ACTS Tracking For Muon Collider

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BERKELEY LAB
Lawrence Berkeley National Laboratory

ACTS Dev Meeting

Muon Collider Detector

hadronic calorimeter

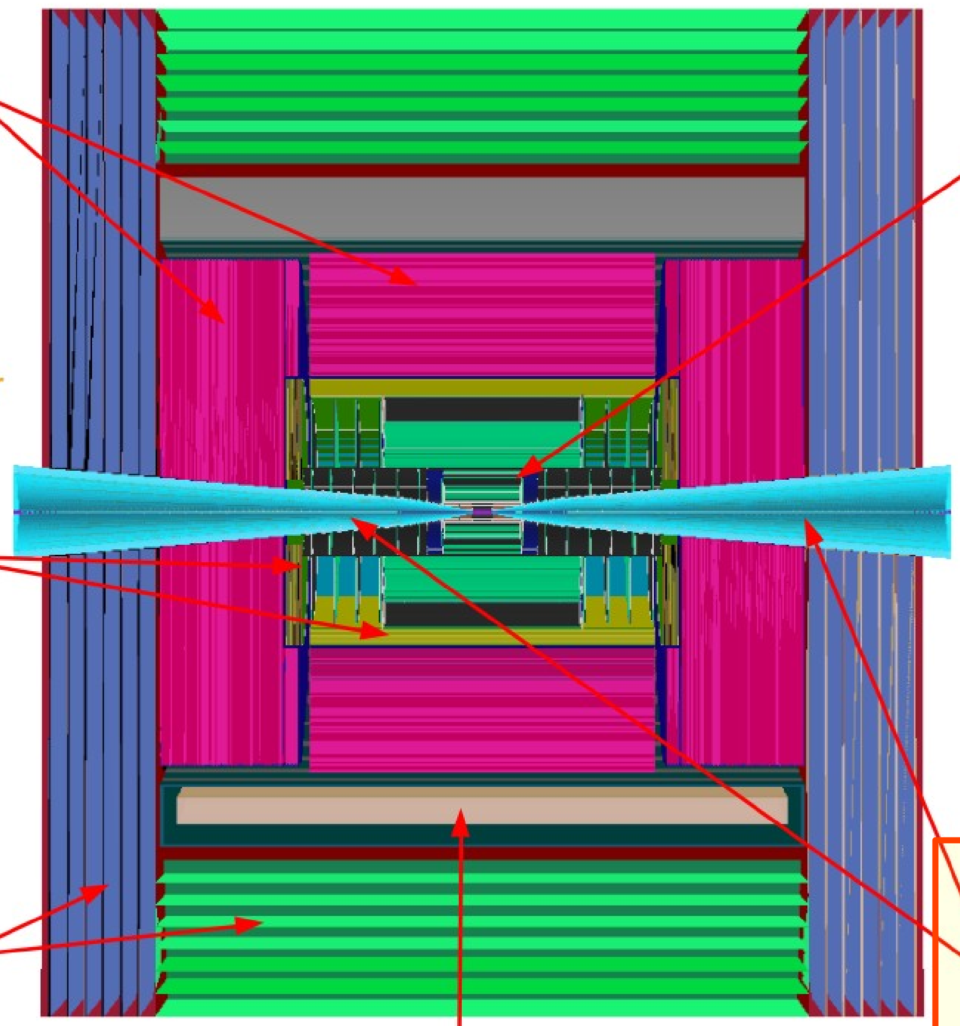
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

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

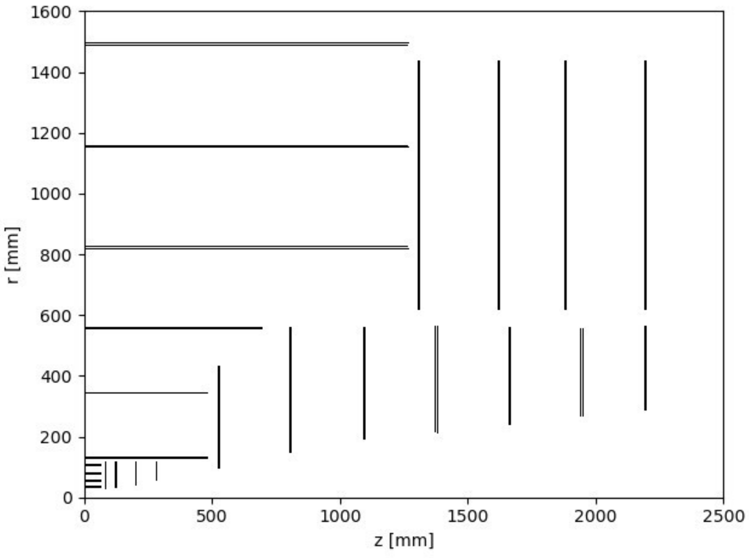
- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip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

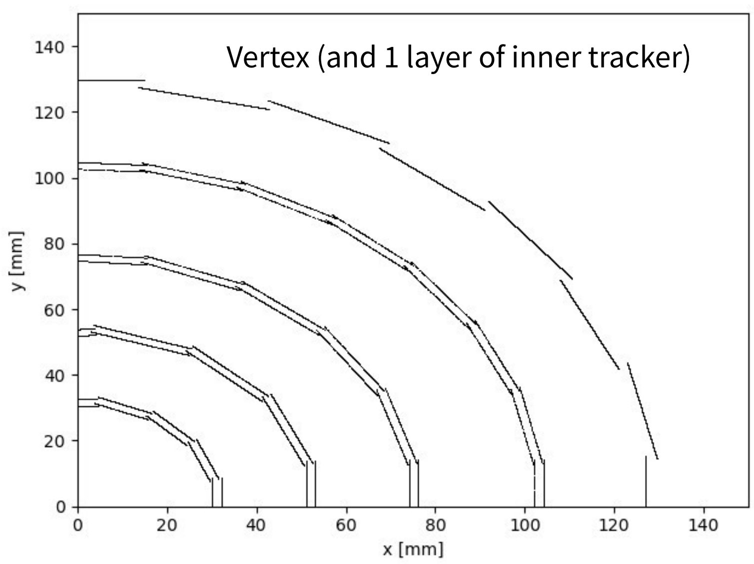
shielding nozzles

- Tungsten cones + borated polyethylene cladding.

The Tracker

- Three subdetectors (vertex, inner and outer tracker)
- Doublet layers in the vertex detector
- Precision timing will be important in rejecting BIB hits



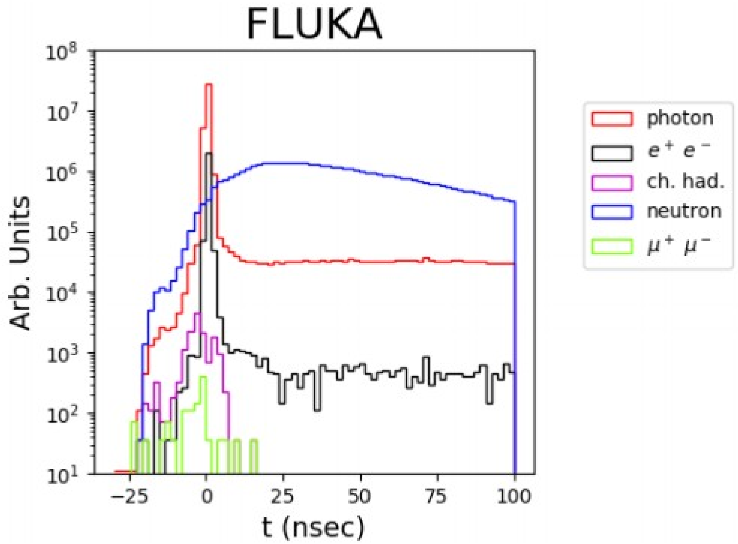


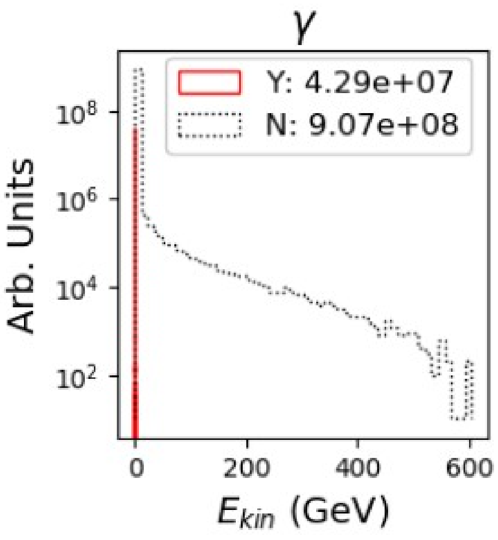
		cell size	sensor thickness	time resolution	spatial resolution
Vertex Detector	**B**	25 µm x 25 µm pixels	50 µm	30 ps	5 µm x 5 µm
	E	25 µm x 25 µm pixels	50 µm	30 ps	5 µm x 5 µm
Inner Tracker	**B**	50 µm x 1 mm macropixels	100 µm	60 ps	7 µm x 90 µm
	E	50 µm x 1 mm macropixels	100 µm	60 ps	7 µm x 90 µm
Outer Tracker	**B**	50 µm x 10 mm microstrips	100 µm	60 ps	7 µm x 90 µm
	E	50 µm x 10 mm microstrips	100 µm	60 ps	7 µm x 90 µm

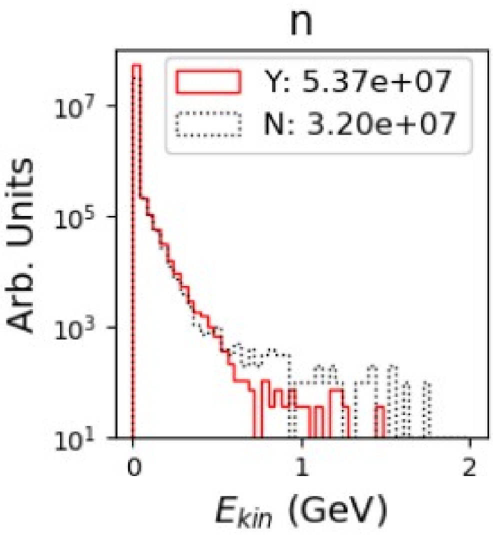
Beam Induced Background

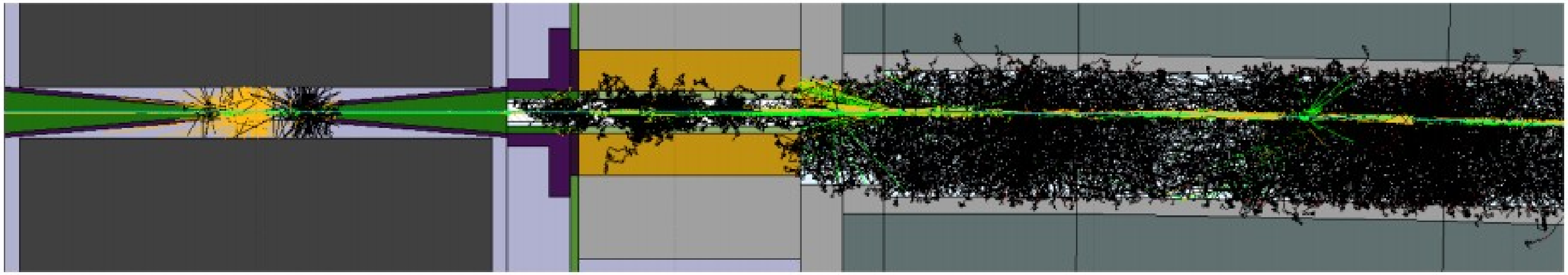
Details

- **Decays from beam muons strike detector and accelerator**
  - Simulated overlay include accelerator complex 100 m downstream
- **Decay products form a 5-10 cm “cloud” around beam**

