Long-range correlation studies at the SPS energies in MC model with string fusion

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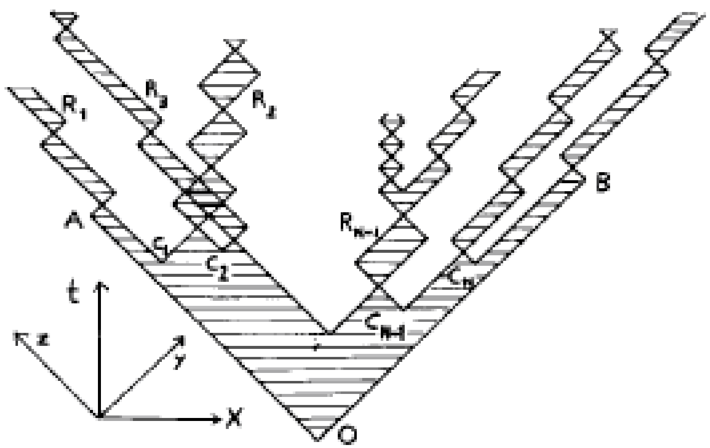
XXII International Baldin Seminar
on High Energy Physics Problems

Relativistic Nuclear Physics &
Quantum Chromodynamics

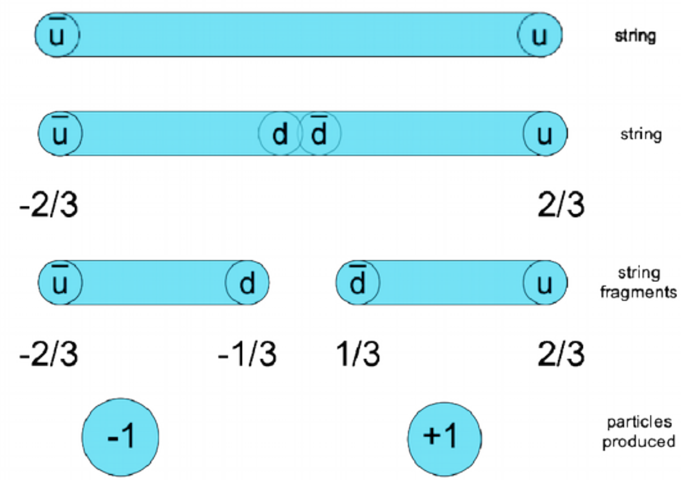
September 15-20, 2014, Dubna, Russia

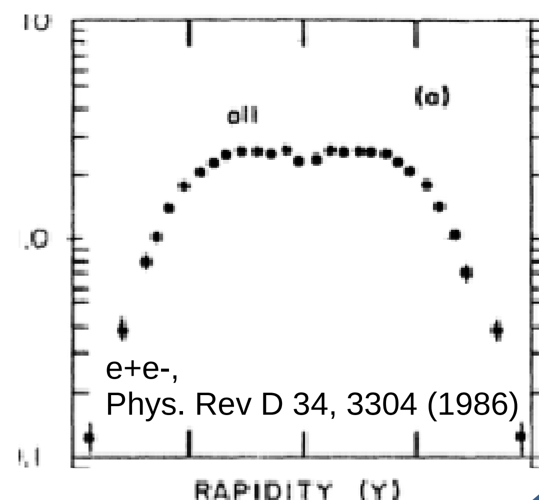
Overview

- 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”,



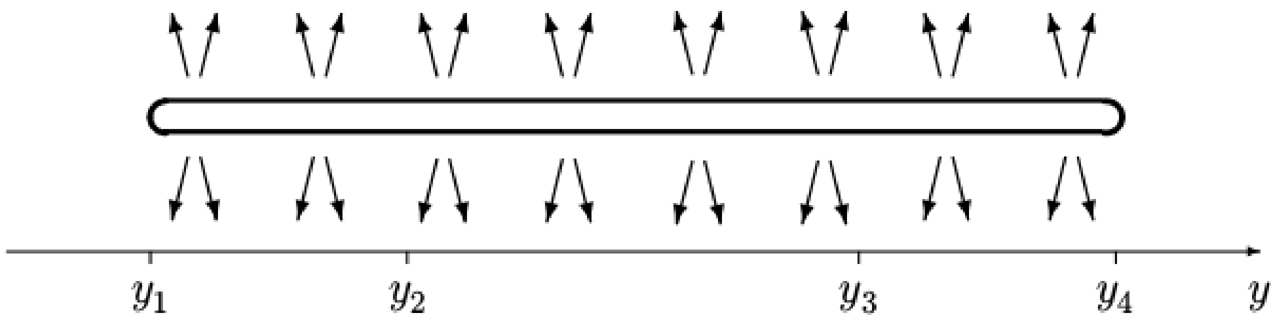


e+e-,
Phys. Rev D 34, 3304 (1986)

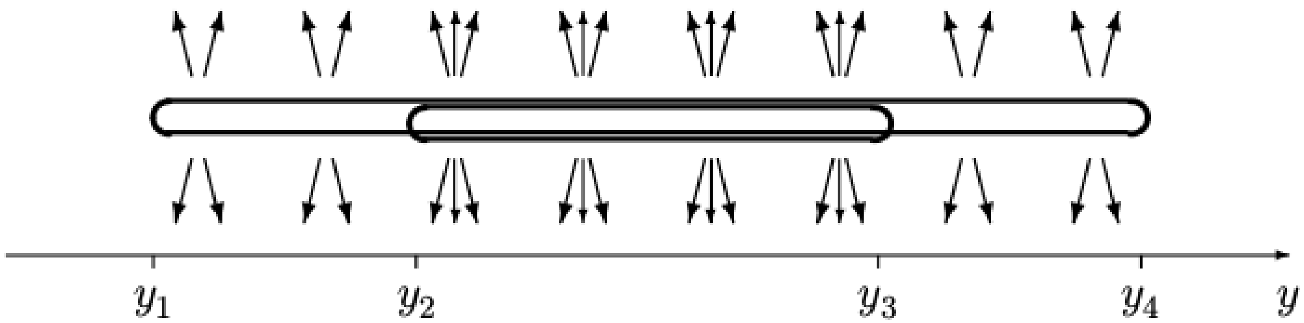
- Almost <u>flat rapidity distribution</u> from one string
- <u>Independet particle production</u> in each rapidity bin

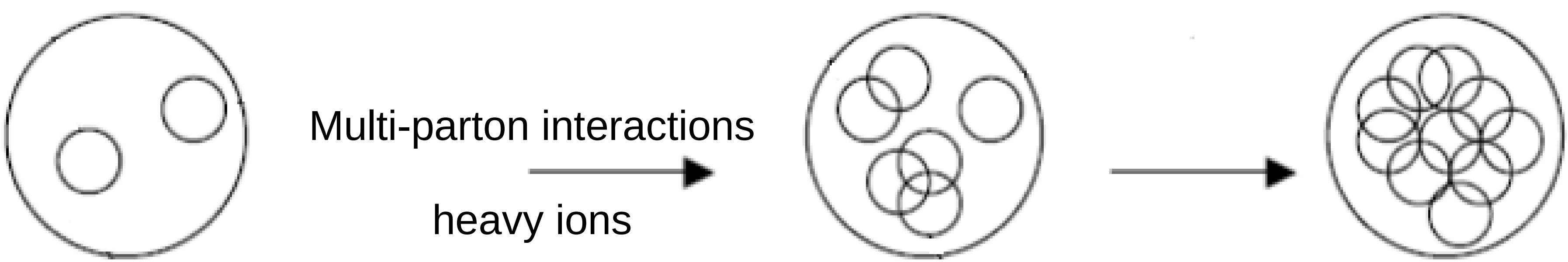
String in rapidity space

- Each string is charectirized by rapidity edges: y_{min} to y_{max}
- Uniform rapidity distribution of produced charged particles from one string



several strings can overlap





–->>> sqrt(s) increases -->>> –->>> –->>>

String fusion

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

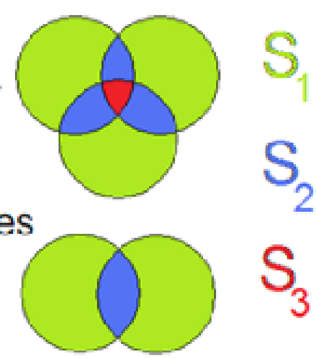
$$\left\langle Q^2(n) \right\rangle = nQ^2(1)$$

overlaps

SFM

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

S_k – area covered k-times



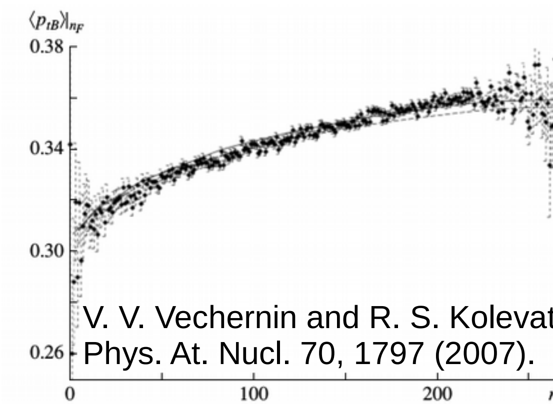
$$\langle \mu \rangle_k = \mu_0 \sqrt{k} \frac{S_k}{\sigma_0} \qquad \langle p_t^2 \rangle_k = p_0^2 \sqrt{k} \qquad \langle p_t \rangle_k = p_0 \sqrt[4]{k}$$

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 multiplicity in pp, pA and AA collisions
– growth of strange particle yields

– results are in a good agreement with the experiment

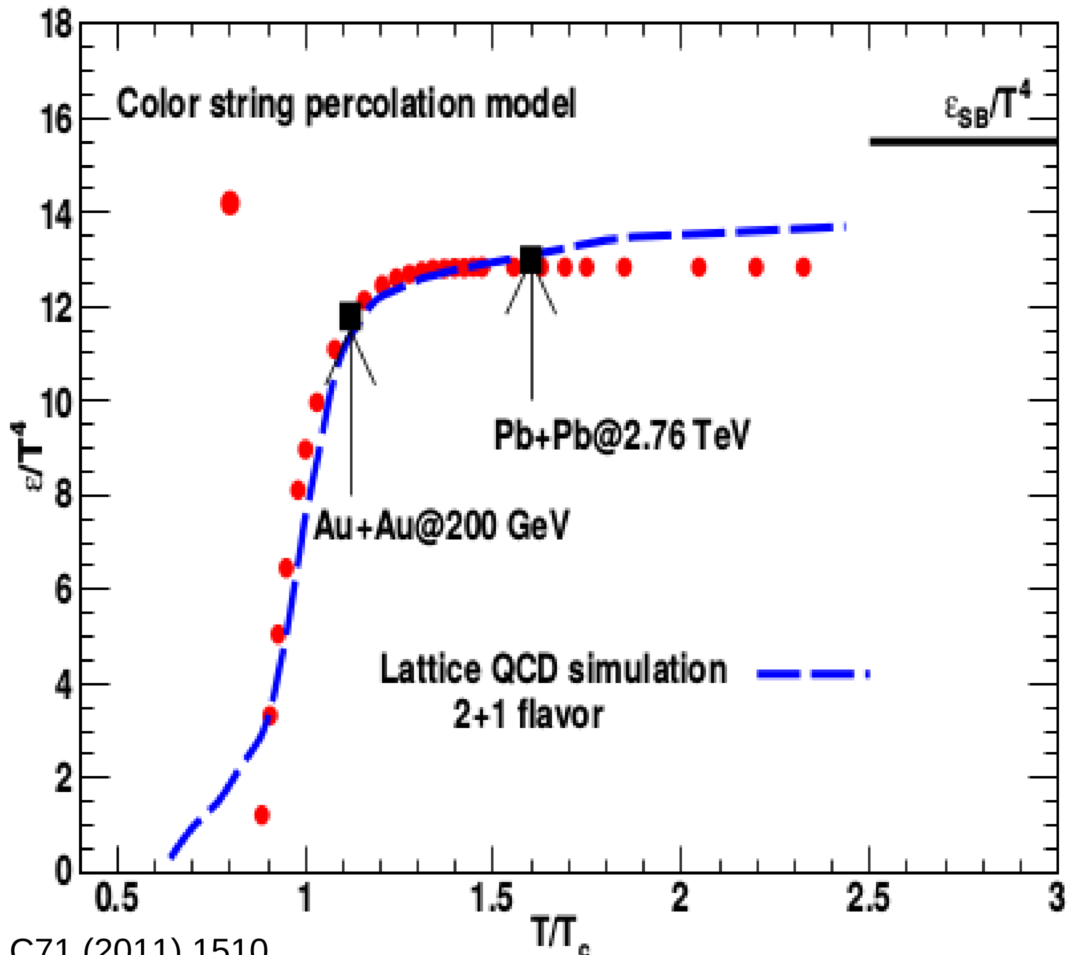


V. V. Vechernin and R. S. Kolevatov, Phys. At. Nucl. 70, 1797 (2007).

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

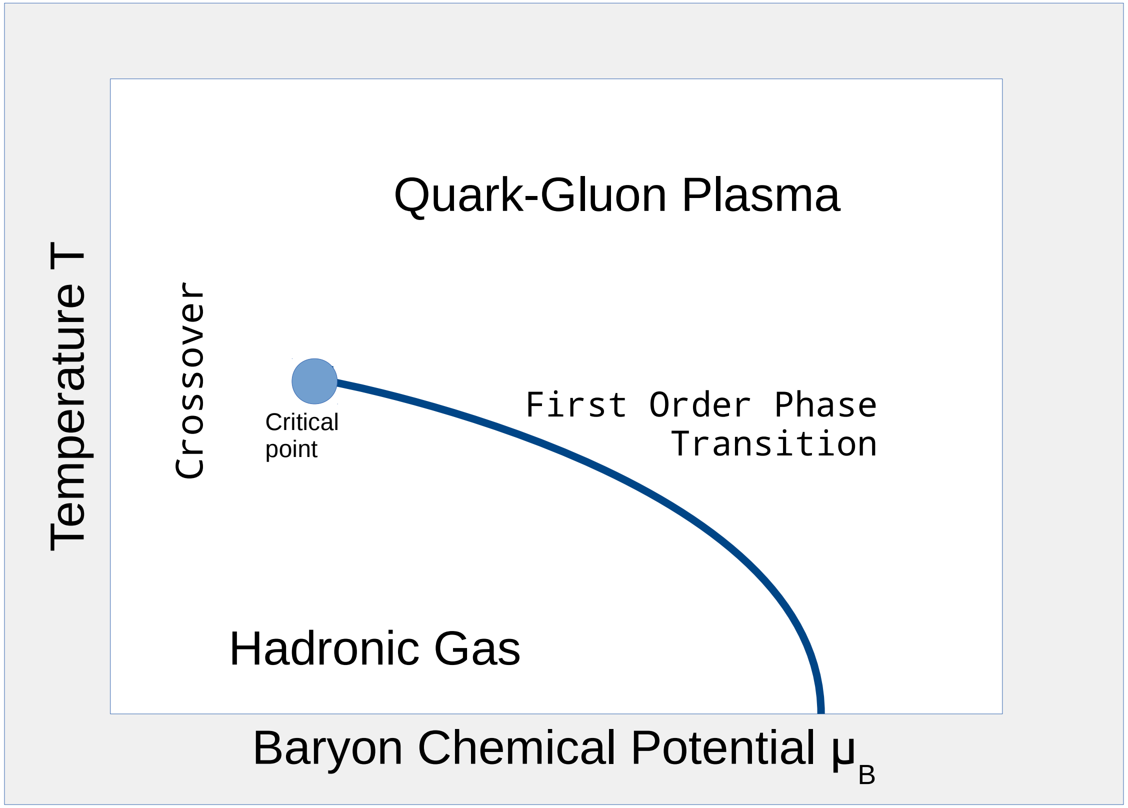
In the recent papers
it was shown that the equation of state of QGP (ε/T^4 as a function of T) at zero chemical potential, obtained in the colour string percolation model is in a good agreement with the lattice results.



