Onset of deconfinement and search for the critical point of strongly interacting matter at CERN SPS energies

Maciej RYBCZYŃSKI
Jan Kochanowski University
Kielce, Poland

(for the NA49 Collaboration)

Jan Kochanowski University

Melbourne, July 4 – 11 2012

CERN

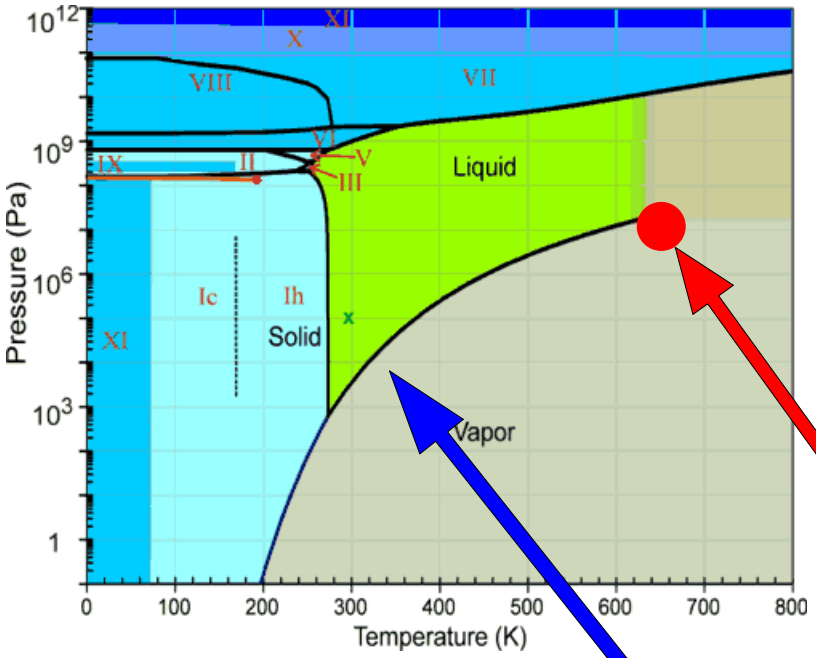
NA49

OUTLINE

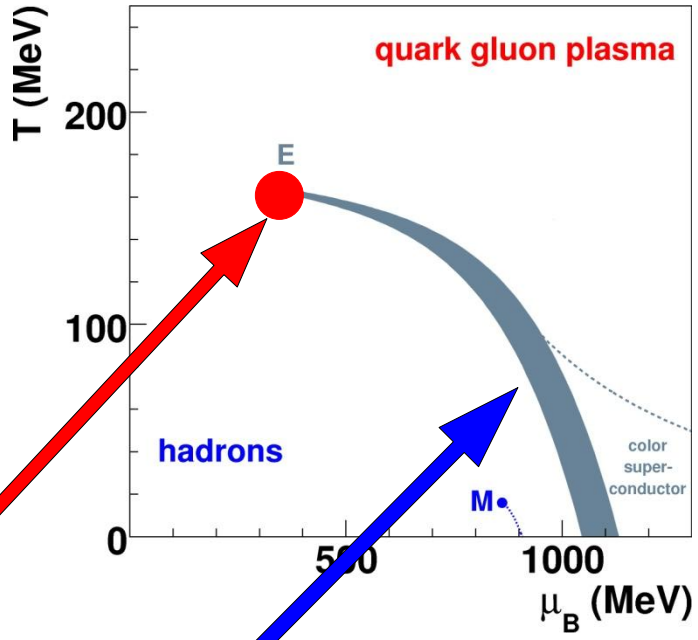
- Confirmation of onset of deconfinement
- Search for critical point of strongly interacting matter
  - ✓ results on fluctuations
  - ✓ intermittency in particle production

