EIC Event Generator and Jet Physics

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Outline

- **Introduction**
- Overview of BeAGLE
- Overview of DJANGOH
- Key Differences between BeAGLE and DJANGOH
- Analysis and Comparisons
- Summary and Conclusion

Introduction

- MC event generators - **BeAGLE** and **DJANGOH** especially **tuned for electron-ion collision**, which can be used to simulate EIC collisions.

- **Target Jet Substructure** - proposed to analyze the internal energy flow of target jets in electron–ion collisions to uncover nuclear effects and so on.

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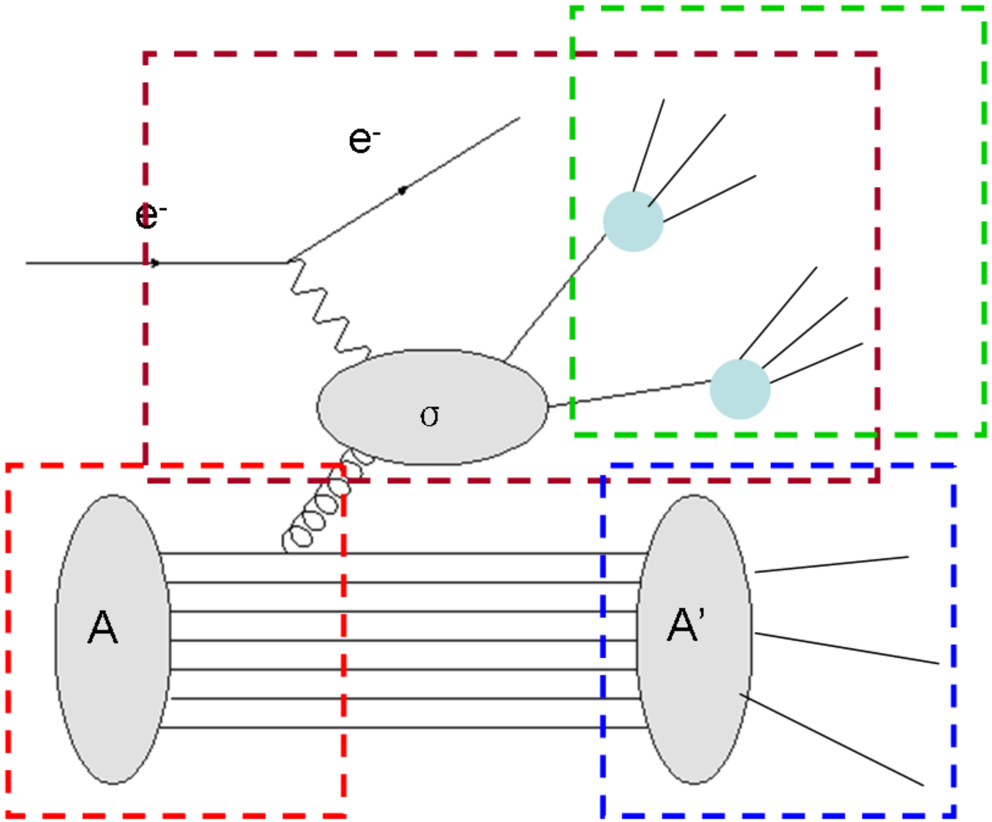
Overview of BeAGLE[1][2]

- **Purpose** : A Monte Carlo event generator for eA collisions, modeling both hard scattering and nuclear remnants.
- **Core idea** : Combines modern parton-level DIS modeling with realistic nuclear geometry and transport. Incorporating nPDFs and parton energy loss, BeAGLE reproduces essential nuclear effects in electron–nucleus collisions.

Overview of BeAGLE[1][2]



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

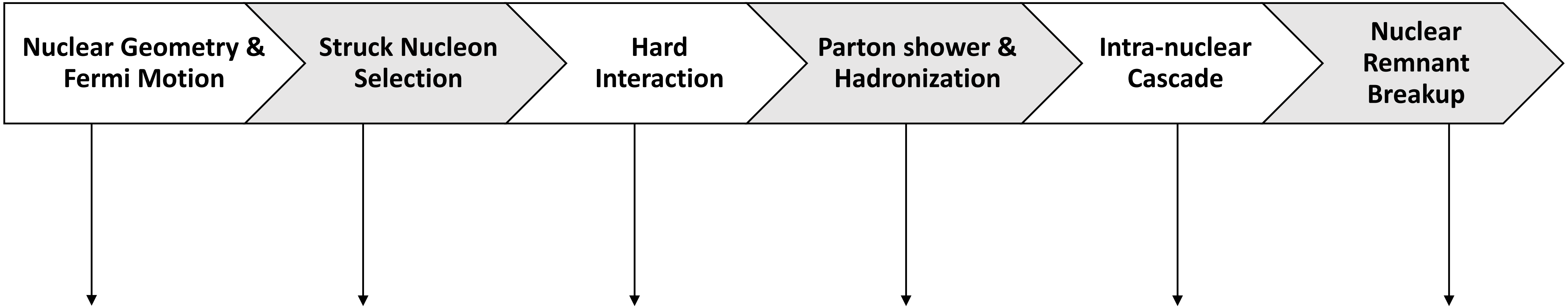
Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

Overview of BeAGLE [1][2]

Physics Architecture and Simulation Flow



BeAGLE core + PyQM

Nucleons are distributed in the nucleus with Woods–Saxon geometry and intrinsic Fermi motion.

Glauber model + EPS09 nPDFs (via LHAPDF)

A struck nucleon is chosen via a Glauber model and weighted by nuclear PDFs.

PYTHIA-6

The virtual photon interacts with the struck nucleon at parton level, with cross sections from PYTHIA-6 scaled by nuclear PDFs.

PYTHIA-6 (Lund string) + PyQM (energy loss)

Partons shower & Hadronization through the Lund string model, with optional energy loss.

DPMJet

Produced hadrons propagate through the nucleus, possibly undergoing secondary interactions.

FLUKA

The excited residual nucleus decays via evaporation, fission, breakup, and photon emission.

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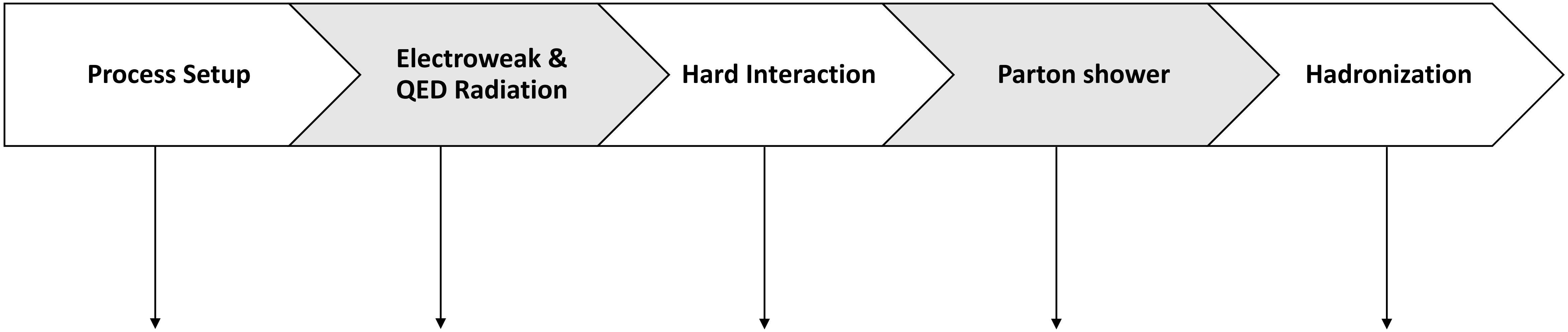
Overview of DJANGOH[3][4]

- **Purpose** : To simulate DIS e–p (NC/CC) scattering with QED and QCD radiation by interfacing HERACLES and LEPTO, **extended for EIC studies via nuclear PDFs through LHAPDF**.

