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Mean transverse momentum, multiplicity and their correlation in pp collisions in string fusion model.

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Abstract

The simple model which enables to take into account the effect of colour string fusion in pp interactions is suggested. The Monte-Carlo algorithm based on the model is developed and the inelastic cross section, the multiplicity and the mean transverse momentum of charged particles produced in pp collisions for the wide range of initial energies are calculated.

It is shown that the effect of the colour string fusion gives the significant contribution to the increase of the mean transverse momentum with energy in pp interactions. The obtained value of the NSD pp scattering cross section is in agreement with the experimental data. In the framework of the suggested model the comparison with the existing data of the observables in pp collisions at LHC energies and forecast for future LHC energies is made.

The correlation function for the long range correlation between the average transverse momentum and the multiplicity is also calculated.

Monte-Carlo algorithm

- For each elementary simulation in our algorithm the first parameter was the impact parameter b.
  b^2 – random uniformly distributed value at the segment [0; b^2_{max}]
  b_{max} – value at which probability of pp-process is negligible
- Using a given b in this simulation we got a number of strings Nstr – random value with poisson distribution with the following mean value:

$$\overline{N}_{str}(b) = N_0 \cdot e^{-\frac{b^2}{2\alpha^2}}$$

- Using the fixed values of b and Nstr we distributed centers of all Nstr strings of this simulation in a transverse plane. Here we used corresponding formulas mentioned above.
- After that we calculated the values of pt and n for this simulation with different means for the string radius using formulas from the string fusion model

Fixing the parameters

- We fixed our main parameters: α, N_0, r_{str}, μ_0 and p_0
- We define α using the experimental data on NSD cross section of pp interactions.
- We fixed μ_0 and p_0 so that we have a good agreement of our results for average multiplicity and average transverse momentum with the corresponding experimental data at the minimal initial energy:
  we fixed μ_0 = 0.56 per unit of rapidity and p_0 = 0.32 GeV/c
- We fixed N_0 at different energies using the experimental data on the central charged-particle pseudorapidity density:

$$N_0(E) = 258.22 - 111.98 \ln(E) + 12.196 \ln^2(E)$$

- String radius r_{str} was chosen equal to 0.4 fm in correspondence to the increase of the experimental mean pt data with energy.

pp interactions

QGSM

A.B. Kaidalov Phys.Lett. **B116**, 459, (1982)

A.B. Kaidalov, K.A. Ter-Martirosyan Phys.Lett. **B117**, 247, (1982)

DPM

A. Capella, U.P. Sukhatme, C.-I.Tan, J.Tran Thanh Van Phys.Lett. **B81**, 68, (1979)

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

AA interactions

SFM

M.A. Braun, C. Pajares Phys. Lett. **B287**, 154, (1992)

M.A. Braun, C. Pajares Nucl. Phys. **B390**, 542, (1993)

mean multiplicity and transverse momentum:

$$\langle n \rangle = \sum_C w(C) \langle n \rangle_C \,, \qquad \langle p_t \rangle = \sum_C w(C) \langle p_t \rangle_C$$

$$\sum_C w(C) \ldots = \frac{1}{n_{sim}} \sum_{sim} \ldots$$

p_t-n correlation correlation function (regression):

$$\langle p_t \rangle_n = \frac{\sum_C w(C)\ \langle p_t \rangle_C\ P_C(n)}{\sum_C w(C)\ P_C(n)}$$

$$P_C(n) = P_{\langle n \rangle_C}(n) = e^{-\langle n \rangle_C} \frac{(\langle n \rangle_C)^n}{n!}$$

Braun M.A., Pajares C., Vechernin V.V. Phys. Lett. B493 (2000) 54

Vechernin V.V., Kolevatov R.S., hep-ph/0304295; hep-ph/0305136

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

String fusion effects

local fusion (overlaps)

M.A. Braun, C. Pajares Eur.Phys.J. **C16**, 349, (2000)

$$\langle n \rangle_k = \mu_0 \sqrt{k}\, S_k/\sigma_0 \,, \qquad \langle p_t^2 \rangle_k = p_0^2 \sqrt{k} \,, \qquad k = 1, 2, 3, \ldots$$

Here $\langle n \rangle_k$ is the average multiplicity of charged particles originated from the transverse area S_k, where k strings are overlapping, and $\langle p_t^2 \rangle_k$ is the same for their squared transverse momentum. The μ_0 and p_0 are the average multiplicity and transverse momentum of charged particles produced from a decay of one single string, and σ_0 is its transverse area.

global fusion (clusters)

M.A. Braun, F. del Moral, C. Pajares, Phys.Rev. **C65**, 024907, (2002)

$$\langle p_t^2 \rangle_{cl} = p_0^2 \sqrt{k_{cl}} \,, \qquad \langle n \rangle_{cl} = \mu_0 \sqrt{k_{cl}} S_{cl}/\sigma_0 \,, \qquad k_{cl} = k\sigma_0/S_{cl}$$

