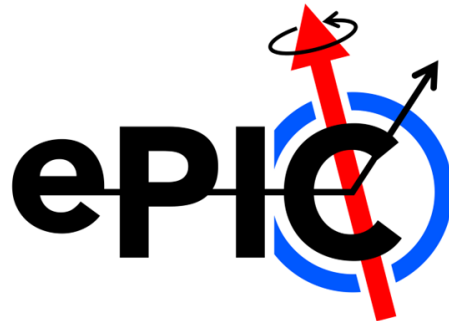
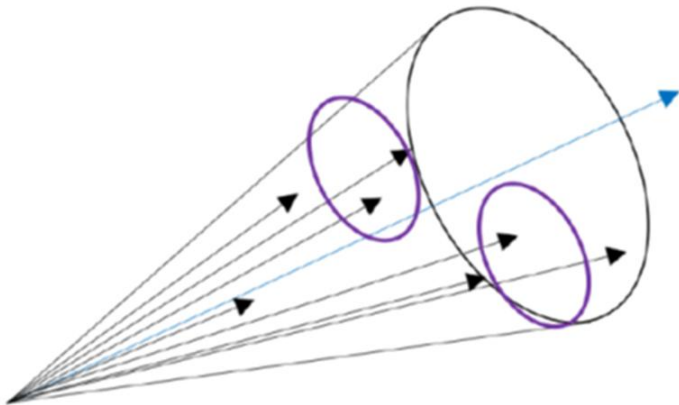


Jet Reconstruction and Control of Systematics

Brian Page

ePIC and EIC Physics Readiness Workshop

March 17 – 19, 2026



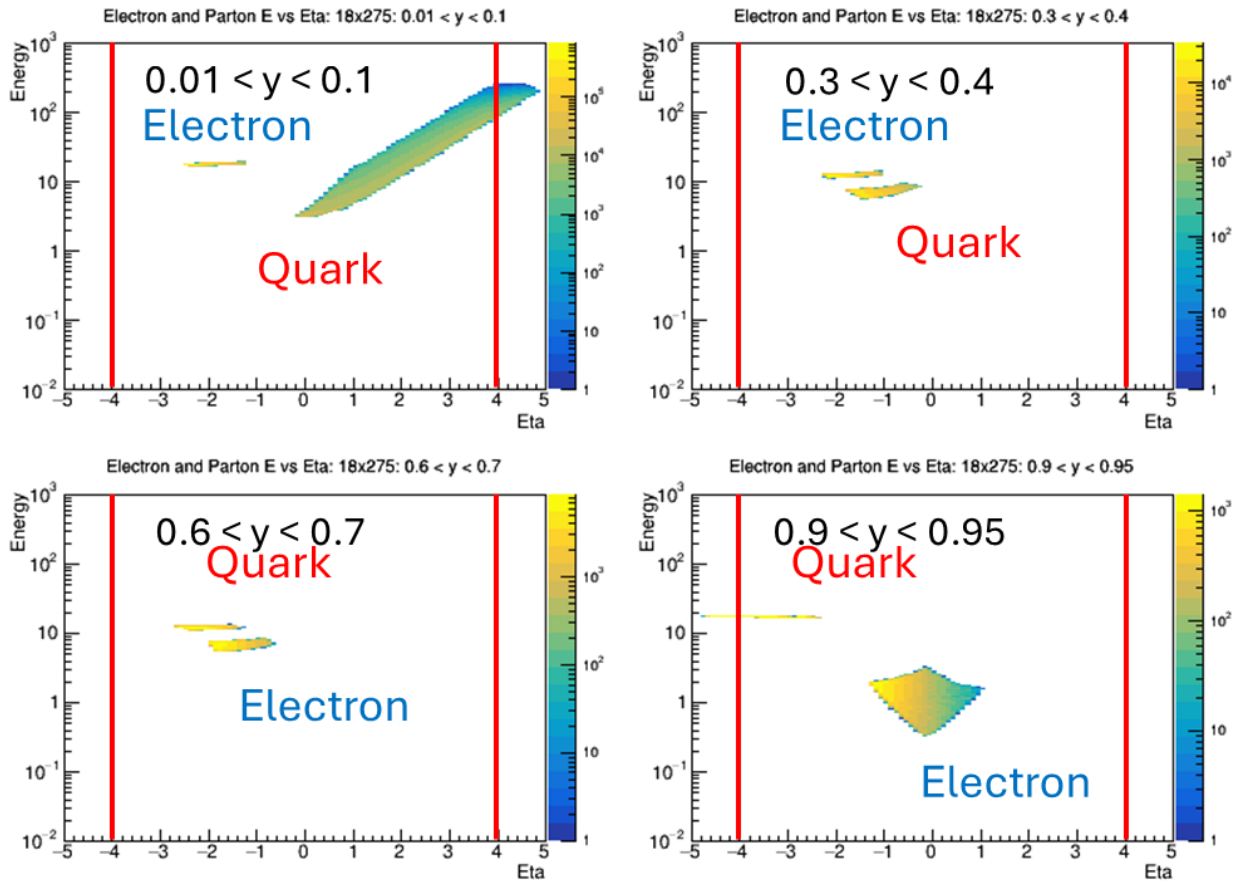
Brookhaven
National Laboratory

Introduction

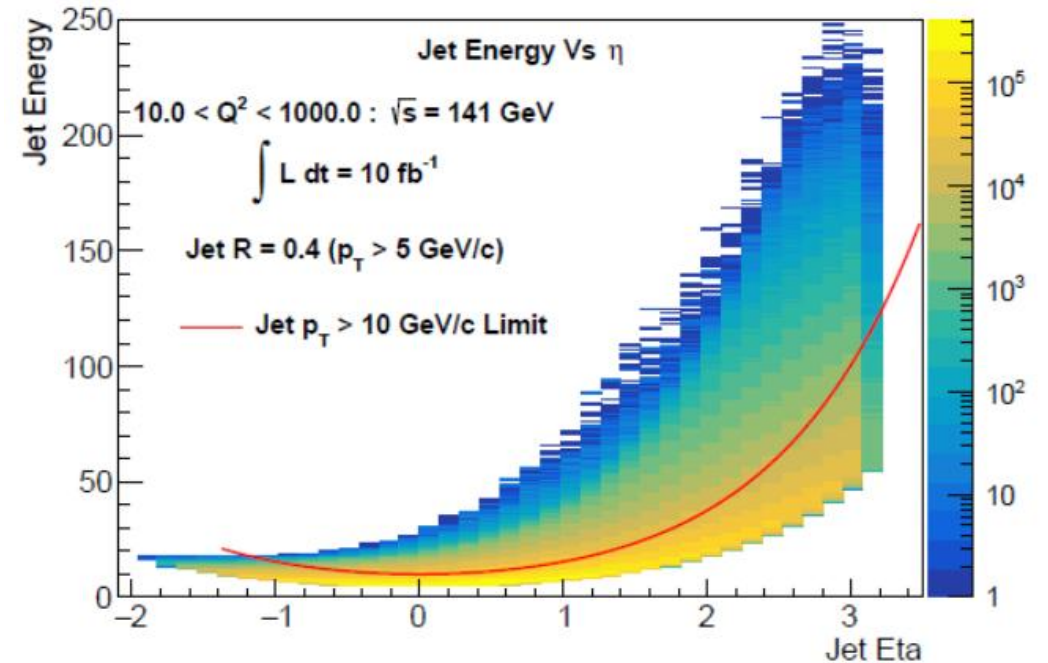
- ❑ Intro on jet kinematics and algorithms
- ❑ Jet finding process at ePIC
- ❑ Jet performance in the presence of background

Jet Kinematics

$10 < Q^2 < 100$



- ❑ As $y \rightarrow 0$, the struck quark can take the full ion beam energy
- ❑ As $y \rightarrow 1$, the struck quark takes the full electron beam energy
- ❑ Different detector considerations in forward and backward regions



Jet Algorithms and Frames

Anti- k_T

$$d_{ij} = \min[p_{ti}^{-2}, p_{tj}^{-2}] \Delta R_{ij} / R$$

EE- k_T (Spherically Invariant)

$$d_{ij} = 2 * \min[E_i^2, E_j^2] (1 - \cos \Delta_{ij})$$

Centauro

$$d_{ij} = \left[(\Delta f_{ij})^2 + 2f_i f_j (1 - \cos \Delta \phi_{ij}) \right] / R^2$$

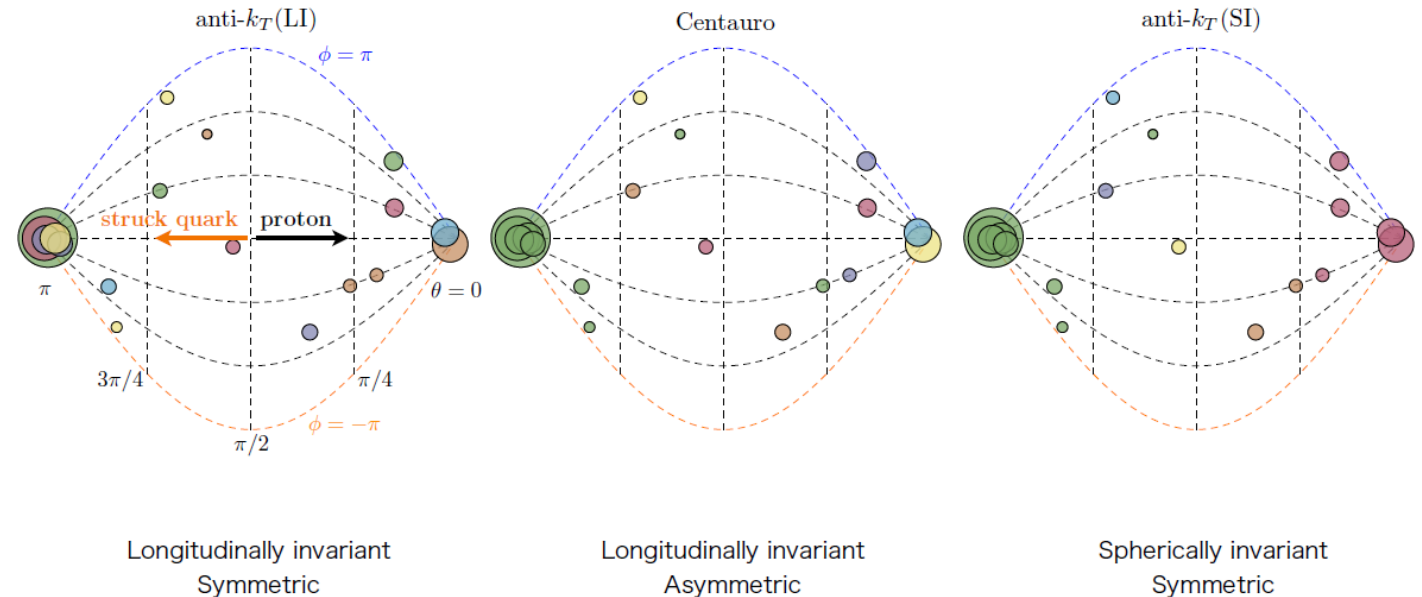
Asymmetric measure is necessary

$$f(x) = x + \mathcal{O}(x^2)$$

$$\bar{\eta}_i = -\frac{2Q}{\bar{n} \cdot q} \frac{p_i^\perp}{n \cdot p_i}$$

$$\bar{\eta}_i(\text{BF}) = 2p_i^\perp / p_i^+$$

- Sequential recombination algorithms, especially Anti- k_T , have been the “industry standard” at hadron colliders for a number of years
- Is this appropriate for very forward jets or Born-level jets in the Breit frame where transverse momenta are by definition small?
- Look at alternative distance measures such as spherically invariant and symmetric EE- k_T or longitudinally invariant and anti-symmetric centauro algorithms



