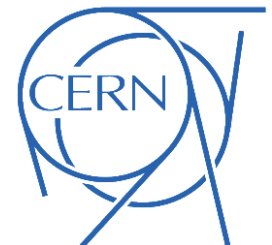


Correlations and fluctuations in p+p and Be+Be at the SPS energies from NA61/SHINE

Andrey Seryakov
for the NA61/SHINE collaboration
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Laboratory of Ultra-High Energy Physics
St. Petersburg State University

25/08/2015
Crete, Greece

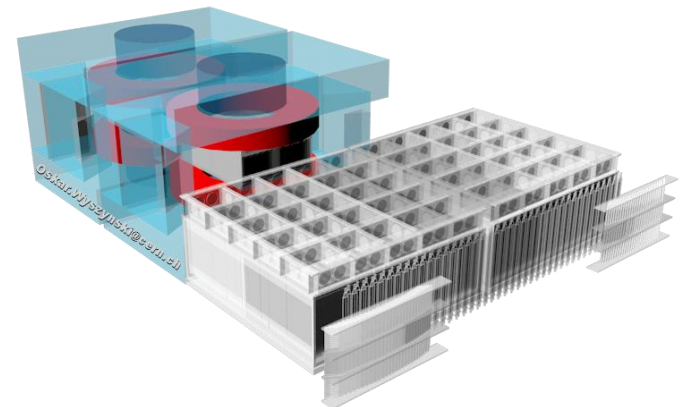


Correlations:

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

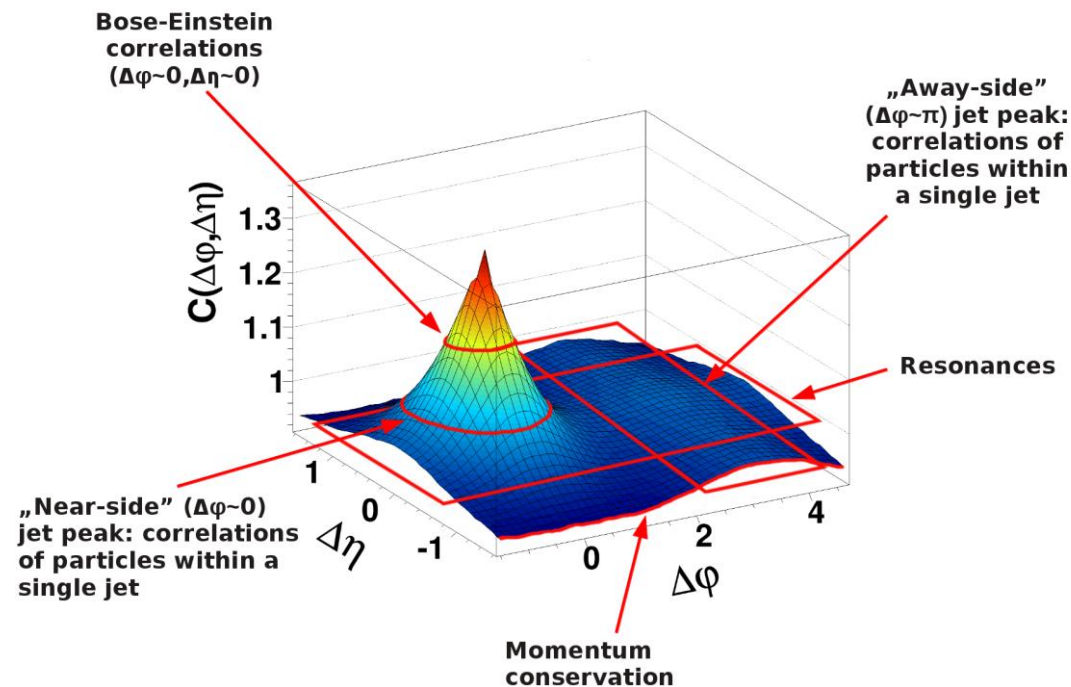
Fluctuations (ω , Δ , Σ):

- Transverse momentum and multiplicity fluctuations in p+p and Be+Be



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

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

$$\Delta\eta = |\eta_1 - \eta_2|$$

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 $\Delta\varphi = 2\pi - \Delta\varphi$

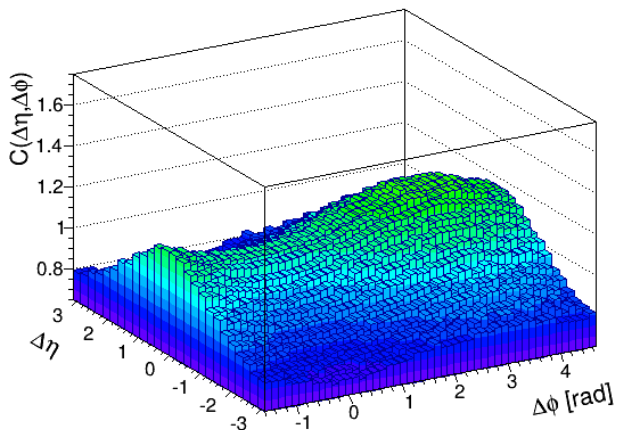
$$C(\Delta\eta, \Delta\varphi) = \frac{N_{mixed}^{pairs}}{N_{data}^{pairs}} \frac{S(\Delta\eta, \Delta\varphi)}{M(\Delta\eta, \Delta\varphi)}$$
$$S(\Delta\eta, \Delta\varphi) = \frac{d^2 N^{signal}}{d\Delta\eta d\Delta\varphi}; \quad M(\Delta\eta, \Delta\varphi) = \frac{d^2 N^{mixed}}{d\Delta\eta d\Delta\varphi}$$

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).

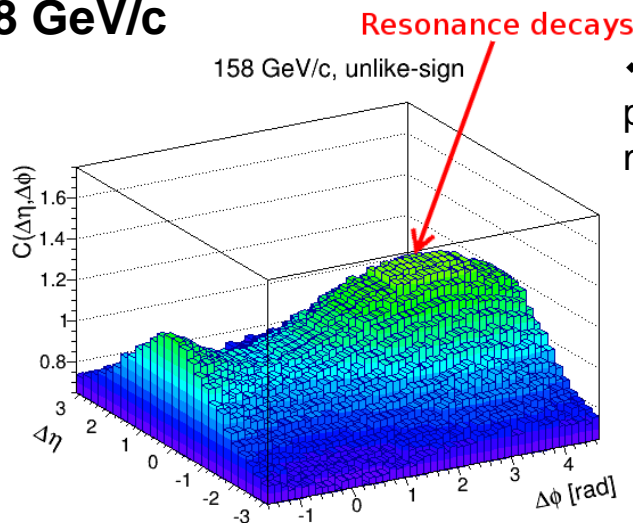
NA61/SHINE preliminary

p+p 158 GeV/c

158 GeV/c, all charged

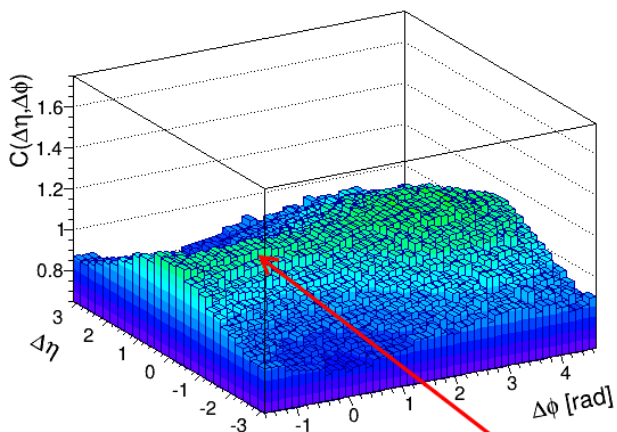


158 GeV/c, unlike-sign

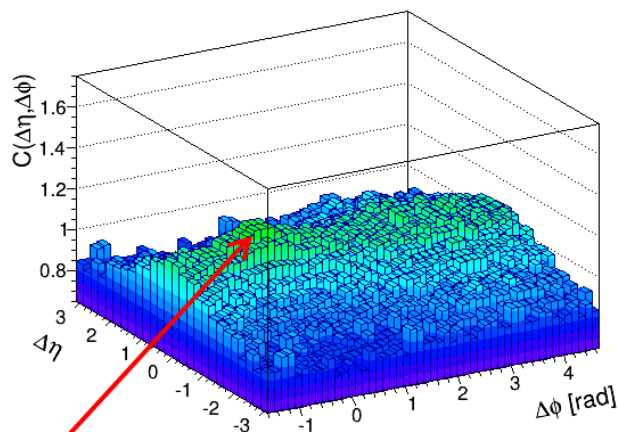


- ❖ Maximum at $(\Delta\eta, \Delta\phi) = (0, \pi)$ probably resonance decays and momentum conservation.
 - the strongest in unlike-sign pairs,
 - still visible in positively charged pairs (Δ^{++} decay),
 - non-visible in negatively charged (almost no double-negative resonances).

158 GeV/c, pos. charged



158 GeV/c, neg. charged

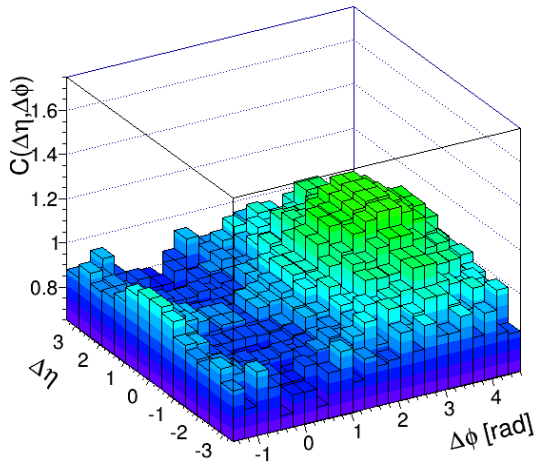


- ❖ An enhancement at $(0; 0)$ - probably Coulomb or quantum statistics effects.
 - weak in unlike-sign pairs,
 - clearly visible in same charge pairs.

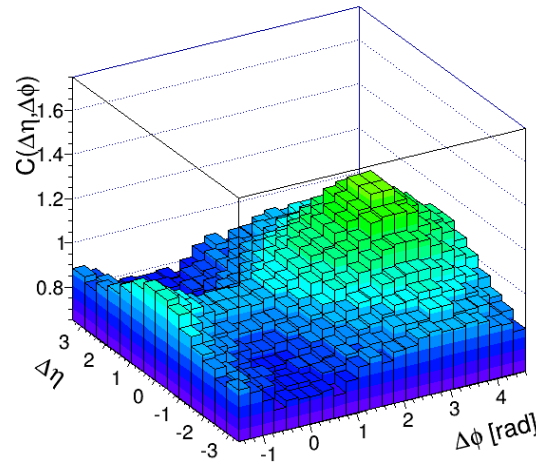
Bose-Einstein correlations

NA61/SHINE preliminary

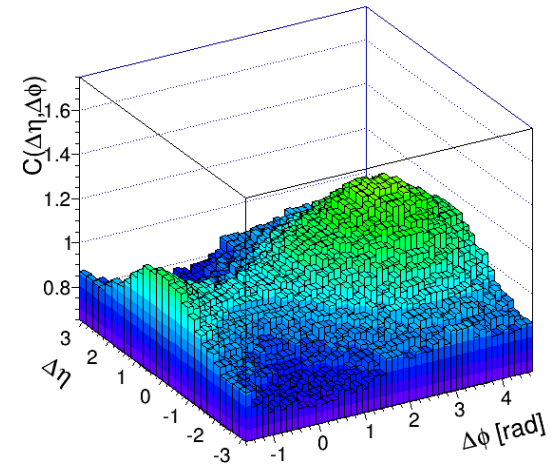
20, GeV/c, all charged, $p_T < 1.5$ GeV/c



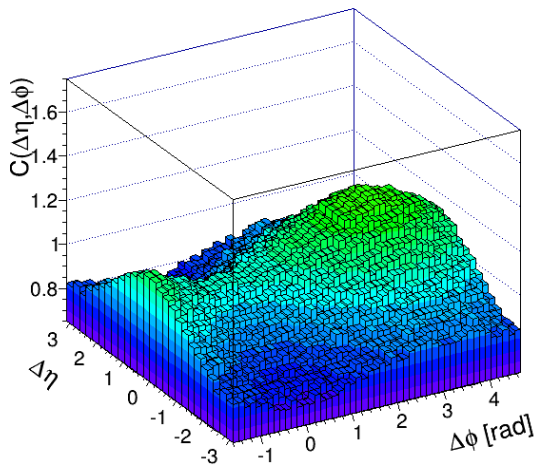
31, GeV/c, all charged, $p_T < 1.5$ GeV/c



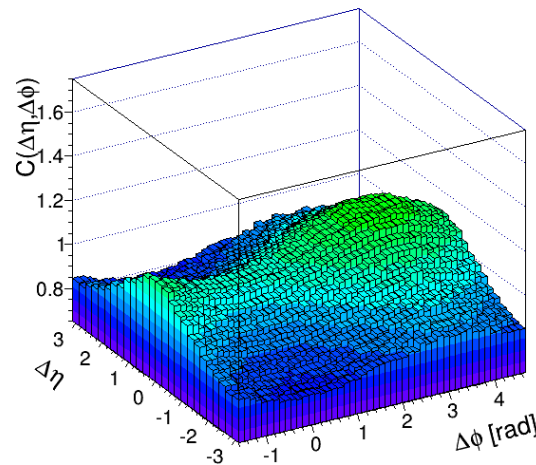
40, GeV/c, all charged, $p_T < 1.5$ GeV/c



