoryName*, *histograms*)

Parameters

- **tfile** (*ROOT.TFile.*) – TFile object to write to.
- **directoryName** (*str (e.g. "Event/PerEntryHistograms")*) – Full path of directory you wish to write the histograms to.
- **histograms** (*[ROOT.TH1,..]*) – List of ROOT histograms to write.

Write a list of histograms (ROOT.TH*) to a directory (str) in a ROOT.TFile instance.

13.7 pybdsim.Field module

Utilities to convert and prepare field maps.

Most of the plots assume magnetic fields for the labels, but they work equally well for electric fields.

class pybdsim.Field._Field.**Field**(*array=array([], dtype=float64)*, *columns=[]*, *flip=False*, *doublePrecision=False*)

Bases: object

Base class used for common writing procedures for BDSIM field format.

This does not support arbitrary loop ordering - only the originally intended xyzt.

AddComment(*commentString*)

Add a string that will be put on a comment line at the beginning of the file.

Write(*fileName*, *writeLoopOrderReversed=False*, *overrideLoopOrder=None*)

Parameters

- **writeLoopOrderReversed** (*bool*) – Write this field map with the other loop order.

- **overrideLoopOrder** (*str*) – string to write irrespective of internal data as the loop order.

gzip - if the file ends with ".gz" the file will be compressed automatically.

For overrideLoopOrder it should be only 'xyzt' or 'tzyx'. This option is provided in case a field is prepared in the other order somehow and you want to control the writing of this header variable independently.

WriteFLUKA2DFormat1(*fileName*)

Write one of the FLUKA formats (x,y,Bx,by) in cm,T with no header.

Very simple and only works for Field2D - can be improved.

class pybdsim.Field._Field.**Field1D**(*data*, *doublePrecision=False*, *column='X'*)

Bases: *Field*

Utility class to write a 1D field map array to BDSIM field format.

The array supplied should be 2 dimensional. Dimensions are: (x,value) where value has 4 elements [x,fx,fy,fz]. So a 120 long array would have np.shape of (120,4).

This can be used for both electric and magnetic fields.

Example:

```
>>> a = Field1D(data)
>>> a.Write('outputFileName.dat')
```

class pybdsim.Field._Field.**Field2D**(*data*, *flip=False*, *doublePrecision=False*, *firstColumn='X'*, *secondColumn='Y'*)

Bases: *Field*

Utility class to write a 2D field map array to BDSIM field format.

The array supplied should be 3 dimensional. Dimensions are: (x,y,value) where value has 5 elements [x,y,fx,fy,fz]. So a 100x50 (x,y) grid would have np.shape of (100,50,5).

Example:

```
>>> a = Field2D(data) # data is a prepared array
>>> a.Write('outputFileName.dat')
```

The 'flip' boolean allows an array with (y,x,value) dimension order to be written as (x,y,value). Values must still be (x,y,fx,fy,fz).

The 'doublePrecision' boolean controls whether the field and spatial values are written to 16 s.f. (True) or 8 s.f. (False - default).

class pybdsim.Field._Field.**Field3D**(*data*, *flip=False*, *doublePrecision=False*, *firstColumn='X'*, *secondColumn='Y'*, *thirdColumn='Z'*)

Bases: *Field*

Utility class to write a 3D field map array to BDSIM field format.

The array supplied should be 4 dimensional. Dimensions are: (x,y,z,value) where value has 6 elements [x,y,z,fx,fy,fz]. So a 100x50x30 (x,y,z) grid would have np.shape of (100,50,30,6).

Example:

```
>>> a = Field3D(data) # data is a prepared array
>>> a.Write('outputFileName.dat')
```

The 'flip' boolean allows an array with (z,y,x,value) dimension order to be written as (x,y,z,value). Values must still be (x,y,fx,fy,fz).

The 'doublePrecision' boolean controls whether the field and spatial values are written to 16 s.f. (True) or 8 s.f. (False - default).

class pybdsim.Field._Field.**Field4D**(*data*, *flip=False*, *doublePrecision=False*)

Bases: *Field*

Utility class to write a 4D field map array to BDSIM field format.

The array supplied should be 5 dimensional. Dimensions are: (t,y,z,x,value) where value has 7 elements [x,y,z,t,fx,fy,fz]. So a 100x50x30x10 (x,y,z,t) grid would have np.shape of (10,30,50,100,7).

Example:

```
>>> a = Field4D(data) # data is a prepared array
>>> a.Write('outputFileName.dat')
```

The 'flip' boolean allows an array with (t,z,y,x,value) dimension order to be written as (x,y,z,t,value). Values must still be (x,y,fx,fy,fz).

The 'doublePrecision' boolean controls whether the field and spatial values are written to 16 s.f. (True) or 8 s.f. (False - default).

pybdsim.Field._Field.**Load**(*filename*, *debug=False*)

Parameters
filename (*str*) – name of file to load

Load a BDSIM field format file into a numpy array. Can either be a regular ascii text file or can be a compressed file ending in ".tar.gz".

returns a numpy array with the corresponding number of dimensions and the dimension has the coordinates and fx,fy,fz.

pybdsim.Field._Field.**MirrorDipoleQuadrant1**(*field2D*)

2	1
3	4

Parameters
field2D (*pybdsim.Field._Field.Field2D instance*) – field object

returns an instance of the same type.

For a 2D field (i.e. function of x,y but can include Bx,By,Bz), for the quadrant #1, mirror it and generate a bigger field for all four quadrants.

1. original data
2. data mirrored in x, (x,Bx) *= -1
3. data mirrored in x,y, (x,y,By) *= -1
4. data mirrored in y, (y,Bx) *= -1

This is based on a dipole field.

pybdsim.Field._Field.**SortUnorderedFieldMap2D**(*field*)

Rearrange the data in a 2D field map to be in a linearly progressing loop of (x,y). In future this could be generalised to more dimensions and also any two dimensions, not just x,y.

Parameters
field (*pybdsim.Field.Field2D*) – Incoming jumbled field map

Returns a new Field2D object

class `pybdsim.Field.FieldPlotter.`**`FourDData`**(*filename*, *xind=0*, *yind=1*, *zind=2*, *tind=3*)

Class purely to simplify plotting of fields. Not for general use.

class `pybdsim.Field.FieldPlotter.`**`OneDData`**(*filename*)

Class purely to simplify plotting of fields. Not for general use.