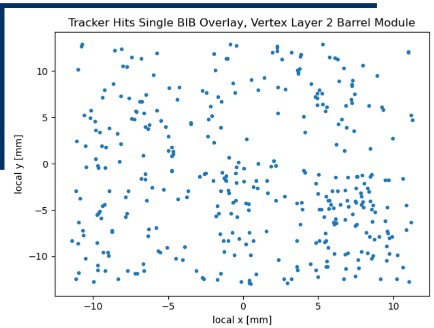




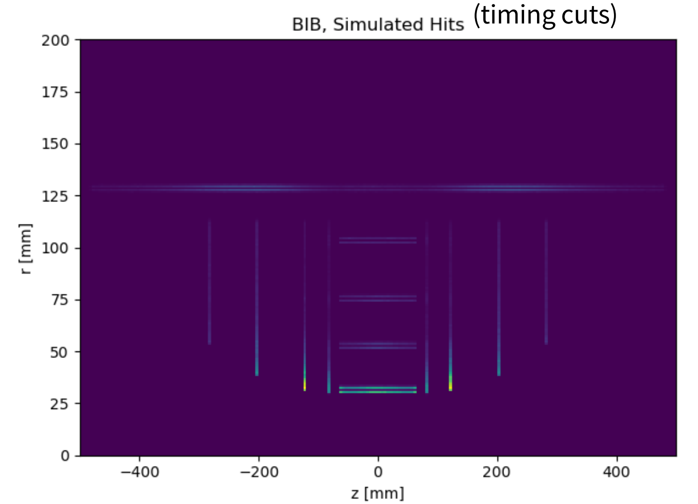


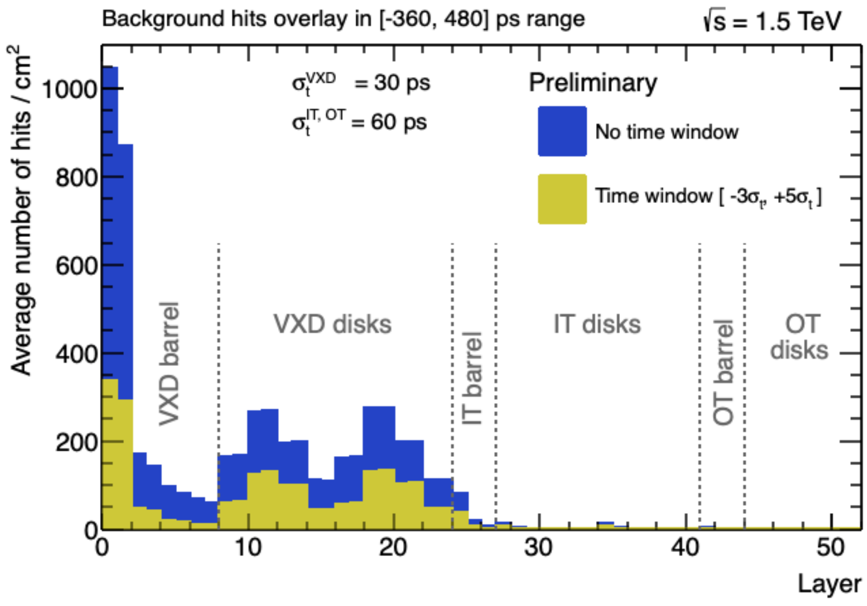


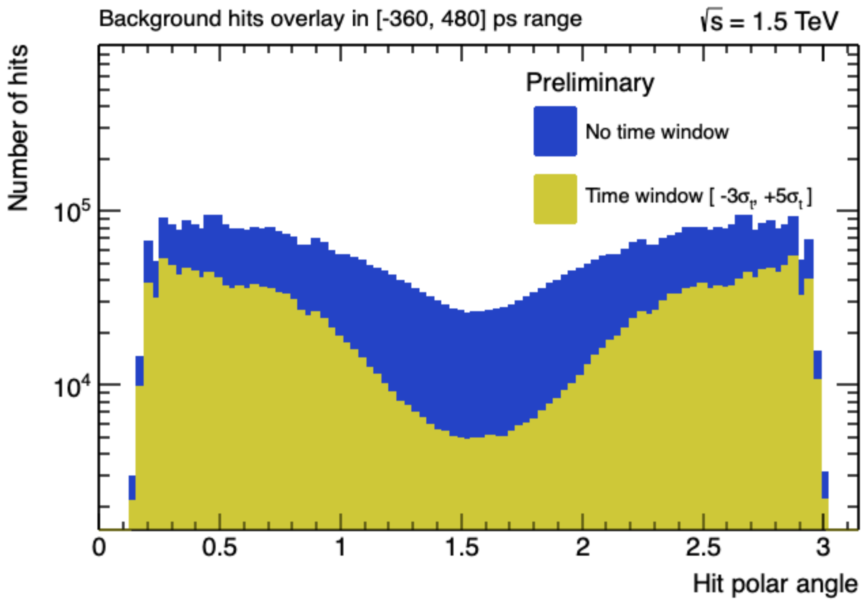
BIB in Tracker



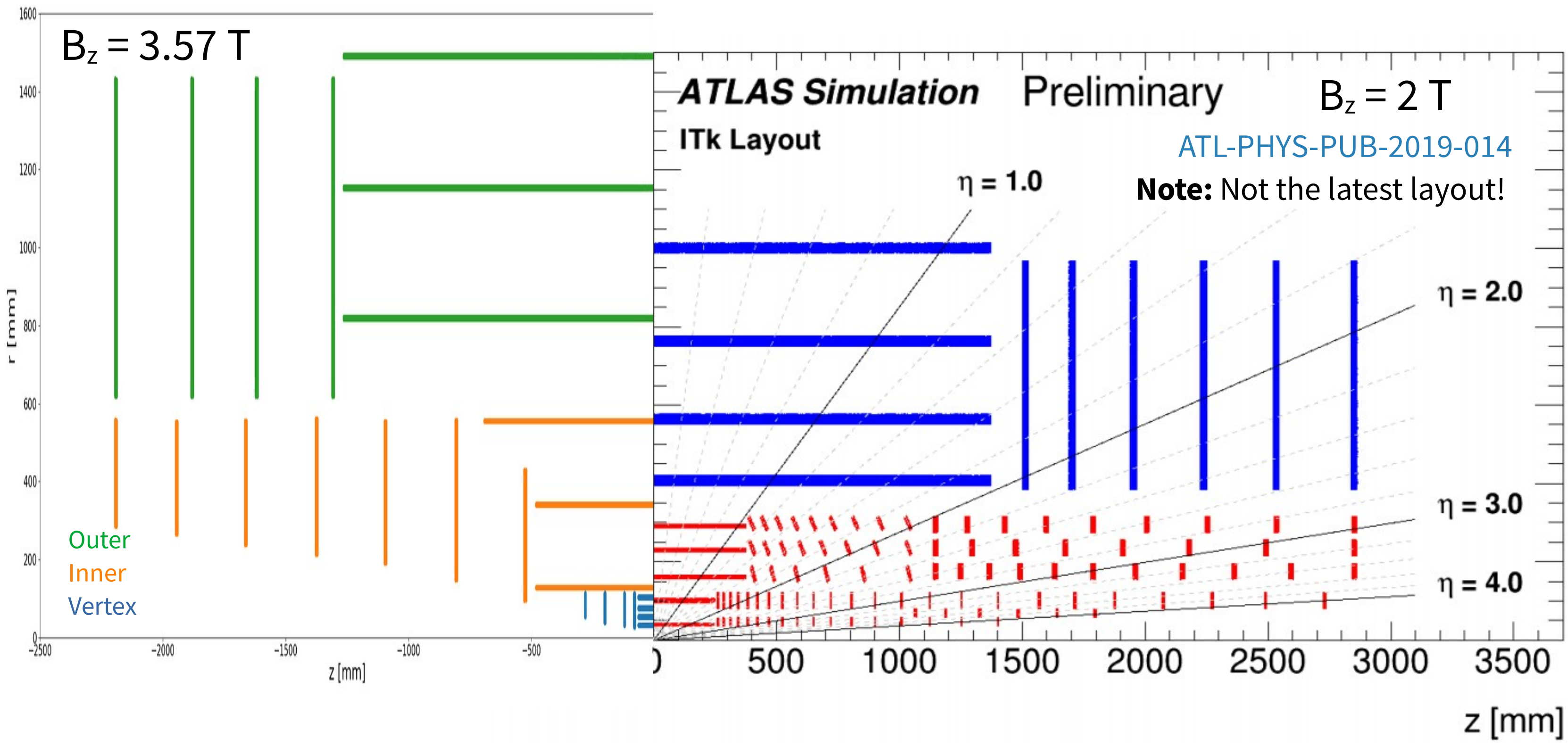
- **Timing cuts current main handle to reject BIB hits**
- **Realistic digitization can also help (WIP)**
- **Most are concentrated near the beamline**
  - Unlike at LHC, where most are concentrated near IP







Comparison With HL-LHC ATLAS



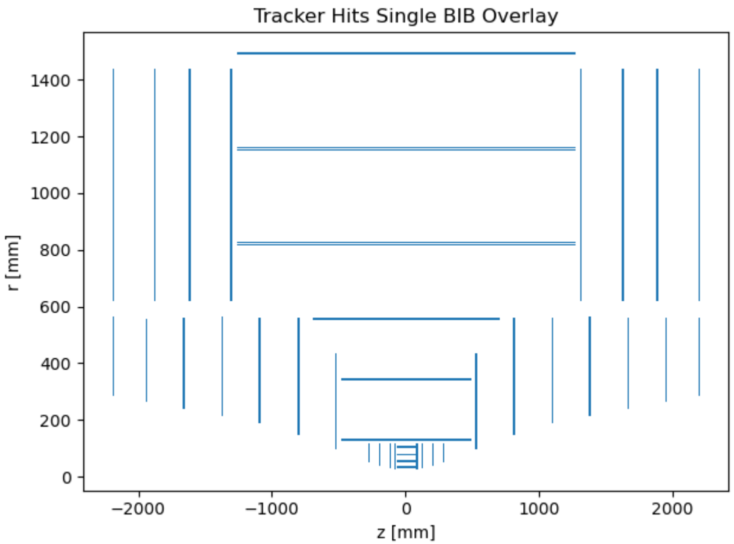
	ITk Hit Density [mm^{-2}]	MCC Equiv. Hit Density [mm^{-2}]
Pix Lay 0	0.643	3.68
Pix Lay 1	0.022	0.51
Str Lay 1	0.003	0.03

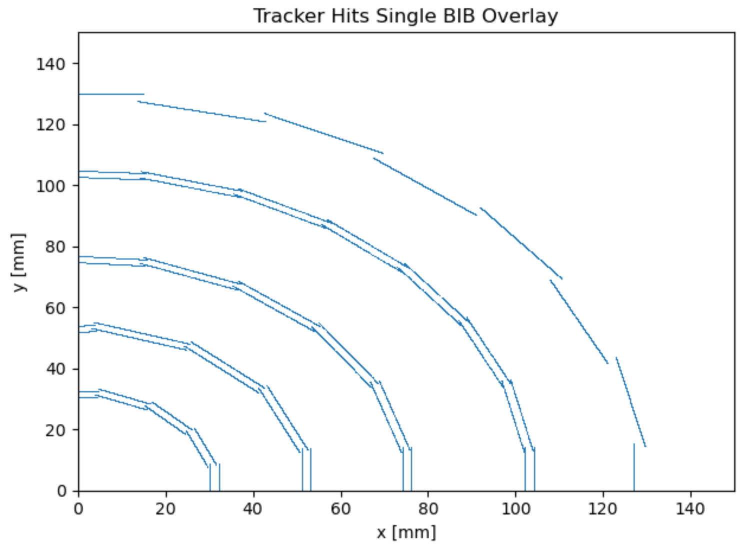
ITk Pixels TDR, ITk Strips TDR

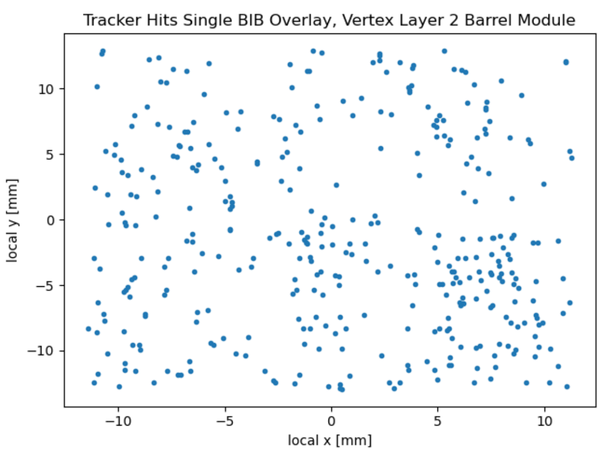
Current Tracking Implementation

More Information:
- Detector overview from Simone
- Tracking overview from Massimo

- **Designed for the e^+e^- environment**
  - Inherited as part of the CLIC software framework
- **Implements conformal tracking (1908.00256)**
  - Transform circular tracks into straight lines using conformal map
  - Use *cellular automata* to look for lines, allowing for deviations
- **Problem: $\mu^+\mu^-$ collider is much busier due to Beam Induced Bkg**
  - Heavy pre-filtering of hits is necessary for conformal tracking to work







A Few Technical Notes

- **Small modification to ACTS for double layers**

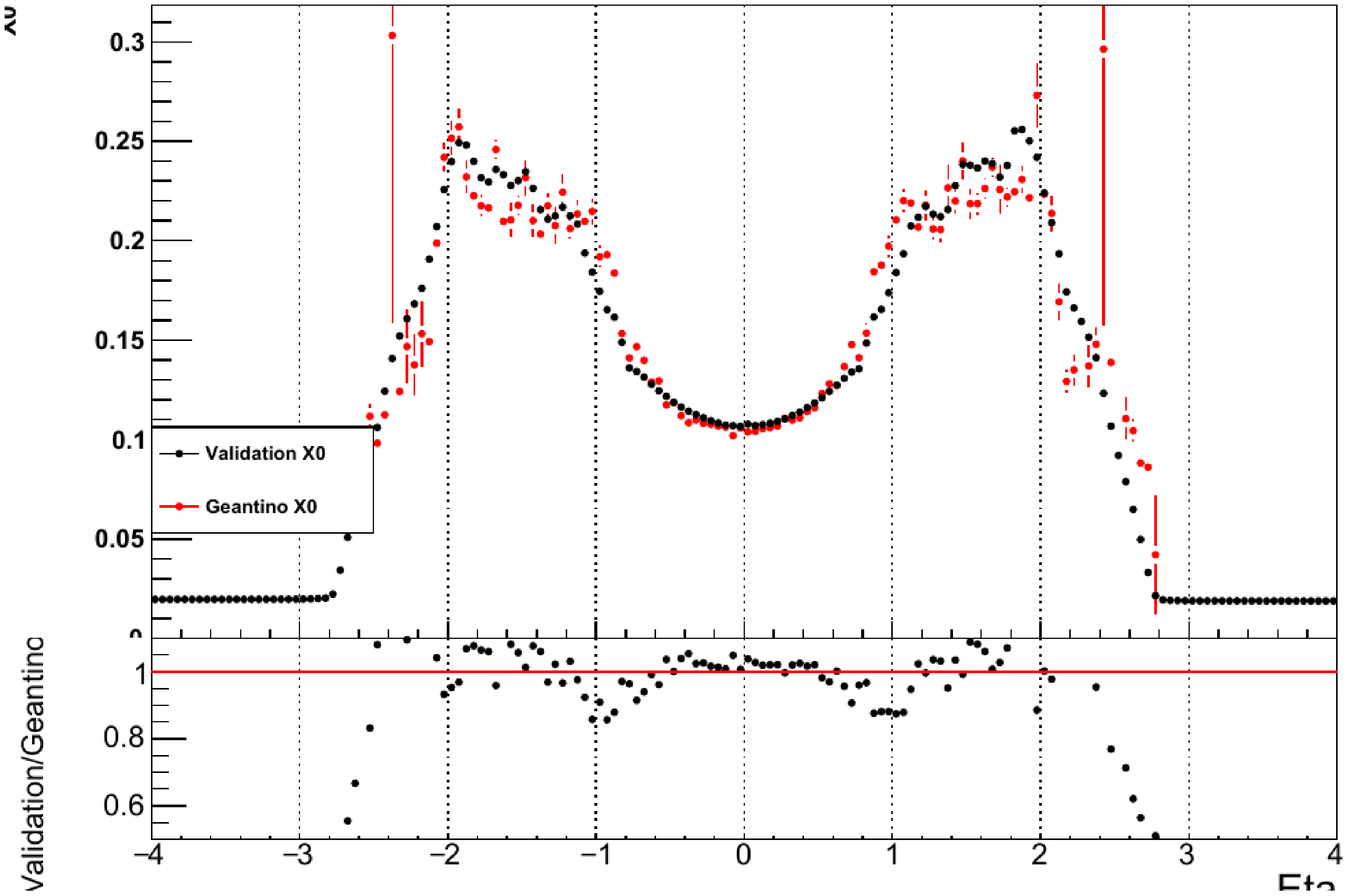
```diff
@@ -73,8 +73,8 @@ class TGeoLayerBuilder : public ILayerBuilder {
         : volumeName(""),
           sensorNames({}),
           localAxes("XZY"),
-          envelope(std::pair<double, double>(1 * UnitConstants::mm,
-                                             1 * UnitConstants::mm)) {}
+          envelope(std::pair<double, double>(0.1 * UnitConstants::mm,
+                                             0.1 * UnitConstants::mm)) {}
   };

   /// @struct Config
```

- **Using TGeo plugin to load geometry**
  - Slow to load, but our DD4hep “tree” is not supported by Acts
- **Implemented in MCC’s software framework (gitlab)**
  - Ready* to be used in the full event reconstruction chain
  - Based on CentOS8. ACTS’ Boost version is not a “minimal dependency” (issue)
- **Using ACTS release 9.2.0**
  - Updated a week ago, but do rarely in general

* Missing extrapolation to calorimeter for PF.

