Number and density of quark-gluon strings and collective effects in hadron collisions

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XXII Quark Confinement and the Hadron Spectrum

Thessaloniki (Greece) from 29th August to 3rd September 2016, ROOM, Clio, *(Makedonia Palace)*, 16:40 – 17:00, Friday 02/09/2016

https://indico.cern.ch/event/353906/

The author of this report acknowledges the support by the Russian Science Foundation research grant 16-12-10176

Outline

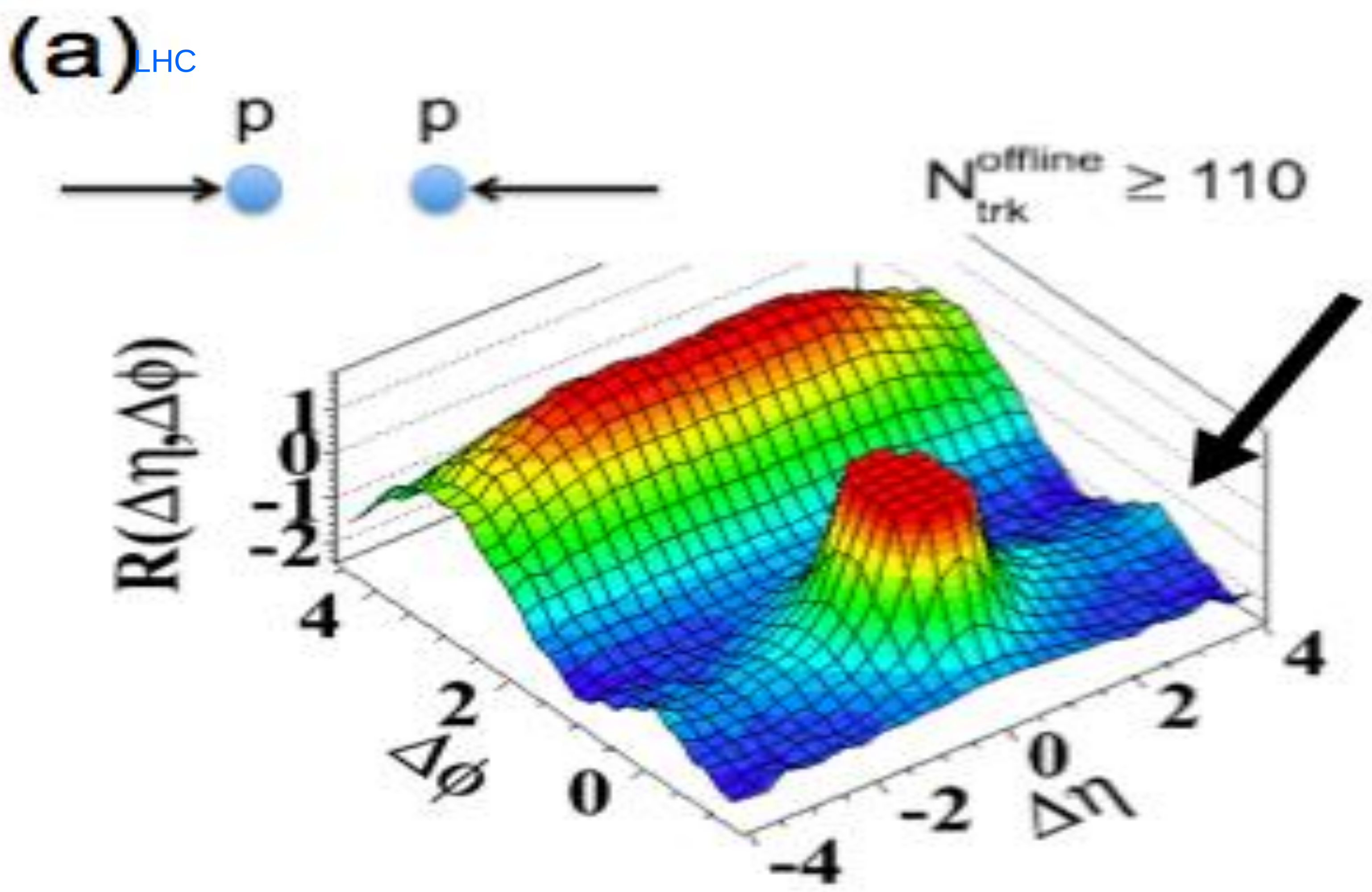
1) Introduction (motivation)

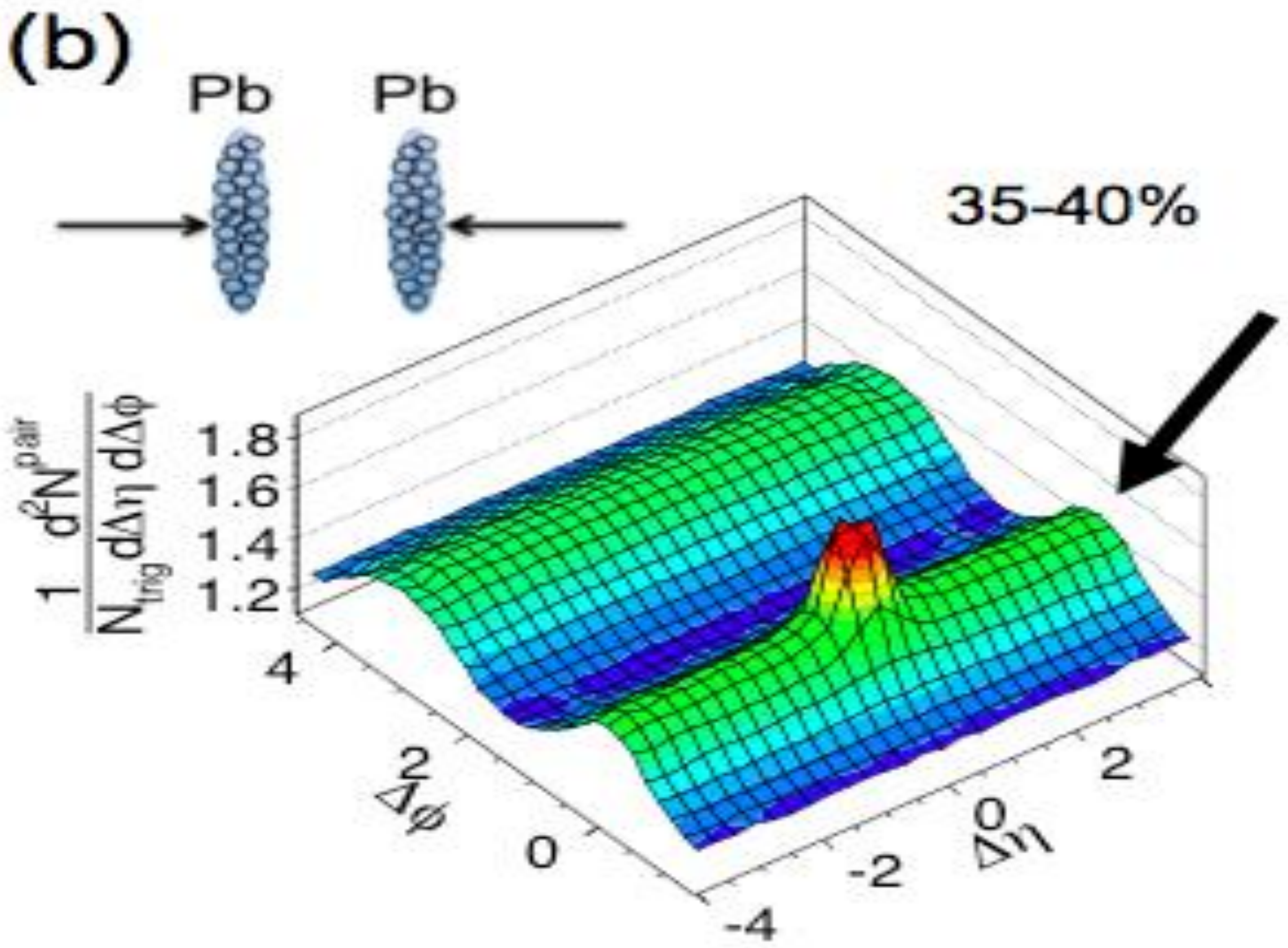
2) Estimates of:

- Number of MPIs from PYTHIA
- Constraints on number of strings in percolation approach basing on the onset of ridge in Au+Au collisions at RHIC
- The multipomeron exchange model with string fusion phenomenon

3) Conclusions

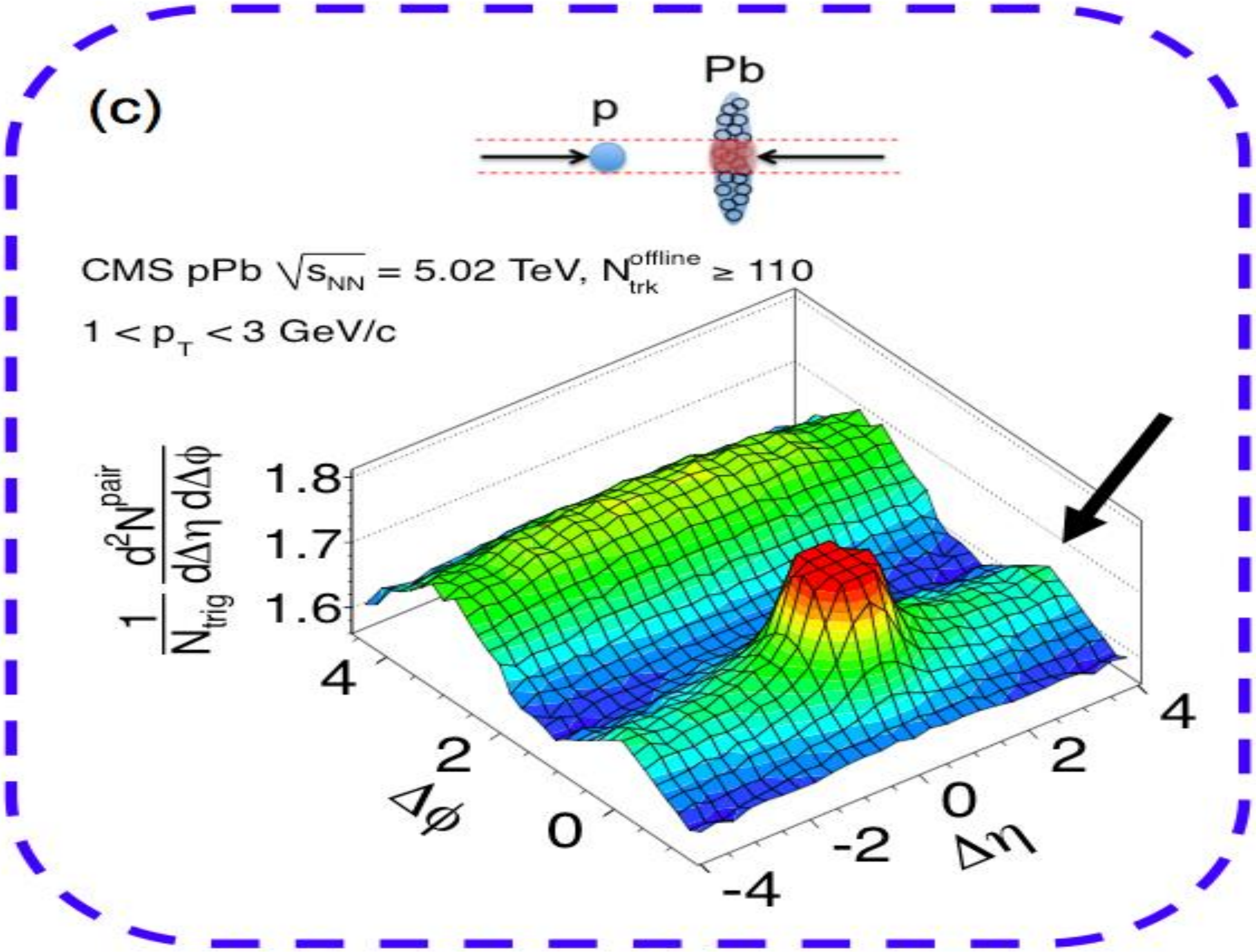
Unexpected long-range correlations observed in pp and p-Pb similar to Pb-Pb collisions





JHEP 09 (2010) 091

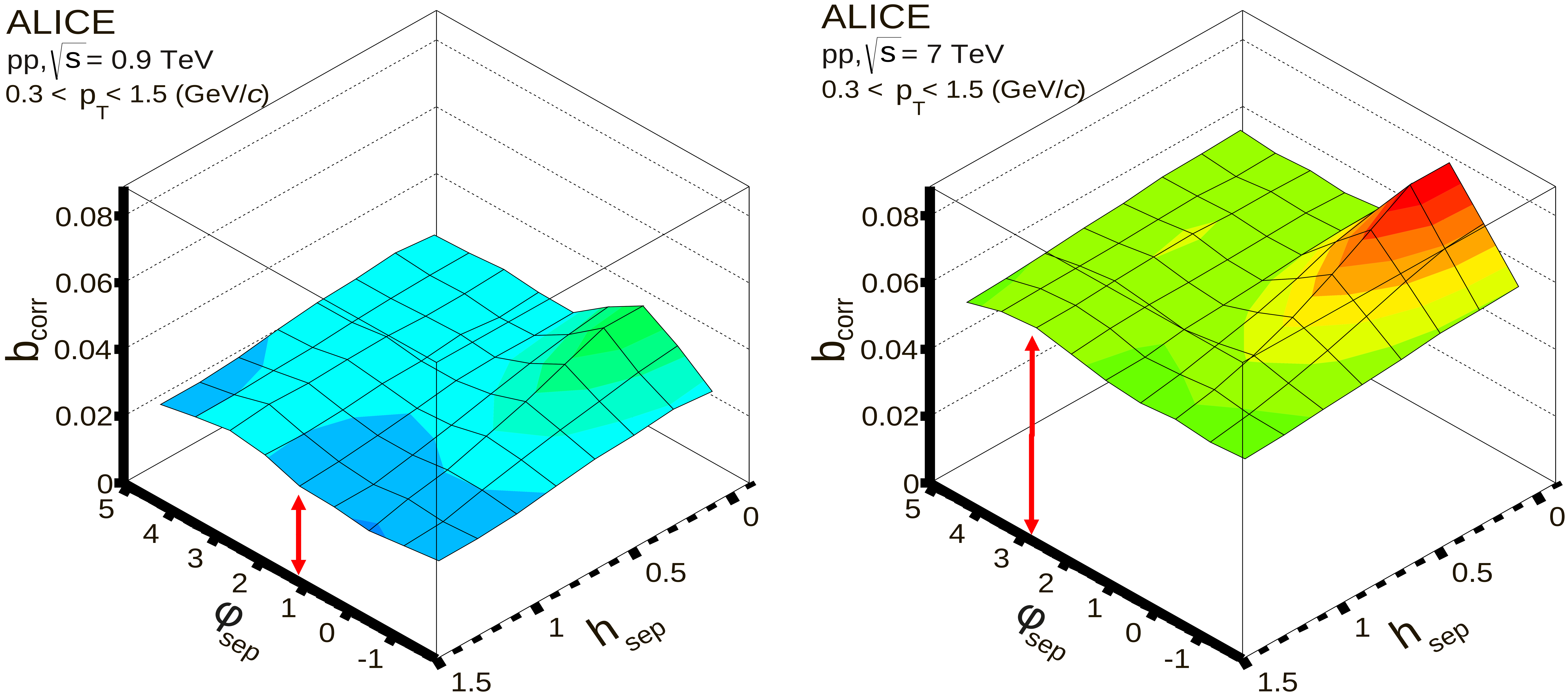
Eur. Phys. J. C 72 (2012)



Phys. Lett. B 718 (2013) 795

arXiv:1210.5482 [nucl-ex]

Forward-Backward multiplicity correlations in pp@LHC



(a) (b)

