Energy dependence of fluctuations in p+p and Be+Be collisions from NA61/SHINE

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SPbSU, Laboratory of Ultra-High Energy Physics

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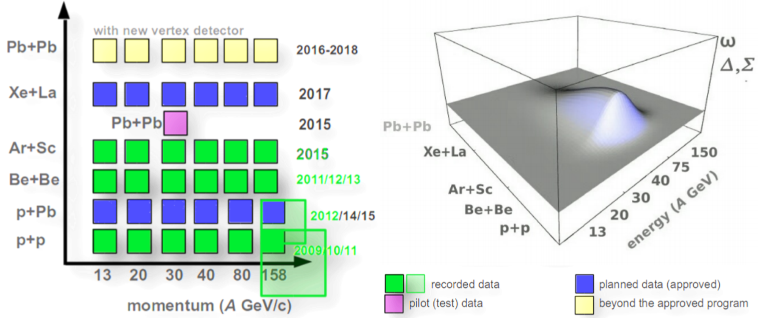
Motivation of the NA61/SHINE strong interaction programme

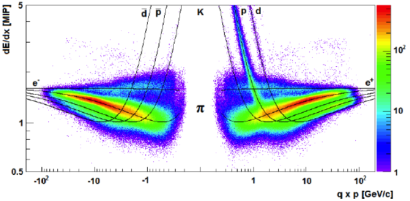
Search for CP and OD

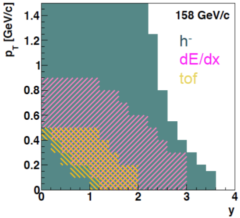


p+p and ^{7}Be+^{9}Be results to be shown in this presentation

Analysis

- Analyzed data:
  - inelastic p+p at $\sqrt{s} = 6.3, 7.7, 8.7, 12.3, 17.3$ GeV
  - centrality selected ^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 6.27, 8.73, 11.94, 16.83$ GeV
- Results of NA61/SHINE to be shown include statistical errors and first estimates of systematic uncertainties
- Second moments of identified particle multiplicity distributions are corrected for the misidentification effect using the identity method
- Different acceptance maps for measurements with all charged particles and with identified particles were applied





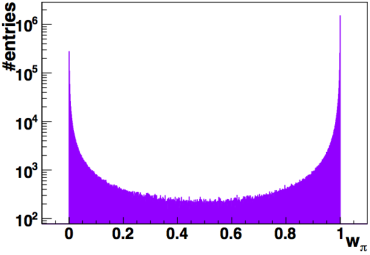
Identity method: single particle identity

The identity method allows to obtain second and third moments (pure and mixed) of identified particle multiplicity distributions corrected for misidentification effect.

The particle identity is calculated as:

$$w_i = \frac{\rho_i(dE/dx)}{\rho(dE/dx)}$$

where ρ_i - function fitted to i^{th} particle type (i: π, K, p) and ρ - function fitted to total dE/dx distribution in a given phase-space bin $\{q, p_T, p\}$



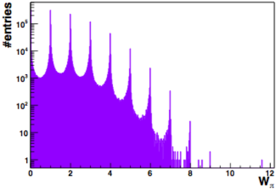
example of w_π distribution for p+p at 12.3 GeV

Identity method: event identity measure

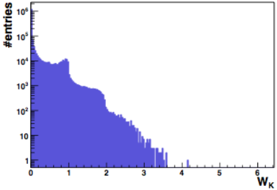
Event quantity W_i defined as: $W_i = \sum_{q=1}^{N} w_i(q)$, where

summation runs over all particles in an event

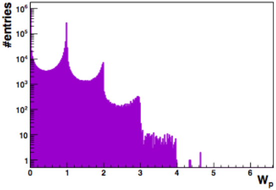
- For perfect particle identification W_i distribution equals the multiplicity distribution
- For particles with larger PID contamination (like K) W_i distribution gets smoother



example of event variable W_π,



W_K,



$W_{p+\overline{p}}$ for p+p at 12.3 GeV

$$\rho_i, \langle W_i \rangle, \langle {W_i}^2 \rangle, \langle W_i W_j \rangle \rightarrow \langle {N_i}^2 \rangle, \langle N_i N_j \rangle$$

Details of this calculations can be found in the references below

M. Gazdzicki *et al.* PRC83:054907
M. Gorenstein PRC84:024902
A. Rustamov, M. Gorenstein PRC86:044906

Multiplicity fluctuation measures

We consider fluctuation quantities with convenient properties in the reference models (e.g. WNM or GCE)

