

Pseudorapidity dependence of multiplicity and transverse momentum fluctuations in pp collisions at the SPS energies

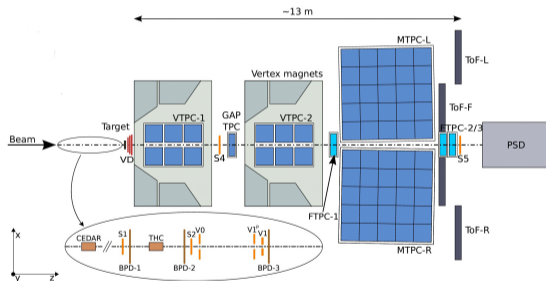
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NA61/SHINE experiment at the SPS CERN

NA61/SHINE (**S**PS **H**eavy **I**on and **N**eutrino **E**xperiment) is a particle physics fixed-target experiment at the Super Proton Synchrotron (SPS) at the European Organization for Nuclear Research (CERN)



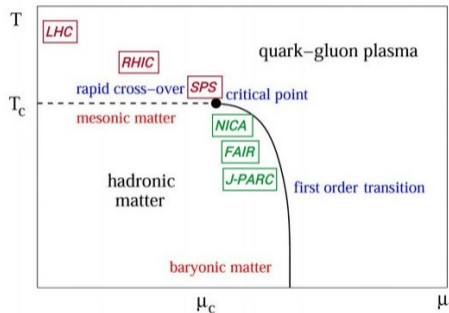
Schematic picture of the NA61/SHINE experiment

Location

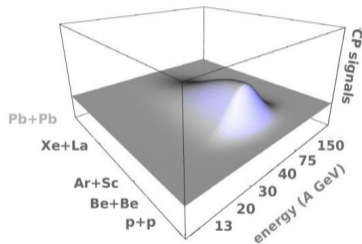
Strong interaction programme at the NA61/SHINE

- study the properties of the onset of deconfinement
- search for the critical point (CP) of strongly interacting matter

Gazdzicki et al. Acta Phys.Polon.B47:1201



Sketch of the phase diagram of strongly interacting matter



Sketch of the expected «critical hill», where the characteristic fluctuation signals of the CP are maximal

Study p+p collisions is a baseline for comparison with heavier systems

What is the CP signal amplitude? What if it is shadowed by trivial fluctuations?

Intensive and Strongly intensive quantities

Let A and B be any extensive event quantities. Then one can define intensive quantity as the scaled variance (still depends on volume fluctuations):

$$\omega[A] = \frac{\langle A^2 \rangle - \langle A \rangle^2}{\langle A \rangle} \quad (1)$$

and two families of strongly intensive quantities (don't depend on volume and event-by-event volume fluctuations in statistical model of the ideal Boltzmann gas in the grand canonical ensemble):

$$\Delta[A, B] = \frac{1}{C_\Delta} [\langle B \rangle \omega[A] - \langle A \rangle \omega[B]] \quad (2)$$

$$\Sigma[A, B] = \frac{1}{C_\Sigma} [\langle B \rangle \omega[A] + \langle A \rangle \omega[B] - 2 \cdot (\langle A \cdot B \rangle - \langle A \rangle \langle B \rangle)] \quad (3)$$

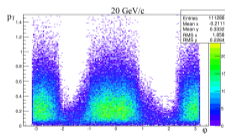
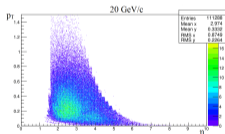
$\omega[A] = 1$ for the Poisson distribution of A , $\Sigma[A, B] = \Delta[A, B] = 1$ for independent particle model;
 $\omega[A] = 0$, $\Sigma[A, B] = \Delta[A, B] = 0$ in the absence of A and B fluctuations.

