Fluctuation Results from PHENIX

Correlation and Fluctuations in Relativistic Nuclear Collisions Workshop – 4/22/05

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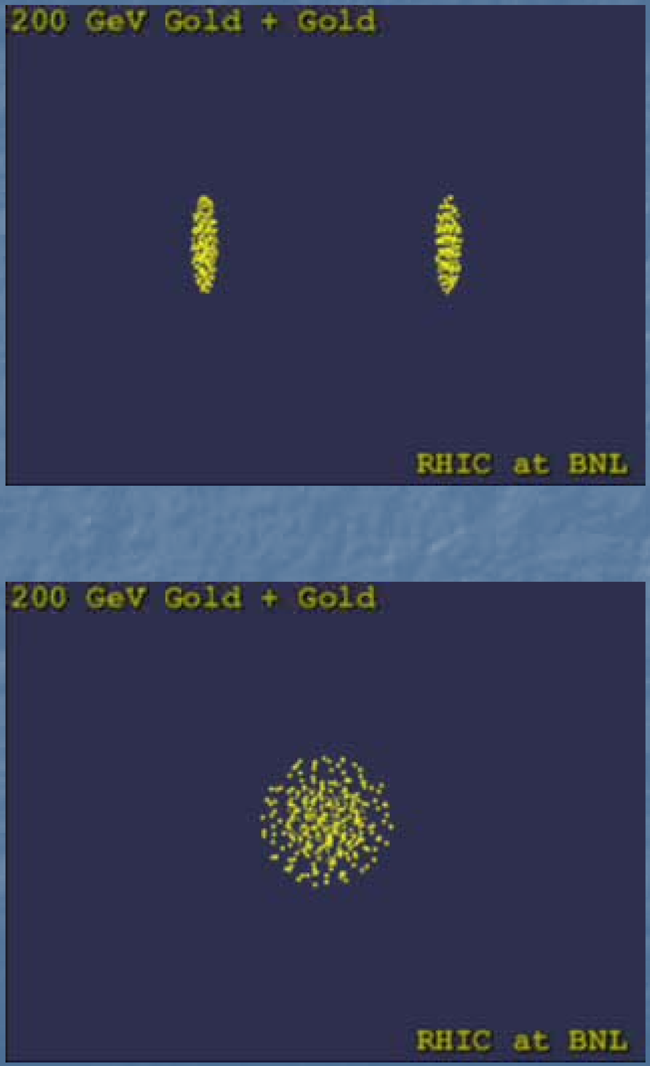
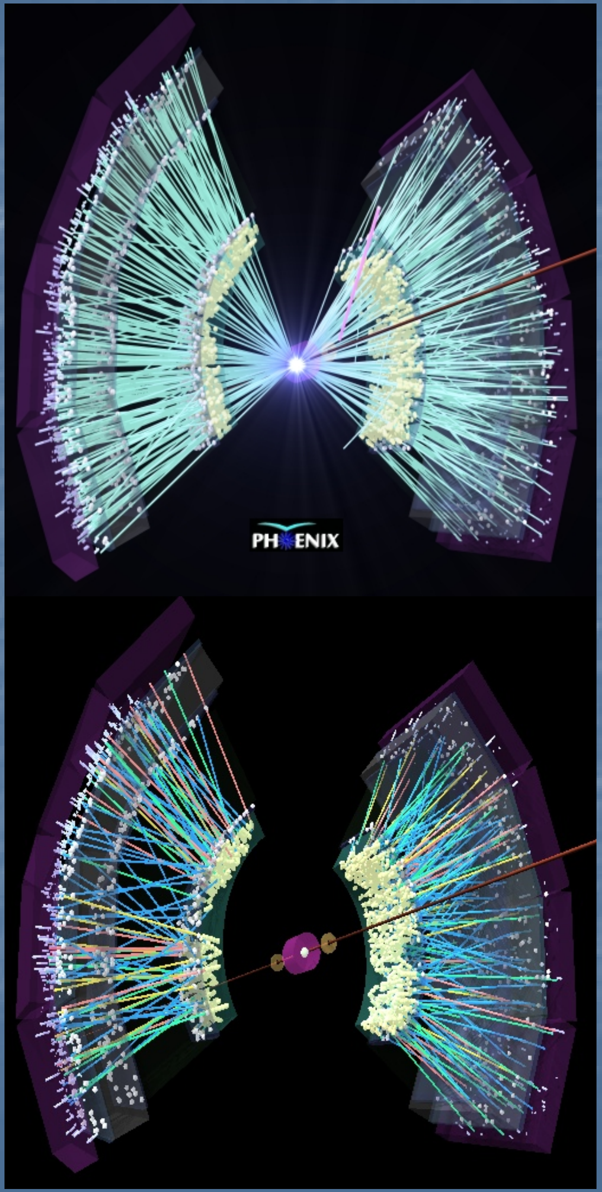
Outline

- **Charge Fluctuations**
- **$<p_T>$ Fluctuations**
- **Multiplicity Fluctuations**

The PHENIX Dataset: Au + Au

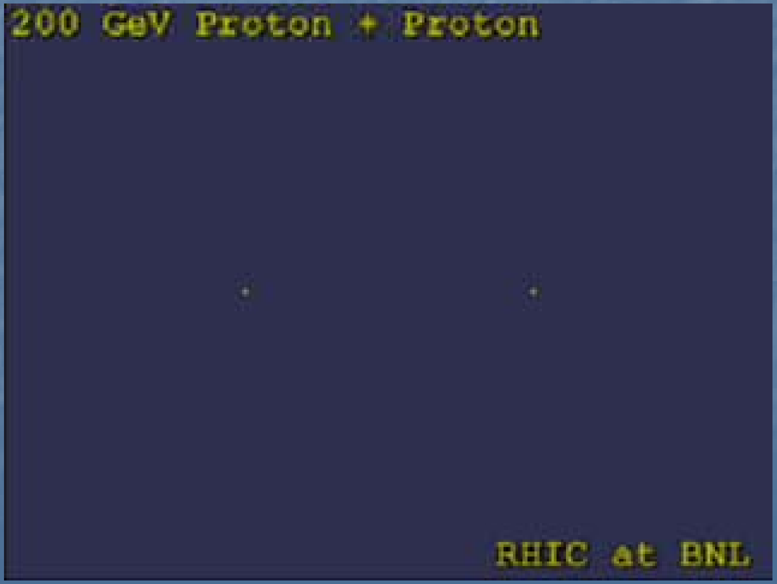


200 GeV Au+Au: RHIC Run-2 and Run-4



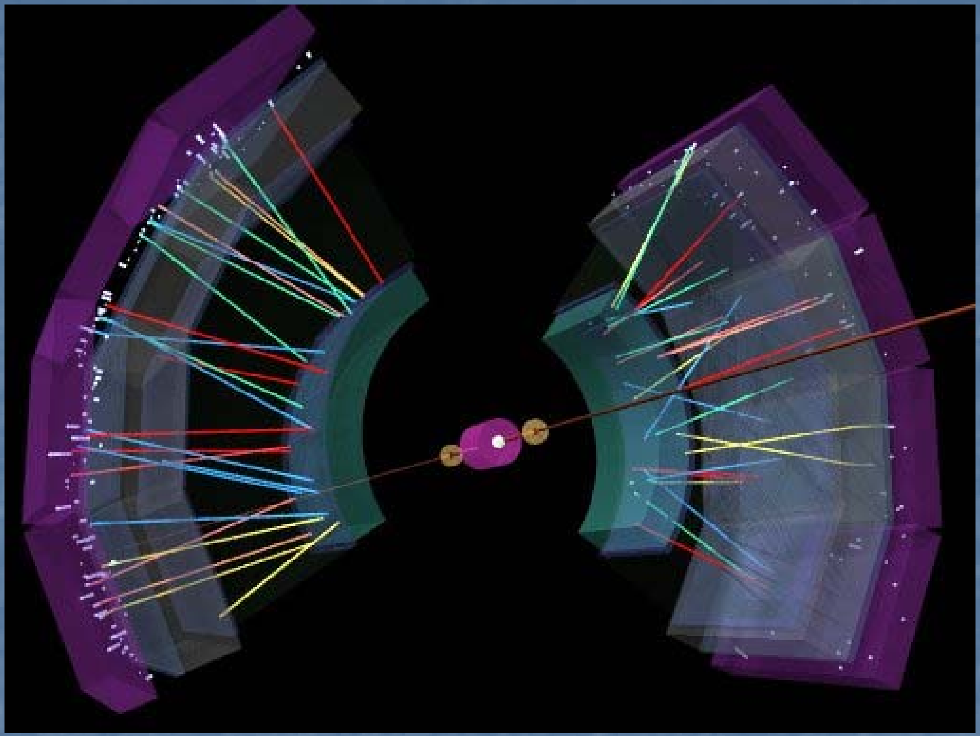
The PHENIX Dataset: p+p, d+Au

200 GeV d+Au: RHIC Run-3



200 GeV p+p: RHIC Run-2+

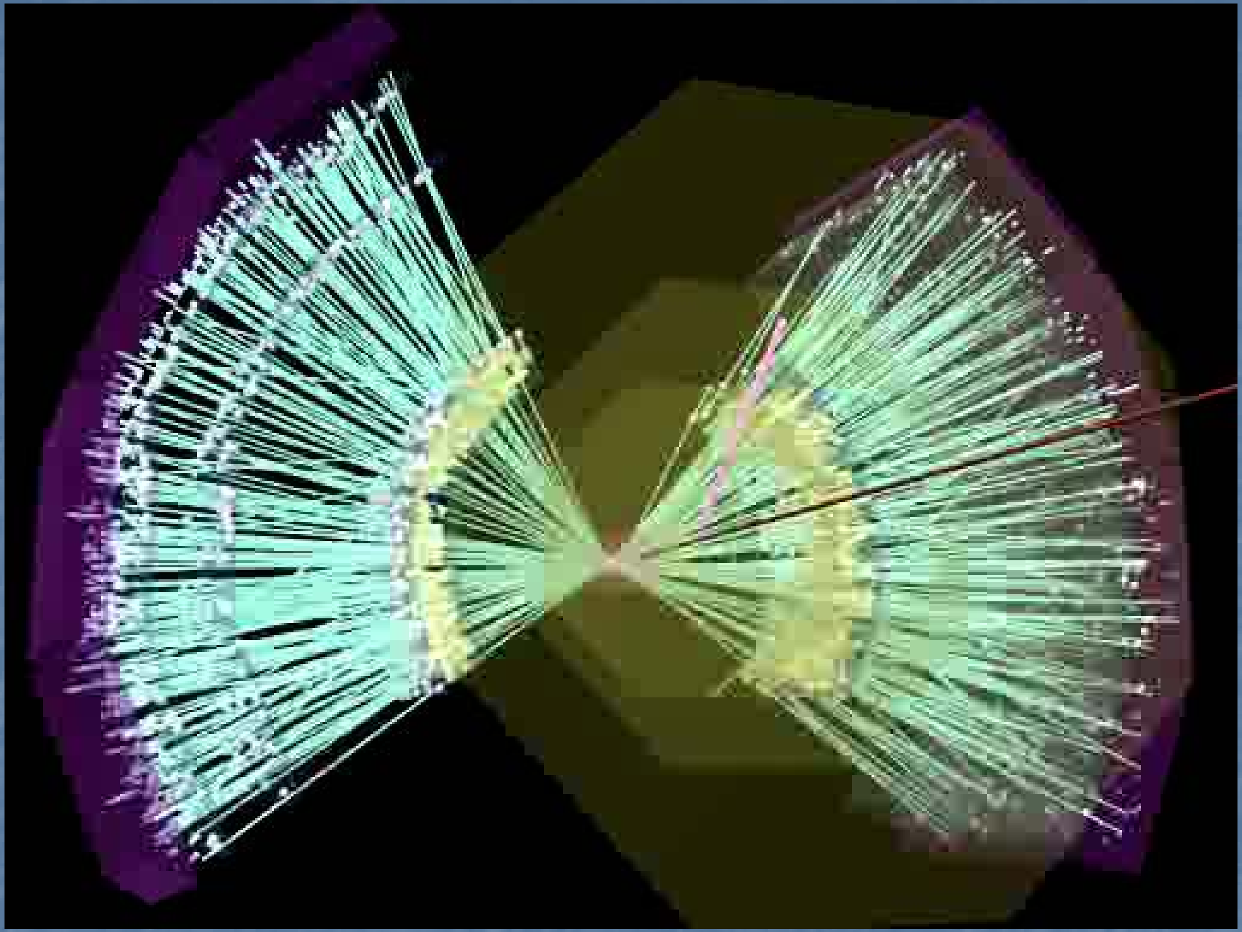
The PHENIX Dataset: Cu+Cu



62 GeV Au+Au: RHIC Run-4

200, 62, 19 GeV Cu+Cu: RHIC Run-5

The PHENIX Detector



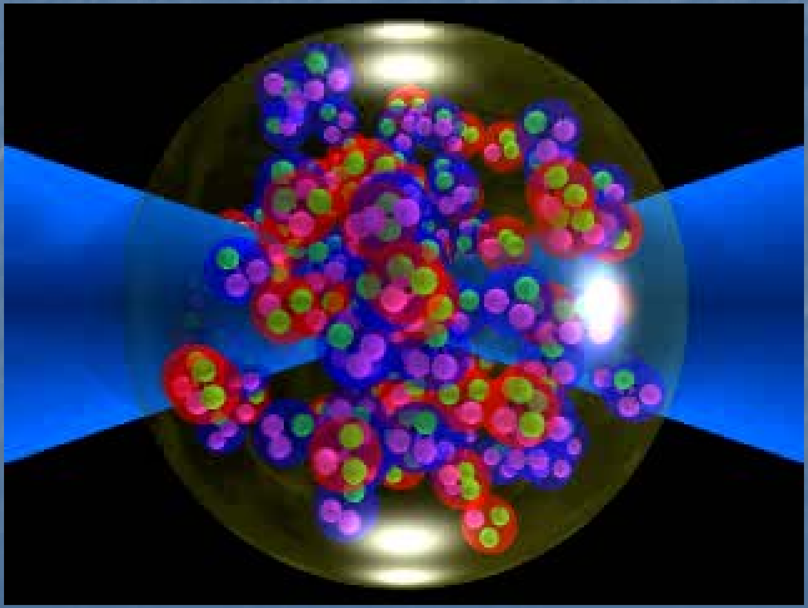
Although the PHENIX acceptance is traditionally considered small for event-by-event measurements, the acceptance is large enough to provide a competitive sensitivity to most observables.

Charge Fluctuations

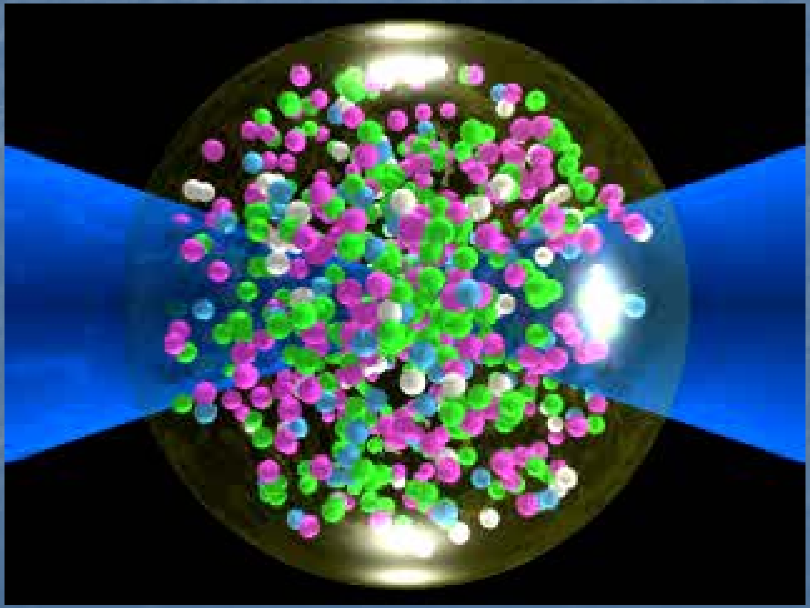
Hypothesis: Fluctuations in net charge and net baryon number may be significantly reduced if a QGP is formed in the collisions

Asakawa, Heinz, Müller PRL 85(2000)2072; Jeon & Koch PRL 85(2000)2076

Fractional electric charges of the quarks ==>
Charges more evenly spread in a plasma ==> Reduced net charge fluctuations in a small region of phase-space



Hadron Gas Scenario



Quark-Gluon Plasma Scenario

Summary of Charge Fluctuation Measures

$$Variance\left\langle \delta X^2 \right\rangle = \left\langle X^2 \right\rangle - \left\langle X \right\rangle^2$$

$$R = \frac{\langle N_+ \rangle}{\langle N_- \rangle}$$

$$v(Q) \equiv \left\langle \delta Q^2 \right\rangle / \left\langle N_{CH} \right\rangle$$

PHENIX

$$N_{CH} = N_+ + N_-$$

$$Q = N_+ - N_-$$

STAR

$$D \equiv \langle N_{ch} \rangle \langle \delta R^2 \rangle = 4 \frac{\langle \delta Q^2 \rangle}{\langle N_{CH} \rangle}$$

$$v(Q) \approx 1 + \frac{\langle N_+ + N_- \rangle}{4} \nu_{+-,dyn}$$

$$D \approx 4 + \langle N_+ + N_- \rangle \nu_{+-,dyn}$$

$$D = 4v(Q)$$

$$\Phi_q \approx \frac{\langle N_+ \rangle^{3/2} \langle N_- \rangle^{3/2}}{\langle N_{CH} \rangle^2} \nu_{+-,dyn}$$

$$\Gamma = v(Q)$$

$$\nu_{+-,dyn} = \nu_{+-} - \nu_{+-,stat}$$

$$\nu_{+-} = \left\langle \left(\frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 \right\rangle$$

$$\nu_{+-,stat} = \frac{1}{\langle N_+ \rangle} + \frac{1}{\langle N_- \rangle}$$

$$\overline{z^2} = 4 \frac{\langle N_+ \rangle \langle N_- \rangle}{\langle N_{CH}{}^2 \rangle}$$

$$Z = Q - \frac{\langle Q \rangle}{\langle N_{CH} \rangle} N_{CH}$$

NA49

$$\Phi_q = \sqrt{\frac{\langle Z^2 \rangle}{\langle N_{CH} \rangle}} - \sqrt{\overline{z^2}}$$

