Jet and Heavy Flavor Measurements at the EIC

Brian Page

MC4EIC – IPPP Durham

June 6, 2024

Brookhaven National Laboratory

and some other things
I want to talk about
^

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Outline

- ❑ Overview of EIC goals and jet / HF probes
- ❑ Select Jet and HF measurements (Yellow Report)
- ❑ Implications for MCEGs
- ❑ Pythia8 for DIS ‘min-bias’ generation
- ❑ Incorporating beam effects into simulation
- ❑ Summary

Biases and Caveats

- There is of course much I need to leave out
  - Saturation
  - Diffraction

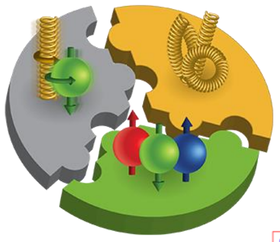
- The results shown and discussion revolve mostly around PYTHIA as this is the MCEG that has been most heavily used in the YR / Proposals / ePIC work so far. We of course need to make an effort to incorporate other general purpose MCEGs and hopefully this can begin once the EPIC core software stabilizes and analyses for the pre-TDR have begun.

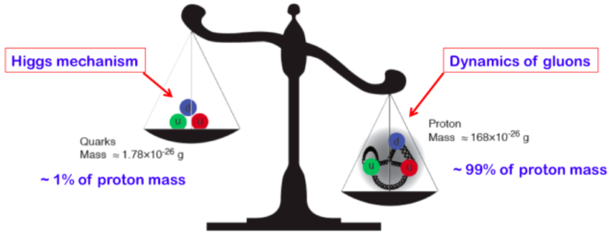
- As always, any mistakes or misrepresentations are on me

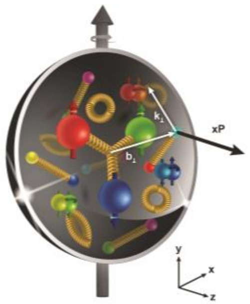
The EIC Physics Pillars

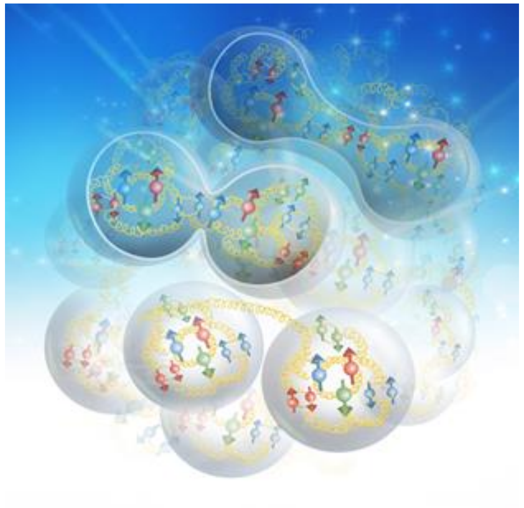
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

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









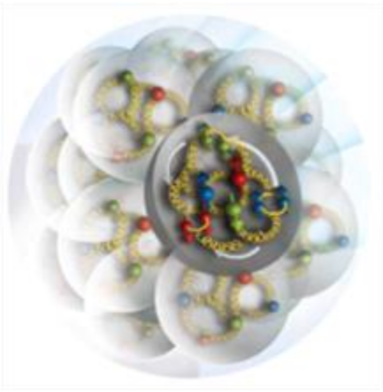
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

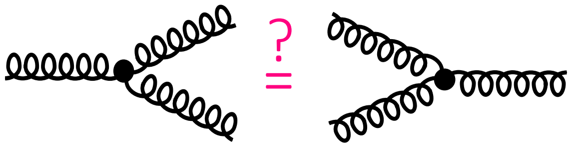
How do the confined hadronic states emerge from these quarks and gluons?

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?

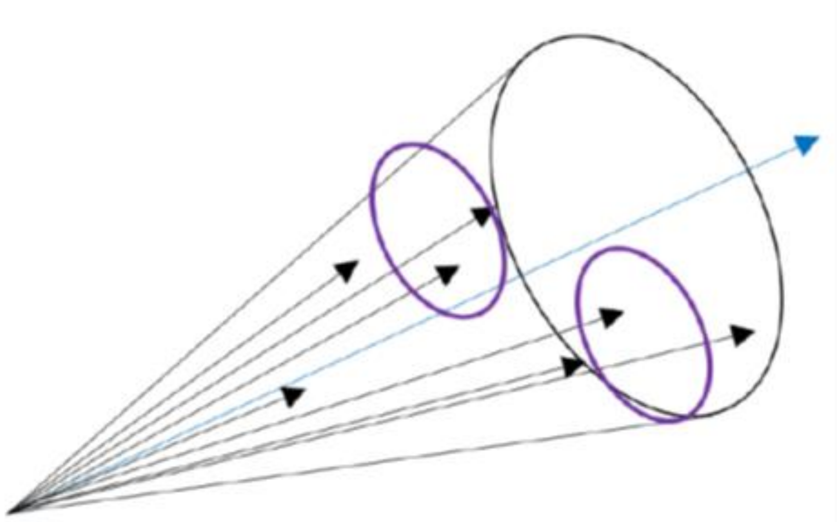
What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

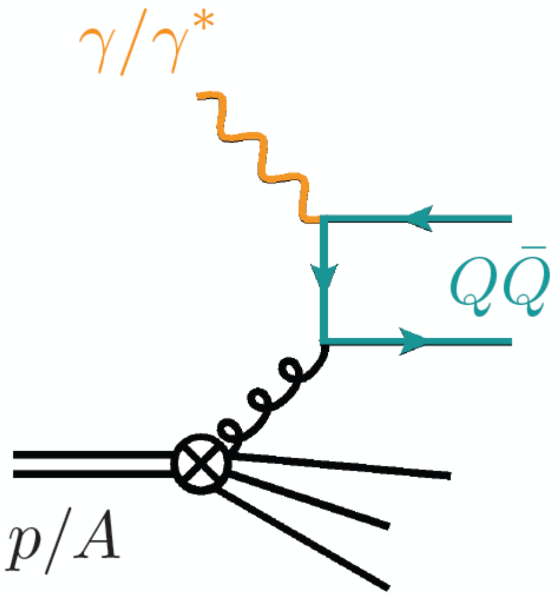




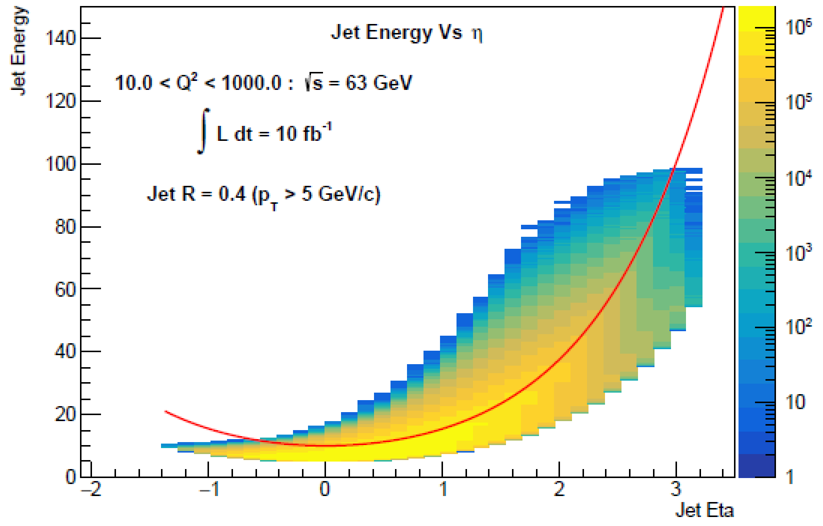
Why Look at Jets / Heavy Flavor?

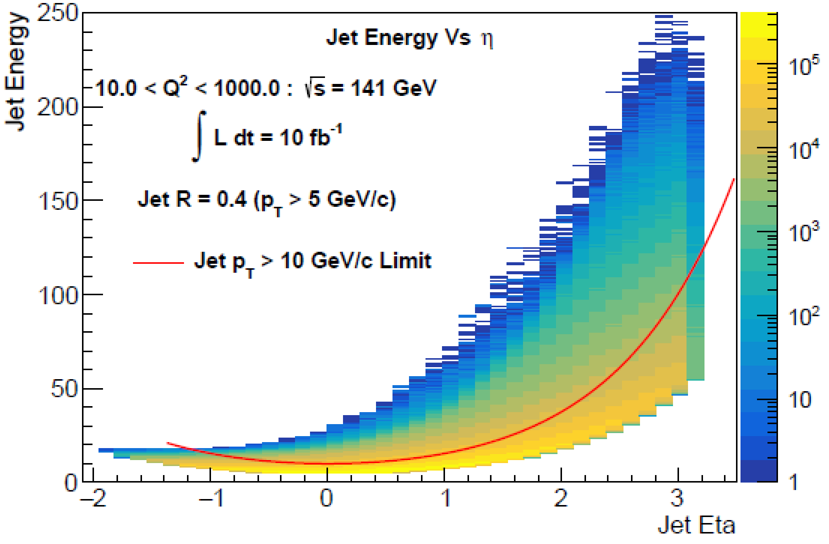
- ❑ Jets are comprised of the same particles used in traditional SIDIS (or diffractive) analyses – what benefits arise from forming a jet? – Why explicitly reconstruct HF?
- ❑ Jets represent the kinematics of the underlying parton better than single particle observables
- ❑ Jet showers probe QCD from hard interaction to hadronization scale within the same event – can explore dynamics at different time (angular) scales and trace evolution of shower. Precision tools exist to probe shower evolution
- ❑ Heavy flavor arises predominantly from a single subprocess (PGF) which is complimentary to (semi) inclusive DIS
- ❑ Larger mass scale will affect hadronization and propagation of heavy quarks in the nuclear medium

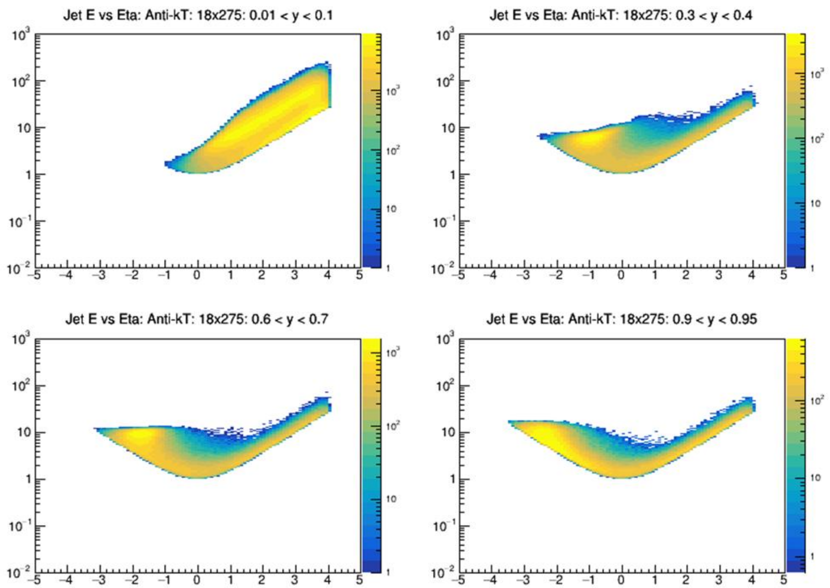


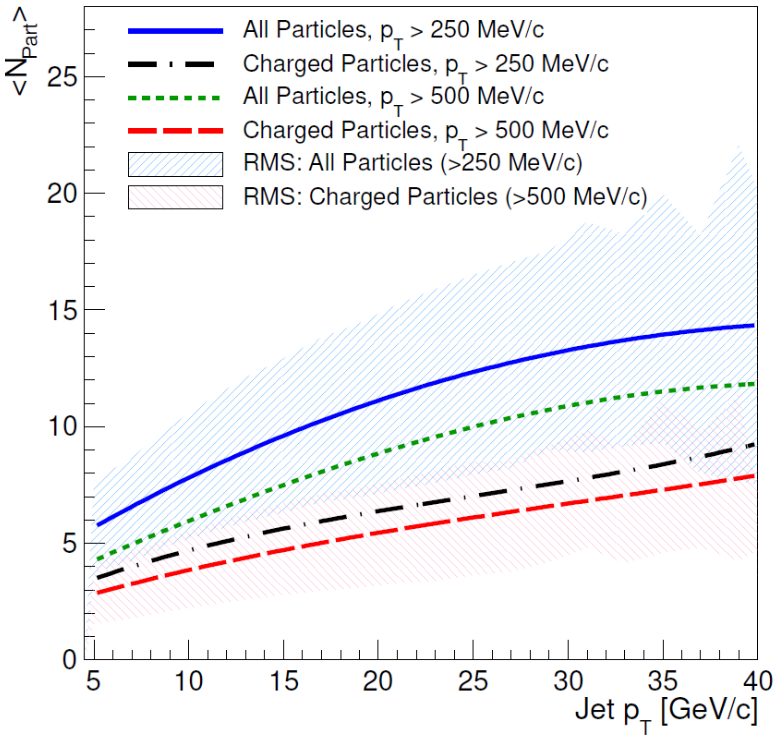


Jet Kinematics







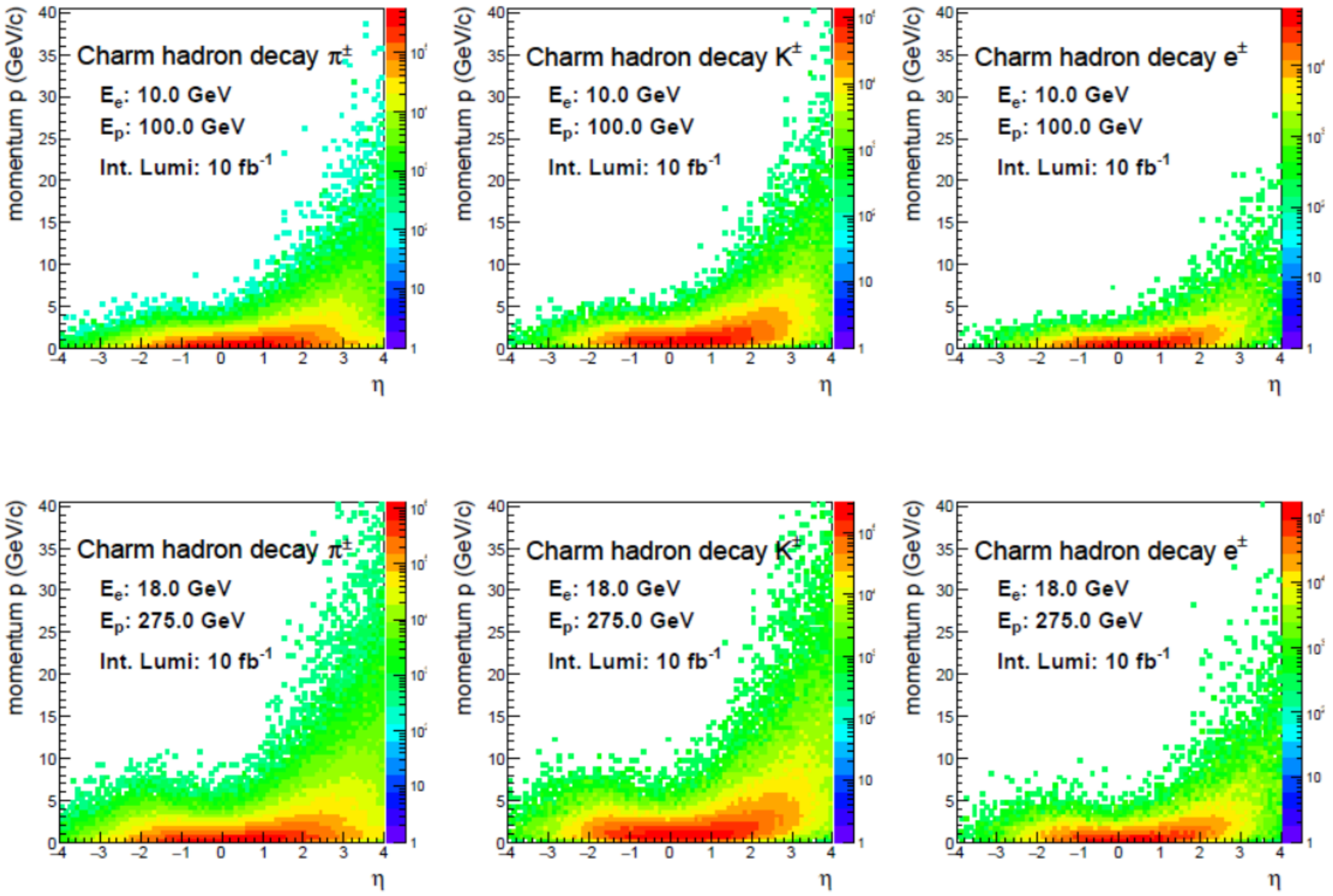


- ❑ Jet energy will be highly dependent on pseudorapidity with largest energies coming in the forward (hadron beam going) region
- ❑ Jet energy increases again at negative (electron going) pseudorapidities, taking the e-beam energy for high y
- ❑ Jets will be quite broad and have relatively low charged particle multiplicity
- ❑ Must ensure theory and MC can make robust predictions for low energy jets and hadronization models can handle low multiplicity jets

Heavy Flavor Kinematics

- Products from heavy flavor (in this case D0) decays largely follow the same pattern as jets in terms of energy vs pseudorapidity

- The dependence on angle and event kinematics is not as pronounced as for the jets since the D0 decay products do not track the struck parton kinematics as well as jets



Jets and HF in the Yellow Report

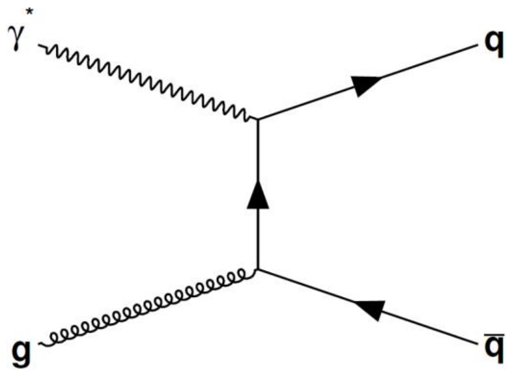
The EIC Measurements and Studies

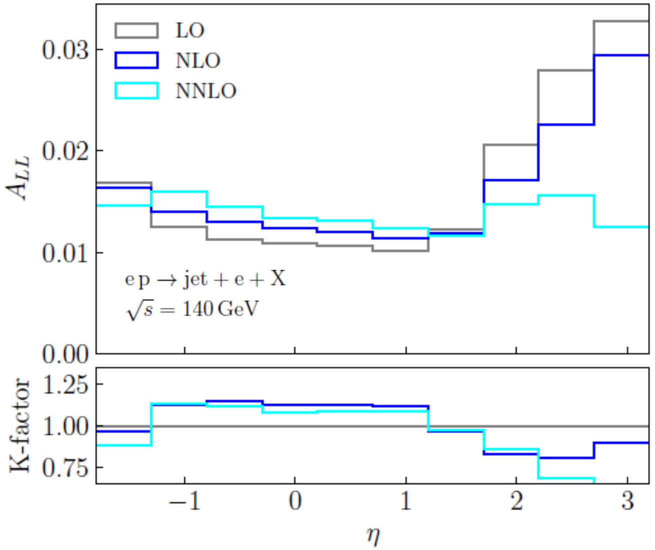
- Global properties and parton structure of hadrons
  - Unpolarized parton structure of the proton and neutron
  - Spin structure of the proton and neutron
  - Inclusive and hard diffraction
  - Global event shapes and the strong coupling constant
- Multi-dimensional imaging of nucleons, nuclei and mesons
  - Imaging of quarks and gluons in momentum space
  - Wigner functions
- The nucleus: a laboratory for QCD
  - High parton densities and saturation
  - Particle propagation in matter and transport properties
  - Special opportunities with jets and heavy quarks
- Understanding hadronization
  - Hadronization in the vacuum
  - Hadronization in the nuclear environment

Nuc. Phys. A, vol 1026, Oct 2022, 122447

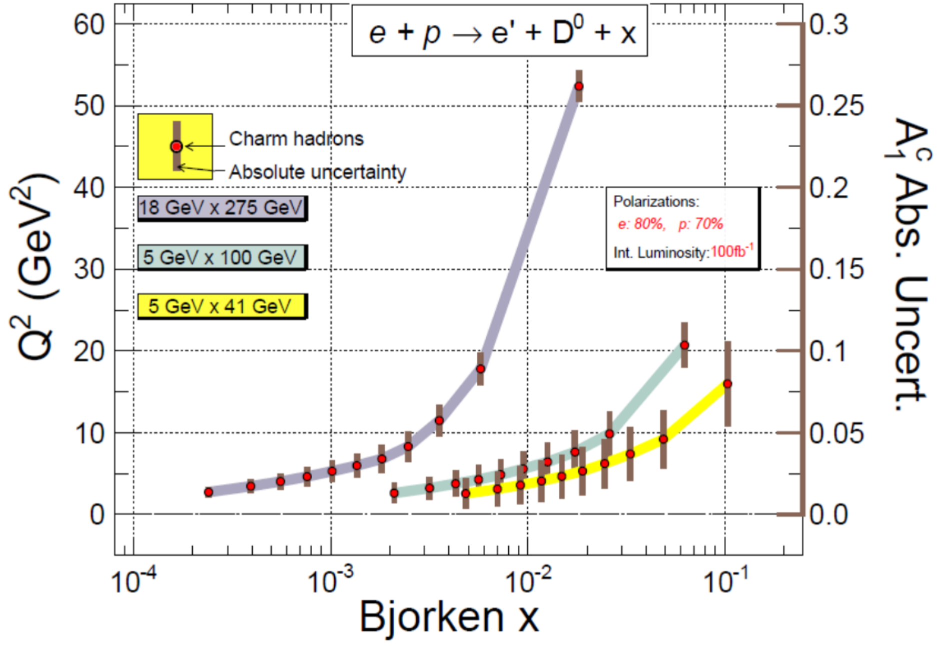
Longitudinal Spin Structure with Jets / HF

- Recent results on inclusive jet A_{LL} at NLO and NNLO both with and without tagged lepton
- NLO formalism for HF production from polarized DIS also recently developed
- Feasibility studies for dijet A_{LL} in the Breit frame and D^0 A_{LL} have been preformed and show ability to constrain ΔG

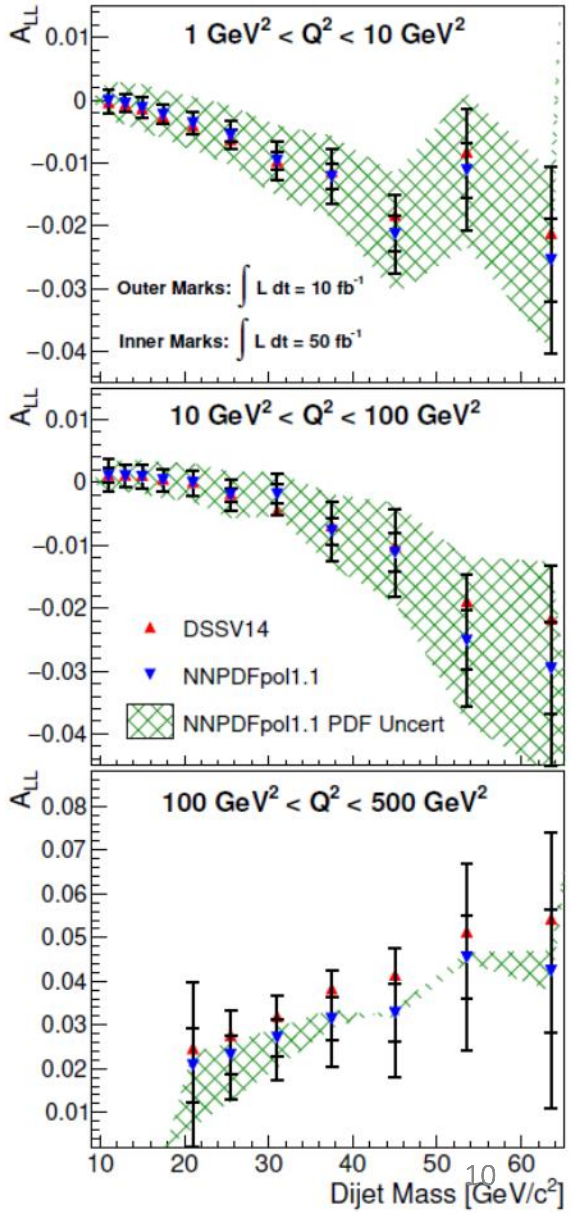




Borsa, de Florian, Pedron `20



Phys.Rev.D 104 (2021) 11, 114039

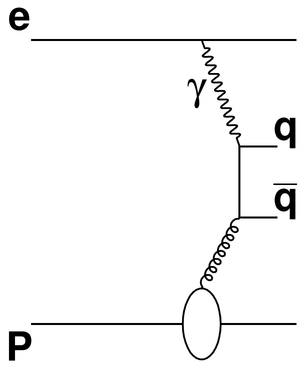


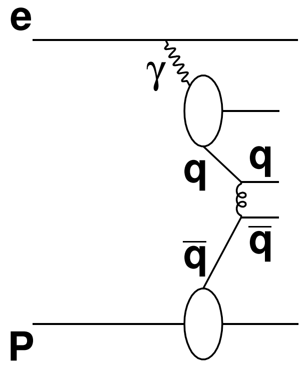
Page, Chu, Aschenauer `20

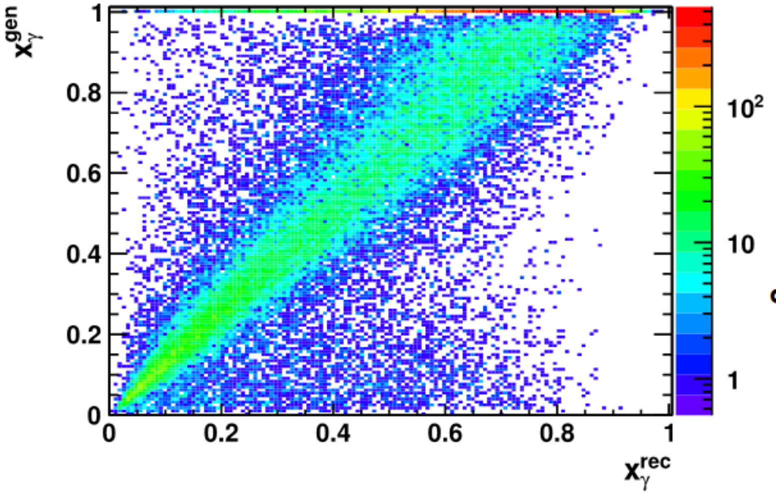
(Polarized) Photon Structure

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

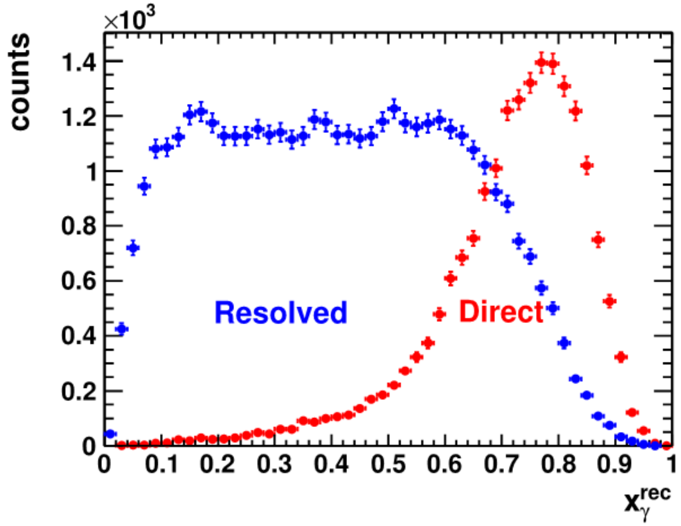
- At low Q2, virtual photon can behave hadronically and initiate 2->2 type scattering events
- Results in a quark/anti-quark final state with high transverse momentum
- Dijet allows to reconstruct event characteristics to separate signal and background and characterize the structure of the photon