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



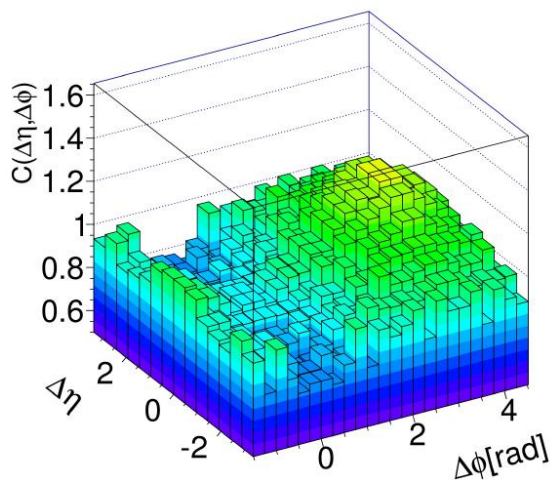
158, GeV/c, all charged, $p_T < 1.5$ GeV/c



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

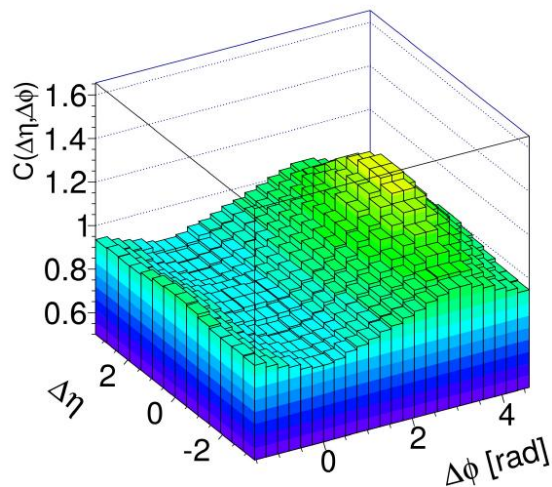
NA61/SHINE

NA61/SHINE preliminary, 20 GeV/c



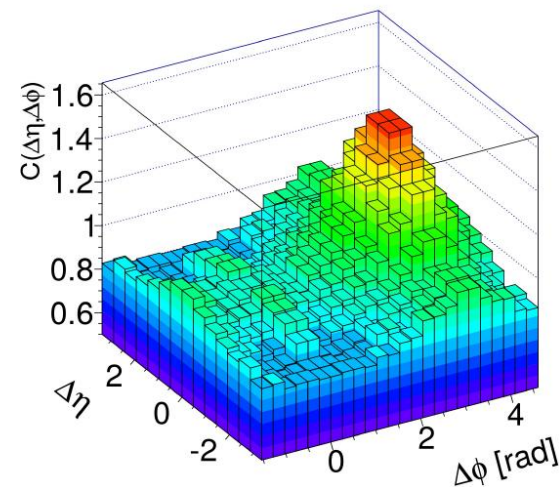
EPOS 1.99

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

B. Maksiak,
NA61-Theory meeting,
03.12.2014

EPOS qualitatively agree with the data
UrQMD disagree

Long-range pseudorapidity correlations between particles are expected to be sensitive to the early stage of heavy ion collisions

- Color string fusion phenomenon (SFM)

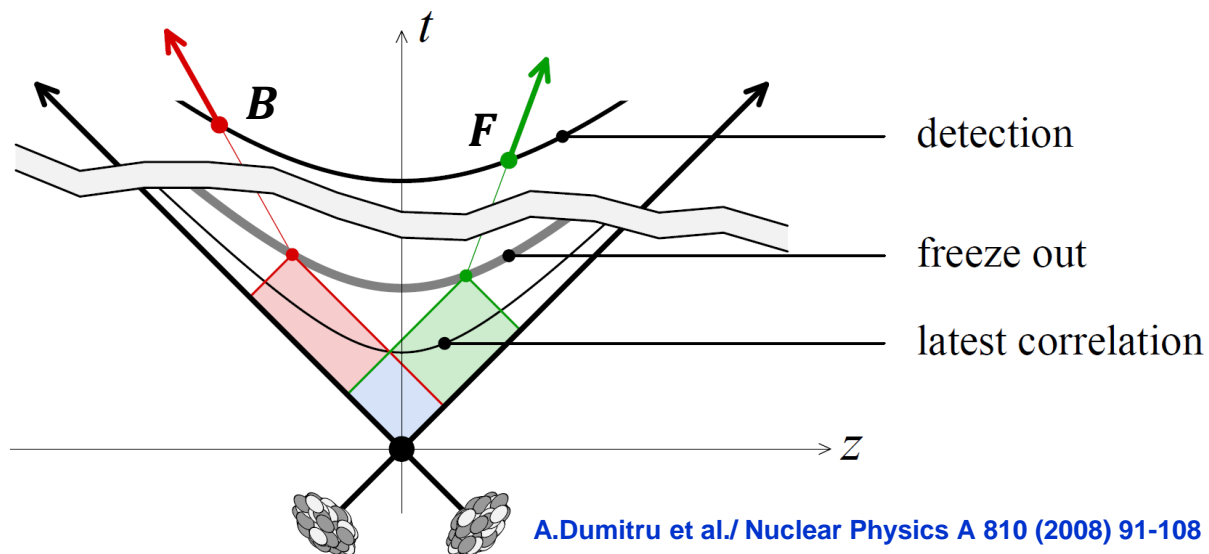
M.A.Braun and C.Pajares (see Phys. Lett. B287 (1992) 154; Nucl. Phys. B390 (1993) 542, 549);

- Color Glass Condensate (CGC) and Glasma flux tubes

L.McLerran, Nucl.Phys.A699,73c(2002)

However many other effects could play role in pseudorapidity correlations:

- Jets
- Flow
- Resonance decays
- Quantum statistic effects
- Conservation laws



B – an observable in “backward” pseudorapidity windows
 F – an observable in “forward” pseudorapidity windows

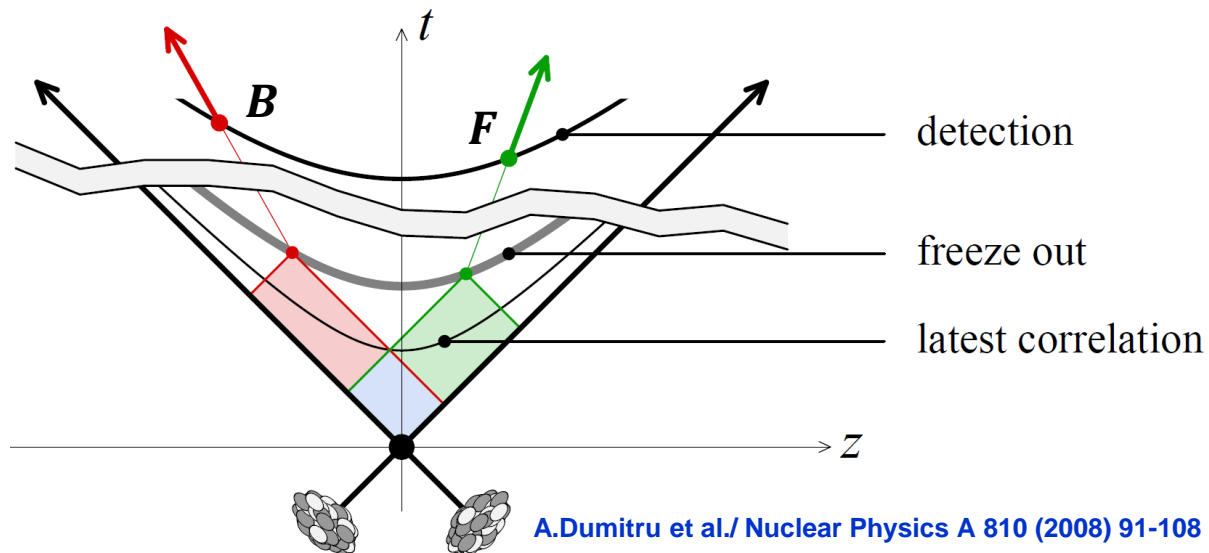
$$b[B, F] = \frac{\langle BF \rangle - \langle B \rangle \langle F \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$

To reduce trivial correlations
 du to variation of volume

$$B \rightarrow B / \langle B \rangle = B_{rel}$$

$$F \rightarrow F / \langle F \rangle = F_{rel}$$

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

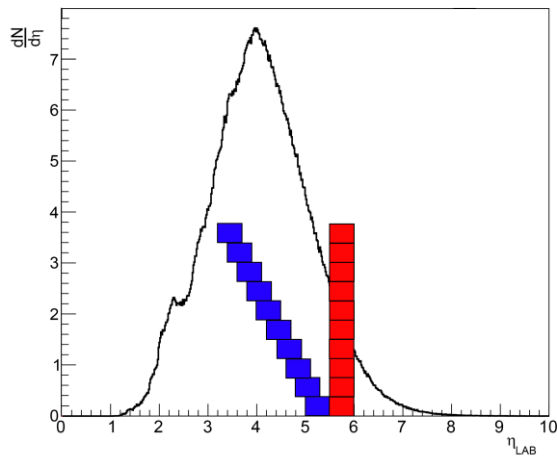
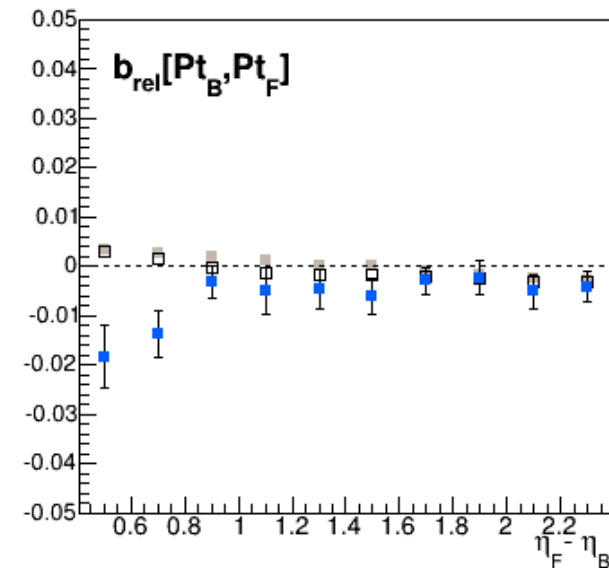
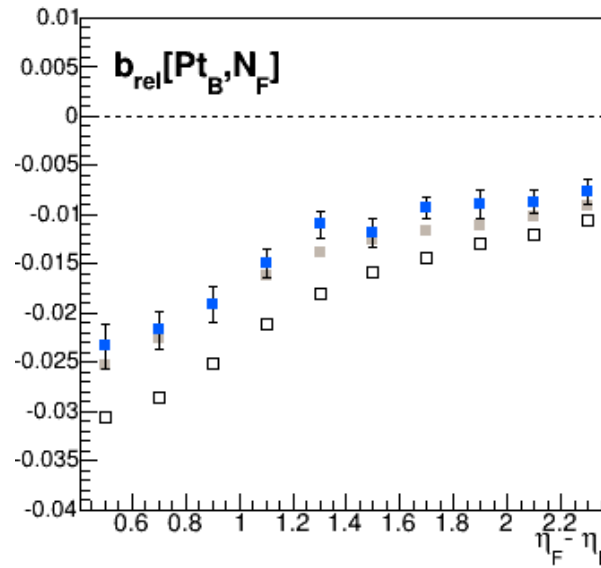
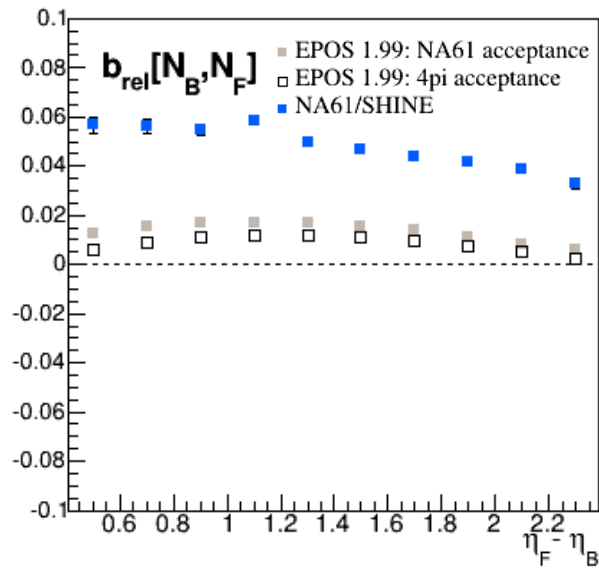


Possible selections of B and F :

- $N_B N_F$ - the correlation between charged particle multiplicities
- $Pt_B N_F$ - the correlation between the **event mean** transverse momentum (B) and multiplicity (F)
- $Pt_B Pt_F$ - 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

NA61/SHINE preliminary

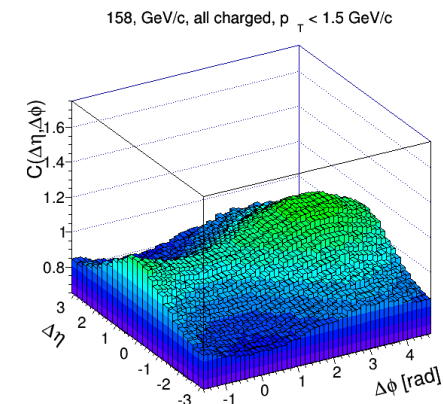
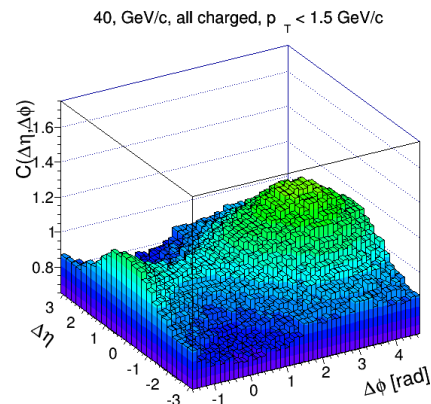
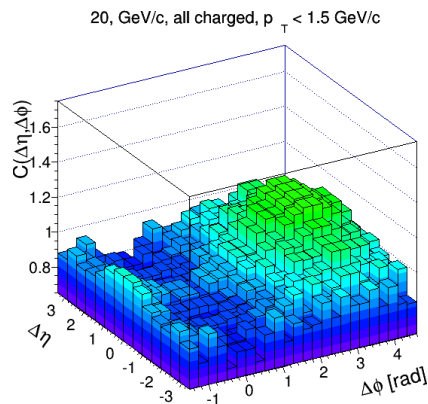
Disconnected windows



