Signatures of critical fluctuations in intermittency analysis of the proton transverse momenta in A+A collisions at the NA49 experiment (SPS, CERN)

N. G. Antoniou, N. Davis, F. K. Diakonos
for the NA49 Collaboration

University of Athens,
Department of Physics,
Sector of Nuclear and Elementary Particle Physics

ICFP 2012, 10-16 June 2012, Kolymbari, Crete, Greece

Observables for critical fluctuations

- Detection of "chiral" critical point (CP) $\Rightarrow$ critical fluctuations of the order parameter
- Order parameter = "chiral" condensate

$$\sigma(x) = \langle \bar{q}(x) q(x) \rangle$$

  ($q(x)$ = quark field, sigma-field $\sigma(x)$=quantum state (wave function) describing the "chiral" condensate)

- In medium (finite baryon density) sigma-field mixes with net baryon density
- (Critical) fluctuations of the sigma field transferred to the net baryon density
- Look for observables tailored for CP search in ion collisions. Scan the phase diagram for the existence and location of the CP by varying the energy and size of the collision system.

Self-similar density fluctuations

- In our analysis, we use local observables $\Rightarrow$ not sensitive to experimental acceptance, contrary to global observables.
- Local observable $\Rightarrow$ self-similar density fluctuations of the order parameter in transverse configuration space (random fractal) $\Rightarrow$ power-law dependence of the density-density correlation functions in transverse momentum space $\Leftrightarrow$ intermittency analysis (critical opalescence, correlation length vs. size [F. K. Diakonos, N. G. Antoniou and G. Mavromanolakis, PoS(CPOD2006)010, Florence]).

Local observables

- Power-law exponents are determined by universality class (critical exponents). For $3-D$ Ising:

$$\langle n_\sigma(k) n_\sigma(k') \rangle \sim |k-k'|^{-4/3} \quad ; \quad \langle n_B(k) n_B(k') \rangle \sim |k-k'|^{-5/3}$$

  $n_\sigma(k) = \sigma^2(k)$, $n_B =$ net baryon density at midrapidity, k, k' are transverse momenta.

- The coupling of the (isospin zero) σ-field with protons transfers critical fluctuations to the net proton density [Y. Hatta and M. A. Stephanov, PRL**91**, 102003 (2003).]

Local observables (ideal case)

- Search for critical power-law fluctuations ⇒ Calculation of second factorial moments (F_2) in transverse momentum space for **net protons at mid-rapidity**
- Expected behaviour in the absence of background (intermittency):

$$F_2^{(p)}(M) \sim (M^2)^{\phi_{cr}^{(p)}}$$

M^2=number of cells in transverse momentum space,

$$\phi_{cr}^{(p)} = \frac{5}{6}$$

(predictions of critical QCD).

Analysis scheme for net protons

- Neglect antiprotons (much fewer than protons).
- Calculate the Vertical Second Factorial Moment in transverse momentum of protons in the central rapidity region:

$$-0.75 \leq y_{CM} \leq 0.75$$

where y_{CM}=proton center of mass rapidity

- Mid-rapidity region selected $\Rightarrow$ Approximately constant proton density in rapidity in this region. [N. G. Antoniou, F. K. Diakonos, A. S. Kapoyannis and K. S. Kousouris, PR**L. 97**, 032002 (2006).].
- Main background: Uncorrelated and/or misidentified protons (simulated and subtracted using mixed events).

Local observables (real experiment)

- **Protons:** Calculate the correlator

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

$(d) \equiv$ data, $(m) \equiv$ mixed events, $M^2 =$ number of cells in transverse momentum space

Expected behaviour for the critical freeze-out state:

$$\Delta F_2^{(p)}(M) \sim (M^2)^{\phi_{2,cr}^{(p)}}$$

with:

$$\phi_{2,cr}^{(p)} = \frac{5}{6} = 0.8\bar{3}$$

Measures for critical fluctuations

- The intermittency index ϕ_2 carries information for the critical fluctuations (universality class).
- It can be calculated through a power-law fit of $\Delta F_2(M)$ $\Rightarrow$ exponent of the power-law.
- The intermittency index ϕ_2, obtained by the power-law fit, is expected to decrease with distance from the critical point. Coefficient of determination R^2, is likewise expected to deteriorate.
- Therefore, the difference $|\phi_2 - \phi_{2,cr}|$ is an indication of the distance from the critical point. The quantity $1 - R^2$ is sensitive to statistics but it can also measure this distance.

