Tacking At A Muon Collider With ACTS

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Introduction

A $\mu^+\mu^-$ collider is a possible candidate for a future particle collider[1][2]. The fundamental nature of the muon means that the intial state of the colliding particles is fully known. Just like an e^+e^- collider, this allows for precision measurements of the newly discovered Higgs boson and other Standard Model particles. But unlike an e^+e^- collider, the massive muons emit less synchroton radiation and allow the beam to reach higher energies. This extends the reach for Beyond the Standard Model searches.

One feature of a muon collider is the decay of the muon beams. This results in the high energy decay products (electrons) striking the accelerator complex and detector, fragmenting further and spraying th detector in a large multitude of particles. The depositions from this is referred to as Beam Induced Background (BIB)[3].

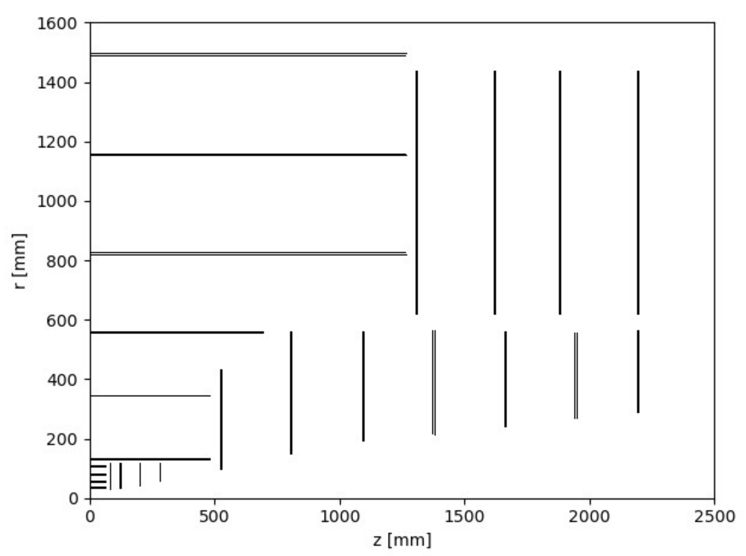
The large particle multiplicity (~x10 HL-LHC) in the tracking detector complicates the track reconstruction problem. The current implementation, based on conformal transformation with celluralr automata[4], takes a week per event to complete. This poster reports on the progress of off replacing it with a Combinatorial Kalman Filter based approach implected via the ACTS library[5].

Technical Details

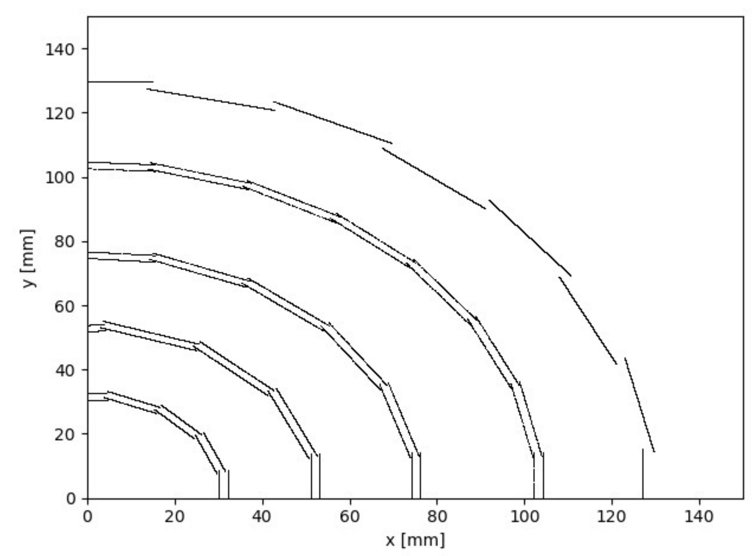
The **ACTS library v9.2.0** was implemented inside the **iLCSoft framework** used for physics at the Muon Collider studies. It serves as a drop-in replacement for the current tracking algorithm.

Single muon events generated uniformly with momentum up 10 GeV are used for all results.

