Collision geometry and breakup determination in eA collisions

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BROOKHAVEN NATIONAL LABORATORY

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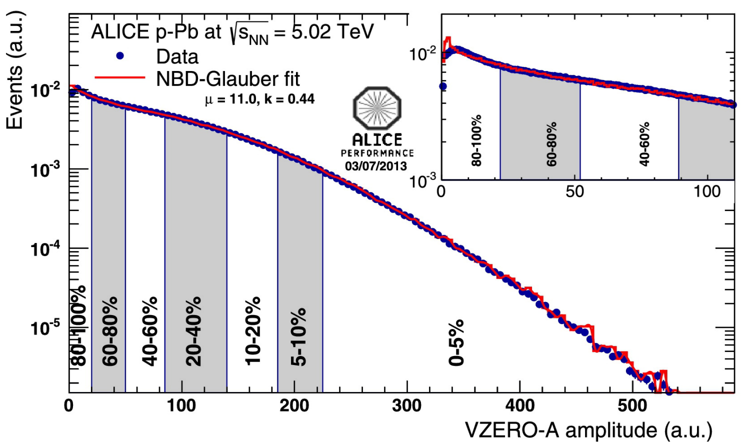
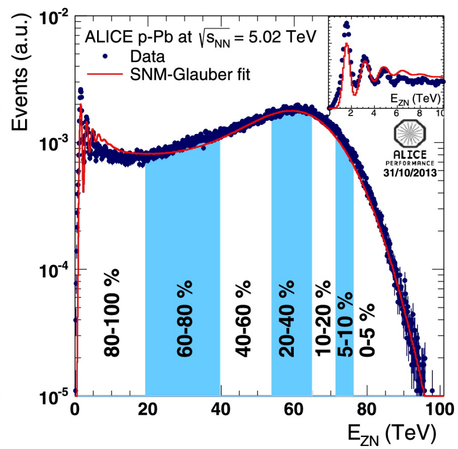
Outline

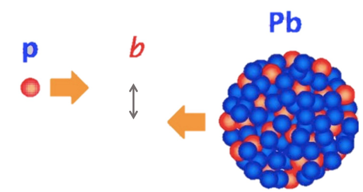
- Motivations
- Collision geometry definition
- BeAGLE simulation framework
- Constraint on the eA collision geometry
- Summary

Motivation

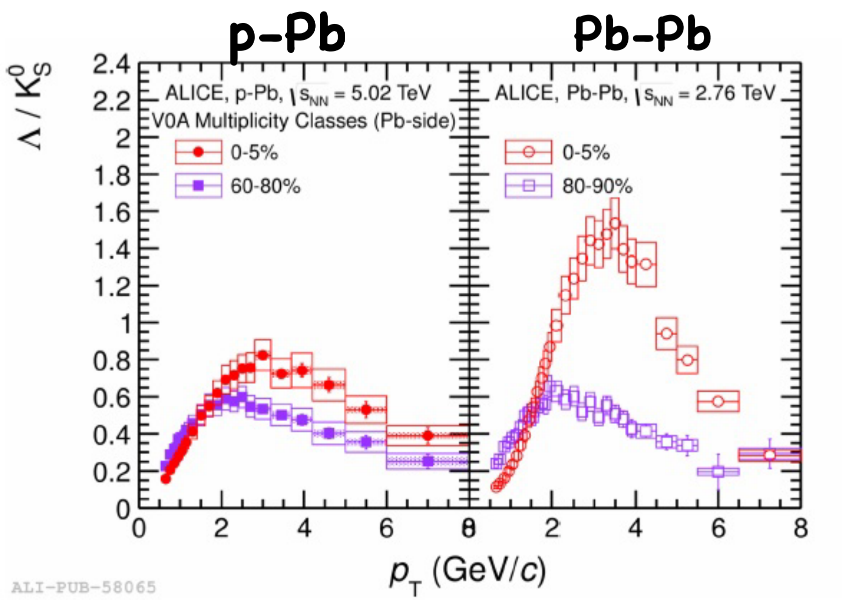
- Centrality is an important variable in heavy ion physics and it's an experimental handle to the collision geometry.
- Various nuclear effects depend on the collision geometry.







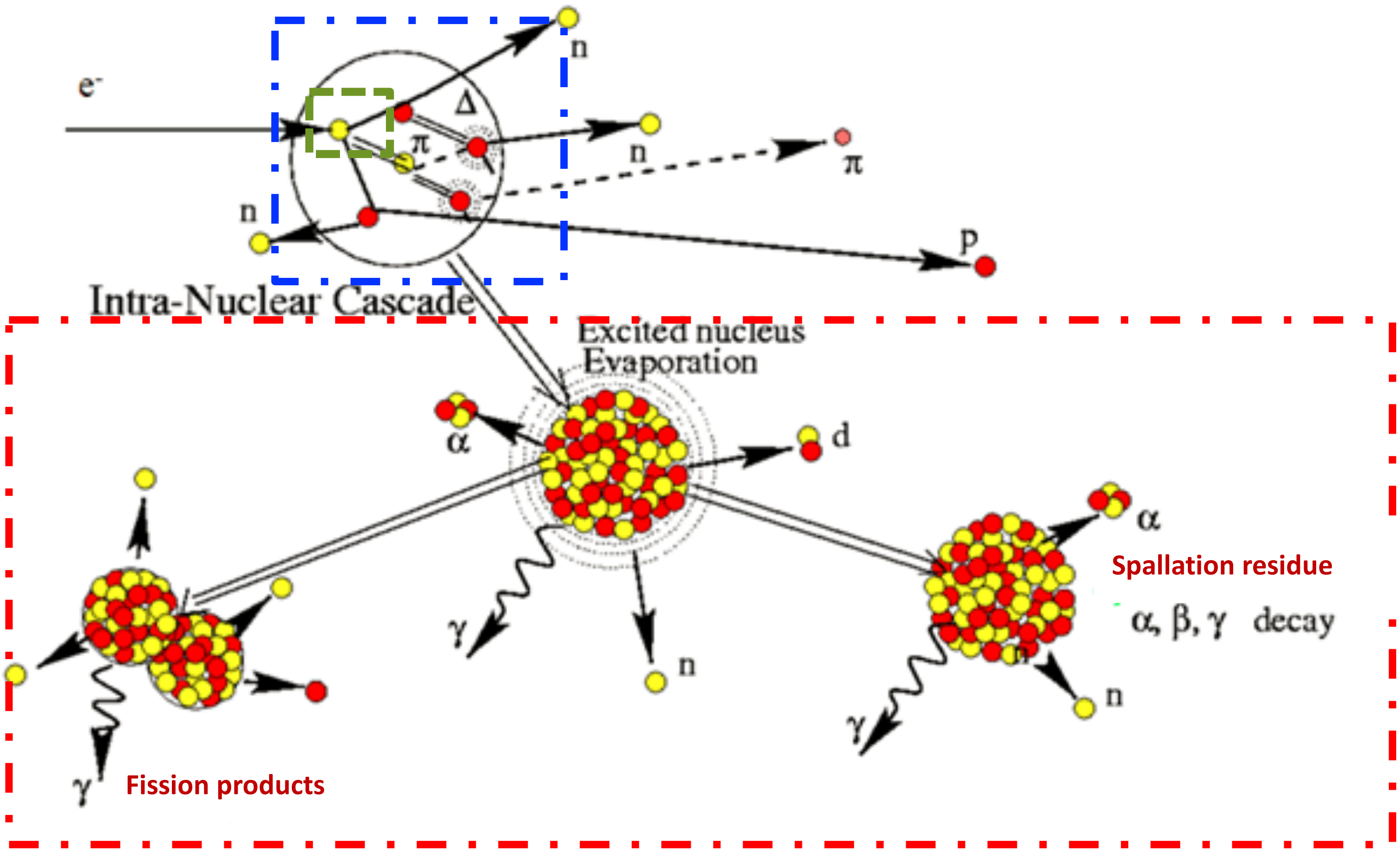
In heavy ion collisions, the centrality can be estimated by measuring either the charged particle multiplicity or the zero degree energy.



