News on transverse momentum fluctuations in p+p energy scan from NA61/SHINE and comparison with A+A energy scans

Tobiasz Czopowicz for the **NA61/SHINE Collaboration**
Faculty of Physics, Warsaw University of Technology

Physics Motivation

The NA61/SHINE experiment aims to discover the Critical Point of strongly interacting matter and study the properties of the Onset of Deconfinement. Close to the phase transition and close to the Critical Point enhancement of fluctuations is predicted.

NA61/SHINE performs two-dimensional scans of the phase diagram of strongly interacting matter. Various beams (p, Be, Ar, Xe) with various momenta ($13A$ – $158A$ GeV/c) are used. Proton and beryllium energy scans have already been completed.

Fluctuation Measures

Fluctuations in nucleus+nucleus collisions are susceptible to two trivial sources: the finite and fluctuating number of produced particles and event-by-event fluctuations of the collision geometry. Suitable statistical tools have to be chosen to extract the fluctuations of interest. Three different event-by-event fluctuation measures are used to describe transverse momentum fluctuations: the Δ and Σ measures introduced recently in Ref. [1] and the Φ quantity proposed in Ref. [2] which was already successfully employed by the NA49 experiment to study average p_T fluctuations, charge fluctuations and recently also azimuthal angle fluctuations.

We call quantities extensive which do **not** depend on the volume of the system. However, in heavy ion collisions the volume of the produced matter cannot be fixed and changes significantly from one event to another. Therefore, it is very important to be able to measure the properties of the created matter independently of volume fluctuations. The quantities which allow this are called **strongly intensive** measures. They depend neither on the volume nor on the volume fluctuations. In Ref. [1] it was shown that, in fact, there are at least two families of strongly intensive measures: Δ and Σ. The previously introduced Φ measure belongs to the Σ-type family.

$$\Delta[P_T,N] = \frac{1}{\langle N\rangle\omega[p_T]}[\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]]$$

$$\Sigma[P_T,N] = \frac{1}{\langle N\rangle\omega[p_T]}[\langle N\rangle\omega[P_T] + \langle P_T\rangle\omega[N] - 2(\langle P_T,N\rangle - \langle P_T\rangle\langle N\rangle)],$$

$$\Phi_{p_T} = \sqrt{\overline{p_T}\omega[p_T]}[\sqrt{\Sigma[P_T,N]} - 1]$$

where:

$$P_T = \sum_{i=1}^{N} p_{T i} \qquad \omega[P_T] = \frac{\langle P_T^2\rangle - \langle P_T\rangle^2}{\langle P_T\rangle} \qquad \omega[N] = \frac{\langle N^2\rangle - \langle N\rangle^2}{\langle N\rangle}$$

are the scaled variances of two fluctuating extensive event quantities P_T and multiplicity N, respectively. The quantity $\omega[p_T]$ is the scaled variance of the inclusive p_T distribution:

$$\omega[p_T] = \frac{\overline{p_T^2} - \overline{p_T}^2}{\overline{p_T}}$$

Properties of Φ_{p_T}, $\Delta[P_T,N]$, and $\Sigma[P_T,N]$ in the absence of fluctuations ($N = const.$, $P_T = const.$), in the Independent Particle Model (IPM) and in the Model of Independent Sources (MIS) are listed below.

	unit	No fluctuations	IPM	MIS (with N_s the number of sources)
Φ_{p_T}	MeV/c	$\Phi_{p_T} = -\sqrt{\overline{p_T}\omega[p_T]}$	$\Phi_{p_T} = 0$	does not depend on N_s and its fluctuations
$\Delta[P_T,N]$	dimensionless	$\Delta[P_T,N] = 0$	$\Delta[P_T,N]$	
$\Sigma[P_T,N]$	dimensionless	$\Sigma[P_T,N] = 0$	$\Sigma[P_T,N]$	

There is an important difference between $\Delta[P_T,N]$ and $\Sigma[P_T,N]$. Only the first two moments: $\langle P_T\rangle$, $\langle N\rangle$, and $\langle P_T^2\rangle$, $\langle N^2\rangle$ are required to calculate $\Delta[P_T,N]$, whereas $\Sigma[P_T,N]$ includes the correlation term $\langle P_T,N\rangle - \langle P_T\rangle\langle N\rangle$. Thus $\Delta[P_T,N]$ and $\Sigma[P_T,N]$ can be sensitive to various physics effects in different ways. In Ref. [1] all strongly intensive quantities which include the correlation term are named the Σ family, and those only derived from mean values and variances the Δ family. As already mentioned, the Φ_{p_T} measure belongs to Σ-type family.

