Strongly intensive fluctuations and correlations in ultrarelativistic nuclear collisions in the model with string fusion

Vladimir Kovalenko

Saint Petersburg State University

XXIV International Baldin Seminar

on High Energy Physics Problems

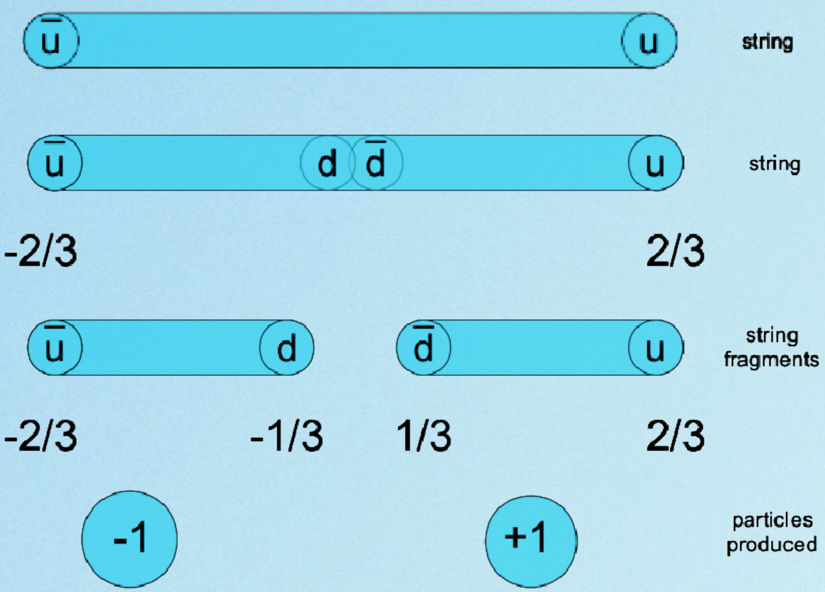
Relativistic Nuclear Physics & Quantum Chromodynamics

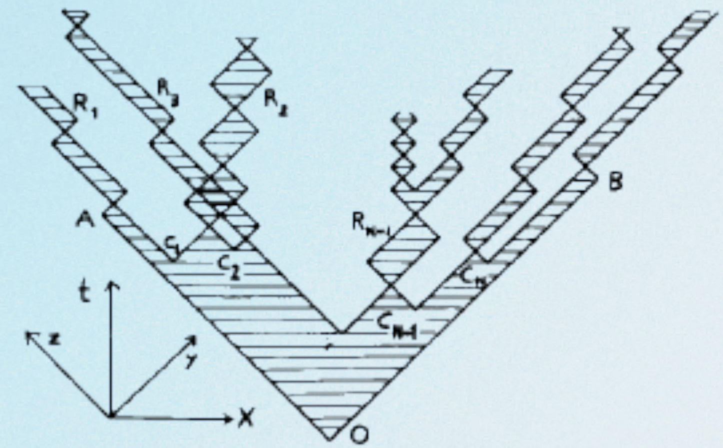
September 17 - 22, 2018, Dubna, Russia

The work was supported by the grant of the Russian Foundation for Basic Research (project 18-32-01055 mol_a).

Initial stages

- The soft QCD processes is not described by usual perturbation theory
- The model of quark-gluon strings, stretched between projectile and target partons
  – semiphenomenological approach to the multiparticle production





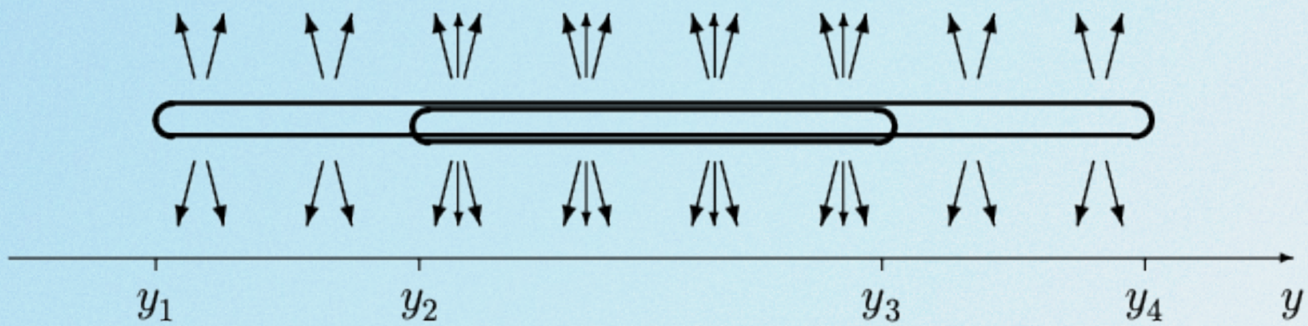
X. Artru and G. Mennessier, Nucl Phys B 70 (1974) 93
“String Model and Multiproduction”,

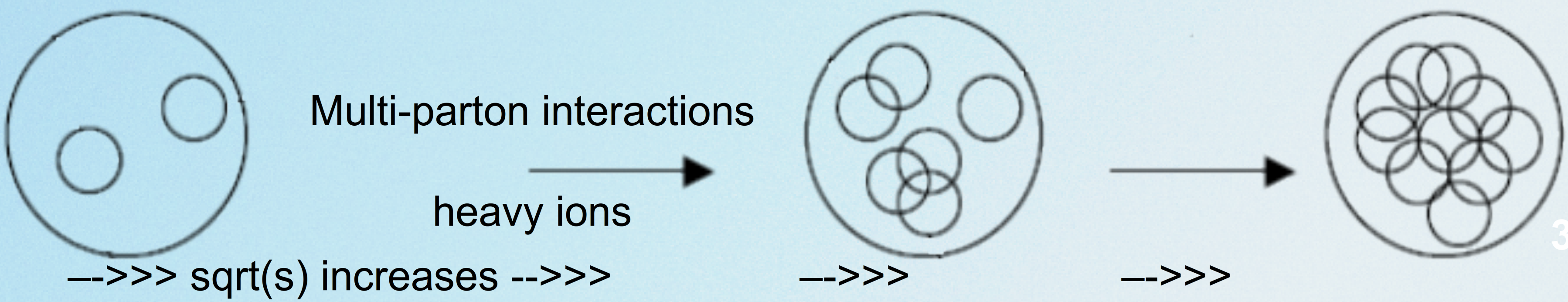
- Correlations play crucial role:
  – causality requires appearance of long-range correlations – if they exist –
  at the very early stages between particles detected in separated rapidity intervals

Strings in rapidity space

- Uniform and independent distribution of particles on rapidity from y_{min} to y_{max}

- Can study string overlaps:





3

String fusion

$$Q^2(n) = \left(\sum_{i=1}^{n} \vec{Q}_i(1) \right)^2 = \sum_{i=1}^{n} Q_i^2(1) + \sum_{i \neq j} \vec{Q}_i(1) \cdot \vec{Q}_i(1)$$

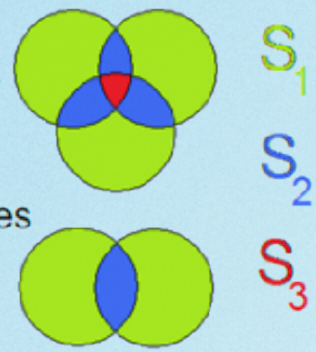
$$\langle Q^2(n) \rangle = n Q^2(1)$$

overlaps

SFM

$C = \{S_1, S_2, \ldots\}$

S_k – area covered k-times



String fusion mechanism predicts:

– decrease of multiplicity
– increase of p_T
– growth of p_T with multiplicit in pp, pA and AA collisions
– growth of strange particle yields

