Hadron in jet production at the EIC

Xilin Liang, Miguel Arratia
University of California, Riverside

The 2nd Workshop on Jets for 3D Imaging at the EIC

Sep 28, 2021

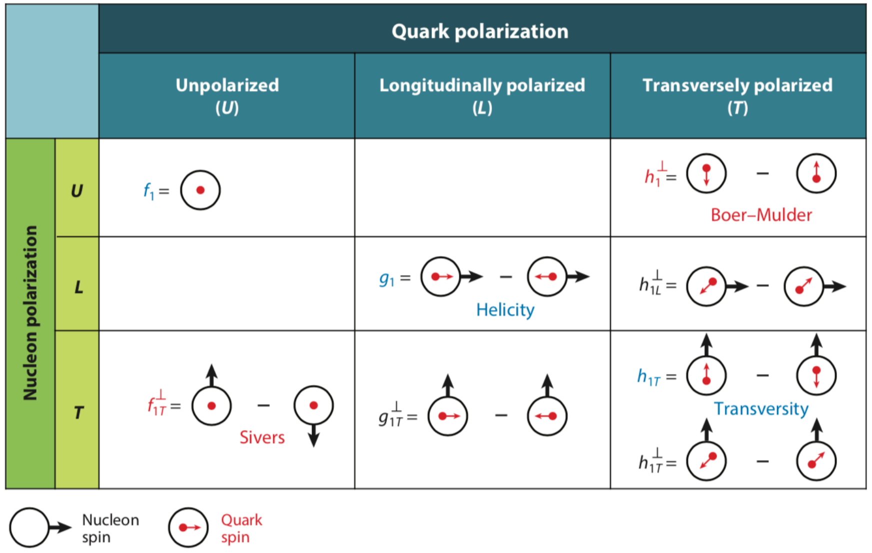
UC RIVERSIDE

Outline

- Motivation
- Particle Identification (PID) performance check
- Hadron in jet PID purity study
- Conclusion and outlook

Motivation

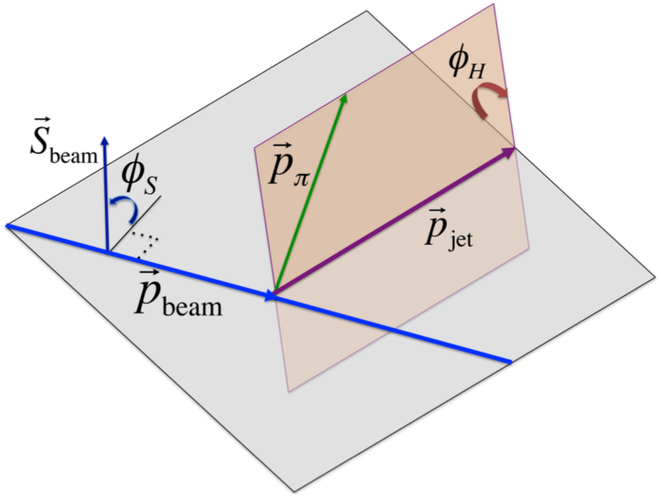
- Jets, which are collimated sprays of particles in high energy particle collision, are useful tools to study Quantum Chromodynamics(QCD).
- Jets can probe the 3D hadronic structure encoded in TMD PDFs and FFs*
  - In polarized collision, jets can probe Sivers effects and Collins effect.
- Jet substructure provides innovative advances to study these effects and explore 3D hadronic structure.

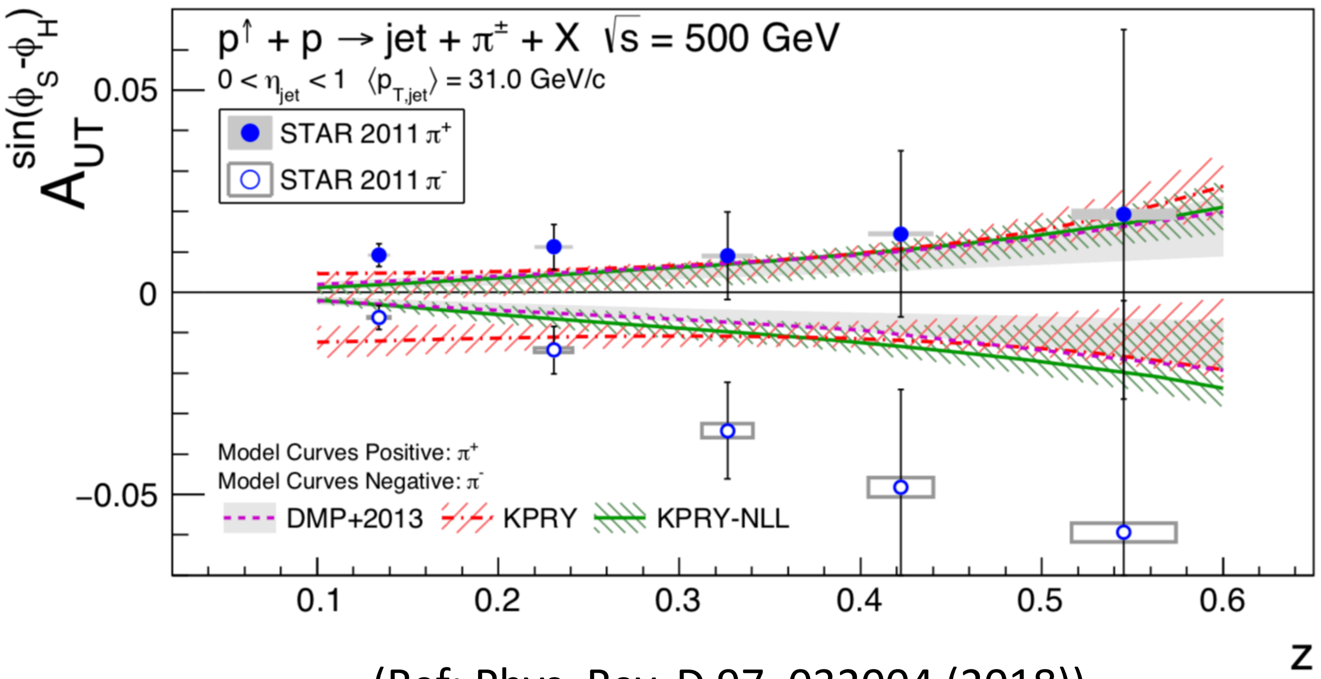


*TMD PDFs and FFs: Transverse Momentum Dependence Parton Distribution Functions and Fragmentation Functions

Motivation

- Collins effect with hadrons in jets. (Ref: Phys. Rev. D 97, 032004 (2018))
- For hadronic tracks in jets, high PID purity is critical for the measurement.
- At the EIC, we could expect to have a higher precision measurement.