Can we also define centrality in eA?

Yes!

Collision geometry definition



1. Deep inelastic scattering off a nucleon: **primary interaction**
2. Intra-nuclear cascade process: **secondary interactions**
3. Nuclear remnant breaks up depending on the excitation: **evaporation**

How to define the centrality in eA?

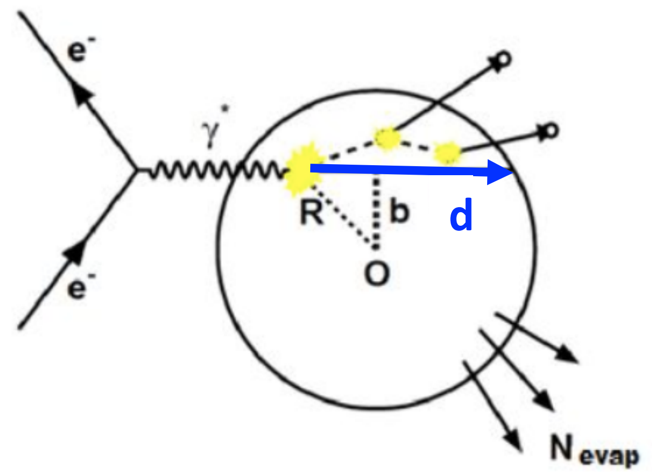
Collision geometry definition

Three relevant quantities to describe the collision geometry:

- b: impact parameter
- d: the projected virtual photon traveling length
- Nuclear thickness:

$$T(b)/\rho_0 = \int_{-\infty}^{+\infty} dz\, \rho(b,z)/\rho_0 \text{ in fm}$$

ρ_0 is the nucleon density in the center of the nucleus



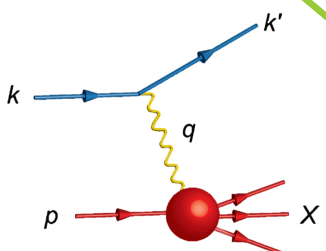
N_{evap}: number of particles (neutrons) from evaporation.

Formation time: $\tau = \tau_0 \frac{E}{m} \frac{m^2}{m^2+p_\perp^2}$, τ_0 is a free formation length parameter.

The larger d is, the more nucleons are expected to be removed from the nuclear remnant, and the more neutrons can be emitted during the evaporation.

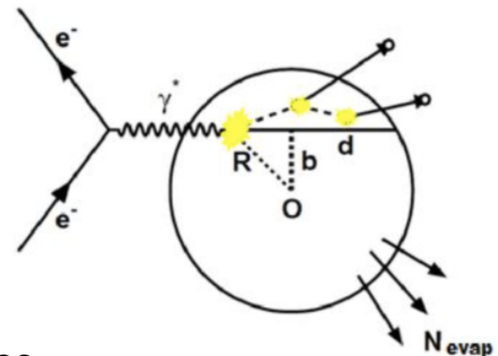
BeAGLE simulation framework

We are using BeAGLE (**B**enchmark **eA** **G**enerator for **LE**ptoproduction) package for the e+A event simulation.

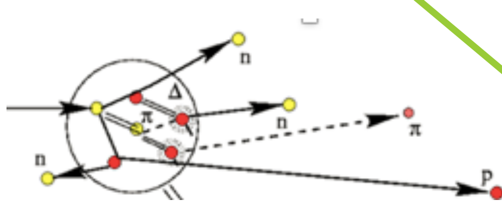


Primary interaction

Primary interaction treated by **PYTHIA** hard collision.

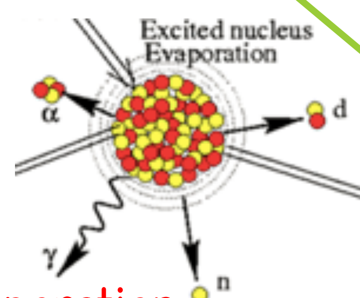


Cascade process handled by **DPMJET**.



Intra-nuclear cascade

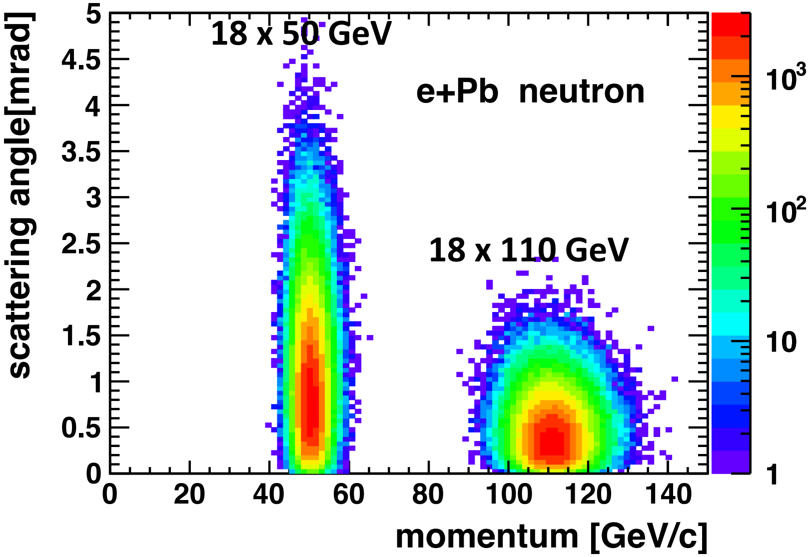
Target remnant evaporation and break up included by **FLUKA**.