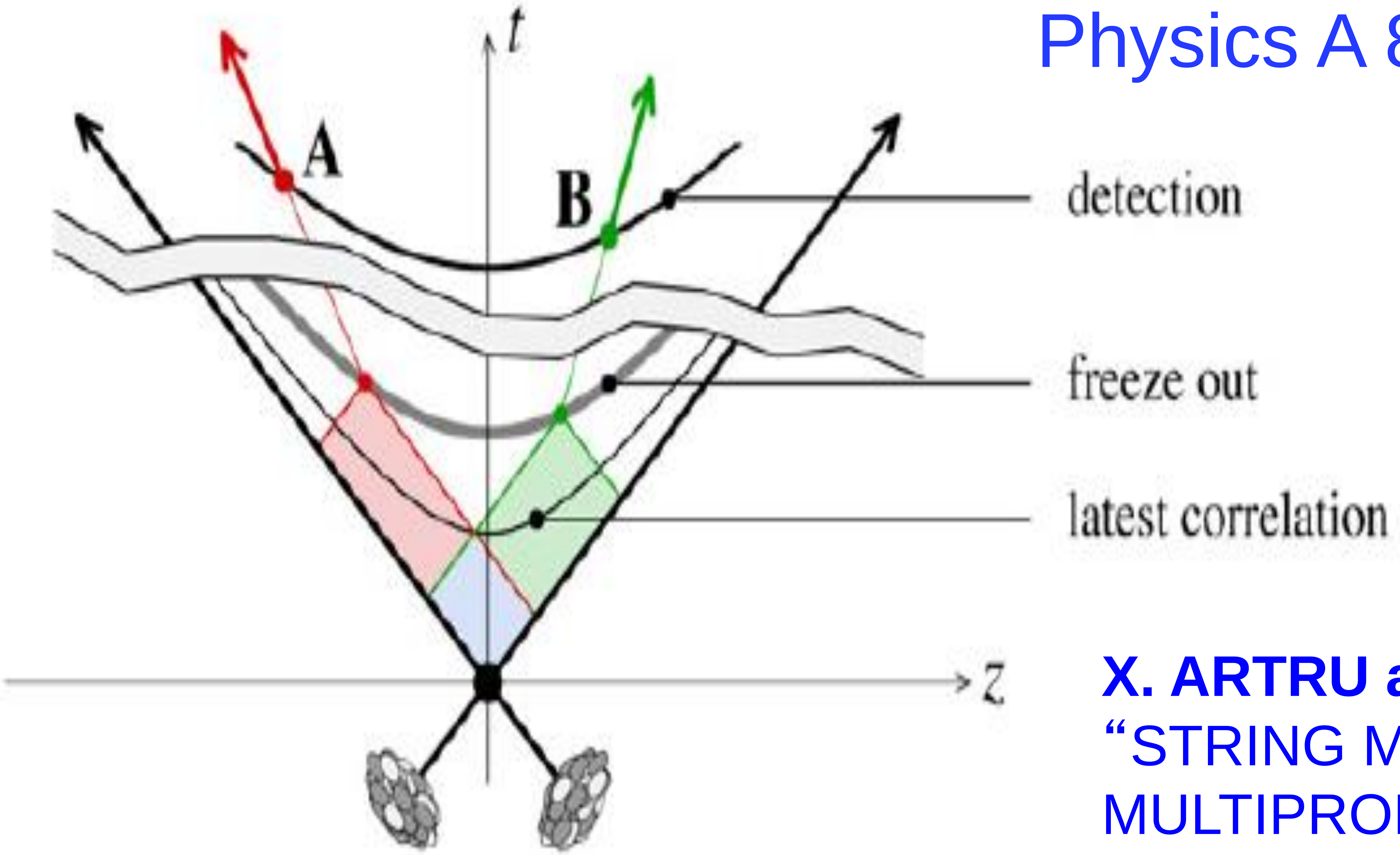
$\sqrt{s}$ = 0.9 TeV **$\sqrt{s}$ = 7 TeV**

ALICE, JHEP 05 (2015) 097; arxiv:1502.00230

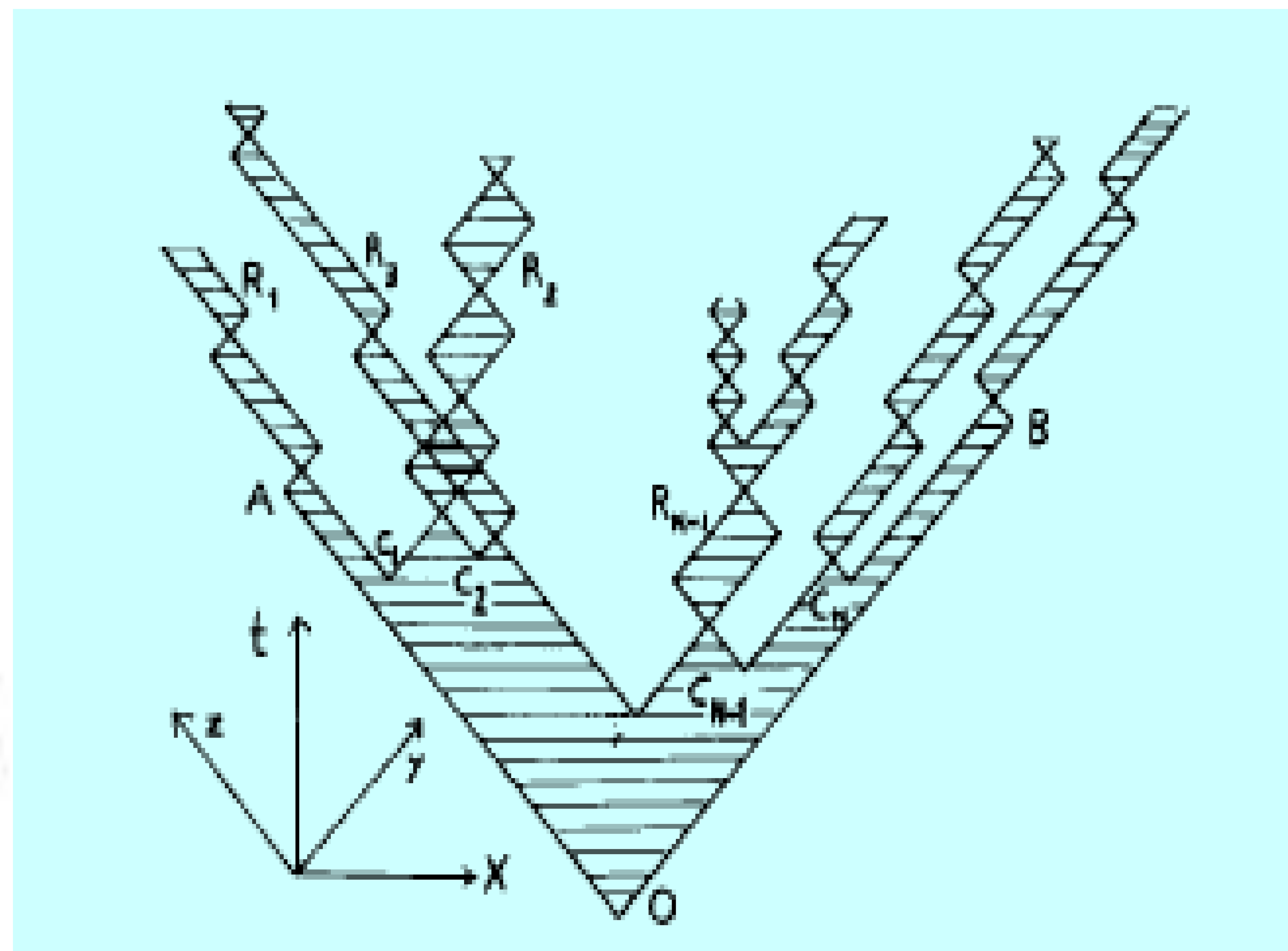
$$b_{corr} = \frac{\langle n_B n_F \rangle - \langle n_B \rangle \langle n_F \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

- **Short-Range(SR) and Long-Range(LR) components**
- **Strong energy dpendence for LR)**
- In PYTHIA the LR is *dominated by MPI*

Long-Range Correlations:
a general question - WHY?



A.Dumitru et al./ Nuclear Physics A 810 (2008) 91-108



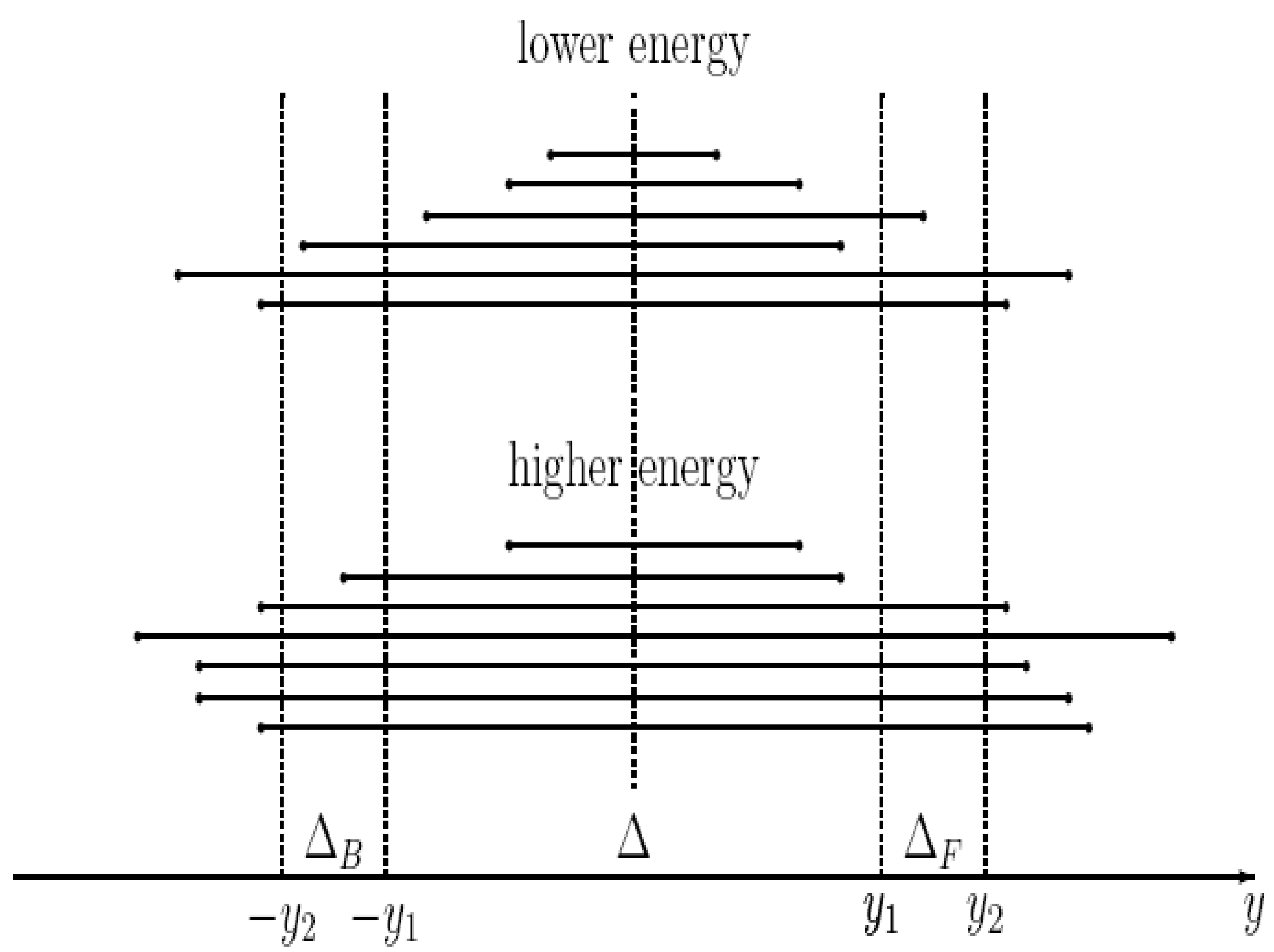
X. ARTRU and G. MENNESS1ER,
“STRING MODEL AND MULTIPRODUCTION”,
Nuclear Physics B70 (1974) 93-115

Causality requires that correlations –if they exist - of Long Range in rapidity between particles (A and B) must be made very early

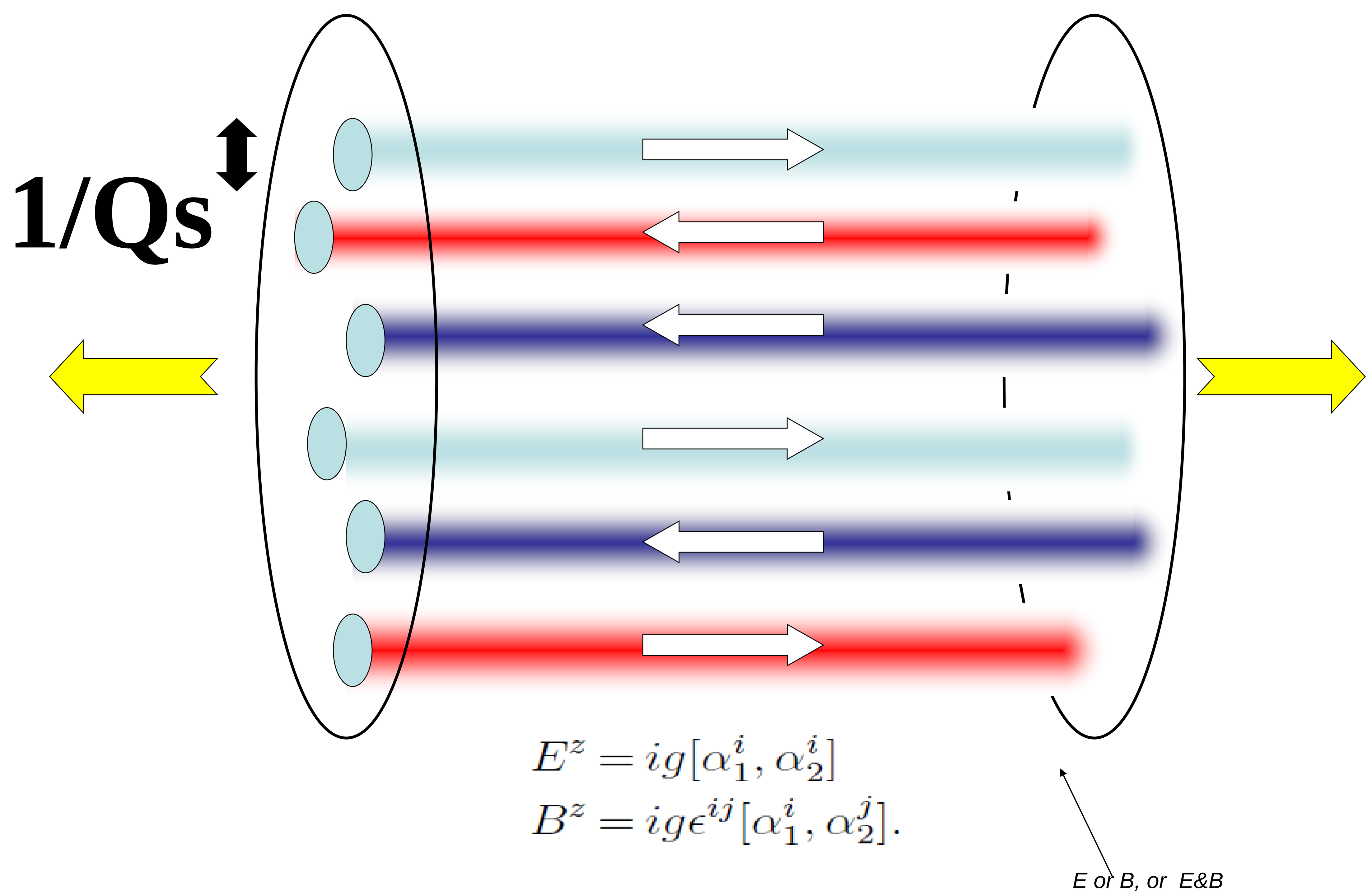
The initial conditions for the QGP formation in A-A collisions:

Color string fusion phenomenon (SFM)
M.A.Braun and C.Pajares
Phys. Lett. B287 (1992) 154;
Nucl. Phys. B390 (1993) 542.

Color Glass Condensate (CGC) and Glasmaflux tubes, L.McLerran,
Nucl.Phys.A699,73(2002);
T. Lappi and L. McLerran,
Nucl. Phys. A772 (2006) 200.



Schematics of strings formed just after the collision in cases of lower and of higher energy.



