Jets at the EIC: A Primer

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EICUG Early Career Workshop

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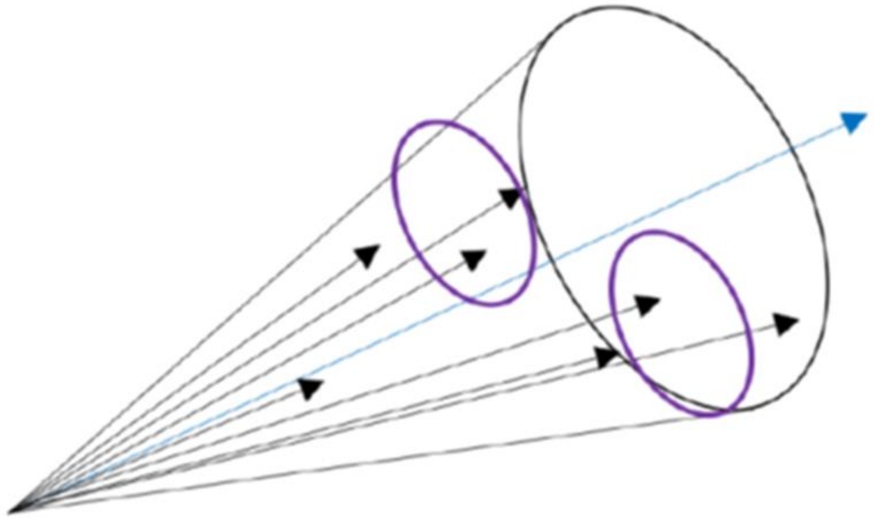
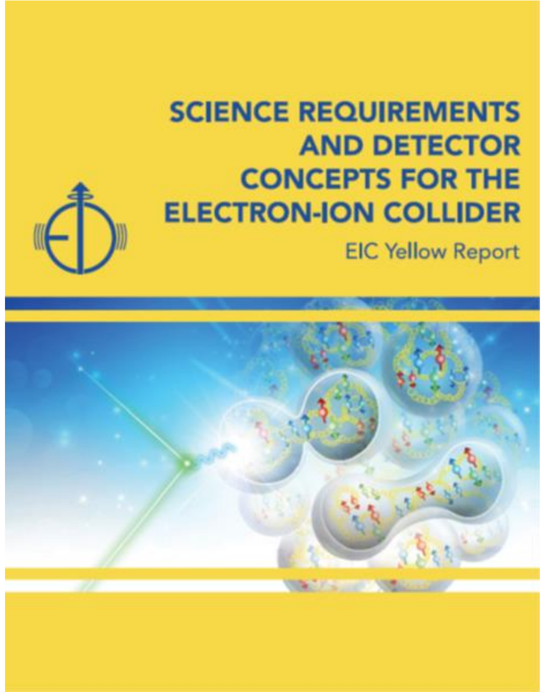


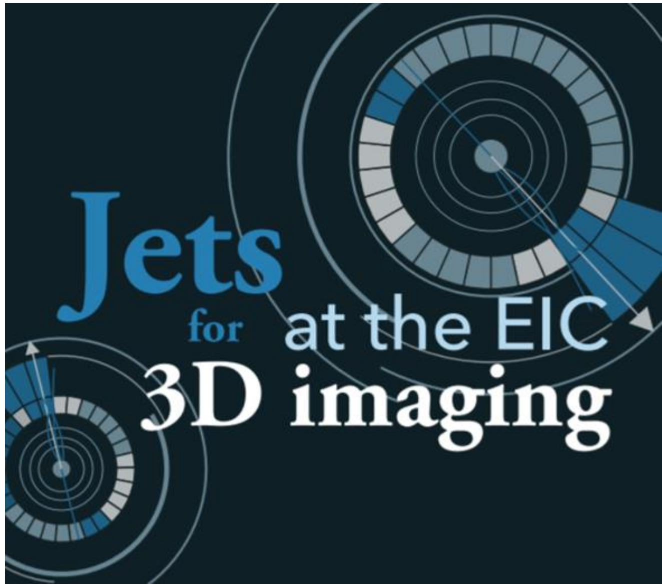
Outline

- Introduction to Jets
- Jet Considerations for the EIC: Subprocesses, Kinematics, etc
- Physics with Jets at the EIC
- Beam Crossing Angles
- Jet Finding at ePIC

Jets at the EIC: A Brief History

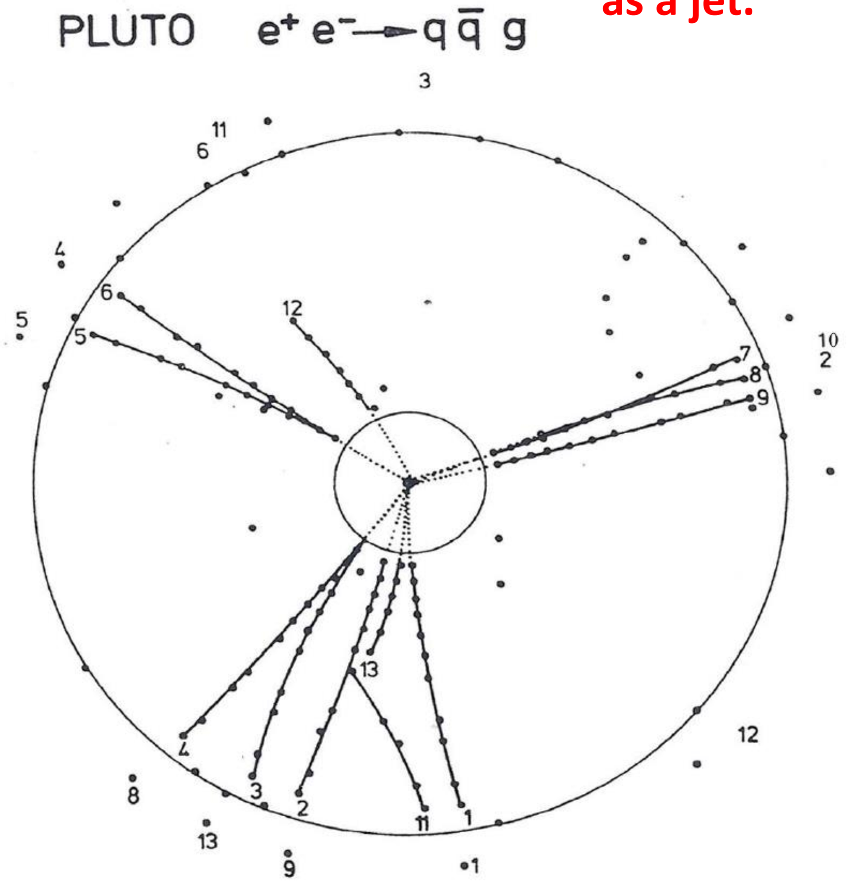
- Initially, jets did not receive much attention and were only mentioned in passing in the initial EIC Whitepaper
  - EIC a relatively low energy machine – will jets be a useful probe?
  - SIDIS is well established and understood – will jets be redundant?
- Last ~10+ years have seen a significant uptick in interest in jet physics at the EIC as evidenced by:
  - Increasing number of papers
  - Dedicated treatment in EICUG Yellow Report
  - Dedicated WGs in EIC proto-collaborations and current project detector collaboration - ePIC
- All this activity is driven by the realization that jets will have a robust and unique role to play in the EIC science program

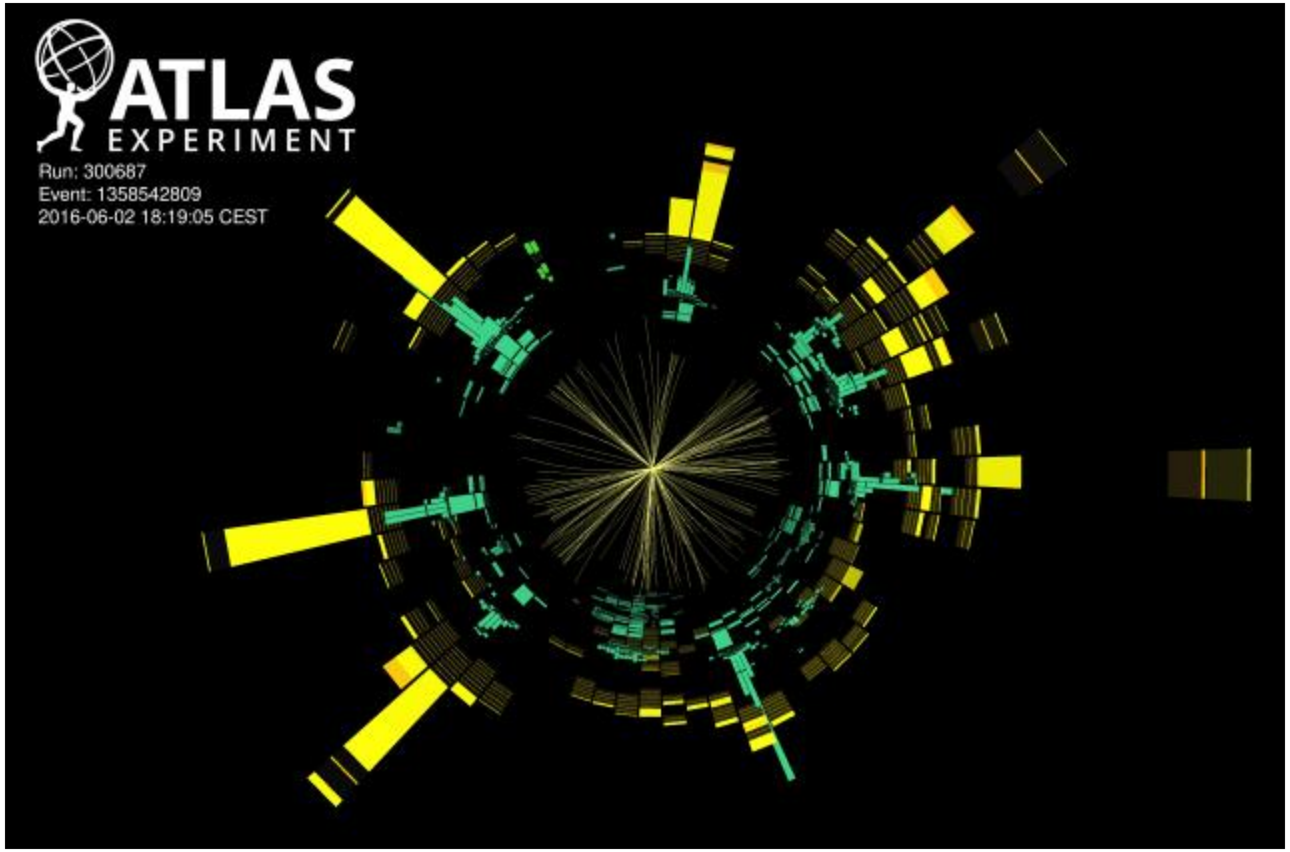




What is a Jet?

ChatGPT: **In particle physics, a jet is a narrow cone of particles produced by the hadronization of a quark or gluon**. When high-energy quarks or gluons are produced in particle collisions, such as those in a particle accelerator, they cannot exist freely due to a phenomenon called color confinement. Instead, **they fragment and hadronize, forming a shower of hadrons** (particles composed of quarks bound together by the strong force) that travel in roughly the same direction. **This collection of hadrons is what is observed as a jet.**





What is a Jet?

The above definition is not very useful from a physics standpoint. A more precise statement is that a jets is the result of applying a **jet definition** to a set of final state objects

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- ❑ A jet algorithm is a recipe for mapping a set of constituents into a set of jets
- ❑ Broadly divided into cone and sequential recombination type algorithms
- ❑ Cone: Midpoint-cone & SIScone
- ❑ S.R.: (Anti)k_T

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Jet Definition = Jet Algorithm + Recombination Scheme

- A recombination scheme tells us how to add together the energy and momenta of the jet constituents into that of the jet
- E-scheme: constituent 4-momenta are simply added – is by far the most common
- Winner-Take-All: adds energies but sets direction to lay along hardest constituent – thrust axis insensitive to soft radiation

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Jet Definition = **Jet Algorithm** + **Recombination Scheme**

- A good jet definition should
  - Be applicable to experimental measurements, parton-shower MC, and theory calculations
  - Be “well behaved” theoretically
  - Be relatively insensitive to “non-jet” contributions like underlying event or pile-up

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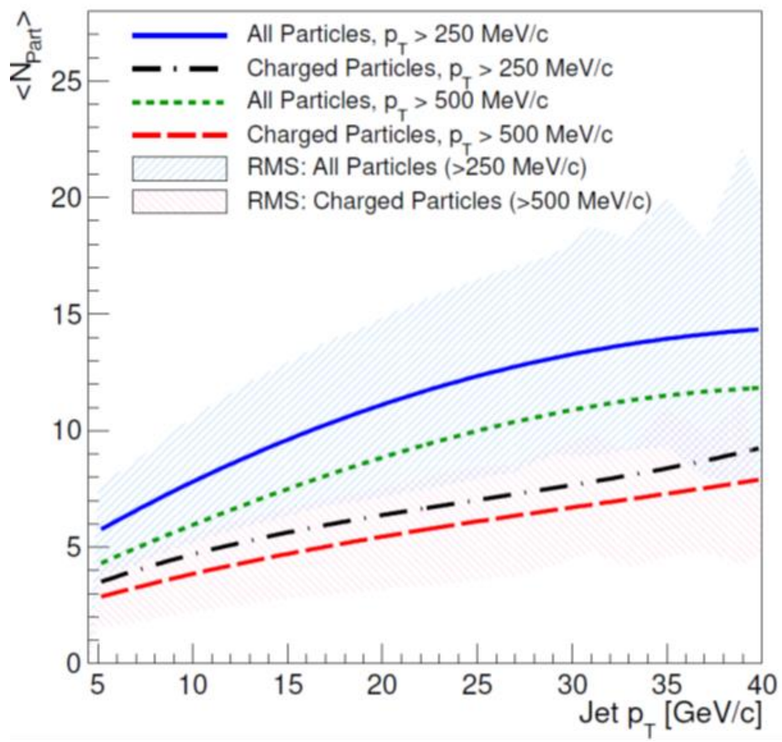
Jets at the EIC

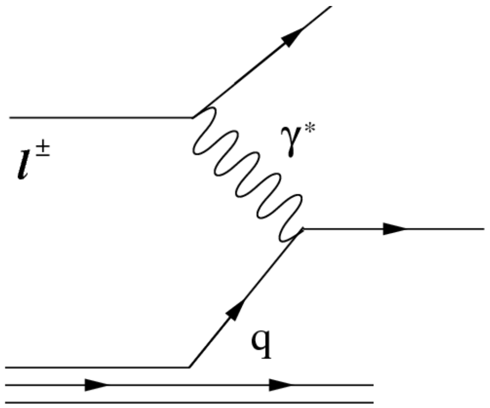
Jet analyses at the EIC will in many ways be similar to those at hadron colliders, but there are several aspects one should be aware of:

- Relevant subprocesses: there are many subprocesses which give rise to final state jets in ep collisions. Each can have different kinematic dependencies and probe different physics
- Reference frames: the lab frame is generally the only useful reference frame in hadron colliders, but the properties of ep collisions allows us to define and access other useful frames
- Kinematics: the asymmetric nature of collisions at the EIC and strong correlations between kinematic variables means jets in different parts of the detector can have very different energies and probe different areas of phase space
- Jet Algorithms: jet algorithms besides the standard anti-kT prevalent at hadron colliders will be useful in many cases
- Jet environment: ep collisions are ‘cleaner’ than hadron-hadron collisions meaning underlying event contamination won’t be as much of an issue. Pile-up will also be rare. EIC jets will be relatively sparse objects, with few charged particles spread over a wide cone

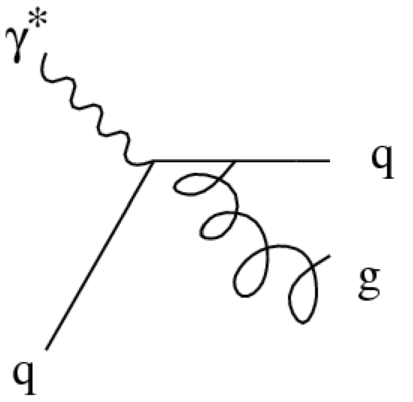


Relevant Subprocesses

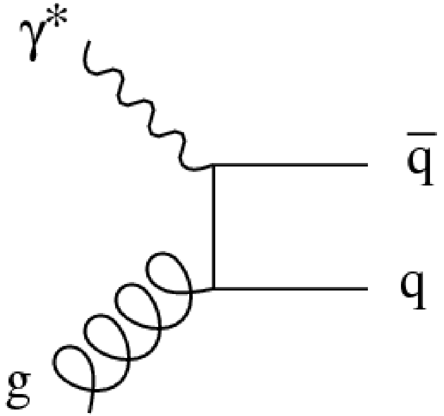
DIS



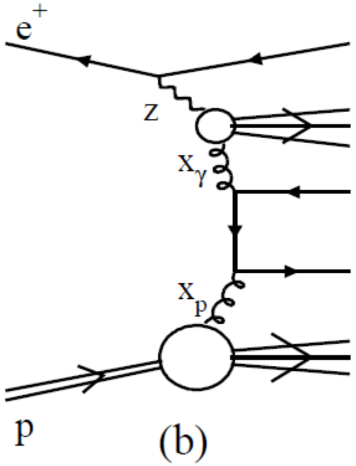
QCD-Compton (QCDC)



Photon-Gluon Fusion (PGF)



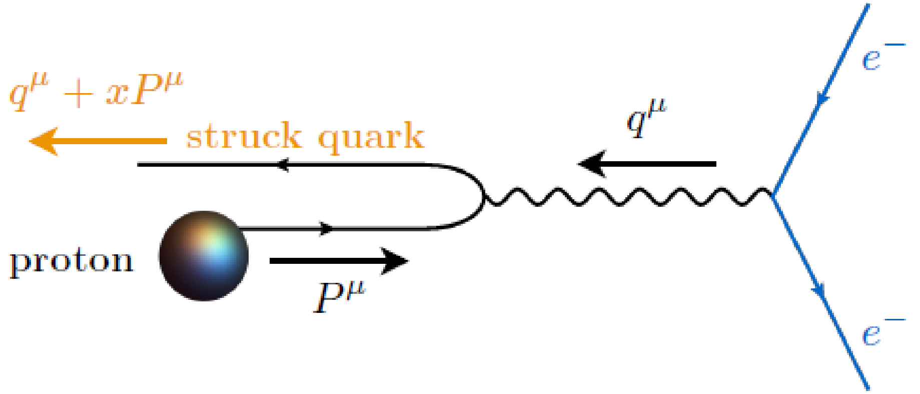
Resolved



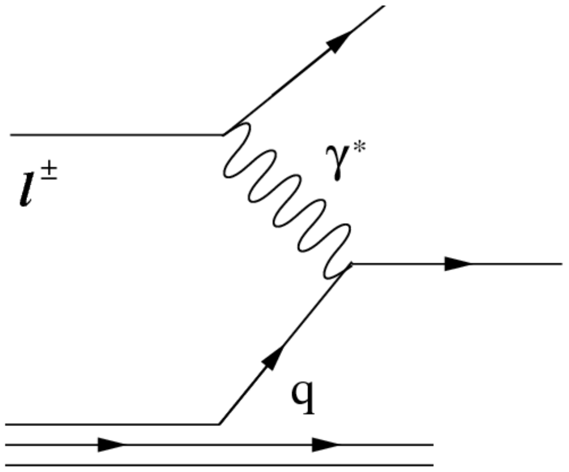
- ❑ Leading order process gives rise to a single jet (not counting target remnant) whose kinematics are largely determined by the underlying event kinematics
- ❑ Higher-order corrections to this process can give rise to back-to-back jet configurations (dijets) which break the dependencies on event kinematics
- ❑ At low Q2, the hadronic (resolved) nature of the virtual photon becomes important and parton – parton (2 -> 2) scattering can give rise to dijet states
- ❑ Jets can also arise from diffractive events and charged current interactions

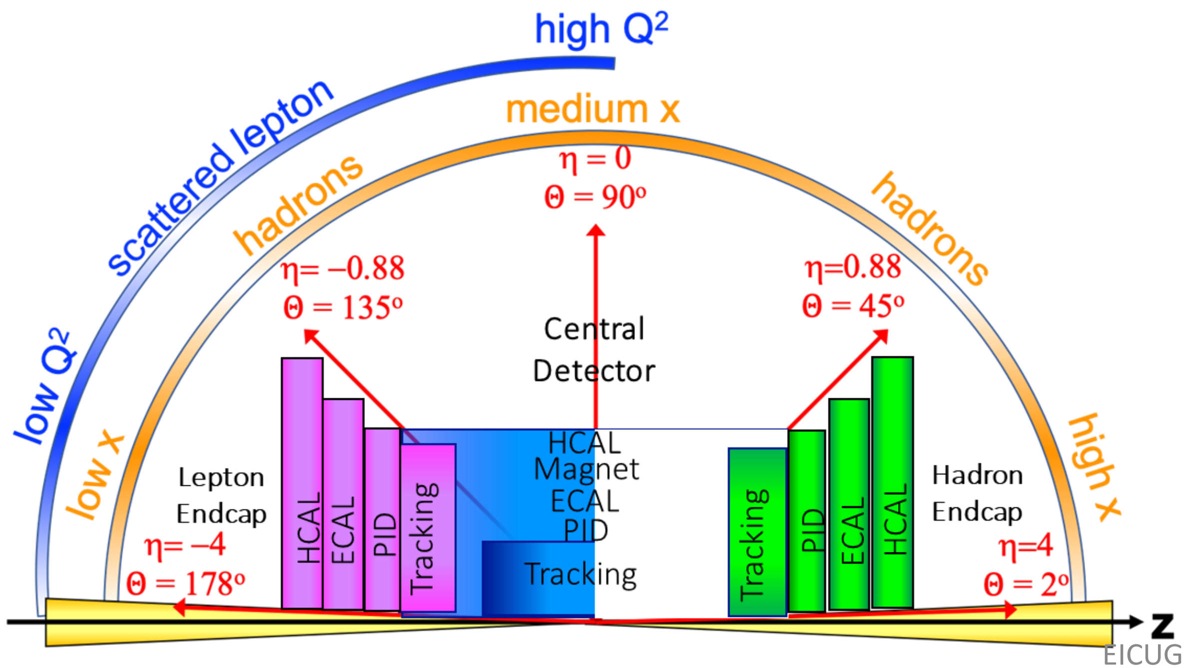
A Note on Frames

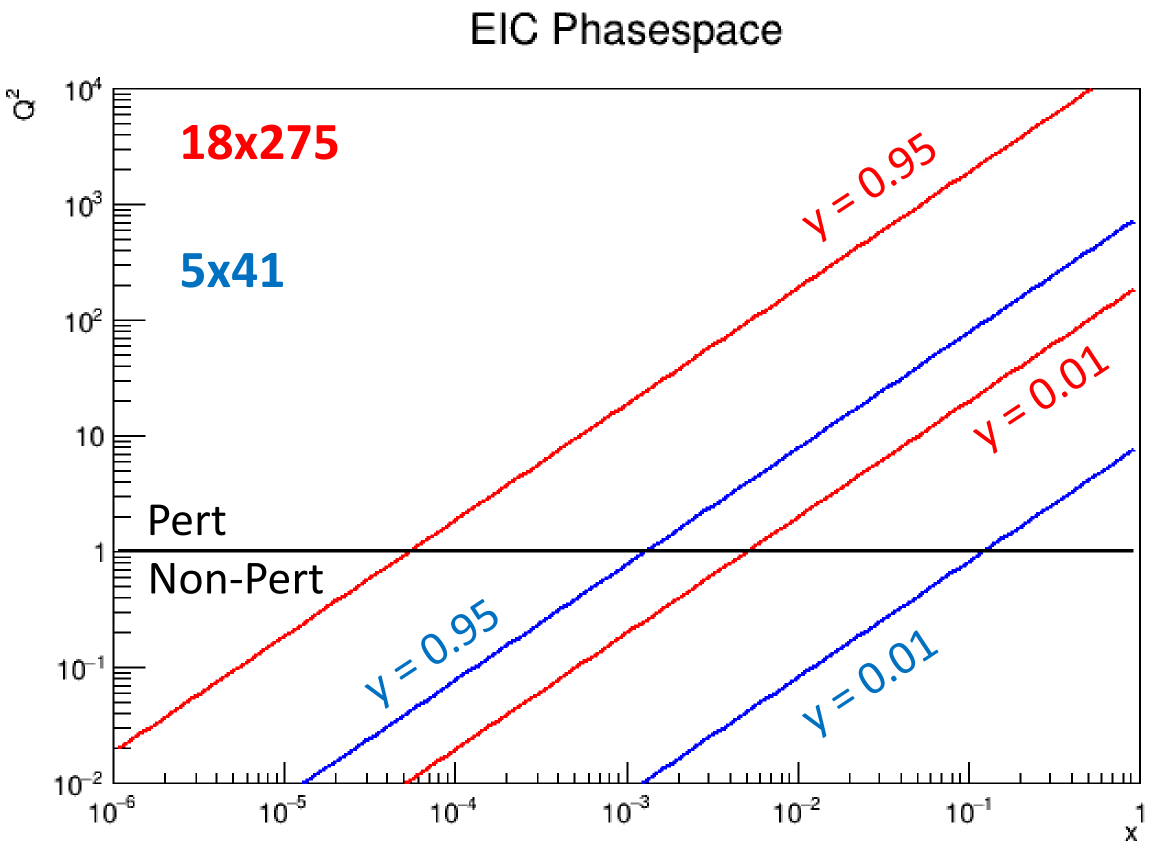
- As is the case with hadron-hadron colliders, some EIC jet measurements will be carried out in the detector or lab frame (this is complicated somewhat by the presence of a crossing angle between the beams)
- For many measurements, it will be convenient to measure momenta with respect to the direction of the virtual photon
- Can define a set of these frames all related by longitudinal boosts
- Of particular interest is the Breit (or Brick Wall) frame in which the scattered quark has equal but opposite momentum as the incoming quark – event separated into current and target hemispheres
- Leading order jets will have 0 transverse momentum in these frames and will not be properly clustered by standard (anti)kT algorithms (although energy based algos like Centauro can) but dijets arising from higher order processes will be back-to-back with significant pT



DIS Event Kinematics



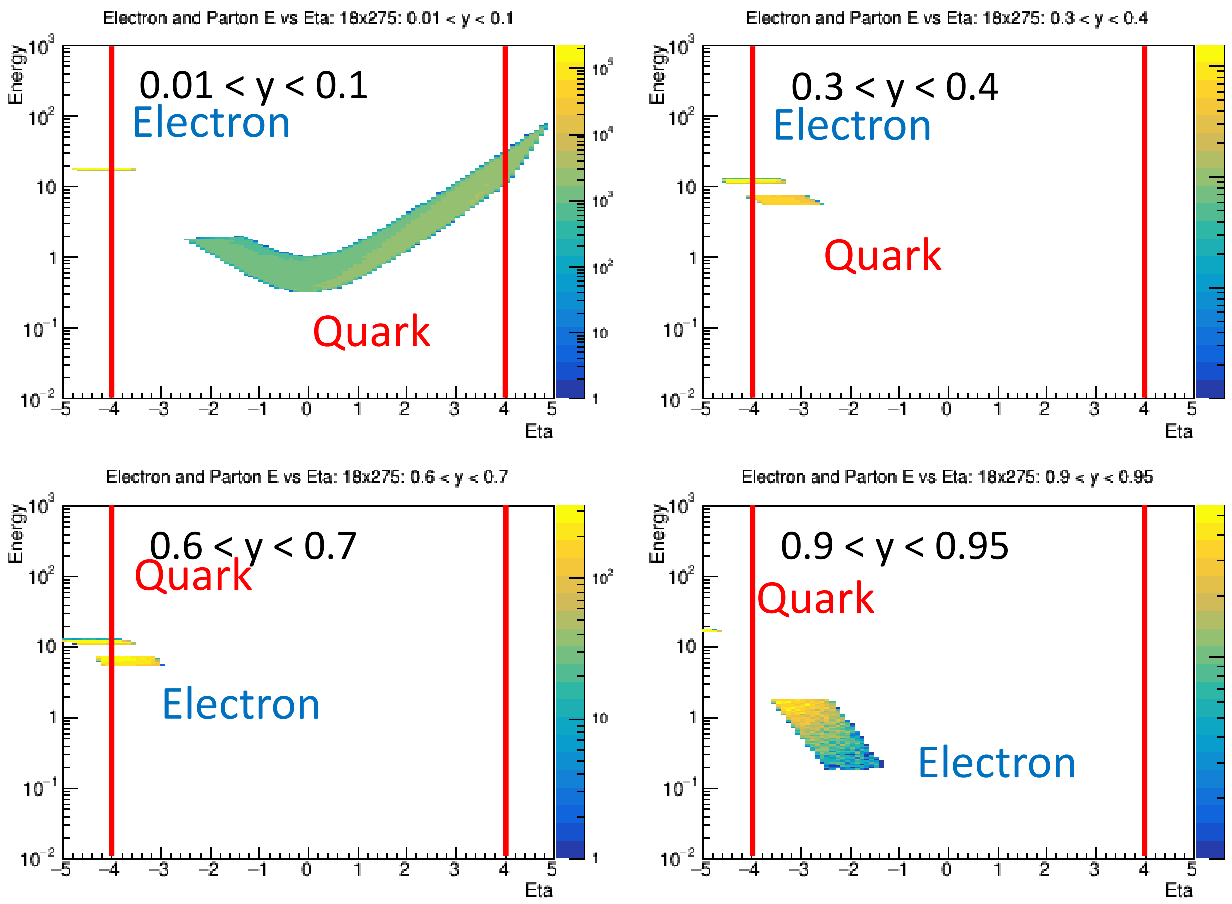




- ❑ For the leading order process, jet location and energy are dictated by the event kinematics (x, Q^2, y)
- ❑ For a given Q^2, inelasticity determines x value probed and pseudorapidity of the jet
  - ➢ Low y -> high x, jet at positive pseudorapidity
  - ➢ High y -> low x, jet at negative pseudorapidity

