Particle correlations in the model of interacting colour strings for p+p collisions

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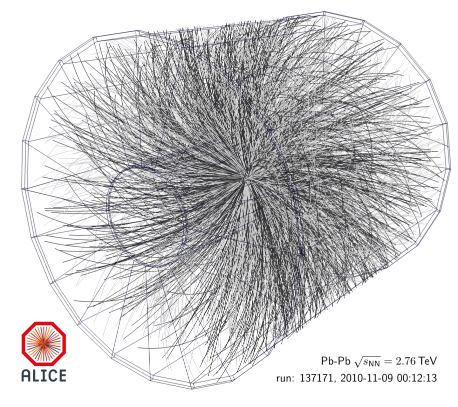
Typical event browser in High Energy *AA* collision



[https://cds.cern.ch/record/2032743]

- soft particle production dominates ($p_T < 1$ GeV/c)
- complexity of perturbative QCD calculations
- phenomenological model of colour strings!
- the largest contribution to errors in model calculations comes from uncertainties in initial states

Multipomeron exchange in inelastic $p + p$ interaction

Number of strings in an event, $n_{\mathrm{str}} = 2n_{\mathrm{pom}}$ [A.Capella et al, Phys. Rep. 1994, **236**, 225–329] , determined by the **number of cut pomerons** following [A.Kaidalov, K. Ter-Martirosyan, Phys. Lett. B 1982, **117**, 247–251] :

$$P(n_{\mathrm{pom}}) = C(z)\frac{1}{zn_{\mathrm{pom}}}\left(1 - \exp(-z)\sum_{l=0}^{n_{\mathrm{pom}}-1}\frac{z^l}{l!}\right), \qquad (1)$$

where $z = \frac{2w\gamma s^{\Delta}}{R^2+\alpha' \ln s}$, $w = 1.5$, $\Delta = \alpha(0) - 1 = 0.2$, $\gamma = 1.035\ \mathrm{GeV}^{-2}$ и $R^2 = 3.3\ \mathrm{GeV}^{-2}$, $\alpha^{'} = 0.05\ \mathrm{GeV}^{-2}$ [V.Vechernin, S.Belokurova, J. Phys. Conf. Ser. 2020, **1690**, 012088] .

Event **multiplicity** is defined as

$$P(N_{\mathrm{ch}}) = \sum_{n_{\mathrm{pom}}=1}^{\infty} P(n_{\mathrm{pom}})\, P_{n_{\mathrm{pom}}}(N_{\mathrm{ch}}), \qquad (2)$$

where $P_{n_{\mathrm{pom}}}(N_{\mathrm{ch}})$ - multiplicity distribution from a fixed number of pomerons.

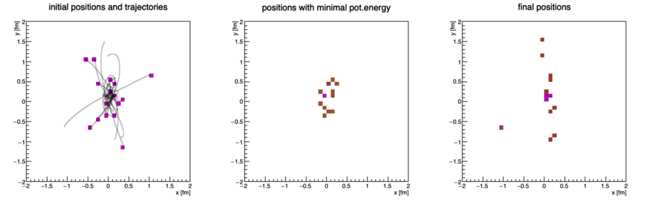
Dynamics of colour strings in the transverse plane

The strings move **as a whole** according to [T.Kalaydzhyan, E.Shuryak, Phys. Rev. C 2014, **90**, 014901] :

$$\ddot{\vec{r}}_i = \vec{f}_{ij} = \frac{\vec{r}_{ij}}{\tilde{r}_{ij}}(g_N\sigma)m_\sigma 2K_1(m_\sigma \tilde{r}_{ij}), \quad (3)$$

with $\tilde{r}_{ij} = \sqrt{r_{ij}^2 + s_{\mathrm{string}}^2}$, $s_{\mathrm{string}} = 0.176$ fm, $g_N\sigma = 0.2$, $m_\sigma = 0.6$ GeV$/c^2$.

String density depends on **system evolution time** τ:



Example for 16 strings in an event: (**left**) initial positions and trajectories, (**center**) positions at time τ_{deepest} when the minimum potential energy of the string system is reached , (**right**) positions at $\tau = 1.5$ fm$/c$.

