Stony Brook University

Center for Frontiers in Nuclear Science

Atomic nuclei imaging at the Electron-Ion Collider

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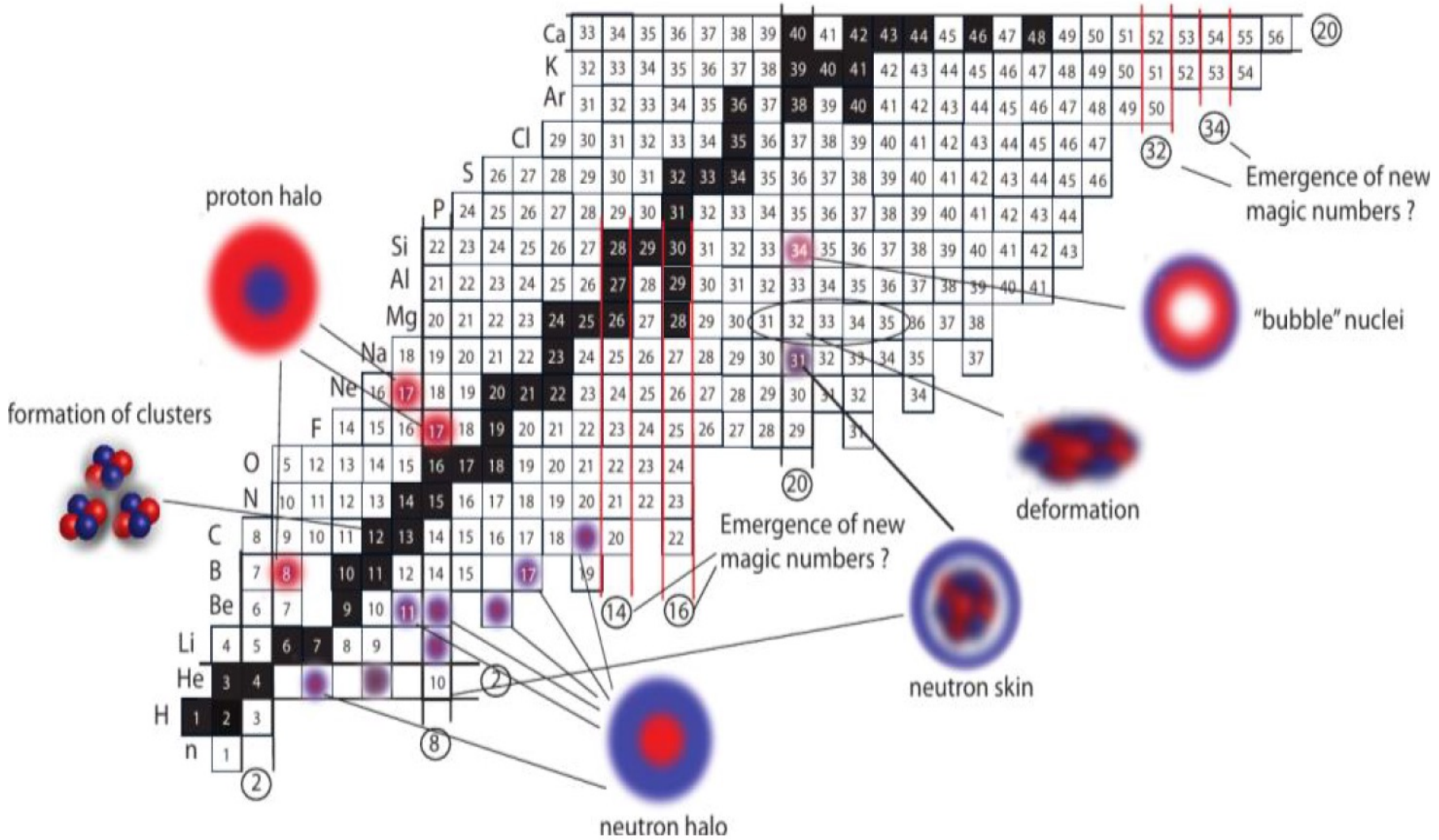
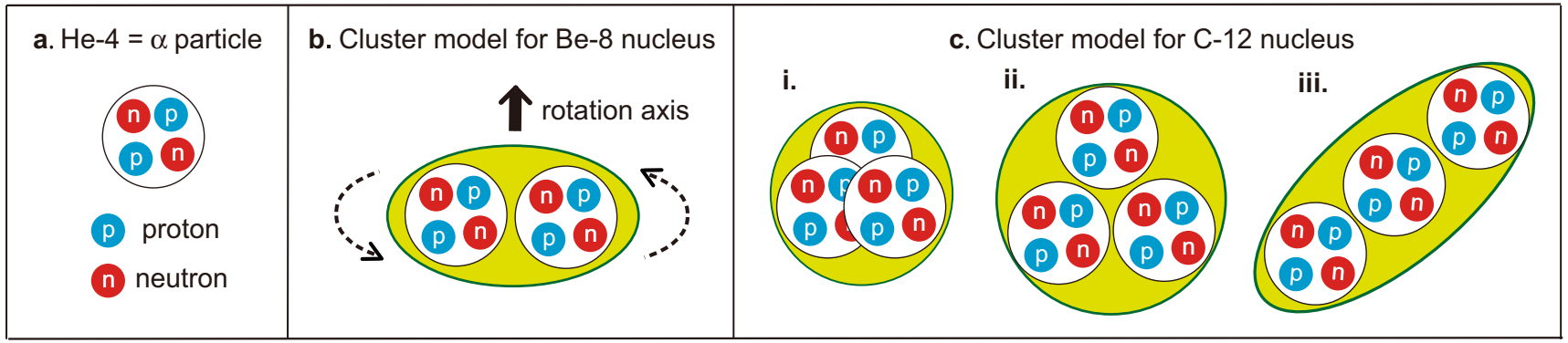
❖ Motivation

