Acts+ODD Performance

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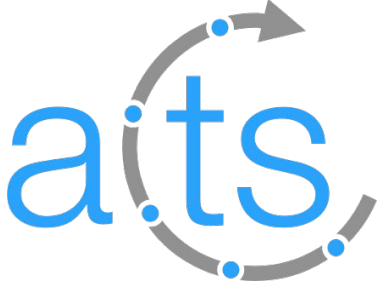
Acts



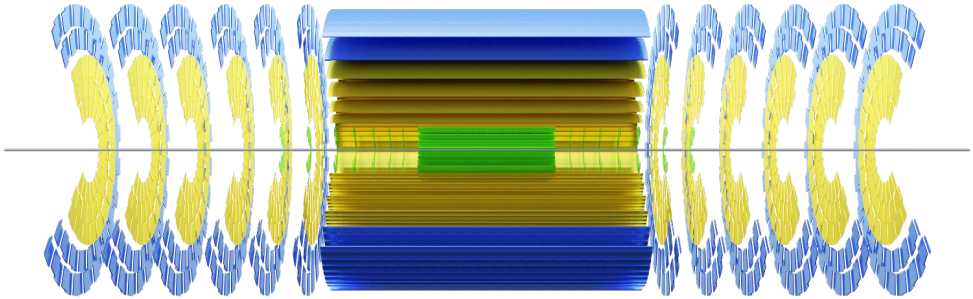
- A Common Tracking Software

  RTD / GitHub description: *Experiment-independent toolkit for track reconstruction implemented in modern C++*

- ACTS provides algorithms for clusterization, track finding, track fitting, vertexing, …
- It is not: reconstruction chain, I/O and scheduling
- Key objectives: thread-safe, modular, composable, modern code, R&D platform
- Benefits of being experiment-independent: knowledge transfer, common solutions for various domain specific problems
- Already used in production by various experiments

GitHub: https://github.com/acts-project/acts
RTD: https://acts.readthedocs.io/
Weekly dev meeting: https://indico.cern.ch/event/1329289

ODD



- Open Data Detector

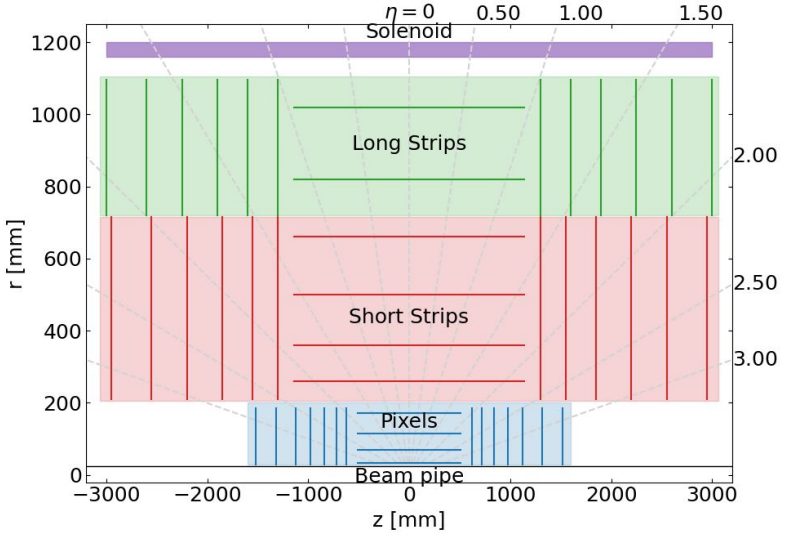
  … provides a template (HL-)LHC style particle detector for algorithm research and development

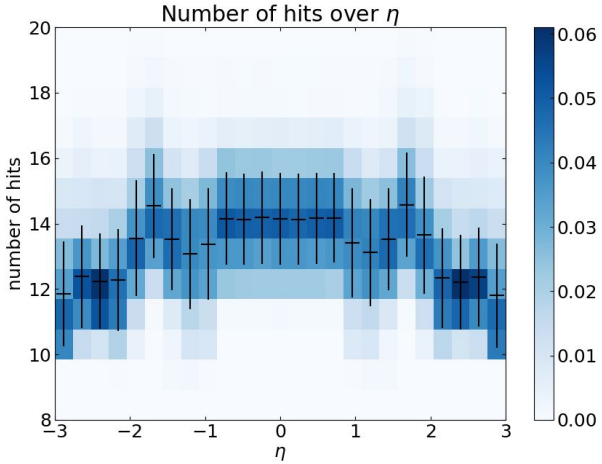
- An evolution of the TrackML detector with more realistic material budget and full simulation support
- Full silicon prototype inner detector based on DD4hep
- The detector description does not specify digitization
- Used in Acts for validation and performance studies
- Recently extended by calorimeters and potentially muon system
- For our studies only the silicon part was important

GitLab: https://gitlab.cern.ch/acts/OpenDataDetector
ACAT 2021: https://indico.cern.ch/event/855454/contributions/4596738
CHEP 2023: https://indico.jlab.org/event/459/contributions/11546

ODD Layout

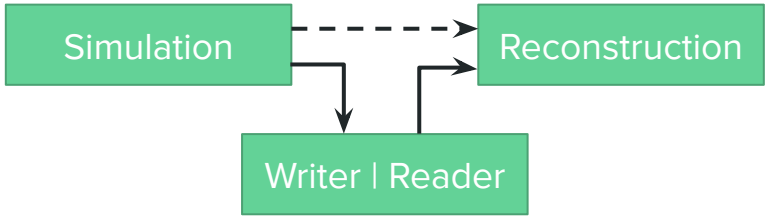
- Pixel
  - 2D + time
  - Resolution: 15 µm spatial, 25 mm time
  - 4 barrel layers
  - 7 endcap disks
- Short strips
  - 2D
  - Resolution: 43 µm / 1.2 mm spatial
  - 4 barrel layers
  - 6 endcap disks
- Long strips
  - 1D, two sided, with stereo angle
  - Resolution: 72 µm spatial
  - 2 barrel layers
  - 6 endcap disks





Acts + ODD

- Acts has plugin support for cylindrical detectors based on DD4hep
- Combination provides a foundation for validation and evaluation of reconstruction algorithms
- Examples Framework comes with multiple simulation algorithms
  - Particle gun and Pythia8 for event generation
  - Fast track simulation (Fatras) and Geant4 for detector simulation
  - Smeared and geometric digitization
- A Sequencer executes reconstruction and simulation algorithms in order and provides stable random numbers
- Readers and Writers allow to break the simulation and reconstruction chain into smaller, independent junks



Reconstruction chain

- Truth smeared seeding
  - Initials parameters from the particles origin with gaussian smearing
  - For non truth based seeding see L. Coelho talk!
- **Track finding**
  - **CKF** starts from seed and propagates through the detector
  - Encountered measurements are considered for branching with cuts on chi2
- **Track fitting**
  - **CKF** or KF or GSF or (GX2F)
- **Ambiguity solution**
  - **Greedy** approach which cuts on a maximum number of shared hits on tracks
  - Shorter tracks and higher chi2 sums are removed first
- Vertexing
  - Iterative Vertex Finder (IVF) or Adaptive Multi Vertex Finder (AMVF)