- **Core idea** : **HERACLES** provides complete one-loop electroweak and QED radiative corrections, coupled with **LEPTO** for parton-level DIS; hadronization is modeled using the **JETSET/LUND** string model, while **SOPHIA** generates low-mass hadronic final states.

Overview of DJANGOH[3][4]

Physics Architecture and Simulation Flow



LEPTO (with LHAPDF)

Define DIS kinematics (NC/CC), and select PDFs via LHAPDF.

HERACLES

Provides full one-loop electroweak corrections, photon emission from lepton/quark lines, and QED radiative effects.

LEPTO (PDFs via LHAPDF)

Virtual photon (or W/Z) interacts with struck quark, using PDFs to describe the structure.

LEPTO / ARIADNE

Generates QCD cascades: gluon emission and parton showering before hadronization.

JETSET (LUND), SOPHIA

Hadronisation through the LUND string fragmentation model (JETSET); if the hadronic mass is too low, the final state is generated by SOPHIA.

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Key Difference between BeAGLE and DJANGOH

BeAGLE operates at the nucleus scale (eA), while DJANGOH remains at the nucleon scale (ep)

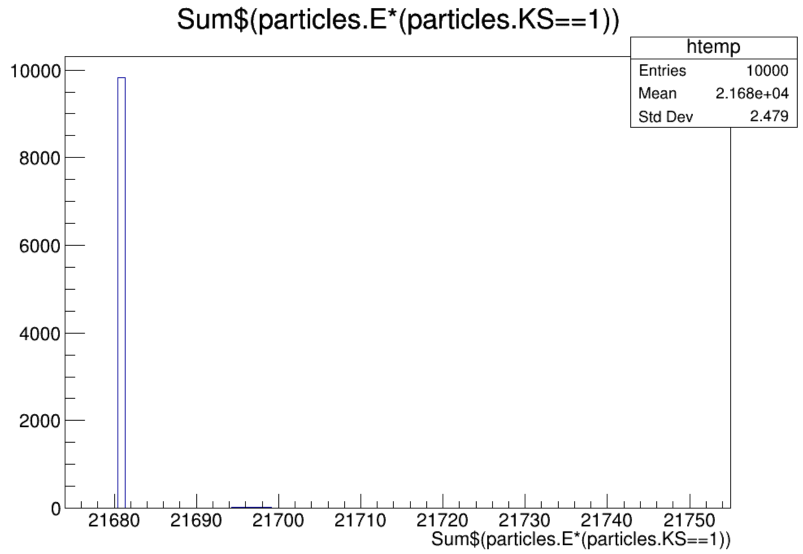
BeAGLE simulates the **full nucleus with cascading and breakup**, while DJANGOH **only sees the struck nucleon with nPDFs corrections**

Key Difference between BeAGLE and DJANGOH

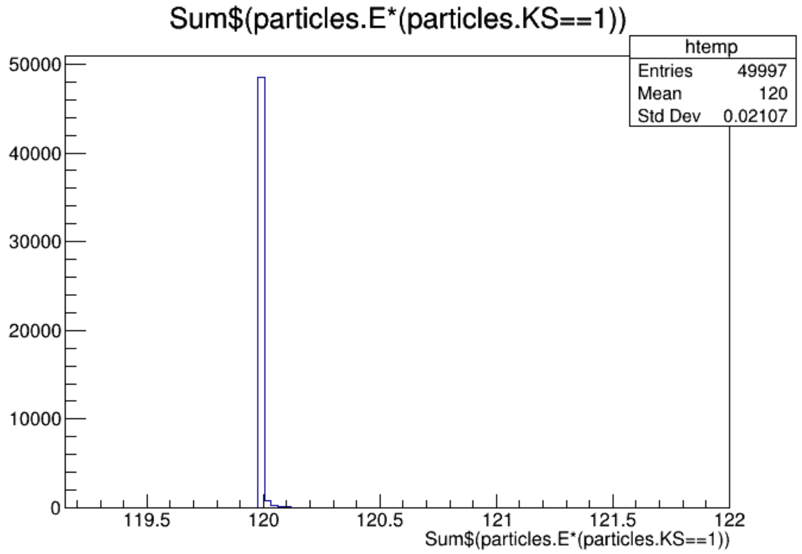
- **BeAGLE** : Models the **entire nucleus (eA)**—including nuclear geometry (Glauber), Fermi motion, intra-nuclear cascade (INC), and remnant de-excitation/breakup (FLUKA), with optional parton energy-loss (PyQM).
- **DJANGOH** : Essentially a **single-nucleon (ep)** DIS generator. **The EIC upgrade adds access to nPDFs via LHAPDF**, which replaces the free-nucleon PDFs used by LEPTO—modifying cross sections and parton densities—but **does not** introduce nuclear geometry, in-medium transport, or target-fragmentation modeling.

Key Difference between BeAGLE and DJANGOH

- In e–Au collisions (10 GeV electron on 110 GeV per nucleon), BeAGLE records about 21,680 GeV total energy since it includes the full gold nucleus (A≈197), while DJANGOH gives only ~120 GeV because it simulates scattering off a single nucleon.



BeAGLE Sample



DJANGOH sample

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Analysis and Comparisons

Simulation tools & Generator Versions

System	BeAGLE v1.03.02	DJANGOH 4.6.10	Other tools
WSL2	FLUKA 2024.1	LHAPDF 5.9.1	Fastjet 3.4.3
Ubuntu 22.04	LHAPDF 5.9.1	CERNLIB 2024.09.16.0	eic-smear 1.1.12
	RAPGAP 3.302		HepMC3 3.2.7
	PYTHIA 6.4.28		
	DPMJET 3.0-5		
	PHOJET 1.12		

Analysis and Comparisons

- The outputs of BeAGLE and DJANGOH are processed with the eic-smear package, writing them to a ROOT file in a tree data structure.
- Some analysis is performed after jet clustering with the anti-kt algorithm (R = 0.7), implemented via FastJet.

Analysis and Comparisons

sample production for ep, ed and eAu collision

We study three collision systems (**e-p, e-d, e-Au**), each with **two BeAGLE** samples and **one DJANGOH** sample

ep (18/275 GeV/c)

1. e18p275 (BeAGLE)
2. my Beagle (BeAGLE)
3. my Djangoh (DJANGOH)

ed (10/110 GeV/c)

1. e10d110 (BeAGLE)
2. my Beagle (BeAGLE)
3. my Djangoh (DJANGOH)

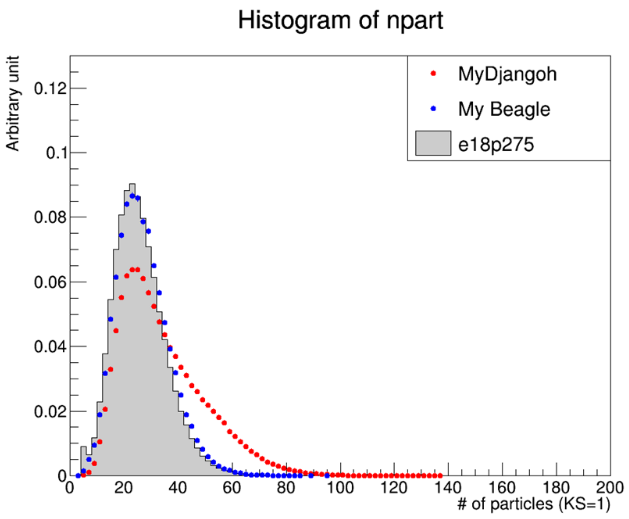
eAu (10/110 GeV/c)