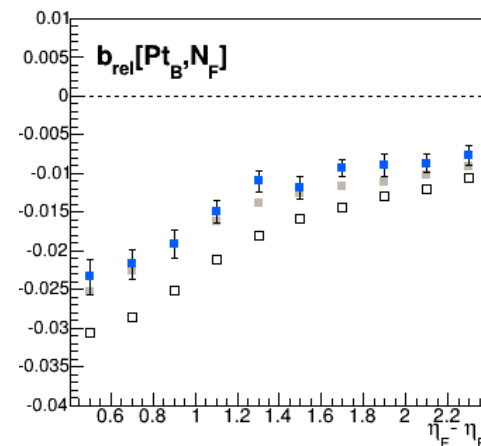
- Strong dependence on the windows position
- EPOS 1.99 describes the data only qualitatively

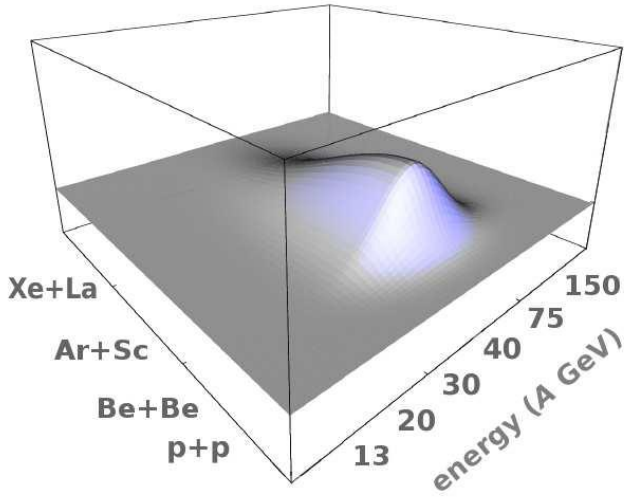
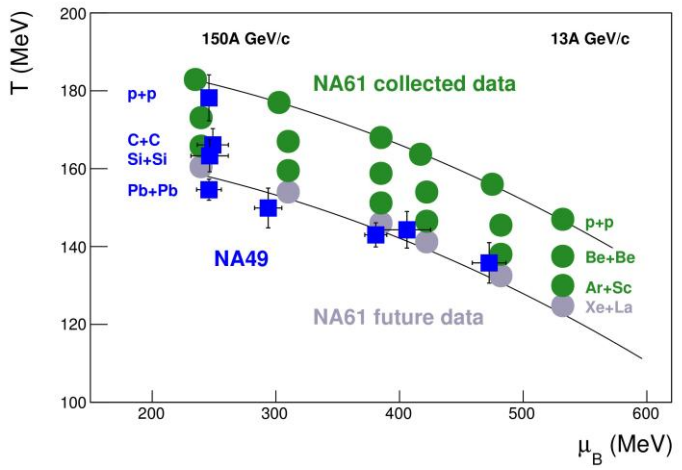
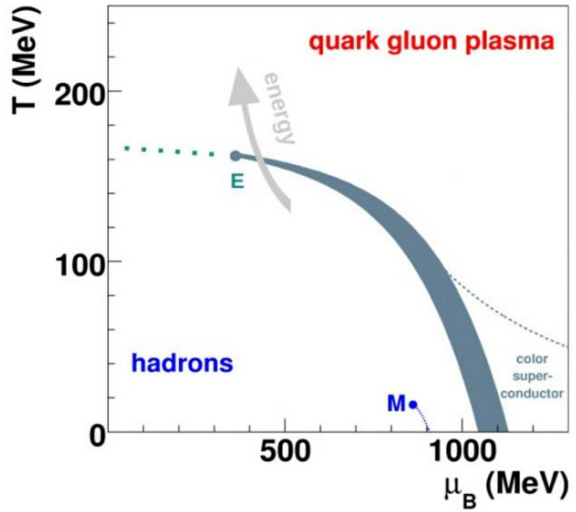
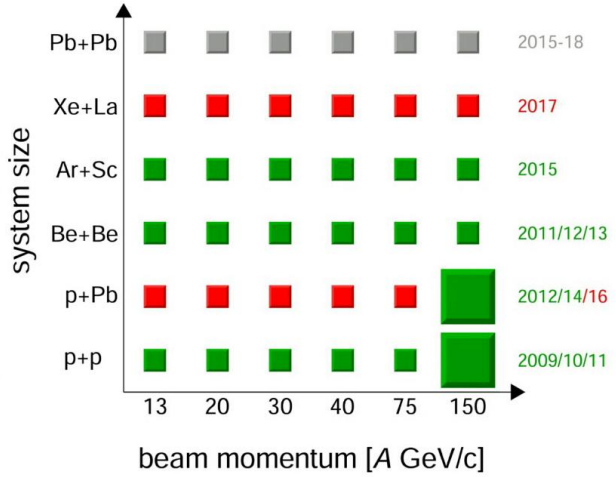
Event and track cuts were chosen to select only inelastic interactions with particles produced in strong and EM processes within the NA61/SHINE acceptance. The results are corrected on detector effects: tracking inefficiencies, trigger bias. The results are preliminary, only statistical errors are shown

- Two-particle correlations in $\Delta\eta\Delta\phi$ 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 $150A$ 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.





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

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

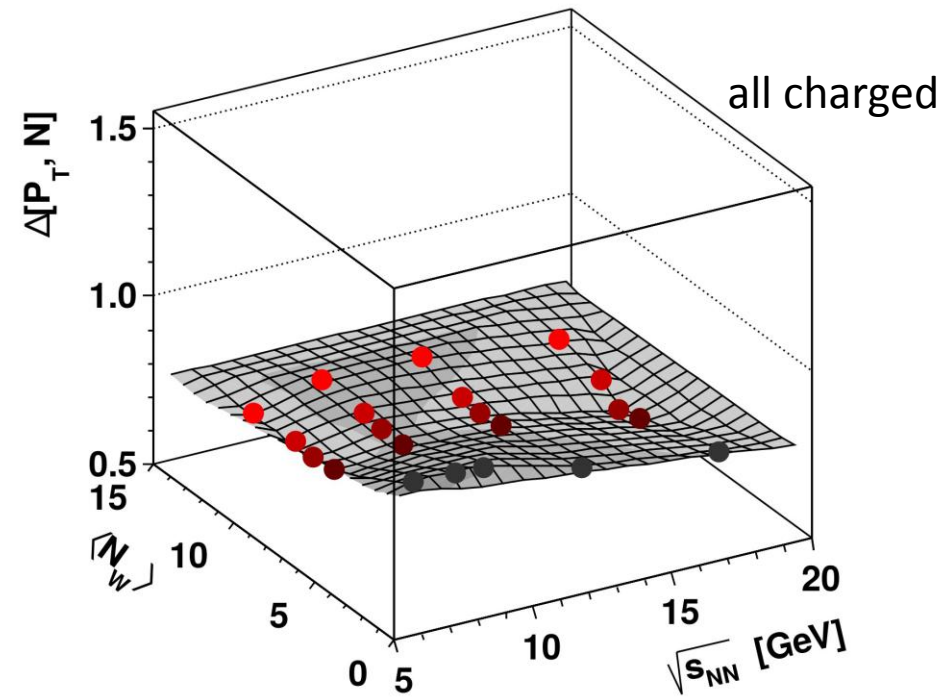
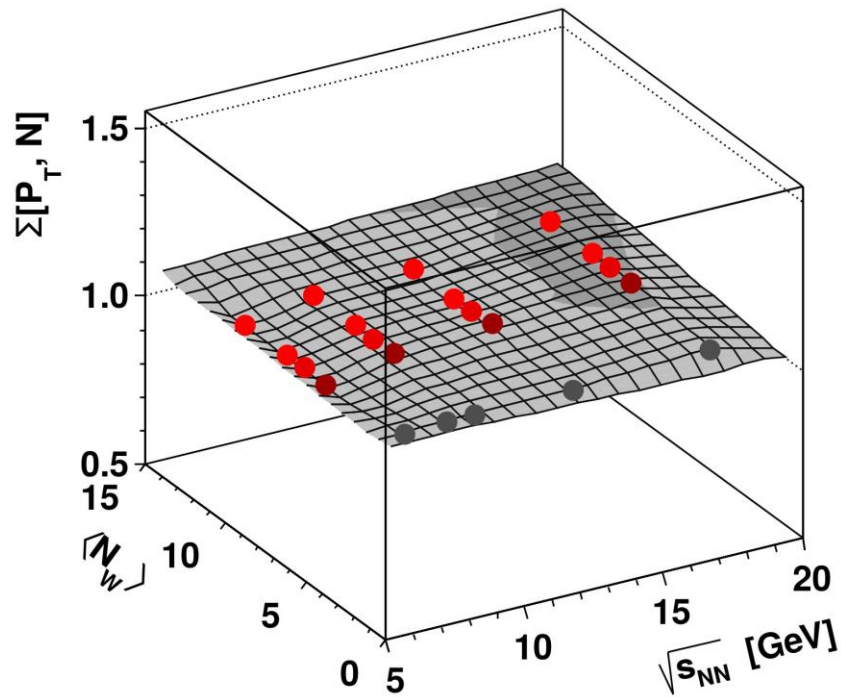
- both quantities are dimensionless
- $\Delta[A, B] = \Sigma[A, B] = 1$ for the Independent Particle Model

Transverse momentum and multiplicity fluctuation:

- $A = P_t = \sum_{event} p_{t_i}$
- $B = N$
- $C_\Delta = C_\Sigma = \langle N \rangle \omega(p_t)$

M.Gorenstein, M.Gazdzicki, Phys. Rev. C **84** (2011) 014904

M.Gorenstein, M.Gazdzicki, M.Mackowiak-Pawlowska, Phys. Rev. C **88** (2013) 2, 024907



- 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 ...

M. Gaździcki, P. Seyboth, arXiv:1506.08141;
 based on T. Czopowicz, CPOD 2014
 (slides and arXiv:1503.01619)

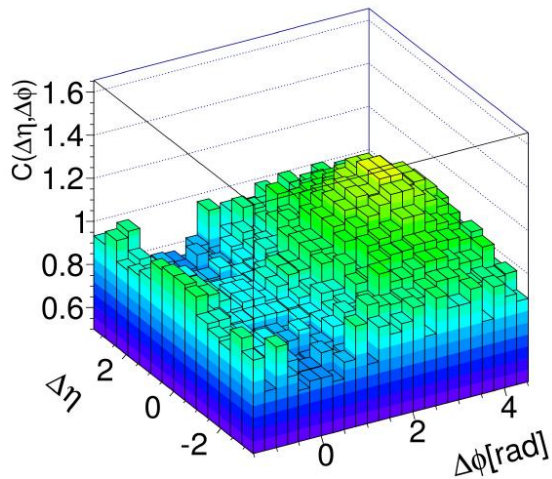
Thank you!