- ➢ The rich structure of atomic nuclei:
  - ✓ Clustering, halo, skin …
  - ✓ Quadrupole/octupole/hexdecopole deformations



❖ Motivation

The atomic nuclei carry non-trivial shapes and structures beyond the simple spherical Woods-Saxon distribution. For instance, it has been suggested that the wave functions of light nuclei, such as ^{12}C, contain alpha clustering. In such a scenario, the nucleus appears more like three α particles rather than six protons and six neutrons behaving independently.



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Such effects are essential for understanding the nuclear structure and can serve as a background estimate for other studies (e.g., the nuclear short-range correlation studies**).

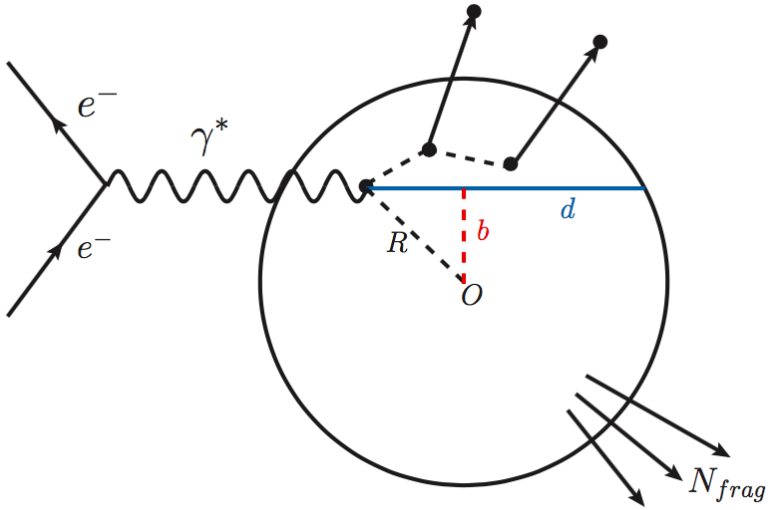
Our study goals can be summarized as:
(1) Can the EIC detectors (ePIC and 2nd detector) differentiate between different geometries, such as spherical ^{12}C versus a triple-alpha cluster configuration of ^{12}C?
(2) How can the nuclear structure impact other EIC physics programs?

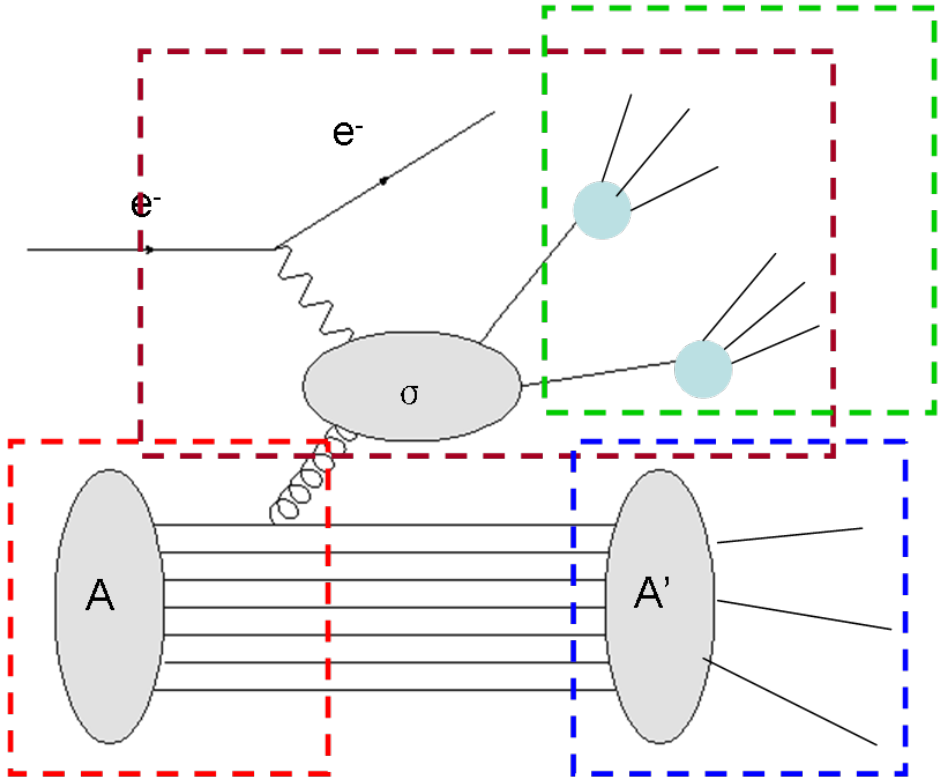
** *Lei Shen, Bo-Song Huang, and Yu-Gang Ma Phys.Rev.C* 105 (2022) 1, 014603

❖ The work plan

(1) Identifying the EIC model simulations that can be used to study the alpha clustering in light nuclei.

