Multiplicity fluctuations of identified hadrons in p+p interactions at SPS energies

Based on Ph.D. Thesis of Maja Maćkowiak-Pawłowska

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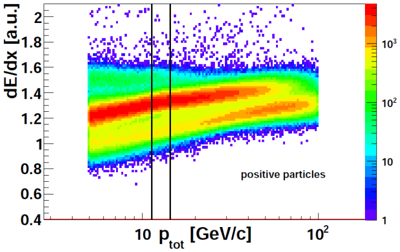
Data sets

- The results are based on the NA61/SHINE data collected in 2009:
  1. p(31 GeV/c)+p ($\sqrt{s}$ = 7.6 GeV): 3.5×10^6 events
  2. p(40 GeV/c)+p ($\sqrt{s}$ = 8.7 GeV): 5.8×10^6 events
  3. p(80 GeV/c)+p ($\sqrt{s}$ = 12.3 GeV): 5.0×10^6 events
  4. p(158 GeV/c)+p ($\sqrt{s}$ = 17.3 GeV): 4.0×10^6 events
- event and track cuts were chosen to select only inelastic interactions with particles produced in strong and EM processes within the NA61/SHINE acceptance.
- analysis focuses on fluctuations of $\pi = \pi^+ + \pi^-$, $K = K^+ + K^-$ and $p + \bar{p}$ as well as positively charged hadrons (p, K^+, π^+) by getting first and second (pure and mixed) moments of identified particle multiplicity distributions.
- second moments of identified particle multiplicity distributions are corrected for the misidentification effect using the identity method.[1]
- Presented results of NA61/SHINE include statistical errors and first estimates of systematic uncertainties (work to finalize systematic uncertainties is in progress e.g. feed down and detector effects).

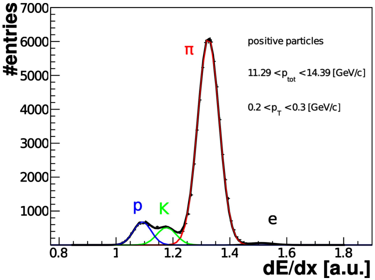
[1] PRC83:054907,PRC84:024902,PRC86:044906

Particle identification

Particle identification for chemical fluctuation analysis is based on dE/dx measurements in relativistic rise region.



Inclusive dE/dx spectra are sliced in p_{tot}, p_T



sum of Gaussian functions is fitted in each phase-space bin.

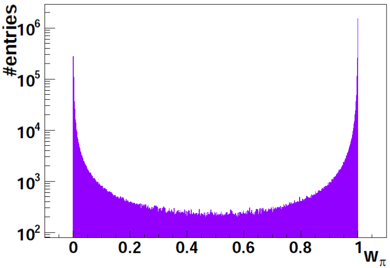
Identity method

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:

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

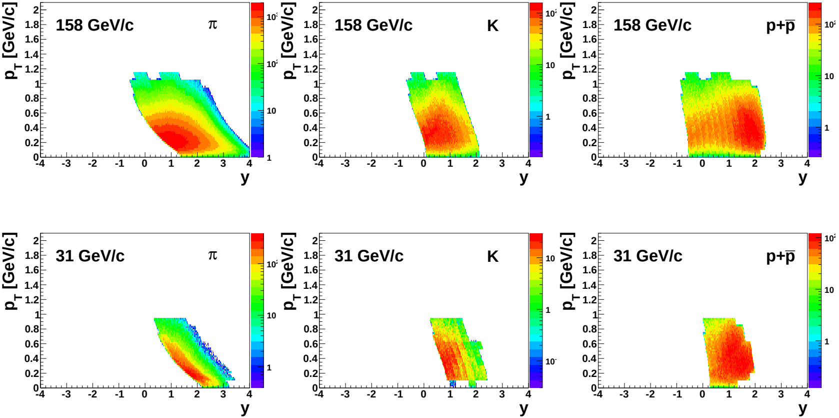
where ρ_i - function fitted to the i^{th} particle type and ρ - function fitted to the total dE/dx distribution in a given phase-space bin.



