Proton and net-proton High-Order Cumulants: can we do better with MPD at NICA?

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MPD Cross-PWG , March 18, 2025

INDICO:
https://indico.jinr.ru/event/5294/

ZOOM:
https://cern.zoom.us/j/61007466545?pwd=ZXR1WWhxMlQwK1hEUHJUQ3RsYnlPQT09

The author acknowledges Saint-Petersburg State University for a research project 103821868

Talk layout

1. Some definitions
2. Hot topic: net-proton fluctuations
3. Can we do better with MPD at NICA?

Event-by-event fluctuations of conserved quantities

- Net electric charge Q,
- Net strangeness S,
- Net baryon number B,

…are sensitive to the degrees of freedom that are active in the system.

- **The moments** (Variance (σ^2), Skewness(S), Kurtosis(k)) of distributions of conserved quantities, such as net-baryon, net-charge and net-strangeness, **are predicted to be sensitive to the correlation length of hot dense matter** created in the collisions [1]**, i.e. sensitive to the QCD critical endpoint** of the first order phase transition between quark-gluon plasma and hadron gas

- Net proton number (as a proxy to net-baryon) : $N_{p-\bar{p}} = N_p - N_{\bar{p}} = \Delta N_p$
- We will use **N** below to represent **the net-proton number $N_{p-\bar{p}}$ in one event**

[1] M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).

Cumulants
and correlation length ξ of hot dense matter

- **Correlation length ξ of hot dense matter[1]**
  --- the cubic central moment of multiplicity $\langle(\delta N)^3\rangle \sim \xi^{4.5}$
  --- the quartic cumulant $\langle(\delta N)^4\rangle \sim \xi^{7}$
- **Correlation length ξ will diverge (reach the maximum value) at the critical point[2]**

[1] M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).
{2} M. A. Stephanov, K. Rajagopal and E. V. Shuryak, Phys.Rev. D 60, 114028 (1999) [arXiv:hep-ph/9903292].

Fluctuations of conserved quantities and susceptibilities

Fluctuations of **conserved quantities (N or Q_i in this slide)** relate directly to **the susceptibilities χ_i,** which are quantities that can be calculated for thermodynamic systems, e.g. in lattice QCD.
Susceptibilities are defined as derivatives of the pressure with respect to the chemical potential.
Deviations δQ_i are related to susceptibilities ξ_n^{Qi} by[1]:

$$\langle(\delta Q_i)^n\rangle = T^n \frac{\partial^n}{\partial \mu_i^n} \ln Z(T, \mu_i) = VT^3 \chi_n^{Q_i},$$

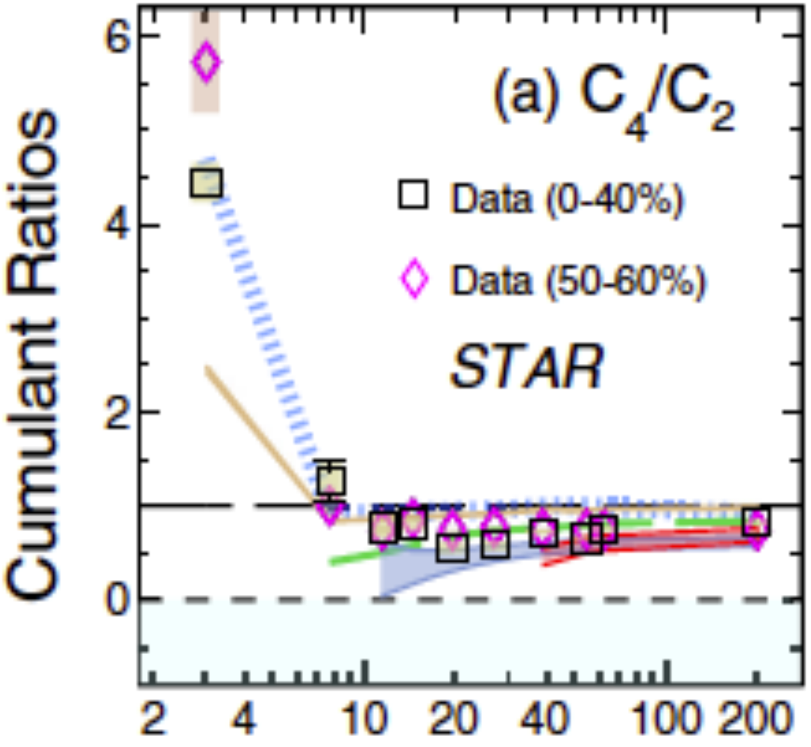
Here -- Q_i is a conserved charge of interest,
T the temperature, μ_i the corresponding chemical potential and Z the partition function [1].

- **Therefore the experimental values (in the Left) could be used to define thermodynamic model parameters (in the Right)**
- **It is tempting in such simplified approach to use the ratios of cumulants in order to get rid of volume dependence**

[1] Hannah Elfner and Berndt Müller 2023, J. Phys. G: Nucl. Part. Phys. 50 103001

Hot topic in 2023: Proton and net-proton High-Order Cumulants

DEFINITIONS of central moments and cumulants [1]	
the proton multiplicity in a given event	N
the average over all events	<….>
Mean:	$M = \langle N \rangle = C_1$,
Deviation,	$\delta N = N - \langle N \rangle$
Variance	$\sigma^2 = \langle (\delta N)^2 \rangle = C_2$,
skewness	$S = \langle (\delta N)^3 \rangle / \sigma^3 = C_3/C_2^{3/2}$,
kurtosis	$k = \langle (\delta N)^4 \rangle / \sigma^4 - 3 = C_4/C_2^2$



Left: collision energy dependence of the ratios of cumulants C4/C2, for net proton (red circles) from 0%–40% and 50-60% Au + Au collisions at RHIC ([2]).

- Fluctuation of conserved quantities were predicted to be sensitive -- near CEP, to the correlation length [3]

[1] Xiaofeng Luo, Nu Xu, NUCL SCI TECH (2017) 28:112
DOI 10.1007/s41365-017-0257-0;
[2] B.E.Aboona et al. *STAR Collaboration), “**Beam Energy Dependence of Fifth- and Sixth-Order Net-Proton Number Fluctuations in Au+Au Collisions at RHIC**”, Phys. Rev. Lett. **130**, 082301,(2023) https://doi.org/10.1103/PhysRevLett.130.082301
[3] C. Athanasiou, K. Rajagopal, M. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).doi:10.1103/PhysRevD.82.074008

In 2021: Non-monotonic energy dependence of net-proton number fluctuations[1]

The first evidence of a nonmonotonic variation in kurtosis times variance of the net-proton number (proxy for net-baryon number) distribution as a function of √s_{NN} with 3.1s significance, for central Au+A collisions measured using the STAR detector at RHIC [1]

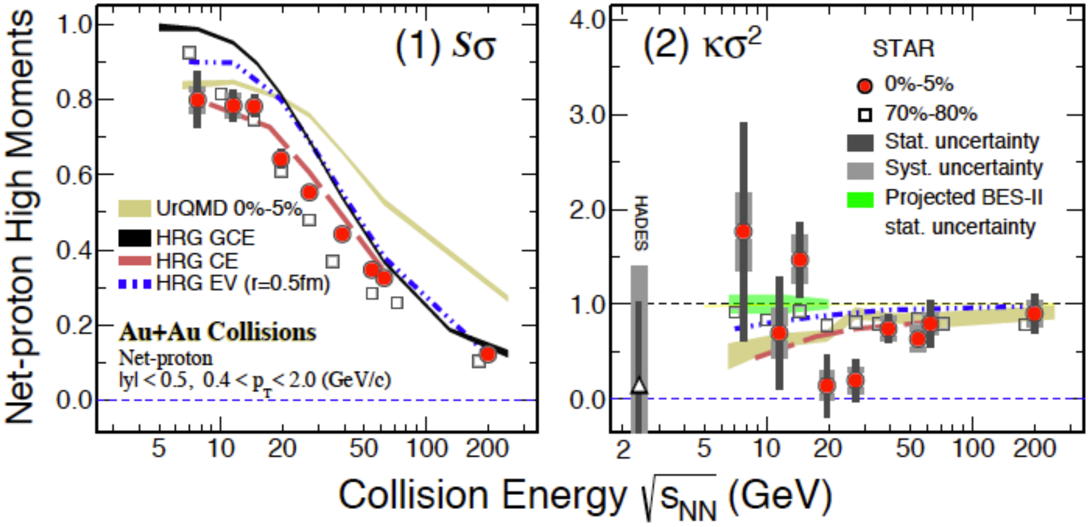


FIG. 4. Sσ (1) and kσ^2 (2) as a function of collision energy for net-proton distributions measured in Au+Au collisions. The results are shown for central (0-5%, filled circles) and peripheral (70-80%, open squares) collisions within 0.4 < pT (GeV/c) < 2.0 and jyj < 0.5 [1].

