Fluctuations in Nuclear Collisions at the CERN SPS

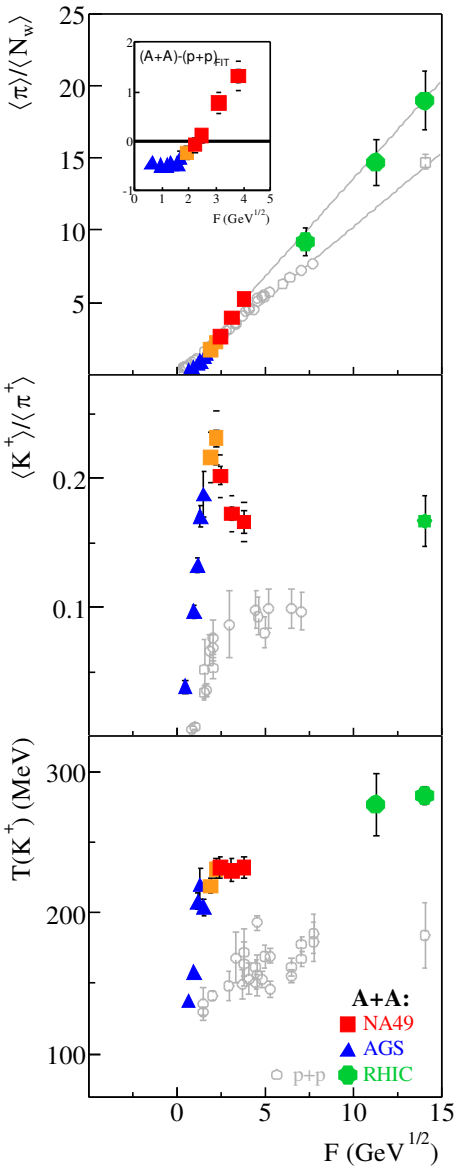
M. Gazdzicki, Frankfurt, Kielce

- Onset of deconfinement ...
- ... and fluctuations

- Onset of deconfinement ...

hadron production properties

AGS SPS RHIC



Kink

Horn

Step

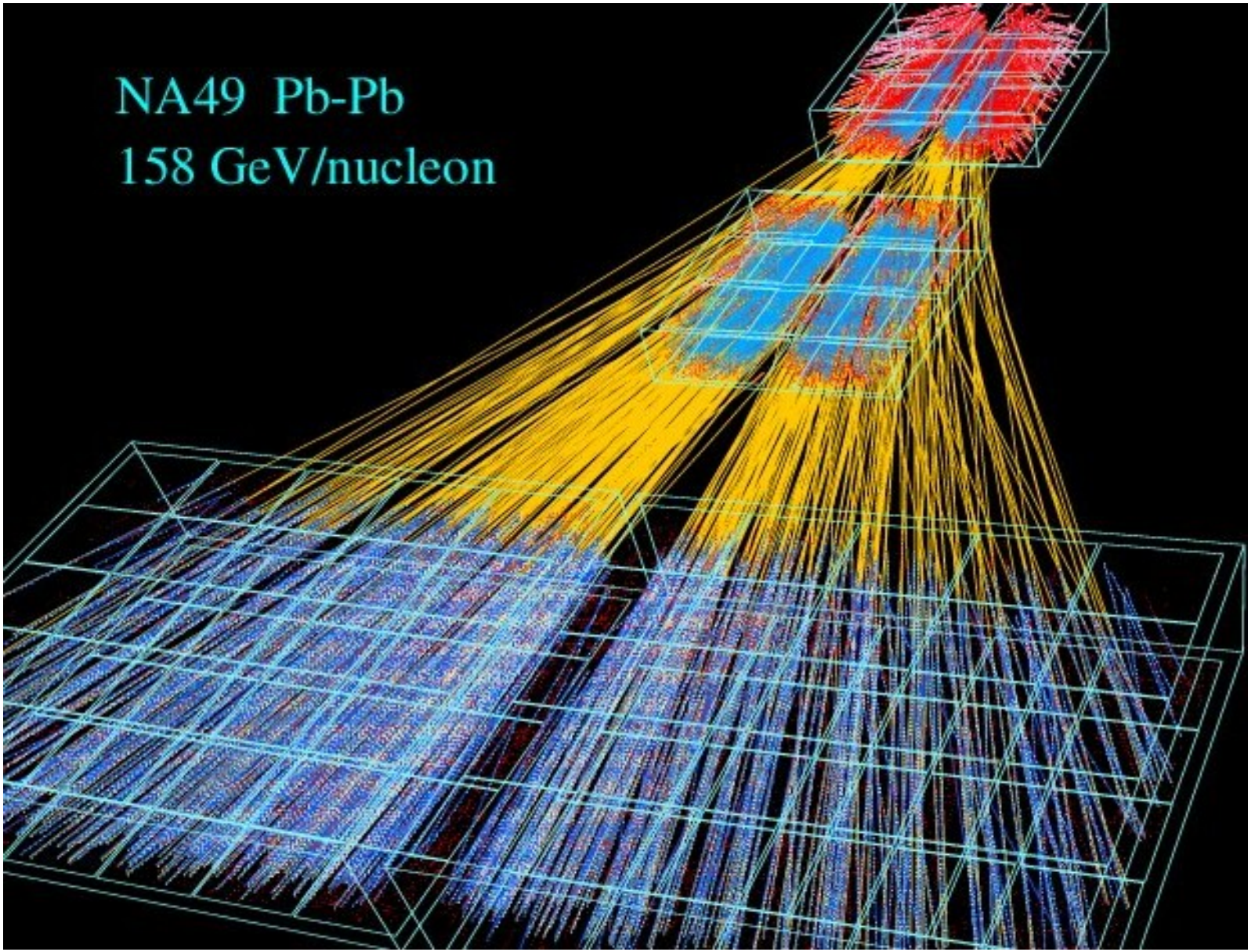
collision energy

Onset of deconfinement at the low SPS energies suggested by energy dependence of hadron production properties averaged over many collisions

How are the event-by-event fluctuations affected by the onset of deconfinement?

Are the expected effects seen in the data?

