Strongly intensive fluctuations in nucleus-nucleus collisions at high energy in Monte Carlo model with string fusion

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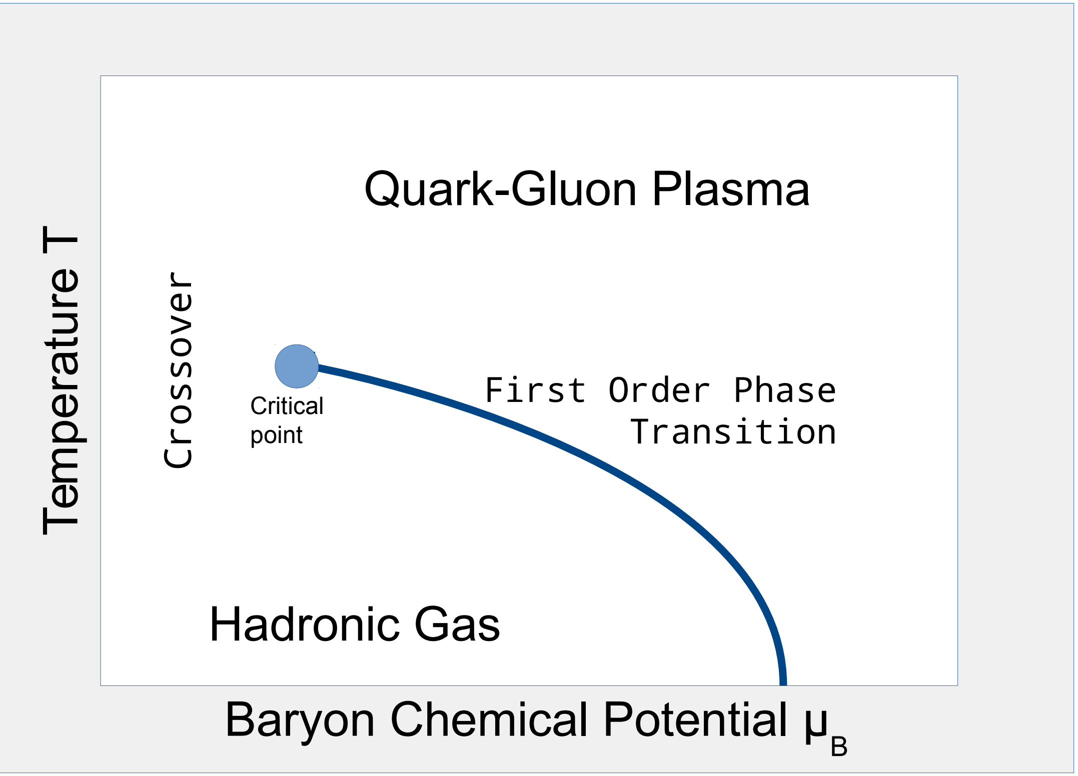
QCD phase diagram and search for critical point

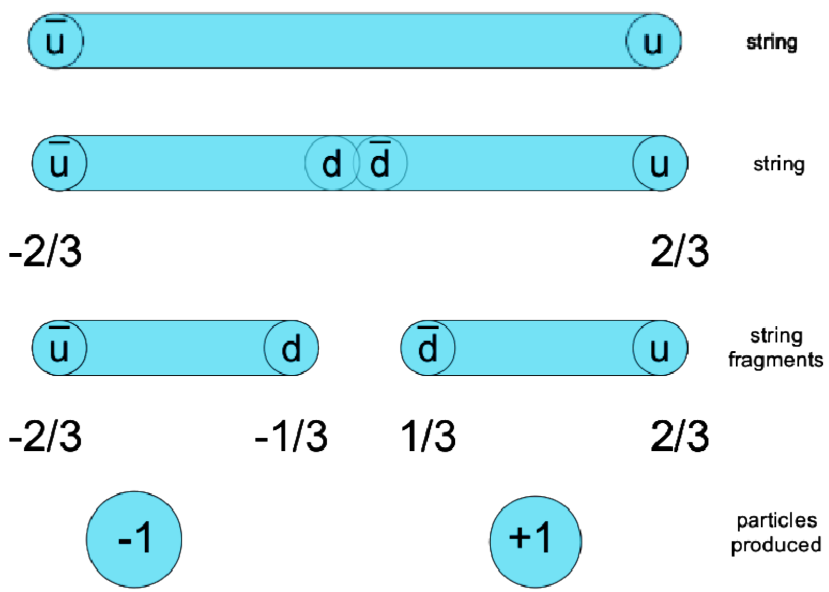


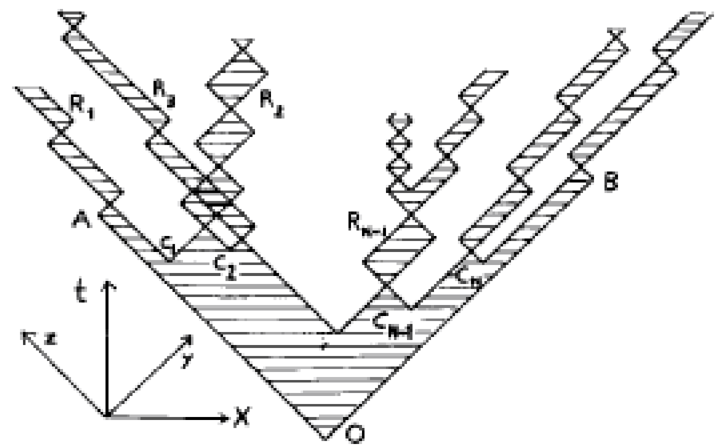
HADES, GSI	2.3 – 2.7 GeV	p+p, Au+Au, Ar+KCl, C+C
NA61, SPS, CERN	6.3 - 17.3 GeV	p+p, Be+Be, p+Pb, Ar+Ca, Xe+La, Pb+Pb, ...
CBM, FAIR, GSI	2.7 - 8.3 GeV	p, Ca, Au
RHIC BES	5 - 200 GeV	Au+Au
NICA, JINR	3 - 11 GeV	from p to Au

$$\frac{\bar{p}}{p} = \frac{e^{-(E+\mu_B)/T}}{e^{-(E-\mu_B)/T}} = e^{-(2\mu_B)/T}$$

