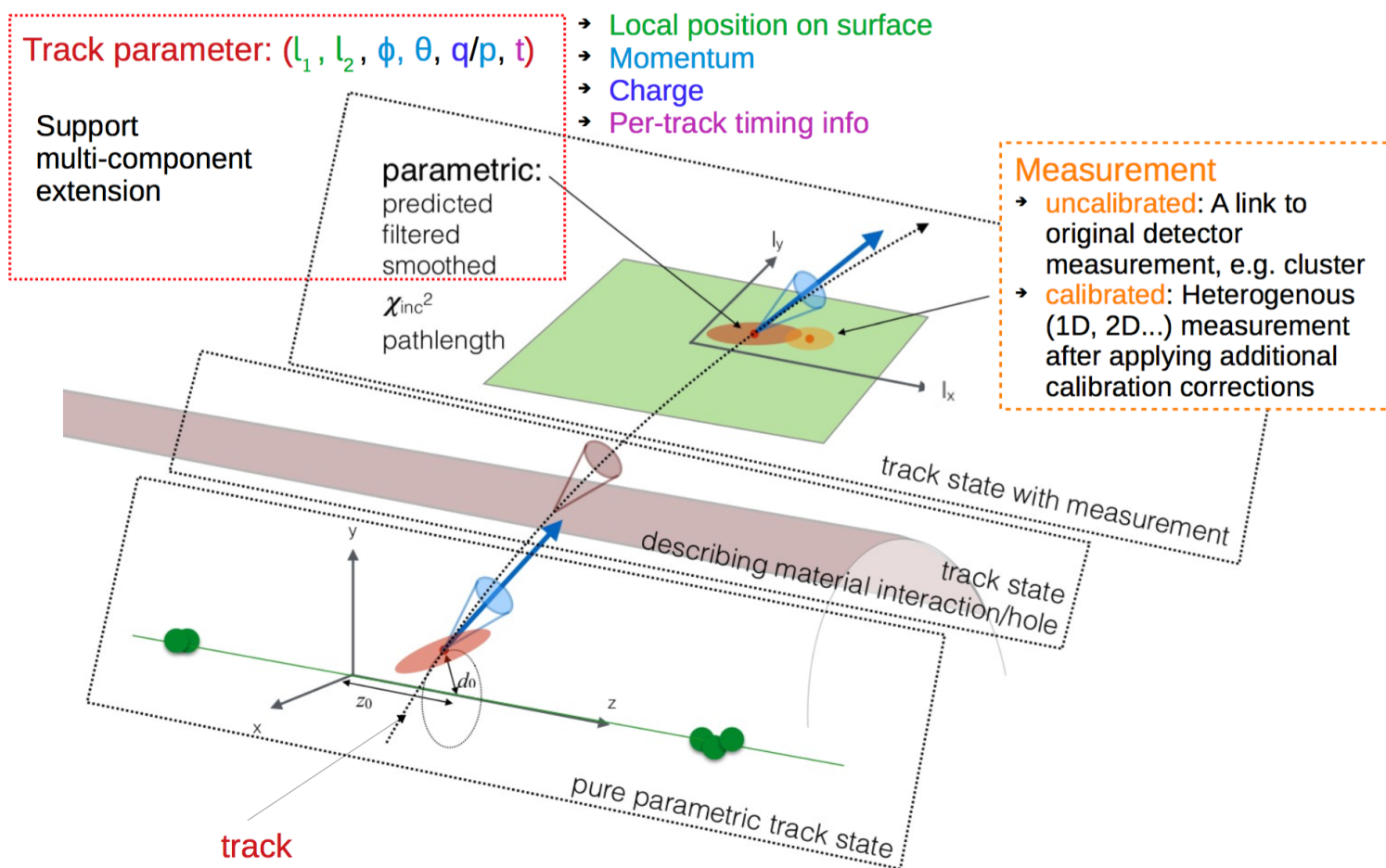# Track recosntruction with ACTS in ATHENA software

Wenqing Fan, Shujie Li, YueShi Lai, Sakib Rahman, Wouter Deconinck, Sylvester Joosten, ACTS experts and many others

▸ **Kalman-filter (KF) type track finding/fitting**

- ◈ B field map, material map, track seeds fed to KF model for predicted track calculation
- ◈ Track parameters at event vertex: momentum, local position
- ◈ Track parameters at detector surfaces: momentum, local position, pathlength etc.

Track parameter: $(l_1, l_2, \phi, \theta, q/p, t)$

Support multi-component extension

parametric:
predicted
filtered
smoothed
χ_{inc}^2
pathlength

→ Local position on surface
→ Momentum
→ Charge
→ Per-track timing info

Measurement
→ uncalibrated: A link to original detector measurement, e.g. cluster
→ calibrated: Heterogenous (1D, 2D...) measurement after applying additional calibration corrections