CONFIRMATION OF ONSET OF DECONFINEMENT

The phase diagram of water is well established



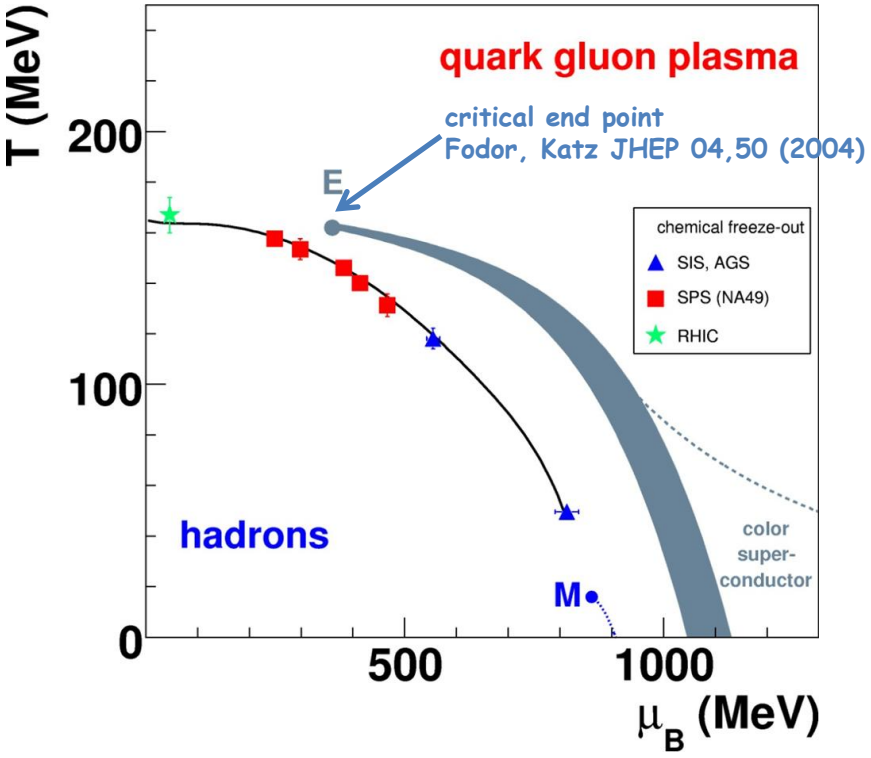
The phase diagram of strongly interacting matter is under study



critical point

1st order phase transition

CONFIRMATION OF ONSET OF DECONFINEMENT



QCD considerations suggest
a 1st order phase boundary
ending in a critical point

hadro-chemical freeze-out points
are obtained from statistical model fits
to measured particle yields

T and μ_B approach phase boundary
and estimated critical point at SPS

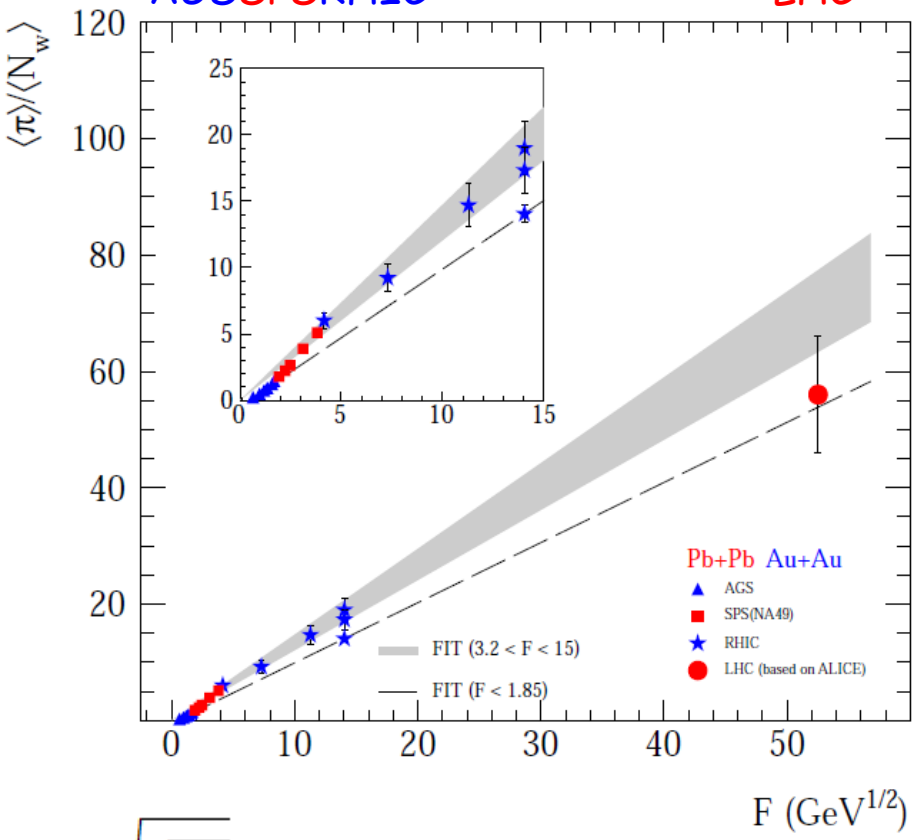
evidence of onset of deconfinement
from rapid changes
of hadron production properties