Analysis

Physics goals

The goal of the analysis is to measure transverse momentum fluctuations in all inelastic proton-proton collisions using strongly intensive quantities.

Data set

A few millions of proton-proton collisions recorded in 2009 at each of several beam momenta ($20A$, $31A$, $40A$, $80A$ and $158A$ GeV/c) have been analyzed.

Event selection

In order to select only good quality inelastic collisions, a number of cuts were applied to select events with good quality beam signal and properly fitted main vertex. Also, events with off-time beam particles passing too close to the triggering beam were rejected. Elastic scattering of the beam proton was also taken into account.

Track selection

To make sure that only tracks with good momentum fit are used in the analysis, a cut on the minimum number of points of energy deposition was applied. Also, the distance between the back extrapolated track and the main vertex was checked for consistency. Only tracks with transverse momentum less than 1.5 GeV/c were retained. Electrons were removed by a graphical cut based on the dE/dx vs p distribution.

Accepted tracks

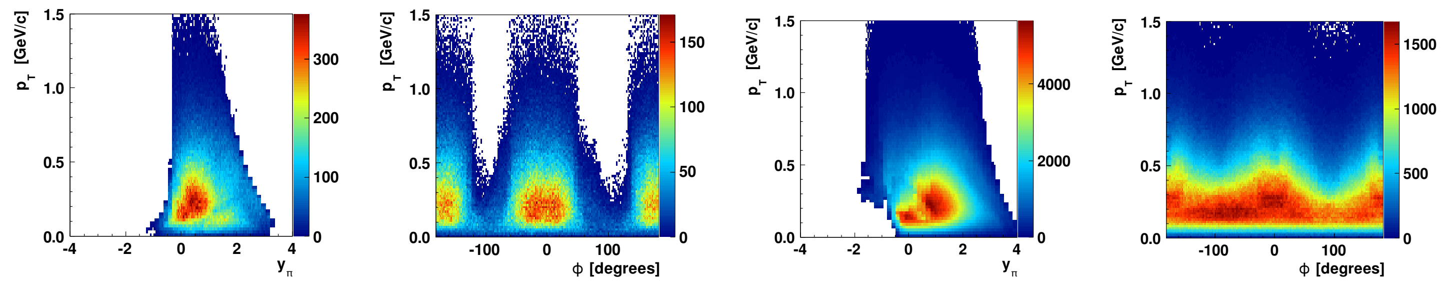

Figure 1: Scatter plots of transverse momentum and azimuthal angle vs center-of-mass rapidity (assuming pion mass) for 20 GeV/c (left) and 158 GeV/c (right).

Corrections

The results are corrected for **non-target interactions**, **detector effects**, and the **trigger bias**. The former is done using data recorded without the target. This *target-removed* data results are normalized using the main vertex z coordinate distribution and subtracted from the *target-inserted* data results.

The second correction is done using EPOS model simulations. Each simulated event is represented by six quantities: multiplicity, sum of transverse momenta and sum of squared transverse momenta of negative and positive particles. Then, 6D correction factor tables are prepared by comparing the data before and after standard NA61/SHINE reconstruction and quality selection.