(Ref: Phys. Rev. D 97, 032004 (2018))

Basic idea for Particle Identification (PID) hypothesis

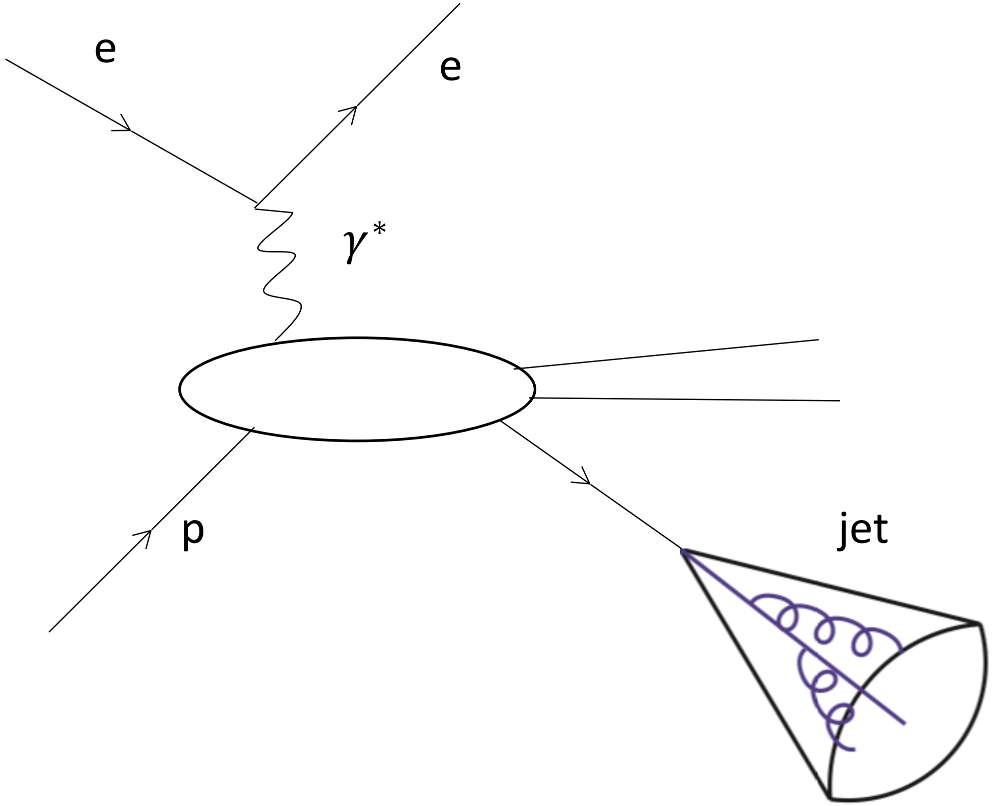
- For tracks, they are given the PID value for particles to indicate their particle species.
- The particle identification systems are implemented in Delphes simulation as identification maps which encode the efficiency that a track with truth identity A will be identified as PID hypothesis B.
- The PID hypothesis is based on assumption that two species should separate by "n sigma", which comes from EICUG PID group and Yellow Report.
  - Track pseudorapidity, momentum serve as the main aspect in PID hypothesis for hadrons.
- Check for Pion, Kaon and Proton tracks.
- Check for 3 different PID system

PID system	Pseudorapidity Range	Momentum Range
	$-3.5 < \eta < -1.0$	$\leq 7\,\text{GeV}/c$
1. barrelDIRC	$-1.0 < \eta < 0.5$	$\leq 10\,\text{GeV}/c$
1. barrelDIRC	$0.5 < \eta < 1.0$	$\leq 15\,\text{GeV}/c$
2. dualRICH_aerogel, 3. dualRICH_c2f6	$1.0 < \eta < 1.5$	$\leq 30\,\text{GeV}/c$
2. dualRICH_aerogel, 3. dualRICH_c2f6	$1.5 < \eta < 2.5$	$\leq 50\,\text{GeV}/c$
2. dualRICH_aerogel, 3. dualRICH_c2f6	$2.5 < \eta < 3.0$	$\leq 30\,\text{GeV}/c$
2. dualRICH_aerogel, 3. dualRICH_c2f6	$3.0 < \eta < 3.5$	$\leq 20\,\text{GeV}/c$

Requested PID momentum coverage for 3σ pion/kaon separation.
Ref: EIC Yellow Report arXiv:2103.05419