Longitudinal dynamics of colour strings

The **initial** positions of strings' ends in rapidity are determined by the momenta and masses of the corresponding partons:

$$y_q^{\mathrm{init}} = \pm \,\mathrm{arcsinh}\left(\frac{x_q p_{\mathrm{beam}}}{m_q}\right), \tag{4}$$

Due to string tension, $|\frac{dp_q}{dt}| = -\sigma$, rapidity of strings' **massive ends** decreases [C.Shen, B.Schenke, Phys. Rev. C 2018, **97**, 024907] by:

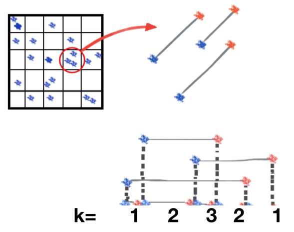
$$y_q^{\mathrm{loss}} = \mp \,\mathrm{arccosh}\left(\frac{\tau^2\sigma^2}{2m_q^2} + 1\right), \tag{5}$$

where τ - as in transverse dynamics, $\sigma = 0.16$ GeV/fm.

Result: a set of parallel strings of different lengths and at different positions with respect to midrapidity.

String fusion and formation of string clusters

String fusion **on a grid** [M.Braun et al, Eur. Phys. J. C 2004, **32**, 535–546] :



Schematic representation of the 3-D pattern of string fusion: 3 strings with $k = 1, 1, 1$, centered in the same cell (0.3 fm) in the transverse plane, after taking into account overlaps - 2 strings with $k = 1, 1$ and 3 string clusters with $k = 2, 3, 2$.

Changing the average multiplicity from **cluster of k strings** [M.Braun et al, Int. J. Mod. Phys. A 1999, **14**, 2689–2704] : $\langle \mu \rangle_k = \mu_0 \sqrt{k}$

and average transverse momentum $\langle p_T \rangle_k = p_0 k^{\beta}$, где $\beta = 1.16[1 - (\ln\sqrt{s} - 2.52)^{-0.19}]$ [V.Kovalenko et al, Universe 2022, **8**, 246] .

μ_0 and p_0 - characteristics of independent sources - free **parameters** of the model.

Efficient string hadronisation

Splitting strings in rapidity **into segments of length** $\varepsilon = 0.1$:

- mean multiplicity from ε interval $\langle N_\varepsilon \rangle = \mu_0 \varepsilon \sqrt{k}$
- multiplicity from **Poisson** distribution $N_\varepsilon = P(\langle N_\varepsilon \rangle)$

For each particle we define **transverse momentum** [E.Gurvich, Phys. Lett. B 1979, **87**, 386–388] according to

$$f(p_T) = \frac{\pi p_T}{2\langle p_T \rangle_k^2} \exp\left(-\frac{\pi p_T^2}{4\langle p_T \rangle_k^2}\right), \tag{6}$$

and its **sort** according to $\sim \exp(-\pi m_i^2/\sigma_{\rm eff} k^{2\beta})$, where i corresponds to π, K, p particles and ρ resonance, $\sigma_{\rm eff} = 4p_0^2$.

Knowing m_i, we find p_z and **pseudorapidity**:

$$\eta = \frac{1}{2} \ln \left(\frac{|\vec{p}| + p_z}{|\vec{p}| - p_z} \right), \tag{7}$$

where $|\vec{p}| = \sqrt{p_T^2 + p_z^2}$.

Correlation observables

1. **Correlation function** $\langle p_T \rangle - N$, where $\langle p_T \rangle$ is event average particle transverse momentum and N is charged particles multiplicity

2. **Correlation coefficient** b_{B-F} [S.Uhlig et al, Nucl. Phys. B 1978, **132**, 15–28]

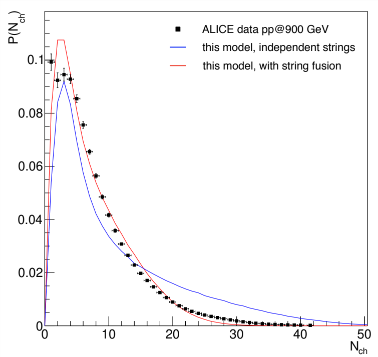
$$b_{B-F} = \left. \frac{d\langle N_B(N_F)\rangle}{dN_F} \right|_{N_F=\langle N_F\rangle}, \tag{8}$$

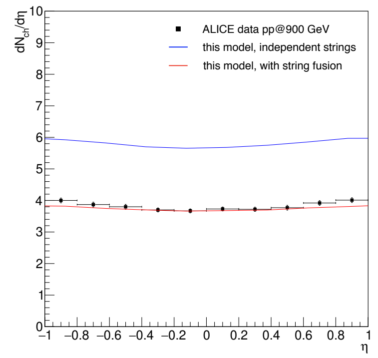
which for the case of a linear correlation function $\langle N_B(N_F)\rangle$ [A.Capella, J. Tran Thanh Van, Phys. Rev. D 1984, **29**, 2512–2516] reads:

$$b_{\mathrm{corr}}[N_F, N_B] = \frac{\langle N_F N_B\rangle - \langle N_F\rangle\langle N_B\rangle}{\langle N_B^2\rangle - \langle N_B\rangle^2}. \tag{9}$$

Approximation of ALICE data at $\sqrt{s} = 900$ GeV for $N_{\rm ch}$ and η

Average multiplicity per rapidity unit: $\mu_0 = 0.87$.