- ✓ The BeAGLE model





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

PRD 106, 012007 (2022)

❖ The α clustering

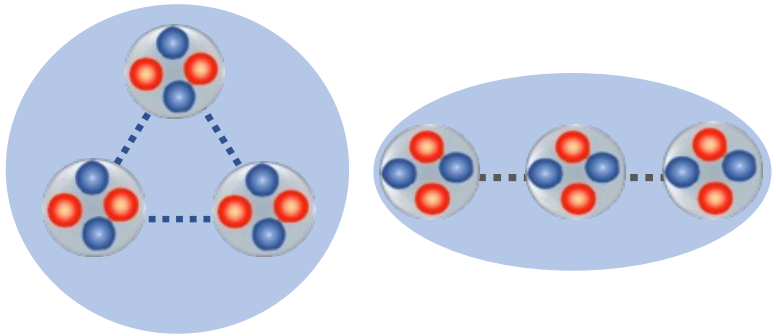
Modifying the EIC model simulations with initial nuclear configurations, which include alpha clustering.

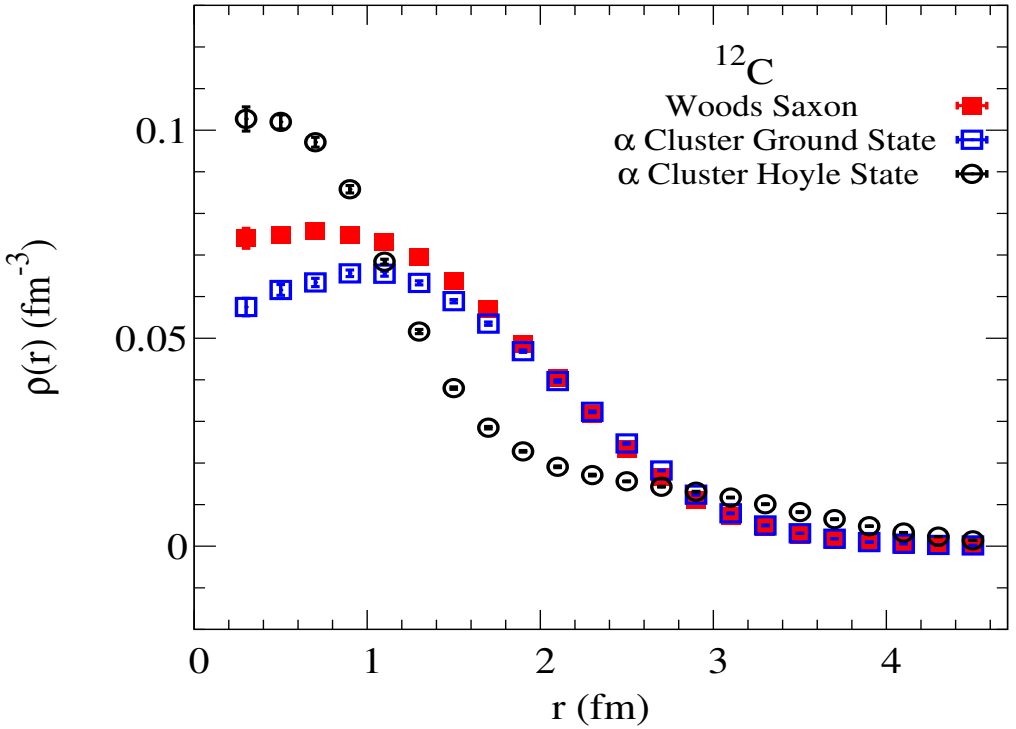
- ✓ The nuclear shape and structure picture have been into the BeAGLE model

The α clustering implementation:

In $^{9}_{4}Be$, $^{12}_{6}C$, and $^{16}_{8}O$ we include the α clustering as:

- ✓ Chose the centers of the n-α clusters with a particular configuration
- ✓ Construct the α cluster with four nucleons
- ✓ Generated random configuration event by event



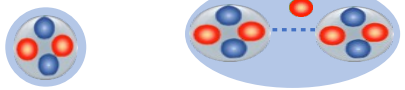


The normalized density distribution of the different configurations of the ^{12}C was introduced into the BeAGLE model.

