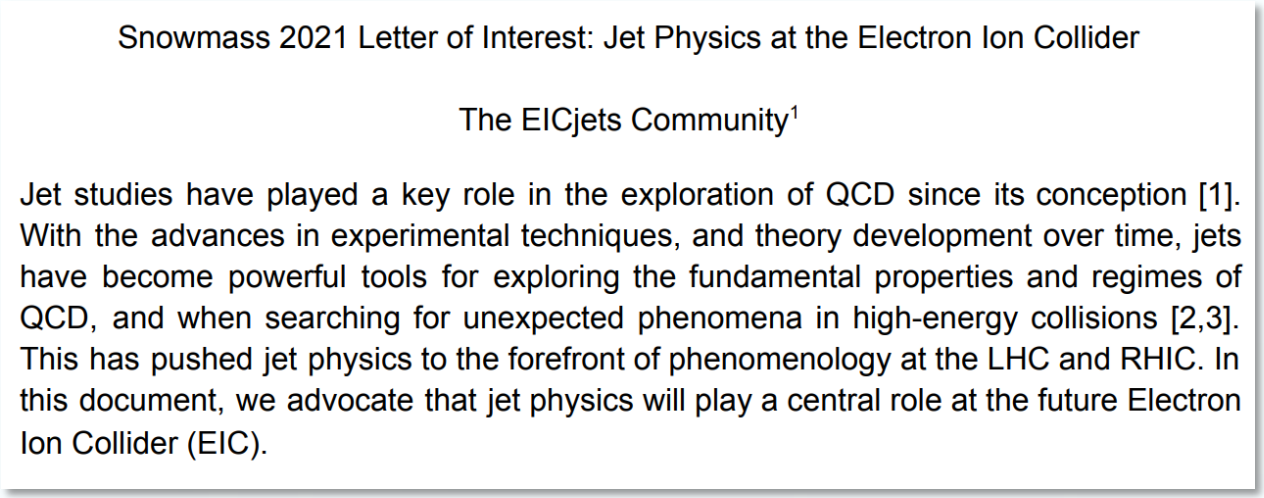
Theory aspects of EIC jets

Zhongbo Kang
UCLA

EF06/07 Jets at EIC
November 9, 2020

Letter of Interest

- Google docs
  - Miguel Arratia, Zhongbo Kang, Stefan Prestel
  - https://docs.google.com/document/d/1jSk3xPv_VQNzuiDld1mD7tTlDeYn3ada04uzLzFEHSw/edit?usp=sharing



Snowmass 2021 Letter of Interest: Jet Physics at the Electron Ion Collider

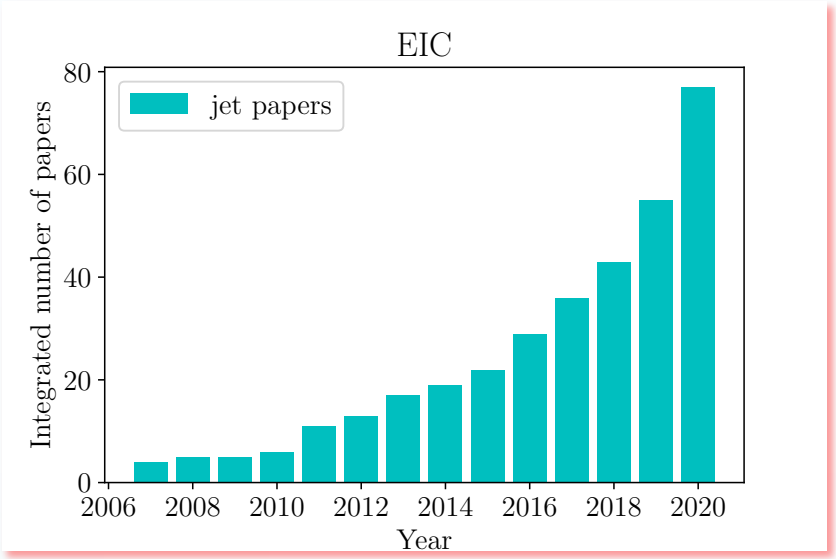
The EICjets Community[1]

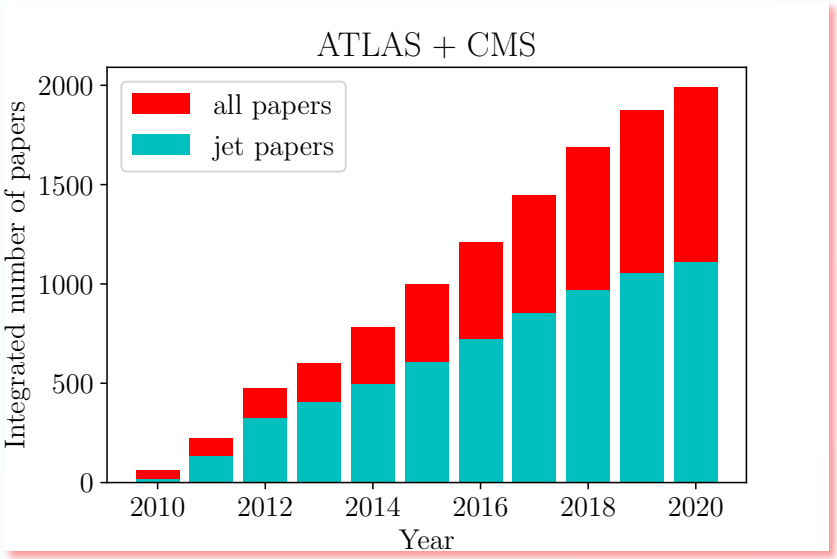
Jet studies have played a key role in the exploration of QCD since its conception [1]. With the advances in experimental techniques, and theory development over time, jets have become powerful tools for exploring the fundamental properties and regimes of QCD, and when searching for unexpected phenomena in high-energy collisions [2,3]. This has pushed jet physics to the forefront of phenomenology at the LHC and RHIC. In this document, we advocate that jet physics will play a central role at the future Electron Ion Collider (EIC).