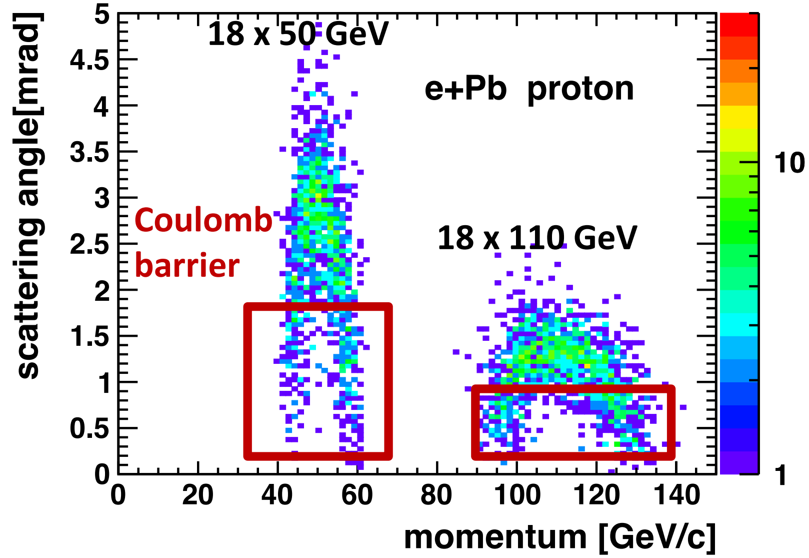
Nuclear remnant evaporation

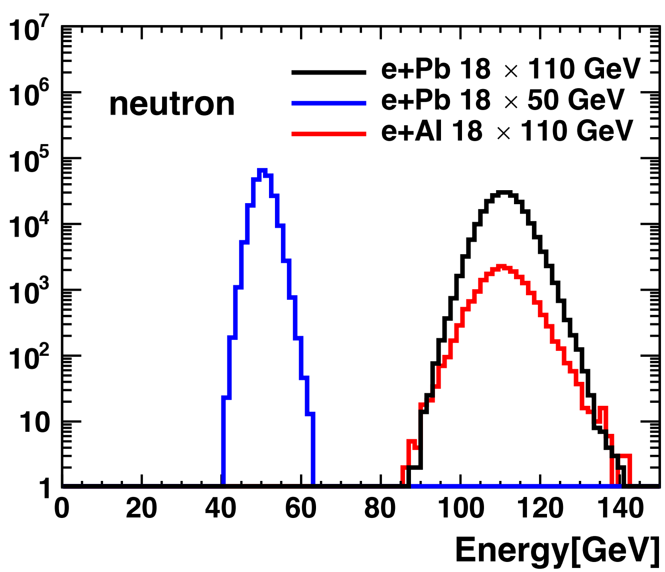
Kinematics of evaporation neutrons and protons

neutron



proton





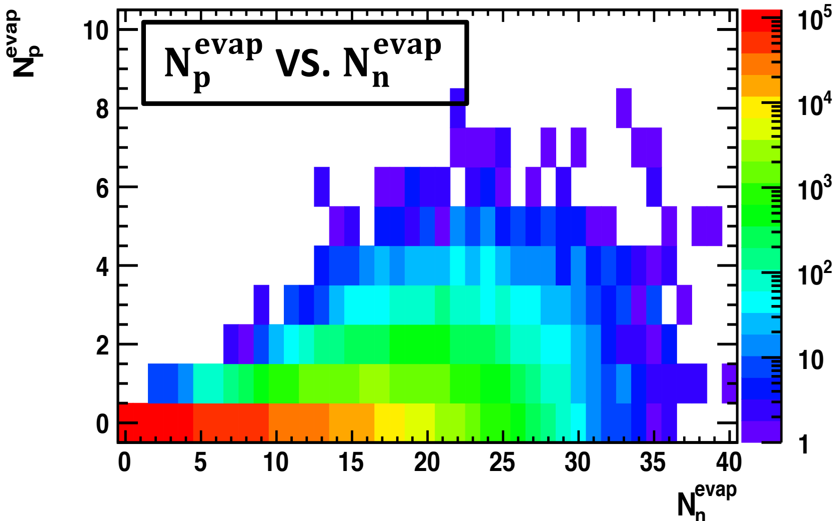
- Evaporation neutrons and protons:
  → momentum (energy) is close to beam energy, scattering angle is small.
- Decreasing Beam Energy:
  → lower momentum, scattering angle is larger.
- Proton emission during evaporation process is greatly suppressed compared to that of neutrons.

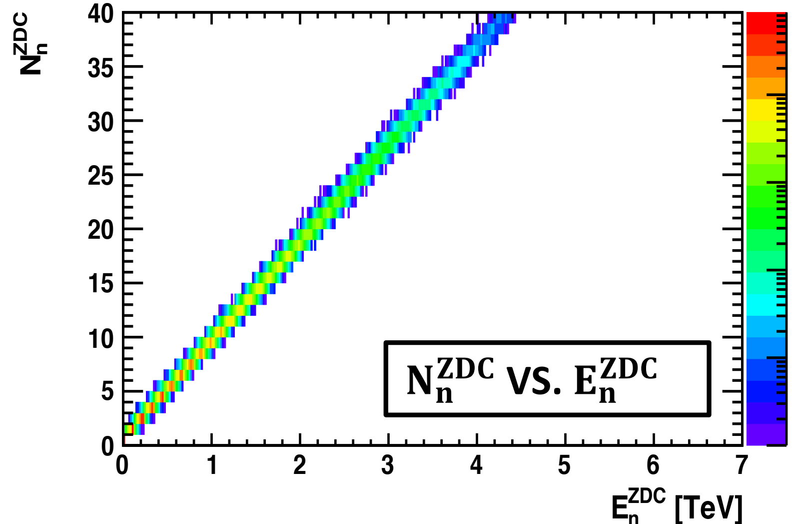
- Energy doesn't depend on A.

