Overview of Select Jet Physics Topics at an EIC

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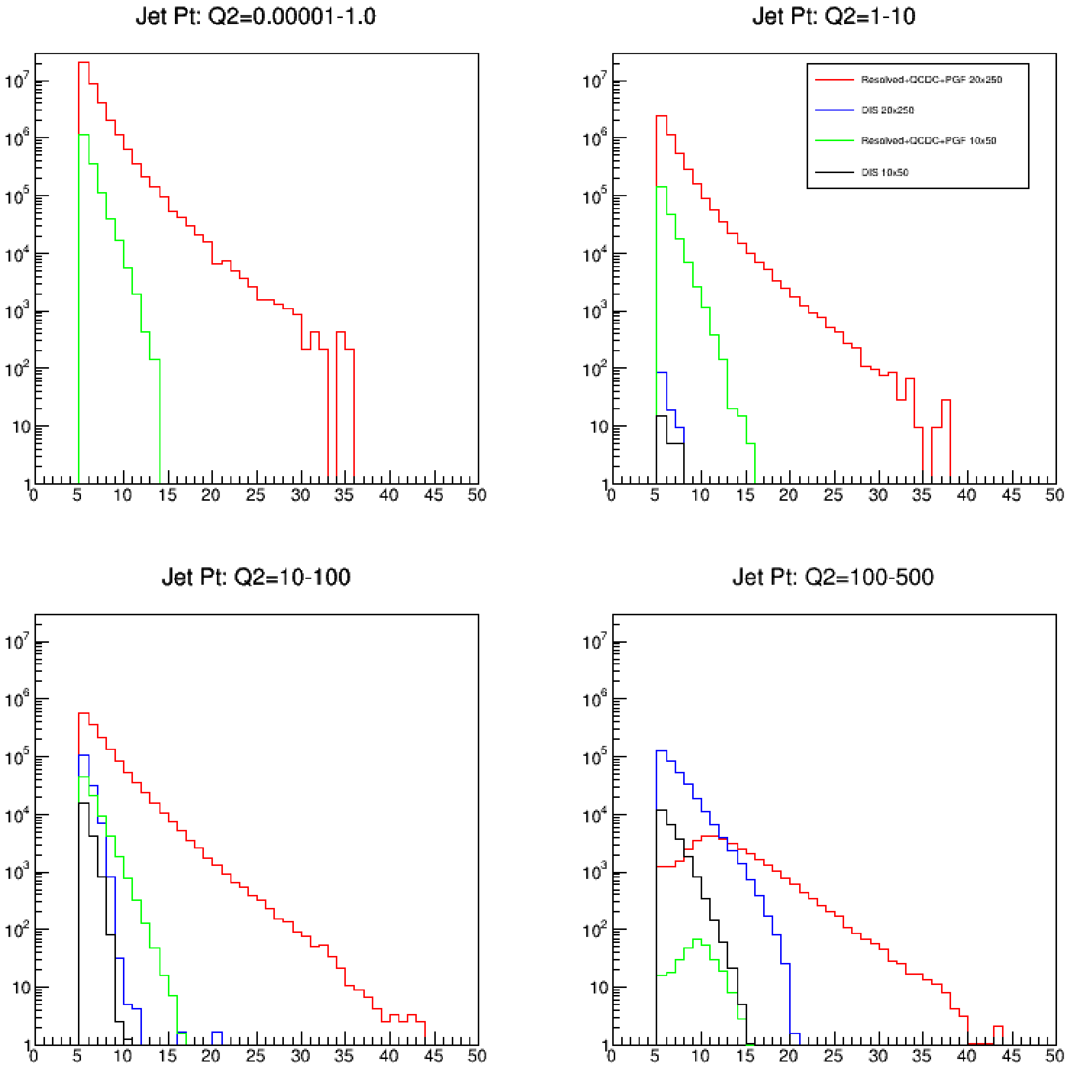
EIC Users Meeting: Paris

Simulation Details / Particle Cuts

- Electron – Proton events generated using PYTHIA6
  - 20x250 and 10x50
- Cut on inelasticity: $0.01 \leq y \leq 0.95$ ($0.2 \leq y \leq 0.8$ for angularity)
- Jet Algorithm: Anti_k_T ($R = 1.0$) (0.8, 0.4 for angularity)
- Jets found in Breit frame (lab frame for angularity)
- Particles used in jet finding:
  - Stable
  - $p_T \geq 250$ MeV
  - $\eta \leq 4.5$
  - Parent cannot originate from scattered electron

Jet Kinematics: Inclusive Jet p_T

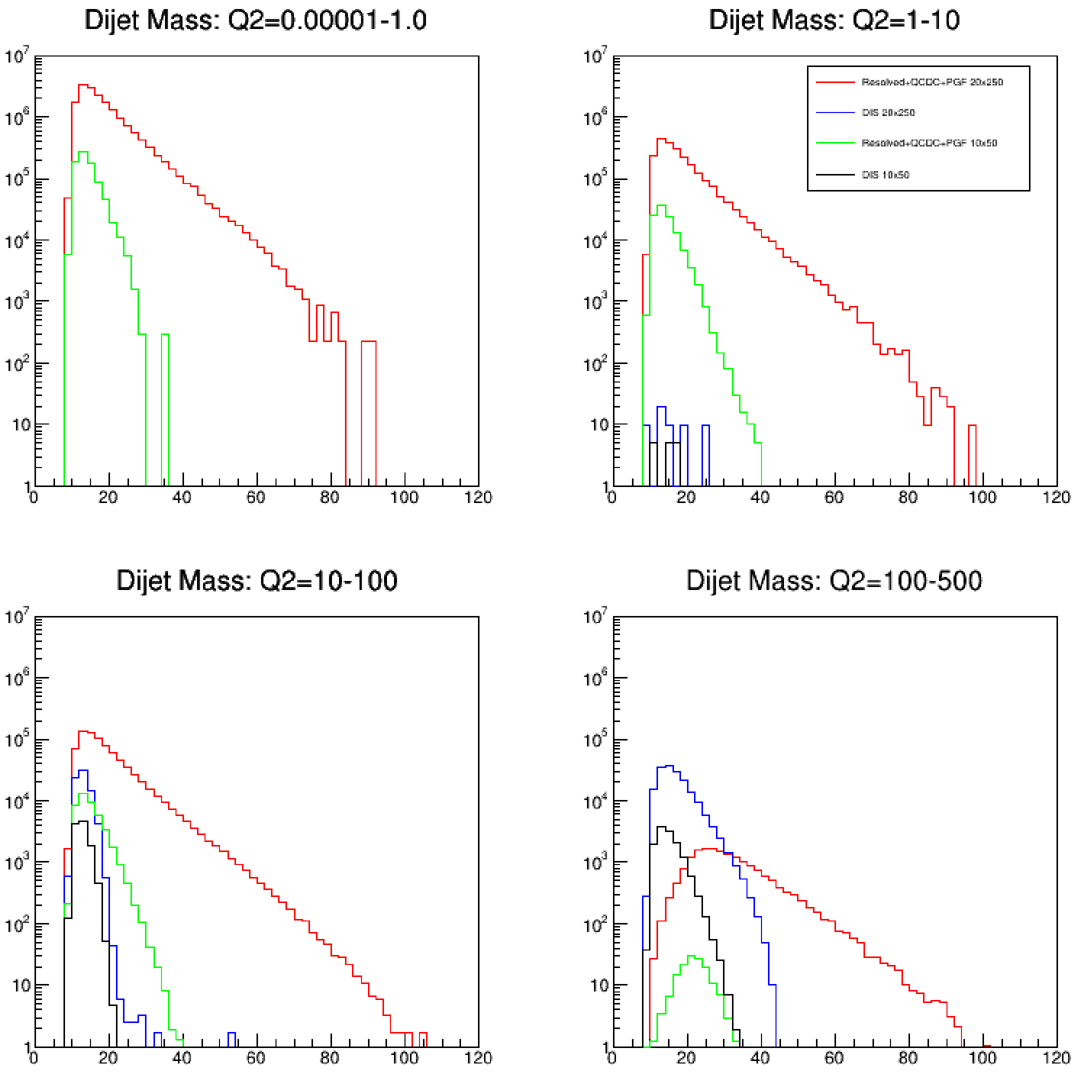


- Resolved, QCDC, PGF: 20x250
- LO DIS: 20x250
- Resolved, QCDC, PGF: 10x50
- LO DIS: 10x50