- **Higher moments of distributions of conserved quantities (N) are more intersting due to their stronger dependence on the correlation length**
- **Centrality bin width correction (CBWC) is applied[3]**

[1] J. Adam et al. (STAR Collaboration), Phys. Rev. Lett. 126, 092301 (2021).

[2] M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).

[3] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013).

In 2021: Non-monotonic energy dependence of net-proton number fluctuations[1]

DEFINITIONS of central moments and cumulants [1]	
the proton multiplicity in a given event	N
the average over all events	<….>
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Deviation,	$\delta N = N - \langle N \rangle$
Variance	$\sigma^2 = \langle (\delta N)^2 \rangle = C_2$,
skewness	$S = \langle (\delta N)^3 \rangle / \sigma^3 = C_3/C_2^{3/2}$,
kurtosis	$k = \langle (\delta N)^4 \rangle / \sigma^4 - 3 = C_4/C_2^2$

$$C_1 = M, \quad C_2 = \sigma^2, \quad C_3 = S\sigma^3, \; C_4 = \kappa\sigma^4$$

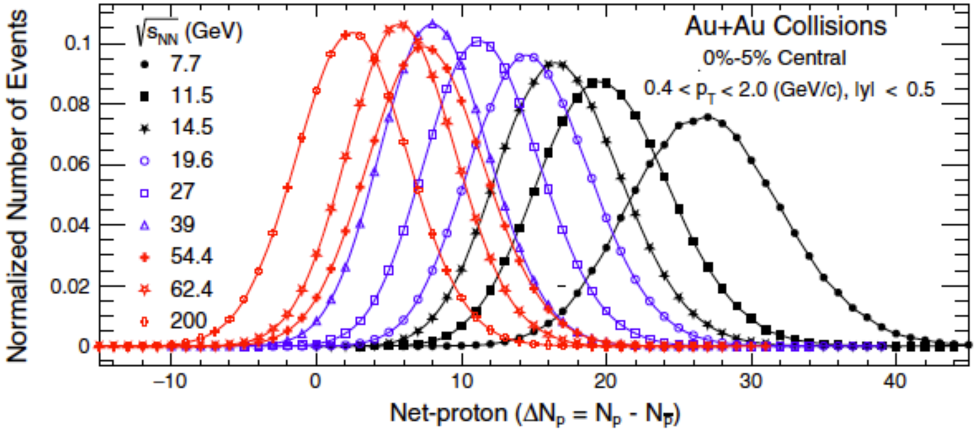


FIG. 1. Event-by-event net-proton number distributions for head-on (0%–5% central) Au +Au collisions for nine $\sqrt{s_{NN}}$ values measured by STAR [2].

- **Non-gaussian shape of net-baryon distribution is expected near the CEP (M.Stepanov - 2008)**

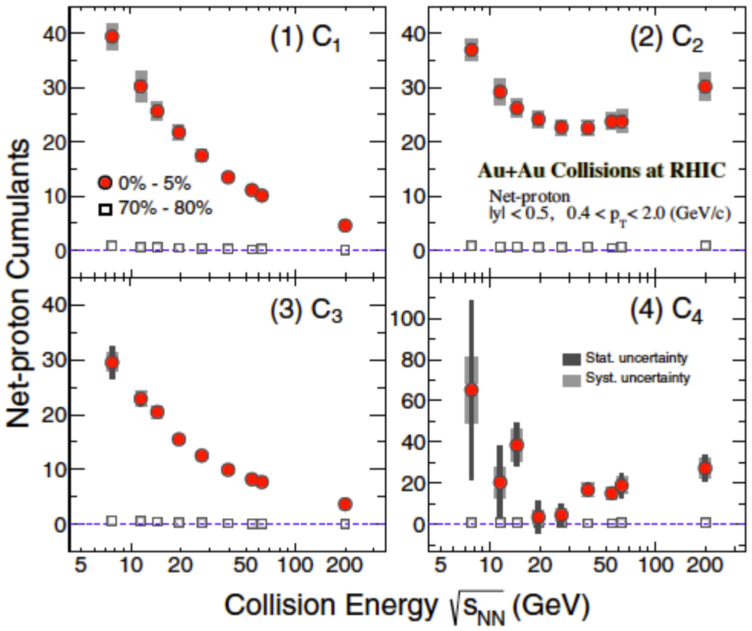


FIG. 2. Cumulants (Cn) of the net-proton distributions for central (0%–5%) and peripheral (70%–80%) Au +Au collisions as a function of collision energy[2].

- The cumulants are corrected for the Centrality Bin Width Effect[3]

[1] Xiaofeng Luo, Nu Xu, NUCL SCI TECH (2017), 28:112, DOI 10.1007/s41365-017-0257-0;

[2] (STAR Collaboration), PHYSICAL REVIEW LETTERS, 126, 092301 (2021)

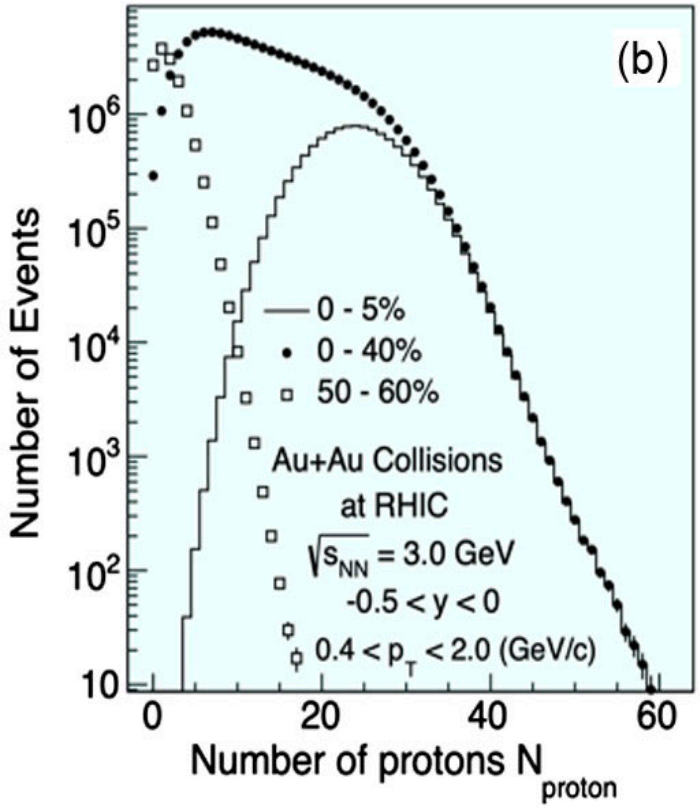
[3]] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013)

Non-Gaussian fluctuations near the QCD critical point -

- “Higher, non-Gaussian,moments of the fluctuations are significantly more sensitive to the proximity of the critical point than the commonly employed measures based on quadratic moment” [1]
- “The fluctuations of the net proton number is a good proxy to the baryon number fluctuations, whose magnitude, proportional to the baryon number susceptibility, must diverge at the critical point”

[1] **M.A.Stepanov,”**Non-Gaussian fluctuations near the QCD critical point”, 2008, http://arxiv.org/abs/0809.3450v1
Phys. Rev. Lett. **102**, 032301 – **Published 20 January, 2009**
DOI: https://doi.org/10.1103/PhysRevLett.102.032301

Example of proton multiplicity distributions from three collision centralities [1].

