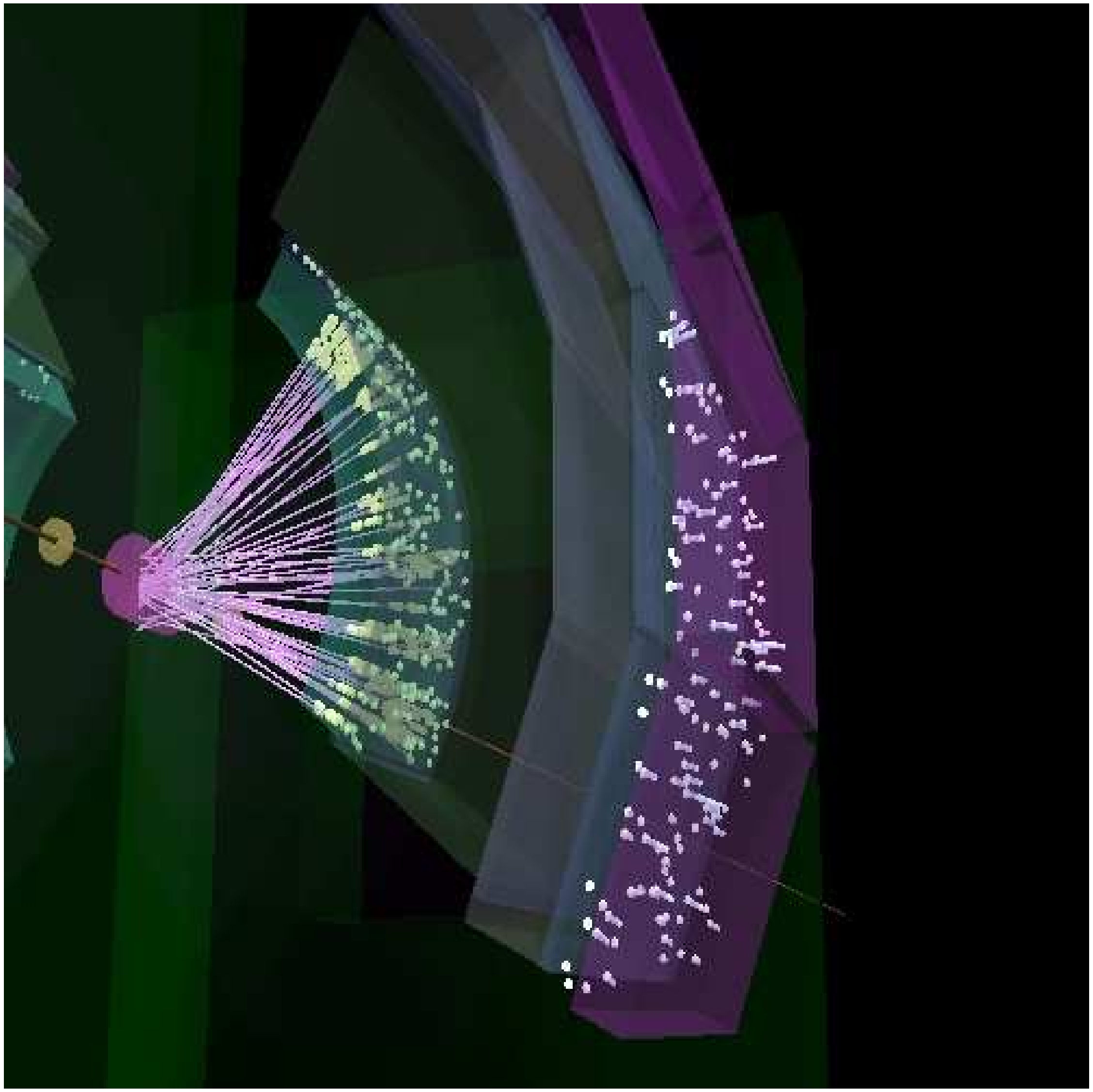
Event-by-event fluctuations in the mean P_t (and E_t) of particles produced in Au+Au Collisions in the PHENIX Experiment at RHIC



Jeffery T. Mitchell

(Brookhaven National Laboratory)

for the PHENIX Collaboration

American Chemical Society Meeting

8/30/01

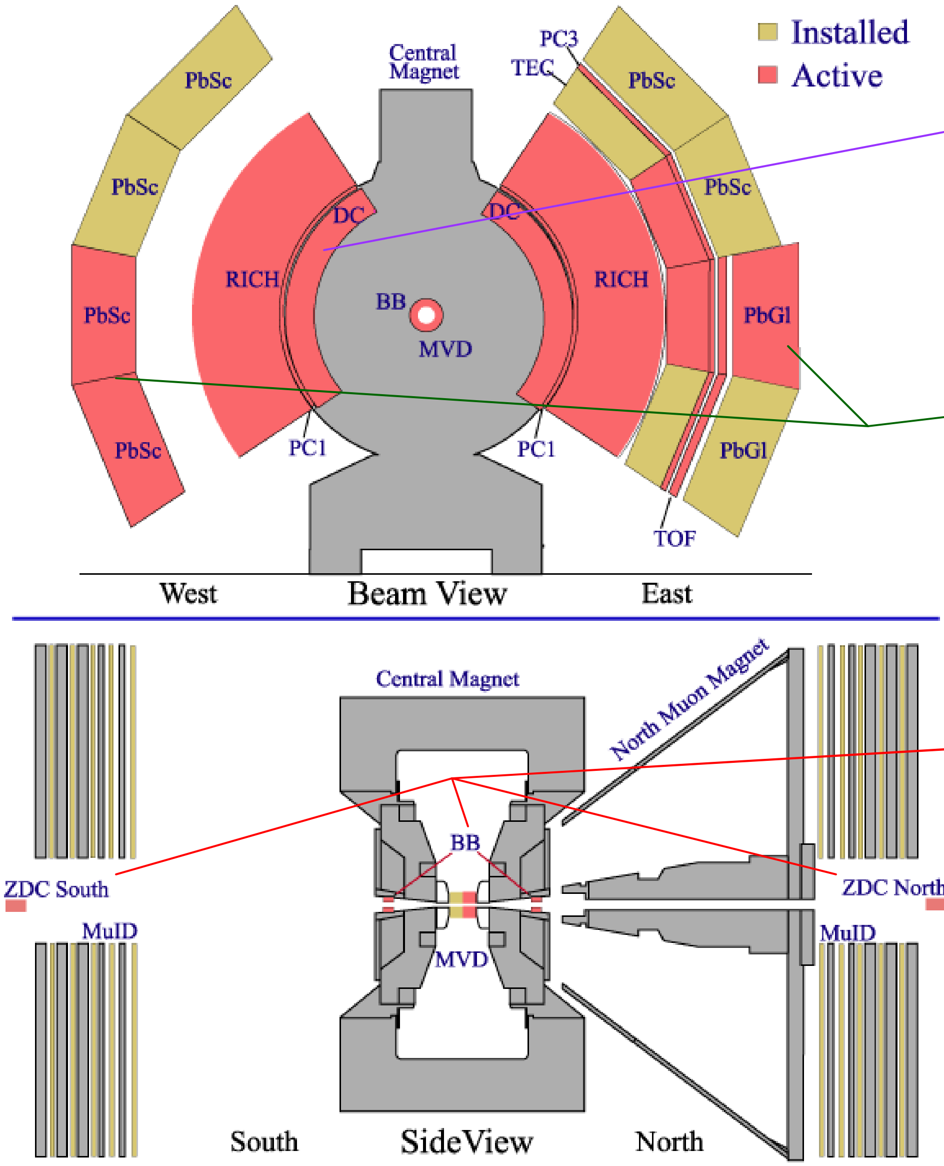
Fluctuation Measurements: Searching for a Phase Transition

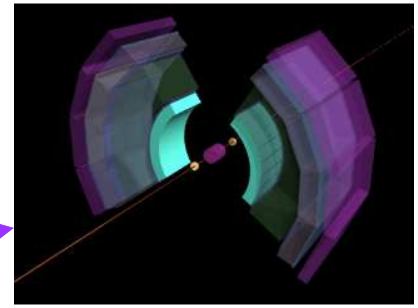
• ***S. Mrowczynski (see Phys. Lett. B314 (1993) 118.)*** **Instability of the plasma could be present, initiated as random color fluctuations. For some events, the fluctuations of particle transverse quantities would be magnified.**

• ***M. Stephanov, et. al. (see hep-ph/9903292)*** **suggest that near a tri-critical point in the QCD phase diagram, the event-by-event fluctuations in p_t could increase significantly.**

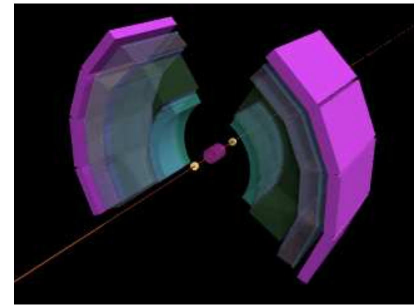
Analogy: Critical Opalescence

PHENIX for Fluctuations

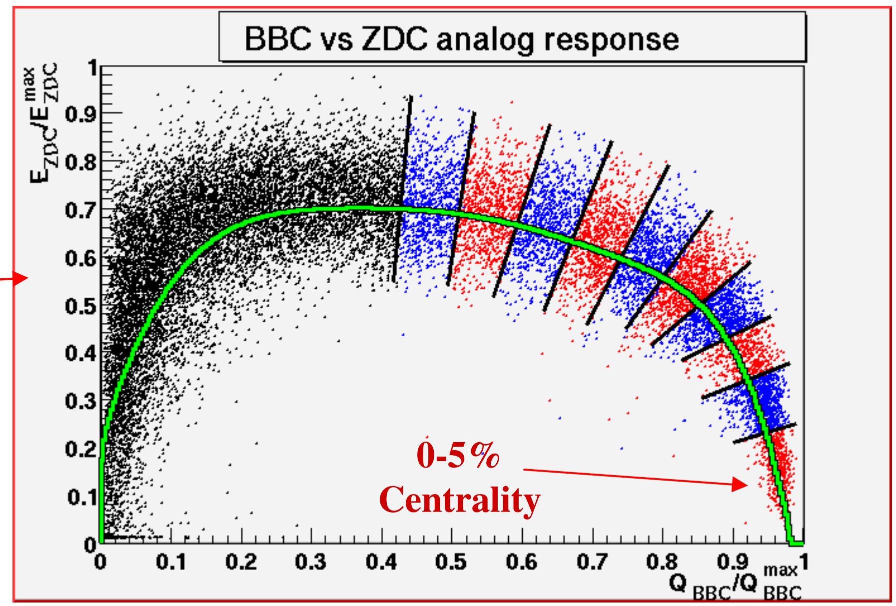




Drift Chamber:
$\langle P_t \rangle$



Calorimeters:
$\langle E_t \rangle$



Centrality Selection

Analysis Details...

