MULTIPLICITY FLUCTUATIONS IN RELATIVISTIC HEAVY ION COLLISIONS

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for NA49 Collaboration

OUTLINE

1. Introduction
2. NA49 Experiment & Data Sets
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4. The Results:
    a) Pb+Pb minimum bias collisions at 158 AGeV
    b) p+p and central C+C, Si+Si collisions at 158 AGeV
5. Interpretation
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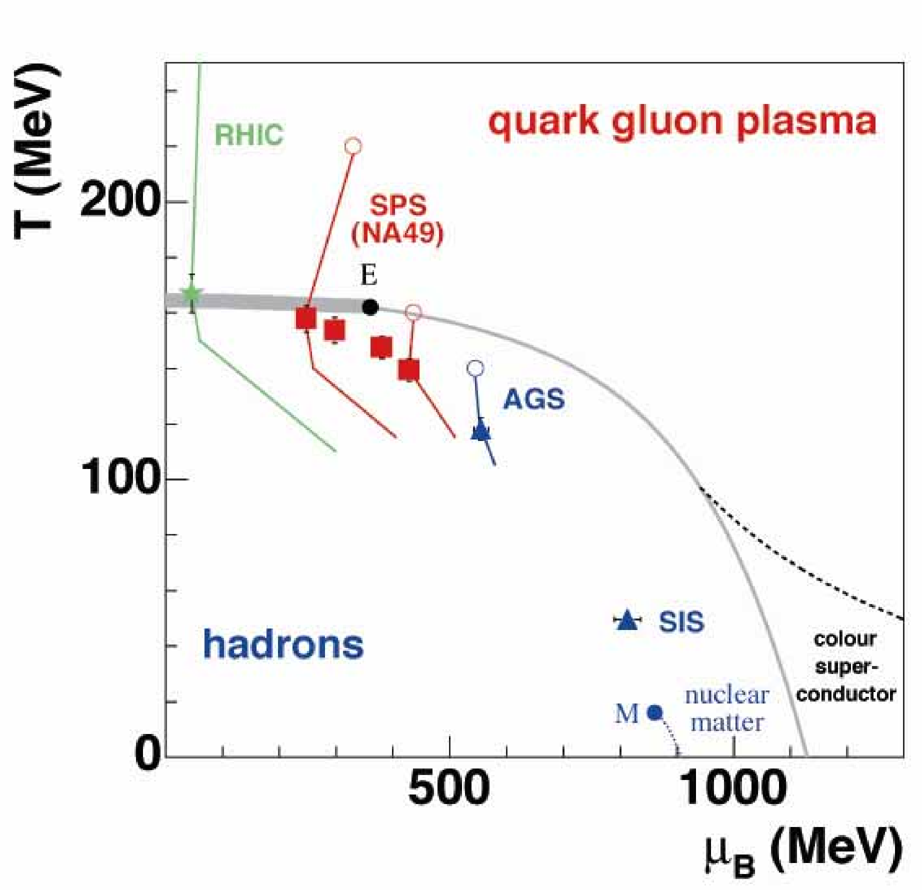
INTRODUCTION

SEARCHING FOR QGP STATE



The transition to the QGP state is expected when the matter is:

$10\times$ denser than atomic nuclei

$10^5\times$ hotter than interior of the Sun

$$T \sim 150\, MeV \quad \left(1\, eV \sim 10^4\, K\right)$$

$$\varepsilon \sim 1\, GeV/fm^3$$

FLUCTUATIONS AT PHASE BOUNDARIES!

OBSERVABLES

$$\langle N \rangle = \sum N \cdot P(N)$$

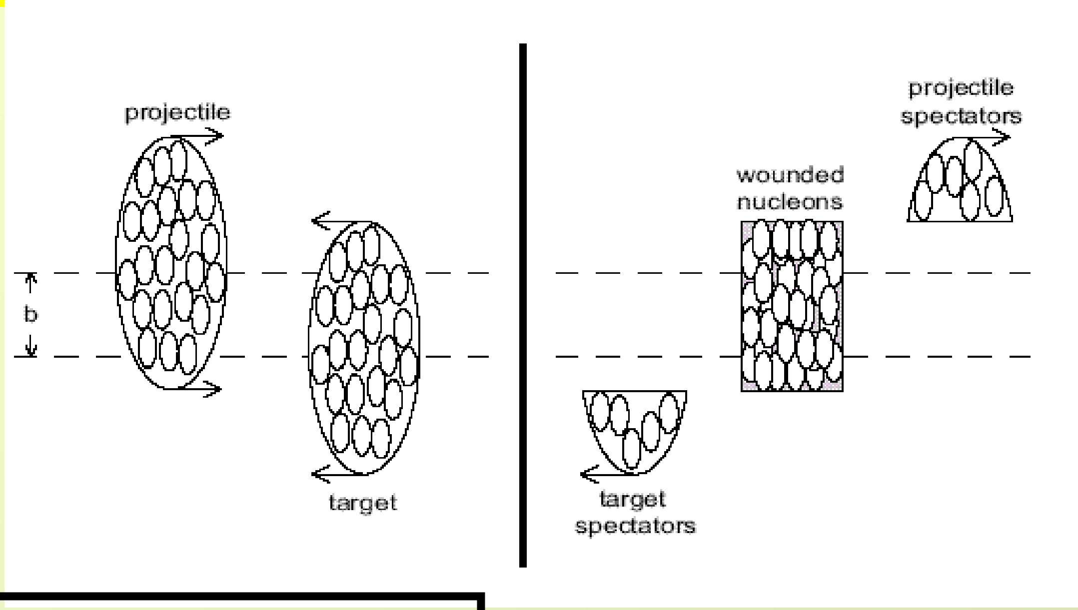
$$\langle N^2 \rangle = \sum N^2 \cdot P(N)$$

$$Var(N) = \langle N^2 \rangle - \langle N \rangle^2$$

For Poisson distribution:

$$P(N) = \frac{\langle N \rangle^N}{N!} \cdot e^{-\langle N \rangle} \qquad \Rightarrow \qquad Var(N) = \langle N \rangle$$

PARTICIPANTS, SPECTATORS…



CENTRAL COLLISION:

Almost all nucleons participate in collision

PERIPHERAL COLLISION:

Almost all nucleons are spectators

N_P - number of participants

$2 \cdot A - N_P$ - number of spectators

MULTIPLICITY FLUCTUATIONS IN WOUNDED NUCLEON MODEL

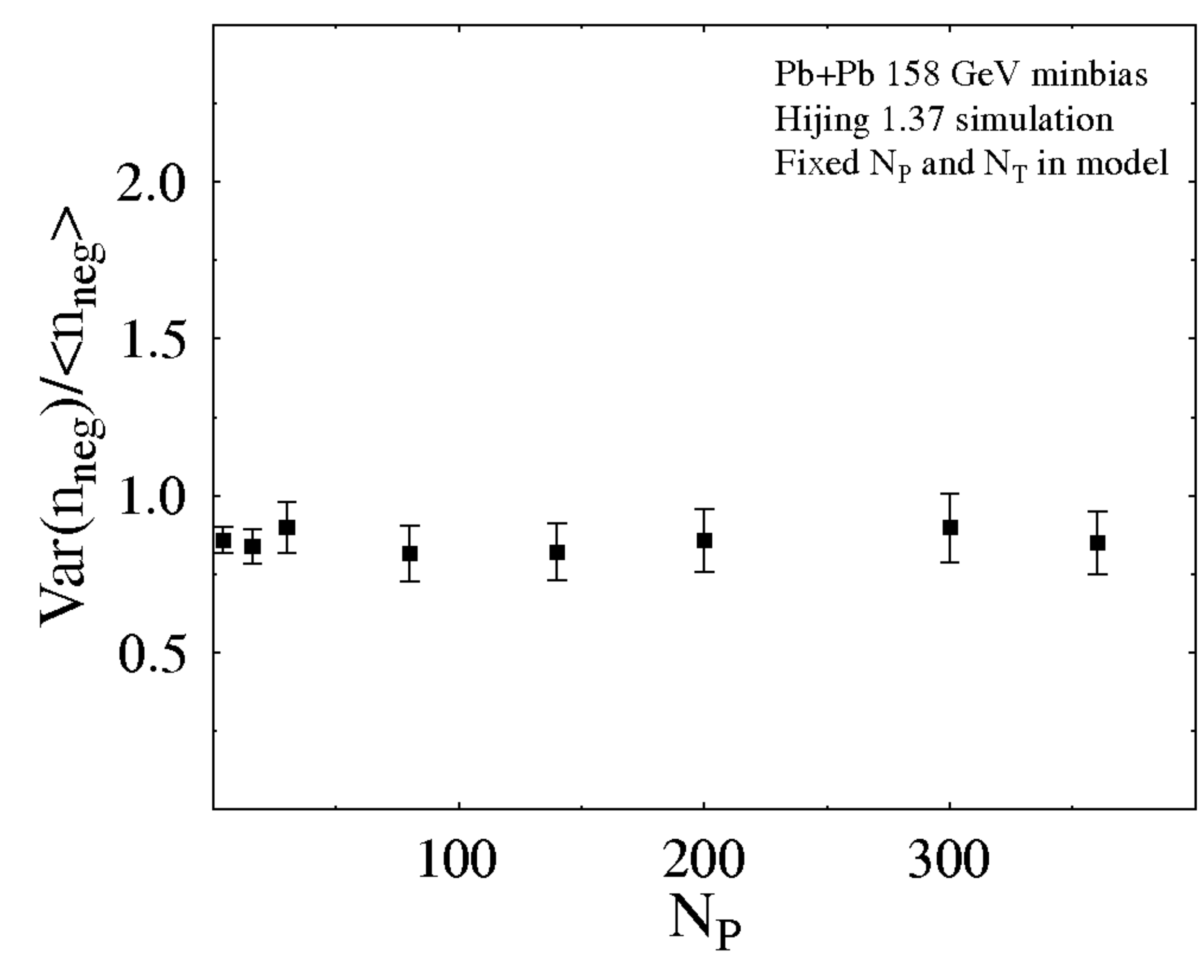
$$N = \sum_{i=1}^{N_P} n_i$$

$$\langle N \rangle = \langle N_P \rangle \cdot \langle n \rangle$$

$$Var(N) = \langle N_P \rangle \cdot Var(n) + \langle n \rangle^2 \cdot Var(N_P)$$

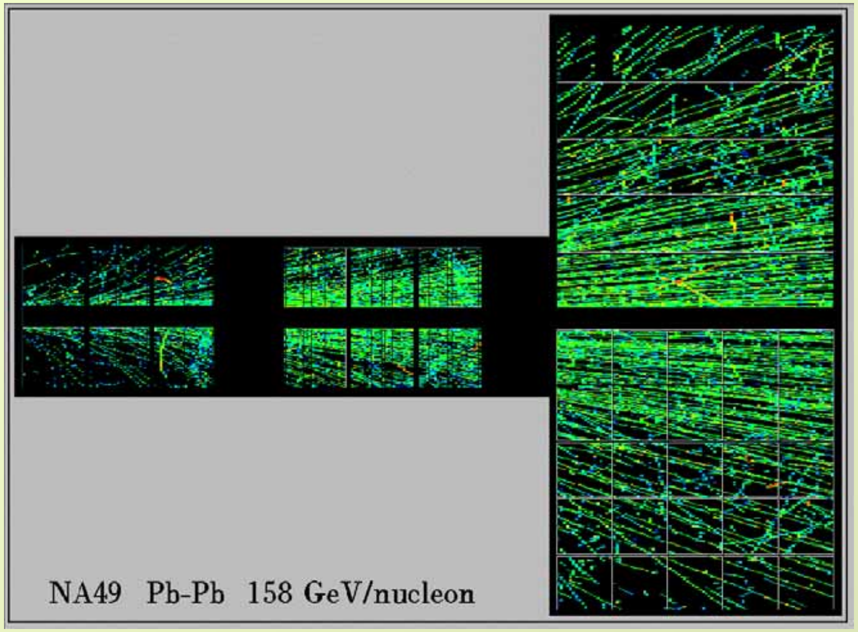
$$\frac{Var(N)}{\langle N \rangle} = \frac{Var(n)}{\langle n \rangle} + \langle n \rangle \frac{Var(N_P)}{\langle N_P \rangle}$$

STRING-HADRONIC MODEL HIJING



The number of participant nucleons can be fixed in simulation!

