Centrality definition and nuclear structure study;
Using the BeAGLE model

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https://www.star.bnl.gov/~jjiastar/index.html

Our research is focused on understanding:

1) The transport properties of the QGP
2) The heavy ion collisions' initial state
3) The shape of atomic nuclei in heavy ion collisions

Our research is carried out at:

1) The Relativistic Heavy Ion Collider (RHIC), the STAR experiment
2) The Large Hadron Collider, the ATLAS experiment

Publication

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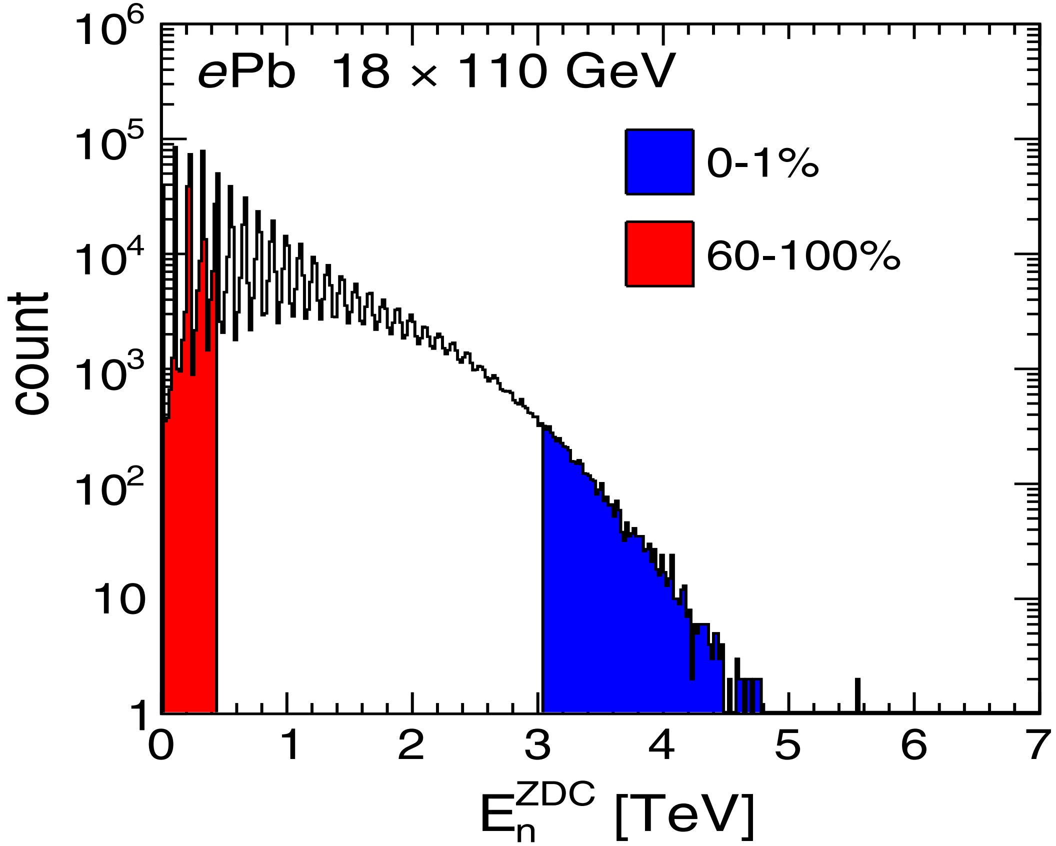
❖ Motivation

- ➢ The centrality had been studied before.
- ➢ More detailed studies are done considering:
  - ✓ Neutrons from different processes
  - ✓ Gamma from π^0 decay
  - ✓ Correlations between ZDC energy and impact parameter



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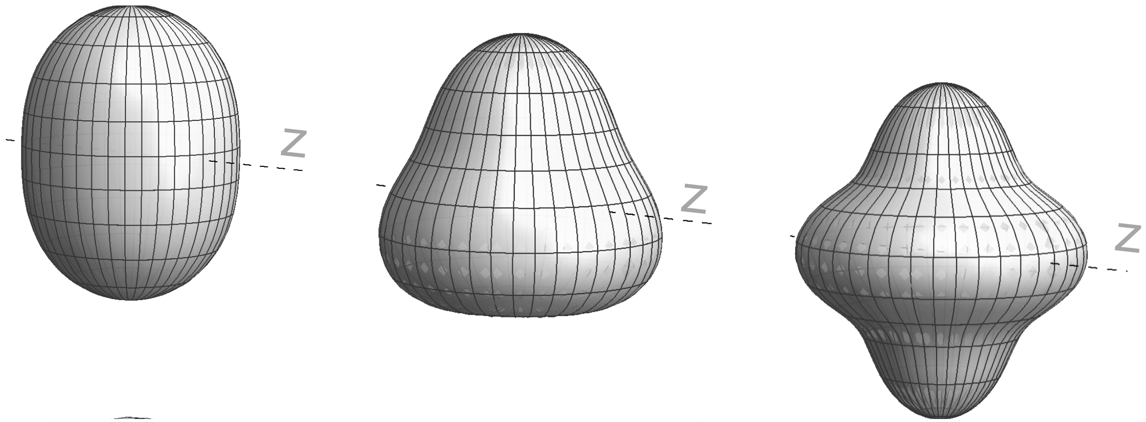
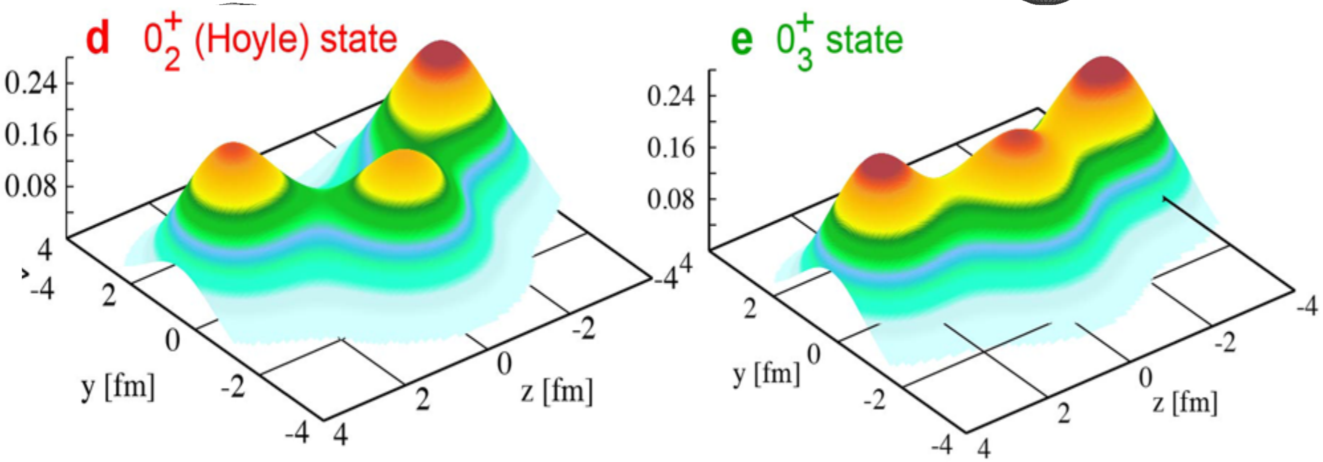
❖ Motivation

