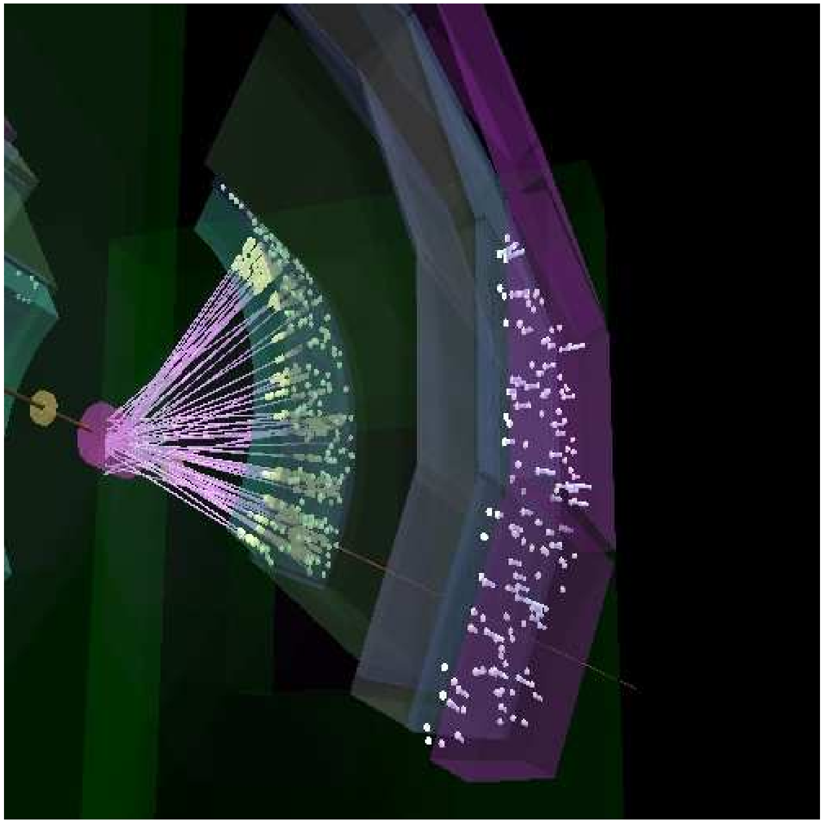
Event-by-event fluctuations in the mean P_t (and E_t) of particles produced in Au+Au Collisions in the PHENIX Experiment at RHIC



Jeffery T. Mitchell

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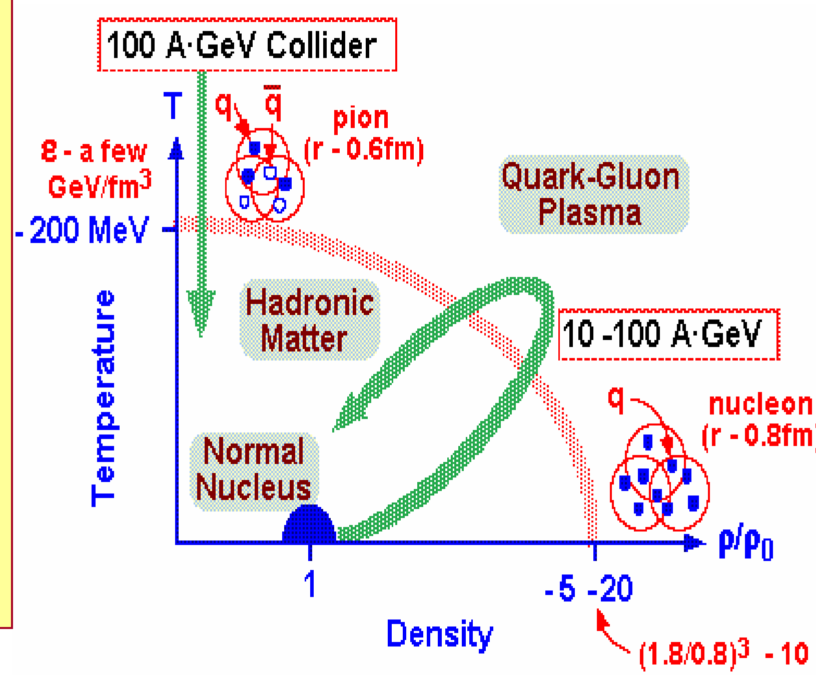
for the PHENIX Collaboration

4/30/01

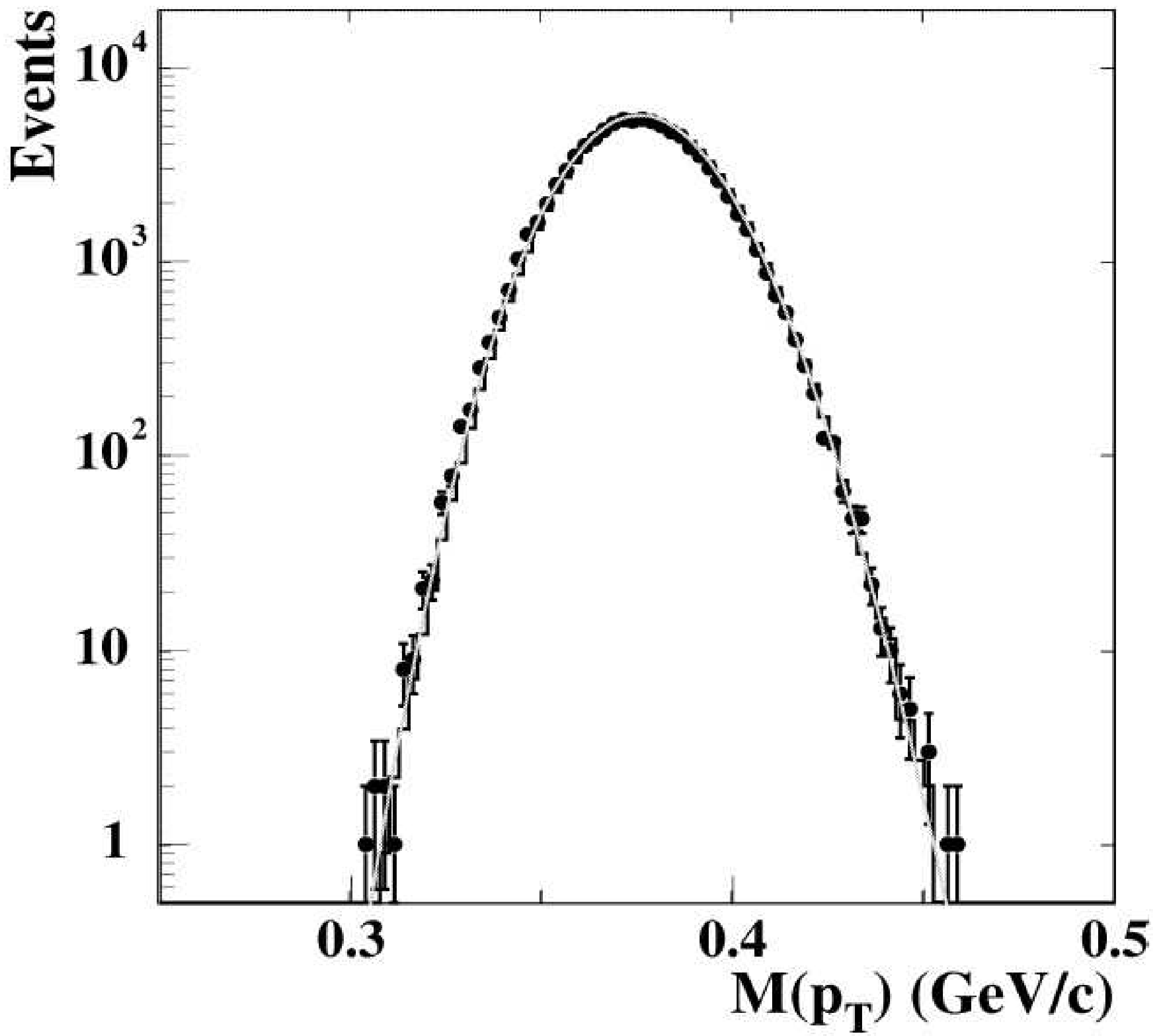
Fluctuation Measurements: Searching for a Phase Transition



• *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.

