# What are the effects of the initial-condition fluctuations in hydrodynamical description of heavy-ion collisions?

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## Plan of presentation:

1. Purpose of the study
2. Method
3. Results
4. Conclusions

# Purpose of the study

Usual hydrodynamic approach

$\Downarrow$

Symmetric and smooth initial conditions:
(mean distributions of velocity, temperature,
energy density, etc. )

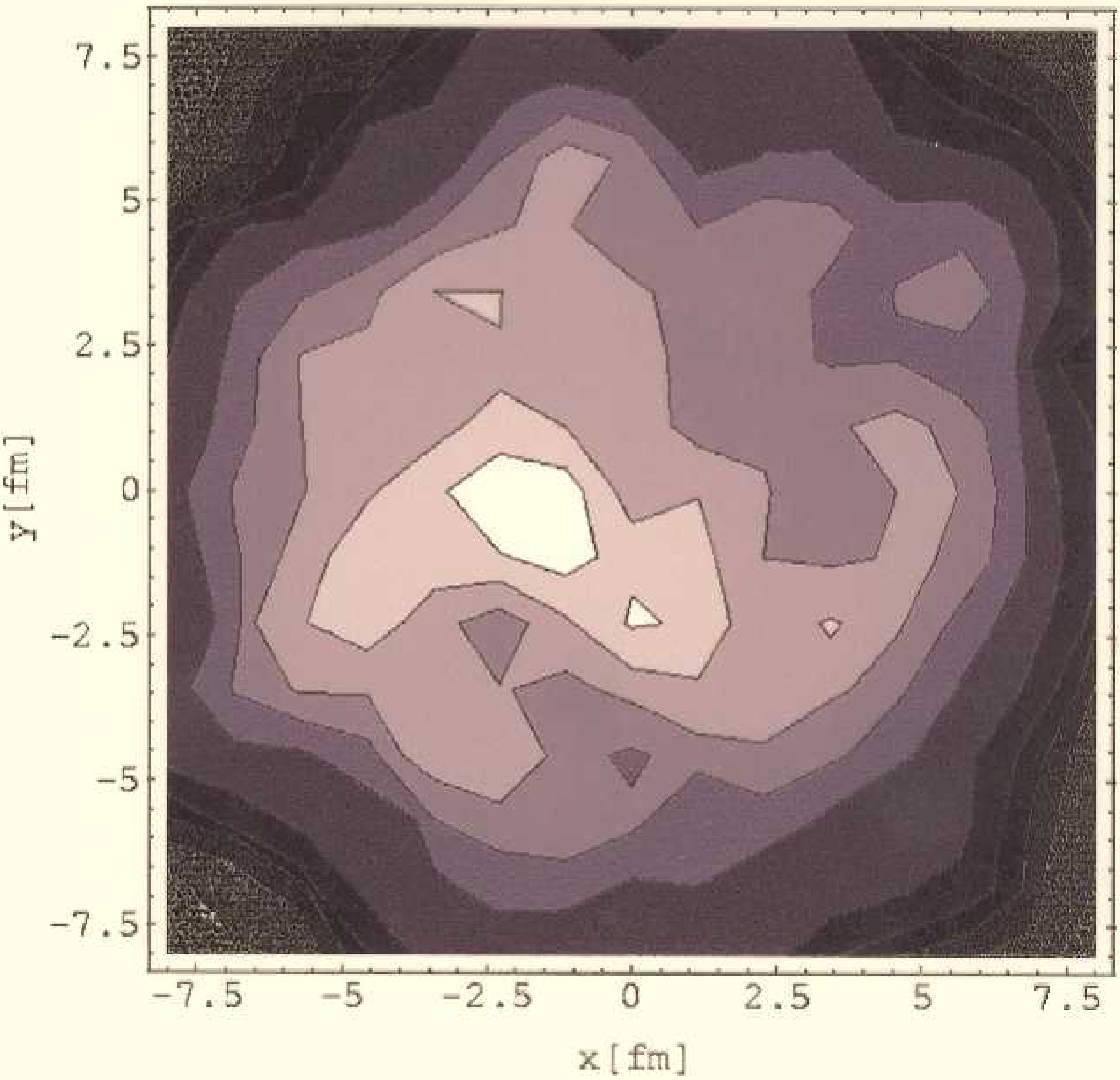
However, our systems are not large enough.

$\Downarrow$

Large fluctuations are expected.

What are the effects of the event-by-event fluctuation of the initial conditions?

- Are they sizable?
- Do they depend on the equation of state?
- Which are the most sensitive variables?
- ...




Initial energy density distribution on $z = 0$ plane of a typical Au+Au event at $\sqrt{s} = 200A\,\mathrm{GeV}$, impact parameter $b = 0$, produced by NeXus event generator.

In previous reports [1], by neglecting baryon-number and strangeness conservation and using simple parametrizations for EoS [4], we showed that

- indeed they are sizeable

  and

- they do depend on the EoS.

Here, we shall present comparison of results obtained

with **fluctuating initial conditions**

and those

with **averaged initial conditions.**

The EoS used is more realistic one [4], with baryon-number conservation taken into account and with an explicit inclusion of many resonances.

# Method of study

Generation of
Initial Conditions
**NeXus**

Equation of state
- Hadron gas
- QGP + hadron gas

⇒ ⇓

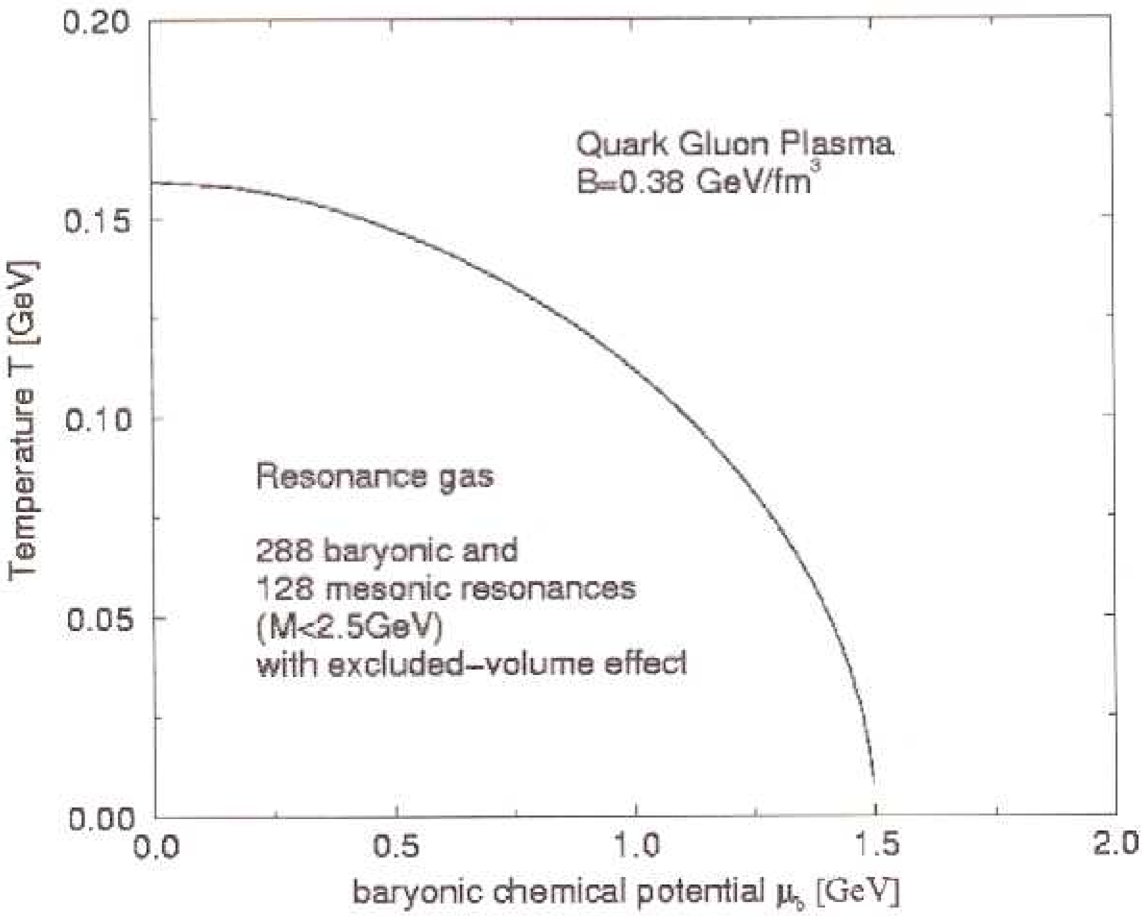
Resolution of hydrodynamic
equations
**SPheRIO**

⇓

Computation of
observables
$< v_2 >, \frac{dN}{dy}, \frac{d\sigma}{dm_T},$
...

# Equation of State

We consider an EoS with first-order transition between QGP and resonance-gas (RG) phases, with baryon-number conservation and excluded volume effects taken into account. The strangeness conservation has not been introduced yet.



# Smoothed Particle Hydrodynamics

The main characteristics are

- To attach conserved quantities (baryon number, strangeness, entropy, etc. ) to small volumes called "particles";
- Physical quantities are computed by averaging over particles, using some interpolating kernel;
- The particle motions are described by using Lagrangian coordinates.

Advantages:

- No extra grid points are needed;
- The precision is controlled by the interpolating kernel and the volumes of the particle.

## SPH equations of motion

In the present work, besides the energy and momentum, we have chosen the entropy as our conserved quantity. Then, its density (in the space-fixed frame) is parametrized as

$$s^*(\mathbf{x},t) = \sum_i^N \nu_i \, W(\mathbf{x} - \mathbf{x}_i(t); h) \ ,$$

where

$$\begin{cases} W(\mathbf{x} - \mathbf{x}_i(t); h) \text{ is the normalized kernel;} \\ \mathbf{x}_i(t) \text{ is the } i\text{-th. particle position, so} \\ \qquad \text{the velocity is } \mathbf{v}_i = d\mathbf{x}_i/dt \ ; \\ h \text{ is the smoothing scale parameter;} \end{cases}$$

and we have

$$S = \int d^3\mathbf{x} \; s^*(\mathbf{x},t) = \sum_i^N \nu_i \ .$$

The equations of motion write

$$\frac{d}{dt}\left(\nu_i \frac{P_i + \varepsilon_i}{s_i} \gamma_i \mathbf{v}_i\right) + \sum_j \nu_j \left[\frac{P_i}{s_i^{*2}} + \frac{P_j}{s_j^{*2}}\right] \nabla_i W(\mathbf{x}_i - \mathbf{x}_j; h) = 0 \, ,$$

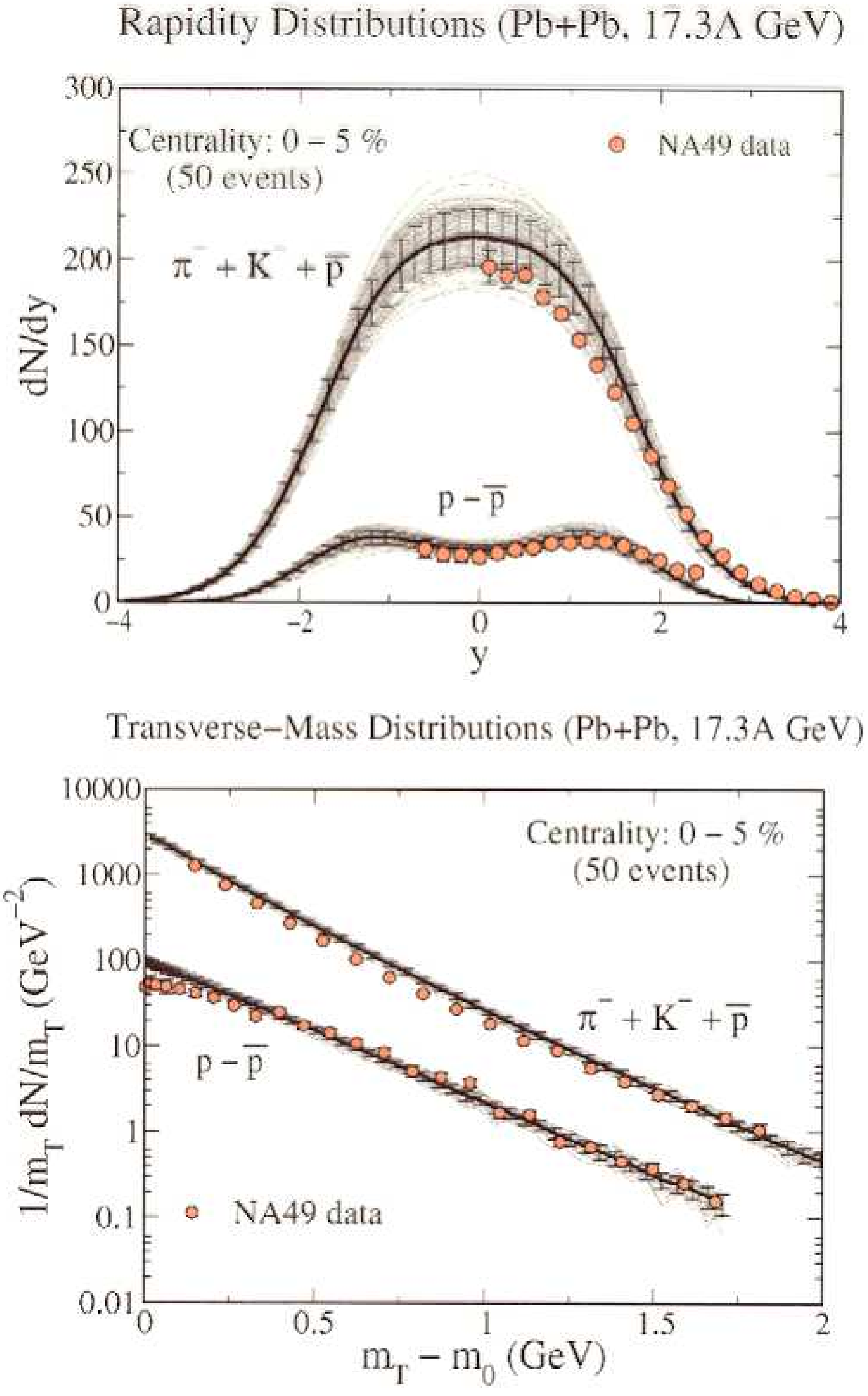
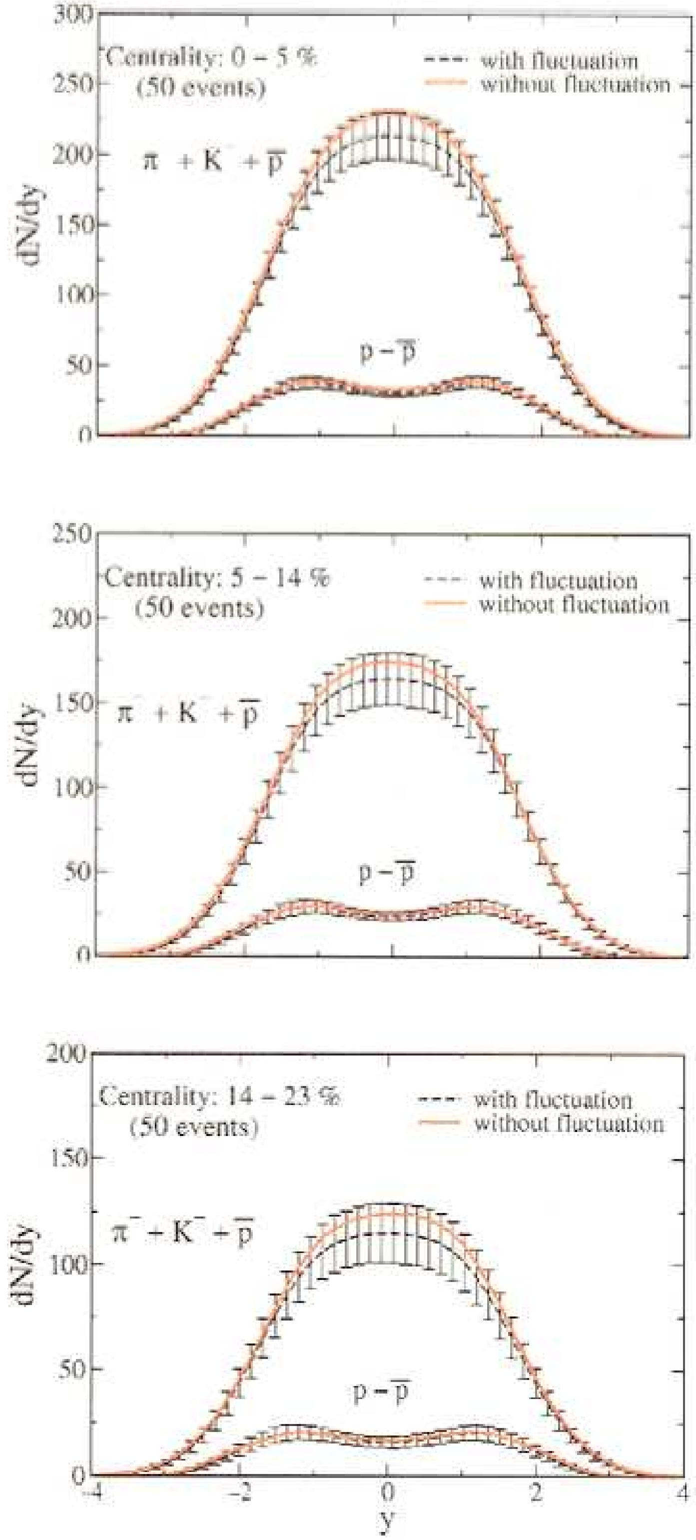
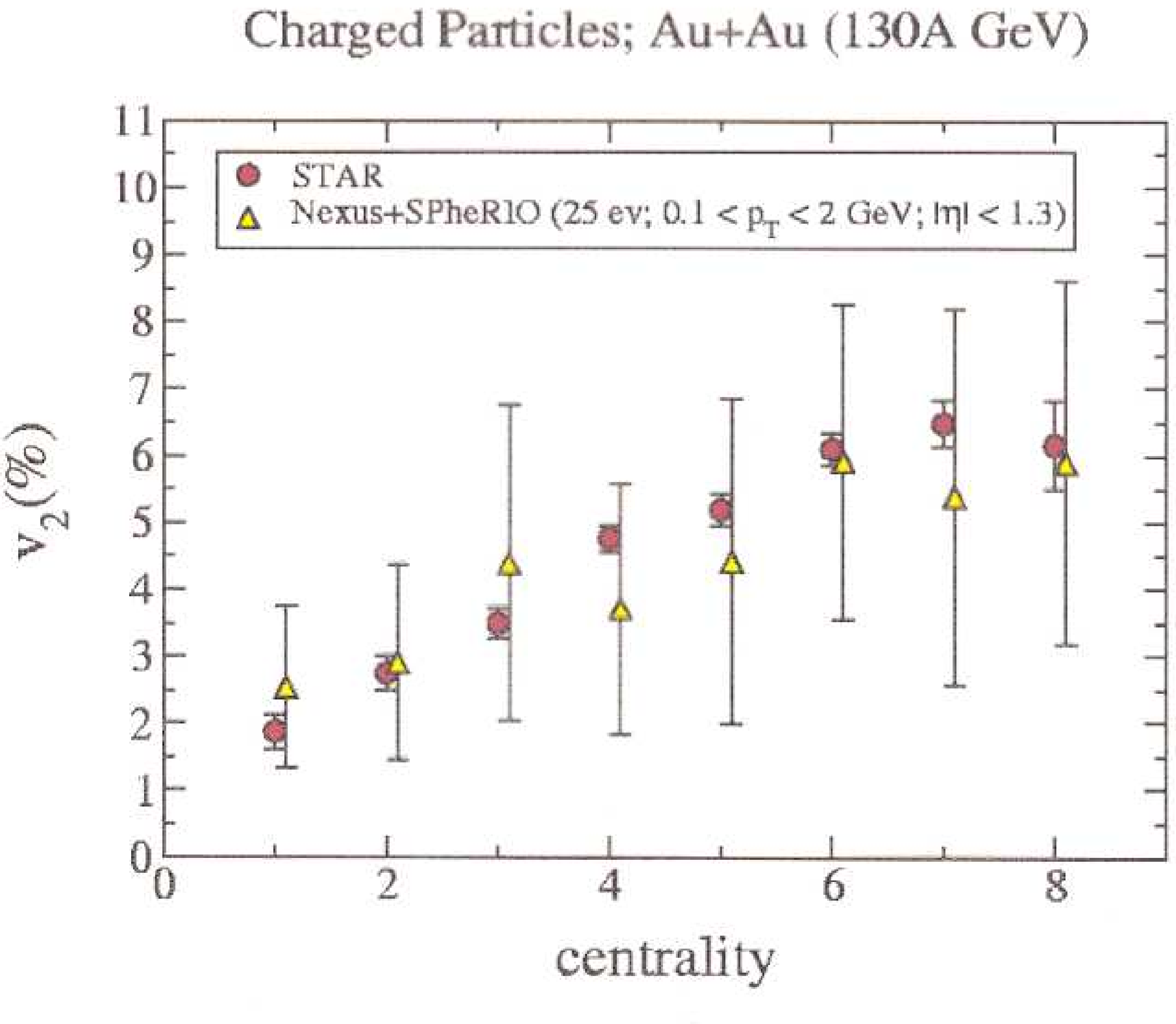


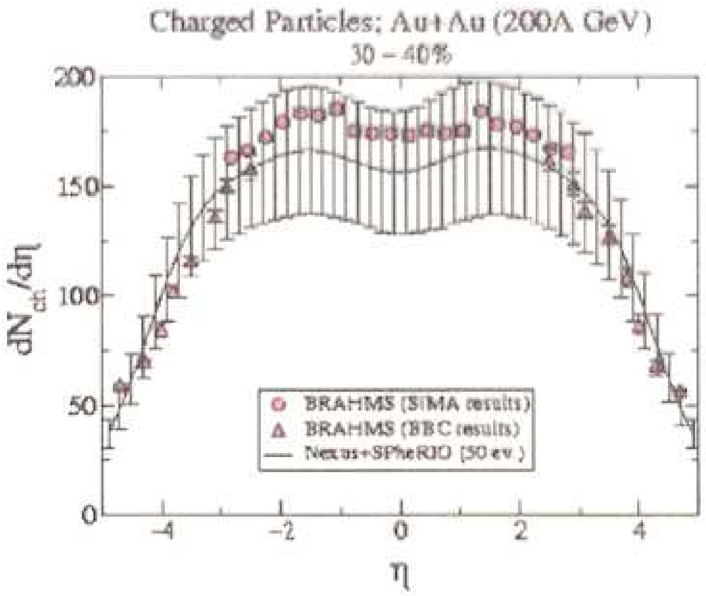

Fig. 2: Event-by-event fluctuating distributions, compared with data [10]. The average distributions with corresponding dispersions are also shown.

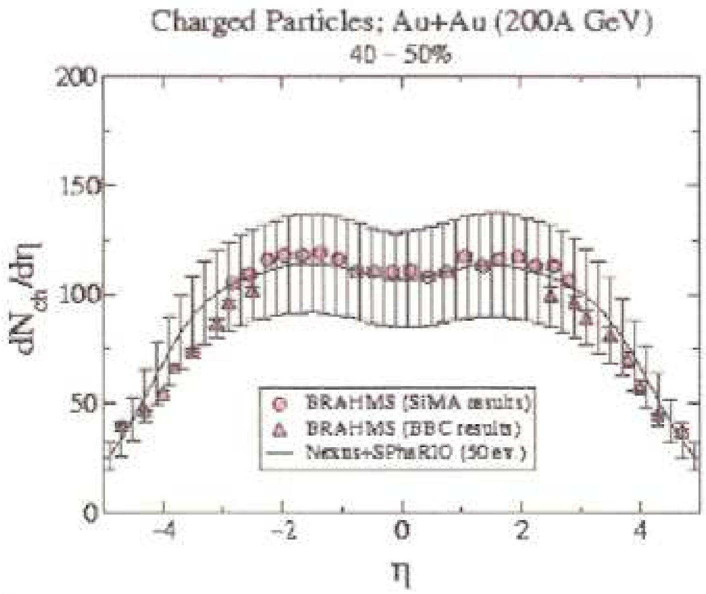
# Rapidity Distributions (Pb+Pb, 17.3A GeV)

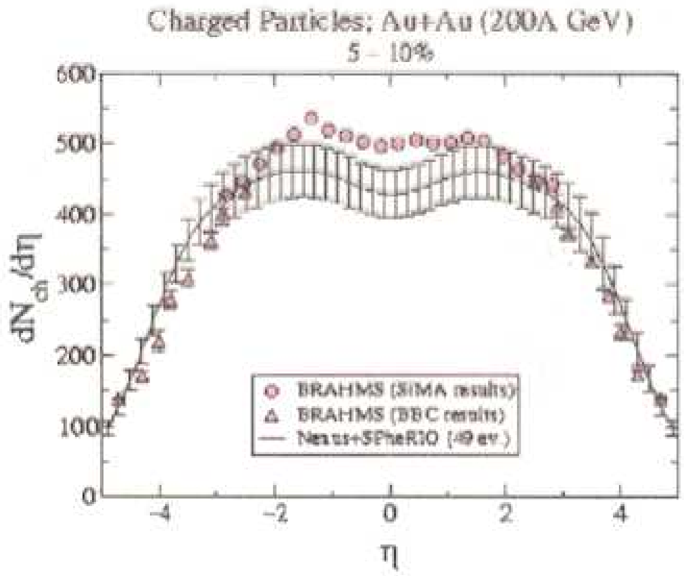




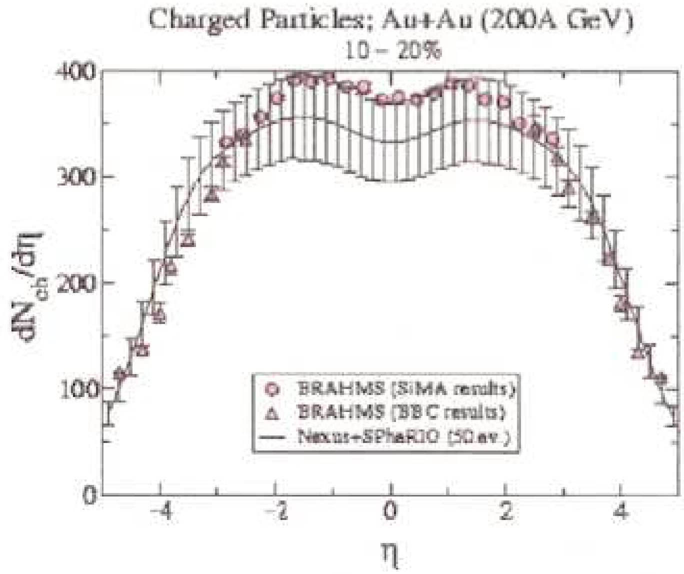
Charged Particles; Au+Au (130A GeV)
STAR
Nexus+SPheRIO (25 ev; 0.1 < p_T < 2 GeV; |η| < 1.3)
v_2(%)
centrality
0
1
2
3
4
5
6
7
8
9
10
11
0
2
4
6
8


Charged Particles; Au+Au (200A GeV)
30 – 40%
$dN_{ch}/d\eta$
$\eta$
BRAHMS (SiMA results)
BRAHMS (BBC results)
Nexus+SPheRIO (50 ev.)

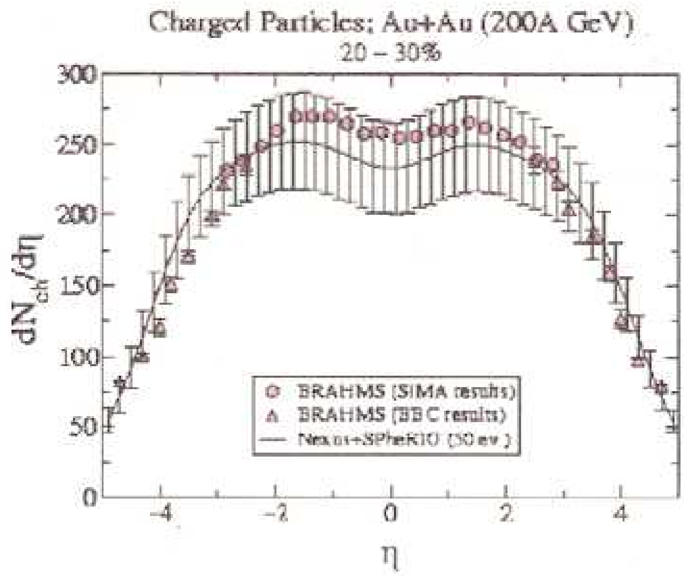

Charged Particles; Au+Au (200A GeV)
40 – 50%
$dN_{ch}/d\eta$
$\eta$
BRAHMS (SiMA results)
BRAHMS (BBC results)
Nexus+SPheRIO (50 ev.)



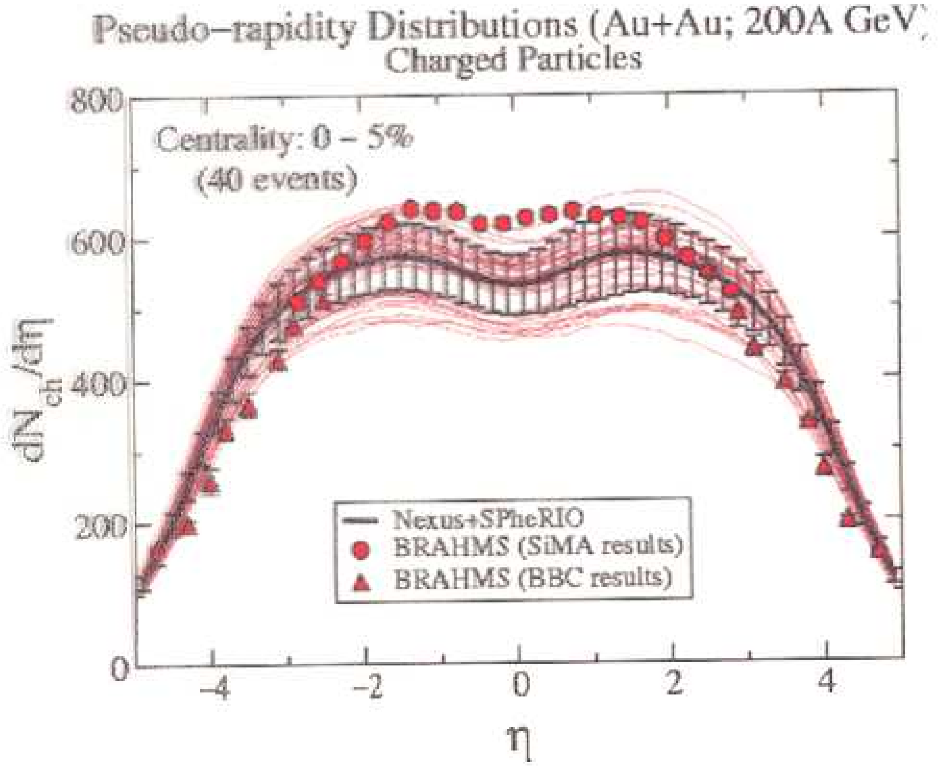
Charged Particles; Au+Au (200A GeV)
5 – 10%
dN_ch/dη
η
BRAHMS (SiMA results)
BRAHMS (BBC results)
Nexus+SPheRIO (49 ev.)

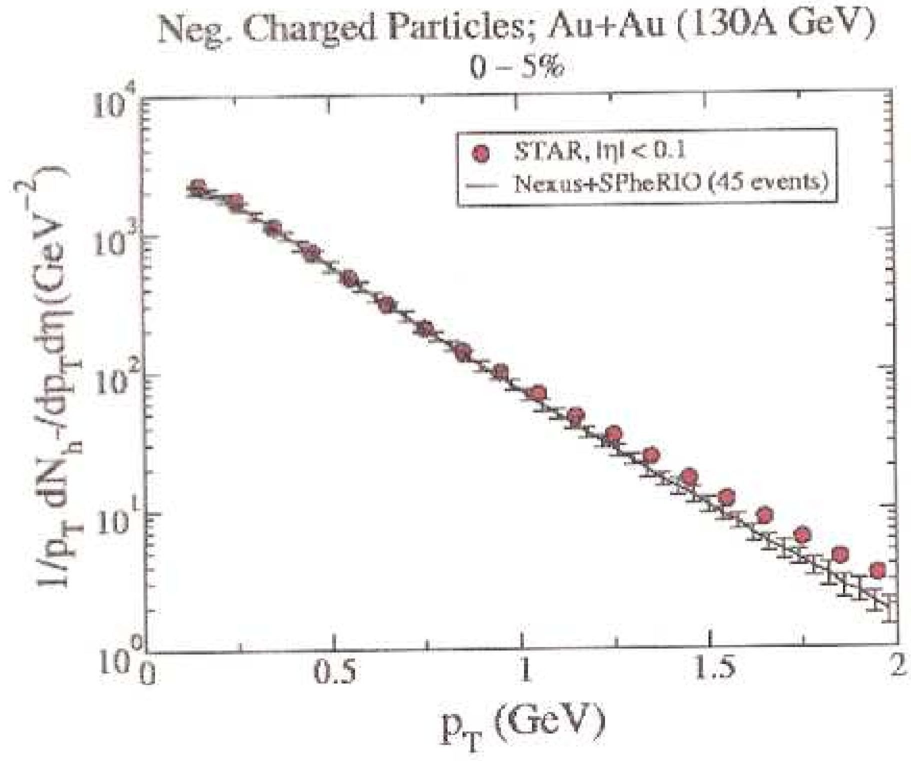



Charged Particles; Au+Au (200A GeV)
10 – 20%
dN_ch/dη
η
BRAHMS (SiMA results)
BRAHMS (BBC results)
Nexus+SPheRIO (50 ev.)

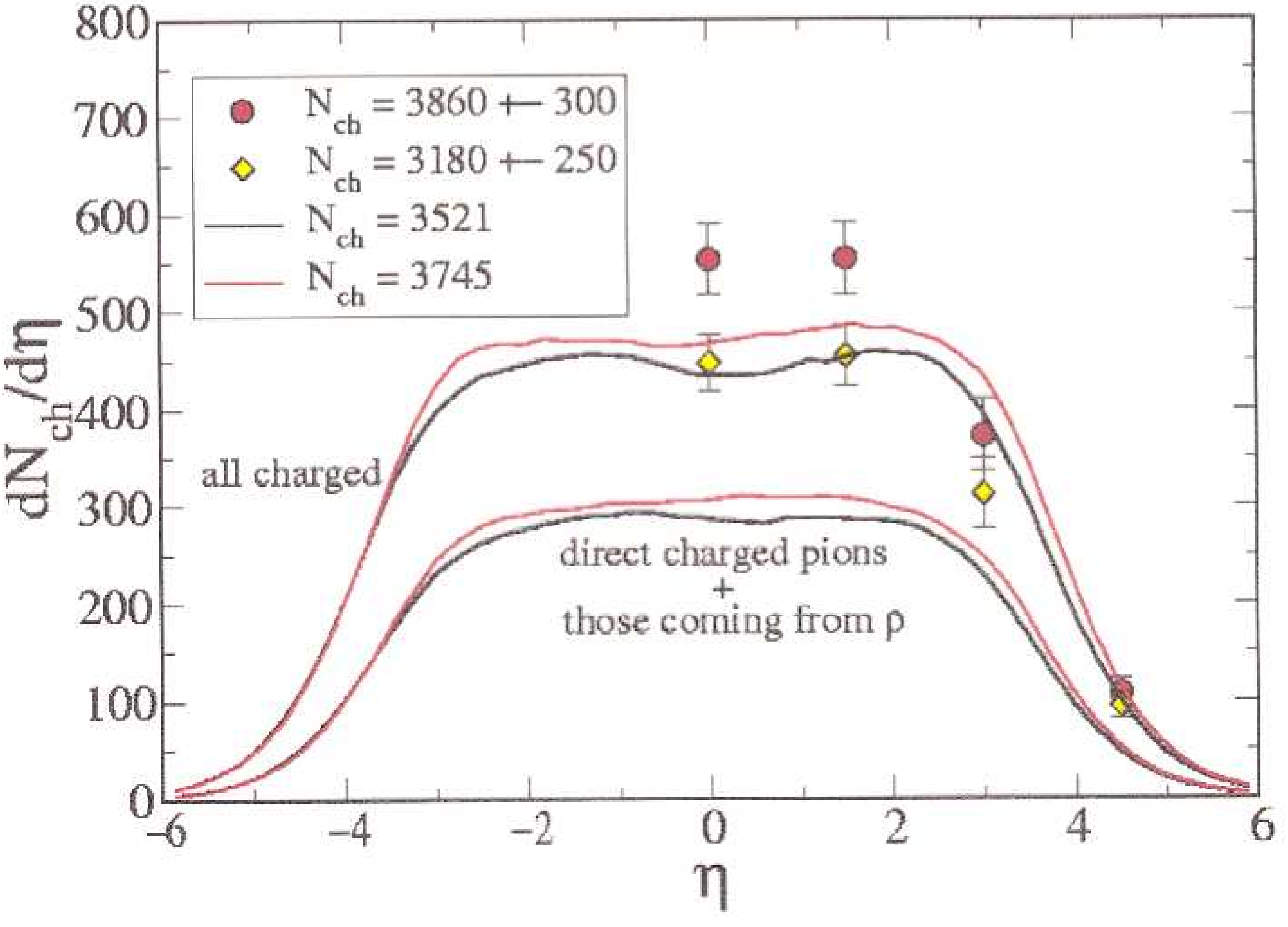



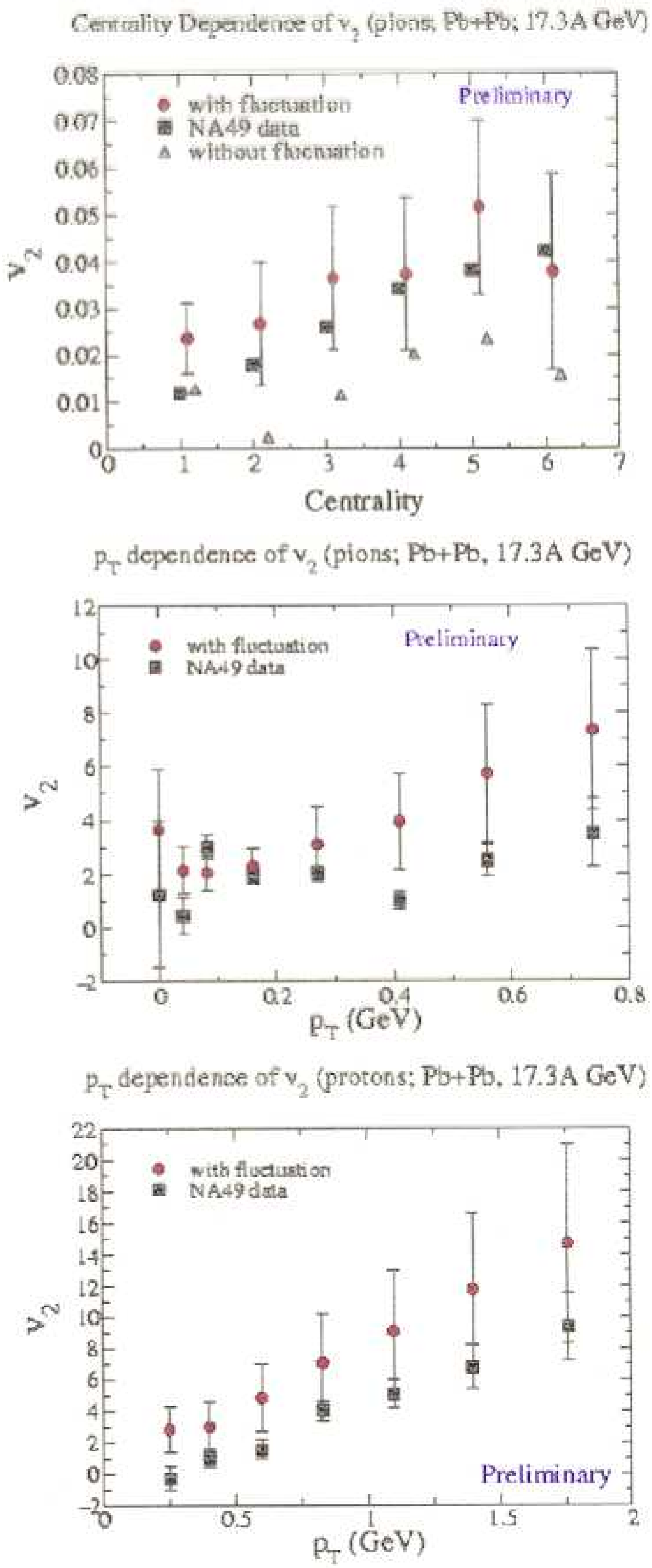
Charged Particles; Au+Au (200A GeV)
20 – 30%
dN_ch/dη
η
BRAHMS (SiMA results)
BRAHMS (BBC results)
Nexus+SPheRIO (50 ev.)


Pseudo–rapidity Distributions (Au+Au; 200A GeV)
Charged Particles
Centrality: 0 – 5%
(40 events)
Nexus+SPheRIO
BRAHMS (SiMA results)
BRAHMS (BBC results)
dNch/dη
η
800
600
400
200
0
-4
-2
0
2
4


Neg. Charged Particles; Au+Au (130A GeV)
0 – 5%
STAR, |η| < 0.1
Nexus+SPheRIO (45 events)
1/pT dNh-/dpTdη(GeV-2)
pT (GeV)
0
0.5
1
1.5
2

## Pseudorapidity Distributions (Au+Au, 130A GeV)

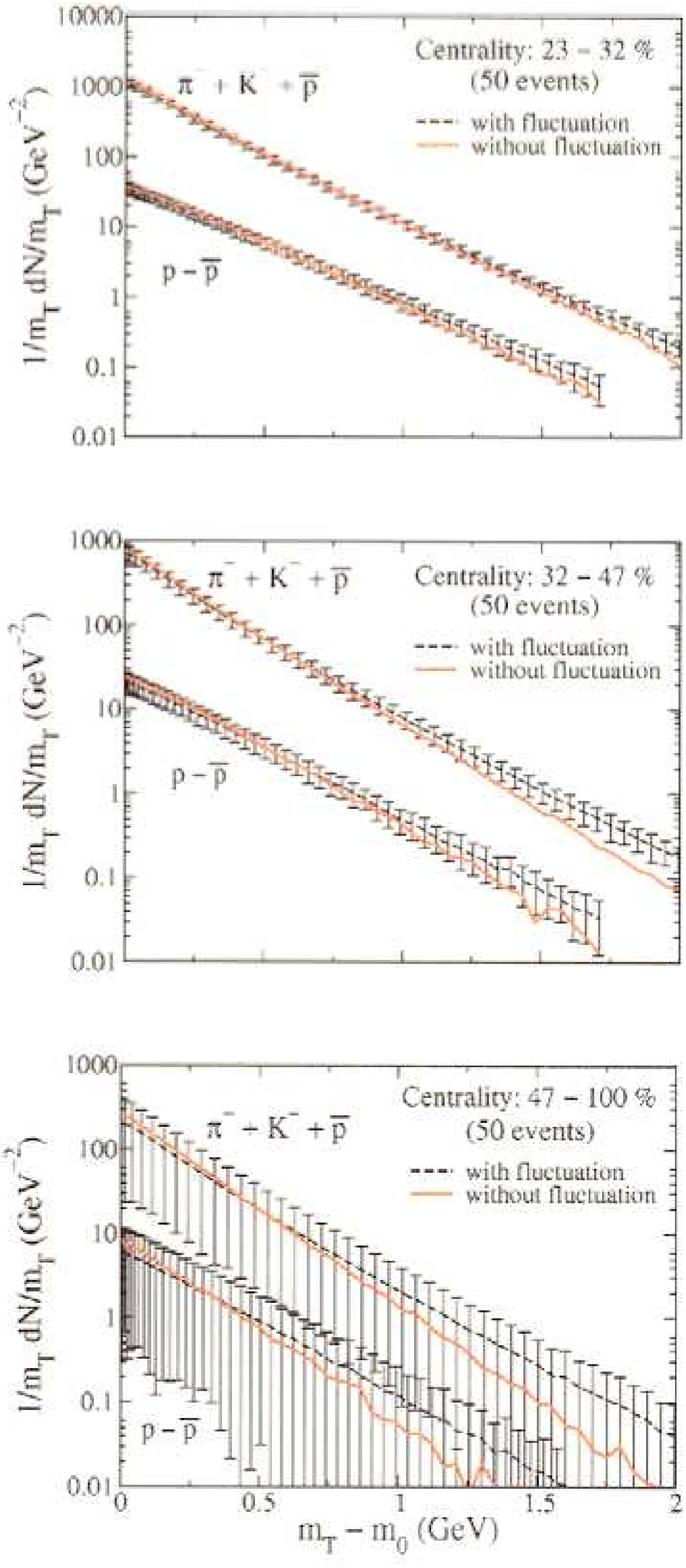




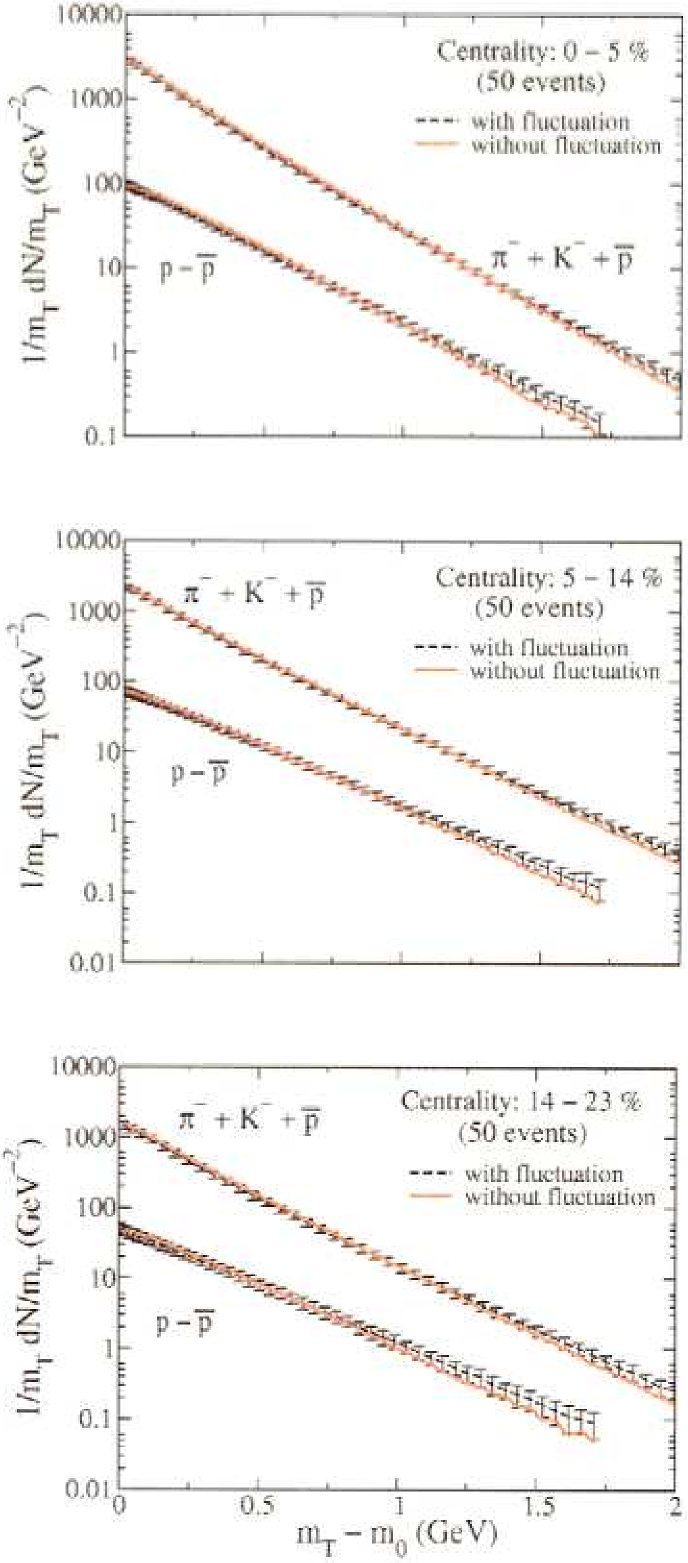
Centrality Dependence of v2 (pions; Pb+Pb; 17.3A GeV)
with fluctuation
NA49 data
without fluctuation
Preliminary
v2
Centrality
pT dependence of v2 (pions; Pb+Pb, 17.3A GeV)
with fluctuation
NA49 data
Preliminary
v2
pT (GeV)
pT dependence of v2 (protons; Pb+Pb, 17.3A GeV)
with fluctuation
NA49 data
Preliminary
v2
pT (GeV)


Fig. 5

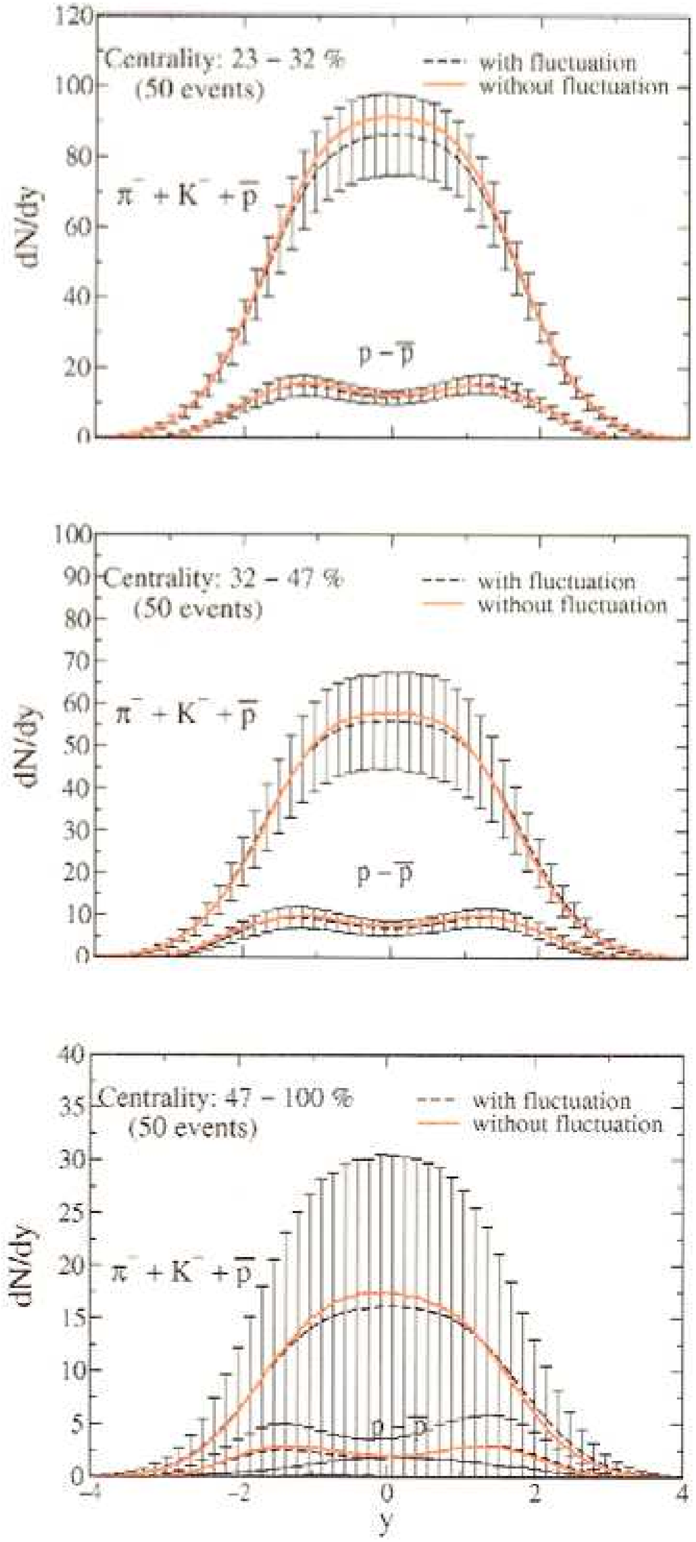
# Transverse Mass Distributions (Pb+Pb, 17.3A GeV)



# Transverse Mass Distributions (Pb+Pb, 17.3A GeV)



# Rapidity Distributions (Pb+Pb, 17.3A GeV)



# Conclusions and outlook

The effects of the event-by-event fluctuation of the initial conditions in hydrodynamics are large and should be considered in data analyses .

We emphasize that such fluctuations are not only due to the uncontrollable event-dependent impact-parameter fluctuation, but they appear even if the impact-parameter could be fixed and are due to the finite size of our systems.

In the present work, many important factors have not been considered : strangeness conservation, continuous emission effects, spectators, etc.

Also, there are many other observables : spectra for different species, correlations, etc.

We are working on some of them and will continue to work on the others.

# References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