# *Forward-backward multiplicity correlations in pp collisions at high energy in Monte Carlo model with string fusion*


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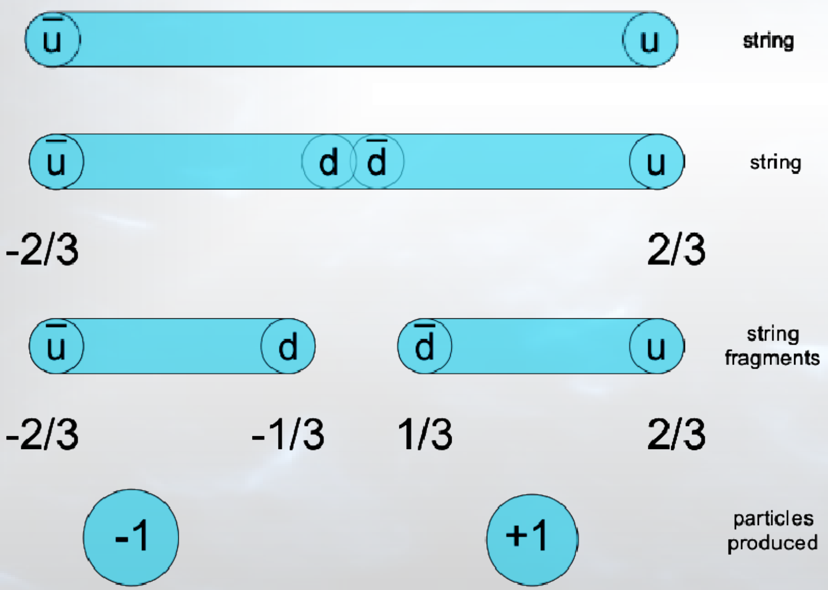
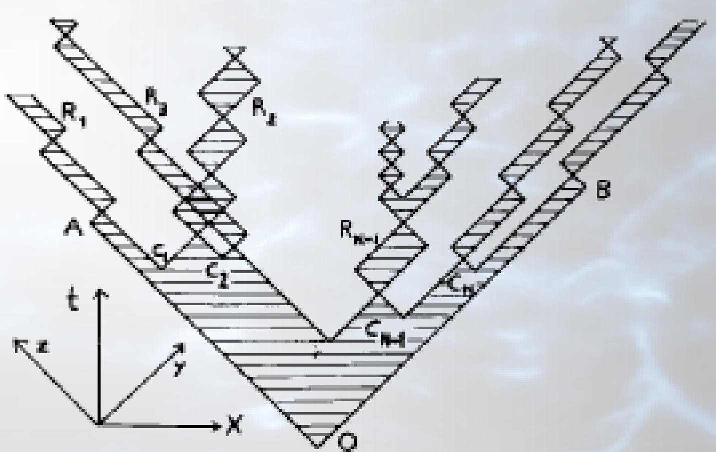
# Overview