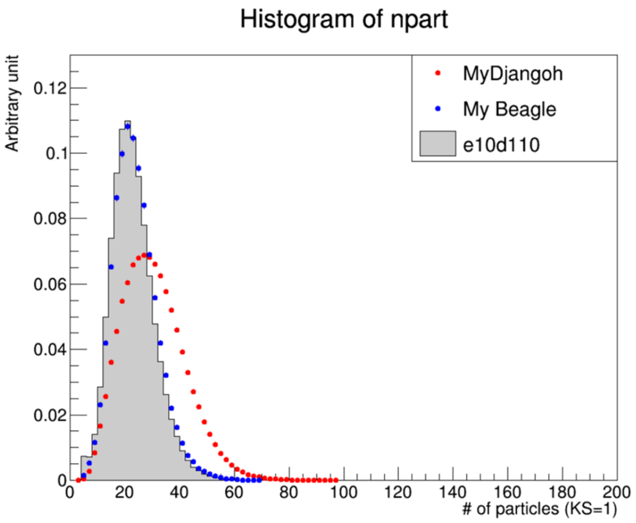
1. e10Au110 (BeAGLE)
2. my Beagle (BeAGLE)
3. my Djangoh (DJANGOH)

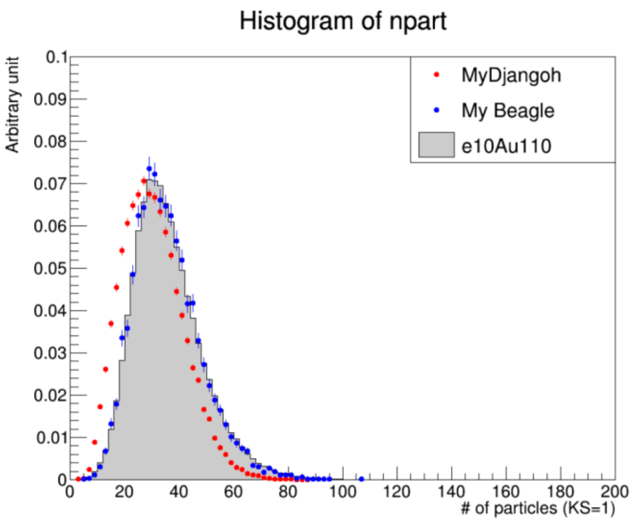
Analysis and Comparisons

collision **before** jet clustering

KS = 1 stand for final state particles





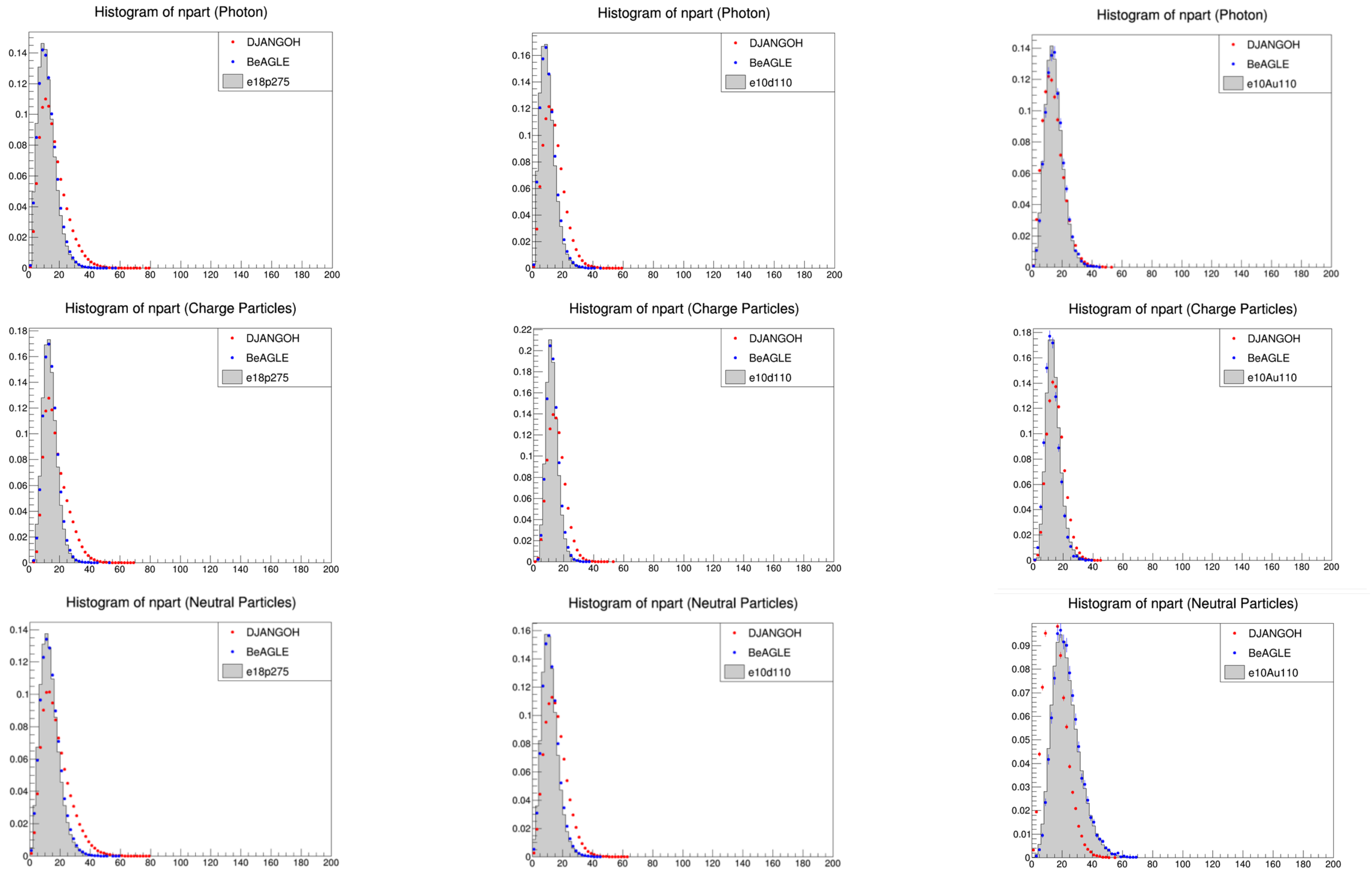


BeAGLE's INC and remnant breakup strengthen A-scaling—more soft secondaries

in heavy nuclei, while DJANGOH stays parton-level with weak A-scaling

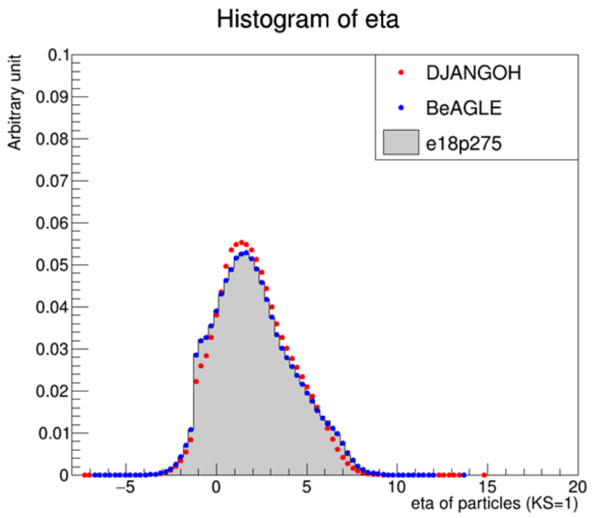
Analysis and Comparisons

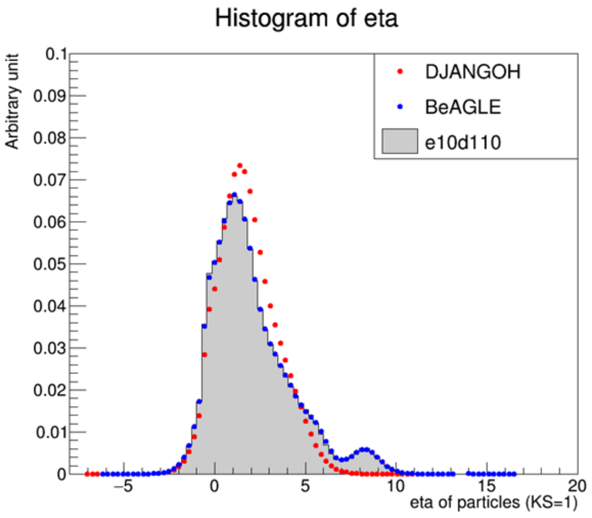
collision **before** jet clustering – multiplicities by particle type