NA49 DETECTOR & DATA SETS

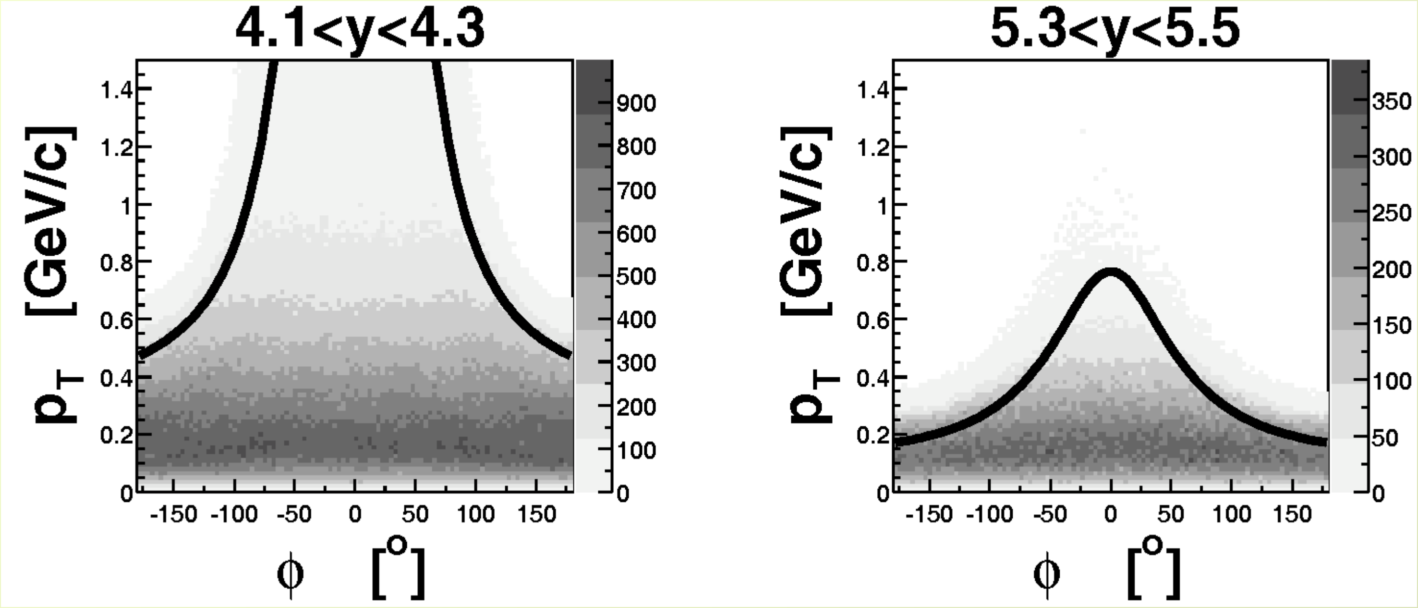


DATA SETS USED FOR THIS ANALYSIS

	No. of events
p+p	320 000
C+C	51 000
Si+Si	59 000
Pb+Pb	65 000

at 158 AGeV

EXAMPLES OF THE NA49 ACCEPTANCE



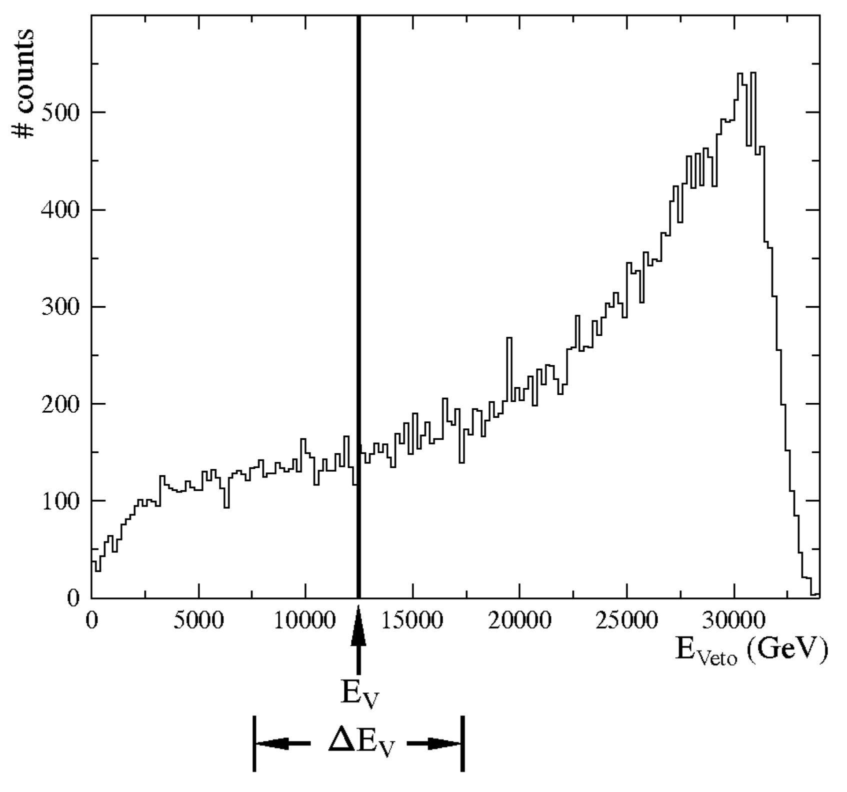
The acceptance used for the analysis:

$$4 < y < 5.5$$ *(midrapidity at y=2.9)*

$$0.005 < p_T < 1.5\, GeV/c$$

$\phi(p_T, y)$ given in hep-ex/0311009

Distribution of energy of the projectile spectators registered by the NA49 Veto Calorimeter

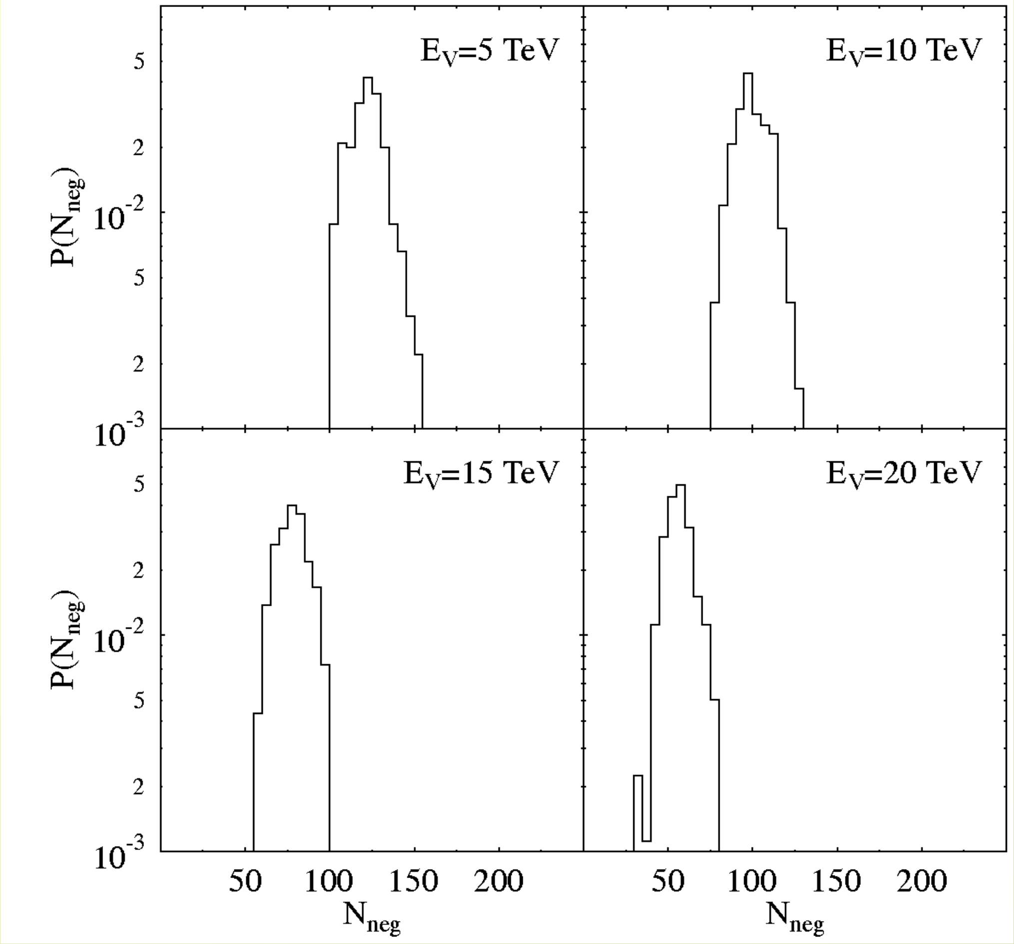


Events are selected within narrow ΔE_V intervals in E_{Veto} centered at various positions E_V

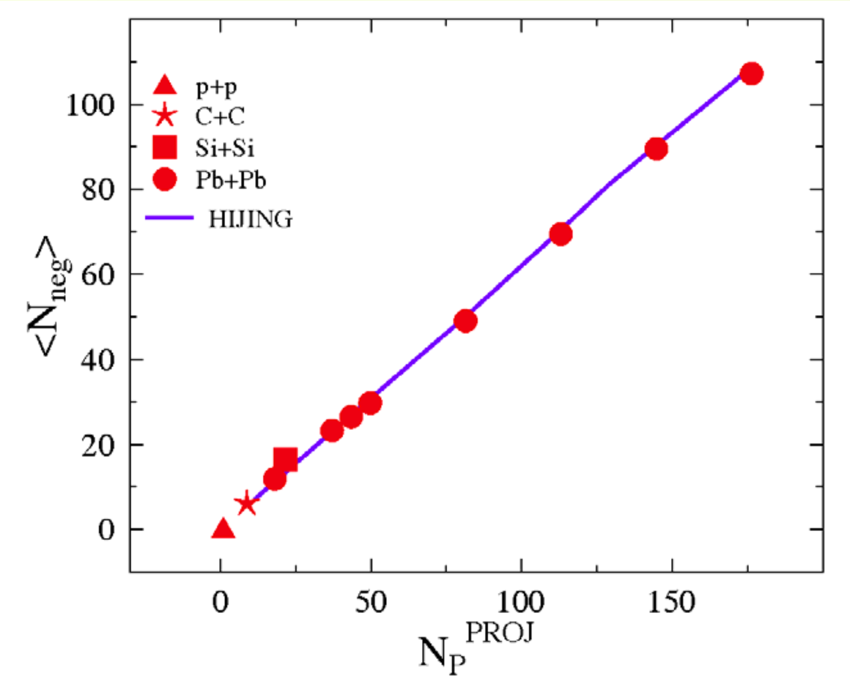
$$N_P^{PROJ} = A - \frac{E_{Veto}}{E_{LAB}}$$

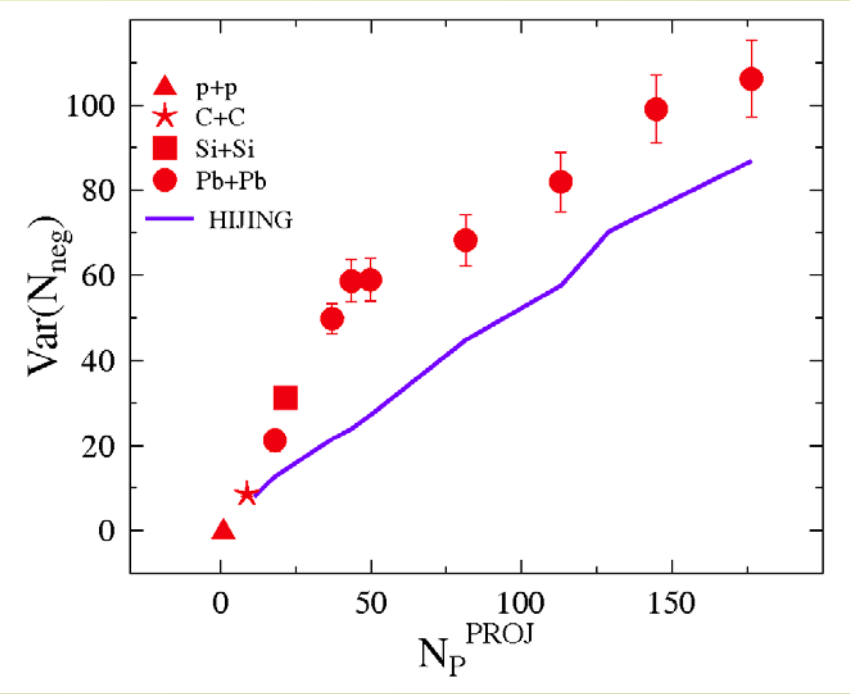
Uncorrected multiplicity distributions of negatively charged particles