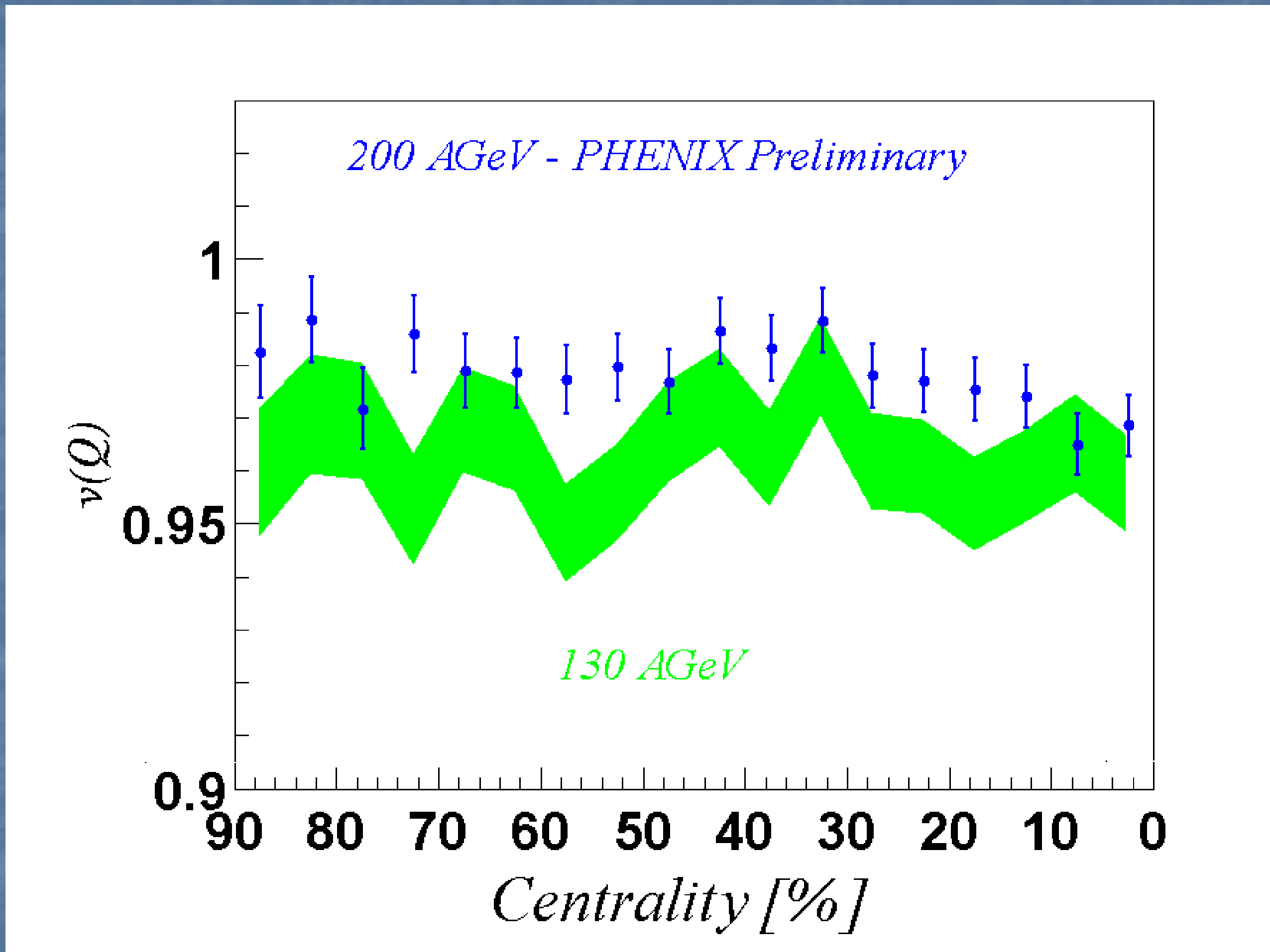
Quoted in this presentation

$$\Gamma \equiv \frac{1}{\langle N_{CH} \rangle} \left\langle \left(Q - \frac{\langle Q \rangle}{\langle N_{CH} \rangle} N_{CH} \right)^2 \right\rangle$$

Charge Fluctuation Magnitude Expectations

	v(Q)	D	$\nu_{+-,dyn}$ (STAR)	$\nu_{+-,dyn}$ (PHENIX)	Φ_q (NA49)
Independent Particle Emission	1.0	4.0	0.0	0.0	0.0
Resonance Gas	0.75	3.0	-0.0013	-0.006	-0.125
Quark-Gluon Plasma	0.25	1.0	-0.0038	-0.019	-0.375
Quark Coalescence	0.83	3.33	-0.0008	-0.004	-0.084

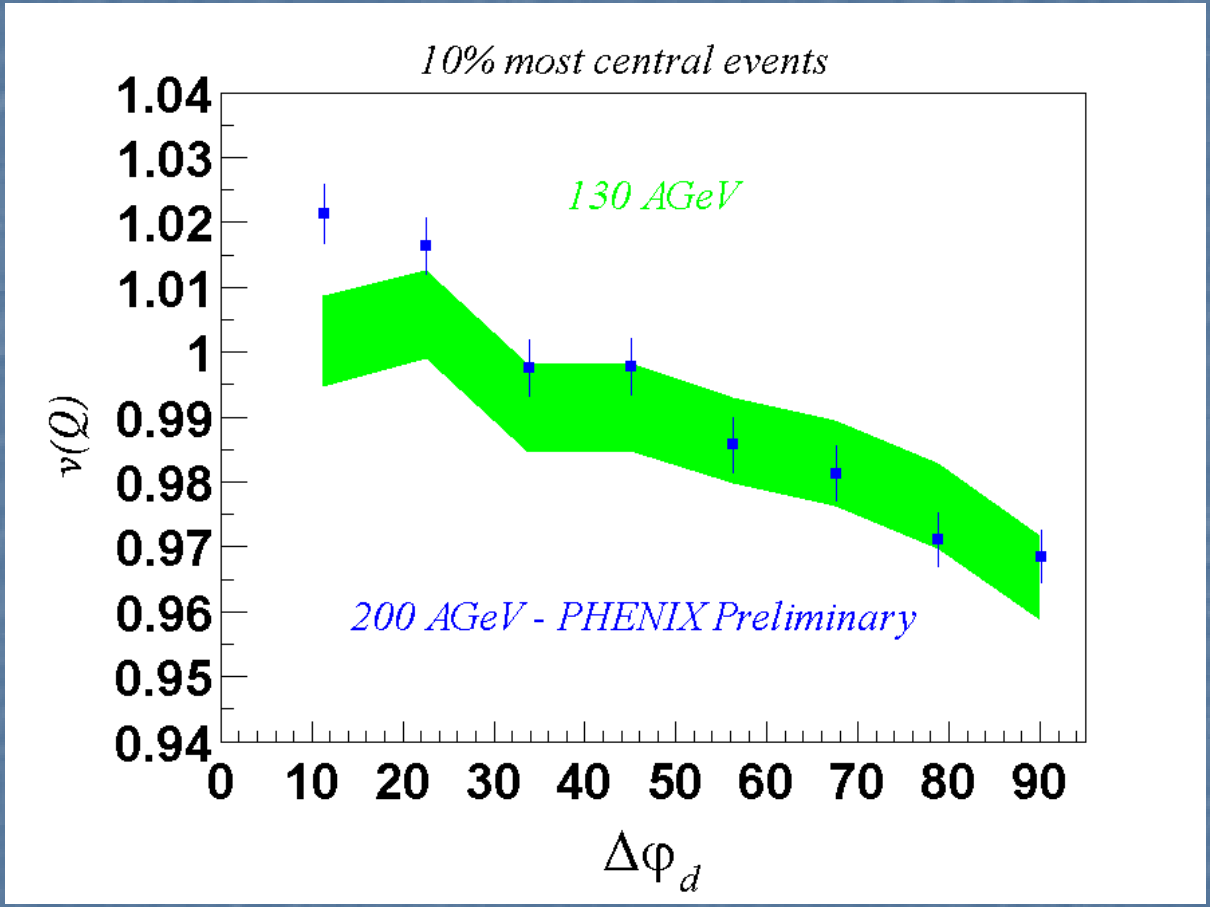
v(Q) as a function of centrality



$|\eta| \leq 0.35$, $\Delta\varphi=\pi/2$,
$0.3 \leq p_T \leq 2.0$ GeV/c

No dramatic change at 200 GeV - the upward shift of ~0.01 units can be explained by harder track quality cuts leading to a reduced acceptance.

v(Q) as a function of azimuthal acceptance range



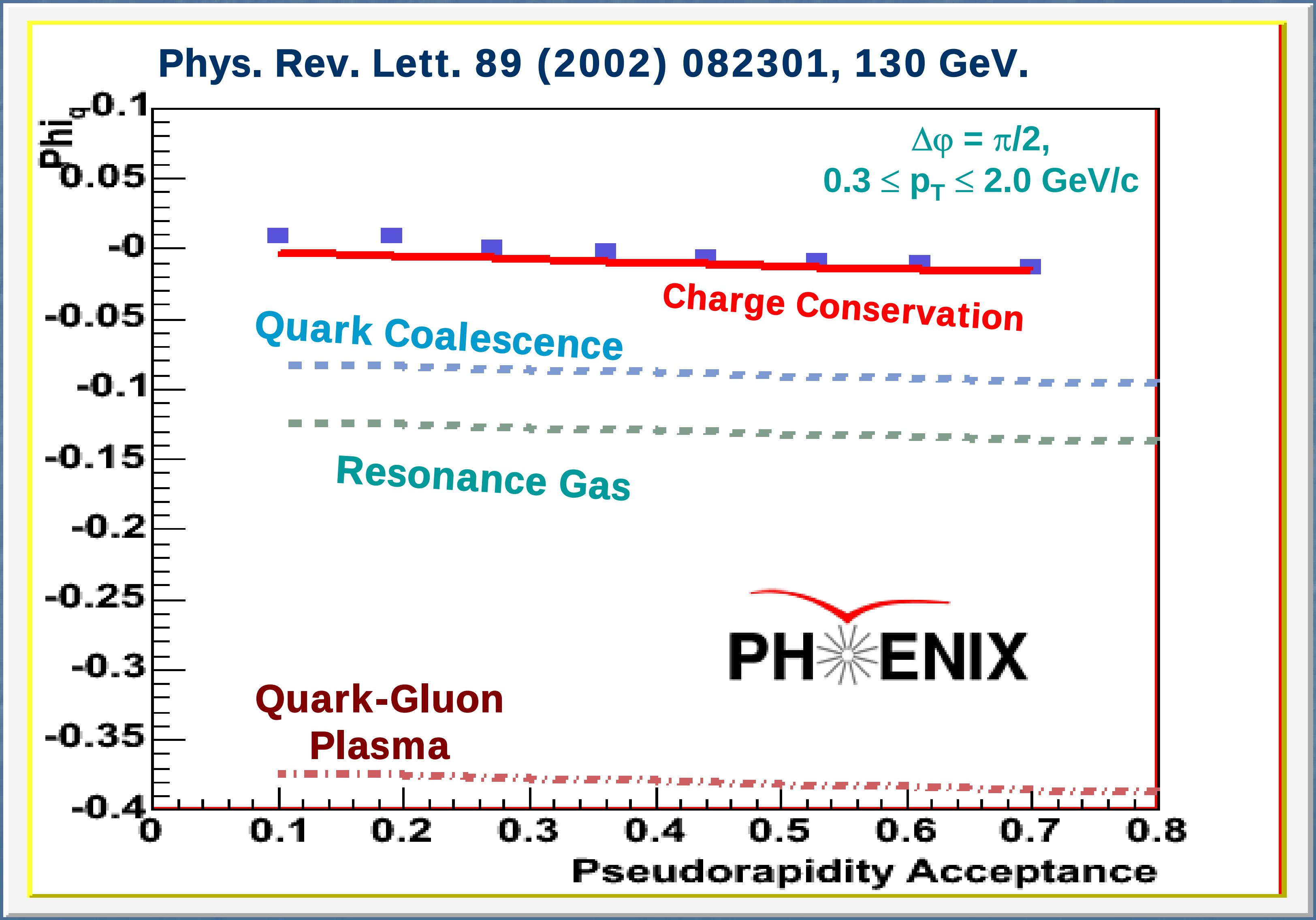
10% most central collisions. For $|\eta|<0.35$, $p_T > 200$ MeV/c, $\Delta\varphi=\pi/2$:

v(Q) = 0.965 ± 0.007(stat.) – 0.019 (syst.) $\sqrt{s_{nn}}$ = 130 GeV

v(Q) = 0.969 ± 0.006(stat.) ± 0.020 (syst.) $\sqrt{s_{nn}}$ = 200 GeV (PRELIMINARY)

Similar trend and slope at 130 and 200 GeV

PHENIX Charge Fluctuations vs. Rapidity Acceptance



$<p_T>$ Fluctuations

Analogy: Critical Opalescence

Movie of a sealed container containing freon on a hot plate at the critical point. The image is projected onto a wall.

Movie by the University of Minnesota Physics Department

M. Stephanov et al., Phys. Rev. Lett. 81 (1998) 4816: Suggest that near a tri-critical end-point in the QCD phase diagram, event-by-event fluctuations in average p_T could increase significantly.

B. Berdnikov and K. Rajagopal, Phys. Rev. D61 (2000) 105017: Estimate that the effect could be a 10-20% increase in average p_T fluctuations.

Summary of Event-by-event <p_T> Fluctuation Measures

Goal of the observables:

State a comparison to the expectation of statistically independent particle emission.

F_{pT} PHENIX

$$F_{p_T} \approx \frac{\Phi_{p_T}}{\sigma_{p_T,incl.}}$$

$\sigma^2_{pT,dyn}$ STAR

$$\sigma^2_{p_T,dyn} \cong \frac{2\Phi_{p_T}\sqrt{\overline{\Delta p_T^2}}}{\langle N \rangle}$$

$\Delta\sigma_{pT,n}$ STAR

$$\Delta\sigma_{p_T,n} \cong \sqrt{\left(\Phi_{p_T} + \sigma_{p_T,incl}\right)^2 - \sigma^2_{p_T,incl}}$$

$$\sigma_{p_T,incl.} = \sqrt{\left\langle p_T^2 \right\rangle - \left\langle p_T \right\rangle^2}$$

$$\overline{\Delta p_T^2} \equiv \overline{p_T^2} - \overline{p_T}^2$$

$$\Sigma_{p_T} = \frac{\sigma_{p_T}}{\overline{p_T}}\sqrt{\frac{2F_{p_T}}{<N>}}$$

$$\Sigma_{p_T} \equiv \mathrm{sgn}\left(\sigma^2_{p_T,dyn}\right)\frac{\sqrt{|\sigma^2_{p_T,dyn}|}}{\overline{p}_T}$$