Focus of this talk

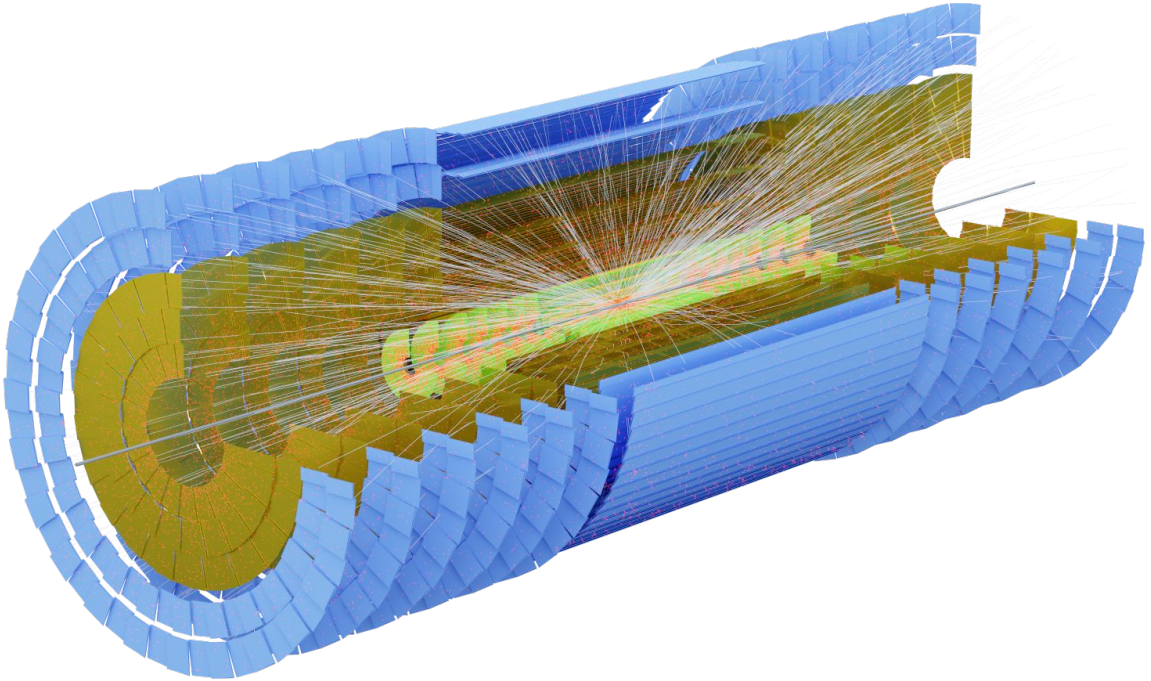
Reconstruction chain

Simulation

- ttbar (PU 200, 14 TeV) event generated using Pythia8
- Geant4 simulation
- Measurement by hit smearing

Reconstruction

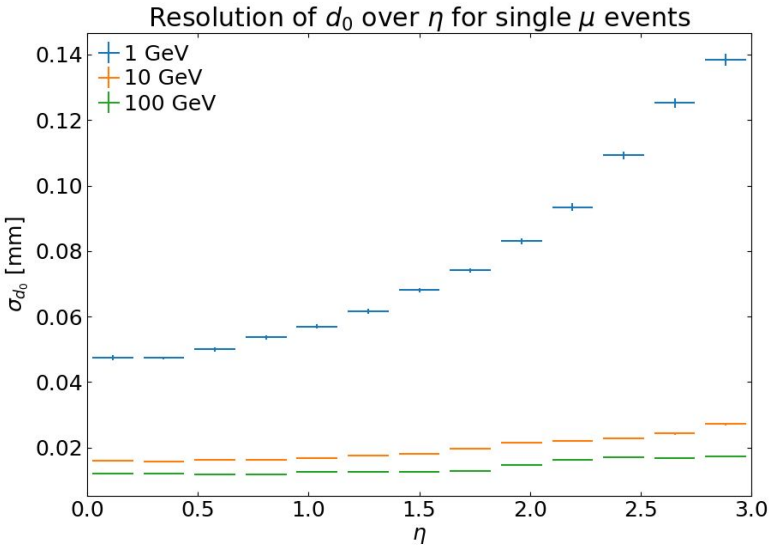
- Truth smeared seeding
- Track finding and fitting using CKF
- Vertexing using AMVF

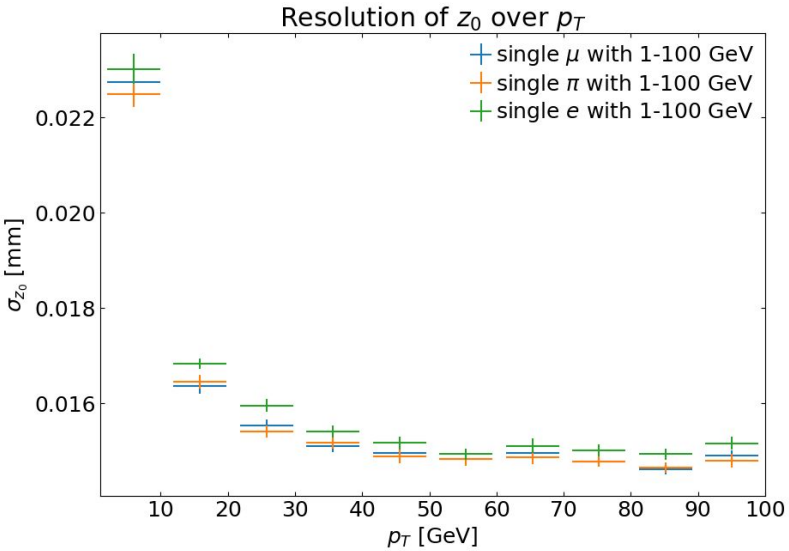


Truth matching

- Association of truth particles with reconstructed tracks based on measurements
- Cutting on particles with
  - Primary vertex, non pileup
  - Charged
  - Originating from the beam pipe
  - pT >= 1 GeV, |eta| < 3
  - hits >= 7, pixel hits >= 3, pixel layer 1 hits >= 1
- Cutting on tracks with
  - measurements >= 7
  - matched / all measurements >= 50%
  - Using longest track with lowest chi2 sum

Impact parameter resolution

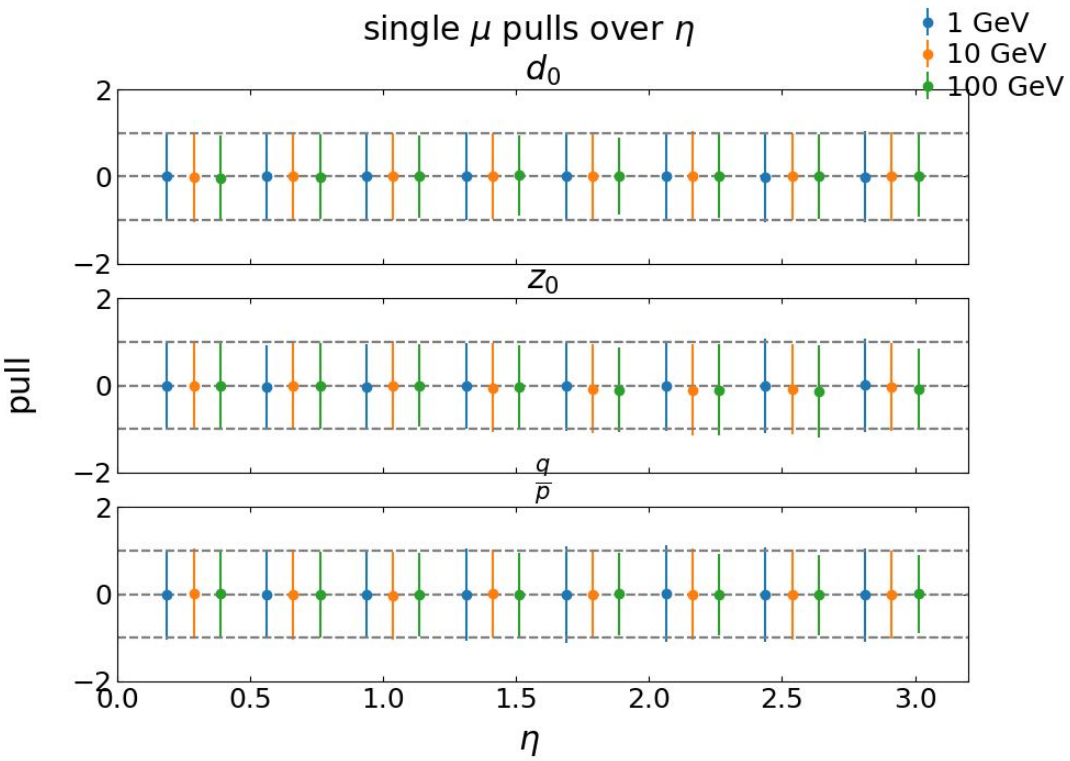




- Resolution given by standard deviation of parameter residuals
- ➢ Approaching intrinsic resolution limit for high-momentum

