This work is supported by the Russian Science Foundation,
grant 17-72-20045.

A HINT OF PERCOLATION THRESHOLD IN HEAVY ION COLLISIONS AT SPS ENERGIES

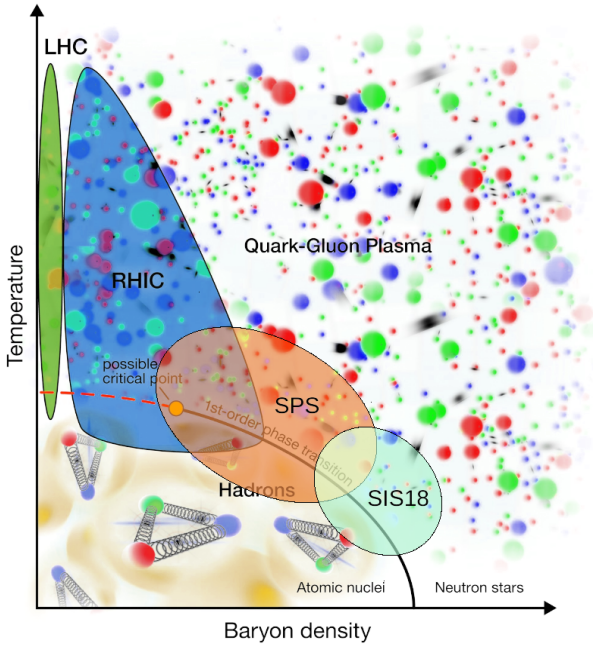
Andrey Seryakov
for the NA61/SHINE collaboration

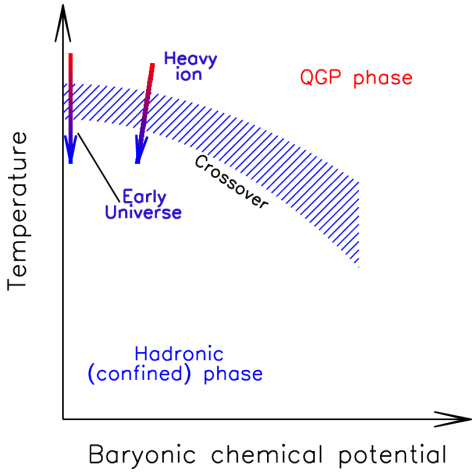
Laboratory of Ultra-High Energy Physics

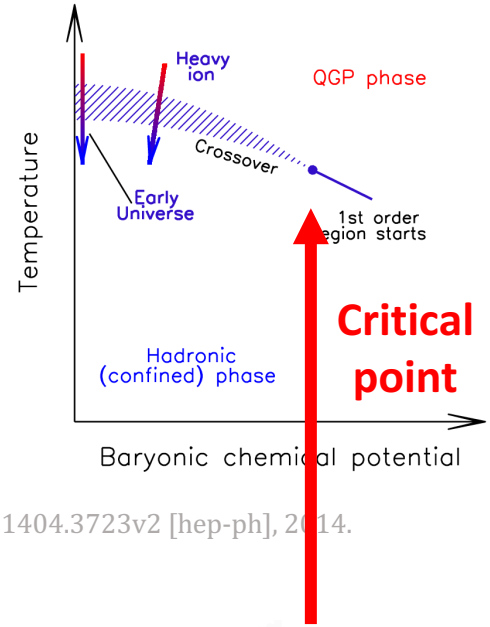
St. Petersburg State University

QUARKS - 2018
1/06/18

Motivation







N. Brambilla et al., arXiv:1404.3723v2 [hep-ph], 2014.

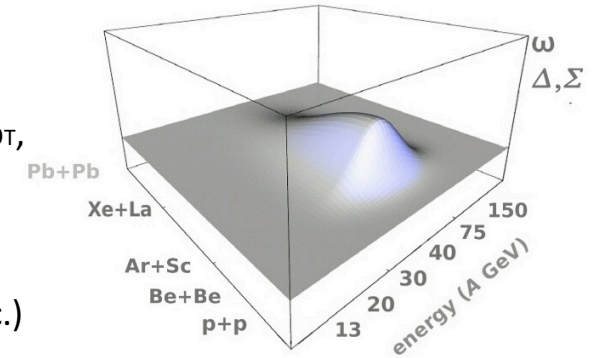
NA61/SHINE heavy ion program:

- **Search for the critical point**

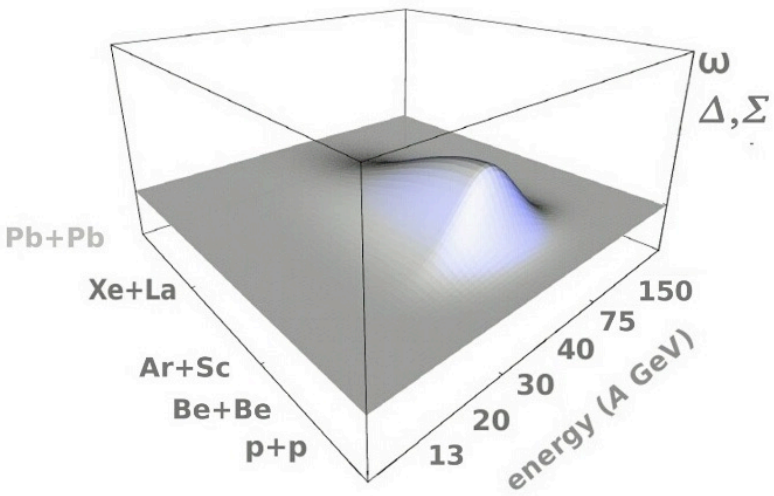
Search for non-monotonic behavior of CP signatures: fluctuations of N, average p_T, etc., intermittency, when system freezes out close to CP

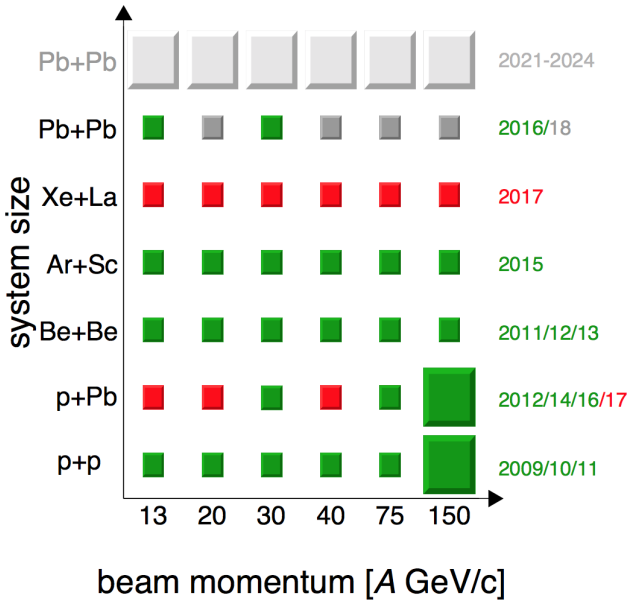
- **Study of the properties of the onset of deconfinement**

Search for the onset of the horn/kink/step/dale in collisions of light nuclei; additional analysis of fluctuations and correlations (azimuthal, particle ratios, etc.)



NA61/SHINE experiment



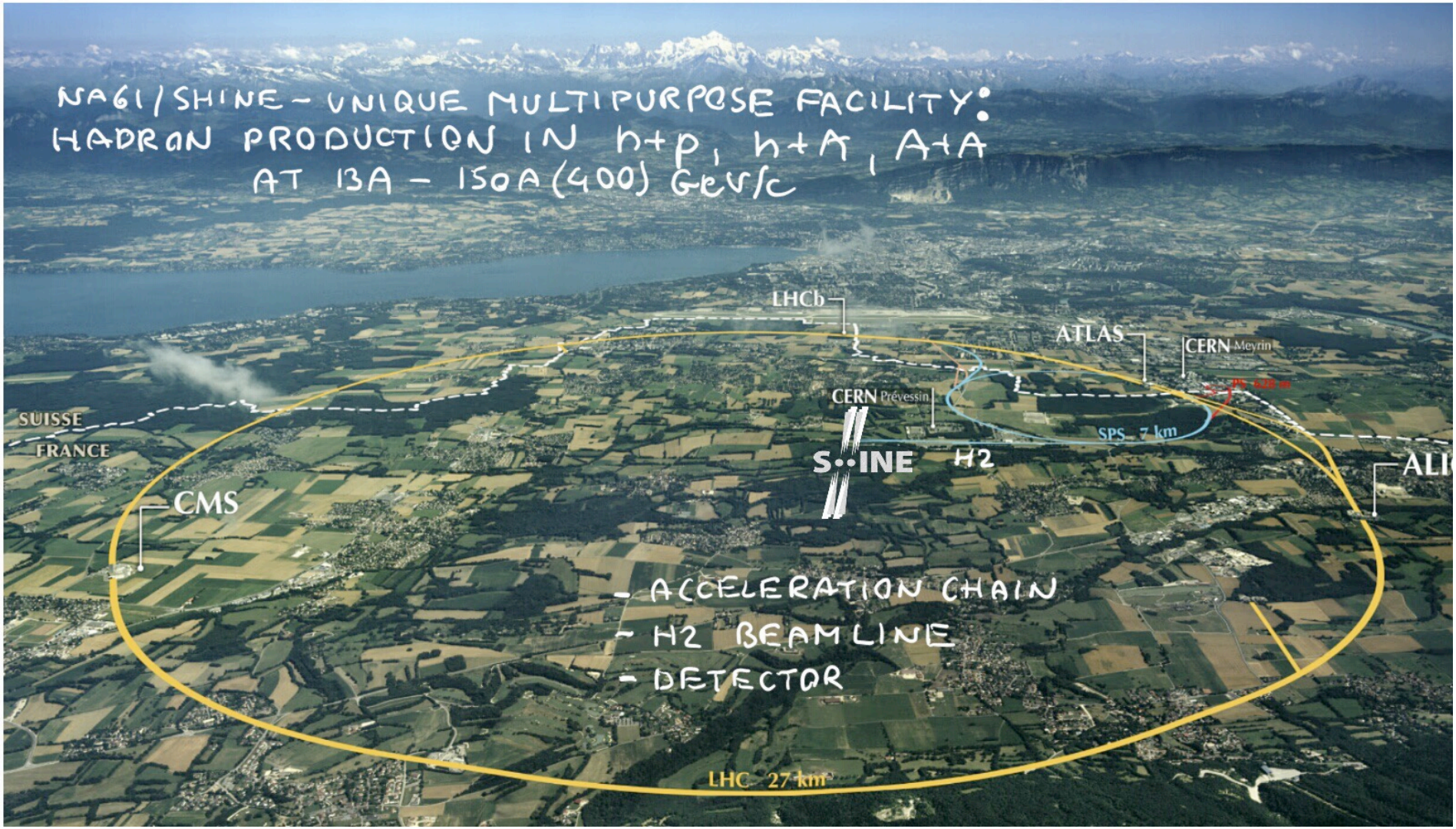


Comprehensive scan with light and intermediate mass nuclei in momentum range 13*A*-158*A* GeV/c

