String fusion approach for MC modelling of pp, pA and AA collisions and possible application in Geant4 FTF and QGS

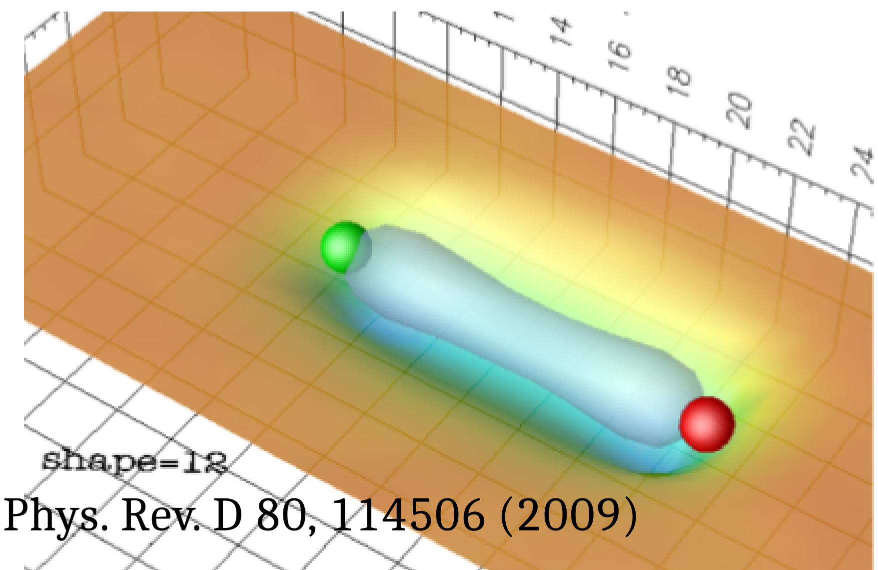
Vladimir Kovalenko

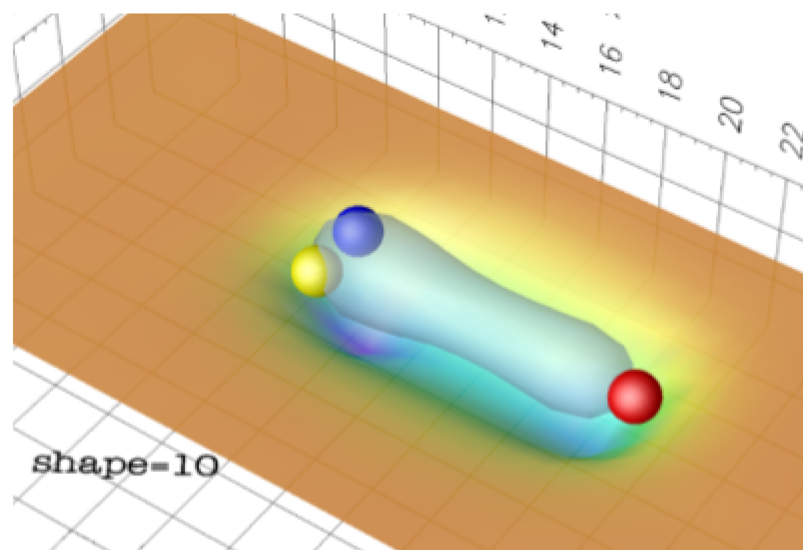
Saint Petersburg State University, Russia

Geant4 Hadronic Working Group Meeting
Wednesday 14 Nov 2018, 17:00

Strings

- 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.
- <u>Strings as colour tubes</u>, streached between pair quark-antiquark are found also in the lattice QCD calculations



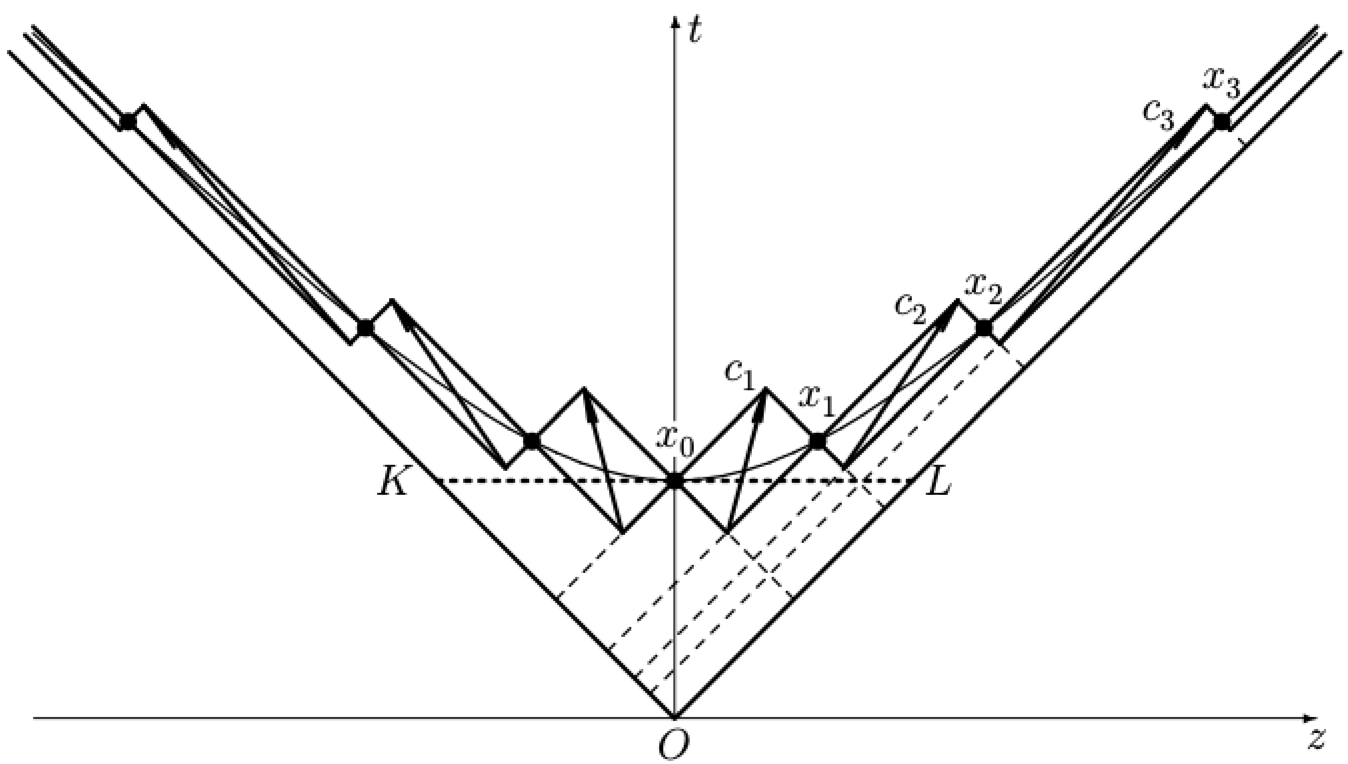


[6.1] Phys. Rev. D 80, 114506 (2009)

String fragmentaion

$$dP(x) = S_0^{-1} \exp\left(-S_x / S_0\right) dS_x$$

- Dominant string decay

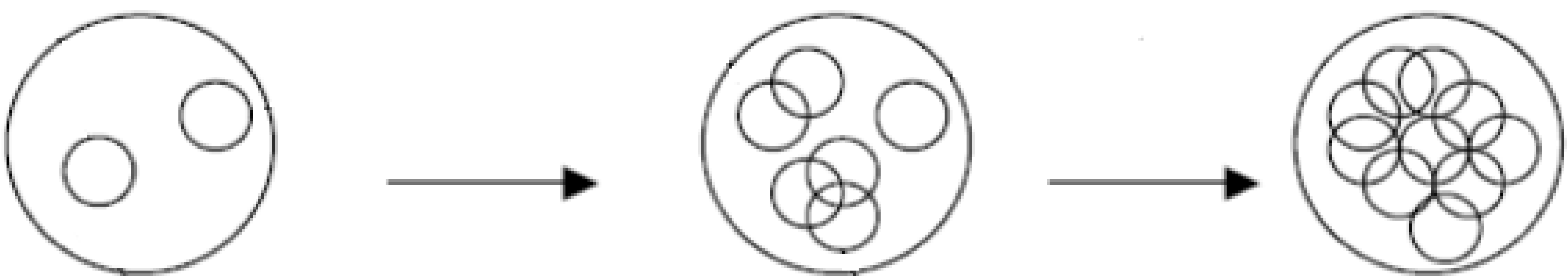


The dominant string decay.