Intensive quantity

Independent of event-mean system volume $\langle V \rangle$

$\omega [N_i] = \frac{\langle {N_i}^2 \rangle - \langle N_i \rangle^2}{\langle N_i \rangle}$ • $\omega [N_i] = 1$ for Poisson N_i distribution

Strongly intensive quantity

Independent of $\langle V \rangle$ and $\omega [V]$ • $\Delta [N_i, N_j] = \Sigma [N_i, N_j] = 1$ for independent particle production

$$\Delta [N_i, N_j] = (\langle N_i \rangle \omega [N_j] - \langle N_j \rangle \omega [N_i]) / \langle N_i - N_j \rangle$$

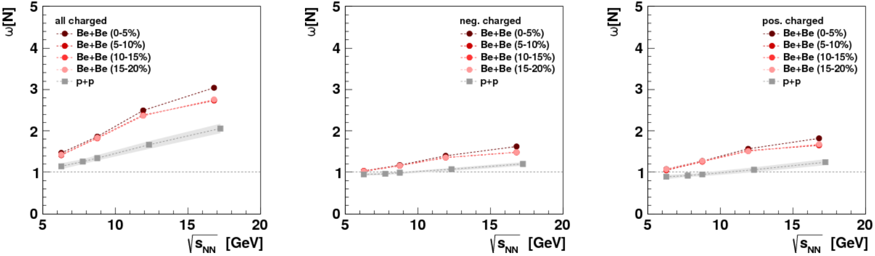
$$\Sigma [N_i, N_j] = (\langle N_i \rangle \omega [N_j] + \langle N_j \rangle \omega [N_i] - 2cov (N_i, N_j)) / \langle N_i + N_j \rangle$$

M. Gorenstein, M. Gazdzicki, PRC84:014904

Note that commonly used $\nu^{ij}_{dyn} = \frac{\langle N_i + N_j \rangle}{\langle N_i \rangle \langle N_j \rangle} (\Sigma [N_i, N_j] - 1)$

Scaled variance for charged particles

p+p *vs.* ^{7}Be+^{9}Be



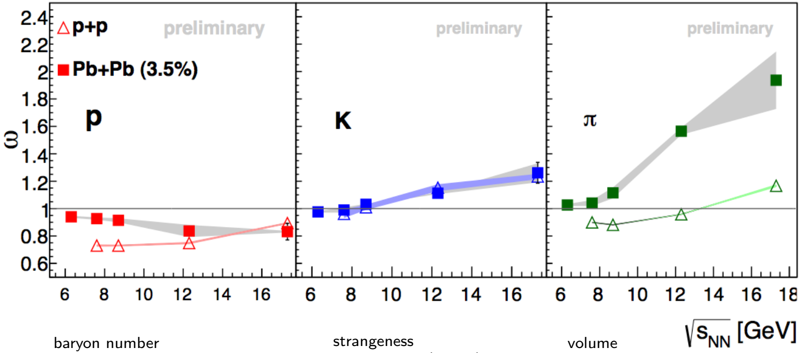
In GCE $\omega[N] = \omega[n] + \overline{n}\omega[V]$

$\omega[N]$ for ^{7}Be+^{9}Be is larger than for p+p (due to volume fluctuations?).

T. Czopowicz [for the NA61/SHINE collaboration], PoS(CPOD2014)054

Scaled variance for identified hadrons (p, K, π)

p+p *vs.* Pb+Pb (NA49)



baryon number conservation (B = 2)?

strangeness conservation (S = 0)?

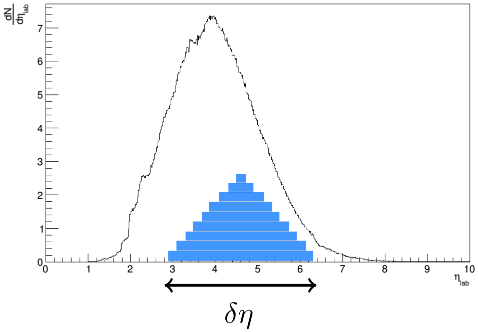
volume influence

In GCE $\omega[N] = \omega[n] + \overline{n}\omega[V]$

M. Gazdzicki, P. Seyboth, arXiv:1506.08141

$\Delta [N_+, N_-]$, $\Sigma [N_+, N_-]$: analysis

Dependence on pseudorapidity interval width was studied for $\{N_+, N_-\}$ fluctuations for ^{7}Be+^{9}Be at 16.83 GeV