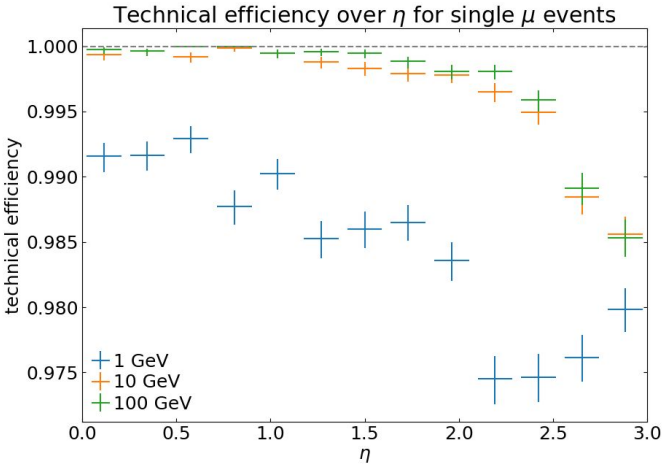
Pulls

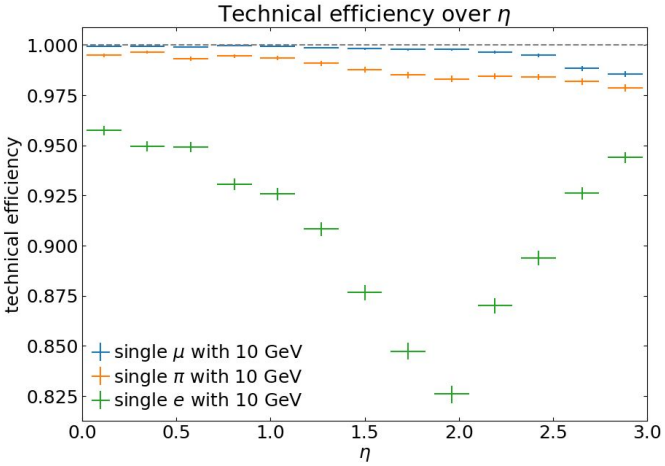
- Validates correct handling of uncertainties in reconstruction
- ➢ Good control of material effects and cluster uncertainties



Technical efficiency for single particles

- Technical efficiency = Reconstructible vs reconstructed particles
- ➢ Track finding under investigation to improve low pT and electron efficiencies
- ➢ Potential issues
  - Small search window
  - Navigation issues
- After potential electron tracks are found and identified as such they can be refitted using our GSF

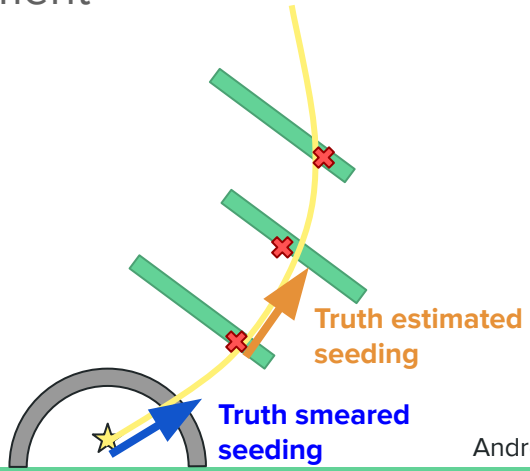




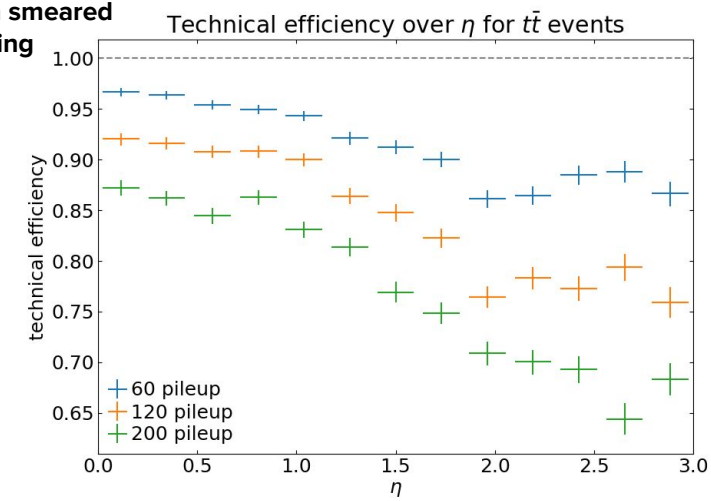
Technical efficiency for ttbar

- Strong PU dependency with truth smeared seeding
- Better results with truth estimated seeding

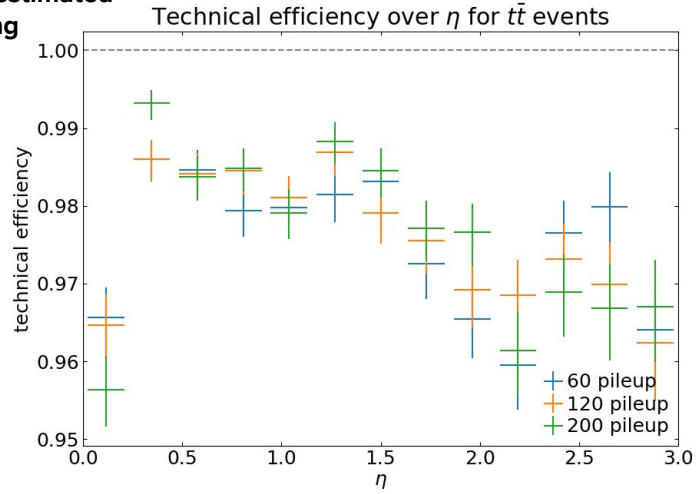
➢ Track finding easier when starting from measurement



Truth smeared seeding



Truth estimated seeding



Summary

- Established baseline track finding and fitting performance with Acts+ODD
- Good control over material effects, cluster uncertainties are handled correctly
- ➢ Viable R&D platform for tracking algorithm research

Outlook

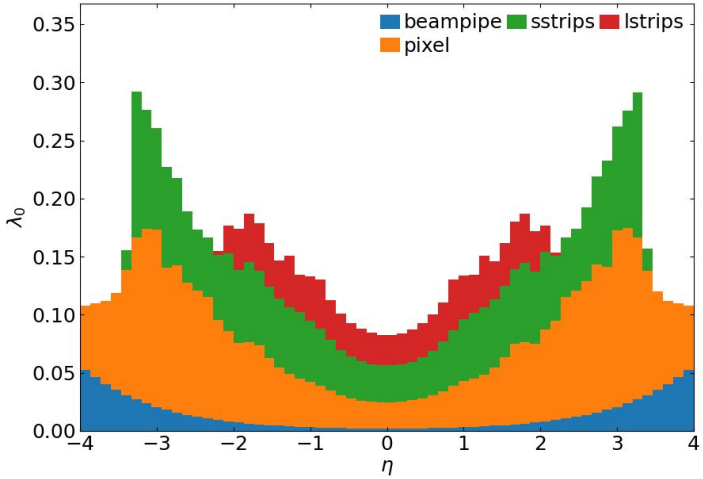
- Investigations to improve track finding efficiencies for small pT and electrons
- Extend study towards more realistic setup (digitization, seeding)
- Also: Include refitting, ambiguity resolution and vertexing performance