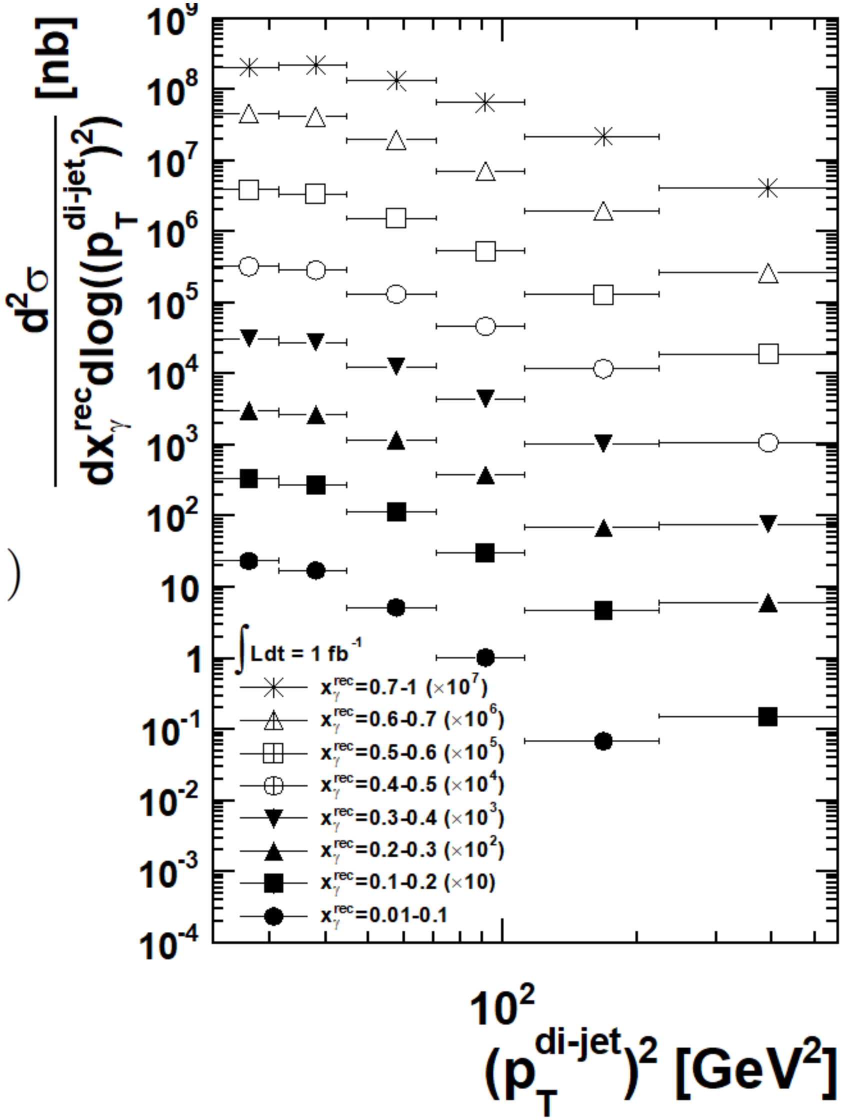




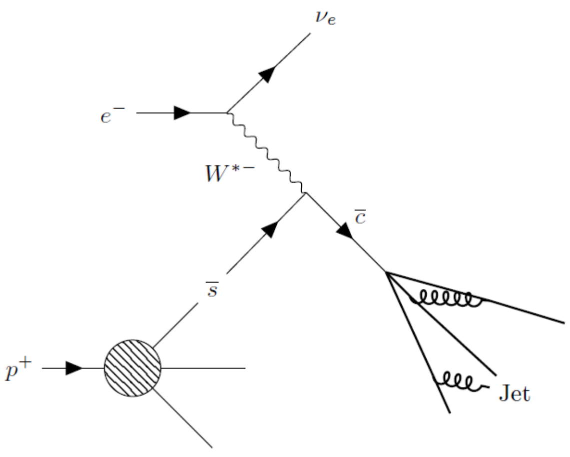


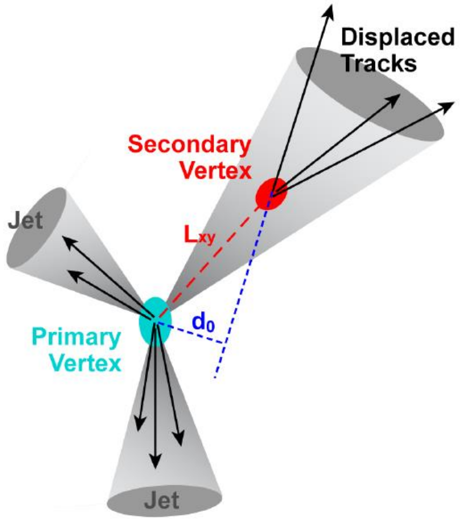
$$x_\gamma^{rec} = \frac{1}{2E_e y}\left(p_{T1}e^{-\eta_1} + p_{T2}e^{-\eta_2}\right)$$

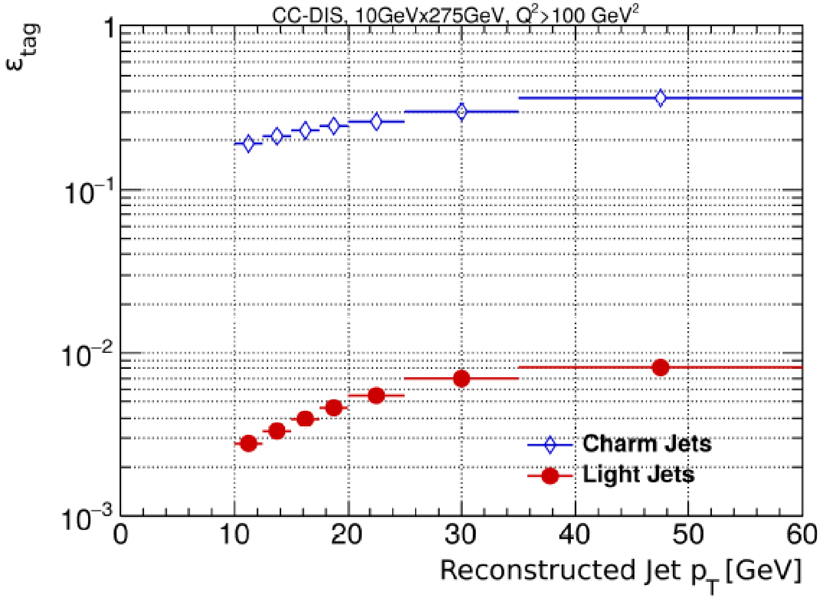




Charm Jet Tagging for Strangeness





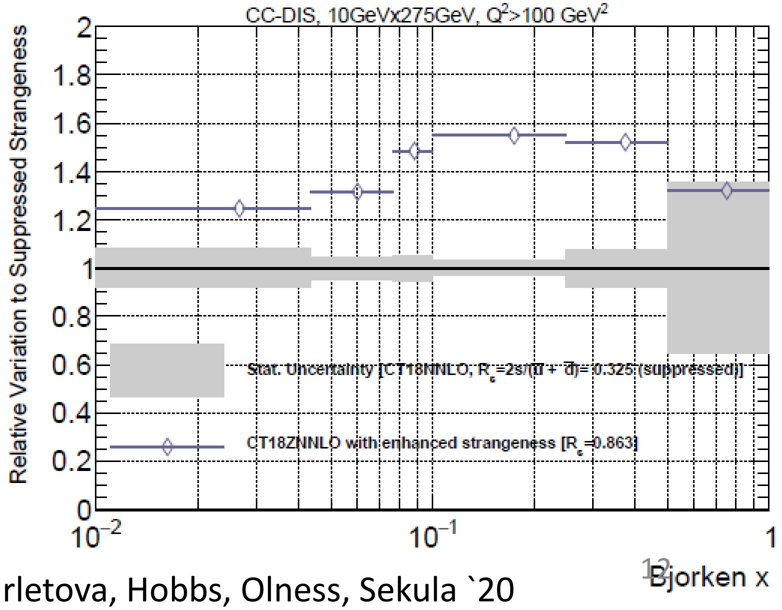


- Tension exists between neutrino DIS and SIDIS measurements of strange content and LHC extractions

- 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

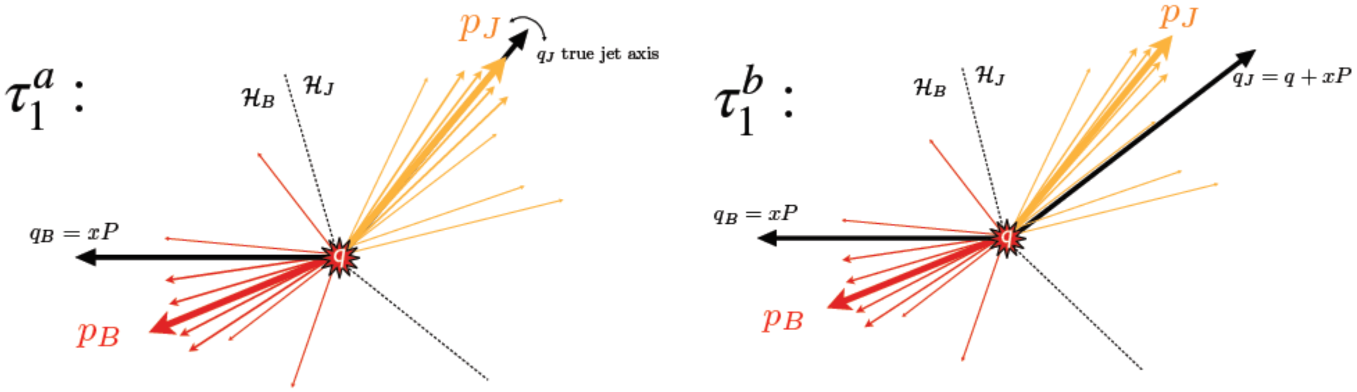
- Charm jet measurements at EIC should be able to discriminate between low and high strangeness scenarios

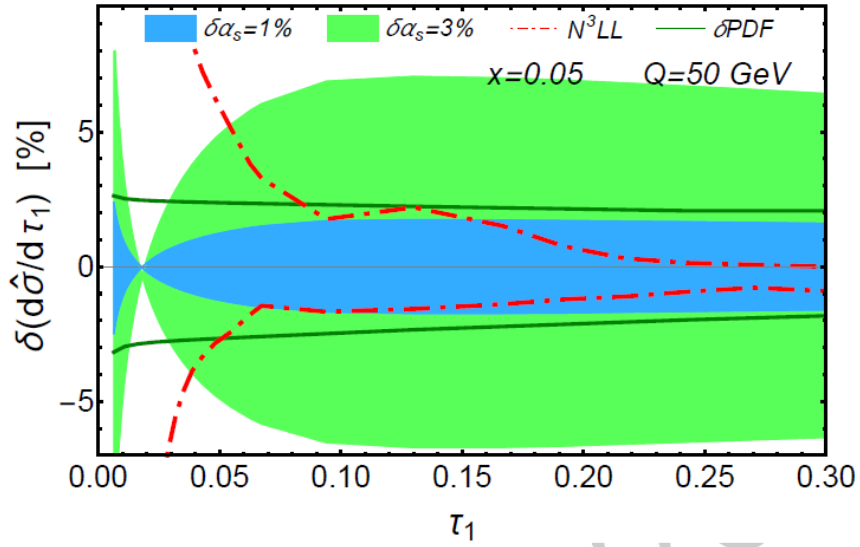


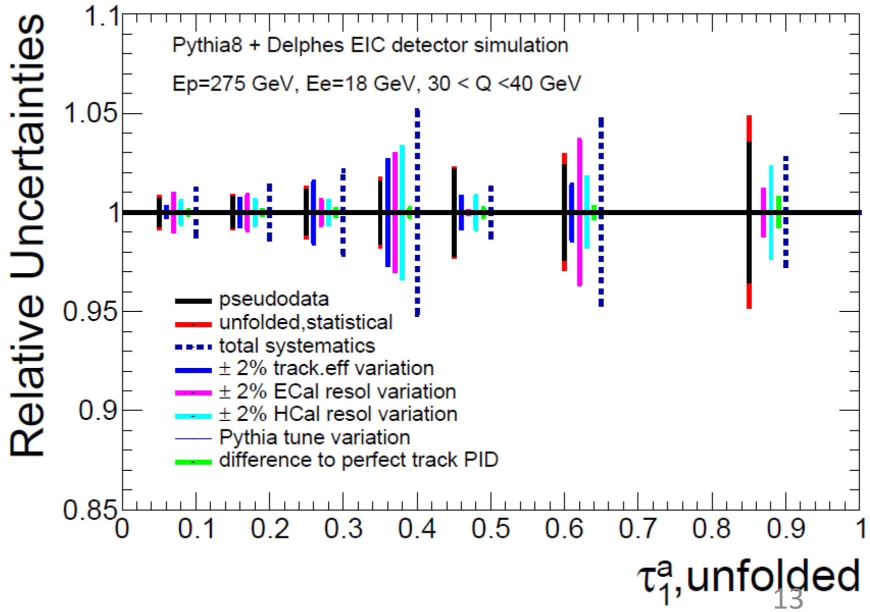
Arratia, Furletova, Hobbs, Olness, Sekula `20

Global Event Shapes

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



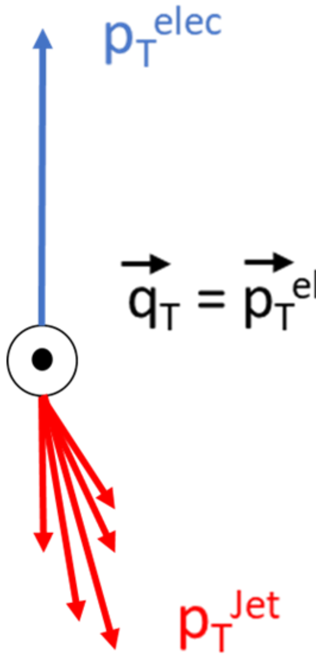




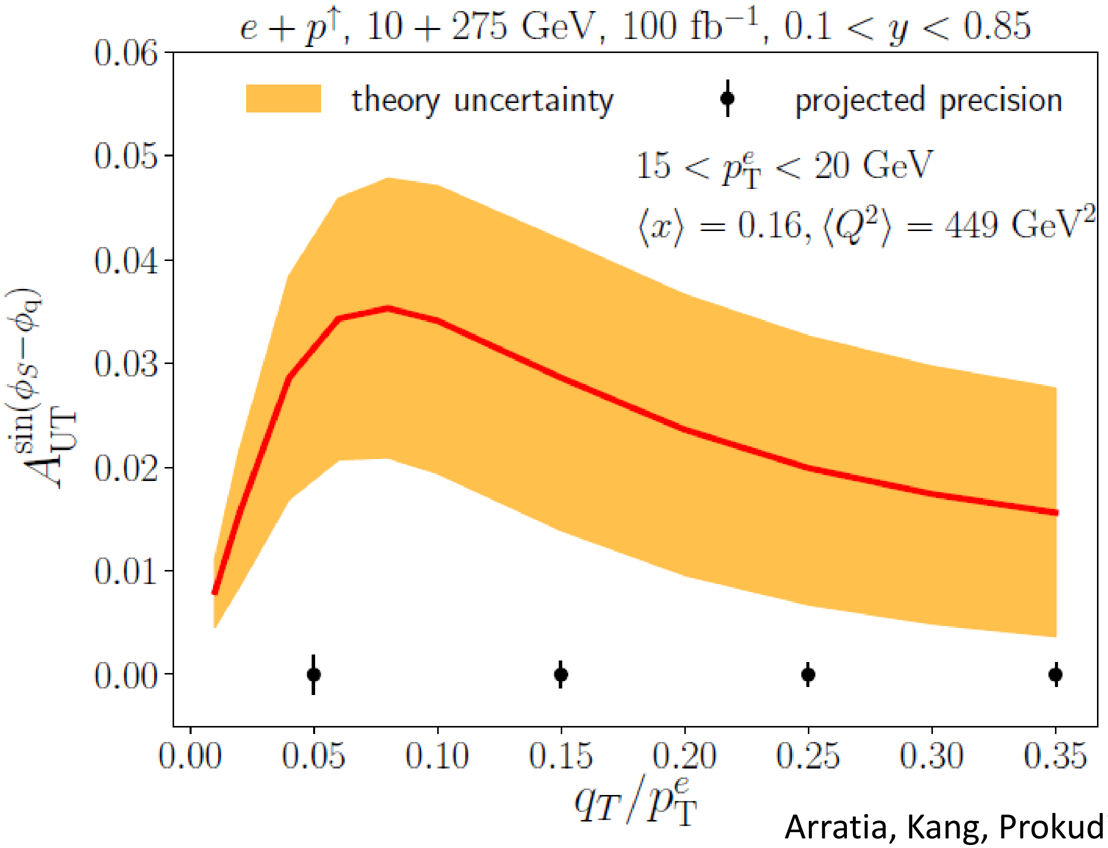
- Global event shapes offer possibility of very high precision measurements for extractions of non-perturbative parameters such as the strong coupling constant
- Feasibility study of 1-jettiness measurement was carried out for the YR effort with total 2-4% statistical and systematic error – better if using only charged tracks
- At N^3LL, roughly 1% precision is possible, challenging experimental problem, but recent studies show promise

TMDs With Jets

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



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



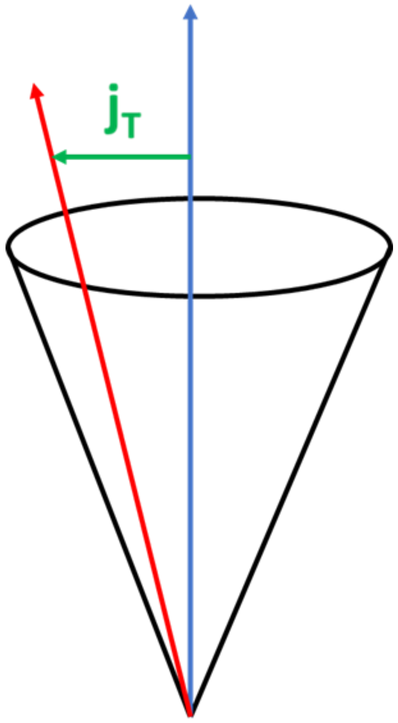
- ❑ Jets are complementary to standard SIDIS extractions of TMDs and provide better surrogates for parton kinematics while allowing cleaner separation of target and current fragmentation regions
- ❑ Jet measurements allow independent constraints on TMD PDFs and FFs from a single measurement
- ❑ Azimuthal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