search for indications of the critical point
as a maximum in fluctuations

CONFIRMATION OF ONSET OF DECONFINEMENT

The kink in pion multiplicity

AGSSPSRHIC LHC



Deconfinement

↓

Increased entropy production

↓

Steepening of the increase of pion production

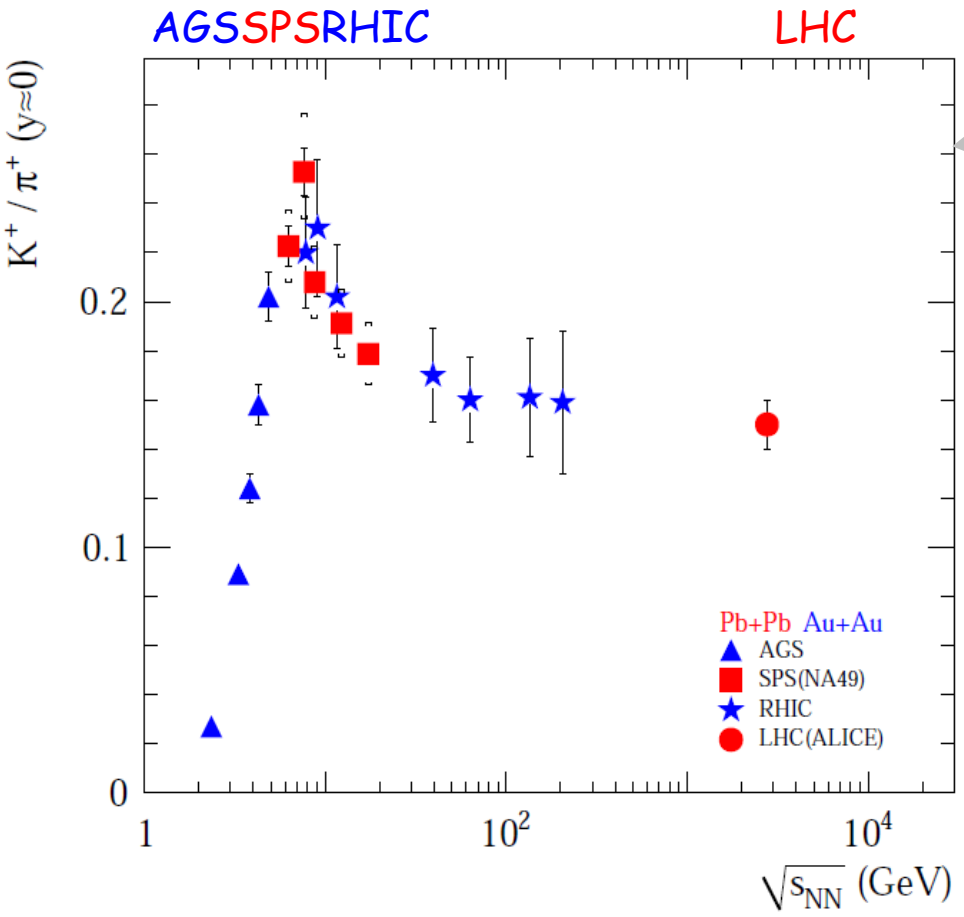
$$F = \sqrt{\sqrt{s_{NN}}}$$

$\langle\pi\rangle$ - total pion multiplicity

$\langle N_W\rangle$ - number of interacting nucleons

CONFIRMATION OF ONSET OF DECONFINEMENT

The horn in strangeness yield



Deconfinement

↓

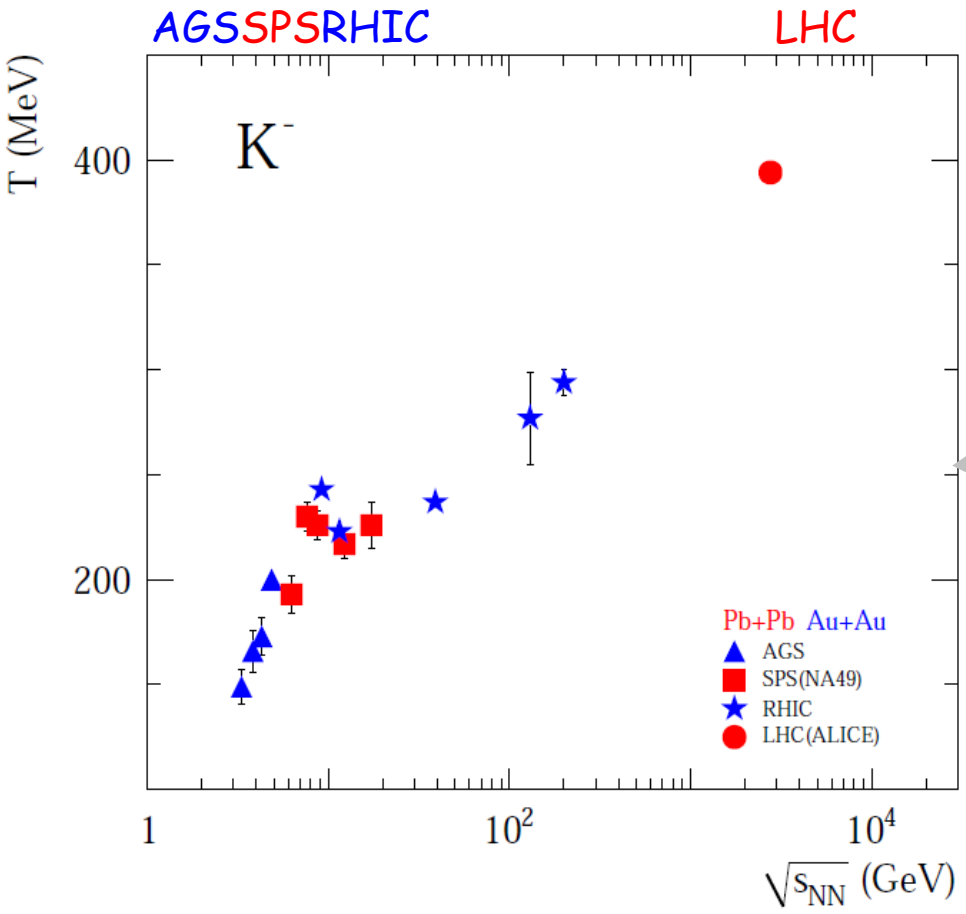
Decrease of masses of strangeness carriers and the number ratio of strange to non-strange degrees of freedom

