Hadrons correlation study in the NA61/SHINE experiment at CERN

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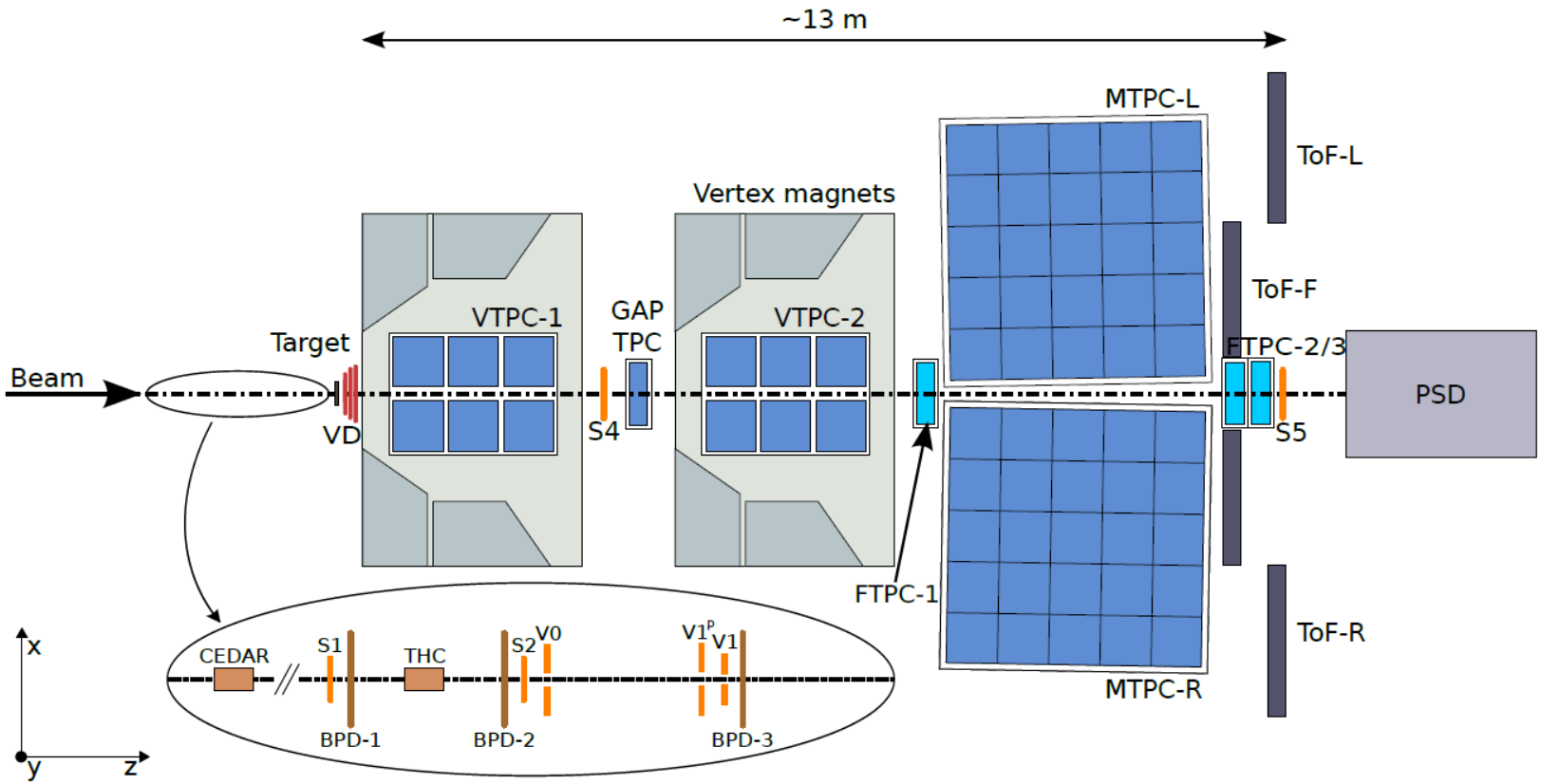
The NA61/SHINE experiment