- Four Q2 ranges:
  - 10^{-5} – 1 GeV^2
  - 1 – 10 GeV^2
  - 10 – 100 GeV^2
  - 100 – 500 GeV^2

- Jets from LO DIS in the Breit frame arise at large Q^2 when FSR imparts a large transverse kick

Jet Kinematics: Dijet Mass


Dijet Mass: Q2=0.00001-1.0

Dijet Mass: Q2=1-10

Dijet Mass: Q2=10-100

Dijet Mass: Q2=100-500

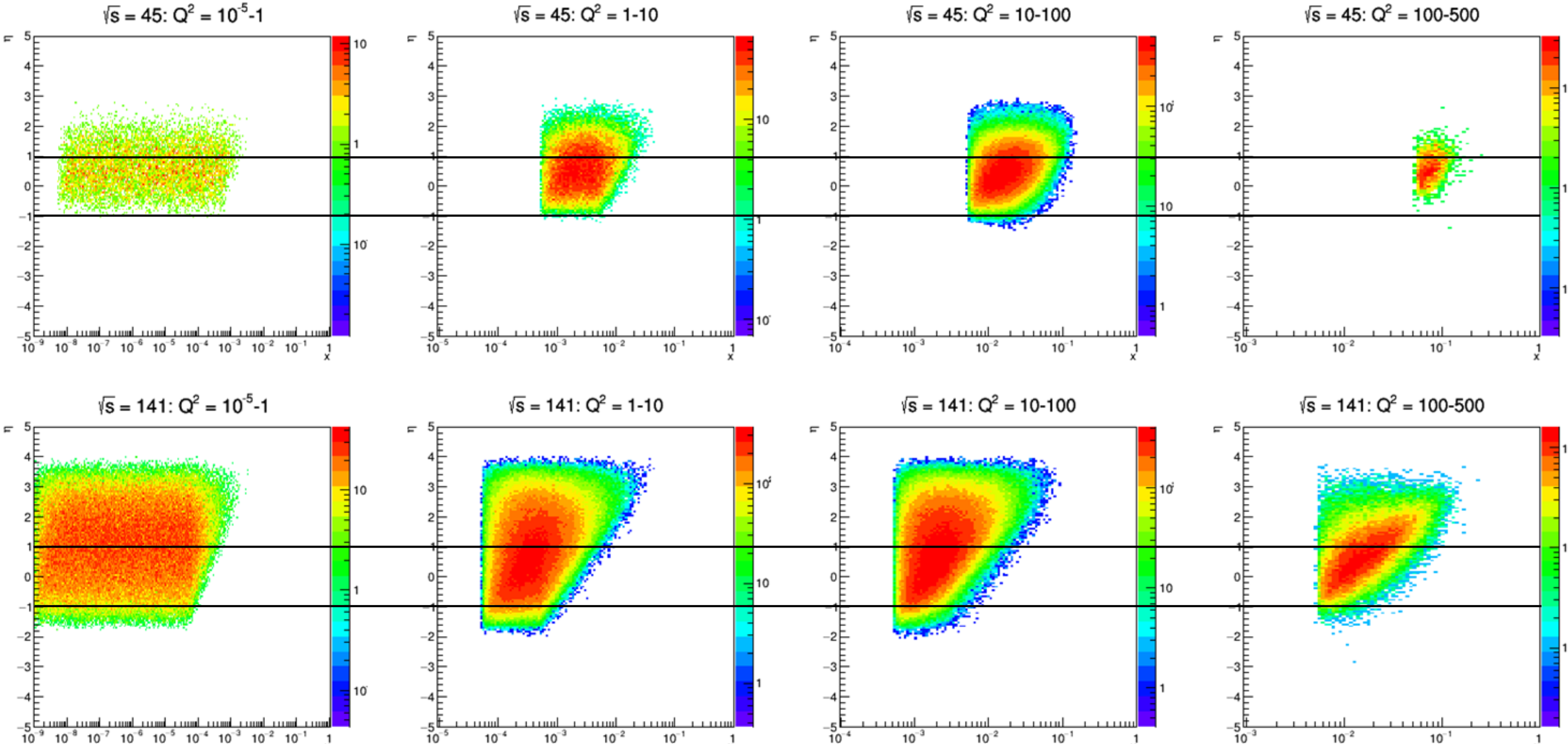
- Resolved, QCDC, PGF: 20x250
- LO DIS: 20x250
- Resolved, QCDC, PGF: 10x50
- LO DIS: 10x50

- Four Q2 ranges:
  - 10^{-5} – 1 GeV^2
  - 1 – 10 GeV^2
  - 10 – 100 GeV^2
  - 100 – 500 GeV^2

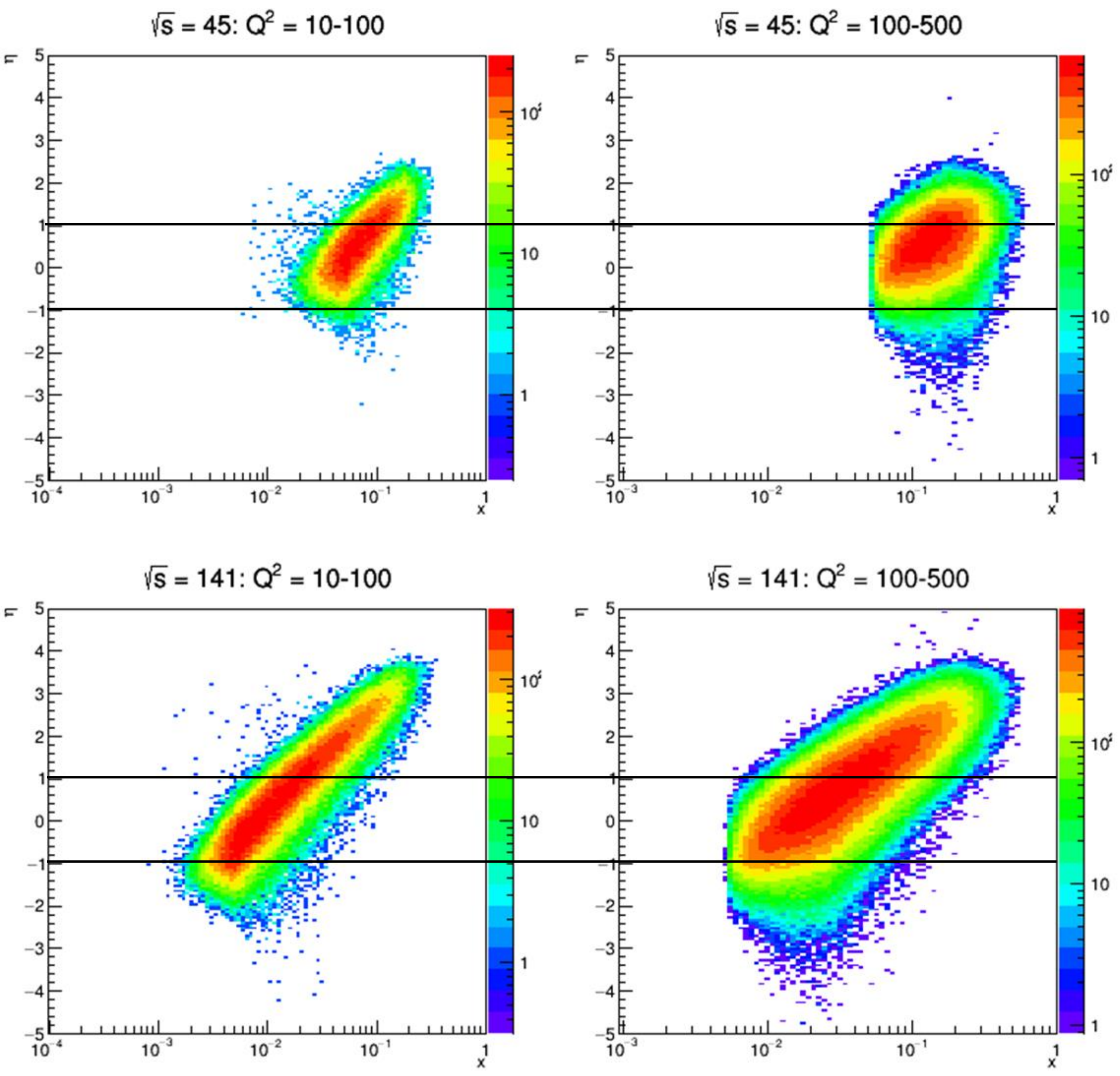
- Second jet in LO DIS comes from target remnant