↓

A sharp maximum in the strangeness to pion ratio

CONFIRMATION OF ONSET OF DECONFINEMENT

The step in m_T slopes



Deconfinement

↓

Constant temperature and pressure in the mixed phase region

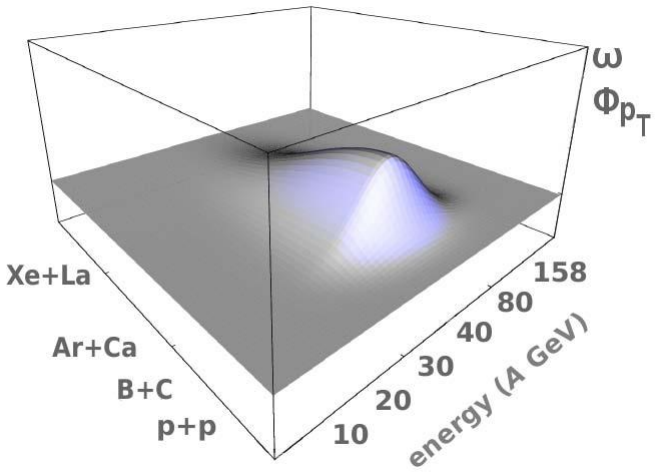
↓

Weaker transverse expansion and thus weaker energy dependence of T

SEARCH FOR CRITICAL POINT
RESULTS ON FLUCTUATIONS

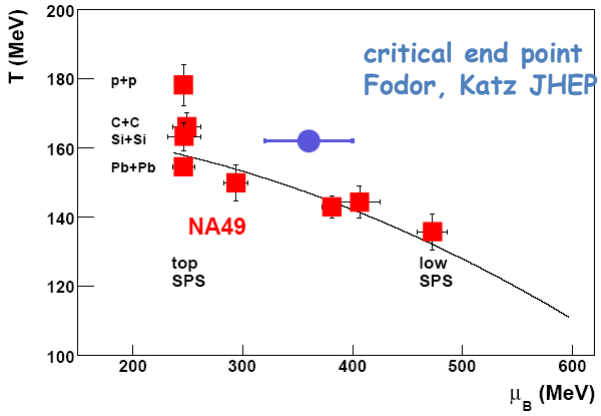
search strategy: 2-dimensional (T, μ_B) scan of phase diagram

expected "hill" of fluctuations



freeze-out points from stat. model

Becattini et al, PRC73, 044905 (2006)



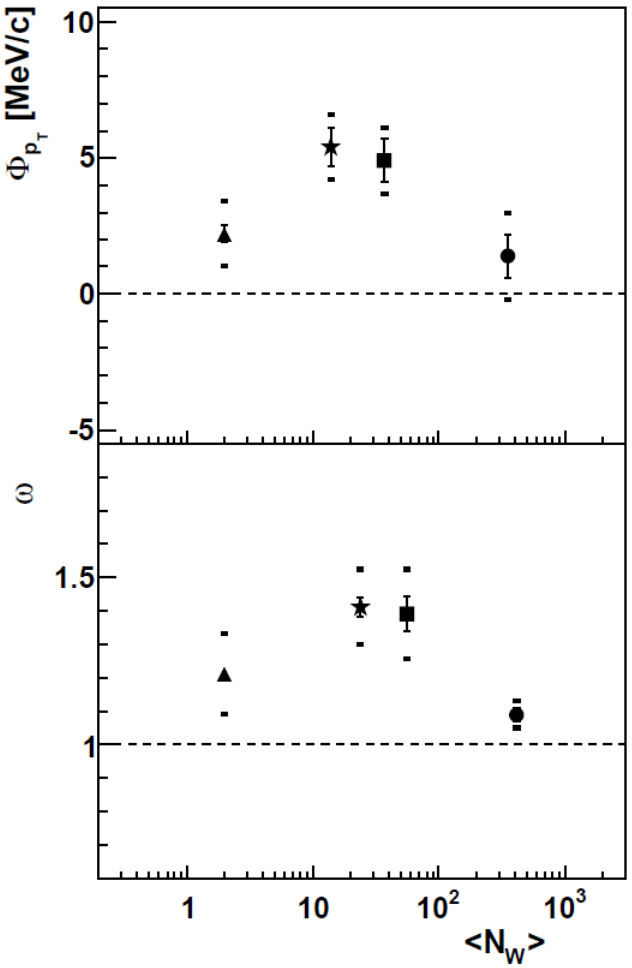
- ✓ Deconfinement necessary for observing CP effect (above 30A GeV)
- ✓ Expected size of fluctuation signals (~ξ^2) limited by short lifetime and size of collision system (correlation lengths ξ~3-6 fm for Pb+Pb)

