Monte Carlo model for pp, pA and AA collisions at high energy: parameters turning and results

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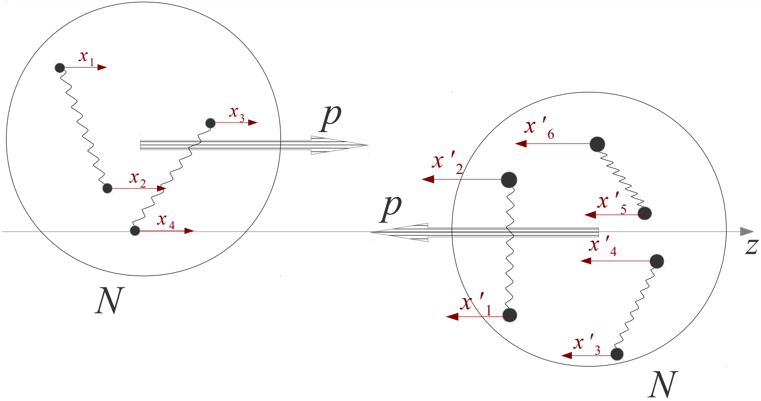
Outline

- MC model description
- Parameters and fixing procedure
    - Results for pp and p-Pb collisions
- Results for Pb-Pb collisions
- Conclusions

Color dipoles inside a nucleon



$$\sum_i x_i p = p \qquad \sum_i x_i' p = p$$

$$\sum_i x_i = 1 \qquad \sum_i x_i' = 1$$

p-p interaction: 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 distribution as the valence quarks.
- Poisson distribution for the number of quark-antiquark (diquark) pairs (n) 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

p-p interaction: parton distributions

- Corresponding exlusive distribution of the momentum fractions:

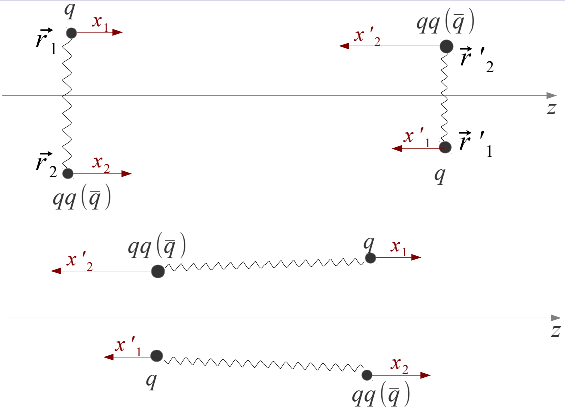
$$\rho(x_1, ...x_N) = c \cdot \prod_{j=1}^{N-1} x_j^{-\frac{1}{2}} \cdot x_N^{\alpha_N} \cdot \delta(\sum_{i=1}^{N} x_i - 1)$$

- Valence quark is labelled by N-1, the diquark by N, and the other refers to sea quarks and antiquarks.
- N=2*n

6 Distribution in the 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: $< r_N^2 >= \frac{3}{2} r_0^2$.

Monte Carlo model: Color dipoles



Interaction probability amplitude [4, 5]:

$$(1)\quad f=\frac{\alpha_s^2}{2}\ln^2\frac{|\vec{r}_1-\vec{r}_1'||\vec{r}_2-\vec{r}_2'|}{|\vec{r}_1-\vec{r}_2'||\vec{r}_2-\vec{r}_1'|}$$

Two dipoles interact more probably, if the ends are close to each other, and (others equal) if they are wide.

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

Miscellaneous

- With confinement taken into we obtain [4, 5]:

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

  where K_0 is modified Bessel function.

- At $r \to 0$ $K_0(r/r_{max}) \approx -\ln(r/(2r_{max}))$ and we return back to the formula (1).
- At $r \to \infty$: $K_0(r/r_{max}) \approx \sqrt{\frac{\pi r_{max}}{2r}} e^{-r/r_{max}}$

and amplitude decrease exponentially.