`pybdsim.Field.FieldPlotter.`**`Plot1DFxFyFz`**(*filename*)

Plot a bdsim 1D field map file.

Parameters

filename (*str, pybdsim.Field._Field.Field1D instance*) – name of the field map file or object

`pybdsim.Field.FieldPlotter.`**`Plot2D`**(*filename*, *scale=None*, *title=None*, *flipX=False*, *flipY=False*, *firstDimension='X'*, *secondDimension='Y'*, *aspect='equal'*)

Plot a bdsim field map file using any two planes. The corresponding field components are plotted (e.g. X:Z -> Fx:Fz).

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **scale** (*float*) – numerical scaling for quiver plot arrow lengths.
- **title** (*str*) – title for plot
- **flipX** (*bool*) – whether to plot x backwards to match the right hand coordinate system of Geant4.
- **firstDimension** (*str*) – Name of first dimension, e.g. "X"
- **secondDimension** (*str*) – Name of second dimension, e.g. "Z"
- **aspect** (*str*) – Matplotlib axes aspect (e.g. 'auto' or 'equal')

`pybdsim.Field.FieldPlotter.`**`Plot2DXY`**(*filename*, *scale=None*, *title=None*, *flipX=False*, *firstDimension='X'*, *secondDimension='Y'*, *aspect='equal'*, *figsize=(6, 5)*)

Plot a bdsim field map file using the X,Y plane.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **scale** (*float*) – numerical scaling for quiver plot arrow lengths.
- **title** (*str*) – title for plot
- **flipX** (*bool*) – whether to plot x backwards to match the right hand coordinate system of Geant4.
- **firstDimension** (*str*) – Label of first dimension, e.g. "X"
- **secondDimension** (*str*) – Label of second dimension, e.g. "Z"
- **aspect** (*str*) – Matplotlib axes aspect (e.g. 'auto' or 'equal')

`pybdsim.Field.FieldPlotter.`**`Plot2DXYBx`**(*filename*, *scale=None*, *title=None*, *flipX=False*, *aspect='equal'*)

Plot a bdsim field map file use the X,Y plane, but plotting By component.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **scale** (*float*) – numerical scaling for quiver plot arrow lengths.

- **title** (*str*) – title for plot
- **aspect** (*str*) – Matplotlib axes aspect (e.g. 'auto' or 'equal')

`pybdsim.Field.FieldPlotter.`**`Plot2DXYBy`**(*filename*, *scale=None*, *title=None*, *flipX=False*, *aspect='equal'*)

Plot a bdsim field map file use the X,Y plane, but plotting By component.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **scale** (*float*) – numerical scaling for quiver plot arrow lengths.
- **title** (*str*) – title for plot
- **aspect** (*str*) – Matplotlib axes aspect (e.g. 'auto' or 'equal')

`pybdsim.Field.FieldPlotter.`**`Plot2DXYBz`**(*filename*, *scale=None*, *title=None*, *flipX=False*, *aspect='equal'*)

Plot a bdsim field map file use the X,Y plane, but plotting By component.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **scale** (*float*) – numerical scaling for quiver plot arrow lengths.
- **title** (*str*) – title for plot
- **aspect** (*str*) – Matplotlib axes aspect (e.g. 'auto' or 'equal')

`pybdsim.Field.FieldPlotter.`**`Plot2DXYComponent`**(*filename*, *componentIndex=2*, *scale=None*, *title=None*, *flipX=False*, *aspect='equal'*)

Plot a bdsim field map file use the X,Y plane, but plotting By component.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **componentIndex** (*int*) – index of field component (0,1,2) for Fx, Fy, Fz
- **scale** (*float*) – numerical scaling for quiver plot arrow lengths.
- **title** (*str*) – title for plot
- **aspect** (*str*) – Matplotlib axes aspect (e.g. 'auto' or 'equal')

`pybdsim.Field.FieldPlotter.`**`Plot2DXYConnectionOrder`**(*filename*)

Plot a point in orange and a line in blue (default matplotlib colours) for each locationin the field map. If the field map is constructed correctly, this should show a set of lines with diagonals between them. The other plots with the arrows are independent of order unlike when BDSIM loads the fields. So you might see an OK field map, but it could be wrong if hand written.

`pybdsim.Field.FieldPlotter.`**`Plot2DXYFxFyFz`**(*filename*, *title=None*, *aspect='auto'*, *extent=None*, ***imshowKwargs*)

Plot Fx,Fy,Fz components of a field separately as a function of X,Y.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field1D instance*) – name of field map file or object
- **title** (*None, str*) – optional title for plot
- **aspect** (*str*) – aspect ratio for matplotlib imshow

- **extent** (*list, tuple*) – list or tuple of (xmin,xmax,ymin,ymax) for each plot (optional)

`pybdsim.Field.FieldPlotter.`**`Plot2DXYMagnitude`**(*filename*, *title=None*, *flipX=False*, *firstDimension='X'*, *secondDimension='Y'*, *aspect='equal'*, *zlabel='|$B_{x,y}$| (T)'*, *figsize=(6, 5)*)

Plot a the magnitude of a 2D bdsim field map file using any two planes.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D instance*) – name of field map file or object
- **title** (*str, None*) – title for plot
- **flipX** (*bool*) – whether to plot x backwards to match the right hand coordinate system of Geant4.
- **firstDimension** (*str*) – Name of first dimension, e.g. “X”
- **secondDimension** (*str*) – Name of second dimension, e.g. “Z”
- **aspect** (*str*) – Matplotlib axes aspect (e.g. ‘auto’ or ‘equal’)
- **zlabel** (*str*) – Label for colour bar

`pybdsim.Field.FieldPlotter.`**`Plot2DXYStream`**(*filename*, *density=1*, *zIndexIf3D=0*, *useColour=True*, *aspect='equal'*)

Plot a bdsim field map file using the X,Y plane as a stream plot and plotting Fx, Fy.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D or Field3D instance*) – name of field map file or object
- **density** (*float*) – arrow density (default=1) for matplotlib streamplot
- **zIndexIf3D** (*int*) – index in Z if using 3D field map (default=0)
- **useColour** (*bool :param aspect: Matplotlib axes aspect (e.g. 'auto' or 'equal')*) – use magnitude of field as colour.