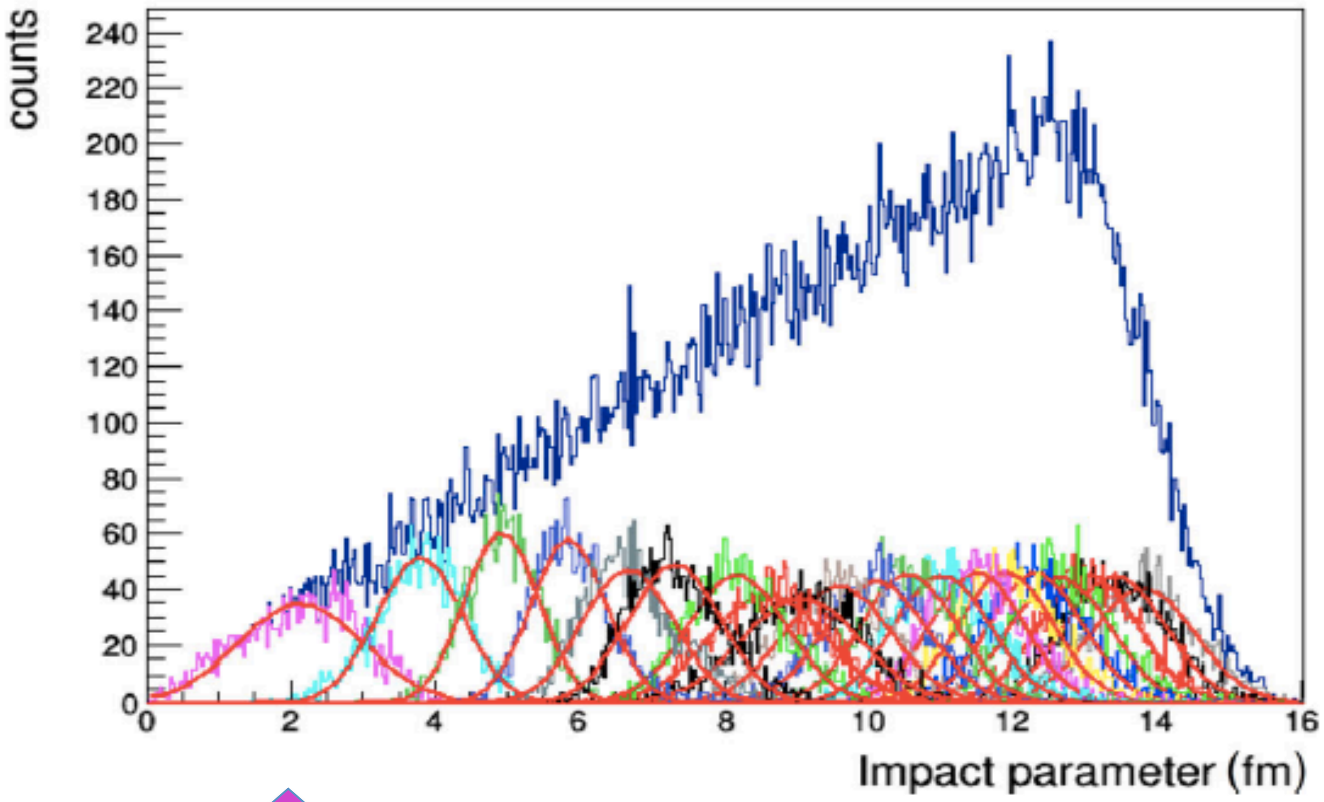


Example of proton multiplicity distributions from three collision centralities. These distributions are not corrected for detector efficiency and pileup effects.[1]

- Non-Gaussian shape of proton multiplicity distributions -- both in 0-5% and 0-40% centrality classes, could be due to the volume fluctuation effects
- To suppress the initial-volume fluctuation effects on cumulants for a given centrality, Centrality bin width correction [2] is performed in [1]

[1] STAR Collaboration, PHYSICAL REVIEW LETTERS 130, 082301 (2023)
[2] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013).

Problems of using δN=N-<N>



0-5% class

- V is a strongly fluctuating quantity, see , for example, impact parameter distribution **for 0-5% class** in MC simulations for Au+Au collisions at $\sqrt{s_{NN}}$ =7.7 GeV (Fig.44 from ref.[1]).
- Event-by-event fluctuations of impact parameter *b* in the given centrality class selected for analysis will produce trivial volume fluctuations

[1]The MPD Collaboration, Status and initial physics performance studies of the MPD experiment at NICA, Eur. Phys. J. A (2022) 58:140, https://doi.org/10.1140/epja/s10050-022-00750-6

Volume dependence and volume fluctuations

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skewness	$S = \langle (\delta N)^3 \rangle / \sigma^3 = = C_3 / C_2^{3/2}$,
kurtosis	$k = \langle (\delta N)^4 \rangle / \sigma^4 - 3 = = C_4 / C_2^2$

$$C_1 = M, \quad C_2 = \sigma^2, \quad C_3 = S\sigma^3, \quad C_4 = \kappa\sigma^4$$

$$\chi_1^B = \frac{1}{VT^3} \langle N_B \rangle \, ,$$

$$\chi_2^B = \frac{1}{VT^3} \langle (\delta N_B)^2 \rangle \, ,$$

$$\chi_3^B = \frac{1}{VT^3} \langle (\delta N_B)^3 \rangle \, ,$$

$$\chi_4^B = \frac{1}{VT^3} \left(\langle (\delta N_B)^4 \rangle - 3 \langle (\delta N_B)^2 \rangle^2 \right) ,$$

Susceptibility ratios:
$\sigma^2/M = \chi_2/\chi_1$, $S\sigma = \chi_3/\chi_2$, $\kappa\sigma^2 = \chi_4/\chi_2$

- baryon number N_B distribution can be measured via the net proton distribution
- $\langle \cdots \rangle$ -- the ensemble average
- $\delta N_B = N_B - \langle N_B \rangle$

- **Volume V is fixed here (as well as T)!**
- **Ratios of cumulants are used to reduce volume dependence**: $C_2/C_1 = \sigma^2/M$, $C_3/C_2 = S\sigma$, and $C_4/C_2 = \kappa\sigma^2$.

- **Volume dependence and volume fluctuations ?**

[1] -Xiaofeng Luo (STAR Collab.) , Probing the QCD Critical Point with Higher Moments of Net-proton Multiplicity Distributions, arXiv:1106.2926v1,J. Phys.: Conf. Ser. 316, 012003 (2011), DOI:https://doi.org/10.1088/1742-6596/316/1/012003; Skokov, 1205.4756v2.pdf arXiv:1205.4756:;
[2] S. Ejiri, F. Karsch, and K. Redlich, **Hadronic fluctuations at the QCD phase transition,**Phys. Lett. B 633, 275 (2006).
[3] W. J. Fu, X. Luo, J. M. Pawlowski, F. Rennecke, R. Wen, and S. Yin, Hyper-order baryon number fluctuations at finite temperature and density , Phys. Rev. D 104, 094047 (2021).

