Reported by Alexey Aparin

XIII Collaboration Meeting of the MPD Experiment

24.04.2024

PWG1 conveners

A.Aparin (JINR), G. Feofilov (SPbSU)

Outline

- Hot topics
- Status of PWG1 activity
- First day collisions and the 2^{nd} collaboration paper – how to proceed?
  - Centrality calculation methods
  - Opportunities for MPD
  - Organizational matters – task forces in the MPD collaboration
- Summary

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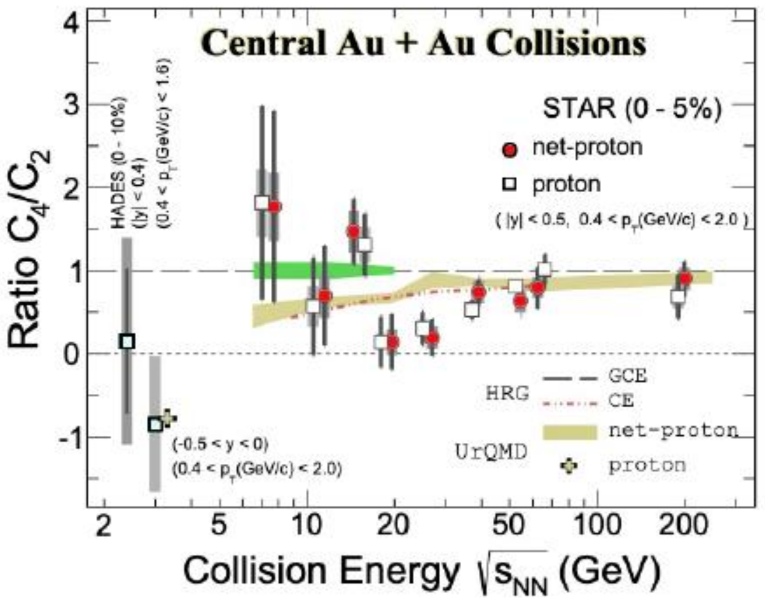
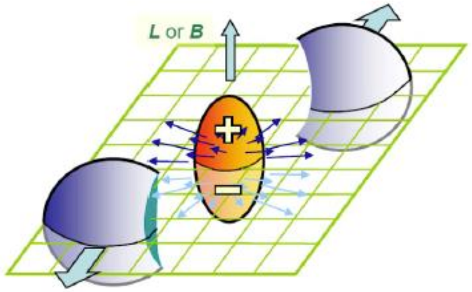
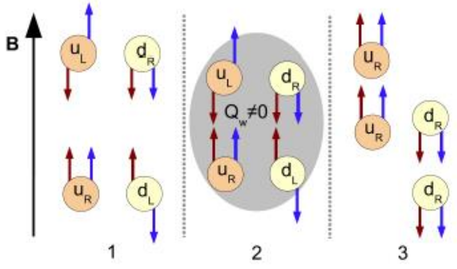
Global observables at MPD

PRL (2021) 092301; PRL 128 (2022) 202303

D.Kharzeev, arXiv:1312.3348







- **A couple of hot topics :**

Search for QCD critical point and non-monotonic energy dependence of net-proton $k\sigma^2 = C_4/C_2$ for 5% most central events recently observed by STAR;

Chiral magnetic effect search in isobar collisions: charge separation due to anomaly induced chiral imbalance and large (10^{15} T) magnetic field. The Chiral Magnetic Effect can only operate in the deconfined, chirally symmetric phase.

$$\frac{dN_\alpha}{d\phi^*} \approx \frac{N_\alpha}{2\pi}\left[1 + 2v_{1,\alpha}\cos(\phi^*) + 2a_{1,\alpha}\sin(\phi^*) + 2v_{2,\alpha}\cos(2\phi^*) + \cdots\right],$$

$\Phi^* = \Phi - \Psi_{RP}$, with Φ and Φ_{RP} being the azimuthal angle of a particle and of the Reaction Plane (RP).

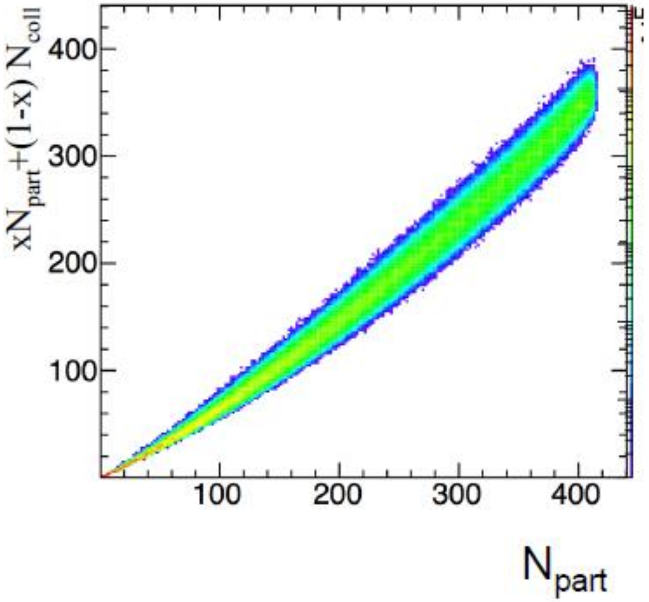
The "γ correlator: $\gamma_{\alpha\beta} = \langle\cos(\varphi_\alpha + \varphi_\beta - 2\Psi_{RP})\rangle$. Here φ_α and φ_β are the azimuthal angles of particles of interest (POIs).

- **Both items require precise event centrality and reaction plane (RP) definition**

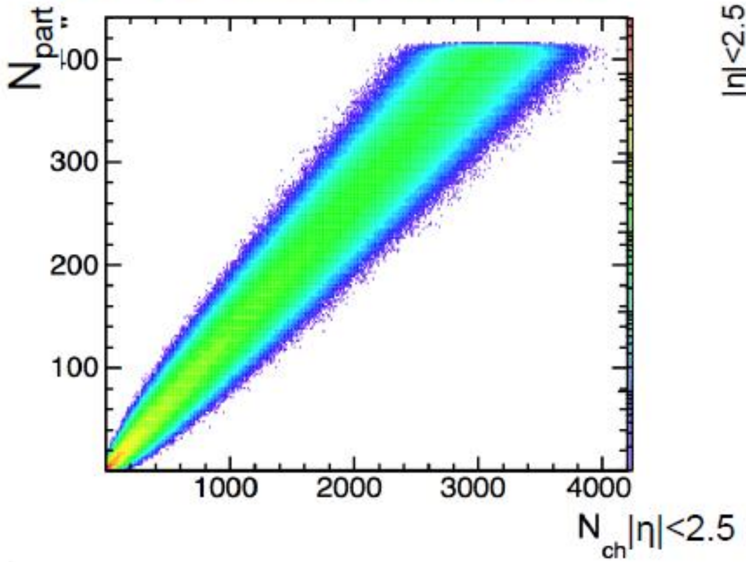
Centrality calculation methods

- Many variables to quantify centrality/volume.
  - At initial state: b, N_{part} , xN_{part}+(1-x) N_{coll}, N_{qp} , ···
  - At final state: N_{ch}, E_T, $N_{neutron}$, ···
- In absence of fluctuation→ all centrality measures are equivalent.
  - Due to one-to-one mapping between different measures
  - In reality, fluc.. exist between different initial or final state variables.

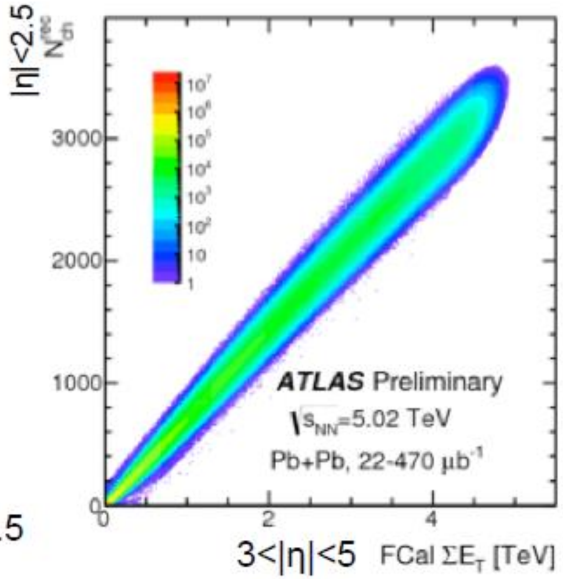
Between initial states variables



Between initial & final states



Between final states variables



Unique opportunities for MPD

Usually applied class of 0-5% centrality is a mixture of different impact parameter events.