Analysis details

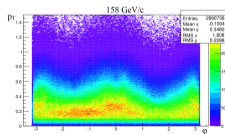
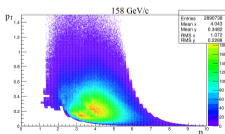
- The final results refer to **charged hadrons** with $p_T < 1.5$ GeV/c produced in the analysis acceptance <https://edms.cern.ch/document/1549298/1> of the NA61/SHINE experiment in 2009 in inelastic p+p collisions at

p_{beam}^{lab} [GeV/c]	20	31	40	80	158
$\sqrt{s_{NN}}$ [GeV]	6.27	7.62	8.73	12.32	17.27

- The results are corrected only for off-target interactions (simulation-based corrections for other biases are in progress)
- NA61/SHINE acceptance: fixed-target experiment \rightarrow acceptance depends on collision energy



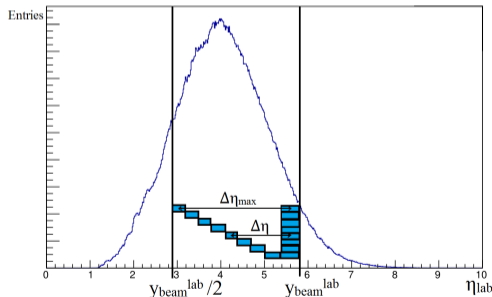
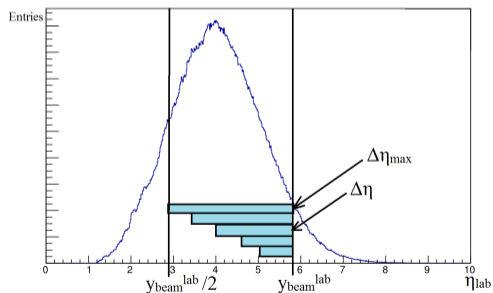
20 GeV/c



158 GeV/c

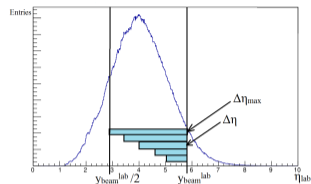
Pseudorapidity dependence study

- **One Window Analysis:** $\omega[N]$, $\Delta[P_T, N]$ and $\Sigma[P_T, N]$ in one window with changing window width
- **Two Windows Analysis:** $\Sigma[N_F, N_B]$ in two separated windows with changing distance between windows



Definitions for One Window Analysis

Let us consider A as event multiplicity of charged hadrons N and B as total event transverse momentum P_T . If $\langle \dots \rangle$ means the average value over all events, $\overline{\dots}$ means the inclusive average value (over all particles and all events), then one can define:



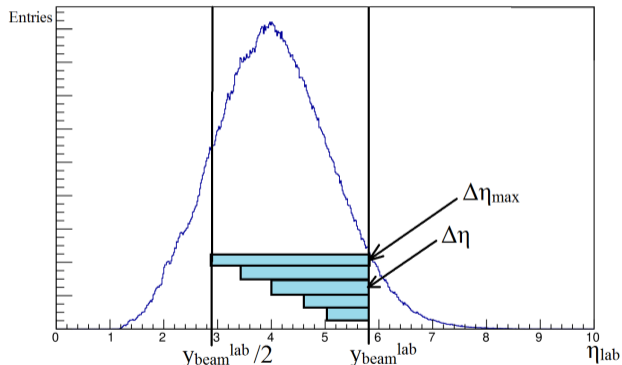
$$\omega[N] = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}, \quad \omega[P_T] = \frac{\langle P_T^2 \rangle - \langle P_T \rangle^2}{\langle P_T \rangle}, \quad \omega(p_T) = \frac{\overline{p_T^2} - \overline{p_T}^2}{\overline{p_T}} \quad (4)$$

$$\Sigma[P_T, N] = \frac{1}{C_\Delta} [\langle N \rangle \omega[P_T] + \langle P_T \rangle \omega[N] - 2 \cdot (\langle P_T \cdot N \rangle - \langle P_T \rangle \langle N \rangle)] \quad (5)$$

$$\Delta[P_T, N] = \frac{1}{C_\Delta} [\langle N \rangle \omega[P_T] - \langle P_T \rangle \omega[N]], \quad C_\Delta = C_\Delta = \langle N \rangle \omega(p_T) \quad (6)$$

