Atomic nuclei imaging at the Electron-Ion Collider

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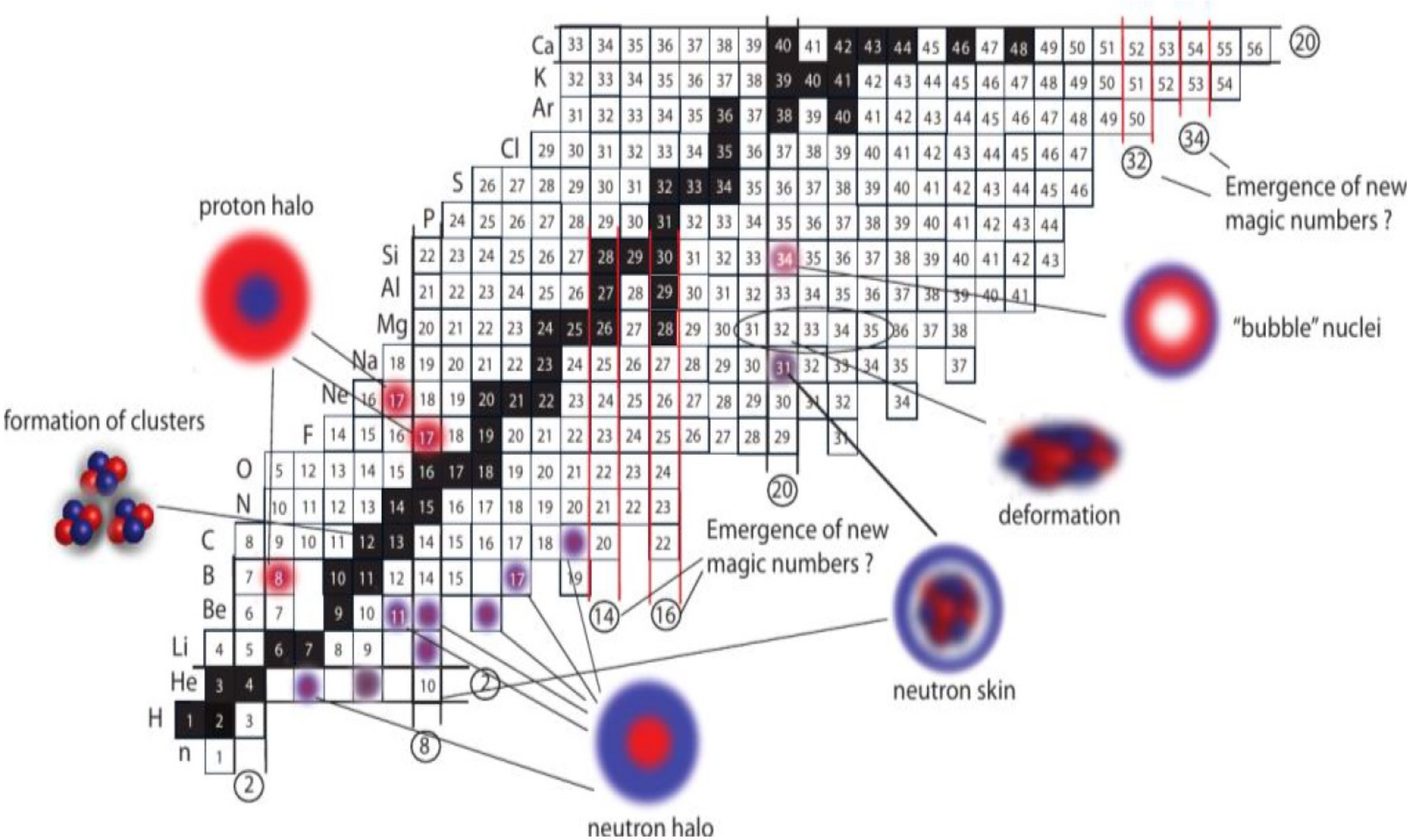
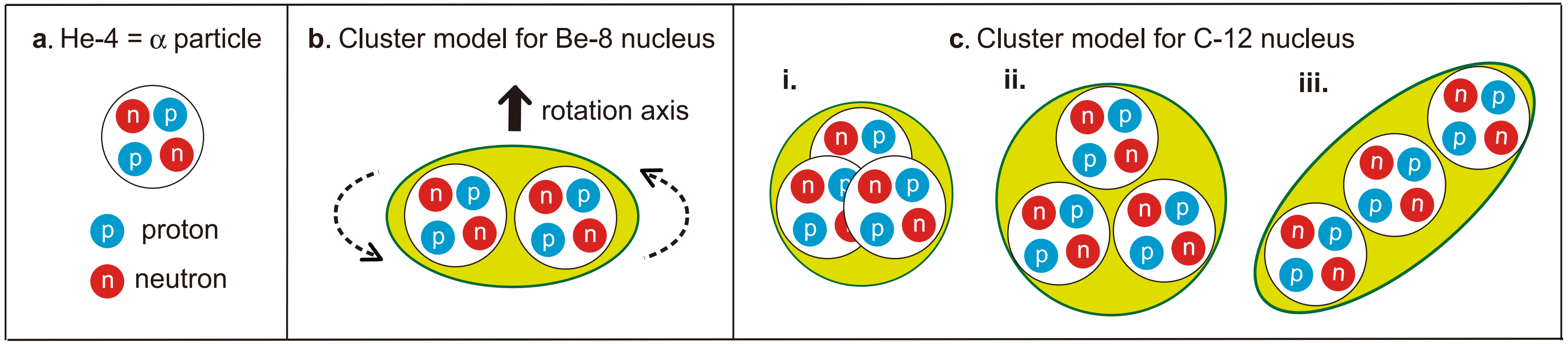
❖ Motivation