Data set

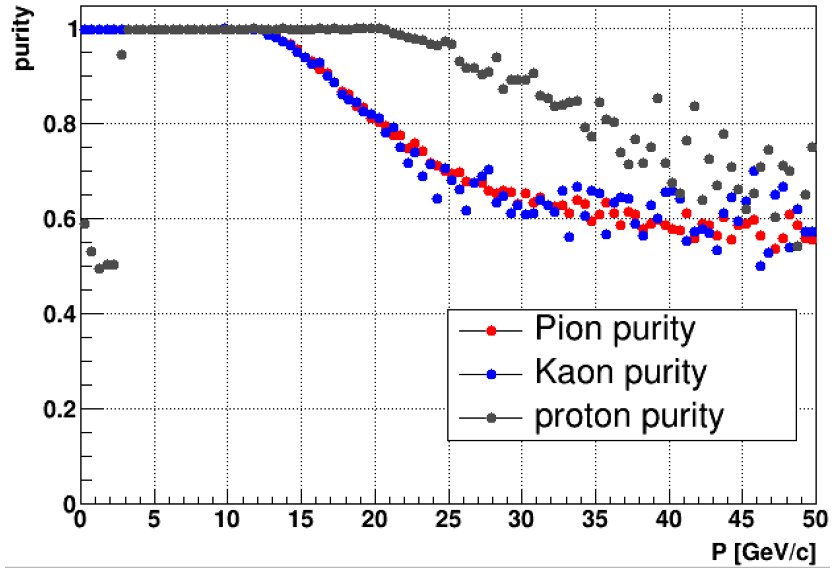
- Use Pythia8 to simulate Deep Inelastic Scattering (DIS) process
- Use Delphes to do the EIC detector respond simulation
  - Delphes card: **ATHENA.tcl** , where PID hypothesis is implemented for calorimeter systems.
- Number of event generated: 1 M
- E_{proton} = 275 GeV
- $E_{electron}$ = 10 GeV
- Q^2 > 25 GeV
- Jet finding algorithm:
  - Anti-kT , R=1.0 , P_T > 3 GeV



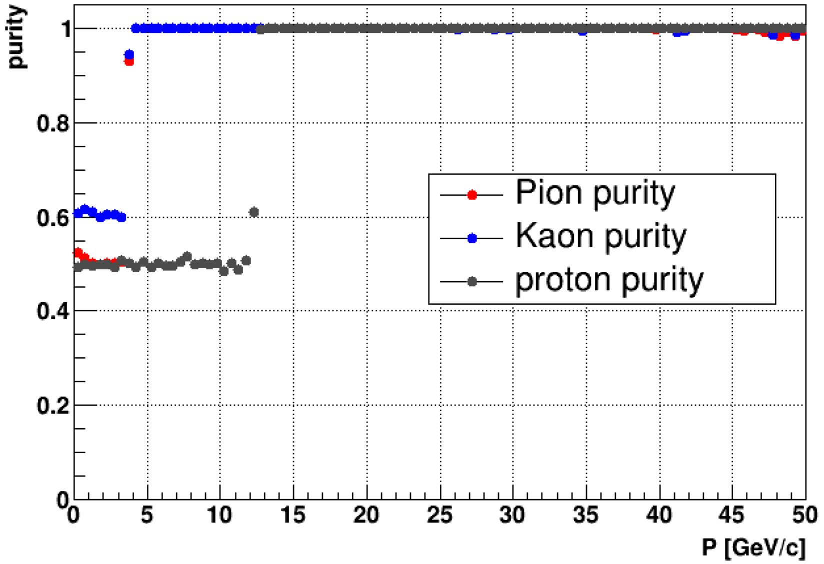
PID performance check for the PID systems

- Particle type: Pion, Kaon, proton
- PID purity: $\frac{number\ of\ correctly\ identified\ tracks\ in\ PID\ system\ for\ each\ tyoe}{number\ of\ all\ true\ level\ tracks\ in\ PID\ system\ coverage\ for\ each\ type}$
  - π purity = $\frac{n(\pi\rightarrow\pi)}{n(\pi\rightarrow\pi)+n(\pi\rightarrow K)+n(\pi\rightarrow Pr)}$

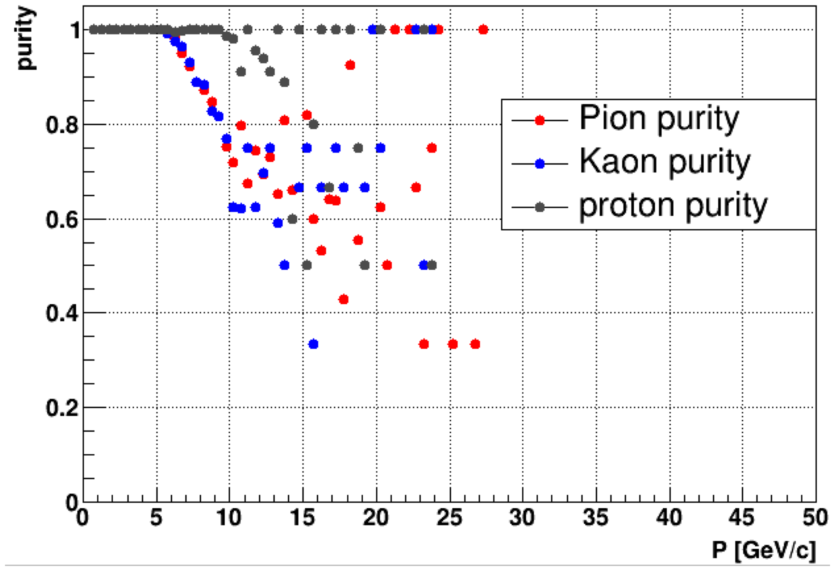
dualRICH_aerogel



dualRICH_c2f6



barrelDIRC



Track PID purity study from jet

- Goal: check PID purity for tracks in jets with different track energy and the track longitudinal momentum fraction (z) from the jet.
  - Check PID purity with changing different (x,Q^2) as the next step.
  - Track longitudinal momentum fraction (z) from jet : $\mathrm{z} = \frac{\vec{p}_{track} \cdot \vec{p}_{jet}}{\vec{p}_{jet}^{2}}$
- Check for 3 PID system:
  - dualRICH_aerogel: $1 < \eta < 3.5$
  - dualRICH_c2f6: $1 < \eta < 3.5$
  - barrelDIRC: $-1 < \eta < 1$
- Check for Pion, Kaon and Proton tracks.