➢ EIC can be a unique tool for understanding the nuclear structure

- ✓ Understanding the nuclear deformation
- ✓ Understanding the α clustering





❖ The detector's acceptance:

Caption text

Detector	Acceptance	Notes
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5$ mrad ($\eta > 6$)	About 4.0 mrad at $\phi \sim \pi$
Roman Pots (2 stations)	$0.0^* < \theta < 5.0$ mrad ($\eta > 6$)	$0.65 < p\_(z, nucleon)/p\_(z, beam) < 1.0$ -- *10σ cut
Off-Momentum Detectors (2 stations)	$0.0 < \theta < 5.0$ mrad ($\eta > 6$)	Roughly $0.3 < p\_(z, nucleon)/p\_(z, beam) < 0.6$
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, Roman Pots (RP), and B_0

The BeAGLE model is used in the current study

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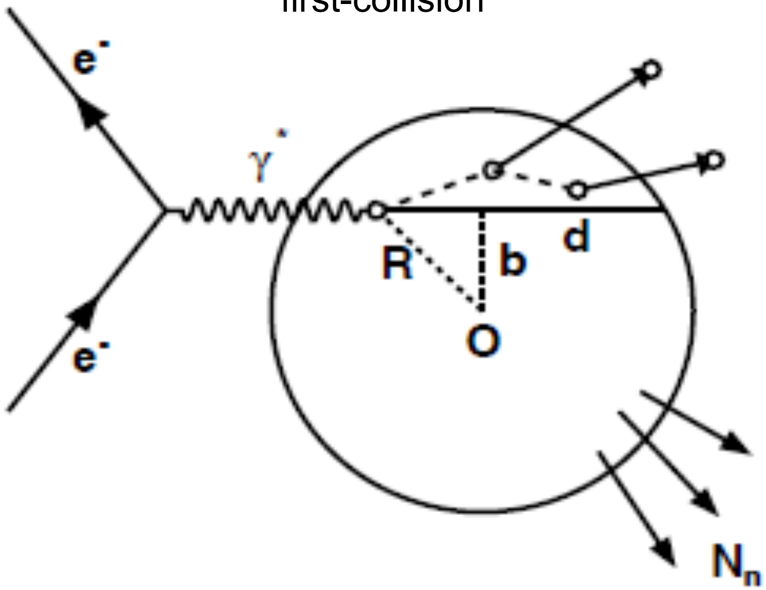
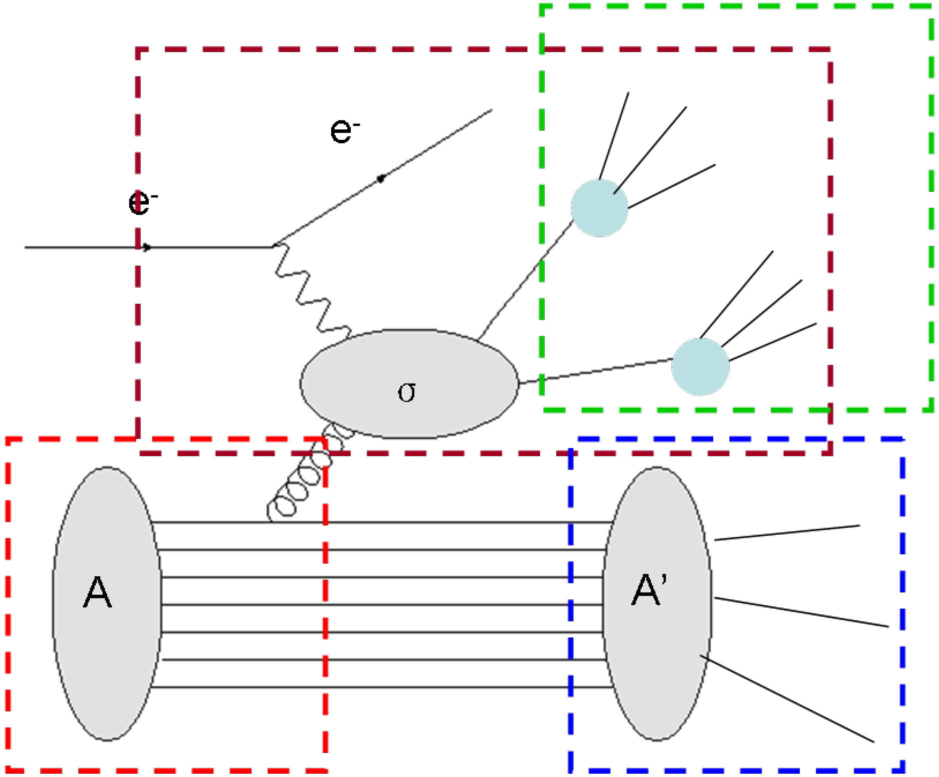
❖ The BeAGLE model:

$d \equiv \int dz\, \rho/\rho_0$

from $Z_{\text{first-collision}} \rightarrow \infty$





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

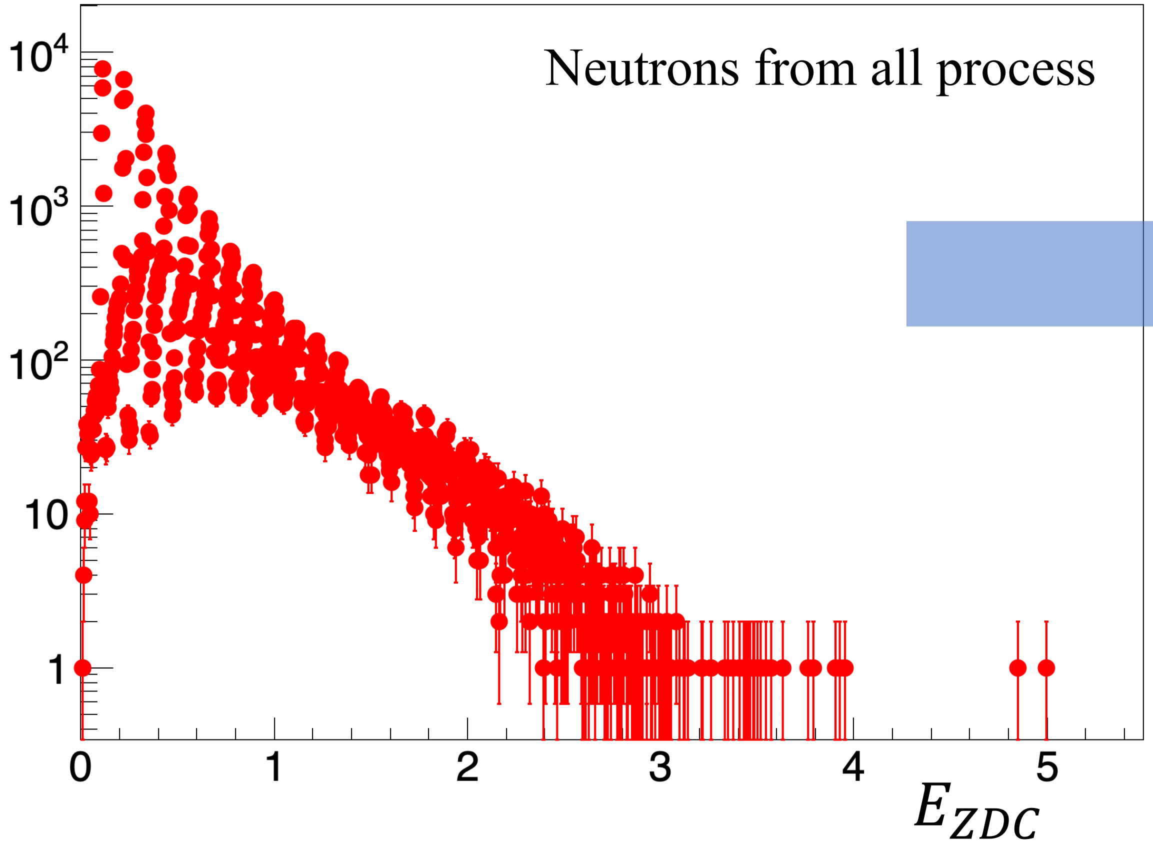
Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