track state with measurement

describing material interaction/hole

track state

l_y

l_x

y

z_0

d_0

z

x

pure parametric track state

track

Hybrid tracking system

▸ **Full geometry of (baseline-2) hybrid tracking systems implemented**

◈ Canyonland version: Silicon + MPGD

◈ Death valley version: LGAD TOF layers added to barrel tracking

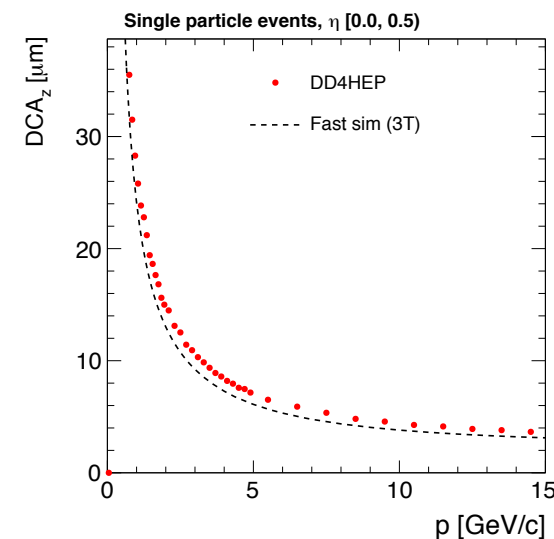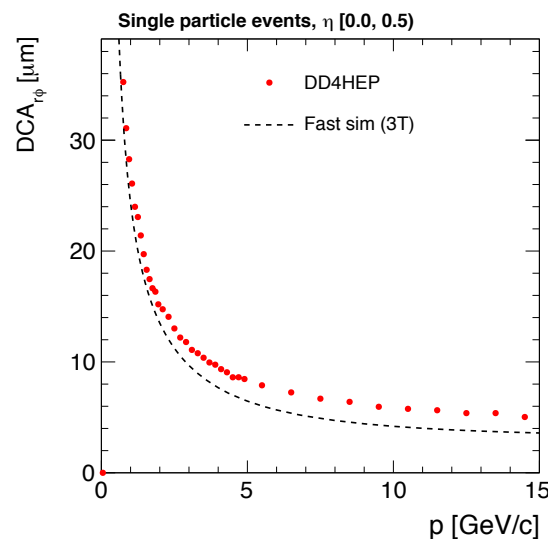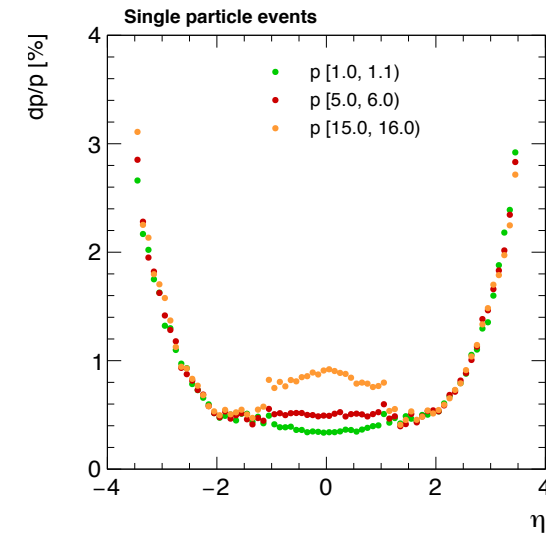◈ Material map included in each version
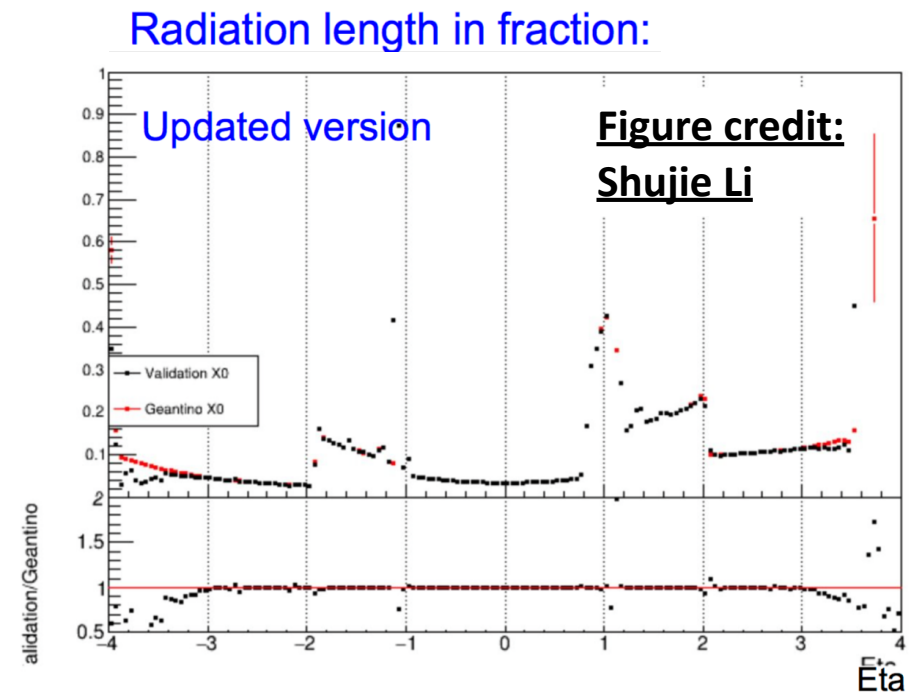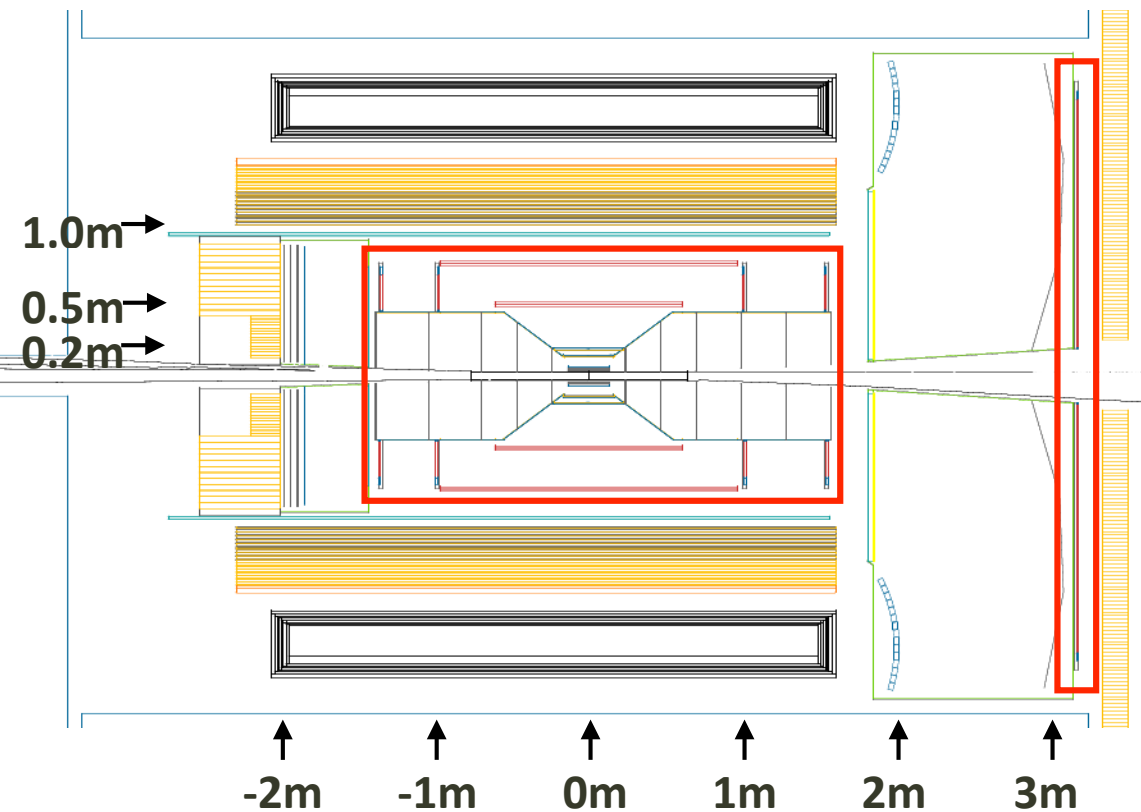
▶ **Momentum reconstruction**