Data taking schedule:

- **Taken data (green)**
- **Approved (red)**
- **Proposed extensions (gray)**

NA61/SHINE experiment



Multiplicity fluctuations

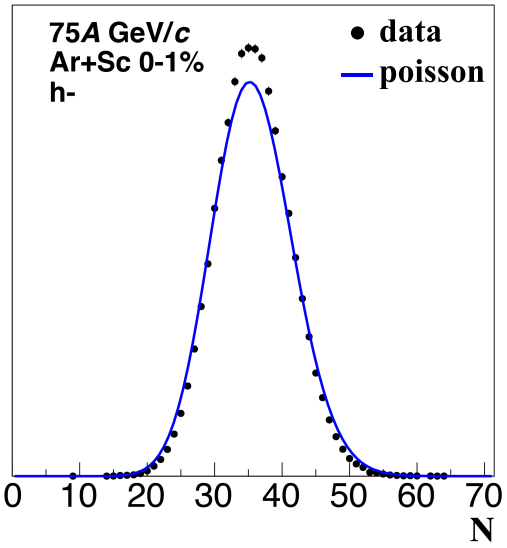
How to estimate the strength of multiplicity fluctuations?

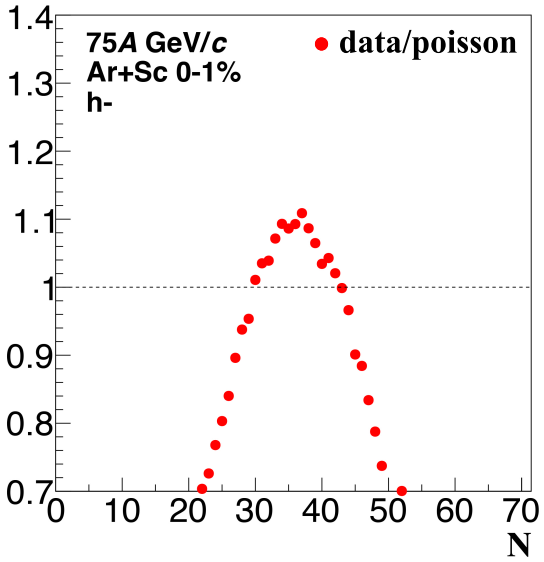
$$\omega[N] = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}$$

For the models with independent particle sources (wounded nucleons model):

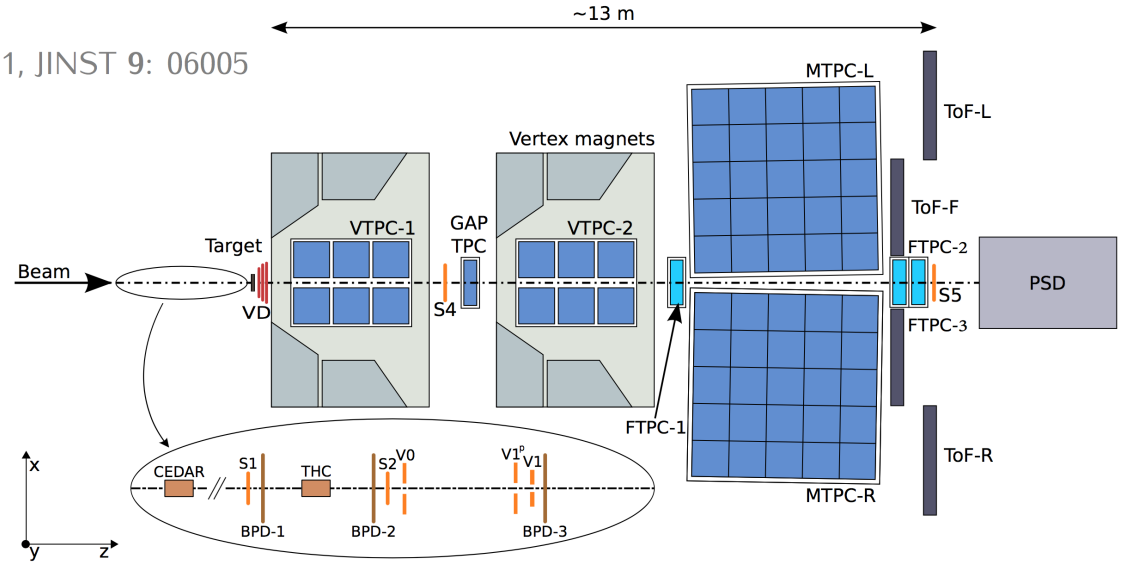
$$\omega[N] = \omega[n] + \bar{n}\omega[N_s]$$

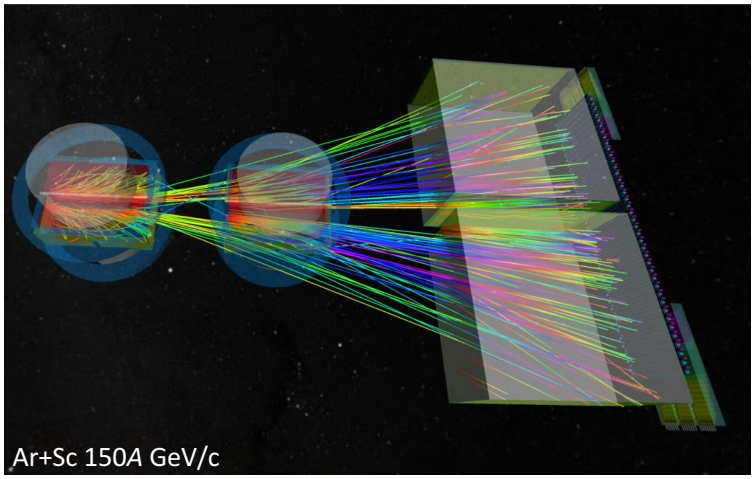
where $\mathbf{n}$ is a multiplicity from a single source (wounded nucleon). Consequently $\boldsymbol{\omega}[\mathbf{N}]$ depends on the number of sources $\mathbf{N_s}$ fluctuations





NA61/SHINE experiment





NA61/SHINE in virtual reality: http://shine3d.web.cern.ch/shine3d/

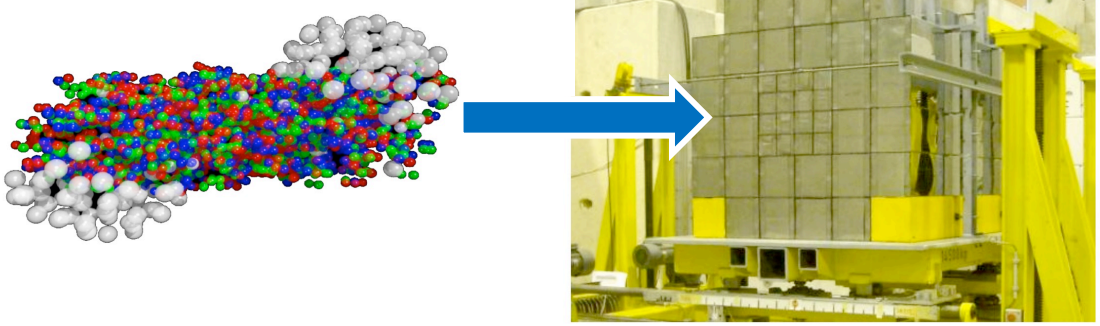
- Large acceptance hadron spectrometer - coverage of the full forward hemisphere, down to $p_T = 0$ GeV/c
- Performs measurements on hadron production in h+p, h+A, A+A at 13A – 150(8)A GeV/c
- Event selection in A+A collisions by measurements of forward energy with PSD
- Recent upgrades:
  - Vertex detector (open charm measurements)
  - FTPC-1/2/3

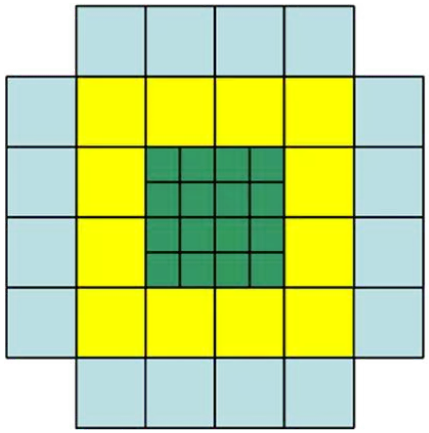
Events selection

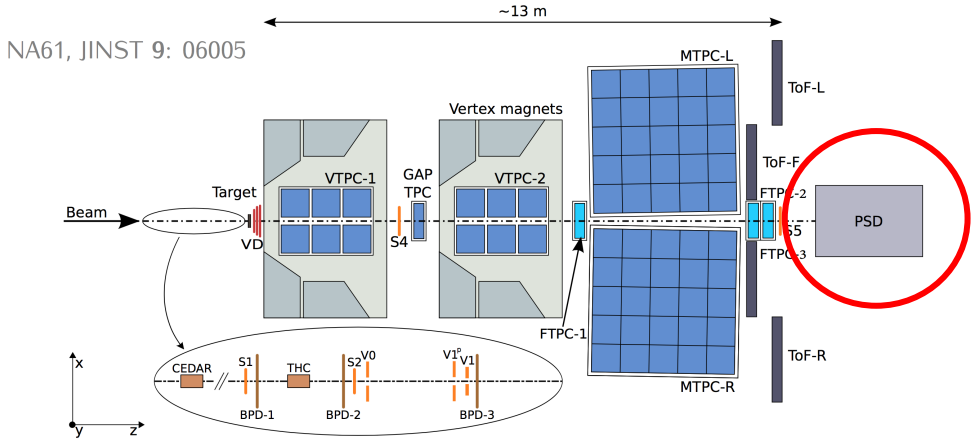
Event selection is based only on the forward energy related to projectile spectators