Pb+Pb at 158 A GeV; $\Delta E_V = 100\ GeV$



Mean value and variance of the multiplicity distribution versus N_P^{PROJ}

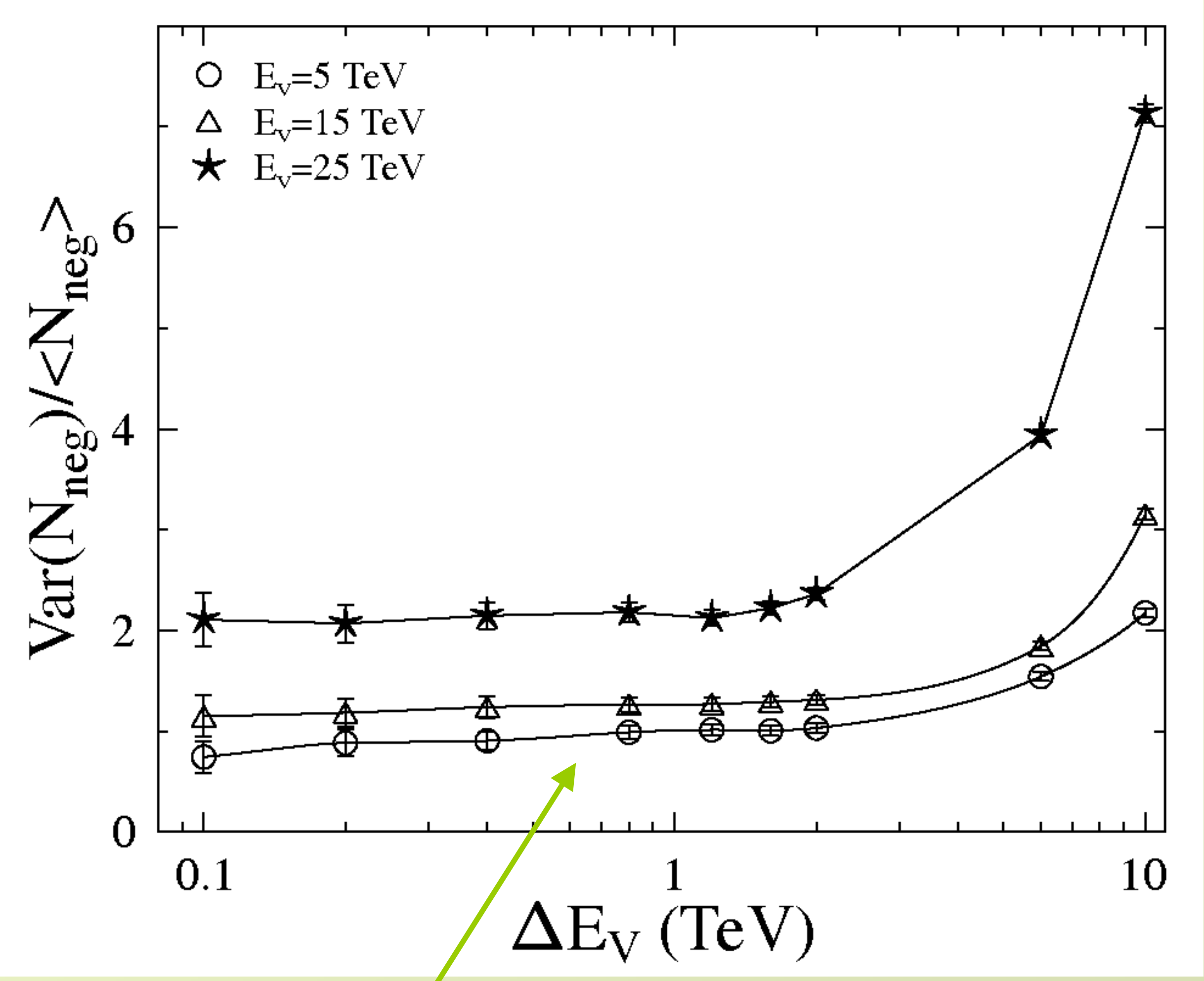




CORRECTIONS

&

SYSTEMATIC ERROR



Saturation for $\Delta E_V < 1\,TeV$

In general, the scaled variance depends on:

- interval width ΔE_V
- experimental resolution of the E_{Veto} measurement

With the superposition model the correction can be calculated as:

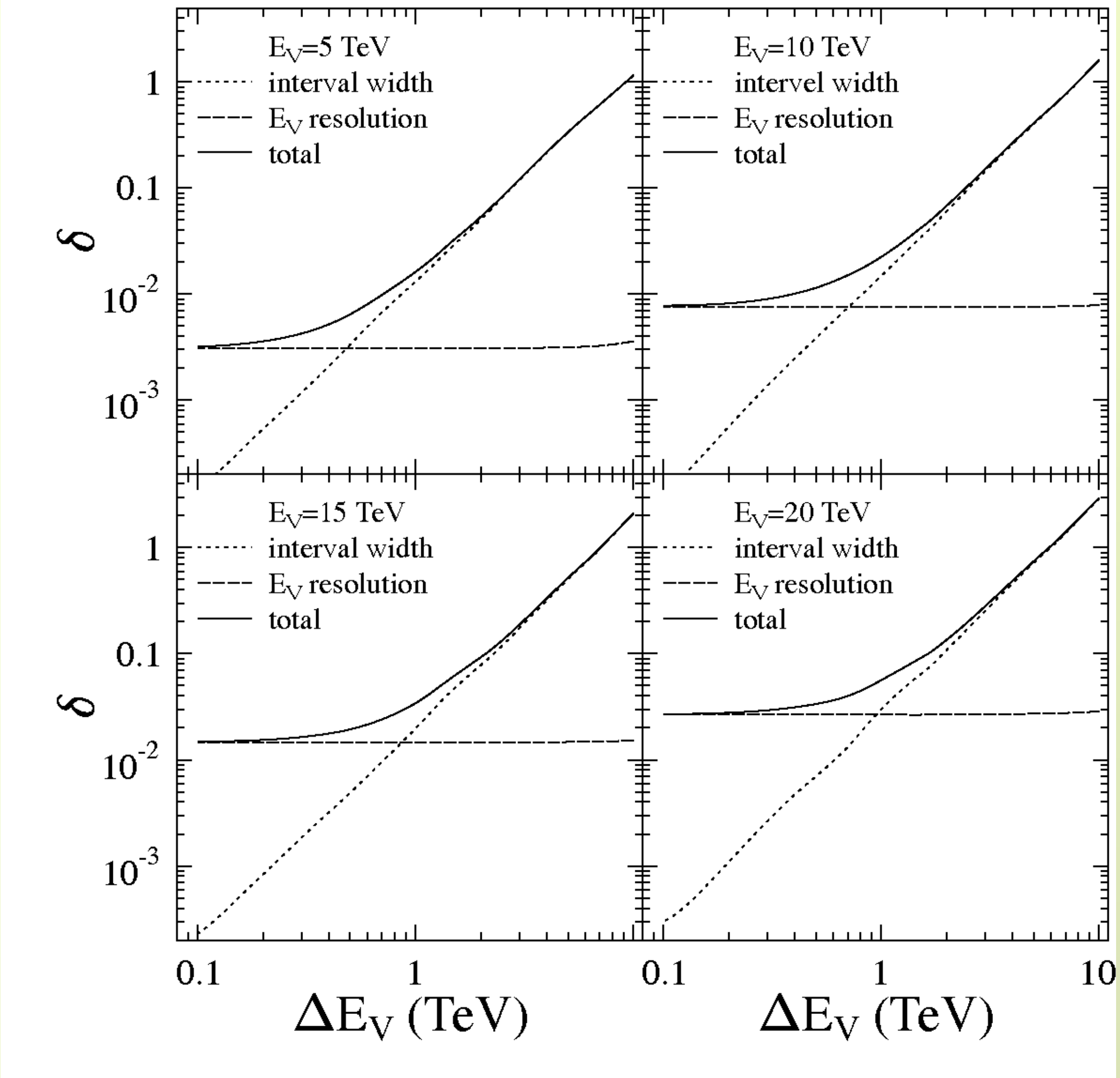
$$\delta = \frac{\langle N \rangle \cdot \left(Var_{\Delta}(E_V) + Var_R(E_V)\right)}{\left(E_{BEAM} - \langle E_V \rangle\right)^2}$$

