Constraints on string percolation model from anomalous centality evolution data in Au-Au collisions at sqrt(s)=62 and 200 GeV

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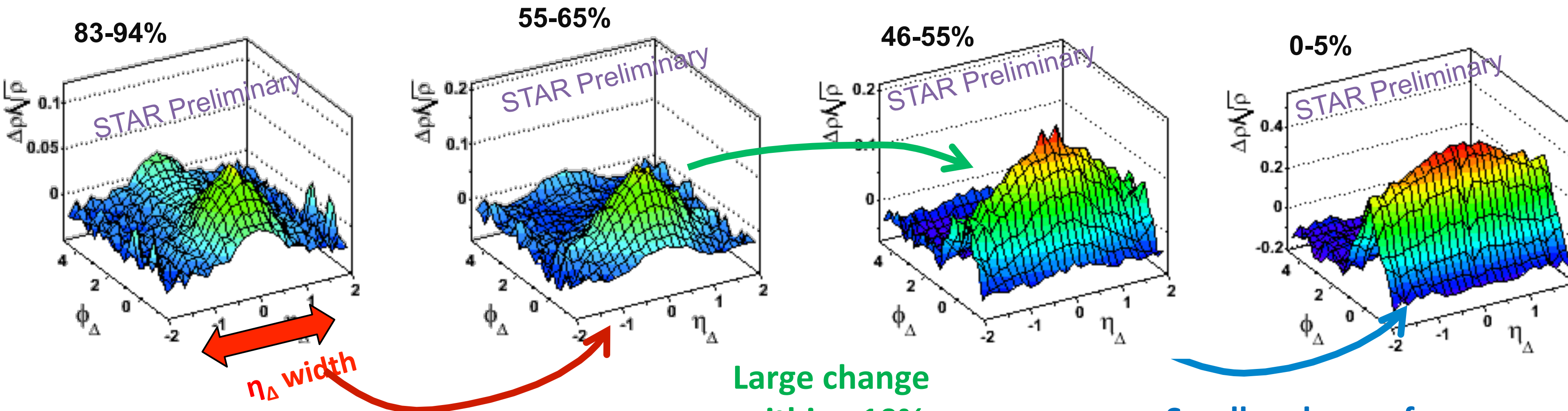
Layout

- Motivation
- Percolation of quark-gluon strings
- Toy model

New phenomena in AA collisions observed by STAR [1]

Variation of low-p_T "ridge" with centrality (Npart).

(pt> 0.15 GeV/c)



Shape changes little from peripheral to the transition

Large change within ~10% centrality

Smaller change from transition to most central

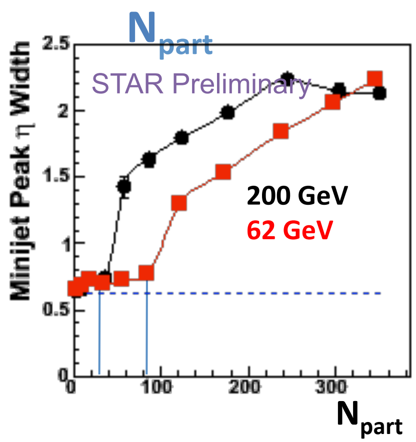
Low-p_T manifestation of the "ridge"

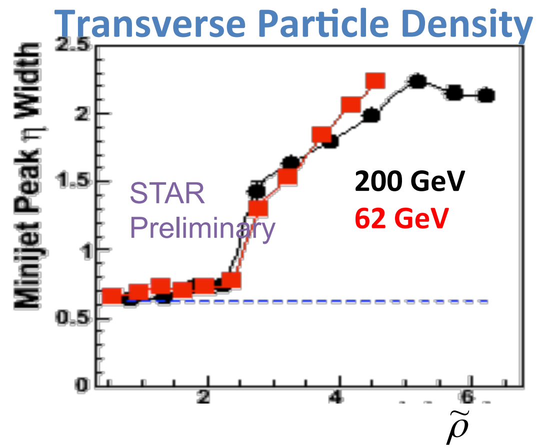
The data showed a <u>sharp transition</u> at some definite energy-dependent centrality: **growing of peak amplitude** and **stretching of width**.

[1] Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. **M. Daugherity(QM2008), J.Phys.G35:104090,2008**

Variation of low-p_T “ridge” with centrality (Npart).

A sudden increase of the **peak amplitude** and **η width** of ***the near-side low p_t ridge*** were found at an *energy-dependent* centrality point ***marked by the definite number*** of participating nucleons **Npart**. **(M. Daugherity(QM2008), J.Phys.G35:104090,2008)**





$$\tilde{\rho} = \frac{3}{2}\frac{dN_{ch}}{d\eta}/S$$

We estimate:
For 62 GeV
“Critical value” N_{part}≈90

For 200 GeV
“Critical value” N_{part}≈40

$$\tilde{\rho}_{crit} = 2{,}6 \pm 0{,}2\, fm^{-2}$$

Same-side Gaussian peak width. Points show eleven centrality bins for each energy (84-93%, 74-84%, 65-74%, 55-65%, 46-55%, 37-46%, 28-37%, 19-28%, 9-19%, 5-9%, and 0-5%) transformed to tranvserse density.

Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. M. Daugherity. QM2008, J.Phys.G35:104090,2008

Hypothesis:

- The onset of phenomena of the near-side low p_T ridge in AA collisions is relevant to ***the string percolation phase transition*** that happens at some definite ***("critical")*** number of participating nucleons Npart.
- As a result of ***interaction between strings*** the new kind of particle-emitting sources appear, the phenomenon could be characterized by the long-range correlations in the event-by-event studies

Concept *of interacting chromoelectric tubes - 1988*

Long-range azimuthal correlations in multiple-production processes at high energies

V. A. Abramovskiĭ, É. V. Gedalin, E. G. Gurvich, and O. V. Kancheli
Institute of Physics, Academy of Sciences of the Georgian SSR

(Submitted 18 January 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 6, 281–283 (25 March 1988)

The interaction between chromoelectric tubes formed in high-energy hadron reactions leads to an azimuthal asymmetry in the distribution of secondary particles.

