Searching for the critical point: news from fluctuations study in the NA61/SHINE experiment

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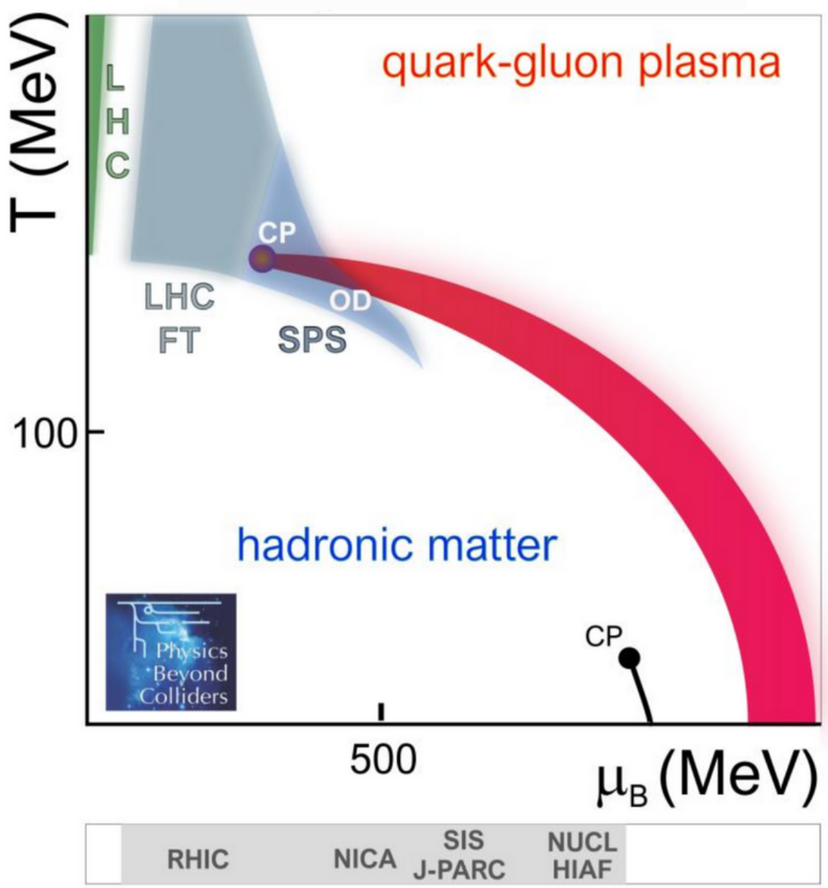
How well do we know the QCD phase diagram?

Does the critical point exist?

What are the properties of the onset of deconfinement?



