Target jet substructure and correlation

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Physics Opportunities at an Electron-Ion Collider XI

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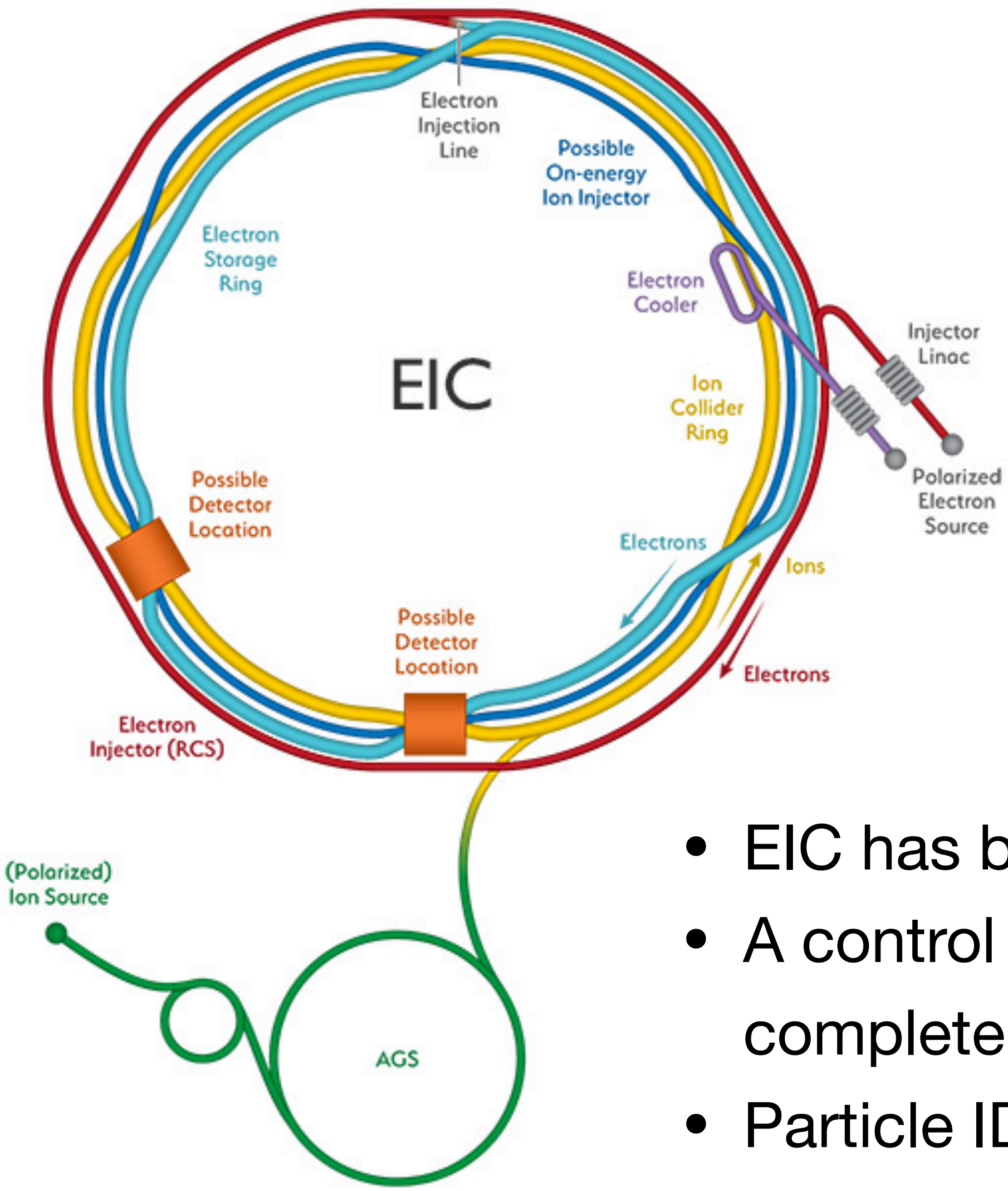
Electron Ion Collider



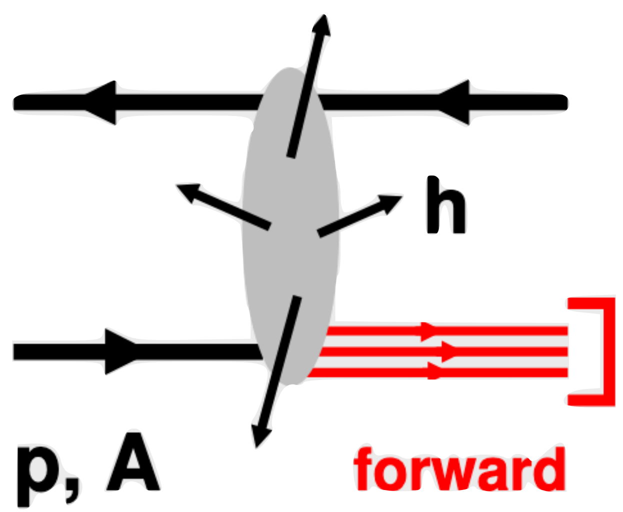
January 9, 2020

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

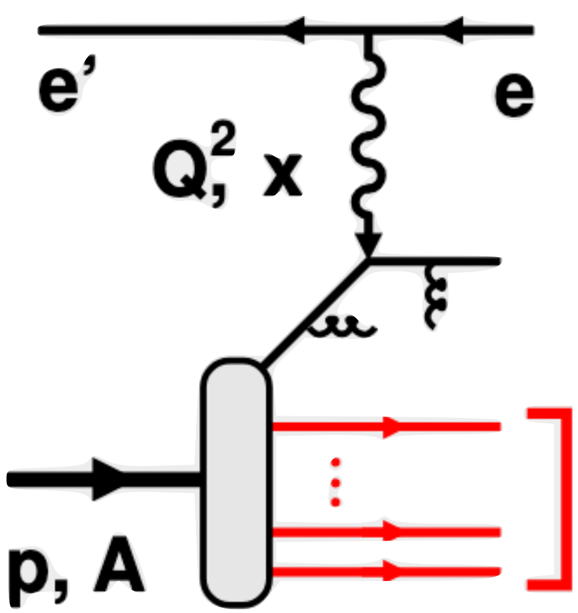
March 21, 2022
Project detector selected and ePIC collaboration being formed

- EIC has been making a steady progress toward realization
- A control over spin and polarization d.o.f. allows a complete tagging of partonic quantum numbers
- Particle ID and high statistics are important for precision extraction of proton 3D structure
- What role can the second detector play beyond ePIC? What phase space can it look into?

Target fragmentation

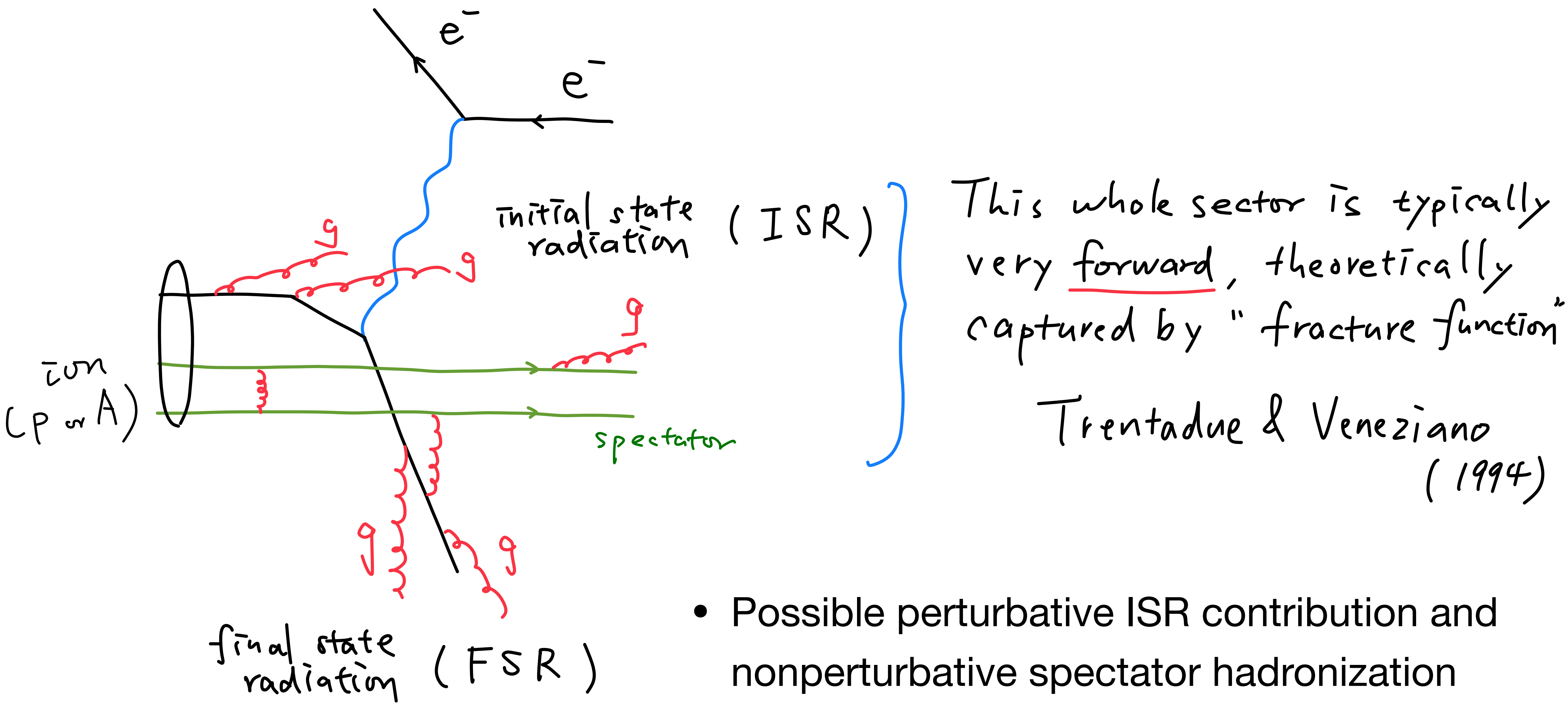


- Refers to hadron production in the target rapidity region
- For collider experiments, these are forward hadrons close to beam rapidity
- Physics interest: Structure of target, configurations in high-energy process, correlation with central event



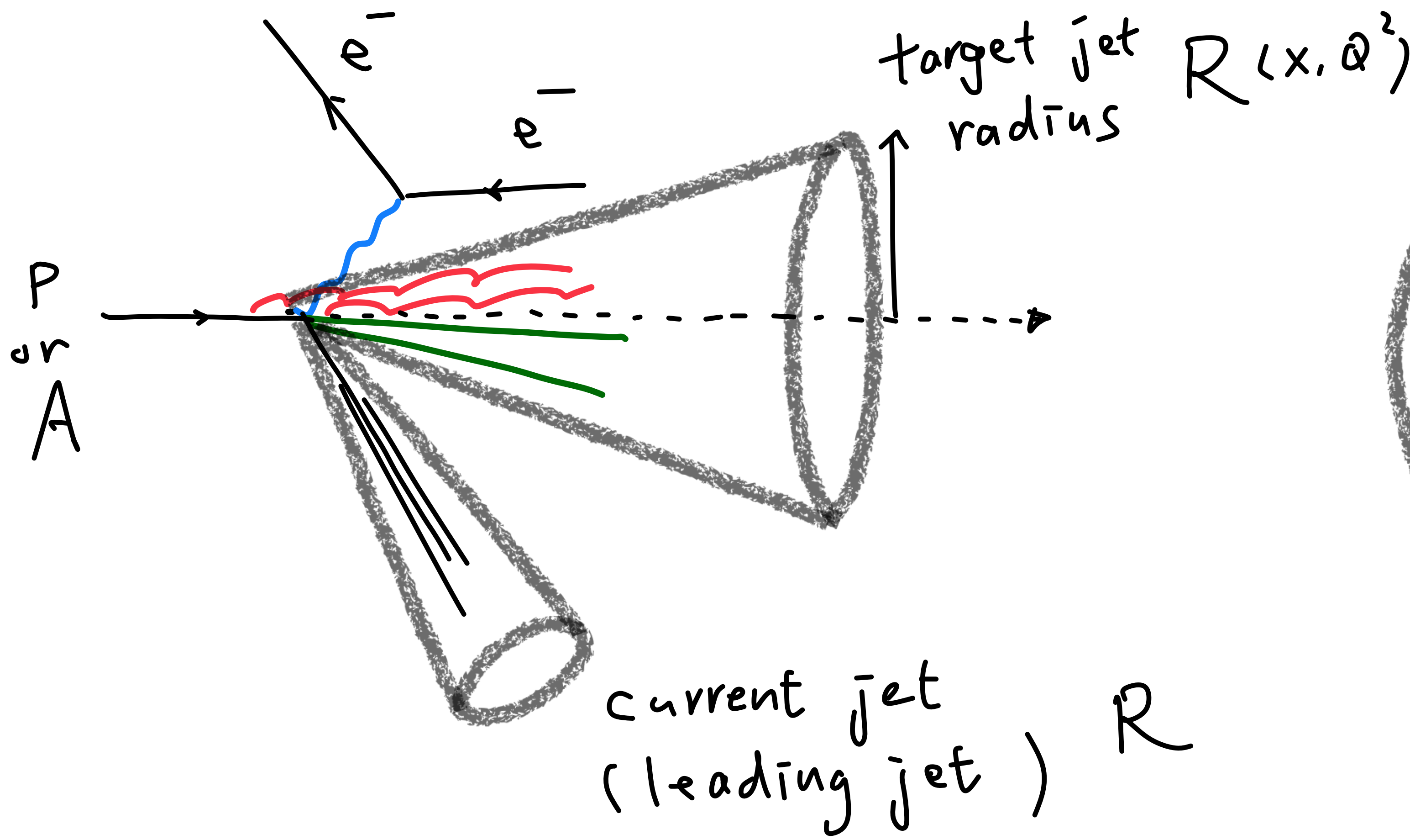
- For Electron-ion (ep/eA) collisions, target fragmentation and diffraction in DIS can provide insights into factorization, fracture functions, and differential PDFs

