Net Charge Fluctuations in *AA* Collisions in a Simple String-Inspired Model

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Outline

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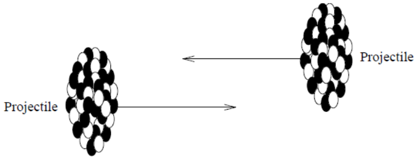
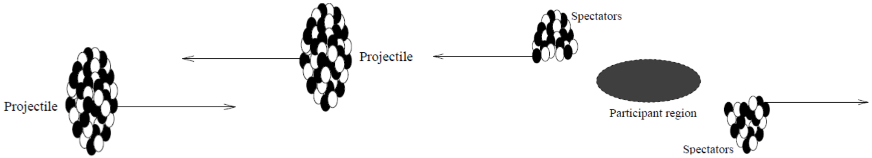
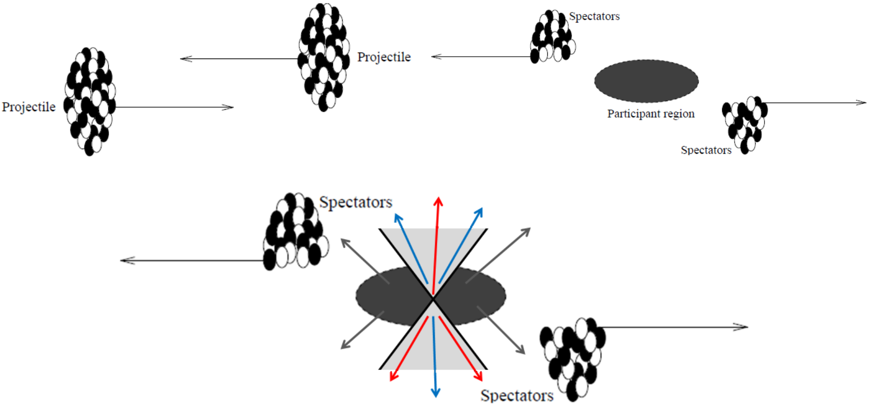
Net charge



Net charge


Projectile
Projectile
Spectators
Participant region
Spectators

Net charge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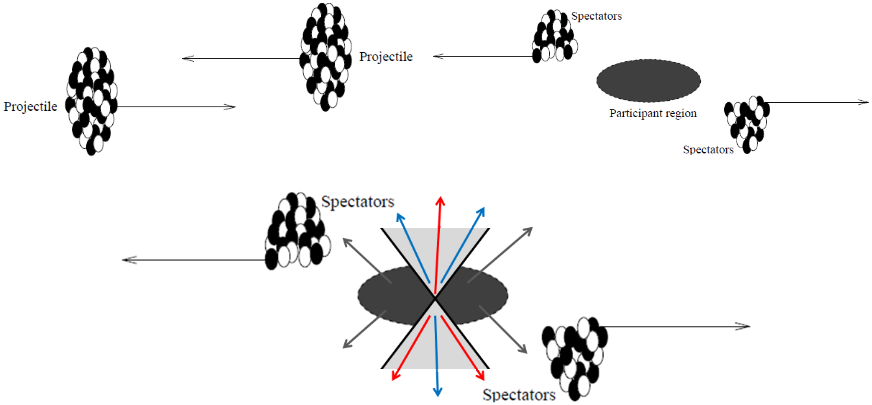
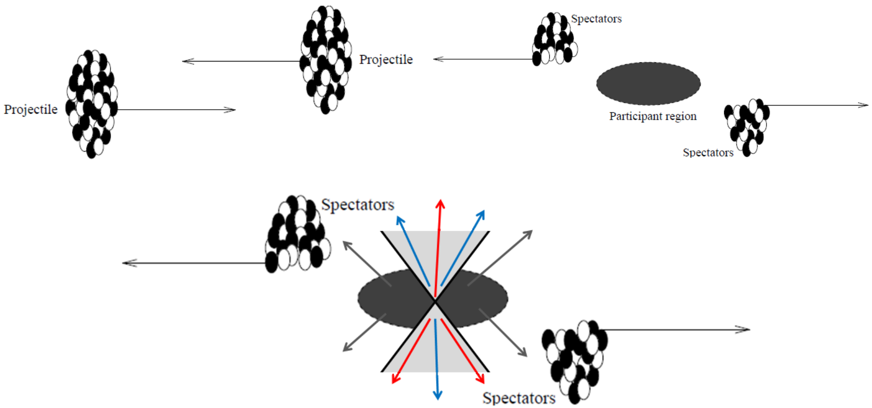


N_+ and N_- are the numbers of positive and negative particles in a **specific transverse momentum and rapidity window**.