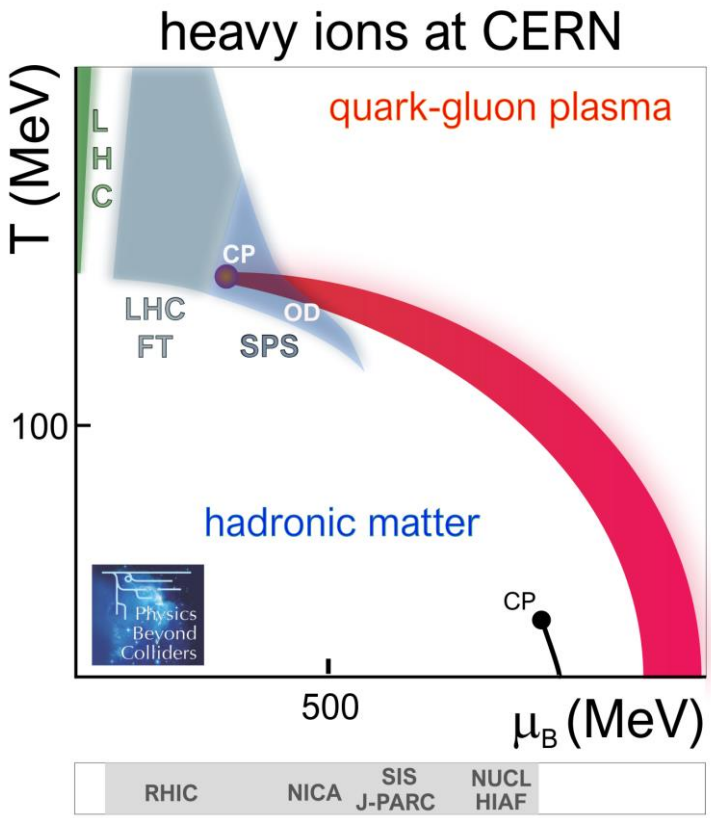
Ions: Be, Ar, Xe, Pb
$13A - 150A$ GeV/c

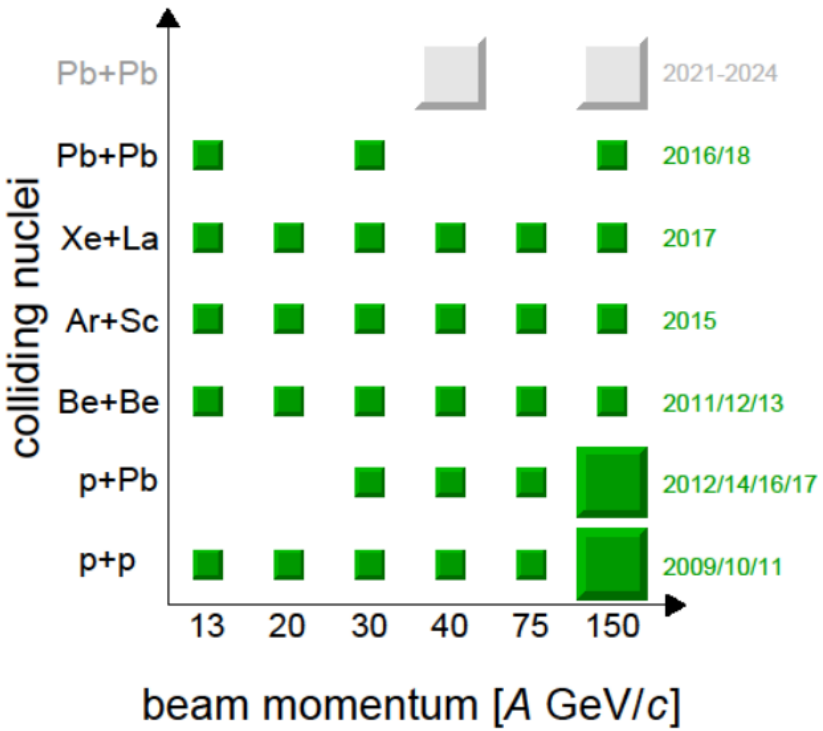
Hadrons (n, K, p)
$13 - 400$ GeV/c

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

Two-dimensional scan at NA61/SHINE

