Combinants of multiplicity distribution in the Monte Carlo model with string fusion

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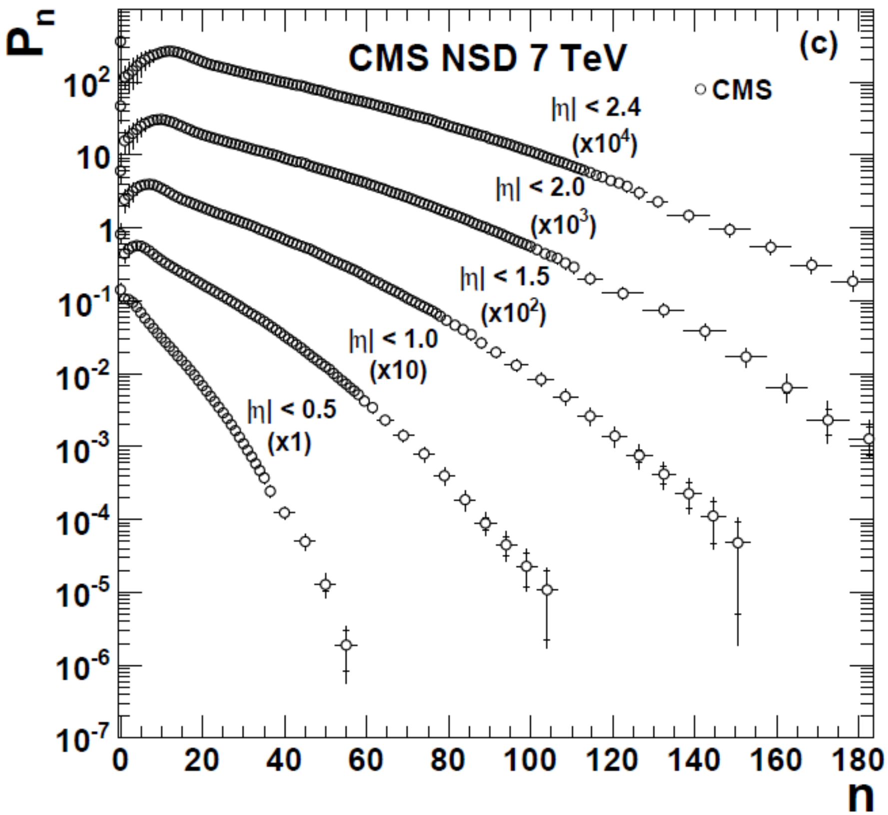
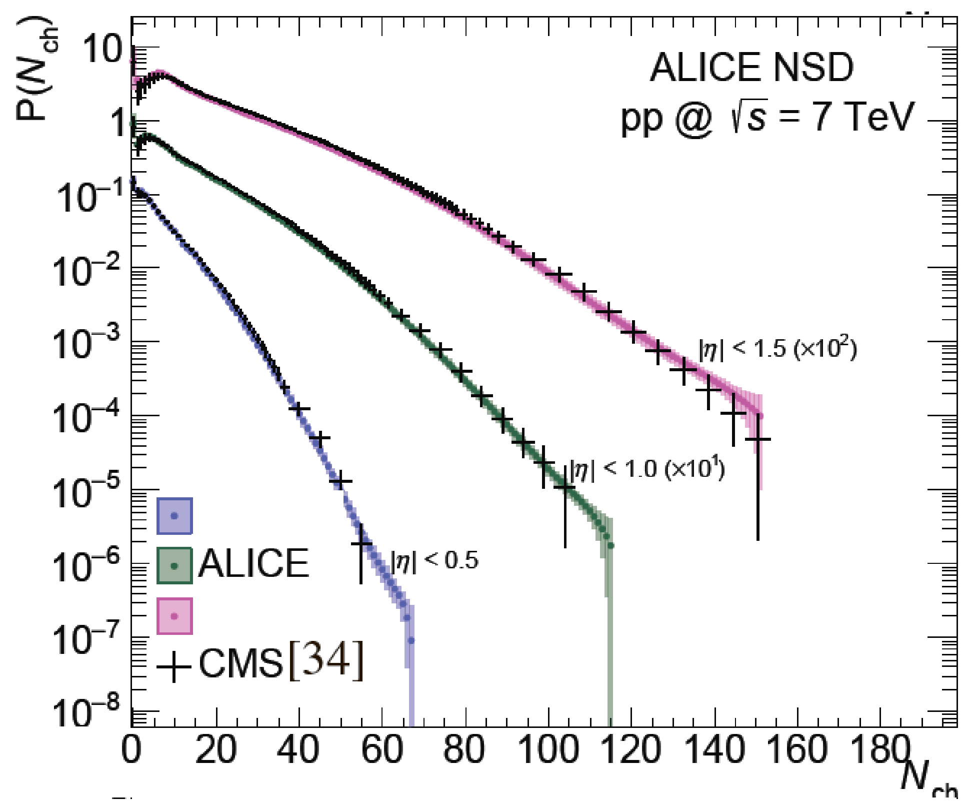
Multiplicity distributions





- CMS Collaboration, JHEP 01, 079 (2011).
- ALICE Collaboration, Eur.Phys.J.C77, 33 (2017).

$$(N+1)P(N+1) = \sum_{j=0}^{N} C_j P(N-j)$$

Combinants

- Generating function for multiplicity distribution:

$$G(t) = \sum_{N=0}^{\infty} P(N)\, t^N$$

- Generating function for combinants:

$$F(t) = \sum_{j=0}^{\infty} C^*(j)\, t^j \,, \qquad \text{where} \qquad F(t) = \ln G(t)$$

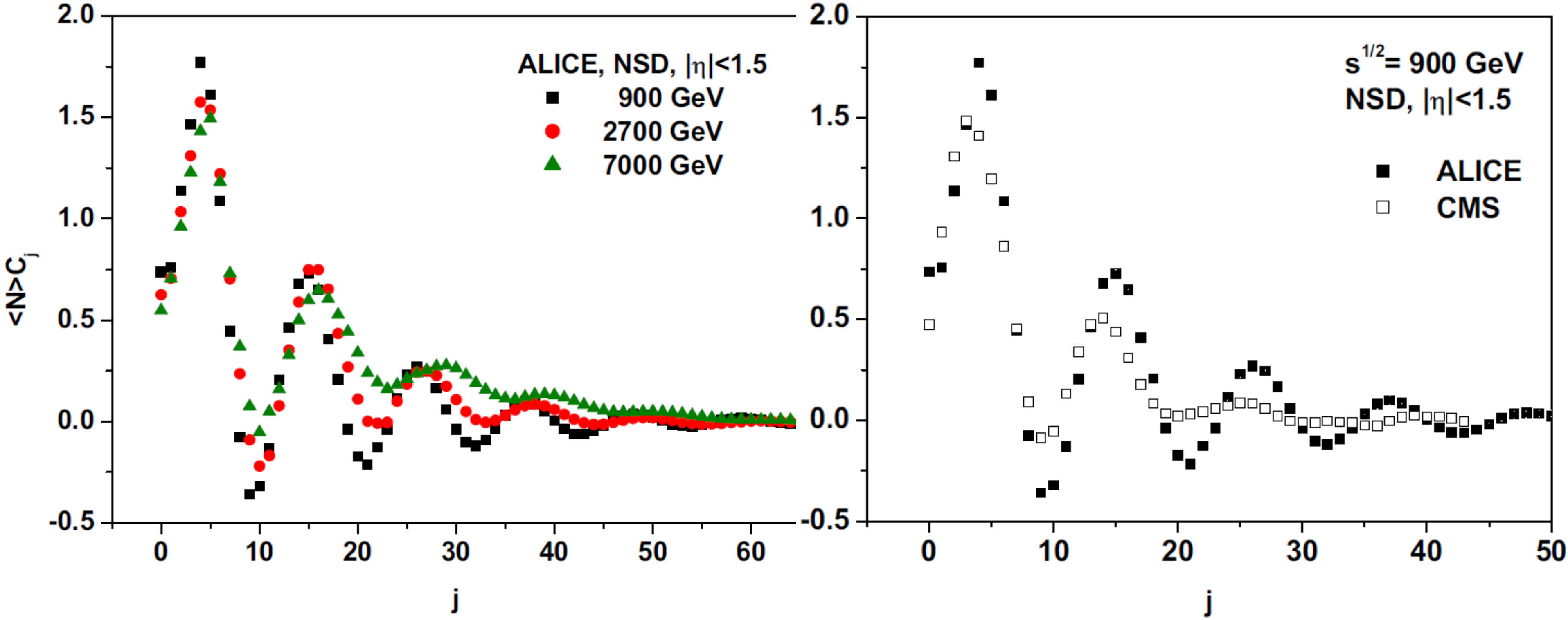
- Modified combinants:

$$C(j) \equiv \frac{j+1}{\langle N \rangle} C^*(j+1) \,, \qquad \text{where} \qquad \langle N \rangle = \sum_{N=1}^{\infty} N\, P(N)$$

$$(N+1)\, P(N+1) = \langle N \rangle \sum_{j=0}^{N} C(j)\, P(N-j)$$

Combinants

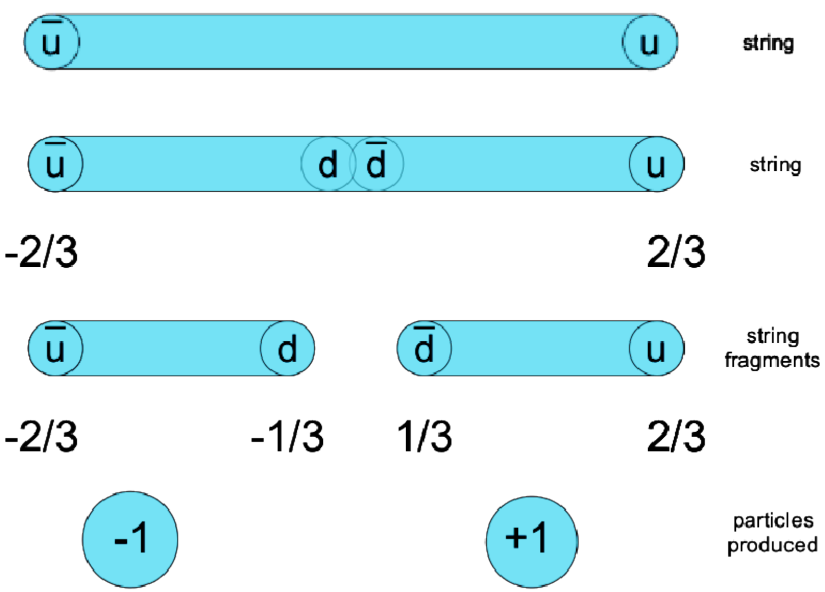
G. Wilk, Z. Włodarczyk, J. Phys. G 44, 015002 (2017).

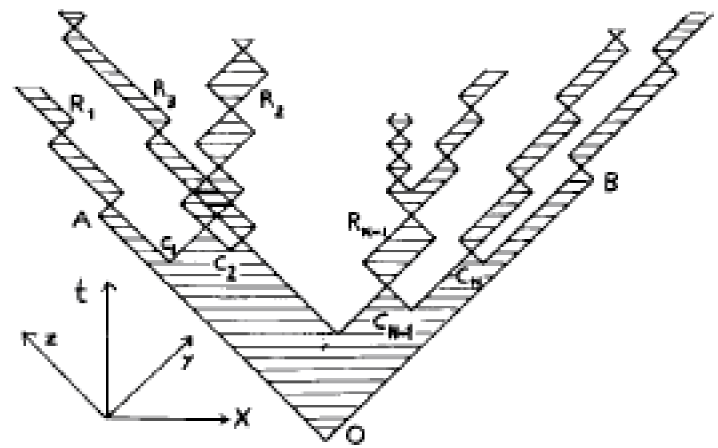


$$(N+1)\,P(N+1) = \langle N\rangle \sum_{j=0}^{N} C(j)\,P(N-j)$$

Initial stages

- 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

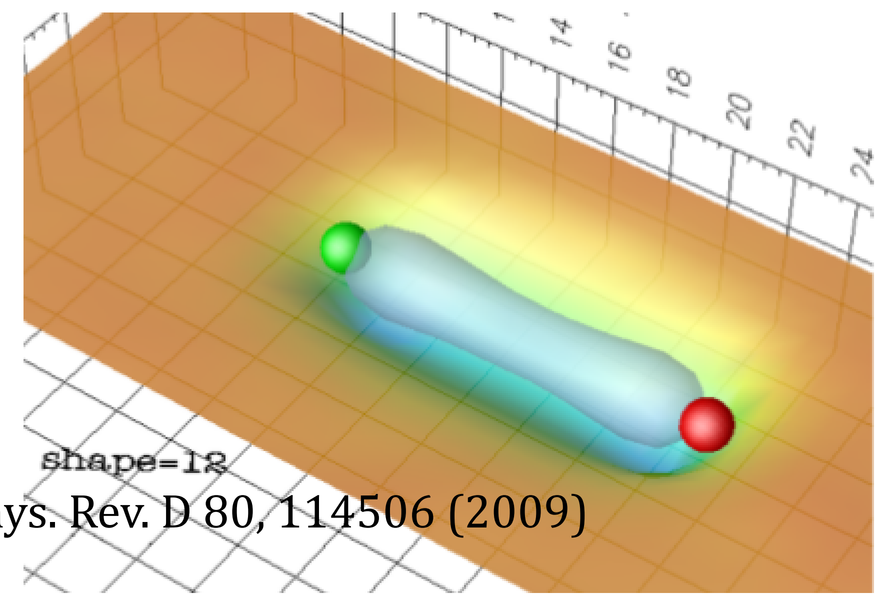




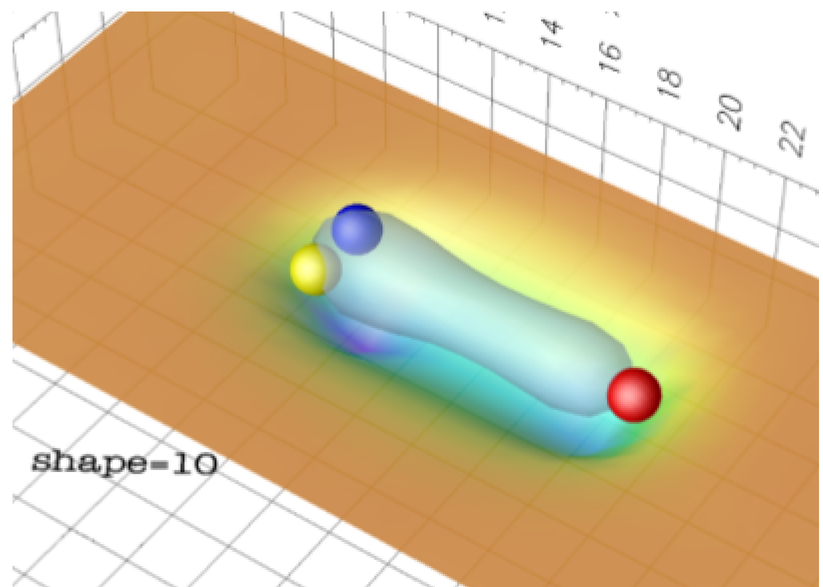
X. Artru and G. Mennessier, Nucl Phys B 70 (1974) 93
“String Model and Multiproduction”,

Strings – color tubes

- Strings are one-dimensional extended objects
- Strings first were intorduced during the late 1960s and early 1970s as a theory of hadrons
- It was able to describe such phenomena as Regge trajectories: the mesons families were discovered with masses related to spins in a way that one can be expected from rotating strings.
- Strings as colour tubes, streached between pair quark-antiquark are found also in the lattice QCD calculations