– results are in a good agreement with the experiment

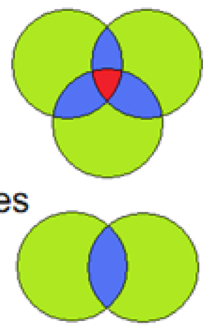
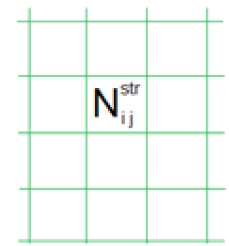
$$\langle \mu \rangle_k = \mu_0 \sqrt{k} \frac{S_k}{\sigma_0} \qquad \langle p_t^2 \rangle_k = p_0^2 \sqrt{k} \qquad \langle p_t \rangle_k = p_0 \sqrt[4]{k}$$

S_k – area, where k strings are overlapping, σ_0 single string transverse area,
μ_0 and p_0 – mean multiplicity and transverse momentum from one string

M. A. Braun, C. Pajares, Nucl. Phys. B 390 (1993) 542.
M. A. Braun, R. S. Kolevatov, C. Pajares, V. V. Vechernin, Eur. Phys. J. C 32 (2004) 535.
N.S. Amelin, N. Armesto, C. Pajares, D. Sousa, Eur.Phys.J.C22:149-163 (2001), arXiv:hep-ph/0103060
G. Ferreiro and C Pajares J. Phys. G: Nucl. Part. Phys. 23 1961 (1997)

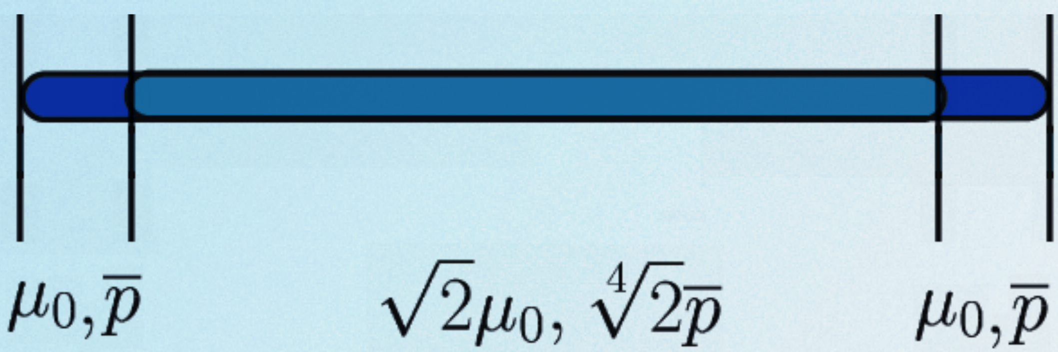
String fusion

- Lattice realization of string fusion model

	"overlaps" (local fusion)		"overlaps" (local fusion)
SFM	○ $C=\{S_1,S_2,\ldots\}$ S_k – area covered k-times  S_1 S_2 S_3	cellular analog of SFM	□ $C=\{N_{ij}^{str}\}$  $k_{ij}=N_{ij}^{str}$ – "occupation" numbers

V. V. Vechernin and R. S. Kolevatov, Vestn. SPb. Univ., Ser. Fiz. Khim., No. 2, 12 (2004); hep-` ph/0304295.
V. V. Vechernin and R. S. Kolevatov, Vestn. SPb. Univ., Ser. Fiz. Khim., No. 4, 11 (2004); hep-ph/0305136.
I. A. Lakomov, V. V. Vechernin, PoS (Baldin ISHEPP XXI) 072 (2012).

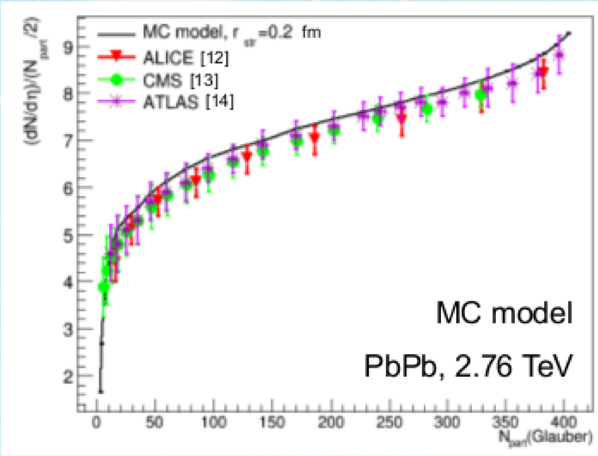
- Fusion of finite rapidity strings



Monte Carlo model

- Partonic dipole-based picture of nucleons interaction.
- Energy and angular momentum conservation in the initial state of a nucleon.
- The probability of dipoles are defined by heir transverse coordinates [7-8]:

$$f = \frac{\alpha_s^2}{2} \ln^2 \frac{|\vec{r}_1 - \vec{r}_1'||\vec{r}_2 - \vec{r}_2'|}{|\vec{r}_1 - \vec{r}_2'||\vec{r}_2 - \vec{r}_1'|}$$



Multiplicity and transverse momentum are obtained in the approach of colour strings, stretched between projectile and target partons

- The interaction of strings is realized in the accordance with the **string fusion** model
- Multiplicity from one string is distributed according to Poisson

V. N. Kovalenko.. Phys. Atom. Nucl. 76, 1189 (2013), arXiv:1211.6209 [hep-ph]
V. Kovalenko, V. Vechernin., PoS (Baldin ISHEPP XXI) 077, arXiv:1212.2590 [nucl-th], 2012

Forward-backward correlations

Select 2 variables in windows:

F, B:

n – number of charged particles in the window ($Q=n_+ - n_-$)

$p_t = \frac{1}{n}\sum_{i=1}^{n} p_{ti}$ – mean (in the event!) transverse momentum of charged particles in the given window

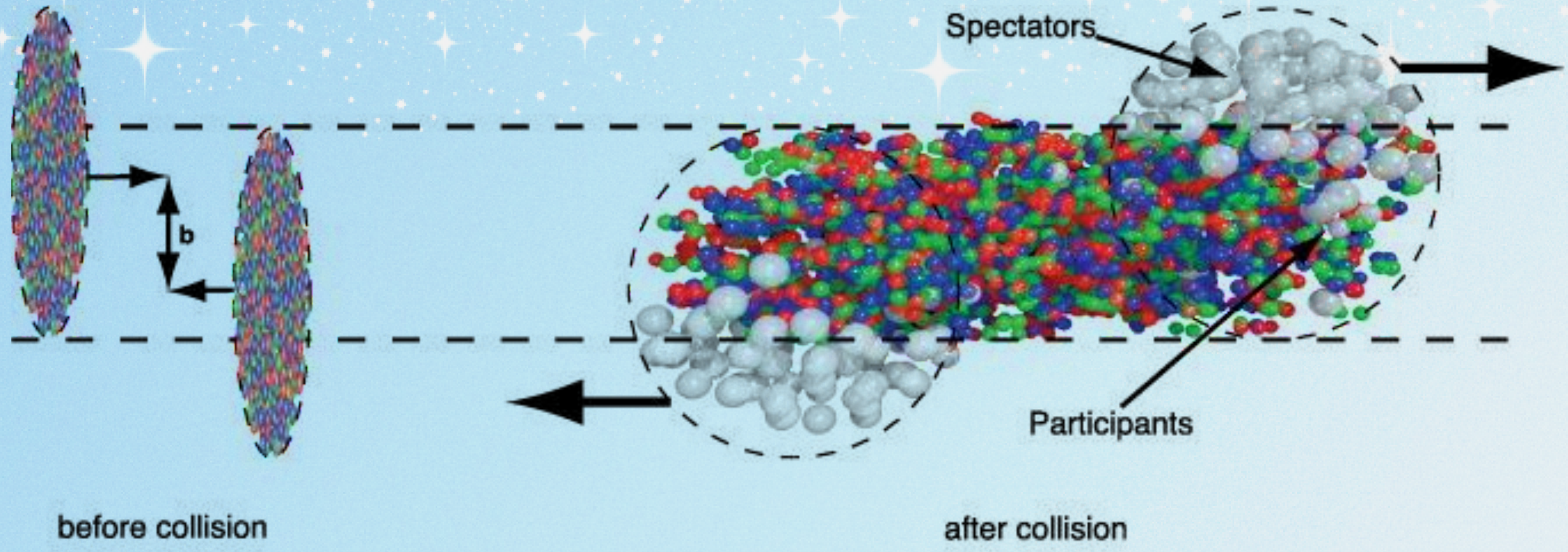
correlation coefficient

$$b = \frac{\langle F\,B\rangle - \langle F\rangle\langle B\rangle}{\langle F^2\rangle - \langle F\rangle^2}$$

