Unconventional Track Signatures at a 10 TeV Muon Collider

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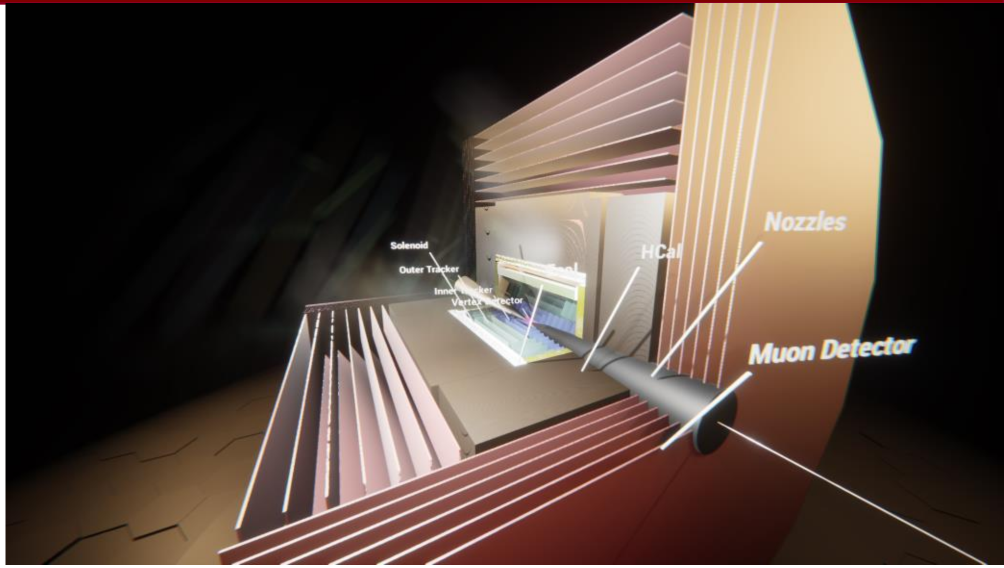
- Muon Collider Basics
- Tracking Performance
- Long Lived Particles

What is a Muon Collider

- Colliding Muons: $\mu^+$and μ^-
- Muons are **fundamental**, like electrons
- Muons are **207 times** more massive than electrons
- **Leptons are the ideal probes of short-distance physics**
  - All the energy is stored in the colliding particle
  - No energy “waste” due to parton distribution functions
- Best of both worlds!



10 TeV Motivation

See here for further motivation

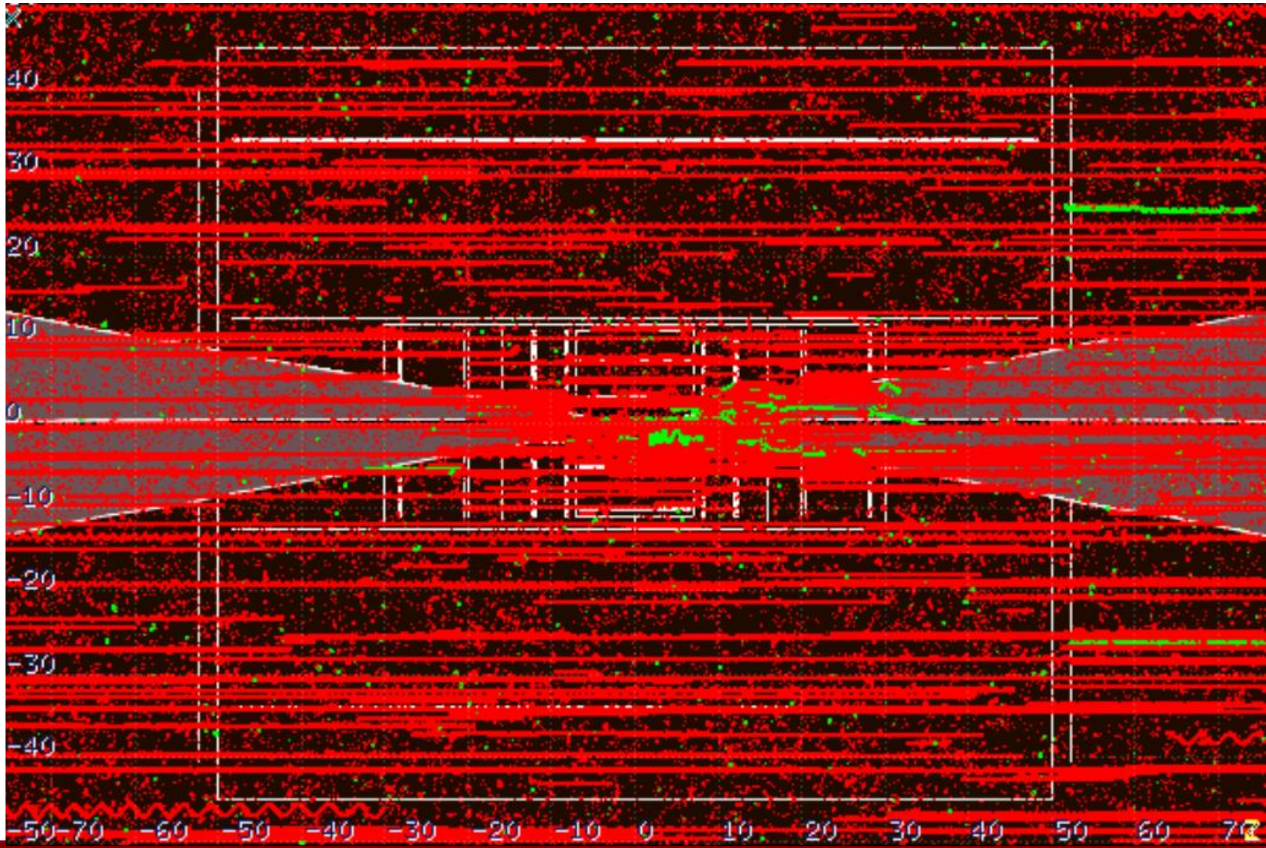
A 10 TeV Collider is required to:

- Explore extensions of the standard model
- Investigate dark matter and exotic particles
- Address the hierarchy problem

Design exists for a $\sqrt{s}$ = 3 TeV detector (see paper), working on a 10 TeV design

Challenges

- Muons only have a lifetime of **2μs**
- Muons decaying in the pipeline lead to a shower of particles onto the detectors, called **Beam Induced Background** (**BIB**)
- BIB contains 13 EeV (million TeV)!
- BIB track properties:
  - Low number of hits
  - Low pT
  - Non-pointing
  - Out of time



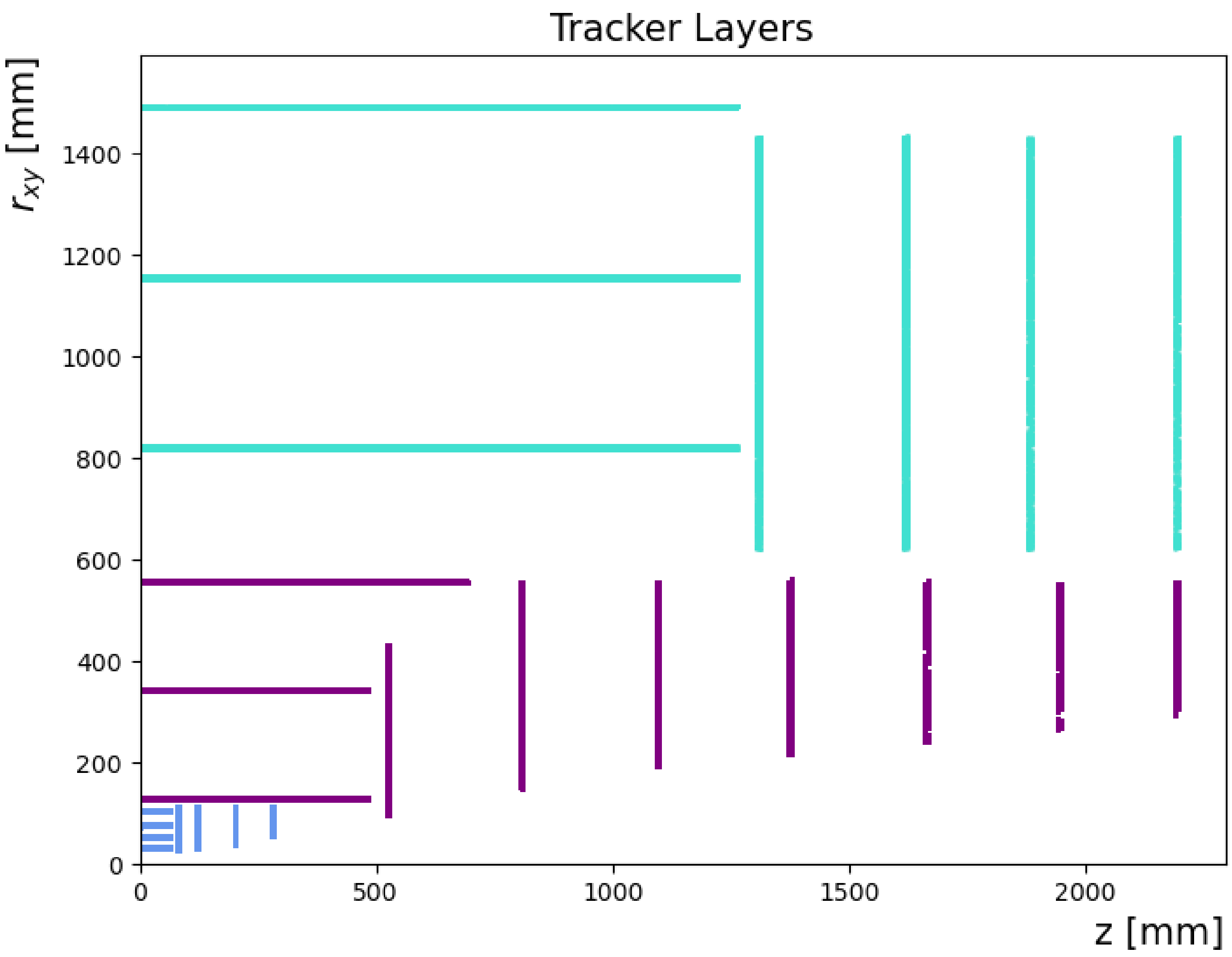
see here for more details!