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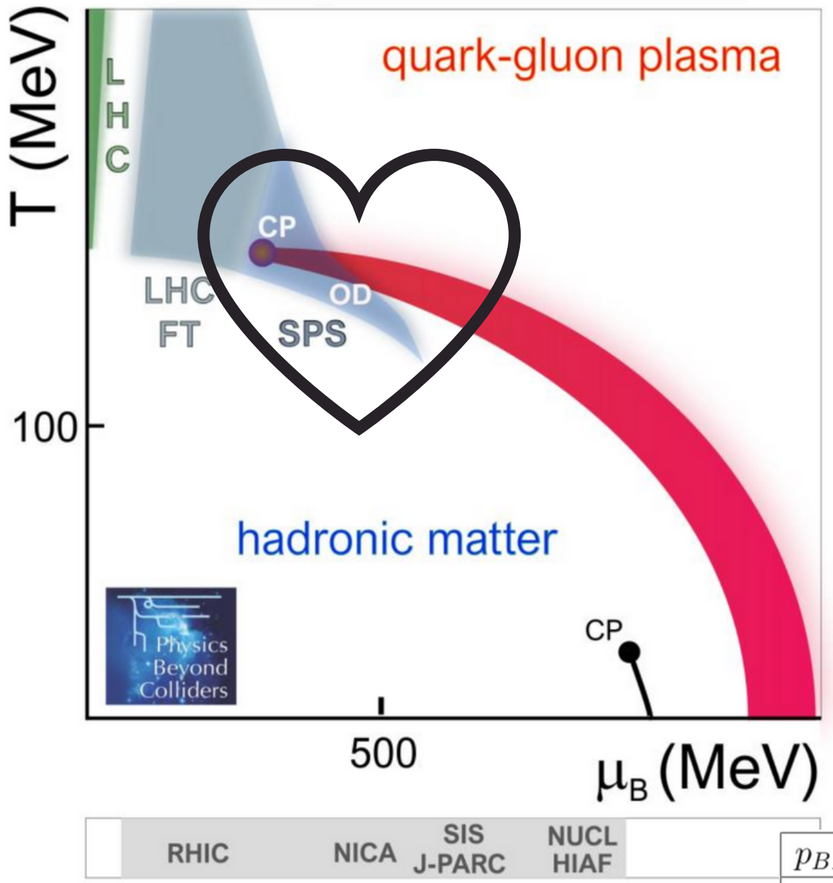
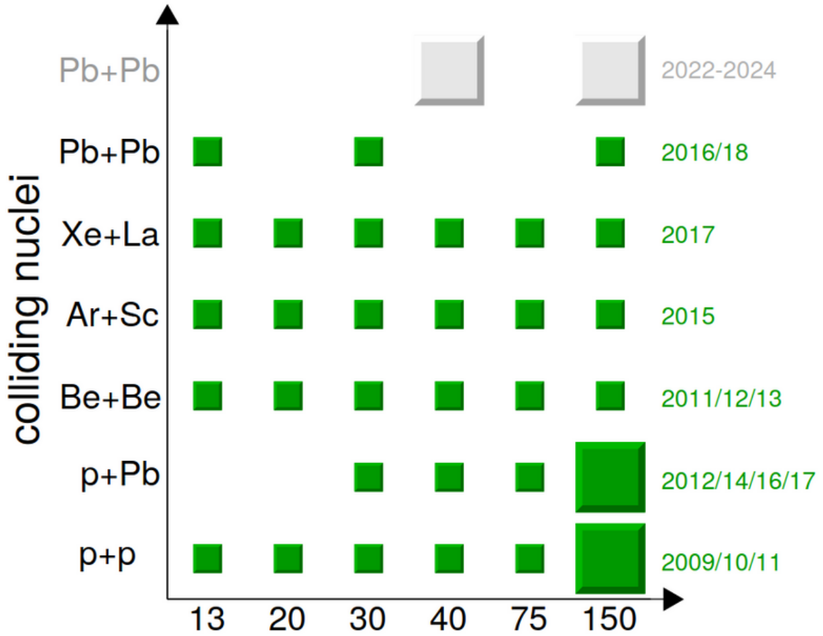
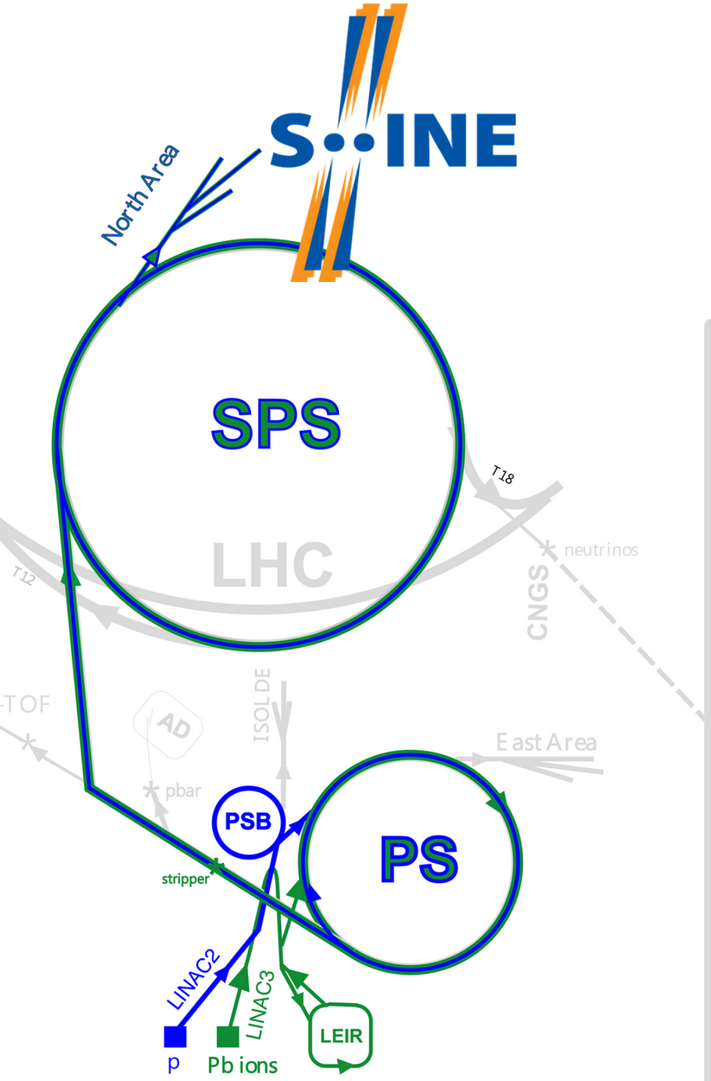


is looking for the answers by doing **system size - beam energy scan**.