The color electric and magnetic flux tubes just after the collision (see arXiv:0803. 0410)

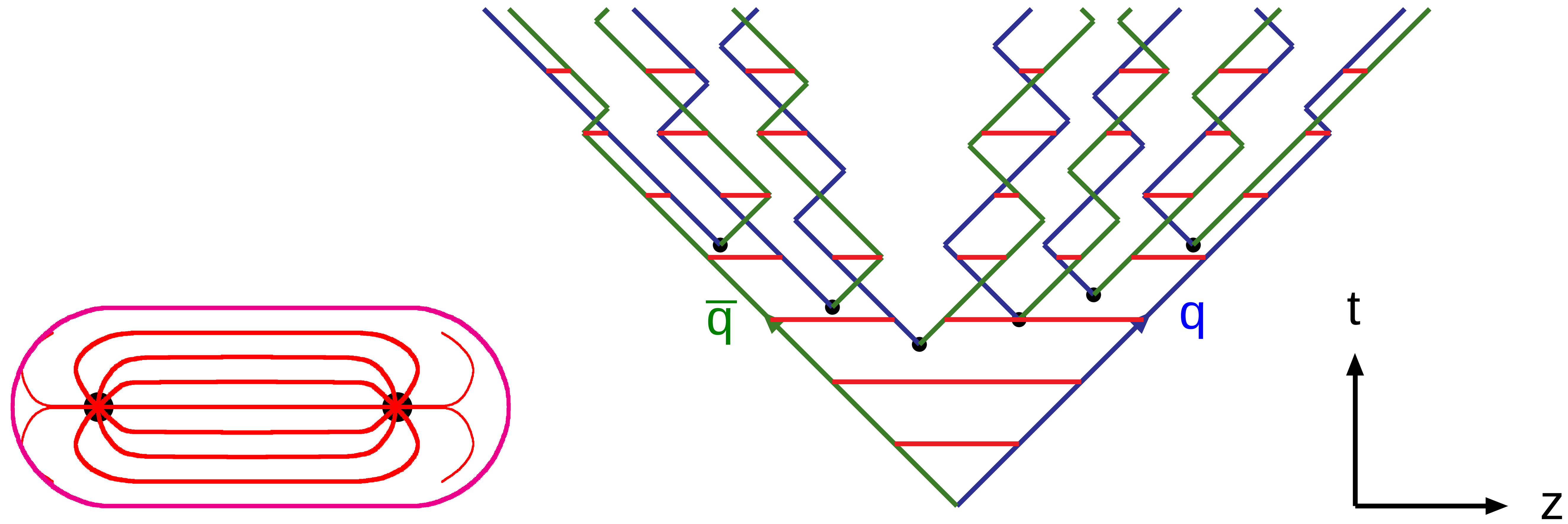
See talks at this conference%
Tuomas Lappi, "Initial conditions in AA and pA collisions"
Soeren Schlichting,"Initial state and pre-equilibrium effects in small systems"

Color-flux tubes as particle emitting sources: quark-gluon strings

2-stage scenario :

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

- **A.B.Kaidalov and K.A.Ter-Martirosyan** , Phys.Lett., **117B**(1982)247.



(a) (b)

See in: **Andy Buckley et al.**,
General-purpose event generators for LHC physics
arXiv:1101.2599, 2011

Application of string models

Investigations of the charged particles long-range multiplicity correlations, measured for well separated rapidity intervals, can give us information on the number of emitting centers and hence on the fusion of colour strings[2,3].

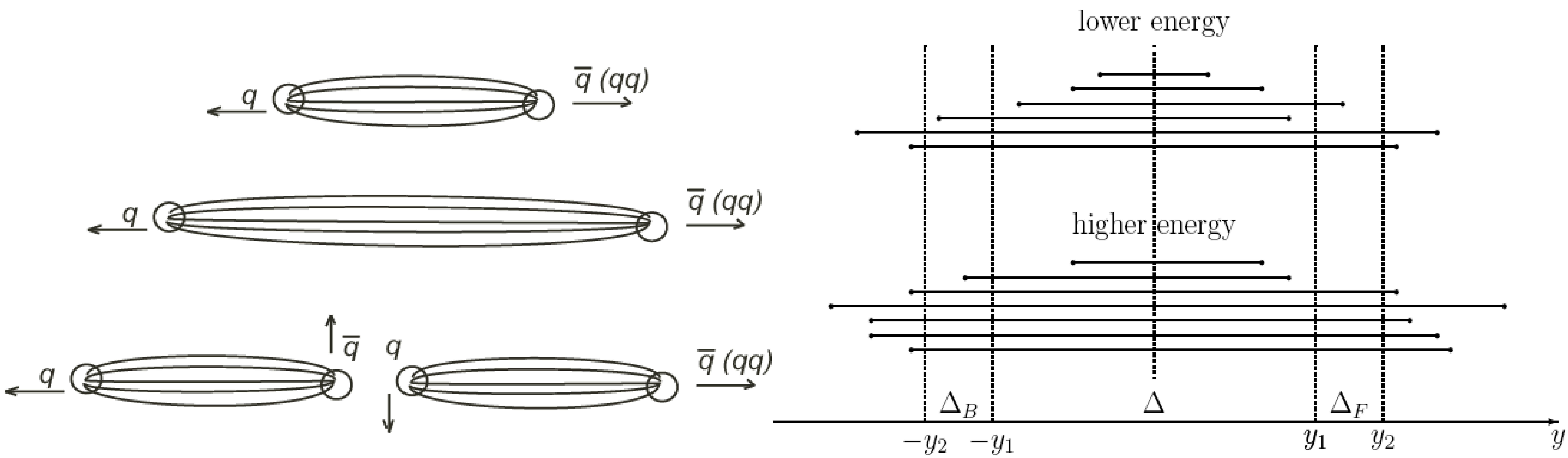
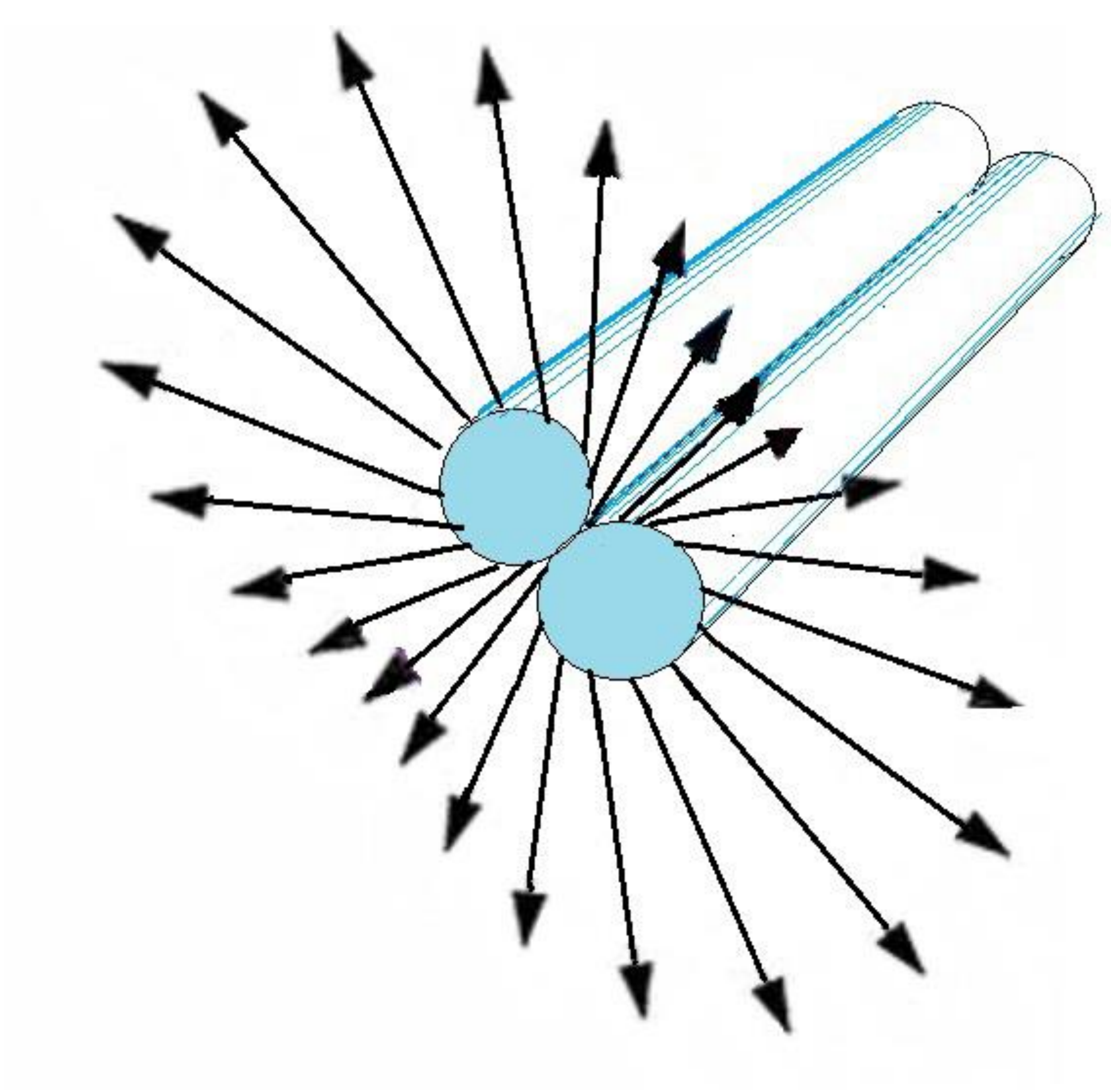


Fig.1. Quark-gluon strings and schematics for studies of Long-Range Correlations (LRC) using forward (ΔF) and backward (ΔB) rapidity windows [2]

[2] **M.A.Braun, C.Pajares and V.V.Vechernin,** Low pT Distributions in the Central Region and the Fusion of Colour Strings, Internal Note/FMD ALICE-INT-2001-16
[3] **А. Абрамовский, О.В. Канчели**// Письма в ЖЭТФ, т.31, 566, 1980

Do these color strings interact ?

***V.A. Abramovsky*, *O.V. Kanchely*,**
JETP letters 31, (*1980*) 566;
Abramovskii V. A., Gedalin E. V.,
Gurvich E. G., Kancheli O. V.,
JETP Lett., vol.47, 337-339 , 1988.



***Attraction or repulsion** depending on the directions of color fluxes*

q *-- momentum of particle*

k *-- momentum of the boosted string*

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

Color string fusion phenomenon

SFM: M.A.Braun and C.Pajares,
Phys. Lett. B287(1992) 154;
Nucl. Phys. B390} (1993)
542, 549

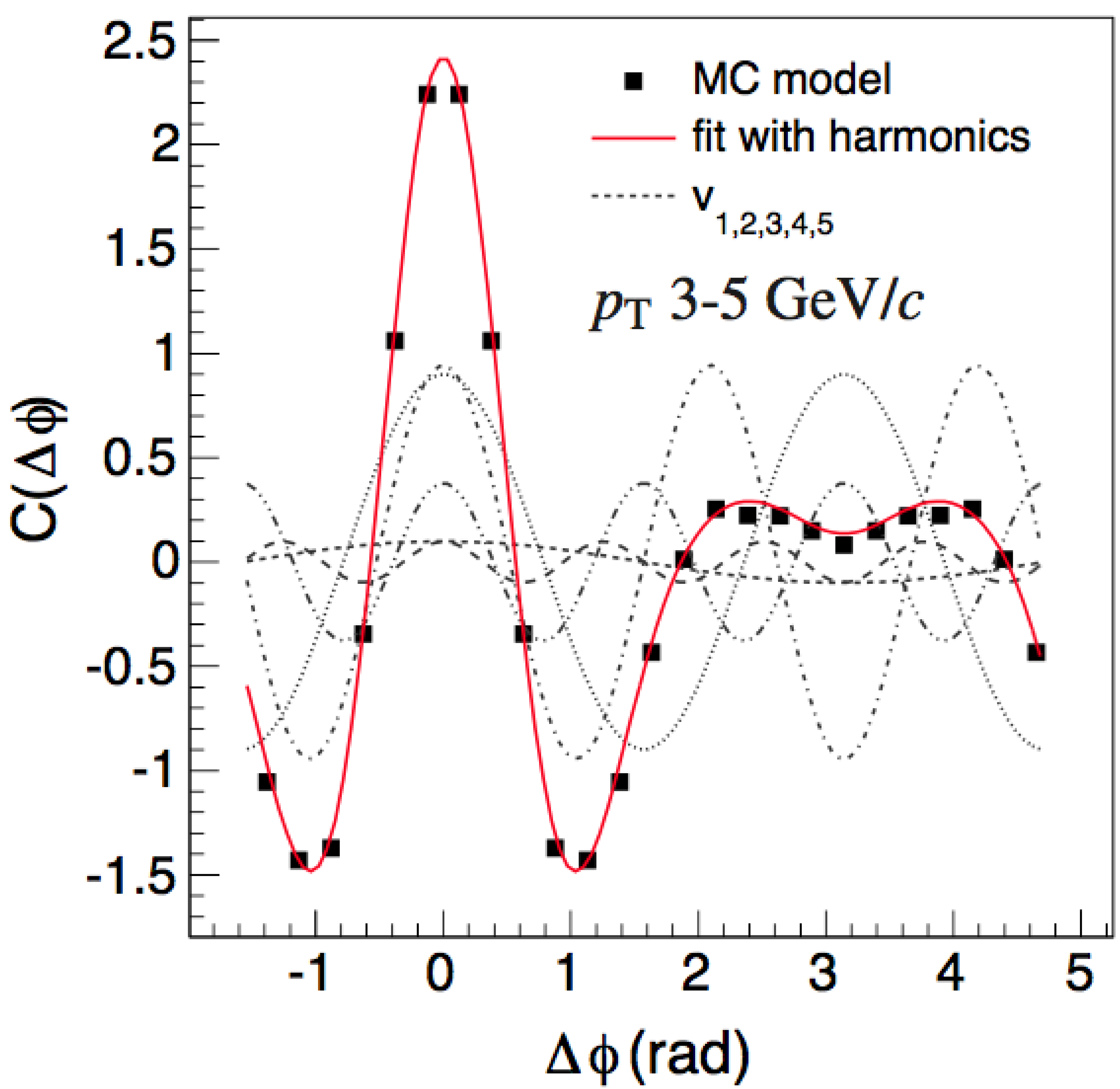
Colour rope model

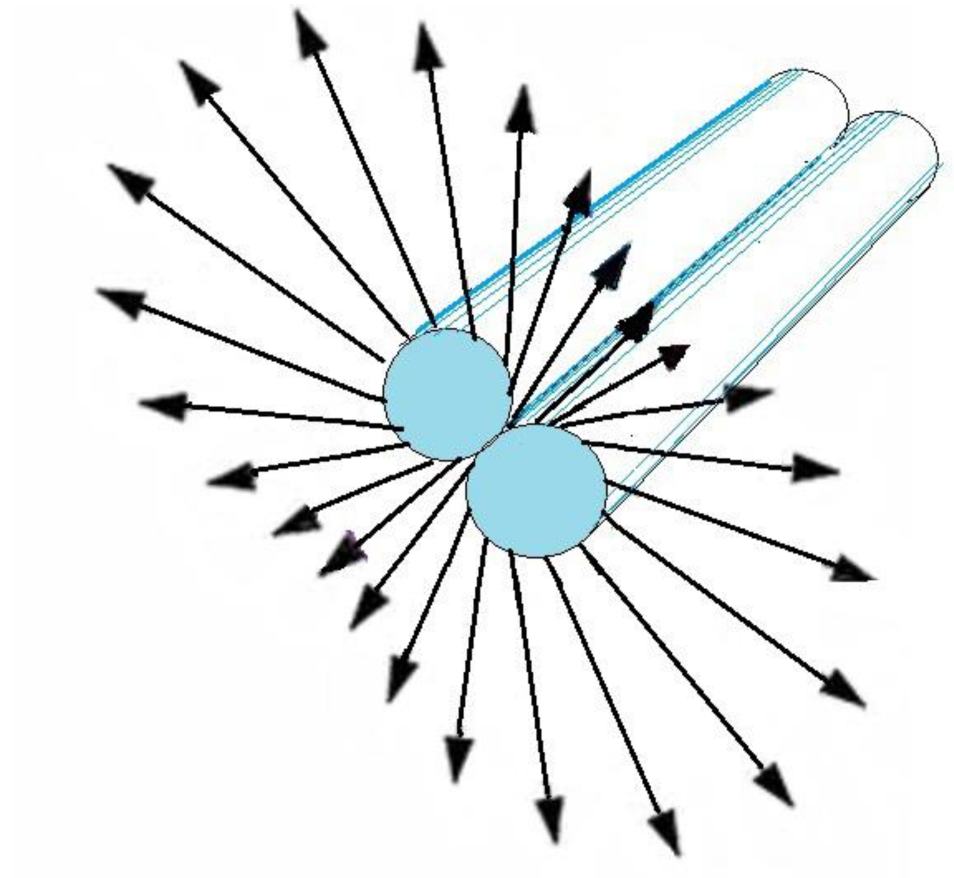
Biro, T.S. *et al*. Nucl.Phys. B245 (1984) 449-468
C.Bierlich et al., arXiv:1412.6259 [hep-ph] (The DIPSY model)