Detector Design

- Detector design: Tracker, Solenoid, ECAL, HCAL, Muon detector
- Shielding **nozzles** cover the beam as it enters the detector

TRACKER

Sub Detector	Size	Timing
Vertex Detector	25 µm x 25 µm	30 ps
Inner Tracker	50 µm x 1 mm	60 ps
Outer Tracker	50 µm x 10 mm	60 ps



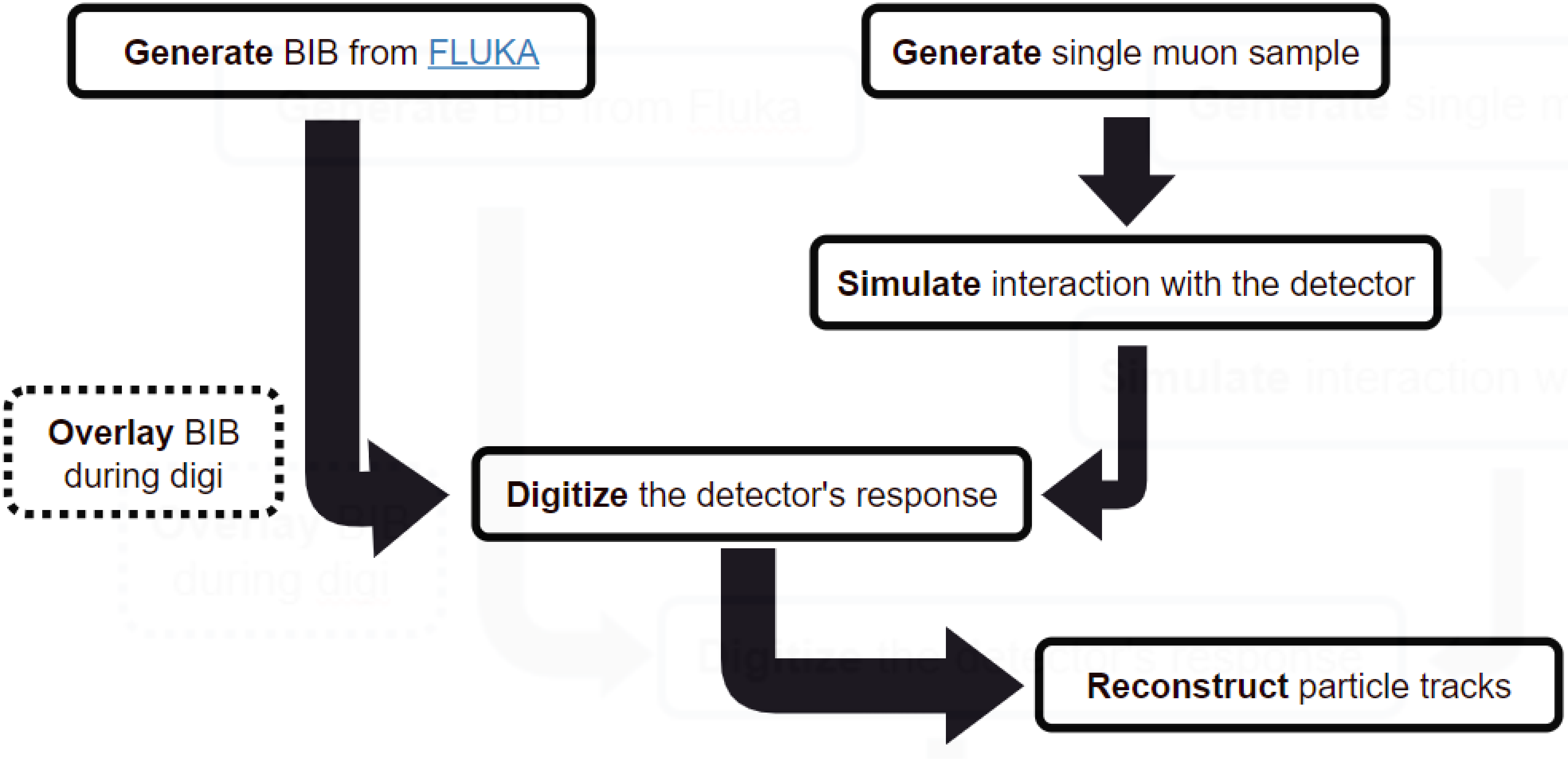
Tracking Performance

Tracking Performance

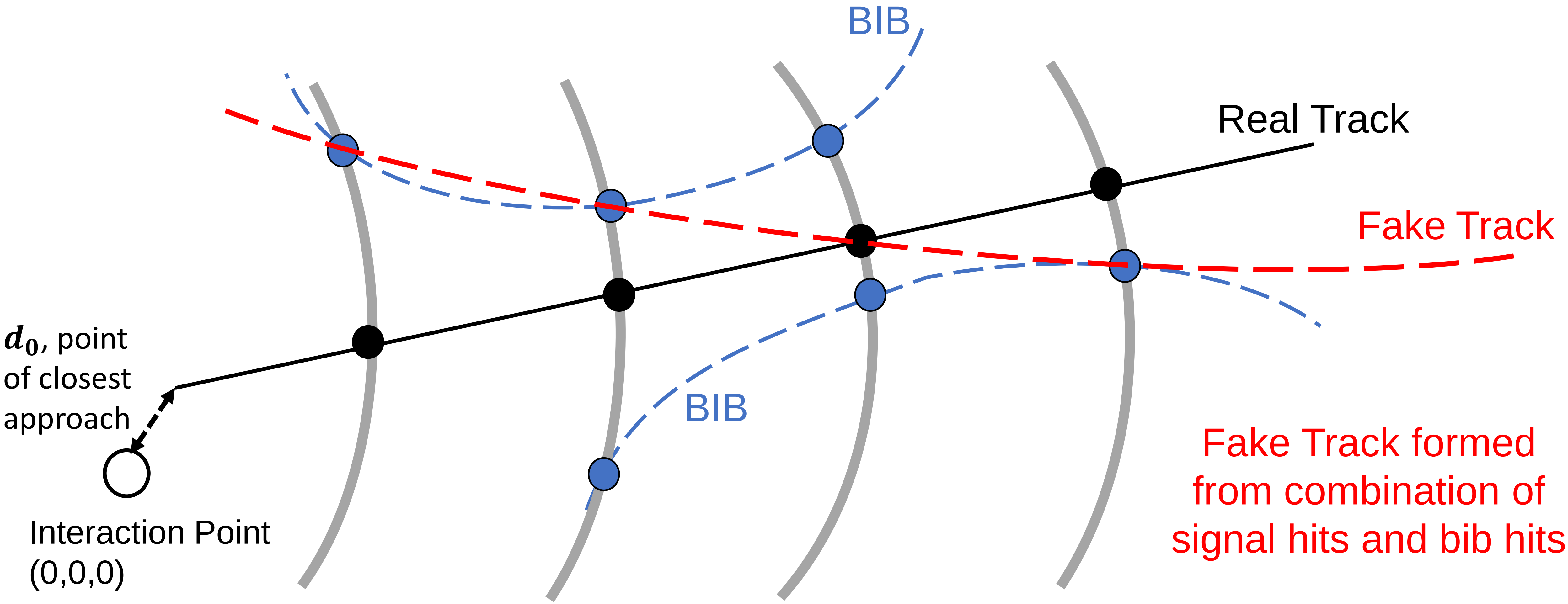
How well do we reconstruct standard (prompt, high pT) tracks:

- The **fake rate,** how often we reconstruct unmatched tracks
  - This is only a real issue with BIB
- The **reconstruction efficiency,** how often we reconstruct truth particles
- The **resolution,** how well can our detector resolve pT and d_0

Simulation Setup



BIB Hits and Fake Tracks



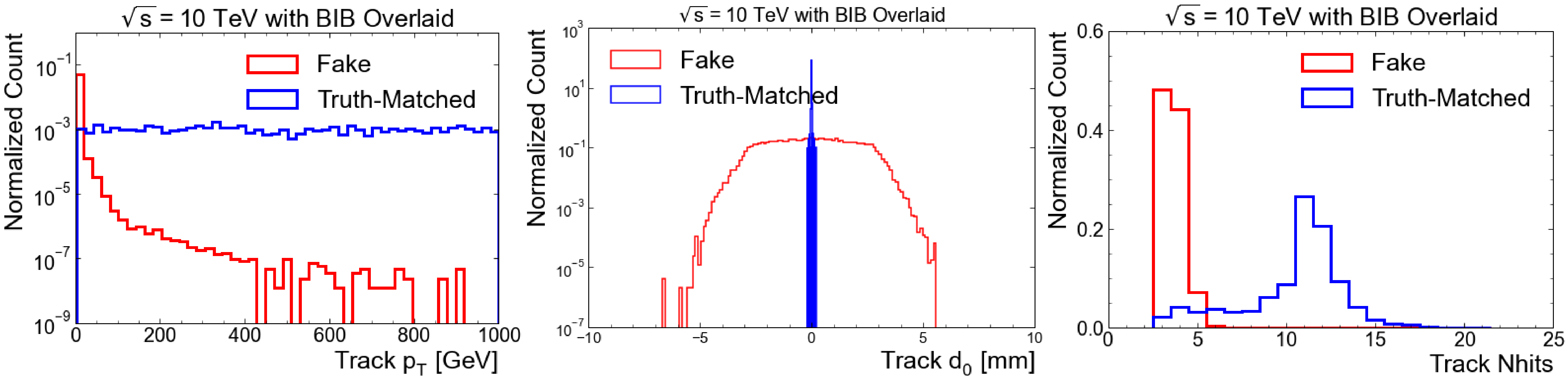
Fake Track formed from combination of signal hits and bib hits

Basic Track Distributions

- First compare truth-matched tracks to **fake tracks**

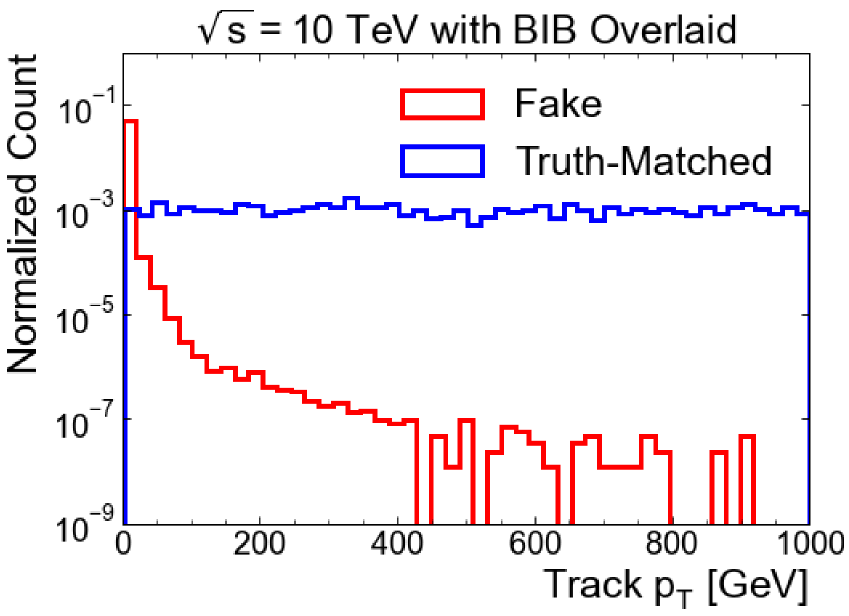
- Come up with cuts to eliminate fake tracks

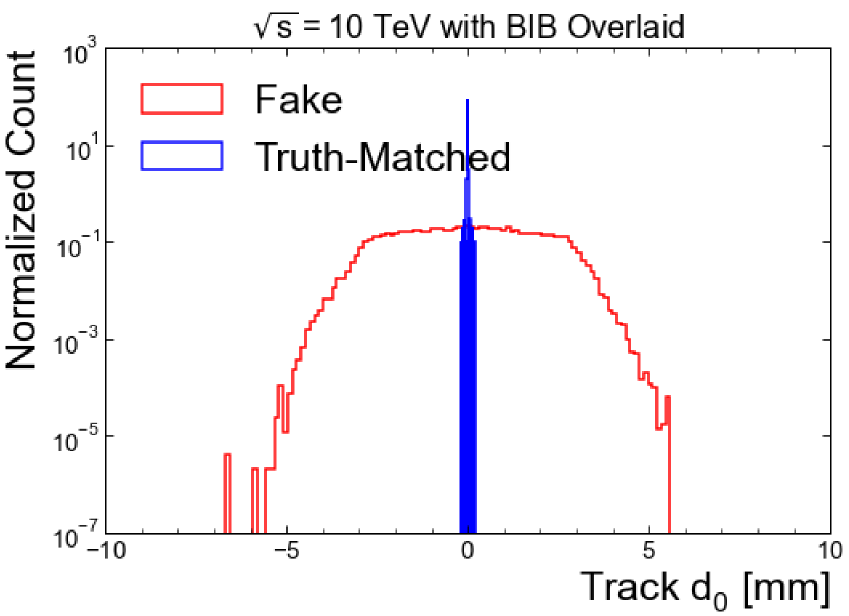
  - (Only look at BIB; without BIB there are almost no fake tracks)