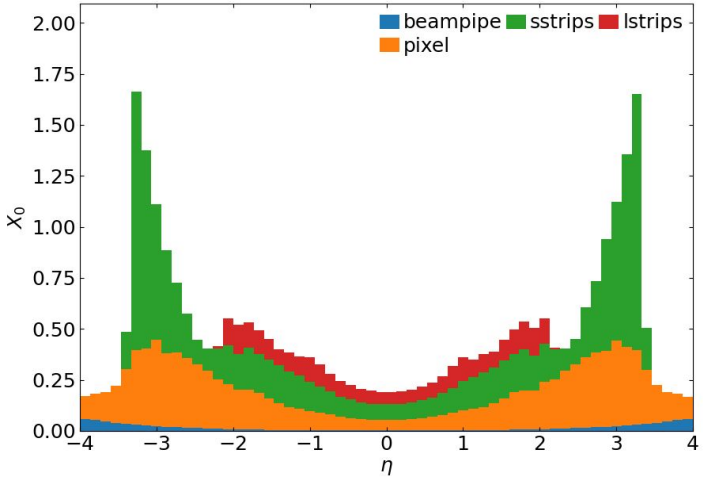
GitHub: https://github.com/andiwand/ctd-2023-acts-odd-performance

Backup

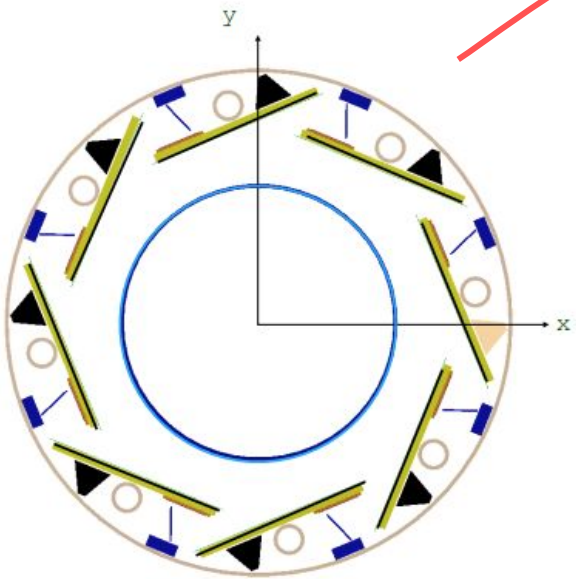
ODD Material

- ODD can be scanned using Geant4 to measure material amounts, λ_0, X_0 in different regions or directions
- Scans are used in Acts to map material on specific layers (CPU optimization)



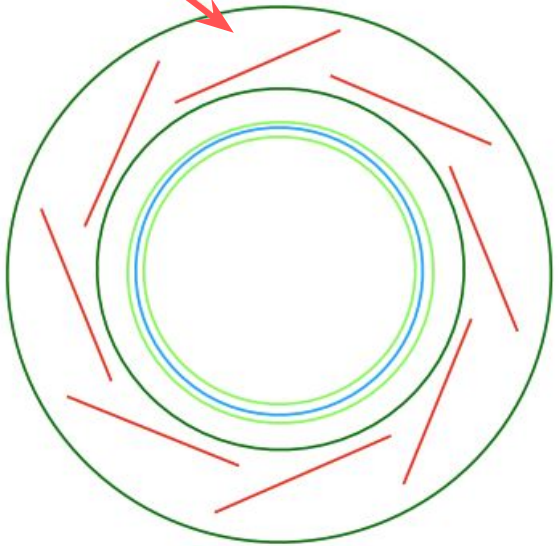


Tracking geometry



3D geometry model

(Plugin, e.g. GeoModel, DD4Hep, TGeo)



Acts tracking geometry

Truth seeding

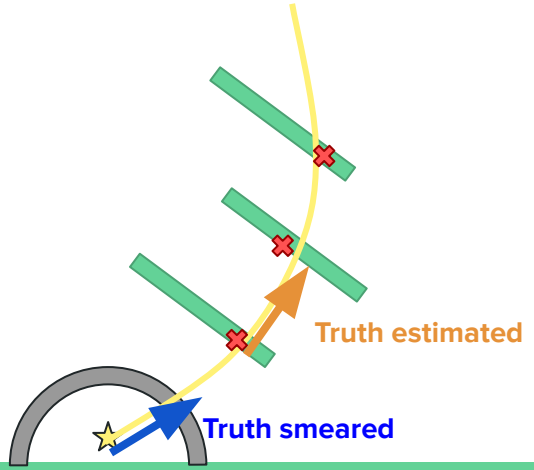
Truth smeared seeding

- Use truth parameters of particles origin
- Smear space, time, direction, momentum with gaussian noise
- Form a seed with smeared parameters and initial covariance

```
particleSmearingSigmas = ParticleSmearingSigmas(
    d0=20 * u.um,
    d0PtA=30 * u.um,
    d0PtB=0.3 / u.GeV,
    z0=20 * u.um,
    z0PtA=30 * u.um,
    z0PtB=0.3 / u.GeV,
    t0=1 * u.ns,
    phi=0.1 * u.degree,
    theta=0.1 * u.degree,
    pRel=0.01,
)
```

Truth estimated seeding

- Use truth hits to estimate track parameters at the first measurement
- Deduplicate by selecting the “best” parameters

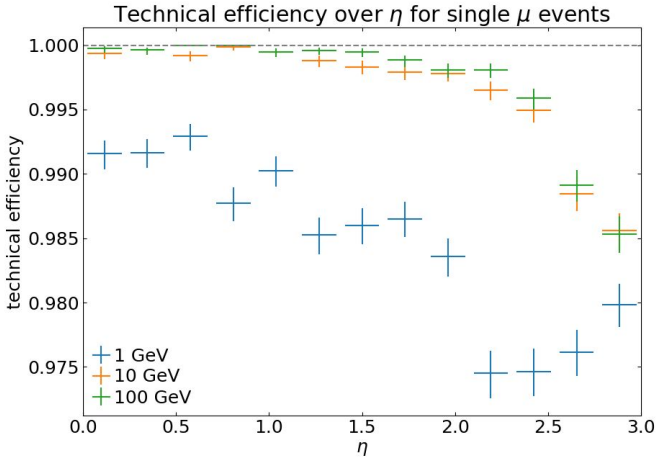


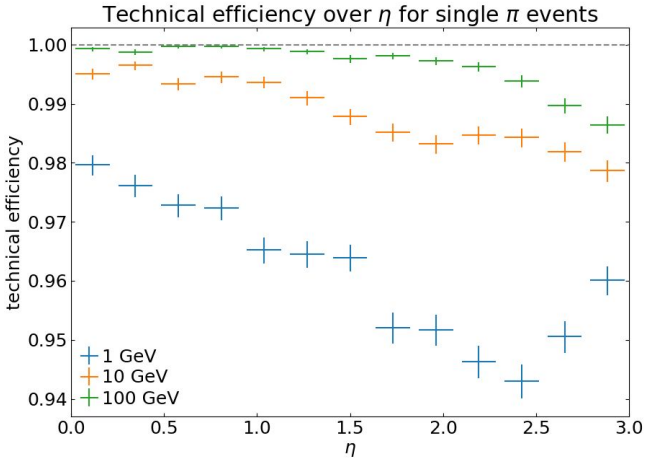
Initial covariance inflation

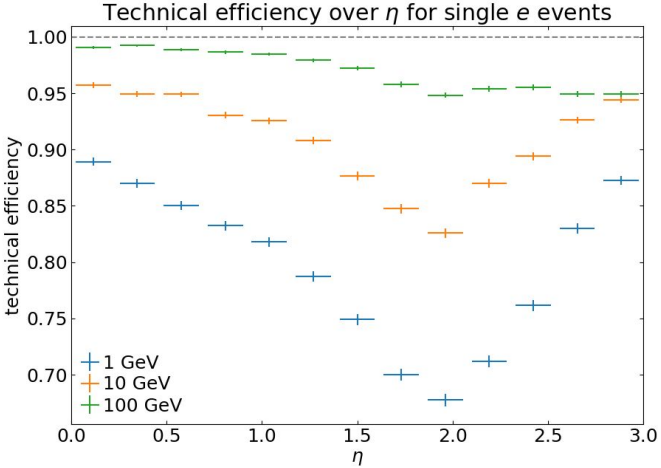
- Track fitting needs initial parameter covariance
- Seeding usually provides track parameters without covariance
- Track fitting can estimate the covariance best by providing a highly inflated initial covariance (numerical precision is the upper limit here)
- Track finding using CKF will encounter surfaces differently depending on the initial covariance (unintentional changes in direction is the upper limit here)
- Note: time is measured in mm/c with c=1 in Acts which sets this parameter on a different scale. This can lead to numerical imprecisions because of covariance matrix operations.