Several types of correlation coefficient:

n-n , pt-n, **pt-pt, Q-Q**

Centrality of AA collisions



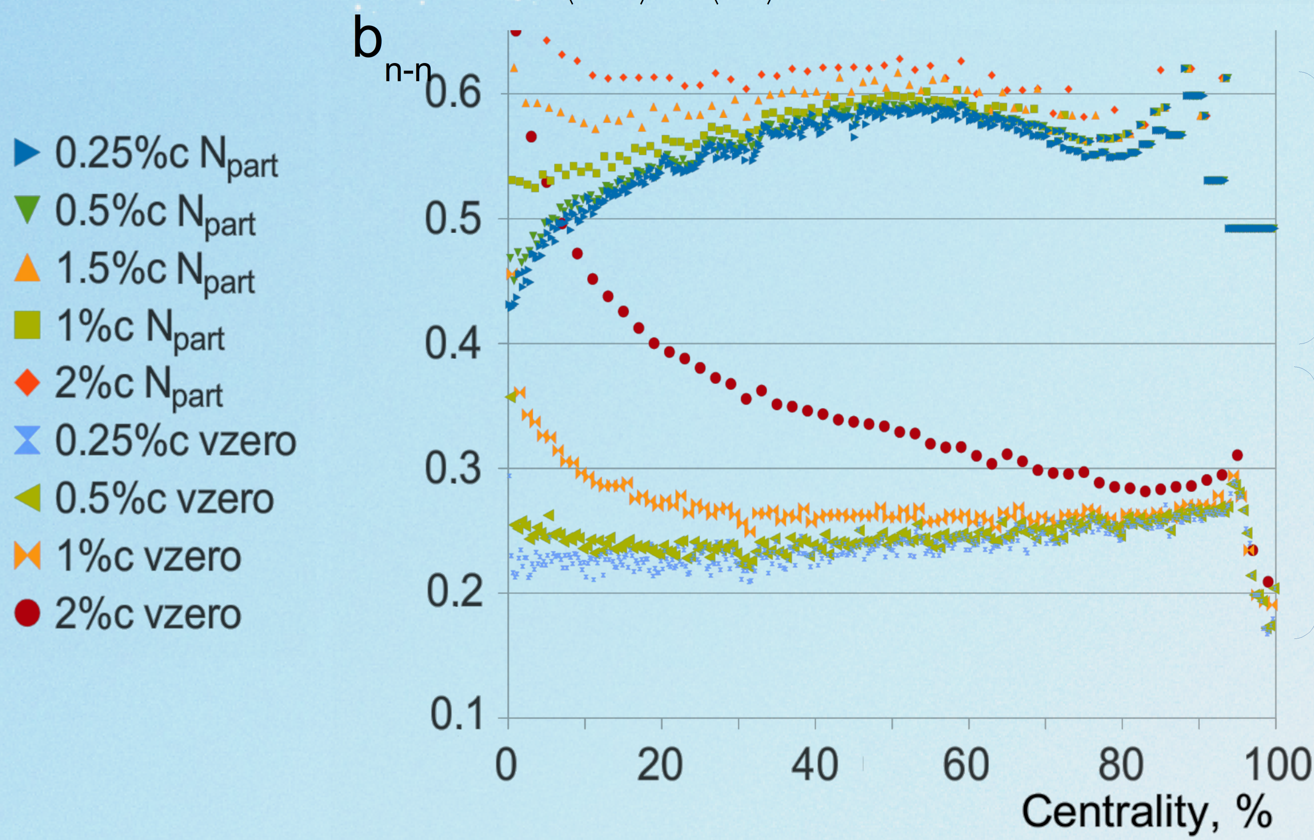
- Nucleon-participants N_{part} - nucleons collided at least once
- Nucleon-spectators N_{spect} - nucleons, which didn't interact
- Number of nucleon-nucleon collisions N_{coll}
- Multiplicity of charge particles N_{ch}

Forward-backward correlations in AA

multiplicity – extensive variable

n-n correlation coefficient

$$b = \frac{\langle F\,B \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$



Pb-Pb, 2.76 TeV

depends on

method of centrality determination

width of centrality class

V. Kovalenko, V. Vechernin. EPJ Web of Conferences 66, 04015 (2014), arXiv:1308.6618 [nucl-th]

Mean pt-pt correlations in SF model

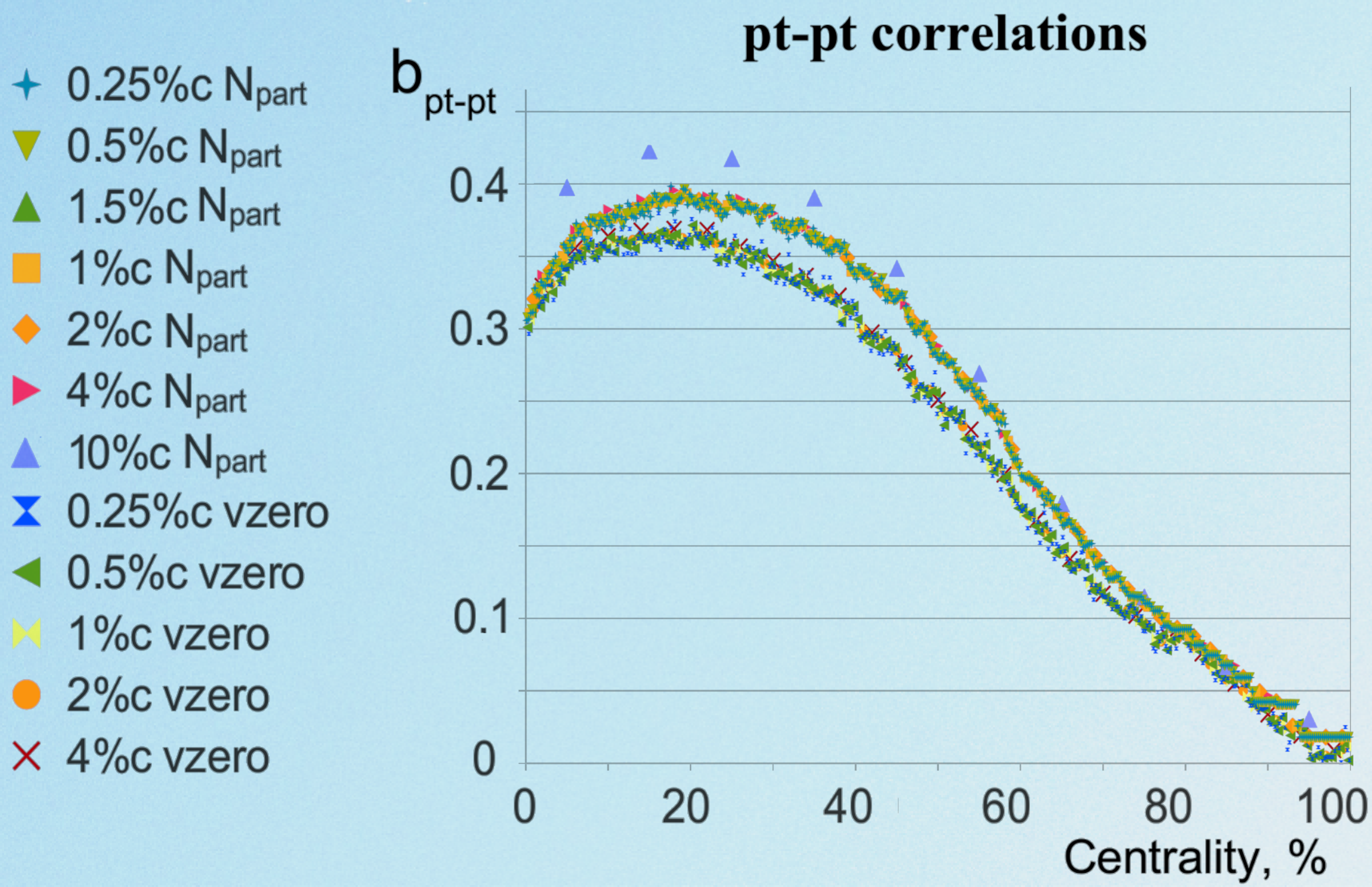
mean event transverse momentum – **intensive** variable