Jet Kinematics: η vs x

- Jet pseudorapidity (lab frame) vs x for √s = 45 and 141 GeV, four Q^2 ranges, and higher order subprocesses (resolved, QCD-Compton, and photon-gluon fusion
- For a given Q^2 range and x, jets sit at larger rapidities (driven by proton energy) at the larger center of mass energy



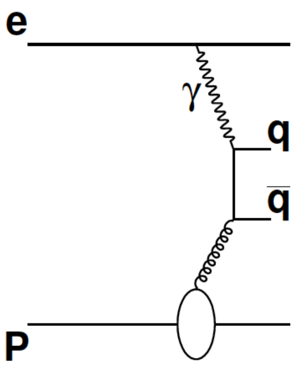
Jet Kinematics: η vs x

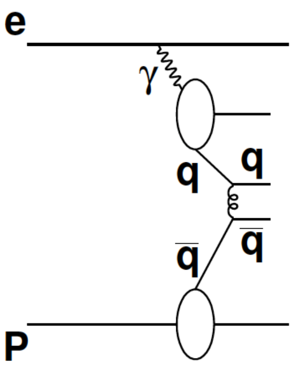


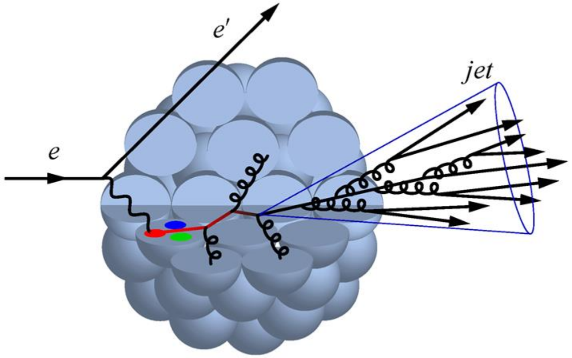
- Jet pseudorapidity (lab frame) vs x for √s = 45 and 141 GeV, two Q^2 ranges, for the LO DIS subprocess
- Same trends with x, Q^2, and pseudorapidity as for the higher order processes
- See a tighter correlation between x and pseudorapidity because the outgoing parton momentum determined by event kinematics
- Width in distribution due to finite Q^2 range and final state radiation

Why Jets?

- Jets reproduce underlying partonic kinematics
  - Kinematics for inclusive process determined by scattered electron
  - For higher order processes, multiple partons involved and their kinematics are no longer determined only by electron
  - Jets can be surrogates for these partons and can be used to constrain quantities such as momentum fraction contributed to the hard interaction from the virtual photon

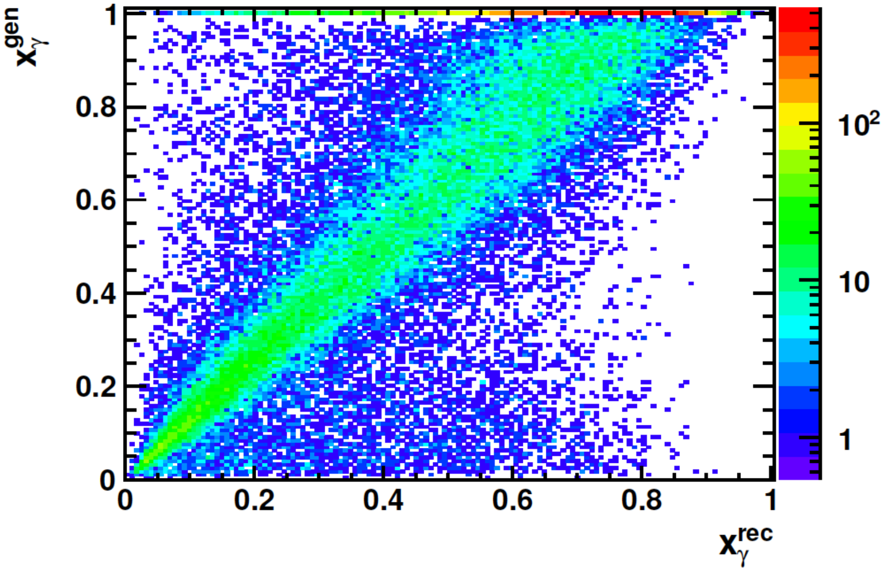




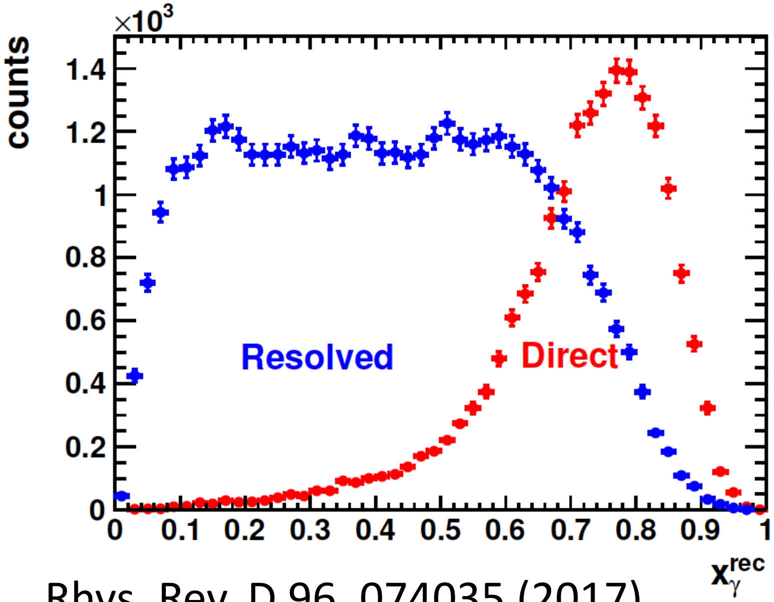


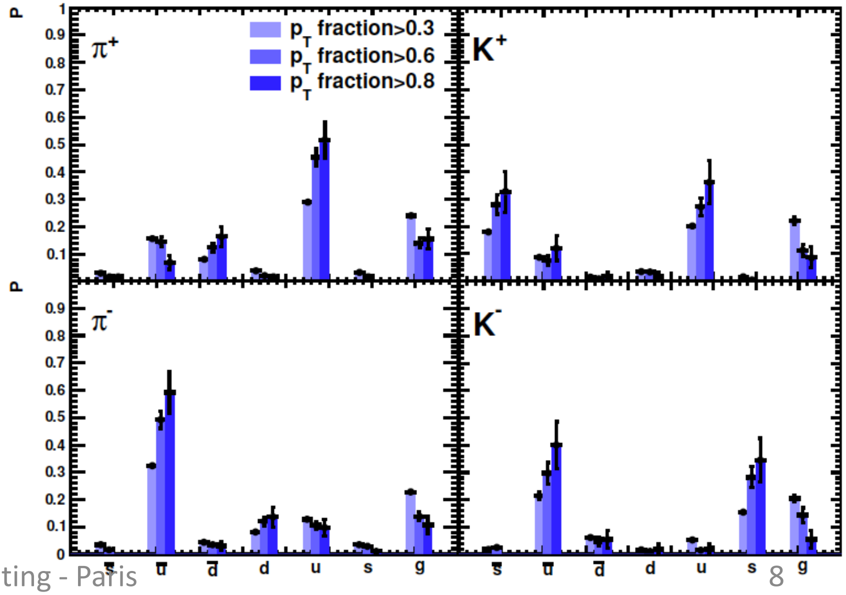
- Jets have substructure
  - Substructure observables quantify how energy is distributed within a jet
  - Modification of substructure in eA collisions may be sensitive to various details of cold nuclear matter