Current Jet Reconstruction Flow

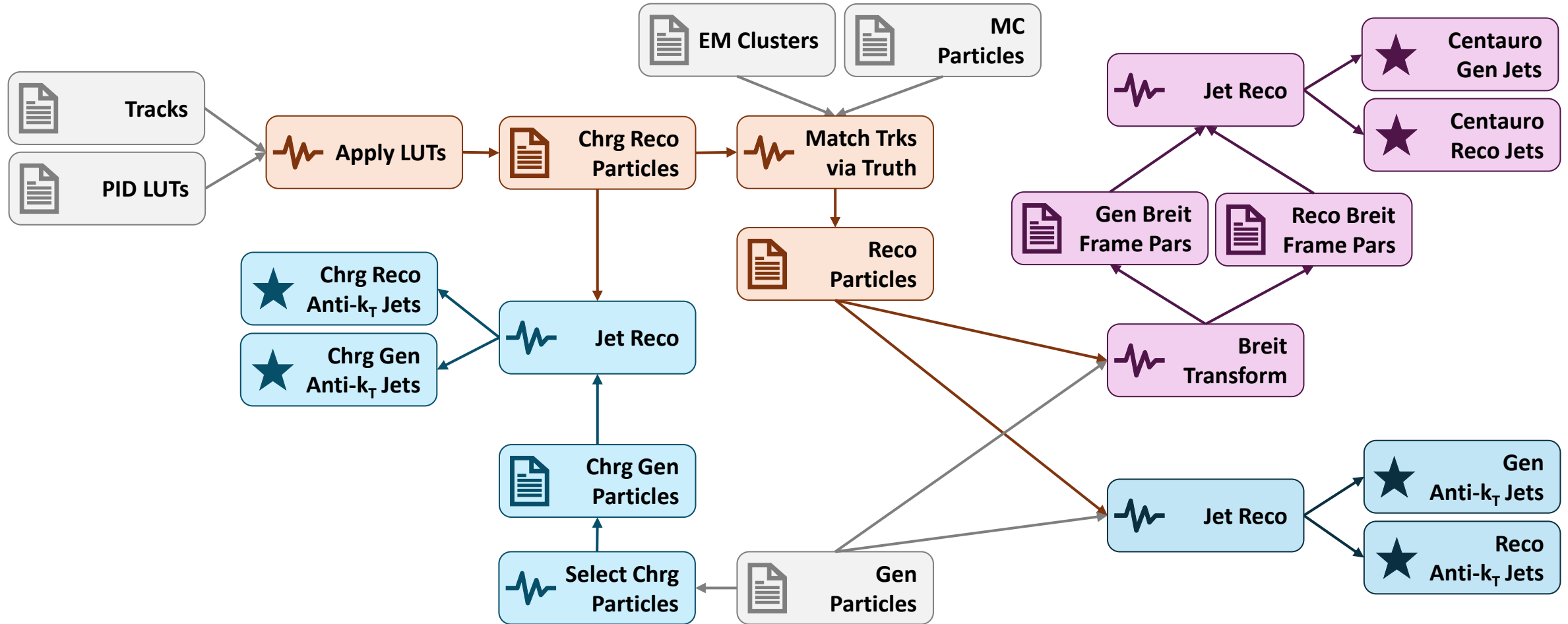


Fig. by D. Anderson

Future Jet Reconstruction Flow

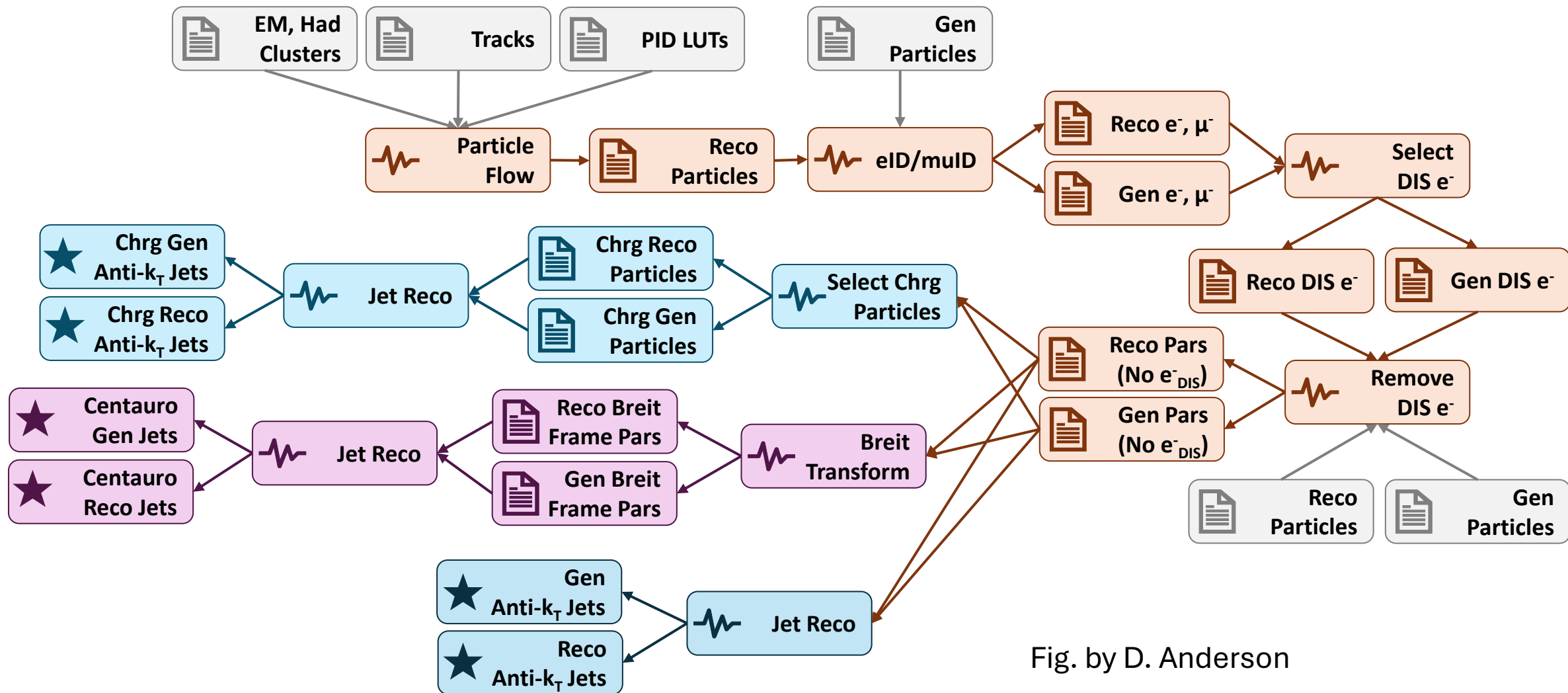
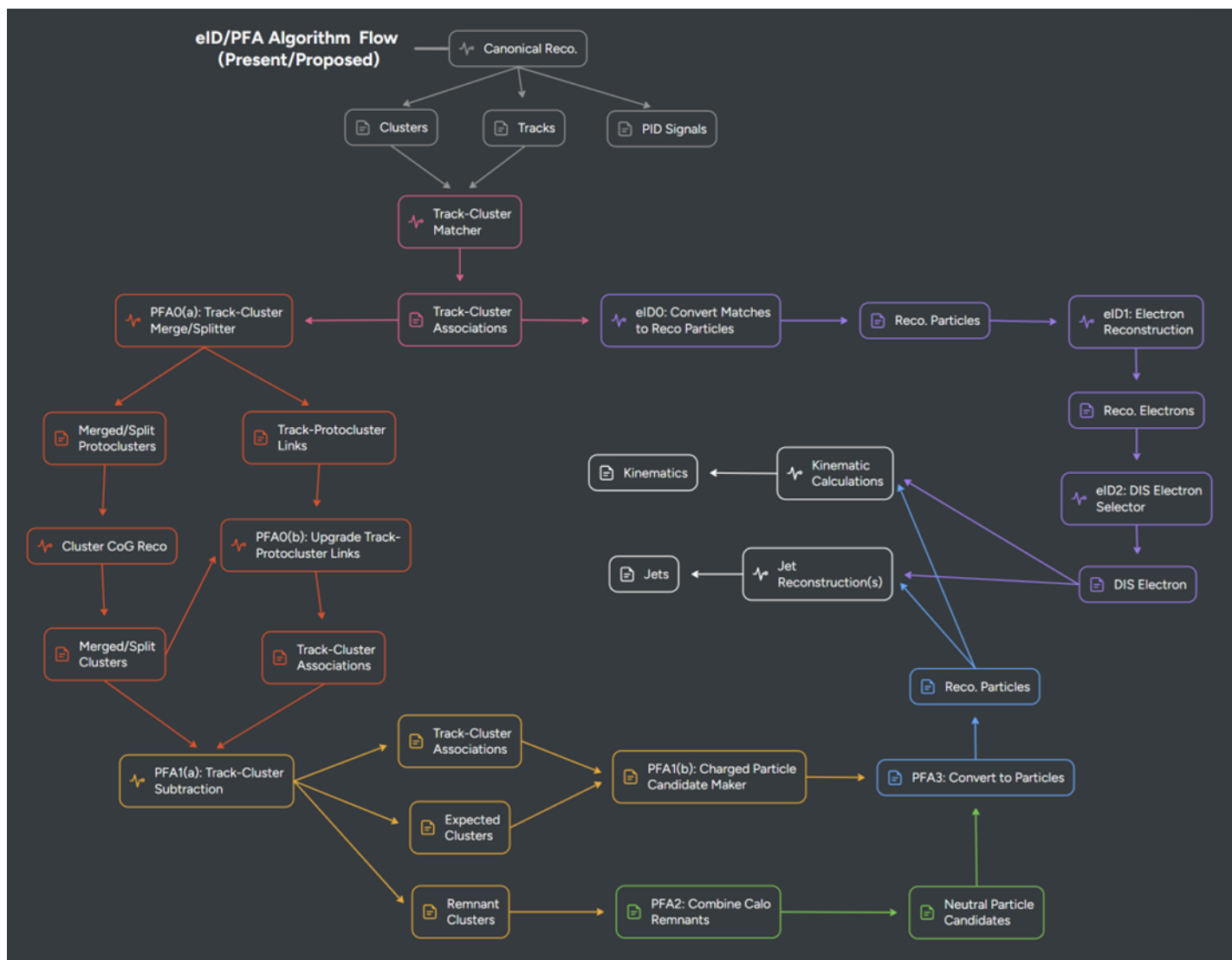


Fig. by D. Anderson

Particle Flow Algorithm



See Derek's Talk Tomorrow

Jet Reconstruction To-Do's

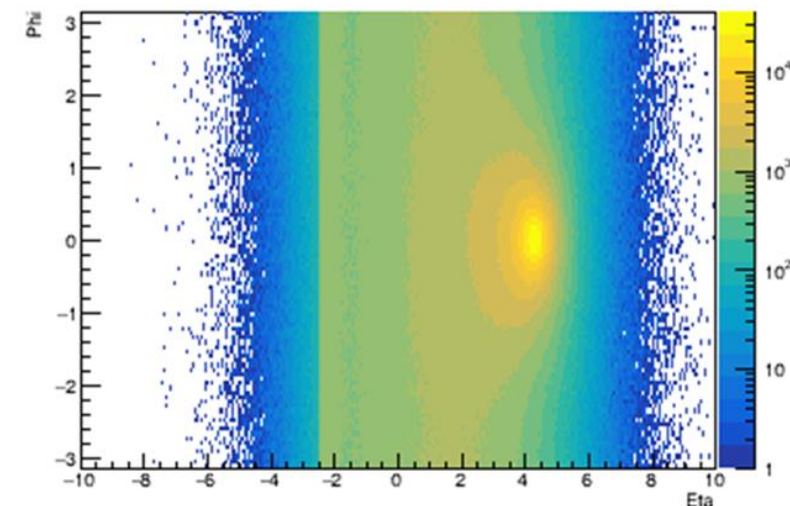
❑ EICrecon To-Do's:

- 1) Investigate performance of Centauro jet factory
- 2) Move to head-on frame to remove crossing angle effects
- 3) Update [algorithm](#), [benchmarks](#) to use new jet datatype when ready
- 4) Wire in PF output to full jet collections when ready
- 5) Remove DIS e^- candidates from *Reconstructed*, *Generated Particles*, wire in filtered collections
- 6) Reassess/optimize kinematic cuts + jet finding algorithms (e.g. p_T^{jet} not ideal to cut on for forward jets)

❑ Notes:

- Jet datatype (right) approved and should be in 26.04 release
- EICrecon jet reconstruction algorithm can be used in analysis code (see snippet [here](#))

Final State Particle Phi Vs Eta: 18x275 25mRad



```
edm4eic::Jet:
Description: "A reconstructed jet, inspired by the FastJet PseudoJet"
Author: "D. Anderson"
Members:
- uint32_t      type           // Jet type as enumerated in fastjet::JetAlgorithm
- float         area           // Jet area
- float         energy         // Jet energy [GeV]
- float         backgroundEnergyDensity // Background energy density [GeV/area]
- edm4hep::Vector3f momentum // Jet 3-momentum [GeV]
OneToManyRelations:
- edm4eic::ReconstructedParticle constituents // Constituents of this jet
ExtraCode:
declaration: "
/// Compute the background energy in [GeV]\n
float getBackgroundEnergy() const { return getArea() * getBackgroundEnergyDensity(); }\n
"
```

Jet Algorithm Parameters

{Reconstructed, Generated} Charged Jets

- Inputs:
 - › *ReconstructedChargedParticles*
 - › *GeneratedChargedParticles*
- Anti- k_T algorithm
- E-scheme recombination
- $R_{jet} = 1.0$
- $p_T^{cst} \in (0.2, 100)$ GeV/c
- $p_T^{jet} > 1$ GeV/c

{Reconstructed, Generated} Centauro Jets

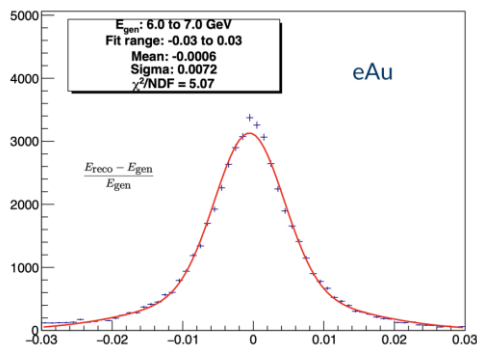
- Inputs:
 - › *ReconstructedBreitFrameParticles*
 - › *GeneratedBreitFrameParticles*
- Centauro algorithm
- E-scheme recombination
- $R_{jet} = 0.8$
- $p_T^{cst} \in (0.2, 100)$ GeV/c
- $p_T^{jet} > 1$ GeV/c

{Reconstructed, Generated} Jets

- Inputs:
 - › *ReconstructedParticles*
 - › *GeneratedParticles*
- Anti- k_T algorithm
- E-scheme recombination
- $R_{jet} = 1.0$
- $p_T^{cst} \in (0.2, 100)$ GeV/c
- $p_T^{jet} > 1$ GeV/c

- **Area parameters** (common to all collections)
 - Active area
 - $|\eta_{ghost}| < 3.5$
 - $N_{repeat}^{ghost} = 1$
 - $A_{ghost} = 0.01$
- Jet area currently not stored

Charge Jet Performance: JES / JER (pTDR)