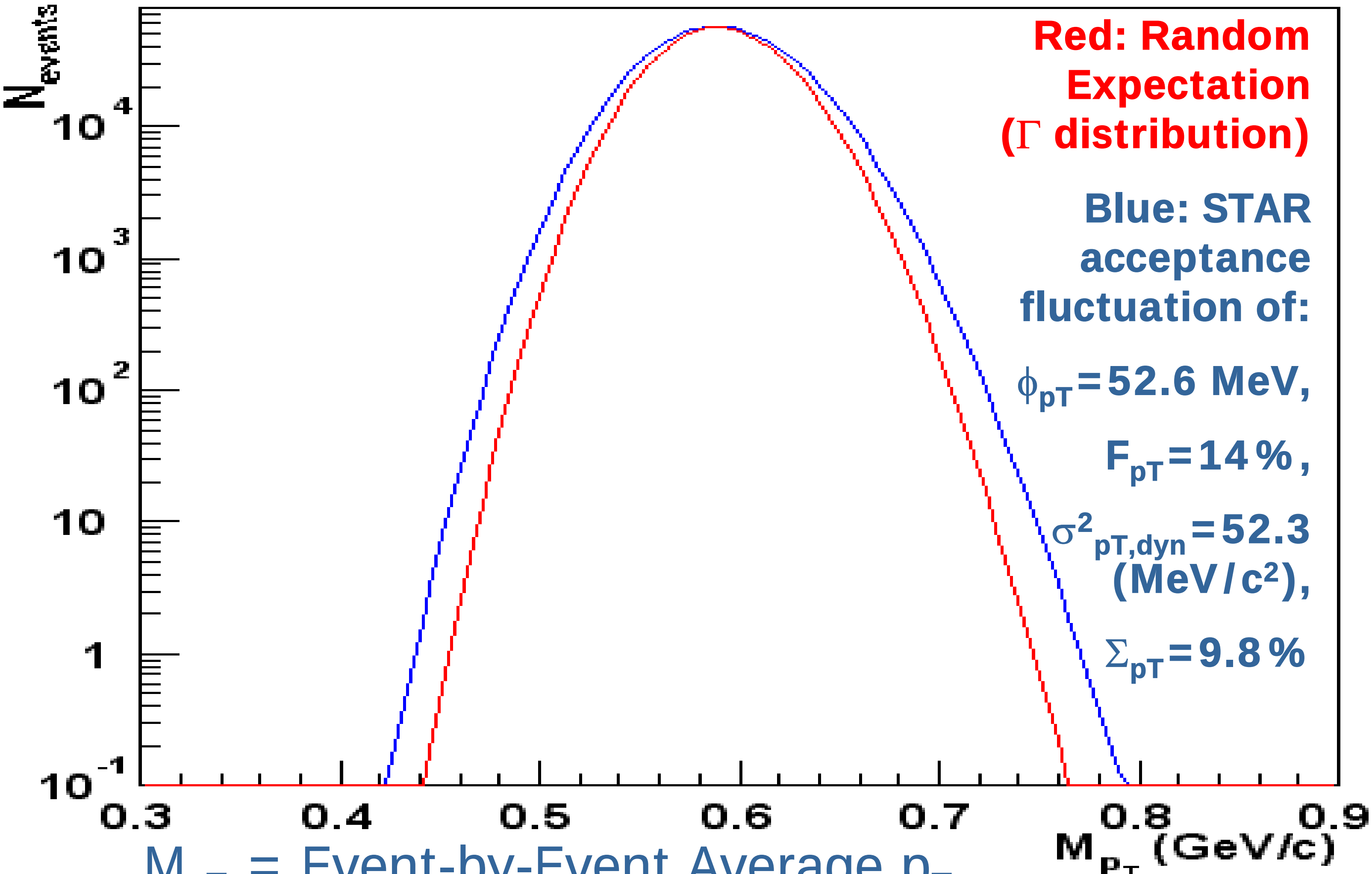
Σ_{pT} CERES

Quoted in this presentation

NA49 Φ_{pT}

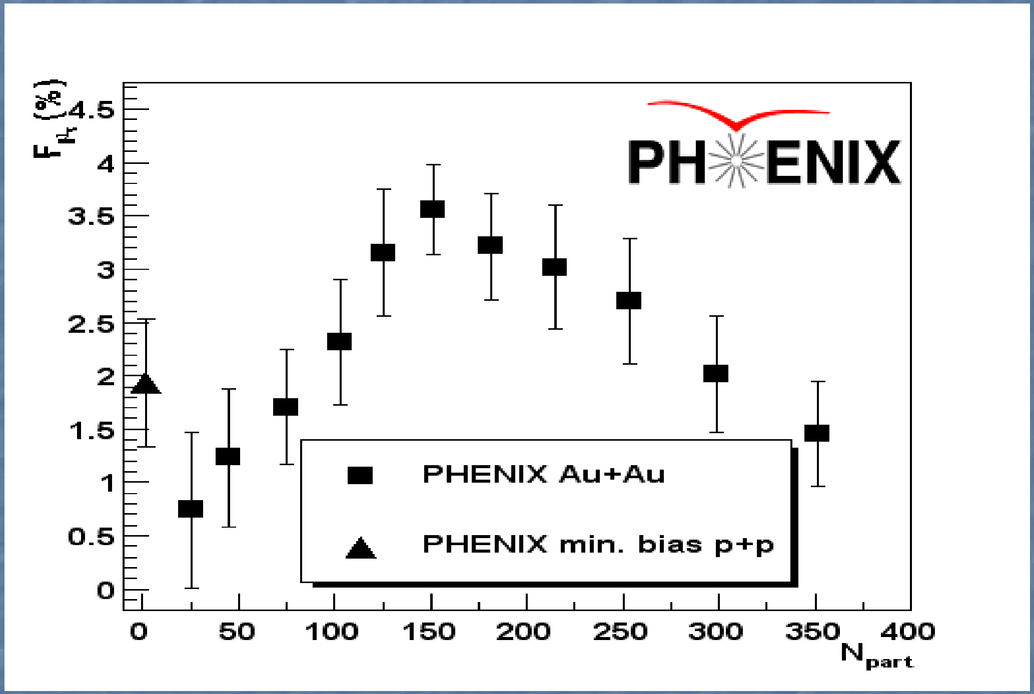
How To Measure A Fluctuation

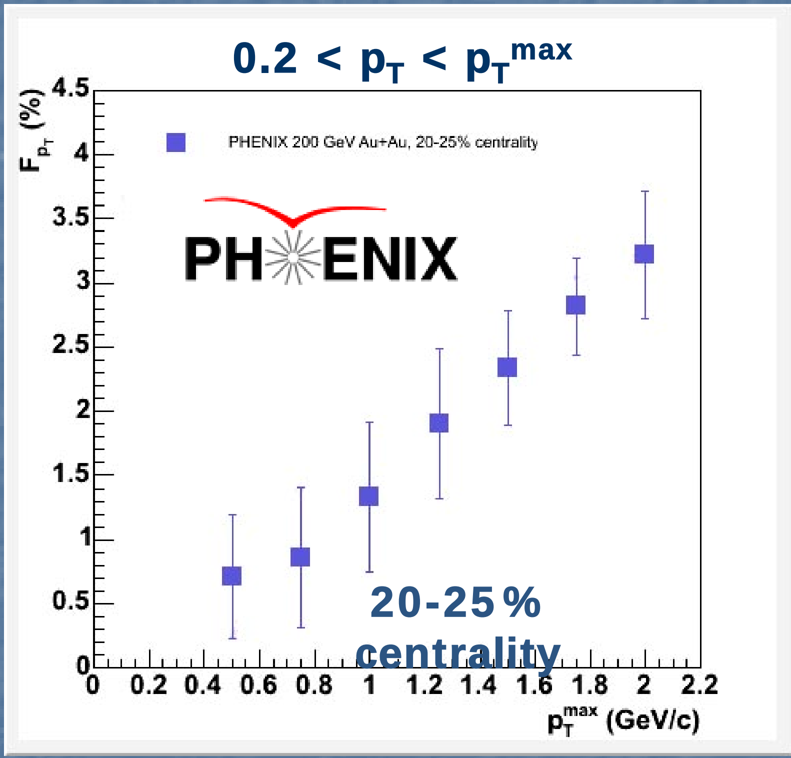
Gamma distribution calculation for statistically independent particle emission with input parameters taken from the inclusive spectra. *See M. Tannenbaum, Phys. Lett. B498 (2001) 29.*



M_{pT} = Event-by-Event Average p_T

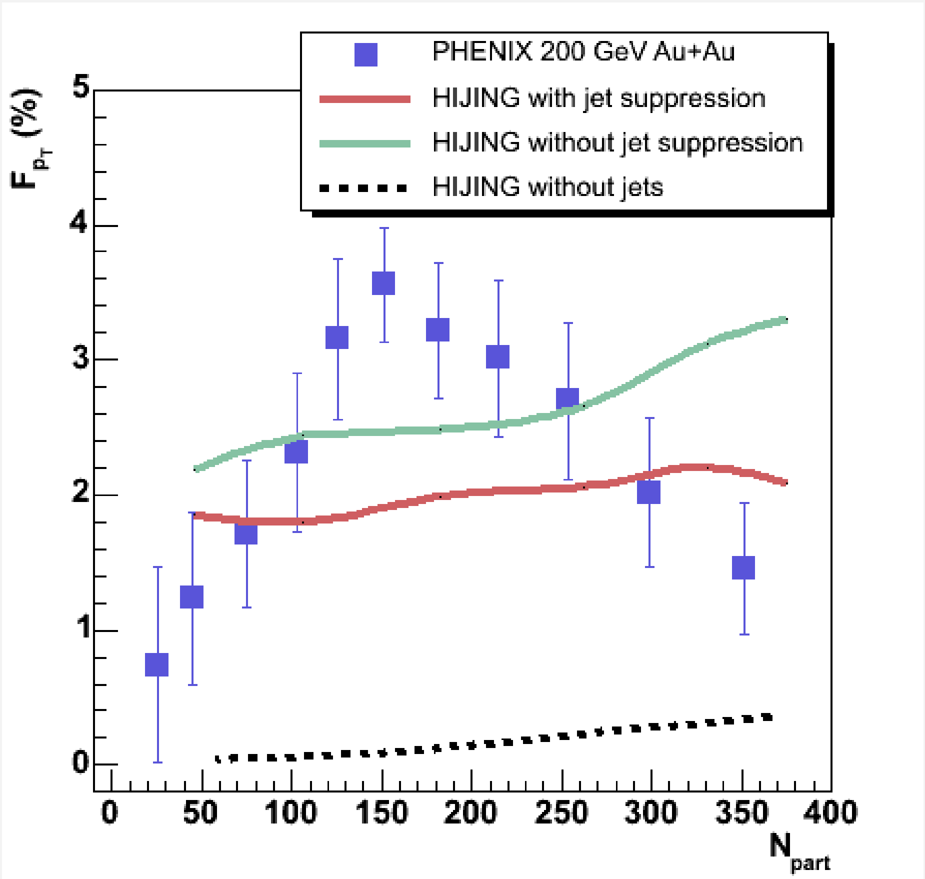
PHENIX Event-by-Event $<p_T>$ Fluctuation Results

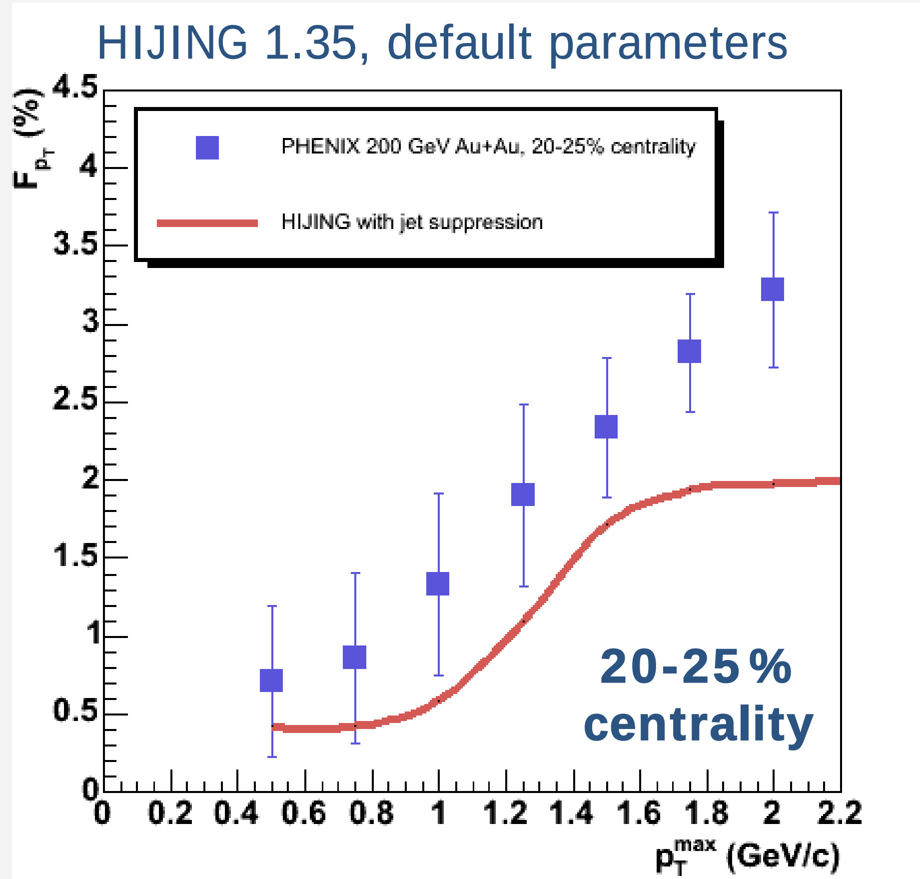




S. Adler et al., Phys. Rev. Lett. 93 (2004) 092301.

Fluctuations According to HIJING





HIJING cannot reproduce the centrality dependence of the fluctuations.

One problem is that <N> changes depending on the HIJING settings – it is not matched to the observed dataset. Matching would increase F_{pT} without jet suppression.

For example: for 0-5% centrality in PHENIX: <N> = 93.0 with jet suppression (close to the measured data value), 76.6 without suppression, and 51.2 without jets entirely.

Designing a Baseline Simulation for Fluctuation Studies, “Mean Max”

This is a data-driven simulation designed to simulate statistically independent particle production via the following method:

- Generate the number of particles in an event, N, by sampling a Gaussian distribution fit to the data.

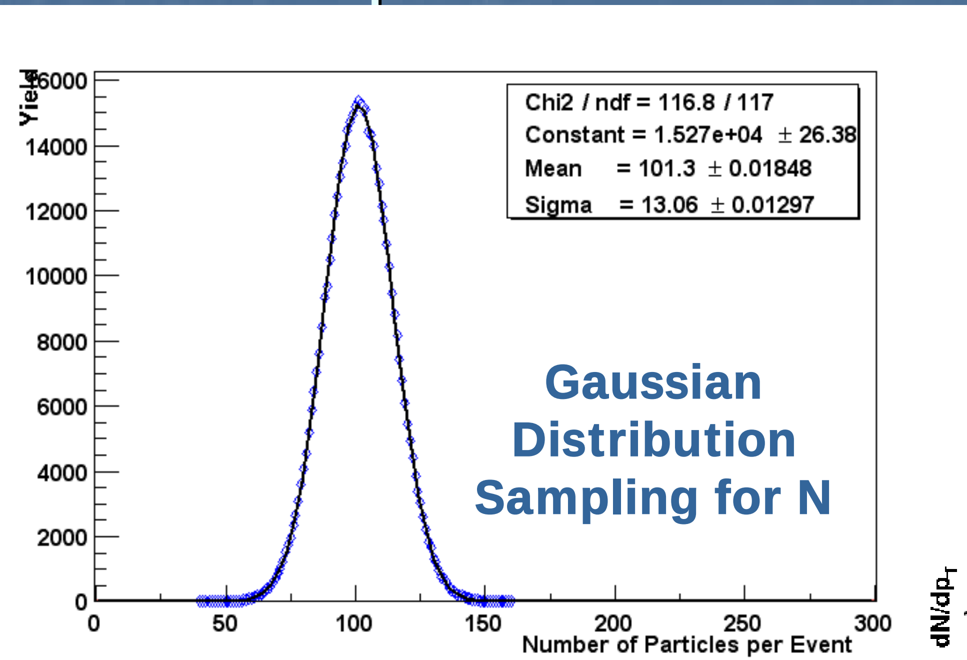
- Assign a p_T to each particle by sampling an m_T exponential distribution fit (or double exponential, or Gamma distribution) to the data inclusive p_T distribution.

- Calculate the event-by-event $\langle p_T \rangle$, M_{pT}, over a specified p_T range.

- Generate mixed events for calculation of fluctuation quantities from the simulated data events.

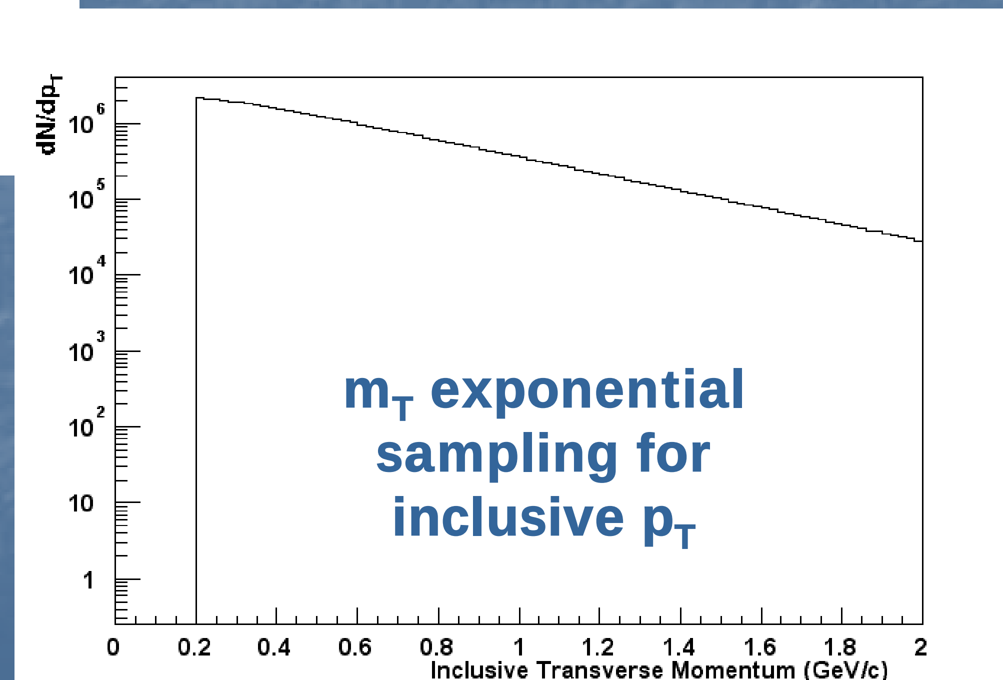
The only input parameters are: $\langle N \rangle$, $\sigma_{\langle N \rangle}$, inclusive p_T function parameters, p_T range for the $\langle p_T \rangle$ calculation.

Sample Results from the Baseline Simulation



Sample: Using a match to PHENIX 0-5% centrality data

Inclusive $<p_T>$, σ_{pT}, $<N>$, $\sigma_{<N>}$ matched to the data for each centrality class.



Fluctuations: A Jet Contribution?

Jets are simulated using a hybrid algorithm which embeds Pythia hard scattering events into Mean Max baseline events.