Arratia, Kang, Prokudin, Ringer \`20

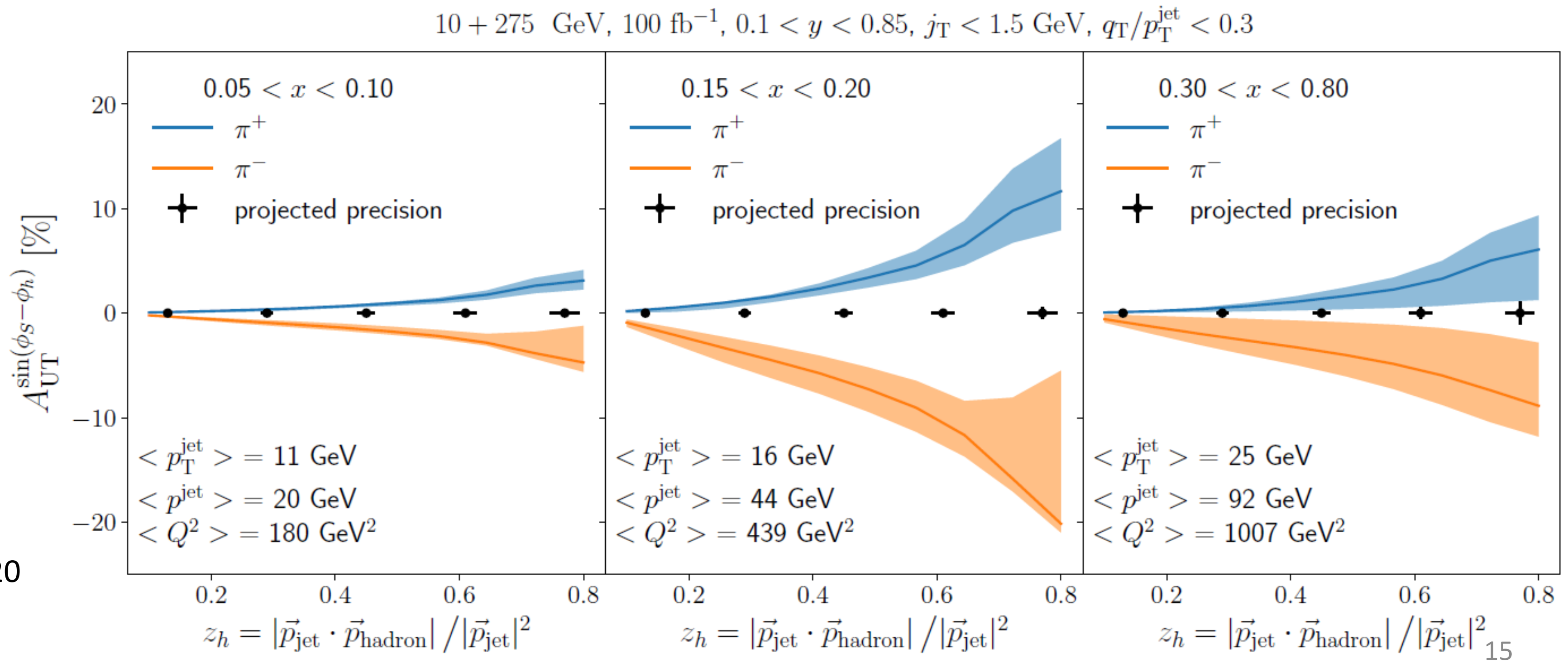
TMDs With Jets

- 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

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

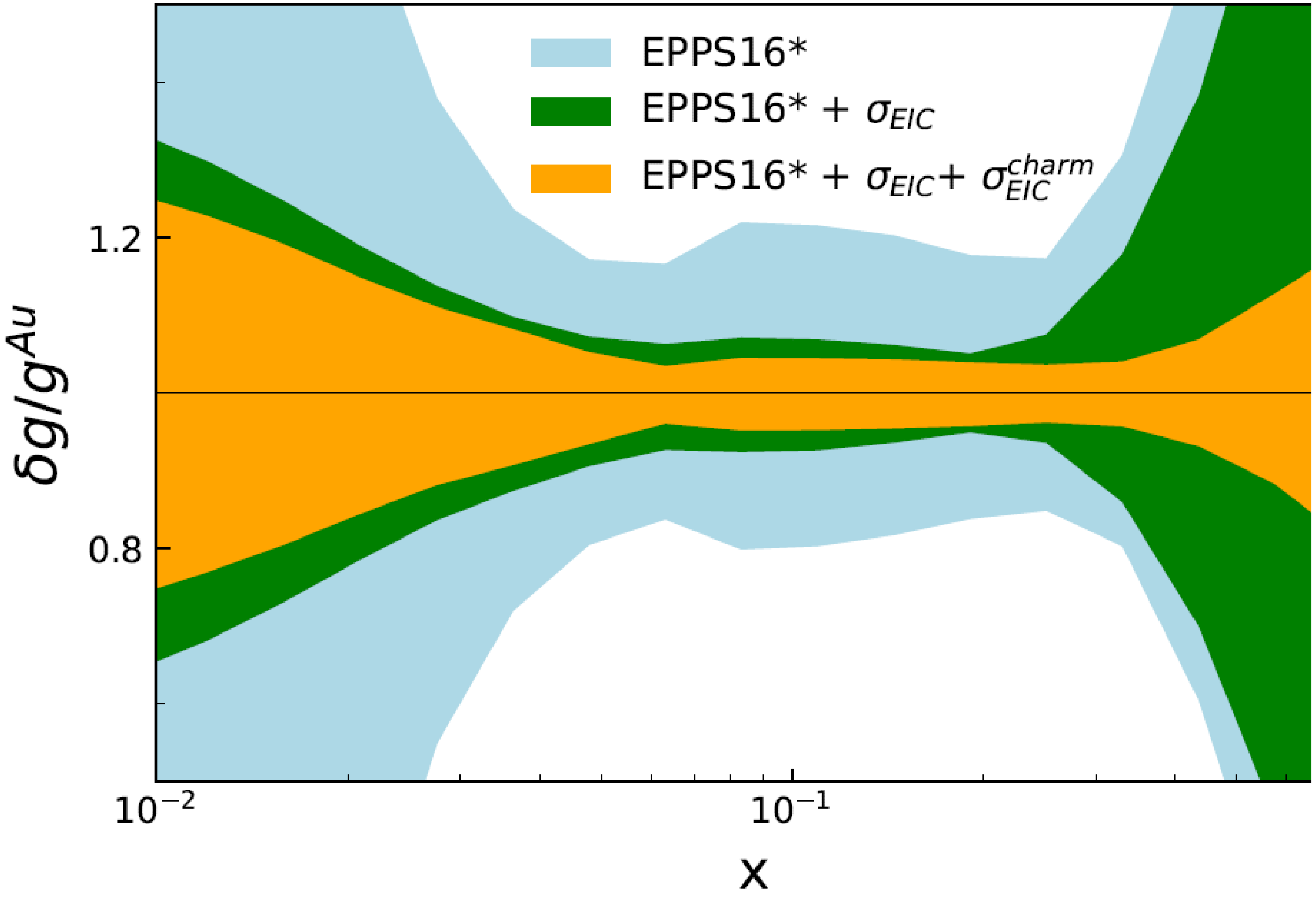


Arratia, Kang, Prokudin, Ringer `20



Nuclear PDFs

Phys. Rev. D96, 114005 (2017) and YR



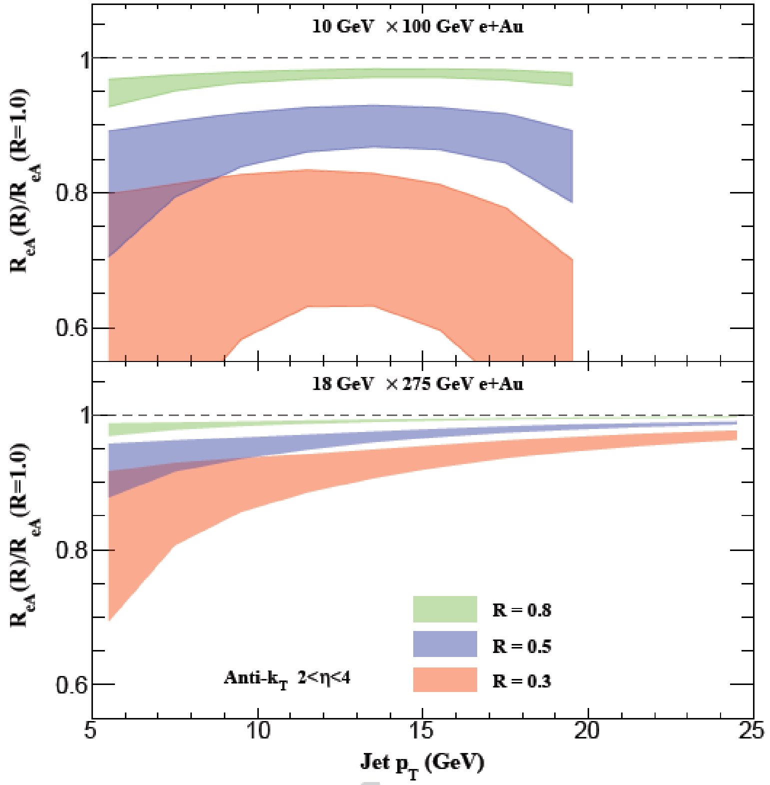
- With its large kinematic coverage and ability to run a variety of nuclear beams, the EIC will vastly improve our knowledge of nuclear PDFs
- Fully inclusive data will improve nPDFs for valence and sea distributions, along with gluons for much of the relevant x-range
- Adding charm data will greatly reduce uncertainties for the gluon nPDF in the high-x region

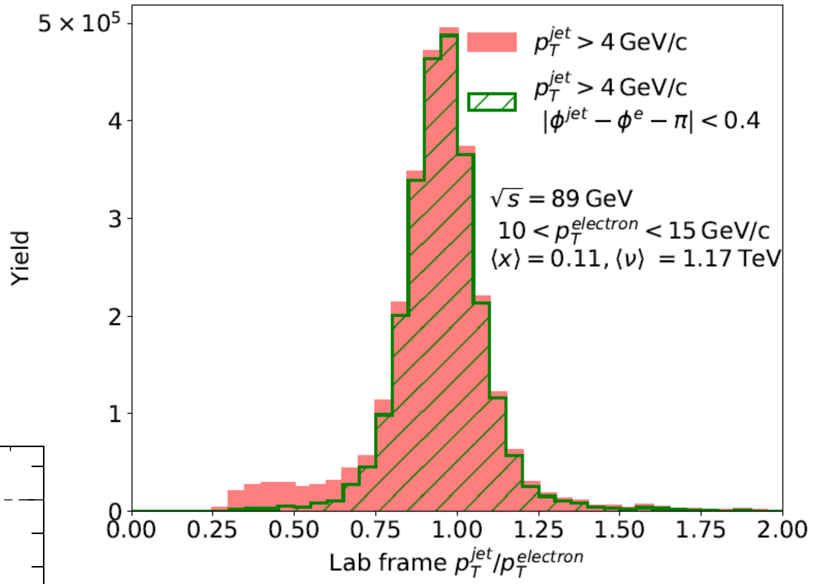
Jets in the Medium

- 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

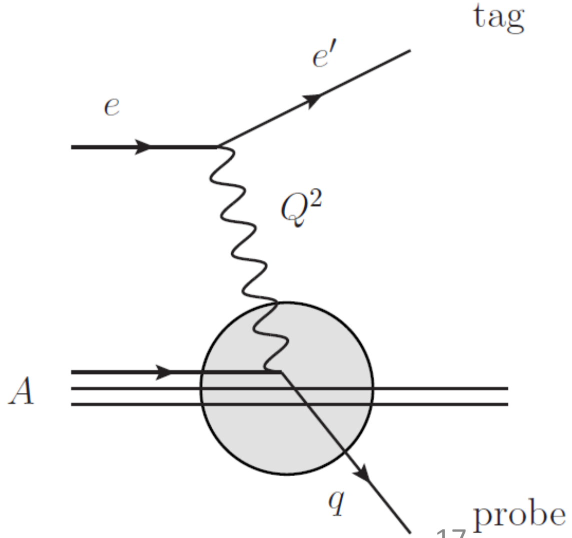
$$R_{eA}(R) = \frac{1}{A}\frac{\int_{\eta 1}^{\eta 2} d\sigma/d\eta dp_T|_{e+A}}{\int_{\eta 1}^{\eta 2} d\sigma/d\eta dp_T|_{e+p}}$$

Li & Vitev ‘20



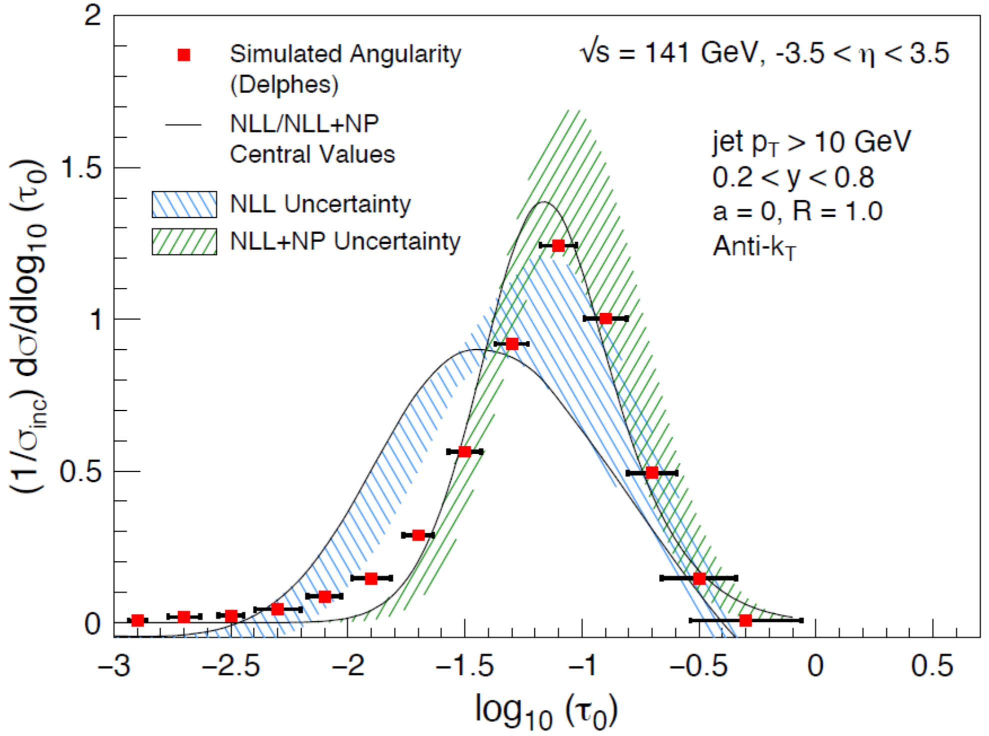


Arratia, Song, Ringer, Jacak ‘20



Hadronization with Jets and HF

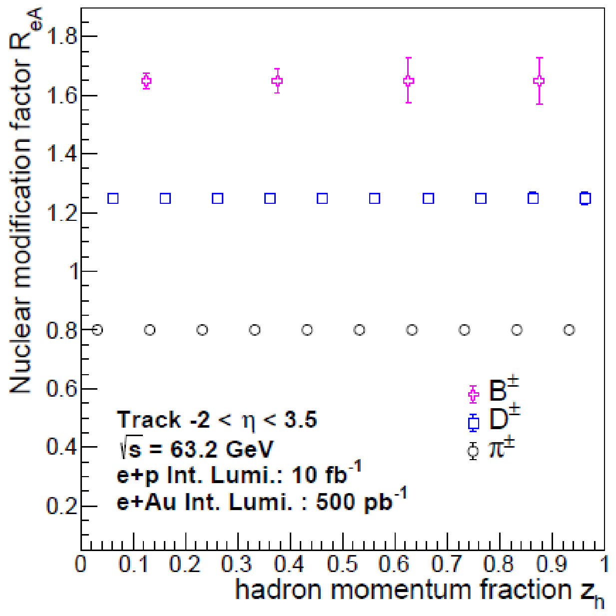
$$\tau_a \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta R_{iJ}\right)^{2-a}$$

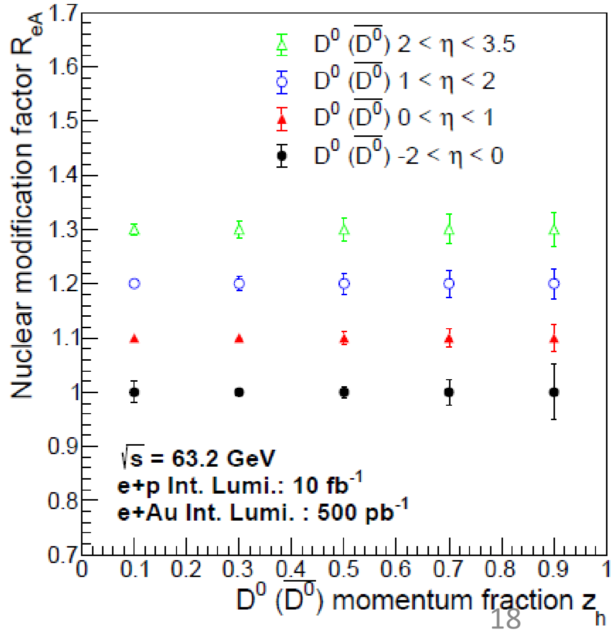


Aschenauer, Lee, Page, Ringer `20 & ATHENA Proposal

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

- Both jets and HF observables are well suited to the study of hadronization, both in vacuum and the nuclear medium
- Jet substructure will allow measurements of the flow of energy within a shower and shower evolution
- Nuclear modification (R_{eA}) of heavy mesons will be particularly sensitive to details of energy loss / hadronization





Implications for MCEGs

- EIC measurements will cover both the photoproduction and electroproduction regions
- Many different subprocesses (DIS, H.O., diffractive) will be relevant for different measurements in different kinematic regions

→ General purpose MCEGs need to be able to 'smoothly' move between photoproduction and electroproduction regimes with consistent subprocess cross section behavior. A 'min-bias' setting that automatically incorporates all subprocesses in a given Q^2 range in the appropriate ratios would be very useful.

- Nearly every measurement at the EIC will require precise knowledge of event kinematics (x, Q^2, etc)
- This is especially true of measurements to constrain PDFs

→ General purpose MCEGs should incorporate precise QED radiative corrections so impacts on kinematics can be determined and correction / mitigation strategies developed

Implications for MCEGs

- Exploration of spin structure of the nucleon will be a primary focus of the EIC
  - Helicity PDFs
  - TMDs

General purpose MCEGs should incorporate polarization into all stages of simulation: initial state, hard-scattering, and shower / hadronization to reduce biases and systematic effects in measurements

Including transverse momentum dependence into initial and final states will also help reduce biases in those measurements

Implications for MCEGs

- ❑ The study of the properties of cold nuclear matter and how energetic color charges interact with that matter will be another pillar of the EIC physics program

→ It would be useful to have eA capability with tunable energy loss and transport properties as well as nuclear breakup effects. (Aware of course of BeAGLE, JETSCAPE, Angantyr, etc.) Modeling of collective effects and transition to a saturated regime will also be important.

- ❑ The detailed study of the hadronization process is another key aspect of the EIC program

- ❑ Study hadronization in vacuum and medium with a variety of probes including HF and very differential jet observables (substructure)

→ Different hadronization models should be available which describe both vacuum and medium hadronization, can handle HF propagation, and describe the structure of low multiplicity jets.

MCEG ‘Utilitarian’ Needs

- In addition to physics analysis driven needs, MCEGs play a critical role in detector and interaction region design
- Need to understand detector occupancies for DAQ and FEE design
- Need to understand backgrounds to scattered electron measurement
- Need to understand backgrounds coming from beam sources for rad hardness requirements

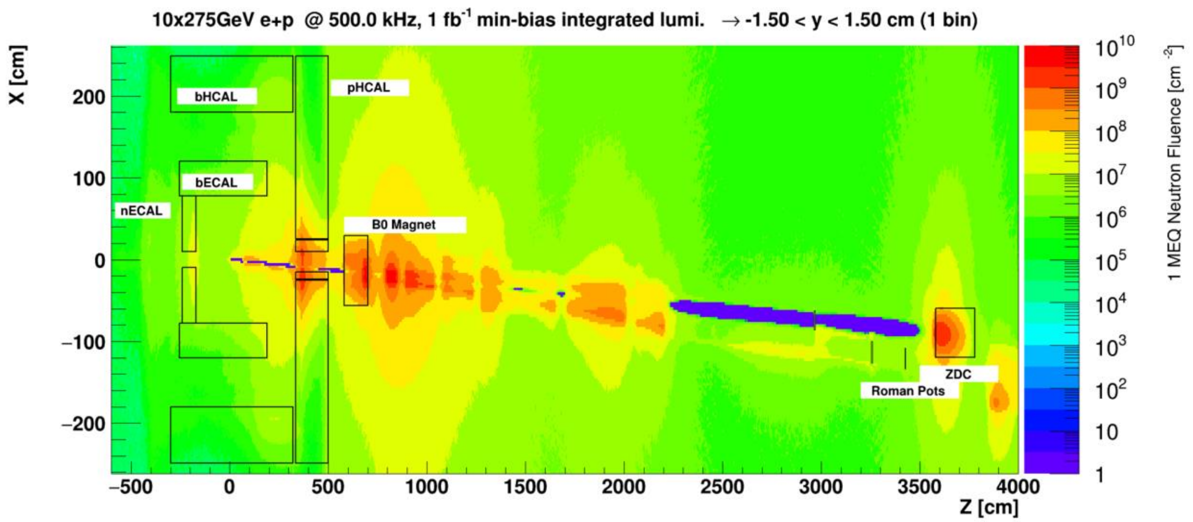
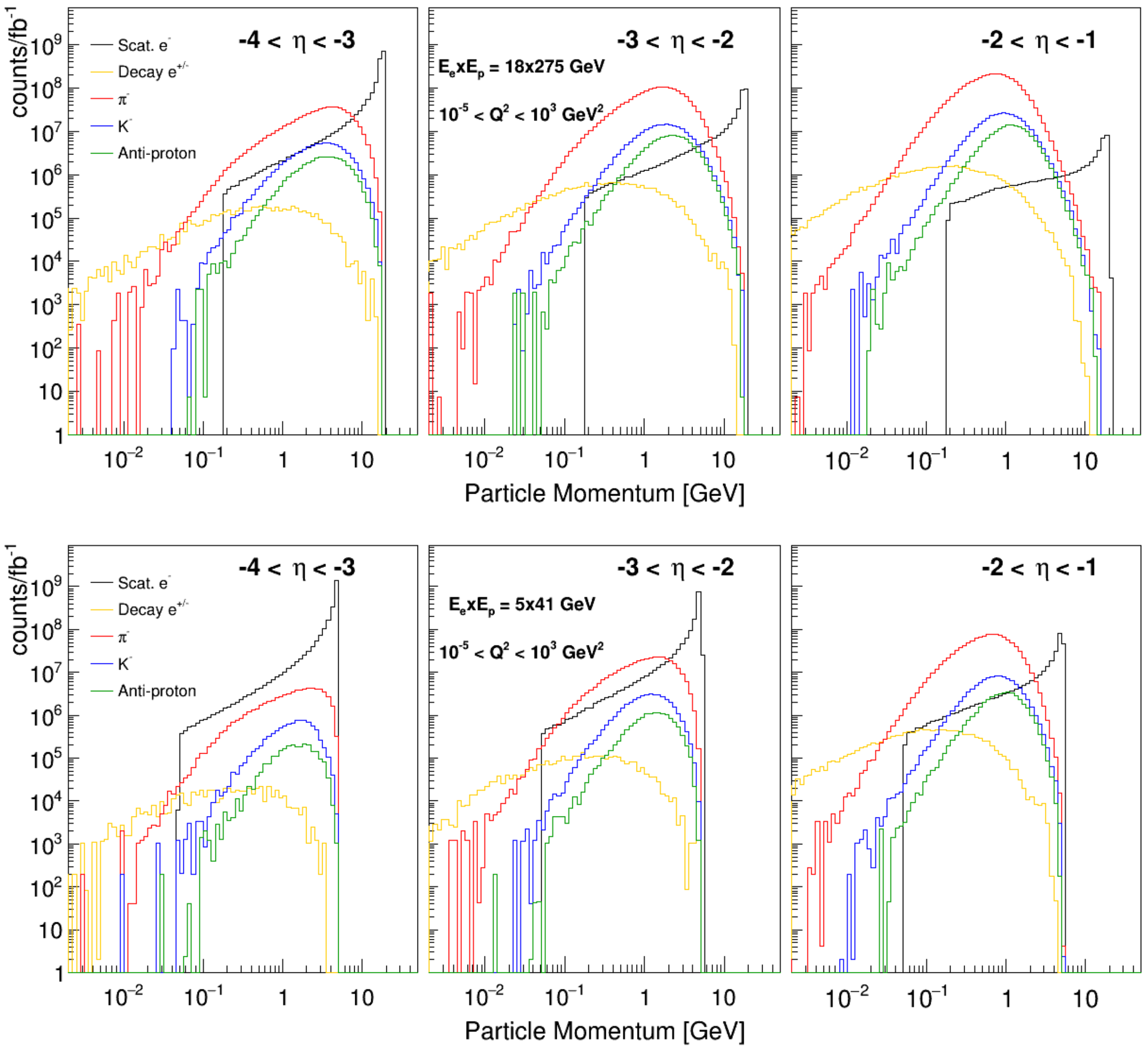
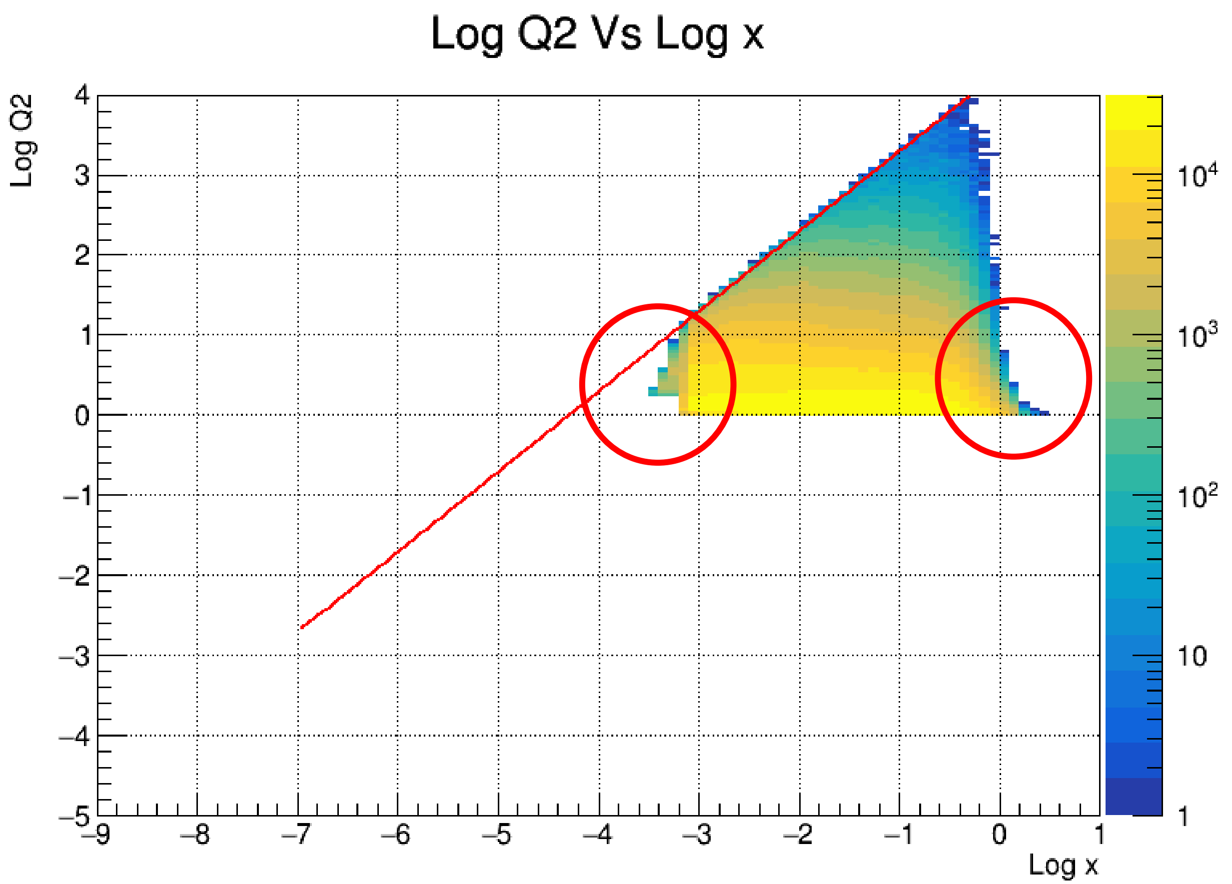