The two corrections are applied at the same time – while calculating moments of distributions needed for Δ, Σ and Φ using the following formula:

$$\langle Q\rangle = \frac{1}{\sum_{i=1}^{n^{TI}} c_i^{TI} - B \sum_{j=1}^{n^{TR}} c_j^{TR}} \times \left(\sum_{i=1}^{n^{TI}} c_i^{TI} Q_i^{TI} - B \cdot \sum_{j=1}^{n^{TR}} c_j^{TR} Q_j^{TR}\right)$$

Q - any of the event quantities (i.e. $\langle N\rangle$, $\langle N^2\rangle$, $\langle P_T\rangle$, $\langle P_T^2\rangle$, $\langle P_T N\rangle$)
B - normalization factor of target-removed data
n^{TI}, n^{TR} - number of target-inserted and target-removed events
c_i^{TI}, c_j^{TR} - correction factors used for target-inserted and target-removed data

Uncertainties

Statistical uncertainties were calculated by dividing the data sets into 30 sub-samples. The statistical error is taken as the standard deviation of the sub-sample results divided by $\sqrt{30}$. Systematic uncertainties introduced by biases of the analysis method were estimated by varying event and track selection criteria and the choice of model for simulation.

Results

Corrected results are presented in Fig. 2. Also EPOS, VENUS and UrQMD predictions are shown. The model predictions agree with our measurements of Φ and Σ. Results for Δ lie below 1 and all models overpredict the data.