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

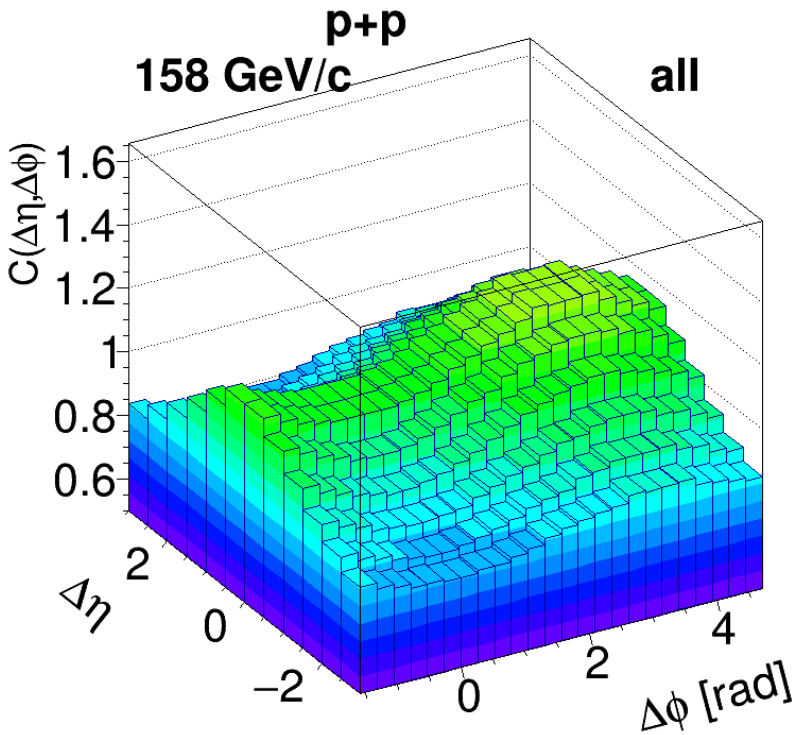




Two-particle correlations in $\Delta\eta\Delta\phi$

Two-particle correlations in $\Delta\eta = |\eta_1 - \eta_2|$, $\Delta\phi = |\phi_1 - \phi_2|$.