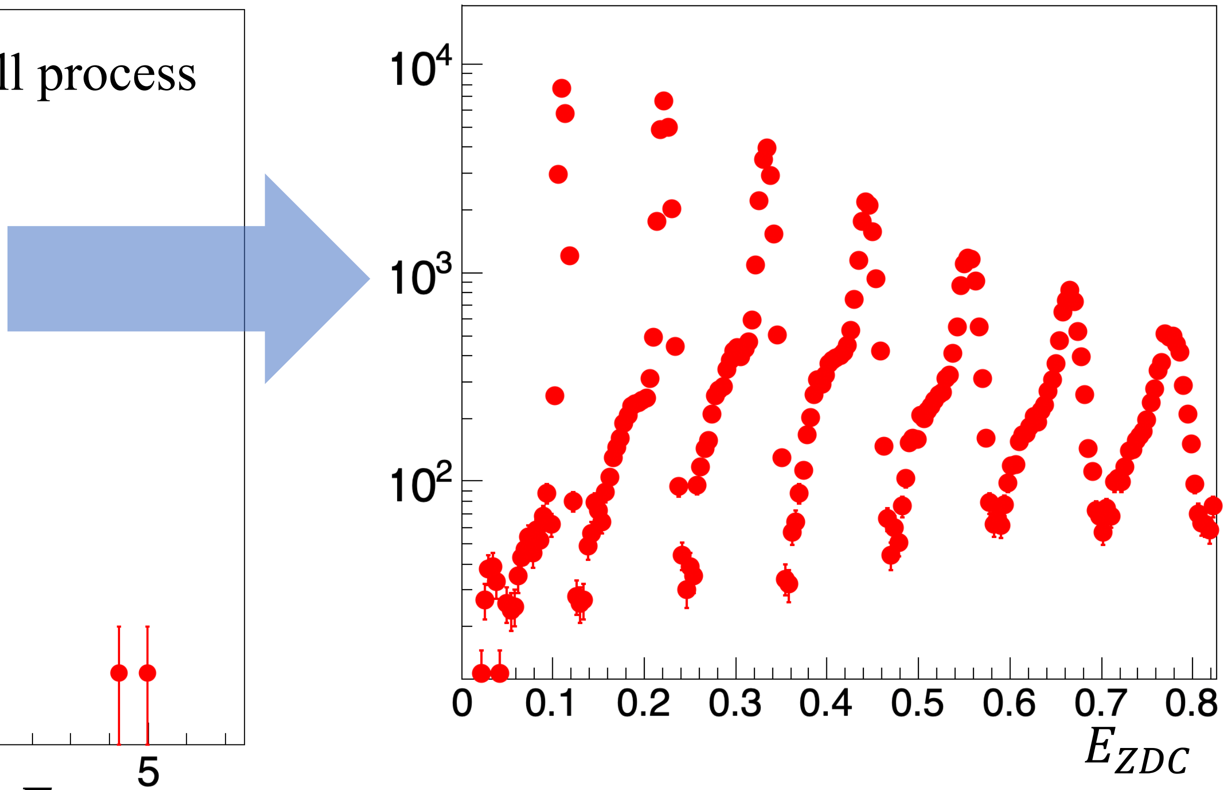
- Particles in the model:
  - X= 0, 2 create in hard collisions not affected by internuclear cascade (INC))
  - X= 3 Create in the evaporation process
  - X > 11 Particles created during the Intra-nuclear cascade
  - ……….

Can we use the neutrons in ZDC to cut on the impact parameter?

