Correlations and fluctuations in p+p and Be+Be at the SPS energies from NA61/SHINE

Andrey Seryakov
for the NA61/SHINE collaboration
seryakov@yahoo.com

Laboratory of Ultra-High Energy Physics
St. Petersburg State University

25/08/2015
Crete, Greece
Outline: selected results

Correlations:
• Two-particle $C(\Delta \eta, \Delta \varphi)$
  in $p+p$ 20 – 158 GeV/c ($\sqrt{s_{NN}} = 6.3–17.3$ GeV)
• Pseudorapidity correlations
  in Be+Be 150A GeV/c ($\sqrt{s_{NN}} = 16.8$ GeV)

Fluctuations ($\omega, \Delta, \Sigma$):
• Transverse momentum and multiplicity fluctuations in $p+p$ and Be+Be
Two-particle correlations: motivation

Two-particle correlations in $\Delta \eta, \Delta \varphi$

- Studied at RHIC and LHC.
- Allow to disentangle different sources of correlations:
  - Jets
  - Flow
  - Resonance decays
  - Quantum statistic effects
  - Conservation laws

The motivation
To study correlations and their sources at the SPS-energies
Two-particle correlations: definition

Correlations are calculated by finding the difference in pseudo-rapidity and azimuthal angle between two particles in the same event.

$$\Delta \eta = |\eta_1 - \eta_2|$$  \text{transformed from LAB to CMS assuming pion mass}

$$\Delta \varphi = |\varphi_1 - \varphi_2|$$

The azimuthal angle is folded (to improve statistics):
if $\Delta \varphi > \pi$ then $\Delta \varphi = 2\pi - \Delta \varphi$

$$C(\Delta \eta, \Delta \varphi) = \frac{N^{pairs \text{ mixed}}}{N^{pairs \text{ data}}} \frac{S(\Delta \eta, \Delta \varphi)}{M(\Delta \eta, \Delta \varphi)}$$

$$S(\Delta \eta, \Delta \varphi) = \frac{d^2 N^{signal}}{d\Delta \eta d\Delta \varphi}; \quad M(\Delta \eta, \Delta \varphi) = \frac{d^2 N^{mixed}}{d\Delta \eta d\Delta \varphi}$$

Correlation function ratio is calculated and normalized in restricted region: $0 < \Delta \eta < 3$
Event and track cuts were chosen to select only inelastic interactions with particles produced in strong and EM processes within the NA61/SHINE acceptance.
All results are corrected for detector effects: tracking inefficiencies, trigger bias (see backup).
Two-particle correlations: results

**p+p 158 GeV/c**

- Maximum at $(\Delta \eta, \Delta \phi) = (0, \pi)$ probably resonance decays and momentum conservation.
  - the strongest in unlike-sign pairs,
  - still visible in positively charged pairs (\(\Delta^{++}\) decay),
  - non-visible in negatively charged (almost no double-negative resonances).

- An enhancement at (0; 0) - probably Coulomb or quantum statistics effects.
  - weak in unlike-sign pairs,
  - clearly visible in same charge pairs.

B.Maksiak [for the NA61/SHINE collaboration], PoS(CPOD2014)055
Two-particle correlations: energy dependence

The enhancement “saddle” at (0,0) rises with increasing beam momentum

B. Maksiak [for the NA61/SHINE collaboration], PoS(CPOD2014)055
Two-particle correlations: model test

NA61/SHINE

EPOS 1.99

UrQMD 3.4

EPOS and UrQMD are with NA61 acceptance; all charged particles

EPOS qualitatively agree with the data
UrQMD disagree

B. Maksiak, NA61-Theory meeting, 03.12.2014
Long-range pseudorapidity correlations between particles are expected to be sensitive to the early stage of heavy ion collisions

- **Color string fusion phenomenon (SFM)**

- **Color Glass Condensate (CGC) and Glasma flux tubes**

However many other effects could play role in pseudorapidity correlations:
- Jets
- Flow
- Resonance decays
- Quantum statistic effects
- Conservation laws

Pseudorapidity correlations: definition

\[ b[B,F] = \frac{\langle BF \rangle - \langle B \rangle \langle F \rangle}{\langle F^2 \rangle - \langle F \rangle^2} \]

To reduce trivial correlations due to variation of volume

\[ B \rightarrow B / \langle B \rangle = B_{\text{rel}} \]
\[ F \rightarrow F / \langle F \rangle = F_{\text{rel}} \]

\[ b_{\text{rel}}[B,F] = b[B,F] \langle F \rangle / \langle B \rangle \]