V.V. Vechernin, Proc. Baldin ISHEPProblems (2008) 276, arxiv: 0812.0604 [hep-ph]

Application to pp and AA collisions...

- A contents valence quark-diquark pair
  and a several sea quark-antiquark pairs
- Due to MPI it is possible to produce several strings at the same time->
  they will overlap in transverse plane!
- Effect is more crusial in AA collisions



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

String fusion

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

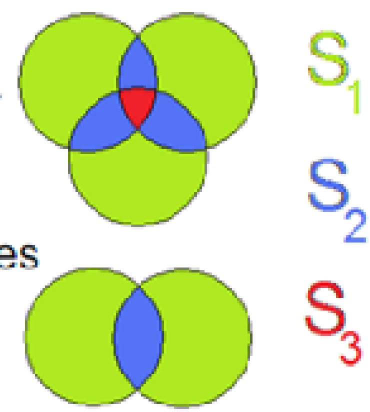
$$\left\langle Q^2(n) \right\rangle = nQ^2(1)$$

overlaps

SFM

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

S_k – area covered k-times



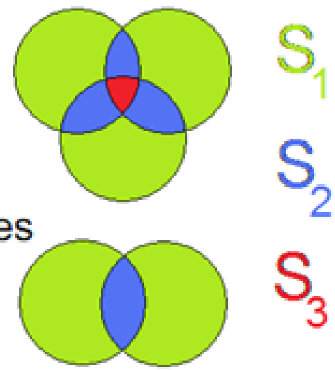
$$\langle \mu \rangle_k = \mu_0 \sqrt{k} \frac{S_k}{\sigma_0} \qquad \langle p_t^2 \rangle_k = p_0^2 \sqrt{k} \qquad \langle p_t \rangle_k = p_0 \sqrt[4]{k}$$

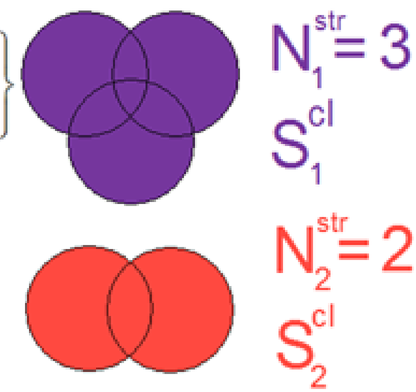
S_k – area, where k strings are overlapping, σ_0 single string transverse area, μ_0 and p_0 – mean multiplicity and transverse momentum from one string

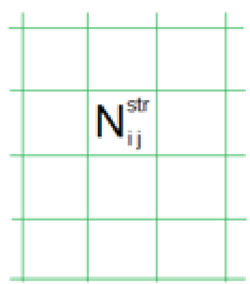
M. A. Braun, C. Pajares, Nucl. Phys. B 390 (1993) 542.
M. A. Braun, R. S. Kolevatov, C. Pajares, V. V. Vechernin, Eur. Phys. J. C 32 (2004) 535.

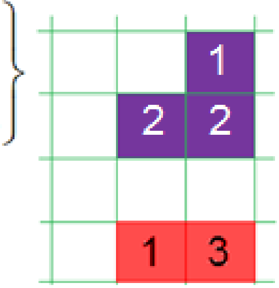
String fusion: mechanism versions

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









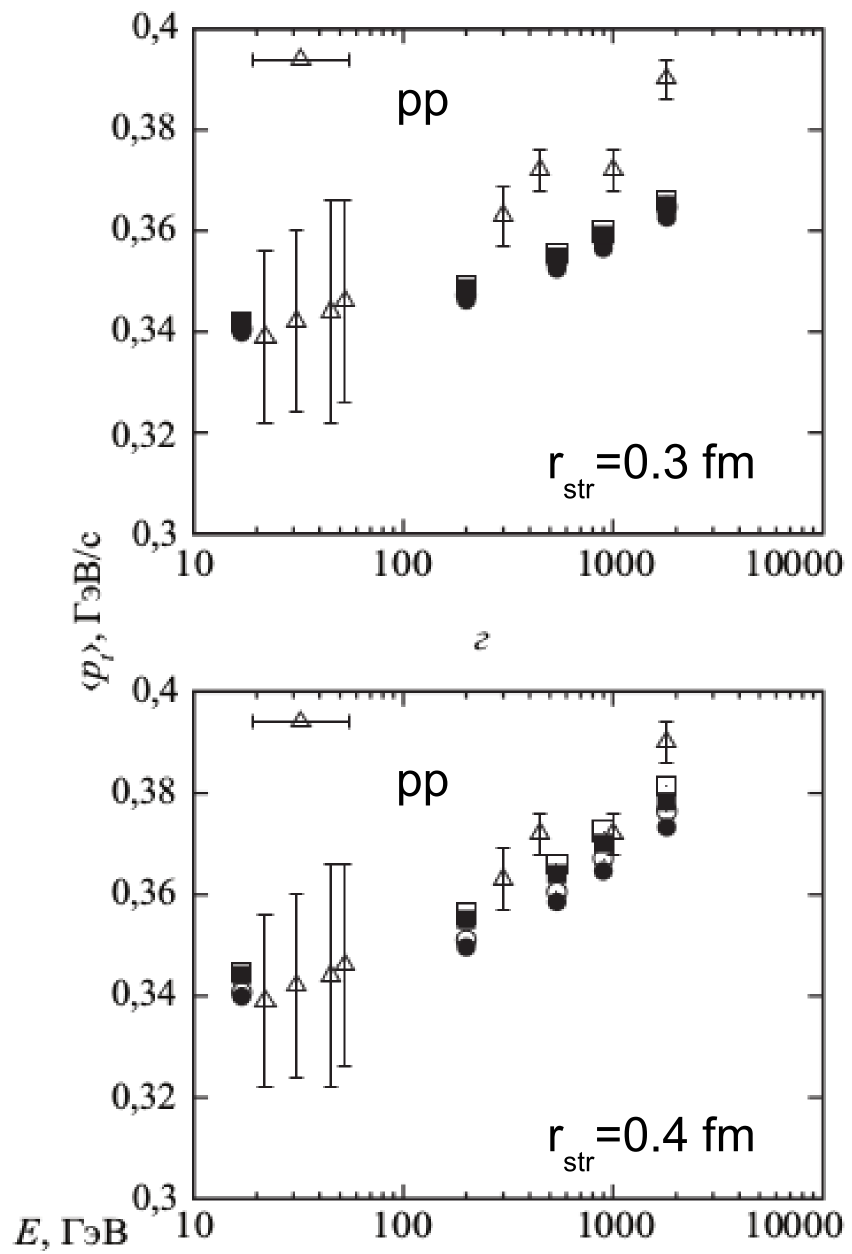
$S_1^{cl}=3\sigma_0$; $N_1^{str}=5$; $k_1^{cl}=5/3$

$S_2^{cl}=2\sigma_0$; $N_2^{str}=4$; $k_2^{cl}=2$

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.