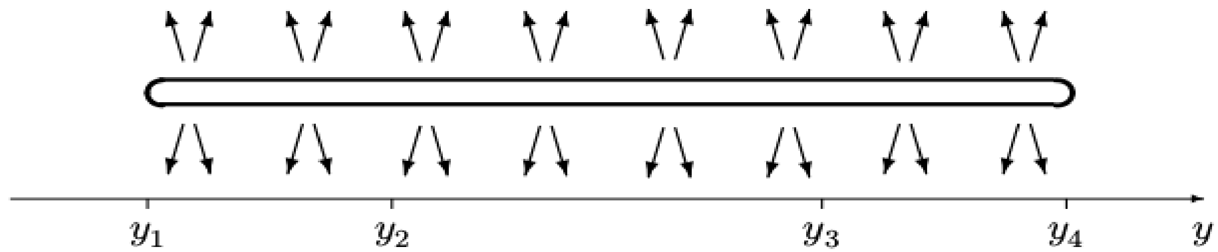


Phys. Rev. D 80, 114506 (2009)

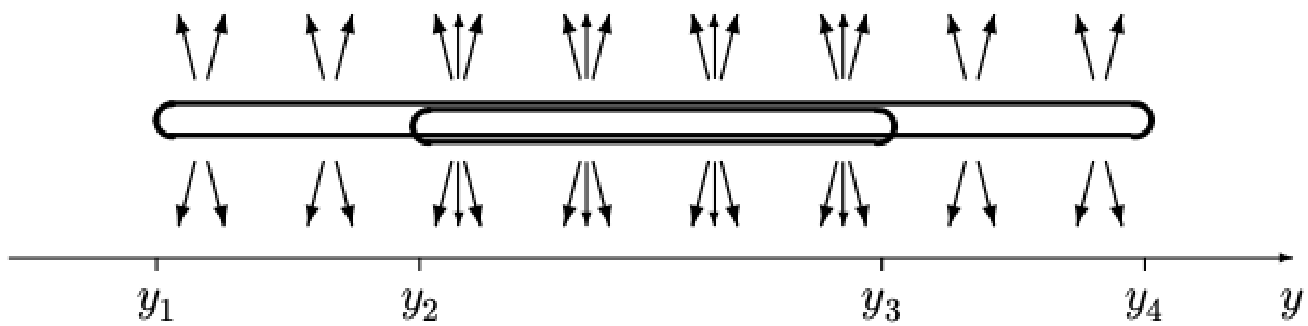


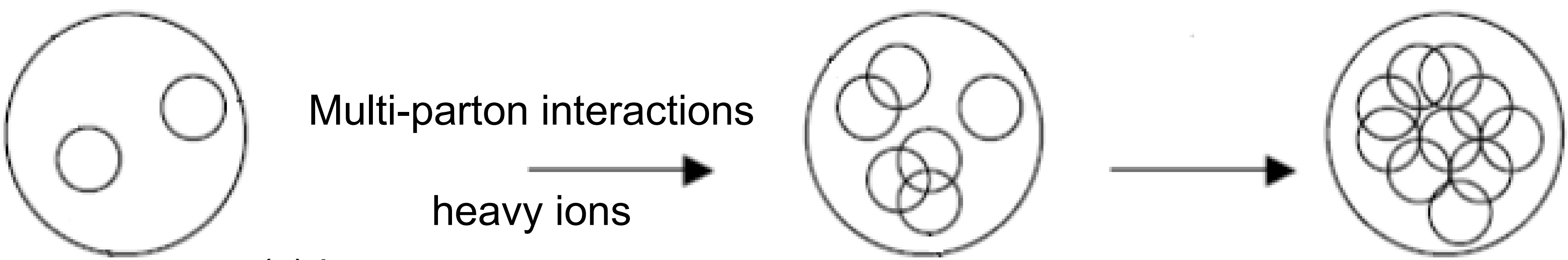
Strings in rapidity space

- Uniform and independent distribution of particles on rapidity from y_{min} to y_{max}



Are all the strings the same?
What if some stings overlap?





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

String fusion

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

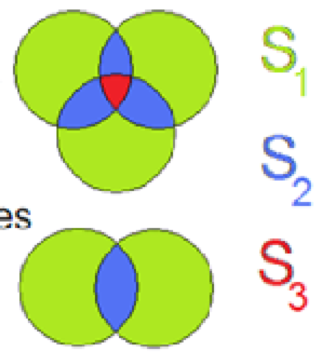
$$\langle Q^2(n) \rangle = nQ^2(1)$$

overlaps

SFM

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

S_k – area covered k-times



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

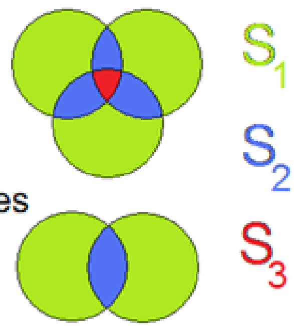
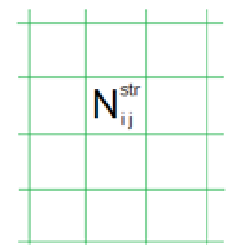
$$\langle \mu \rangle_k = \mu_0 \sqrt{k} \frac{S_k}{\sigma_0} \qquad \langle p_t^2 \rangle_k = p_0^2 \sqrt{k} \qquad \langle p_t \rangle_k = p_0 \sqrt[4]{k}$$

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

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)

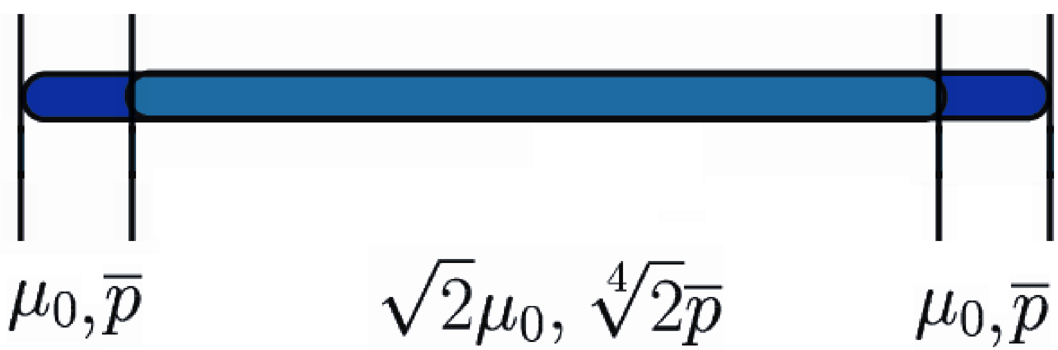
String fusion

- Lattice realization of string fusion model

	"overlaps" (local fusion)		"overlaps" (local fusion)
SFM	○ $C=\{S_1, S_2, \dots\}$ S_k – area covered k-times 	cellular analog of SFM	□ $C=\{N_{ij}^{str}\}$  $k_{ij} = N_{ij}^{str}$ – "occupation" numbers

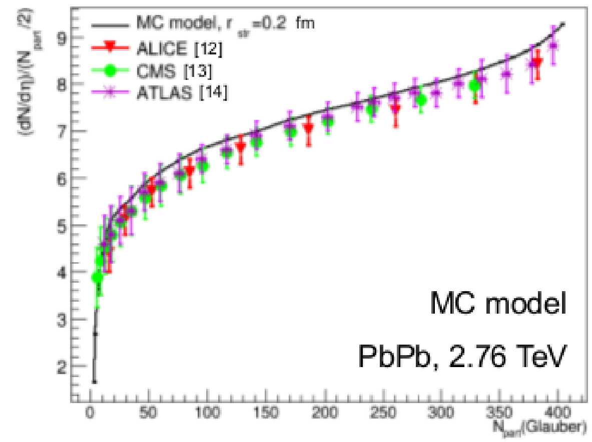
V. V. Vechernin and R. S. Kolevatov, Vestn. SPb. Univ., Ser. Fiz. Khim., No. 2, 12 (2004); hep-` ph/0304295.
V. V. Vechernin and R. S. Kolevatov, Vestn. SPb. Univ., Ser. Fiz. Khim., No. 4, 11 (2004); hep-ph/0305136.
I. A. Lakomov, V. V. Vechernin, PoS (Baldin ISHEPP XXI) 072 (2012).

