Track Seed Finding in ACTS

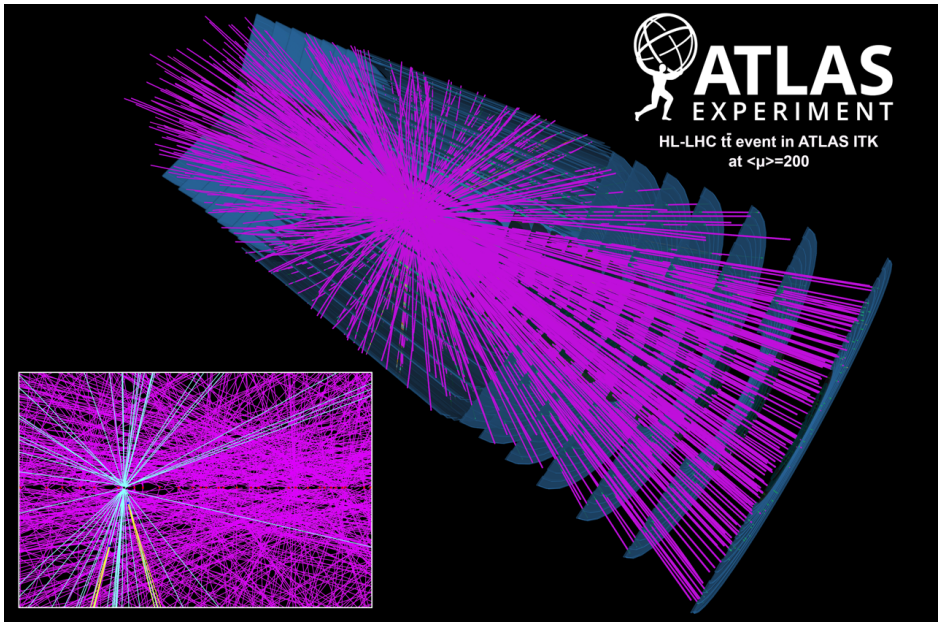
Tomohiro Yamazaki (UC Berkeley) for the ACTS developers

IRIS-HEP topical meeting for HL-LHC R&D

March 24, 2021

Challenges at HL-LHC

- Many interesting physics programs, such as measurements of Higgs rare decays and searches for BSM with small xsec, are expected at HL-LHC from 2026.
- Tracking performance needs to be retained/ improved under the high pile-up environment.
- For HL-LHC tracking, concurrent algorithms exploiting modern computing architectures with many cores are necessary