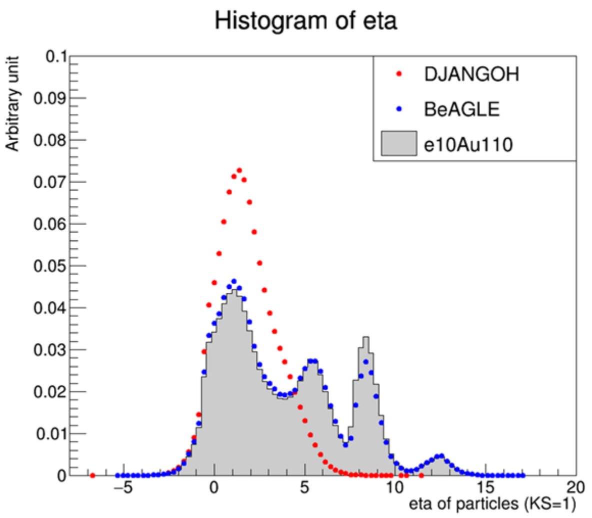


- BeAGLE's INC and remnant breakup yield many soft neutrals, making neutral multiplicities differ most from DJANGOH—especially in e–Au.

Analysis and Comparisons
collision **before** jet clustering – Eta distribution







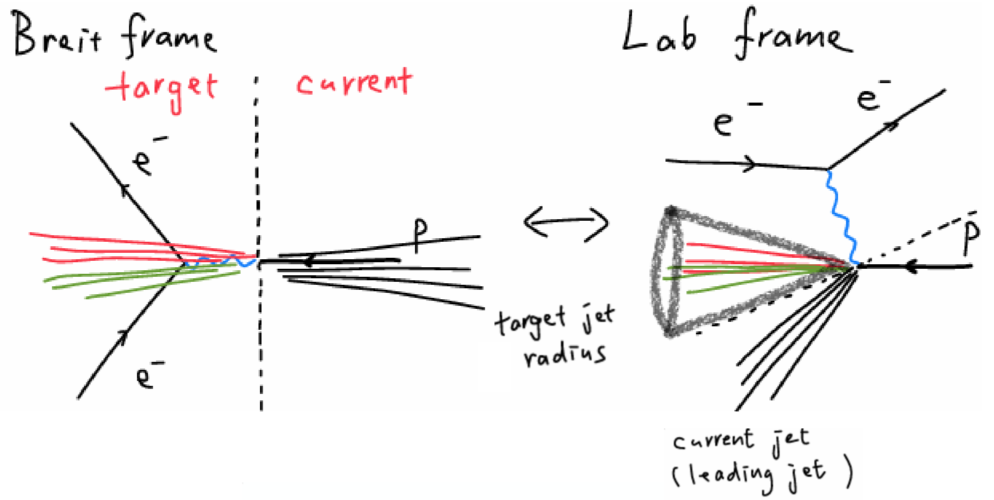
BeAGLE exhibits an additional forward (high-η) peak that is absent in DJANGOH, with the

effect strengthening from e-p to e-d to e-Au

Analysis and Comparisons

Target Jet Substructure[6][7]

- We classify the jet into **electron-leading jet** and **target jet** by define current region and target.
- η_t is proposed to define a "Target Jet" in lab frame, including all particles which $\eta > \eta_t$.
- Define **leading jet charge, target jet charge** and **combined charge**.

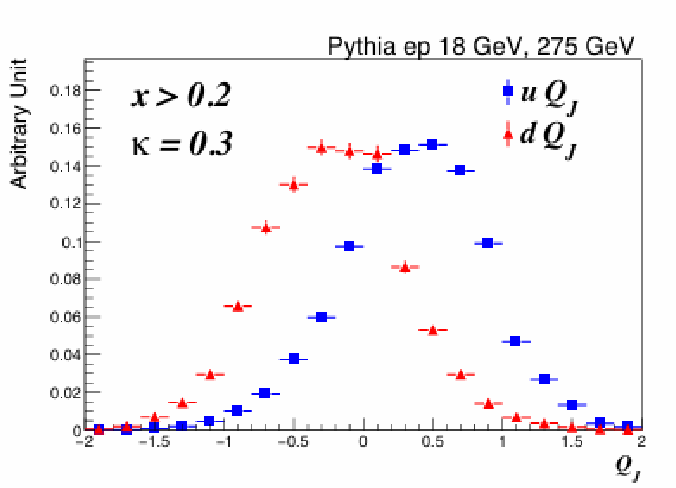


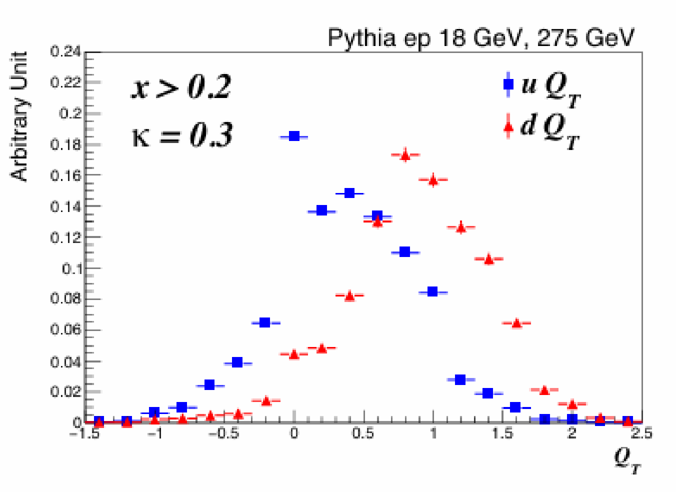
$$\eta_t = \log \frac{\sqrt{1 + \frac{E_e}{x^2 E_p}\frac{Q^2}{E_{CM}^2 - Q^2/x}} - 1}{\sqrt{\frac{E_e}{x^2 E_p}\frac{Q^2}{E_{CM}^2 - Q^2/x}}}$$

$$Q_J = \sum_{i \in L_J} z_i^{\kappa} Q_i\,, \quad z_i = \frac{p_{T,i}}{p_{T,L_J}} \qquad Q_T = \sum_{i \in T_J} z_i'^{\kappa} Q_i\,, \quad z_i' = \frac{e_i}{e_{T_J}} \qquad Q_c = Q_J - Q_T$$

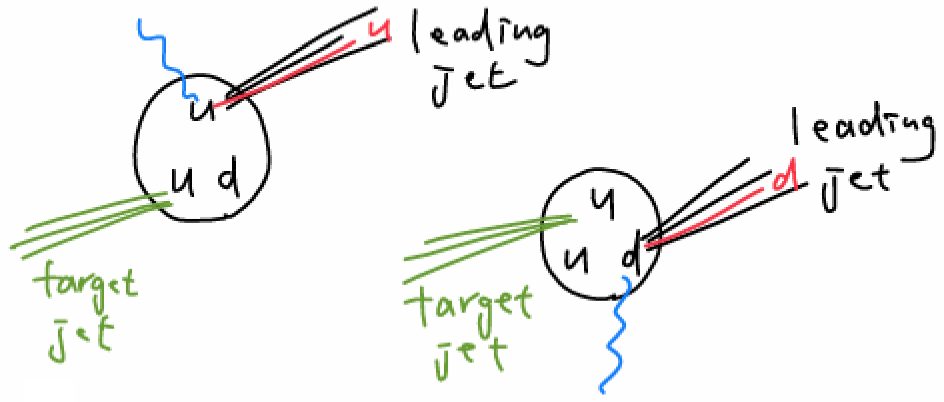
Analysis and Comparisons

Target Jet Substructure[6][7]



