Royal Holloway Backgrounds Group, BDSIM & pyg4ometry

L. Nevay, S. Gibson, S. Boogert, A. Abramov, S. Alden, H. Lefebvre, W. Shields, S. Walker

laurie.nevay@rhul.ac.uk

14th May 2020

PSI Meeting

Backgrounds Group

Stewart Boogert

pyg4ometry

Laurie Nevay (JAI)

Crystal Collimation
Physics Debris
BDSIM

Will Shields

Medical Accelerators

Stephen Gibson

NCB, Laserwire

Andrey Abramov

HL-LHC / BDSIM

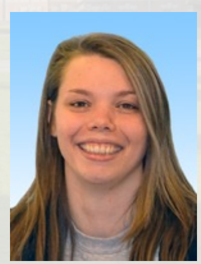
(CERN based)

Stuart Walker

LHC / ATLAS Backgrounds

just passed viva

Siobhan Alden



FETS Laserwire

Helena Lefebvre

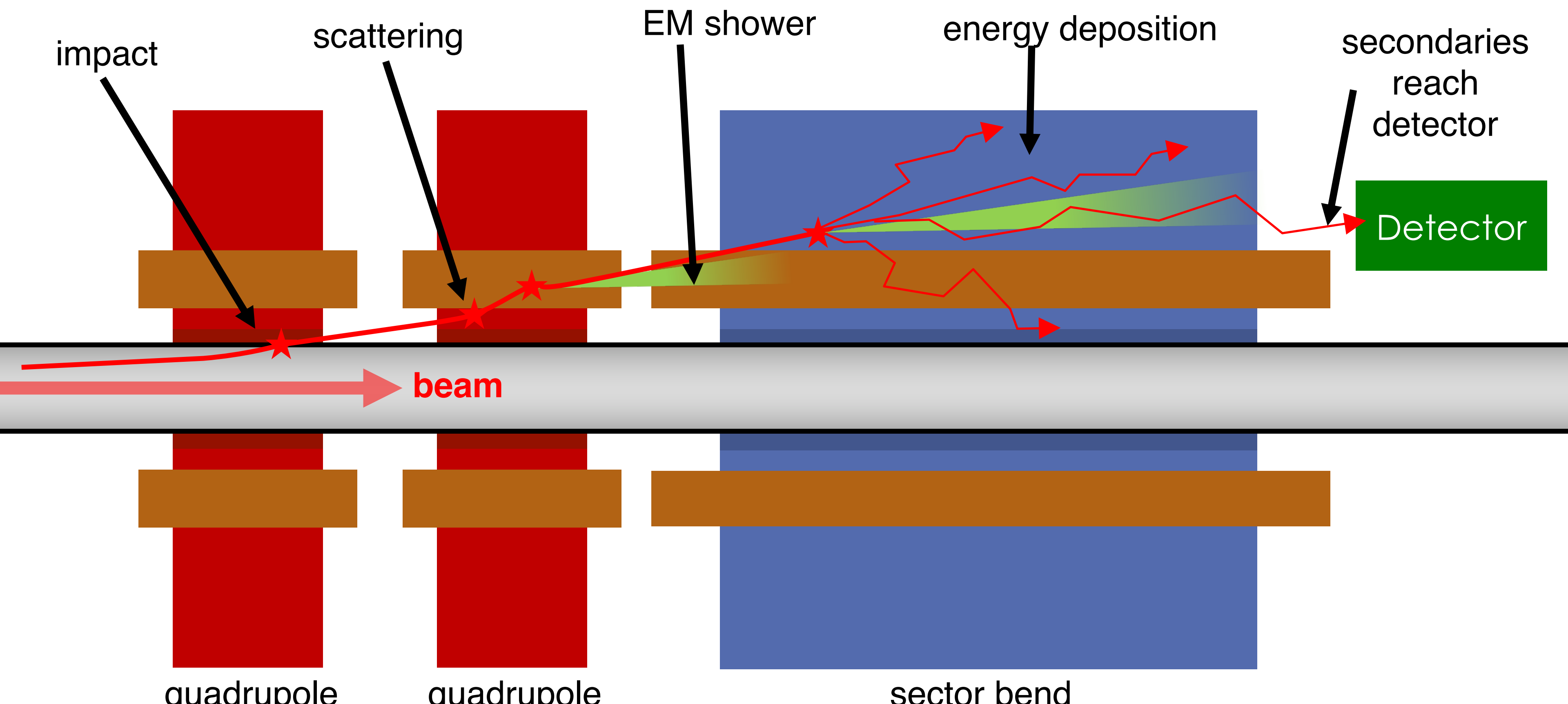
LHC backgrounds

Gian Luigi D'Alessandro

Beyond Colliders

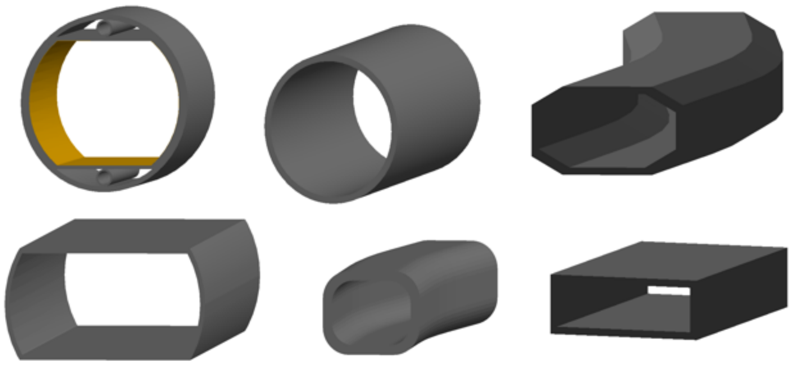
Beam Loss

- Cut-through of an accelerator
- Particle impacts aperture at some point
- Secondary particles and radiation propagate some distance
- Energy deposited in many components

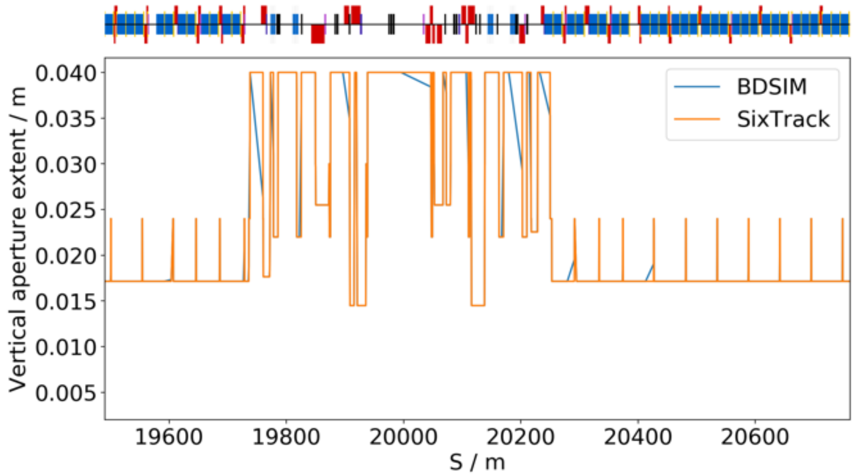


Tracking-only Losses

- Specialised codes exist for accelerator tracking
  - MADX, PTC, SixTrack, Zgoubi, OPAL etc
- Most have specialty area and some with some limited physics
- Typically 'losses' are when coordinates exceed aperture
- Need the interaction with material
- But also need accuracy of tracking