String models

- 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

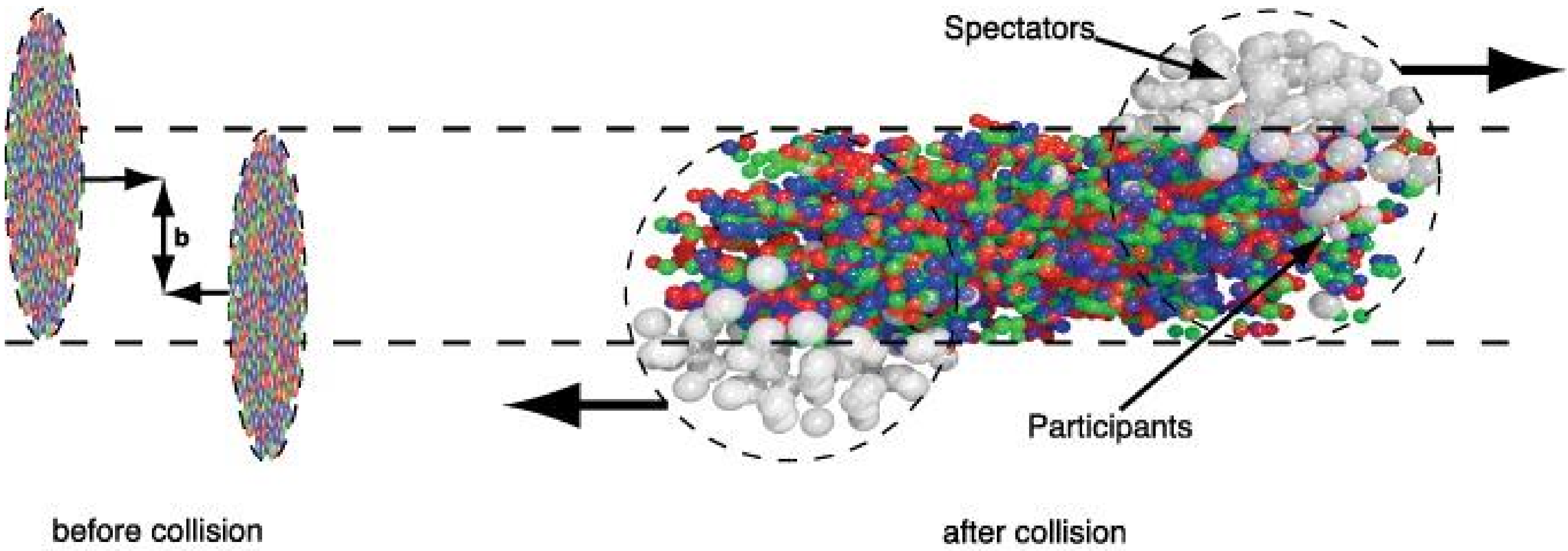




X. Artru and G. Mennessier, Nucl Phys B 70 (197
"String Model and Multiproduction",

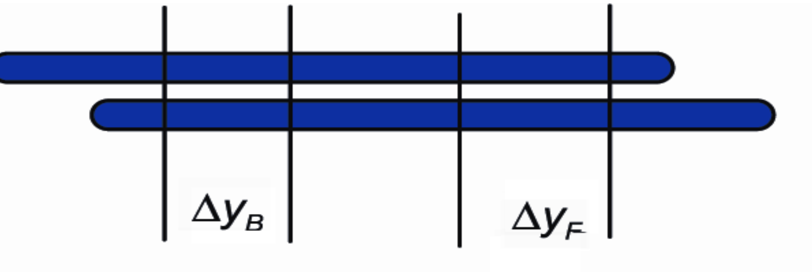
- Correlations play crucial role:
  – causality requires appearance of long-range correlations – if they exist – at the very early stages between particles detected in separated rapidity intervals

Centrality



- 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}

Long-range correlations and fluctuations



Select 2 variables in windows (or in one window):

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

Several types of correlations and fluctuations:

n-n , pt-n, pt-pt

long-range/one window, etc

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

scaled variance $\omega = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle}$

String fusion

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

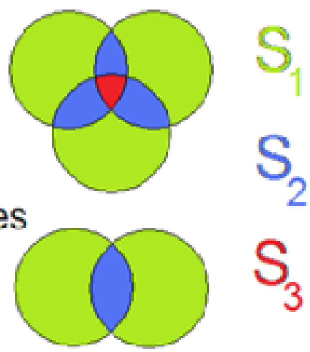
$$\langle Q^2(n) \rangle = nQ^2(1)$$

overlaps

SFM

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

S_k – area covered k-times



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

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

String fusion mechanism predicts:

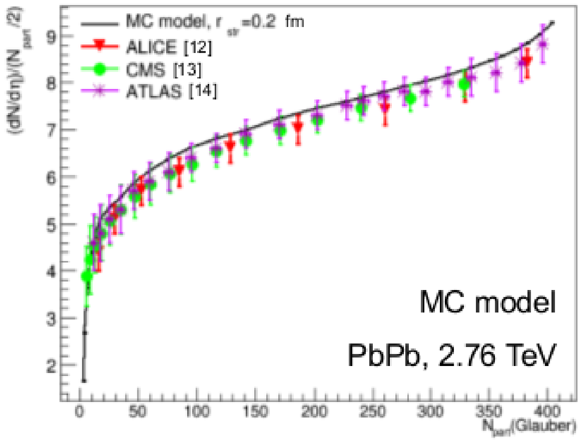
– decrease of multiplicity
– increase of p_T
– growth of p_T with multiplicit in pp, pA and AA collisions
– growth of strange particle yields

– results are in a good agreement with the experiment

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)

Monte-Carlo model

- <u>Partonic</u> 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 <u>colour strings</u>, stretched between projectile and target partons

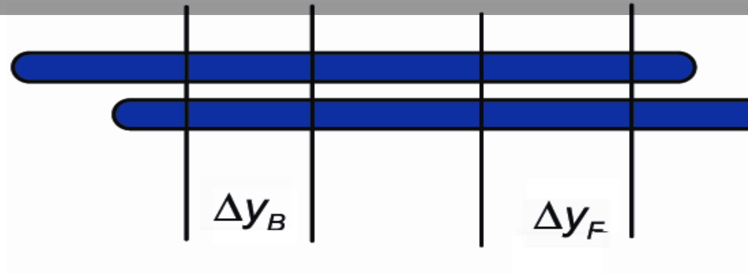
- The interaction of strings is realized in the accordance with the **string fusion** model
- Multiplicity from one string is distributed according to Poisson

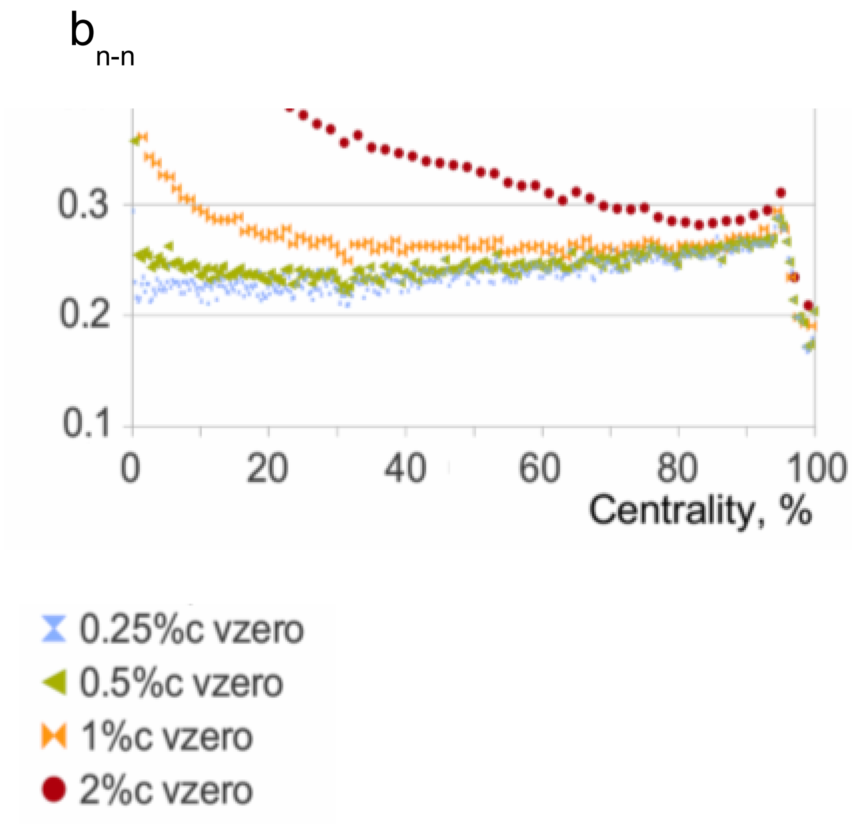
V. N. Kovalenko.. Phys. Atom. Nucl. 76, 1189 (2013), arXiv:1211.6209 [hep-ph]
V. Kovalenko, V. Vechernin., PoS (Baldin ISHEPP XXI) 077, arXiv:1212.2590 [nucl-th], 2012