seryakov@yahoo.com

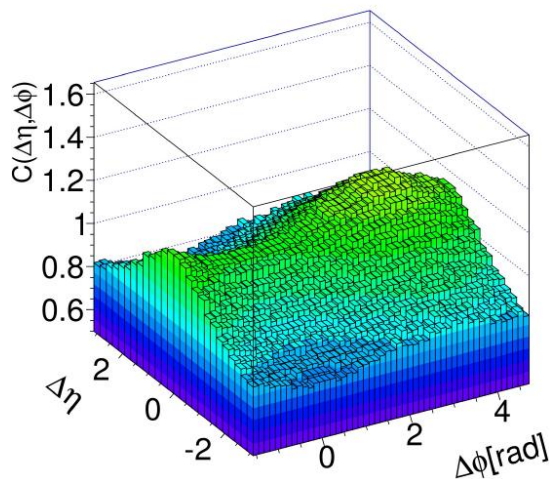


NA61/SHINE

NA61/SHINE preliminary, 20 GeV/c

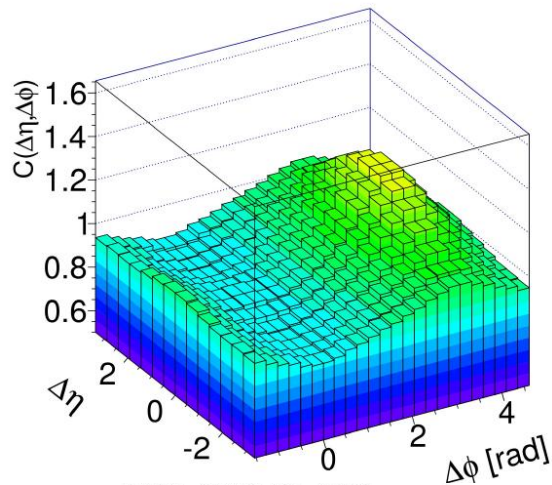


NA61/SHINE preliminary, 158 GeV/c

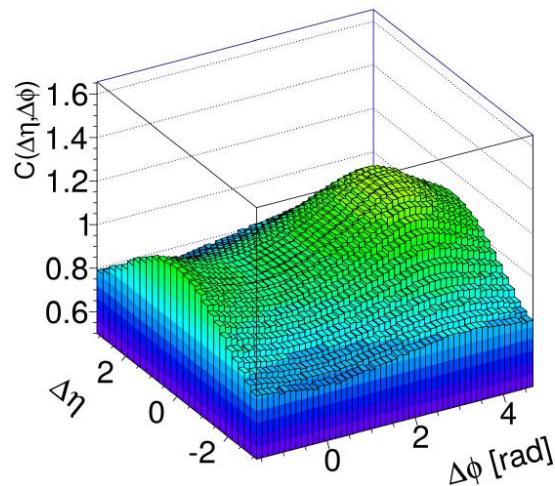


EPOS 1.99

EPOS, 20 GeV/c, NA61 acceptance

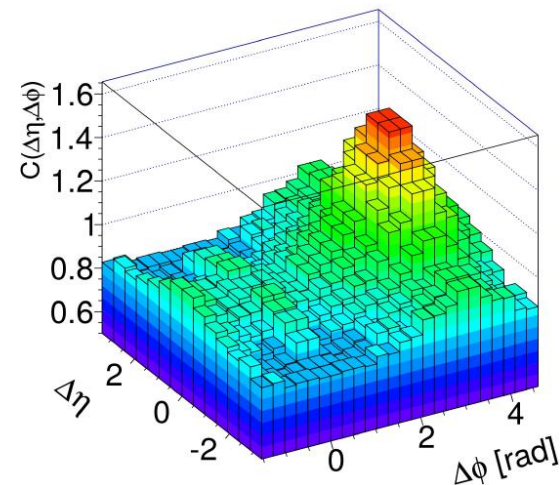


EPOS, 158 GeV/c, NA61 acceptance

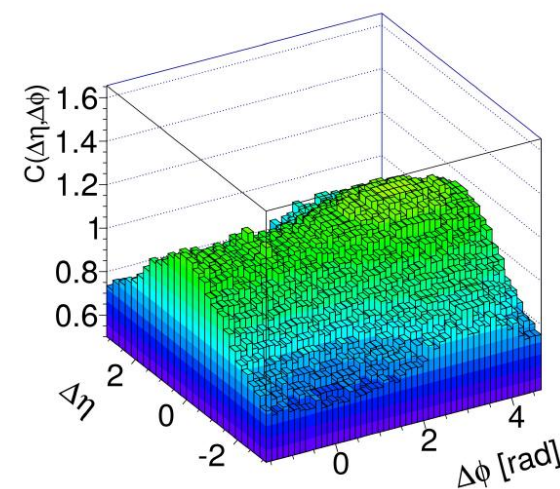


UrQMD 3.4

UrQMD, 20 GeV/c, NA61 acceptance

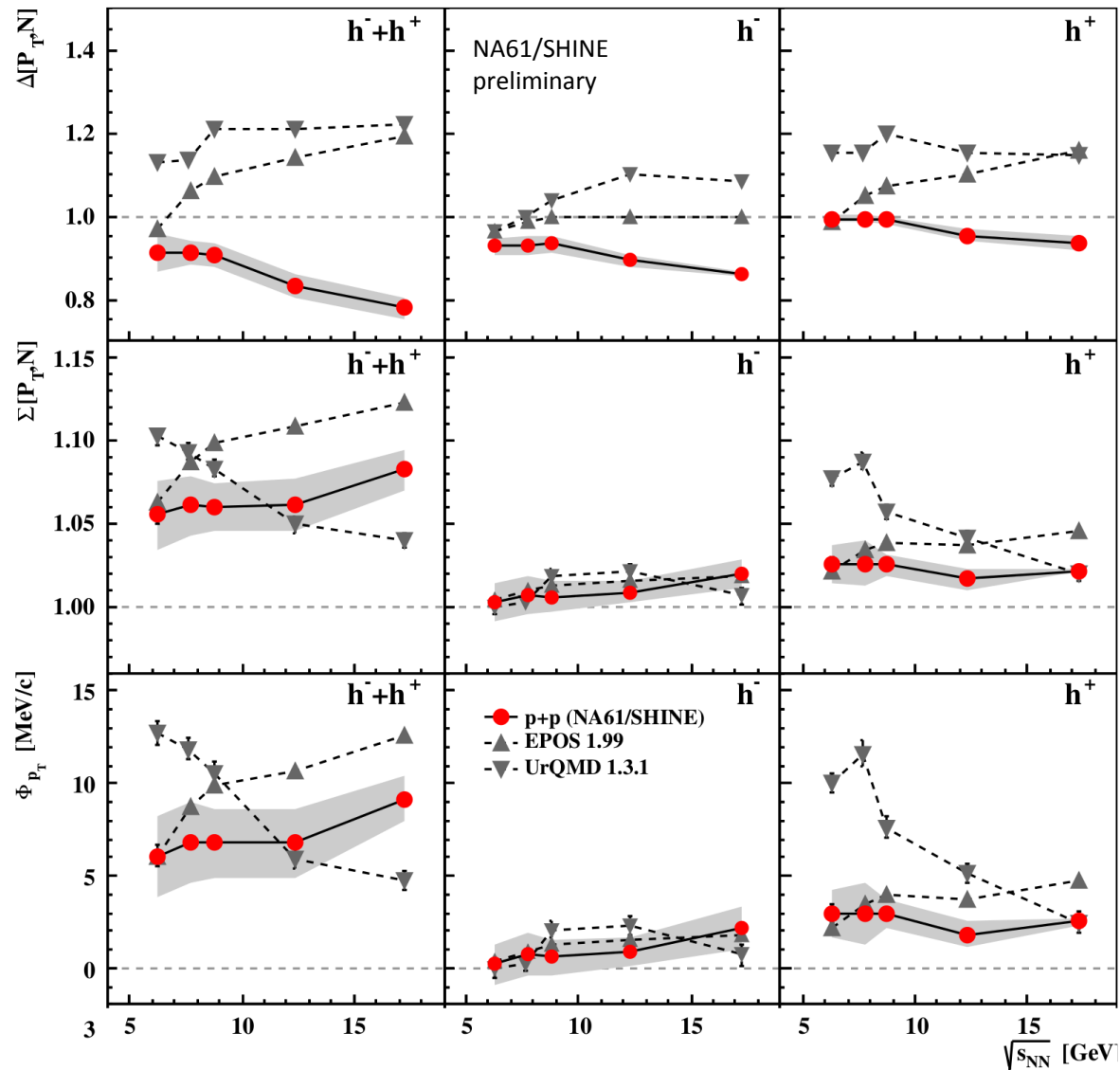


UrQMD, 158 GeV/c, NA61 acceptance

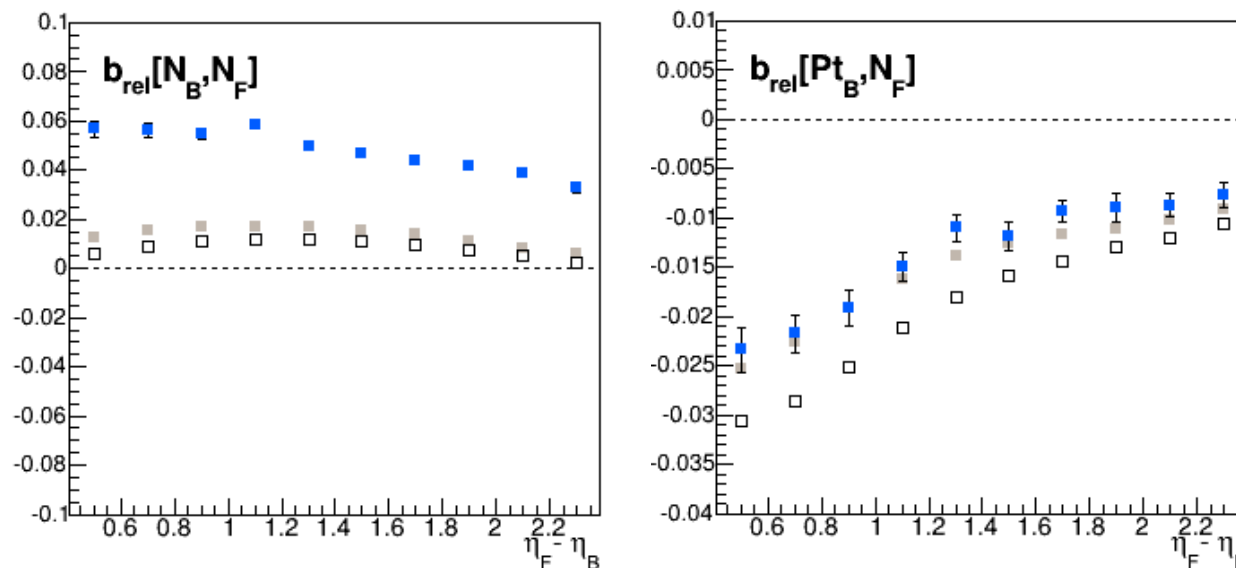


EPOS and UrQMD are with NA61 acceptance; all charged particles
EPOS qualitatively agree with the data, UrQMD disagree.

B. Maksiak,
NA61-Theory meeting,
03.12.2014



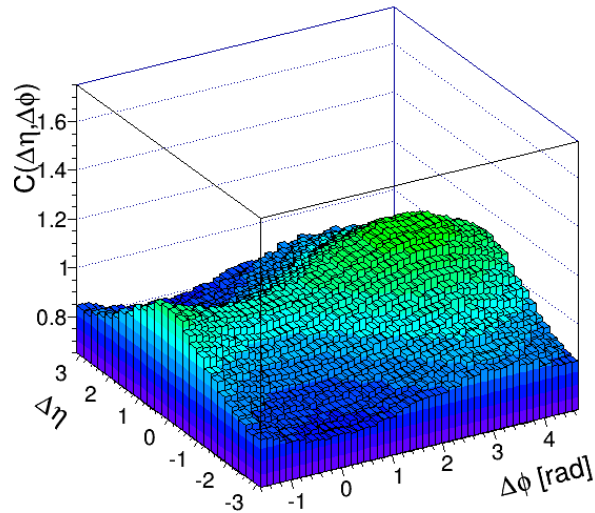
- Pseudorapidity correlations in inelastic Be+Be collisions at beam momenta $150A$ GeV/c ($\sqrt{s_{NN}} = 16.8$ GeV) were measured.
- Results are strongly dependent on the position and the distance between the windows
- Long-range multiplicity and event-mean transverse momentum correlations are observed.



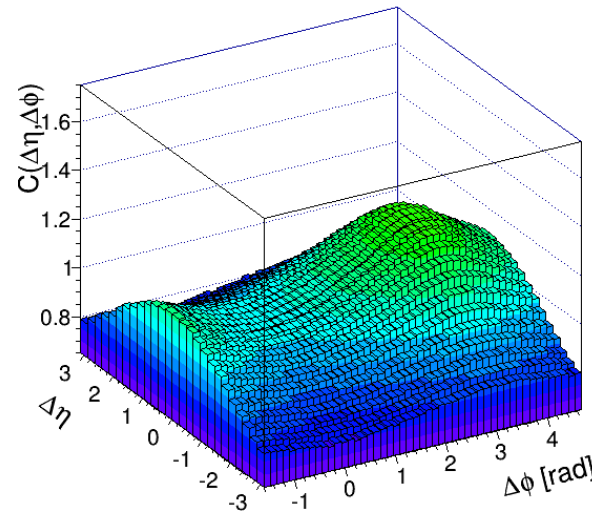
NA61/SHINE preliminary

p+p 158 GeV/c all charged

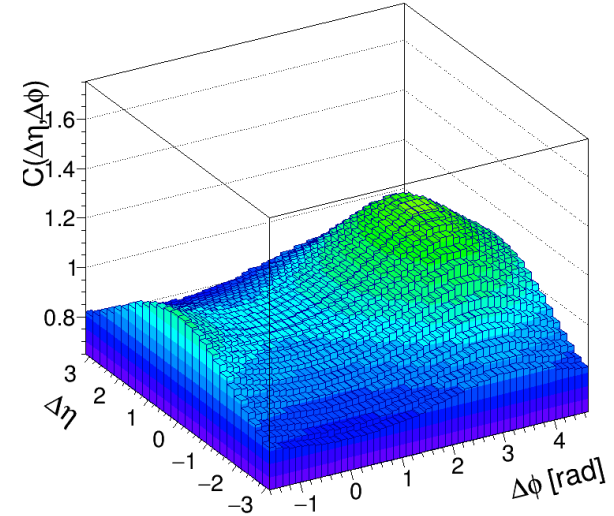
NA61/SHINE



EPOS: NA61 acceptance



EPOS: 4π acceptance

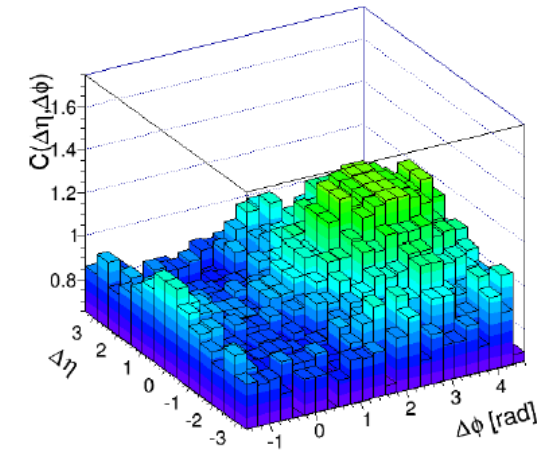


- Qualitative agreement with EPOS data
- NA61 acceptance affects weekly results

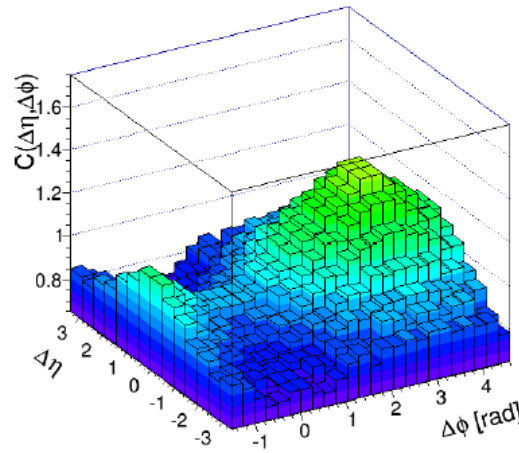
NA61/SHINE preliminary

Unlike-sign charges

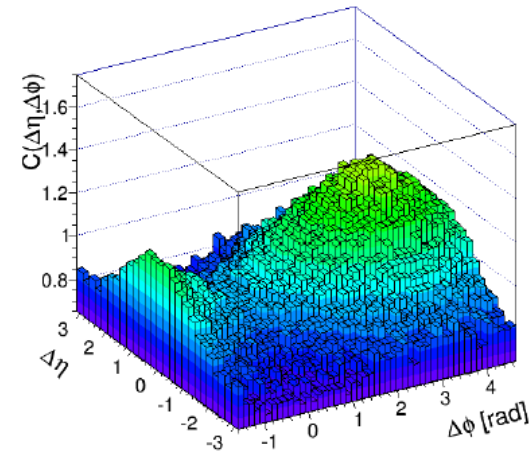
20, GeV/c, unlike-sign, $p_T < 1.5$ GeV/c