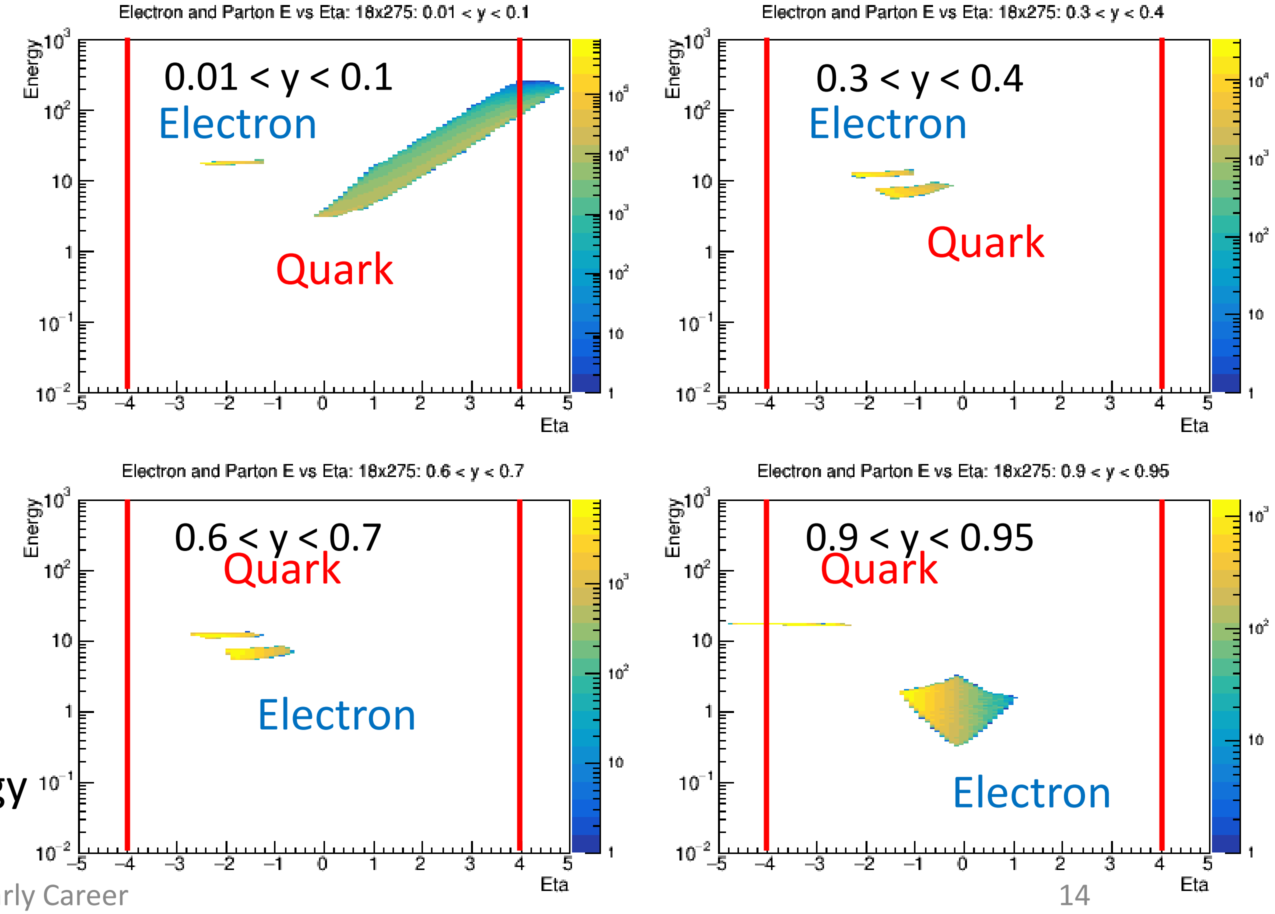
Electron and Struck Quark (18x275)

- 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



$0.1 < Q^2 < 1.0$

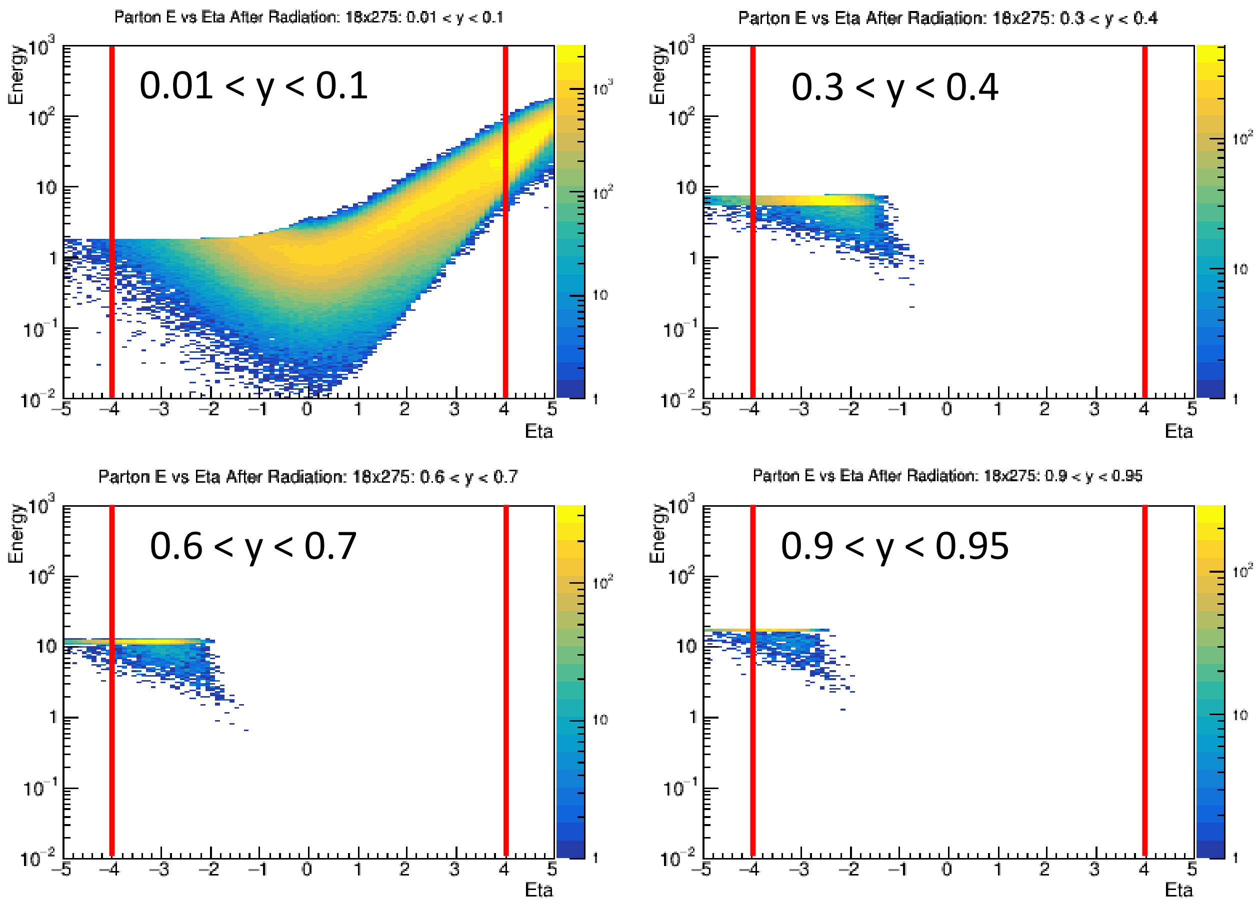
$10 < Q^2 < 100$



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

Struck Quark + FSR (18x275)

- For Born-level process, struck quark kinematics are correlated with event kinematics
- Final state radiation can alter quark kinematics significantly



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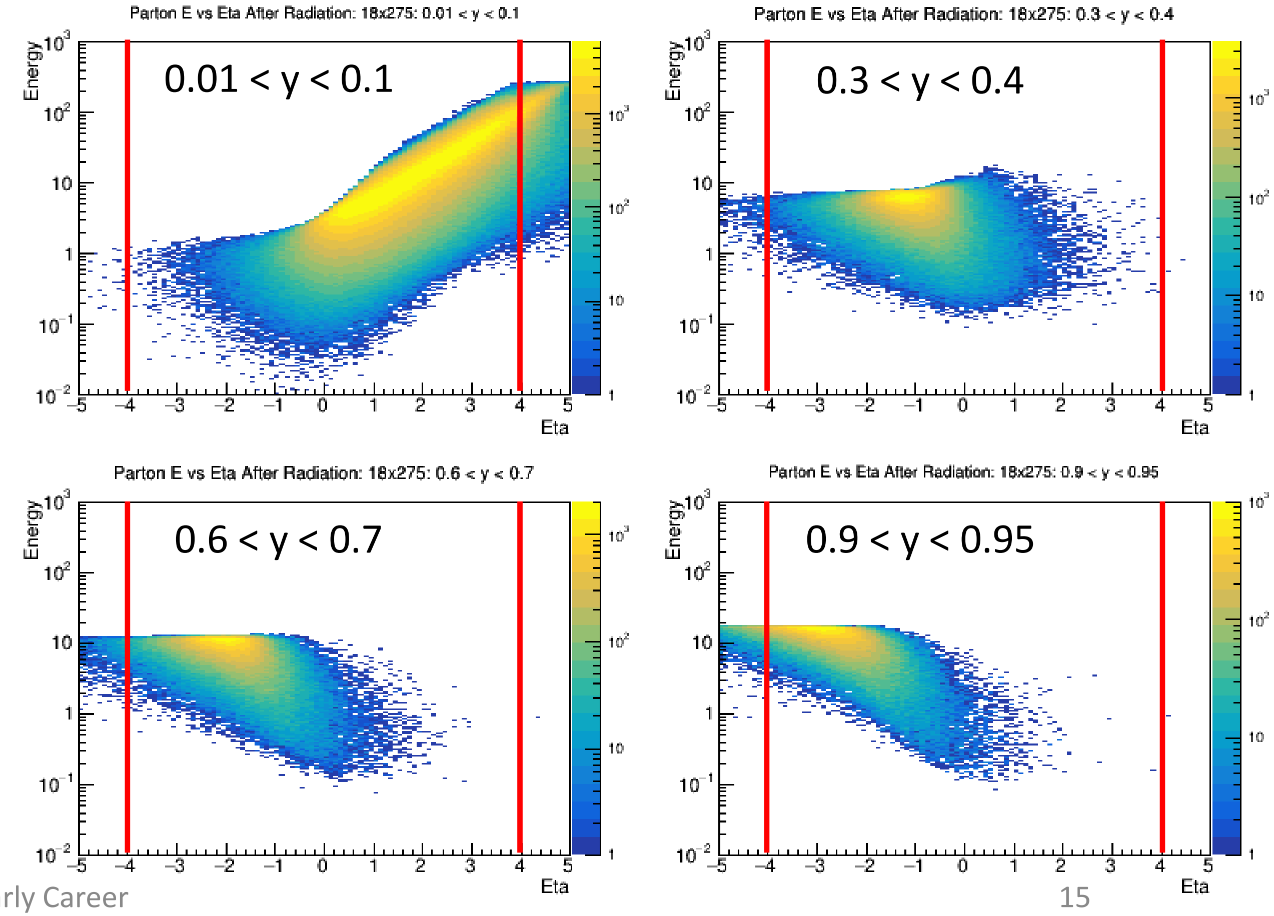
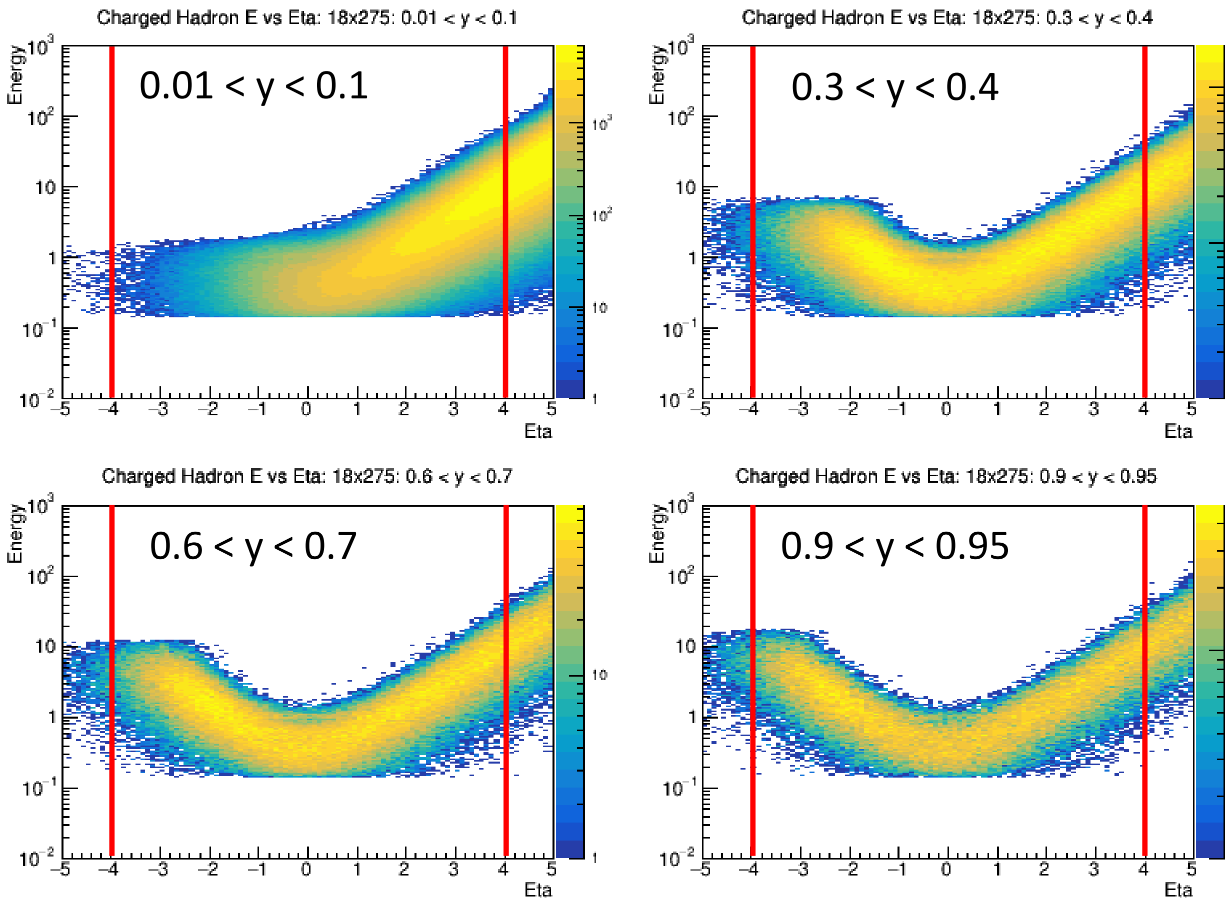


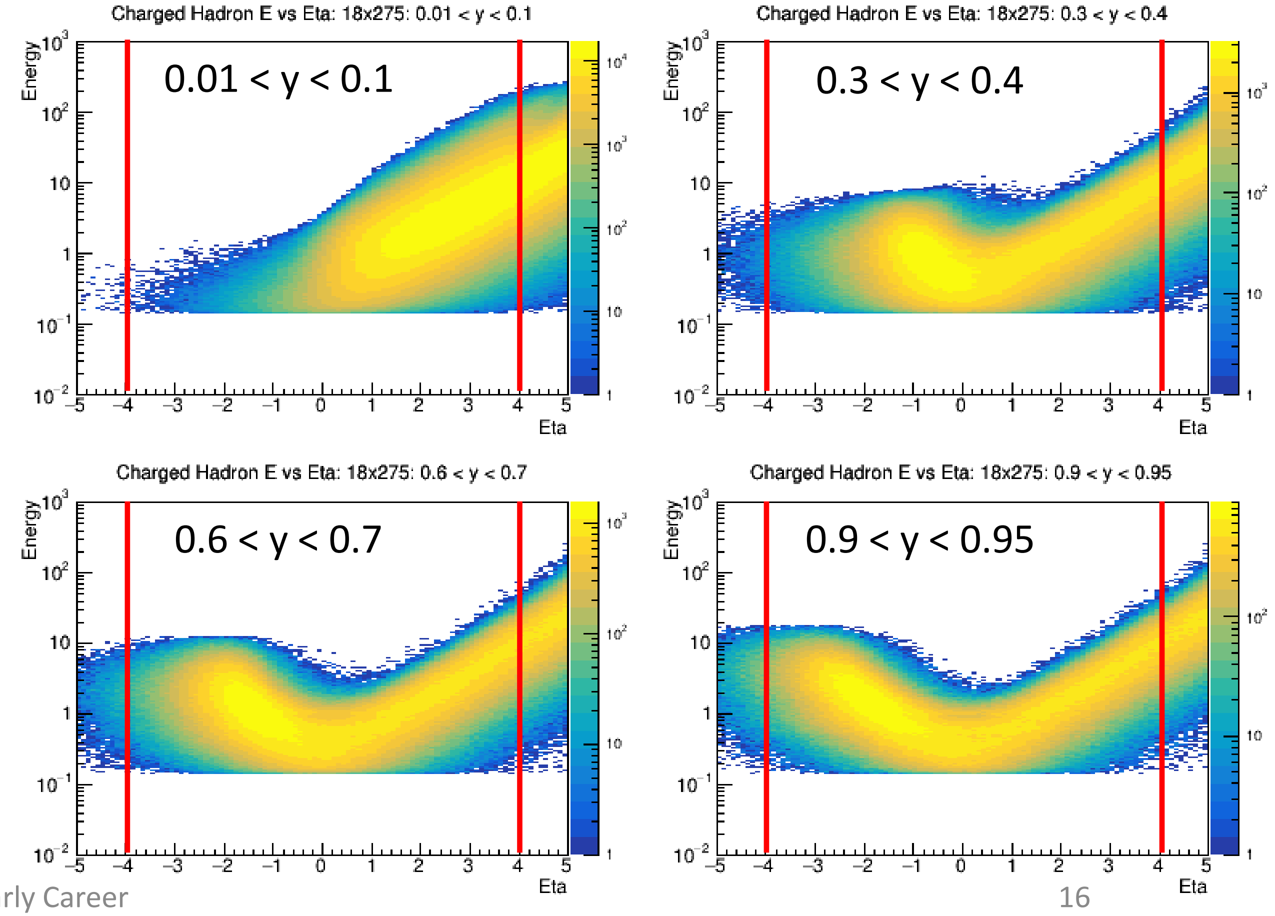
(Charged) Particle Distributions (18x275)



0.1 < Q² < 1.0

- ❑ Higher energy extends energy range somewhat, but basic distributions are similar

10 < Q² < 100



- ❑ How well can we reconstruct the parton kinematics from these particles?
- ❑ Can we form jets away from the struck parton?

Jet Algorithms Revisited

Anti_k$_T$

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

EE_kT (Spherically Invariant)

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

Centauro

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

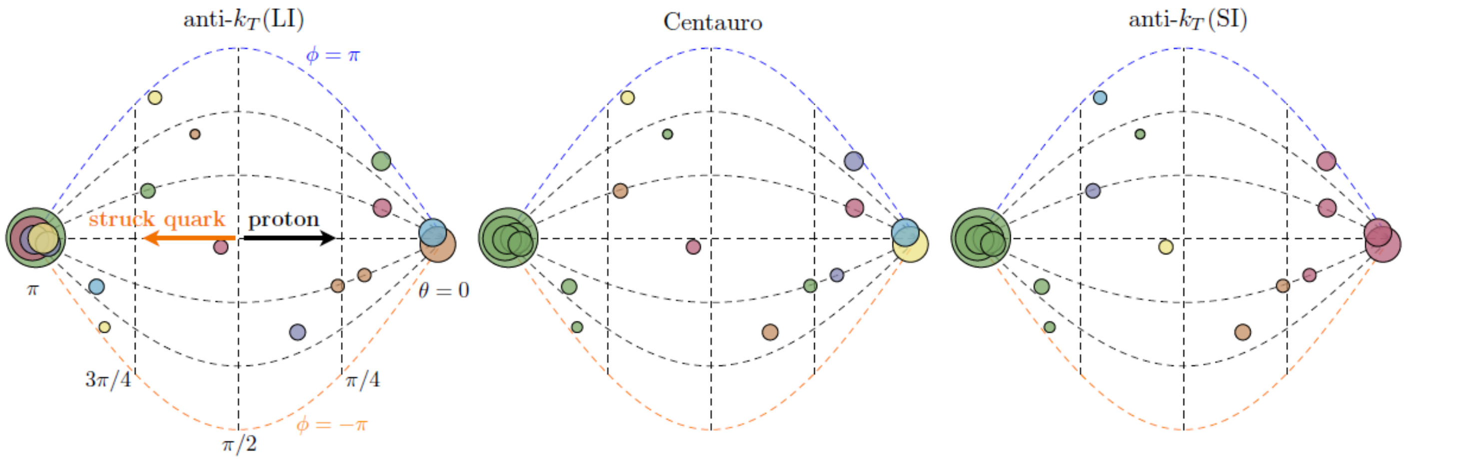
Asymmetric measure is necessary

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

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

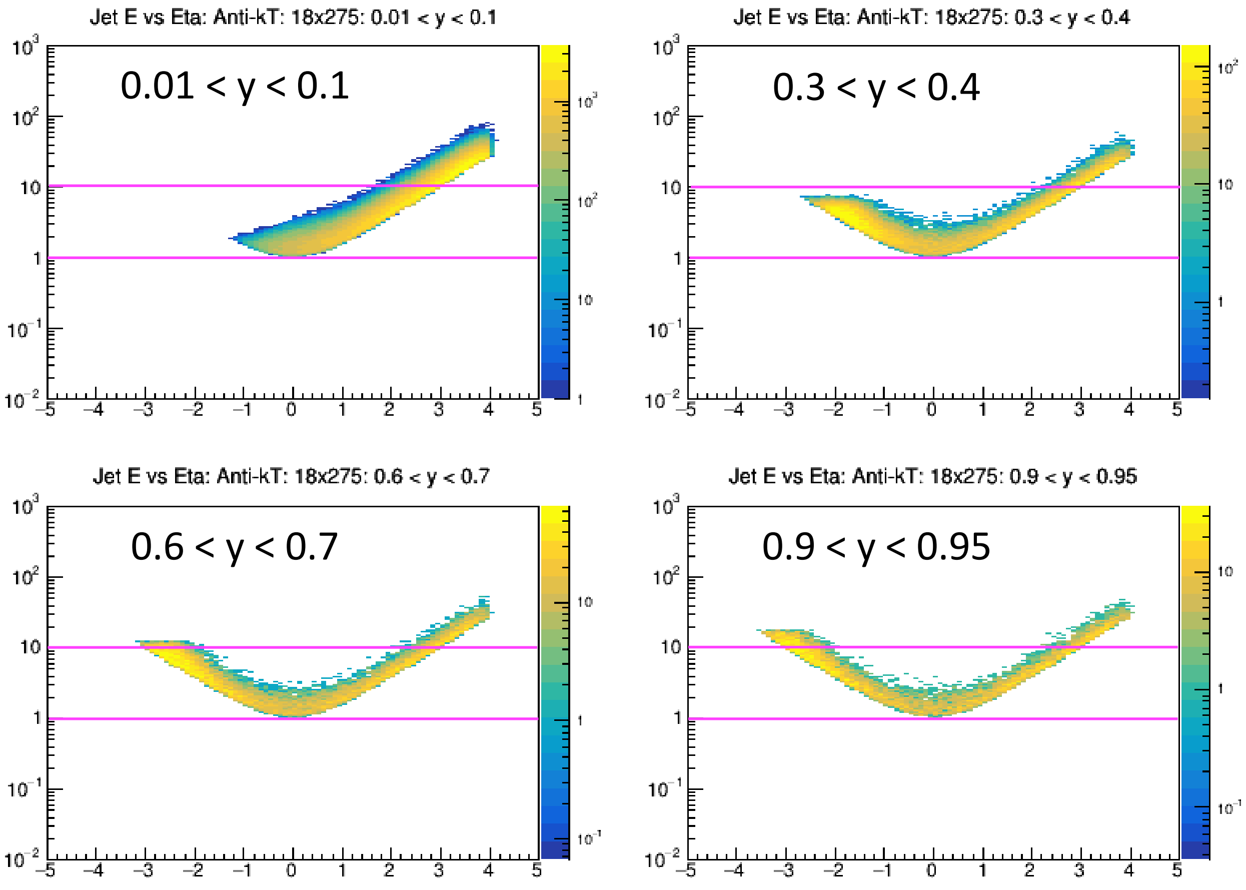
$$\bar{\eta}_i(\mathrm{BF}) = 2p_i^{\perp}/p_i^{+}$$

- 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



Longitudinally invariant Symmetric | Longitudinally invariant Asymmetric | Spherically invariant Symmetric

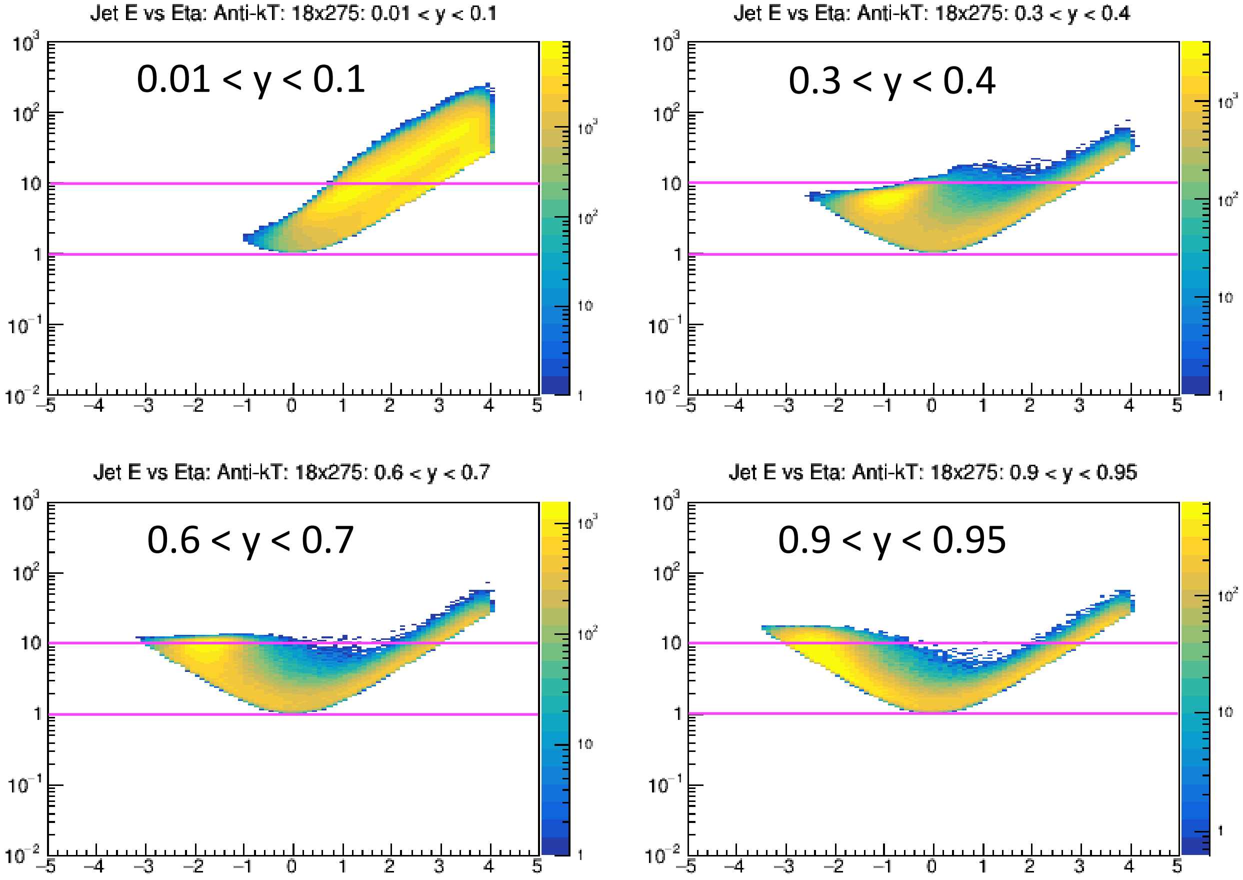
Jet Distributions: Anti_k_T (18x275)



0.1 < Q^2 < 1.0

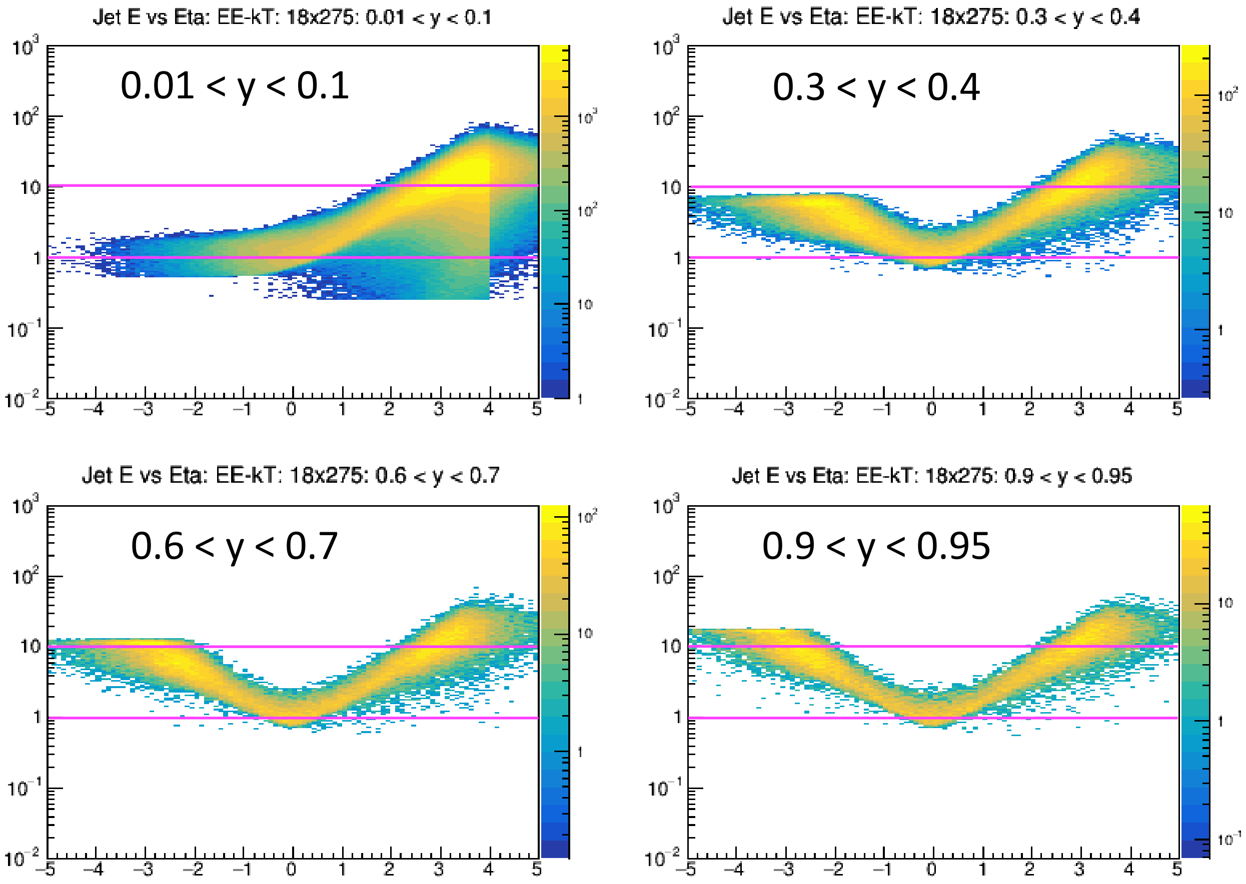
- ❑ Run inclusive Anti_k_T on all stable particles (|eta| < 4) with 1 GeV minimum p_T cut
- ❑ Jets roughly follow particle distributions

10 < Q^2 < 100



Jet Distributions: EE_k_T (18x275)

- Overall distributions are similar for EE_k_T algorithm
- In general, see larger number of jets, more jets at higher eta, and more jets away from struck quark



