Search for the critical point of strongly interacting matter by NA61/SHINE at the CERN SPS

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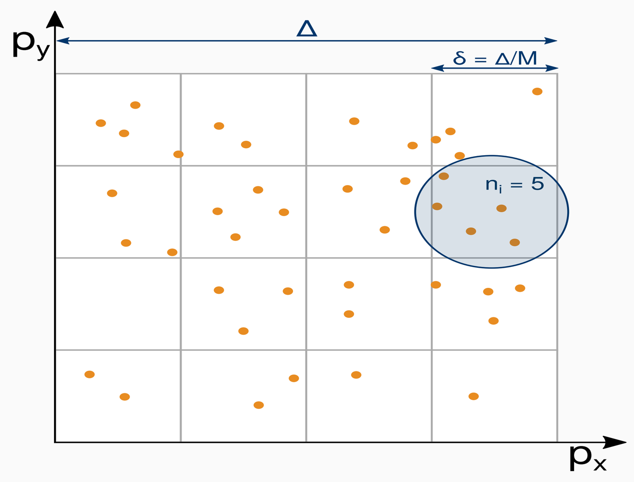
Motivation

The goal of this work is to search the **critical point** (a hypothetical endpoint of first-order phase transition line (QGP-HM) that has properties of second-order phase transition) of the strongly interacting matter by measuring **second scaled factorial moments** of proton multiplicity distribution from a selection of Pb+Pb collisions at beam momentum of 13A GeV/c ($\sqrt{s_{NN}} \approx$ 5.1 GeV) and 30A GeV/c ($\sqrt{s_{NN}} \approx$ 7.5 GeV), and Ar+Sc collisions at beam momenta of 13A-150A GeV/c ($\sqrt{s_{NN}} \approx$ 5.1-17 GeV) using **cumulative variables** and **statistically independent data points**.

Second scaled factorial moments

In NA61/SHINE [1], intermittency analysis [2] is performed at mid-rapidity, and particle fluctuations are studied in the transverse-momentum plane to search the QCD critical point [3, 4] by measuring scaled factorial moments of multiplicity distribution:



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

n_i: numbers of particles in ith bin

< .... >: averaging over events

M: number of subdivision intervals of the selected range Δ

When the system is a simple fractal and $F_2(M)$ follows a power law dependence [5, 6, 7, 8]:

$$F_2(M) = F_2(\Delta) \cdot (M^2)^{\varphi_2} \quad (2)$$

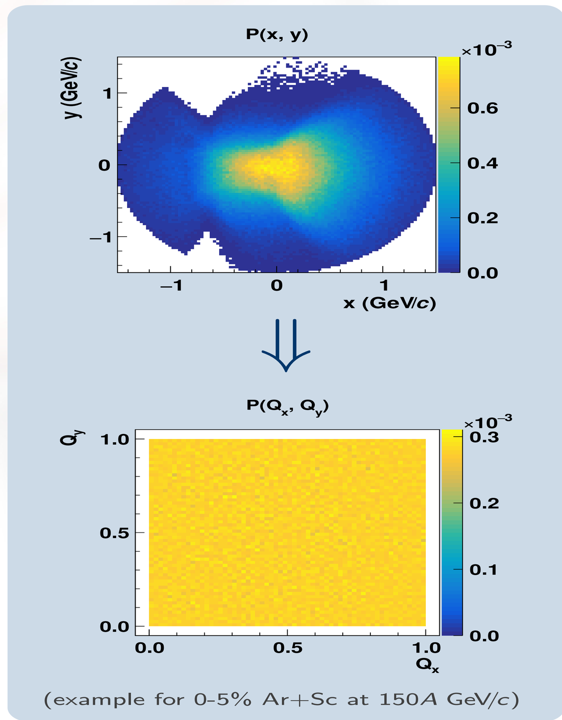
where critical exponent or intermittency index for proton intermittency, $\varphi_2 = \frac{5}{6} \approx 0.83$ [6]

The statistical uncertainties can be calculated using the statistical uncertainty propagation:

$$\frac{\sigma_{F_2}}{|F_2|} = \sqrt{\frac{(\sigma_{N_2})^2}{{N_2}^2} + 4\frac{(\sigma_N)^2}{N^2} - 4\frac{(\sigma_{N_2 N})^2}{N N_2}}\,. \quad (3)$$

New approach to intermittency analysis

Cumulative variables: The SFMs are sensitive to the shape of the single-particle momentum distribution, which biases the signal of critical fluctuations. In our approach, to eliminate the bias, the cumulative transformation technique [9] is used, which has the following properties:

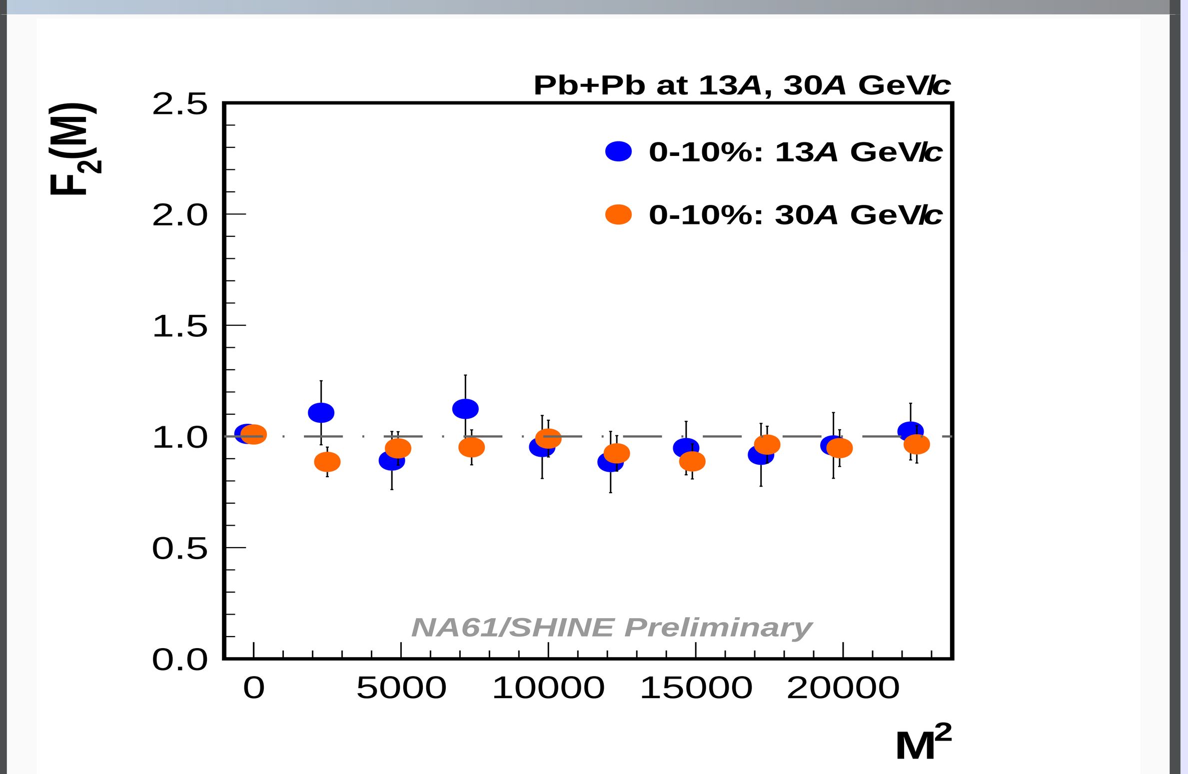


- transforms single-particle distribution into a uniform one ranging from 0 to 1
- remove the dependence of $F_2(M)$ on the shape of the single-particle distribution
- intermittency index of an ideal power-law correlation function was proven to remain invariant after the transformation

Statistically independent data points: Statistically-independent data subsets are used to obtain results for each subdivision number. As a result,

- for different subdivision numbers, results are statistically independent
- only diagonal elements of the covariance matrix are non-zero, and the complete relevant information needed to interpret the results is easy to present graphically