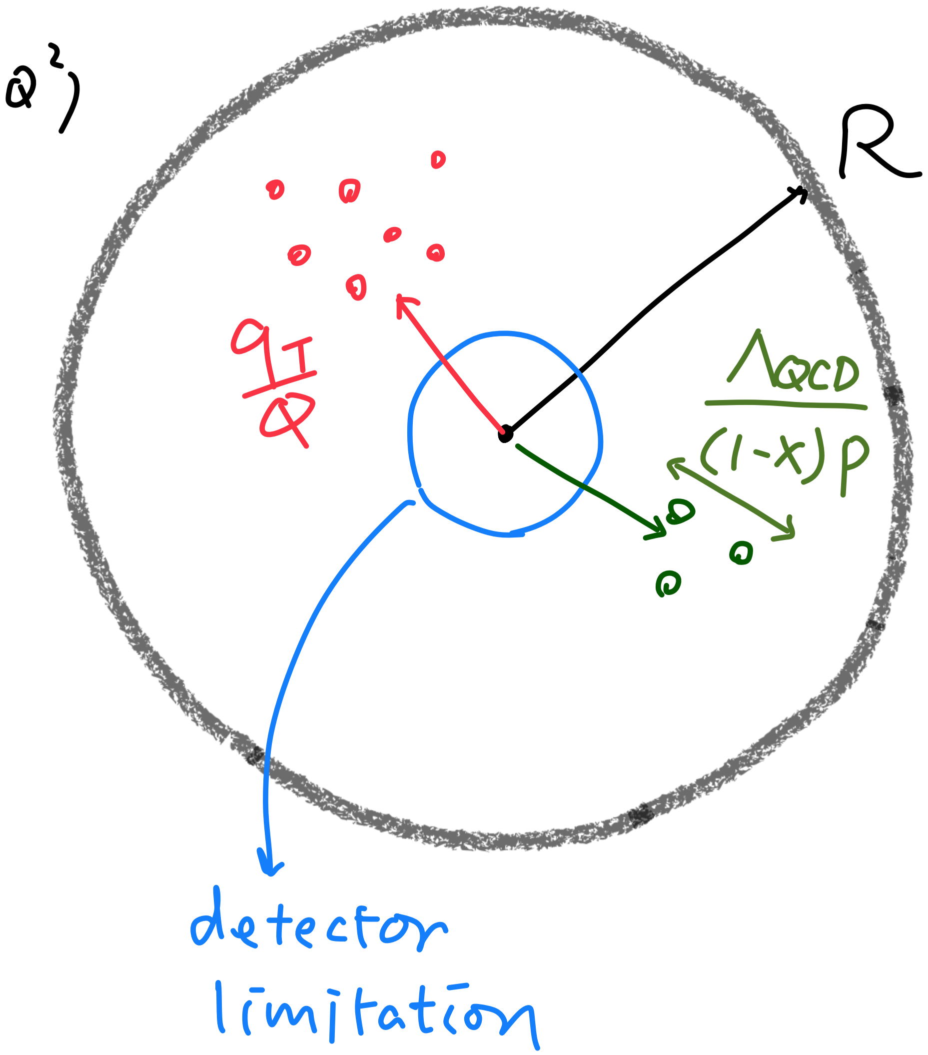
A schematic picture of target fragmentation for DIS

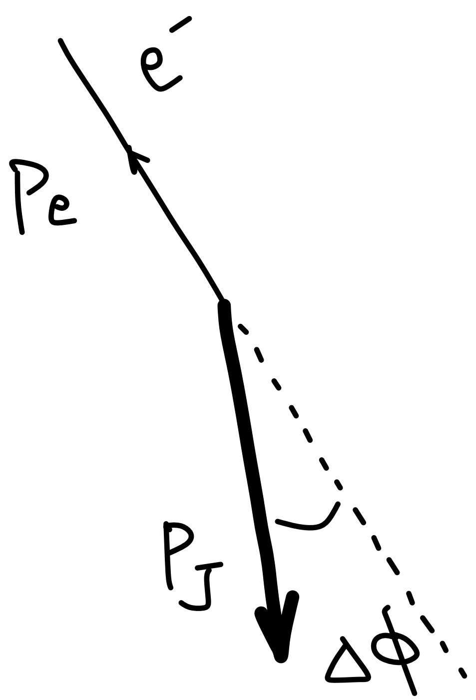


- Possible perturbative ISR contribution and nonperturbative spectator hadronization

Electron-leading jet and target jet





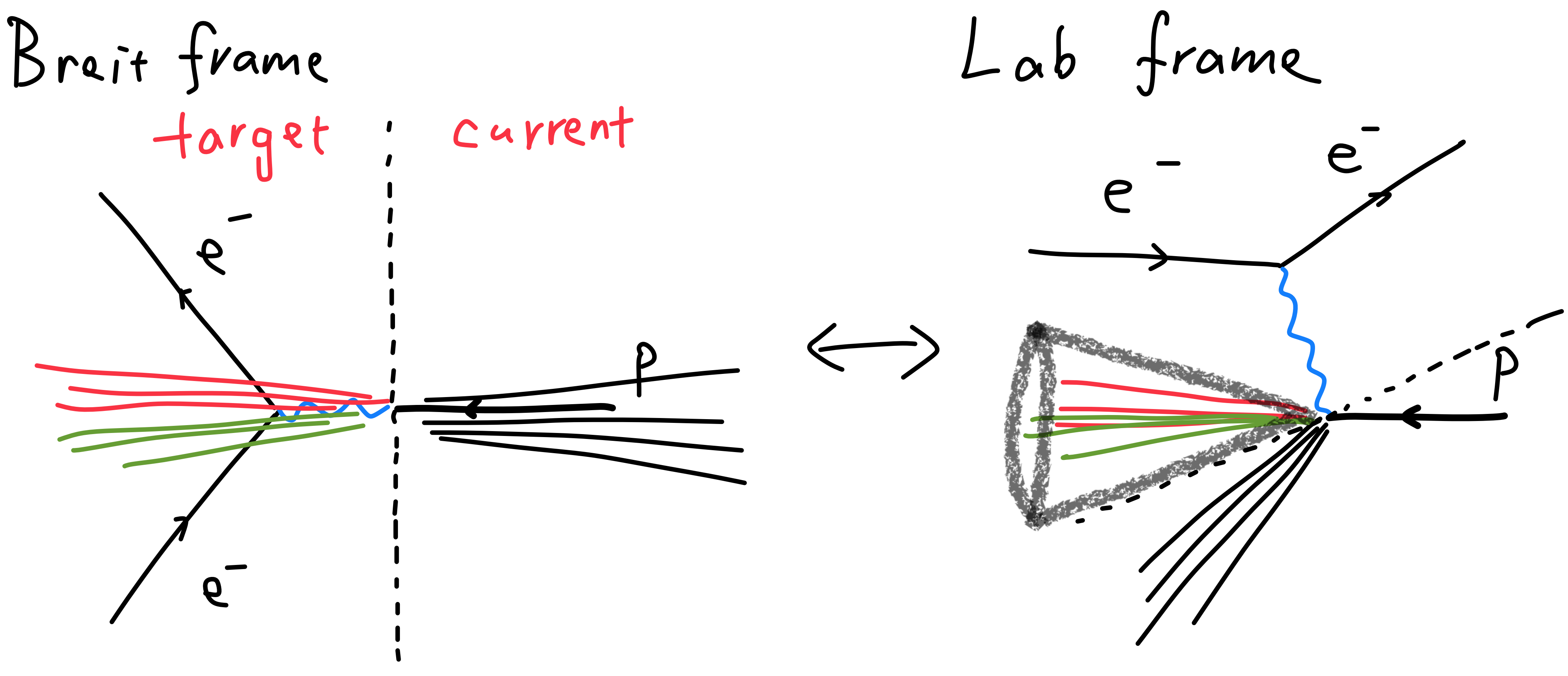


$$q_T = \left| \left(\vec{P_e} + \vec{P_J} \right)_T \right|$$

$\Delta\phi$: azimuthal angle decorrelation

- Carving out two collinear energy flows

Target jet definition



- It is quite intuitive to define current and target region in Breit frame
- What is the corresponding analysis strategy in the lab frame?

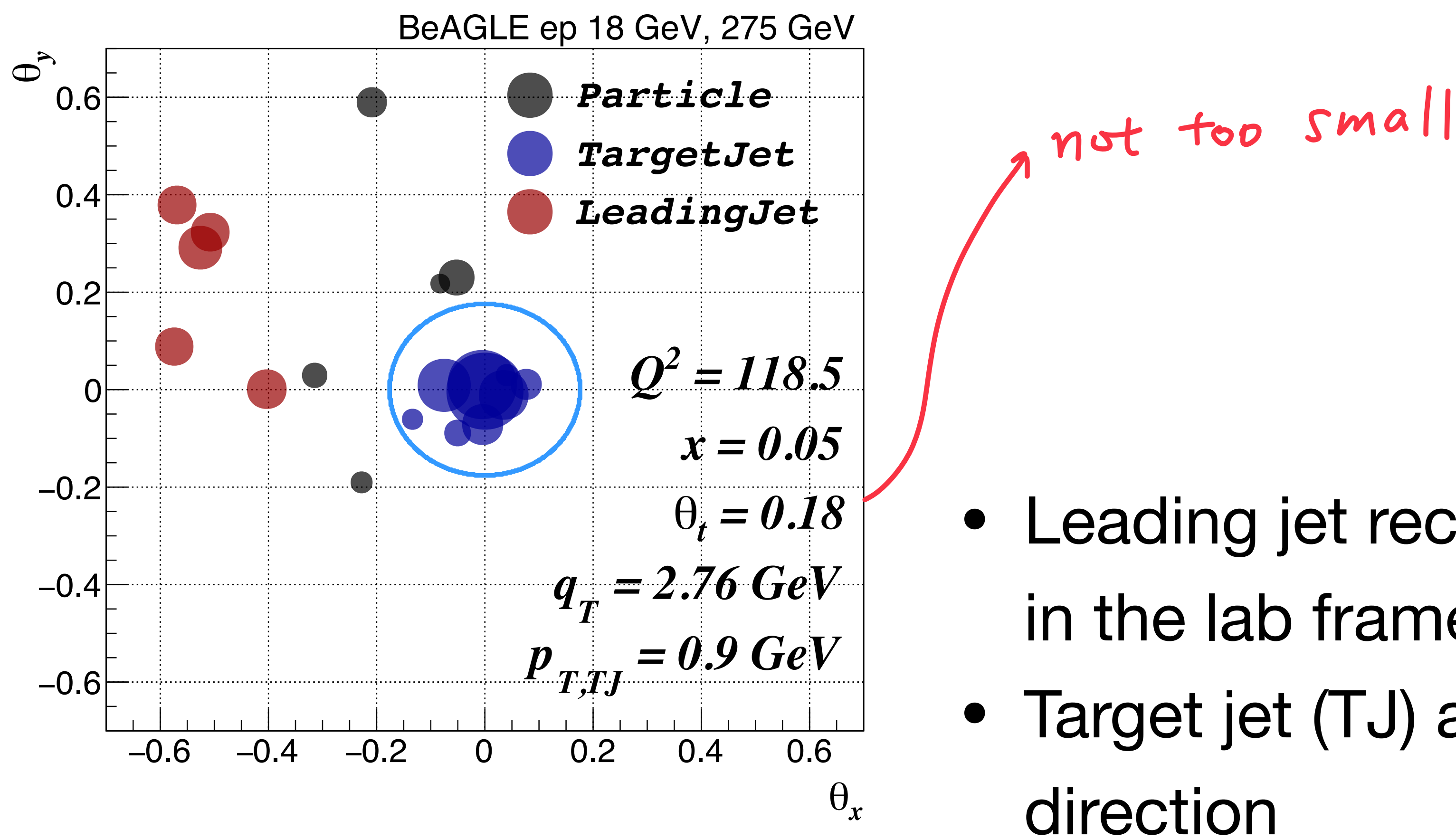
$$\eta_t = \log \frac{\sqrt{1 + \frac{E_e}{x^2 E_p} \frac{Q^2}{E_{CM}^2 - Q^2/x}} - 1}{\sqrt{\frac{E_e}{x^2 E_p} \frac{Q^2}{E_{CM}^2 - Q^2/x}}}$$

