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INITIAL STAGES
OF HIGH-ENERGY NUCLEAR
COLLISIONS

# Forward-backward multiplicity correlations with strongly intensive observables in pp collisions

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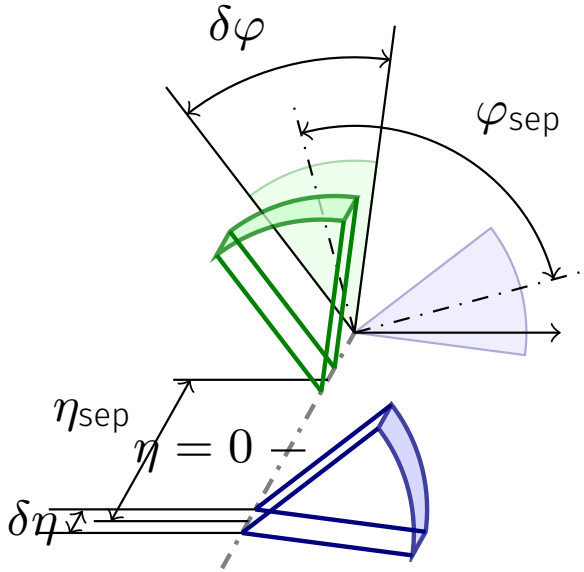
# Strongly instensive quantities

A physical quantity is called *strongly intensive* if it does not depend on system volume and its fluctuations.




An example of such quantity depending on first and second moments of particle multiplicities produced in 2 (**F**orward and **B**ackward) phase-spase windows is

$$\Sigma\left[n_{\mathrm{F}}, n_{\mathrm{B}}\right] = \frac{\langle n_{\mathrm{F}}\rangle\omega[n_{\mathrm{B}}] + \langle n_{\mathrm{B}}\rangle\omega[n_{\mathrm{F}}] - 2\,\mathrm{cov}\left(n_{\mathrm{F}}, n_{\mathrm{B}}\right)}{\langle n_{\mathrm{F}}\rangle + \langle n_{\mathrm{B}}\rangle},$$

where $\omega[n] \equiv \frac{\langle n^2\rangle - \langle n\rangle^2}{\langle n\rangle}$ and the averaging is over all events.

Windows of size $\delta\eta$ (and $\delta\varphi$) are separated in pseudorapidity (and azimuth).

Windows are arranged symmetrically with respect to $\eta = 0$ and the distance between their centers is denoted by $\eta_{\text{sep}}$. The distance between windows' centers in azimuth is denoted by $\varphi_{\text{sep}}$.

$\Sigma\left[n_{\mathrm{F}}, n_{\mathrm{B}}\right] = 1$ in the model of independent particle production [*Phys. Rev.* C84 (2011), p. 014904; *Phys. Rev.* C88.2 (2013), p. 024907].

# $\Sigma\left[n_{\mathrm{F}}, n_{\mathrm{B}}\right]$ in the model of indepentent identical strings

In this model, $\Sigma$ is also a strongly intensive quantity and depends on fundamental characteristics of one string:

$$\Sigma(\Delta\eta) = 1 + \mu_0 \delta\eta \left[\Lambda(0) - \Lambda(\Delta\eta)\right] \ ,$$