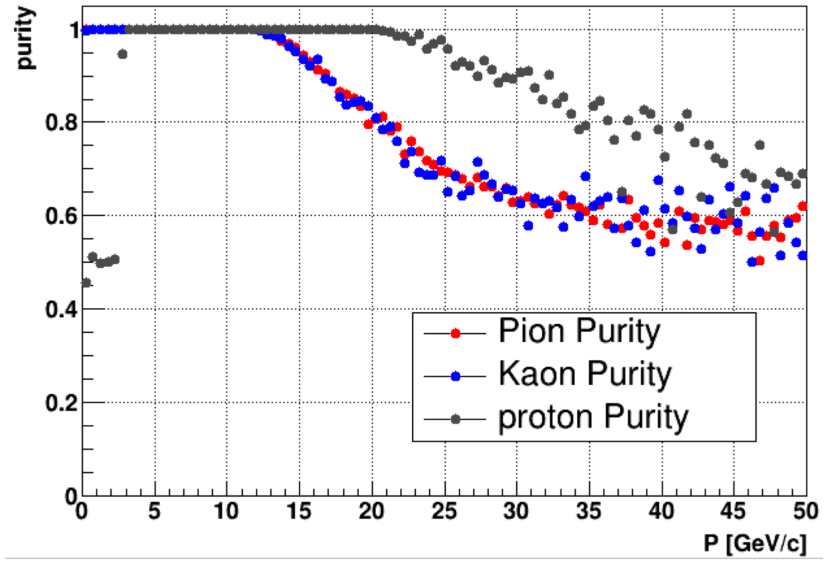
Jet finding algorithm:

Anti-kT , R=1.0 , P_T > 3 GeV

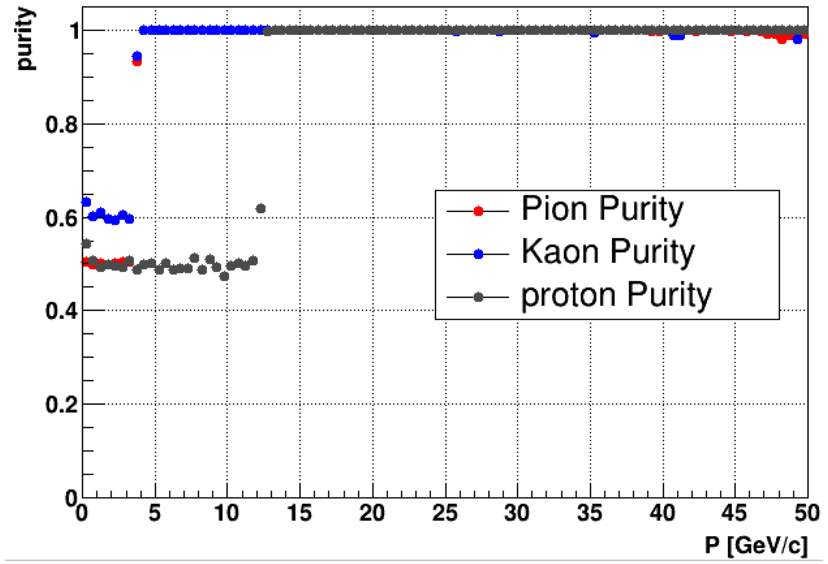
Track in jet purity result with different P

- purity: $\frac{number\ of\ correctly\ identified\ tracks\ in\ PID\ system}{number\ of\ all\ tracks\ in\ jet\ within\ PID\ system\ coverage}$
  - "Correctly identified track": PID value for track in jet is same as the PID value for the corresponding track in PID system hypothesis.
- The purity results distributions look similar with the purity in the PID performance check.