- 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



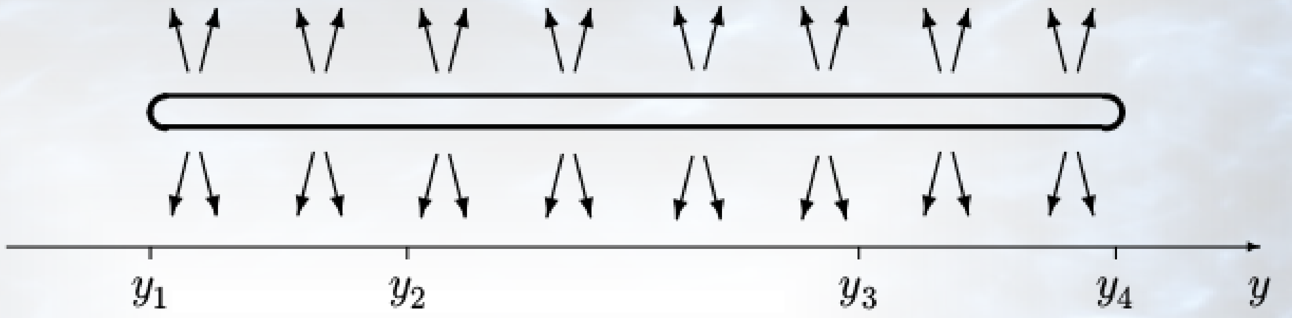




X. Artru and G. Mennessier, Nucl Phys B 70 (1974) 93
“String Model and Multiproduction”,

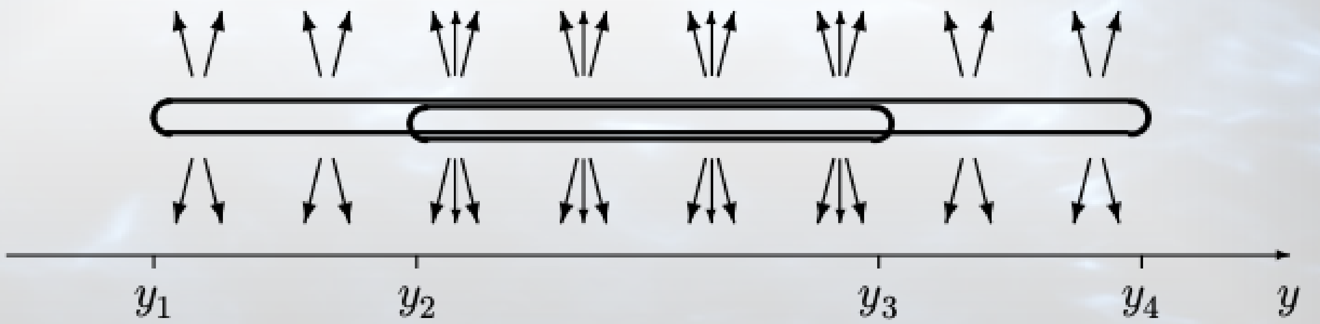
- Correlations play crucial role:
  – causality requires appearance of long-range correlations – if they exist –
at the very early stages between particles detected in separated rapidity intervals

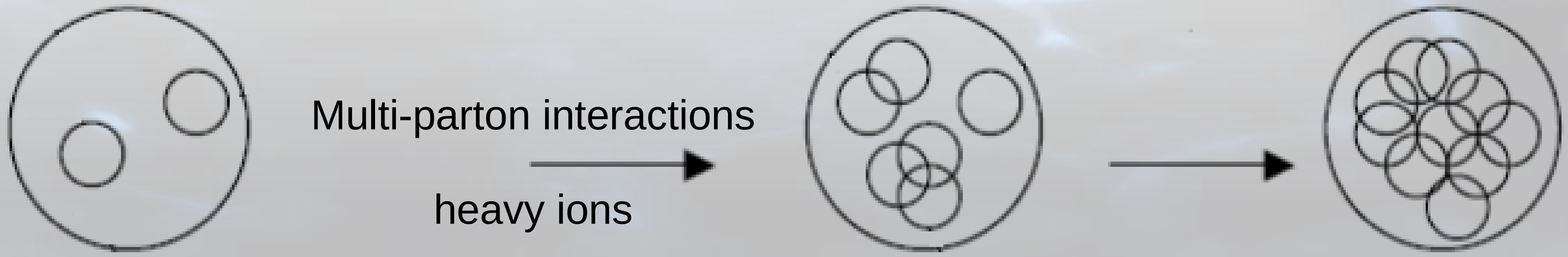
# String in rapidity space

- Uniform distribution of particles from $y_{min}$ to $y_{max}$




- Can study string overlaps:




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

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# String fusion

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

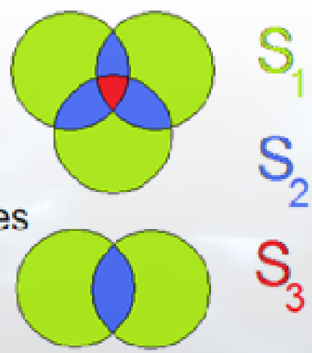
$$\left\langle Q^2(n) \right\rangle = n Q^2(1)$$

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, $\sigma_0$ single string transverse area,
$\mu_0$ and $p_0$ – mean multiplicity and transverse momentum from one string

String fusion mechanism predicts:

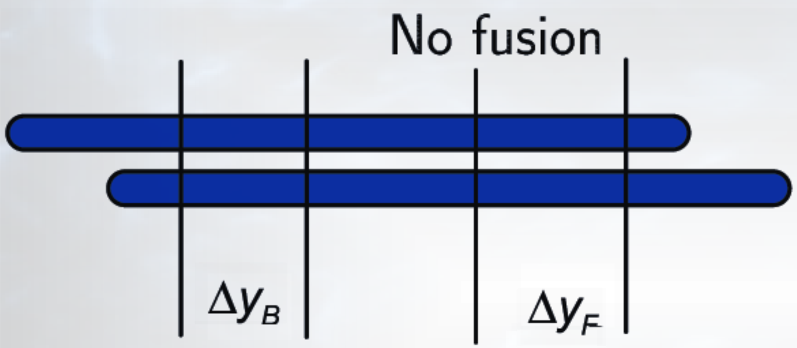
– decrease of multiplicity
– increase of $p_T$
– growth of $p_T$ with multiplicity in pp, pA and AA collisions
– growth of strange particle yields

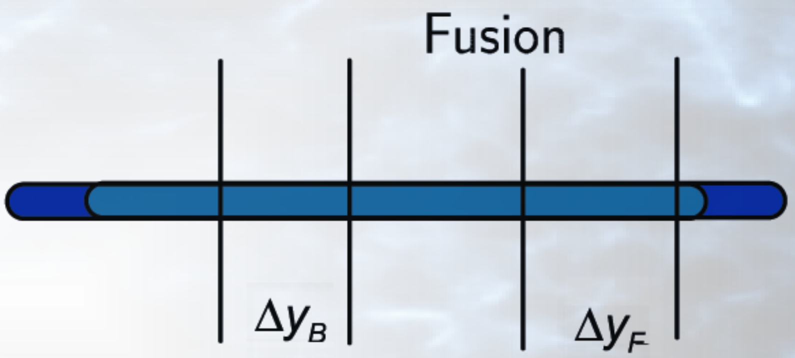
– results are in a good agreement with the experiment

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)

# Long-range (forward-backward) correlations

- Sensitive tool for studying of string fusion phenomena



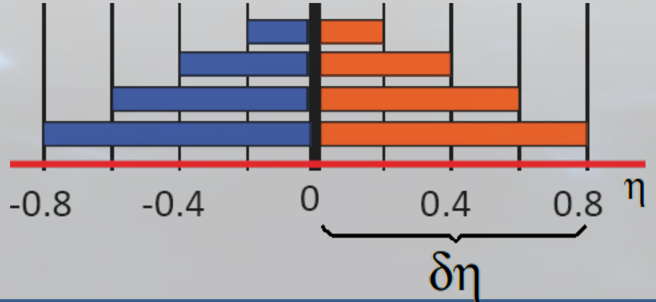



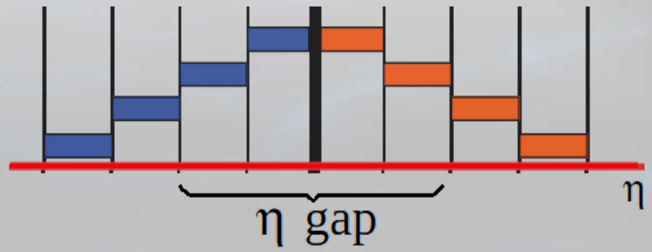

$$\langle n_F \rangle = 2\mu_0, \quad \langle p_{tB} \rangle = \overline{p}$$

$$\langle n_F \rangle = \sqrt{2}\mu_0, \quad \langle p_{tB} \rangle = \sqrt[4]{2}\overline{p}$$

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

$n_B$, $n_F$ – number of charged particles in backward and forward rapidity window