- Fusion of finite rapidity strings



Monte Carlo model

- <u>Partonic</u> dipole-based picture of nucleons interaction.



- Energy and angular momentum conservation in the initial state of a nucleon.
- The probability of dipoles are defined by heir transverse coordinates [7-8]:

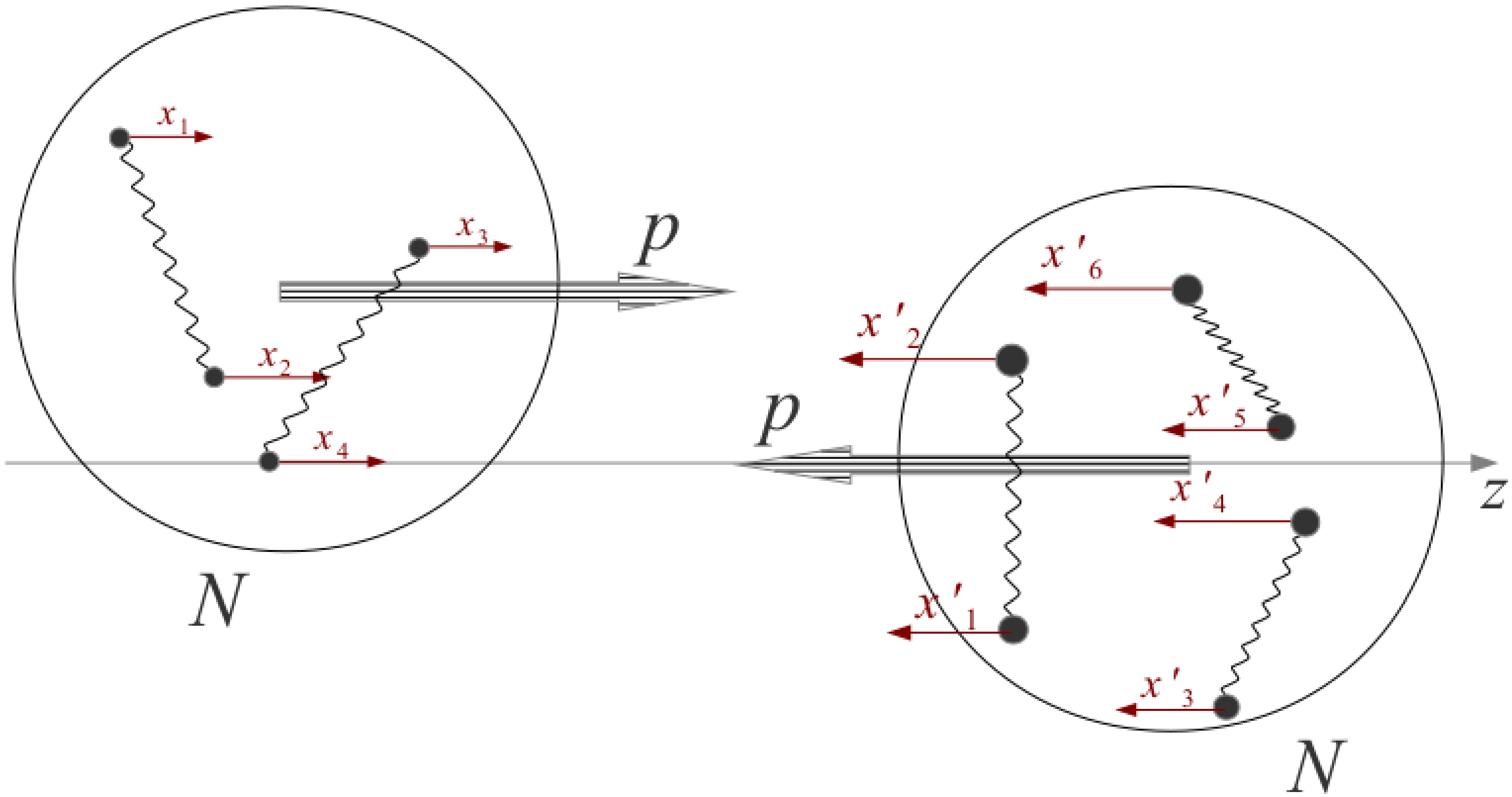
$$f = \frac{\alpha_s^2}{2} \ln^2 \frac{|\vec{r}_1 - \vec{r}_1'||\vec{r}_2 - \vec{r}_2'|}{|\vec{r}_1 - \vec{r}_2'||\vec{r}_2 - \vec{r}_1'|}$$

Multiplicity and transverse momentum are obtained in the approach of <u>colour strings</u>, stretched between projectile and target partons

- The interaction of strings is realized in the accordance with the **string fusion** model
- Multiplicity from one string is distributed according to **Poisson** – *other option considered:* ***NBD***

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

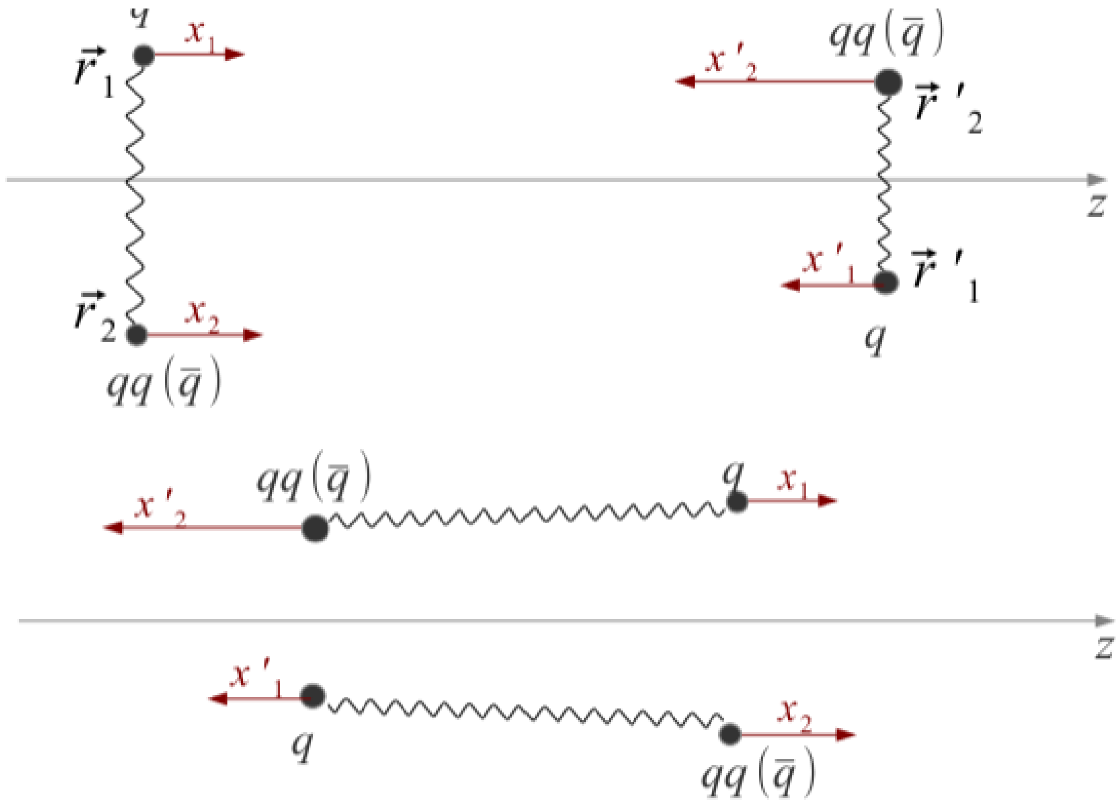
Monte Carlo model



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

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

Monte Carlo model



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)

Monte Carlo model

- 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.