   ◈ Reasonable momentum and angular resolution

   ◈ Efficiency drop at very high momentum

▶ **DCA reconstruction**

   ◈ Reasonable $DCA_{r\phi}$ resolution

   ◈ Reasonable DCA_z resolution in mid-rapidity, unexpected behavior at forward

▶ **Trajectory**

   ◈ Track projection at PID surfaces

   ◈ Track path length at TOF detector
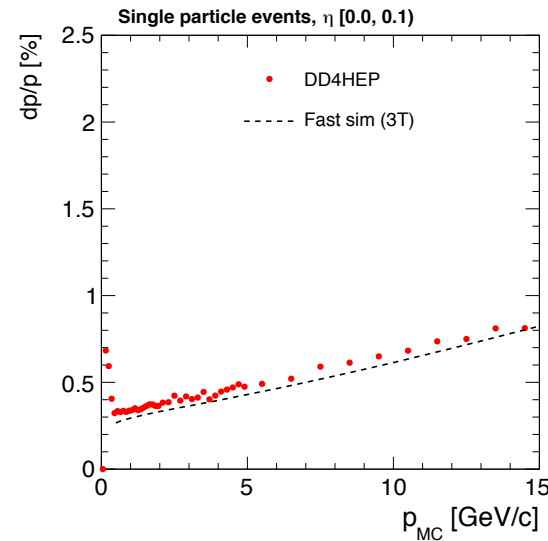
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Single particle events, η [2.5, 2.6]

- DD4HEP
- Fast sim (3T)

not well-understood range

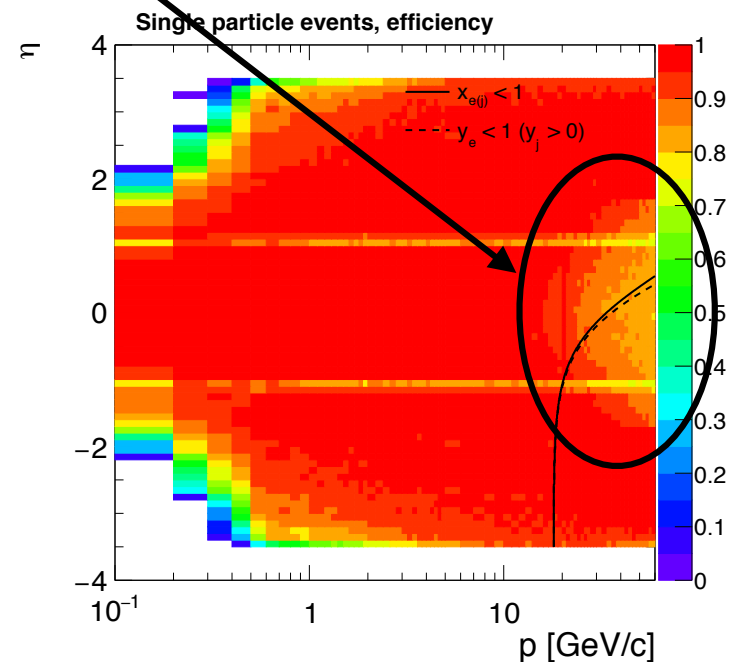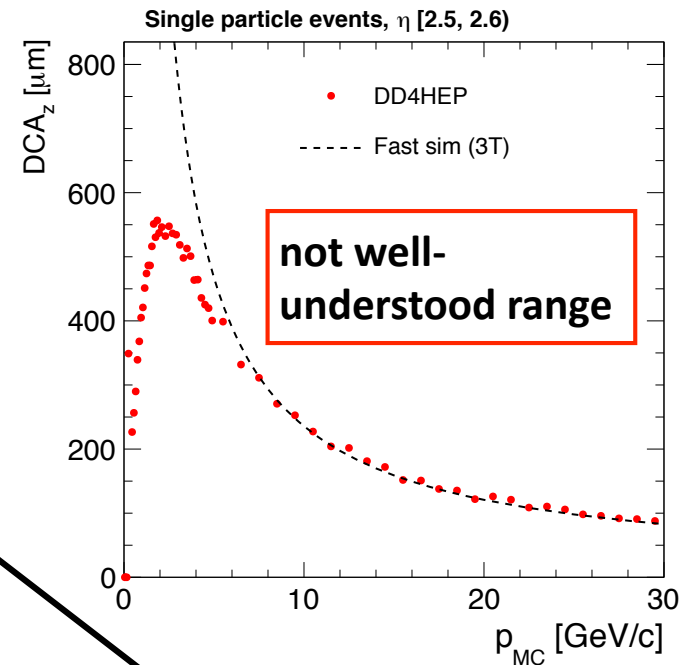Single particle events, efficiency

