Analyzing ePIC Tracking Performance with and without Beam-related background via Agentic Workflow

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Condition

Detector Configuration: epic_craterlake

Campaign: 26.07.1

Collision type: /DIS/NC/

Energy: 10 GeV x 100 GeV

Event configurations:

- 300 clean files (26.07.1, minQ2=1): 300K ep collisions
- 500 background files (26.07.1, minQ2=1): 50K ep collisions

Every metric is computed separately in each 3-D bin (Binned in truth quantities):

- p in 8 log-spaced bins (0.1–20 GeV),
- 5 species (e±, π±, K±, p, $\bar{p}$).
- Barrel (|eta|<1.5 and 1.0), backward endcap (-4.0<eta<-1.5) and forward endcap (1.5<eta<4.0)

Criteria:

- a reco track counts as matched to a truth particle only if > 50% of its hits came from that particle (the CentralCKFTrackAssociations.weight majority rule).
  - Below that it's combinatorics, and the fake-rate metric counts it as fake.
- Any bin with fewer than 50 raw entries is reported as insufficient stats.

INPUT COLLECTIONS

TRUTH REFERENCE (all metrics)

- *MCParticles* — PDG, generatorStatus, momentum.x/y/z, mass

→ truth pT/η, species, primary-particle filter

TRUTH HITS via _<Collection>_particle.index (acceptance & efficiency)

- Track in acceptance if **Nhits>=4 && N(si hits)>=3**
- **Same condition** for fake rate and resolution

RECONSTRUCTION (efficiency, resolution, fake rate)

- *CentralCKFTrackParameters* — qOverP, theta, phi → track momentum, p = 1/|qOverP|
- *CentralCKFTracks* — charge, pdg, chi2, ndf (pdg = reconstructor's mass hypothesis for PID confusion)

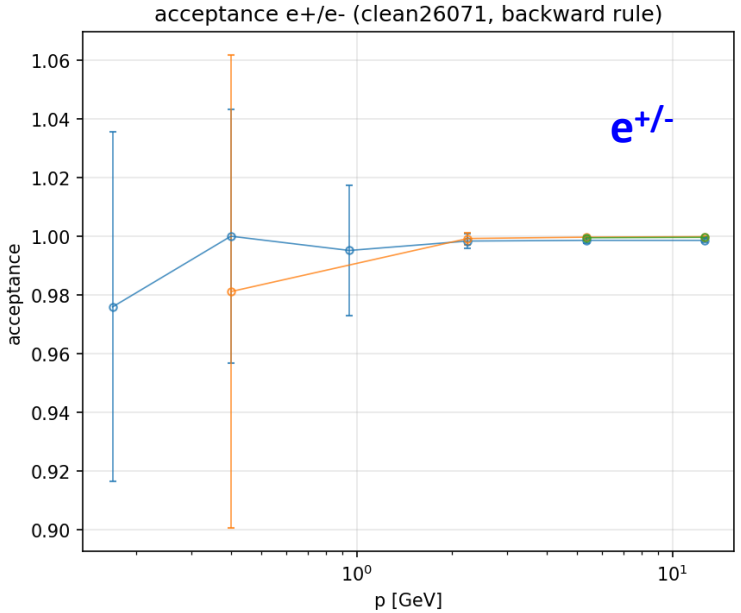
TRUTH–RECO MATCHING (efficiency, resolution, fake rate)

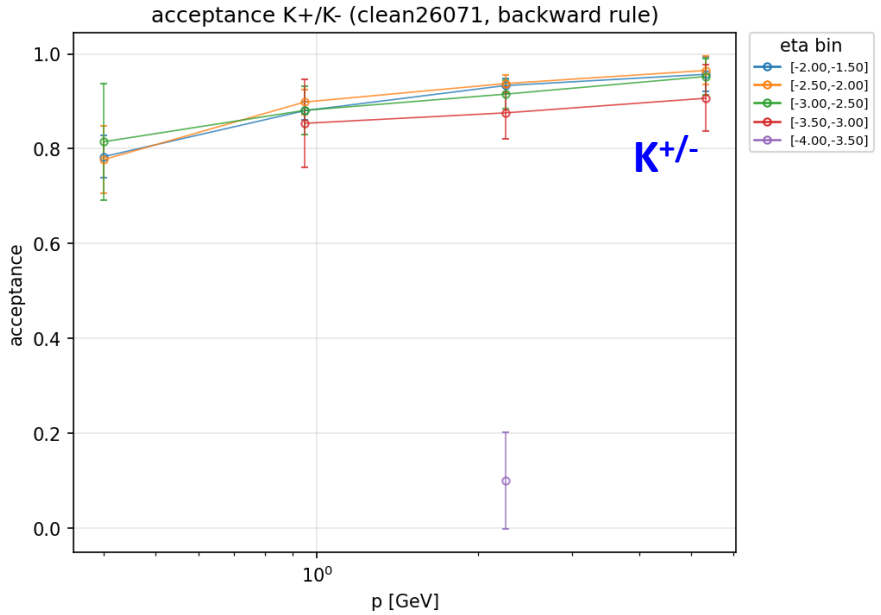
- *CentralCKFTrackAssociations* — weight, rec.index, sim.index → genuine match at weight **> 0.5**

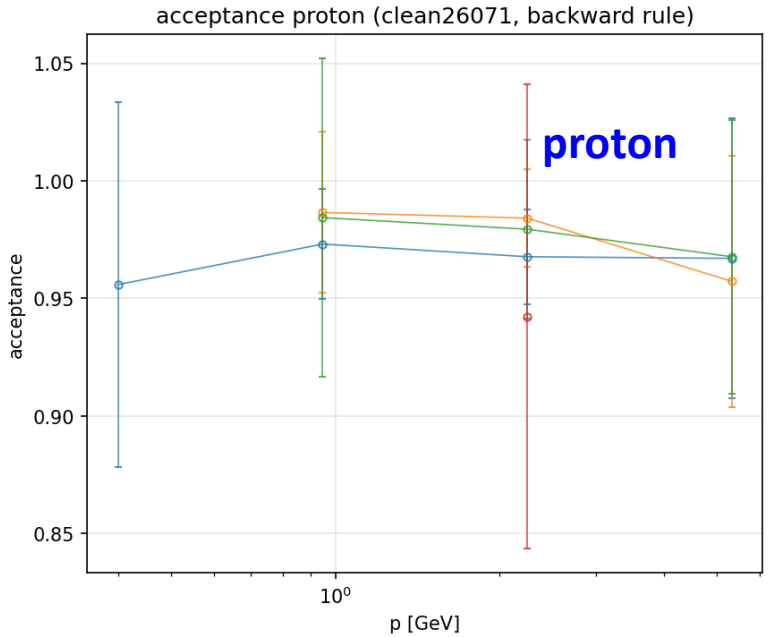
BY METRIC

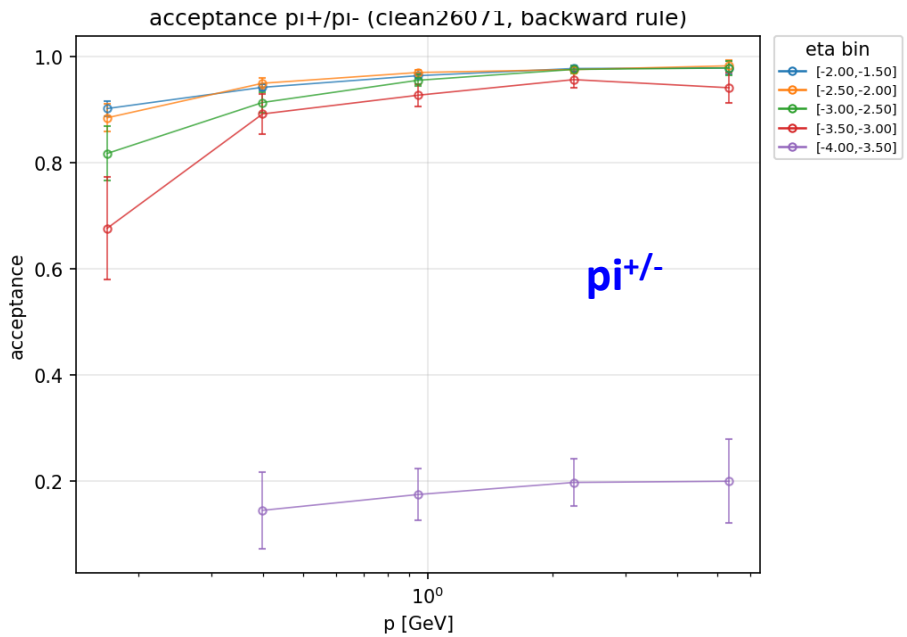
- Acceptance ..... truth + hits only (no matching)
- Efficiency ..... truth + hits + tracks + parameters + associations
- Resolution, fake rate . truth + tracks + parameters + associations

Geometric acceptance: backward endcap (-4.0<η<-1.5)