Different aperture shapes

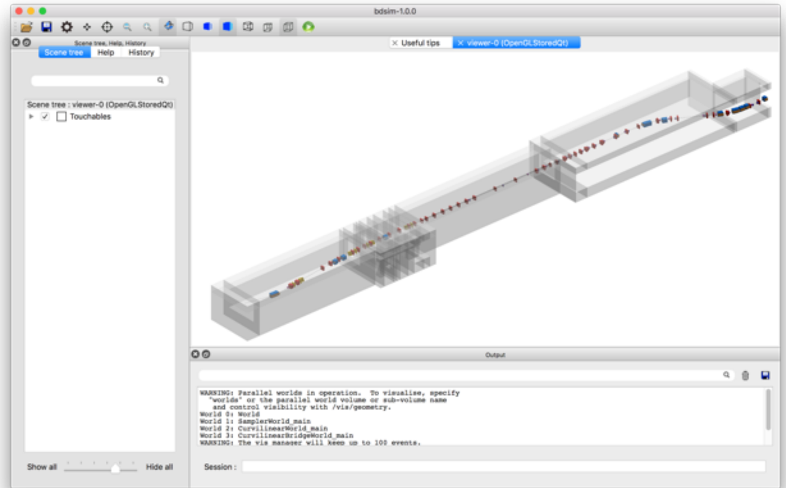


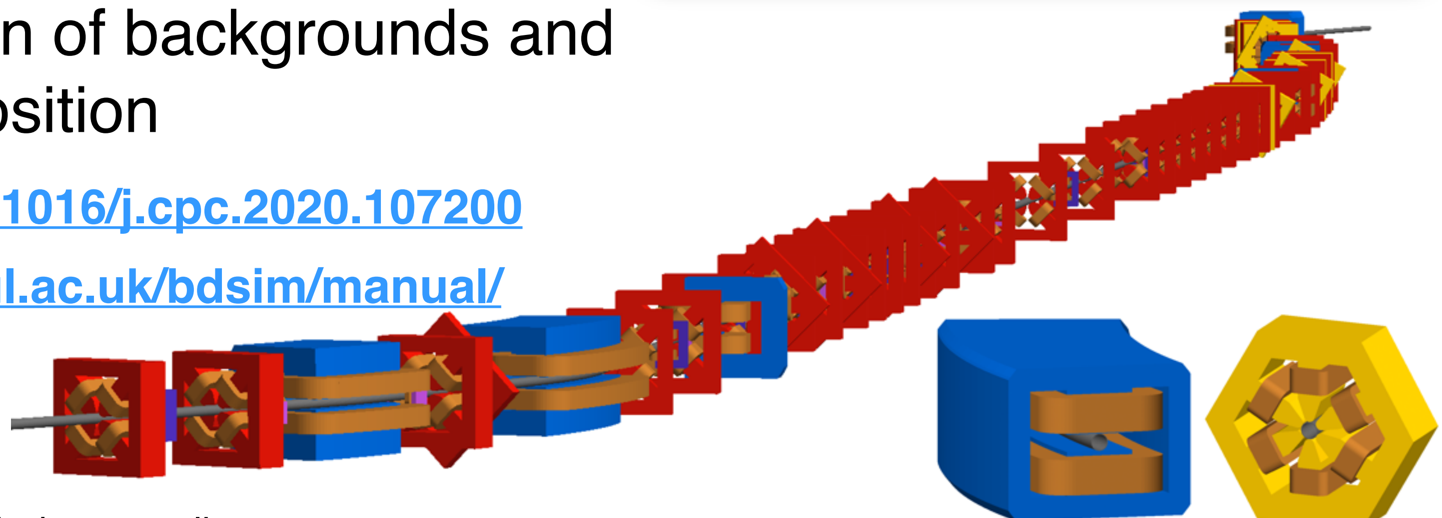
Vertical Aperture models compared.

Beam Delivery Simulation

BDSIM
Beam Delivery Simulation

- Build Geant4 model of accelerators
  - library of scalable generic geometry
  - convert from common accelerator formats
- Thick lens 1st order matrices used for in-vacuum tracking
  - replaces Geant4's 4th order Runge-Kutta
  - matches MADX / MAD8 & TRANSPORT
- Customisable geometry and fields
- Identify origin of backgrounds and energy deposition





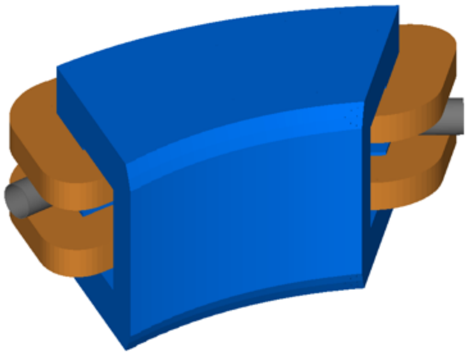
https://doi.org/10.1016/j.cpc.2020.107200