Material Validation



Truth Tracking

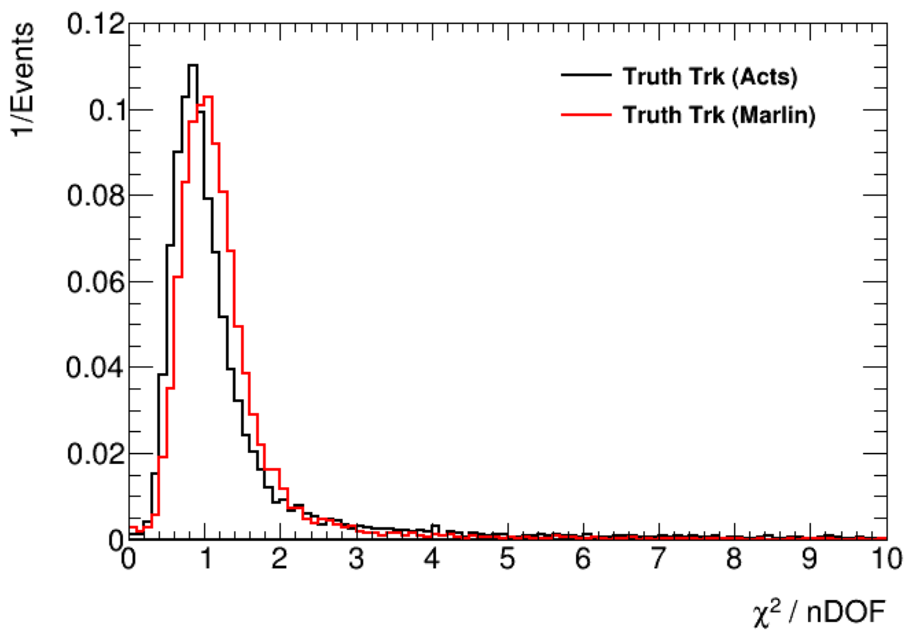
Pattern Recognition

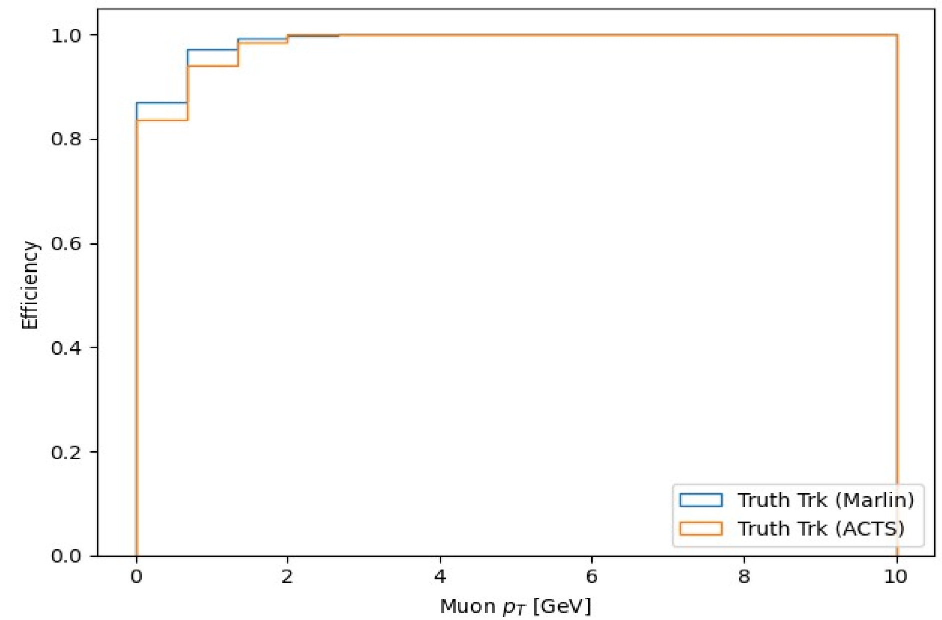
- Use hits associated to MC particle (100% efficiency)
- Same code for Marlin and ACTS

Fit Library	Execution Time
ACTS	0.5 ms / evt
Marlin	100 ms / evt

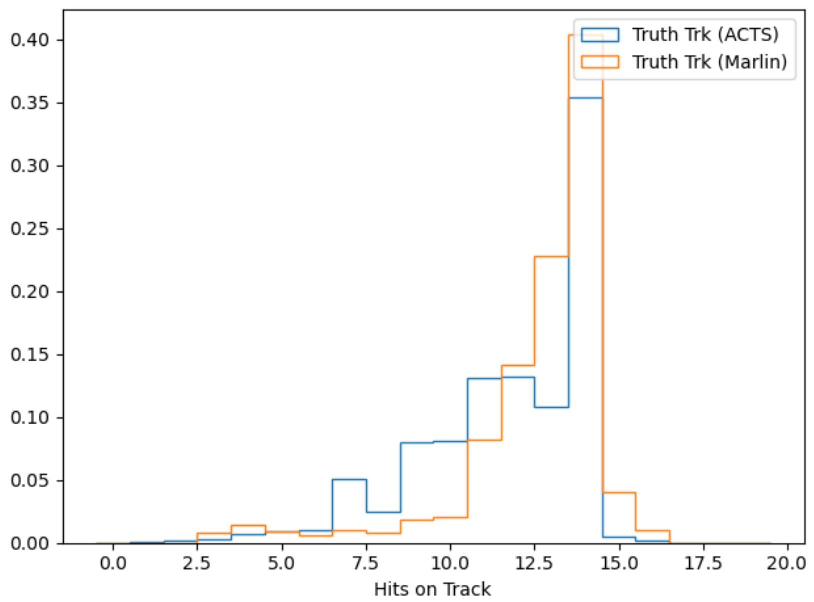
Track Fit

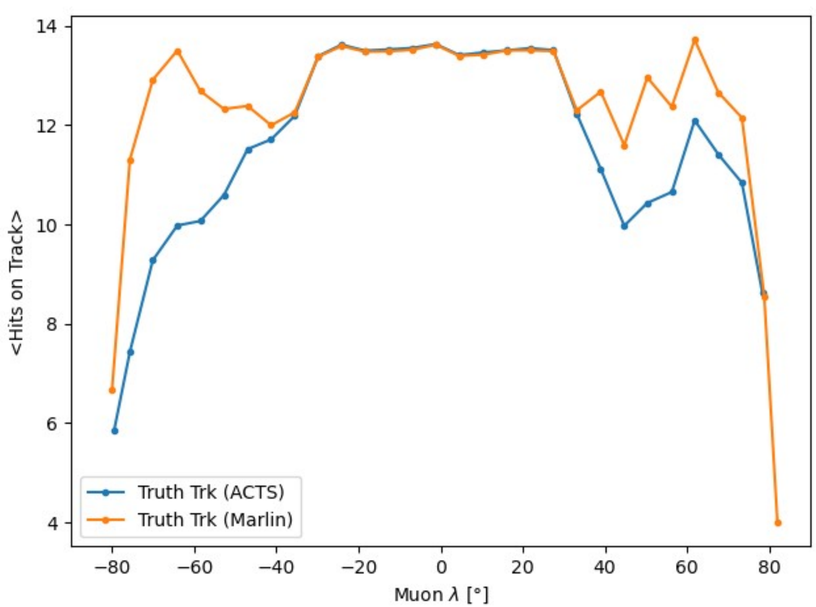
- Kalman Filter, but ACTS vs Marlin implementation



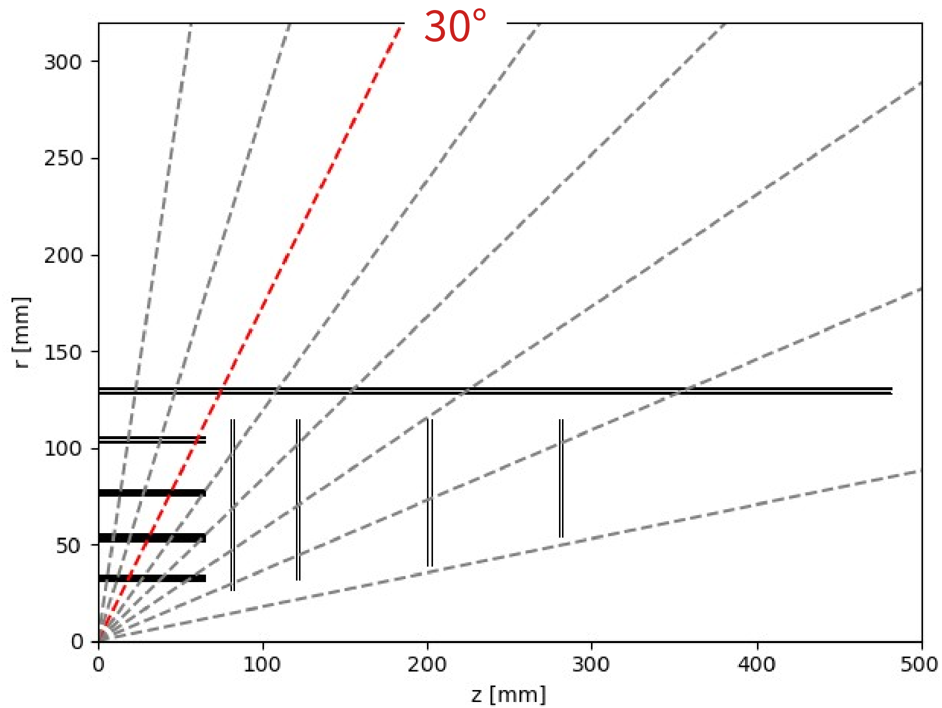


Hits on Track

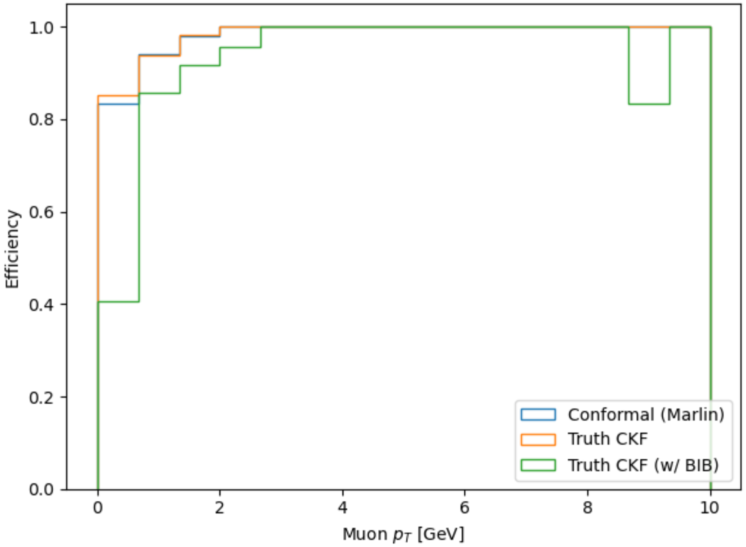




- **Good agreement in hits when in barrel**
  - Failed χ^2 cut?
- **Issues with material description from nozzle?**



Truth CKF Tracking



Seeding (the truth part)

- Use MC particle kinematics

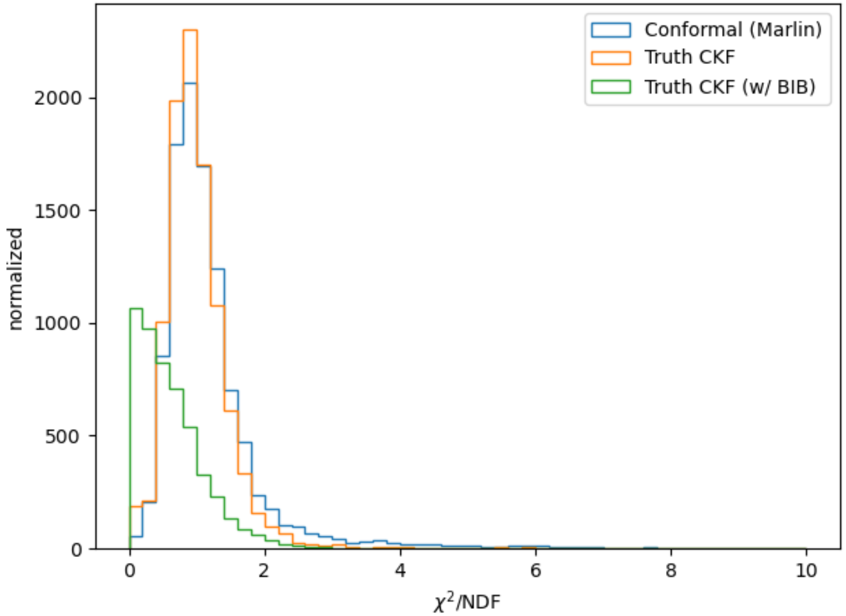
Track Fit

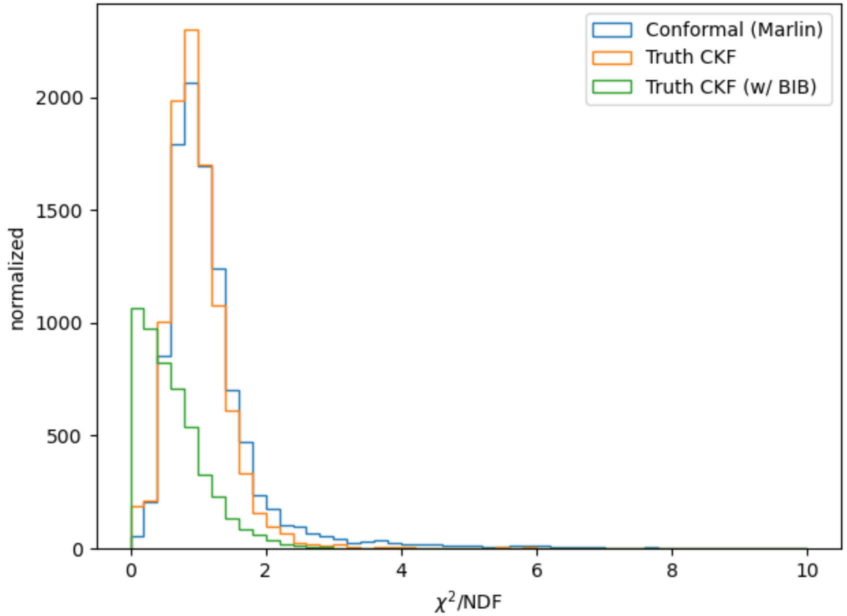
- Combinatorial Kalman Filter in ACTS

Fit Library	Execution Time
ACTS	0.6 ms / evt
ACTS (w/ BIB)	7 s / evt
Conformal	120 ms / evt

Overlap Removal

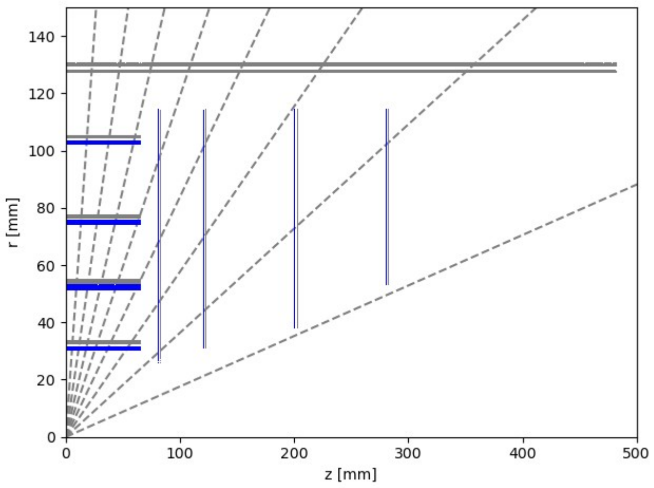
- Group by tracks sharing 50% of the hits, pick one with most (or highest χ^2)