The volume fluctuations are dominant!

- we need more precise selection of centrality classes
- we need events with well defined initial conditions and optimized class width
- we need combination of several observables – proxies of centrality, capable to minimize trivial volume fluctuations

Eur. Phys. J. A (2022) 58:140
https://doi.org/10.1140/epja/s10050-022-00750-6

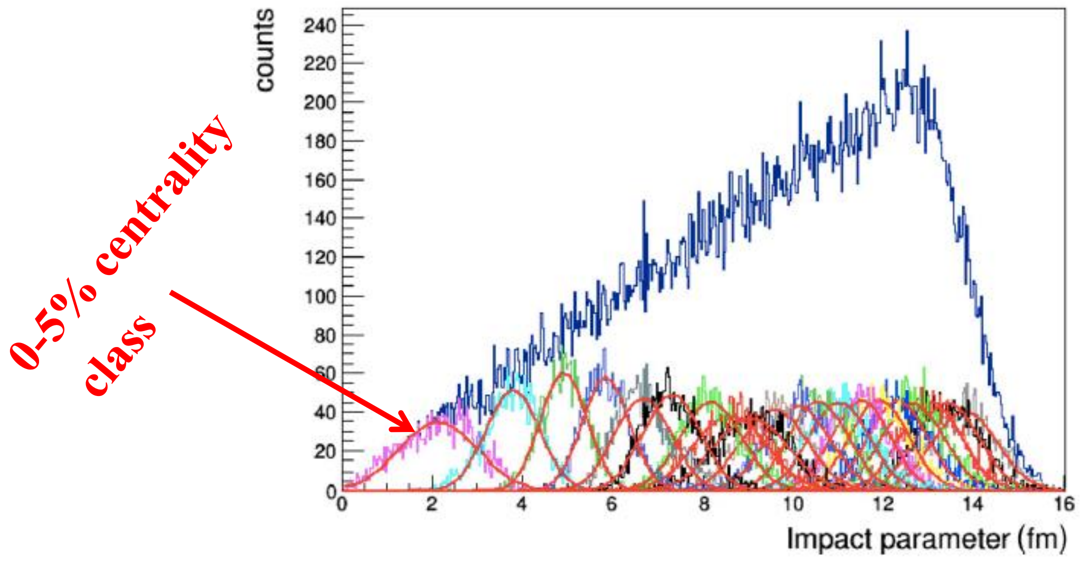


Fig. 44 Top: correlation of the energy deposition in the FHCal and the height of the cone, obtained from the linear fit of the two two-dimensional energy distributions in the FHCal modules. The different colors indicate groups of events within 5% centrality ranges. Bottom: distributions of the MC-generated impact parameters for each 5% group of events fitted to a Gaussian

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PWG1 activity since previous meeting

There were 4 reports at cross-PWG since the previous collaboration meeting

1) A. Seryakov *Centrality selection through fluctuation measures,* **17 Oct 2023**

2) A. Svetlichnyi *Participant and spectator nucleons: GlauberMC vs UrQMD,* **14 Nov 2023**

3) V. Riabov *MPD trigger efficiency in the fixed target mode,* **28 Nov 2023**

4) S. Simak *Accounting of energy losses in the framework of the modified Monte Carlo Glauber model,* **16 Apr 2024**

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First day collisions

- Colliding systems: Xe+Xe, Bi+Bi or …?
- Energy: $\sqrt{s_{NN}}$ = 9.2, 7, 5 GeV ?
- Centrality classes

  -- type of estimator,

  -- combination of estimators,
- Event plane resolution

We need to act together with the accelerator department and detector experts to make a proof of sustainability

Information from previous MPD meeting

Technological run at cryomagnetic system testing– Summer 2024

Report by Evgeny Syresin

Commissioning – Autumn 2024

First beam run – the end of 2024

✓ $6{\cdot}10^8$ elementary charges ~ $2.5{\cdot}10^7$ of Xe^{28+}

Ar^{16+} - $5{\cdot}10^8$ ions per pulse
Xe^{28+} - $2{\cdot}10^8$ ions per pulse
Bi^{35+} - $2{\cdot}10^8$ ions per pulse

First Collider beam run is planed with Xe^{28+} и Bi^{35+} ions

What should we expect as the first beam and when?

Second collaboration paper

From Victor Ryabov's talk

- PWG1:
  - ✓ Trigger efficiency and biases
  - ✓ T0 resolution and multiplicity-dependent corrections
  - ✓ Centrality, EP event categorization

How do we make a contribution for the 2-nd physics paper if we don't know the colliding system or energy?

Centrality wagon: mpdroot/physics/evCentrality

Event plane wagon: mpdroot/physics/evPlane

Question 1: who is responsible in the MPD collaboration for the proper tuning of centrality class parameters in line with the PWG1 requests?

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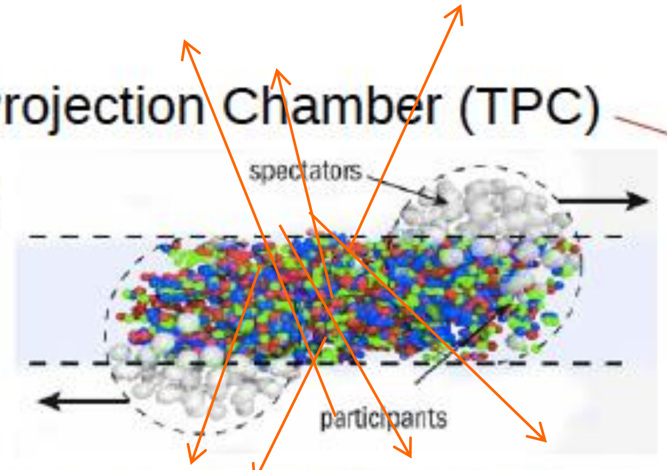
Centrality estimators in MPD

What should be the main estimator for centrality in MPD?

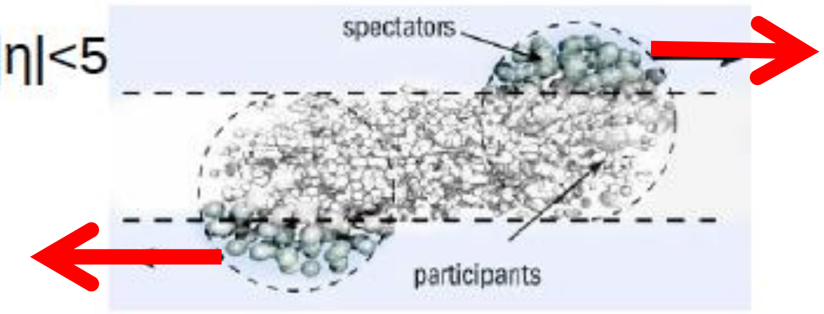
- Time Projection Chamber (TPC)