Note, matplotlibs streamplot may raise an exception if the field is entriely 0 valued.

`pybdsim.Field.FieldPlotter.`**`Plot2DXZStream`**(*filename*, *density=1*, *yIndexIf3D=0*, *useColour=True*, *aspect='equal'*)

Plot a bdsim field map file using the X,Z plane as a stream plot and plotting Fx, Fz.

Parameters

- **filename** (*str, pybdsim.Field._Field.Field2D or Field3D instance*) – name of field map file or object
- **density** (*float*) – arrow density (default=1) for matplotlib streamplot
- **yIndexIf3D** (*int*) – index in Z if using 3D field map (default=0)
- **useColour** (*bool*) – use magnitude of field as colour.
- **aspect** (*str*) – Matplotlib axes aspect (e.g. ‘auto’ or ‘equal’)

Note, matplotlibs streamplot may raise an exception if the field is entriely 0 valued.

`pybdsim.Field.FieldPlotter.`**`Plot3DXY`**(*filename*, *scale=None*)

Plots (B_x,B_y) as a function of x and y.

`pybdsim.Field.FieldPlotter.`**`Plot3DXZ`**(*filename*, *scale=None*)

Plots (B_x,B_z) as a function of x and z.

class pybdsim.Field.FieldPlotter.**ThreeDData**(*filename*)

Class purely to simplify plotting of fields. Not for general use.

class pybdsim.Field.FieldPlotter.**TwoDData**(*filename*)

Class purely to simplify plotting of fields. Not for general use.

13.8 pybdsim.Gmad module

Survey() - survey a gmad lattice, plot element coords
Loader() - load a gmad file using the compiled bdsim parser
GmadFile() - modify a text based gmad file

class pybdsim.Gmad.**GmadFile**(*fileName*)

Bases: `object`

Class to determine parameters and gmad include structure

class pybdsim.Gmad.**GmadFileBeam**(*fileName*)

Bases: `object`

Class to load a gmad options file to a buffer and modify the contents

class pybdsim.Gmad.**GmadFileComponents**(*fileName*)

Bases: `object`

Class to load a gmad components file to a buffer and modify the contents

Example : python> g = pybdsim.Gmad.GmadFileComponents("./atf2_components.gmad") python> g.change("KEX1A","l","10") python> g.write("./atf2_components.gmad")

change(*element*, *parameter*, *value*)

Edit element dictionary

elementNames()

Make a list of element names, stored in self.elementNameList

findElement(*elementName*)

Returns the start and end (inclusive location of the element lines as a tuble (start,end)

getParameter(*element*, *parameter*)

Edit element dictionary

getType(*element*)

parseElement(*elementString*)

Create element dictionary from element

write(*fileName*)

class pybdsim.Gmad.**GmadFileOptions**(*fileName*)

Bases: `object`

Class to load a gmad options file to a buffer and modify the contents

class pybdsim.Gmad.**Lattice**(*filename=None*)

Bases: `object`

BDSIM Gmad parser lattice.

Use this class to load a bdsim input file using the BDSIM parser (GMAD) and then interrogate it. You can use this to regenerate a lattice with less information for example

```
>>> a = Lattice("filename.gmad")
```

or

```
>>> a = Lattice()
>>> a.Load("filename.gmad")
>>> a  # this will tell you some basic details
>>> print(a) # this will print out the full lattice
```

GetAllNames()

GetAngle(*index*)

GetAper1(*index*)

GetAper2(*index*)

GetAper3(*index*)

GetAper4(*index*)

GetApertureExtents()

GetApertureType(*index*)

GetColumn(*column*)

GetElement(*i*)

GetIndexOfElementNamed(*elementname*)

GetKs(*index*)

GetLength(*index*)

GetName(*index*)

GetType(*index*)

IndexFromNearestS(*S*)

return the index of the beamline element clostest to S

Load(*filename*)

Load the BDSIM input file and parse it using the BDSIM parser (GMAD).

ParseLattice()

Put lattice data into python data structure

Print(*includeheaderlines=True*)

PrintZeroLength(*includeheaderlines=True*)

Print elements with zero length with s location

next()

class pybdsim.Gmad.**Survey**(*filename=None*)

Bases: `object`

Survey - load a gmad lattice and have a look

Example:

```
>>> a = Survey()
>>> a.Load('mylattice.gmad')
>>> a.Plot()
```

CompareMadX(*fileName*)

FinalDiff()

FindClosestElement(*coord*)

Load(*filename*)

Plot()

Step(*angle*, *length*)

13.9 pybdsim.ModelProcessing module

ModelProcessing

Tools to process existing BDSIM models and generate other versions of them.

pybdsim.ModelProcessing.**GenerateFullListOfSamplers**(*inputfile*, *outputfile*)

inputfile - path to main gmad input file

This will parse the input using the compiled BDSIM parser (GMAD), iterate over all the beamline elements and generate a sampler for every elements. Ignores samplers, but may include already defined ones in your own input.

pybdsim.ModelProcessing.**GetAxisAlignedBoundingBoxOfCollimator**(*modelData*, *collimatorName*)

Inspect pybdsim.Data.ModelData assuming collimator info was stored to give an axis aligned bounding box set of ranges in global coordinates.

pybdsim.ModelProcessing.**GetMaterialIDOfCollimator**(*modelData*, *collimatorName*)

Inspect pybdsim.Data.ModelData assuming collimator info was stored to give an axis aligned bounding box set of ranges in global coordinates.

pybdsim.ModelProcessing.**WrapLatticeAboutItem**(*maingmadfile*, *itemname*, *outputfilename*)

13.10 pybdsim.Options module

See Options class inside this module.

pybdsim.Options.**ElectronColliderOptions**()

class pybdsim.Options.**Options**(**args*, ***kwargs*)

Bases: `dict`

Inherits a dict. Converting to a string or using ReturnOptionsString() will give a suitable GMAD string to write out to a file.

o = pybdsim.Options.Options() o["trajectoryConnect"] = 1 o["aper1"] = (5, 'm') str(o) 'option, trajectoryConnect=1,

aper1=5*m;'

There is no checking on the option if using []. A tuple of (value, unitsString) can be used too resulting in value*unitsString.