Long-range correlations and fluctuations

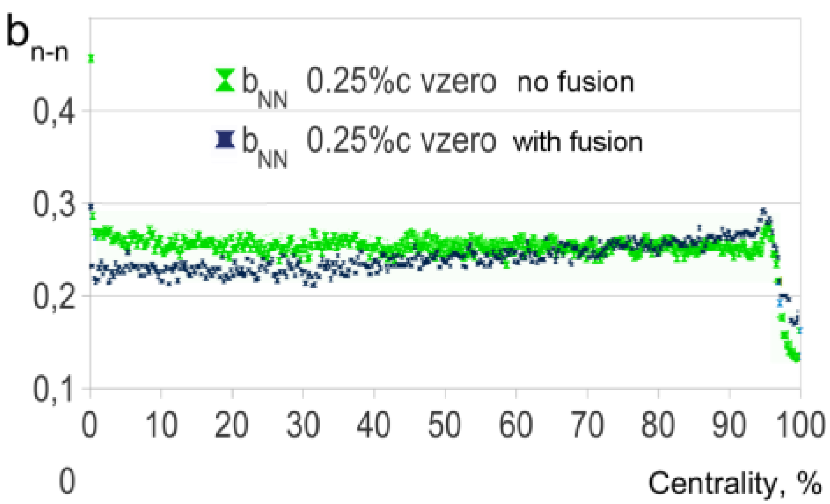
n-n correlation coefficient

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





Pb-Pb, 2.76 TeV



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

Long-range correlations and fluctuations

pt-n correlation coefficient

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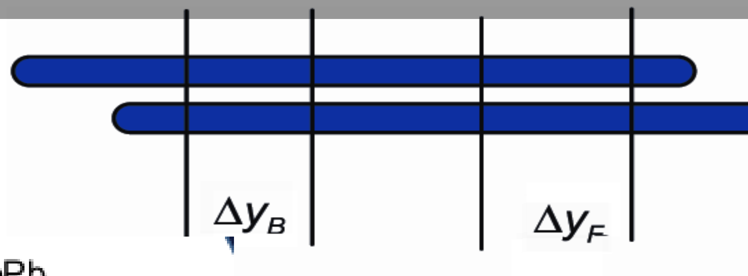
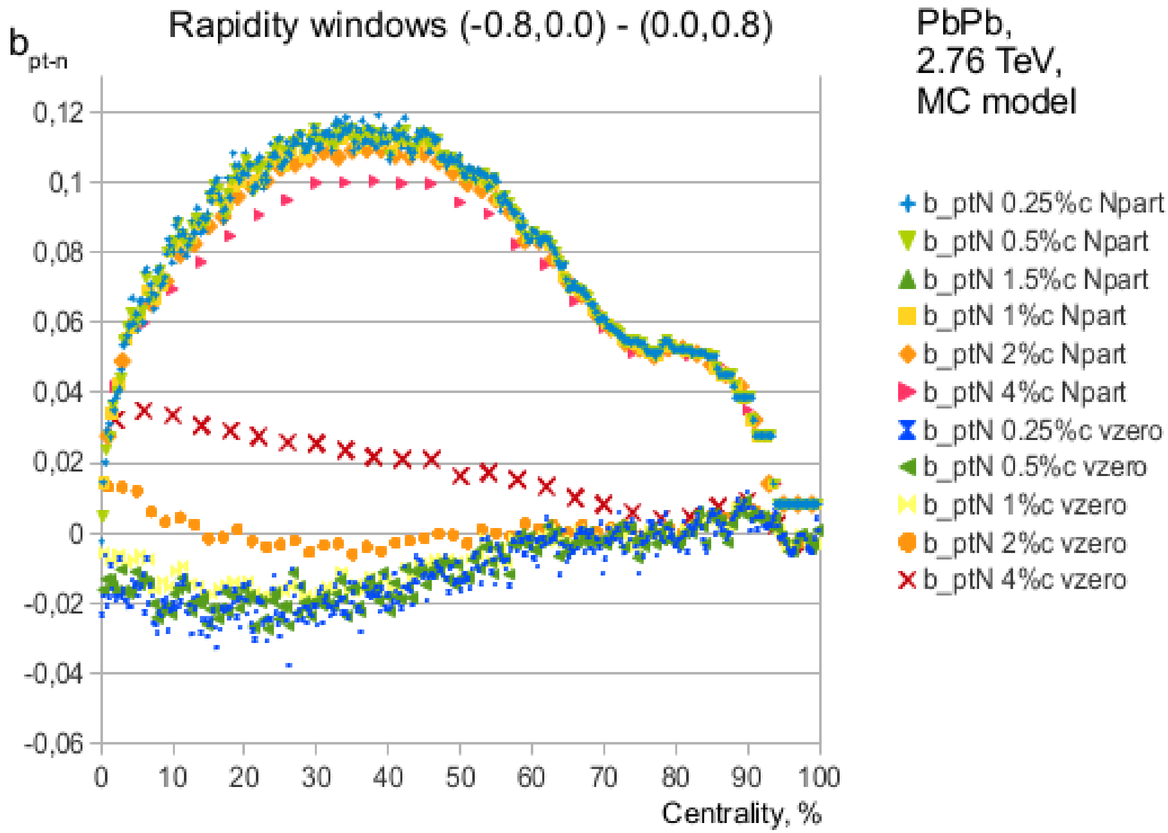