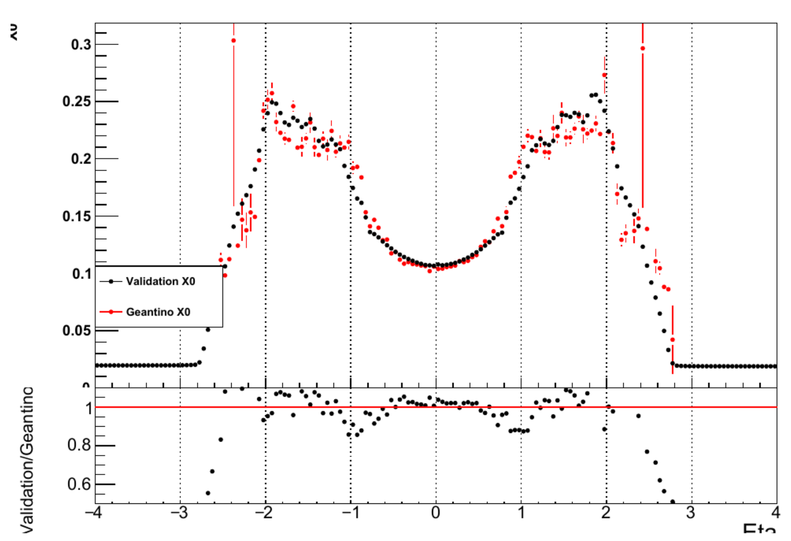
Tracking Detector

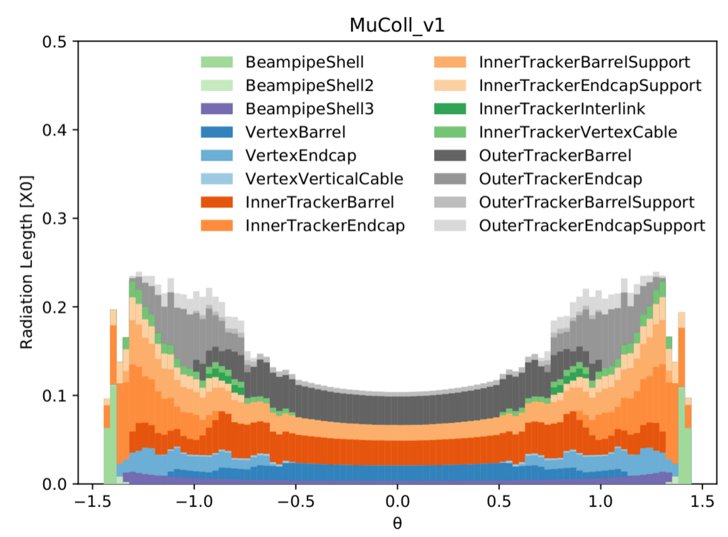


An **all-silicon tracking detector** is assumed. The forward coverage is limited by a tungsten "**nozzle**" used to **shield BIB**.



The **vertex detector** employs a **double layer** design.