M.Stephanov, K.Rajagopal,E.Shuryak, PRD60,114028(1999)

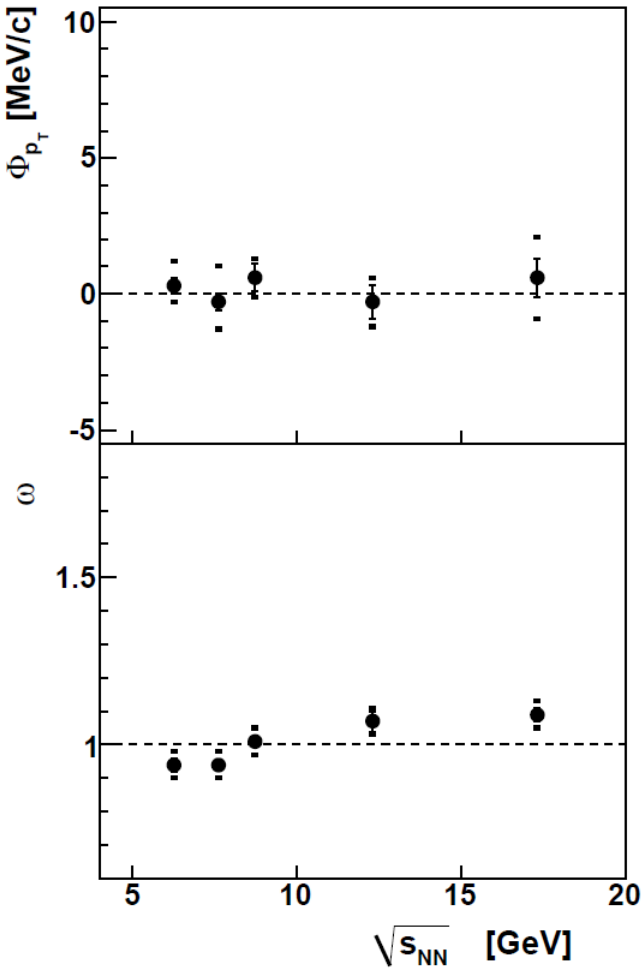
SEARCH FOR CRITICAL POINT
RESULTS ON FLUCTUATIONS

dependence on

system size: p+p, C+C, Si+Si, Pb+Pb



energy (central Pb+Pb)



SEARCH FOR CRITICAL FLUCTUATIONS PROTON INTERMITTENCY ANALYSIS

Predictions of critical QCD

1. Net baryon density at midrapidity is an order parameter for the QCD critical point.
2. At the critical point the density-density correlation function in transverse momentum space of net baryons at midrapidity obeys a power-law:

$$\langle n_B(\overrightarrow{p_T}) n_B(0)\rangle \sim |\overrightarrow{p_T}|^{2\phi_{2,c}}$$

3. For the *3D* Ising universality class $\phi_{2,c} = 5/6$
4. The critical power-law behaviour of the net baryon density-density correlation is transferred also to the proton density-density correlation.

Methodology

- Such a power-law distribution can be observed through proton intermittency analysis in transverse momentum space.
- We have to calculate the second factorial moment of the proton transverse momentum distribution $F_2(M)$ as a function of M (M^2 = number of transverse momentum bins).
- For protons originating from a critical state (without background) we expect:

$$F_2(M) \sim M^{5/3}$$

- In real data background is always present and has to be removed.