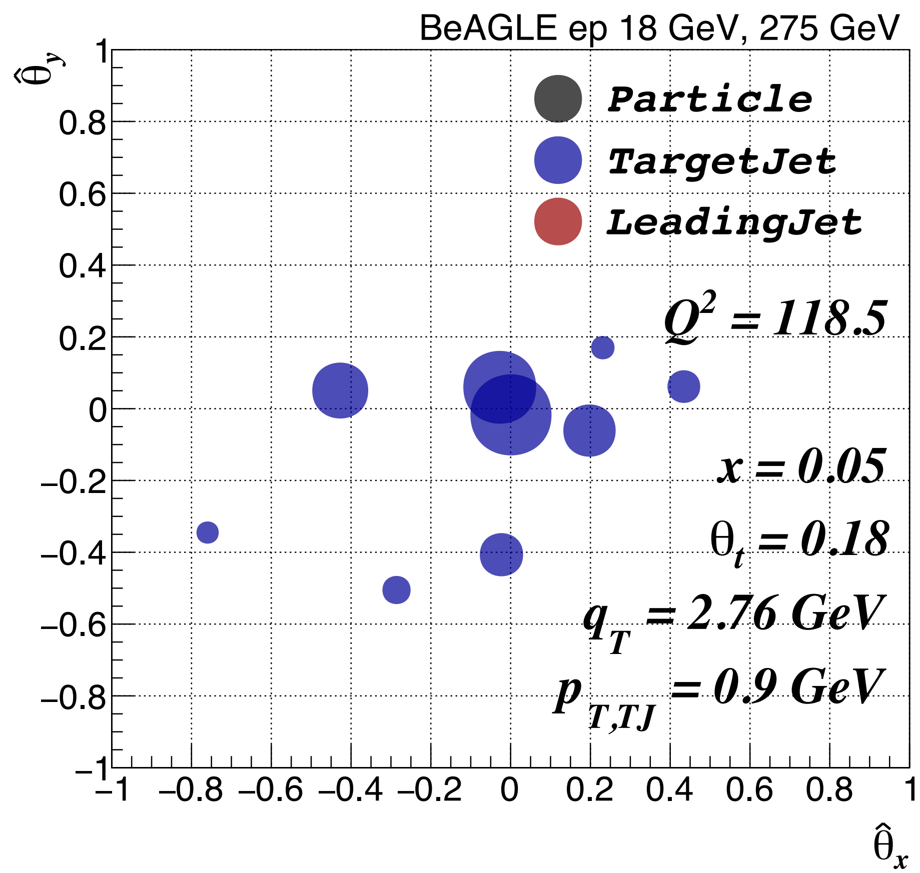
Monte Carlo simulations

- BeAGLE - Benchmark eA Generator for LEptoproduction
  - Built on Pythia 6, FLUKA, DPMJet, PyQM, LHAPDF5
  - 18 GeV electron beam + 275 GeV proton beam
  - 10 GeV electron beam + 100 GeV ion (deuteron, gold) beam
- For ep collisions we also compare with Pythia 8 to help with simulation development
  - QED shower and ISR contributions
- Impose $Q^2 > 100\,\mathrm{GeV}^2$ to have jet currents with higher transverse momentum

Disclaimer : We assumed that ALL final state particles can be reconstructed and proceed to see that physics information one can extract !

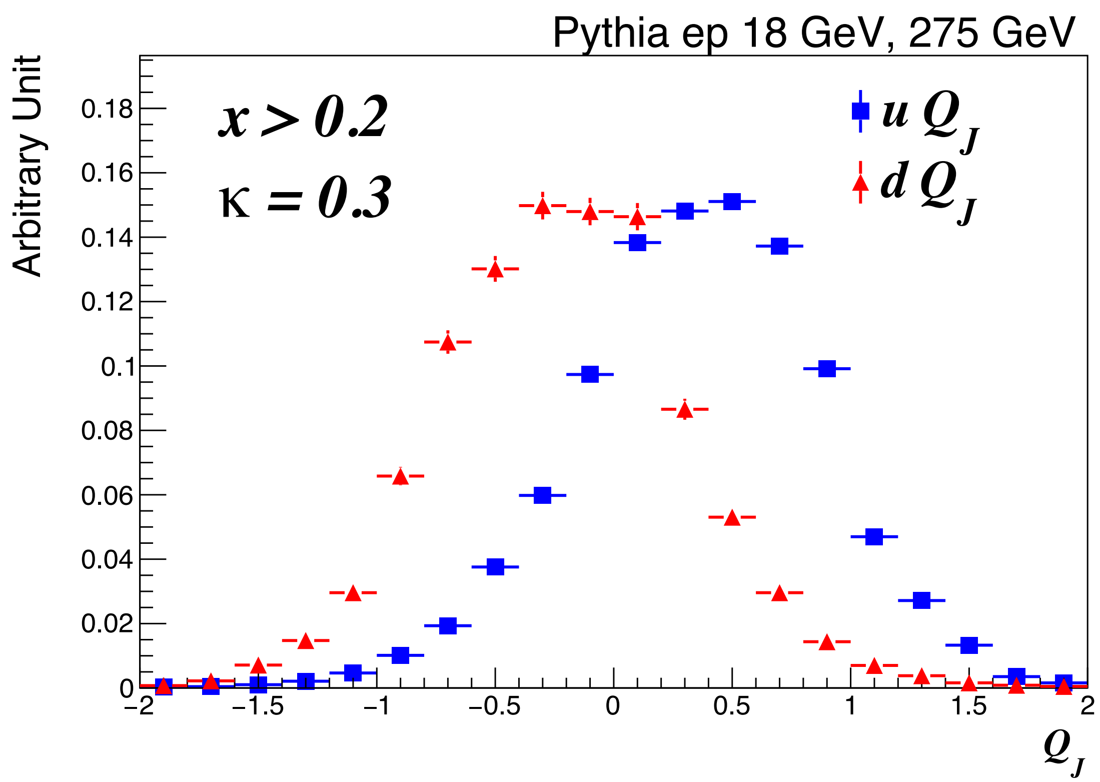
Forward event display

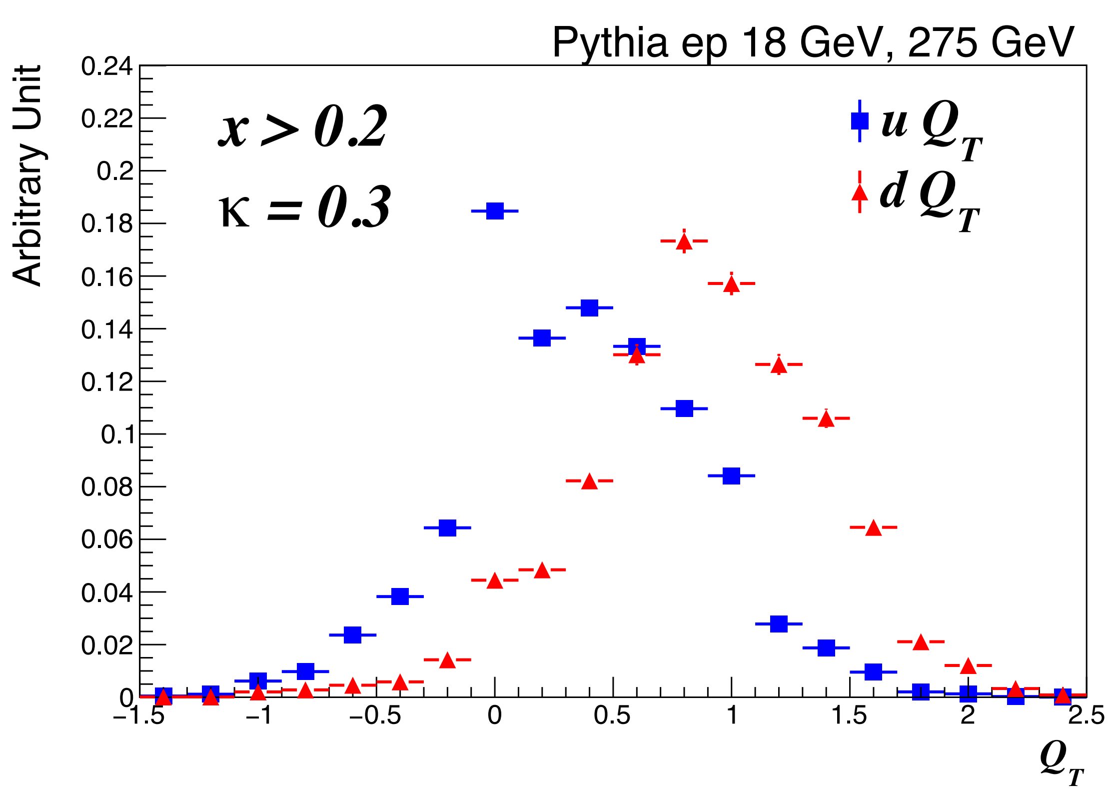




- Leading jet reconstructed using anti-kt R = 1.0 in the lab frame
- Target jet (TJ) as a cone along the beam direction
- $\hat{\theta}_{x,y} = \theta_{x,y}/\theta_t$: geometric angle normalized by the target jet angle θ_t

Leading jet and target jet charge



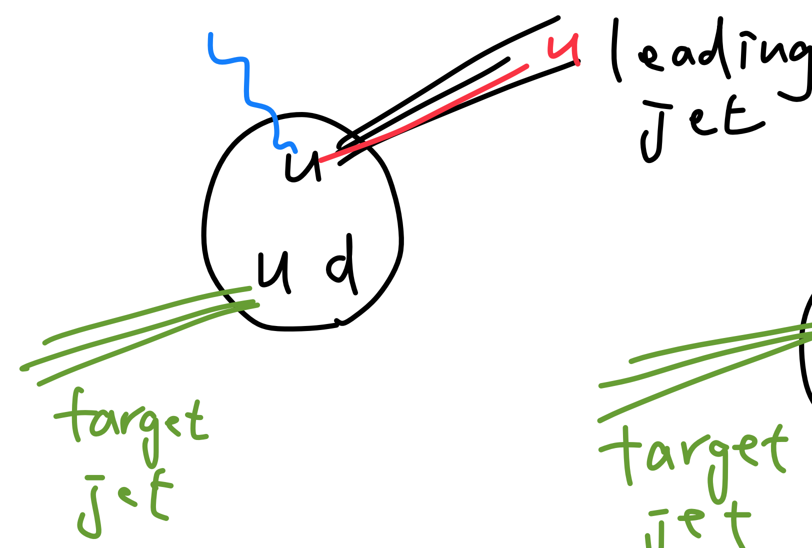


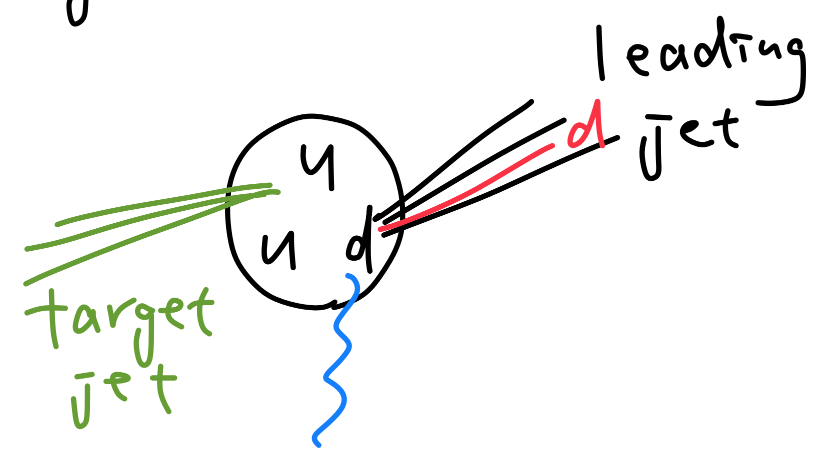
$$Q_J = \sum_{i \in L_J} z_i^{\kappa} Q_i \,, \qquad z_i = \frac{p_{T,i}}{p_{T,L_J}}$$

$$Q_T = \sum_{i \in T_J} z_i'^{\kappa} Q_i \,, \qquad z_i' = \frac{e_i}{e_{T_J}}$$

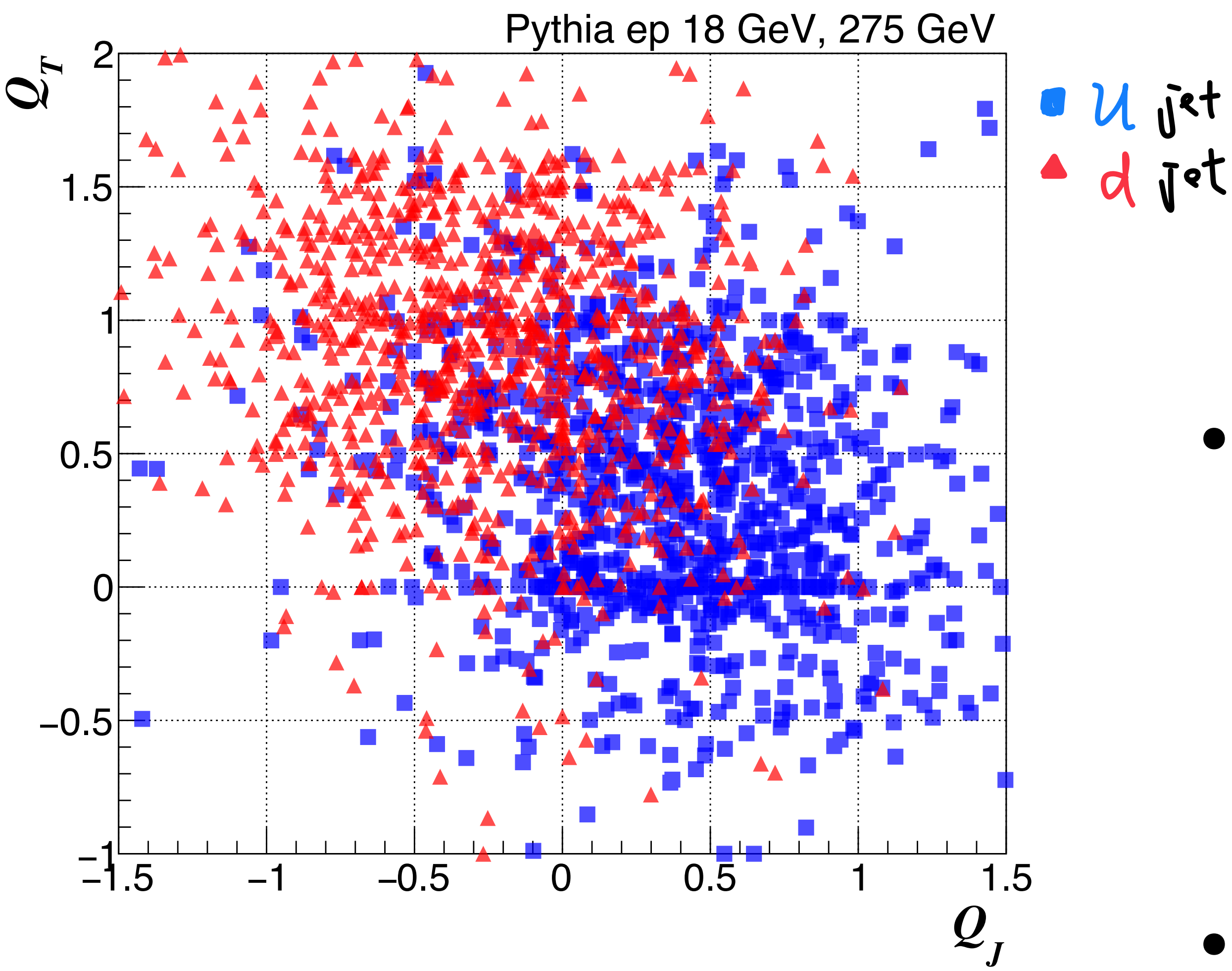
Jet charge
Field & Feynman (1978)