Analysed data sets - technical issues

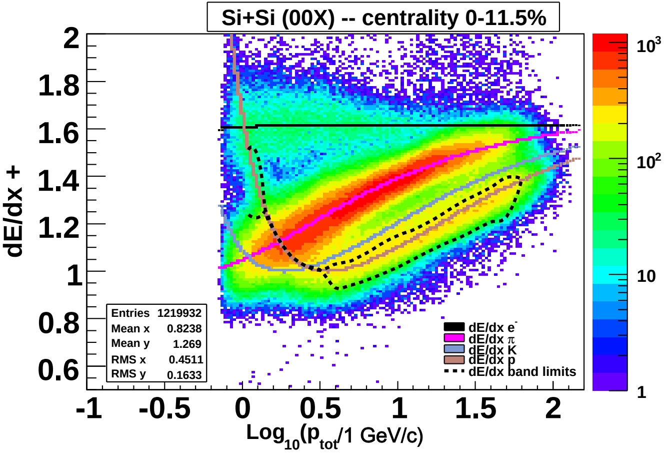
	"C"+C*	"Si"+Si*	Pb+Pb
beam energy	158 A GeV		40, 158 A GeV
centrality range	$0 \to 11.5\%$		$0 \to 12.5\%$
# of events	201 189	175 943	1 480 587

** Beam Components: "C" = C,N, "Si" = Si,Al,P*

- Standard event and track selection cuts of NA49 experiment [T. Anticic *et al*, PR**C 81**, 149 (2010)].
- Particle (protons, pions) identification with purity $> 80\%$.
- Correlations between $\Delta F_2(M)$ for nearby M's were checked and taken into account.

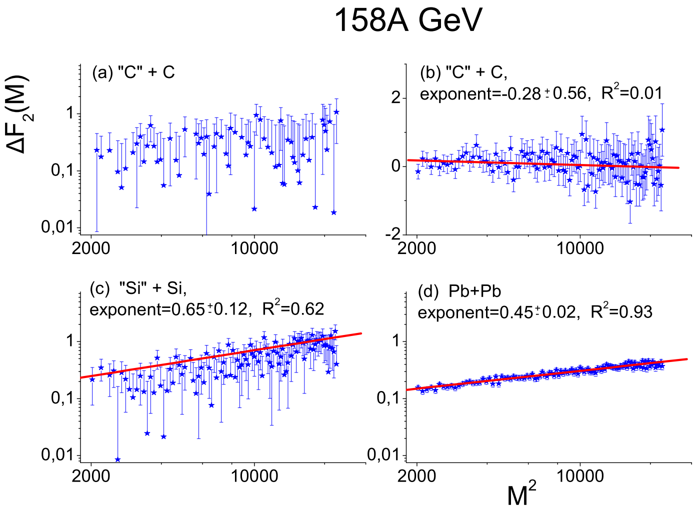
Analysed data sets - proton identification

- dE/dx histograms for small p_{tot} “slices” – fit with sum of 4 gaussians (e,p,K,π).

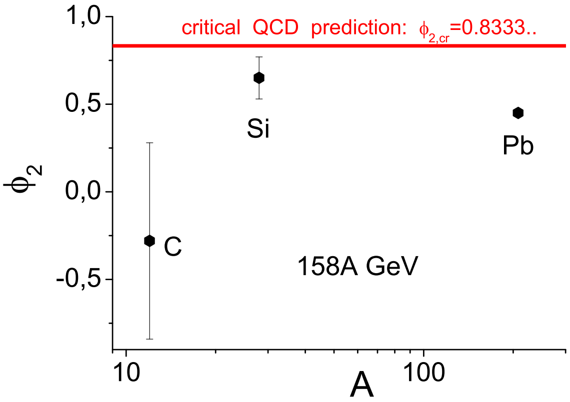


- Width & overlap of fitted peaks
  ⇒
  Selection bands around proton theoretical curve that maximize purity.

Analysis results - Protons

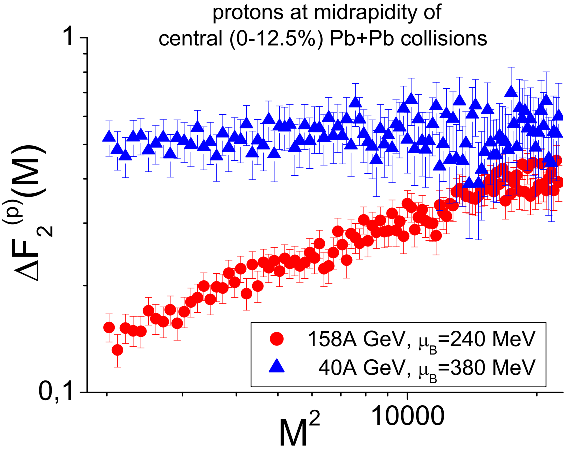


Analysis results - Size dependence of ϕ_2



Significant power-law fluctuations for Si and Pb systems at 158A GeV. The intermittency index ϕ_2 for **Si is closest** to the critical QCD prediction.