❖ The α clustering

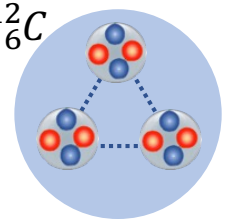
The BeAGLE model is updated to consider the α clustering

$^{4}_{2}He = \alpha$ $^{9}_{4}Be$



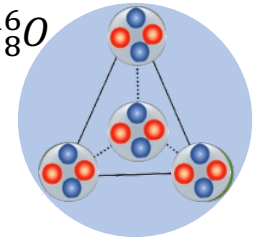
2- α Clustered on the Z axes

$^{12}_{6}C$

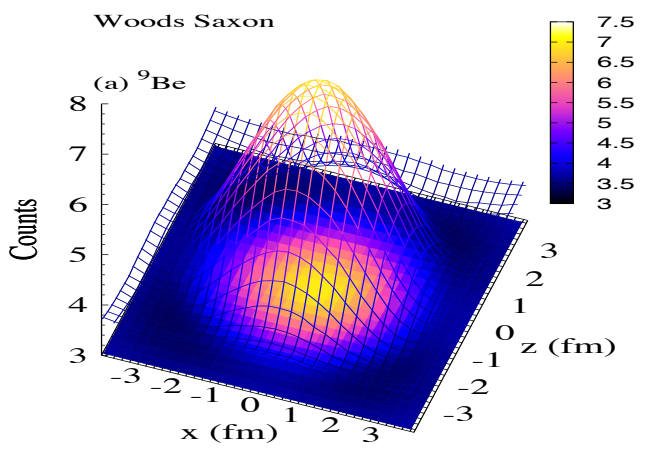


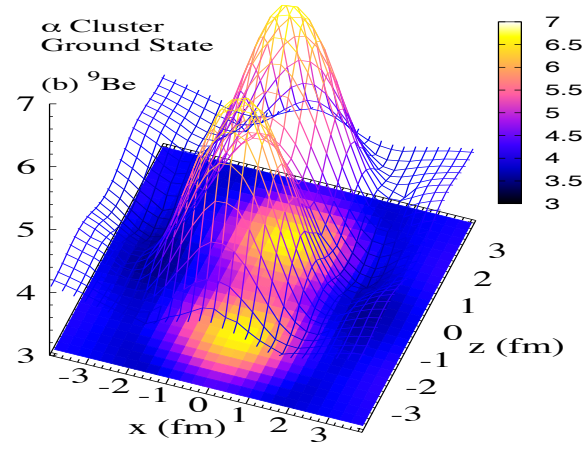
3- α Clustered in the x-y plane

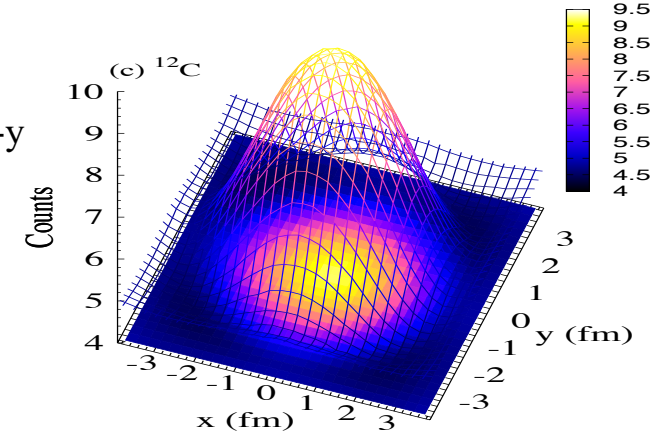
$^{16}_{8}O$

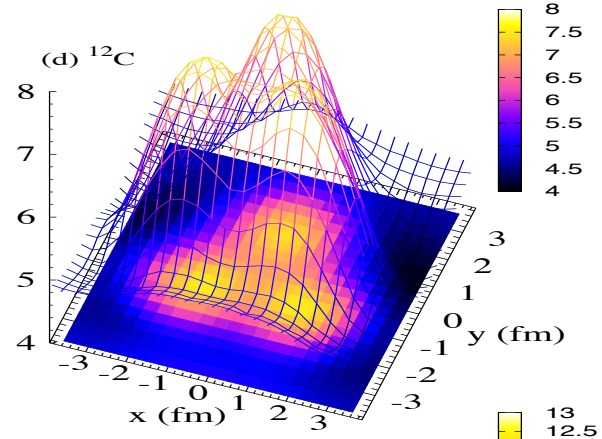


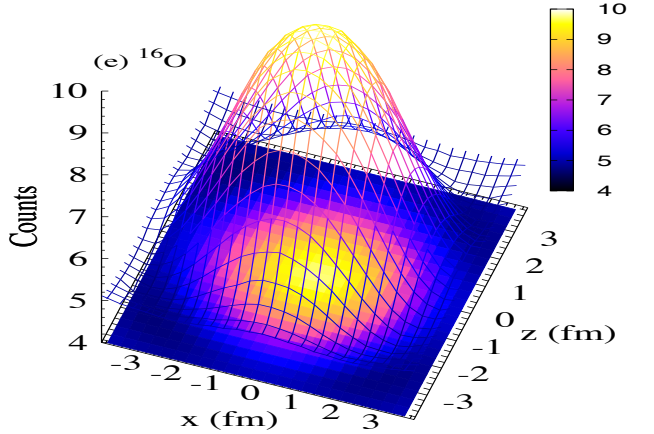
3- α Clustered in the x-y plane 1- on the Z axes