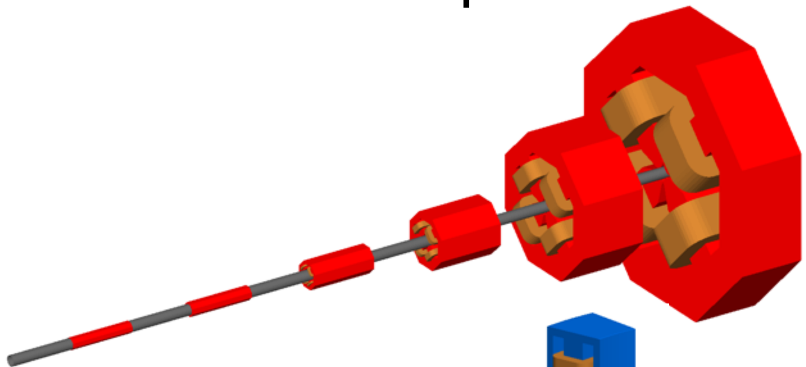
http://www.pp.rhul.ac.uk/bdsim/manual/

BDSIM - don't forget the 'i' when googling

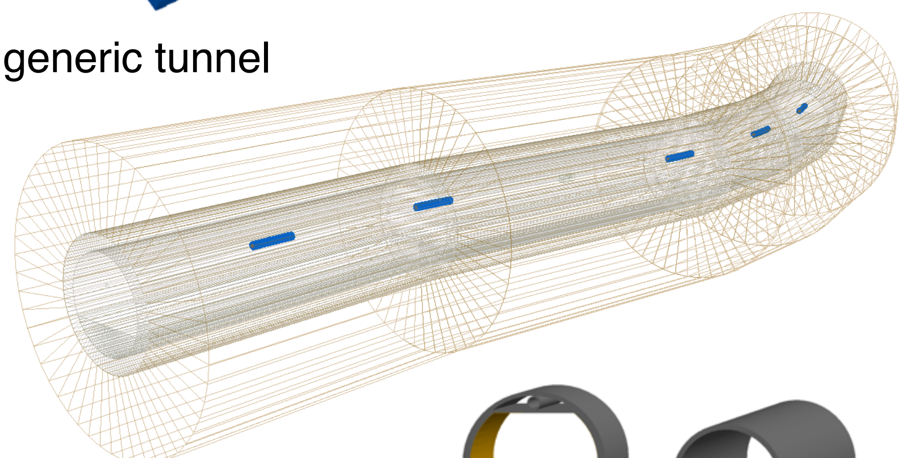
Generic & Scalable Geometry

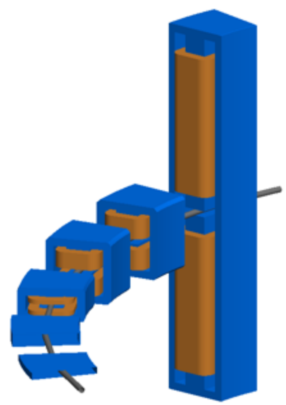
- Variety of styles for each component



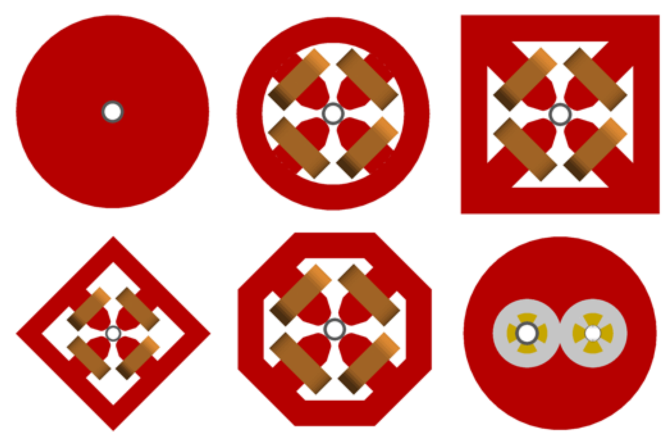


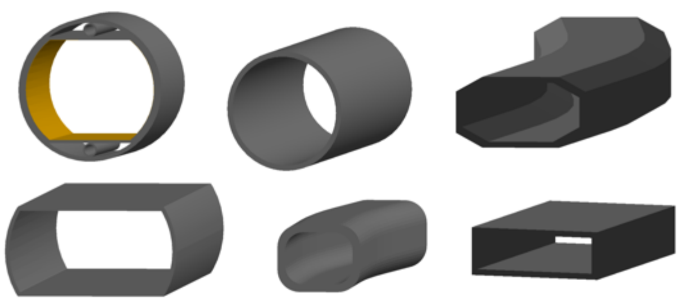
generic tunnel





different yoke styles





all common aperture types available

Key Features

- Optical agreement with MADX model of accelerator
- Conversion from MADX model in minutes
- Fully customisable geometry and fields
- Highly flexible biasing interface
  - bias cross-sections per particle / volume / process
  - used for beam-gas interactions regularly
- ROOT output with per-event storage
  - highly customisable - observation planes, ***scoring*** meshes, energy deposition
  - optionally store filtered truth tree with links to observations planes and primaries
- Simple but powerful analysis
- Determine origin and history of losses or radiation sources
- Supports all geant4 reference and modular physics lists
  - support for Geant4.10.0 -> latest

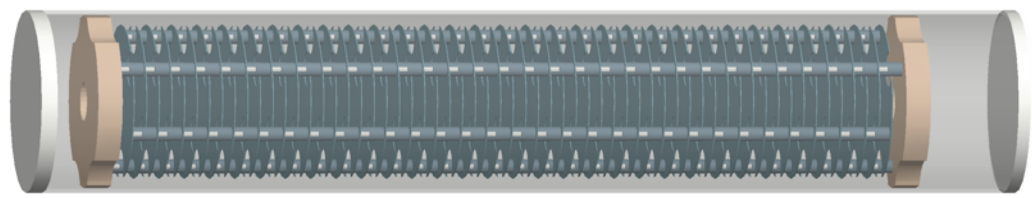
Currents Studies

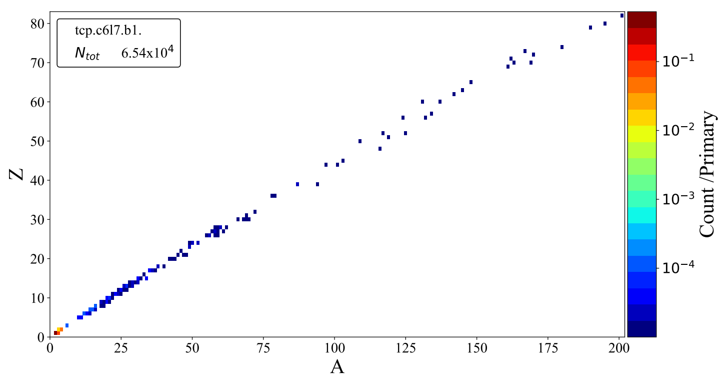
- CERN:
  - LHC / HL-LHC Collimation
  - LHC non-collision backgrounds
  - AWAKE Plasma Accelerator Spectrometer (CERN / UCL)
  - Gamma Factory signal & background
  - FASER muon and neutrino propagation from IP1
  - KLEVER & NA62 complete beam line
  - Linac4 H- laserwire
- Medical
  - IBA proton therapy gantries (collaboration with ULB)
  - CCAP at Imperial College London - radiobiology research facility
  - Clatterbridge Ocular Proton Therapy Line (UCL / Liverpool)
- DESY
  - XFEL undulator dose, wire and screen diagnostics
- Other
  - ILC / CLIC muon backgrounds

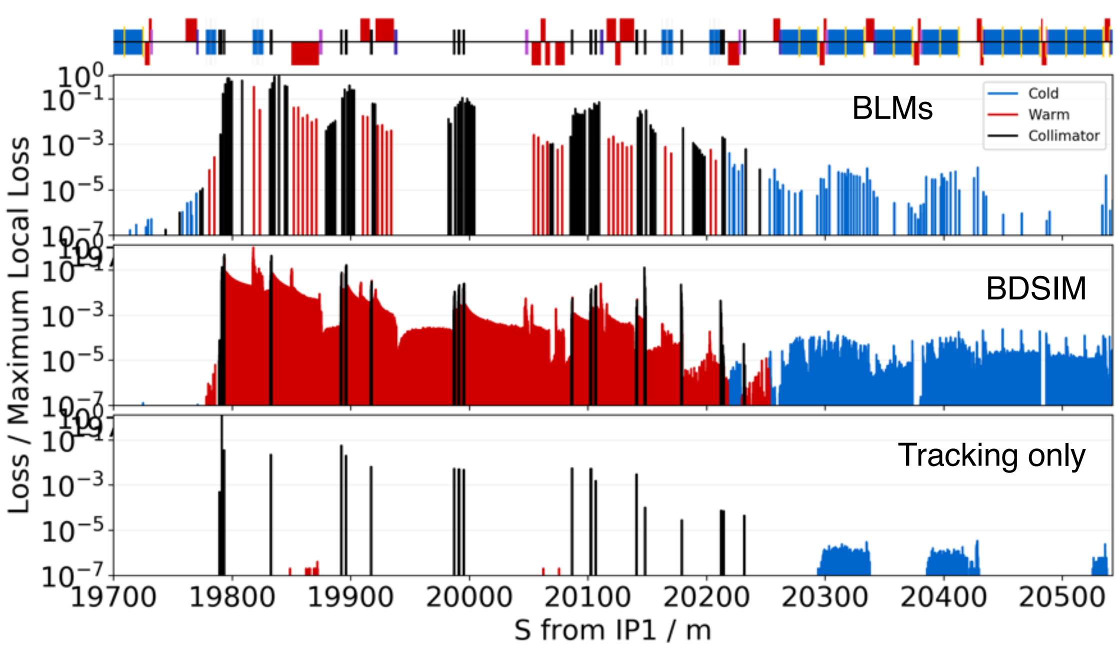
LHC Collimation

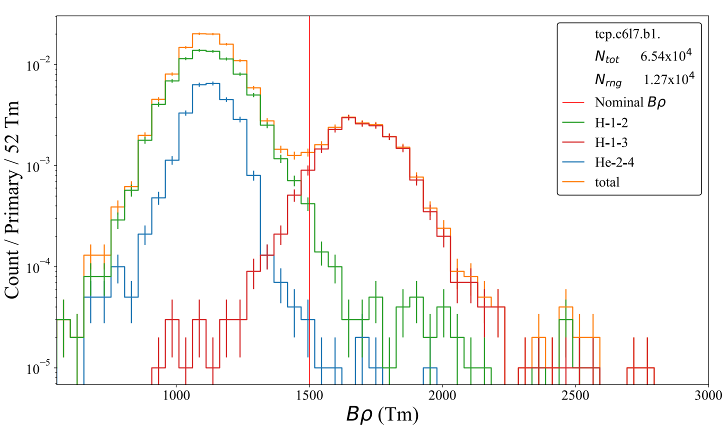
- Application to energy deposition and backgrounds from collimation system in LHC - both protons and ions
- Paper in preparation this summer