SEARCH FOR CRITICAL FLUCTUATIONS
PROTON INTERMITTENCY ANALYSIS

Intermittency analysis was performed in the following systems:

- C+A with A = C, N (50000 events)
- Si+A with A = Al, Si, P (100000 events)
- Pb+Pb (1500000 events)

Event and track selection criteriae:

- Events corresponding to central collisions (centrality 0-12%)
- Particles with center of mass rapidity in the interval [−0.75, 0.75]
- Tracks corresponding to identified protons with at least 80% purity

Background is removed by subtracting the moments of constructed mixed events from those of the data:

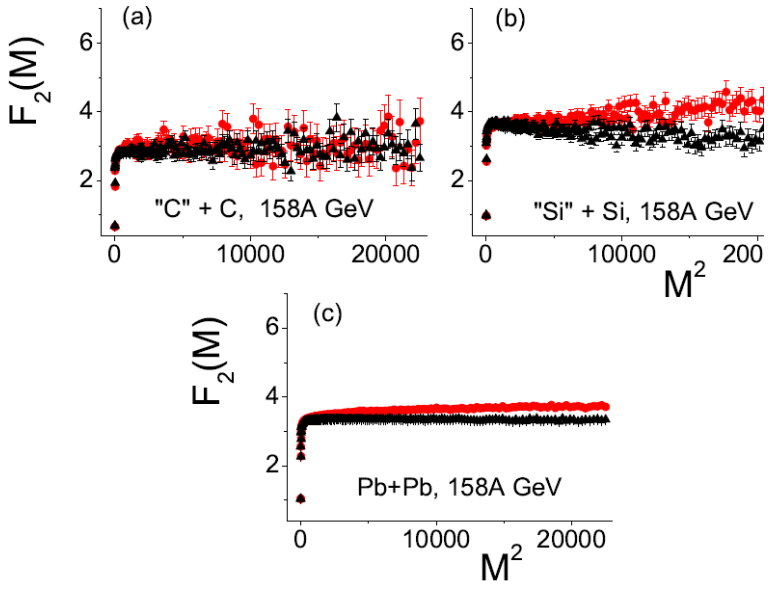
$$\Delta F_2(M) = F_2^{(data)}(M) - F_2^{(mixed)}(M)$$

We look for a power-law behaviour $\Delta F_2(M) \sim M^{2\phi_2}$
(exactly at the critical point $\phi_2 = \phi_{2,c} = 5/6$)

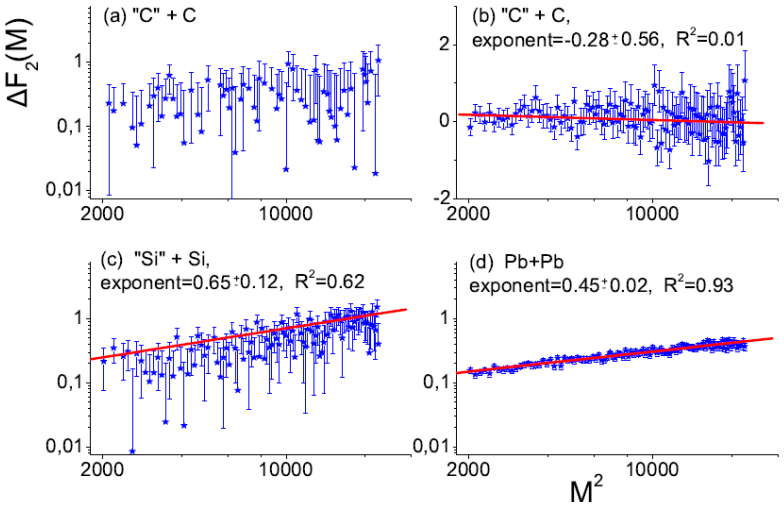
SEARCH FOR CRITICAL FLUCTUATIONS PROTON INTERMITTENCY ANALYSIS

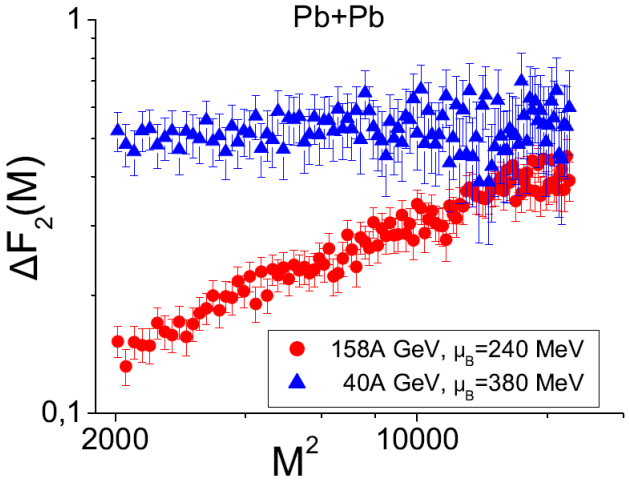
● NA49 data (centrality 0-12%)
▲ mixed events

rapidity cuts: y_{CM} in [-0.75,0.75]