1. In a currently popular picture of hadron reactions, the final multiparticle state is formed from ruptures in a system of chromoelectric tubes which "stretch out" as the color states that arise in the collision fly off. This picture is naturally blended in with the Regge and dual-topology models, in which a pomeron and branchings are described approximately by a gluon exchange followed by the formation of several quark tubes. The ruptures of these tubes occur in a quasi-independent way.[1] The quark tubes have a finite radius $r_0 \sim 1$ fm, and the transverse distances between them are also on the order of r_0. They accordingly overlap and may interact. The exact form of this interaction is not known, but an examination of the tubes on a lattice shows that in the $SU(3_C)$ gauge theory tubes in which the chromoelectric fields are in the same direction attract each other in the transverse direction, while tubes with oppositely directed chromoelectric fields repel each other [in $SU(N_C)$, the energy of this interaction is $\sim N_C^{-1}$; Ref. 2].

Couple of formulas from this 1988 paper by Abramovsky et al.:

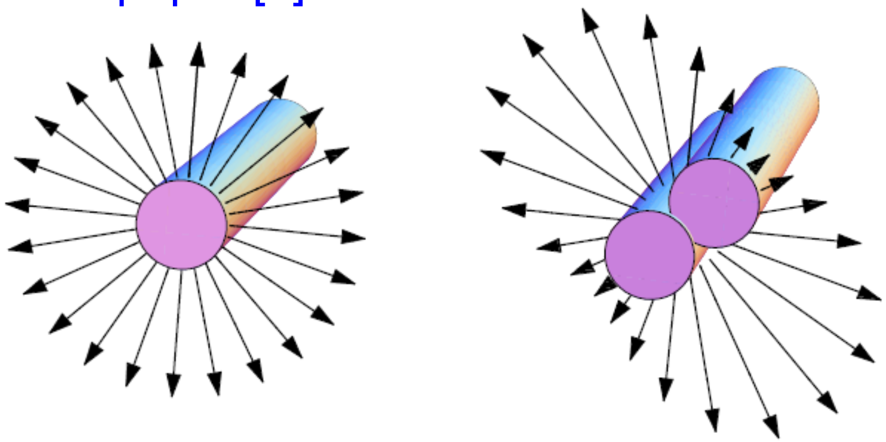
$$f(\mathbf{k}+\mathbf{q}) + f(\mathbf{k}-\mathbf{q}) . \qquad (1)$$

Adopting $f \sim \exp[-B\mathbf{k}^2]$, taking an average over $|\mathbf{k}|$, and using the approximation of small values of $\mathbf{q}^2/\langle \mathbf{k}^2 \rangle \ll 1$, we find the following azimuthal distribution of the secondary particles for a given $\mathbf{q}$:

$$F_1(\varphi, y) \sim 1 + a_1(y)\cos^2\phi, \qquad a \approx 2Bq^2 , \qquad (2)$$

Motivation: more of Theory

This old concept *of interacting chromoelectric tubes [1],* ***extended in rapidity***, may be illustrated by some nice figure from the quite recent paper [2] :



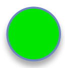
"Fig. 1. Sketch of the one and two flux tubes configurations considered. On the left a single flux tube elongated in space-time rapidity generates azimuthally symmetric flow. On the right a configuration with two strings leads to an **azimuthally asymmetric flow** in the transverse plane" [2].

[1] Abramovskii V. A., Gedalin E. V., Gurvich E. G., Kancheli O. V. , Long-range azimuthal correlations in multiple-production processes at high energies, JETP Lett., vol.47, 337-339 , 1988
[2] Piotr Bozek, "Observation of the collective flow in proton-proton Collisions", arXiv:// 0911.2392v2 [nucl-th] 22 Jan 2010