Analysis results - Energy dependence of $\phi_2^{(p)}$



No trace of power-law fluctuations in Pb+Pb at 40A GeV (not enough statistics for "C"+C and "Si"+Si) $\Rightarrow$ CP closer to 158A GeV freeze out conditions.

Summary and outlook

Intermittency analysis in transverse momentum space of NA49 data for central "C"+C, "Si"+Si and Pb+Pb collisions has been performed.

- For protons at midrapidity we have found significant power-law fluctuations in Si and Pb at 158A GeV.

- The **intermittency index ϕ_2** for the **Si system approaches the critical QCD prediction**.

Summary and outlook

- **First experimental evidence** for the **approach to the vicinity of the critical point**.

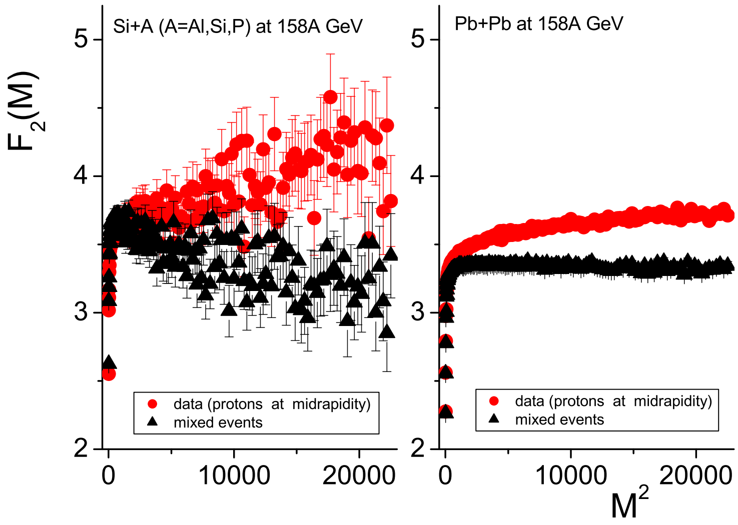
- No power-law behaviour is observed for protons of Pb+Pb system at 40A GeV.

- The critical baryochemical potential seems closer to 240 MeV (than to 380 MeV).

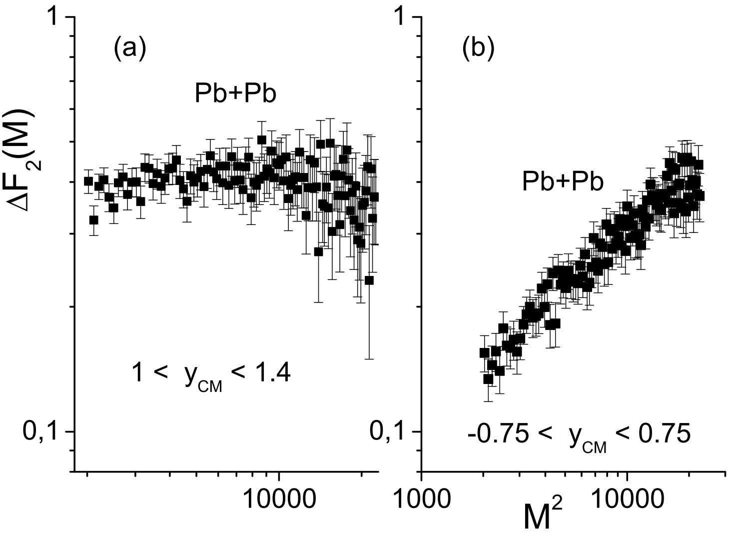
Exploring peripheral Pb+Pb collision data of NA49 at 158 A GeV and performing a systematic **intermittency study in lighter systems** (Be+Be, Ar+Ca, Xe+La) as function of energy **in NA61** will hopefully lead to an **accurate determination of the critical point location**.

THANK YOU!

Factorial moments for protons in Si+A and Pb+Pb



Correlator of protons, Pb+Pb



Event & track cuts for Si+A

Event cuts:

- Iflag $= 0$, chi$^2 > 0$
- Beam charge cuts (Al,Si,P)
- Vertex cuts:
  - -0.4 cm $\leq V_x \leq 0.4$ cm
  - -0.5 cm $\leq V_y \leq 0.5$ cm
  - -580.3 cm $\leq V_z \leq -578.7$ cm

Track cuts:

- Iflag $= 0$
- Npoints ≥ 30
  (for the whole detector)
- Ratio $\frac{\text{Npoints}}{\text{NMaxPoints}} \geq 0.5$
- ZFirst ≤ 200
- Impact parameters:
  $|B_x| \leq 2$, $|B_y| \leq 1$
- dE/dx cuts for particle identification
- p_{tot} cuts (via dE/dx cut)
- rapidity cut