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



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

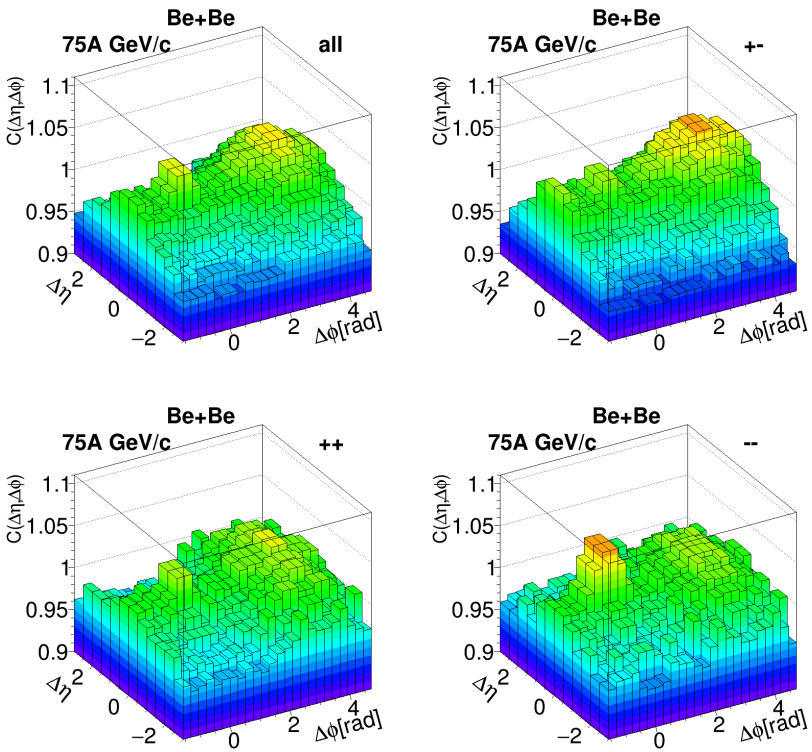
Two-particle correlations - definitions

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

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

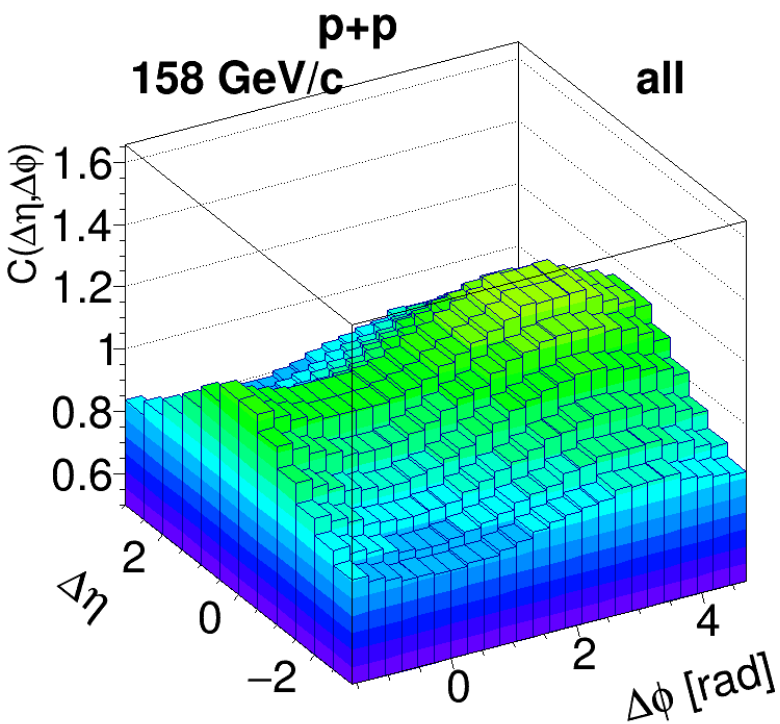
$$S(\Delta\eta, \Delta\phi) = \frac{d^2 N^{pairs}_{signal}}{d\Delta\eta d\Delta\phi} \quad \text{and} \quad B(\Delta\eta, \Delta\phi) = \frac{d^2 N^{pairs}_{bkg}}{d\Delta\eta d\Delta\phi}$$

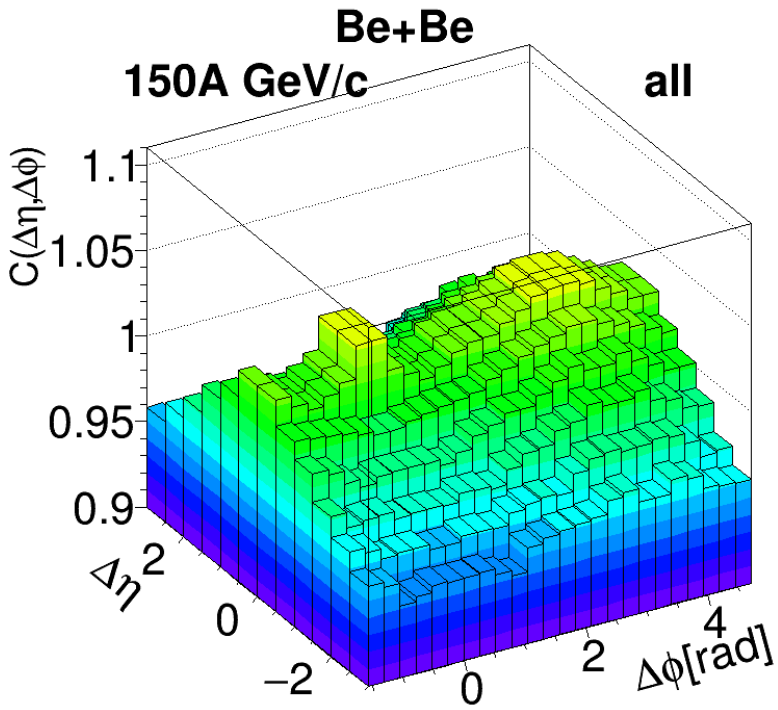
Example results in Be+Be – charge scan



- 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.