Problems of using δN=N-<N>

$$\sigma^2 = \langle(\delta N)^2\rangle$$

$$\text{skewness:} \quad S = \langle(\delta N)^3\rangle/\sigma^3 \quad = C_3/C_2^{3/2}$$

kurtosis	$k=\langle(\delta N)^4\rangle/\sigma^4 - 3 \quad = C_4/C_2^2$

- δN =N − <N>brings an added weight to the outliers
- The 2nd,3rd or the 4th power of <δN> gives more weight
- Volume (V) dependence of baryon number susceptibilities.
- V is also a strongly fluctuating quantity

- ”Therefore, we conclude that fluctuations of conserved charges in heavy ion collisions can provide robust probes of the chiral phase boundary **if a good control of volume fluctuations can be achieved.**” (see in [1]).

[1] V.Skokov, B. Friman and K. Redlich, Volume fluctuations and higher order cumulants of the net baryon number, arXiv:1205.4756;

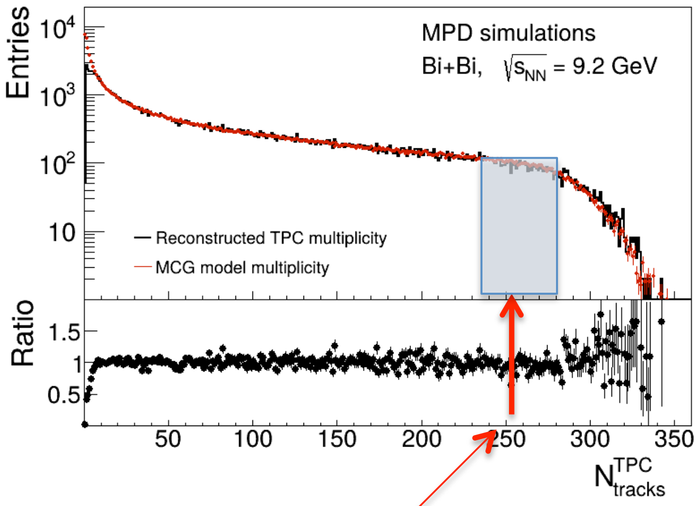
Centrality Bin Width Correction procedure (CBWC) [1]

$$\sigma = \frac{\sum_r n_r \sigma_r}{\sum_r n_r} = \sum_r \omega_r \sigma_r$$

$$S = \frac{\sum_r n_r S_r}{\sum_r n_r} = \sum_r \omega_r S_r$$

$$\kappa = \frac{\sum_r n_r \kappa_r}{\sum_r n_r} = \sum_r \omega_r \kappa_r$$

Selection of multiplicity class from multiplicity distribution
Of chatged particles
measured in some pseudorapidity interaval



Some r^{th} multiplicity bin
In the selected multiplicity class

Here n_r is the number of events in r^{th} multiplicity for centrality determination, the **σ_r, S_r and k_r represent the standard deviation, skewness and kurtosis** of particle number distributions at r^{th} multiplicity. The corresponding weight for the r^{th} multiplicity is $\omega_r = n_r/\Sigma n_r$

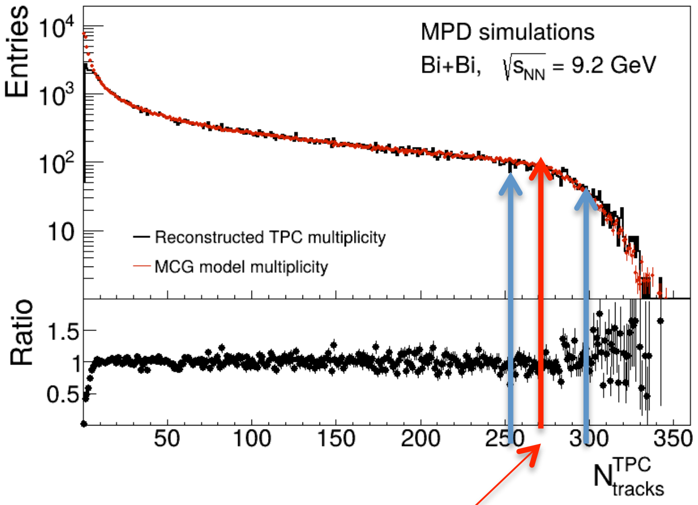
[1] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013).

Centrality Bin Width Correction procedure (CBWC) [1]

$$\sigma = \frac{\sum_r n_r \sigma_r}{\sum_r n_r} = \sum_r \omega_r \sigma_r$$

$$S = \frac{\sum_r n_r S_r}{\sum_r n_r} = \sum_r \omega_r S_r$$

$$\kappa = \frac{\sum_r n_r \kappa_r}{\sum_r n_r} = \sum_r \omega_r \kappa_r$$



Here n_r is the number of events in r^{th} multiplicity bin

EXAMPLE:

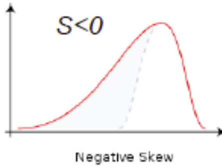
---The reconstructed TPC (black) and MCG modeled (red) multiplicity distributions for Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV [2]

---Blue arrows − multiplicity class boundaries

----Red arrow—some r^{th} multiplicity bin

---- followed by calculations of :

n_r, σ_r, S_r and k_r



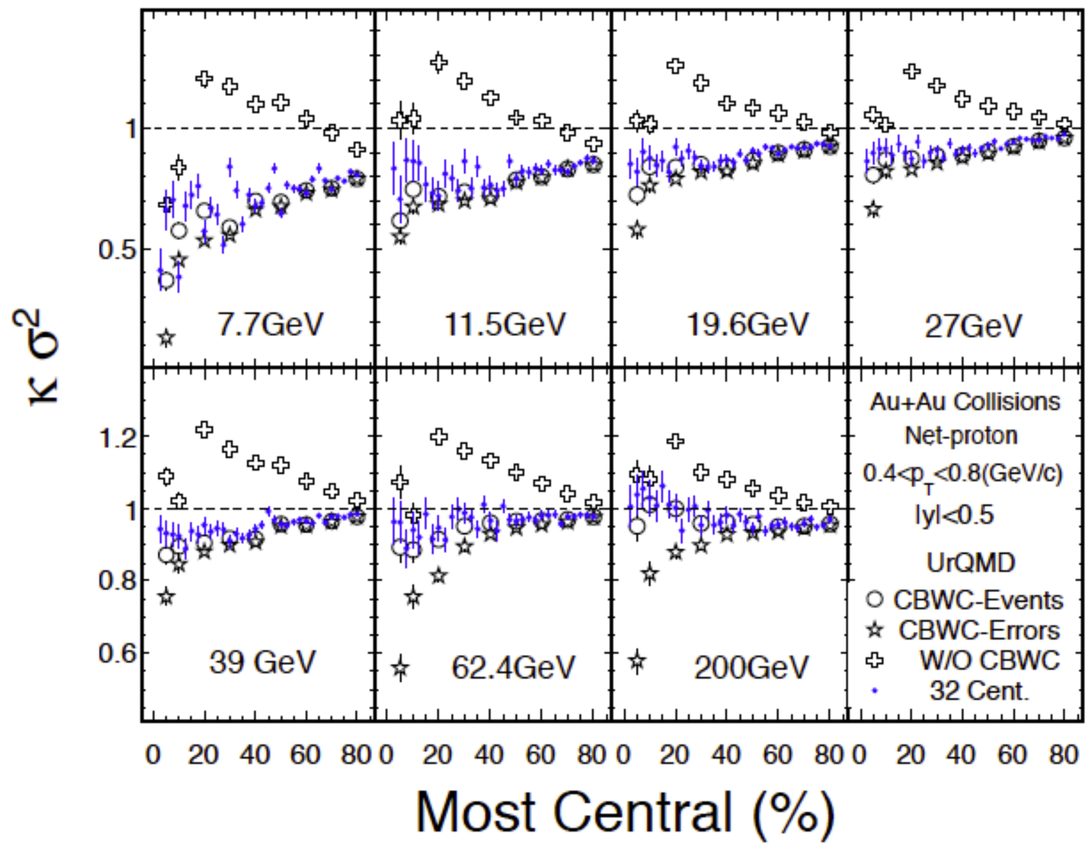
for the net-proton r^{th} distribution in the r^{th} multiplicity bin

---- and then − by calculation of the average values of σ, *S* and *k*

[1] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013).