- Signed by "The EICjets Community" [BOOST Community]
  - About 80 people
  - Please continue to sign your name on the above google docs if you are interested, as we proceed to develop a white paper via the Snowmass process

Jet physics at EIC vs LHC

- Extremely active developments in the last a few years

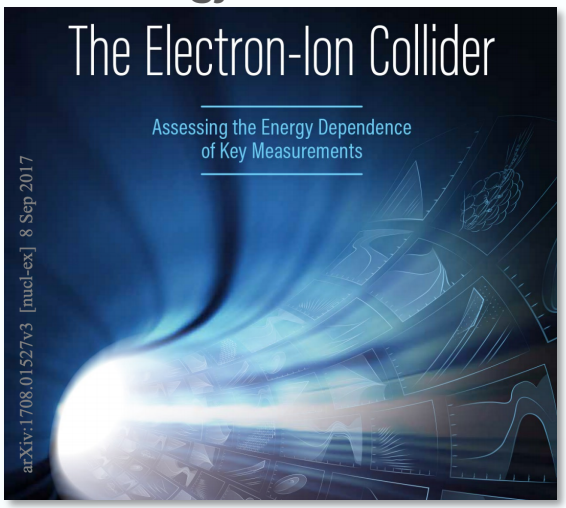




- Following similar trend for jet studies at the LHC, however
  - We use jets for very different purposes
    - EIC: mostly QCD is our signal (to study)
    - LHC: mostly QCD is our background (to remove)
  - Jets produced at EIC are different from those at the LHC
    - Because of CM energy difference
    - This would add important puzzles to our study [instead of adopting LHC results with zero change]

EIC jets are expected to be very “clean”

- Clean at EIC vs LHC
  - Little energy is not associated with the jets



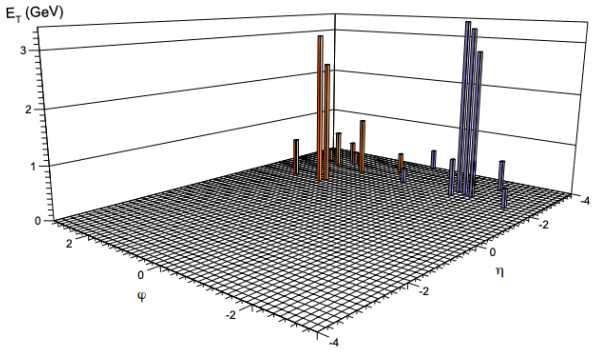
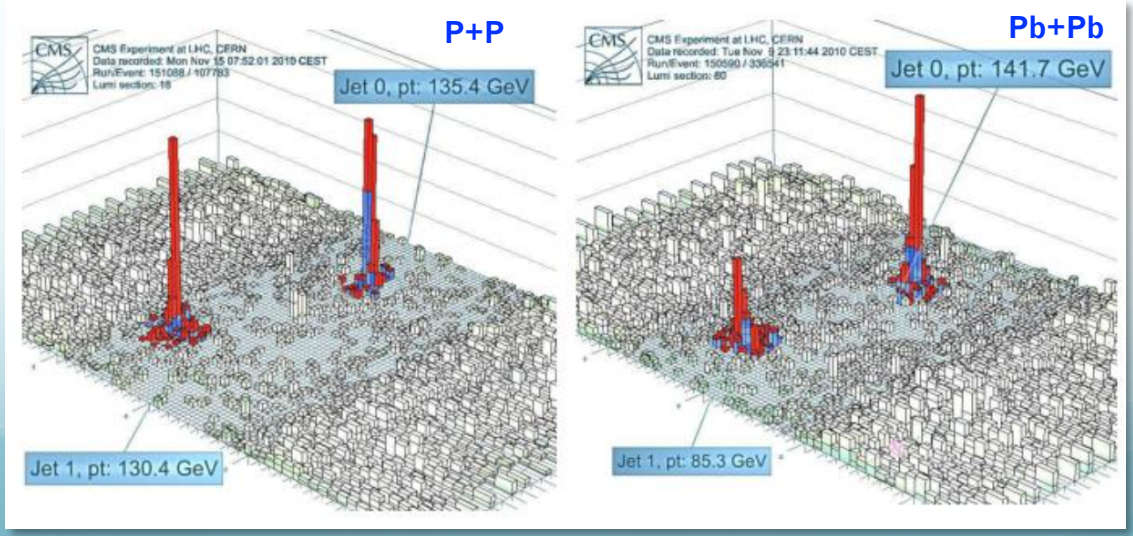


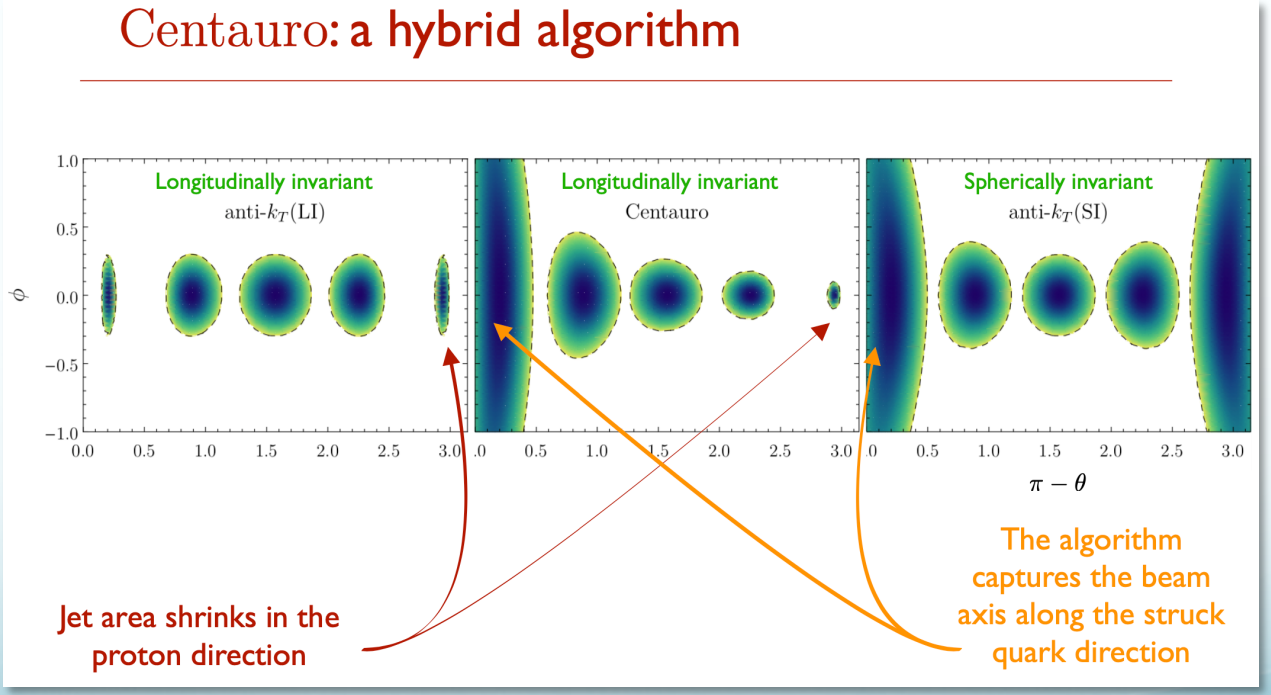
Figure 32: Visualization of a typical $e+p$ dijet event showing the transverse energy and distribution of particles in rapidity-phi space in the Breit frame.