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)

Hints of percolation transition & ridge effect...

QCD phase diagram and search for the critical point

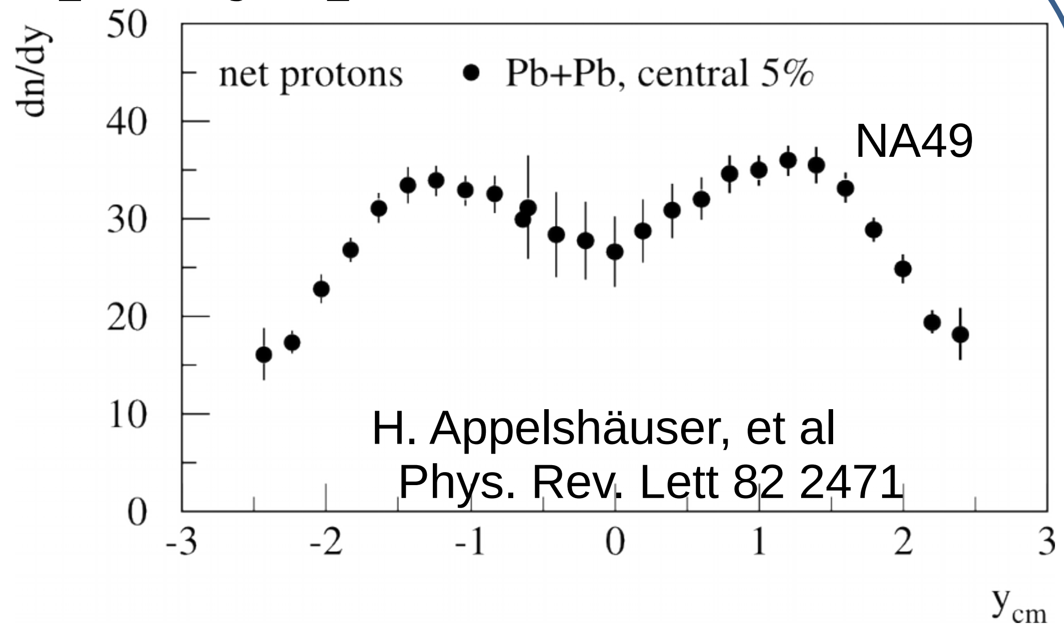


HADES, GSI	2.3 – 2.7 GeV	p+p, Au+Au, Ar+KCl, C+C
NA61, SPS, CERN	6.3 - 17.3 GeV	p+p, Be+Be, p+Pb, Ar+Ca, Xe+La, Pb+Pb, ...
CBM, FAIR, GSI	2.7 - 8.3 GeV	p, Ca, Au
RHIC BES	5 - 200 GeV	Au+Au
NICA, JINR	3 - 11 GeV	from p to Au

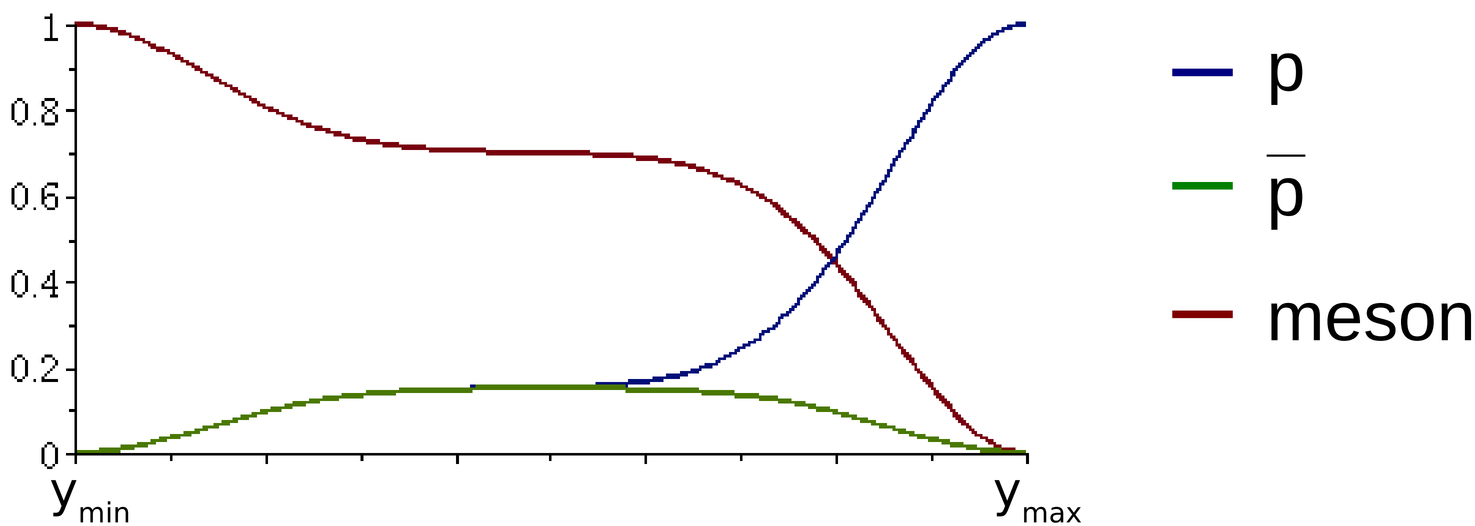
$$\frac{\bar{p}}{p} = \frac{e^{-(E+\mu_B)/T}}{e^{-(E-\mu_B)/T}} = e^{-(2\mu_B)/T}$$

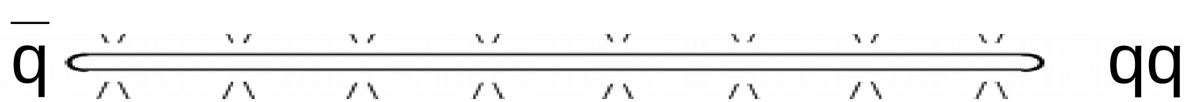
String in rapidity space

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



Particle composition from one string





String in rapidity space

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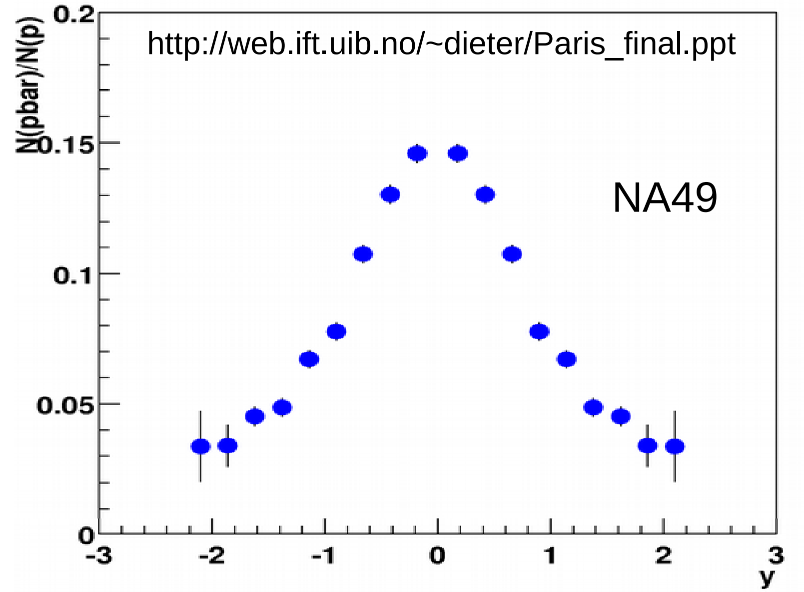

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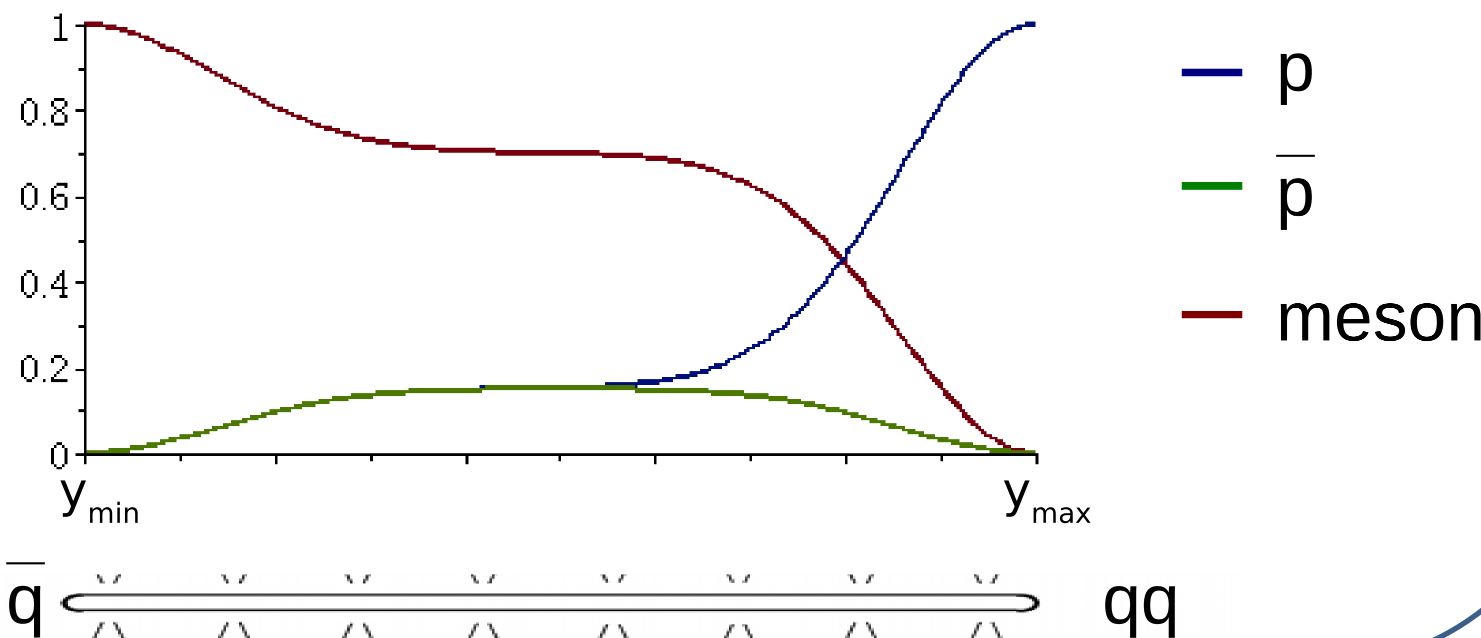
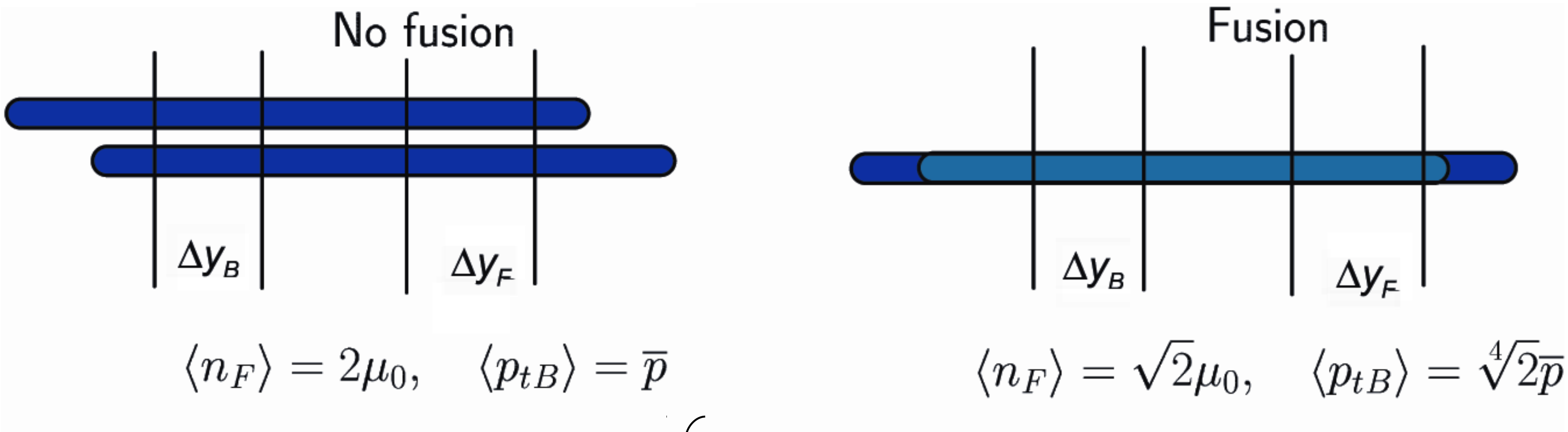