p+p vs. Be+Be comparison



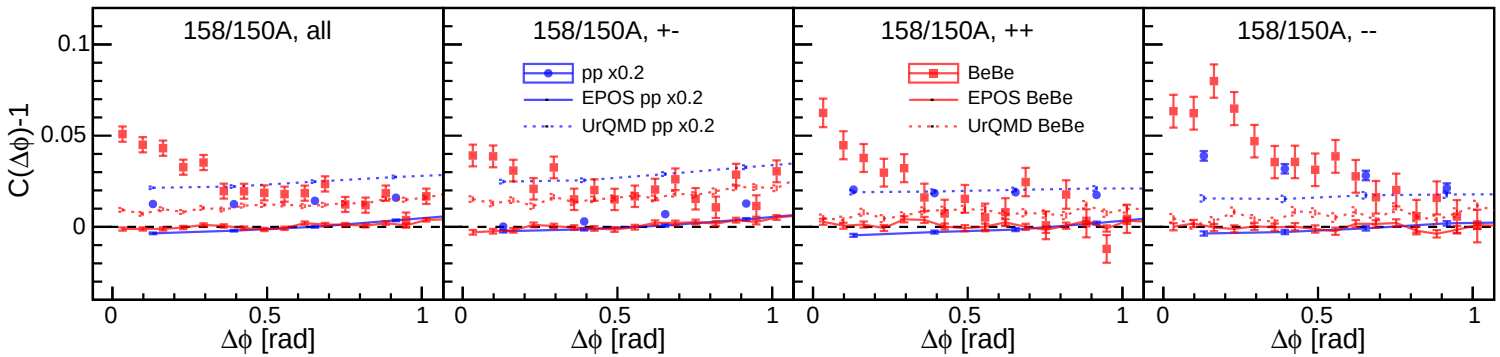


Eur.Phys.J. C77 (2017) no.2, 59

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).

p+p vs. Be+Be comparison – 1D

Comparison of p+p and Be+Be results taken at 158/150A GeV/c



Only the bin $\Delta\eta \in [0; 0.5)$ is plotted and $\Delta\phi$ is zoomed to range $\Delta\phi \in [0; 1]$ rad. p+p data scaled down.

Be+Be shows increase towards $\Delta\phi = 0$. The explanation of correlation excess in Be+Be w.r.t. p+p and its width is *only partially* explained by correlations from quantum statistics (Hanburry-Brown-Twiss), Coulomb and Final State Interactions.

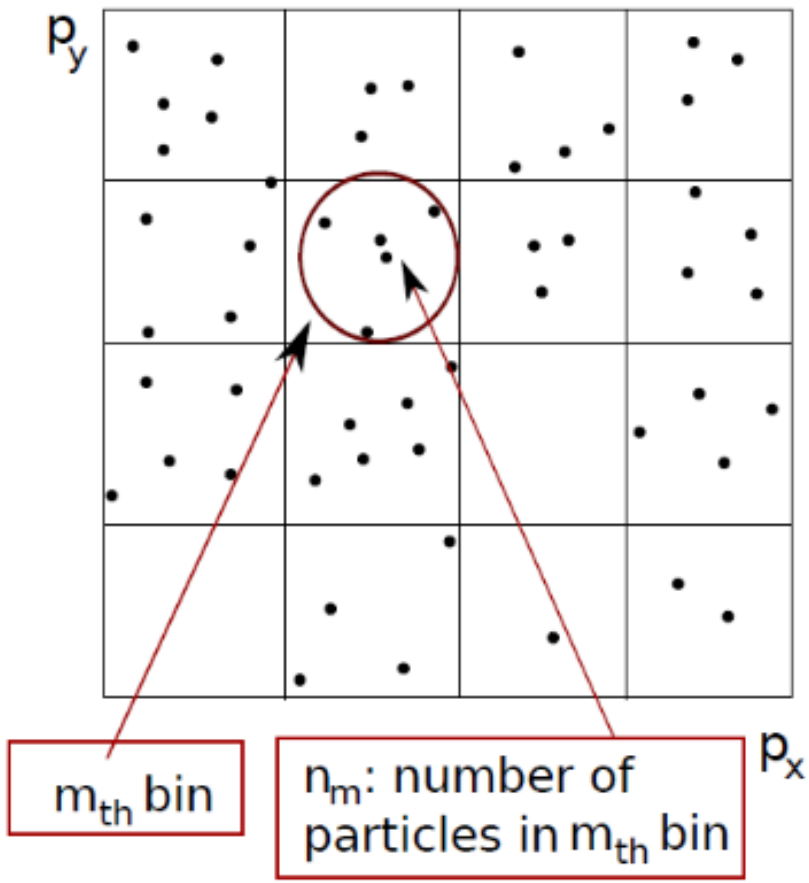
Search for critical point: proton intermittency

A second order phase transition (QCD CP) may manifest as fluctuations of the baryon density. This effect can be searched for by studying scaling behavior of second factorial moments $F_2(M^2)$ with the cell size in (p_x, p_y) space (i.e. divided into $M \times M$ bins).