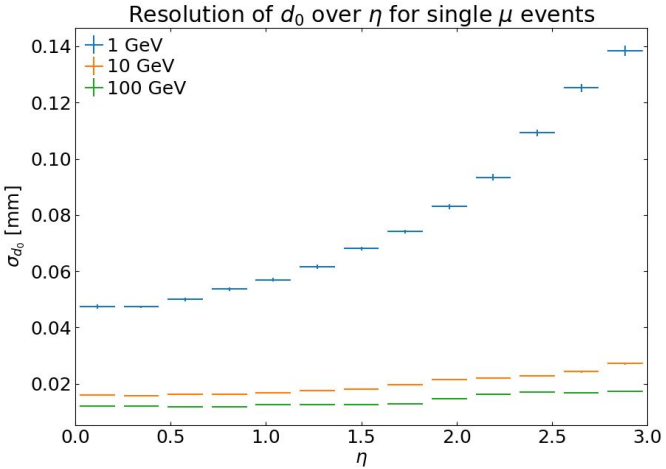
Simulation setup + Key Performance Indicators

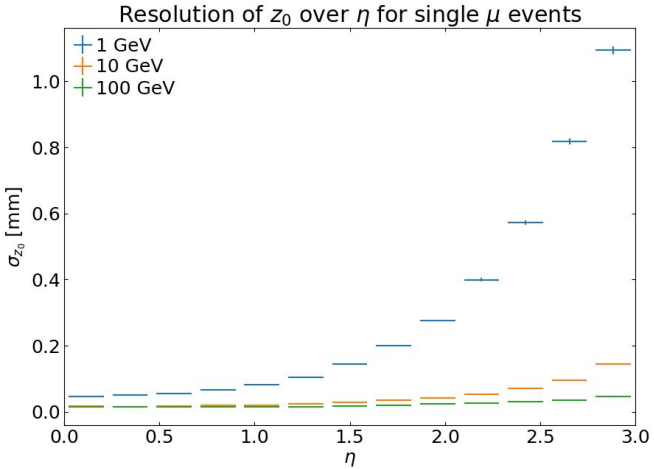
- Generated events
  - Single mu/pi/e with 1/10/100 pT and |eta| < 3 uniform using Particle Gun
  - Single particles with 1-100 pT uniform
  - ttbar with 60/120/200 pileup using Pythia8
- Detector simulation
  - Geant4
  - Smeared digitization
- Key Performance Indicators
  - Technical efficiency over eta
  - Residuals and pulls of d0/z0/qop over eta/pT

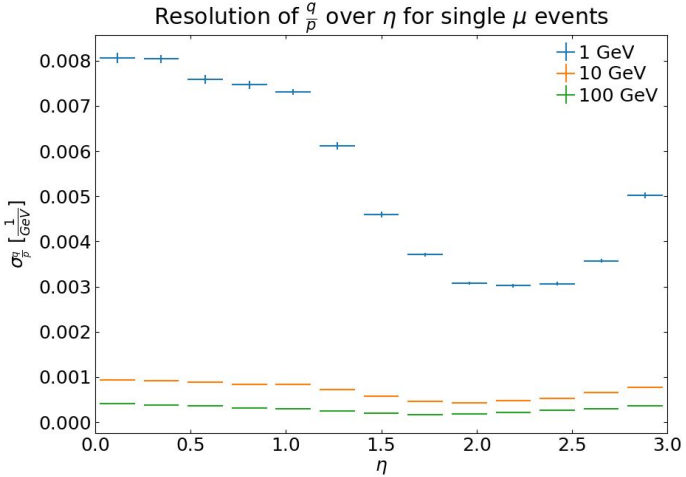

Technical efficiency over η for single μ events
technical efficiency
η
1 GeV
10 GeV
100 GeV

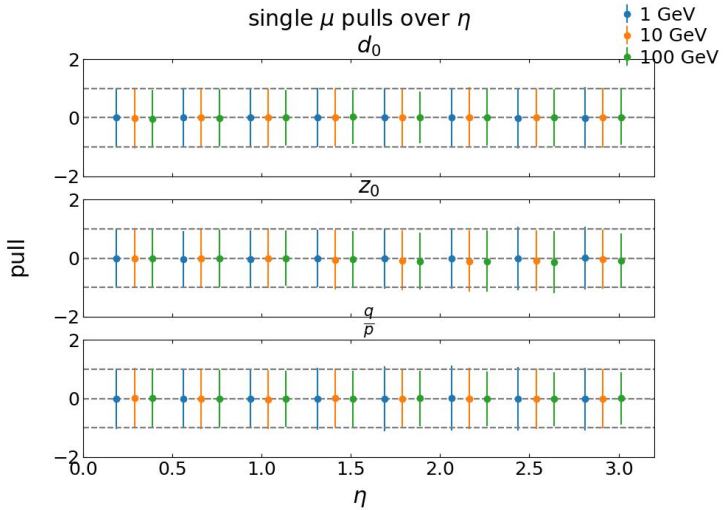

Technical efficiency over η for single π events
technical efficiency
η
1 GeV
10 GeV
100 GeV

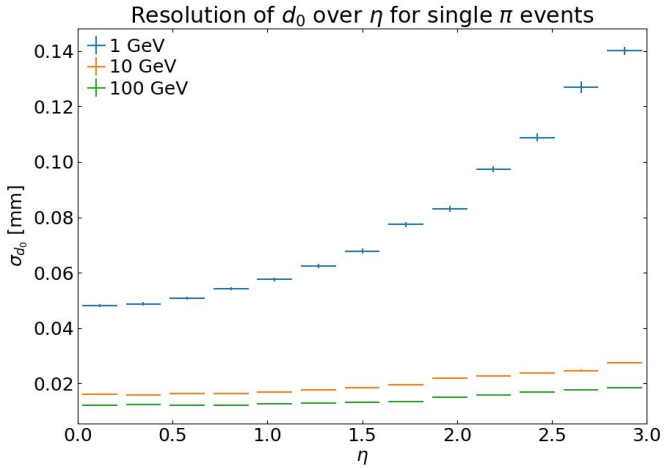

Technical efficiency over η for single e events
technical efficiency
η
1 GeV
10 GeV
100 GeV