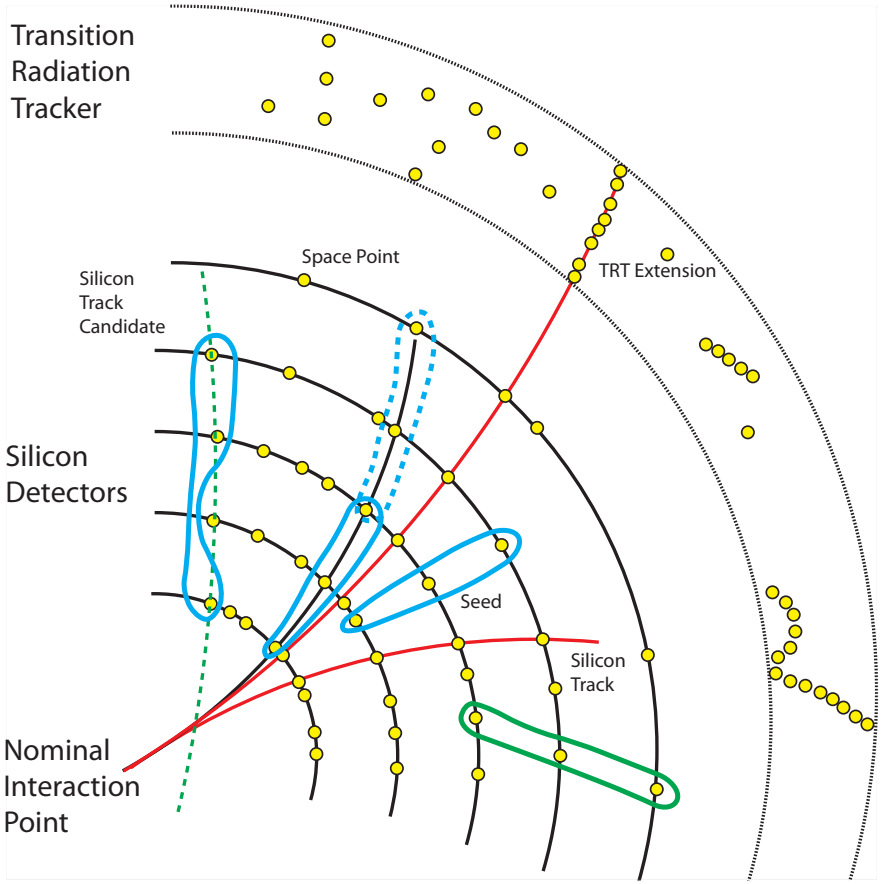


- The ATLAS tracking detector will be replaced with the full silicon detector for HL-LHC.
  → **ITk**
- Tracking software also needs to be replaced with a new accurate, efficient, and fast software.
  → **ACTS**

A Common Tracking Software (ACTS)

- ACTS is an experiment-independent tracking for future detectors
- Based on ATLAS tracking algorithms
- Modern C++17 and minimal dependencies
- Facilitates new R&D project for new tracking techniques, e.g. ML, GPU
- Increases maintainability and usability
- Allows parallelization/vectorization
- ACTS PV reconstruction has been implemented in athena for ATLAS Run 3
- gitHub, documentation
- Previous ACTS talks by Paul, Xiaocong 1, 2, Irina

Track Reconstruction

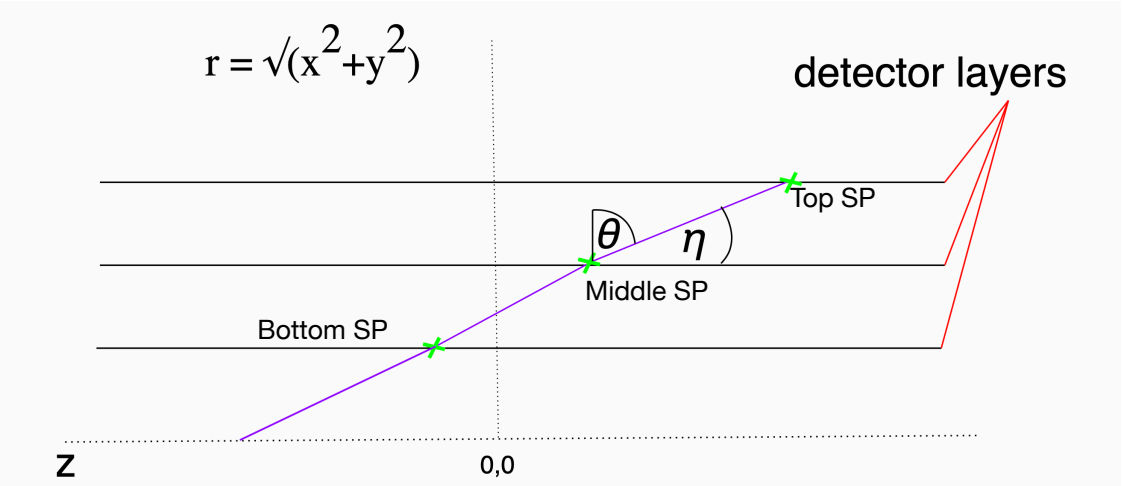


- Starts with **Space Point** formation from local measurements on silicon layers
- **Seeds** are then formed from triplets of hits
- **Combinatorial Kalman Filter** is used to extend the seeds and build track candidates (**Track Finding**)
- Track candidates are scored according to track quality to remove duplicate tracks (**Ambiguity Solving**)