[2] MPD Collaboration^ "MPD physics performance studies in Bi+Bi collisions at √1sNN = 9.2 GeV", to be published

Some examples of CBWC results in UrQMD model obtained in [1]



- FIG. 3. The centrality dependence of the moments products ($k\sigma^2$) of net-proton multiplicity distributions for Au+Au collisions at $\sqrt{s_{NN}}$=7.7, 11.5, 19.6, 27, 39, 62.4, 200GeV in UrQMD model. See in [1].

➢ **CBWC works and it is more important for the central collisions**

[1] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013); arXiv:1302.2332v2

Effects of different pseudorapidity intervals [1]

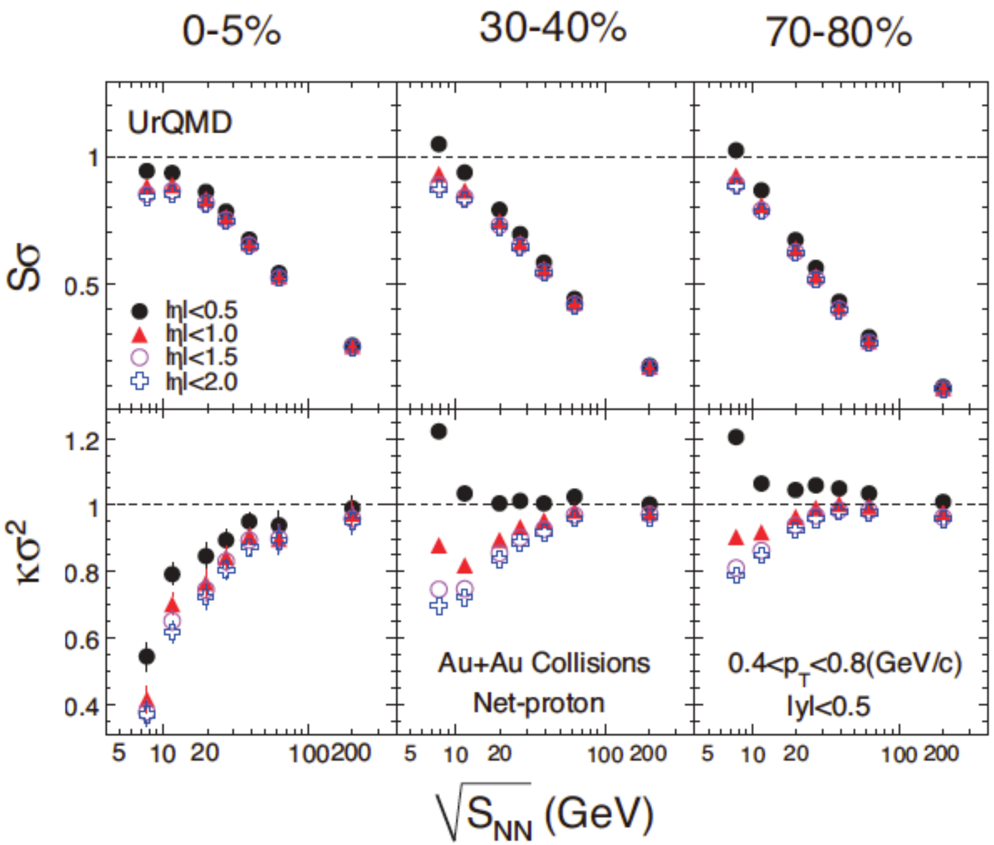


FIG. 7, See in [1]. The energy dependence of the moments products (Sσ, kσ^2) of net-proton multiplicity distributions for Au+Au collisions at $\sqrt{s_{NN}}$=7.7, 11.5, 19.6, 27, 39, 62.4, 200 GeV in UrQMD model with different centrality definition. See in [1].

- Centrality definition is using here different pseudorapidity intervals |η|: <0.5, <1.0, <1.5, <2.0

- **But we have to avoid in MPD such application as in [1} due to the fact that here different types of particle-emitting sources are mixed in case of a wide pseudorapidity region**

[1] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013); arXiv:1302.2332v2

Auto-correlation Effect (ACE)in UrQMD model [1]

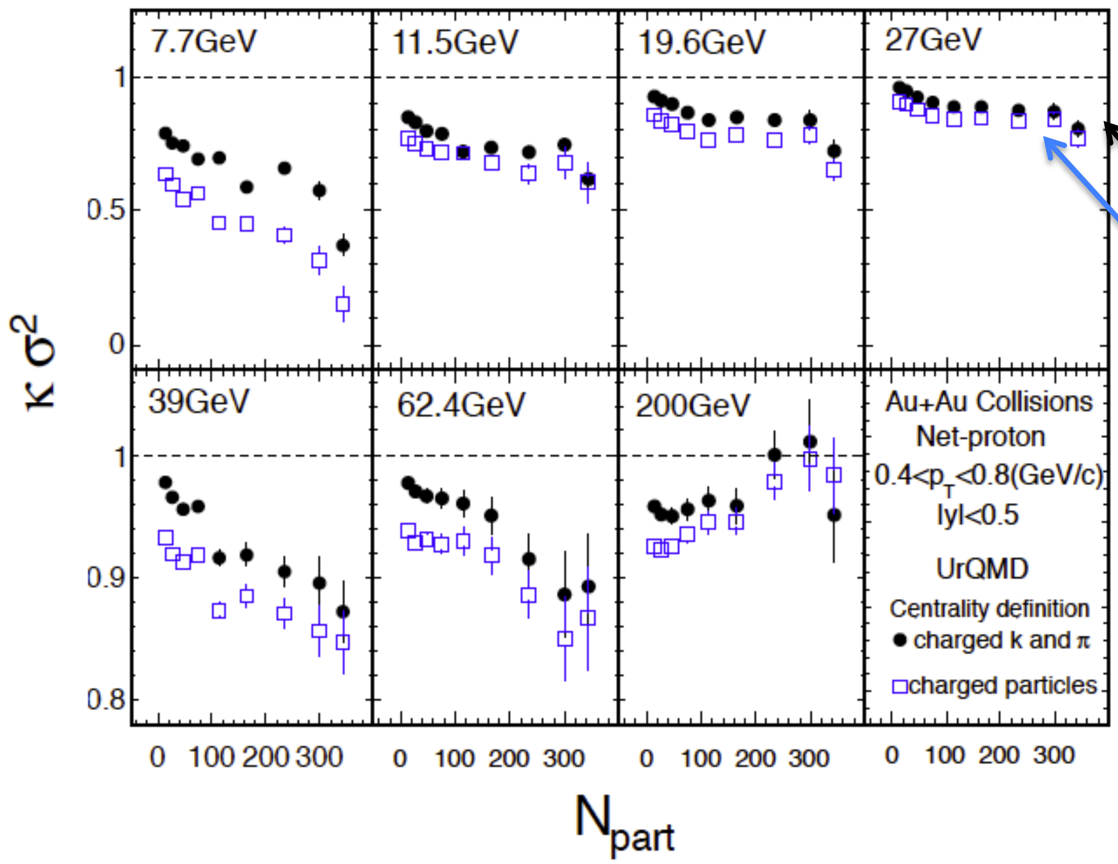


FIG. 12. FIG. 12. (Color online) The centrality dependence of the moments products $k\sigma^2$ of net-proton multiplicity distributions for Au+Au collisions at $\sqrt{s_{NN}}$=7.7, 11.5, 19.6, 27, 39, 62.4, 200 GeV in UrQMD model with two type of centrality definition. See in [1].