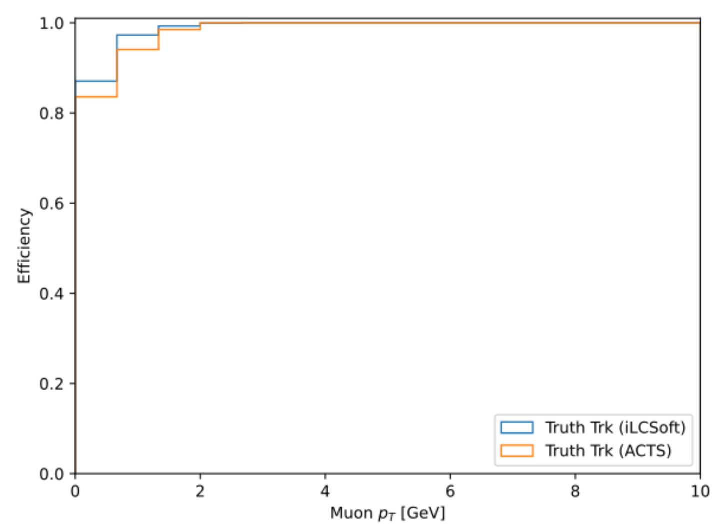


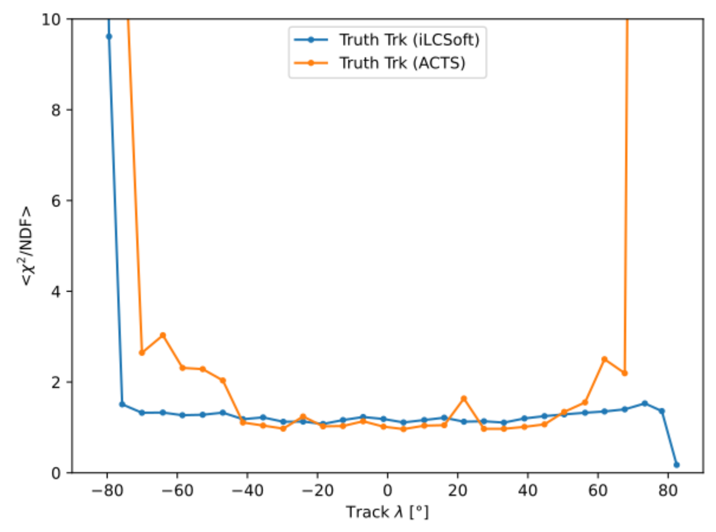


ACTS simplifies the track propagation through the detector by using a **binned material map based on a GEANT simulation**.

Truth Tracking Results

Hits truth-associated with the generated muon are fit a Kalman Filter. The algorithm is the same between ACTS and iLCSoft. The only difference is the implementation.



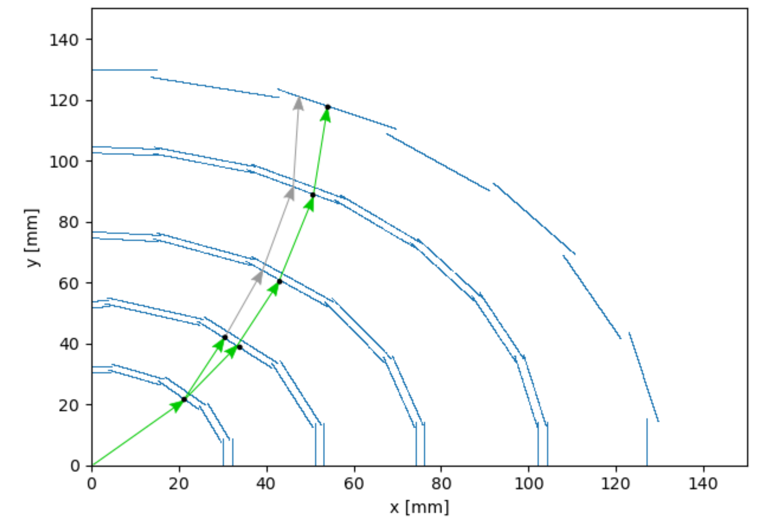


Fit Library	Execution Time
ACTS	0.5 ms / evt
iLCSoft	100 ms / evt

► Validates the ACTS tracker description.
► Small differences in the forward region (nozzle?).
► ACTS benefits from expert code optimization.