Effects of string fusion: Increase of mean pt with energy

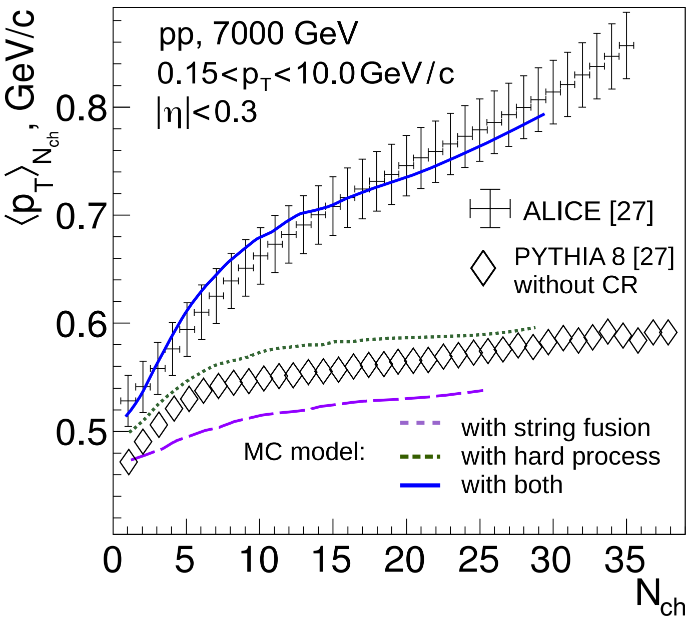
- Number of sea pairs growth with sqrt(s)
- More strings are formed-> more overlaps
- -> more fusion, pt grows

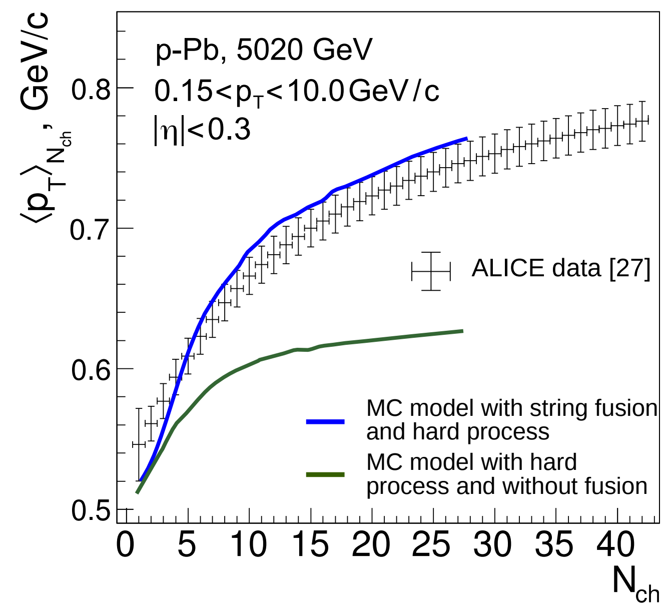


V. V. Vechernin, I. A. Lakomov, A. M. Puchkov, Vestn. SPb. Univ., Ser. 4: Fiz. Khim., No. 3, 3 (2010)

Effects of string fusion: Increase of mean pt with multiplicity:

In pp and p-A collisions

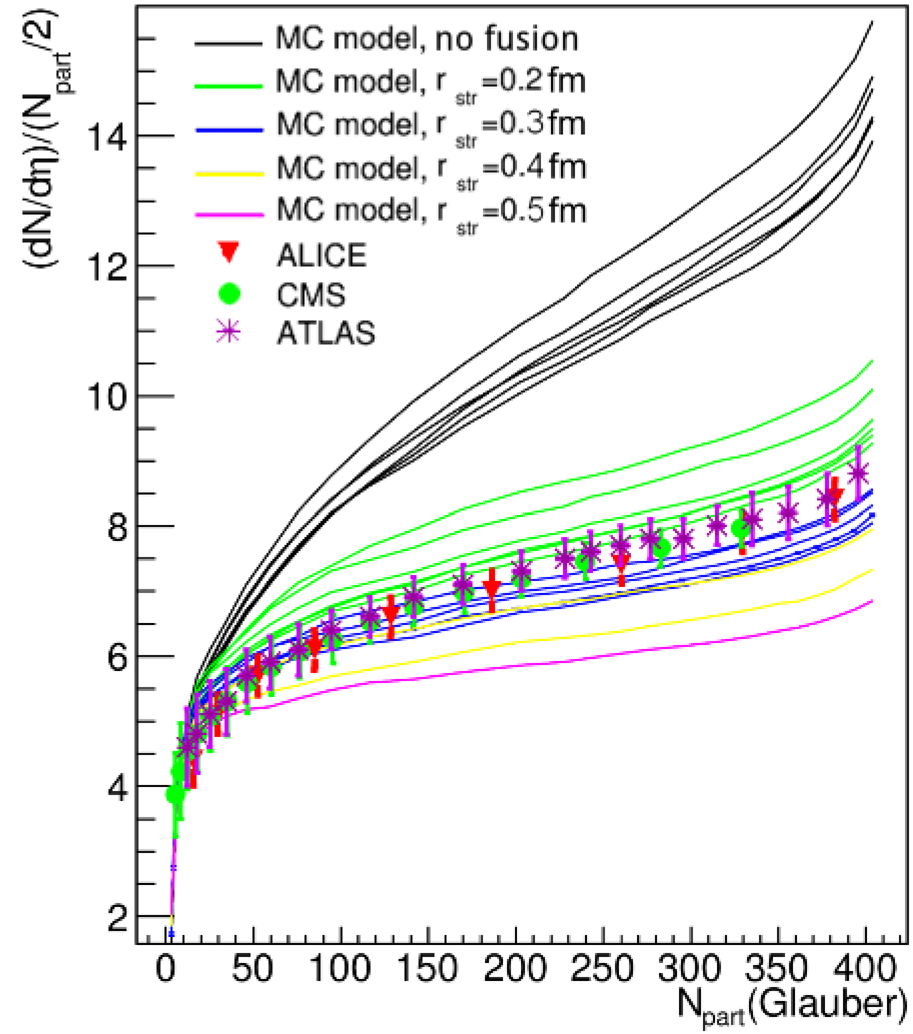


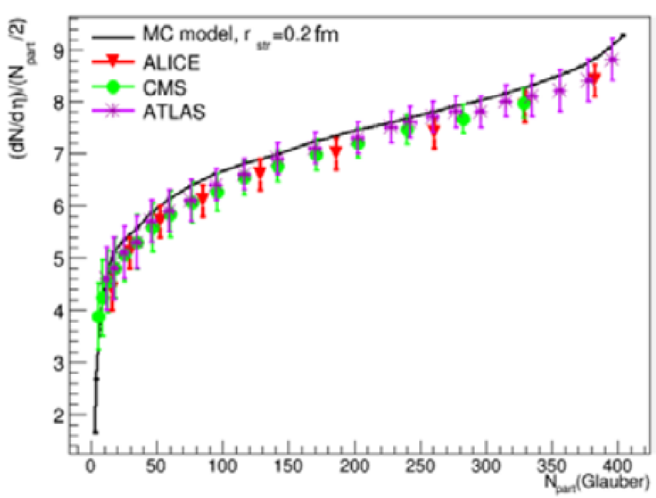


V. N. Kovalenko, Physics of Particles and Nuclei. 48, 6, p 945-948

Decrease of multiplicity

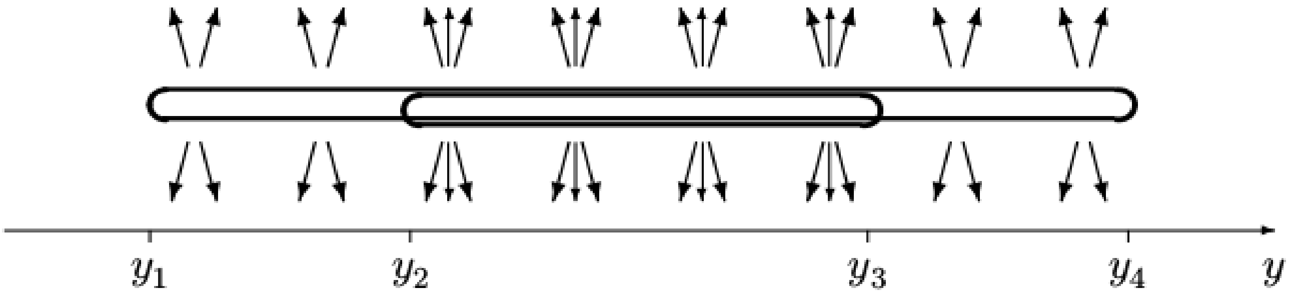
- Decrease of multiplicity, which is pronunced especiallty in PbPb collisions (compared to non-fusion case)
- Cluster of n fused strings emits sqrt{n} times less particles, than n independed strings





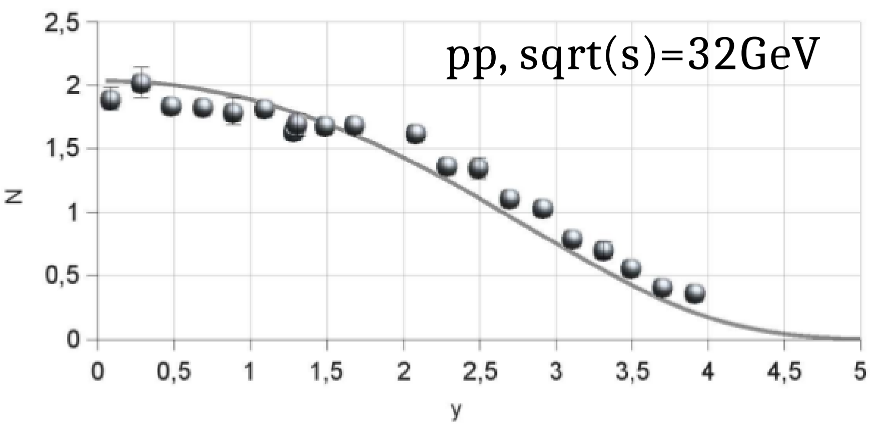
V. Kovalenko. PoS (QFTHEP 2013) 052, 2013

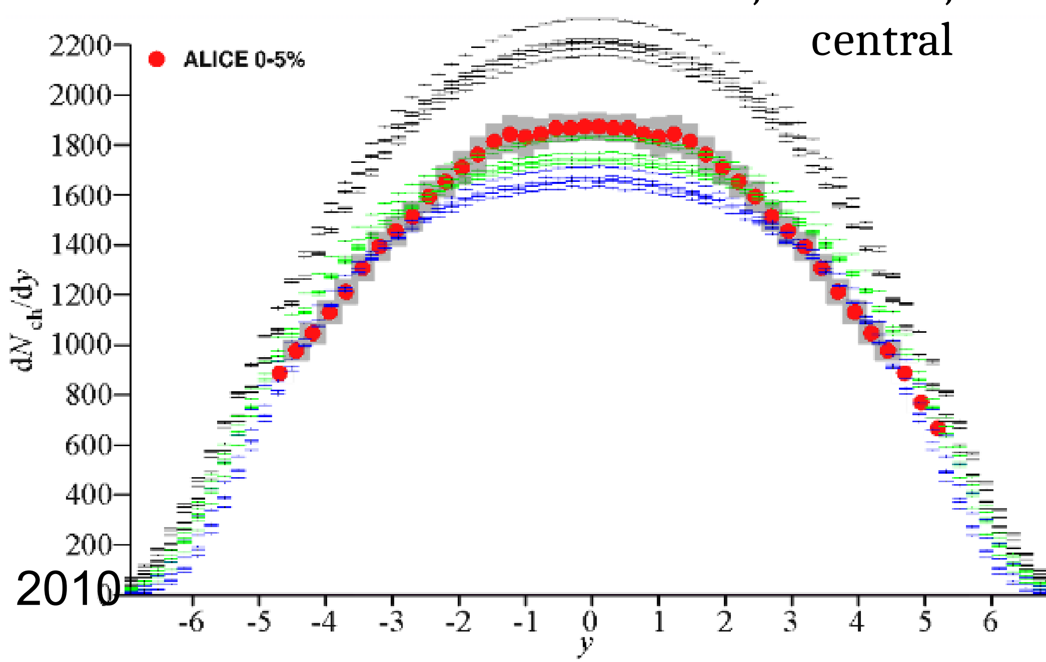
Rapidity distribution of multiplicity



- Accounting the finite rapidity width of the strings, together with string fusion, allows to calculate rapidity distribution of the multiplicity