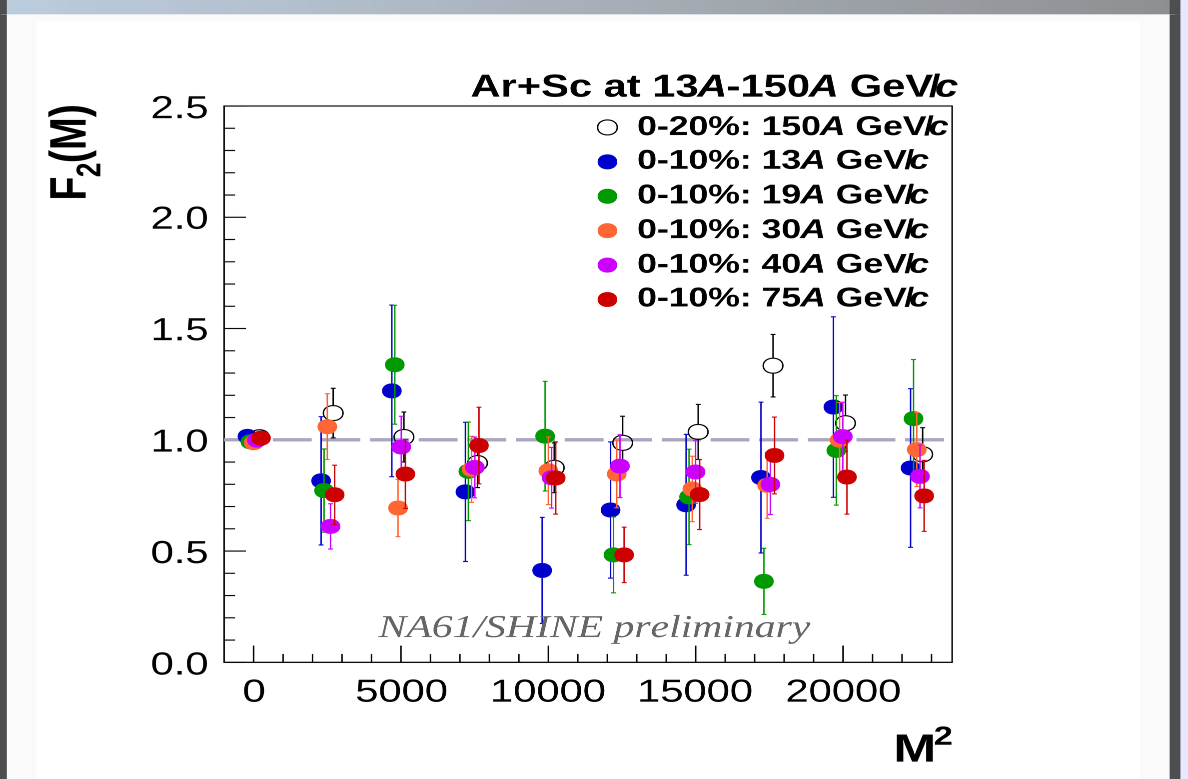
Proton intermittency results: Pb+Pb data