158A GeV

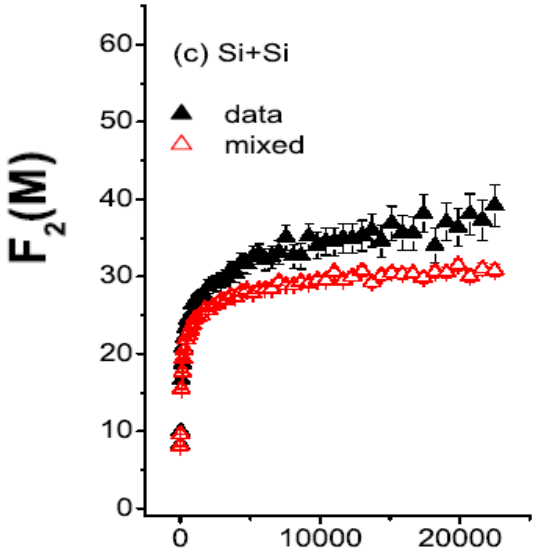


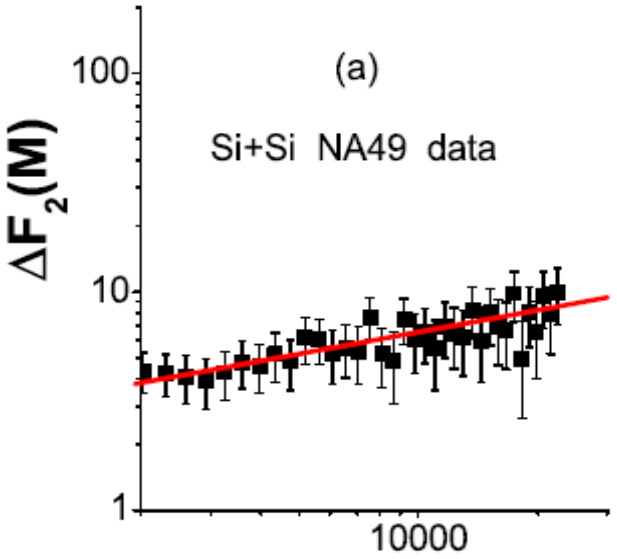


✓At 158A GeV intermittency signal in Si+Si and Pb+Pb
✓No intermittency at 40A GeV in Pb+Pb