- The total probability of the inelastic interaction of two protons in the eikonal approximation:

$$p = 1 - e^{-\sum_{i,j} f_{ij}}$$

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

Calculation of multiplicity

- Multiplicity is calculated in the framework of colour strings, stretched between colliding partons; x_i determine rapidity ends of strings.

y_{min} and y_{min} are calculated supposing that a string fragments into only two particle with masses 0.15 GeV (for pion) and 0.94 GeV for proton and transverse momentum of 0.3 GeV (and higher at LHC)

- dN/dy from one string is supposed to be constant μ_0.
- String fusion effects considered

string fusion

The interaction of colour strings in transverse plane is carried out in the framework of local string fusion model [6]
with the introduction of the lattice in the impact parameter plane.
The finite rapidity length of strings is taken into account [7-9].

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

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

[6] Braun, M.A. and Pajares, C. Eur. Phys. J. (C),16,349,2000
[7] V. Vechernin and R. Kolevatov, Physics of Atomic Nuclei 70, 1797 (2007)
[8] V. Vechernin and R. Kolevatov, Physics of Atomic Nuclei 70, 1809 (2007)
[9] Vechernin, V. V. and Kolevatov, R. S., Simple cellular model of long-range multiplicity and pt correlations in high-energy nuclear collisions 2003 http://arxiv.org/abs/hep-ph/0304295v1

Description of a nucleus

- We use usual Woods-Saxon form of nuclear distribution:

$$\rho(r) = \rho_0 \frac{1}{1 + exp\left(\frac{r - R}{\alpha}\right)}$$

- All partons from each nucleon are considered together

- A nucleus is participating in the collision
  if at least one of it's partons collides with other from the proton.

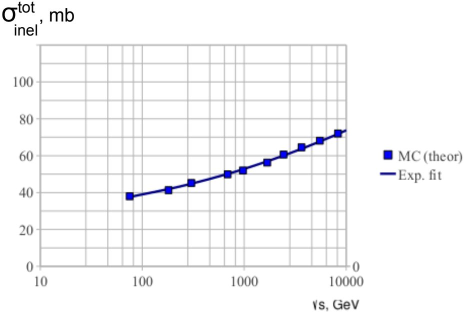
- **Every parton can interact with other one only once –** this provide energy conservation in the initial state

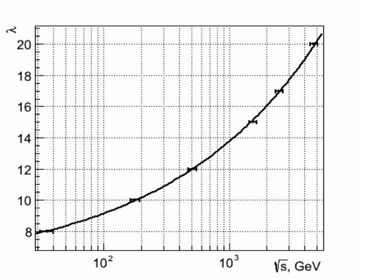
p-p interaction: parameter fixing

Strategy for parameters fixing:

- Correspondence of mean number of dipoles λ and energy is obtained using data on total inelastic cross section

- Performed for each parameters set





p-p interaction: parameter fixing

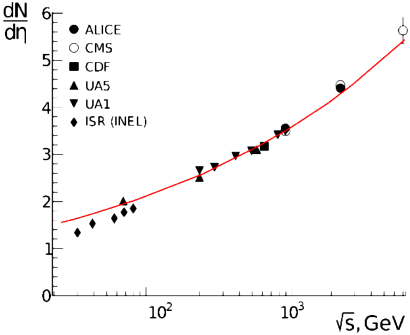
Strategy for parameters fixing:

- Mean multiplicity per rapidity from one string μ_0 is fixed once at intermediate LHC energy (2.36 TeV)

- Data on energy dependence of multiplicity in pp collisions is used to constrain the rest of parameters

- p-Pb at 5.02 GeV minimum bias: <dN/deta>=16.81 ± 0.71 [10]

- Look at PbPb collisions

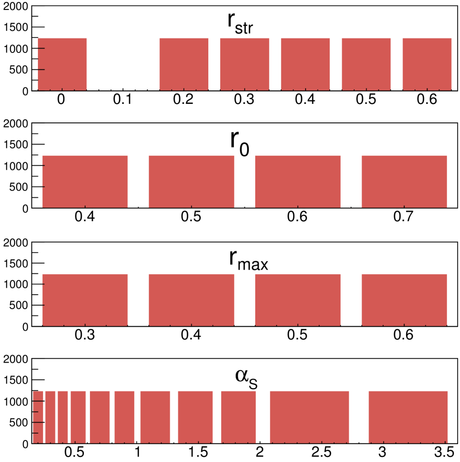


[10] B. Abelev et al (ALICE Collaboration) Phys. Rev. Lett. 110, 032301, 2013

p-p interaction: parameter fixing

Initial range of parameters:

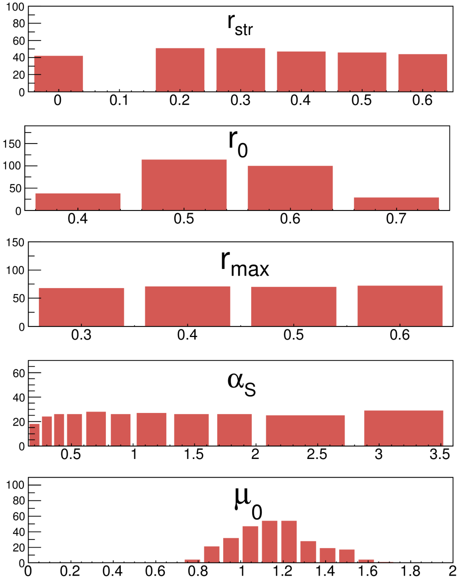
- r_0: 0.4 – 0.7 fm
- r_{max}/r_0: 0.3 – 0.6
- α_S: 0.2 – 2.8
- r_{str}: 0 (no fusion); 0.2-0.6 fm
- Energy range: 53 – 7000 GeV



parameter fixing: After accounting of pp multiplicity

pp multiplicity in the model

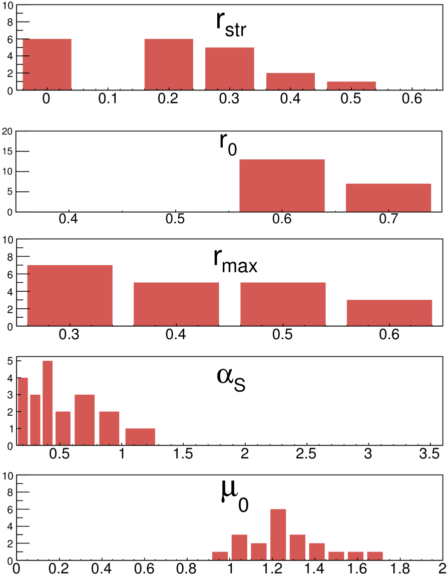
- Not sensitive to string fusion
- r_0 arounf 0.5 – 0.6 is favoured
- r_{max} and α_S: no conclusion
- μ_0: always about 1.1 – 1.2



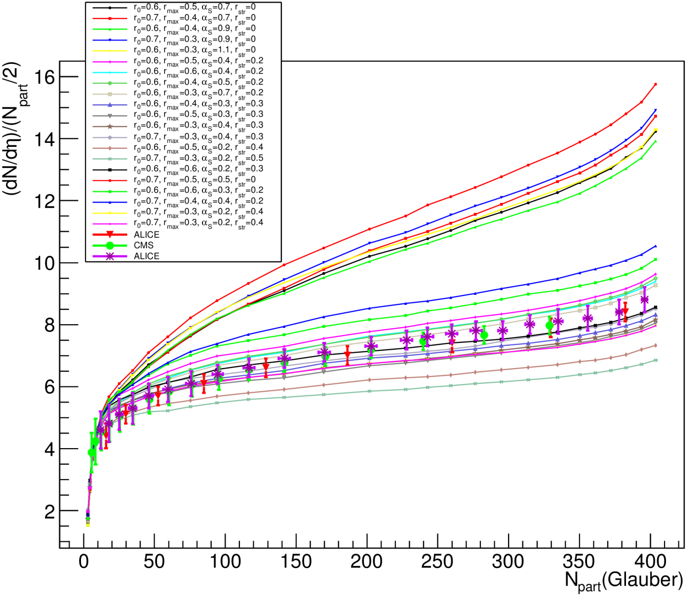
parameter fixing: After accounting of p-Pb multiplicity

p-Pb multiplicity gives us:

- Large string radius is disfavoured
- r_0 of 0.4 – 0.5 fm is excluded
- large α_S excluded
- for both r_{max} and α_S: less are favoured: higher λ and lower elementary collision probability
- μ_0: is still about 1.1 – 1.2