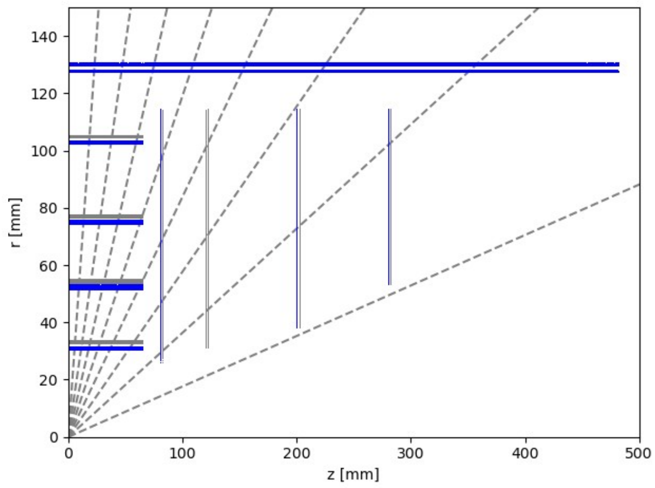


Seeding Layers

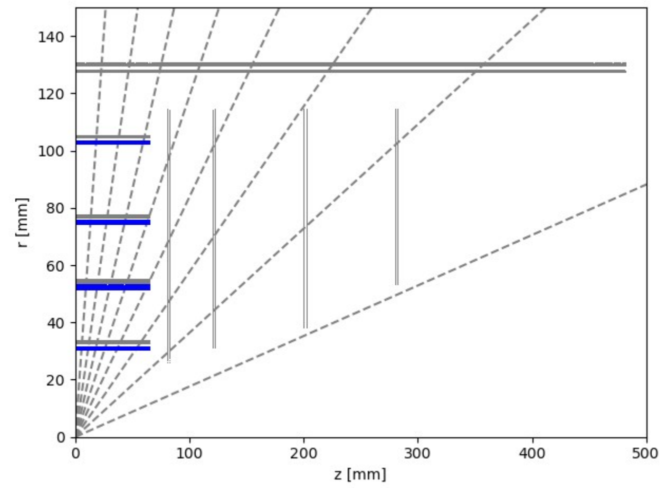
Seed 0: Vertex detector



Seed 1: Skip busiest EC layer



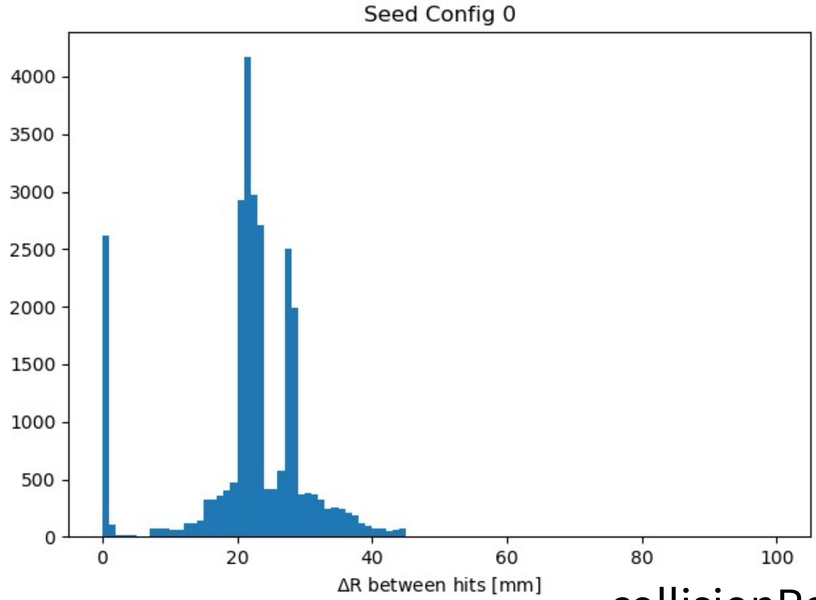
Seed 2: barrel only vertex



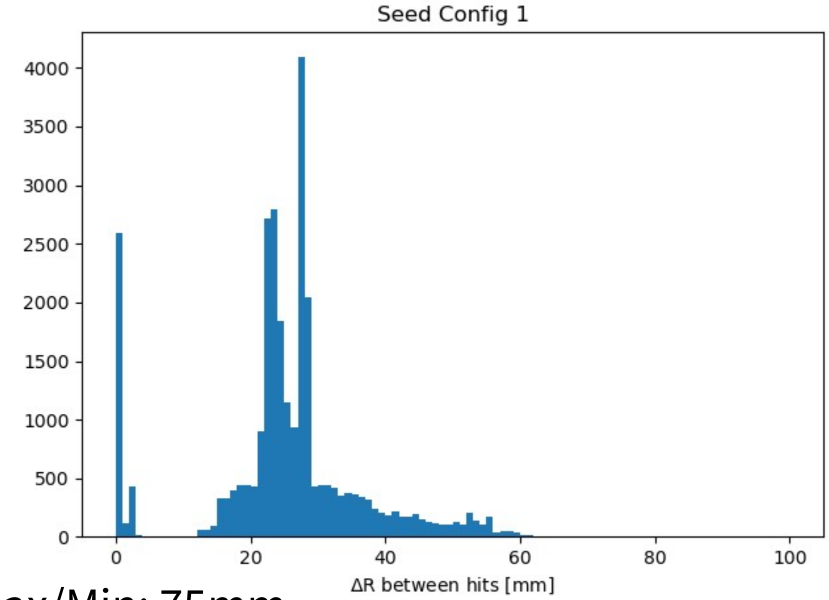
- **Using only inner part of the Vertex doubles**
  - Prevents redundant "too close together" combinations
  - Future: Reduce hits with doublet requirements in double layer?
- **Seed 1 reduces combinations in the forward region**
  - Took out the layer with most hits
- **Seed2: Barrel only due to huge combinatorics in forward region**

Optimizing Seeding Settings

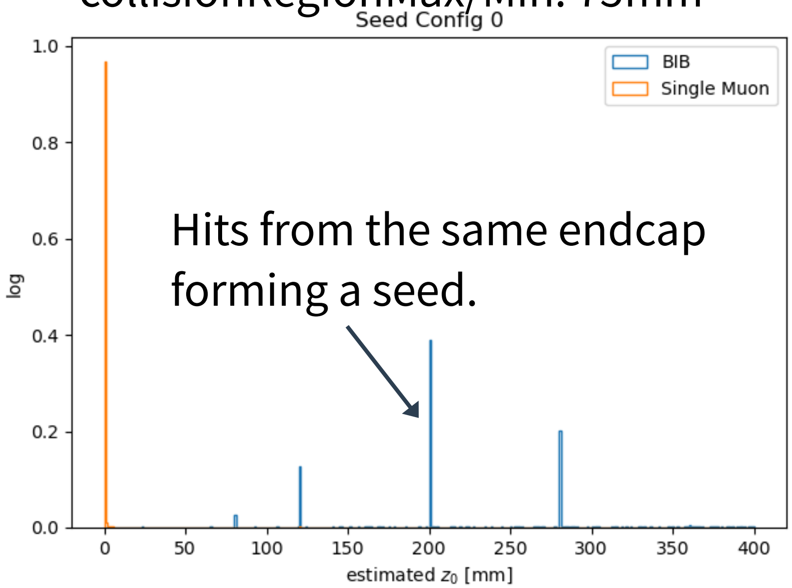
deltaRMin: 5 mm to remove same layer



deltaRMax: 80 mm



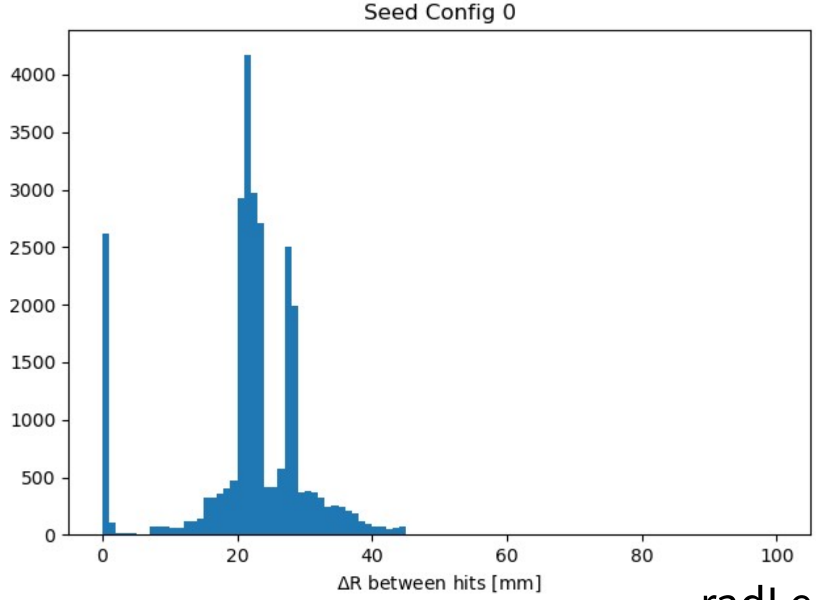
collisionRegionMax/Min: 75mm

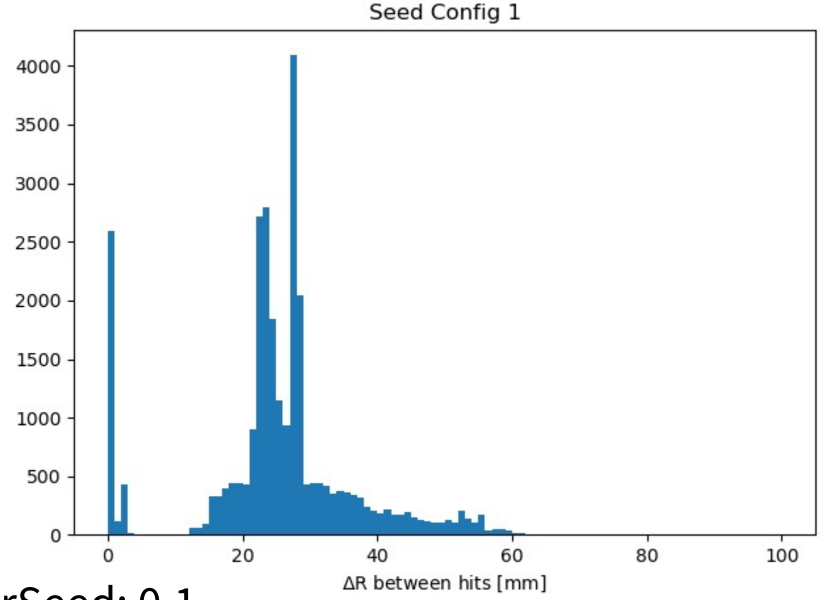


Need to keep collisionRegion cuts loose to allow for displaced tracks

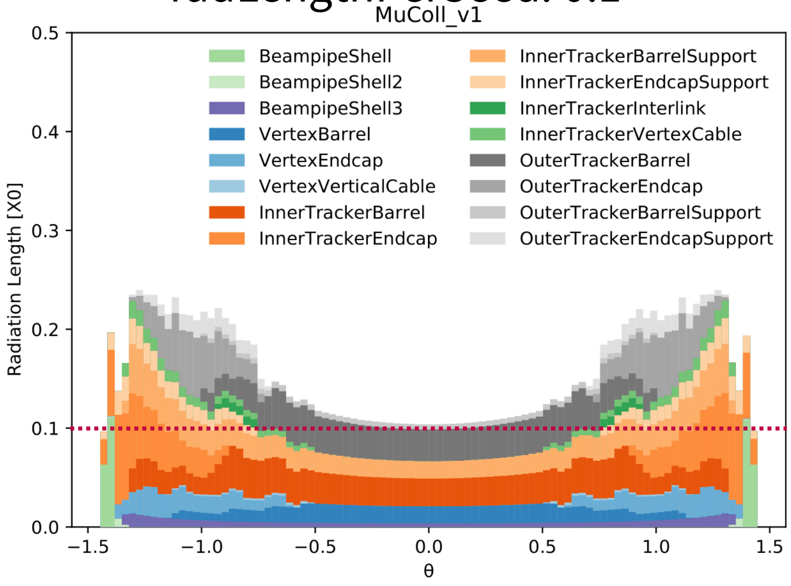
Optimizing Seeding Settings

deltaRMax: use 80 for both

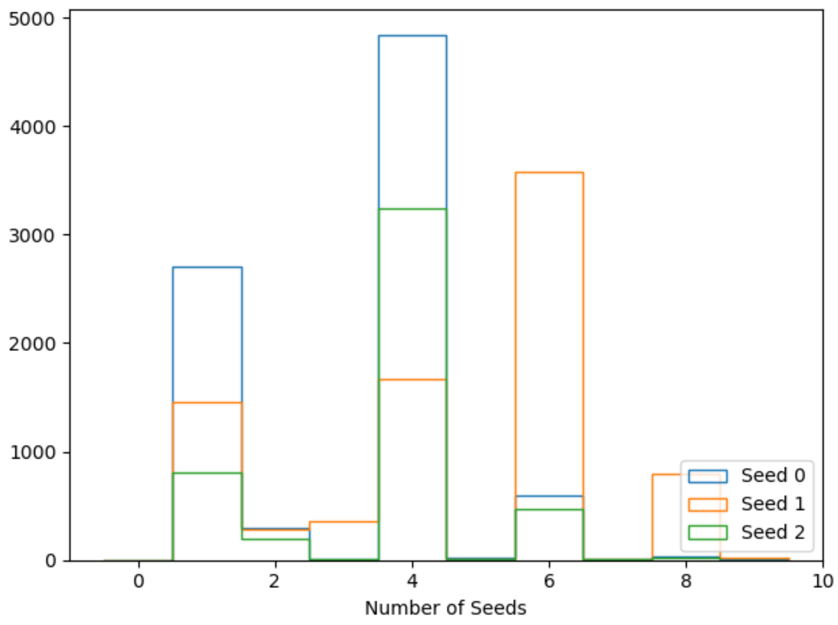




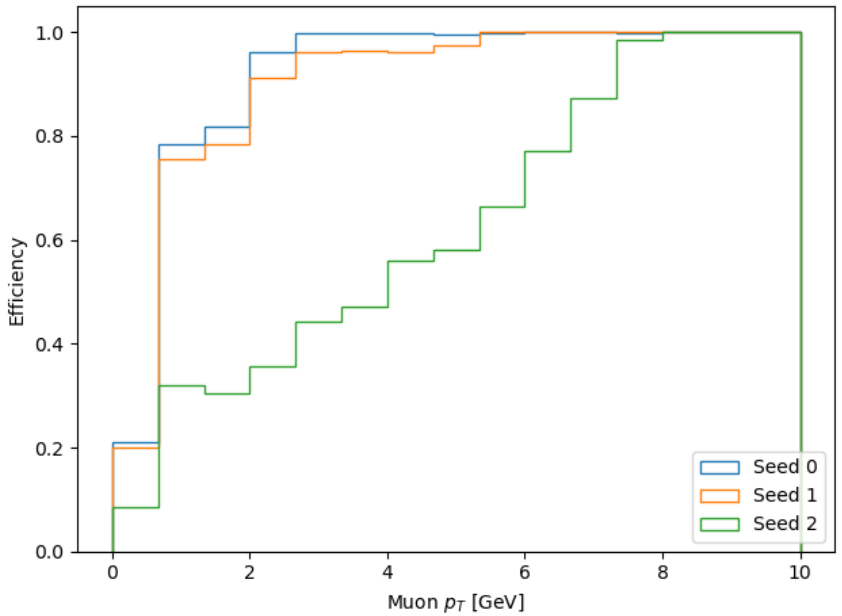
radLengthPerSeed: 0.1

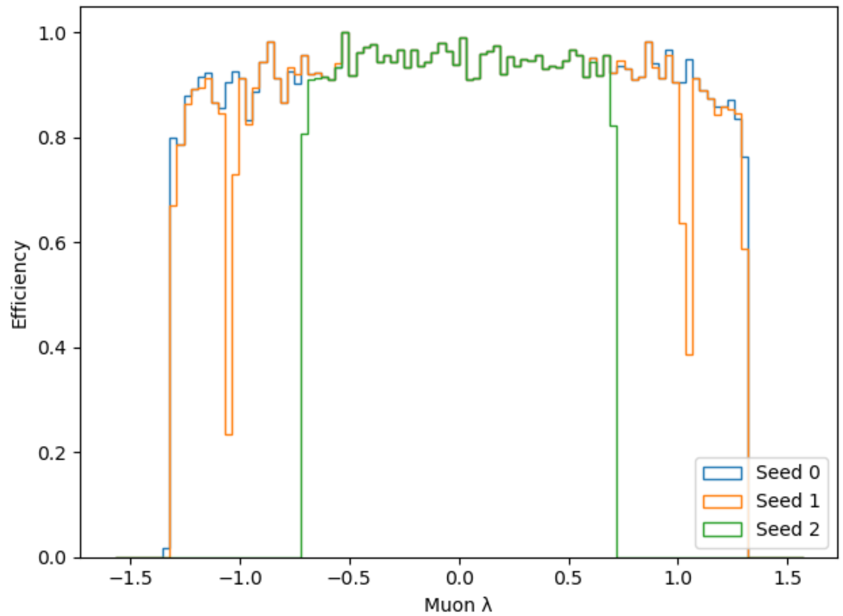


Found Seeds (no BIB)