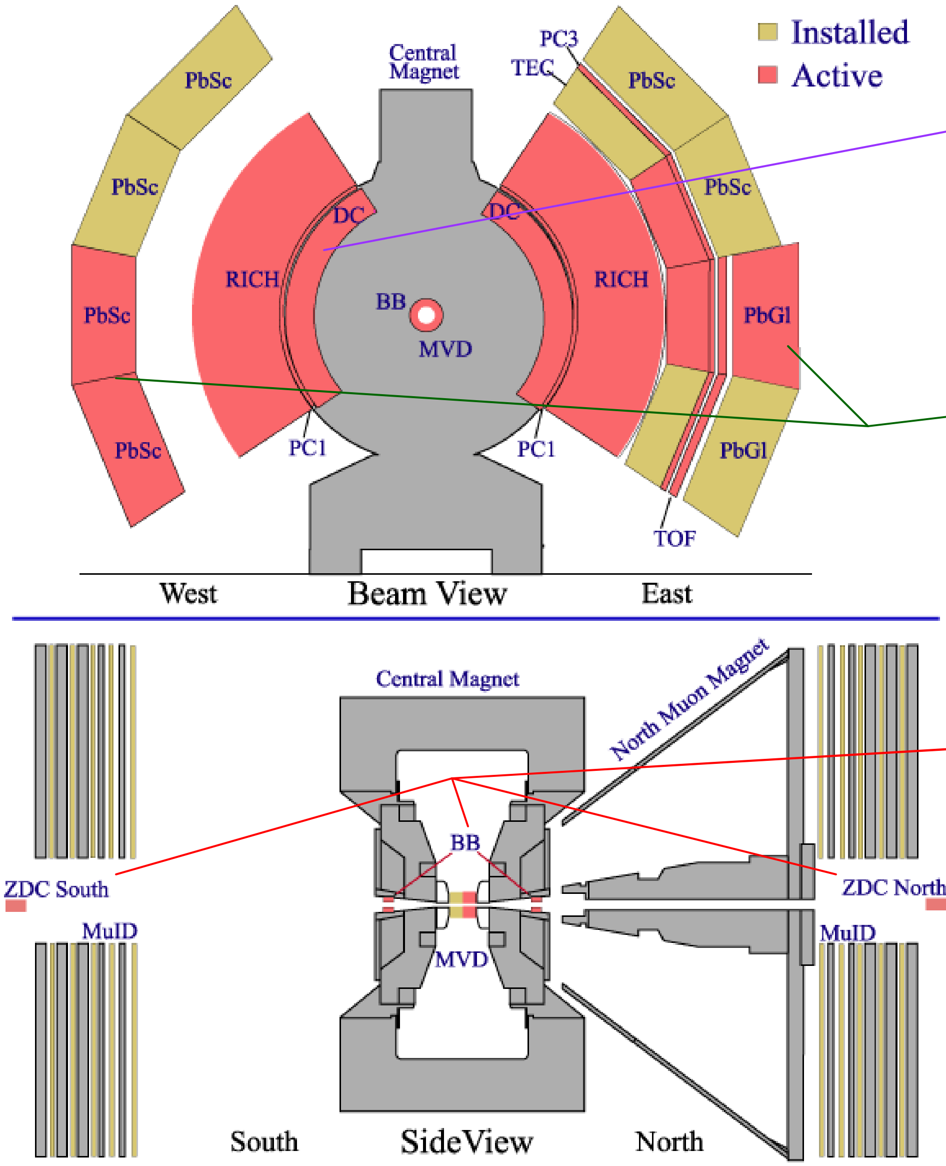
• *M. Stephanov, et. al. (see hep-ph/9903292)* suggest that near a tri-critical point in the QCD phase diagram, the event-by-event fluctuations in p_t could increase significantly.

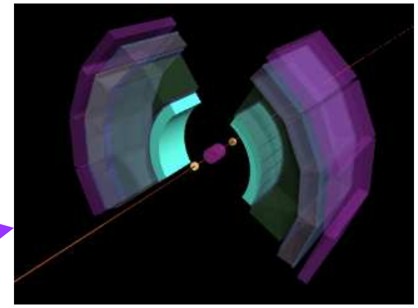
$\langle P_t \rangle$ Measurement from CERN Experiment NA49



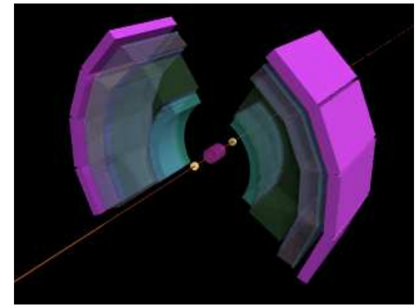
- See H. Appelshauser, et. al., Phys. Lett. B459 (1999) 679.
- Distribution is compatible with independent particle production.

PHENIX Detector - First Year Physics Run

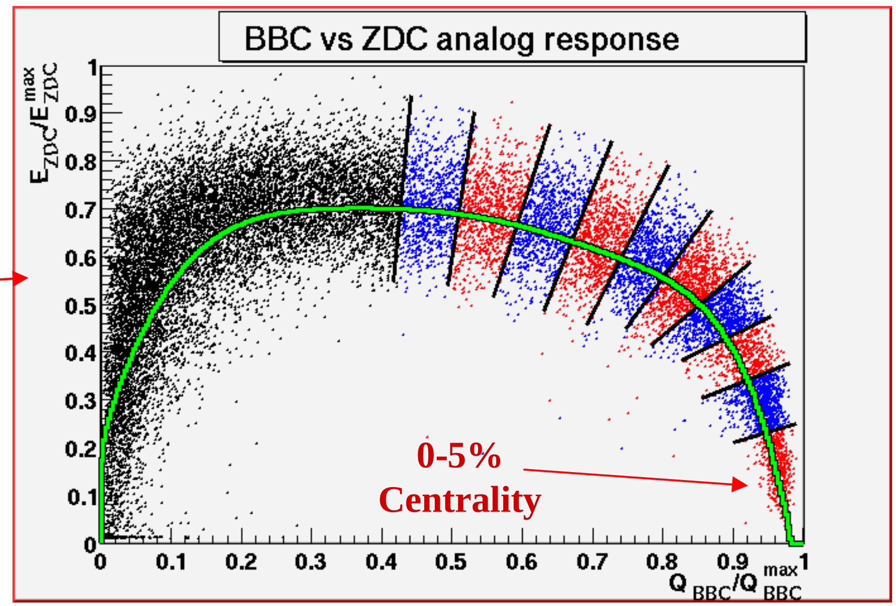




Drift Chamber:
$\langle P_t \rangle$



Calorimeters:
$\langle E_t \rangle$



Centrality Selection

$\langle P_t \rangle$ Dataset Statistics

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

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

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

Centrality	$\langle n \rangle$	$\langle P_t \rangle$
0-5%	60.5±10.7	.523±.290
0-10%	55.6±11.7	.523±.290
10-20%	39.4±9.9	.523±.290
20-30%	28.0±7.6	.522±.290
30-40%	18.9±6.4	.519±.287

Analysis Details...

Data:

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

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

• ***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:

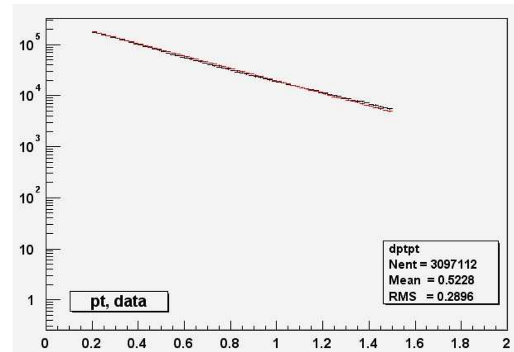
• Mixed event distributions are built from reconstructed tracks/clusters in real events.

• *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.*

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*. Gamma distribution.
- Using parameters extracted from the semi-inclusive distributions, calculate:

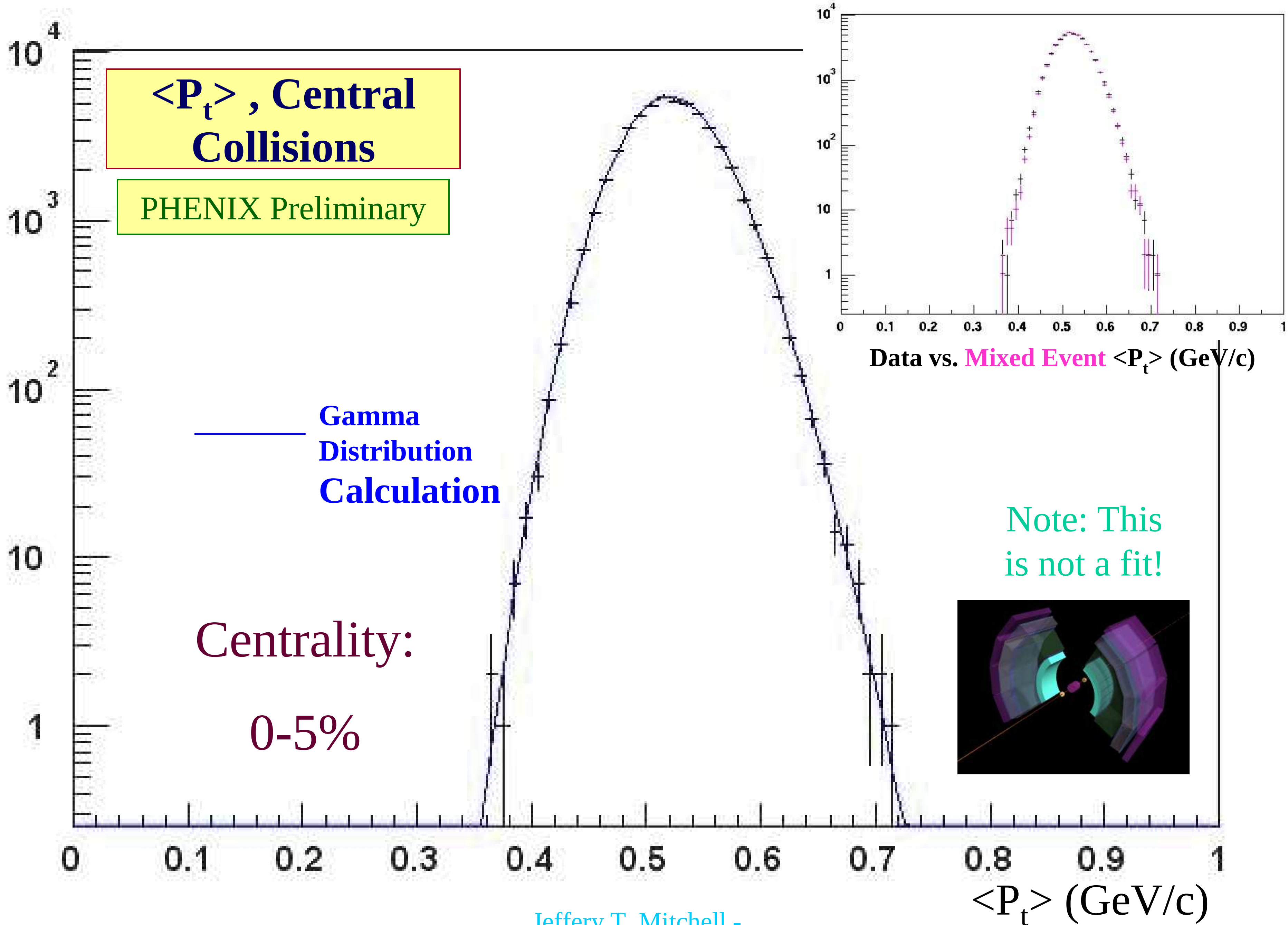
$$f(M_{Xt}) = \Sigma f_{NBD}(n,1/k,\langle n\rangle) f_{\Gamma}(M_{Xt},np,nb),$$

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

Simulation for Statistically Independent Emission:

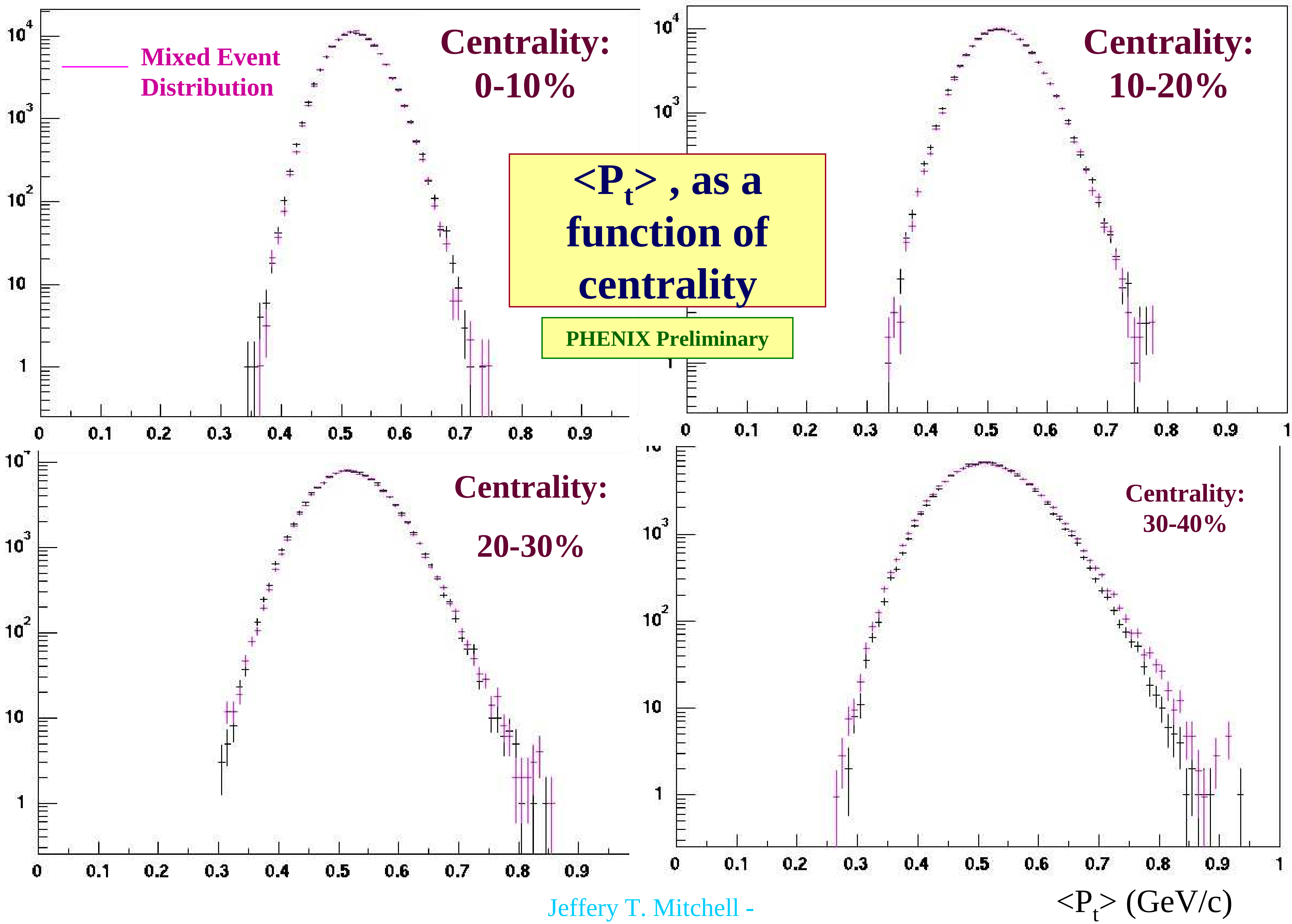
MEAN MAX

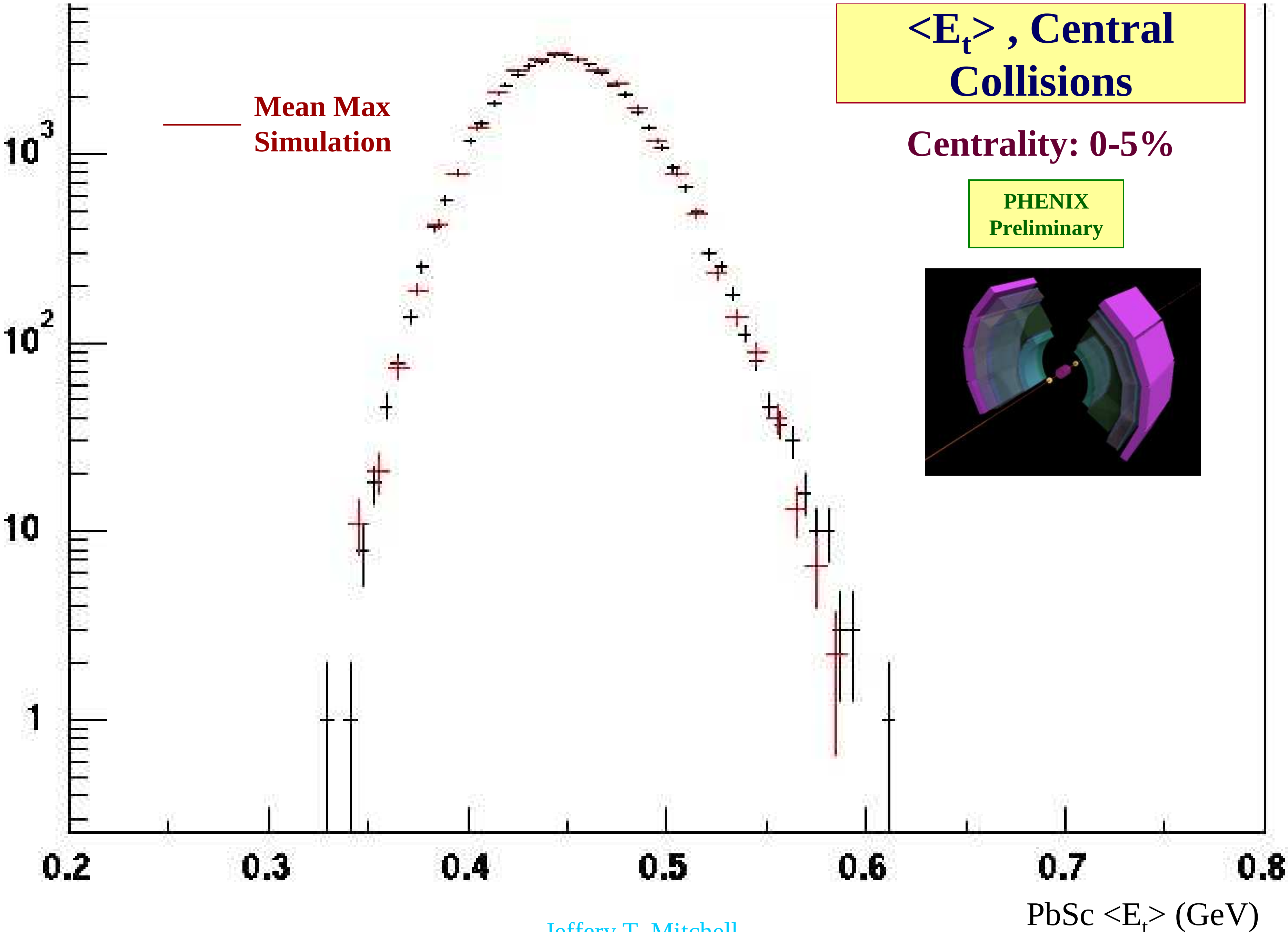
- Parameterizes the semi-inclusive P_t or E_t (exponential) and $\langle n\rangle$ (Gaussian) distributions over the same ranges used to calculate $\langle P_t\rangle$ and $\langle E_t\rangle$.
- Generates $\langle P_t\rangle$, $\langle E_t\rangle$ after applying cuts on n_{min}, P_t, and E_t ranges.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


$\langle P_t \rangle$, Central Collisions
PHENIX Preliminary
Gamma Distribution Calculation
Centrality:
0-5%
Note: This is not a fit!
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
$\langle P_t \rangle$ (GeV/c)
Data vs. Mixed Event $\langle P_t \rangle$ (GeV/c)

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

PHENIX Preliminary





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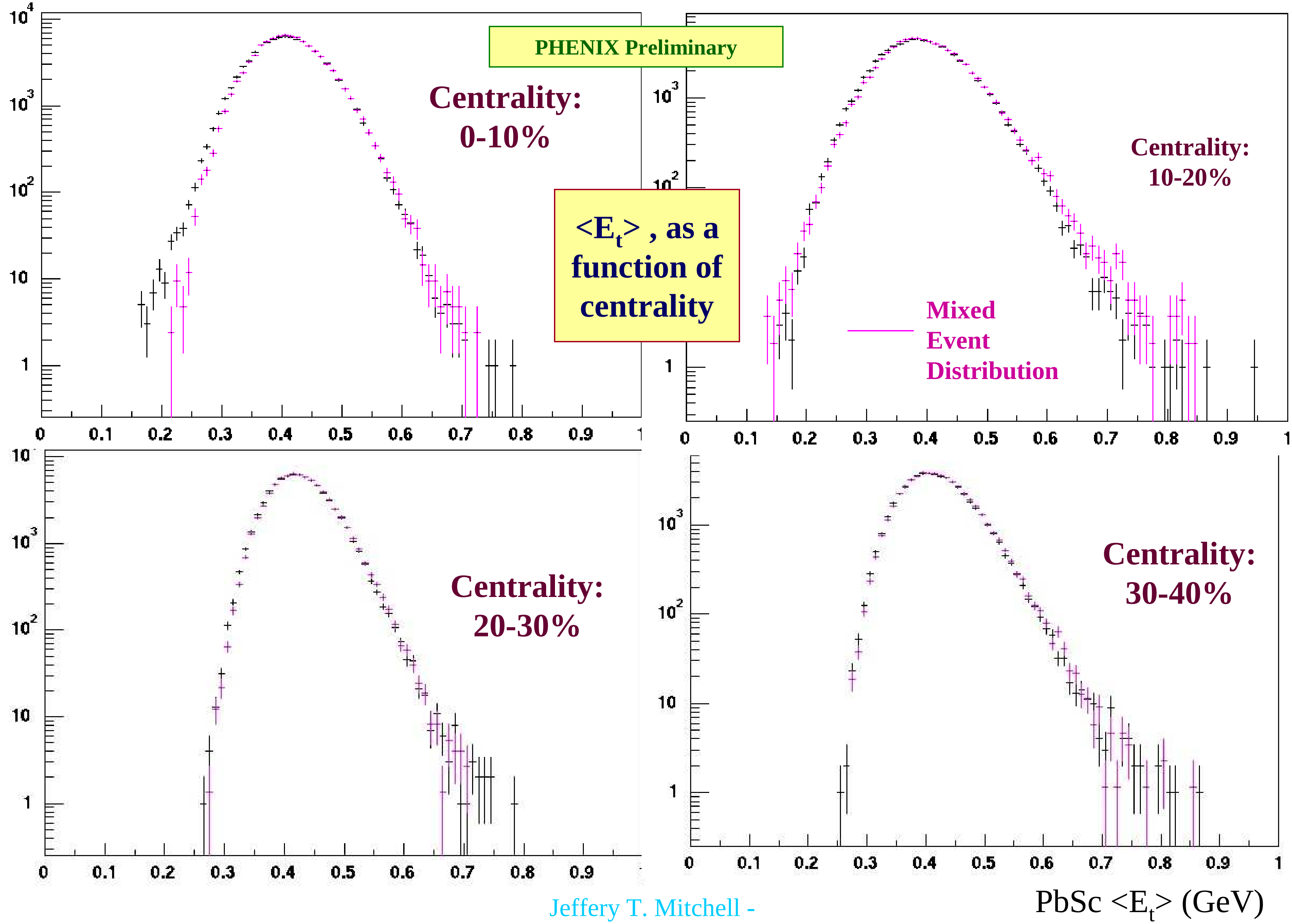
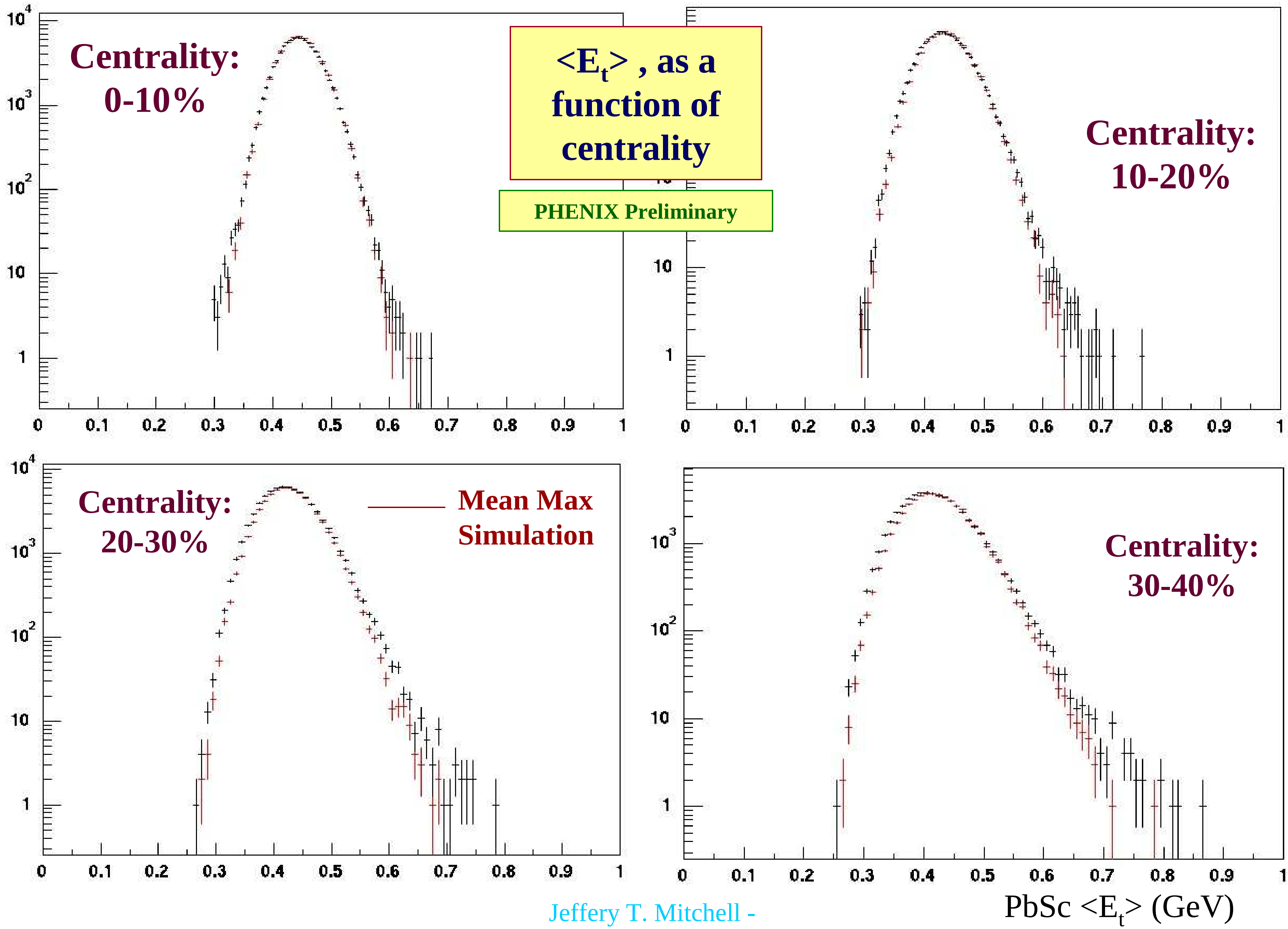