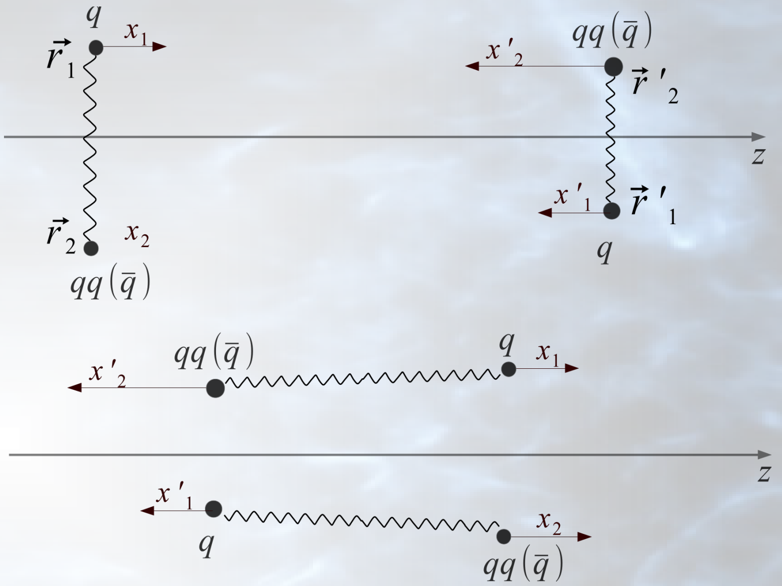


# Monte Carlo model

- Partonic picture based on dipole interaction
- Energy and angular momentum conservation in the initial state
- The probability amplitude depends on transverse coordinates:

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

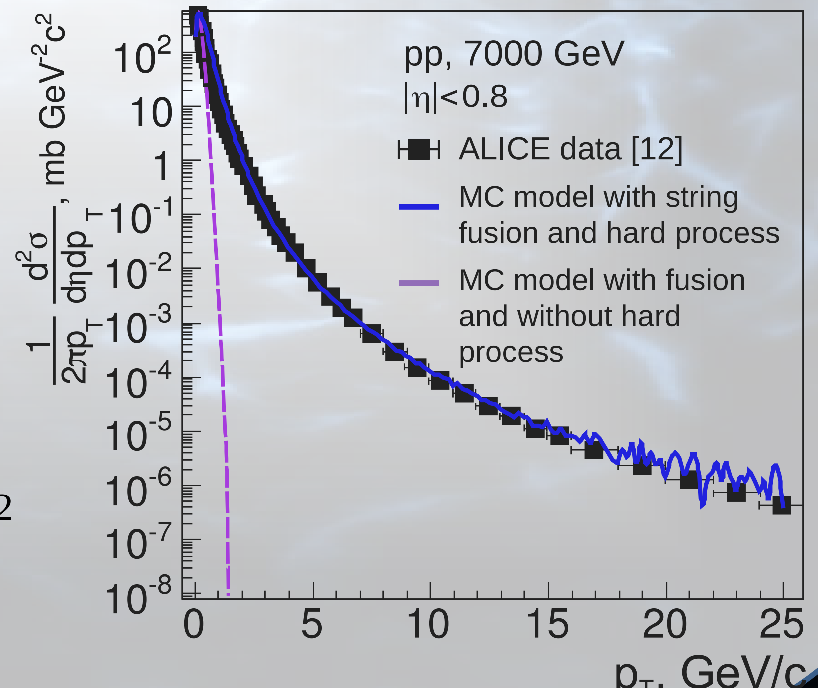



- The **hardness** of the elementary collisions is defined by transverse size of dipoles:

$$d_{1i} = |\vec{r}_1 - \vec{r}_2|, d_i' = |\vec{r}_1\,' - \vec{r}_2\,'|$$

- Transverse momentum of a cluster of strings:

$$p_1^{\ 4} = \sum_i^k p_{T\,str\,i}^{\ 4}, \quad p_{T\,str\,i}^{\ 2} = \frac{1}{d_i^2} + \frac{1}{d_i'^2} + p_0^{\ 2}$$