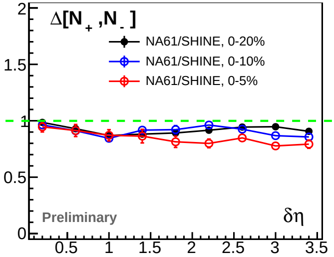


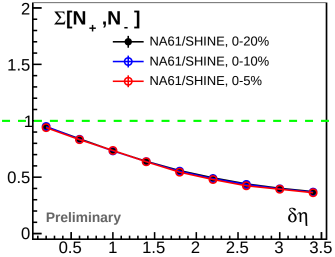
9 pseudorapidity intervals
$\delta\eta = 0.2 + i * 0.4,\ i \in \{0 \cdots 8\}$

Can be sensitive to electric charge conservation effect and resonance decays?

$\Delta[N_+, N_-]$, $\Sigma[N_+, N_-]$: centrality dependence

^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 16.83$ GeV

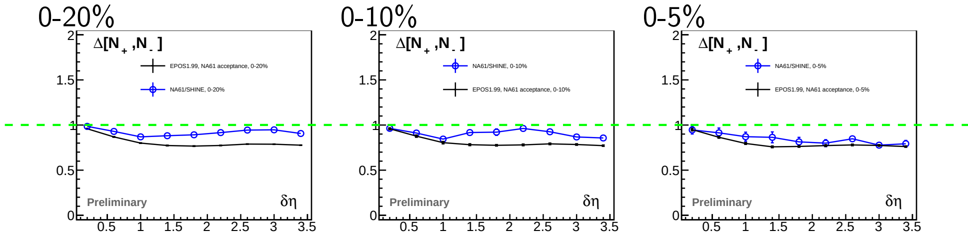




- Both Δ and Σ are almost independent of centrality
- Both Δ and Σ are smaller than 1
- Σ decreases significantly with the growth of $\delta\eta$
- Systematic errors were estimated to be less than 5% for all points

$\Delta\,[N_{+}, N_{-}]$: comparison with EPOS 1.99

^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 16.83$ GeV

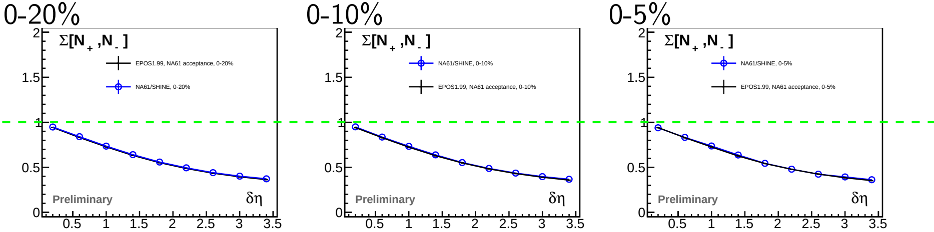


EPOS model describes Δ behaviour qualitatively

NA61/SHINE
EPOS 1.99

$\Sigma[N_+, N_-]$: comparison with EPOS 1.99

^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 16.83$ GeV



EPOS model describes Σ behaviour both qualitatively and quantitatively

NA61/SHINE
EPOS 1.99

Summary-1

- Preliminary results on $\omega[N]$ for all, negatively and positively charged hadrons in p+p at $\sqrt{s} = 6.3, 7.7, 8.7, 12.3, 17.3$ GeV and ^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 6.27, 8.73, 11.94, 16.83$ GeV were presented
- Preliminary results on $\omega[N]$ for identified hadrons (π, K, p) in p+p at $\sqrt{s} = 7.7, 8.7, 12.3, 17.3$ GeV were shown in comparison with the corresponding results for 3.5% of most central events in Pb+Pb from NA49
- Preliminary results on $\Delta[N_+, N_-]$ and $\Sigma[N_+, N_-]$ in ^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 16.83$ GeV for 9 pseudorapidity intervals were presented

Summary-2

- $\omega\left[N_{ch}\right]$, $\omega\left[N_{+}\right]$, $\omega\left[N_{-}\right]$ for p+p are smaller than that for ^{7}Be+^{9}Be at all centralities (due to the volume fluctuations?)
- $\omega\left[\pi\right]$ for Pb+Pb is significantly higher than that for p+p (due to the volume fluctuations?)
- $\omega\left[K\right] \geqslant 1$ both for p+p and Pb+Pb
- $\omega\left[p\right] \leqslant 1$ both for p+p and Pb+Pb