Results:
PbPb collisions at 2.76 TeV



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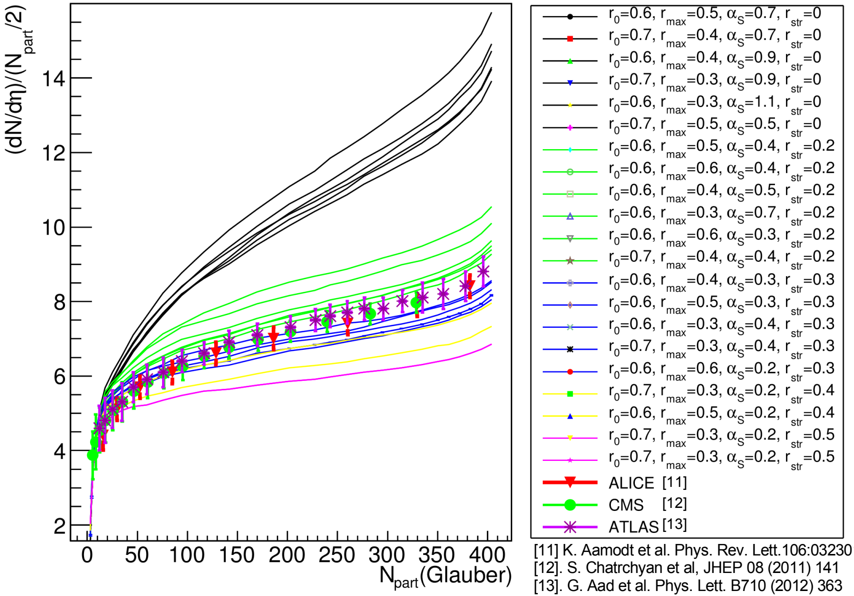
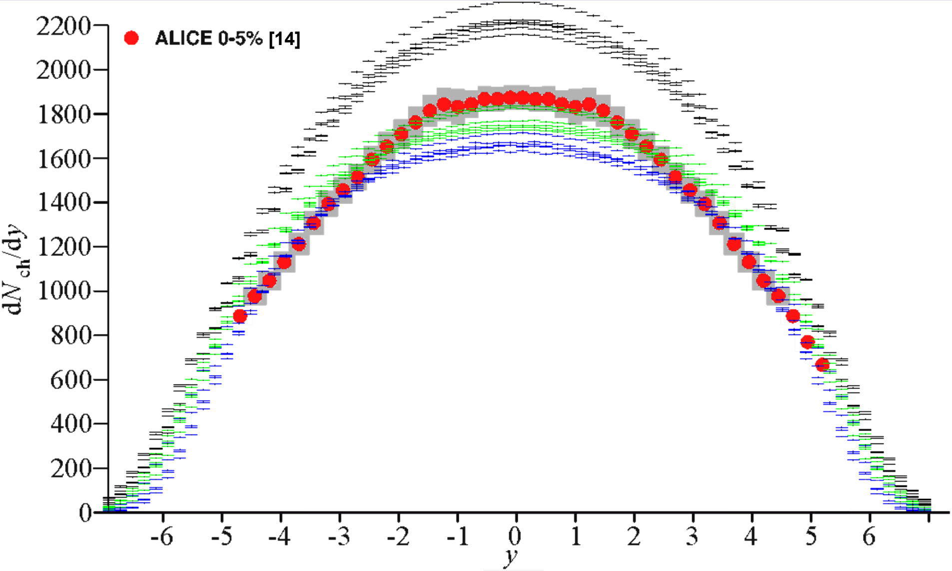