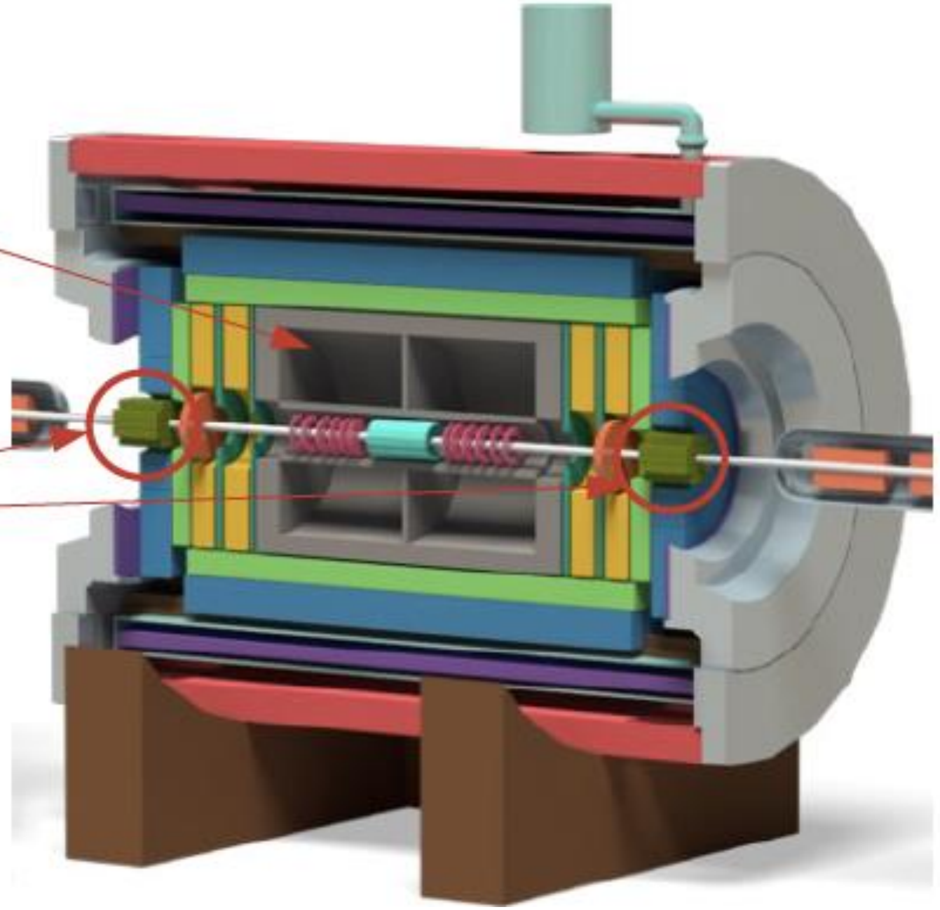
$|\eta|<1.5$



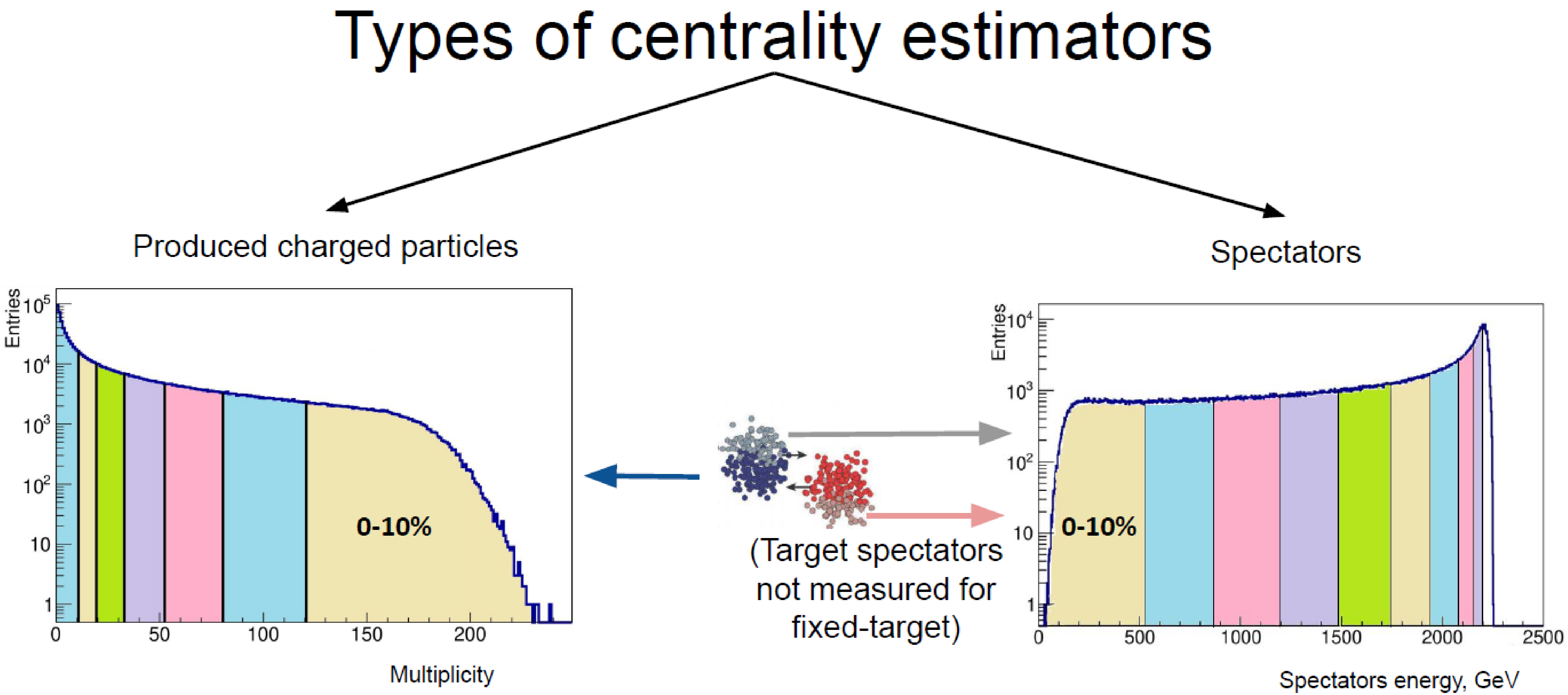
- Forward Hadron Calorimeter (FHCal)

$2<|\eta|<5$





Centrality estimators in MPD



High order moments

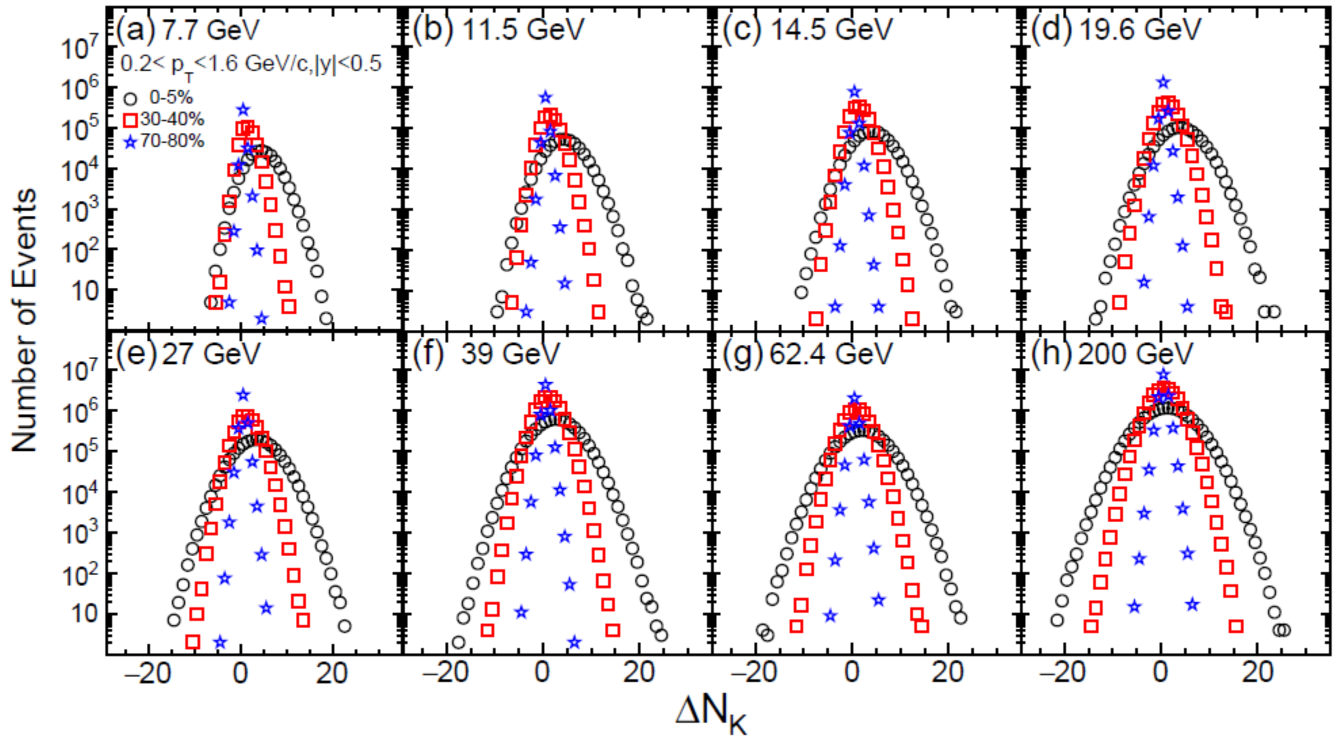
Analysis require very precise depiction of the tracks (charge, strangeness, proton etc.)