Example: Photon Structure



- Virtual photon is a superposition of a bare photon and hadronic state
- Can access the hadronic component by tagging resolved events – what are the (polarized) photon PDFs?
- Can use dijet to accurately reconstruct photon momentum fraction which can isolate events of interest
- Can also use flavor tagging to enhance contribution from specific initial states





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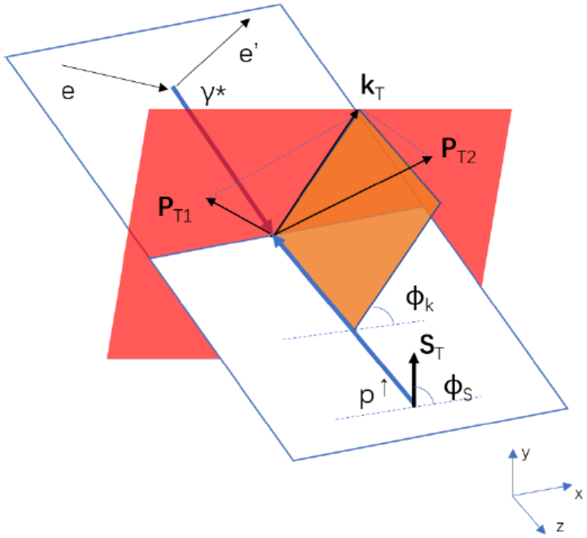
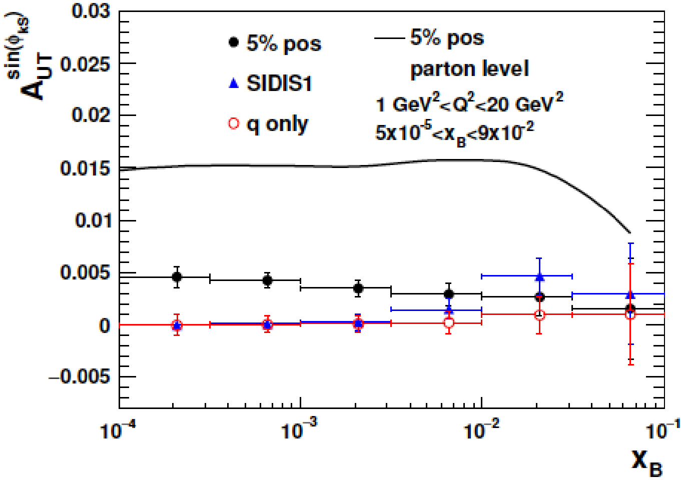
Example: Gluon Sivers Function

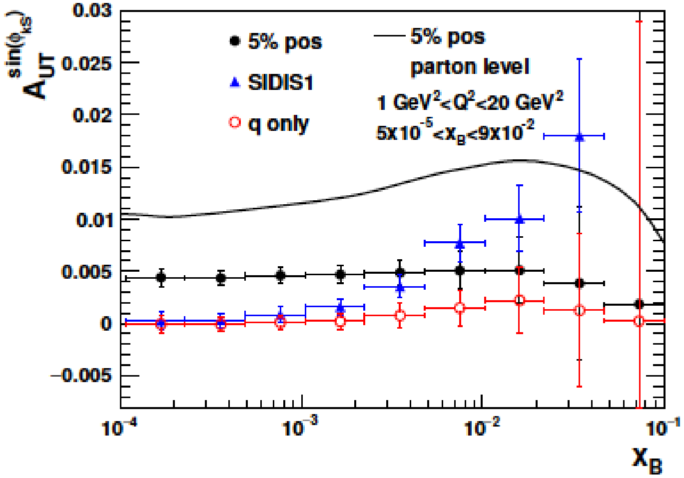


- Modulations of the angle between the proton spin vector and the sum of the di-parton system provide access to gluon sivers function
- Use of dijets has several advantages over di-hadrons including lower dilution of asymmetry and better separation between models of gluon sivers effect
- Jets don't suffer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

Di-Hadrons



Dijets

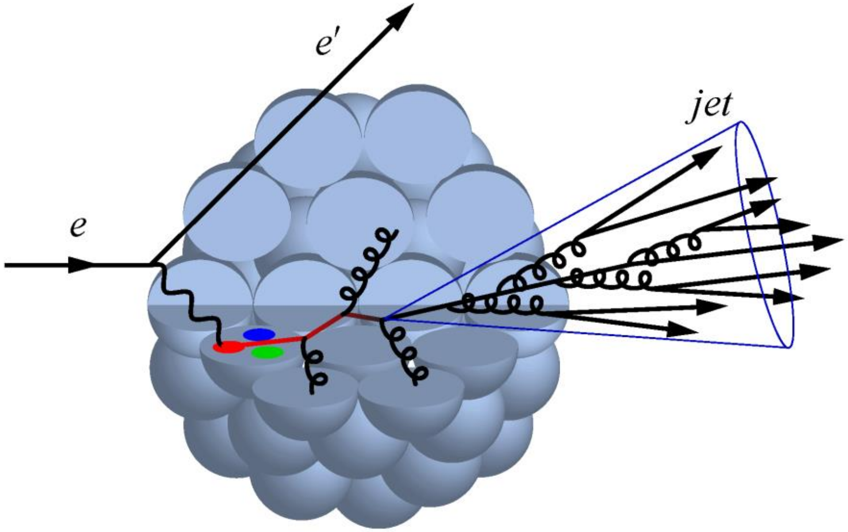


Phys. Rev. D 98, 034011 (2018)

Jet Substructure: Angularity

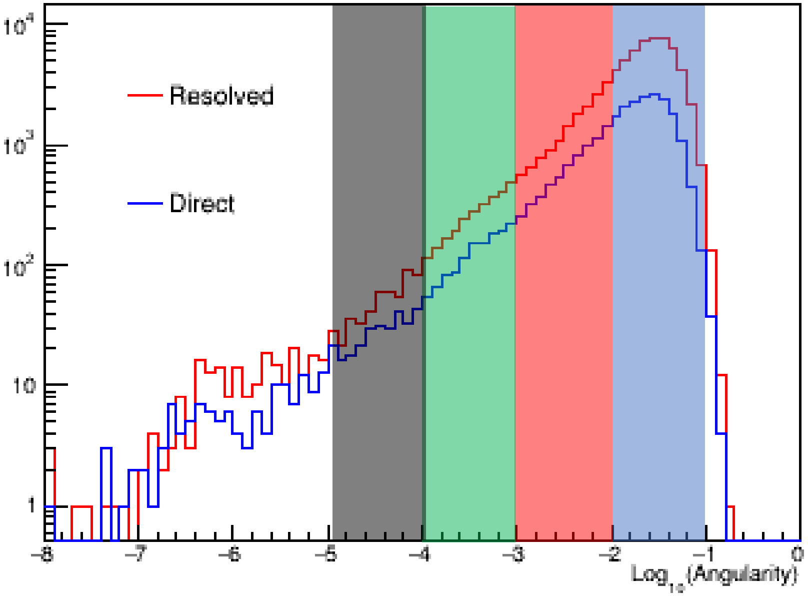
$$\tau_a \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta R_{iJ}\right)^{2-a}$$

- Jet substructure observables track how energy is distributed within the jet – this section will focus on Angularity
- Substructure studies may be useful at an EIC for characterizing the properties of cold nuclear matter – look at modification of energy distribution between ep and eA
- Also pure theoretical interest in better understanding the factorization needed to describe the radiation patterns within the jet
- This work: characterize the behavior of jets and angularity observables at EIC energies
- Look at lab frame jets in the photoproduction region