-- only charged pions and kaons

-- all charged particles

- **Auto-correlation Effect on $k\sigma^2$ is shown here as a result of using the same particles for centrality definitions and for moment analysis!**
- **This should be avoided by the MPD analysis**

[1] X. Luo, J. Xu, B. Mohanty, and N. Xu, J. Phys. G 40, 105104 (2013); arXiv:1302.2332v2

Multiplicity and N_{part} in MC Glauber model

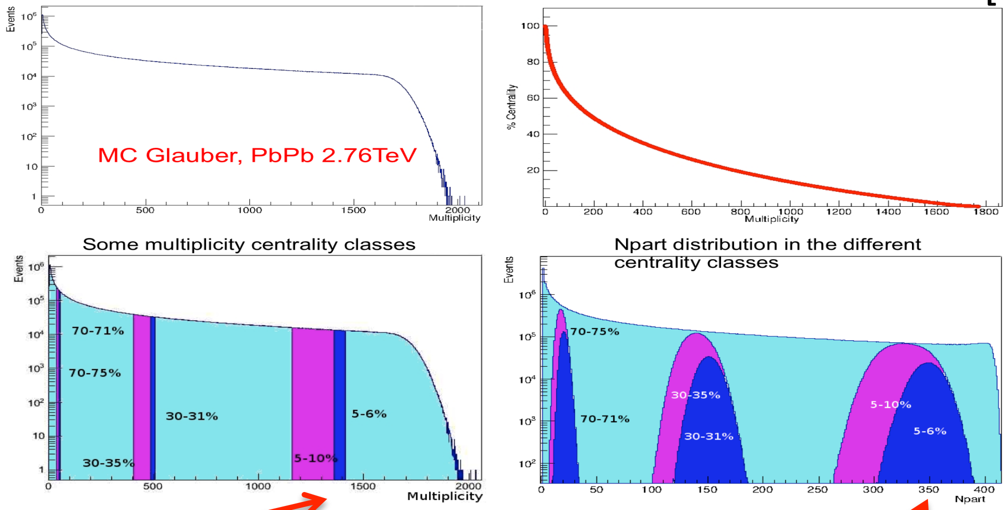
$$\chi_1^B = \frac{1}{VT^3} \langle N_B \rangle \,,$$

$$\chi_2^B = \frac{1}{VT^3} \langle (\delta N_B)^2 \rangle \,,$$

$$\chi_3^B = \frac{1}{VT^3} \langle (\delta N_B)^3 \rangle \,,$$

$$\chi_4^B = \frac{1}{VT^3} \left(\langle (\delta N_B)^4 \rangle - 3 \langle (\delta N_B)^2 \rangle^2 \right),$$

MC Glauber calculations Pb+Pb 2.76 TeV [4]



- For the class of selected events, the mean volume V and temperature T are supposed here to be fixed in [1] during the CBWC procedure [2]

- But narrow *class in multiplicity*, e.g. of **1%** width,

does not mean narrow distribution neither in *the impact parameter b [3]* nor in Npart[4]

- **Volume V is not fixed in the event-by-event study!**

This will skew distribution of N_{part} and N_B

[1] W. J. Fu, X. Luo, J. M. Pawlowski, F. Rennecke, R. Wen, and S. Yin, Hyper-order baryon number fluctuations at finite temperature and density Phys. Rev. D 104, 094047 (2021).
[2] Bin width effect -Xiaofeng Luo (STAR Collab.) , Probing the QCD Critical Point with Higher Moments of Net-proton Multiplicity Distributions, arXiv:1106.2926v1,J. Phys.: Conf. Ser. 316, 012003 (2011), DOI: https://doi.org/10.1088/1742-6596/316/1/012003
[3] see Fig.44 in the paoer:The MPD Collaboration, Status and initial physics performance studies of the MPD experiment at NICA, Eur. Phys. J. A (2022) 58:140, https://doi.org/10.1140/epja/s10050-022-00750-6
[4] T. A. Drozhzhova,V. N. Kovalenko,A. Yu. Seryakov,G. A. Feofilov, Physics of Atomic Nuclei, September 2016, Volume 79, Issue 5, pp 737–748

Fluctuations of conserved quantities and Volume fluctuations[1]

Consider a fixed volume V , where the net baryon number B fluctuates with the probability distribution P (B, V). The n-th order moments of the net baryon number are then defined by [1]:

$$\langle B^n \rangle_V = \sum_{B=-\infty}^{\infty} B^n P(B,V). \qquad (1)$$

The first four reduced cumulants in ref.[1] are:

$$\begin{aligned}
\kappa_1(T,\mu) &= \frac{1}{V}\langle B\rangle_V, \\
\kappa_2(T,\mu) &= \frac{1}{V}\langle(\delta B)^2\rangle_V, \\
\kappa_3(T,\mu) &= \frac{1}{V}\langle(\delta B)^3\rangle_V, \qquad (2)\\
\kappa_4(T,\mu) &= \frac{1}{V}\left[\langle(\delta B)^4\rangle_V - 3\langle(\delta B)^2\rangle_V^2\right],
\end{aligned}$$

where $\delta B = B - \bar{B}$ and $\bar{B} = \langle B\rangle_V$.

[1] V. Skokov,1, B. Friman,2 and K. Redlich3, “Volume fluctuations and higher order cumulants of the net baryon number”. arXiv:1205.4756v2

Proposal-1 for MPD: New Bin Width Correction procedure with the account of Volume fluctuations (CBWC –V)

Ratios of cumulants $C_2/C_1=\sigma^2/M$, $C_3/C_2.=S\sigma$, and $C_4/C_2=\kappa\sigma^2$ were used to reduce the volume dependence.

However, the average values of σ, *S* and *k* **are calculated assuming the fixed value of volume V in all events!.**

- **We propose to use the** reduced cumulants, similar to **[1], but on the event-by-event basis, following the new CBWC-V procedure with V^r in each r^{th} multiplicity bin:**

$M = \langle N\rangle = C_1$,

$\delta N = N - \langle N\rangle$

$\sigma^2 = \langle(\delta N)^2\rangle = C_2$,

$S = \langle(\delta N)^3\rangle/\sigma^3 = C_3/C_2^{3/2}$,

$k = \langle(\delta N)^4\rangle/\sigma^4 - 3 = C_4/C_2^2$

$c1 = M/V^r = \langle N^r/V^r\rangle$,

$\delta N^r = N^r/V^r - \langle N^r/V^r\rangle$

$c2 = \sigma_r^2 = \langle(\delta N^r)^2\rangle$,

$S_r = \langle(\delta N^r)^3\rangle/\sigma_r^3$,

$k_r = \langle(\delta N^r)^4\rangle/\sigma_r^4 - 3$

- **We assume that for any r^{th} multiplicity bin the relevant mean volume V^r is proportional to the mean number of participants $\langle N^r_{part}\rangle$:**

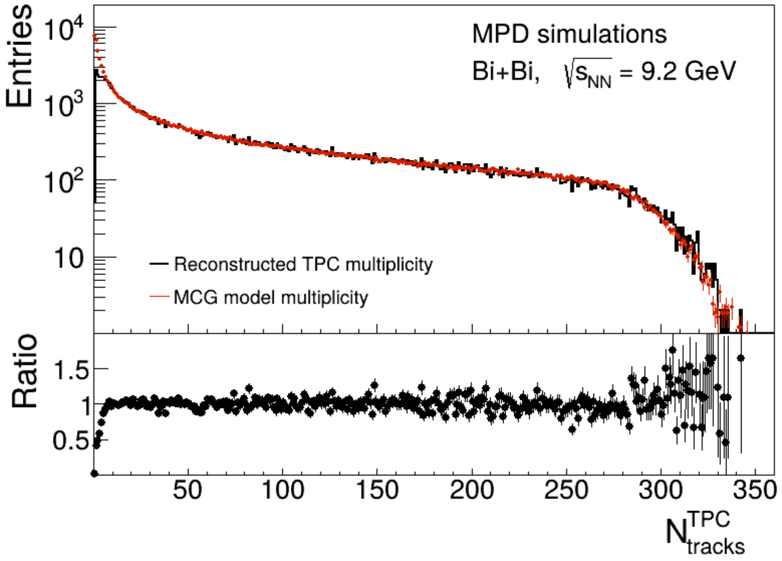
$$V^r = \langle N^r_{part}\rangle V_0$$

Here a volume factor $V_0 = 2.83\ fm^3$ (see in [1]).