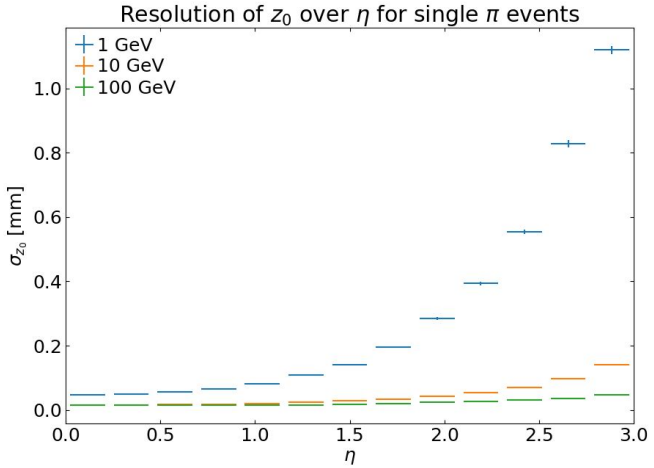

Resolution of d_0 over η for single μ events
1 GeV
10 GeV
100 GeV
σ_{d_0} [mm]
η

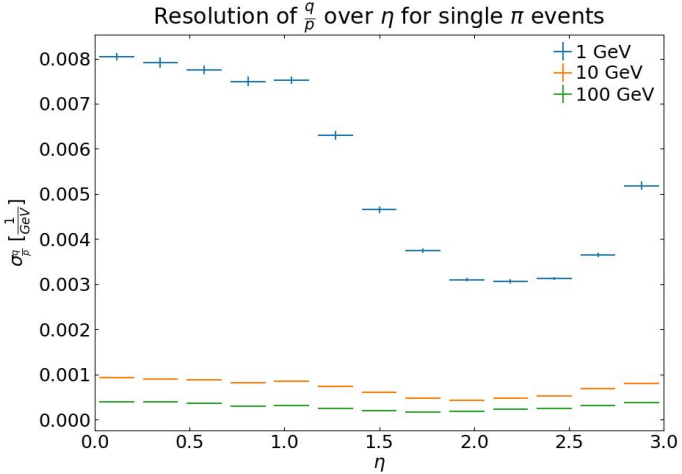

Resolution of z_0 over η for single μ events
1 GeV
10 GeV
100 GeV
σ_{z_0} [mm]
η

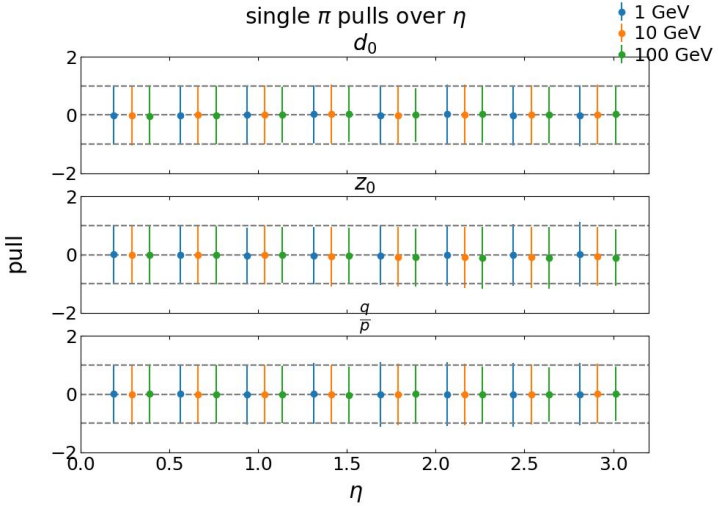

Resolution of $\frac{q}{p}$ over η for single μ events
1 GeV
10 GeV
100 GeV
$\sigma_{\frac{q}{p}}$ [$\frac{1}{GeV}$]
η

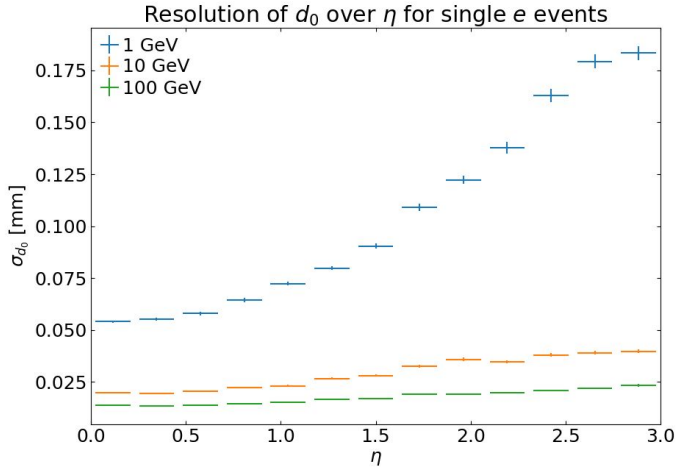

single μ pulls over η
1 GeV
10 GeV
100 GeV
d_0
z_0
$\frac{q}{p}$
pull
η

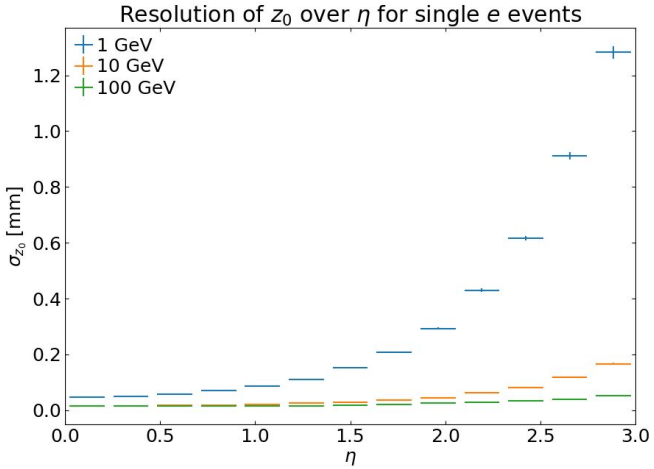

Resolution of d_0 over η for single π events
1 GeV
10 GeV
100 GeV
σ_{d_0} [mm]
η

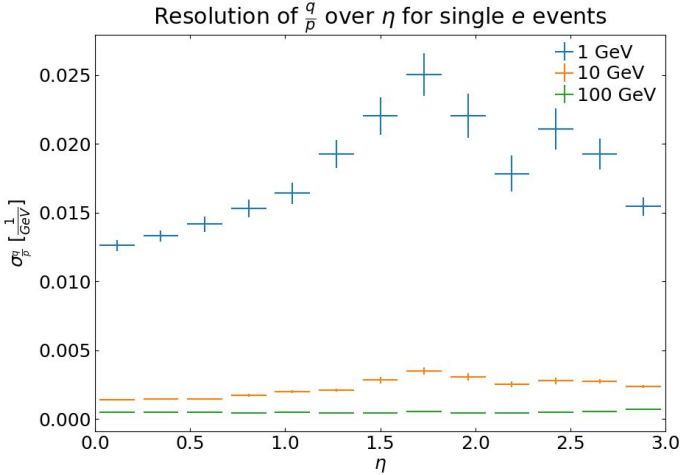

Resolution of z_0 over η for single π events
1 GeV
10 GeV
100 GeV
σ_{z_0} [mm]
η

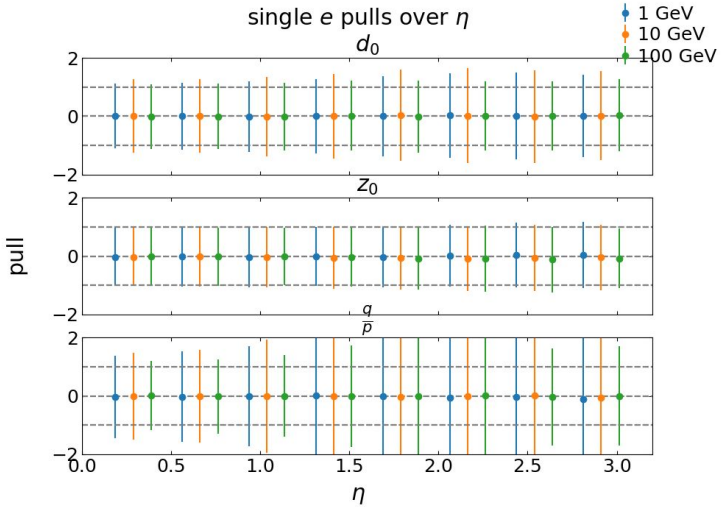

Resolution of $\frac{q}{p}$ over η for single π events
1 GeV
10 GeV
100 GeV
$\sigma_{\frac{q}{p}}$ $[\frac{1}{GeV}]$
η