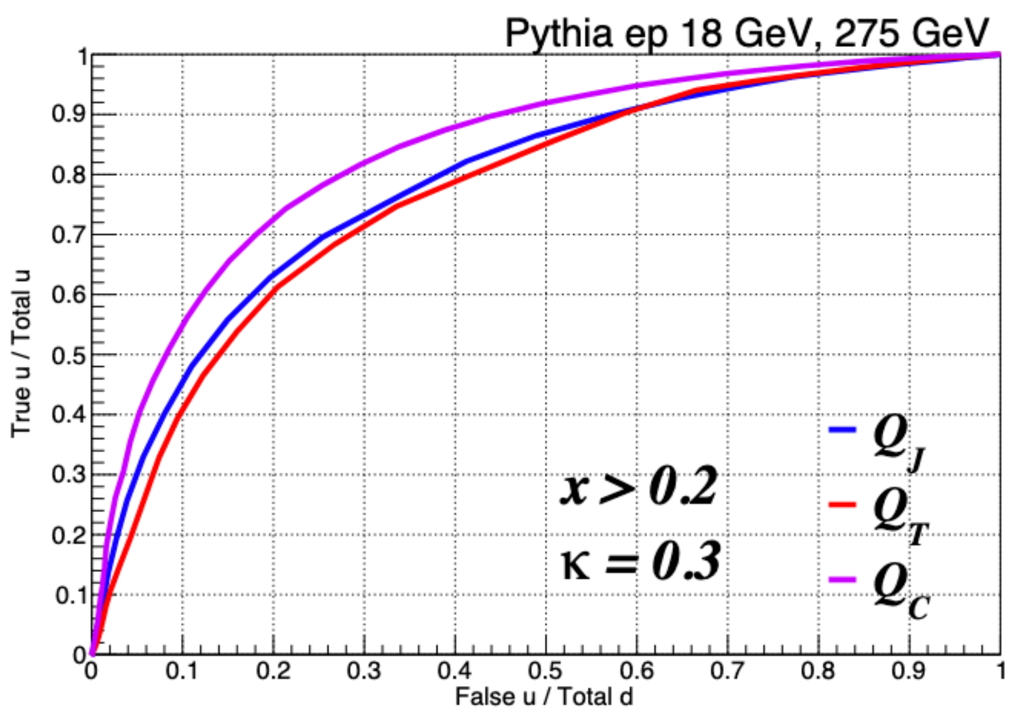
- u (+2/3) quark jet v.s. ud (+1/3) diquark remnant
- d (-1/3) quark jet v.s. uu (+4/3) diquark remnant





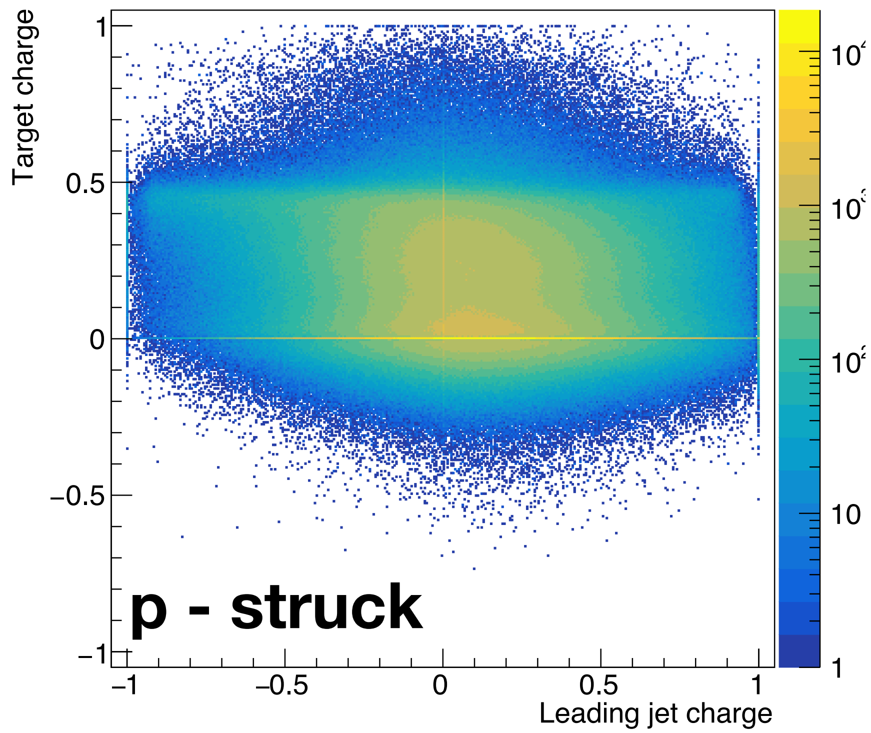
Leading jet and target jet charge

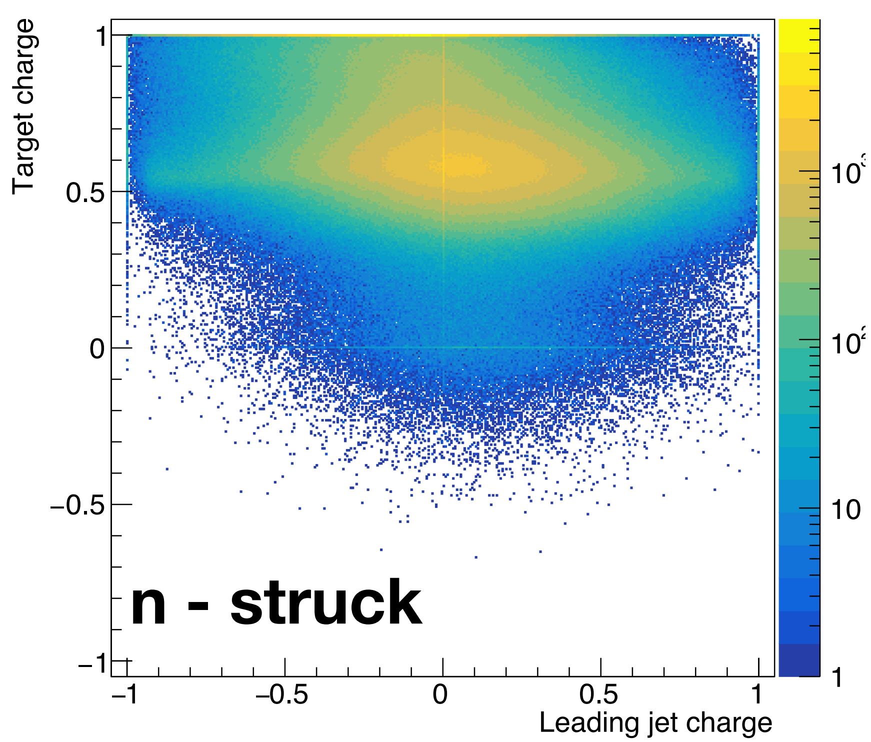


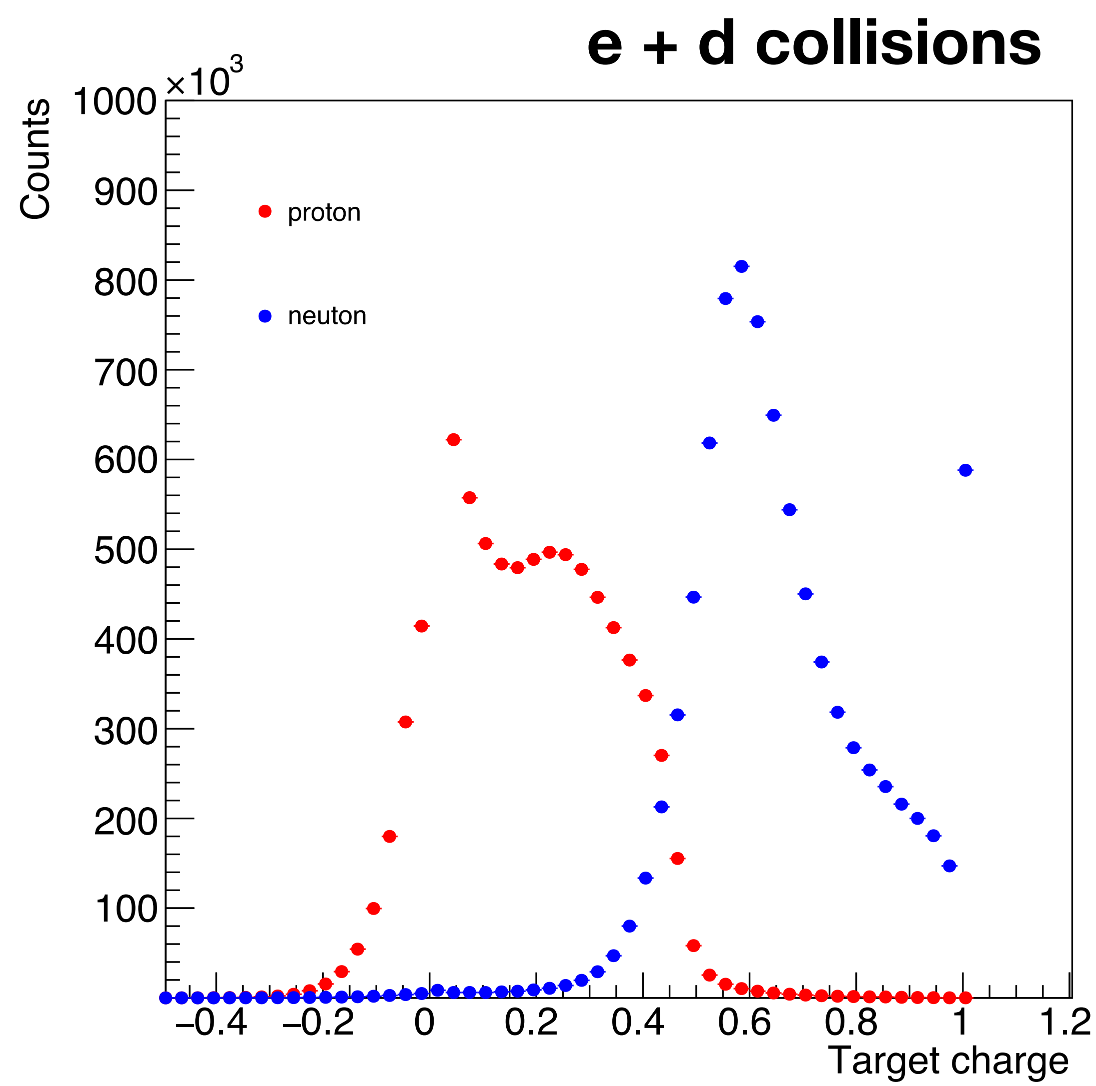


- Evaluate the information content with leading jet tagging
  - Using leading jet charge
  - Using target jet charge
  - Using both
- Target jet charge provides significantly extra information and improves the tagging performance