▸ **Momentum reconstruction**

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▸ **Trajectory**

　◈ Track projection at PID surfaces

　◈ Track path length at TOF detector

Projection to DIRC, $\eta = 0.0$

Fit function $f(p) = \frac{A}{p} \oplus B$

A = 1.78, B = 0.25

$\Delta\phi$ [mrad]　p [GeV/c]

Projection to DIRC, $\eta = 0.0$

Fit function $f(p) = \frac{A}{p} \oplus B$

A = 0.81, B = 0.06

$\Delta\theta$ [mrad]　p [GeV/c]

barrel TOF, $\eta = 0.0$

Fit function $f(p) = \frac{A}{p} \oplus B$

A = 0.09, B = 0.00

ΔL_{path} [mm]　p [GeV/c]
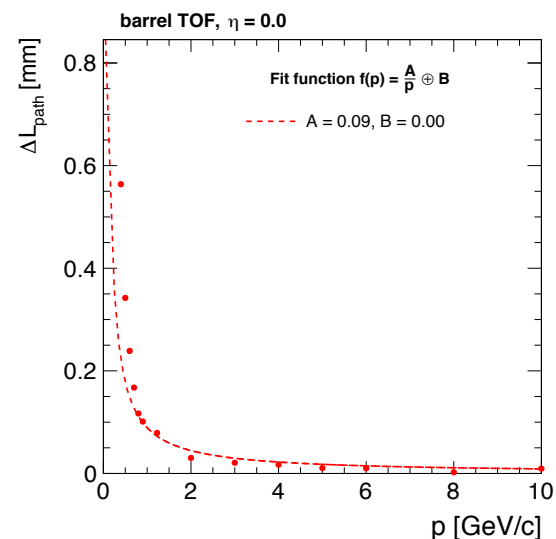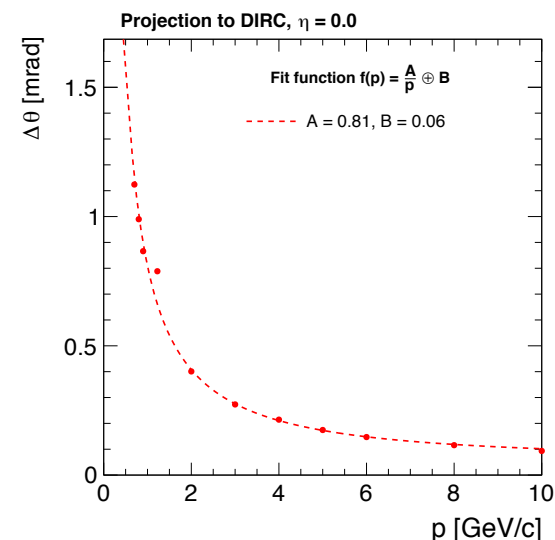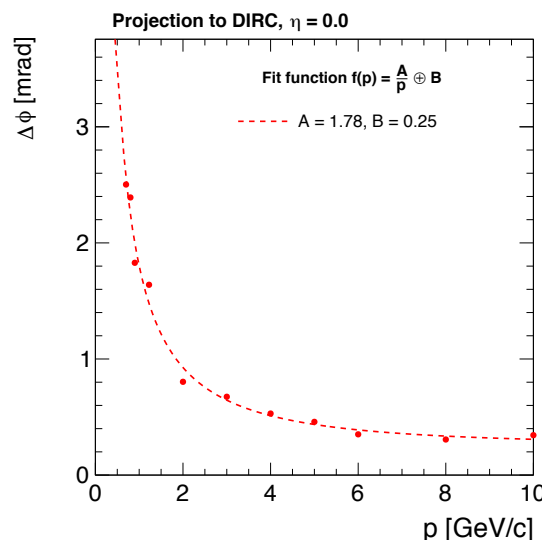
▸ **A good seeding algorithm**