Data:

- The mean P_t and E_t are determined on an event-by-event basis:

$$\langle P_t \rangle = \Sigma\, P_{t,\, i} \backslash N \qquad \langle E_t \rangle = \Sigma\, E_{t,\, i} \backslash N$$

- ***200 MeV/c < P_t < 1.5 GeV/c,   225 MeV < E_t < 2.0 GeV***

- *An event must have at least 10 tracks/clusters per event to be included in the mean distribution.*

Mixed Events:

- Mixed event distributions are built from reconstructed tracks/clusters in real events.

- *No 2 tracks/clusters from the same real event are allowed in the same mixed event.*

- *The number of tracks/clusters distribution, <n>, in mixed events are matched to that for the data.*

$<P_t>$ Dataset Statistics

Small apertures in the PHENIX central arm spectrometers, but particles are plentiful in RHIC Collisions…

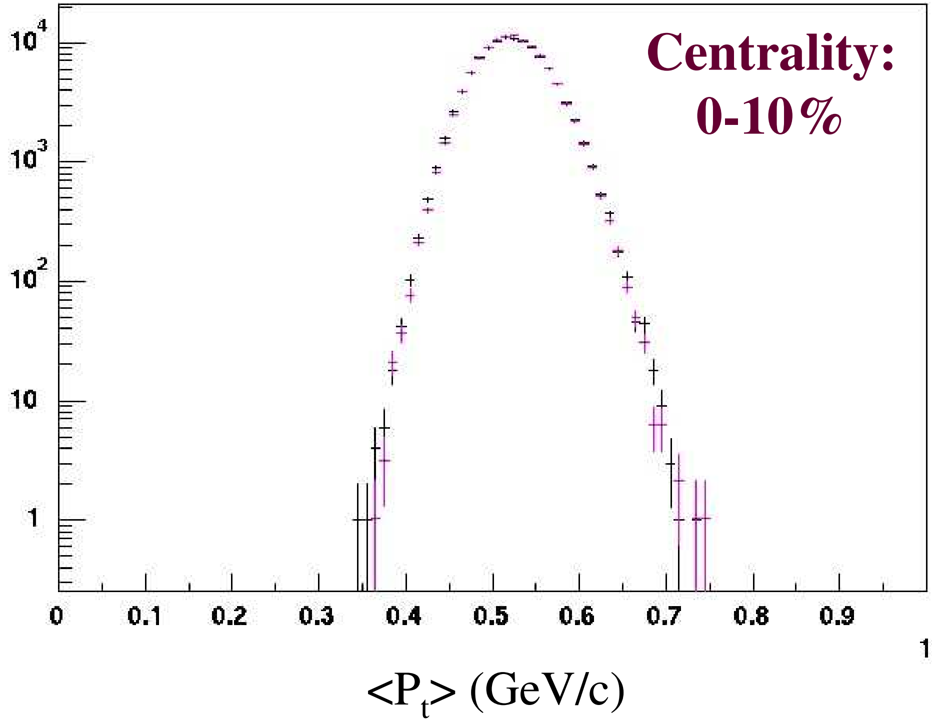
Acceptance: $\eta<|0.35|$, $\Delta\phi \sim 45^0$

NOTE: Distributions are left uncorrected for static acceptance/efficiency

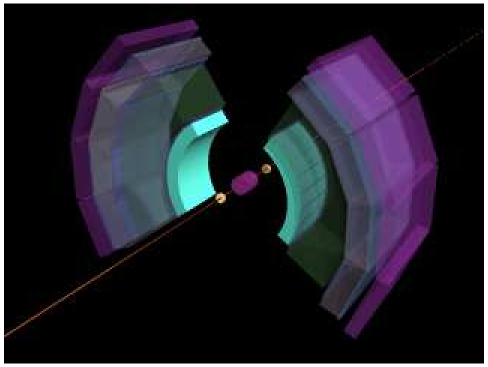
Centrality	$<n>$	$<P_t>$
0-5% 51,163 events	60.5±10.7	.523±.038
0-10% 110,122 events	55.6±11.7	.523±.041
10-20% 119,248 events	39.4±9.9	.523±.050
20-30% 112,301 events	28.0±7.6	.522±.061
30-40% 112,388 events	18.9±6.4	.519±.073