Angularity Overview

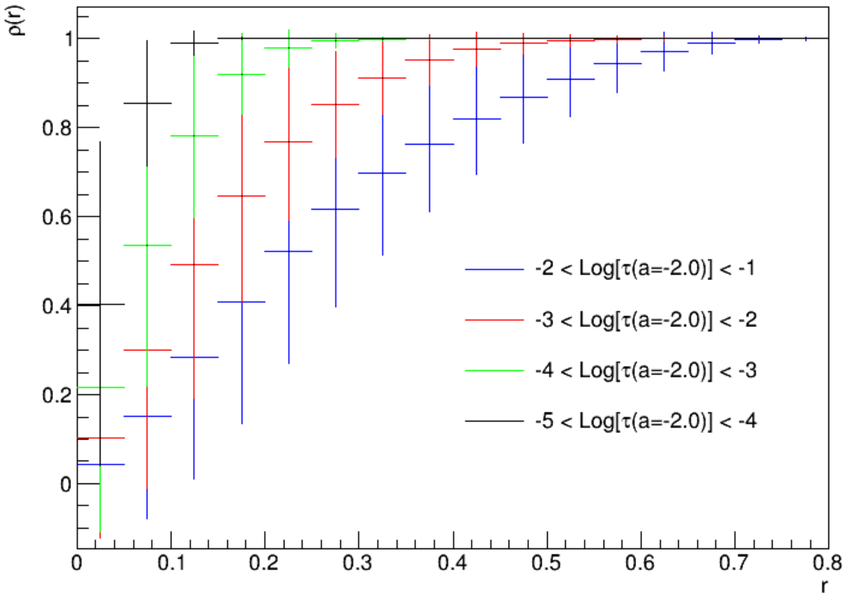
Angularity: R = 0.8; a = -2.0



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

- Angularity sums over each p_T of the particles in the jet weighted by the distance of the particle from the jet thrust axis
- The ‘a’ parameter controls how heavily the distance is weighted

- Log of the angularity spectrum with ‘a’ = -2.0 is shown above for resolved and direct jets with R = 0.8
- The jet profiles of the jets in the 4 colored regions are shown to the right
- Jet Profile is the fraction of p_T contained in a radius ‘r’ from the center of the jet
- For a given ‘R’ and ‘a’, jets with lower angularity are more collimated



Non-Perturbative Effects

- Non-perturbative effects are modeled using a single parameter shape function which is convoluted with the perturbative cross section

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

- Non-perturbative effects (MPI and pileup) are large at the LHC but the correction shifts the perturbative results to match the data

- At the EIC, non-perturbative effects are much smaller and a smaller correction is needed to improve the agreement between PYTHIA and theory

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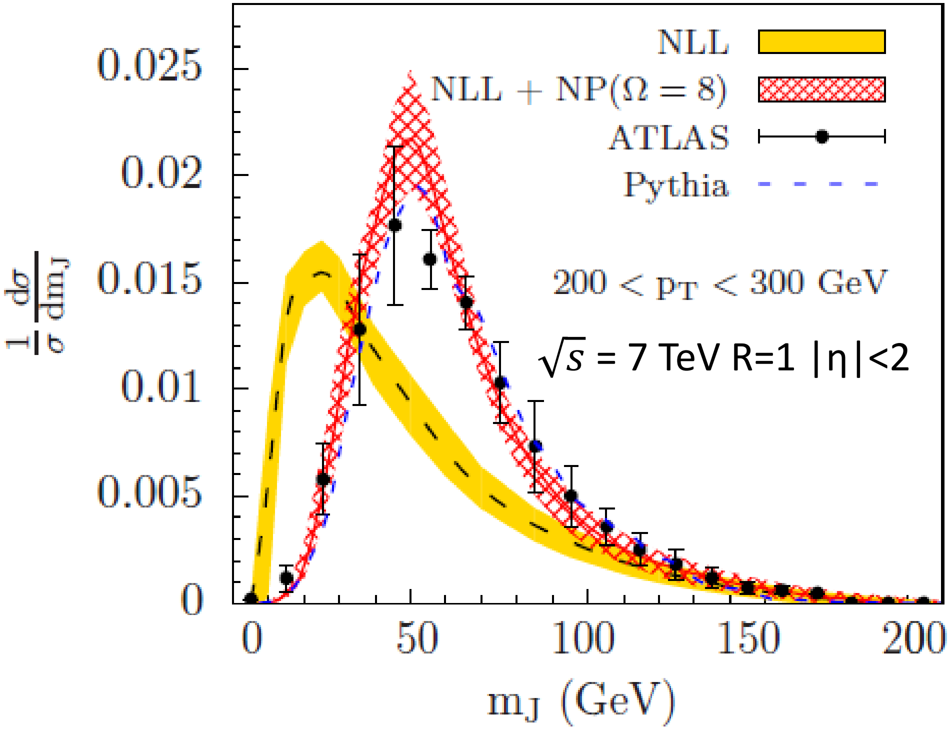
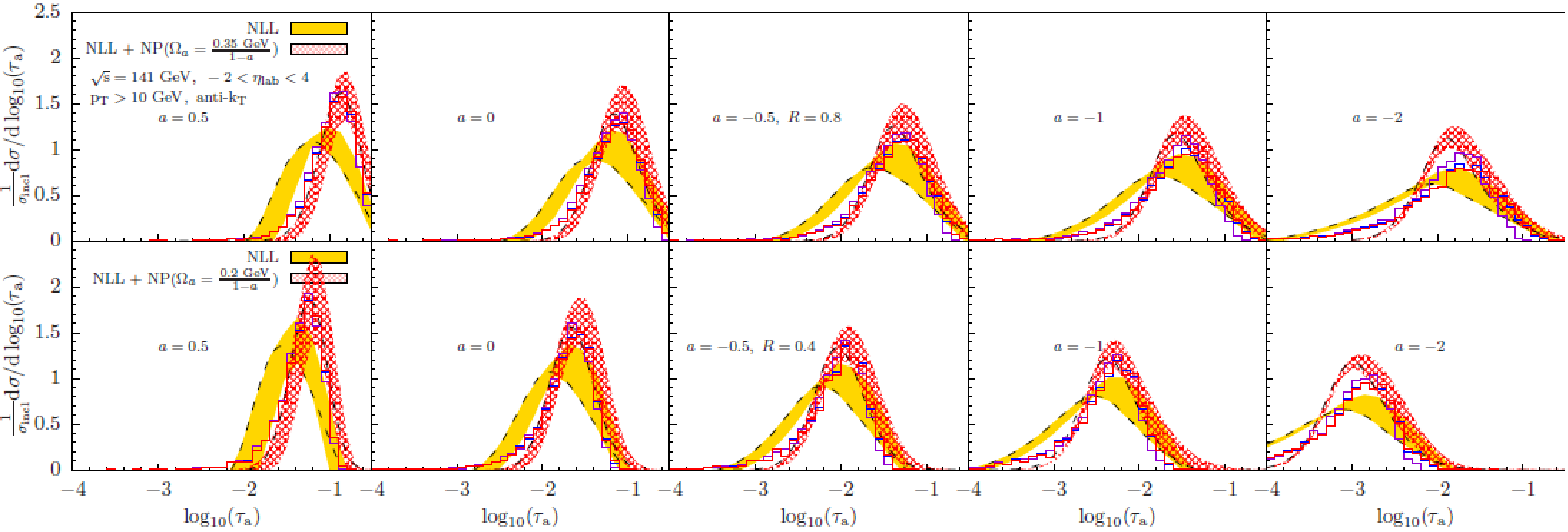


With F. Ringer & K. Lee

Angularity: Theory Vs PYTHIA

- Comparison between angularity as found from PYTHIA (histograms), bare NLL theory (yellow band), and NLL + NP (red band) for different ‘a’ values and radii
- NP corrections:
    - ‘R’ = 0.8: Ω = 0.35
    - ‘R’ = 0.4: Ω = 0.2
- Expect larger ‘R’ values to have higher NP corrections (compare to LHC which had NP correction factor of 8). Agreement is better at larger ‘a’ values
- Way to use a hard probe to quantify soft physics



