HIGHER ORDER MOMENTS OF NET-CHARGE AND MULTIPLICITY DISTRIBUTIONS IN $p + p$ INTERACTIONS AT SPS ENERGIES FROM NA61/SHINE*

Maja Maćkowiak-Pawłowska

for the NA61/SHINE Collaboration

Faculty of Physics, Warsaw University of Technology
Koszykowa 75, 00-662 Warszawa, Poland

NA61/SHINE at the CERN SPS is a fixed-target experiment pursuing a rich physics program including measurements for heavy-ion, neutrino and cosmic ray physics. The main goal of the ion program is to study the properties of the onset of deconfinement and to search for the signatures of the critical point. A specific property of the critical point, the increase in the correlation length, makes fluctuations its basic signal. Higher order moments of suitable observables are of special interest as they are more sensitive to the correlation length than typically studied second order moments. In this contribution, preliminary results on higher order fluctuations of negatively-charged hadron multiplicity and net charge in $p + p$ interactions will be shown. The new data will be compared with model predictions.

1. Introduction

One of the most important goals of high-energy heavy-ion collisions is to establish the phase diagram of strongly interacting matter by finding the possible phase boundaries and critical points. A specific property of the critical point, the increase in the correlation length ξ, makes fluctuations its basic signal [1]. Fluctuations are quantified by moments of measured distributions of suitable observables of the order higher than the first.

---

* Presented at the "Critical Point and Onset of Deconfinement" Conference, Wrocław, Poland, May 30–June 4, 2016.

Critical point fluctuations are expected to increase as (approximately) ξ^2 for the variance (second moment) of event-by-event observables such as multiplicities or mean transverse momenta of particles. Higher, non-Gaussian, moments of fluctuations should depend more sensitively on ξ, *e.g.* the fourth moment is expected to grow as ξ^7 near the critical point [2].

This contribution shows results on fluctuations of negatively-charged hadron and net-charge multiplicity distributions defined by moments or cumulants up to the fourth moment. The net charge is defined as the difference between positively- and negatively-charged hadron multiplicities in $p + p$ interactions collected by the NA61/SHINE experiment [3] in 2009. The reason to focus on multiplicity of negatively-charged particle is the fact that the underlying correlations are almost insensitive to resonance decays as there are very few resonances decaying into pairs of negatively charged particles. The net charge, under some assumptions allows to compare data to QCD calculations on lattice.

2. Fluctuation measures

In the grand canonical ensemble mean, variance and, in general, cumulants (denoted with index c) of a multiplicity distribution are extensive quantities (they are proportionl to volume $\sim V$). A ratio of two extensive quantities is an intensive quantity *e.g.*

$$\omega[N] = \frac{\mathrm{Var}[N]}{\langle N \rangle} \,,$$

where $\mathrm{Var}[N]$ and $\langle N \rangle$ are variance and mean of the multiplicity distribution. The scaled variance is independent of V (for event ensembles with fixed V) but it depends on fluctuations of V (even if $\langle V \rangle$ is fixed). For the Poisson distribution (independent particle production), $\omega = 1$.

For the third and fourth order cumulants, there are several possibilities for deriving intensive measures. The two most popular are

$$\frac{\langle N^3 \rangle_{\mathrm{c}}}{\mathrm{Var}[N]} \,, \qquad \frac{\langle N^4 \rangle_{\mathrm{c}}}{\mathrm{Var}[N]} \,, \tag{1}$$

where $\langle N^3 \rangle_{\mathrm{c}}$ and $\langle N^4 \rangle_{\mathrm{c}}$ are the third and fourth order cumulants of the multiplicity distribution [5]. The related quantities skewness S and kurtosis κ are defined as

$$S = \frac{\langle N^3 \rangle_{\mathrm{c}}}{(\mathrm{Var}[N])^{3/2}} = \frac{\langle N^3 \rangle_{\mathrm{c}}}{\sigma^3} \,, \qquad \kappa = \frac{\langle N^4 \rangle_{\mathrm{c}}}{\mathrm{Var}[N]} = \frac{\langle N^4 \rangle_{\mathrm{c}}}{\sigma^4} \,, \tag{2}$$

where σ^2 is the variance of the multiplicity distribution $(\mathrm{Var}[N] = \langle N^2 \rangle_\mathrm{c})$. Thus,

$$S\sigma = \frac{\langle N^3 \rangle_\mathrm{c}}{\mathrm{Var}[N]}, \qquad \kappa\sigma^2 = \frac{\langle N^4 \rangle_\mathrm{c}}{\mathrm{Var}[N]}. \tag{3}$$

3. Results

Preliminary results were obtained from $p + p$ data collected in 2009 at 20, 31, 40, 80 and 158 GeV/c beam momenta. Table I shows the analysis statistics. The analysis acceptance is the same as used for multiplicity and transverse momentum fluctuation analysis [6]. The corrected results refer to inelastic interactions and particles produced in strong and electromagnetic processes within the analysis acceptance.

TABLE I

Number of $p + p$ events taken in 2009 by the NA61/SHINE experiment.

$\sqrt{s_{NN}}$ [GeV]	6.3	7.6	8.7	12.3	17.3
Events	0.2M	0.9M	3.0M	1.7M	1.6M

As in Ref. [6], multiplicity distributions were corrected for:

— off-target interactions,

— detector effects,

— event selection (trigger bias and analysis procedure),

— track selection within the analysis acceptance,

— contribution of weak decays,

— secondary interactions.

Statistical uncertainties were calculated using the sub-sample method[1]. Systematic uncertainties were estimated by varying the event and track selection criteria.