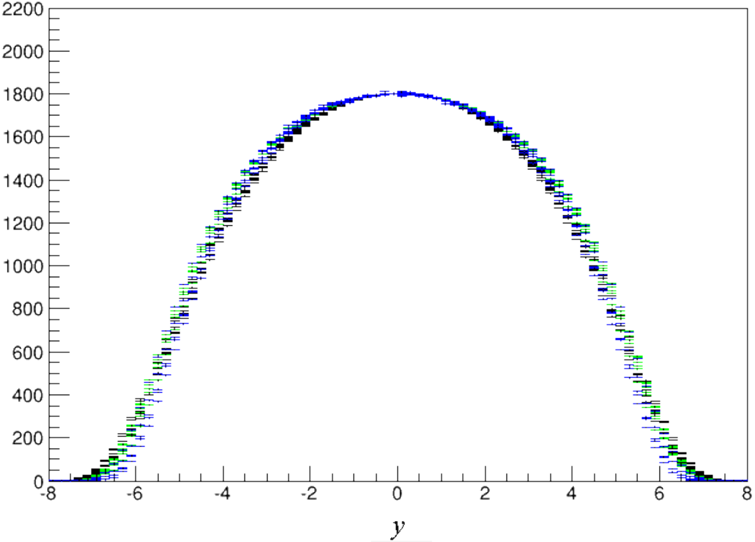
[11] K. Aamodt et al. Phys. Rev. Lett.106:032301, 2011
[12]. S. Chatrchyan et al, JHEP 08 (2011) 141
[13]. G. Aad et al. Phys. Lett. B710 (2012) 363

Results: PbPb collisions at 2.76 TeV
dN/dy



[14] E. Abbas, et al. (ALICE Collaboration) arXiv:1304.0347 [nucl-ex], 2013

Results: PbPb collisions at 2.76 TeV dN/dy, normalized at y=0

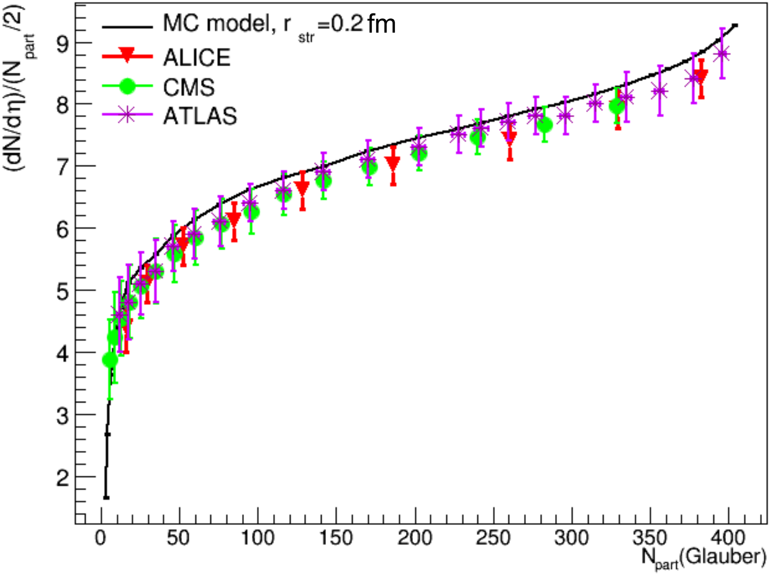


Conclusions

- The present non-Glauber Monte-Carlo model describes multiplicity yields in wide energy range and for different colliding systems.
- The results on pp collisions do not fully constrain the model and one have to use other colliding systems
- Multiplicity per rapidty from one single string is about 1.0 – 1.2
- Comparison with experiment of the dependence of multiplicity per participant on the centrality in PbPb collisions at 2.76 TeV shows that good agreement is obtained only when the string fusion effects are present with the radius of string 0.2-0.3 fm.
- Both energy conservation in the initial state and string fusion are important in PbPb collisions for the description of multiplicity

[15] Irais Bautista, Carlos Pajares, José Guilherme Milhano, Jorge Dias de Deus. Phys. Rev. C 86, 034909 (2012) arXiv:1206.6737 [nucl-th]

Conclusions



Backup

References

- V.Kovalenko. Modelling of exclusive parton distributions and long-range rapidity correlations for pp collisions at the LHC energy
accepted at Phys. Atom. Nucl. Vol. 93, N 10 (2013)
arXiv:1211.6209 [hep-ph]

- V.Kovalenko, V.Vechernin. Model of pp and AA collisions for the description of long-range correlations
PoS (Baldin ISHEPP XXI) 077
arXiv:1212.2590 [nucl-th]