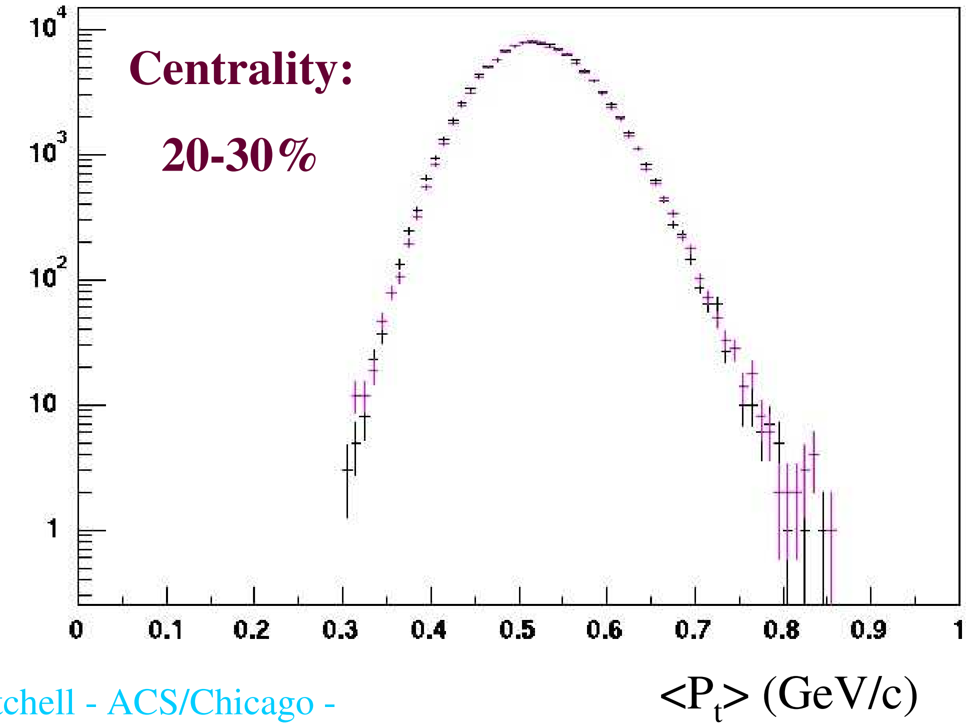
$<P_t>$, as a function of centrality

PHENIX Preliminary



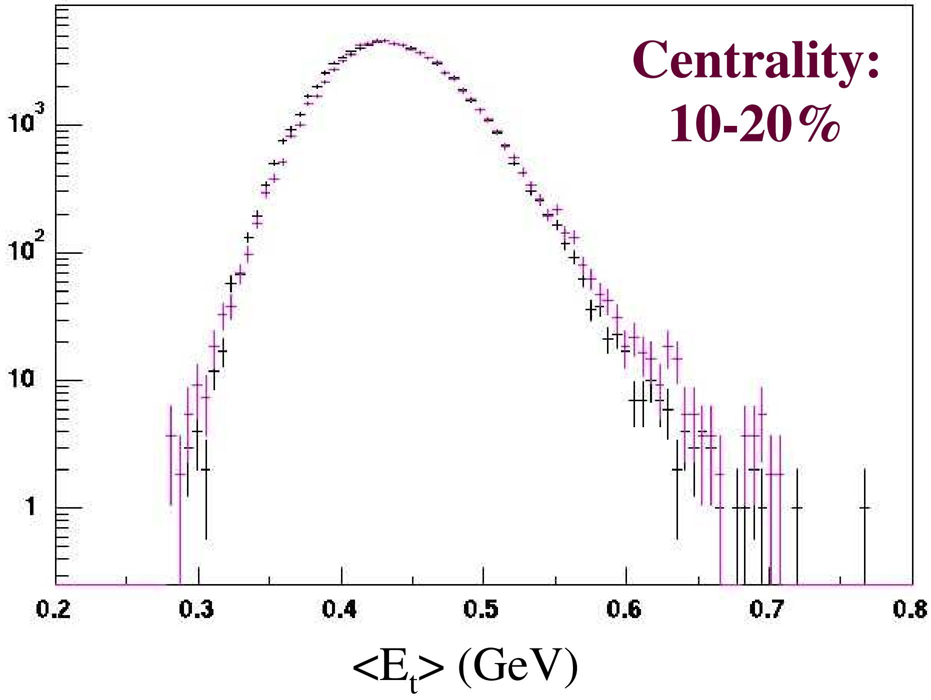
Mixed Event Distribution



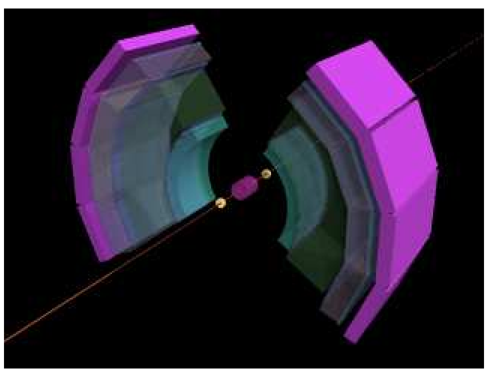


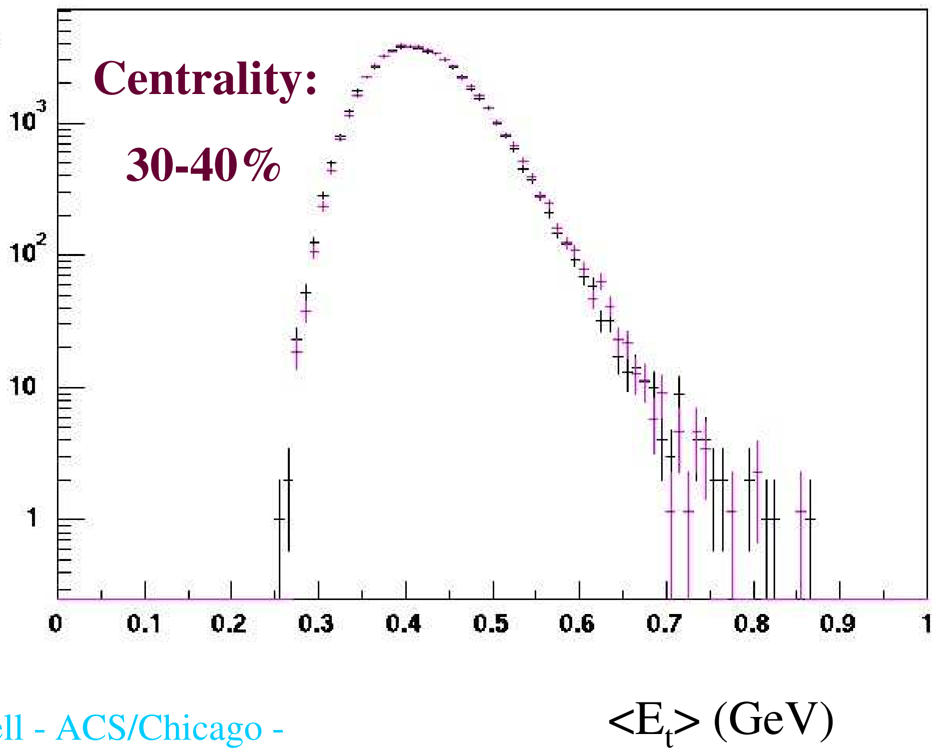
$\langle E_t \rangle$, as a function of centrality

PHENIX Preliminary



Mixed Event Distribution





Relating Semi-inclusive to Event-by-Event P_t and E_t Spectra

Calculation for Statistically Independent Emission:

- See *M. Tannenbaum, Phys. Lett. B498 (2001) 29*.

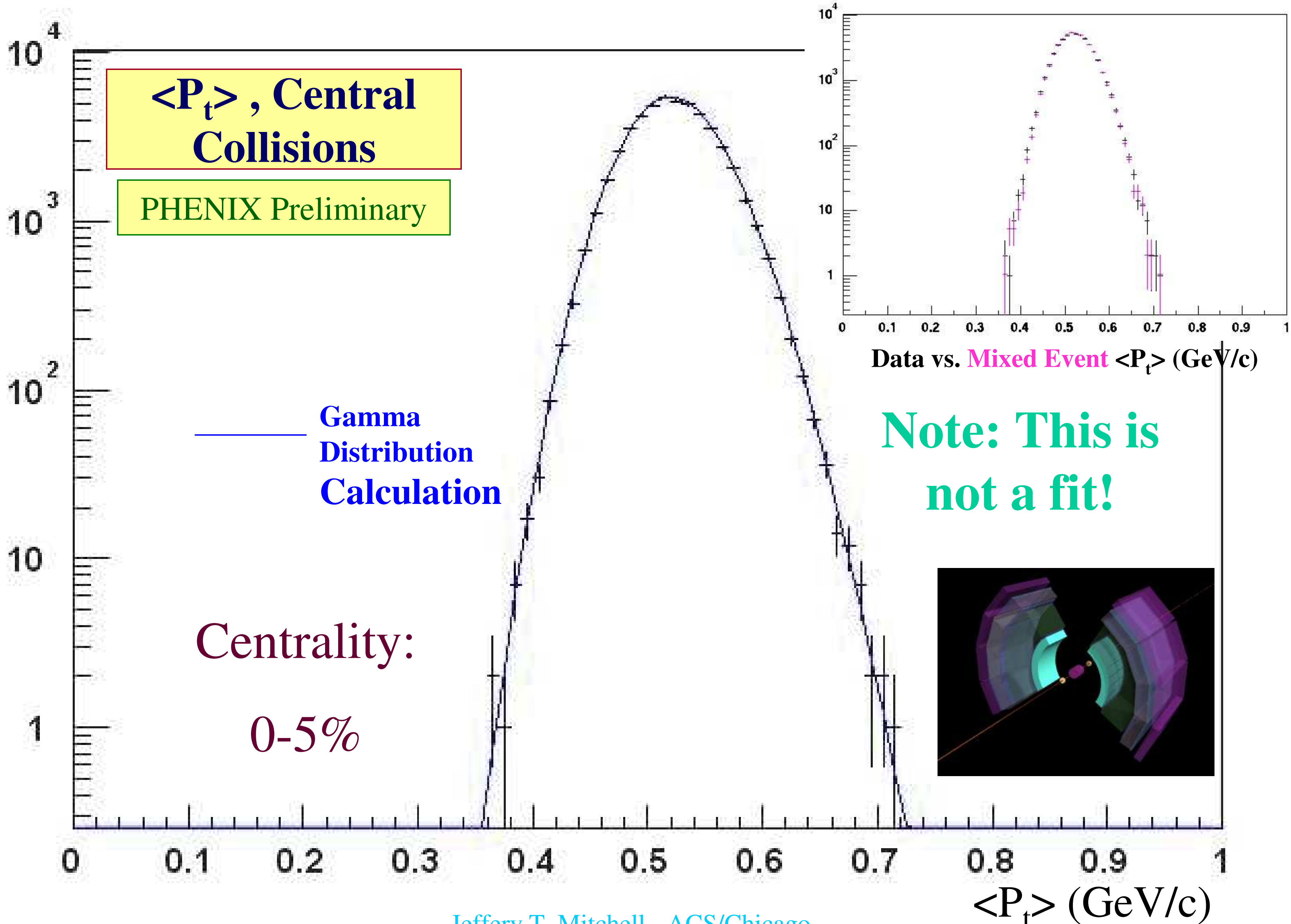
The random distribution is a gamma distribution, $f_\Gamma(M_X,np,nb)$, where

$$p = \frac{<X>^2}{\sigma_X^2} \qquad b = \frac{<X>}{\sigma_X^2}$$

- Using these parameters extracted from the semi-inclusive distributions, calculate:

$$f(Mean_X) = \Sigma\, f_{NBD}(n,1/k,<n>)\, f_\Gamma(Mean_X,np,nb),$$

summed from $n=n_{min}$ to $n=n_{max}$



<Pt> , Central Collisions
PHENIX Preliminary
Gamma Distribution Calculation
Centrality:
0-5%
Note: This is not a fit!
Data vs. Mixed Event <Pt> (GeV/c)
<Pt> (GeV/c)
10^4
10^3
10^2
10
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Quantifying the Fluctuations

Define the magnitude of a fluctuation, ω:

$$\omega = \frac{\sqrt{< X^2 > - < X >^2}}{< X >} \times 100\% = \frac{\sigma}{\mu} \times 100\%$$

Define the percent fluctuation difference from random, d:

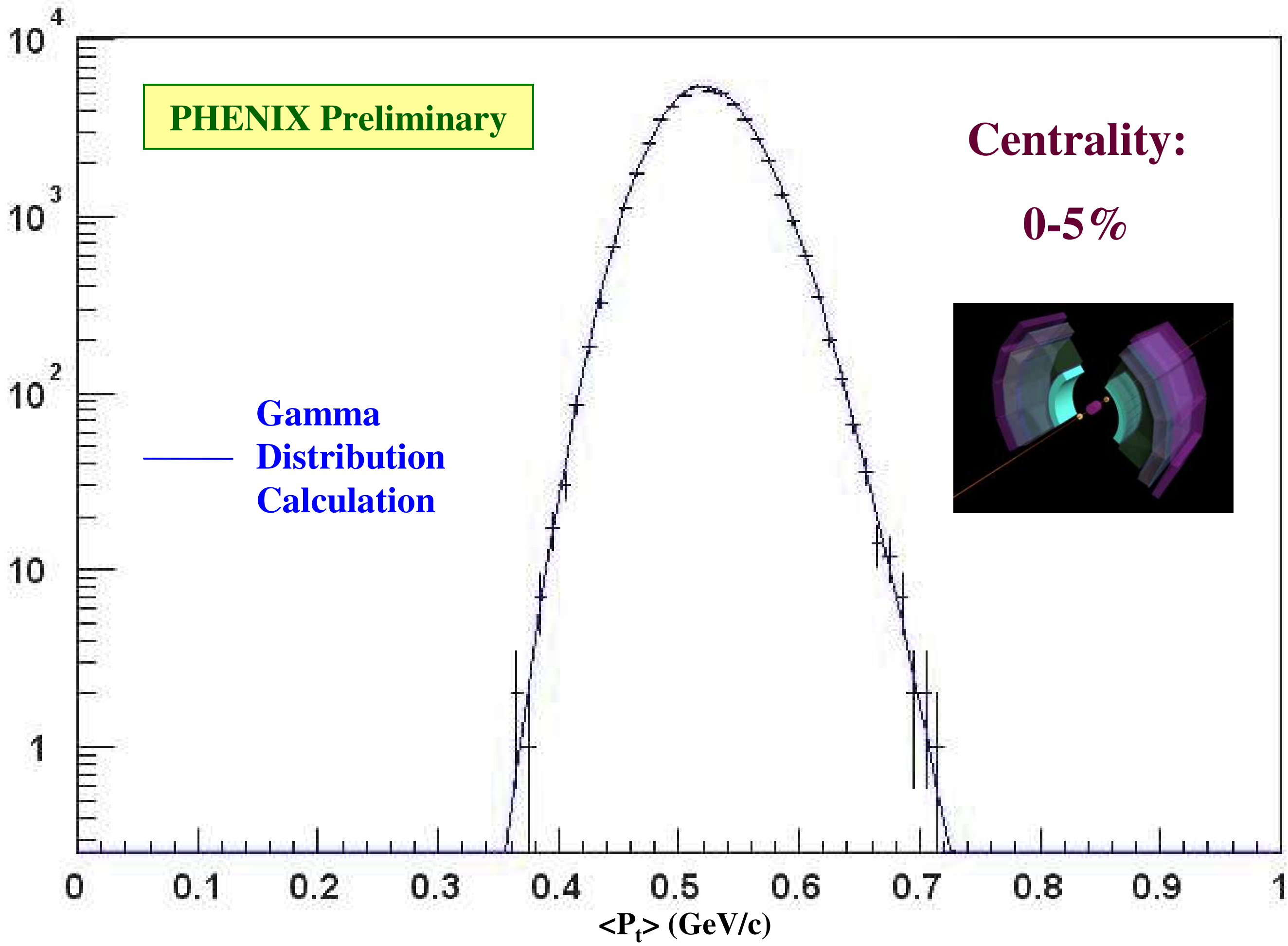
$$d = \omega_{data} - \omega_{random}$$

Also commonly used is the variable, ϕ:

$$\phi = \sqrt{n}\left(\sigma_{data} - \sigma_{random}\right) = d\mu\sqrt{n}$$

Quantifying the Fluctuations

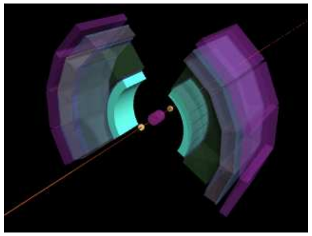
$d = 0.26 \pm 0.1\%$ $\phi = 10.5 \pm 1.5$ MeV



Comparing Data to Mixed Event Distributions

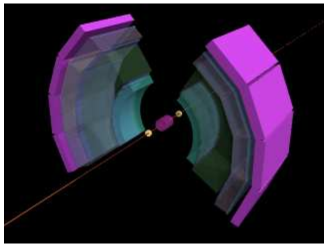
$\langle P_t \rangle$:

Centrality	Δ	φ
0-5%	0.14 ± 0.11%	5.65 ± 4.44 MeV
0-10%	0.16 ± 0.18%	6.14 ± 6.91 MeV
10-20%	0.19 ± 0.19%	6.01 ± 6.01 MeV
20-30%	0.21 ± 0.33%	5.49 ± 8.63 MeV
30-40%	0.26 ± 0.29%	5.23 ± 5.83 MeV



$\langle E_t \rangle$:

Centrality	Δ	φ
0-10%	0.34 ± 0.58%	11.5 ± 19.6 MeV
10-20%	-0.04 ± 0.38%	-1.06 ± 10.56 MeV

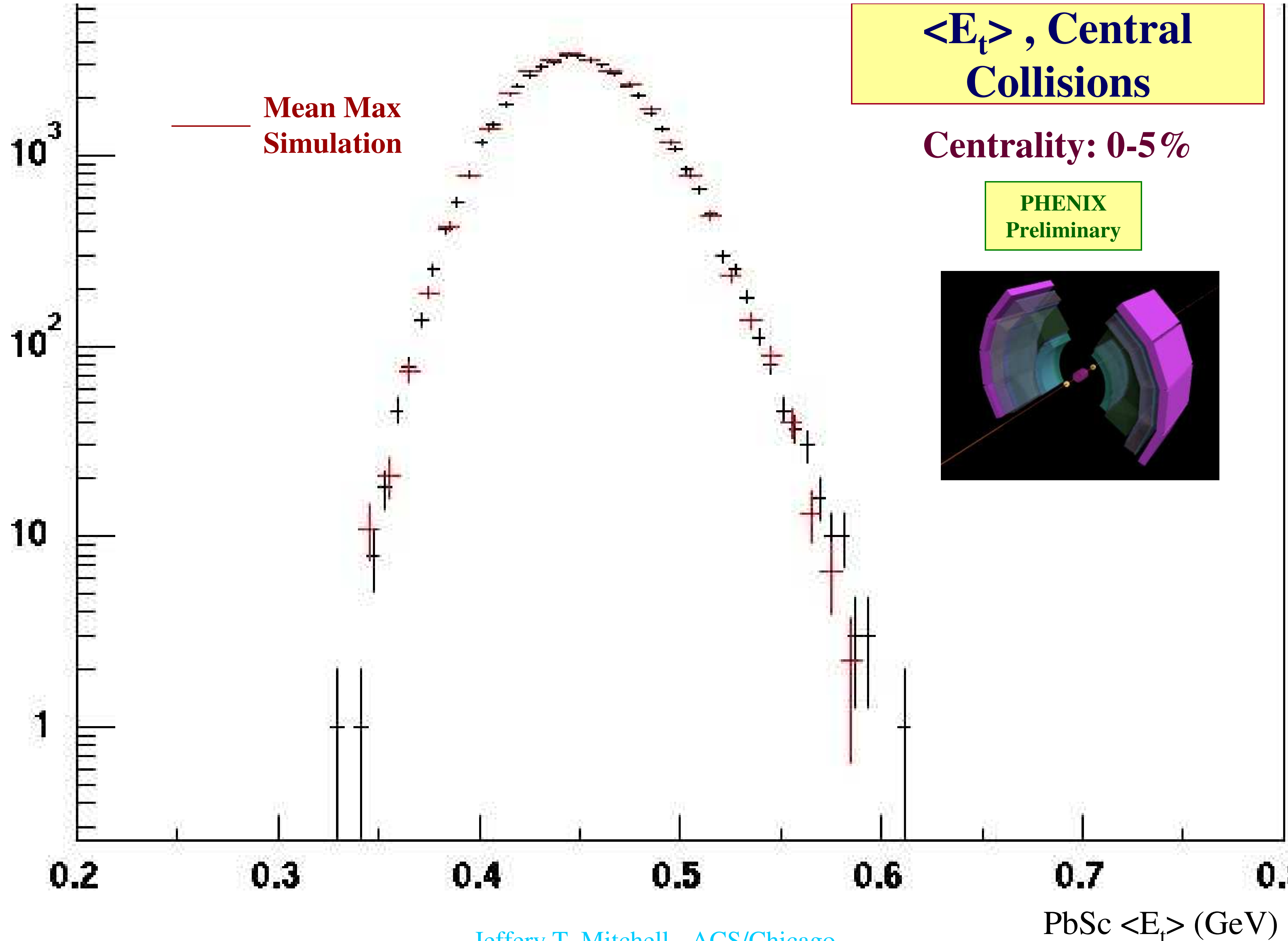


Determining the Fluctuation Sensitivity

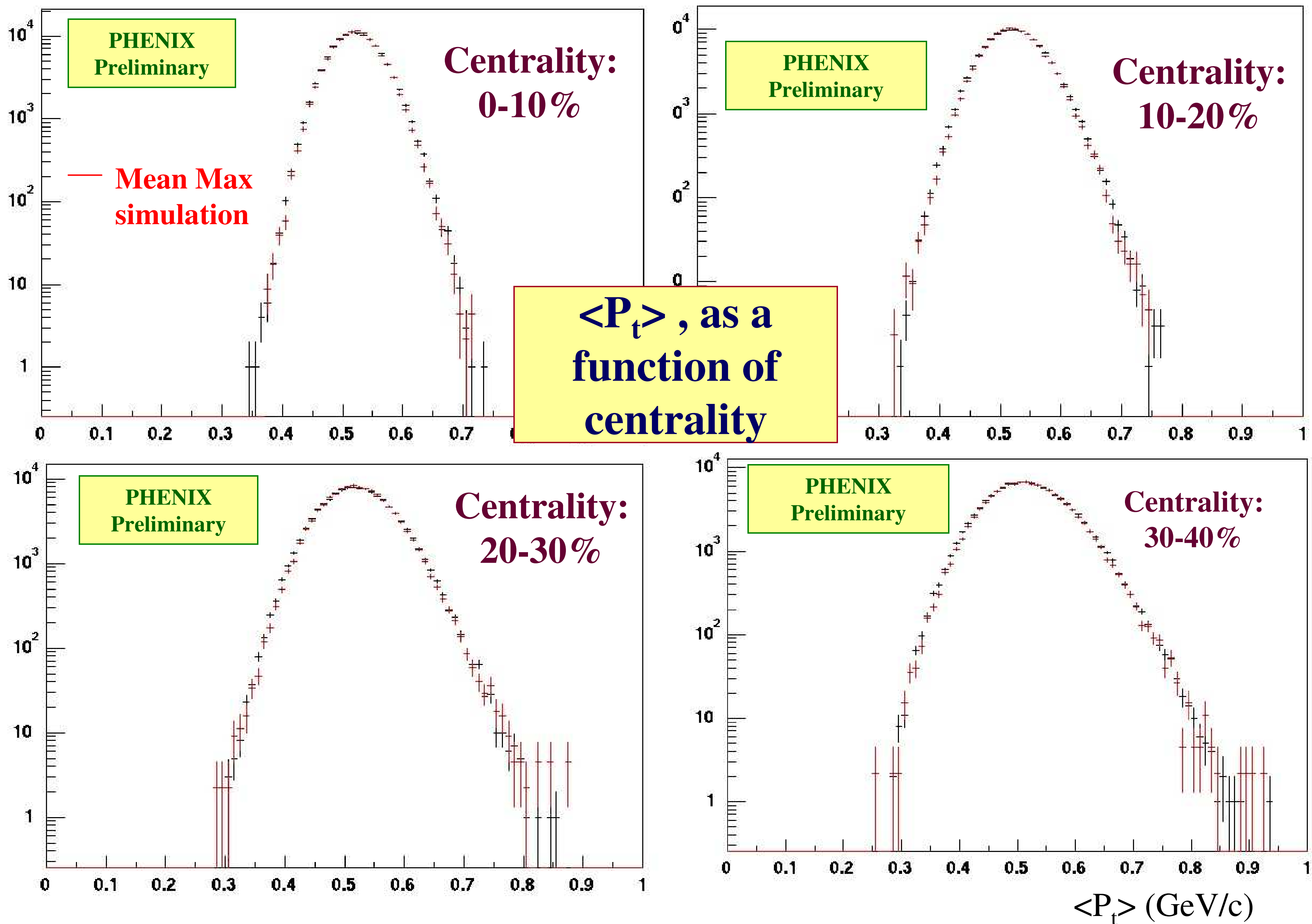
Simulation for Statistically Independent Emission:

MEAN MAX

- Parameterizes the semi-inclusive P_t or E_t (as a Gamma or exponential distribution) and $\langle n \rangle$ (Gaussian) distributions over the same ranges used to calculate $\langle P_t \rangle$ and $\langle E_t \rangle$ for the data.
- Generates $\langle P_t \rangle$, $\langle E_t \rangle$ after applying cuts on n_{min}, P_t, and E_t ranges.
- For the calorimeter, cluster merging is simulated by matching the cluster separation distribution, per event, to the data.


$\langle E_t \rangle$, Central Collisions
Centrality: 0-5%
PHENIX Preliminary
Mean Max Simulation
10^3
10^2
10
1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
PbSc $\langle E_t \rangle$ (GeV)

$\langle P_t \rangle$, as a function of centrality



Modelling a fluctuation

Goal: Produce a fluctuation that does not change the mean of the final semi-inclusive distribution.

- The final semi-inclusive distribution can be expressed as:

$$\frac{d\sigma}{dp_t} = b^2 p_t e^{-bp_t} = \Gamma(p_t, p = 2, b = 2/\langle p_t \rangle)$$

where T = 1/b is the *inverse slope parameter* of the distribution.

- Define the event-by-event fluctuation fraction, q:

$$q = N_{events,\,fluctuating} / N_{events,\,non-fluctuating}$$

Modelling a fluctuation

Goal: Produce a fluctuation that does not change the mean of the final semi-inclusive distribution.

- The distribution for a fluctuating sample can be taken as:

$$f(p_t) = q \times \Gamma(p_t, b1, p1) + (q-1) \times \Gamma(p_t, b2, p2)$$

- For both distributions to have the same μ:

$$\mu = {}^{p}\!/_{b} = {}^{p_1}\!/_{b_1} = {}^{p_2}\!/_{b_2}$$

- Choose p1 and q. Obtain p2 using:

$$p_2 = \frac{1-q}{{}^{1}\!/_{p} - {}^{q}\!/_{p_1}}$$

- Use the constant μ to extract b1 and b2.

An example of a modelled large fluctuation

Black = baseline distribution within the PHENIX acceptance. No fluctuation modelled.

Red = Fluctuation distribution with

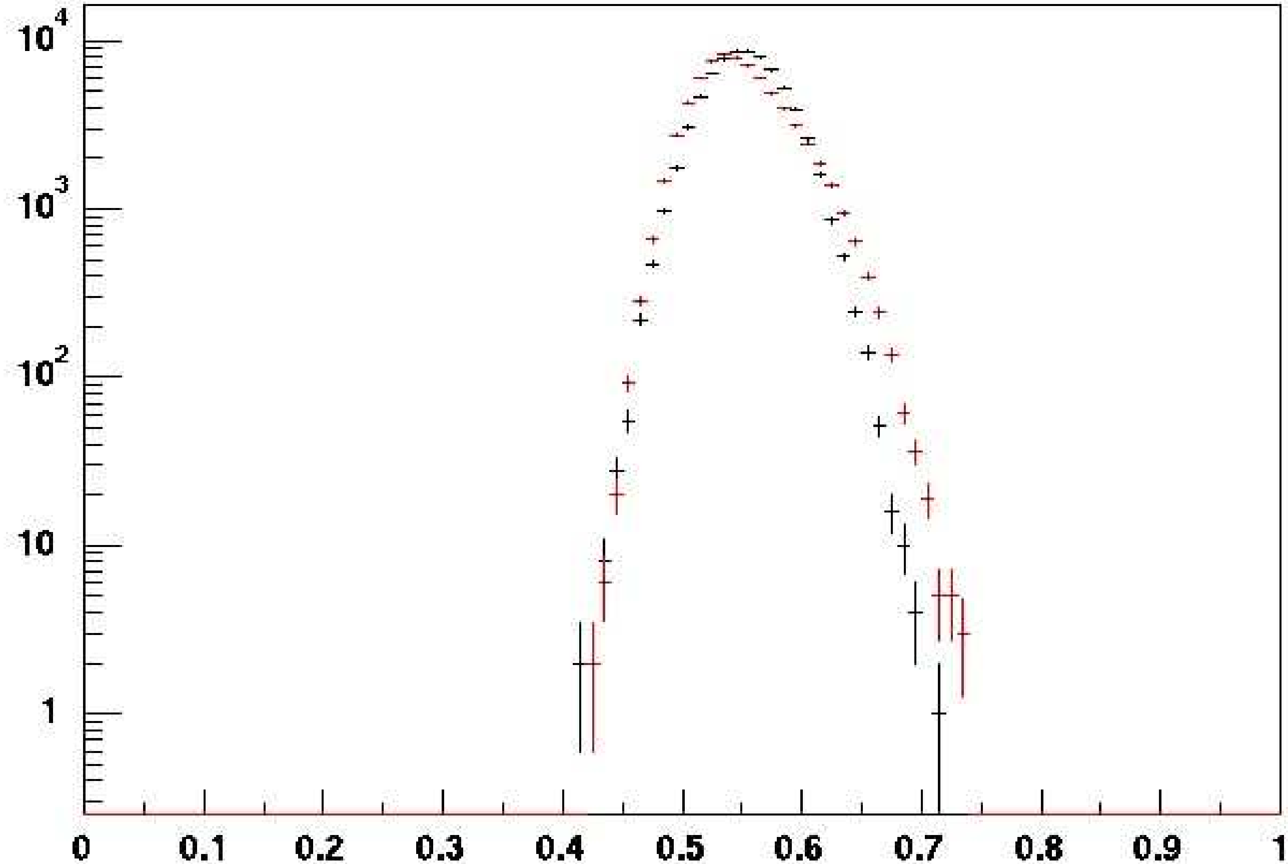
$q = 60\%$, $b_1 = 87.1$ MeV, $b_2 = 257$ MeV.

$\omega_{base} = 6.02\%$

$\omega_{model} = 6.98\%$

$d = 0.96\%$

$\phi = 38.7$ MeV



Determining the Fluctuation Sensitivity

Procedure

• Start with identical <n> and semi-inclusive spectra as for the data.

• Scan over the fluctuation fraction q, and p1.

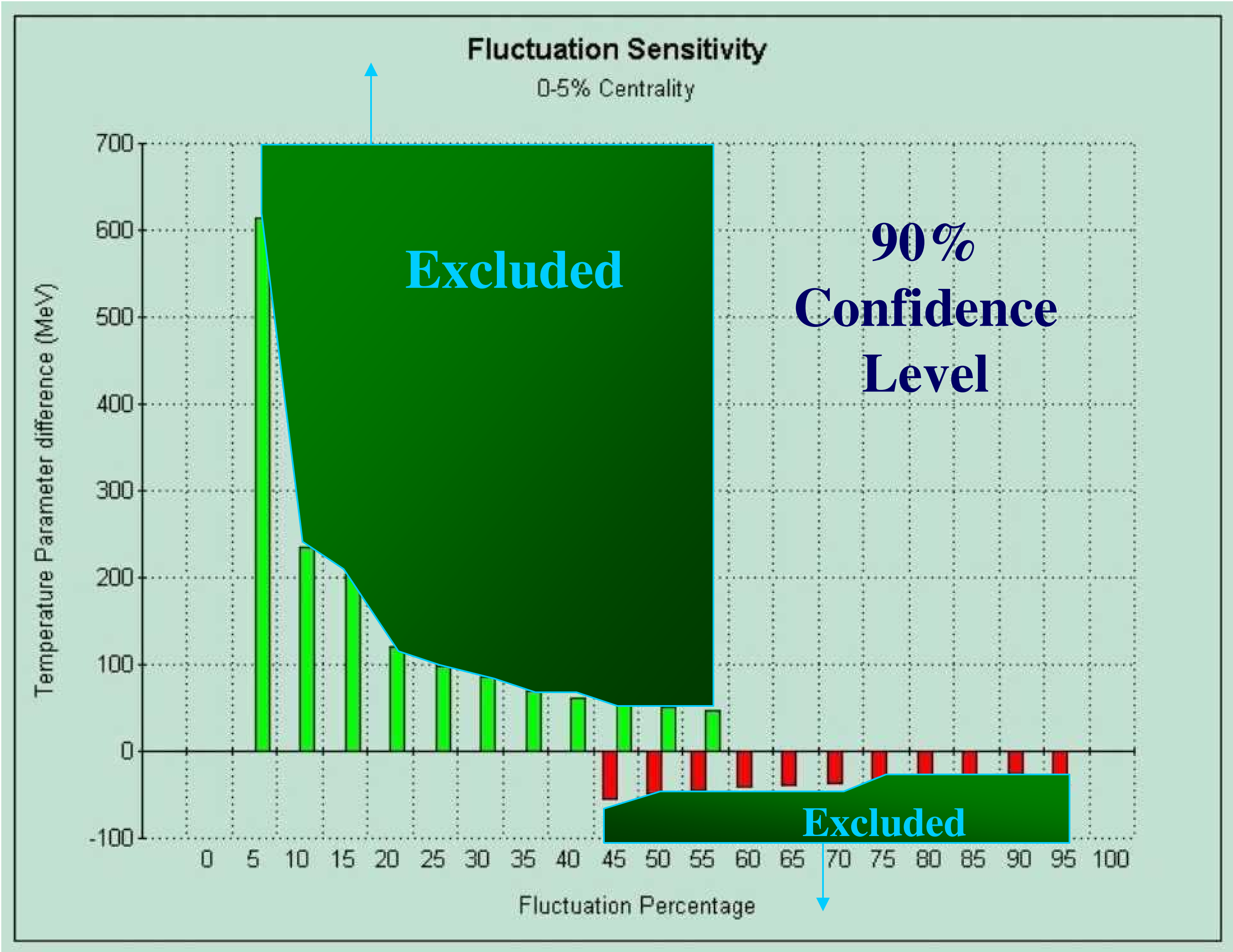
• Randomly determine fluctuating events against q.