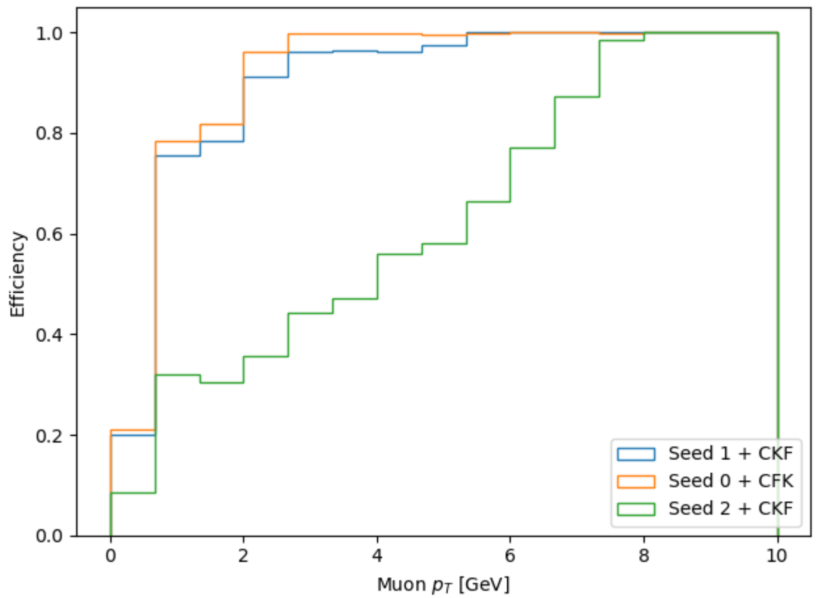
- **Assume hit in all 4 layers**
  - 3 choose 4 = 4
- **Missing seeds at low p_T**
- **~90% efficiency in barrel**
  - Mostly missing <2 GeV tracks

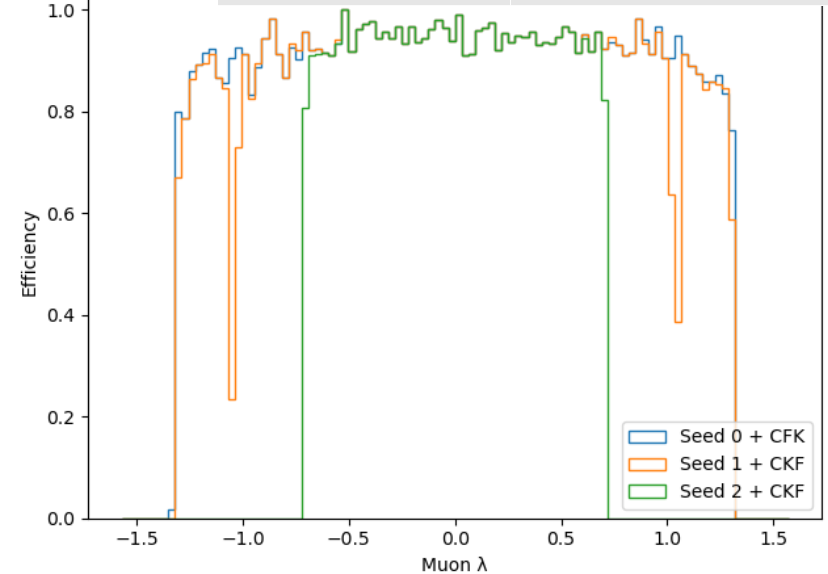




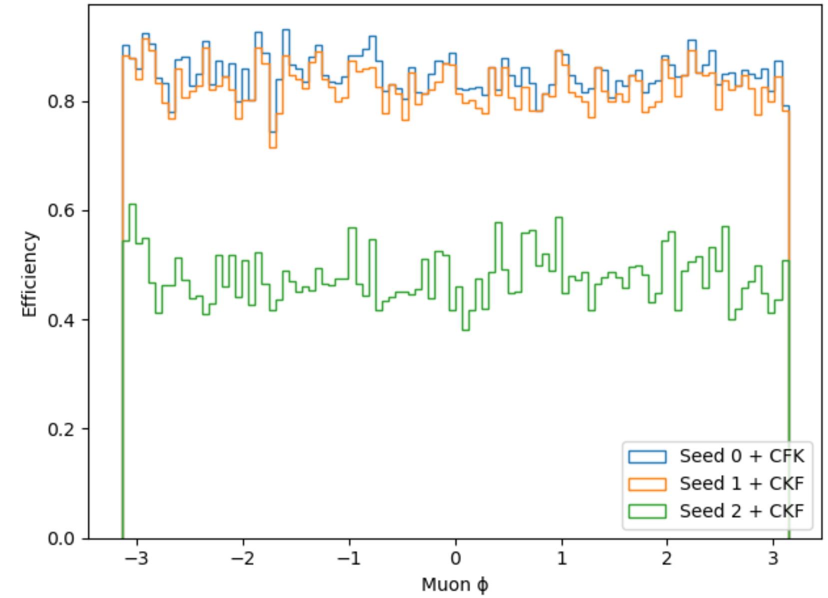
Tracking Performance

Fit Library	Execution Time
CKF	5 ms / evt
Conformal	120 ms / evt



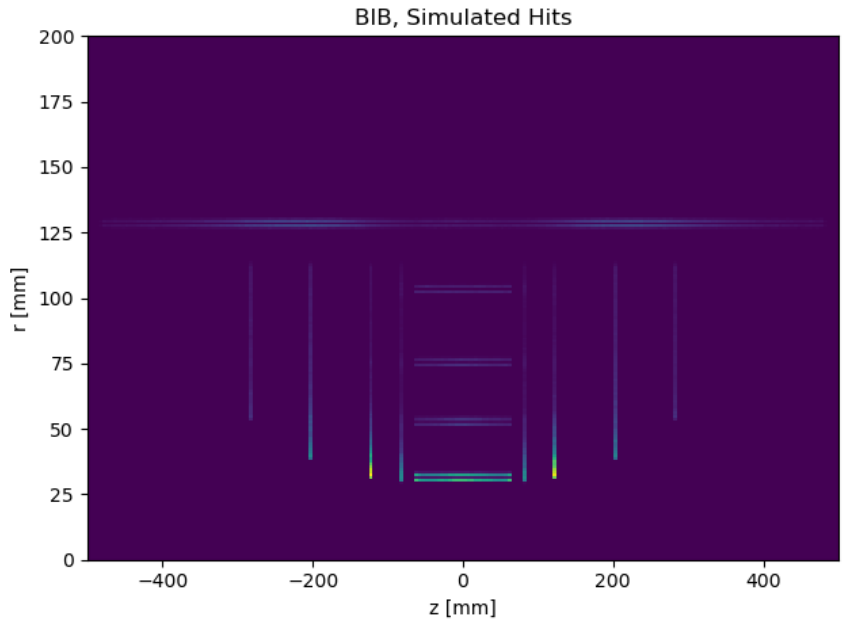


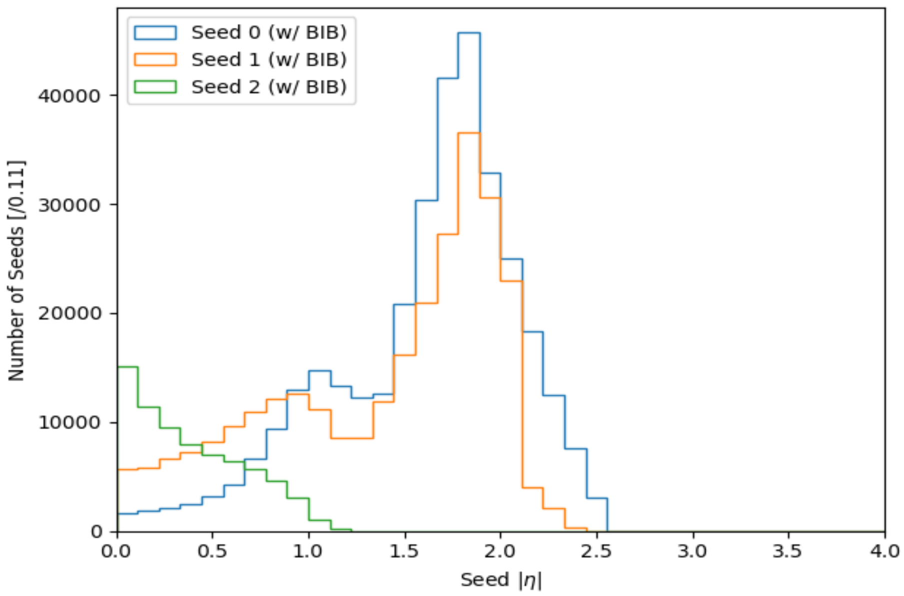
- Track reconstruction efficiency is limited by seeding

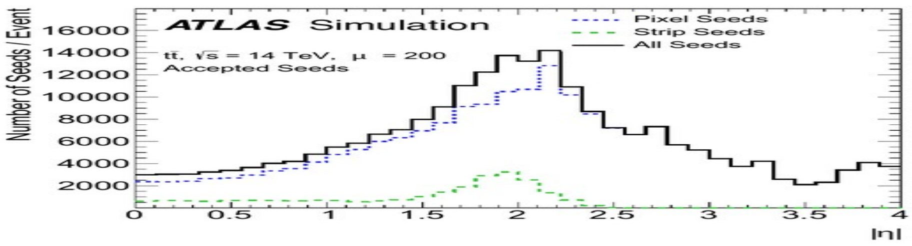


Found Seeds in Full BIB

- **Very slow (~30 min) in the full BIB environment**
  - Haven't study what the bottleneck is
- **~4x as many seeds as HL-LHC**
- **Large combinatorics close to beam**



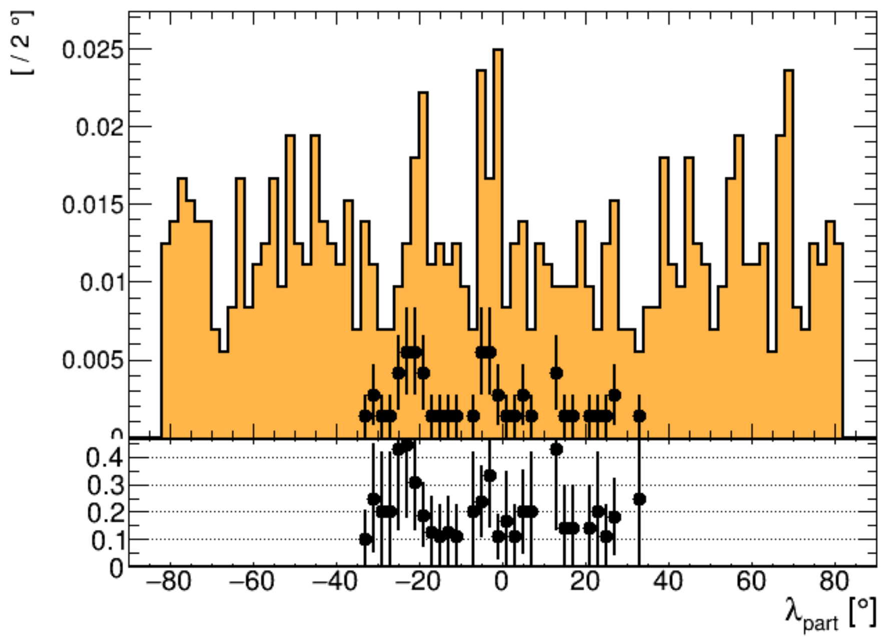




Full Detector Tracking

Time CKF / seed x Nseeds = 80 ms x 300000 = ~ 6 hours

- **Full detector tracking not practical yet, focus on barrel**
- **Also low track reconstruction in efficiency (<20%)**
  - Need to study seed finding efficiency more



Towards Full Detector Tracking: Seeding

- **Need to reduce number of seeds by at least x10**
  - Reduce hits via cluster shape analysis (WIP by Simone)
  - Optimize seed finding parameters (WIP by Kyle the summer student)
    - Larger radius layers might be helpful
  - Consistent timing of hits within a triplet
  - Consistent hits within doublet layers
- **Need to recover seed efficiency at low p_T**
  - Optimization of seed finding configuration

Towards Full Detector Tracking: CKF

- **Can we speed up CKF?**
  - Study scaling vs BIB amount
  - Study scaling vs search radius and max branching
- **Saw significant speed-up with few software optimizations**
  - 6.0.0 → 9.2.0 ACTS version
  - Using flat_multiset instead of vector for fast GeometryIdentifier access
- **Try attempt #2 at running MCC events in ACTS examples**
  - Use ACTS Fatras + manual BIB overlay
  - Easier to get feedback, check that interface with ACTS is optimal

Towards Usable Tracking: Barrel Only

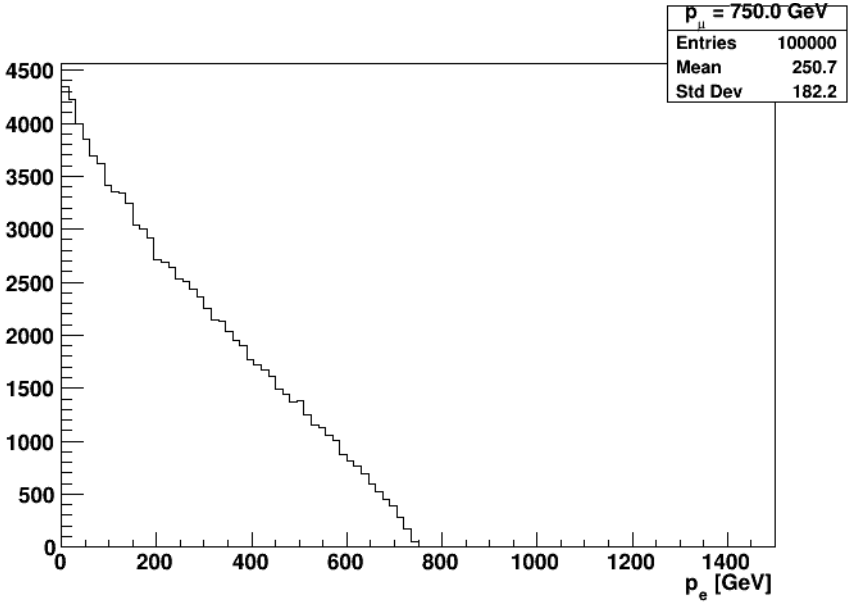
- **Need to understand low track reconstruction efficiency**
  - Study seeding finding efficiency
  - Possible issue in seed overlap (shared middle hit) removal?