- ➢ 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

To reach the project goals, we executed our plan in the following order:

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

- ✓ The BeAGLE model

(2) 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

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

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

(4) Identify the study cavities that will need further investigation.

(5) Further investigation

❖ The work plan

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

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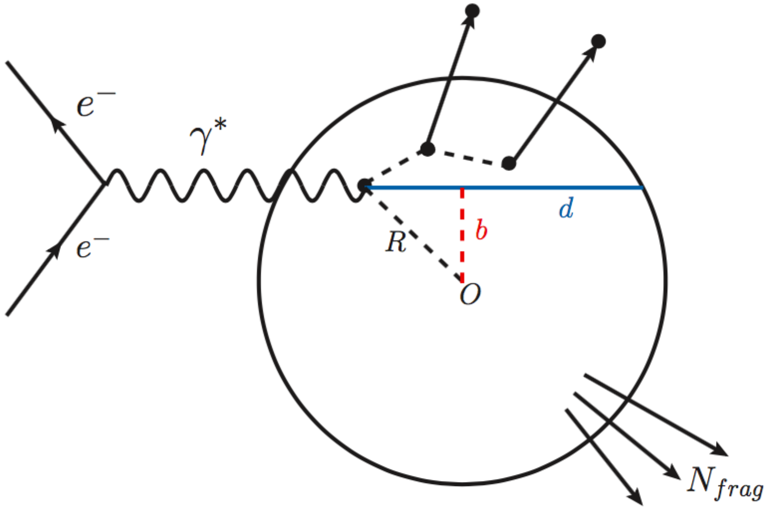
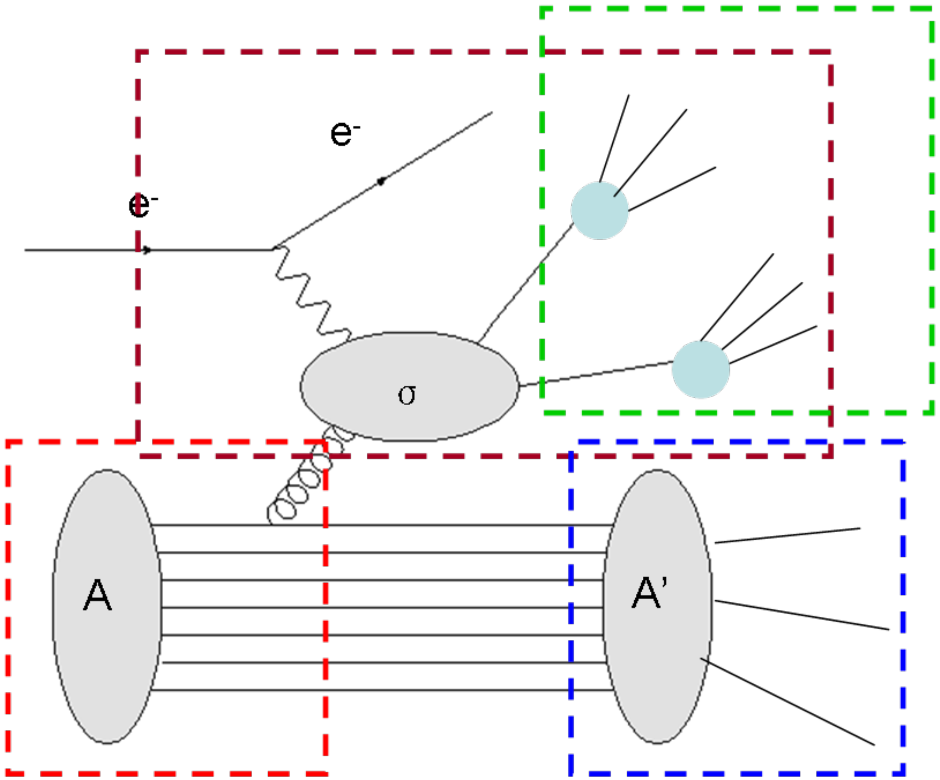




A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

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 work plan

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

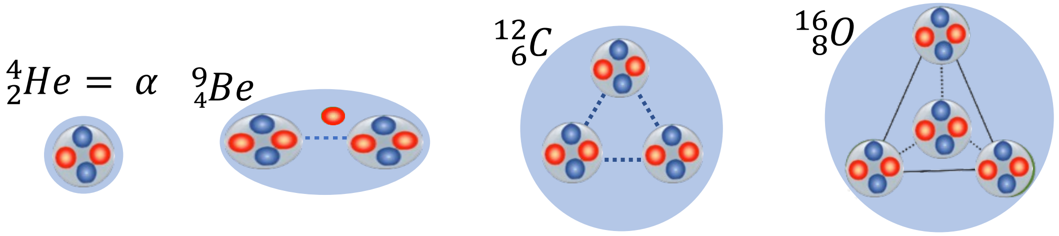
✓ The nuclear shape and structure picture have been into the BeAGLE model

The α clustering implementation:

In ${}^{9}_{4}Be$, ${}^{12}_{6}C$, and ${}^{16}_{8}O$ we include the α clustering as [3]:

- ✓ 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 BeAGLE model is updated to consider the α clustering