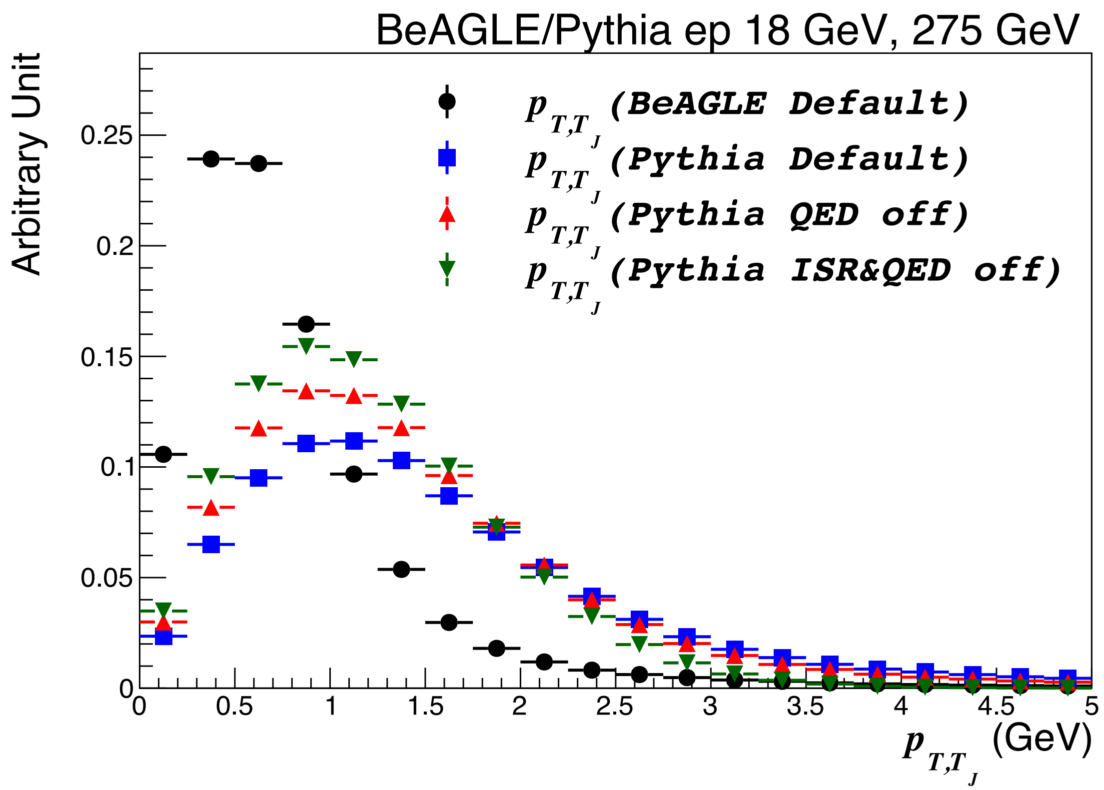
Leading jet and target jet charge

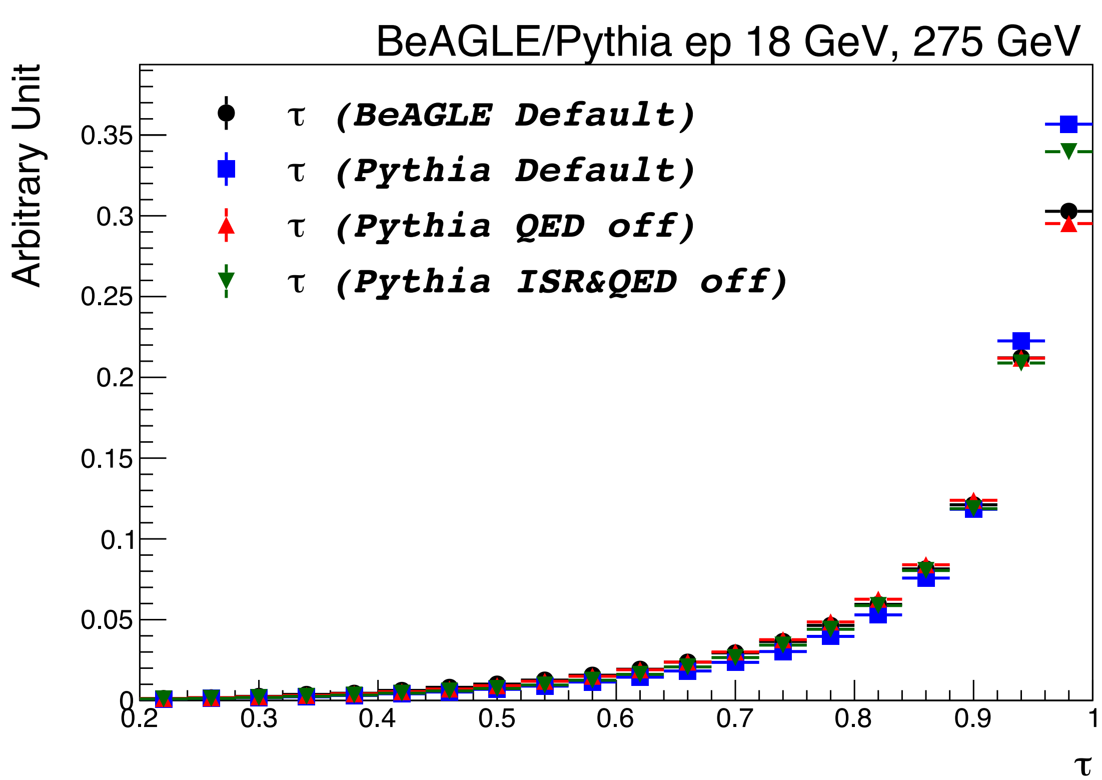






Target jet kinematics



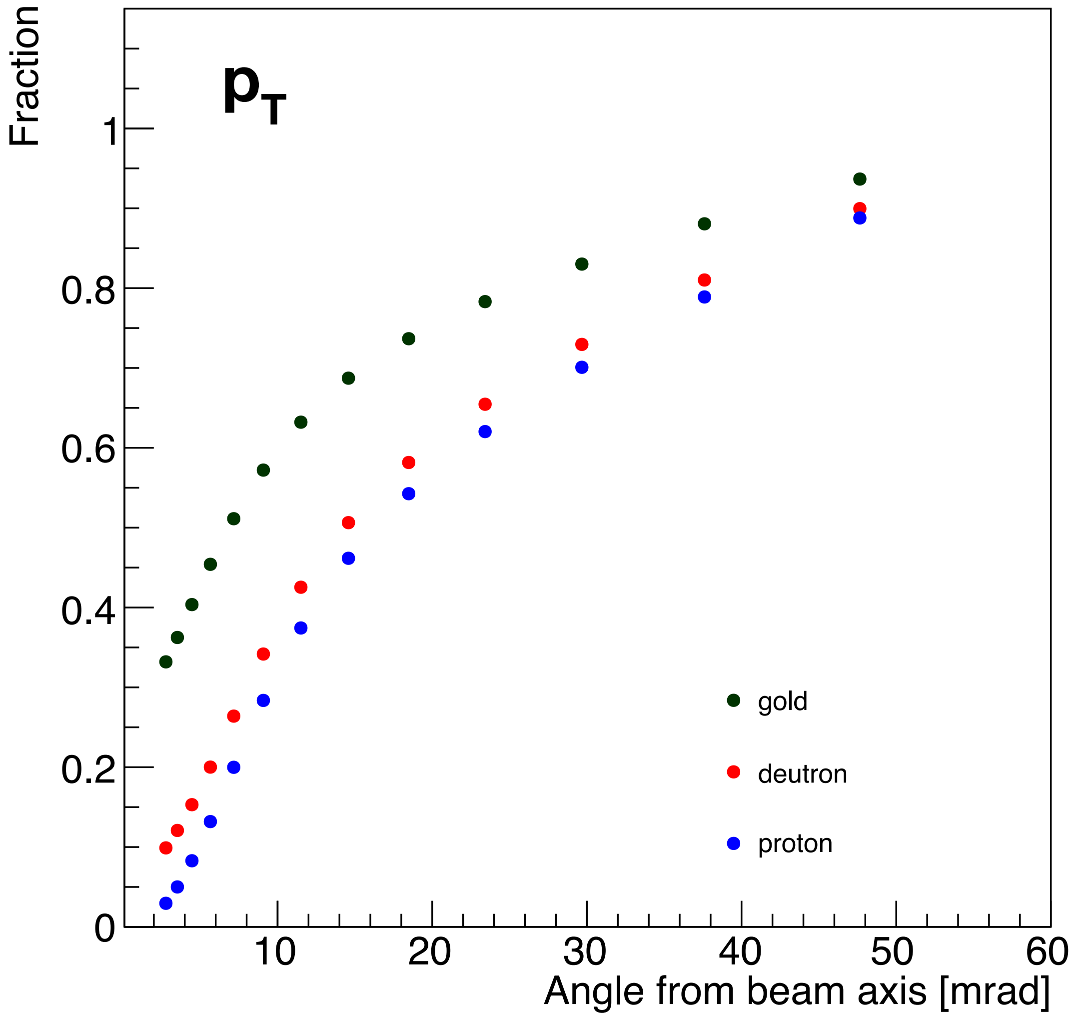


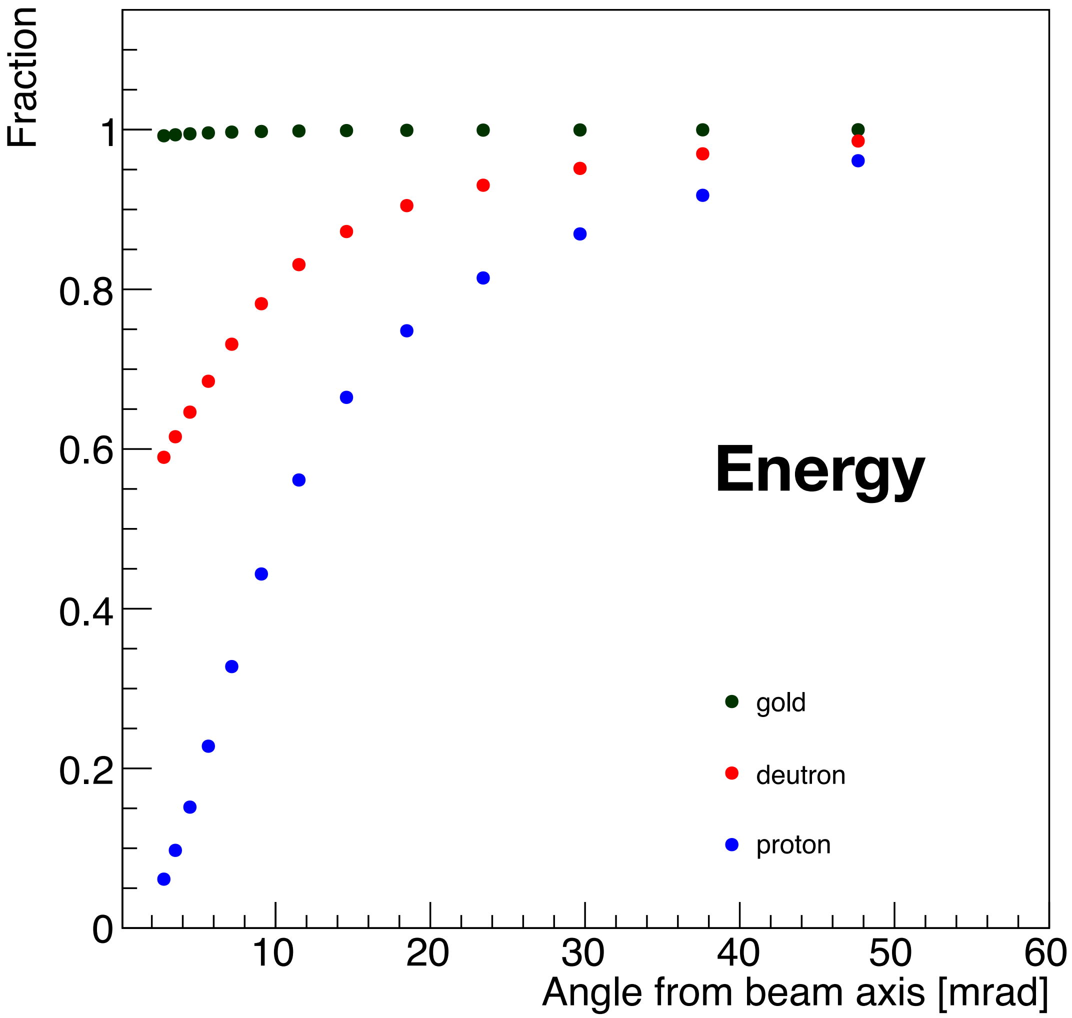
- The kinematic distribution of target jet
  - Transverse
  - Longitudinal
- Target jet has transverse momentum therefore asymmetric w.r.t. beam direction
- Significant difference between BeAGLE and Pythia 8
- Sizable effects from QED shower and ISR implemented in Pythia 8

$$\tau = \frac{p_{z,T_J}}{E_p}$$

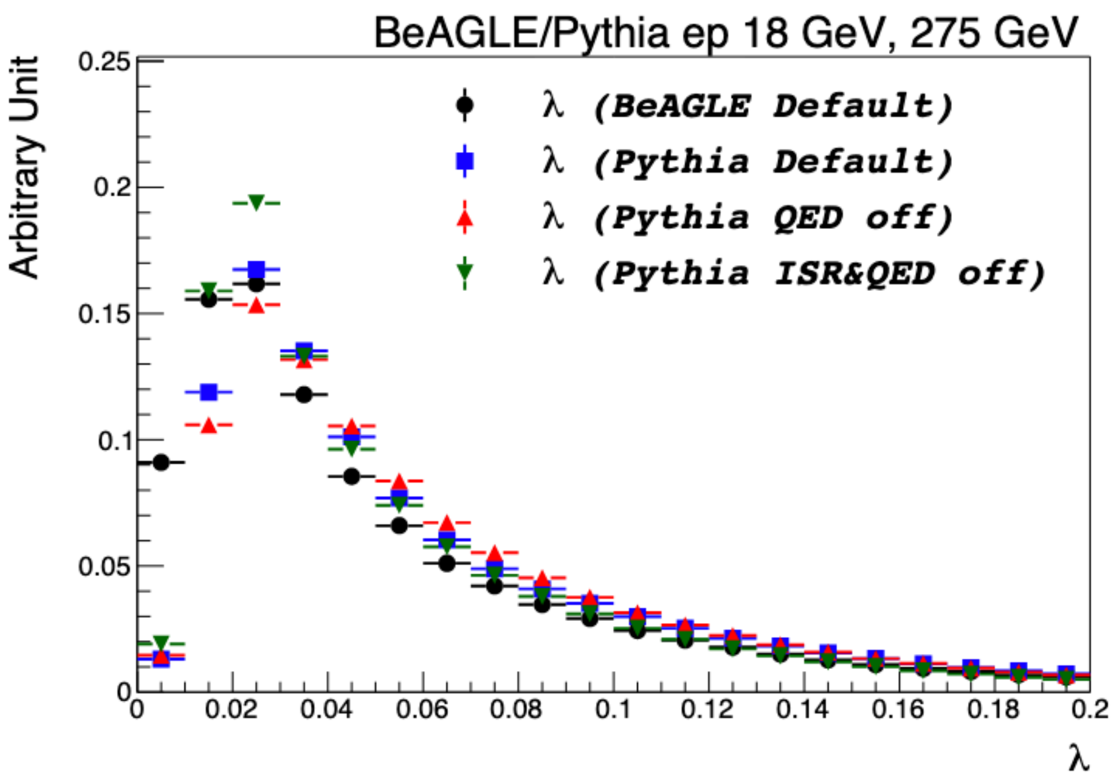
* Related to PDF
  $\tau \longleftrightarrow 1-x$?
* Target jet thrust