$Var_{\Delta}(E_V)$ - variance of the E_{Veto} due to finite width of E_{Veto} bin

$Var_R(E_V)$ - variance of the E_{Veto} due to finite Veto calorimeter resolution

$\langle E_V \rangle$ - mean value of E_{Veto}

$E_{BEAM} = 158 \cdot A\,[GeV]$ - total beam energy



In order to keep the corrections small,
the final resuls are given for $\Delta E_V = 100\, GeV$

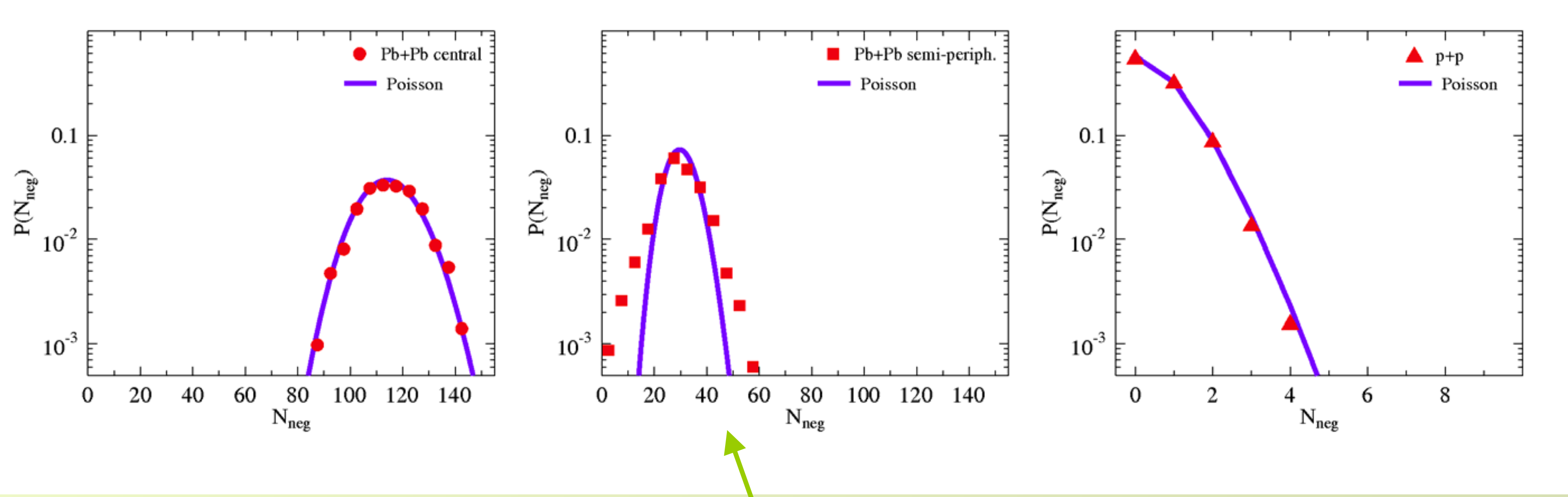
Finally the scaled variance is calculated as:

$$\frac{Var(n)}{\langle n \rangle} = \frac{Var(N)}{\langle N \rangle} - \delta$$

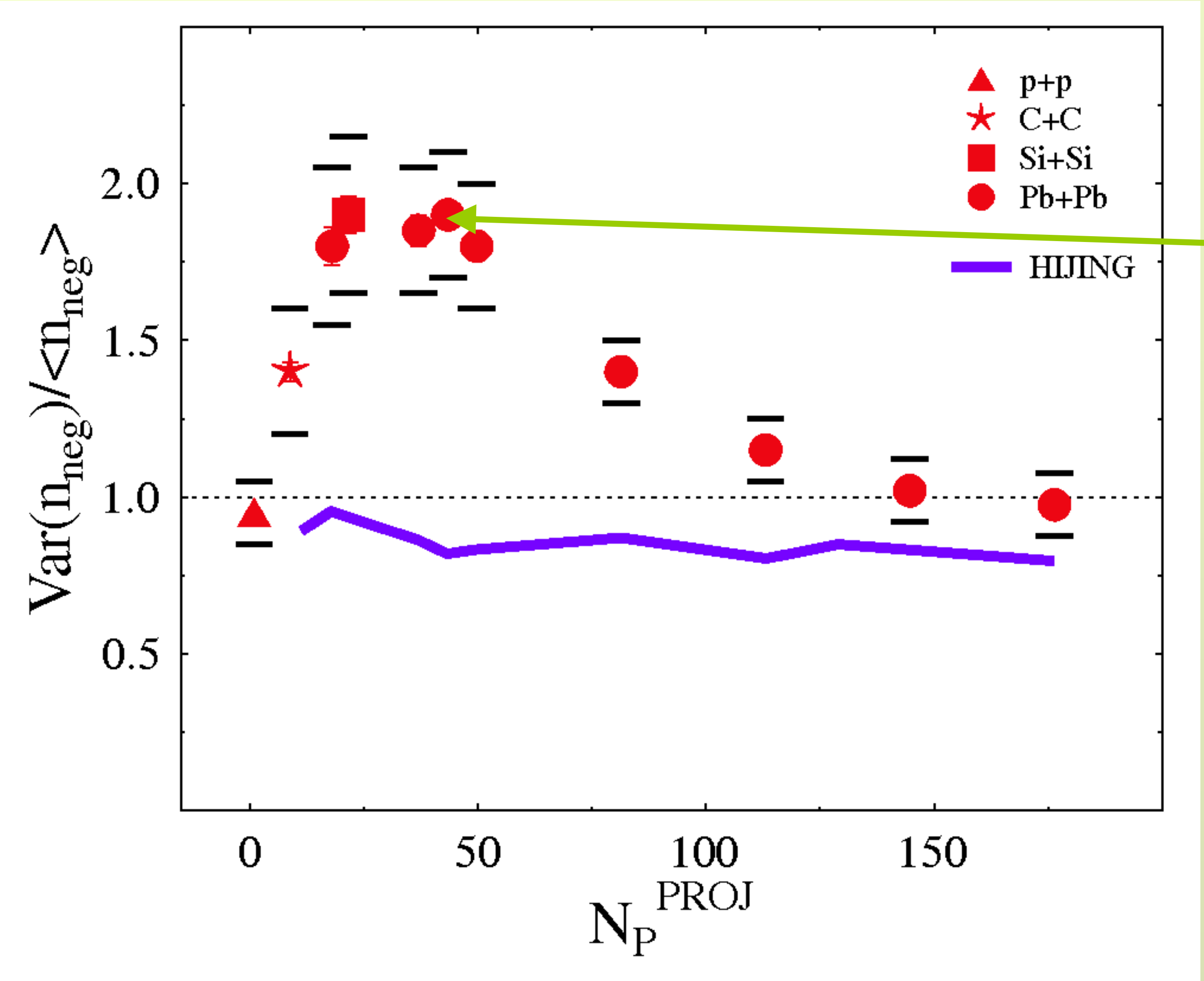
The systematic error was estimated by varying event and track selection cuts and simulations.