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

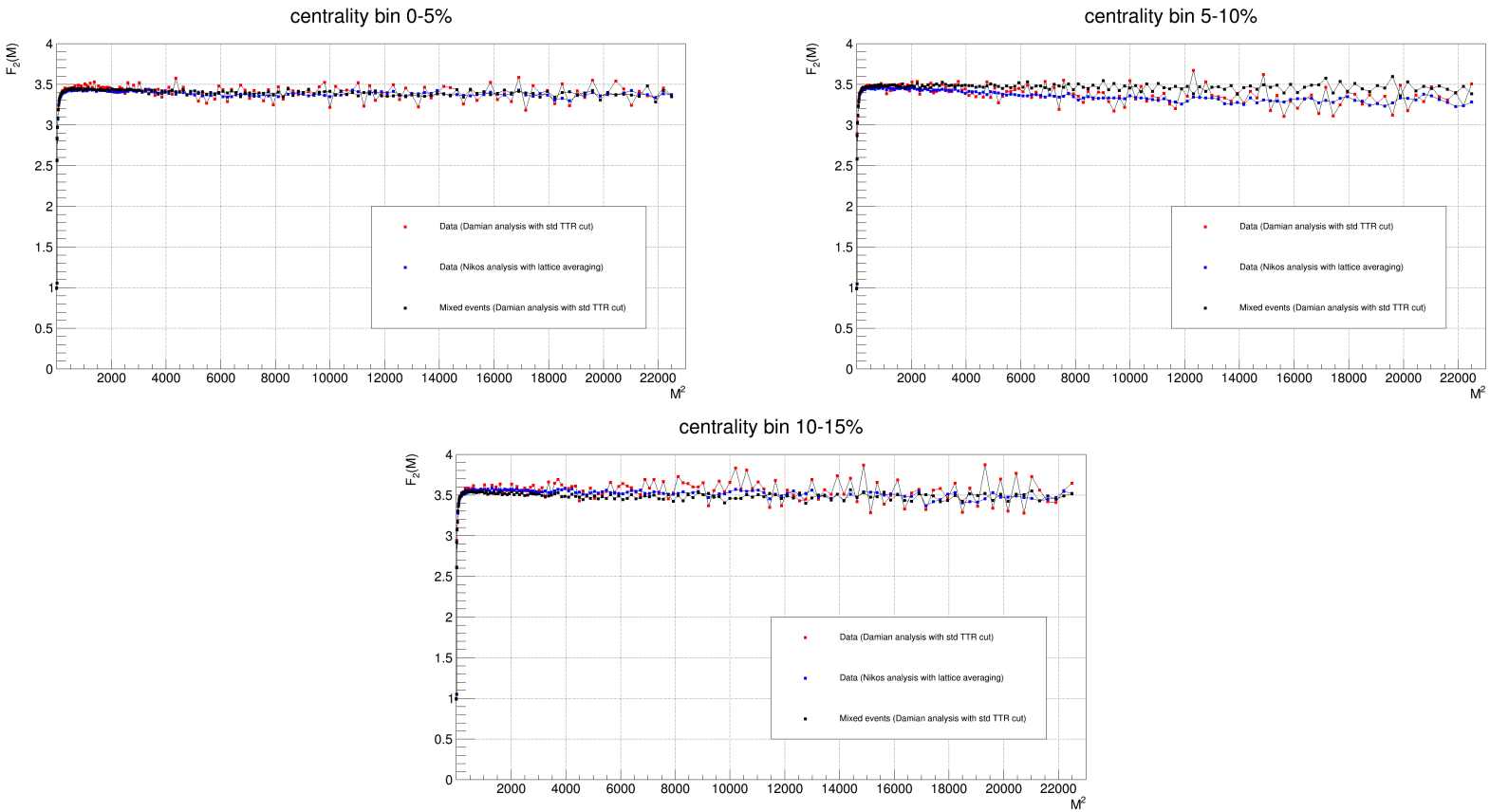
At the critical point, a power law dependence with M^2 is expected:

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



Search for critical point: proton intermittency

Example for Ar+Sc at 150A GeV/c



Unfortunately, in Ar+Sc collisions we do not see any signal in $F_2(M^2)$.
The analysis of Pb+Pb at 30A GeV/c data is ongoing.

Summary

- The NA61/SHINE experiment has finished energy and system-size scan in 2018 (before the Long Shutdown 2). The restart of the data taking is planned for 2021.
- Still many datasets need calibration, reconstruction and analysis.

Latest news

- We have finished the calibration of the first two Xe+La datasets (at 40A and 150A GeV/c beam momenta).
- We are working on the remaining Xe+La datasets, Pb+Pb at 150A GeV/c and unique p+p at 400 GeV/c.
- Current plan for NA61/SHINE: with the GRIEG grant proposal accepted, we will upgrade the detector before its restart after the Long Shutdown 2.
  - First test runs early summer 2021.
  - First production runs autumn 2021.