Power Corrections

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

$$\tau_a^{e^+e^-} = \frac{1}{2E_J} \sum_{i \in J} \left|p_T^{iJ}\right| exp\left(-\left|\eta_{iJ}\right|(1-a)\right)$$

$$\tau_a = \left(\frac{2E_J}{p_T}\right)^{2-a} \tau_a^{e^+e^-} + \mathcal{O}(\tau_a^2)$$

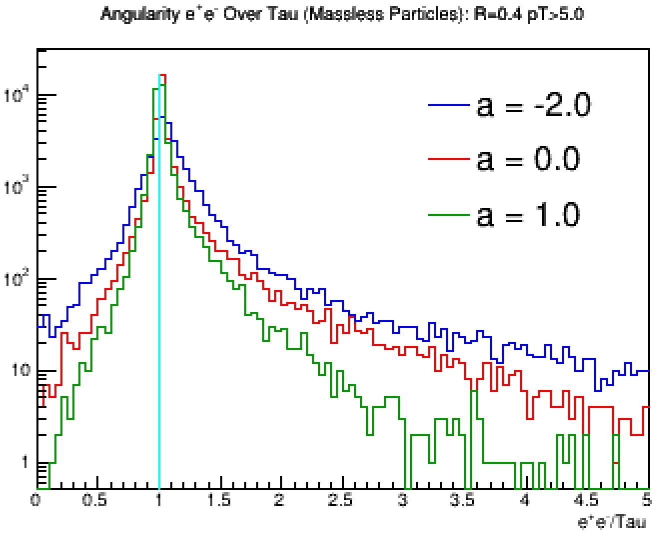
- In addition to the definition given before, can define angularity in terms of particle p_T and eta with respect to the jet thrust axis – call this τ^e+e-
- The original angularity is equal to τ^e+e- times a prefactor plus power corrections
- Factorizations used in theoretical determination of angularity are valid up to these power corrections
- Can explore the behavior of these corrections by taking a ratio of τ^e+e- to the original definition
- Significance of power corrections can be controlled by varying R, jet p_T, and ‘a’

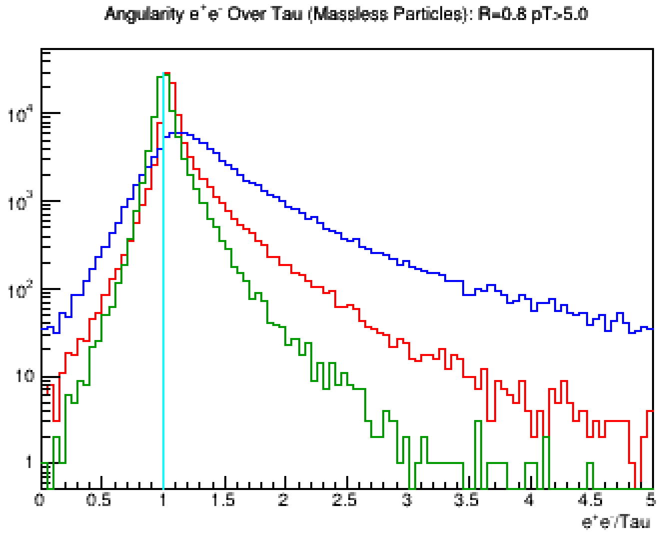
Power Corrections: Compare ‘a’