example of w_π distribution for p+p at 12.3 GeV

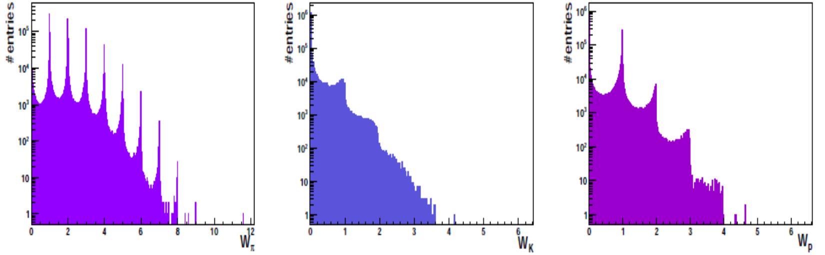
Identified hadron acceptance

Single particle identity allows to obtain identified hadron acceptance by taking each particle with its corresponding *w* as weight.



Identity method - event identity measure

Event quantity W_i defined as: $W_i = \sum w_j$ where summation runs over all particles in an event



example of event variable W_π, W_K, $W_{p+\bar{p}}$ for p+p at 12.3 GeV

Once, detector response (ρ_i) and W distributions are known the identity method is used to obtain moments of identified particle multiplicity distributions.

Fluctuation quantities

In the Wounded Nucleon Model or the GCE one may define two families of quantities:

Intensive quantities

A ratio of two extensive quantities (N_W) is an intensive measure e.g.:

$$\omega_i = \frac{<N_i^2> - <N_i>^2}{<N_i>}$$

- independent of N_W
- depends on fluctuations of N_W - not good for comparison of p+p with wide A+A centrality bins
- $\omega = 1$ for Poisson distribution

In WNM $\omega_i = \frac{Var(n_i)}{<n_i>} + <n_i> \frac{Var(N_W)}{<N_W>}$, where n_i - particles produced from single wounded nucleon

Strongly intensive quantities

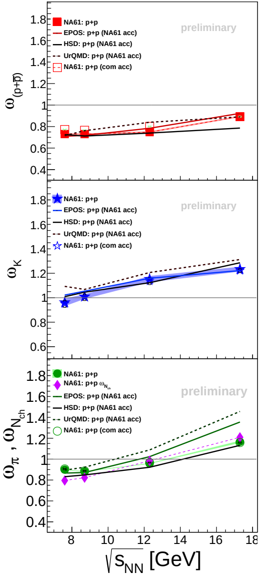
Special combinations of extensive quantities can be strongly intensive measures e.g.:

$$\Phi_{ij} = \frac{\sqrt{<N_i><N_j>}}{<N_i+N_j>} \times \left(\sqrt{\Sigma^{ij}} - 1\right),$$

- independent of N_W
- independent of fluctuations of N_W
- $\Phi_{ij} = 0$ for independent particle emission

where $\Sigma^{ij} = [<N_i>\omega_j + <N_j>\omega_i - 2(<N_iN_j> - <N_i><N_j>)]/<N_i+N_j>$

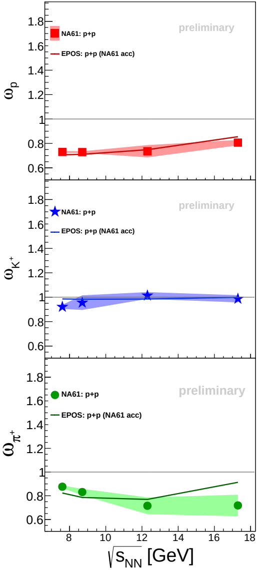
Multiplicity fluctuations of identified hadrons



- Results are presented in NA61 acceptance[a] and in common acceptance of NA49 and NA61
- $\omega_{p+\bar{p}}$ is below 1 for all SPS energies possibly due to baryon number conservation (B = 2)
- ω_K is above 1 for all SPS energies possibly due to strangeness conservation (S = 0)
- ω_π increases with increasing energy
- HSD, EPOS, and UrQMD reproduce measured scaled variances