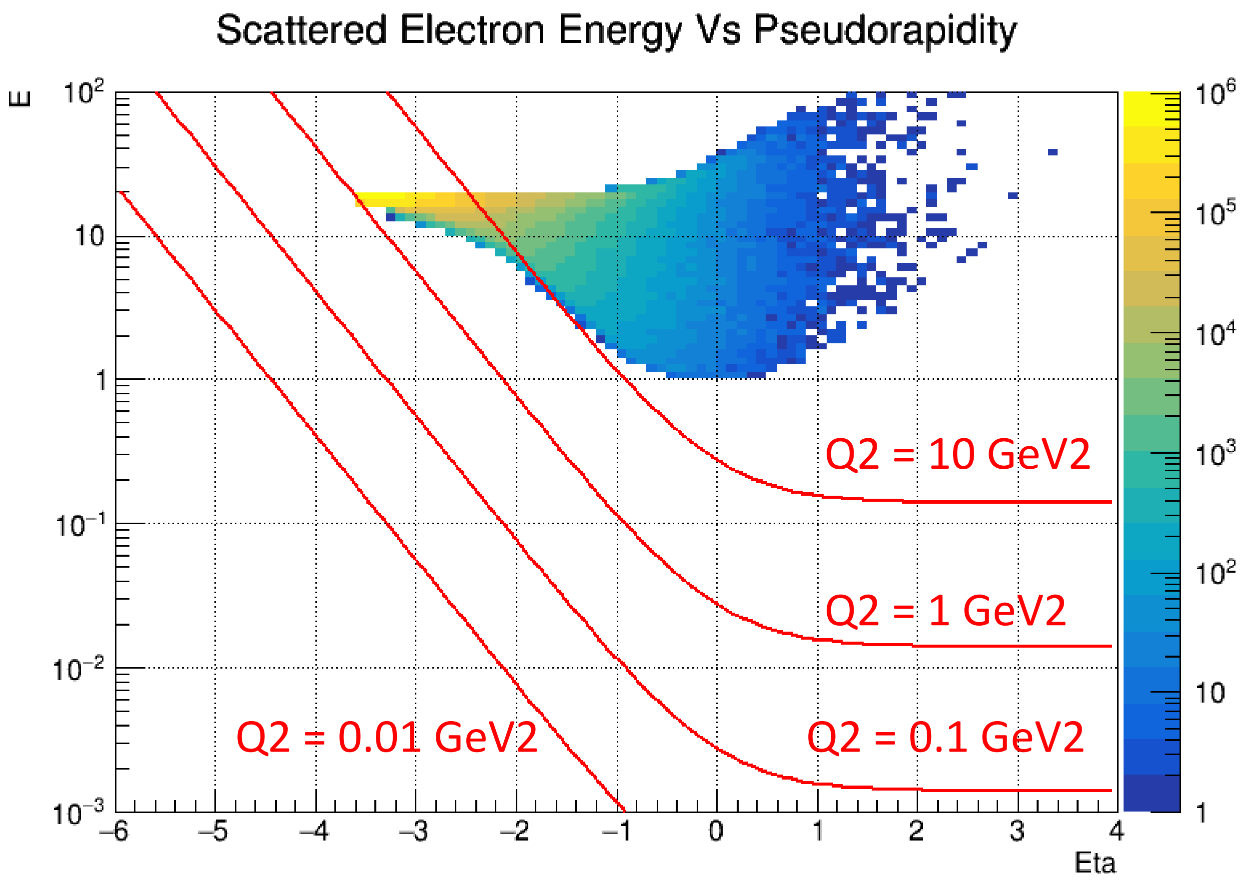
Fig. by A. Jentsch



DIS Generation in Pythia8: Default Settings

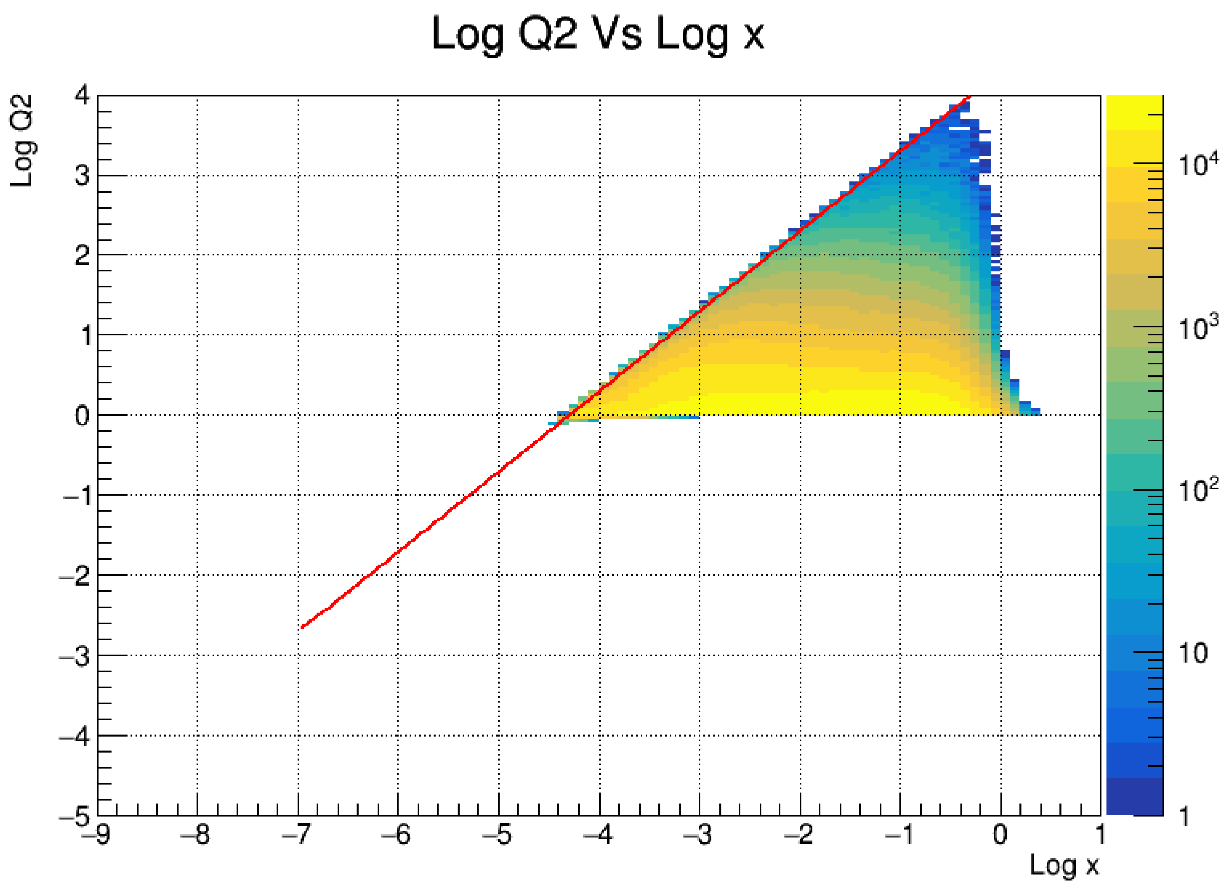


- Generation of events with 1 < Q2 < 10 show obvious pathologies
- Impacts very important region for detector design (subsystems tasked with IDing scattered electron)



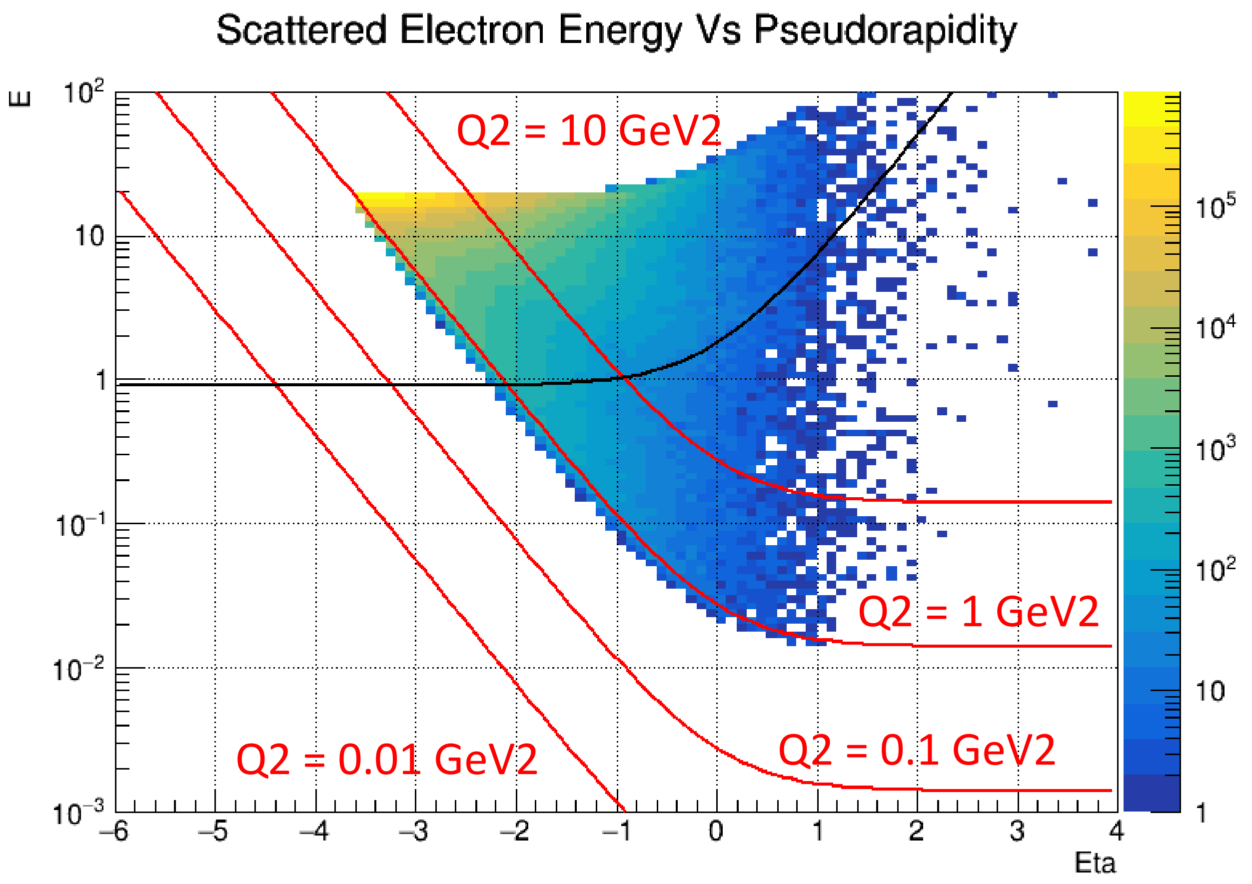
PhaseSpace:mHatMin = 4 GeV
PhaseSpace:pTHatMin = 0 GeV
PhaseSpace:pTHatMinDiverge = 1 GeV
PhaseSpace:Q2Min = 1 GeV2

DIS Generation in Pythia8: Loosened Settings

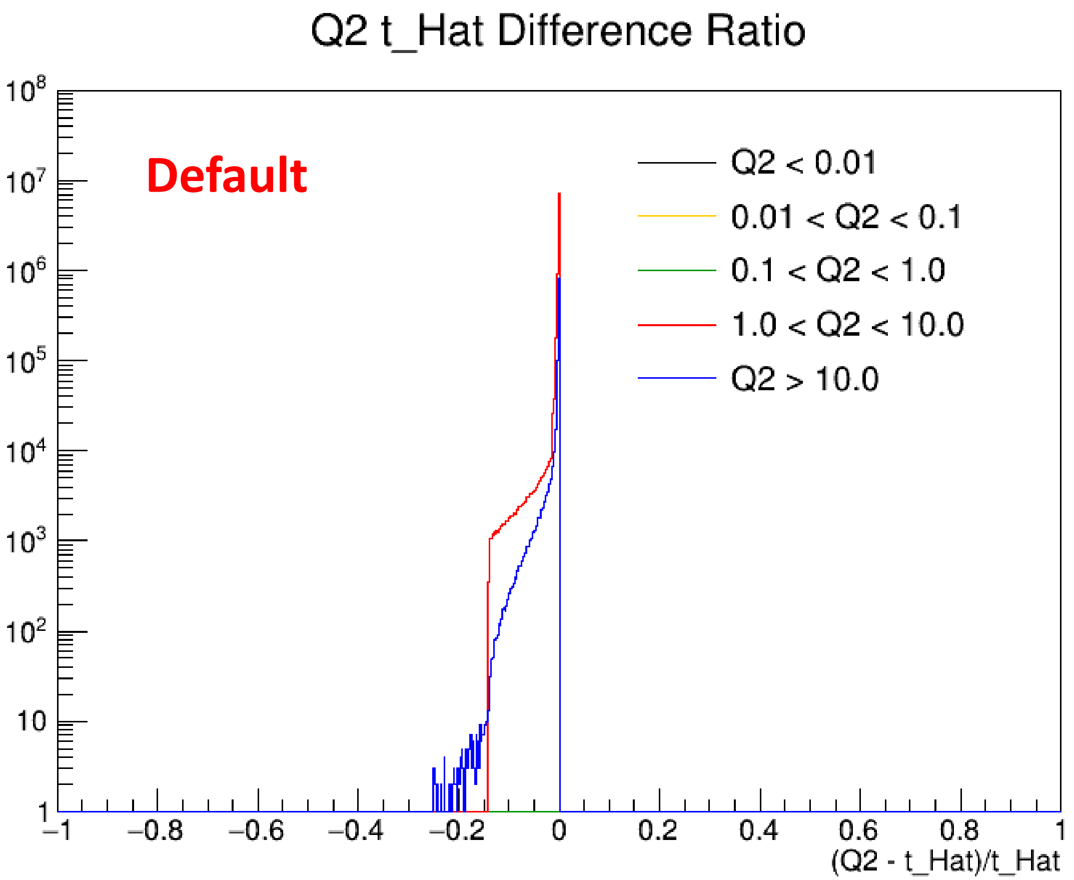


- ❑ With mHatMin and pTHatMinDiverge lowered, see much better coverage of phase space
- ❑ Still see events at x > 0 and now some events with Q2 < 1

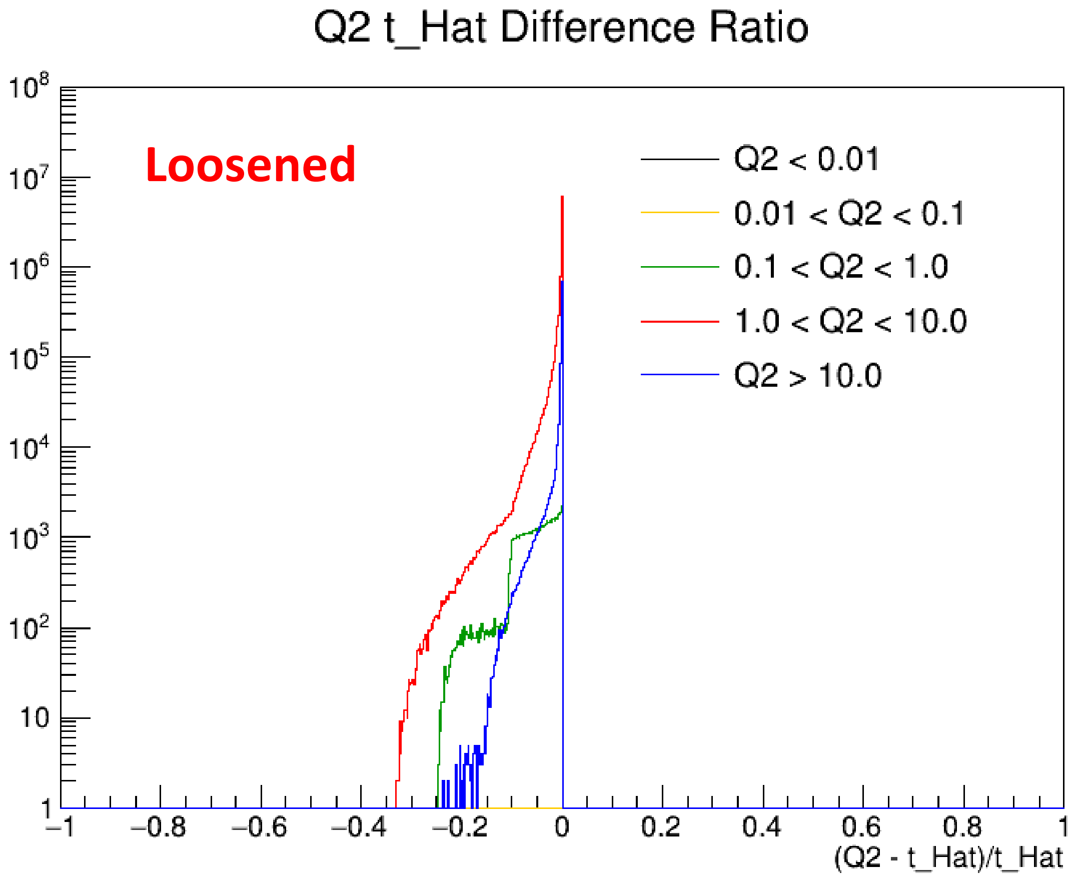
- ❑ Reduce mHatMin to 1 GeV and force pTHatMinDiverge to 0.01 GeV



DIS Generation in Pythia8: Sanity Check

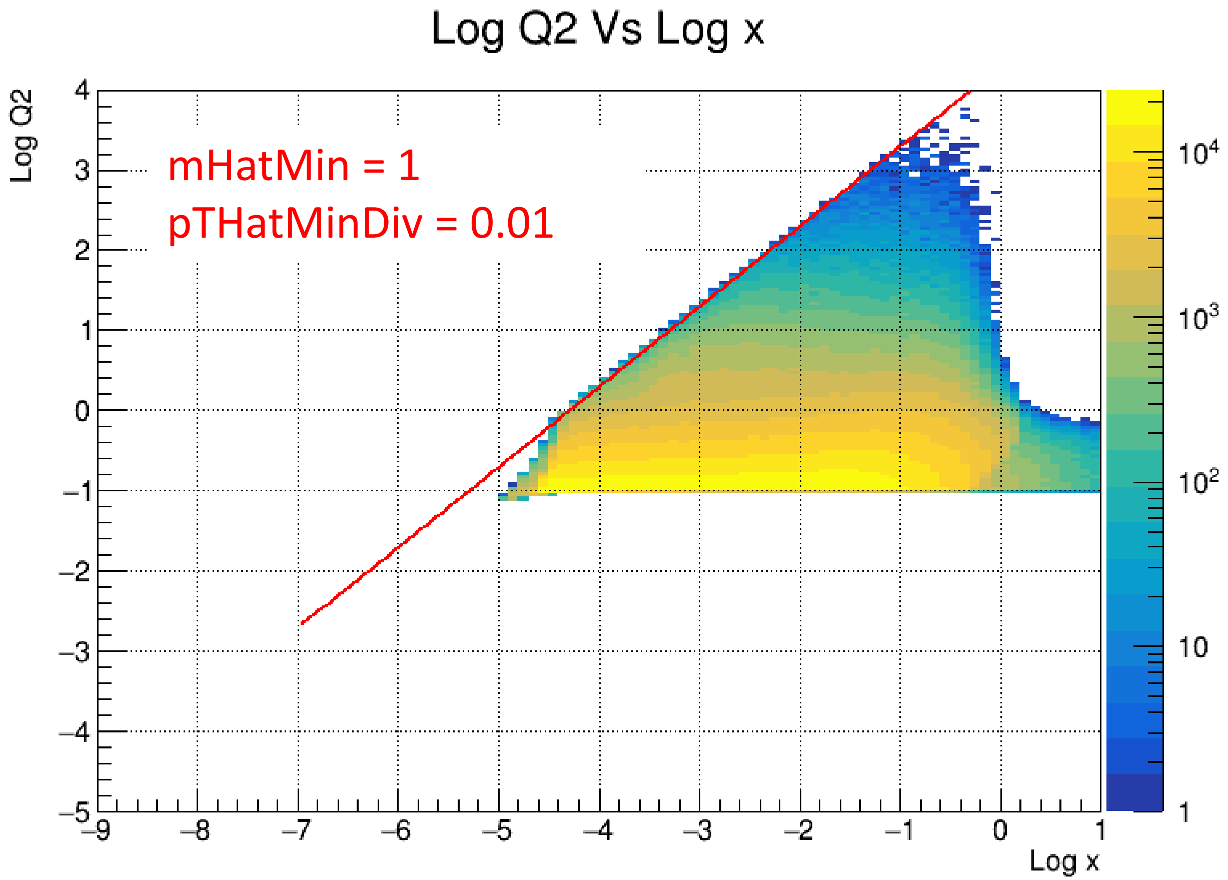


- In the above, x and Q2 are calculated via the incoming and scattered electron beam kinematics
- Compare calculated Q2 with -tHat, they should be equivalent



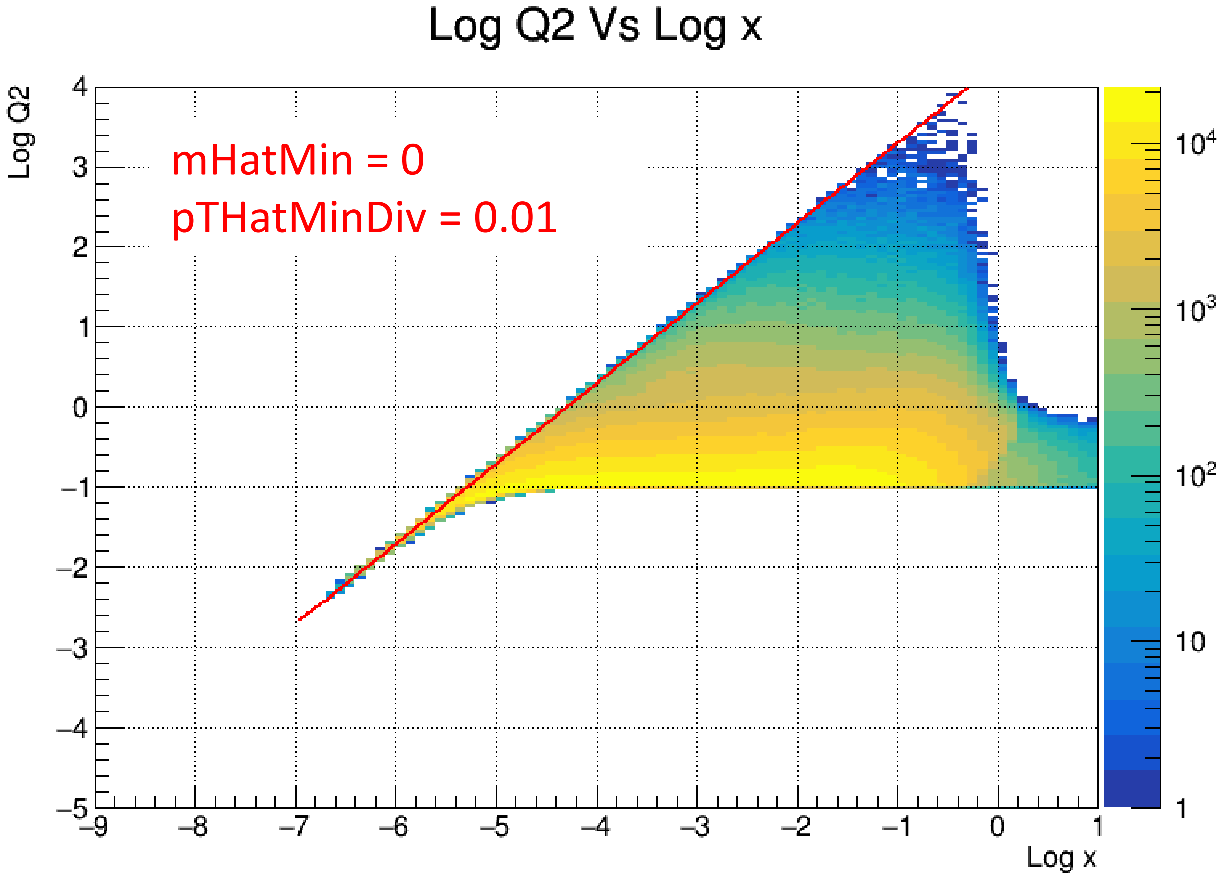
- See that even for the default settings there are tails indicating mis-match
- The mis-match for 1 < Q2 < 10 becomes worse with the looser settings – are we generating sensible events?

DIS Generation in Pythia8: Lower Q2?