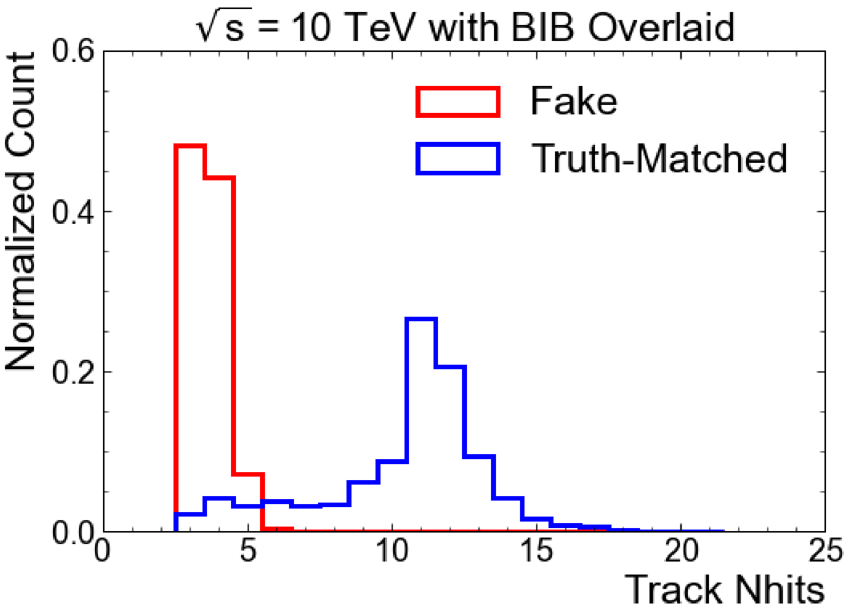


Basic Track Distributions

- The following track cleaning cuts are made:
  - $p_T > 1$ GeV, $|d_0| < 0.1$ mm, and nhits > 4

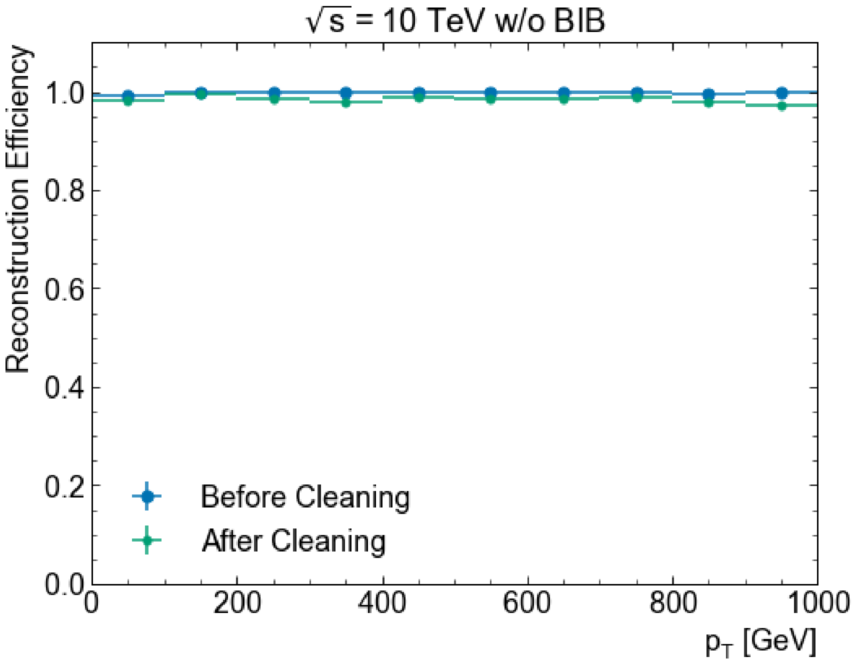


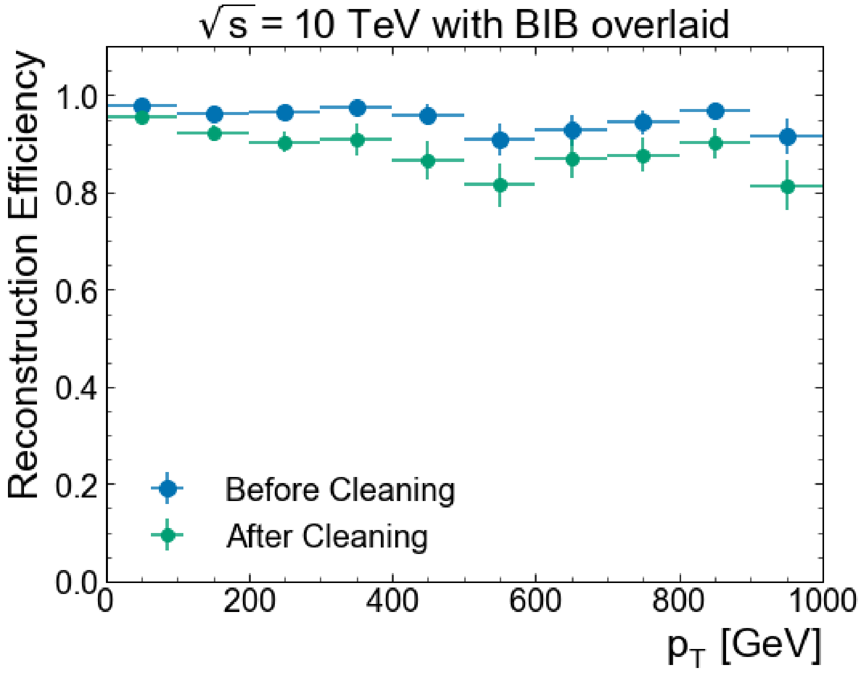


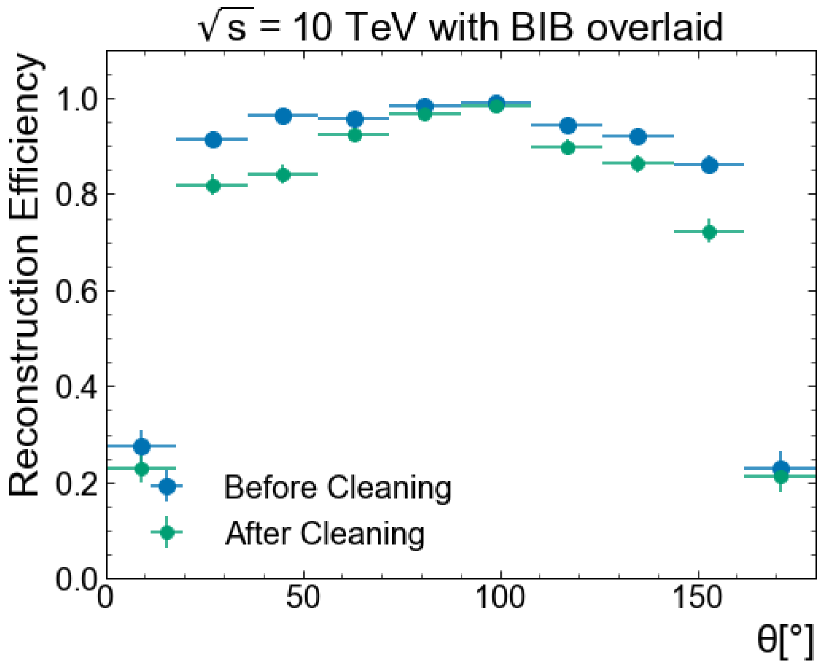


Reconstruction Efficiency

- Endcap has more complex geometry than Barrel, lowering efficiency
- Fakes that survive cleaning: 0.04%
- Efficiency with BIB overlaid w/o cleaning: 96%
- Efficiency lost from cleaning: 6%