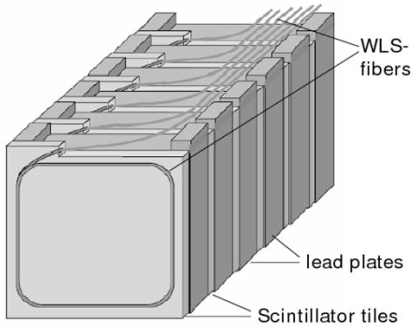
The forward energy consists of two components:

- spectators
- produced particles





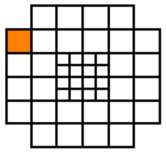


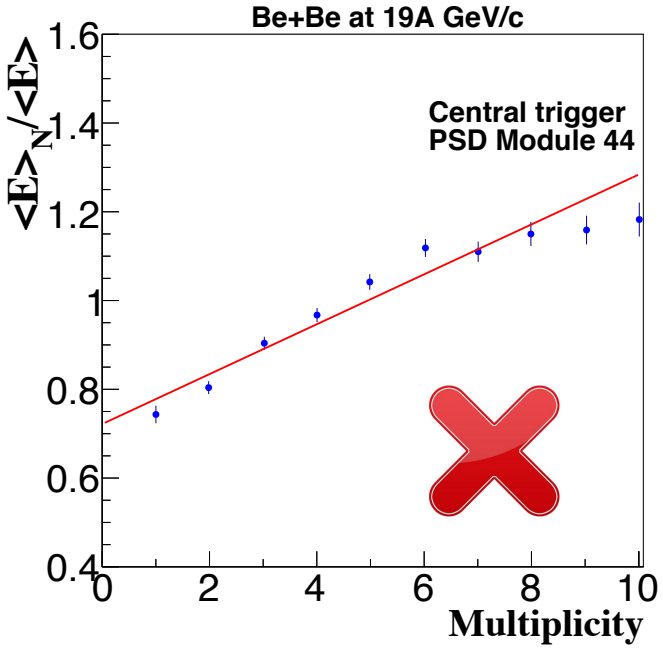


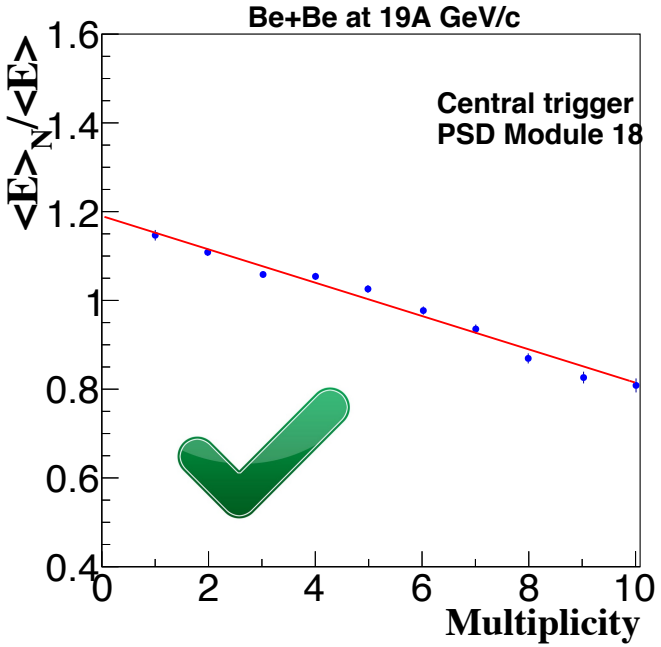
Events selection

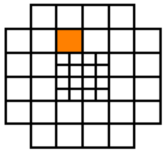
- One needs to choose set of modules with dominating contribution of spectators and minimal contribution from the produced particles

- The proposed selection is data-driven and is based on correlations between energy and track multiplicity in TPCs - negative correlation implies dominance of spectators in a specific module



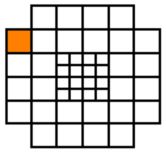


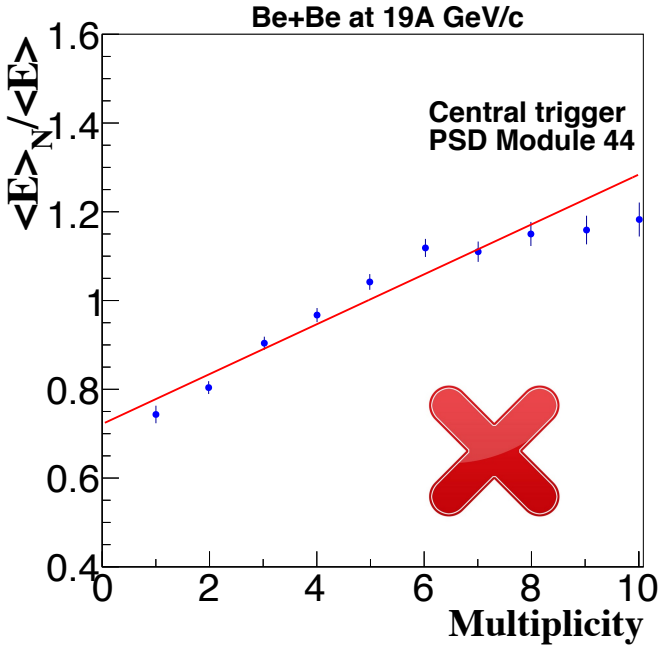


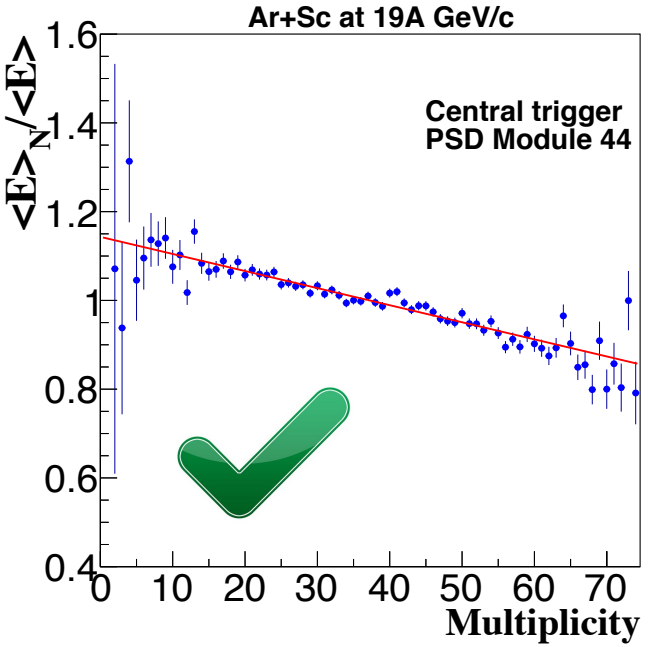


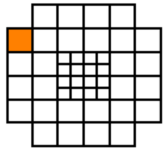
Centrality selection

- Due to the differences in magnetic field and PSD position for various energies, different set of modules is chosen to calculate forward energy
- Unexpectedly, for the same collision energy but for different colliding systems same modules show different behavior









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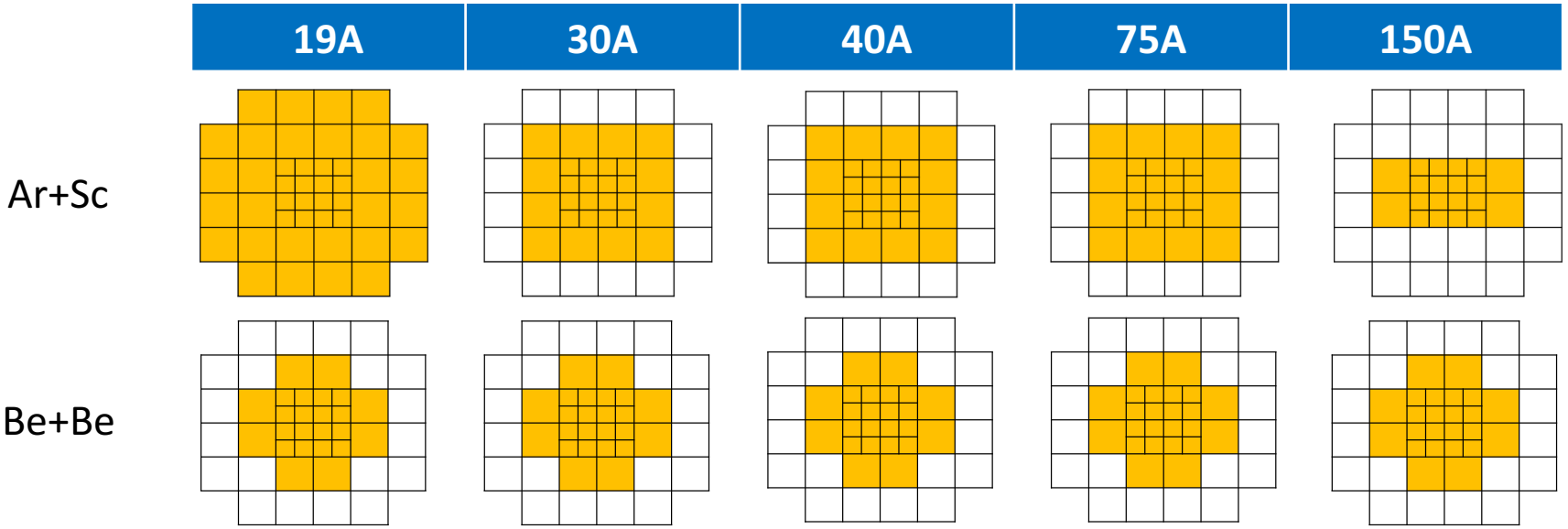
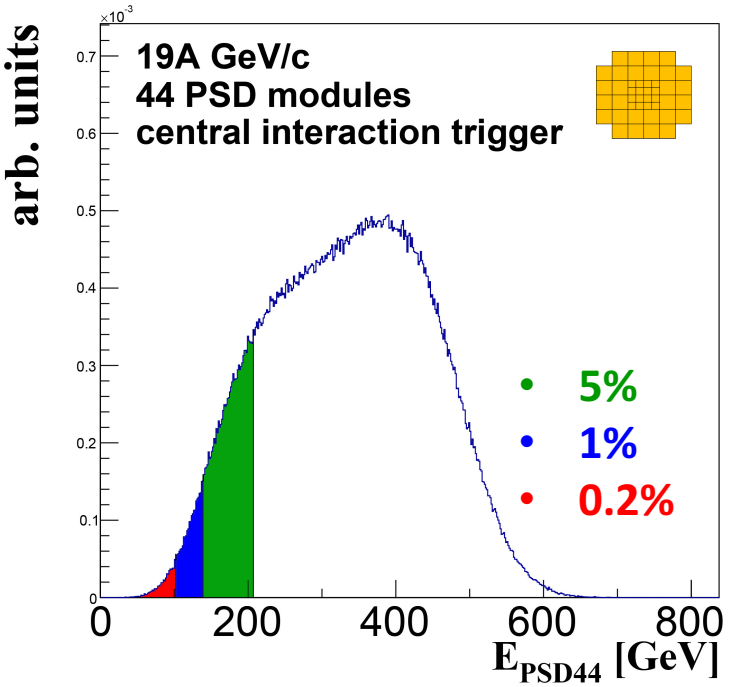