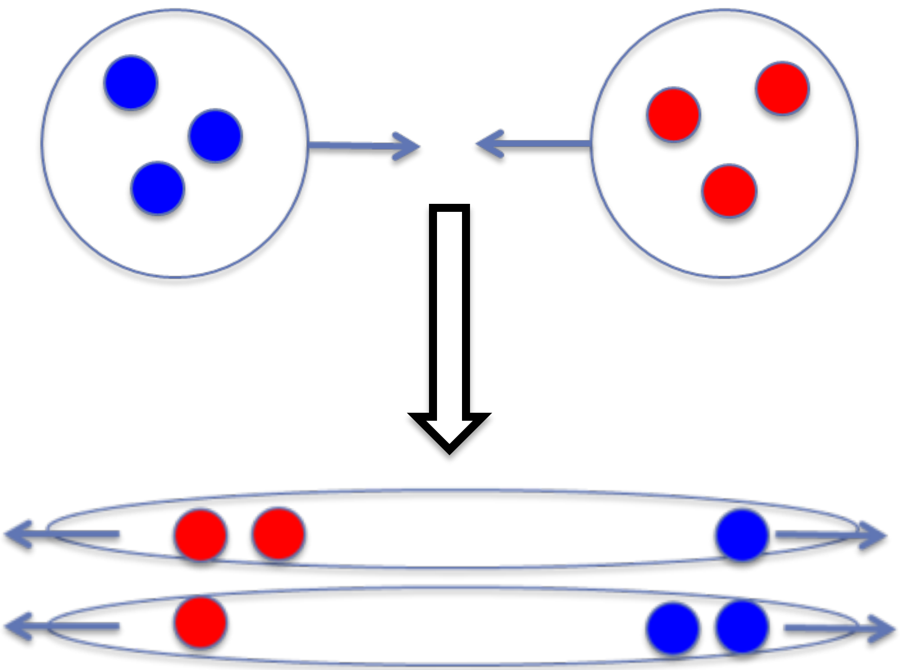
…more…

Two stage scenario of particles production

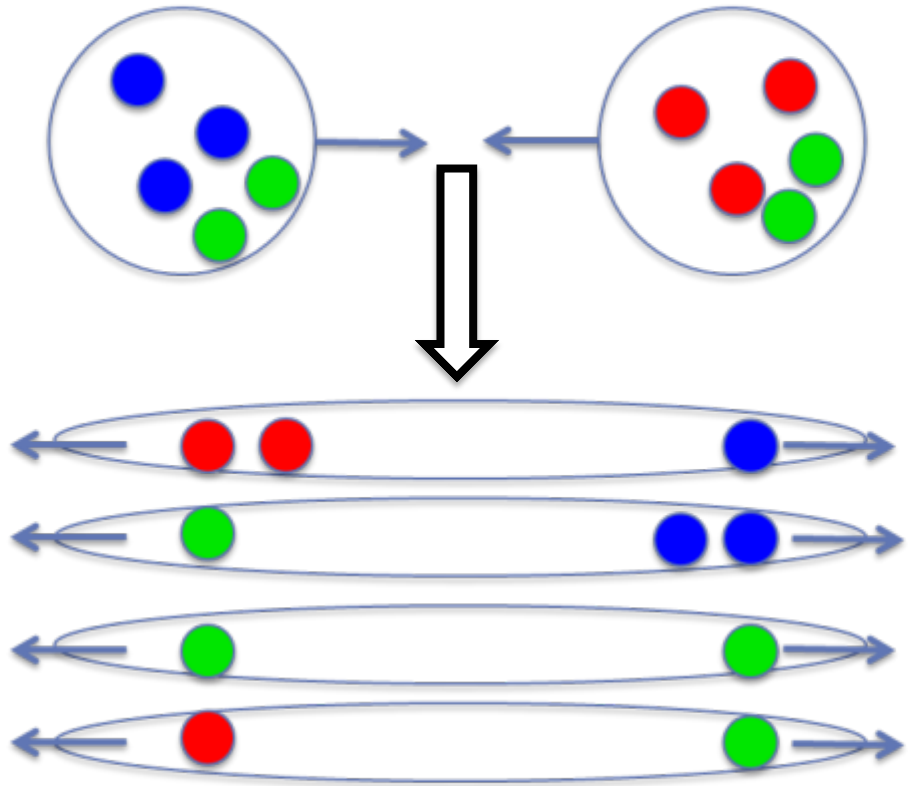
I stage: strings formation.



p-p case, low energy



p-p case, high energy

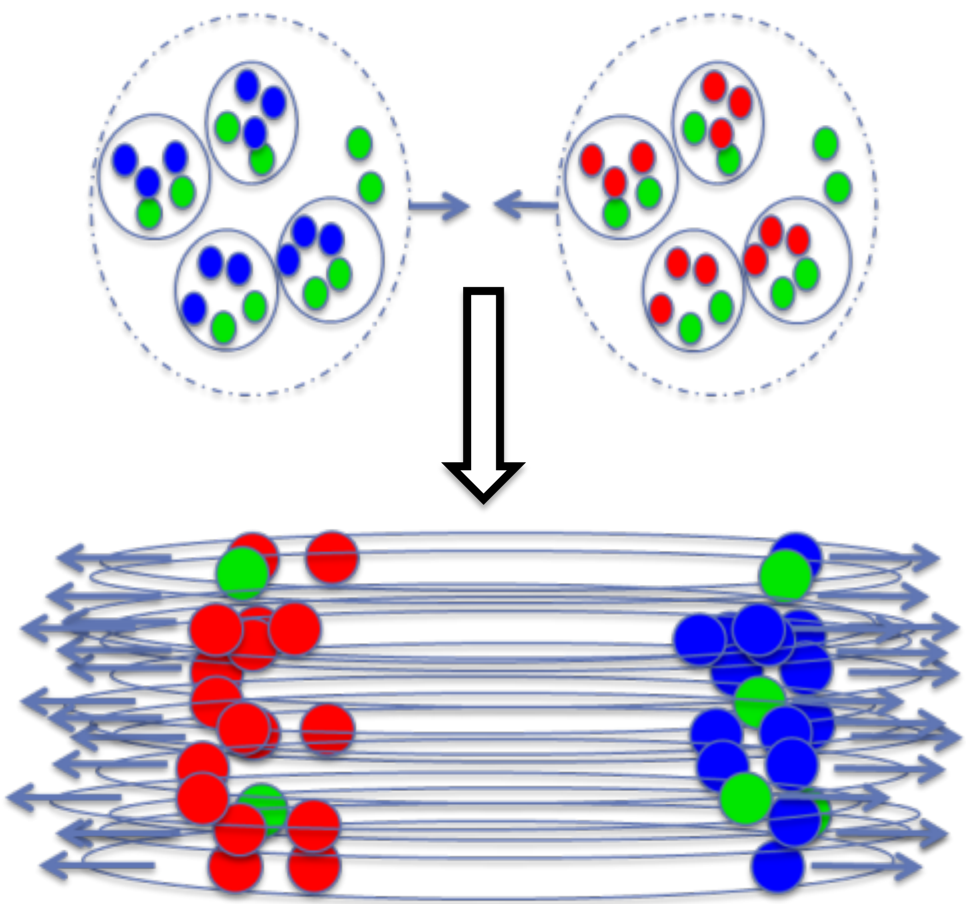


[1]A.Capella, U.P.Sukhatme, C.I.Tan and J.Tran Thanh Van, Phys. Lett. B81 (1979) 68; Phys. Rep. **236** (1994) 225.
[2]A.B.Kaidalov, Phys. Lett., 116B(1982)459

Slide from report: E. Andronov, A. Seryakov
NA61/NA49 Collaboration meeting Dubna, 10/04/14

Two stage scenario of particles production

A-A case



[1]A.Capella, U.P.Sukhatme, C.I.Tan and J.Tran Thanh Van, Phys. Lett. B81 (1979) 68; Phys. Rep. **236** (1994) 225.