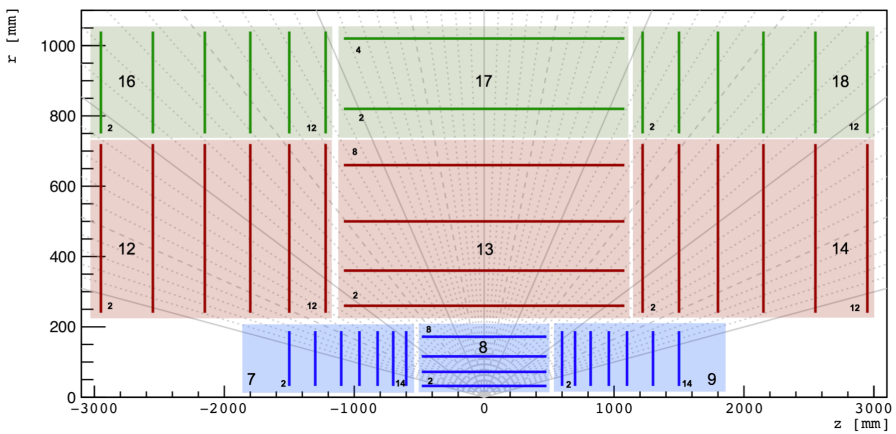
Seed finding in ACTS

- The **ACTS seeding** implementation is based on the ATLAS track seeding.
- Space Points on pixel layers are used for seeding

- Seed finding algorithm iterates over middle SP
- For each middle SP, top-middle and bottom-middle doublets are formed.
- Apply some cuts (eta, origin along z-axis, distance in r between SP)
- Top-middle and bottom-middle doublets are tested for compatibility
- Seed triplet is created by combining the compatible doublets.



Seed finding in Generic Detector



Long strip detector

Short strip detector

Pixel detector

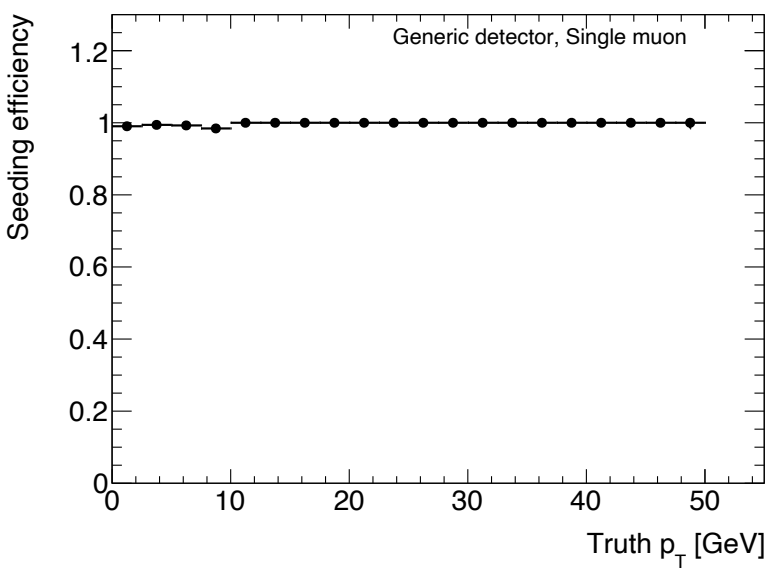
- Examples of ACTS tracking reconstruction chains are available in ACTS
- With the generic detector geometry,
  - Hits on the pixel detector are used for seed finding.
  - Only a simple seed finding configulation is available.
  - The same parameters for the barrel and endcap for now.
  - Detector specific weights are not used.
- Fatras simulation with a 2 T magnetic field
- Optimization for the ATLAS ITk layout is ongoing, but this is not shown today.