2- α Clustered on the Z axes

3- α Clustered in the x-y plane

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

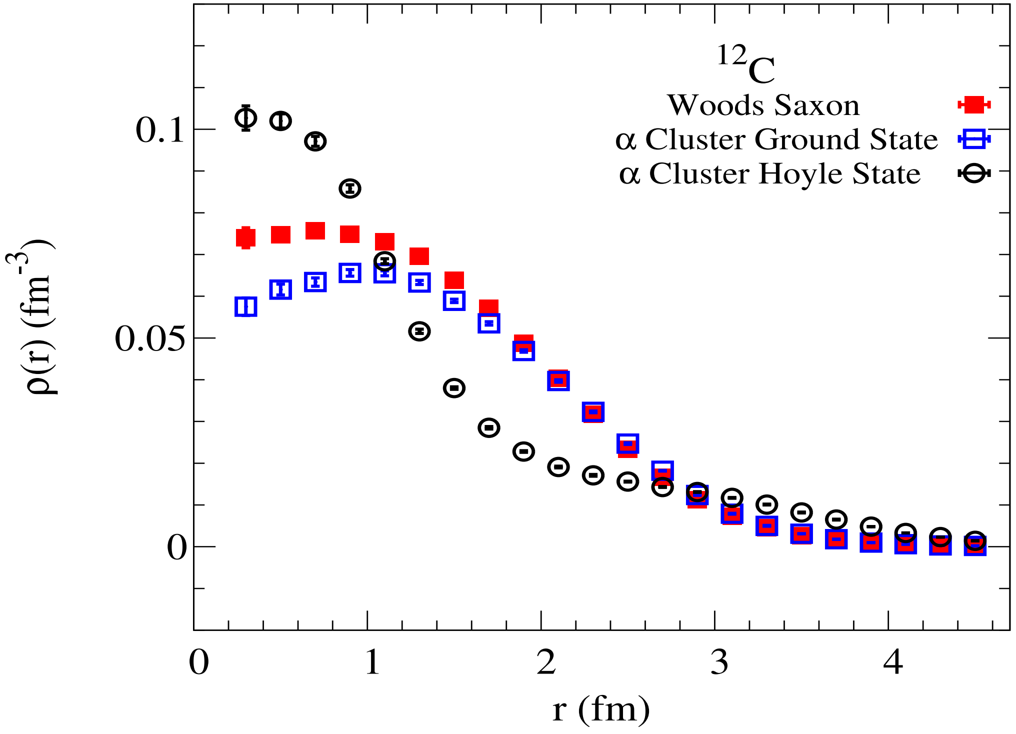


Figure.1: The normalized density distribution of the different configurations of the ${}^{12}C$ introduced into the BeAGLE model.