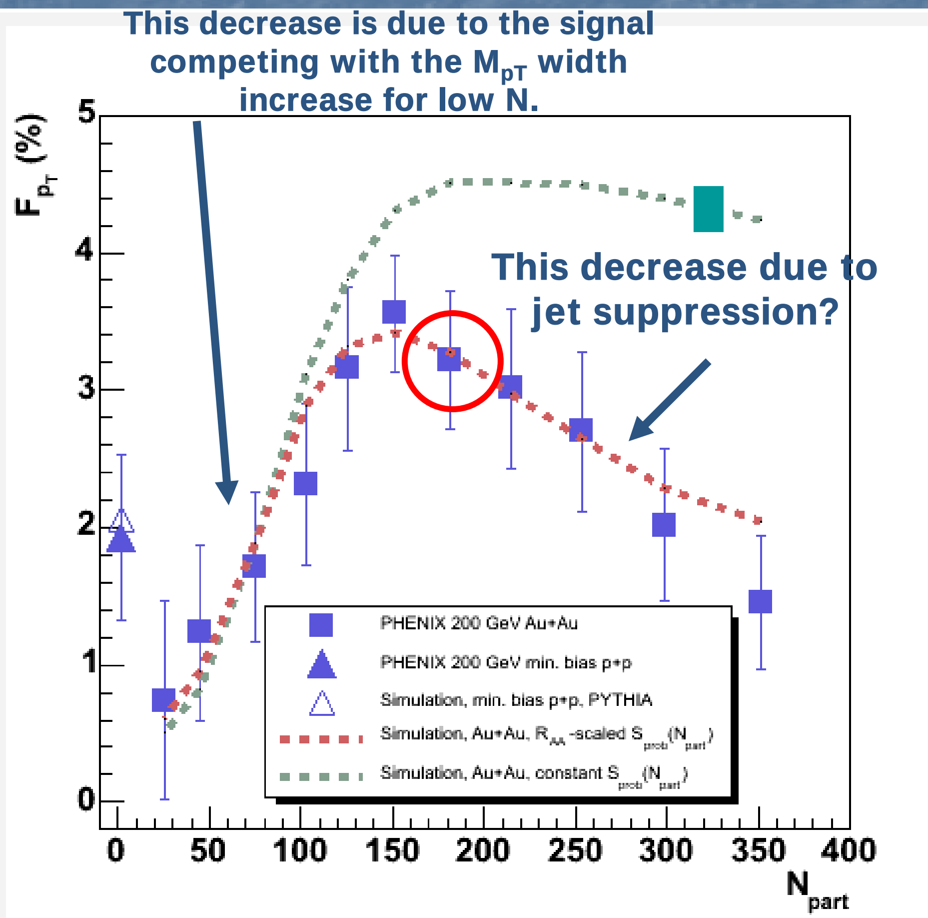
A single varying parameter is defined: A hard scattering probability factor, S_{prob}, is randomly tested for each thrown particle. If the test is true, a single PYTHIA event is embedded into the baseline event after applying experimental acceptance criteria.

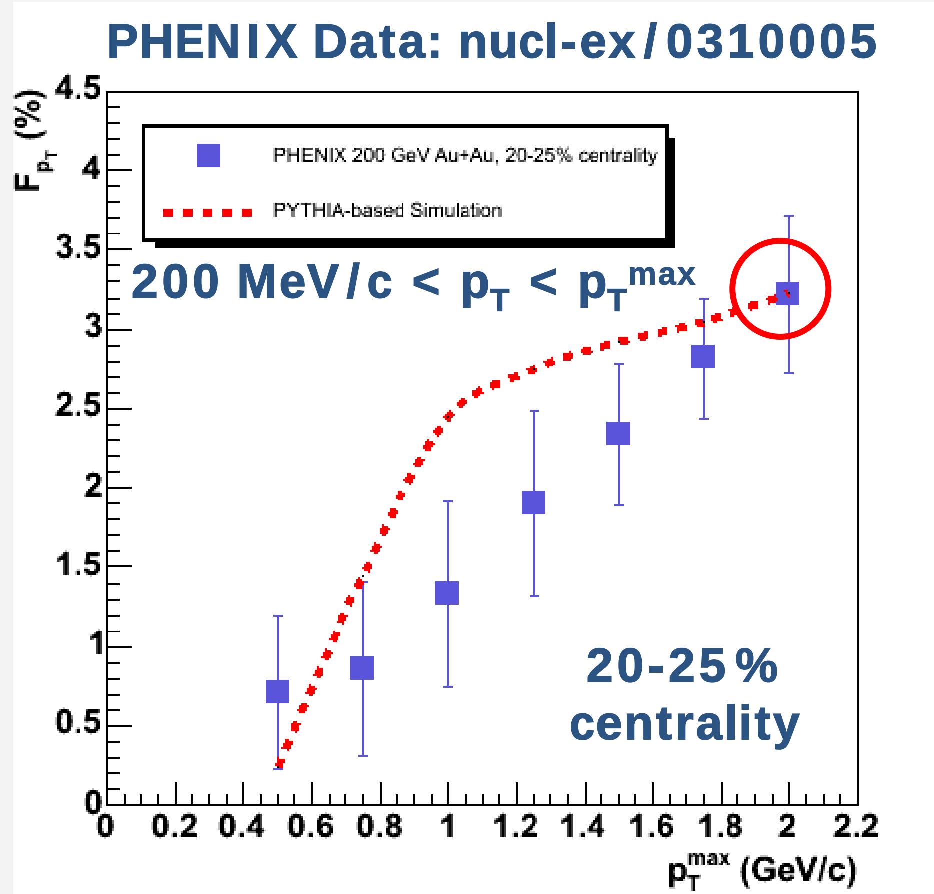
NOTE: The N distribution is preserved in this simulation. The inclusive <p_T> and $\sigma(p_T)$ are affected by less than 1%.

To mock up jet suppression, S_{prob} is scaled by the experimentally measured value of the nuclear modification factor, R_{AA}, as a function of centrality.

Jet Simulation Results: PHENIX at $\sqrt{s_{NN}}$ = 200 GeV

The S_{prob} parameter is initially adjusted so that F_{pT} from the simulation matches F_{pT} from the data for 20-25% centrality (circled). It is then FIXED and finally scaled by R_{AA} for all other centralities.





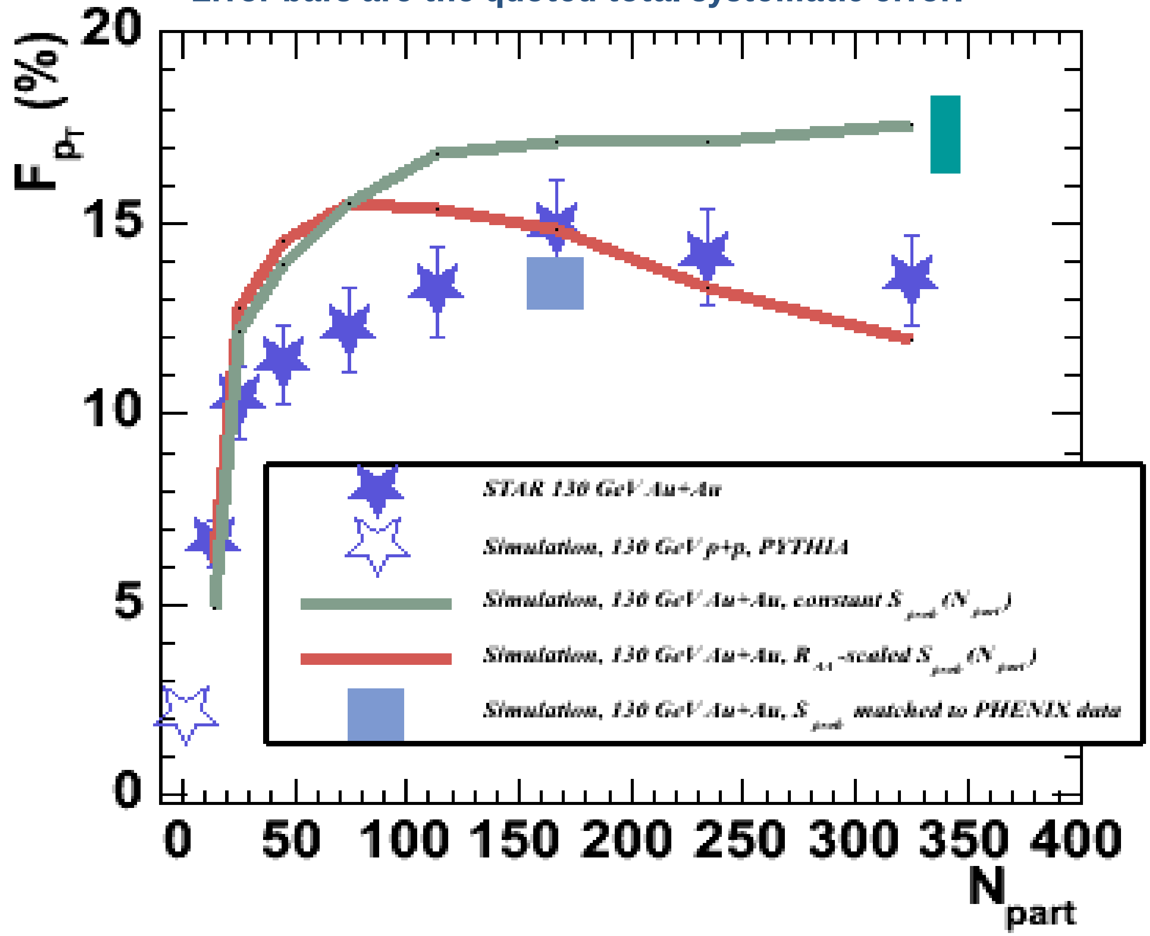
Jet Simulation Results: STAR at sqrt(s_{NN}) = 130 GeV

The square is the result using the initial value of S_{prob} that matches the PHENIX data with the PYTHIA events filtered through the increased STAR acceptance. The lines are the result with S_{prob} adjusted to reproduce the STAR 20-30% centrality data.

PREDICTION: The STAR values of F_{pT} should increase by ~15% for centralities 0-40% at sqrt(s_{NN})=200 GeV.

STAR data: nucl-ex/0308033

Error bars are the quoted total systematic error.



Estimate of the Magnitude of Residual Event-by-Event Temperature Fluctuations

$$\frac{\sigma_T}{<T>} = \sqrt{\frac{2F_{p_T}}{p(<N>-1)}}$$

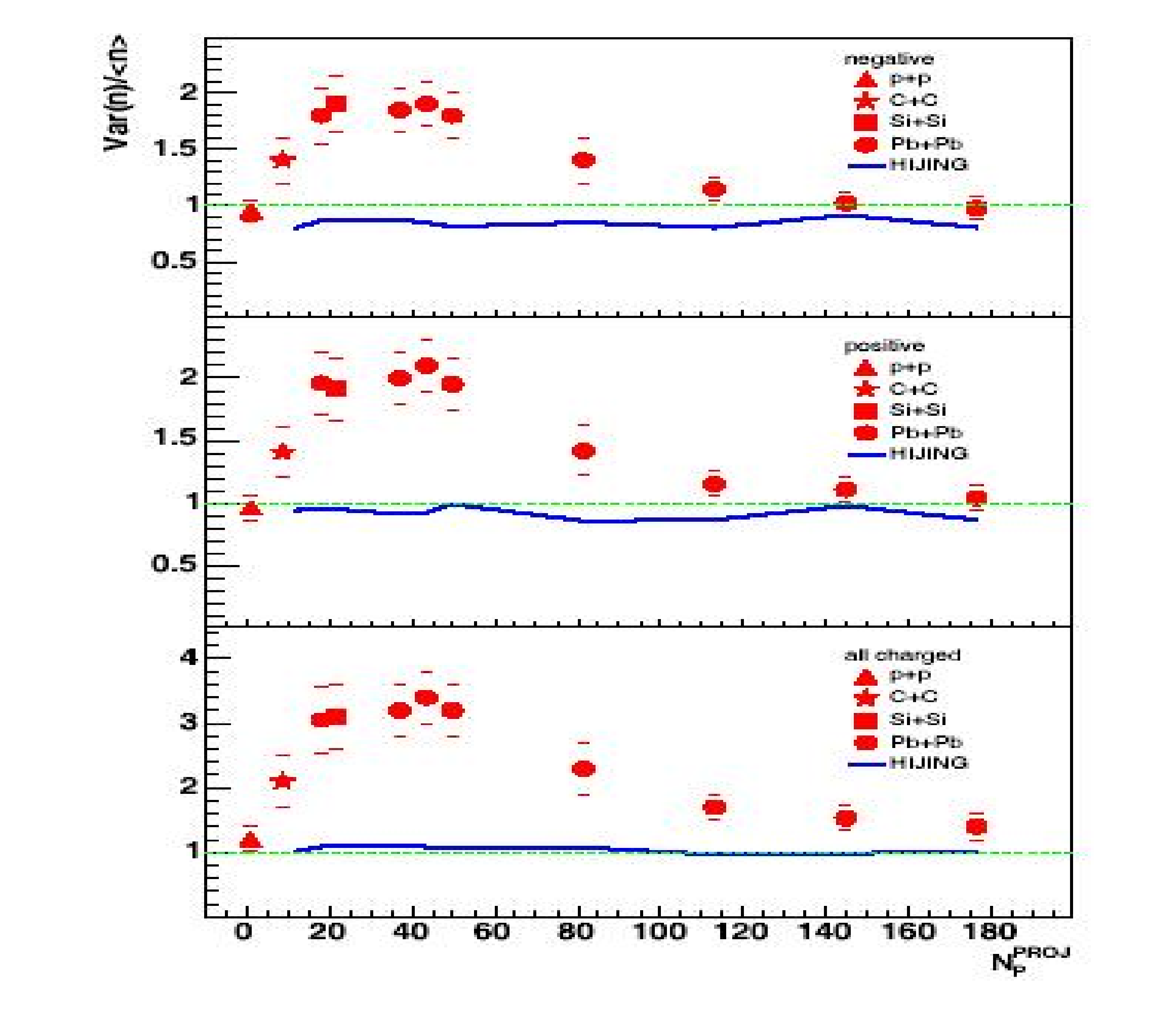
p →inclusive p_T, $\Gamma(p,b)$, p~1

R. Korus and S. Mrowczynski,

Phys. Rev. C64 (2001) 054908.

Measurement	sqrt(s_{NN})	σ_T / <T>, Most central	σ_T / <T>, At the peak
PHENIX	200	1.8%	3.7%
STAR	130	1.7%	3.8%
CERES	17	1.3%	2.2%
NA49	17	0.7%	4.1%

Multiplicity Fluctuations

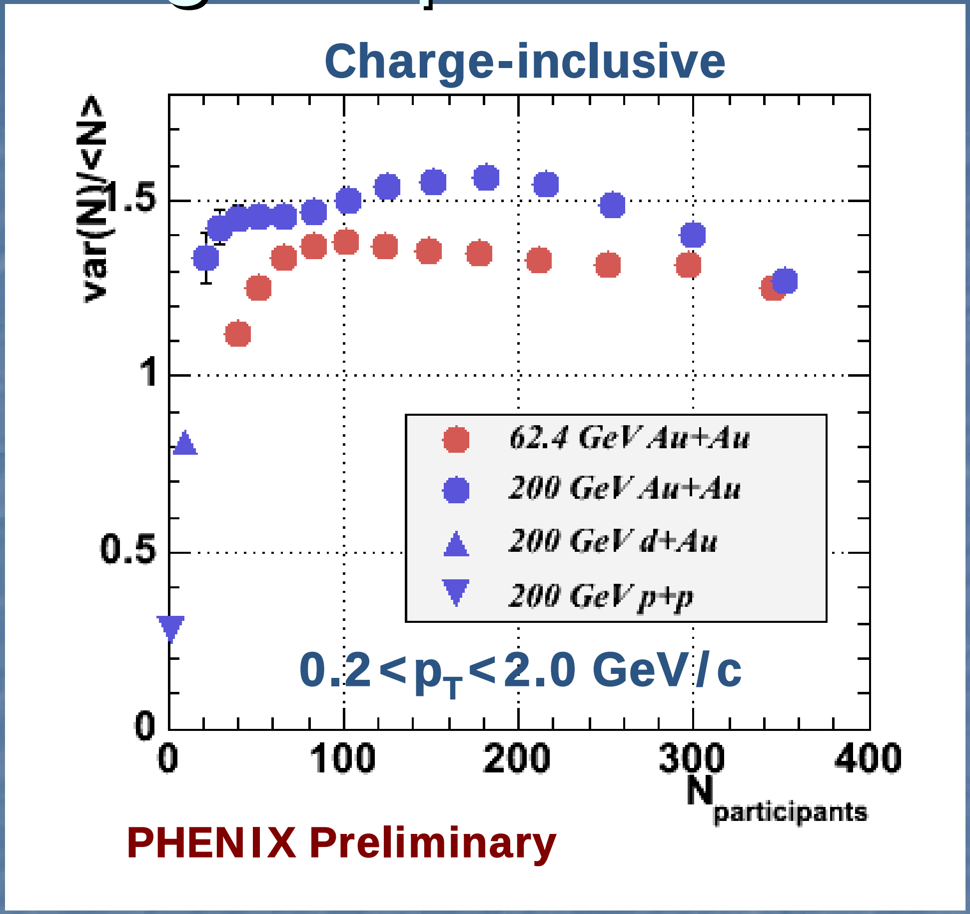


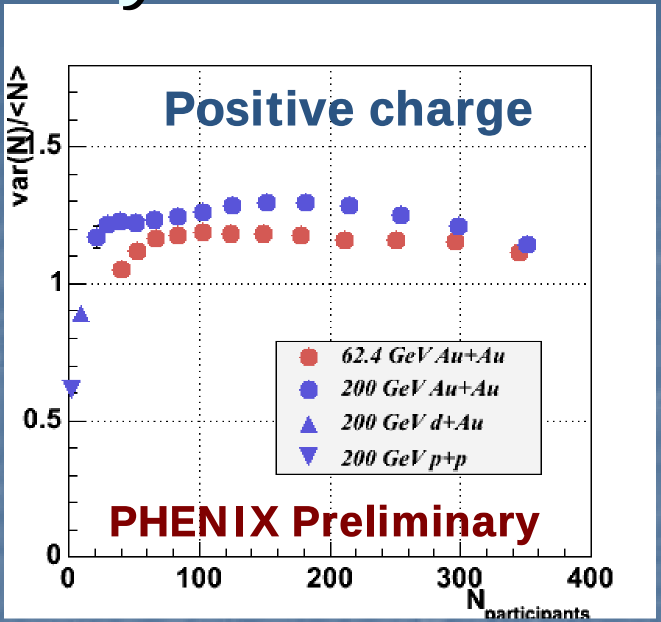
NA49 Pre-print nucl-ex/0409009

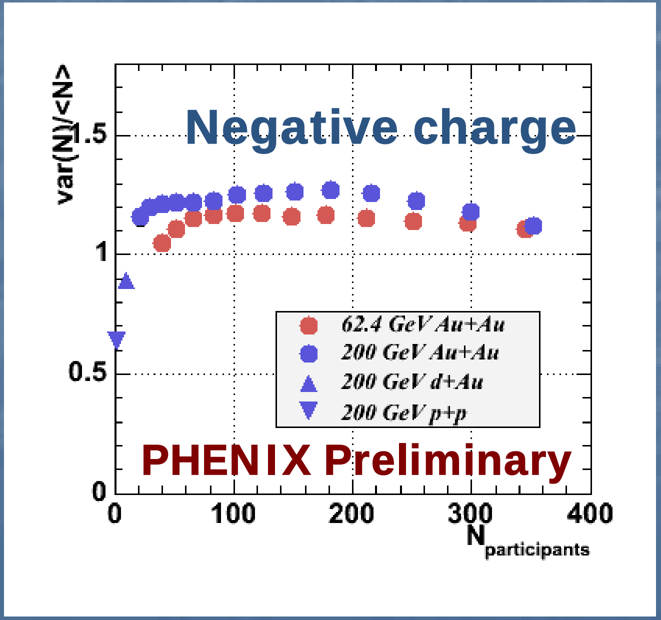
A peak is reported in multiplicity fluctuations as a function of N_{part}.