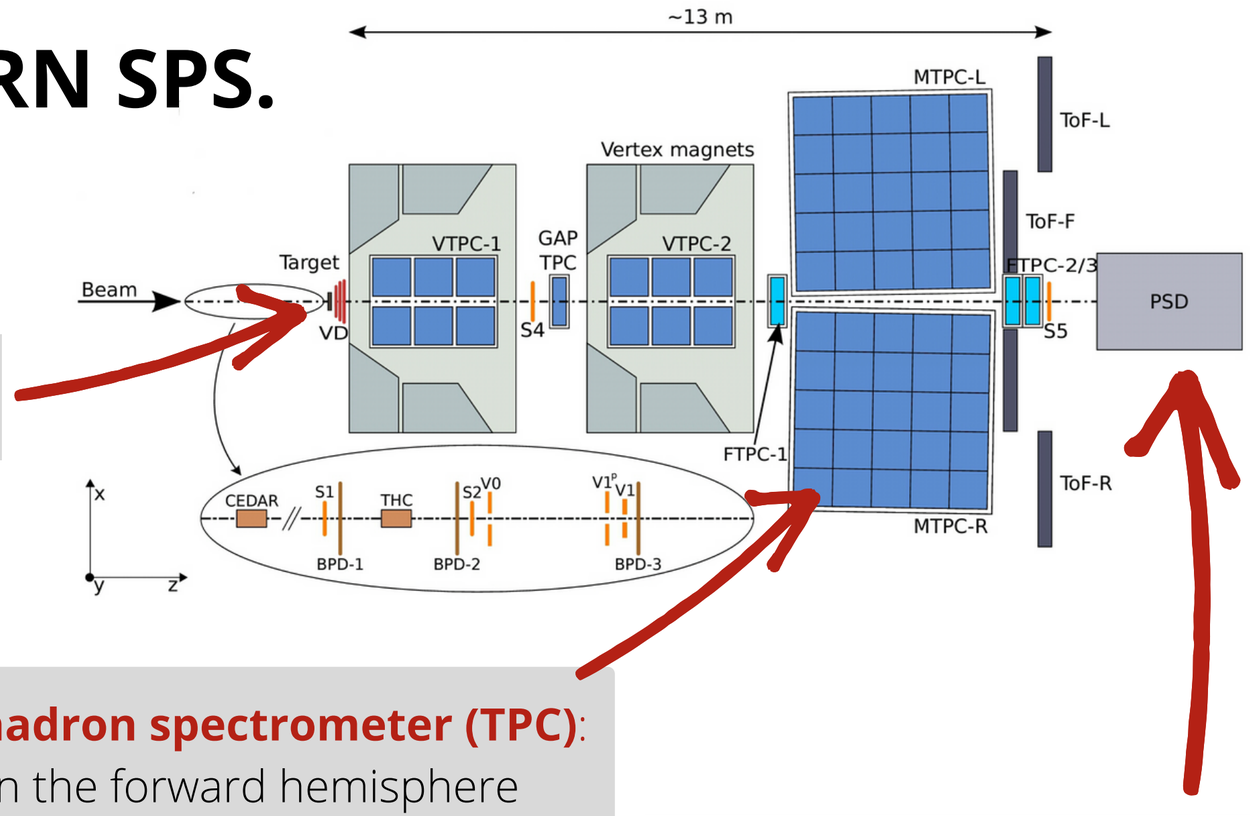


p_{BEAM} (A GeV/c)	13	19	30	40	75	150
$\sqrt{s_{NN}}$ (GeV)	5.12	6.12	7.62	8.77	11.94	16.84

NA61/SHINE is located at CERN SPS.

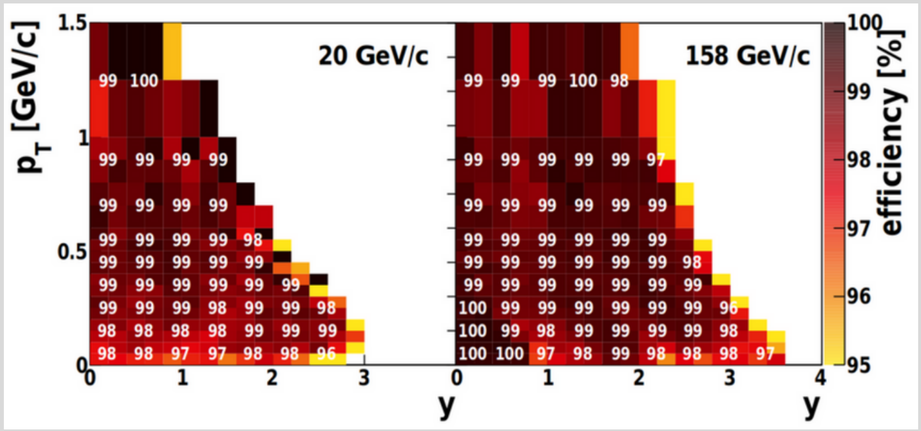


Fixed target



Large acceptance hadron spectrometer (TPC):

- full coverage in the forward hemisphere (down to pT = 0)
- high tracking efficiency (>90%)



Centrality selection and event plane determination in nucleus-nucleus collisions possible thanks to **Projectile Spectator Detector (PSD)**

event-by-event fluctuations measures:
higher-order moments of multiplicity and net-charge

Intensive quantities

- independent of the system size: W (WNM)
- dependent on the fluctuations of the system size: P(W) (WNM)

(WNM - Wounded Nucleon Model)

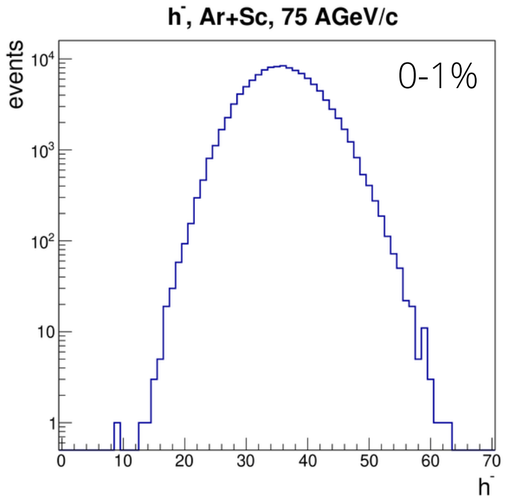
Reference values of intensive quantities:

0 - for no fluctuations

1 - for Poisson/Skellam distribution

multiplicity → Poisson

- $\frac{\kappa_2[h]}{\kappa_1[h]}$
- $\frac{\kappa_3[h]}{\kappa_2[h]}$
- $\frac{\kappa_4[h]}{\kappa_2[h]}$

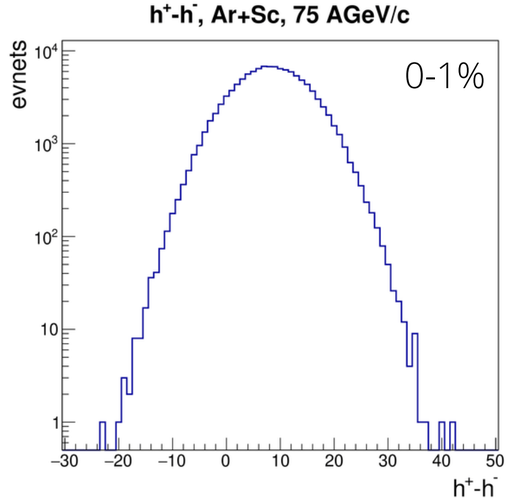


κ_n- n-th order cumulant

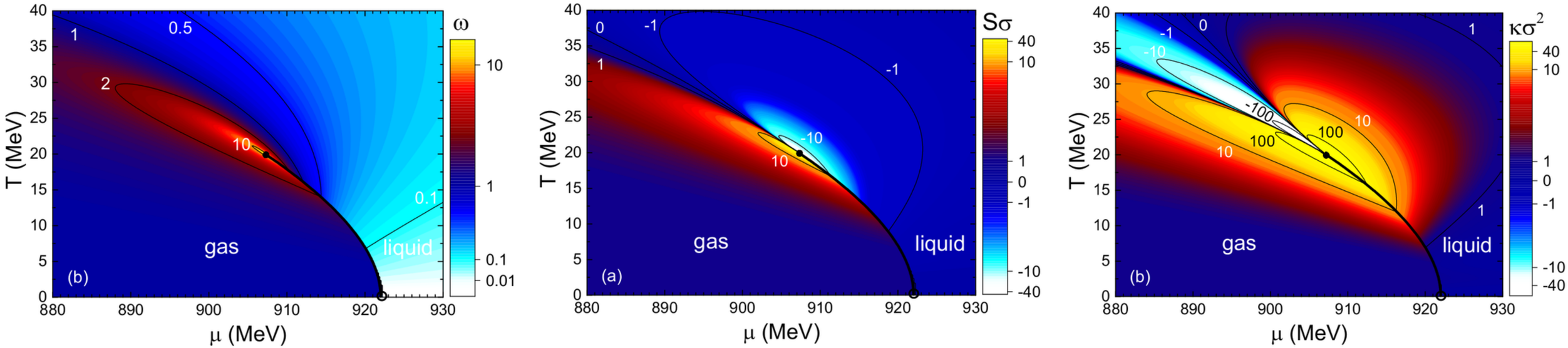
net-charge → Skellam

difference of two statistically independent random variables, each Poisson-distributed

- $\frac{\kappa_2[h^+-h^-]}{\kappa_1[h^+]+\kappa_1[h^-]}$
- $\frac{\kappa_3[h^+-h^-]}{\kappa_1[h^+-h^-]}$
- $\frac{\kappa_4[h^+-h^-]}{\kappa_2[h^+-h^-]}$



It is predicted that in the vicinity of the critical point the higher-order moments rapidly change their values due to the diverging correlation length.



Predictions for scaled variance (κ2/κ1), scaled skewness (κ3/κ2) and scaled kurtosis (κ4/κ2) in the phase transition assuming nuclear matter described with van der Waals equations.

Vovchenko et al., Physical Review C, 92(5):054901, 2015

DETAILS OF DATA ANALYSIS

p+p

- inelastic interactions
- corrected for detector effects
- acceptance: forward rapidity with pT < 1.5 GeV/c

Be+Be

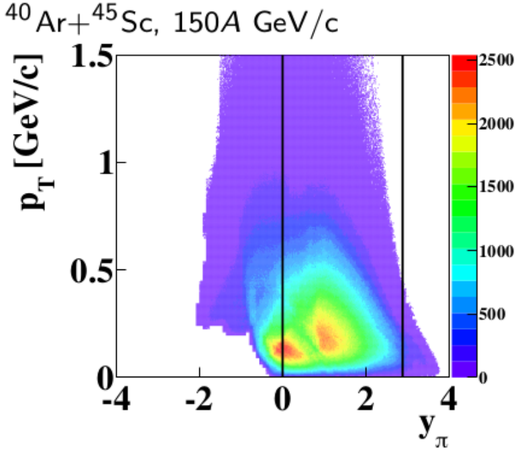
- 0-1% most central interactions
- uncorrected
- systematic bias estimated
- acceptance: p+p acceptance map with restriction for forward rapidity: $0 < y_{\pi} < y_{beam}$ and pT < 1.5 GeV/c

Ar+Sc

- 0-1% most central interactions
- systematic bias estimated
- energies 5.1-8.8 GeV uncorrected, energies 11.9-16.8 GeV corrected
- acceptance: Ar+Sc acceptance map with restriction for forward rapidity: $0 < y_{\pi} < y_{beam}$ and pT < 1.5 GeV/c

Statistical uncertainty estimation: bootstrap method

Correction method: 1D Unfolding



p+p acceptance map: https://edms.cern.ch/document/1549298/1
Ar+Sc acceptance map: https://edms.cern.ch/document/2487456/1

CENTRALITY SELECTION

The centrality selection is crucial for the fluctuation studies since intensive variables (especially higher-order moments) are sensitive to fluctuations of the system size. The bigger the centrality bin, the more system size fluctuates from event to event. To compromise this effect and the need for proper statistics, the centrality 0-1% was chosen.