Multiplicity from one string is distributed according to **Poisson** – *other option considered: **NBD***

Options considered

- String Fusion (r_{str}=0.2-0.3 fm) / no Fusion (r_{str} = 0)

- Finite rapidity strings / infinite strings (y_{min} = -8, y_{max} = 8)

- No resonances / with resonances decays

Schwinger mechanism of particle production: $Y_\nu \sim \exp\left(\frac{\pi\left(p_t^2 + m_\nu^2\right)}{t}\right)$
+ decay tables

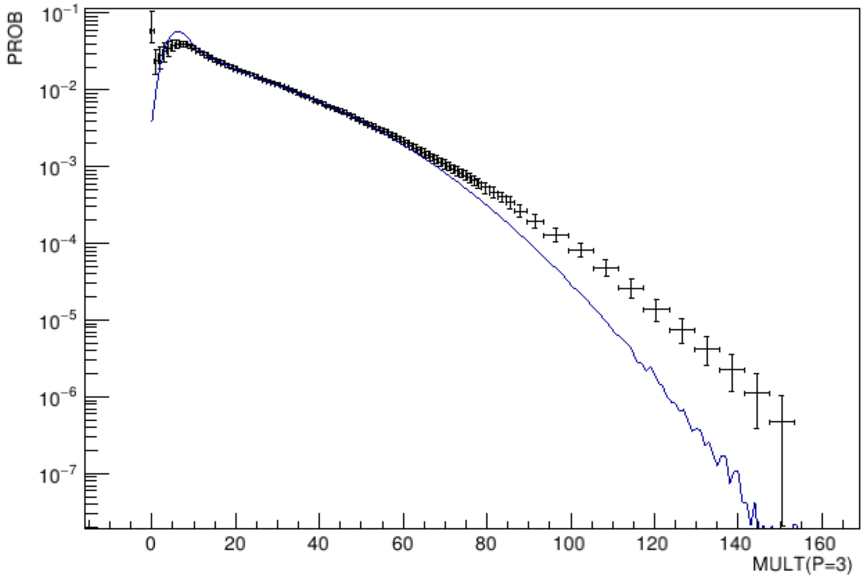
- Poisson distribution from one string / NBD distribution

$$\Pr(X = k) = \binom{k + \frac{\mu^2}{\sigma^2 - \mu} - 1}{k} \left(\frac{\sigma^2 - \mu}{\sigma^2}\right)^k \left(\frac{\mu}{\sigma^2}\right)^{\mu^2/(\sigma^2 - \mu)}.$$

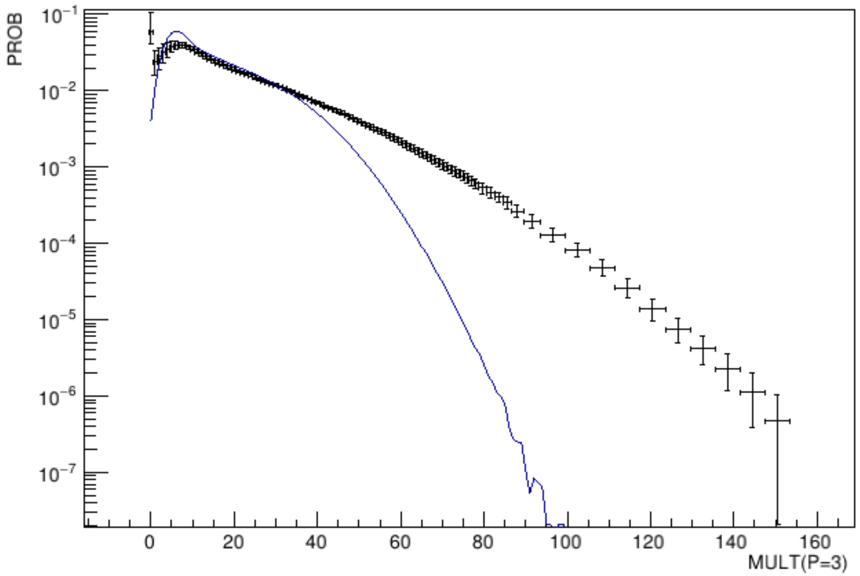
$$\sigma^2 = \omega \cdot \mu, \quad \omega = \mathrm{Var}/\mathrm{mean}\,;\ \omega > 1$$

Multiplicity distributions

- No String Fusion (default)

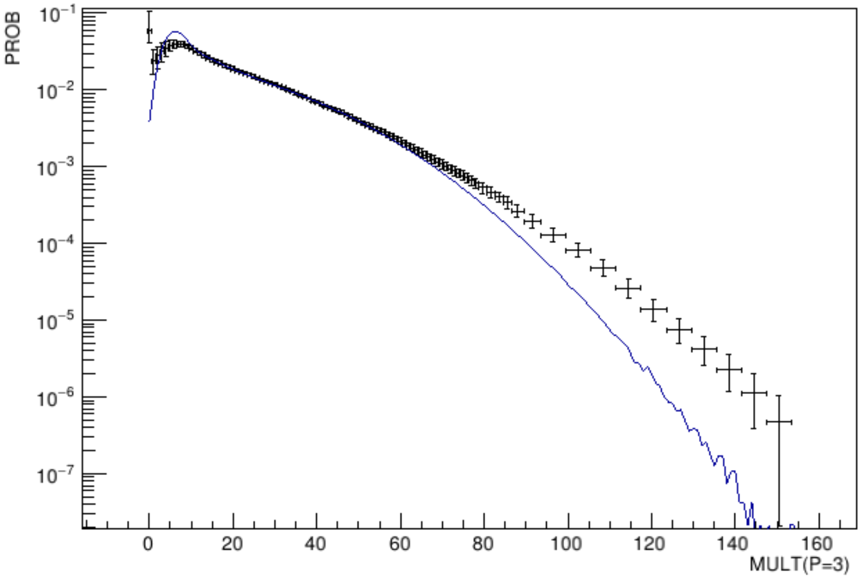


With fusion

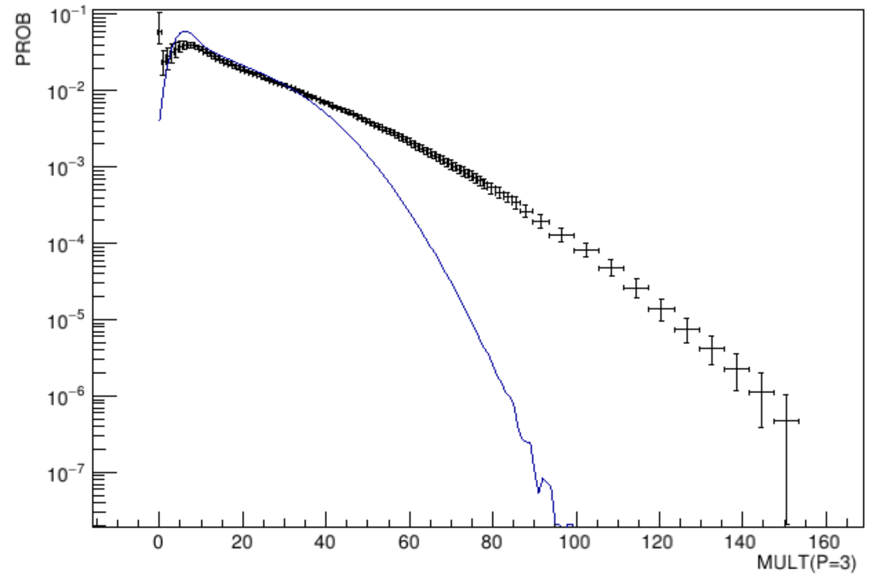


Multiplicity distributions

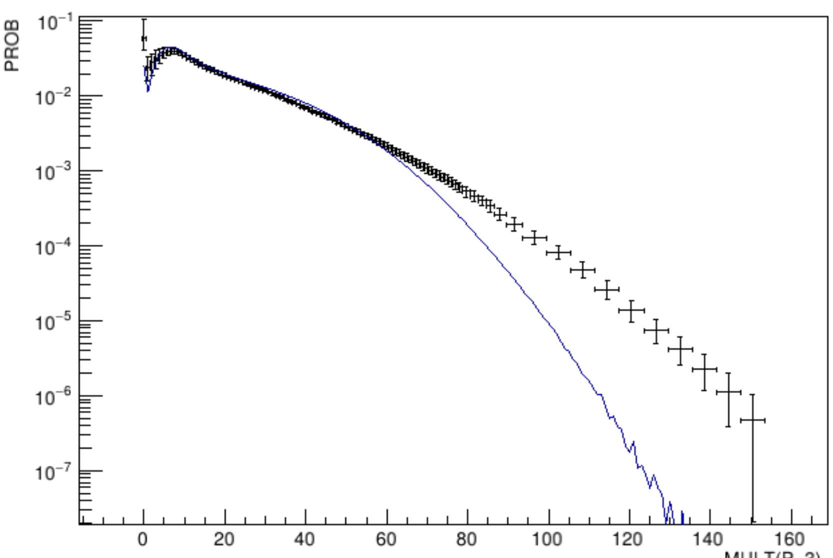
- No String Fusion (default)