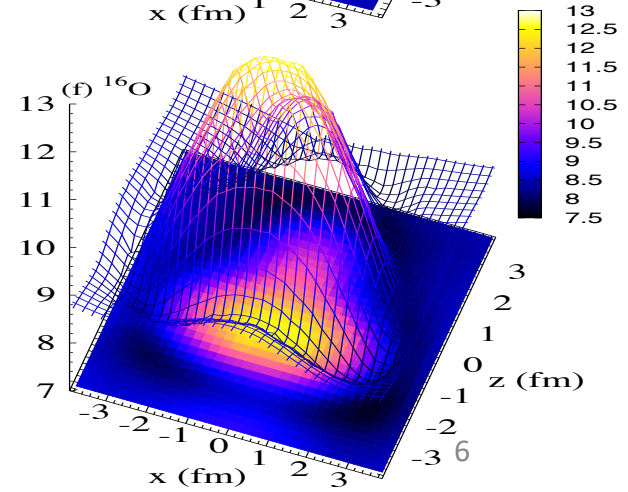












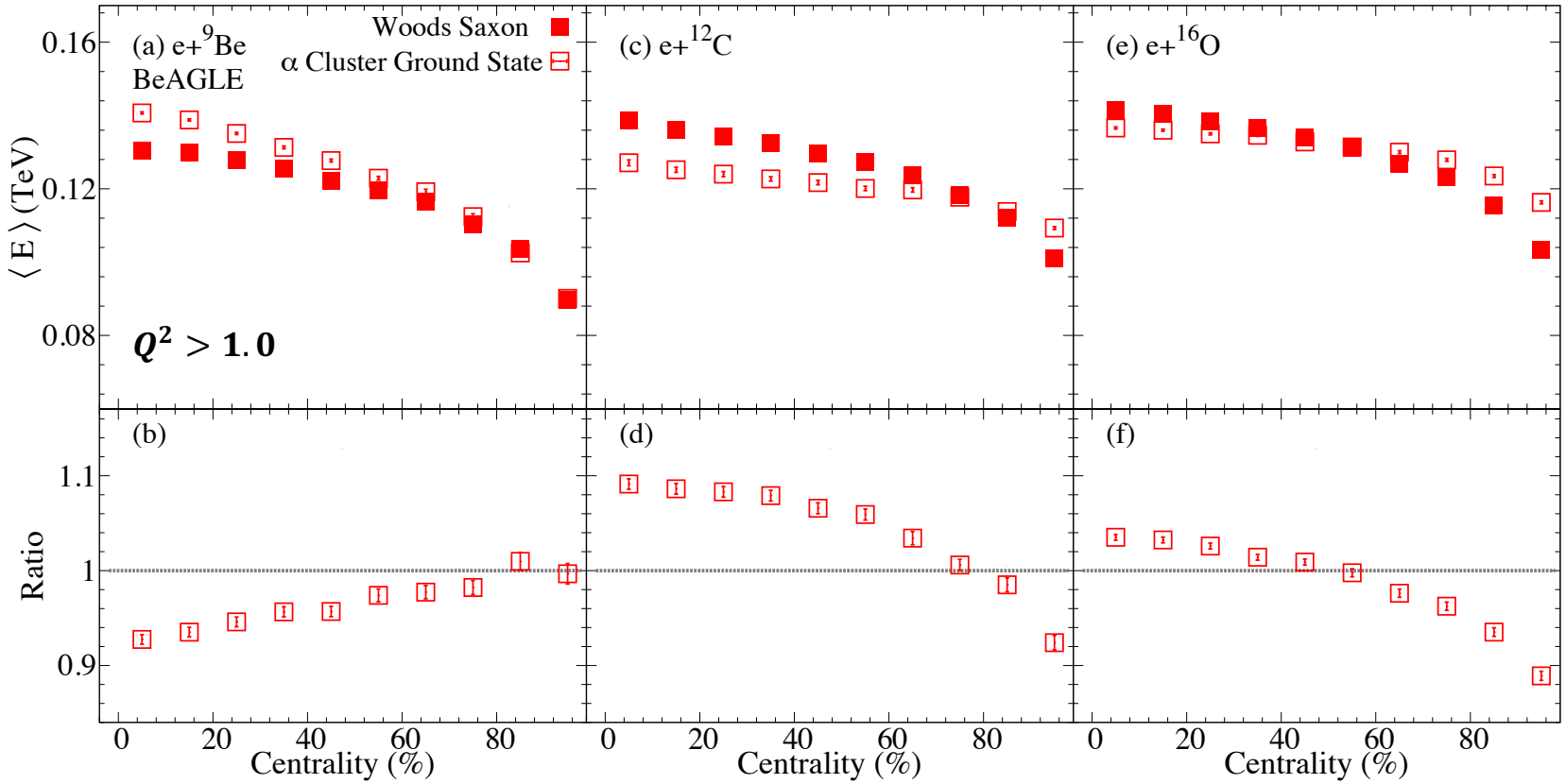
❖ The α clustering

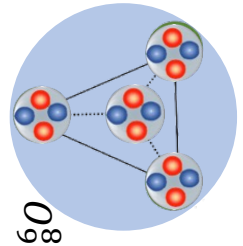
Identify the physics observables that can be used in such work.