  - Lots of background at LHC



Lower particle multiplicity in EIC jets

- EIC jets contain relatively few particles and each particle has moderate energy
  - This offers unique challenges, as well as opportunities
- For example
  - Rethinking jet algorithms [anti-kT defines all jets at the LHC, what about EIC?]



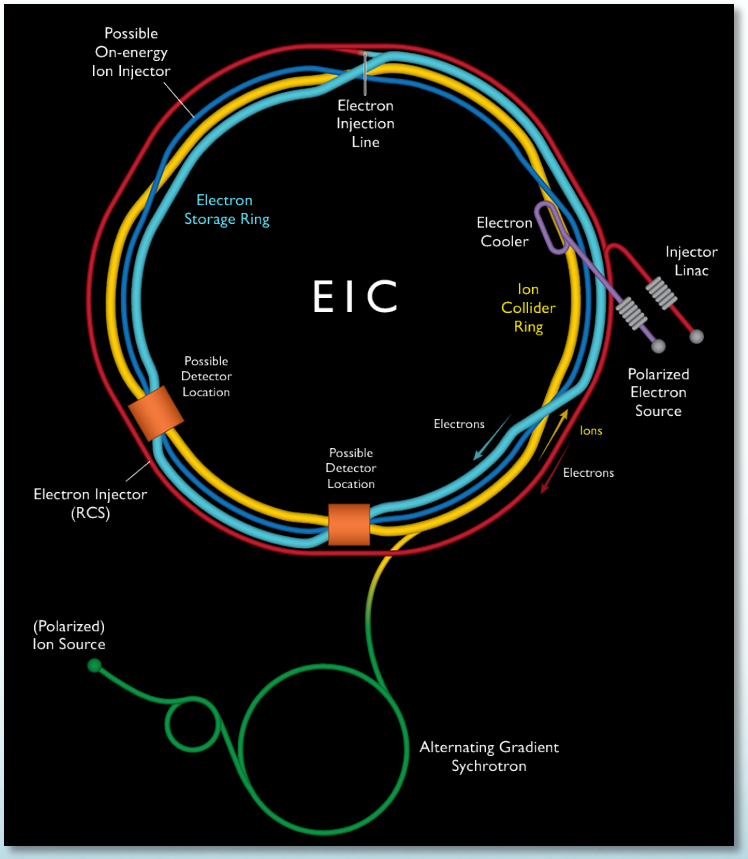
Arratia, Makris, Neill, Ringer, Sato, 2006.10751

Continue

- With fewer particles in the jet
  - Difference in jet algorithms and jet substructure methods can become very apparent, e.g., one might have to study “jet clustering” effect in more detail
- With moderate energy for each particle
  - The hadronization effect could become much more important and has to be model more carefully [which is good for us, since EIC community is inherently interested in hadronization effects]
- With a clean environment
  - Underlying event contamination will become less an issue
  - This is still a major challenge for LHC, e.g., soft-drop grooming might not be that relevant, or one has to use soft-drop for a different purpose

Most importantly

- EIC has polarized beam + nuclear beam
  - This would provide a whole new set of opportunities, which would not be possible at the LHC or HERA



What can we use jets for?

- 2017:

3.7 Jet Physics

Since the earliest days of collider physics, jets have been an important tool in the exploration of QCD and have provided important discoveries and insights in all colliding systems, including e^++e^-, e+p hadron+hadron, and nucleus+nucleus. (See for example [88].) With the advances in experimental techniques, and corresponding advances in theoretical understanding over time, jets have become precision tools for studying the parton structure of matter. Jets are guaranteed to contribute at the EIC to a variety of key electron-nucleus and electron-hadron physics topics, such as:

- The study of hadronization, to shed light on the nature of color neutralization and confinement (see [42])
- Parton shower evolution in strong color fields to measure cold nuclear matter transport coefficients (see [42])
- The study of diffractive dijet production, which can possibly provide direct access to the gluon Wigner function (see [89, 90])
- Constraints on high-x quark and gluon PDFs
- Precision measurements of (un)polarized hadronic photon structure (see [91])
- Measurement of the gluon helicity distribution in the proton, Δg, and its evolution via the photon-gluon fusion process.

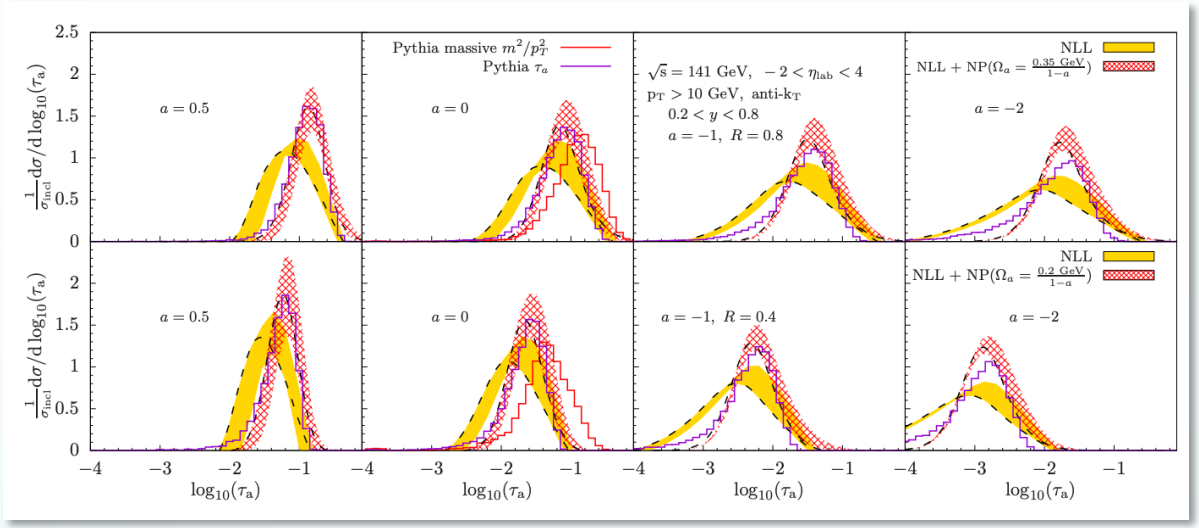
- Our LOI:

A variety of key measurements include (but are not limited to):

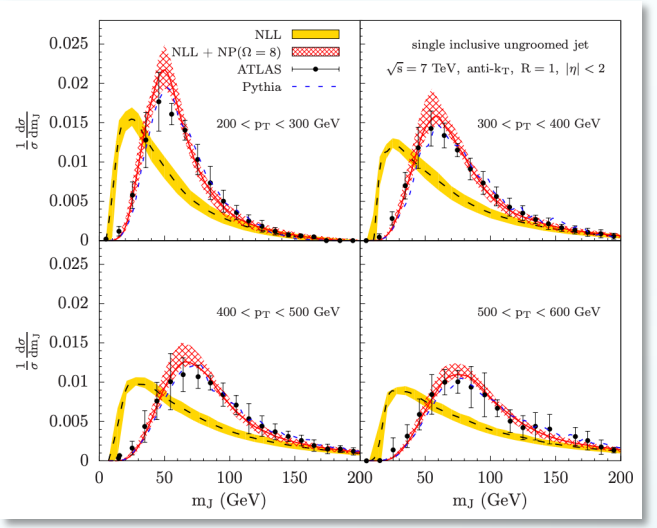
- Jet substructure (such as jet shape, jet mass, jet angularity, etc) in electron-proton collisions as powerful probes for QCD dynamics
- Jet-based observables and event shapes (such as 1-jettiness) as precision probes for extraction of fundamental QCD parameters, notably the strong coupling constant and its running
- Jets for studies of flavor and spin structure of the nucleon, in particular three-dimensional (3D) imaging of the nucleon and even 5D Wigner distribution
- Modification of jets and jet substructure from e+p to e+A collisions for studying the transport of partons through nuclear matter

Direction 1: Jet substructure

- Jet substructure as powerful probes for QCD dynamics
  - Jet shape, jet mass, jet angularity, etc
  - Hadronization might be the main non-perturbative contribution



EIC, Aschenauer, Lee, Page, Ringer, 19

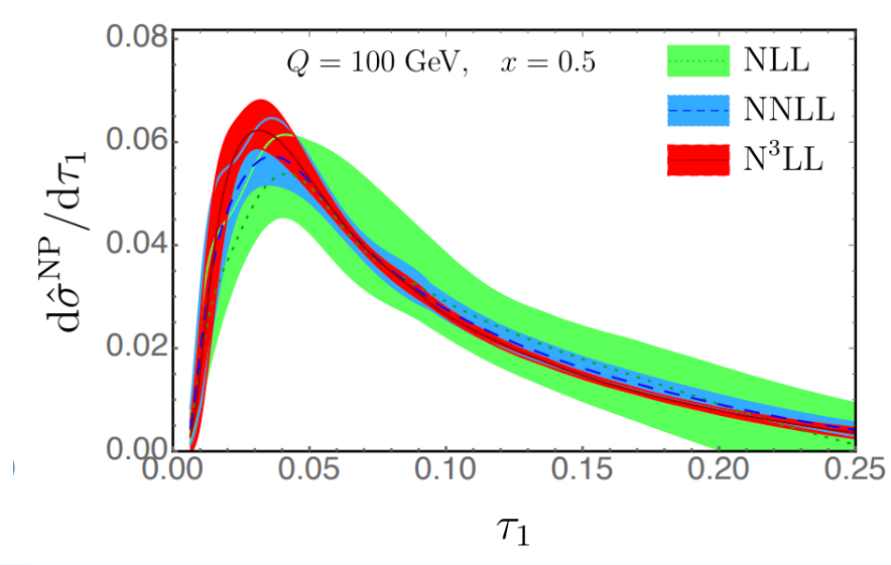


LHC, Kang, Lee, Ringer, 18

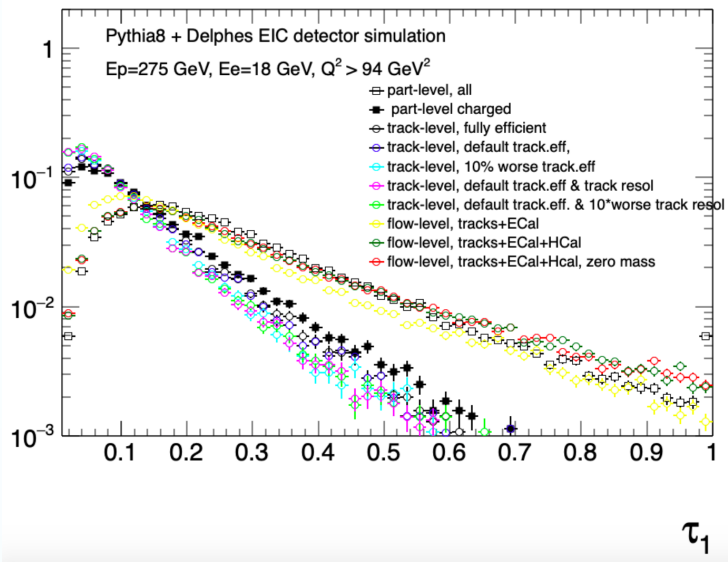
- Modification of such jet substructure in e+A would then inform us the hadronization process more directly [without too much contamination from other non-perturbative contamination]

Direction 2: Global event shape as precise probe of coupling constant

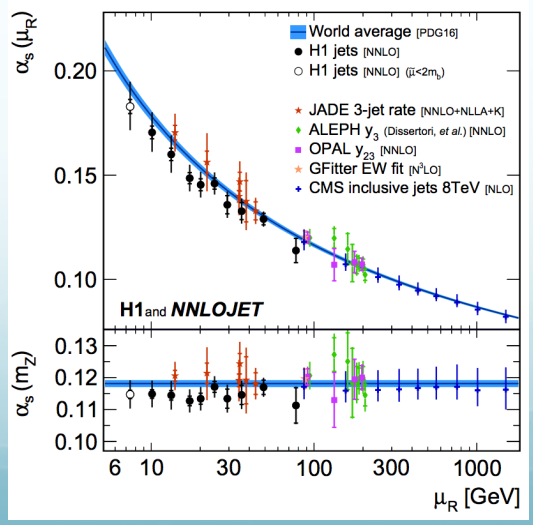
- 1-jettiness: extraction of strong coupling constant