❖ The work plan

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

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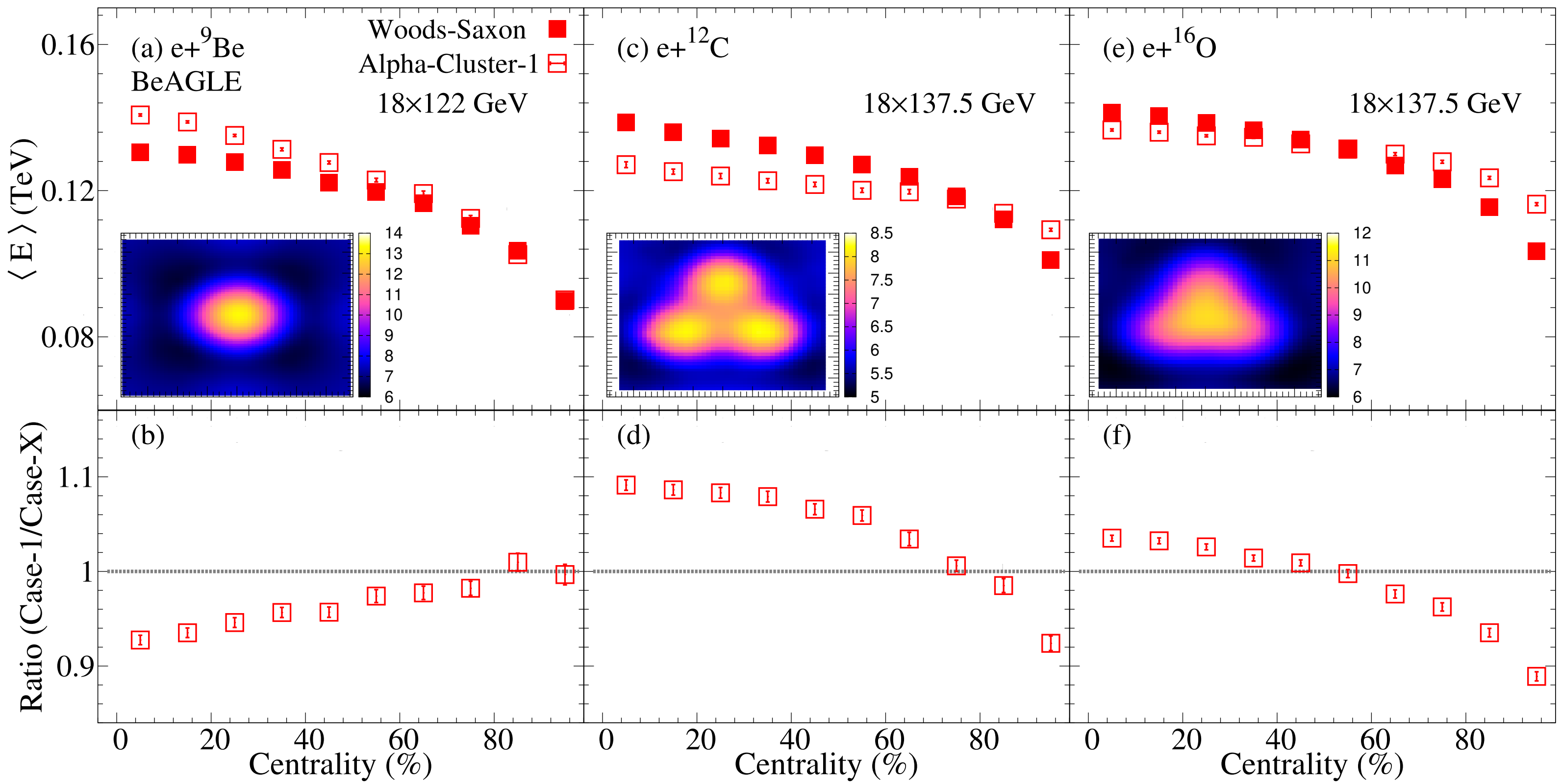
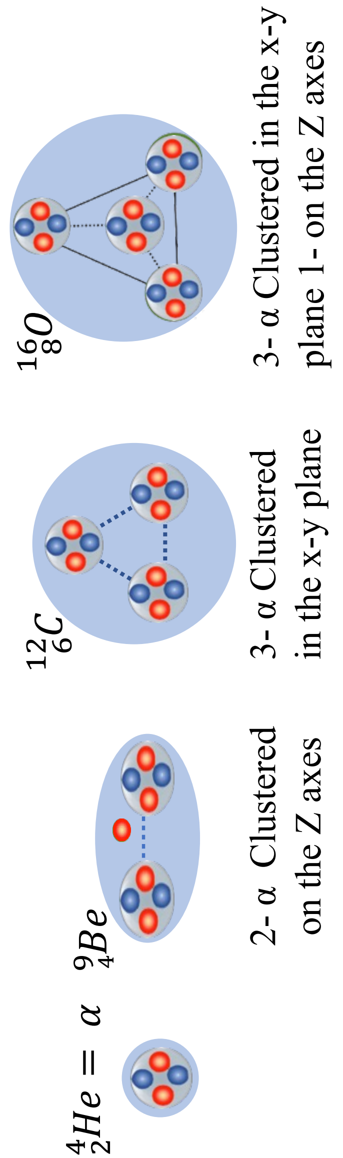
The $\langle E \rangle$ in the forward B0 detector acceptant Vs centrality for fixed orientation nuclei.