Summary-3

- $\Delta[N_+, N_-]$ and $\Sigma[N_+, N_-]$ are almost independent of centrality
- $\Delta[N_+, N_-]$ and $\Sigma[N_+, N_-]$ are smaller than 1 for all rapidity intervals (possibly due to the energy-momentum conservation and charge conservation effects)
- EPOS describes $\Delta[N_+, N_-]$ and $\Sigma[N_+, N_-]$ behaviour quite well

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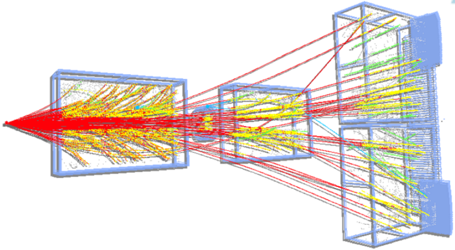
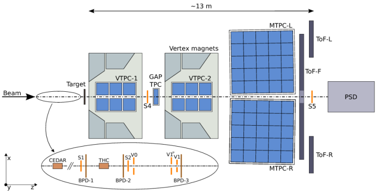
Thank You!

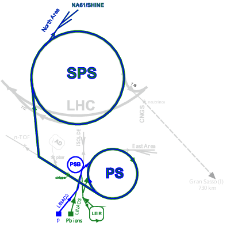


Back-up

NA61/SHINE experiment

- Located at the CERN/SPS
- Fixed-target experiment
- Successor of NA49 experiment
- Approved in 2007. First physics run in 2009



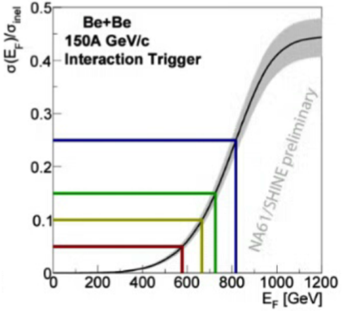


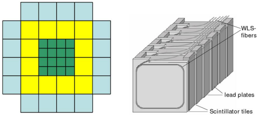
NA61/SHINE detector

- Large acceptance: 50%
- High momentum resolution: $\frac{\sigma(p)}{p^2} \approx 10^{-4}(GeV/c)^{-1}$ (at full $B = 9Tm$)
- ToF walls resolution: $\sigma(t) \approx 60ps$
- Good particle identification: $\frac{\sigma(dE/dx)}{dE/dx} \approx 0.04$, $\sigma(m_{inv}) \approx 5MeV$
- High detector efficiency: 95%
- Event recording rate: 70 events/sec

PSD detector. Centrality determination.

PSD (Projectile Spectator Detector) is located on the beam axis and measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus

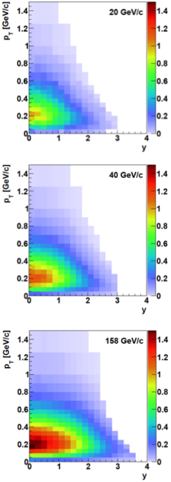




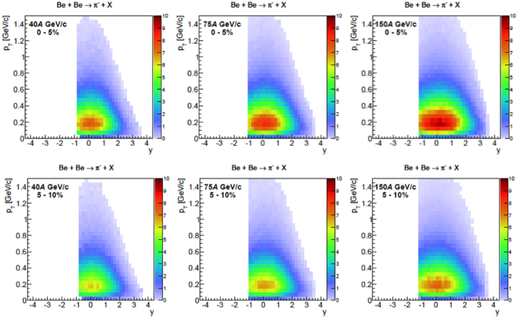
- $\approx 25\%$
- $\approx 15\%$
- $\approx 10\%$
- $\approx 5\%$