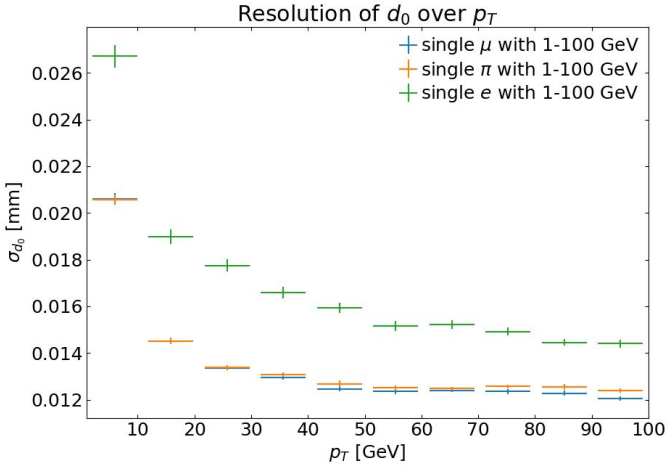

single π pulls over η
1 GeV
10 GeV
100 GeV
d_0
z_0
$\frac{q}{p}$
pull
η

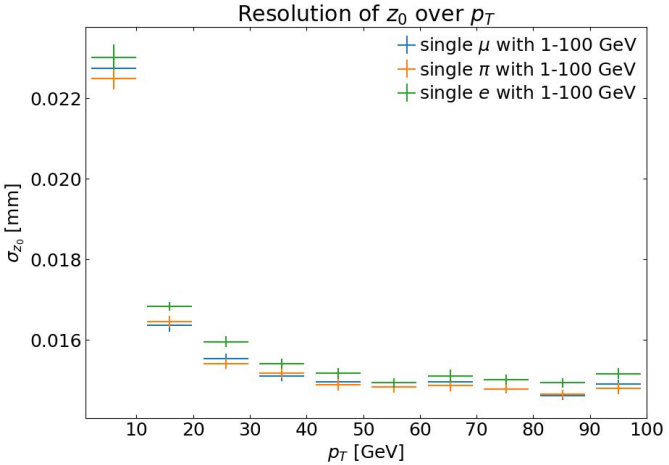

Resolution of d_0 over η for single e events
1 GeV
10 GeV
100 GeV
σ_{d_0} [mm]
η

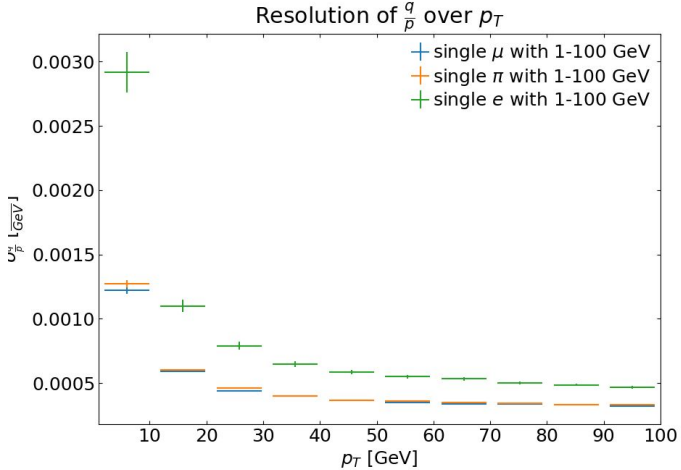

Resolution of z_0 over η for single e events
1 GeV
10 GeV
100 GeV
σ_{z_0} [mm]
η


Resolution of $\frac{q}{p}$ over η for single e events
1 GeV
10 GeV
100 GeV
$\sigma_{\frac{q}{p}}$ [$\frac{1}{GeV}$]
η

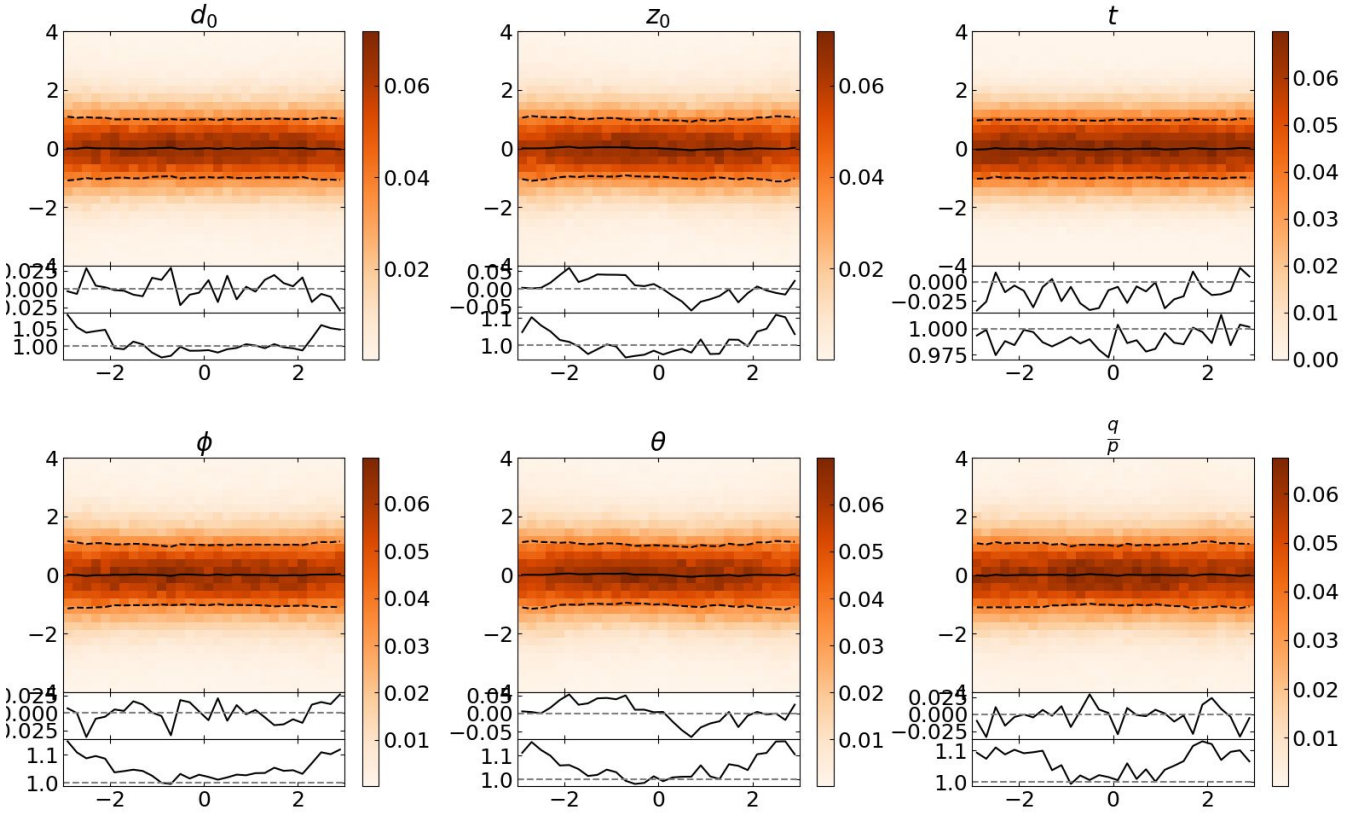

single e pulls over η
1 GeV
10 GeV
100 GeV
d_0
z_0
$\frac{q}{p}$
pull
η


Resolution of d_0 over p_T
single μ with 1-100 GeV
single π with 1-100 GeV
single e with 1-100 GeV
σ_{d_0} [mm]
p_T [GeV]