❖ Neutrons in ZDC in central collisions

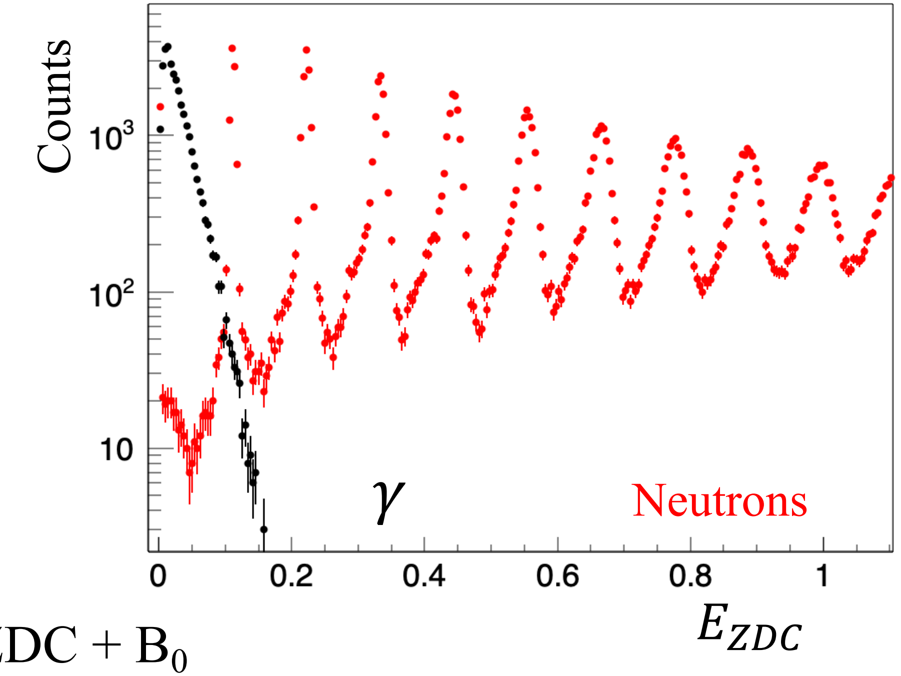
$$E_{ZDC} = \sum_{hit=0}^{N} E_{hit}$$

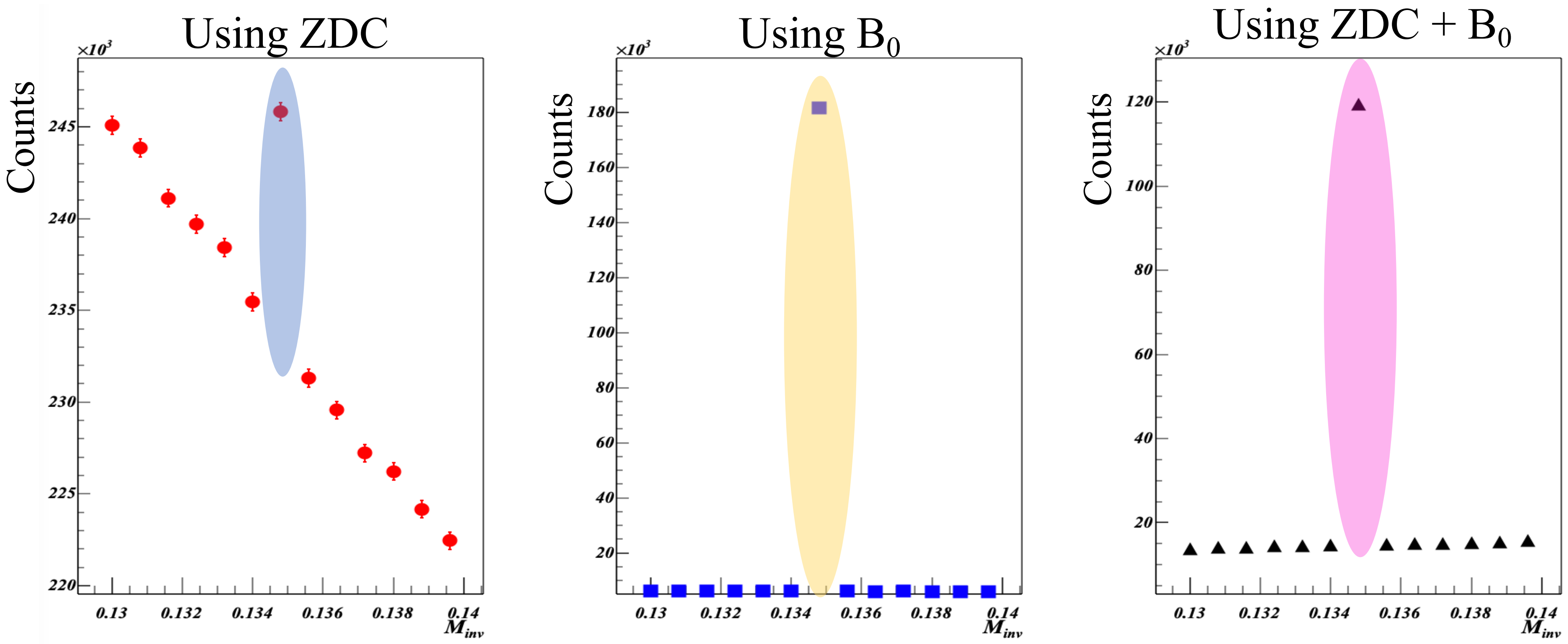




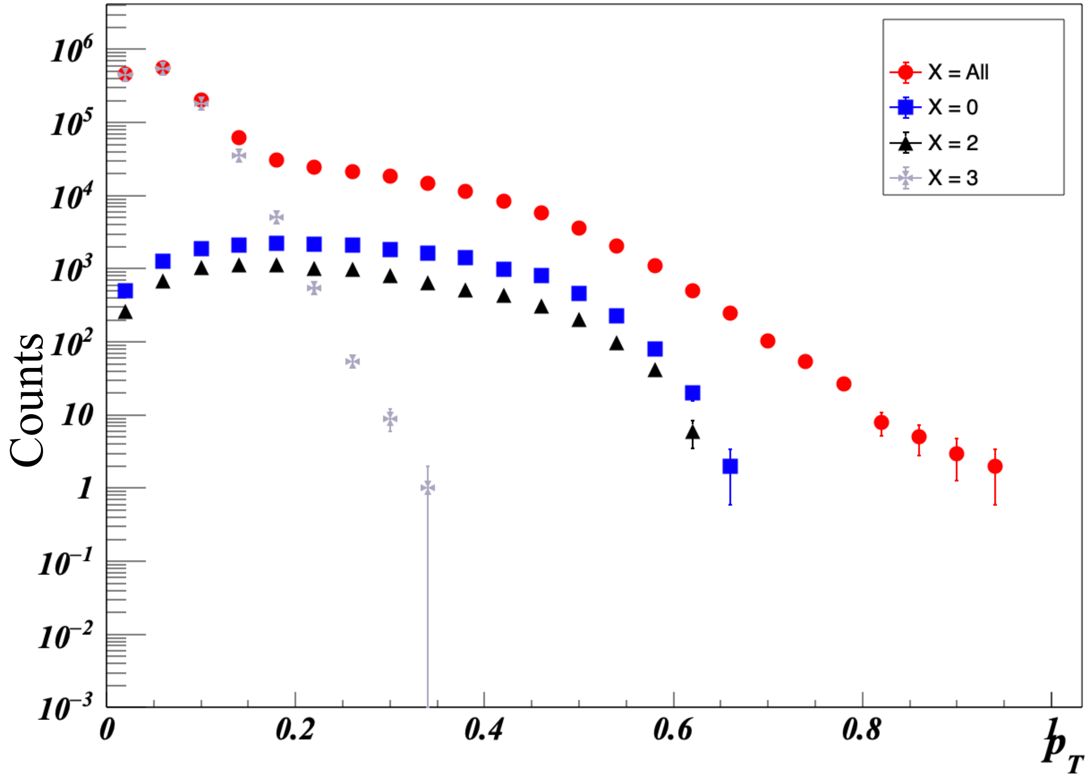
- ➢ Many peaks from evaporation processes.
- ➢ Can evaporation neutrons be used to study centrality?