Confinement

- We have to introduce a new parameter – r_{max}
- Confinement effects can be taken into account by the replacement of the Coulomb propagator $\Delta(\vec{r}) = \int \frac{d^2\vec{k}}{(2\pi)^2}\frac{e^{i\vec{k}\cdot\vec{r}}}{k^2}$, by the Yukawa one: $\frac{1}{k^2+M^2}$, where $M = 1/r_{max}$ is the confinement specific scale.
- As a result, we get for the probability amplitude the following:

$$f = \frac{\alpha_s^2}{2}\Big[K_0\left(\frac{|\vec{r}_1-\vec{r}_3|}{r_{max}}\right) + K_0\left(\frac{|\vec{r}_2-\vec{r}_4|}{r_{max}}\right) - \\ -K_0\left(\frac{|\vec{r}_1-\vec{r}_4|}{r_{max}}\right) - K_0\left(\frac{|\vec{r}_2-\vec{r}_3|}{r_{max}}\right)\Big]^2 \qquad (4)$$

- Squared ratio of the quark and hadron radiuses should be about $\frac{1}{10}$. It leads $r_{max} \simeq 0.2 - 0.3 fm$.

p-p interaction: color dipoles

- The probability amplitude for the collision of two dipoles with coordinates (r_1,r_2), (r_3,r_4) [3,4]:

$$f = \frac{\alpha_S^2}{2}\ln^2\frac{|\vec{r_1}-\vec{r_3}|\cdot|\vec{r_2}-\vec{r_4}|}{|\vec{r_1}-\vec{r_4}|\cdot|\vec{r_2}-\vec{r_3}|}$$

- Confinement is taken into account by introduction of some cut off at $r_{max} \simeq 0.2 - 0.3$fm. It leads:

$$f = \frac{\alpha_s^2}{2}\Big[K_0\left(\frac{|\vec{r}_1-\vec{r}_3|}{r_{max}}\right)+K_0\left(\frac{|\vec{r}_2-\vec{r}_4|}{r_{max}}\right)- -K_0\left(\frac{|\vec{r}_1-\vec{r}_4|}{r_{max}}\right)-K_0\left(\frac{|\vec{r}_2-\vec{r}_3|}{r_{max}}\right)\Big]^2$$

- The total probability of the inelastic interaction of two protons in the eikonal approximation:

$$p = 1 - e^{-\sum\limits_{i,j} f_{ij}}$$

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

p-p interaction: string fusion

The interaction of colour strings in transverse plane is carried out in the framework of local string fusion model [5]
with the introduction of the lattice in the impact parameter plane.
The finite rapidity length of strings is taken into account [6-8].

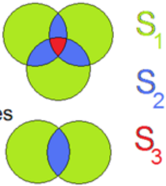
$$\langle \mu \rangle_k = \mu_0 \sqrt{k} \frac{S_k}{\sigma_0} \qquad \left\langle p_t^2 \right\rangle_k = p_0^2 \sqrt{k} \qquad \langle p_t \rangle_k = p_0 \sqrt[4]{k}$$

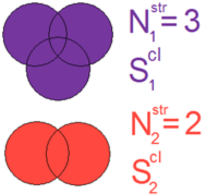
Sk – area, where k strings are overlapping, σ_0 single string transverse area, μ_0 and p_0 – mean multiplicity and transverse momentum from one string

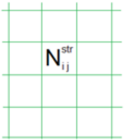
[5] Braun, M.A. and Pajares, C. Eur. Phys. J. (C),16,349,2000
[6] V. Vechernin and R. Kolevatov, Physics of Atomic Nuclei 70, 1797 (2007)
[7] V. Vechernin and R. Kolevatov, Physics of Atomic Nuclei 70, 1809 (2007)
[8] Vechernin, V. V. and Kolevatov, R. S., Simple cellular model of long-range multiplicity and pt correlations in high-energy nuclear collisions 2003 http://arxiv.org/abs/hep-ph/0304295v1