PRELIMINARY RESULTS

Examples of multiplicity distributions



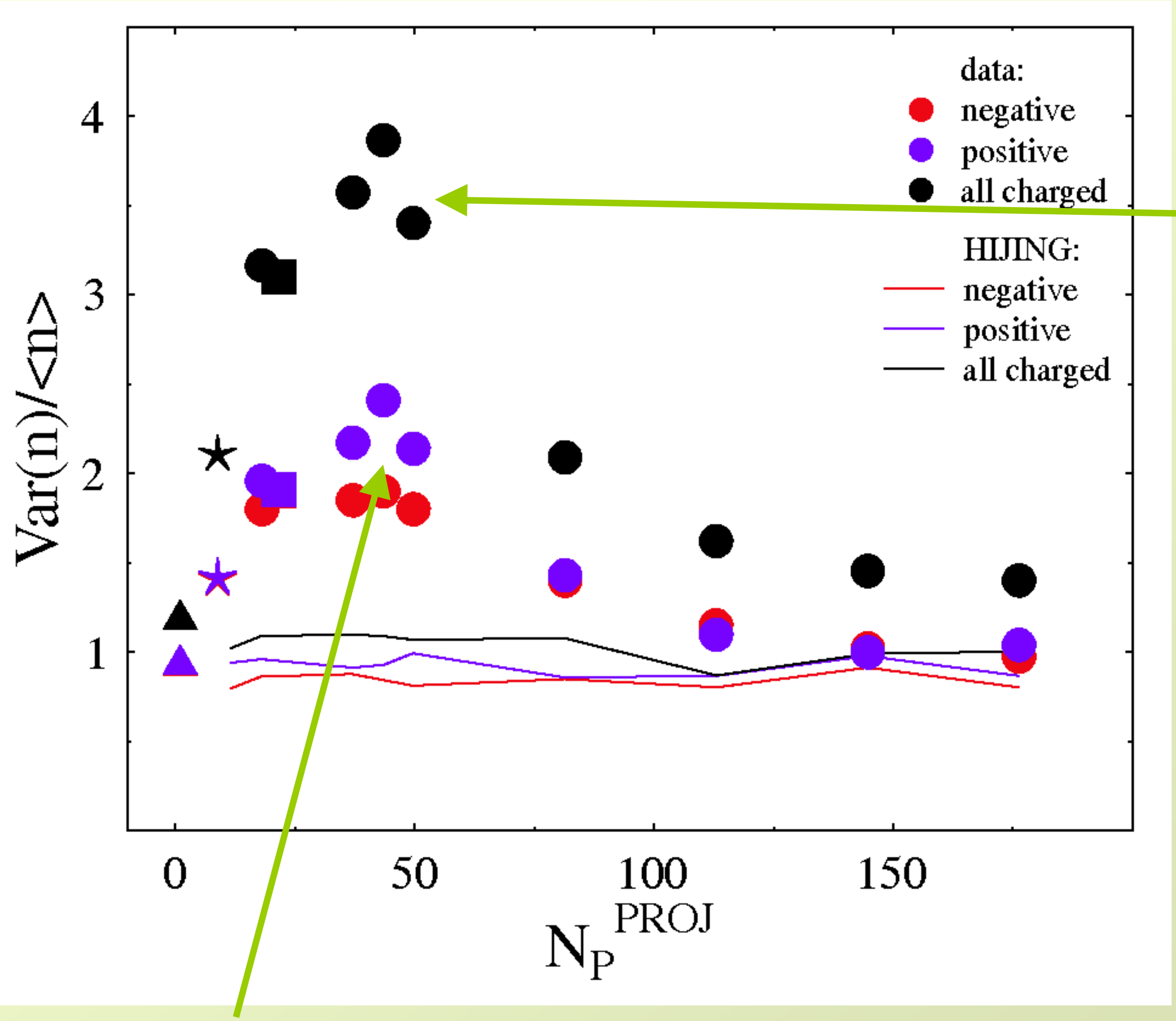
Large fluctuations for semi-peripheral Pb+Pb collisions



MAXIMUM

of fluctuations

for $N_P^{PROJ} \approx 35$



Large fluctuations for all charged particles

Similar behaviour for positively and negatively charged particles

MODELS

THERMODYNAMICAL MODEL $\longrightarrow$ POISSON DISTRIBUTION

DOES NOT WORK! $\left(Var(N)/\langle N\rangle >> 1\right)$

STRING-HADRONIC MODEL (HIJING)

DOES NOT WORK! (no system-size dependence of scaled variance)

TWO - POTENTIAL MODEL

WORKS!

ASSUMPTIONS OF THE TWO – POTENTIAL MODEL:

1. The gas of interacting particles is considered

2. The interactions are modelled via the two potentials:

   a) the attractive Yukawa-like nuclear potential at short range (1 fm)

   b) the repulsive Debye-like electrostatic potential at long range (3.5 fm)

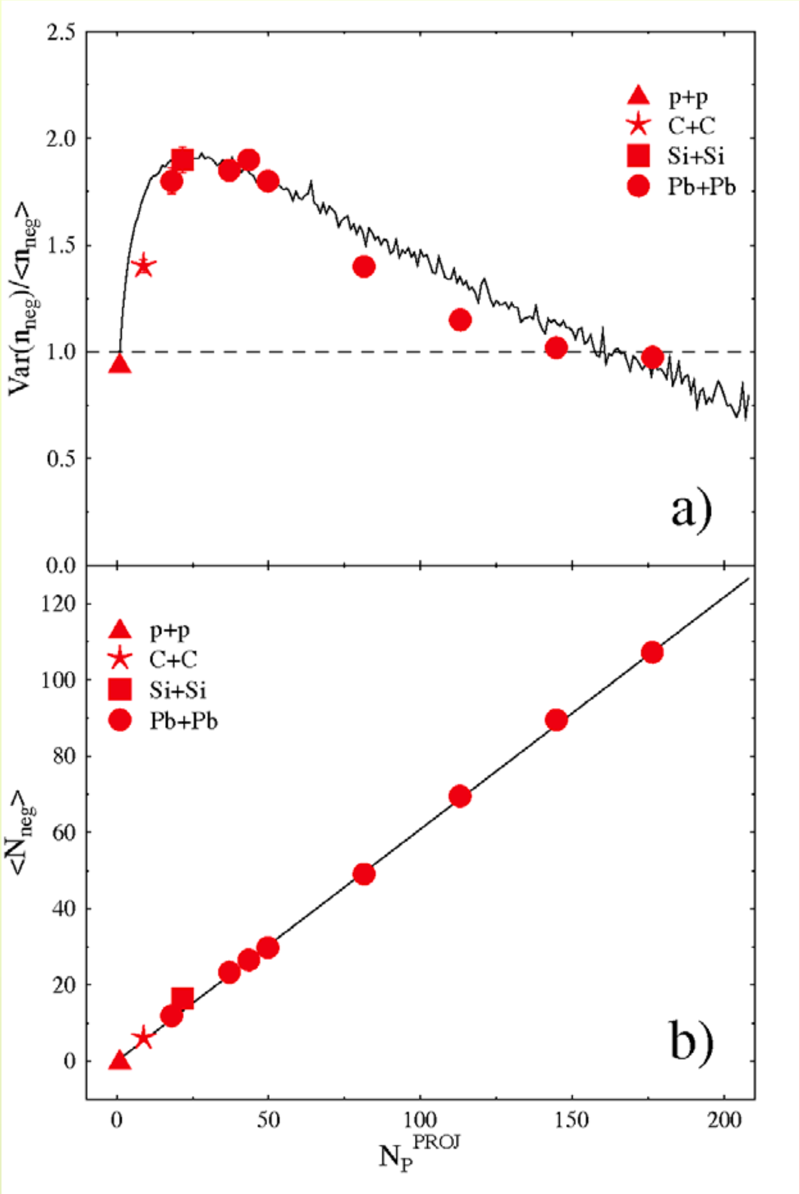
CORRELATIONS AND FLUCTUATIONS!