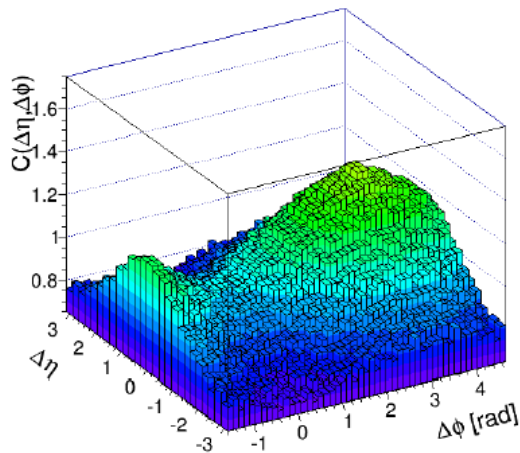
31, GeV/c, unlike-sign, $p_T < 1.5$ GeV/c



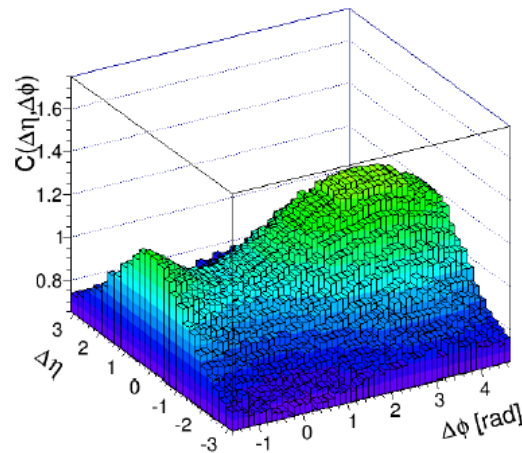
40, GeV/c, unlike-sign, $p_T < 1.5$ GeV/c



80, GeV/c, unlike-sign, $p_T < 1.5$ GeV/c



158, GeV/c, unlike-sign, $p_T < 1.5$ GeV/c

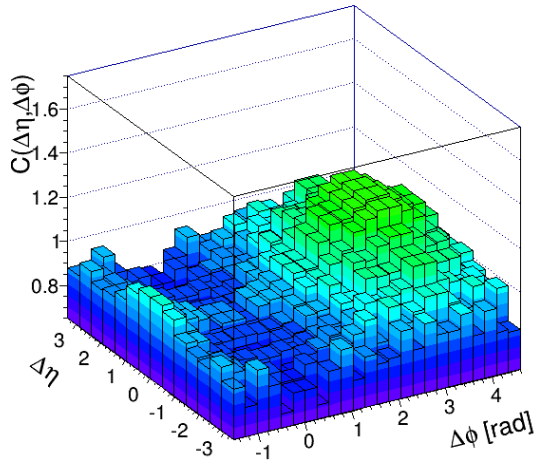


The enhancement “saddle” at (0,0) rises, like in previous slide, with increasing beam momentum

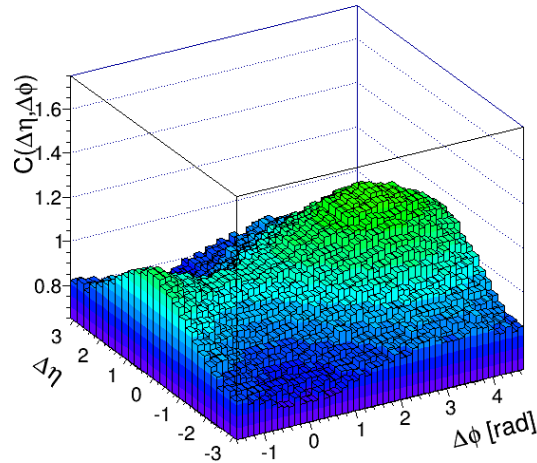
Two-particle correlations: NA61/SHINE vs ALICE

NA61/SHINE preliminary

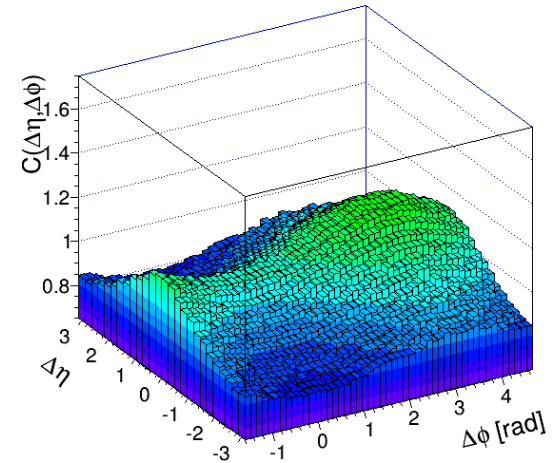
20, GeV/c, all charged, $p_T < 1.5$ GeV/c



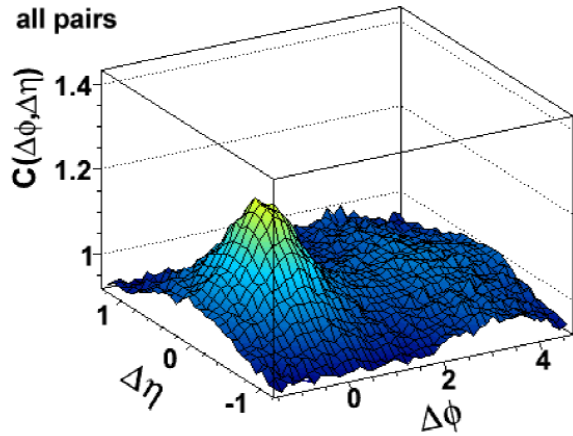
80, GeV/c, all charged, $p_T < 1.5$ GeV/c



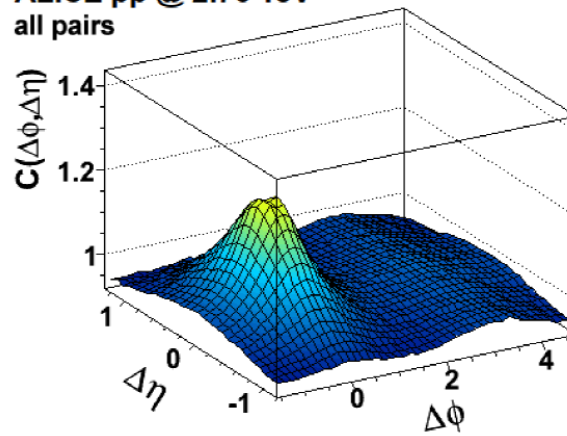
158, GeV/c, all charged, $p_T < 1.5$ GeV/c



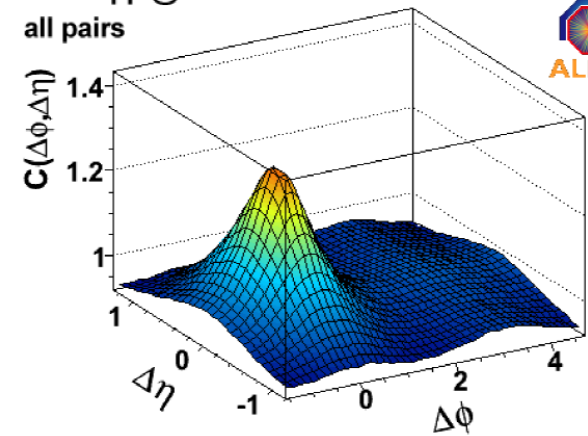
ALICE pp @ 0.9 TeV
all pairs



ALICE pp @ 2.76 TeV
all pairs



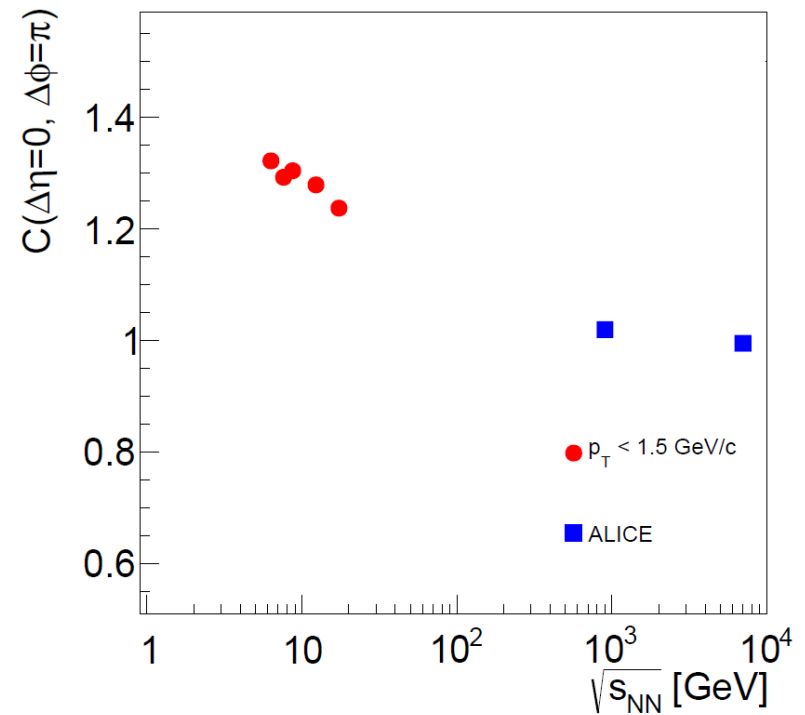
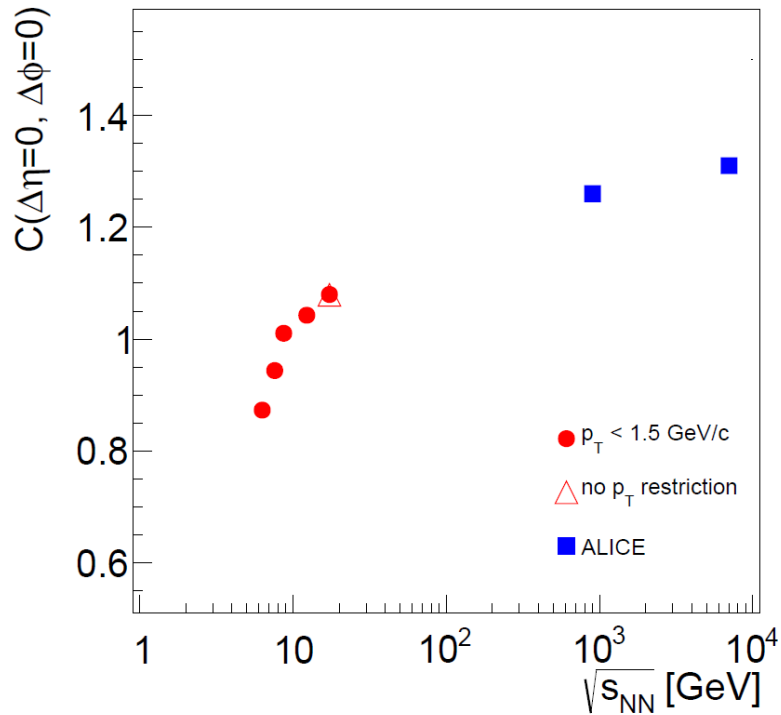
ALICE pp @ 7 TeV
all pairs