D. Kang, Lee, Stewart, 13, 19

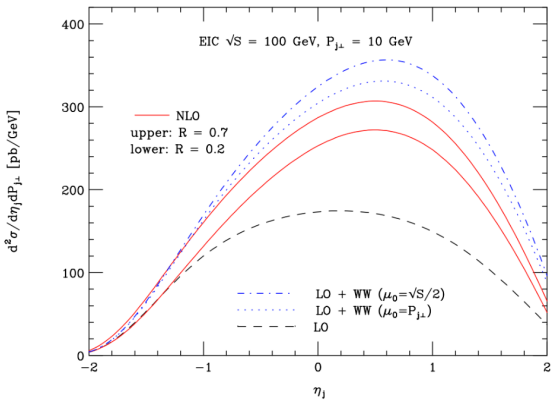


Leticia Cunqueiro, 10/20, EIC YR

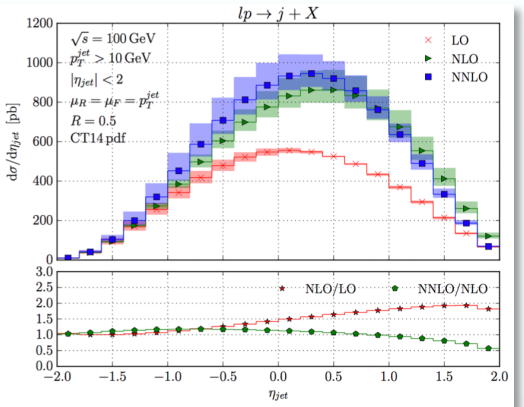


Direction 3: Jets for flavor and spin structure of nucleon

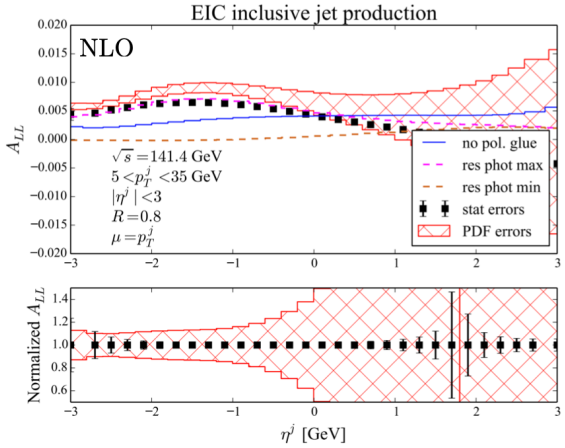
- 1D structure: e.g., unpolarized and helicity distribution



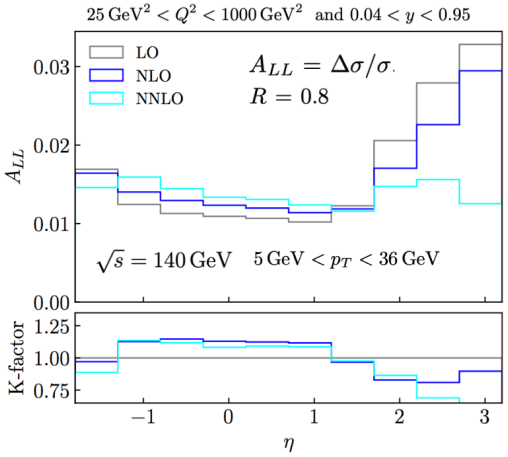
Hinderer, Schlegel, Vogelsang `15



Abelof, Boughezal, Liu, Petriello `16



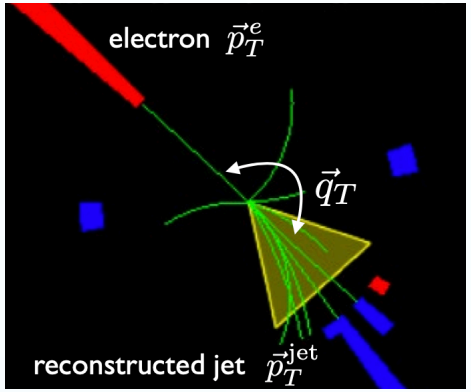
Boughezal, Petriello, Xing `18
see also Hinderer, Schlegel, Vogelsang `17

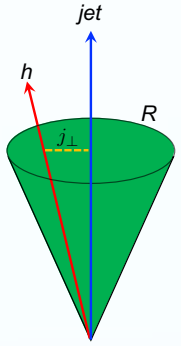


Borsa, Florian, Pedron `20

Continue

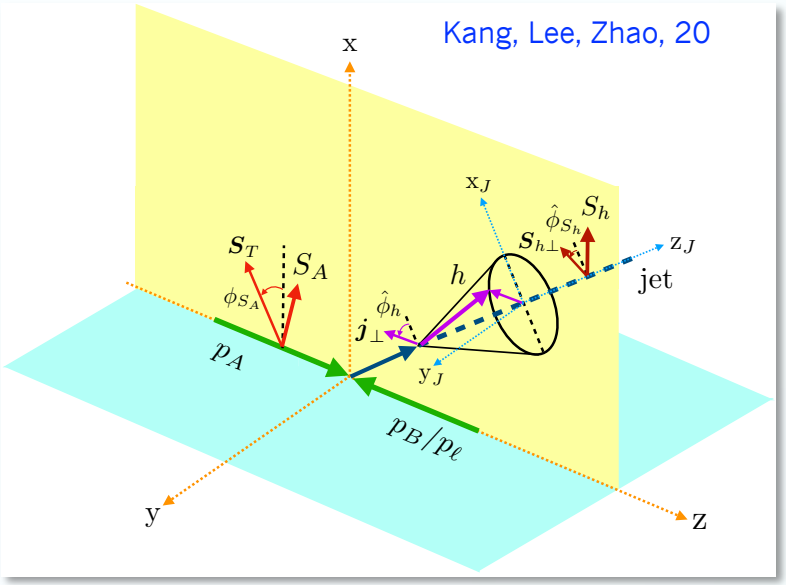
- 3D structure: TMDs, ...
  - Lepton-jet correlation: TMD PDFs
  - Jet fragmentation functions: TMD FFs