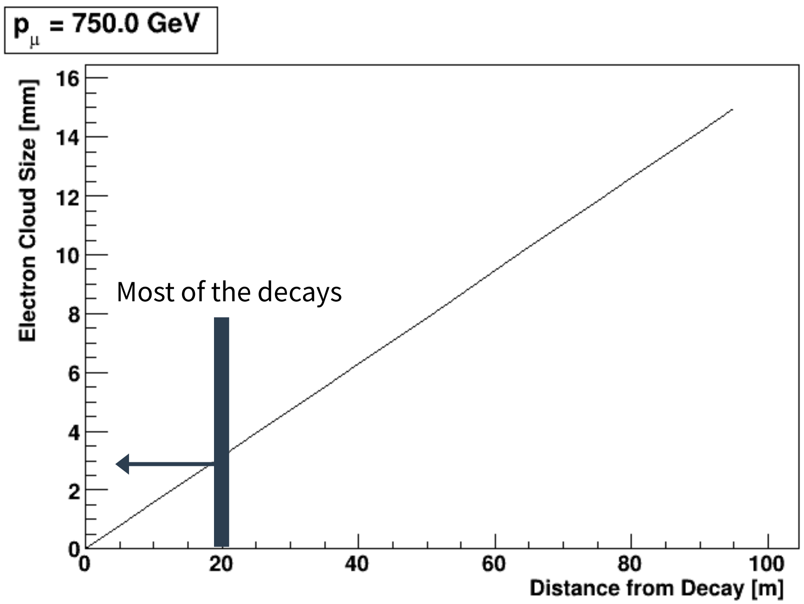
Conclusion

- **Muon Collider's Beam Induced Background results in a difficult environment for tracking**
  - 10x as many hits per layer as HL-LHC
- **ACTS implemented in MCC's software framework**
  - Just code-base itself is significantly faster
- **Some practical issues with Seeding + CKF remain**
  - ~few hours / event for full detector tracking
- **Next steps (possibly done in parallel)**
  - Reduce seeds per event
  - Understand computation performance of CKF
  - Understand tracking performance of CKF in barrel only

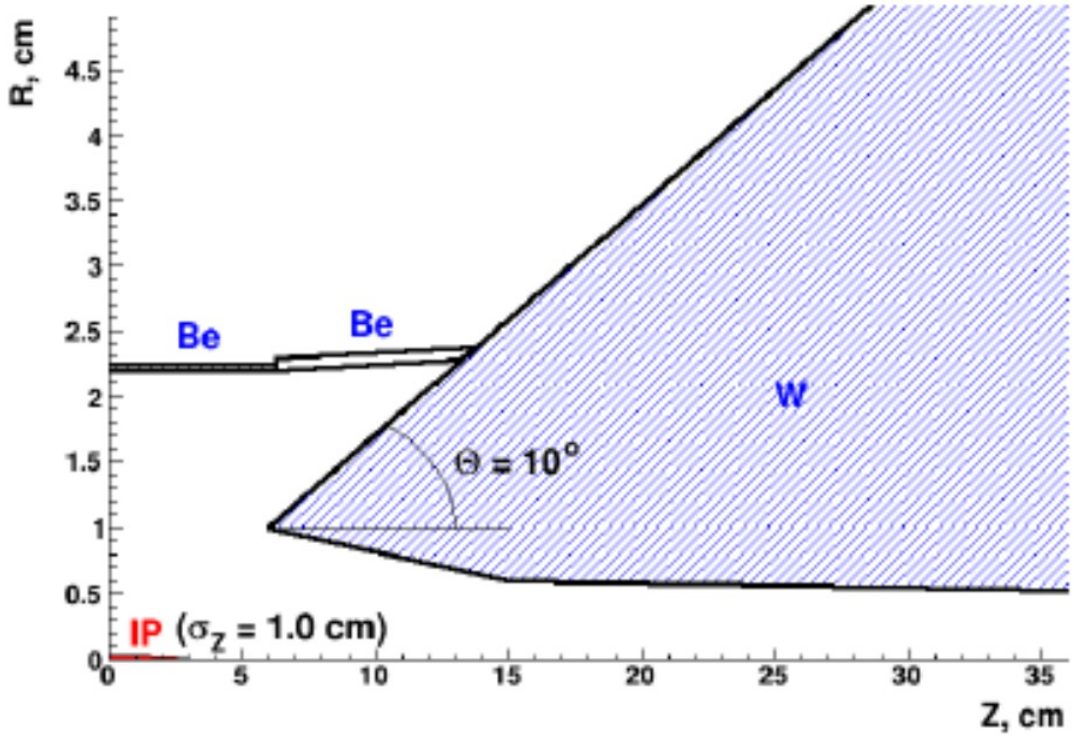
BACKUP

Muon Decay Products

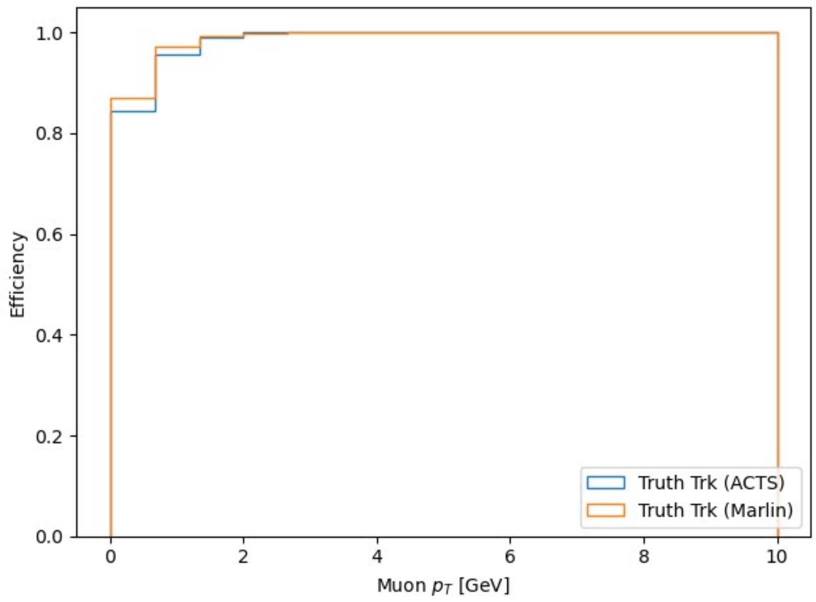


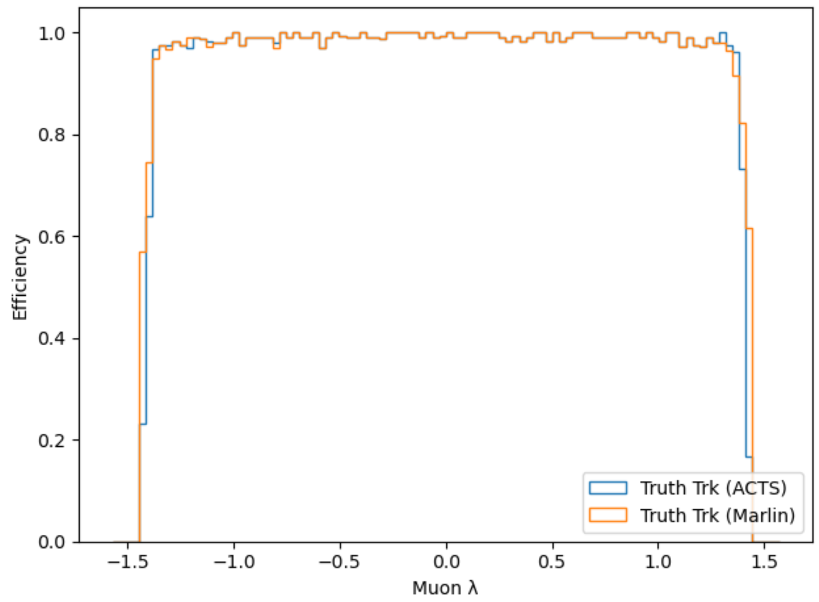


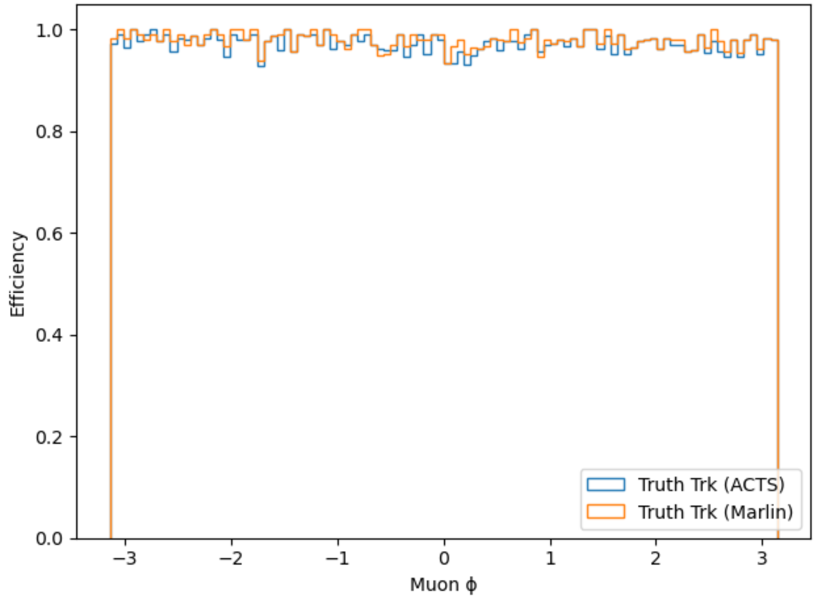
- **Simulated with TGenPhaseSpace**
- **Cloud is a bit smaller than nozzle**
  - Except possibly at the "narrowing" (not shown)