Need to be careful with corrections

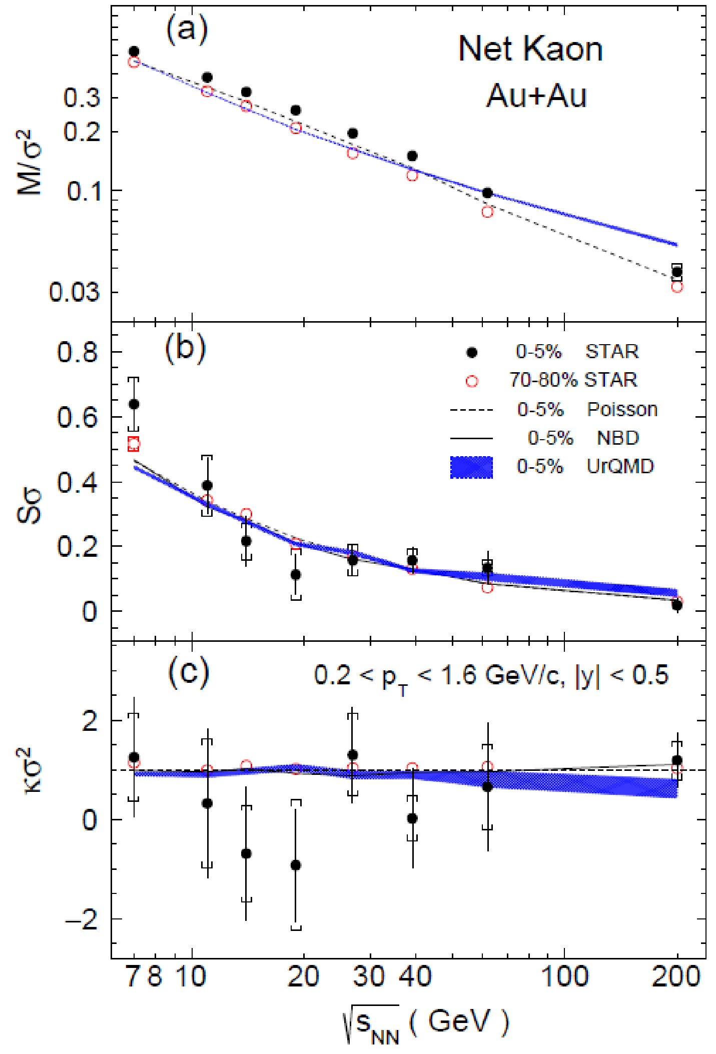
$$C_1 = \langle N \rangle$$
$$C_2 = \langle (\delta N)^2 \rangle$$
$$C_3 = \langle (\delta N)^3 \rangle$$
$$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2$$

$$M = C_1, \sigma^2 = C_2, S = \frac{C_3}{(C_2)^{\frac{3}{2}}}, \kappa = \frac{C_4}{(C_2)^2}$$

$$\kappa\sigma^2 = \frac{C_4}{C_2}, S\sigma = \frac{C_3}{C_2}$$

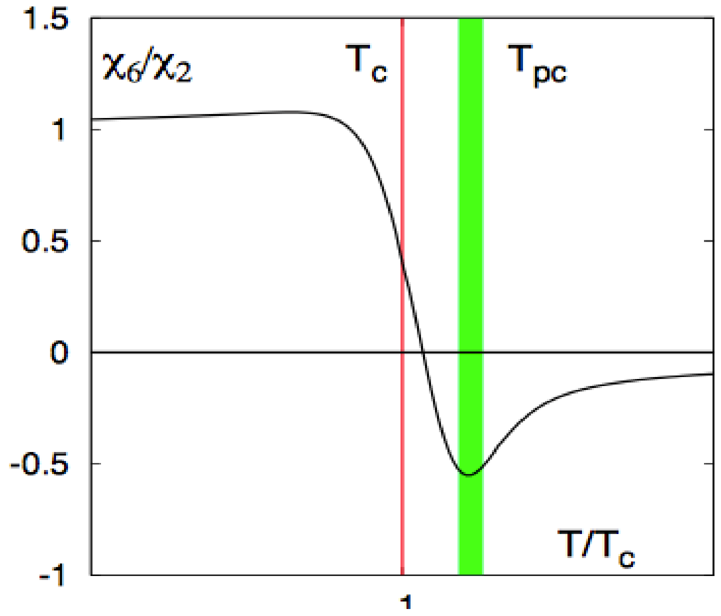


High order moments



Main corrections for the cumulant analysis

- Separate the analyzed tracks from centrality calculation
- Centrality bin width correction
- Proper resolution corrections



Susceptibility ratios fluctuate near the CP. It can be measured via cumulants of net-values

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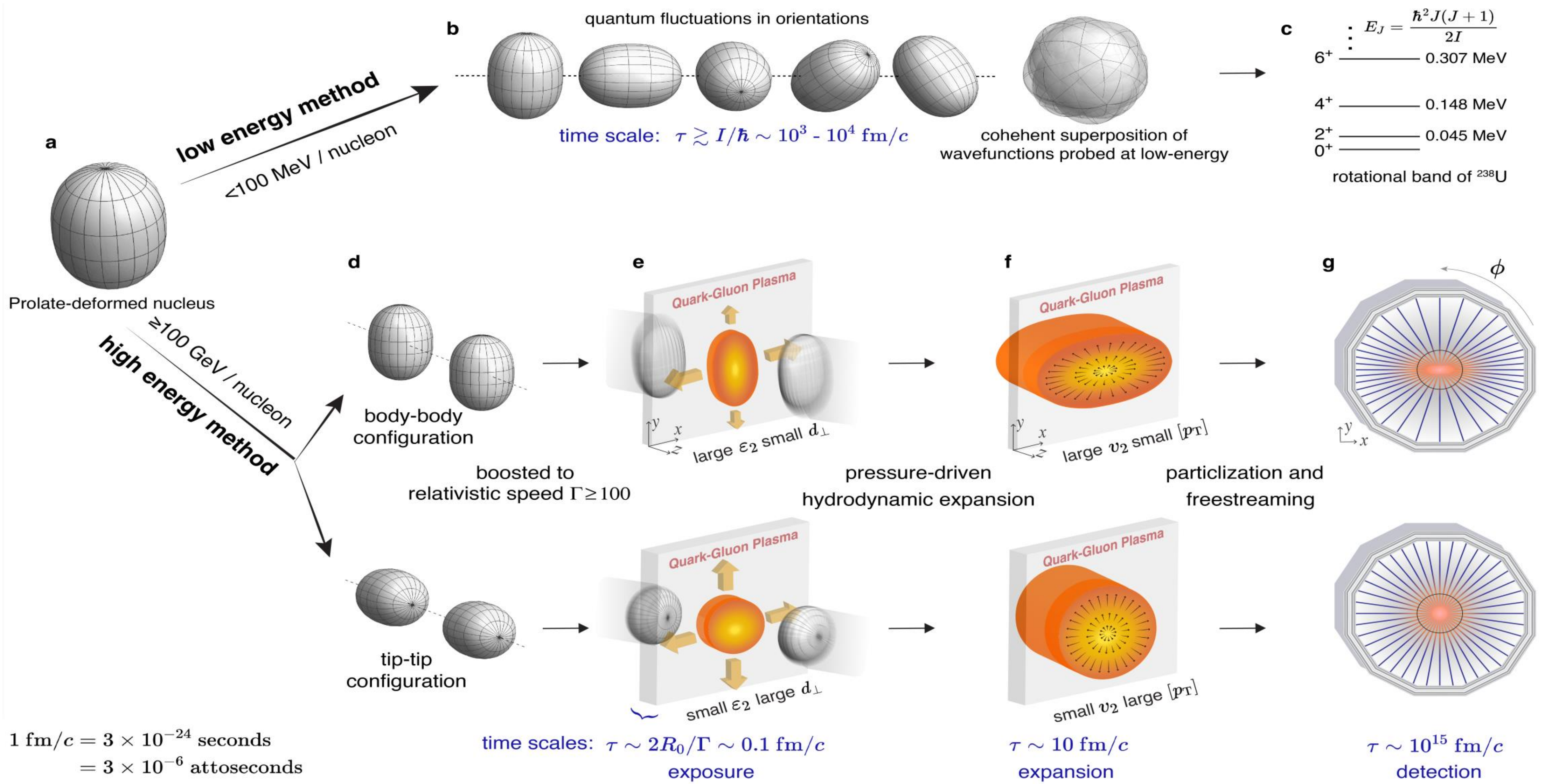
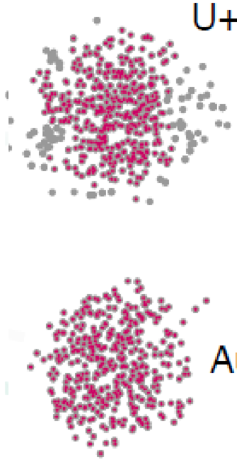
System size dependent analysis