PHENIX Preliminary
$\langle E_t \rangle$, as a function of centrality
Centrality: 0-10%
Centrality: 10-20%
Centrality: 20-30%
Centrality: 30-40%
Mixed Event Distribution
PbSc $\langle E_t \rangle$ (GeV)

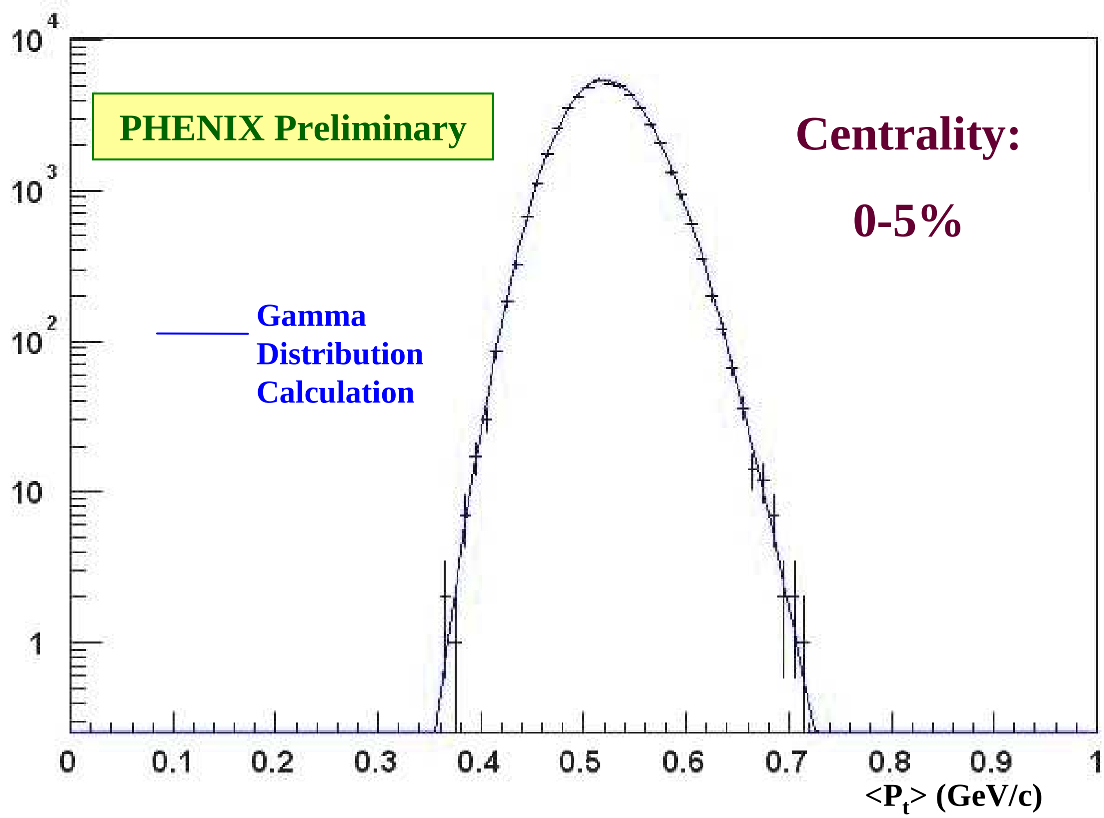
$\langle E_t \rangle$, as a function of centrality



Quantifying the Fluctuations

Define a quantity, Δ, to provide a measure of the deviation from statistically independent emission (*baseline*):

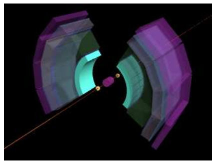
$$\Delta = |RMS_{data} - RMS_{baseline}|/RMS_{baseline} \text{ x } 100\%.$$



Δ = 0.54 % (±2.4%)

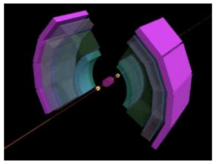
Comparing Data to Mixed Event Distributions

<P_t>:



Centrality	Δ
0-10%	2.09%
10-20%	1.87%
20-30%	0.76%
30-40%	5.26%

<E_t>:



Centrality	Δ
0-10%	4.08%
10-20%	0.91%
20-30%	0.58%
30-40%	0.16%
0-5% (PbGl)	3.26%

Systematic Errors are <u>estimated</u> to be ~3-5% *(>5% for the 0-10% E_t due to cluster merging effects).*

The quantities are consistent with statistically independent emission of particles.

Conclusions and Outlook

Conclusions:

- This analysis sees no significant 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. All event-by-event spectra can be described by the semi-inclusive spectra.

Prospects:

- Extension of this analysis to cover more peripheral collisions will be possible in the upcoming 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.

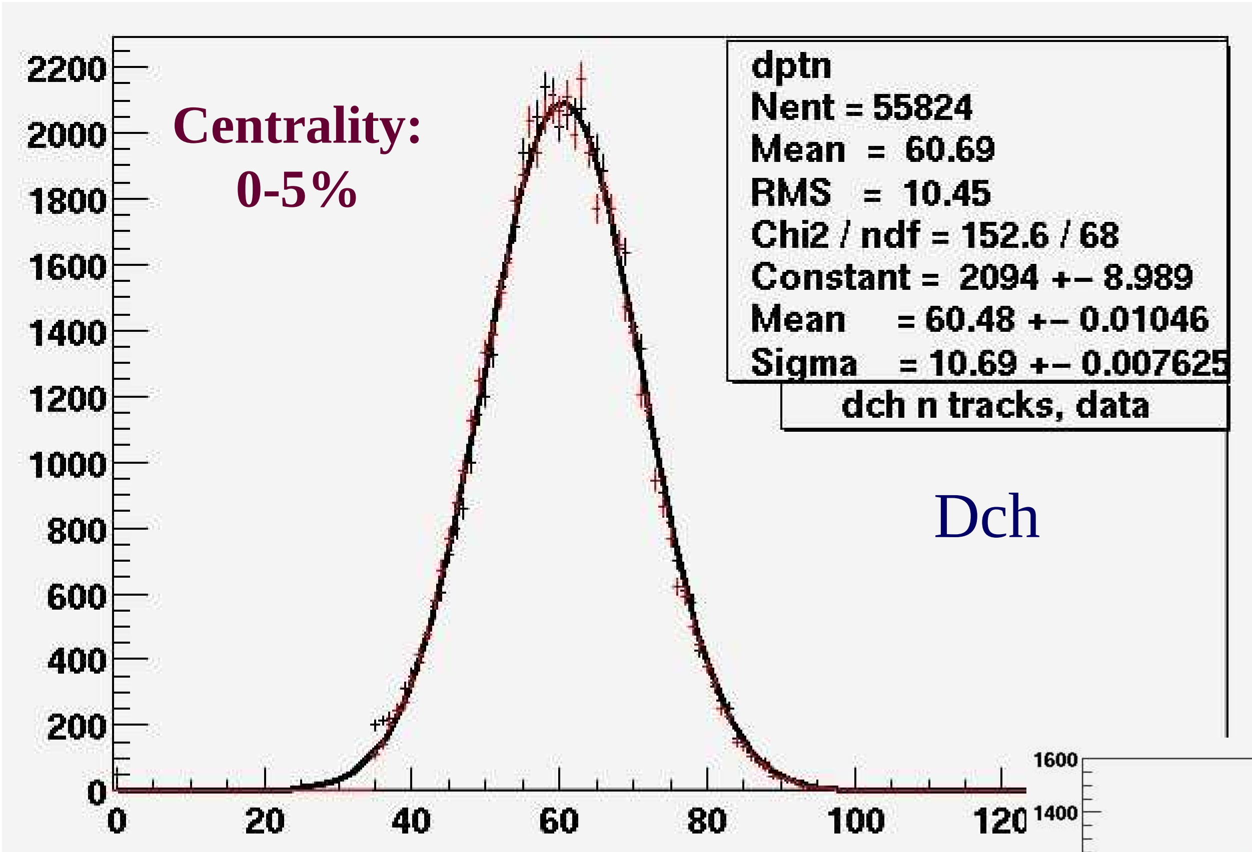
• Once the $\pi\pi$ threshold is exceeded, the decay proceeds rapidly since the $\sigma\pi\pi$ coupling is large. This occurs after freeze-out, so the pions don't thermalize.

