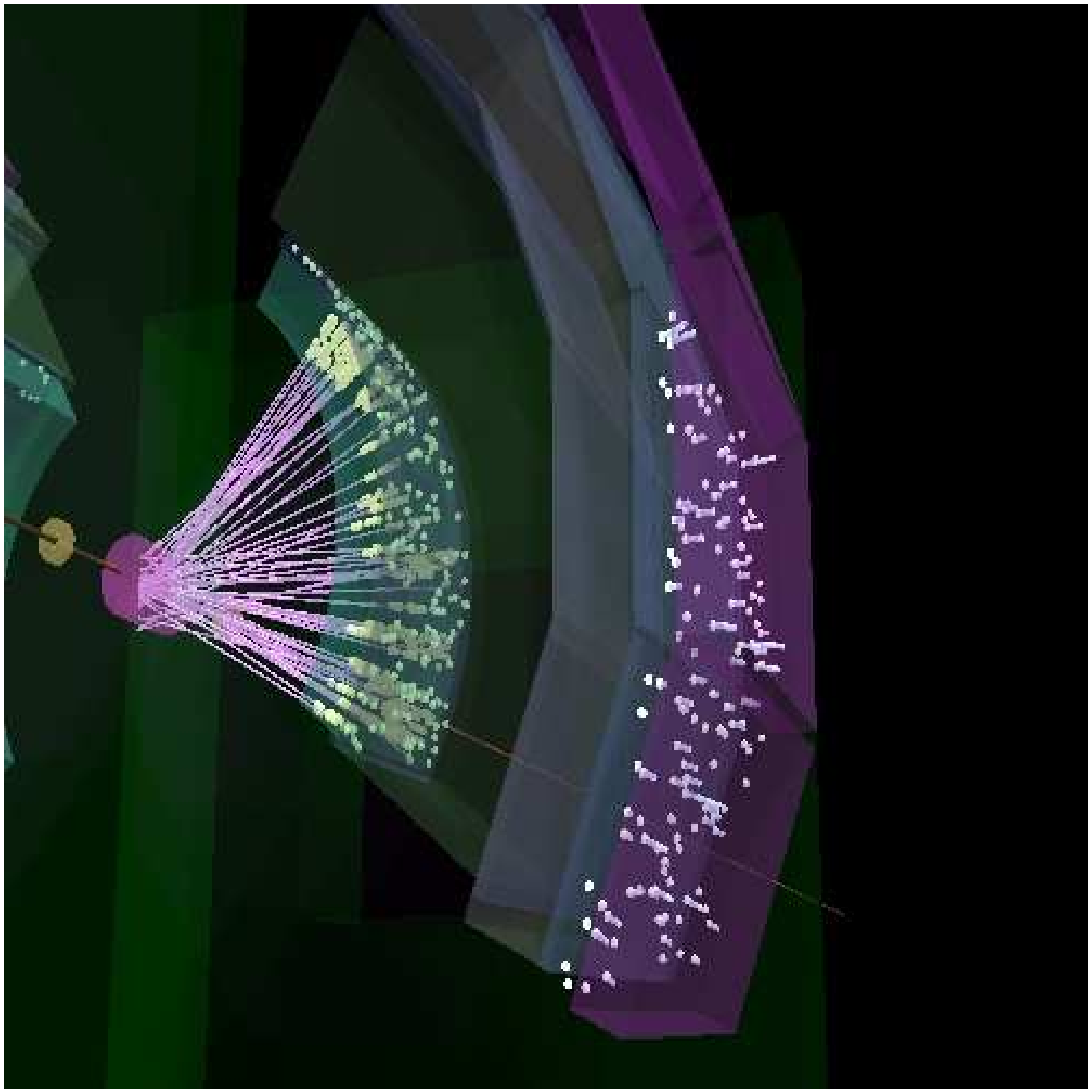
Event-by-event fluctuations in the mean p_t (and e_t) of particles produced in γ=130 GeV Au+Au Collisions in the PHENIX Experiment at RHIC