R = 0.4

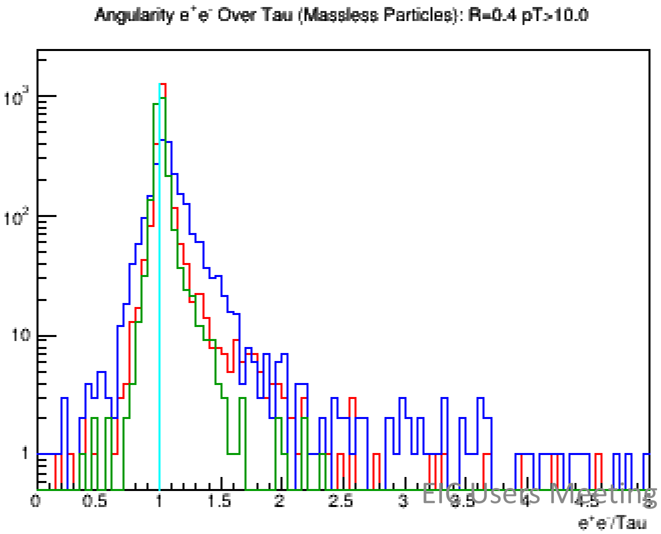
R = 0.8

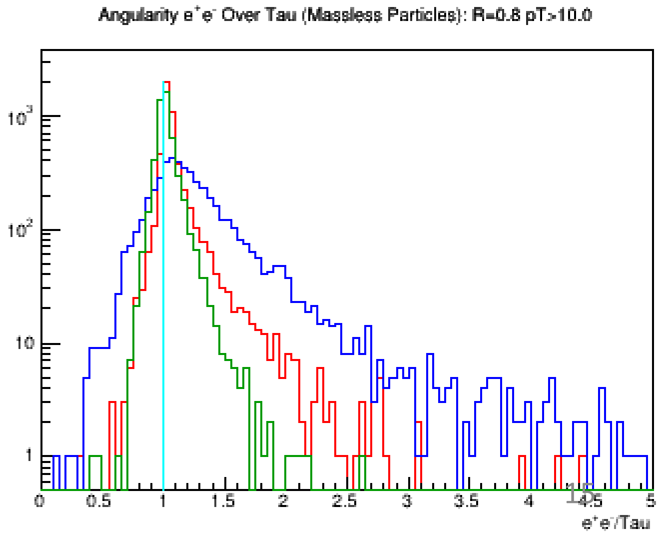
$p_T > 5.0$





$p_T > 10.0$



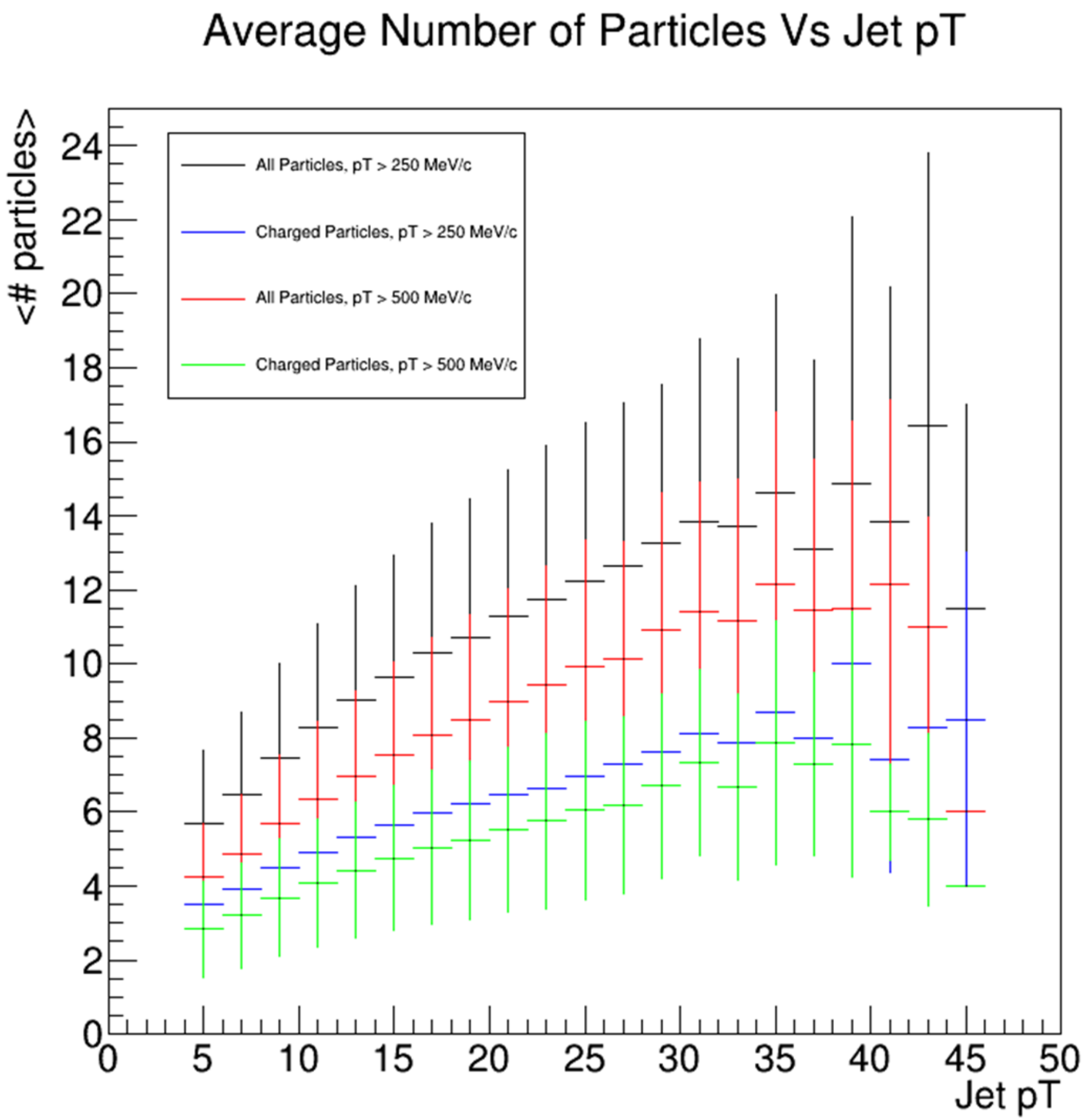


Summary and Outlook

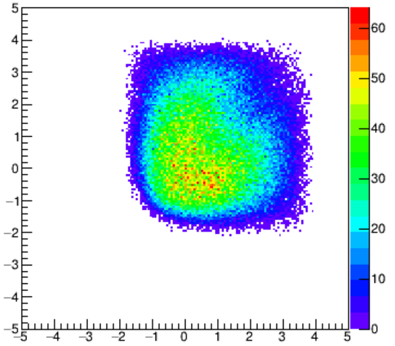
- Basic jet kinematics, such as p_T/mass and pseudorapidity distributions, were reviewed
- The utility of jets as parton surrogates was demonstrated via photon structure and gluon Sivers analyses
- A potentially new application for jets would be in exclusive diffractive dijet production which is sensitive to the gluon Wigner distribution at low x
- The angularity substructure observable was studied with Monte Carlo in the photoproduction region for kinematics relevant to an EIC
- Angularity values from Monte Carlo were compared with NLO+NLL predictions and were found to agree well, while small perturbative corrections were seen to improve agreement
- Such measurements may point to the viability of using hard jet probes to study ‘soft’ physics
- A method for systematically studying the role of power corrections by comparing different angularity definitions was also presented

