Theoretical motivations to study the Σ observable (a short version)

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Strongly intensive observable $\Sigma(n_F, n_B)$

We define the strongly intensive observable $\Sigma(n_F, n_B)$ between multiplicities in forward (n_F) and backward (n_B) windows in accordance with [*M.I.Gorenstein,M.Gazdzicki,Phys.Rev.C84(2011)014904*] as

$$\Sigma(n_F, n_B) \equiv \frac{1}{\langle n_F\rangle + \langle n_B\rangle}[\langle n_F\rangle\,\omega_{n_B} + \langle n_B\rangle\,\omega_{n_F} - 2\,\mathrm{cov}(n_F\, n_B)]\ , \qquad (1)$$

where

$$\mathrm{cov}(n_F, n_B) \equiv \langle n_F n_B\rangle - \langle n_F\rangle\langle n_B\rangle\ , \qquad (2)$$

and ω_{n_F} and ω_{n_B} are the corresponding scaled variances of the multiplicities:

$$\omega_n \equiv \frac{D_n}{\langle n\rangle} = \frac{\langle n^2\rangle - \langle n\rangle^2}{\langle n\rangle}\ . \qquad (3)$$

[*E.V.Andronov,Theor.Math.Phys.185(2015)1383*]

Σ in the model with independent identical strings

The fundamental characteristics of a string:
one- and two-particle rapidity distributions from a single string decay:

$$\lambda(\eta) = \mu_0, \qquad \lambda_2(\eta_1, \eta_2) = \lambda_2(\eta_1 - \eta_2) = \lambda_2(\Delta\eta)$$

$\Lambda(\Delta\eta)$ - two-particle correlation function of a string:

$$\Lambda(\eta_1, \eta_2) \equiv \frac{\lambda_2(\eta_1, \eta_2)}{\lambda(\eta_1)\lambda(\eta_2)} - 1 = \frac{\lambda_2(\Delta\eta)}{\mu_0^2} - 1 = \Lambda(\Delta\eta) \ .$$

$\delta\eta$ - the width of the observation windows (below we suppose $\delta\eta \ll \eta_{corr}$),
$\Delta\eta = \eta_{sep}$ - the distance between the observation windows.

$$\boxed{\Sigma(\Delta\eta) = 1 + \mu_0 \delta\eta [\Lambda(0) - \Lambda(\Delta\eta)]}$$

Andronov E, Vechernin V 2019 Eur. Phys. J. A 55 14
Vechernin V, Andronov E 2019 Universe 5 15
Vechernin V 2018 Eur. Phys. J.: Web of Conf. 191 04011

Properties of Σ in model with independent identical strings

- We see that in the model with identical strings the $\Sigma(\Delta\eta)$ is a really strongly intensive quantity. It does not depend nor on the mean number of strings $\langle N\rangle$, nor on their event-by-event fluctuations $\omega_N \equiv D_N/\langle N\rangle$. It depends ONLY on string parameters: μ_0 and $\Lambda(\Delta\eta)$.

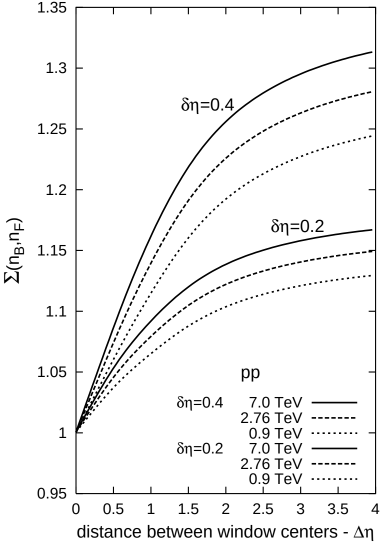
- The $\Sigma(0) = 1$ and increases with the gap between windows, $\Delta\eta$, as the $\Lambda(\Delta\eta)$ decrease to 0 with $\Delta\eta$, since the correlations in a string go off with increase of $\Delta\eta$.

- The rate of the $\Sigma(\Delta\eta)$ growth with $\Delta\eta$ is proportional to the width of the observation window $\delta\eta$ and μ_0 - the multiplicity produced from one string.