PbPb, 2.76 TeV, central

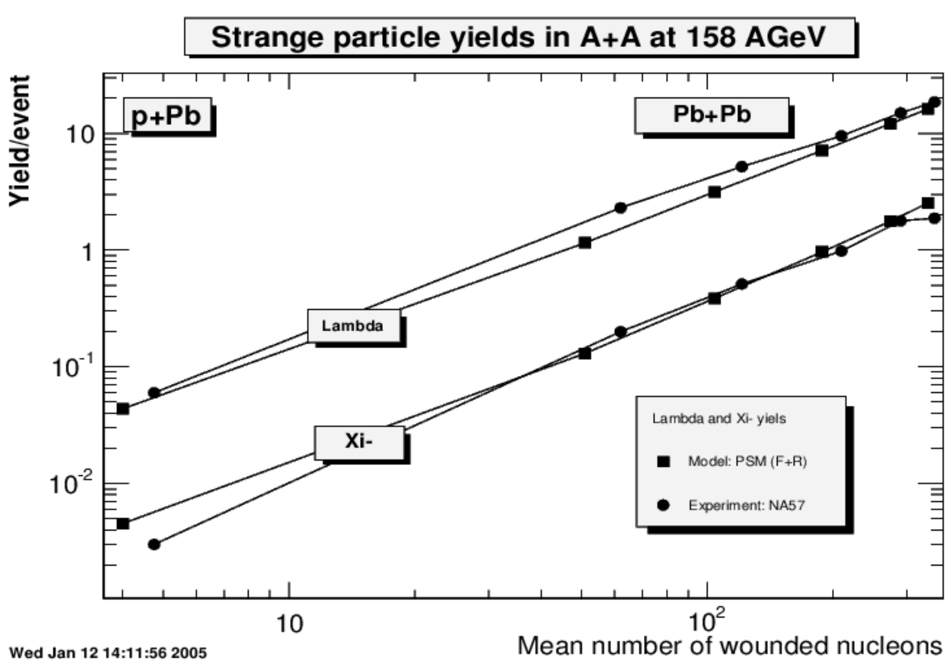


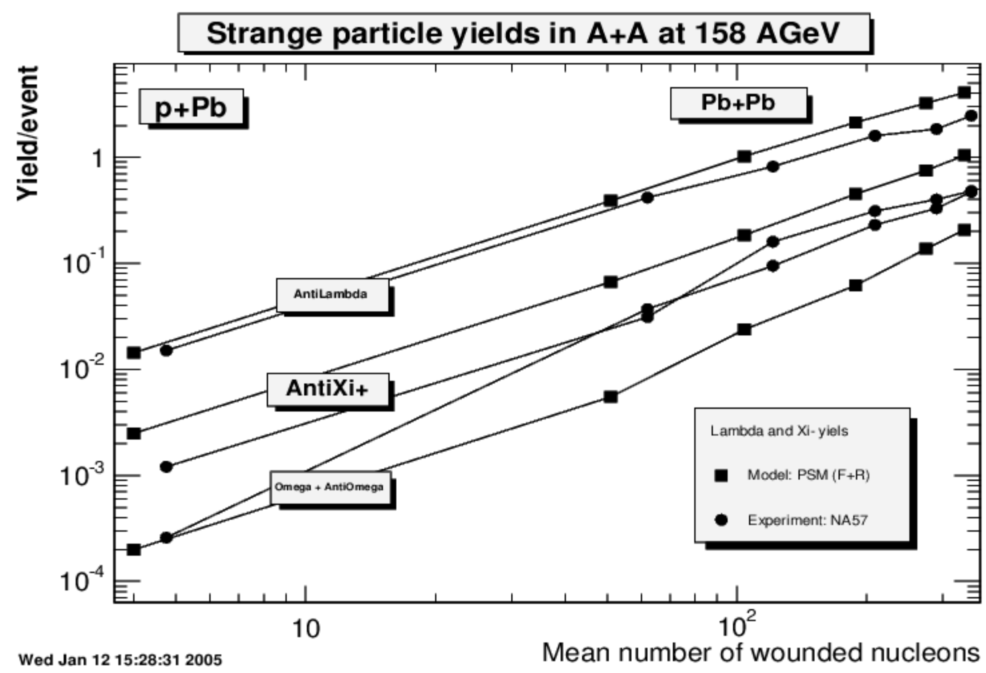


V. Kovalenko. Proc. Sciense and Progress, SPb, 2010
V. Kovalenko. PoS (QFTHEP 2013) 052, 2013

Centrality dependence of strange particles yields at SPS

- Strings with higher tension -> more probability to produce heavier particles
- Schwinger mechanism: $$\frac{d^2N_{\text{ch}}}{dp_T^2} \sim \exp\left(\frac{-\pi(p_t^2+m^2)}{t}\right)$$

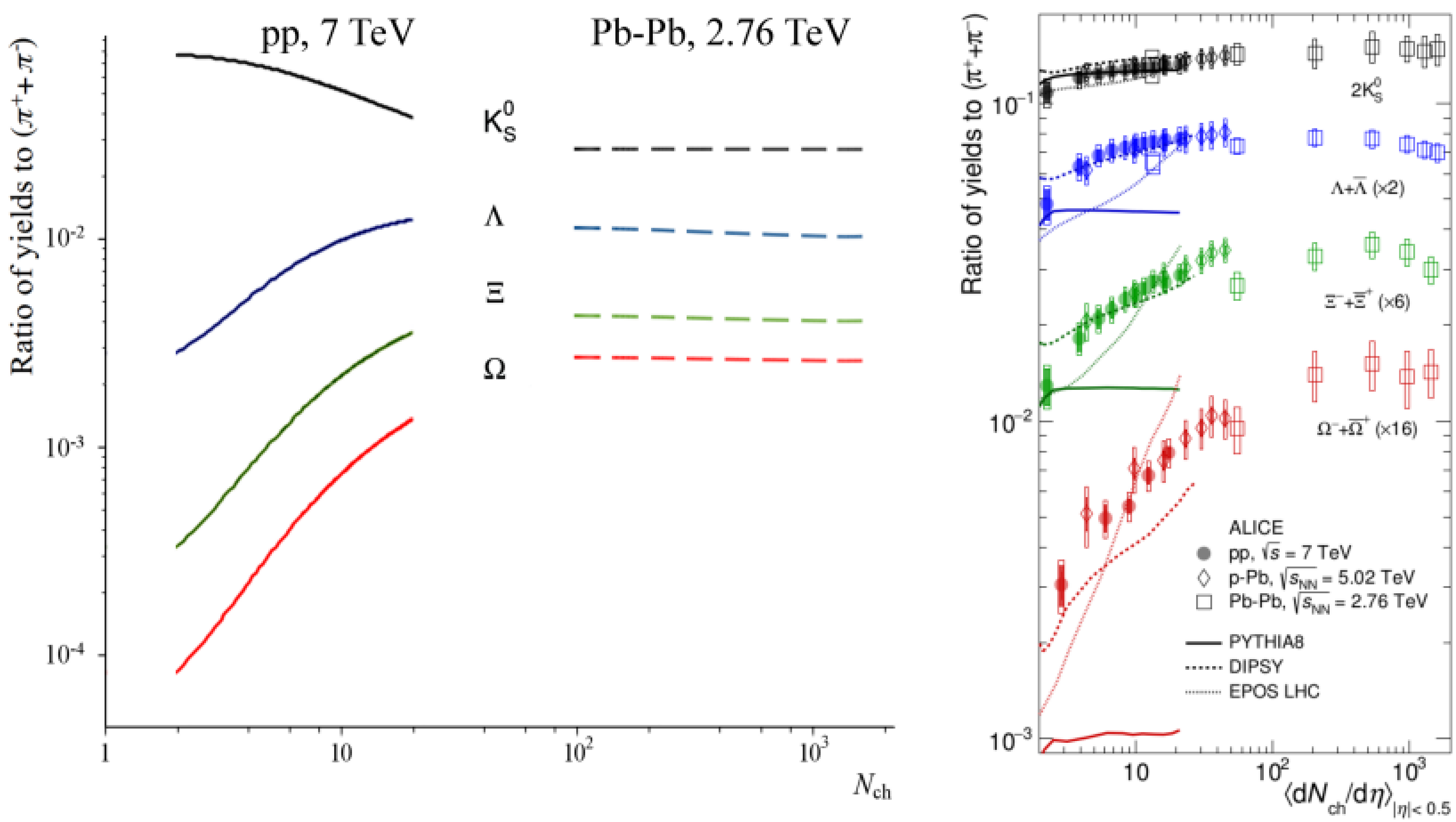




J. Schwinger, Phys. Rev. 82, 664 (1951); T. S. Biro, H. B. Nielsen, and J. Knoll, Nucl. Phys. B 245, 449 (1984).

G. Feofilov, et. al, Proc. QFTHEP 2004 p. 412-418, V. P. Kondrat’ev, G. A. Feofilov, Physics of Particles and Nuclei 42, 911–962 (2011)

Multiplicity dependence of strangeness production at LHC

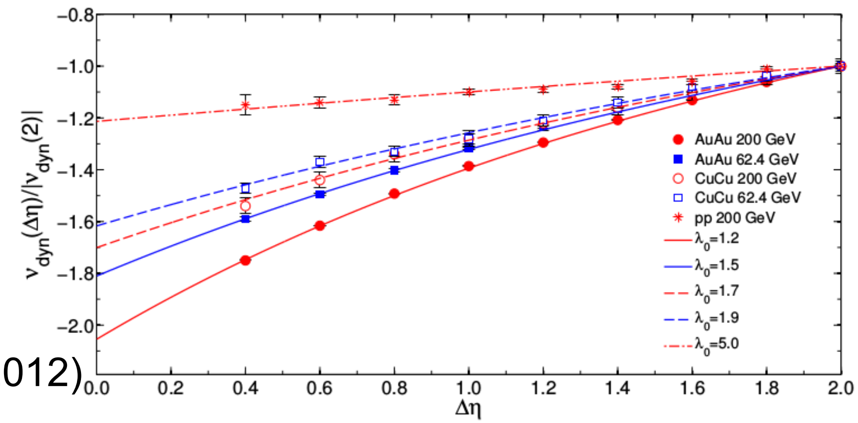


Feofilov G., Kovalenko V., Puchkov A. // arXiv:1710.08895 [hep-ph]. 2017.
Feofilov G., Kovalenko V., Puchkov A. // EPJ Web of Conferences. 2018. Vol. 171, P. 18003, arXiv:1711.00842 [nucl-th].
Experiment: J. Adam, et al (ALICE Collaboration) // Nature Physics 13, 535-539 (2017).