The S_{cl} and k_{cl} are the transverse area of a cluster and corresponding overlapping factor.

the cellular version of SFM

Vechernin V.V., Kolevatov R.S., hep-ph/0304295; hep-ph/0305136

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

Distribution of strings in the transverse plane

AA interactions

$$\langle N_{str}(b) \rangle \sim \langle N_{coll}(b) \rangle = AB \frac{\sigma_{NN}}{\sigma_{AB}(b)} \int T_A(\vec{s} - \vec{b}/2) T_B(\vec{s} + \vec{b}/2) d^2\vec{s}$$

$$\sigma_{AB} = \int \sigma_{AB}(b)\ d^2\vec{b}$$

$$T_A(\vec{s}) = \int_{-\infty}^{+\infty} \rho_A(\vec{s}, z) dz$$

$$w_{str}(\vec{s}, \vec{b}) \equiv d\langle N_{str}(b) \rangle / d^2\vec{s}$$

$$w_{str}(\vec{s}, \vec{b}) \sim w_{coll}(\vec{s}, \vec{b}) \equiv d\langle N_{coll}(b) \rangle / d^2\vec{s} = AB \frac{\sigma_{NN}}{\sigma_{AB}(b)} T_A(\vec{s} - \vec{b}/2) T_B(\vec{s} + \vec{b}/2)$$

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

Vechernin V.V., Lakomov I.A., Puchkov A.M. "Mean transverse momentum, multiplicity and their correlation in pp collisions in string fusion model" Vestnik SPbU, ser.4, no 3, 2010, pp.3-16 (in Russian).

Event-by-event fluctuations of the number of strings

$$P(N, b) = e^{-\overline{N}(b)} \overline{N}(b)^N / N! \,, \qquad P(0, b) = e^{-\overline{N}(b)}$$

$$\widetilde{P}(N, b) = P(N, b)/[1 - P(0, b)] \,, \qquad \sum_{N=1} \widetilde{P}(N, b) = 1$$

$$\langle N_{str}(b) \rangle = \sum_{N=1} N\, \widetilde{P}(N, b) = \overline{N}(b)/[1 - P(0, b)]$$

$$\langle N_{str}(b) \rangle \sim e^{-b^2/2\alpha^2}/\sigma_{pp}(b)$$

$$\sigma_{pp}(b) = 1 - P(0, b) = 1 - \exp(-\overline{N}(b))$$

$$\Rightarrow \quad \boxed{\overline{N}(b) = N_0 e^{-b^2/2\alpha^2}}$$

$$\boxed{\langle N_{str}(b) \rangle = \overline{N}(b)/[1 - \exp(-\overline{N}(b))]}$$

Some analytical results for mean values

$$f(b) = \sigma_{pp}(b)/\sigma_{pp} \,, \qquad \int f(b)\, d^2\vec{b} = 1$$

$$\langle N_{str} \rangle = \int \langle N_{str}(b) \rangle\, f(b)\, d^2\vec{b} = \int \overline{N}(b)\, d^2\vec{b}/\sigma_{pp} = 2\pi\alpha^2 N_0/\sigma_{pp}$$

$$\langle N_{str}^2 \rangle = \int \langle N_{str}^2(b) \rangle\, f(b)\, d^2\vec{b} = \pi\alpha^2 N_0(N_0 + 2)/\sigma_{pp} = \langle N_{str} \rangle\, (N_0 + 2)/2$$

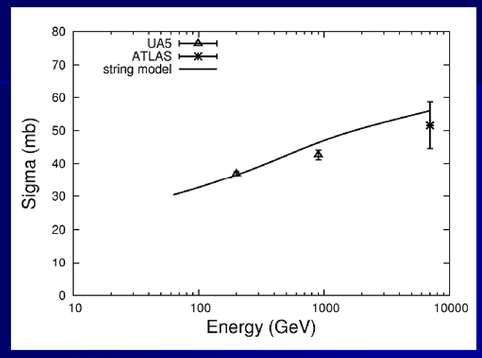
$$DN_{str} = \langle N_{str}^2 \rangle - \langle N_{str} \rangle^2 \,, \qquad \overline{N}(b) = N_0 e^{-b^2/2\alpha^2}$$

$$\sigma_{pp} = \int \sigma_{pp}(b)\, d^2b = \int [1 - P(0, b)]\, d^2b = \int [1 - \exp(-\overline{N}(b))]\, d^2b$$

$$\sigma_{pp} = 2\pi\alpha^2 [E_1(N_0) + \gamma + \ln N_0] \qquad \sigma_{pp} = \pi b_{max}^2 n_{sim}(N \neq 0)/n_{sim}$$

$$E_1(z) = \int_1^\infty e^{-zt} \frac{dt}{t} \,, \qquad \gamma = 0.577\ldots$$

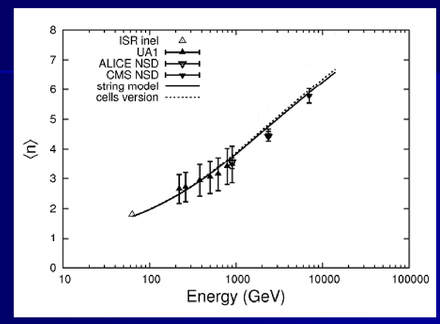
Non-single diffractive cross section



UA5 data: R.E. Ansorge, et al, Z. Phys. C33 (1986) 175;
SD corrections from M.G. Poghosyan arXiv:1005.1806v1 [hep-ph]