ALICE preliminary

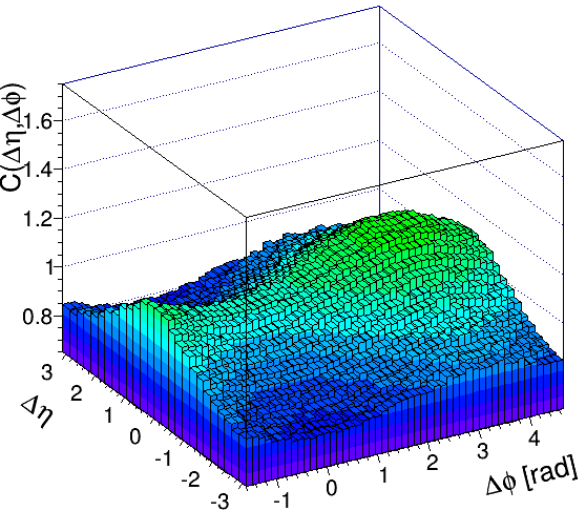


NA61/SHINE preliminary

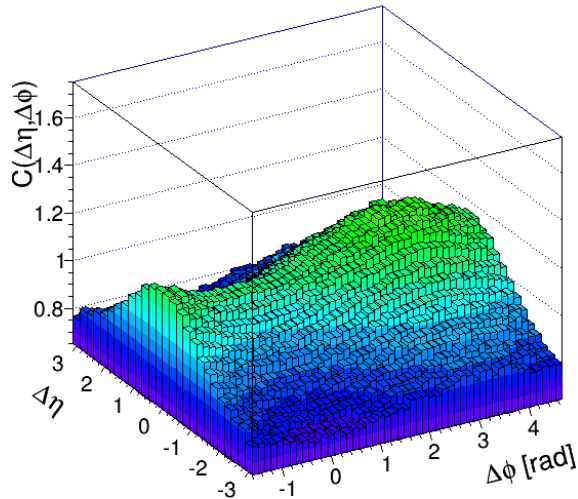


NA61/SHINE preliminary

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

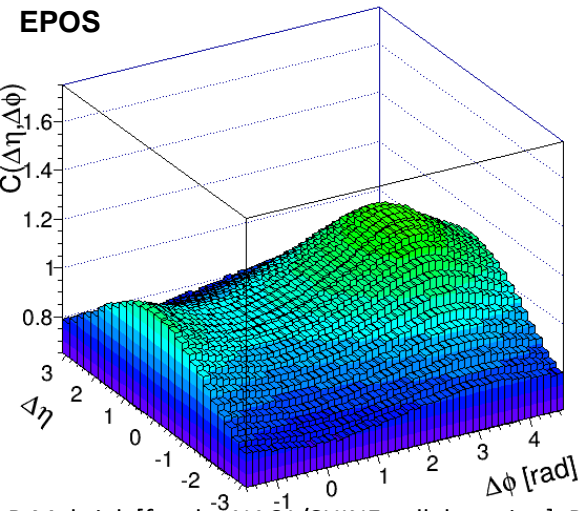


158 GeV/c, all charged, full p_T spectrum

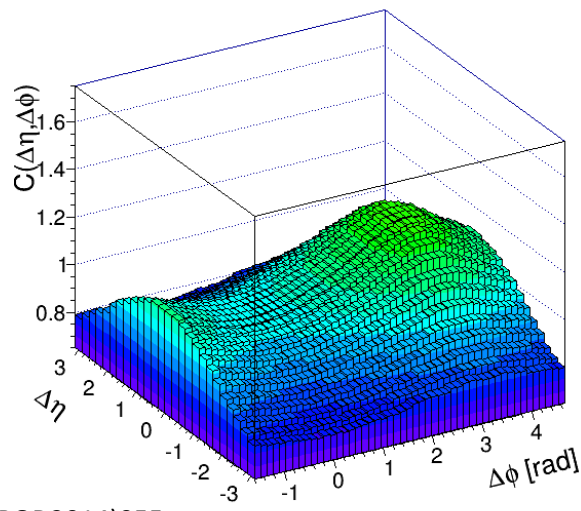


158 GeV/c, all charged, $p_T < 1.5$ GeV/c

EPOS



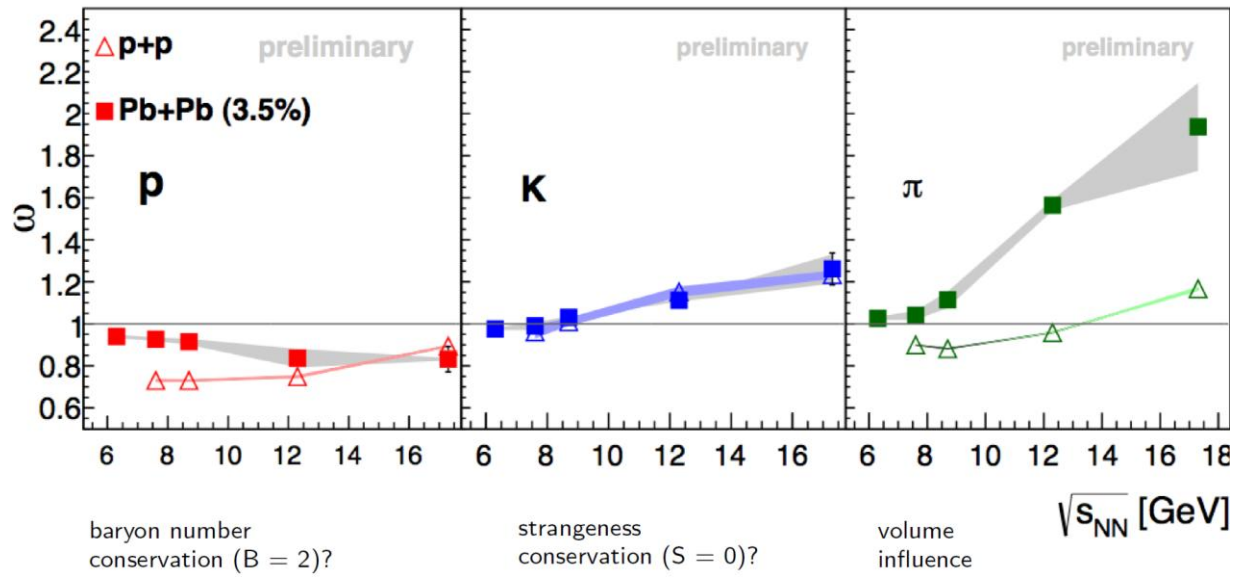
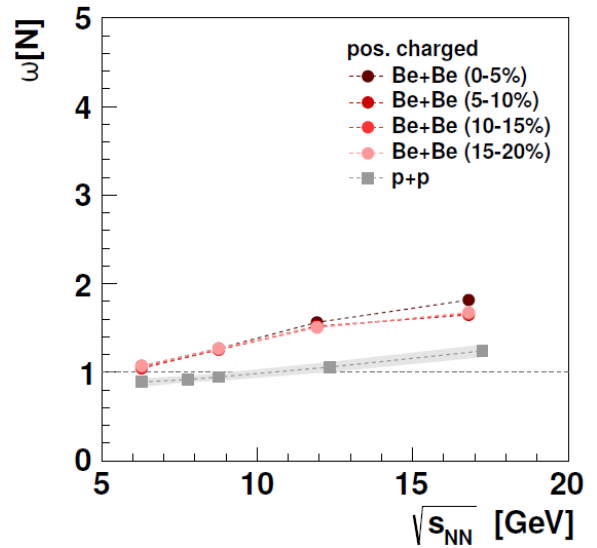
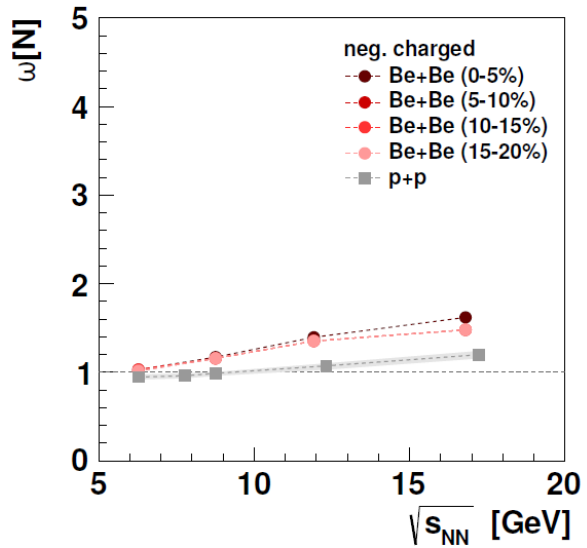
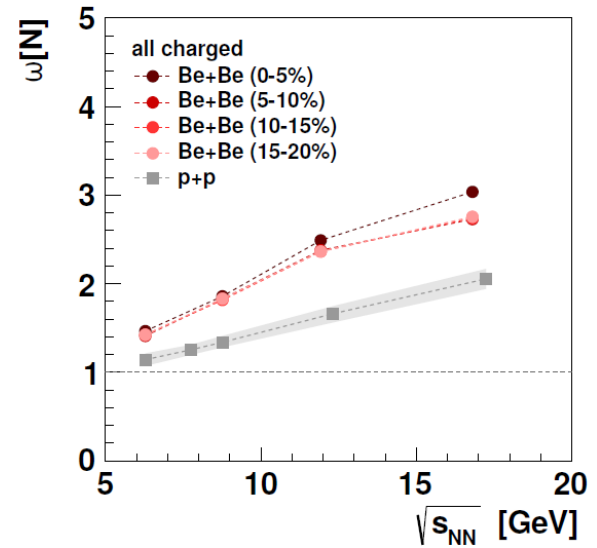
158 GeV/c, all charged, full p_T spectrum



- 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)

NA61/SHINE preliminary

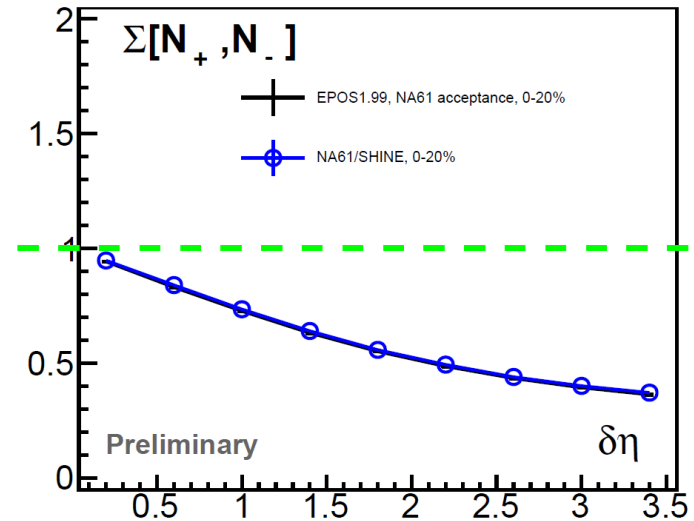
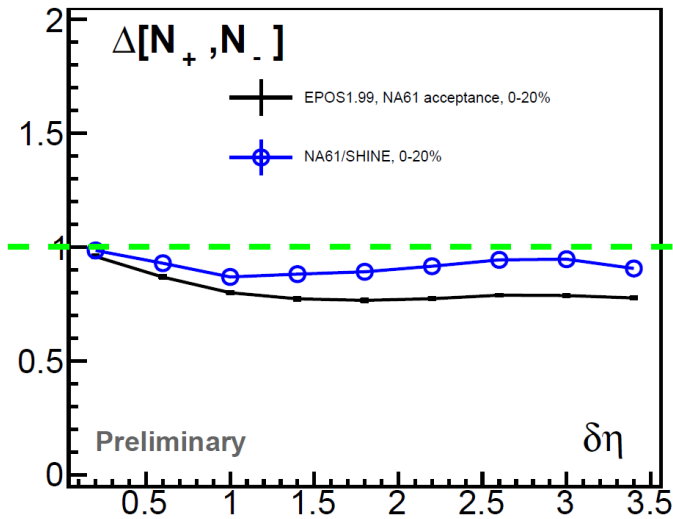
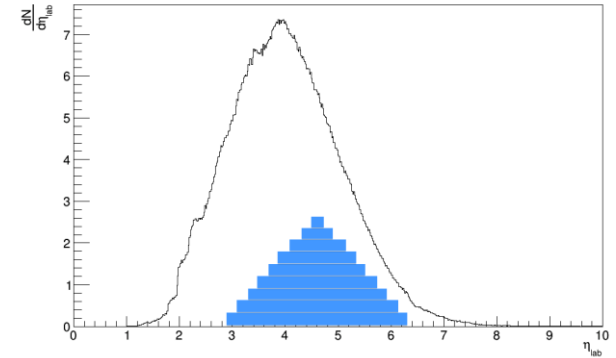
T. Czopowicz[for the NA61/SHINE collaboration], PoS(CPOD2014)055



E.Andronov SQM 2015

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

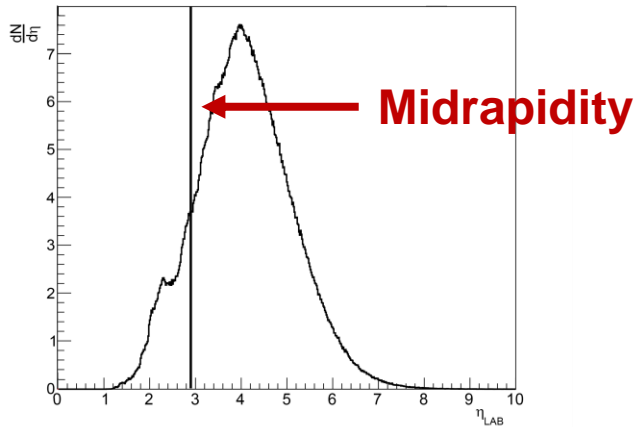
- $A = N_+$ $B = N_-$
- $C_\Delta = N_- - N_+$ $C_\Sigma = N_- + N_+$



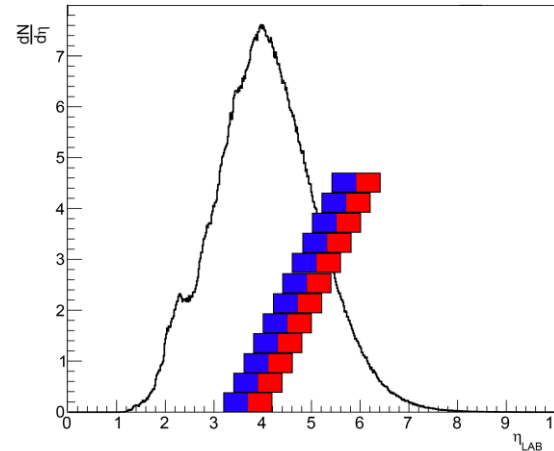
EPOS 1.99 describes behavior qualitatively (Δ) and quantitatively (Σ)

Results for:

Pseudorapidity

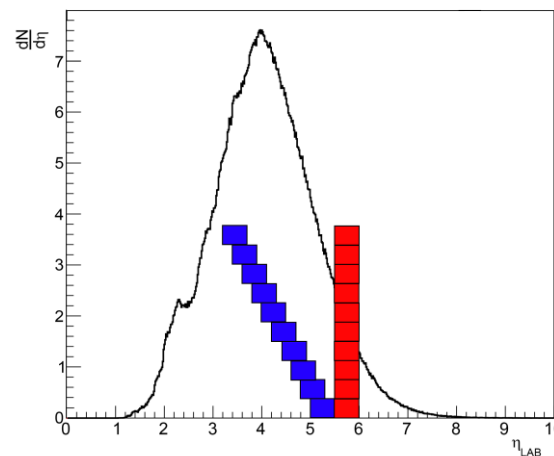


connected windows

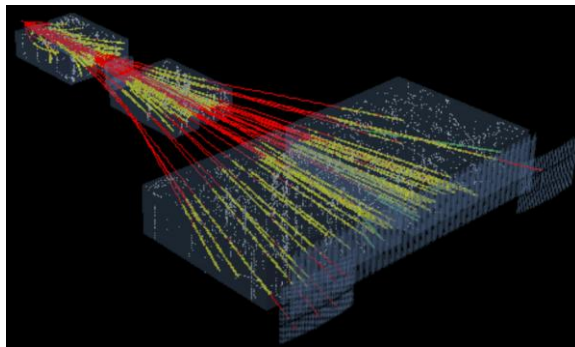


- x-axis: $\frac{\eta_F + \eta_B}{2}$
(windows connection point)
- window length: 0.5

disconnected windows



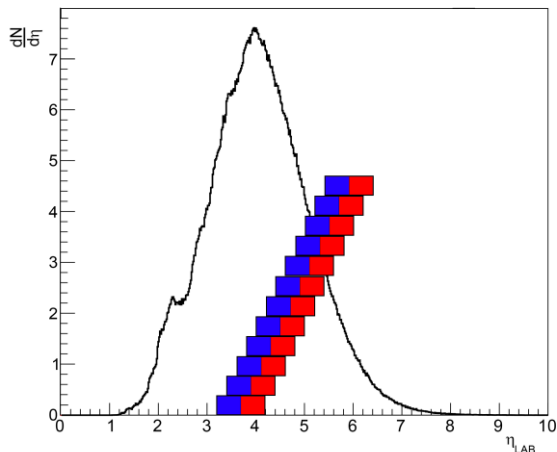
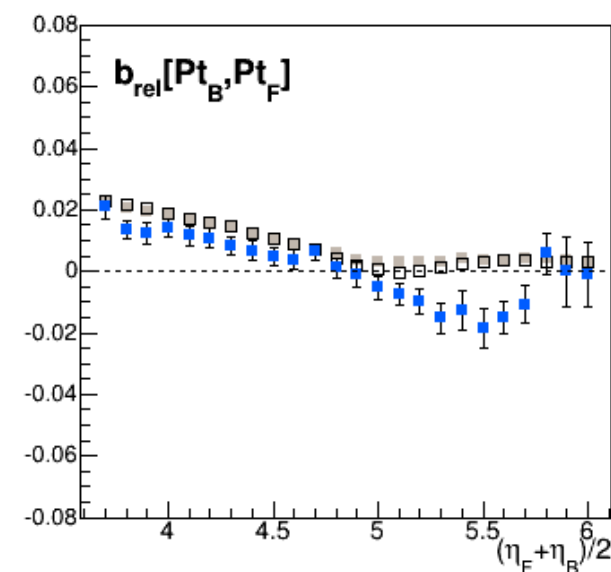
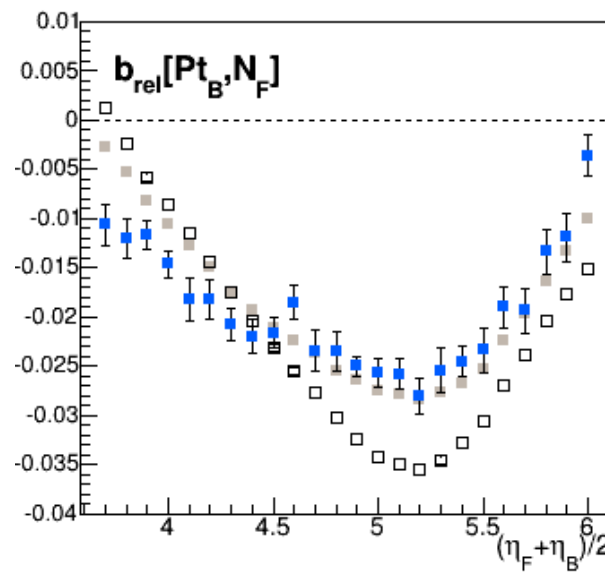
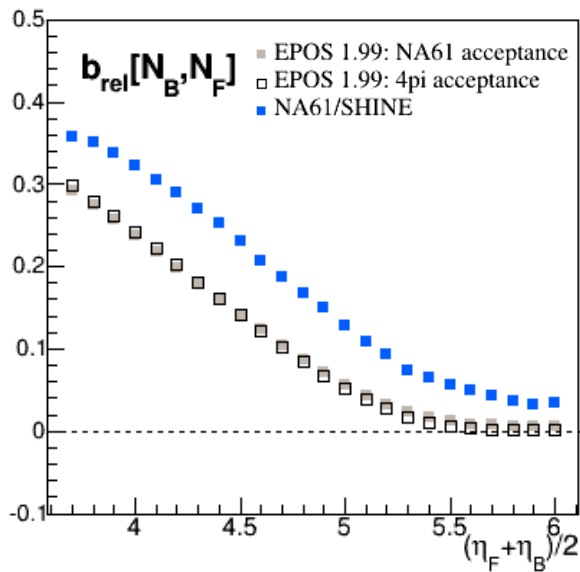
- x-axis: $\eta_F - \eta_B$
(distance between windows)
- window length: 0.5



NA61/SHINE preliminary

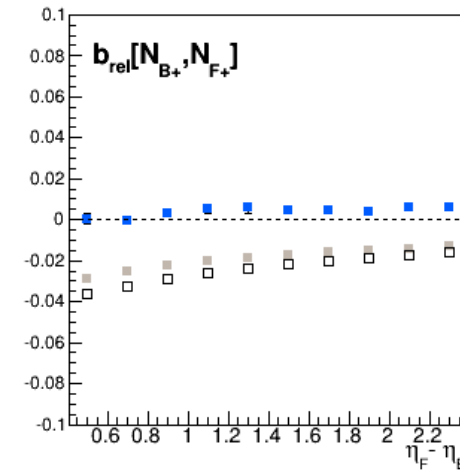
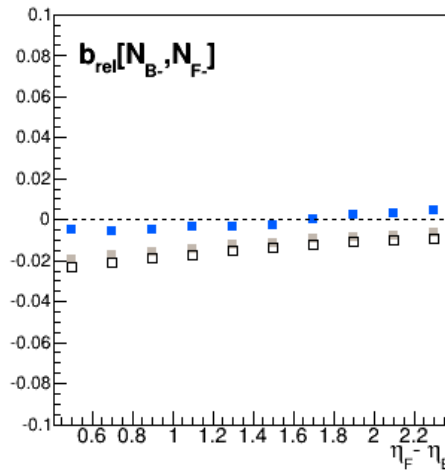
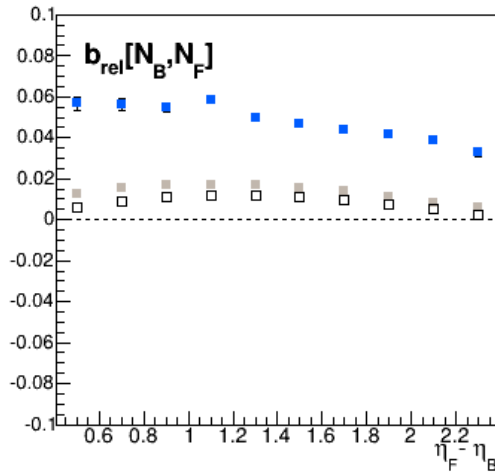
Connected windows

A.Seryakov SQM 2015

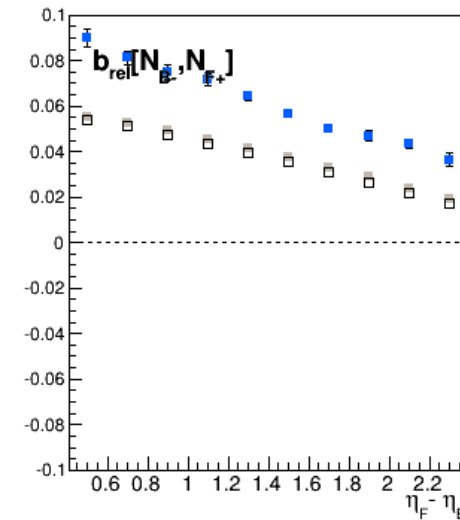
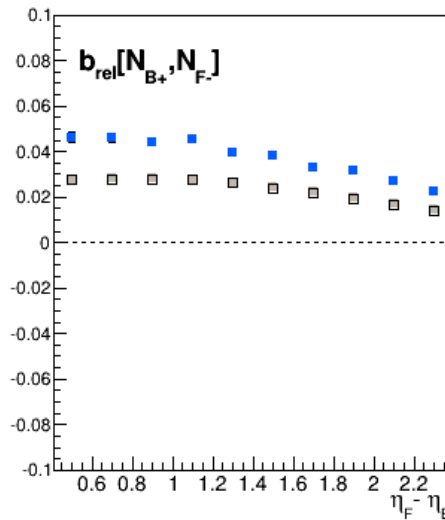
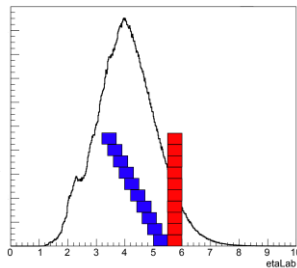


- Strong dependence on the windows position
- EPOS 1.99 describe the data qualitatively

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

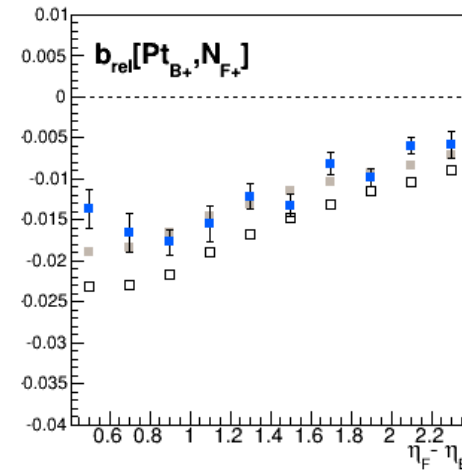
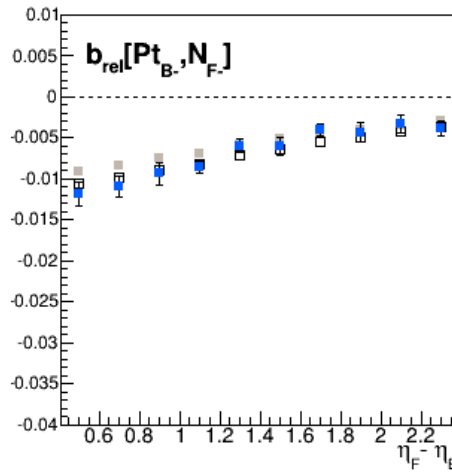
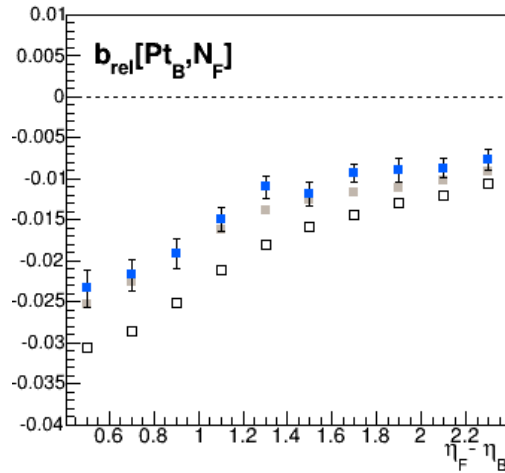


- EPOS 1.99: NA61 acceptance
- EPOS 1.99: 4pi acceptance
- NA61/SHINE

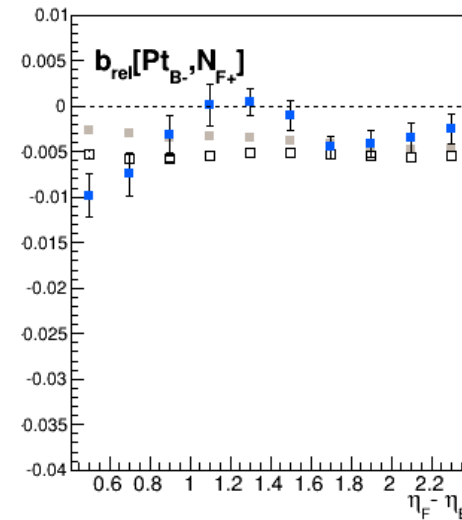
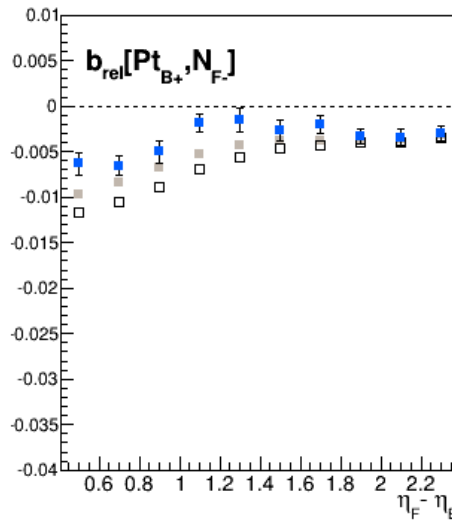
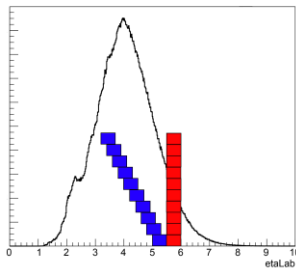