- ✓ Several observables have been introduced (e.g., mean energy observable)

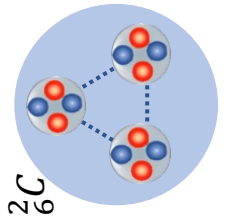
The $\langle E \rangle$ in the forward B0 detector acceptant Vs centrality for fixed orientation nuclei.

- ✓ Centrality is defined via the cutting on the impact parameter.





3- α Clustered in the x-y plane 1- on the Z axes



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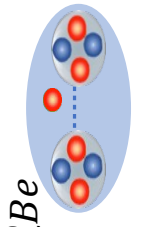

2- α Clustered on the Z axes

The $\langle E \rangle$ in B_0 is sensitive to α clustering in Be^9, C^{12}, and O^{16}

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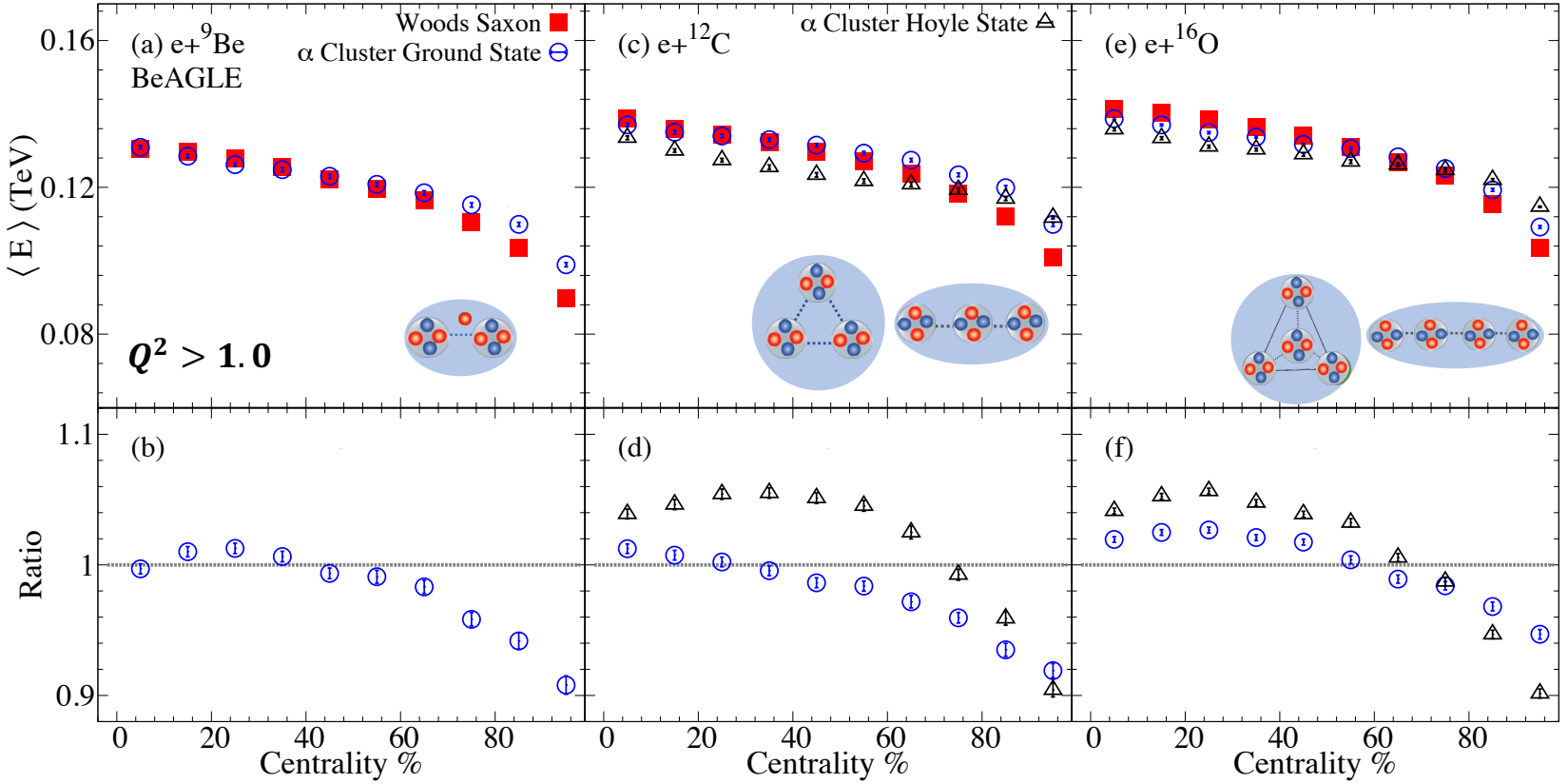


The $\langle E \rangle$ in B_0 is sensitive to α clustering and clustering configurations in Be^9, C^{12}, and O^{16}

❖ The work features

The centrality-dependent calculations can be used to differentiate between several clustering configurations (i.e., the angle between the clusters). Such findings will be unique to EIC.