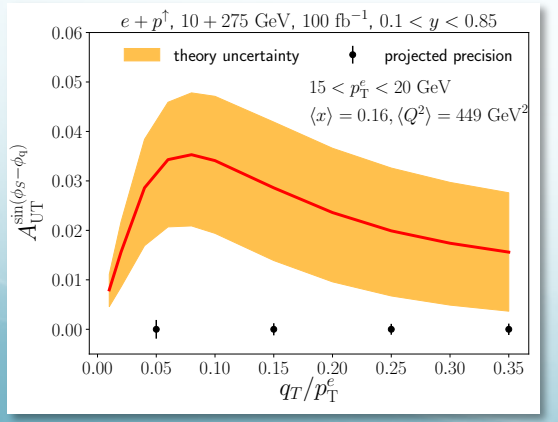


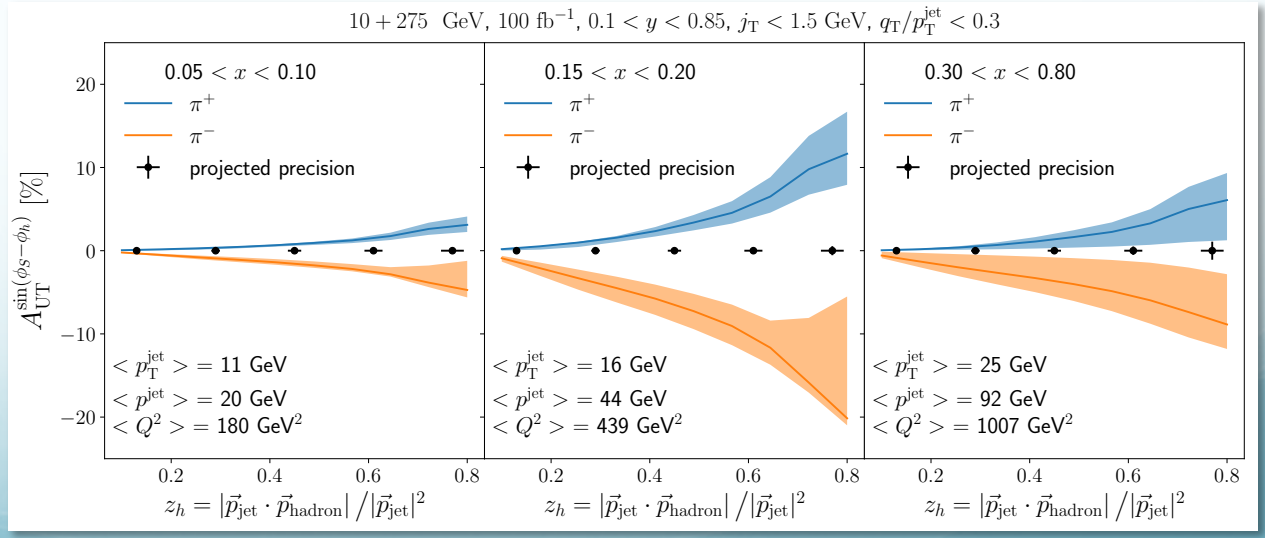
See also Makris, Neill, Scimemi, Wouter, et.al.