• 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 $\langle p_t\rangle$.

$<E_t>$ Dataset Statistics

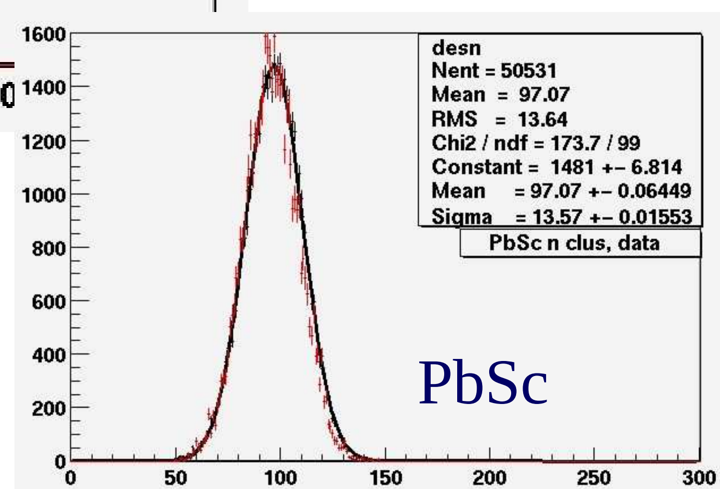
Centrality	$<n>$	$<E_t>$ (GeV)
0-5%	65.9±11.1	.451
0-10%	60.3±12.5	.448
10-20%	42.0±9.4	.438
20-30%	28.8±7.9	.428
30-40%	19.0±6.8	.422



Number of tracks (clusters) per event:

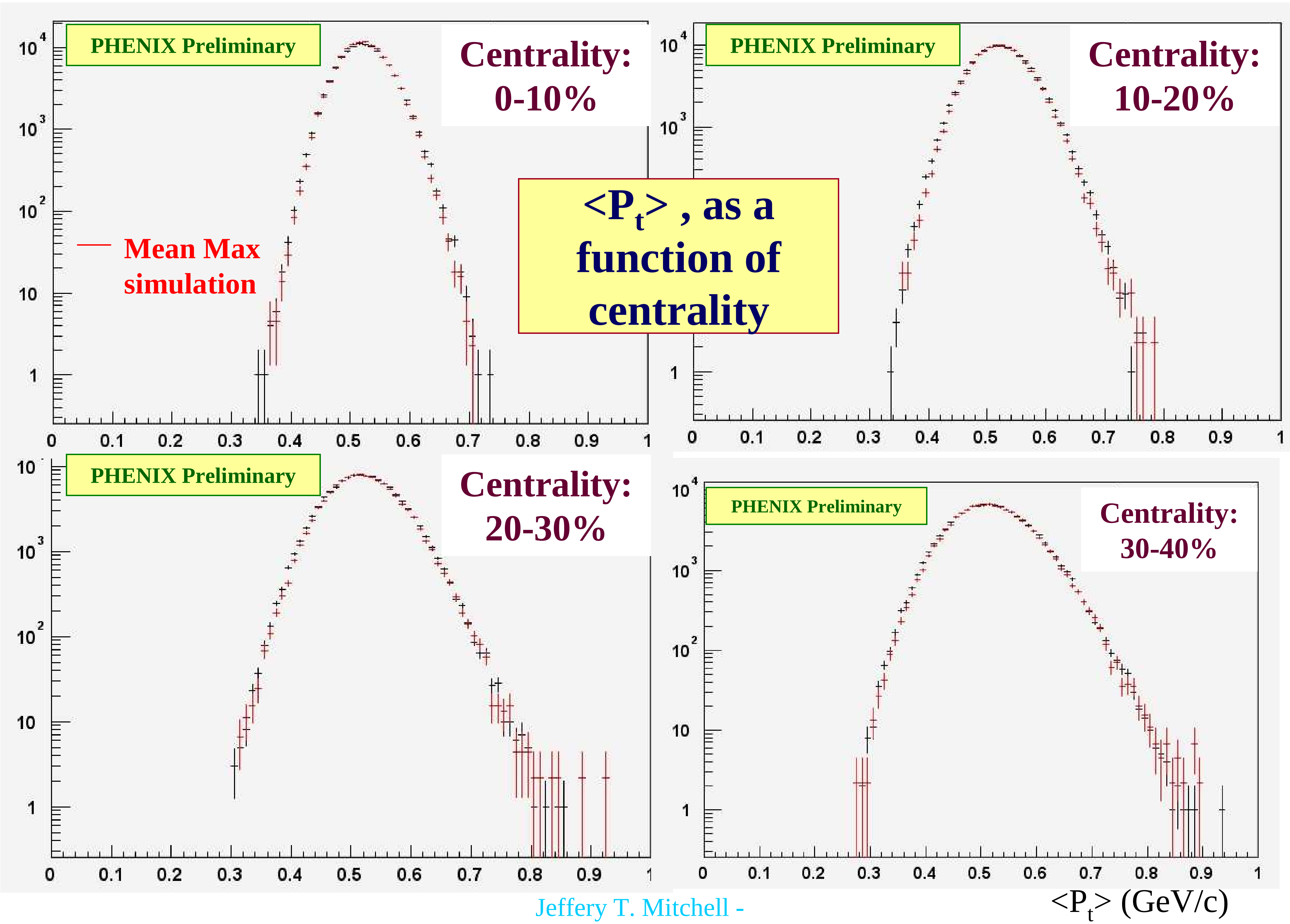
Black = data

Red = mixed events



Matching Mixed Event Characteristics to Real Event Characteristics

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



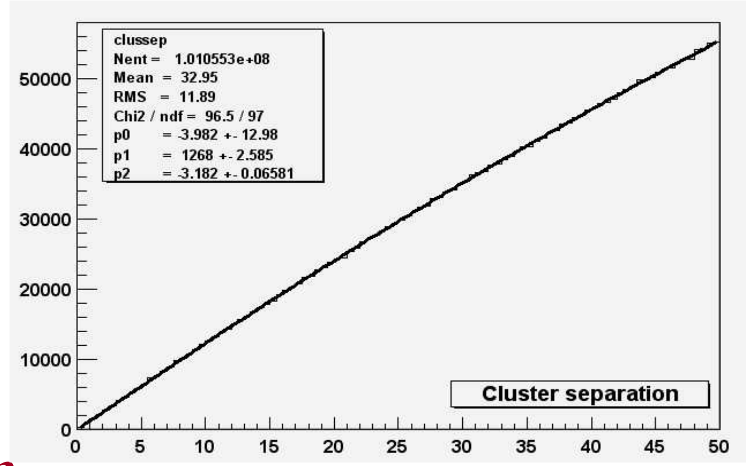
PbSc Mean Et: Cluster Merging Introduces Correlations.

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

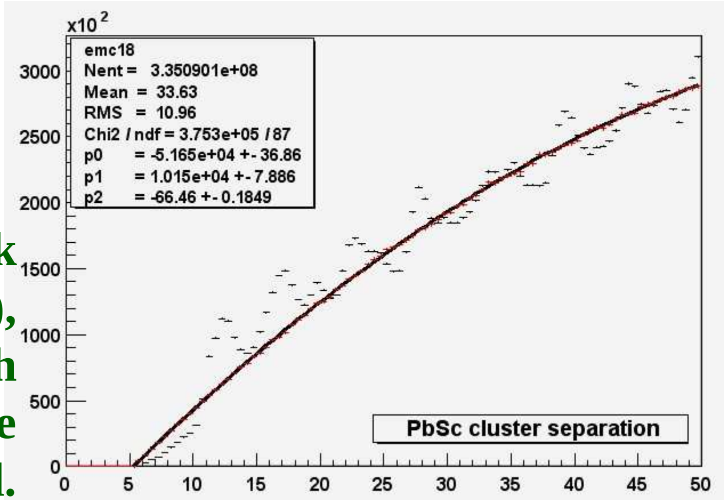
Procedure: Generate clusters one at a time using the same prescription as used for M_{pt}.