[2]A.B.Kaidalov, Phys. Lett., 116B(1982)459

Slide from report: E. Andronov, A. Seryakov
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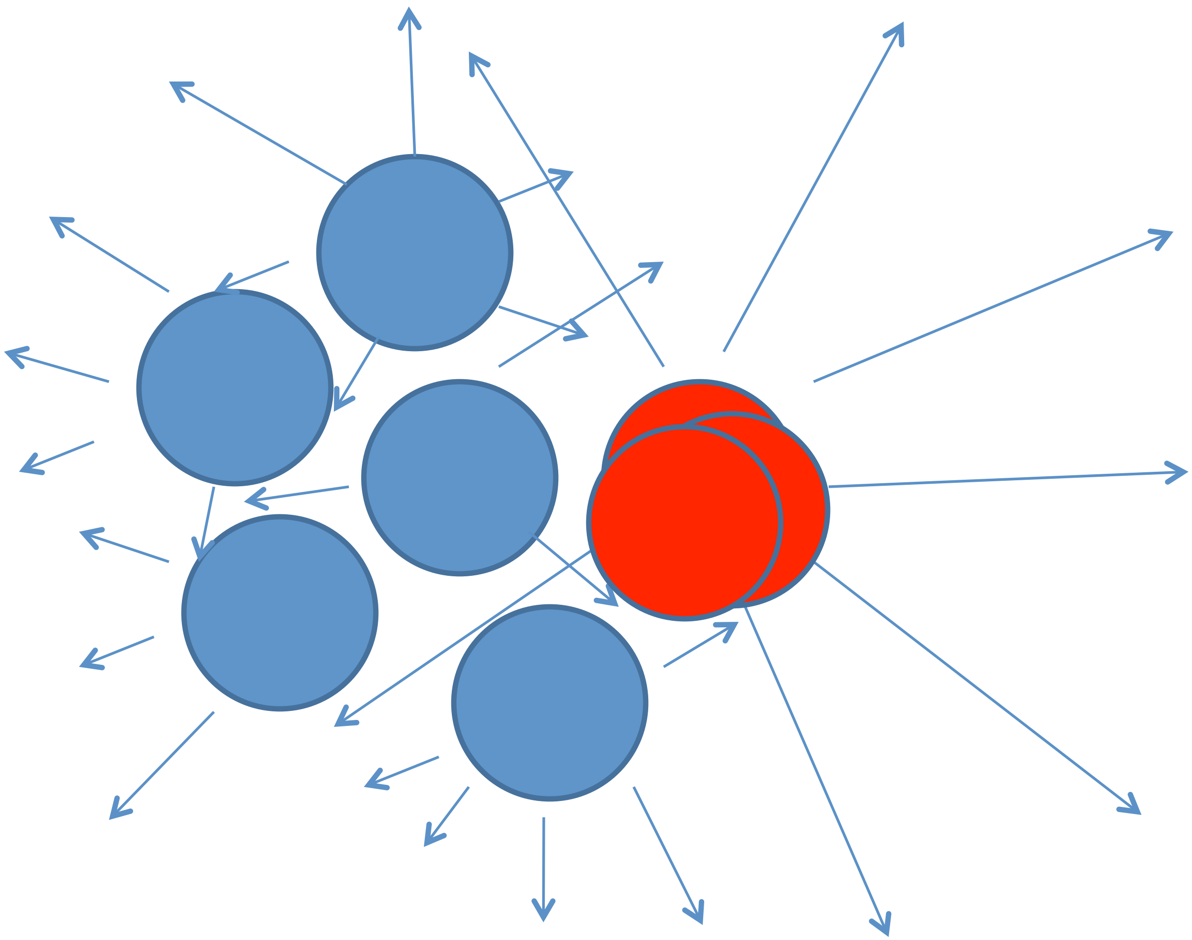


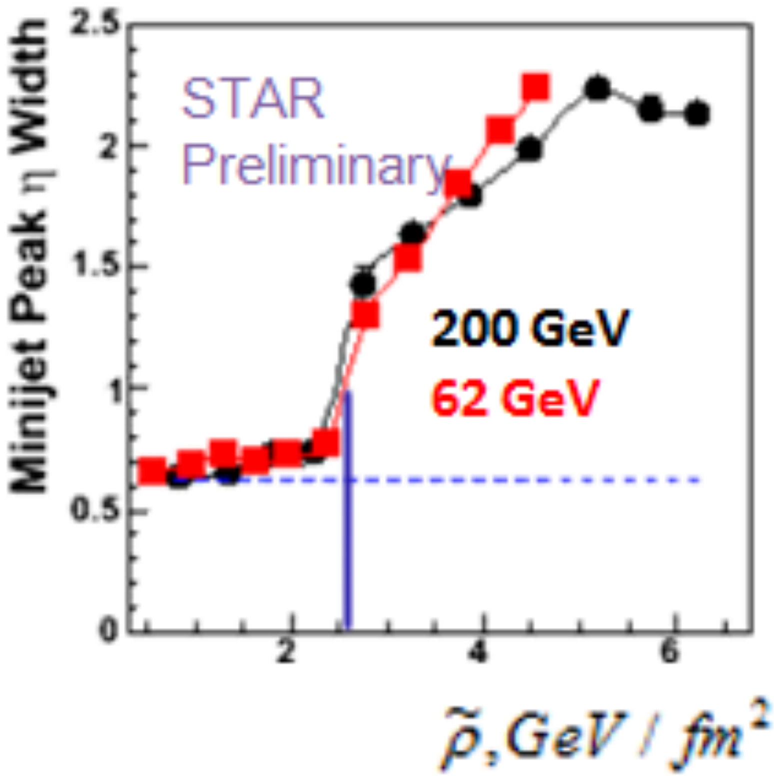
Transverse plane schematics of formation and decay of the "macroscopic" cluster composed of several overlapped strings - red, and the “ordinary strings - - - blue

Multiplicity density and mean p_t

in case of fusion of n strings(M.Braun, C.Pajares):

$$\mu_n = \sqrt{\frac{nS_n}{S_1}}\mu_1 \; ; \; \langle p_T^2 \rangle_n = \sqrt{\frac{nS_1}{S_n}} \langle p_T^2 \rangle_1$$

Transverse particle density

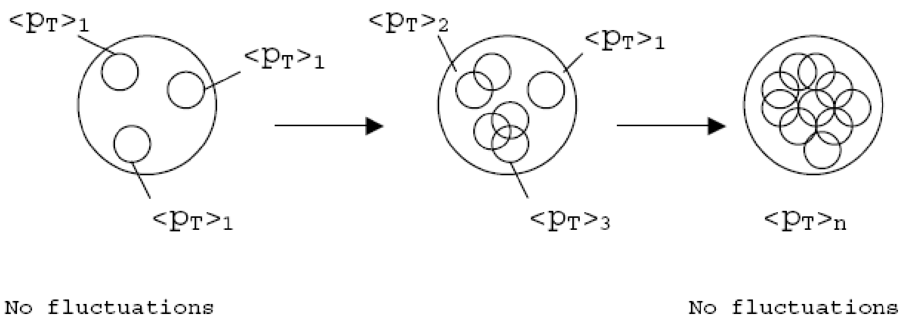


$$\tilde{\rho} = \frac{3}{2}\frac{dN_{ch}}{d\eta} / S$$

$$\tilde{\rho}_{crit} = 2,6 \pm 0,2\, fm^{-2}$$

Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. M. Daugherity. QM2008, J.Phys.G35:104090,2008

String model. Estimate of string percolation parameter.