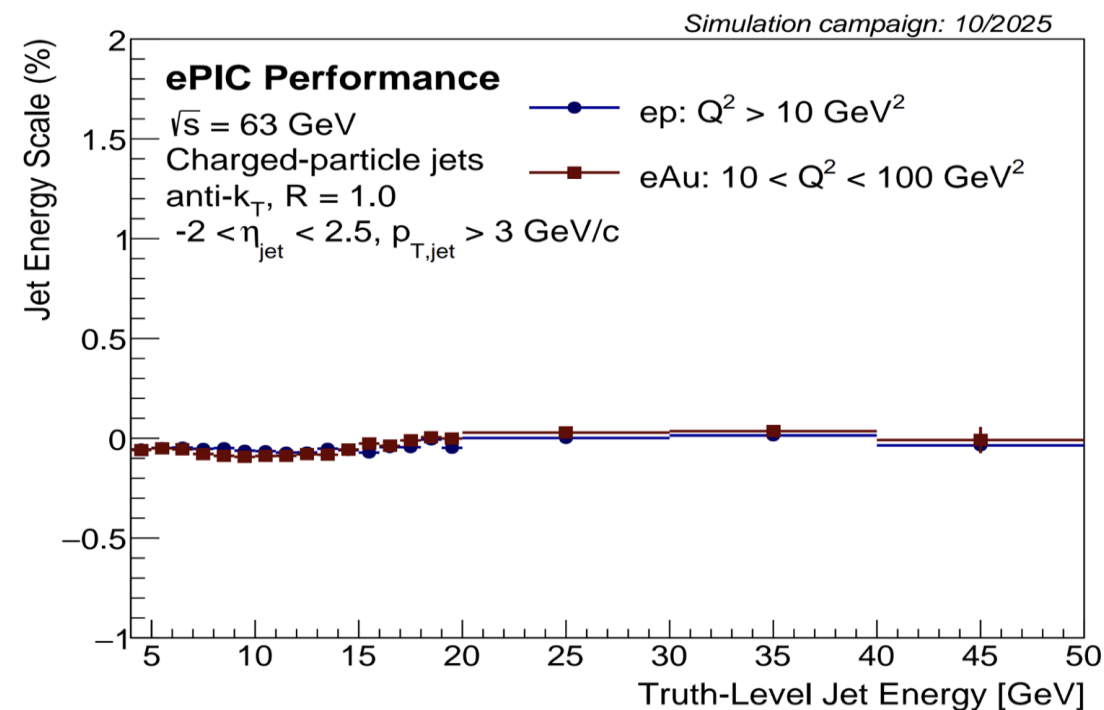
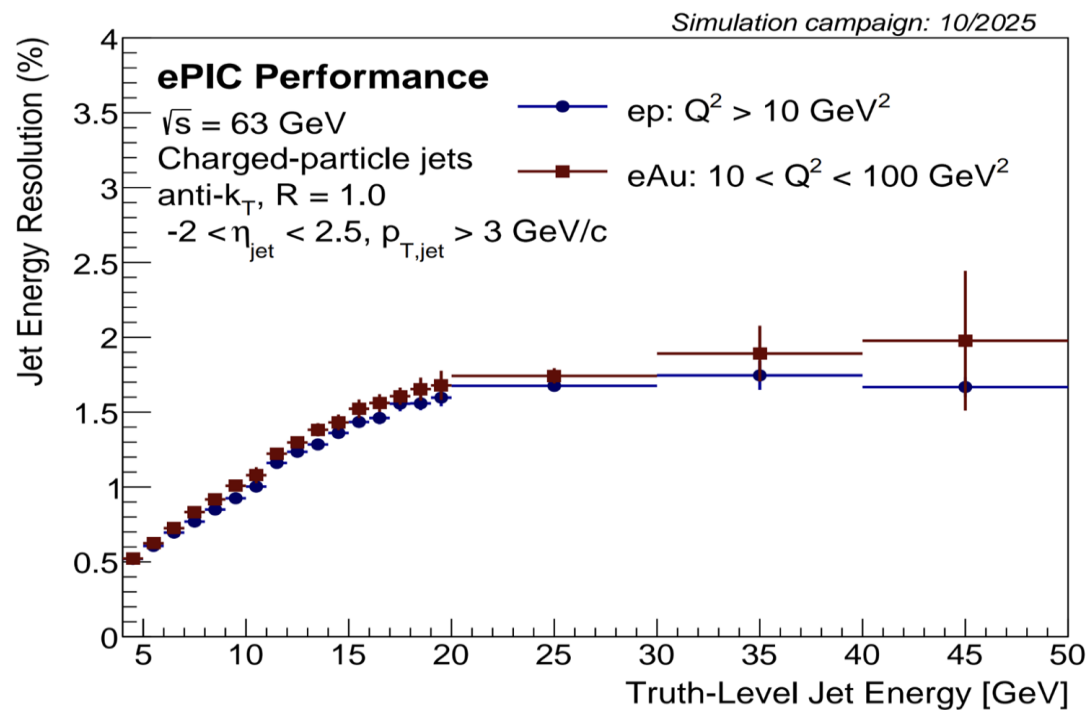
$$f(x) = Y_1 \exp\left(-\frac{(x - \mu)^2}{2\sigma_1^2}\right) + Y_2 \exp\left(-\frac{(x - \mu)^2}{2\sigma_2^2}\right)$$

$$\sigma = \sqrt{\frac{Y_1}{Y_1 + Y_2} \sigma_1^2 + \frac{Y_2}{Y_1 + Y_2} \sigma_2^2}$$

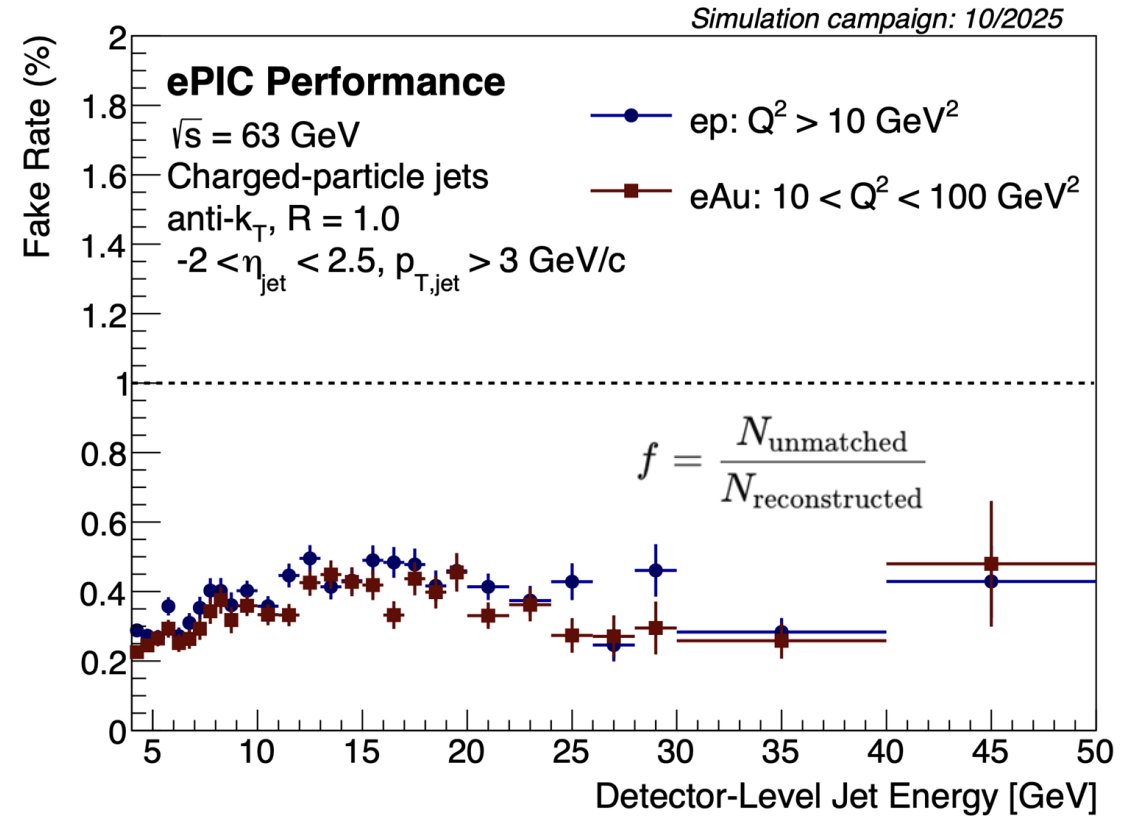
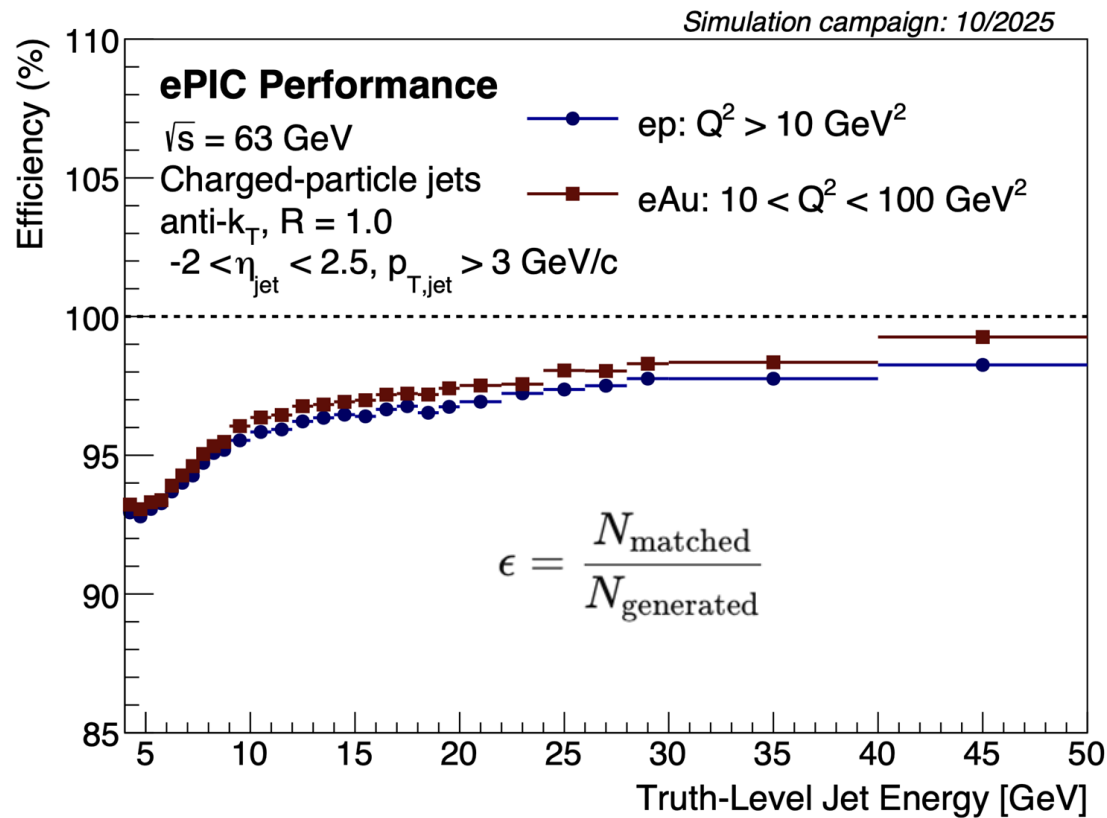
❑ Pure simulation (no bkgd) jet energy scale and resolution

❑ Anti-kT, R=1.0, lab frame, 10x100 GeV, ep & eAu

❑ Plots and analysis by Dener De Souza



Charge Jet Performance: Efficiencies and Fake Rates (pTDR)



Dener De Souza

Impact of Machine Background: Gold Coating and Energy

root://dtn-

eic.jlab.org//volatile/eic/EPIC/RECO/26.02.0/epic_craterlake/Bkg_Exact1S_2us/GoldCt/10um/DIS/NC/10x100/minQ2=1/pythia8NCDIS_10x100_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_1.*.eicrecon.edm4eic.root

203K events

root://dtn-

eic.jlab.org//volatile/eic/EPIC/RECO/26.02.0/epic_craterlake/Bkg_Exact1S_2us/GoldCt/5um/DIS/NC/10x100/minQ2=1/pythia8NCDIS_10x100_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_1.0000.eicrecon.edm4eic.root

180K events

root://dtn-

eic.jlab.org//volatile/eic/EPIC/RECO/26.02.0/epic_craterlake/Bkg_Exact1S_2us/GoldCt/10um/DIS/NC/10x275/minQ2=1/pythia8NCDIS_10x275_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_1.0000.eicrecon.edm4eic.root

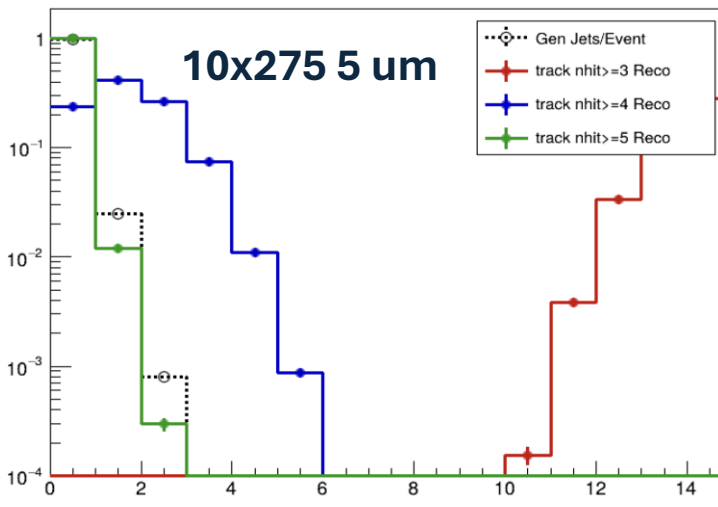
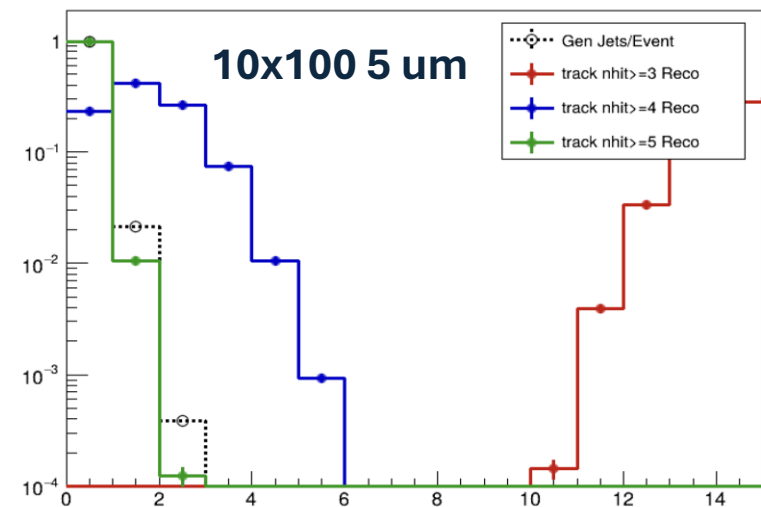
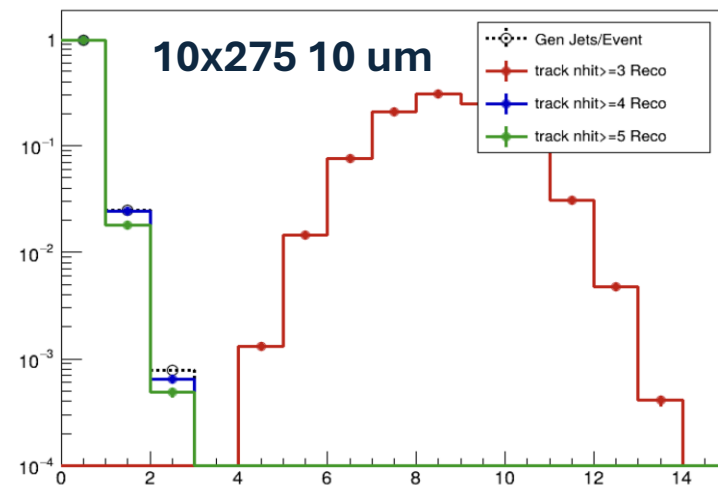
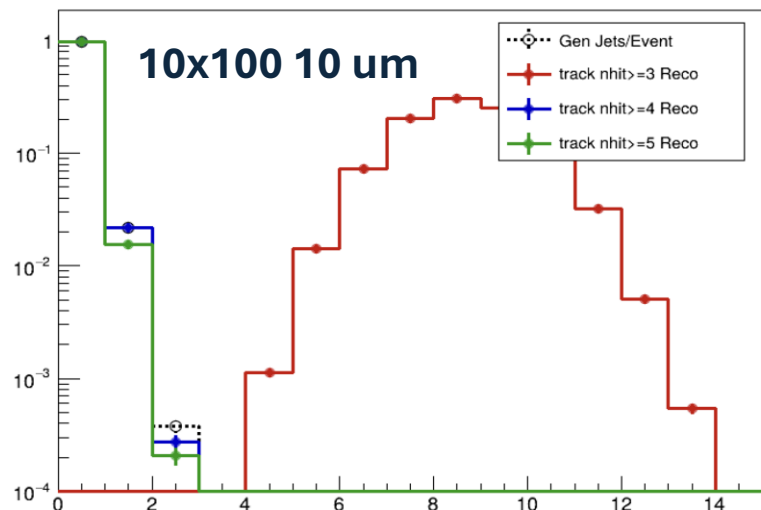
209K events