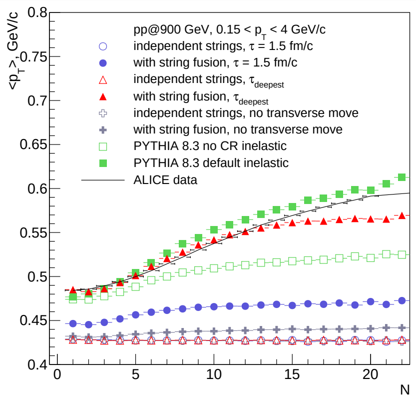




Model calculation for independent sources (blue lines) and for interacting strings (red lines) compared to ALICE data [K.Aamodt et al. [ALICE Collaboration] Eur. Phys. J. C 2010, **68**, 345–354] (black squares) for inelastic $p + p$ interactions at $\sqrt{s} = 900$ GeV. **Left**: multiplicity distribution for $|\eta| < 1$, **right**: η-spectrum

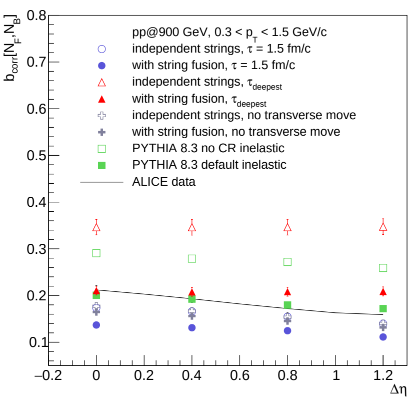
Approximation of $\langle p_T \rangle - N$ correlation function in ALICE data

Average transverse momentum: $p_0 = 0.38$ GeV/c.



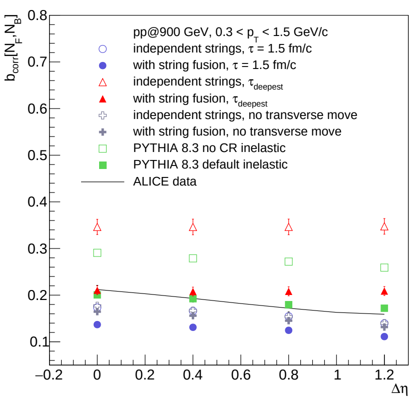
$\langle p_T \rangle$–N correlation function for particles with $|\eta| < 0.8$ and $0.15 < p_T < 4$ GeV/c in inelastic $p + p$ interactions at $\sqrt{s} = 900$ GeV. Adjusting the model (red triangles) to ALICE data [K. Aamodt et al [ALICE Collaboration]. Phys. Lett. B 2010, **693**, 53-68] (black line).

Correlation coefficient $b_{\mathrm{corr}}[N_F, N_B]$



$b_{\mathrm{corr}}[N_F, N_B]$ as a function of the distance $\Delta\eta$ between the Forward and Backward η intervals for inelastic $p+p$ interactions at $\sqrt{s} = 900$ GeV. Particle selection 0.3 GeV/c < $p_T < 1.5$ GeV/c. Line drawn through ALICE data [J.Adam et al. [The ALICE Collaboration] J. High Energy Phys. 2015, **5**, 97]. PYTHIA event generator with and without colour reconnection [C.Bierlich et al arXiv:2203.11601].

Correlation coefficient $b_{\mathrm{corr}}[N_F, N_B]$



- no dependence on $\Delta\eta$ for τ_{deepest}, because for $\langle\tau_{\mathrm{deepest}}\rangle = 0.73$ fm/c the strings fragment on average into both η-windows
- for $\tau = 1.5$ fm/c the correlation weakens with $\Delta\eta$, since short strings appear fragmenting into only one η-window
- PYTHIA and ALICE data decrease due to short-range correlations

Summary and Outlook

The novelty of the approach: simultaneous consideration of 3-D string dynamics and the mechanism of string fusion.

Main observations:

1. need to introduce a string fusion mechanism to describe the $\langle p_T \rangle - N$ correlation function
2. nontrivial dependence of $b_{\mathrm{corr}}[N_F, N_B]$ on the evolution time of the string density τ: modification of the background of long-range correlations

Plans: study of azimuthal correlations along with rapidity ones.

THANK YOU FOR YOUR ATTENTION

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