◈ It finds at least one seed for each particle that should be found

◈ It doesn't find many seeds which do NOT correspond to particles

◈ It doesn't find many seeds per particle

▸ **ACTS seeding tool**

◈ Use triplet of hits for seed finding

◈ All hits used in ATHENA for seed finding

▸ **Plug-in to juggler and configure to ATHENA environment**

◈ Developed by YueShi Lai

◈ Currently testing the performance with single pion events

y

x

Helix radius

Detector radius

Helix center

⌒ Particle path within detector

× Particle measurement on detector surface

$r = \sqrt{(x^2+y^2)}$

detector layers

θ η

z

0,0

https://acts.readthedocs.io/en/v9.0.0/core/seeding.html
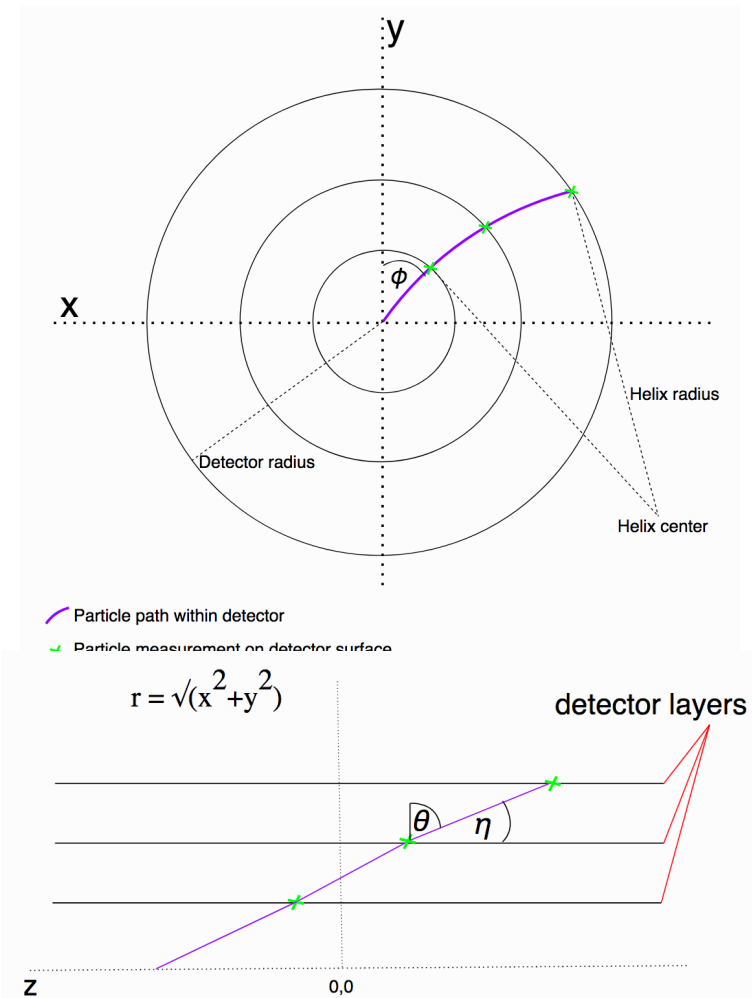
▸ A well **reconstructed track**: tracks can be associated to a generated particle by mathcing the momentum algorithm (**association criteria: Δp/p within 10%, Δφ within 50mrad, Δθ within 10mrad**)

▸ A track that is not associated to any simulated particle is considered to be a **fake track**.

▸ Duplicate tracks occur when multiple tracks are associated to the same generated particle.

Efficiency vs. η

Fake rate vs. η

Duplication rate vs. η

Fake rate < 10^{-4}

Duplication rate ~ 5%, could be suppressed by tighter KF χ^2 criteria

Efficiency ~ 99% with |η|<1
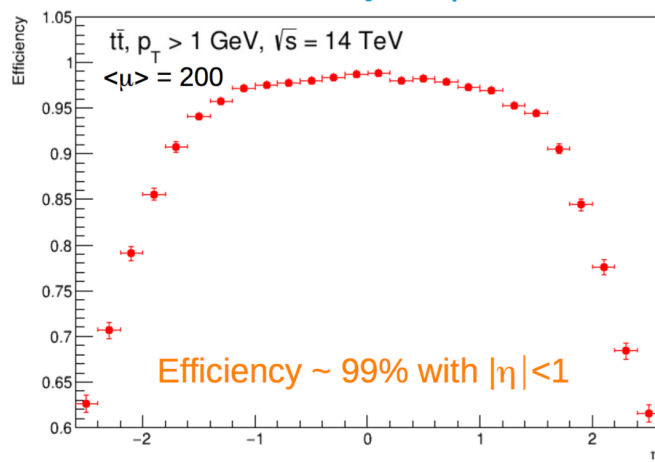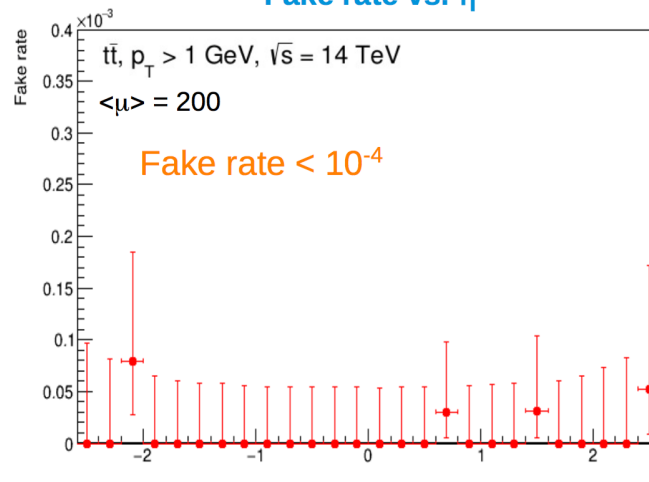
From Xiaocong Ai's presentation, TrackML detector, ATLAS B field

Truth seeding

Realistic seeding

Single particle events, p [1.0, 2.0] GeV/c, η [0.0, 0.5]