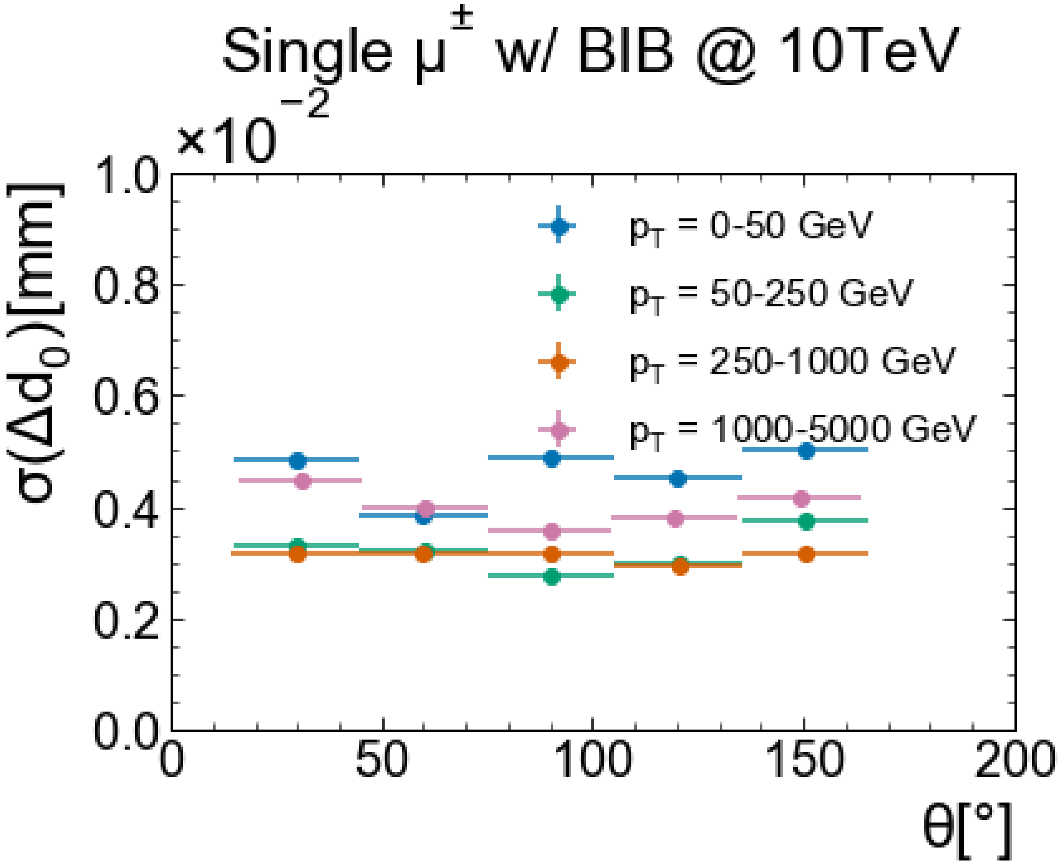






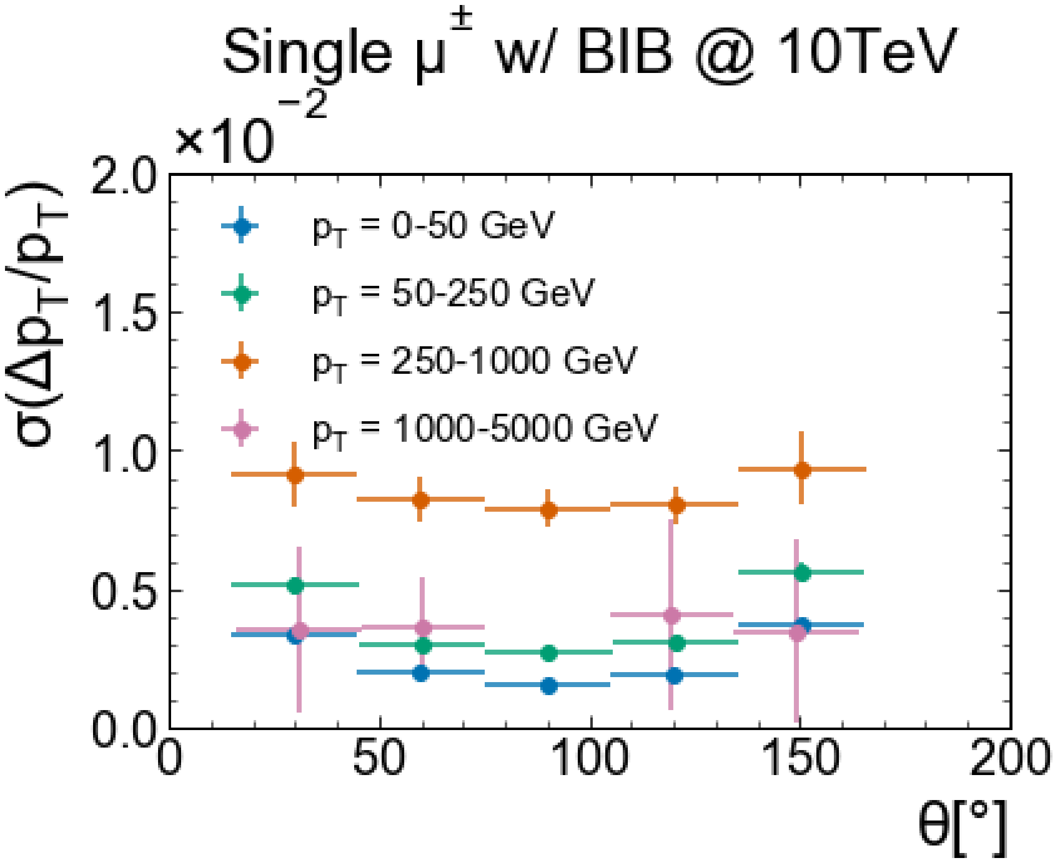
d_0 Resolution

- Resolutions: first compute residuals, then take the width of those distributions
- (Residual is Δ between truth and reconstructed)
- True d_0 is 0 - residual is just the displacement from 0
- Resolution is symmetric in θ, worse in the endcaps, and better in the barrel
- High p_T tracks curve less → easier to trace back d_0



p_T Resolution

- $\Delta p_T / p_T$ = (truth p_T - reco p_T) / truth p_T for matched muons
- Again, resolution is symmetric in θ, worse in the endcaps, and better in the barrel
- High p_T tracks curve less → harder to resolve p_T



Conclusions for standard tracking

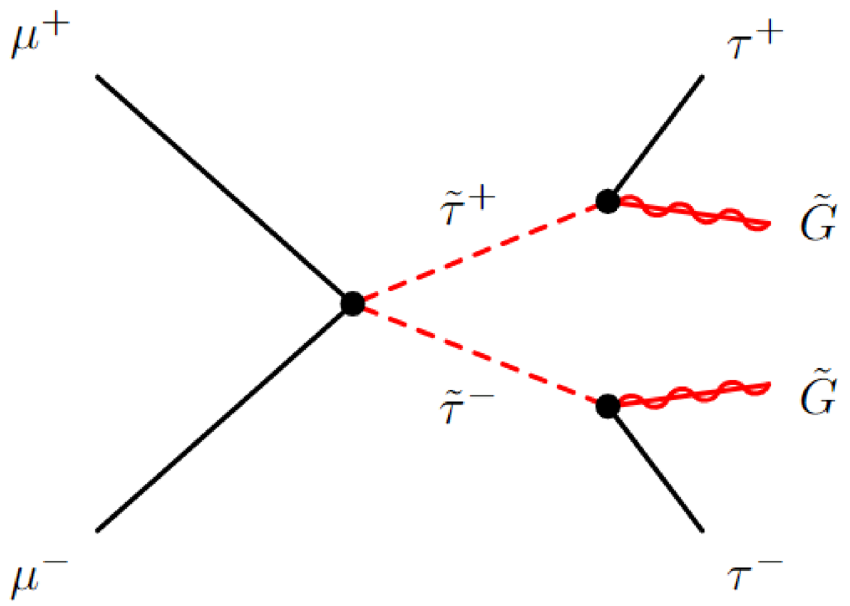
- Standard tracking status
  - Good background rejection
  - High efficiency
  - Good resolution
- For muon Gun data we look good! (NB: Paper forthcoming!)
- Now we want to understand how well we can do with more challenging scenarios

Long Lived Particles

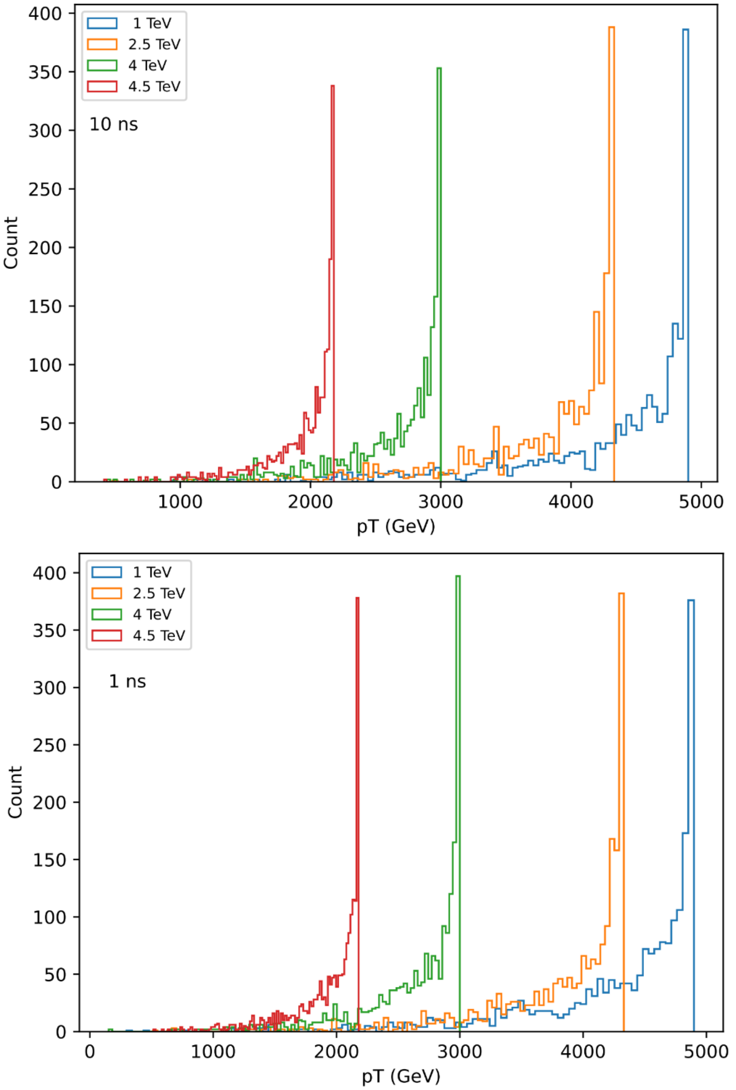
Motivation

- Want to make sure we're sensitive to BSM physics
- How do BIB selections affect our ability to reconstruct displaced/slowly moving tracks from LLPs?
- In particular we will use the Stau - supersymmetric partner of the tau – as a benchmark model that gives us multiple LLP signatures
- Decay products can be reconstructed as displaced tracks