BLM model in development by A. Abramov





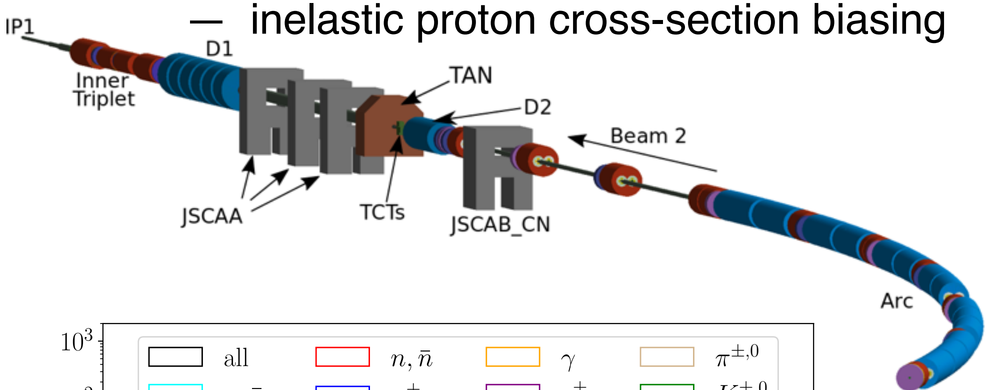


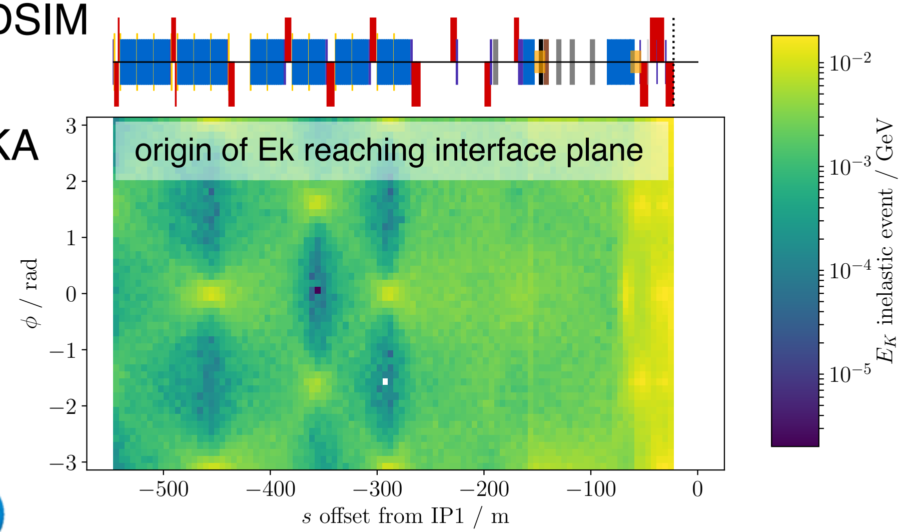


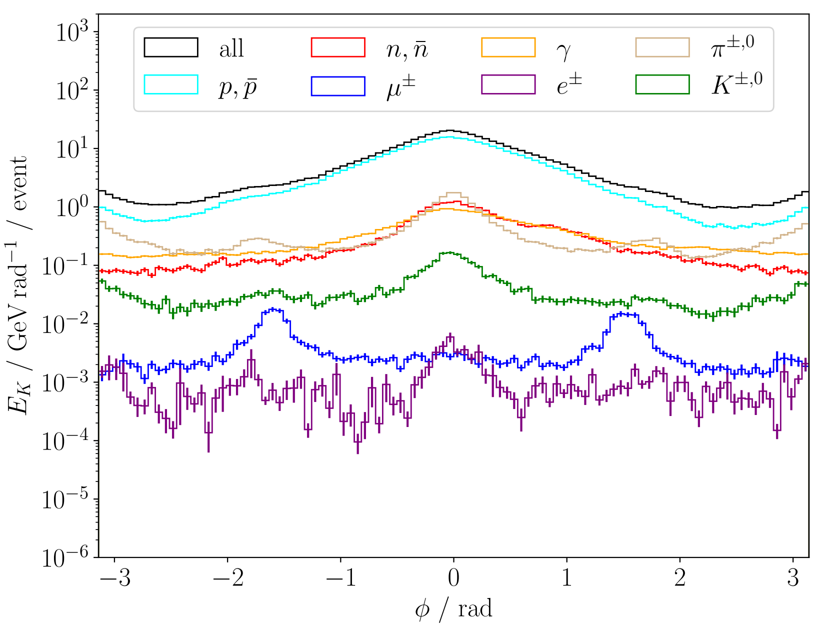
S. Walker, A. Abramov, L. Nevay

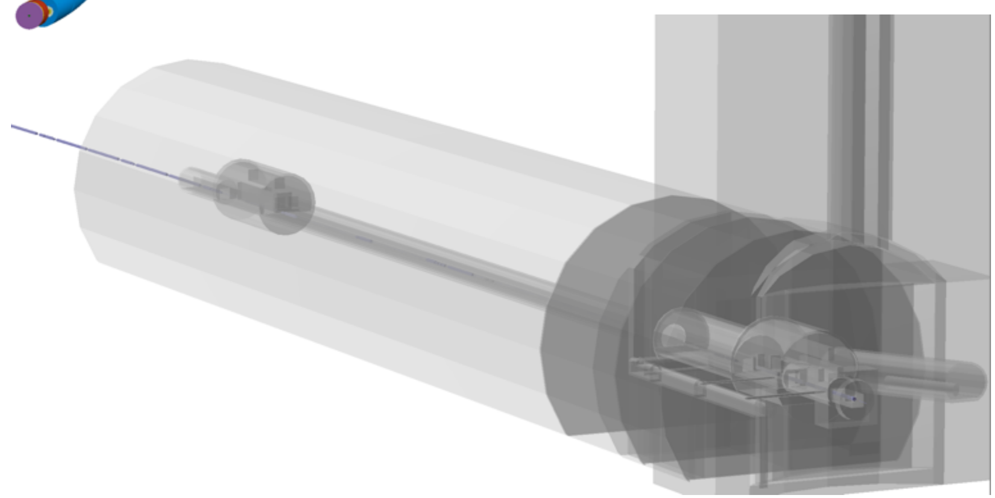
LHC Non-Collision Backgrounds

- Work by Helena Lefebvre & Stuart Walker
  - Modelling ATLAS background using BDSIM
  - last 550m of machine before ATLAS
  - IR1 tunnel model converted from FLUKA
  - inelastic proton cross-section biasing