Long-range correlations

- Sensitive tool for studying of string fusion phenomena



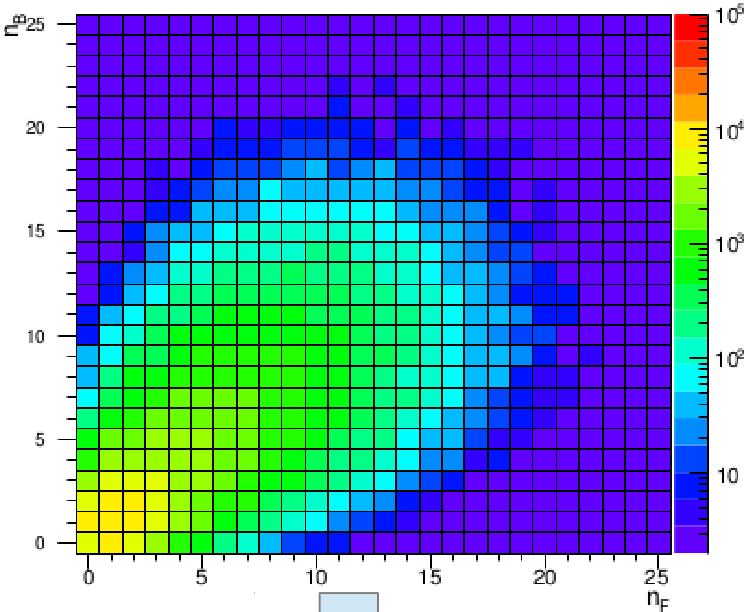
Select 2 variables in windows:

$$F, B = \begin{cases} N_{ch} & \text{– number of charged particles in the window} \\ p_t = \frac{1}{n}\sum_{i=1}^{n} p_{ti} & \text{– mean (in the event!) transverse momentum of charged particles in the given window} \end{cases}$$

Three types of correlation coefficients:

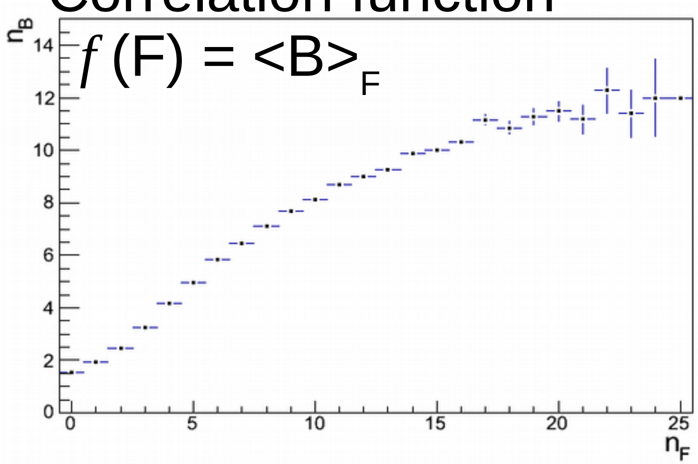
n-n , pt-n, pt-pt

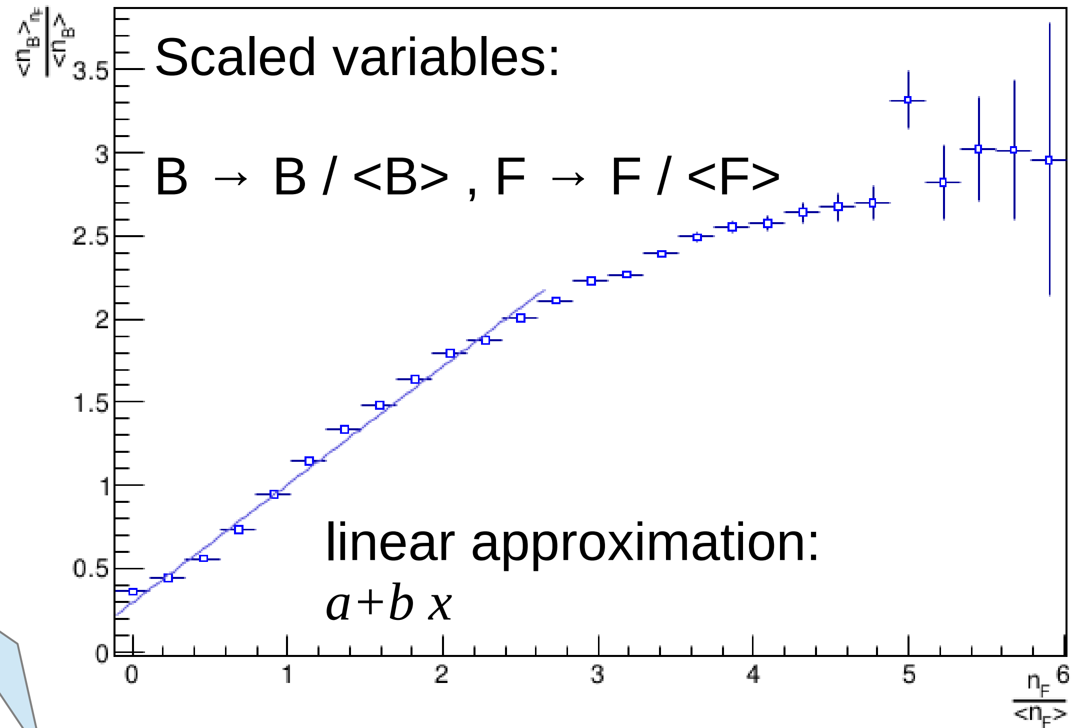
Long-range correlations



Correlation function

$f(F) = \langle B \rangle_F$





Correlation coefficients:

$$b_{nn} = \frac{< n_F >}{< n_B >} \cdot \frac{d < n_B >}{d n_F} \Big|_{n_F = < n_F >},$$

$$b_{p_t - n} = \frac{< n_F >}{< p_{tB} >} \cdot \frac{d < p_{tB} >}{d n_F} \Big|_{n_F = < n_F >},$$

$$b_{p_t - p_t} = \frac{< p_{tF} >}{< p_{tB} >} \cdot \frac{d < p_{tB} >}{d p_{tF}} \Big|_{p_{tF} = < p_{tF} >}.$$

note alternative definition of correlation coefficient (correlator formula):

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

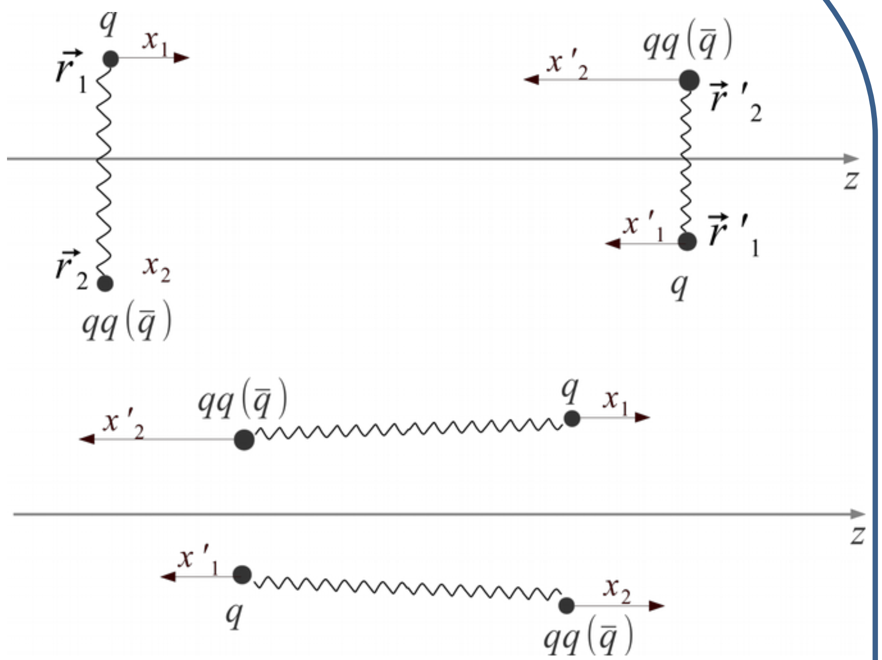
Parton distributions

- Inclusive momentum distributions are taken from [1,2]:

$$\begin{aligned} f_u(x) &= f_{\bar{u}}(x) = C_{u,n}\, x^{-\frac{1}{2}}(1-x)^{\frac{1}{2}+n}, \\ f_d(x) &= f_{\bar{d}}(x) = C_{d,n}\, x^{-\frac{1}{2}}(1-x)^{\frac{3}{2}+n}, \\ f_{ud}(x) &= C_{ud,n}\, x^{\frac{3}{2}}(1-x)^{-\frac{3}{2}+n}, \\ f_{uu}(x) &= C_{uu,n}\, x^{\frac{5}{2}}(1-x)^{-\frac{3}{2}+n}. \end{aligned}$$

- At n>1 the sea quarks and antiquarks have the same inclusive distribution as the valene quarks.
- Poisson distribution for the number of quark-antiquark (diquark) pairs is assumed with some parameter λ

[1] A.B. Kaidalov, O.I.Piskunova. Zeitschrift fur Physik C 30(1):145-150, 1986
[2] G.H. Arakelyan, A.Capella, A.B.Kaidalov, and Yu.M.Shabelski. Eur.Phys.J (C), 26(1):81-90, 2002



V. N. Kovalenko, Phys. Atom. Nucl. 76, 1189 (2013), arXiv:1211.6209 [hep-ph]
V.Kovalenko, V. Vechernon, PoS (Baldin ISHEPP XI)
V. Kovalenko, PoS (QFTHEP 2013) 052 (2013).

- Corresponding exlusive distribution of the momentum frations:

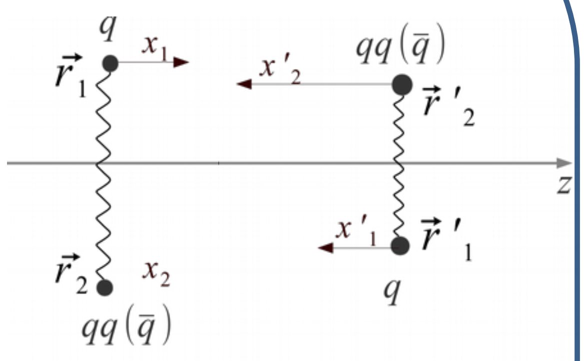
$$\rho(x_1, \dots x_N) = c \cdot \prod_{j=1}^{N-1} x_j^{-\frac{1}{2}} \cdot x_N^{\alpha_N} \cdot \delta\left(\sum_{i=1}^{N} x_i - 1\right)$$

- N=2*n

- Valene quark is labelled by N-1, the diquark by N, and the other refers to sea quarks and antiquarks.
- The rapidity string edges y_{min}, y_{max} are determined by parton momentum fractions x_i and defined from a kinematic condition of a decay to at least two particles

Distribution in impact parameter plane

- Exclusive distribution in the impact parameter plane is constructed from the following suppositions:
  1. Centre of mass is fixed: $\sum_{j=1}^{N} \vec{r}_j \cdot x_j = 0$.
  2. Inclusive distribution of each parton is the 2-dimentional Gaussian distribution.
  3. Normalization condition $< r^2 >=< \frac{1}{N} \sum_{j=1}^{N} {r_j}^2 >= {r_0}^2$.



- The parameter ${r_0}^2$ is connected with the mean square radius of the proton by the formula: $< r_N^2 >= \frac{3}{2} r_0^2$.

- The probability amplitude of the elementary interaction depends on transverse coordinates:

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

- With confienment taken into account with Yukawa's model with $r_{max} \simeq 0.2$- 0.3fm:

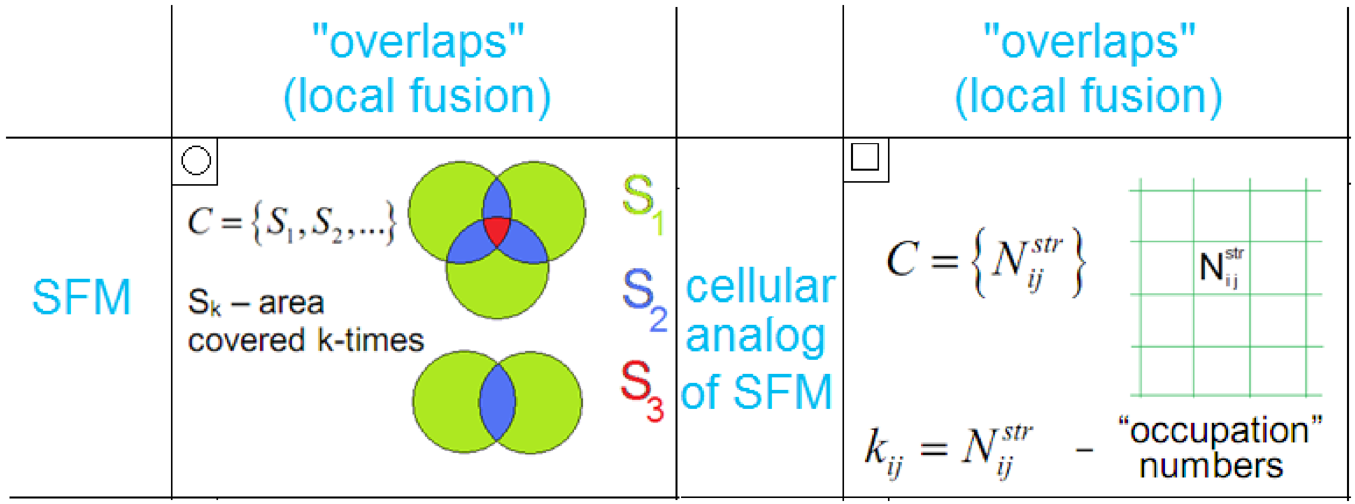
$$f = \frac{\alpha_s^2}{2} \left[K_0\left(\frac{|\vec{r}_1 - \vec{r}_1\,'|}{r_{max}}\right) + K_0\left(\frac{|\vec{r}_2 - \vec{r}_2\,'|}{r_{max}}\right) - K_0\left(\frac{|\vec{r}_1 - \vec{r}_2\,'|}{r_{max}}\right) - K_0\left(\frac{|\vec{r}_2 - \vec{r}_1\,'|}{r_{max}}\right) \right]^2$$

where K_0 is modified Bessel function.