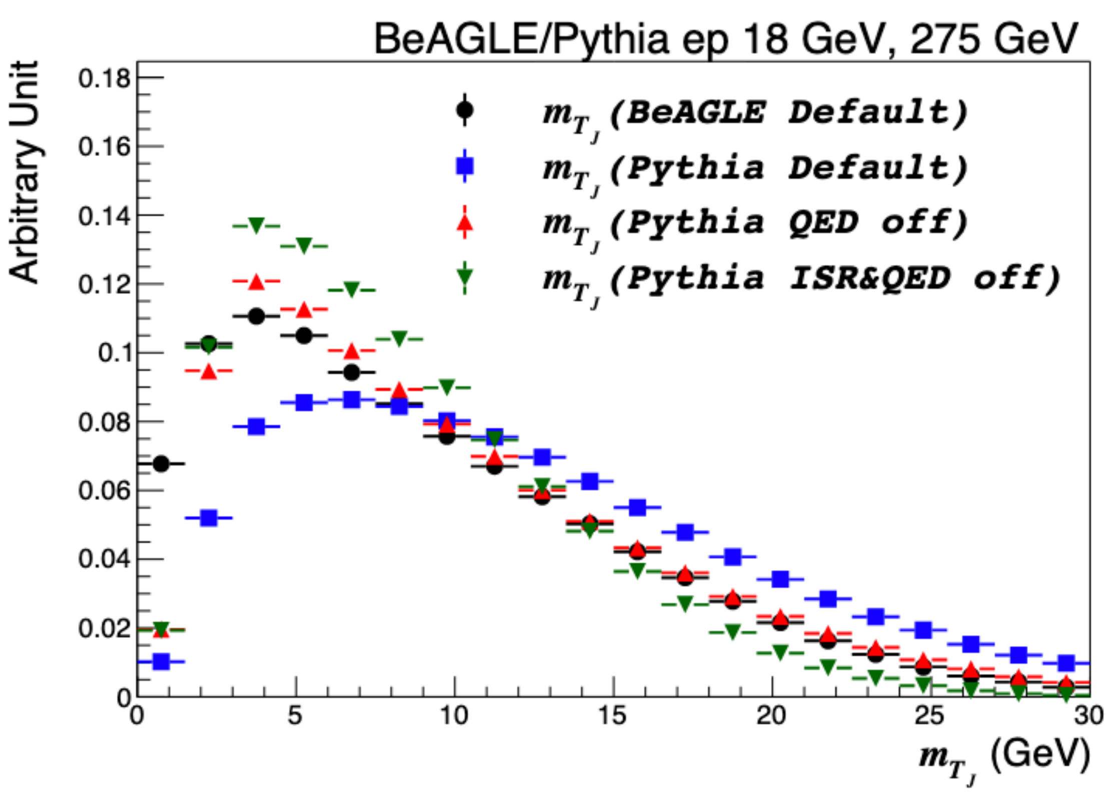
Target jet kinematics





Target jet substructure





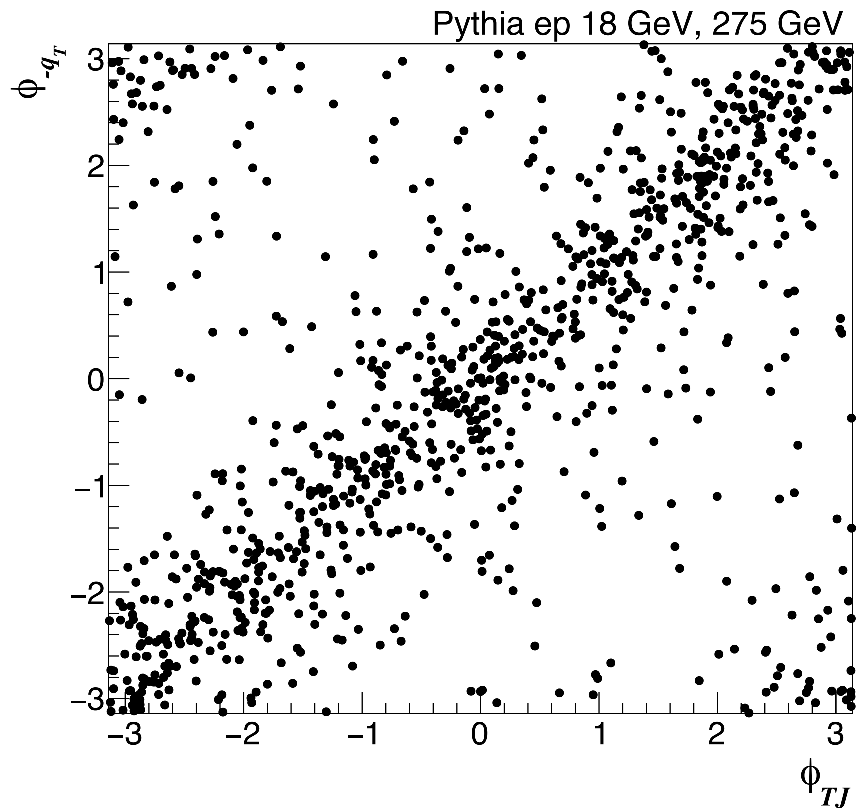
$$\lambda = \sum_{i \in S_T} \frac{e_i}{e_{T_J}} \left(\frac{\Delta R_i}{R_{T_J}} \right)^{\alpha}$$

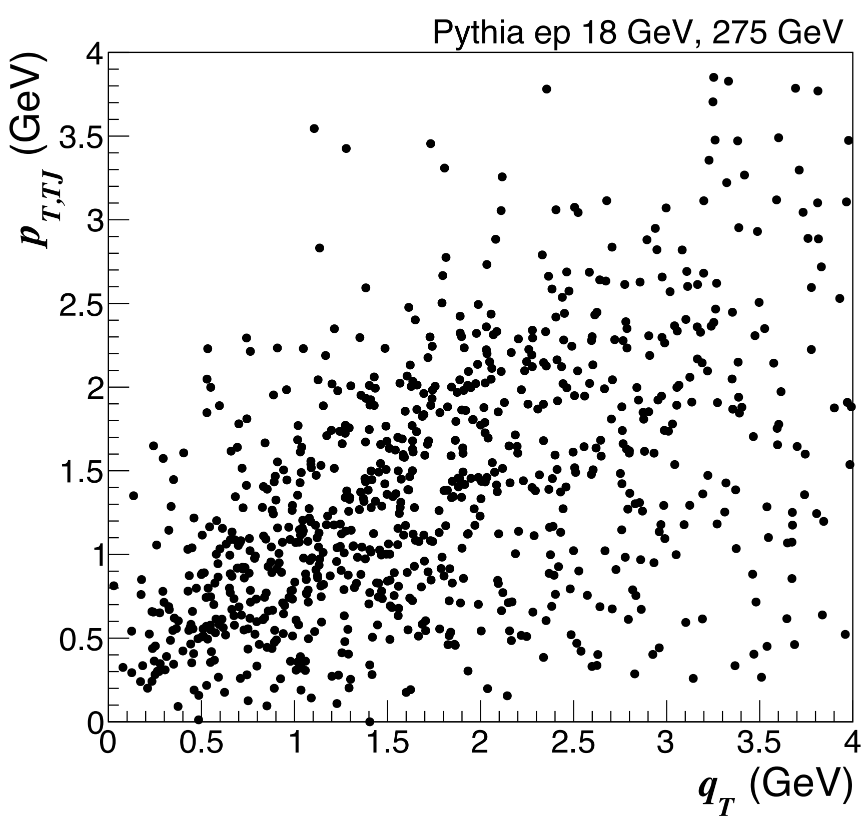
$\alpha = 1$

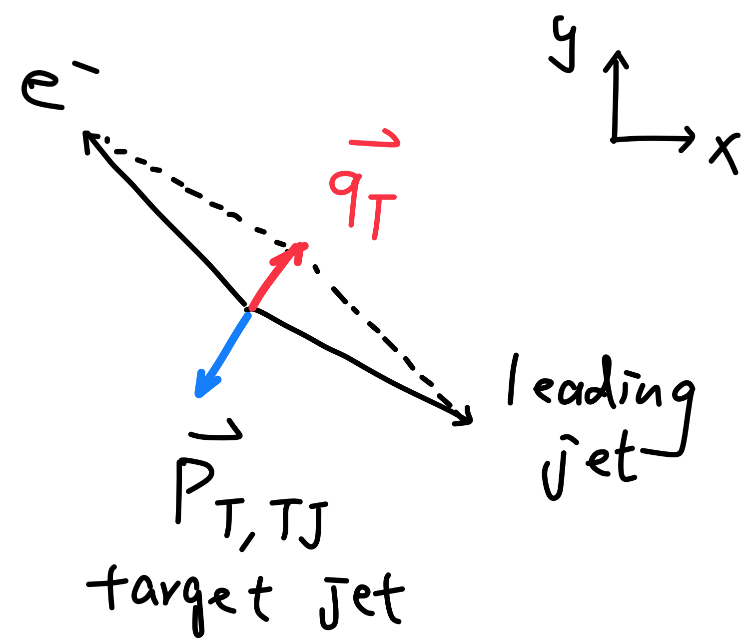
$\alpha = 2 \rightarrow$ mass

- Angularity and mass probe the spread out of target jet
- Target jet mass scale quite high
- Significant difference between BeAGLE and Pythia 8
- Sizable effects from QED shower and ISR implemented in Pythia 8