pt-pt correlation coefficient

$$b = \frac{\langle F B \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$

$$B, F, \rightarrow p_t = \frac{1}{n} \sum_{i=1}^{n} p_{ti}$$

Pb-Pb, 2.76 TeV



robust

V. Kovalenko, V. Vechernin. EPJ Web of Conferences 66, 04015 (2014), arXiv:1308.6618 [nucl-th]

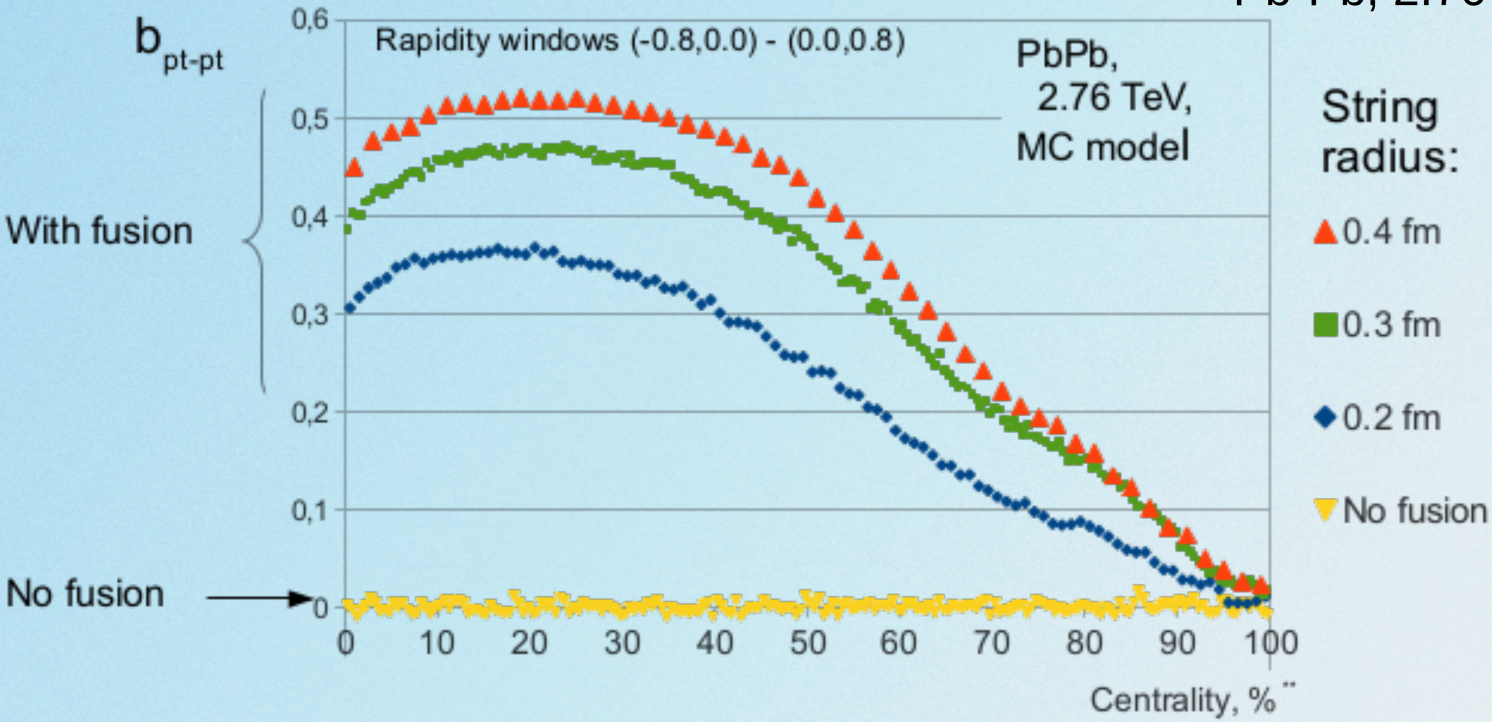
Mean pt-pt correlations in SF model

correlation coefficient

$$b = \frac{\langle F B \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$

$$B, F, \rightarrow p_t = \frac{1}{n} \sum_{i=1}^{n} p_{ti}$$

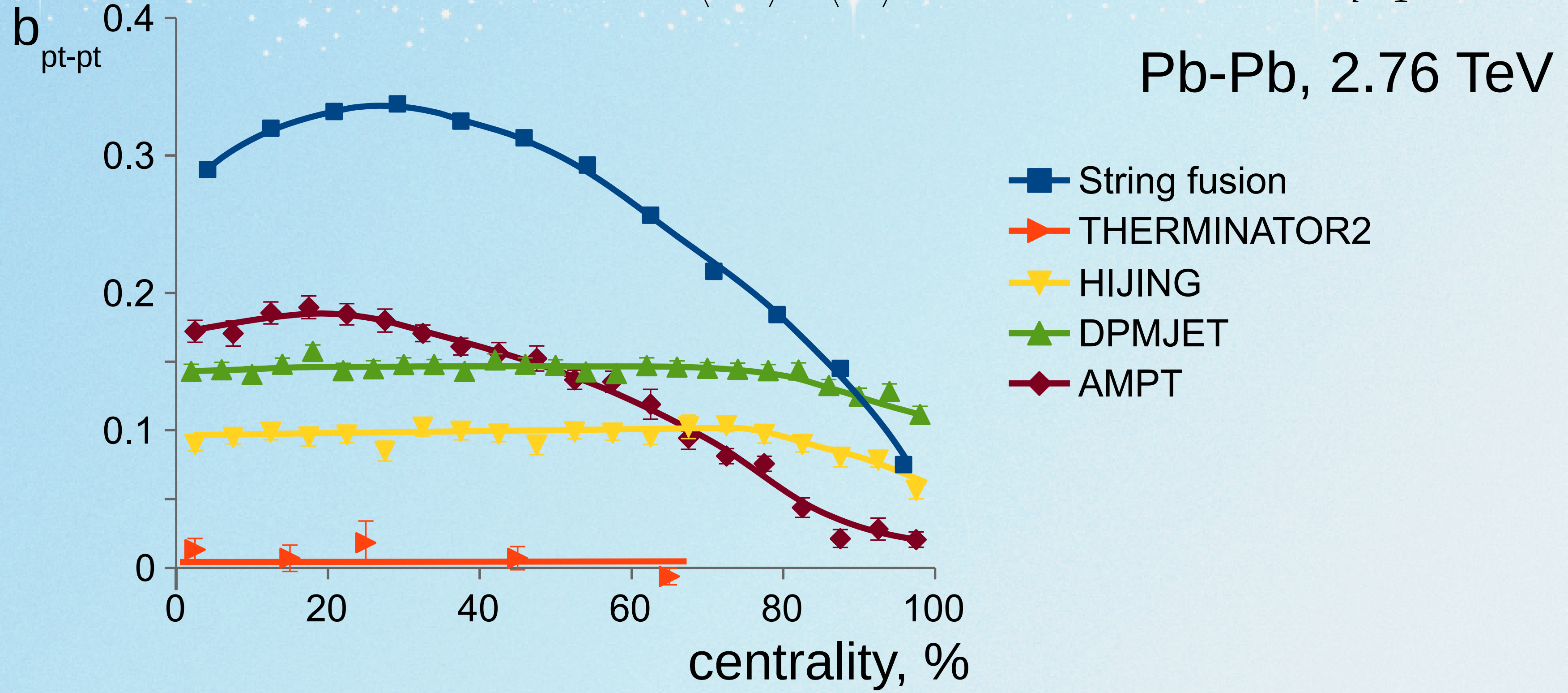
Pb-Pb, 2.76 TeV



V. Kovalenko, V. Vechernin. EPJ Web of Conferences 66, 04015 (2014), arXiv:1308.6618 [nucl-th]