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





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

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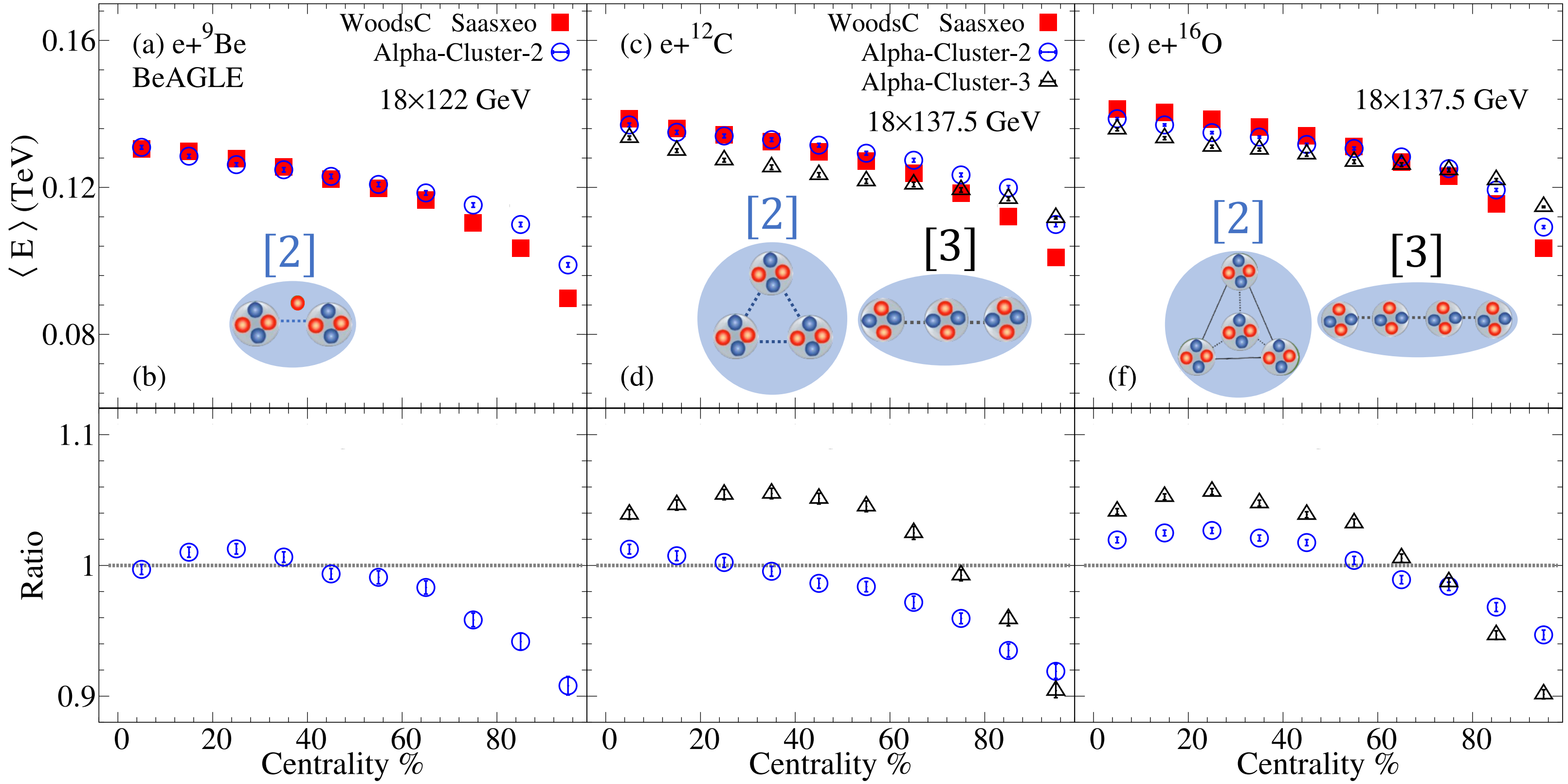

The $\langle E \rangle$ in B_0 is sensitive to α clustering and clustering configurations in Be^9, C^{12}, and O^{16}

❖ The work plan

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Proposal-1

Measure the $\langle E \rangle$ in B0 acceptance then extract the nuclear structure via data model comparisons.

Proposal-2 [Future work]

Measure the $\langle E \rangle$ in B0 acceptance, then extract the nuclear structure via isotopes comparisons.