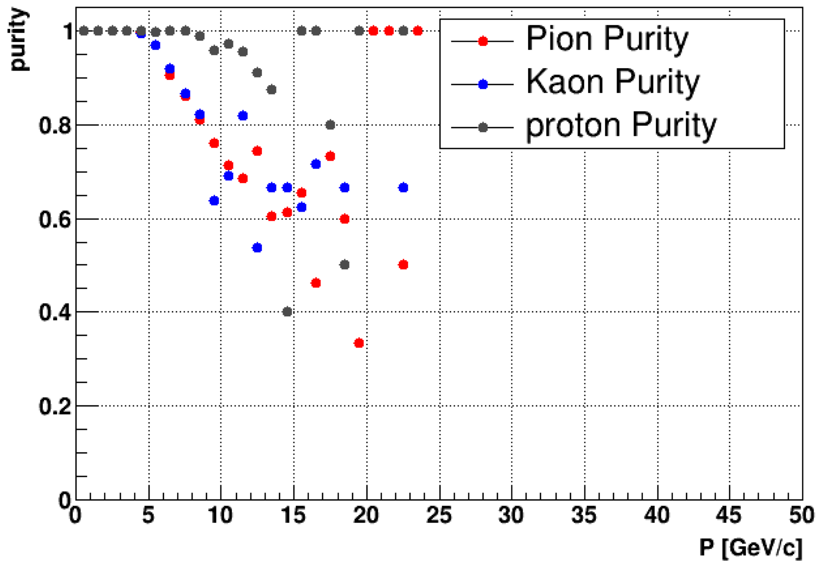
dualRICH_aerogel



dualRICH_c2f6



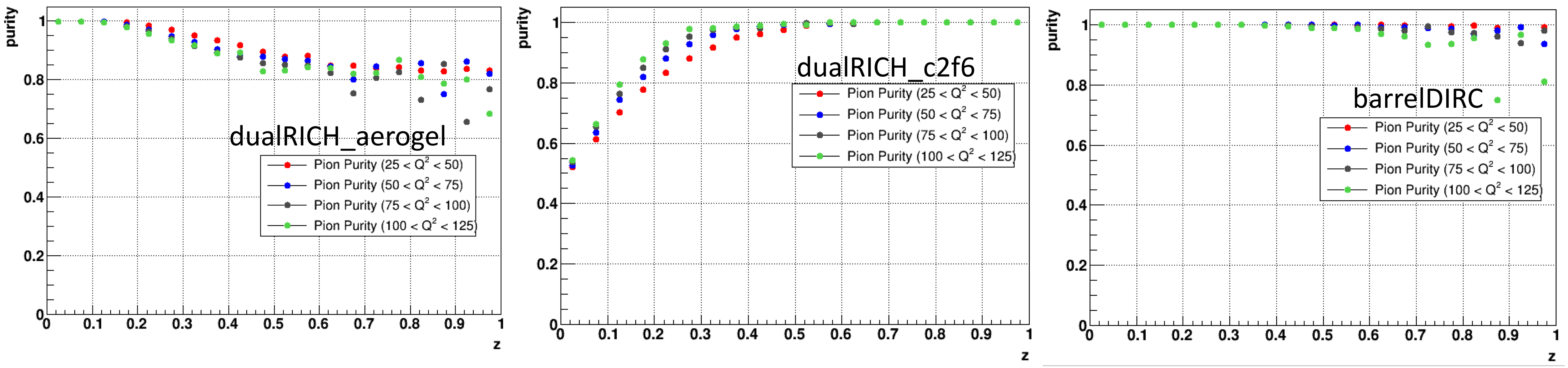
barrelDIRC



Pion track purity result for different z

- purity: $\frac{number\ of\ correctly\ identified\ tracks\ in\ PID\ system}{number\ of\ all\ tracks\ in\ jet\ within\ PID\ system\ coverage}$
  - "Correctly identified track": PID value for track in jet same as the PID value for the corresponding track in PID system hypothesis.
  - Z: track longitudinal momentum fraction from the jet
  - Try to look at the pion track purity with the change of Q^2.

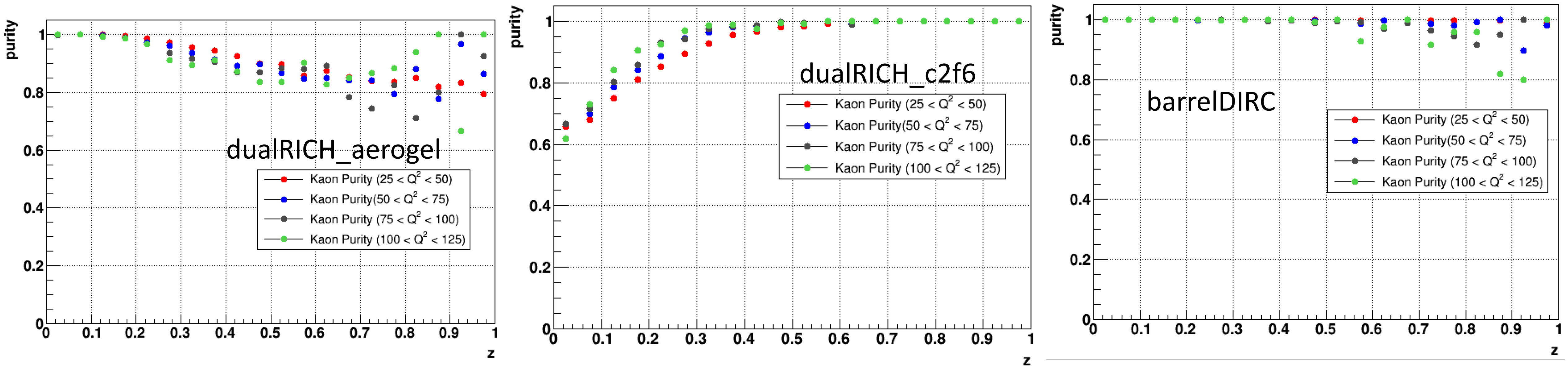
$$z = \frac{\vec{p}_{track} \cdot \vec{p}_{jet}}{\vec{p}_{jet}^{\,2}}$$



Kaon track purity result for different z

- purity: $\frac{number\ of\ correctly\ identified\ tracks\ in\ PID\ system}{number\ of\ all\ tracks\ in\ jet\ within\ PID\ system\ coverage}$
  - "Correctly identified track": PID value for track in jet same as the PID value for the corresponding track in PID system hypothesis.
  - Z: track longitudinal momentum fraction from the jet

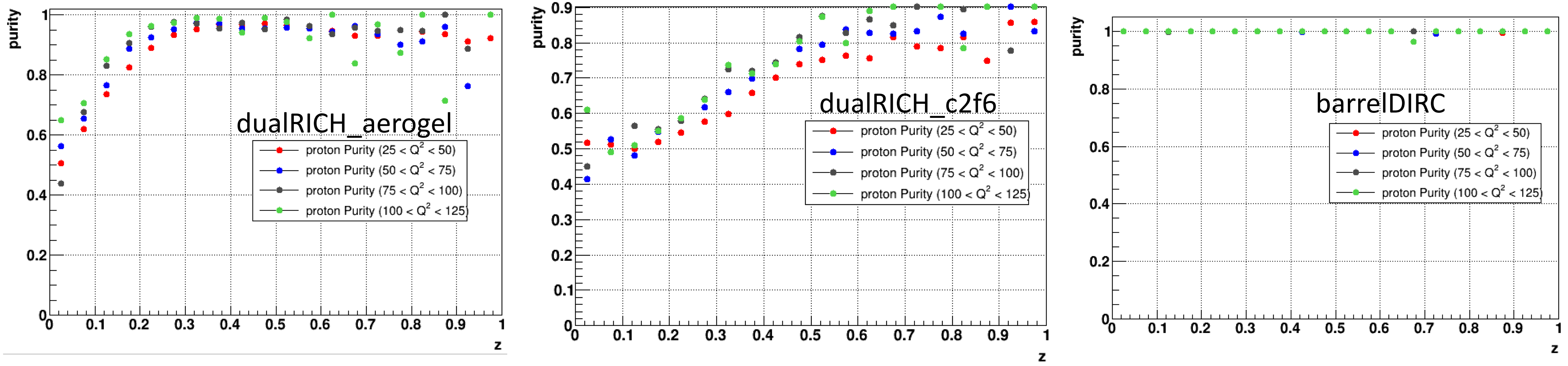
$$z = \frac{\vec{p}_{track} \cdot \vec{p}_{jet}}{\vec{p}_{jet}^{\,2}}$$