Mackowiak-Pawlowska, M. Naskręt, M. Gazdzicki,
Nucl.Phys.A 1014 (2021) 122258

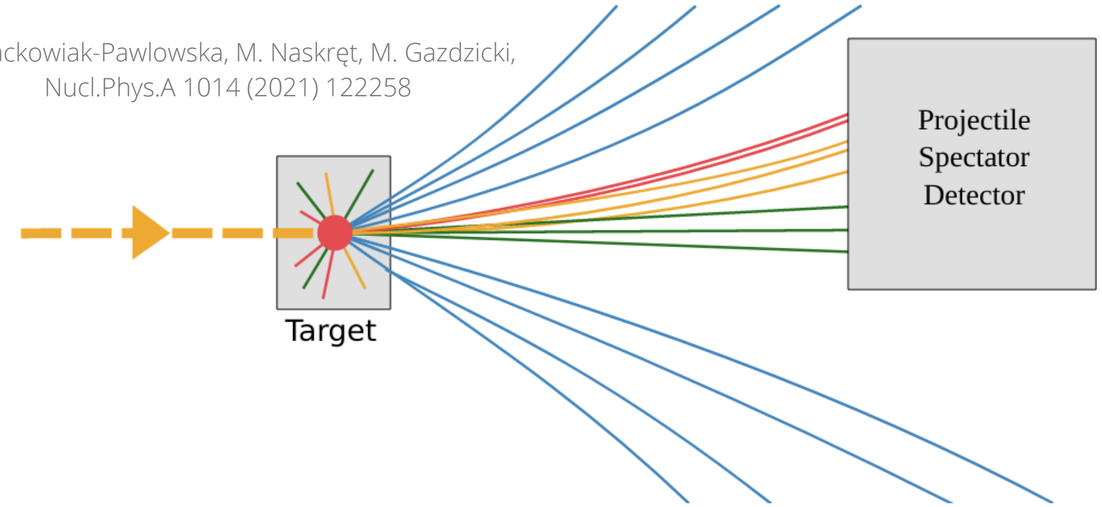
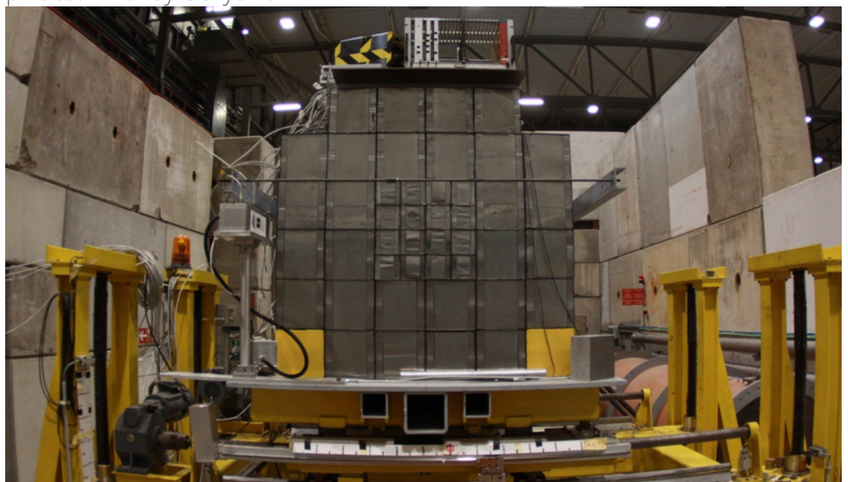
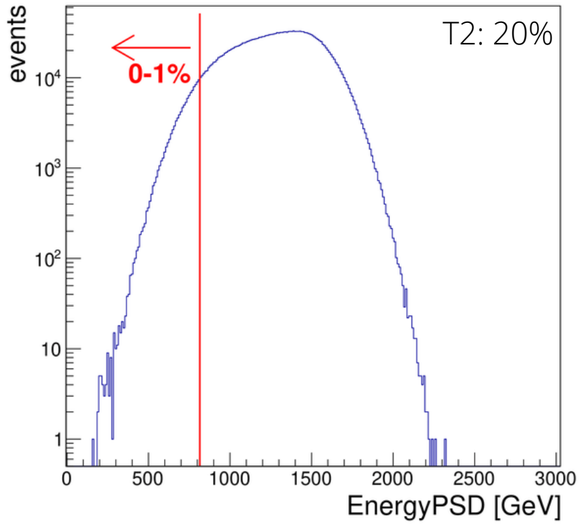


photo: Andrey Seryakov



Events with centrality (0-1%) are selected as events with the lowest energies at the PSD energy distribution.