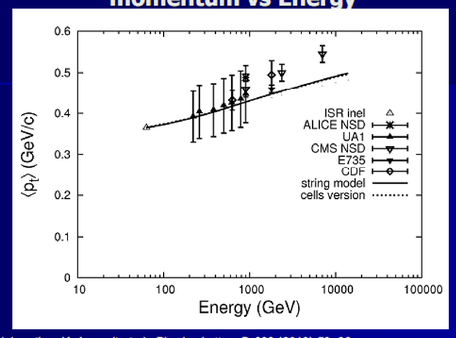
ATLAS data: http://indico.cern.ch/getFile.py/access?contribId=7&resId=0&materialId=slides&confId=110042;
SD corrections: A.B. Kaidalov and M.G. Poghosyan arXiv:0909.5156 [hep-ph]

Central charged-particle pseudorapidity density vs Energy



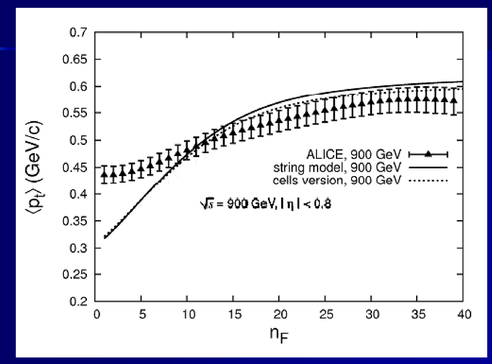
Data: K. Aamodt et al. (ALICE Collaboration), submitted to Eur. Phys. J. C. arXiv:1004.3034 [hep-ex] (2010);
V. Khachatryan et al. (CMS Collaboration), J. High Energy Phys. 2010, 02041 (2010);
W. Thome et al., Nucl. Phys. B 129, 365 (1977);
K. Alpgård et al. (UA5 Collaboration), Phys. Lett. B 112, 183 (1982);
M. Ambrosio et al., AIP Conf. Proc. 85, 602 (1982);
C. Albajar et al. (UA1 Collaboration), Nucl. Phys. B 335, 261 (1990).

Mean transverse momentum vs Energy



Data: ALICE Collaboration, K. Aamodt et al., Physics Letters B 693 (2010) 53–68;
CMS Collaboration, V. Khachatryan, et al., JHEP 1002 (2010) 041;
UA1 Collaboration, C. Albajar, et al., Nucl. Phys. B 335 (1990) 261;
A.M. Rossi, G. Vannini, A. Bussiere, E. Albini, D. D'Alessandro, G. Giacomelli, Nucl. Phys. B 84 (1975) 269;
E735 Collaboration, T. Alexopoulos, et al., Phys. Rev. Lett. 60 (1988) 1622;
CDF Collaboration, F. Abe, et al., Phys. Rev. Lett. 61 (1988) 1819;
CMS Collaboration, V. Khachatryan, et al., Phys. Rev. Lett. 105 (2010) 022002, arXiv:1005.3299 [hep-ex]
Lines: string fusion model calculations (ALICE work in progress)

pt-n correlation function at 900 GeV



Data: ALICE Collaboration, K. Aamodt et al., Physics Letters B 693 (2010) 53–68.
Lines: string fusion model calculations (ALICE work in progress)

Conclusions

- The simple model, which enables to take into account the effect of the colour strings fusion in pp interactions, is suggested.
- Using the Monte-Carlo algorithm based on the model we calculated the NSD cross section, the central charged-particle pseudorapidity density and the mean transverse momentum of charged particles produced in pp collisions for the wide range of initial energies.
- It is demonstrated that one can practically fully explain the increase of the mean transverse momentum with energy in pp interactions by the effect of the colour strings fusion. Slower increase of the calculated mean transverse momentum with energy than the experimentally observed one, possibly has concern with the additional contribution of hard processes, which can't be taken into account in the framework of the present approach.
- It is shown also that the obtained value of the NSD pp scattering cross section does not depend on the string radius option and is in agreement with the experimental data.
- In the framework of suggested model calculations are made for values of the observables in pp collisions at present and future ALICE energies.
- The correlation function for the long range correlation between the average transverse momentum and the central charged-particle pseudorapidity density is obtained.