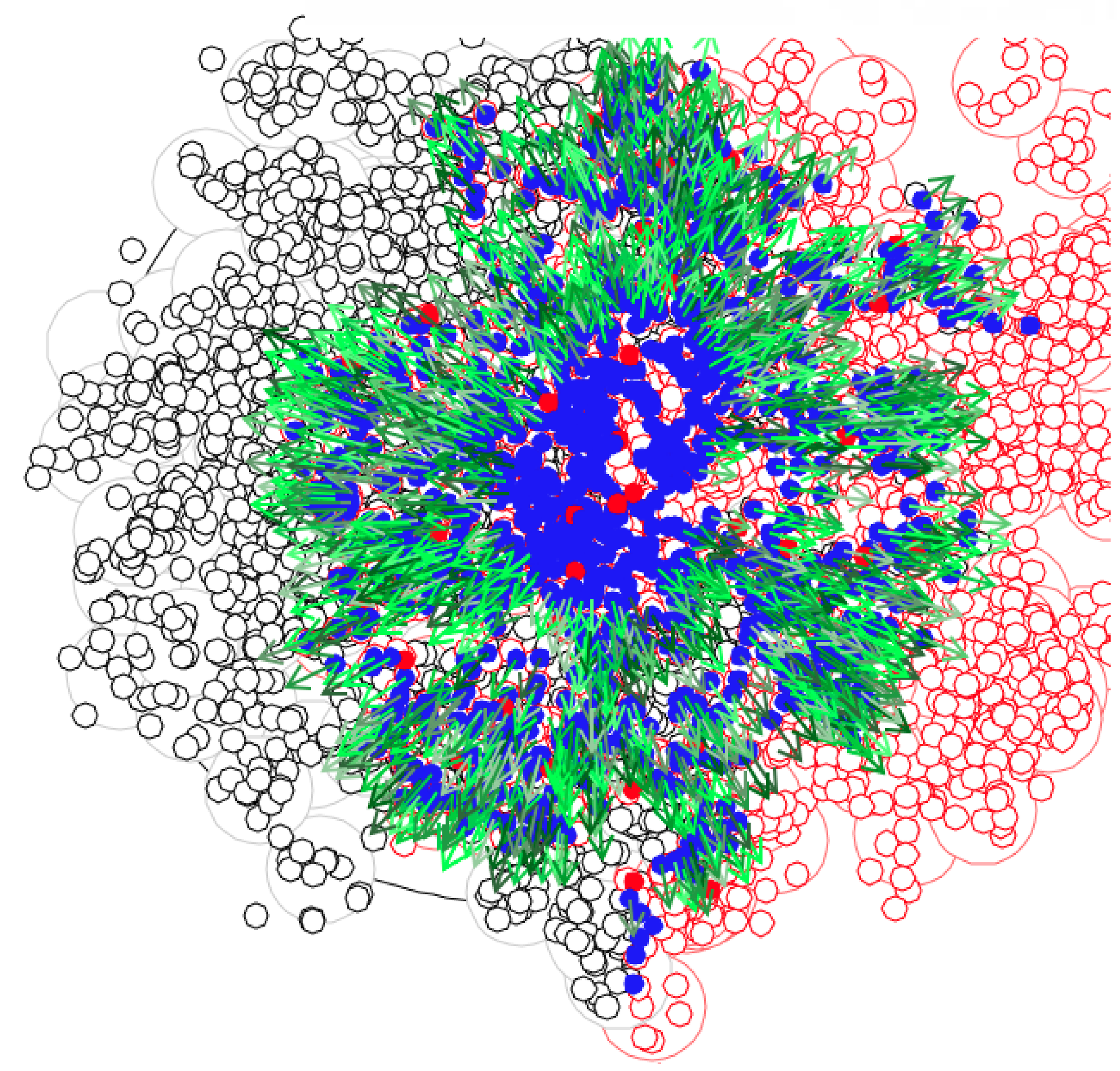
- N.S.Amelin, M.A.Braun and C.Pajares, Phys. Lett. {\bf B306} (1993) 312;\\ Z.Phys. {\bf C63} (1994) 507.
- N.S.Amelin, N.Armesto, M.A.Braun, E.G.Ferreiro and C.Pajares,Phys. Rev. Lett. {\bf 73} (1994) 2813.
- N.Armesto, M.A.Braun, E.G.Ferreiro and C.Pajares,\\Phys. Rev. Lett. {\bf 77} (1996) 3736.
- M.Nardi and H.Satz, Phys. Lett. {\bf B442} (1998) 14;\\H.Satz, Nucl. Phys. {\bf A661} (2000) 104c.
- M.A.Braun, C.Pajares and J. Ranft.\\Int. J. of Mod. Phys. {\bf A14} (1999) 2689.
- M.A.Braun and C.Pajares, Eur. Phys. J. {\bf C16} (2000) 349.
- M.A.Braun, R.S.Kolevatov, C.Pajares. V.V.Vechernin, Eur.Phys.J.C.32.535-546(2004)
- N/Armesto,M.A.Braun.E.C.Fereiro.C.Pajares,'Z.Phys.C.,67, 489-493,(1995),
- M.A.Braun,C.PajaresPhys.Rev.Let, v.85.no.23,4864-4867,2000
- M.A.Braun,C.PajaresEur.Phys.J.C16, 349-359(2000)

See the talk on string fusion by V.Kovalenko at this conference

Repulsion of quark-gluon strings and flow harmonics: MC model





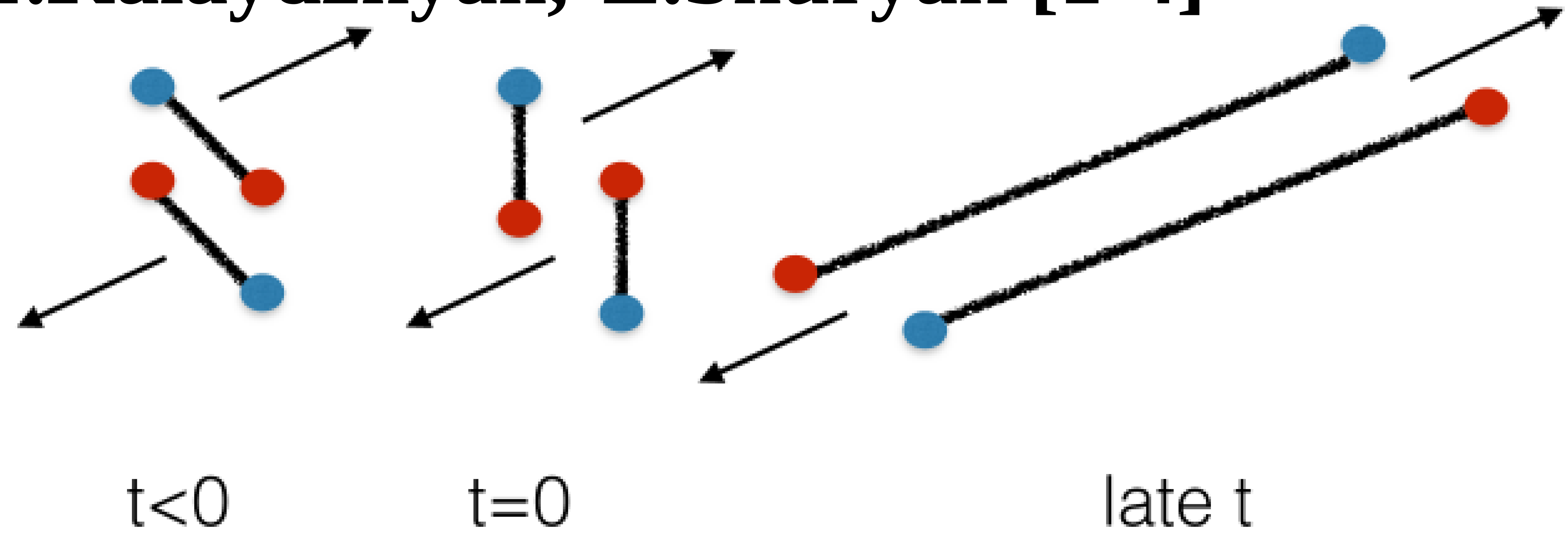


Pb-Pb collision at b=4 fm
blue circles – strings
green arrows – string boosts

[1] **I.Altsybeev,** AIP Conf.Proc. 1701 (2016)
[2] **I.Altsybeev, G.Feofilov and O.Kochebina,** AIP Conf. Proc. 1701, 060011 (2016).

QCD string-string interactions and "Spaghetti implosion"

T.Kalaydzhyan, E.Shuryak [1-4]



Attraction between strings due to σ-meson exchange and concept of σ-meson cloud[3]

Small sigma-string coupling

$$g_N \sigma_T = \frac{\langle\sigma\rangle^2 C^2}{4\sigma_T} \ll 1$$

in the range $10^{-1} - 10^{-2}$

is compensated by large number of strings [3]

→ flows [3]

[1] E.Shuryak, ArXiv:1412.8393,29 Dec.2014

[2] T.Kalaydzhyan and E.Shuryak, arXiv:1402.7363,

[3] T.Kalaydzhyan and E.Shuryak,, arXiv:1404.1888.

[4] T.Kalaydzhyan and E.Shuryak, Phys. Rev. C 91, 054913 (2015) , **arXiv:1503.05213 [hep-ph]**

QUESTIONS:

1) What is the number of these sources extended in rapidity and produced

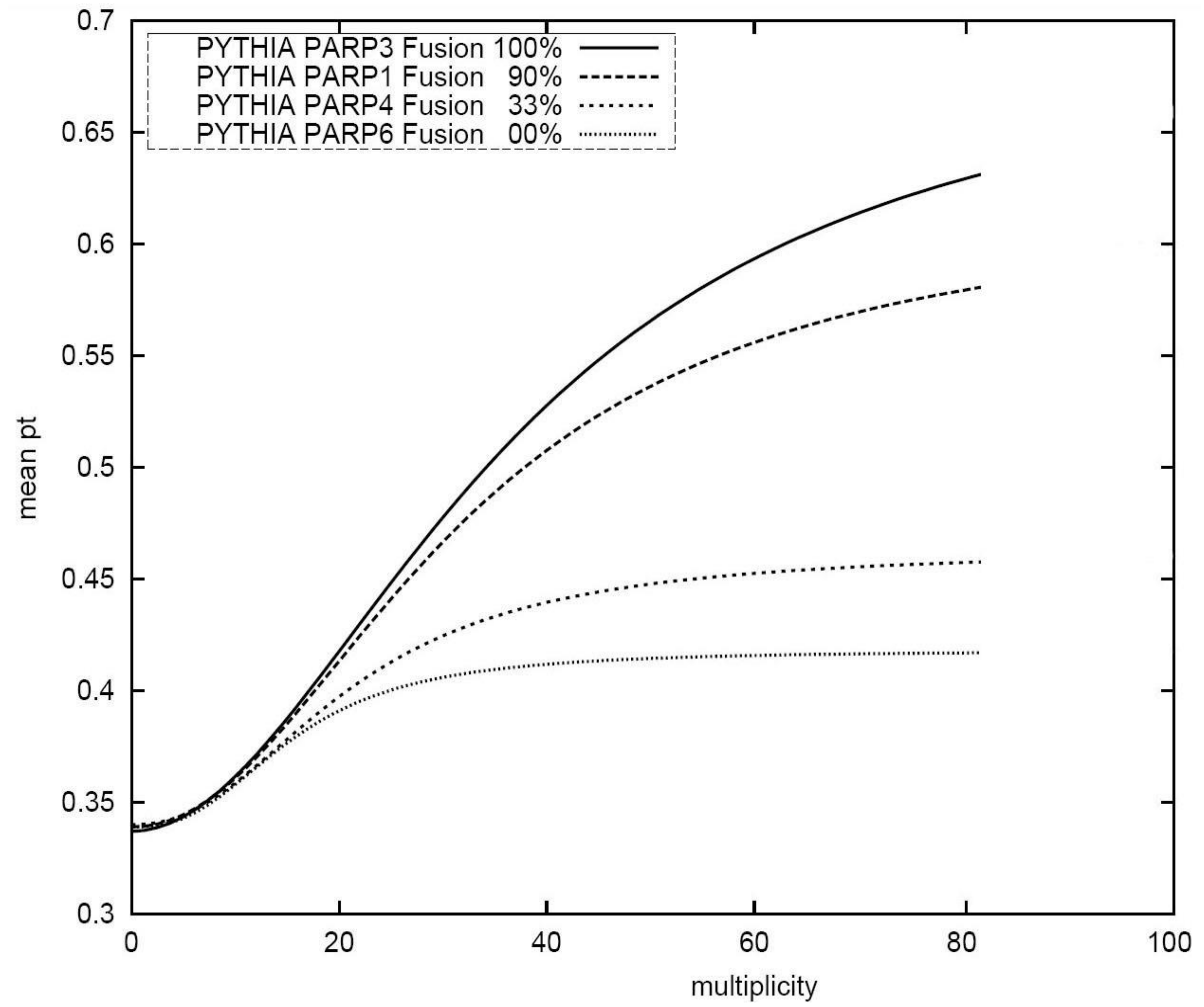
in case of small systems,

in *particular, in pp collisions*?

2) Is the density of these sources suffients to start overlap and ***to interact*** producing new kinds of particle production sources?

ESTIMATE-1
MPI in pp

Collectivity in PYTHIA: Color Reconnection and Long-Range correlations (LRC)



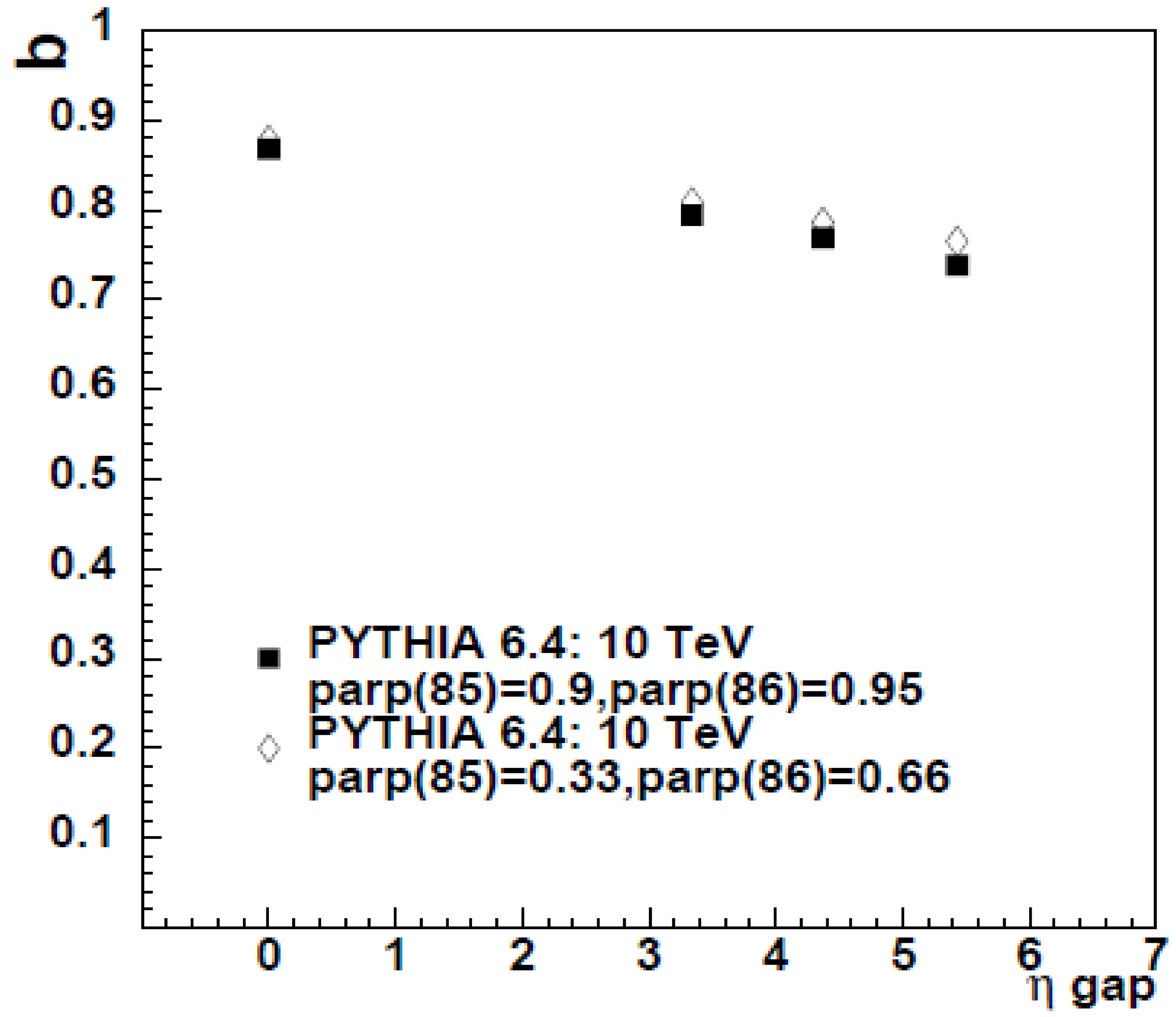


Figure 3: PYTHIA: The n-n correlation strength for pp collisions at $\sqrt{s}=$ 10 TeV as a function of the pseudorapidity gap for 2 sets of collectivity parameters: (0.33, 0.63) (open diamonds), (0.9, 0.95) (black squares).