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

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

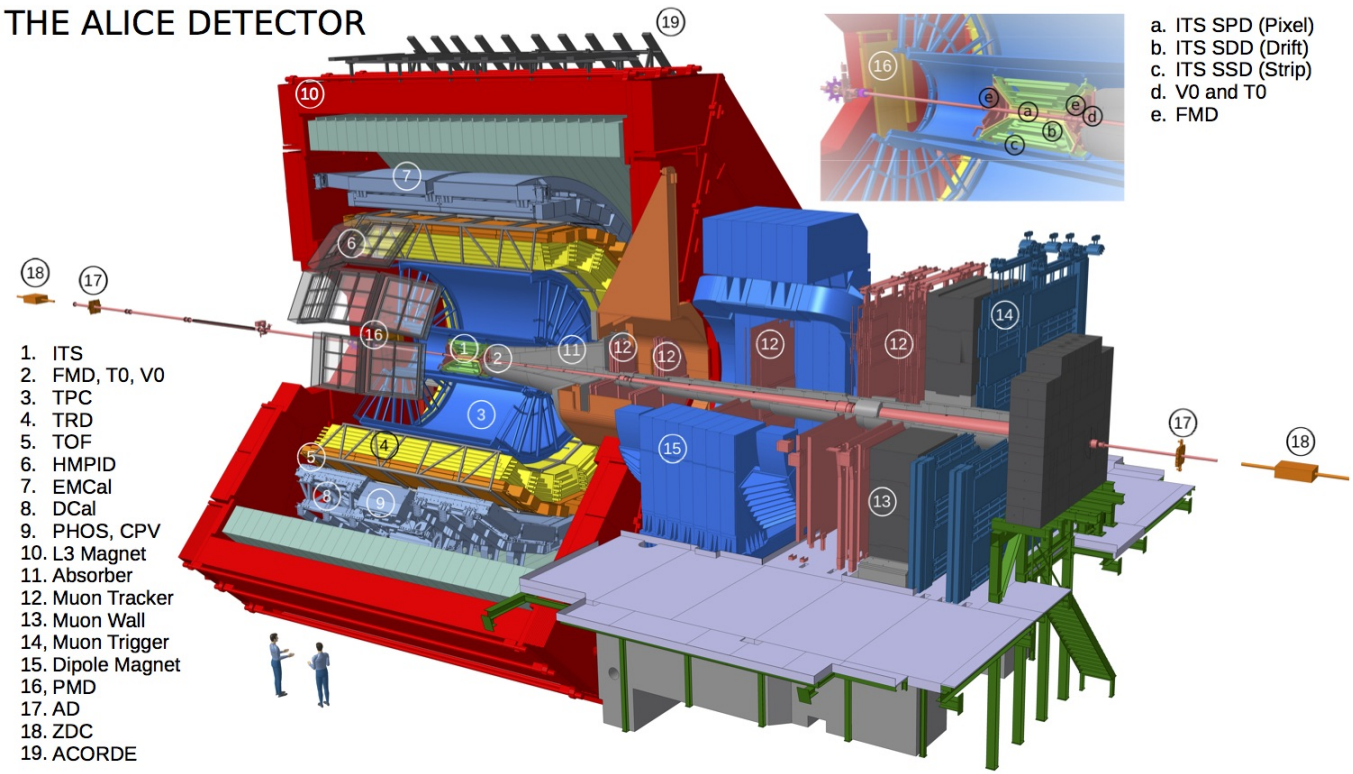
where $\lambda(\eta) = \mu_0$ and $\lambda_2(\eta_1, \eta_2) = \lambda_2(\eta_1 - \eta_2) = \lambda_2(\Delta\eta)$ are one- and two-particle rapidity distributions of a single string decay [*Eur. Phys. J. A* 55.1 (2019), p. 14; *Universe* 5.1 (2019), p. 15; *EPJ Web Conf.* 191 (2018), p. 04011].

By fitting data one can extract the characteristics of partice emitting sources.

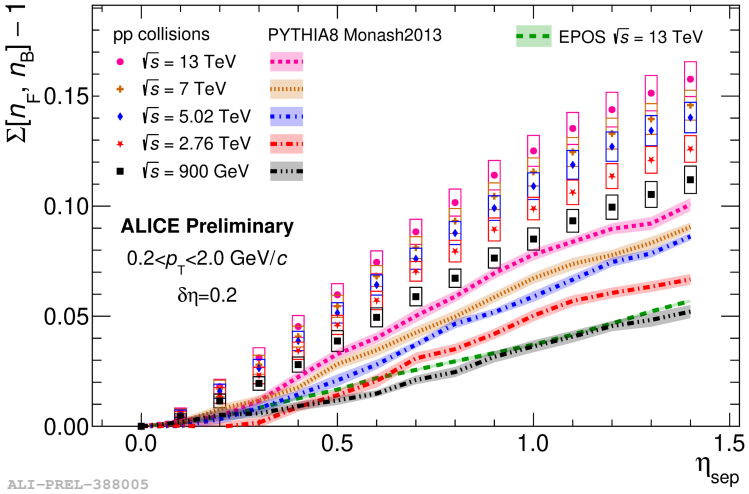
For a more detailed discussion about $\Sigma$ in string models (including a model with string fustion) see an IS2021 talk “Properties of the strongly intensve observable $\Sigma$ in high energy pp collisions in a string fusion model” by Vladimir Vechernin and Svetlana Belokurova.