H. Adhikary[for NA61/SHINE Collaboration], EPJ Web Conf.274 (2022) 06008

No indication for power-law increase with bin size and/or scaling

Proton intermittency results: Ar+Sc data

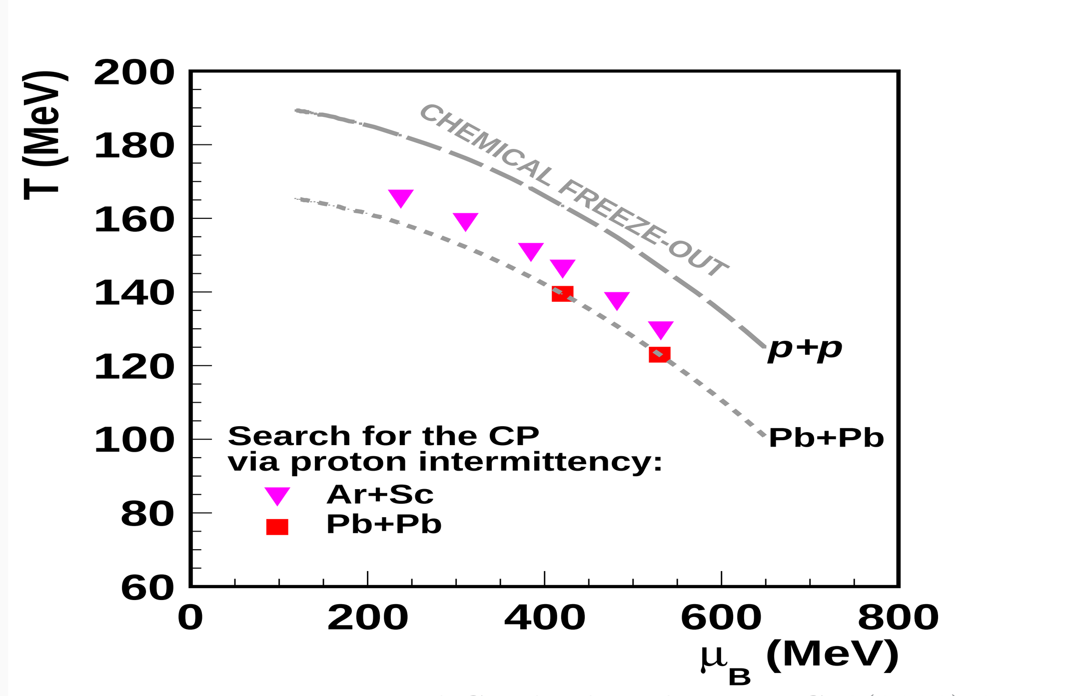


H. Adhikary[for NA61/SHINE Collaboration], EPJ Web Conf.274 (2022) 06008

H. Adhikary et al.[for NA61/SHINE Collaboration], arXiv:2305.07557v1 [nucl-ex]

No indication for power-law increase with bin size and/or scaling

Proton intermittency summary



Becattini, Manninen and Gazdzicki, Phys.Rev.C73(2006) 044905

Summarize the ongoing NA61/SHINE critical point search program via proton intermittency of Pb+Pb and Ar+Sc data sets on the diagram of chemical freeze-out temperature and chemical potential

- - no indication of a power-law increase - -

Power-Law model

The Power-Law model generates events that reproduce the experimental multiplicity and transverse momentum distributions of particles. Correlated-particle pairs' transverse momentum difference follows a power-law distribution:

$$\rho(|\Delta\vec{p}_T|) = (|\Delta\vec{p}_T|)^{-\varphi_2} \quad (4)$$

It has two main parameters:

- ratio of correlated to uncorrelated particles
- power-law exponent (φ_2)

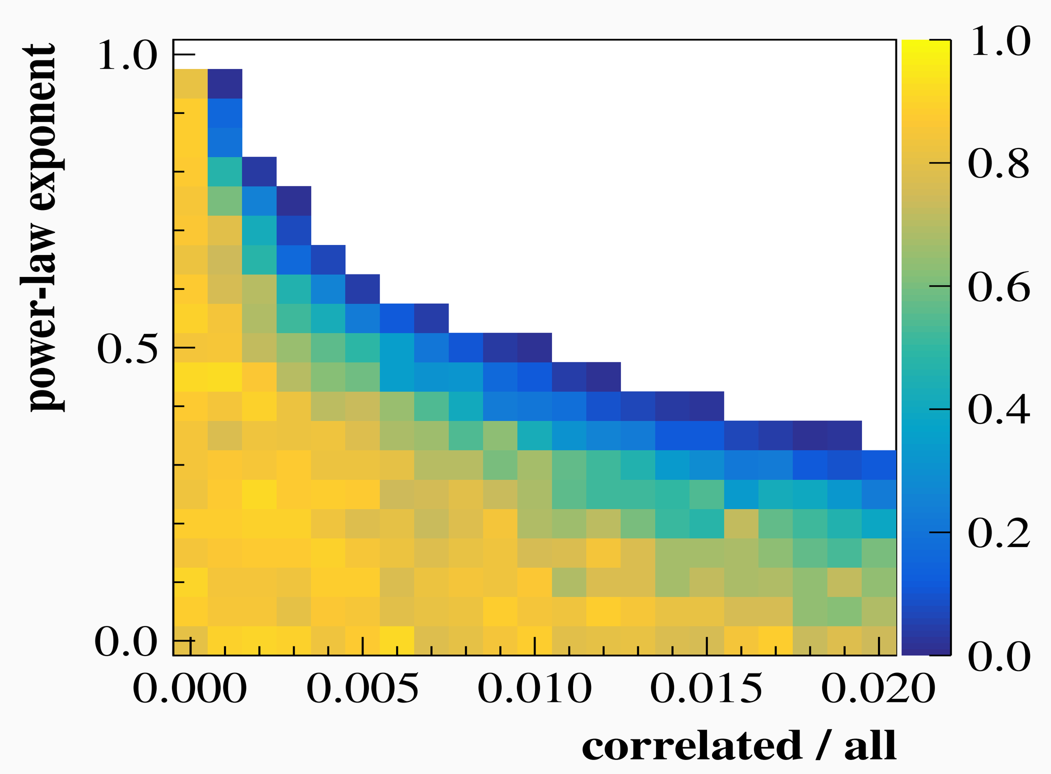
Lots of model data sets are generated:

- correlated-to-all ratio: vary from 0.0 to 2.0%,
- power-law-exponent: vary from 0.0 to 1.0,

and compared with the experimental data.

H. Adhikary et al.[for NA61/SHINE Collaboration], arXiv:2305.07557v1

Exclusion plot (for Ar+Sc at 150A GeV)



white area: p-value < 0.01

exclusion plots for parameters of the Power-Law model

References

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