# of reconstructed (generated) particles 74752 (75663)

μ = -0.00 (χ^2/ndf = 39.6) — good (matched) track
σ = 0.4% — duplicate track
effciency = 97.9% — fake (unmatched) track
duplicate rate = 0.0%
fake rate = 0.4%

Single particle events, p [1.0, 2.0] GeV/c, η [2.0, 2.5]
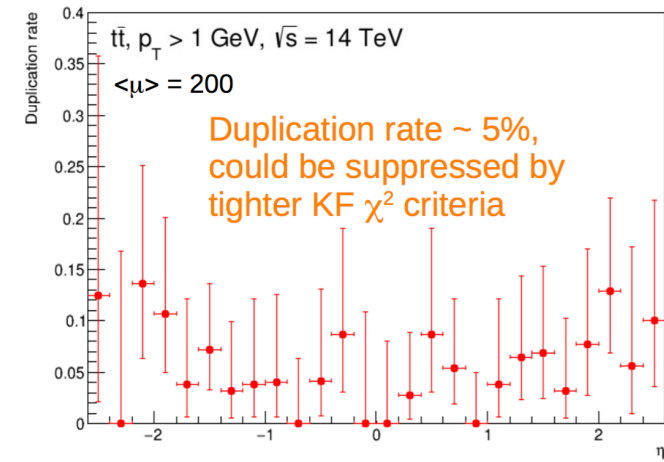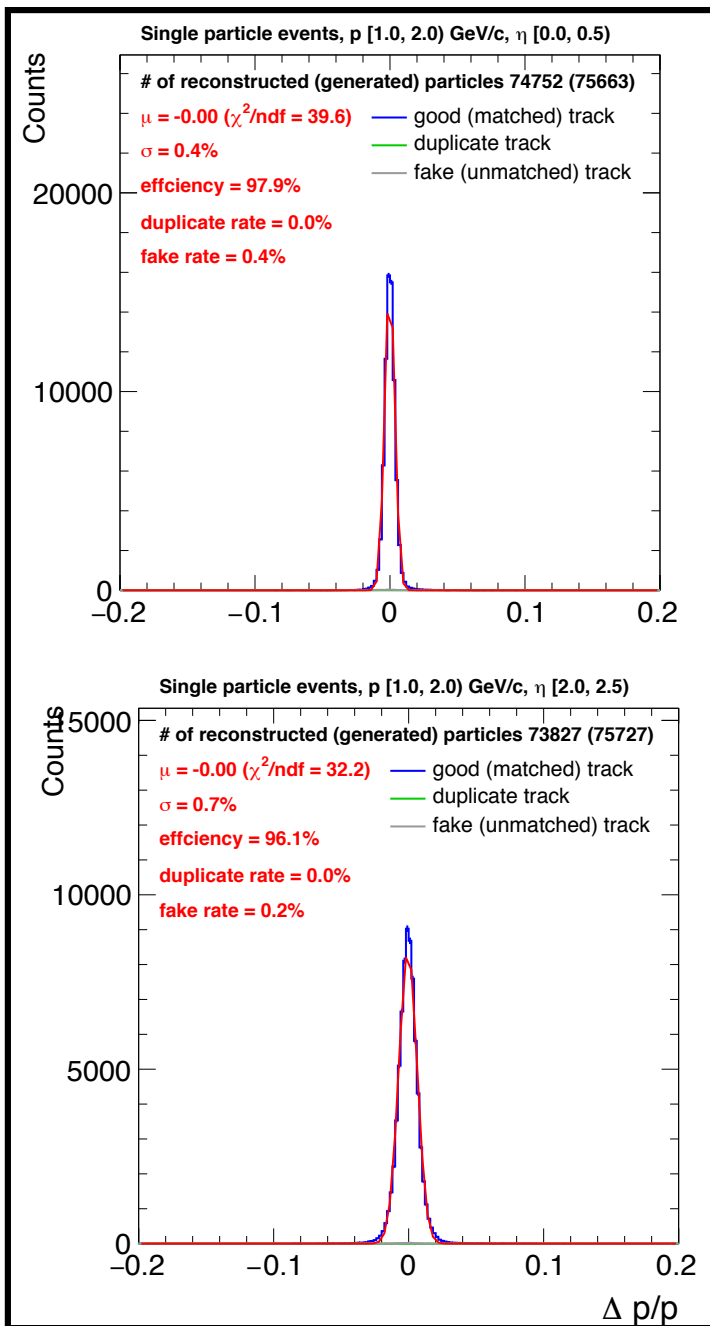
# of reconstructed (generated) particles 73827 (75727)

μ = -0.00 (χ^2/ndf = 32.2) — good (matched) track
σ = 0.7% — duplicate track
effciency = 96.1% — fake (unmatched) track
duplicate rate = 0.0%
fake rate = 0.2%

Single particle events, p [1.0, 2.0] GeV/c, η [0.0, 0.5]

# of reconstructed (generated) particles 94363 (95010)

μ = -0.00 (χ^2/ndf = 57.3) — good (matched) track
σ = 0.4% — duplicate track
effciency = 98.4% — fake (unmatched) track
duplicate rate = 8.8%
fake rate = 0.2%

Single particle events, p [1.0, 2.0] GeV/c, η [2.0, 2.5]

# of reconstructed (generated) particles 9385 (94986)

μ = -0.01 (χ^2/ndf = 3.4) — good (matched) track
σ = 1.1% — duplicate track
effciency = 3.1% — fake (unmatched) track
duplicate rate = 1.2%
fake rate = 71.7%