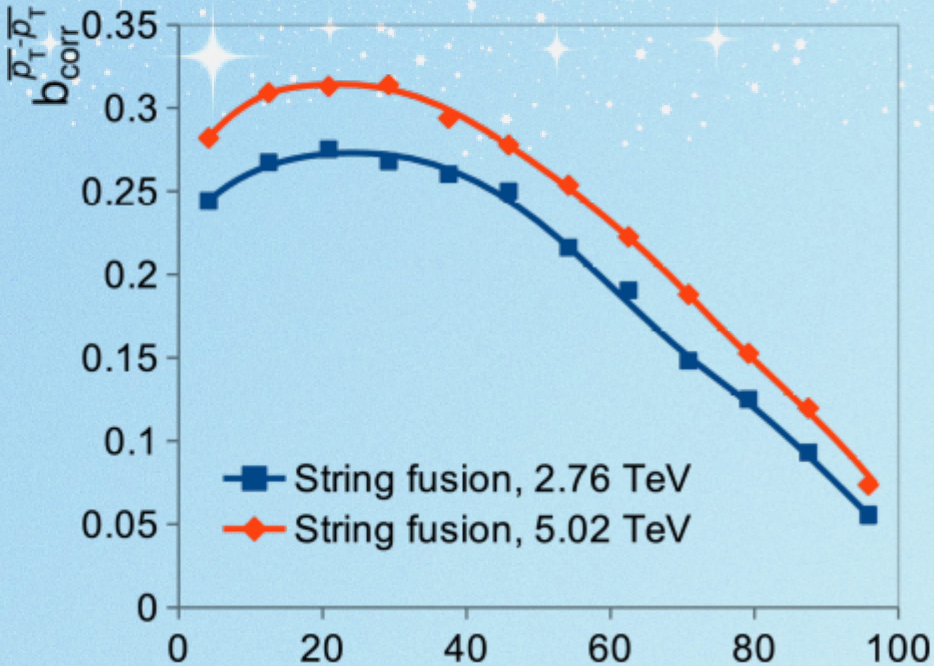
Mean pt-pt correlations in different models

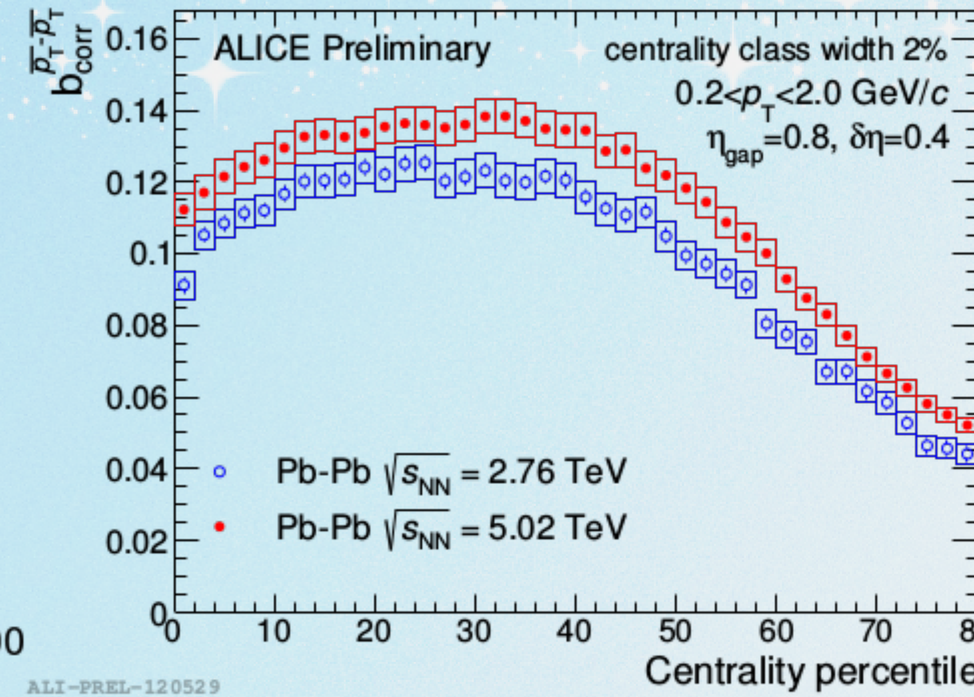
$$b = \frac{\langle F B \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2} \qquad B, F, \rightarrow p_t = \frac{1}{n} \sum_{i=1}^{n} p_{ti}$$



Vladimir Kovalenko, Vladimir Vechernin, J. Phys. Conf. Ser. 798, 012053 (2017), arXiv:1611.07274 [nucl-th]

Energy dependence of pt-pt correlation coefficient

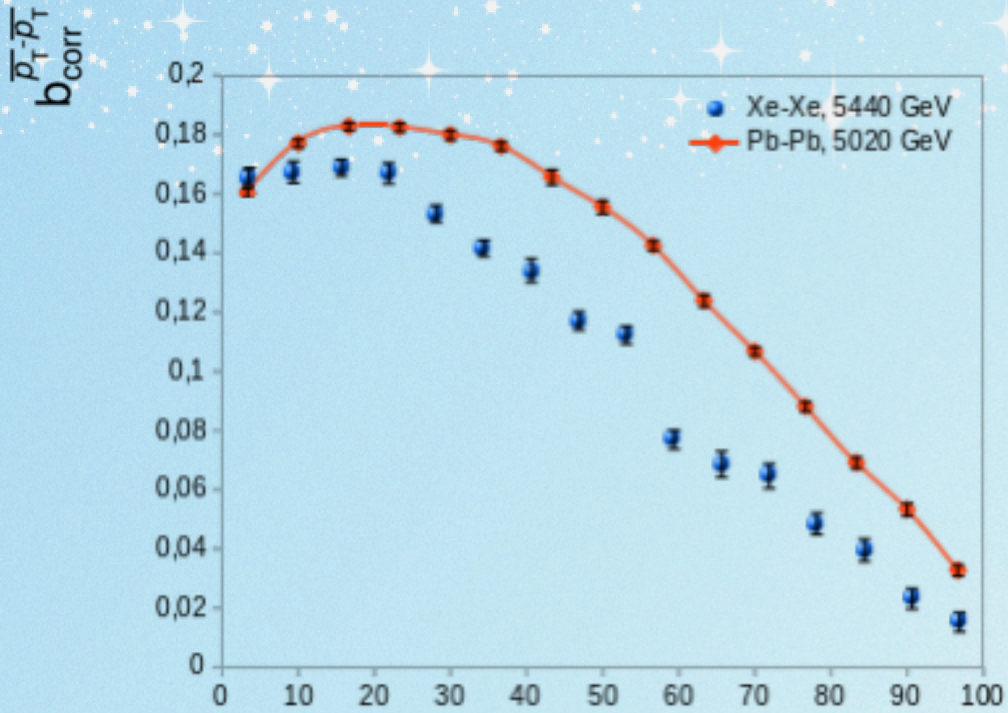




- String fusion model predicts the increase of $b_{pt\text{-}pt}$ from 2.76 TeV to 5.02 TeV at the level of 20%, that agrees with the experiment