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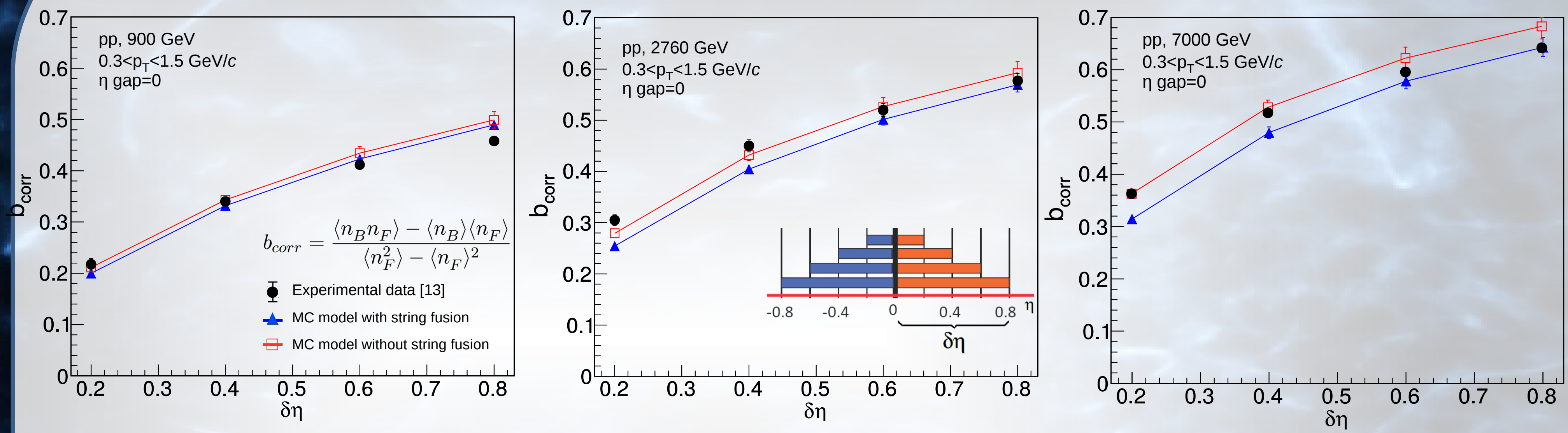
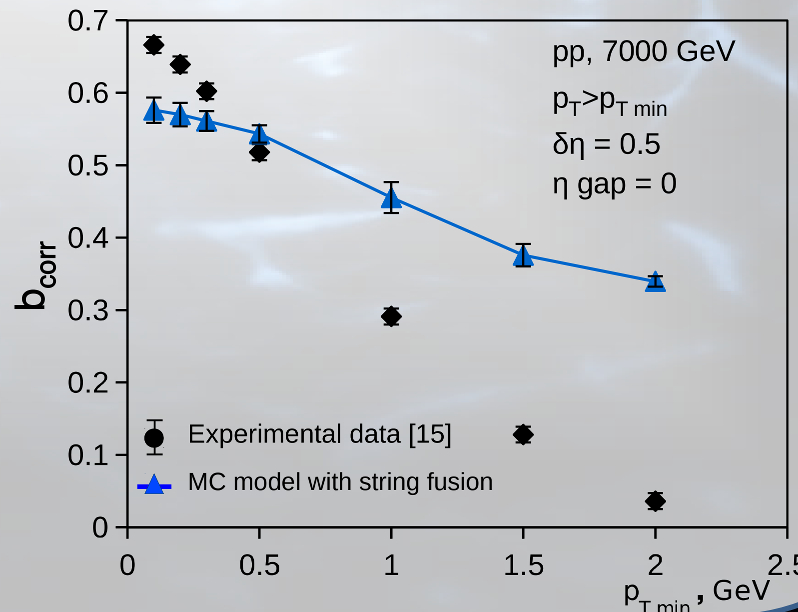
# Dependence of $b_{corr}$ on window size