NA49 at SPS – a dedicated facility to study event-by-event fluctuations in nuclear collisions



... and fluctuations

Ideas and data

- **Net-electric charge fluctuations**

  Jeon, Koch, PRL 85: 2076, 2000

  Asakawa, Heinz, Muller, PRL 85:2072, 2000

- **Multiplicity fluctuations**

  M.G., Gorenstein, Mrowczynski, PL B585:115, 2004

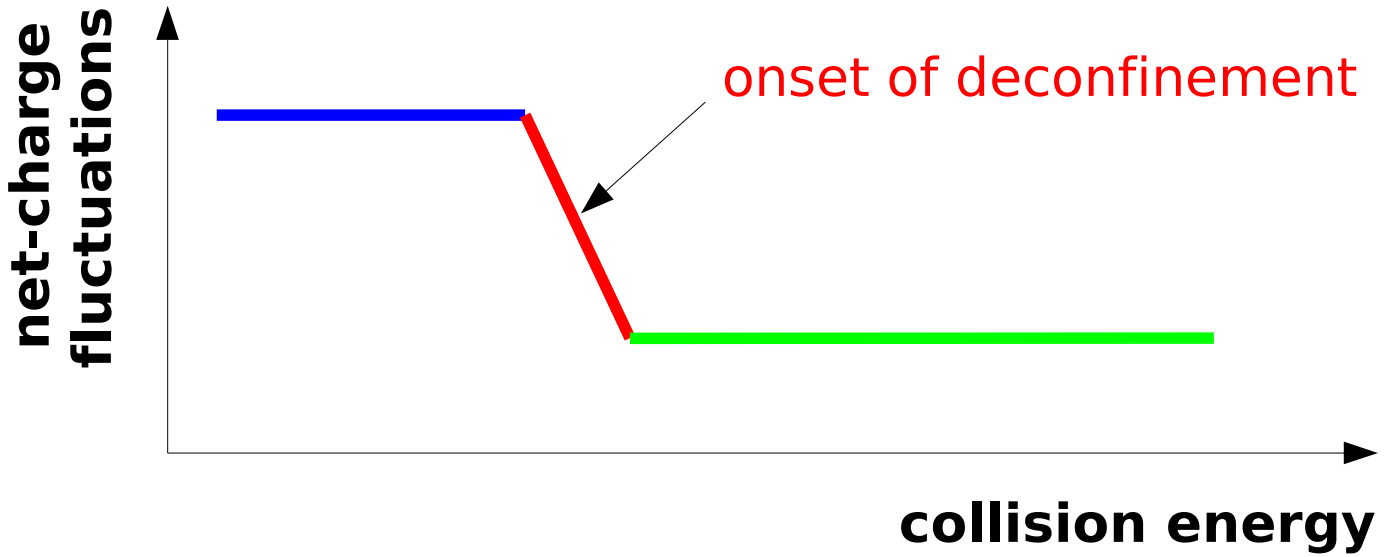
- **Strangeness fluctuations**

  Gorenstein, M.G., Zozulya, PL B585:237, 2004

Net-electric charge fluctuations

The basic idea …

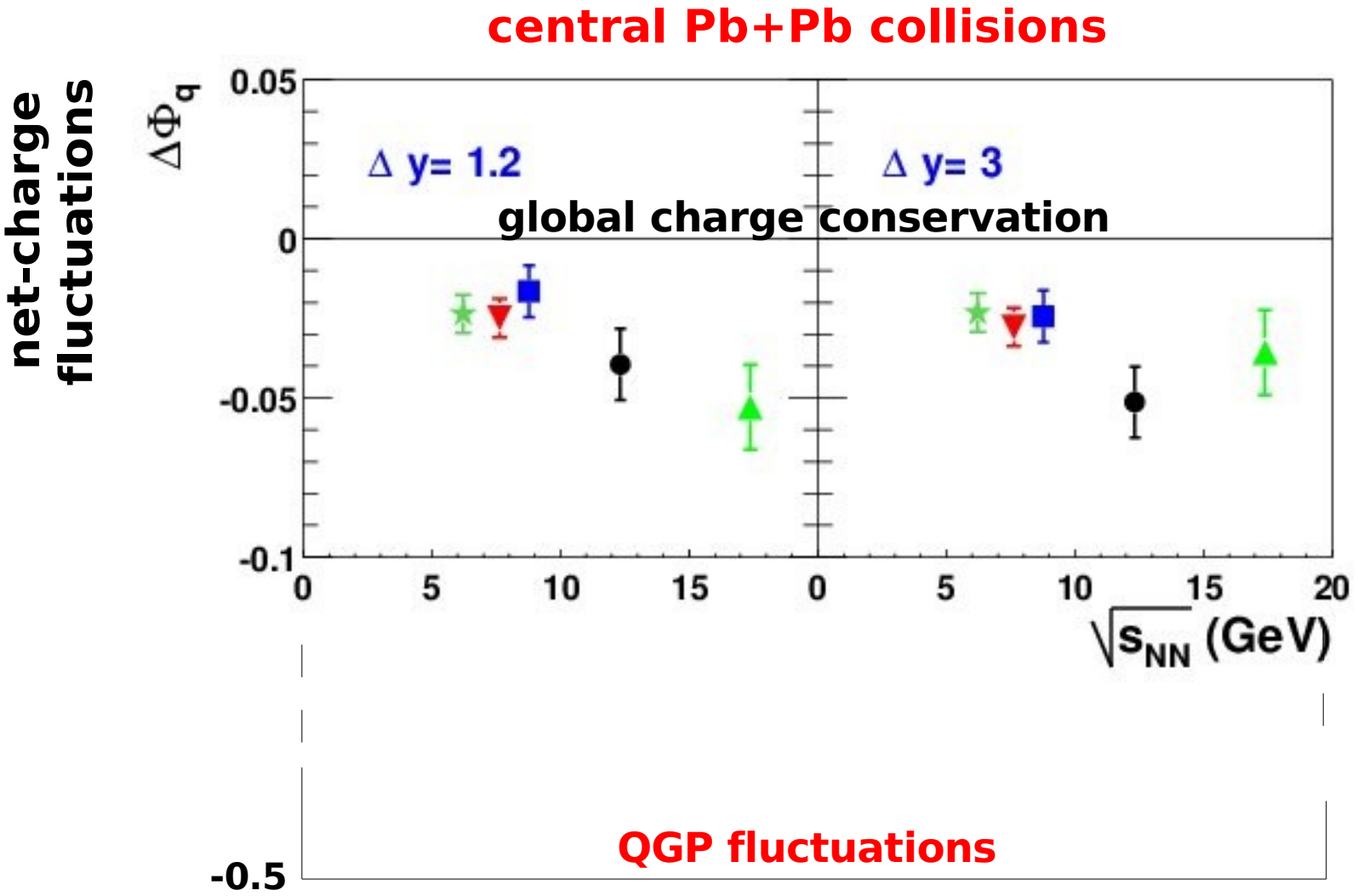
Net-charge fluctuations will be smaller in QGP (due to fractional charges of quarks) than in gas of hadrons