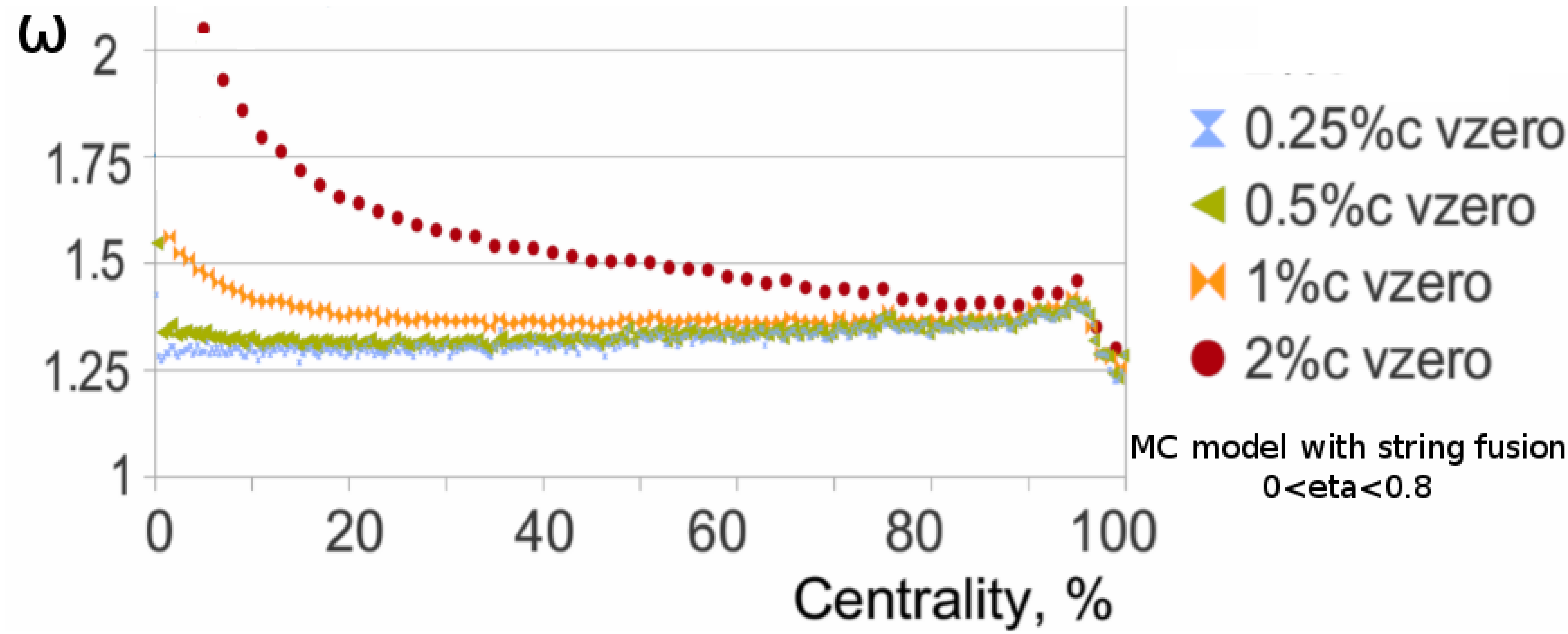
Pb-Pb, 2.76 TeV

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

Long-range correlations and fluctuations

scaled variance $$\omega = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle}$$

Pb-Pb, 2.76 TeV



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mean pt-pt correlations

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

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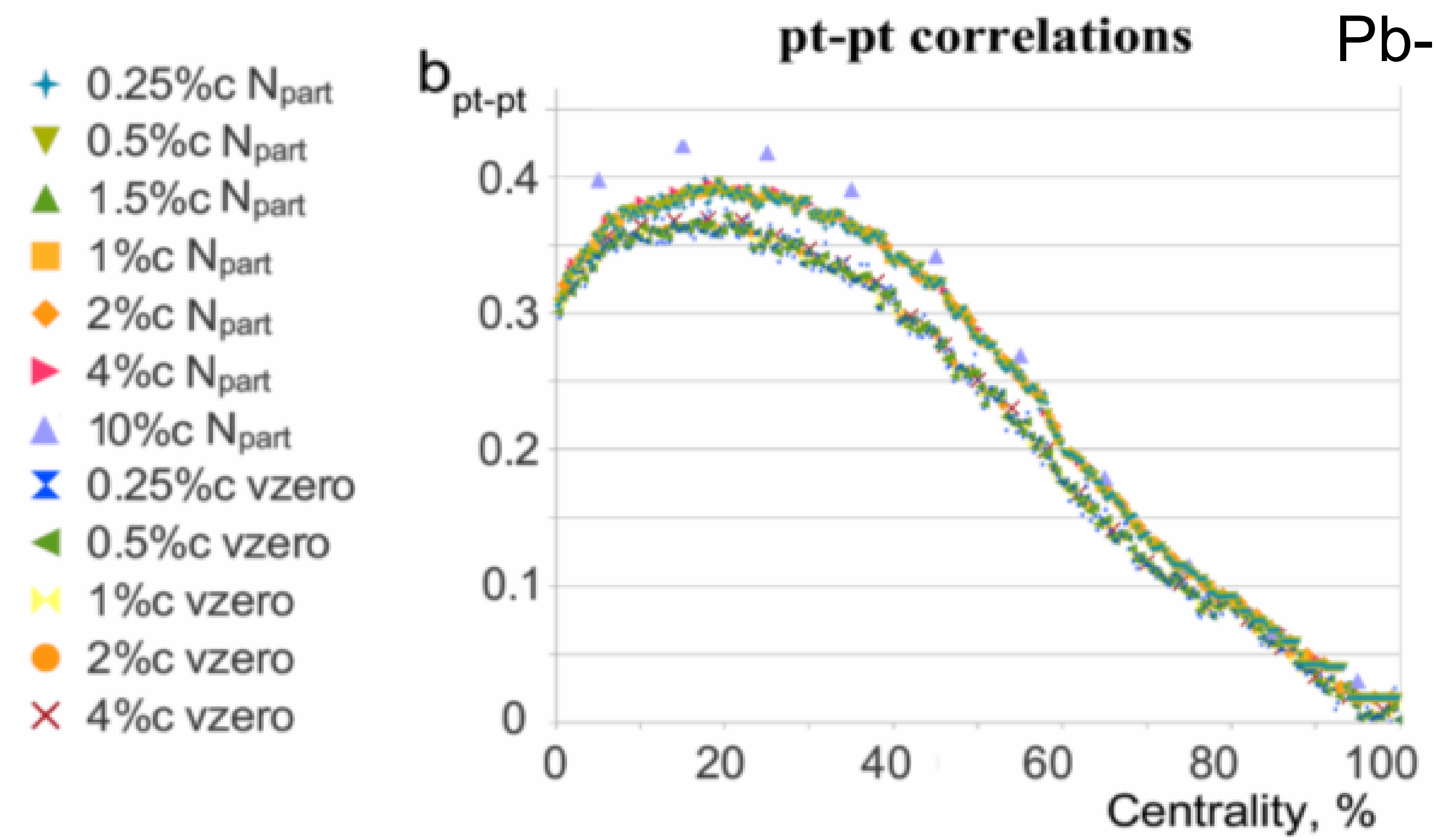

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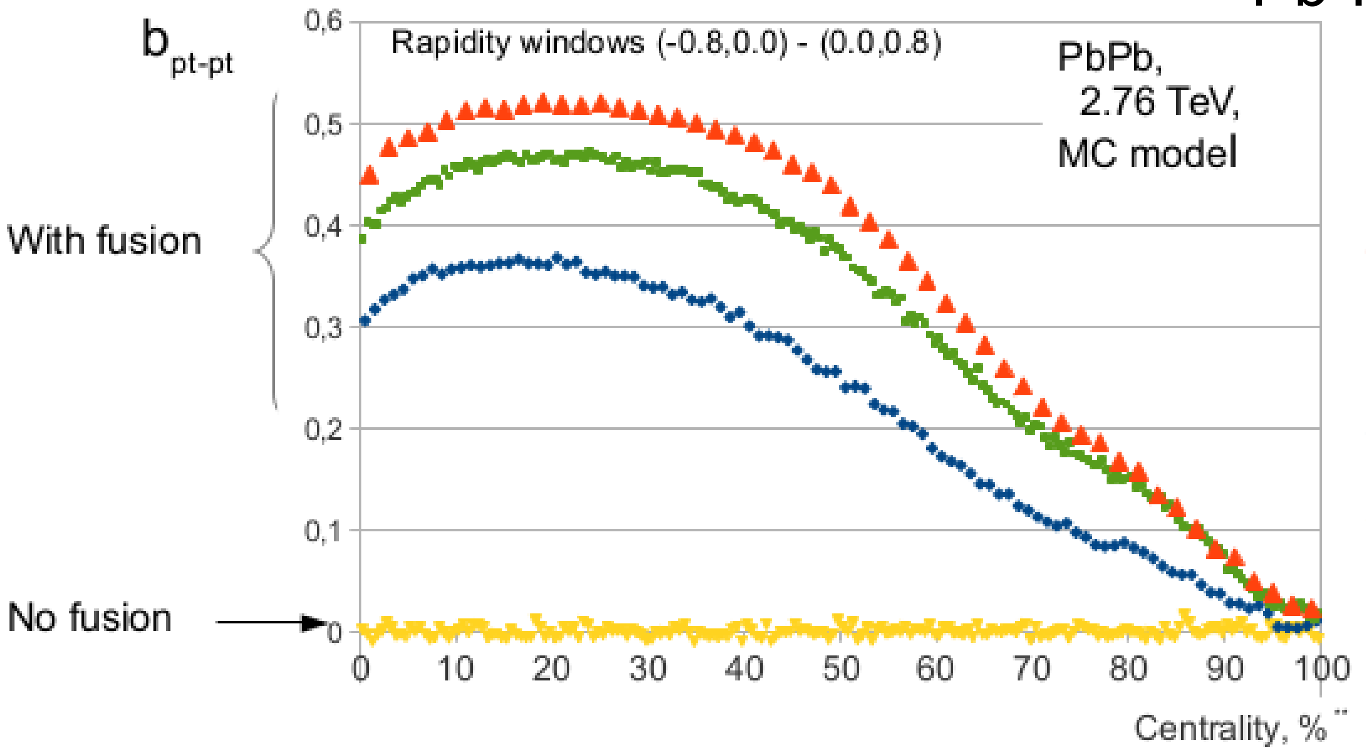