Possible selections of \( B \) and \( F \):

- \( N_B N_F \) - the correlation between charged particle multiplicities
- \( P_{t_B} N_F \) - the correlation between the event mean transverse momentum \( (B) \) and multiplicity \( (F) \)
- \( P_{t_B} P_{t_F} \) - the correlation between the event mean transverse momenta
- \( \Delta Q_B \Delta Q_F \) - the correlation between the event net charges in \( B \) and \( F \)
Pseudorapidity correlations: results
Be+Be 150A GeV/c 0-20% centrality

• Strong dependence on the windows position
• EPOS 1.99 describes the data only qualitatively

Event and track cuts were chosen to select only inelastic interactions with particles produced in strong and EM processes within the NA61/SHINE acceptance. The results are corrected on detector effects: tracking inefficiencies, trigger bias. The results are preliminary, only statistical errors are shown.
Two-particle correlations in $\Delta \eta \Delta \varphi$ in inelastic $p+p$ collisions at beam momenta 20-158 GeV/c ($\sqrt{s_{NN}} = 6.3-17.3$ GeV) were measured.

- $p+p$ data shows structures coming mainly from resonance decays, conservation laws, quantum statistics and Coulomb interactions.
- $C(0; 0)$ increases with energy.
- $C(0; \pi)$ decreases with energy.
- Qualitative agreement with EPOS, disagreement with UrQMD 3.4

Pseudorapidity correlations in inelastic $Be+Be$ collisions at beam momenta 150$A$ GeV/c ($\sqrt{s_{NN}} = 16.8$ GeV) were measured.

- Results are strongly dependent on the position and the distance between the windows
- Long-range multiplicity and event-mean transverse momentum correlations are observed.
Fluctuations: motivation

A.Seryakov

NA61/SHINE proposal
http://cds.cern.ch/record/995681?ln=en
Fluctuations: definitions

Intensive quantity:
- Scaled variance $\omega[A] = \frac{\langle A^2 \rangle - \langle A \rangle^2}{\langle A \rangle}$ Independent of the volume

Strongly intensive quantity:
- $\Delta[A, B] = \frac{1}{C_\Delta} [\langle B \rangle \omega[A] - \langle A \rangle \omega[B]]$
- $\Sigma[A, B] = \frac{1}{C_\Sigma} [\langle B \rangle \omega[A] + \langle A \rangle \omega[B] - 2(\langle AB \rangle - \langle A \rangle \langle B \rangle)]$
  Independent of the volume and the volume fluctuations

$\Delta[A, B] = \Sigma[A, B] = 0$ in the absence of fluctuations
Normalization factors chosen such, that
- both quantities are dimensionless
- $\Delta[A, B] = \Sigma[A, B] = 1$ for the Independent Particle Model

Transverse momentum and multiplicity fluctuation:
- $A = P_t = \sum_{\text{event}} p_{t_i}$
- $B = N$
- $C_\Delta = C_\Sigma = \langle N \rangle \omega(p_t)$

• No centrality dependence in Be+Be
• No sign of any anomaly that can be attributed to CP (both in p+p and Be+Be)

... waiting for Ar+Sc results ...
Thank you!
seryakov@yahoo.com
Two-particle correlations: model test

**NA61/SHINE**
NA61/SHINE preliminary, 20 GeV/c

**EPOS 1.99**
EPOS, 20 GeV/c, NA61 acceptance

**UrQMD 3.4**
UrQMD, 20 GeV/c, NA61 acceptance

EPOS and UrQMD are with NA61 acceptance; all charged particles
EPOS qualitatively agree with the data, UrQMD disagree.

B. Maksiak,
NA61-Theory meeting,
03.12.2014
Transverse momentum and multiplicity fluctuations
Generators test

NA61/SHINE preliminary

A.Seryakov

NA61/SHINE CERN

LUHEP SPbSU
Pseudorapidity correlations: summary

- Pseudorapidity correlations in inelastic Be+Be collisions at beam momenta $150A$ GeV/c ($\sqrt{s_{NN}} = 16.8$ GeV) were measured.

- Results are strongly dependent on the position and the distance between the windows.

- Long-range multiplicity and event-mean transverse momentum correlations are observed.
Two-particle correlations: EPOS 1.99 vs data

- Qualitative agreement with EPOS data
- NA61 acceptance affects weekly results

B. Maksiak [for the NA61/SHINE collaboration], PoS(CPOD2014)055
Two-particle correlations: energy dependence

Unlike-sign charges

The enhancement “saddle” at (0,0) rises, like in previous slide, with increasing beam momentum.