Δ p/p

For 1GeV tracks at mid-rapidity: high efficiency, ~10% duplicate tracks with realistic seeding

For 1GeV tracks at forward-rapidity: low efficiency, bad reconstruction for track momentum

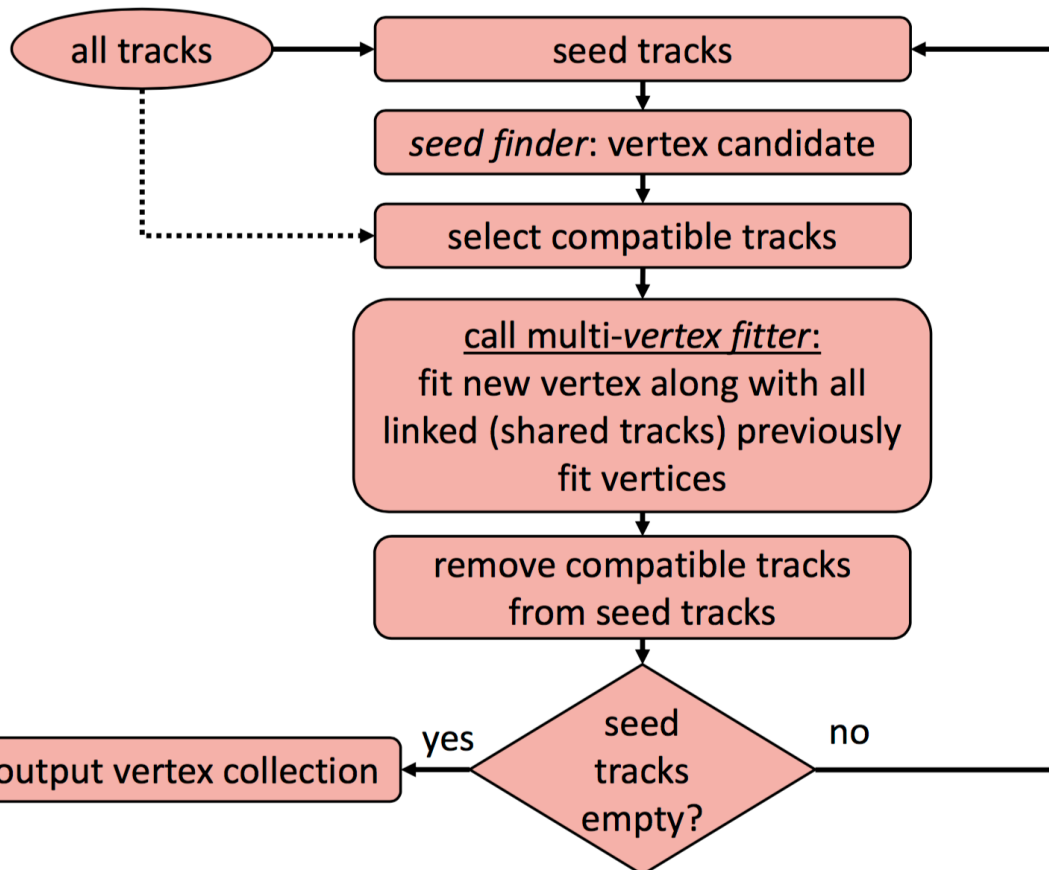▸ AdaptiveMultiVertexFinder (AMVF)   https://acts.readthedocs.io/en/v9.0.0/howto/setup_and_run_vertexing.html

◆ Existing tool from ACTS (other vertex finders available too)

◆ Current status: a draft plug-in version to juggler *PrimaryVertexFinder.cpp*, need to compile with latest ACTS version and test


Adaptive Multi-Vertex Fit:

- weighted adaptive Kalman filter using deterministic annealing scheme
- subject to beamspot and seed constraint
- Simultaneous refit of all vertices connected through a chain of vertices and tracks, with weights:

$$\omega_i(\chi_i^2, T) = \frac{e^{-\frac{1}{2}\chi_i^2/T}}{\sum_j e^{-\frac{1}{2}\chi_j^2/T} + e^{-\frac{1}{2}\chi_0^2/T}}$$

→ *Finding-through-fitting approach*

Slides by Bastian Schlag: https://indico.cern.ch/event/902131/contributions/3797615/subcontributions/302749/attachments/2007646/3353484/vertexing_updates.pdf#search=bastian

▸ **Require new cylindrical geometry from ACTS**

- ◈ **Detector geometry already setup in DD4HEP**
- ◈ **Not symmetric about the global z-axis, which is not supported by ACTS**
- ◈ **Implement this new geometry into ACTS code**

