Advances in the study of event-by-event strangeness fluctuations

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   - https://indico.jinr.ru/event/4578/
   - https://indico.jinr.ru/event/5021/
   - Feedback from previous presentations: need for efficiency, purity, and contamination plots; local efficiency correction; and reducing Monte Carlo dependence.
2. Cumulants and Moments
3. Data Analysis
   - Efficiency and contamination
   - Local Efficiency Corrections
4. Summary

Cumulants and Moments

Let $\Delta N = N - \bar{N}$ be the net multiplicity of a particle, then the standard deviation is $\delta N = \Delta N - \langle \Delta N \rangle$, and the first order cumulants are defined as:

$$C_1 = \langle \Delta N \rangle, \quad C_2 = \langle (\delta N)^2 \rangle, \quad C_3 = \langle (\delta N)^3 \rangle, \tag{1}$$
$$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2.$$

The cumulants are related with the statistical moments as:

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

Data Analysis

Data sample

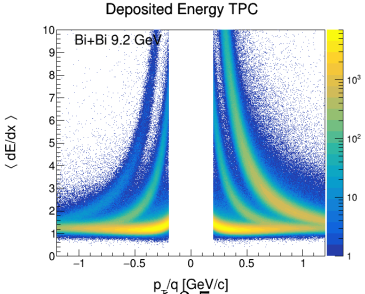
The following events were generated using UrQMD.

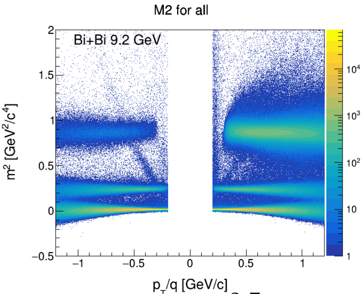
Collision Type	$\sqrt{S_{NN}}$	Events	Analysis
Bi+Bi (Request 25)	9.2 GeV	$\sim$ 3 Million	Reconstructed

- The analysis is implemented using the train system.
- A custom wagon was developed that depends on the Centrality and PID wagons.
- This wagon computes the cumulants and only requires an efficiency distribution as input.

Particle Identification

TPC and TOF information to identify K using the PID wagon. $|\sigma_{DCA}| \leq 2$, and the following cuts were applied: $0{,}2 \leq p_T \leq 1{,}2$ GeV/c, $|y| \leq 0{,}5$, nHits> 15.





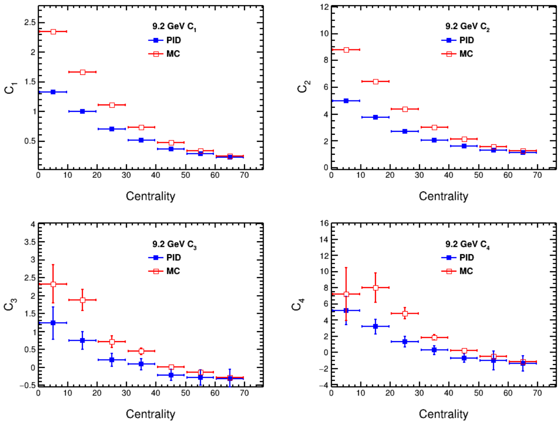
$p_T \leq 0{,}5$

- $|\sigma_{TPC}|, |\sigma_{TOF}| \leq 2$
- Or $|\sigma_{TPC}| \leq 2$ ($|\sigma_{\phi,z}| > 2$)

$p_T > 0{,}5$ $(|\sigma_{\phi}|, |\sigma_z| \leq 2)$

- $|\sigma_{TPC}| \leq 2$
- and $|\sigma_{TOF}| \leq 2$

Calculation of cumulants (uncorrected)

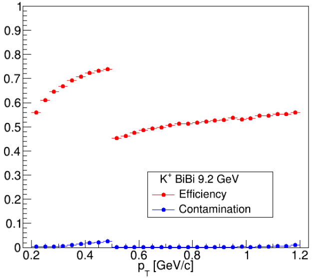


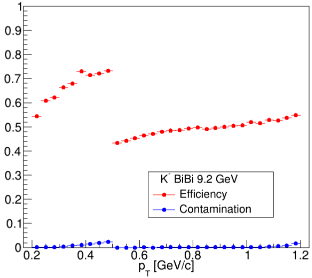
Statistical cumulants without correction.

Efficiency and purity and contamination

The efficiency, purity, and contamination are defined as

$$\epsilon(p_T) = \frac{N_k(PID)}{N_k(MC)}, \quad C(p_T) = \frac{N_k(FP)}{N_k(PID)}, \quad P(p_T) = 1 - C.$$





Efficiency and contamination of K^+ (left), and K^- (right). Efficiency shows discontinuity due to PID: TOF is used only within its coverage range.

Cumulants Efficiency Corrections

To perform the correction, we assume that the difference between the real distribution P and the measured distribution p can be modeled as a binomial distribution, so defining the factorial moments of p and P as

$$f_{ik} = \left\langle \frac{n_1!}{(n_1-i)!} \frac{n_2!}{(n_2-k)!} \right\rangle, \quad F_{ik} = \left\langle \frac{N_1!}{(N_1-i)!} \frac{N_2!}{(N_2-k)!} \right\rangle \tag{3}$$

we can get the relation

$$F_{ik} = \frac{1}{p_+^i p_-^k} f_{ik}. \tag{4}$$

p_+ and p_- the efficiency of the identification. With this relation, is possible to obtain the real value of the cumulants.

Cumulants Corrections

Using the previous relations and by the definition of statistical cumulants, the following equalities are obtained:

$$
\begin{aligned}
C_1 &= F_{10} - F_{01}, \\
C_2 &= N - C_1^2 + F_{02} - 2F_{11} + F_{20}, \\
C_3 &= C_1 + 2C_1^3 - F_{03} - 3F_{02} + 3F_{12} + 3F_{20} - 3F_{21} + F_{30} \\
&- 3C_1(N + F_{02} - 2F_{11} + F_{20}), \\
C_4 &= N - 6C_1^4 + F_{04} + 6F_{03} + 7F_{02} - 2F_{11} - 6F_{12} - 4F_{13} \\
&+ 7F_{20} - 6F_{21} + 6F_{22} + 6F_{30} - 4F_{31} + F_{40} \\
&+ 12C_1^2(N + F_{02} - 2F_{11} + F_{20}) - 3(N + F_{02} - 2F_{11} + F_{20})^2 \\
&- 4C_1(C_1 - F_{03} - 3F_{02} + 3F_{12} + 3F_{20} - 3F_{21} + F_{30}).
\end{aligned}
$$

C_n are the cumulants of the real distribution.

What if the efficiency is not constant?

To incorporate transverse momentum dependence to the efficiency from the particle x, and from the negative particle $\overline{x}$, we introduce local factorial moments A_{ik} and a_{ik}:

$$\begin{aligned} A_{ik} \quad & (x_1,\ldots,x_i;\overline{x}_1,\ldots,\overline{x}_i) = \langle N(x_1)[N(x_2)-\delta_{x_1,x_2})]\cdots \\ [\quad & N(x_i)-\delta_{x_1,x_i}-\cdots-\delta_{x_{i-1},x_i}]\overline{N}(\overline{x}_2)-\delta_{\overline{x}_1,\overline{x}_2})]\cdots \\ [\quad & \overline{N}(\overline{x}_i)-\delta_{x_1,x_i}-\cdots-\delta_{x_{i-1},x_i}]\rangle \end{aligned} \tag{5}$$

$$\begin{aligned} a_{ik} \quad & (x_1,\ldots,x_i;\overline{x}_1,\ldots,\overline{x}_i) = \langle n(x_1)[n(x_2)-\delta_{x_1,x_2})]\cdots \\ [\quad & n(x_i)-\delta_{x_1,x_i}-\cdots-\delta_{x_{i-1},x_i}]\overline{n}(\overline{x}_2)-\delta_{\overline{x}_1,\overline{x}_2})]\cdots \\ [\quad & \overline{n}(\overline{x}_i)-\delta_{x_1,x_i}-\cdots-\delta_{x_{i-1},x_i}]\rangle \end{aligned} \tag{6}$$

Local efficiency correction

Using

$$F_{ik} = \sum_{x_1,\ldots,x_i} \sum_{\overline{x}_1,\ldots,\overline{x}_i} A_{ik}(x_1,\ldots,x_i;\overline{x}_1,\ldots,\overline{x}_i) \qquad (7)$$

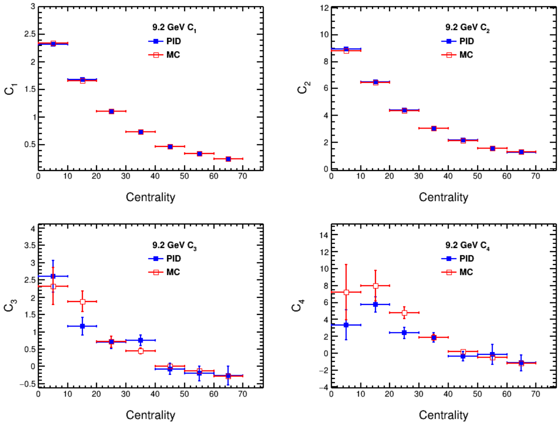
and

$$a_{ik} = \epsilon(x_1)\ldots\epsilon(x_i)\overline{\epsilon}(\overline{x}_1)\ldots\overline{\epsilon}(\overline{x}_i)A_{ik} \qquad (8)$$

where ϵ an $\overline{\epsilon}$ are the local acceptance of N and $\overline{N}$.