EPSD, Ar+Sc, 75 AGeV/c



CORRECTION METHOD: 1D UNFOLDING

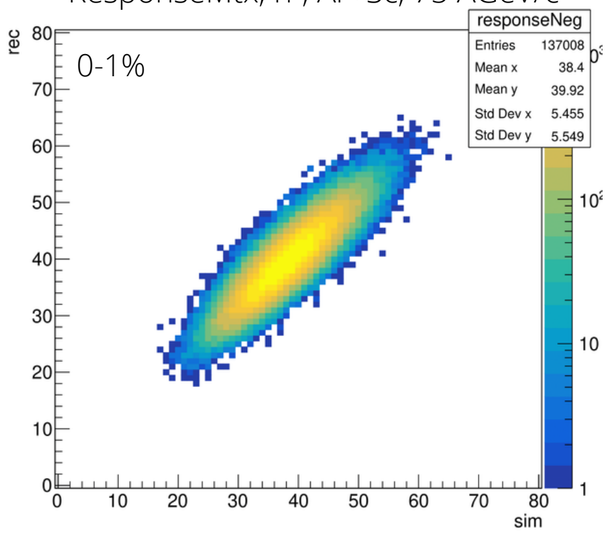
The results need to be corrected for several unwanted phenomena:

- gain of peripheral events
- loss of wanted events
- gain of tracks
- loss of tracks

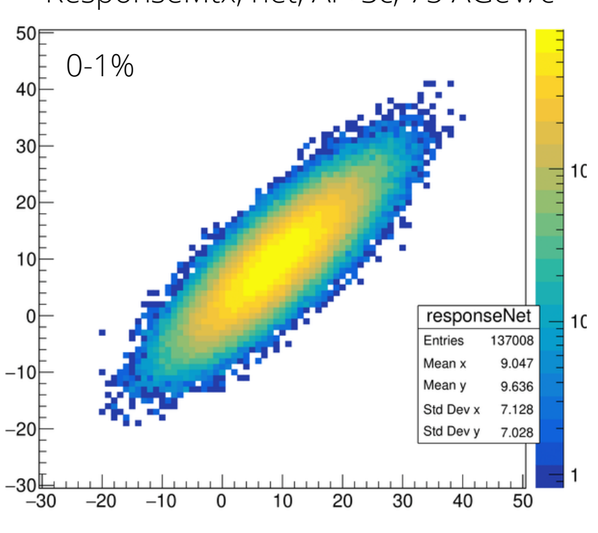
Unfolding is a method offering many approaches, of which a Bayesian approach was chosen. The method corrects the given histogram (i.e. multiplicity or net-charge) using the Response Matrix made of MC events.