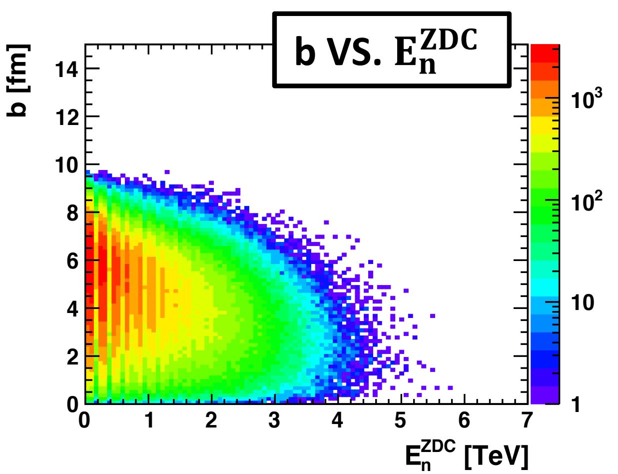
Measuring forward neutron

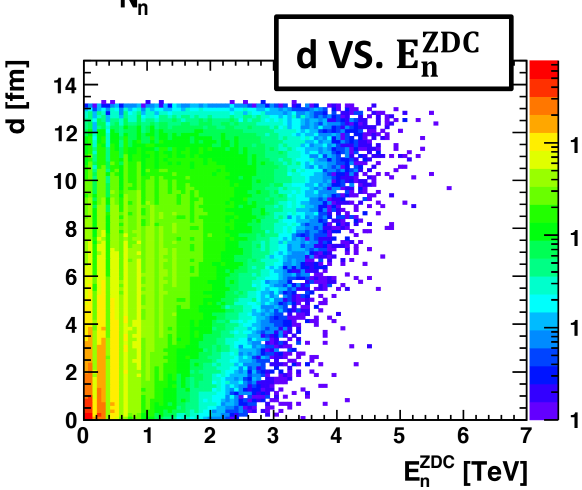
e+Pb 18 x 110 GeV   ZDC acceptance < ± 4 mrad

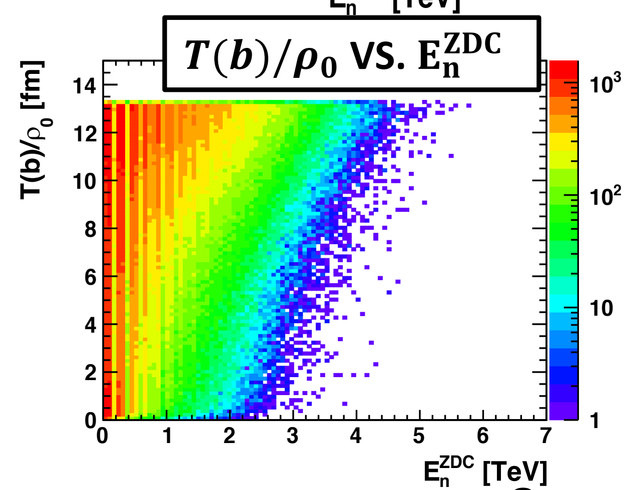
- ❑ Why neutrons
  - Dominant products from evaporation
  - Isolated by bending magnets
- ❑ How to measure
  - Zero degree calorimeter (ZDC)
  - Cover most forward rapidity



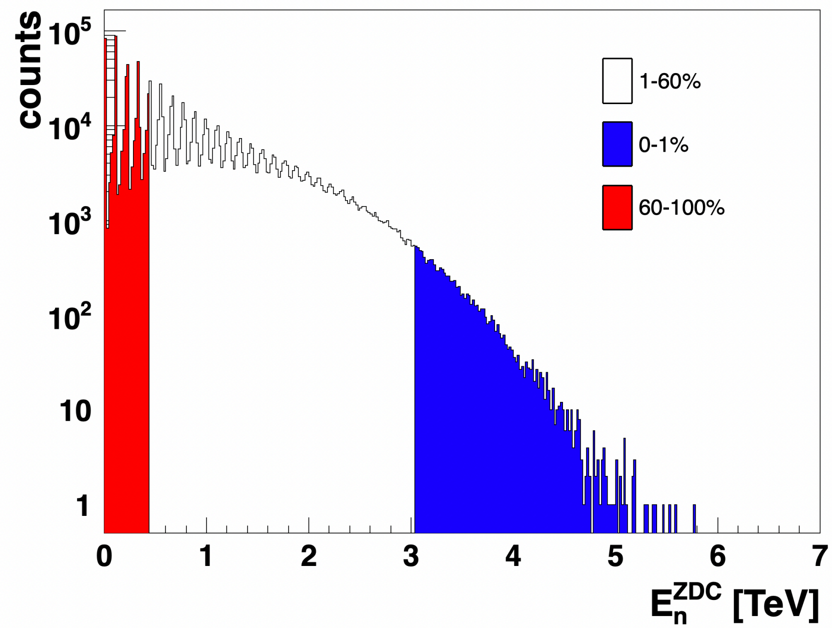








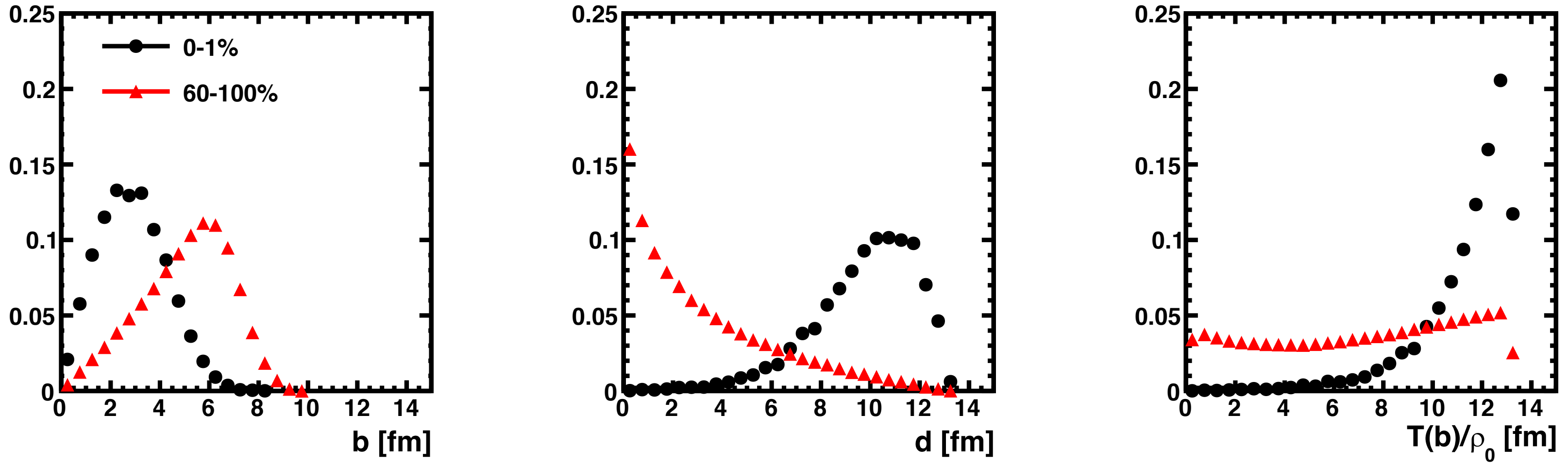
Selection of centrality



- Centrality is selected by the energy deposition. 0-1% represents top 1% highest energy deposition.