- Can γ affect the centrality given by the ZDC
  - Small contributions from the γ to ZDC energy
  - ZDC and B0 can be used to construct the π^0
  - We can remove γ from the π^0 if needed



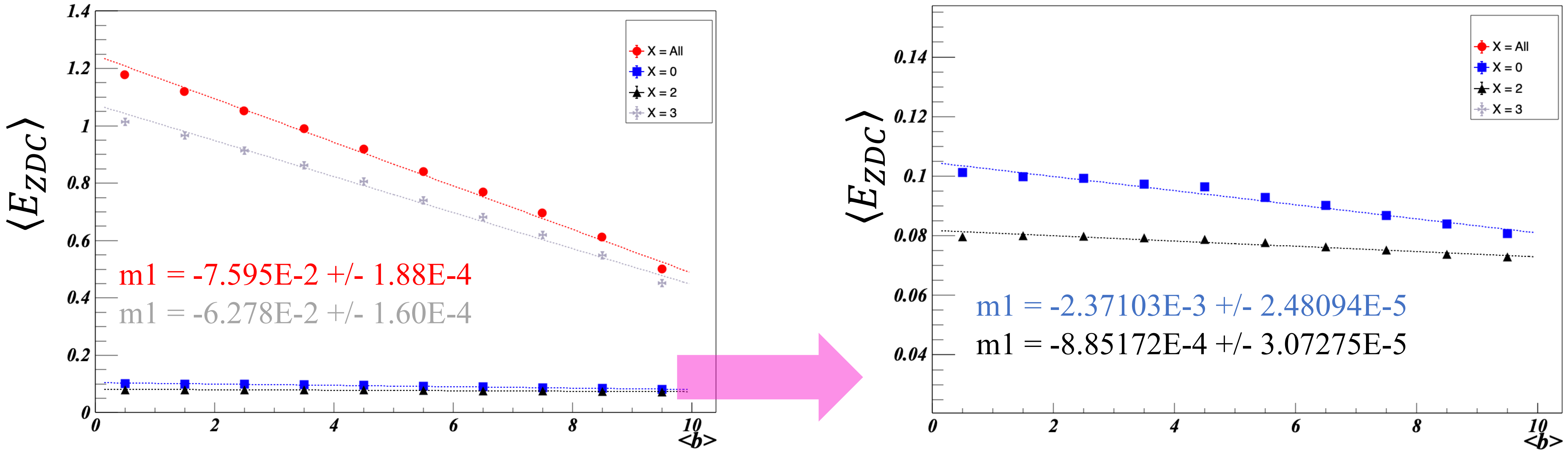


- The p_T of the neutrons in ZDC
  - X= All neutrons created in all process
  - X= 0, 2 neutrons created in hard collisions
  - X= 3 neutrons created in the evaporation process



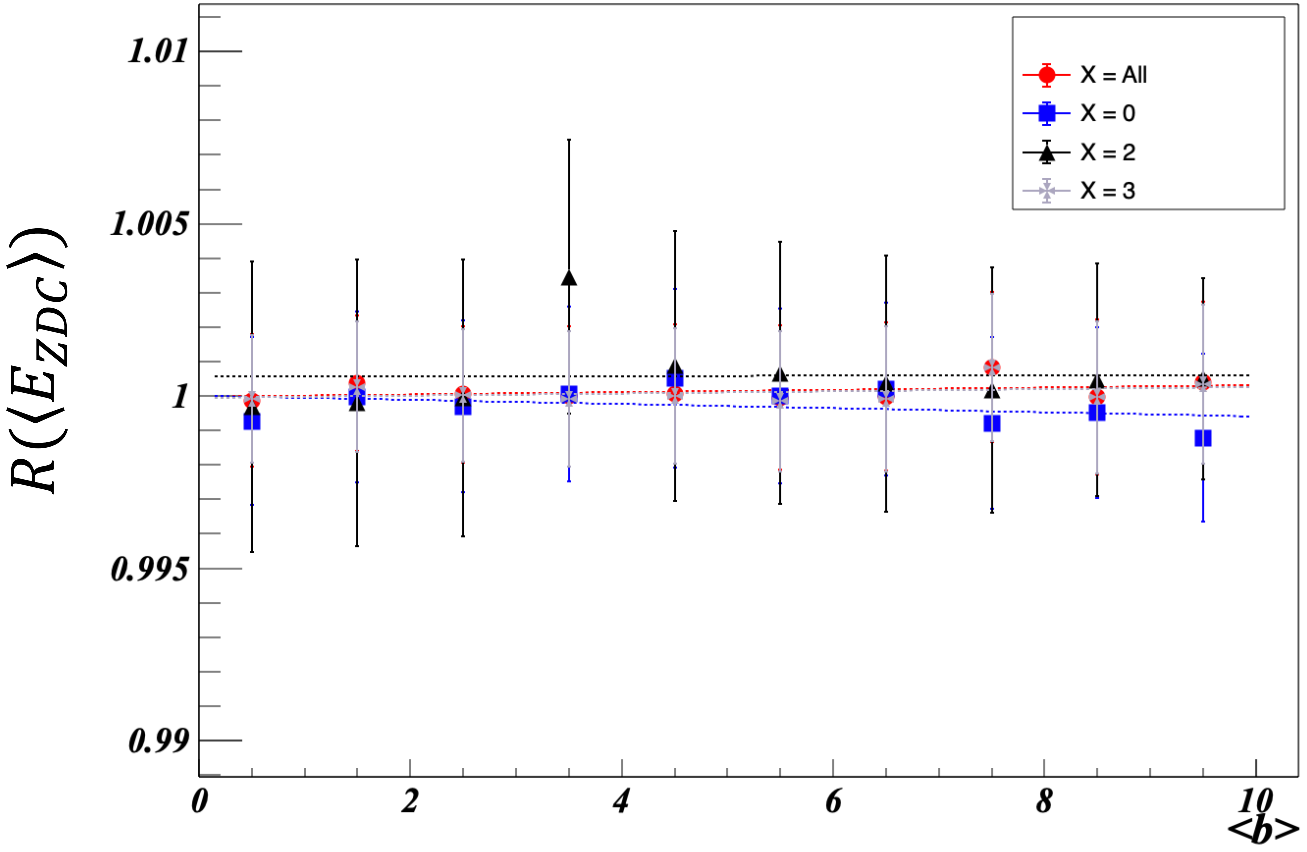
As expected evaporation neutrons are low p_T particles

- Correlations of the $\langle E_{ZDC} \rangle$ and impact parameter
  - X= All neutrons created in all process
  - X= 0, 2 neutrons created in hard collisions
  - X= 3 neutrons created in the evaporation process



Neutrons from all sources can be used for centrality definition

- Correlations of the $\langle E_{ZDC} \rangle$ and impact parameter with 4% energy smearing



The ratio of ZDC Energy with a smear of 4% shows no change

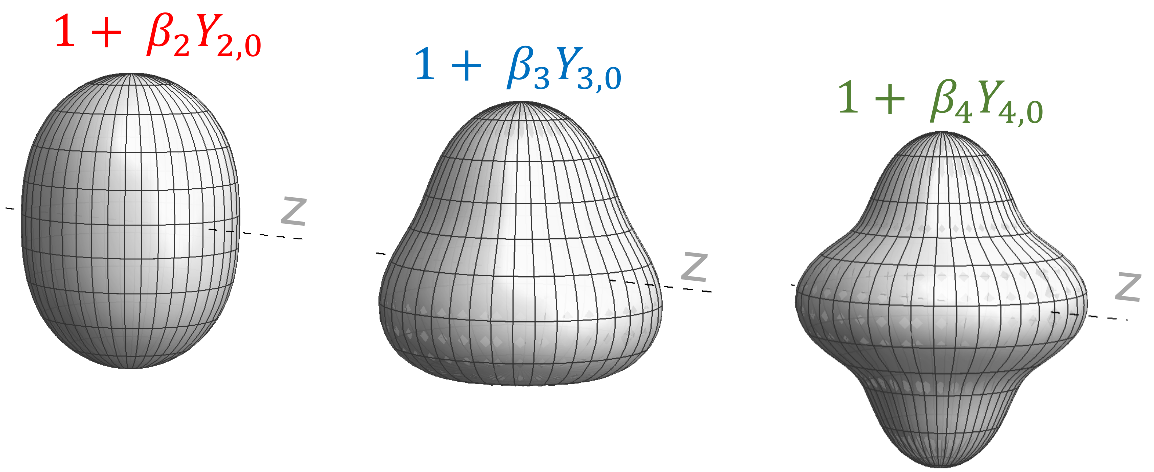
❖ Conclusions

We investigated the ability of the ZDC to be used in the centrality definition. In addition, we investigated the ability to use the Forwarded rapidity detector to investigate the nuclear shape:

- Neutrons from all sources can be used for centrality definition.
- An energy smear of 4% shows no change on the $\langle E_{ZDC} \rangle$ and impact parameter correlation.

➢ Forwarded rapidity and nuclear shape

The shape of the nucleus in nuclear physics is often modeled through a nucleon density profile of the Woods-Saxon $\rho(r, \theta, \phi)$.



- $Y_{n,0}$ are spherical harmonics
- β_n are deformation parameters
  - ✓ n=2 -> Quadrupole
  - ✓ n=3 -> Octupole
  - ✓ n=4 -> Hexadecapole

$$\rho(r, \theta, \phi) = \frac{\rho_0}{1 + e^{[r - R(\theta,\phi)/a_0]}}$$

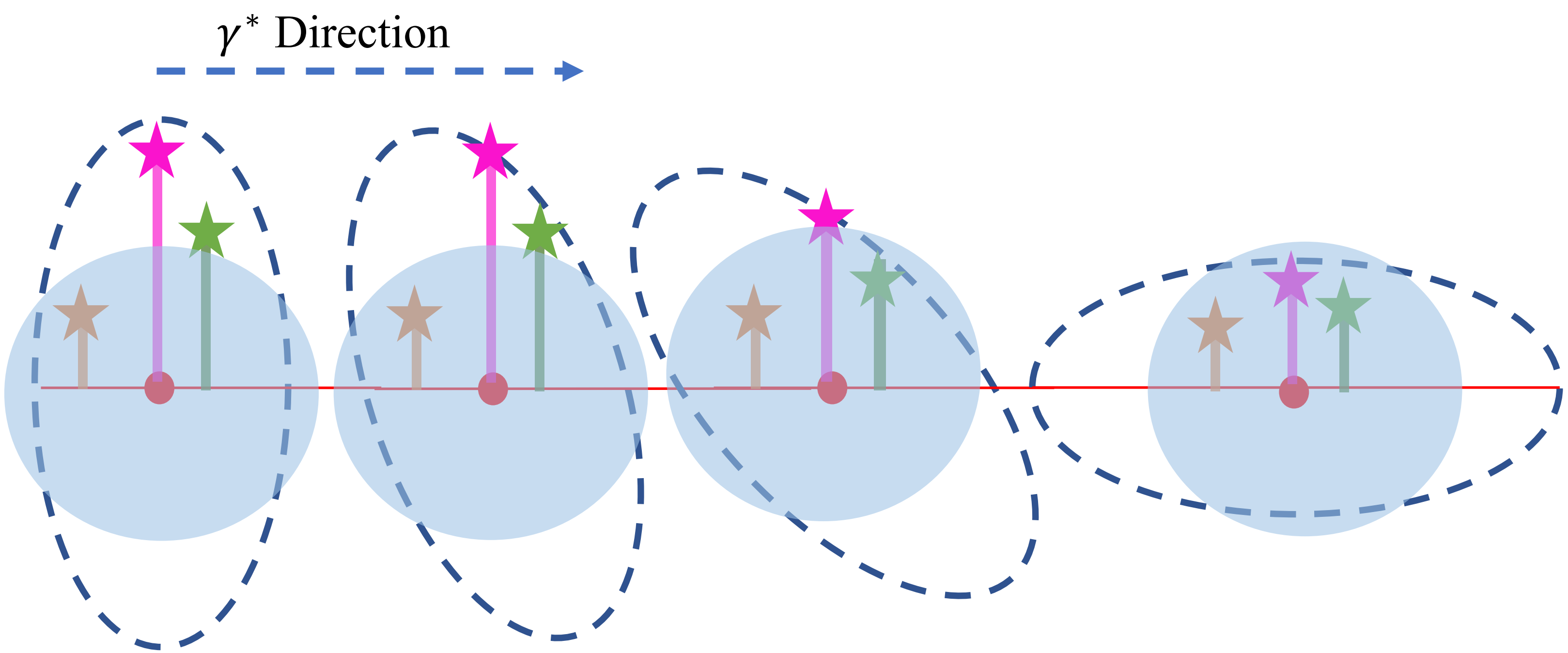
$$R(\theta, \phi) = R_0 \left(1 + \beta_2 Y_{2,0}(\theta, \phi) + \beta_3 Y_{3,0}(\theta, \phi) + \beta_4 Y_{4,0}(\theta, \phi)\right)$$