Pseudorapidity intervals definition for One Window Analysis

Sketch of η_{lab} uncorrected spectrum of charged hadrons with suggested windows

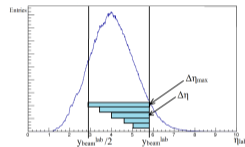
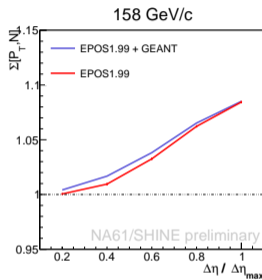
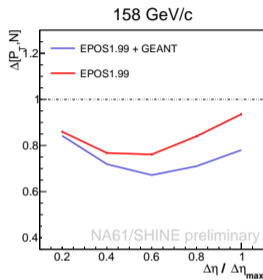
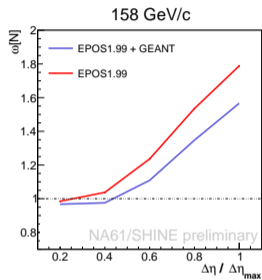


$$y_{beam}^{lab} = \frac{1}{2} \frac{\sqrt{m_p^2 + p_{beam}^2} + p_{beam}}{\sqrt{m_p^2 + p_{beam}^2} - p_{beam}}$$

- 5 pseudorapidity intervals of different width are considered
- η is considered in the range of $(y_{beam}^{lab}/2, y_{beam}^{lab})$ to exclude the influence of bad acceptance coverage at small η^{lab} and to reduce elastic processes effects at $\eta^{lab} > y_{beam}^{lab}$
- studied quantities are plotted as functions of $\Delta\eta/\Delta\eta_{max}$

Pseudorapidity width dependence study corresponds to observation of different baryochemical potentials → additional way to extend the phase diagram scan

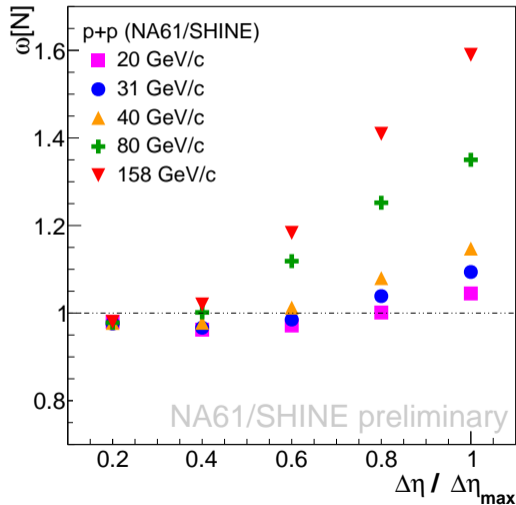
Comparison between EPOS1.99 and EPOS1.99 + GEANT for future simulation-based corrections



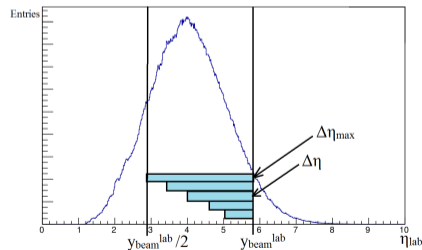
Example of the difference between pure and reconstructed Monte Carlo simulations due to experimental biases for beam momentum 158 GeV/c.

Simulation-based corrections are in progress. Could be significant due to trigger biases for p+p collisions

Energy dependence of $\omega[N]$ for $h^+ + h^-$

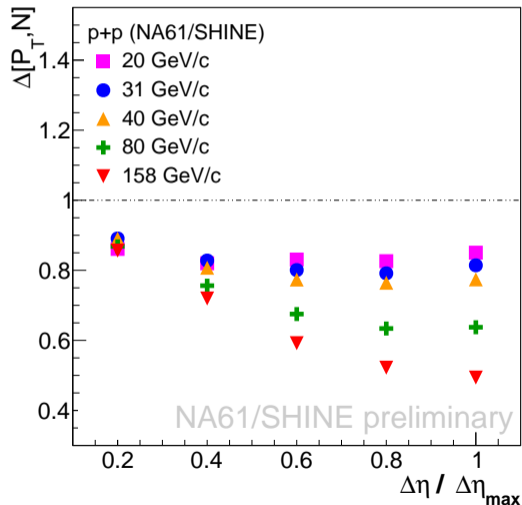


The value of $\omega[N]$ grows rapidly with pseudorapidity interval width. It is more pronounced for higher collision energy. $\omega[N]$ is almost equal to 1 for small window width for all energies