`ReturnOptionsString`()

`SetBLMLength`(*length=50.0*, *unitsstring='cm'*)

`SetBLMRadius`(*radius=5.0*, *unitsstring='cm'*)

`SetBeamPipeRadius`(*beampiperadius=5.0*, *unitsstring='cm'*)

`SetBeamPipeThickness`(*bpt*, *unitsstring='mm'*)

`SetBeamlineS`(*beamlineS=0*, *unitsstring='m'*)

`SetBuildTunnel`(*tunnel=False*)

`SetBuildTunnelFloor`(*tunnelfloor=False*)

`SetCherenkovOn`(*on=True*)

`SetChordStepMinimum`(*csm=1.0*, *unitsstring='nm'*)

`SetDefaultBiasMaterial`(*biases=''*)

`SetDefaultBiasVaccum`(*biases=''*)

`SetDefaultRangeCut`(*drc=0.7*, *unitsstring='mm'*)

`SetDeltaChord`(*dc=0.001*, *unitsstring='m'*)

`SetDeltaIntersection`(*di=10.0*, *unitsstring='nm'*)

`SetDeltaOneStep`(*dos=10.0*, *unitsstring='nm'*)

`SetDontSplitSBends`(*dontsplitsbends=False*)

`SetELossHistBinWidth`(*width*)

`SetEMLeadParticleBiasing`(*on=True*)

`SetEPAnnihilation2HadronEnhancementFactor`(*ef=1.0*)

`SetEPAnnihilation2MuonEnhancementFactor`(*ef=1.0*)

`SetGamma2MuonEnahncementFactor`(*ef=1.0*)

`SetGeneralOption`(*option*, *value*)

`SetIncludeFringeFields`(*on=True*)

`SetIncludeIronMagField`(*iron=True*)

`SetIntegratorSet`(*integratorSet='"bdsim"'*)

`SetLPBFraction`(*fraction=0.5*)

`SetLengthSafety`(*ls=10.0*, *unitsstring='um'*)

`SetMagnetGeometryType`(*magnetGeometryType='"none"'*)

`SetMaximumEpsilonStep`(*mes=1.0*, *unitsstring='m'*)

`SetMaximumStepLength`(*msl=20.0*, *unitsstring='m'*)

`SetMaximumTrackingTime`(*mtt=-1.0*, *unitsstring='s'*)

`SetMinimumEpsilonStep`(*mes=10.0*, *unitsstring='nm'*)

`SetNGenerate`(*nparticles=10*)

`SetNLinesIgnore`(*nlines=0*)

`SetNPerFile`(*nperfile=100*)

`SetOuterDiameter`(*outerdiameter=2.0*, *unitsstring='m'*)

`SetPhysicsList`(*physicslist=''*)

`SetPipeMaterial`(*bpm*)

`SetPrintModuloFraction`(*pmf=0.01*)

`SetProductionCutElectrons`(*pc=100.0*, *unitsstring='keV'*)

`SetProductionCutPhotons`(*pc=100.0*, *unitsstring='keV'*)

`SetProductionCutPositrons`(*pc=100.0*, *unitsstring='keV'*)

`SetRandomSeed`(*rs=0*)

`SetSRLowX`(*lowx=True*)

`SetSRMultiplicity`(*srm=2.0*)

`SetSamplerDiameter`(*radius=10.0*, *unitsstring='m'*)

`SetSensitiveBeamPipe`(*on=True*)

`SetSensitiveBeamlineComponents`(*on=True*)

`SetSenssitiveBLMs`(*on=True*)

`SetSoilMaterial`(*sm*)

`SetSoilThickness`(*st=4.0*, *unitsstring='m'*)

`SetStopSecondaries`(*stop=True*)

`SetStoreTrajectory`(*on=True*)

`SetStoreTrajectoryParticle`(*particle='muon'*)

`SetSynchRadiationOn`(*on=True*)

`SetThresholdCutCharged`(*tcc=100.0*, *unitsstring='MeV'*)

`SetThresholdCutPhotons`(*tcp=1.0*, *unitsstring='MeV'*)

`SetTrackSRPhotons`(*track=True*)

`SetTrajectoryCutGTZ`(*gtz=0.0*, *unitsstring='m'*)

`SetTrajectoryCutLTR`(*ltr=10.0*, *unitsstring='m'*)

`SetTunnelFloorOffset`(*offset=1.0*, *unitsstring='m'*)

`SetTunnelMaterial`(*tm*)

`SetTunnelOffsetX`(*offset=0.0*, *unitsstring='m'*)

`SetTunnelOffsetY`(*offset=0.0*, *unitsstring='m'*)

`SetTunnelRadius`(*tunnelradius=2.0*, *unitsstring='m'*)

SetTunnelThickness(*tt=1.0*, *unitsstring='m'*)

SetVacuumMaterial(*vm*)

SetVacuumPressure(*vp*)

Vacuum pressure in bar

SetWritePrimaries(*on=True*)

pybdsim.Options.**ProtonColliderOptions**()

13.11 pybdsim.Plot module

Useful plots for bdsim output

pybdsim.Plot.**AddMachineLatticeFromSurveyToFigure**(*figure*, *surveyfile*, *tightLayout=True*, *sOffset=0.0*, *fraction=0.9*)

Add a machine diagram to the top of the plot in a current figure sOffset offsets survey along s fraction controls fraction of the figure for the plot, the remainder being used for the survey

pybdsim.Plot.**AddMachineLatticeFromSurveyToFigureMultiple**(*figure*, *machines*, *tightLayout=True*)

Similar to AddMachineLatticeFromSurveyToFigure() but accepts multiple machines.

pybdsim.Plot.**AddMachineLatticeToFigure**(*figure*, *tfsfile*, *tightLayout=True*)

A forward to the pymadx.Plot.AddMachineLatticeToFigure function.