	0-1%	60-100%
E_n^{ZDC}[TeV]	>3.04	<0.42

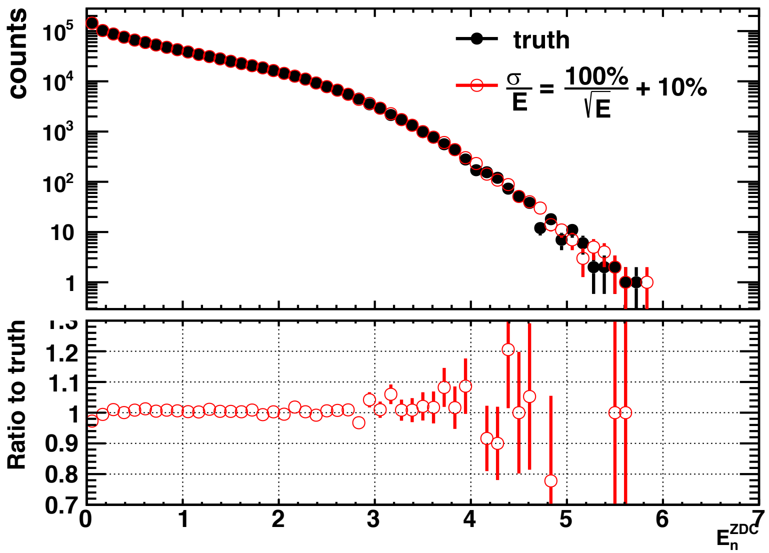
b, d, $T(b)/\rho_0$ can be used as the probe of centrality in BeAGLE framework.

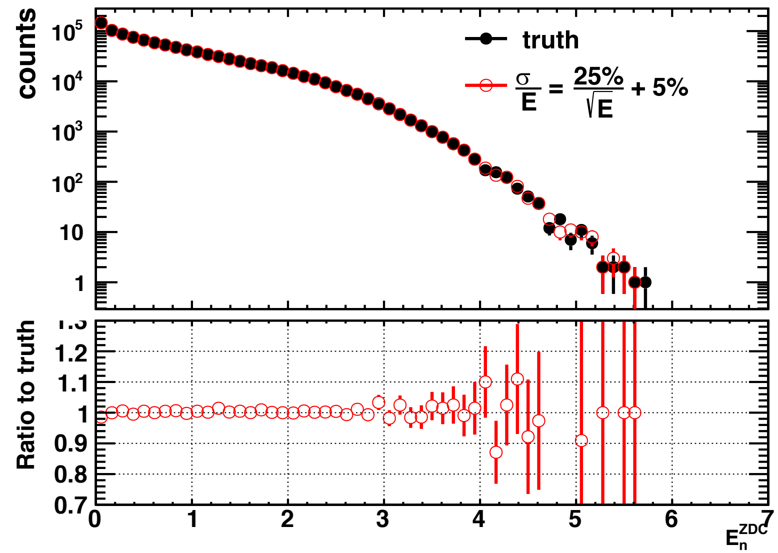


Detector smearing

Energy resolution: 1. $\frac{\sigma}{E} = \frac{100\%}{\sqrt{E}} + 10\%$ **2.** $\frac{\sigma}{E} = \frac{25\%}{\sqrt{E}} + 5\%$

Smear each individual neutron by a Gaussian representing the resolution.

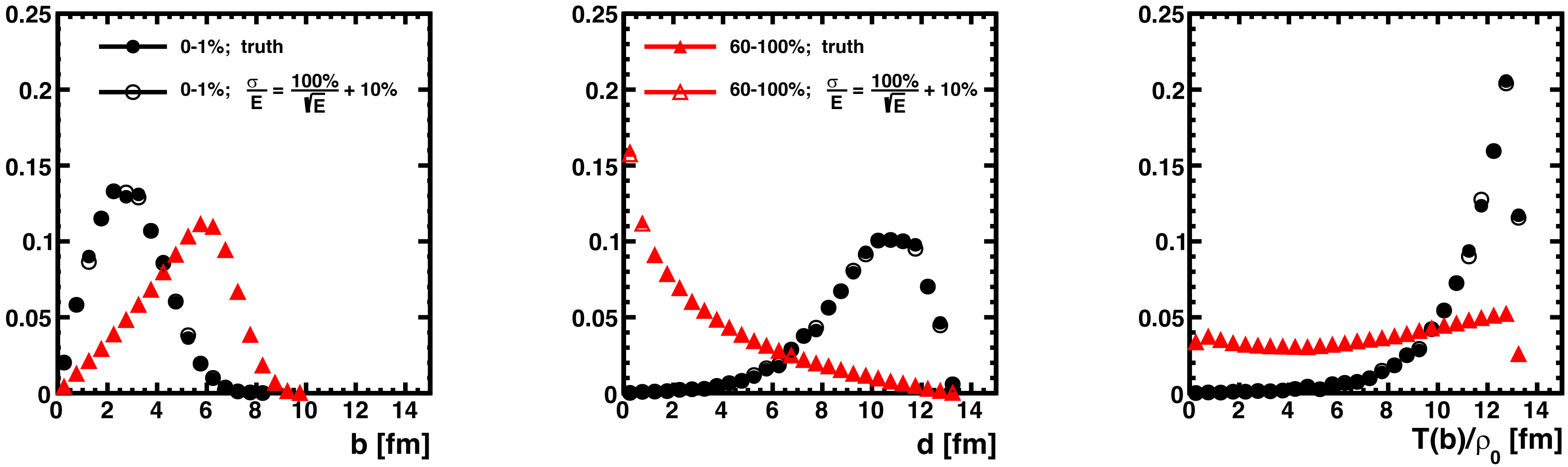




- ➢ The true distribution and the smeared one are almost identical.
- ➢ A higher resolution calorimeter is not required for this analysis.

Detector smearing

The b, d, $T(b)/\rho_0$ comparison between generated and smeared distributions in **central** and peripheral collisions.