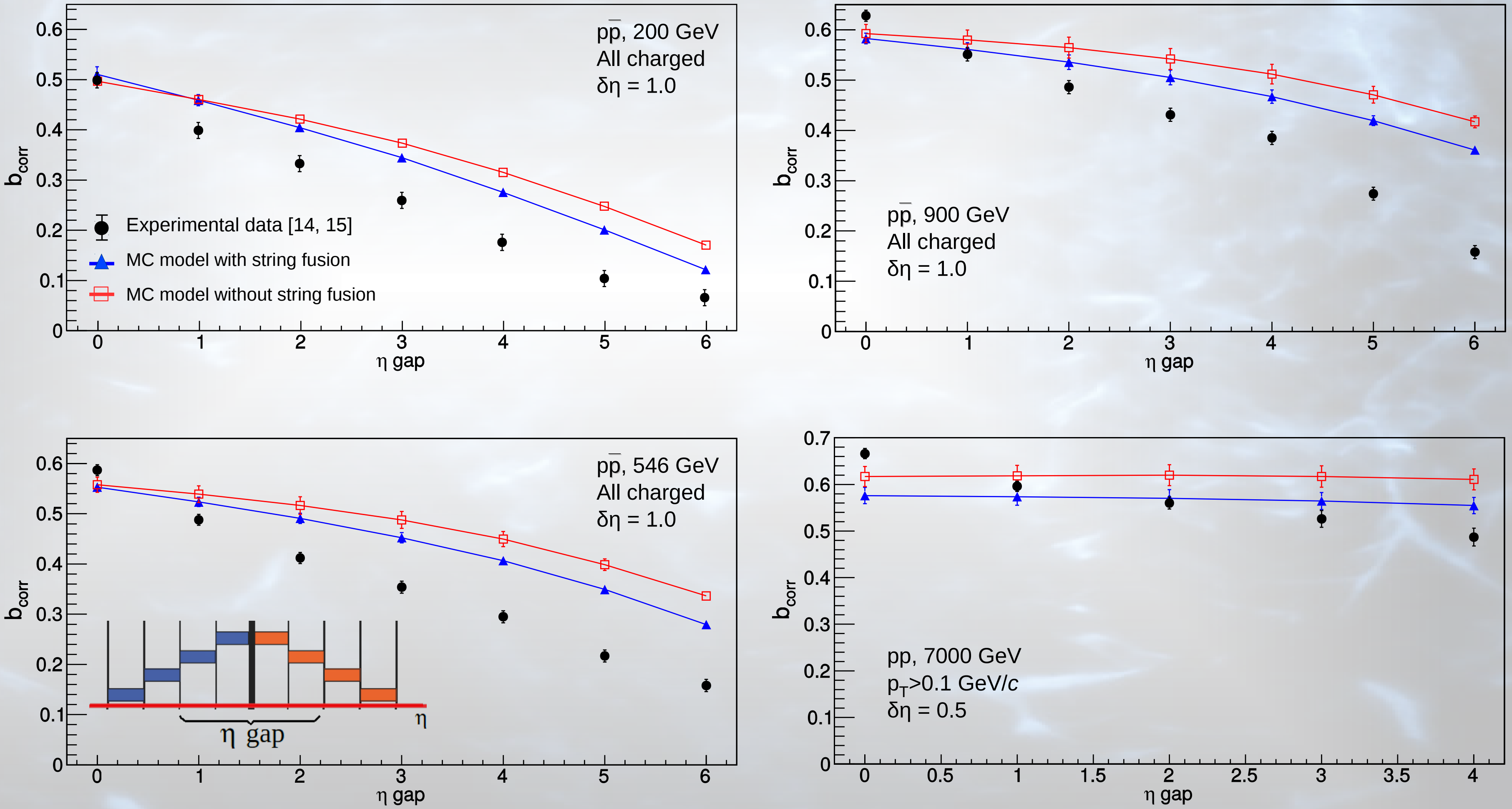



## and on $p_T$ region

- The general trends (growth of $b_{corr}$ with energy and pseudorapidity windows width) are well described by the model
- The data does not allow to distinguish between fusion/no fusion
- Qualitative agreement of the dependence on the lower bound of the $p_T$ range



# Dependence of $b_{corr}$ on pseudorapidity gap




- The model describes the behavior of $b_{corr}$ in wide energy range
- At small η gap the data is contaminated by short-range effects
- The model <u>with</u> string fusion is better supported by the data

# Summary and conclusions

- The forward-backward multiplicity correlations in pp collisions are studied in the Monte Carlo model with string formation and fusion
- The Monte Carlo model reasonably describes the main features of the correlation coefficient in a wide energy range:
    - The general growth of the correlation coefficient with collision energy
    - Growth of $b_{corr}$ with increase of the pseudorapidity window size and decrease of $b_{corr}$ with increase of the gap between windows
    - Decrease of $b_{corr}$ with increase of lower $p_T$ bound.
- The model with string fusion is better supported by the data, while the case without string fusion is disfavored

# End Of Presentation

Thank you!