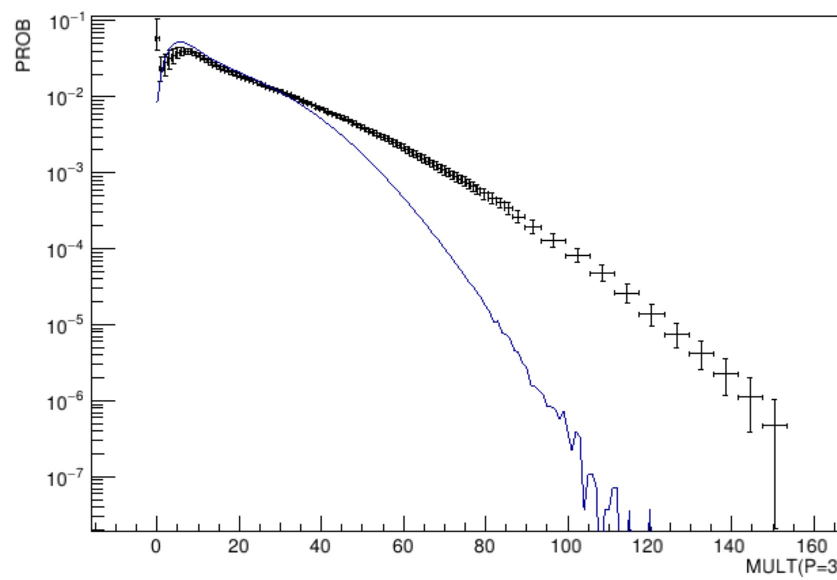
With fusion



With Fusion and resonances

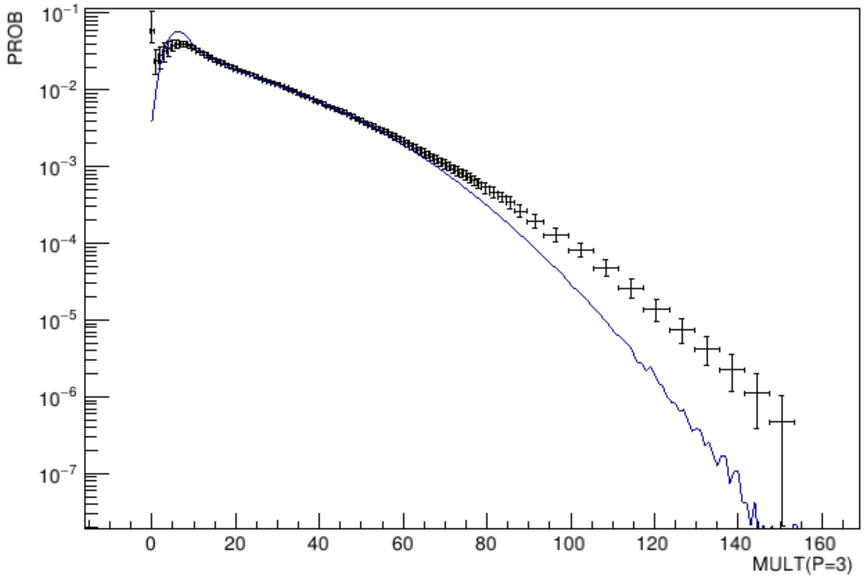


With Fusion and NBD from one string

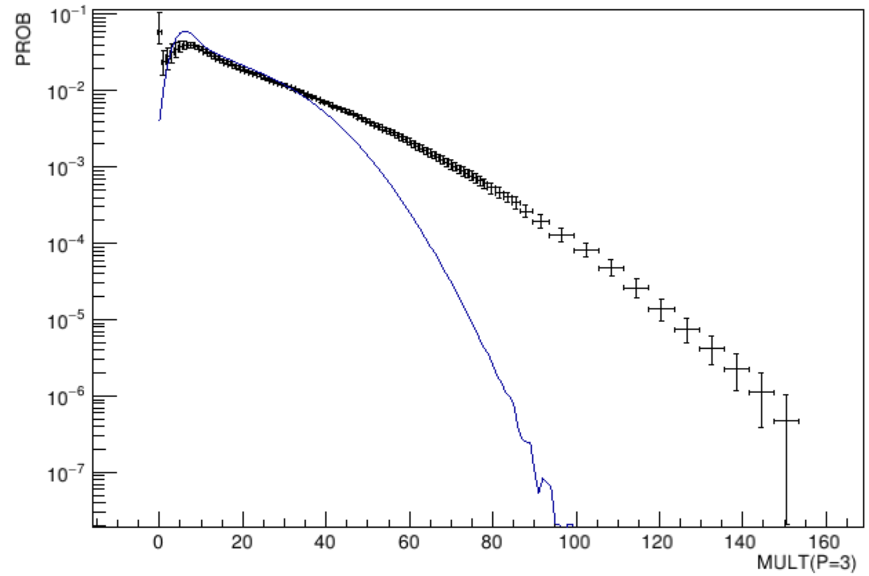


Multiplicity distributions

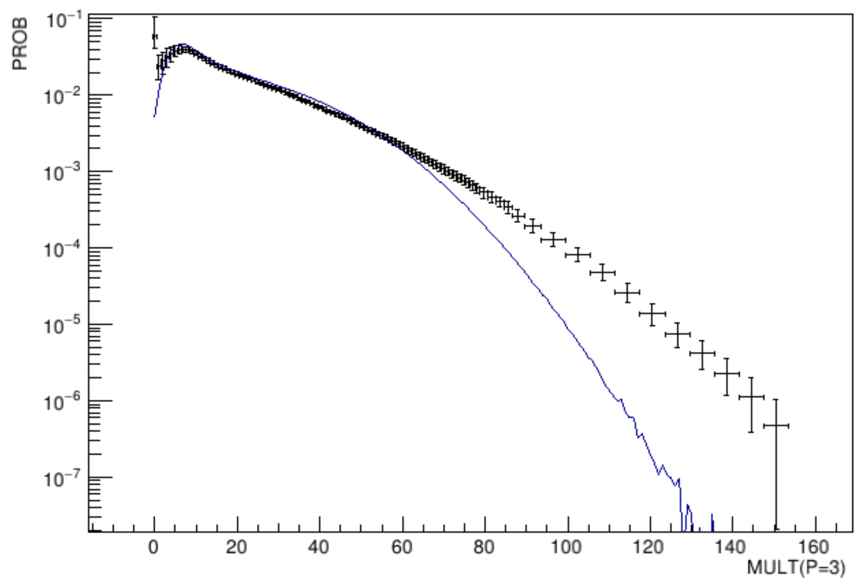
- No String Fusion (default)