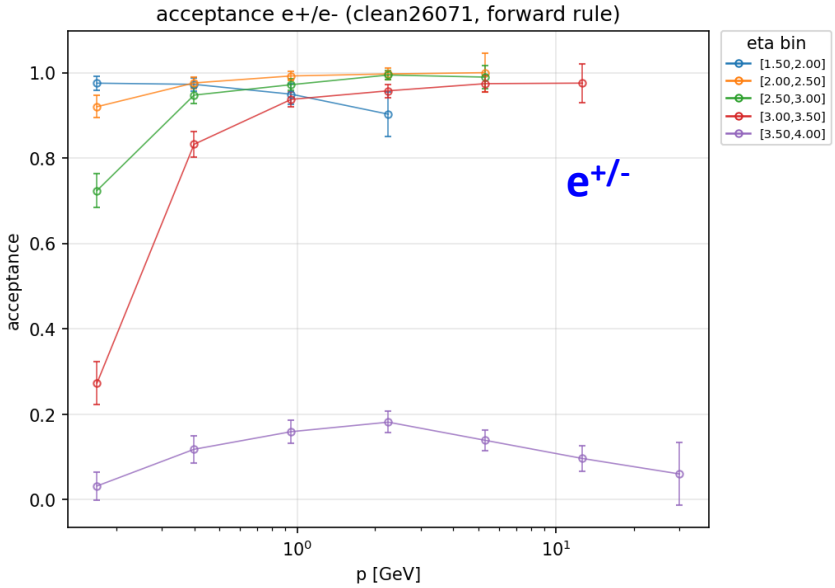


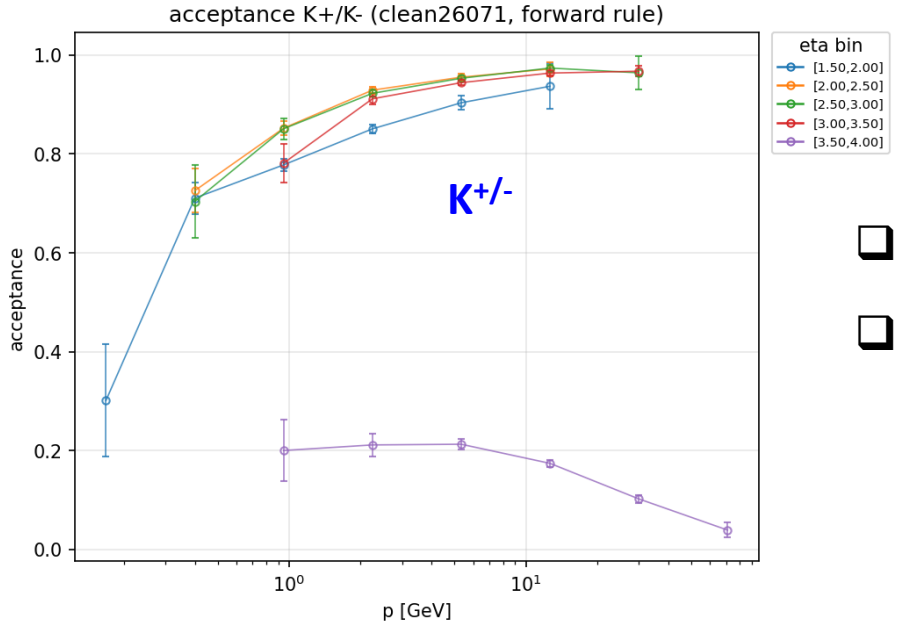


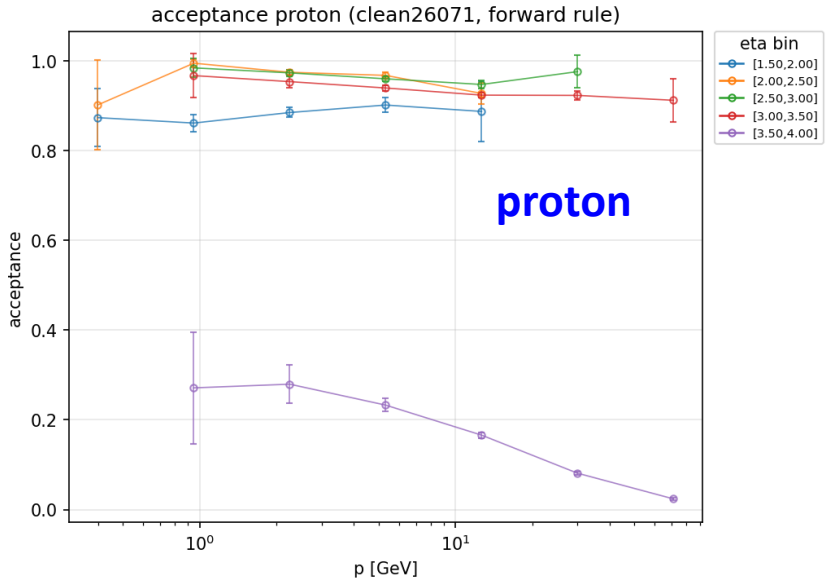
$$\alpha = \frac{N(in\ acc)}{N(gen)}$$

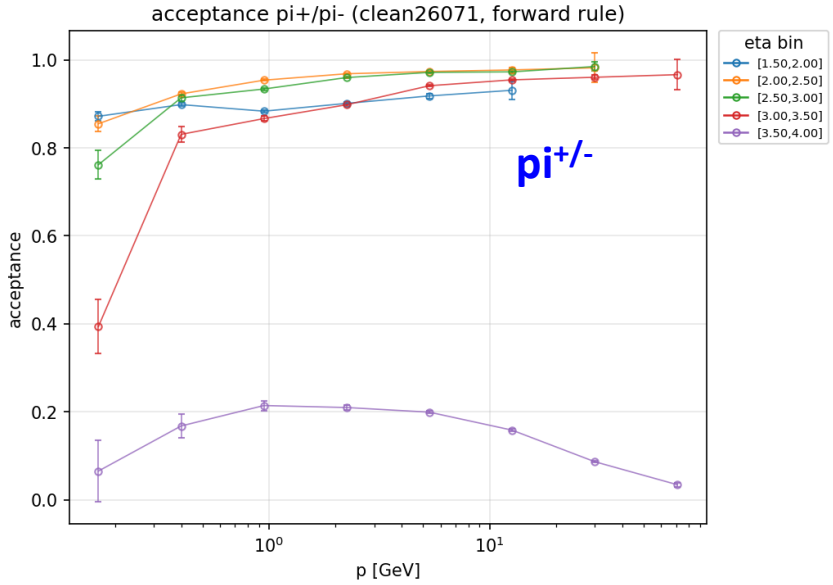
- From events **without** background
- Similar in -3.0 < η <-1.5.
- Slightly lower in [-3.5, -3.0] & significant drop in η > -3.5
  - slip through the beam-pipe-side cutouts hole, which is to accommodate beam pipe.

Geometric acceptance: Forward endcap (1.5<η<4.0)





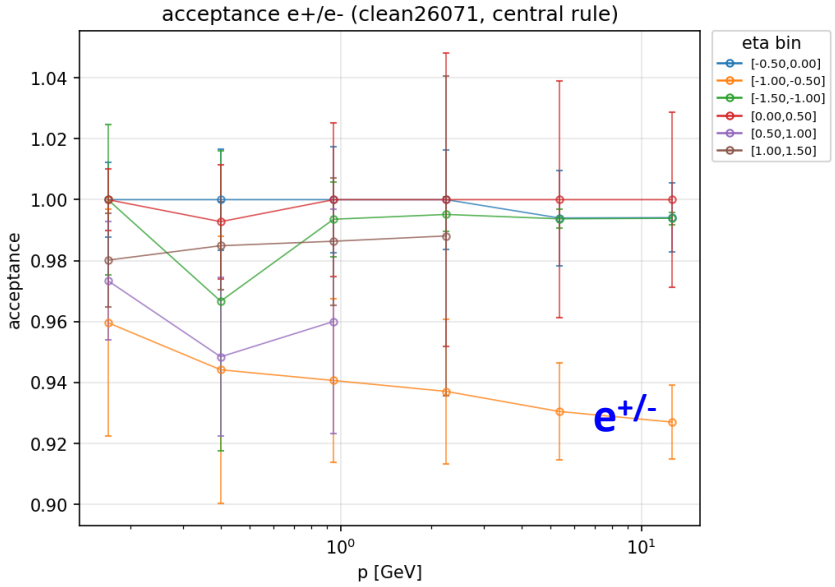


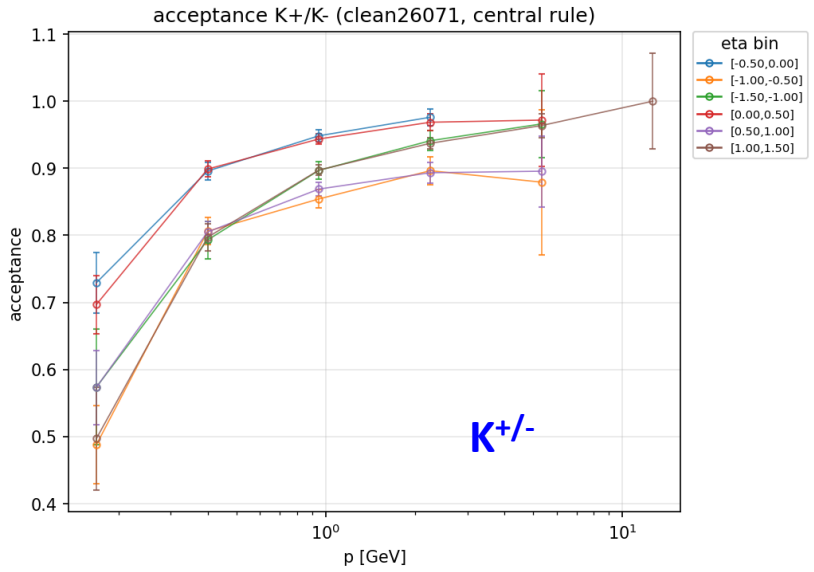


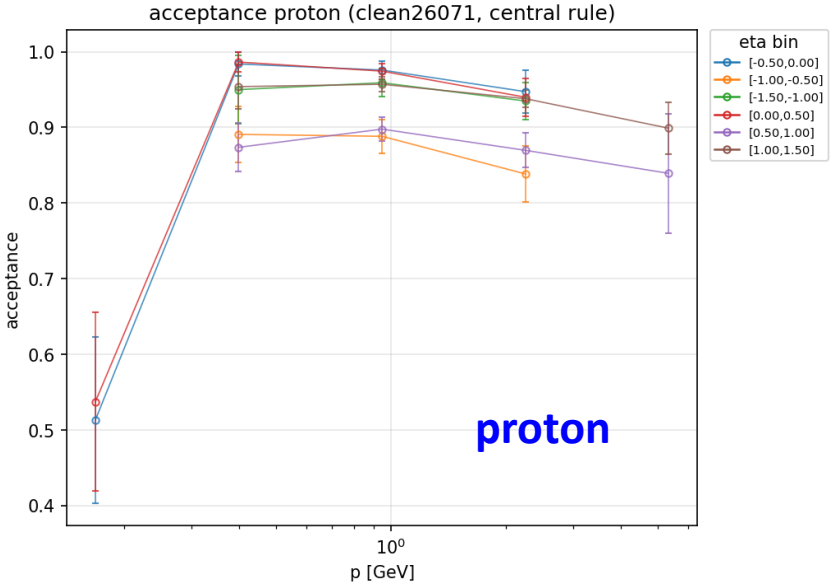
$$\alpha = \frac{N(in\ acc)}{N(gen)}$$

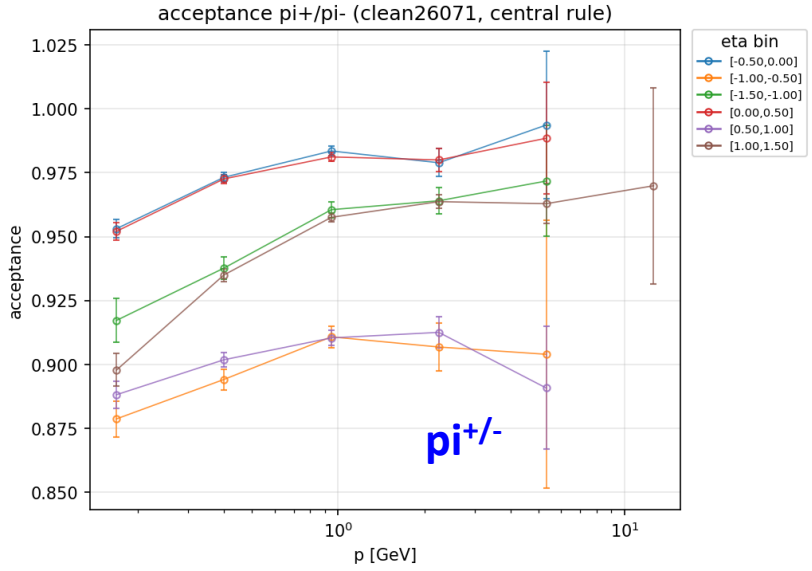
- ❑ Acceptance peaks in [2.0, 3.0]
- ❑ Smaller acceptance in the other region.
  - barrel↔forward transition gap
    - graze the outer edges of the backward disks
  - slip through the beam-pipe-side cutouts hole, which is to accommodate beam pipe.

Geometric acceptance: Central Region(|η|<1.5)





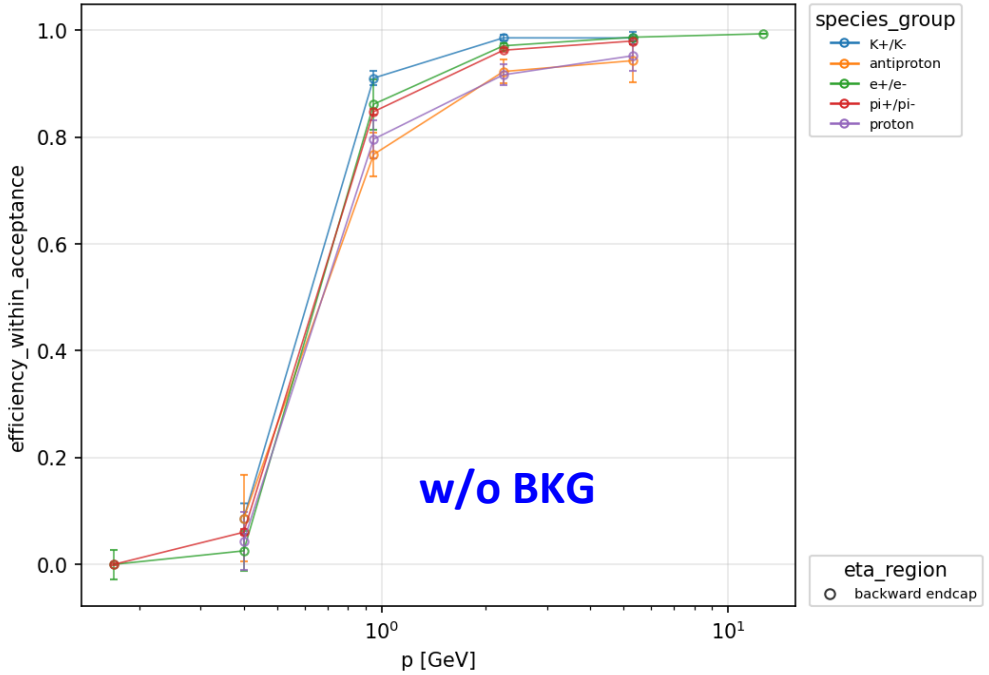


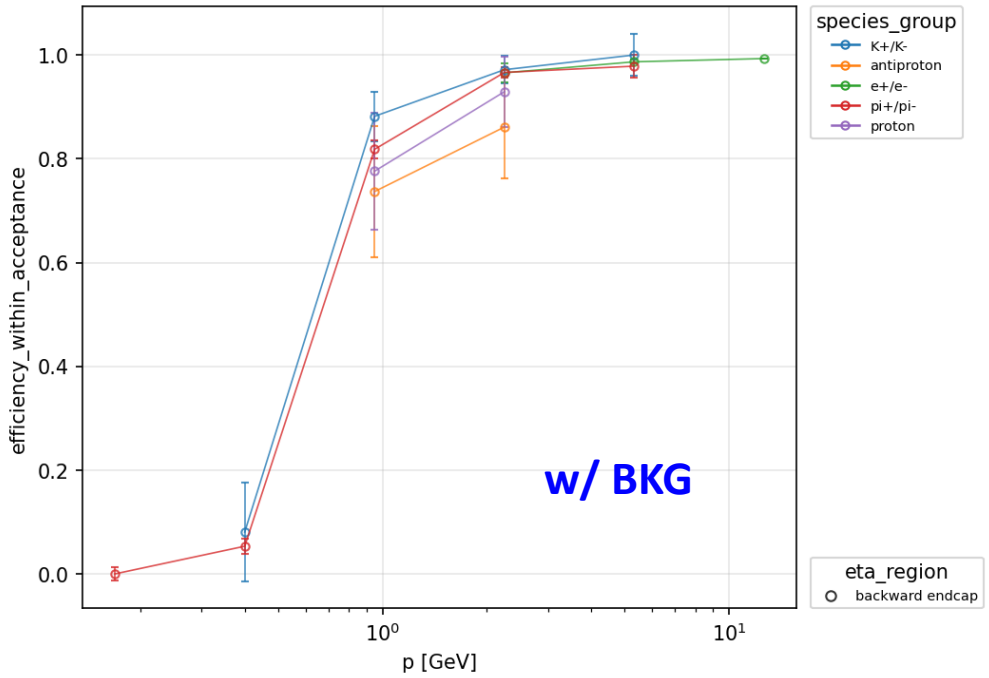


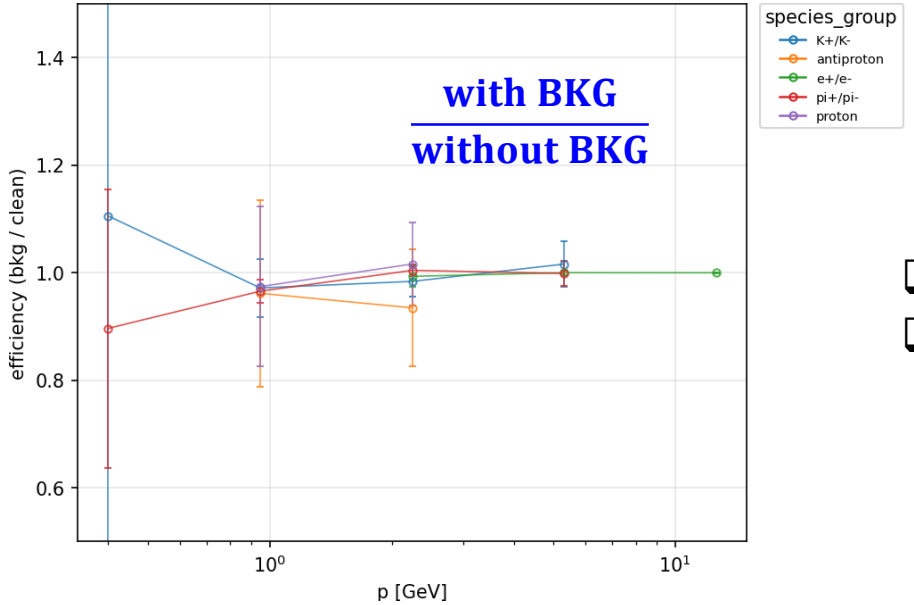
$$\alpha = \frac{N(in\ acc)}{N(gen)}$$

- The dip at 0.5<|η|<1.0 is a detector-geometry seam (symmetric in ±η)
  - Less possibility for Nhit(barrel si)>3
- The rise at |η| = 1.0-1.5: Nhit(barrel+endcap si) >= 3
- p dependence due to particle decays, dE/dx and hadronic interactions
  - Higher cross section for proton→lowers towards higher momentum (?)

Reco Efficiency: backward endcap (-4.0<η<-1.5)



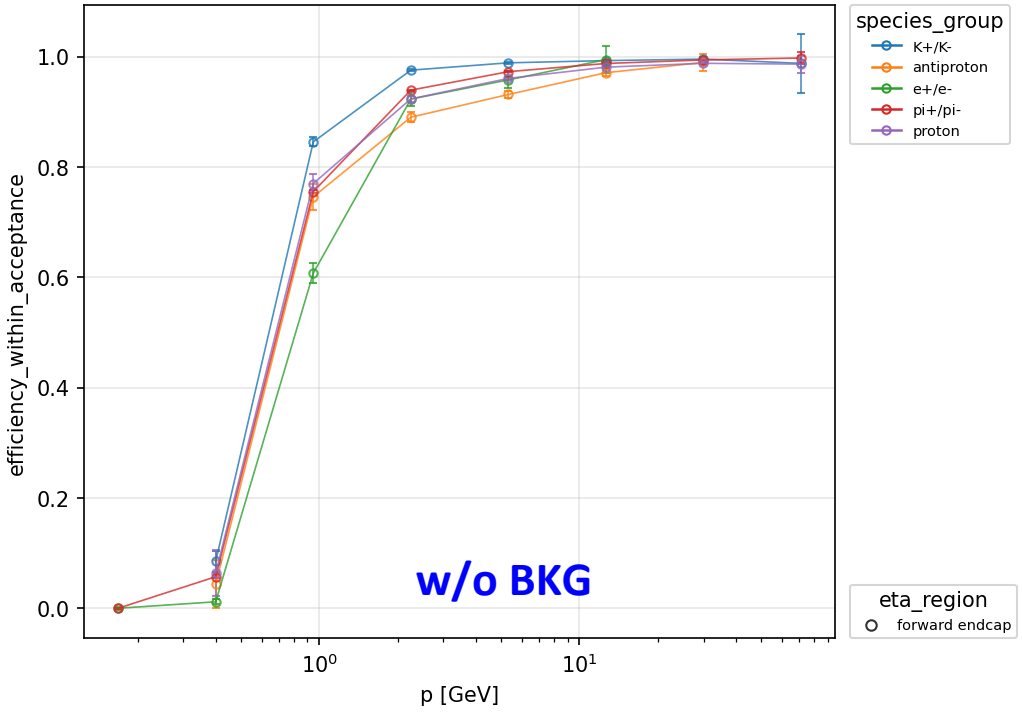


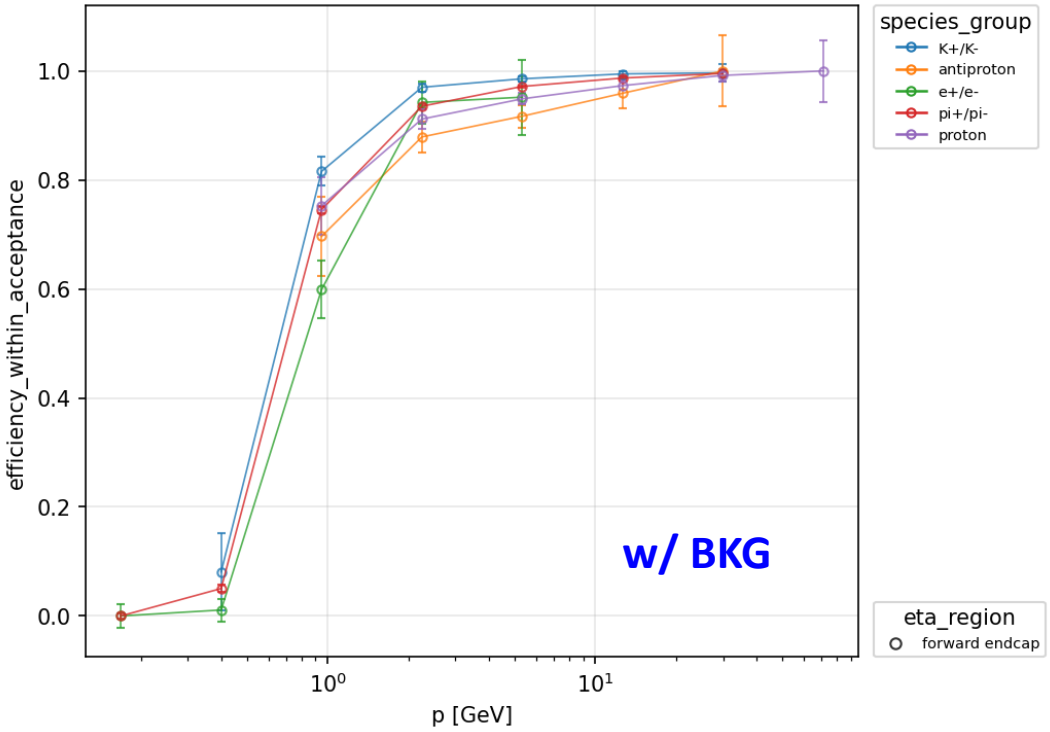


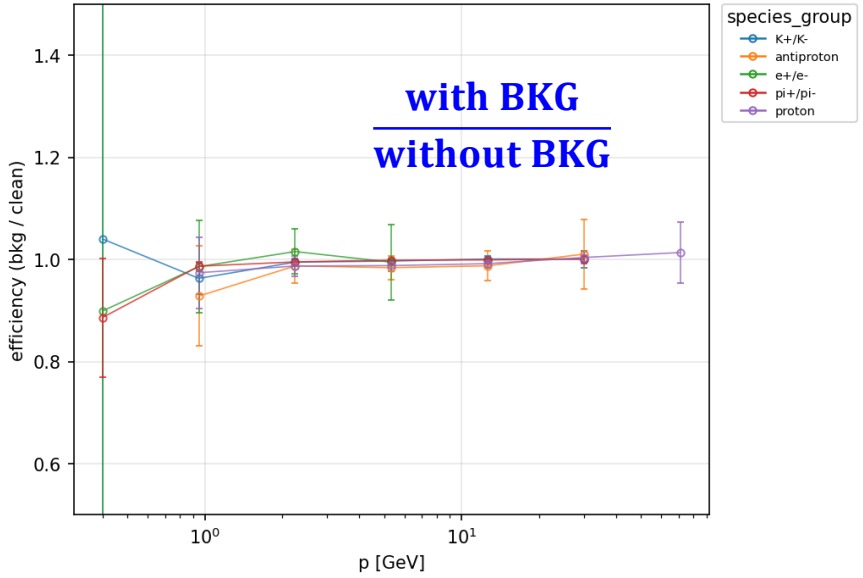
$$\varepsilon = \frac{N(reco\ matched: in-accp)}{N(gen: in-accp)}$$

- Beam-related background has **little effects** on reco efficiency
- In low pT region:
  - K/pi: decay in-flight.
  - p/pbar: dE/dx

Reco Efficiency : Forward endcap (1.5<η<4.0)







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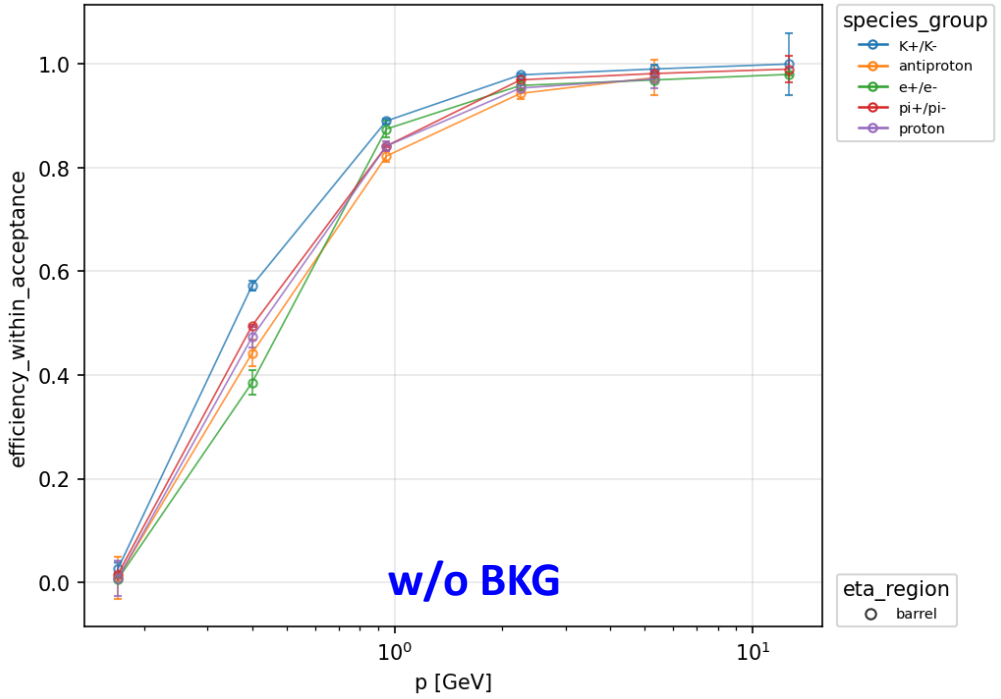
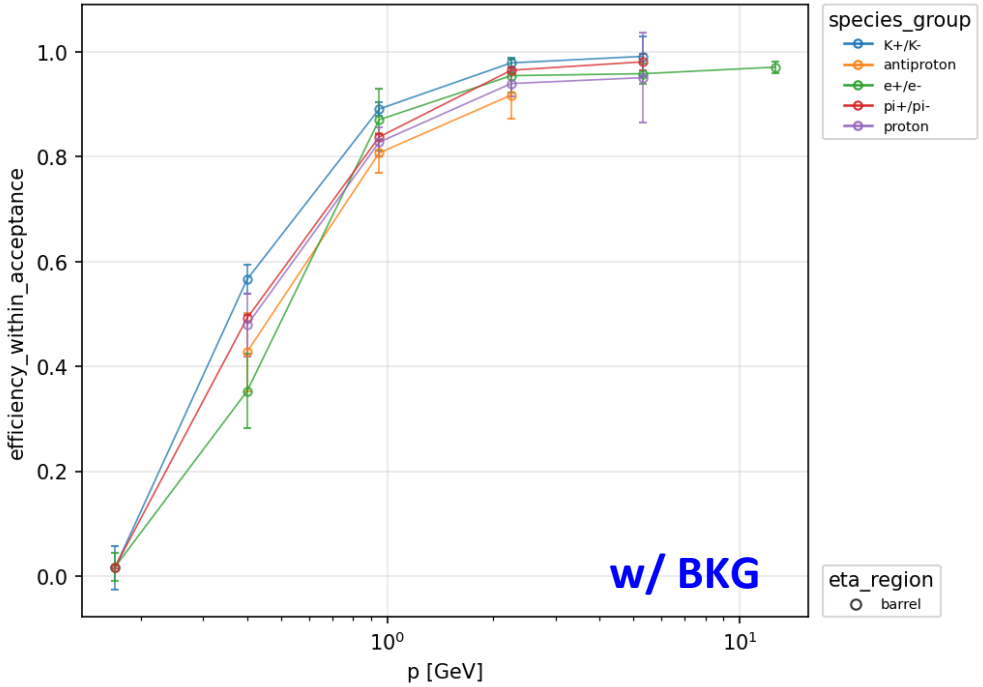
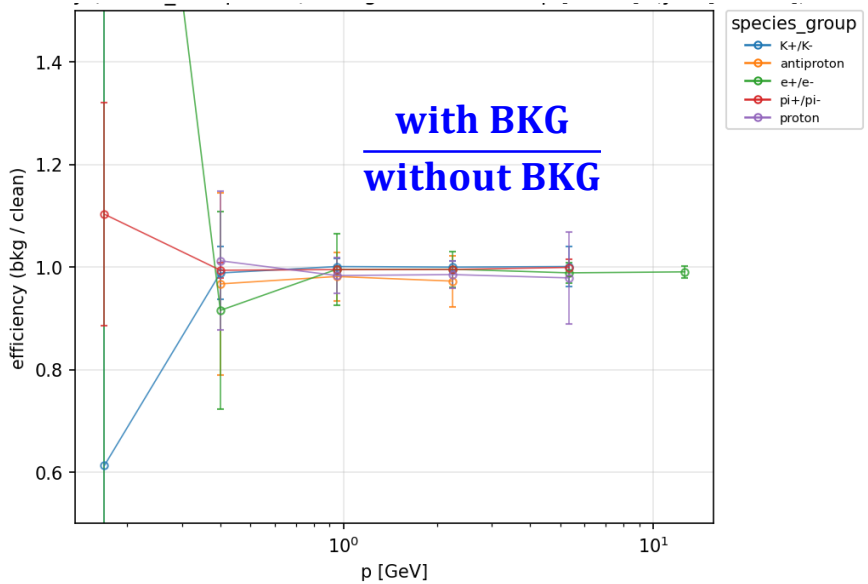
Reco Efficiency: Central Region (|η|<1.5)







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- ❑ Beam-related background has **little effects** on reco efficiency
- ❑ In low pT region:
  - K/pi: decay in-flight.
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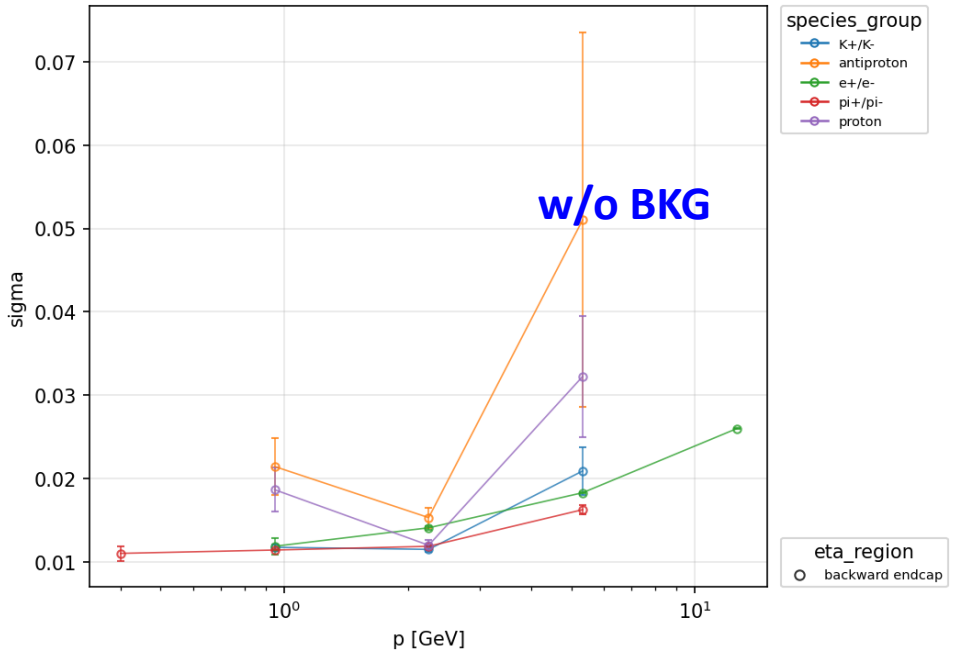
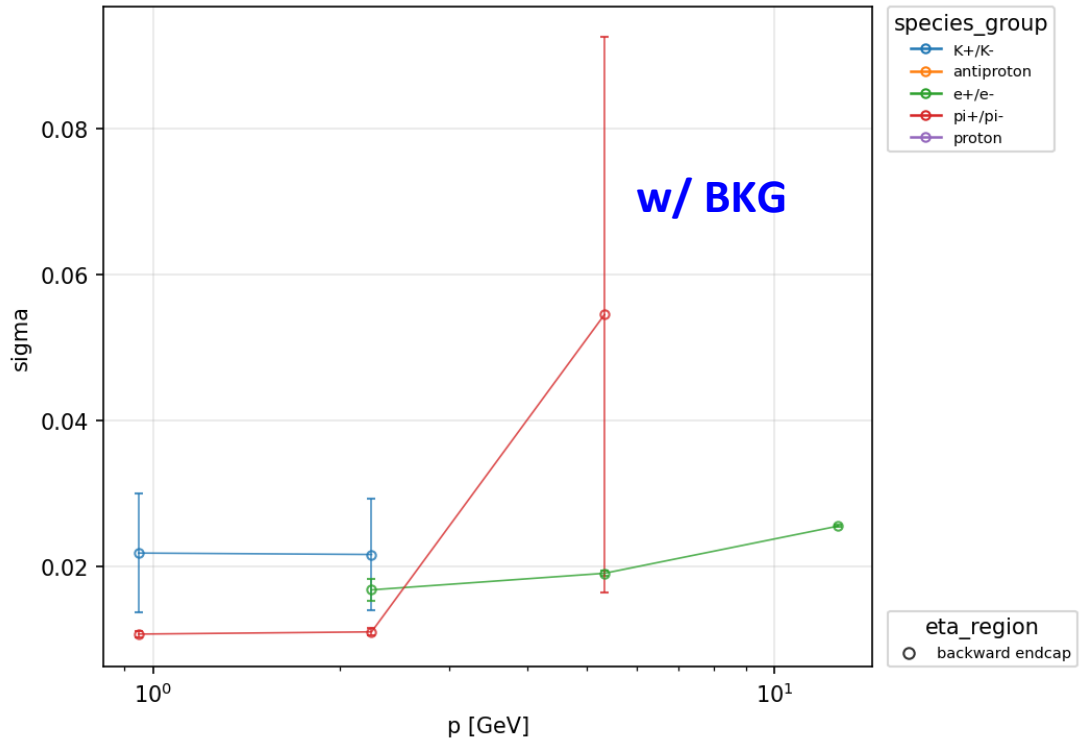
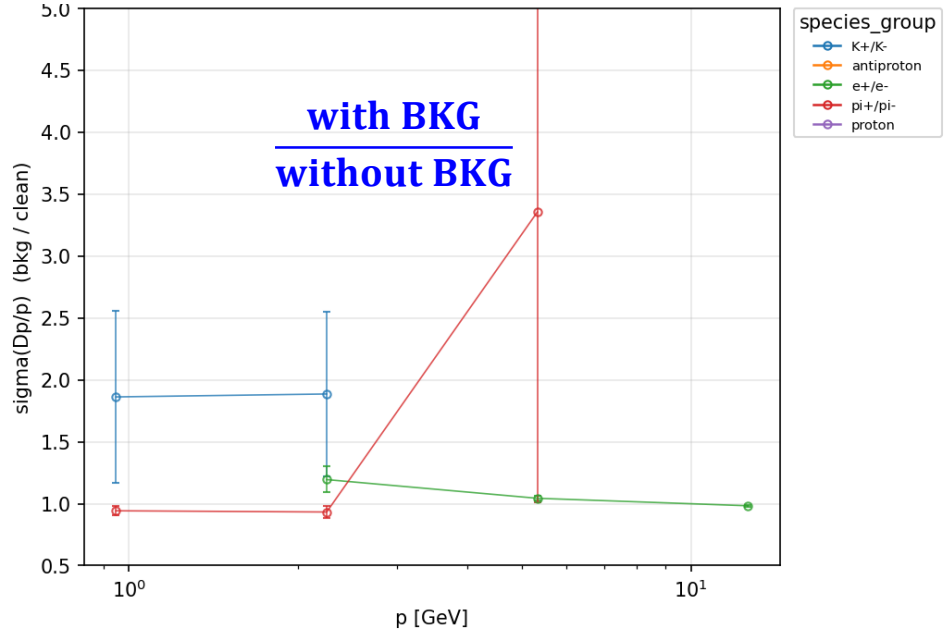
p resolution: backward endcap (-4.0<η<-1.5)



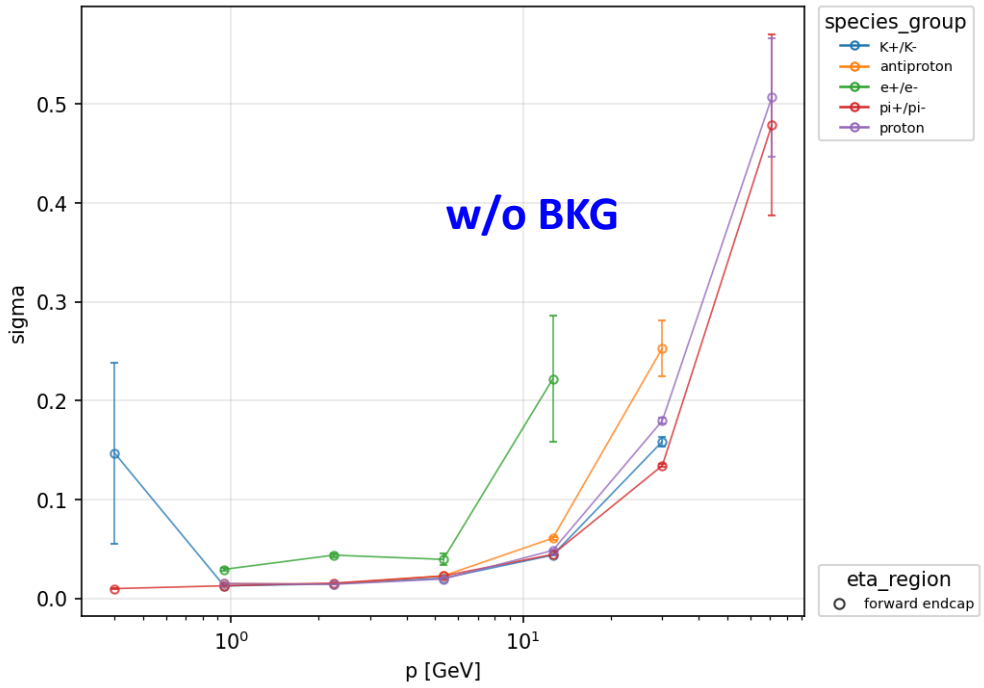


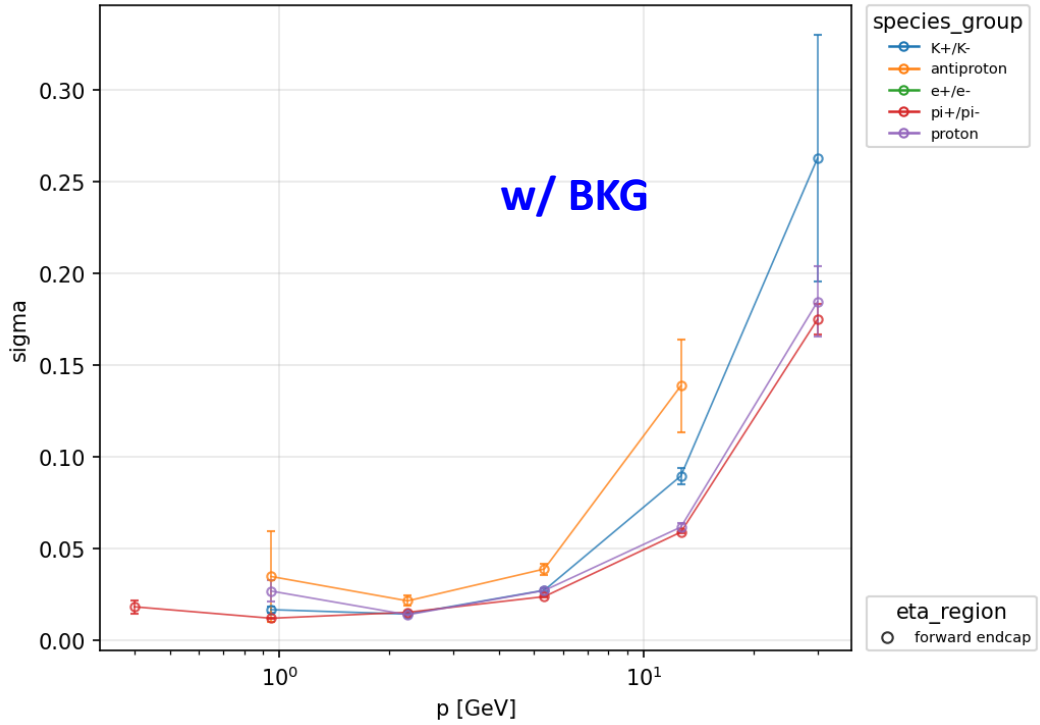


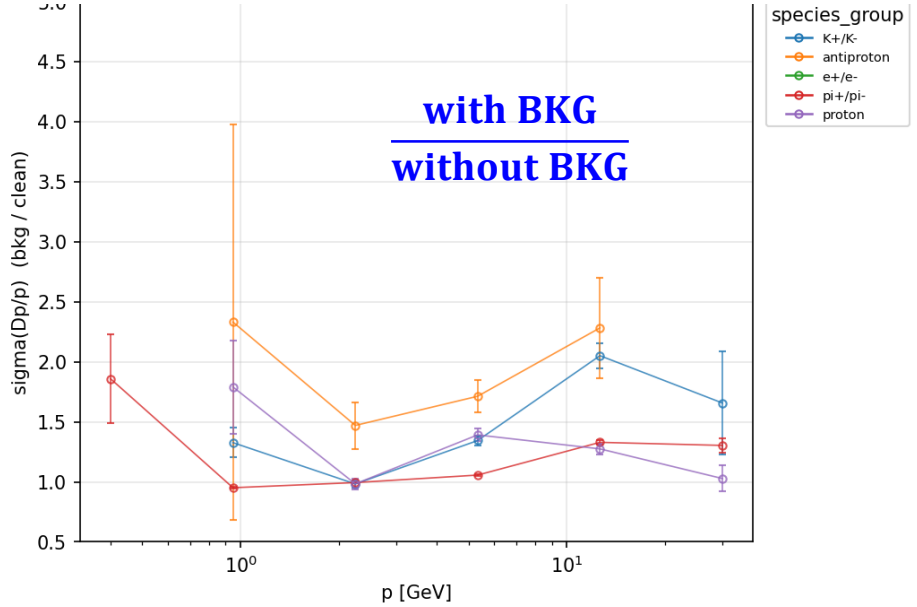
$$\sigma = \frac{|p(reco) - p(gen)|}{p(gen)}$$

- Beam-related background has **small effects** on electron and pion
- Statistics of Kaon too small to draw conclusion.
  - Need to run more events on background mixed file.

p resolution: Forward endcap (1.5<η<4.0)



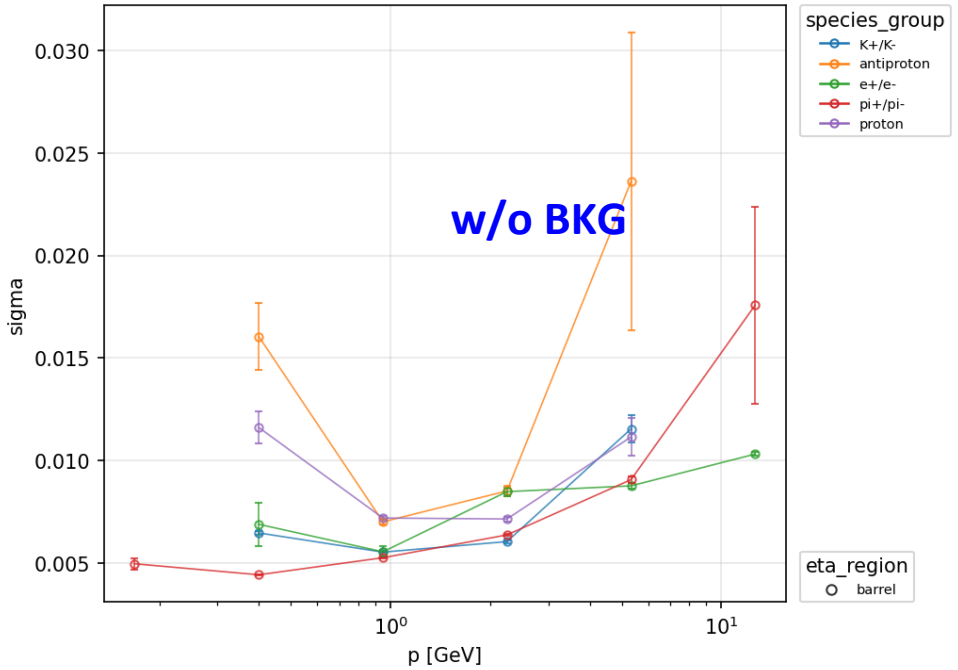


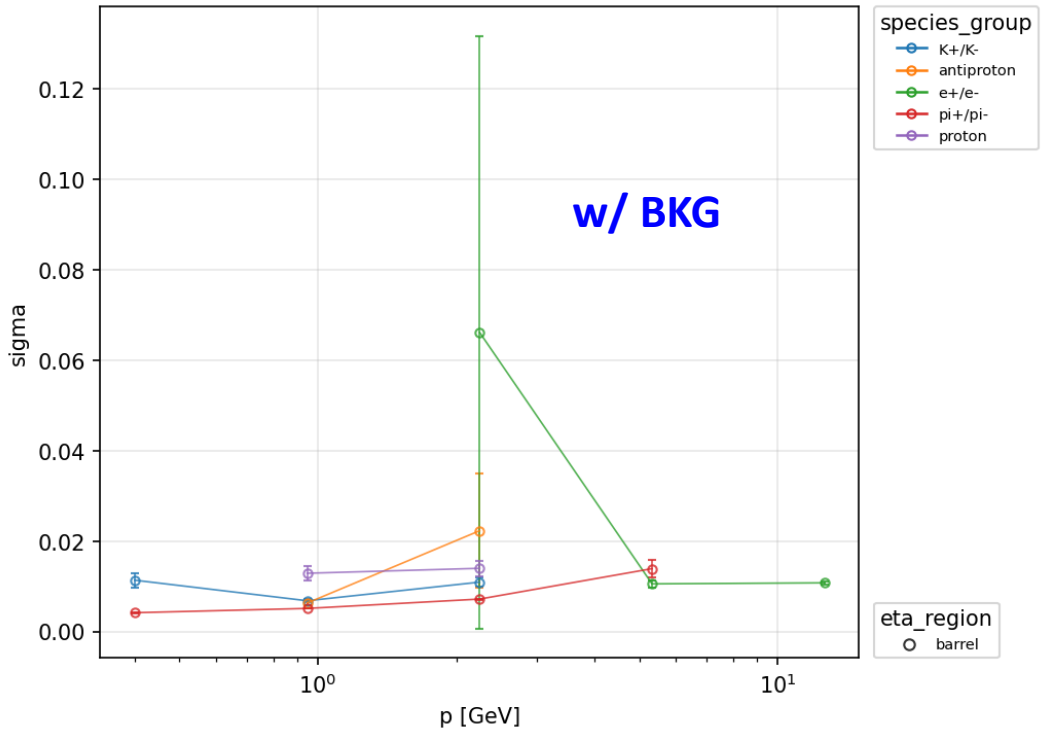


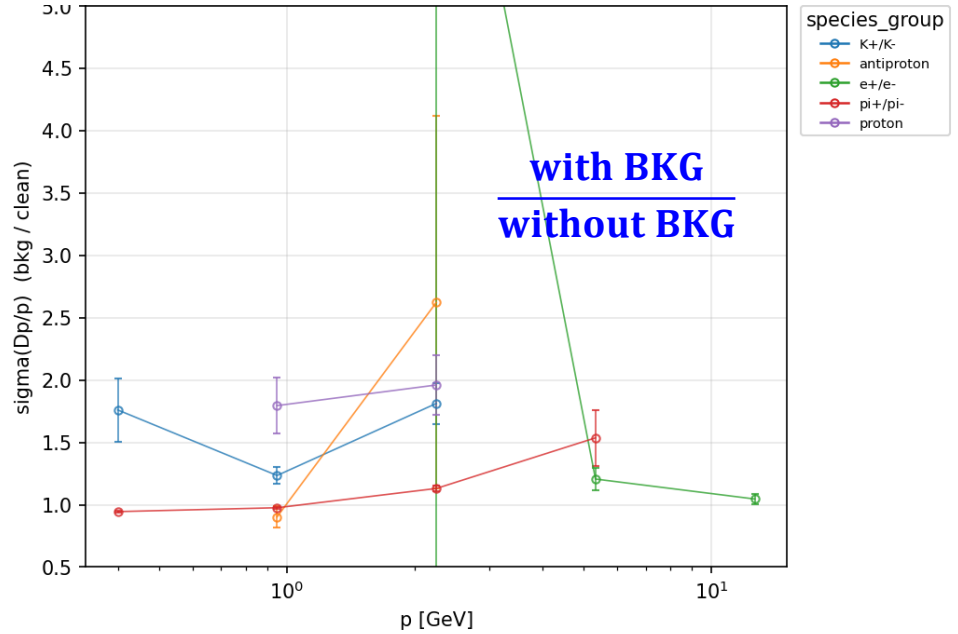
$$\sigma = \frac{|p(reco) - p(gen)|}{p(gen)}$$

- Beam-related background
  - has **smaller effects** on pion at low momentum
  - **Degrade significantly** on resolution of kaon and proton

p resolution: Central Region (|η|<1.5)



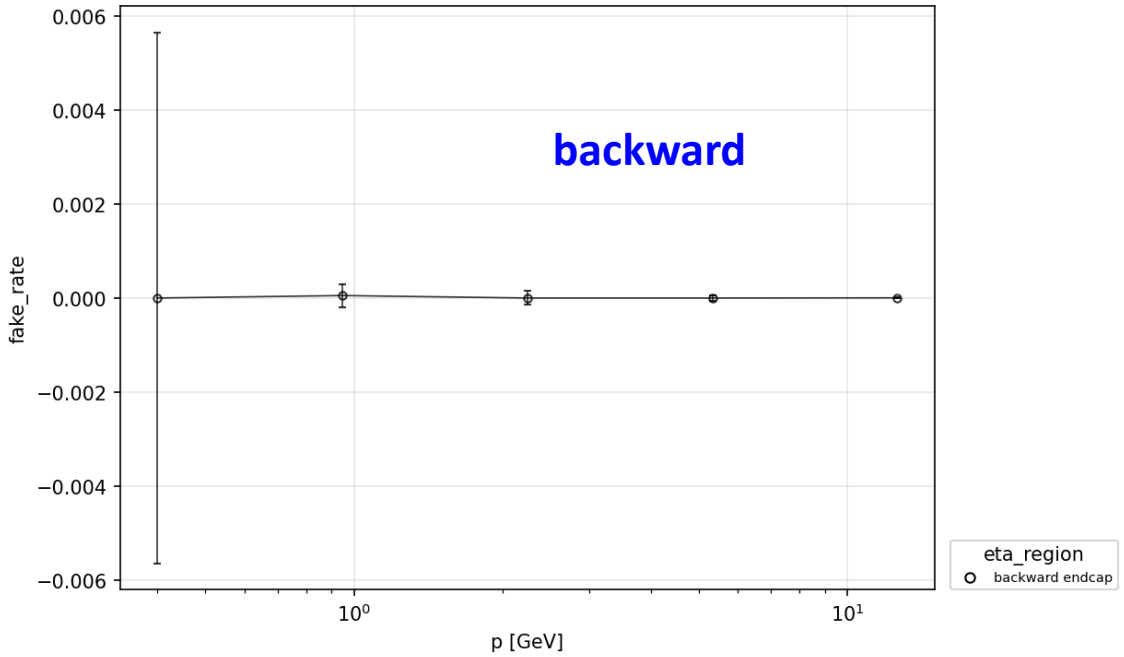




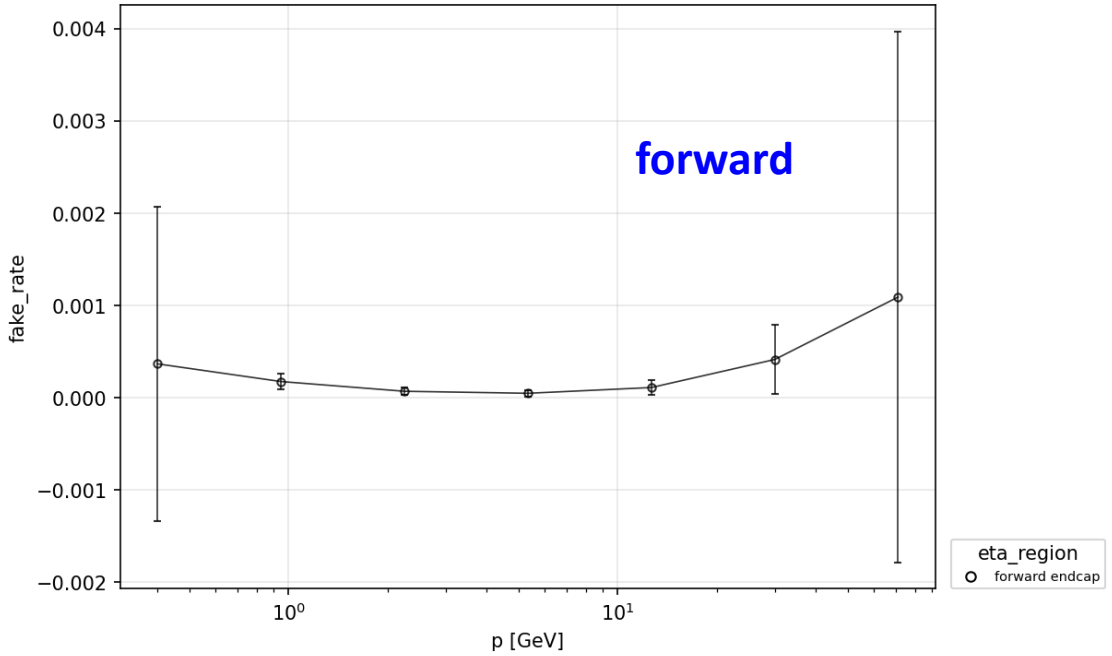
$$\sigma = \frac{|p(reco) - p(gen)|}{p(gen)}$$

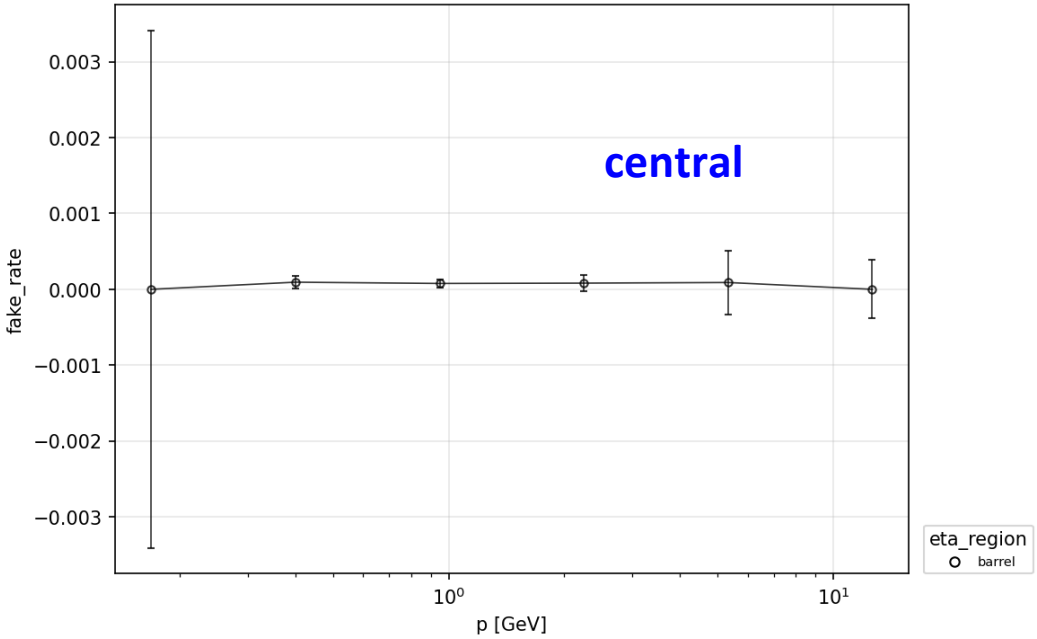
- Beam-related background
  - has **smaller effects** at low momentum pion
  - **Degrade significantly** on resolution of Kaon and proton

Fake Rate: without Beam-related Background



$$f = \frac{N_{fake}}{N_{reco}}$$

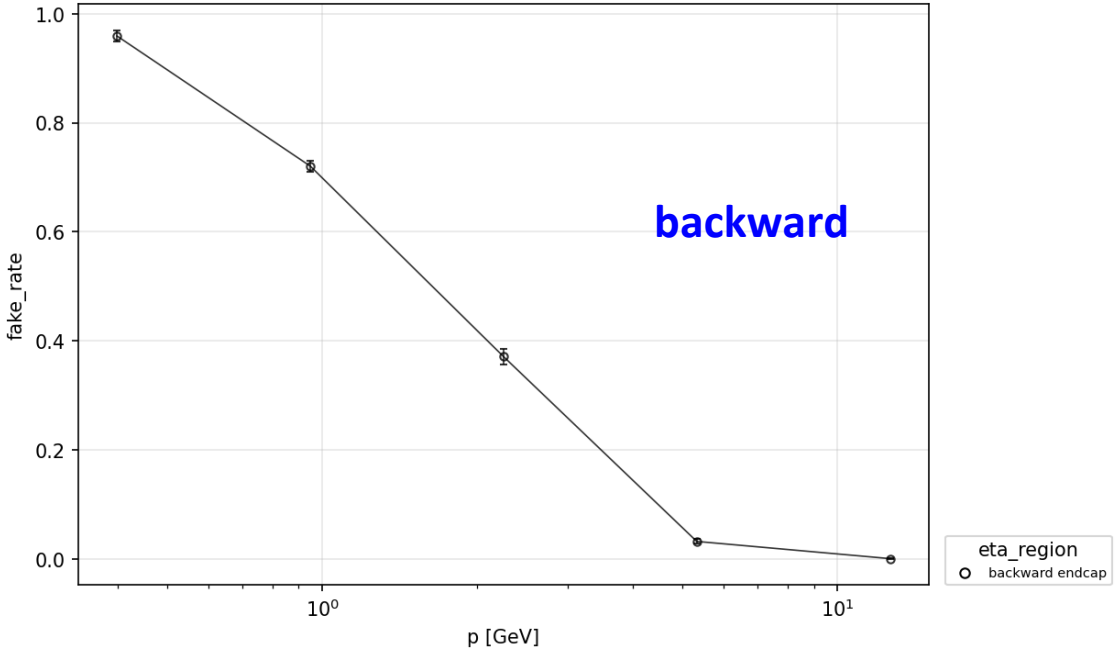


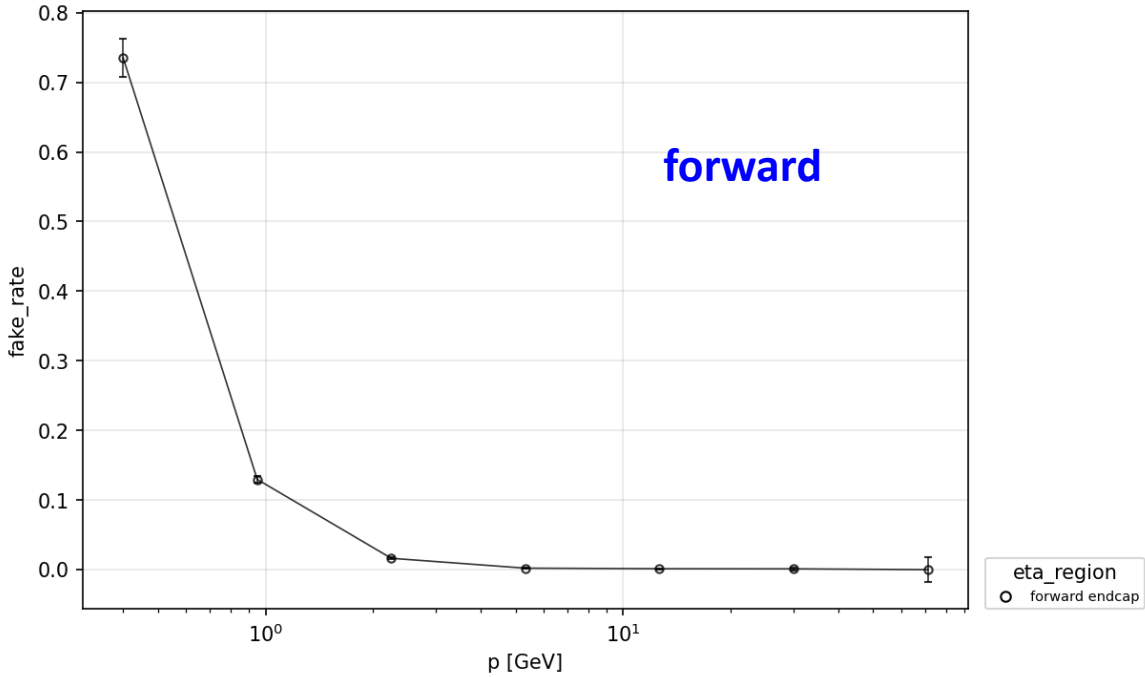


- fake track: reco track with weight<0.5
  - Weight: fraction of a reconstructed track's hits produced by a truth particle
- Fake rate ≈ 0 in all three regions
  - Low multiplicity->low fake rate

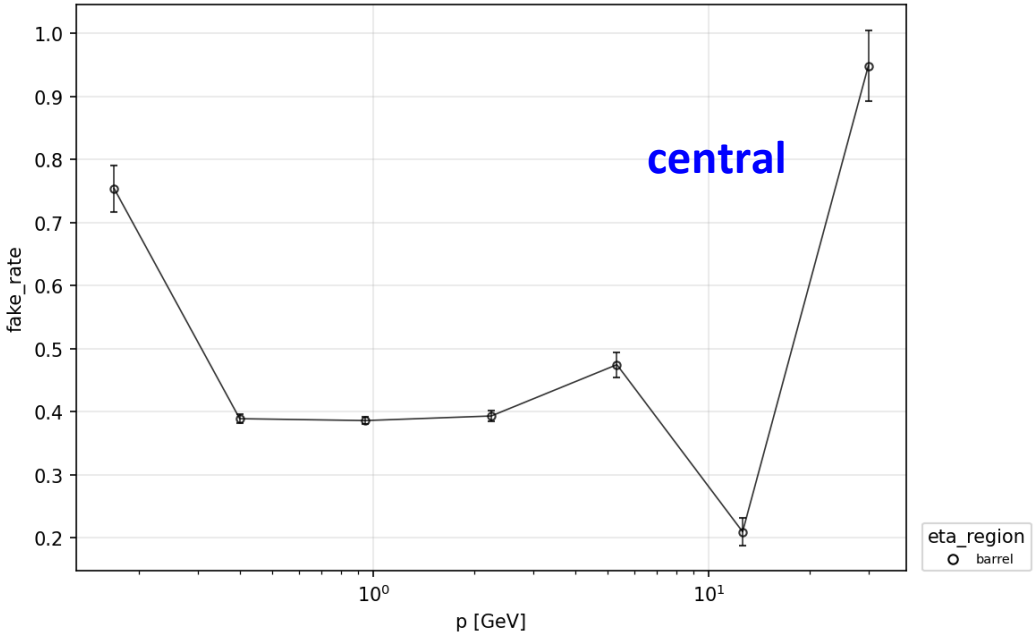
region (|η|)	fake / ev	real / ev	fake fraction
barrel |η|<1.5	0.0001	0.824	0.008%
forward endcap η>1.5	0.0002	1.926	0.010%
backward endcap η<-1.5	0.0000	1.038	0.000%
all (|η|<4)	0.0003	3.788	0.007%

Fake Rate : with Beam-related Background





$$f = \frac{N_{fake}}{N_{reco}}$$



- Significant enhancement of fake rate in all three regions
- Backward:
  - Low fake rate at high p but up to ~90% at low p
- Central:
  - ~20-90%
- Forward:
  - Low fake rate at high p but ~up to 70% at low p

Fake Rate : possible reasons

region (|η|)	fake / ev	real / ev	fake fraction
barrel |η|<1.5	0.526	0.815	39.21%
forward endcap η>1.5	0.075	1.931	3.72%
backward endcap η<−1.5	0.193	1.036	15.68%
all (|η|<4)	0.794	3.783	17.34%

Barrel makes the most ghosts; forward endcap makes the least.

- The background itself piles up centrally.
  - Beam-induced hits (incoherent pairs curling in the solenoid, beam-gas secondals) concentrate at central rapidity: *TOFBarrelClusterHits jumps 8.7 → 565/event (65×)* with background, while the physics multiplicity doesn't change. Ghost rate scales combinatorially with hit density, so the barrel drowns first.
- Barrel geometry is ghost-friendly, disks are not.
  - Random barrel-layer hits easily arrange into helix candidates — a 5-parameter helix is cheap to satisfy accidentally. Curling low-pT background particles loop through the cylinders laying down many hits per particle, each seeding new ghosts.
  - Endcap ghosts must instead line up hits across physically separated disks at consistent slopes — a much stricter coincidence, which is why forward (stiff tracks through disks) stays at 5 %.
- Backward gets the electron-beam debris fan.
  - Synchrotron and beam-gas products of the incoming electron beam spray backward, feeding the backward disks — hence the highest absolute ghost count (0.28/event) despite only 1.2 real tracks there.

Agentic Workflow

- Used **opencode v1** with *Copilot/claude* for planning and part of the building. Majority of the workload is done by *Zen/big-pickle* and audited multiple times by *NRP/Owen3 and Zen/Must Spark 1.3*.

https://github.com/Agentic-AI-for-EIC/baseline_tracking_performance_agent#epic-tracking-performance-with-and-without-beam-related-background-using-agent

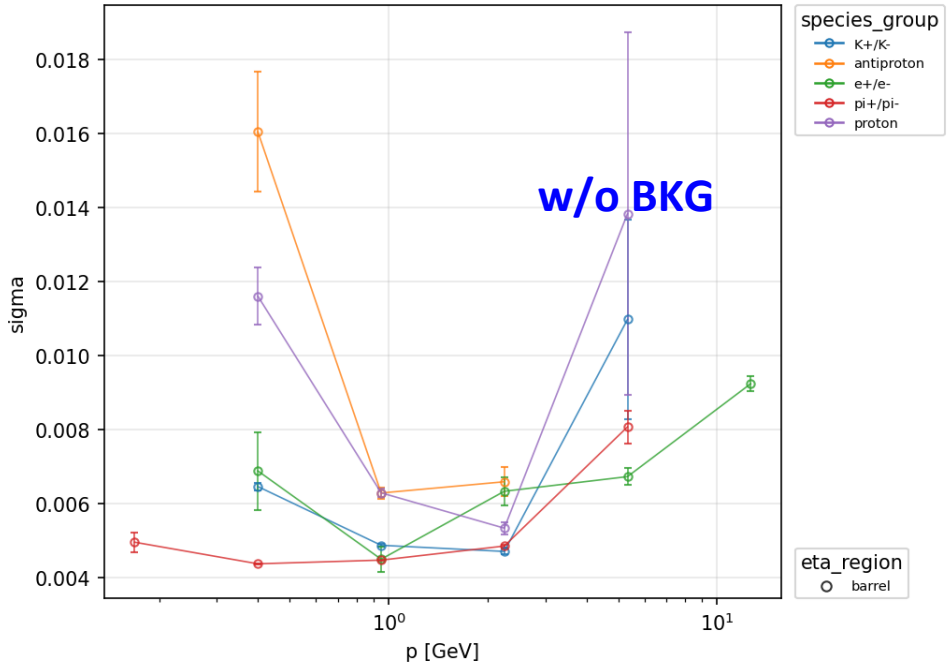
  - Include all auto-generated analysis codes for **people to check**
  - To run this in another agent flow, the **PLAN.md** is the starting point. Just ask the agent to digest the PLAN.md and move on .
  - to continue the agent flow after it stopped, update continue.sh to give instruction to the agent to continue. Note: continue.sh should be run *outside of eic-shell*
  - “Opencode.jsonc” defines where the API key is defined.