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10/17/01

Outline

- Motivation
- Analysis
- Results
- Sensitivity
- Conclusions

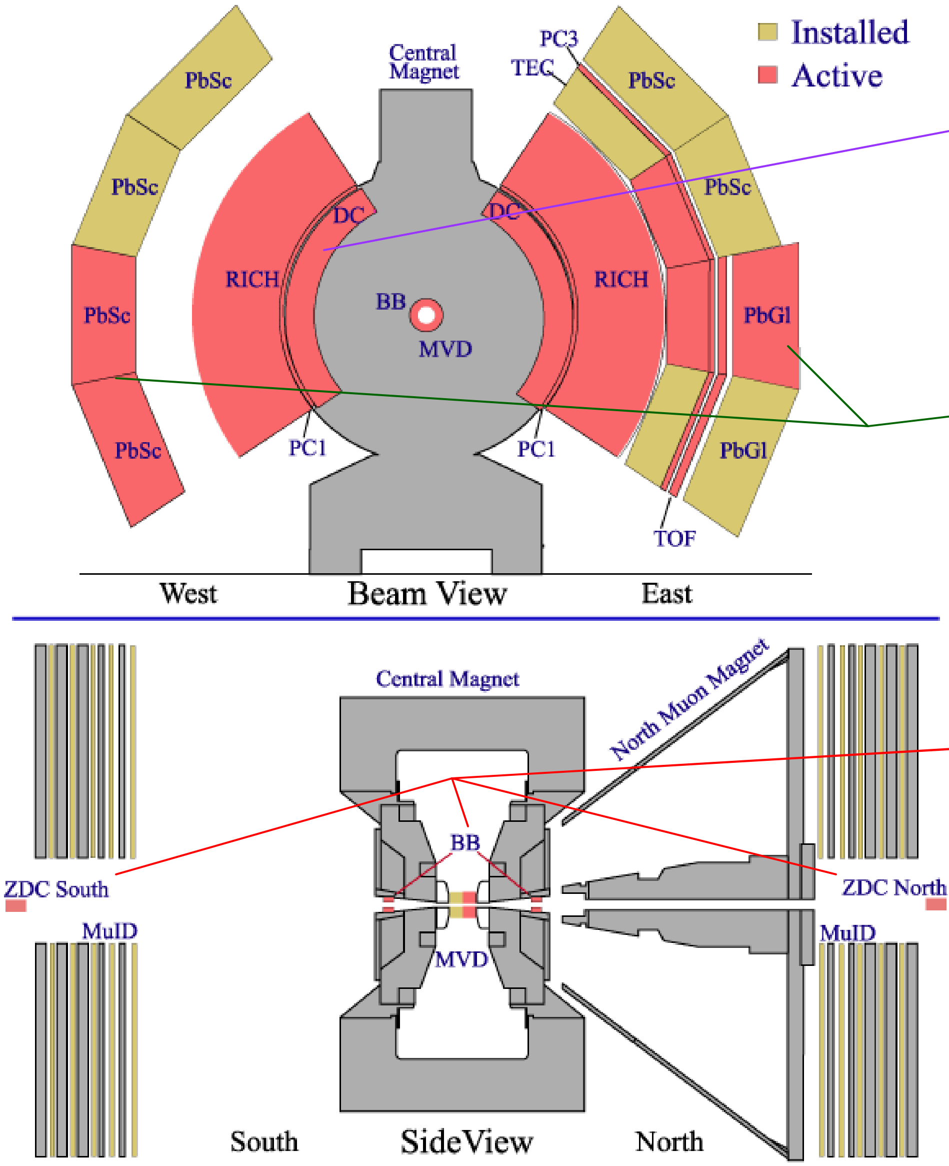
Fluctuation Measurements: Searching for a Phase Transition

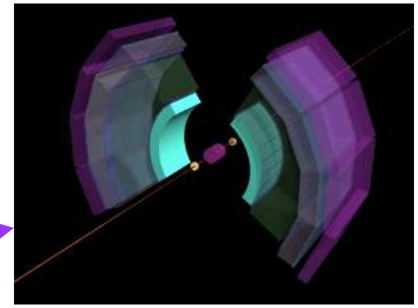
• *S. Mrowczynski (see Phys. Lett. B314 (1993) 118.)* **Instability of the plasma could be present, initiated as random color fluctuations. For some events, the fluctuations of particle transverse quantities would be magnified.**