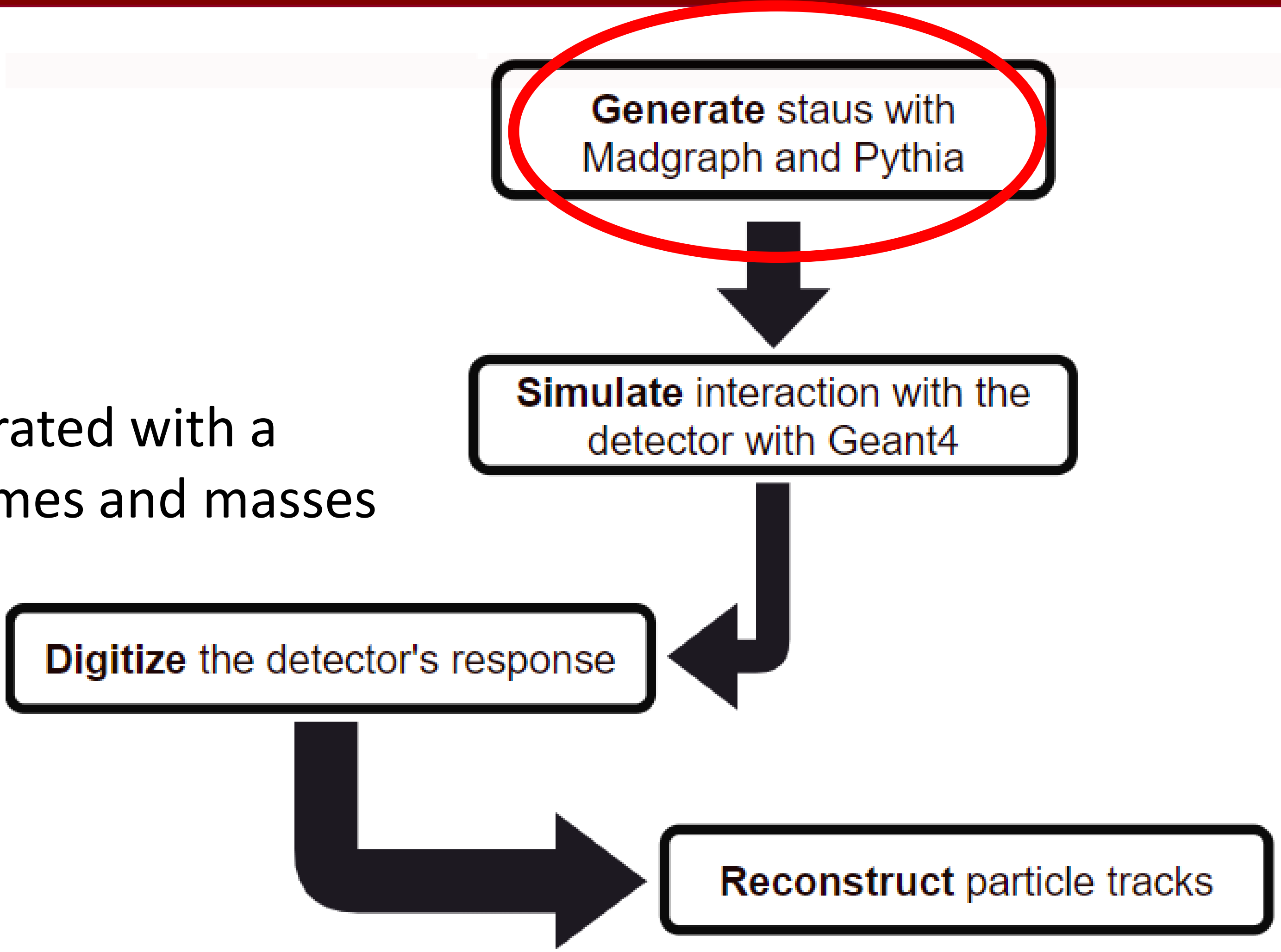
Muons → Staus → Taus + Gravitinos



Generation

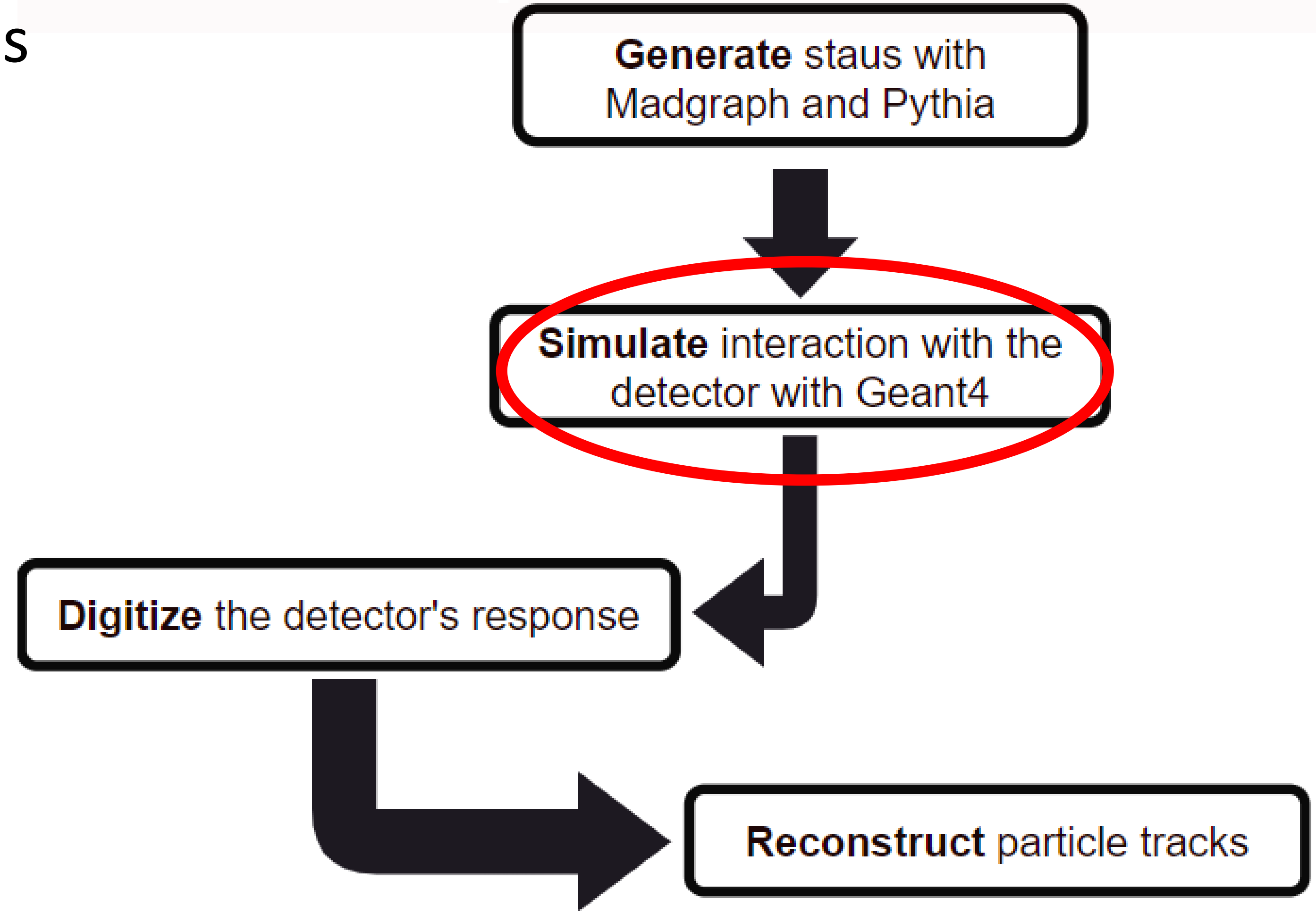


Staus are generated with a variety of lifetimes and masses



Simulation

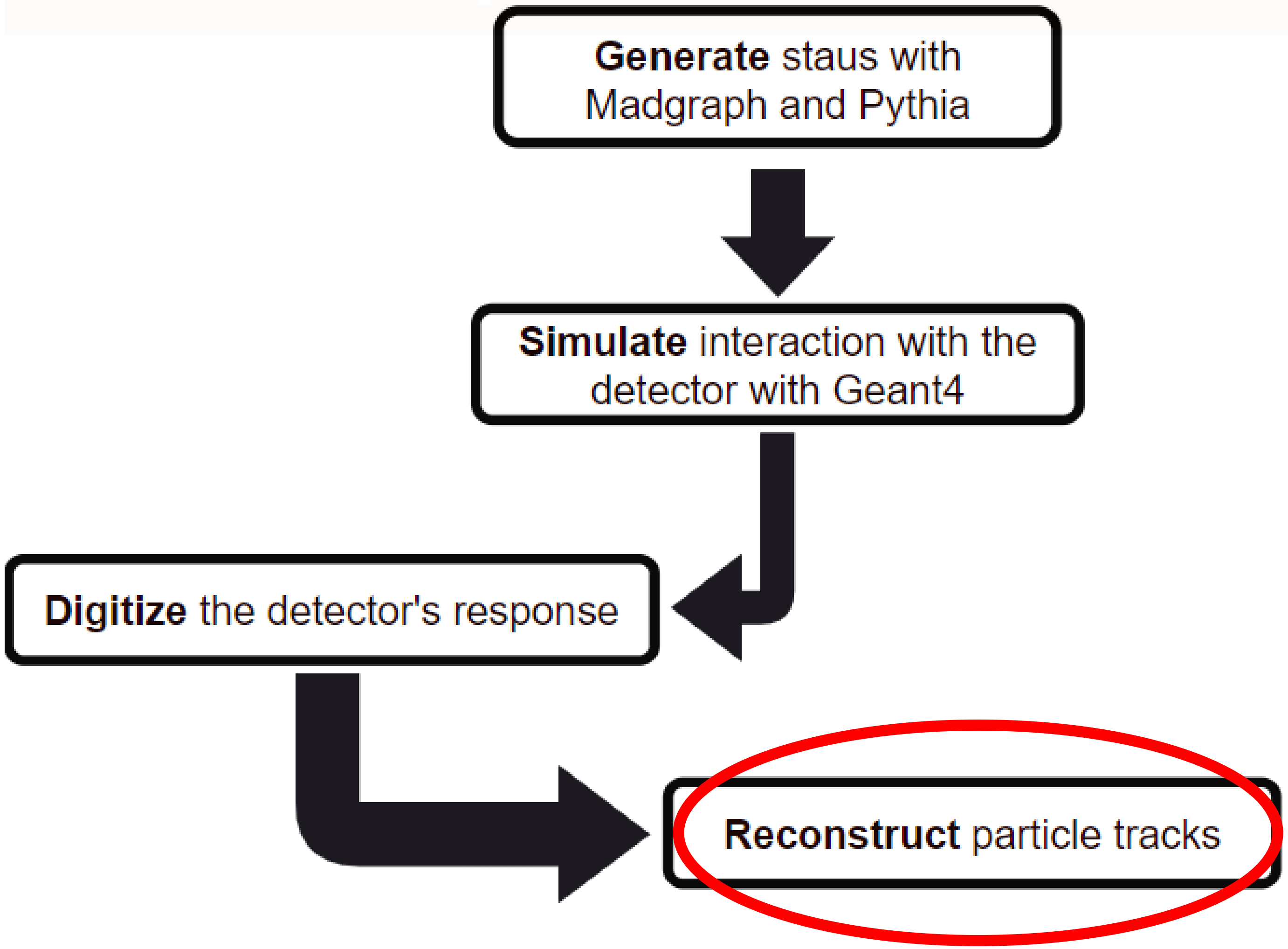
- Use Geant4 to simulate interactions with the detector
- Need to loosen timing window because Staus are slowly moving
- BIB still generated and simulated separately



Reconstruction

Requirements for Stau tracks:

- Loosen timing window
- Loosen track impact parameter requirements
- Adapt track seeding

