Intermittency analysis in NA61/SHINE:

hunting for critical point signature in proton fluctuations

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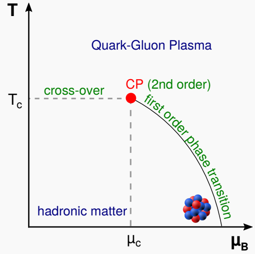
Introduction

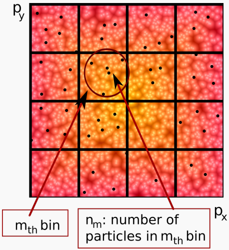
Motivation & Methodology



- We look for **experimental signatures** of the **critical point of strongly interacting matter** in **NA61/SHINE medium to large-size system** (Be+Be, Ar+Sc, Xe+La, Pb+Pb) collisions at **maximum collision energy** available for the **CERN SPS** ($\sqrt{s_{NN}} = 17.3$ **GeV**).
- We consider **local observables** related to the **order parameter** of the **chiral phase transition**, the **chiral condensate** $\sigma(\mathbf{x}) = \langle \bar{q}(\mathbf{x}) q(\mathbf{x}) \rangle$;
- At **finite baryon density**, the **critical fluctuations** of the chiral condensate are transferred to the **net-baryon density** [1]. For a critical system, we expect **proton density fluctuations** to obey **power-laws** with critical exponents determined by the **3D Ising universality class** [2–4];
- **Self-similar proton density fluctuations** correspond to **power-law scaling** of the proton **density-density correlation function** in **transverse momentum space**.
- **Intermittency analysis** examines how **Second Scaled Factorial Moments** (SSFM) $F_2(M)$ of proton transverse momenta **scale** with the **number of 2D bins** M^2 at mid-rapidity:

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

where $\langle \ldots \rangle$ denotes average over events.



[Image by I. Sputowska]

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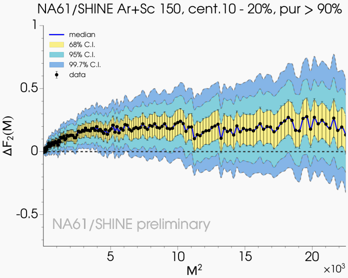
Analysis Results

Experiment & Simulation


NA61/SHINE Ar+Sc 150, cent.10 - 20%, pur > 90%

- For a **pure critical system**, we predict [4]:

$$F_2(M) \sim M^{2\cdot\phi_{2,cr}} \quad , \quad \phi_{2,cr}^{(p)} = 5/6 \tag{2}$$

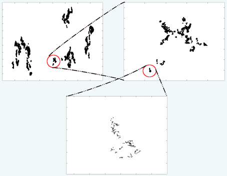
- For a **noisy system**, **mixed event** moments must be **subtracted** from the data to reveal **critical component** [5]:

$$\Delta F_2(M) = F_2^{(d)}(M) - F_2^{(m)}(M) \tag{3}$$

- Analysis of **peripheral Ar+Sc** collisions at **150A GeV/c** [6] reveals a **non-trivial scaling effect**; however, **large uncertainties** in $F_2(M)$ and ***M*-bin error correlations** [7] prevent an **unbiased estimation** of $\boldsymbol{\phi_2}$ **confidence intervals**; there must be a **better way**!

- Instead of **fitting** for ϕ_2, it is preferable to **model** $\boldsymbol{F_2(M)}$ using **simulations** such as the **Critical Monte Carlo (*CMC*)**, [4] which simulate both **critical** and **background** components through **Lévy (fractal) random walk** *(fig. right)*;
- A **new computational technique** [8] allows us to **swiftly** compute $\boldsymbol{F_2(M)}$ for a **large number** of **simulated events**; subsequently, we can **compare experimental** and **simulated** $\boldsymbol{F_2(M)}$ through a χ^2 **goodness-of-fit** test;
- Our **Monte Carlos** can simulate a **wide range** of **power-law behaviors** and **critical levels**, which we **scan** for the **optimal agreement** with experiment.

Lévy walk example



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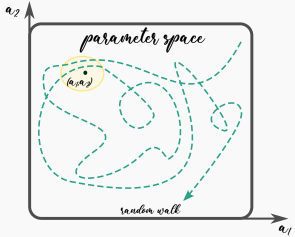
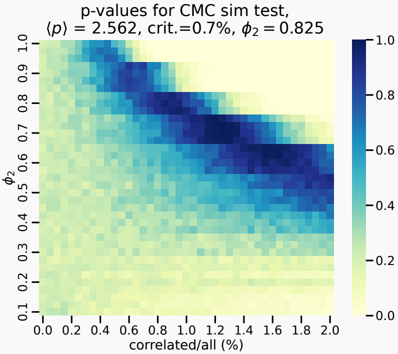
Monte Carlo scan and exclusion plot



- Given a **Monte Carlo** with a set of **free parameters**, a dedicated software [9, 10] **randomly samples parameter space**; each selected point corresponds to a **model** of the **experimental data**, which is then **simulated** and **evaluated**;
- The **model** can be as **sophisticated** as (realistically) possible; **detector effects** can be included;

- From **each model/experiment** comparison, a **p-value** is exctracted, which quantifies the **probability** that a set **similar** to the **experimental** one could have come from **the model**;
- **Collecting p-values** over a **scan of models**, we create an **exclusion plot**;
- We **test** the exclusion plot technique by giving our scan algorithm a **simulated** data set, e.g. created by CMC *(fig. right)*;
- Regions with **very low** **p-value** can be considered to be **“excluded”**; we see in the example that **the stronger** the **power-law**, the **larger the excluded region**, particularly for **strong critical component**.



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Conclusions
& Bibliography

- **Proton intermittency analysis** is a **promising tool** for **detecting the critical point** of strongly interacting matter; however, the conventional method of performing intermittency cannot handle large uncertainties (due to small event statistics) and bin correlations present in the data;
- We have developed **new techniques** able to **handle statistical** and **systematic uncertainties**, based on **Monte Carlo model simulation and weighting**; along with the **software tools** that drive a **wide scan** in **model parameter space**;

- Evidence is still **inconclusive** as to the presence of intermittency in **Ar+Sc collisions at 150*A* GeV/*c***;
- Creation of an **exclusion plot** for **NA61/SHINE** data, through a **carefully calibrated Monte Carlo**, is still **in progress**;
- Once available, such a result will allow us to estimate ϕ_2 and **critical component confidence intervals**;
- The new techniques can then be utilised in the study of **other NA61/SHINE** available systems **(Pb+Pb, Xe+La)**.

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