- The model predicts saturation of the $\Sigma(\Delta\eta)$ on the level

$$\Sigma(\Delta\eta) = 1 + \mu_0\delta\eta\,\Lambda(0) = \omega_\mu = D_\mu/\langle\mu\rangle$$

at large $\Delta\eta$, since $\Lambda(\Delta\eta) \to 0$ at the $\Delta\eta \gg \eta_{corr}$, where the η_{corr} is a string correlation length.



It was used the $\Lambda(\Delta\eta, \Delta\phi)$, extracted in [V.Vechernin,Nucl.Phys.A939(2015)21] from the ALICE pp data on forward-backward correlations in windows of small acceptance, $\delta\eta = 0.2, \delta\phi = \pi/4$, separated in azimuth and rapidity [ALICE collab.,JHEP05(2015)097].

The string parameters occur dependent on initial energy (!?)

Hint on the increase of the string cluster contribution to $\Sigma(n_F, n_B)$ with collision energy in pp collisions

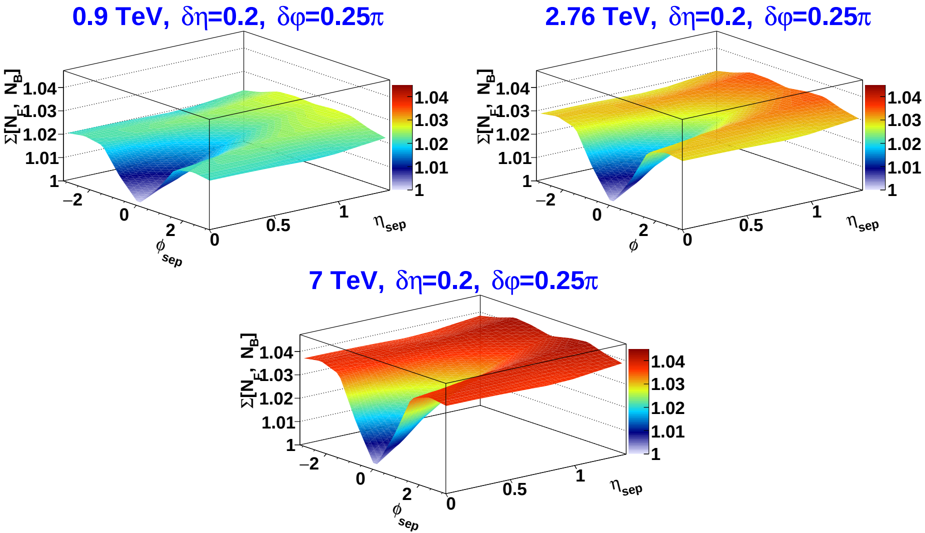
$\Sigma(n_F, n_B)$ in windows separated in azimuth and rapidity

For small observation windows:

$$\Sigma(\Delta\eta,\Delta\phi) = 1 + \frac{\delta\eta\,\delta\phi}{2\pi}\mu_0\ [\Lambda(0,0) - \Lambda(\Delta\eta,\Delta\phi)]$$

$$\Delta\eta \equiv \eta_{sep}, \qquad \Delta\phi \equiv \phi_{sep}$$

Σ for $\delta\eta\ \delta\phi$ windows separated in azimuth and rapidity



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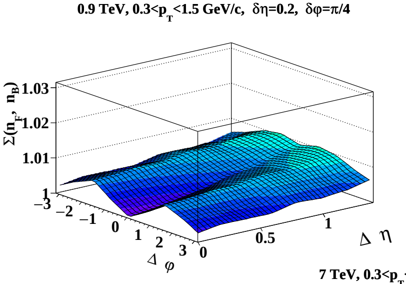
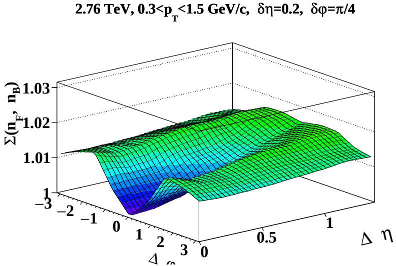
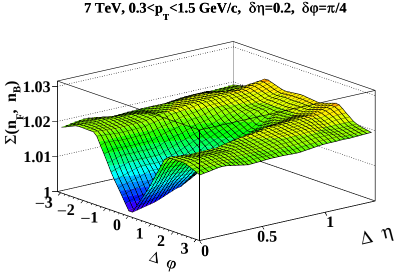
Σ for $\delta\eta\ \delta\phi$ windows - PYTHIA