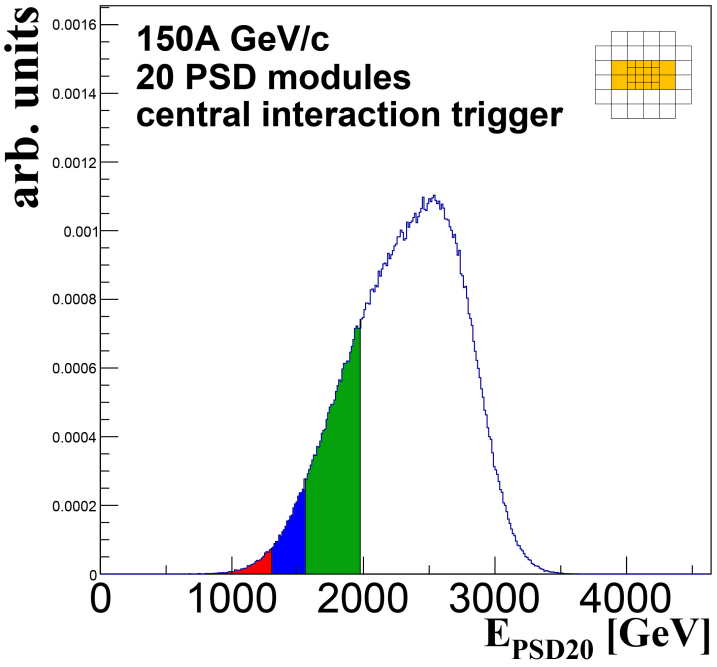
- PSD kinematic regions are different for different energies and systems

Events selection

- The measured energy allows selection of the ”centrality classes”

Ar+Sc





For cross-sections look PoS CPOD2014 (2015) pp.053

Analysis

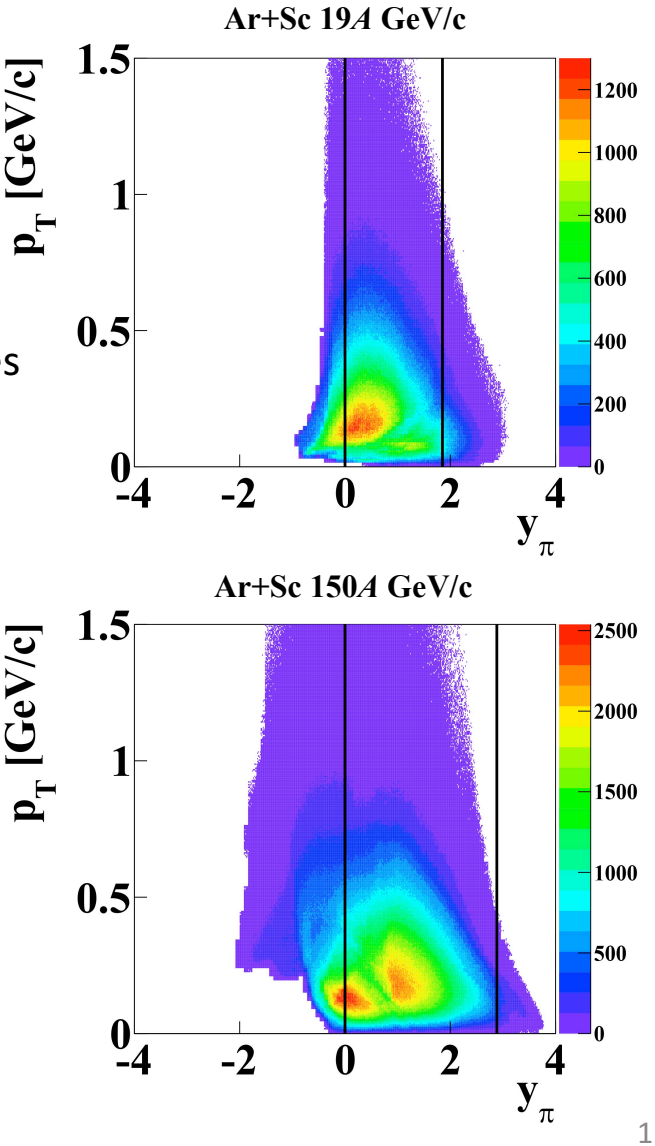
Analysed data:

- centrality selected in $^{40}\mathrm{Ar} + {}^{45}\mathrm{Sc}$ and $^{7}\mathrm{Be} + {}^{9}\mathrm{Be}$ at beam momentum 19*A*, 30*A*, 40*A*, 75*A*, 150*A* GeV/c or at $\sqrt{s_{NN}}$ = 6.12, 7.62, 8.76, 11.94, 16.83 GeV

- Event and track selection criteria were chosen to select only **inelastic** (centrality selected) interactions and particles produced in strong and EM processes

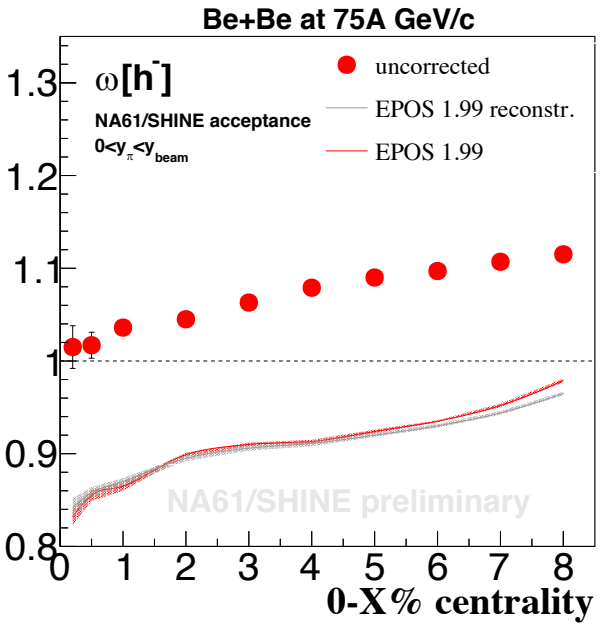
- **centrality selected by forward energy**
  (In simulations – selections is based on energy of all particles hitting the selected PSD modules)

- Track selection criteria:
  - **the NA61/SHINE acceptance**
    https://edms.cern.ch/document/1549298/1
  - **not electron or positron**
  - **p_T < 1.5 GeV/c**
  - **0 < y_π < y_{beam}**



Analysis

- Currently results are not corrected for experimental biases
- To estimate magnitude of these biases pure and reconstructed MC data sets were analyzed. The differences between results are less than 5%
- Statistical uncertainties were calculated using the sub-sample method

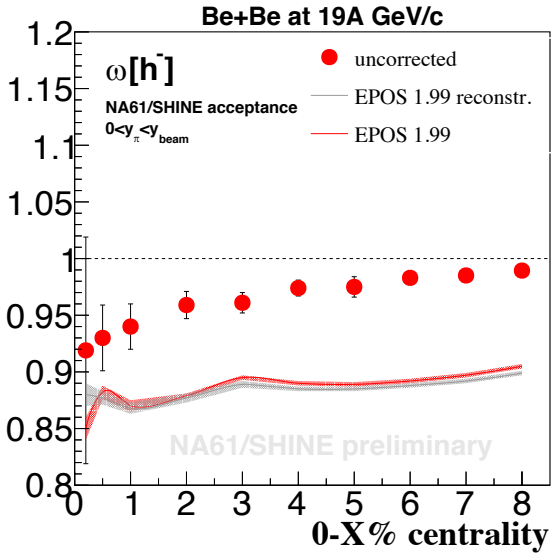


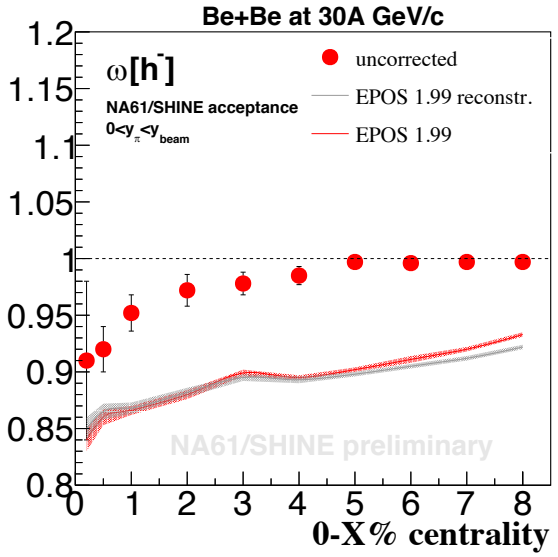
EPOS1.99 - Werner, *et al.*, PRC 74:044902

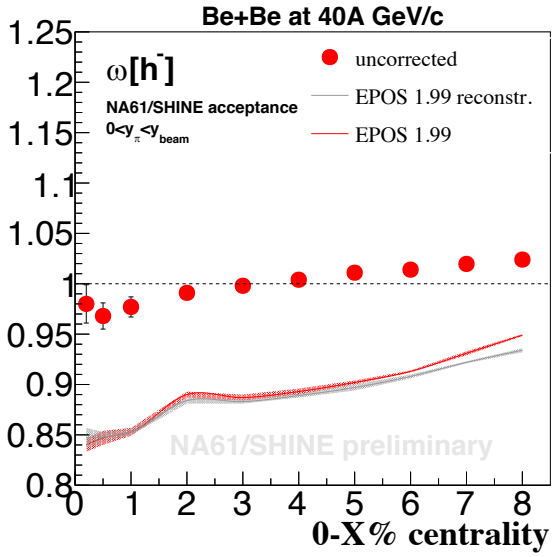
NOTE!