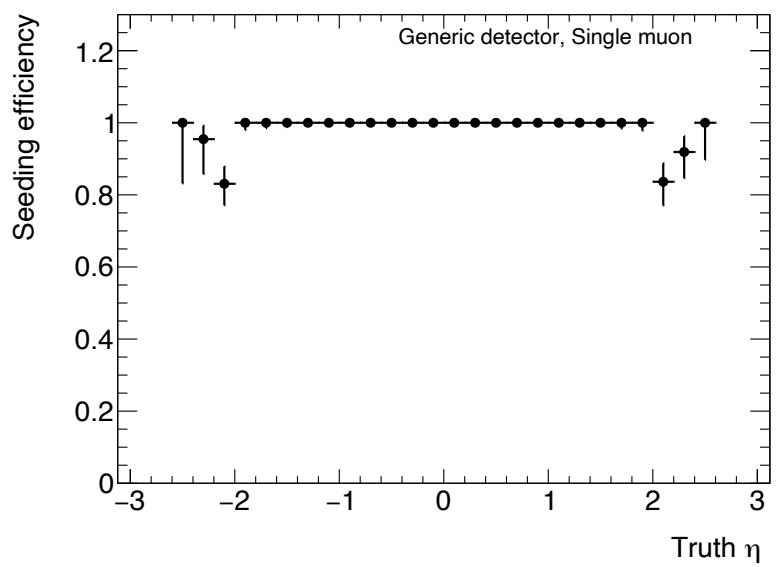
ACTS Seeding Performance

- Seed finding has been added in ACTS Example for validation
- The tracking efficiency can not be higher than seeding efficiency -> High efficiency required
- Validated with Generic detector
- Event generation, fatras simulation, and seeding/tracking examples in ACTS
- 99.7% efficiency for single muon events

$$\text{Efficiency} = \frac{N_{truth}\,(\text{selected, matched to reco})}{N_{truth}\,(\text{selected})}$$

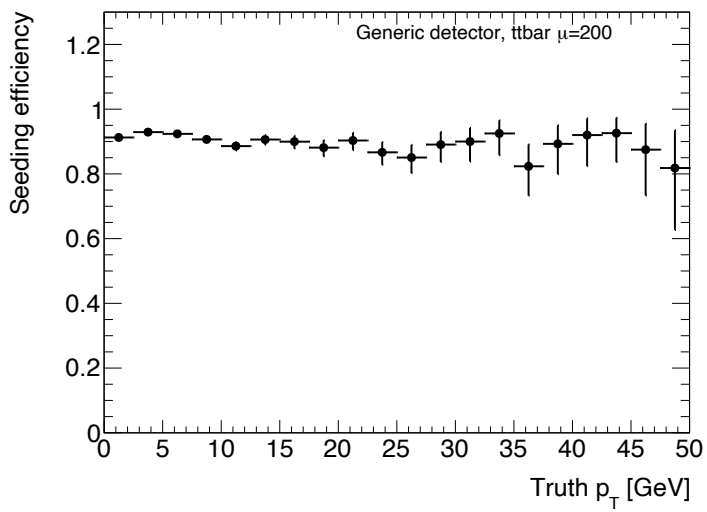
Truth particles with (p_T> 1 GeV and >= 9 hits) are considered

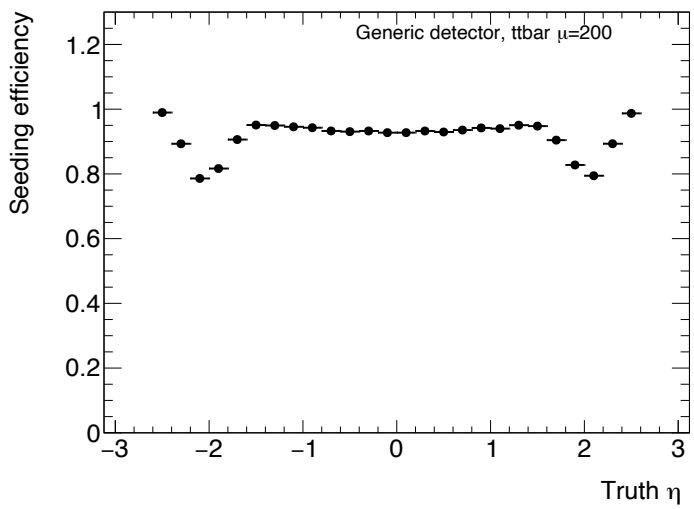




ACTS seeding under the HL-LHC environment

- Seed finding performance for ttbar events with μ=200 at √s = 14 TeV
  - ~5k particles/event
- 91.4% efficiency
- The current configuration is not optimal for the barrel-endcap gap
  - No detector specific weights are used.
  - Need confugrations for the barrel and endcap separately