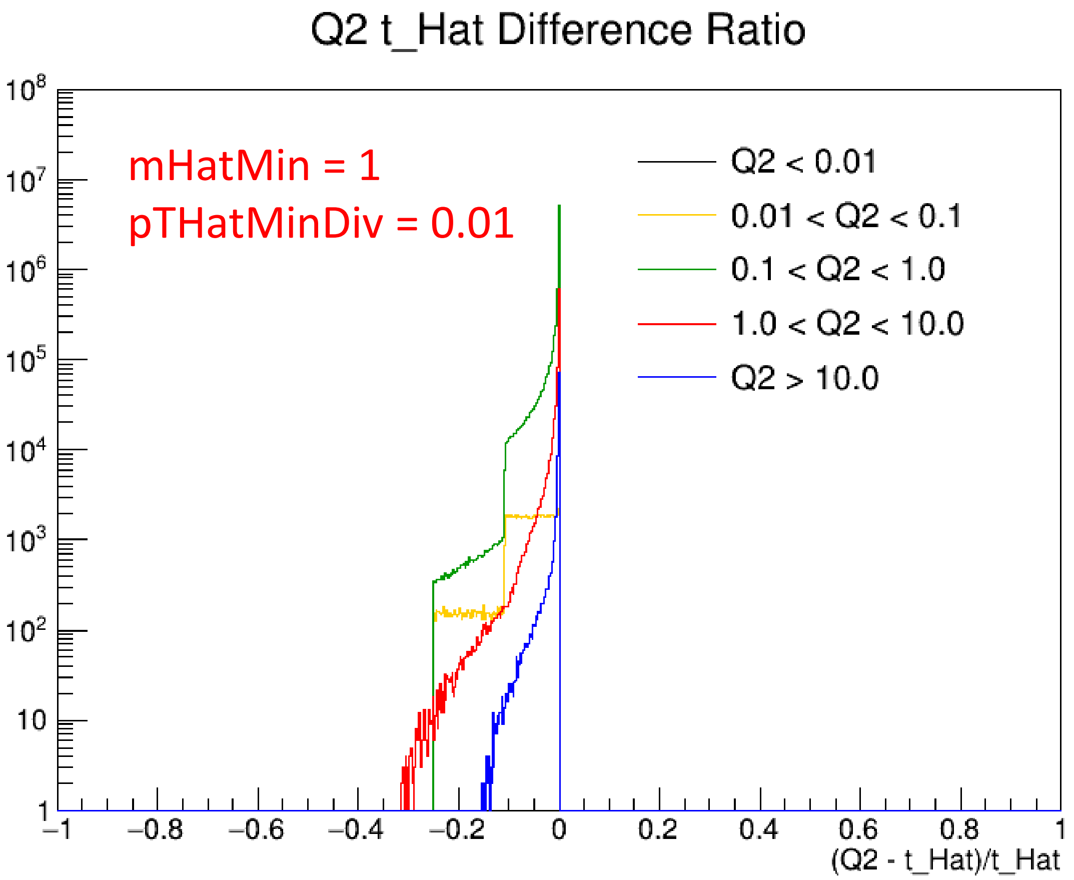


- ❑ Try lowering mHatMin from 1 down to 0
- ❑ Phasespace is now covered, but see a large 'tail' of events with reconstructed Q2 less than the specified limit of 0.1

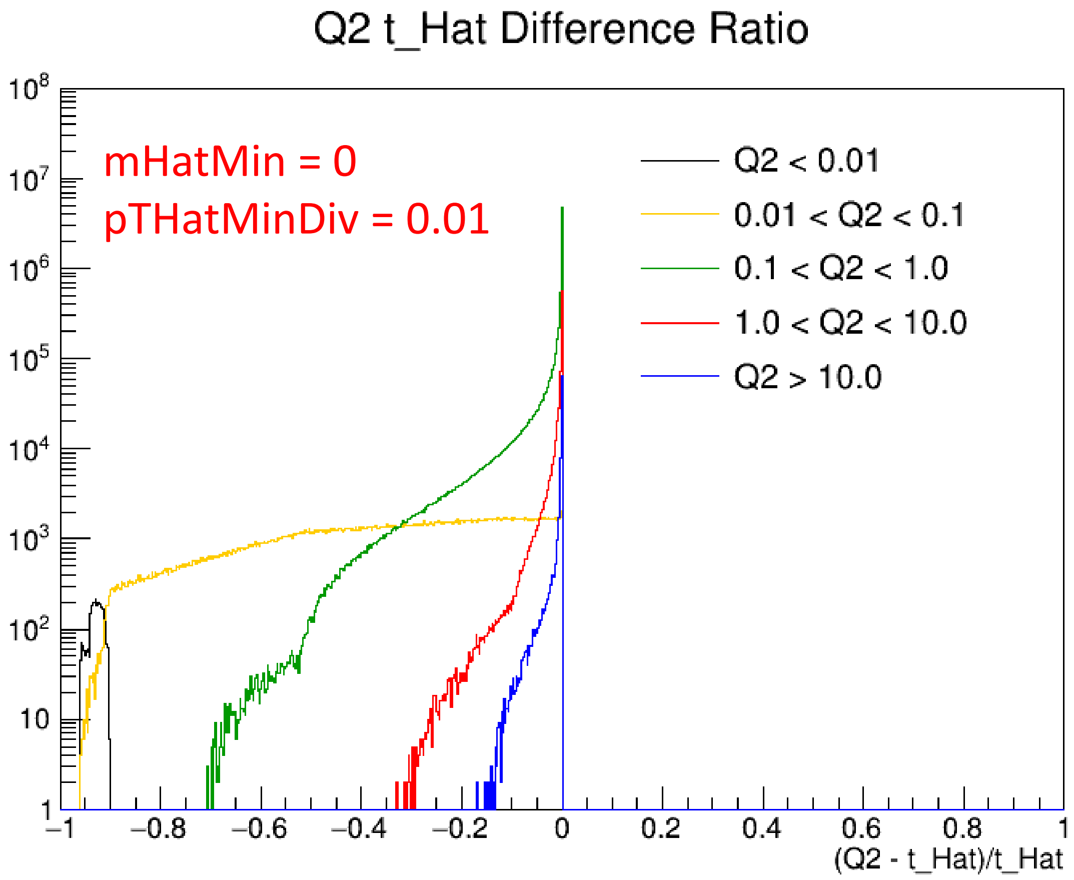
- ❑ What happens when we push Q2Min below unity, say to 0.1?
- ❑ Previous settings again do not fully cover the available phasespace with low Q2 – low x region missing



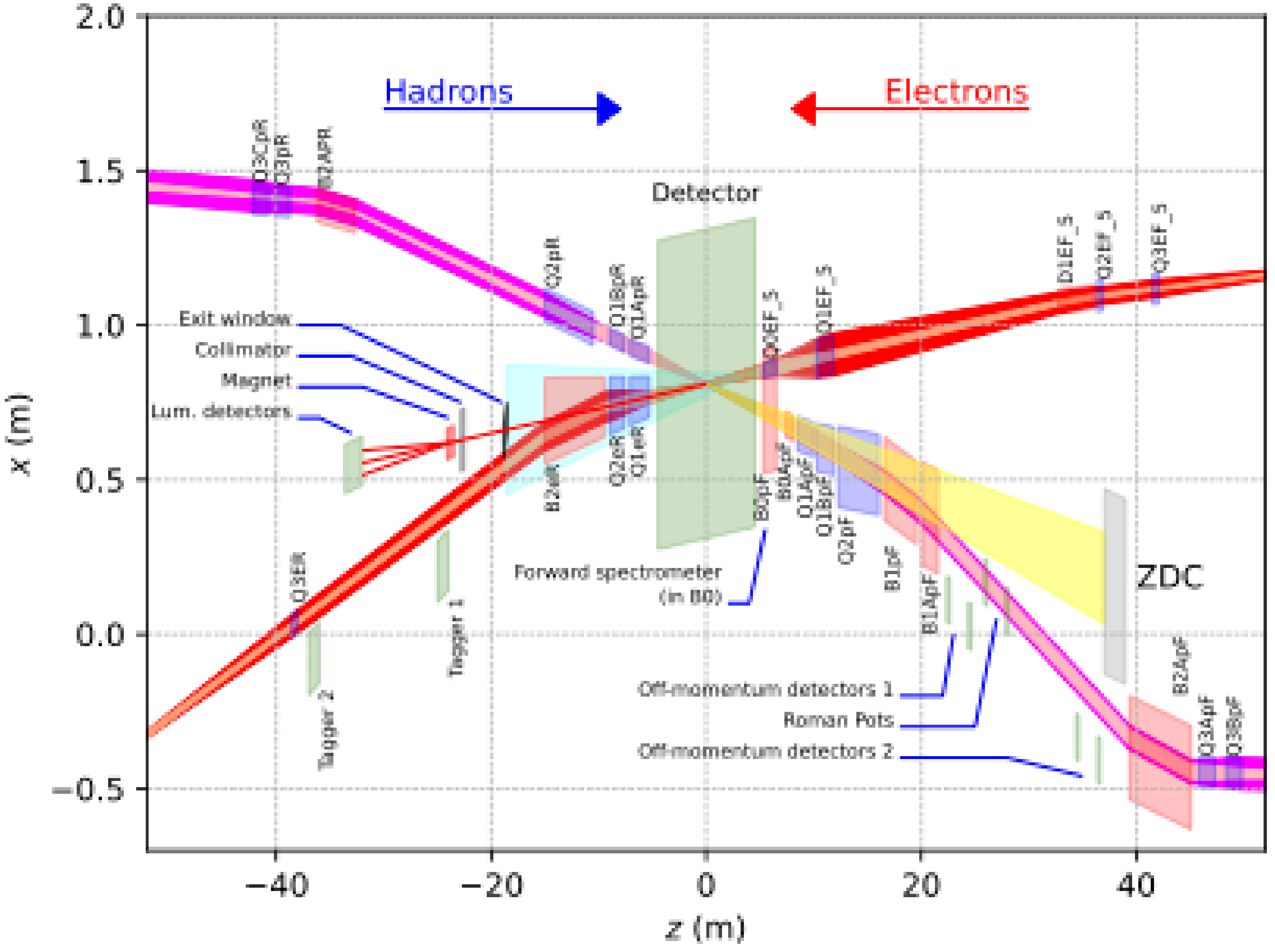
DIS Generation in Pythia8: Lower Q2?



- We again see large disagreement between Q2 calculated from the beam electrons and the reported generated t_hat
- We can fill the phase space, but do we trust the result?

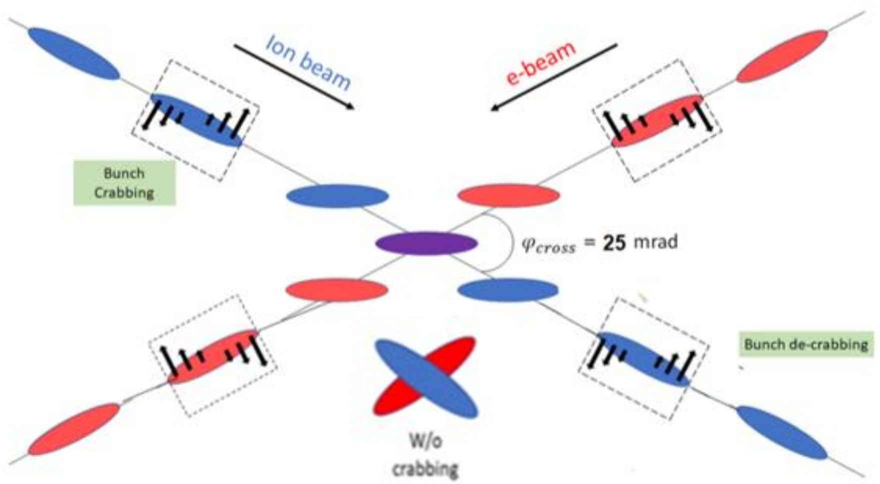


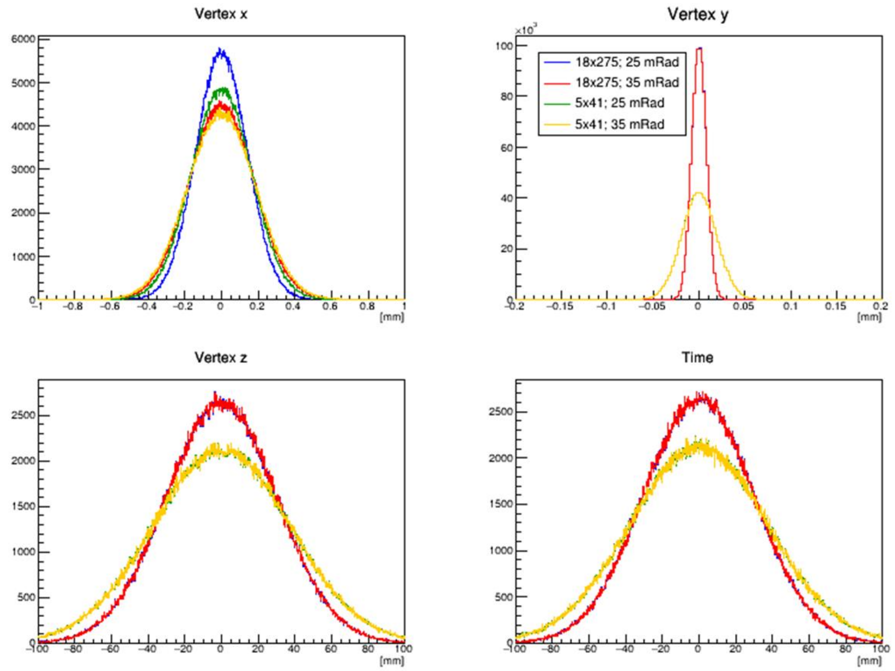
Simulating Beam Effects



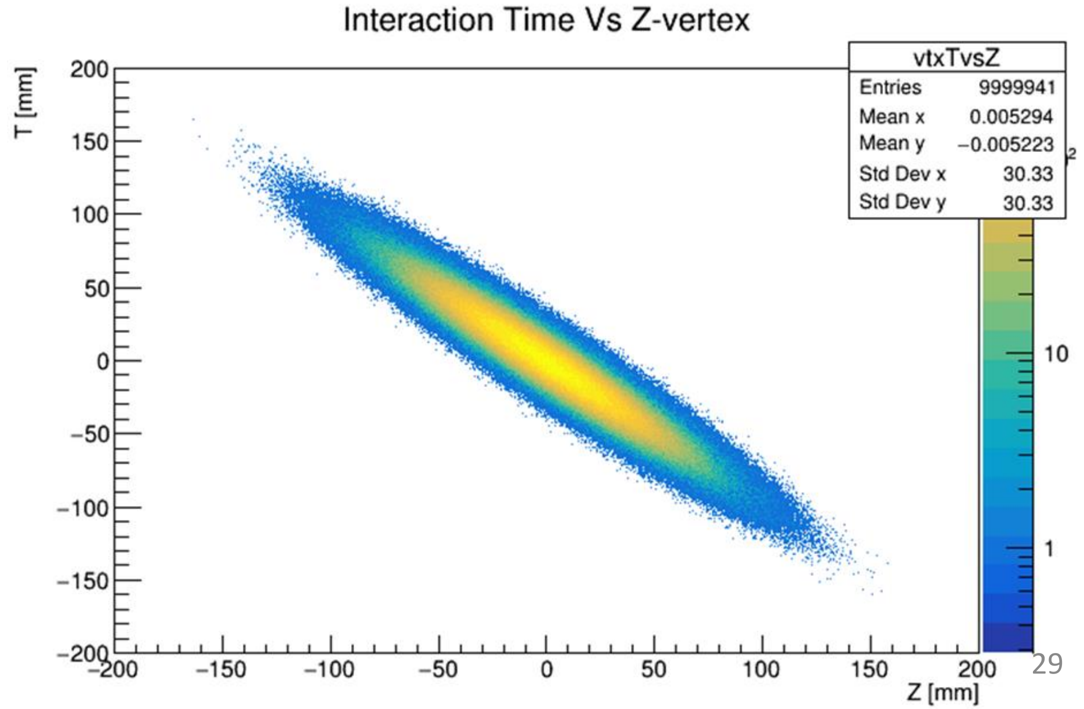
- ❑ Both interaction regions at the EIC will feature significant beam crossing angles (25 mRad for IP6 and 35 mRad for IP8)
- ❑ Presence of crossing angle will affect acceptance and detector design in the proton-going endcap
- ❑ Other beam properties like angular divergence and crab cavity kicks can have large impacts in far-forward region
- ❑ A summary of beam effects and methods for simulating these can be found in the technical note here: https://zenodo.org/record/6514605#.ZETiIOzMJAY
- ❑ Beam effects included either natively in Pythia8 using the BeamShape functionality or via a dedicated ‘afterburner’

Beam Crossing, Crabbing, and Vertex Structure

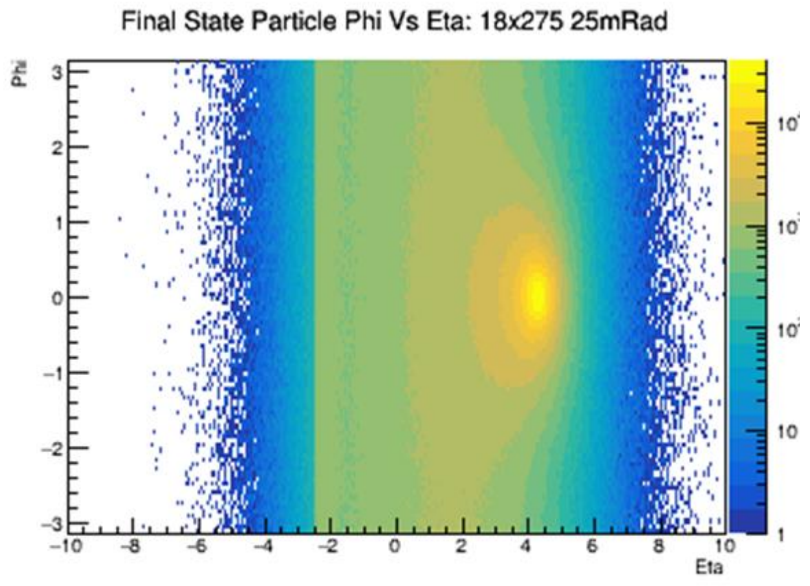


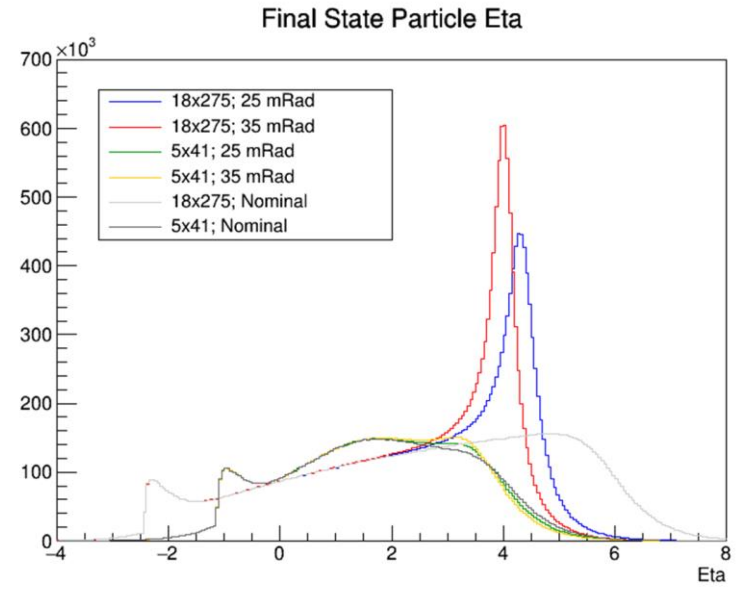


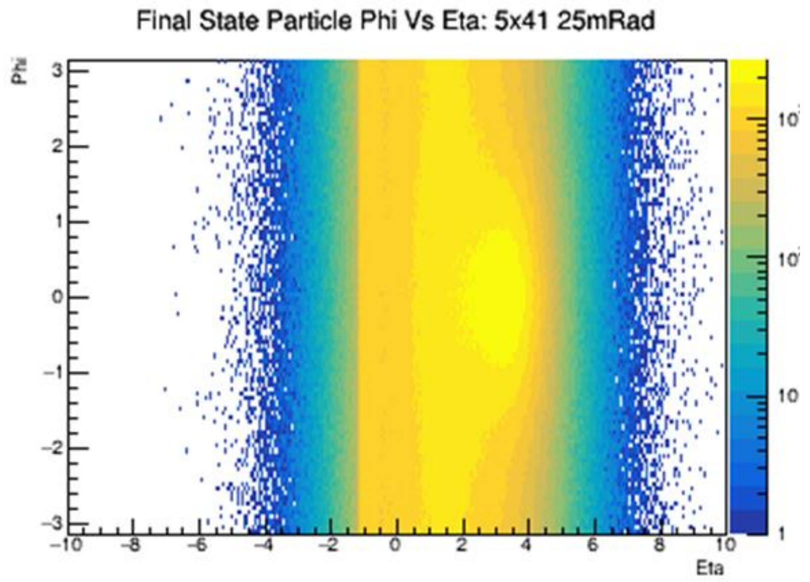
- ❑ Crossing angle between beams and crabbing have non-trivial impacts on vertex distributions
- ❑ Crabbing refers to the rotating of bunches to increase overlap and preserve luminosity with crossed beams
- ❑ Crossing and crabbing give rise to novel vertex structure – bunches traverse x direction (plane of crossing angle) as they interact
- ❑ Simultaneous determination of x and z vertex provide interaction time with resolution of ~20 ps

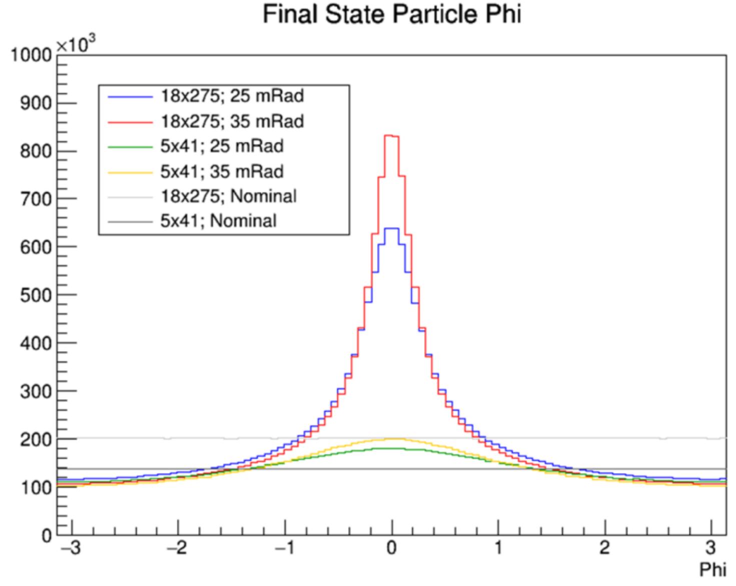


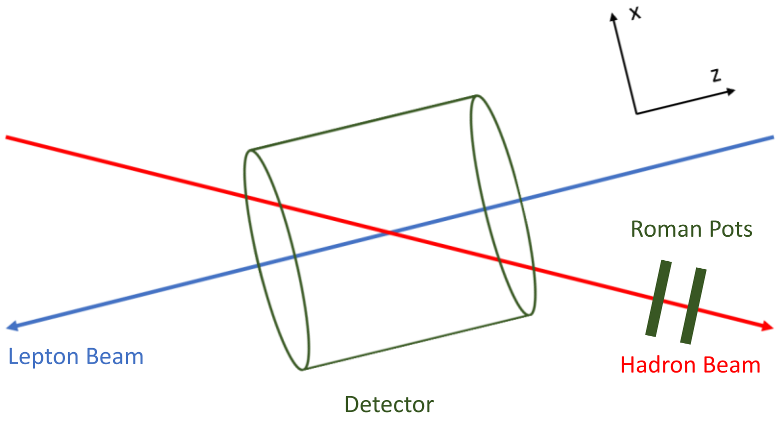
Final State Particle Distributions







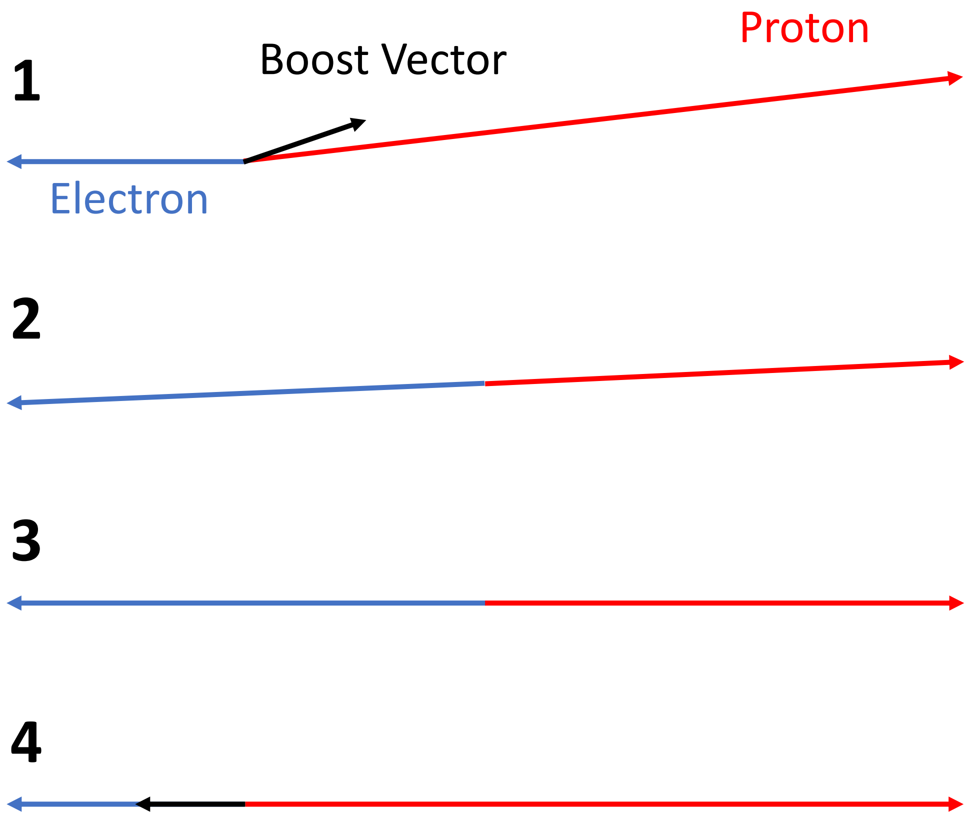




- Detector solenoid must align with electron beam to minimize synchrotron radiation: “lab frame” -> electron beam = z-axis
- When measuring in lab frame coordinates – see a hot spot in eta/phi corresponding to the beam direction
- More pronounced for more relativistic beams
- How do we mitigate these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