Prelimenary experimental data – I.Altsybeev, “KnE Energy and Physics, pages 304-312, 2018 DOI: 10.18502/ken.v3i1.1759 arXiv:1711.04844 [nucl-ex]

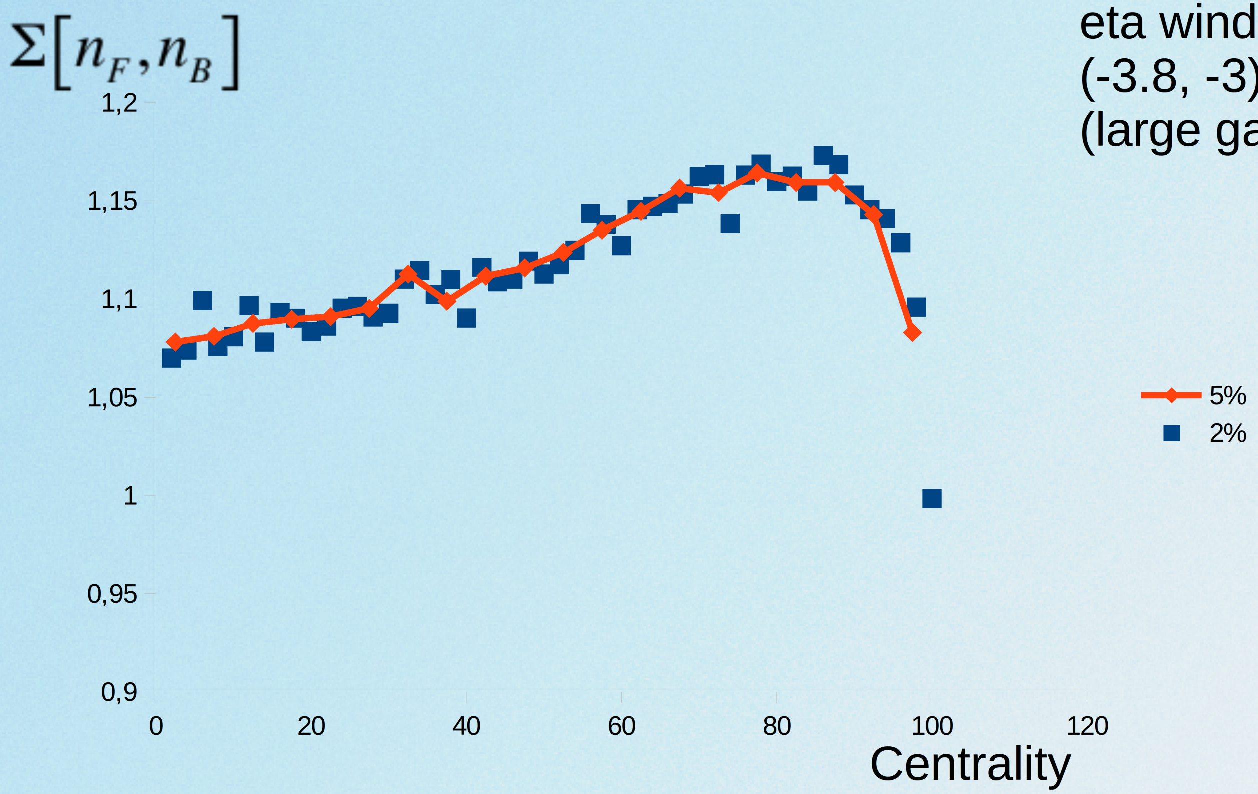
System size dependence of pt-pt correlation coefficient



- Correlation coefficients $b_{pt\text{-}pt}$ shows decrease in very central collisions only in Pb-Pb, in smaller system Xe-Xe it reaches plateau.

Long-range Strongly Intensive multiplicity fluctuations

$$\Sigma[n_F, n_B] = \frac{\langle n_B \rangle \omega[n_F] + \langle n_F \rangle \omega[n_B] - 2\left(\langle n_B n_F \rangle - \langle n_B \rangle \langle n_F \rangle\right)}{\langle n_B \rangle + \langle n_F \rangle}$$



Pb-Pb, 2.76 TeV
eta windows:
(-3.8, -3), (3, 3.8)
(large gap)

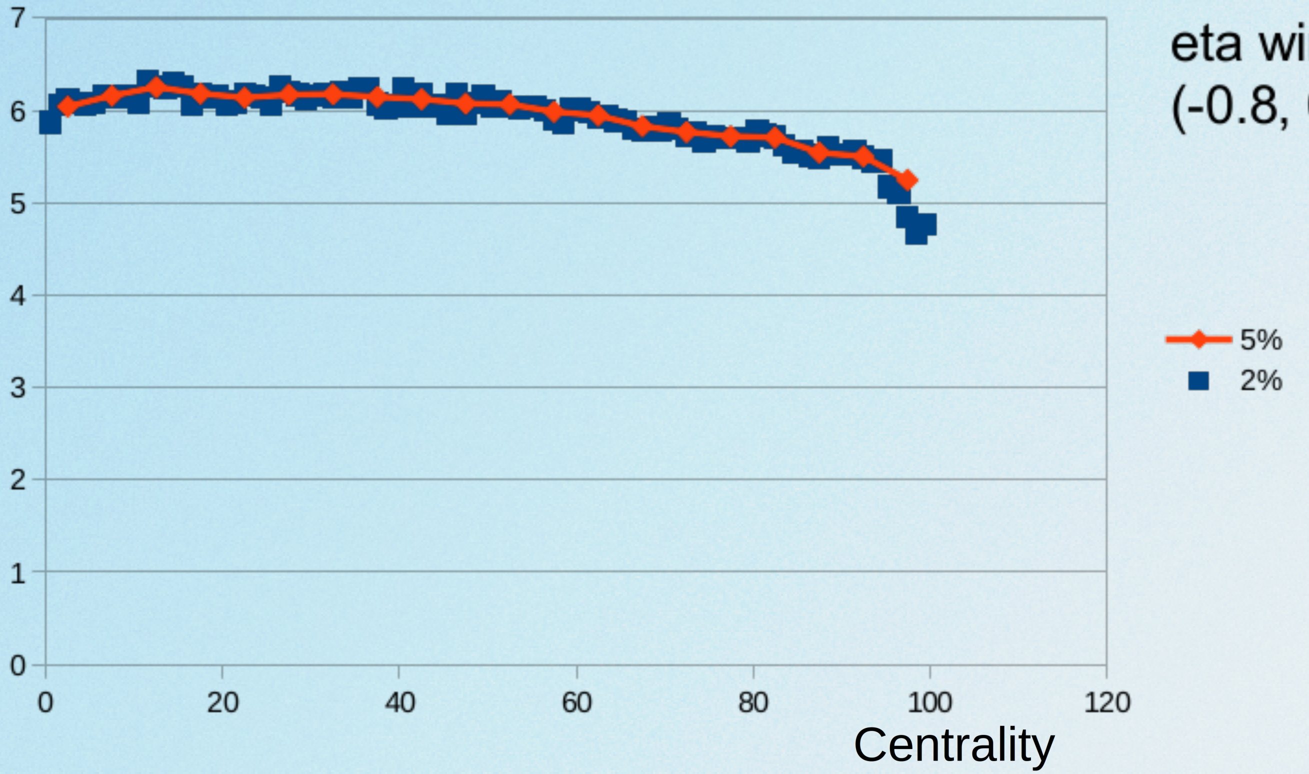
Idea of introducing such variables - M. Gorenstein, M. Gazdzicki, arXic:1101.4865 [nucl-th]