[1] A. Asryan, G. Feofilov,

Studies of **pT-Nch correlation**

in pp collisions in the framework
of PSM and PYTHIA generators, ALICE Week, Physics Forum, CERN, 11 **October 2006**.

[2] **A. Asryan, D.Derkach, G. Feofilov "Correlation pt-Nch and collective effects in pp and ppbar collisions from ISR up to Tevatron and LHC", Vestnik SPbSU, ser.4 ,v.2,2008,**3-16, accepted 18 Dec.2007.

- LRC in PYTHIA due to fluctuating, from event to event, number of strings.
- pT-Nch correlation – due to Color Reconnection

Collectivity in PYTHIA:

MPI in pp collisions

2 assumptions:

----the number of MPIs is proportional to the hard collisions cross section

-- soft particle multiplicity scales with the number of MPIs

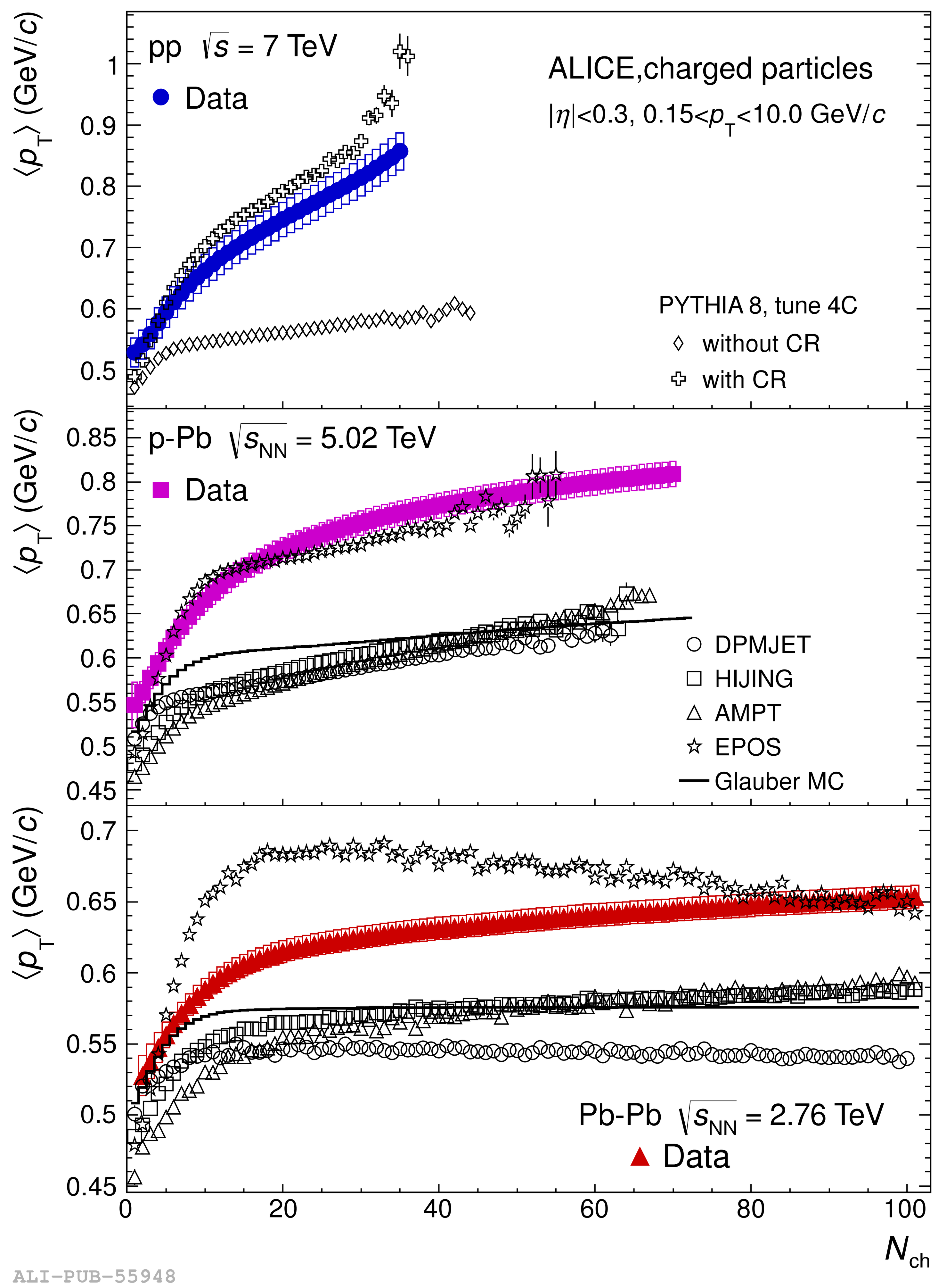


Figure 2. The mean particle transverse momentum as a function of multiplicity in $|\eta| < 0.3$ for pp collisions at $\sqrt{s} = 7$ TeV (upper panel), p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (middle panel) and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV (lower panel) [11].

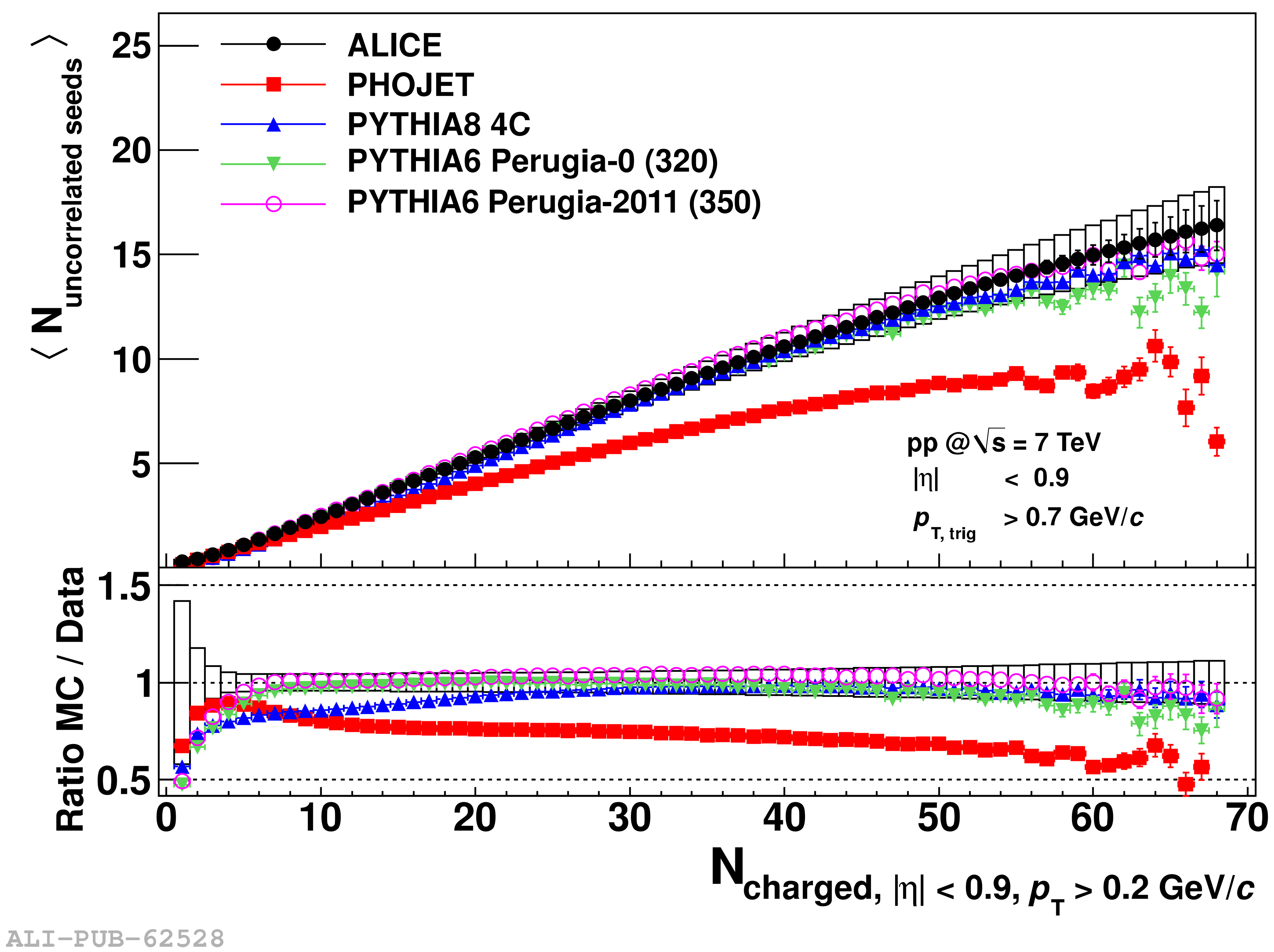


Figure 4. Number of uncorrelated seeds as defined in the text from two-particle azimuthal correlations with $p_{T,trig}, p_{T,assoc} > 0.7$ GeV/c in pp collisions at $\sqrt{s} = 7$ TeV [13].

Andreas Morsch,
for the ALICE Collaboration
Journal of Physics: Conf Seri. **535** (2014) 012012
arXiv: 1407.3628

$\langle N_{uncor.seeds} \rangle$ -- up to ~ 15 in pp@7TeV for p_T trig >0.7 GeV/c

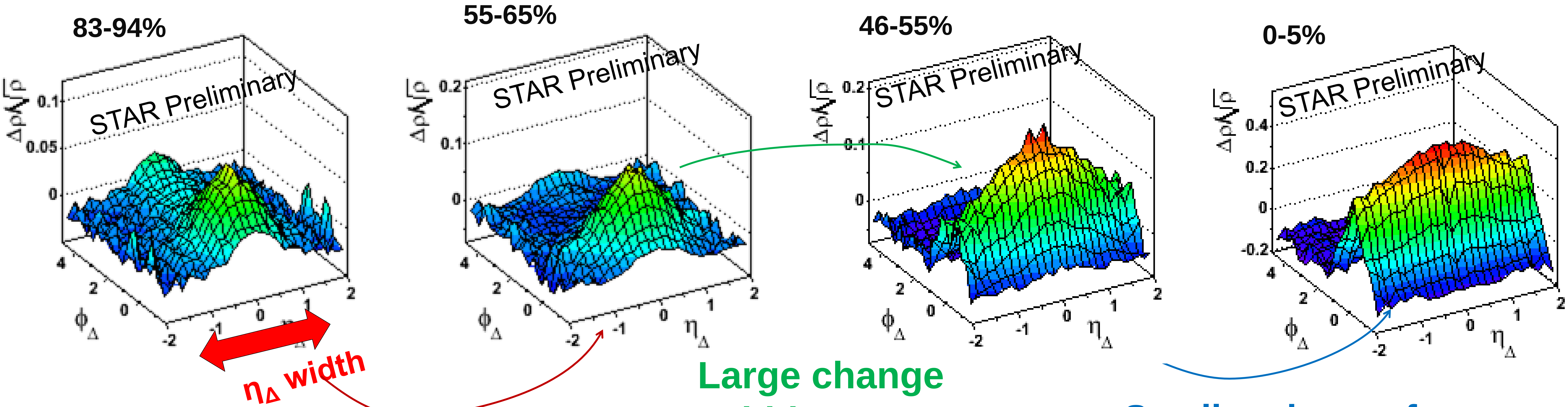
ESTIMATE-2
based on the onset of ridge in Au-Au@RHIC

O.Kochebina, G.Feofilov, Arxiv:1012.0173

Threshold 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

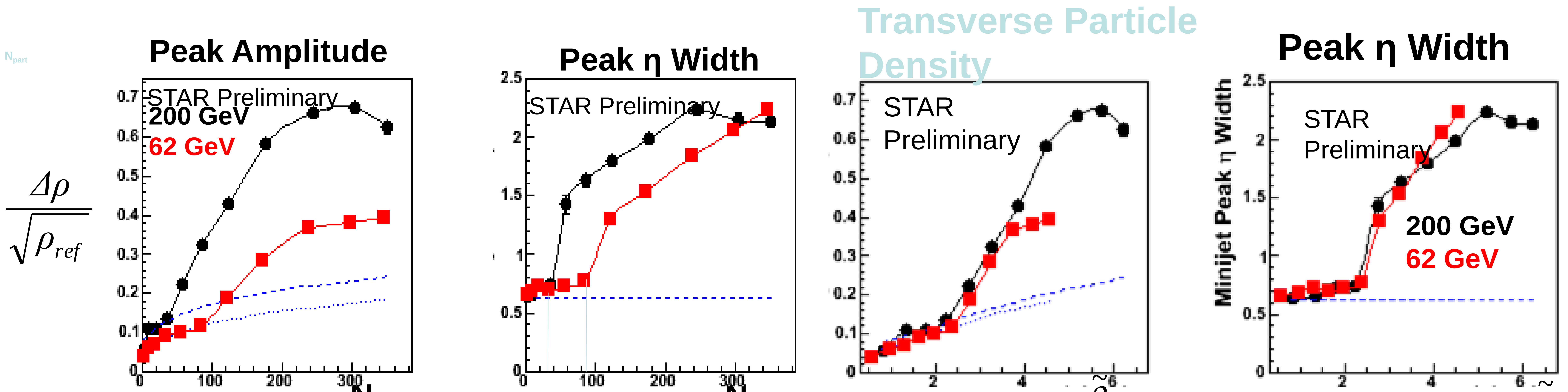
Smaller change from transition to most central

Low-p_T manifestation of the "ridge"

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

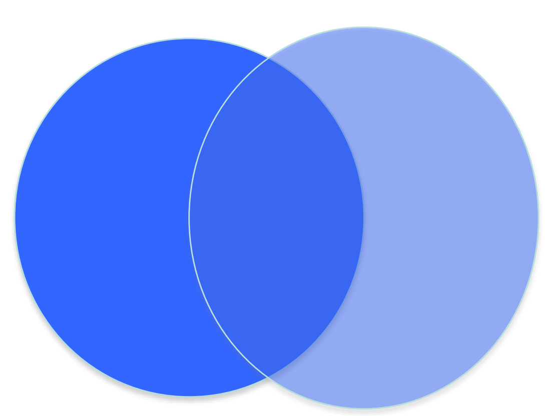
[1]Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. M. Daugherity. QM2008.

Variation of low-p_T "ridge" with centrality

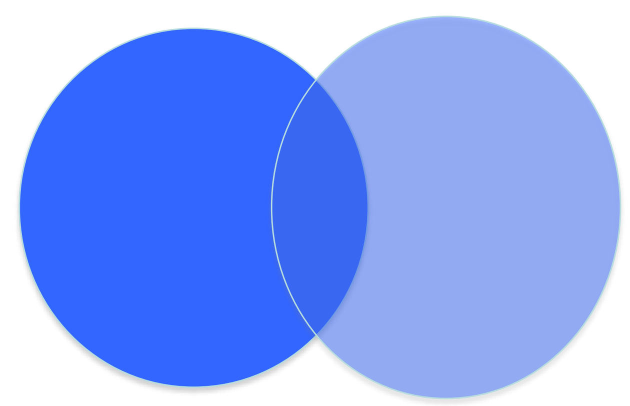


Same-side gaussian peak amplitude, width. Points show eleven centrality bins for each energy (84-93%, 74-84%, 65-74%, 55-65%, 46-55%, 37-46%, 28-37%, 19-28%, 9-19%, 5-9%, and 0-5%) transformed to tranvserse density.