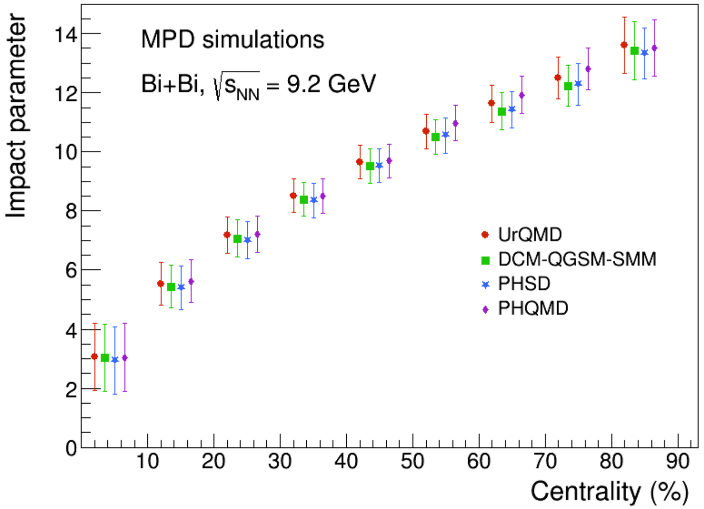
- **Thus we obtain the reduced deviation $\delta N^r = N^r/V^r - \langle N^r/V^r\rangle$ for the relevant distribution of conserved quantity N^r**

[1] V. Skokov, B. Friman and K. Redlich, “Volume fluctuations and higher order cumulants of the net baryon number”. arXiv:1205.4756v2

Proposal-2 for MPD: careful centrality selection



The reconstructed TPC (black) and MCG modeled (red) multiplicity distributions for Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV [1]



Mean impact parameter for 10% centrality intervals for Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV, modeled with the UrQMD, PHSD, DCM-QGSM-SMM, and PHQMD in [1]

- **The width of the class of centrality of A+A collisions is directly related to the unavoidable volume fluctuations [2]: We should select much narrow central classes of multiplicity for the analysis of net-proton fluctuations [2]**
- **Another approach − to measure spectator fragments with Hadron Calorimeter in parallel with multiplicity**
- **Application of ML to select narrow centrality classes in ToF technique with high timing resolution [3]**

[1] MPD Collaboration, ”MPD physics performance studies in Bi+Bi collisions at √1sNN = 9.2 GeV”, to be published

[2] T. A. Drozhzhova,V. N. Kovalenko,A. Yu. Seryakov,G. A. Feofilov, Physics of Atomic Nuclei, 2016, V 79, Issue 5, pp 737–748

[3] Galaktionov K., Rudnev V., Valiev F. , Physics of Particles and Nuclei, v54, N3, (2023), 446-448, DOI: 10.1134/s1063779623030152

Proposal-3 for MPD:

We have to avoid Auto-correlation Effects

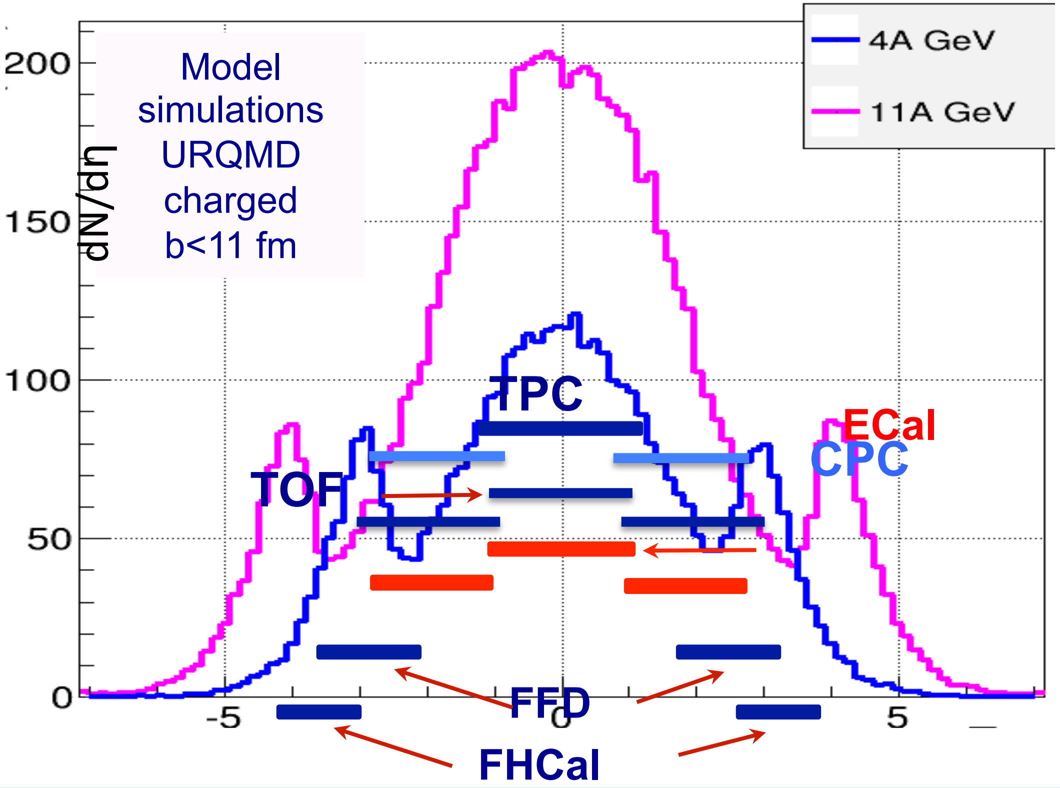
- **We have to avoid Auto-correlation Effects in the future analysis of net-proton fluctuations**

