GANs for the Muon Shield Optimisation

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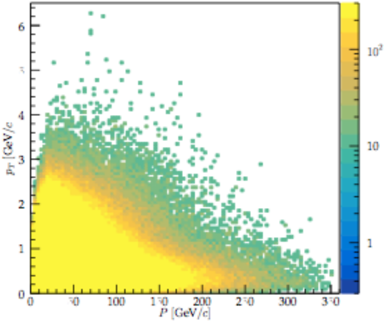
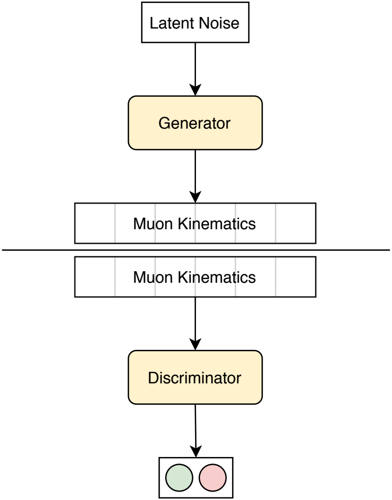
Enhanced Muon Distribution



(Source: Oliver's thesis)

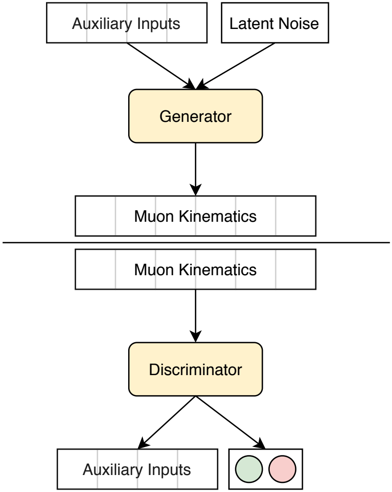
- Limited time to run muons during optimisation, need to enhance the tails of the distribution.
- Initially this was done with a small muon sample, capping the height of the distribution and applying phi rotations to events in the tails.
- **This library is able to quickly generate similar distributions based a much larger muon background sample.**

Vanilla GAN



- Traditional GAN:
  - Generator has single input: latent noise, and outputs a generated muon kinematic vector.
  - Discriminator takes a muon kinematic vector as an input, and has a single output: a prediction at whether the sample was from the generator or the training sample.

Auxiliary GAN



- Auxiliary GAN:
  - Generator now has **two** inputs: noise and an additional auxiliary vector. The generator then outputs as before a generated muon kinematic vector.
  - Discriminator still takes a single kinematic vector as an input, however now has **two** outputs: a prediction at real/fake along with predictions for the values of the auxiliary inputs of the kinematic vector.

Properties of an Auxiliary GAN

- Before training the GAN the auxiliary values are calculated for the each vector in the training sample:
  - 4 auxiliary values are defined based on local density in the directions [x/y, z, P_t, P_z]
  - The auxiliary values are mapped to easy to sample distributions, in this case a single tailed normal.
  - In this case a low auxiliary value encodes means the muon sample is from the core of the distribution.

Some advantages over the Vanilla GAN:

- Training with the extra auxiliary information can add stability to the training progress.
- After training we can tune the auxiliary distribution to mould the generated output distribution as required.

Loading the library

The **muGAN** GitHub repository is available here. It includes the pre-trained GAN models and all the code needed to generate from them.

To make full use of this library an installation of both Keras and uproot are required.

To begin load the library with the following:

```
import numpy as np
''' Load the muon GAN module from the SHiP_GAN_module
    package. '''
from SHiP_GAN_module import muGAN

''' Initialise the muGAN class.'''
muGAN = muGAN()
```