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

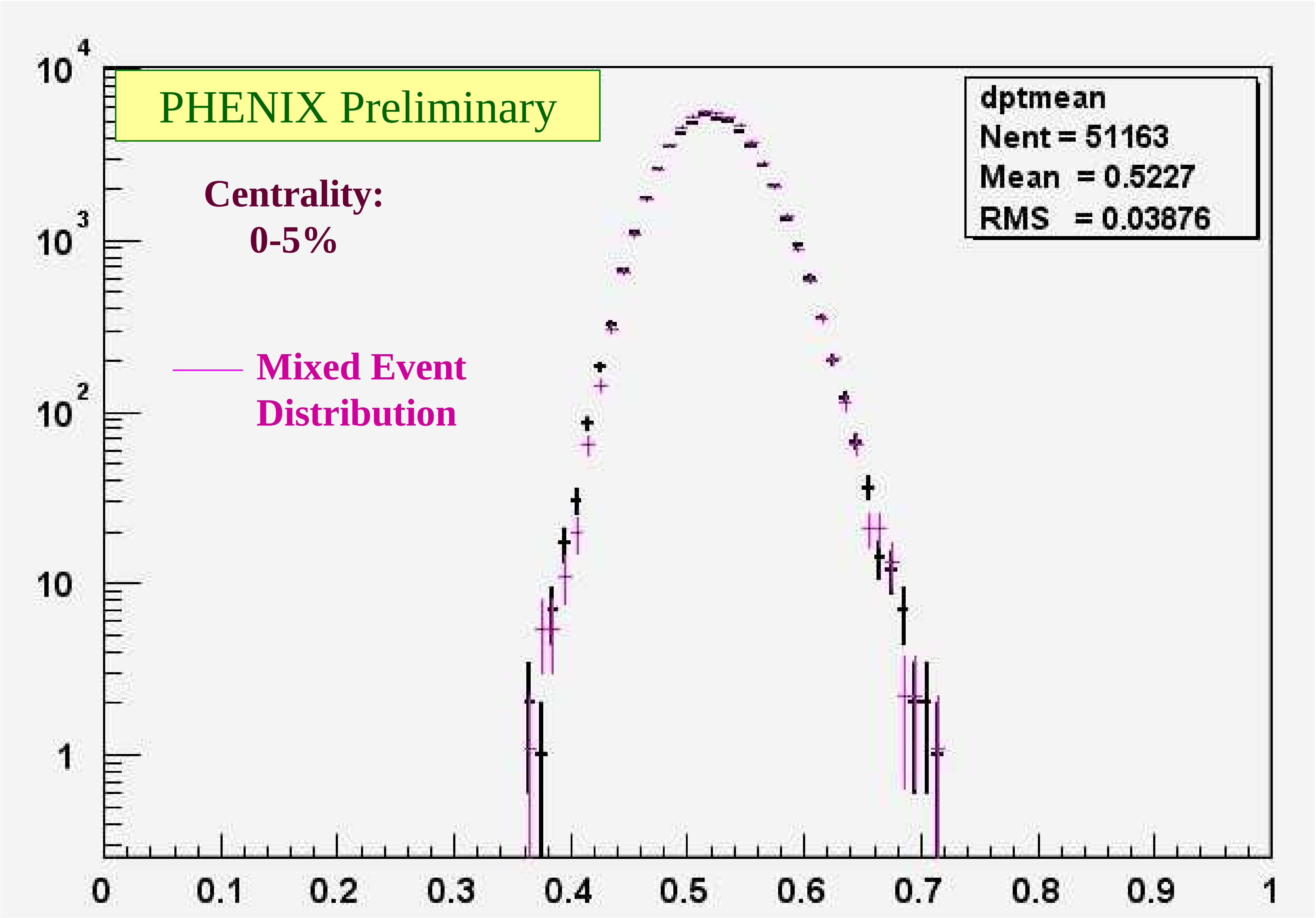
For each additional cluster, calculate its separation from each existing cluster in the event. Consult a "merging probability" distribution, R(d) (see right), to test for a merge. If merged, add the energies and don't increment the cluster counter. If no merge to any existing cluster is tagged, just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

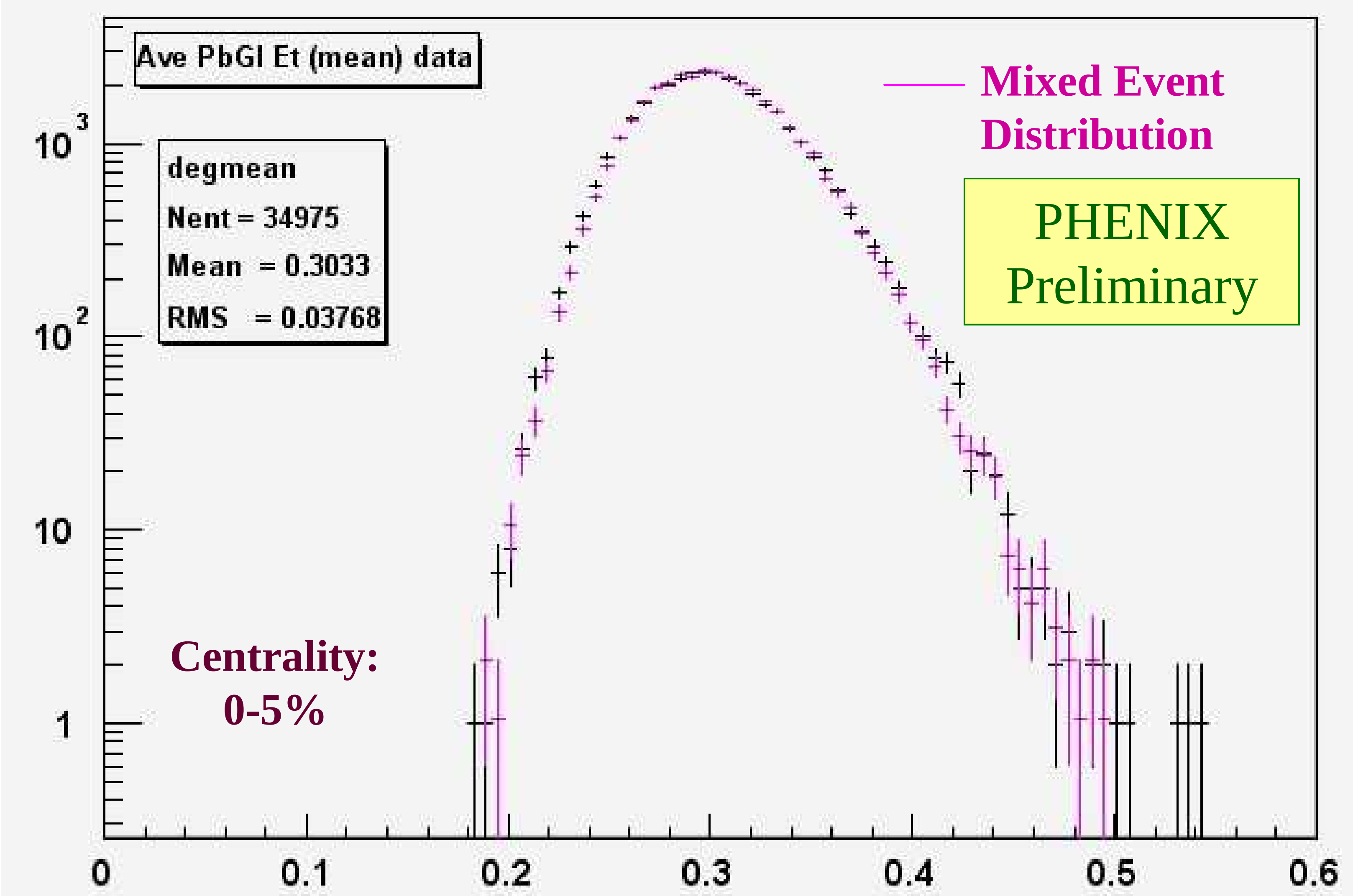


The cluster separation from the data (black points), a 2nd order polynomial fit (P(d)), and the generated distribution (red), which is R(d) = S P(d)/B(d). S is a scale factor. The data oscillations are not modelled.