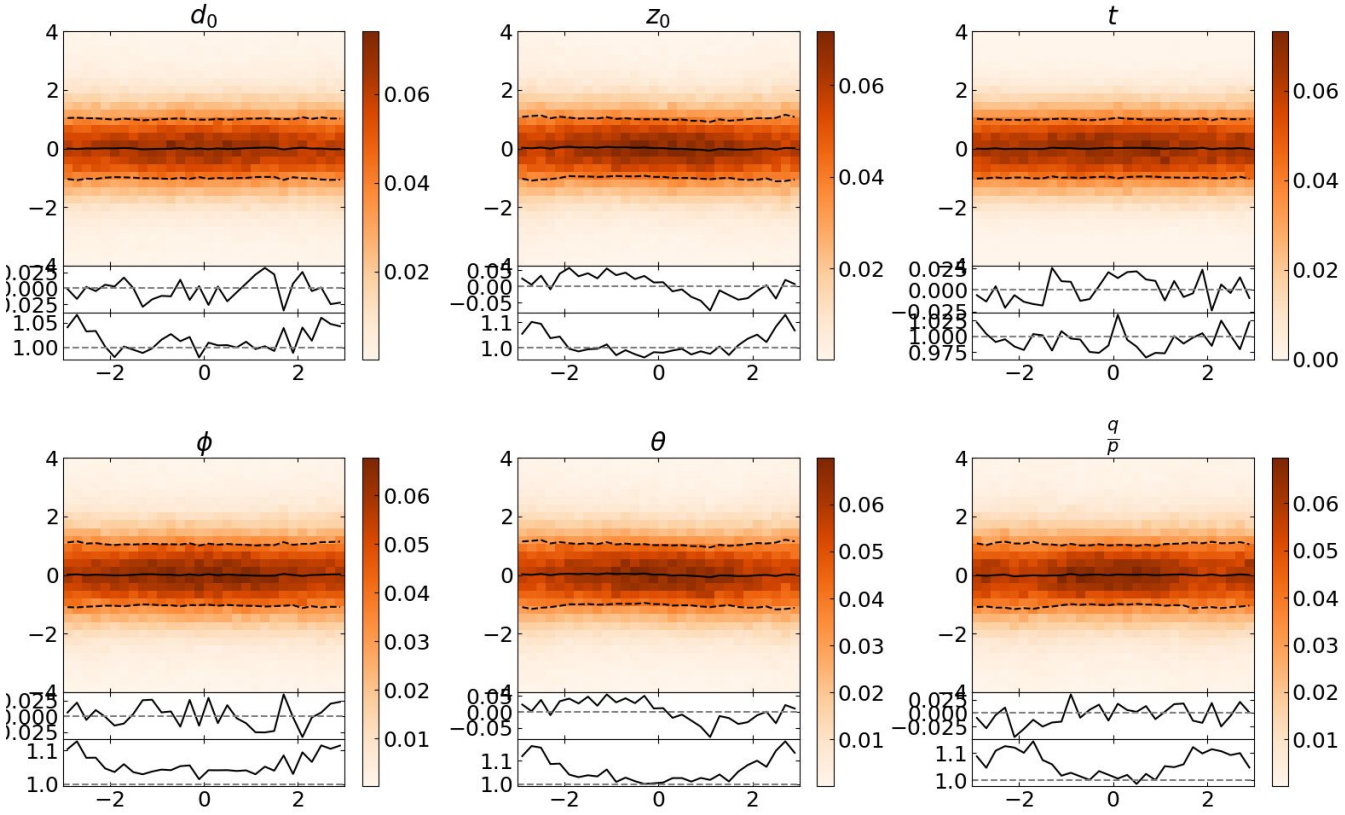

Resolution of z_0 over p_T
single μ with 1-100 GeV
single π with 1-100 GeV
single e with 1-100 GeV
σ_{z_0} [mm]
p_T [GeV]


Resolution of $\frac{q}{p}$ over p_T
single μ with 1-100 GeV
single π with 1-100 GeV
single e with 1-100 GeV
p_T [GeV]

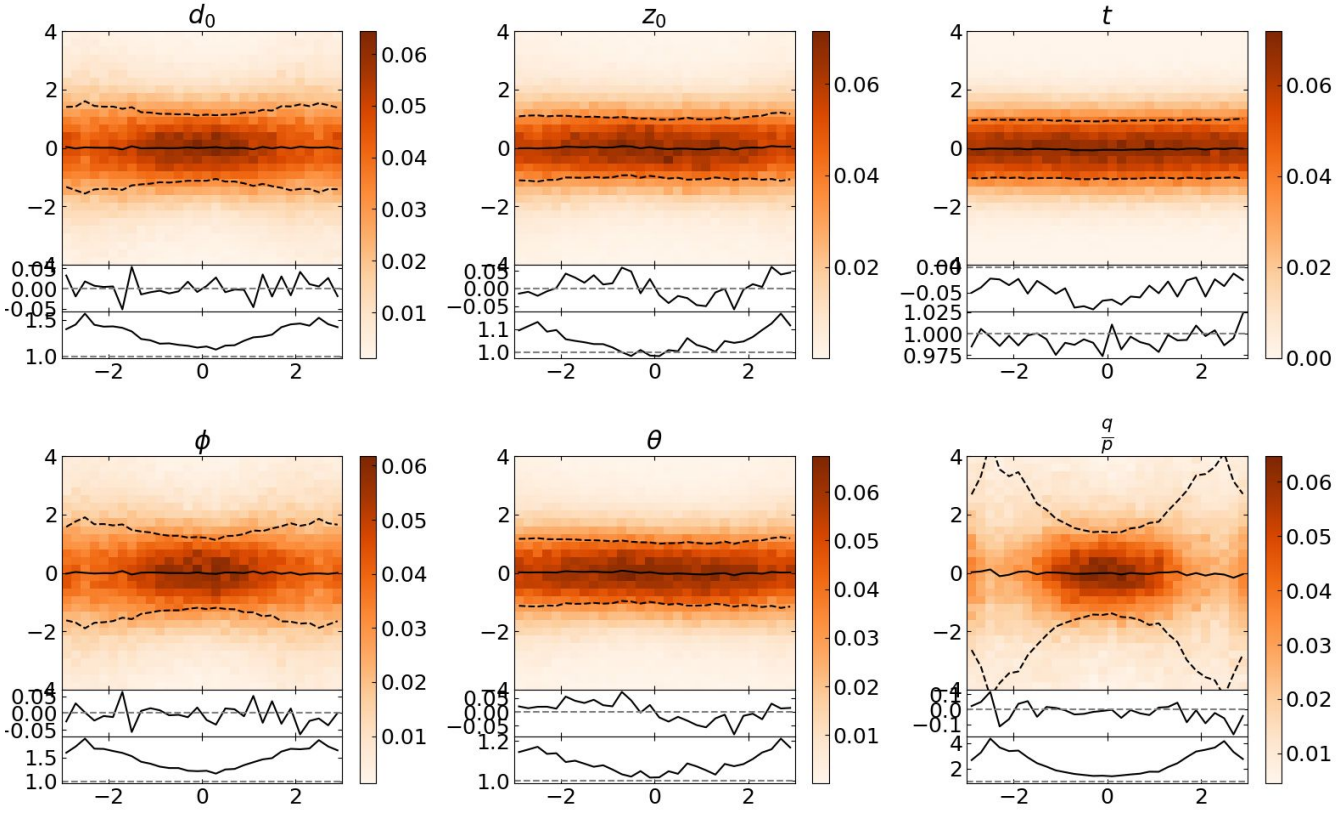
Single muon pulls 1 GeV pT



Single pion pulls 1 GeV pT



Single electron pulls 1 GeV pT



Refitting electrons

- After potential electron tracks are found and identified as such they can be refitted using our GSF
- This results in better resolutions as bremsstrahlung is included in the fitter model