Net charge fluctuations

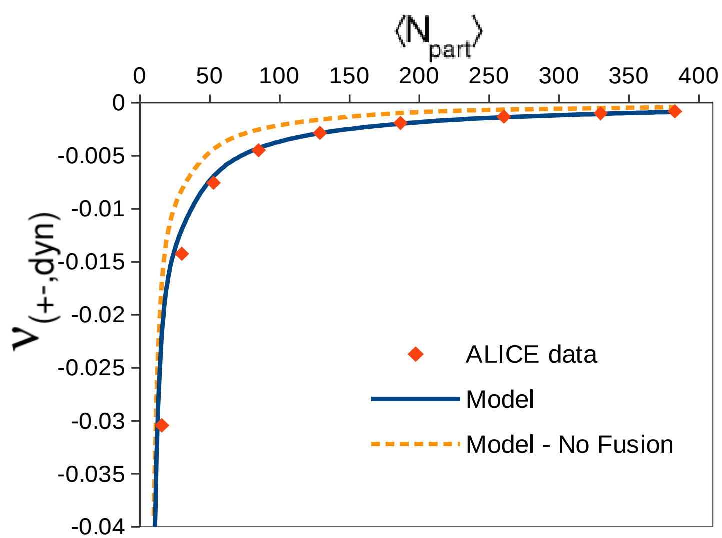
$$v_{\rm dyn} = \left\langle \left(\frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 \right\rangle - \frac{1}{\langle N_+ \rangle} + \frac{1}{\langle N_- \rangle}$$

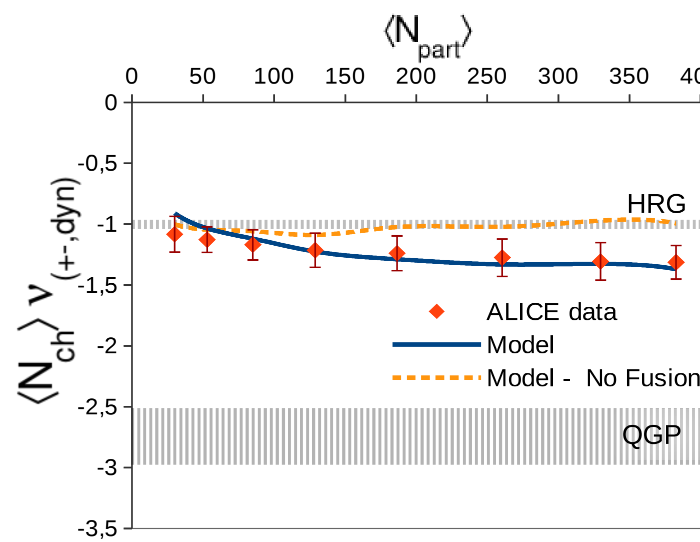
- String model enables to describe the dependence on the rapidity window width of net charge fluctuations
- The correlation length decreases with increase of sqrt(s), from peripheral to central, from pp to AA -> more fusion, more intensive sources emit particles



A. Titov, V. Vechernin, PoS (Baldin ISHEPP XXI) 047 (2012)

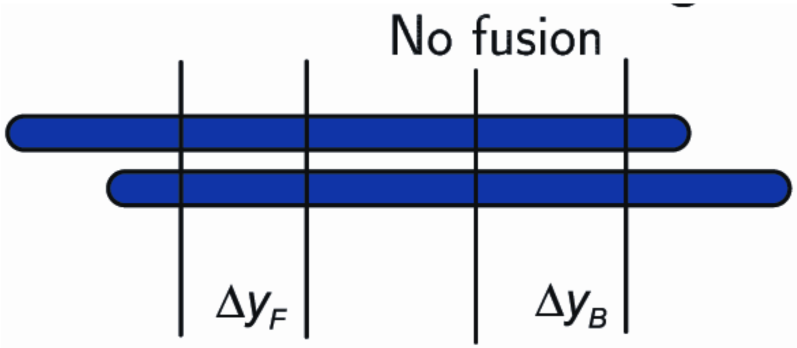
V. Kovalenko, PoS(Confinement2018)254 (2018, in press)

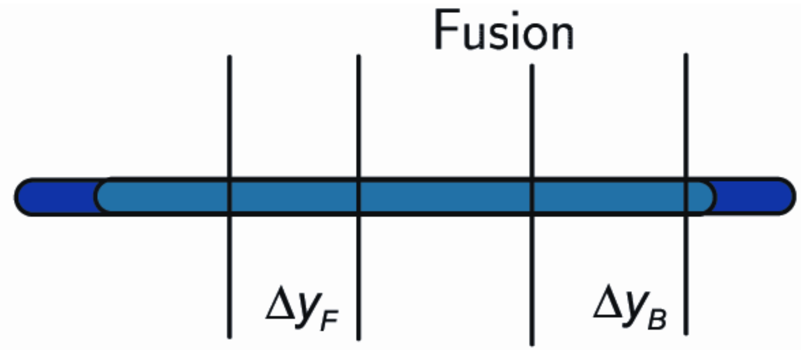




Long-range (forward-backward) correlations

- Sensitive tool for studying of string fusion phenomena





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

Positive correlations n–n, p_t–p_t.
p_t–n correlations can be negative!