62 GeV
"Critical value"
Npart≈90



200 GeV
"Critical value"
Npart≈40



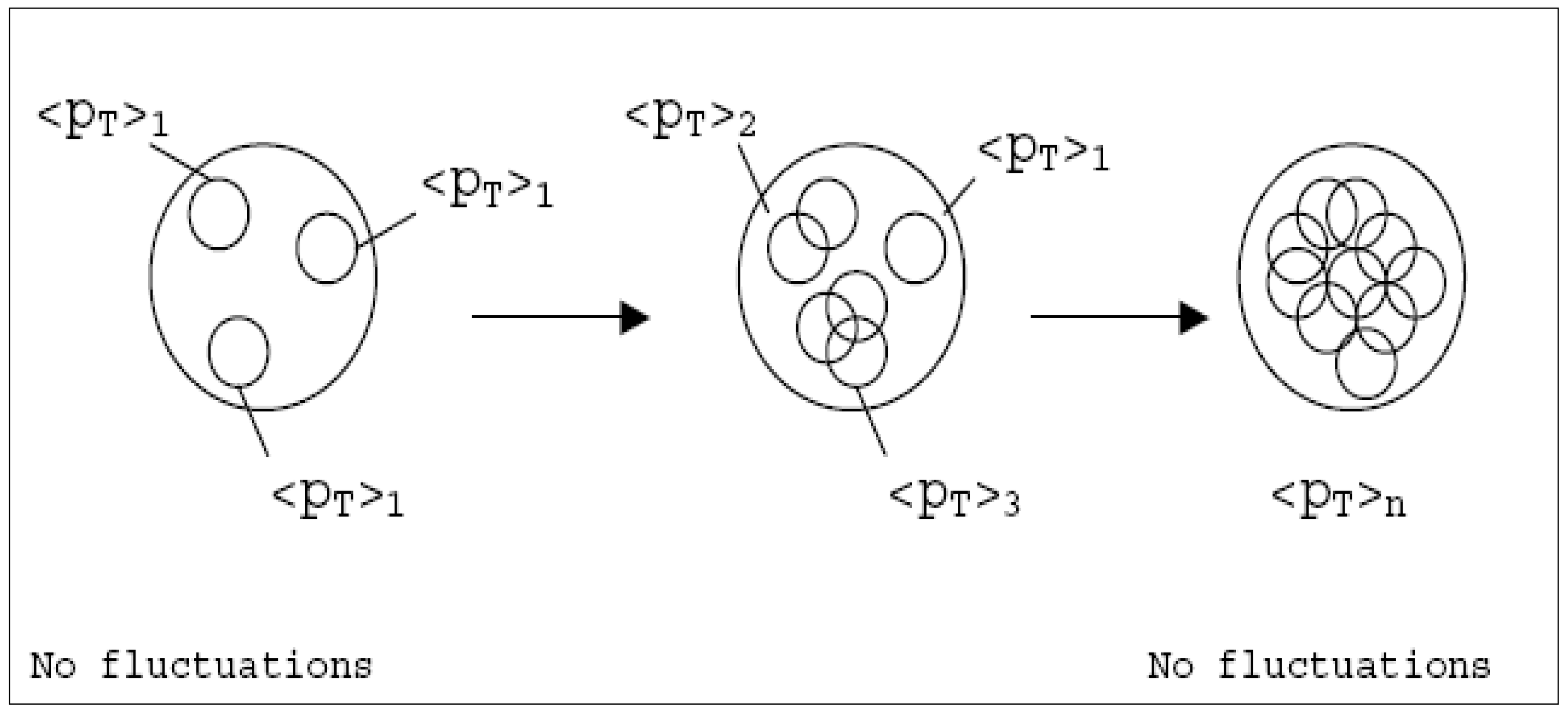
The transverse particle density:

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

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

[1] Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. M. Daugherity. QM2008.

String percolation and mean number of strings

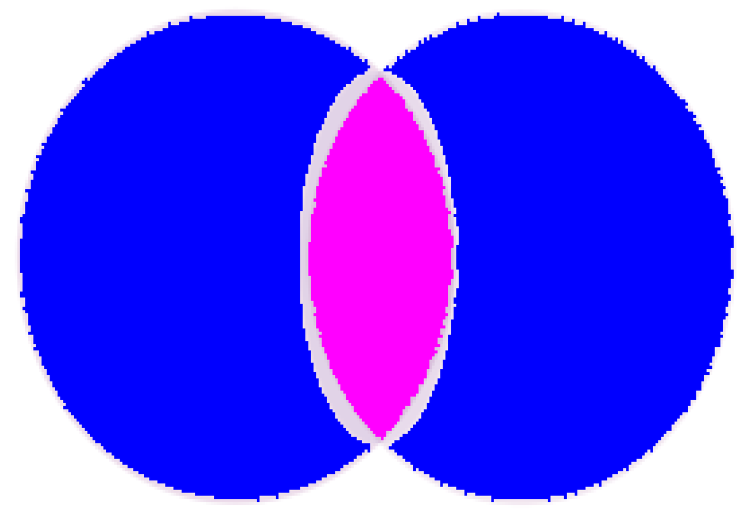


$$\tilde{\eta} = \frac{\pi r_0^2 N_{str}}{< S >}$$

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

Percolation parameter:

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



η_c= 1,15 ([4])

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

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

N_{str} --number of strings,

πr_0^2 -- string transverse area,

S -- overlap area

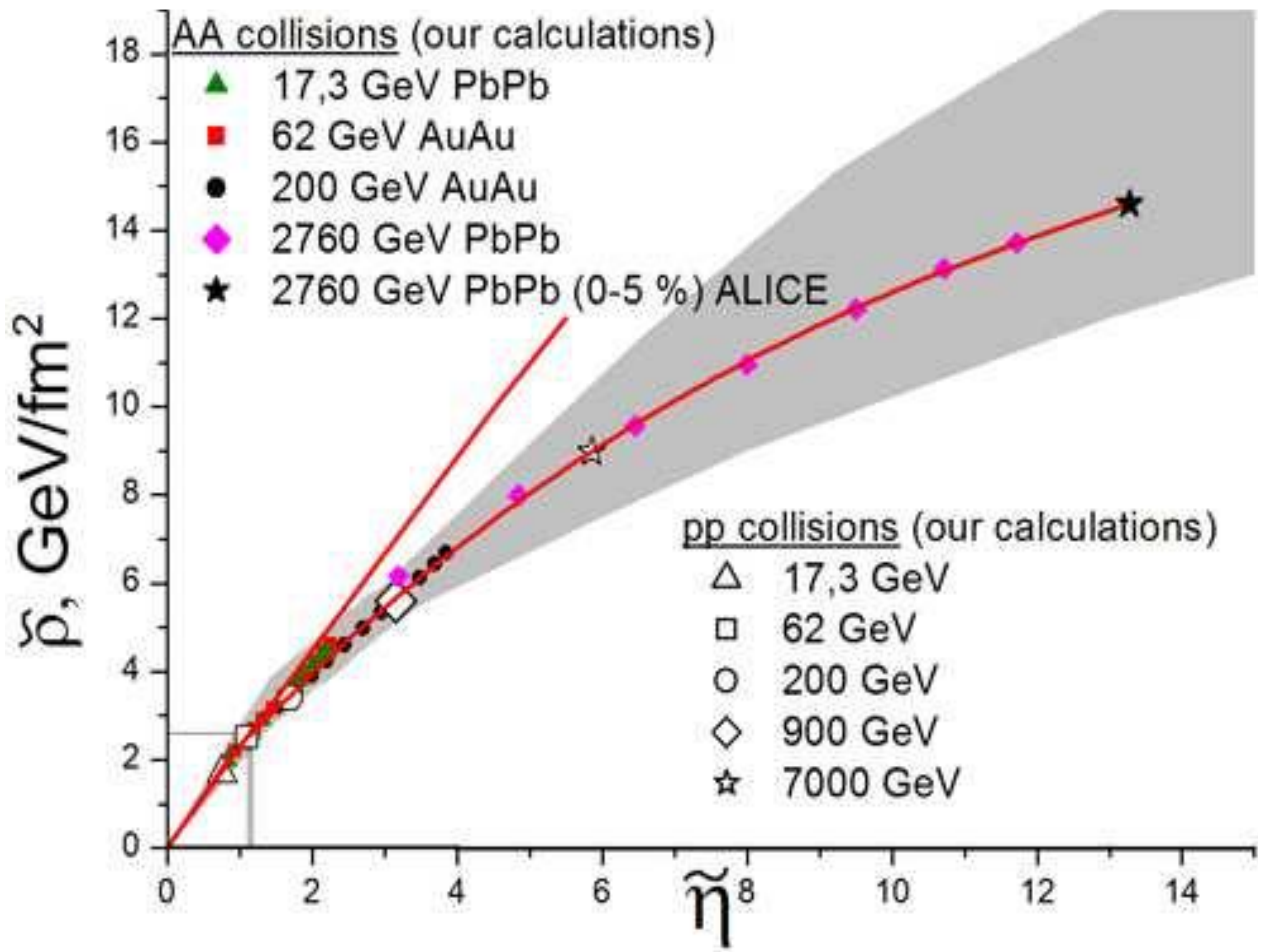
r_0=0,2-0,25 fm – string radius

$$\frac{\tilde{\rho}^{crit}(N_{part})}{\tilde{\eta}^{crit}(N_{part})} = \frac{3}{2}\frac{1}{\pi r_0^2}\frac{dN_{ch}}{dy}\frac{1}{N_{str}} = 2.3 \pm 0.2 fm^{-2},$$

O.Kochebina, G.Feofilov, Arxiv:1012.0173

[4] J.Dias de Deus and A. Rodrigues// Phys. Rev. C 67, 064903 (2003)
[3] C. Pajares // arXiv:hep-ph/0501125v1 14 Jan 2005

String percolation and number of strings: from A-A colllisions to pp



The transverse particle density vs. string density

O.Kochebina, G.Feofilov, Arxiv:1012.0173

From A-A colllisions to pp: mean number of strings

Table 1: 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 P bP b collisions at 17.3 GeV. The calculations are done for r_0 = 0.25 fm.[1].

$\sqrt{s}$, GeV	N_{part}	$dN_{ch}/d\eta$	N_{str}	N_s	N_{coll}	a
200(AuAu)	40	2.97 ± 0.30 [22]	194 ± 25	155 ± 23	59 ± 4	2.6 ± 0.4
62 (AuAu)	90	2.30 ± 0.23 [23]	352 ± 28	262 ± 23	167 ± 4	1.6 ± 0.2
17.3 (PbPb)	110	1.62 ± 0.21 [24]	302 ± 45	192 ± 30	158 ± 5	1.2 ± 0.2

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.

$\sqrt{s}$, GeV	$dN_{ch}/d\eta$	$\tilde{\rho}$, GeV/fm^2	$\tilde{\eta}$	N_{str} our estim.
7000	6.02 ± 0.50 [27]	9.0 ± 0.5	5 ± 1	30 ± 12
900	3.78 ± 0.19 [28]	5.6 ± 0.4	3.2 ± 0.8	16 ± 6
200($p\bar{p}$)	2.30 ± 0.20 [29]	3.4 ± 0.2	1.7 ± 0.4	9 ± 4
62	1.64 ± 0.17 [30]	2.5 ± 0.1	1.1 ± 0.6	6 ± 4
17.3	1.14 ± 0.12 [31]	1.70 ± 0.08	0.7 ± 0.4	4 ± 3

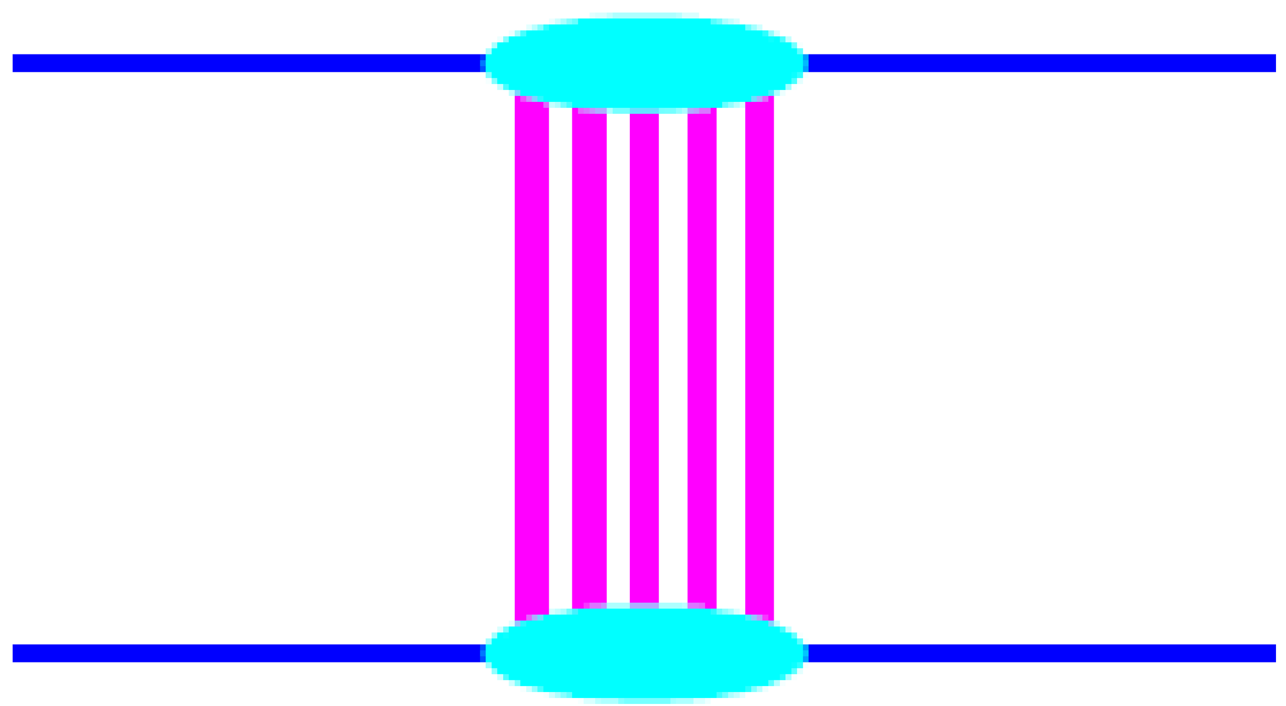
[1] O.Kochebina, G.Feofilov, Arxiv:1012.0173

for pp@7TeV: $<N_{srings}>$ ~ 30 +- 12

ESTIMATE-3

Multi-pomeron exchange model with effective account of interaction between strings

(EPEM)

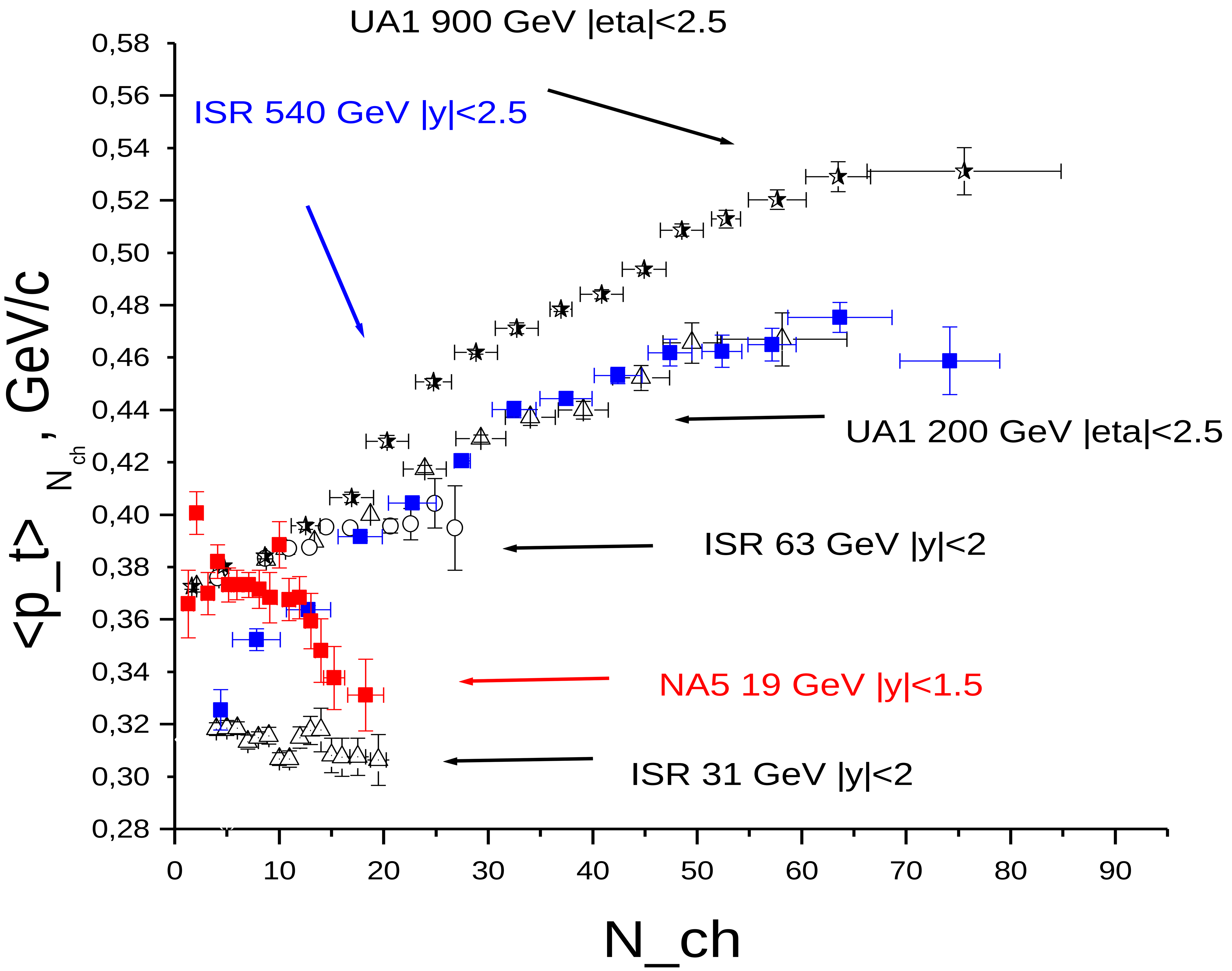


[1] Armesto, N., Derkach, D., and Feofilov, G., Phys. At. Nucl., 2008, vol. 71, p. 2087.