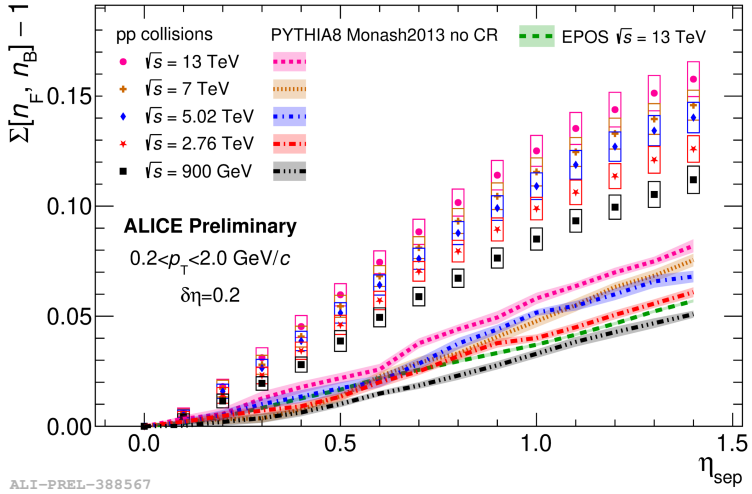
# Analysis of the ALICE data

- pp collisions at 0.9 TeV, 2.76 TeV, 5.02 TeV, 7 TeV and 13 TeV were analyzed
- $p_{\mathrm{T}} \in (0.2, 2.0)$ GeV/$c$
- tracking: Inner Tracking System (ITS) and Time Projection Chamber (TPC)
- event multiplicity classes: by V0 detector