https://wiki.bnl.gov/athena/index.php/FarForward
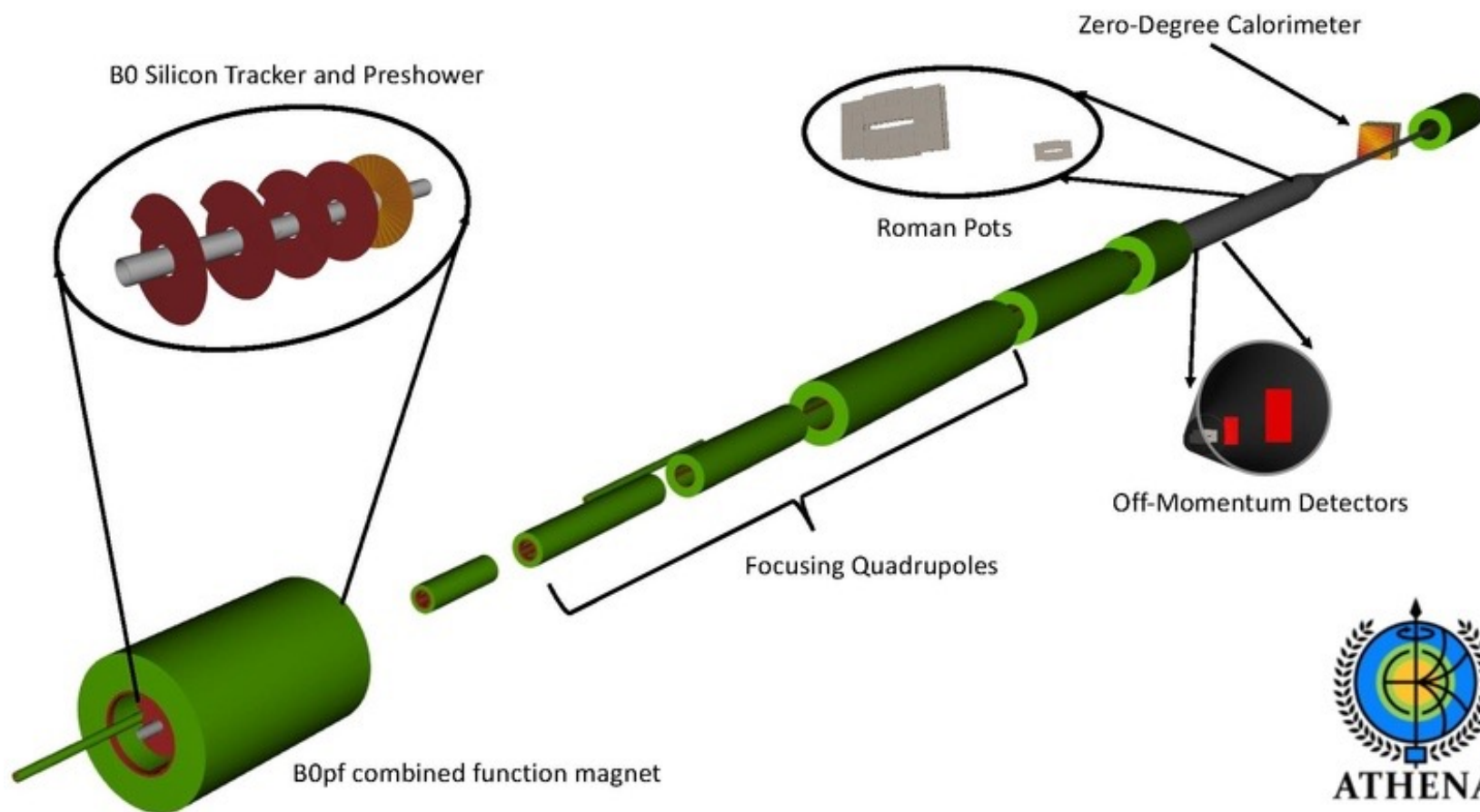
▸ **Output structure: eicd data structure**

   ◈ Basic track parameters in *TrackParameters*

▸ **More info added:**

   ◈ Hits asscoiated to tracks

   ◈ Track projection, path length, etc.

https://eicweb.phy.anl.gov/EIC/eicd/-/blob/master/eic_data.yaml

```
eic::TrackParameters:
    Description: "ACTS Bound Track parameters"
    Author: "W. Armstrong, S. Joosten"
    Members:
      - eic::Index          ID              // Unique track ID.
      - eic::FloatPair      loc             // Tracking location
      - eic::FloatPair      locError        // Error on the location
      - eic::Direction      direction       // Track direction (theta, phi) [rad, 0-pi and
-pi->pi]
      - eic::Direction      directionError  // Error on the direction [rad]
      - float               qOverP          // [e/GeV]
      - float               qOverPError     // Error on qOverP
      - float               time            // Track time [ns]
      - float               timeError       // Error on the time
      - float               charge          // Assumed track charge, units of [e]

  eic::Trajectory:
    Description: "Trajectory"
    Author: "W. Armstrong, S. Joosten"
    Members:
      - eic::Index          ID              // Unique trajectory ID
      - eic::Index          trackID         // Corresponding track ID
      - eic::VectorXYZ      p               // 3-momentum at the vertex for the trajectory
      - float               charge          // Charge of the particle trajectory
    VectorMembers:
      - eic::TrajectoryPoint  points        // Points along this trajectory

  eic::Track:
    Description: "Track information"
    Author: "W. Armstrong, S. Joosten"
    Members:
      - eic::Index          ID              // Unique track ID, same as the ID in the
corresponding TrackParameters
      - eic::VectorXYZ      p               // Track momementum
      - float               charge          // Charge of particle trajectory
      - float               length          // Track length from first to last hit[mm]
      - float               TOF             // Time of flight from first to last hit [ns]
```

Summary

▸ **Current status**

  ◈ Detector geometry all setup with material map

  ◈ Truth seeding works well with a few outstanding issues in single track event

  ◈ Cross-check tracking performance in DIS events

  ◈ Including synchrotron radiation

▸ **Ongoing**

  ◈ Realistic seeding underway

  ◈ Primary vertexing being developed

  ◈ B0 tracker and forward tracking

  ◈ eicd data structure and JUGGLER version control

▸ **Athena-ACTS bi-weekly meeting on Monday 9:30am EST**

  ◈ Subscription: https://lists.bnl.gov/mailman/listinfo/eic-athena-trk-recon-l

  ◈ Indico page: https://indico.bnl.gov/event/14537/