STAR, arXiv:2401.06625v1



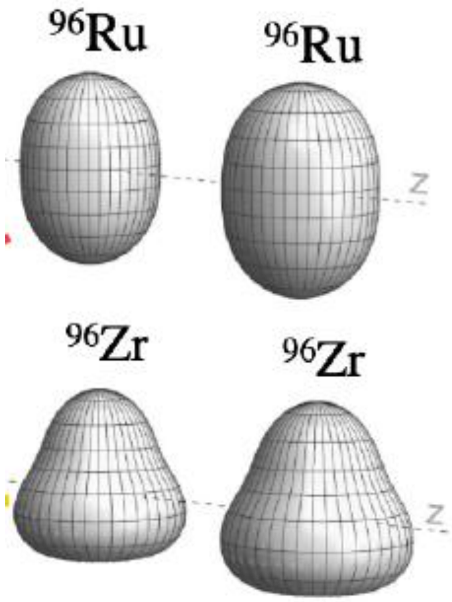
Nuclear shape effects

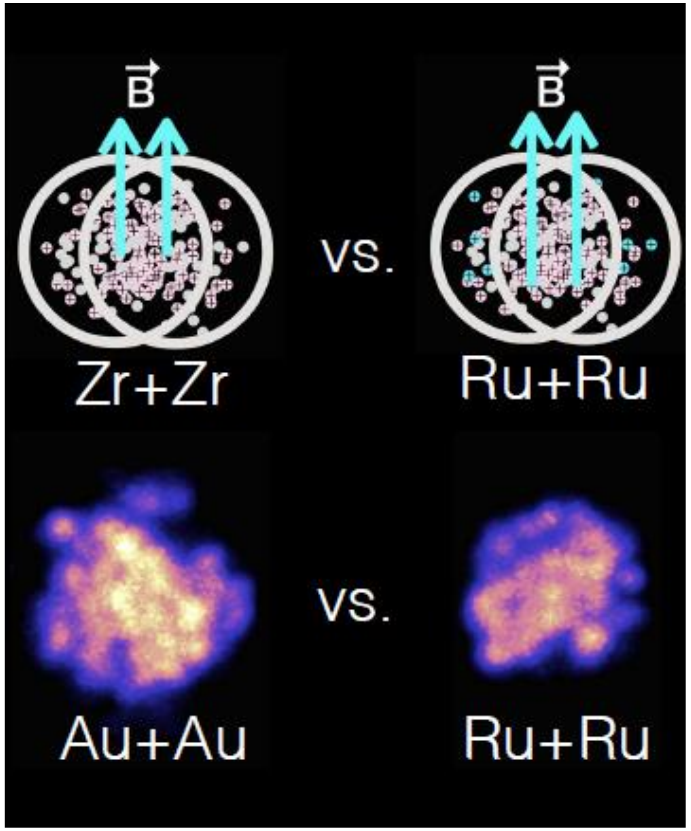


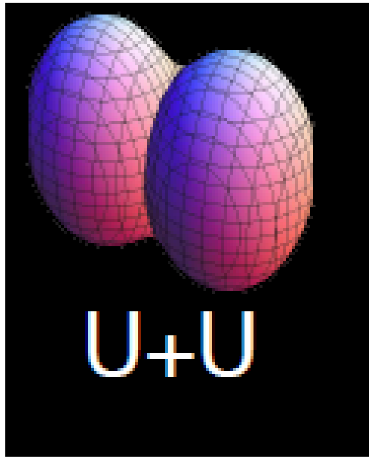
U+U (N_{part}=394)

B-field is different
in Au+Au and U+U

Au+Au (N_{part}=394)



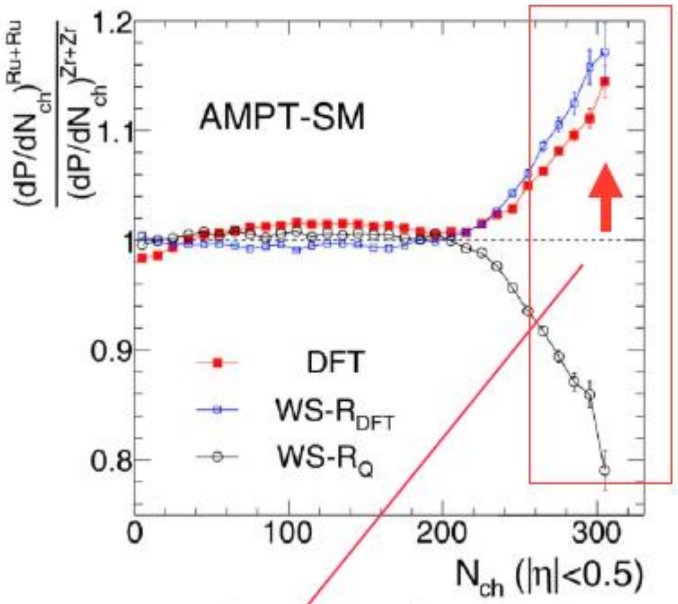


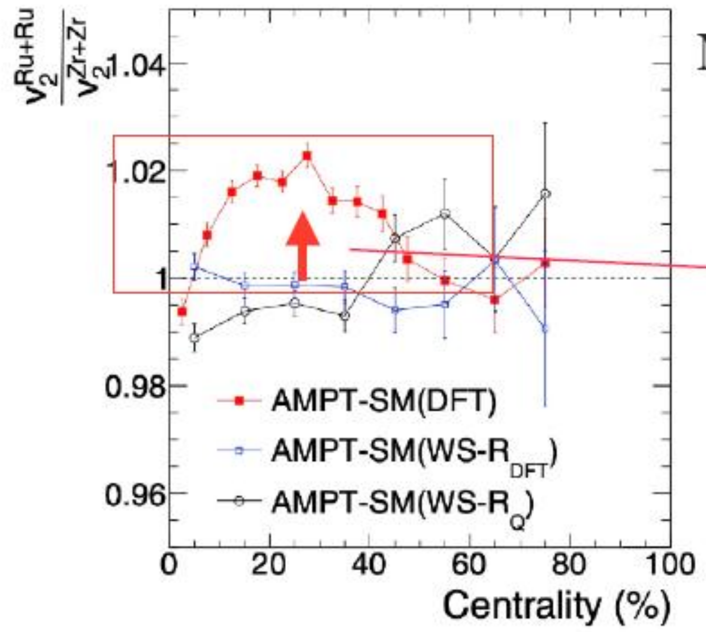


Gold nuclei is well shaped – almost an ideal sphere, so is lead nuclei

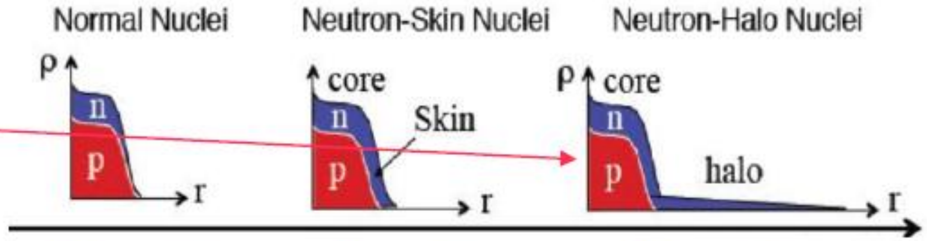
Other nuclei has much more variable shapes, thus we need to carefully take into account trivial effects of interaction region geometry due to the shapes and exact conditions of the collision

Neutron skin effects



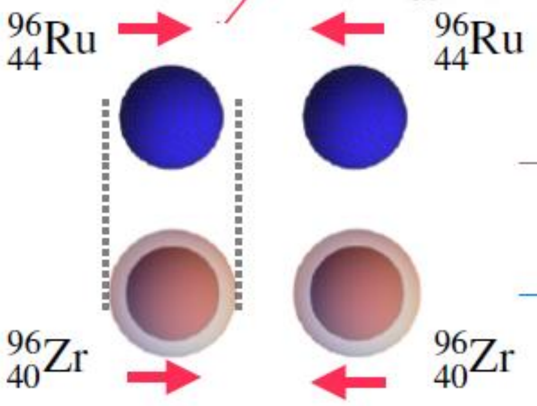


Neutron skin thickness $\Delta r_{np} \equiv \sqrt{\langle r_n^2 \rangle} - \sqrt{\langle r_p^2 \rangle}$