Net charge



N_+ and N_- are the numbers of positive and negative particles in a **specific transverse momentum and rapidity window**.

$Q = N_+ - N_-$ is the **net charge**.

Measure D of the fluctuations

A value of the net charge event-by-event fluctuations has been proposed as an indicator of the formation of quark-gluon plasma (QGP) in high-energy nucleus-nucleus collisions [1, 2].

$$N_{\rm ch} = N_+ + N_- \text{ is the charge multiplicity.}$$

$$R = N_+/N_- \text{ is the charge ratio.}$$

$$D \equiv \langle N_{\rm ch}\rangle \left(\langle R^2\rangle - \langle R\rangle^2\right),$$

where $\langle ... \rangle$ denotes an average of the quantity over an ensemble of events.

If $\langle N_{\rm ch}\rangle \gg \langle Q\rangle$, then

$$D \approx 4\frac{\langle Q^2\rangle - \langle Q\rangle^2}{\langle N_{\rm ch}\rangle}.$$

[1] S. Jeon and V. Koch, Phys. Rev. Lett. **85**, 2076 (2000).

[2] M. Asakawa, U. Heinz and B. Müller, Phys. Rev. Lett. **85**, 2072 (2000).

Measure ν_{dyn} of the fluctuations

The observable ν is determined as the second moment of the difference between the relative multiplicities $N_+/\langle N_+\rangle$ and $N_-/\langle N_-\rangle$ as follows:

$$\nu = \left\langle \left(\frac{N_+}{\langle N_+\rangle} - \frac{N_-}{\langle N_-\rangle} \right)^2 \right\rangle .$$

If the particle distributions are independent from each other and Poissonian, the quantity ν is equal to

$$\nu_{\text{stat}} = \frac{1}{\langle N_+\rangle} + \frac{1}{\langle N_-\rangle}.$$

The "**nonstatistical**" or "**dynamical**" fluctuations are the difference between the above two quantities:

$$\nu_{\text{dyn}} = \nu - \nu_{\text{stat}} \quad \text{and} \quad \langle N_{\text{ch}}\rangle \nu_{\text{dyn}} \approx D - 4.$$

D-measure and ν_{dyn} are related to each other.

Theoretical predictions

- $D \approx 4$ for an uncorrelated pion gas.
- $D \approx 3$ for a hadron gas after accounting for resonance yields.
- $D \approx 1.0 - 1.5$ for a QGP.

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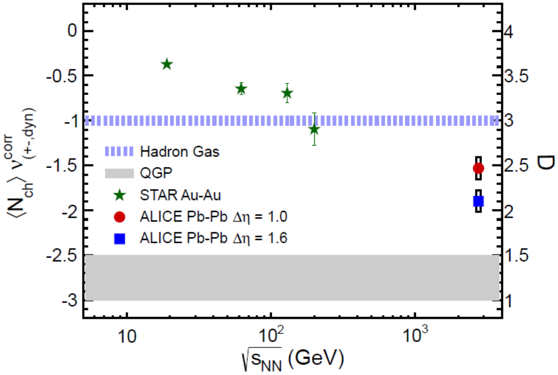


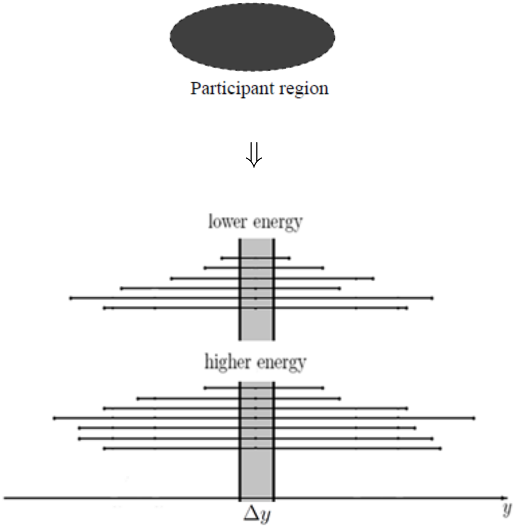
The ALICE Collaboration, arXiv:1207.6068 [nucl-ex] (2012).