What happens at RHIC energies? Are there any differences?

Charge-Dependent Multiplicity Fluctuations

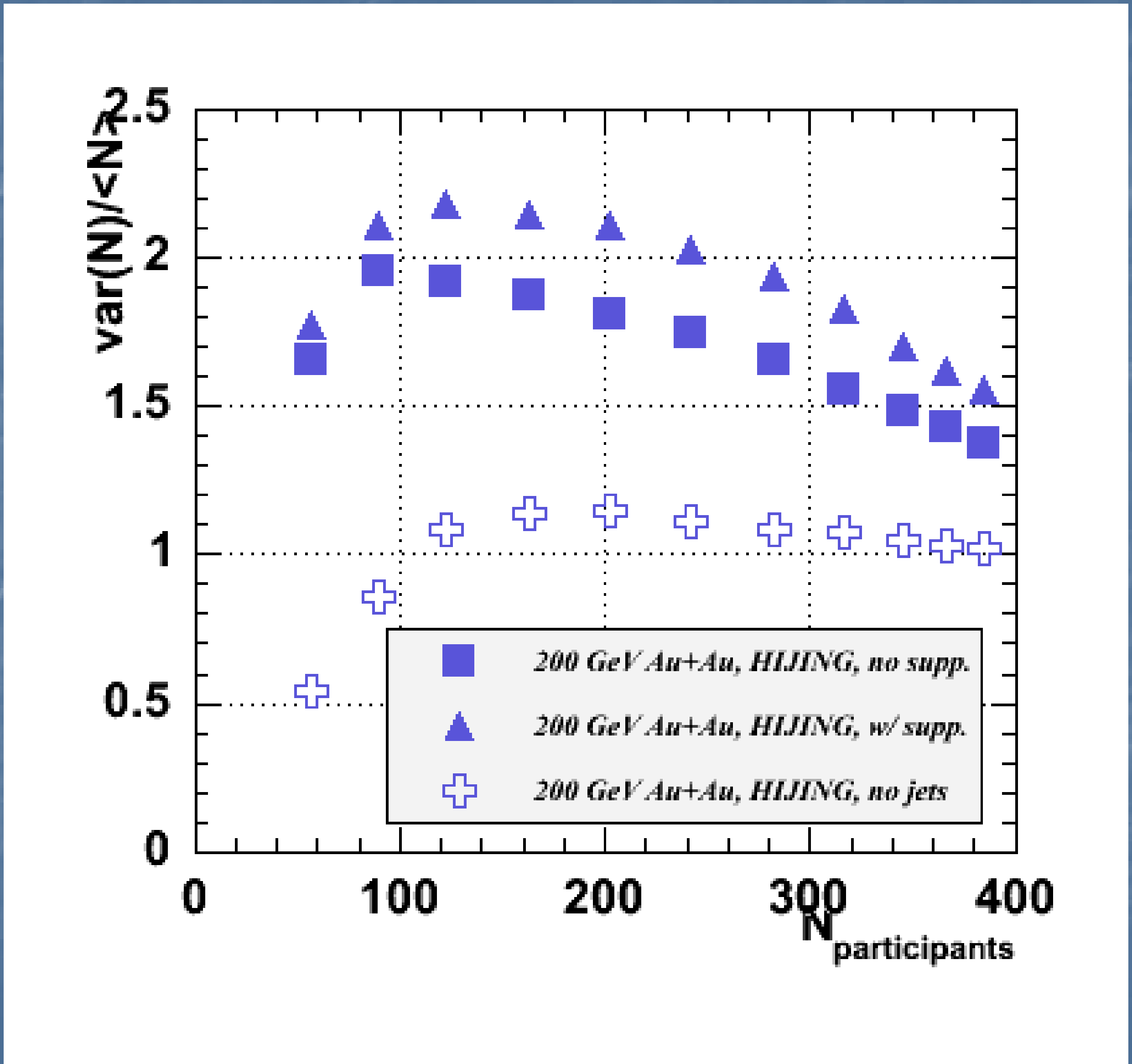






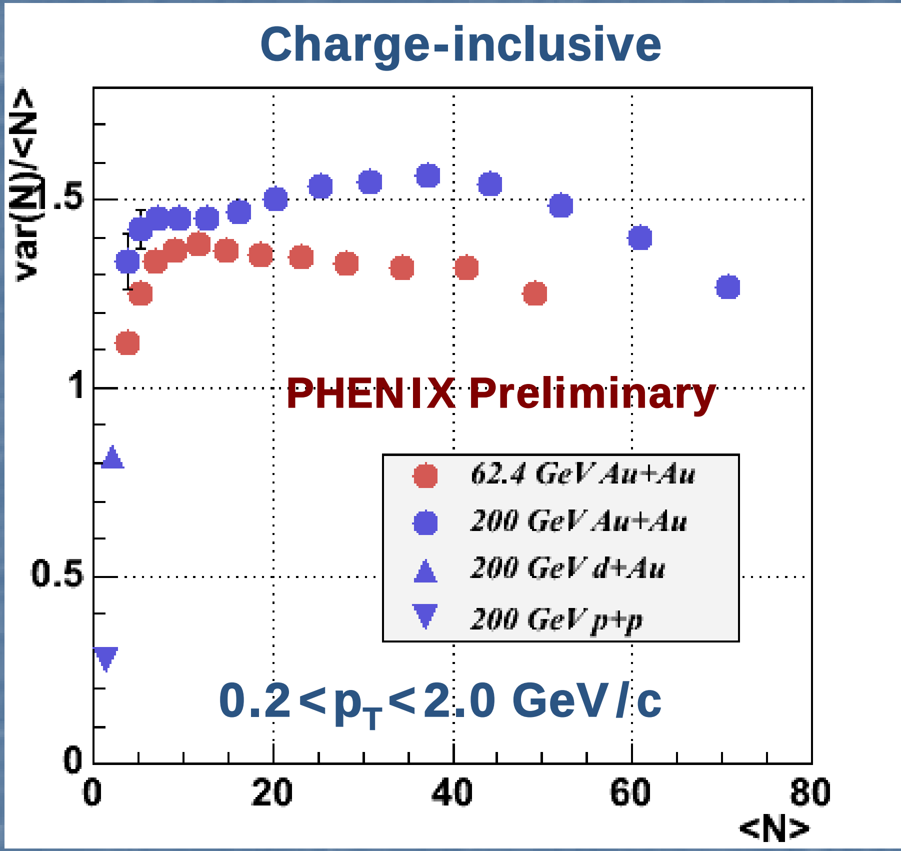
A different behavior is observed at RHIC energies. The distribution is relatively flat. The charge-dependent behavior is the same as at SPS energies.

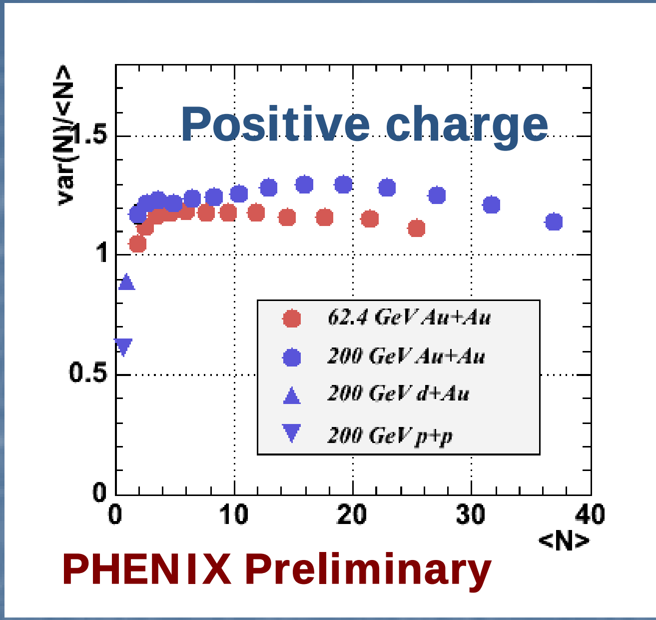
Multiplicity Fluctuations: HIJING 1.35

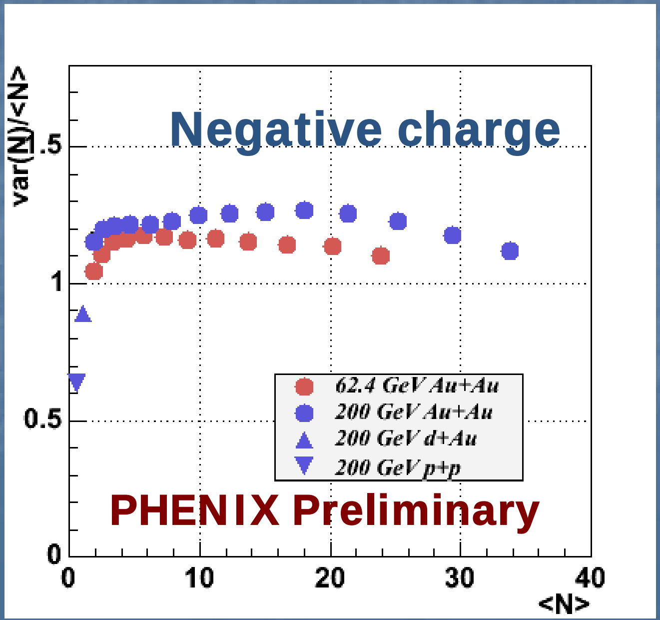


HIJING 1.35, 200 GeV Au+Au, filtered through the PHENIX acceptance. The structure apparent in the 200 GeV data may be due to hard processes.

PHENIX Fluctuations vs. <N>







The centrality-dependent fluctuations do not scale with <N>. Also, the peripheral fluctuations start decreasing at the same value of <N>.

Negative Binomial Distributions: k

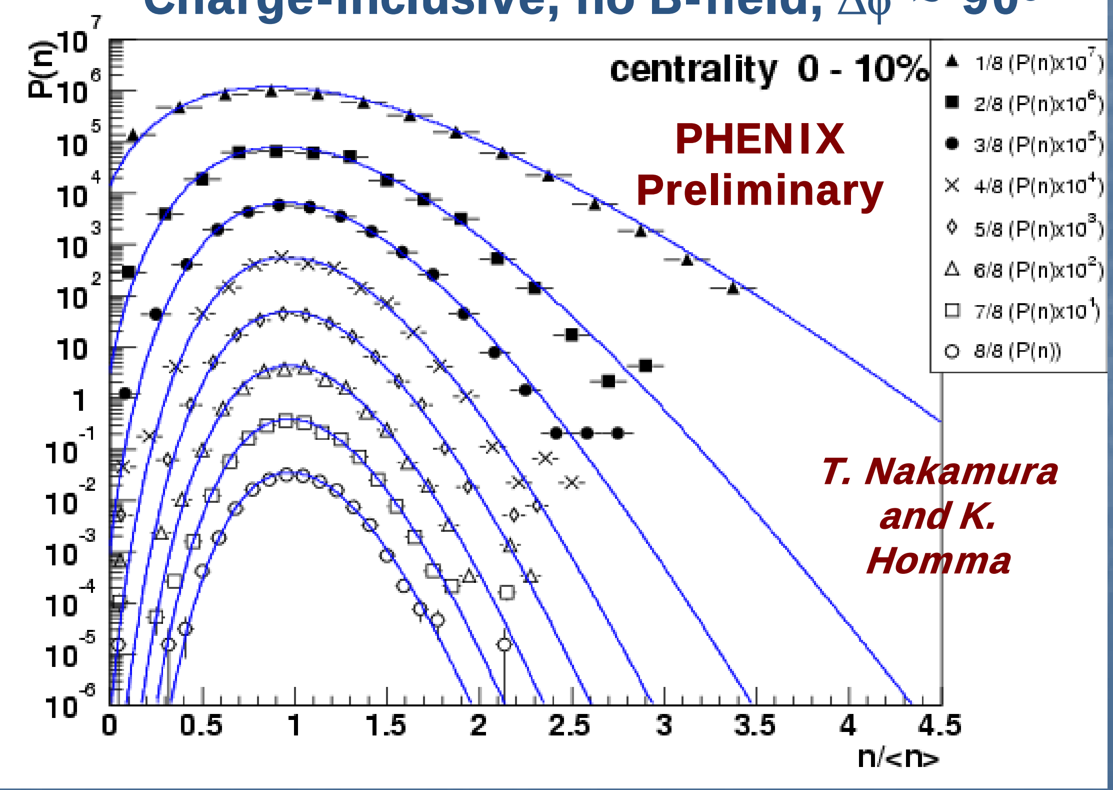
We know that multiplicity distributions can be described by the Negative Binomial Distribution. This has been confirmed for all centralities by fitting them to an N.B.D. distribution. The magnitude of k describes the deviation from a Poisson distribution – higher k means more Poissonian. k from the fit and from the formula below agree within errors for all centralities and p_T ranges.

$\delta\eta$= 0.09 (1/8) : P(n) x 10^7
$\delta\eta$= 0.18 (2/8) : P(n) x 10^6
$\delta\eta$= 0.35 (3/8) : P(n) x 10^5
$\delta\eta$= 0.26 (4/8) : P(n) x 10^4
$\delta\eta$= 0.44 (5/8) : P(n) x 10^3
$\delta\eta$= 0.53 (6/8) : P(n) x 10^2
$\delta\eta$= 0.61 (7/8) : P(n) x 10^1
$\delta\eta$= 0.70 (8/8) : P(n)

$$P(m) = \frac{(m+k-1)!}{m!(k-1)!} \frac{\left(\mu/k\right)^m}{\left(1+\mu/k\right)^{m+k}}$$

$$\frac{1}{k} = \frac{\sigma^2}{\mu^2} - \frac{1}{\mu}$$

Charge-inclusive, no B-field, $\Delta\phi \sim 90^o$



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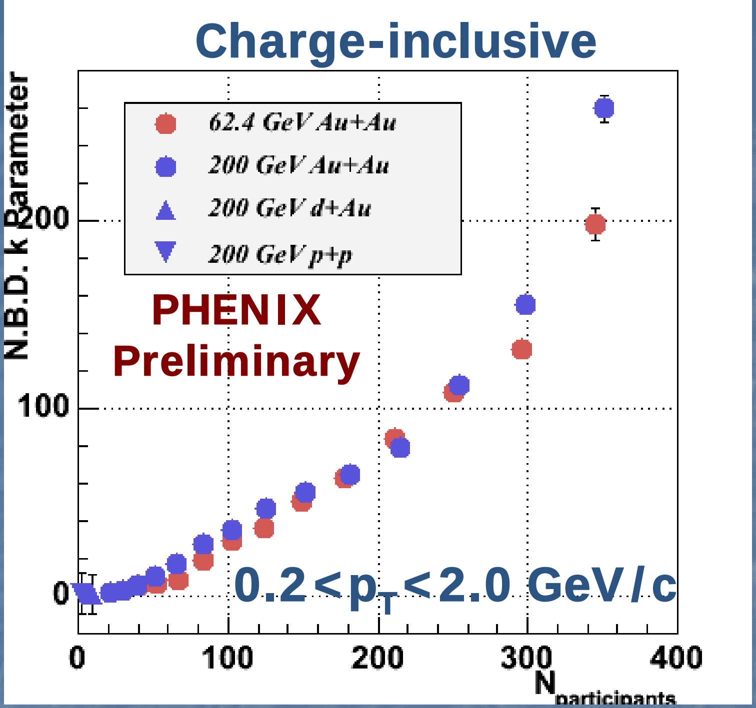