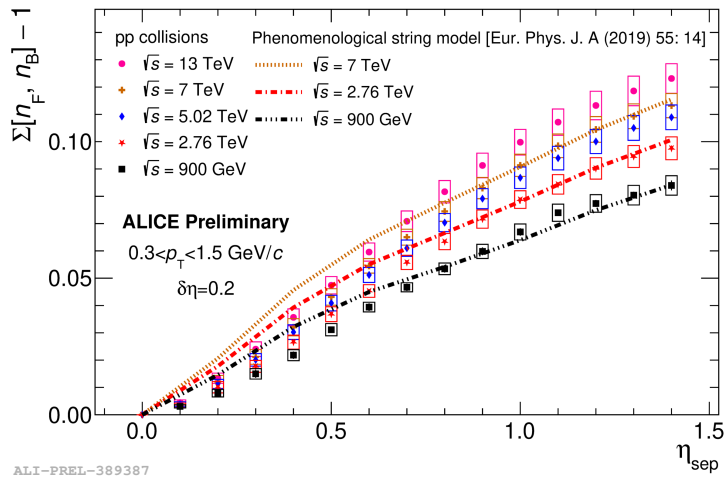


# Energy dependence

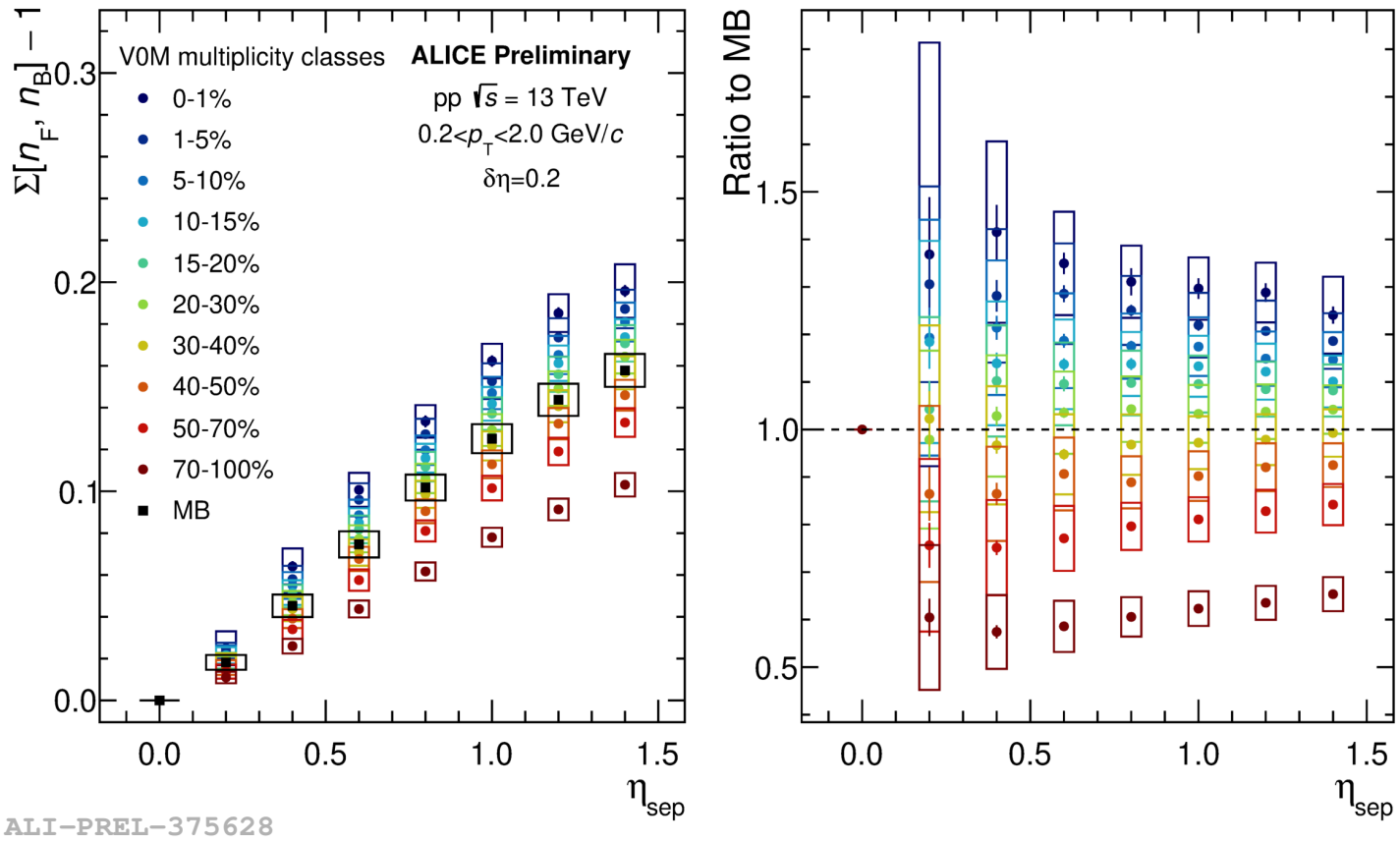



- The value of $\Sigma\,[n_F, n_B]$ grows with collision energy, which may indicate the formation of particle emitting sources with different properties, for example, through the string fusion mechanism.
- Neither PYTHIA8 nor EPOS are able to reproduce this behavior quantitatively.
- Turning off the Colour Reconnection (the right plot) makes the values of $\Sigma\,[n_F, n_B]$ smaller.
- Phenomenological string model reproduces the quantitative behavior better, at least for large $\eta_{sep}$.