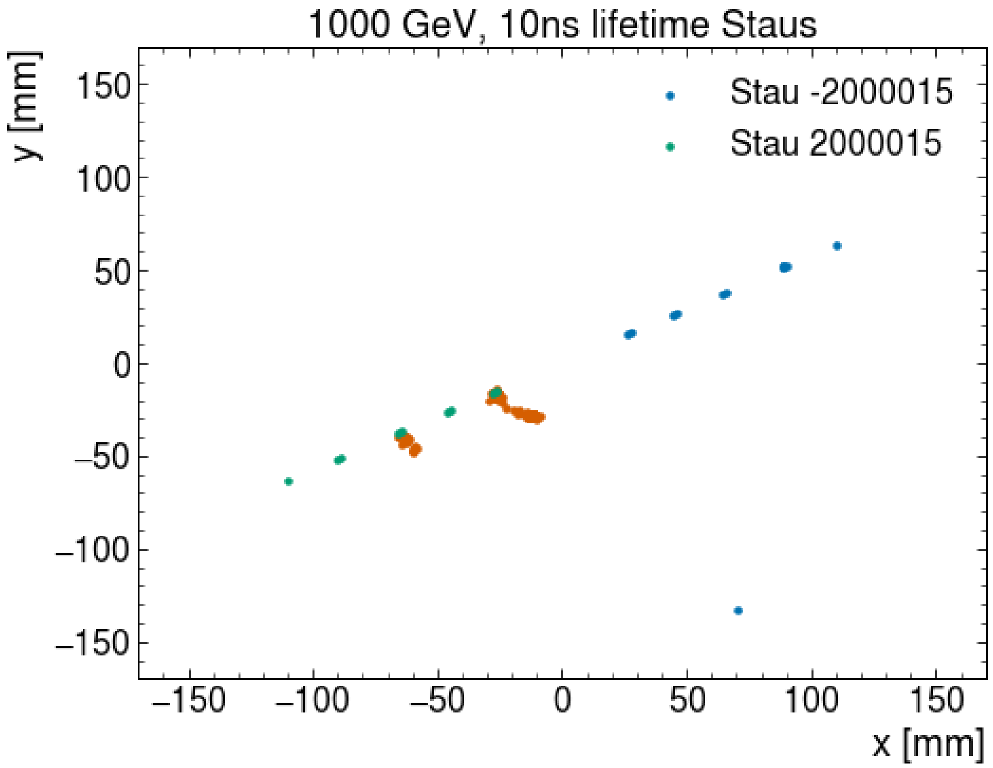


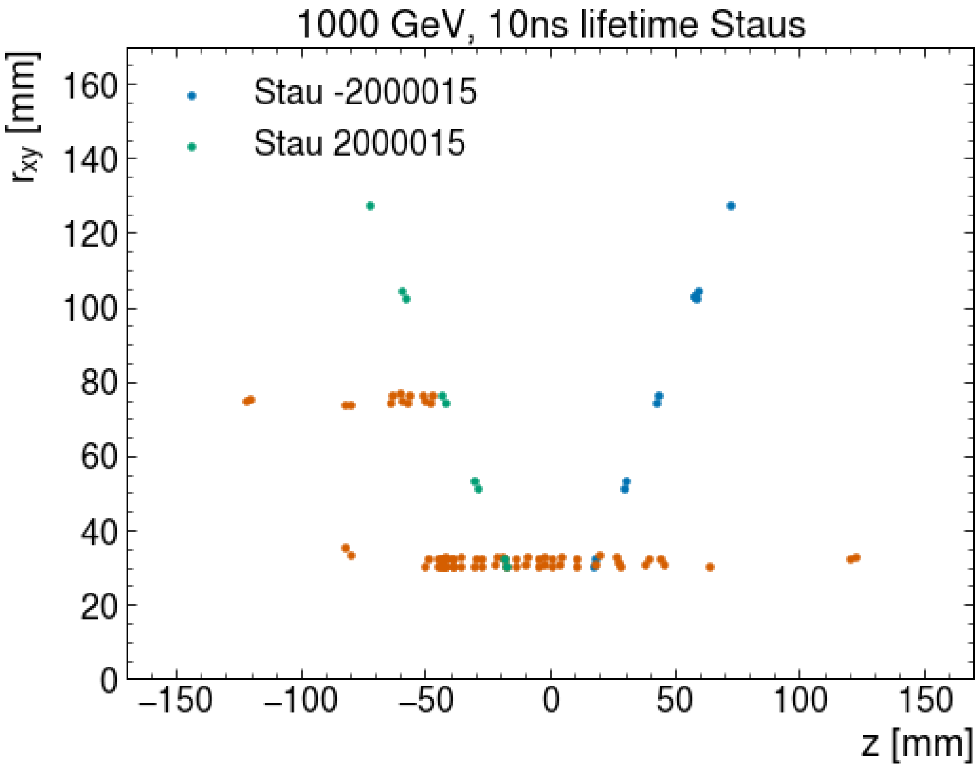
Status Code Issue

- We had challenges passing staus with certain hepMC status codes to Geant4 for simulation
- Discussed with the dd4hep team here, and they've now included a way to set alternative decay status
- Still sorting out a few things but issue mostly fixed

Stau Hits

- We are beginning to be able to see stau hits in simulation but not for every situation – iterating with dd4hep personnel





Next Steps

- Once we have all particles properly simulated, we can move on and ensure we are able to reconstruct the tracks
- With tracks properly reconstructed for signal samples, we can then add BIB and see if our track reconstruction is robust enough to handle the large amount of background

Acknowledgements

10 TeV Studies:

- Federico Meloni, Thomas Madlener, Priscilla Pani (DESY); Daniele Calzolari (CERN).
- Karri DiPetrillo, Ben Rosser, Anthony Badea (UChicago).
- Tova Holmes, Larry Lee, Charles Bell, Ben Johnson, Micah Hillman, Adam Vendrasco (UTK).
- Sergo Jindariani, Kevin Pedro, (FNAL); Rose Powers (Yale).
- Simone Pagan Griso (LBNL); Isobel Ojalvo, Junjia Zhang, Elise Sledge (Princeton).

LLPs Studies:

- Karri DiPetrillo, Ben Rosser, Tate Flicker, Kane Huang, Noah Virani (UChicago).

Backup

Existing Detector Design

- Existing detector concept **based on CLIC** with addition of **shielding nozzles** to reduce BIB.

hadronic calorimeter

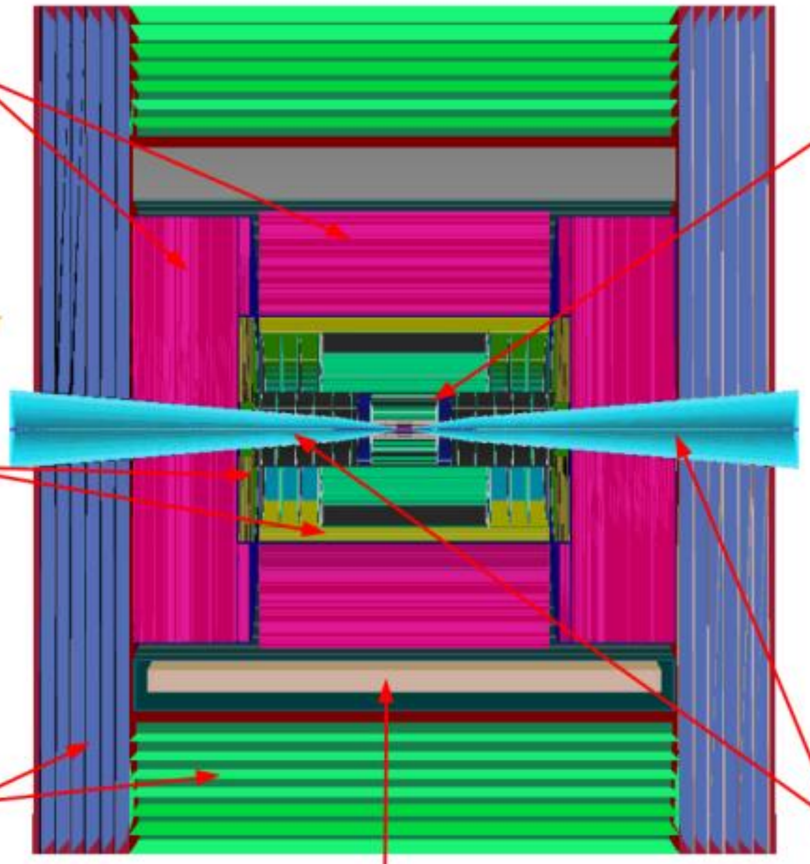
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip Si sensors.

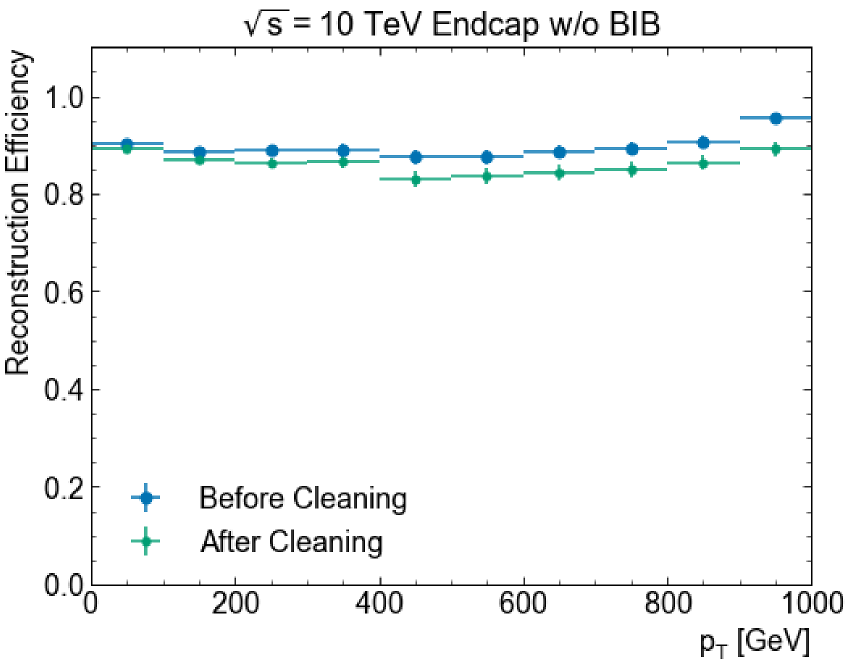
shielding nozzles

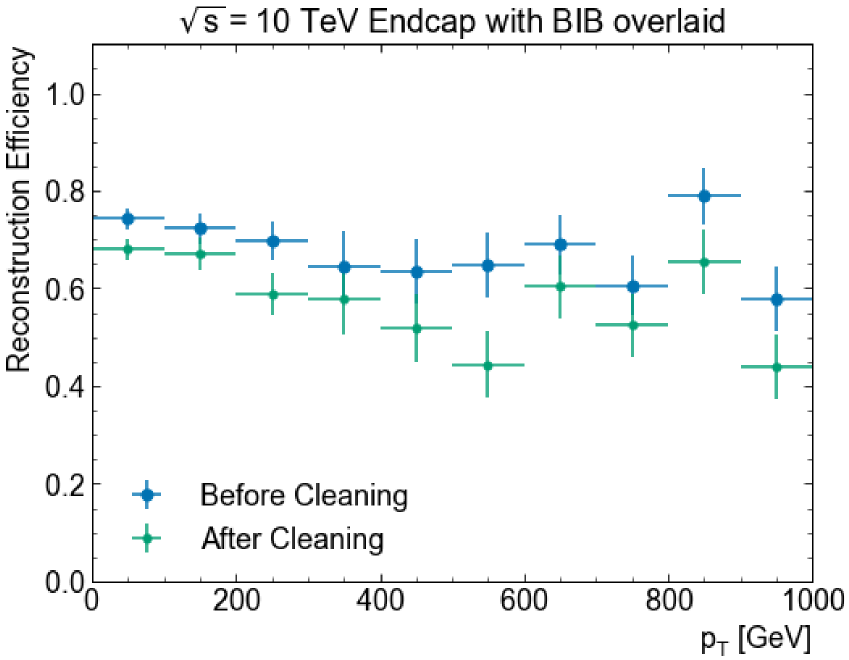
- Tungsten cones + borated polyethylene cladding.