Proton track purity result for different z

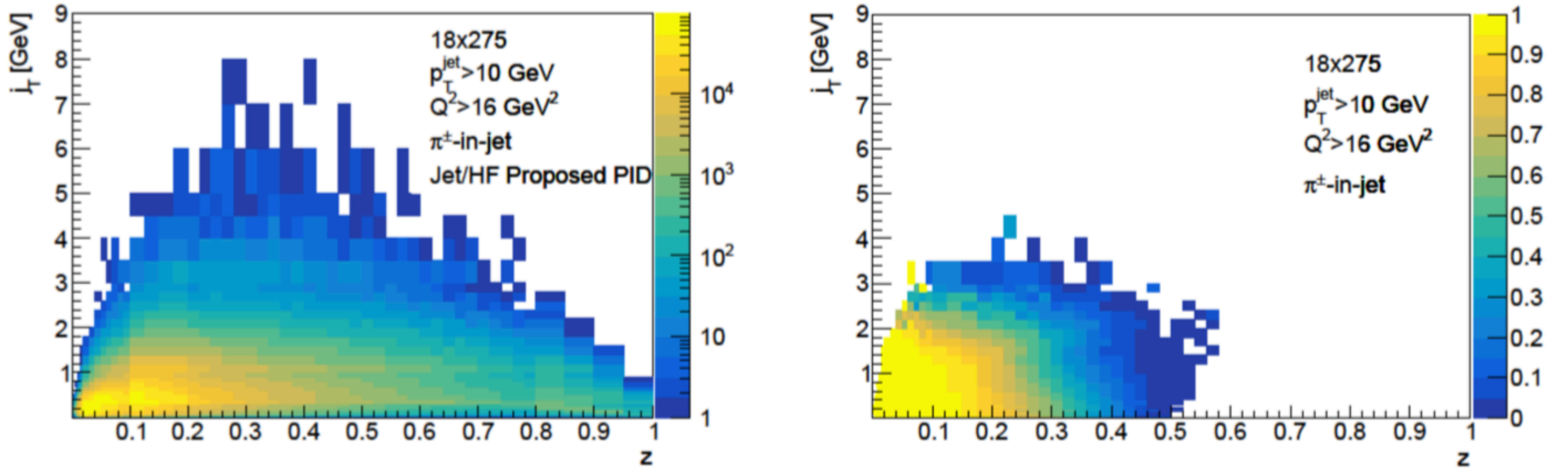
- purity: $\frac{number\ of\ correctly\ identified\ tracks\ in\ PID\ system}{number\ of\ all\ tracks\ in\ jet\ within\ PID\ system\ coverage}$
  - "Correctly identified track": PID value for track in jet same as the PID value for the corresponding track in PID system hypothesis.
  - Z: track longitudinal momentum fraction from the jet.

$$z = \frac{\vec{p}_{track} \cdot \vec{p}_{jet}}{\vec{p}_{jet}^{\,2}}$$



Further investigation on PID with limited phase space

- The restricted momentum coverage (right plot) taken based on pseudorapidity range will limit the phase space and cause the high z range to be inaccessible.
    - The restricted momentum coverage is based on expected performance range.

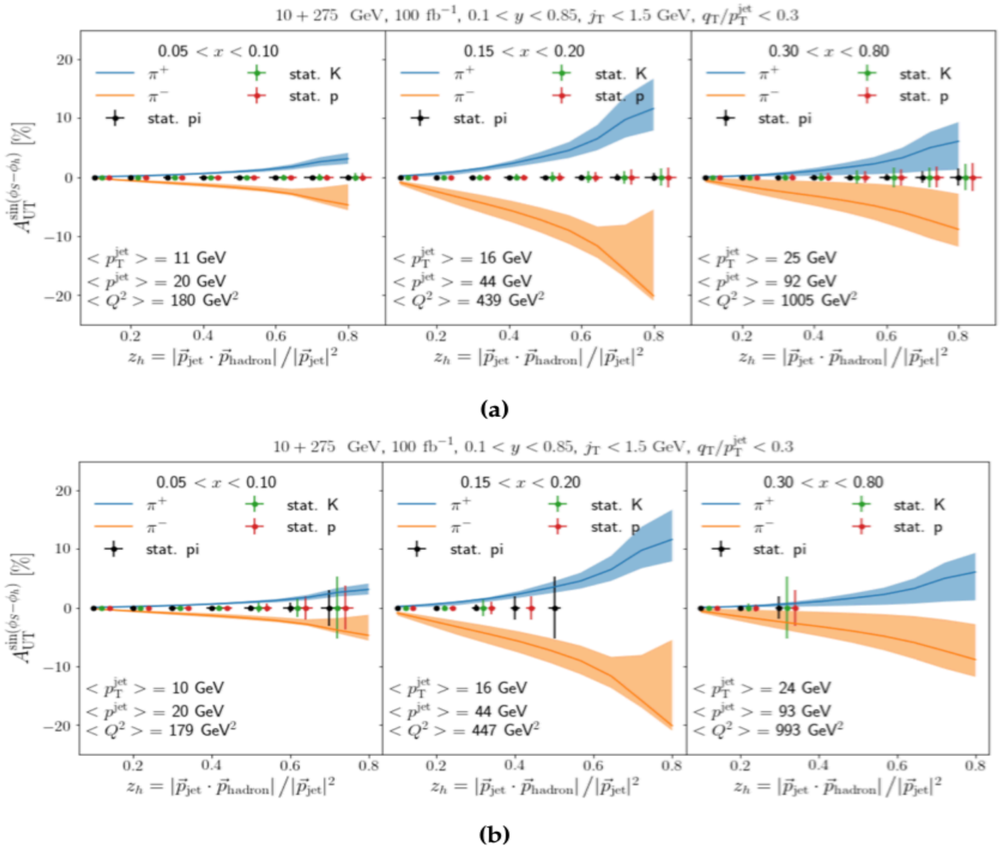


(a) (b)

Ref: EIC Yellow Report arXiv:2103.05419

Impact on physics measurement with restricted momentum coverage

- Top row plots are Collins asymmetry with hadrons in perfect expected PID.
- Bottom row plots are Collins asymmetry with hadrons in restricted momentum reach PID.
- Our ongoing step is to investigate how the PID purity change in limited phase space by choosing different (x,Q^2).