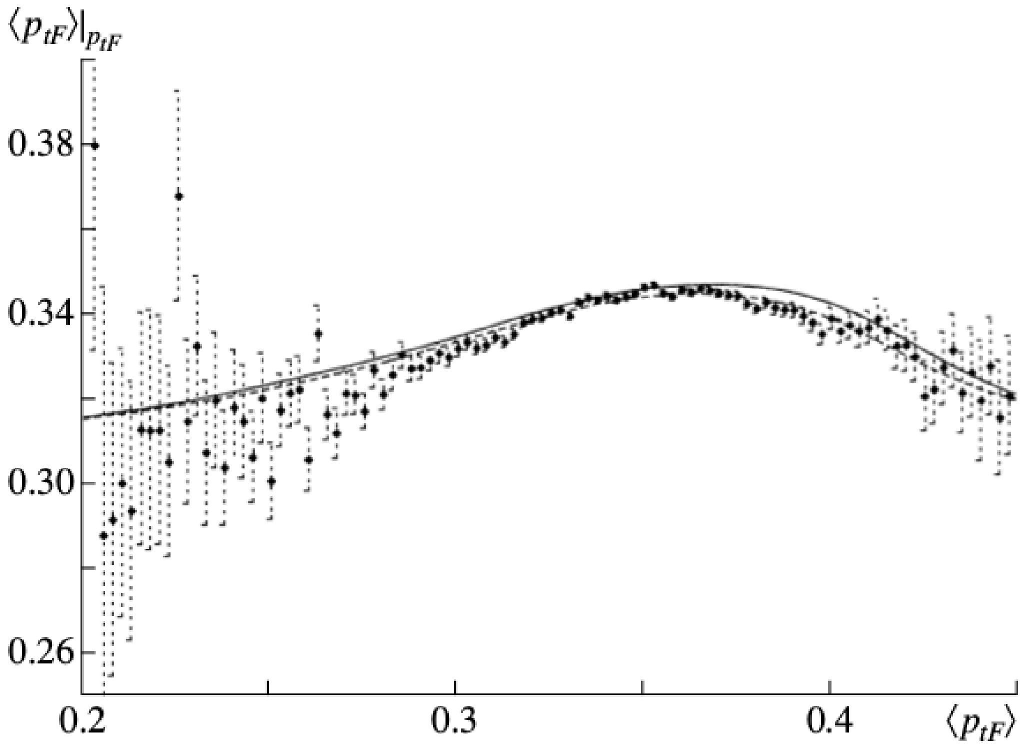
- Important (intensive) observable

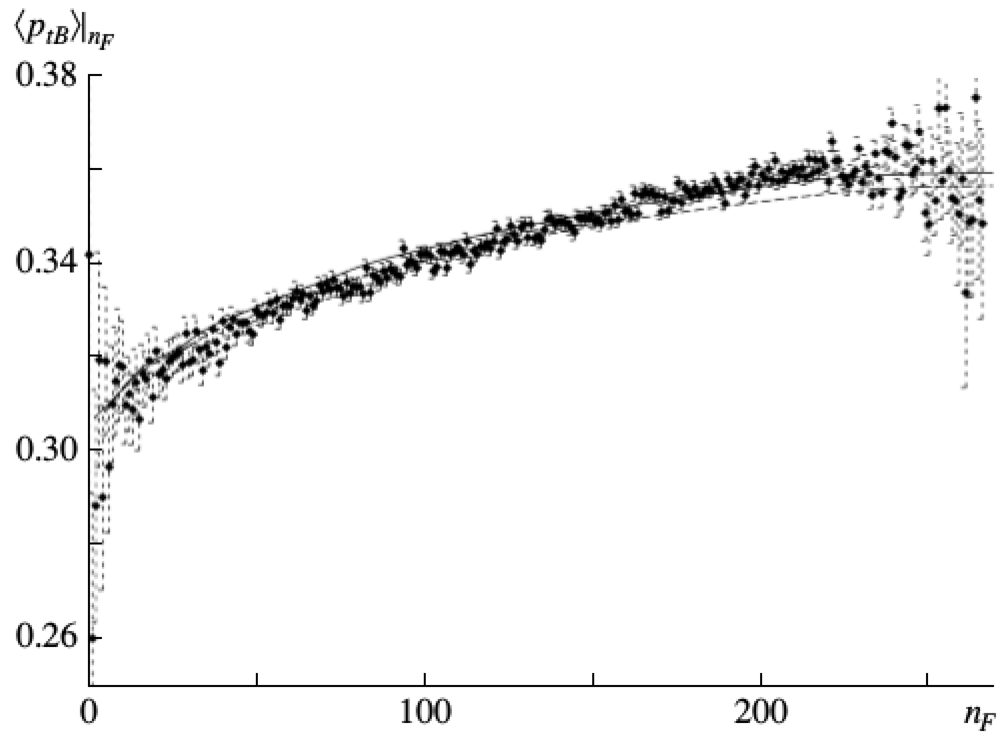
event mean transverse momentum $p_{tF(B)} = \dfrac{p_{t1} + \ldots + p_{tn_{F(B)}}}{n_{F(B)}}$

characterizes whole the event,
expected to be robust against centrality determination issues

Long-range (forward-backward) correlations at SPS energy

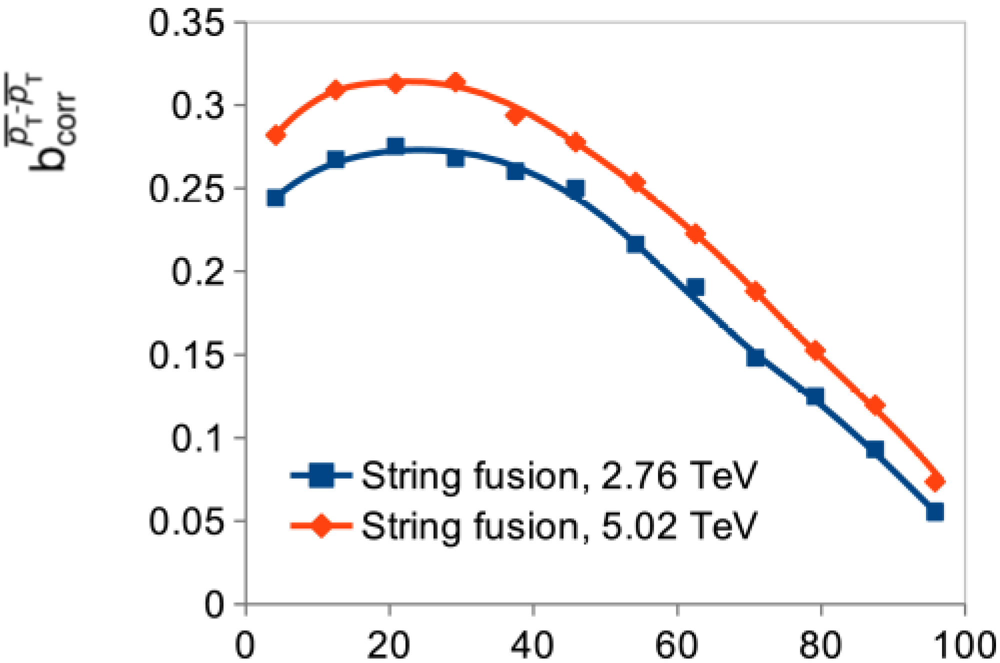
- pt-pt and pt-n correlations in Pb-Pb collisions at the SPS (NA49 data)
  lines – calculatinos in string fusion model