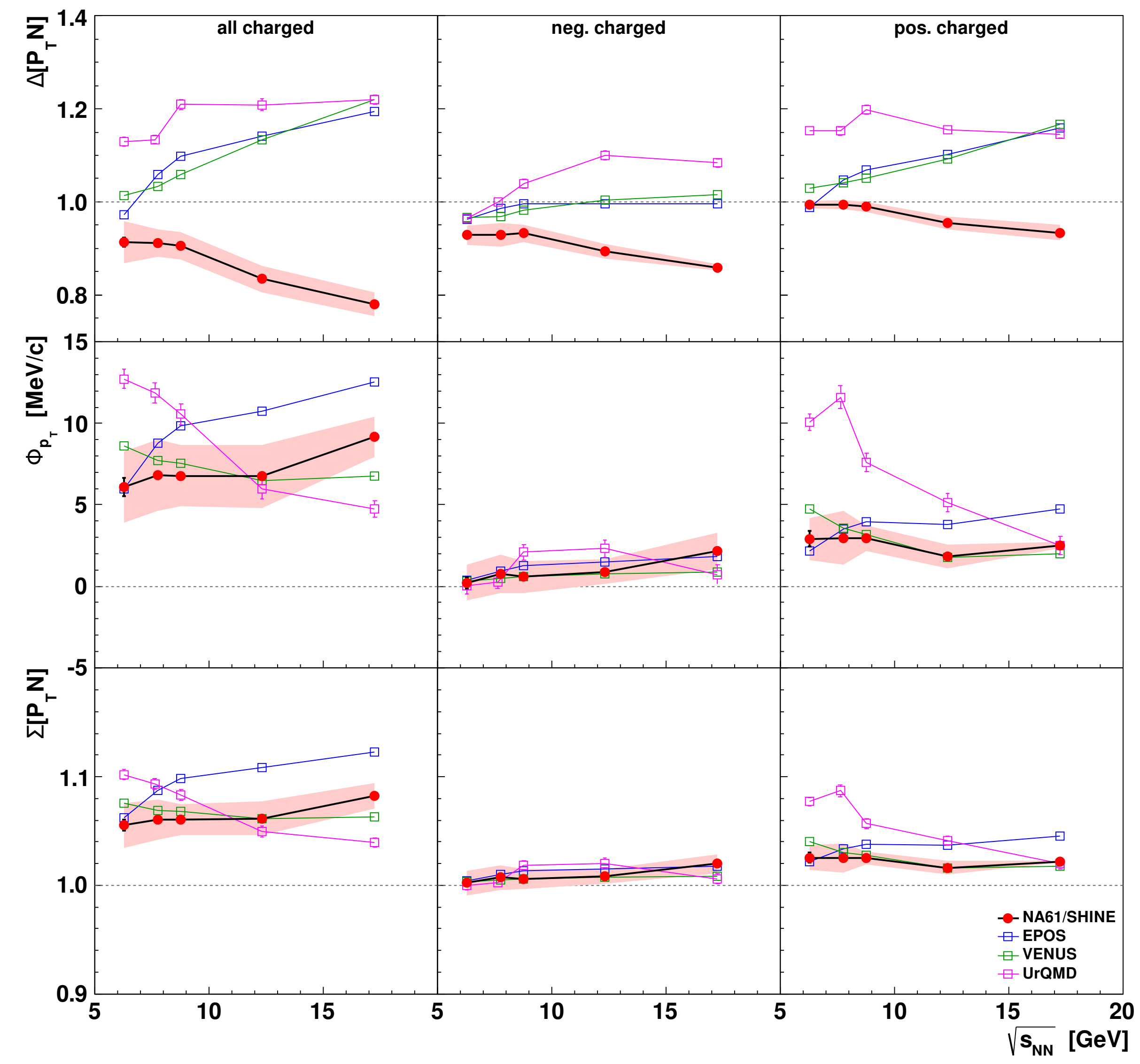

Figure 2: Corrected results of NA61/SHINE on transverse momentum fluctuations in inelastic p+p collision (within the detector acceptance) compared with models.

Critical Point search

The system size scan of proton, carbon, silicon and lead collisions at top SPS energy performed by NA49 revealed non monotonic behaviour of transverse momentum fluctuations (Φ_{p_T}) with a maximum for medium-sized systems (Fig. 3 left). In the energy scan neither p+p (NA61) nor Pb+Pb (NA49, Ref. [3]) collisions show an enhancement as expected in the vicinity of the Critical point.

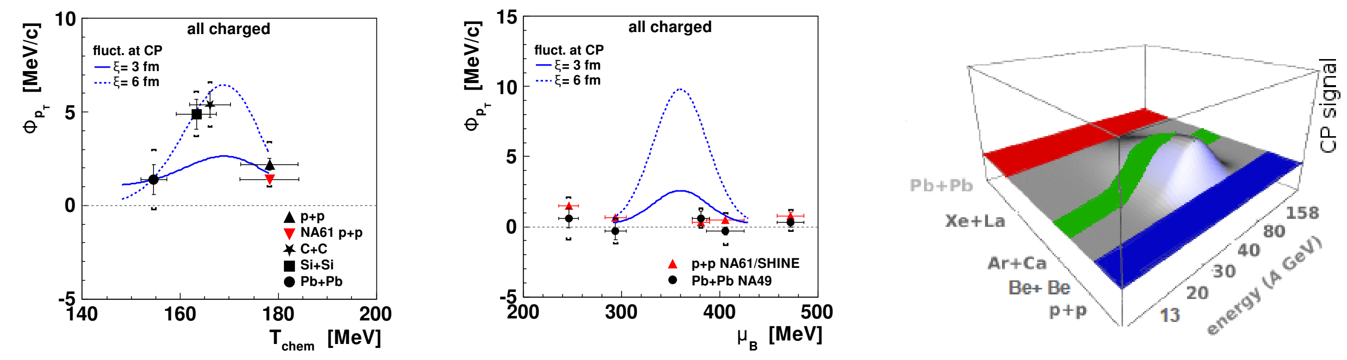

Figure 3: Left: NA49 system size scan at the top SPS energy compared to the NA61/SHINE p+p (in NA49 acceptance). Middle: comparison of NA49 Pb+Pb (Ref. [3]) and NA61/SHINE p+p (in NA49 acceptance) energy scans. Lines show predictions for CP (Ref. [4]). Right: schematic view of the fluctuations expectations.

A comparison of Φ_{p_T} from p+p and Pb+Pb collisions is shown in Fig. 3 middle. After limiting the NA61 acceptance to match NA49 (forward rapidity region only, common azimuthal angle acceptance for all energies), NA61/SHINE p+p results almost coincide with NA49 Pb+Pb (Fig. 3 middle, Ref. [3]). It is expected that the medium-sized systems still planned to be recorded by NA61/SHINE will show indications of the Critical Point (Fig. 3 right).

References

[1] Phys.Rev. C84 (2011) 014904; Phys.Rev. C88 (2013) 2 024907.
[2] Z.Phys. C54 (1992) 127.
[3] Phys. Rev. C70 (2004) 034902.
[4] Nucl.Phys. A830 (2009) 547C-550C

e-mail: Tobiasz.Czopowicz@cern.ch