Two-particle correlations in azimuthal angle and pseudorapidity in ^{7}Be+^{9}Be collisions at SPS energies

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Two-particle correlations - definitions

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

$\Delta\eta = |\eta_1 - \eta_2|$ η transformed from LAB to CMS assuming pion mass
$\Delta\phi = |\phi_1 - \phi_2|$
The azimuthal angle is folded (to improve statistics):
if $\Delta\phi > \pi$ then $\Delta\phi$ becomes $\Delta\phi = 2\pi - \Delta\phi$.

Correlation function

$$C^{raw}(\Delta\eta, \Delta\phi) = \frac{N^{pairs}_{bkg}}{N^{pairs}_{signal}} \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)};$$

$$S(\Delta\eta, \Delta\phi) = \frac{d^2N^{signal}}{d\Delta\eta d\Delta\phi}; \quad B(\Delta\eta, \Delta\phi) = \frac{d^2N^{bkg}}{d\Delta\eta d\Delta\phi}$$

Signal and background distributions are calculated and normalized in restricted $\Delta\eta$ region: $0 < \Delta\eta < 3$. In order to make correlation functions more readable, they are mirrored around $(\Delta\eta, \Delta\phi) = (0, 0)$ point.
Event and track cuts were chosen to select the 5% most violent collisions with particles produced in strong and EM processes within the NA61/SHINE acceptance.

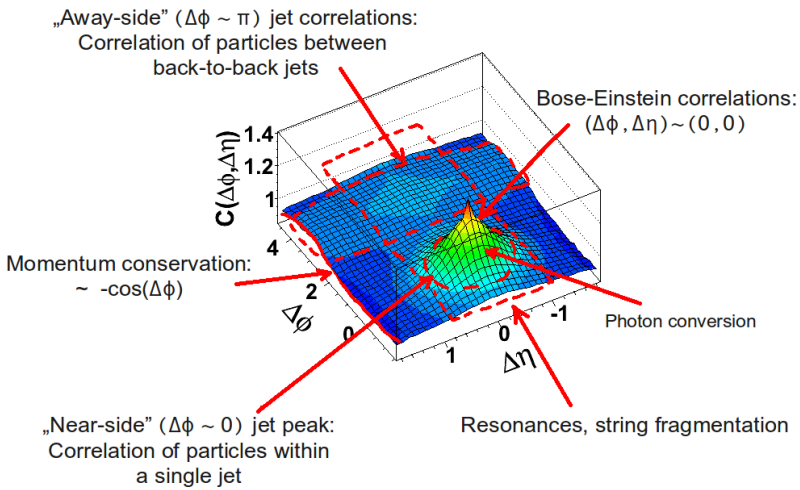
Two-particle correlations

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

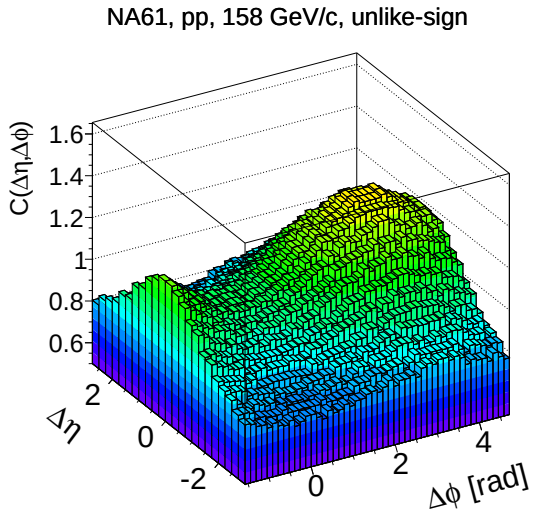
- Studied extensively at RHIC and LHC.
- This method allows to disentangle different sources of correlations:
  - jets,
  - flow,
  - resonance decays,
  - quantum statistics effects,
  - conservation laws.

Motivation

- To study two-particle correlations in a fixed-target experiment at energies lower than LHC and where CP can be located.
- To check differences in correlation structures in various systems (p+p already done).



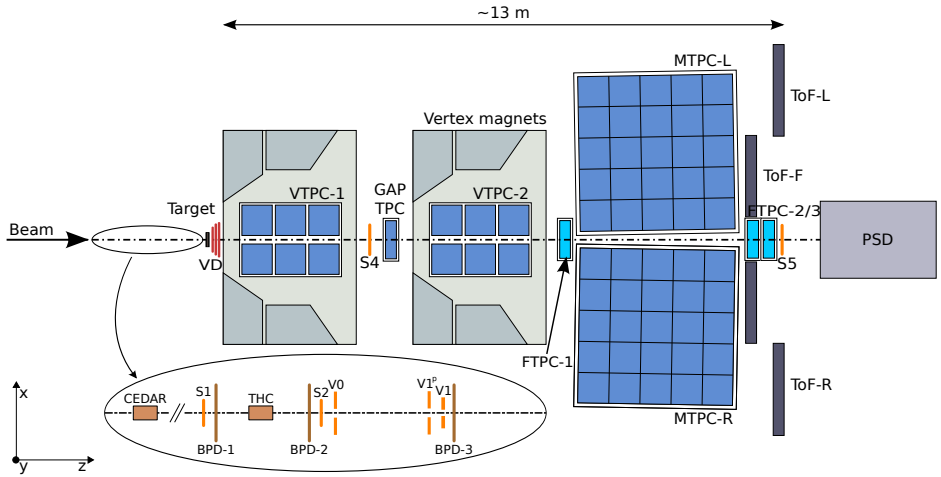
Source: Nucl. Phys. A926:205, 2014

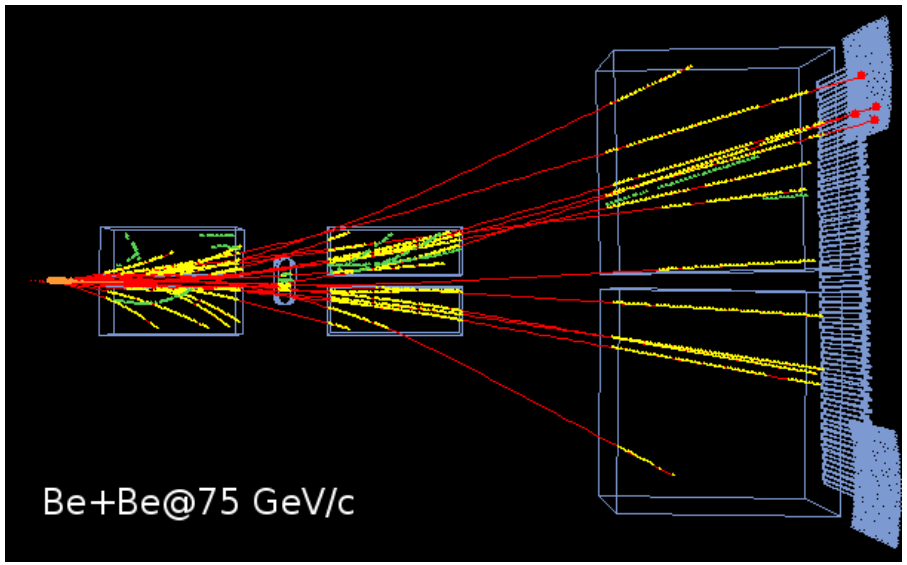


Source: Eur.Phys.J. C77 (2017) no.2, 59

NA61/SHINE experiment

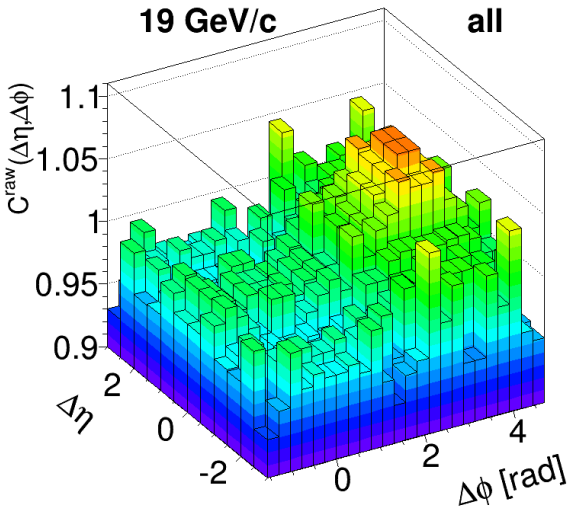
- Fixed target experiment
- Located in the North Area of the CERN SPS accelerator
- Large acceptance ($\approx 50\%$ at $p_T < 2.5$ GeV/c)
- High momentum resolution: $\frac{\sigma(p)}{p^2} \approx 10^{-4}$ [GeV/c]$^{-1}$ (at full 9 Tm magnetic field)
- Good particle identification:
  - $\sigma(TOF) \approx 60 \div 120$ ps,
  - $\frac{\sigma(dE/dx)}{\langle dE/dx \rangle} \approx 0.04$,
  - $\sigma(m_{inv}) \approx 5$ MeV.
- Event selection based on forward energy (projectile spectators) measured by PSD

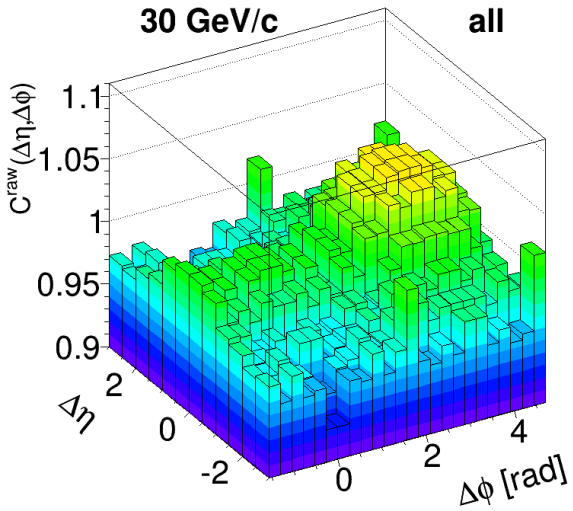


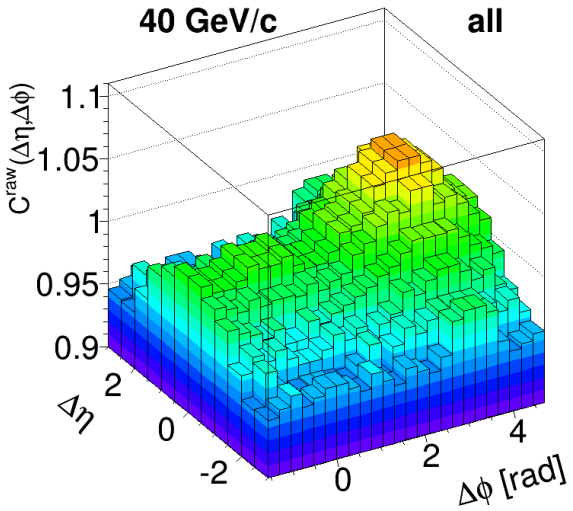


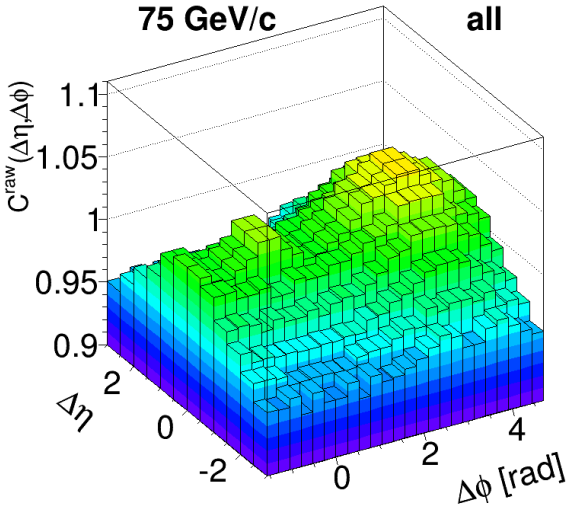
Results

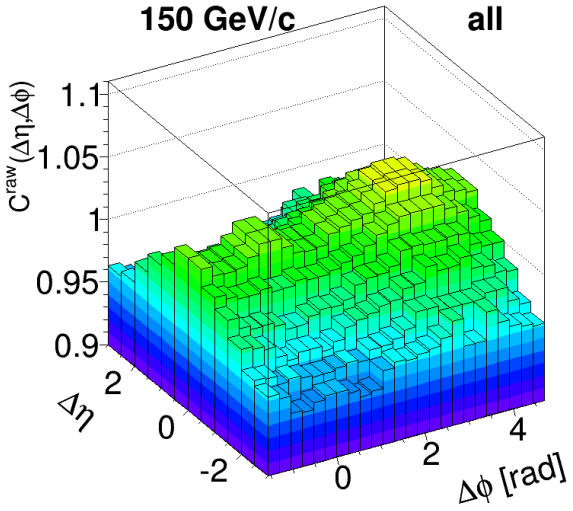
Be+Be: energy dependence, all charged







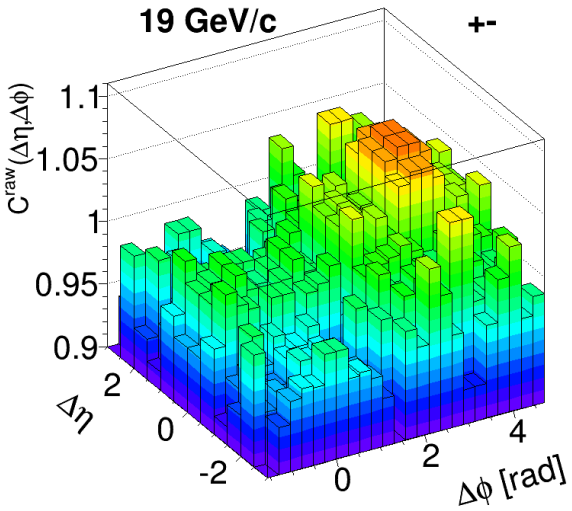


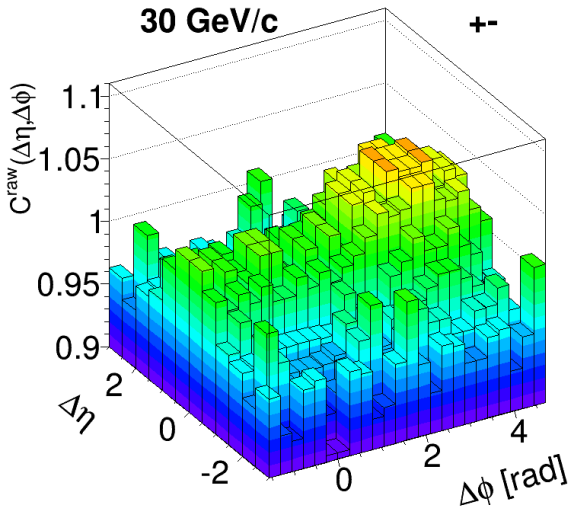


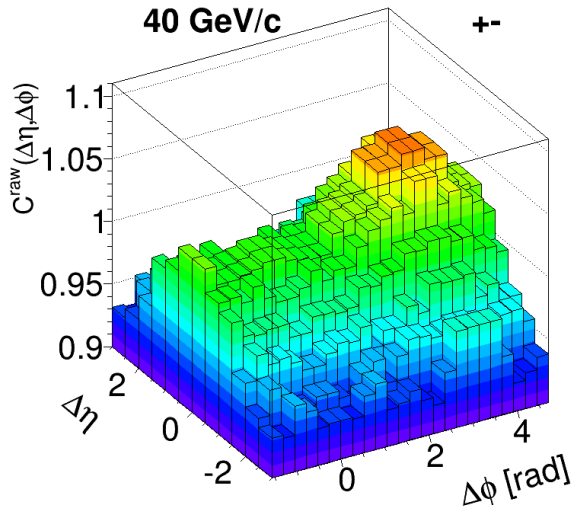
Two main structures visible:

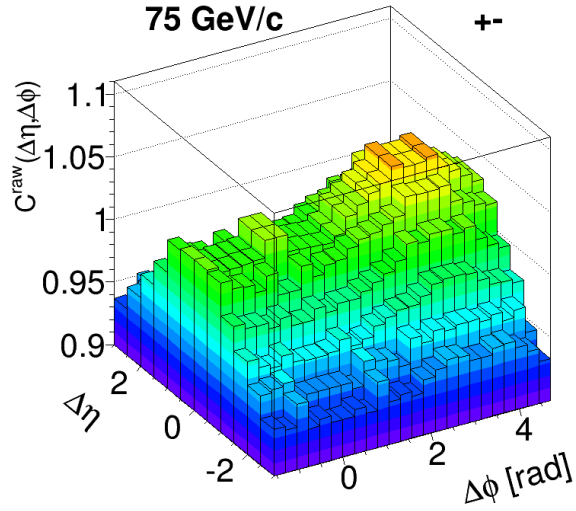
- Maximum at $(\Delta\eta, \Delta\phi) = (0, \pi)$ – probably resonance decays and momentum conservation.
- Enhancement at $(0, 0)$ – probably Coulomb and quantum statistics effects.

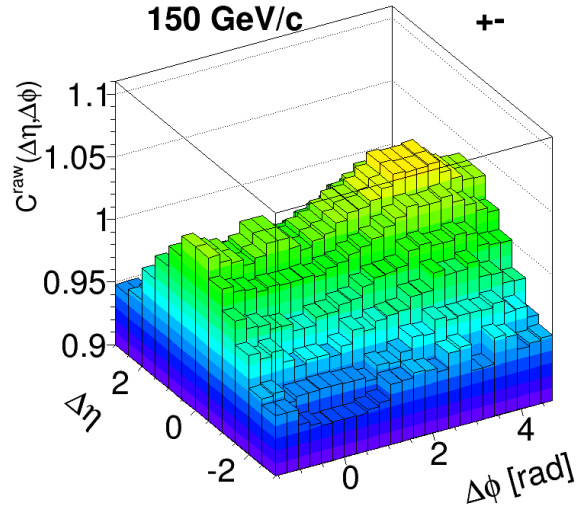
Be+Be: energy dependence, unlike-sign









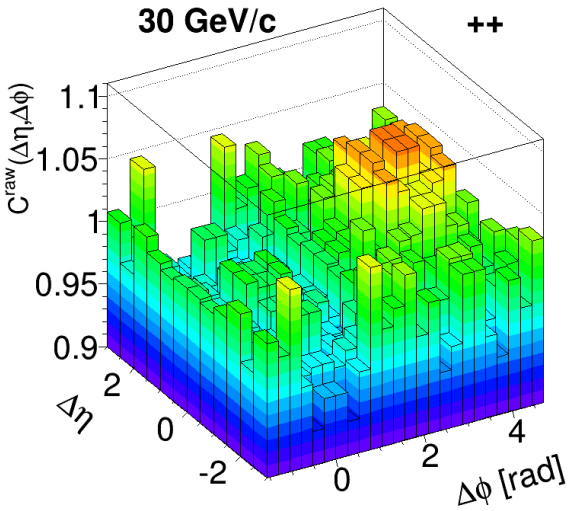


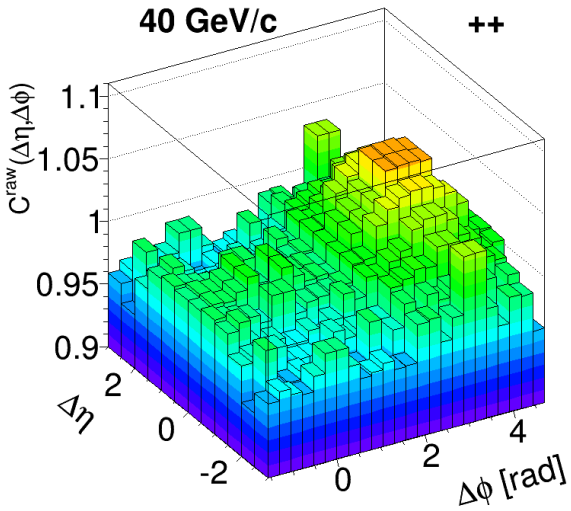
- Maximum at $(\Delta\eta, \Delta\phi) = (0, \pi)$ – probably resonance decays and momentum conservation.
- A hill at $(0, 0)$ in unlike-sign is probably due to Coulomb attraction (products of γ conversion were rejected during analysis).

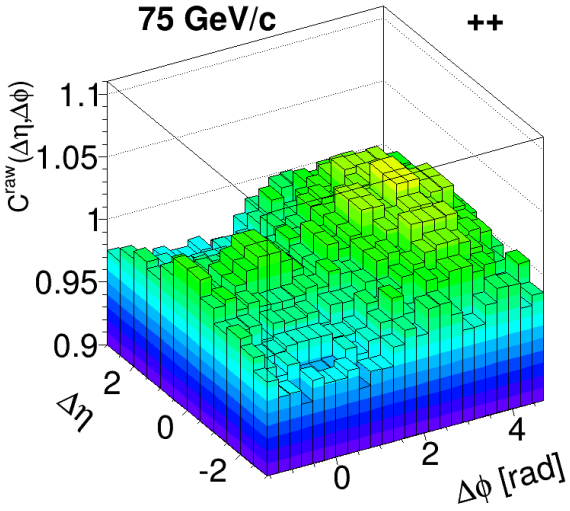
Be+Be: energy dependence, positively charged

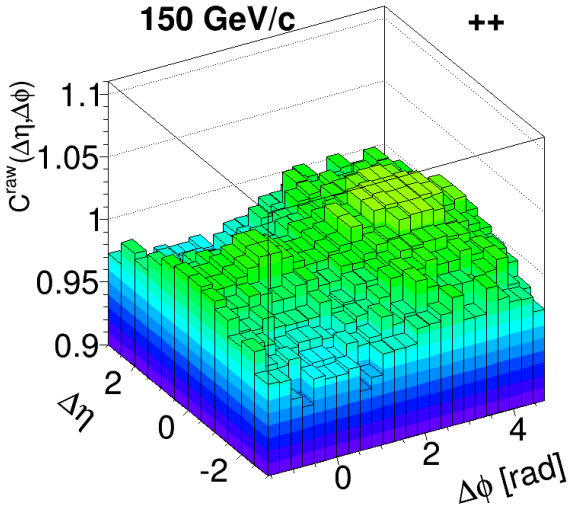
19 GeV/c

Insufficient statistics







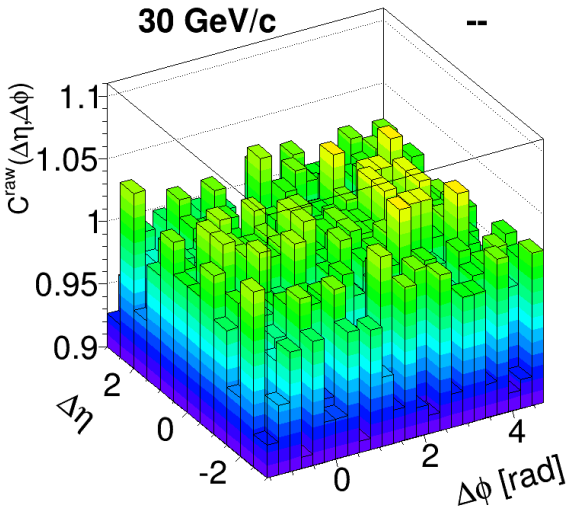


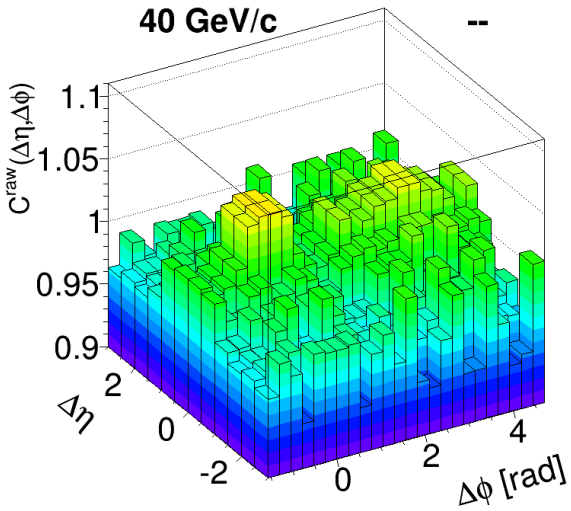
- Away-side enhancement is lower in positively charged pairs due to a small number of resonances decaying into two positively charged particles (e.g. Δ^{++}).
- A small near-side enhancement visible – Bose-Einstein statistics.

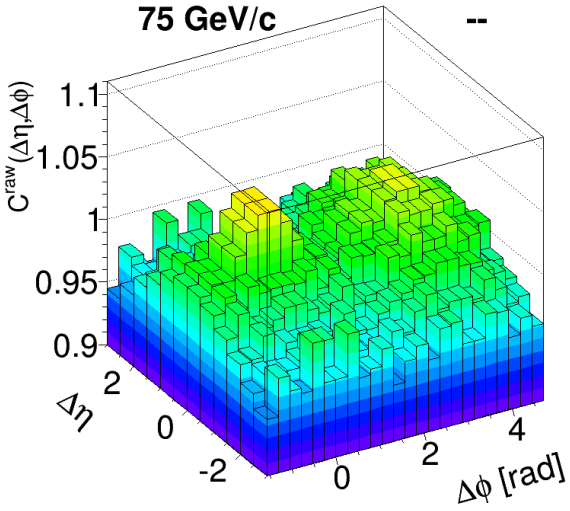
Be+Be: energy dependence, negatively charged

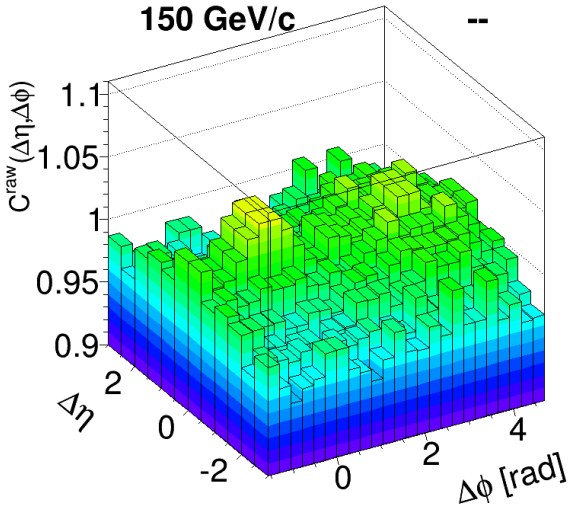
19 GeV/c

Insufficient statistics



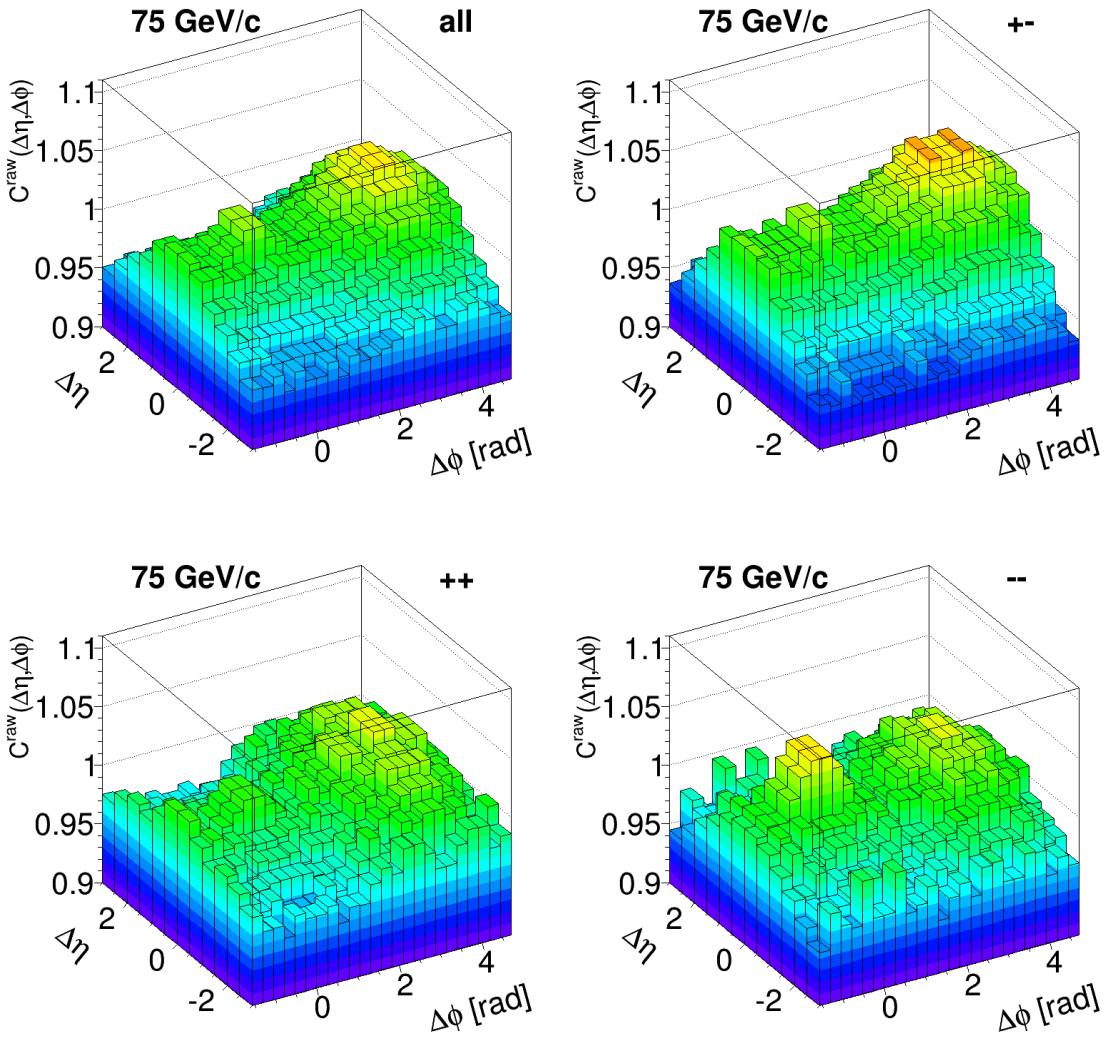






- Almost no away-side enhancement – low multiplicity of double-negative resonances.
- Peak at $(\Delta\eta, \Delta\phi) = (0, 0)$ prominent – Bose-Einstein statistics.

Be+Be: charge dependence

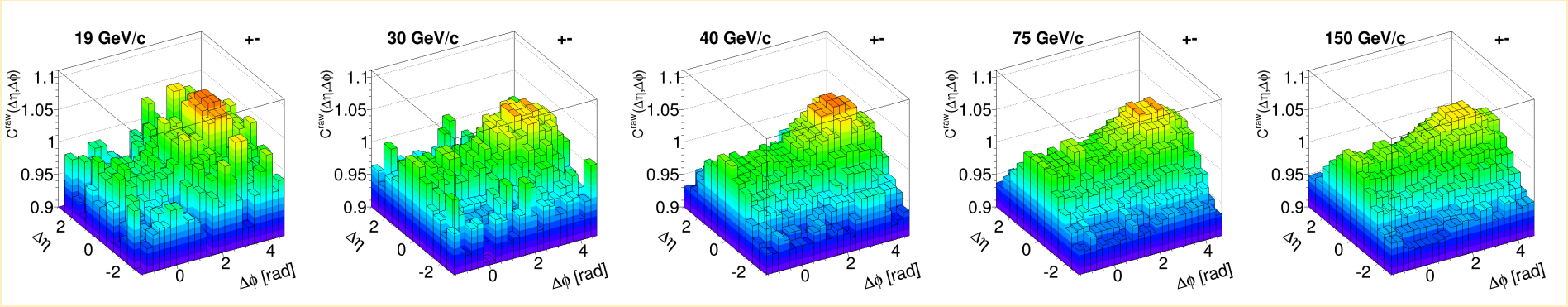


- Peak around $(\Delta\eta, \Delta\phi) = (0, 0)$ strong also in like-sign pairs. Especially in negatively charged.
- Its height in negatively charged can be explained as a result of Bose-Einstein statistics (produced particles are mostly π^-).
- It is lower in positively charged pairs because of Bose-Einstein and Fermi-Dirac statistics interplay (correlation due to bosons: π^+ and anti-correlation due to fermions: protons).