pybdsim.Plot.**Aperture**(*rootFileName*, *filterThin=False*, *surveyFileName=None*)

pybdsim.Plot.**BDSIMAperture**(*data*, *machineDiagram=True*, *plot='xy'*, *plotApertureType=True*, *removeZeroLength=False*, *removeZeroApertures=True*)

Plot the aperture from a BDSIM DataLoader instance. By default it's colour coded and excludes any 0 aperture elements. Zero length elements are included.

pybdsim.Plot.**BDSIMApertureFromFile**(*filename*, *machineDiagram=True*, *plot='xy'*, *plotApertureType=True*, *removeZeroLength=False*, *removeZeroApertures=True*)

Plot the aperture from a BDSIM output file. By default it's colour coded and excludes any 0s.

pybdsim.Plot.**BDSIMOptics**(*rebdsimOpticsOutput*, *outputfilename=None*, *saveall=True*, *survey=None*, ***kwargs*)

Display all the optical function plots for a rebdsim optics root file. By default, this saves all optical functions into a single (outputfilename) pdf, to save the optical functions separately, supply an outputfilename with saveall=false.

pybdsim.Plot.**DrawMachineLattice**(*axesinstance*, *bdsasciidataobject*, *sOffset=0.0*)

pybdsim.Plot.**EnergyDeposition**(*filename*, *outputfilename=None*, *tfssurvey=None*, *bdsimsurvey=None*)

Plot the energy deposition from a REBDSIM output file - uses premade merged histograms.

Optional either Twiss table for MADX or BDSIM Survey to add machine diagram to plot. If both are provided, the machine diagram is plotted from the MADX survey.

pybdsim.Plot.**EnergyDepositionCoded**(*filename*, *outputfilename=None*, *tfssurvey=None*, *bdsimsurvey=None*, *warmaperinfo=None*, ***kwargs*)

Plot the energy deposition from a REBDSIM output file - uses premade merged histograms.

Optional either Twiss table for MADX or BDSIM Survey to add machine diagram to plot. If both are provided, the machine diagram is plotted from the MADX survey.

If a BDSIM survey is provided, collimator positions and dimensions can be taken and used to split losses into categories: collimator, warm and cold based on warm aperture infomation provided. To enable this, the "warmaperinfo" option must be set according to the prescription below.

The user can supply a list of upper and lower edges of warm regions or give the path to a coulmn-formated data file with this information via the "warmaperinfo" option. Set warmaperinfo=1 to treat all non-collimator losses as warm or set warmaperinfo=-1 to treat them as cold. Default is not perform the loss classification.

If no warm aperture information is provided, the plotting falls back to the standard simple plotting provided by a pybdsimm.Plot.Hisgogram1D interface.

Args:

filename (str): Path to the REBDSIM data file outputfilename (str, optional): Path where to save a pdf file with the plot. Default is None.

tfssurvey (str, optional): Path to MADX survey used to plot machine diagram on top of figure. Default is None.

tfssurvey (str, optional): Path to BDSIM survey used to classify losses into collimator/warm/cold and/or plot machine diagram on top of figure. Default is None.

warmaperinfo (int|list|str, optional): Information about warm aperture in the machine. Default is None. **kwargs: Arbitrary keyword arguments.

Kwargs:

skipMachineLattice (bool): If enabled, use the BDSIM survey to classify losses, but do not plot the lattice on top.

Returns:

matplotlib.pyplot.Figure object

`pybdsim.Plot.`**`Histogram1D`**(*histogram*, *xlabel=None*, *ylabel=None*, *title=None*, *scalingFactor=1.0*, *xScalingFactor=1.0*, *figsize=(6.4, 4.8)*, *log=False*, ***errorbarKwargs*)

Plot a pybdsim.Data.TH1 instance.

Parameters

- **`xlabel`** – x axis label
- **`ylabel`** – y axis label
- **`title`** – plot title
- **`scalingFactor`** – multiplier for values
- **`xScalingFactor`** – multiplier for x axis coordinates
- **`log`** – whether to automatically plot on a vertical log scale

return figure instance

`pybdsim.Plot.`**`Histogram1DMultiple`**(*histograms*, *labels*, *log=False*, *xlog=False*, *xlabel=None*, *ylabel=None*, *title=None*, *scalingFactors=None*, *xScalingFactors=None*, *figsize=(10, 5)*, *legendKwargs={}*, ***errorbarKwargs*)

Plot multiple 1D histograms on the same plot. Histograms and labels should be lists of the same length with pybdsim.Data.TH1 objects and strings.

return figure instance

xScalingFactors may be a float, int or list

Example:

```
Histogram1DMultiple([h1,h2,h3],
                    ['Photons', 'Electrons', 'Positrons'],
                    xlabel=r'$\mu$m',
```

(continues on next page)

(continued from previous page)

```
                       ylabel='Fraction',
                       scalingFactors=[1,100,100],
                       xScalingFactors=1e6,
                       log=True)
```

`pybdsim.Plot.`**`Histogram1DRatio`**(*histogram1*, *histogram2*, *label1=''*, *label2=''*, *xLogScale=False*, *yLogScale=False*, *xlabel=None*, *ylabel=None*, *title=None*, *scalingFactor=1.0*, *xScalingFactor=1.0*, *figsize=(6.4, 4.8)*, *ratio=3*, *histogram1Colour=None*, *histogram2Colour=None*, *ratioColour=None*, *ratioYAxisLimit=None*, ***errorbarKwargs*)

Plot two histograms with their ratio (#1 / #2) in a subplot below.

Parameters

- **`histogram1`** – a *pybdsim.Data.TH1* instance
- **`histogram2`** – a *pybdsim.Data.TH1* instance
- **`label1`** – legend label for histogram1 (str or "" or None)
- **`label2`** – legend label for histogram2
- **`ratio`** – integer ratio of main plot height to ratio plot height (recommend 1 - 5)
- **`ratioYAxisLimit`** (*`tuple(float, float)`*) – ylim upper for ratio subplot y axis

If the labels are "" then the histogram.title string will be used. If None, then no label will be added.