root://dtn-

eic.jlab.org//volatile/eic/EPIC/RECO/26.02.0/epic_craterlake/Bkg_Exact1S_2us/GoldCt/5um/DIS/NC/10x275/minQ2=1/pythia8NCDIS_10x275_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_1.0000.eicrecon.edm4eic.root

205K events

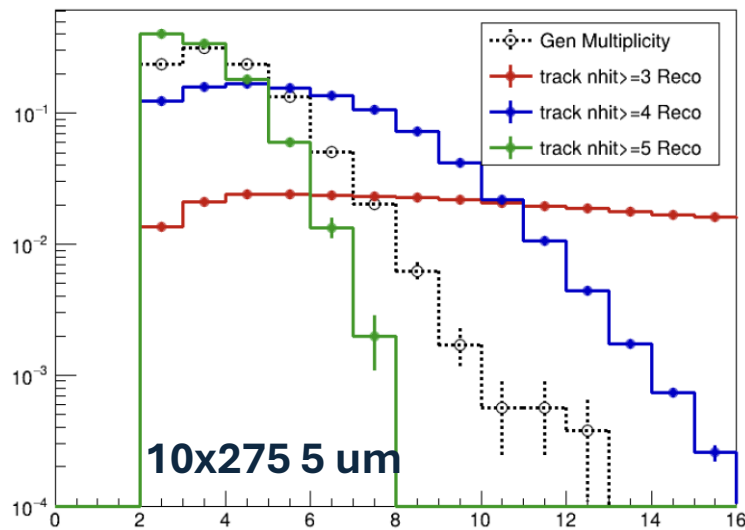
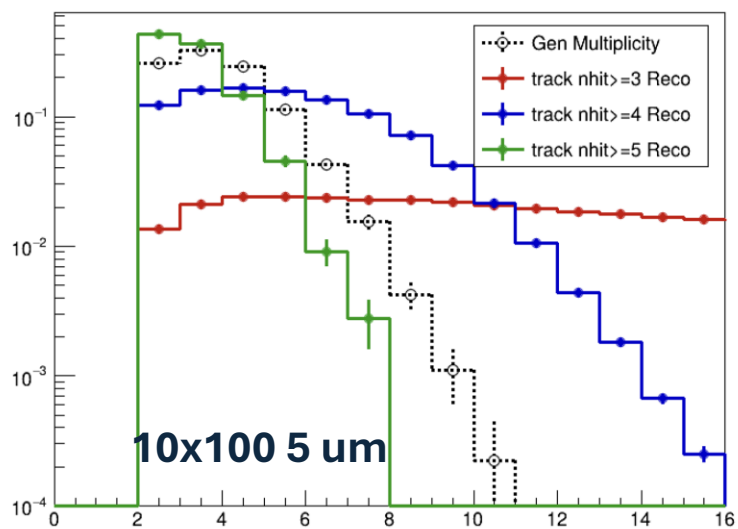
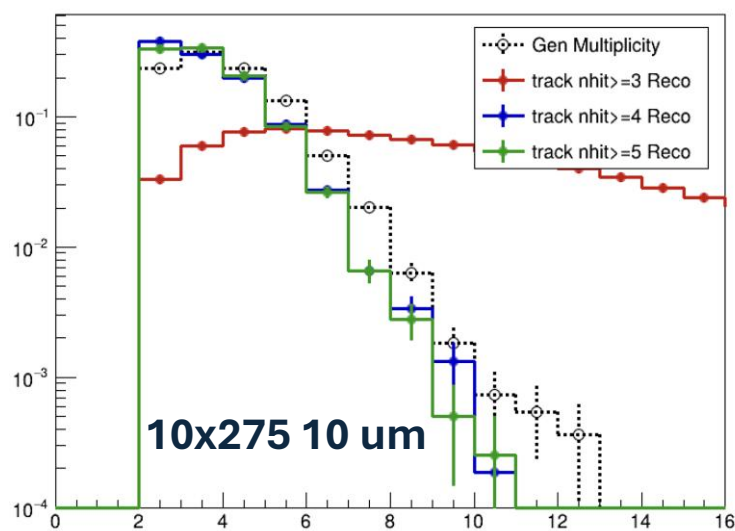
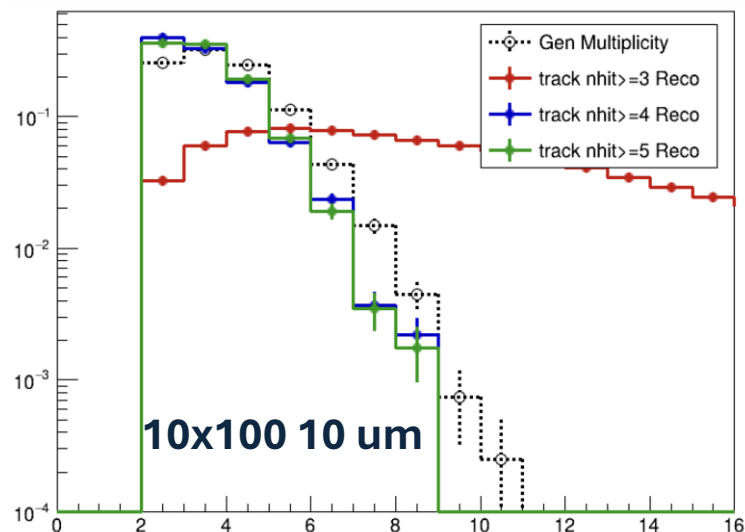
Impact of Beam Background: Jet Multiplicities



- Look at effect of backgrounds on jet quantities
- Vary beam energy and beam pipe gold coating thickness
- Place cuts on track nHits to remove background
- Gold coating thickness has large impact on fake jet rates
- In all cases, nHits >= 3 cut insufficient to remove background

Plots by Jeetendra Gupta

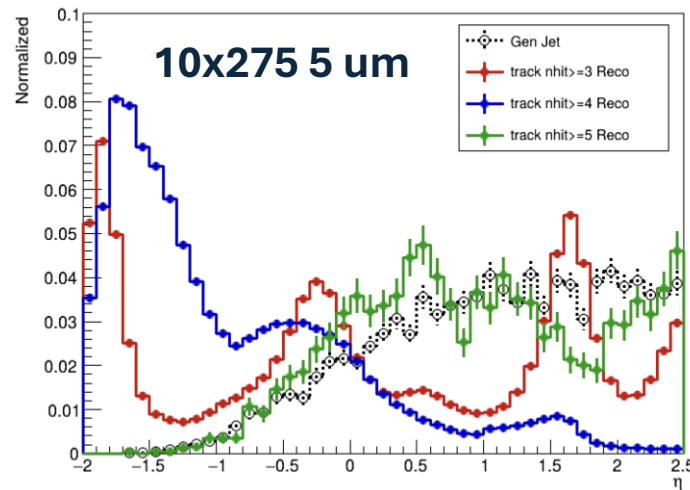
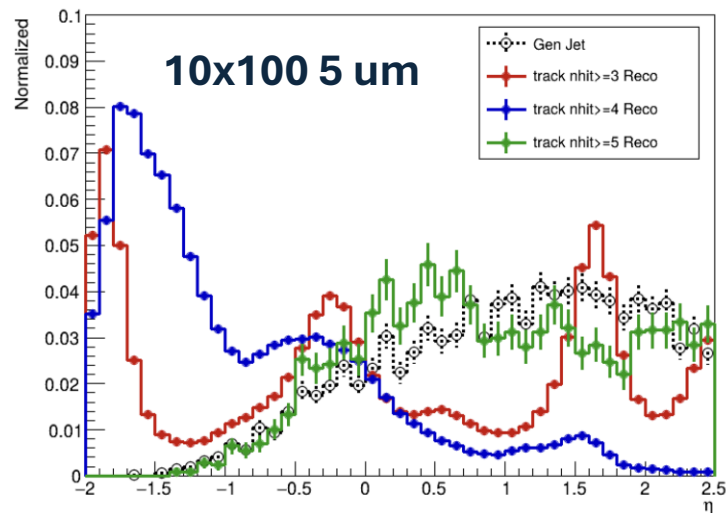
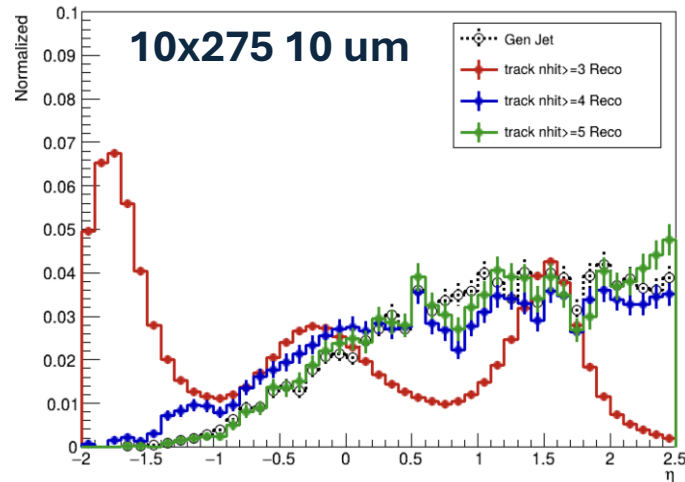
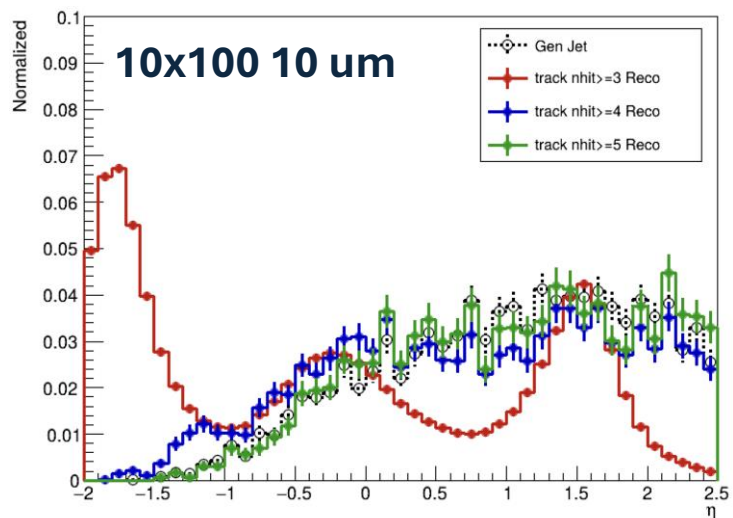
Impact of Beam Background: Constituent Multiplicities



- ❑ Number of constituents (tracks) inside jet tells same story
- ❑ High contamination from background tracks
- ❑ 10 μm gold coating important for background control