B. Maksiak [for the NA61/SHINE collaboration], PoS(CPOD2014)055
Two-particle correlations:
NA61/SHINE vs ALICE

NA61/SHINE preliminary

20, GeV/c, all charged, $p_T < 1.5$ GeV/c

80, GeV/c, all charged, $p_T < 1.5$ GeV/c

158, GeV/c, all charged, $p_T < 1.5$ GeV/c

ALICE pp @ 0.9 TeV
all pairs

ALICE pp @ 2.76 TeV
all pairs

ALICE pp @ 7 TeV
all pairs

ALICE preliminary

B. Maksiak [for the NA61/SHINE collaboration], PoS (CPOD2014)055
Two-particle correlations: $(0,0) (0,\pi)$

NA61/SHINE preliminary

B. Maksiak [for the NA61/SHINE collaboration], PoS(CPOD2014)055
Two-particle correlations: Pt-influence

- Data and EPOS are in qualitative agreement.
- Results with and without $p_t < 1.5$ GeV/c cut are similar.
- No jet peak is visible at 158 GeV/c ($\sqrt{s_{NN}} = 17.3$ GeV)
Fluctuations: **scaled variance**

NA61/SHINE preliminary

T. Czopowicz [for the NA61/SHINE collaboration], PoS(CPOD2014)055
Charge pseudorapidity fluctuations
Be+Be 150A GeV/c 0-20% centrality

- $\Delta[A, B] = \frac{1}{C_\Delta} \left[ \langle B \rangle \omega[A] - \langle A \rangle \omega[B] \right]
- $\Sigma[A, B] = \frac{1}{C_\Sigma} \left[ \langle B \rangle \omega[A] + \langle A \rangle \omega[B] - 2(\langle AB \rangle - \langle A \rangle \langle B \rangle) \right]

- $A = N_+$
- $B = N_-$
- $C_\Delta = N_- - N_+$
- $C_\Sigma = N_- + N_+$

EPOS 1.99 describes behavior qualitatively ($\Delta$) and quantitatively ($\Sigma$)
Pseudorapidity correlations: windows selection

Results for:

**Pseudorapidity**

**connected windows**

- x-axis: $\frac{\eta_F + \eta_B}{2}$
  (windows connection point)
- window length: 0.5

**disconnected windows**

- x-axis: $\eta_F - \eta_B$
  (distance between windows)
- window length: 0.5
Pseudorapidity correlations: results
Be+Be 150A GeV/c 0-20% centrality

- Strong dependence on the windows position
- EPOS 1.99 describe the data qualitatively

Event and track cuts were chosen to select only inelastic interactions with particles produced in strong and EM processes within the NA61/SHINE acceptance. The results are corrected on detector effects: tracking inefficiencies, trigger bias. The results are preliminary, only statistical errors are shown.
Pseudorapidity correlations: results
Be+Be 150A GeV/c 0-20% centrality

Disconnected windows

A.Seryakov SQM 2015
Pseudorapidity correlations: results
Be+Be 150A GeV/c 0-20% centrality

NA61/SHINE preliminary

Disconnected windows

$\beta_{rel}[Pt_{B^{-}}, N_{F^{+}}]$
Pseudorapidity correlations: results
Be+Be 150A GeV/c 0-20% centrality

NA61/SHINE preliminary

Disconnected windows

\[ b_{rel}[Pt_B, Pt_F] \]

\[ b_{rel}[Pt_{B*}, Pt_{F*}] \]

\[ b_{rel}[Pt_{B-}, Pt_{F-}] \]
Pseudorapidity correlations: \textbf{results} 
\textbf{Be+Be} 150A GeV/c 0-20\% centrality

\textbf{NA61/SHINE preliminary}

\textbf{Connected windows}

\begin{itemize}
  \item $b_{\text{rel}}[N_{B^*},N_F]$
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\end{itemize}

\begin{itemize}
  \item EPOS 1.99: NA61 acceptance
  \item EPOS 1.99: 4pi acceptance
  \item NA61/SHINE
\end{itemize}
Pseudorapidity correlations: results
Be+Be 150A GeV/c 0-20% centrality

NA61/SHINE preliminary

Connected windows

![Graphs showing pseudorapidity correlations with various markers and data points]

- EPOS 1.99: NA61 acceptance
- EPOS 1.99: 4pi acceptance
- NA61/SHINE
Pseudorapidity correlations: results
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Connected windows

- EPOS 1.99: NA61 acceptance
- EPOS 1.99: 4pi acceptance
- NA61/SHINE

A.Seryakov
NA61/SHINE CERN
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