• Generate *qN* events with distribution 1, and *(1-q)N* events with distribution 2.

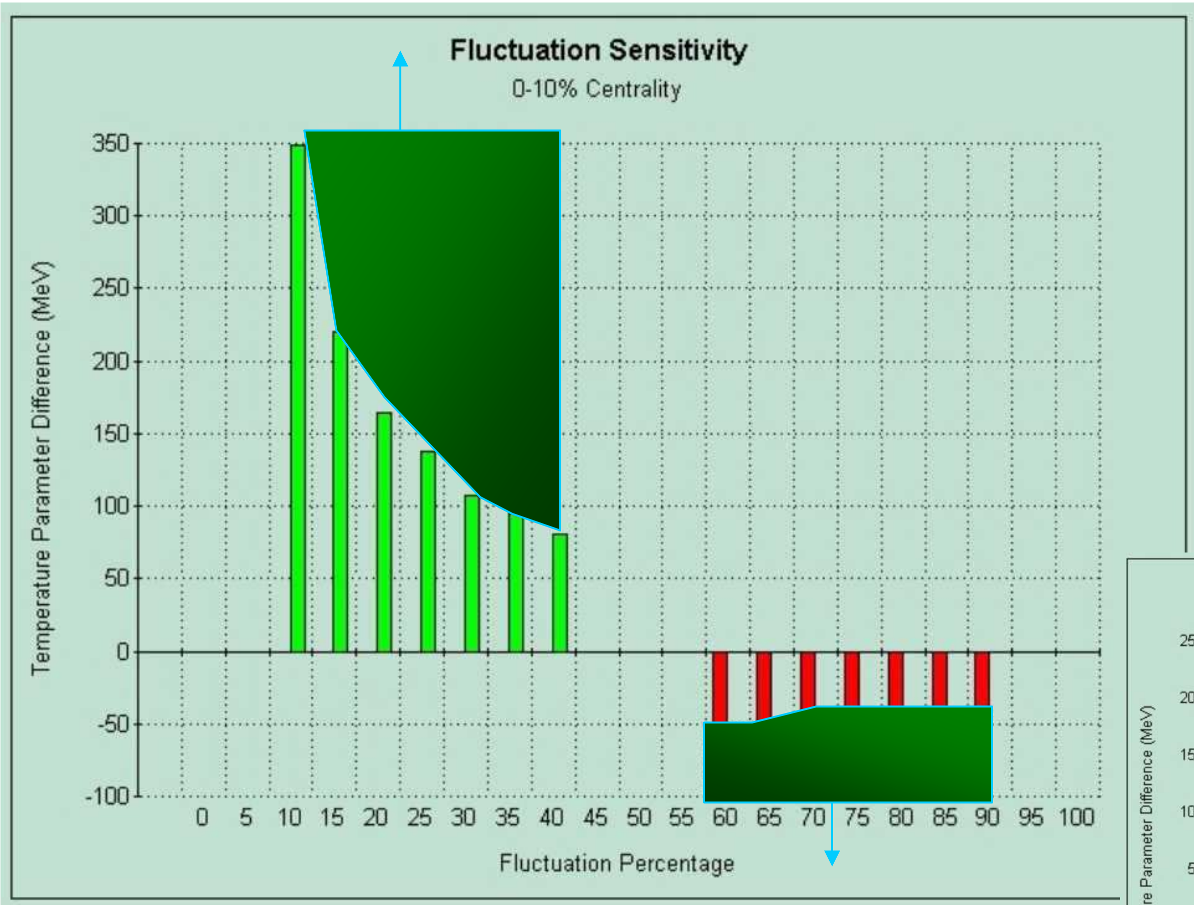
• Include separate background distributions on a per particle basis. These are estimated by processing HIJING events through *GEANT* + *detector response* + *track and momentum reconstruction*.

• Calculate <P_t> for all events and calculate *d*.

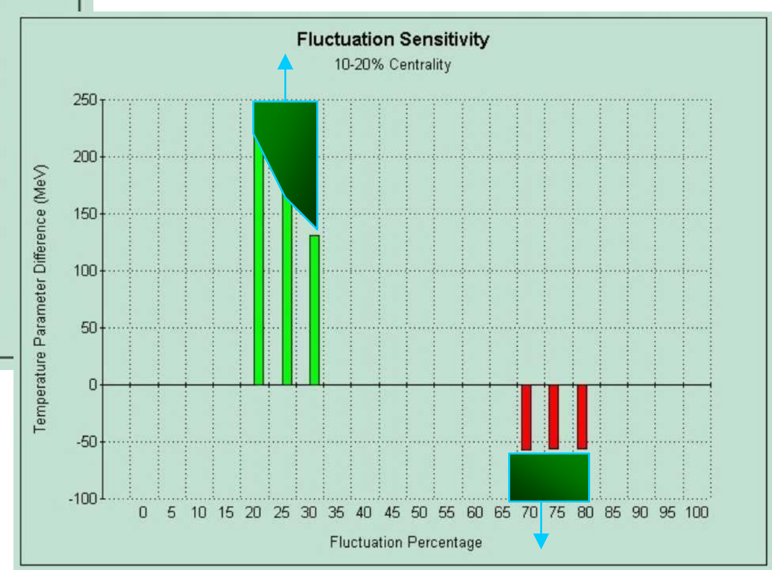
<P_t> Fluctuation Limits: 0-5% Centrality



$<P_t>$ Fluctuation Limits: 0-20% Centrality



90% Confidence Level



Conclusions and Outlook

Conclusions:

- This analysis does not see large non-statistical fluctuations in the event-by-event mean transverse momentum or mean transverse energy spectra within centralities ranging from the upper 0-40% of the total cross section at mid-rapidity.
- All event-by-event spectra can be described by the semi-inclusive spectra.
- Given a simple temperature fluctuation model, limits have been set on the level of fluctuations based upon these measurements.

Outlook:

- Extension of this analysis to cover more peripheral collisions will be possible in the 2001 PHENIX run due to a factor of ~4 increase in acceptance in the central arm spectrometers.

Explaining Increased Fluctuations Near a Tri-Critical Point

- According to: *M. Stephanov, et. al. (see hep-ph/9903292)*

- At freeze-out (as a chiral transition), the σ meson is the most numerous particle species, and it is nearly massive at this time. All fields can fluctuate at the QCD tri-critical point.