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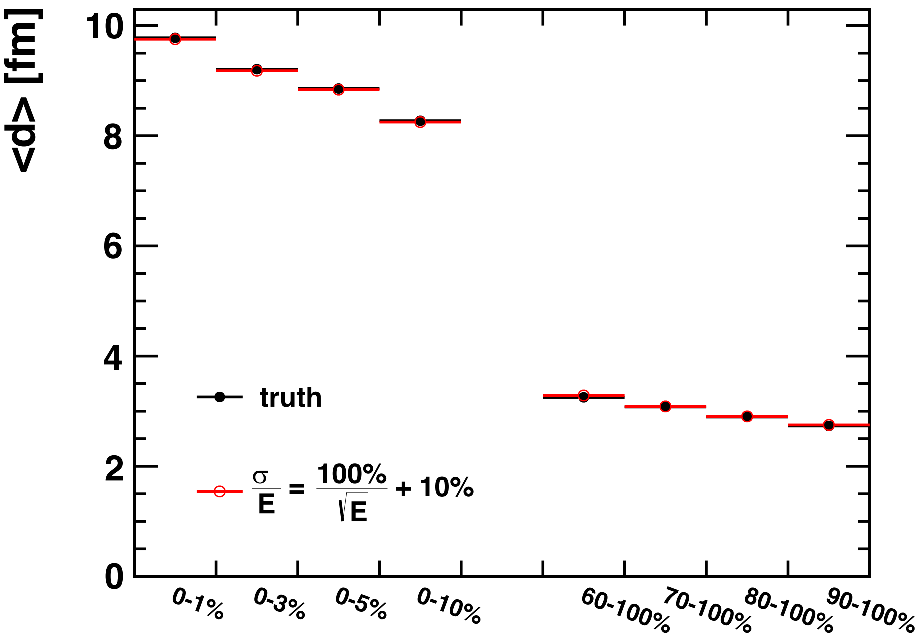
Detector smearing



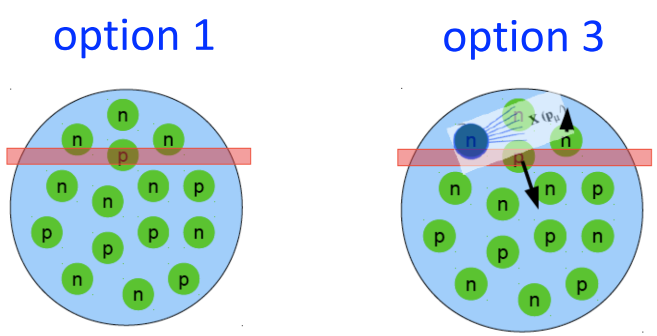
The energy range for different centrality bins:

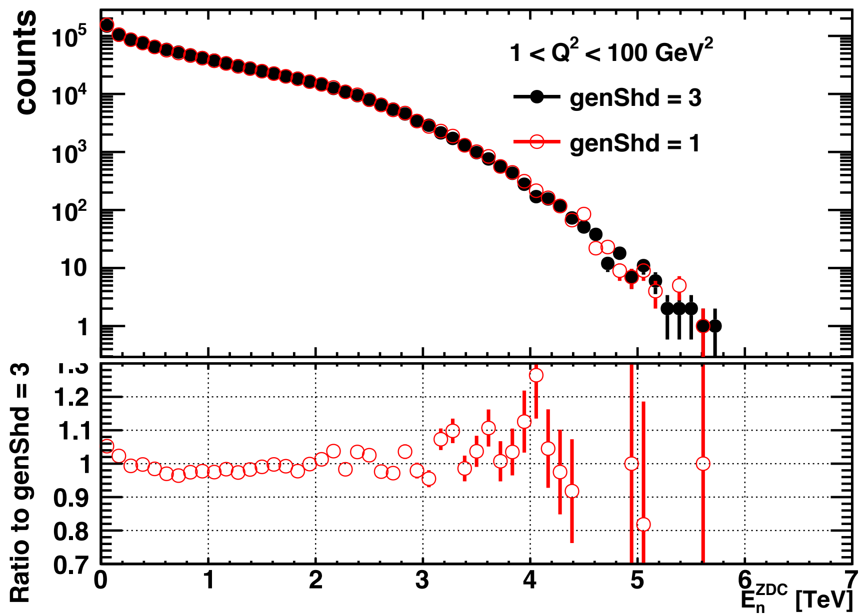
	truth	$\frac{\sigma}{E} = \frac{100\%}{\sqrt{E}} + 10\%$
0-1%	>3.04	>3.06
0-3%	>2.58	>2.58
0-5%	>2.32	>2.32
0-10%	>1.88	>1.88
60-100%	<0.42	<0.42
70-100%	<0.30	<0.28
80-100%	<0.18	<0.16
90-100%	<0.08	<0.06

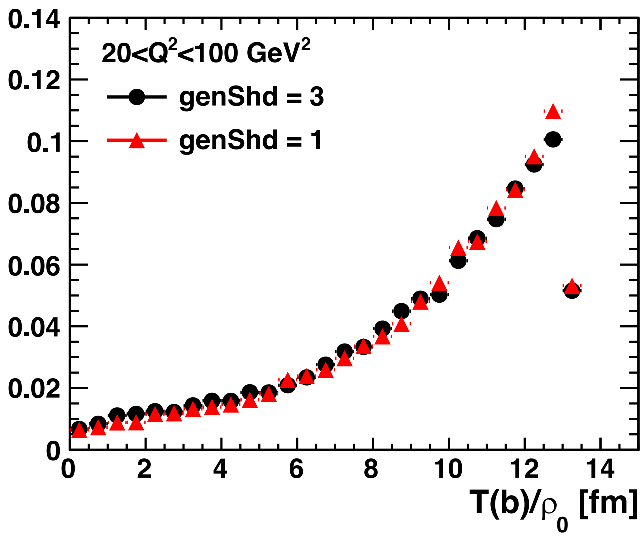
- The average d decreases from 0-1%, 0-3% to 0-5%, 0-10%.
- The decreasing trend is not obvious in peripheral collisions.
- There is no difference between the true distribution and the smeared one.