$$F_{ik} = \sum_{x_1,\ldots,x_i} \sum_{\overline{x}_1,\ldots,\overline{x}_i} \frac{a_{ik}(x_1,\ldots,x_i;\overline{x}_1,\ldots,\overline{x}_i)}{\epsilon(x_1)\ldots\epsilon(x_i)\overline{\epsilon}(\overline{x}_1)\ldots\overline{\epsilon}(\overline{x}_i)}. \qquad (9)$$

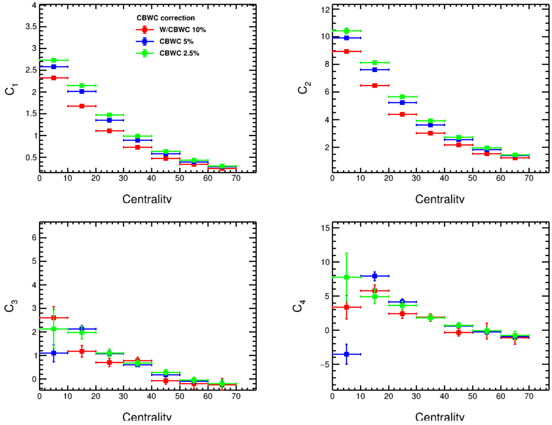
Cumulants Ratios after efficiency corrections



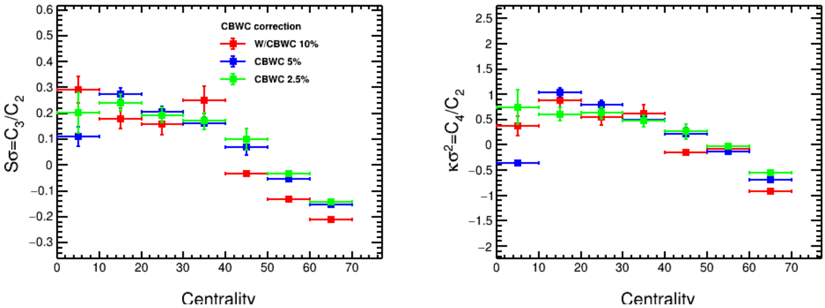
Cumulants ratios with correction. Discrepancy in central collisions.

Centrality Bin Width Correction (CBWC)

To correct volume fluctuations, we apply the Centrality Bin Width Correction: $C_i = \frac{\sum_r n_r C_{i,r}}{\sum_r n_r}$. Where n_r is the number of events in the $r-$th multiplicity.

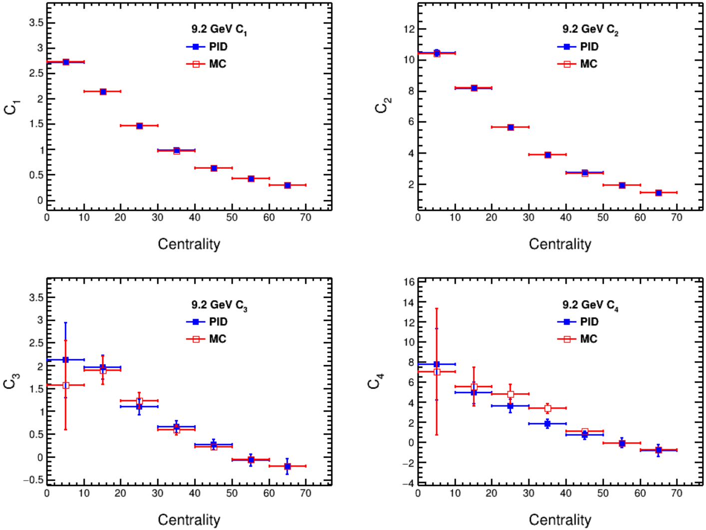


Centrality Bin Width Correction (CBWC)

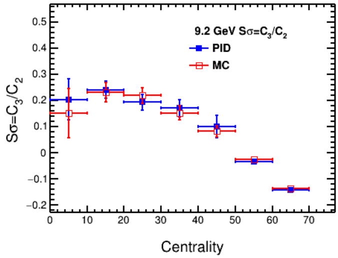


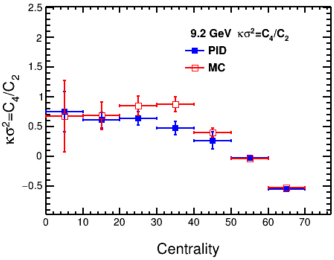
Cumulant ratios. Different CBWC corrections, bin size of 10 %, 5 % and 2.5 %.