SEARCH FOR CRITICAL FLUCTUATIONS PROTON INTERMITTENCY ANALYSIS

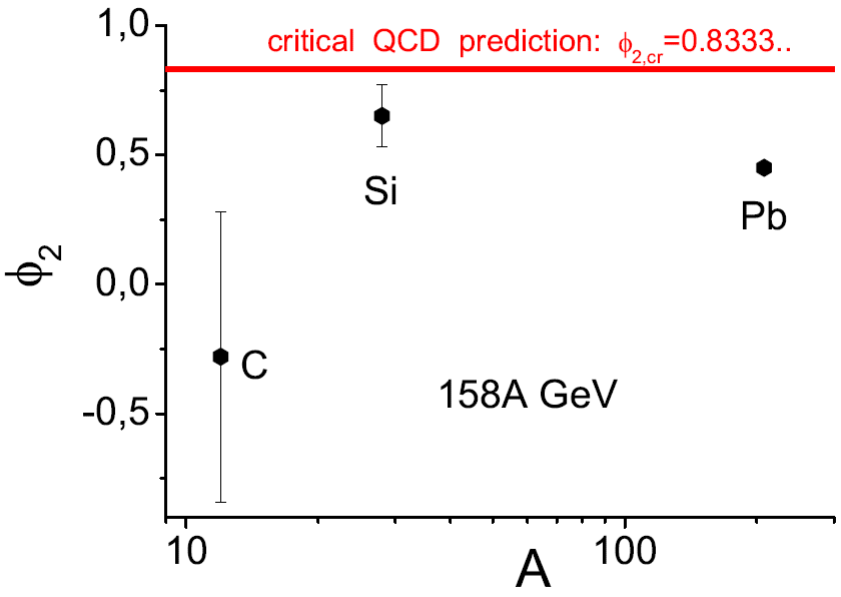
$\pi^+\pi^-$ pairs



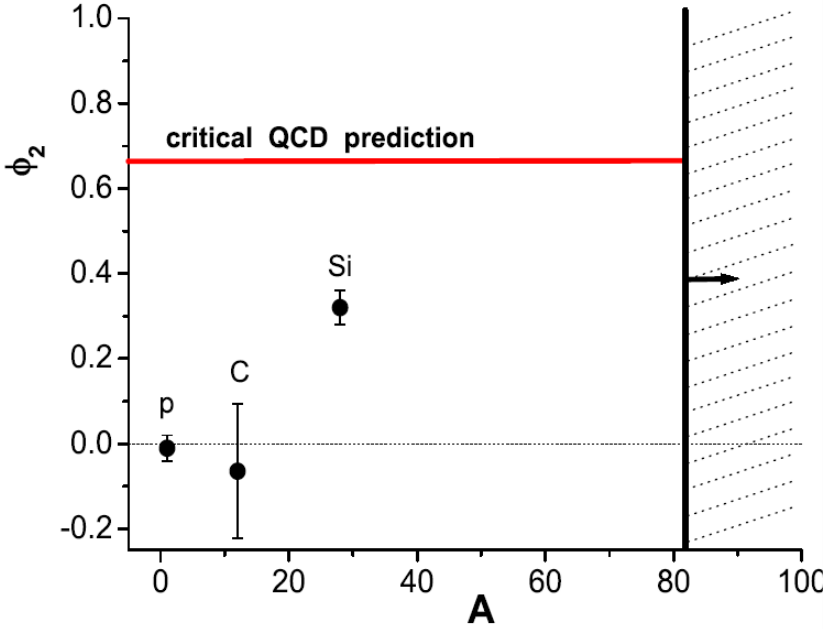


SEARCH FOR CRITICAL FLUCTUATIONS
PROTON INTERMITTENCY ANALYSIS

protons



$\pi^+\pi^-$ pairs



SUMMARY

Onset of deconfinement: discovery confirmed

- first LHC data confirm the interpretation,

- results from RHIC agree with the relevant NA49 data

Search for the critical point:

- hints of a maximum of fluctuations in Si+Si at 158A GeV

- the Si+Si and the Pb+Pb systems show strong power-law correlations in the transverse momentum space of protons at midrapidity.

- this finding is compatible with the existence of a critical point in the neighbourhood of the freeze-out states of these systems. The freeze-out state of the C+C system lies at the edge of this critical region and therefore the power-law behaviour is suppressed.

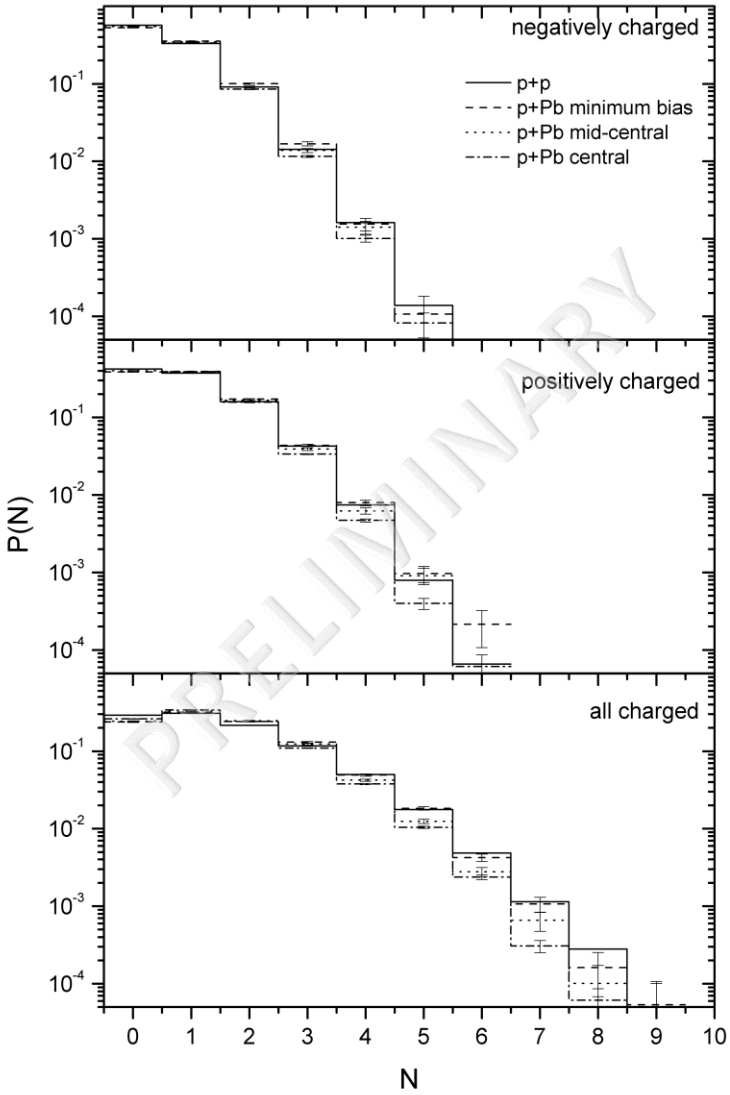
- especially for the Si+Si system these findings support the indication of critical fluctuations.

Back-up slides

SEARCH FOR CRITICAL POINT
RESULTS ON FLUCTUATIONS

p+p, p+Pb, forward hemisphere ($1.1 < y_{CM} < 2.6$)

	ω_{neg}	ω_{pos}	ω_{all}
p+p	0.956 ± 0.003	0.949 ± 0.003	1.211 ± 0.004
p+Pb (minbias)	0.916 ± 0.012	0.902 ± 0.011	1.074 ± 0.013
p+Pb (mid-central)	0.912 ± 0.012	0.892 ± 0.011	1.01 ± 0.012
p+Pb (central)	0.92 ± 0.005	0.883 ± 0.005	1.01 ± 0.005



Multiplicity fluctuations
are similar for all analyzed systems