Shadowing effect

Shadowing option 1: One and only one nucleon participates in the interaction
Shadowing option 3: Multiple nucleons interact with photon. The first struck nucleon undergoes a hard scattering, any additional ones undergo an elastic scattering





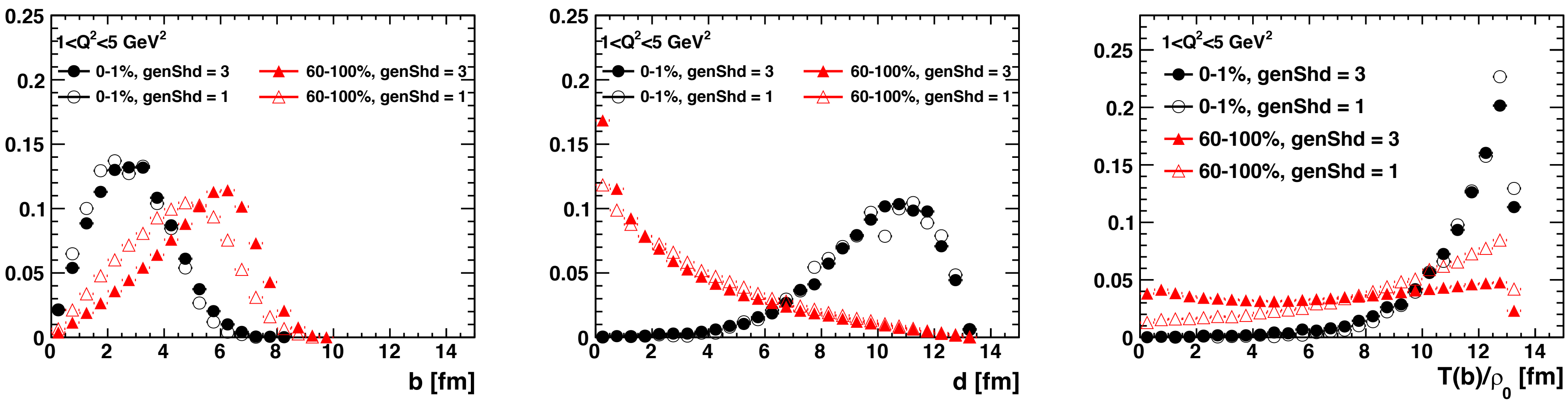


The model doesn't predict any difference for this two shadowing options for b, d, $T(b)/\rho_0$ at high Q^2.

What will happen at low Q^2?

Shadowing effect kinematics dependence

For low Q², $1 < Q^2 < 5\ \mathrm{GeV}^2$, the comparison of shadowing option 1 and 3 in **central** and **peripheral** collisions:

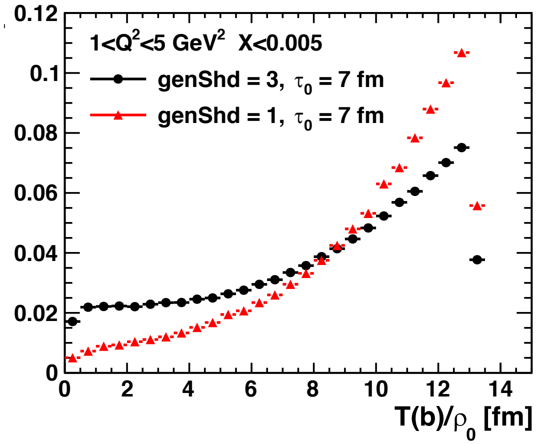


- The model **doesn't predict any difference** for this two shadowing options for b, d, $\mathrm{T}(b)/\rho_0$ in **central collisions**, there are some **small differences** predicted in the **peripheral collisions**.

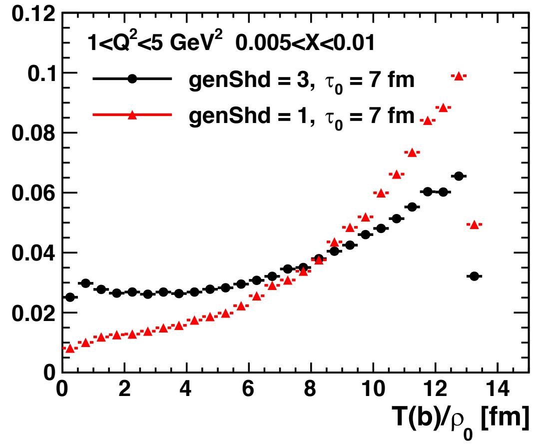
Shadowing effect kinematics dependence

For low Q^2, $1 < Q^2 < 5\ \mathrm{GeV}$, the comparison of shadowing option 1 and 3 in different x-bins: x<0.005, 0.005<x<0.01, x>0.01