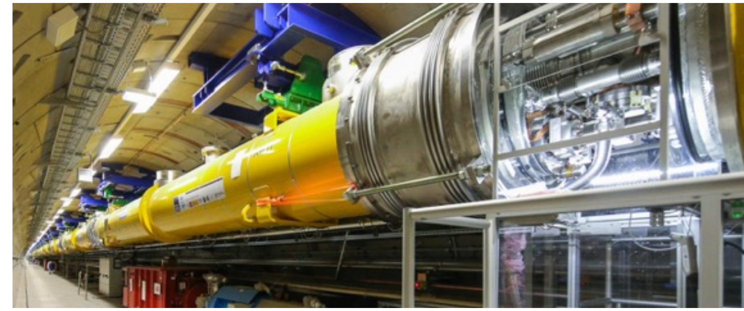


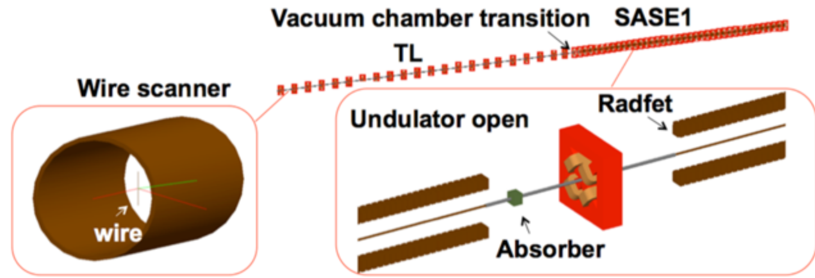


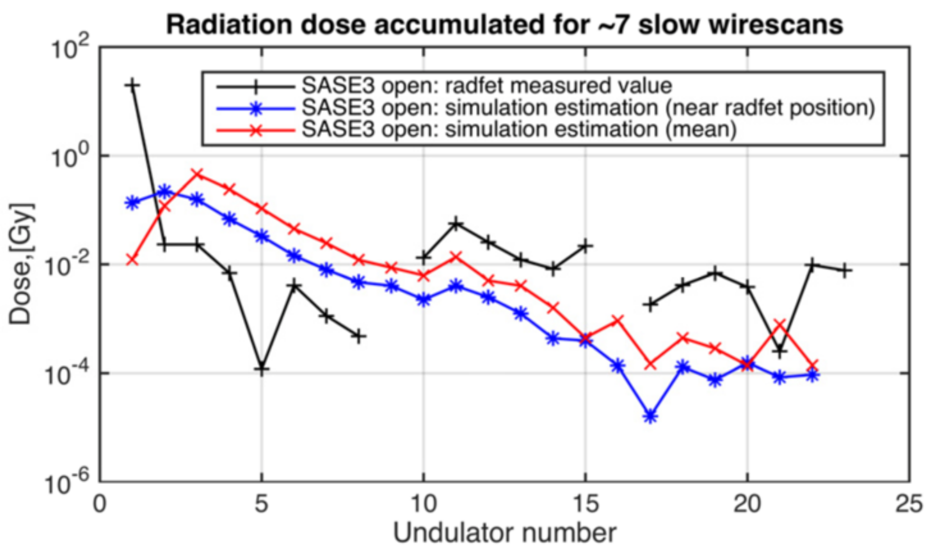
S. Walker, S. Gibson, H. Lefebvre

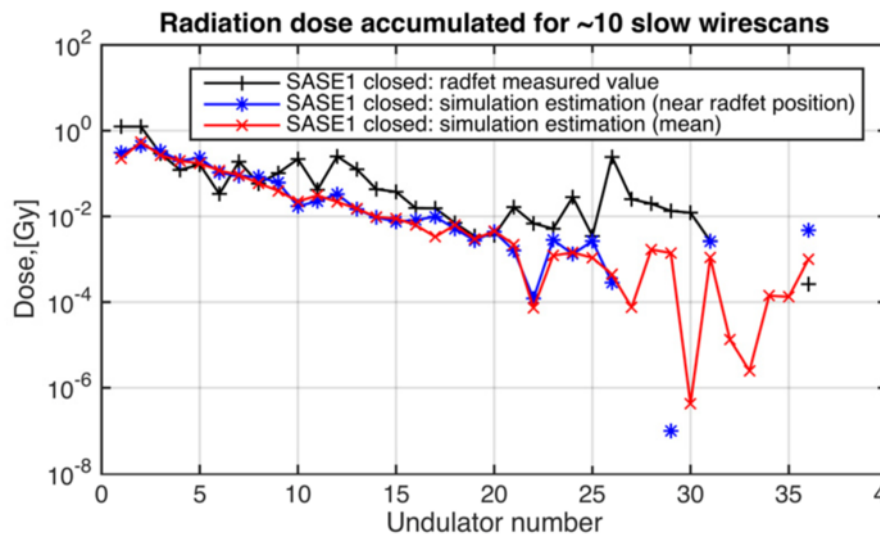
DESY XFEL Undulator Dose

- Undulator dose higher than original design
- Caused by secondary neutrons and synchrotron radiation
- Simulations compare to RADFET detectors on each undulator
- Improving shielding
- Diagnostics create radiation









https://doi.org/10.18429/JACoW-IPAC2018-THPMF022

S. Liu, I. Agapov at DESY w. L. Nevay, S. Boogert

Rapid Geometry Preparation

with *pyg4ometry*

https://bitbucket.org/jairhul/pyg4ometry

http://www.pp.rhul.ac.uk/bdsim/pyg4ometry/index.html

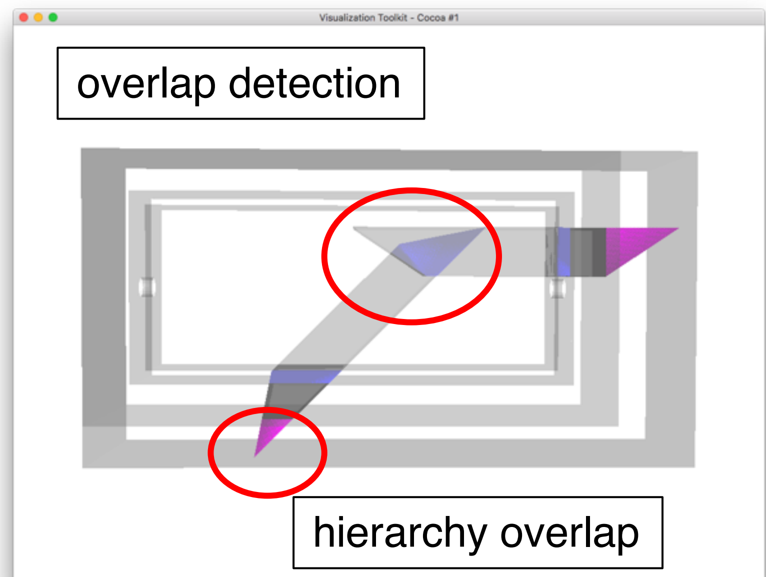
pyg4ometry

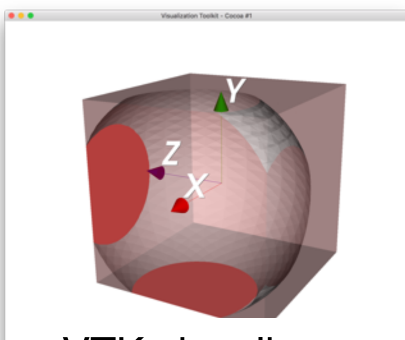
https://bitbucket.org/jairhul/pyg4ometry

- Python package to create Geant4 geometry in GDML
  - Python class for each Geant4 primitive solid
- Combine with meshes from STL / STEP
- Visualise and debug ***overlaps, coplanar faces, hierarchy problems***
- Convert to and from FLUKA / Geant4

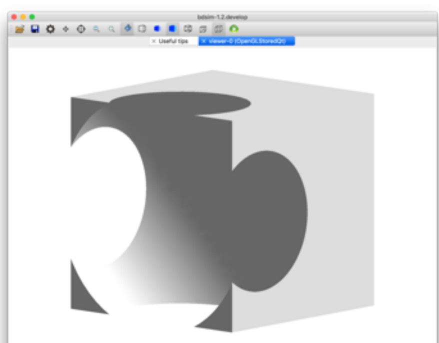
```
boxSolid1    = _g4.solid.Box('box1',100,56,78)
boxLogical1  = _g4.LogicalVolume(boxSolid1,'G4_Cu','boxLogical1')
boxPhysical1 = _g4.PhysicalVolume([0,0,0],[0,0,0],boxLogical1,'boxPhysical1',worldLogical)
```