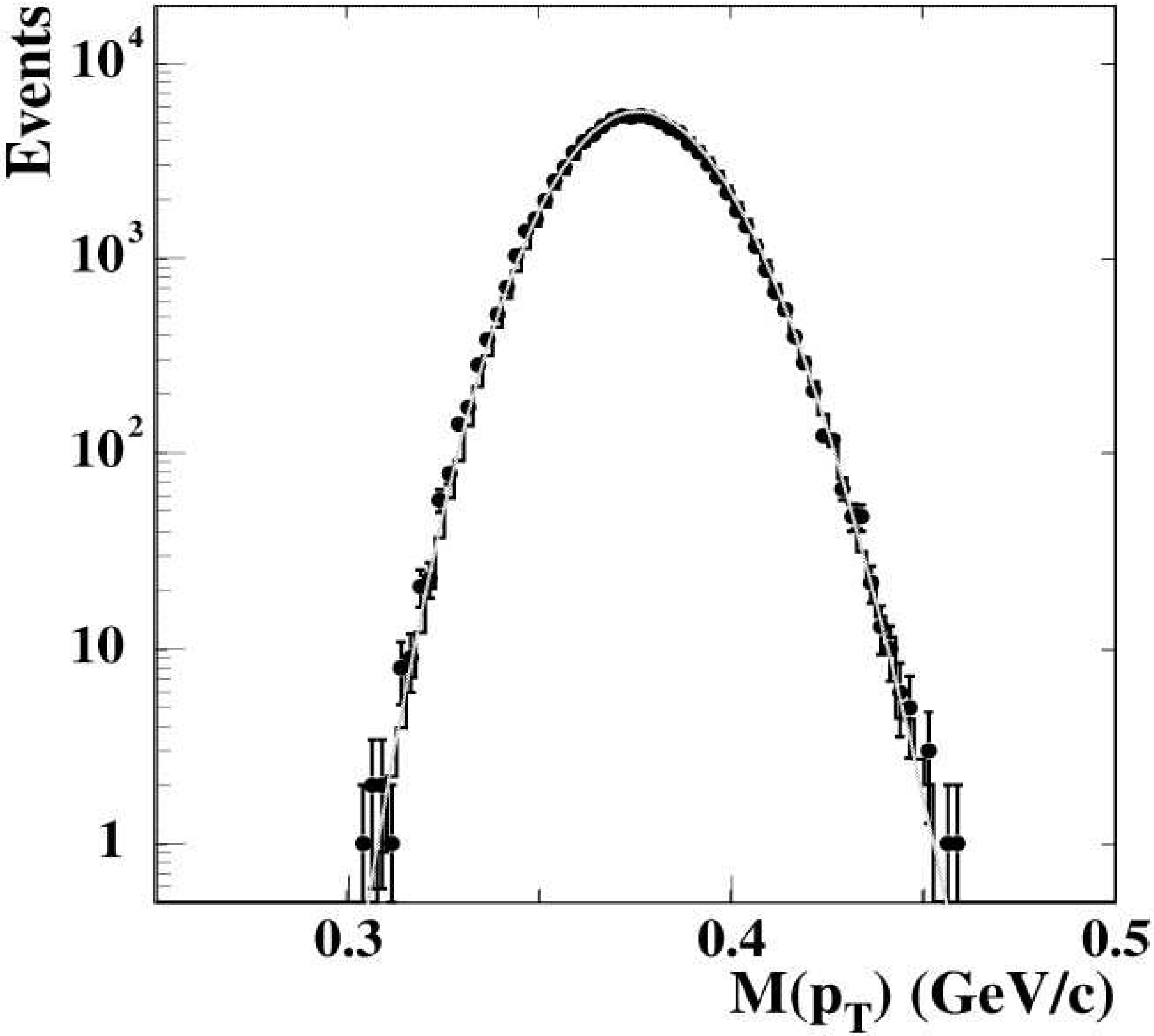
- Since the π is massive, the σ cannot immediately decay. It must wait for the density to decrease and for its mass to rise towards the vacuum value.

- Once the $\pi\pi$ threshold is exceeded, the decay proceeds rapidly since the $\sigma\pi\pi$ coupling is large. This occurs after freeze-out, so the pions don't thermalize.

- If the σ mass at freeze-out is $< T$, the thermal fluctuations of N_σ are determined by the classical statistics of the σ field rather than by Poisson statistics of the particles. This implies that $\langle N_\sigma^2\rangle - \langle N_\sigma\rangle^2 \sim \langle N_\sigma\rangle^2$ rather than $\langle N_\sigma\rangle$.

- Therefore, large event-by-event fluctuations could be expected in N_π and $\langle p_t\rangle$.

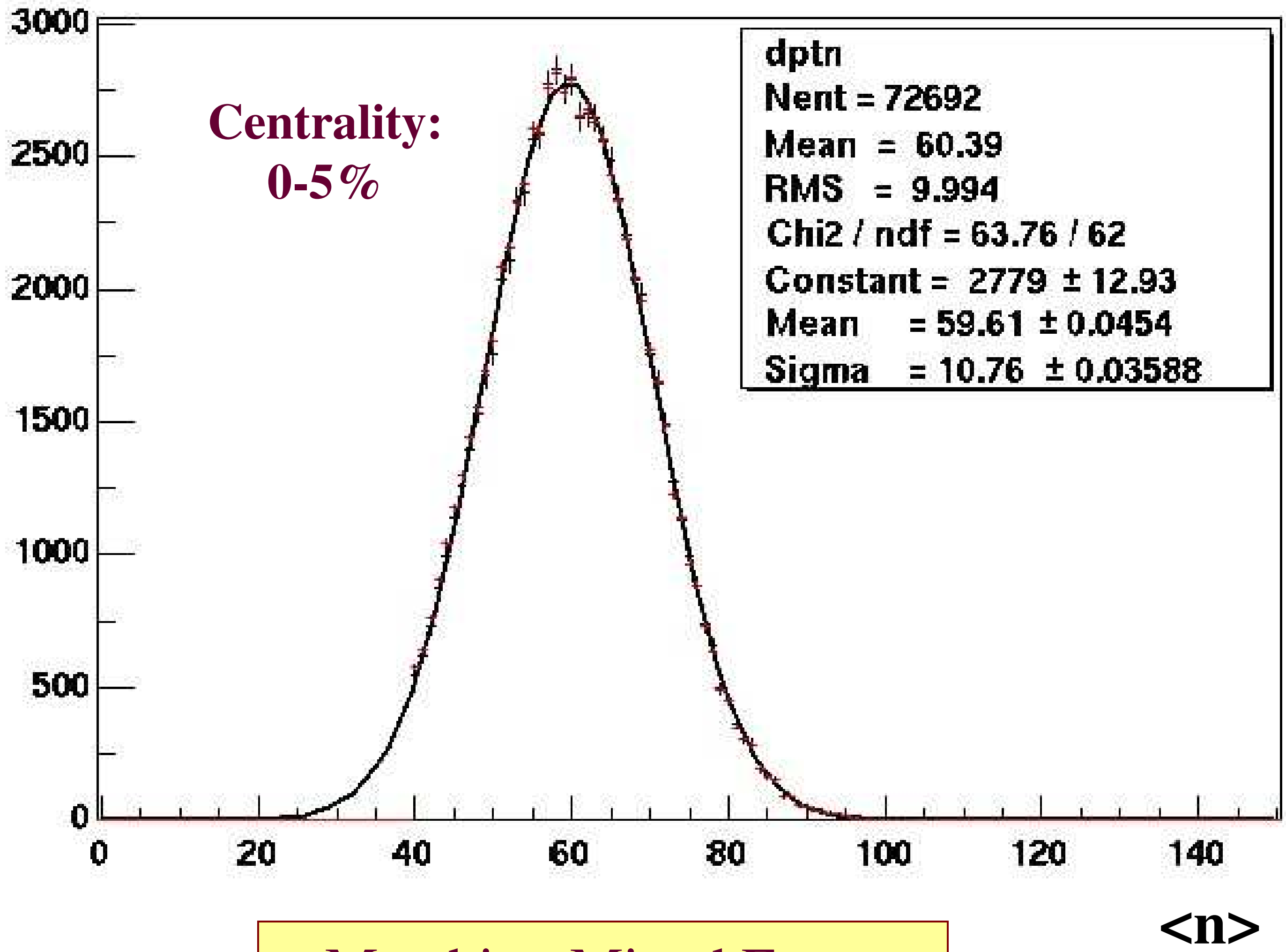
$\langle P_t \rangle$ Measurement from CERN Experiment NA49



- See H. Appelshauser, et. al., Phys. Lett. B459 (1999) 679.
- Distribution is compatible with independent particle production.

$\langle E_t \rangle$ Dataset Statistics

Centrality	$\langle n \rangle$	$\langle E_t \rangle$ (GeV)
0-5% 45,042 events	65.9±11.1	.451
0-10% 90,151 events	60.3±12.5	.448
10-20% 75,289 events	42.0±9.4	.438
20-30% 73,634 events	28.8±7.9	.428
30-40% 51,427 events	19.0±6.8	.422



Number of tracks (clusters) per event:

Black = data

Red = mixed events

Matching Mixed Event Characteristics to Real Event Characteristics

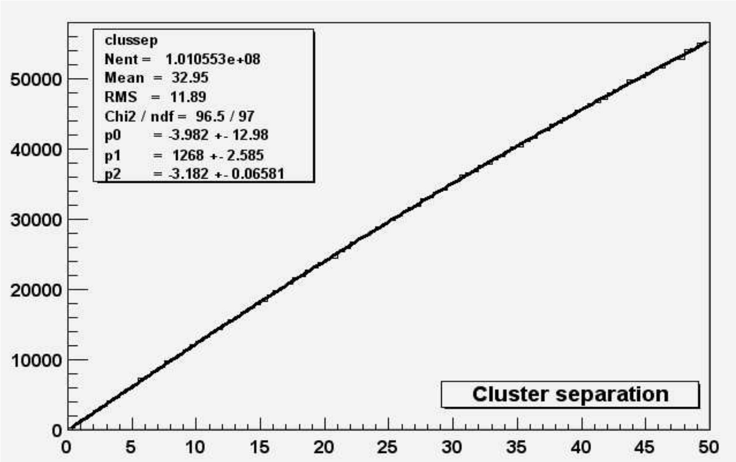
PbSc Mean Et: Cluster Merging Introduces Correlations.

Mean Max is again used to model the affect of merged clusters.

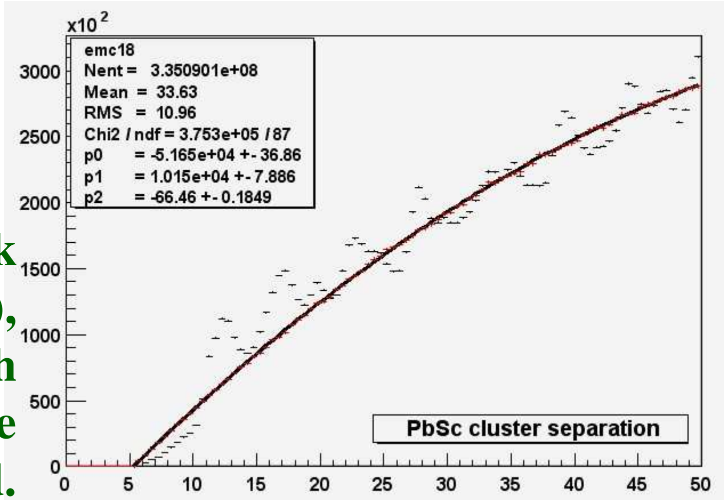
Procedure: Generate clusters one at a time using the same prescription as used for M_{pt}.