➢ Forwarded rapidity and nuclear shape

We will look to

- **Neutrons in ZDC**
- **Neutrons in B_0**
- **Protons in RP**

Impact parameter

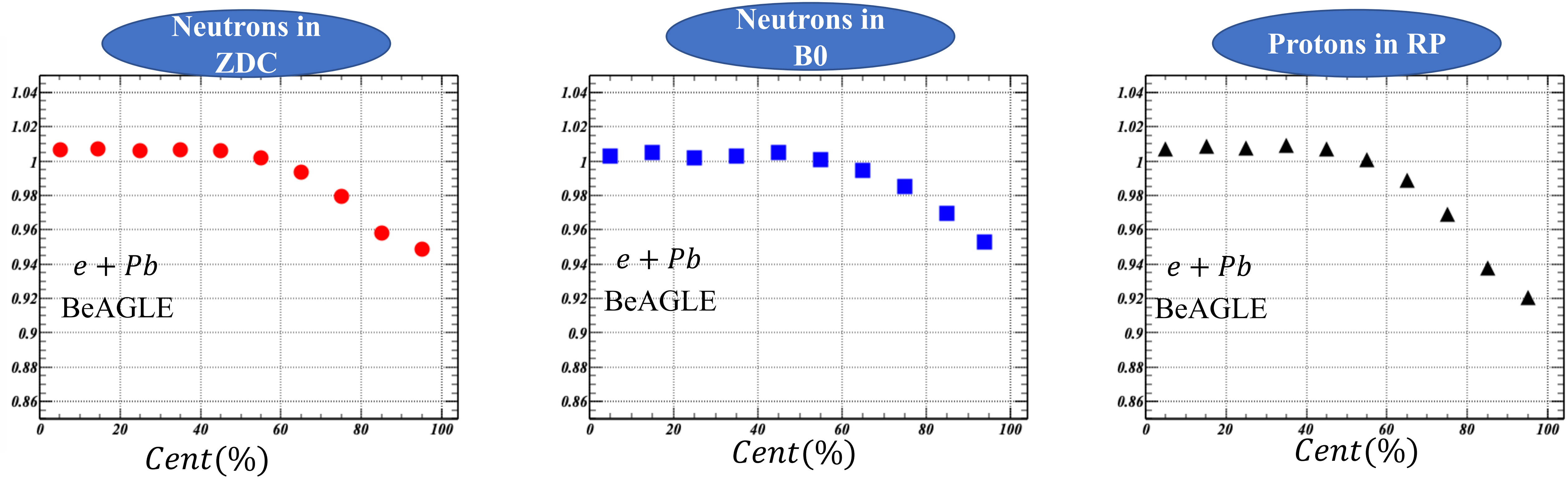


- Deformed Pb ($\beta_2 > 0$ and $\beta_4 > 0$) is used for this exercise

Measurements related to the impact parameter will be sensitive to the nuclear shape.

➢ Deformed Pb ($\beta_2 = 0.28$)

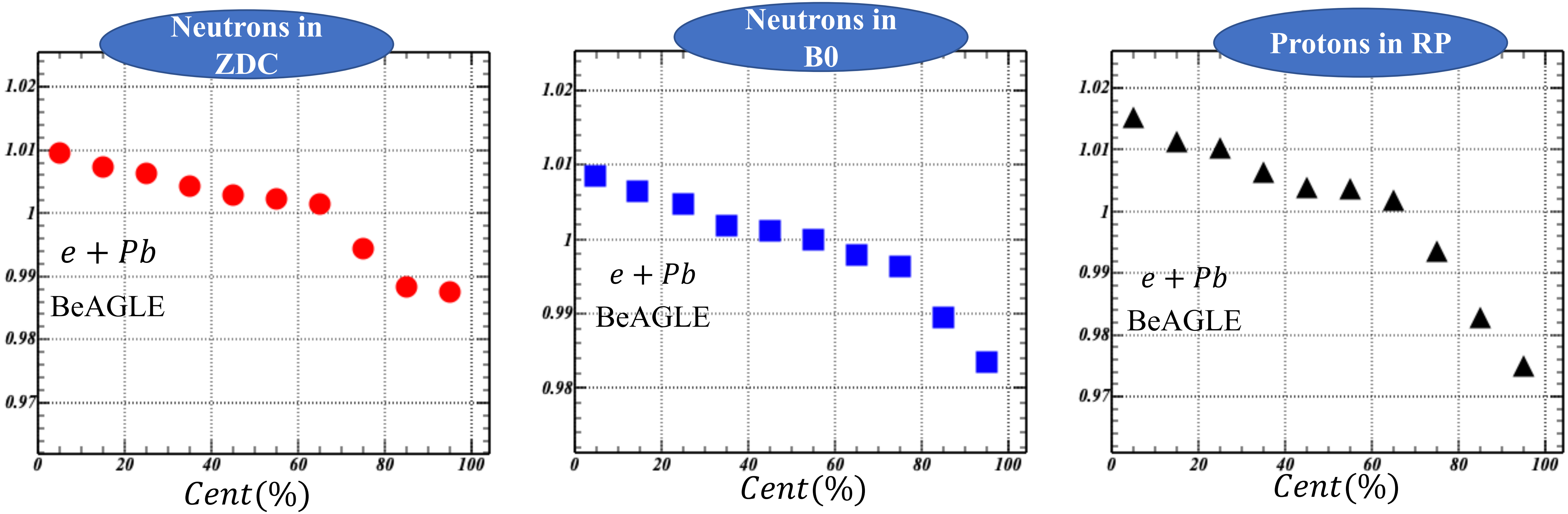
- ✓ The ratio of the undeformed to deformed Pb



Neutrons and Protons from all sources in forward rapidity show sensitivity to β_2 deformation in centrality > 50%.

➢ Deformed Pb ($\beta_4 = 0.093$)

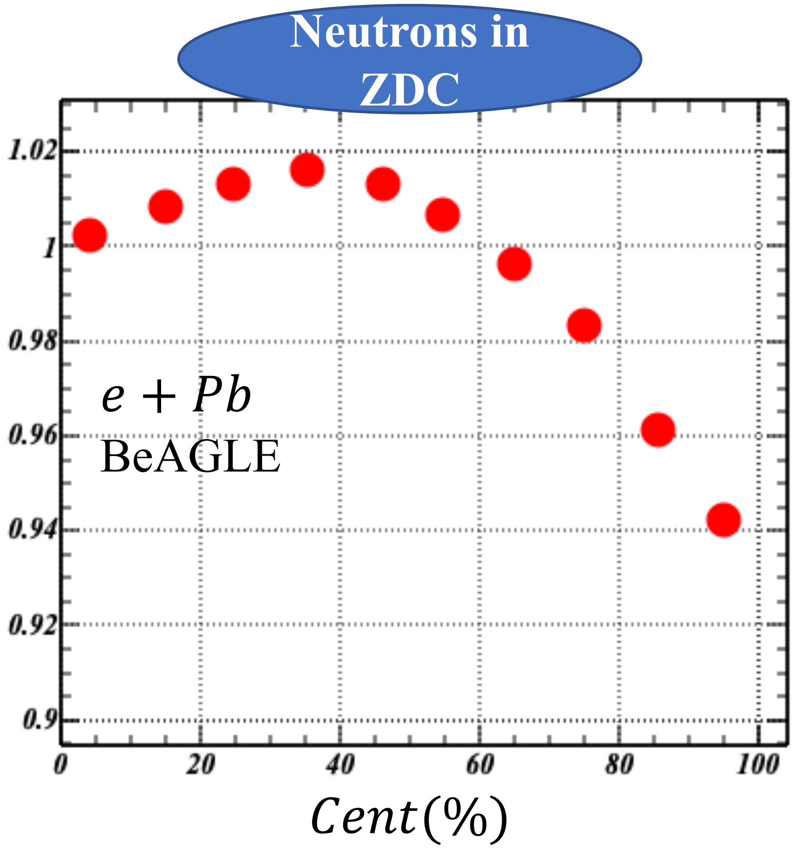
✓ The ratio of the undeformed to deformed Pb