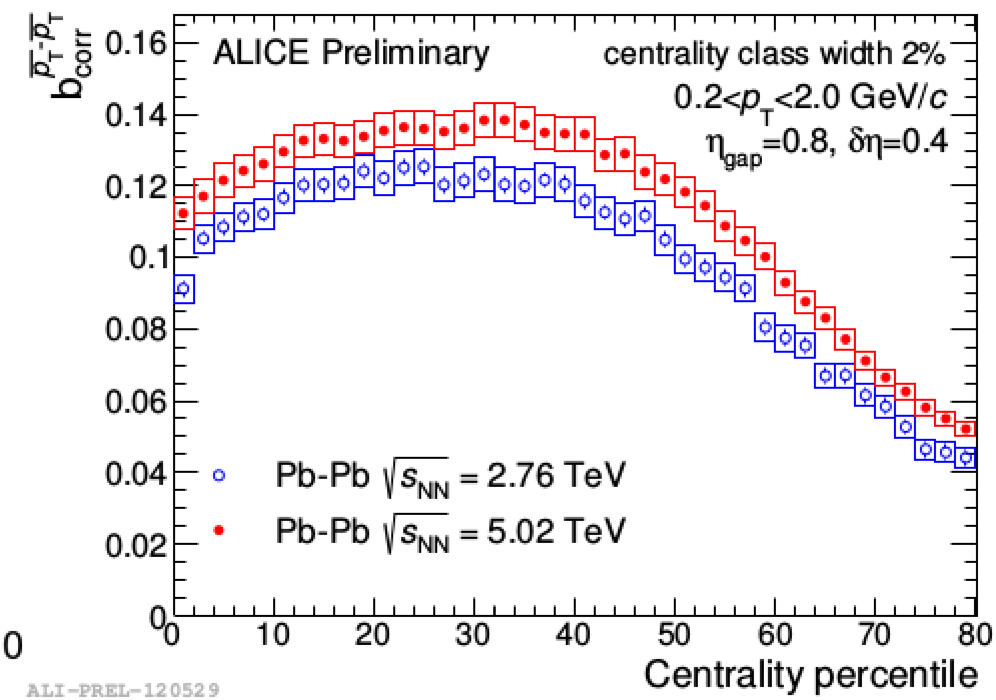


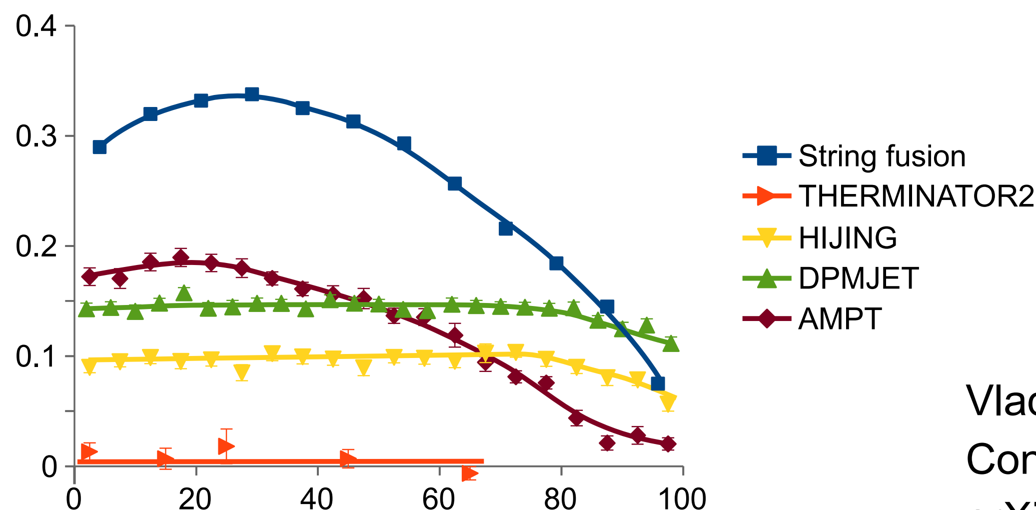


V. V. Vechernin, R. S. Kolevatov, Phys. Atom. Nucl. 70 (2007) 1858
V. V. Vechernin, R. S. Kolevatov, Phys. Atom. Nucl. 70 (2007) 1797

forward-backward pt-pt correlations at LHC energy: PbPb







Prelimenary experimental data – I.Altsybeev, "KnE Energy and Physics, pages 304-312, 2018 DOI: 10.18502/ken.v3i1.1759 arXiv:1711.04844 [nucl-ex]

Vladimir Kovalenko, Vladimir Vechernin, J. Phys. Conf. Ser. 798, 012053 (2017), arXiv:1611.07274 [nucl-th]

Current realisations of string fusion/string tension modification

PSM (Parton-string model) Monte Carlo generator (N. Amelin et al.)

Only pairs of strings can be fuesd :(, Fortran

Extended Multi-Pomeron Exchange model (EPEM) N. Armesto, et al Phys. Atom. Nucl. 2008, V. 71, P. 2087. E. O. Bodnia, V. N. Kovalenko, A. M. Puchkov, G. A. Feofilov // AIP Conf. Proc. 2014, 1606, 273

Semi-analitical calculations, parametrisation. Promisisng results at qualitative level

Monte Carlo dipole-based model V. N. Kovalenko, Phys. Atom. Nucl. 76, 1189 (2013),] V. Kovalenko, V. Vechernin, PoS (Baldin ISHEPP XXI) 077 (2012), arXiv:1212.2590 [nucl-th].

Finite Strings in rapidity space, C++/root

Pythia 8 tune - Thermodynamical String Fragmentation N. Fischer, T Sjöstrand JHEP 1701 (2017) 140

Very basic way

Pythia 8 / DIPSY - Rope Hadronization. C. Bierlich, EPJ Web Conf. 171 (2018) 14003

For pythia needs transverse position of strings. Promisisng results/under development

Monte Carlo models by V. V. Vechernin, R. S. Kolevatov, Phys. Atom. Nucl. 70 (2007) 1858; Phys. Atom. Nucl. 70 (2007) 1797, Vechernin, Lakomov PoS(Baldin ISHEPP XXI)072

Discontinued

Rough proposals for Geant 4

QGS model

Fragmentation functions for string decay

->

String fusion can be realizated as a parametric dependence of these functions on string density

Parametrisation of string density can be taken from EPEM

FTF

Realization of Lund string fragmentation. C++. Possible p-A, AA

->

Lund fragmentation parameters can be made dependent on string density,
In a way similar to what PYTHIA8/DIPSY is doing

In parallel – quick cross-checks with results of Dipole-based Monte Carlo model with string fusion

Summary

- Modification of string tension is supported by many experimental data
- Strings overlap – string fusion -> source of collectivity in AA, pA and even pp!
- String fusion works as smooth transition from low density up pp to Pb-Pb at LHC

Ideas for Geant 4

- String fusion effects can be implemented in G4 models FTF and QGS
- Hopefully can help concerning tension at different energies
- This should increase the applicability range of these models up to higher energy and heavy ion collisions

Of couse all should be done and validated in a separate branch before going into production

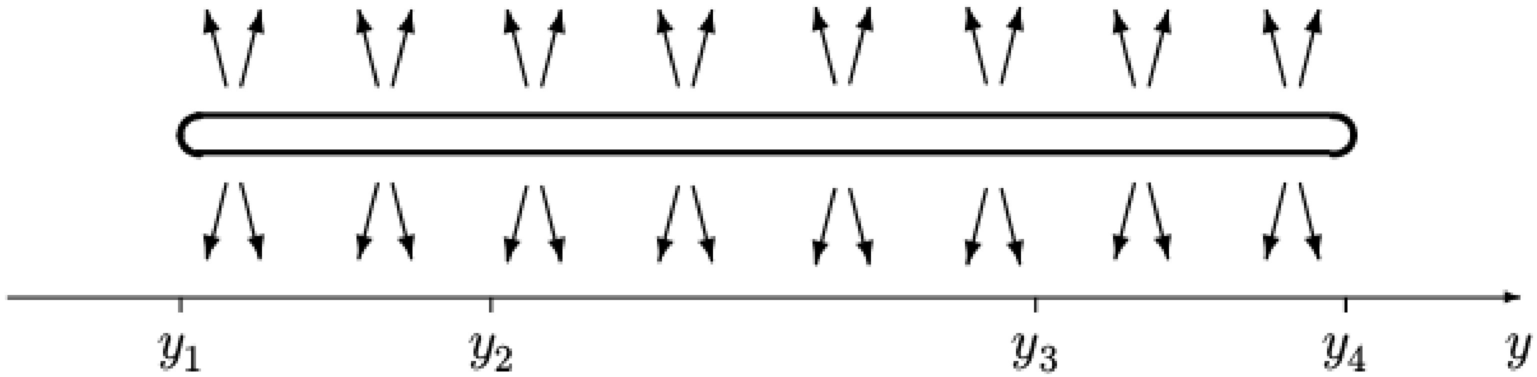
End Of Presentation

The author acknowledges the support by the grant of the Russian Science Foundation (project 16-12-10176).

Backup

String in rapidity space

- Uniform distribution of partocles from y_{min} to y_{max}
- y_{min} to y_{max} are defined as a kinematical condition to decay into at least two particles



- Can study string overlaps: