Quark Gluon Plasma in NA61/SHINE

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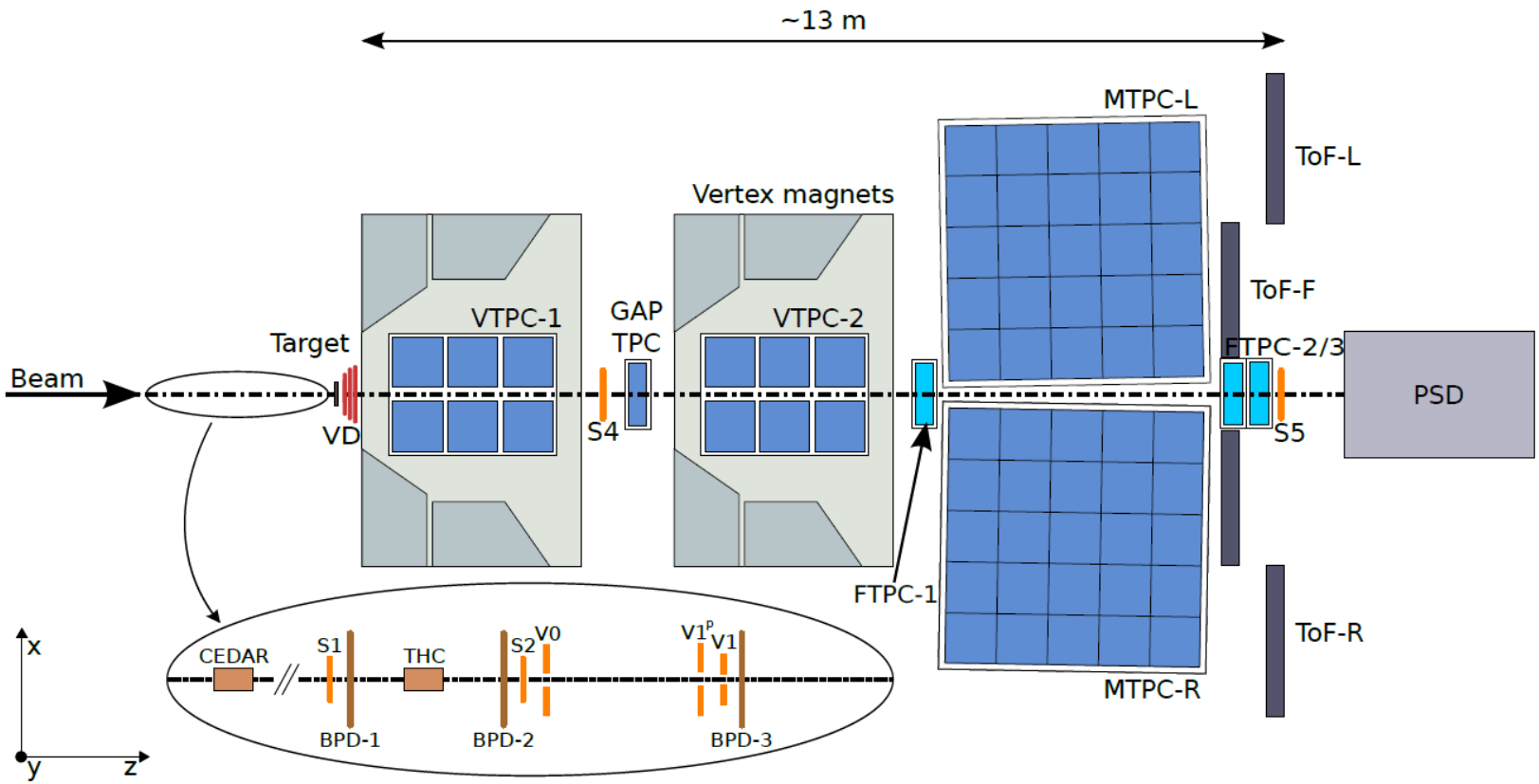
The NA61/SHINE experiment



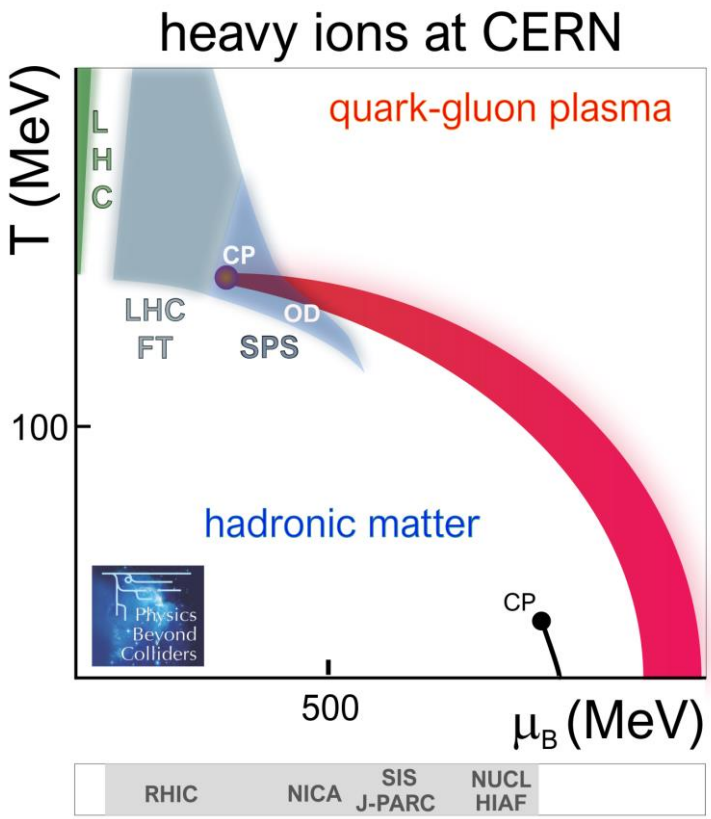
Ions: Be, Ar, Xe, Pb
$13A - 150A$ GeV/c

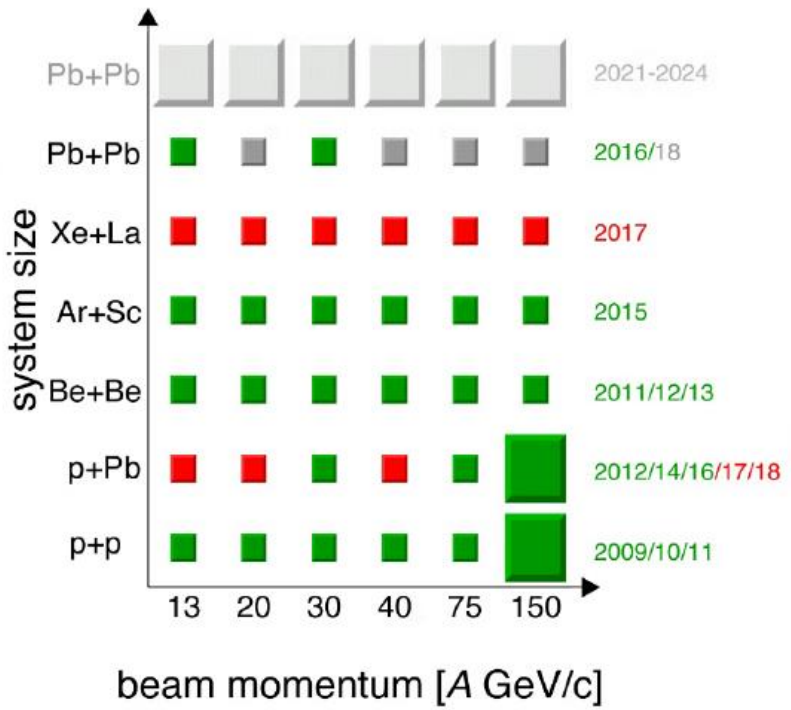
Hadrons (n, K, p)
$13 - 400$ GeV/c

$\sqrt{s_{NN}} =$
$5.1 - 16.8(27.4)$ GeV

Two-dimensional scan at NA61/SHINE

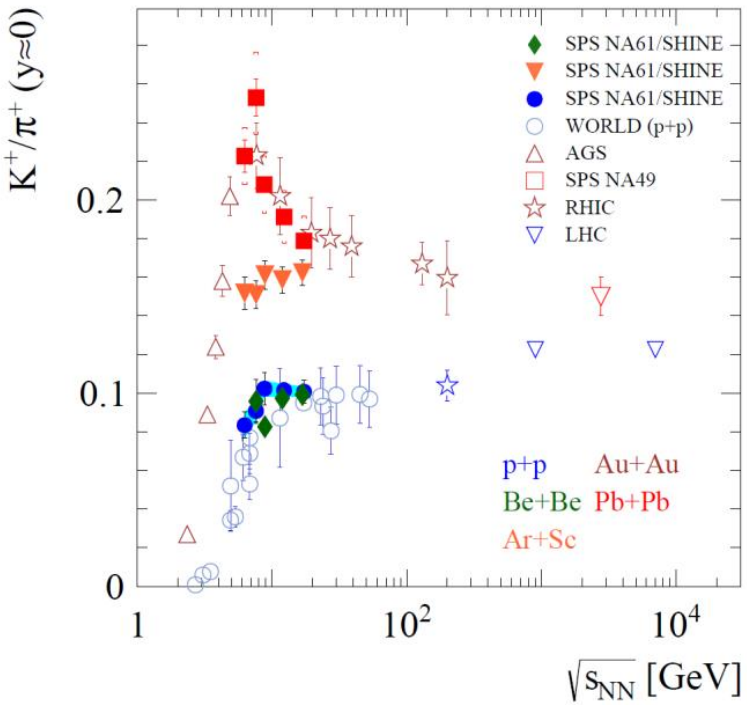
In years 2009-2018 NA61/SHINE studied the phase diagram of strongly interacting matter by performing 2D scan in collision energy and system size

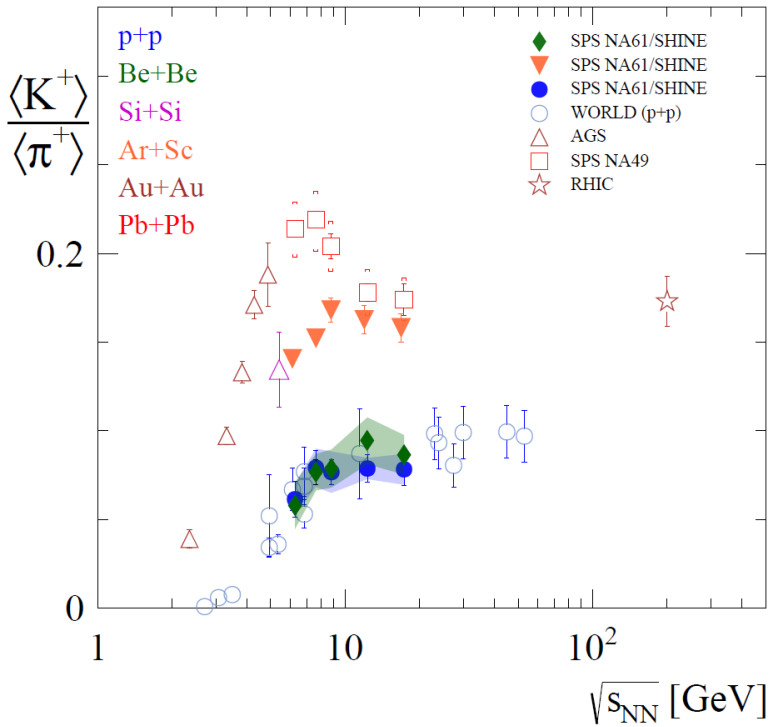




Onset of deconfinement: horn

Horn is one of the structures predicted by SMES[1] as a signature of onset of deconfinement. It was observed as rapid changes in K^+/π^+ in Pb+Pb collisions.



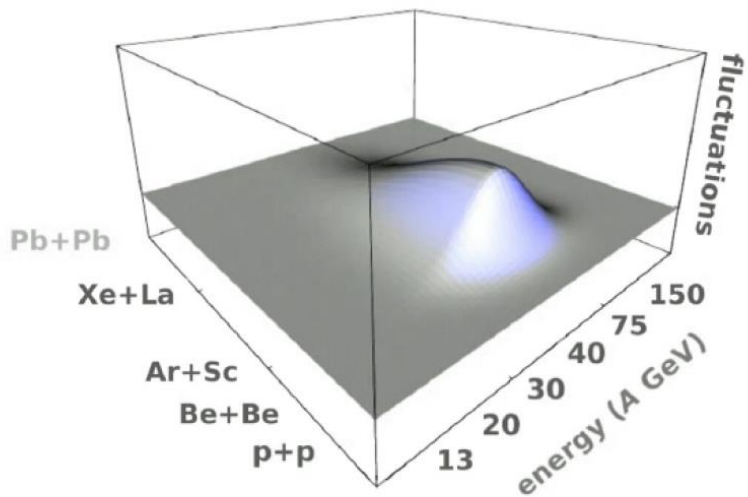


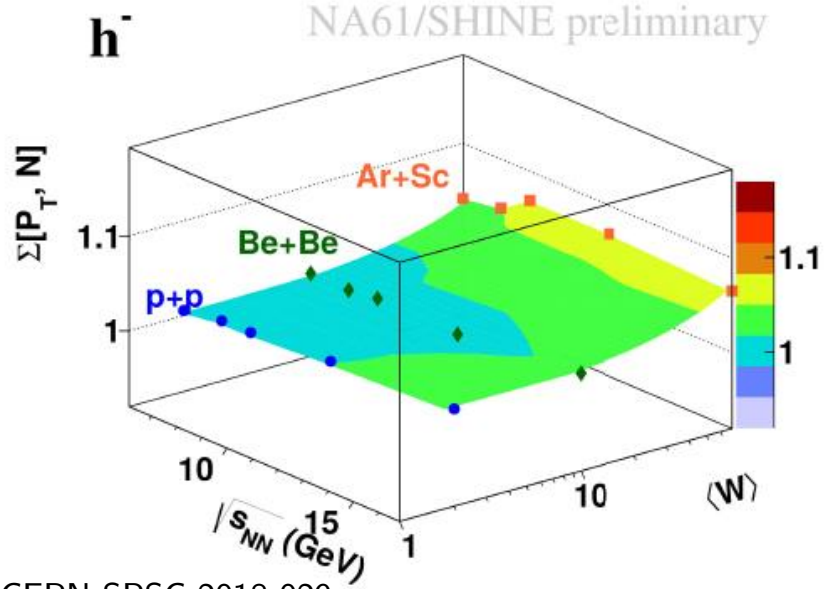
- p+p shows plateau-like structure
- Be+Be close to p+p
- Ar+Sc higher than p+p, but energy dependence is similar – no horn

[1] M. Gazdzicki and M. I. Gorenstein *Acta Phys.Polon.* **B30** (1999) 2705

Search for critical point: strongly intensive measures

Near the critical point (2nd order phase transition) large dynamical fluctuations may appear and manifest as non-monotonic dependence on energy, system-size or centrality of the collision.





CERN-SPSC-2018-029

In contrary to original expectations, so far we do not see any prominent structures that could be related to critical point.

Search for critical point: proton intermittency

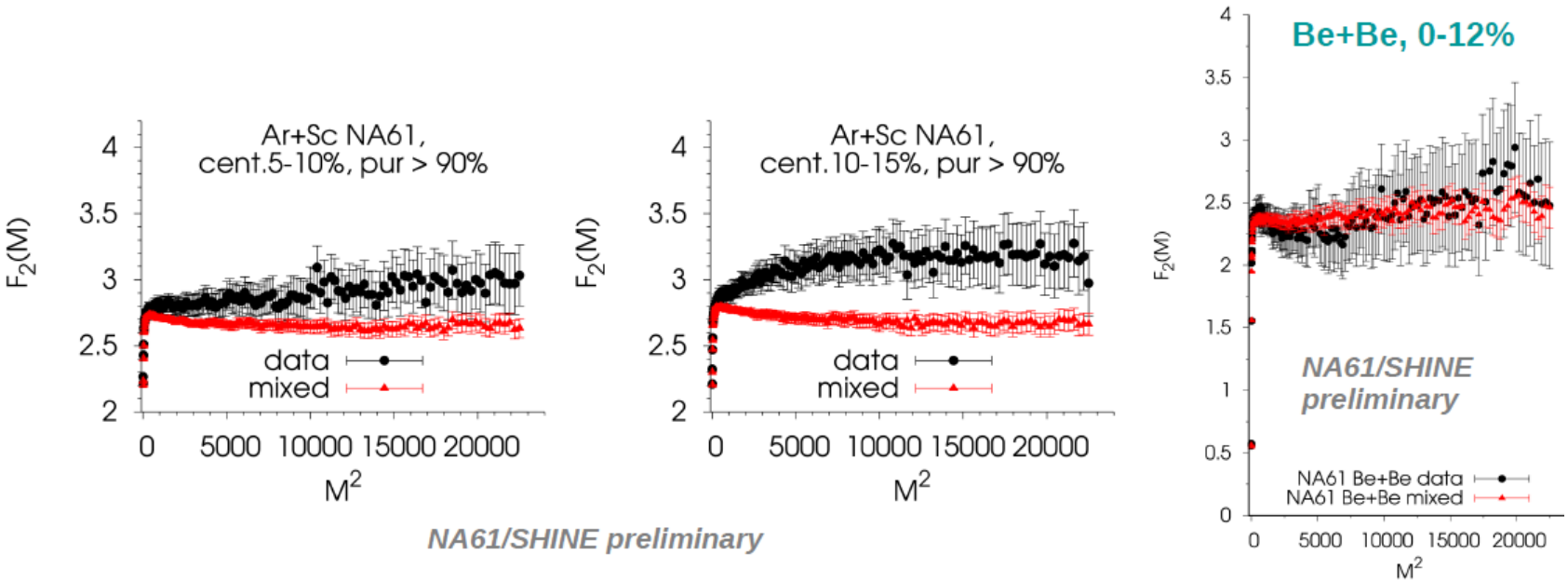
- Second order phase transition may manifest in the fluctuations of local power-law of the baryon density.
- This can be searched by studying scaling behavior of second factorial moments $F_2(M)$ with the cell size in (p_x, p_y) space (i.e. divided onto $M \times M$ bins).

$$F_2 = \frac{\left\langle \frac{1}{M^2} \sum_{m=1}^{M^2} n_m(n_m - 1) \right\rangle}{\left\langle \frac{1}{M^2} \sum_{m=1}^{M^2} n_m \right\rangle^2} \tag{1}$$

- at critical point power law dependence is expected

$$\Delta F_2(M) \sim (M^2)^{\phi_2} \tag{2}$$

Search for critical point: proton intermittency



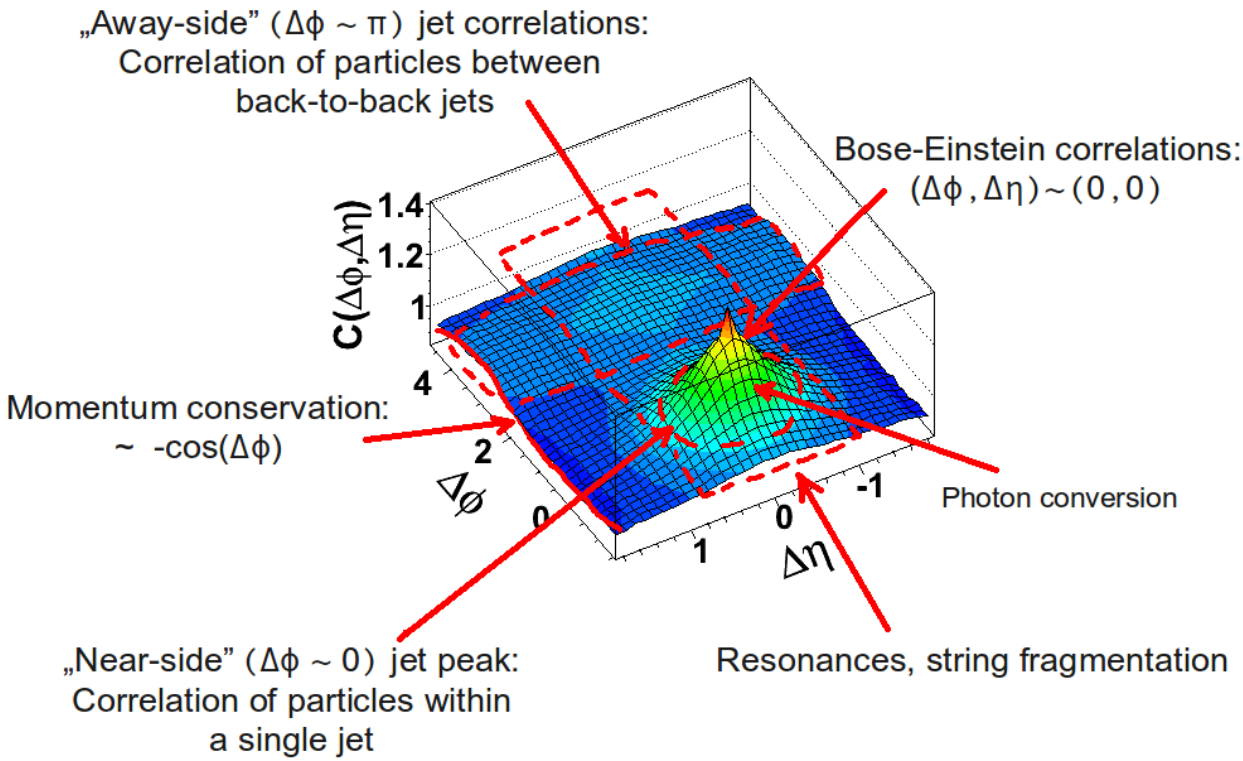
In Ar+Sc collisions $F_2(M^2)$ moments are higher in data than in mixed events. More detailed investigation is ongoing. In Be+Be collisions, there is no such signal.

Damian Pszczel is one of the investigators.

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

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.



Source: Nucl. Phys. A926:205, 2014

Analysis performed by BM. Results from correlations in p+p already published in Eur.Phys.J. C77 (2017) no.2, 59.

Two-particle correlations - definitions

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

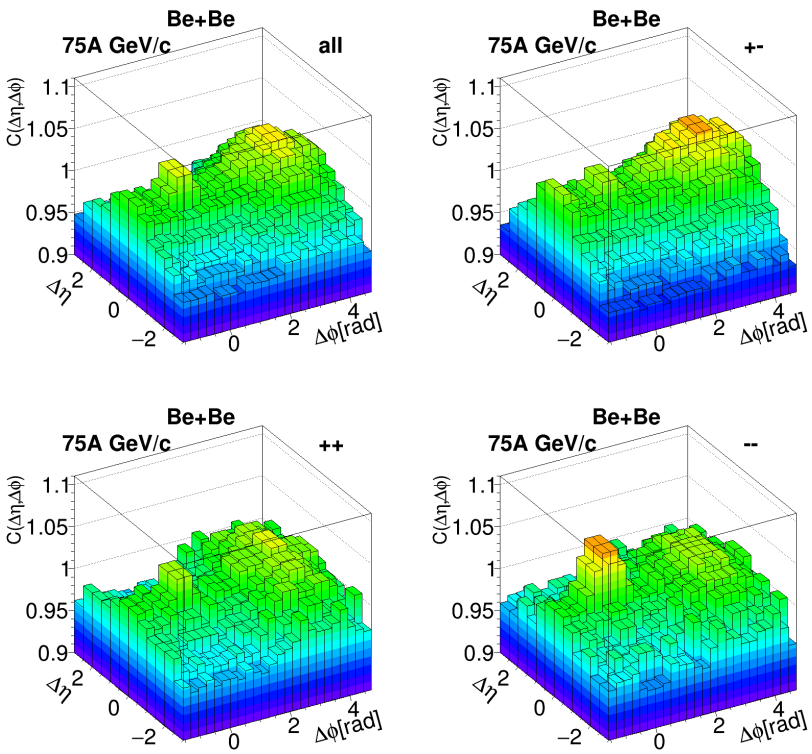
$$\Delta\eta = |\eta_1 - \eta_2|$$
$$\Delta\phi = |\phi_1 - \phi_2|$$

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

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

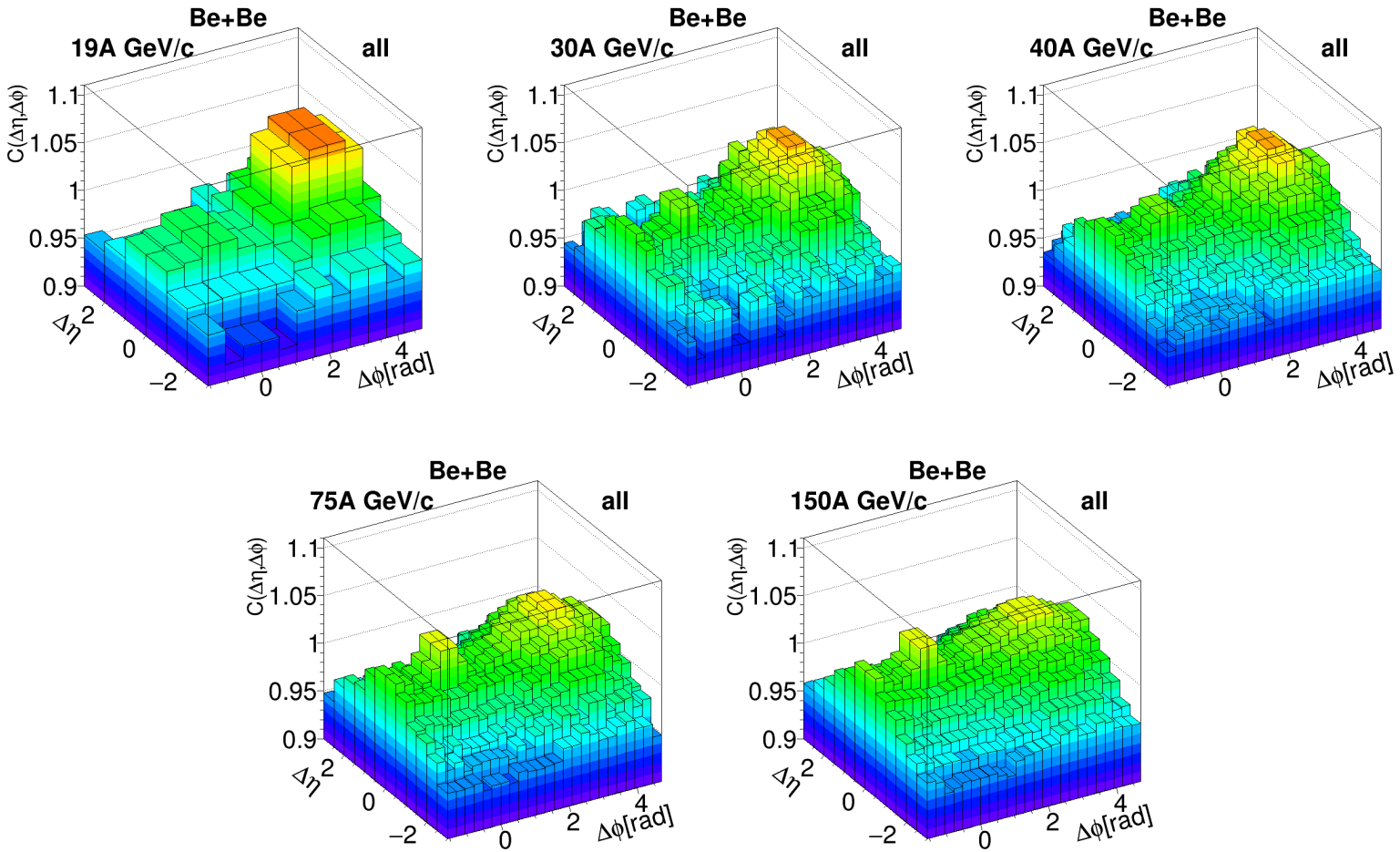
Signal and background distributions are calculated and normalized in restricted $\Delta\eta$ region: $0 < \Delta\eta < 3$. In order to make correlation functions more readable, they are mirrored around $(\Delta\eta, \Delta\phi) = (0, 0)$ point.

Example results in Be+Be - charge scan

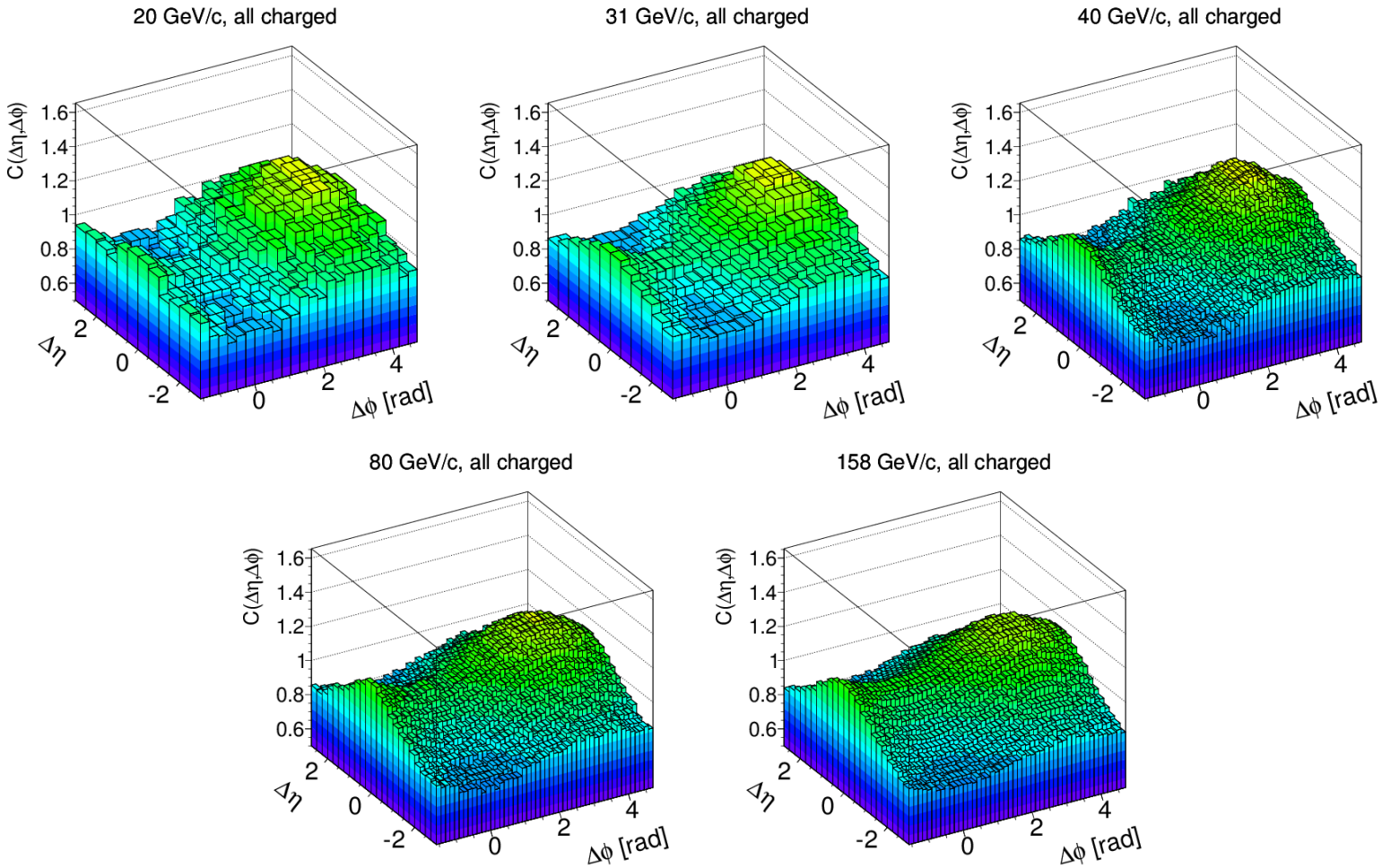


- Maximum at $(\Delta\eta, \Delta\phi) = (0, \pi)$ (i.e. away-side) – probably resonance decays and momentum conservation.
- A hill at $(0, 0)$ (i.e. near-side) in unlike-sign (+-) is probably due to Coulomb attraction (products of γ conversion were rejected during analysis). For like-sign pairs prominent peak – Bose-Einstein 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^{++}). Almost no away-side enhancement in negatively charged (- -) pairs – low multiplicity of double-negative resonances.