- Paper available shortly on arXiv
- Python2 -> updating to Python3





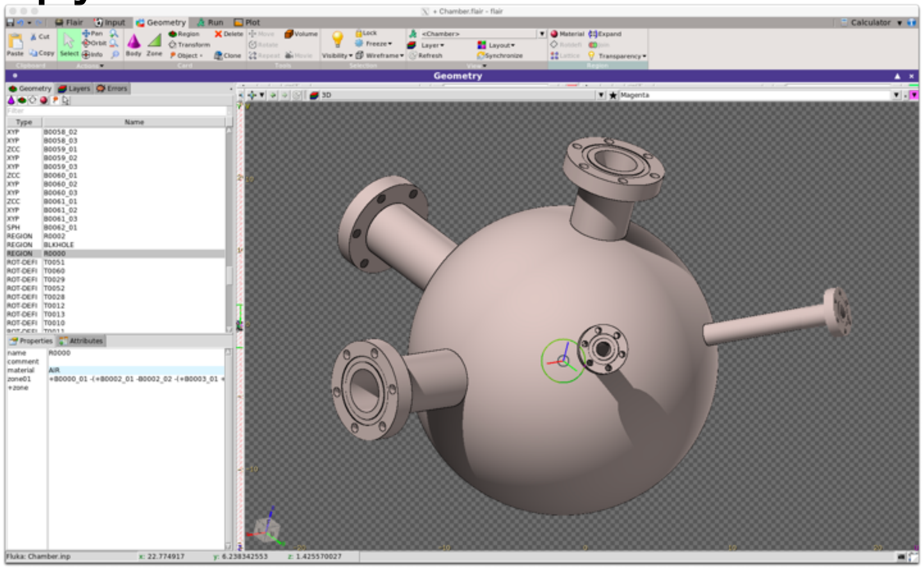
VTK visualiser



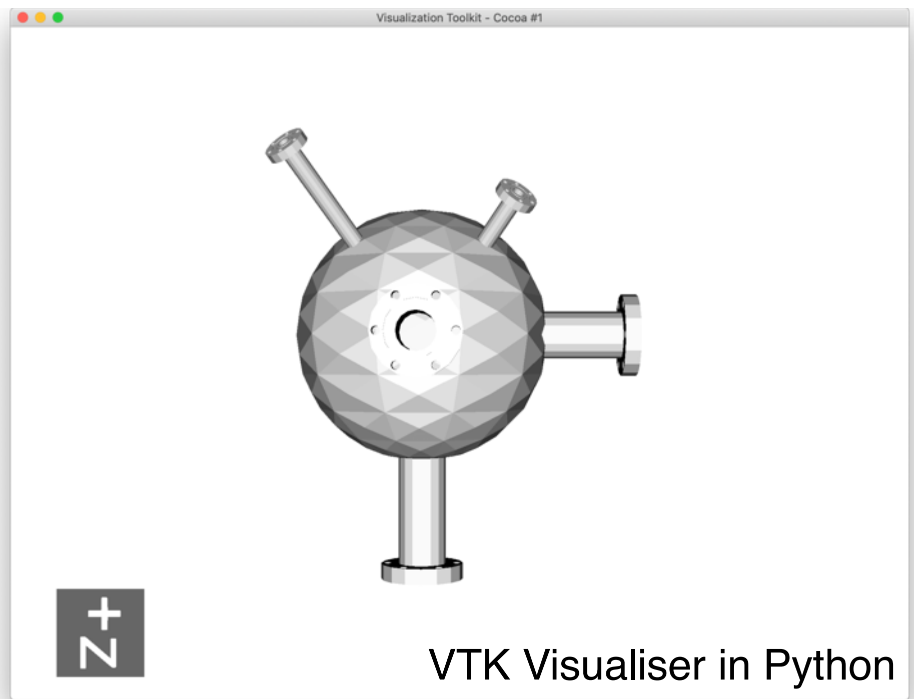
BDSIM

Example

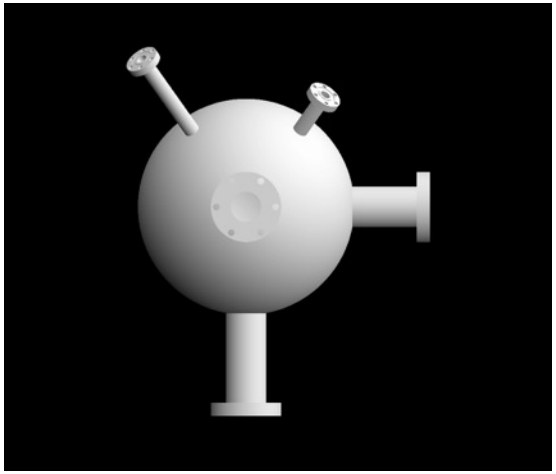
- Chamber + beam pipes
- Programmatically generated in python
  - like a beam pipe factory
- ~ 2 hrs to write and check
  - with basic knowledge of CSG



Flair / FLUKA



VTK Visualiser in Python



Geant4

Good Housekeeping

http://www.pp.rhul.ac.uk/bdsim/pyg4ometry/index.html

- Testing
  - Over 400 unit tests
  - > 90% test coverage

```
sics/coderepos/pyg4ometry/pyg4ometry/geant4/SkinSurface.py                 11      1    91%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/__init__.py                    12      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Box.py                   27      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Cons.py                  84      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/CutTubs.py              116     10    91%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Ellipsoid.py            109      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/EllipticalCone.py        97      4    96%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/EllipticalTube.py        60      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/ExtrudedSolid.py         63      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/GenericPolycone.py       44      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/GenericPolyhedra.py      47      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/GenericTrap.py           82      1    99%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Hype.py                 132      0   100%
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sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Layer.py                 39     10    74%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/MultiUnion.py            37      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/OpticalSurface.py        19      2    89%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Orb.py                   74      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Para.py                  46      0   100%
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sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Tet.py                   43      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Torus.py                129      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Trap.py                 107      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Trd.py                   33      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/Tubs.py                 103      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/TwistedBox.py            66      1    98%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/TwistedSolid.py          55      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/TwistedTrap.py           98      1    99%
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sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/TwoVector.py             50      8    84%
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sics/coderepos/pyg4ometry/pyg4ometry/geant4/solid/__init__.py              40      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/pycsg/__init__.py                      1      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/stl/Reader.py                         45      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/stl/__init__.py                        1      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/transformation.py                    125      4    97%
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sics/coderepos/pyg4ometry/pyg4ometry/visualisation/Mesh.py                 59      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/visualisation/VisualisationOptions.py  7      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/visualisation/VtkViewer.py           345     76    78%
sics/coderepos/pyg4ometry/pyg4ometry/visualisation/Writer.py               16      0   100%
sics/coderepos/pyg4ometry/pyg4ometry/visualisation/__init__.py              4      0   100%
--------------------------------------------------------------------------------------------
                                                                        10480   1428    86%
```
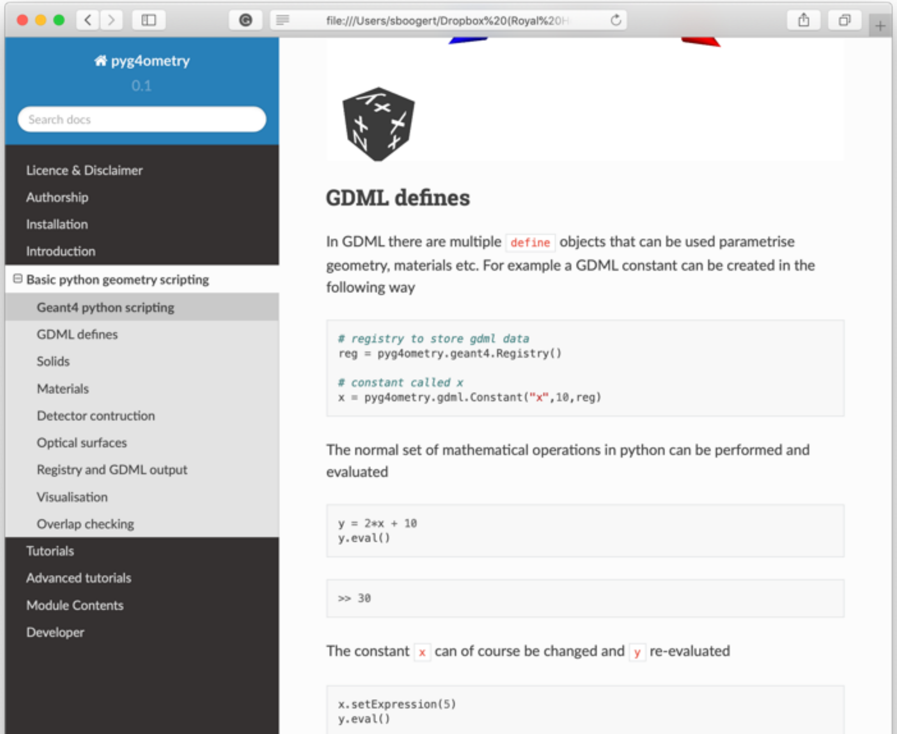