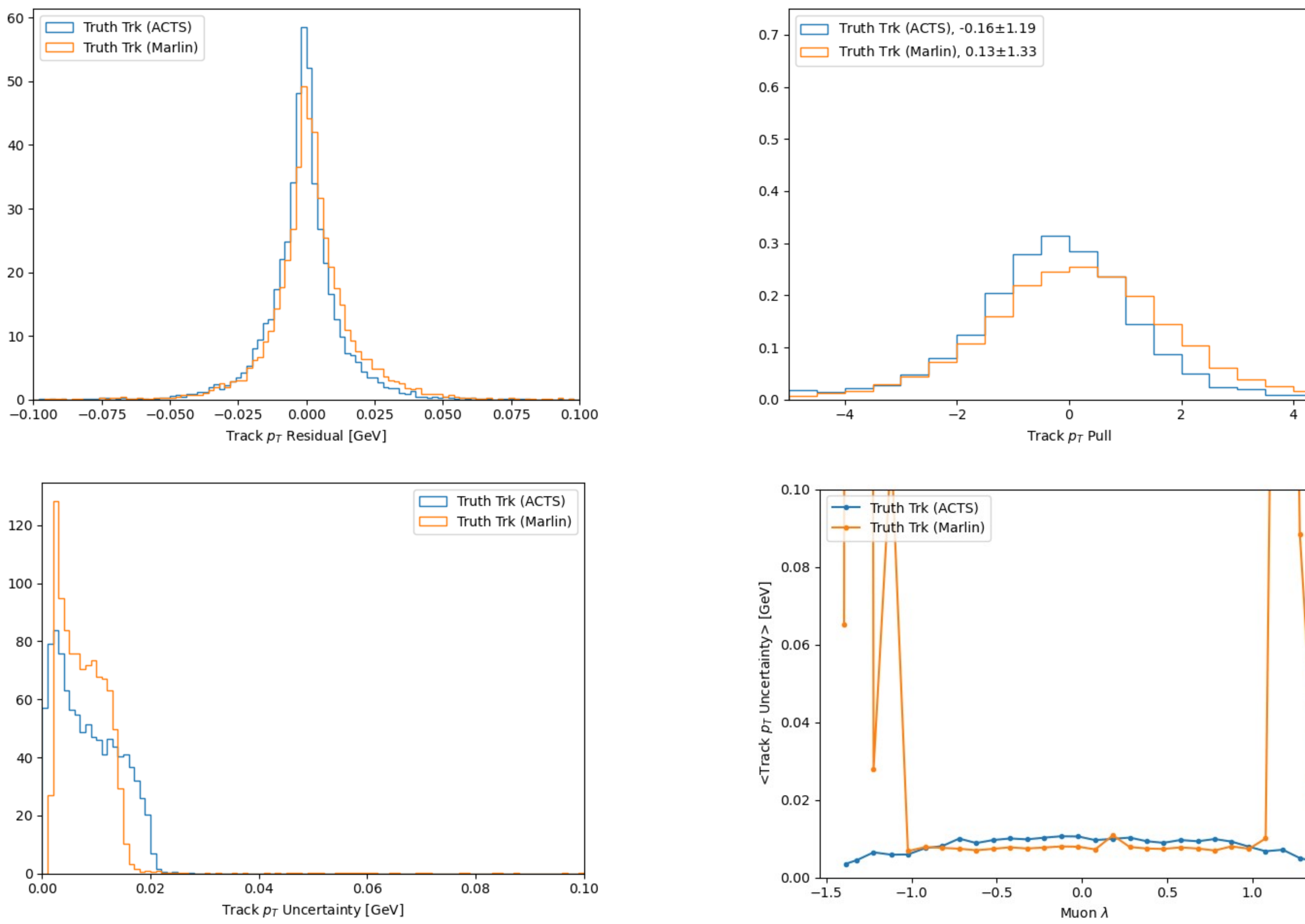
Truth Tracking - Efficiencies



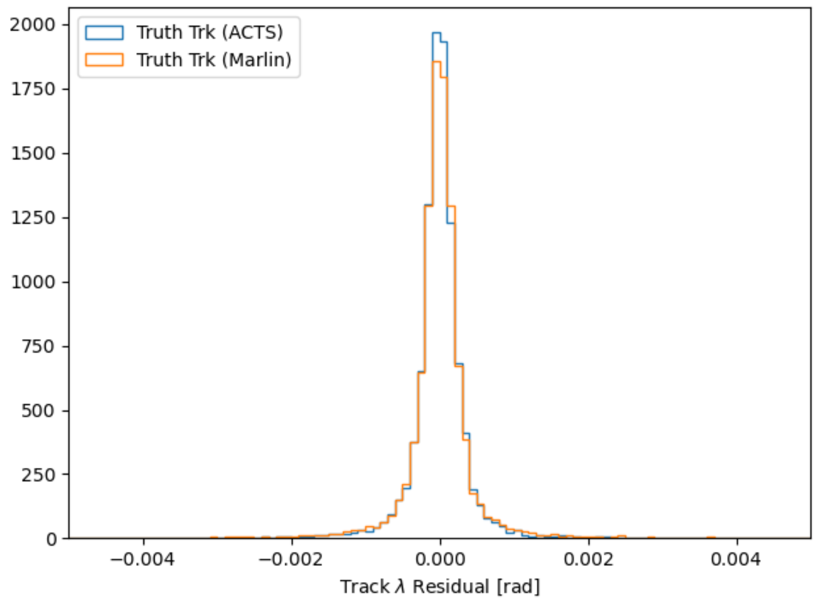


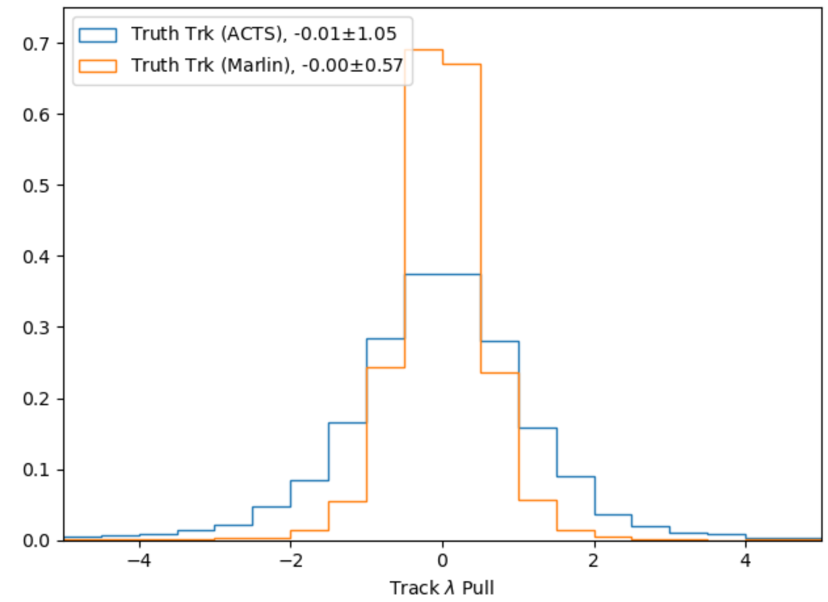


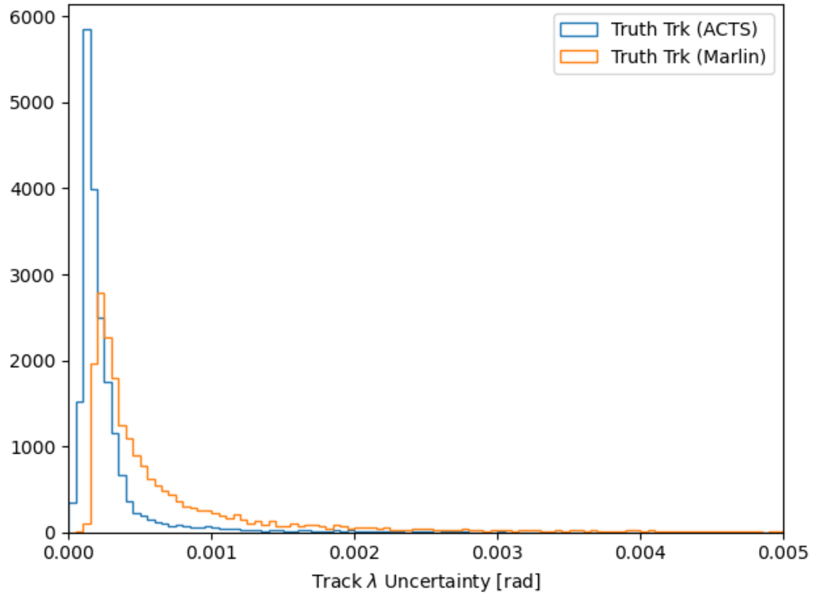
Truth Tracking - p_T

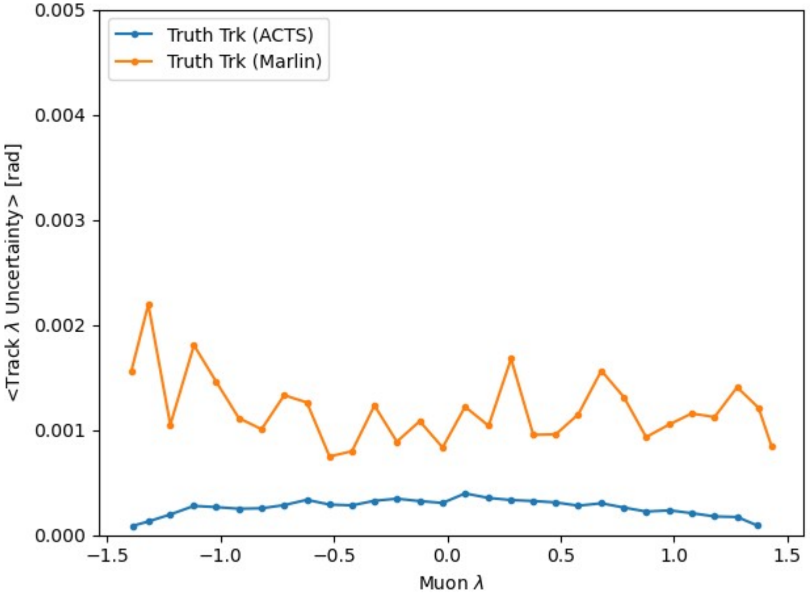


Truth Tracking - λ

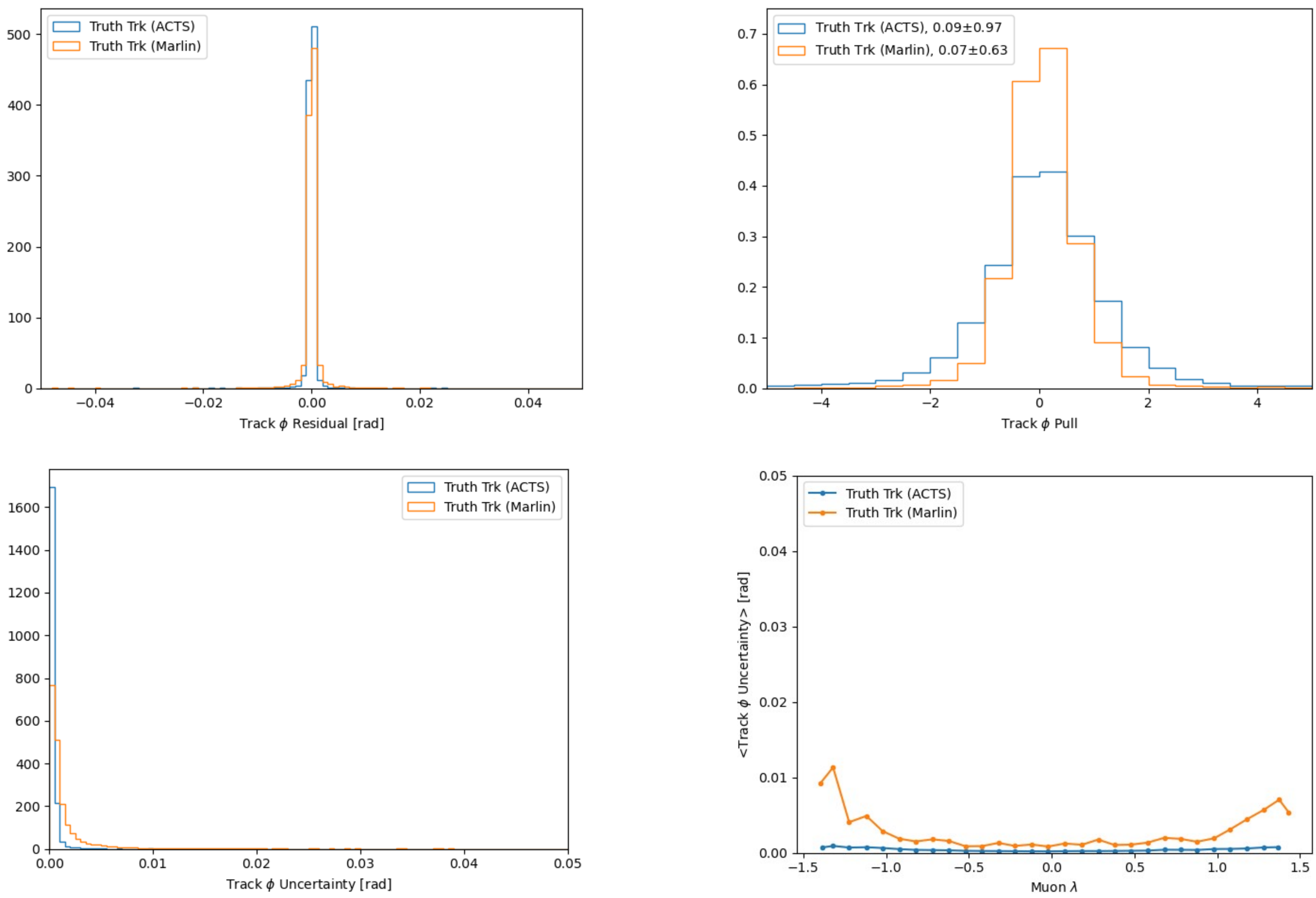




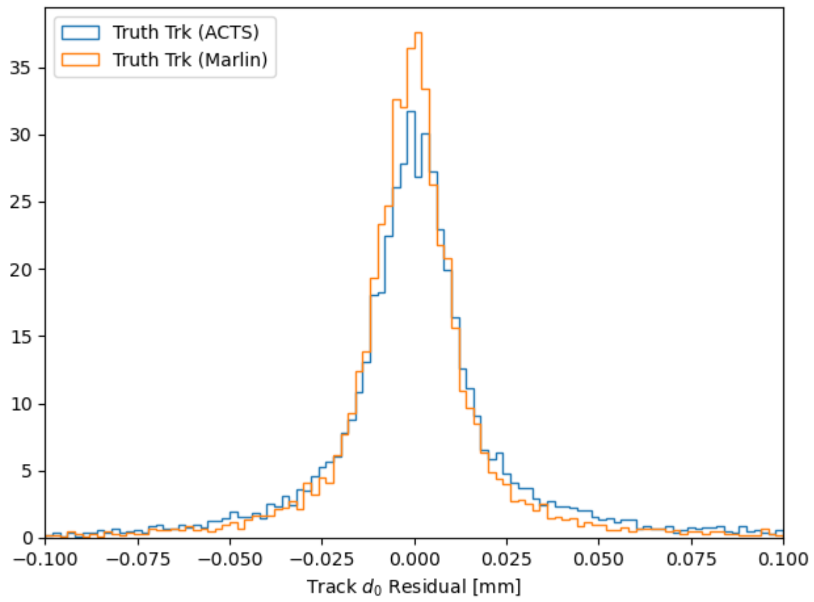


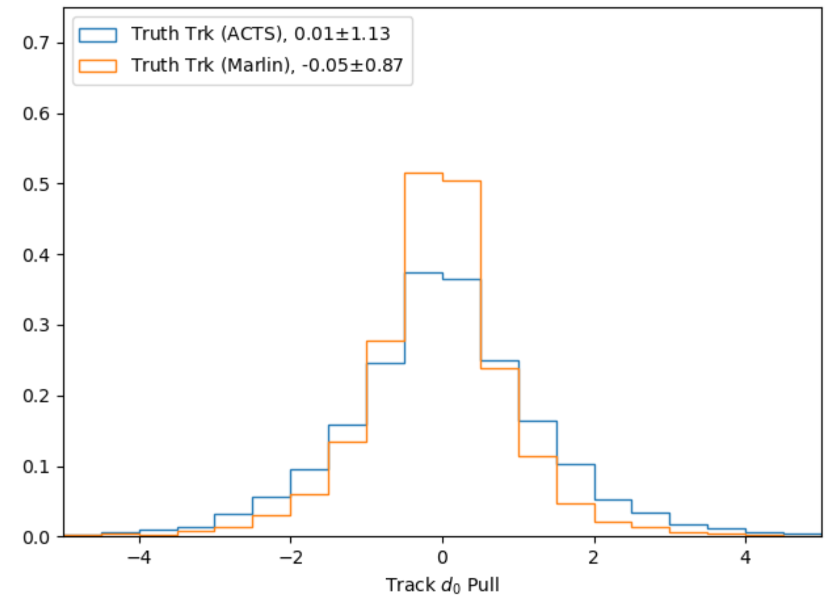


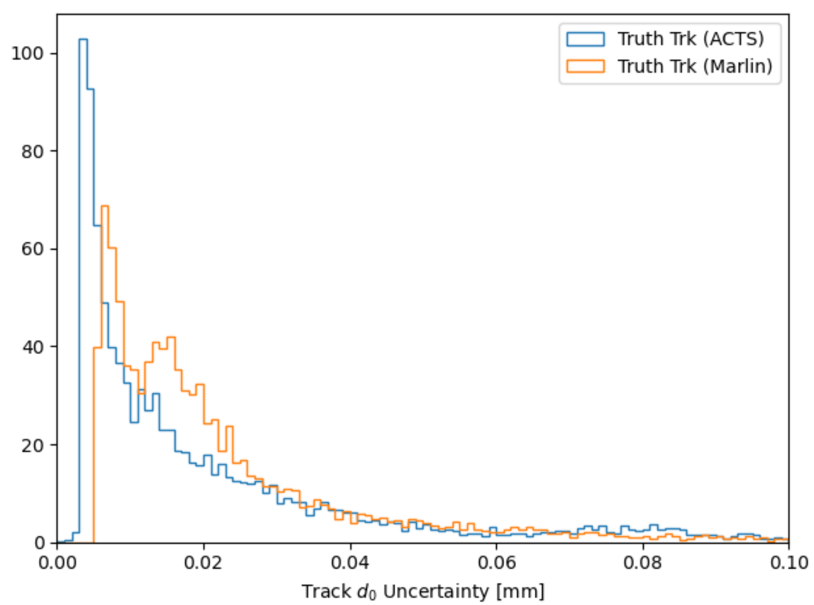
Truth Tracking - φ

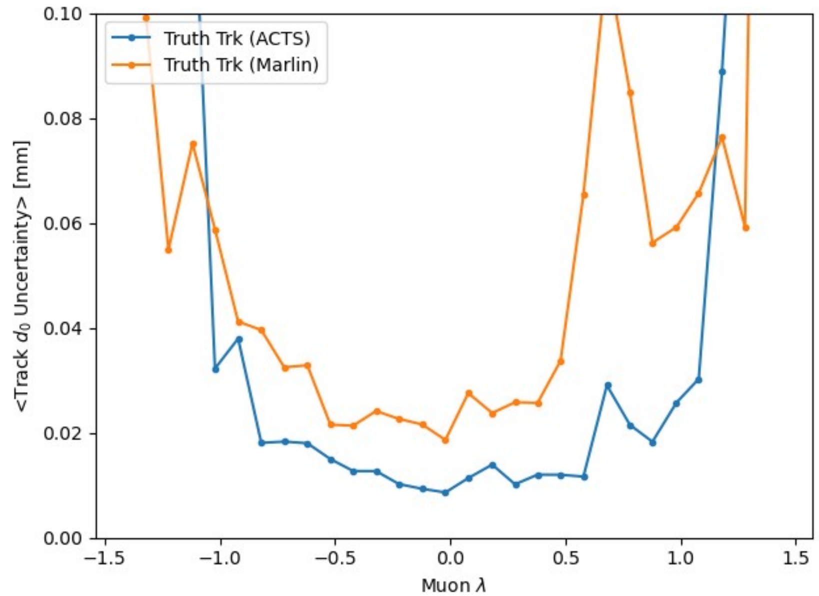


Truth Tracking - d_0