Normal Nuclei	Neutron-Skin Nuclei	Neutron-Halo Nuclei
$R_n = R_p$	$R_n > R_p$	$R_n = R_p$
$a_n = a_p$	$a_n = a_p$	$a_n > a_p$

$$\rho = \frac{\rho_0}{1 + \exp\left[\frac{r-R}{a}\right]}$$



→ Smaller r, larger density → Larger N_{ch} and $\langle p_T \rangle$

→ Larger r, smaller density → Smaller N_{ch} and $\langle p_T \rangle$

HJX, et.al., PRL121, 022301 (2018)
H. Li, HJX, et.al., PRC98, 054907 (2018)
HJX, et.al., PLB819, 136453 (2021)

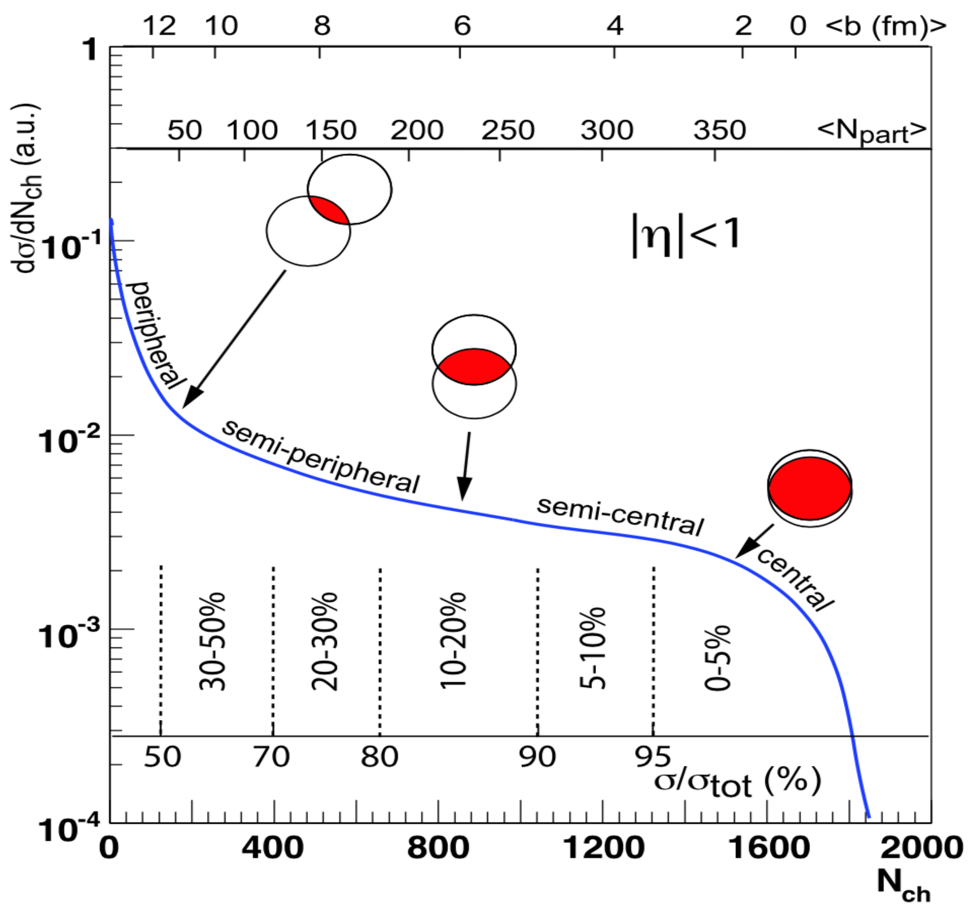
Centrality in pp, pA, AA

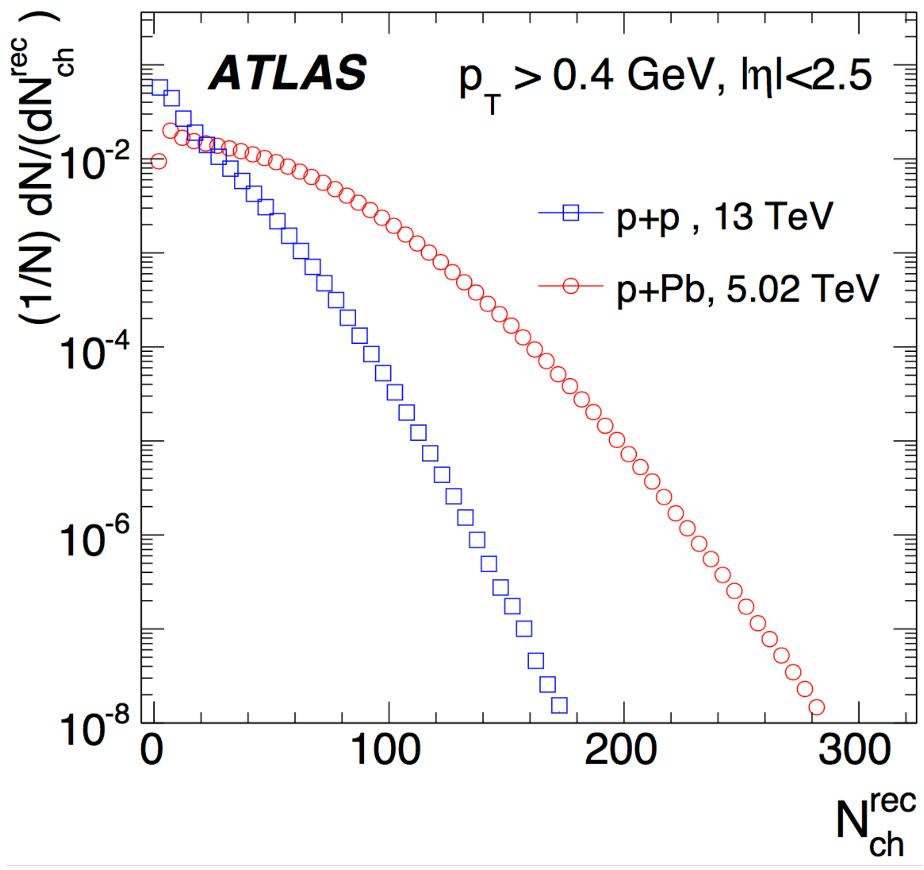
Many variables to quantify centrality/volume.

- At initial state: b, N_{part}, $xN_{part}+(1-x)\,N_{coll}$, N_{qp}, ···
- At final state: N_{ch}, E_T, $N_{neutron}$, ···

Main feature: Shoulder & Knee.