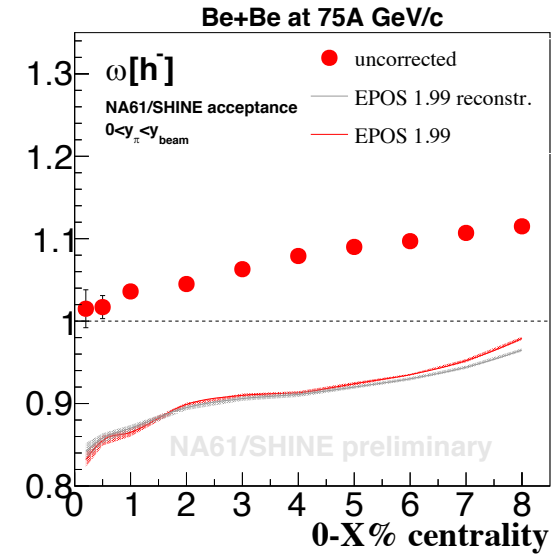
All results (p + p, $^{7}\mathrm{Be} + {}^{9}\mathrm{Be}$, $^{40}\mathrm{Ar} + {}^{45}\mathrm{Sc}$) will be shown in NA61/SHINE acceptance with $0 < y_\pi < y_{beam}$ and without systematic uncertainties

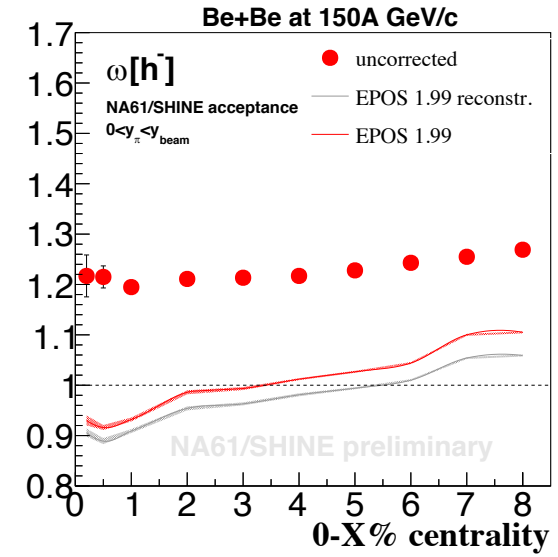
Multiplicity fluctuations: centrality dependence







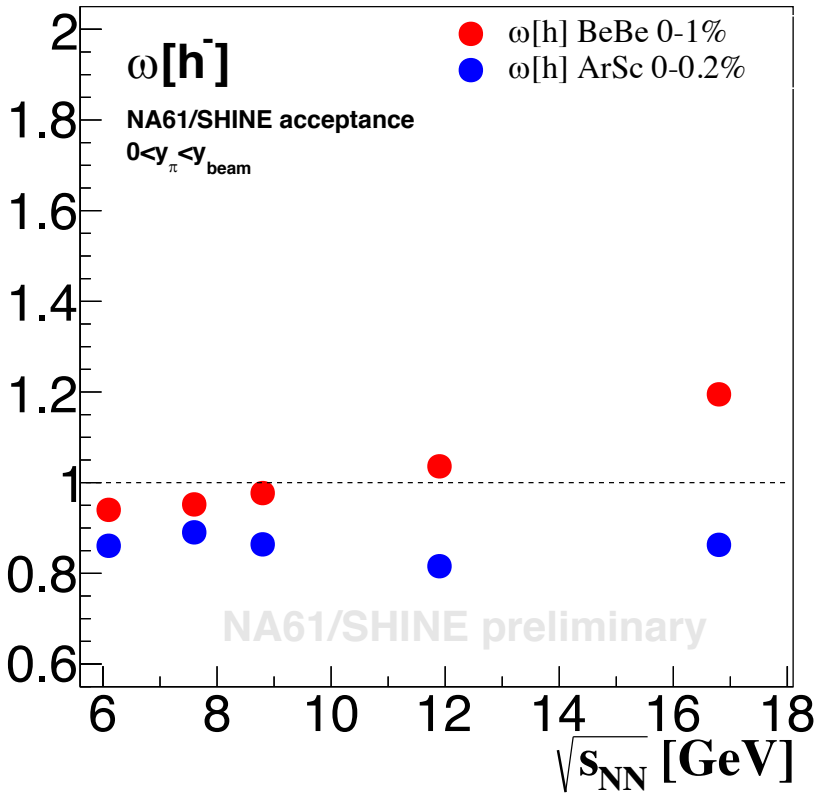




$\omega[h^-]$ is larger for broader centrality intervals both in data and in model $\Longrightarrow$ volume fluctuations?

EPOS 1.99 underestimates $\omega[h^-]$

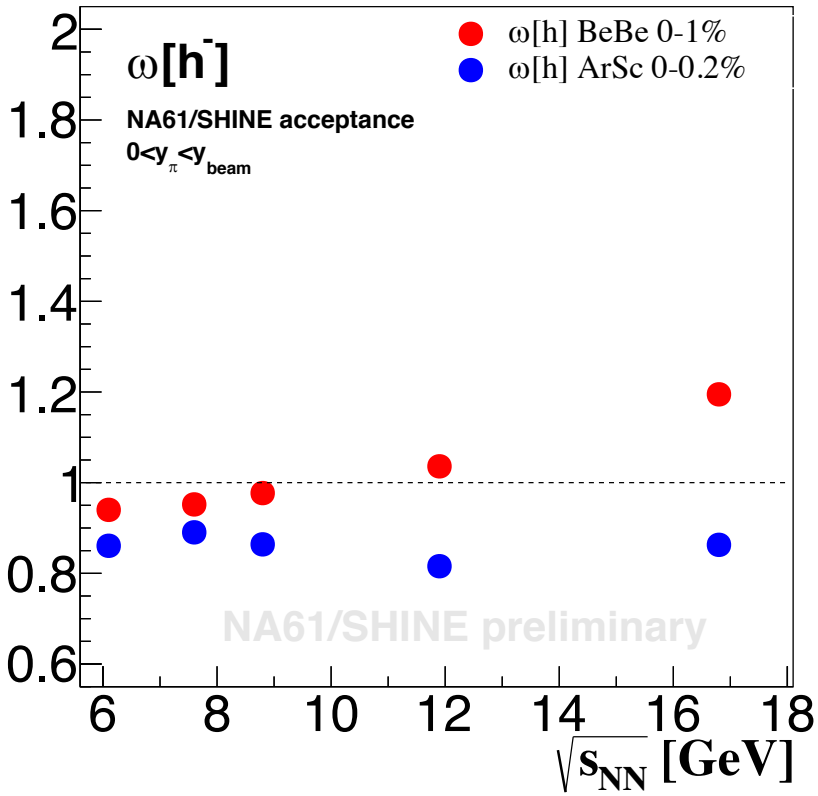
Multiplicity fluctuations: energy dependence



Different energy dependence for Be+Be and Ar+Sc collisions!

$\omega[N]$ increases with collision energy in Be+Be but remains particularly constant in Ar+Sc

Multiplicity fluctuations: energy dependence



Different energy dependence for Be+Be and Ar+Sc collisions!

$\omega[N]$ increases with collision energy in Be+Be but remains particularly constant in Ar+Sc

Is it a volume effect???

Strongly intensive quantities

A new strongly intensive quantity can be constructed:

$$\Omega[A,B] = \omega[A] - \frac{\langle AB\rangle - \langle A\rangle\langle B\rangle}{\langle B\rangle}$$

R. V. Poberezhnyuk, M. I. Gorenstein, M. Gazdzicki, arXiv:1509.06577v2 [hep-ph] 23 Sep 2015

and if A and B are uncorrelated from a single source ($\langle ab\rangle = \langle a\rangle\langle b\rangle$), then

$$\Omega[A,B] = \omega[a]$$

where $\omega[a]$ is scaled variance of A from a single source.