In addition, generate a cluster position randomly across the face of the calorimeter (in ϕ and z).

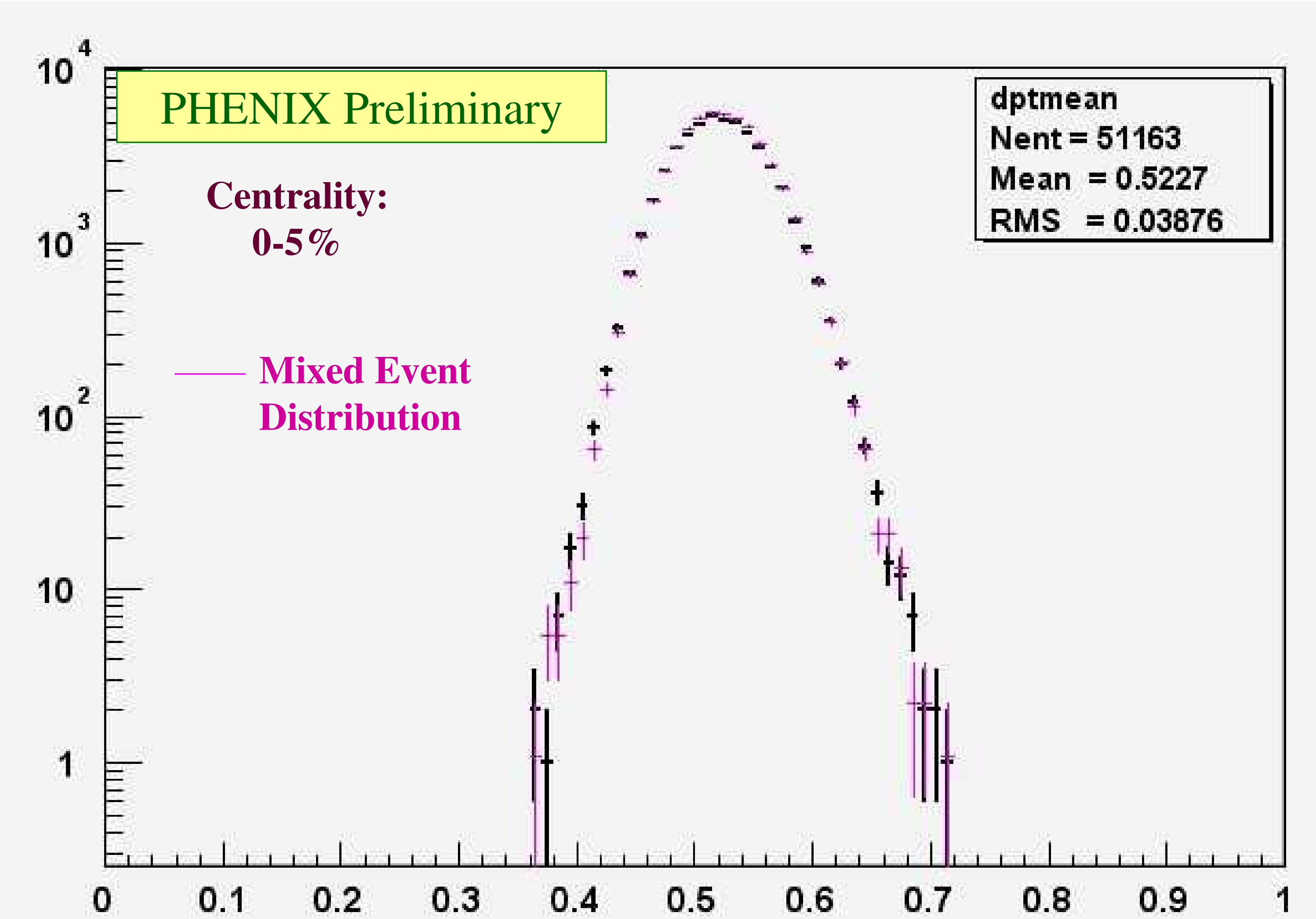
For each additional cluster, calculate its separation from each existing cluster in the event. Consult a "merging probability" distribution, R(d) (see right), to test for a merge. If merged, add the energies and don't increment the cluster counter. If no merge to any existing cluster is tagged, just add the new cluster to the event as is.



Cluster separation from a random position distribution of clusters without merging. The fit is a 2nd order polynomial.



The cluster separation from the data (black points), a 2nd order polynomial fit (P(d)), and the generated distribution (red), which is R(d) = S P(d)/B(d). S is a scale factor. The data oscillations are not modelled.


PHENIX Preliminary
Centrality:
0-5%
Mixed Event
Distribution
dptmean
Nent = 51163
Mean = 0.5227
RMS = 0.03876
10^4
10^3
10^2
10
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Net charge fluctuations: A signal for QGP?

(S. Jeon & V. Koch PRL 85(2000)2076)

(M. Asakawa, U. Heinz, B. Müller, PRL 85(2000)2072)

Expected fluctuations in net charge, $Q\ (= N_+ - N_-)$:

Hadron gas : $$\frac{<Q^2>}{<N_{ch}>} = 1$$

(A reduction is expected due to global charge conservation and resonances, depending on the acceptance.)

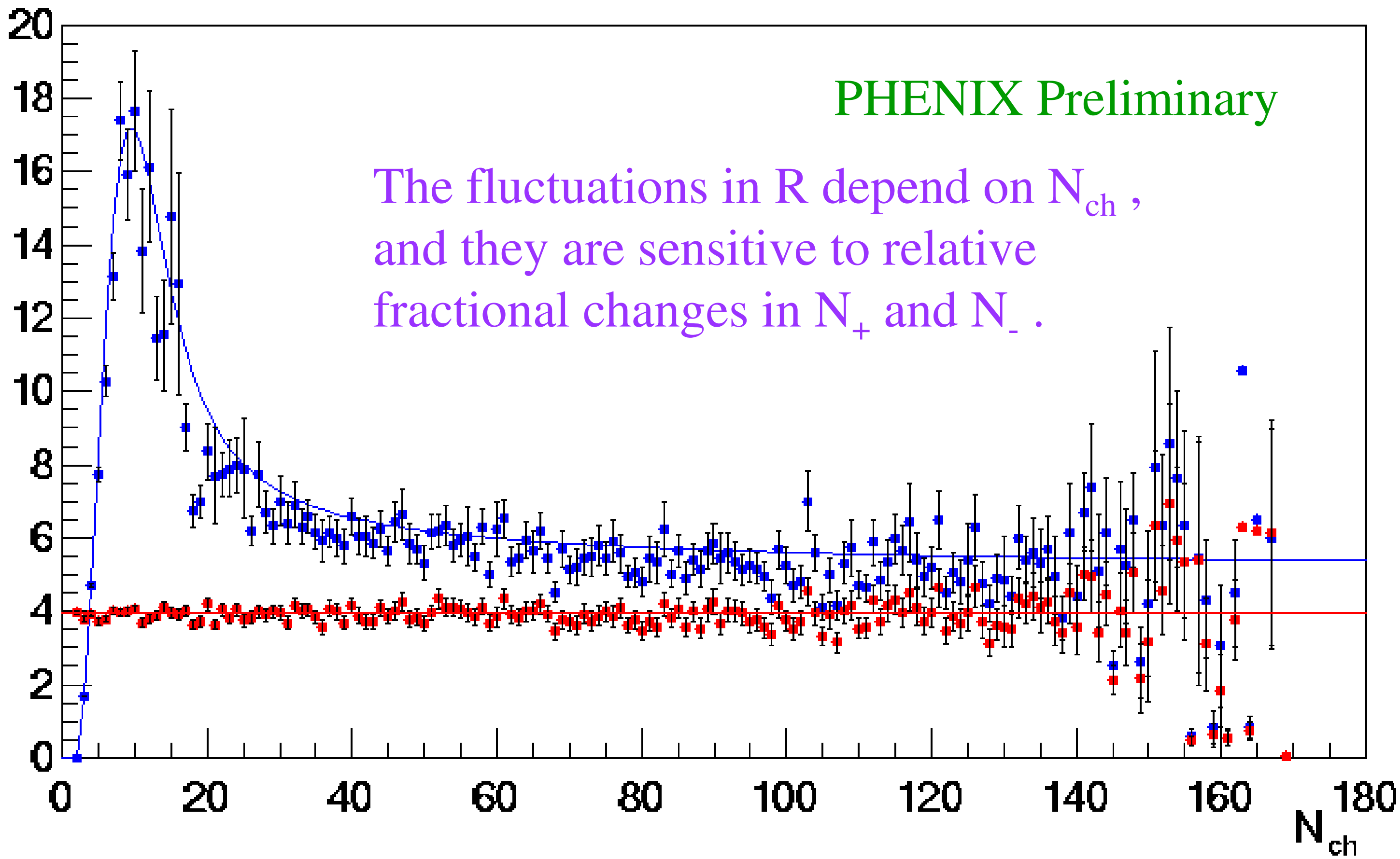
QGP : $$\frac{<Q^2>}{<N_{ch}>} \approx 0.20 - 0.25$$ (S. Jeon & V. Koch PRL 85(2000)2076)

The use of $R = N_+ / N_-$ is proposed.

Asymptotically, for large N_{ch} :

$$<N_{ch}> < R^2 - <R>^2 > \approx 4 \frac{<Q^2>}{<N_{ch}>}$$

PHENIX Charge Fluctuations



$(\langle R^2\rangle - \langle R\rangle^2) * N_{ch}$ $\quad$ $(R = N_+/N_-)$

$4(\langle Q^2\rangle - \langle Q\rangle^2) / N_{ch}$ $\quad$ $(Q = N_+ - N_-)$