V. Kovalenko, V. Vechernin. EPJ Web of Conferences 66, 04015 (2014), arXiv:1308.6618 [nucl-th]

Strongly intensive variables

Let A and B be two *extensive* quantities. Combining $\langle A\rangle$, $\langle A^2\rangle$, $\langle B\rangle$, $\langle B^2\rangle$, $\langle AB\rangle$ one can get:

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

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

M. Gorenstein, M. Gazdzicki, arXiv:1101.4865 [nucl-th]

Independent particle model.

In IPM we have for A and B for an event with n particles:

$$A = \alpha_1 + \cdots \alpha_n$$

$$B = \beta_1 + \cdots \beta_n$$

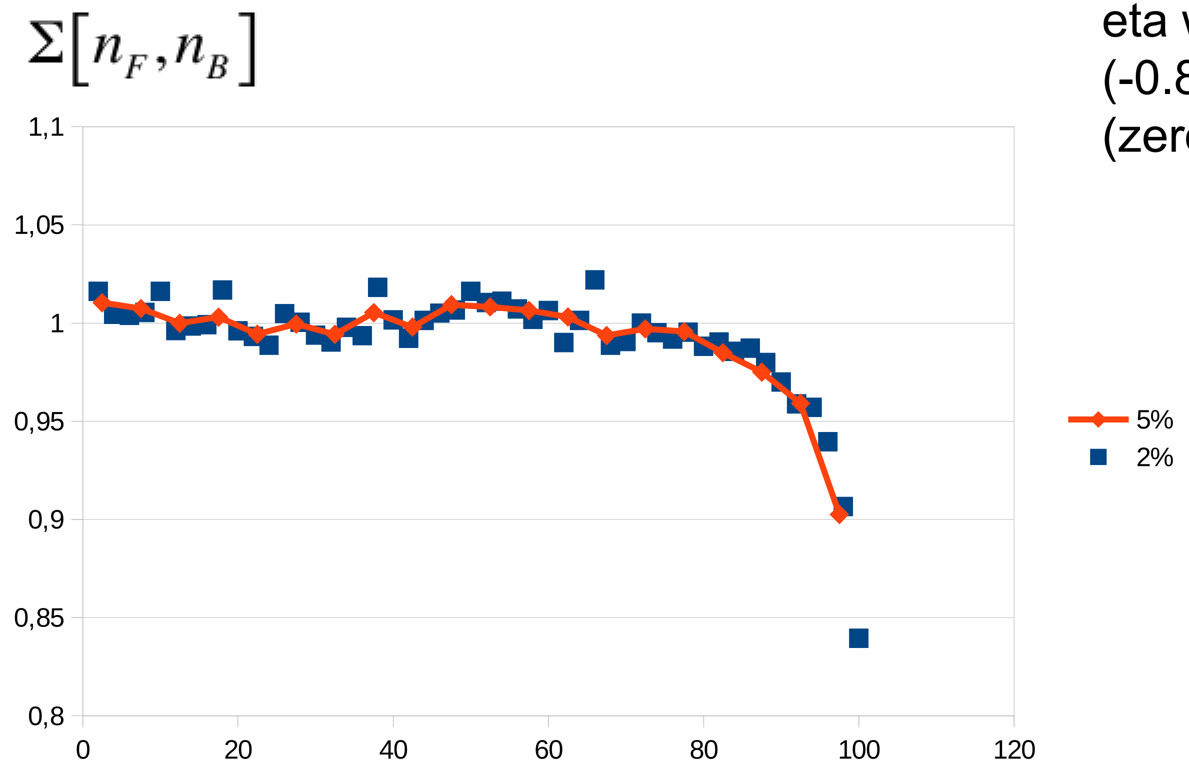
where for α_i and β_i we may introduce moments: $\overline{\alpha}$, $\overline{\alpha^2}$, $\overline{\beta}$, $\overline{\beta^2}$, $\overline{\alpha\beta}$
Particles are "independent" and "identical":

$$P(\alpha_1,\beta_1,\cdots\alpha_n,\beta_n) = P_{mult}(n) * P_{part}(\alpha_1,\beta_1) * \cdots * P_{part}(\alpha_n,\beta_n)$$

Long-range SI multiplicity fluctuations

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

Pb-Pb, 2.76 TeV
eta windows:
(-0.8, 0), (0, 0.8)
(zero gap)