[3] G. Gustafson, Acta Phys. Polon. B40, 1981 (2009)
[4] C. Flensburg, G. Gustafson, and L. Lonnblad, Eur. Phys. J. (C) 60, 233 (2009)

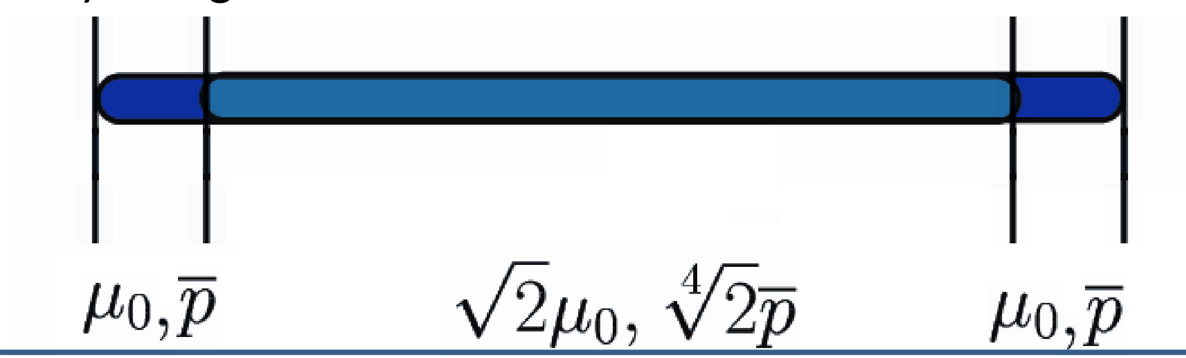
String fusion and finite rapidity strings

- The transverse coordinates of the centers of a string are equal to the arithmetic mean of corresponding transverse coordinates of the partons at the ends of strings
- The cellular option for string fusion is applied

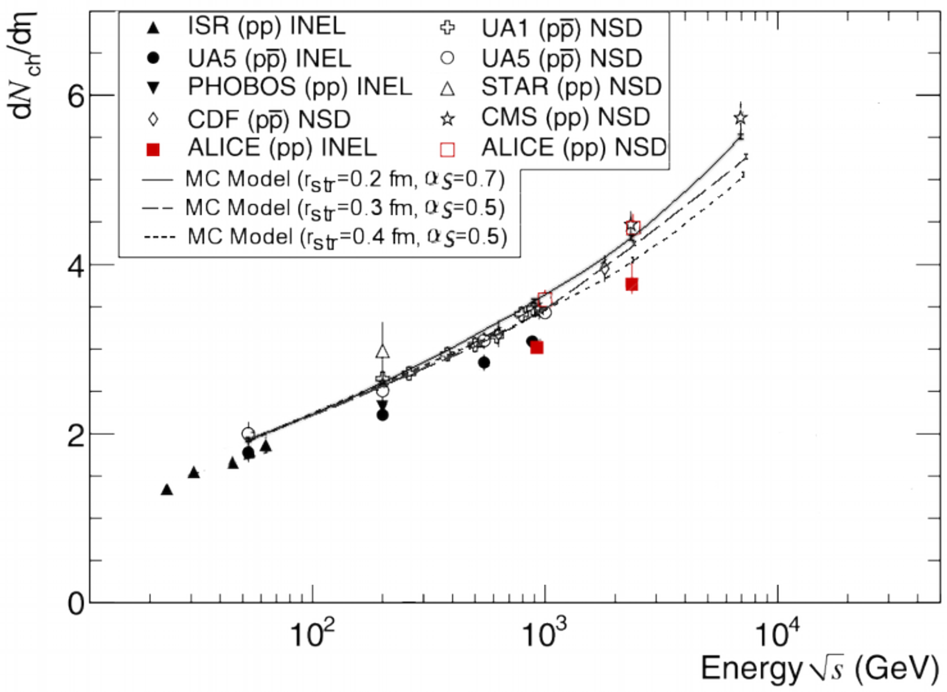


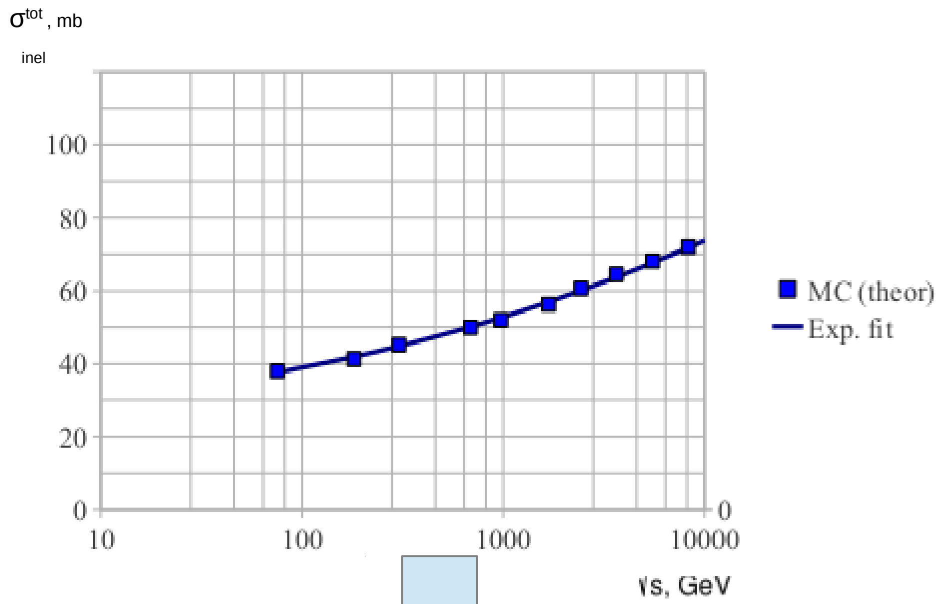
V. V. Vechernin and R. S. Kolevatov, Vestn. SPb. Univ., Ser. Fiz. Khim., No. 2, 12 (2004); hep-` ph/0304295.
V. V. Vechernin and R. S. Kolevatov, Vestn. SPb. Univ., Ser. Fiz. Khim., No. 4, 11 (2004); hep-ph/0305136.

- Separate processing of the rapidity intervals with different (but integer) number of rapidity strings

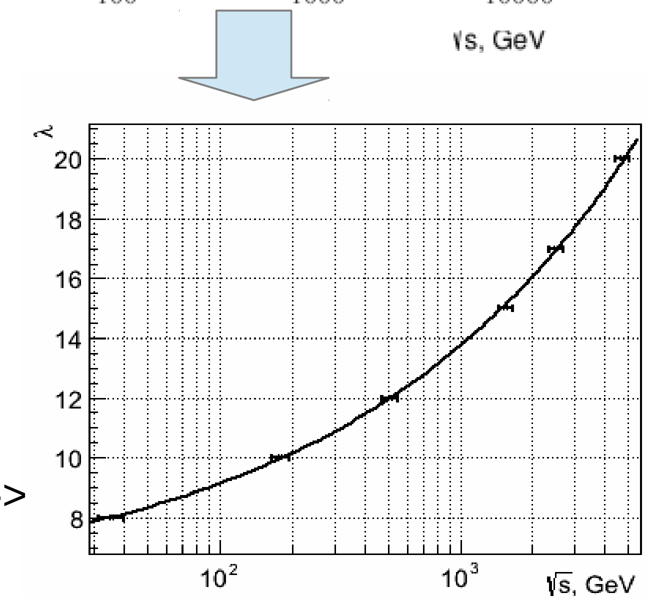


Parameters fixing





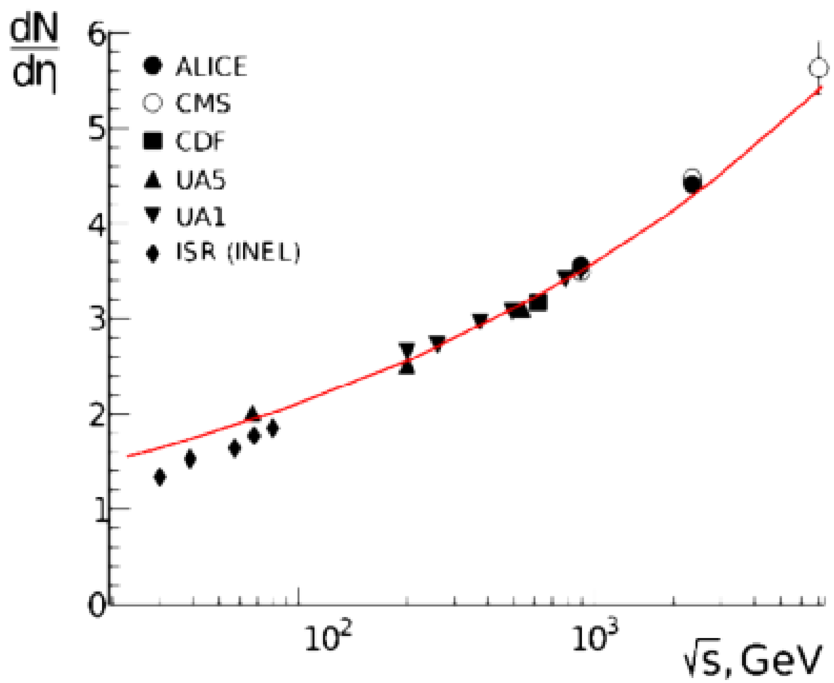
r_{str}=0.2, α_s= 0.4, μ_0=1.152, r_0=0.6fm, r_0/r_{max}=0.5 ✔

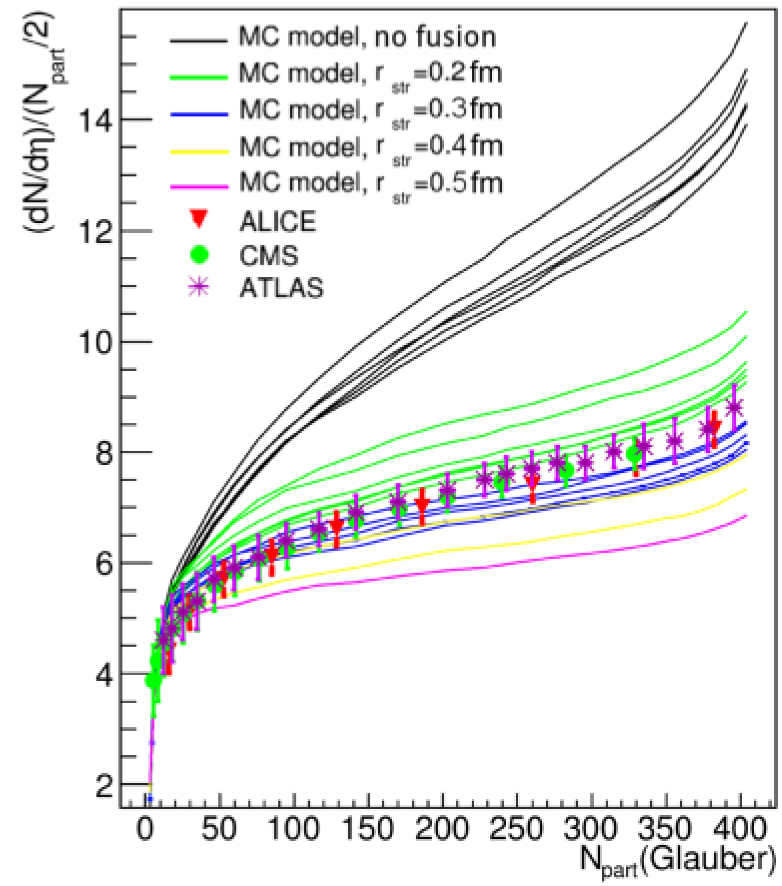


Connection of λ with collision energy ->

V. N. Kovalenko, Phys. Atom. Nucl. 76, 1189 (2013), arXiv:1211.6209 [hep-ph]
V. Kovalenko, PoS (QFTHEP 2013) 052 (2013).

Parameters fixing: pp and AA





- The model describes
  - total inelastic cross section of pp collisions
  - charged multiplicity pseudorapidity density in pp collisions
  - multiplicity in minimum bias p-Pb collisions at 5.02 TeV
  - centrality dependence of multiplicity in Pb-Pb collisions

V. N. Kovalenko, Phys. Atom. Nucl. 76, 1189 (2013), arXiv:1211.6209 [hep-ph]
V. Kovalenko, PoS (QFTHEP 2013) 052 (2013).

Selection of observables

Colliding systems

p+p, Be7+Be9, p+Pb, Ar+Ca, Au+Au, Pb+Pb

Colliding energies

$\sqrt{s}$: 5 GeV, 8 GeV, 17 GeV, 27 GeV, 39 GeV,

Centrality

min. bias for p+p, Be+Be, p+Pb;

two classes (N_{part}<(A+B)/2, N_{part}>(A+B)/2) for Ar+Ca, Au+Au, Pb+Pb

Rapidity windows configurations

(-1 ; 0) – (0 ; 1)
(0 ; 1) – (1 ; 2)
(0 ; 1) – (2 ; 3)

Correlation coefficients

n-n, pt-n, pt-pt

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, ...
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RHIC BES	5 - 200 GeV	Au+Au
NICA, JINR	3 - 11 GeV	from p to Au

Selection of observables

Colliding systems

p+p, Be7+Be9, p+Pb, Ar+Ca, Au+Au, Pb+Pb

Colliding energies

$\sqrt{s}$: 5 GeV, 8 GeV, 17 GeV, 27 GeV, 39 GeV, 62.4 GeV

Centrality

min. bias for p+p, Be+Be, p+Pb;

two classes ($N_{part}<(A+B)/2$, $N_{part}>(A+B)/2$)

for Ar+Ca, Au+Au, Pb+Pb

Rapidity windows configurations

(-1 ; 0) – (0 ; 1)