Head-On (Minimum Boost) Frame

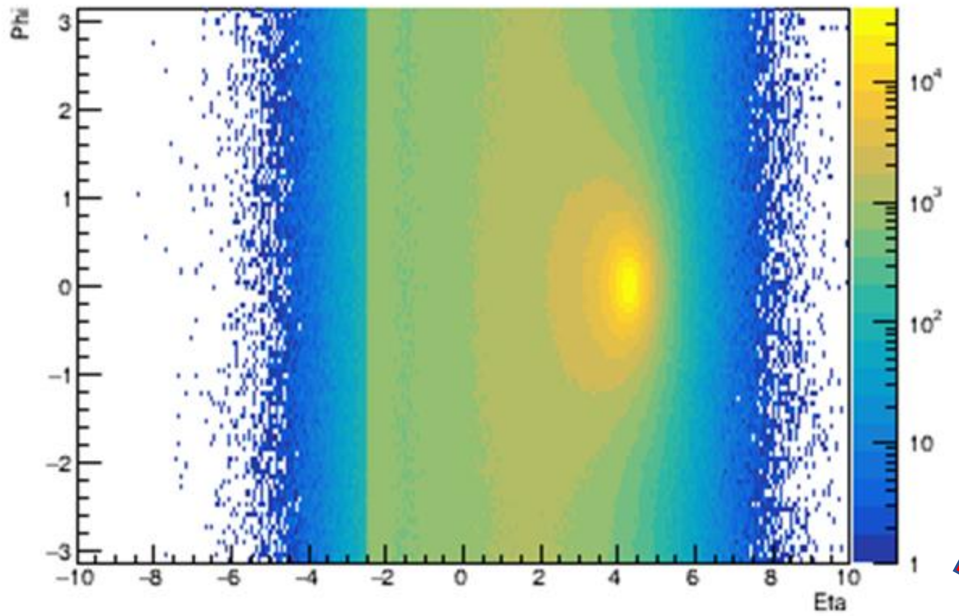
- Can boost and rotate into a frame in which the beams are collinear (no crossing angle) and energies are very close to the original (minimum boost)
- This should give an undistorted distribution of particles at high and low eta simultaneously



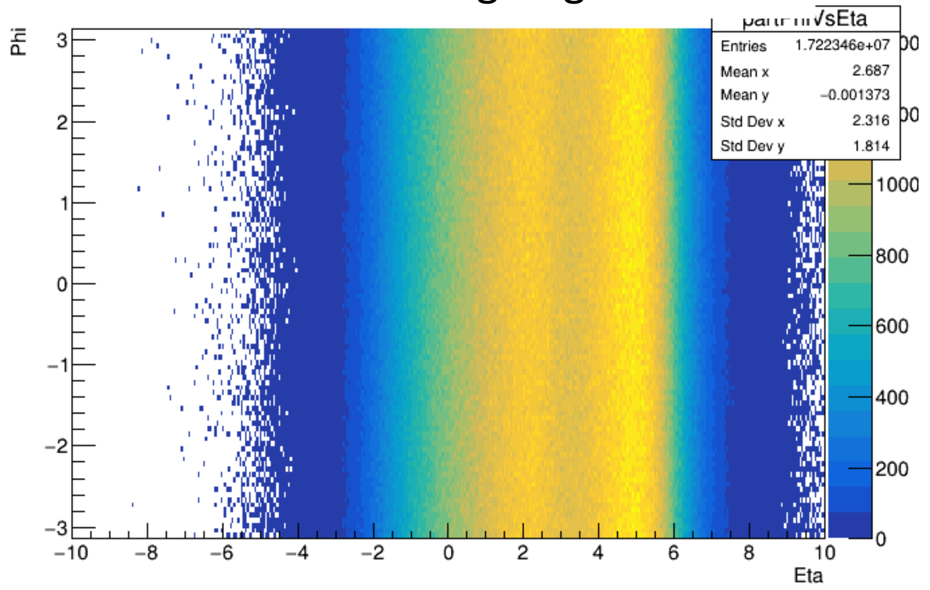
1. Initial Configuration in the Lab Frame includes a relative angle between the beams
2. Boost by sum of beam 4-momenta to get to CM Frame
3. Rotate about y-axis to eliminate x-component of momentum
4. Boost back along z to (nearly) restore original beam energies

Head-On Frame Particle Distributions

Lab Frame Distribution

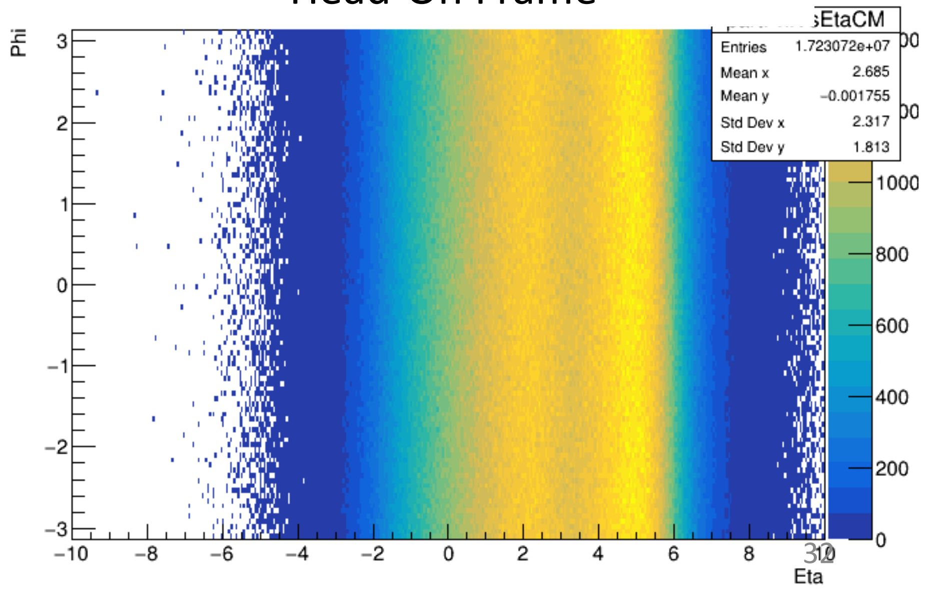


No Crossing Angle



Transform to Head-On

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

Summary

- The EIC will be an incredibly powerful tool for the exploration of strongly interacting matter and it will take close coordination between all stakeholders (experiment, theory, phenomenology, data science, etc) to ensure the EIC reaches its full potential

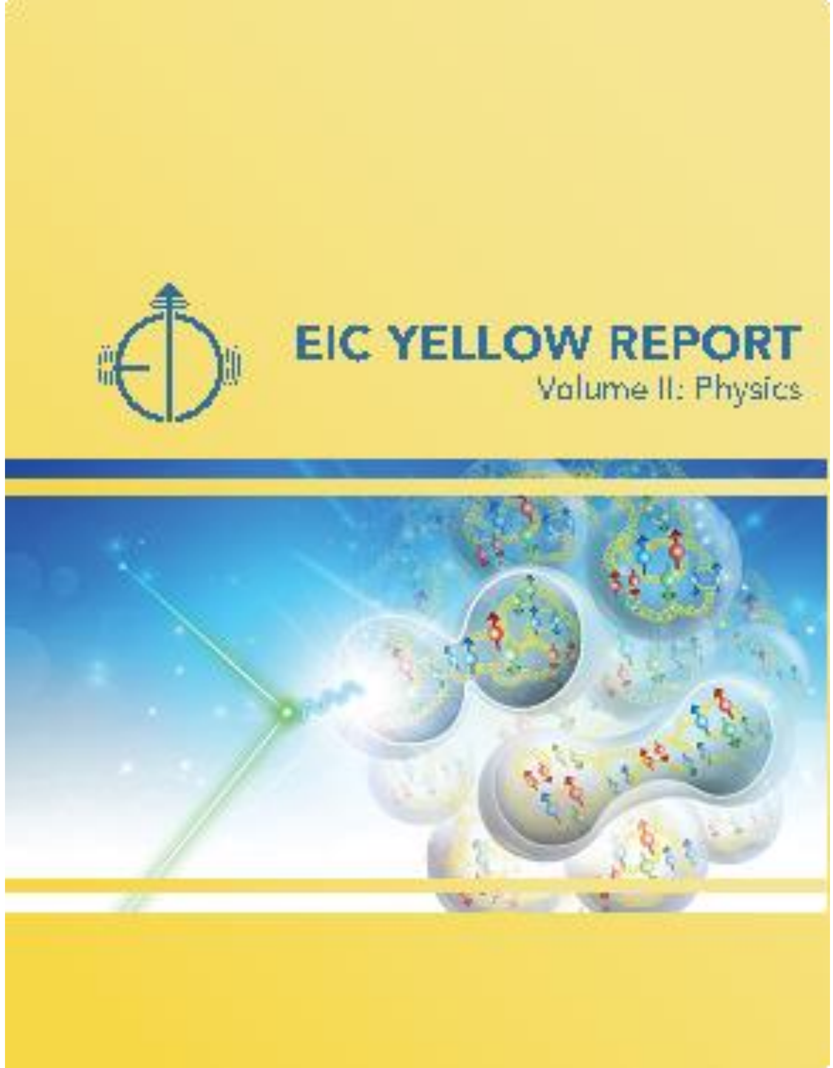
- Jet and HF measurements will provide critical input on many of the major topics the EIC is being designed to address

- The EIC science program will place strong demands on MCEGs, include things like a consistent treatment across Q2, inclusion of polarization and TMD effects, support for nuclear effects (medium effects, breakup, saturation, etc), and multiple hadronization models

- Simulation plays a large role even now, long before data will be taken to inform many aspects of detector and interaction region design

Backup

EICUG Yellow Report Effort (Physics)



Explore measurements needed for new and existing physics topics and quantify implications for detector requirements (Physics Group)

Study detector concepts based on requirements defined by the Physics Group and quantify impacts on physics measurements (Detector Group)

Physics Working Group:

Inclusive Reactions

Semi-Inclusive Reactions

Jets, Heavy Quarks

Exclusive Reactions

Diffractive Reactions & Tagging

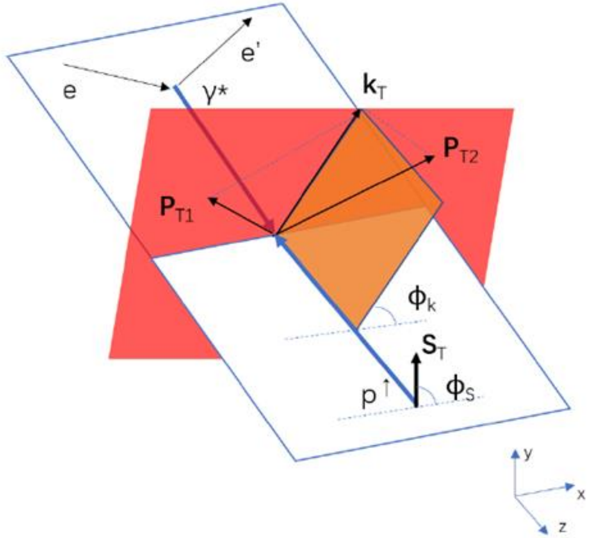
Detector Working Group:

Tracking + Vertexing
Particle ID
Calorimetry
DAQ/Electronics
Polarimetry/Ancillary Detectors
Central Detector: Integration & Magnet
Far- Forward Detector & IR Integration

The EIC Users Group: EICUG.ORG
Report: https://arxiv.org/abs/2103.05419

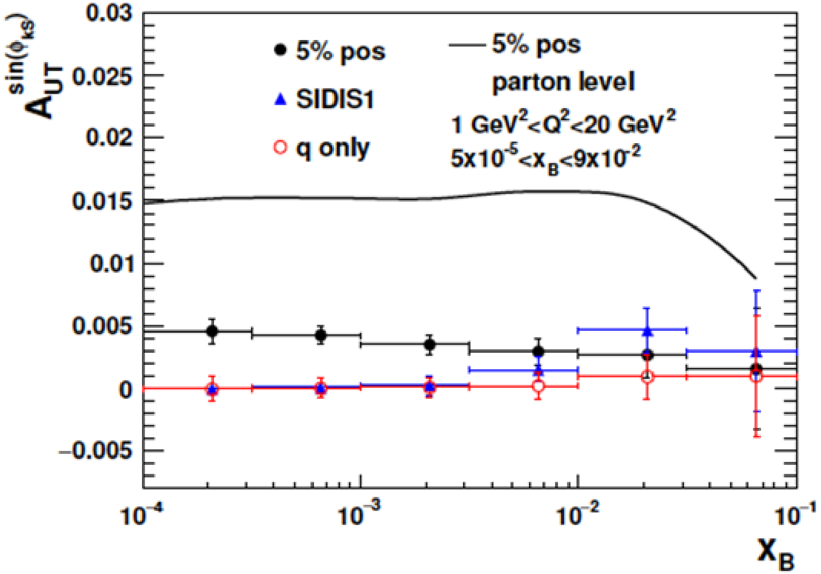
Gluon Sivers Function

Phys. Rev. D 98, 034011 (2018)

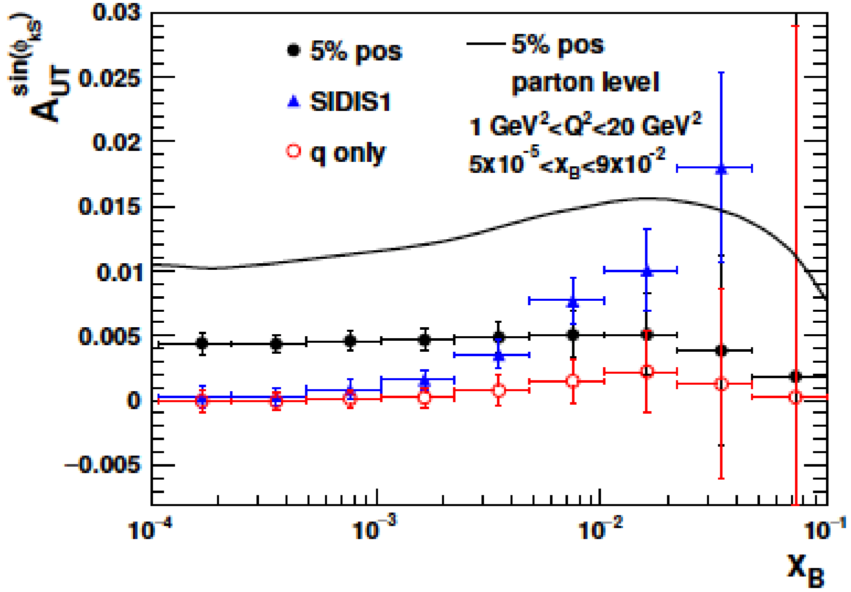


- ❑ Modulations of the angle between the proton spin vector and the sum of the di-parton system provide access to gluon sivers function
- ❑ Use of dijets has several advantages over di-hadrons including lower dilution of asymmetry and better separation between models of gluon sivers effect
- ❑ Jets don't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

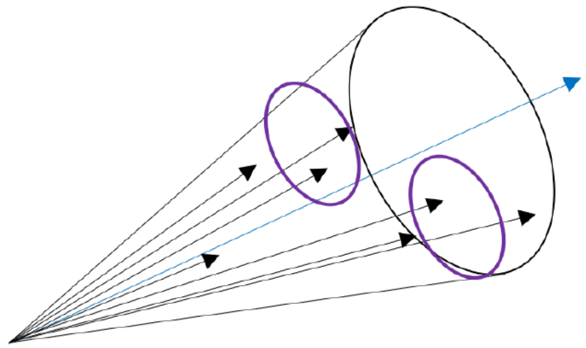
Di-Hadrons



Dijets



Soft Drop (Heavy) Jet Substructure



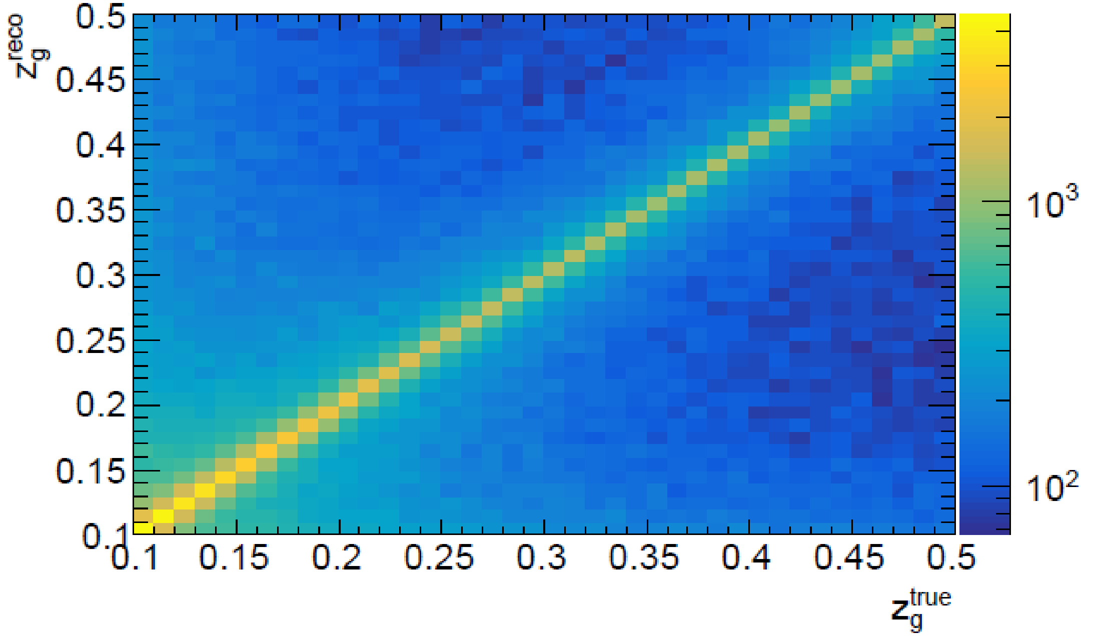
$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

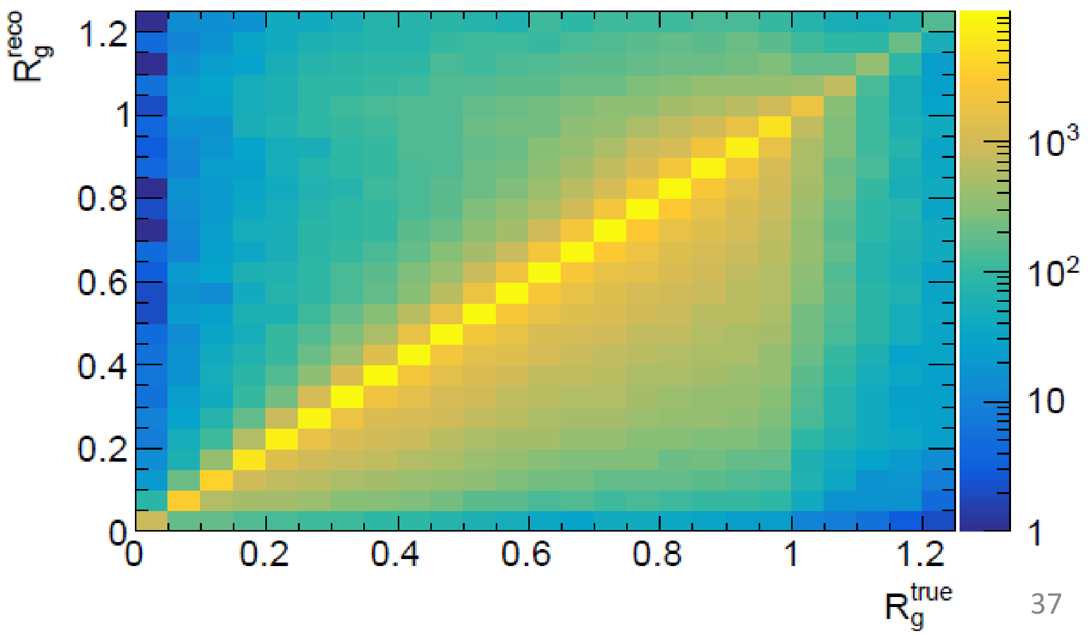
$$R_g = \Delta R(p_{T,1}, p_{T,2})$$

- Techniques such as soft drop declustering / grooming will allow us to trace the ‘history’ of parton fragmentation

- Comparing ep and eA will tease out differences in fragmentation and hadronization in vacuum vs the nuclear medium – groomed heavy quark jets for mass dependence

- Given low number of particles in jets at the EIC, no guarantee grooming will work – initial studies are promising





Angularity

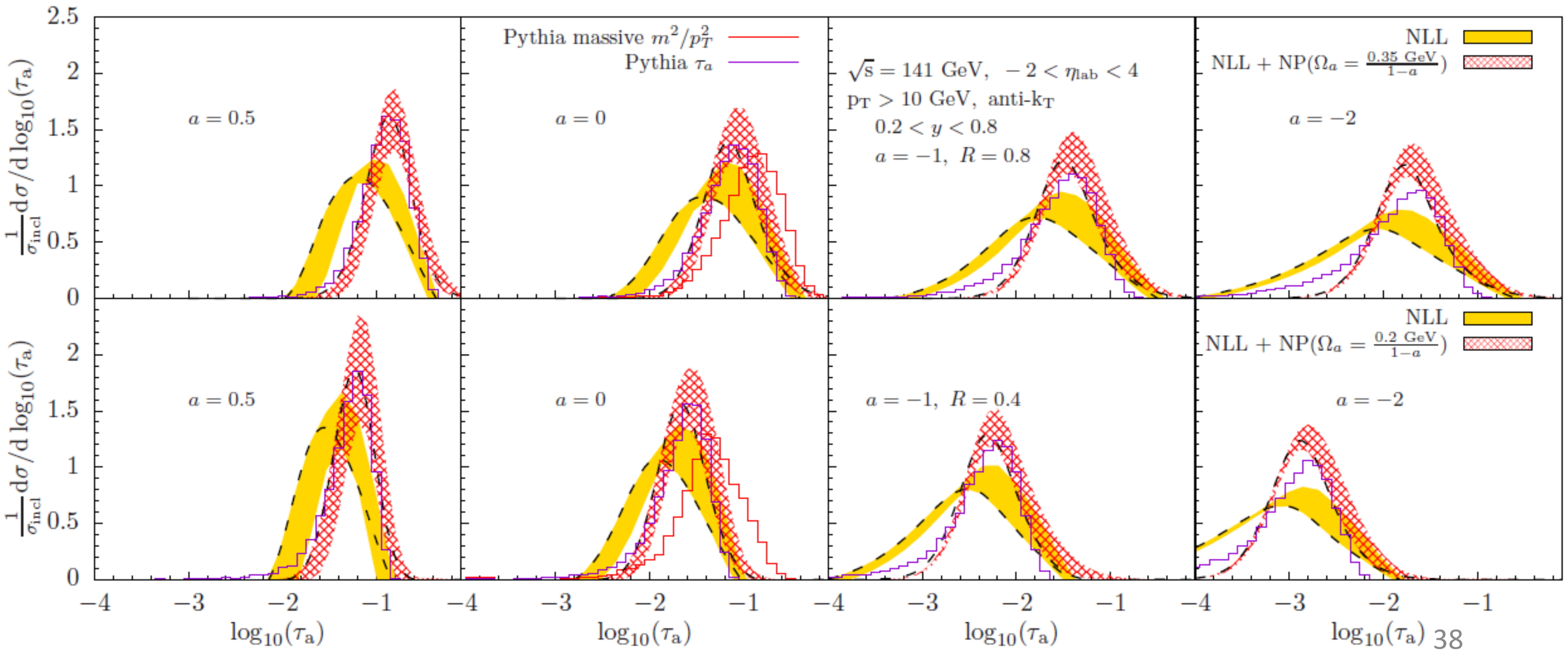
$$\tau_a \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta R_{iJ}\right)^{2-a}$$

- 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
- Comparison with alternative definition allows quantification of significance of sub-leading power corrections

- Angularity is sensitive to hadronization effects via a convolution with the non-perturbative shape function Ω1
- Values are seen to be much less than at LHC
- Look at changes between ep and eA

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

Aschenauer, Lee, Page, Ringer `20



New (and Not-so-New) Tools

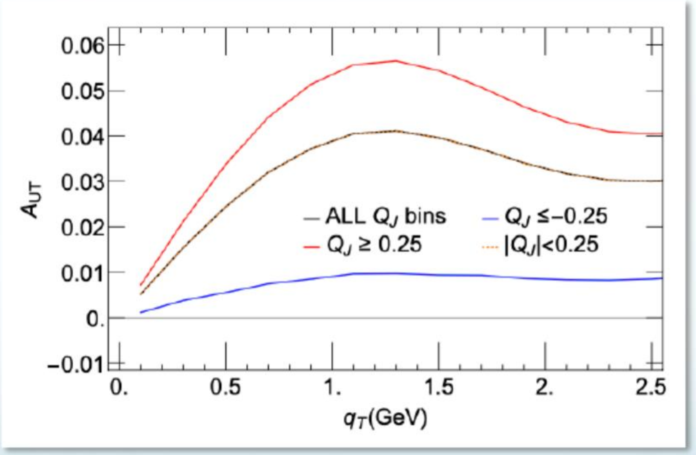
- Renewed interest in jet charge as a method for disentangling light quark flavors in a number of settings

- New longitudinally invariant asymmetric clustering algorithm for jet finding in the Breit frame

Kang, Liu, Mantry, Shao `20

$$Q_\kappa = \sum_h Q_\kappa^h \equiv \sum_{h\in\text{jet}} z_h^\kappa Q_h$$

$$A_{UT}(Q^N_{\kappa,\text{bin}}) = \frac{d\sigma(S^\uparrow) - d\sigma(S^\downarrow)}{d\sigma(S^\uparrow) + d\sigma(S^\downarrow)} = \frac{d\sigma_{UT}(Q^N_{\kappa,\text{bin}})}{d\sigma_{UU}(Q^N_{\kappa,\text{bin}})}$$