Ref: EIC Yellow Report, arXiv:2103.05419
M. Arratia, Z. Kang, A. Prokudin, F. Ringer Phys.Rev.D 102 (2020) 7, 074015

Conclusion and outlook

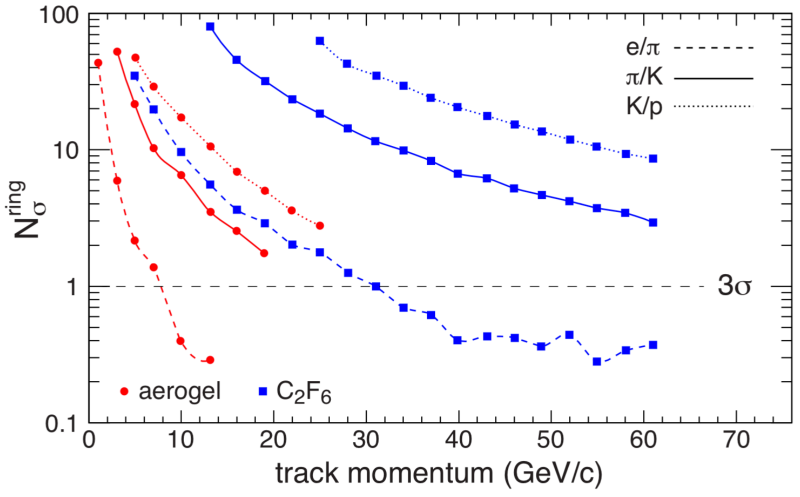
- At EIC, we would expect to explore TMD and probe hadronic structure with higher precision.
  - High PID purity for tracks in jet plays an essential role.
- The PID purity for dualRICH_aerogel, dualRICH_c2f6 system and barreDIRC system works well in the simulation and match with the expectation from EIC design.
- The PID purity for tracks in jets looks reasonable and we will continue to work with different (x,Q^2) ranges to explore the PID purity with the limited phase space.

Thank you!

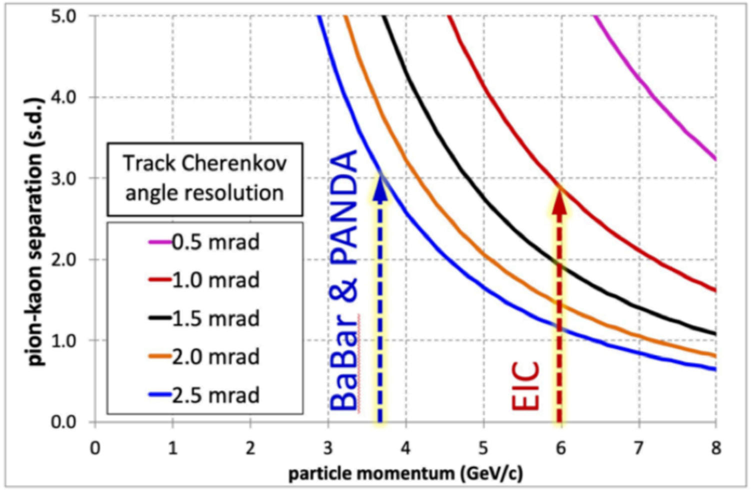
Back up

PID ability for dualRICH and barrelDIRC system

- **Dual RICH** system utilize two different radiator:
  - Aerogel radiator and gas radiator (C_2F_6)
- dualRICH system coverage for PID ability is $1 < \eta < 3.5$
- Two different radiator have different particle species separation ability for track momentum.



- **Barrel DIRC** system is based on Detection of Internally Reflected Cherenkov light (DIRC).
- Coverage for PID ability is $-1 < \eta < 1$
- To satisfy the physics goals for EIC, π/K identification are required up to 5 – 7 GeV/c.