Figure 1 shows results on fluctuations of negatively-charged hadron multiplicity. The measures $\omega[h^-]$, $S\sigma[h^-]$ and $\kappa\sigma^2[h^-]$ rise with the collision energy and cross 1 between 40 and 80 GeV/c. These results are not reproduced by statistical models (GCE or CE) [7] (for details, see the conference slides).

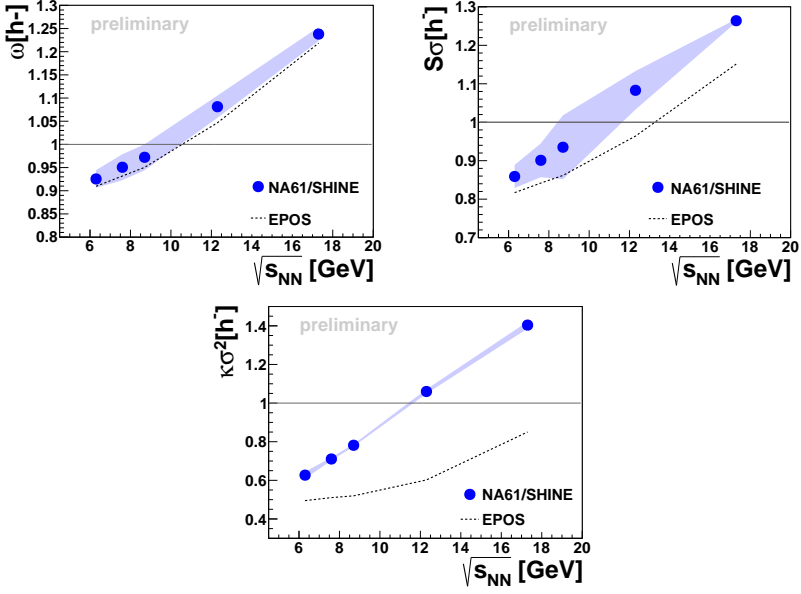[1] Statistical uncertainties are smaller than the marker size in the figures.

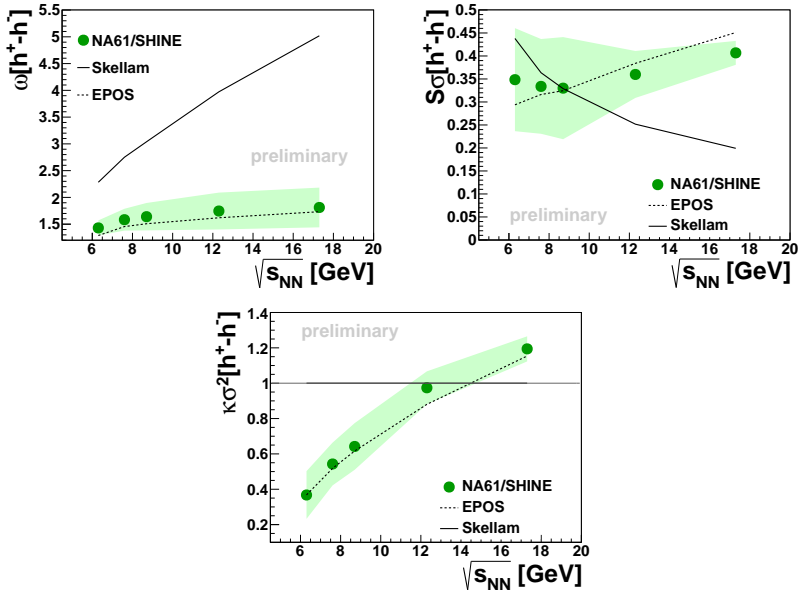Fig. 1. The energy dependence of $\omega[h^-]$, $S\sigma[h^-]$ and $\kappa\sigma^2[h^-]$ in $p+p$ interactions.

Fig. 2. The energy dependence of $\omega[h^+ - h^-]$, $S\sigma[h^+ - h^-]$ and $\kappa\sigma^2[h^+ - h^-]$ in $p+p$ interactions.

Figure 2 shows results on fluctuations of net charge. The scaled variance, $\omega[h^+ - h^-]$, as well as $S\sigma[h^+ - h^-]$ depends very weakly on collision energy, whereas $\kappa\sigma^2[h^+ - h^-]$ rises with collision energy and crosses 1 at 80 GeV/c. Net-charge fluctuations measured by $\omega[h^+ - h^-]$ are smaller than predictions of the independent particle production model for which the net-charge distribution is described by the Skellam distribution. The energy dependences of $S\sigma$ and $\kappa\sigma^2$ are completely different from those predicted by the model.

The EPOS 1.99 model describes the observed values of $\omega[h^-]$, $S\sigma[h^-]$ and net-charge fluctuations but it underestimates the value of $\kappa\sigma^2[h^-]$.

REFERENCES

[1] M.A. Stephanov, *Acta Phys. Pol. B* **35**, 2939 (2004).

[2] M.A. Stephanov, *J. Phys. G* **38**, 124147 (2011).

[3] N. Antoniou *et al.* [NA49-future Collaboration], CERN-SPSC-2006-034, CERN-SPSC-P-330, CERN-SPSC-2012-022, SPSC-P-330-ADD-6.

[4] N. Abgrall *et al.* [NA61 Collaboration], *JINST* **9**, P06005 (2014).

[5] M. Asakawa, M. Kitazawa, *Prog. Part. Nucl. Phys.* **90**, 299 (2016).

[6] A. Aduszkiewicz *et al.* [NA61/SHINE Collaboration], *Eur. Phys. J. C* **76**, 635 (2016) [arXiv:1510.00163 [hep-ex]].

[7] V.V. Begun, *Acta Phys. Pol. B Proc. Suppl.* **10**, 901 (2017), this issue.