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

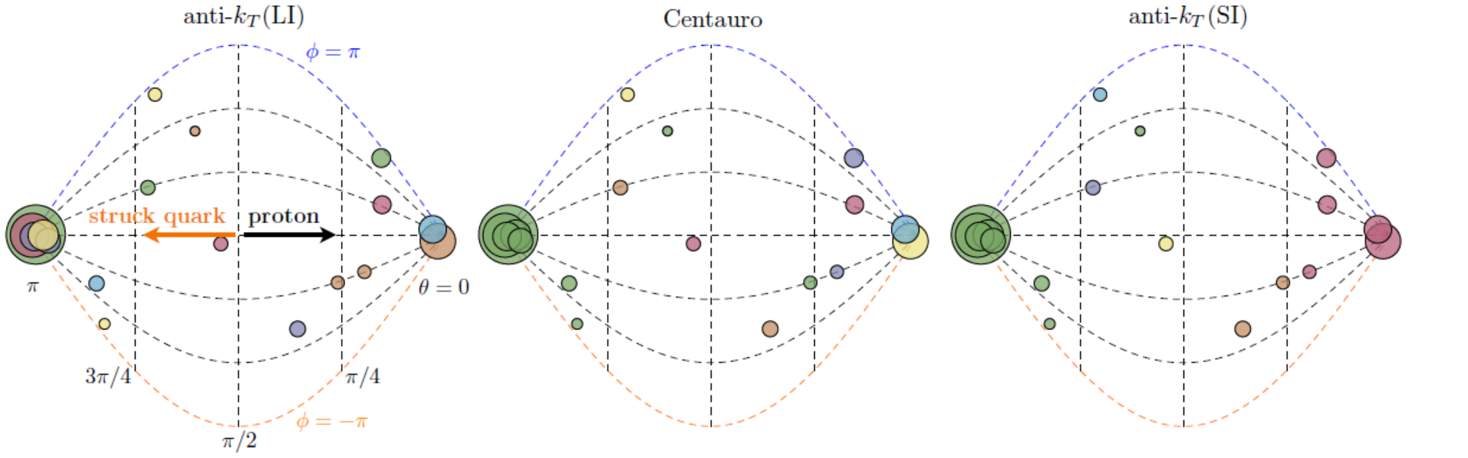
Asymmetric measure is necessary

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

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

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

Arratia, Makris, Neill, Ringer, Sato `20



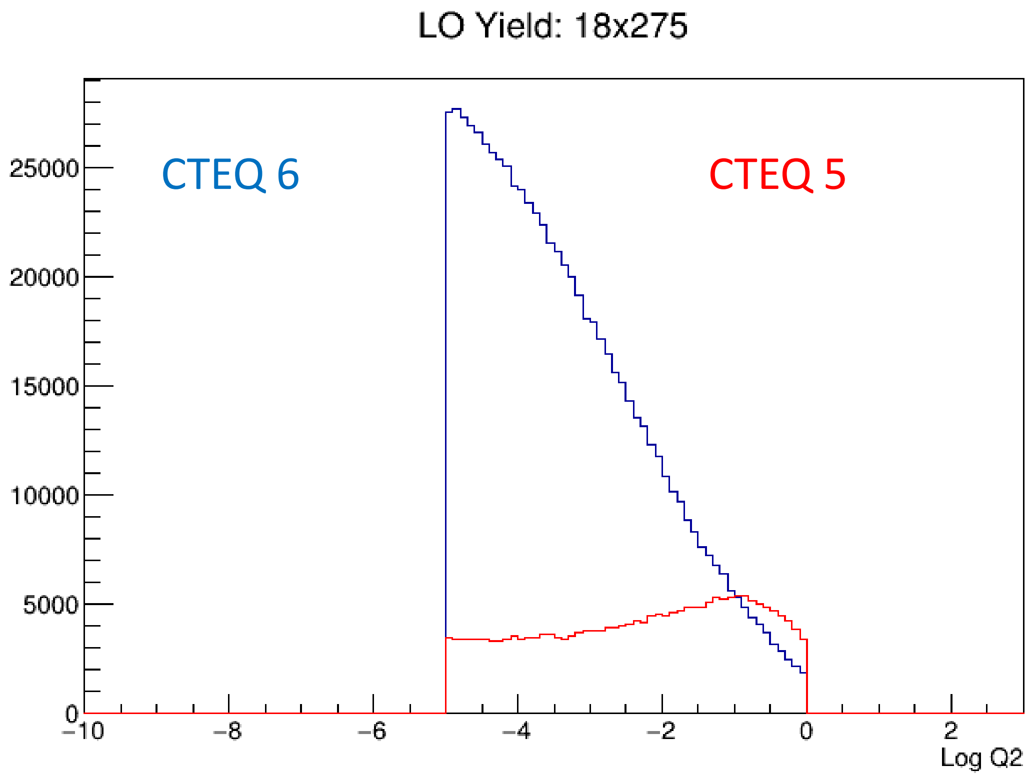
Longitudinally invariant Symmetric

Longitudinally invariant Asymmetric

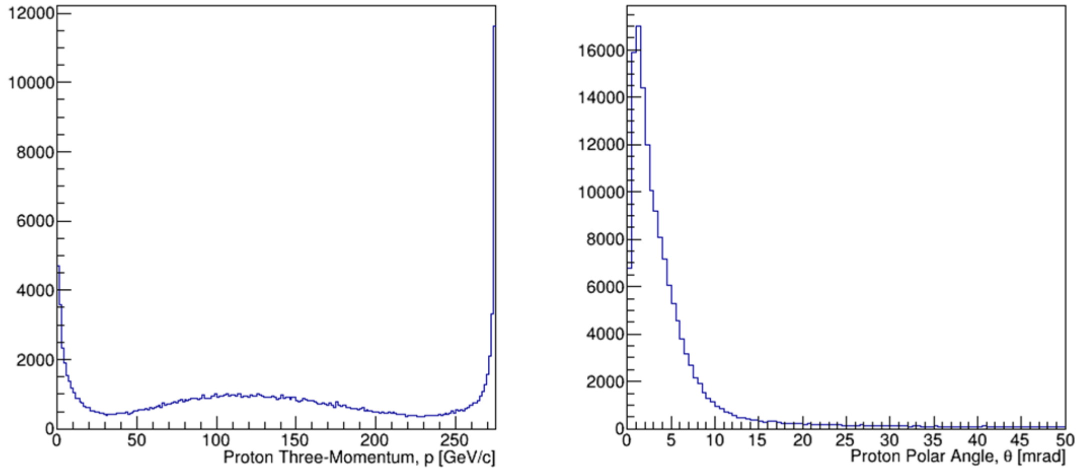
Spherically invariant Symmetric

Low Q2 Cross Section and PDFs

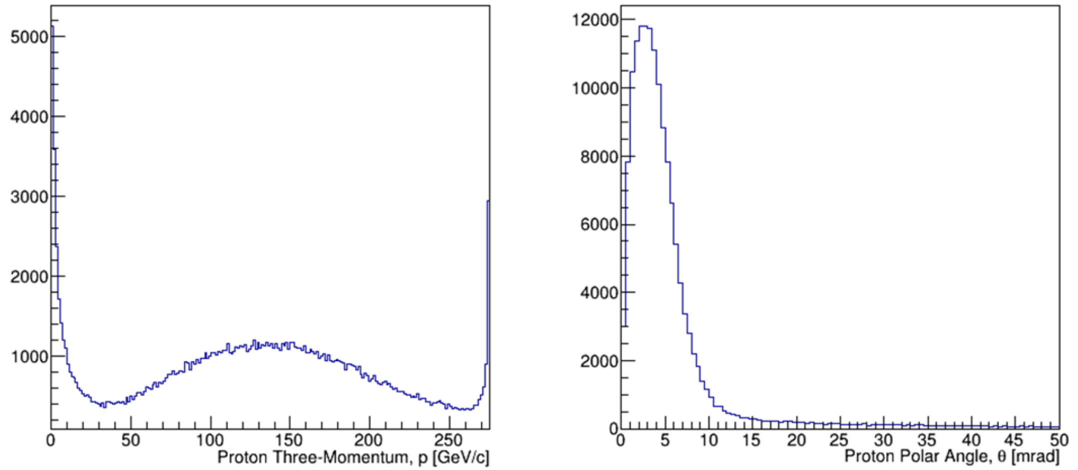
- While Pythia6 seems to populate the low-Q2 phase space as one would expect care needs to be taken in PDF set choice
- It was observed that the low-Q2 cross section returned with CTEQ6 PDF sets were abnormally high – factor of 3 greater than found with CTEQ5
- Issue traced to the way newer PDF sets truncate low-x extrapolations



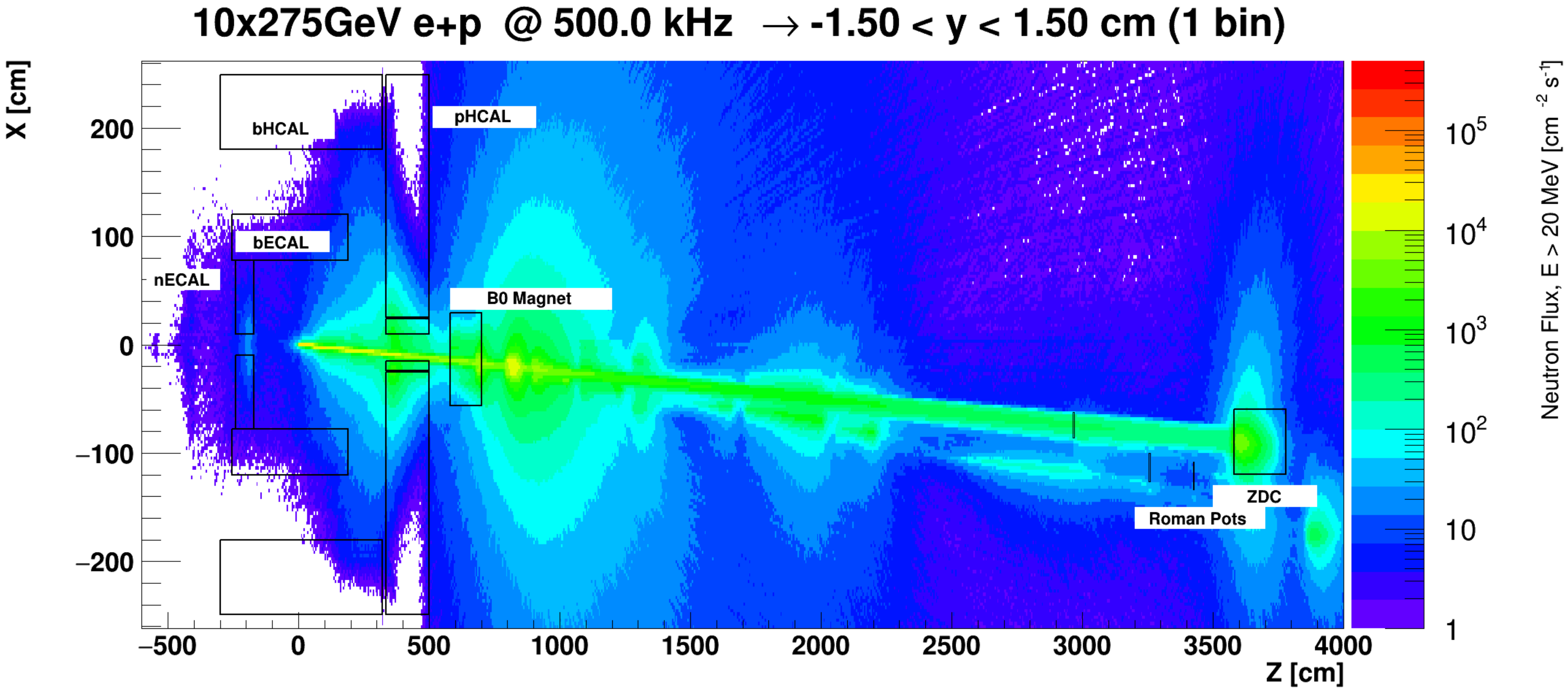
CTEQ 5



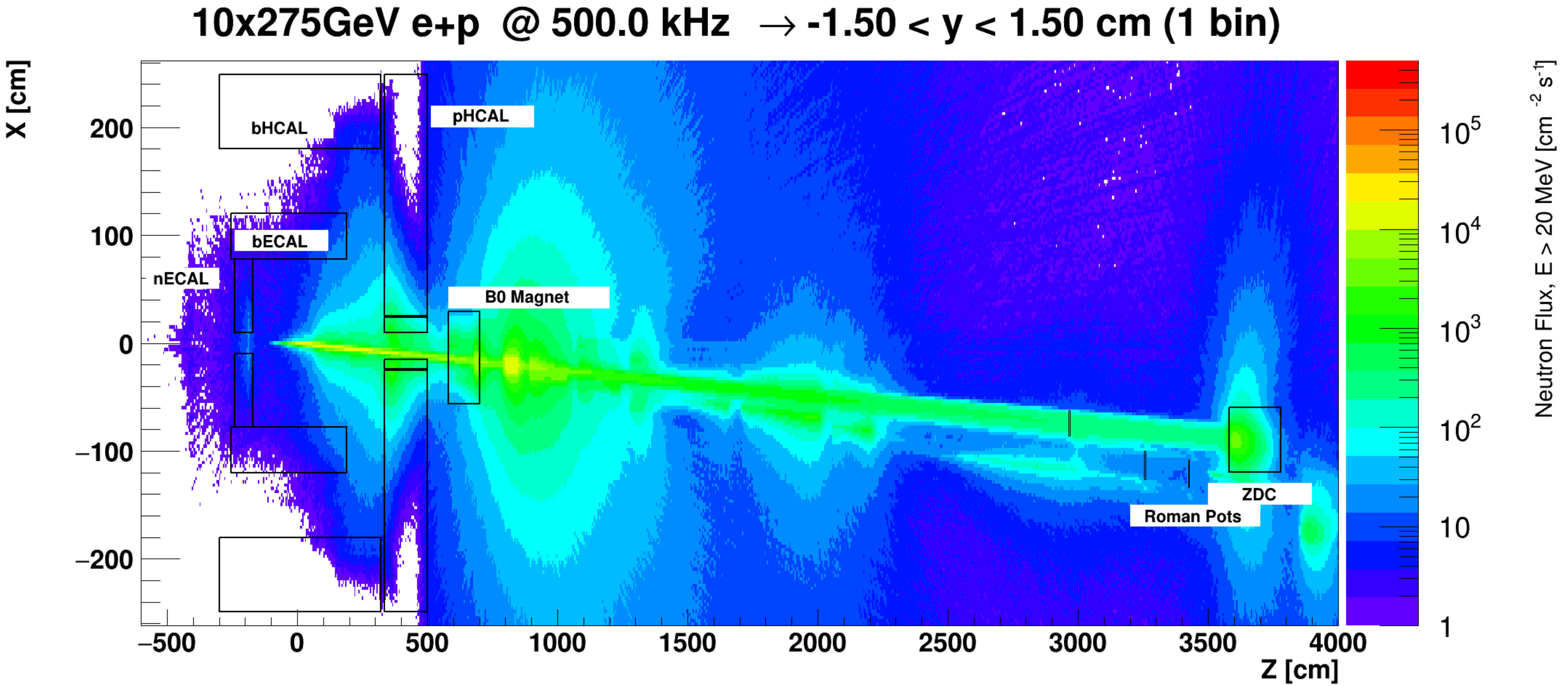
CTEQ 6



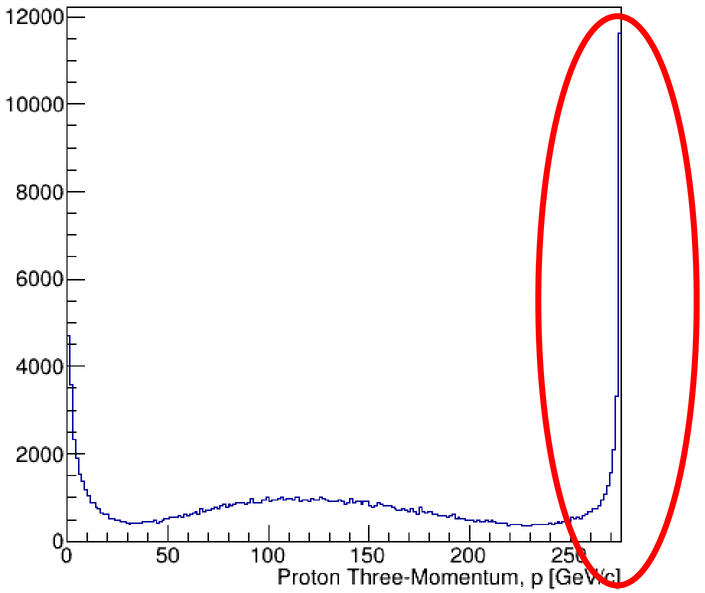
E > 20 MeV Neutron Flux – CTEQ5 (nominal)

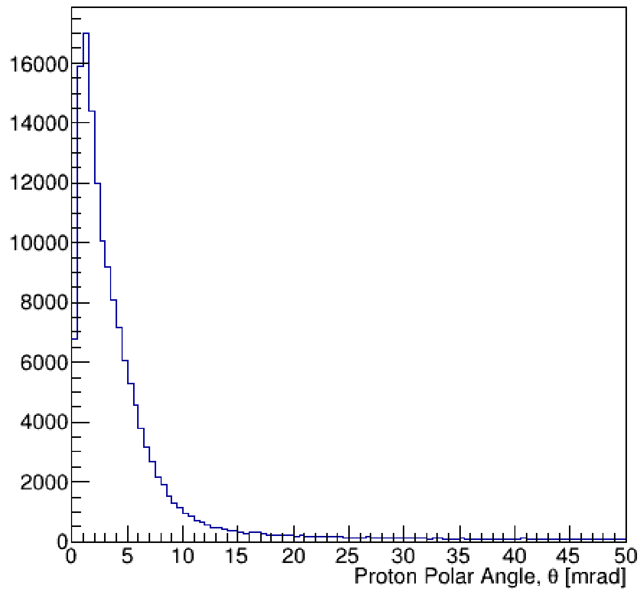


E > 20 MeV Neutron Flux – CTEQ6



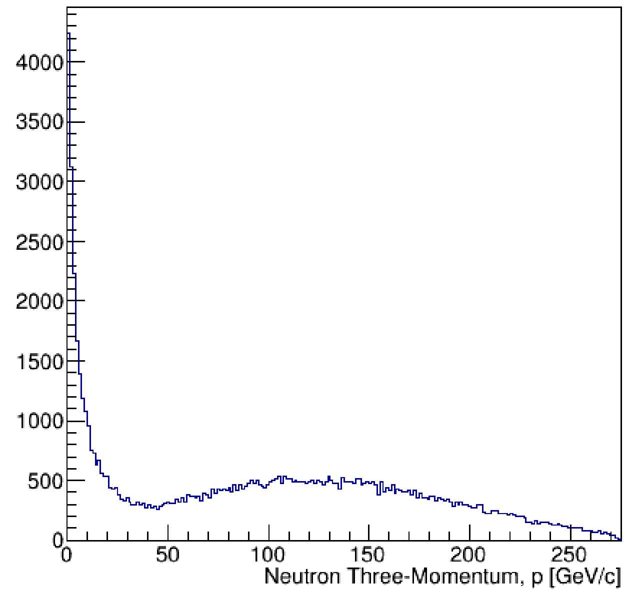
Proton/neutron distributions – CTEQ5 (nominal)

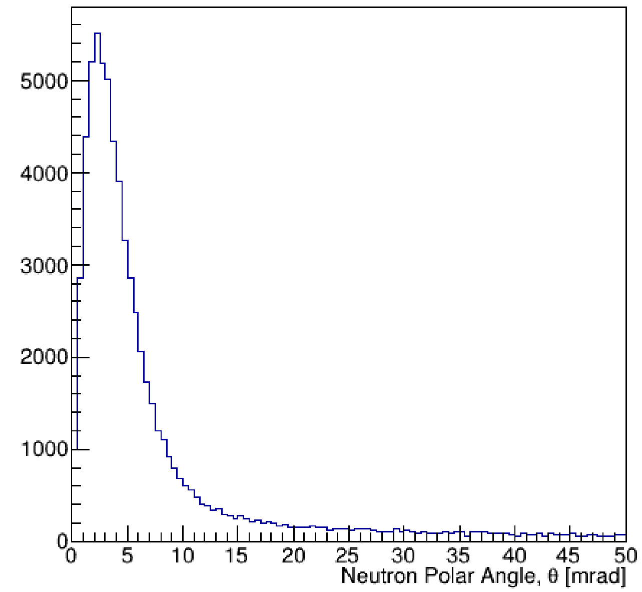




Protons

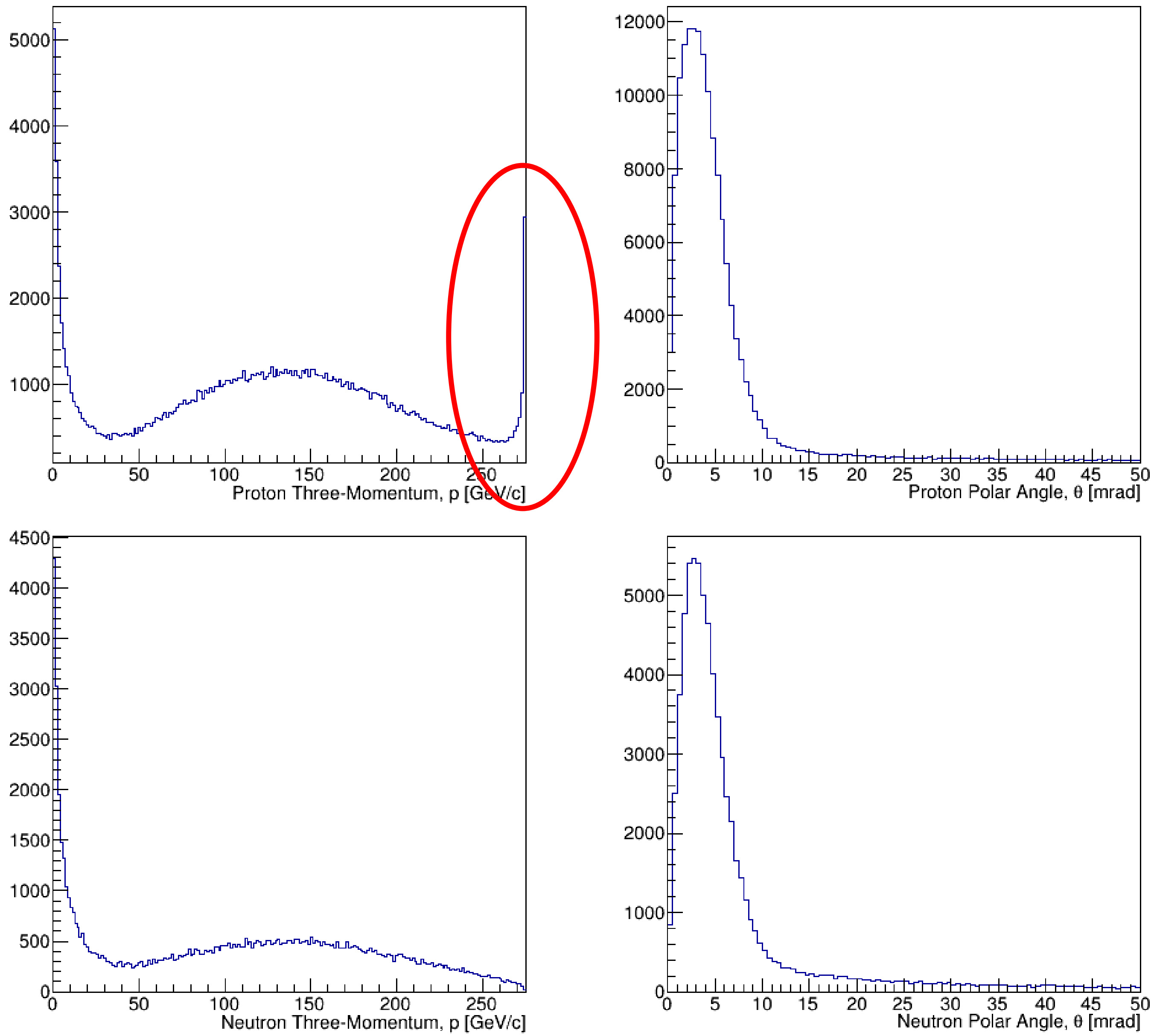
Diffractive proton events – protons have ~ beam momentum, go very far-forward through magnets and can interact with Roman pots and magnets/beam pipe to create hadronic showers.