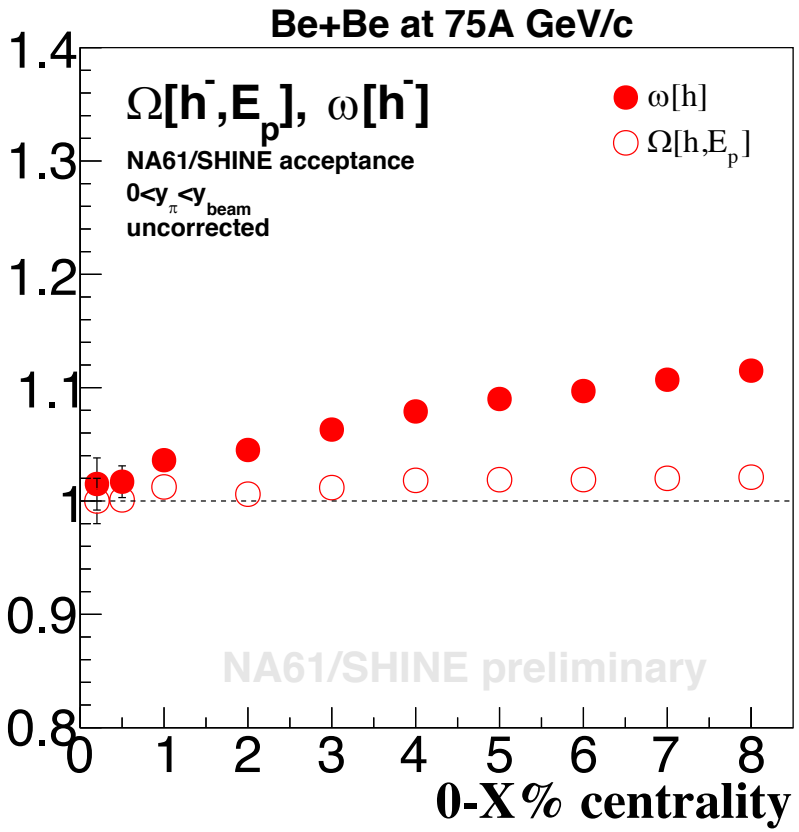
If A = $\mathbf{N}$ and B = $\mathbf{E_{beam} - E_{PSD}} = \mathbf{E_P}$, then

$$\Omega[N,E_P] = \omega[n]$$

If a centrality interval is narrow enough, we can expect:

$$\Omega[N,E_P] \approx \omega[N]$$

$\Omega[N, E_P]$, $\omega[N]$: centrality dependence

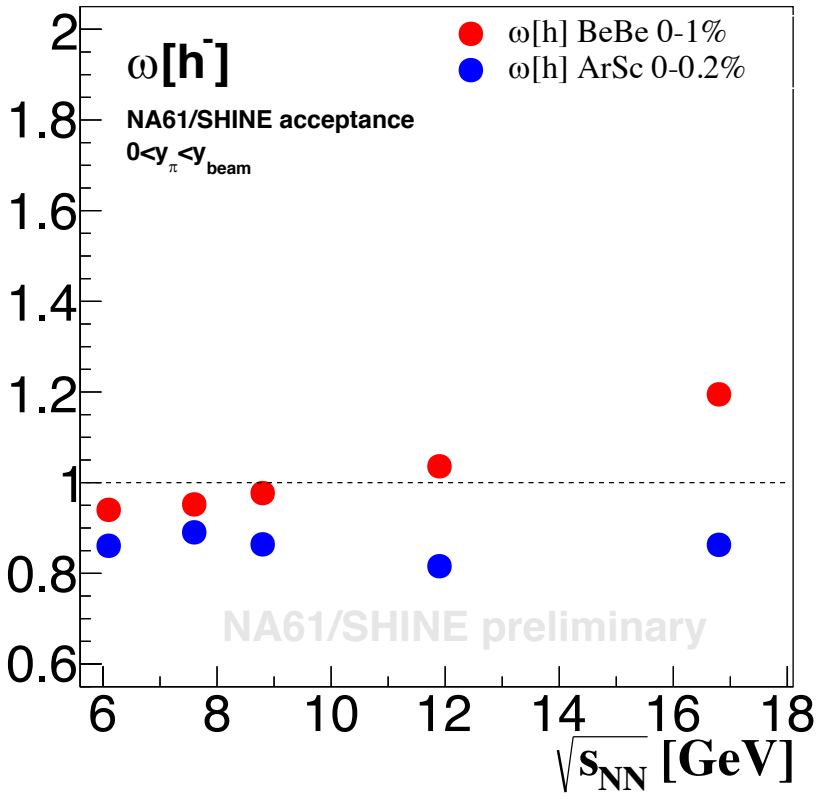


$\Omega[N, E_P]$ almost does not depend on centrality – strongly intensive!

$\Omega[N, E_P]$ and $\omega[N]$ converges to a common limit for very central events

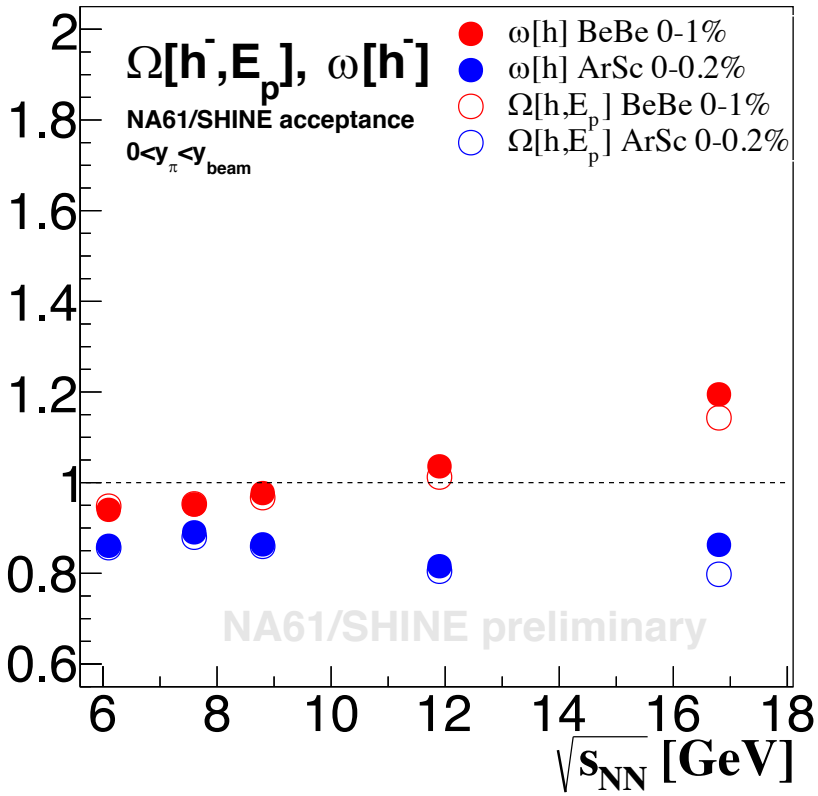
Is this common limit $\omega[n]$?

Multiplicity fluctuations: energy dependence



Different energy dependence for Be+Be and Ar+Sc collisions!

$\Omega[N, E_P]$, $\omega[N]$: energy dependence

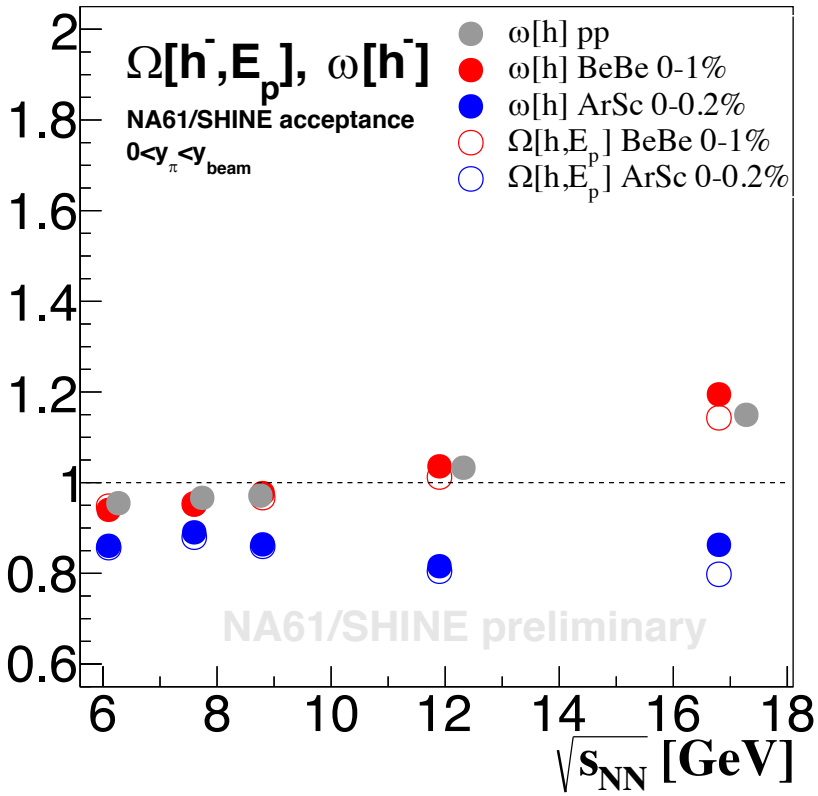


$\Omega[N, E_P]$ and $\omega[N]$ converges to a common limit for very central events for both systems

$\omega[N]$ is significantly larger for the central Be+Be collisions than for central Ar+Sc collisions!

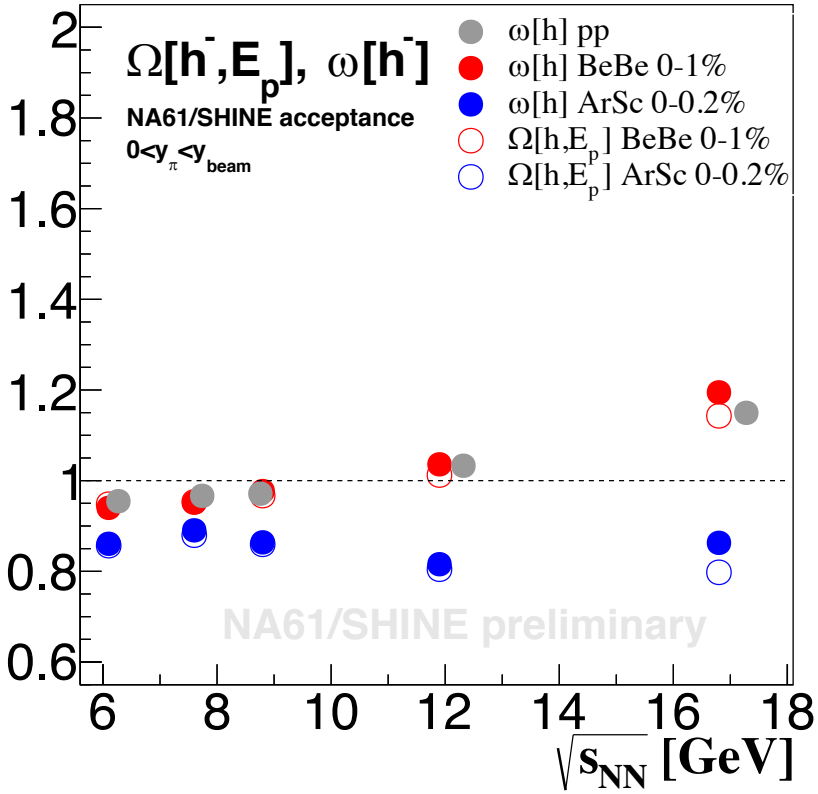
Different magnitudes of $\omega[n]$ for different systems?