↓

$\nu_2(r)$ two-particle correlation function

↓

$$\frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle} = 1 + n \int_V dr\, \nu_2(r_{12})$$



$$\nu_2(r) = \exp\left(a_n \frac{\exp(-r/\lambda_n)}{r} - a_e \frac{\exp(-r/\lambda_e)}{r} \right) - 1$$

$$a_n = \beta g^2$$

$$a_e = \beta e^2 = \left(4\pi n \lambda_e^2\right)^{-1}$$

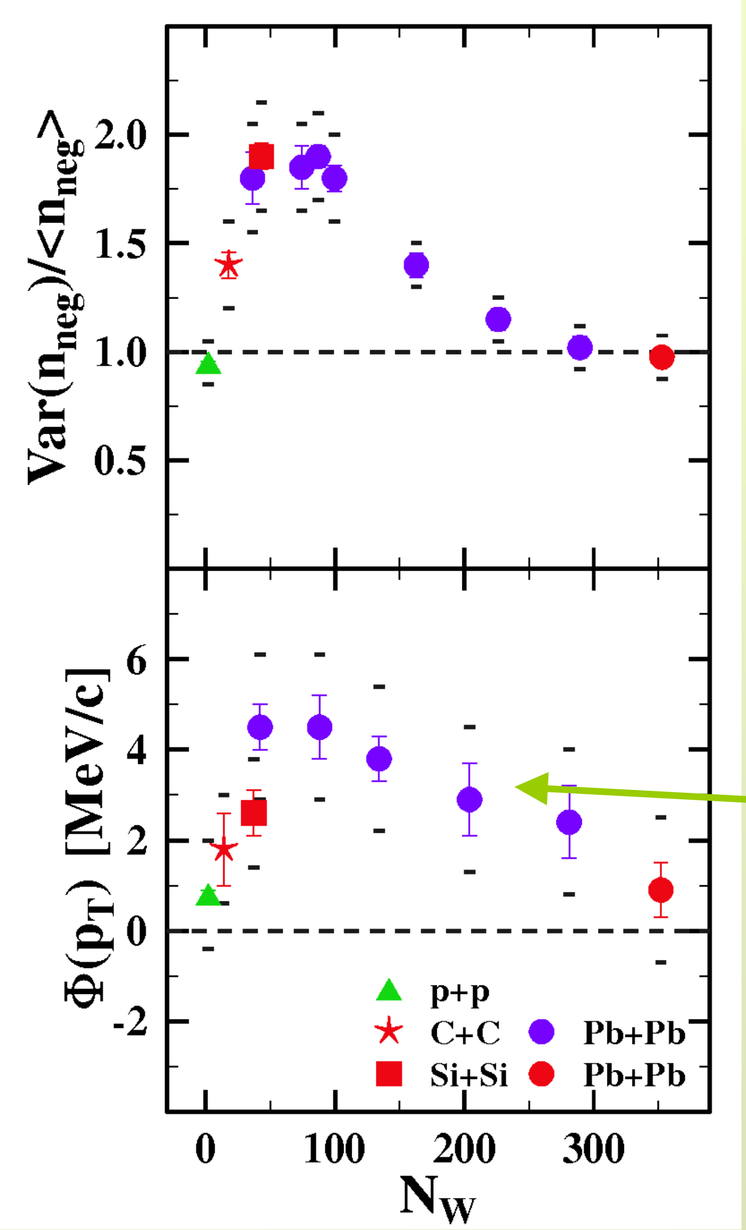
$$\lambda_n = \frac{h}{2\pi mc}$$

$$\lambda_e = \frac{1}{\sqrt{4\pi e^2 n \beta}}$$

See details in: **nucl-th/0408023**

CONNECTIONS

WITH <p_T> FLUCTUATIONS



$$\Phi(p_T) = \sqrt{\frac{\overline{Z^2}}{\langle N \rangle}} - \sqrt{\overline{z^2}}$$

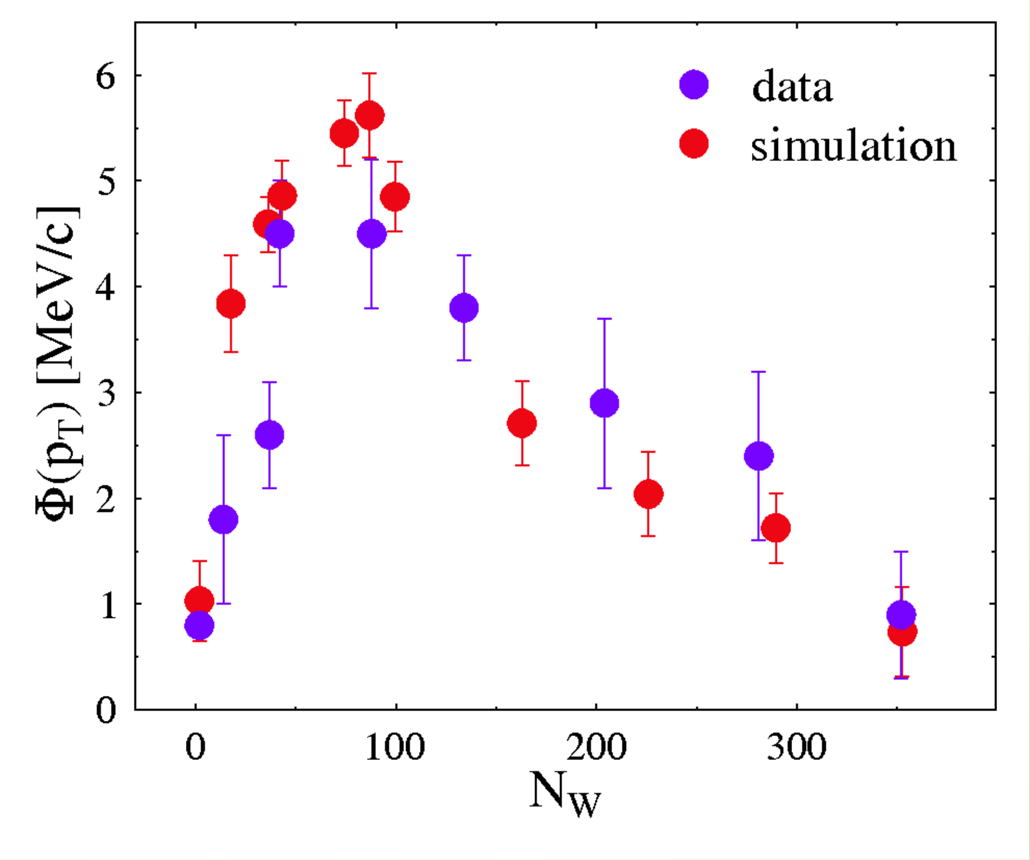
$$z = p_T - \langle p_T \rangle$$

$$Z = \sum_{i=1}^{N} z_i$$

Details in:

Phys. Rev. C 70 (2004) 034902

$\Phi(p_T)$ as a function of number of wounded nucleons.