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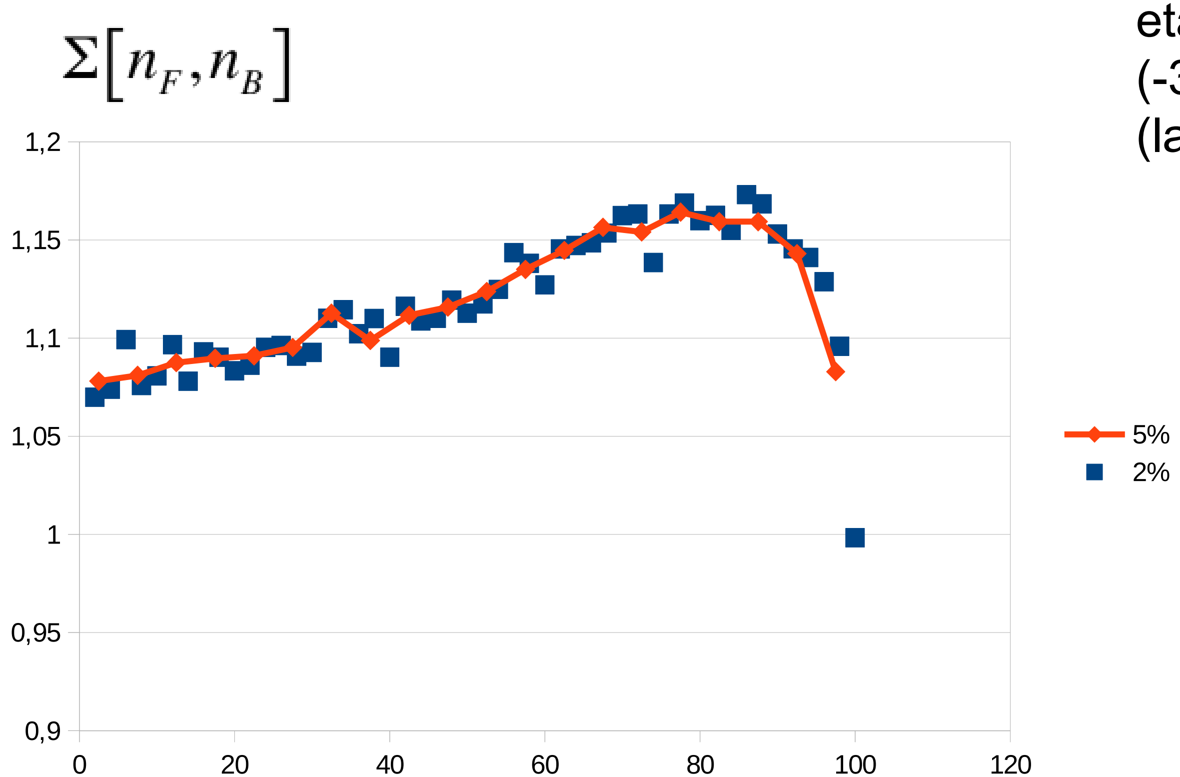
Pb-Pb, 2.76 TeV
eta windows:
(-3.8, -3), (3, 3.8)
(large gap)

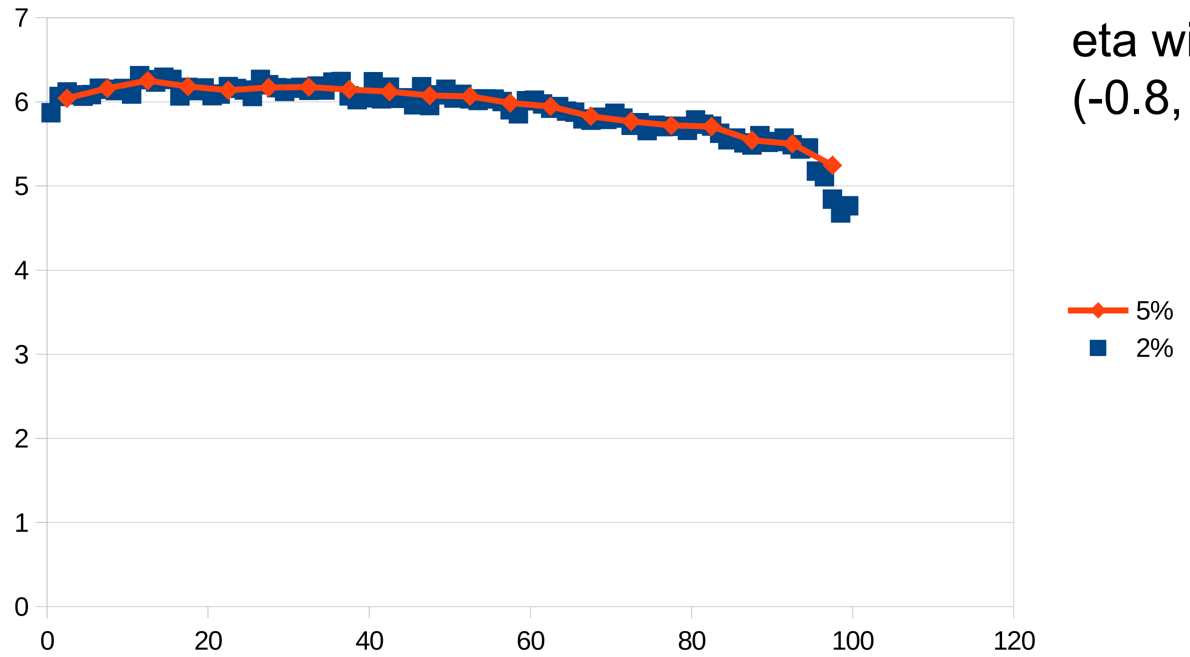


SI Pt-multiplicity fluctuations

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

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

$$\Sigma\left[P_T\ N\right]$$



Pb-Pb, 2.76 TeV

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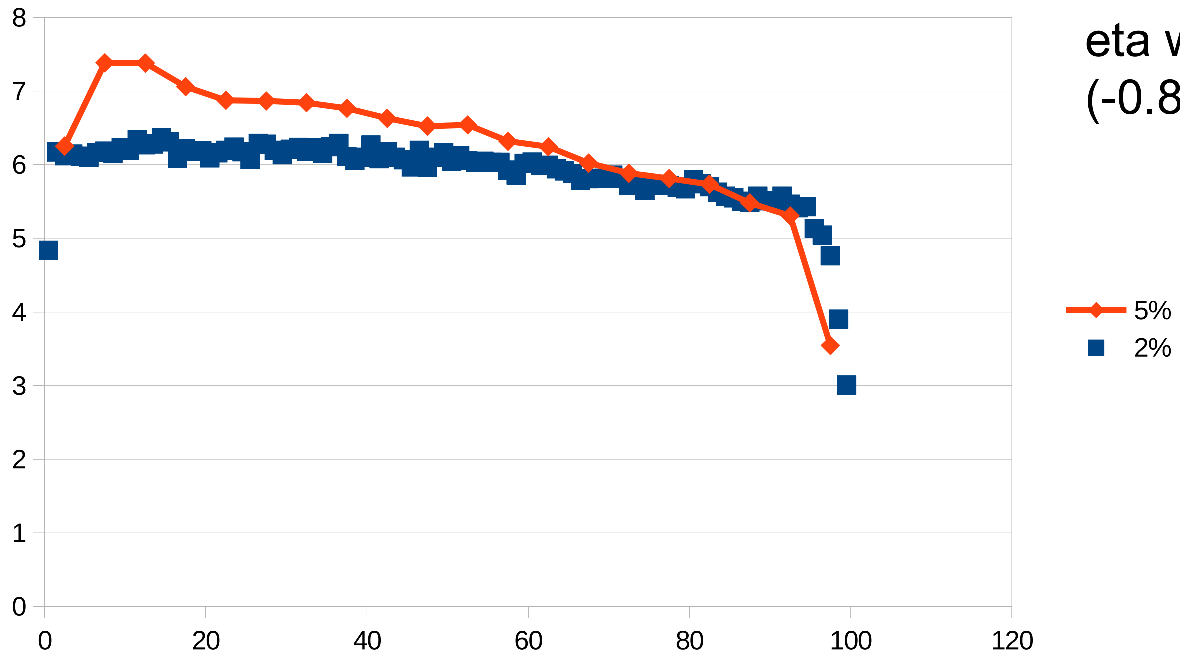
$\Delta[P_T\ N]$