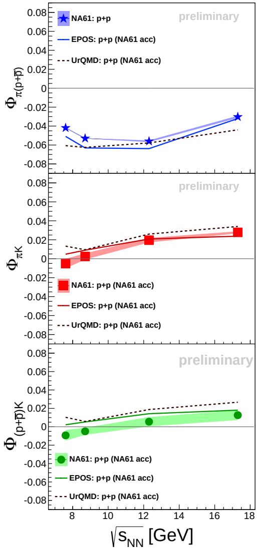
[a] https://edms.cern.ch/document/1237791/1

Multiplicity fluctuations of positively charged hadrons



- ω_p similar to $\omega_{p+\bar{p}}$. Small fraction of antiprotons
- $\omega_{K^+} \approx 1$
  $\omega_{K^+} < \omega_K$ which suggests that strangeness conservation contributes to ω_K
- suppressed fluctuations of π^+. $\omega_{\pi^+} < \omega_\pi$ possibly due to charge conservation
- EPOS reproduces scaled variances of positively charged hadrons

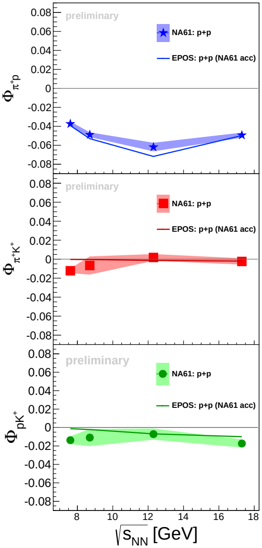
Chemical fluctuations of charged hadrons



- fluctuations of $\pi(p+\bar{p})$ are affected by conservation laws and resonance decays[a] - $\Phi_{\pi(p+\bar{p})} < 0$
- small increase of πK fluctuations with increasing energy
- $\Phi_{(p+\bar{p})K} \approx 0$ indicates weak if any correlations between $p+\bar{p}$ and K production
- UrQMD and EPOS closely reproduces the data

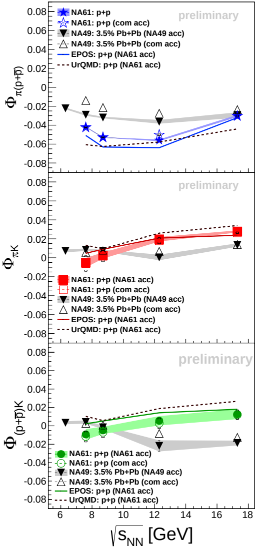
[a] PRC70:064903

Chemical fluctuations of positively charged hadrons



- fluctuations of π^+p agree with both charge fluctuations
- no energy dependence of π^+K^+ and pK^+ fluctuations
- EPOS closely reproduces data

Chemical fluctuations of charged hadrons in p+p (NA61) and Pb+Pb (NA49)



- limiting the analysis to the region of common NA49 and NA61 acceptance does not impact the results in any significant way
- qualitatively similar energy dependence of $\pi(p+\bar{p})$ and πK fluctuations for p+p and central Pb+Pb collisions
- $(p+\bar{p})K$ fluctuations show different tendency in p+p (increase with energy) than in Pb+Pb (decrease)
- note that the results are still preliminary