Calculation of cumulants (Corrected by CBWC 2.5 %)



Cumulant ratios (Corrected by CBWC 2.5) %





Cumulants ratios corrected by CBWC and Local Efficiency

What's next: New proposal for correcting volume fluctuations

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

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This proposal was presented by Gregory at the previous meeting (`https://indico.jinr.ru/event/5294/`).

Summary and perspectives

The study of strangeness number fluctuations and the calculation of the first 4 cumulants were presented at the reconstruction level in the MPD experiment.

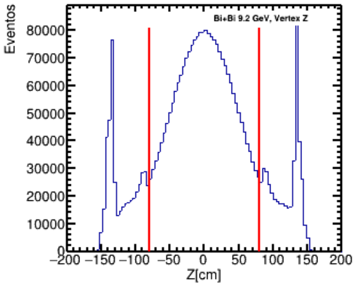
- The cumulants (C_1, C_2, C_3, and C_4) for strangeness were calculated and corrected (Centrality Bin Width and Local Efficiency Corrections).
- Optimize correction parameters (Efficiency bins) and analyze corrections with different cuts.
- I've prepared a technical note, Is there any repository to sent it?.
- Analyze the new correction proposal by Grigory.

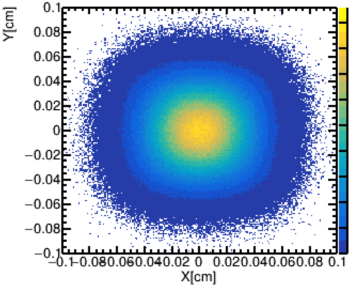
Thank you for your attention [1].

[1] Special thanks to Eleazar Cuautle

Event Selection

Vertex cut $|z| \leq 80$ cm. Events with at least 1 charged kaon.





Collision	$\sqrt{S_{NN}}$	Events	Events after cuts
Bi+Bi	9.2 GeV	$\sim$ 3 Million	$\sim$ 1.5 Million

Efficiency and contamination and purity

The efficiency, purity, and contamination are defined as

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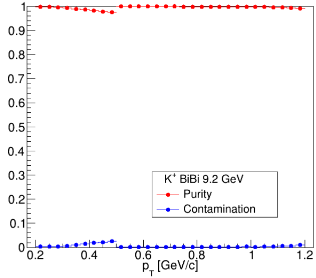
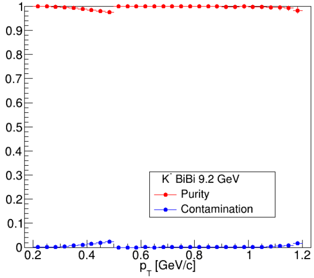
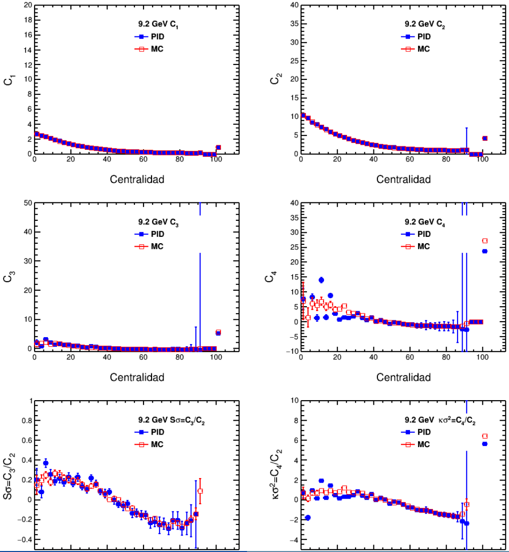




Efficiency and contamination of K^+ (left), and K^- (right).
Efficiency shows discontinuity due to PID: TOF is used only within its coverage range.

Kaon p_T


9.2 GeV C1
PID
MC
C1
Centralidad
9.2 GeV C2
PID
MC
C2
Centralidad
9.2 GeV C3
PID
MC
C3
Centralidad
9.2 GeV C4
PID
MC
C4
Centralidad
9.2 GeV Sσ=C3/C2
PID
MC
Sσ=C3/C2
9.2 GeV κσ²=C4/C2
PID
MC
κσ²=C4/C2