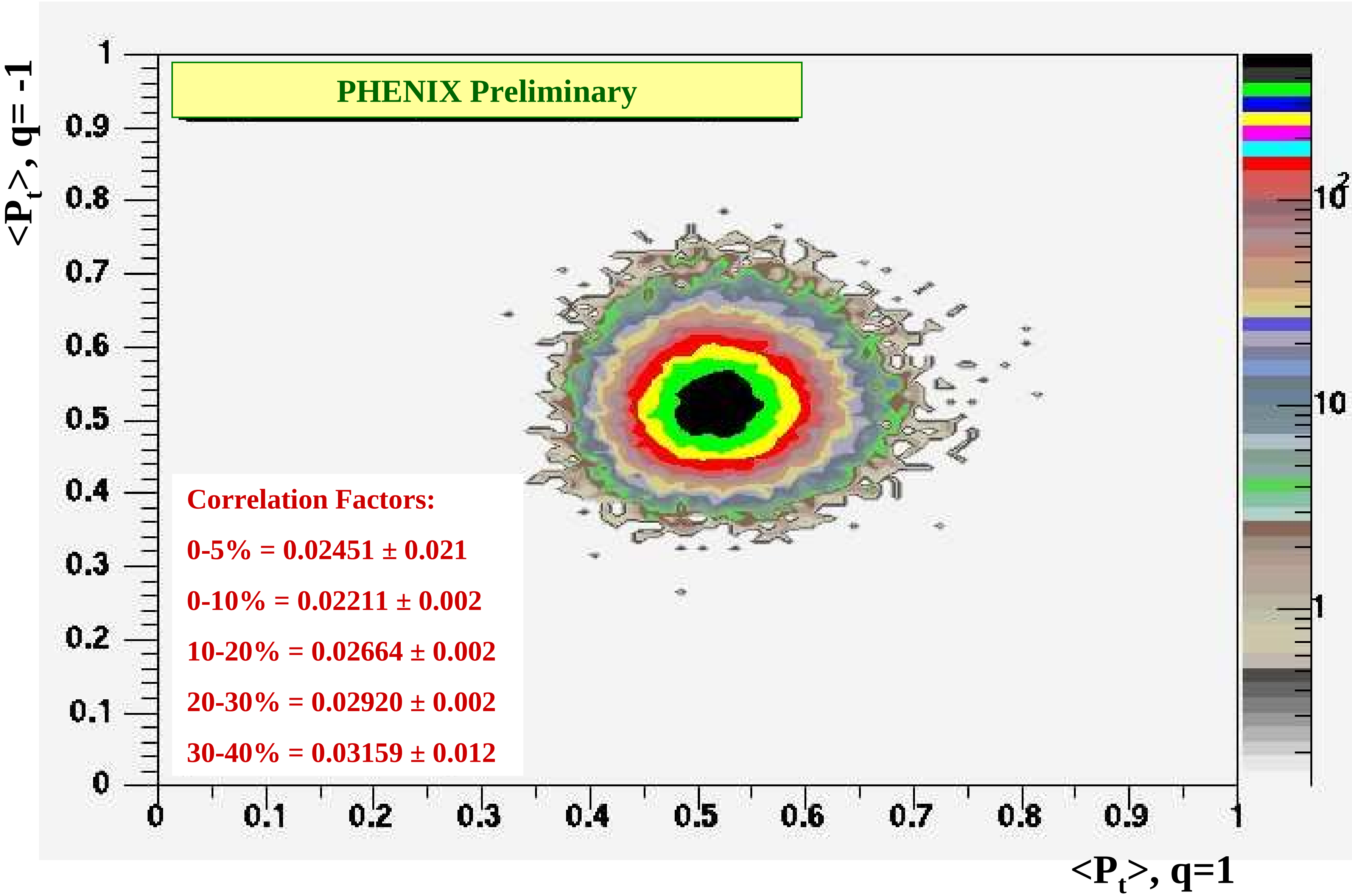


PHENIX Preliminary
Centrality:
0-5%
Mixed Event
Distribution
dptmean
Nent = 51163
Mean = 0.5227
RMS = 0.03876

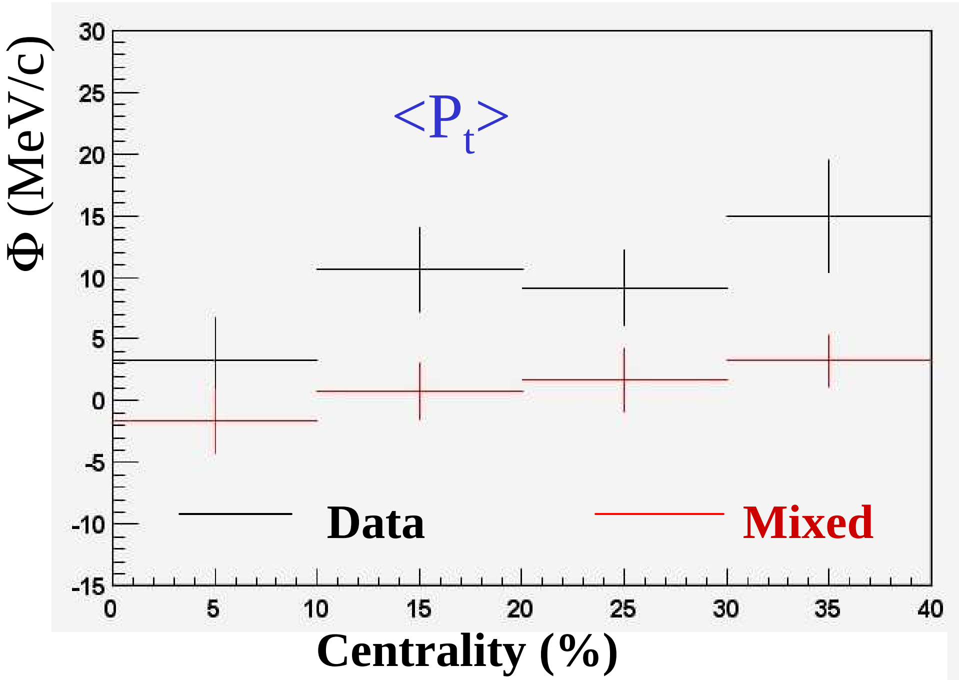
Mean E_t from the PbGl Calorimeter



Event-by-Event $<P_t>$ Correlations vs. charge



Quantifying the fluctuations, Φ variable



What is Φ?

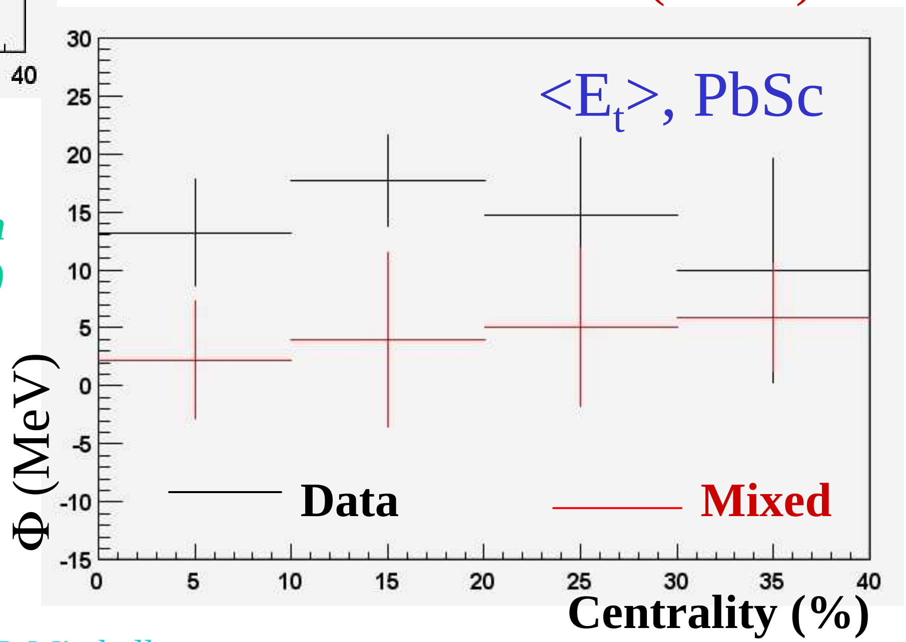
$z_i = p_{t,i}$ - Mean(P_t)

$Z = \Sigma z_i$

$\Phi = \mathrm{Sqrt}(\langle Z^2\rangle/\langle n\rangle) - \mathrm{sqrt}(\mathrm{Mean}(z^2))$

From QM2001:

Φ=7.8±0.9 MeV/c(NA49)



Errors are systematic *(from dataset subsets only)*

Why Φ?

Φ = 0 for statistically independent emission and for fluctuations for an ideal gas of classical particles.