Current-target kinematic correlation



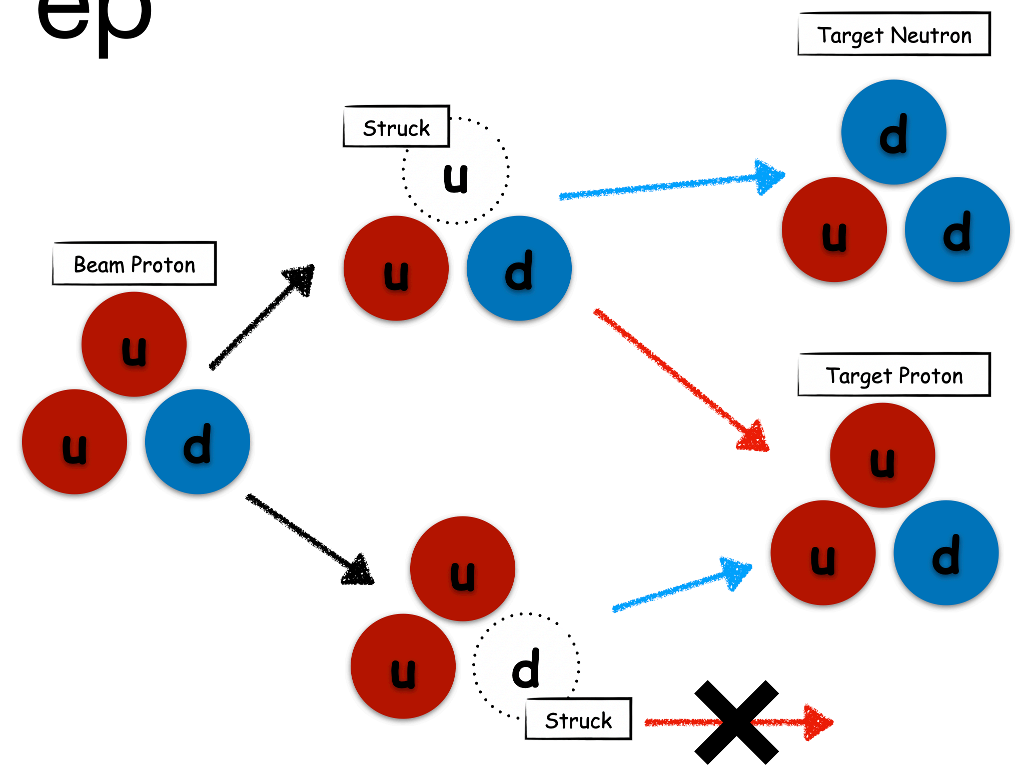


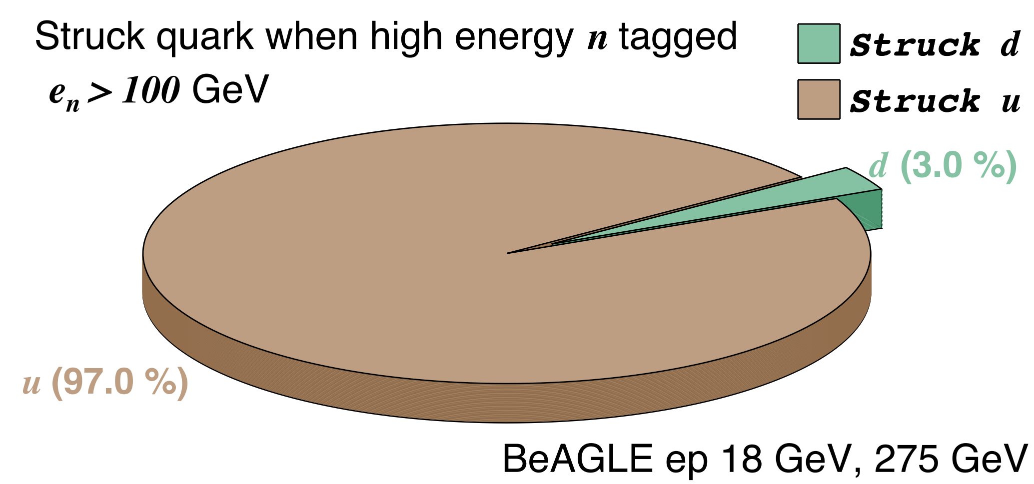


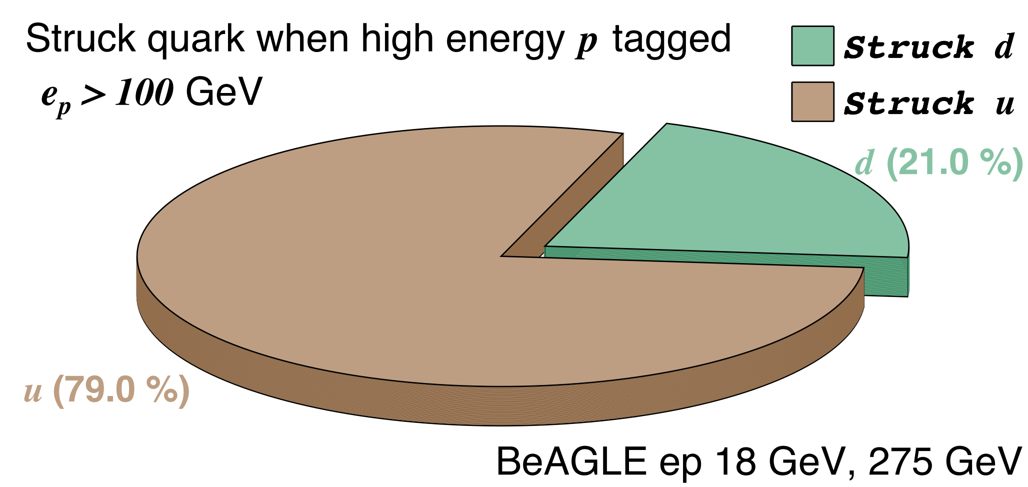
- q_T and target jet mostly back-to-back
- Target jet transverse momentum increases with q_T
- Strong current-target kinematic correlation
  - Energy-momentum conservation at play within these two energy flows

Target tagging: ep

- Effect of tagging forward, energetic neutron
  - High probability of knocking out the u quark, directly probes u distribution
  - Having to knock out a u to turn proton into neutron?
- Effect of tagging forward, energetic proton
  - Both partonic channels are possible
  - How does uu diquark hadronize?

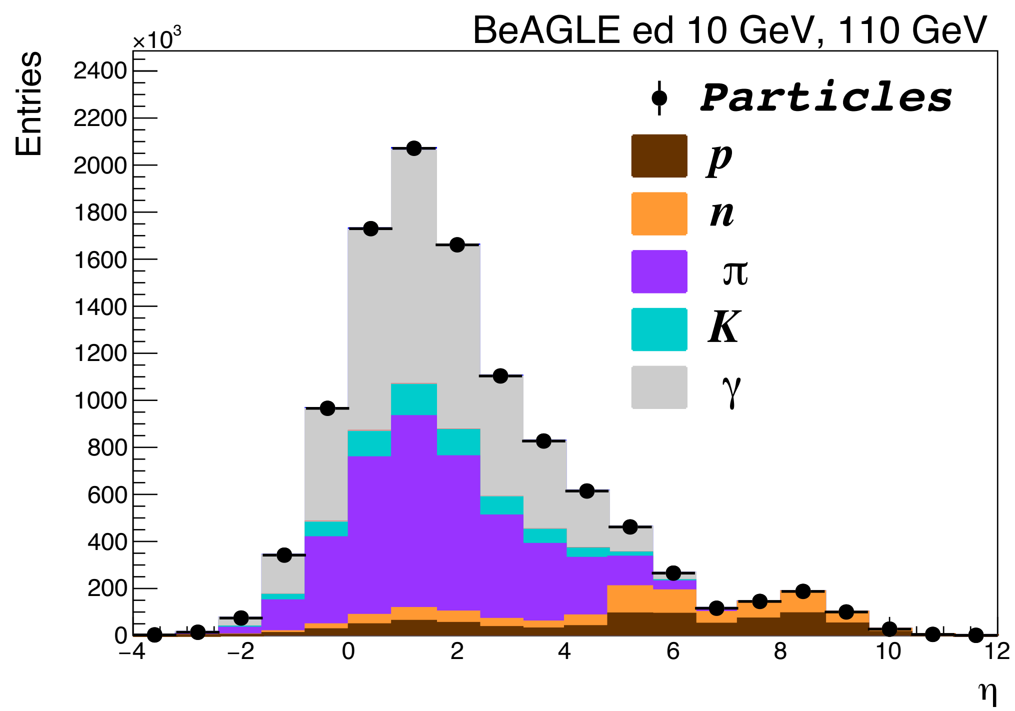


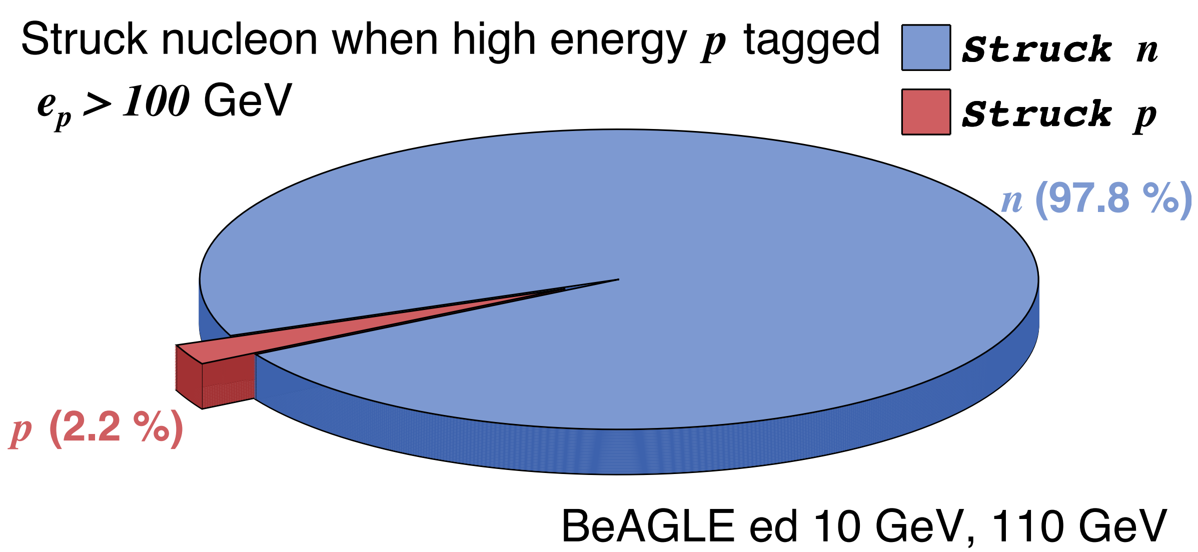


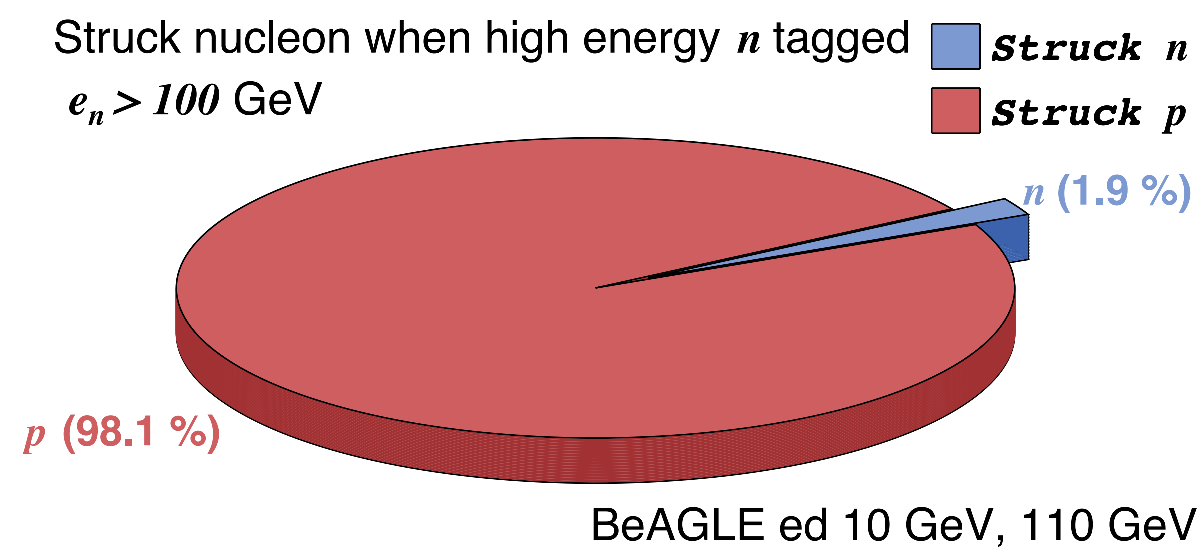


Target tagging: ed

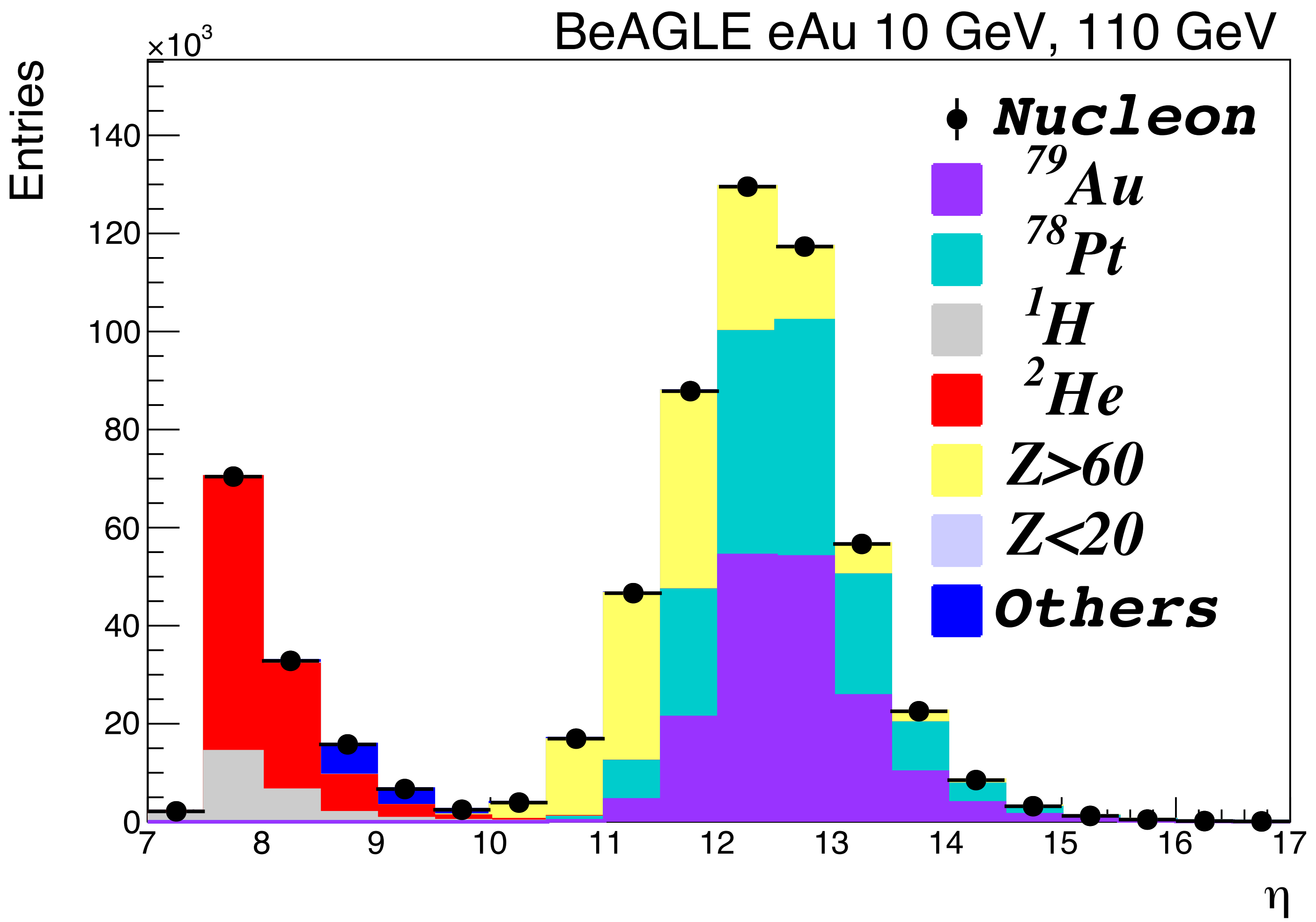
- Proton and neutron within deuteron tends to be more "self-contained"
  - Knocking one out would have the other released
  - Opportunity to probe neutron concretely