With growing energy and/or atomic number of colliding particles, the number of strings grows and they start to overlap, forming clusters, **new type of particle emitting source**.

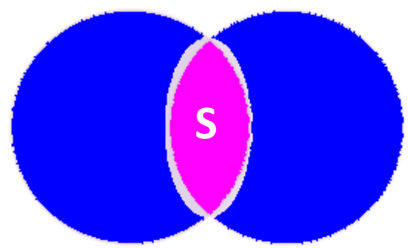
At a critical density a macroscopic cluster appears that marks the percolation phase transition.[3]

Percolation parameter:

$$\eta(b) = \frac{N_{str}(b)\pi r_0^2}{S(b)}$$

Nstr - ?

S - ?



$\eta_c = 1,12\text{-}1,175$ ([4])

$$N_{str} = N_{Sea} + N_{Valent}$$

$$\eta(N_{part}) = N_{str}(N_{part})\pi r_0^2 / S(N_{part})$$

$$N_{str} = N_V + N_S = N_{part} + aN_{coll}$$

$\mathbf{N_{Str}}$ - number of strings, πr_0^2 string transverse area, ***S*** overlap area of two nucleons.

r_0**=0,2-0,3 fm** – change of string radius value results in different percolation parameter

[3] C. Pajares // arXiv:hep-ph/0501125v1 14 Jan 2005

[4] N. Armesto, M.A, Braun, E.G. Ferreiro, C. Pajares// Phys. Rev. Lett. 77, 3736 (1996)

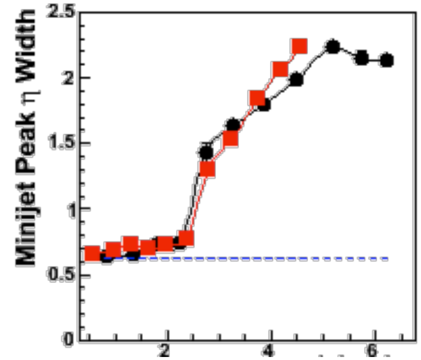
[6] Ncoll, see: G.Feofilov,A.Ivanov “Modified Glauber moel”//Journal of Physics: Conference Series 5 (2005) 230–237

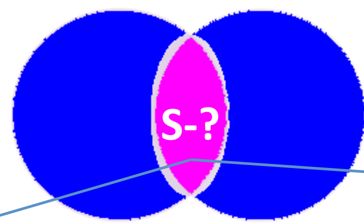
New! Our calculation

Percolation model parameters at **the “critical“ point**

Percolation sting theory[3-5]

Transverse particle density





$$\tilde{\eta} = N_{string}\pi r_0^2 / S$$

$$\tilde{\rho} = \frac{3}{2}\frac{dN_{ch}}{d\eta} / S$$

$\tilde{\rho}$

$$\frac{\tilde{\rho}_{crit}}{n_{crit}}$$

$$\eta_{crit} = 1,12 - 1,175[4]$$

$$\tilde{\rho}_{crit} = 2,6 \pm 0,2\, fm^{-2} [1]$$

Parameters of the model

$$N_{str} = N_V + N_S = N_{part} + aN_{coll}$$

[3] C. Pajares // arXiv:hep-ph/0501125v1 14 Jan 2005
[4] N. Armesto, M.A, Braun, E.G. Ferreiro, C. Pajares// Phys. Rev. Lett. 77, 3736 (1996)
[5]V.V. Vechernin, R.S. Kolevatov, 2007, Yad. Fiz., 2007, Vol. 70, No. 10, pp. 1858–1867.

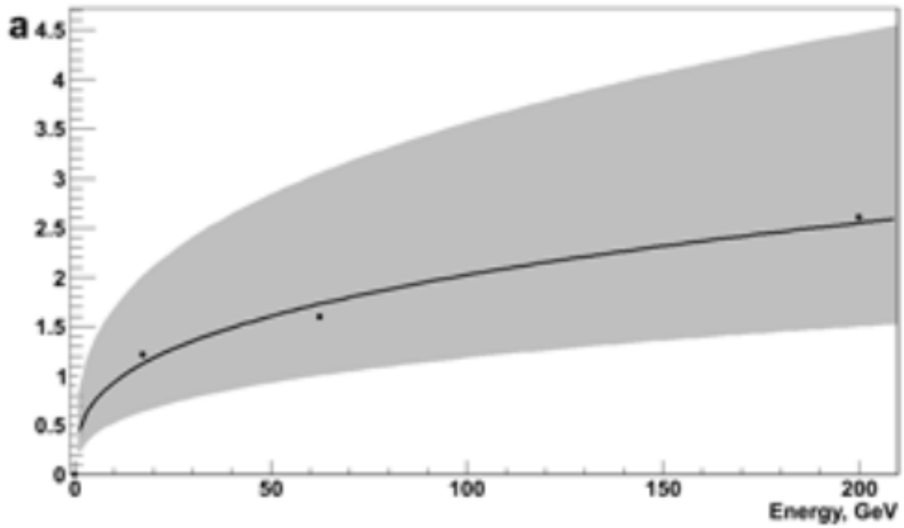
Table 1. Our first estimates of number of particles emitting sources Nstr in case of $r_0=0.2\ fm$

√s, GeV AA collisions	$Npart_{crit}(\sqrt{s})$	S(b)= $S(Npart_{crit}(\sqrt{s}))$, fm^2	η_{crit}	*Nstr*	*Nv*	*Ns*	$\tilde{\rho}_{crit}$ fm^{-2}
62 AuAu	90	62,0	**1,15**	**531**	90	441	2,8 ±0,2
200 AuAu	36	38,7	**1,15**	**303**	36	267	2,9±0,2

Estimates of parameter a:

$$N_{str} = N_V + N_S = N_{part} + aN_{coll}$$

Nstr is defined basing on values of Npart from [1].
Ncoll is defined by using [2].
Uncertanties are at the level of 30% (preliminary estimate).



$$a = A + B(\sqrt{s})^{(1/3)}$$

A=0.04
B=0.1
See [3]

[1] Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. **M. Daugherity(QM2008), J.Phys.G35:104090, 2008**

[2] G.Feofilov, A.Ivanov "Modified Glauber model", Journal of Physics: Conference Series 5 (2005) 230–237

[3] O.Kochebina and G.Feofilov, http://arxiv.org/abs/1012.0173

Table 2. Results (r_{str}=0.25 fm)

… the larger are the radii of strings – the smaller the number of string is …it is natural….