$\Omega[N, E_P]$, $\omega[N]$: energy dependence



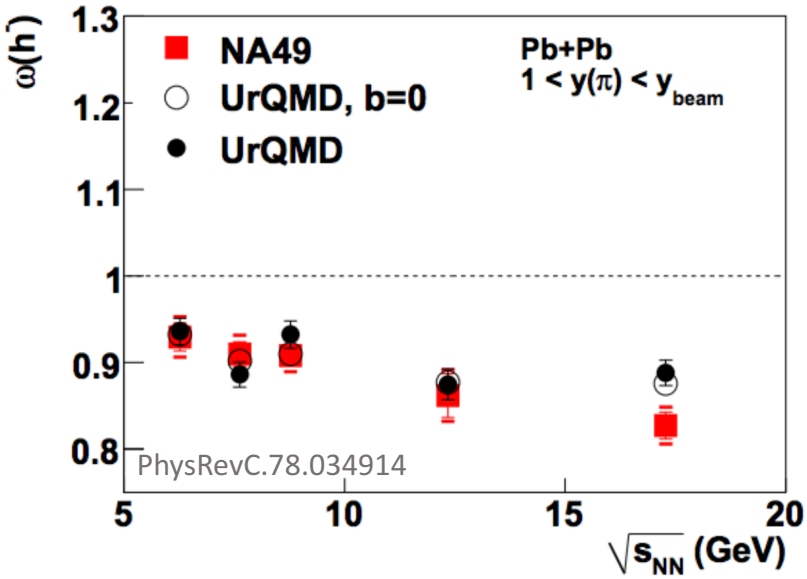
$\omega[N]$ in the central Be+Be collisions behaves exactly like in p+p!

$\Omega[N, E_P]$, $\omega[N]$: energy dependence



NA49 Pb+Pb:

- Smaller acceptance
- Worse centrality

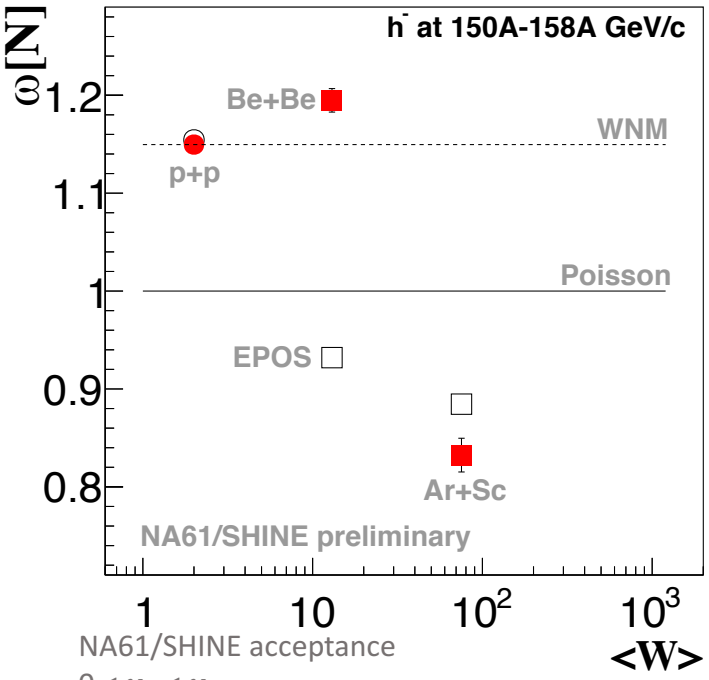


ω[N] in the central Ar+Sc collisions behaves like in Pb+Pb?!!

Multiplicity fluctuations: system size dependence

$\omega[N]$ is significantly larger for inelastic p+p interactions and for the central Be+Be collisions than for central Ar+Sc collisions!

Onset of fireball



NA61/SHINE acceptance
$0 < y_\pi < y_{beam}$
p+p – inelastic
Be+Be – 0-1%
Ar+Sc – 0-0.2%

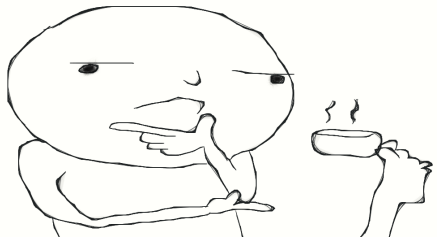
Why $\omega[N]$ in **central** Be+Be collisions is close to p+p value?

Why $\omega[N]$ is suppressed for central Ar+Sc (and Pb+Pb?) collisions in comparison to p+p and Be+Be?

Possible explanations:

- percolation models

Baym, Physica **96A**: 131
Celik, Karsch, Satz PLB **97**: 128
Braun, Pajares, NPB **390**: 542
Armesto, *et al.*, PRL **77**: 3736
Cunqueiro, *et al.*, PRC **72**: 024907

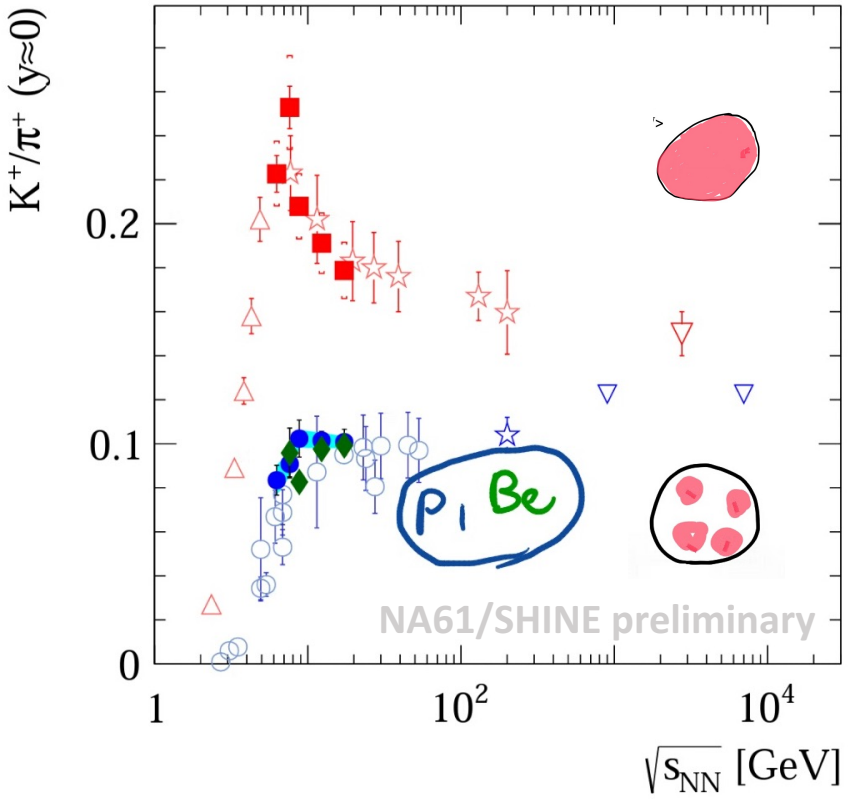


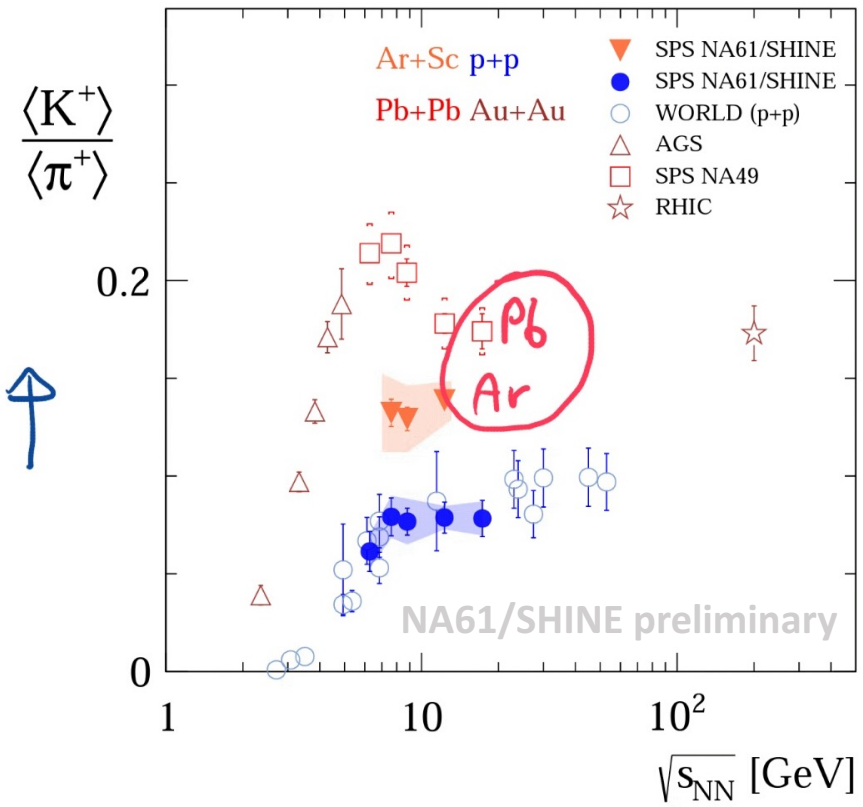
- AdS/CFT correspondence

E. Shuryak Prog. Part. Nucl. Phys. 62 (2009) 48–101, arXiv:0807.3033 [hep-ph]
S. Lin and E. Shuryak Phys. Rev. D79 (2009) 124015, arXiv:0902.1508 [hep-th].