Thank you

Our group at NCNR

Members

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

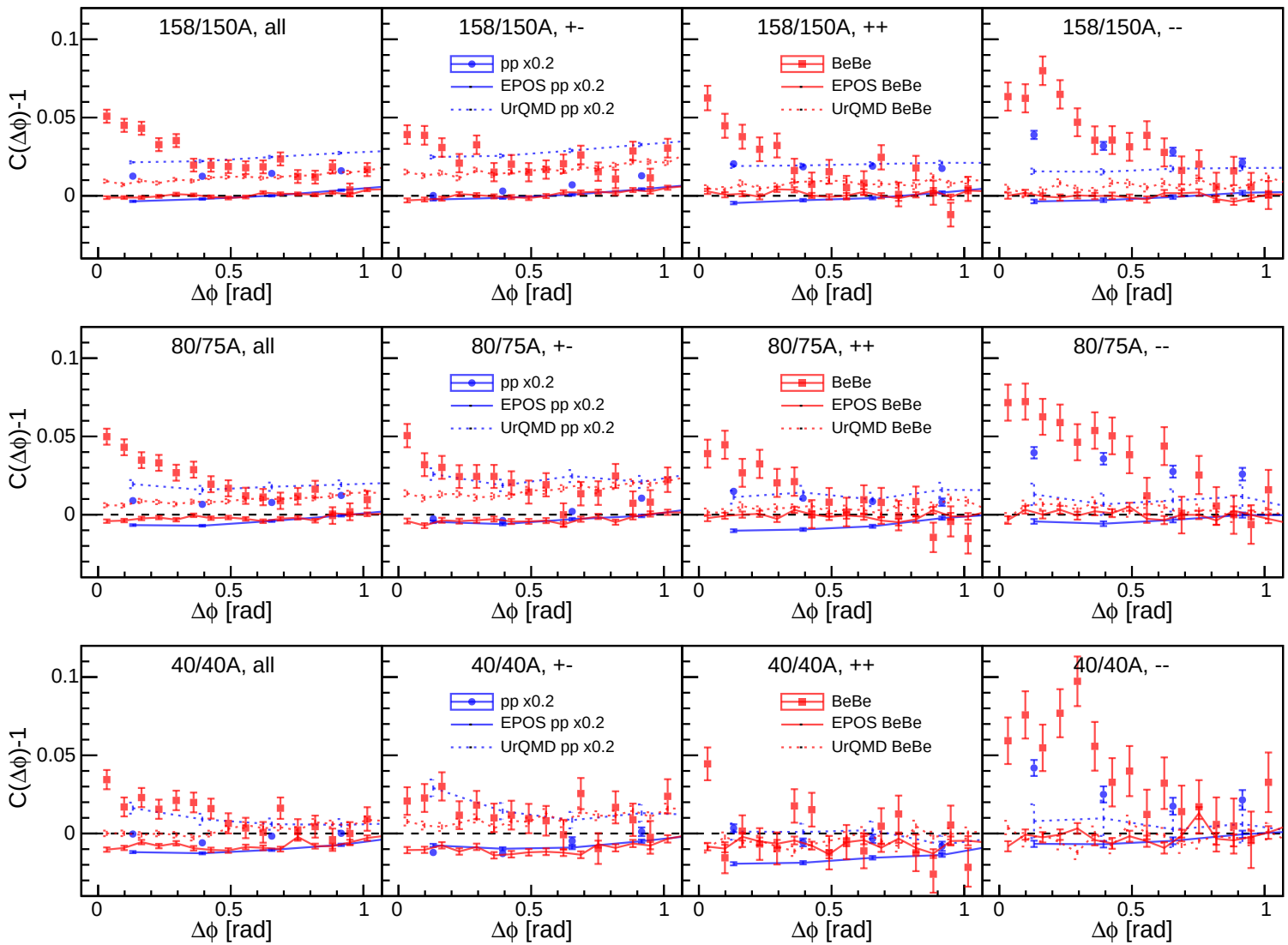
Activities

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

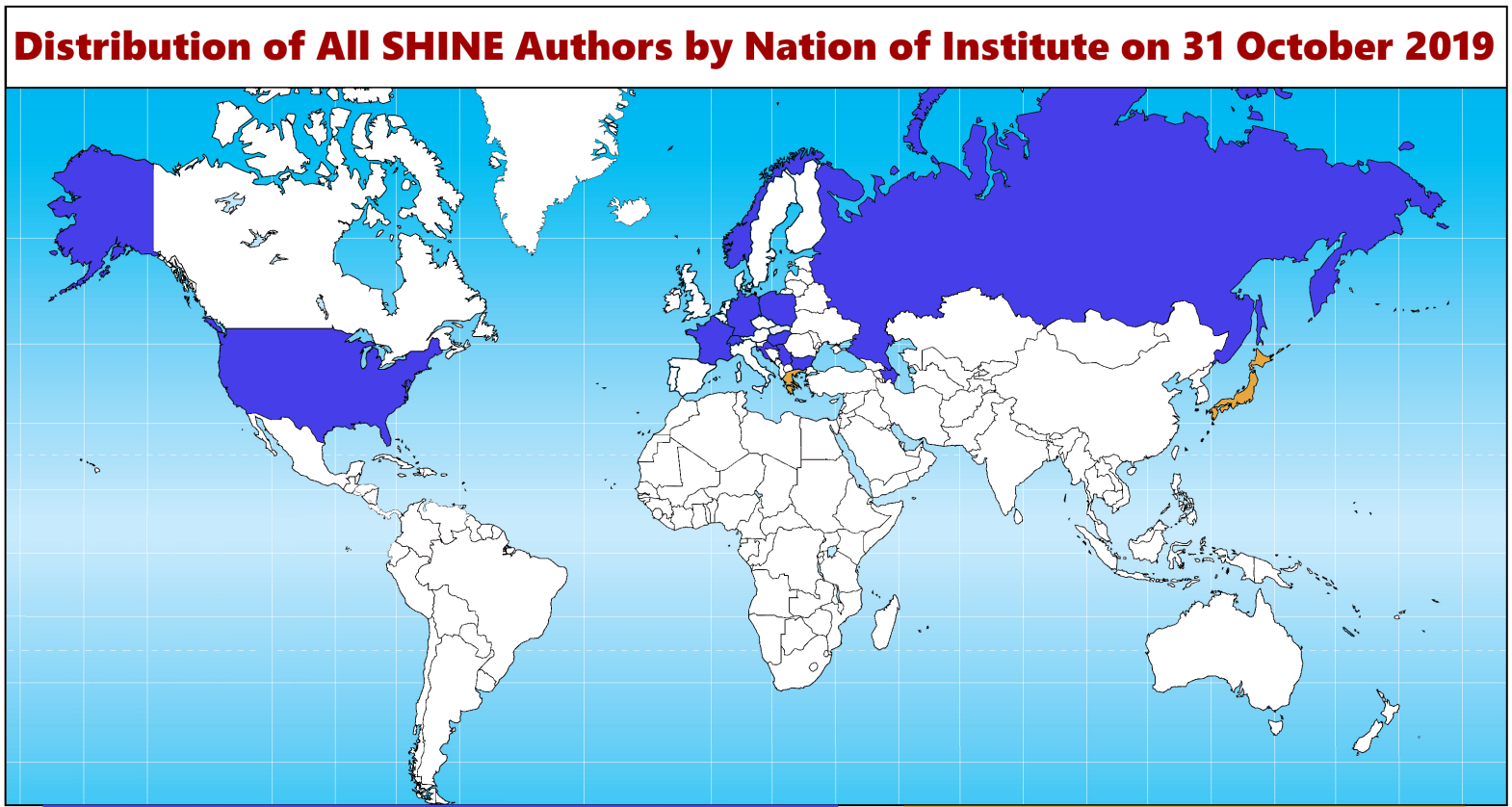
NA61/SHINE publications in 2020

- 10 papers published
- 2 papers accepted for publication, including:
  Two-particle correlations in azimuthal angle and pseudorapidity in central ^{7}Be+^{9}Be *collisions at the CERN Super Proton Synchrotron*
- Applied for SONATA16 grant
- Applied for OPUS as part of 8-institute consortium (leading institution: Jagiellonian University).

p+p vs. Be+Be comparison – energy scan



NA61/SHINE collaboration members map



FULL MEMBERSHIP

AZERBAIJAN	2	BULGARIA	4
CROATIA	3	FRANCE	1
GERMANY	14	HUNGARY	5
NORWAY	1	POLAND	55
RUSSIA	38	SERBIA	3
SWITZERLAND	6	USA	10

LIMITED MEMBERSHIP

GERMANY	5
GREECE	6
JAPAN (KEK)	8
POLAND	10
SWITZERLAND (CERN)	9
USA	4