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$\Sigma(n_F, n_B)$ with charges

$$\Sigma(n_F, n_B) = \Sigma(n_F^+, n_B^+) + \Sigma(n_F^-, n_B^+) - \Sigma(n_F^+, n_F^-) \ .$$

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$$\Sigma(n_F^+, n_B^+) = 1 + \mu_0 \delta\eta [\Lambda^{same}(0) - \Lambda^{same}(\Delta\eta)]/2 \ ,$$

$$\Sigma(n_F^+, n_B^-) = 1 + \mu_0 \delta\eta [\Lambda^{same}(0) - \Lambda^{opp}(\Delta\eta)]/2 \ ,$$

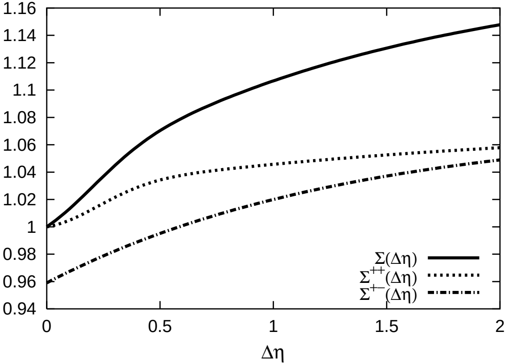
$$\Sigma(n_F^+, n_F^-) = 1 + \mu_0 \delta\eta [\Lambda^{same}(0) - \Lambda^{opp}(0)]/2 \ .$$

The $\Lambda^{same}(\Delta\eta)$ and $\Lambda^{opp}(\Delta\eta)$ was extracted using the connections:

$$\Lambda(\Delta\eta) = \frac{\Lambda^{opp}(\Delta\eta) + \Lambda^{same}(\Delta\eta)}{2}, \qquad B(\Delta\eta) = \mu_0 \frac{\Lambda^{opp}(\Delta\eta) - \Lambda^{same}(\Delta\eta)}{2}.$$

The $\Lambda(\Delta\eta)$ was already extracted in [V.Vechernin,Nucl.Phys.A939(2015)21] from the ALICE pp data on forward-backward correlations [ALICE collab.,JHEP05(2015)097] and the Balance Function $B(\Delta\eta)$ was taken from the paper [ALICE collab.,Eur.Phys.J. C76(2016)86].

$\Sigma(n_F, n_B)$ with charges



Note that similarly to the $\Sigma(n_F, n_B)$ we have

$$\Sigma(n_F^+, n_B^+) \to 1 \quad at \quad \Delta\eta \to 0 \ ,$$

but

$$\Sigma(n_F^+, n_B^-) \to \Sigma(n_F^+, n_F^-) = 1 + \mu_0 \delta\eta [\Lambda^{same}(0) - \Lambda^{opp}(0)]/2 = 0.96 < 1 \ .$$

$\Sigma(n_F, n_B)$ in the model with string clusters formation

In the model with string clusters formation
by a string fusion on transverse grid it was shown
[*S.N. Belokurova, V.V. Vechernin, Theor.Math.Phys. 200(2019)1094*]:

$$\Sigma(n_F, n_B) = \sum_{k=1}^{\infty} \alpha_k \, \Sigma_k(\mu_F, \mu_B) \ , \qquad \alpha_k = \frac{\langle n^{(k)} \rangle}{\langle n \rangle} \ ,$$

where k is a number of stings, which formed a given string cluster and $\langle n^{(k)} \rangle$ is a mean number of particles produced from such clusters, $\sum \alpha_k = 1$.
Here $\Sigma_k(\mu_F, \mu_B)$ is the variable Σ for the cluster formed by k strings:

$$\Sigma_k(\mu_F, \mu_B) = \Sigma_k(\Delta\eta) = 1 + \mu_0^{(k)} \delta\eta [\Lambda_k(0) - \Lambda_k(\Delta\eta)] \ ,$$

where $\mu_0^{(k)}$ and $\Lambda_k(\Delta\eta)$ are the corresponding parameters of the string cluster.

$\Sigma(n_F, n_B)$ in the model with string clusters formation

In the model with string clusters formation the observable $\Sigma(n_F, n_B)$ loses the strongly intensive property, as it becomes equal to the weighted average of its values for different string clusters with the weights depending on collision conditions (the initial energy and centrality).