`pybdsim.Plot.`**`Histogram2D`**(*histogram*, *logNorm=False*, *xLogScale=False*, *yLogScale=False*, *xlabel=''*, *ylabel=''*, *zlabel=''*, *title=''*, *aspect='auto'*, *scalingFactor=1.0*, *xScalingFactor=1.0*, *yScalingFactor=1.0*, *figsize=(6, 5)*, *vmin=None*, *autovmin=False*, *vmax=None*, *colourbar=True*, ***imshowKwargs*)

Plot a pybdsim.Data.TH2 instance. logNorm - logarithmic colour scale xlogscale - x axis logarithmic scale ylogscale - y axis logarithmic scale zlabel - label for color bar scale aspect - "auto", "equal", "none" - see imshow? scalingFactor - multiplier for values xScalingFactor - multiplier for x coordinates yScalingFactor - multiplier for y coordinates autovmin - automatically determin the lower limit of the colourbar from the data vmin - explicitly control the vmin for the colour normalisation vmax - explicitly control the vmax for the colour normalisation

return figure instance

`pybdsim.Plot.`**`Histogram2DErrors`**(*histogram*, *logNorm=False*, *xLogScale=False*, *yLogScale=False*, *xlabel=''*, *ylabel=''*, *zlabel=''*, *title=''*, *aspect='auto'*, *scalingFactor=1.0*, *xScalingFactor=1.0*, *yScalingFactor=1.0*, *figsize=(6, 5)*, *vmin=None*, *autovmin=False*, *vmax=None*, ***imshowKwargs*)

Similar to Histogram2D() but plot the errors from the histogram instead of the contents. See pybdsim.Plot.Histogram2D for documentation of arguments.

`pybdsim.Plot.`**`Histogram3D`**(*th3*)

Plot a pybdsim.Data.TH3 instance - TBC

`pybdsim.Plot.`**`LossAndEnergyDeposition`**(*filename*, *outputfilename=None*, *tfssurvey=None*, *bdsimsurvey=None*, *hitslegendloc='upper left'*, *elosslegendloc='upper right'*, *perelement=False*, *elossylim=None*, *phitsylim=None*)

Load a REBDSIM output file and plot the merged histograms automatically generated by BDSIM.

Optional either Twiss table for MADX or BDSIM Survey to add machine diagram to plot.

`pybdsim.Plot.`**`LossMap`**(*ax*, *xcentres*, *y*, *ylow=None*, ***kwargs*)

Plot a loss map in such a way that works well for very large loss maps. xcentres, xwidth and y are all provided by TH1 python histograms (see pybdsim.Data.TH1).

Parameters

- `ax` – Matplotlib axes instance to draw to
- `xcentres` – centres of bins
- `y` – loss map signal data, same length as xcentres.
- `ylow` – small non-zero value to fill between to ensure works with log scales.

kwargs: * passed to calls to plot and fill_between.

`pybdsim.Plot.`**`MadxTfsBeta`**`(`*tfsfile*, *title=''*, *outputfilename=None*`)`

A forward to the pymadx.Plot.PlotTfsBeta function.

`pybdsim.Plot.`**`ModelBDSIMXZ`**`(`*model*, *ax=None*`)`

`pybdsim.Plot.`**`ModelBDSIMYZ`**`(`*model*, *ax=None*`)`

`pybdsim.Plot.`**`ModelElegantXZ`**`(`*model*, *ax=None*, *transpose=False*`)`

`pybdsim.Plot.`**`ModelElegantYZ`**`(`*model*, *ax=None*, *transpose=False*`)`

`pybdsim.Plot.`**`PhaseSpace`**`(`*data*, *nbins=None*, *outputfilename=None*, *extension='.pdf'*`)`

Make two figures for coordinates and correlations.

Number of bins chosen depending on number of samples.

'outputfilename' should be without an extension - any extension will be stripped off.
Plots are saves automatically as pdf, the file extension can be changed with the 'extension' kwarg, e.g. extension='.png'.

`pybdsim.Plot.`**`PhaseSpaceFromFile`**`(`*filename*, *samplerIndexOrName=0*, *nbins=None*, *outputfilename=None*, *extension='.pdf'*`)`

Load a BDSIM output file and plot the phase space of a sampler (default the primaries). Only accepts raw BDSIM output.

Number of bins chosen depending on number of samples.

'outputfilename' should be without an extension - any extension will be stripped off. Plots are saves automatically as pdf, the file extension can be changed with the 'extension' kwarg, e.g. extension='.png'.

`pybdsim.Plot.`**`PhaseSpaceSeparateAxes`**`(`*filename*, *samplerIndexOrName=0*, *outputfilename=None*, *extension='.pdf'*, *nbins=None*, *energy='total'*, *offsetTime=True*, *includeSecondaries=False*, *coordsTitle=None*, *correlationTitle=None*, *scalefactors={}*, *labels={}*, *log1daxes=False*, *log2daxes=False*, *includeColorbar=True*`)`

Plot the coordinates and correlations of both the transverse and longitudinal phase space in separate plots (four total) recorded in a sampler. Default sampler is the primary distribution.

'outputfilename' is name without extension, extension can be supplied as a string separately. Default = pdf.

The number of bins chosen depending on number of samples. Can be overridden with nbins.

Energy can be binned as either kinetic or total (default), supply either energy='total' or energy='kinetic'.

offSetTime centers the time distribution about the nominal time for the specified sampler rather than the absolute time. Default = True.

Secondaries can be included in the distributions with includeSecondaries. Default = False.

Plot titles can be supplied as strings with coordsTitle and correlationTitle.

Parameter scale factors should be supplied in a dictionary in the format {parameter: scalefactor}, e.g scalefactors={'x': 1000, 'y':1000}. Acceptable parameters are 'x','y','xp','yp', 'T','kinetic', and 'energy' for total energy.

Axis labels for parameters should be supplied as a dictionary in the format {parameter: label}, e.g labels={'x': "X (mm)", 'energy': "Energy (MeV)"}. Acceptable parameters are 'x','y','xp','yp', 'T','kinetic', and 'energy' for total energy.

log1daxes & log2daxes plots the 1D and 2D phase space on logarithmic scales respectively. Defaults = False.

includeColorbar adds a colorbar to the correlation plots. The colorbar is normalised for all plot subfigures. Default = True.