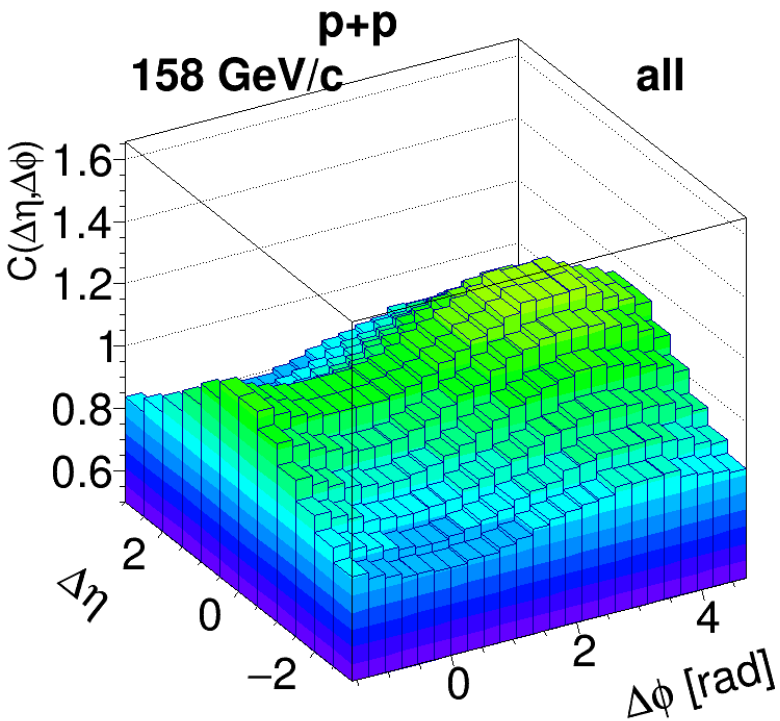
Example results in Be+Be – energy scan

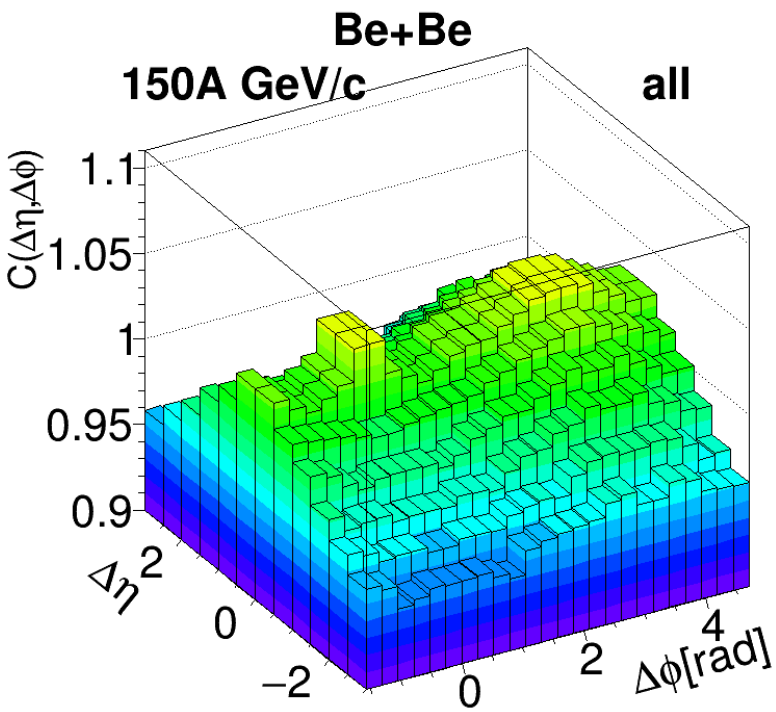


Example results in p+p – energy scan



Two-particle correlations in p+p





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

Be+Be data shows an excessive structure in $(\Delta\eta, \Delta\phi) \approx (0, 0)$ region (the region of quantum statistics effects, Coulomb interactions and jets). The results are still being discussed.

Summary

- The NA61/SHINE experiment finished energy and system-size scan in 2018.
- Collected data is being analyzed now and new results.
- Expect series of new results through next several years!
- Current plan for NA61/SHINE: update of the detector to restart after Long Shutdown 2.

Thank you

Our group at NCNR

Members

- prof. Joanna Stepaniak (leader)
- Damian Pszczel
- Bartosz Maksiak

Activities

- Analysis of proton intermittency (JS, DP)
- Analysis of two-particle correlations in $\Delta\eta\Delta\phi$ (BM)
- Calibration of NA61/SHINE data (DP)
- Reconstruction of NA61/SHINE data (BM)
- Participation in the CosmicWatch project (BM)

NA61/SHINE publications in 2019

- *Measurements of $\pi^{\pm}$, $K^{\pm}$ and proton double differential yields from the surface of the T2K replica target for incoming 31 GeV/c protons with the NA61/SHINE spectrometer at the CERN SPS.*
  Eur. Phys. J C79 (2019) no.2, 100
- *Measurements of production and inelastic cross sections for p+C, p+Be, and p+Al at 60 GeV/c and p+C and p+Be at 120 GeV/c.*
  Phys. Rev. D 100, 11201
- Two publications in the reviewing process
- Two-particle correlations in central Be+Be collisions at SPS energy (in preparation)