Table 2. The total number of strings, the number of sea strings and parameter a obtained in the "critical" points for $AuAu$ collisions at 62 GeV and 200 GeV collision energies and for $PbPb$ collisions at 17.3 GeV. The calculations are done for $r_0 =$ 0.25 fm.

$\sqrt{s}$, GeV	N_{part}	$dN_{ch}/d\eta$	N_{str}	N_s	N_{coll}	a
200($AuAu$)	40	2.97 ± 0.30 [28]	194 ± 25	155 ± 23	59 ± 4	2.6 ± 0.4
62 ($AuAu$)	90	2.30 ± 0.23 [29]	352 ± 28	262 ± 23	167 ± 4	1.6 ± 0.2
17.3 ($PbPb$)	110	1.62 ± 0.21 [30]	302 ± 45	192 ± 30	158 ± 5	1.2 ± 0.2

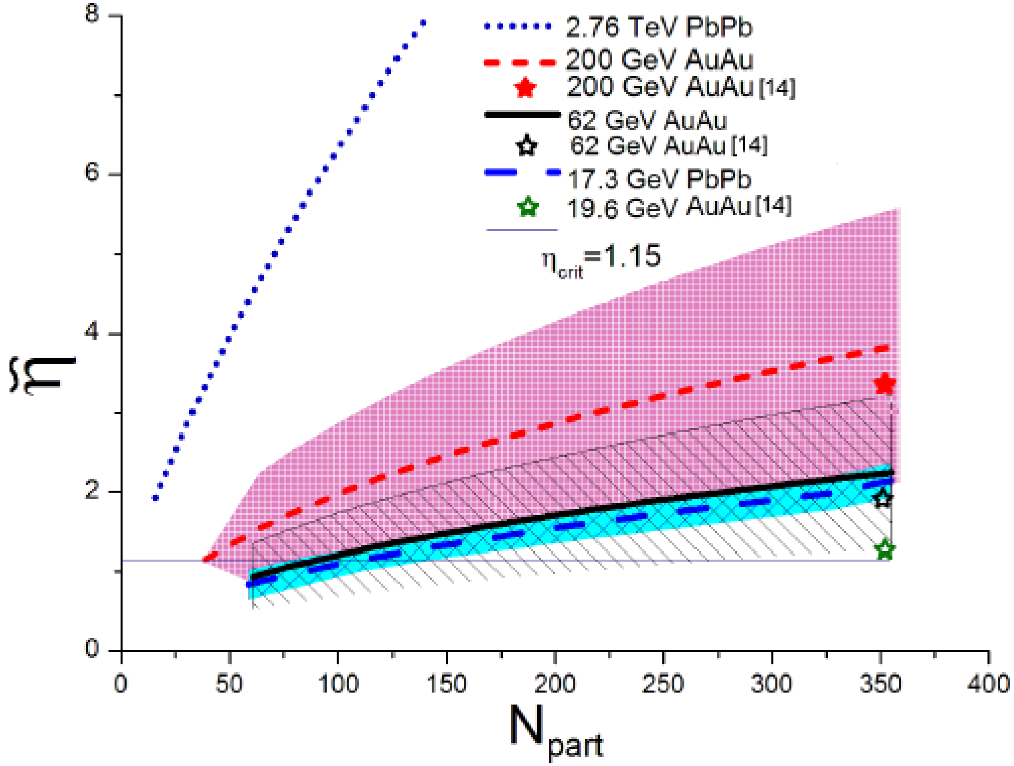


Fig. 3. Centrality dependence of percolation parameter $\tilde{\eta}$ in nucleus collisions at various energies. Shaded areas are representing the uncertainties of our calculations (those for $\sqrt{s}$ = 2.76 TeV are not shown). Stars - independent estimates [14] of $\tilde{\eta}$ for very central collisions (see text). Figure is zoomed on Y-axis.

Collective effects in pp collisions (elliptic flow)?

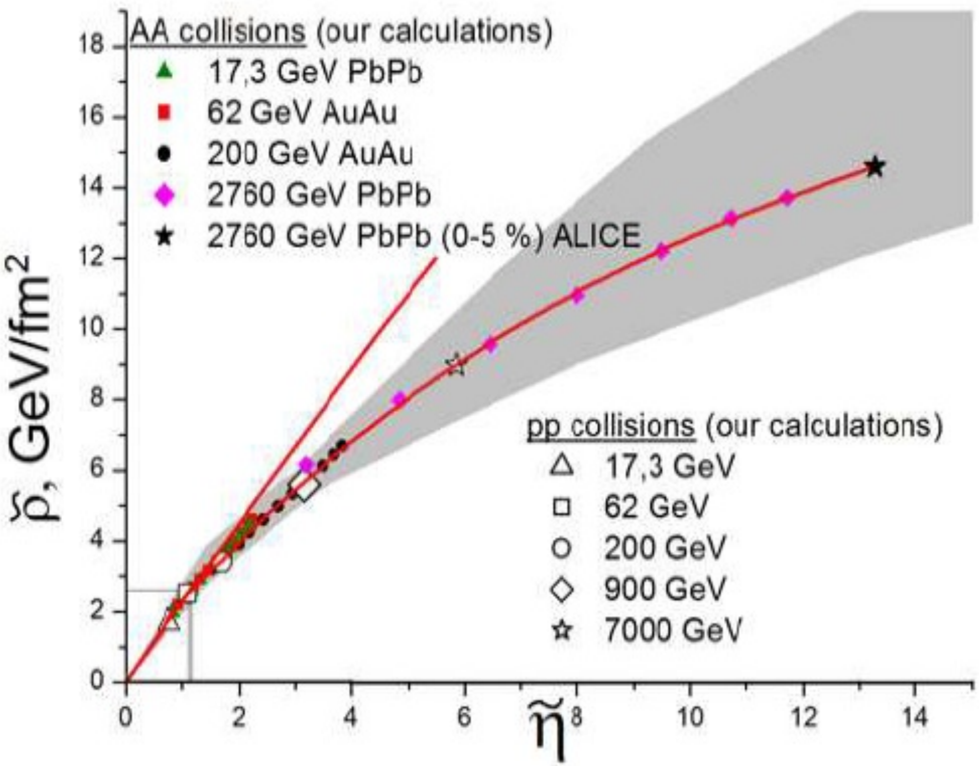


Figure 4: Transverse particle density $\tilde{\rho}$ vs. string density $\tilde{\eta}$ in AA collisions for energy $\sqrt{s} = 17.3$ GeV, $\sqrt{s} = 62$, $\sqrt{s} = 200$ GeV and $\sqrt{s} = 2.76$ TeV. Points are our calculations. Lines are fits to the points. Points for pp collisions are obtained from the experimental data in the range of energies from $\sqrt{s} = 17.3$ GeV to $\sqrt{s} = 7$ TeV (see text).