Outline

Quark-gluon strings

Participant region

Quark-gluon strings



Formulation of the model

We introduce the probability $P(N_+, N_-)$ to have N_+ positive and N_- negative particles from the decays of quark-gluon strings in the central rapidity interval Δy in a given event:

$$P(N_+, N_-) = \sum_N w(N) \sum_{n_1^+,\dots,n_N^+} \sum_{n_1^-,\dots,n_N^-} \delta_{N_+ \; n_1^+ + \dots + n_N^+} \, \delta_{N_- \; n_1^- + \dots + n_N^-} \times$$

$$\times \prod_{i=1}^{N} p(n_i^+, n_i^-).$$

Here N is the number of strings in a given event,

$w(N)$ is the probability to have N strings in a given event,

$p(n_i^+, n_i^-)$ is the probability to have n_i^+ positive and n_i^- negative particles from the decay of a string in the central rapidity interval Δy in a given event.

Formulation of the model

$$p_+(n_i^+) = \sum_{n_i^-} p(n_i^+, n_i^-), \qquad \sum_{n_i^+} p_+(n_i^+) = 1,$$

$$p_-(n_i^-) = \sum_{n_i^+} p(n_i^+, n_i^-), \qquad \sum_{n_i^-} p_-(n_i^-) = 1.$$

For identical strings at any i we have

$$\sum_{n_i^+} n_i^+ \; p_+(n_i^+) = \overline{n}_+, \qquad \sum_{n_i^+} {n_i^+}^2 \; p_+(n_i^+) = \overline{n_+^2},$$

$$\sum_{n_i^-} n_i^- \; p_-(n_i^-) = \overline{n}_-, \qquad \sum_{n_i^-} {n_i^-}^2 \; p_-(n_i^-) = \overline{n_-^2},$$

$$\sum_{n_i^+, n_i^-} n_i^+ n_i^- \; p(n_i^+, n_i^-) = \overline{n_+ n_-}.$$

One string correlator

We define the correlator for one string as follows:

$$k(n^+, n^-) \equiv \frac{\overline{n_+ n_-} - \overline{n}_+ \overline{n}_-}{\sqrt{d(n^+) d(n^-)}},$$

where

$$d(n^+) = \overline{n_+^2} - \overline{n}_+^2, \qquad d(n^-) = \overline{n_-^2} - \overline{n}_-^2.$$

$$-1 \leq k(n^+, n^-) \leq 1$$

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The fluctuations in the number of strings are characterized by $w(N)$:

$$\sum_N w(N) = 1, \qquad \sum_N N\, w(N) = \langle N \rangle, \qquad \sum_N N^2\, w(N) = \langle N^2 \rangle,$$

$$D(N) = \langle N^2 \rangle - \langle N \rangle^2.$$

Calculation of ν_{dyn}

$$\nu_{\text{dyn}} = \frac{D(N_+)}{\langle N_+\rangle^2} + \frac{D(N_-)}{\langle N_-\rangle^2} - 2\frac{\langle N_+ N_-\rangle - \langle N_+\rangle\langle N_-\rangle}{\langle N_+\rangle\langle N_-\rangle} - \frac{1}{\langle N_+\rangle} - \frac{1}{\langle N_-\rangle}$$

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Now we can calculate

$$\langle N_+\rangle = \langle N\rangle\overline{n}_+, \qquad \langle N_-\rangle = \langle N\rangle\overline{n}_-,$$

$$D(N_+) = \langle N_+^2\rangle - \langle N_+\rangle^2 = \langle N\rangle d(n^+) + D(N)\overline{n}_+^2,$$

$$D(N_-) = \langle N_-^2\rangle - \langle N_-\rangle^2 = \langle N\rangle d(n^-) + D(N)\overline{n}_-^2,$$

$$\langle N_+N_-\rangle - \langle N_+\rangle\langle N_-\rangle = \langle N\rangle k(n^+, n^-)\sqrt{d(n^+)d(n^-)} + D(N)\overline{n}_+\overline{n}_-.$$

Calculation of ν_{dyn}

Assumptions at high energies:

- $\overline{n}_+ = \overline{n}_- = \overline{n}$,
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Then

$$\langle N_+ \rangle = \langle N_- \rangle = \langle N \rangle \overline{n},$$

$$D(N_+) = D(N_-) = \langle N \rangle d + D(N) \overline{n}^2,$$

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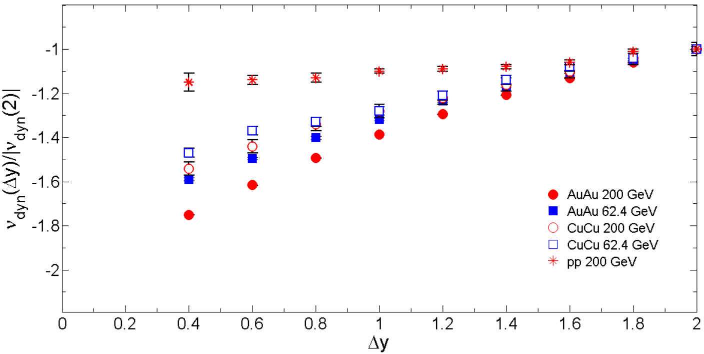
$$\langle N_+ N_- \rangle - \langle N_+ \rangle \langle N_- \rangle = \langle N \rangle k(n^+, n^-) d + D(N) \overline{n}^2.$$

$$\boxed{\nu_{\text{dyn}} = \frac{2}{\langle N \rangle \overline{n}} \Big(\omega(1-k) - 1 \Big),}$$

where $\overline{n}$, d and k are the mean multiplicity, the variance and the correlator for one string, $\omega = d/\overline{n}$ is a scaled variance. $\langle N \rangle$ is the mean number of the strings.

Dependence of ν_{dyn} on Δy

In [1] the dependencies of the normalized quantity $\nu_{\text{dyn}}(\Delta y)/|\nu_{\text{dyn}}(2)|$ on the width of the **pseudorapidity** interval Δy are obtained.



[1] B.I. Abelev et al. (STAR Collaboration), Phys. Rev. C **79**, 024906 (2009).

Dependencies of $\overline{n}$ and ω on Δy

$$\nu_{\text{dyn}} = \frac{2}{\langle N \rangle \overline{n}} \Big(\omega(1-k) - 1 \Big)$$

At small values of Δy one can consider that

$$\overline{n} = \overline{n}_0 \Delta y.$$

It is known for a homogenous distribution of particles in phase space (in rapidity in our case) that

$$\frac{\omega - 1}{\overline{n}} = C,$$

where C does not depend on Δy [1, 2]. Thus

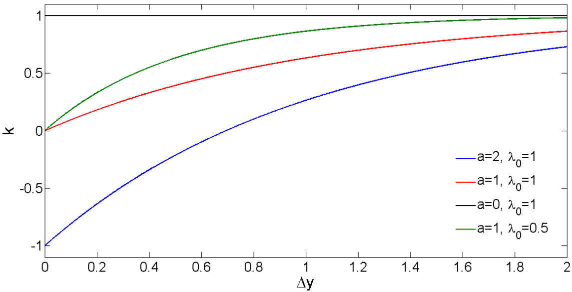
$$\omega = C\overline{n}_0 \Delta y + 1.$$

[1] C. Alt et al. (NA49 Collaboration), Phys. Rev. C **75**, 064904 (2007).
[2] A. Adare et al. (PHENIX Collaboration), Phys. Rev. C **78**, 044902 (2008).

Dependence of $k(n^+, n^-)$ on Δy

Motivated by the string fragmentation picture [1, 2], for the individual string correlator we use the approximation of the following form:

$$k(\Delta y) = 1 - a\exp(-\Delta y/\lambda_0) \quad \text{with} \quad 0 \le a \le 2 \quad \text{and} \quad \lambda_0 \sim 1.$$



[1] X. Artru, G. Mennessier, Nucl. Phys. **B70**, 93 (1974).
[2] V.V. Vechernin. Proceedings of the Baldin ISHEPP XIX, vol.1, JINR, Dubna, 2008, 276-281; arXiv:0812.0604 [hep-ph] (2008).

Dependence of ν_{dyn} on Δy

Taking into account the dependencies of $\overline{n}$, ω and k on Δy, we obtain

$$\nu_{\text{dyn}}(\Delta y) = \frac{2}{\langle N \rangle \overline{n}_0 \Delta y} \Big((C\overline{n}_0 \Delta y + 1) a \exp(-\Delta y/\lambda_0) - 1 \Big).$$

We choose $a = 1$ to have a finite value of ν_{dyn} at $\Delta y \to 0$.