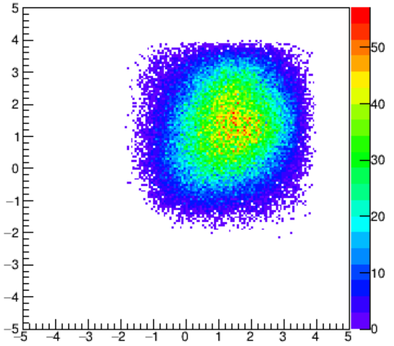
Backup

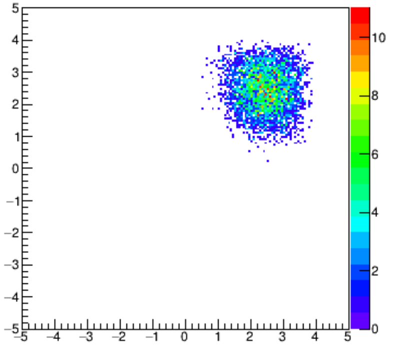
Number of Particles

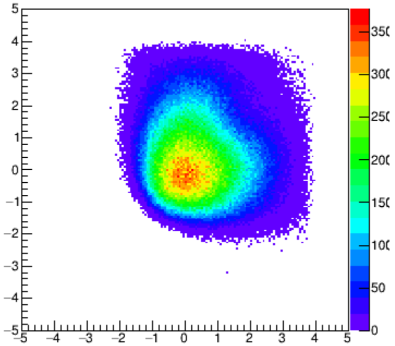


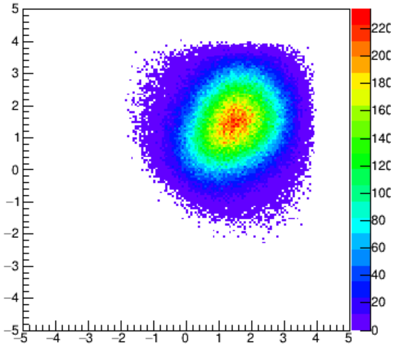
Dijet Eta Vs Eta: Resolved, QCDC, PGF

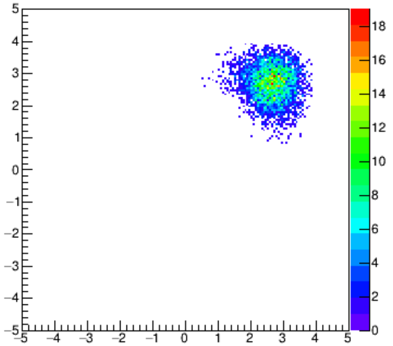

Q2 = 1-10: x = 5*10^-5 - 5*10^-4

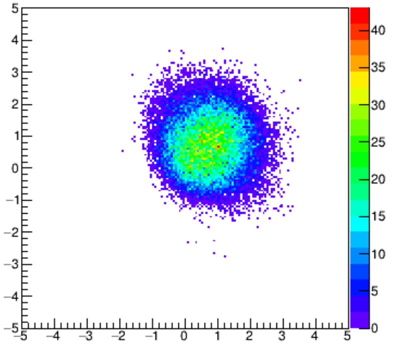

Q2 = 1-10: x = 5*10^-4 - 5*10^-3

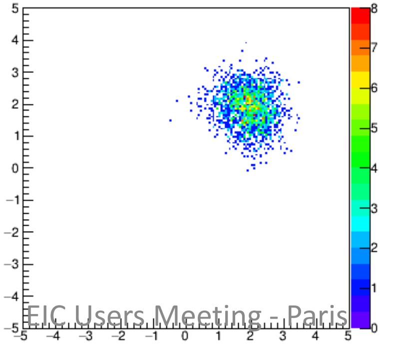

Q2 = 1-10: x = 5*10^-3 - 5*10^-2


Q2 = 10-100: x = 5*10^-4 - 5*10^-3

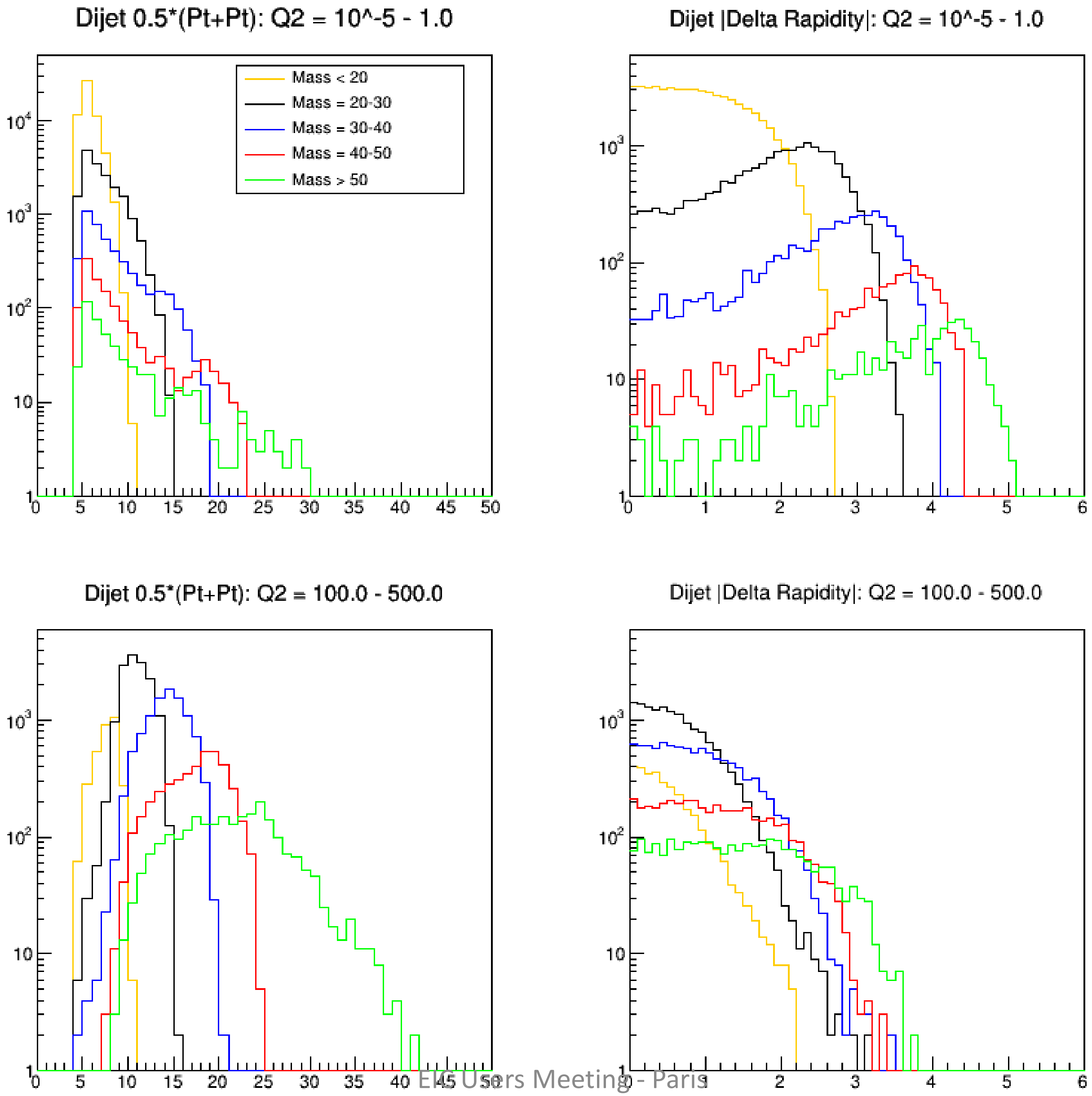

Q2 = 10-100: x = 5*10^-3 - 5*10^-2


Q2 = 10-100: x = 5*10^-2 - 5*10^-1


Q2 = 100-500: x = 5*10^-3 - 5*10^-2


Q2 = 100-500: x = 5*10^-2 - 5*10^-1

Dijet Mass: Pt Vs Δη



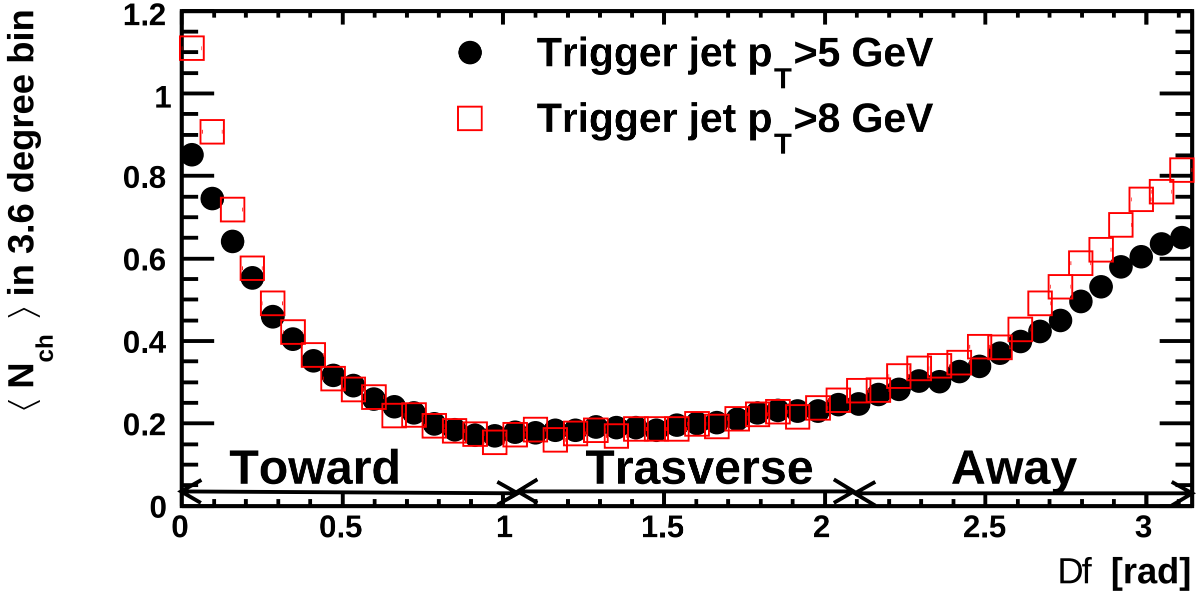
Dijet 0.5*(Pt+Pt): Q2 = 10^-5 - 1.0

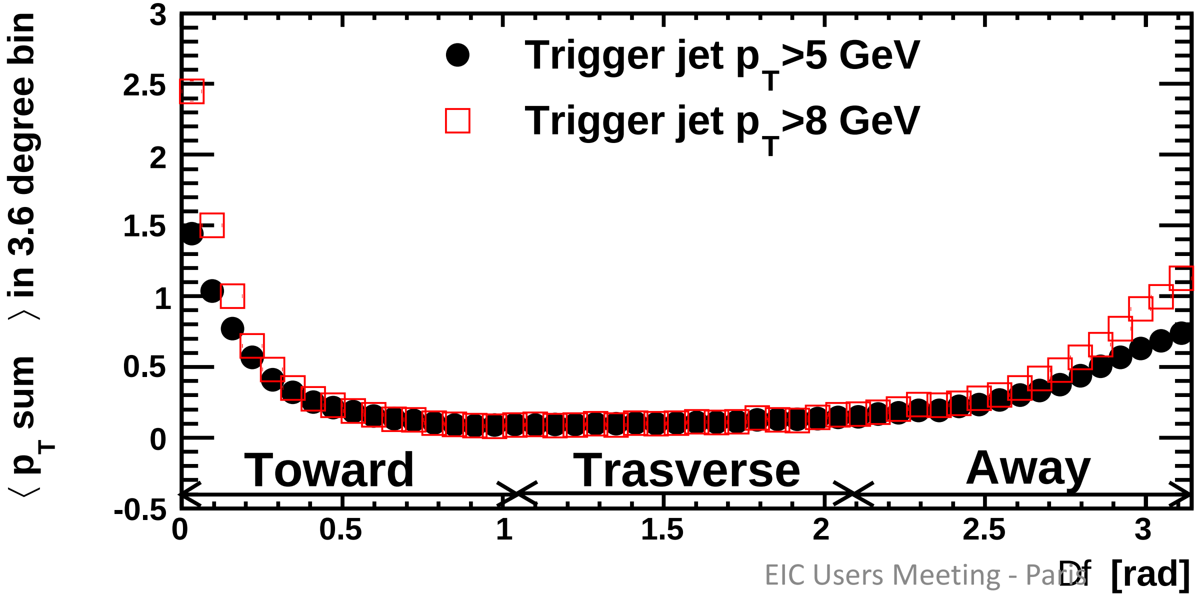
Dijet |Delta Rapidity|: Q2 = 10^-5 - 1.0

Dijet 0.5*(Pt+Pt): Q2 = 100.0 - 500.0

Dijet |Delta Rapidity|: Q2 = 100.0 - 500.0

Underlying Event Characteristics





- Plot average number of charged particles per event as a function of azimuthal angle from trigger jet
- Also plot the average summed particle p_T
- See little dependence on trigger jet p_T
- The number of charged particles and p_T sum in transverse region is small