❖ The work plan

(4) Identify the study cavities that will need further investigation.

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

- ➢ 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.

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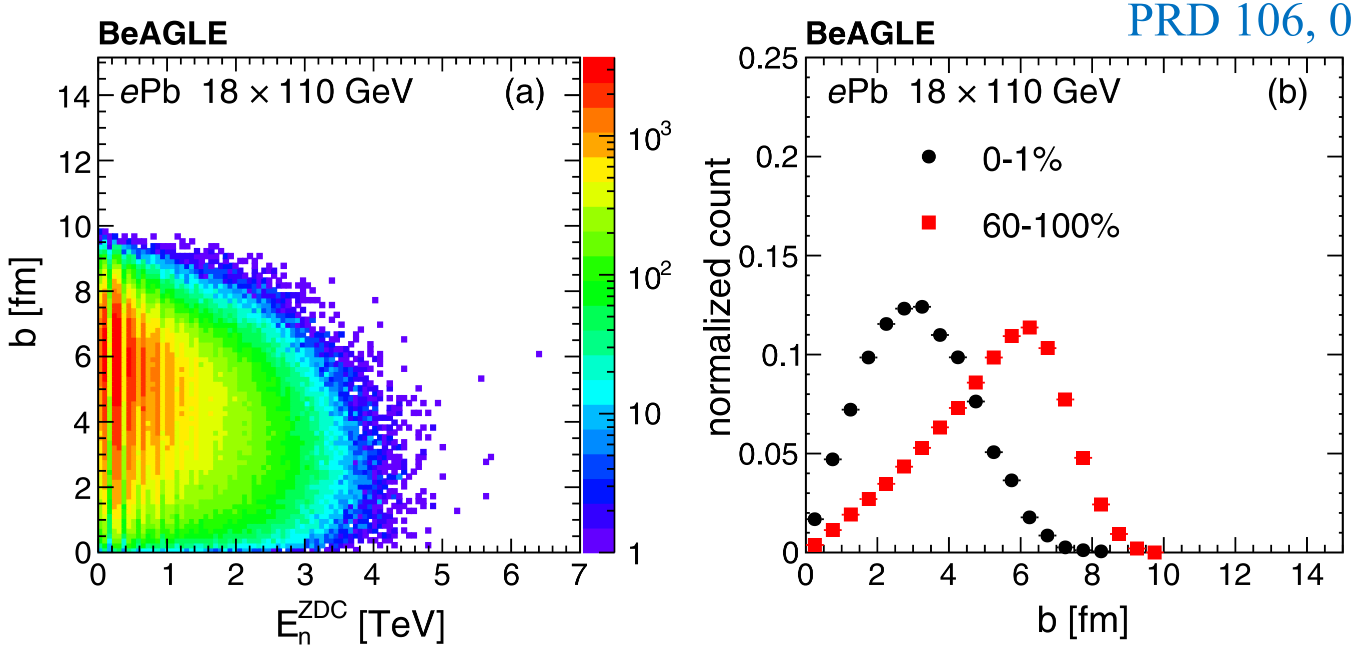

Finding a clever way to define centrality in the e+A collisions at the EIC is too important and is being investigated separetly.