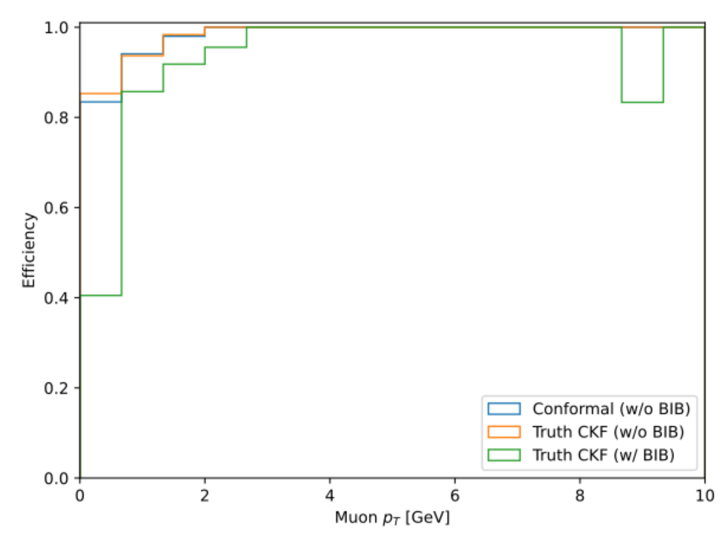
Combinatorial Kalman Filter

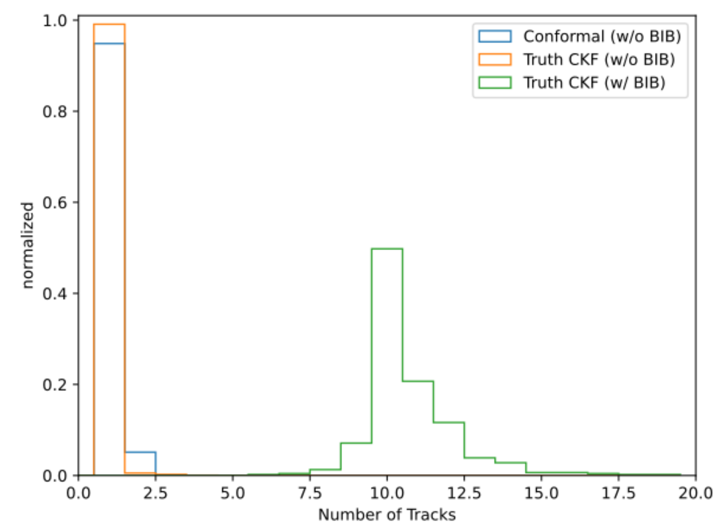
1. Start with an estimate of track parameters.
   ► aka seeds
2. Propagate track to next layer.
3. Look for compatible hits in layer.
4. Update track parameters with new hit.
   ► Create multiple tracks if found multiple hits.
5. Repeat steps 2-5 last layer.
6. Refit all resulting tracks with Kalman Filter.



Truth Seeded CKF Results

Truth seeded Combinatorial Kalman Filter uses truth muon information to create the CKF seed. Conformal tracking (via iLCSoft) is included for comparison.



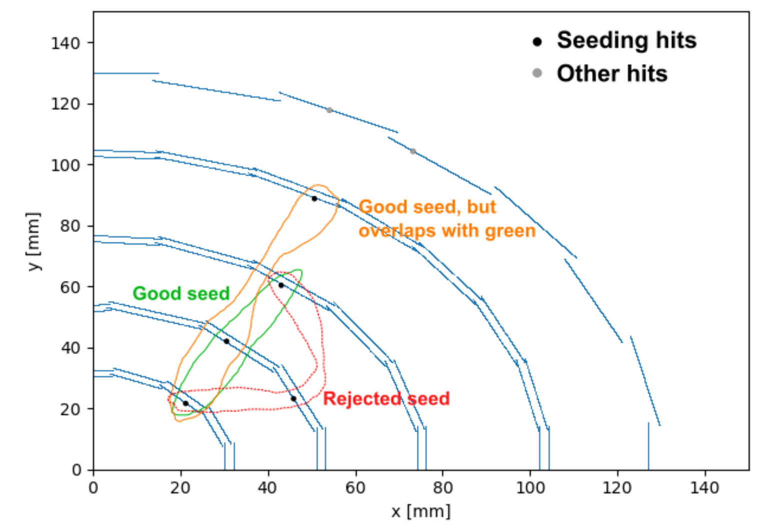


Fit Library	Execution Time
ACTS (w/o BIB)	0.6 ms / evt
ACTS (w/ BIB)	7 s / evt
Conformal (w/o BIB)	120 ms / evt

► CKF has a good track reconstruction performance for good seeds.
► Small efficiency loss at low p_T when including BIB.
► Need to implement selection to remove fake tracks.
► Timing includes (large) overhead from hit format conversion.