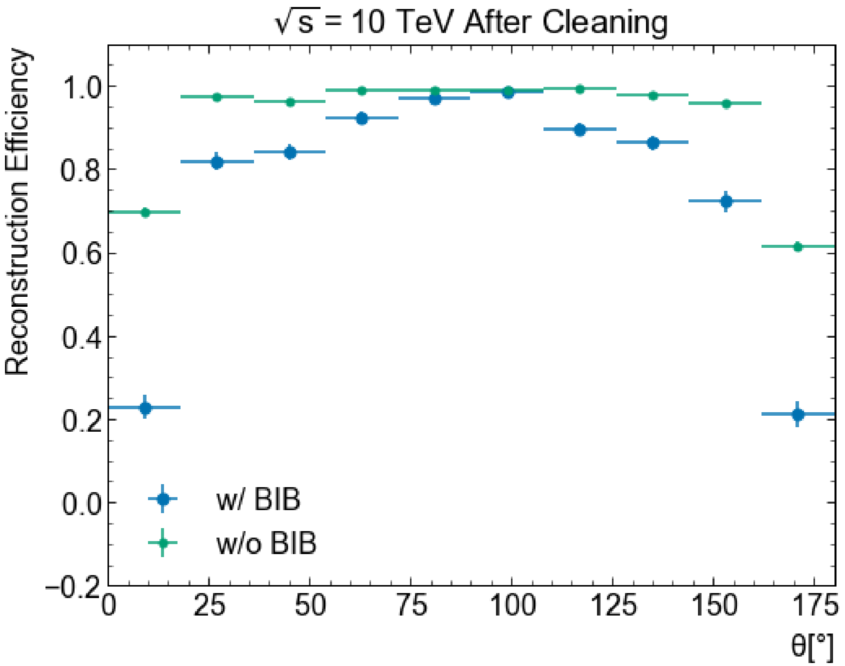
Taken from Ben Rosser

Reconstruction Efficiency

- Endcap plots + theta after cleaning

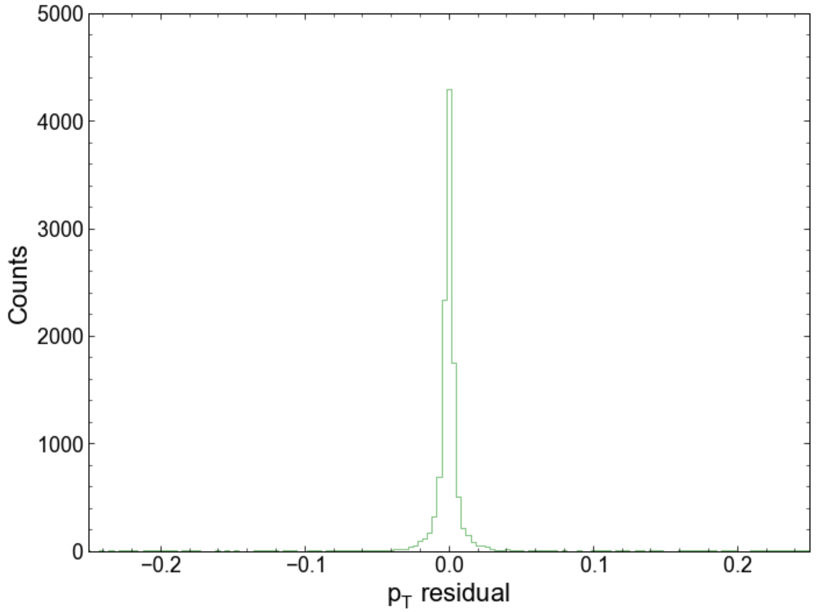


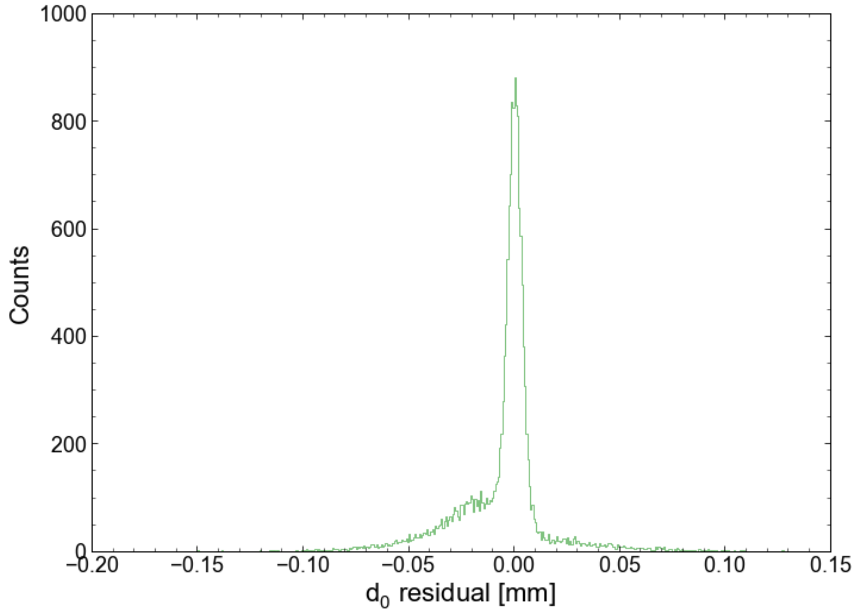




Resolution

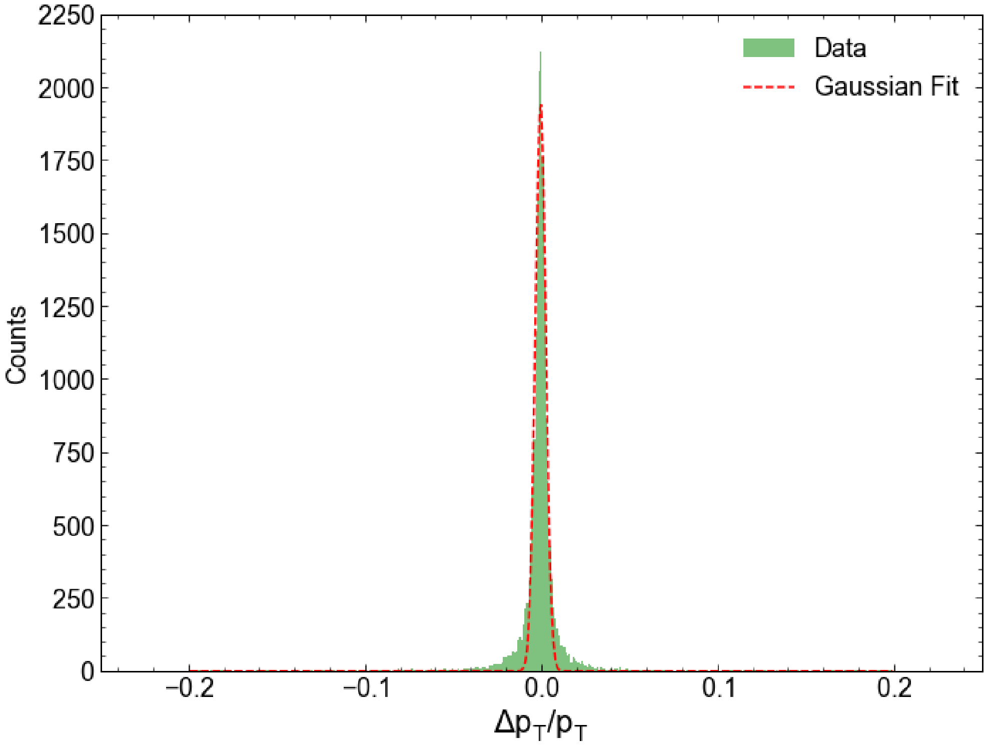
- We want to see how the resolution varies with observable parameters such as η/θ and p_T
- First, we plot the residuals (Δ)
  - $\Delta p_T / p_T$ = truth p_T - reco p_T / truth p_T for matched muons
  - (True d_0 and z_0 are 0 so the residual is just the displacement from 0)

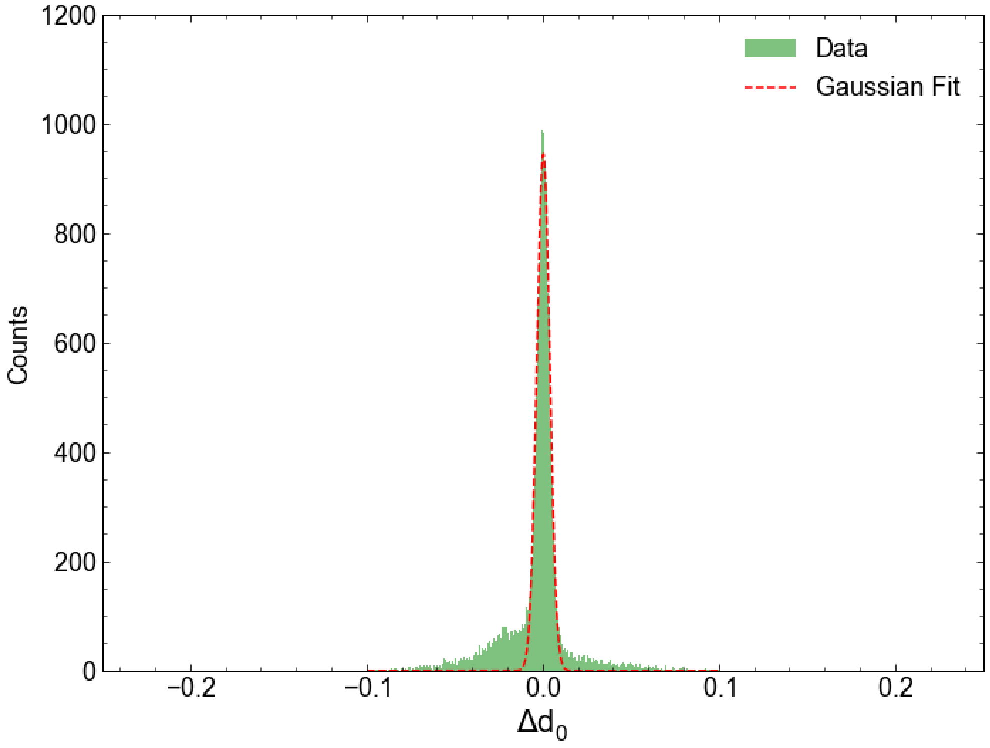




Resolution

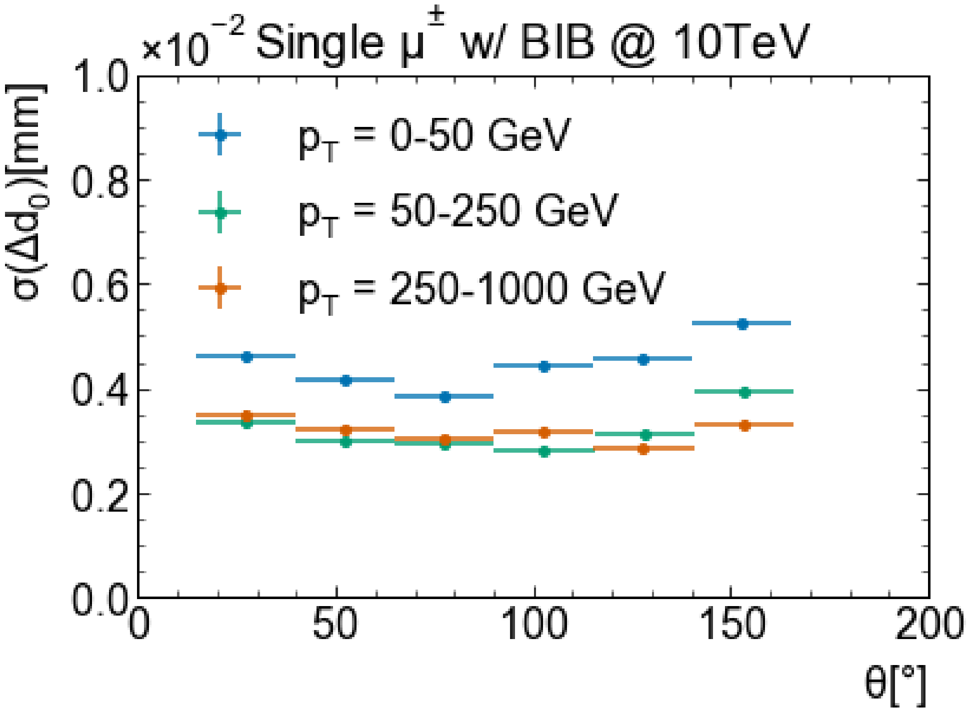
- Then we fit a gaussian to them to see if the data is as expected and to extract the standard deviation