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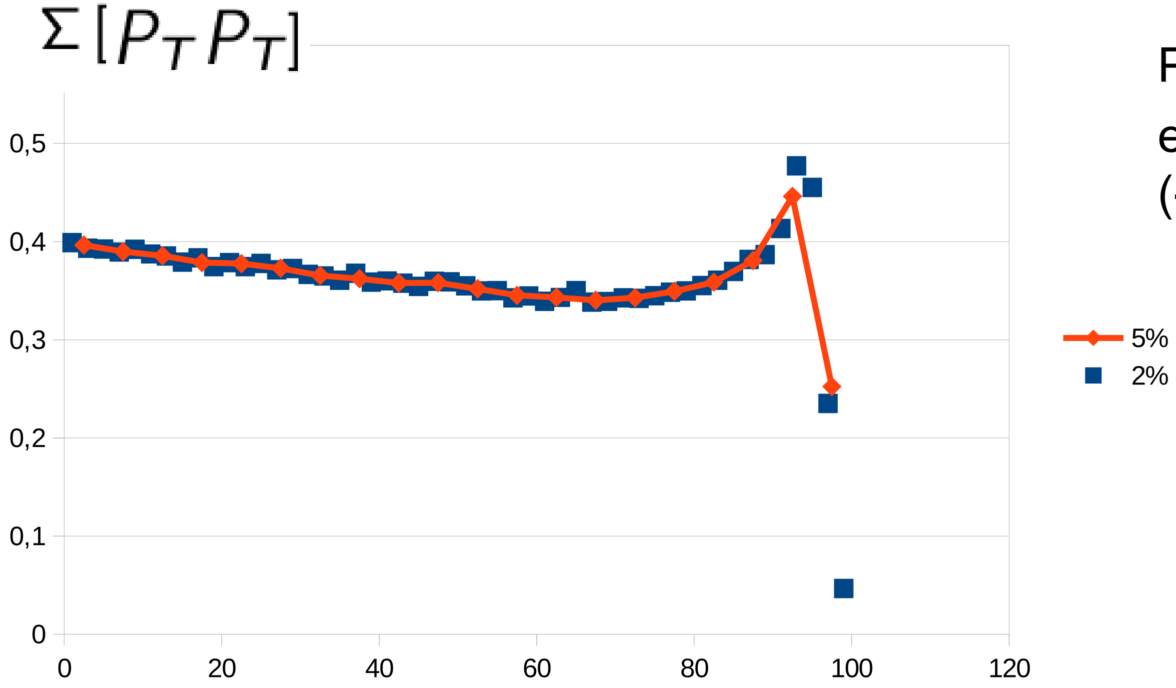


Pb-Pb, 2.76 TeV

eta window: (-0.8, 0.8)

Conclusions and outlook

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

- Introducing of intensive variables helps to overcome the dependence on centrality determination issues

- With SI values, n-n and pt-n long-range correlation variables obtained, which don't depend on the centrality class width; another pt-pt long-range correlational observable introduced

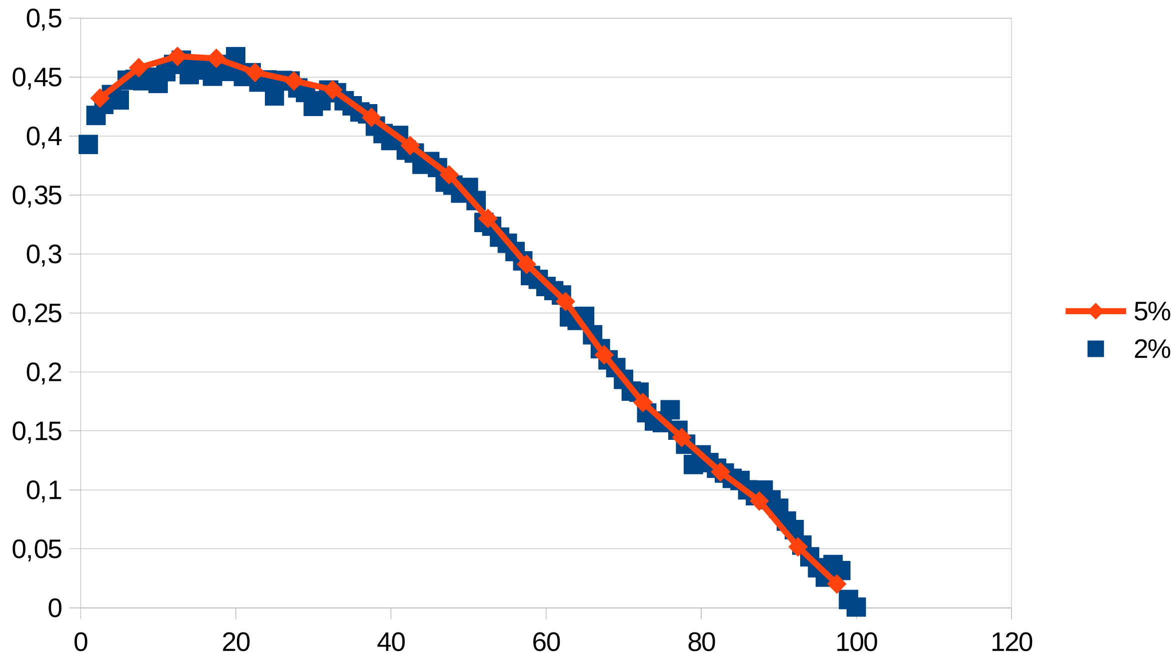
- The set of the observables could be extended using particle species, charge and azimuthal angle – large area for strongly intensive quantities studies

Thank you!