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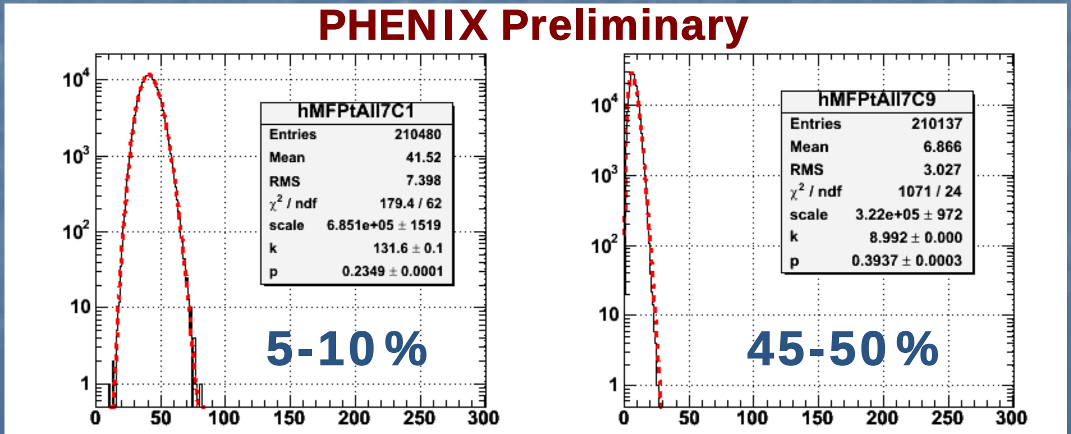
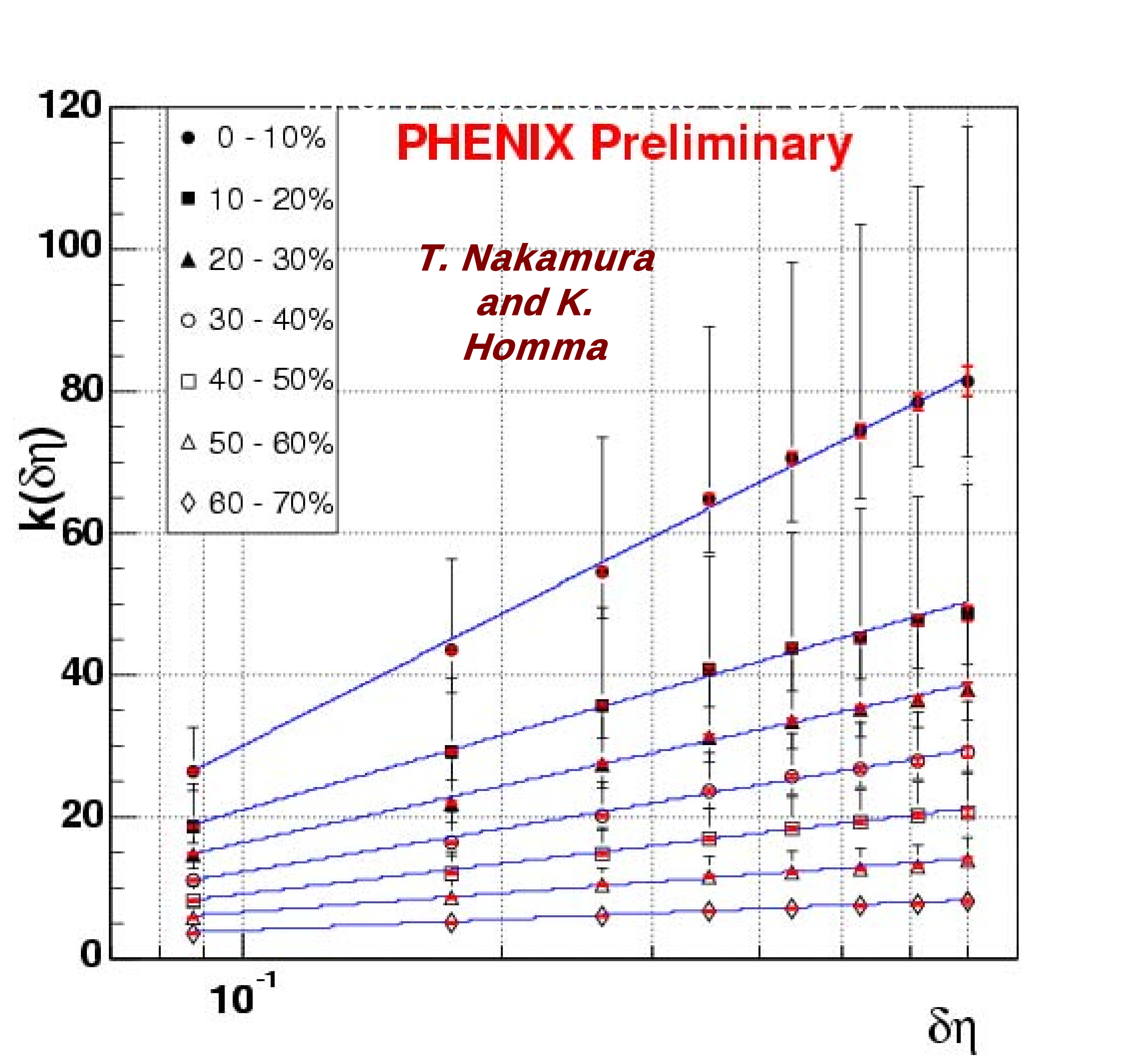
$$\frac{1}{k} = \frac{\sigma^2}{\mu^2} - \frac{1}{\mu}$$



Examples of Negative Binomial Fits: 62 GeV Au+Au

NBD k vs. $\delta\eta$



- Fitting function

$k(\delta\eta) = c1 + c2 \times \ln(\delta\eta)$

c1, c2 : constant

- Fitting Range

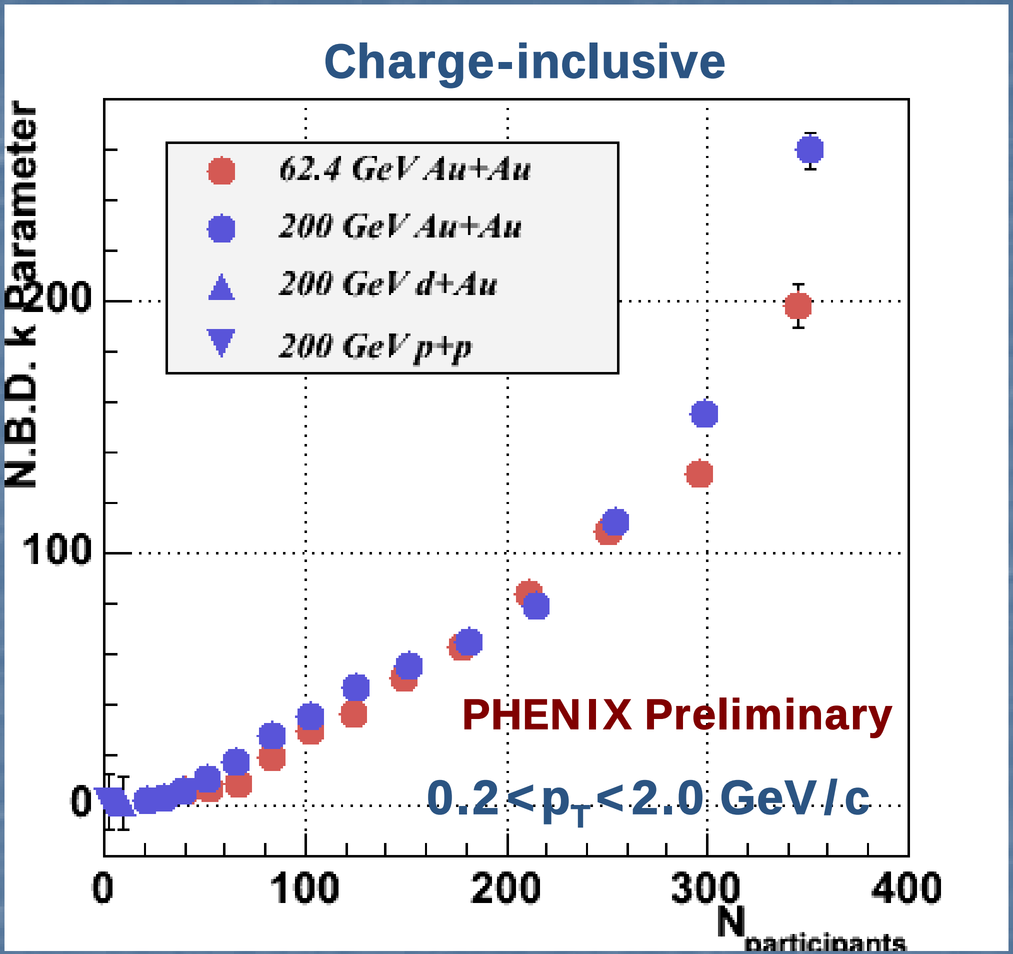
all : $0.09 \leq \delta\eta \leq 0.7$

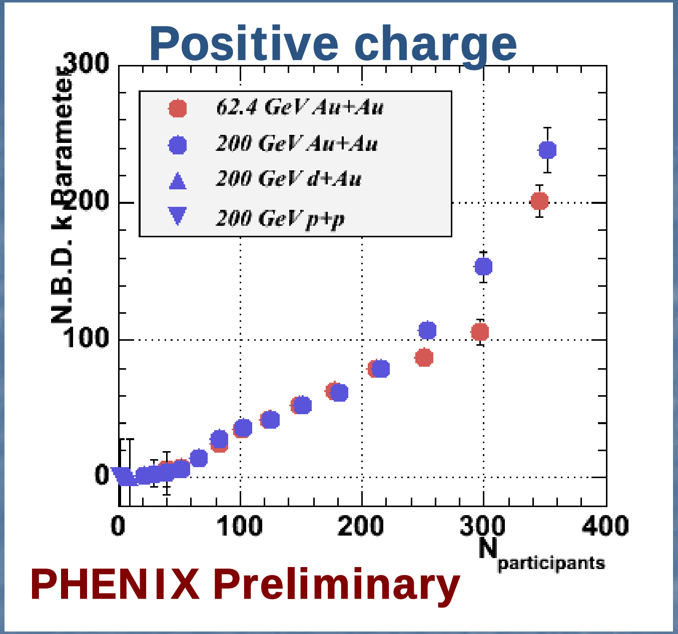
- Errors

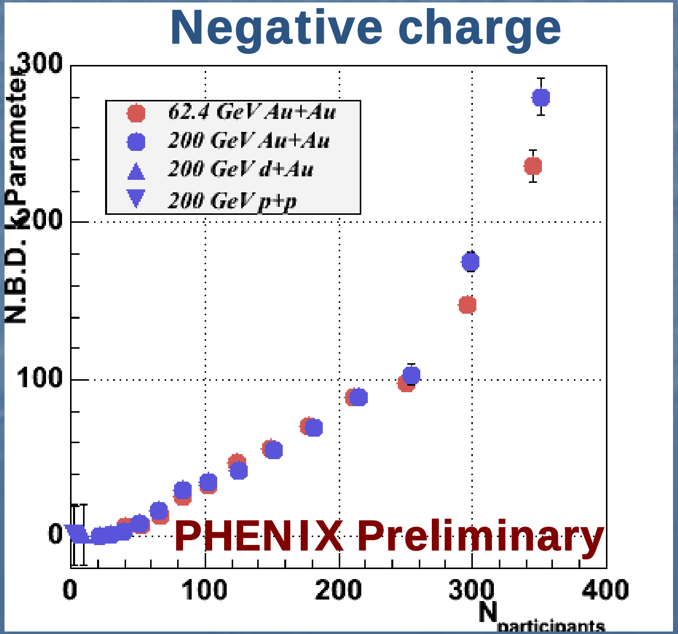
red bar : statistical error of NBD fit

black bar: systematic error of charged track selections and effects of dead area of detectors

Charge-Dependent Negative Binomial Distributions: k

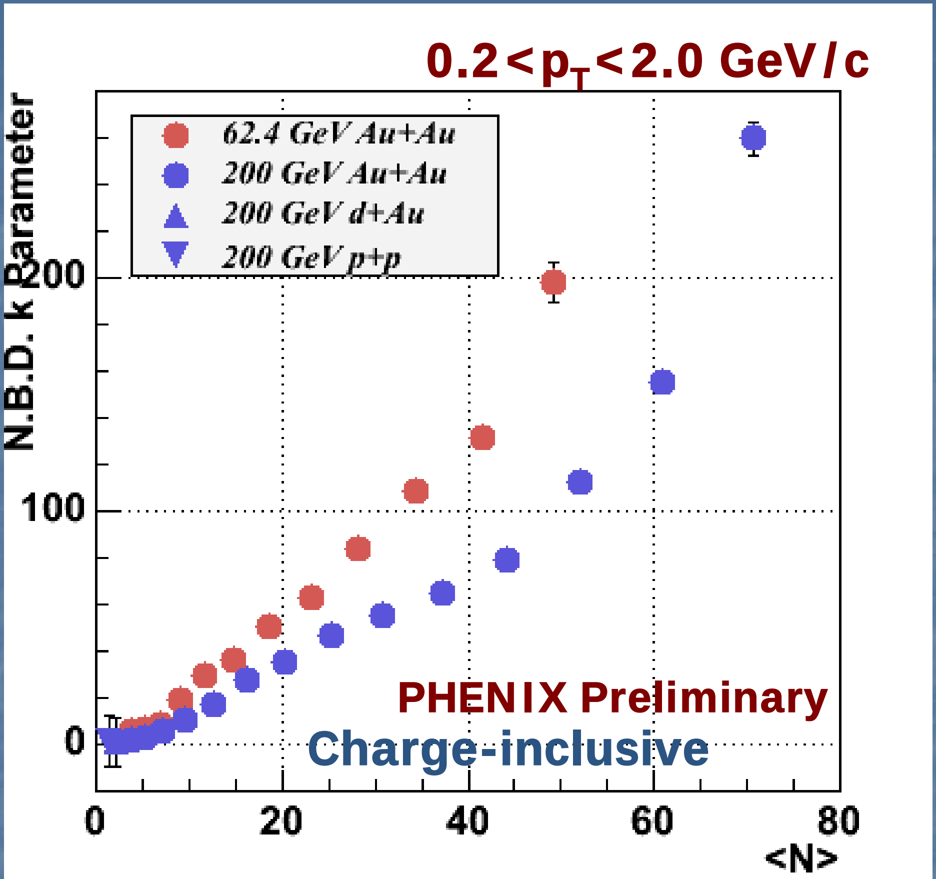


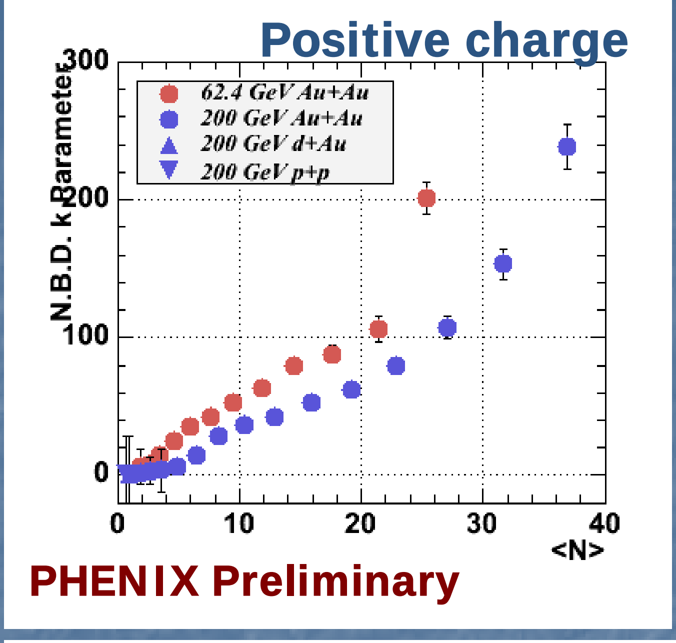


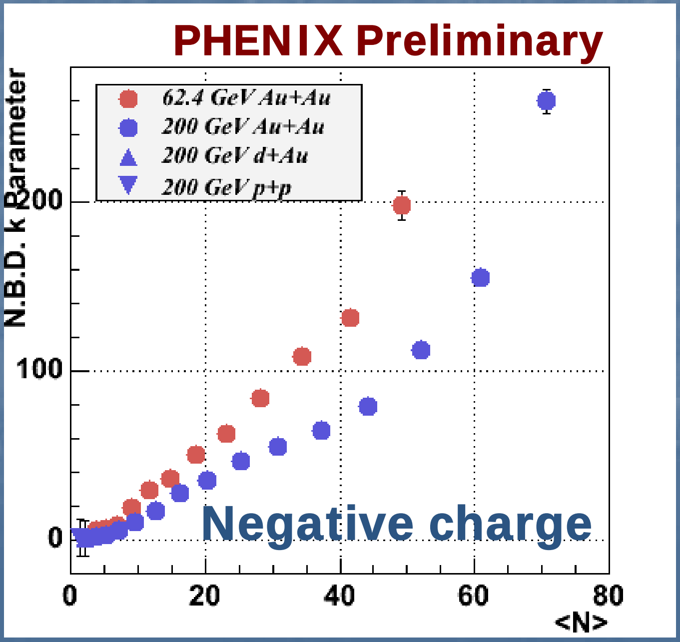


K describes the shape of the distributions and is determined via a fit. 62 GeV and 200 GeV data are very consistent. Sharp increase towards a Poisson distribution for the most central collisions. No significant charge dependence seen.

