Energy dependence of transverse momentum fluctuations

(status of the draft)

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Last Collaboration Meeting – draft of publication:

- Introduction and Motivation
- Measures of fluctuations
- Experimental Set-up
- Data selection and analysis
  - Data sets
  - Event and particle selection
  - Corrections and error estimates
- Results
- Discussion
  - comparison with the UrQMD model (modified)
  - additional $y_p^*$ cut (new)
- Summary
Motivation

For energies close to the phase transition QGP might be created only in a fraction of events – characteristics of these two different groups of events can be different enhanced event-by-event (dynamical) fluctuations for systems close to the phase transition

... or critical QCD end-point

non-monotonic dependence of $p_T$ and $N$ fluctuations on control parameters (energy, centrality, ion size) can help to locate the freeze-out point being a second-order critical end-point
Dynamical fluctuations = fluctuations minus statistical fluctuations (number of particles ≠ ∞)

What do we want to measure?

**Transverse momentum dynamical fluctuation on event-by-event basis**

Methods (to extract the subject of interest – the dynamical part):
1. \( M(p_T) \) distribution – comparison for data and 'mixed' events
2. \( \Phi_{pT} \) correlation measure:
   a) superposition model \( \Phi_{pT}(A+A) = \Phi_{pT}(N+N) \)
   b) independent particle production \( \Phi_{pT} = 0 \)
3. Two-particle correlation plots using cumulative variable 'x'

\[
x(i) = \int_{0}^{p_{Ti}} \rho(p_T) \, dp_T
\]
Event and track selection criteria

- Cut on x, y, z position of the fitted vertex
- ntf/nto > 0.25
- z_first < 200 cm
- |bx| < 2 cm, |by| < 1 cm
- nmp > 30, np/nmp > 0.5
- 0.005 < p_T < 1.5 GeV/c
- 1.1 < y^*_\pi < 2.6  
  forward rapidity

Kinematic + quality cuts and common acceptance ==> we are looking at 5% of particles produced in central Pb+Pb
Results: $M(p_T)$ for data and mixed events

all charged particles

Distributions for data (lower energies) wider than those for mixed – dynamical fluctuations ??
Two particle correlation plots
all charged particles

1. Short range (Bose-Einstein and Coulomb) correlations - diagonal
2. additional source at lower energies...
but for positively charged particles only

...and positively and negatively charged particles, separately (20 AGeV)
Observations:
1. Increased dynamical fluctuations at lower energies but for positively charged particles only
2. Negatively charged ones - in agreement with independent particle production

negatively charged: $\pi^-$ mainly, $K^-$
positively charged: $\pi^+$ and $p$ mainly, $K^+$
Discussion: comparison with the UrQMD model

- Default parameters
- 7.2% most central collisions
- The same kinematic restrictions as for data
- The same $p_T$ – azimuthal angle acceptance

Qualitatively the same structure, but:

1. no BE correlations in UrQMD
2. CERES: UrQMD under-estimates $p_T$ fluctuations, especially at low energies
Particle content in the studied kinematic region (UrQMD events)

Negatively charged particles:
- $\pi^-$ (94% for 20 AGeV; 89% for 158 AGeV)
- $K^-$ (5.6% for 20 AGeV; 9.2% for 158 AGeV)
- anti-$p$ (<2%)

Positively charged particles:
- $\pi^+$ (43% for 20 AGeV; 69% for 158 AGeV)
- $K^+$ (8.5% for 20 AGeV; 10.4% for 158 AGeV)
- $p$ (49% for 20 AGeV; 21% for 158 AGeV)

Re-scattered participants or spectators correlated in $p_T$ (momentum conservation law)

Their fraction different at different energies
**Hypothesis:** increased transverse momentum fluctuations at lower energies may be connected with increased fraction of re-scattered protons (participants or spectators). Other tests:

- No $p_T$ – azimuthal angle restrictions;
- forward rapidity dotted - “4π” accept. - the effect washed out

“4π” acceptance
* protons only
* protons+neutrons
* newly produced (gen.) particles
Additional tests for the data - an attempt to identify particles

Identification used by Panos Christakoglou. Accepted pions (green) and protons (blue) at 20 AGeV.

filled points – data corrected for TTR
open points – “raw” data (better to compare)
solid line – **pions** only (no TTR corr.)
dashed line – (anti-)**protons** only (no TTR corr.)