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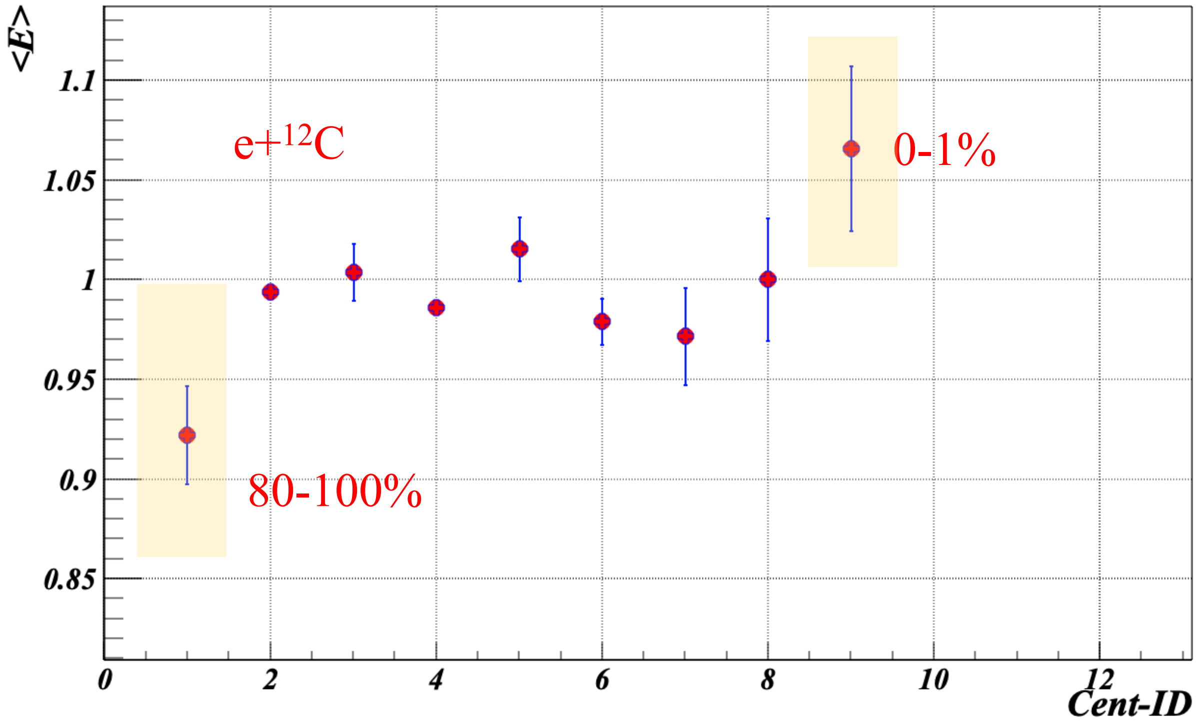


Using ZDC energy in ^{12}C

❖ The work plan

(5) Further investigation

- Investigate the ability to use centrality-independent observables.
- Work on finding a robust centrality definition.
- Investigate the ability to use different isotopes in our study.
- Studying the nuclear structure effect of several measurements (e.g., the nuclear short-range correlation studies)

❖ Conclusion

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

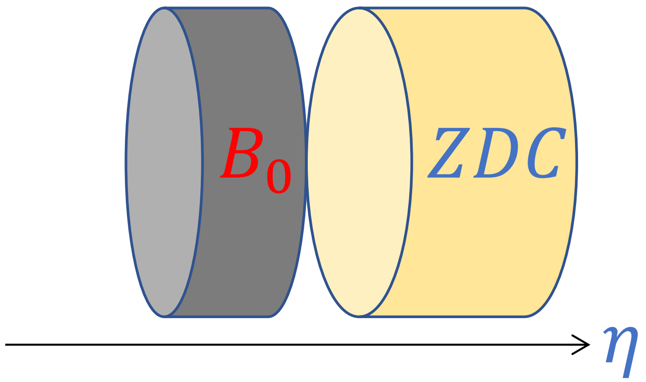
- The $\langle E \rangle$ in $B0$ is sensitive to α clustering in ${}^{9}_{4}Be$, ${}^{12}_{6}C$, and ${}^{16}_{8}O$
- The $\langle E \rangle$ in $B0$ is sensitive to α clustering configuration (i.e., GS and HS)

Thank You

❖ The detector's acceptance:

Caption text

Detector	Acceptance	Notes
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5$ mrad ($\eta > 6$)	About 4.0 mrad at $\phi \sim \pi$
B0 Detector	$5.5 < \theta < 20.0$ mrad ($4.6 < \eta < 5.9$)	Silicon tracking + EM preshower



➢ In this current study, we are using: ZDC and B_0 detectors