Charge-Dependent Negative Binomial Distributions: k

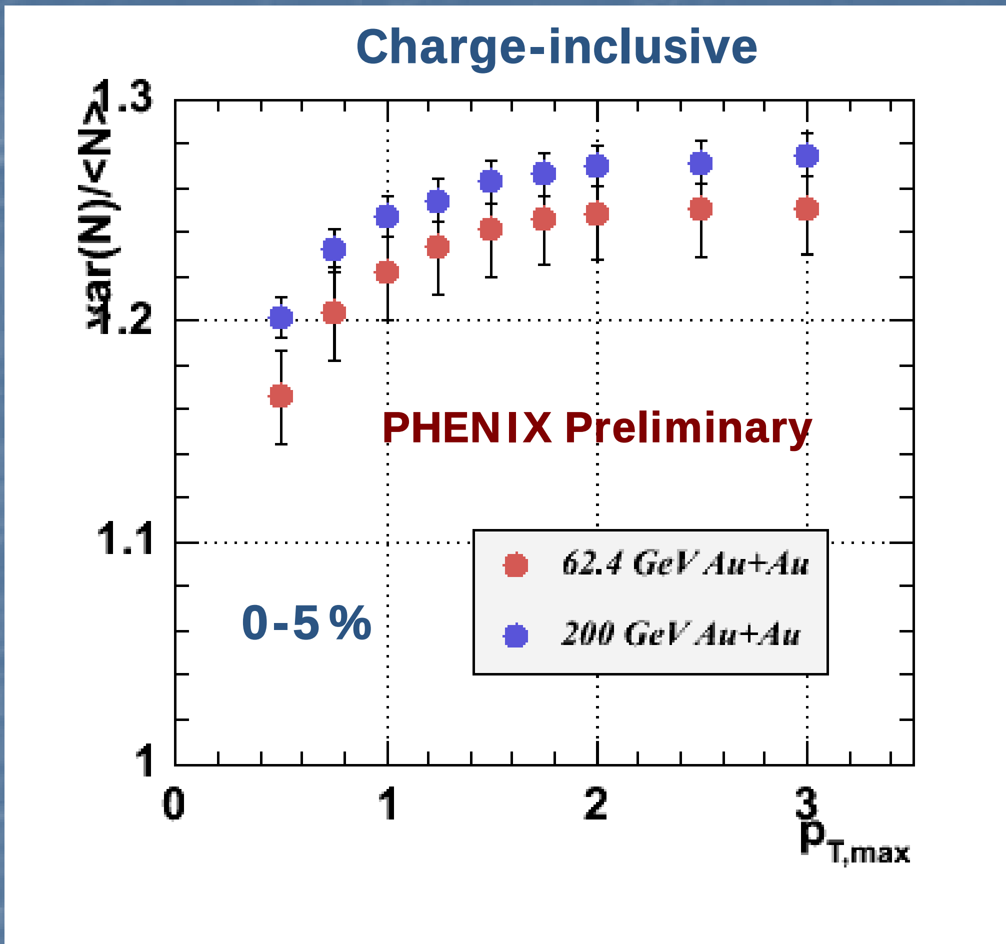


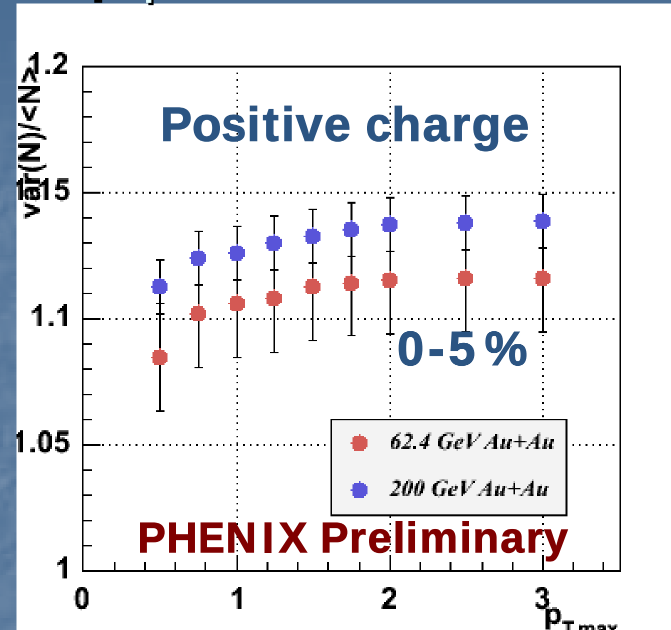


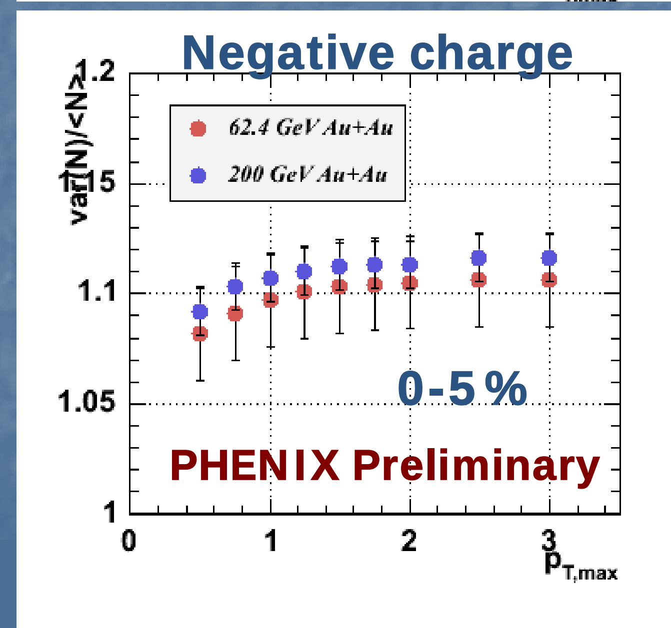


The value of the NBD k parameter does not scale with <N>. Universality of 62 GeV and 200 GeV data appears to be geometry-driven, not multiplicity-driven.

Multiplicity Fluctuations vs. p_T , 0-5% Au+Au

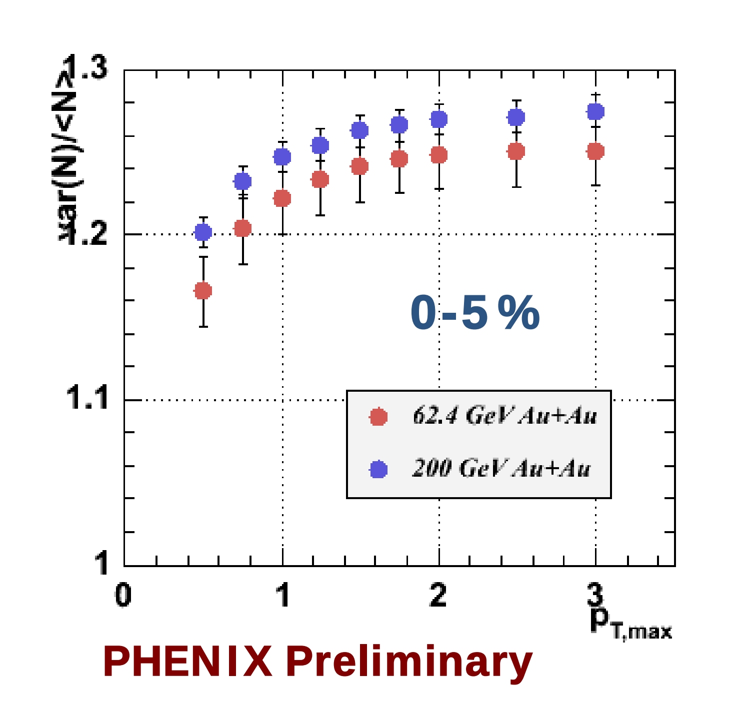


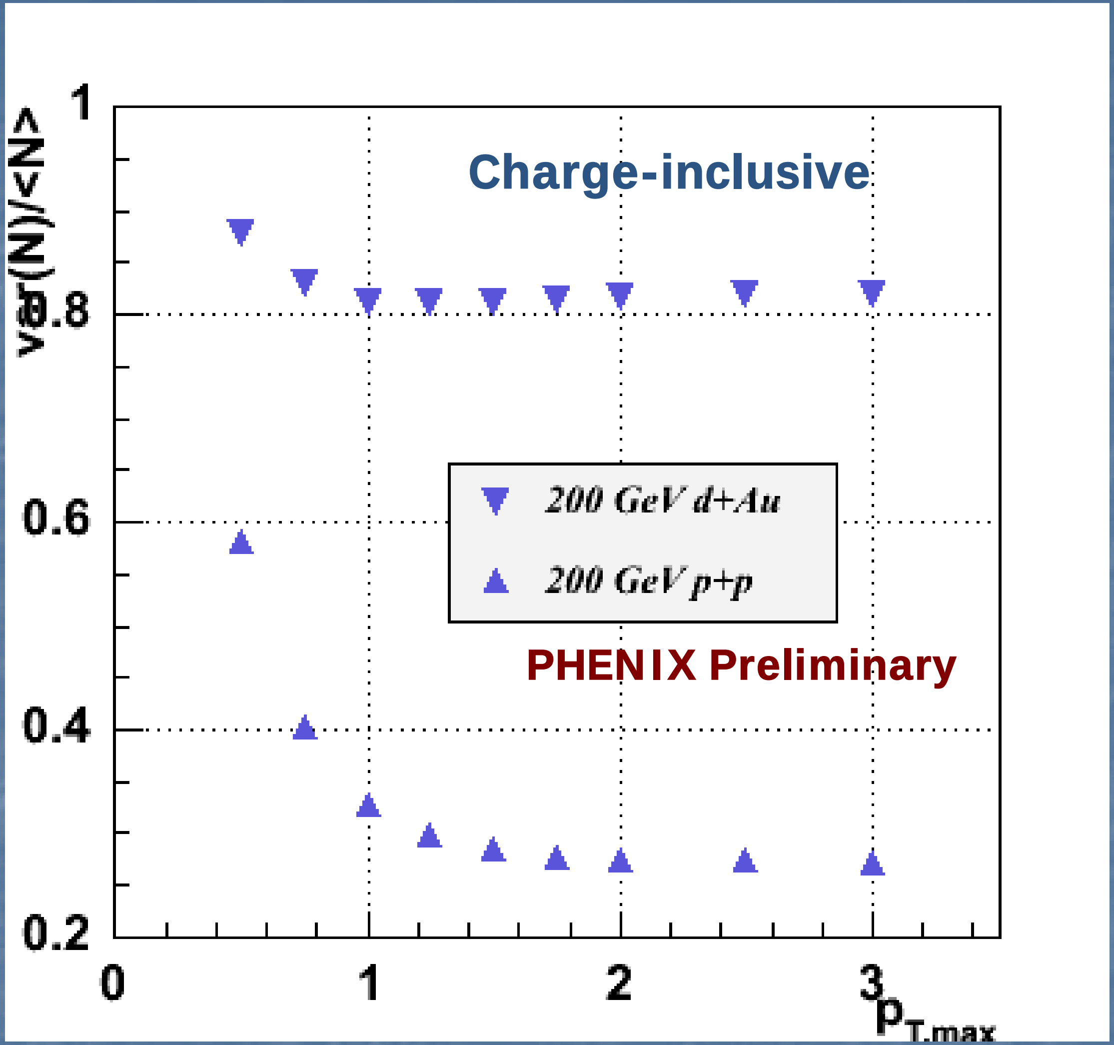




var(N) / <N> increases as more p_T particles are included, independent of charge.

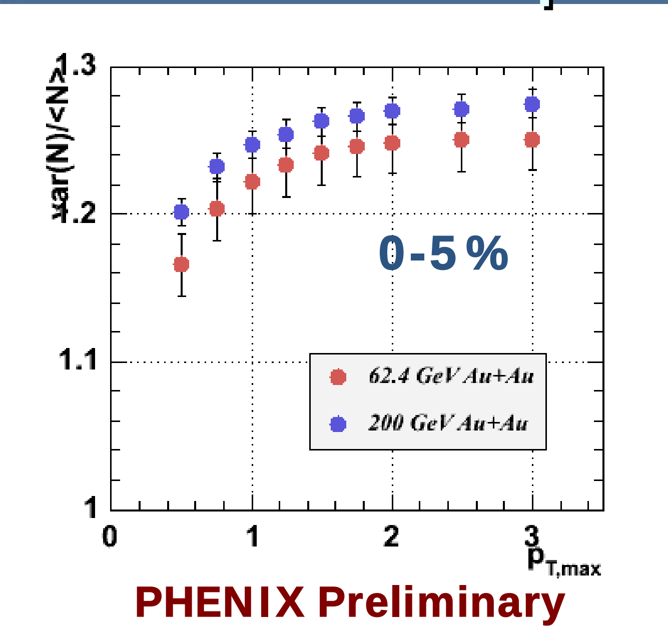
Multiplicity Fluctuations vs. p_T , p+p, d+Au

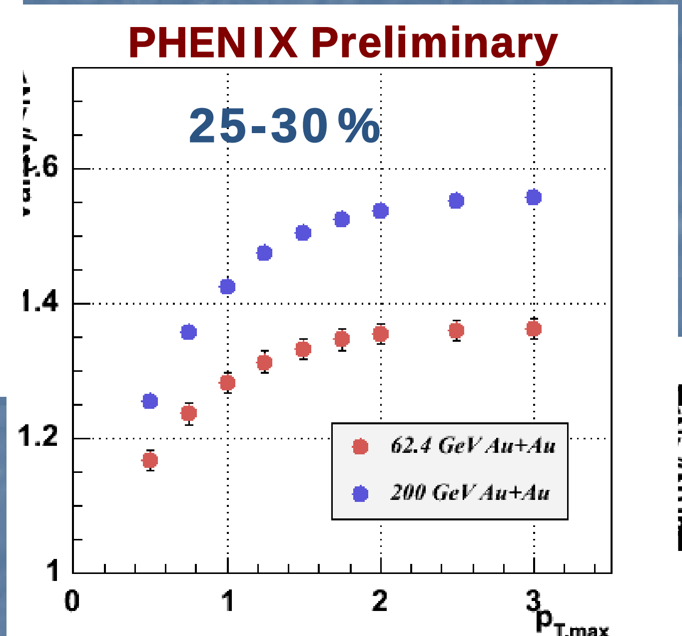


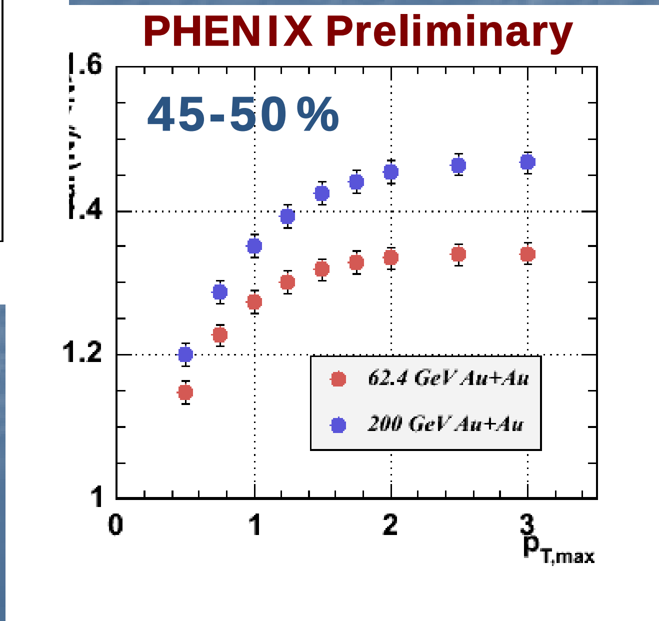


There is differing behavior going from p+p/d+Au to Au+Au

Multiplicity Fluctuations vs. p_T

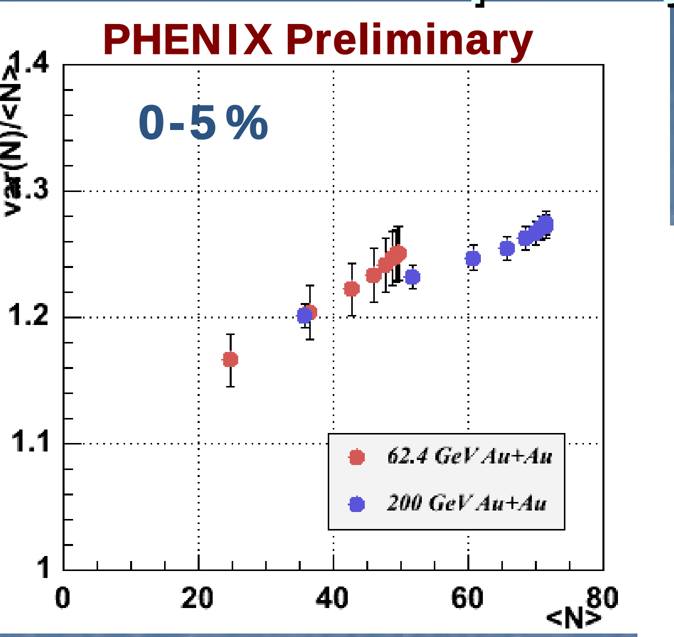


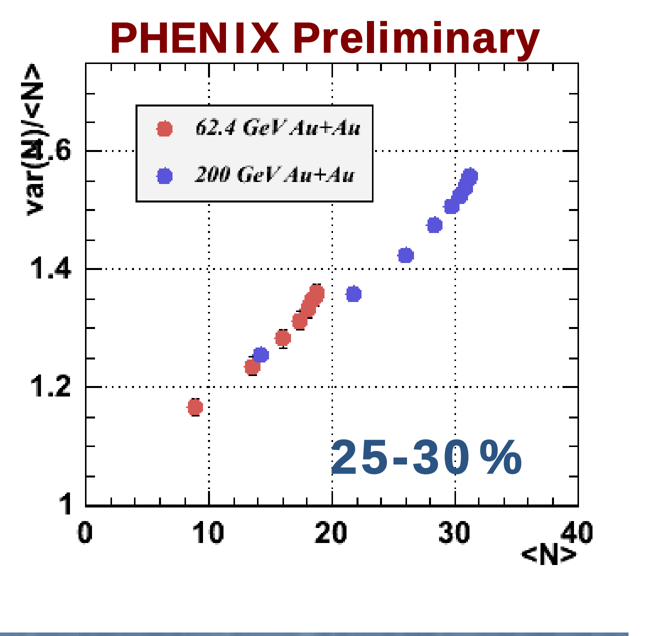


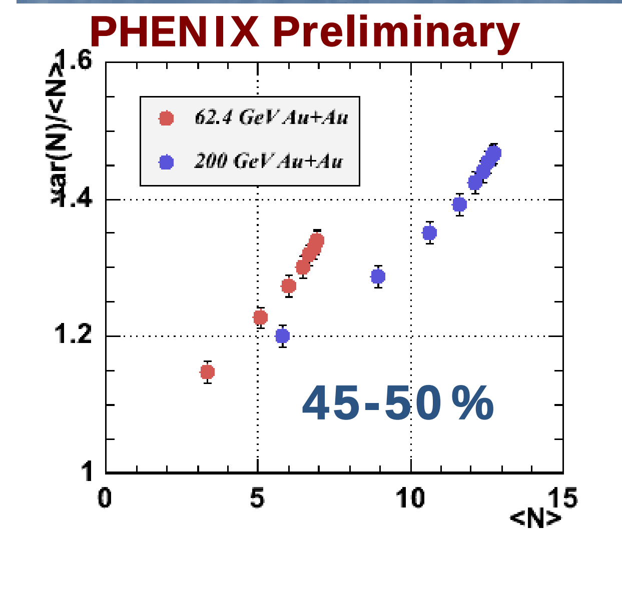


The same trend is seen in Au+Au at all centralities. But notice the change in the upward slope vs. centrality…