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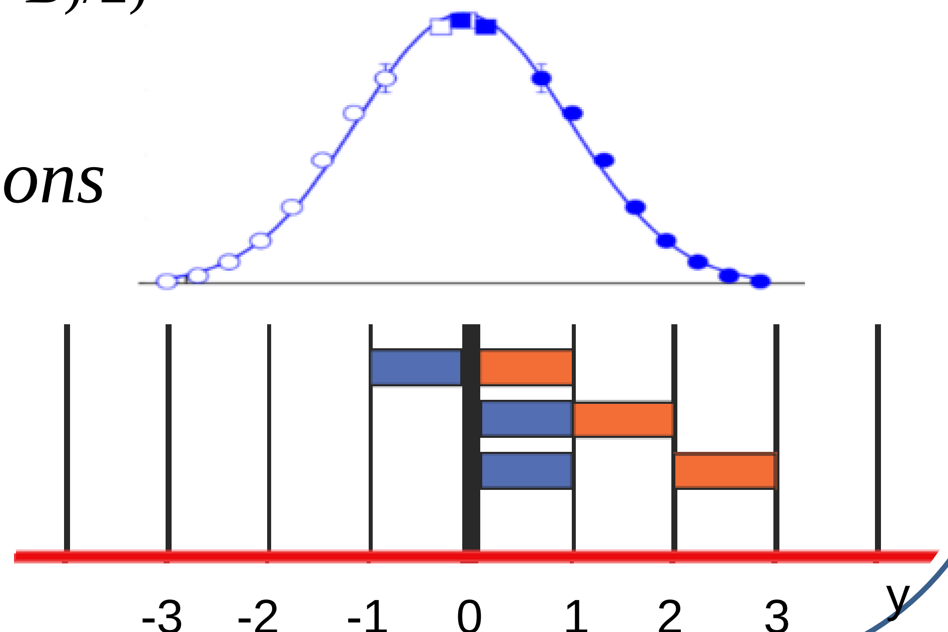
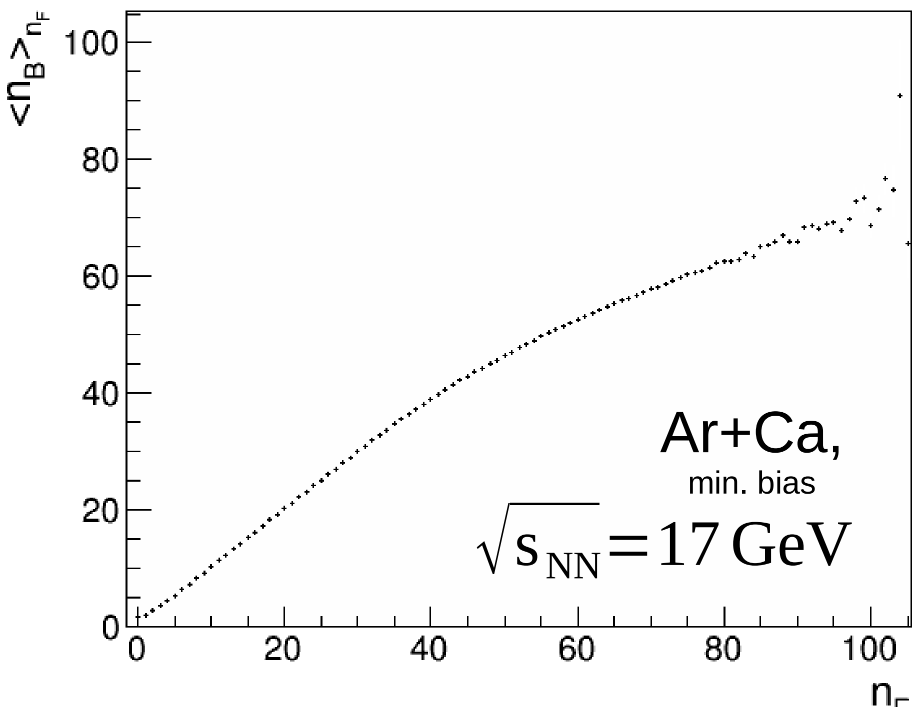
(0 ; 1) – (2 ; 3)

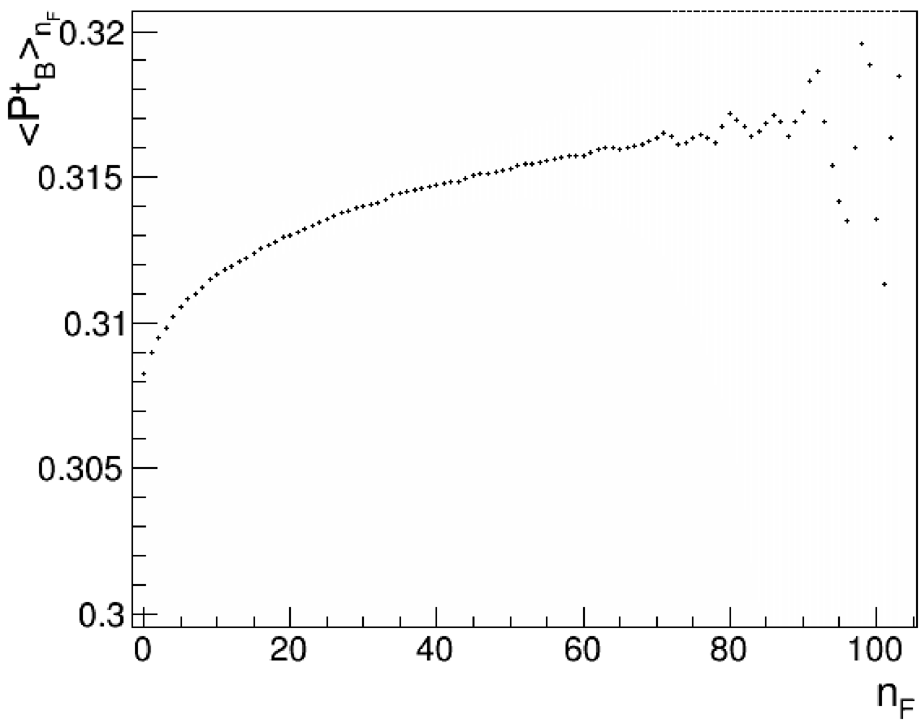
Correlation coefficients

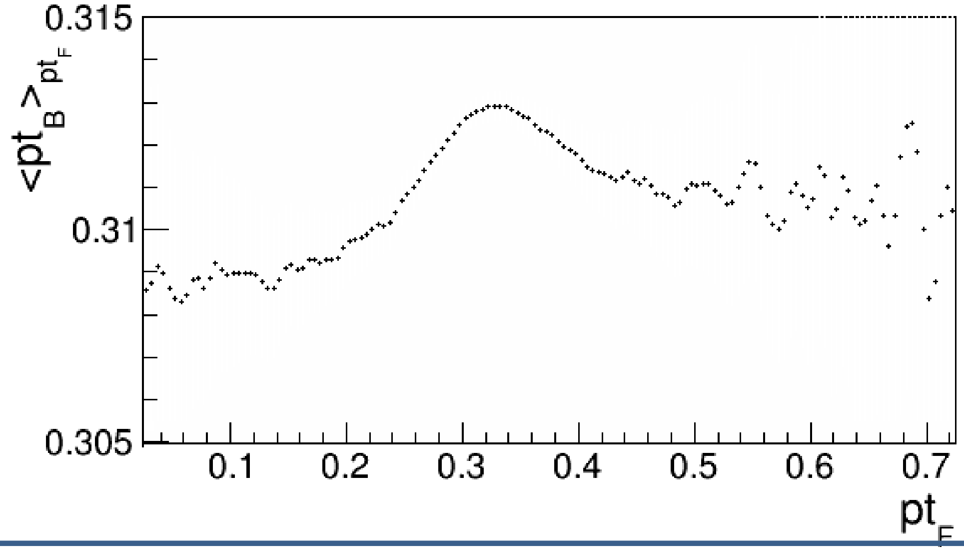
n-n, pt-n, pt-pt

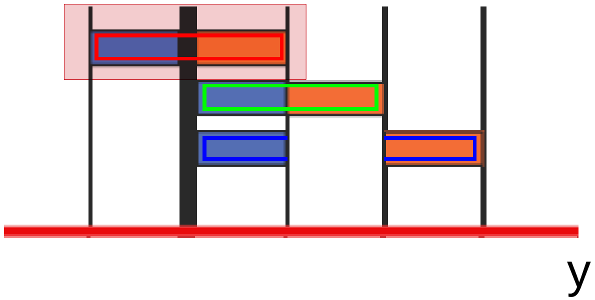


Correlation functions





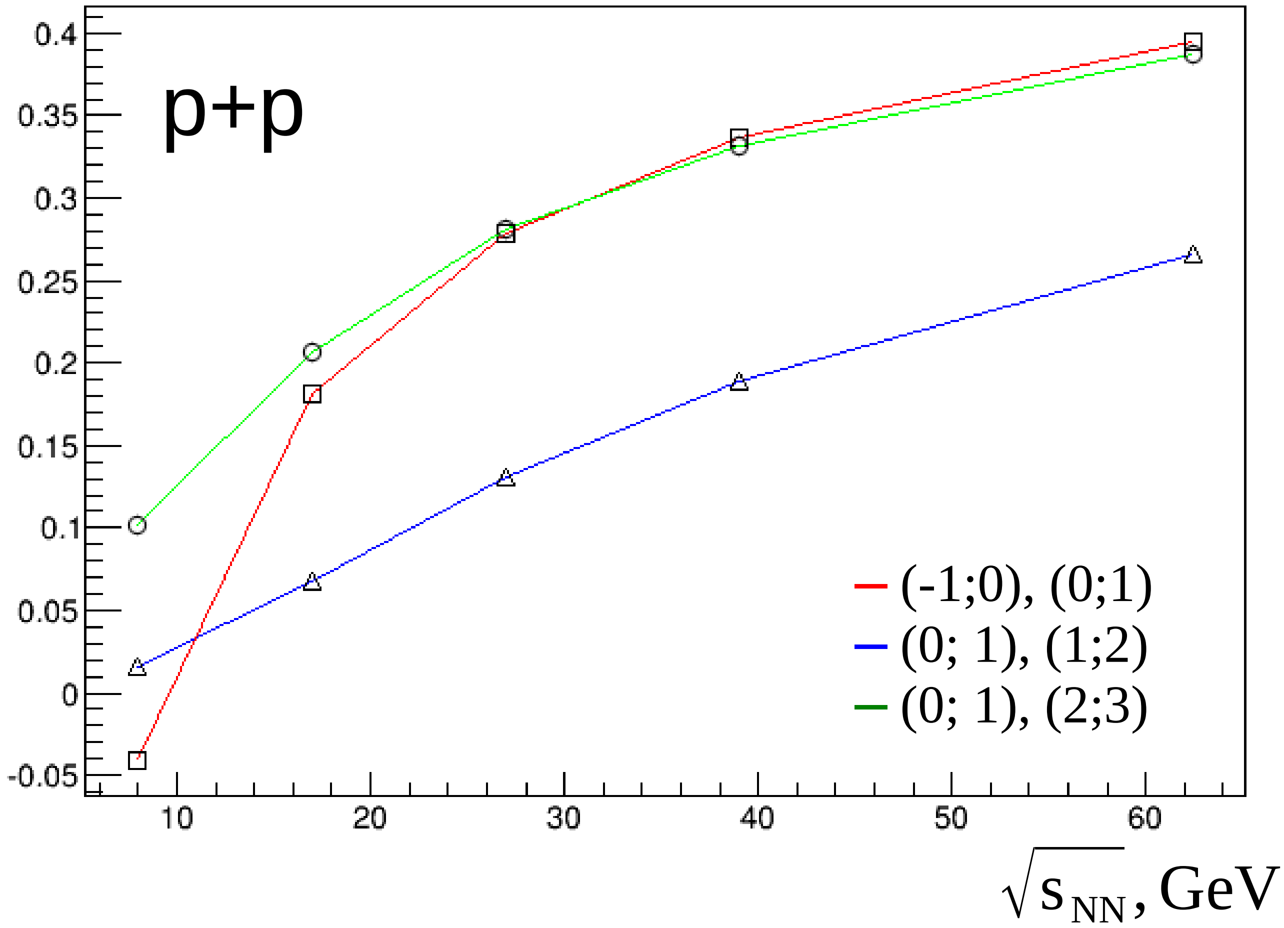




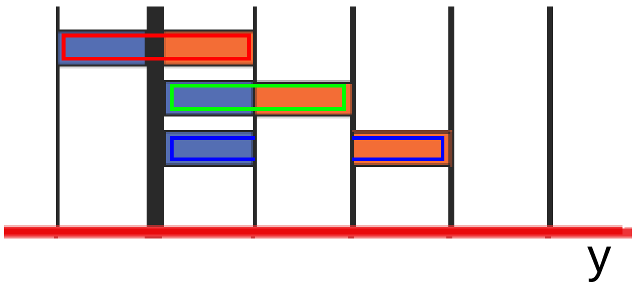
rapidity windows – (-1;0), (0;1)