- Anything else?

Other interesting signals

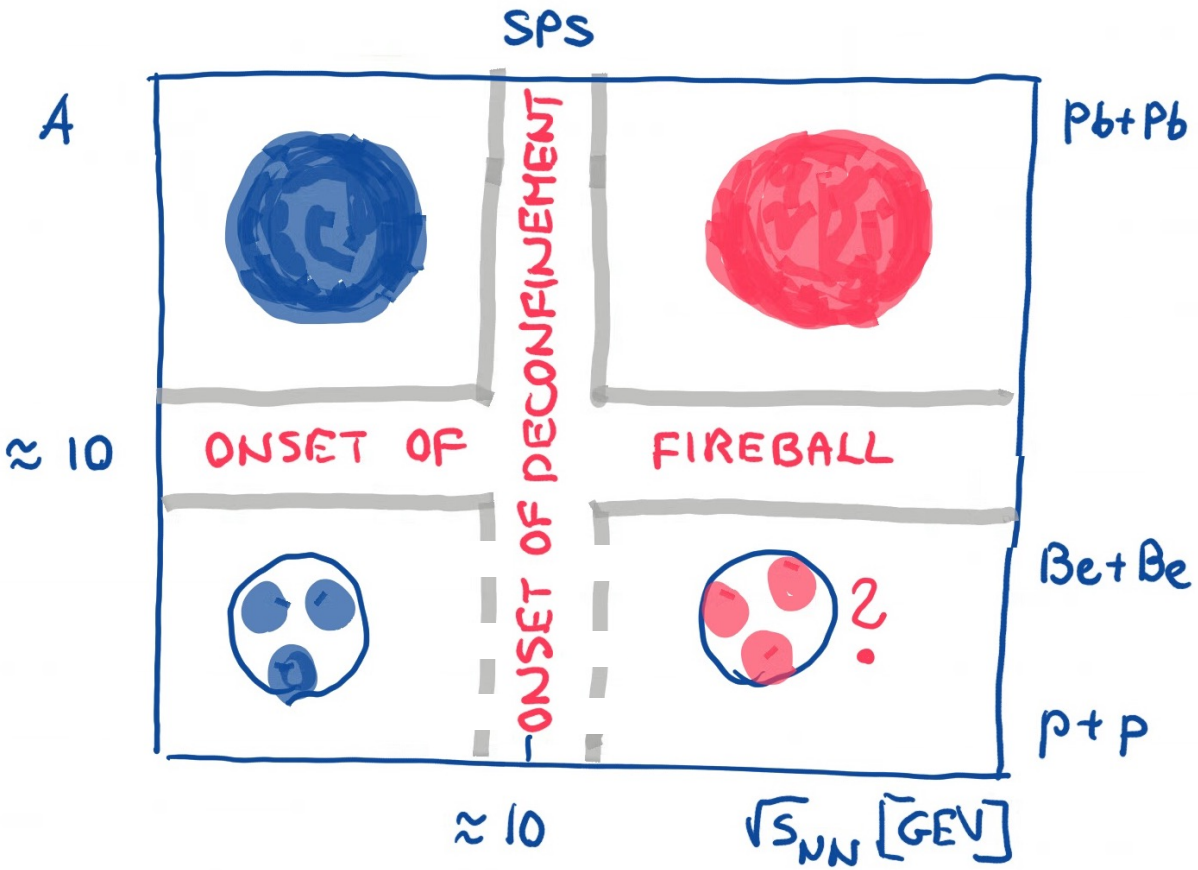


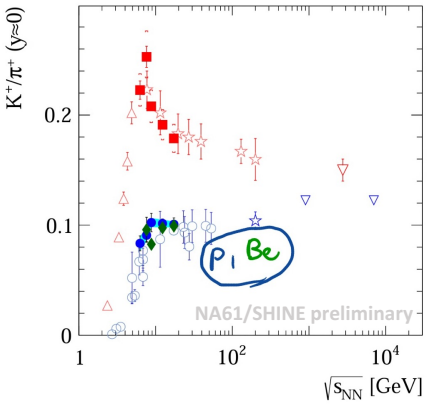


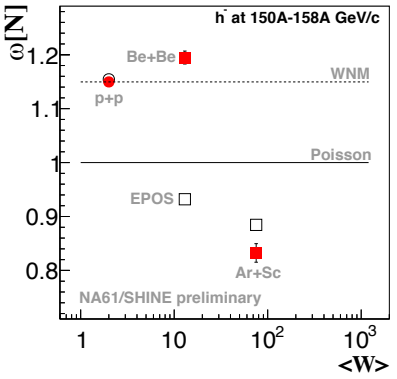
Mean multiplicities ratio shows similar behavior

- p+p is close to central Be+Be
- central Ar+Sc is different

ONSET OF FIREBALL





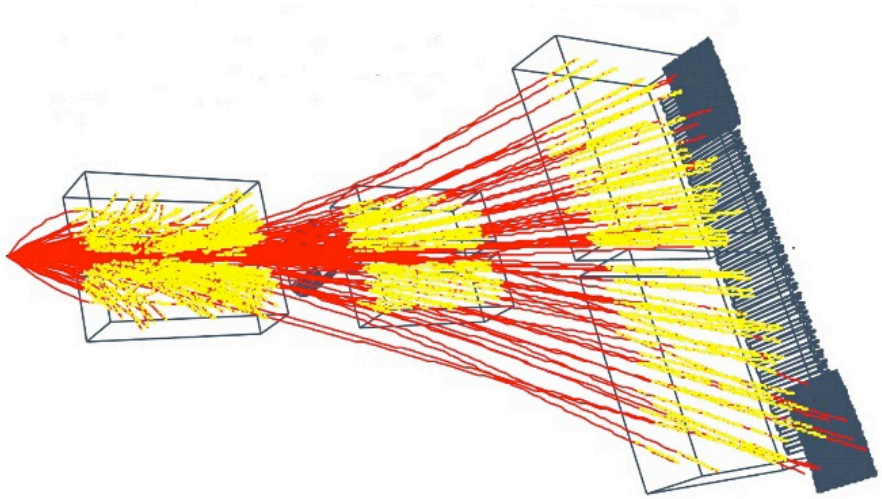


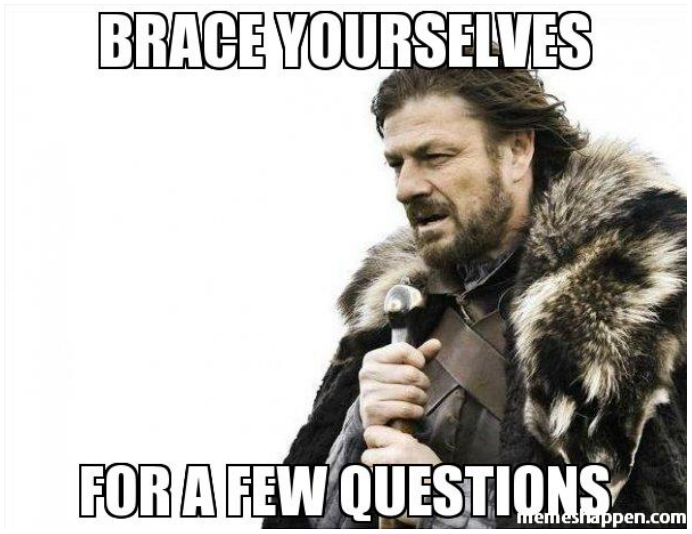
Results on **onset of fireball** and **onset of deconfinement** suggest **four** domains in $A - \sqrt{s_{NN}}$ plane

Working hard to get Xe+La and Pb+Pb data soon

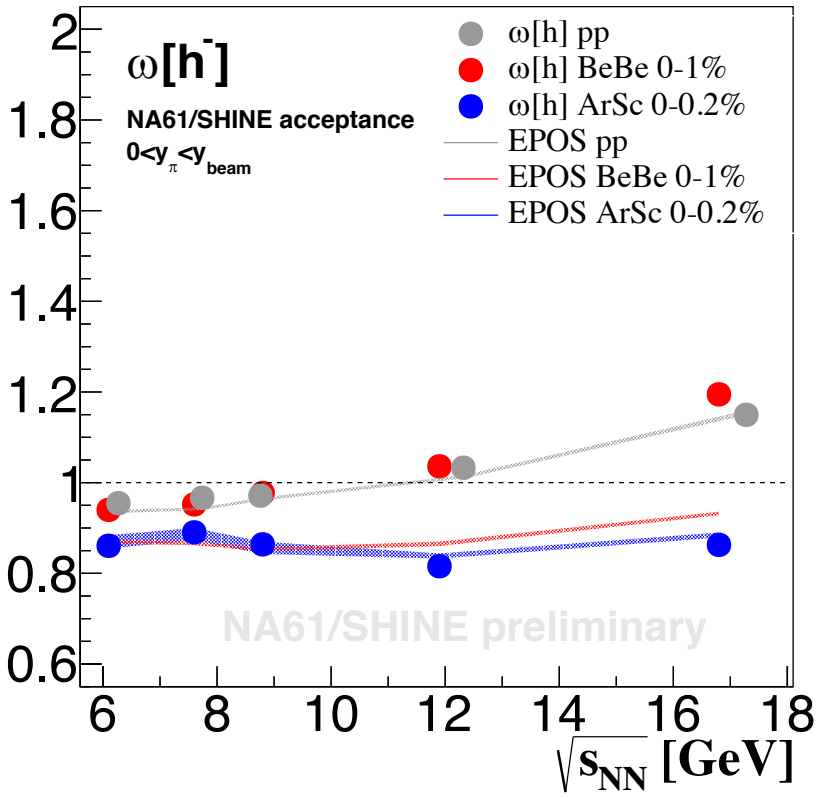
Thank you!

seryakov@yahoo.com





$\Omega[N, E_P]$, $\omega[N]$: energy dependence



$\omega[N]$ is significantly larger for inelastic p+p interactions and for the central Be+Be collisions than for central Ar+Sc collisions!

EPOS 1.99 describes p+p & Ar+Sc but fails in Be+Be