# Backup

# Forward-backward multiplicity correlations in pp collisions at high energy in Monte Carlo model with string fusion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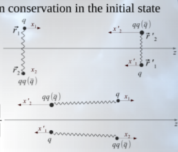
## Abstract and motivation


The magnitude of the correlations between multiplicities in two separated rapidity windows, proposed as a tool for study of the string fusion and percolation phenomena [1], is studied in the framework of the Monte Carlo string-parton model [2-3]. The model is based on the picture of strings formation in elementary collisions of color dipoles. The hardness of the elementary collisions is defined by a transverse size of the interacting dipoles.

In the framework of the model the charged particles spectra with the account of string interaction in the transverse plane is calculated. The interaction of strings is realized in the accordance with the string fusion model [4-6] prescriptions by the introduction of the lattice in the impact parameter plane and taking into account the finite rapidity length of strings. The parameters of the model were fixed with the experimental data on total inelastic cross section and charged multiplicity. The dependencies of the forward-backward correlation strength on the width and position of the pseudorapidity windows and on the transverse momentum range of observed particles were studied. The detailed modeling of the charged particles spectra allowed to make a direct comparison to the results of experimental measurements at different energies.


## Monte Carlo model

- Partonic picture of nucleons interaction [2, 3].
- Energy and angular momentum conservation in the initial state of a nucleon.
- The probability of dipoles interaction depends on their transverse coordinates [7-8] with effective coupling :



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

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

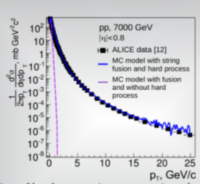
- The interaction of strings is realized in the accordance with the **string fusion** model prescriptions [4-6]. Mean multiplicity and the mean trans verse momentum of the particles produced from a cluster of strings are:

$$\langle\mu\rangle_k = \mu_1 \sqrt{k}\frac{S_k}{\sigma_1} \qquad \langle p_t^2\rangle_k = p_1^2\sqrt{k} \qquad \langle p_t\rangle_k = p_1 \sqrt[4]{k}$$

$S_k$ – area, where $k$ strings overlapping, $\sigma_1 = \pi r_{str}^2$ – single string transverse area, $\mu_1$ and $p_1$ – mean multiplicity and transverse momentum from one string.

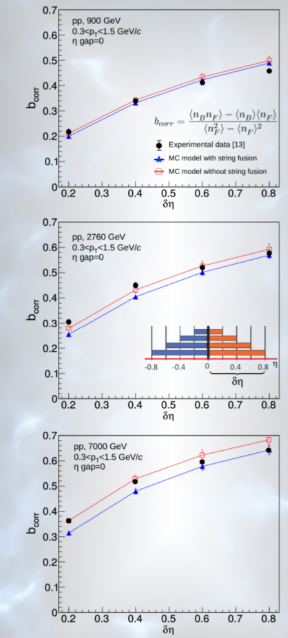
- Multiplicity from one string is distributed according to Poisson distribution, with Gaussian transverse momentum spectra.
- The **hardness** of the elementary collisions is either constant ($p_0$) – in case of no hard subprocess; or it is defined by a transverse size of the interacting dipoles, similarly to DIPSY [9, 10]: $d_{1i} = |\vec{r}_1 - \vec{r}_2|, d_i' = |\vec{r}_1' - \vec{r}_2'|$
- In case of hard process, the transverse momentum of a cluster of strings: $p_1^4 = \sum_i^k p_{T\,str\,i}^4$, where $p_{T\,str\,i}^2 = \frac{1}{d_i^2} + \frac{1}{d_i'^2} + p_0^2$
- Every parton can interact with anther one only once (contrary to Glauber supposition of constant nucleon cross section).
- Parameters of the model are constrained from the data on total inelastic cross-section and multiplicity [2, 11]. We used $r_{str}$=0.2fm (in case with string fusion), and $p_0$ = 0.2 GeV/$c$ in case with the hard process or $p_1$ = 0.4 GeV/$c$ without hard process.