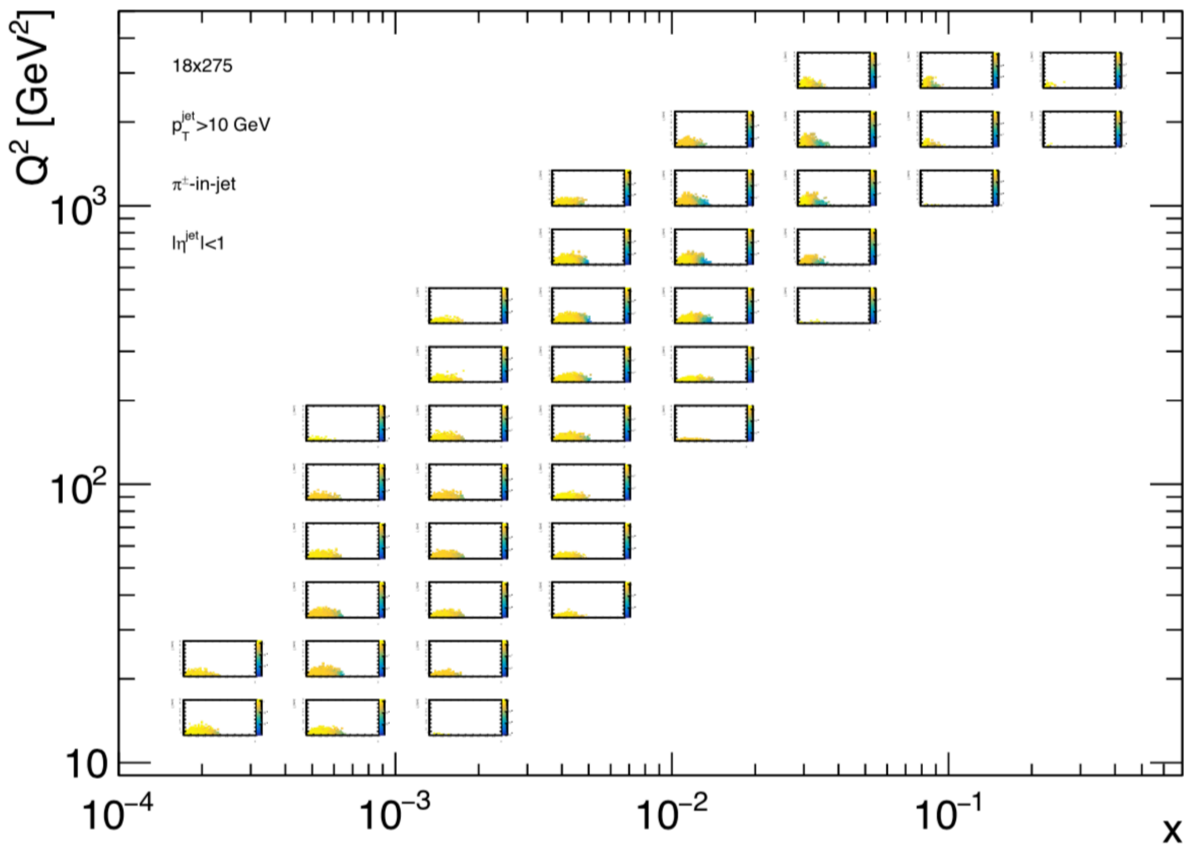
Ref: EIC Yellow Report arXiv:2103.05419

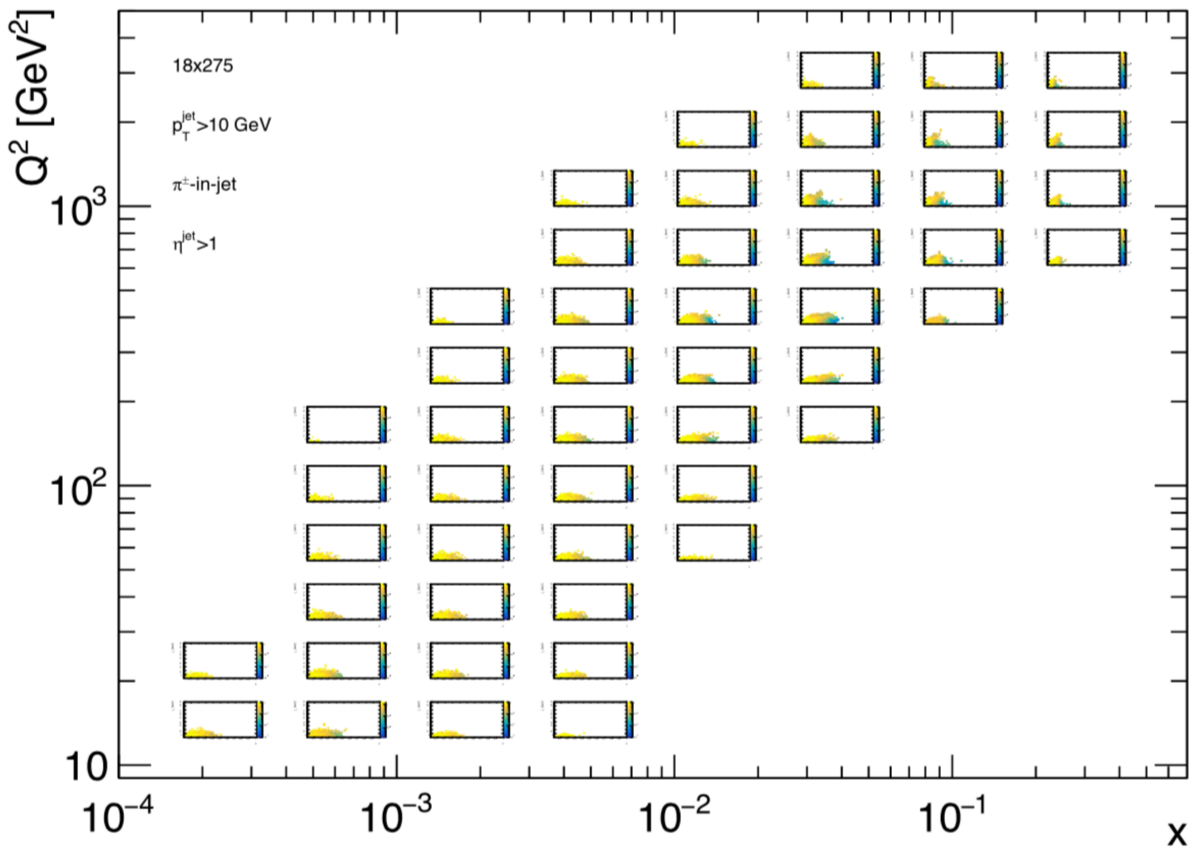
The restricted momentum coverage values

Pesudorapidity range	restricted momentum coverage
$-1.0 < \eta < 1.0$	<= 5 GeV/c
$1.0 < \eta < 2.0$	<= 8 GeV/c
$2.0 < \eta < 3.0$	<= 20 GeV/c
$3.0 < \eta < 3.5$	<= 45 GeV/c

Effects on restricted momentum limit coverage on phase space

- Barrel region jets (left plot) and forward region jets (right plot).





Ref: EIC Yellow Report arXiv:2103.05419