Neutrons

Proton/neutron distributions – CTEQ6



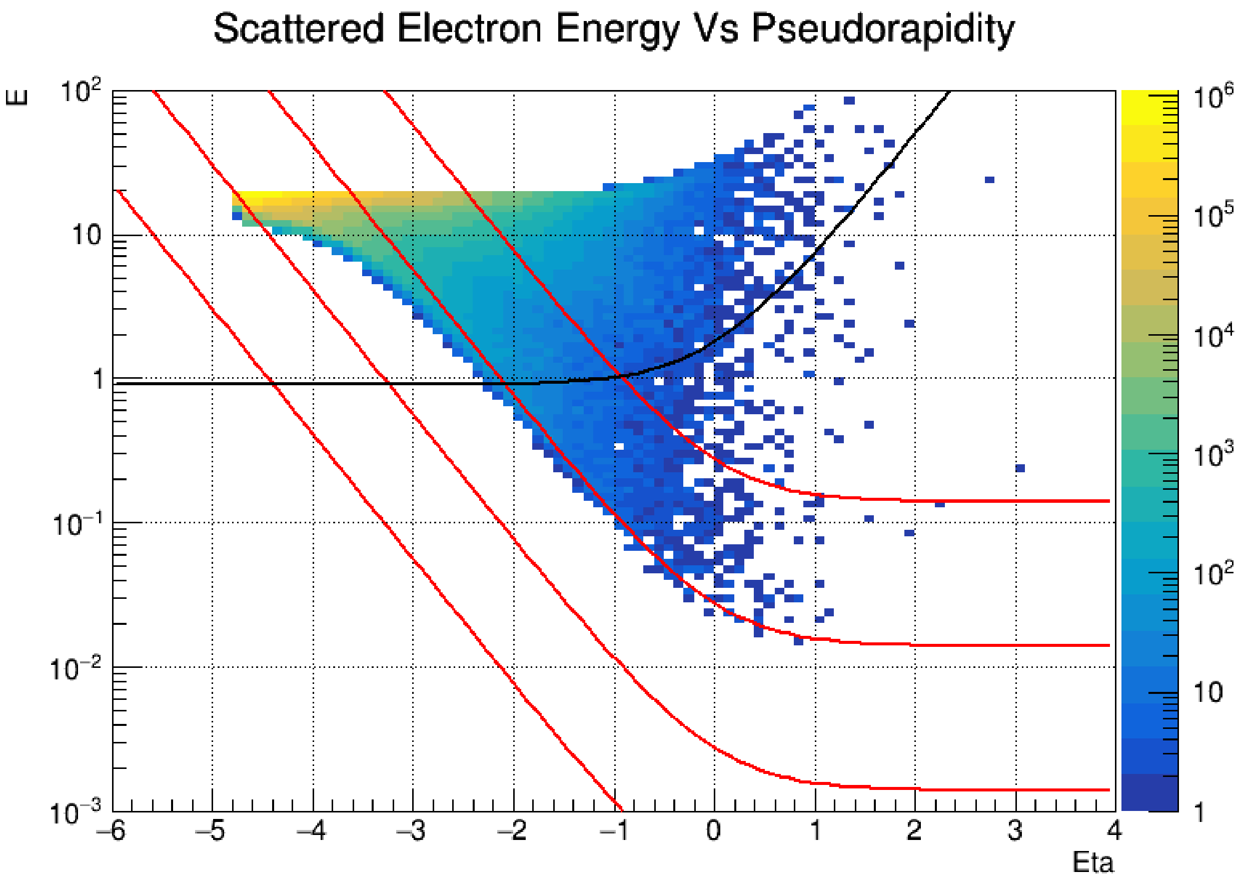
Protons

Neutrons

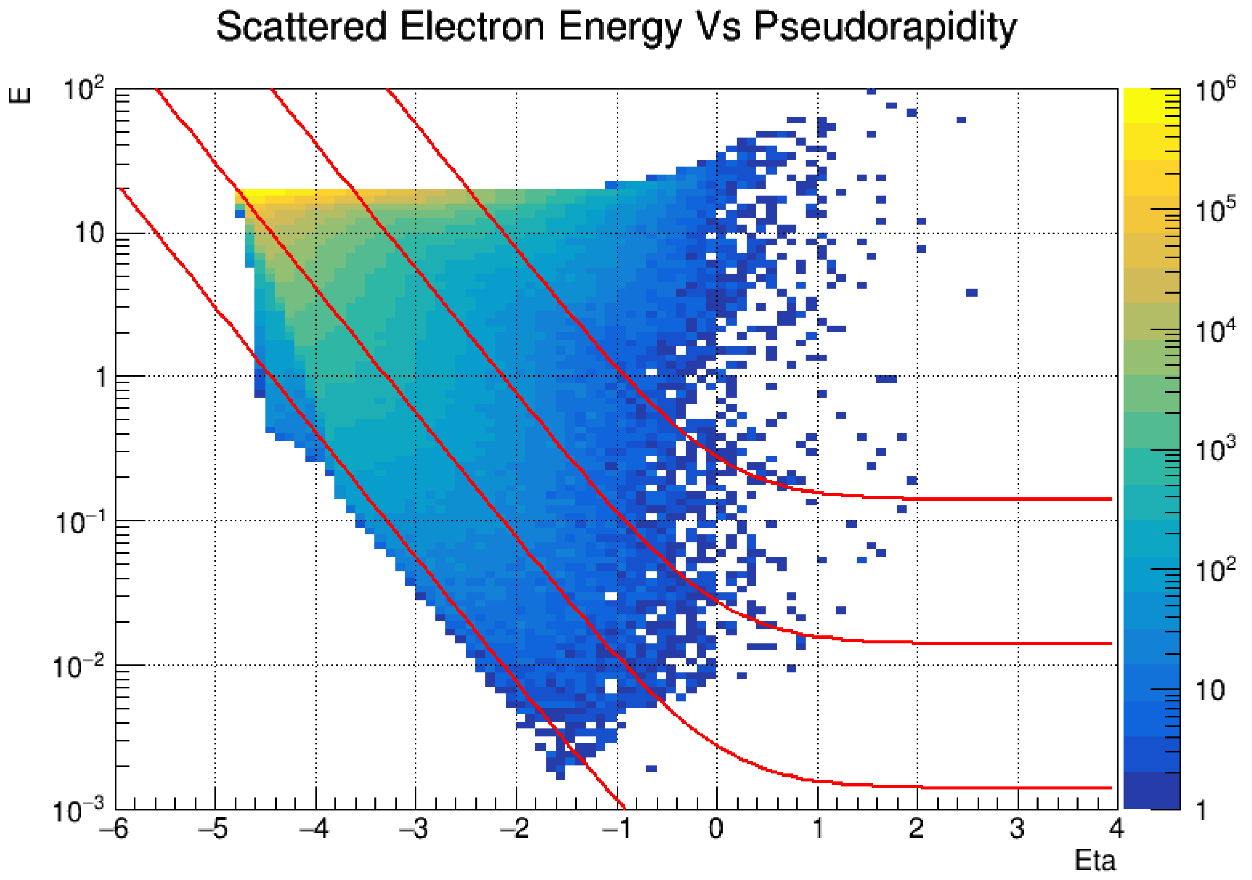
Diffractive proton events – protons have ~ beam momentum, go very far-forward through magnets and can interact with Roman pots and magnets/beam pipe to create hadronic showers.

With CTEQ6, less beam-energy protons, broader angular distribution!

DIS Generation in Pythia8: Lower Q2?

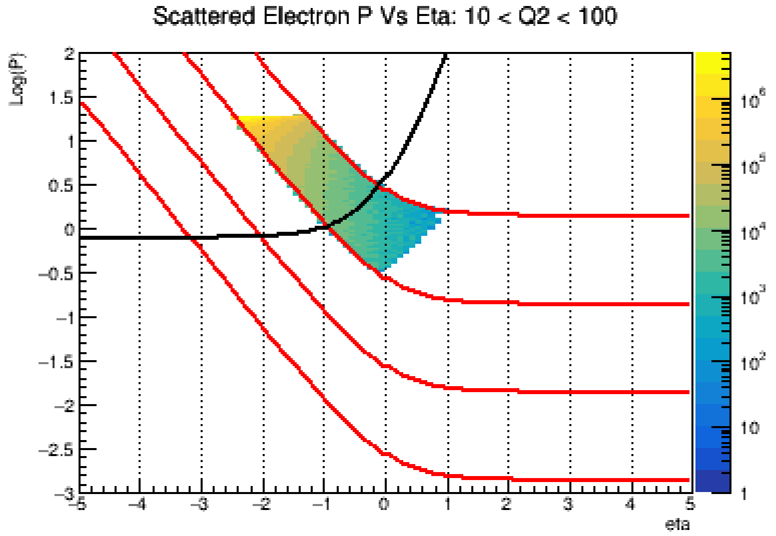


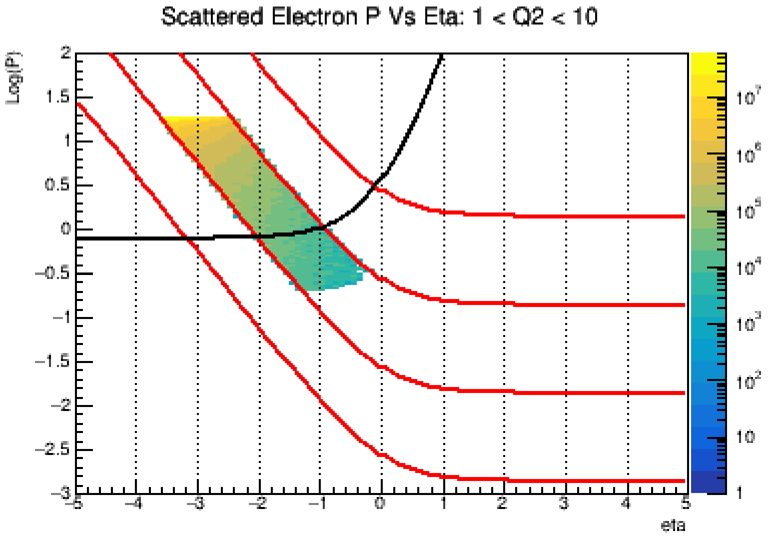
- ❑ What happens when we push Q2Min below unity, say to 0.1?
- ❑ Previous settings again do not fully cover the available phasespace with low Q2 – low x region missing

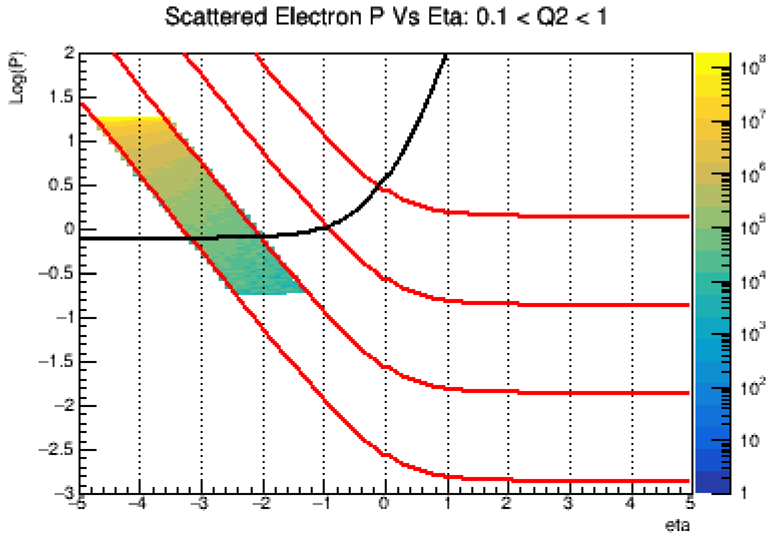


- ❑ Try lowering mHatMin from 1 down to 0
- ❑ Phasespace is now covered, but see a large 'tail' of events with reconstructed Q2 less than the specified limit of 0.1

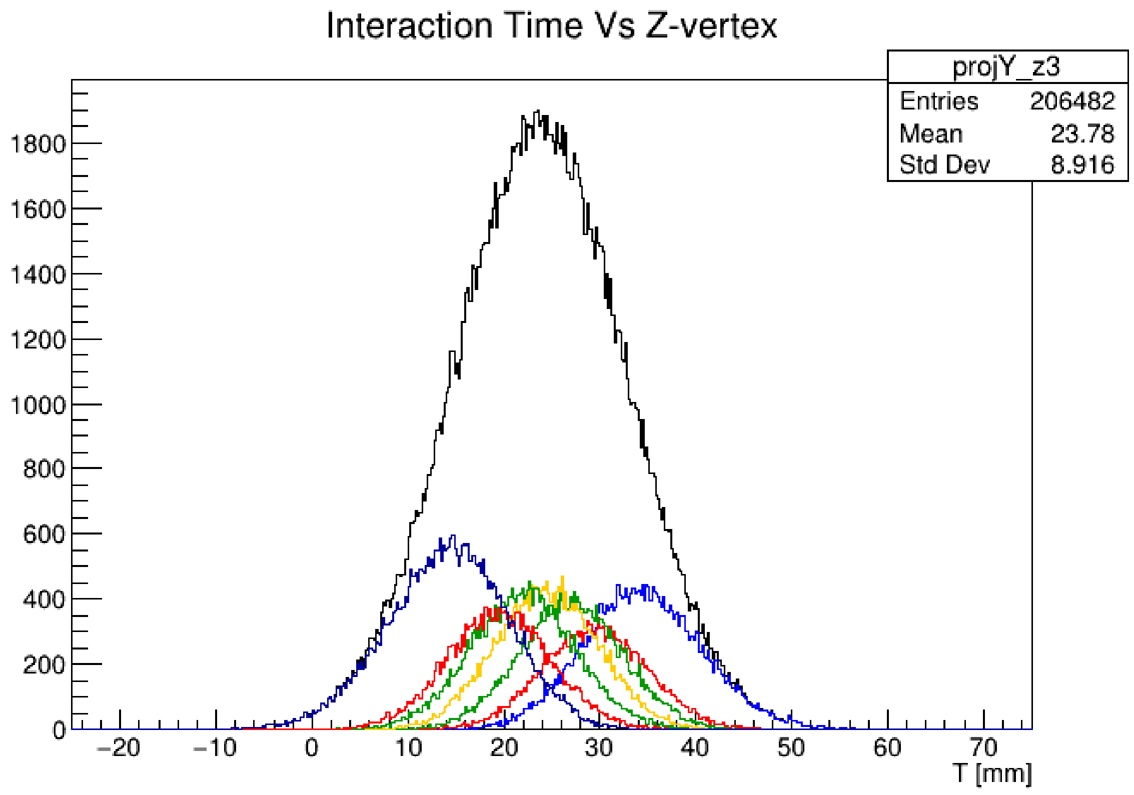
DIS Generation in Pythia6







Adding X-Vertex Information: 18x275



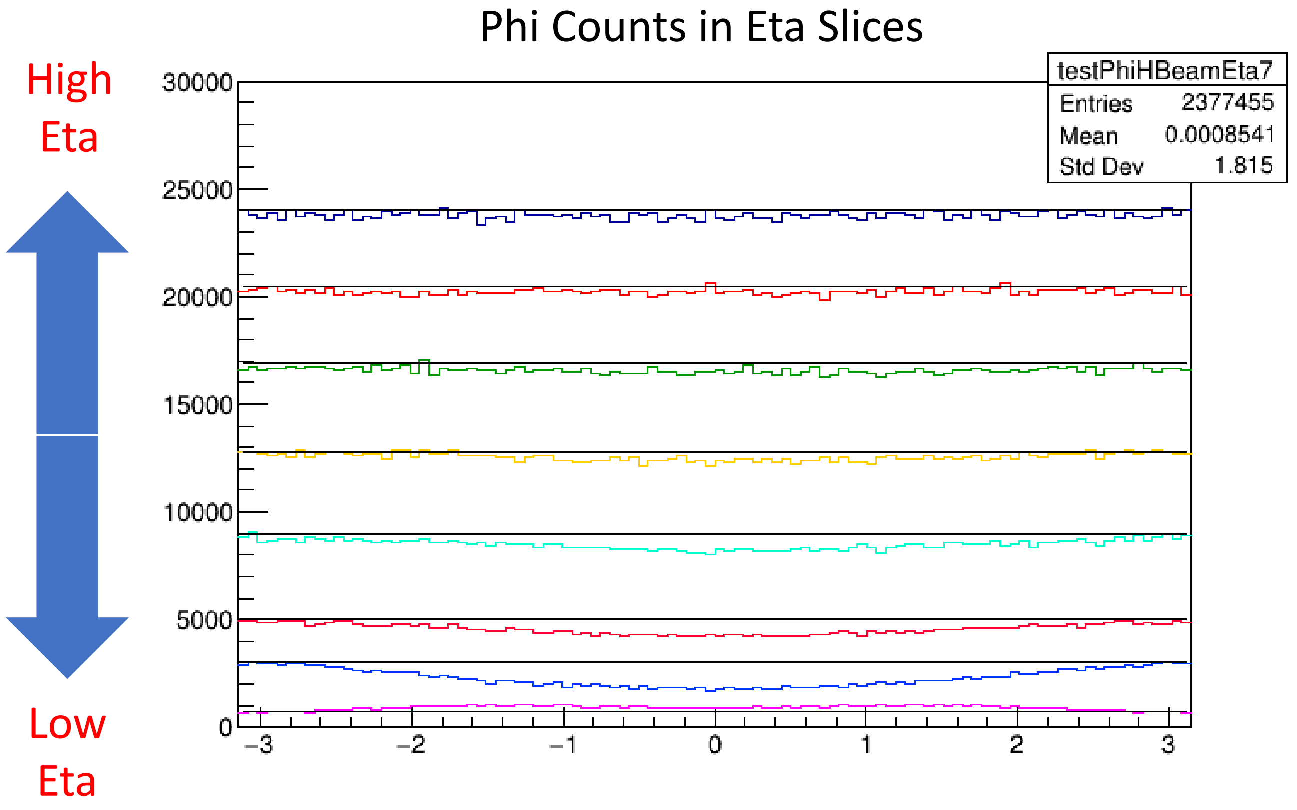
X Bin	Mean [mm]	Sigma [mm]
0	34.6	6.14
1	29.5	5.4
2	27.0	5.36
3	24.5	5.39
4	22.0	5.44
5	19.5	5.38
6	14.1	6.24

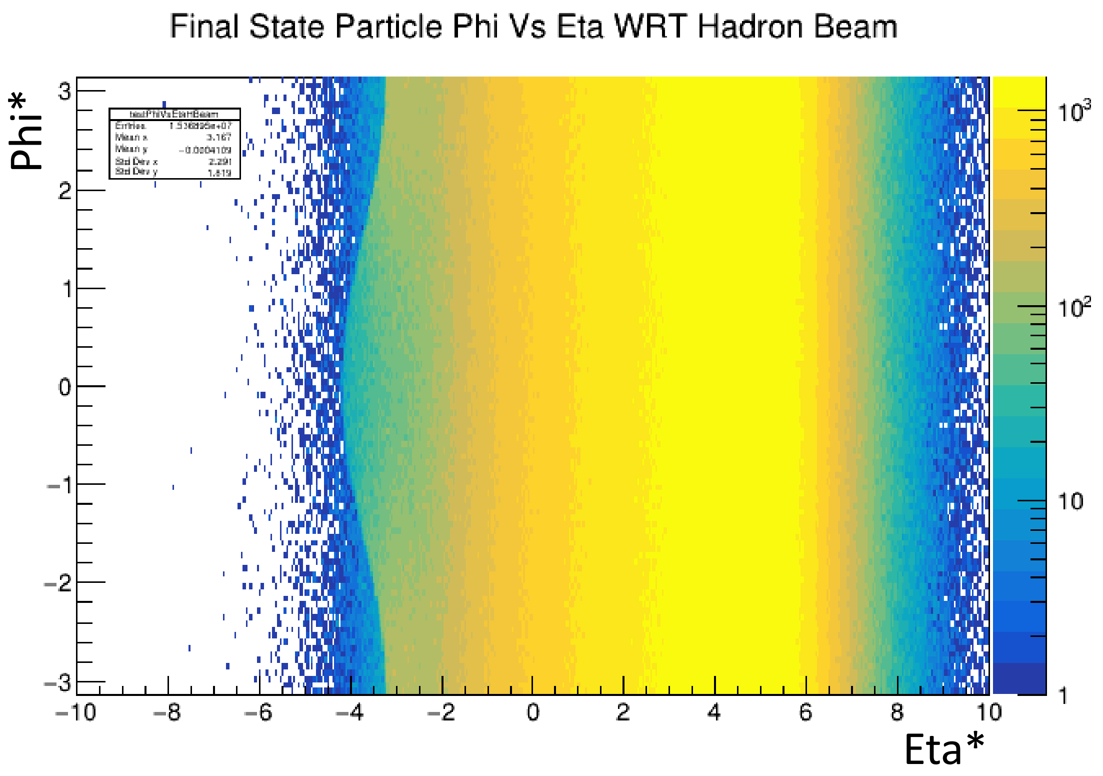
- Choose the Z-vertex bin at -25 mm and look at T0 distributions for various X-vertex bins
- X and Z binned T0 distributions have much better resolution than Z binned alone (~18 vs ~30 ps)

- Basically, X-Vertex position is telling where within the electron bunch the colliding particle comes

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*)

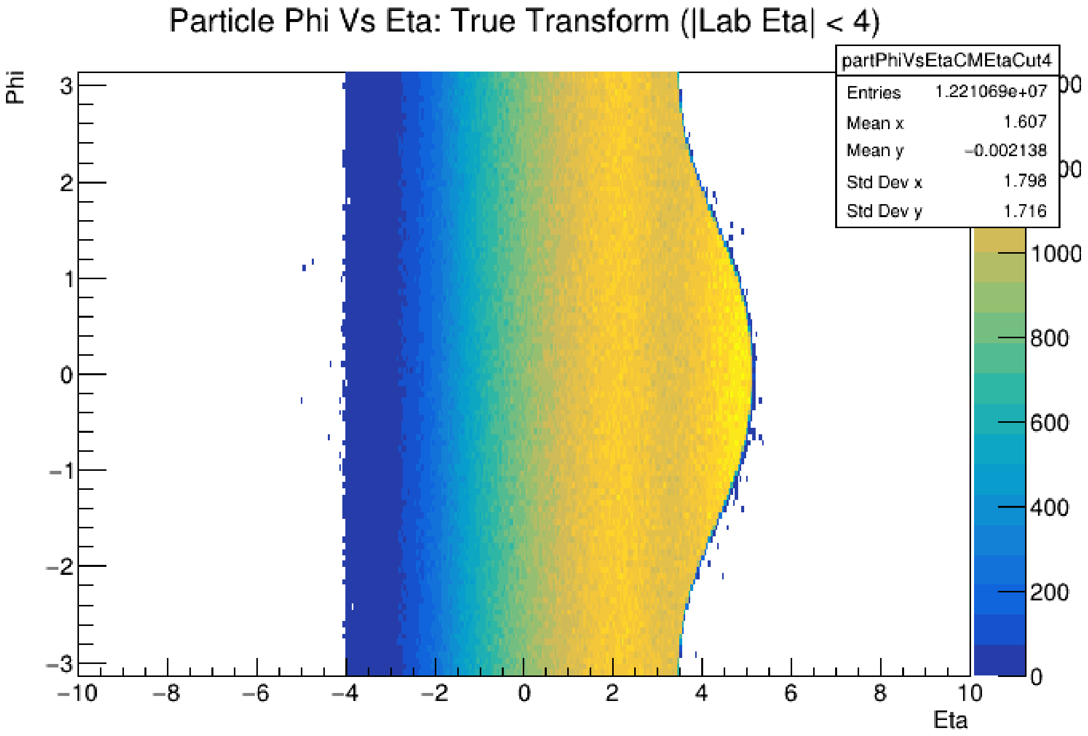




- When defined w.r.t. the hadron beam, the concentrations in eta and phi disappear
- However, because there is no common beam axis, the particle distribution along the electron-going direction becomes distorted
- Can avoid these distortions by boosting to a frame in which the beams are collinear

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



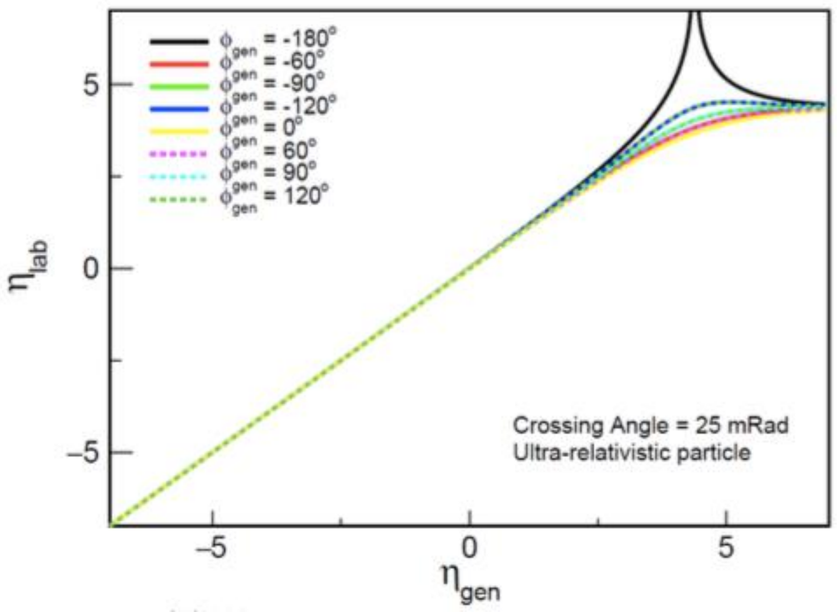
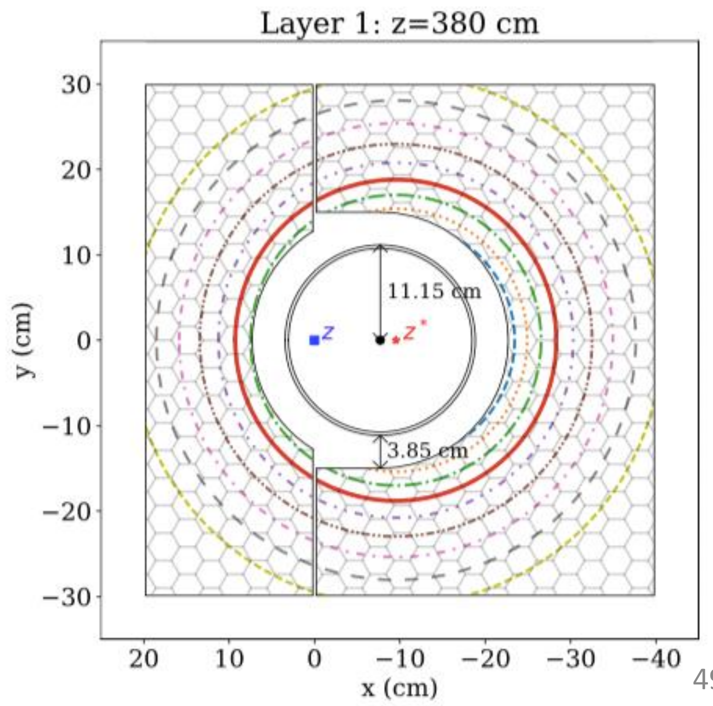


Figure by Barak Schmookler



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