Jeon, Koch, PRL 85: 2076, 2000

Asakawa, Heinz, Muller, PRL 85:2072, 2000

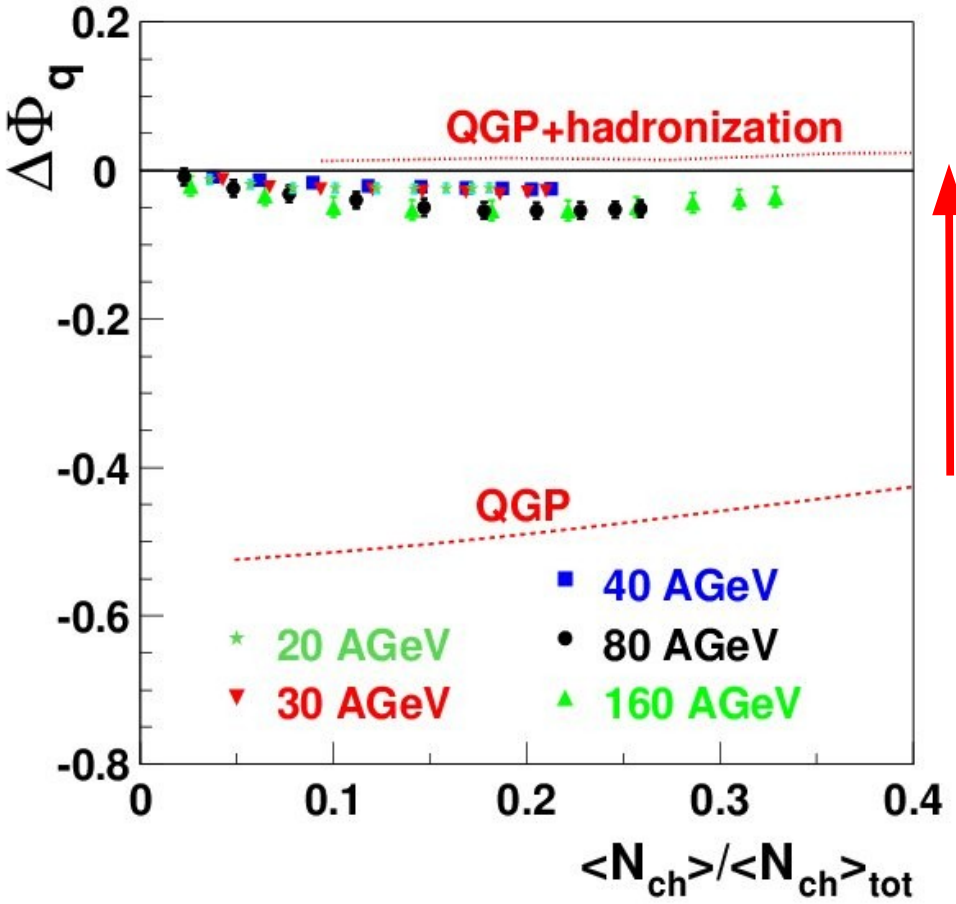
... and the experimental data



A predicted large suppression of the net-charge fluctuations is not observed!

NA49, Phys.Rev.C70:064903,2004

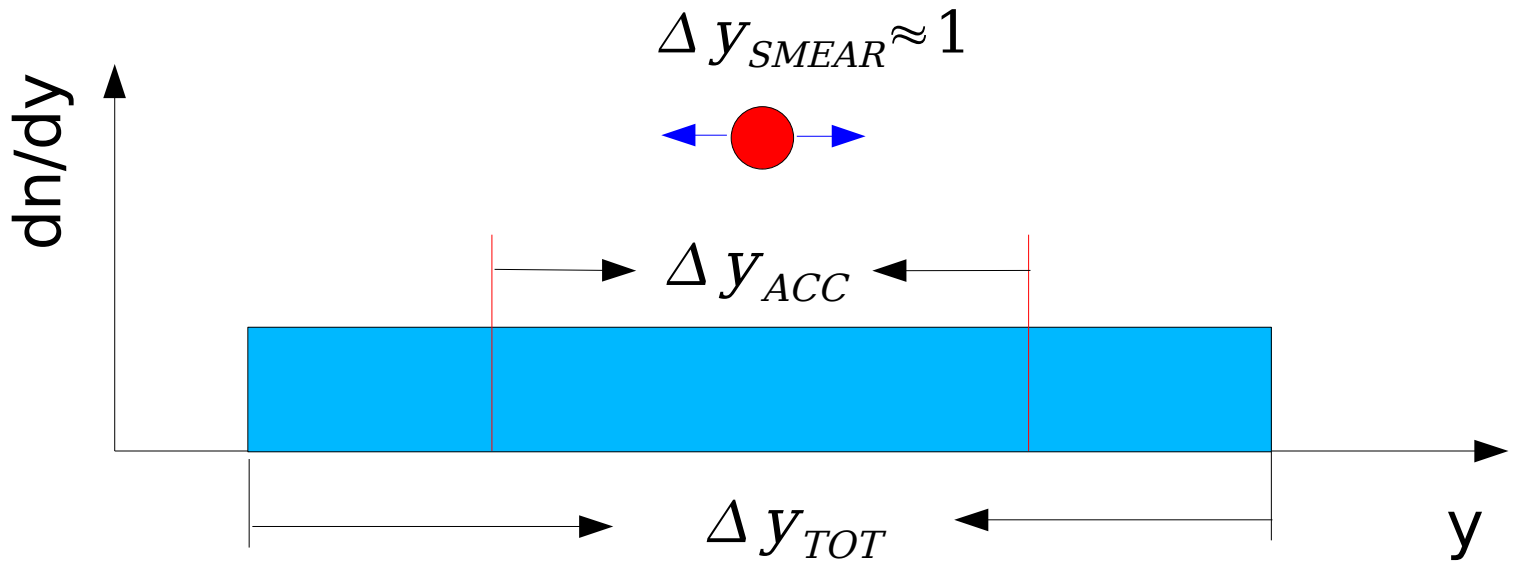
... and its possible explanation



A hadronization of QGP modeled as a creation and a successive decay of resonances lead to a strong increase of the net-charge fluctuations

Zaranek, Phys.Rev.C66:024905,2002
NA49, Phys.Rev.C70:064903,2004

... and the intuition behind it



The observation of the predicted suppression requires:

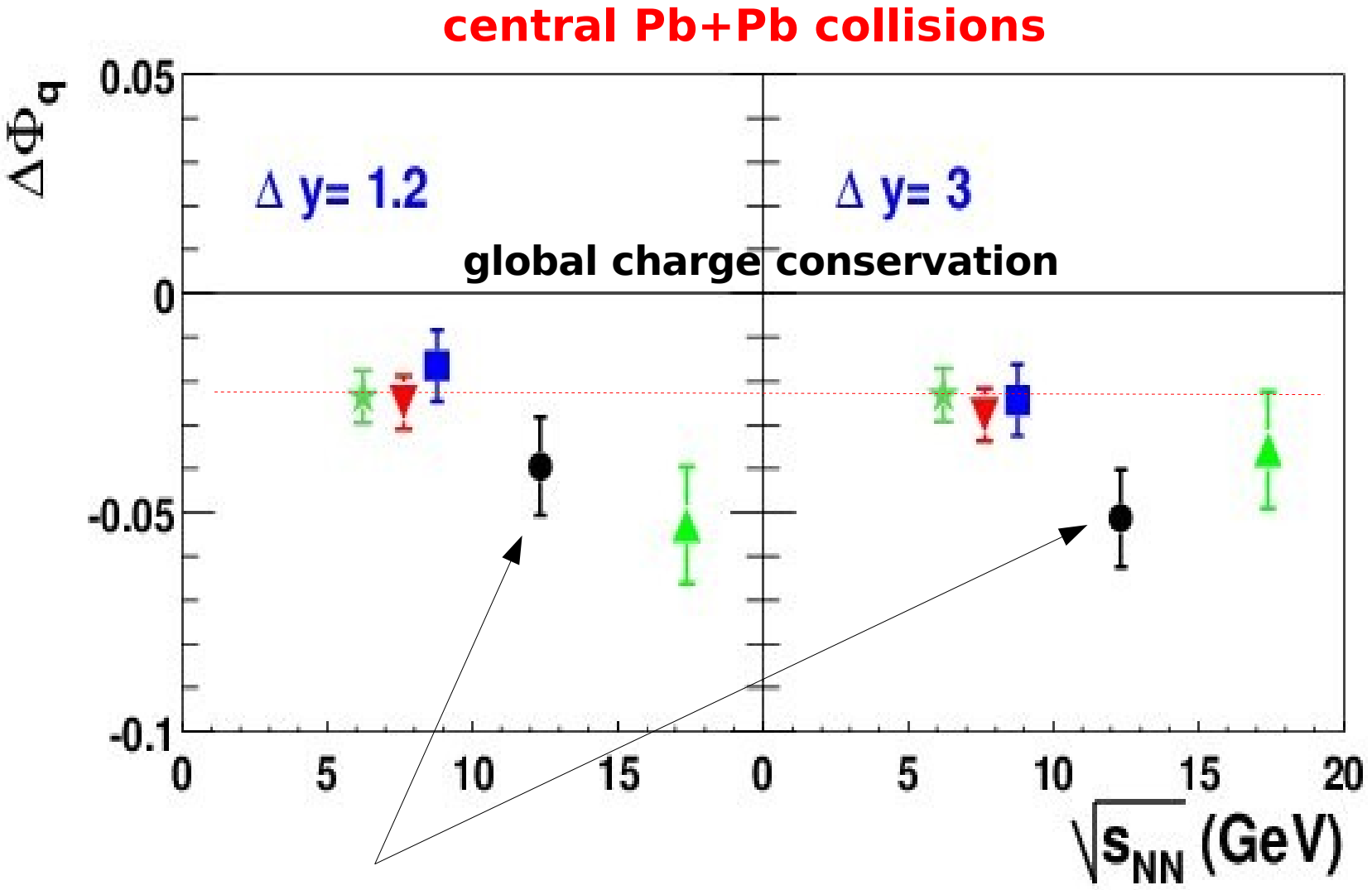
$$\Delta y_{SMEAR} \ll \Delta y_{ACC} \ll \Delta y_{TOT}$$

However at the SPS energies we have:

$$\Delta y_{SMEAR} \approx \Delta y_{ACC} \approx \Delta y_{TOT} \approx 1$$

A low sensitivity of the net-charge fluctuations to the onset of deconfinement

A more detailed look at the data

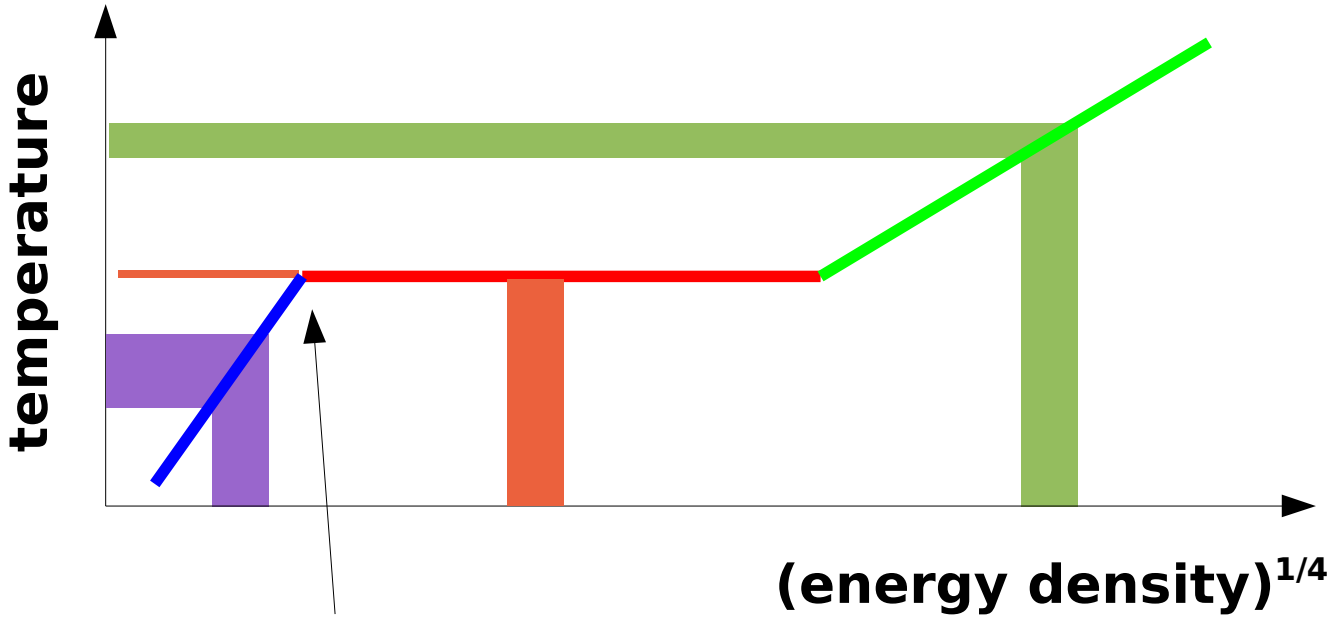


Is the observed reduction of the charge fluctuations at high SPS energies due to the onset of deconfinement?