Correlation coefficients

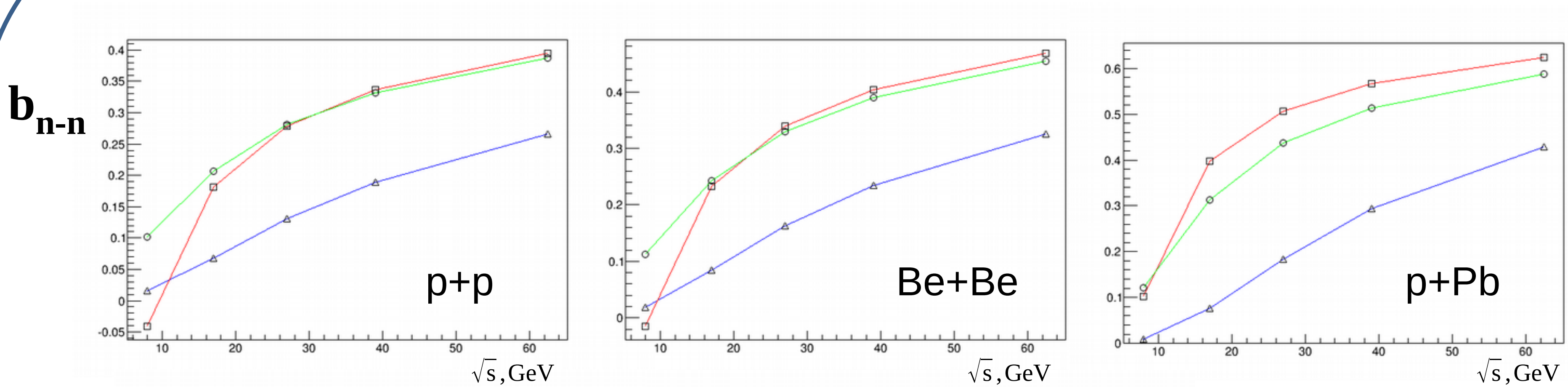
$b_{n\text{-}n}$

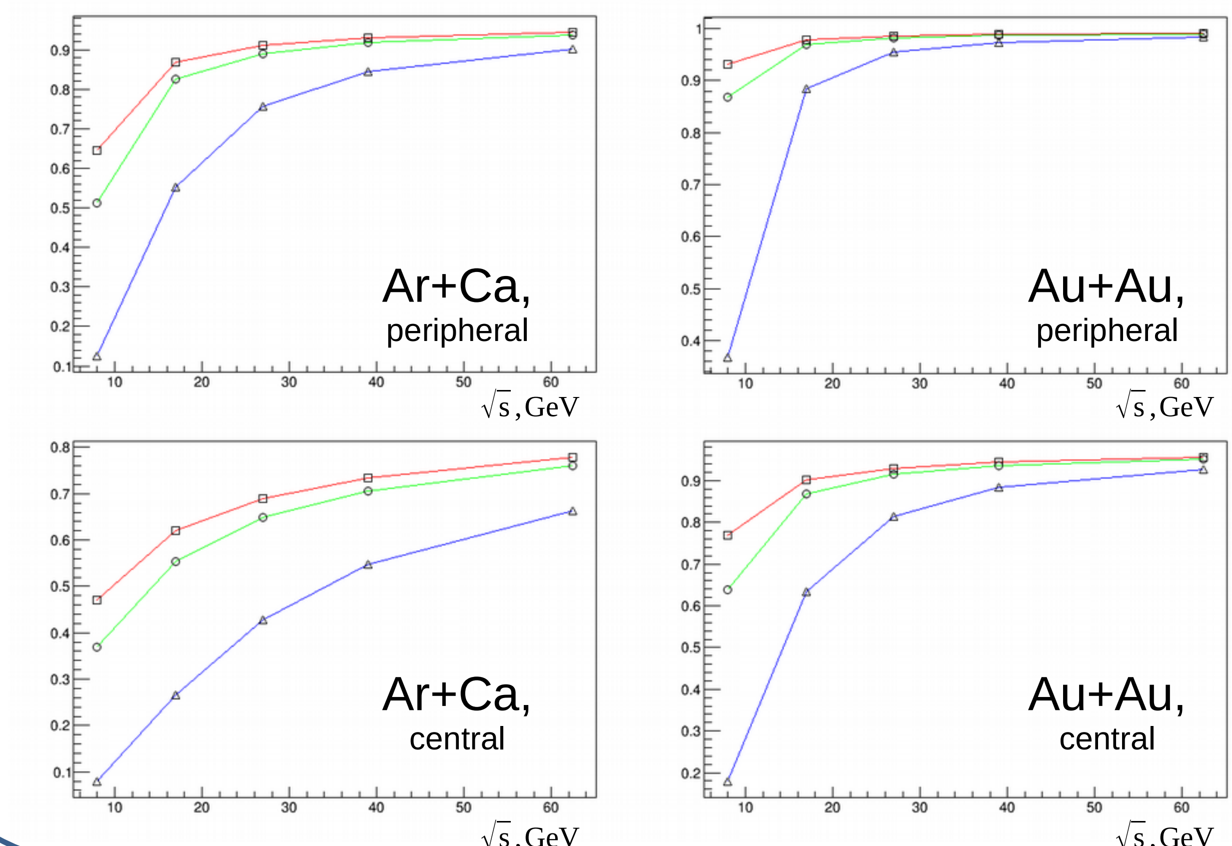


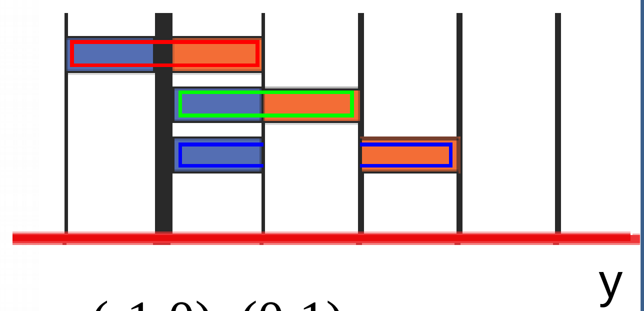
- Rapidity windows configurations:



Results: n-n correlation coefficient







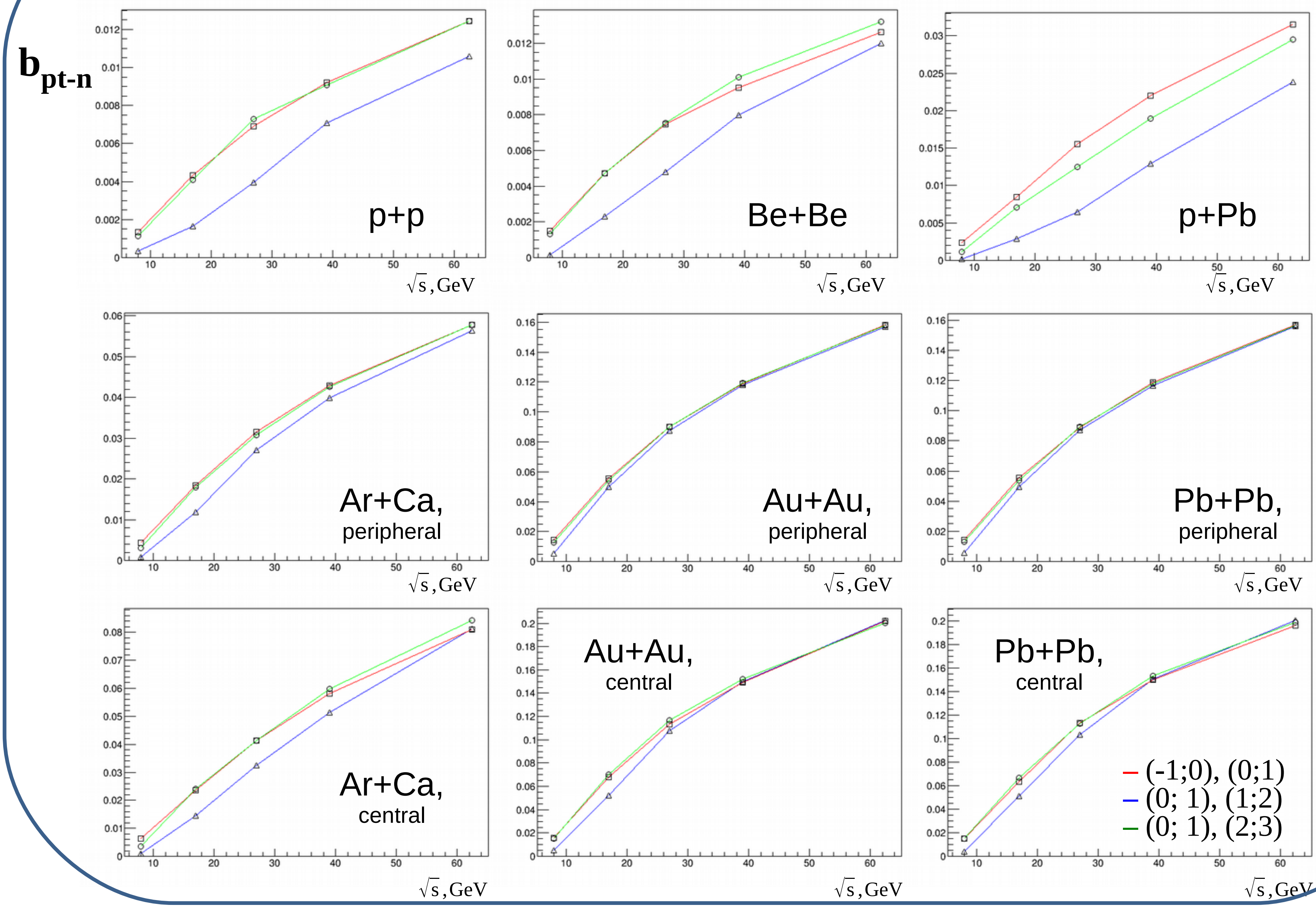
— (-1;0), (0;1)

— (0; 1), (1;2)

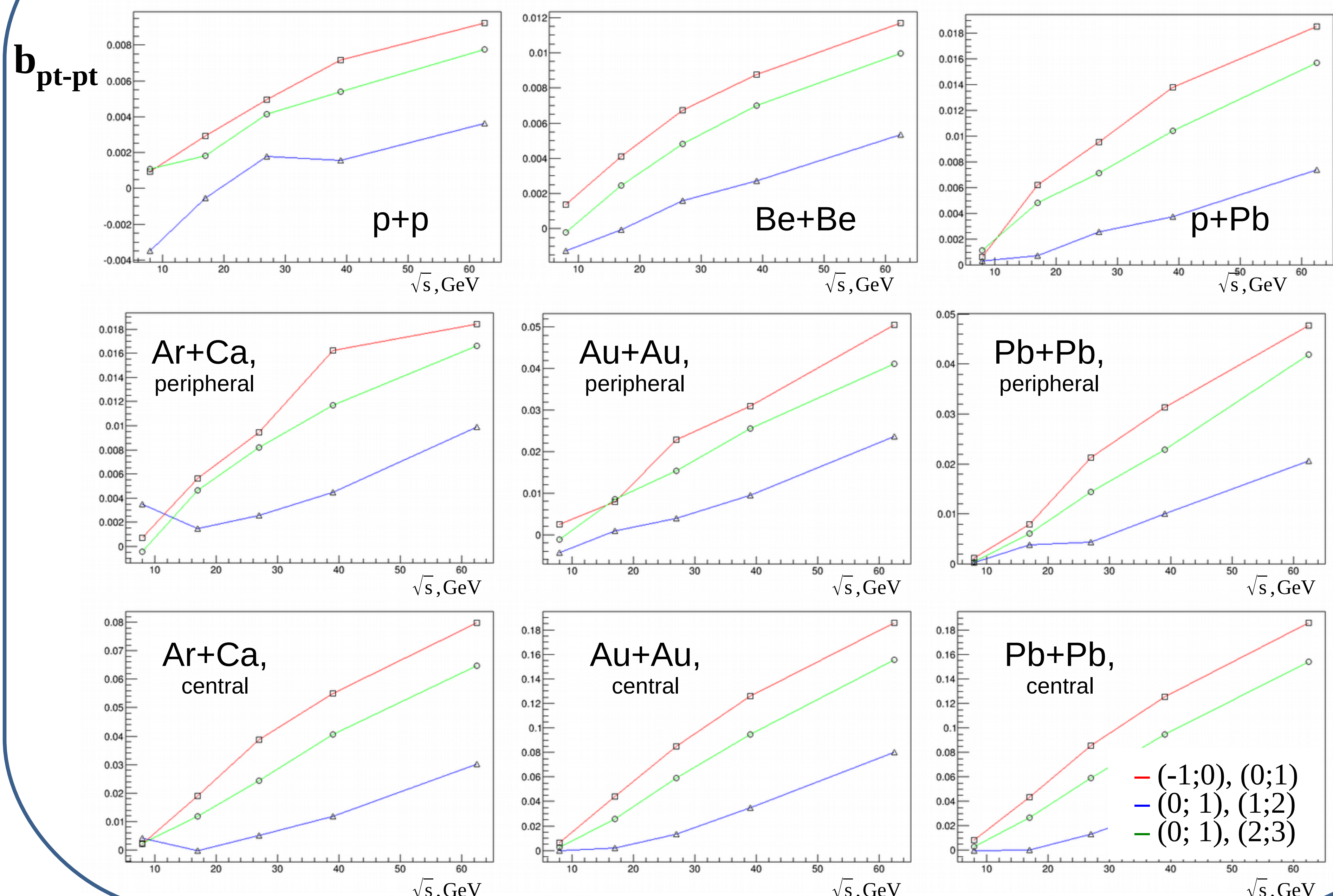
— (0; 1), (2;3)