$\pi^- \; y - p_T$ spectra

p+p



^{7}Be+^{9}Be



Identity method

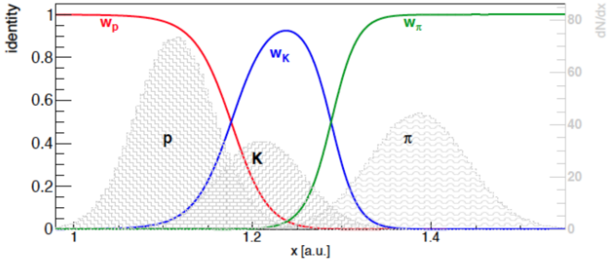
$$\begin{pmatrix} \langle N_p^2 \rangle \\ \langle N_k^2 \rangle \\ \langle N_p N_k \rangle \end{pmatrix} = \begin{pmatrix} \overline{w}_{pp}^2 & \overline{w}_{pk}^2 & 2\overline{w}_{pp}\overline{w}_{pk} \\ \overline{w}_{kp}^2 & \overline{w}_{kk}^2 & 2\overline{w}_{kp}\overline{w}_{kk} \\ \overline{w}_{pp}\overline{w}_{kp} & \overline{w}_{pk}\overline{w}_{kk} & \overline{w}_{pp}\overline{w}_{kk} + \overline{w}_{pk}\overline{w}_{kp} \end{pmatrix}^{-1} \begin{pmatrix} \langle W_p^2 \rangle - b_p \\ \langle W_k^2 \rangle - b_k \\ \langle W_p W_k \rangle - b_{pk} \end{pmatrix}$$

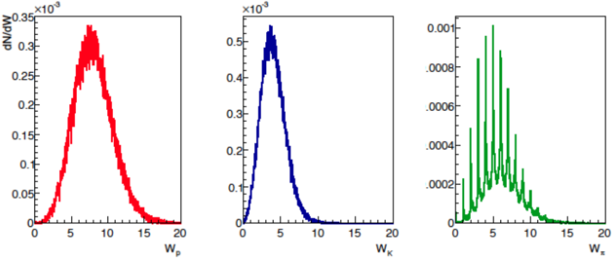
3 equations, 3 unknowns (unique solution)

$$b_i = \sum_{j=p,k} \langle N_j \rangle (\overline{w_{ij}^2} - \overline{w}_{ij}^2), \quad b_{pk} = \sum_{j=p,k} \langle N_j \rangle (\overline{w}_{pkj} - \overline{w}_{pj}\overline{w}_{kj})$$

$$\overline{w_{ij}} = \frac{\int w_i(m)\rho_j(m)dm}{\int \rho_j(m)dm} \qquad \overline{w_{ij}^2} = \frac{\int w_i^2(m)\rho_j(m)dm}{\int \rho_j(m)dm} \qquad \overline{w}_{ikj} = \frac{\int w_i(m)w_k(m)\rho_j(m)dm}{\int \rho_j(m)dm}$$

Identity method





Fluctuation measures

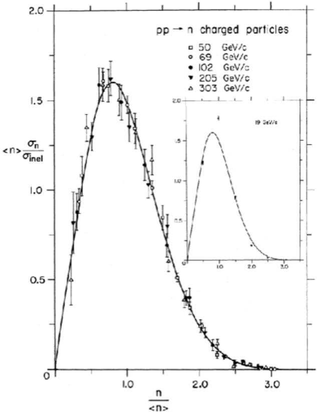
Strongly intensive quantity

Independent of $\langle V \rangle$ and $\omega[V]$

$\Phi_{ij} = \frac{\sqrt{\langle X_i \rangle \langle X_j \rangle}}{\langle X_i \rangle + \langle X_j \rangle} \left(\sqrt{\Sigma_{ij}} - 1 \right)$ • $\Phi_{ij} = 0$ for independent particle production

$\Sigma_{ij} = \left(\langle X_i \rangle \omega[X_j] + \langle X_j \rangle \omega[X_i] - 2cov(X_i, X_j) \right) / \langle X_i + X_j \rangle$

KNO influence on scaled variance?

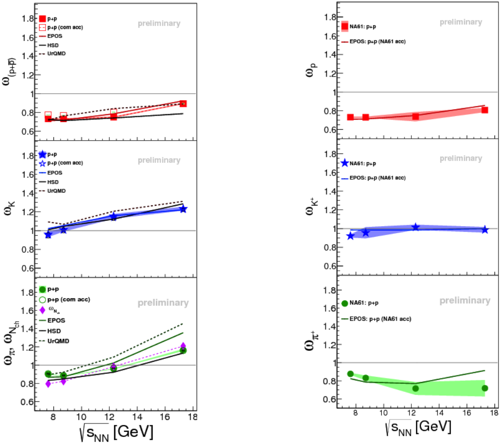


$P(N) = \frac{1}{<N>} \Psi_\alpha\left(\frac{N}{<N>}\right)$
Koba. Nielsen, Olesen (1972)

$\mathrm{KNO} \rightarrow \omega[N] \sim \langle N \rangle$

Scaled variance for identified hadrons (p, K, π): models

p+p



M. Mackowiak-Pawlowska [for the NA61/SHINE collaboration], PoS(CPOD 2013)048