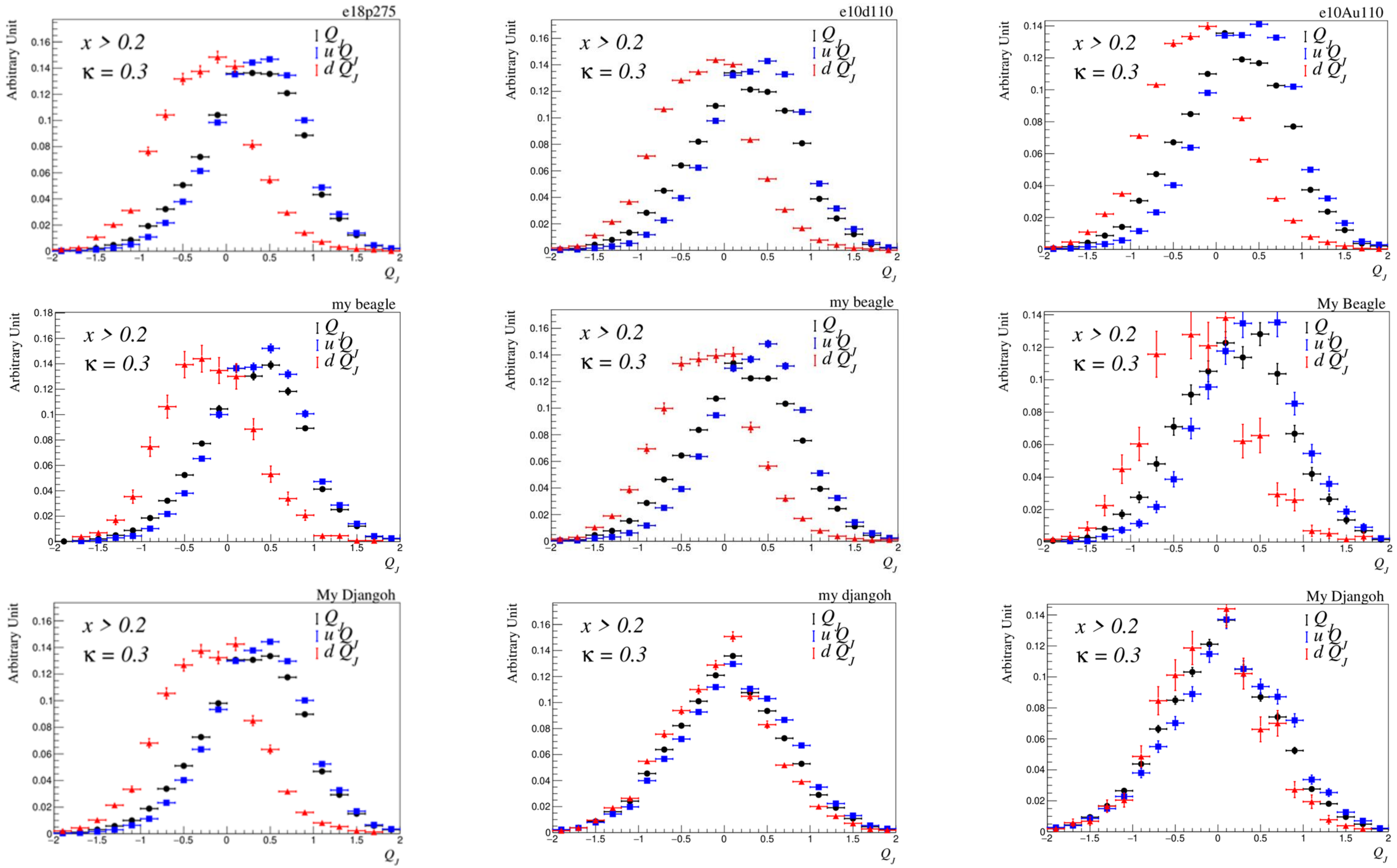


- u (+2/3) quark jet v.s. ud (+1/3) diquark remnant
- d (-1/3) quark jet v.s. uu (+4/3) diquark remnant



Analysis and Comparisons

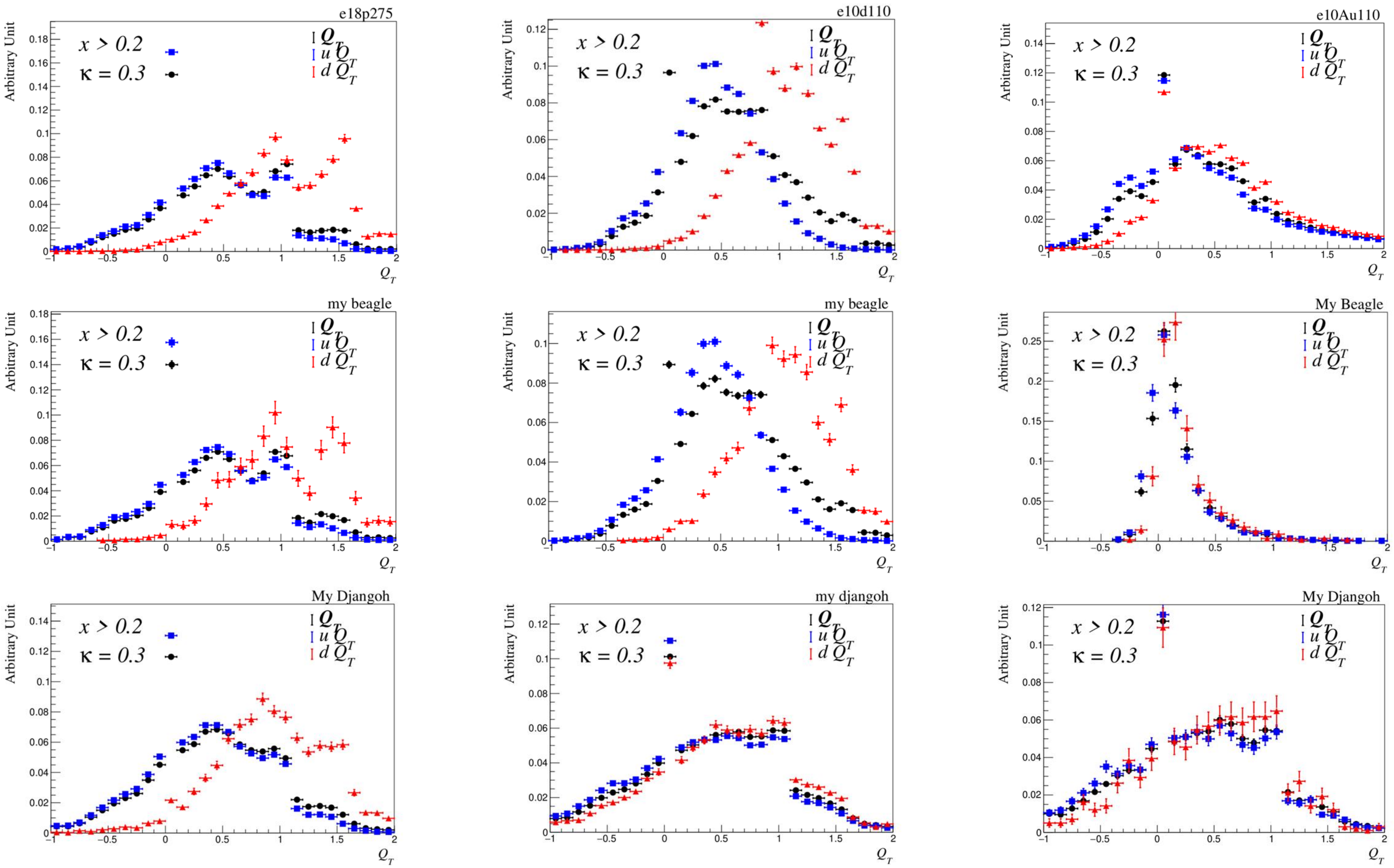
collision **after** jet clustering – Jet charge



- BeAGLE keeps u/d separation in jet charge from e-p to e-Au.
- DJANGOH shows it only in e-p, with e-d/e-Au collapsing near zero.