Nevertheless it can be used for the extraction of the information on the properties of the string clusters (the multiplicity density $\mu_0^{(k)}$ and the pair correlation function $\Lambda_k(\Delta\eta)$ of paricles, produced from a cluster decay).

The increase of the $\Sigma(n_F, n_B)$ in pp collisions with energy can be explained by the increasing role of string fusion processes and the formation of string clusters with new properties (see the next slides).

The increase of the $\Sigma(n_F, n_B)$ with the collision centrality also can be explained by the string fusion processes in the framework of the same approach (see the next slides).

MC calculations of $\Sigma(n_F, n_B)$ in the model with string clusters formation

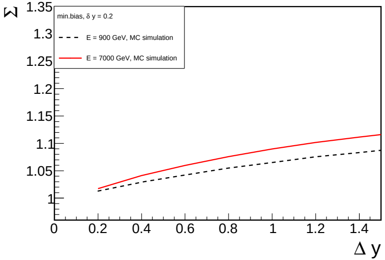
- V.V. Vechernin, S.N. Belokurova, in Proceedings of the 5th International Conference on Particle Physics and Astrophysics (ICPPA-20), 5-9 October 2020, Moscow (online), Journal of Physics: Conference Series (in press).

- S. Belokurova, in Proceedings of the LXX International conference NUCLEUS - 2020, 11-17 October 2020, St.Petersburg (online), Physics of Particles and Nuclei (in press); arXiv:2011.10434 [hep-ph].

- Modelling the initial string distribution in the impact parameter plane of pp collisions for different initial energies to take into account string fusion processes. [*V. Vechernin, I. Lakomov. Proceedings of Science (Baldin ISHEPP XXI) (2013) 072.*]

- Monte Carlo simulation of the weighting factors α_k as a function of centrality and initial energy of pp collision.

- Calculation the $\Sigma(n_F, n_B)$ for different centralities of pp collision at few LHC energies, using the expessions for $\mu_0^{(k)}$ and $\Lambda_k(\Delta\eta) = \Lambda_0^{(k)} exp[-|\Delta\eta|/\eta_{corr}^{(k)}]$.



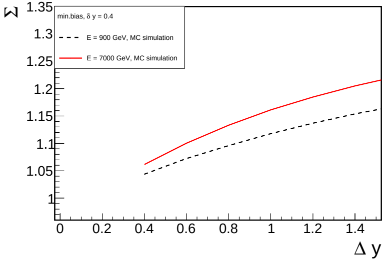


Figure: The strongly intensive observable $\Sigma(n_F, n_B)$ for pp collisions as a function of the rapidity distance $\Delta\eta = \delta y$ between the centers of the FB observation windows, for two widths of windows: $\delta\eta$=0.2 (left panel) and $\delta\eta$=0.4 (right panel), and for two initial energies: 0.9 TeV (dashed lines) and 7 TeV (solid lines), calculated for particles with transverse momenta in the interval 0.3-1.5 GeV/c, as in the experimental analysis in [ALICE collab.,JHEP05(2015)097].

The increase of the $\Sigma(n_F, n_B)$ in pp collisions with energy is caused by the increasing contribution of string fusion processes and the formation of string clusters with new properties.

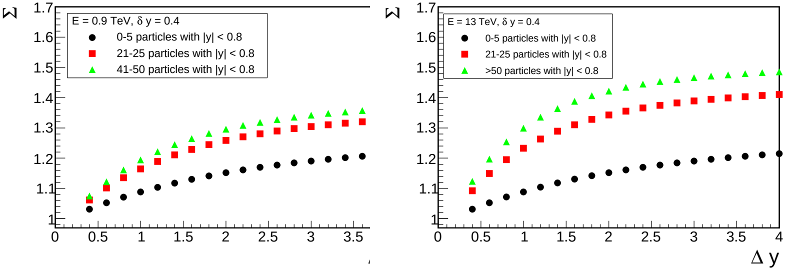


Figure: The strongly intensive variable $\Sigma(n_F,\ n_B)$ at different centralities as a function of the rapidity distance between the observation windows Δy for *pp* collisions at energies 900 and 13000 GeV for the width of the observation windows $\delta y = 0.4$.

The increase of the $\Sigma(n_F, n_B)$ in pp collisions with the collision centrality is also caused by the increasing contribution of string fusion processes and the formation of string clusters with new properties.