Plots by Jeetendra Gupta

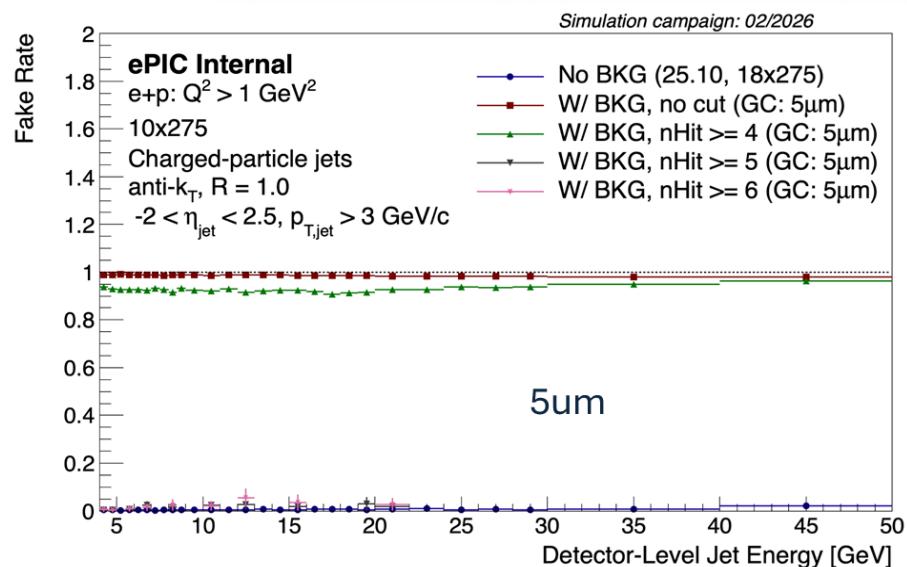
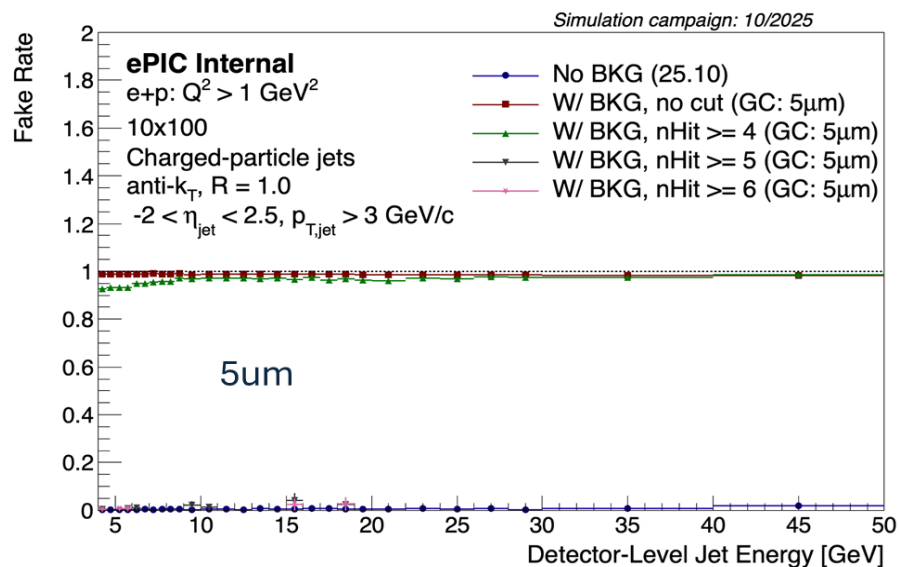
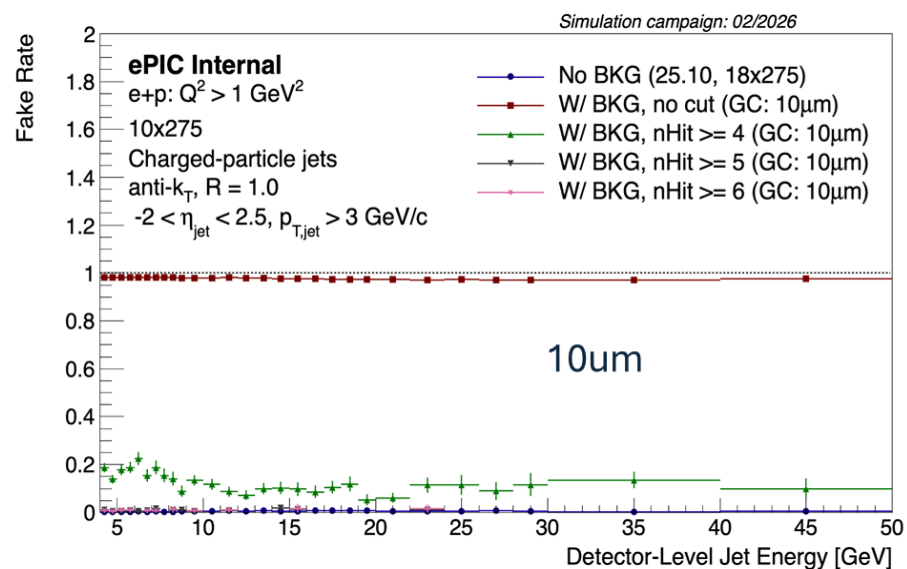
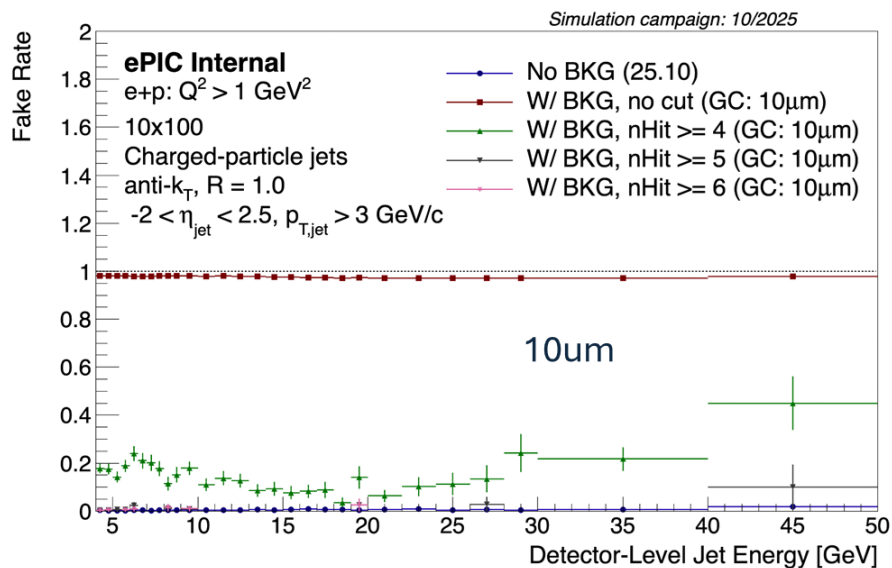
Impact of Beam Background: Jet Eta



- ❑ Jet pseudorapidity distributions show background hotspots
- ❑ nHits ≥ 5 cut needed to fully control background, even for 10 μm gold coating

Plots by Jeetendra Gupta

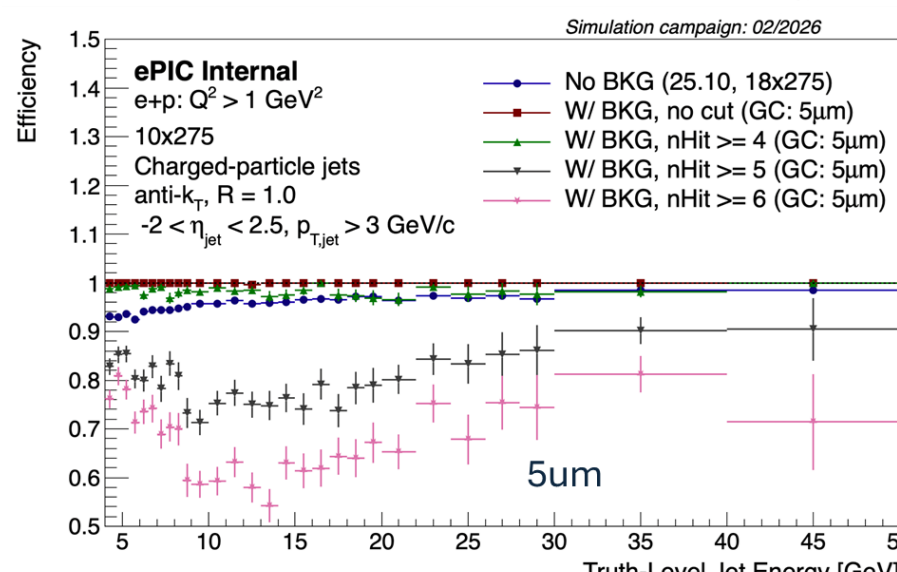
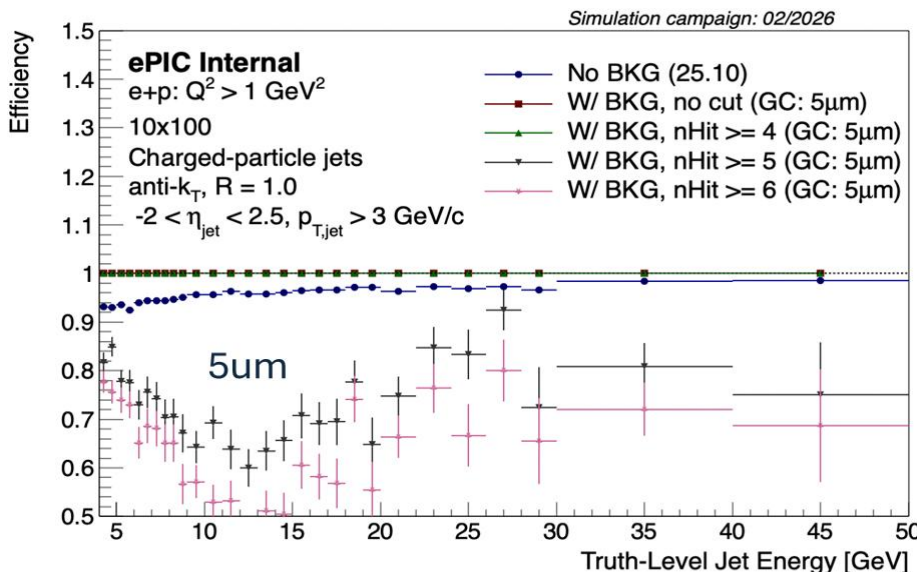
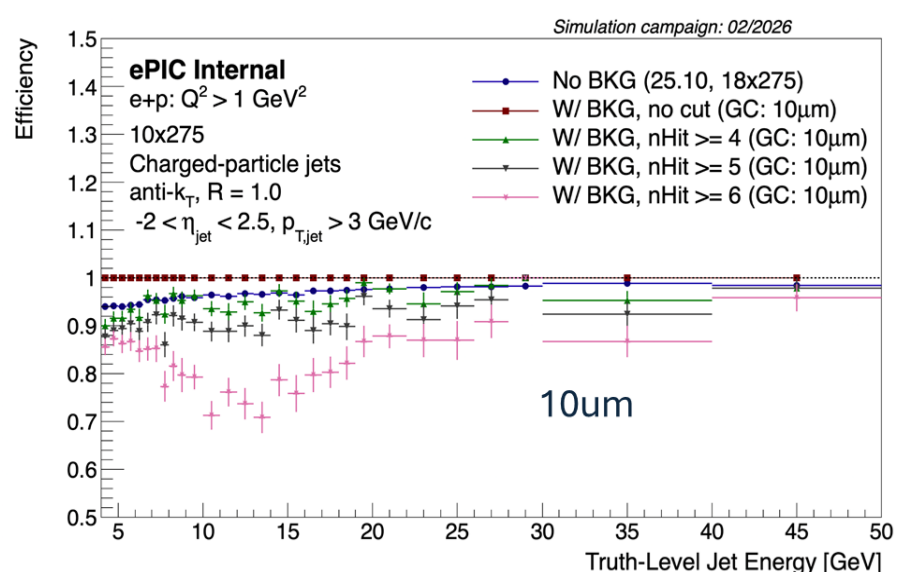
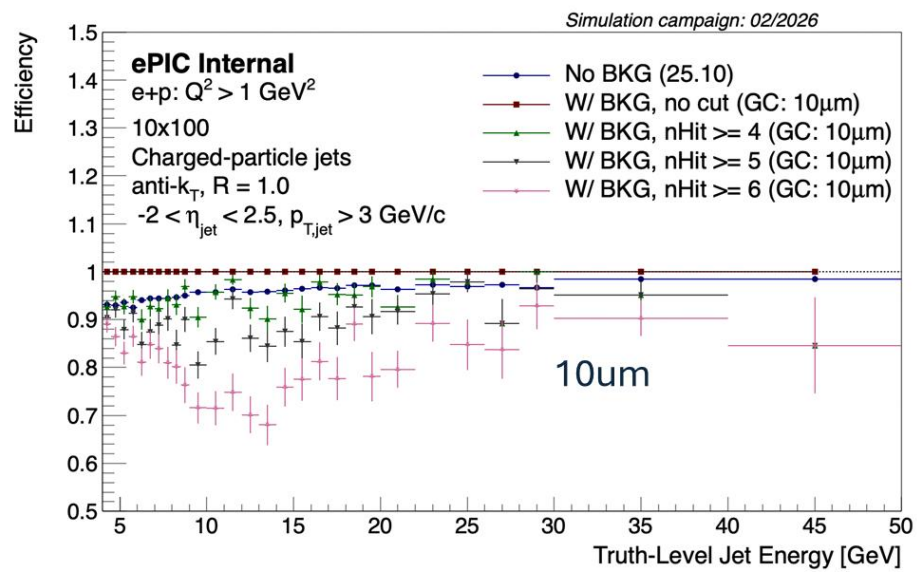
Impact of Beam Background: Fake Rates



□ 10 um gold coating and track nHits ≥ 4 cut brings fake rates to $\sim 20\%$

Dener De Souza

Impact of Beam Background: Efficiencies



- ❑ 10 μm gold coating and track nHits ≥ 4 cut brings fake rates to $\sim 20\%$
- ❑ Harsher nHits cuts improve fake rates at the expense of efficiency
- ❑ Knowledge and control of this tradeoff will be important for assigning / minimizing systematics

Dener De Souza

Summary

- ❑ Jet studies at ePIC / EIC moving from “childhood” to “adolescence”
 - ❑ Charged jets only -> particle flow – treating tracking, calorimetry, and PID on equal footing
 - ❑ e+p jets only -> jets in e+A
 - ❑ Pure Monte Carlo -> inclusion of realistic backgrounds

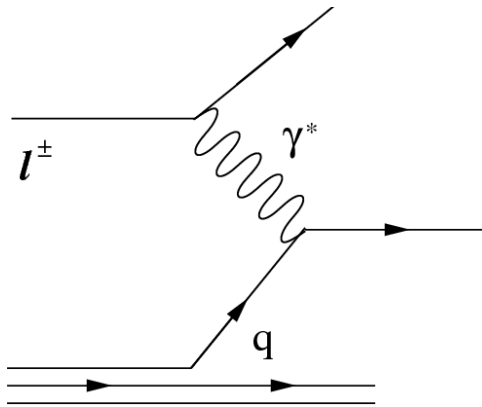
- ❑ Systematics will largely flow from individual inputs – understanding tracking, calorimetry, and PID and how they combine via PF will be key to controlling jet uncertainties

- ❑ Backgrounds can have a significant impact on jet measurements – additional ways to reject background contributions will likely be needed

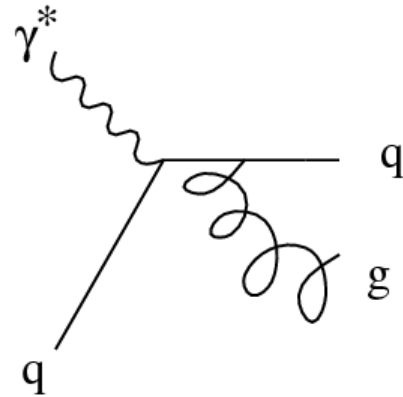
Backup

Relevant Subprocesses

DIS

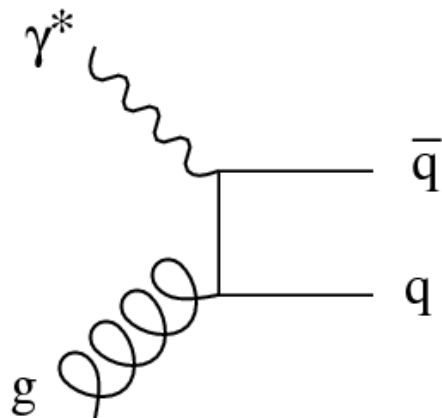


QCD-Compton (QCDC)

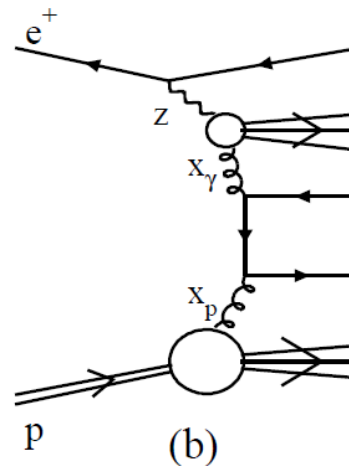


- ❑ Leading order process gives rise to a single jet (not counting target remnant) whose kinematics are largely determined by the underlying event kinematics
- ❑ Higher-order corrections to this process can give rise to back-to-back jet configurations (dijets) which break the dependencies on event kinematics

Photon-Gluon Fusion (PGF)

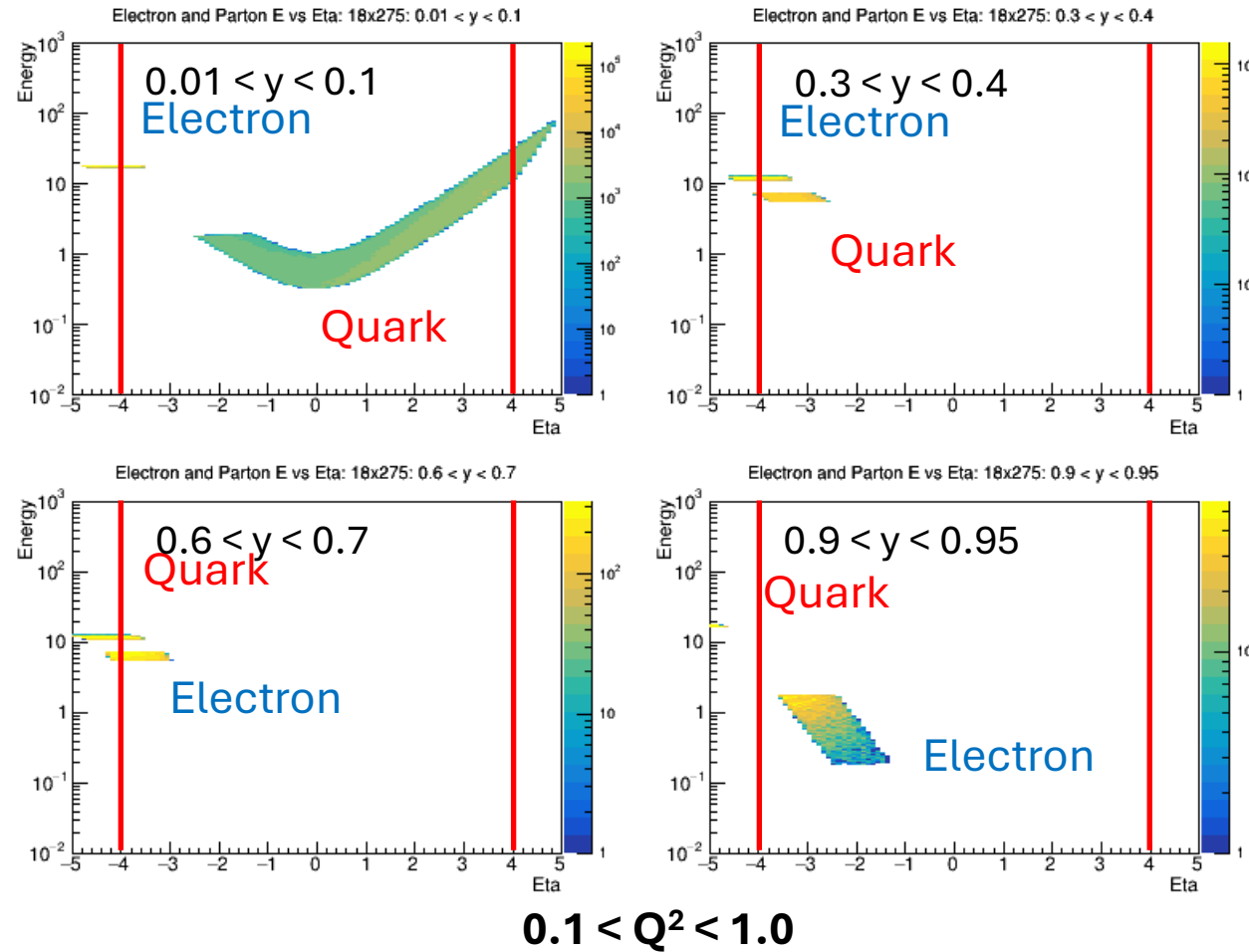


Resolved

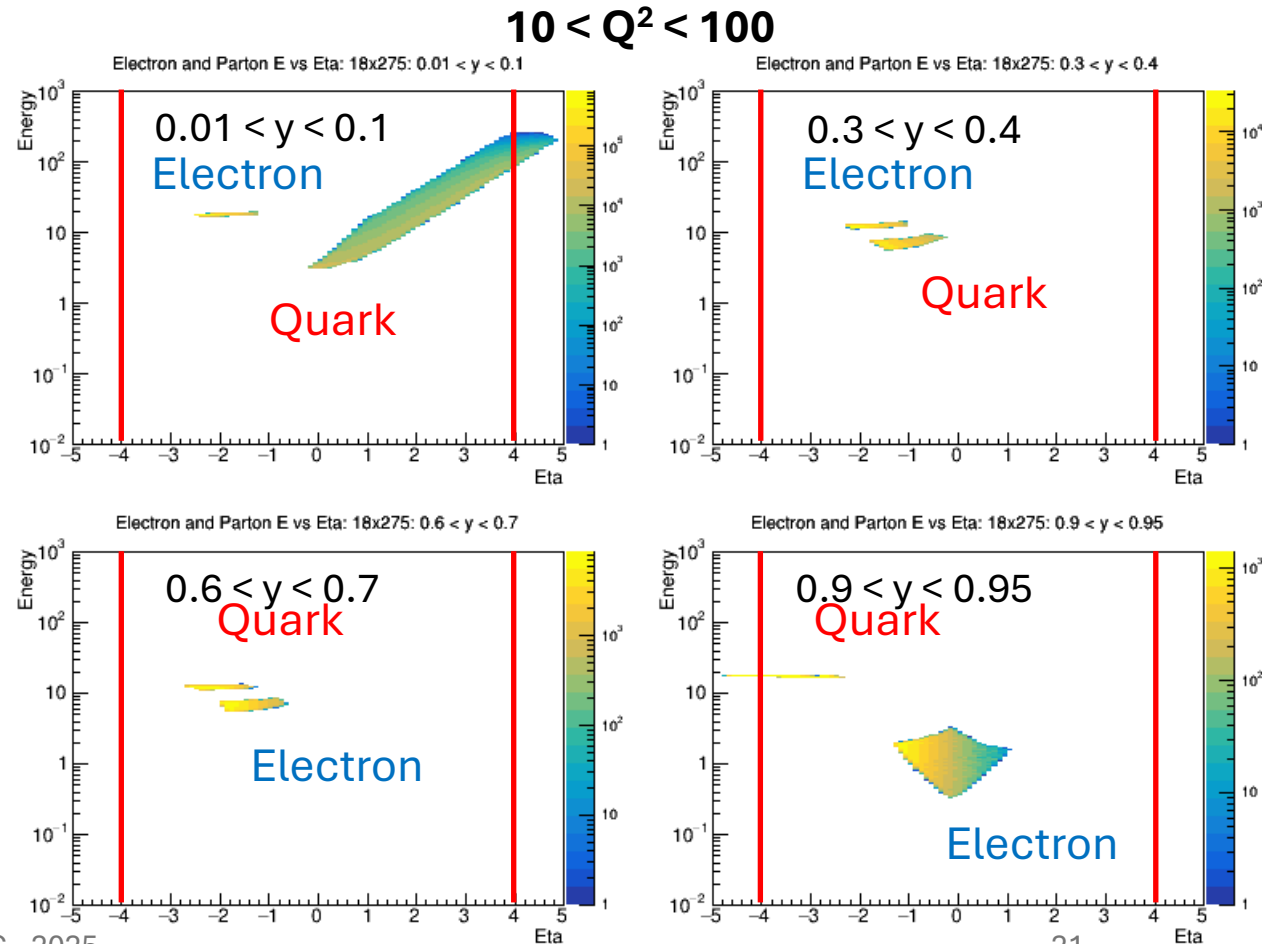


- ❑ At low Q^2 , the hadronic (resolved) nature of the virtual photon becomes important and parton – parton ($2 \rightarrow 2$) scattering can give rise to dijet states
- ❑ Jets can also arise from diffractive events for example

Electron and Struck Quark (18x275)



At fixed Q^2 and y , larger beam energies push the electron and parton to lower pseudorapidity values

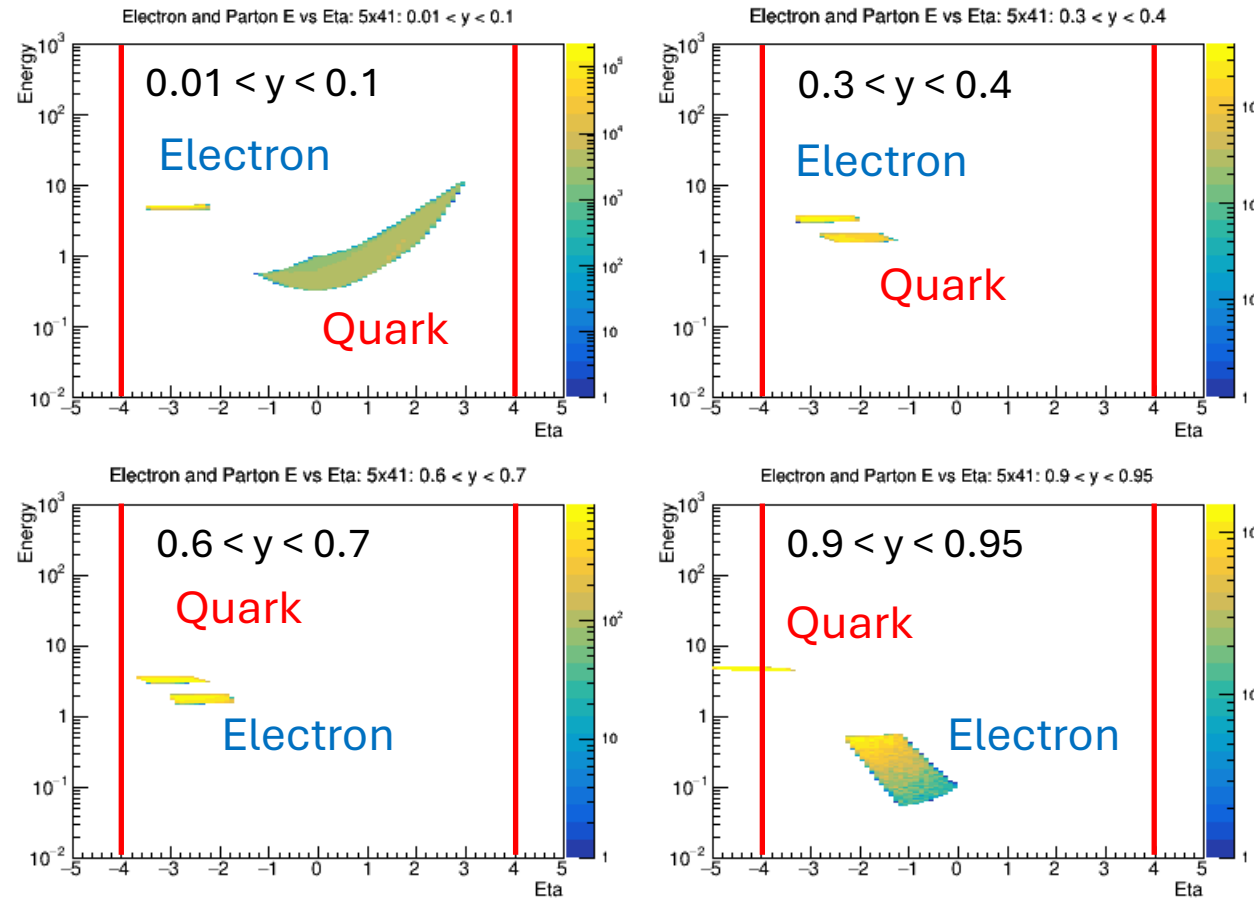


Electron and Struck Quark (5x41)

☐ Look at energy vs pseudorapidity of the scattered electron and struck quark as a function of y and Q^2

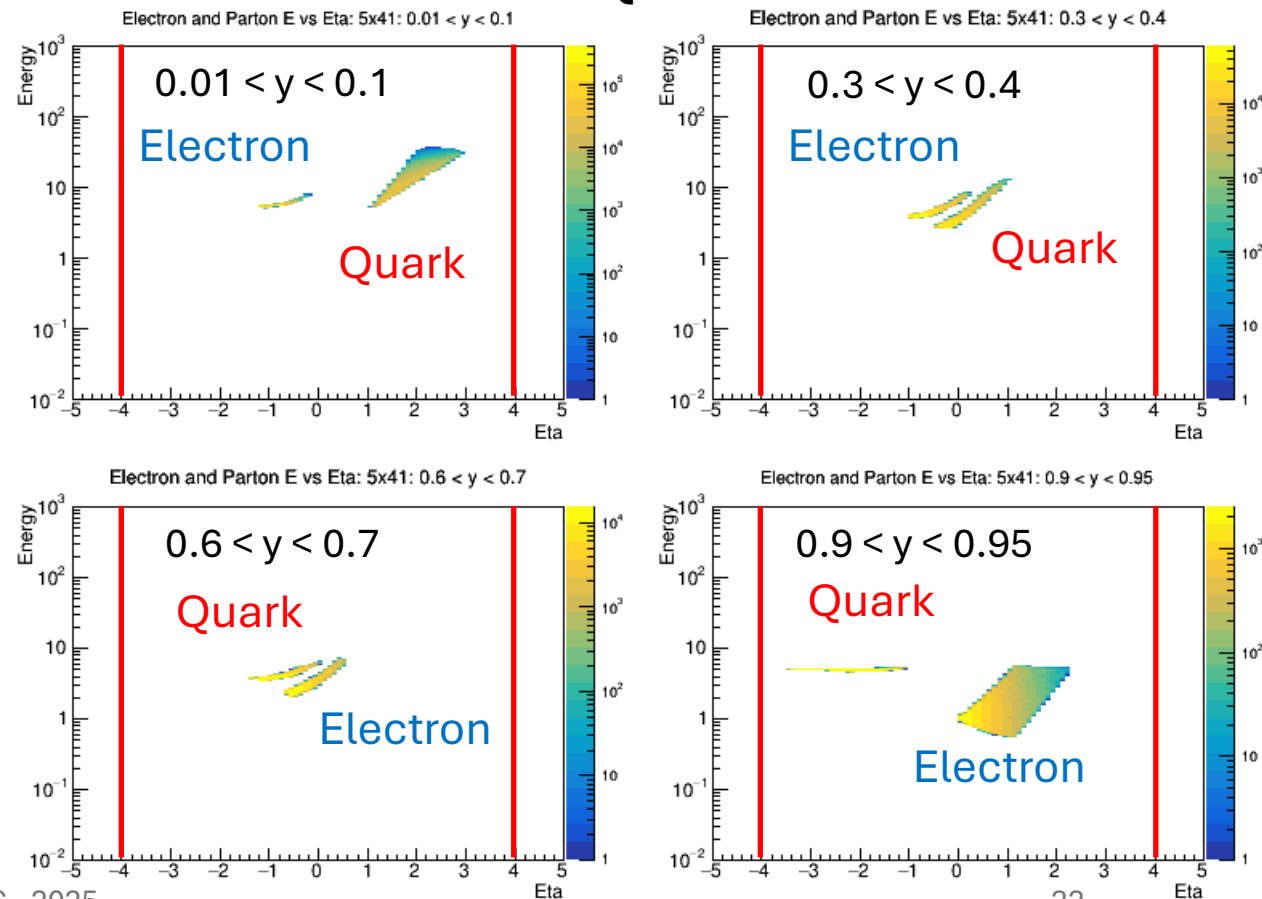
☐ For fixed Q^2 , as y increases, electron eta increases while parton eta decreases

$10 < Q^2 < 100$



$0.1 < Q^2 < 1.0$

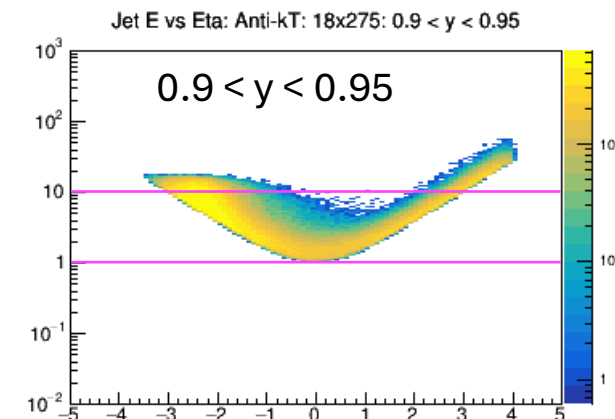
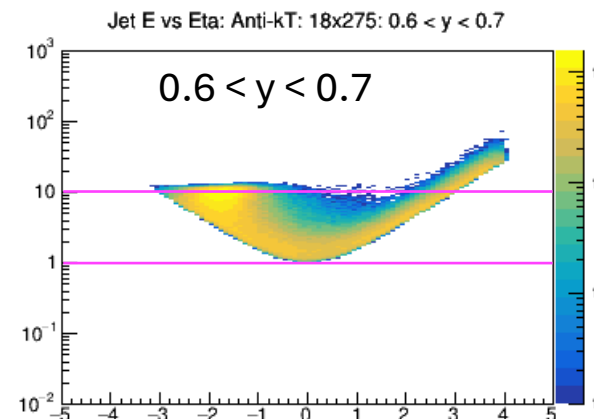
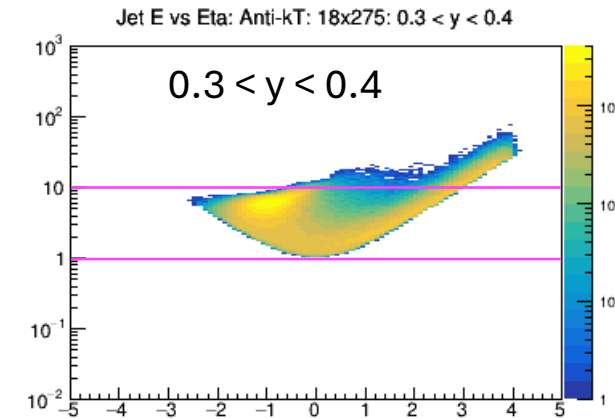
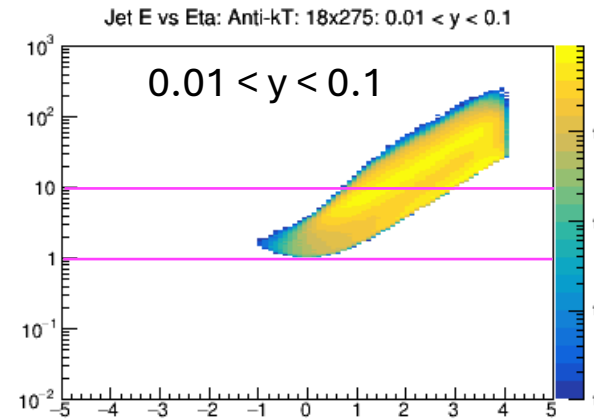
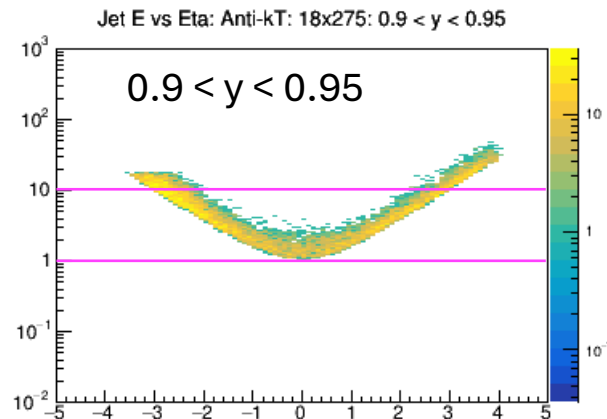
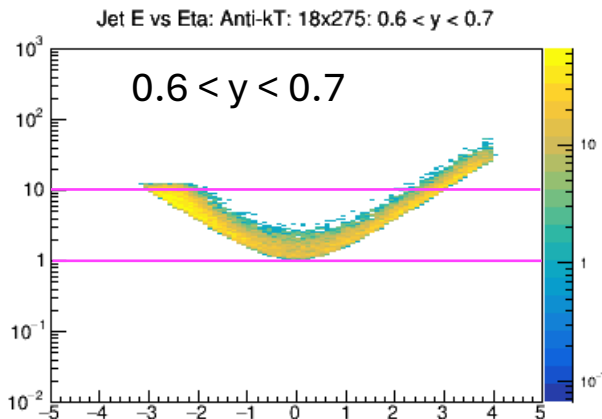
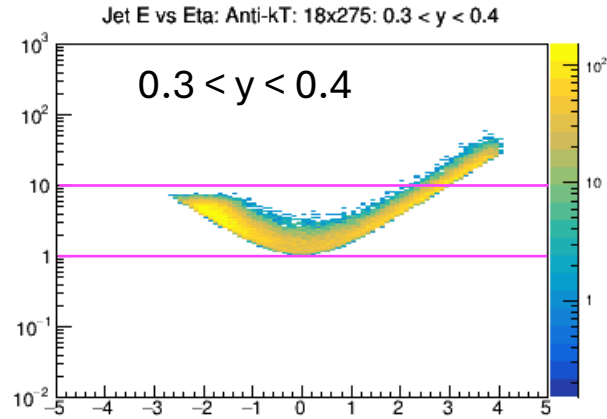
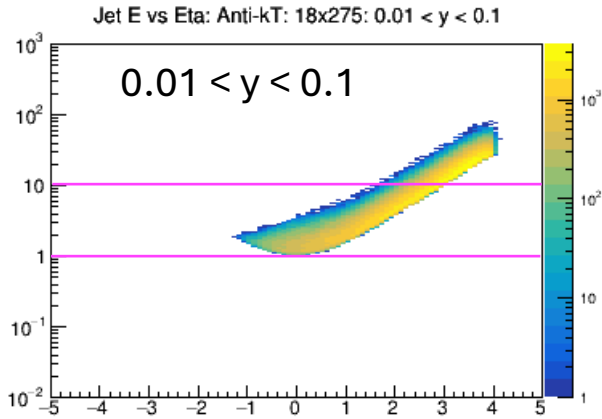
☐ As Q^2 increases, both the scattered electron and struck quark move to larger eta for all values of y



Jet Distributions: Anti- k_T (18x275)

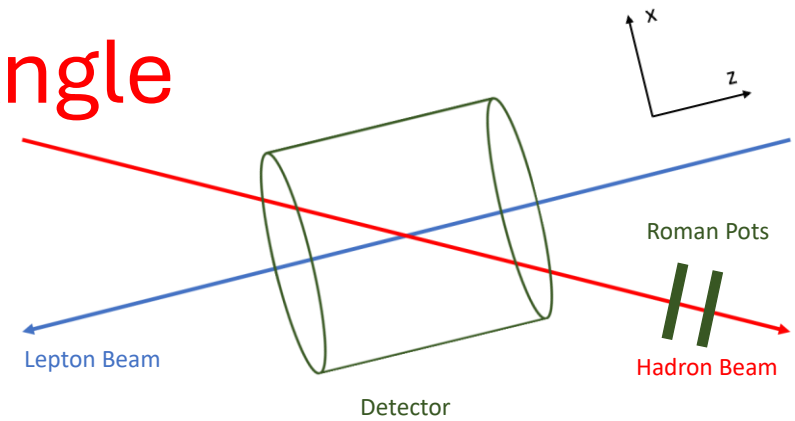
- Run inclusive Anti- k_T on all stable particles ($|\eta| < 4$) with 1 GeV minimum p_T cut
- Jets roughly follow particle distributions

$10 < Q^2 < 100$

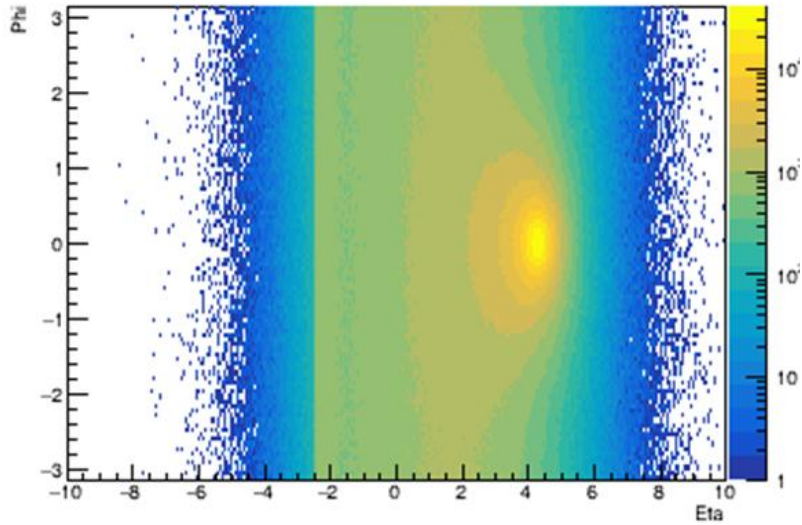


$0.1 < Q^2 < 1.0$

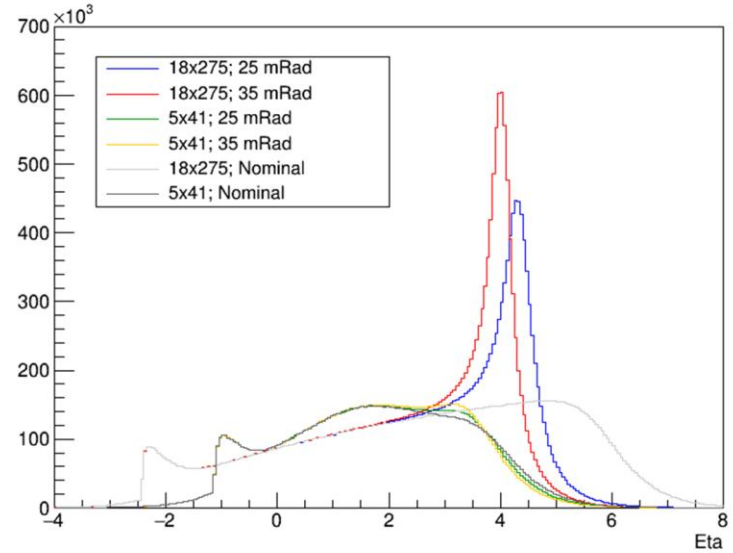
Jet Reconstruction at ePIC: Crossing Angle