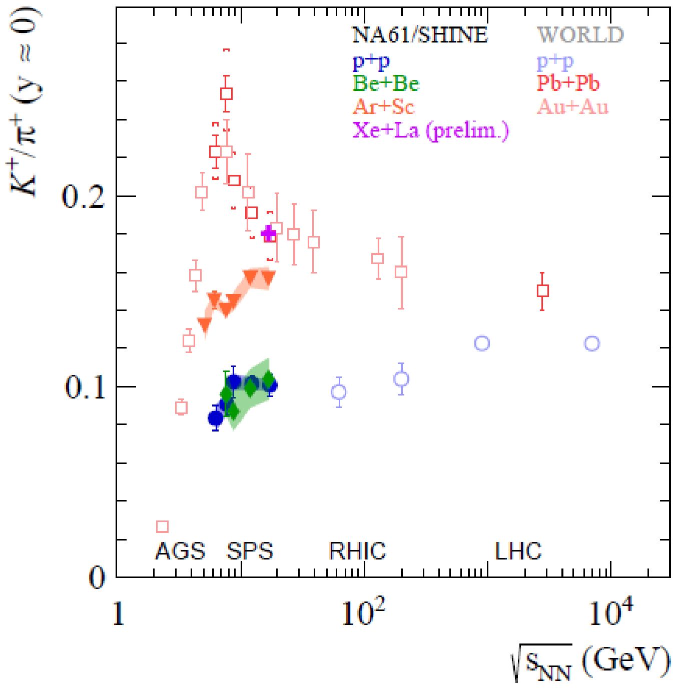
~Absent in pp, pPb

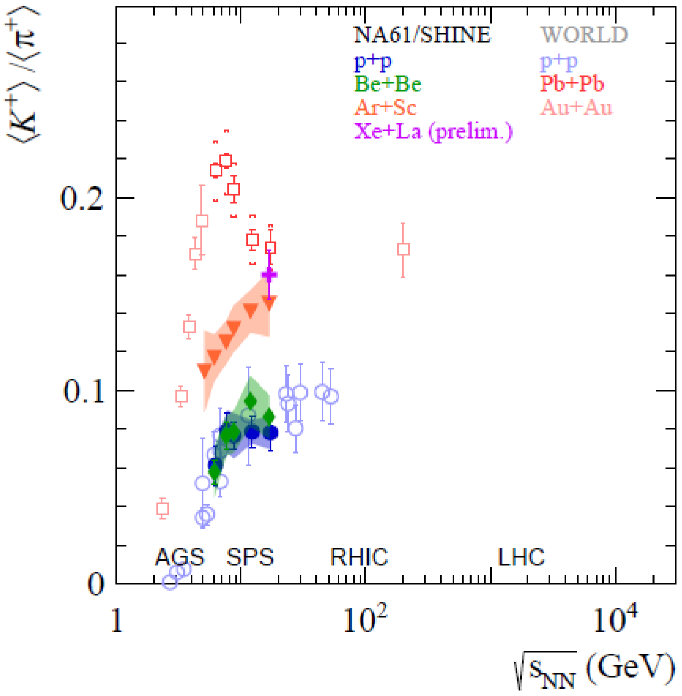


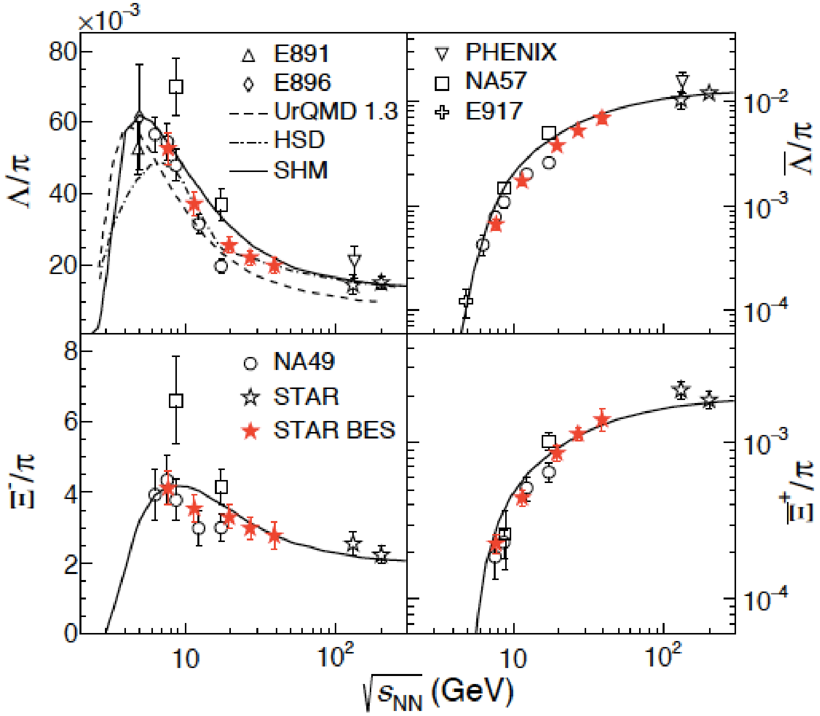


System size dependent analysis

Test well known effects in different colliding systems







MPD can be complimentary with existing experiments
High statistics can allow differential analysis of different observables in different colliding systems

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Task forces in the MPD collaboration:

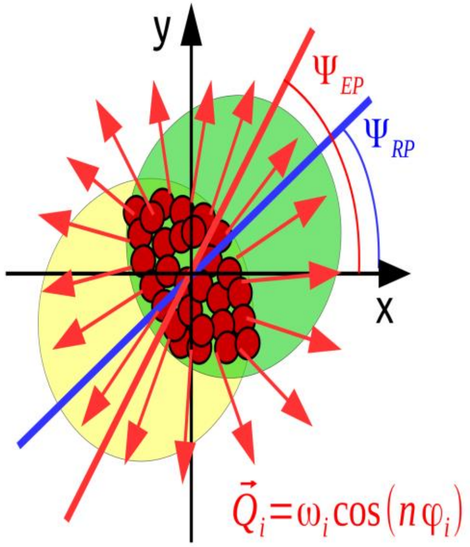
- The general directions and near future tasks relevant to the First Physics are formulated for each of the PWGs of the MPD (see the report by V.Riabov)
- The remaining questions on the beam types should be answered ASAP
- We have to define the fields of interest of different groups of each institute before start of the data taking –participant of the MPD collaboration and have a list of experts leading physics topics

Summary

- ✓ We are approaching to the first beam in the collider
- ✓ Some procedures for calculating centrality and event plane are implemented in the MPDROOT and analysis trains
- ✓ Institutions need to be more active in the working groups to make better analysis in less time
- ✓ Collaboration management should be more cooperative and discuss critical issues with working groups

Back up slides

Reaction plane determination



- Reaction plane (RP) – plane formed by impact parameter *b* and beam line
- *RP cannot be measured in the* experiment since we cannot measure *b*

- Event plane (EP) is the observable estimation of the reaction plane

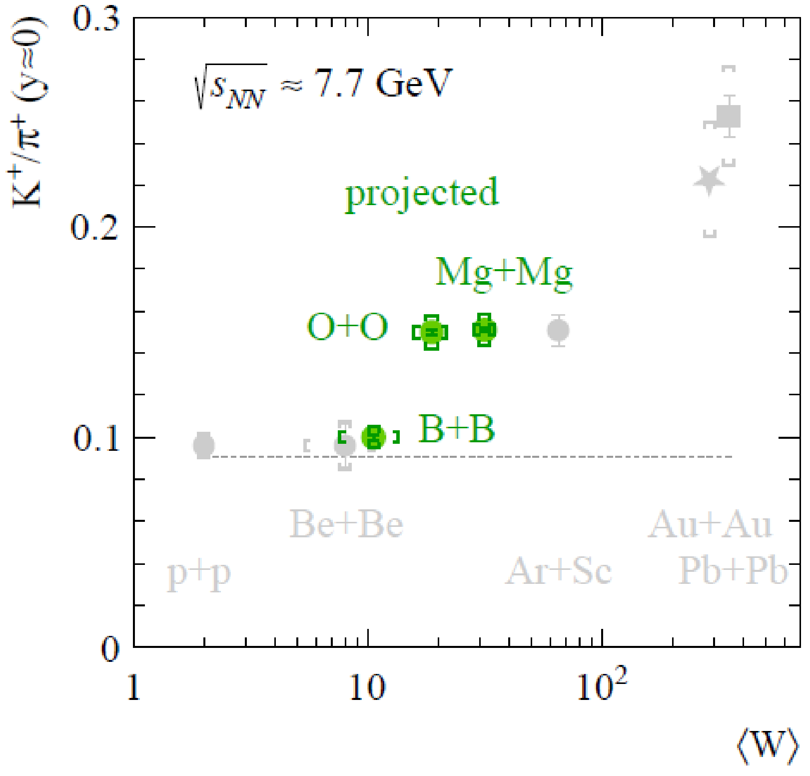
- EP angle is measured using Q-vectors from FHCal and TPC:

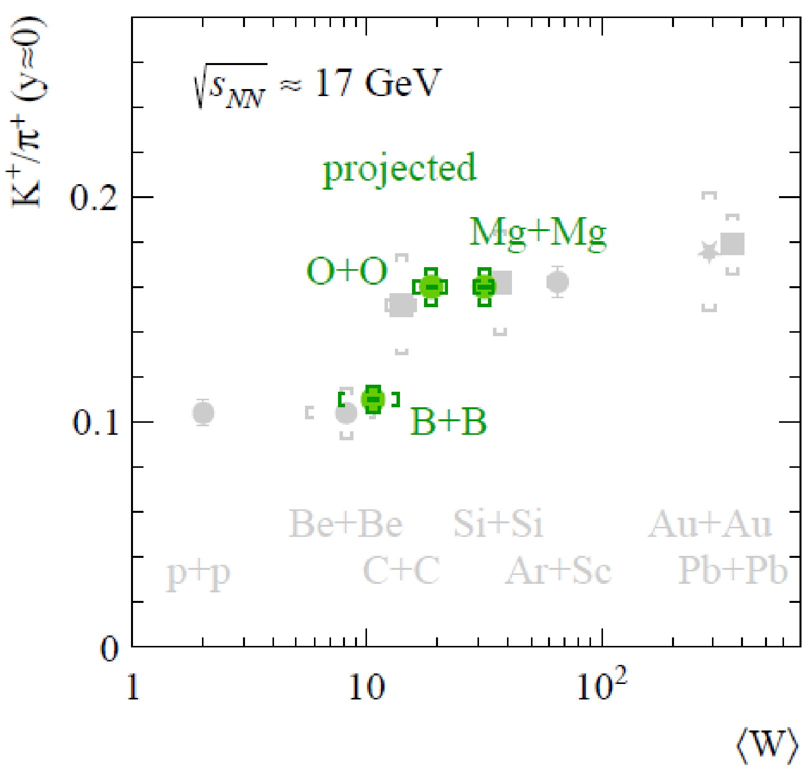
$$Q_{1,x}^{\mathrm{FHCal}} = \frac{1}{\sum E_{dep,i}} \sum E_{dep,i} \cos\phi_i \, , \, Q_{1,y}^{\mathrm{FHCal}} = \frac{1}{\sum E_{dep,i}} \sum E_{dep,i} \sin\phi_i$$

$$Q_{2,x}^{\mathrm{TPC}} = \sum p_{T,i} \cos 2\varphi_i \, , \, Q_{2,y}^{\mathrm{TPC}} = \sum p_{T,i} \sin 2\varphi_i$$

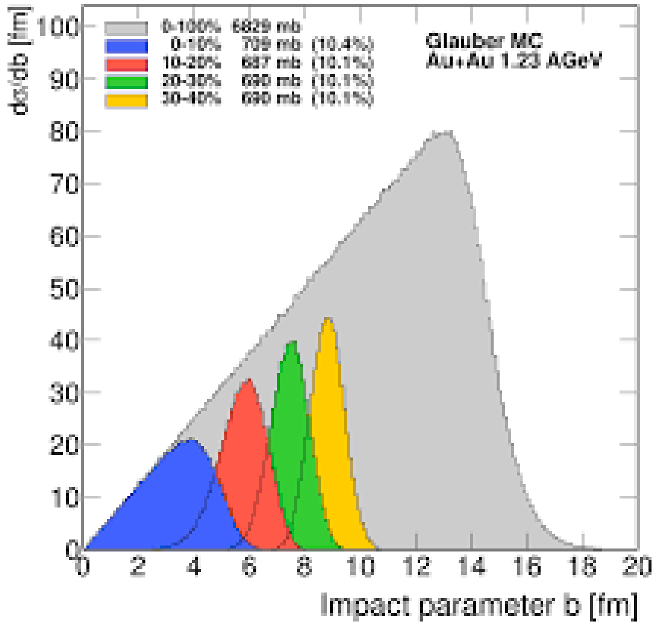
$$\Psi_1^{\mathrm{FHCal}} = \tan^{-1} \frac{Q_{1,y}^{\mathrm{FHCal}}}{Q_{1,x}^{\mathrm{FHCal}}}, \qquad \Psi_2^{\mathrm{TPC}} = \frac{1}{2} \tan^{-1} \frac{Q_{2,y}^{\mathrm{TPC}}}{Q_{2,x}^{\mathrm{TPC}}}$$

System size dependent analysis





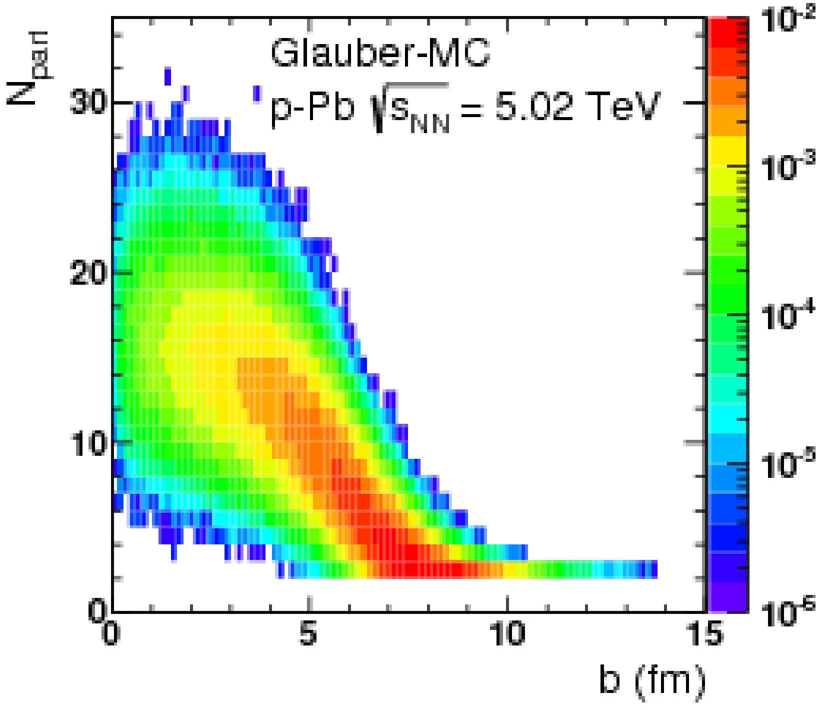
Centrality as an estimation

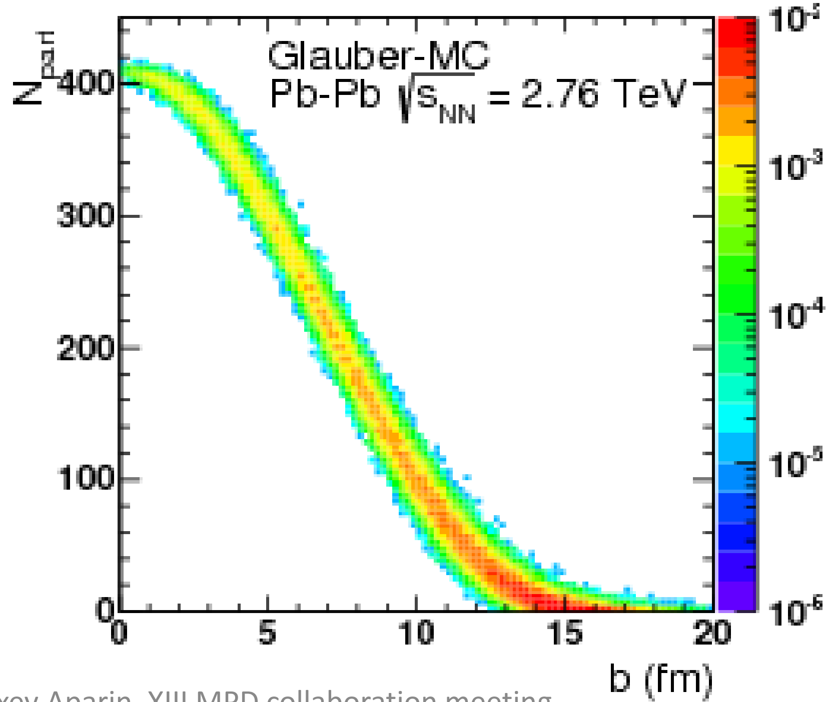


Centrality is not a direct measurement!

We have to use estimations based on models since we can not perform direct measurement

All estimators have it's own limitations and imperfections





STAR results from BES-II

STAR has prepared 5 new papers on the data from BES-II since the previous MPD collaboration meeting:

1) *Global polarization of Lambda and Lambdabar hyperons in Au+Au collisions at sNN = 19.6 and 27 GeV,* **Phys. Rev. C 108 (2023) 14910**
2) *Reaction plane correlated triangular flow in Au+Au collisions at sNN = 3 GeV,* **Phys. Rev. C 109 (2024) 44914**
3) *Production of Protons and Light Nuclei in Au+Au Collisions at sNN = 3 GeV with the STAR Detector,* **arXiv:2311.11020v1**
4) *Imaging Shapes of Atomic Nuclei in High-Energy Nuclear Collisions,* **arXiv:2401.06625v1**
5) *Temperature Measurement of Quark-Gluon Plasma at Different Stages,* **arXiv:2402.01998v1**