Generating and Plotting

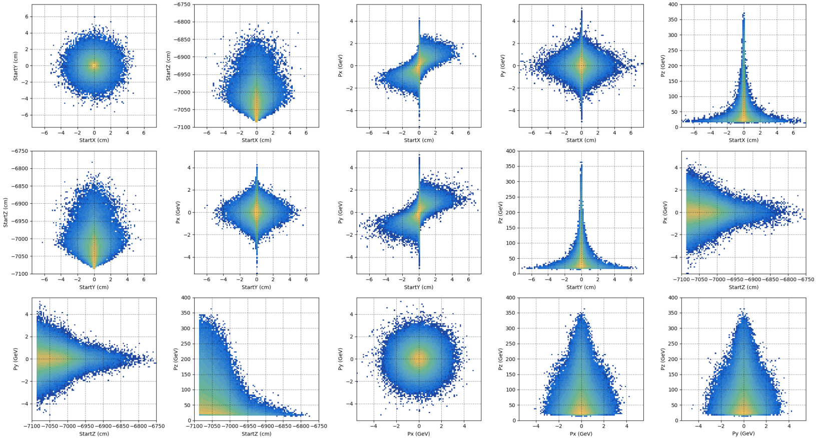
To generate from the GAN using normally distributed auxiliary values, the following `generate()` function may be used. This will produce the GANs effort at generating physical distribution of muons.

```
''' Generate muon vectors with normally distributed
    auxiliary distributions... '''
muon_kinematic_vectors = muGAN.generate(size=10000,
    tuned_aux=True)
''' The columns are as follows: Pdg, StartX, StartY, StartZ,
     Px, Py, Pz. '''
```

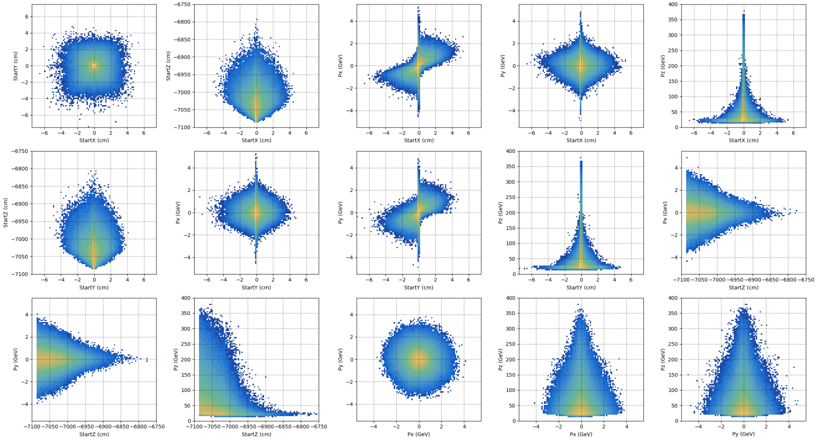
Then, to plot the output:

```
''' Plot kinematics of this generated vector'''
muGAN.plot_kinematics(data=muon_kinematic_vectors)
''' Plot momentum vs transverse momentum'''
muGAN.plot_p_pt(data=muon_kinematic_vectors)
```

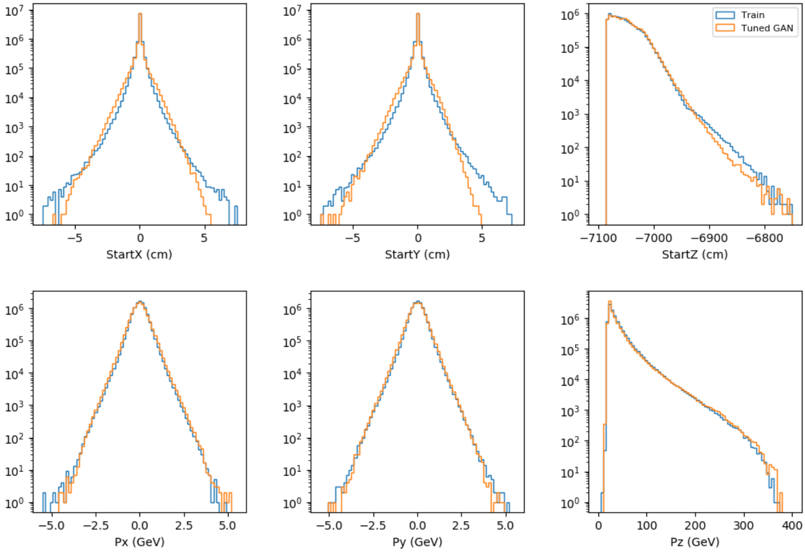
Fully Simulated Sample



GAN output

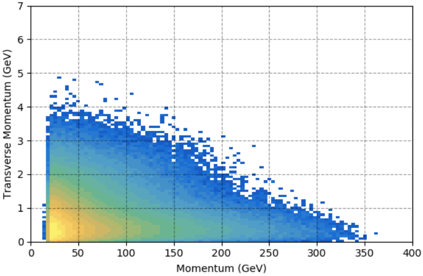


Comparing 1D

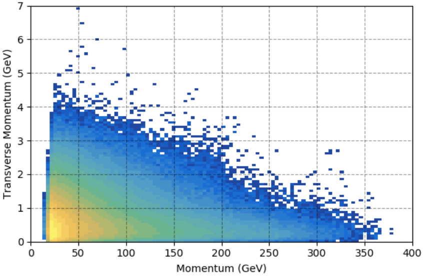


Comparing P_t vs P

Fully simulated:



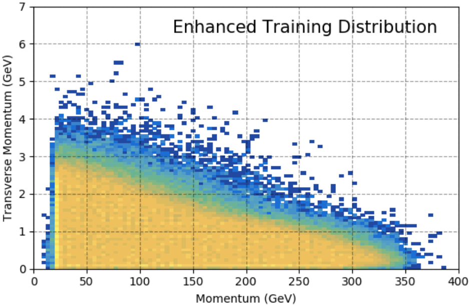
GAN:



Generating Enhanced Distributions

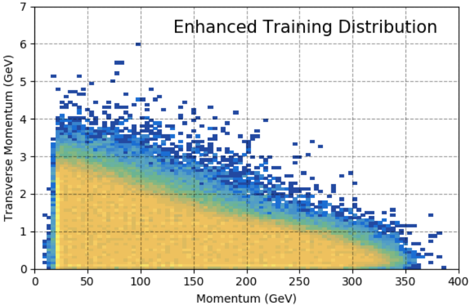
As mentioned, for the Muon Shield Optimisation procedure we will need to generate enhanced distributions. Here are the steps taken in order to do this:

- Firstly, from the GAN training data we select out an enhanced distribution.
    - The script `Create_seed_distribution.py` does this from an selection of GAN training files in my `EOS` directory.



Generating Enhanced Distributions

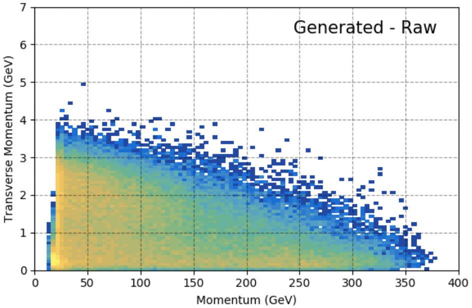
- From this enhanced distribution separate out the **auxiliary vectors**.
  - Auxiliary vectors are 4d arrays appended onto each muon kinematic vector in training which describe how *rare* that muon is.
- This creates a **seed auxiliary distribution** which will be used in the generation step.
  - I have created an example stored in `SHiP_GAN_module/data_files/` which is automatically used if the user does not create their own.



Generating Enhanced Distributions

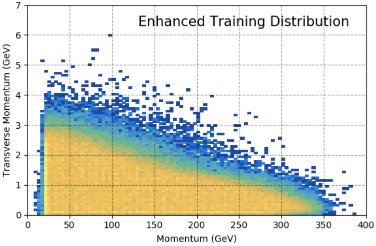
- From this seed of auxiliary values we can generate values with the `generate_enhanced()` function.

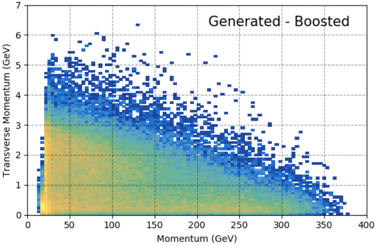
```
boosted_muon_kinematic_vectors = muGAN.generate_enhanced(
    size=int(1E5))
```



Generating Enhanced Distributions

- This enhanced distribution can be boosted further by slightly manipulating the seed auxiliary distribution.
    - This is required as, even in using a seed distribution, we haven't addressed the issue of the GAN underestimating the tails.
- The code to generate this kind of distribution is available in the script `Generation_Muon_Shield_Optimisation.py`.





Creating ROOT files

- The final step for integration with FairShip is the production of ROOT files.
- This is done with the `save_to_ROOT()` function which uses uproot.

```
muGAN.save_to_ROOT(data=muon_kinematic_vectors,filename='
    example.root')
```

The generated ROOT file is compatible with the master `MuonBackGenerator.cxx`. However I struggled to get `run_simScript.py` to quit correctly on reaching the end of the file. So there is a buffer event created at the end of the files and `run_simScript.py` must be run with the option `- n` N. Where N is the number of generated muons.