[2] Bodnia, E., Derkach, D., Feofilov, G., Kovalenko, V., and Puchkov, A., Proc. QFTHEP 2013, St. Petersburg, 2013. http://arxiv.org/abs/1310.1627.

[3] Bodnia, E.O., Kovalenko, V.N., Puchkov, A.M., and Feofilov, G.A., AIP Conf. Proc., 2014, vol. 1606, p. 273.

Motivation: Experimentally Observed p_t-N_{ch} correlations in pp and ppbar collisions:



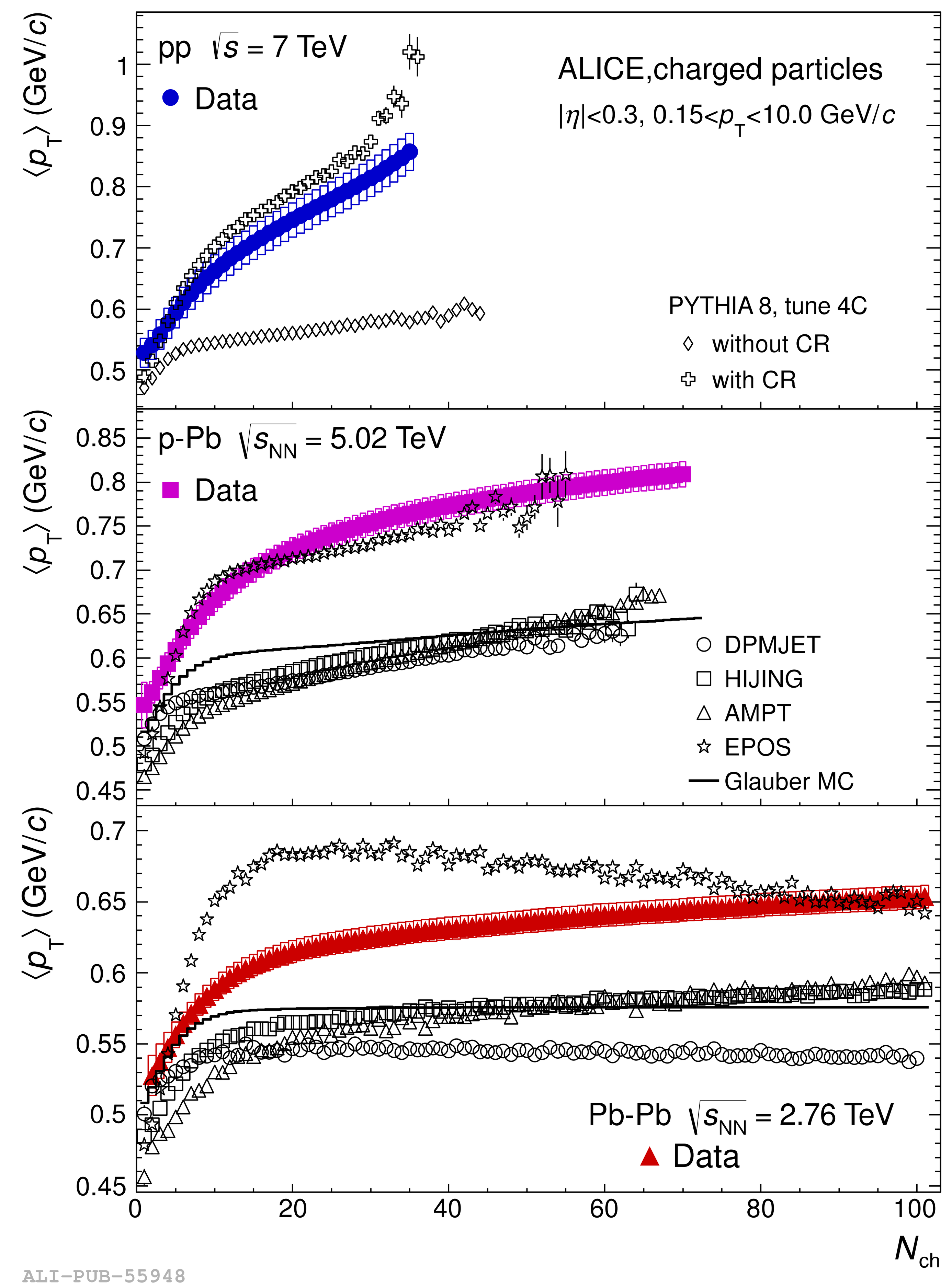


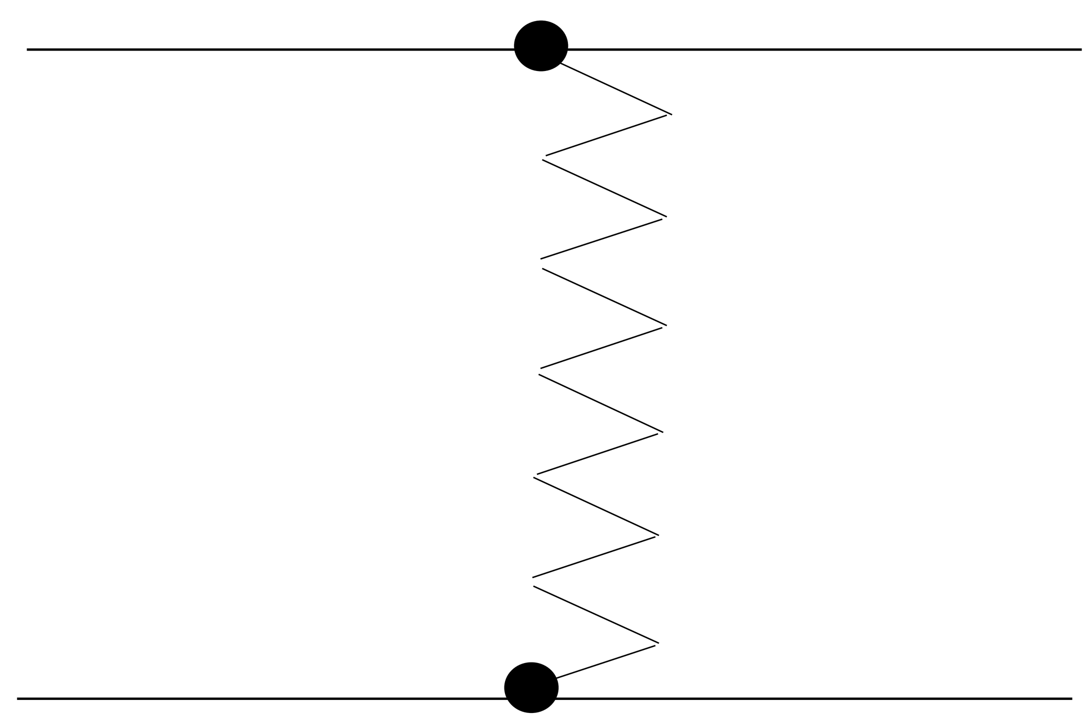
Figure 2. The mean particle transverse momentum as a function of multiplicity in $|\eta| < 0.3$ for pp collisions at $\sqrt{s} = 7$ TeV (upper panel), p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (middle panel) and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV (lower panel) [11].

Compilation of experimental data in:

[1] Armesto, N., Derkach, D., and Feofilov, G., Phys. At. Nucl., 2008, vol. 71, p. 2087.

p_t-N_{ch} correlations @LHC

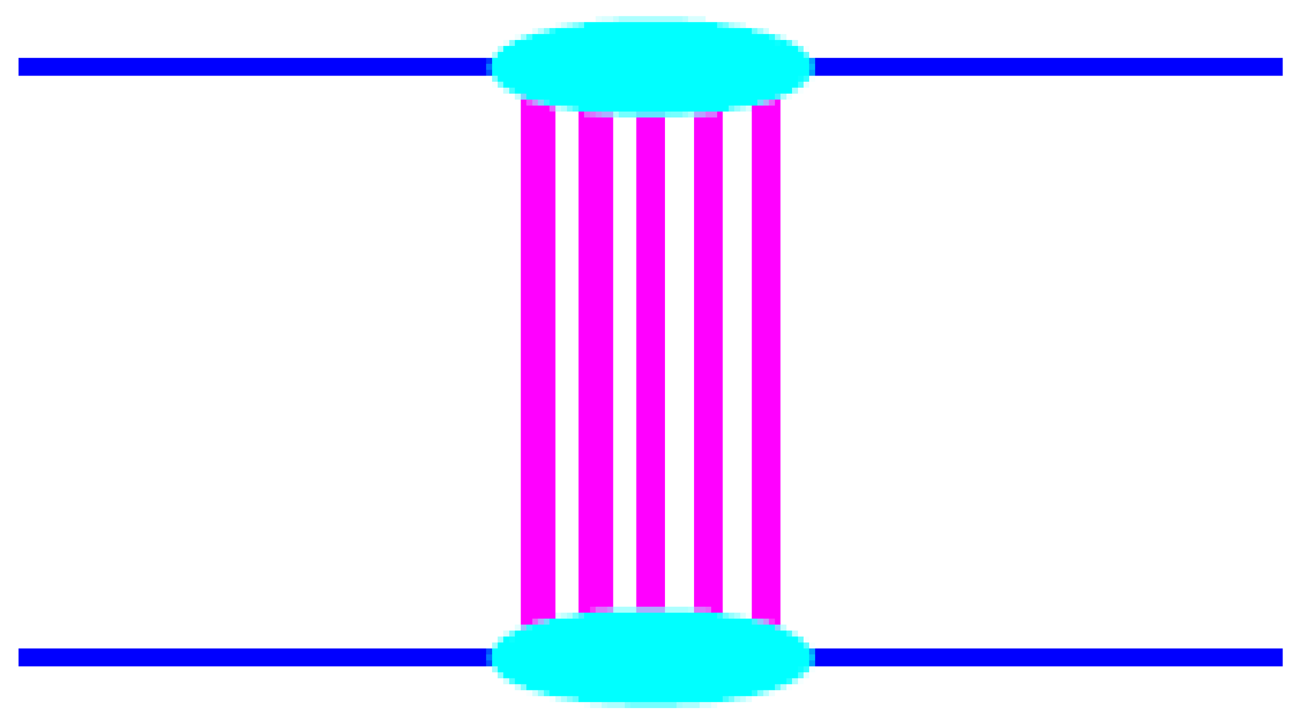
Classical Multi-Pomeron Exchange Model (Regge-Gribov approach)



Pomeron is a virtual particle that is exchanged during the inelastic scatering process with vacuum quantum numbers flow.

It can be considered as a pair of strings.

The number of pomerons exchanged rises with energy.



Collective effects were not included in the model.

A.Capella, U.P.Sukhatme, C.-I.Tan and J.Tran Thanh Van, Phys. Rep.236(1994)225

EPEM[1] Modifications[2]

$\rho(N_{ch}, p_t) =$	Probability distribution
$= \frac{C_w}{z} \sum_{n=1}^{\infty} \frac{1}{n} \left(1 - \exp(-z) \sum_{l=0}^{n-1} \frac{z^l}{l!}\right) \times$	Probability of productioi of *n* pomerons
$\times \exp(-2nk\delta) \frac{(2nk\delta)^{N_{ch}}}{N_{ch}!} \times$	Poisson distribution of the charged particles from 2*n* string
$\times \frac{1}{n^{\beta} \cdot t} \exp\left(-\frac{\pi p_t^2}{n^{\beta} t}\right)$	Modified Schwinger mechanism

t – average string tension

k – mean number of particles produced per unit rapidity by one string

β-- efficient string fusion collective coefficient

[1] Armesto, N., Derkach, D., and Feofilov, G., Phys. At. Nucl., 2008, vol. 71, p. 2087

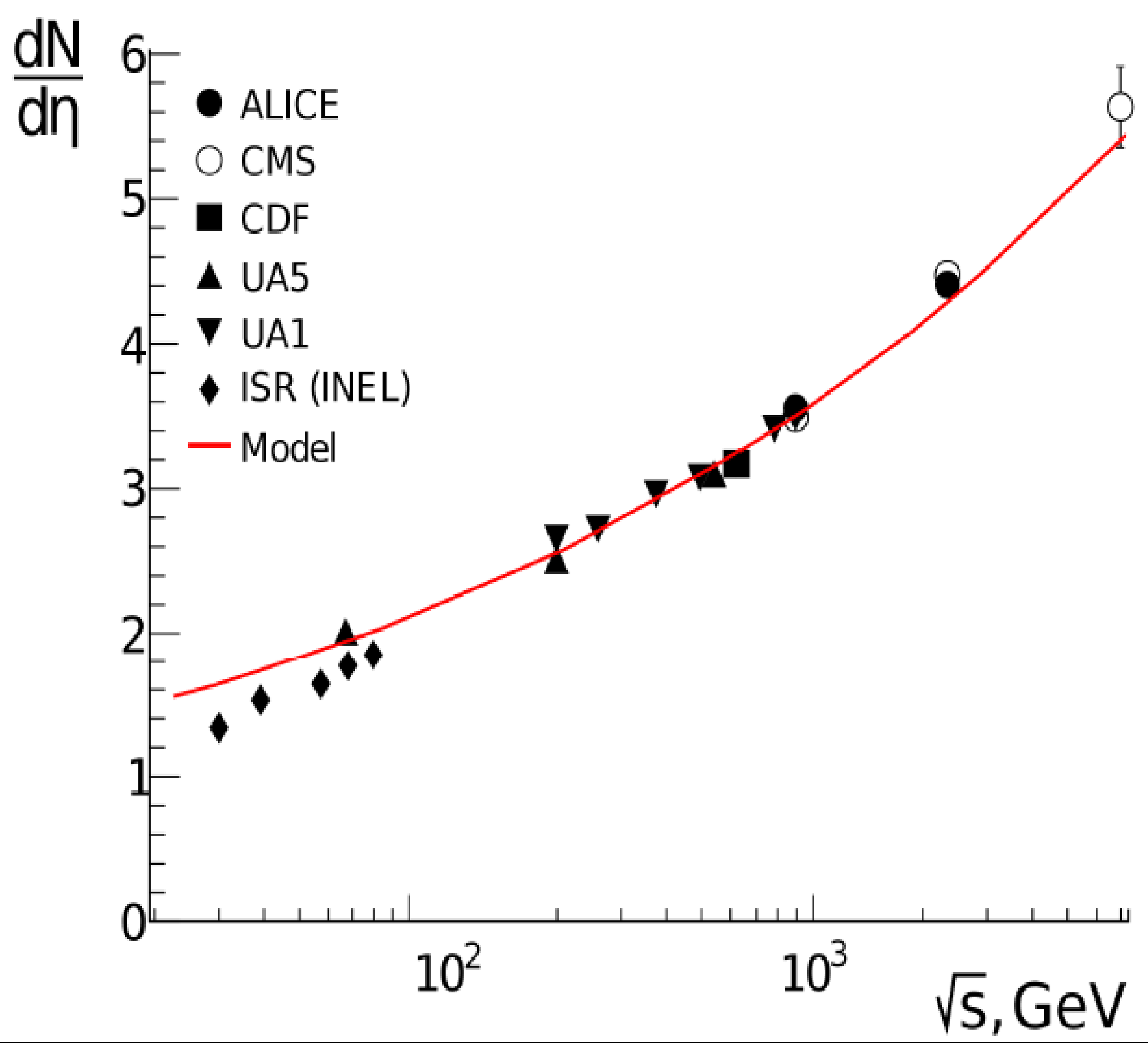
[2] Bodnia, E., Derkach, D., Feofilov, G., Kovalenko, V., and Puchkov, A., Proc. QFTHEP 2013, St. Petersburg, 2013. http://arxiv.org/abs/1310.162