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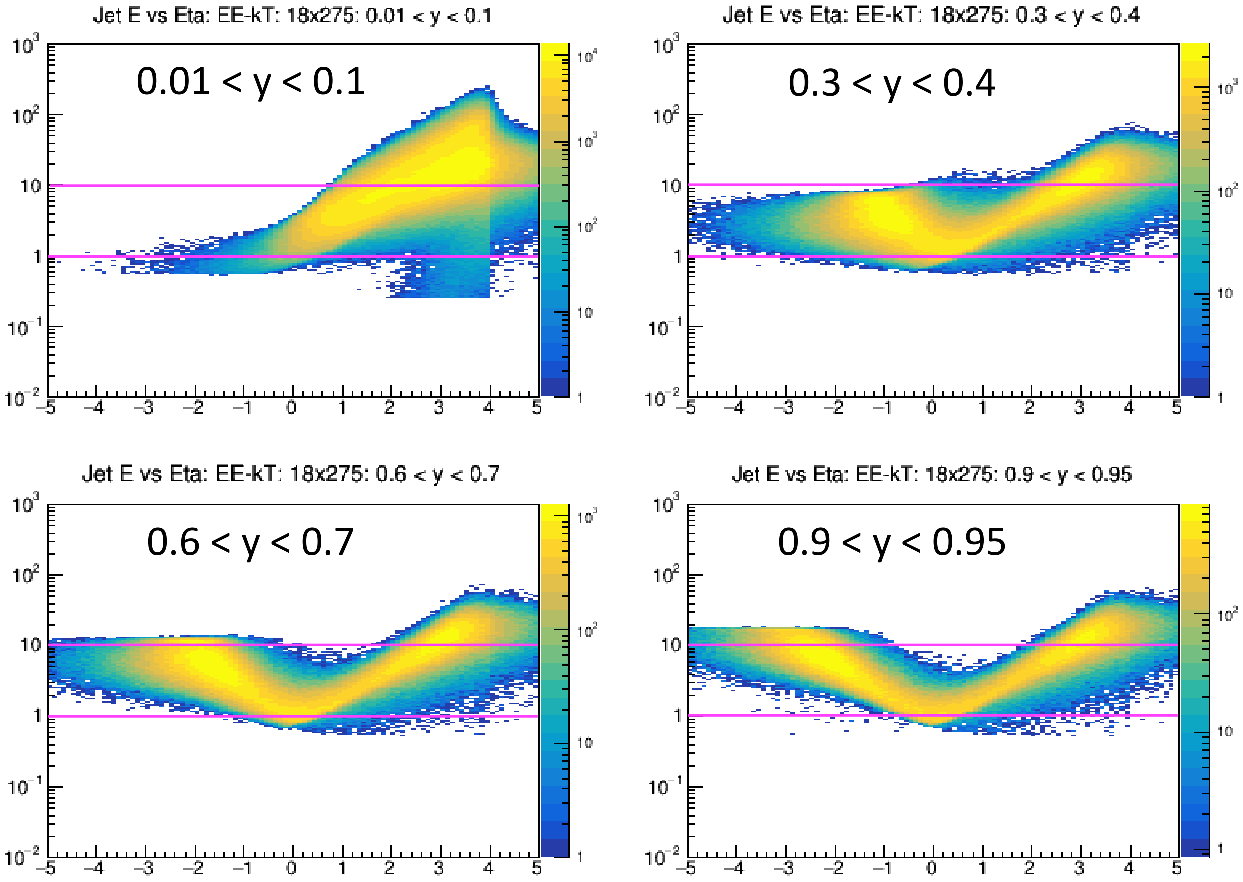
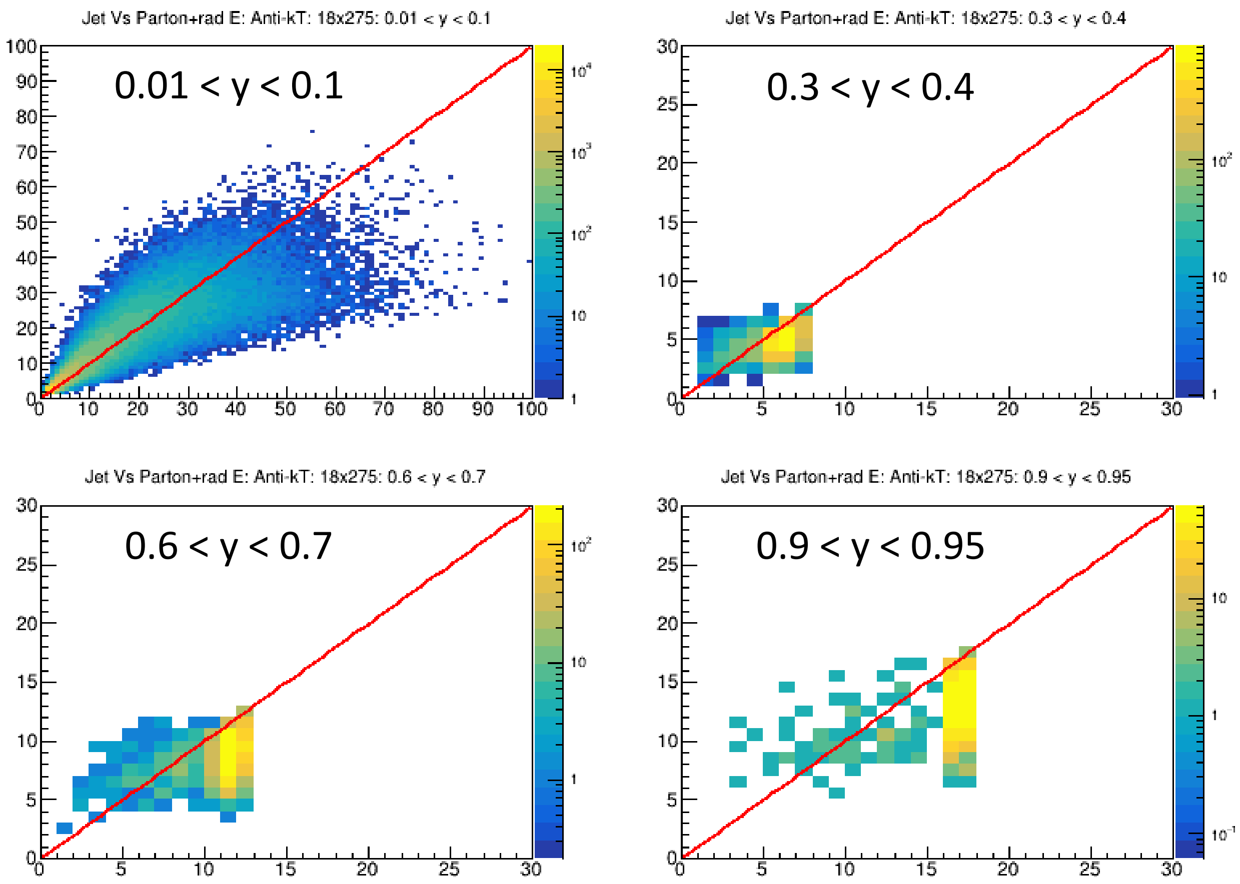


- Need to understand the artifact around eta = 4, must be related to particle eta cut

Jet – Parton Energy Comparison: Anti_k_T (18x275)

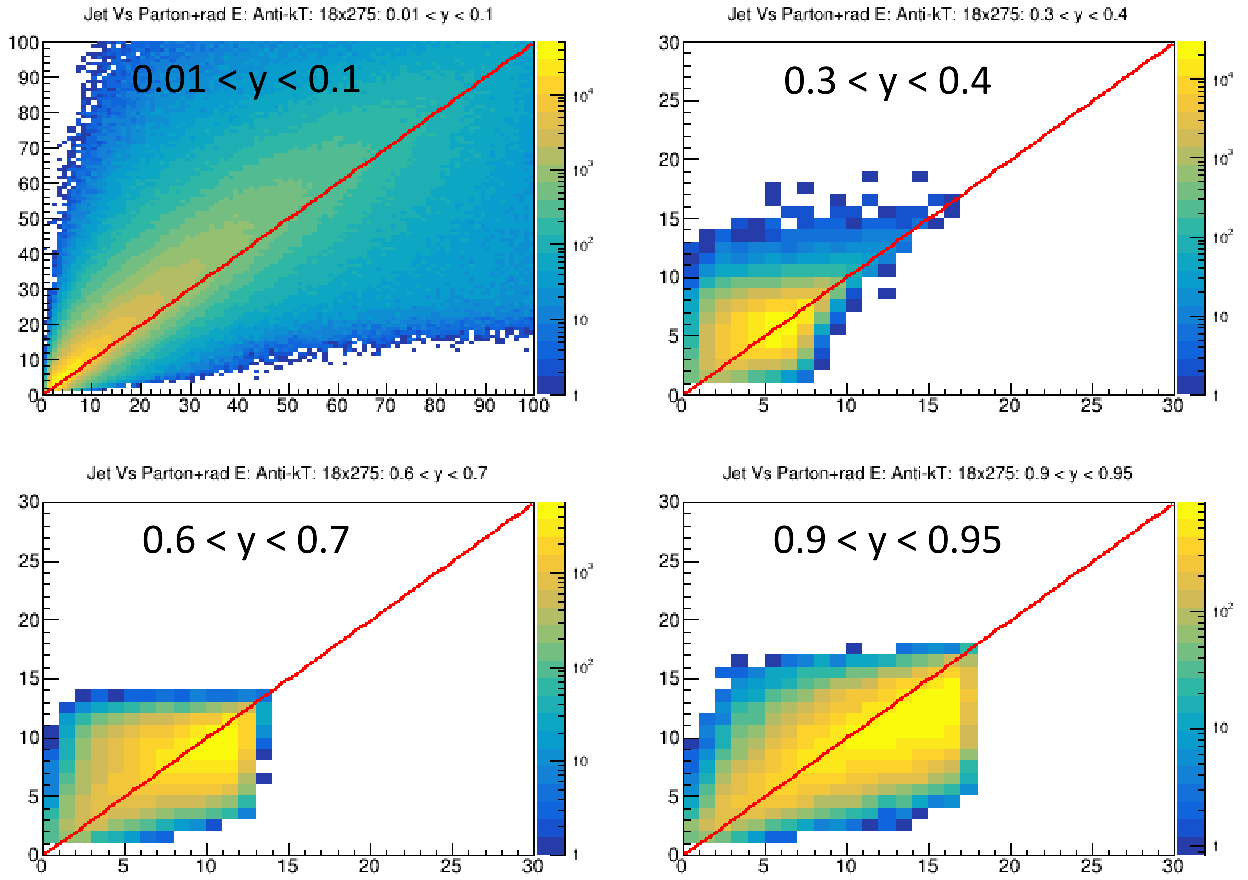


$0.1 < Q^2 < 1.0$

- ❑ Performance degrades somewhat at larger y (backward jets)

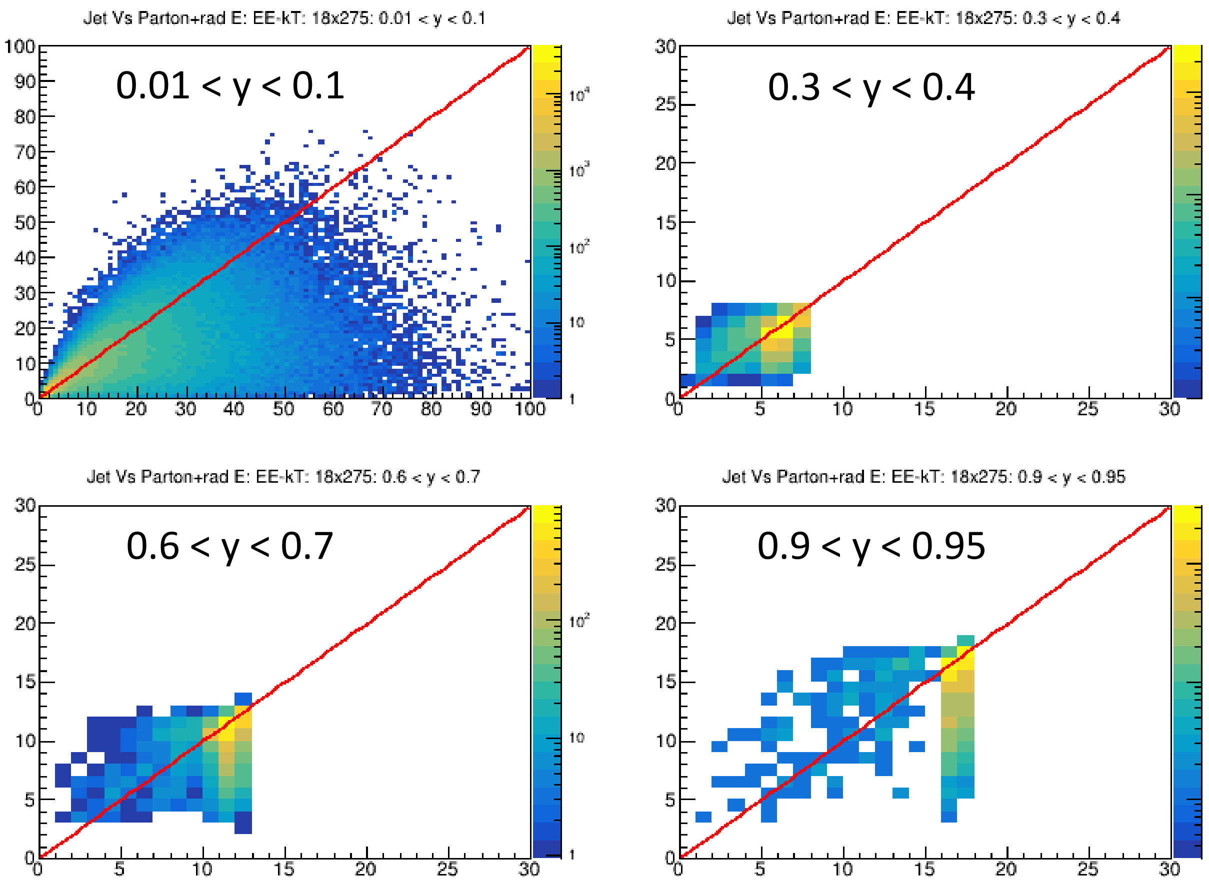
- ❑ How well do jets represent the parton?
- ❑ Plot jet energy vs parton+FSR energy for different Q^2 and inelasticity

$10 < Q^2 < 100$



Jet – Parton Energy Comparison: EE_k_T (18x275)

- Better agreement between parton and jet seen with EE_kT algorithm, especially at high y



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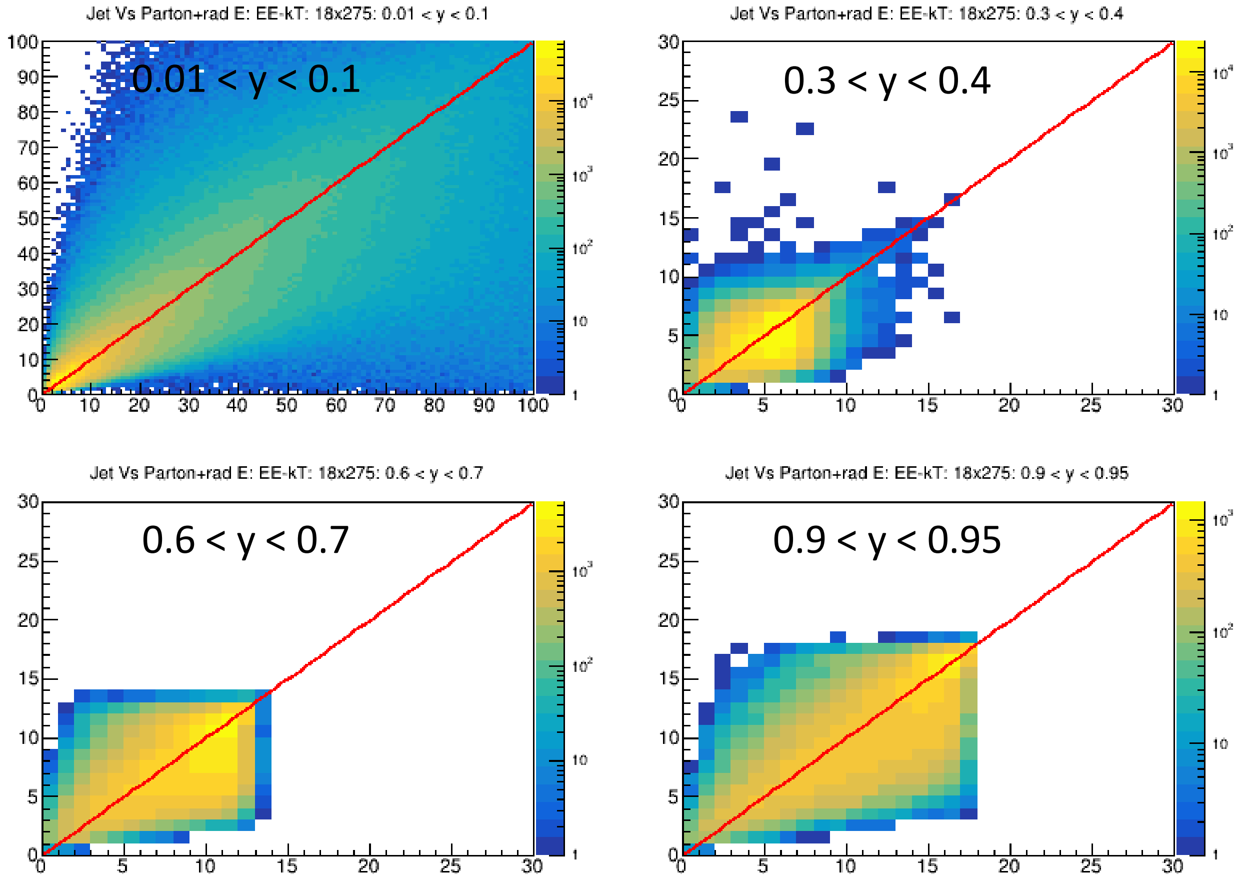
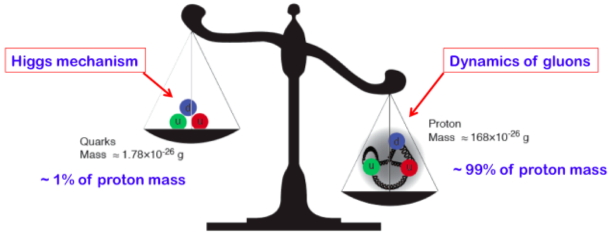
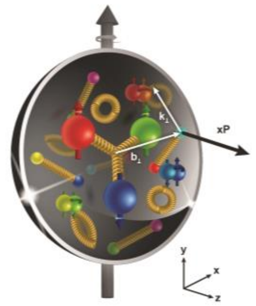


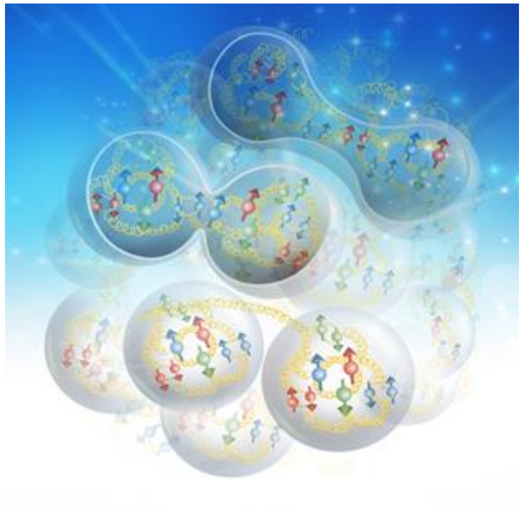
The EIC Physics Pillars

How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

How do the nucleon properties emerge from them and their interactions?







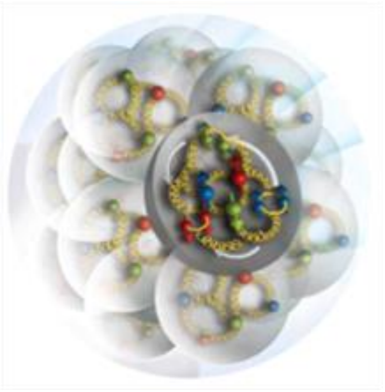
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

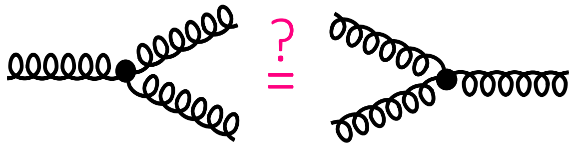
How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?

How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?





Jet Physics at the EIC

Jets have several properties which will make them important tools for realizing the EIC physics program

- Well understood theoretically and experimentally

- Excellent proxies for the underlying parton kinematics

- Showers probe QCD from hard interaction to hadronization scale within the same event – can explore dynamics at different time (angular) scales

- Precision tools exist to probe these shower properties - substructure

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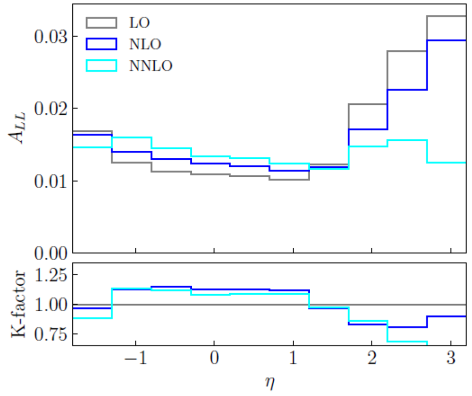
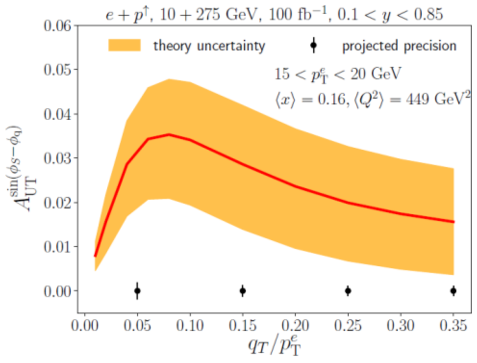
Global properties and parton structure of hadrons



Borsa, de Florian, Pedron `20

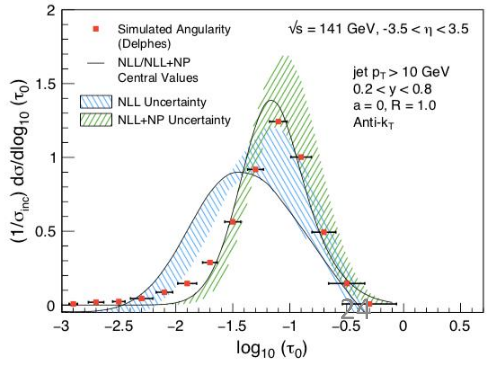
Multi-dimensional imaging of nucleons, nuclei and mesons



Arratia, Kang, Prokudin, Ringer `20

The nucleus: a laboratory for QCD

Understanding hadronization



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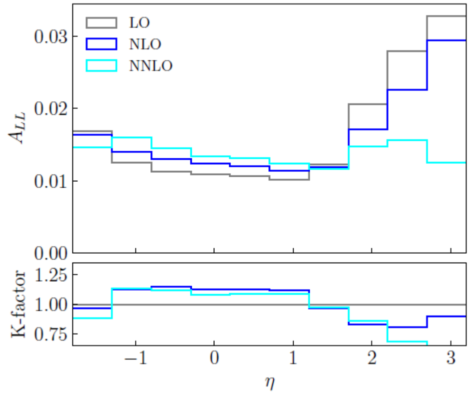

Borsa, de Florian, Pedron `20

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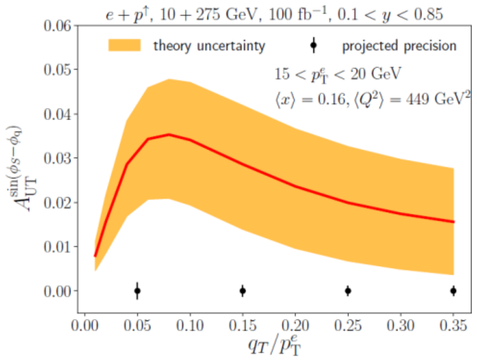

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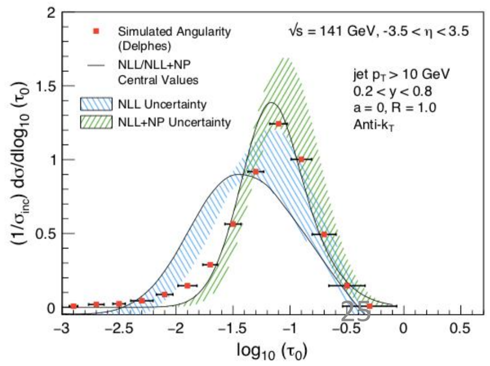

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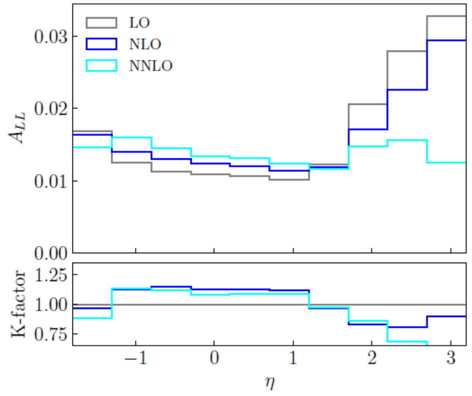

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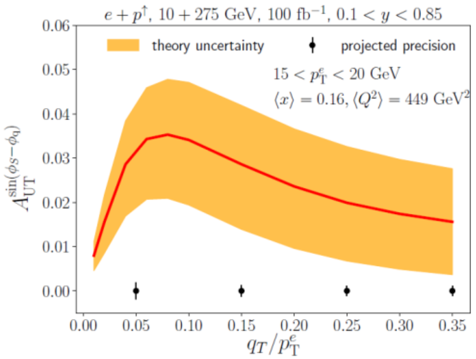

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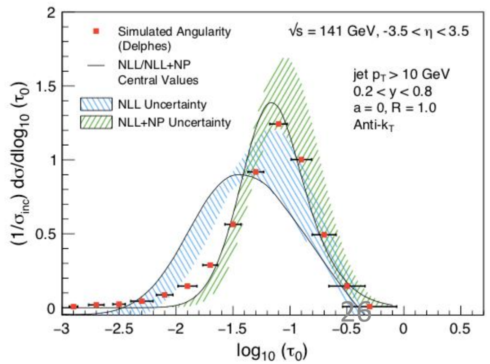

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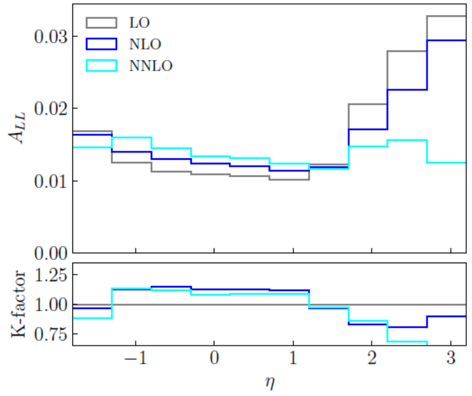
- Well understood theoretically and experimentally
- Excellent proxies for the underlying parton kinematics
- Showers probe QCD from hard interaction to hadronization scale within the same event – can explore dynamics at different time (angular) scales
- Precision tools exist to probe these shower properties - substructure

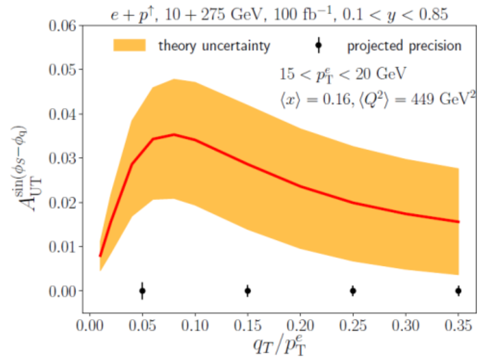
The importance of jet probes was reflected in the EIC Yellow Report where they touched on nearly every major physics topic (Nucl. Phys. A, Vol 1026, 122447)

Global properties and parton structure of hadrons



Borsa, de Florian, Pedron `20

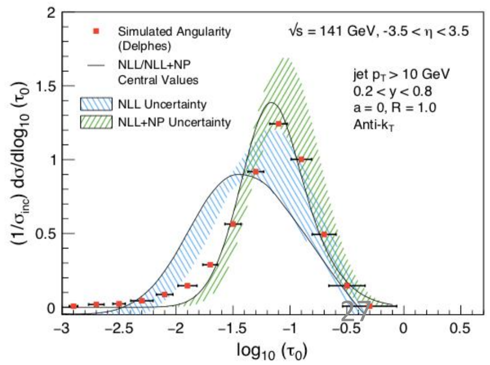
Multi-dimensional imaging of nucleons, nuclei and mesons



Arratia, Kang, Prokudin, Ringer `20

The nucleus: a laboratory for QCD

Understanding hadronization



J. Adam *et al* 2022 *JINST* 17 P10019

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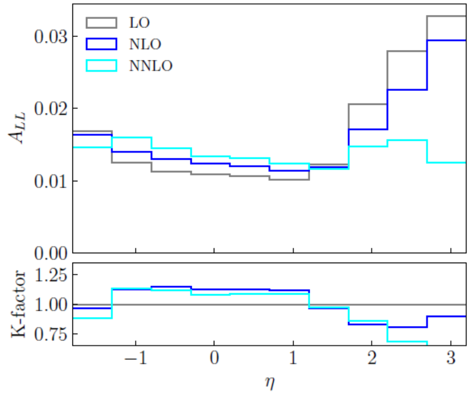

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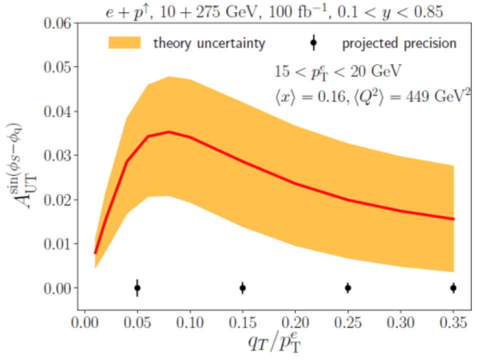

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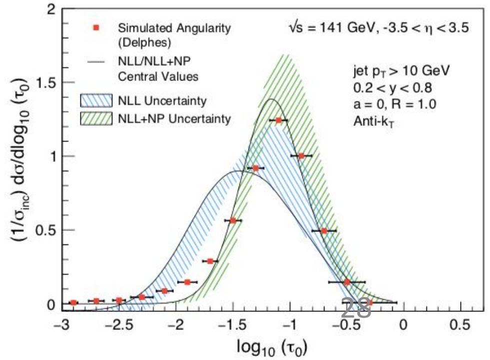