Mean number Nstr in pp collisions, our estimates *(here ro=0.25 fm)* [OK,GF 2010, arxiv 1012.0173]:

$\sqrt{s}$, GeV	$dN_{ch}/d\eta$	$\tilde{\rho}$, GeV/fm^2	$\tilde{\eta}$	N_{str} our estim.	N_{str} estimate using data [32]	Dispersion in N_{str} from [32]
7000	6.02 ± 0.50 [27]	9.0 ± 0.5	5 ± 1	30 ± 12	no data	no data
900	3.78 ± 0.19 [28]	5.6 ± 0.4	3.2 ± 0.8	16 ± 6	6.6	8.6
200($p\bar{p}$)	2.30 ± 0.20 [29]	3.4 ± 0.2	1.7 ± 0.4	9 ± 4	5	5.4
62	1.64 ± 0.17 [30]	2.5 ± 0.1	1.1 ± 0.6	6 ± 4	4	3.6
17.3	1.14 ± 0.12 [31]	1.70 ± 0.08	0.7 ± 0.4	4 ± 3	3	1

Table 2: The transverse particle density, the string density and number of strings estimated for pp collisions for energies from 17.3 GeV to 7000 GeV.

Multipomeron exchange model with collectivity:

[32] N. Armesto, D. Derkach, G. Feofilov, Physics of Atomic Nuclei, 2008, Vol. 71, No. 12, pp. 20872095.

MC toy model of repelling strings

The toy model:

- pair of partons from colliding nucleons can form a string
- strings repel from each other within some distance, and gain momentum kicks
- In its rest frame, string decays into particles isotropically in azimuth, but in lab frame particles are boosted due to string kick

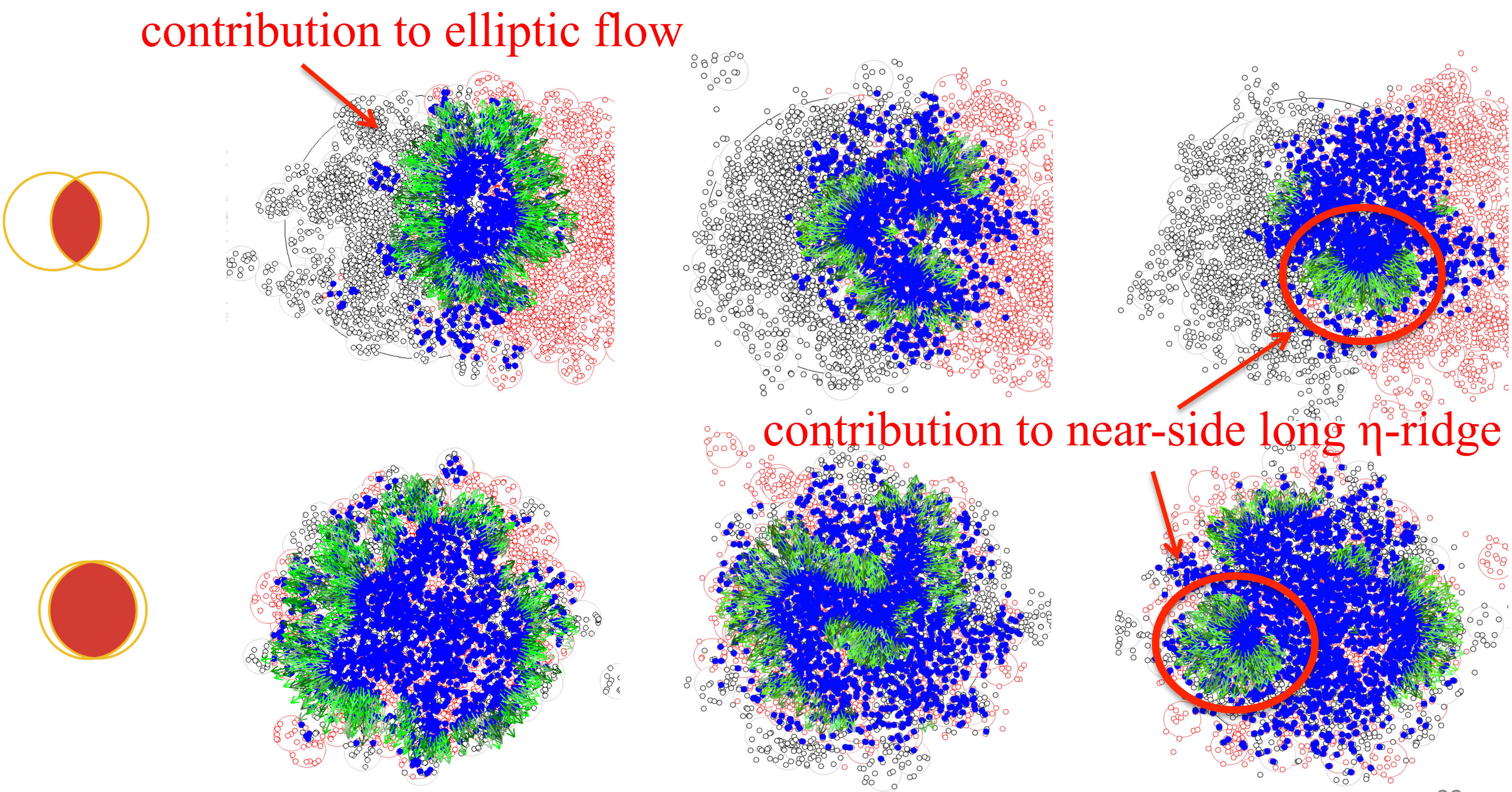
see poster report by I.Altsybeev
https://indico.cern.ch/event/287920/session/55/contribution/159