- Manual
  - Unit tests are an excellent documentation for features
  - Sphinx documentation
  - All examples in this presentation are in Git repository



ROYAL HOLLOWAY UNIVERSITY OF LONDON

Thank you

Backup

Collaborative Development

- BDSIM has a public git repository
- ~ 800 unit tests run daily
- ~ 40k lines of open source C++ under GPL3
- Public issue tracker
  - https://bitbucket.org/jairhul/bdsim/issues
  - also for feature requests
- Complete Doxygen documentation for C++
  - http://www.pp.rhul.ac.uk/bdsim/doxygen/
- Detailed manual regularly updated
  - http://www.pp.rhul.ac.uk/bdsim/manual/
  - http://www.pp.rhul.ac.uk/bdsim/manual-develop/

Example BDSIM Syntax

- "GMAD" - Geant4 + MAD

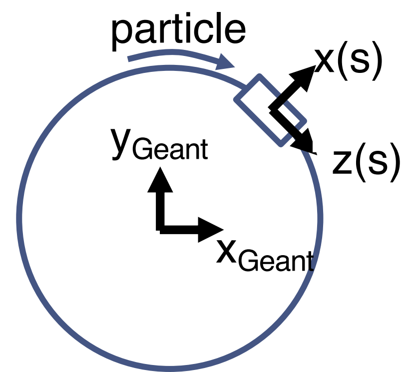
sm.gmad

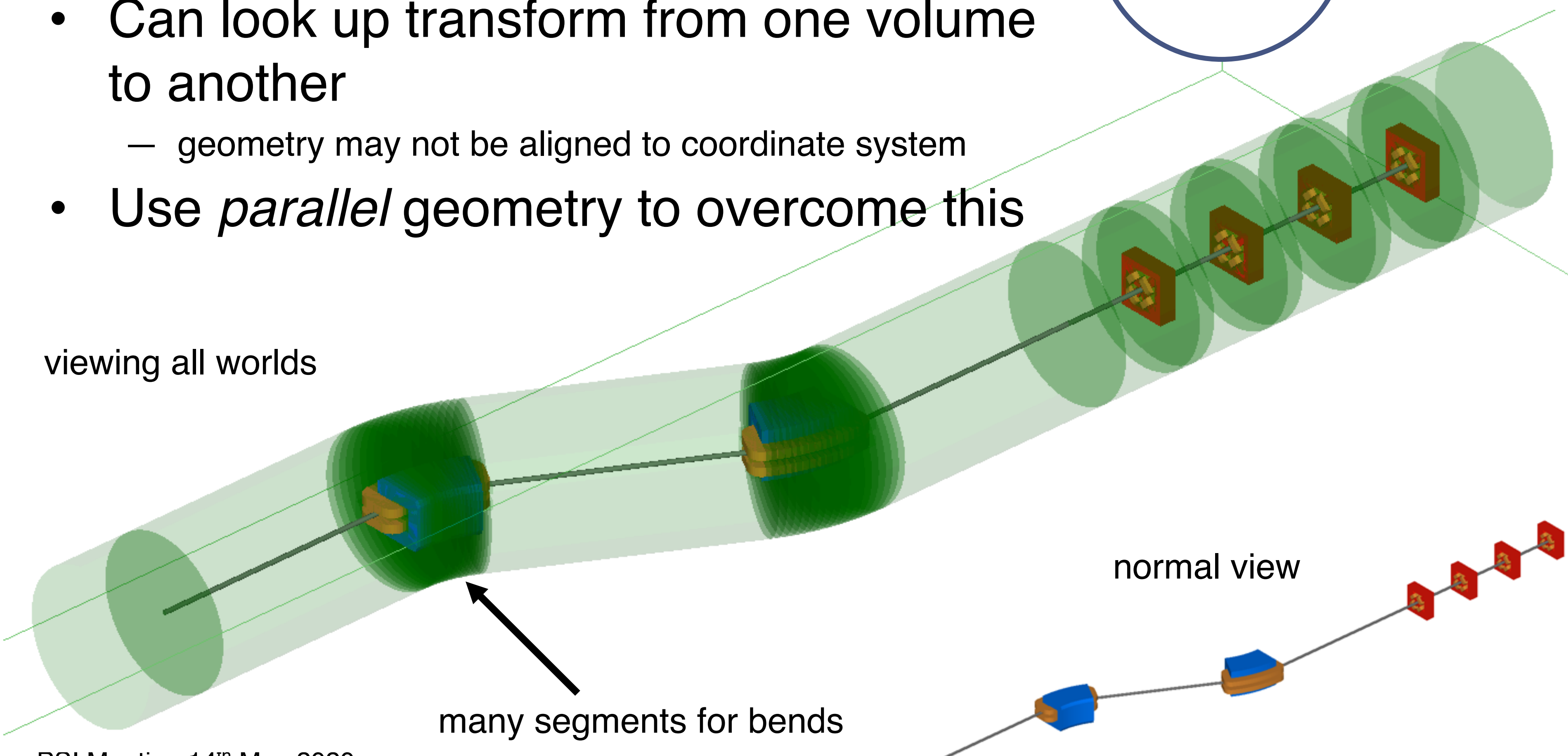
```
d1: drift, l=1*m;
q1: quadrupole, l=1*m, k1=1.3, magnetGeometryType="polesfacet";
c1: rcol, l=0.6*m, ysize=5*mm, xsize=5*mm, material="Copper", outerDiameter=10*cm;
s1: sbend, l=1*m, angle=0.10;

l1: line = (d1, q1, d1, c1, d1, s1);
use,period=l1;

sample, all;

option, ngenerate=1,
        physicsList="em";

beam, particle="proton",
      energy=10.0*GeV,
      X0=0.001,
      Y0=0.001;
```

```
-:---  sm.gmad        All L3     Git:develop  (Fundamental)
Wrote /Users/nevay/physics/reps/bdsim/examples/simpleMachine/sm.gmad
```