Analysis and Comparisons

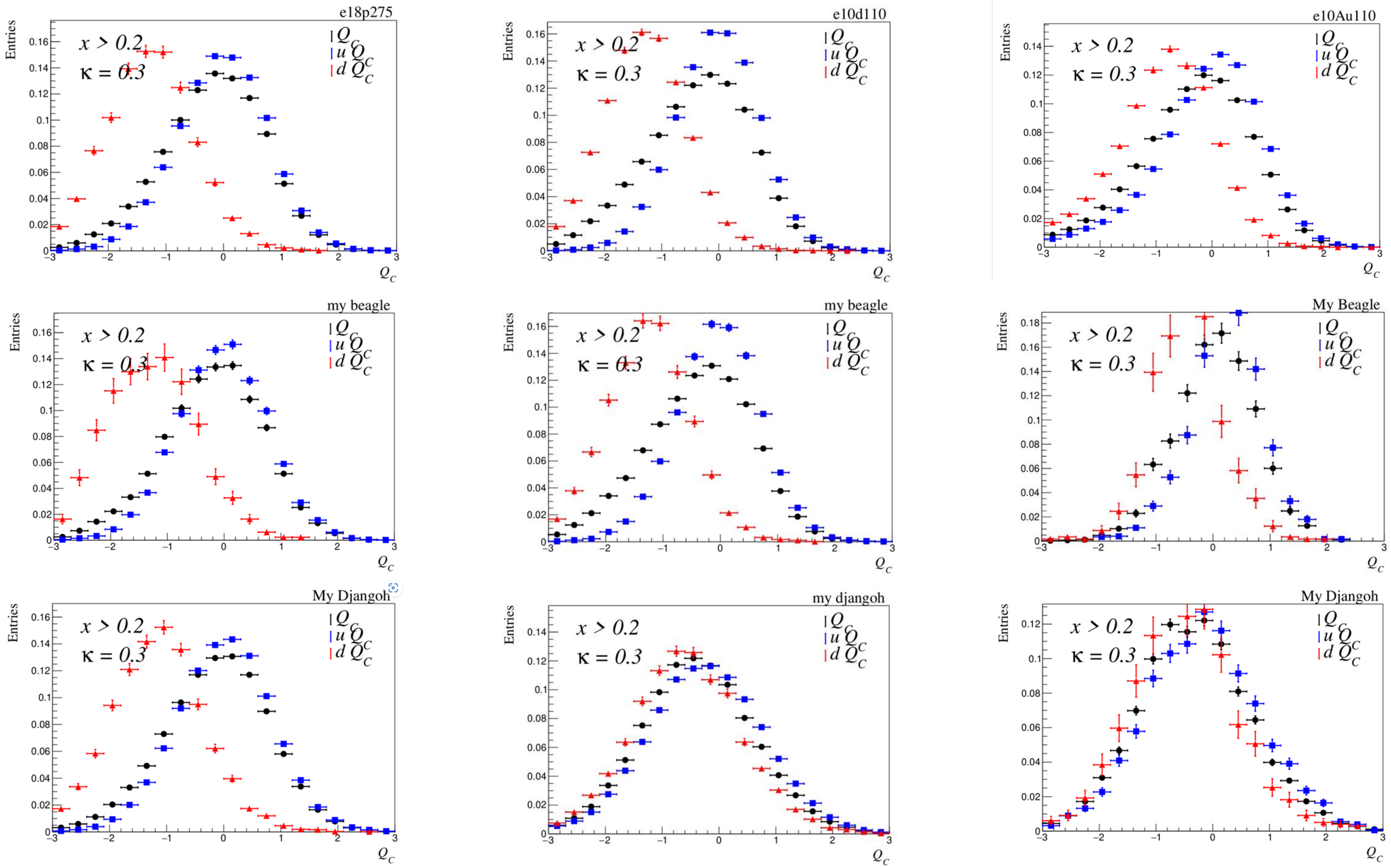
collision **after** jet clustering – Target charge



- In the target-charge distributions, both BeAGLE and DJANGOH show a clear u/d separation in e-p and partially in e-d.
- But in e-Au, the distinction disappears for both generator.

Analysis and Comparisons

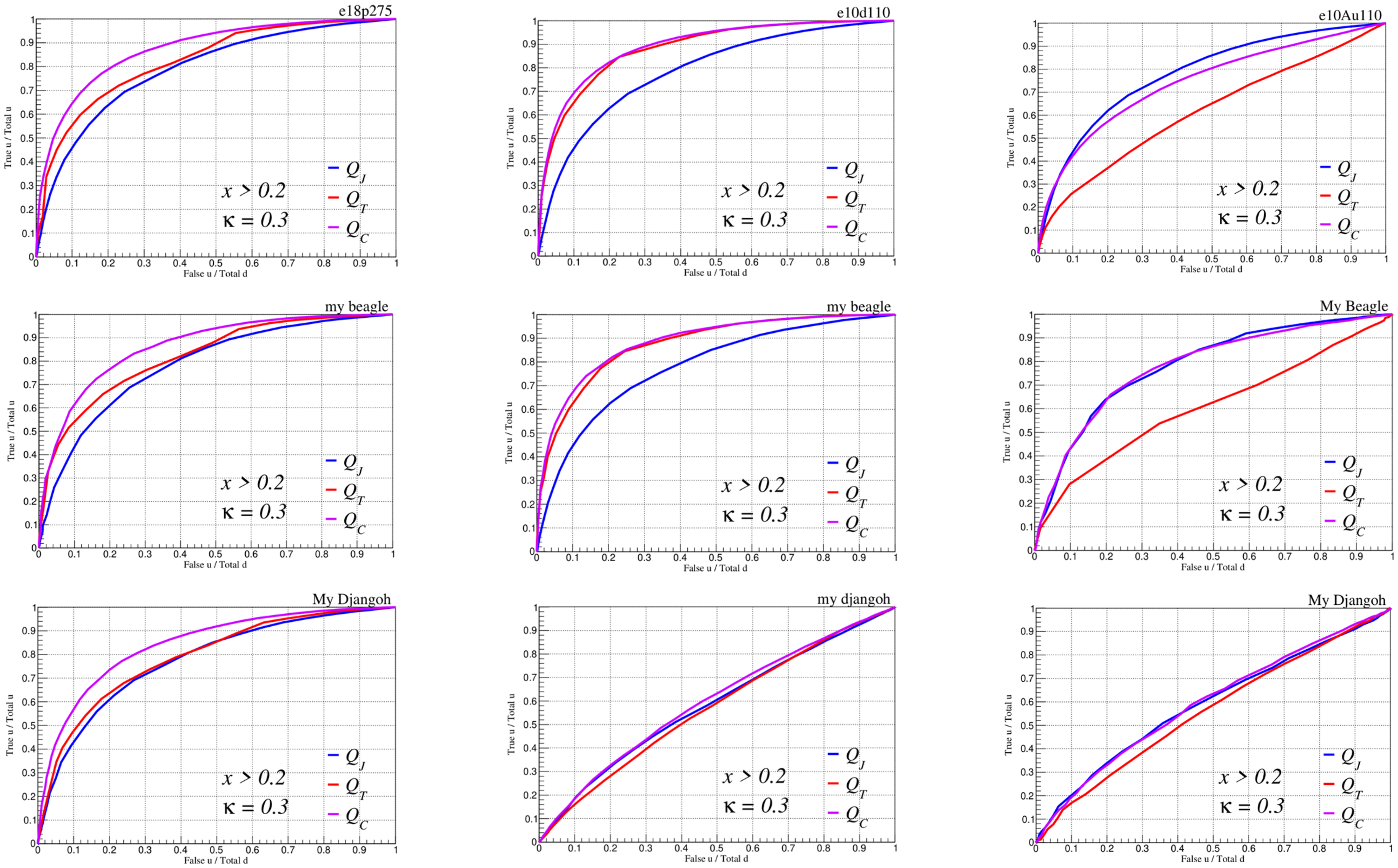
collision **after** jet clustering – Combined charge



- BeAGLE keeps u/d separation in combined charge from e-p to e-Au.
- DJANGOH shows it only in e-p, with e-d/e-Au collapsing near zero.

Analysis and Comparisons

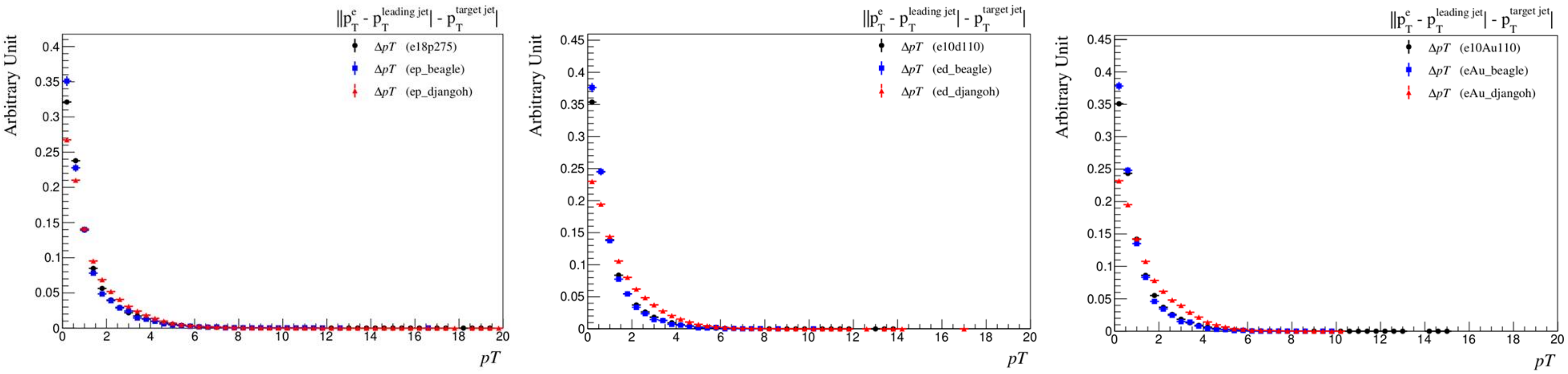
collision **after** jet clustering – Charge ROC curve



- X – axis : Misidentifying down quark as up quark.
- Y – axis : Correctly classify an up quark.
- Different color shows different curve base on Jetcharge, Target charge and Combined charge.

Analysis and Comparisons

collision **after** jet clustering – ΔpT for ||electron - Leading jet| - Target jet |



In deal case, the target jet pT should be back to back with the Δ pT of struck electron and leading jet, the

deviation for DJANGOH is larger than BeAGLE, this may be resulted from the insufficient in DJANGOH

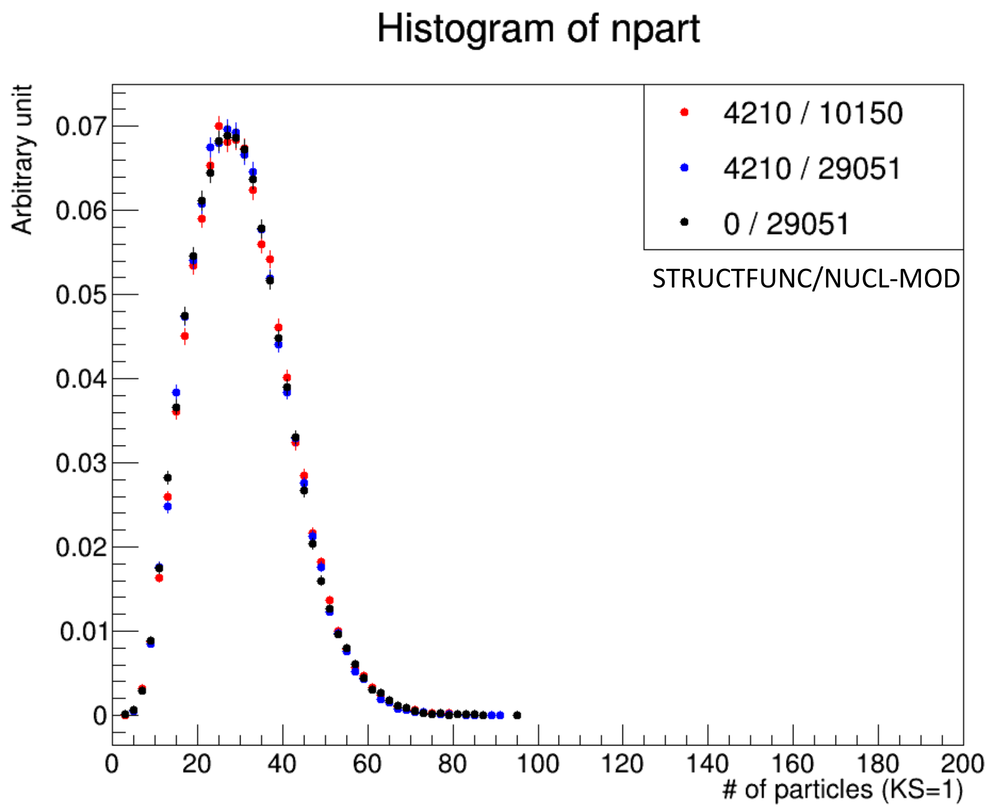
Analysis and Comparisons

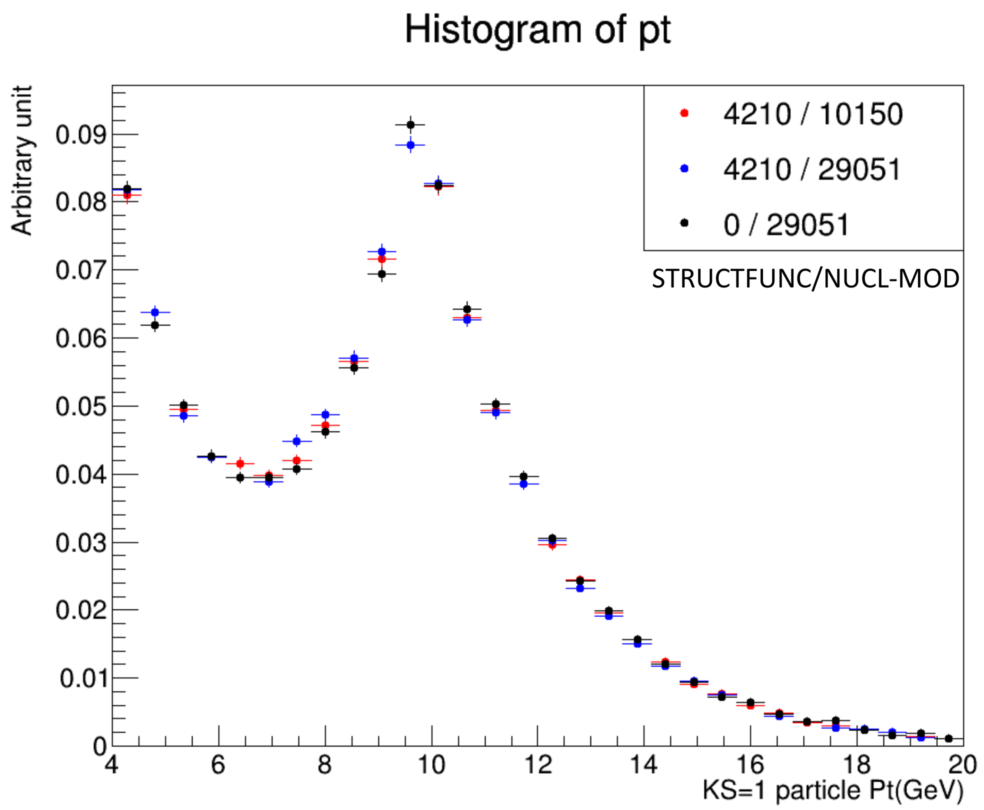
test changing PDFs for DJANGOH in e-Au collision