Multiplicity Fluctuations vs. $N(p_T)$

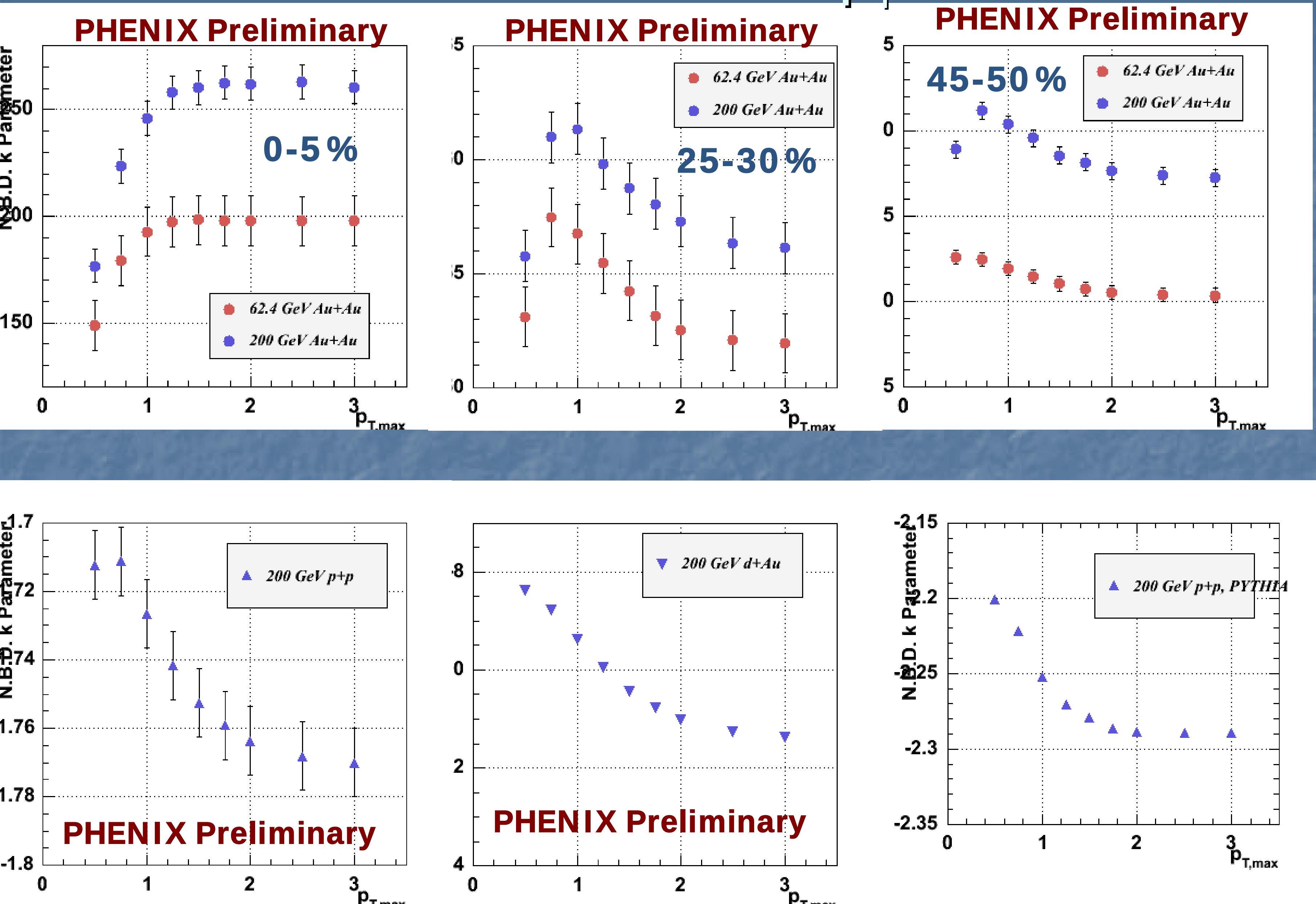






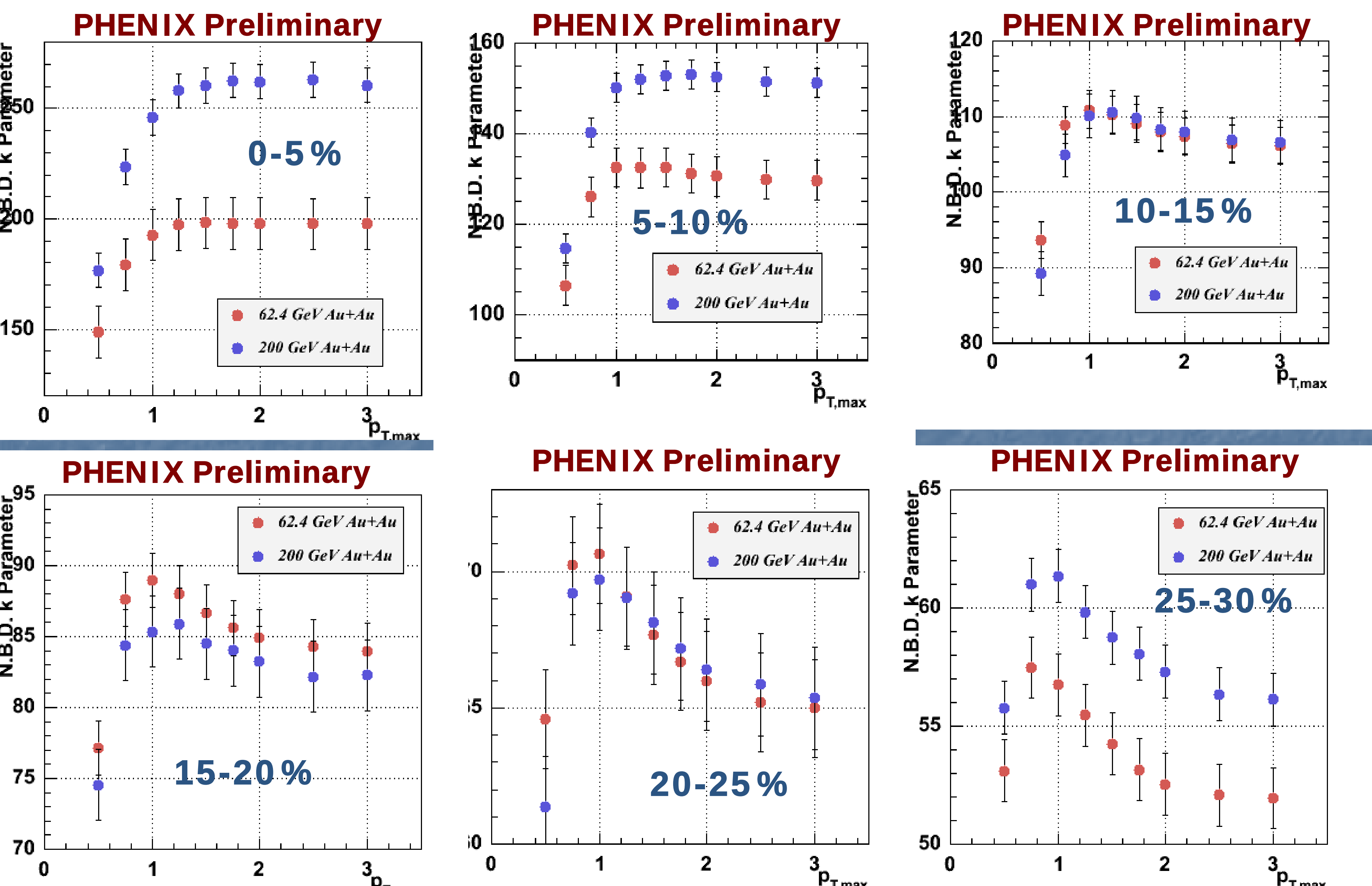
The fluctuations do not scale with <N>

N.B.D. k vs. p_T

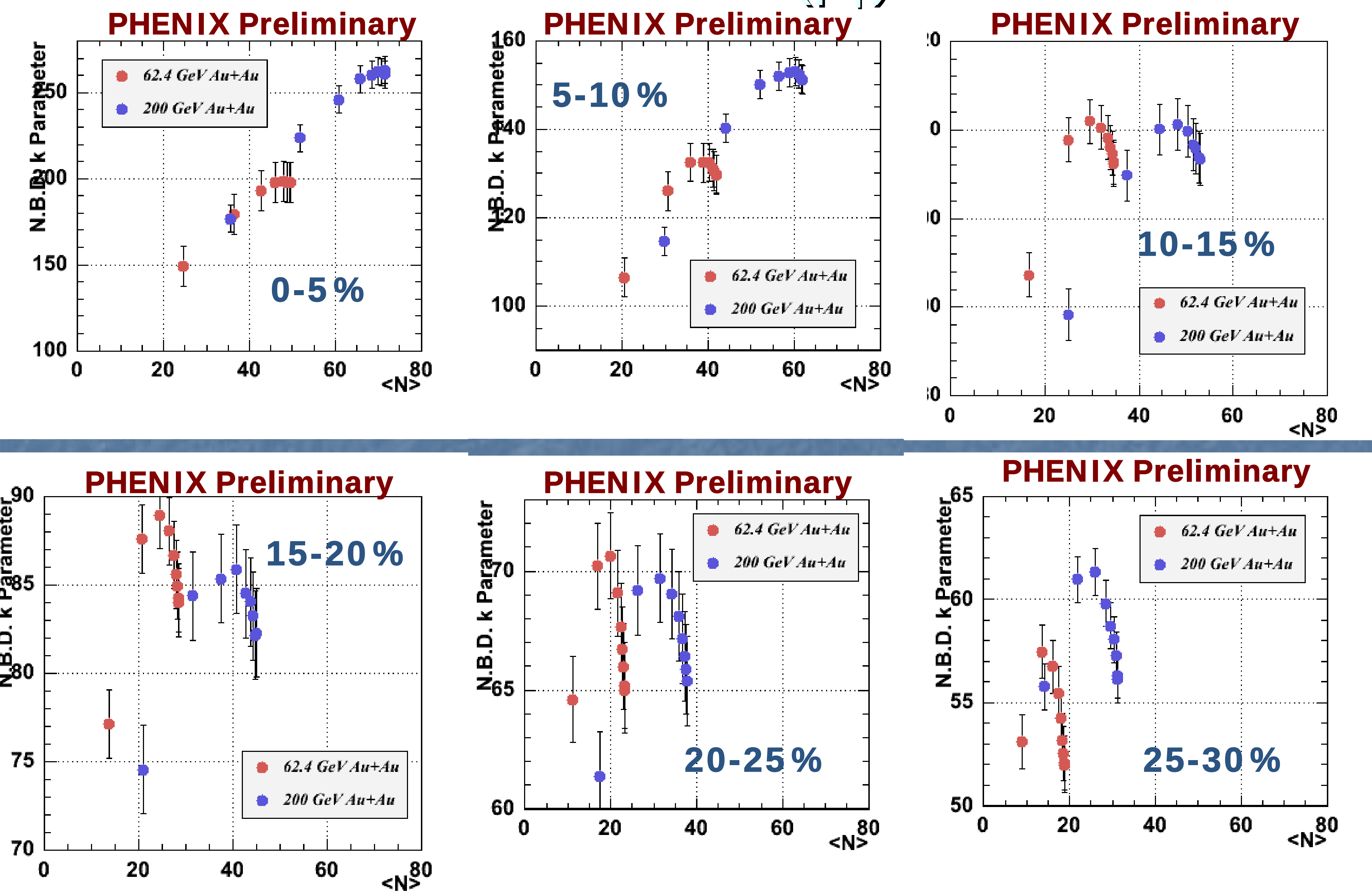


PHENIX Preliminary
0-5 %
62.4 GeV Au+Au
200 GeV Au+Au
N.B.D. k Parameter
$p_{T,max}$
PHENIX Preliminary
25-30 %
62.4 GeV Au+Au
200 GeV Au+Au
$p_{T,max}$
PHENIX Preliminary
45-50 %
62.4 GeV Au+Au
200 GeV Au+Au
$p_{T,max}$
200 GeV p+p
N.B.D. k Parameter
PHENIX Preliminary
$p_{T,max}$
200 GeV d+Au
PHENIX Preliminary
$p_{T,max}$
200 GeV p+p, PYTHIA
N.B.D. k Parameter
$p_{T,max}$

N.B.D. k vs. p_T


PHENIX Preliminary
0-5%
5-10%
10-15%
15-20%
20-25%
25-30%
62.4 GeV Au+Au
200 GeV Au+Au
N.B.D. k Parameter
$p_{T,max}$

N.B.D. k vs. N(p_T)

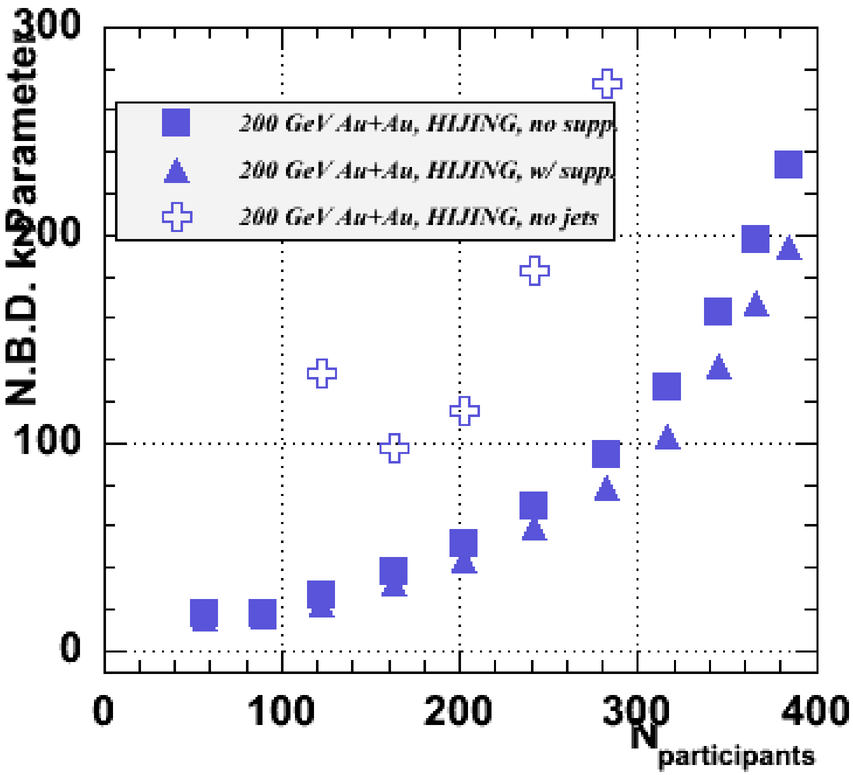

PHENIX Preliminary
0-5%
5-10%
10-15%
15-20%
20-25%
25-30%
62.4 GeV Au+Au
200 GeV Au+Au
N.B.D. k Parameter
<N>

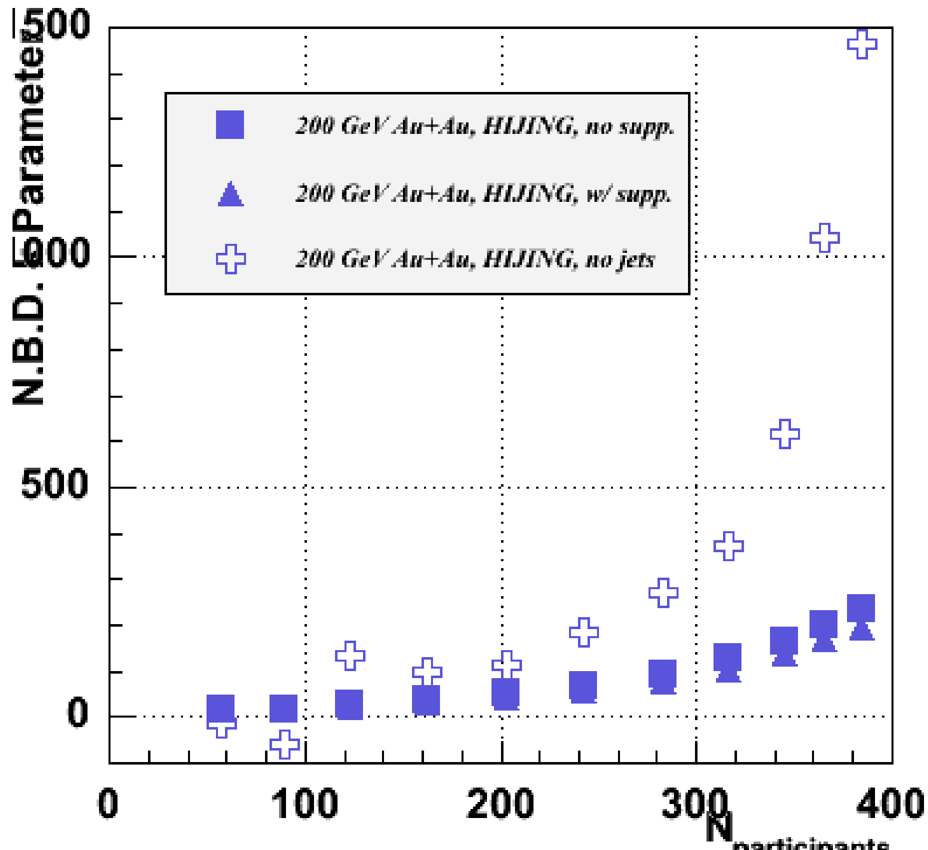
Conclusions

- PHENIX Charge Fluctuations are inconsistent with the QGP predictions.
- PHENIX <pT> Fluctuations vs. Centrality can be explained by introducing a large hard scattering component that is suppressed in central collisions.
- PHENIX multiplicity fluctuations vs. centrality behave differently than at SPS energies, and become more Poisson-like in the most central collisions.
- The behavior of PHENIX multiplicity fluctuations vs. pT range changes between central and peripheral collisions when fit with a Negative Binomial Distribution.

Auxiliary Slides

Multiplicity Fluctuations (k): HIJING 1.35





Elliptic Flow Contribution Simulation

Algorithm: Particles are assigned an azimuthal coordinate based upon the PHENIX measurement of v_2 (wrt the reaction plane) as a function of centrality and p_T. Only particles within the PHENIX acceptance are included in the calculation of M_{pT}.

With the exception of peripheral collisions, the elliptic flow contribution is a small fraction of the observed fluctuation.