MC toy model of repelling strings

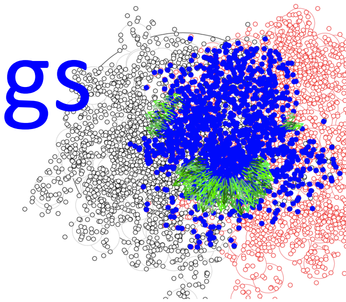
Toy emulation of Pb-Pb collision:

blue points – strings

green arrows – gained kick for string



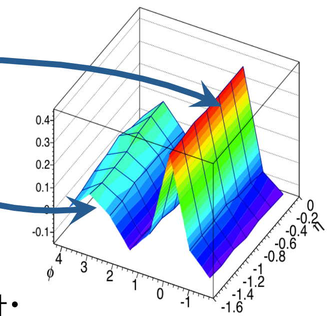
MC toy model of repelling strings



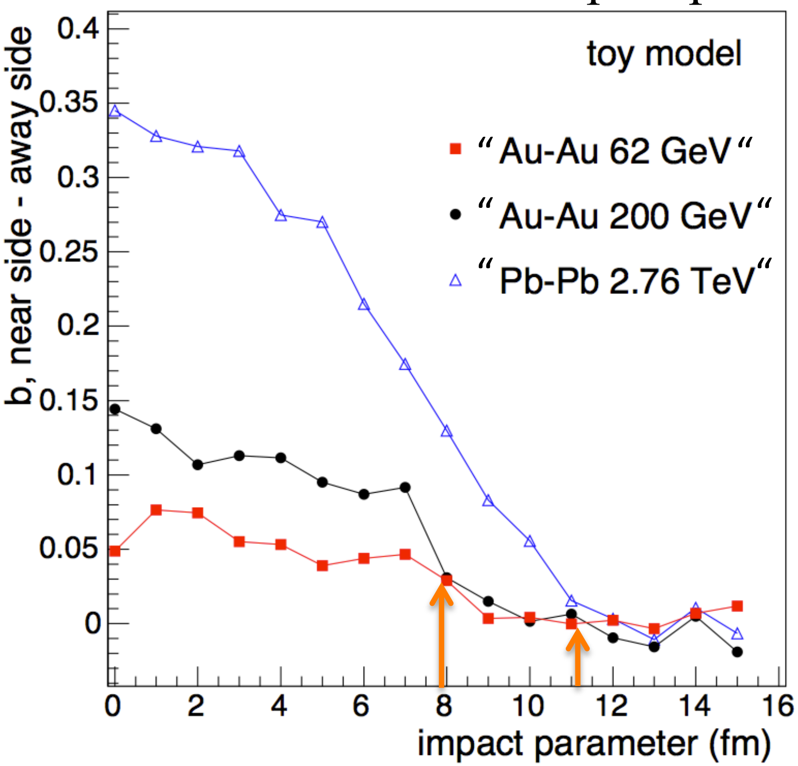
- Comparison of low- and high-density cases using difference in multiplicity correlation coefficient:

$$b_{\rm corr}^{n-n} = \frac{\langle n_{\rm F}\, n_{\rm B}\rangle - \langle n_{\rm F}\rangle\langle n_{\rm B}\rangle}{\langle n_{\rm F}^2\rangle - \langle n_{\rm F}\rangle^2}$$

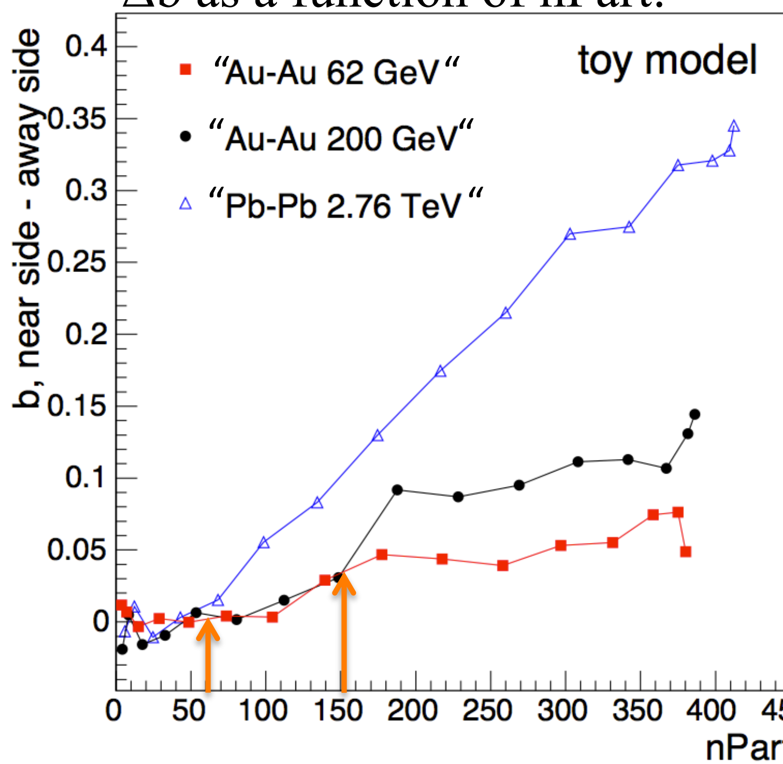
$$\Delta b_{\rm corr} = b_{\rm corr}^{near} - b_{\rm corr}^{away}$$



Δb as a function of impact par:



Δb as a function of nPart:



Conclusions

- The onset of *the near-side low p_T ridge in AA collisions is compatible with the hypothesis of the* ***string percolation phase transition*** that happens at some definite "critical density“ characterized by the relevant number of participating nucleons Npart.
- Results show that is possible to search for the onset of the “near-side low p_T “ridge” phenomenon” in the very central *Pb+Pb* at *17,3 GeV(SPS) , the ridge phenomena (and the elliptic flow) should be seen (and they are there!) in all centrality classes in PbPb collisions at the LHC and could be expected in pp collisions at the energies higher then 62 GeV.*
- Constraints on string percolation model could be obtained from the data on anomalous centrality evolution data in Au-Au collisions at sqrt(s)=62 and 200 GeV. This approach allows to make the following estimates in the framework of quark-gluon string model) :
  1. Number of particle emitting sources (strings)
  2. Mean radius of interacting strings (or some efficient characteristic parameter of interaction)
- Toy model of interacting strings shows that spatial anisotropy of strings formed at the initial stage of the event can produce collective p_T flow phenomena and near-side effects

Thank you!