Final State Particle Phi Vs Eta: 18x275 25mRad

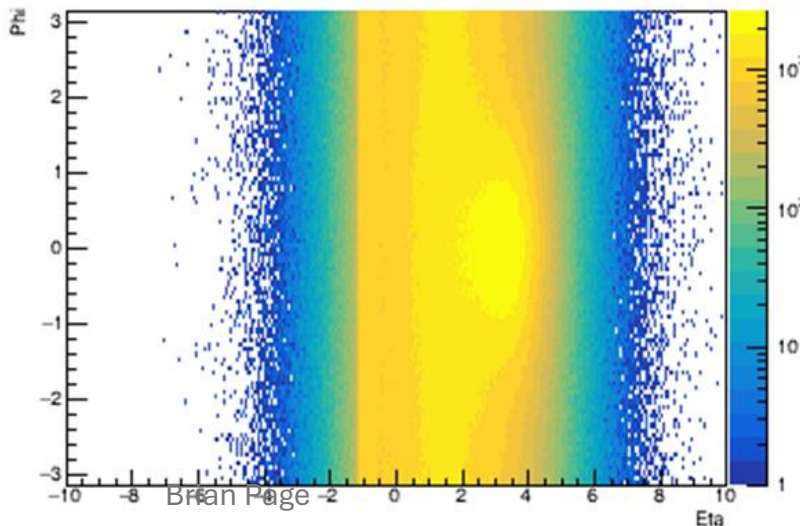


Final State Particle Eta

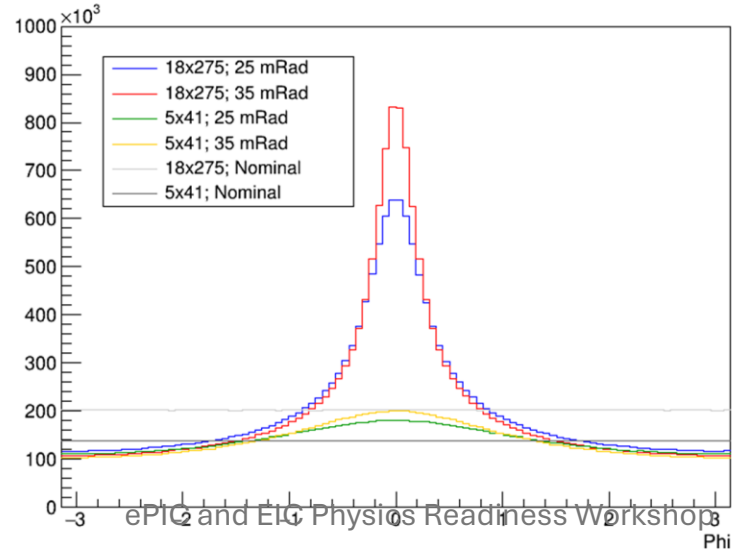


- ❑ Detector solenoid must align with electron beam to minimize synchrotron radiation: “lab frame” -> electron beam = z-axis

Final State Particle Phi Vs Eta: 5x41 25mRad



Final State Particle Phi

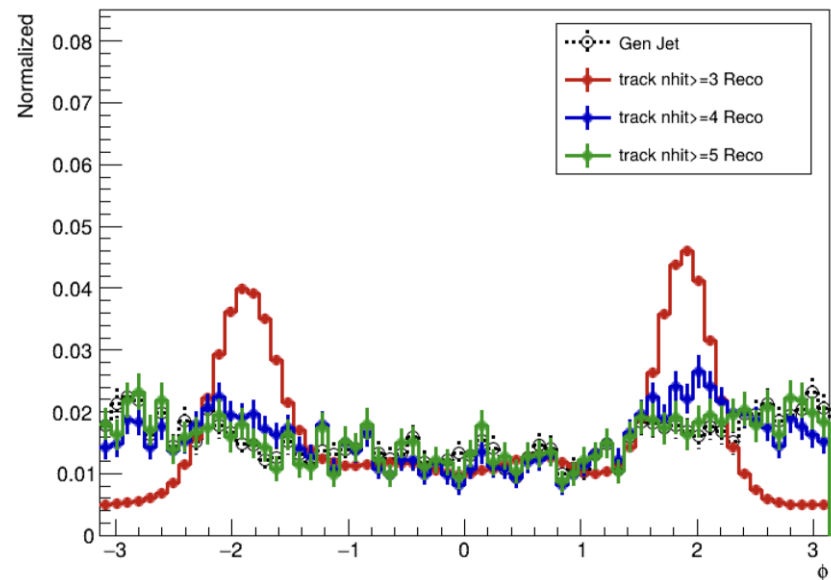


- ❑ When measuring in lab frame coordinates – see a hot spot in eta/phi corresponding to the beam direction

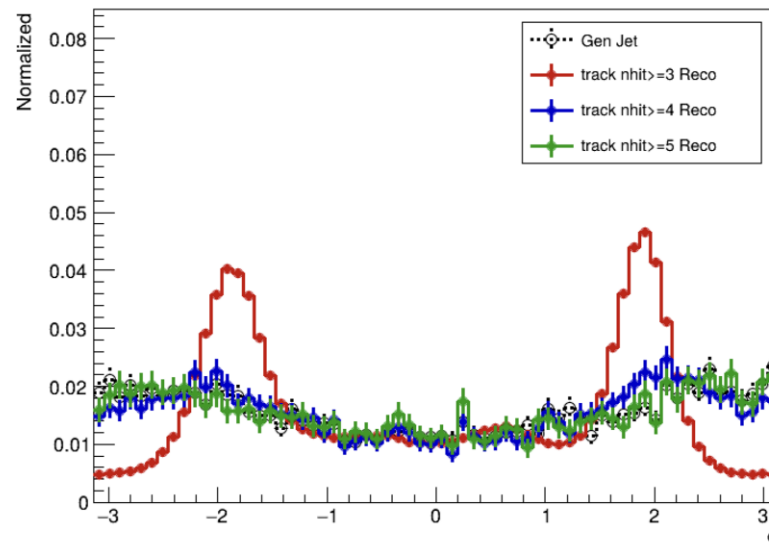
- ❑ More pronounced for more relativistic beams

- ❑ How do we mitigate these features?

10x100 10 μm

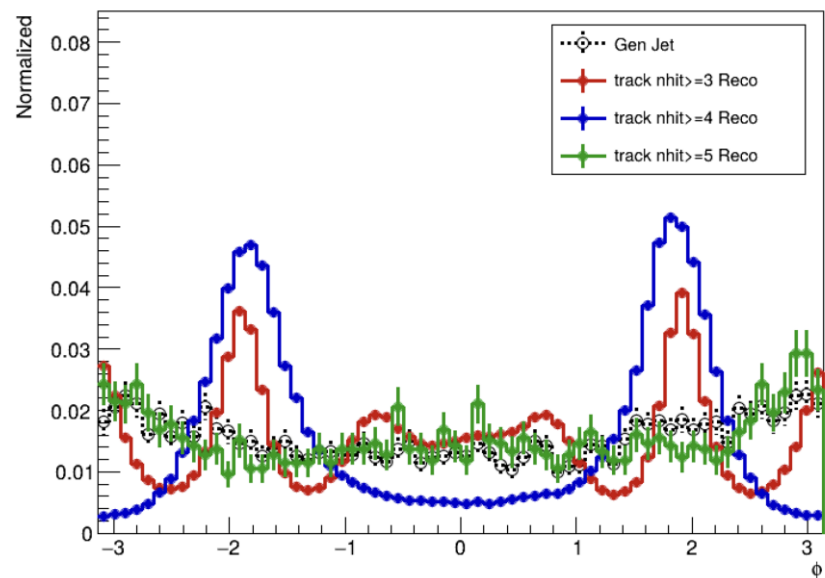


10x275 10 μm

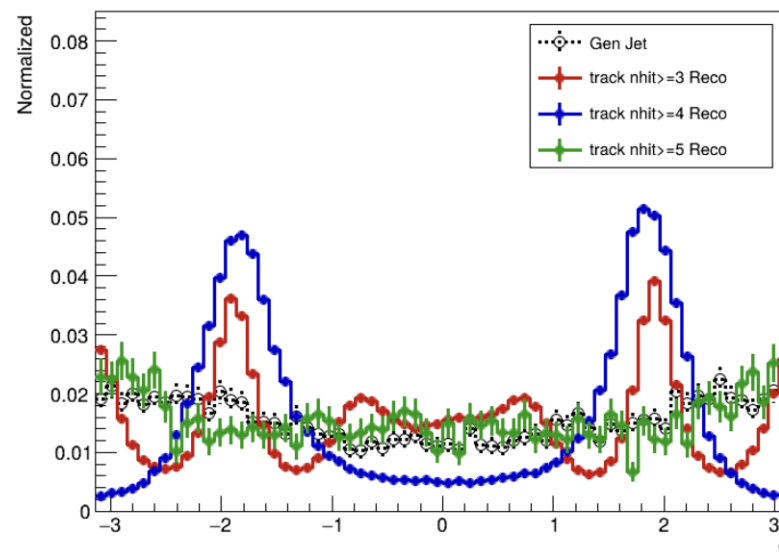


Jet ϕ
Distribution

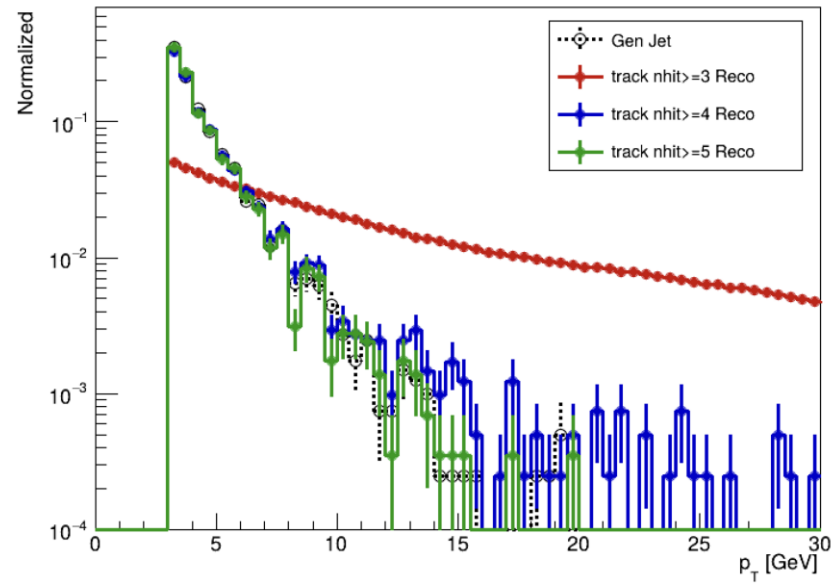
10x100 5 μm



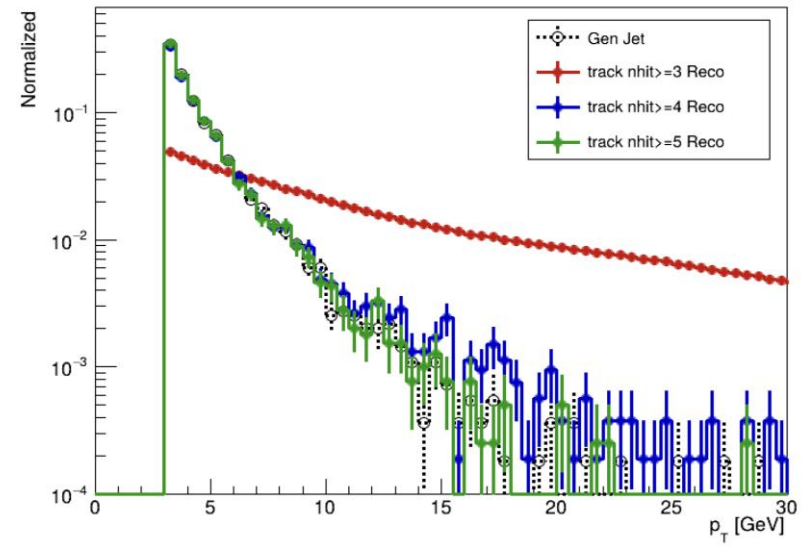
10x275 5 μm



10x100 10 μm

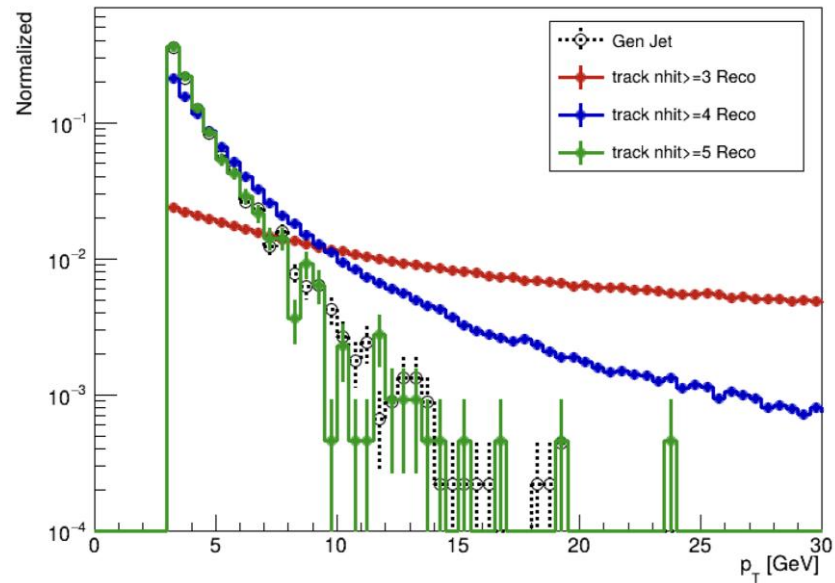


10x275 10 μm



Jet p_T
Distribution

10x100 5 μm



10x275 5 μm