`pybdsim.Plot.`**`PlotAlpha`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotBeta`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotDisp`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotDispP`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotMean`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotNPart`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotSigma`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PlotSigmaP`**`(`*bds*, *outputfilename=None*, *survey=None*, ***kwargs*`)`

`pybdsim.Plot.`**`PrimaryPhaseSpace`**`(`*filename*, *outputfilename=None*, *extension='.pdf'*`)`

Load a BDSIM output file and plot primary phase space. Only accepts raw BDSIM output.

'outputfilename' should be without an extension - any extension will be stripped off. Plots are saves automatically as pdf, the file extension can be changed with the 'extension' kwarg, e.g. extension='.png'.

`pybdsim.Plot.`**`PrimarySurvival`**`(`*filename*, *outputfilename=None*, *tfssurvey=None*, *bdsimsurvey=None*`)`

`pybdsim.Plot.`**`PrimaryTrajectoryAndProcess`**`(`*rootData*, *eventNumber*`)`

`pybdsim.Plot.`**`ProvideWrappedS`**`(`*sArray*, *index*`)`

`pybdsim.Plot.`**`Spectra`**`(`*spectra*, *log=False*, *xlog=False*, *xlabel=None*, *ylabel=None*, *title=None*, *scalingFactors=None*, *xScalingFactors=None*, *figsize=(10, 5)*, *legendKwargs={}*, ***errorbarKwargs*`)`

`pybdsim.Plot.`**`SubplotsWithDrawnMachineLattice`**`(`*survey*, *nrows=2*, *machine_plot_gap=0.01*, *gridspec_kw=None*, *subplots_kw=None*, ***fig_kw*`)`

Create a figure with a single column of axes, sharing the x-axis by default, with the machine drawn from the provided survey on the top row axes. nrows gives the number of axes, the first is always the machine lattice. by default 2 are drawn, the first for the machine, and the second for any data to be plotted to afterwards.

Parameters: survey : BSDIM survey which is used to draw the machine lattice on the top axes. machine_plot_gap : vertical space between the top of the first axes and the bottom of the machine axes. By default this is small.

Returns (figure, machine_axes, (axes1, axes2, …))

figure : Figure instance. machine_axes : Axes instance with the machine drawn on it. Can be used to further edit axes : iterable of axes, in order from the first below the machine, downwards.

`pybdsim.Plot.`**`Trajectory3D`**`(`*rootFileName*, *eventNumber=0*, *bottomLeft=None*, *topRight=None*`)`

Plot e-, e+ and photons only as r,g,b respectively for a given event from a BDSIM output file.

bottomLeft and topRight are optional [xlow,xhigh] limits for plots.

13.12 pybdsim.Run module

Utilities for running BDSIM and other tools from Python.

pybdsim.Run.**Bdsim**(*gmadpath*, *outfile*, *ngenerate=10000*, *batch=True*, *silent=False*, *errorSilent=False*, *options=None*, *bdsimExecutable=None*)

Runs bdsim with gmadpath as inputfile and outfile as outfile. Runs in batch mode by default, with 10,000 particles. Any extra options should be provided as a string or iterable of strings of the form "–vis_debug" or "–vis_mac=vis.mac", etc.

class pybdsim.Run.**ExecOptions**(**args*, ***kwargs*)

Bases: dict

GetExecArgs()

GetExecFlags()

pybdsim.Run.**GetOpticsFromGMAD**(*gmad*, *keep_optics=False*)

Get the optical functions as a BDSAsciiData instance from this GMAD file. If keep_optics is false then all intermediate files are discarded, otherwise the final optics ROOT file is written to ./

class pybdsim.Run.**GmadModifier**(*rootgmadfilename*)

Bases: object

CheckExtensions()

DetermineIncludes(*filename*)

ReplaceTokens(*tokenDict*)

pybdsim.Run.**Rebdsim**(*rootpath*, *inpath*, *outpath*, *silent=False*, *rebdsimExecutable=None*)

Run rebdsim with rootpath as analysisConfig file, inpath as bdsim file, and outpath as output analysis file.

pybdsim.Run.**RebdsimCombine**(*rootpath*, *outpath*, *silent=False*, *rebdsimHistoExecutable=None*)

Run rebdsimCombine

pybdsim.Run.**RebdsimHistoMerge**(*rootpath*, *outpath*, *silent=False*, *rebdsimHistoExecutable=None*)

Run rebdsimHistoMerge

pybdsim.Run.**RebdsimOptics**(*rootpath*, *outpath*, *silent=False*)

Run rebdsimOptics

pybdsim.Run.**RebdsimOrbit**(*rootpath*, *outpath*, *index='1'*, *silent=False*, *rebdsimHistoExecutable=None*)

Run rebdsimOrbit

class pybdsim.Run.**Study**

Bases: object

A holder for multiple runs.

GetInfo(*index=-1*)

Get info about a particular run.

Run(*inputfile='optics.gmad'*, *output='rootevent'*, *outfile='output'*, *ngenerate=1*, *bdsimcommand='bdsim-devel'*, ***kwargs*)

RunExecOptions(*execoptions*, *debug=False*)

13.13 pybdsim.Visualisation module

Work in progress.

class `pybdsim.Visualisation.`**`Helper`**(*surveyFileName*)

Bases: `object`

To help locate objects in the BDSIM visualisation, requires a BDSIM survey file

`draw`()

Quick survey drawing for diagnostic reasons.

`findComponentCoords`(*componentName*)

Returns the XYZ coordinates of a component relative to the centre

`getWorldCentre`(*type='linear'*)

Returns the center in world coordinates of the centre of the visualisation space

13.14 pybdsim.Writer module

Writer

Write files for a pybdsim.Builder.Machine instance. Each section of the written output (e.g. components, sequence, beam etc.) can be written in the main gmad file, written in its own separate file, or called from an external, pre-existing file.