Kang, Lee, Zhao, 20



Arratia, Kang, Prokudin, Ringer, 20

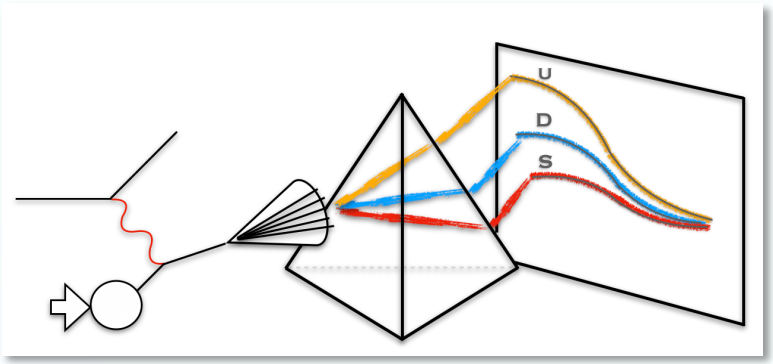


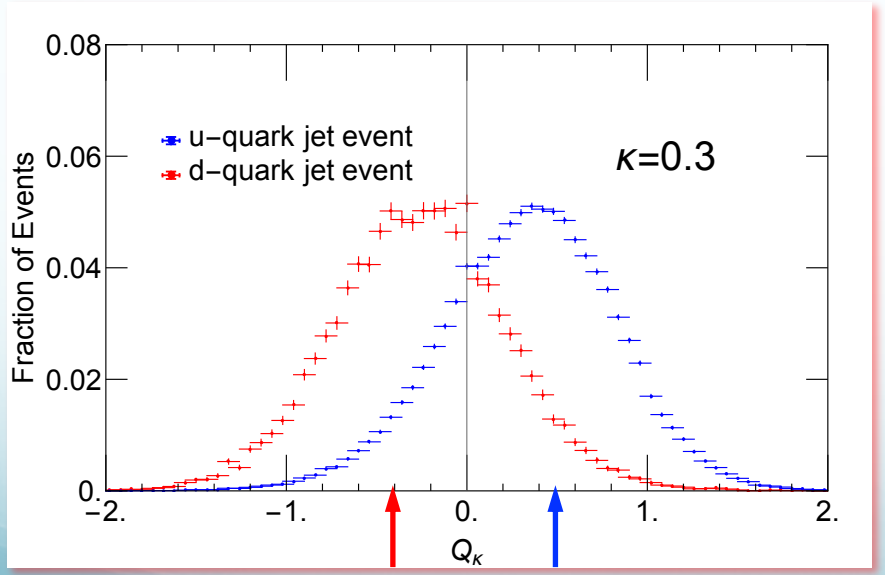


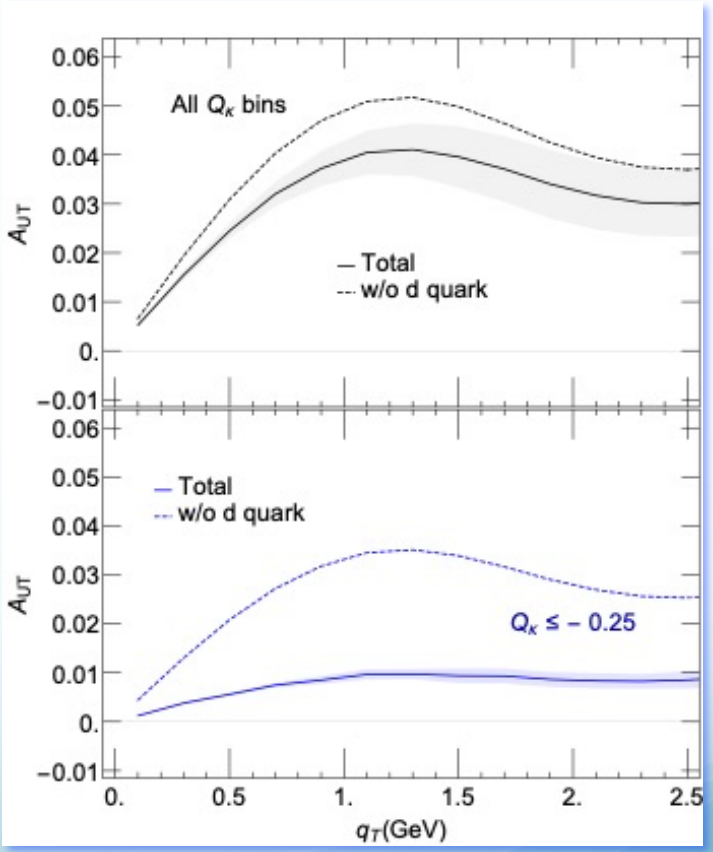
Continue

- Flavor separation: jet charge [borrow ideas from LHC]

Kang, Liu, Mantry, Shao, 20, PRL, in press

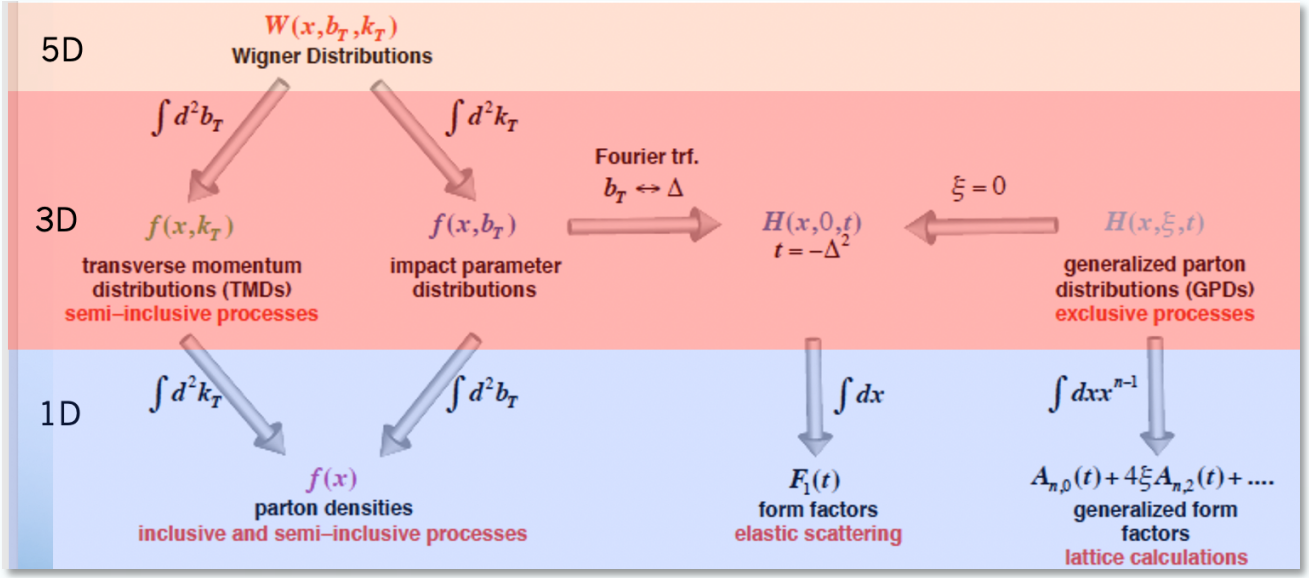




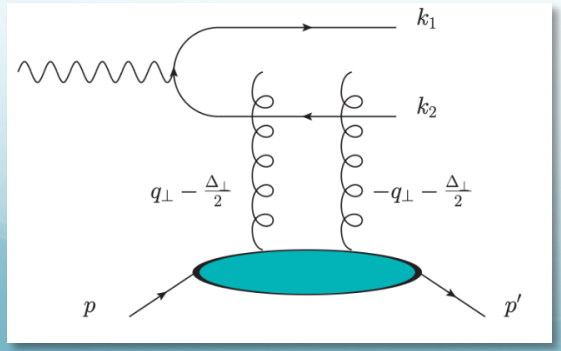


Continue

- 5D structure: Wigner distribution



- Diffractive dijet production in small-x formalism can be connected to Wigner distribution



Hatta, Xiao, Yuan, 16, Hatta, Mueller, Ueda, Yuan, 19,
See also Salazar, Schenke 19, Mantysaari, Mueller, Salazar, Schenke 20
See also Bhattacharya, Metz, Zhou 17

$$\vec{q}_\perp = (\vec{k}_{1\perp} + \vec{k}_{2\perp})$$

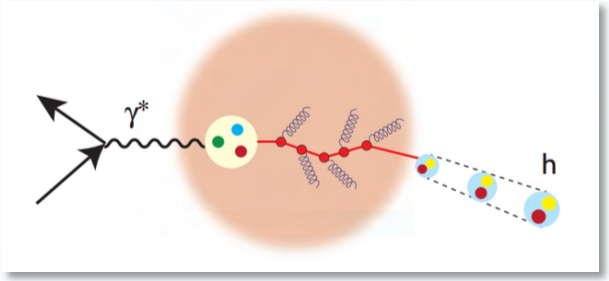
$$\vec{P}_\perp = (\vec{k}_{1\perp} - \vec{k}_{2\perp})/2$$

$$y_{1,2} \gg 1$$

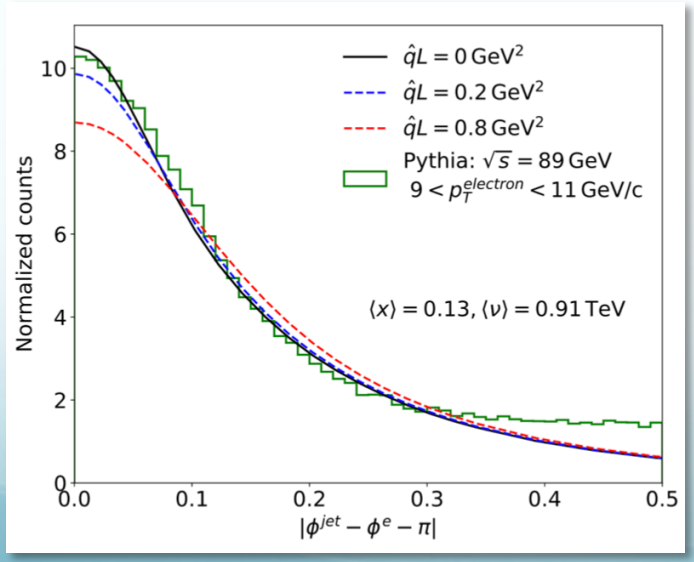
Measure p' to reconstruct $\Delta_\perp$