With fusion

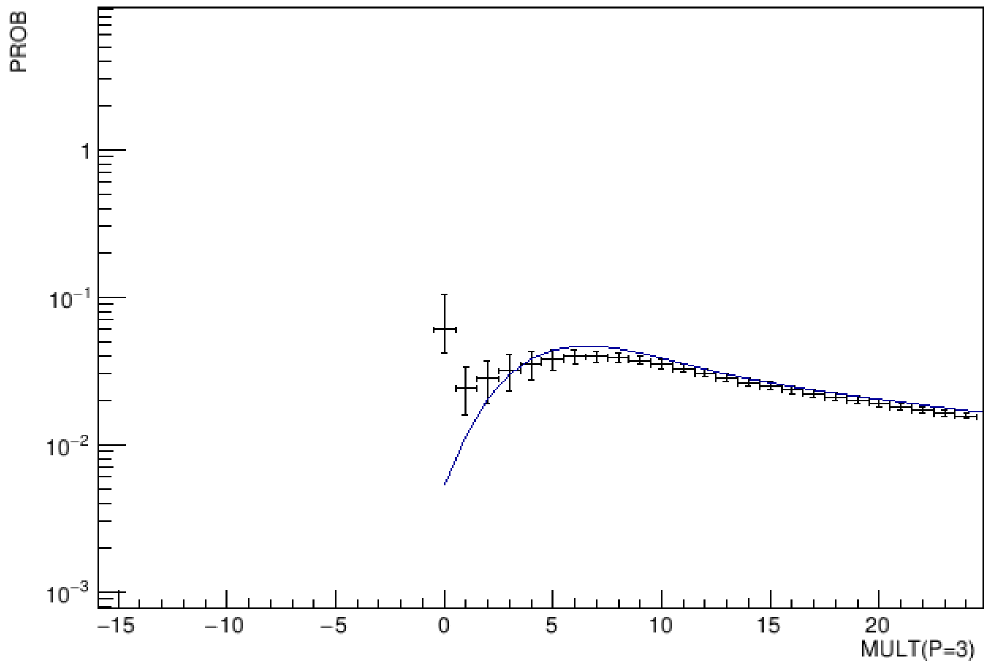


With Fusion and resonances and NBD from one string



Multiplicity distributions

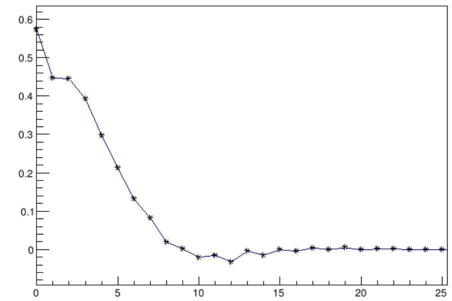
- Problem of 0-th bin



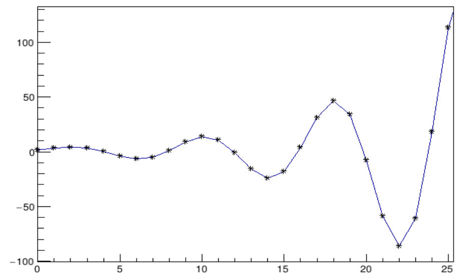
- Contribution of double and central diffraction (NSD distribution)