Coordinate Transforms

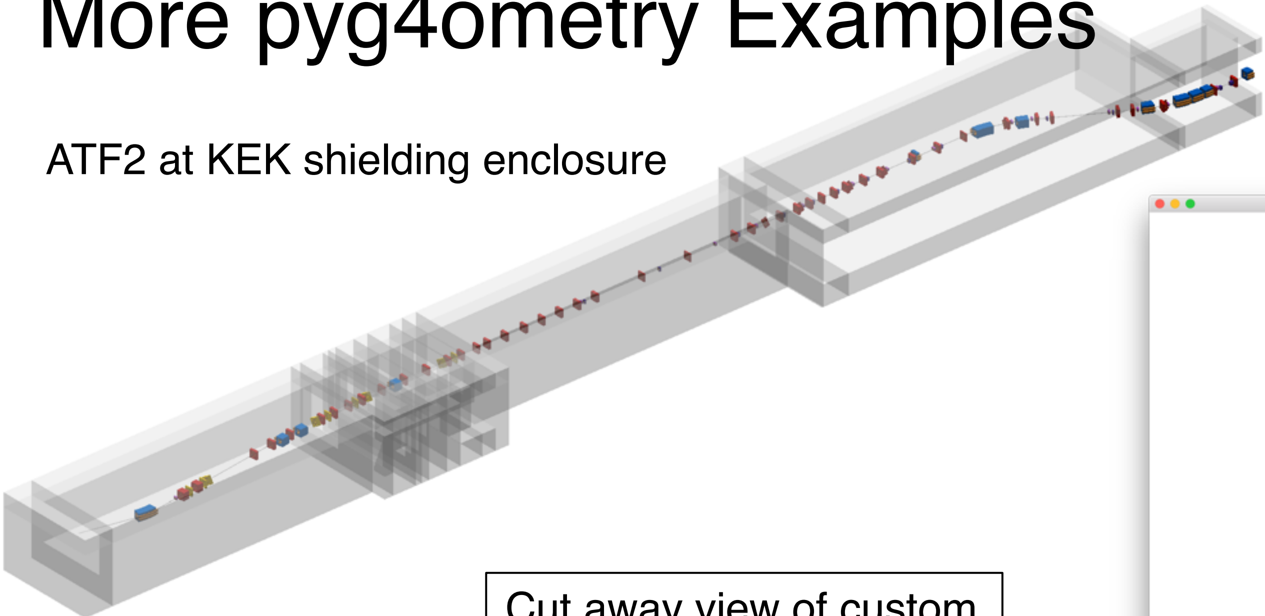
- Accelerator tracking uses a **curvilinear** coordinate system following the beam
- Geant4 uses 3D **Cartesian** coordinates
- Can look up transform from one volume to another
  - geometry may not be aligned to coordinate system
- Use *parallel* geometry to overcome this



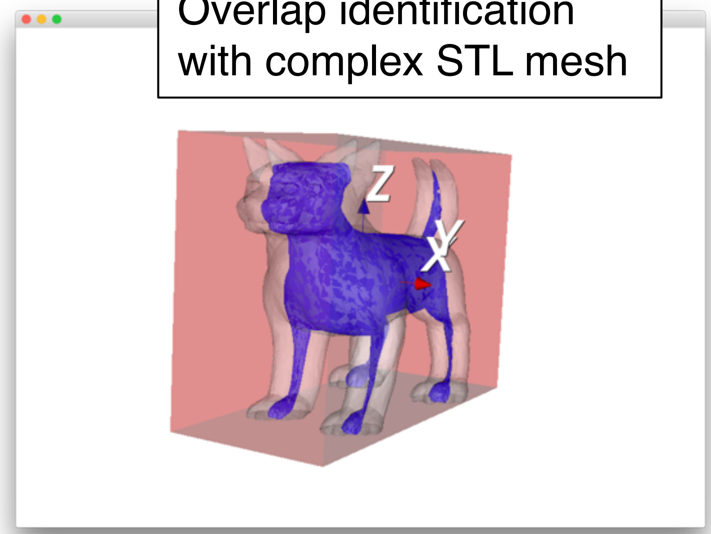


More pyg4ometry Examples

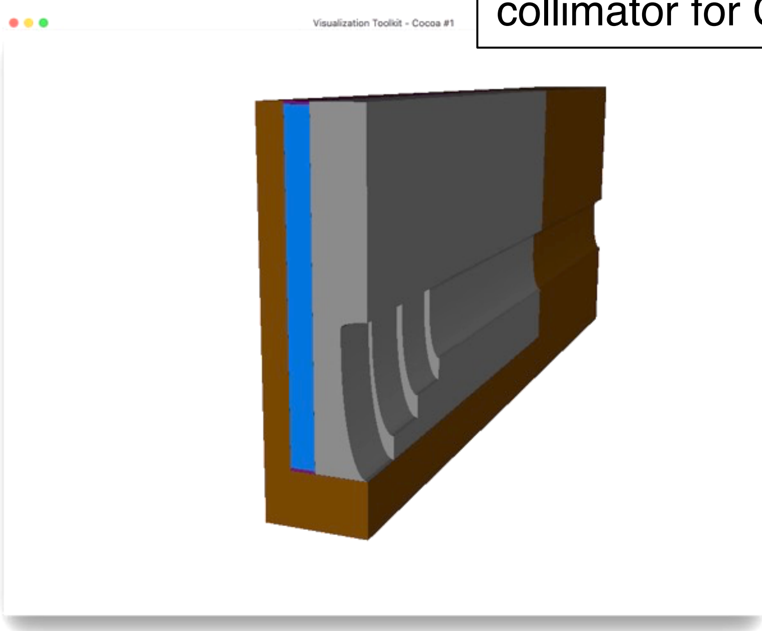
ATF2 at KEK shielding enclosure

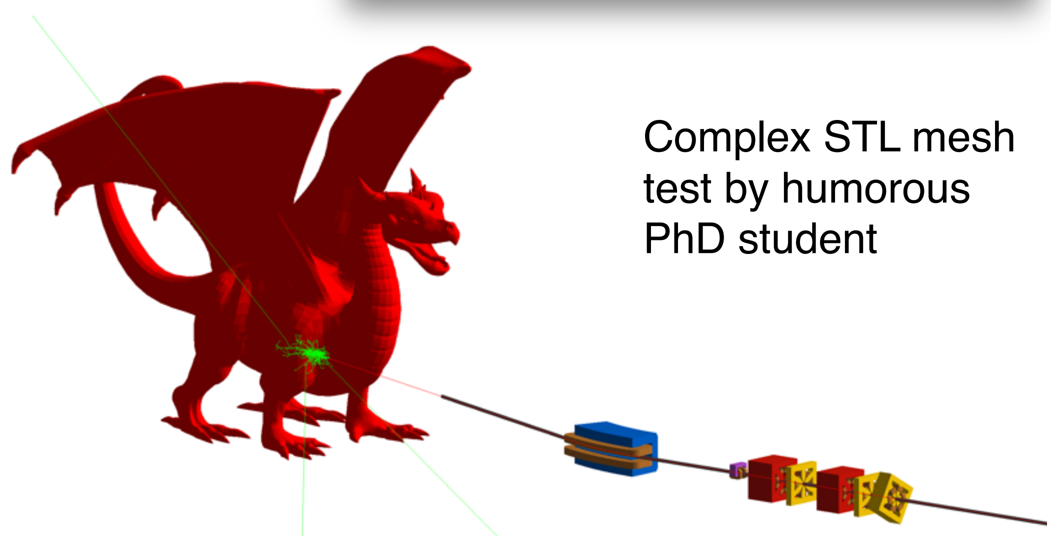


Overlap identification with complex STL mesh



Cut away view of custom collimator for CLIC





Complex STL mesh test by humorous PhD student