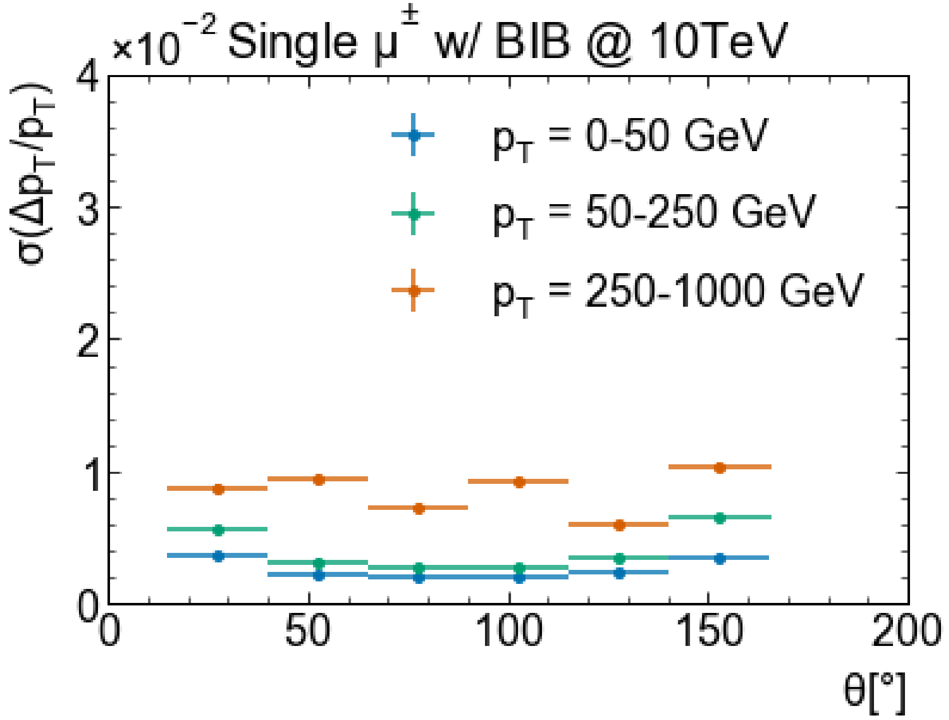




p_T and d_0 Resolution

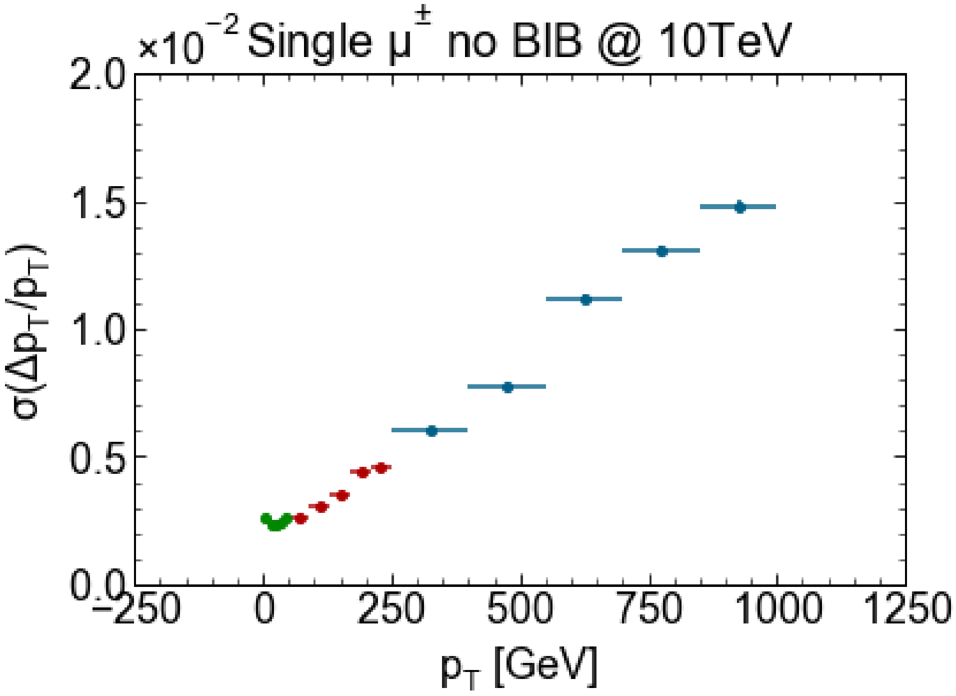
- BIB plots

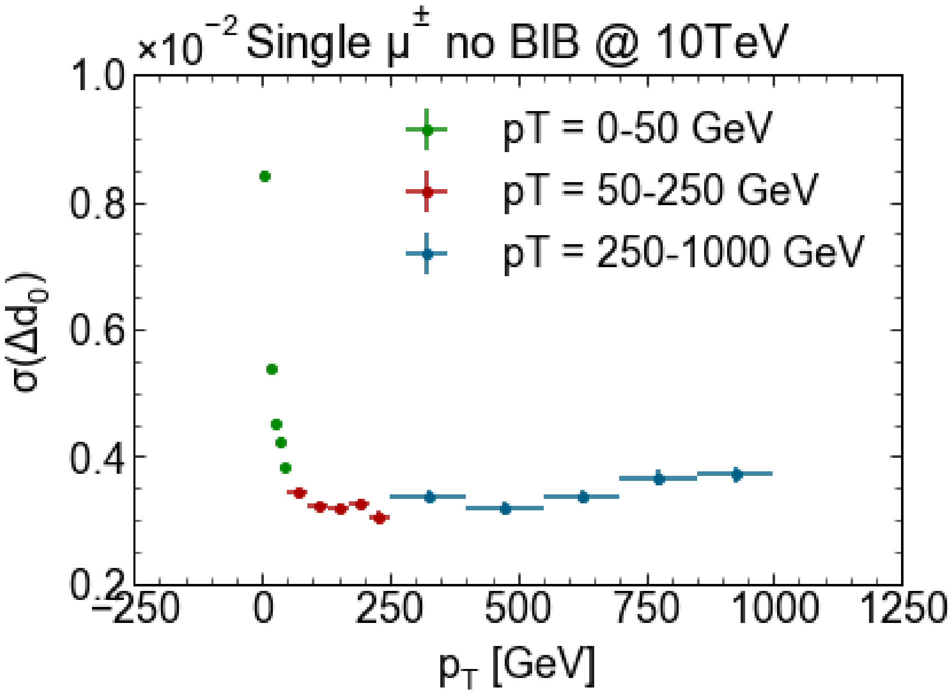




p_T and d_0 Resolution

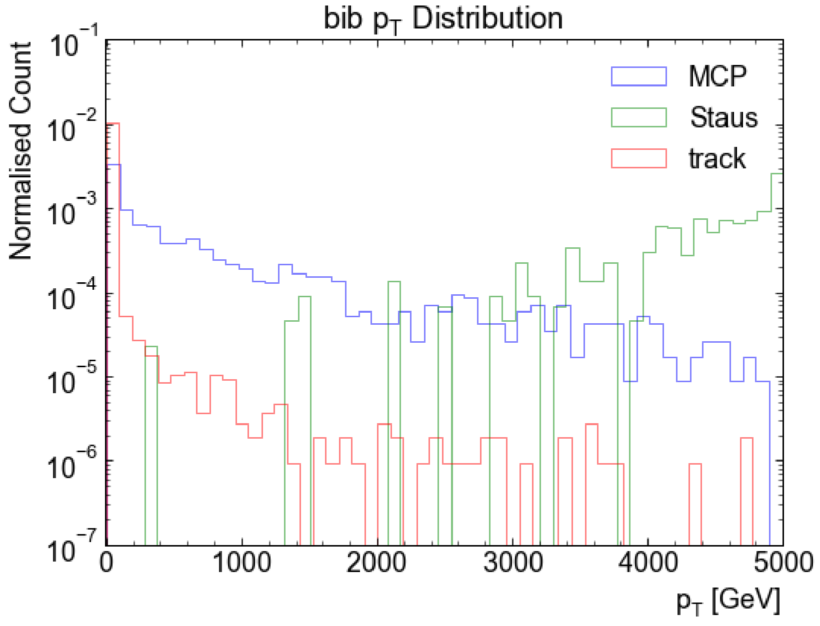
- Against pT

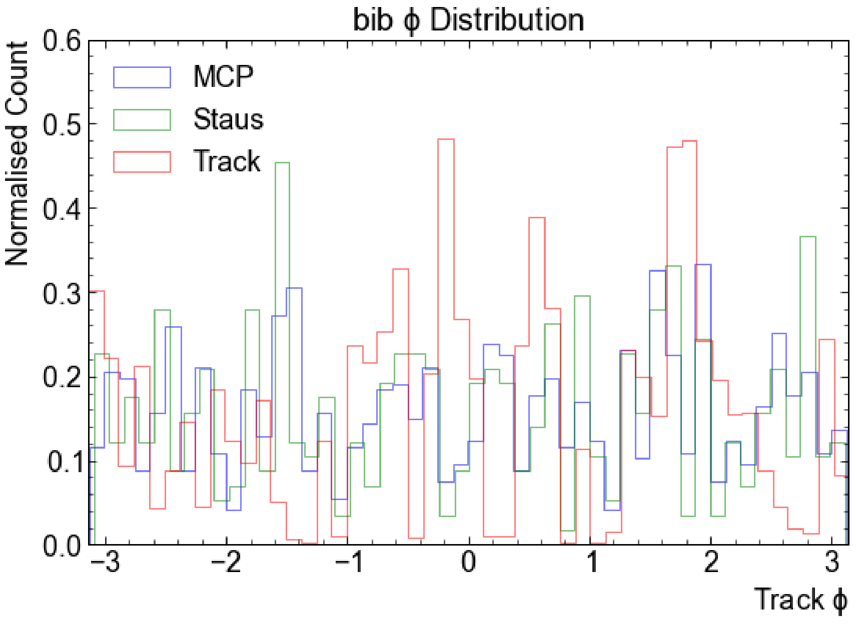


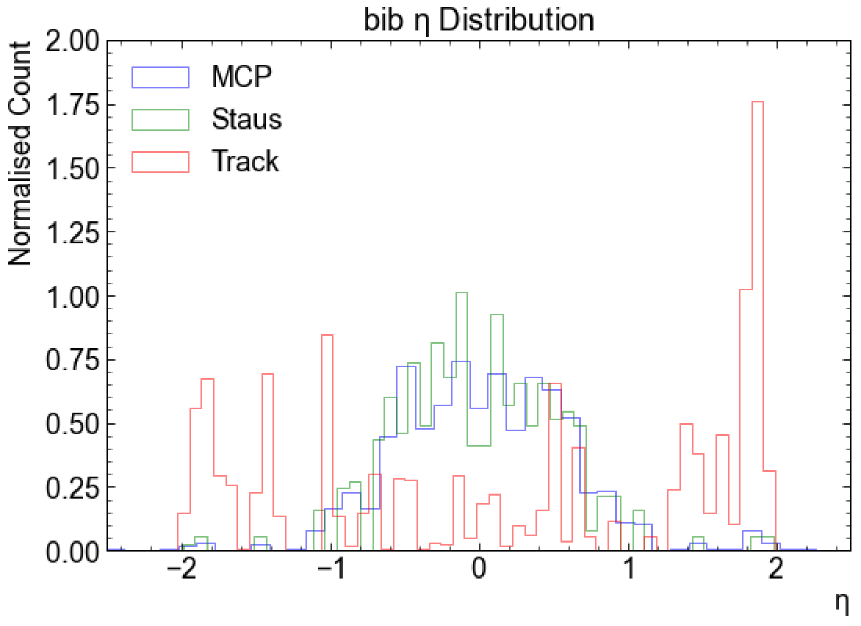


Analysis - Distributions

- Comparing MCPs (with status = 1), Staus, and tracks
- Most particles have < 200 GeV, but Staus have TeV energy
- See a track spike at eta ~ 2, probably due to BIB







LLPs - Pointing

- First isolate hits in the Vertex Barrel Region (because it contains doublet layers)