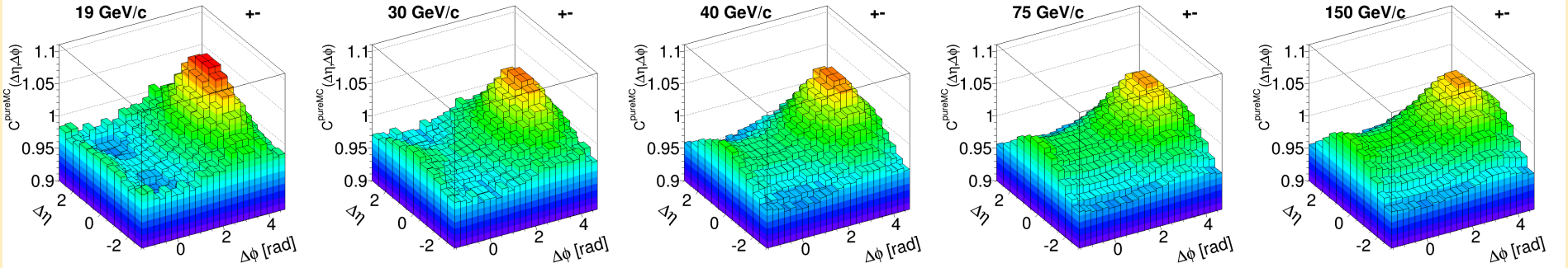
Data vs. EPOS comparison

Data vs. EPOS – unlike-sign

NA61/SHINE data



EPOS1.99 full acceptance

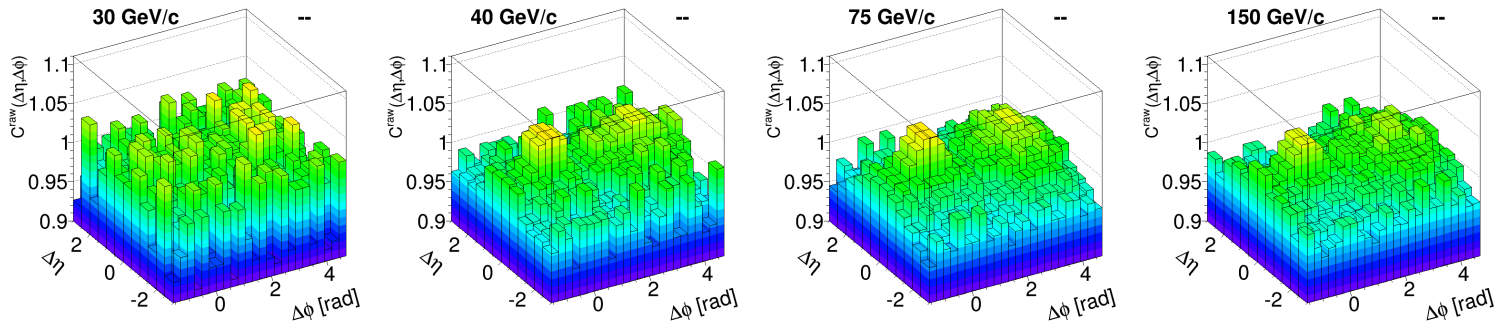


EPOS reproduces data qualitatively well except of Coulomb peak at $(\Delta\eta, \Delta\phi) = (0, 0)$.

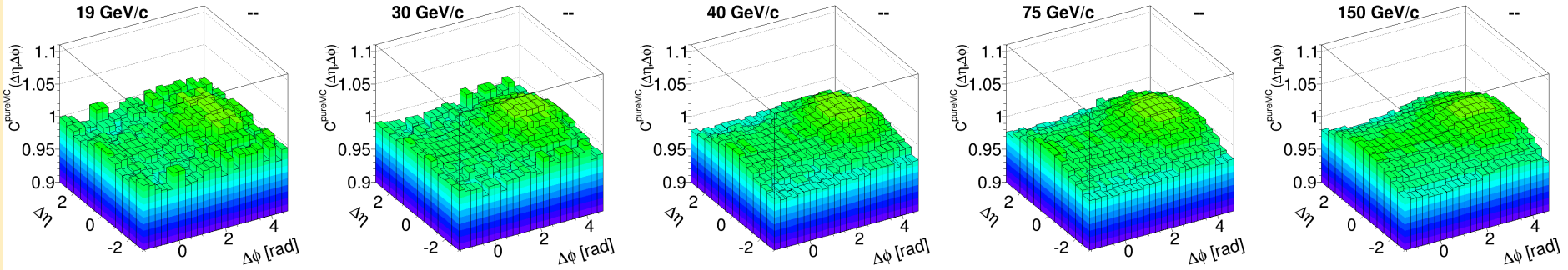
Data vs. EPOS – negatively charged

NA61/SHINE data

19 GeV/c
Insufficient statistics



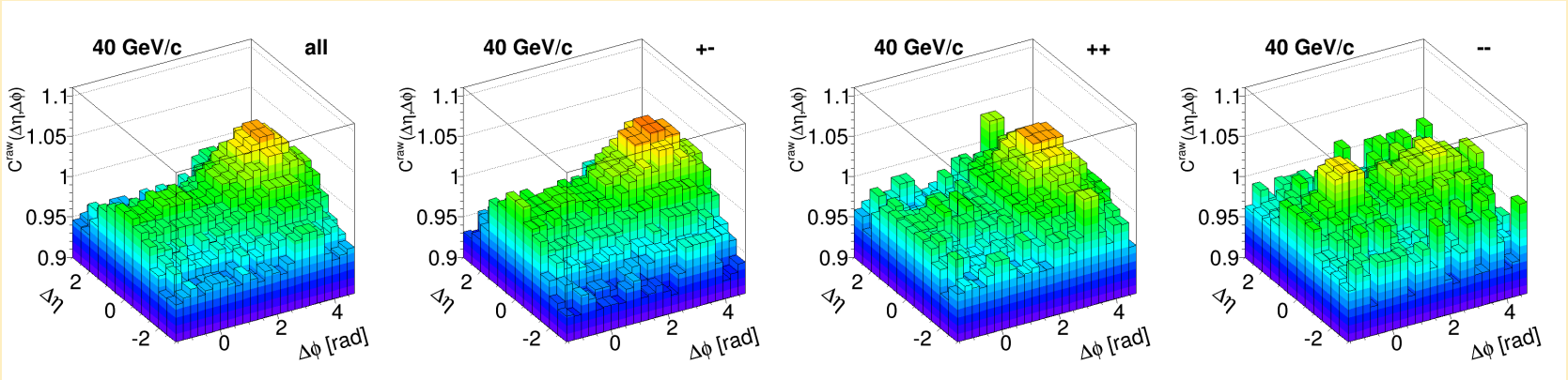
EPOS1.99 full acceptance



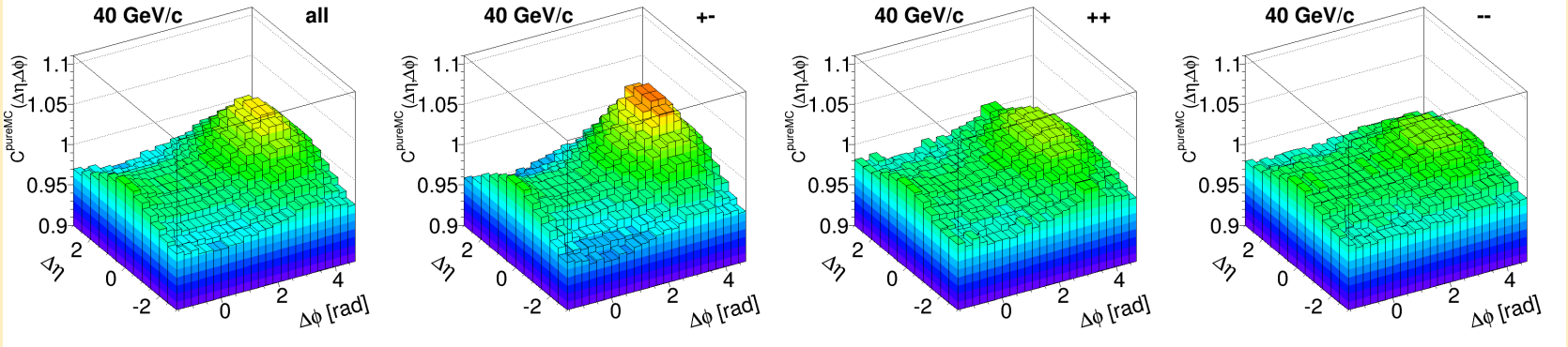
EPOS does not reproduce peak at $(0, 0)$ due to lack of implementation of quantum statistics.

Data vs. EPOS – charge dependence

NA61/SHINE data



EPOS with full acceptance

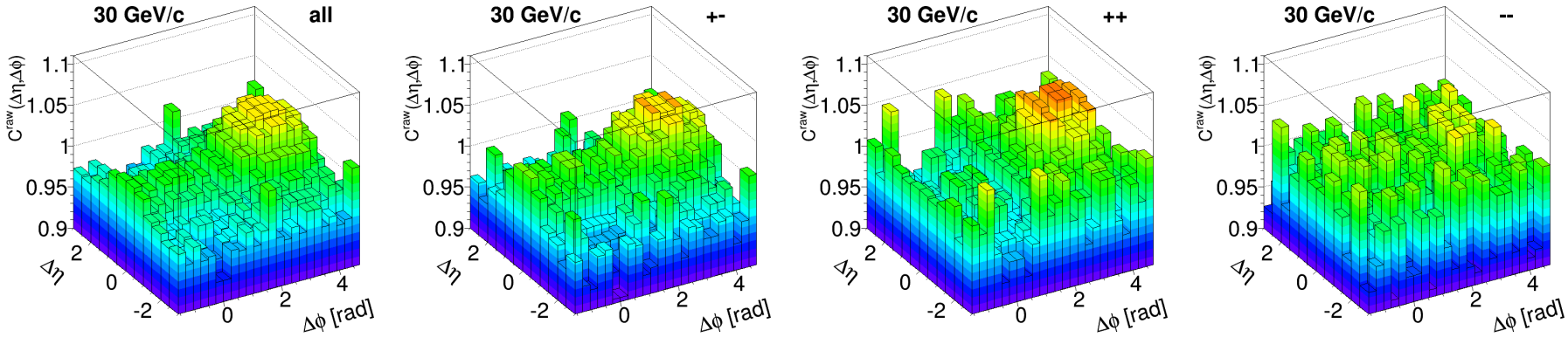


Back to back correlations are qualitatively reproduced by EPOS but Bose-Einstein peak not.

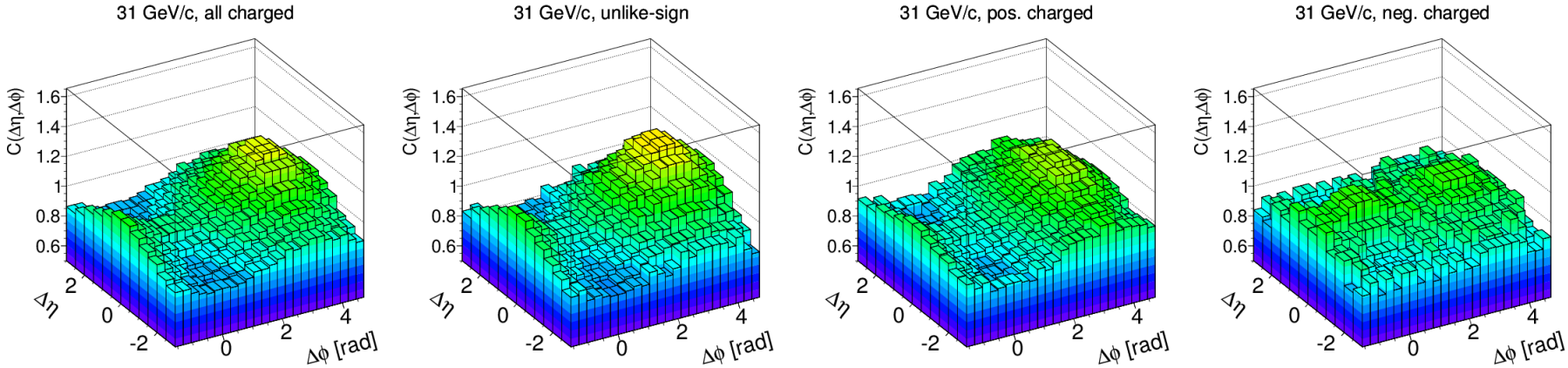
Be+Be vs. p+p comparison

Be+Be 30*A* GeV/c vs. p+p 31 GeV/c

Be+Be



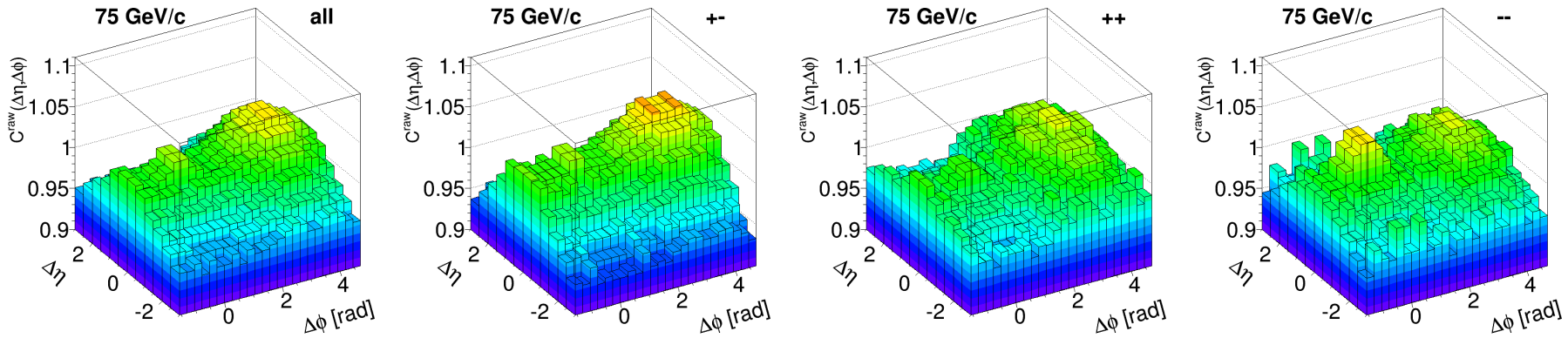
p+p



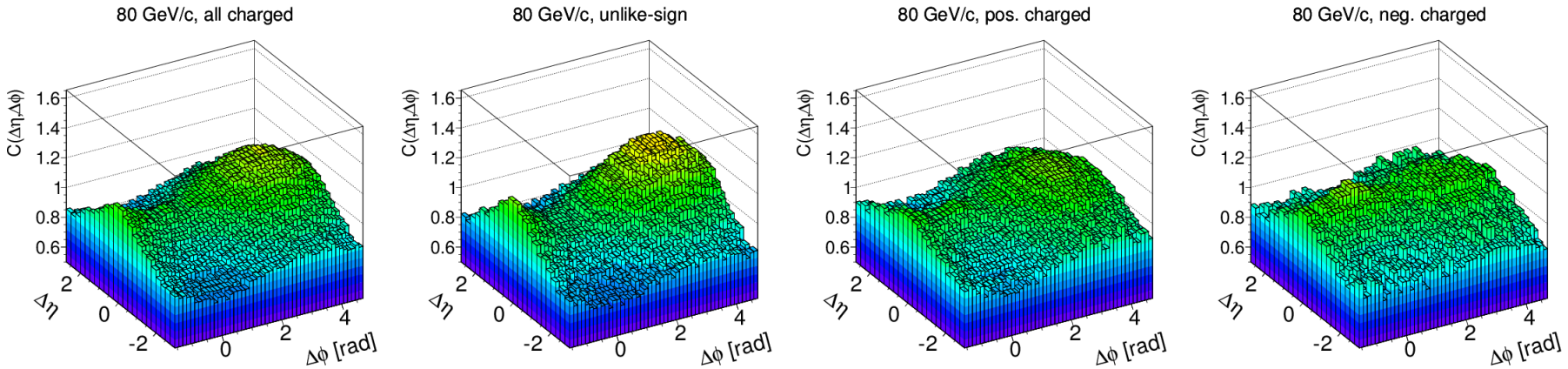
Note vertical scale ranges p+p: $0.5 \div 1.6$, Be+Be: $0.9 \div 1.1$

Be+Be 75A GeV/c vs. p+p 80 GeV/c

Be+Be



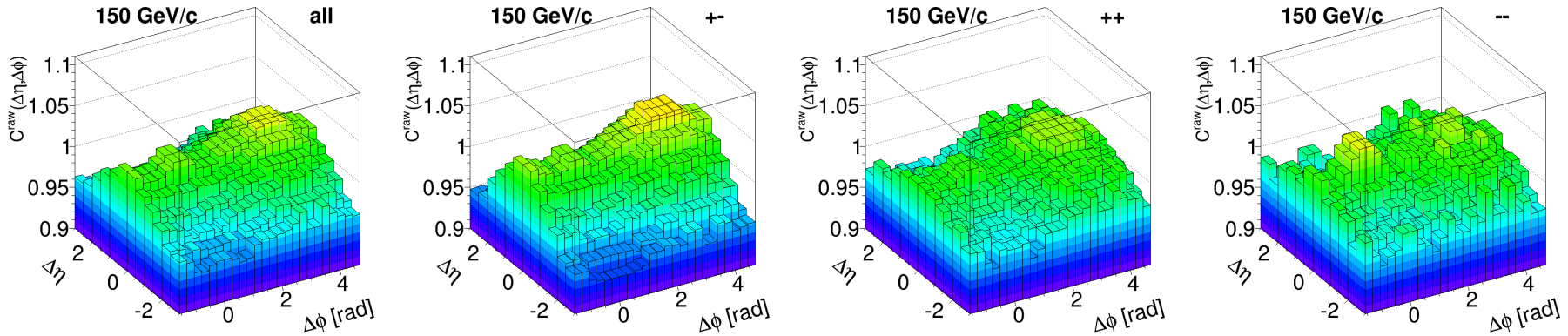
p+p



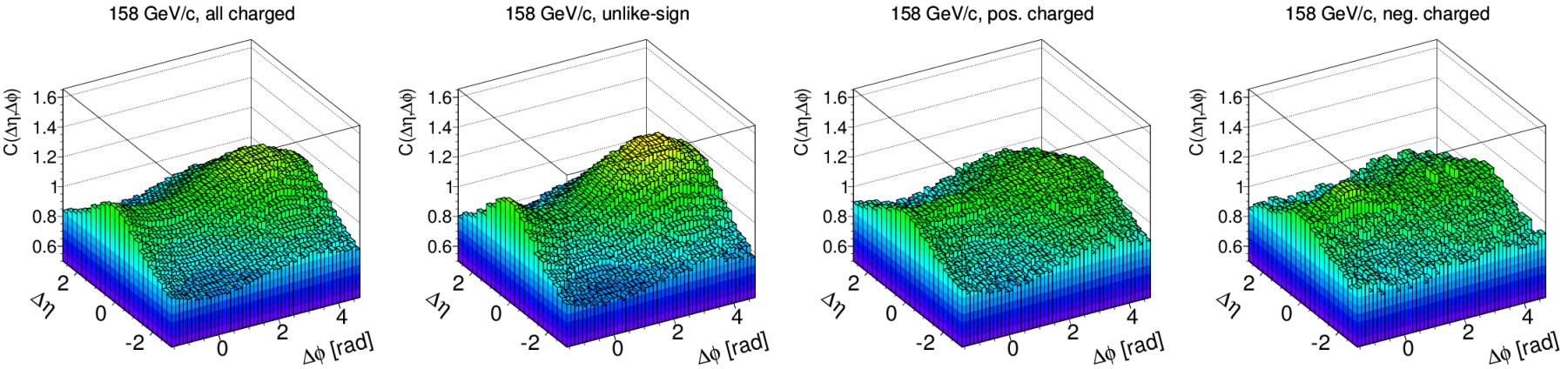
Note vertical scale ranges p+p: $0.5 \div 1.6$, Be+Be: $0.9 \div 1.1$

Be+Be 150A GeV/c vs. p+p 158 GeV/c

Be+Be



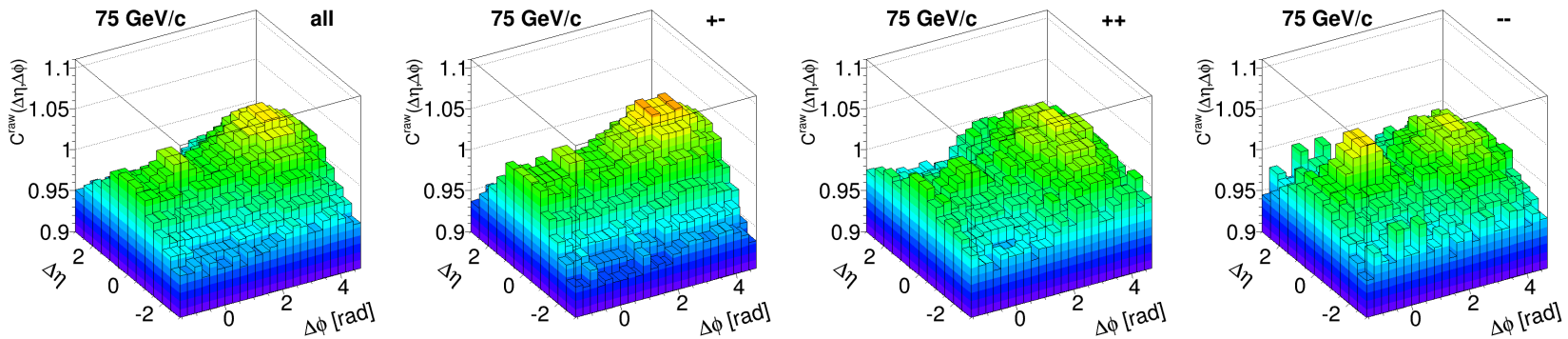
p+p



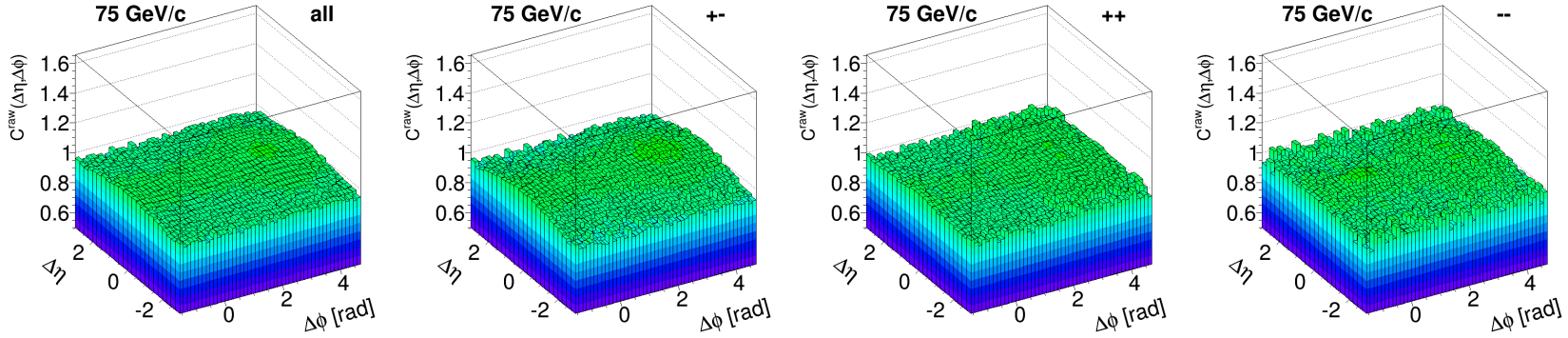
Peak at $(0,0)$ is better visible in $(0,0)$.