J. Adam *et al* 2022 *JINST* 17 P10019

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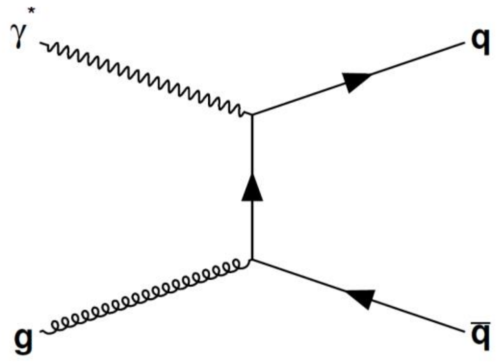
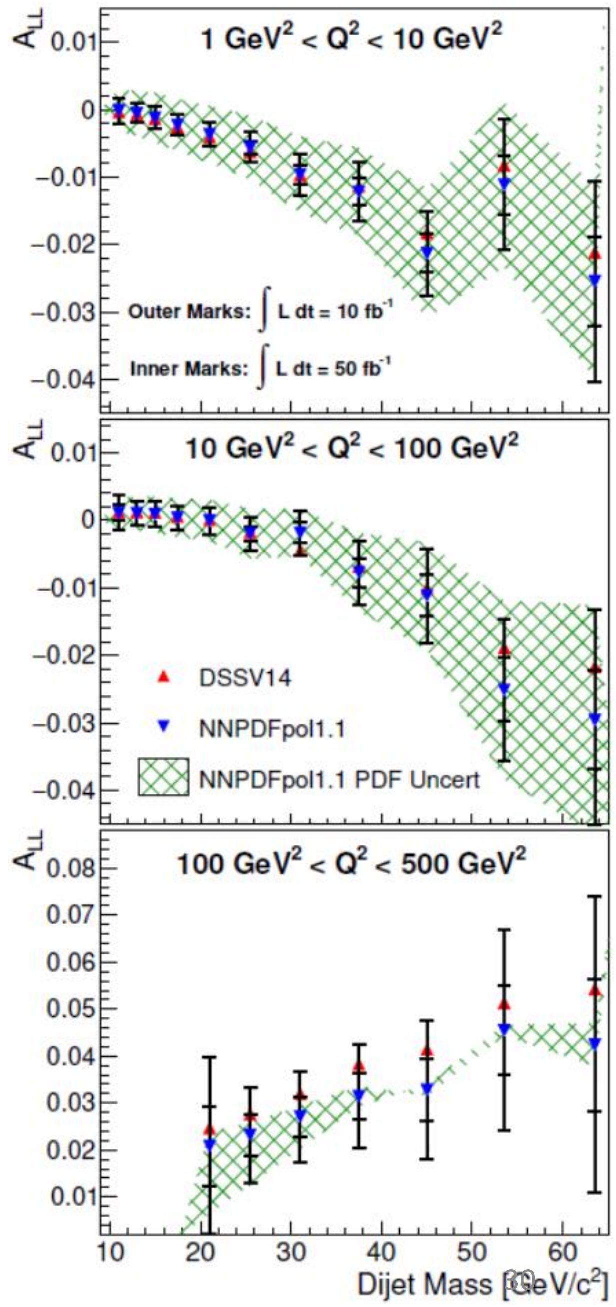
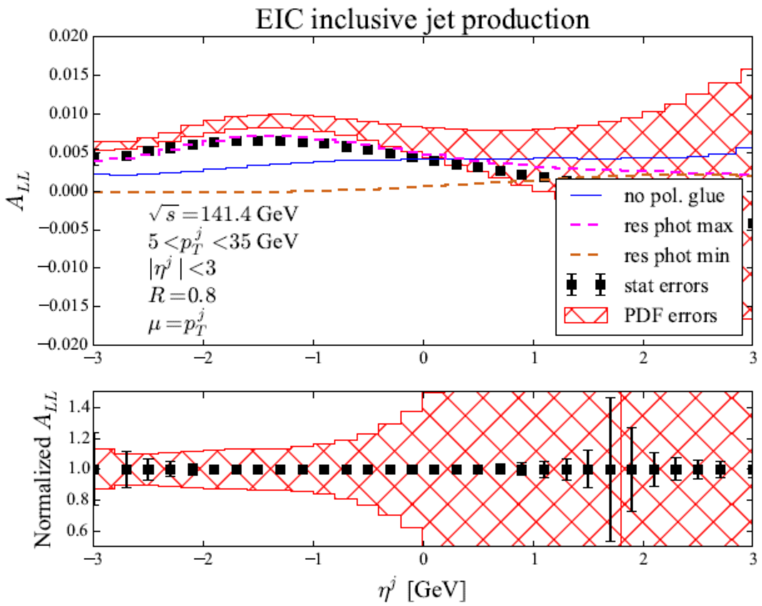
Longitudinal Spin Structure

- Recent results on inclusive jet A_{LL} at NLO and NNLO both with and without tagged lepton
- Will place strong constraints on helicity distributions
- Feasibility study for dijet A_{LL} in the Breit frame also performed – access to gluon via PGF process

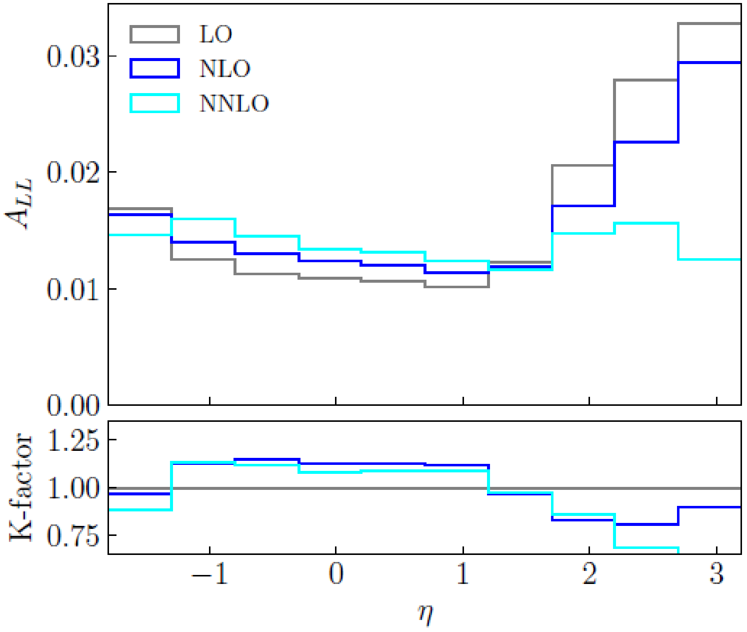


Page, Chu, Aschenauer `20





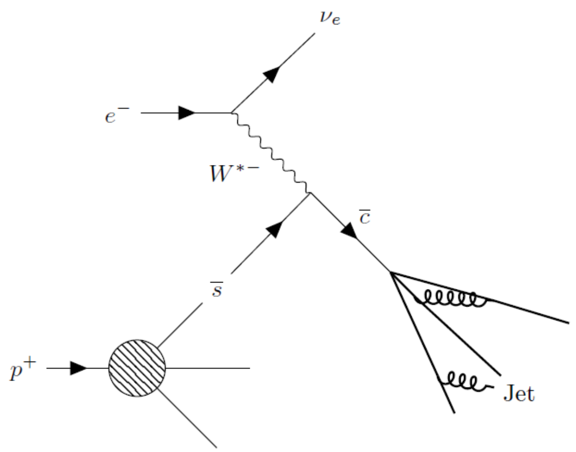
Boughezal, Petriello, Xing `18

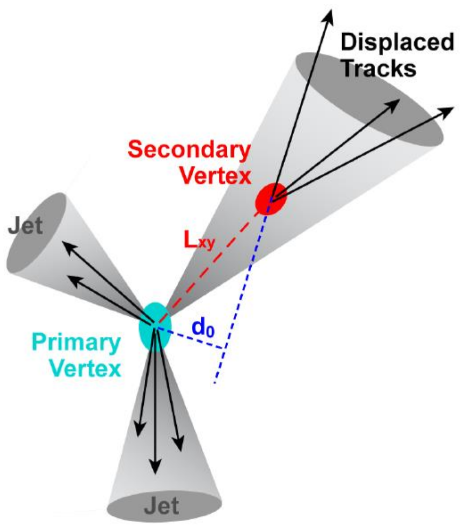


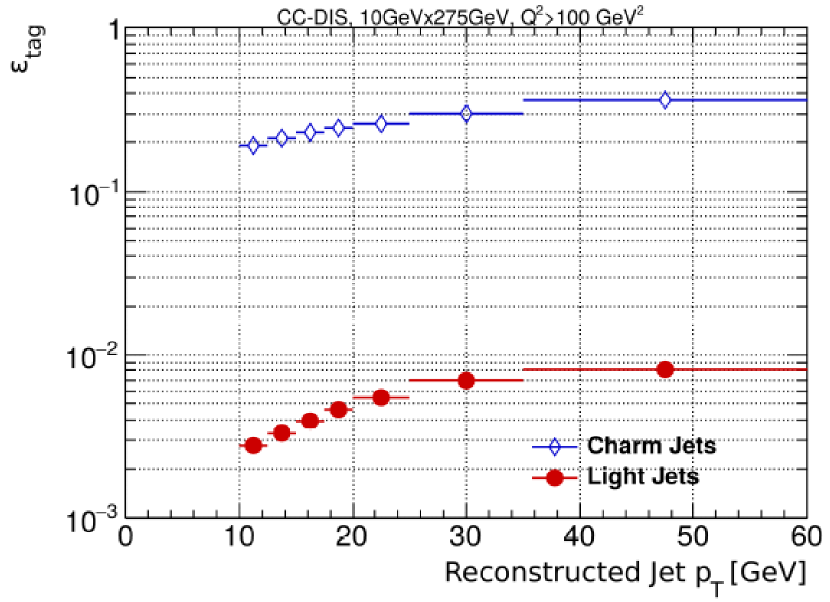
Borsa, de Florian, Pedron `20

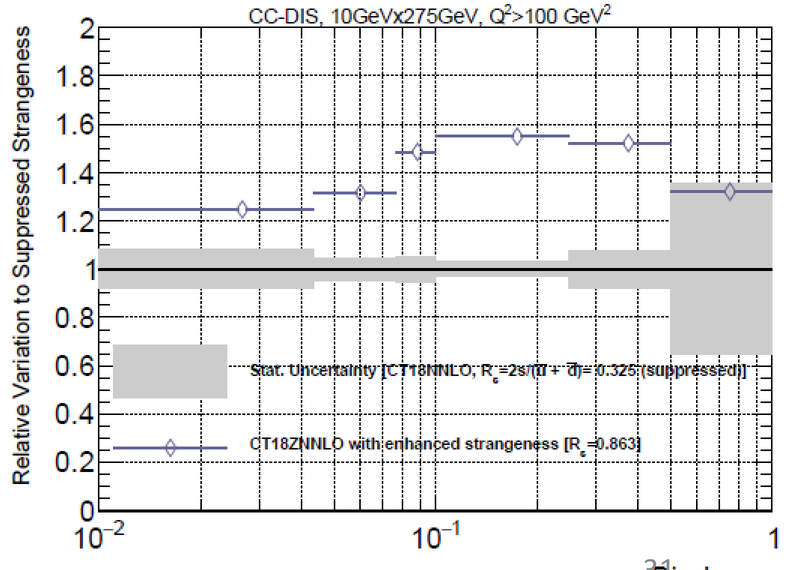
Strangeness PDF: Charm Jets

Arratia, Furletova, Hobbs, Olness, Sekula `20







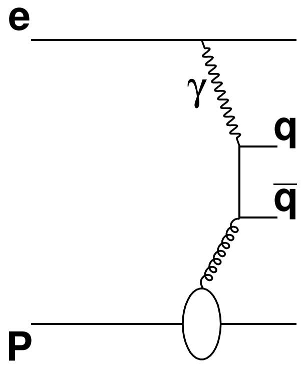


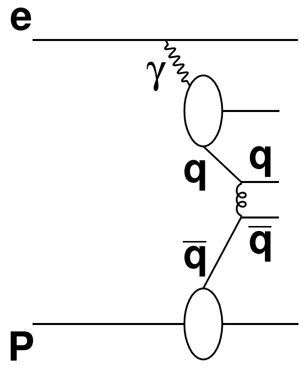
- ❑ Tension exists between neutrino DIS and SIDIS measurements of strange content and LHC extractions
- ❑ EIC is sensitive to strange content via charm production in charged-current DIS
- ❑ Charm is tagged within a jet via the presence of displaced tracks – good charm efficiency is seen, and methods are being refined
- ❑ Charm jet measurements at EIC should be able to discriminate between low and high strangeness scenarios

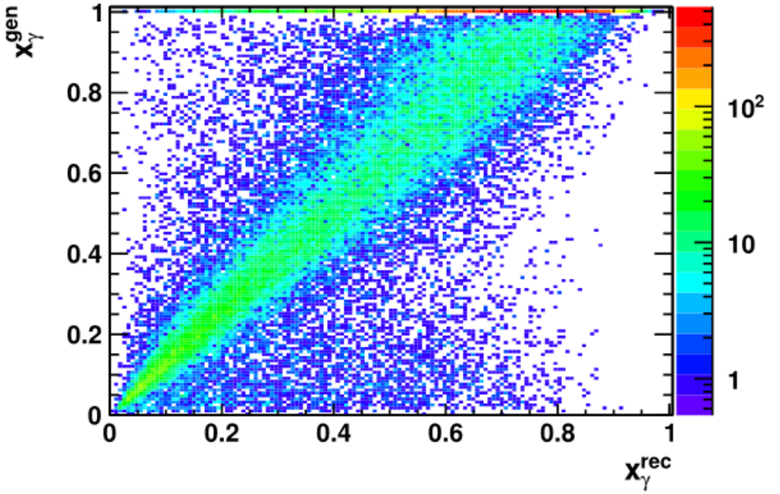
(Polarized) Photon Structure

Phys.Rev.D 96 (2017) 7, 074035

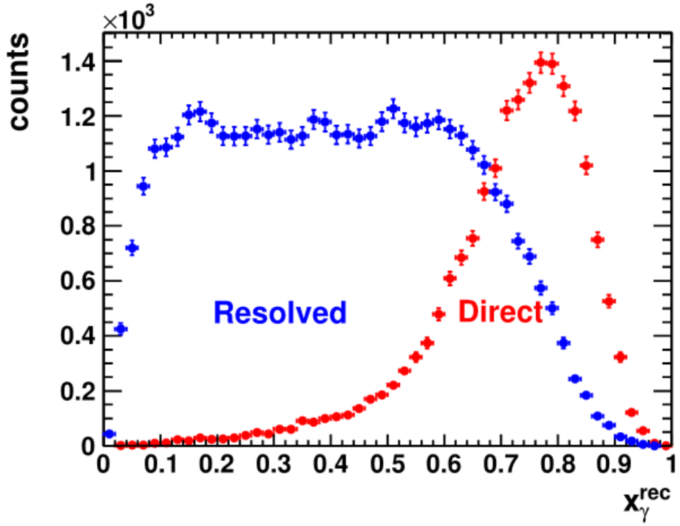
- At low Q2, virtual photon can behave hadronically and initiate 2->2 type scattering events
- Results in a quark/anti-quark final state with high transverse momentum
- Dijet allows to reconstruct event characteristics to separate signal and background and characterize the structure of the photon

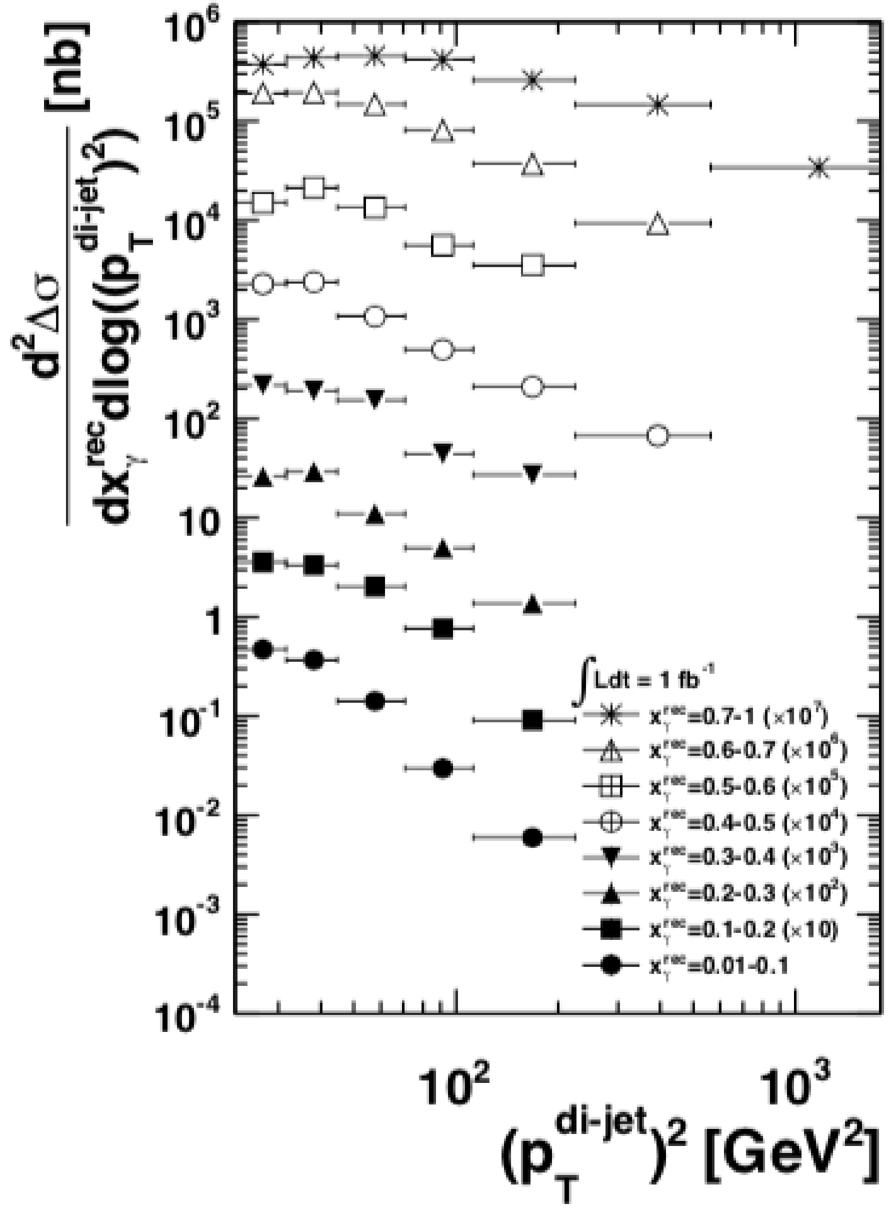






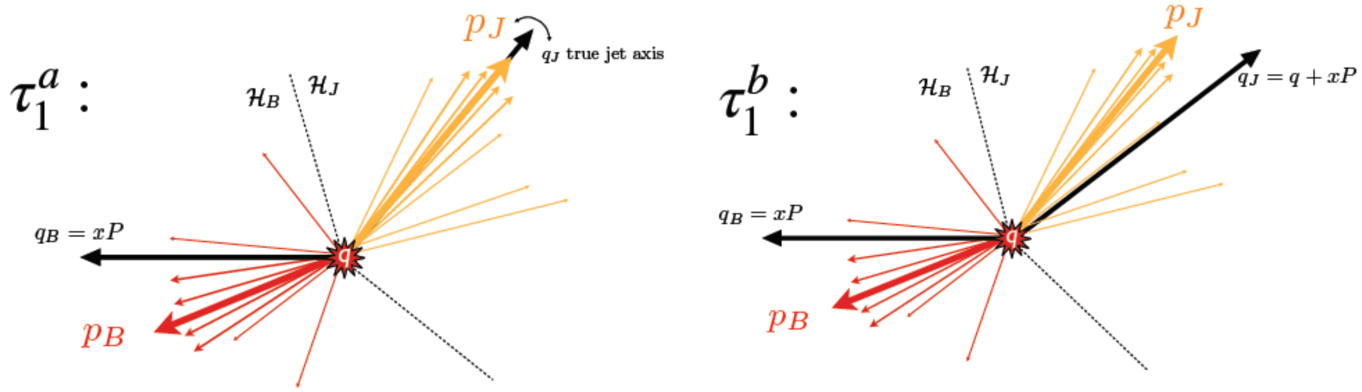
$$x_\gamma^{rec} = \frac{1}{2E_e y}\left(p_{T1}e^{-\eta_1} + p_{T2}e^{-\eta_2}\right)$$

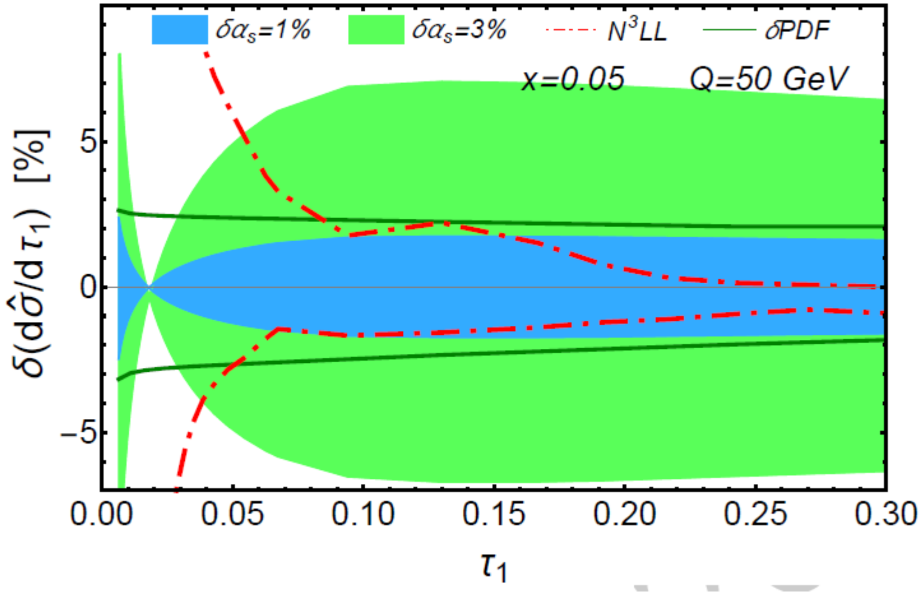


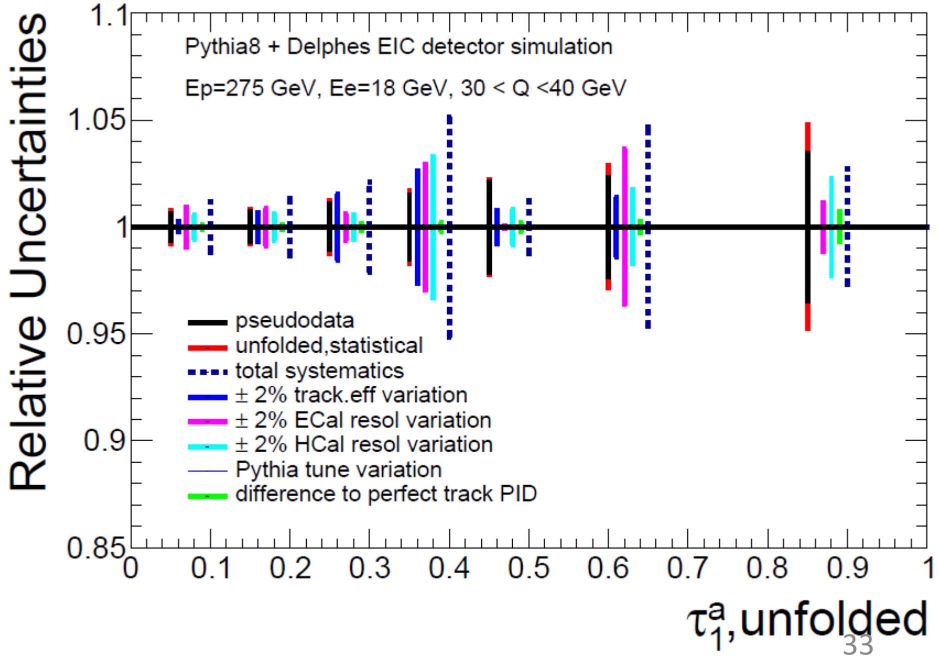


Global Event Shapes

$$\tau_1 = \frac{2}{Q^2} \sum_{i \in X} \min\{q_B \cdot p_i, q_J \cdot p_i\}$$







- Global event shapes offer possibility of very high precision measurements for extractions of non-perturbative parameters such as the strong coupling constant
- Detailed feasibility studies of 1-jettiness observable were carried out as part of the Yellow Report effort taking into account uncertainties on tracking efficiency and calorimeter resolution
- At N^{3}LL, roughly 1% precision is possible, challenging experimental problem, but recent studies show promise

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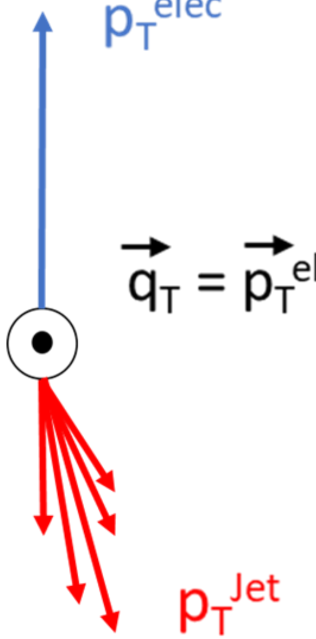
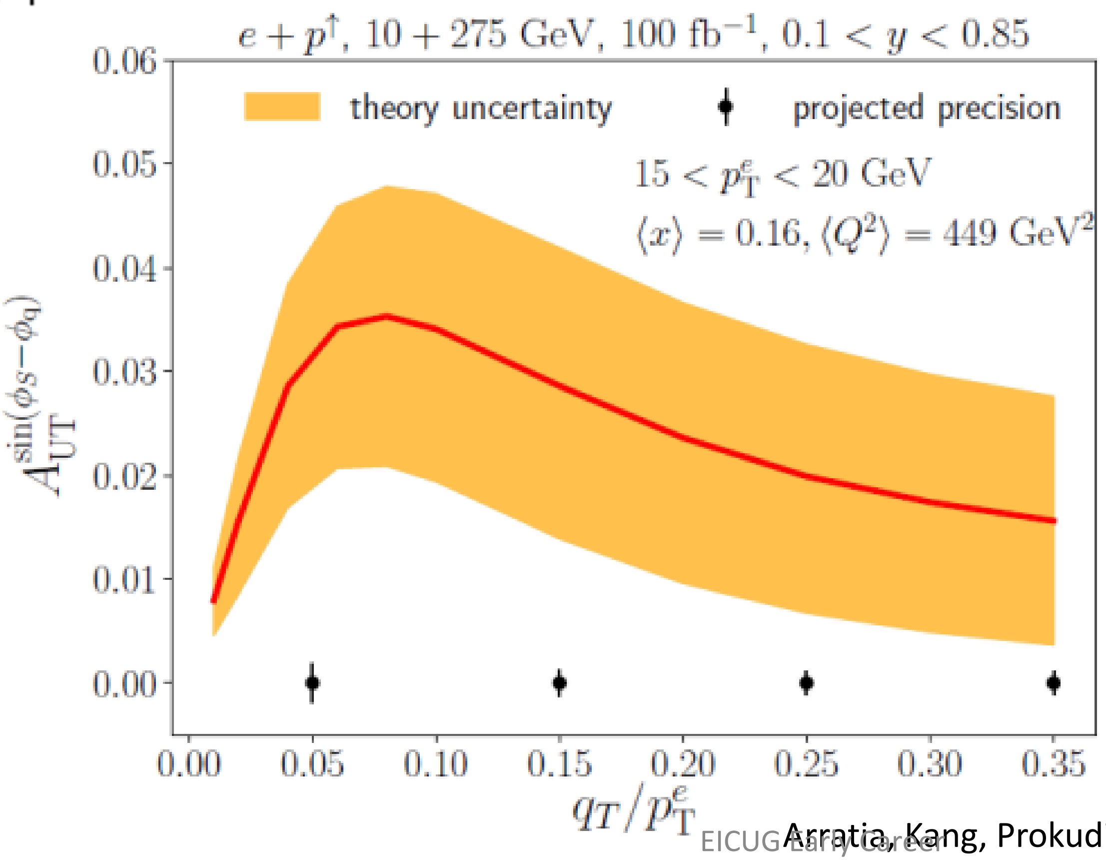
Lepton-Jet Correlations: Sivers TMD



$\vec{q}_T = \vec{p}_T^{elec} + \vec{p}_T^{Jet}$

$$e + p(\vec{s}_T) \to e + (\text{jet}(\vec{q}_T)\, h(z_h, \vec{j}_T)) + X$$

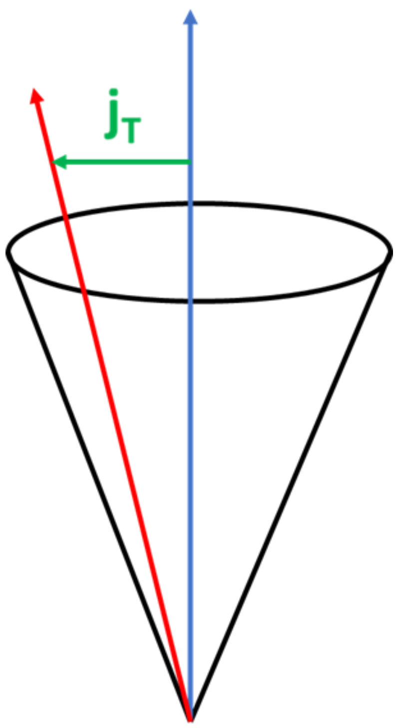


Arratia, Kang, Prokudin, Ringer `20

- ❑ Jet measurements for 3D imaging of nucleons at the EIC is emerging as a fruitful field
- ❑ Jets are complementary to standard SIDIS extractions of TMDs and provide better surrogates for parton kinematics while allowing cleaner separation of target and current fragmentation regions
- ❑ Jet measurements allow independent constraints on TMD PDFs and FFs from a single measurement
- ❑ Azimuthal correlation between jet and lepton sensitive to TMD PDFs (Sivers)