Long-range SI pt-multiplicity fluctuations

$$\Sigma[A,B] = \frac{1}{C_\Sigma}\left(\langle B\rangle\omega[A] + \langle A\rangle\omega[B] - 2(\langle AB\rangle - \langle A\rangle\langle B\rangle)\right)$$

$$A = P_T = \sum_{i=1}^{N} p_{T_i},\ B = N \quad \longrightarrow \quad C_\Delta = C_\Sigma = \langle N\rangle\omega[p_T]$$

$\Sigma[P_T, N]$

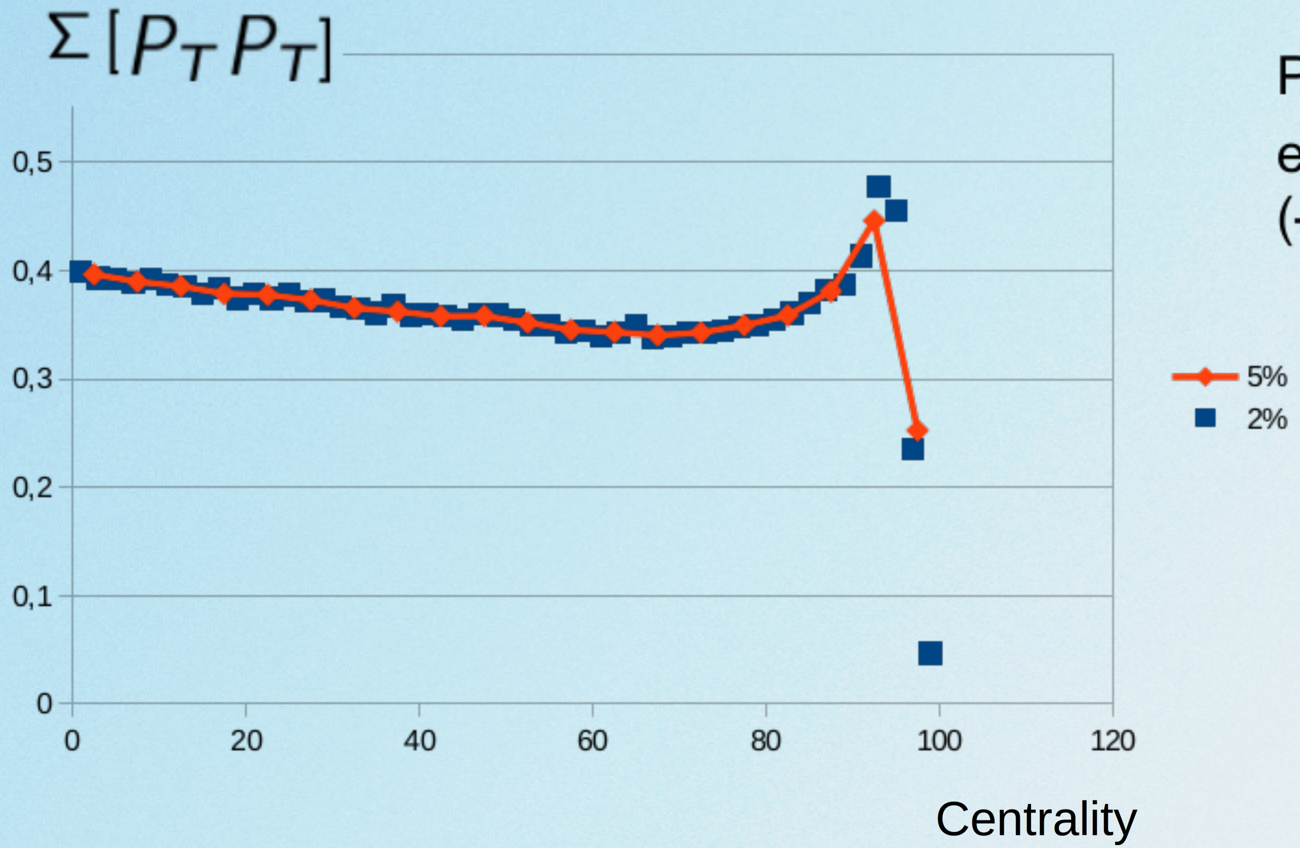


Pb-Pb, 2.76 TeV

eta window:
(-0.8, 0.8)

Long-range SI pt-pt fluctuations

$$\Sigma[A,B] = \frac{1}{C_\Sigma}\left(\langle B\rangle\omega[A] + \langle A\rangle\omega[B] - 2(\langle AB\rangle - \langle A\rangle\langle B\rangle)\right)$$



Pb-Pb, 2.76 TeV

eta window: (-0.8, 0.8)