Be+Be 75A GeV/c in p+p vertical scale

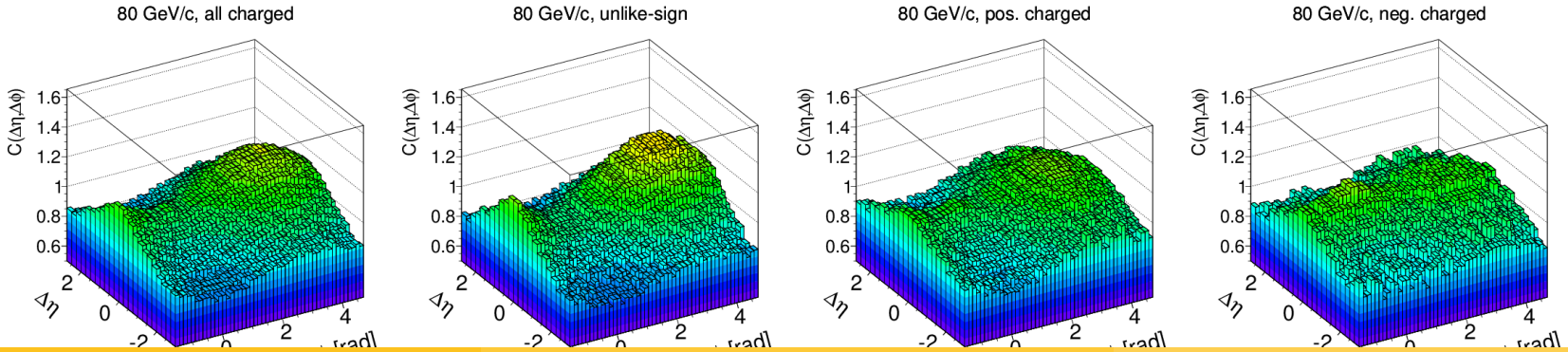
Be+Be



Be+Be in p+p scale

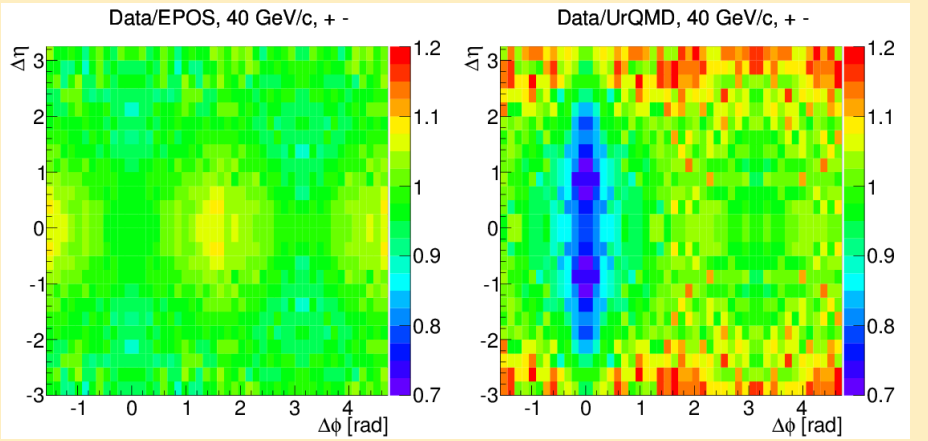


p+p

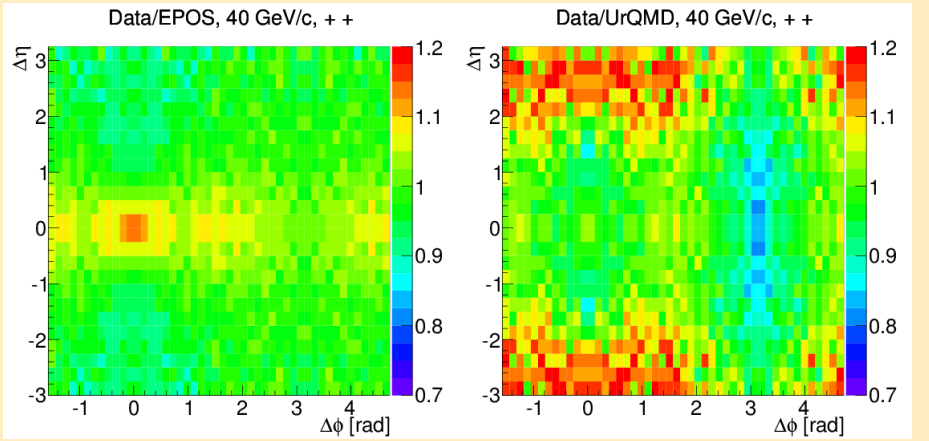


Reminder from p+p: Data/model (EPOS and UrQMD)

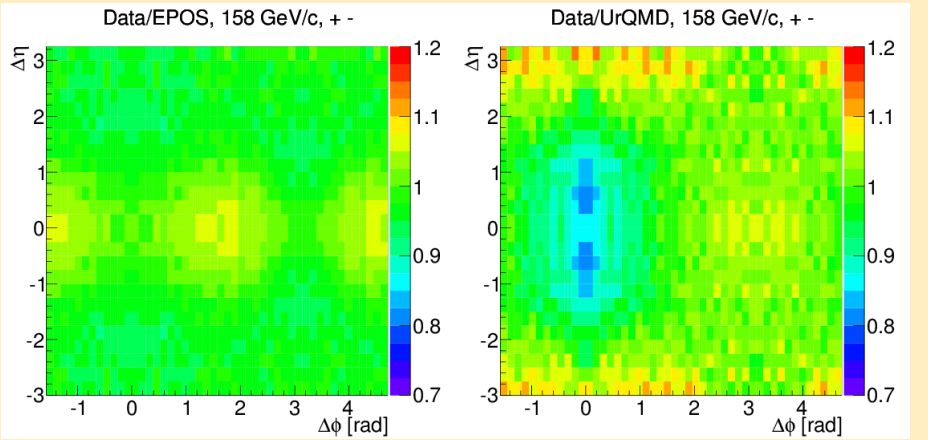
40 GeV/c, +−



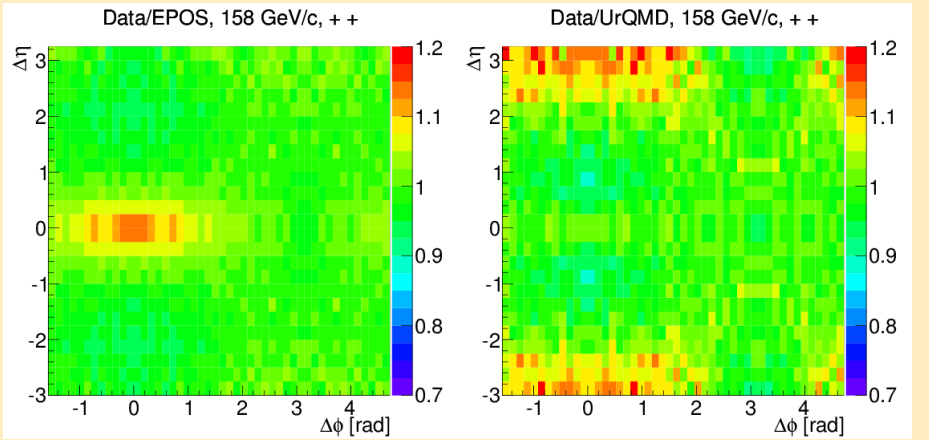
40 GeV/c, ++



158 GeV/c, +−



158 GeV/c, ++



Summary

- The structures extracted from data show:
  - Enhancement at $\Delta\eta \approx 0$ and $\Delta\phi \approx \pi$: Resonance decays and momentum conservation. Significant in unlike-sign and lower in like-sign.
  - Peak around $(\Delta\eta, \Delta\phi) = (0, 0)$
    - The highest in negatively charged pairs – Bose-Einstein statistics effect. Majority of contribution comes from negative pions (bosons).
    - Lower in positively charged pairs – Bose-Einstein and Fermi-Dirac statistics interplay. Correlation from positive pions (bosons) but also anticorrelations from protons (fermions).
    - Small in unlike-sign pairs – Coulomb attraction.
- The EPOS model reproduces data quite well qualitatively with exception of $(0, 0)$ enhancement due to no implementation of quantum statistics effects and Coulomb interactions.
- Be+Be correlations are generally weaker than in smaller system of p+p. The structures however are similar in results of both systems.
- In Be+Be the enhancement around $(\Delta\eta, \Delta\phi) = (0, 0)$ is more prominent than in p+p (sharper Bose-Einstein correlation peak due to larger system).

Thank you for your attention

The project: *Study of two-particle correlations in azimuthal angle and pseudorapidity in Beryllium-Beryllium collisions at the energies of the SPS accelerator* is being executed with support of National Science Centre, Poland.

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