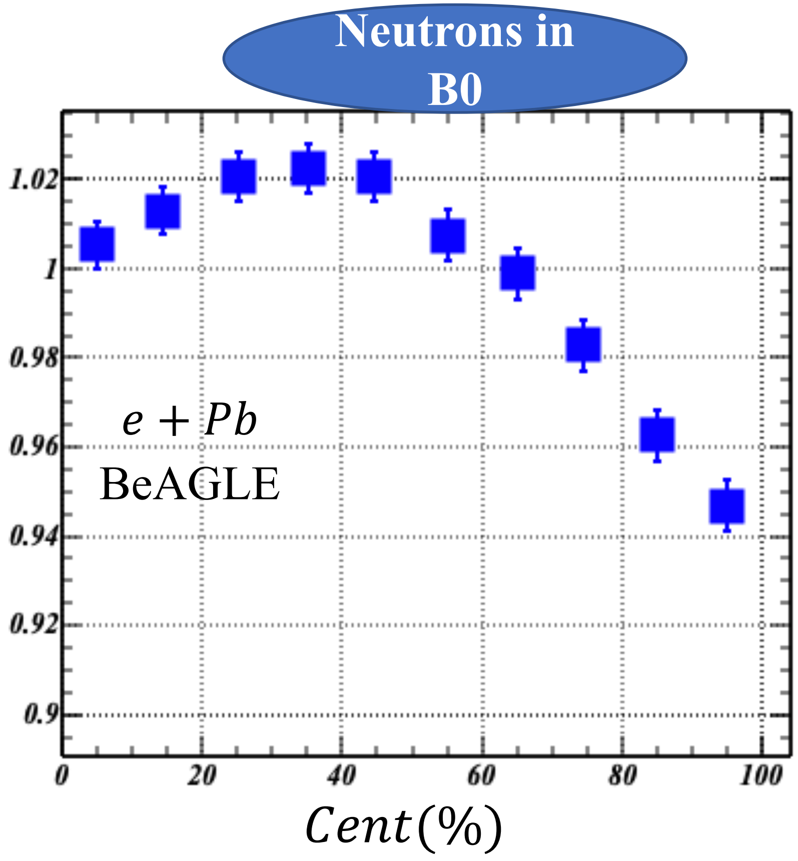


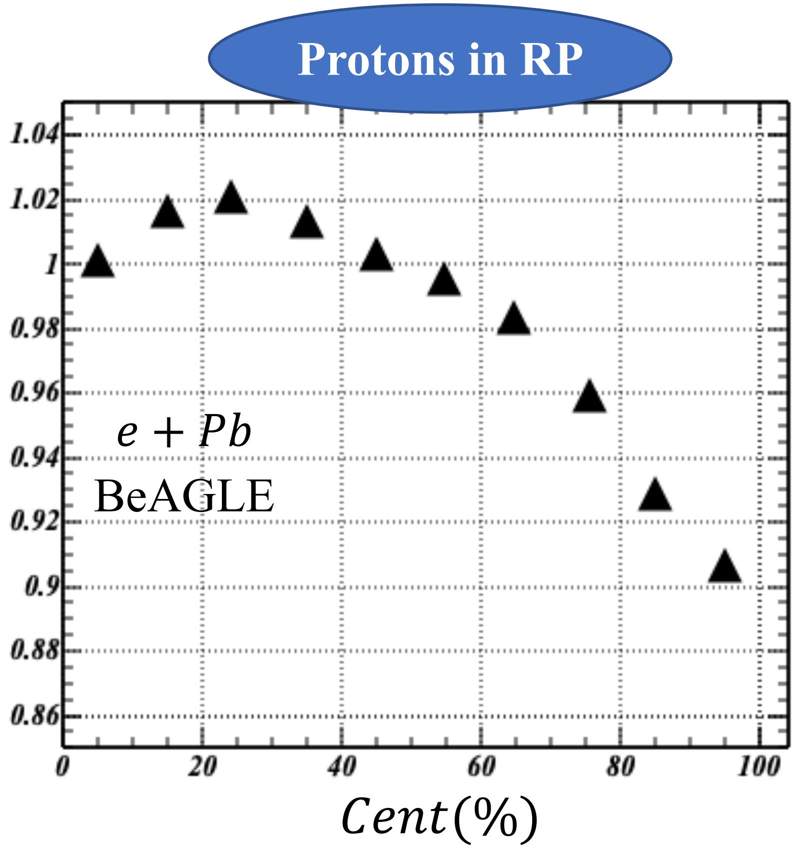
Neutrons and Protons from all sources in forward rapidity show sensitivity to β_4 deformation in different centrality selections.

➢ Deformed Pb ($\beta_2 = 0.28, \beta_4 = 0.093$)

- ✓ The ratio of the undeformed to deformed Pb





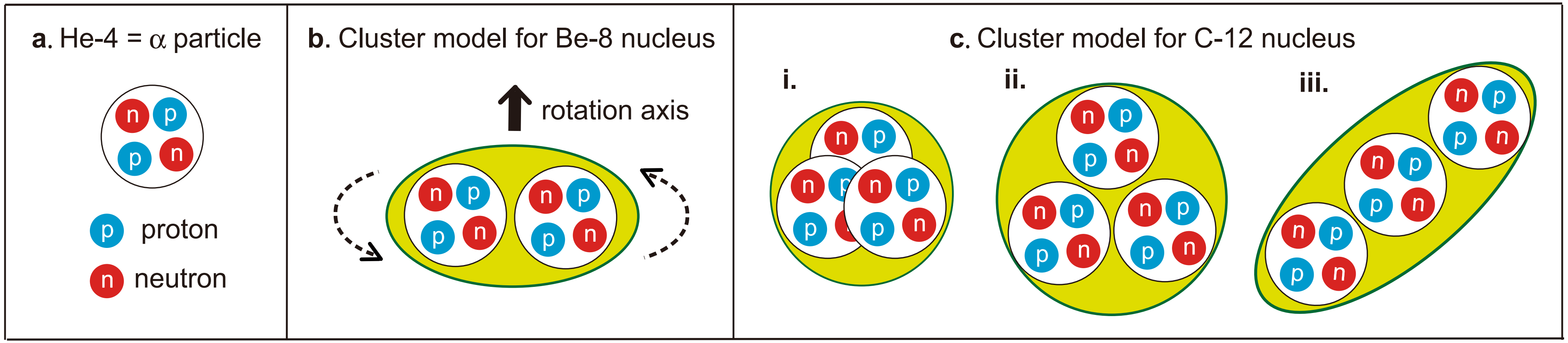


Neutrons and Protons from all sources in forward rapidity show sensitivity to β_2 and β_4 deformation in different centrality selections.

Ongoing work

- Expand the study into a full simulation study
- What can we learn about the nuclear shape and structure (α clustering)
  - ✓ Can α particles be the building block of some nuclei?
  - ✓ No direct experimental evidence has ever been provided.

This a long-standing question that EIC can answer



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- We are putting additional efforts into the simulation in this avenue
  - ✓ Using forwarded physics (ZDC, B_0, and RP)
  - ✓ Using midrapidity physics

❖ Conclusions

We investigated the ability of the ZDC to be used in the centrality definition. In addition, we investigated the ability to use the Forwarded rapidity detector to investigate the nuclear shape:

- ➢ Neutrons from all sources can be used for centrality definition.
- ➢ The Forwarded rapidity detectors are sensitive to nuclear deformation.

- ➢ Ongoing work to understand:
  - ✓ Nuclear shape (deformation)
  - ✓ Nuclear structure (α clustering)

Thank You