NA61/SHINE preliminary

Disconnected windows

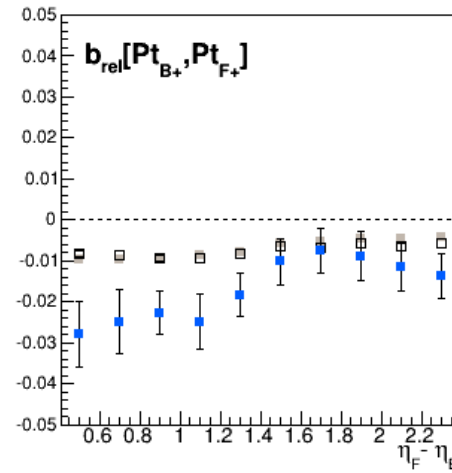
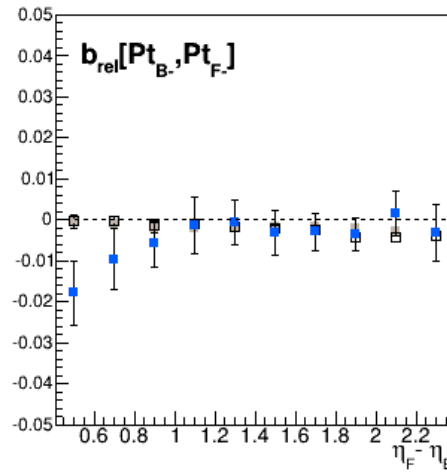
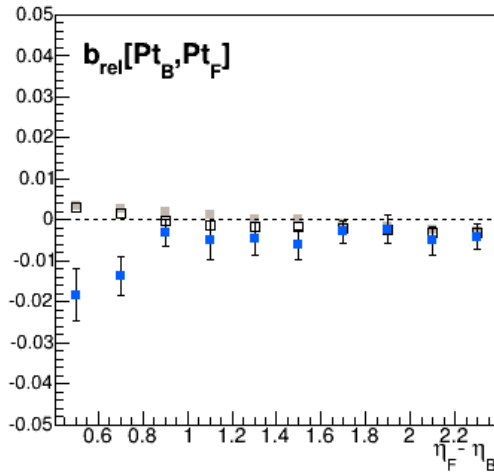


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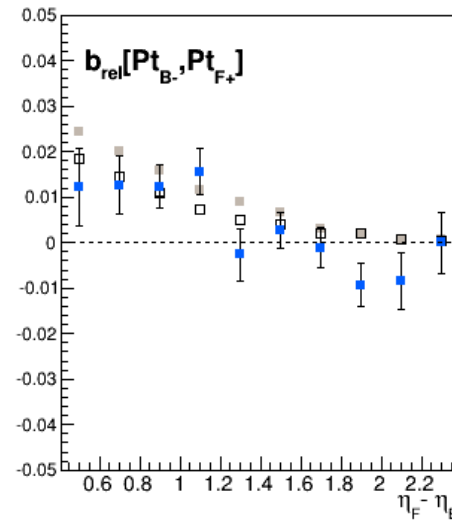
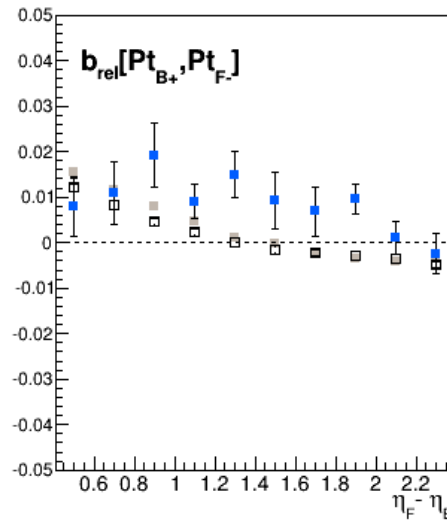
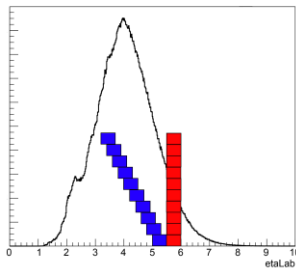


NA61/SHINE preliminary

Disconnected windows

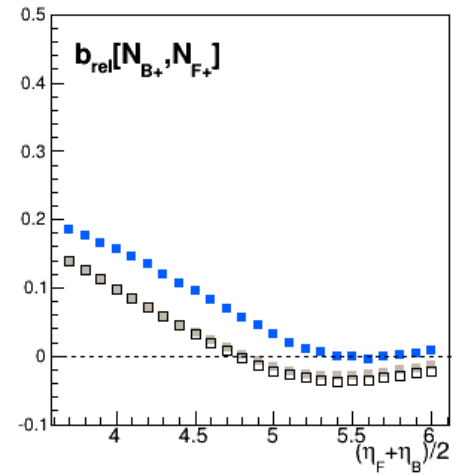
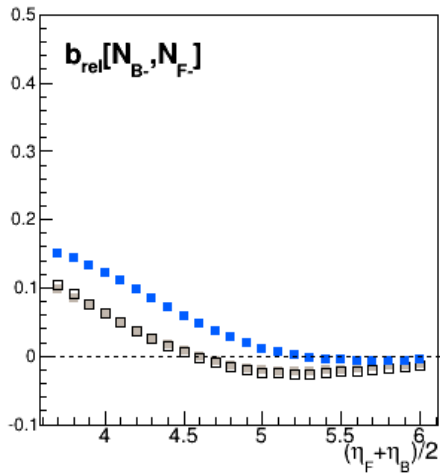
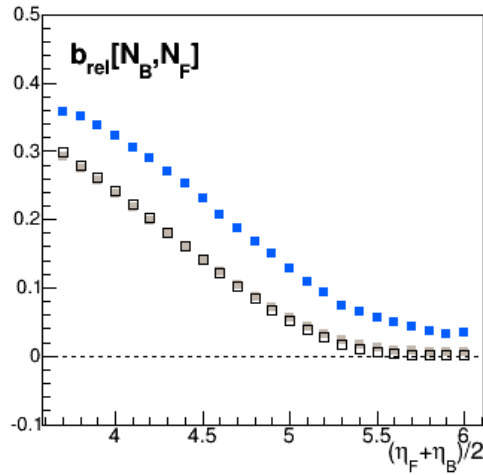


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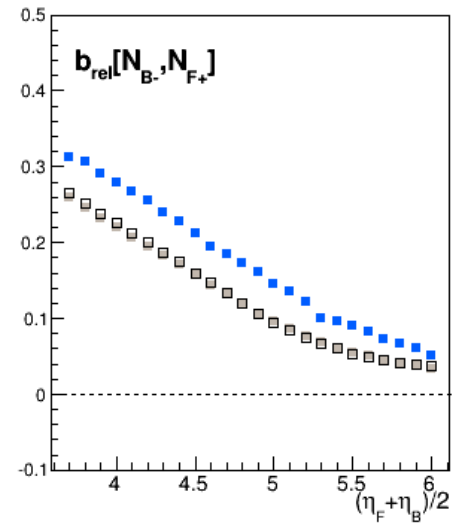
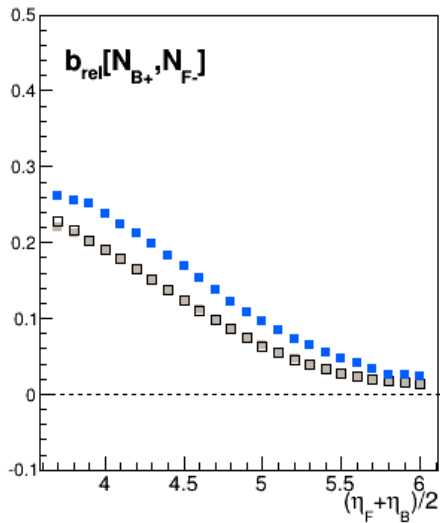
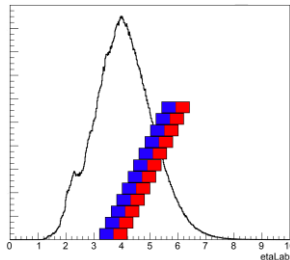


NA61/SHINE preliminary

Connected windows

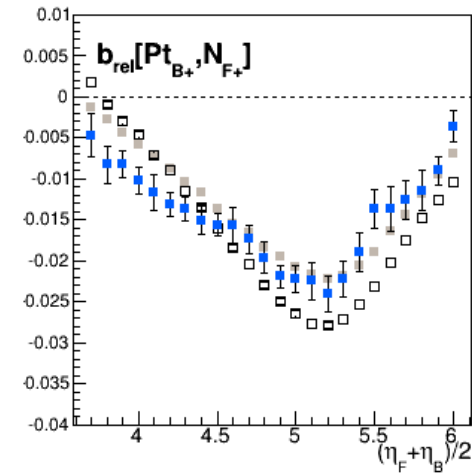
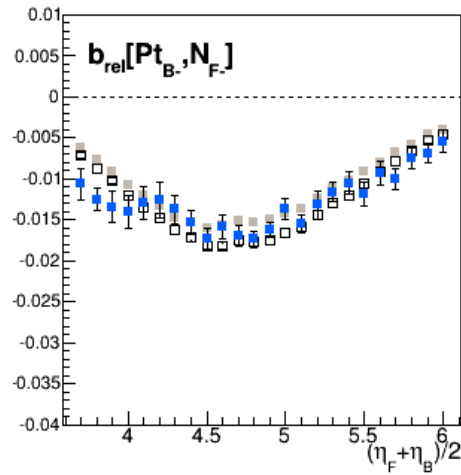
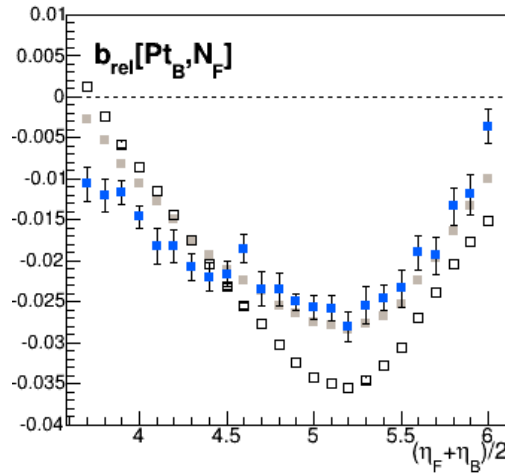


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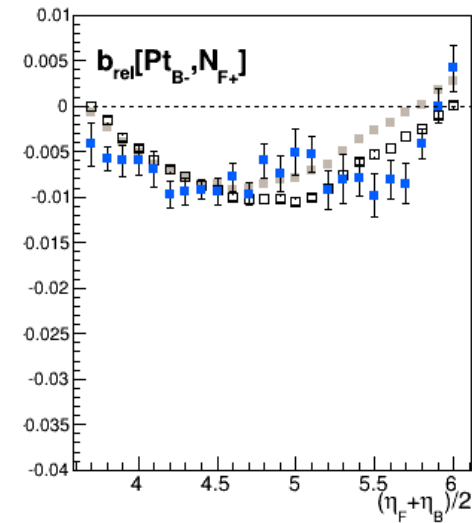
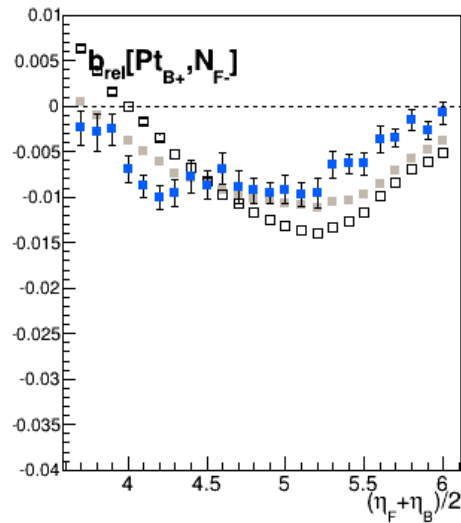
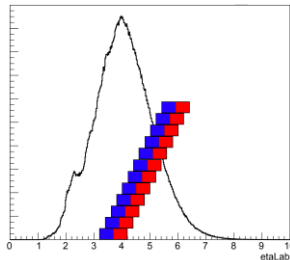


NA61/SHINE preliminary

Connected windows

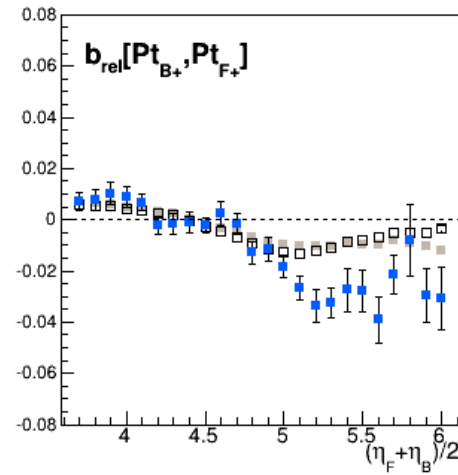
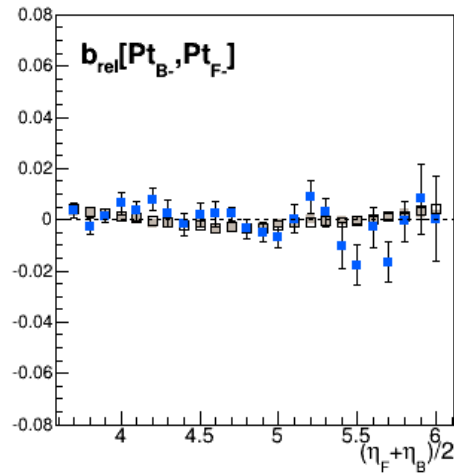
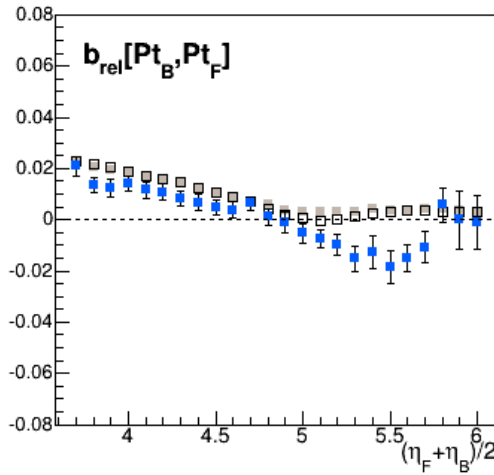


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NA61/SHINE preliminary

Connected windows



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