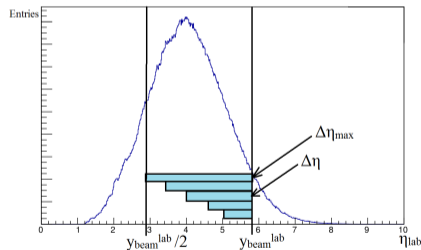


Sketch of η_{lab} uncorrected spectrum of charged hadrons with suggested windows

Energy dependence of $\Delta[P_T, N]$ for $h^+ + h^-$

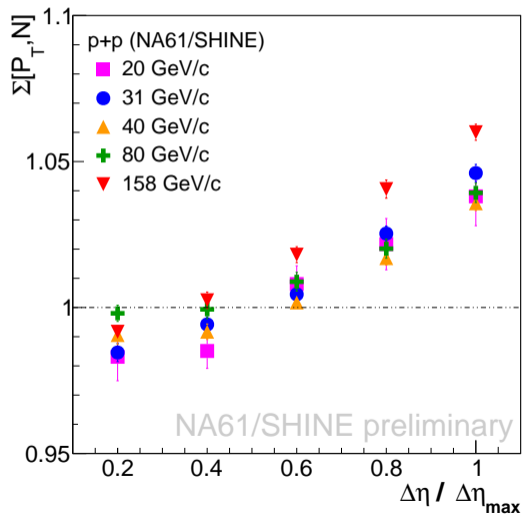


$\Delta[P_T, N]$ decreases monotonically with the increase of pseudorapidity window width. For smaller collision energies $\Delta[P_T, N]$ moreover starts to tend to the 1 with the interval width

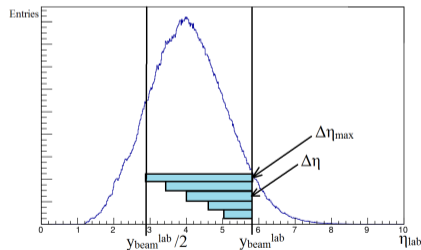


Sketch of η_{lab} uncorrected spectrum of charged hadrons with suggested windows

Energy dependence of $\Sigma[P_T, N]$ for $h^+ + h^-$

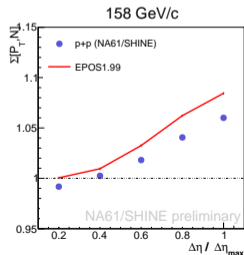
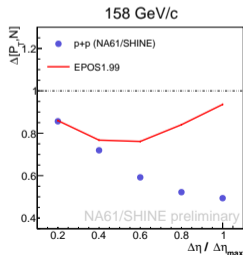
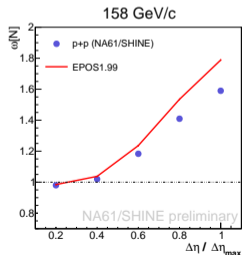
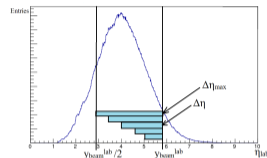
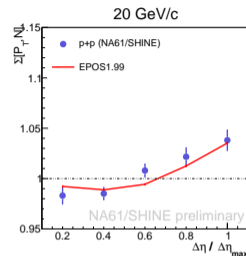
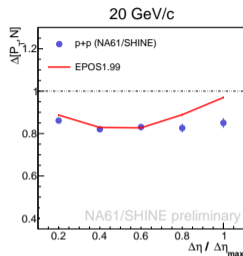
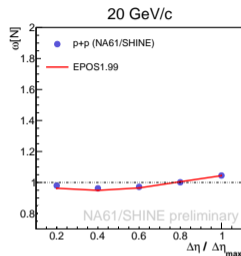


The value of $\Sigma[P_T, N]$ grows monotonically with the pseudorapidity window width. Plots for all collision energies are close to each other. For small pseudorapidity windows $\Sigma[P_T, N]$ approaches the value of 1



Sketch of η_{lab} uncorrected spectrum of charged hadrons with suggested windows

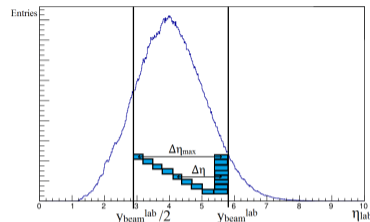
Comparison between experimental data and EPOS1.99