Direction 4: modification of jets and jet substructure

- Lots of progress along this direction recently
  - Understand hadronization process
  - Extract the properties of cold nuclear matter [color glass condensate]



  - Example: broadening in lepton-jet transverse momentum imbalance



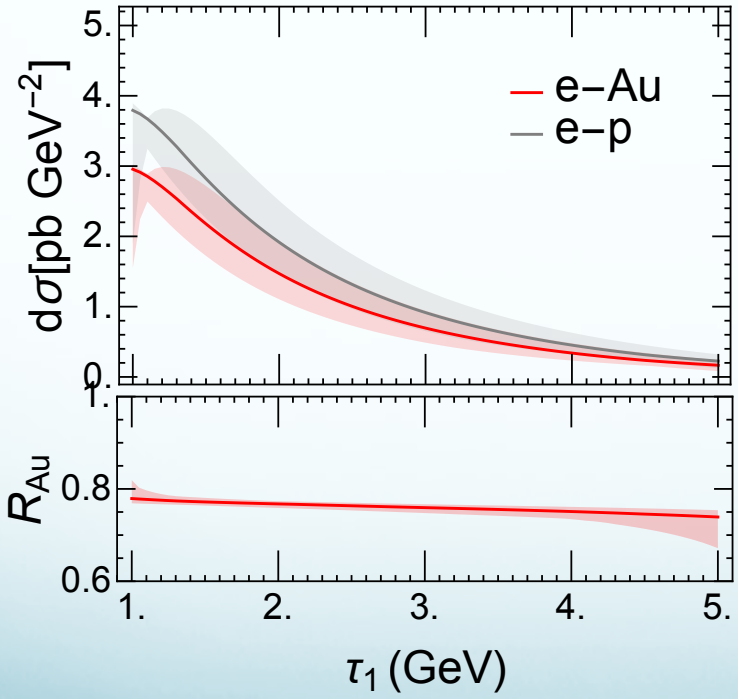
Liu, Ringer, Vogelsang, Yuan 18
Arratia, Jacak, Ringer, Song, 19

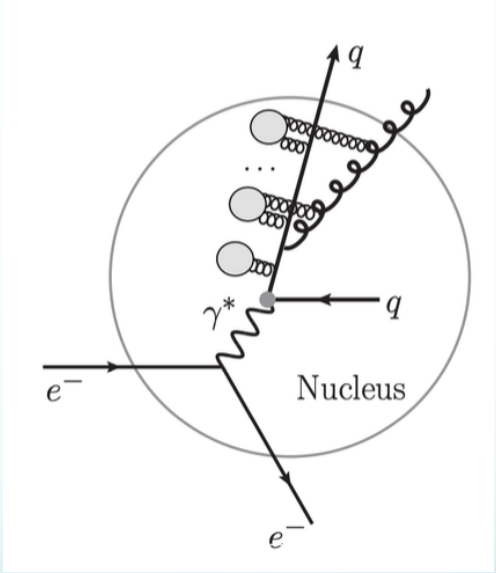
Continue

- Modification of event shape

Kang, Mantry, Qiu, 12,
Kang, Liu, Mantry, Qiu, 13

  - So far only nuclear PDFs is implemented
  - Expect to have final-state multiple scattering which lead to broadening/smearing in the 1-jettiness distribution. The size of the broadening is controlled by q-hat



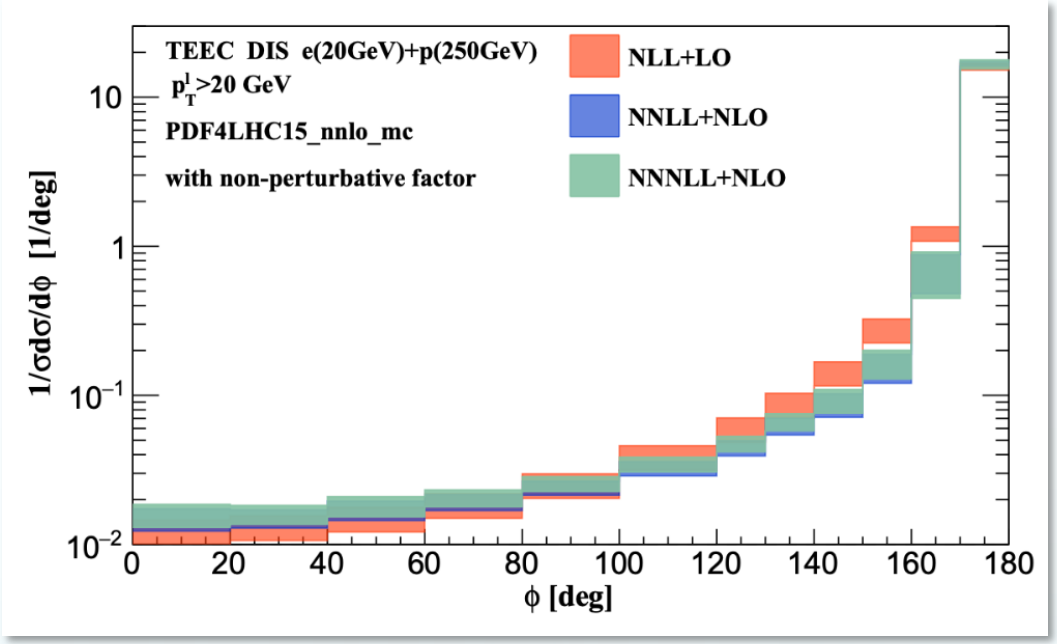


Continue

- Transverse energy-energy correlators

Li, Vitev, Zhu, 20,
see also other works at e+e-, pp

$$\frac{d\sigma}{d\cos\phi} \approx \sum_h \int d\sigma_{lN\to l+h+X} \times \frac{p_T^h}{p_T} \times \delta(\cos\phi_{lh} - \cos\phi)$$



TMD study at the LHC

- Growing field of jet physics at the EIC
- Would be really exciting to develop theory for EIC jets, and continue to work closely with our LHC jet colleagues

Thank you!