## Transverse momentum distribution




- Inclusion of hard process is necessary in order to reproduce the transverse momentum spectra of charged particles in pp collisions.
- Reasonable good description of transverse momentum spectra of charged particles in the MC model with string fusion and hard process included.

## Dependence of $b_{corr}$ on window size




- The general trends (growth of $b_{corr}$ with energy and pseudorapidity windows width) are well described by the model
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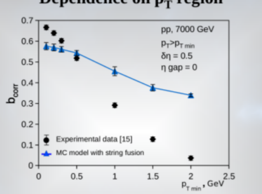
## Dependence on $p_T$ region




- Qualitative agreement with experimental data
- Decrease of the correlation coefficient on the lower bound of the $p_T$ range due to lack of phase space and less multiplicity in the window
- Sensitivity to the details of the $p_T$ spectra

## Summary and conclusions

- The forward-backward multiplicity correlations in pp collisions are studied in the Monte Carlo model with string formation and fusion
- The Monte Carlo model reasonably describes the main features of the correlation coefficient in a wide energy range:
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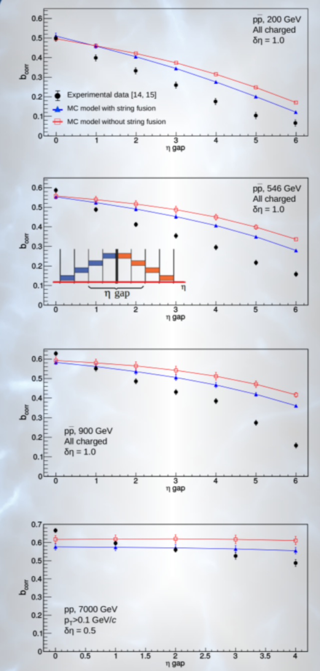


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## References


1. B. Alessandro et al. (ALICE Collaboration), ALICE: Physics Performance Report, Vol. II, J. Phys. G 32, 1295 (Section 6.5.15: Long-range correlations, p. 1749) (2006).
2. V. N. Kovalenko, Phys. Atom. Nucl. 76, 1189 (2013), arXiv:1211.6209 [hep-ph].
3. V. Kovalenko, V. Vechernin, PoS (Baldin ISHEPP XXI) 077 (2012), arXiv:1212.2590 [nucl-th].
4. N. S. Amelin, N. Armesto, M.A. Braun, E.G. Ferreiro, C. Pajares, Phys. Rev. Lett. 73, 2813 (1994).
5. M.A. Braun, R.S. Kolevatov, C. Pajares, V.V. Vechernin, Eur. Phys. J. C32, 535 (2004).
6. M. A. Braun, C. Pajares, and V. V. Vehernin, Phys. Let. B 493, 54 (2000).
7. C. Flensburg, G. Gustafson, and L. Lönnblad, Eur. Phys. J. (C) 60, 233 (2009), arXiv:0807.0325.
8. G. Gustafson, Acta Phys. Polon. B 40, 1981, 2009 arXiv:0905.2492 [hep-ph].
9. C. Flensburg, G. Gustafson, L. Lönnblad, JHEP (2011) 8, 103, arXiv:1103.4321 [hep-ph],
10. C. Flensburg Progr. Theor. Phys. Suppl. No. 193 (2012), 172.
11. V. Kovalenko, PoS (QFTHEP 2013) 052 (2013).
12. B. Abelev, et. al. (ALICE Collaboration), Eur. Phys. J. C 73 (2013) 2662, arXiv:1307.1093 [nucl-ex].
13. G. Feofilov, V. Vechernin, S. De, T. Nayak, B. K. Srivastava, PoS (Baldin ISHEPP XXI) 075 (2012).
14. R .E. Ansorge, et. al (UA5 Collaboration), Z.Phys C 37 (1988) 191-213.
15. G. Aad, et al. (ATLAS Collaboration), JHEP 07 (2012) 019.