- Smooth energy behavior of b_{n-n}
- Fast growth and saturation

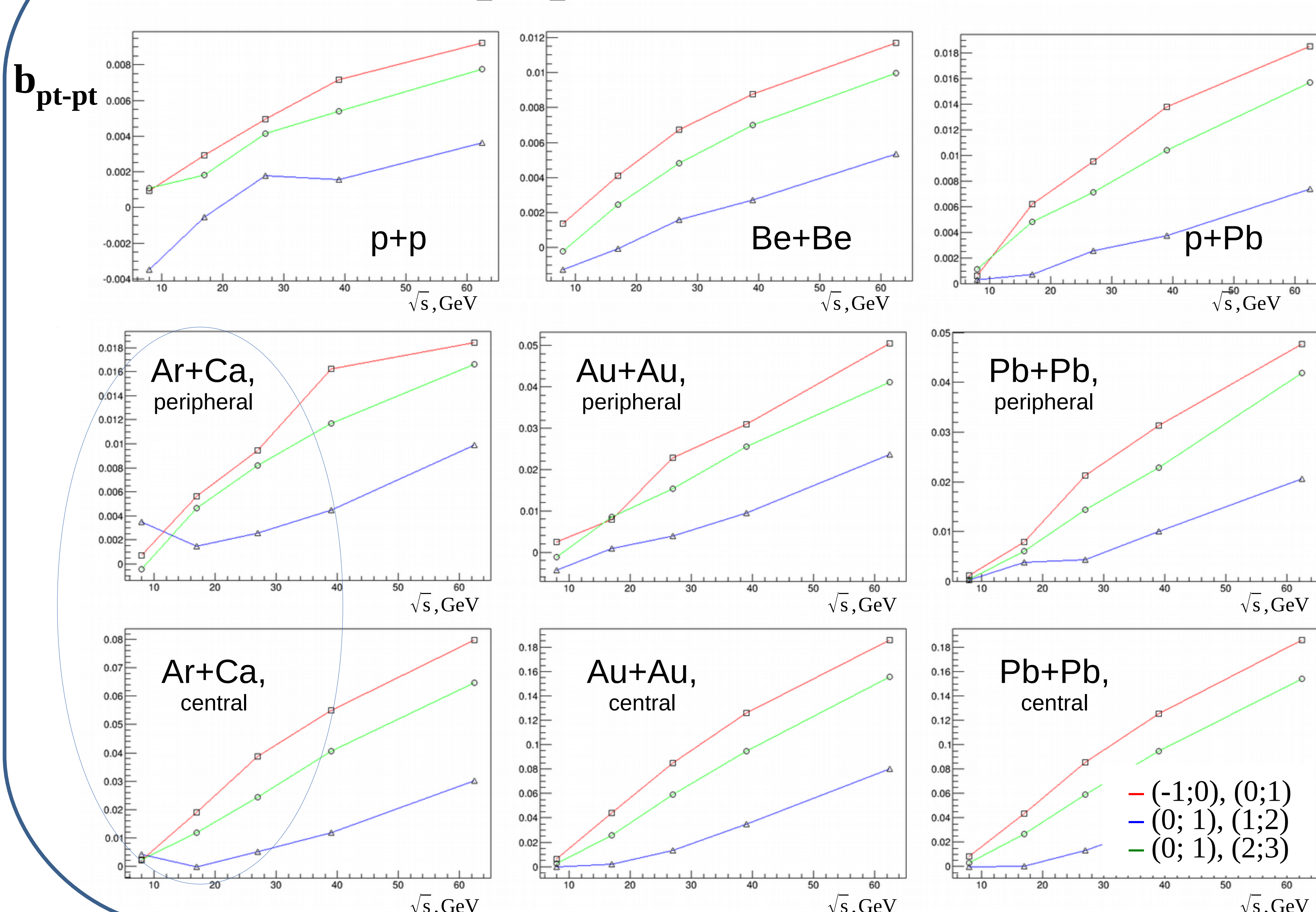
Results: pt-n correlation coefficient



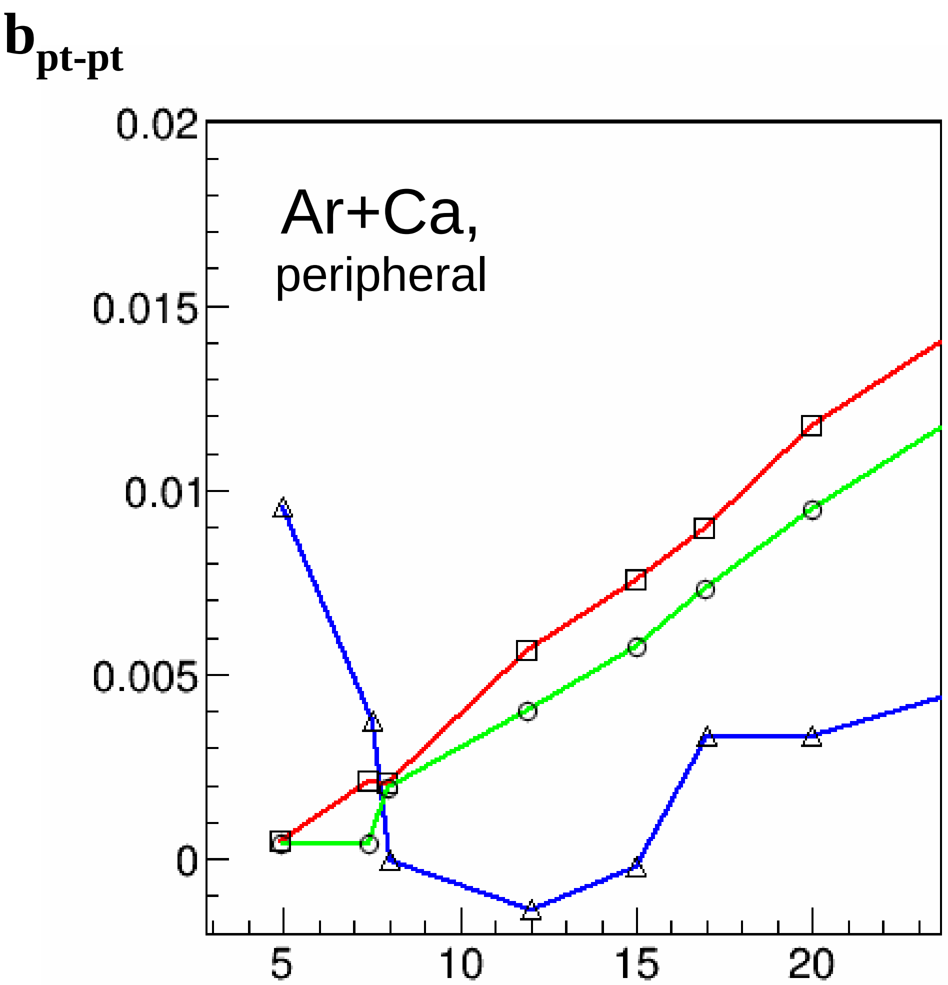
Results: pt-pt correlation coefficient

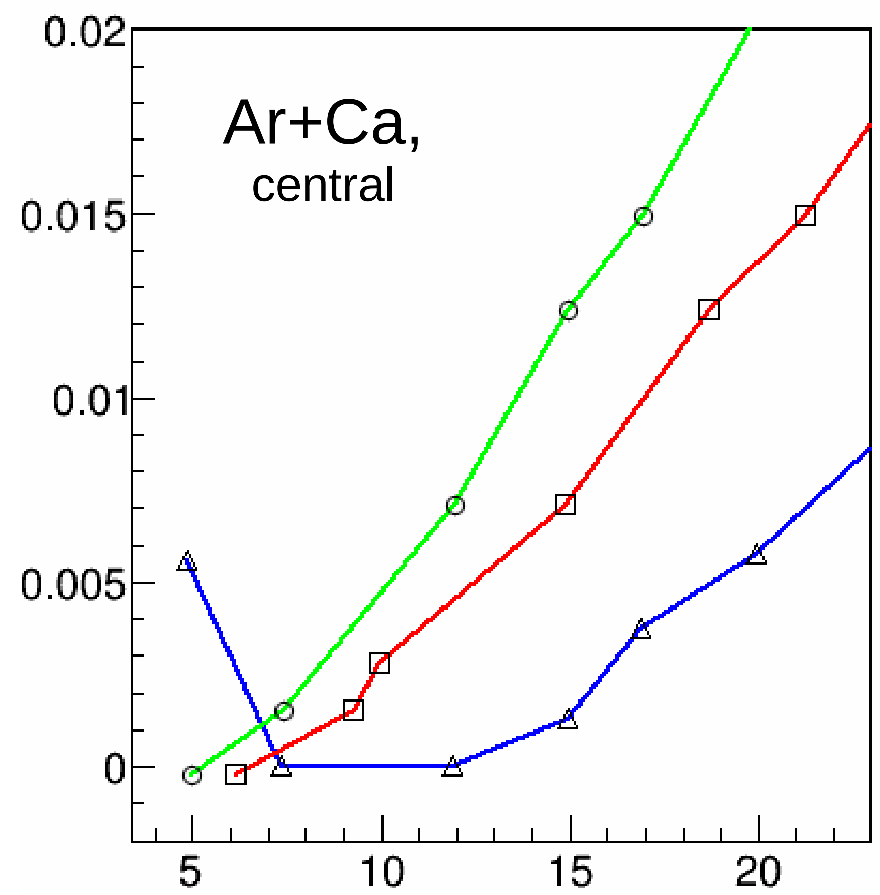


Results: pt-pt correlation coefficient



Results: pt-pt correlation coefficient
Ar+Ca more detailed study



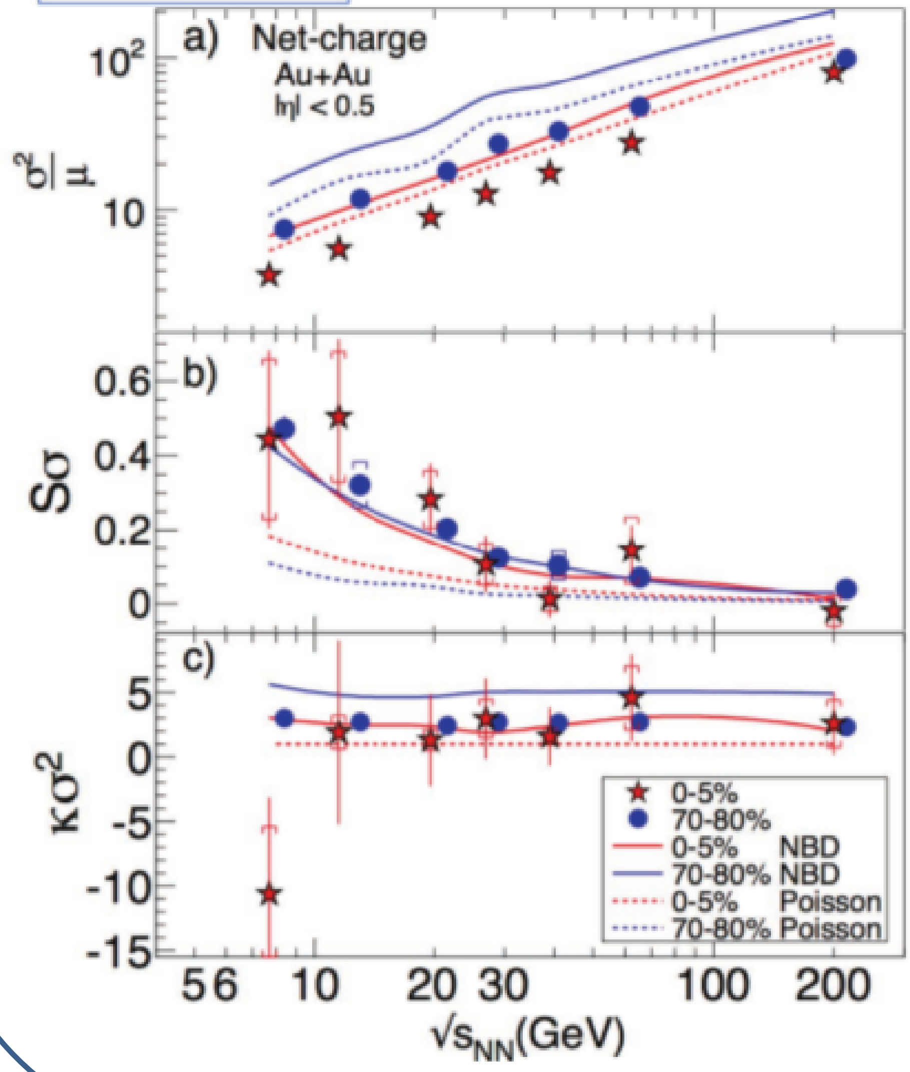


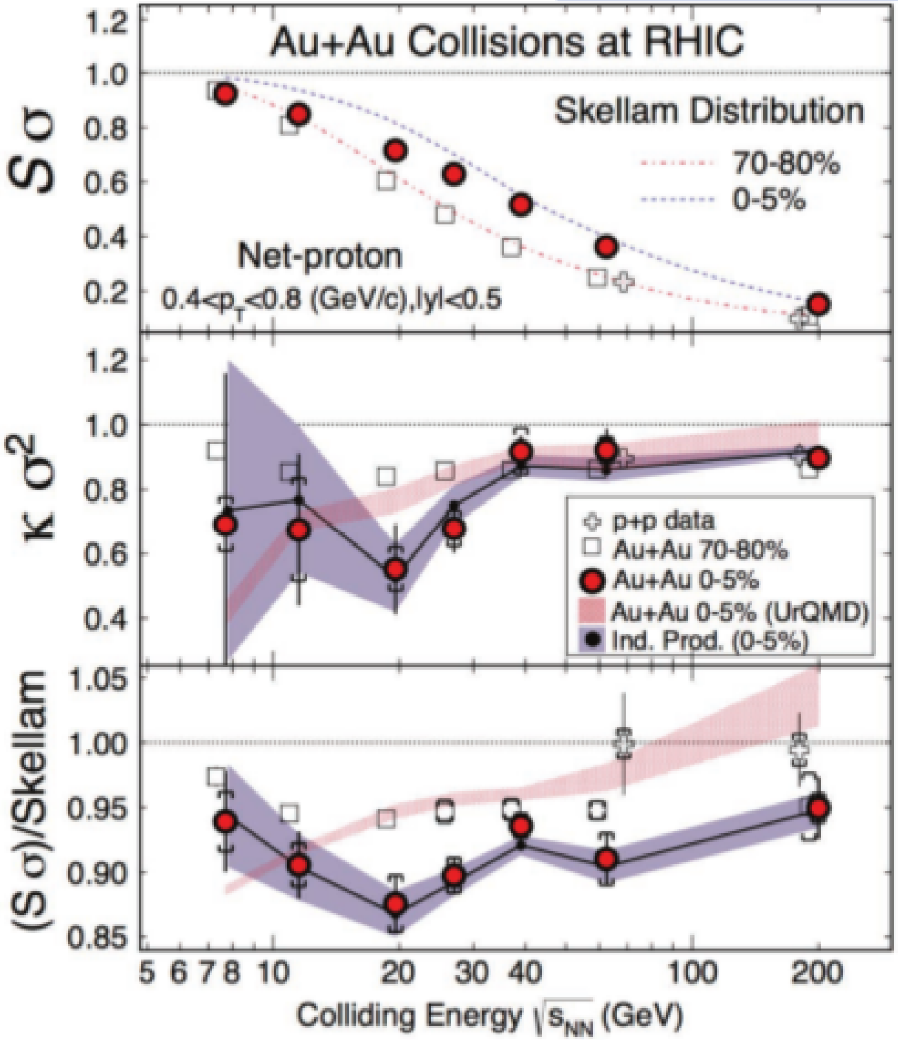
Experiment

STAR publications 2014

arXiv: 1402.1558

PRL 112(2014) 032302





slide from M. J. Tannenbaum, Erice 2014

Summary and outlook

- String fusion approach to the Quark-gluon plasma formation at non-zero baryon chemical potential has been proposed
- A model for the string fusion accounting finite rapidity width of strings for pp, pA and AA collisions is developed and applied at the SPS energies
- Long-range correlation coefficients are studied:
  - Smooth monotonic behavior of n-n and pt-n correlation with energy
  - non-monotonic pt-pt correlations in Ar+Ca collisions

- A more detailed scan, including calculation of correlations in narrow centrality classes, is required
- Extension of the model for net-charge and net-proton fluctuation and correlation studies, exploring the strongly intensive variables

End Of Presentation

Thank you!

Backup

Search for critical point indications in long-range correlations by energy and system size scanning in string fusion approach

Abstract content

Studies of the collisions of various hadrons and nuclei at different centrality and energy enable to explore the QCD phase diagram over a wide range of temperature and baryon density in search of the critical point. In the framework of the string fusion approach [1] the critical behavior takes place when the processes of string fusion and percolation come into play, what can be considered as a possible way of Quark Gluon Plasma formation [2]. Around percolation threshold, strong fluctuations in colors of strings appear what lead to large fluctuations in some observables, which one can find by the event by event analysis.

In the present study, a Monte Carlo model [3] of proton-proton, proton-nucleus, and nucleus-nucleus collisions has been developed and applied to heavy and light ion collisions at the cms energy range from a few up to several hundred GeV per nucleon, where the critical effects are expected. The model takes into account both the string fusion and the finite rapidity length of strings, implementing the hadronic scattering through the interaction of color dipoles. It well describes the proton-nucleus and nucleus-nucleus collisions at the partonic level without using Glauber model of nuclear collisions. All parameters are fixed using experimental data on inelastic cross section and multiplicity. In the framework of the model, we performed a beam energy and system size scan and studied the behaviour of correlation and fluctuation observables. The detailed modeling of the event by event charged particles production allowed to provide predictions in the conditions close to the experimental ones and to make a direct comparison to the existing data.

The authors acknowledge Saint-Petersburg State University for the research grants 11.38.66.2012 and 11.38.197.2014. V. N. Kovalenko also acknowledges the support of Special SPbSU Rectors Scholarship and Dynasty Foundation Scholarship.

[1] N. S. Amelin, M. A. Braun and C. Pajares, Phys. Lett. B306, 312 (1993); Z. Phys. C63,507 (1994).
[2] M. A. Braun, C. Pajares, J. Ranft. Int. J. Mod. Phys. A 14 2689 (1999). [3] 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.