Charge fluctuations

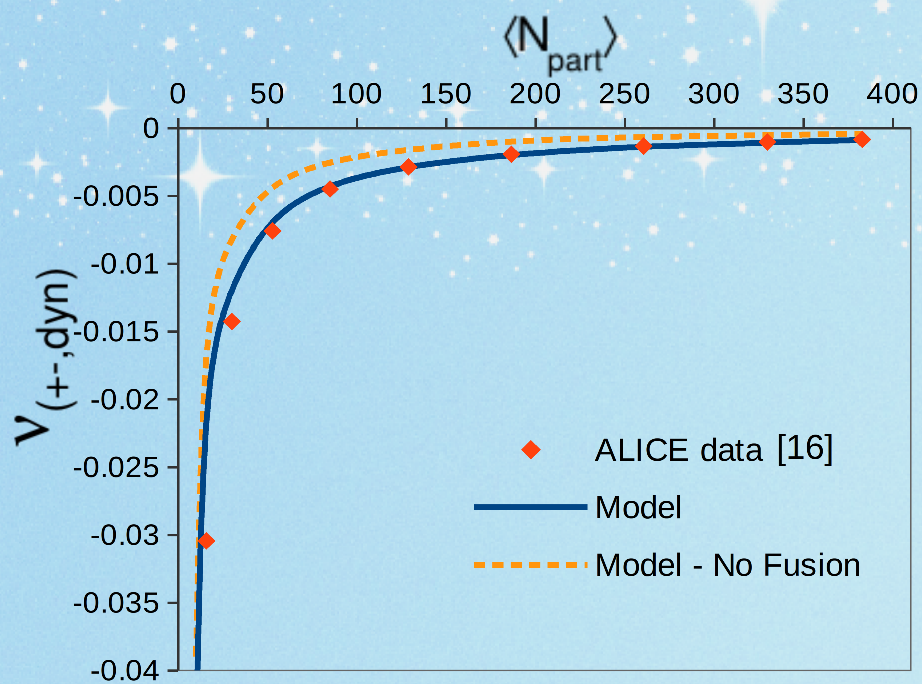
- Expressed in terms of

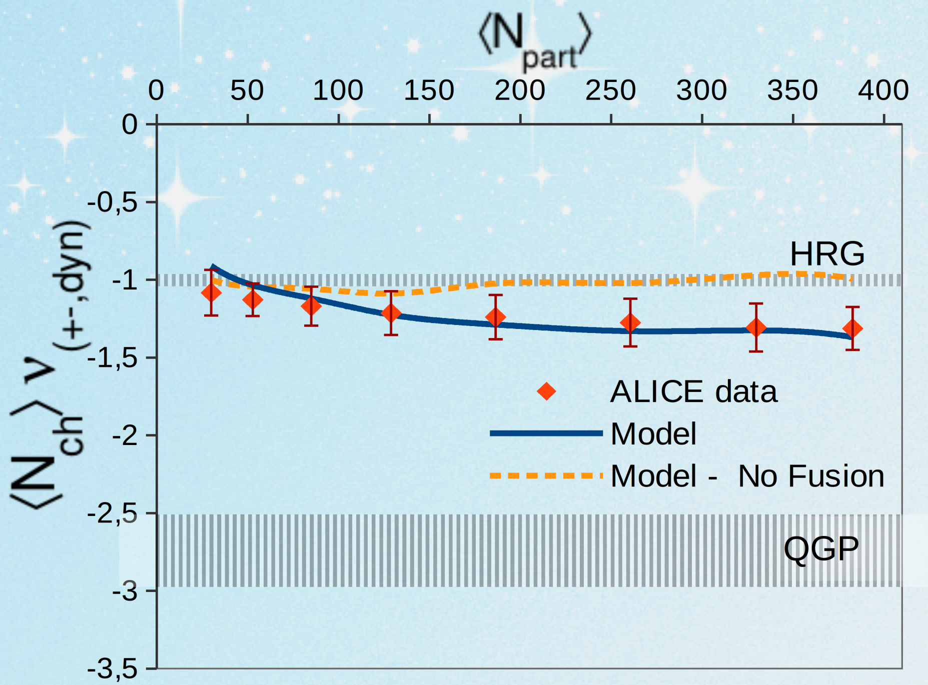
$$\nu_{\rm dyn}=\left\langle\left(\frac{N_+}{\langle N_+\rangle}-\frac{N_-}{\langle N_-\rangle}\right)^2\right\rangle-\left(\frac{1}{\langle N_+\rangle}+\frac{1}{\langle N_-\rangle}\right)$$

- Can be related with degrees of freedom of medium

- $\langle N_{ch}\rangle\,\nu_{(+-,dyn)}$ = -1 for hadron gas
- $\langle N_{ch}\rangle\,\nu_{(+-,dyn)}$ = -2.5 ... -3 for QGP

Charge fluctuations



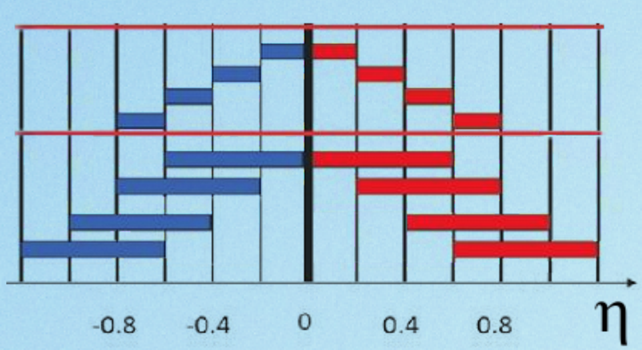


- MC model with string fusion successfully describes the centrality dependence of dynamical net-charge fluctuation.
- Scaling variable $\langle N_{ch} \rangle \nu_{(+-,dyn)}$ decreases with centrality towards the level of QGP estimation (which is in agreement with experiment)

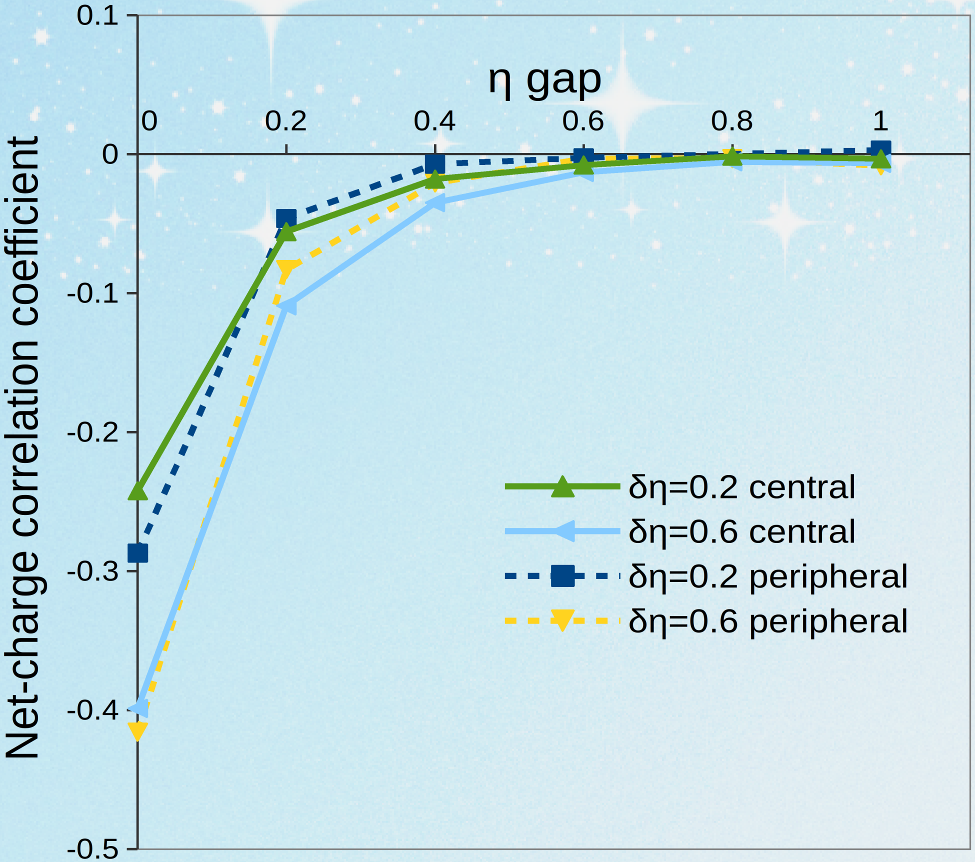
In case of no fusion, it remains constant at the level of HRG

Net-charge correlations

$$b = \frac{\langle Q_F Q_B \rangle - \langle Q_F \rangle \langle Q_B \rangle}{\langle {Q_F}^2 \rangle - \langle Q_F \rangle^2}$$



* In small window can be related to balance function (thanks to I. Altybeev for pointing it out)



- Absolute value of net-charge forward-backward correlation coefficient decreases with the gap.
- Weak depedence on the cenrality
- A hint of a transition from negative to positive at large rapidity gap – to be checked at lower energies (RHIC, SPS, NICA)

Conclusions

- Centrality determination and a width of centrality class influences the value of fluctuational and correlational observables

- Strongly intensive observables and correlations between intensive observables show robust behaviour against the volume fluctuations and the centrality determination methods

- String fusion model explains non-monotonic behaviour of Pt-pt forward-backward correlations

- String fusion model explains the centrality behaviour of the net charge fluctiations in Pb-Pb collisions at LHC energy (string fusion improves the agreement with the experiment).

- The predictions for net-charge forward-backward correlation coefficient have been obtained.

- The observables proposed provide reference to the properties of the initial state of AA collisions and are useful to study both at LHC and NICA energies