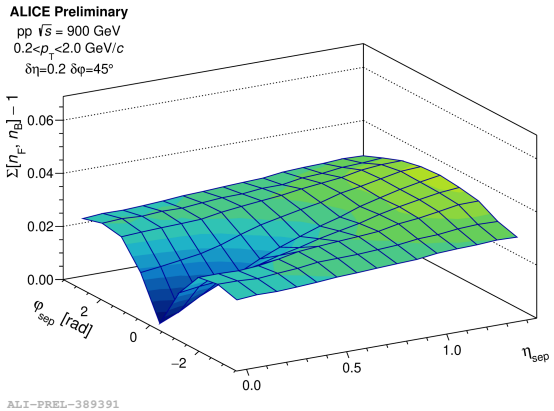


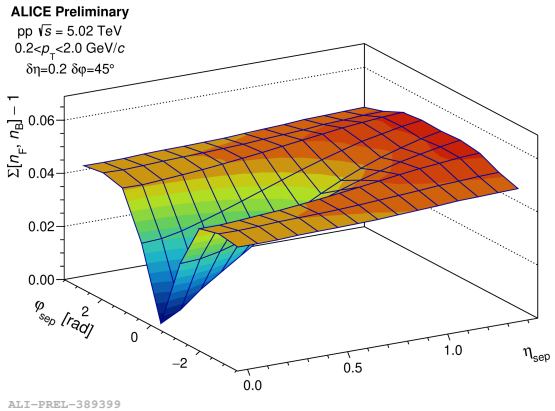
# Multiplicity class dependence

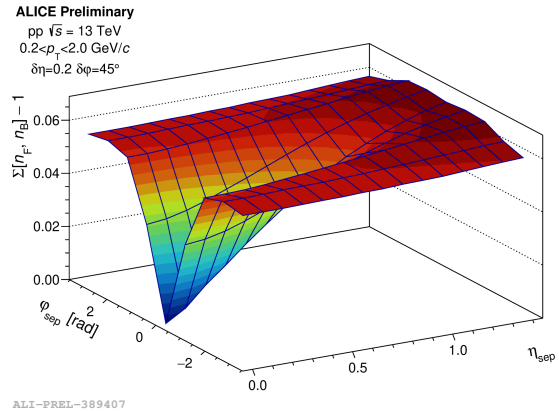


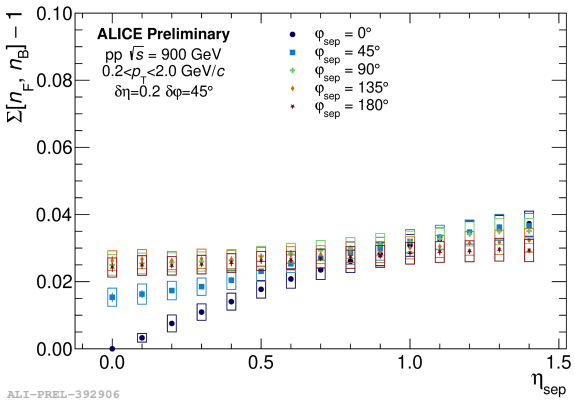

$\Sigma\,[n_F, n_B]$ also grows with the increase of forward event multiplicity, which, in the model of string fusion, can be explained by formation and fusion of more dense string clusters.

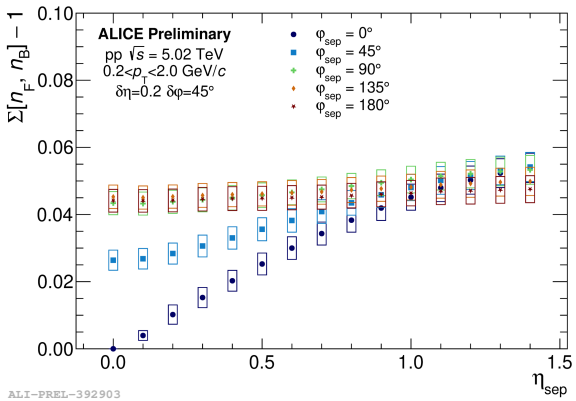
# Analysis with windows separated in azimuth

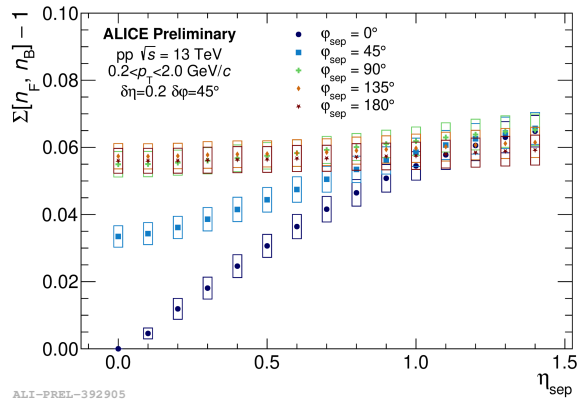



The bottom plots are the sections of the top plots along the $\eta_{\mathrm{sep}}$ axis.

# Summary and outlook

- The value of strongly intensive quantity $\Sigma[n_F, n_B]$ grows with collision energy, and with the increase of forward multiplicity; PYTHIA8 can not reproduce this behavior quantitatively.
- Phenomenological string model from [*Eur. Phys. J. A* 55.1 (2019), p. 14] reproduces the quantitative behavior better than PYTHIA.
- The collision energy and multiplicity class growth of the values of $\Sigma[n_F, n_B]$ need to be studied furhter and compared to the growth of event $\langle n \rangle$ and/or $\langle p_T \rangle$.
- Measurements of forward-backward correlations between same-sign and opposite-sign charged particles could give more insights about particle emitting sources.

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