Then for the normalized quantity, experimentally studied by the STAR collaboration, we have

$$\frac{\nu_{\text{dyn}}(\Delta y)}{|\nu_{\text{dyn}}(2)|} = \frac{2}{\Delta y} \cdot \frac{(C\overline{n}_0 \Delta y + 1) \exp(-\Delta y/\lambda_0) - 1}{|(2C\overline{n}_0 + 1) \exp(-2/\lambda_0) - 1|}.$$

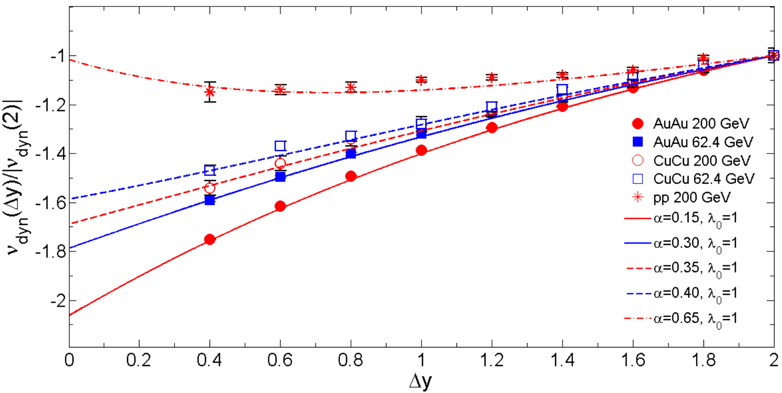
Dependence of ν_{dyn} on Δy

$$\frac{\nu_{\text{dyn}}(\Delta y)}{|\nu_{\text{dyn}}(2)|} = \frac{2}{\Delta y} \cdot \frac{(\alpha \Delta y + 1)\exp(-\Delta y/\lambda_0) - 1}{|(2\alpha + 1)\exp(-2/\lambda_0) - 1|}$$

- $\alpha \equiv C\overline{n}_0$ indicates non-poissonian character of an individual string ($\omega = \alpha \Delta y + 1$).
- λ_0 is the correlation length in rapidity space.

Outline

Comparison with the STAR data



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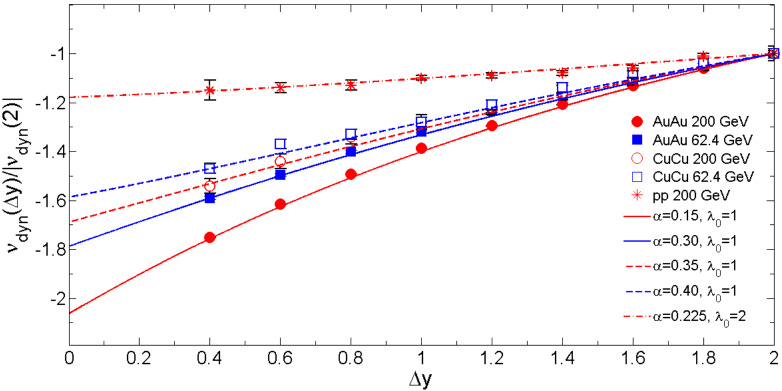

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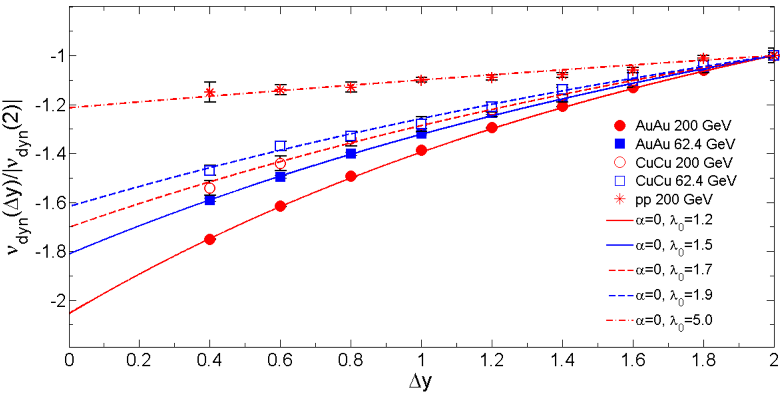

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Outlook

- A further development of the model.
    - More precise expression for $k(\Delta y)$.
    - Accounting for the transport of the positive charge of initial nuclear protons into the mid-rapidity region.
- Comparison with the new data from ALICE at the LHC.