Summary

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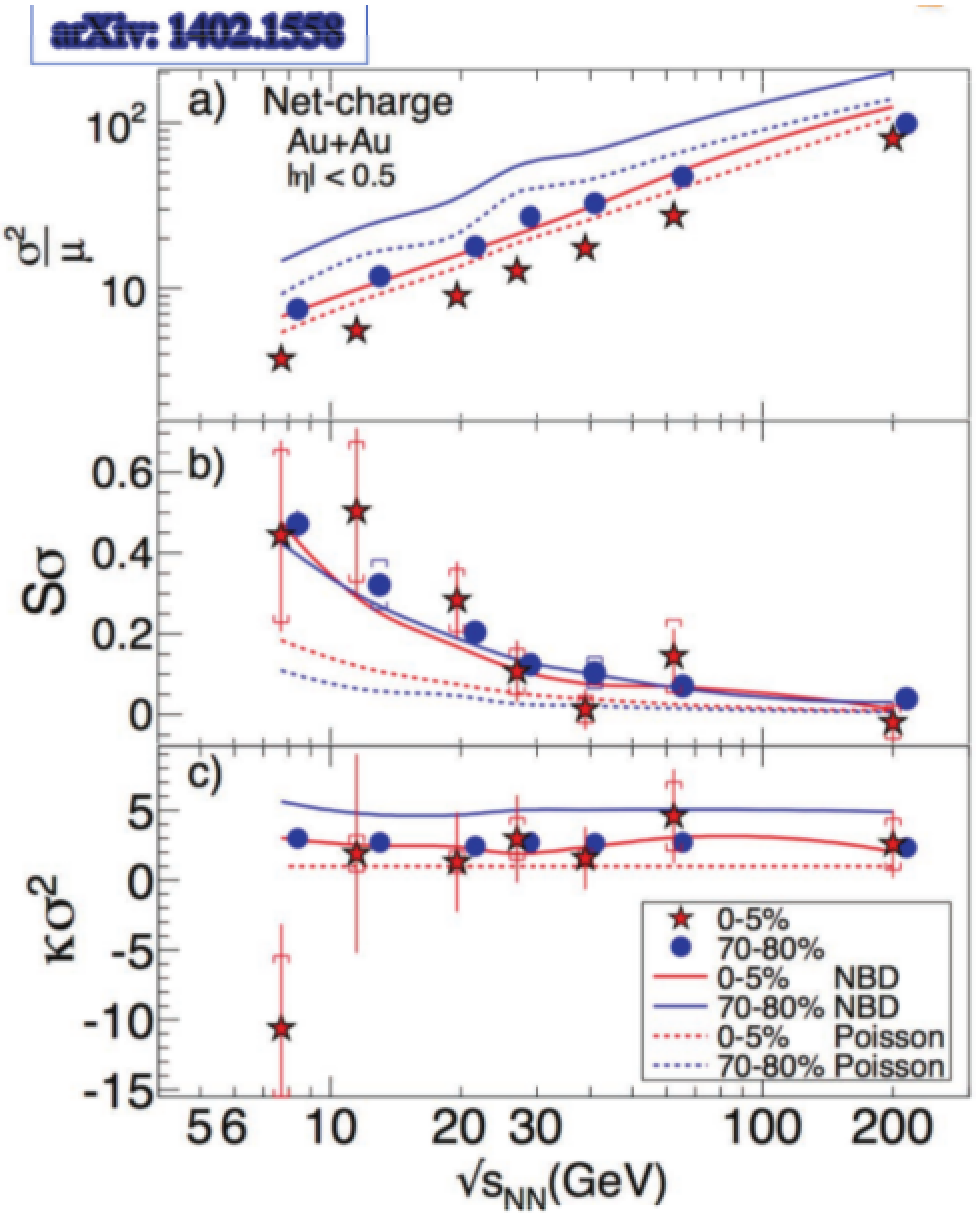
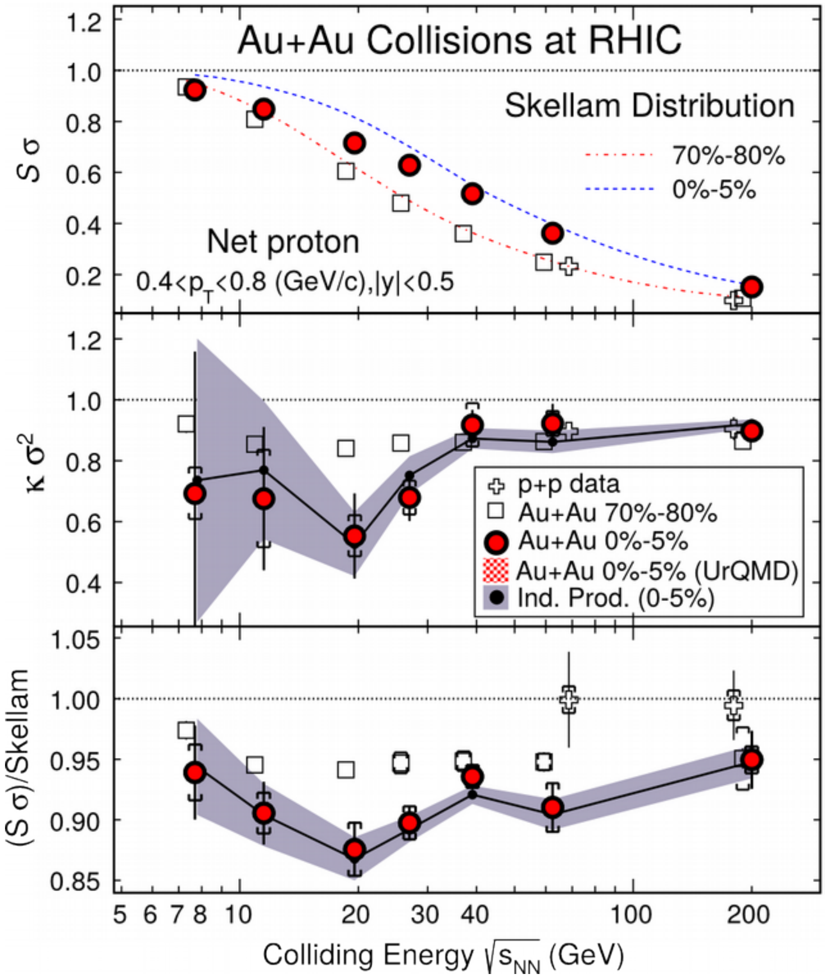
Track Classification : Section D: Deconfinement
Contribution Type : Oral

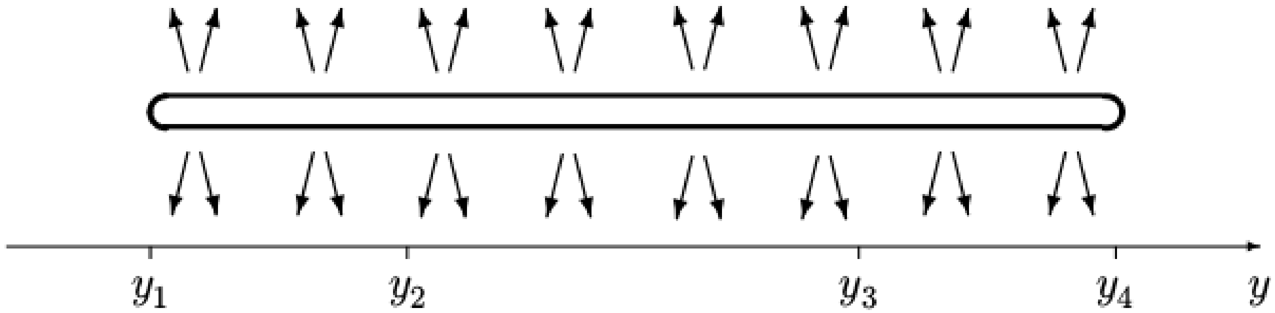
Submitted by **KOVALENKO, Vladimir** on **Sunday 22 June 2014**


arXiv: 1402.1558
a) Net-charge
Au+Au
|η| < 0.5
$\frac{\sigma^2}{\mu}$
b)
Sσ
c)
κσ²
0-5%
70-80%
0-5% NBD
70-80% NBD
0-5% Poisson
70-80% Poisson
√sNN(GeV)

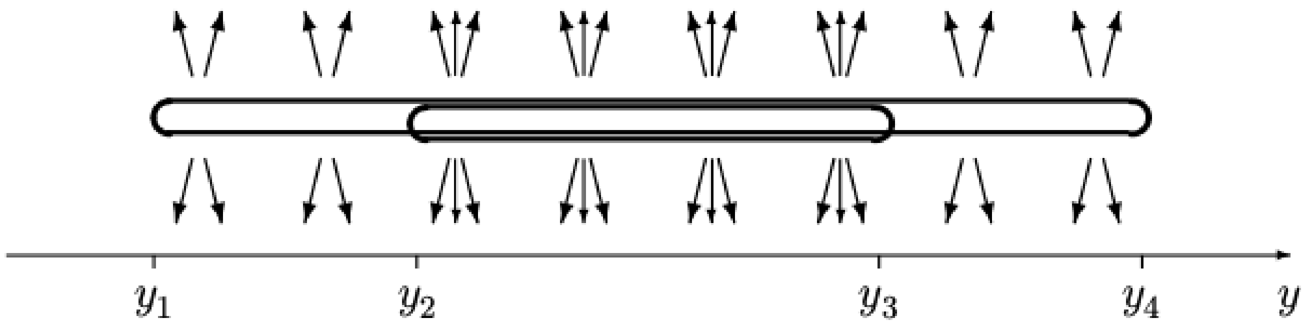

Au+Au Collisions at RHIC
Skellam Distribution
70%-80%
0%-5%
Net proton
0.4<pT<0.8 (GeV/c),|y|<0.5
S σ
κ σ²
p+p data
Au+Au 70%-80%
Au+Au 0%-5%
Au+Au 0%-5% (UrQMD)
Ind. Prod. (0-5%)
(S σ)/Skellam
Colliding Energy √sNN (GeV)

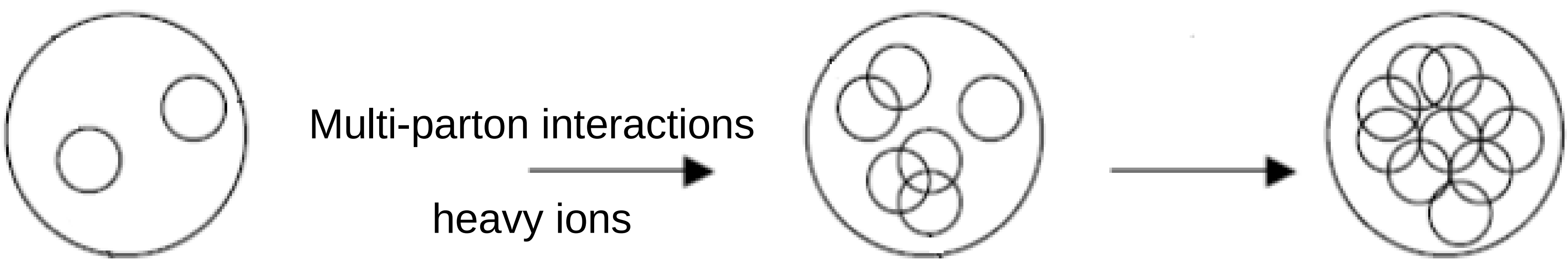
String in rapidity space

- Each string is charectirized by rapidity edges: y_{min} to y_{max}

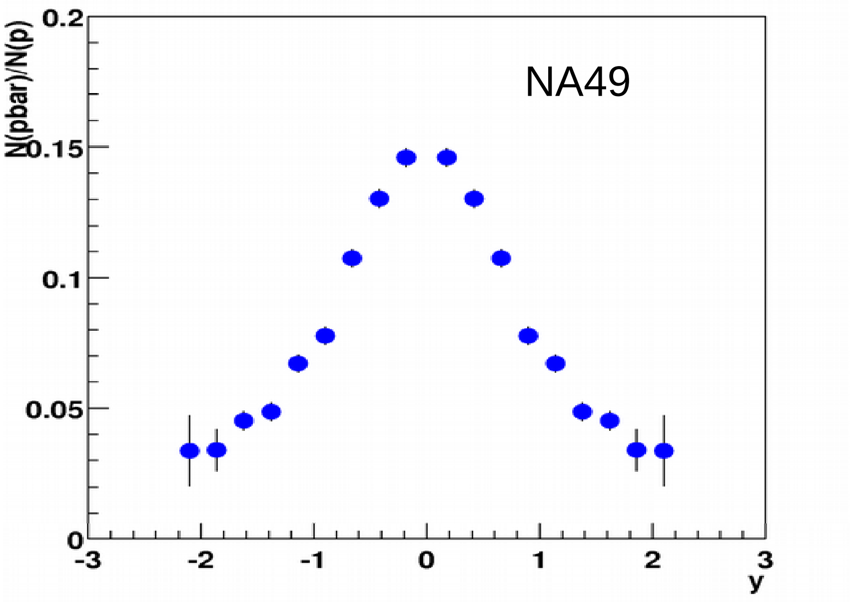


- Uniform rapidity distribution of produced charged particles from one strin





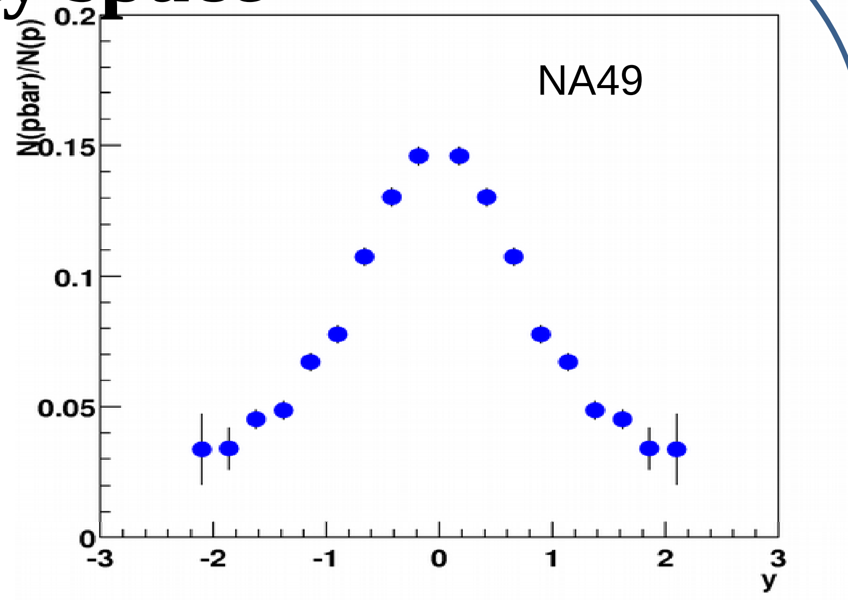
—->>> sqrt(s) increases -->>> —->>> —->>>



http://web.ift.uib.no/~dieter/Paris_final.ppt

String in rapidity space

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



Particle composition from one string