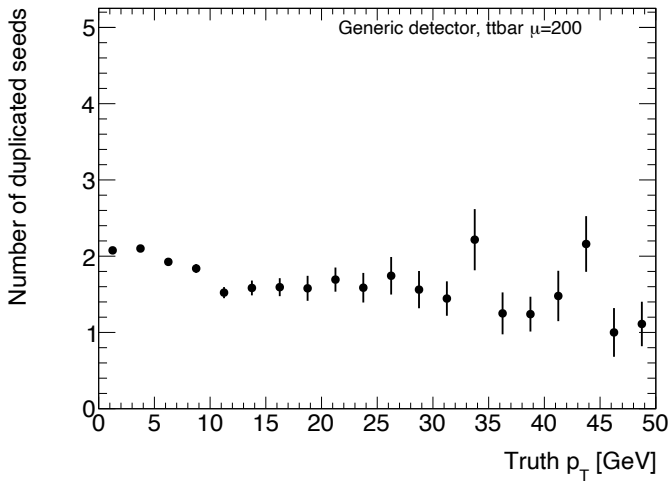


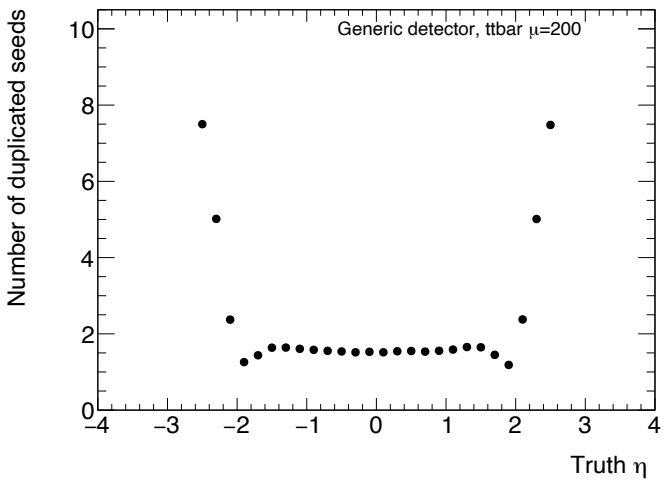
Seed finding performance

- The number of seeds affects the track finding CPU time and performance
  - Avoid creating seeds where there is no tracks (fake)
  - Should not provide many seeds for the same track (duplicated seeds)
- 58% fake rate for ttbar μ=200 with the Generic detector

$$\text{Fake Rate} = \frac{N_{reco}\,(\text{selected, unmatched})}{N_{reco}\,(\text{selected})}$$

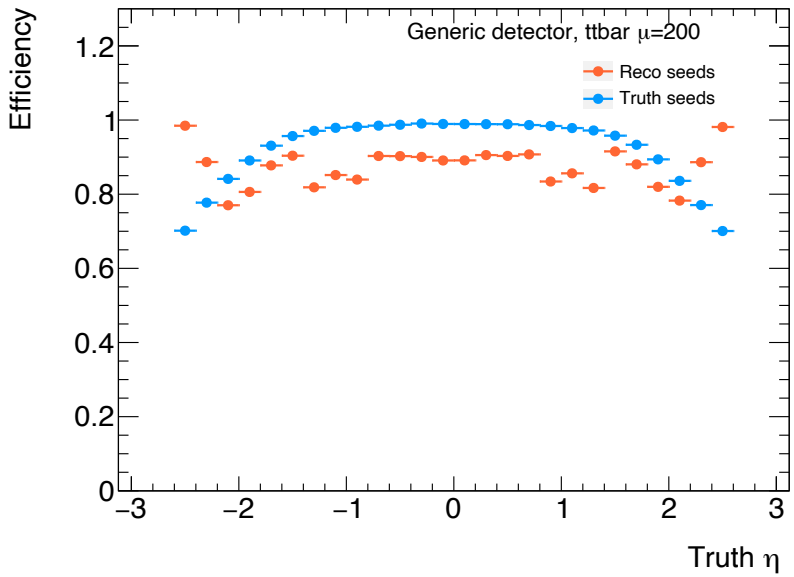
- Number of duplicated seeds:

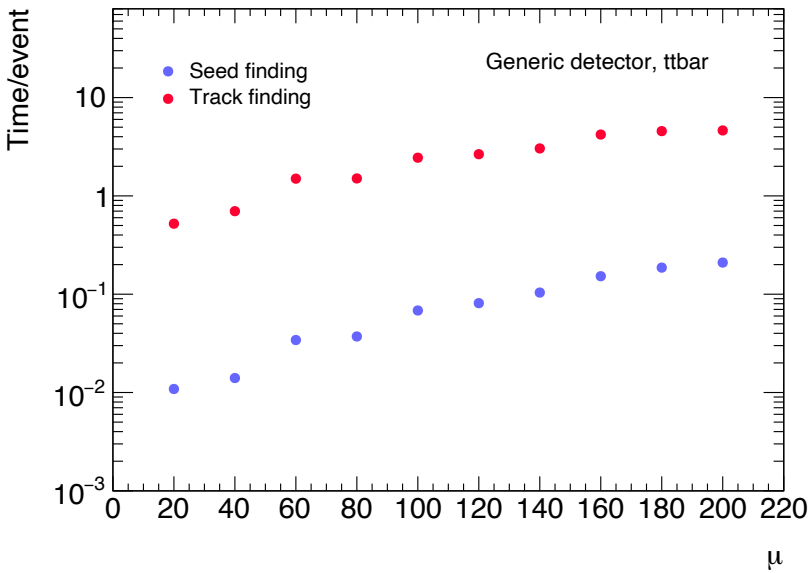




Track Finding with seeds

- Initial track parameters are estimated from seeds (triplets of space points), and used as proto-tracks.
- Combinatorial Kalman Filter (CKF) algorithm is used to extend the proto-tracks and reconstruct tracks





CKF Tracking efficiency for ttbar

Reconstructed seeds as initial parameters

Smeared truth particles as initial parameters

Track finding fake rate and duplication

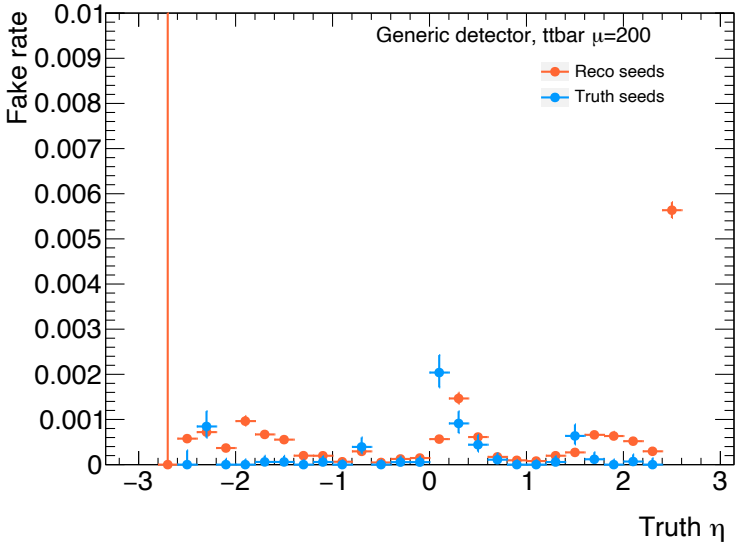
- Fake rate < 10^{-3} for CKF traking from reco and truth seeds

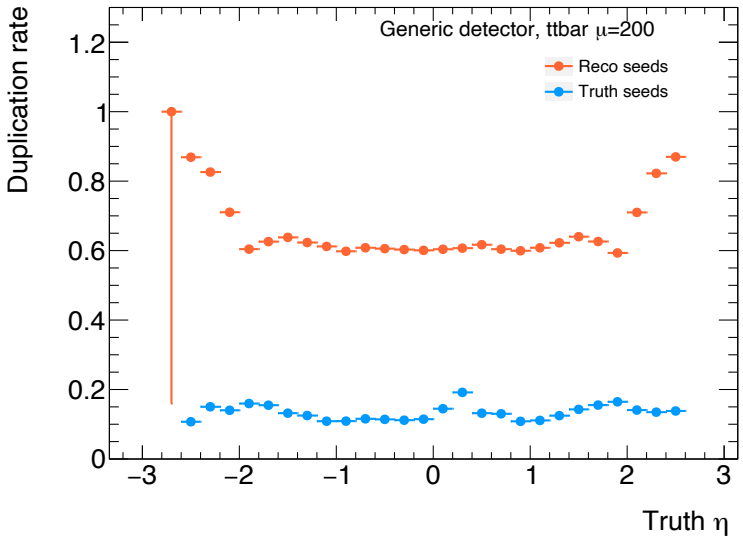
$$\text{Fake Rate} = \frac{N_{reco}\,(\text{selected, unmatched})}{N_{reco}\,(\text{selected})}$$