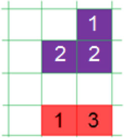
string fusion mechanism versions

	"overlaps" (local fusion)	"clusters" (global fusion)
SFM	○ $C=\{S_1, S_2, \dots\}$ S_k – area covered k-times	● $C=\left\{\begin{matrix} S_1^{cl}, S_2^{cl}, \dots \\ N_1^{str}, N_2^{str}, \dots \end{matrix}\right\}$ $k_i^{cl} = \frac{N_i^{str}\cdot\sigma_0}{S_i^{cl}}$
cellular analog of SFM	□ $C=\{N_{ij}^{str}\}$ $k_{ij} = N_{ij}^{str}$ – "occupation" numbers	■ $C=\left\{\begin{matrix} S_1^{cl}, S_2^{cl}, \dots \\ N_1^{str}, N_2^{str}, \dots \end{matrix}\right\}$ $k_i^{cl} = \frac{N_i^{str}\cdot\sigma_0}{S_i^{cl}}$ $S_1^{cl}=3\sigma_0$; $N_1^{str}=5$; $k_1^{cl}=5/3$ $S_2^{cl}=2\sigma_0$; $N_2^{str}=4$; $k_2^{cl}=2$









Glauber Model [2, 3]

- Nucleus-Nucleus collision is a sequence of nucleons collisions
- Nucleons are distributed according to Woods-Saxson:

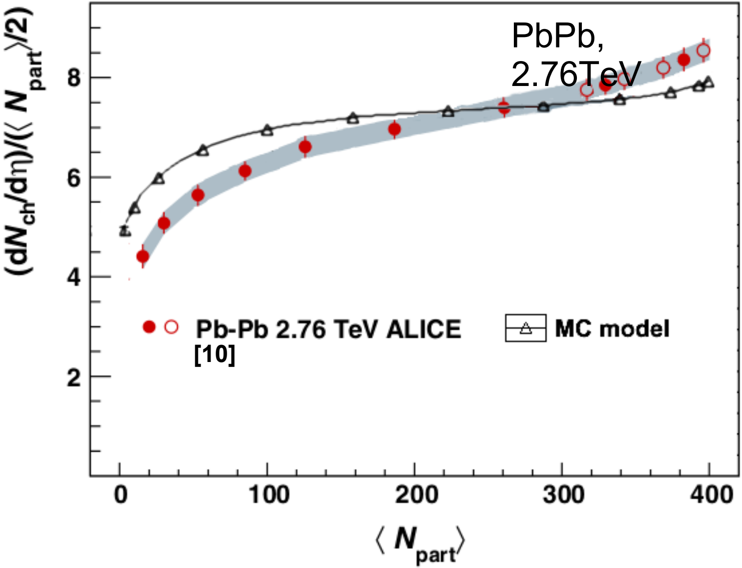
$$\rho(r) = \rho_0 \frac{1}{1 + exp\left(\frac{r-R}{\alpha}\right)}$$

- Trajectories of nucleons are linear
- Each nucleus can collide several times with the same inelastic cross section: ${\sigma_{inel}}^{nn}$=const

  corresponding to proton-proton inelastic cross section
- Energy loss due to particle production is not considered

[2] Bialas A, Bleszynski M, Czy W. Nucl.Phys.B 111:461,1976; Glauber RJ. Nucl. Phys.A 774:3, 2006
[3] M. L. Miller, K. Reygers, S. J. Sanders, P. Steinberg. Ann. Rev. Nucl. Part. Sci., 57:205–243, 2007

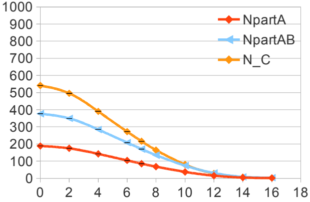
AA interaction: charged multiplicity

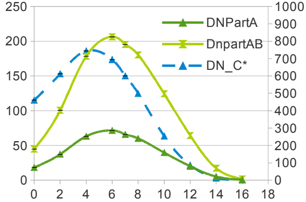


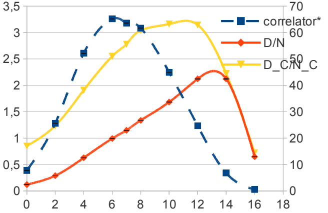
[10] K. Aamodt et al (ALICE Collaboration).Phys. Rev. Lett.,106, 032301, 2011.

AA interactions
Compare with Glauber's model

Number of participant, number of binary collisions, their variations and scaled variatons and correlator for σ^{inel}_{NN} =34mb, calculated in the *model of this work*:







The same for the *Glauber's model* (σ_{NN} =34mb) :