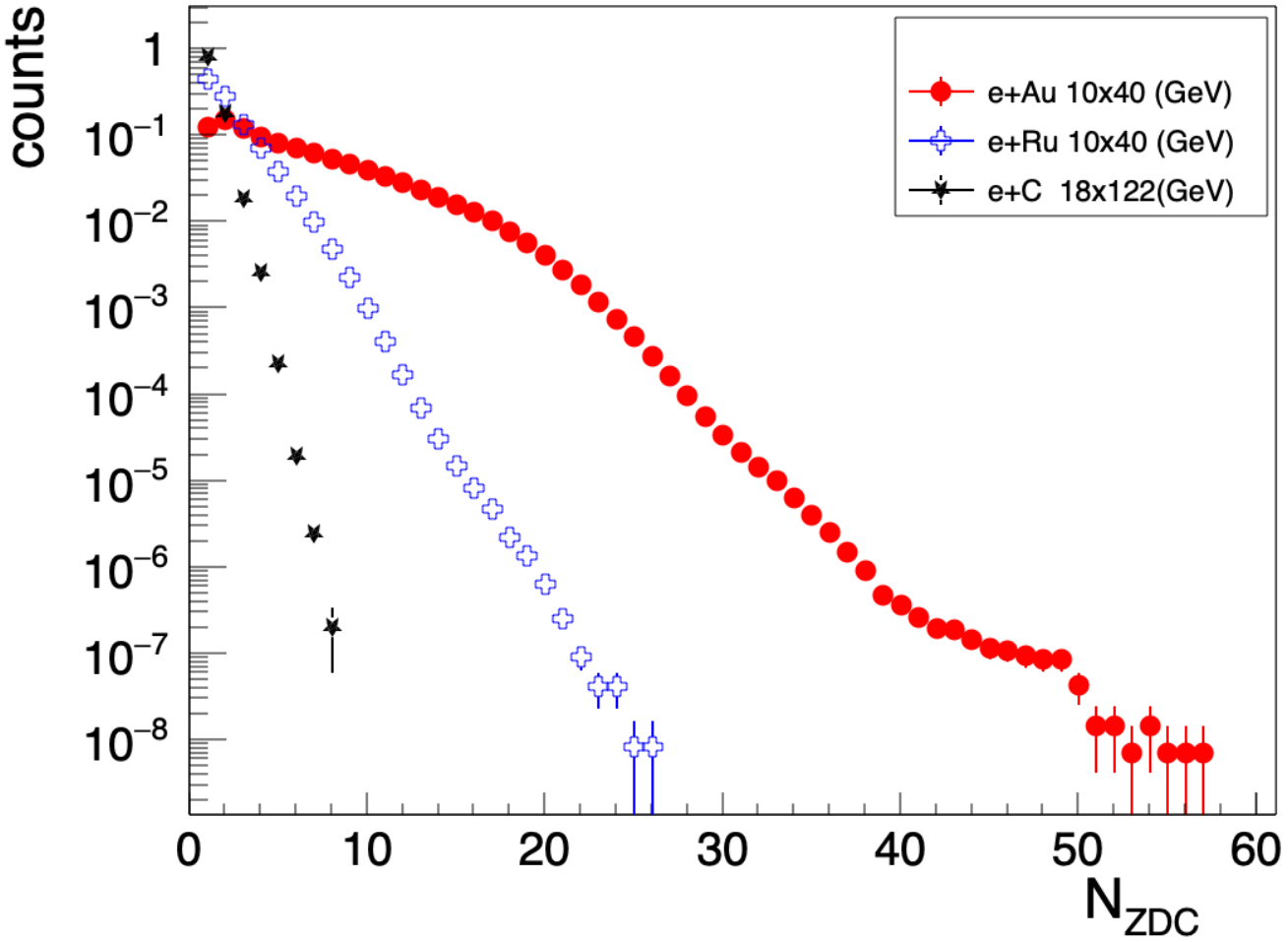
❖ The work cavities

One of the main challenges to this work and the e+A studies at EIC is the definition of centrality.

- In e+A collisions, the impact parameter is independent of the kinematics of the collisions and has a weak dependence on the final state particles.
- It's hard to identify a particular final state measure that can be strongly correlated with the impact parameter.