This crucial disagreement between experimental data and the EPOS1.99 results for pseudorapidity dependence of $\Delta[P_T, N]$ was also observed in ${}^7\text{Be} + {}^9\text{Be}$ (Andronov, ICPPA-2017)

Definitions for Two Windows Analysis

Let us consider extensive event quantities as N_F - multiplicity in **Forward window**, N_B - multiplicity in **Backward window**. Then one can define:



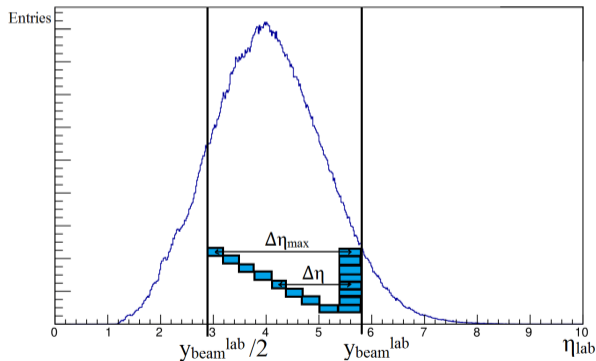
$$\Sigma[N_F, N_B] = \frac{1}{C_\Sigma} [\langle N_B \rangle \omega[N_F] + \langle N_F \rangle \omega[N_B] - 2 \cdot (\langle N_F \cdot N_B \rangle - \langle N_F \rangle \langle N_B \rangle)] \quad (7)$$

$$\omega[N_F] = \frac{\langle N_F^2 \rangle - \langle N_F \rangle^2}{\langle N_F \rangle}, \quad \omega[N_B] = \frac{\langle N_B^2 \rangle - \langle N_B \rangle^2}{\langle N_B \rangle} \quad (8)$$

$$C_\Sigma = \langle N_B \rangle + \langle N_F \rangle \quad (9)$$

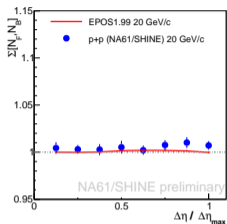
Pseudorapidity intervals definition for Two Windows Analysis

Sketch of η_{lab} uncorrected spectrum of charged hadrons with suggested windows

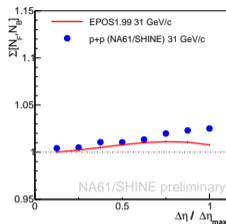


- 8 pairs of separated pseudorapidity intervals of equal width are considered
- η is considered in the range of $(y_{beam}^{lab}/2, y_{beam}^{lab})$ to exclude the influence of bad acceptance coverage at small η^{lab} and to reduce elastic processes effects at $\eta^{lab} > y_{beam}^{lab}$
- studied quantities are plotted as functions of $\Delta\eta/\Delta\eta_{max}$

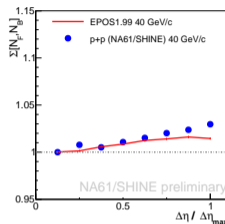
$\Sigma[N_F, N_B]$ in Separated windows for $h^+ + h^-$



20 GeV/c

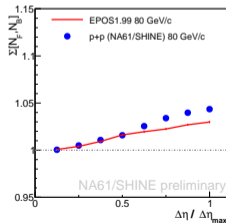


31 GeV/c

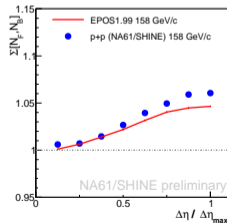


40 GeV/c

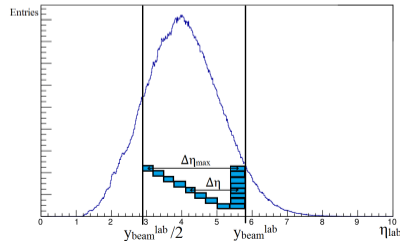
$\Sigma[N_F, N_B]$ increases with the distance between F and B pseudorapidity intervals as it is predicted by the model of independent quark gluon strings (Vechernin, WPCF-2017). EPOS1.99 describes data better for closer windows