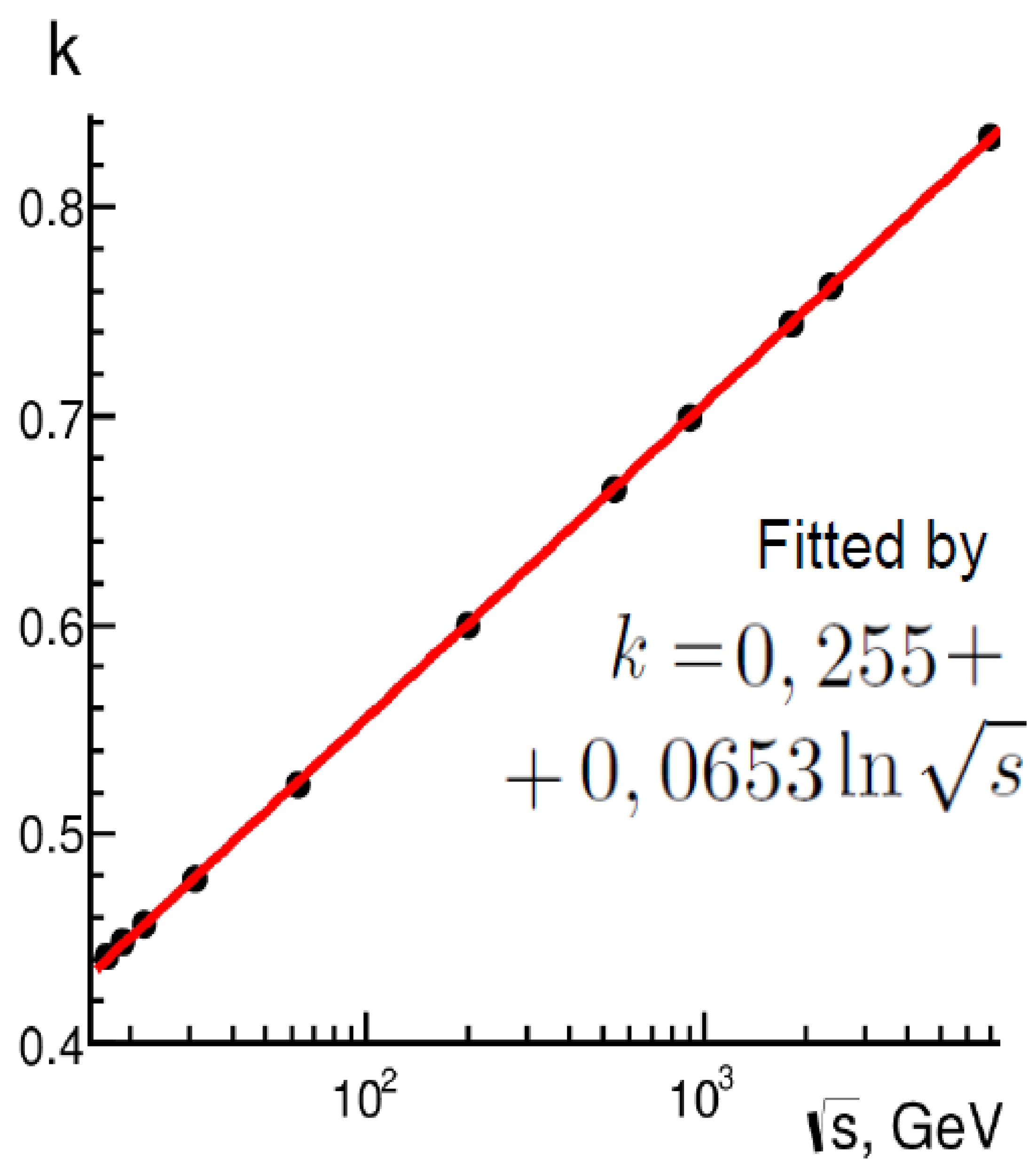
Parameters and results from ISR to LHC

Determination of the parameter k

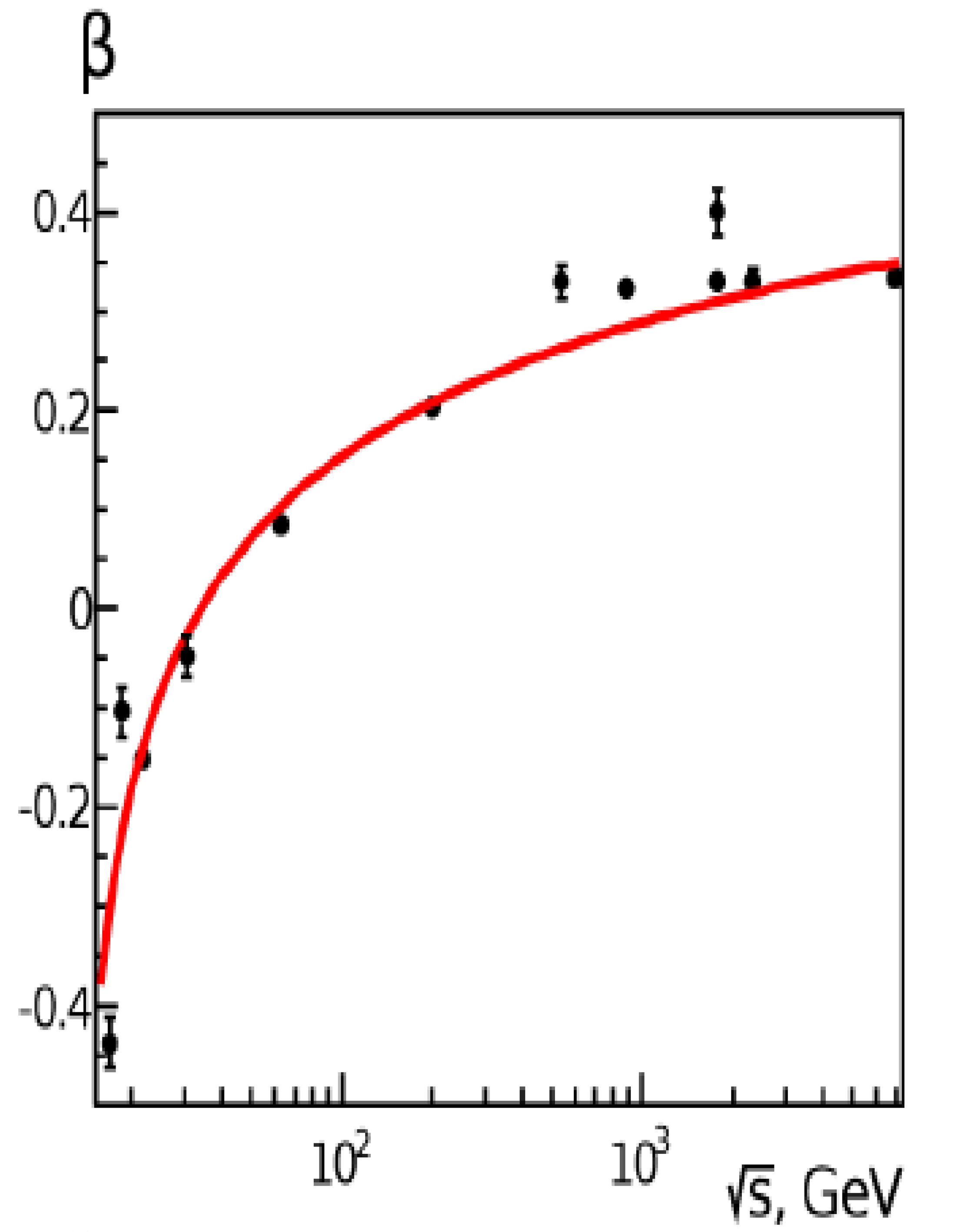
from experimental data on charged multiplicity:

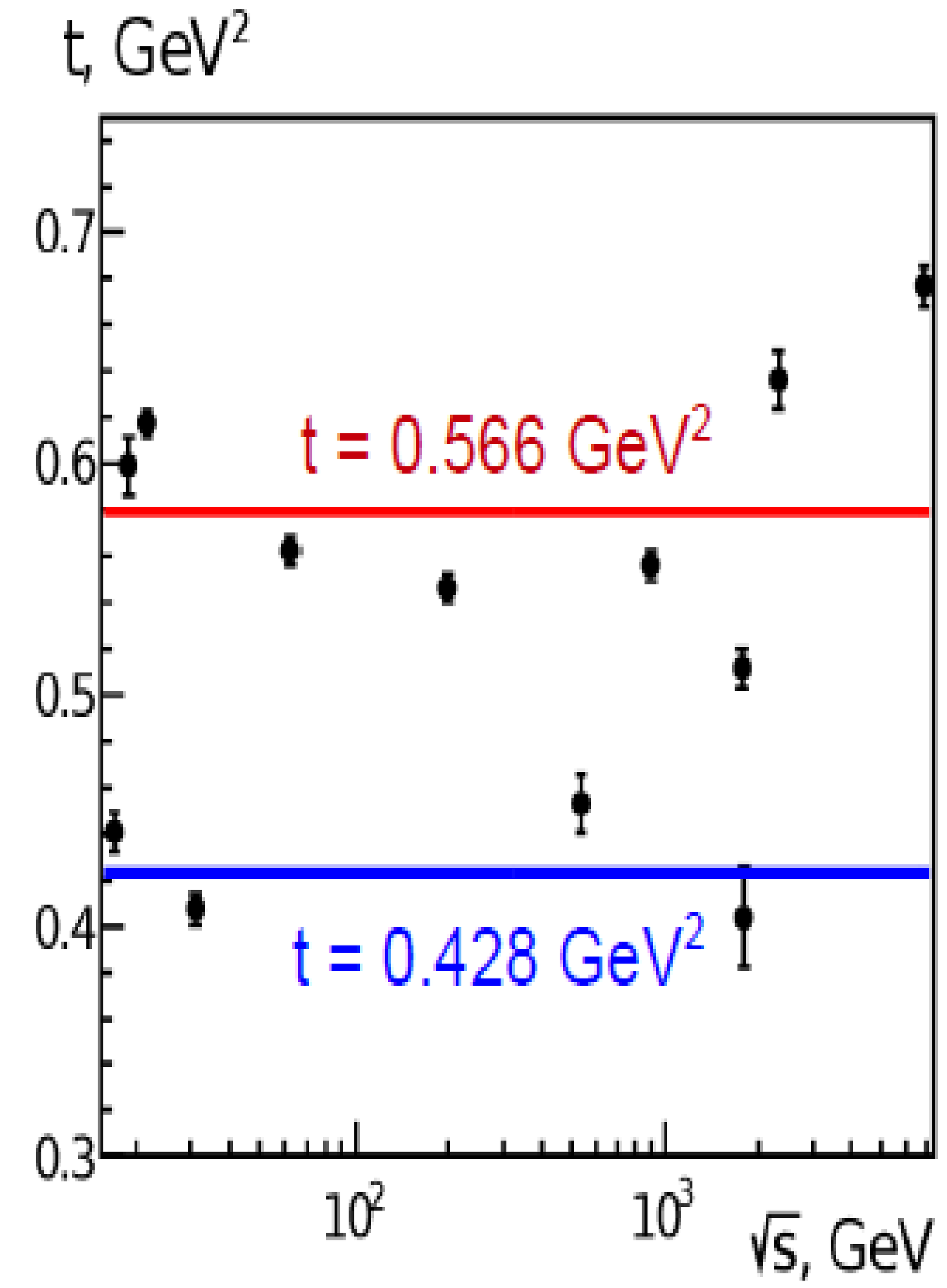
$$\langle N_{ch}\rangle(s) = \sum_{N_{ch}=0}^{\infty} N_{ch}\mathscr{P}(N_{ch}) = 2\langle n\rangle \cdot k \cdot \delta$$





Dependence of the parameters β and t on collision energy





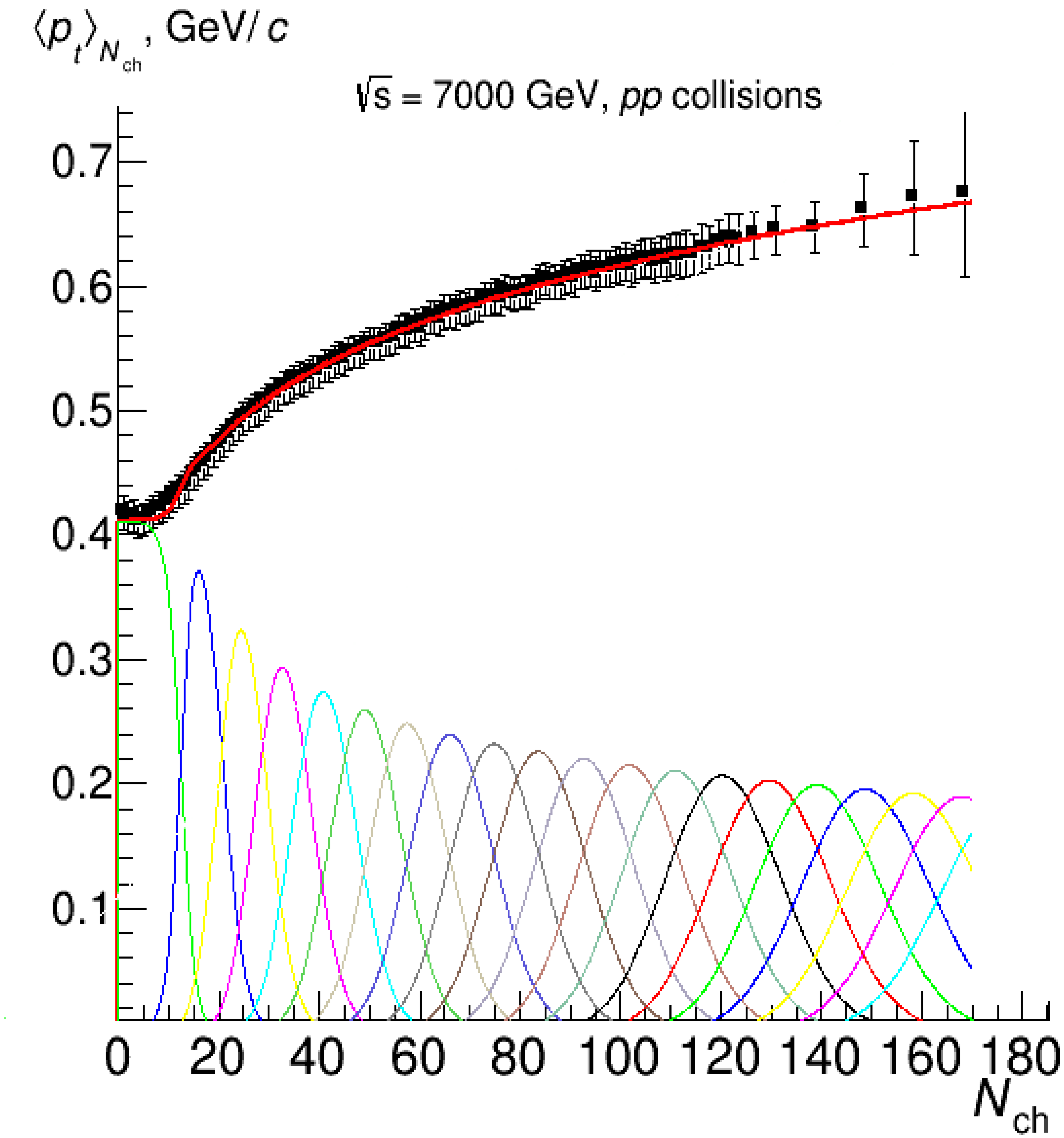
Fitted by

$$\beta = \beta_0\left[1-\left(\ln\sqrt{s}-\beta_2\right)^{-\beta_1}\right]$$

p_t-N_{ch} correlation function in the model is calculated as:

$$\langle p_t\rangle_{N_{ch}}(s) = \frac{\int_0^{\infty} \rho(N_{ch},p_t)p_t^2 dp_t}{\int_0^{\infty} \rho(N_{ch},p_t)p_t dp_t}$$

Number of pomerons involved in pp@7 TeV



For high multiplity events (Nch> 100) we have:

the number of $N_{Pomerons}$ ~ 12–19

the number of N_{srings} ~ 24–38

Summary of estimates of number of sources of particle production at midrapidity (in high multiplicity events) in pp@7TeV

Estimate	N strings
MPI (pt_{TRIG}~ 0.7 GeV/c)[1]	~15
Percolation [2]	30 +/- 12
Multipomeron exchange model [3]	24-38

[1] Andreas Morsch, for the ALICE Collaboration
Journal of Physics: Conf Seri. **535** (2014) 012012 arXiv: 1407.3628
[2] O.Kochebina, G.Feofilov, Arxiv:1012.0173
[3] Bodnia, E., Derkach, D., Feofilov, G., Kovalenko, V., and Puchkov, A.,Proc. QFTHEP 2013, St. Petersburg, 2013. http://arxiv.org/abs/1310.1627.; Bodnia, E.O., Kovalenko, V.N., Puchkov, A.M., and Feofilov, G.A., AIP Conf. Proc., 2014, vol. 1606, p. 273.

Conclusions

- Concept of color flux tubes (quark-gluon strings) as particle production sources is implemented in a number of event generators, phenomenology is tuned and looks feasible for the majority of experimental phenomena at the LHC. It contains some collectivity, manifested in long-range correlations, color-reconnection, flows…
- Independent estimates of number of these sources show that one may expect formation of ~ 20-40 strings in high multipliicty pp collisions at the LHC.
- String-string interaction between these sources in case of high density is an important factor of investigations of new effects like string fusion, “spaghetti” implosion and /or string repulsion, that are responsible for shaping the initial conditions of systems collisions leading to the QGP formation.