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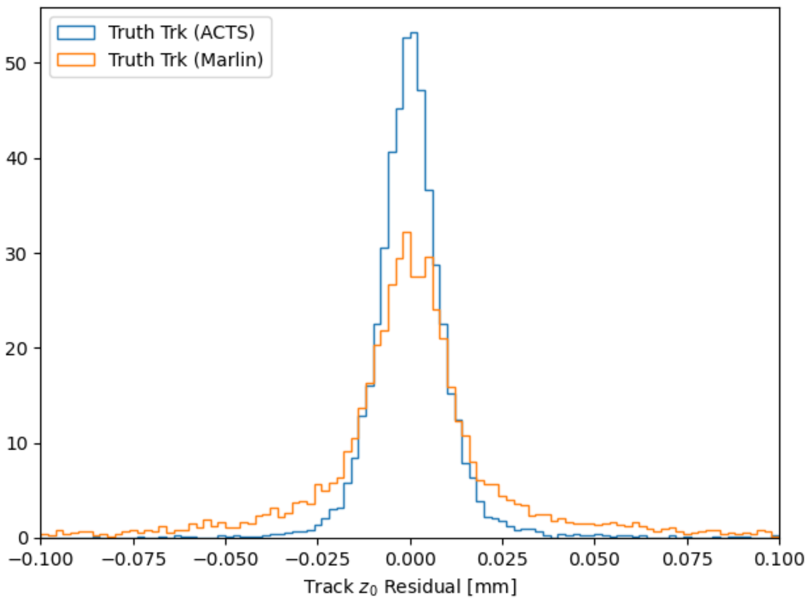
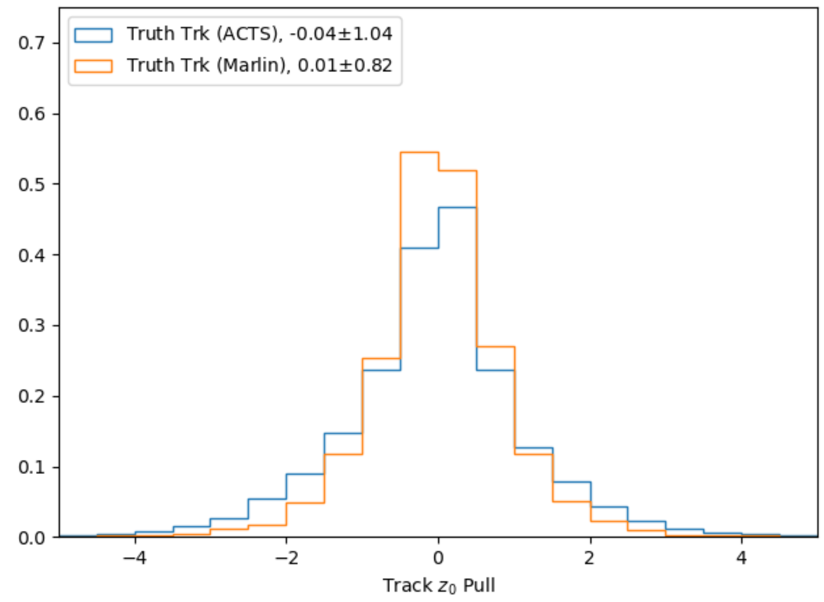
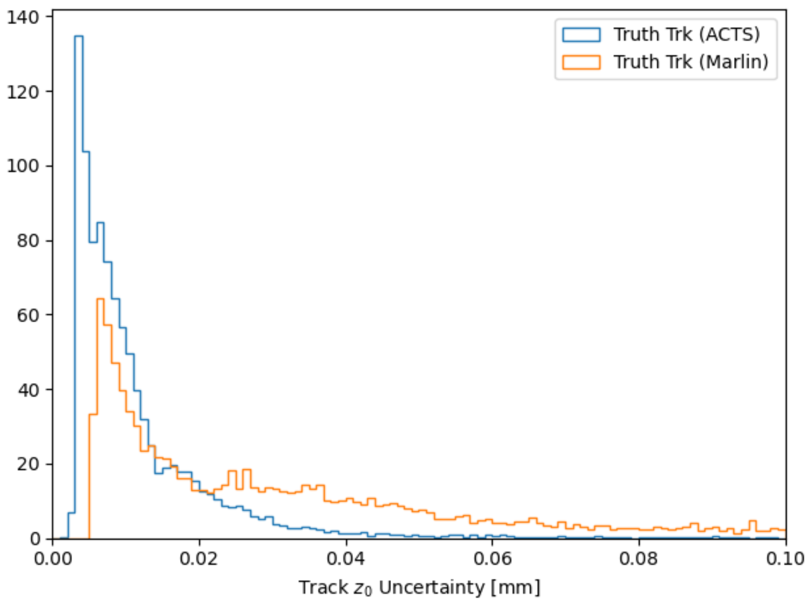
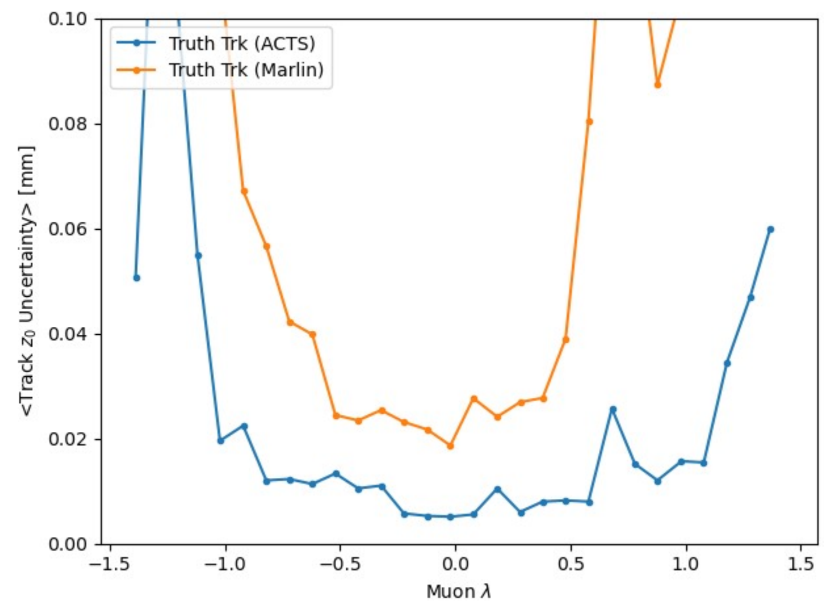
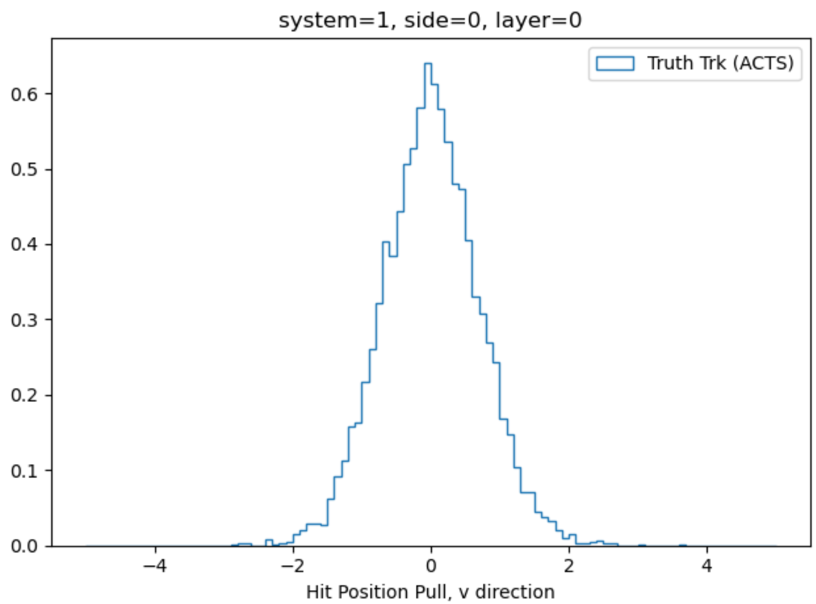


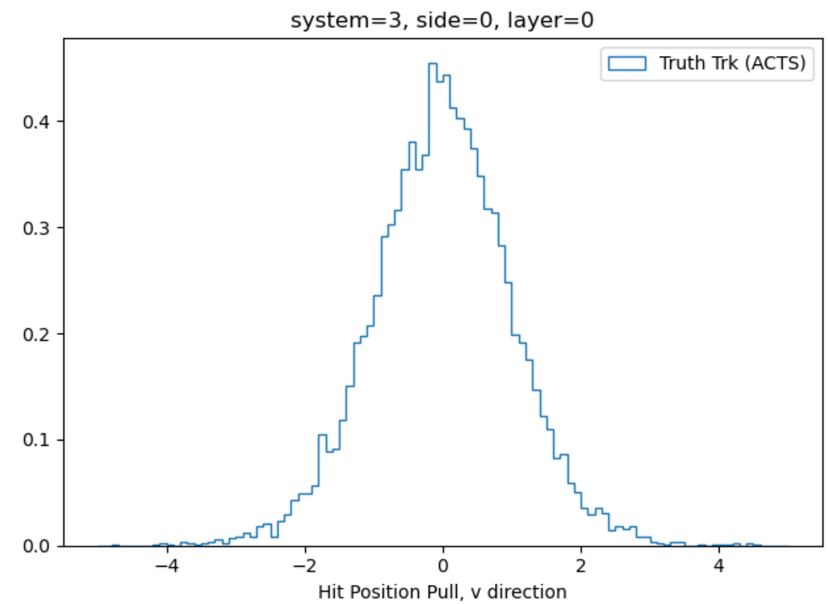


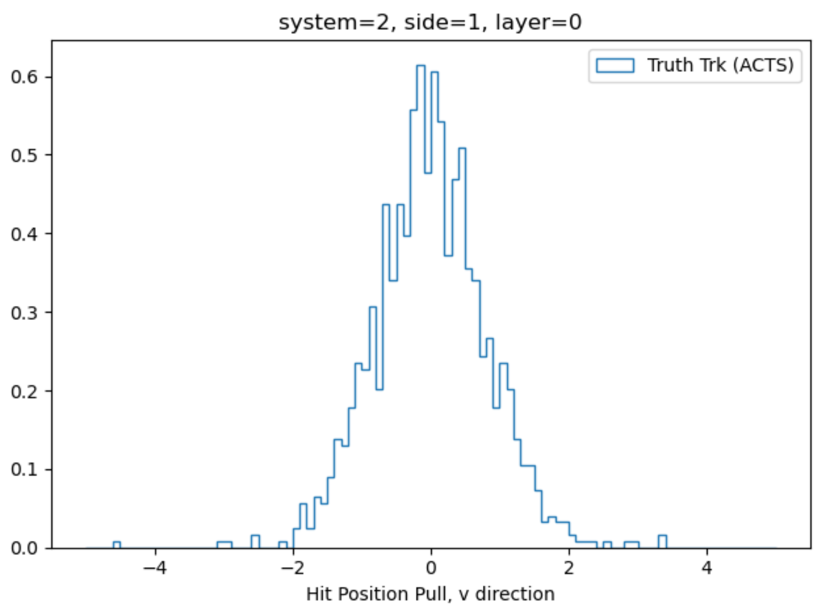


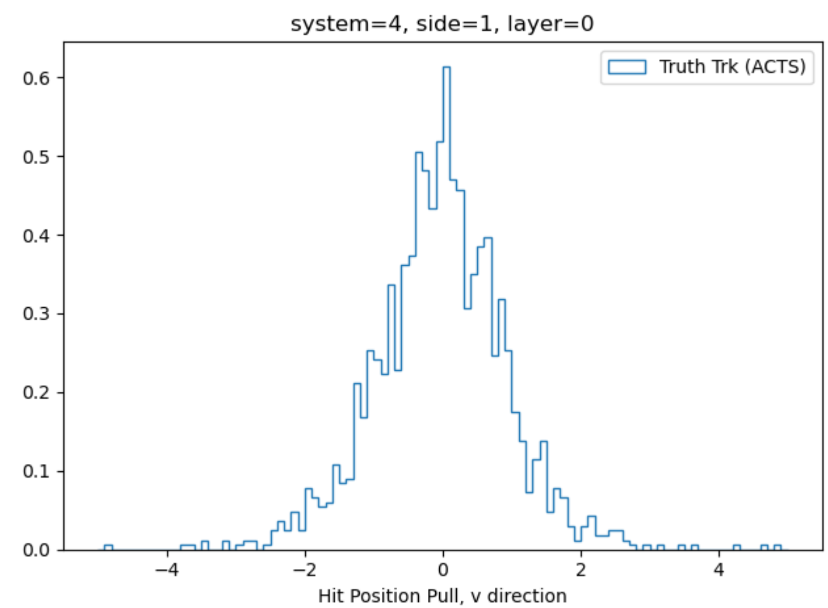


Hit Residuals, v direction

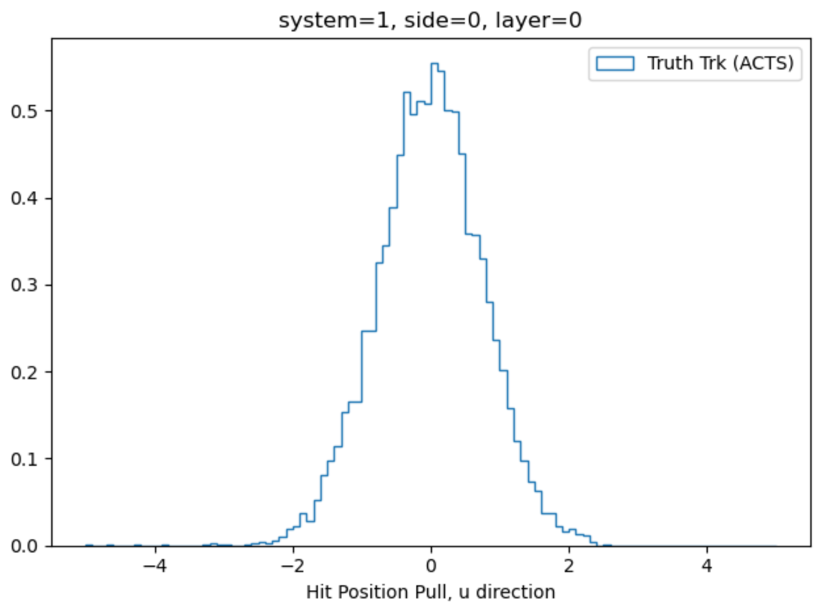


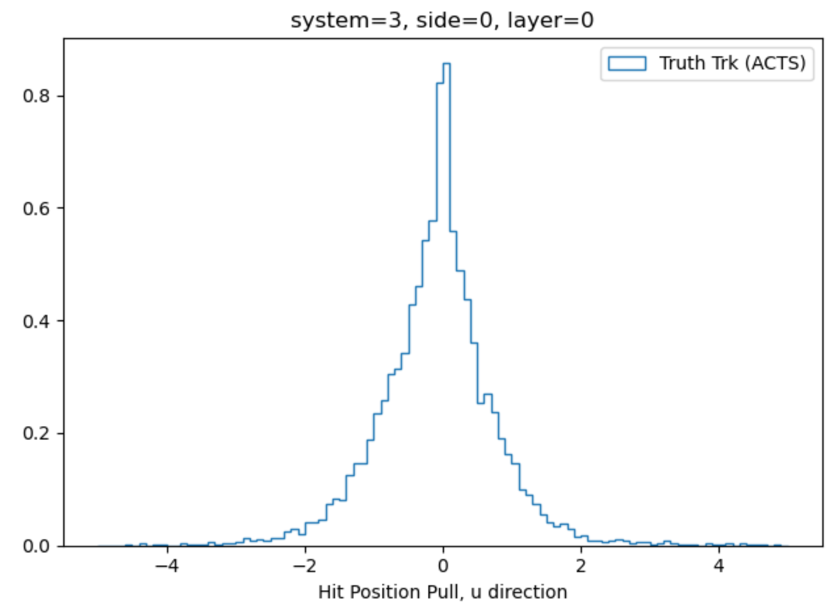


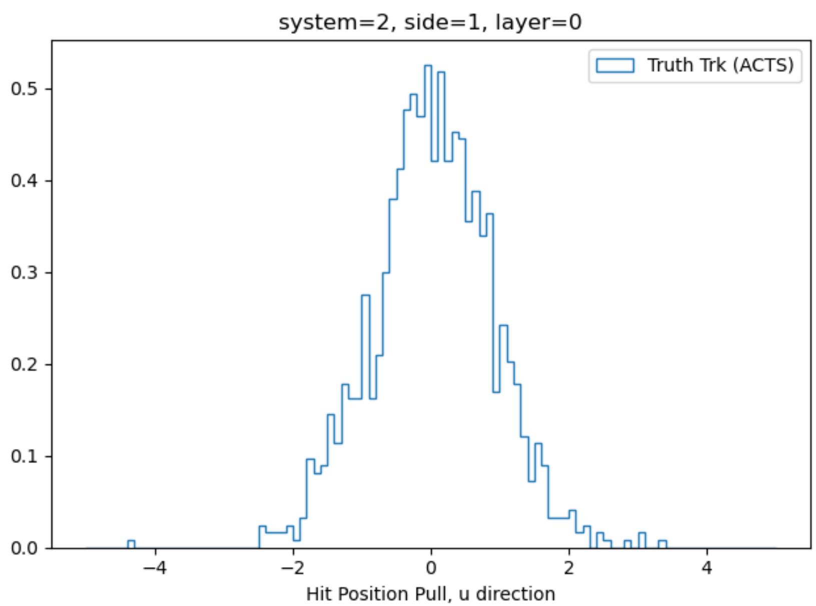


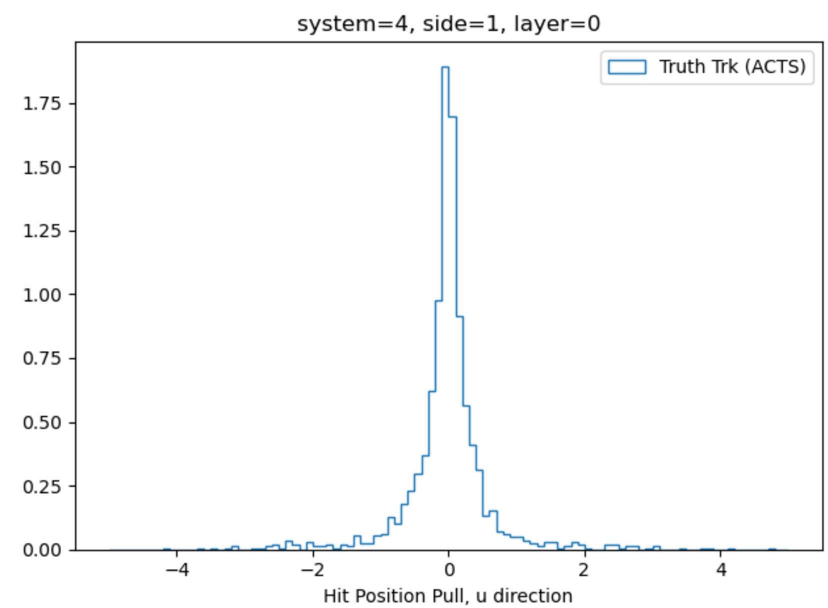


Hit Residuals, u direction









More Truth CKF