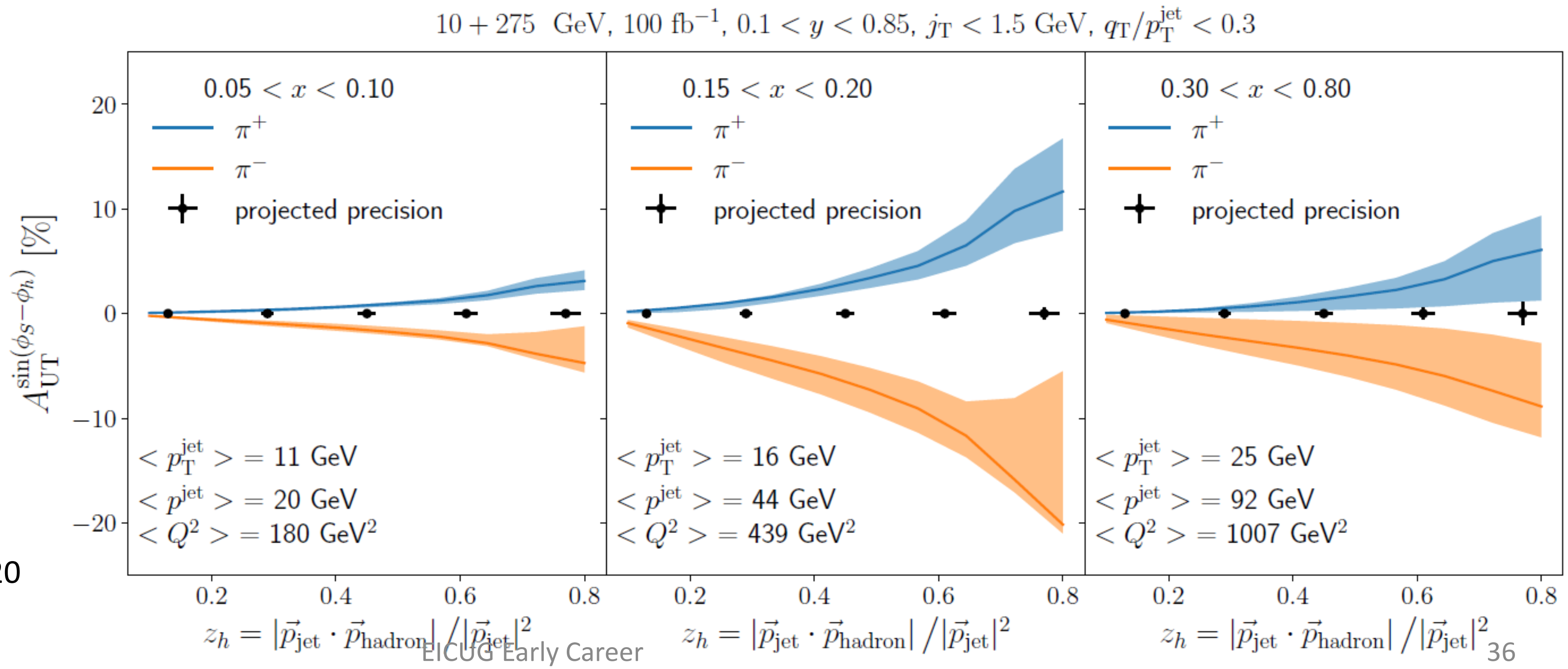
Hadron-in-Jet: Collins TMD

$$e + p(\vec{s}_T) \to e + (\text{jet}(\vec{q}_T)\, h(z_h, \vec{j}_T)) + X$$



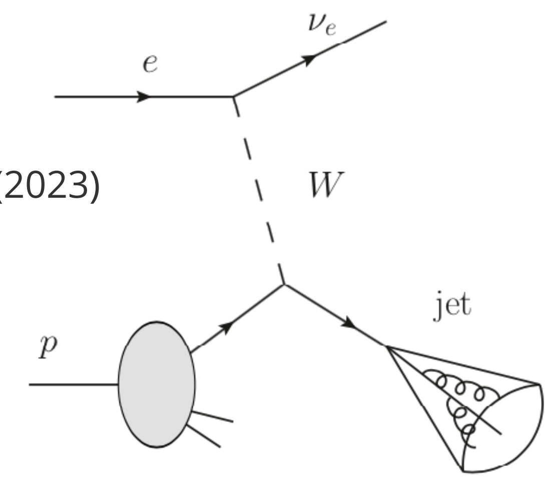
Arratia, Kang, Prokudin, Ringer `20

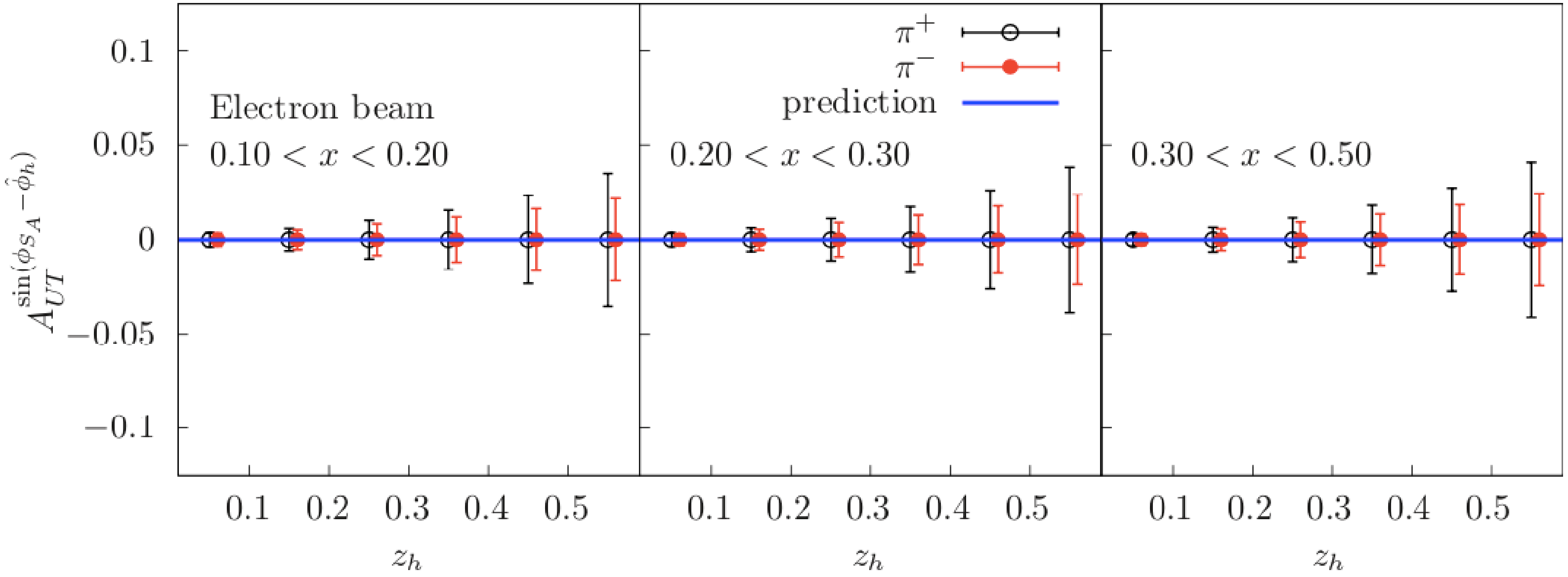
- Measurement of hadrons within jet give access to TMD FFs
- Relevant variables are j_T – transverse momentum of the hadron with respect to the jet and z – fraction of jet momentum carried by hadron
- Collins asymmetry correlates proton spin vector with j_T
- Identified hadrons allow for flavor separation of Collins FF

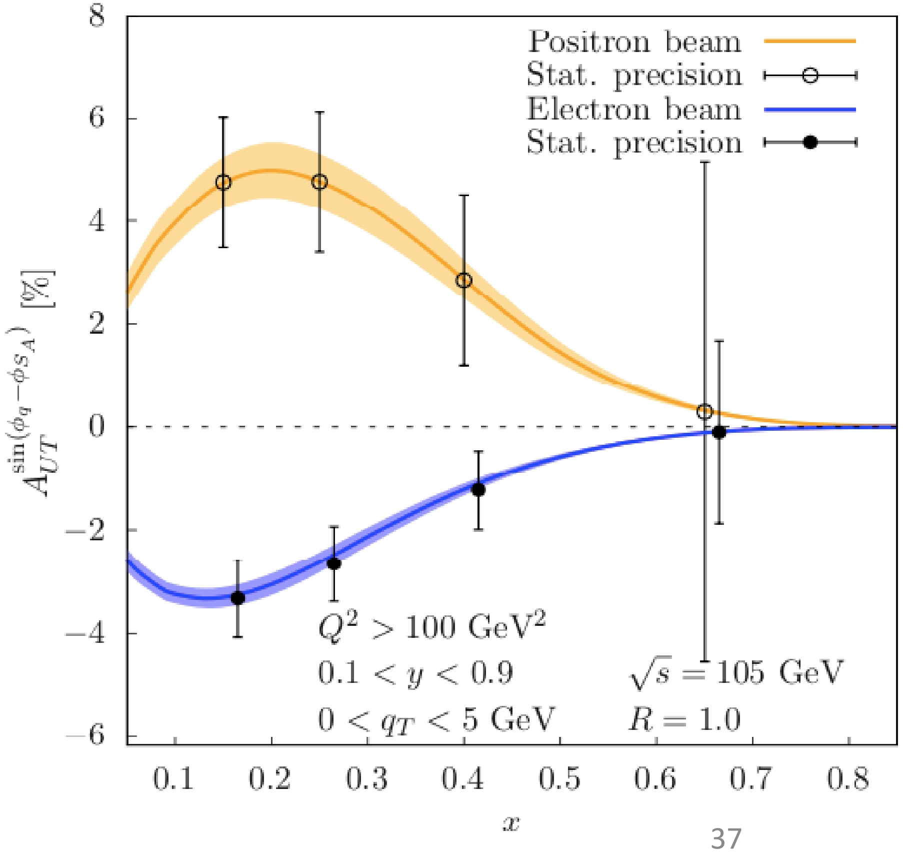


Charged Current Lepton-Jet Correlations

Phys. Rev. D 107, 094036 (2023)



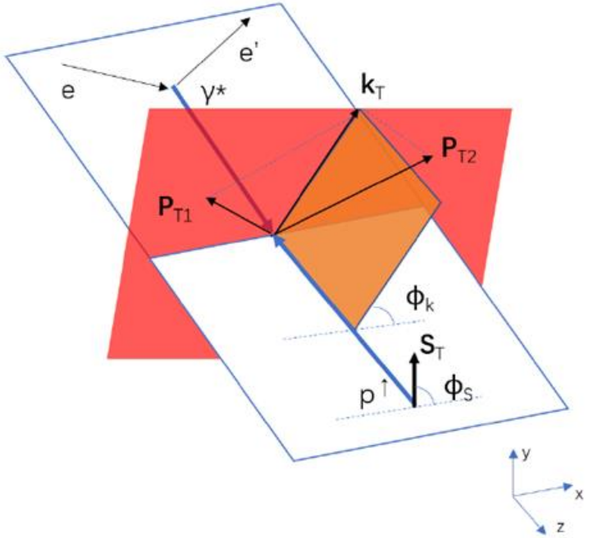




- Previous lepton-jet and hadron-in-jet measurements can also be carried out in charged current DIS where the outgoing neutrino is deduced via missing transverse energy
- Charge conservation leads to flavor separation
- Chiral odd nature of interaction means Collins asymmetries vanish at leading order

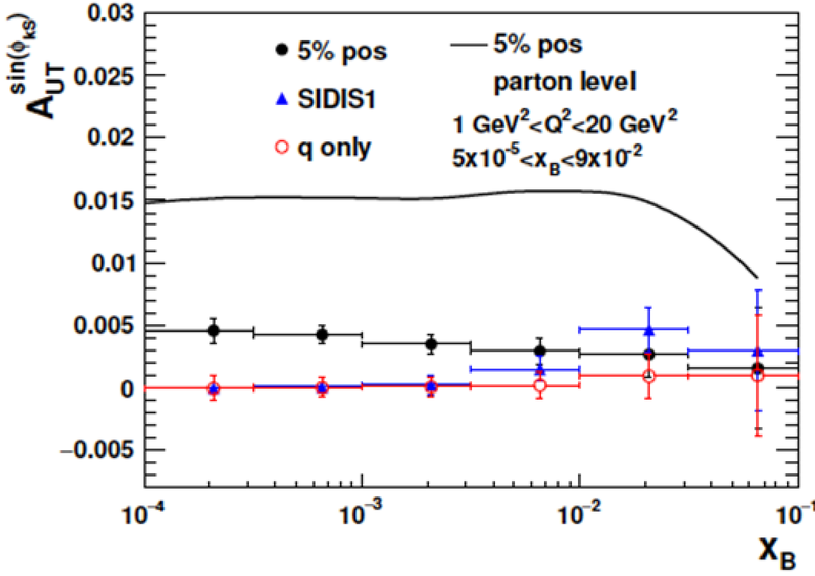
Dijet Correlations: Gluon Sivers TMD

Phys. Rev. D 98, 034011 (2018)

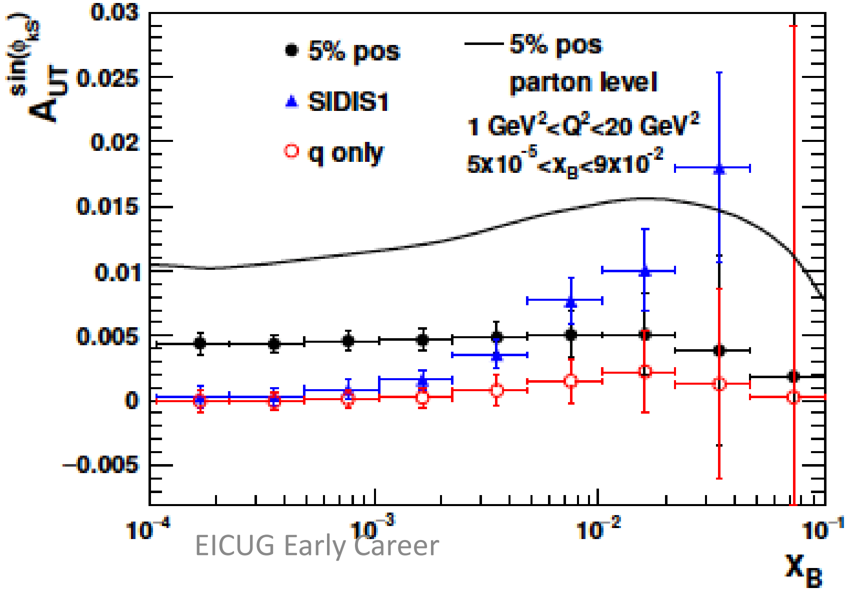


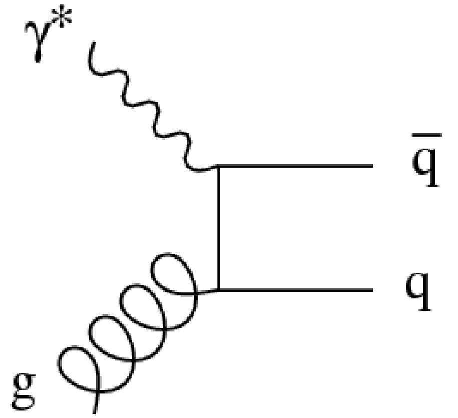
- Modulations of the angle between the proton spin vector and the sum of the di-parton system provide access to gluon sivers function
- Use of dijets has several advantages over di-hadrons including lower dilution of asymmetry and better separation between models of gluon sivers effect
- Jets don't suffer from uncertainties arising due to fragmentation (although hadronization still a concern)

Di-Hadrons



Dijets





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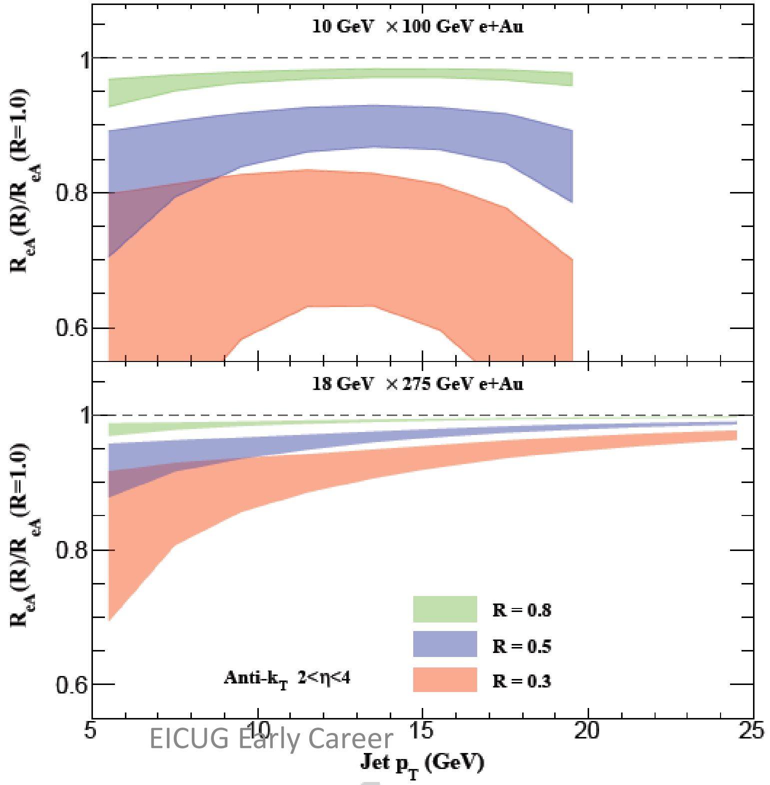
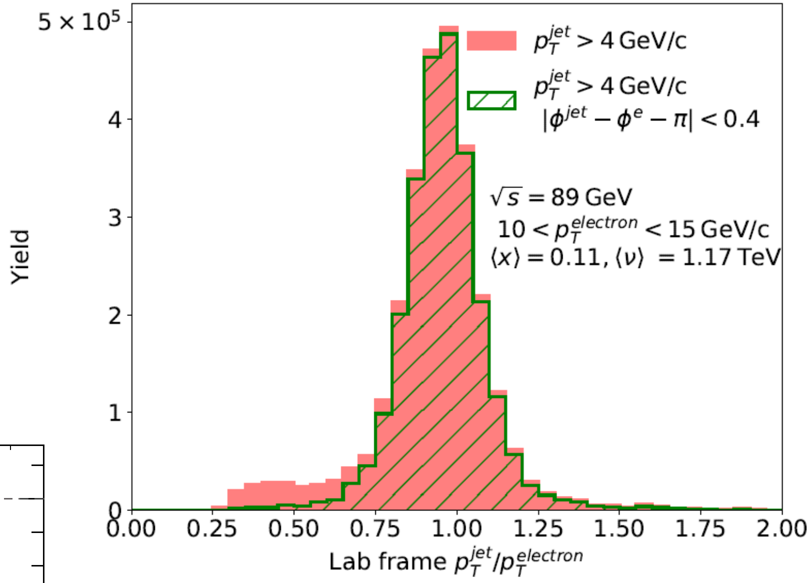
Jets in the Medium: CNM Properties

- Many opportunities to study the properties of cold nuclear matter with jets
- Simple comparisons of jet yields in ep vs eA will be informative – double ratio $R_{eA}(R)/R_{eA}(R = 1.0)$ will reduce impact from nPDFs and enhance final state effects
- Lepton – Jet correlations in Born level DIS can be thought of as analogous to boson – Jet measurements with the lepton as the tag and the jet as the probe of the medium
- Dijets and gamma-dijet correlations also expected to be powerful probes of saturation / small-x dynamics

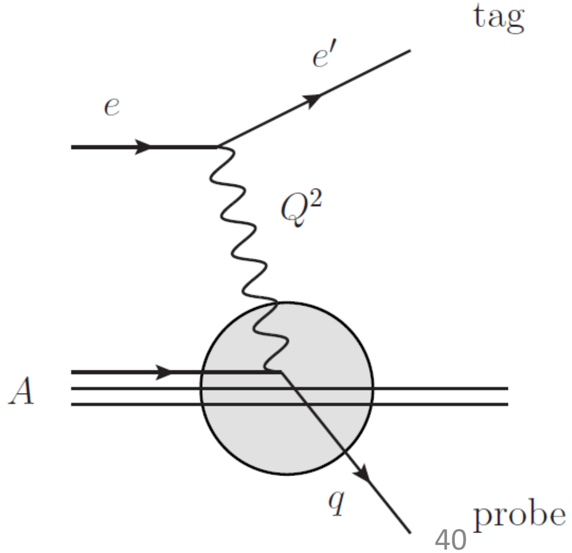
$$R_{\mathrm{eA}}(R) = \frac{1}{A}\frac{\int_{\eta 1}^{\eta 2} d\sigma/d\eta dp_T|_{e+A}}{\int_{\eta 1}^{\eta 2} d\sigma/d\eta dp_T|_{e+p}}$$

Li & Vitev '20





Arratia, Song, Ringer, Jacak '20



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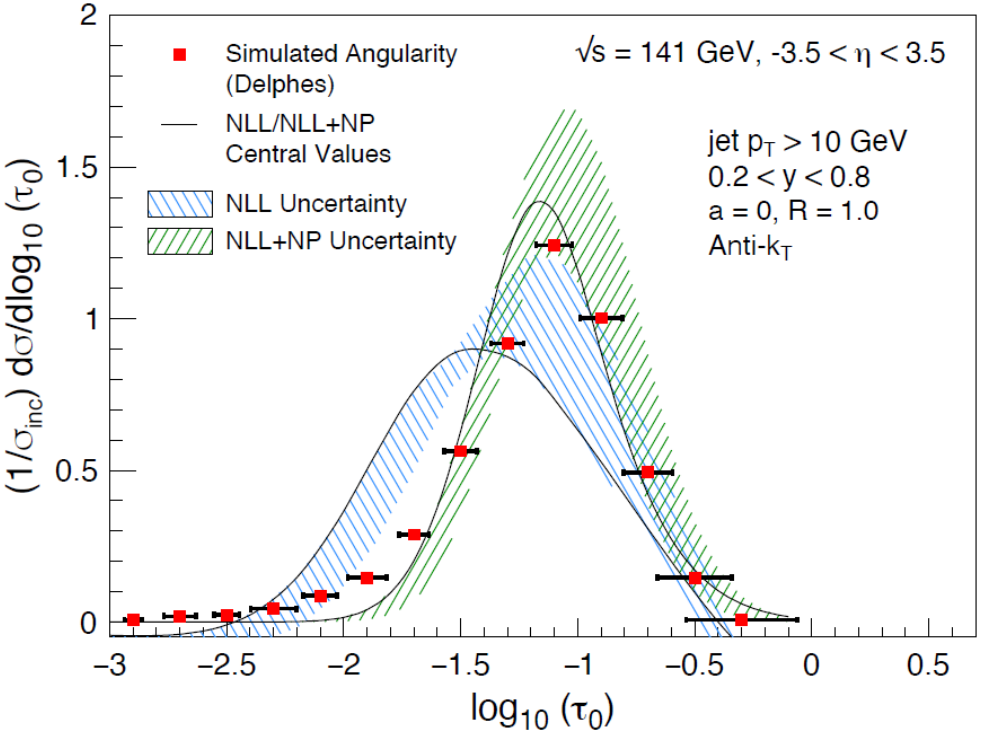
Jet Substructure: Angularity

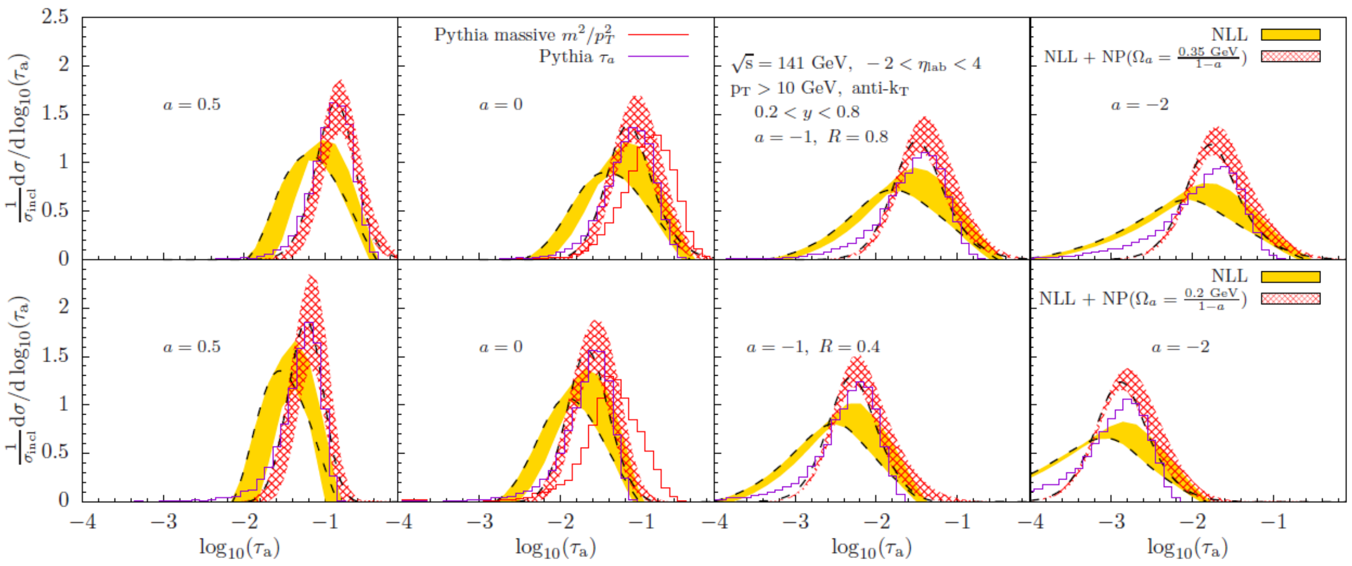
$$\tau_a \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta R_{iJ}\right)^{2-a}$$



Aschenauer, Lee, Page, Ringer `20 & ATHENA Proposal

$$F_\kappa(k) = \left(\frac{4k}{\Omega_\kappa^2}\right) \exp\left(-\frac{2k}{\Omega_\kappa}\right)$$ NP Effects

- ❑ Jet angularity are a family of one-parameter substructure observables correlating momentum and radial distance of particles in a jet
- ❑ Different choices of 'a' parameter interpolate between familiar substructure observables such as mass and broadening
- ❑ Sensitive to hadronization effects via convolution with the non-perturbative shape function Ω_1

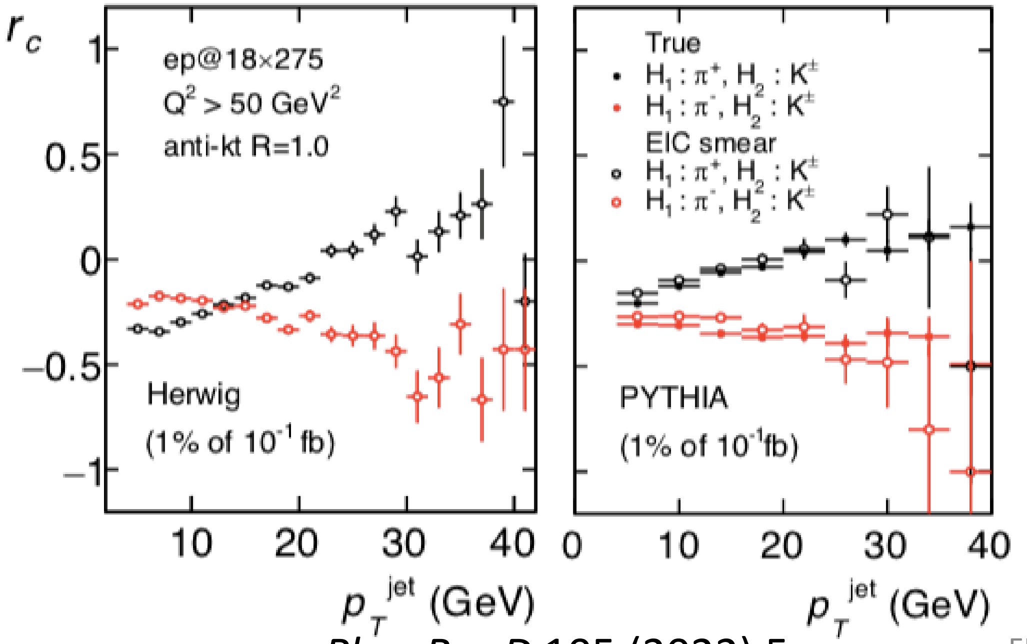


Leading Di-hadron Correlations

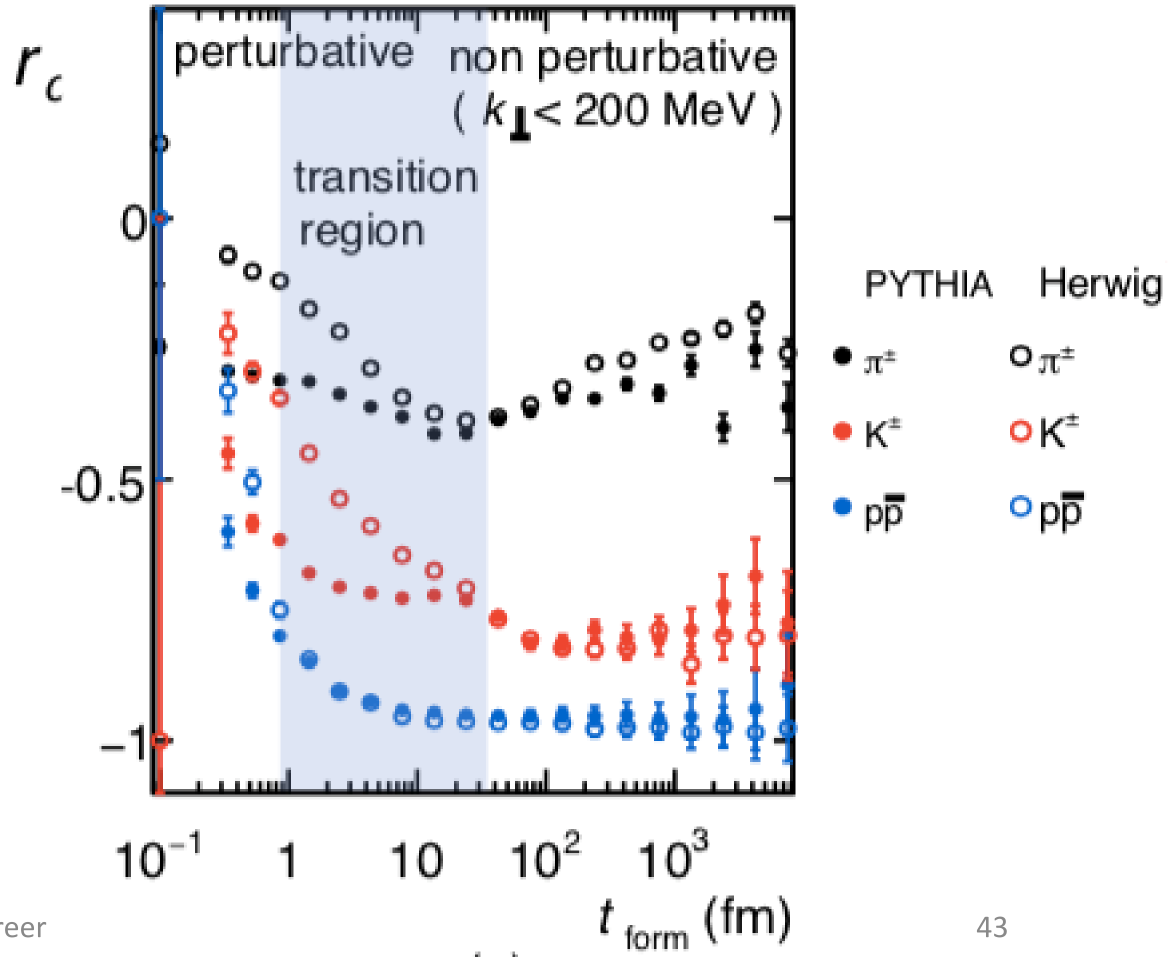
$$r_c(X) = \frac{d\sigma_{h_1 h_2}/dX - d\sigma_{h_1 \overline{h_2}}/dX}{d\sigma_{h_1 h_2}/dX + d\sigma_{h_1 \overline{h_2}}/dX}$$

- Quantify distributions of charge, flavor, spin, etc within a jet -> study hadronization process
- Define the ratio r_c to explore the charge and flavor correlations between leading hadrons within a jet
- See differences in how charge and flavor are distributed vs jet p_T and formation time between different hadronization models

$t_{form} = \frac{z(1-z)p}{k_\perp^2}; p = p_1 + p_2; z = \frac{p_2}{p};\ k_\perp$= rel trans mom