Classes: File - A class that represents each section of the written output - contains booleans and strings. Writer - A class that writes the data to disk.

class `pybdsim.Writer.`**`FileSection`**(*willContain=''*)

Bases: `object`

A class that represents a section of a gmad file. The sections that this class can represent are:

- Components
- Sequence
- Samplers
- Beam
- Options
- Bias
- Material

The class contains booleans and strings relating to the location of that sections data. The section can set to be:

- Written in its own separate file (default)
- Written in the main gmad file
- Called from an external file

These classes are instantiated in the writer class for each section. An optional string passed in upon class instantiation is purely for the representation of the object which will state where the data will be written/called. This string should be one of the section names listed above.

Example:

```
>>> beam = FileSection('beam')
>>> beam.CallExternalFile('../myBeam.gmad')
>>> beam
pybdsim.Writer.File instance
File data will be called from the external file:
../myBeam.gmad
```

CallExternalFile(*filepath=''*)

WriteInMain()

WriteSeparately()

class pybdsim.Writer.**Writer**

Bases: `object`

A class for writing a pybdsim.Builder.Machine instance to file.

This class allows the user to write individual sections of a BDSIM input file (e.g. components, sequence, beam etc.) or write the machine as a whole.

There are 6 attributes in this class which are FileSection instances representing each section of the data. The location where these sections will be written/read is stored in these instances. See the FileSection class for further details.

The optional boolean 'singlefile' in the WriteMachine function for writing the sections to a single file overrides any sections locations set in their respective FileSection instances.

This class also has individual functions (e.g. WriteBeam) to write each file section and the main file (WriteMain) separately. These section functions must be called BEFORE the WriteMain function is called otherwise the main file will have no reference to these sections.

Examples:

Writing the Builder.Machine instance myMachine to separate files:

```
>>> a = Writer()
>>> a.WriteMachine(myMachine,'lattice.gmad')
Lattice written to:
lattice_components.gmad
lattice_sequence.gmad
lattice_beam.gmad
lattice.gmad
All included in main file:
lattice.gmad
```

Writing the Builder.Machine instance myMachine into a single file:

```
>>> a = Writer()
>>> a.WriteMachine(myMachine,'lattice.gmad',singlefile=True)
Lattice written to:
lattice.gmad
All included in main file:
lattice.gmad
```

WriteBeam(*machine, filename=''*)

Write a machines beam to disk: filename.gmad

Machine can be either a pybdsim.Builder.Machine instance or a pybdsim.Beam.Beam instance.

WriteBias(*machine, filename=''*)

Write the machines bias to disk: filename.gmad

WriteComponents(*machine*, *filename=''*)

Write the machines components to disk: filename.gmad

WriteMachine(*machine(machine)*, *filename(string)*, *singlefile(bool)*, *verbose(bool)*)

Write a machine to disk. By default, the machine will be written into the following individual files:

filename_components.gmad	component files (max 10k per file)
filename_sequence.gmad	lattice definition
filename_samplers.gmad	sampler definitions (max 10k per file)
filename_options.gmad	options
filename_beam.gmad	beam definition
filename_bias.gmad	machine biases (if defined)
filename_material.gmad	machine materials (if defined)
filename.gmad	suitable main file with all sub files in correct order

These are prefixed with the specified filename / path

The optional bool singlefile = True will write all the above sections into a single file:

filename.gmad

kwargs: overwrite : Do not append an integer to the basefilename if already exists, instead overwrite existing files.

WriteMain(*machine(machine)*, *filename(string)*)

Write the main gmad file: filename.gmad

The functions for the other sections of the machine (components,sequence,beam,options,samplers,bias,material) must be written BEFORE this function is called.

WriteMaterial(*machine*, *filename=''*)

Write the machines material to disk: filename.gmad

WriteObjects(*machine*, *filename=''*)

Write the machines objects (e.g. crystals) to disk: filename.gmad

WriteOptions(*machine*, *filename=''*)

Write a machines options to disk: filename.gmad

Machine can be either a pybdsim.Builder.Machine instance or a pybdsim.Options.Options instance.

WriteSamplers(*machine*, *filename=''*)

Write the machines samplers to disk: filename.gmad

WriteSequence(*machine*, *filename=''*)

Write the machines sequence to disk: filename.gmad

13.15 pybdsim.XSecBias module

class pybdsim.XSecBias.**XSecBias**(*name*, *particle*, *processes*, *xsecfactors*, *flags*)

Bases: `object`

A class for containing all information regarding cross section definitions.

CheckBiasedProcesses()

SetFlags(*flags*)

Set flags. flags should be a space-delimited string of integers, 1-3, in the same order as the processes,

`SetName`(*name*)
: Set the bias name. Cannot be any upper/lowercase variant of reserved keyword "xsecBias".

`SetParticle`(*particle*)
: Set the particle for bias to be associated with.

`SetProcesses`(*processes*)
: Set the list of processes to be biased. processes hould be a space-delimited string of processes.

`SetXSecFactors`(*xsecs*)
: Set cross section factors. xsecs should be a space-delimited string of floats, e.g. "1.0 1e13 1234.9"

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DEVELOPER DOCUMENTATION

14.1 Release Checklist

The procedure is as follows because the version number is read from the git tag.

1) Update version history
2) Make sure you're in a new venv or uninstall pybdsim from your current venv / pip.
3) Locally tag the new version number on the last commit but don't push the tag.
4) Locally pip install pybdsim so if you were to import pybdsim you'd find this latest tag.
5) Generate html manual and stash for later upload (`cd docs; make html; tar -czf html.tar.gz html`).
6) Generate pdf manual (`cd docs; make latexpdf; cp build/latex/pybdsim.pdf .`) and commit.
7) Delete old (local) tag.
8) Add the same version number tag to the latest commit.
9) Make sure if the *dist* directory exits that it's empty (ignored on git - only local files).
10) `python -m build`
11) `twine upload --repository testpypi dist/*`

You can now uninstall pybdsim through pip again and download it from testpypi:

```
pip install --index-url https://test.pypi.org/simple/ pybdsim
```

Then you can test by importing it and using it. Afterwards, remove it.

1) `twine upload --repository pypi dist/*`

Warning: Once a tag is pushed to pypi, it can **never** be deleted or replaced. Similarly for testpypi. Consider using *v1.2.3-rc* or *v1.2.3-rc1*, which will be recognised as a release candidate by pypi.

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