Multiplicity fluctuations

The basic idea ...

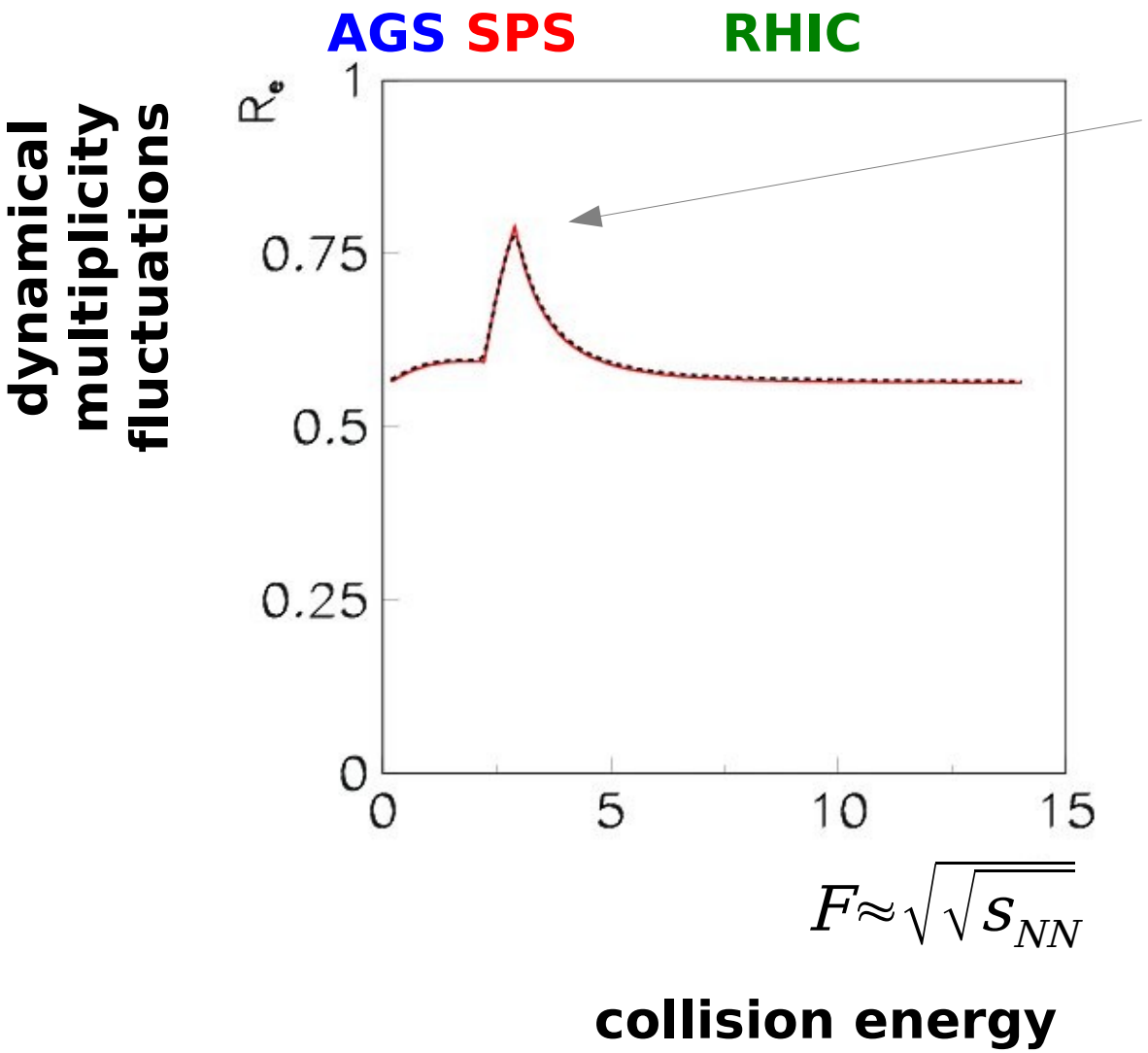
Response to the initial energy density fluctuations depends on the Equation of State at the early stage of the collisions



onset of deconfinement

M.G., Gorenstein, Mrowczynski, PL B585:115, 2004

... and the energy dependence of dynamical multiplicity fluctuations



The onset of deconfinement is signaled by a ''shark fin'' -like structure

The proposed measure

the statistical model of the early stage

Model: $$R_e \equiv \frac{(\delta S)^2 / S^2}{(\delta E)^2 / E^2} = \left(1 + \frac{p}{\epsilon}\right)^{-2}$$

Experiment: $$\frac{\delta S}{S} \approx \frac{\delta \bar{n}}{\bar{n}} \qquad \frac{\delta E}{E} \approx \frac{\delta \bar{E}}{\bar{E}}$$ where →

The R_e measure is:

+ sensitive to the EoS,
+ insensitive to the initial energy density fluctuations,
-sensitive to the geometrical fluctuations,
-sensitive to global conservation laws

Study of the effect of conservation laws in statistical models

Study of the effect of geometrical fluctuations

Important technical details:

the measured variance of multiplicity distribution

$$V(n) = (\delta \bar{n})^2 + \langle (\delta n)^2 \rangle$$

the dynamical
(early stage) fluctuations

the dynamically averaged
statistical fluctuations
can be measured using
the sub-event method provided ....

Voloshin, Koch, Ritter, PR C68:044905, 2003

Two unexpected discoveries:

Study of the effect of conservation laws in statistical models

→ pseudo-intensive variables in statistical physics

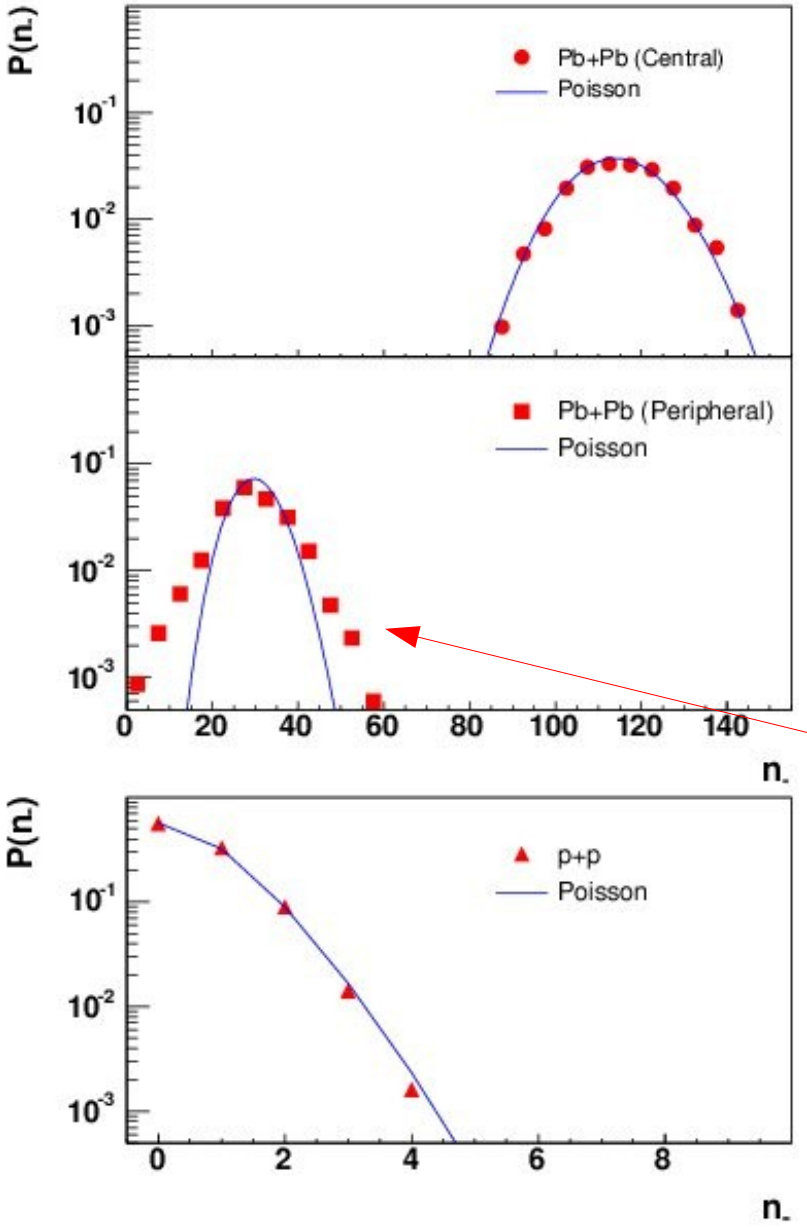
see next talks: Begun, Gorenstein

Study of the effect of geometrical fluctuations

→ Large multiplicity fluctuations in semi-peripheral Pb+Pb collisions

Multiplicity fluctuations in Pb+Pb and p+p collisions

158*A* GeV



Pb+Pb collisions analyzed in narrow intervals of E_{ZDC} (the number of participants is approximately fixed)

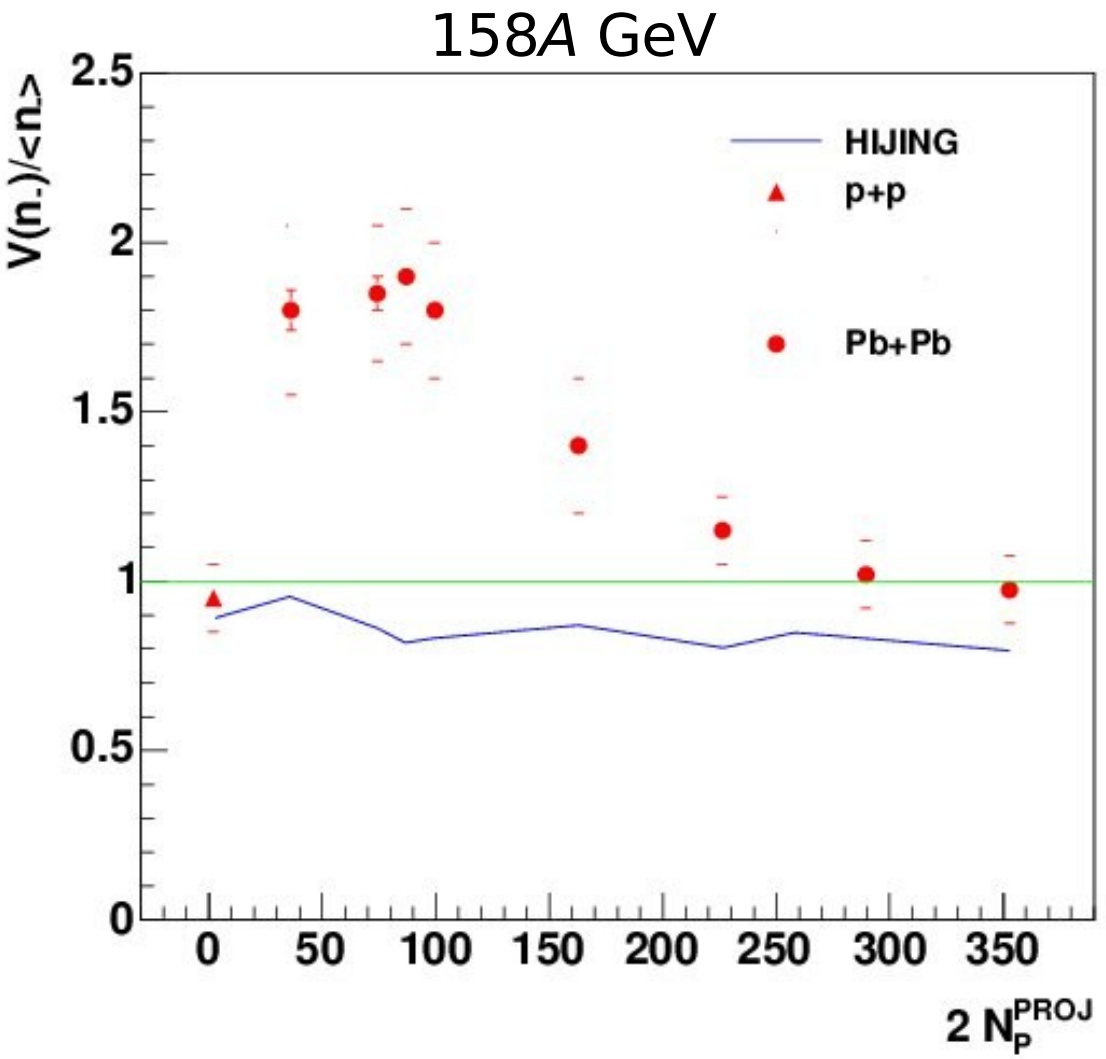
About 20% of all negatively charged hadrons are used

Large fluctuations in semi-peripheral Pb+Pb collisions

Rybczynski et al.,

J. Phys.Conf.Ser.5:74-85,2005

The scaled variance ...



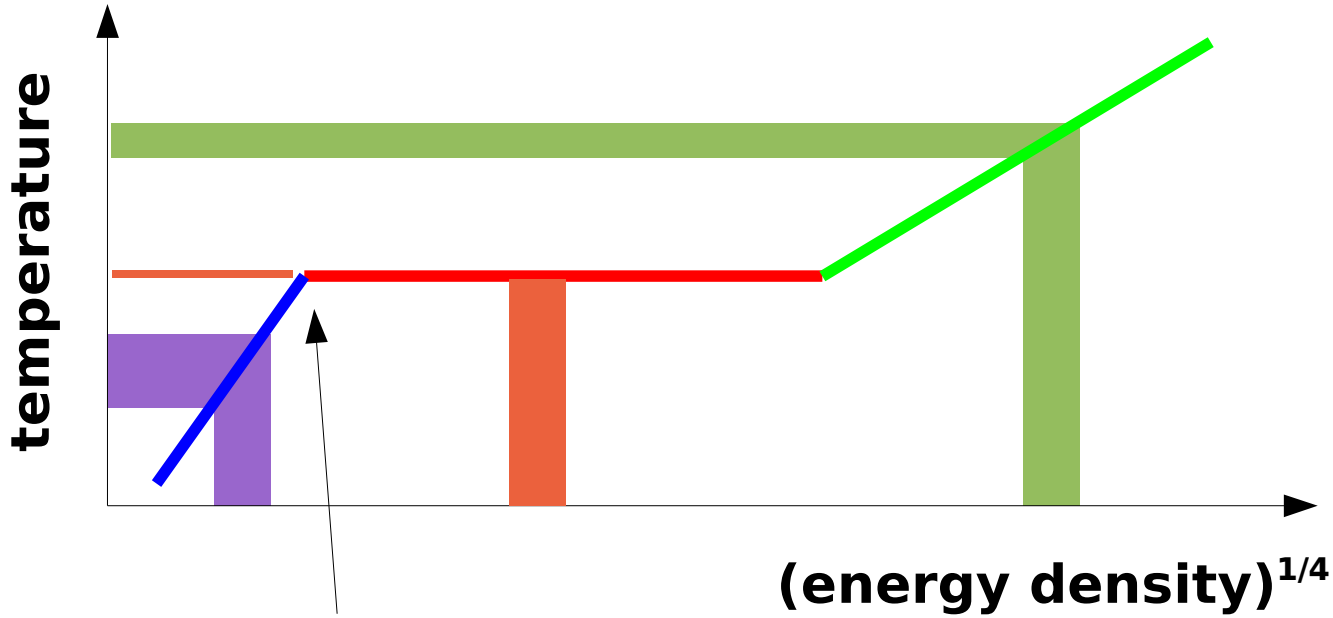
The scaled variance is corrected for the resolution of ZDC and the final width of the E_{ZDC} interval

Study of energy dependence of multiplicity fluctuations in central Pb+Pb collisions is in progress

Strangeness fluctuations

The basic idea as for multiplicity fluctuations

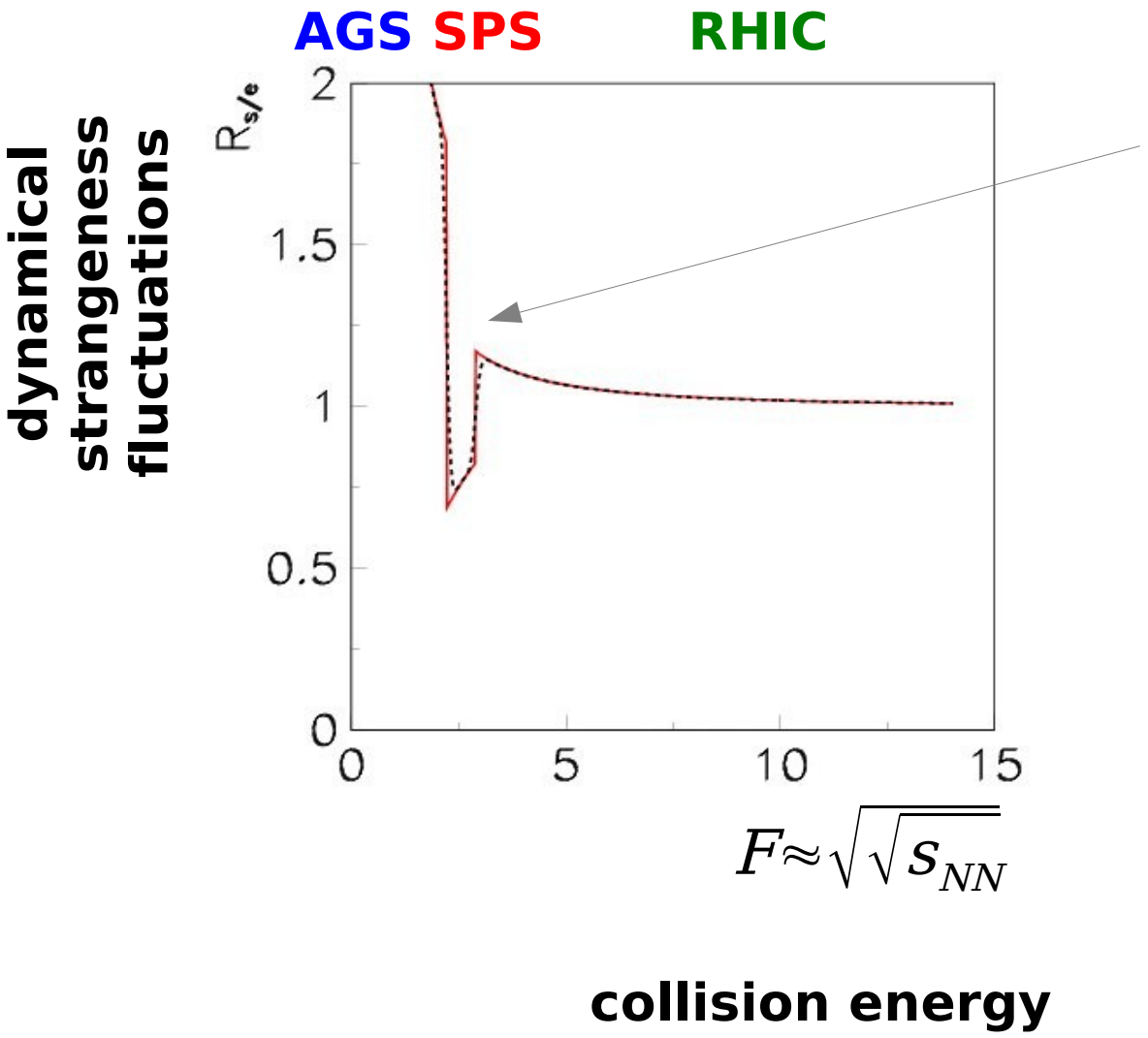
Response to the initial energy density fluctuations depends on the Equation of State at the early stage of the collisions



onset of deconfinement

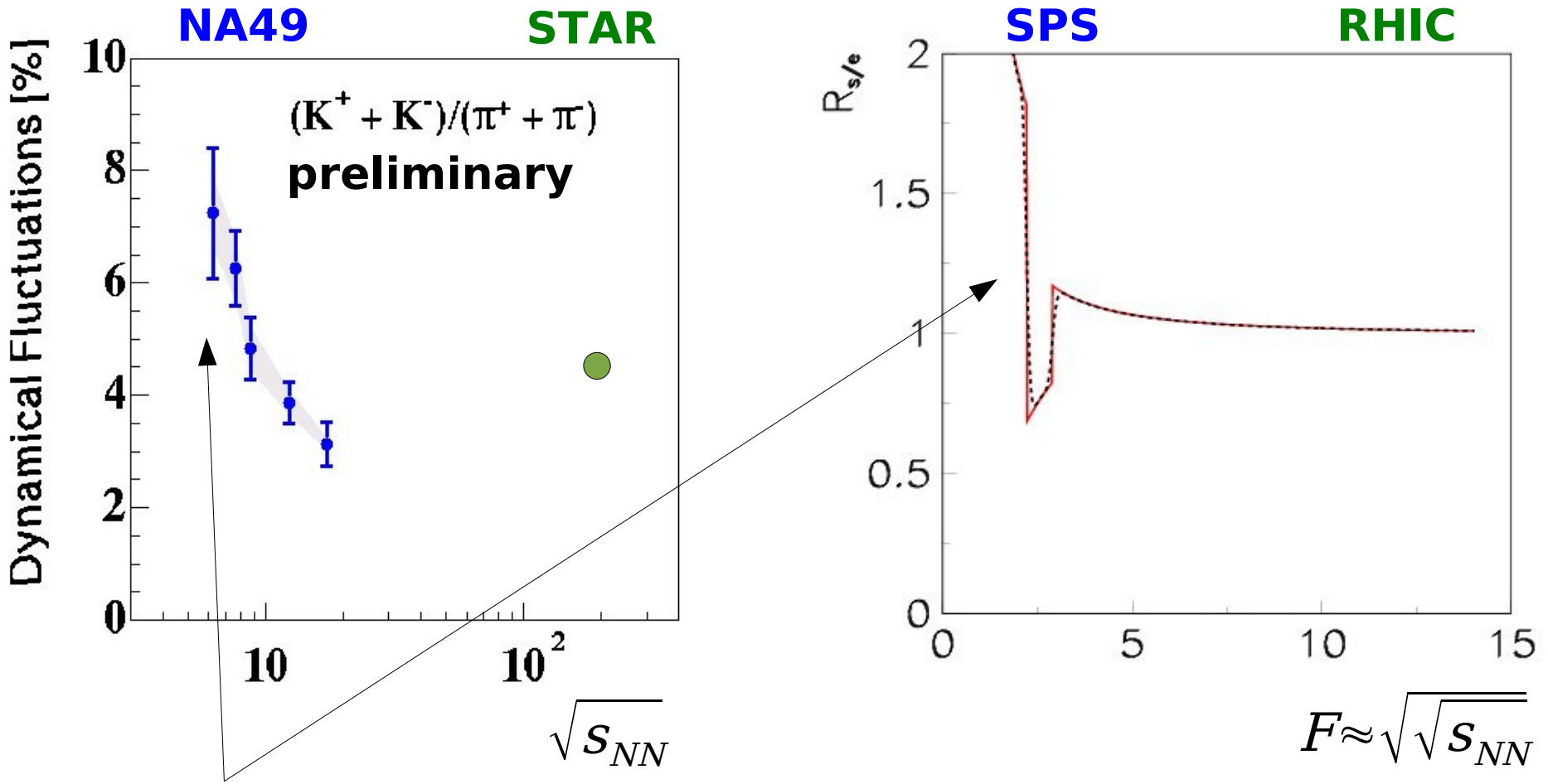
Gorenstein, M.G., Zozulya, PL B585:237, 2004

... and the energy dependence of dynamical strangeness fluctuations



The onset of deconfinement is signaled by a "tooth" -like structure

The NA49 data



Is the increase of fluctuations due to the onset of deconfinement?

Warning: a direct comparison is still impossible as different measures are used for data and model analysis

Onset of deconfinement and fluctuations

- Expected anomalies in energy dependence of event-by-event fluctuations of:
  - net-electric charge,
  - pion multiplicity,
  - kaon multiplicity
- Two unexpected discoveries:
  - pseudo-intensive variables (TH),
  - large fluctuations in peripheral collisions (EXP)
- First promising results on strangeness fluctuations

more to come soon ...

Extra slides

The proposed measure

Model: $$R_{s/e} \equiv \frac{(\delta N_s)^2 / N_s^2}{(\delta S)^2 / S^2}$$

Experiment: $$\frac{\delta N_s}{N_s} \approx \frac{\delta \bar{n}_K}{\bar{n}_K} \qquad \frac{\delta S}{S} \approx \frac{\delta \bar{n}}{\bar{n}}$$

The $R_{s/e}$ measure is:

+ sensitive to the EoS,
+ insensitive to the initial energy density fluctuations,
- sensitive to the geometrical fluctuations,
- sensitive to global conservation laws

The NA49 measure

$$R^2_{NA49} \equiv (\delta n_K / n)^2 / \langle n_K / n \rangle^2$$

$$\left(\quad R_{s/e} \equiv (\delta n_K)^2 / \bar{n}_K^2 \;/\; (\delta n)^2 / \bar{n}^2 \quad \right)$$

The R_{NA49} measure is:

+sensitive to the EoS,

- sensitive to the initial energy density fluctuations,

+insensitive to the geometrical fluctuations,

- sensitive to global conservation laws

Difficult, further work is needed!