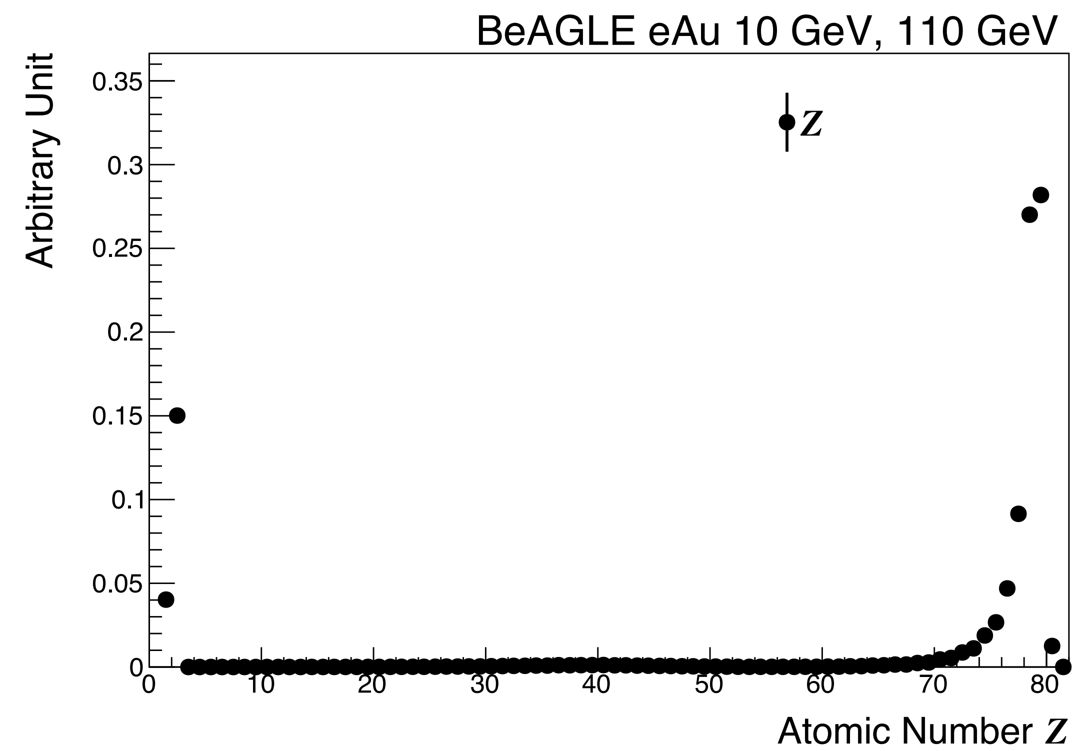


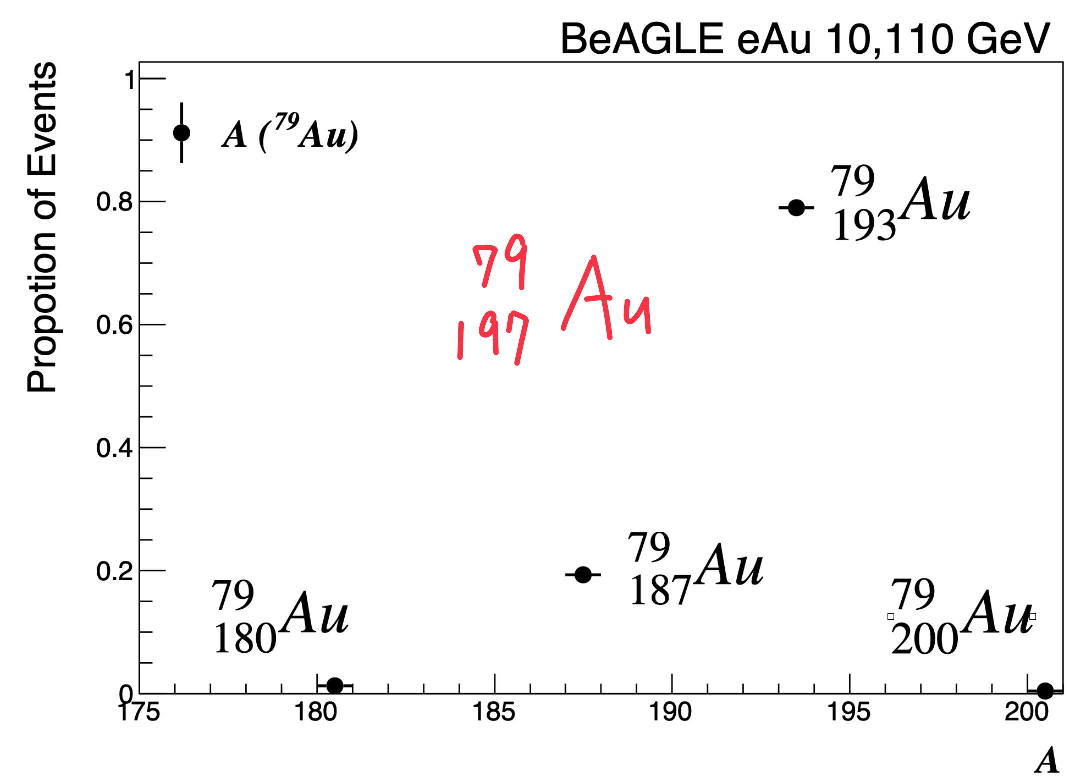




Target tagging: eAu

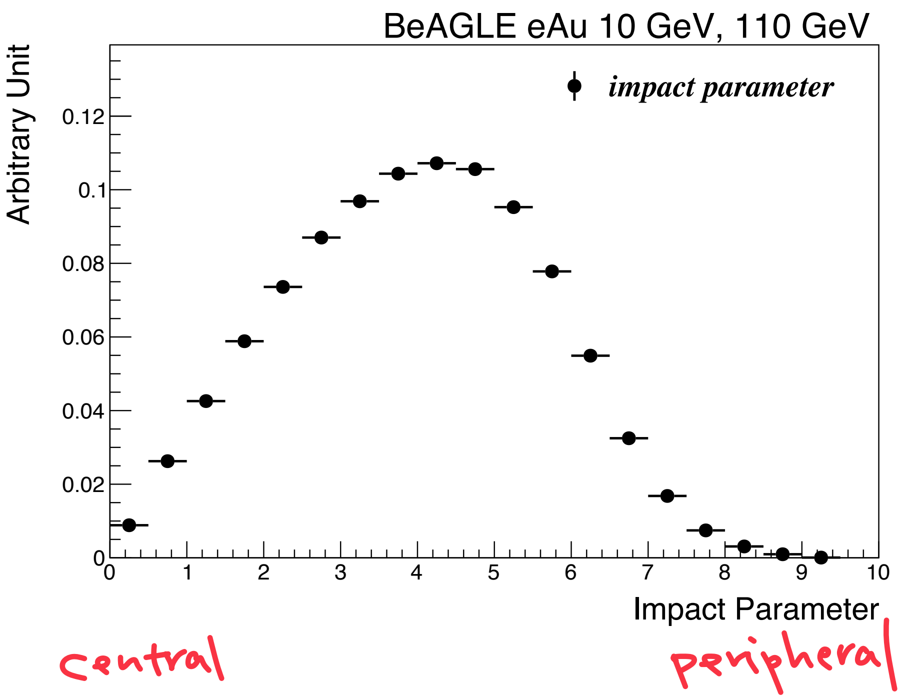


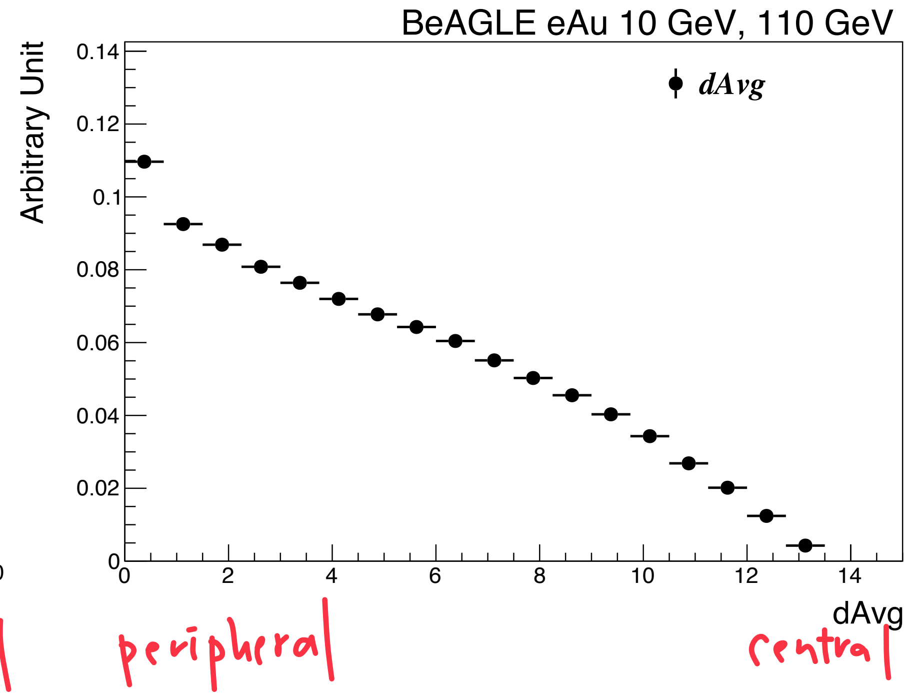


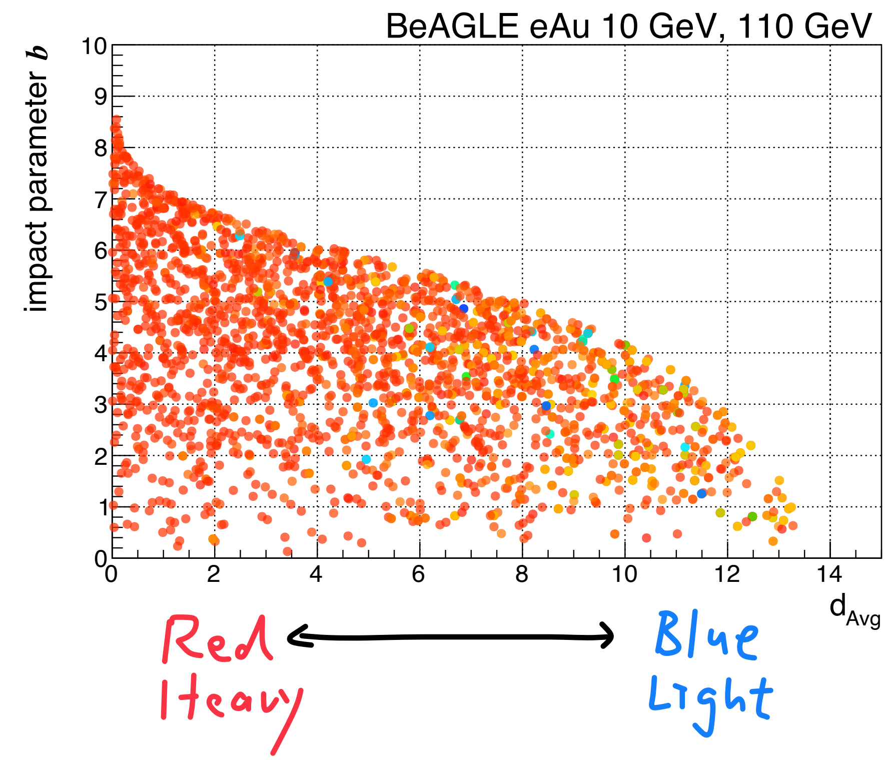


- Most of the time Au breaks very asymmetrically
- Sometimes Au breaks quite symmetrically
- Neutron content of Au can change significantly

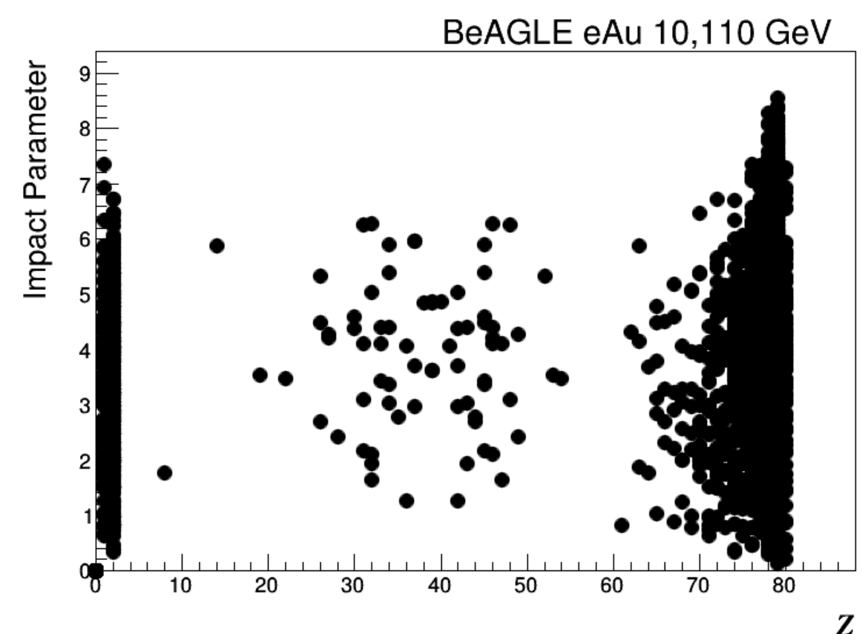
Where does DIS happen?







- Mapping DIS position using impact parameter and dAvg
  - dAvg: average density-weighted distance from all inelastic collisions to the edge of the nucleus
  - Connection to nuclear breakup and other final state particles to be explored



Conclusions

- Target jet contains rich information awaiting us to uncover, if we can measure it
- Knowledge of target jet not only broadens the scope of EIC physics into nuclear dynamics, through current-target correlation it can also help constrain proton and ion 3D structure
- An "ultimate" QCD machine may not want to miss this sector of phenomenology
- Many of the target jet substructure studies ongoing, including soft-drop grooming, factorization, etc.

Thank you for your attention!