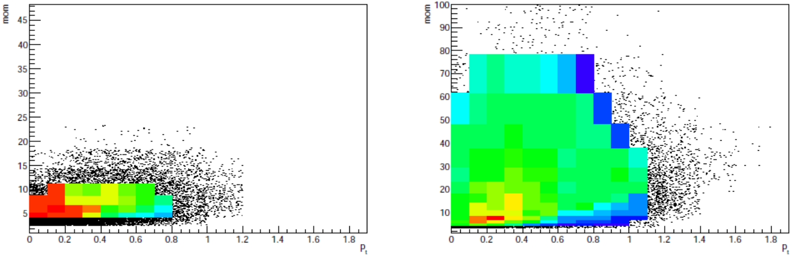
Summary

- multiplicity fluctuations of π, K, p and chemical fluctuations of πp, πK, pK as well as fluctuations of positively charged hadrons were measured by NA61/SHINE at $\sqrt{s_{NN}} = 7.6$ - 17.3 GeV.
- models (EPOS, HSD, UrQMD) describe fluctuations in p+p interactions
- qualitatively similar energy dependence of $\pi(p+\bar{p})$ and πK fluctuations for p+p and central Pb+Pb collisions
- when strongly intensive measure Φ is used, $(p+\bar{p})K$ fluctuations show different tendency in p+p (increase with energy) than in Pb+Pb (decrease)

BACKUP

Common acceptance of NA61 and NA49

In order to compare p+p (NA61) and Pb+Pb (NA49) results the common phase space region for the chemical fluctuation analysis was defined.
Due to significantly lower particle multiplicity in p+p interactions, the region where the track density is sufficient for energy loss analysis is limited in the case of NA61.

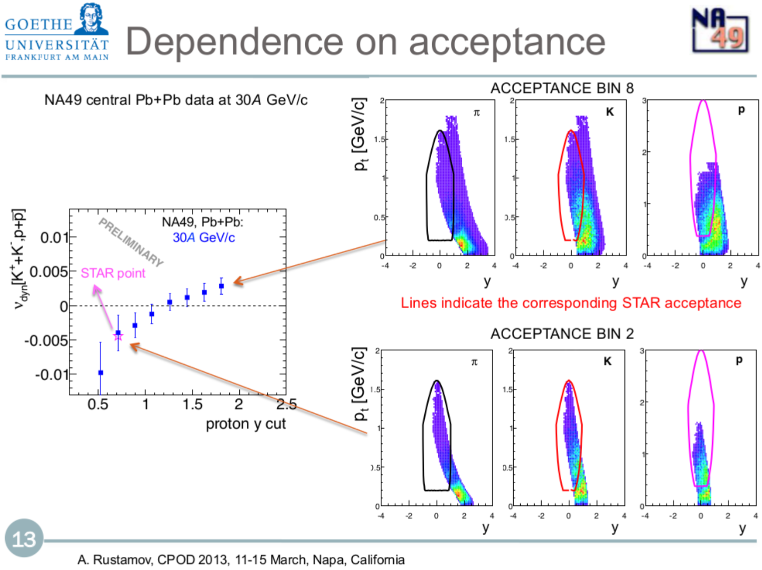


$\sqrt{sNN} = 7.6$ GeV $\sqrt{sNN} = 17.3$ GeV

Coloured region marks common phase-space region used for comparison of p+p and Pb+Pb results (scattered points indicate region used for Pb+Pb analysis only). For details see https://edms.cern.ch/document/1237791/1

Acceptance issues (STAR and NA61)

Dependence on acceptance



Other measures of fluctuations

NA49: $\sigma_{dyn} = \mathrm{sgn}\left(\sigma^2_{data} - \sigma^2_{mixed}\right)\sqrt{\left|\sigma^2_{data} - \sigma^2_{mixed}\right|}$ $\sigma = \frac{\sqrt{Var(A/B)}}{\langle A/B \rangle}$ $\frac{A}{B} = \frac{K}{\pi}, \frac{p}{\pi}, \frac{K}{p}$

STAR: $\nu_{dyn} = \frac{\langle N_1^2 \rangle}{\langle N_1 \rangle^2} + \frac{\langle N_2^2 \rangle}{\langle N_2 \rangle^2} - 2\frac{\langle N_1 N_2 \rangle}{\langle N_1 \rangle \langle N_2 \rangle} - \left(\frac{1}{\langle N_1 \rangle} + \frac{1}{\langle N_2 \rangle}\right)$ $\nu_{dyn} \approx \mathrm{sgn}(\sigma_{dyn})\sigma^2_{dyn}$