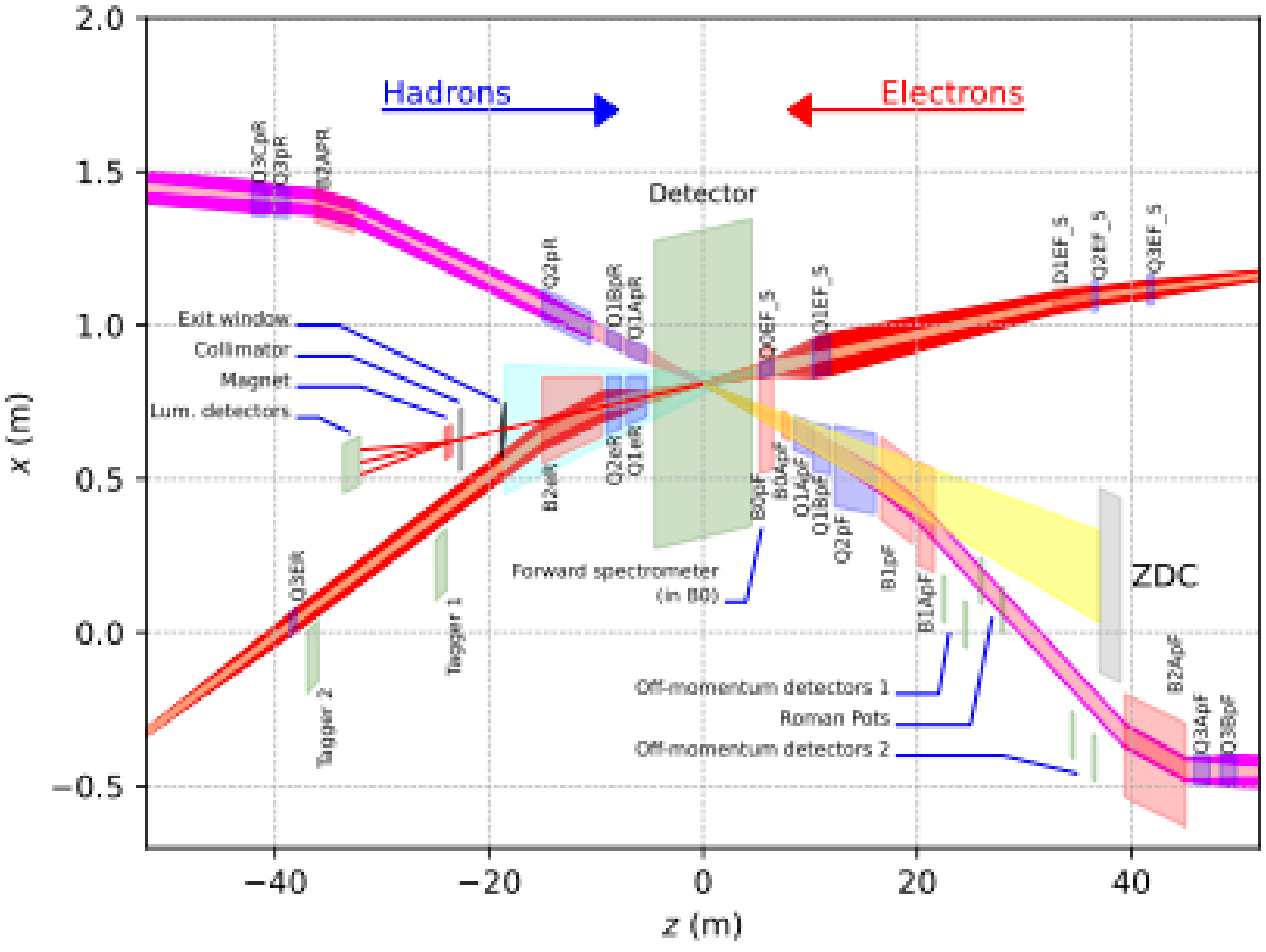


Phys.Rev.D 105 (2022) 5

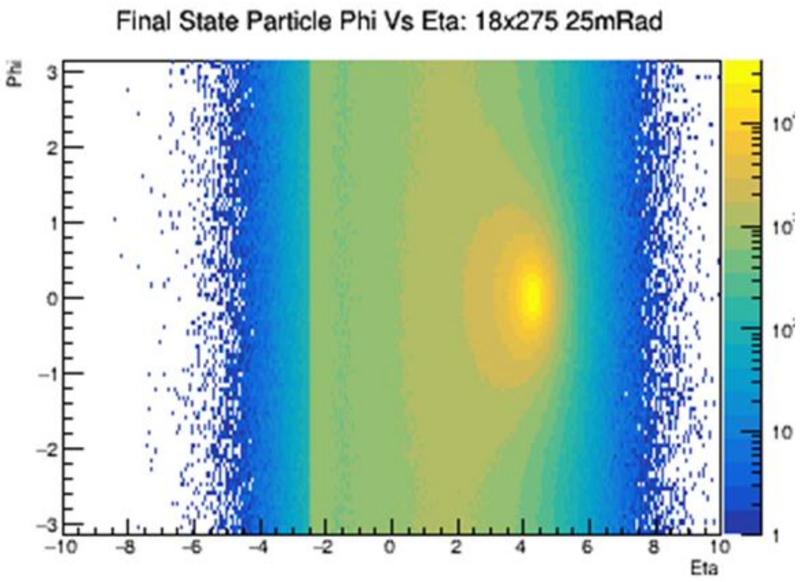


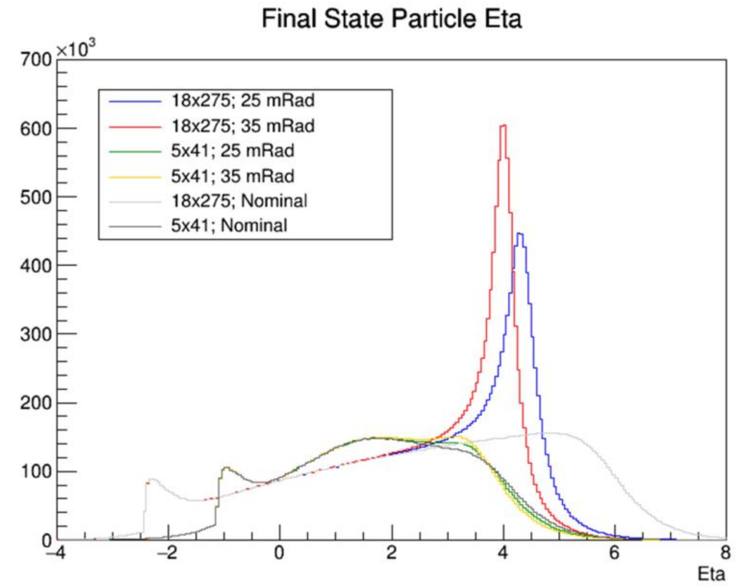
Beam Crossing Angle

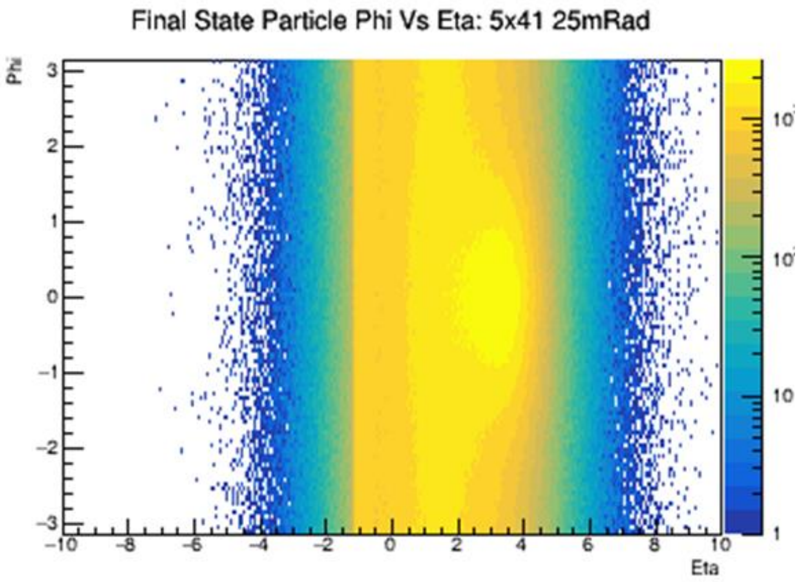
- Both interaction regions at the EIC will feature significant beam crossing angles (25 mRad for IP6 and 35 mRad for IP8)
- Crossing angles needed to avoid parasitic collisions which would degrade beams
- Presence of crossing angle will affect acceptance and detector design in the proton-going endcap – a region of great importance for many jet measurements
- A summary of beam effects, including crossing angle, bunch crabbing, divergence, etc as well as methods for simulating these can be found in the technical note here: https://zenodo.org/record/6514605#.ZETiIOzMJAY

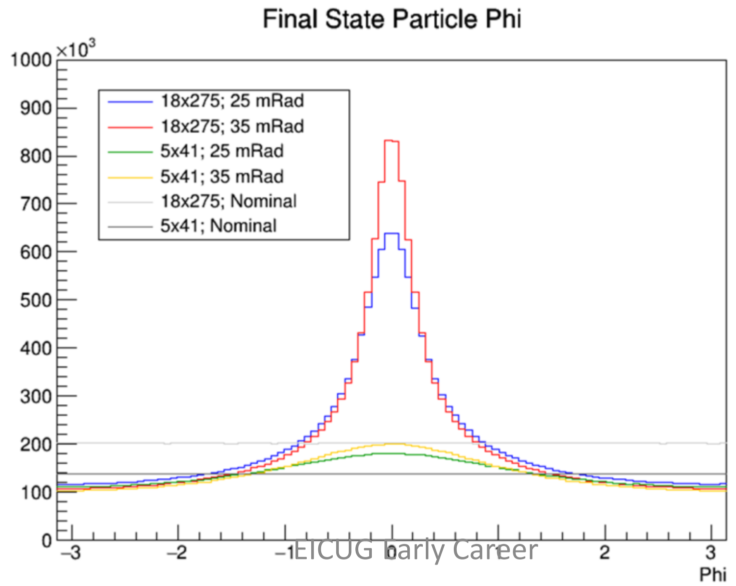


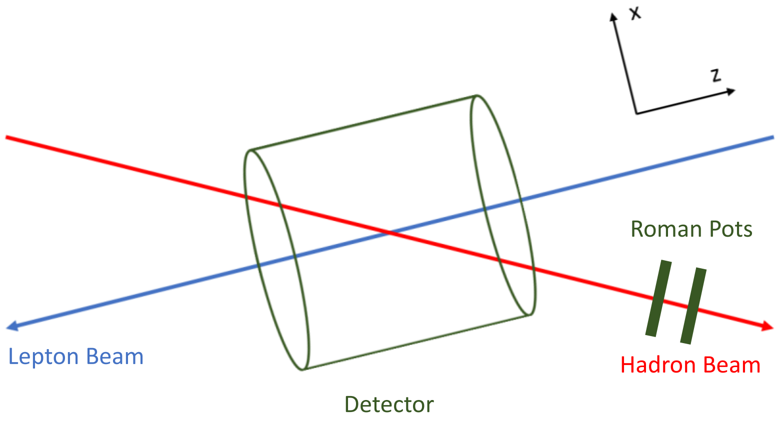
Final State Particle Distributions









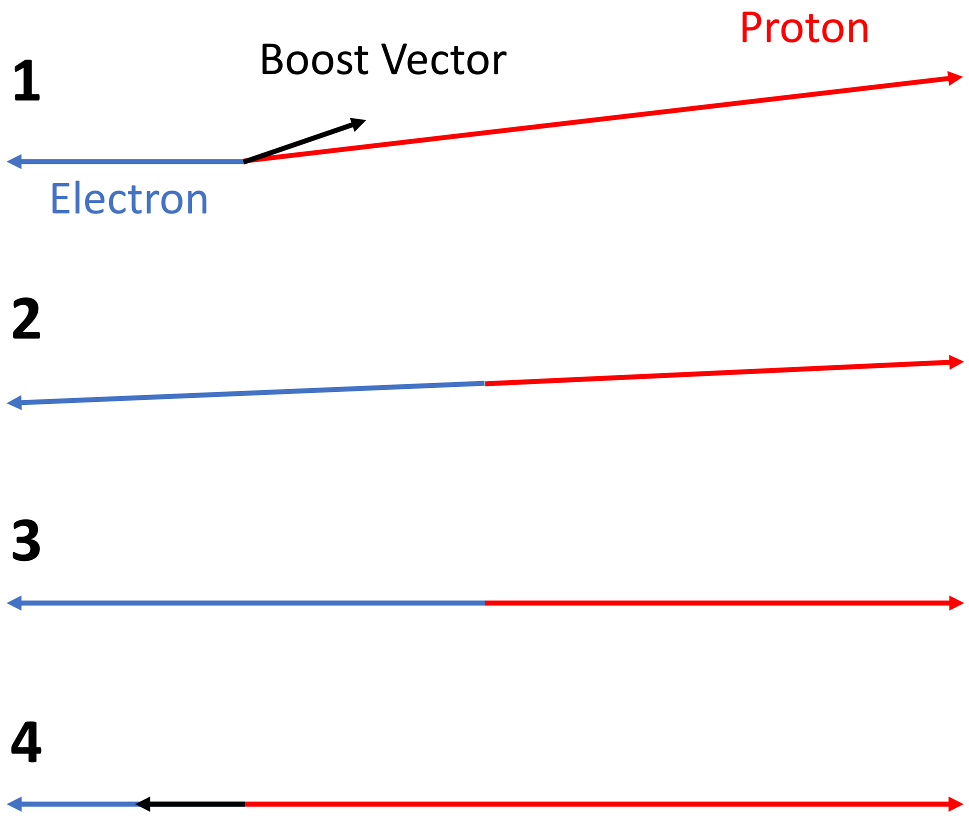


- Detector solenoid must align with electron beam to minimize synchrotron radiation: “lab frame” -> electron beam = z-axis
- When measuring in lab frame coordinates – see a hot spot in eta/phi corresponding to the beam direction
- More pronounced for more relativistic beams
- How do we mitigate these features?

Head-On (Minimum Boost) Frame

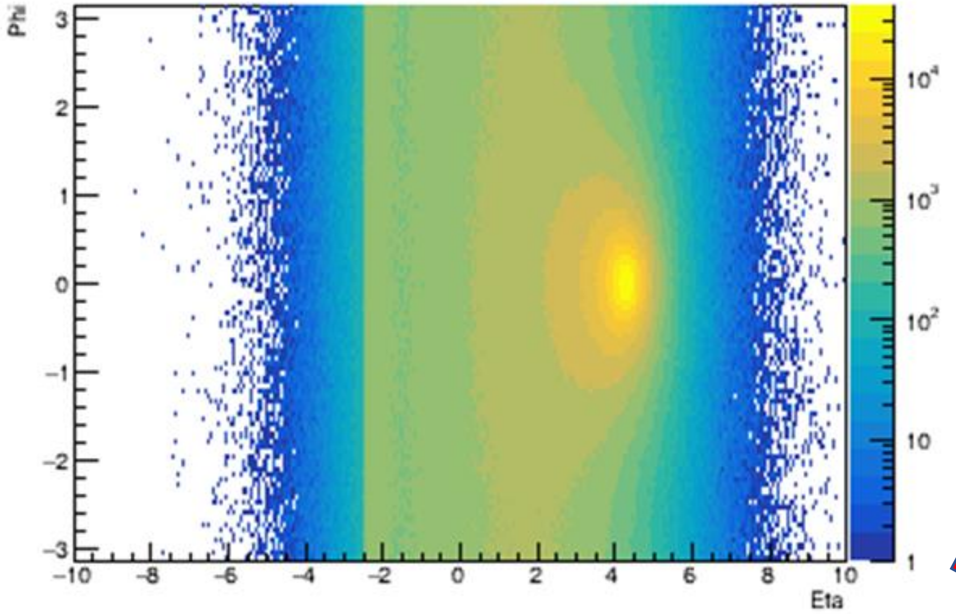
- Can boost and rotate into a frame in which the beams are collinear (no crossing angle) and energies are very close to the original (minimum boost)
- This should give an undistorted distribution of particles at high and low eta simultaneously

1. Initial Configuration in the Lab Frame includes a relative angle between the beams
2. Boost by sum of beam 4-momenta to get to CM Frame
3. Rotate about y-axis to eliminate x-component of momentum
4. Boost back along z to (nearly) restore original beam energies



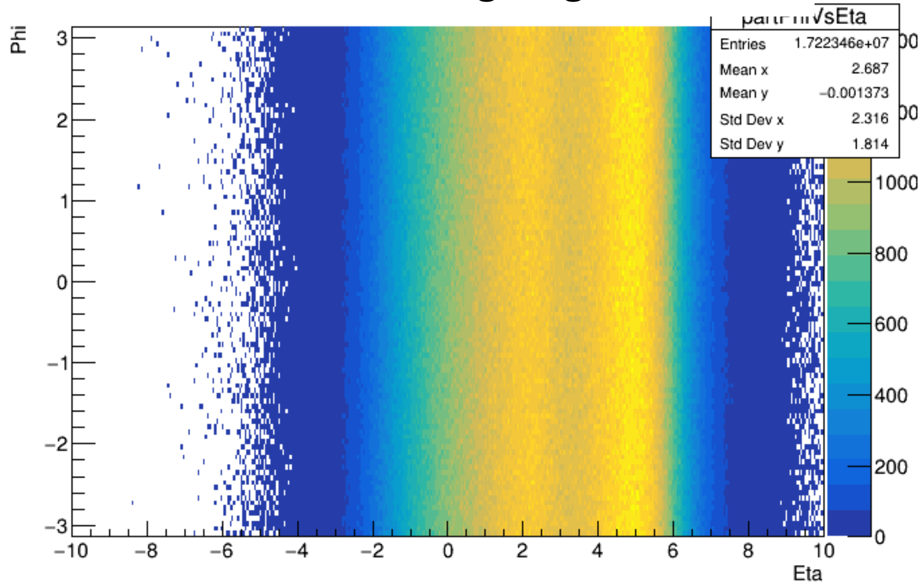
Head-On Frame Particle Distributions

Lab Frame Distribution

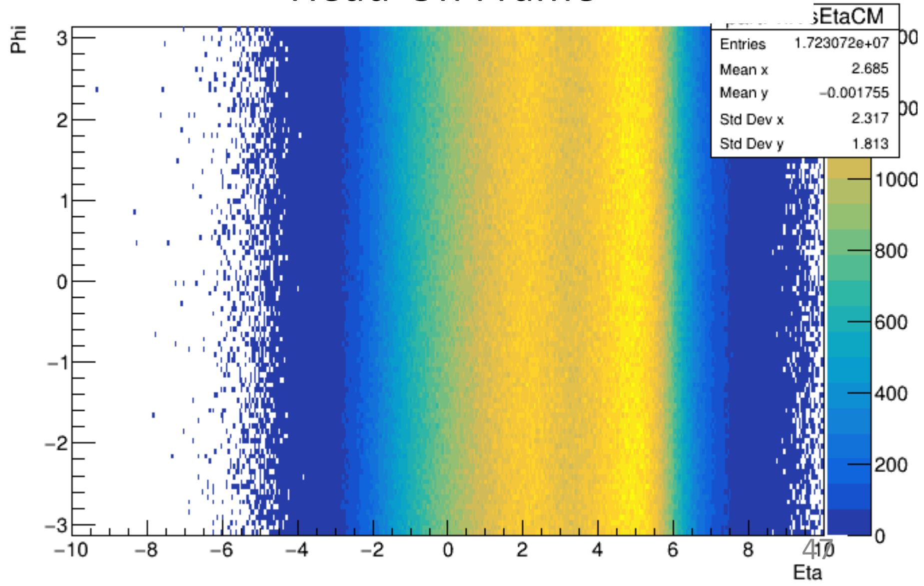


Transform to Head-On

No Crossing Angle



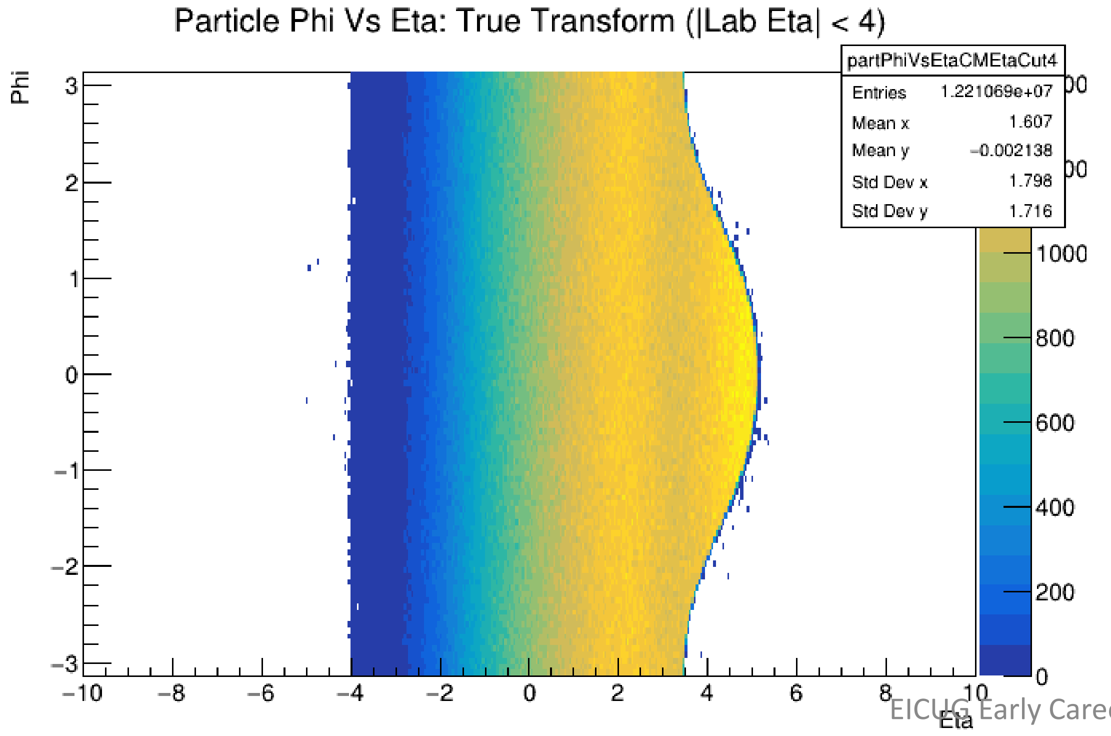
Head-On Frame



- ❑ Transformation to the head-on frame removes all features in the final state particle distribution for forward and backward regions simultaneously
- ❑ Resulting distribution matches that from default simulation with no crossing angle introduced

Detector Acceptance Considerations

- The head-on frame distributions shown previously assumed infinite acceptance – what effect will finite detector acceptance have?
- Displacement between beams means that acceptance cuts in the lab frame (w.r.t. the electron beam) will introduce phi-dependent acceptance features in head-on frame
- Try defining acceptance cuts w.r.t. the hadron beam instead



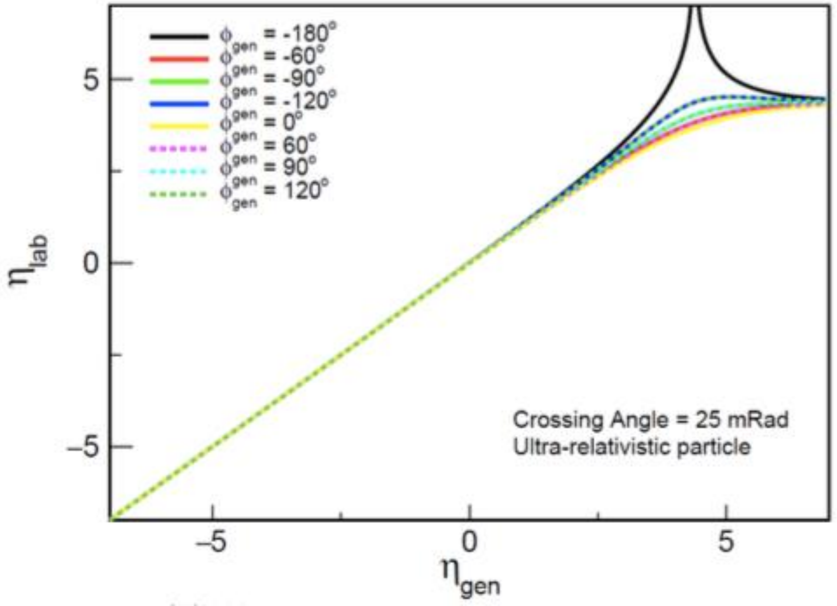
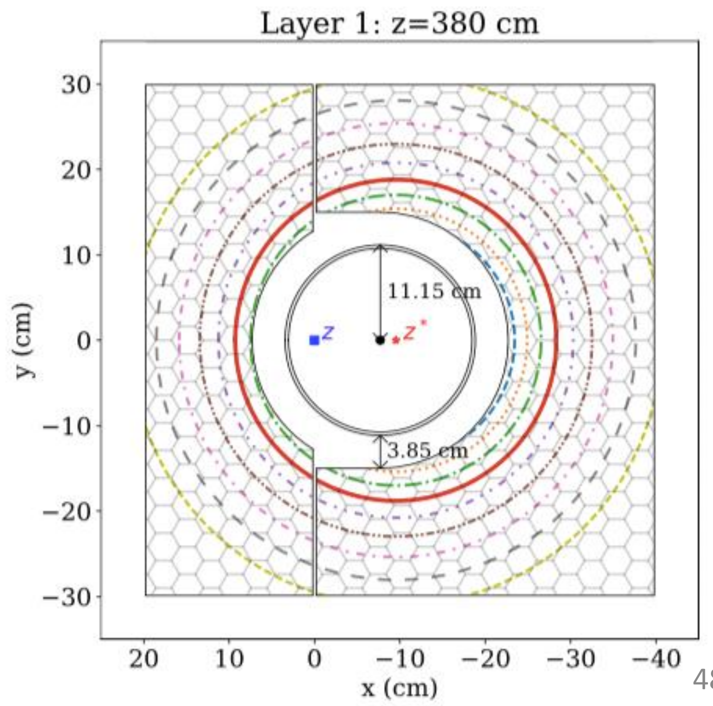


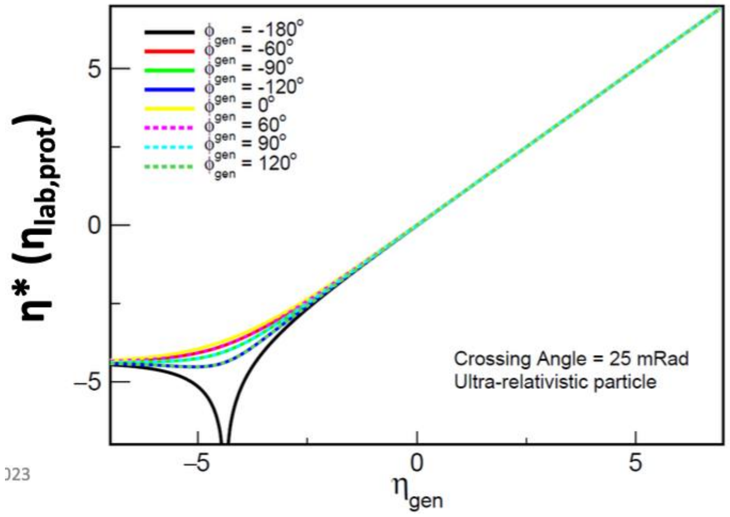
Figure by Barak Schmookler

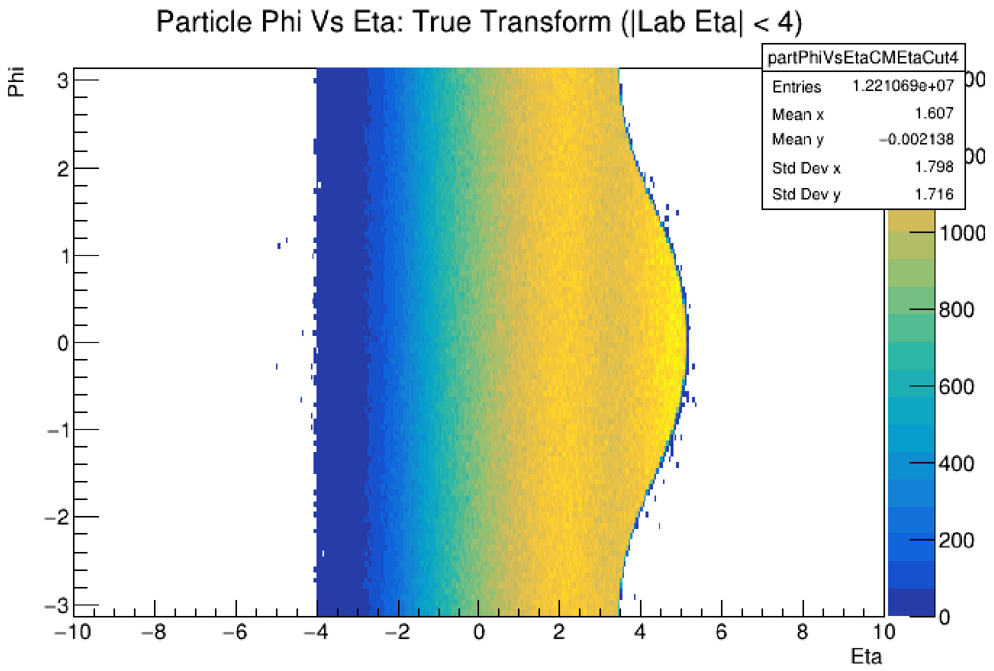


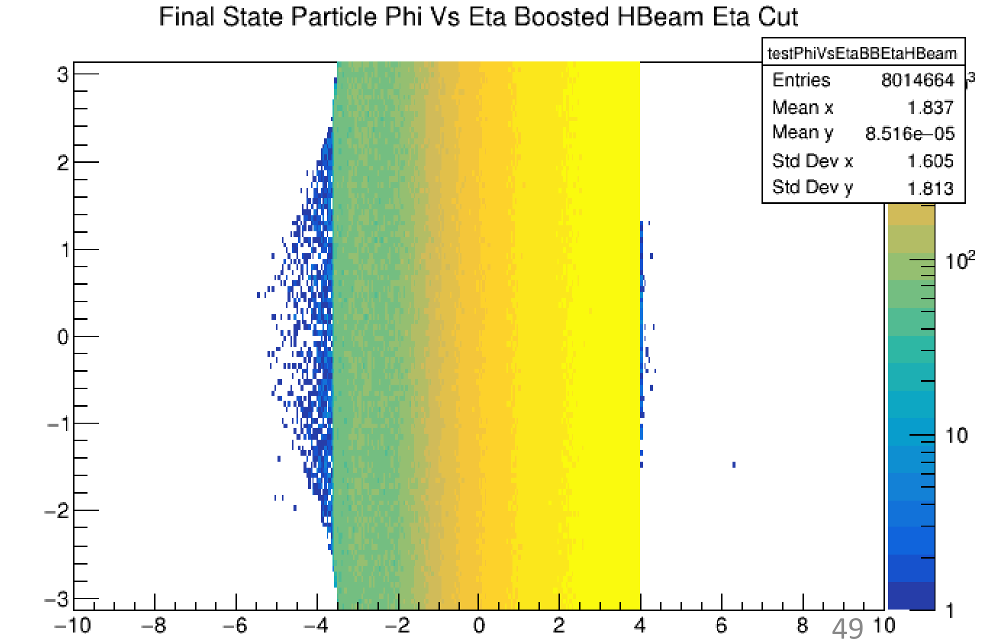
arXiv:2208.05472

Defining Acceptance Cuts

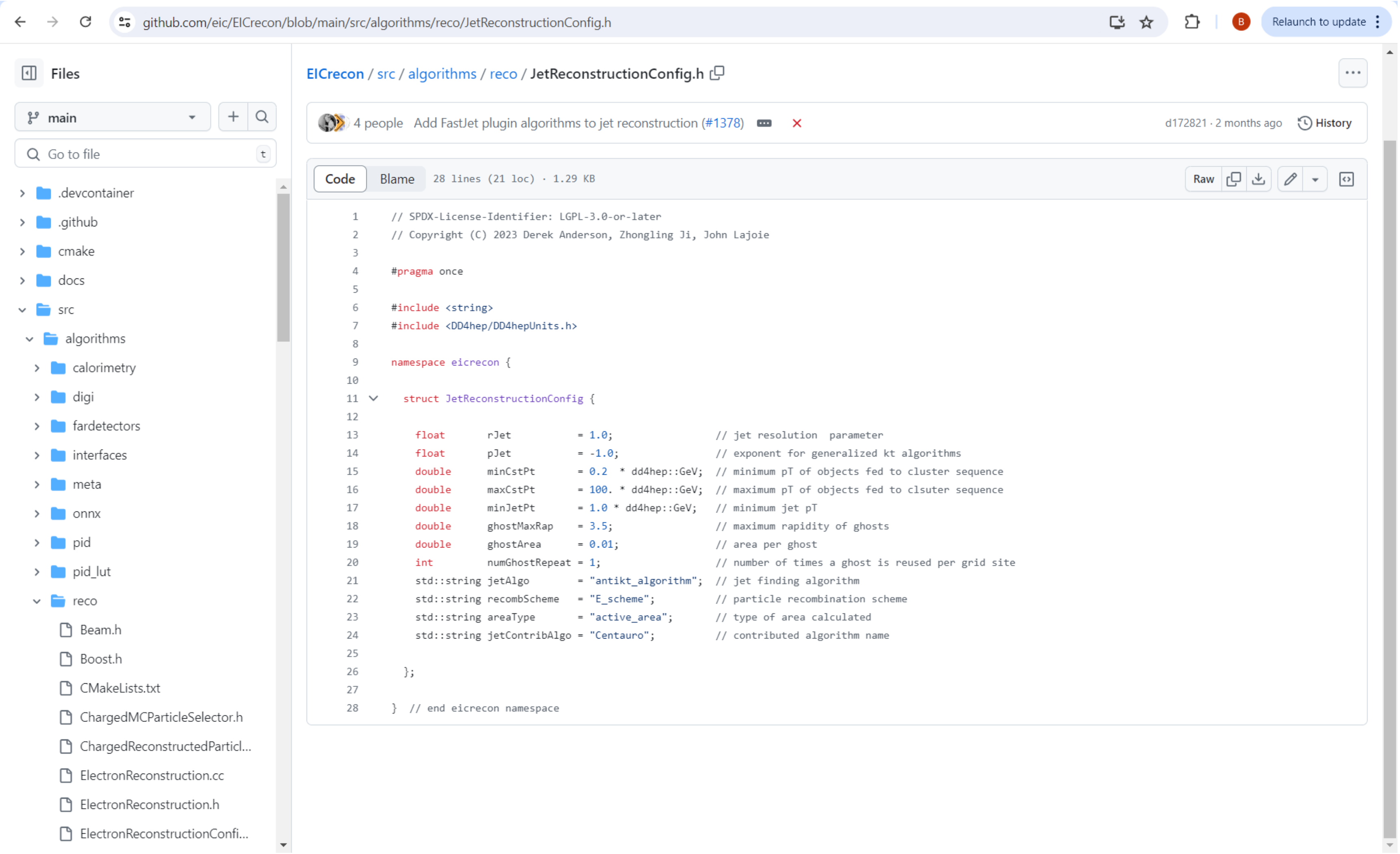
- The beam line shape in the endcap region is complicated, but mostly follows the hadron beam direction
- The z-axis in the head-on frame corresponds to the direction of the lab frame proton beam -> defining detector acceptance w.r.t. the hadron beam should eliminate the phi-dependent artifact
- Both plots on the right show the phi vs eta distribution where these quantities are defined in the head-on frame
  - Top plot applies a cut for |eta| < 4 where eta is defined relative to the electron beam
  - Bottom plot applies a cut for |eta| < 4 where eta is defined relative to the hadron beam