- Duplication rate < 0.2 for CKF tracks with truth seeds
  ~ 0.6 for CKF tracks with reco seeds

$$\text{Duplication Rate} = \frac{N_{reco}\,(\text{selected, matched, duplicated})}{N_{reco}\,(\text{selected, matched})}$$

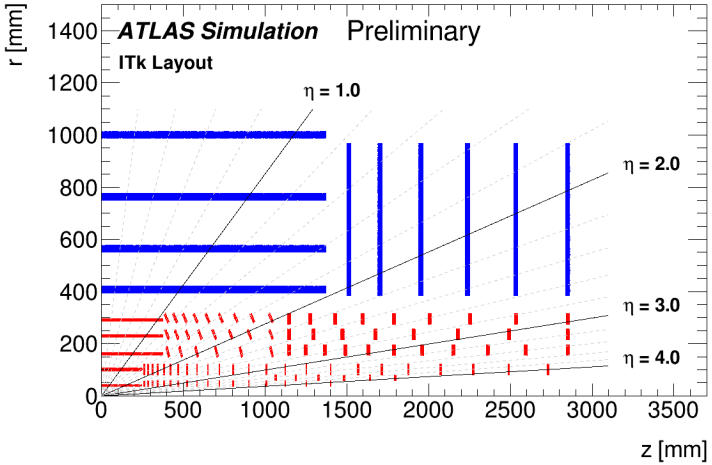
- Ambiguity sover is not used yet. The duplication rate could be suppressed by the ambiguity solver.





Ongoing tasks

- Integration of ACTS into athena is one of the main projects in this year.
  - Develop wrapper to interface ACTS in athena
  - Optimize athena/ITk specific configurations
- For seeding,
  - Optimize layer selection, seeding cofigrations for the barrel and endcap regions for ITk
  - Detector specific weights to reduce duplicated seeds



- Efforts are being made to run ACTS algorithms on GPU (Xiaocong's talk)
  - Long term goal is to port more modules to GPU to have a GPU-based algorithm chain

Summary

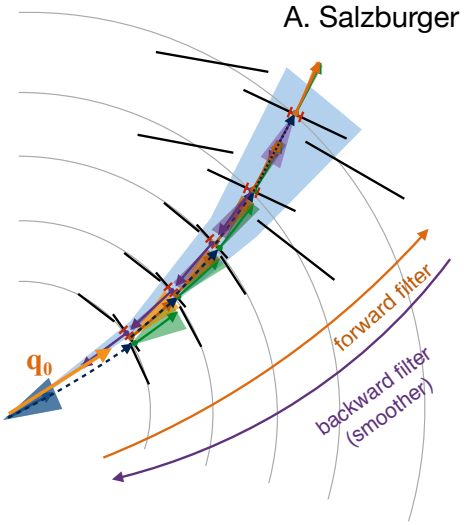
- High performance tracking software is necessary for HL-LHC
- ACTS is an open-source toolkit for track reconstruction
  - Retain/improve tracking performance for various detectors
- Seeds provide Initial track parameters for the CKF tracking.
  - Tracking efficiency cannot be higher than seeding efficiency.
  - Suppression of fake/duplication seeds is important to improve the tracking performance
- Good performance for the generic detector examples. Further optimization is ongoing.
- Working on ACTS integration into athena for HL-LHC
  - Need ITk specific optimization.

Backup

Track Finding

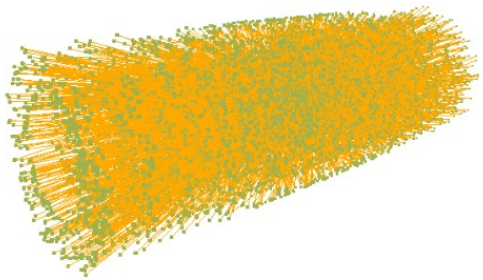
Kalman Filter

- start with transport of track parameters (and covariances) to measurement surface, create predicted parameters ("predicted state")
- combine/update predicted parameters with measurement to updated parameters ("filtered state")



Combinatorial Kalman Filter (CKF)

- Simultaneous track fitting and finding
- Allows track branching if more than one compatible measurements found on a surface
- Allows stopping of bad quality branch



CKF results for ttbar events with μ = 200 (~7k particles, ~80k hits)