- Change STRUCTFUNC **(specify PDFs)** and NUCL-MOD **(correction factors to PDFs)** in my DJANGOH sample.
- Original input : STRUCTFUNC = 10150 and NUCL-MOD = 4201
  - 10150 : CTEQ61M, general PDFs.
  - 4201 : nuclear corrections for Au based on CTEQ61M.
- input1 : STRUCTFUNC = 29051 and NUCL-MOD = 4201
  - 29051 : MRST98nlo, general PDFs.
  - 4201 : nuclear corrections for Au based on CTEQ61M.
- input2 : STRUCTFUNC = 29051 and NUCL-MOD = 0
  - 29051 : MRST98nlo, general PDFs.
  - 0 : No nuclear correction.

Analysis and Comparisons

test changing PDFs for DJANGOH in e-Au collision





There is no marked difference

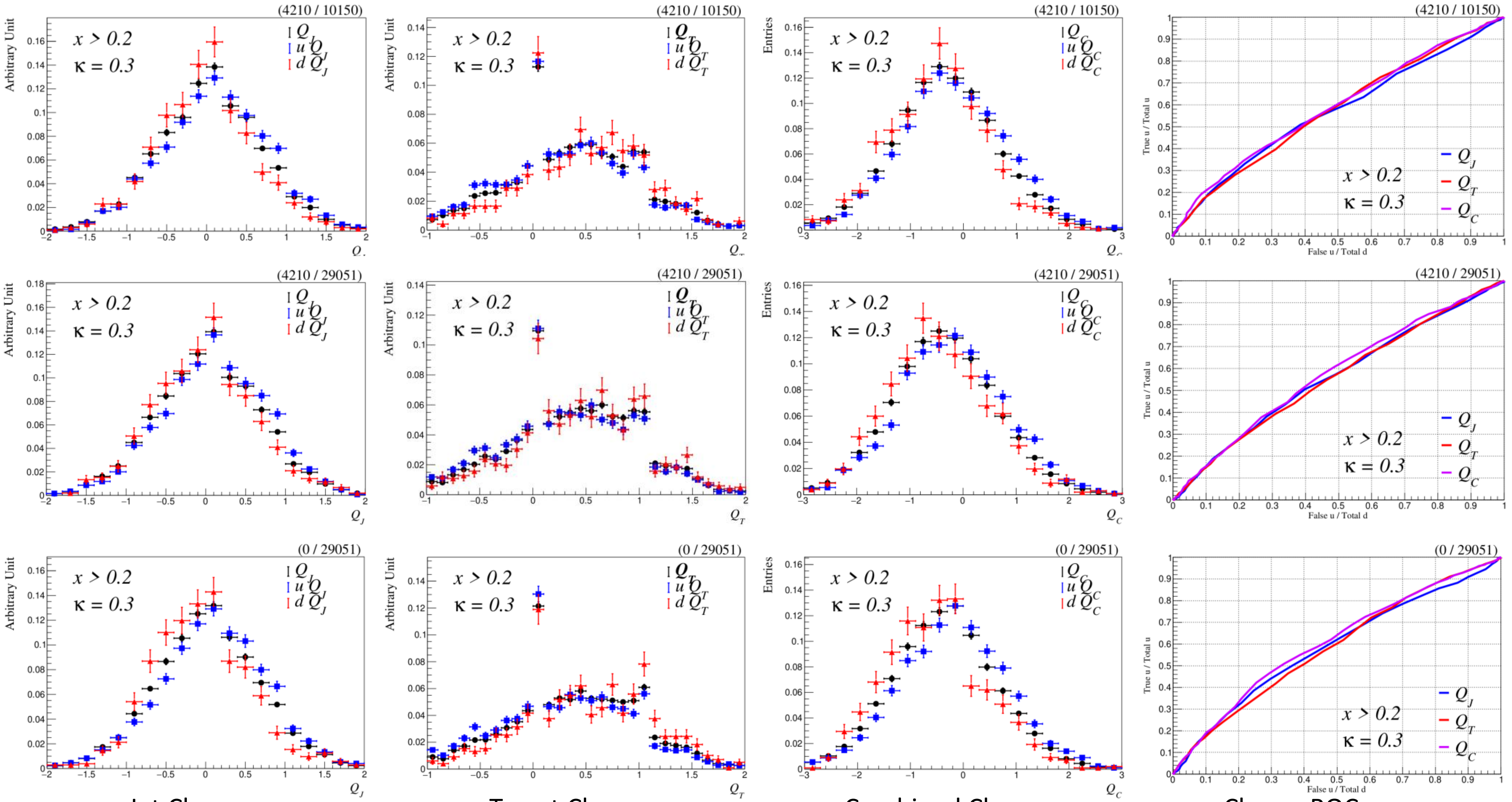
Analysis and Comparisons

test changing PDFs for DJANGOH in e-Au collision

4210/10150

4210/29051

0/29051



Jet Charge | Target Charge | Combined Charge | Charge ROC curve

There is no marked difference either

Analysis and Comparisons

test changing PDFs for DJANGOH in e-Au collision

STRUCTFUNC/NUCL-MOD affect only the initial state (nPDFs), hence they bring little improvement for jet/target-jet charge—observables dominated by final-state nuclear effects—so DJANGOH is limited for this class of eA measurements

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Summary and Conclusion

- BeAGLE explicitly includes nuclear geometry, in-medium transport, and remnant breakup, yielding a more complete eA treatment; DJANGOH remains a single-nucleon DIS model with radiative/nPDFs corrections and lacks nuclear transport and remnant breakup, so its eA final-state predictions are more limited.

Thank You !

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Reference

[1] Chang, W., et al. (2022). "Benchmark e A generator for leptoproduction in high-energy lepton-nucleus collisions." Physical Review D **106**: 012007

[2] EIC. (n.d.). BeAGLE: Benchmark eA Generator for LEptoproduction [Source code]. GitHub. https://github.com/eic/BeAGLE

[3] EIC, “DJANGOH,” EIC Software Documentation, [Online]. Available: https://eic.github.io/software/djangoh.html

[4] EIC, “DJANGOH 4.6.10,” GitLab repository. [Online]. Available: https://gitlab.com/eic/mceg/DJANGOH-4.6.10

[5] EIC, “eic-smear: Fast smearing and reconstruction for EIC detector studies,” GitHub repository, [Online]. Available: https://github.com/eic/eic-smear

[6] Y.-T. Chien, “Target jet substructure and correlation,” presented at the 2nd Workshop on Understanding the Nonperturbative QCD Using Energy Flows, Center for Frontiers in Nuclear Science (CFNS), Nov. 6, 2023. [Online]. Available: https://indico.cfnssbu.physics.sunysb.edu/event/110/contributions/206/attachments/68/91/CFNS_2023.pdf

[7] M.-H. Kuo, K.-F. Chen, Y.-T. Chien, and R. Esha, “Target Jet Substructure and Correlation,” presented at the Quark Matter 2025 Conference, Mar. 2025. [Online]. Available: https://indico.cern.ch/event/1334113/contributions/6306854/attachments/3046388/5382795/QuarkMatter2025.pdf