Backup

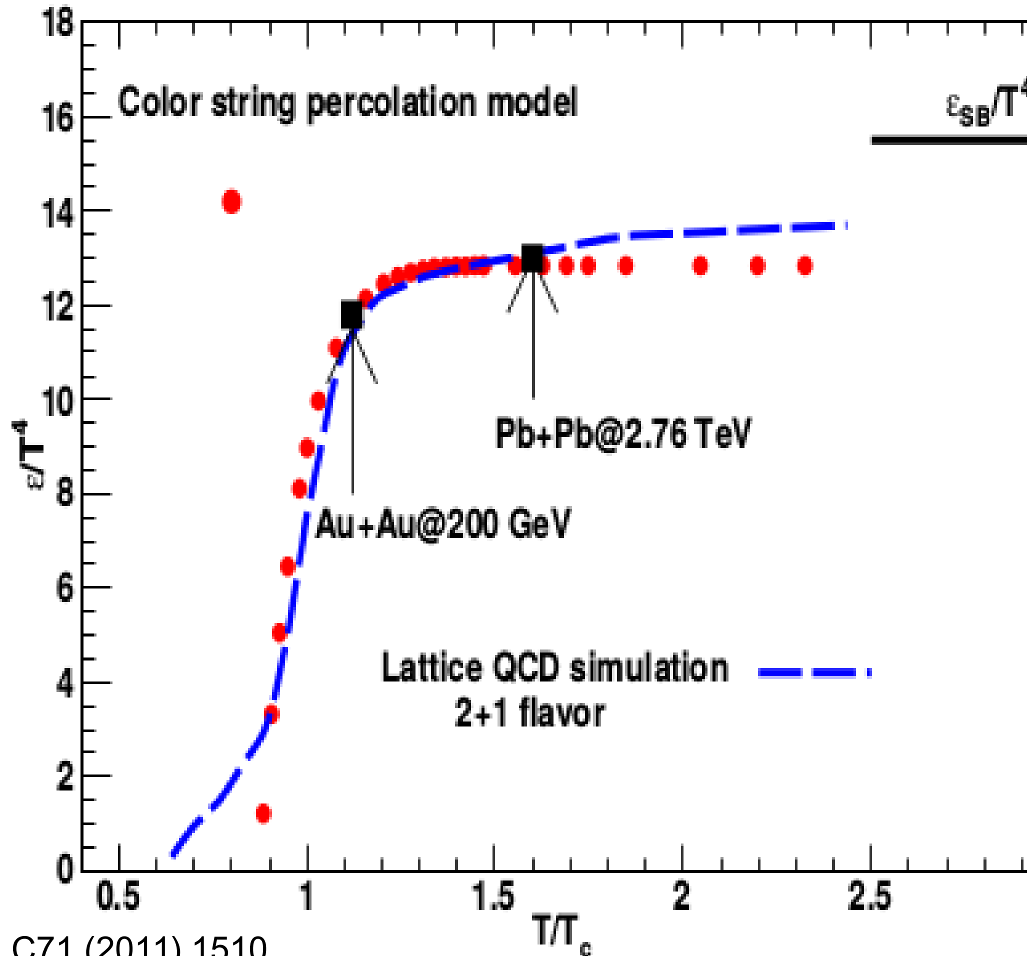
Mean pt-pt correlations

$$b = \frac{\langle pt_F\, pt_B \rangle - \langle pt_F \rangle \langle pt_B \rangle}{\langle pt_F^2 \rangle - \langle pt_F \rangle^2}$$



String fusion

In the recent papers
it was shown that the equation of state of QGP (ε/T^4 as a function of T) <u>at zero chemical potential</u>, obtained in the colour string percolation model is in a good agreement with the lattice results.



R.P. Scharenberg, B.K. Srivastava, A.S. Hirsch Eur.Phys.J. C71 (2011) 1510
J. Dias de Deus , C. Pajares, Phys.Lett. B642 (2006) 455-458
Brijesh K Srivastava, EP J Web of Conferences 70, 00032 (2014)

Mean pt-pt correlations

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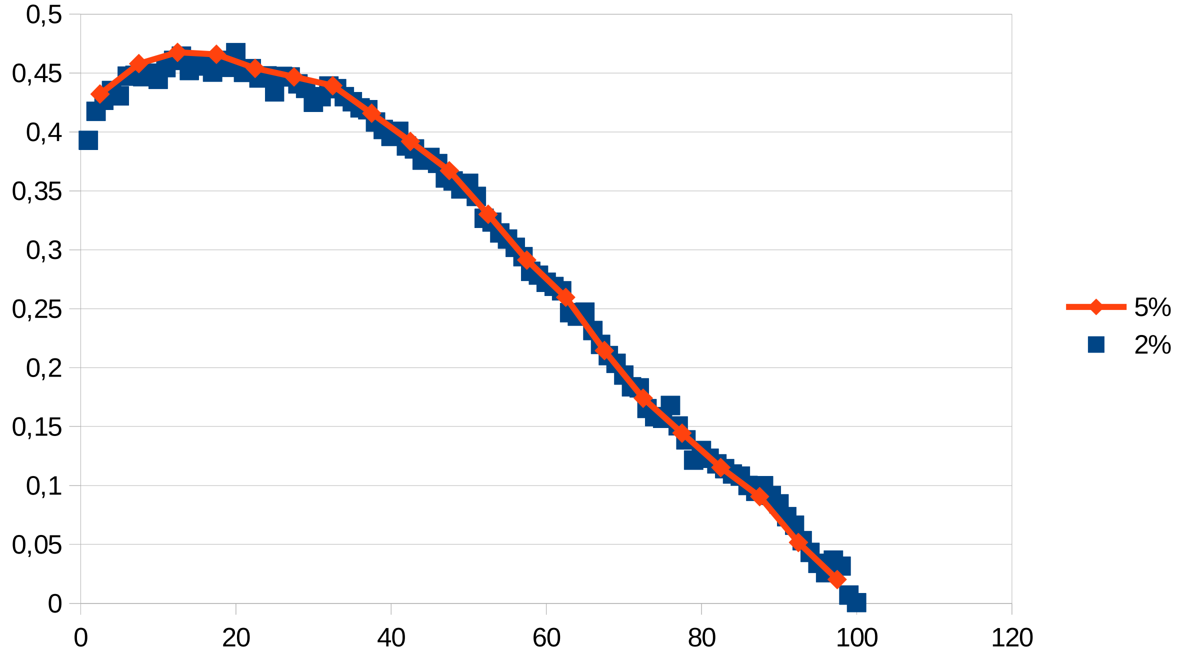

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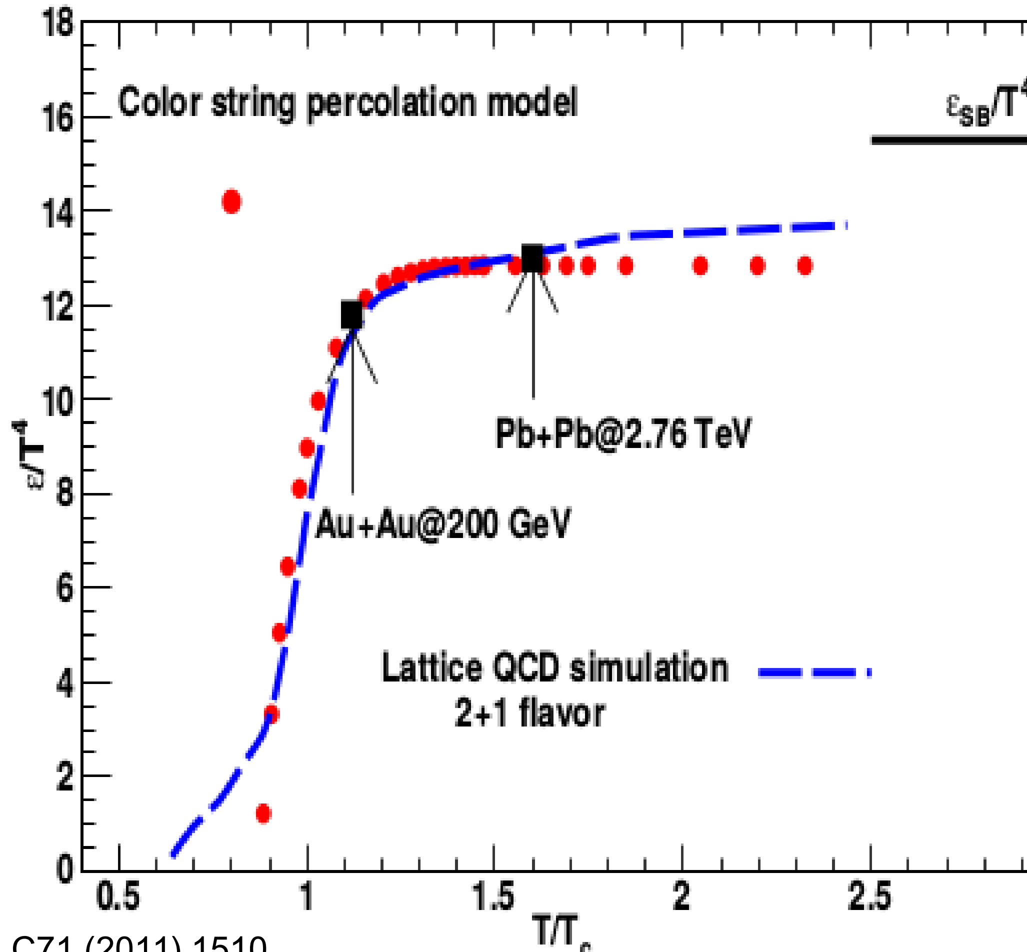

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