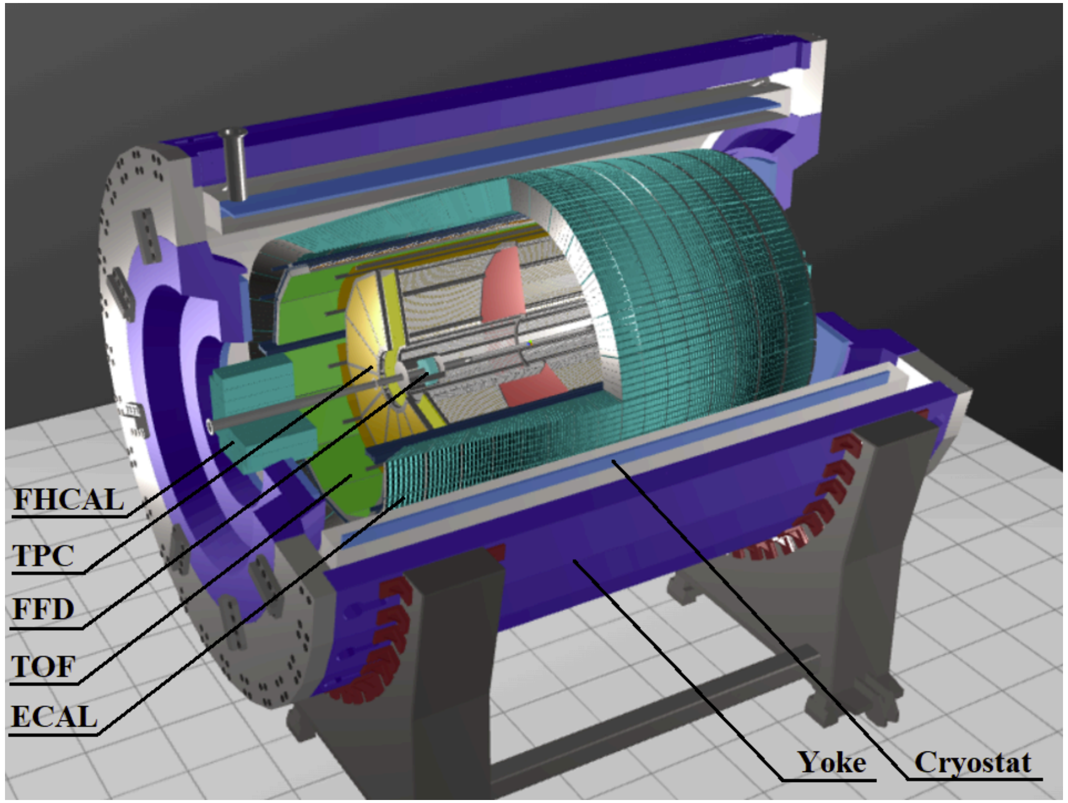
--- we should not use the same particles for centrality definitions and for moment analysis!

--- we should not use the same pseudorapidity intervals for centrality definitions and for moment analysis!

Multi-Purpose Detector (MPD) at the 1st stage of operation[1]

- Strong competition with HADES, NA61/SHINE, STAR BES, and CBM!





[1] MPD Collaboration, "MPD physics performance studies in Bi+Bi collisions at √1sNN = 9.2 GeV", to be published

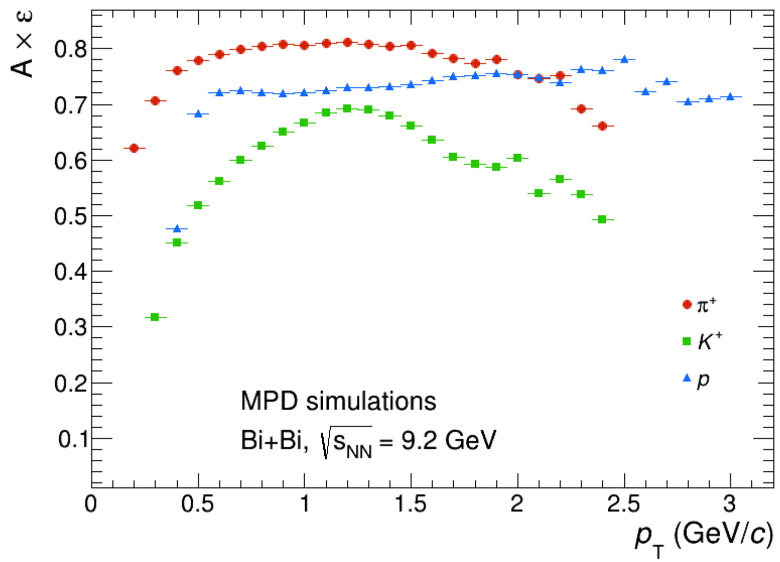
MPD -- a 4π spectrometer for detecting charged hadrons, electrons and photons in A+A collisions at high luminosity. ***FXT and colliding modes***

- ***Wide rapidity coverage, excellent PID capabilities***
- ***Tracking at midrapidity (TPC)***
- ***ToF, FFD, ECal and FHCal***
- **The system-size scan could be also a competitive advantage for MPD!**

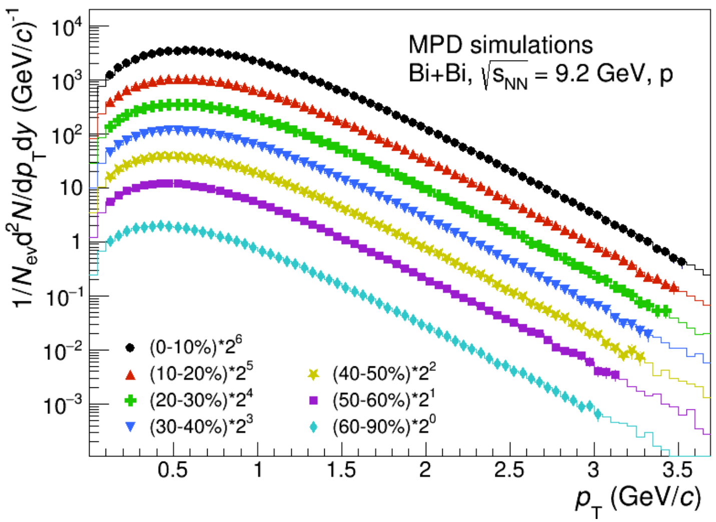
Beams expected at Stage-1:
Xe+Xe/Bi+Bi at $\sqrt{s_{NN}}$=9.02 GeV
Or in the fixed target mode:
Xe/Bi +W at $\sqrt{s_{NN}}$=3.0 GeV

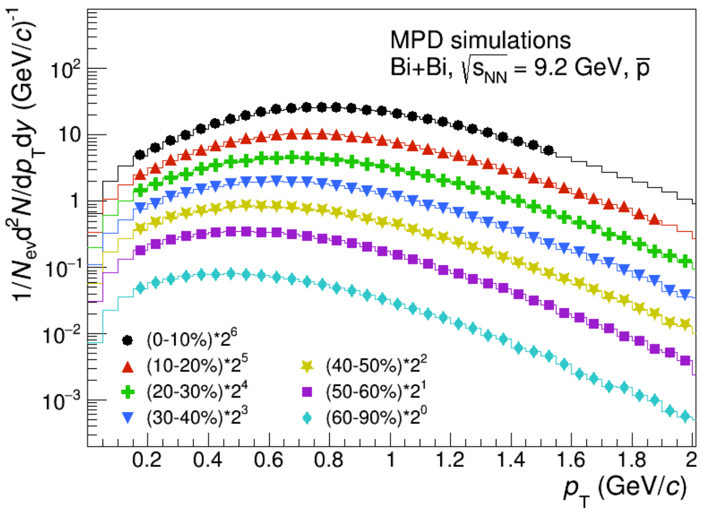
MPD physics performance study:

reconstruction of protons and anti-protons



The overall efficiency for positively charged hadrons as a function of p_T [1]





The reconstructed (markers) and generated (histograms) transverse momentum spectra for p and anti-p for midcentral (|y| < 0.5) Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV in different centrality intervals.

- Different techniques are available at MPD for the PID hadron measurements
- Measurements with contamination corrections span over a wider pT range
- **Important to study the proton and net-proton High-Order Cumulants !**

[1] MPD Collaboration, "MPD physics performance studies in Bi+Bi collisions at √1sNN = 9.2 GeV", to be published

Summary

- **Strong competition of MPD with HADES, NA61/SHINE, STAR BES, and CBM!**
- **Benefits of the MPD:**
  - **-- *Wide rapidity coverage,***
  - **--- Different techniques are available for PID hadron measurements**
  - **-- *Tracking at midrapidity (TPC)***
  - **-- *ToF, FFD, ECal and FHCal***
  - **--- The system-size scan could be a competitive advantage in search of CEP by the MPD!**

- **New procedure is proposed for Bin Width Correction with the account of Volume fluctuations**
- **Centrality selection criteria are being intensively studied in order to minimize trivial volume fluctuations and the auto-correlation effects in the future analysis of net-proton fluctuations in A+A collisions**

Thank you for your attention!