Warning!
Using dE/dx cuts => random rejection of particles => decreasing of correlations => only qualitative comparison
Accepted particles for all energies

pion, kaon and proton mass assumed

beam rapidity

spectators:
\[ y^*_{\text{beam}} \pm 0.3 \]
Results with additional cut $y_p^* < y_{beam}^* - 0.5$

$M(p_T)$ for data / $M(p_T)$ for mixed events

all charged particles

Histograms for data at lower energies are NOT wider any more
Results with additional cut \( y^*_p < y^*_\text{beam} - 0.5 \)

\( \Phi_{pT} \) versus energy (corrected for TTR)

1. New TTR corrections (mixed + Geant + reconstruction)

2. Systematic errors (\( \Phi_{pT} \) stabilities versus \( vz \), \( ntf/nto \), \( bx \) and \( by \), \( np/nmp \)) will be given in the table with results
Results with additional cut $y^*_p < y^*_\text{beam} - 0.5$

Two particle correlation plots for all charged particles

...and positively and negatively charged particles, separately (20 AGeV)
Results with additional cut $y_p^* < y_{\text{beam}}^* - 0.5$

comparison with the UrQMD model

Conclusion: the source of correlations consists of rather small number of protons placed at rapidities close to the rapidity of the beam. Spectators and/or participants re-scattered in an elastic way??

However...

one cannot exclude correlations between high and lower rapidities
$\Phi_{pT}$ for positively charged particles

at 20 AGeV ($y_{beam}^* = 1.88$); no TTR corrections

No additional $y_p^*$ cuts $\quad \Phi_{pT} = 16.0 \pm 0.4$

$y_p^* < 1.4$ (without spectators region) $\quad \Phi_{pT} = 1.5 \pm 0.3$

$y_p^* > 1.4$ (spectators region “only”) $\quad \Phi_{pT} = 3.2 \pm 0.3$ – too small, there may be also correlations between these two regions!

The same tendency in the UrQMD model

Other tests: http://mars.if.pw.edu.pl/~kperl/NA49_PT/results_na49_pt.html
(for data and UrQMD events) suggest also:

1. Correlation between lower and higher transverse momenta
2. Correlation between lower and higher total momenta

Therefore we cannot distinguish whether those protons are spectators or participants or even nuclear fragments
**Last remark (NOT to be included in the draft)**

**System size dependence @ 40 AGeV**
without and with additional cut $y_p^* < y_{beam}^* - 0.5$

- 1. VERY VERY PRELIMINARY!
- 2. NO TTR corrections
- 3. NO systematic error estimation

**Conclusion:**
It is rather a problem with beam spectators/participants region than a proof of a critical point ;-)
Summary:

1. No energy dependence of $p_T$ fluctuations for negatively charged particles
2. Increased $p_T$ fluctuations for positively charged particles at lower SPS energies --> caused by the increased fraction of protons (re-scattered participants and/or spectators from the beam region mainly)
3. **Important message for the others: BE CARREFUL WITH BEAM REGION**
4. Other sources of fluctuations still not excluded
5. The energy dependence of transverse momentum fluctuations does not show any anomalies connected with the fact that system is approaching the phase boundary
6. No evidence for the critical end-point, either (in contrary to the system size dependence @ 158 AGeV)

... and we are still waiting for another proof of our possible critical point @ 158 GeV
Add. slide: other experiments and future plans

- No energy dependence of transverse momentum fluctuations at CERES (Pb+Au @ 40, 80 and 158 AGeV)
- Only very weak energy dependence at STAR (Pb+Pb @ sqrt(s_NN) = 20, 62, 130 and 200 GeV)
- Energy dependence of multiplicity fluctuations in NA49 – ongoing analysis
- The observed energy dependence of K/π fluctuations in NA49 – onset of deconfinement?
- What next?

Energy scan with light ions + existing results on system size dependence ==> location of the critical end-point