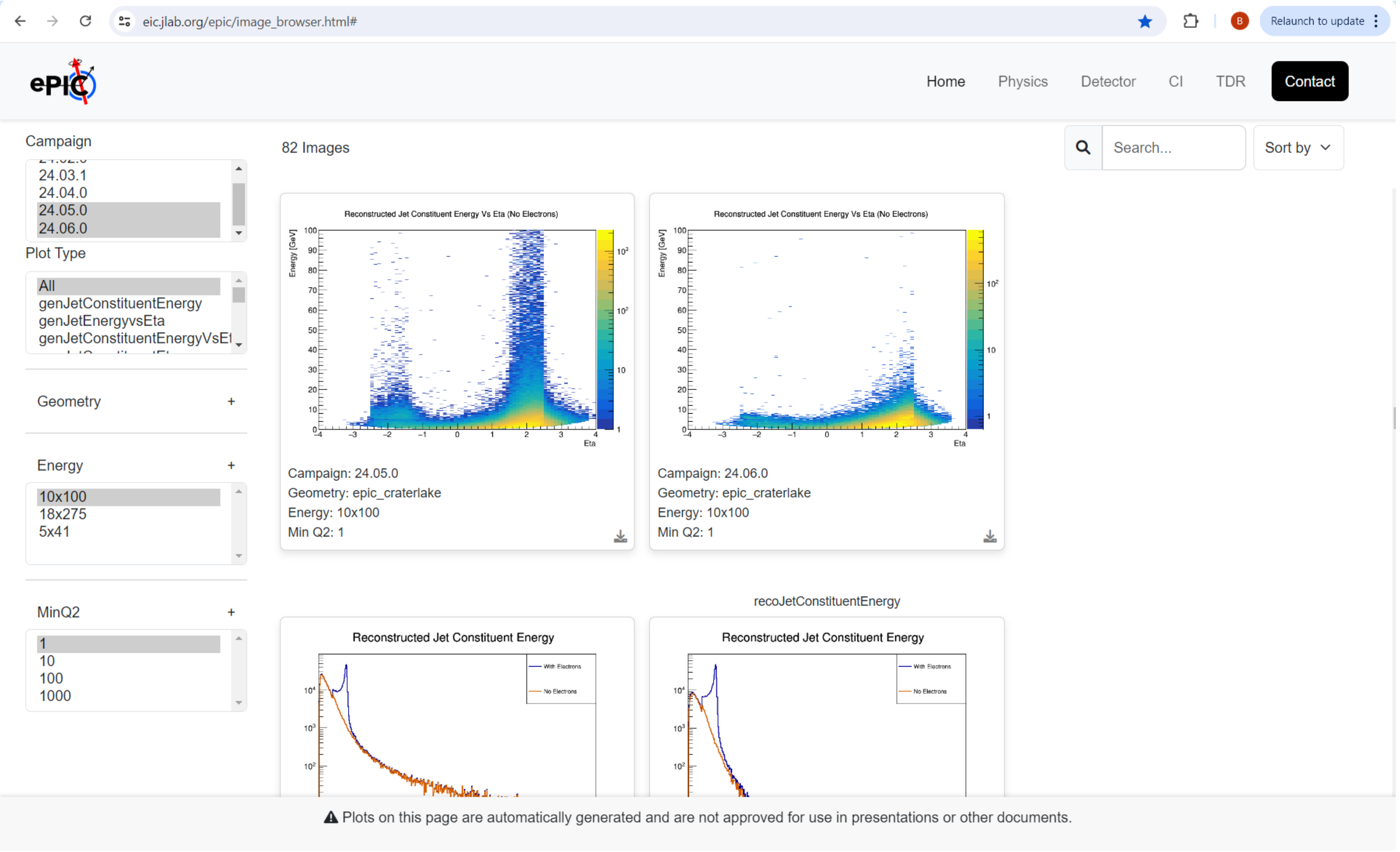
Jet Reconstruction at ePIC




```
// SPDX-License-Identifier: LGPL-3.0-or-later
// Copyright (C) 2023 Derek Anderson, Zhongling Ji, John Lajoie

#pragma once

#include <string>
#include <DD4hep/DD4hepUnits.h>

namespace eicrecon {

  struct JetReconstructionConfig {

    float       rJet            = 1.0;                  // jet resolution  parameter
    float       pJet            = -1.0;                 // exponent for generalized kt algorithms
    double      minCstPt        = 0.2  * dd4hep::GeV;   // minimum pT of objects fed to cluster sequence
    double      maxCstPt        = 100. * dd4hep::GeV;   // maximum pT of objects fed to clsuter sequence
    double      minJetPt        = 1.0 * dd4hep::GeV;    // minimum jet pT
    double      ghostMaxRap     = 3.5;                  // maximum rapidity of ghosts
    double      ghostArea       = 0.01;                 // area per ghost
    int         numGhostRepeat  = 1;                    // number of times a ghost is reused per grid site
    std::string jetAlgo         = "antikt_algorithm";   // jet finding algorithm
    std::string recombScheme    = "E_scheme";           // particle recombination scheme
    std::string areaType        = "active_area";        // type of area calculated
    std::string jetContribAlgo  = "Centauro";           // contributed algorithm name

  };

}  // end eicrecon namespace
```

- ePIC EICrecon output contains several jet branches using both the anti_kT and Centauro algorithms
- The most vetted outputs are based on the charged particles collection (track-only jets): ReconstructedChargedJets & GeneratedChargedJets
- Example demonstrating how to read and analyze the jet branches can be found in the snippets repository: https://github.com/eic/snippets/tree/main/JetsAndHF/jetReaderExamples

Jet Validation at ePIC



- A set of jet performance plots has been developed and run automatically over the monthly productions
- Plots are displayed on a web based interface allowing easy comparison of jet quantities between different simulation campaigns
- Browser: https://eic.jlab.org/epic/image_browser.html#
- Navigate to Physics -> Jets and Heavy Flavor

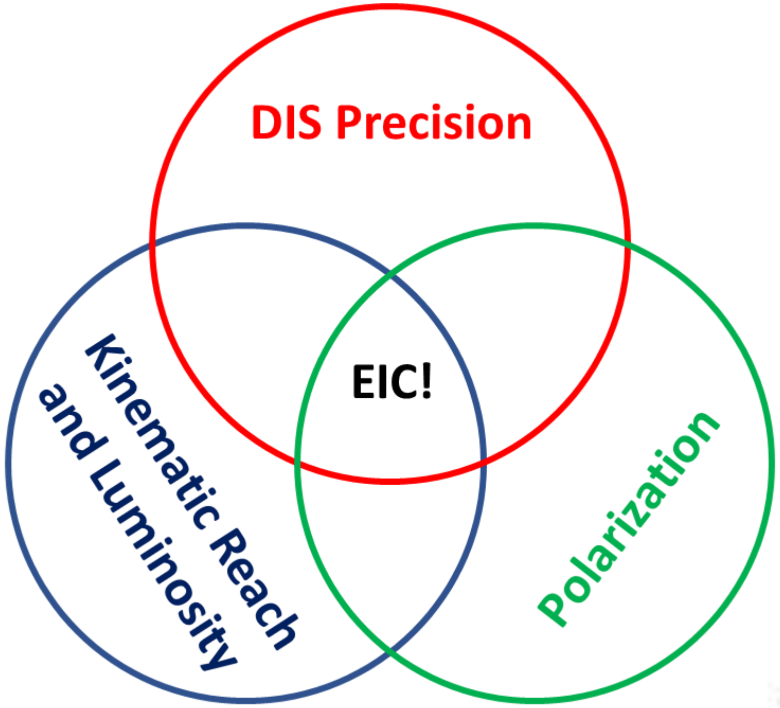
Summary

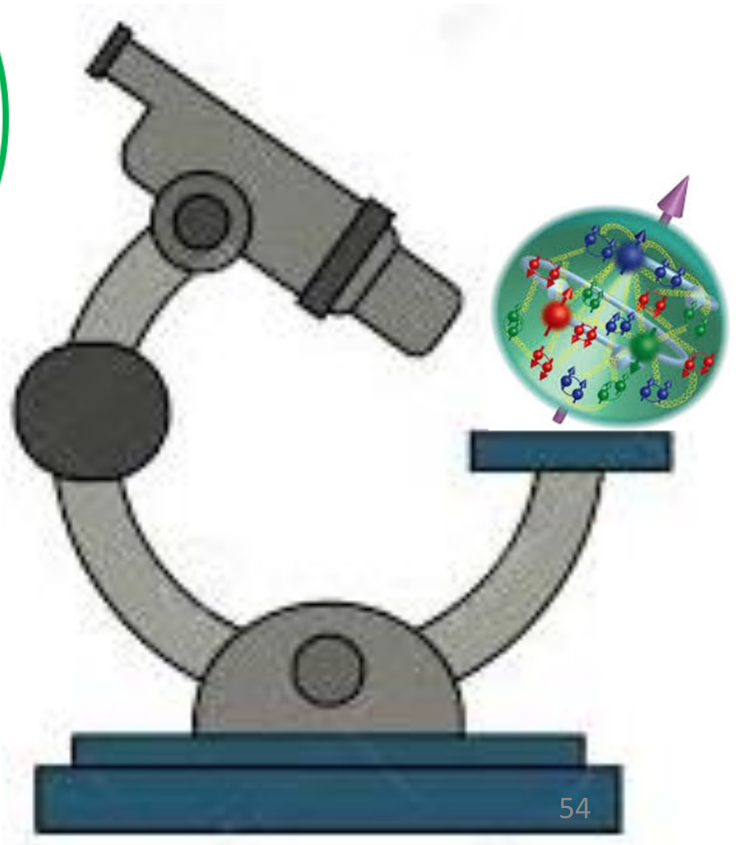
- The last ~10 years have seen a rapid increasing in the amount of theoretical and experimental work exploring the use of jets at the EIC
- The variety of subprocesses, kinematic dependencies and ability to work in different frames will make jets exceedingly versatile probes at the EIC
- Jet observables will contribute to nearly every area of the EIC science program, both complementing more traditional inclusive and semi-inclusive measurements and providing unique capabilities of their own
- The ePIC Collaboration is making strong progress developing the software tools necessary to implement and validate jet measurements

Backup

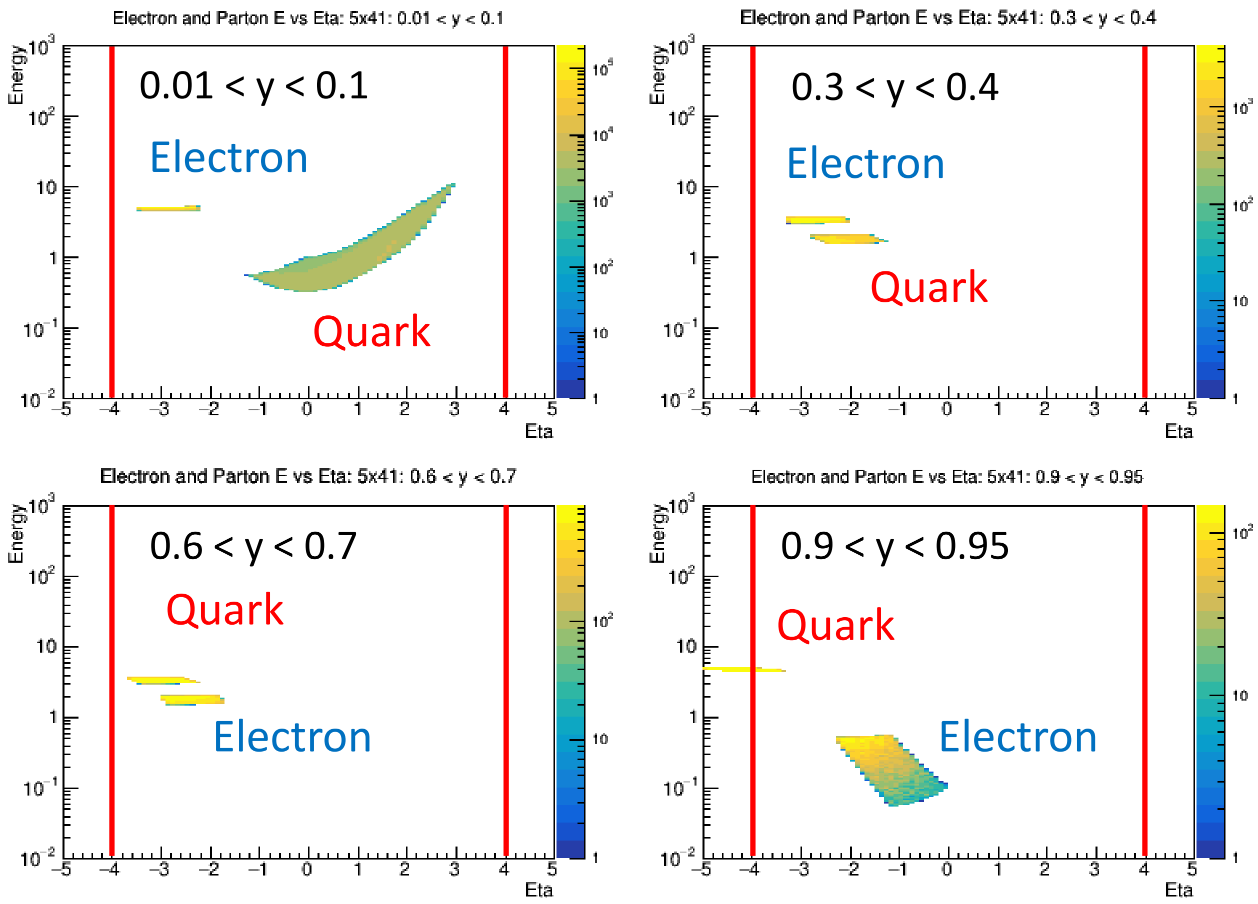
The Ultimate QCD Microscope

- ❑ Understanding internal dynamics of QCD bound states will require precision measurements over a wide kinematic regime – the EIC fits the bill
- ❑ Equally important will be high resolution, hermetic detectors with good PID and far-forward detection capabilities to fully characterize the final states of collisions
- ❑ Finally, need observables which are well understood theoretically, and which connect to the properties we want to explore
- ❑ This talk will focus on the unique capabilities jet observables will bring to the EIC science program





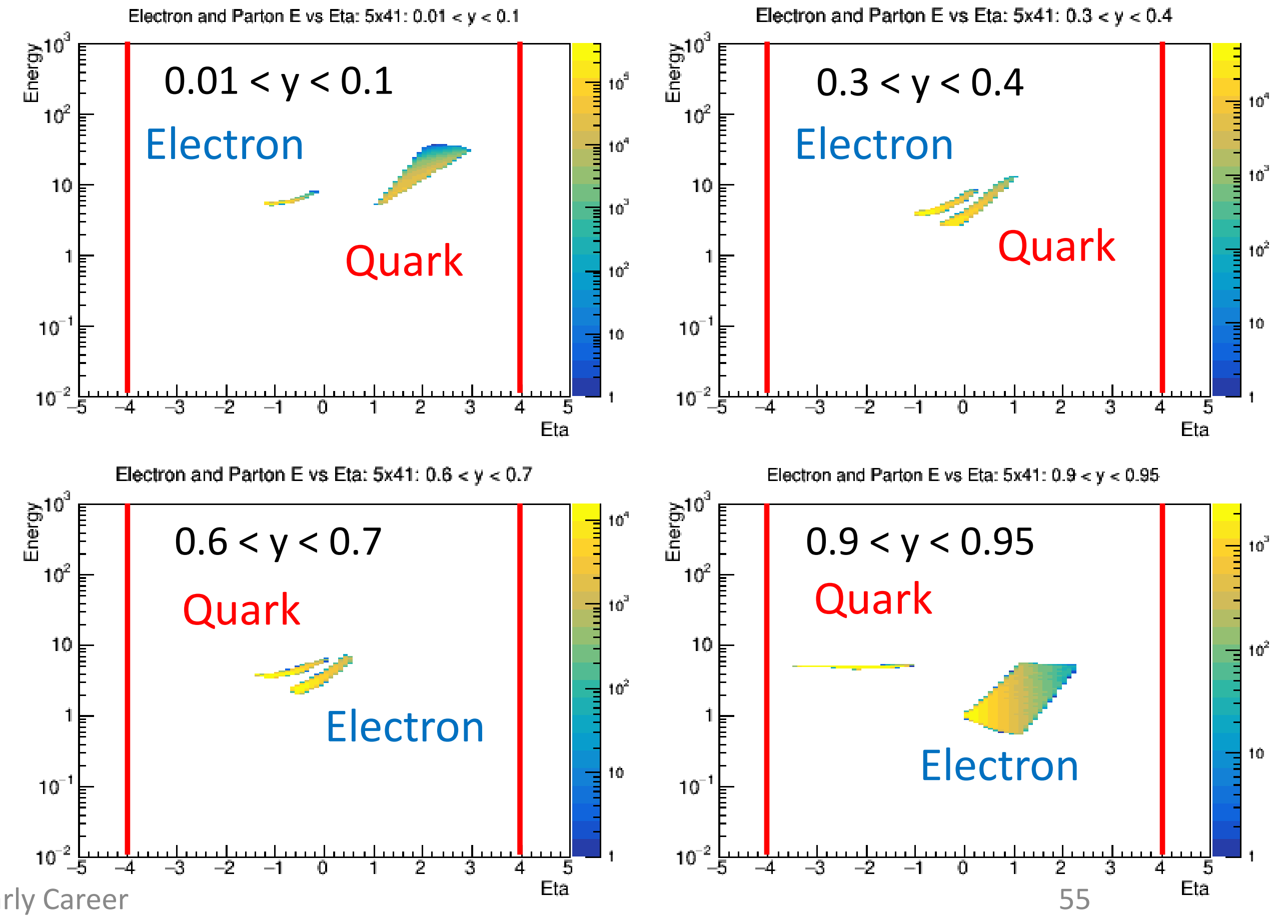
Electron and Struck Quark (5x41)



$0.1 < Q^2 < 1.0$

- ❑ 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

$10 < Q^2 < 100$

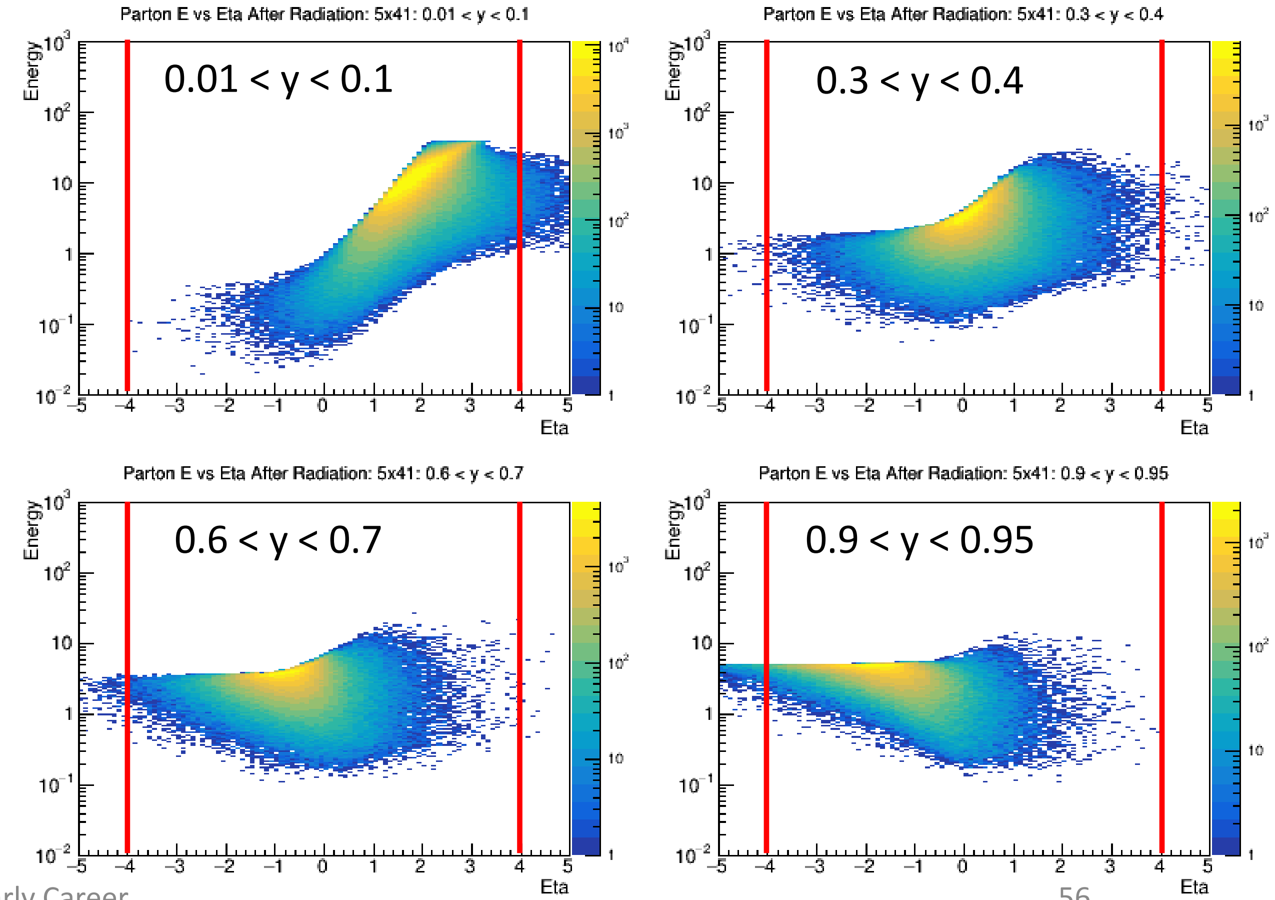


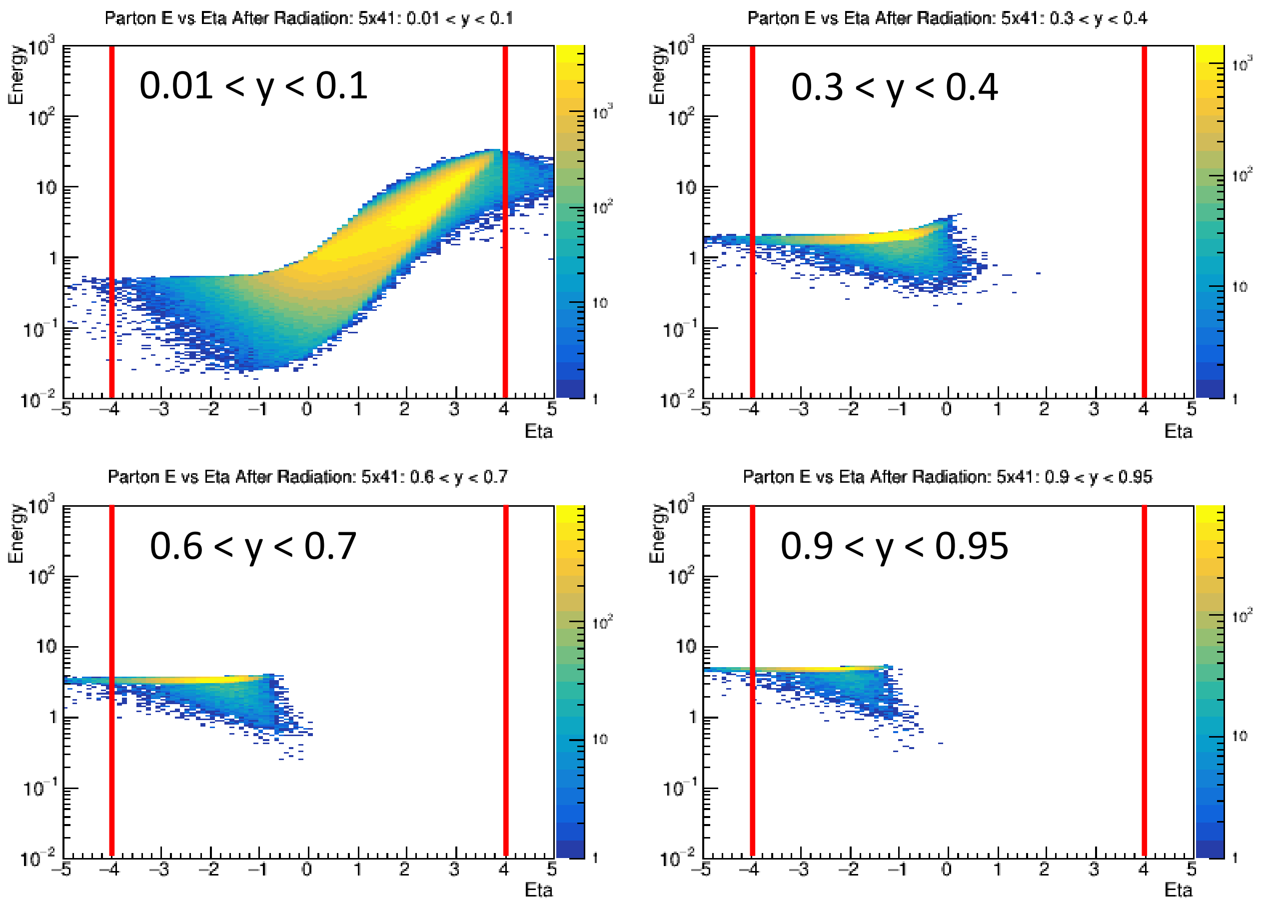
- ❑ As Q^2 increases, both the scattered electron and struck quark move to larger eta for all values of y

Struck Quark + FSR (5x41)