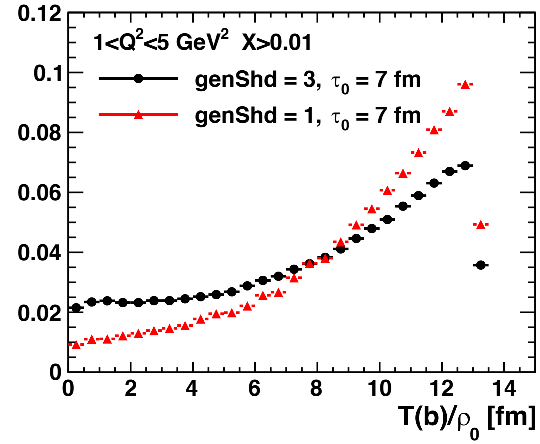
x<0.005



0.005<x<0.01

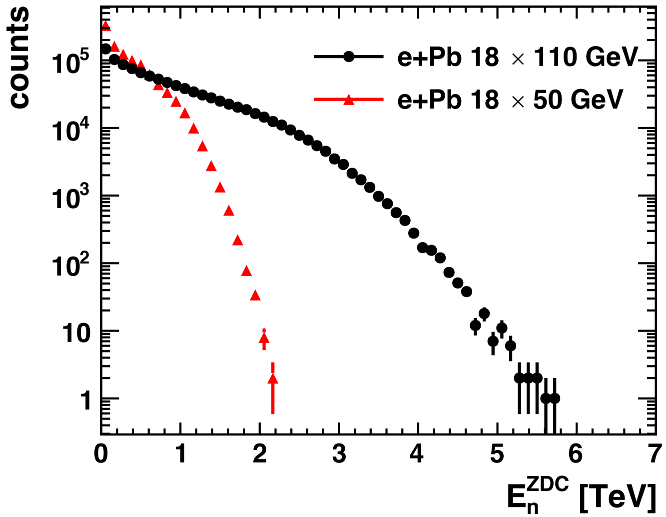


x>0.01



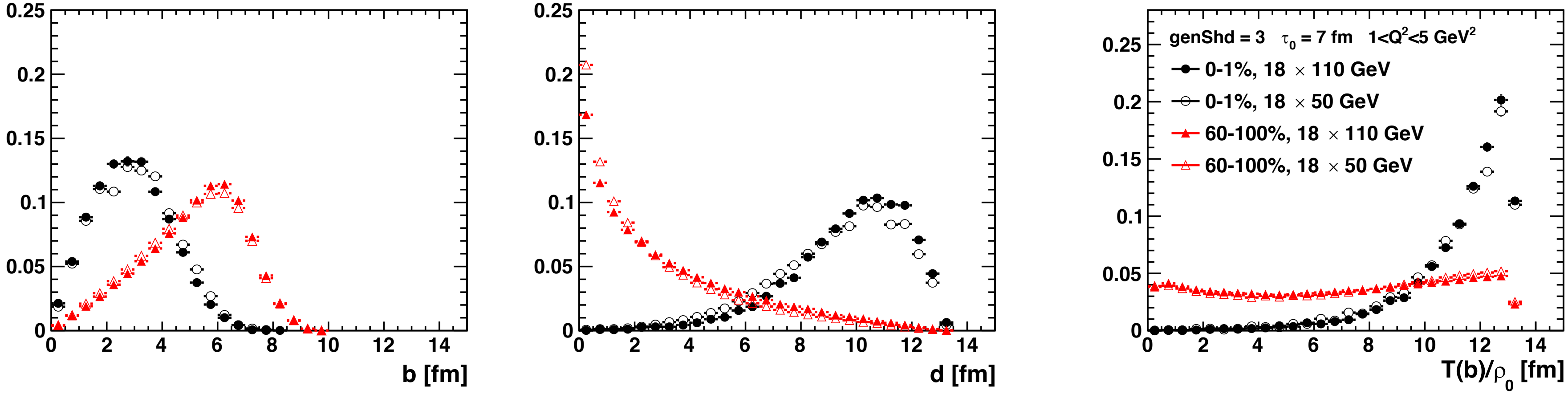
- The distributions in different x bins are almost identical.
- The model predicts no difference as a function of x for this two shadowing options.

110GeV vs. 50GeV

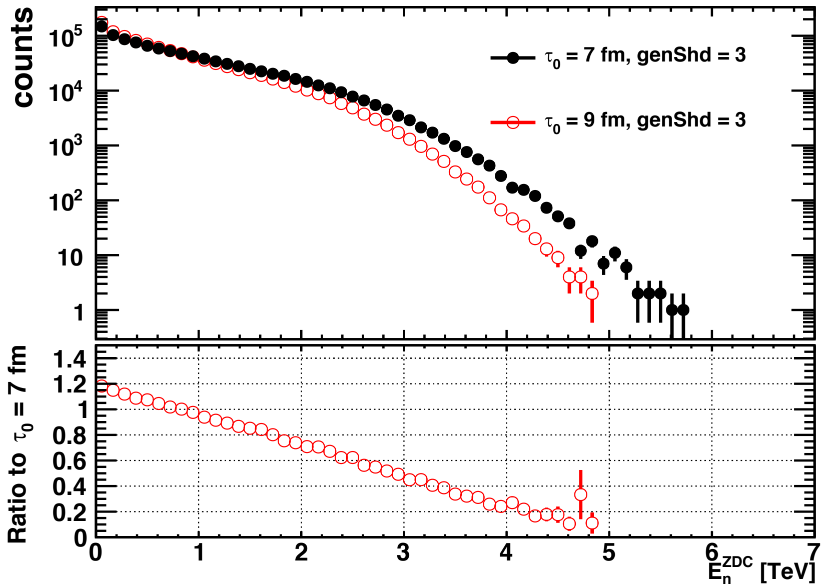


The energy deposition scales with beam energy.

- No difference between 110 GeV and 50 GeV in both **central** and peripheral collisions
- Centrality definition has no energy dependence.



Formation time τ_0



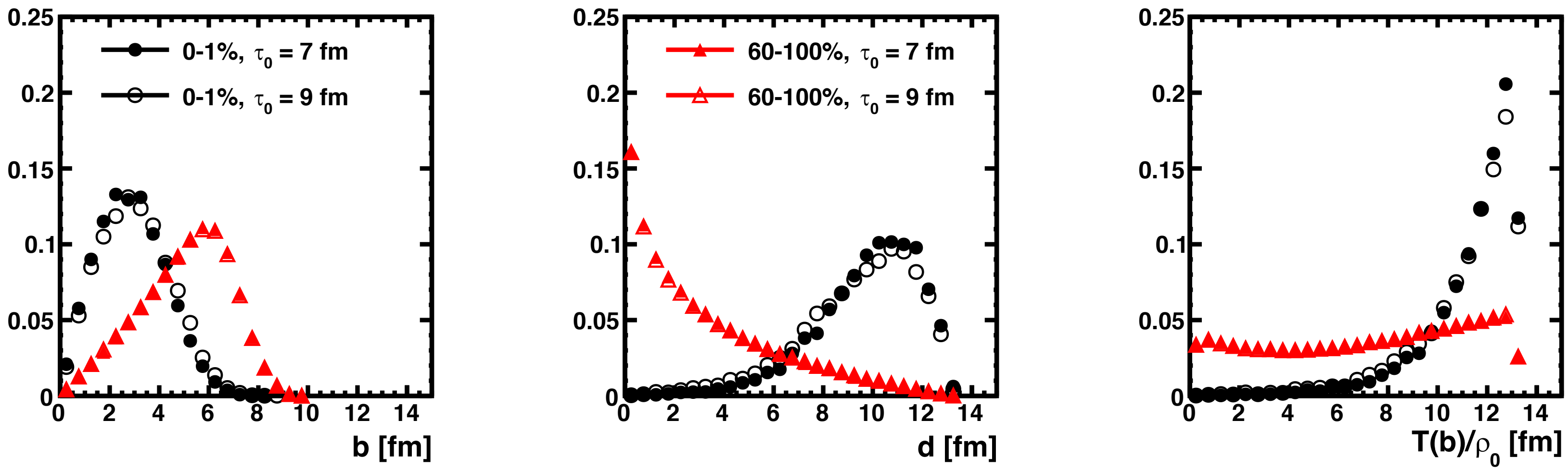
In DIS , the formation time τ is defined as the time before newly created particles can be re-interact with the nucleons:

$$\tau = \tau_0 \frac{E}{m} \frac{m^2}{m^2 + p_\perp^2}$$

τ_0 is a free formation length

E, m, $p_\perp$ are the energy, mass and transverse momentum

The longer τ_0, the less number of neutrons evaporated.



- Centrality definition has no dependence on τ_0

Summary

1. Centrality in eA can be defined by measuring the forward neutron energy deposition in ZDC. It does not require an extremely high energy resolution ZDC.
2. The current model only predicts some small difference for two shadowing options for b, d, $\mathrm{T}(b)/\rho_0$ distributions at low Q^2 in peripheral collisions.
3. Centrality definition has no dependence on beam energy and $\boldsymbol{\tau_0}$.