❖ The problem of the definition

The number of evaporated neutrons in ZDC



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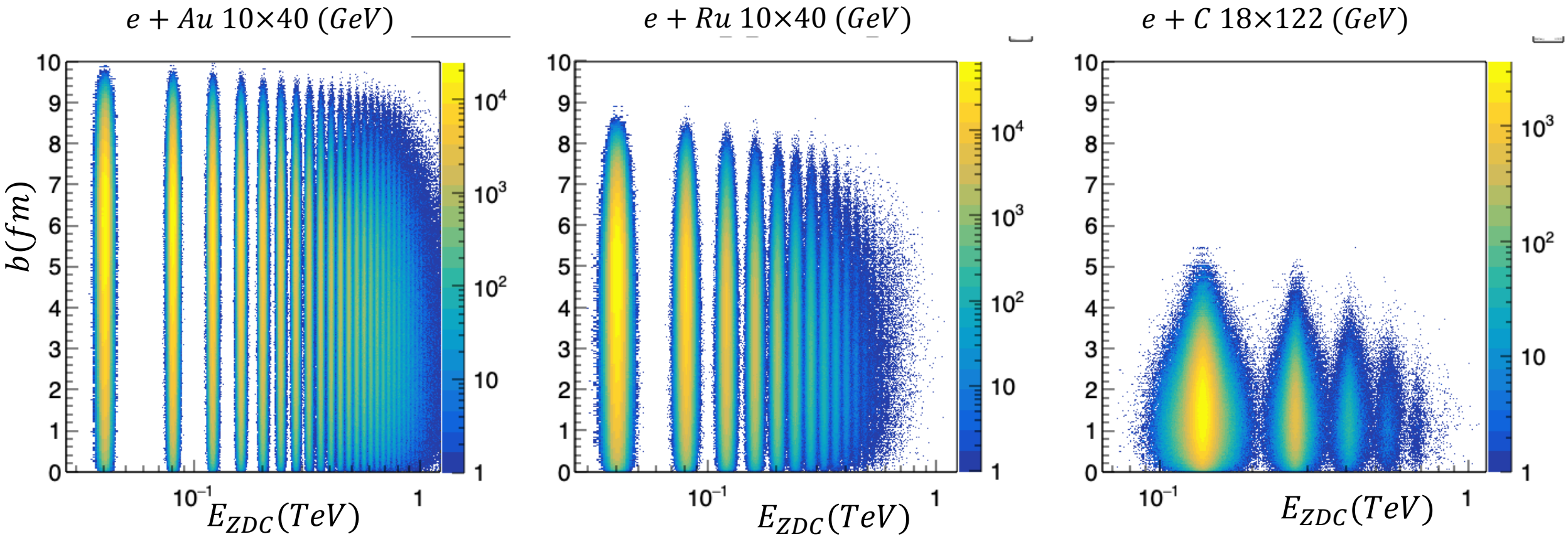
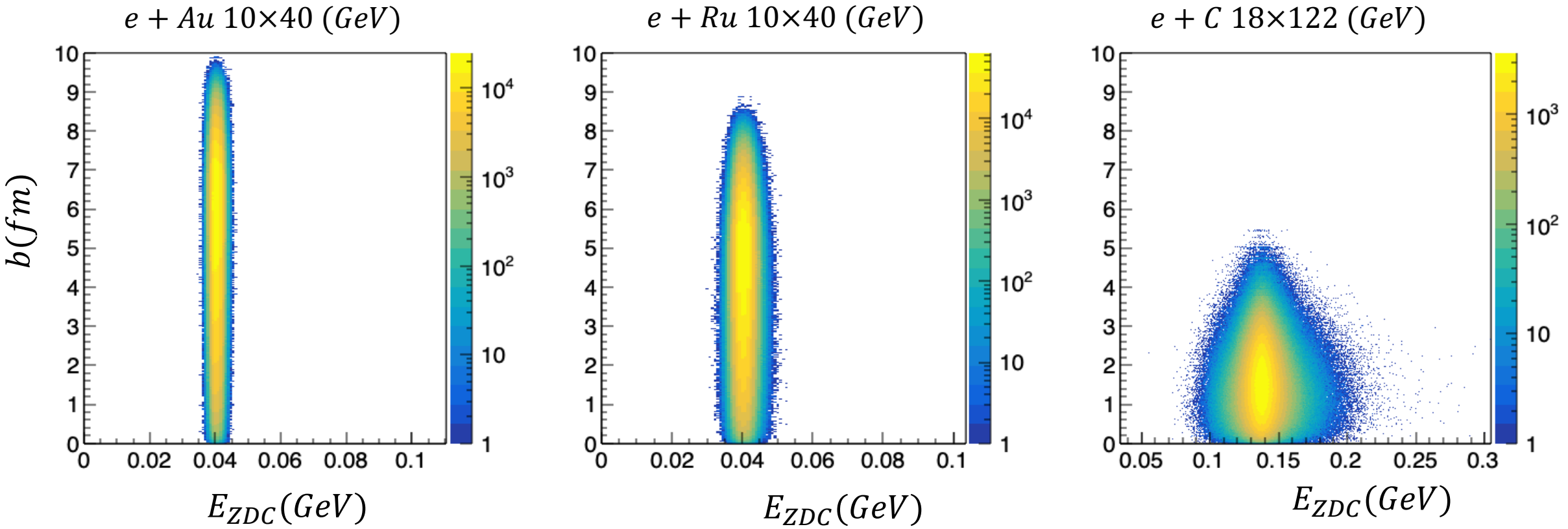


- Different peaks are related to different neutron number
- If we consider all neutrons, it's very hard to get a clear cut on b

❖ The problem of the definition



- For the one neutron event in ZDC,
- If we can know how many hits are in the ZDC, can this help in the centrality definition?
- Ongoing work with the AI group at BNL to find a centrality definition mechanism

❖ Conclusion

We investigated the ability to use the EIC to investigate the α clustering in ${}^{9}_{4}Be, {}^{12}_{6}C$, and ${}^{16}_{8}O$:

- The $\langle E \rangle$ in $B0$ is sensitive to α clustering in ${}^{9}_{4}Be, {}^{12}_{6}C$, and ${}^{16}_{8}O$
- The $\langle E \rangle$ in $B0$ is sensitive to α clustering configuration (i.e., GS and HS)

This is the first academic exercise in this direction with a clear caveat of defining the collision centrally.

Thank You