Combinants: *modes*

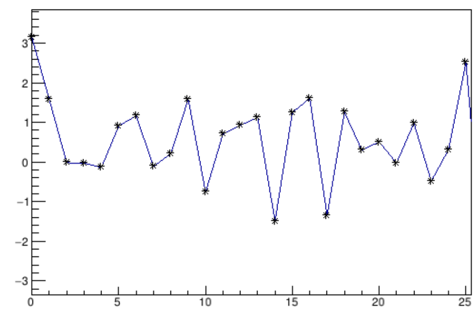
- Monotonic behaviour



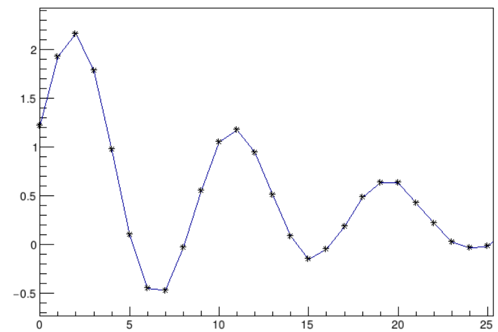
- Oscillating rise



- Fast noise-like oscillations

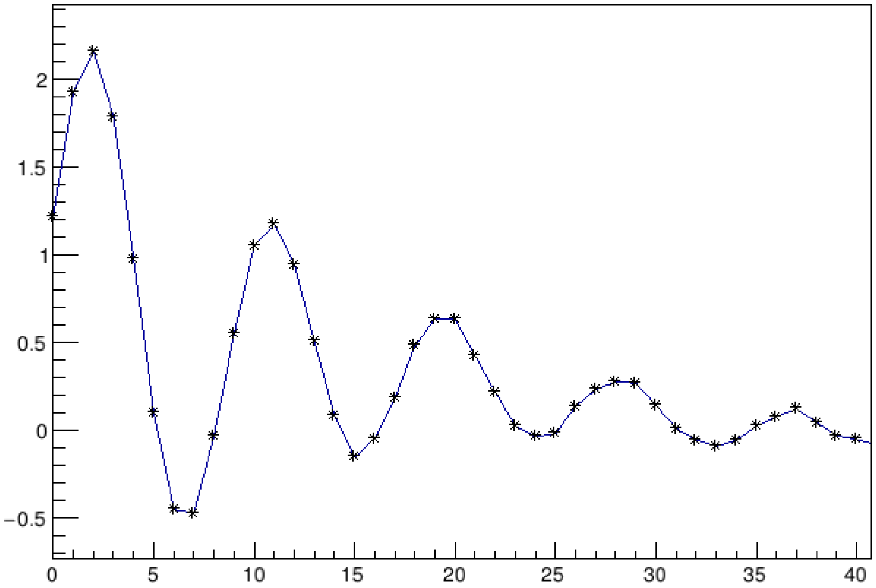


- Decreasing oscillations

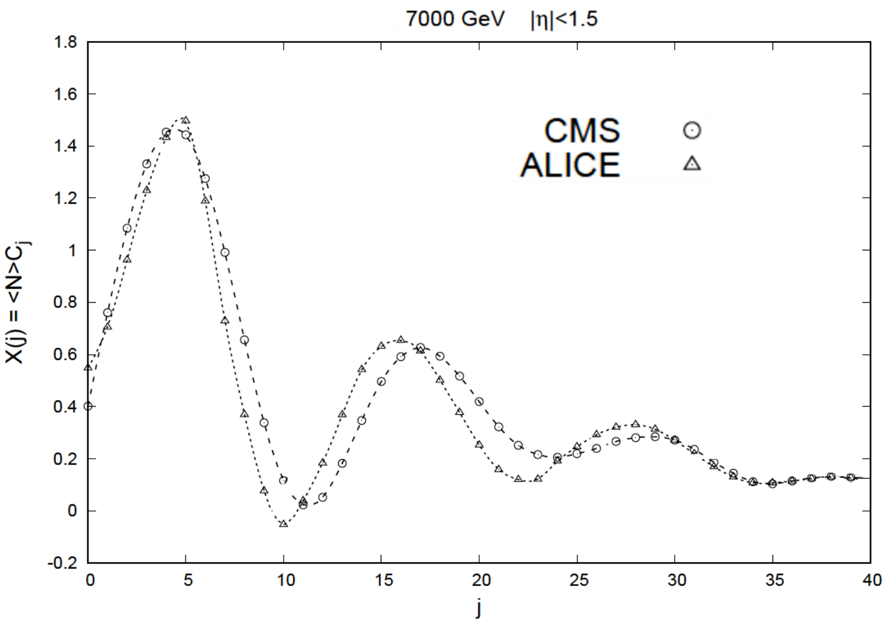


Combinants: ***comparison with experiment***

- Model



Experiment

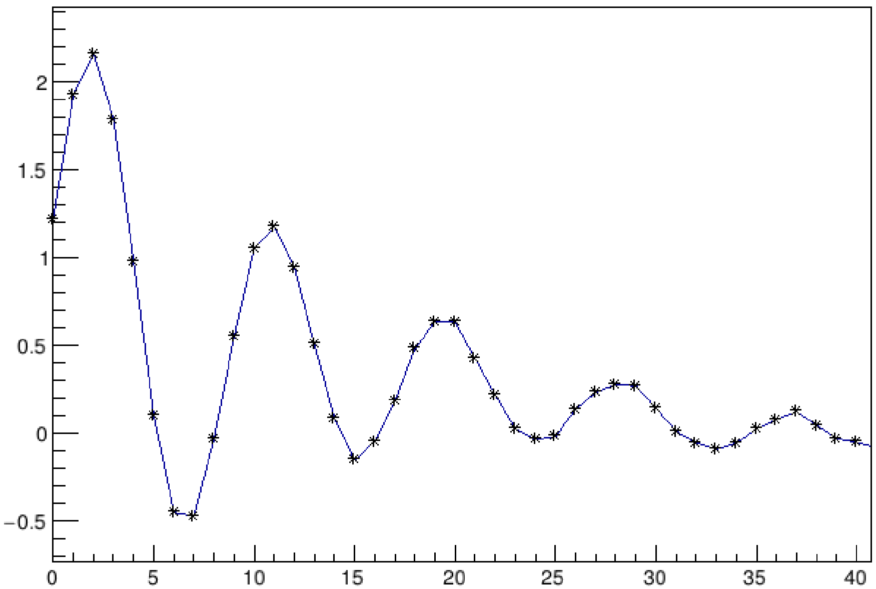


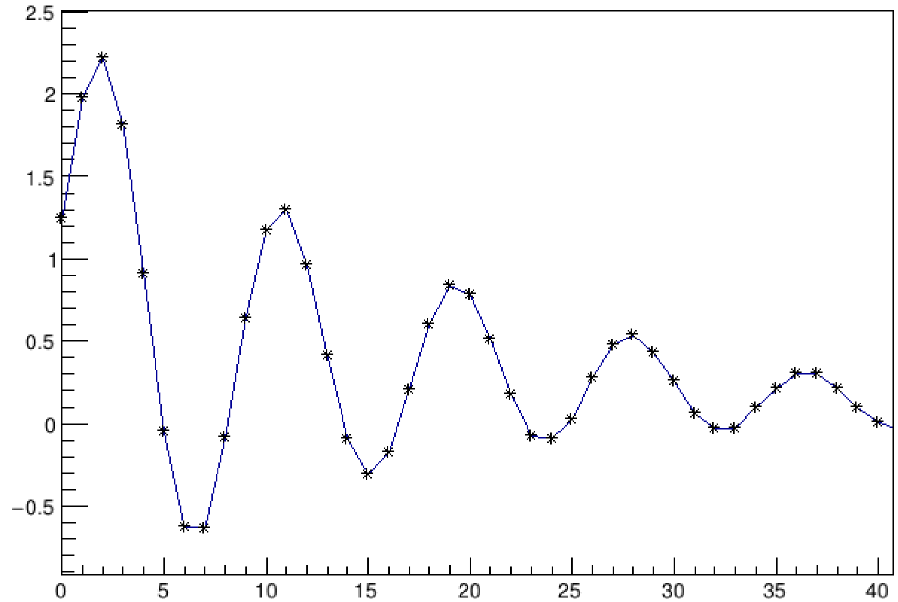
ALICE Collaboration, Eur.Phys.J.C68, 89 (2010); ibid C68, 345(20
CMS Collaboration, JHEP 01, 079 (2011),
ALICE Collaboration, Eur.Phys.J.C77, 33 (2017)
Combinant plot by V. Vechernin at al, Nucleus 2022

- With fusion, NBD (omega=4), 0bin fix, finite rapidity strings

Combinants: *effect of string fusion*

- Model with fusion   no fusion

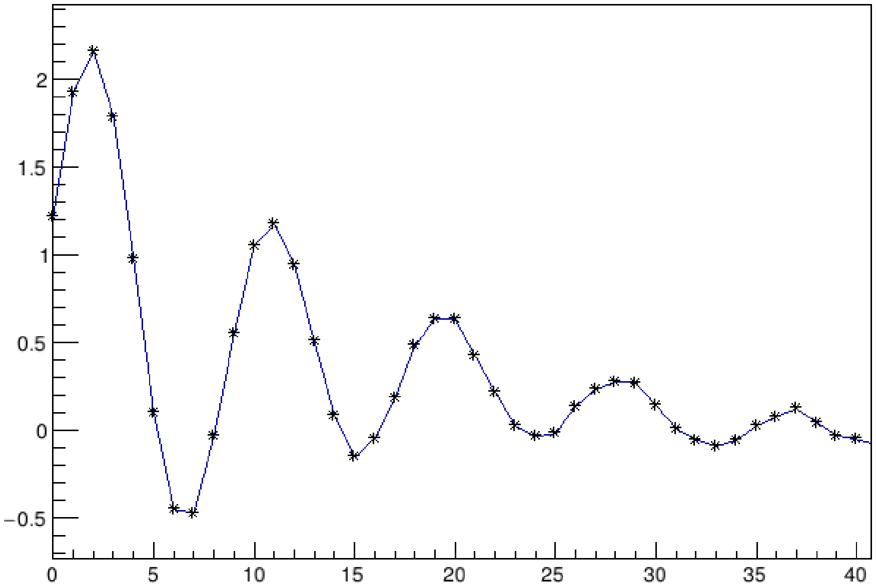


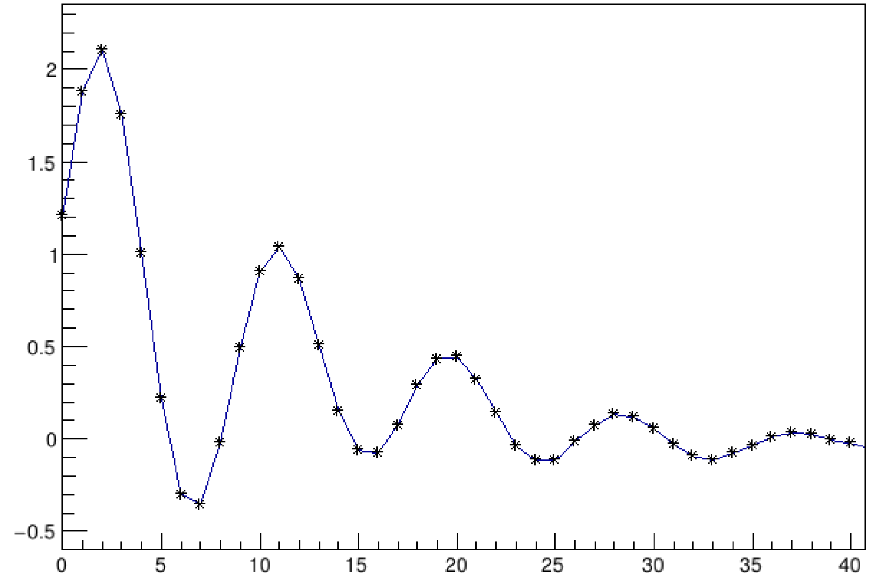


- With fusion, NBD (omega=4), 0bin fix, finite strings

Combinants: ***effect of resonances***

- Model with fusion no resonances   with resonances decays





- With fusion, NBD (omega=4), 0bin fix, finite strings

Conclusions

- Multiplicity combinants dependence appear as observable, very sensitive to the beginning of multiplicity distribution

- Peculiar oscillating behavior with decaying of oscillations is hard to reproduce in models

- In the dipole-based MC model the most important effects to reporduce the oscillating behavior of combinants are:
  - non-Poissonial behavior from one string ($\omega = \mathrm{Var}/\mathrm{mean} > 1$)
  - contribution of diffractive events (correction of 0^{th} bin)
  - finite rapidity size of strings

- String fusion and resonance decays modify the tail of the Nch distribution which is not important for the combinants behavior

- The experimental data on multiplicity distributions and combinants provide important information for the model tuning

Thank you

The author would like to thank Evgeny Andronov, Vladimir Vechernin, Andrey Putchkov for interesting discussions, stimulating interest

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