G.D'Agostini, Nucl.Instrum.Meth.A 362 (1995) 487-498

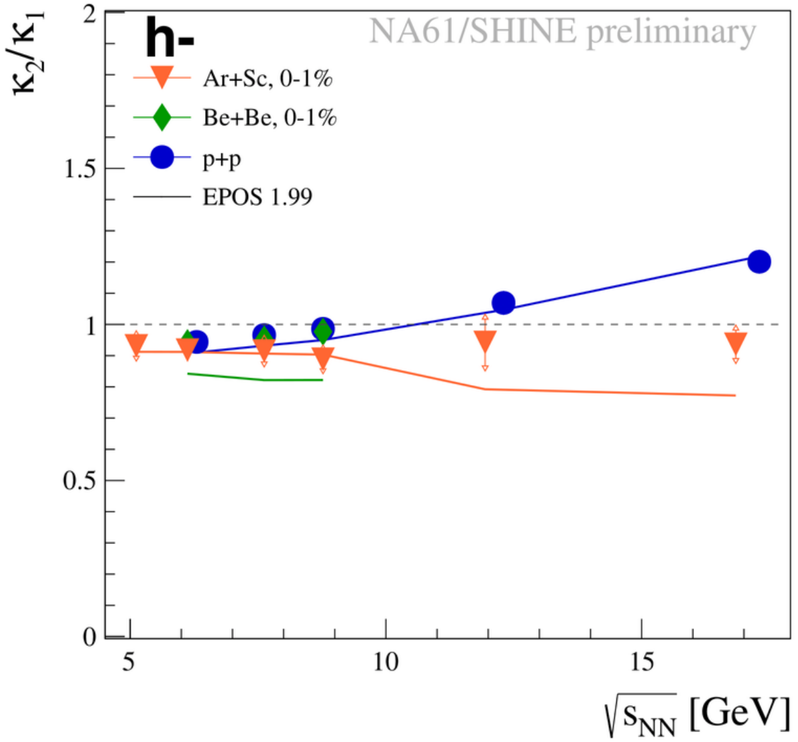
ResponseMtx, h-, Ar+Sc, 75 AGeV/c

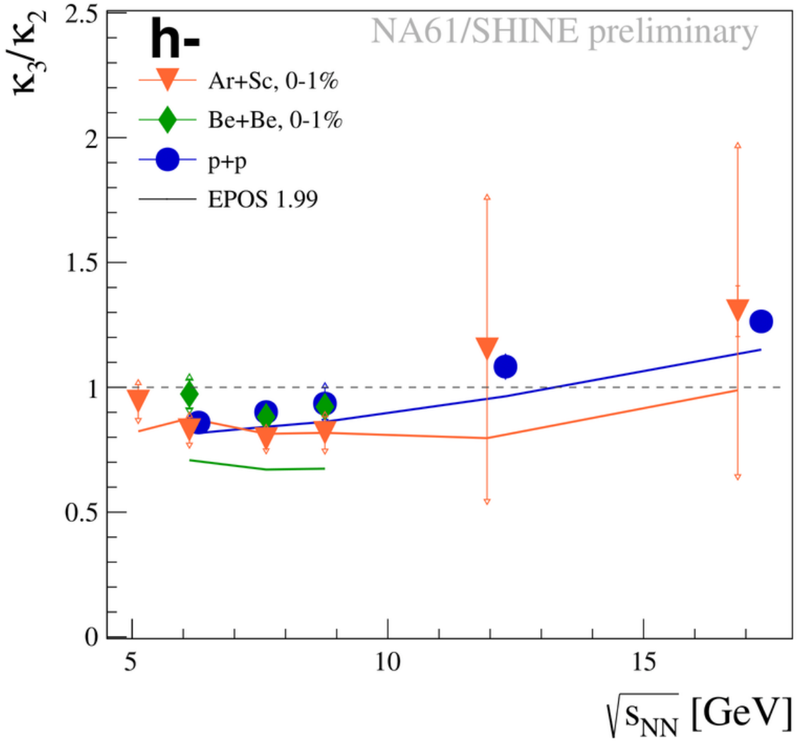


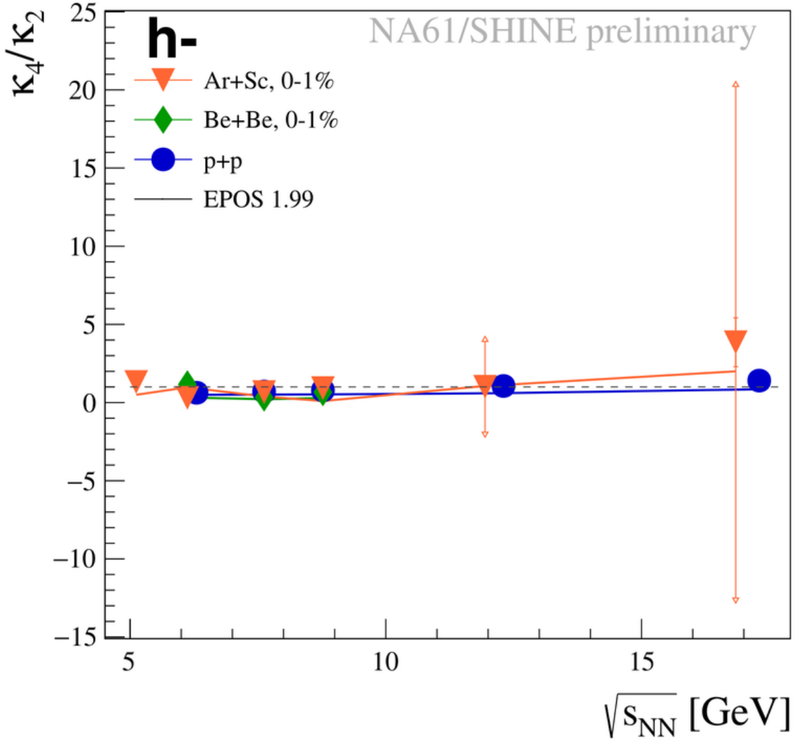
ResponseMtx, net, Ar+Sc, 75 AGeV/c



Higher-order moments of h-



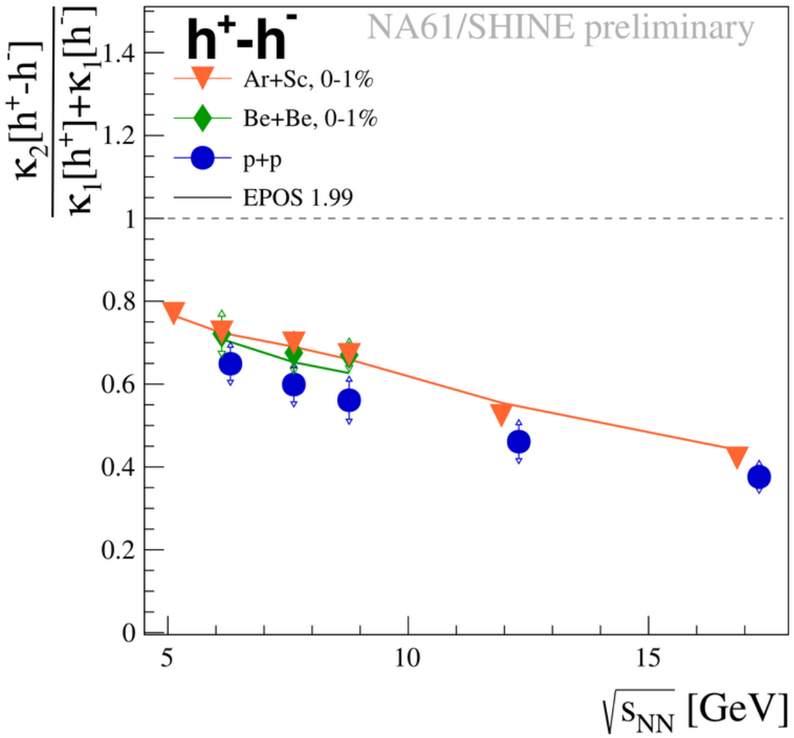


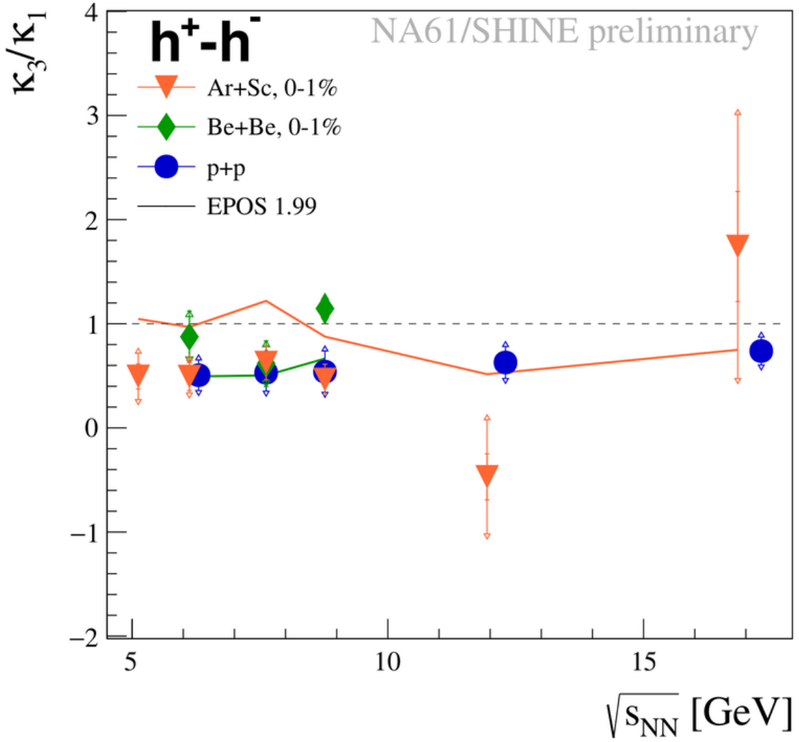


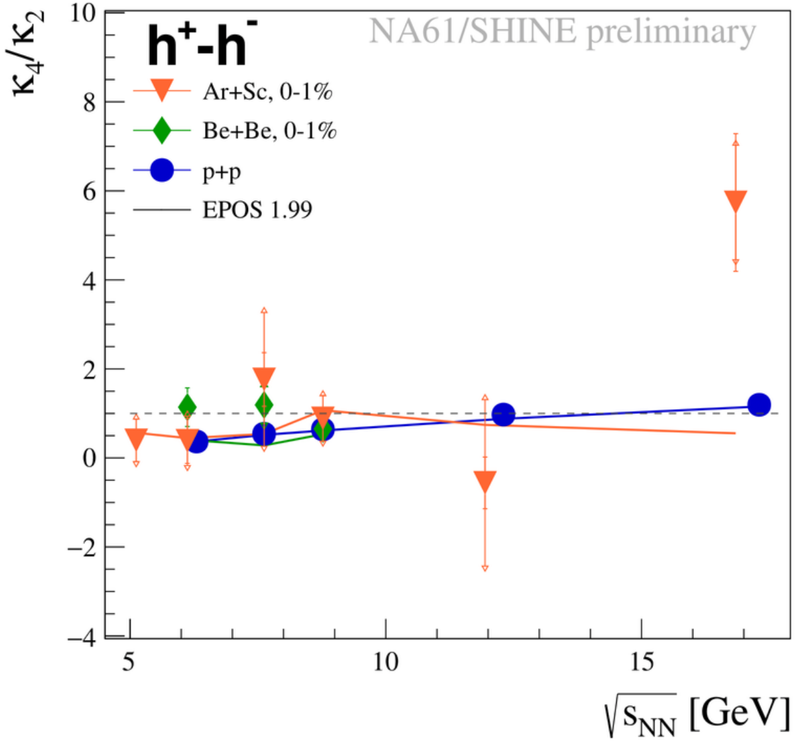
Conclusions:

- increasing difference between scaled variance in light systems (p+p, Be+Be) and heavier system (Ar+Sc)
- scaled skewness and scaled kurtosis of all systems shows similar behavior
- EPOS 1.99 does not fully describe the data

Higher-order moments of net-charge







Conclusions:

- scaled variance of Be+Be and Ar+Sc is systematically higher than p+p
- scaled skewness and kurtosis of Ar+Sc shows nonmonotonic behavior at higher energies
- EPOS 1.99 does not fully describe the data

Summary

3 systems: p+p, Be+Be, Ar+Sc at different energies were analyzed

EPOS 1.99 does not fully describe NA61/SHINE results.

so far no clear indication of the critical point is seen, but...

an interesting behavior of higher-order moments of Ar+Sc at 11.9 and 16.8 GeV is observed - further investigation needed!

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Thank You!

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