80 GeV/c



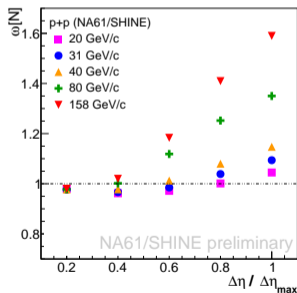
158 GeV/c



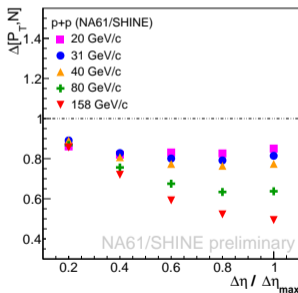
Conclusions

New results on pseudorapidity dependence of fluctuation measures in inelastic p+p collisions were presented

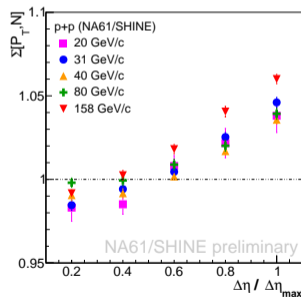
- Studied fluctuation measures significantly depend on width and location of pseudorapidity intervals
- Results for $\omega[N]$ and $\Delta[P_T, N]$ depend on the collision energy, on the other hand $\Sigma[P_T, N]$ has the same tendency for all considered beam momenta



$\omega[N]$



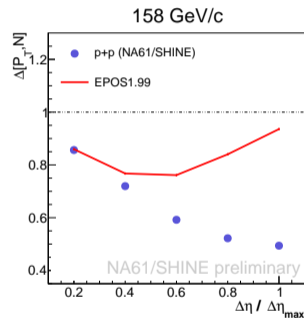
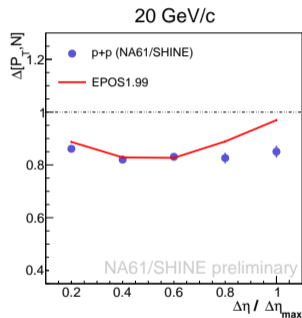
$\Delta[P_T, N]$



$\Sigma[P_T, N]$

Conclusions

- EPOS1.99 does not describe data for $\Delta[P_T, N]$



- The increase of $\Sigma[N_F, N_B]$ value with distance between forward and backward pseudorapidity intervals is more pronounced for higher energy

THANK YOU!



Back-up

Off-Target corrections

To make a correction for off-target interactions one should calculate:

$$\langle X \rangle = \frac{1}{N_{ev}^I - \epsilon \cdot N_{ev}^R} \cdot \left(\sum_{i=1}^{N_{ev}^I} X_i^I - \epsilon \cdot \sum_{j=1}^{N_{ev}^R} X_j^R \right), \quad (10)$$

where N_{ev}^I is a number of events with target inserted, N_{ev}^I - with target removed, ϵ is a normalization factor:

$$\epsilon = \frac{N_{ev}^I}{N_{ev}^R} \Big|_{z > -450cm} \quad (11)$$

z - is the z position of the fitted primary vertex

- T2 trigger = $S1 \wedge S2 \wedge \overline{V0} \wedge \overline{V1} \wedge \overline{V1^P} \wedge \text{CEDAR} \wedge \overline{\text{THC}}$
- no off-time beam particle was detected within $\pm 1.5 \mu\text{s}$ around the trigger particle
- the beam particle trajectory was measured in BPD-3 and at least one of BPD-1 or BPD-2 detectors
- there was at least one track reconstructed in the TPCs and fitted to the interaction vertex
- Good Fit Quality
- z position of the vertex should be between (-620.3, -540.3) cm
- events with a single, well measured positively charged track with absolute momentum close to the beam momentum were rejected: $(p_{beam} - 1) \text{ GeV}/c$

- Track Existence
- the track should be measured in a high tracking efficiency (90%) TPC acceptance (<https://edms.cern.ch/document/1549298/1>)
- the sum of the number of reconstructed points in VTPC-1 and VTPC-2 should be greater than 15 and the number of reconstructed points in the GAP-TPC should be greater than 5
- the total number of reconstructed points on the track should be greater than 30
- $|B_x| < 4$ cm, $|B_y| < 2$ cm
- $p_T < 1.5$ GeV/c
- electrons and positrons are rejected