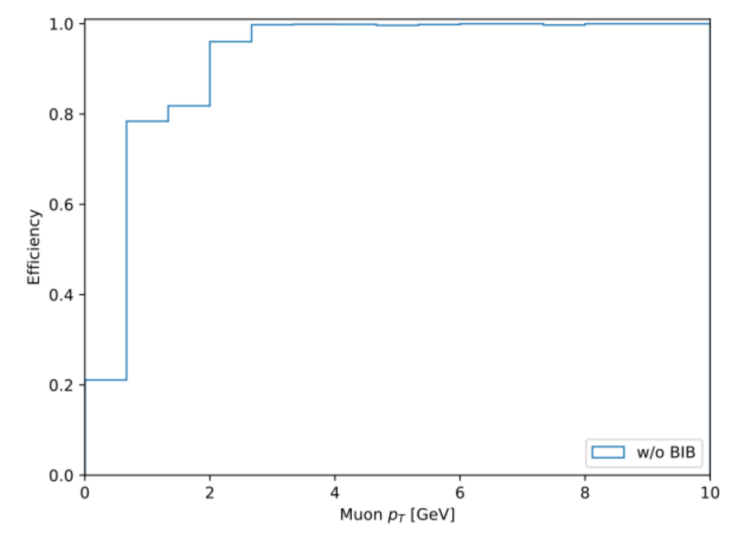
Triplet Seeding

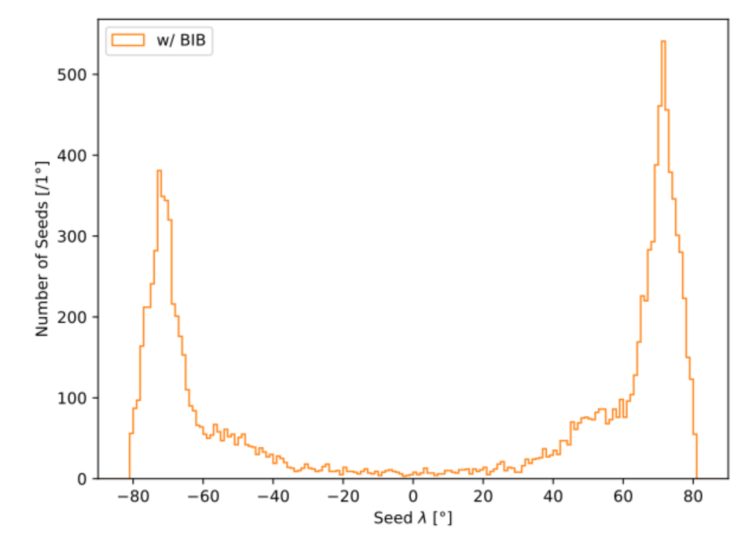
1. Choose *N* layers for seeding
   ► N=4 in our case
2. Form seeds containing three hits
   ► All possible combinations in N layers
3. Remove bad seeds
   ► Based on compatibility with helix
4. Remove overlap between seeds
   ► Based on middle hit in seed
5. Use estimated track parameters for CKF



Triplet Seeding Results

The vertex detector is used for the seeding. Only hits of the inner layer of each doublet are considered. This is not an optimized choice.





► Number of seeds is slightly larger than what is expected at HL-LHC.
► Large hit multiplicity from BIB near beampipe results in large combinatorics in the foward region.
► Extremely low seeding efficiency w/ BIB

Towards Triplet-Seeded CKF

80 ms / seed x 300000 seeds / event = ~ 6 hours / event

While significantly faster than the iLCSoft implementation (~week/event), ACTS still takes an unpractical time per event for track reconstruction. Work needs to happen in the following topics.

Improvements to Seeding
► Need to reduce number of seeds by at least x10
  ► Reduce hits via cluster shape analysis
  ► Optimize seed finding parameters
    ► Larger radius layers might be helpful
  ► Consistent timing of hits within a triplet
  ► Filter by hit consistency within doublet layers
► Improve seed finding efficiency by tuning seed overlap removal

Improvements to CKF
► Better understand bottleneck of CKF
► Try outside-in CKF to reduce branching early on

Study Realistic Tracking Performance
► Limit initial studies to barrel only

*** Muon Collider Physics and Detector Working Group**
https://muoncollider.web.cern.ch/node/15

References:

[1] "The Muon Smasher's Guide", *H. Al Ali et al*, arXiv:2103.14043
[2] "Detector and Physics Performance at a Muon Collider", *N. Bartosik et al*, arXiv:2001.04431
[3] "Advanced assessment of Beam Induced Background at a Muon Collider", *F. Collamati et al*, arXiv:2105.09116
[4] "Conformal Tracking for all-silicon trackers at future electron-positron colliders", *E. Brondolin et al*, arXiv:1908.00256
[5] "A Common Tracking Software Project", *X. Ai et al*, arXiv:2106.13593