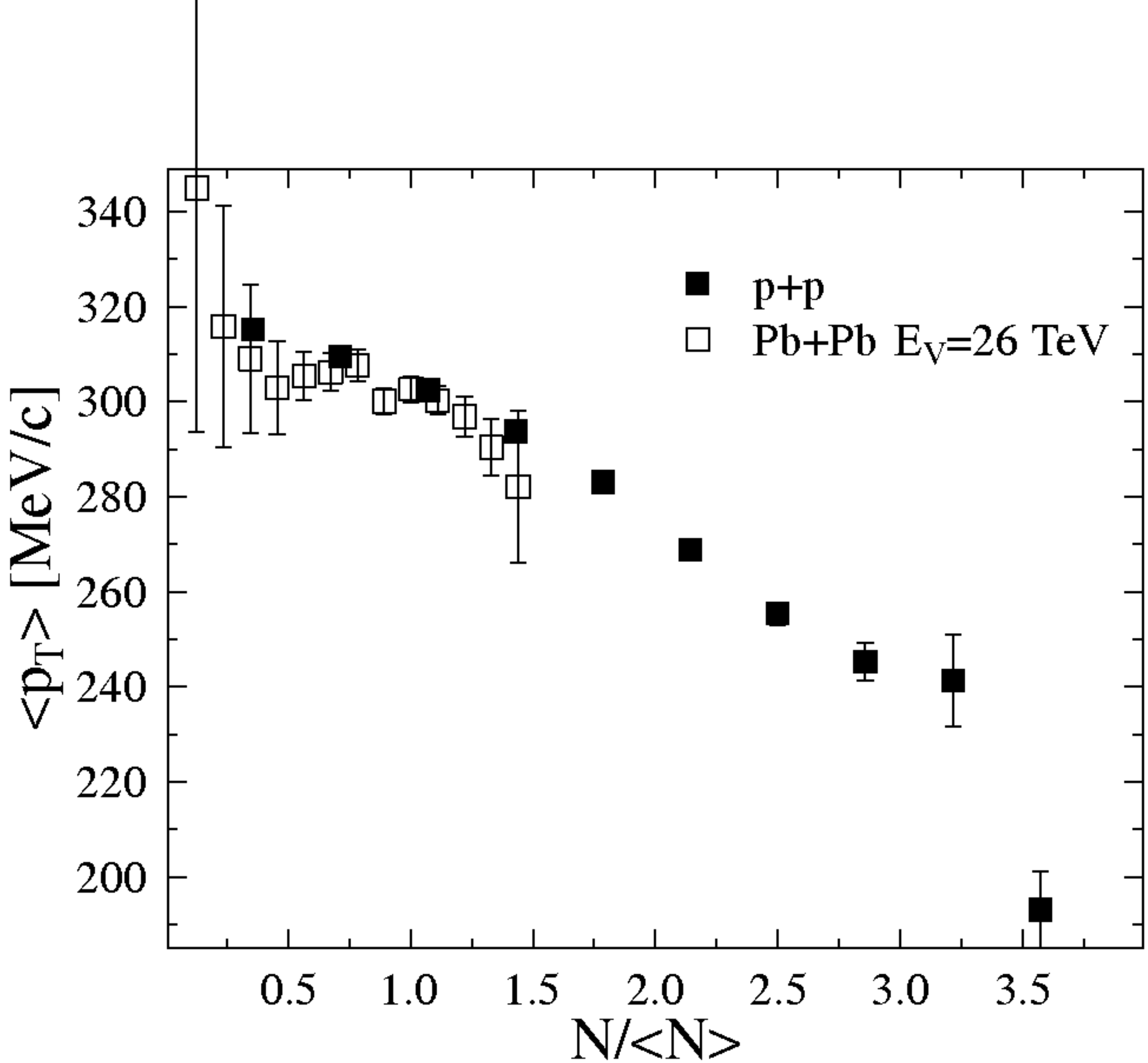
Simulation:

- Var(N)/<N> from the data
- <p_T> vs N/<N> as in p+p

See details in: **nucl-th/0407012**

SUMMARY

- Multiplicity fluctuations in p+p, C+C, Si+Si and Pb+Pb collisions at 158 AGeV were studied
- Non-monotonic system-size dependence of the scaled variance is observed with maximum at $N_P^{PROJ} \approx 35$
- The behaviour of the scaled variance is similar for both positively and negatively charged particles
- Much larger scaled variance value for all charged particles than for like-sign particles is observed
- **THERE IS A POSSIBLE INTERPRETATION OF THE NON-MONOTONIC BEHAVIOUR OF THE SCALED VARIANCE VIA THE TWO-POTENTIAL MODEL**



p+p
Pb+Pb E_V=26 TeV
$\langle p_T \rangle$ [MeV/c]
340
320
300
280
260
240
220
200
0.5
1.0
1.5
2.0
2.5
3.0
3.5
N/<N>

$$\int_V d^3r_1 \int_V d^3r_2\, \nu_2\left(\left|r_1 - r_2\right|\right) = \left\langle \nu_2\left(r_{12}\right)\right\rangle \cdot V^2$$

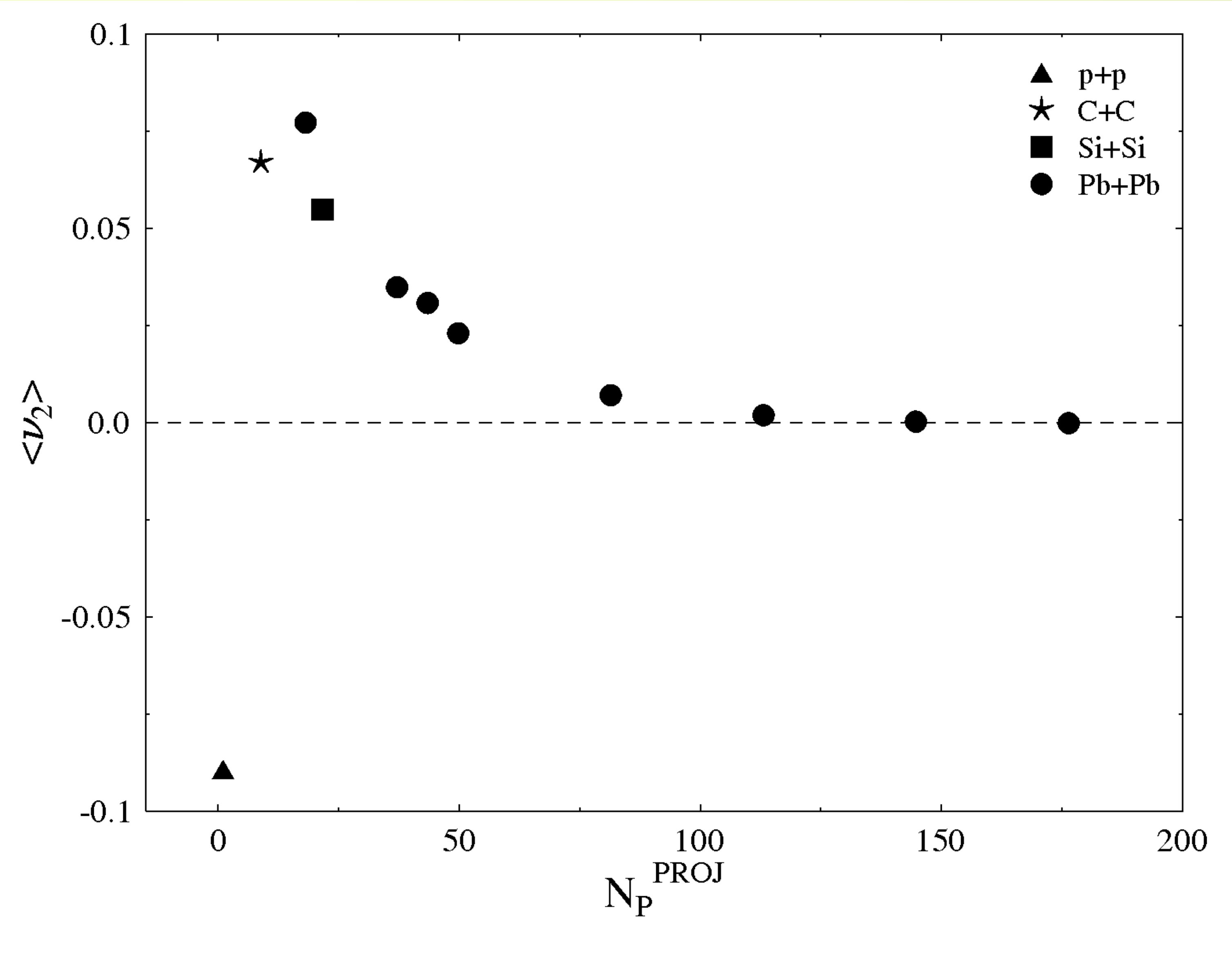
$$\frac{Var(N)}{\langle N \rangle} = 1 + nV\langle \nu_2 \rangle$$

$$\langle \nu_2 \rangle = \frac{\left(\frac{Var(N)}{\langle N \rangle} - 1\right)}{\langle N \rangle}$$

$\langle \nu_2 \rangle$ **is independent from detector's acceptation p**

$$\frac{Var(N)}{\langle N \rangle} = (1 - p) + p\frac{Var\left(N_{p=1}\right)}{\langle N_{p=1} \rangle}$$

$$\langle N \rangle = p \cdot \langle N_{p=1} \rangle$$



Mean value of the two-particle correlation function versus number of projectile participants for negatively charged particles produced in collisions at 158 AGeV.