- Behavior as a function of Q^2, y, and beam energy is still seen

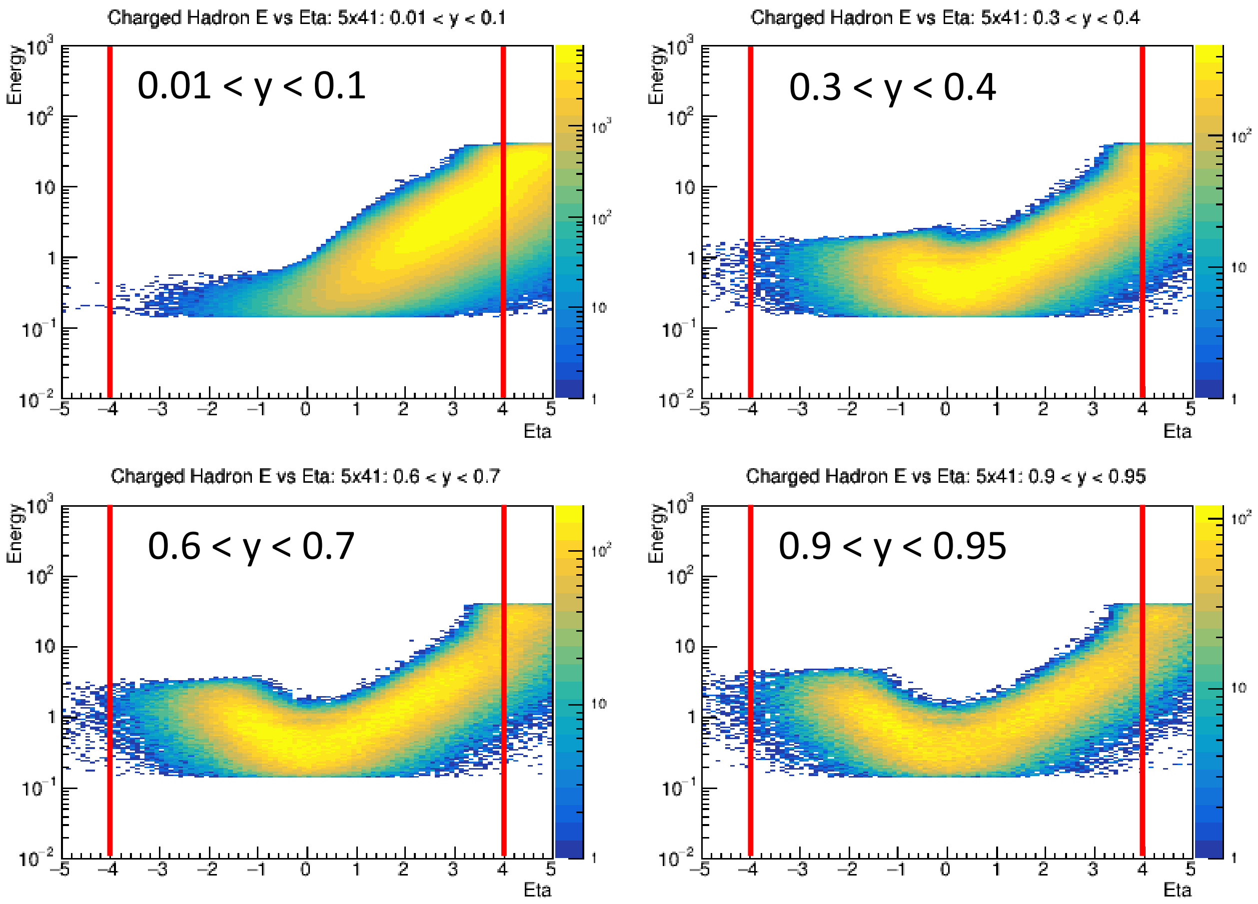
10 < Q^2 < 100





0.1 < Q^2 < 1.0

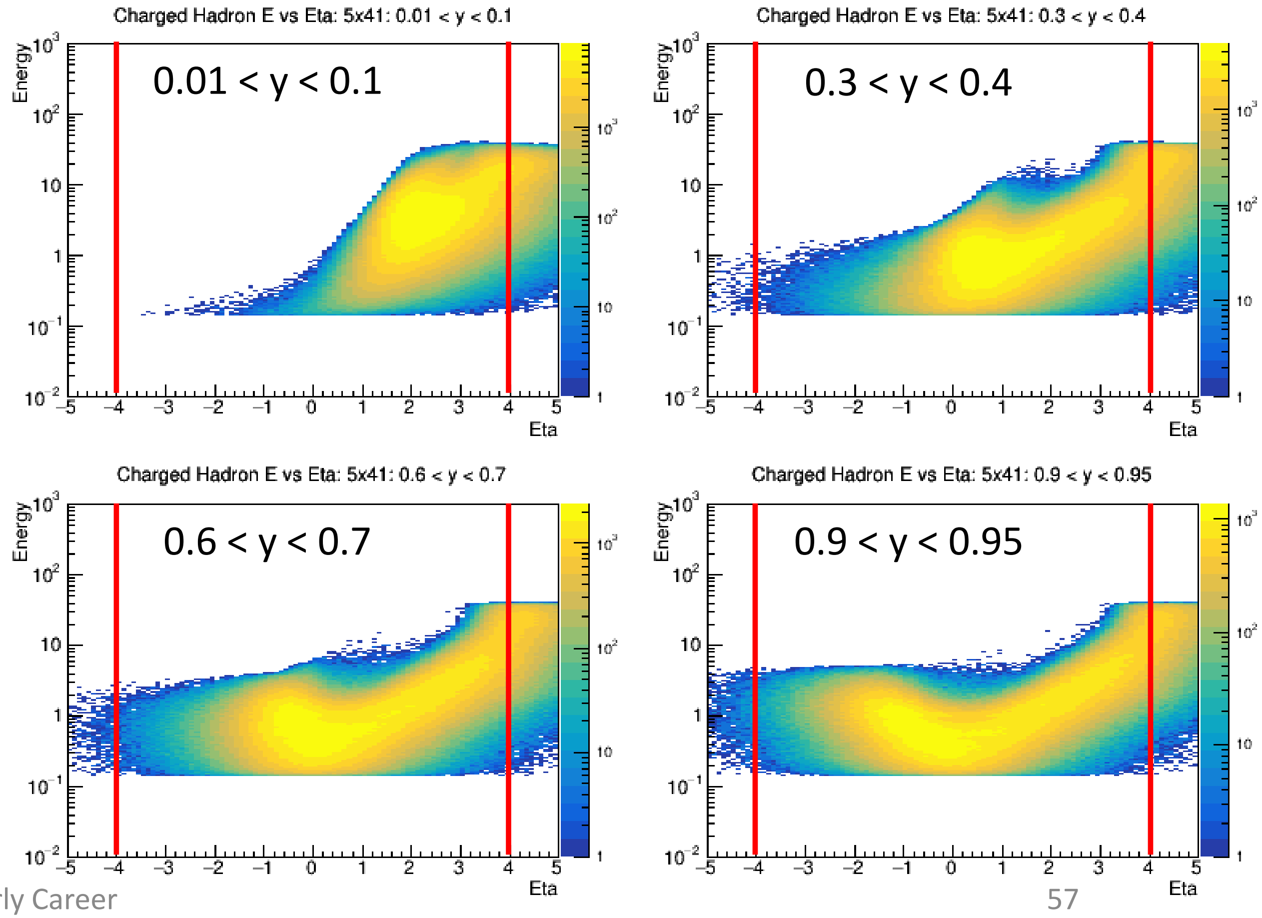
(Charged) Particle Distributions (5x41)



$0.1 < Q^2 < 1.0$

- ❑ Of course, it is final state hadrons which are measured
- ❑ Differences with y and Q2 are now somewhat less pronounced

$10 < Q^2 < 100$

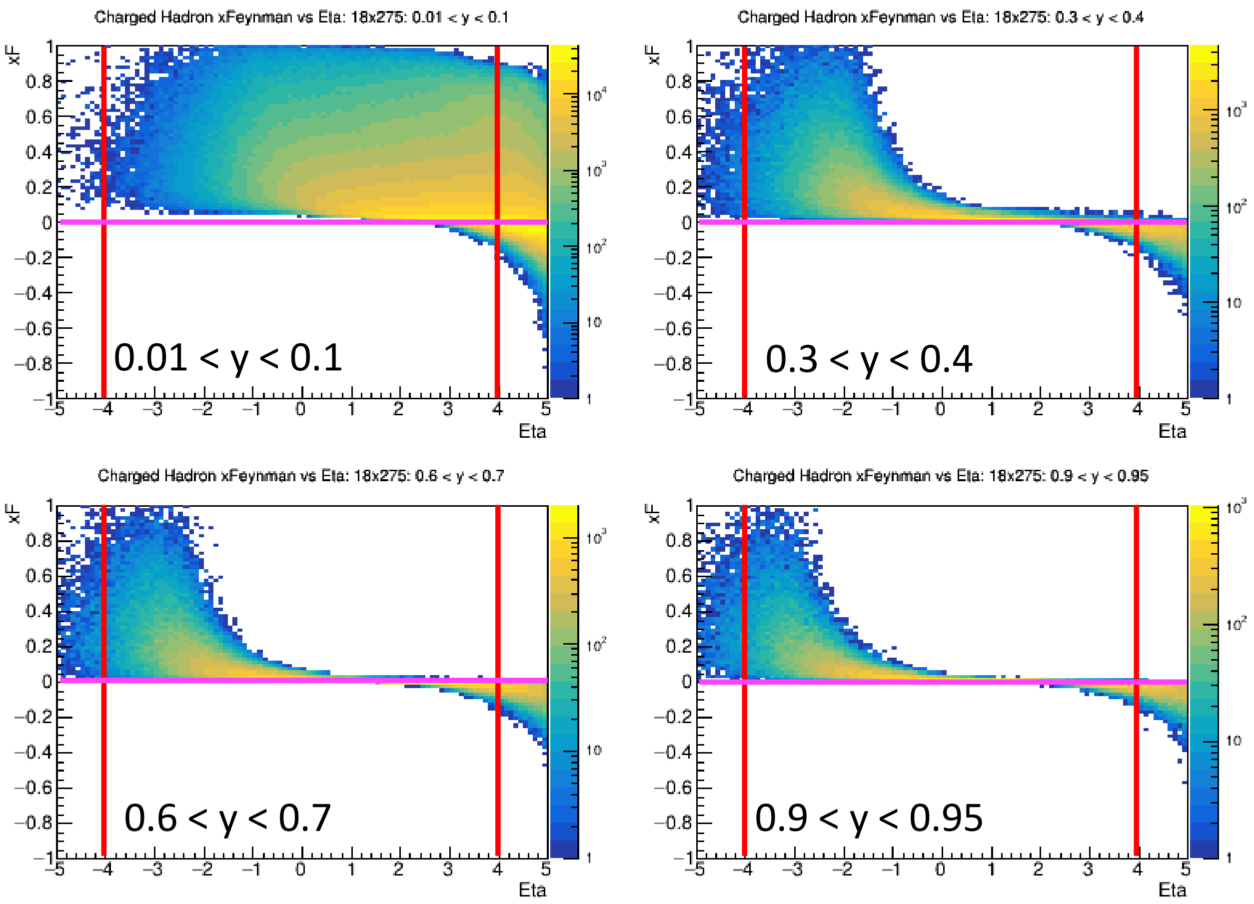


- ❑ Particle production not associated only with struck parton
- ❑ Gammas and neutrals follow same pattern

(Charged) Particle x-Feynman (18x275)

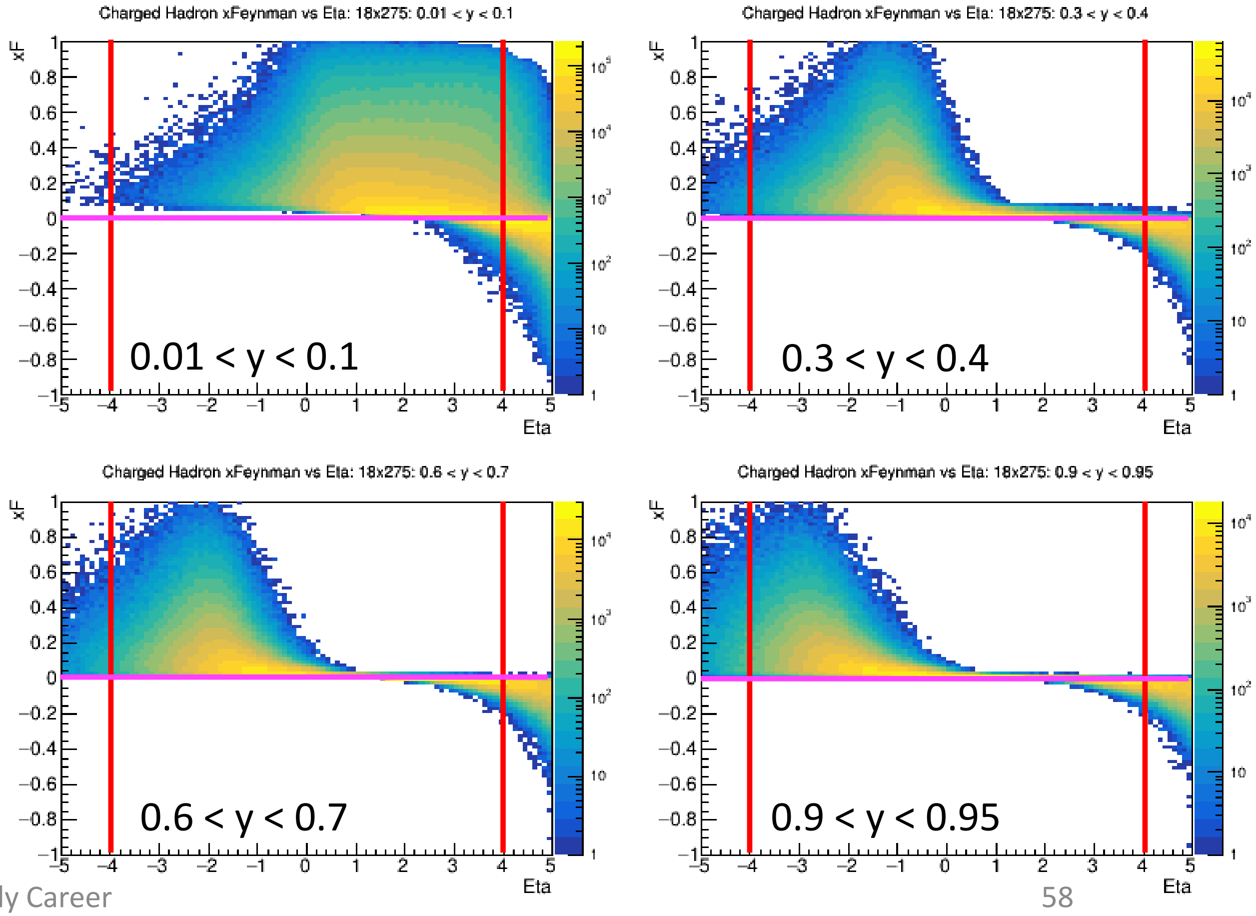
- Define xF as 2*particle_pZ/W in the hadron-boson center of mass frame

- Z-axis defined w.r.t. the virtual photon



0.1 < Q² < 1.0

10 < Q² < 100

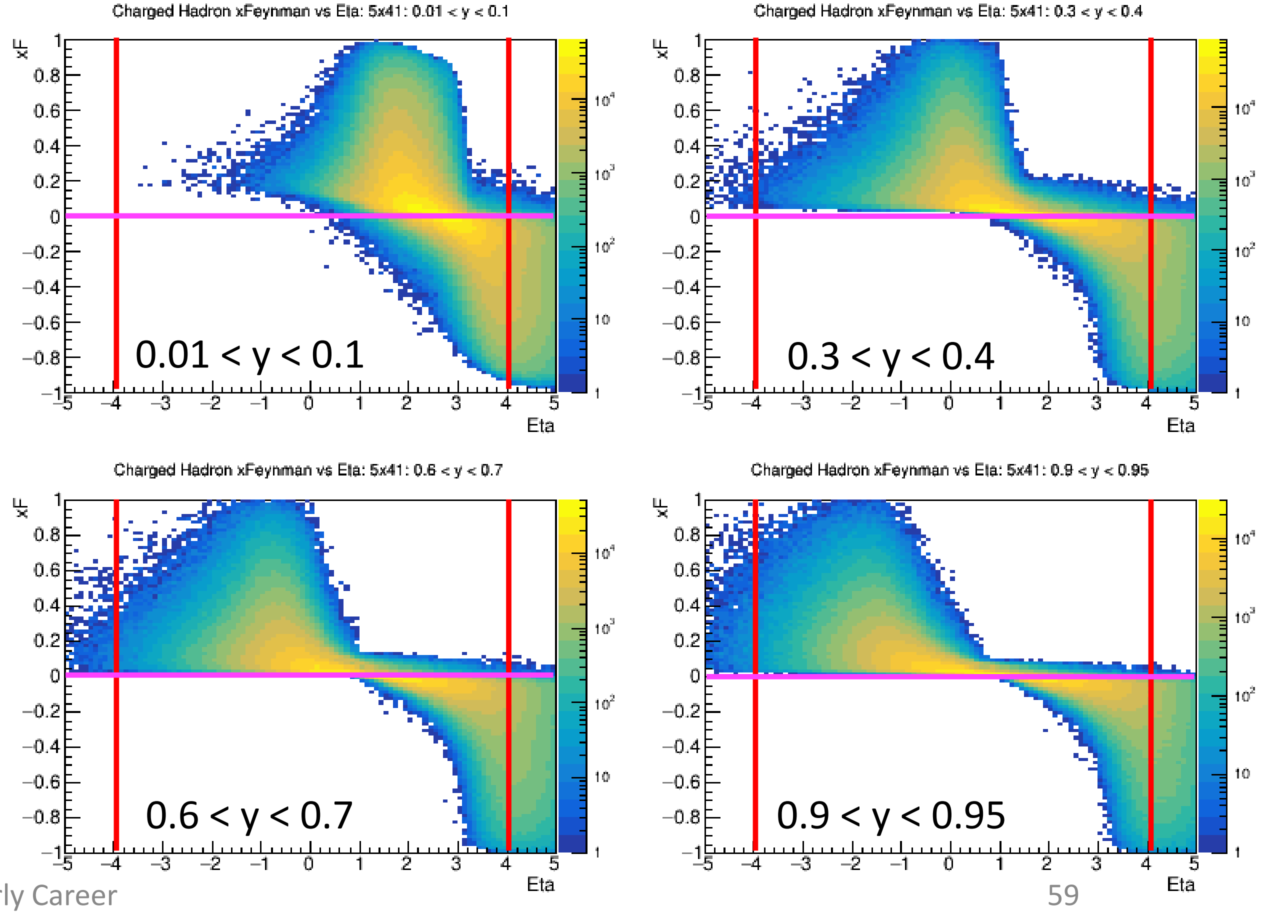


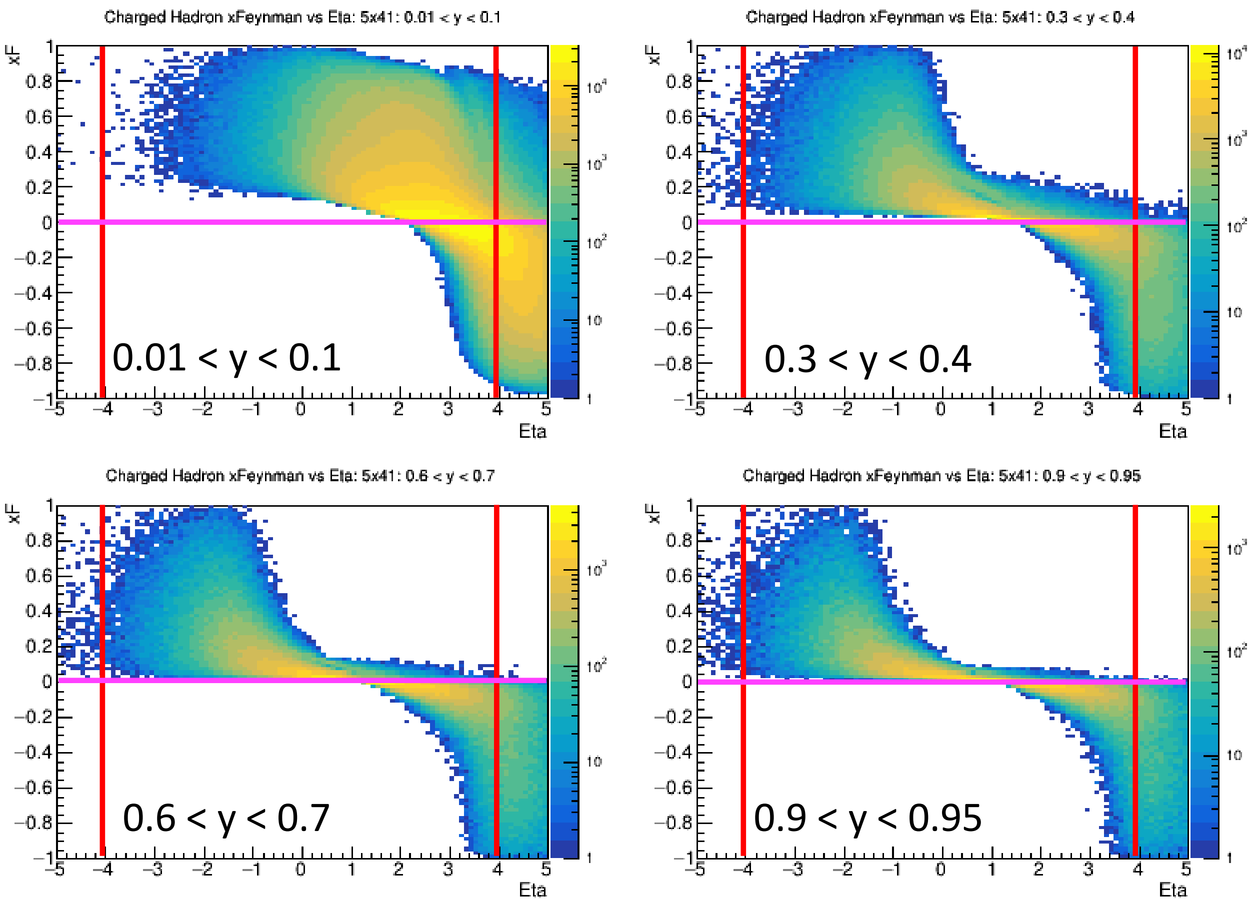
- Positive xF indicates particles more associated with the struck quark

(Charged) Particle x-Feynman (5x41)

- ❑ Larger negative xF particles come into the detector acceptance for lower beam energies

10 < Q^2 < 100

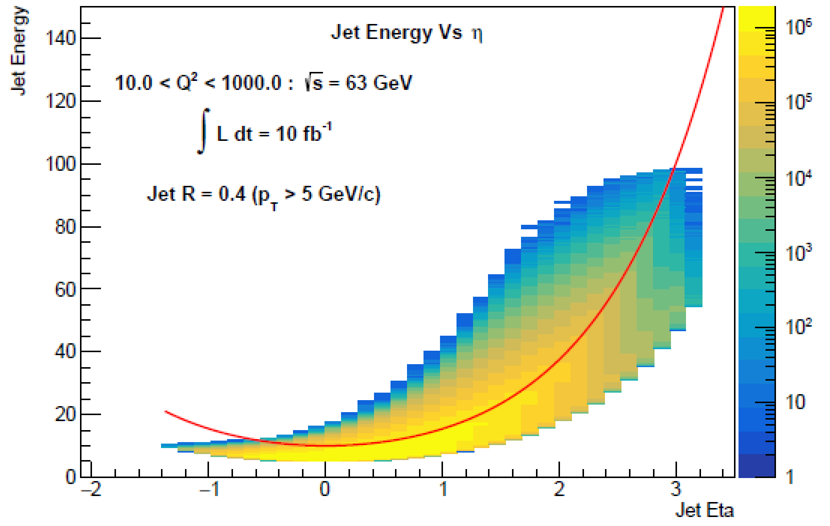


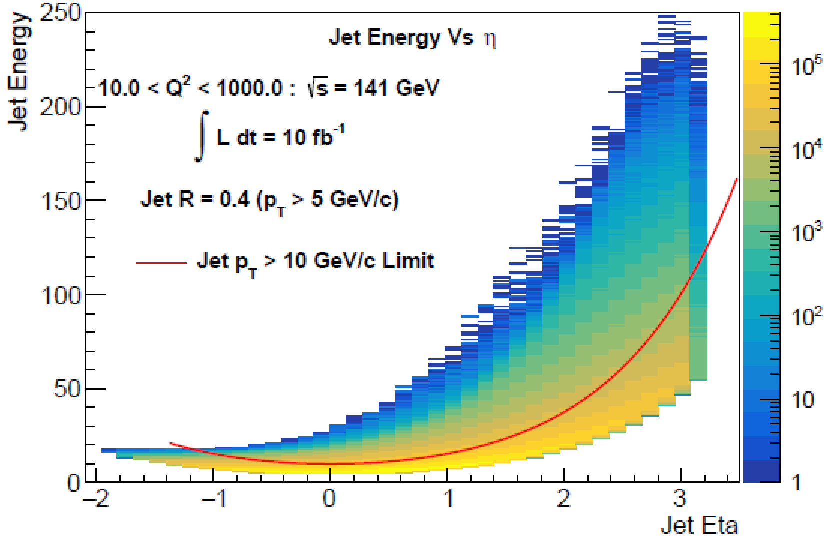


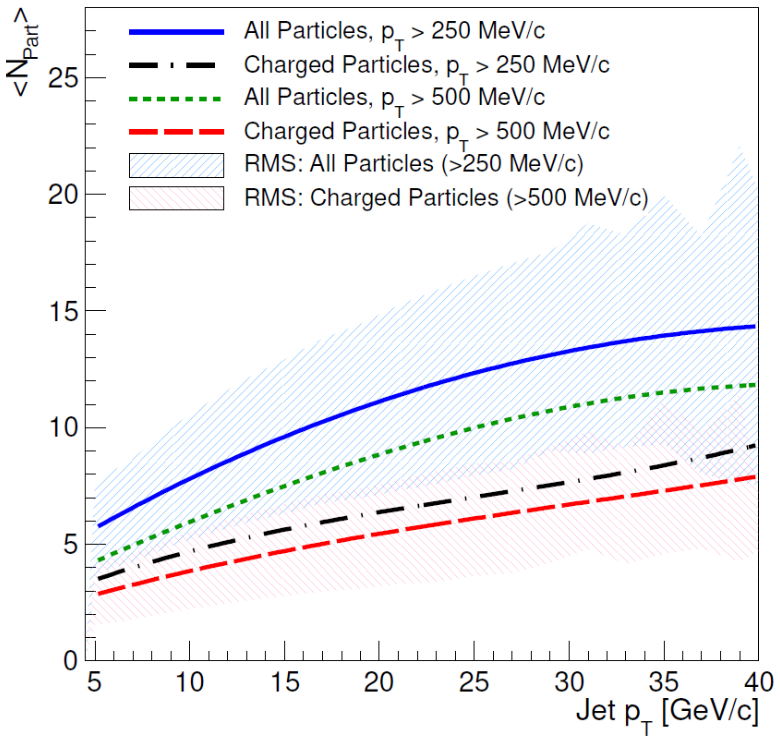
0.1 < Q^2 < 1.0

- ❑ Study differences in fragmentation in these regions
- ❑ Look at correlations between these regions

Jet Kinematics



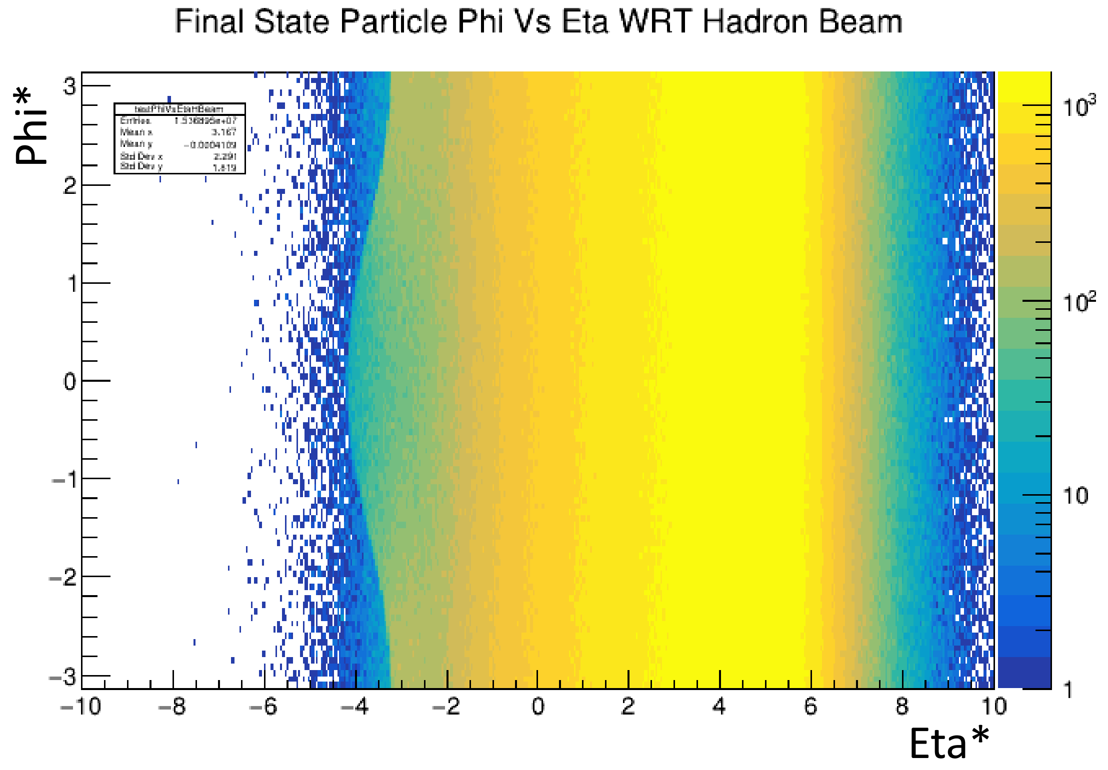


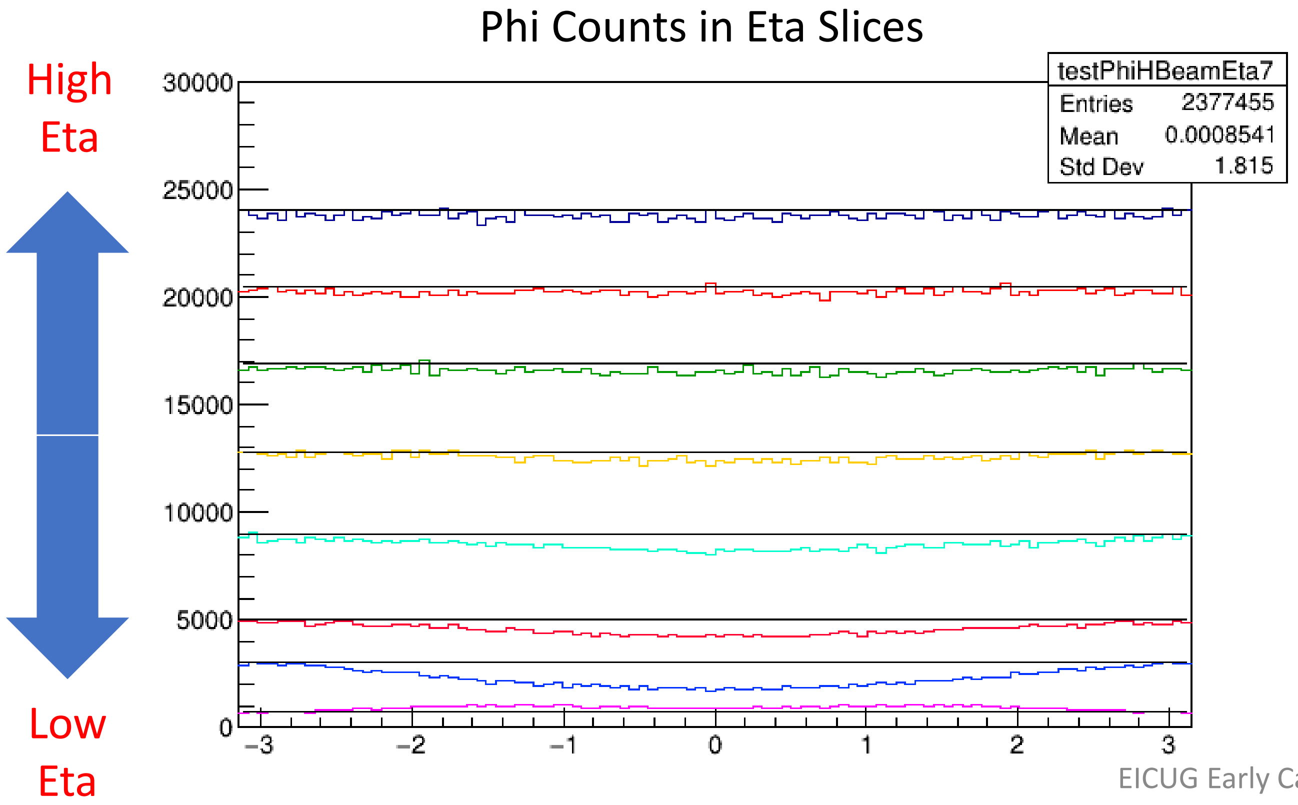


- Bulk of jets produced at the EIC will be low energy / low pT
- Pushing to analyze the lowest energy jets will provide access to the lowest x values, which will be important for spin structure and saturation studies
- In addition to being relatively low energy, jets will be quite broad and have few particles
- Must ensure theory and MC can make robust predictions for low energy jets and hadronization models can handle low multiplicity jets

Coordinates W.R.T. Hadron Beam

- ❑ "Physics" in the forward region should be consistent around the hadron beam regardless of where the beam is pointing
- ❑ In some sense, the features seen above are simply artifacts of measuring about the "wrong" axis -> instead, define eta and phi with respect to the hadron beam direction (Eta*, Phi*)





- ❑ When defined w.r.t. the hadron beam, the concentrations in eta and phi disappear
- ❑ However, because there is no common beam axis, the particle distribution along the electron-going direction becomes distorted
- ❑ Can avoid these distortions by boosting to a frame in which the beams are collinear