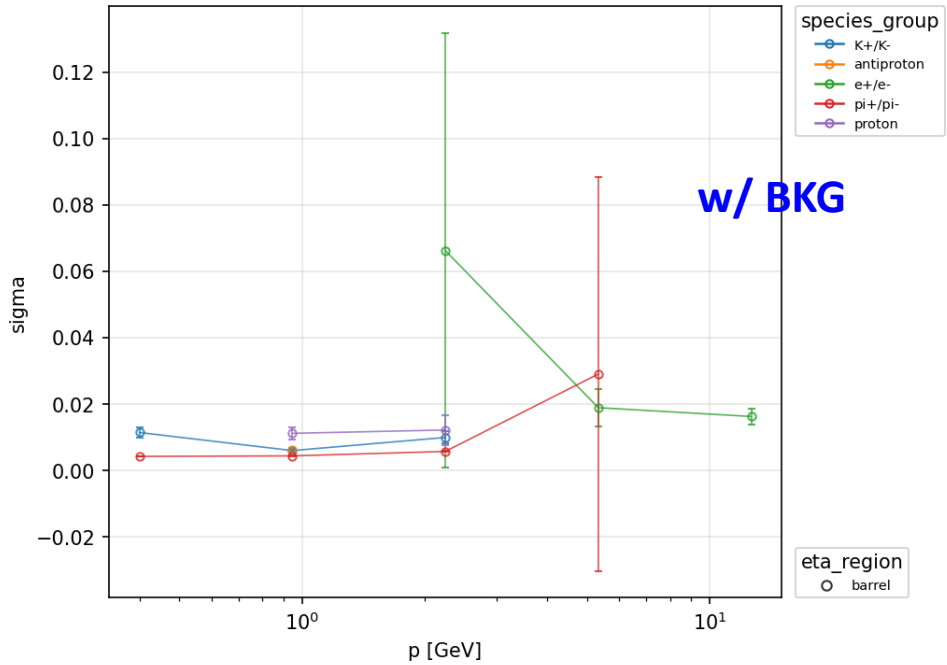
Manual Check

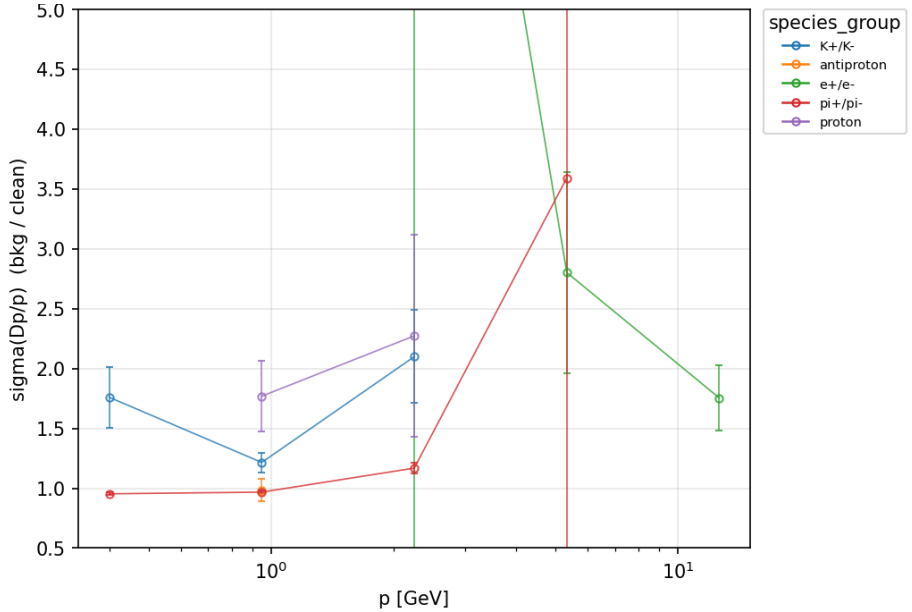
- Let the agent to come up with a simple script and run through a single files.
  - baseline_tracking_performance_agent/manual_check/manual_QA.py
  - Make sure the script output is identical to the project code.
  - Manually read the simple script and found no issue.

Extra slides

p resolution: Central Region (|η|<1.0)



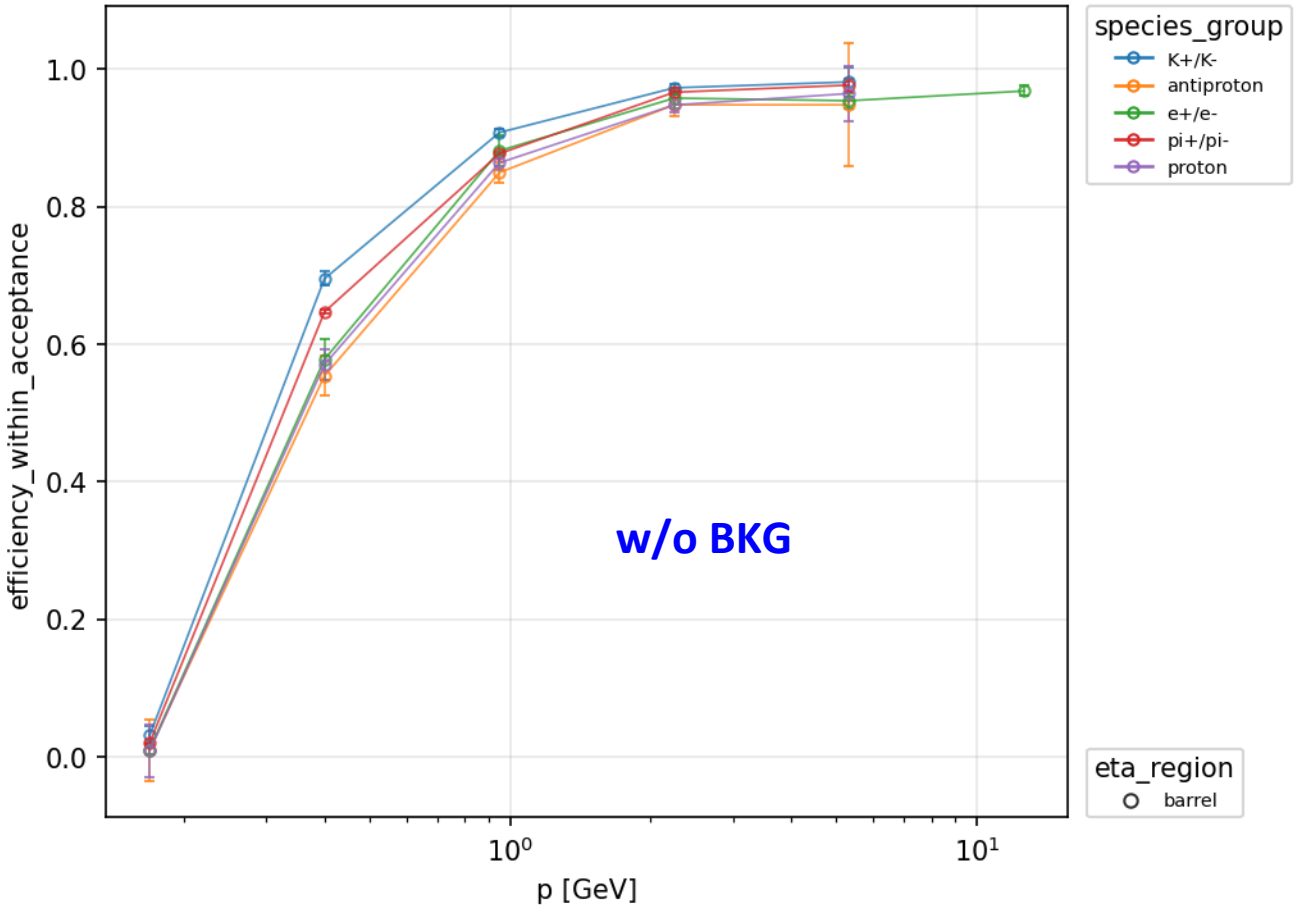


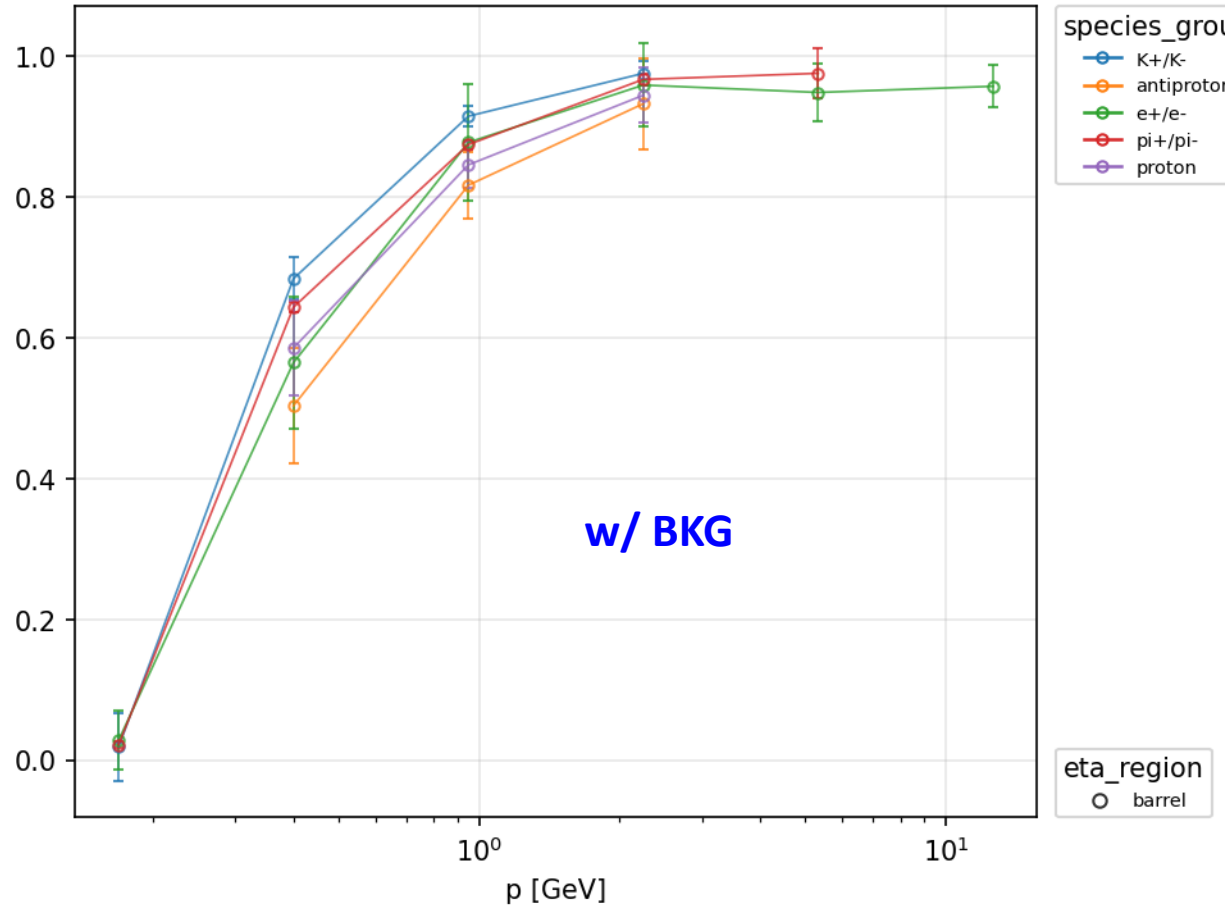


$$\sigma = \frac{|p(reco) - p(gen)|}{p(gen)}$$

- Beam-related background
  - has **little effects** on pion
  - **Degrade significantly** resolution of Kaon and proton
    - Electron as well; differ from |eta|<1.5 which contain electrons from -1.5<eta<-1.0.

Reco Efficiency: Central Region (|η|<1.0)





$$\varepsilon = \frac{N(reco\ matched: in-accp)}{N(gen: in-accp)}$$

- Beam-related background has **little effects** on reco efficiency
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