• *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.**

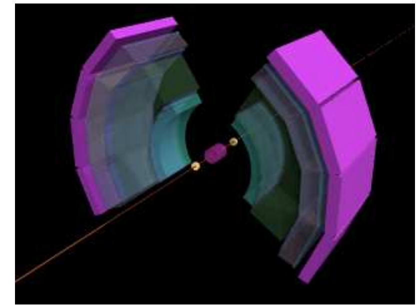
Analogy: Critical Opalescence

PHENIX for Fluctuations, Summer 2000

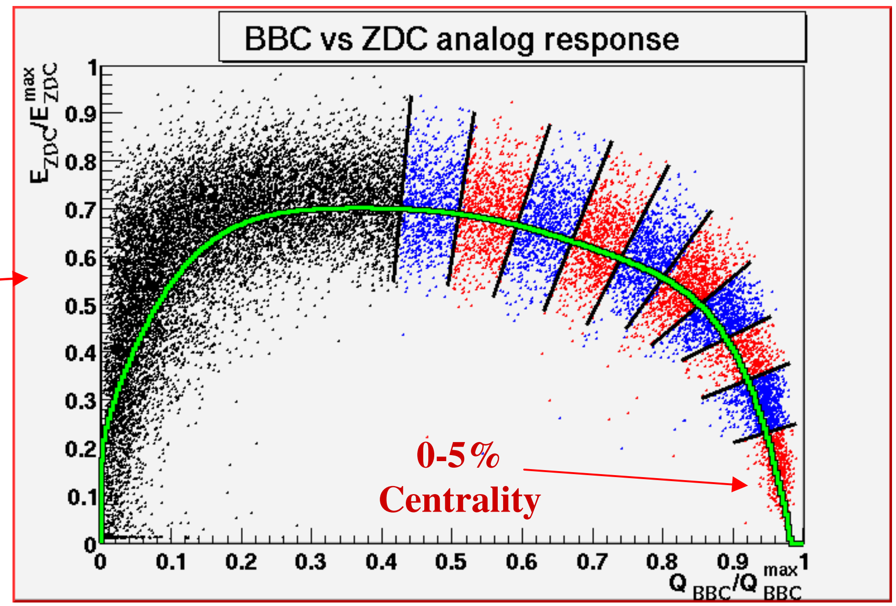




Drift Chamber: Mean p_t



Calorimeters: Mean e_t



Centrality Selection

Analysis Details...

Data:

• The mean p_t and e_t are determined on an event-by-event basis:

$$Mp_t = \Sigma\, p_{t,\,I}/N_{pt} \quad Me_t = \Sigma\, e_{t,\,i}\,/N_{et}$$

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_{pt} or N_{et}, in mixed events are sampled from the data N distribution.*

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

Essential Statistics for the M_{p_t} analysis.

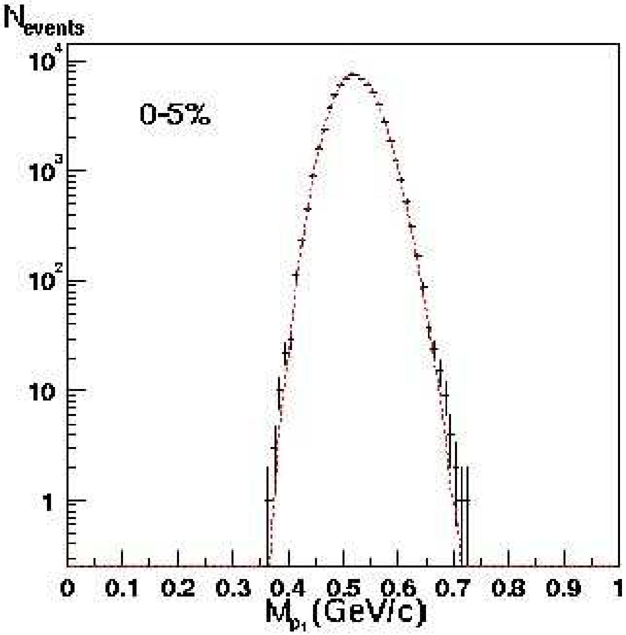
Centrality class	N_{events}	$< N_{tracks} >$	$\sigma_{N_{tracks}}$	$M_{p_t}(MeV/c)$	$\sigma_{M_{p_t}}(MeV/c)$
0 - 5 %	51163	59.6	10.8	523	38.6
0 - 10 %	110122	53.9	12.2	523	41.1
10 - 20 %	119248	36.6	10.2	523	49.8
20 - 30 %	112301	25.0	7.8	520	61.1

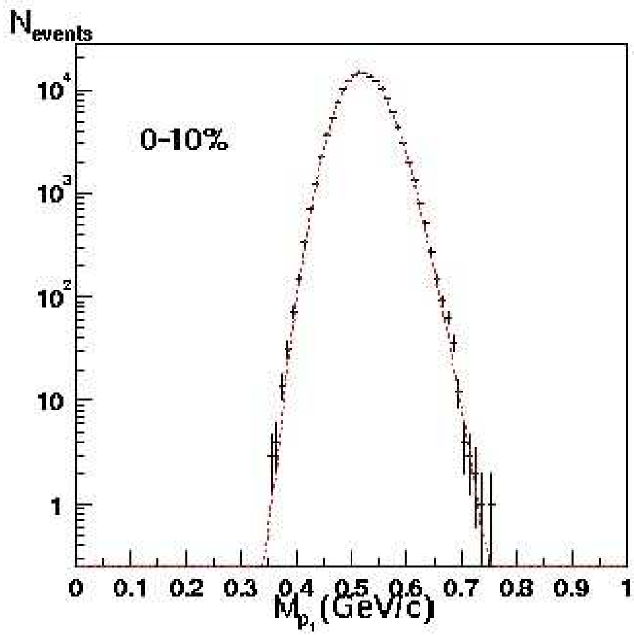
:

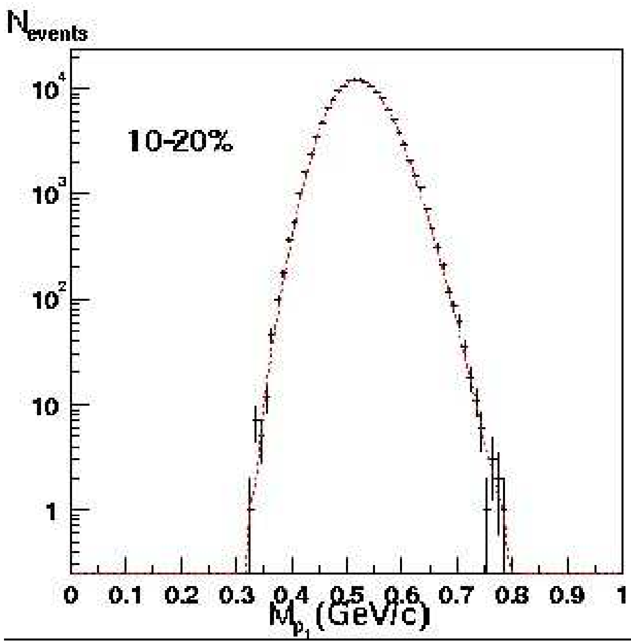
Essential Statistics for the M_{e_t} analysis.

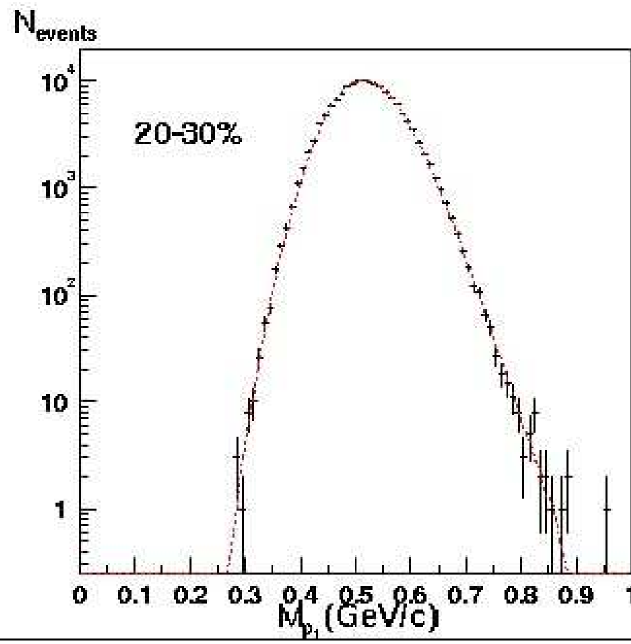
Centrality class	N_{events}	$< N_{tracks} >$	$\sigma_{N_{tracks}}$	$M_{e_t}(MeV)$	$\sigma_{M_{e_t}}(MeV)$
0 - 5 %	69224	68.6	11.6	466	34.1
0 - 10 %	138882	62.1	13.2	462	36.2
10 - 20 %	140461	41.6	10.8	448	43.0
20 - 30 %	137867	28.0	8.3	439	51.8

Mean p_t Distributions

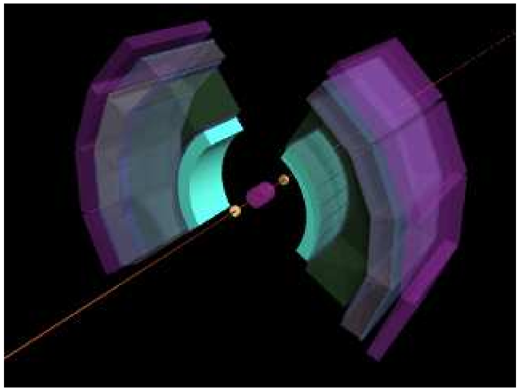




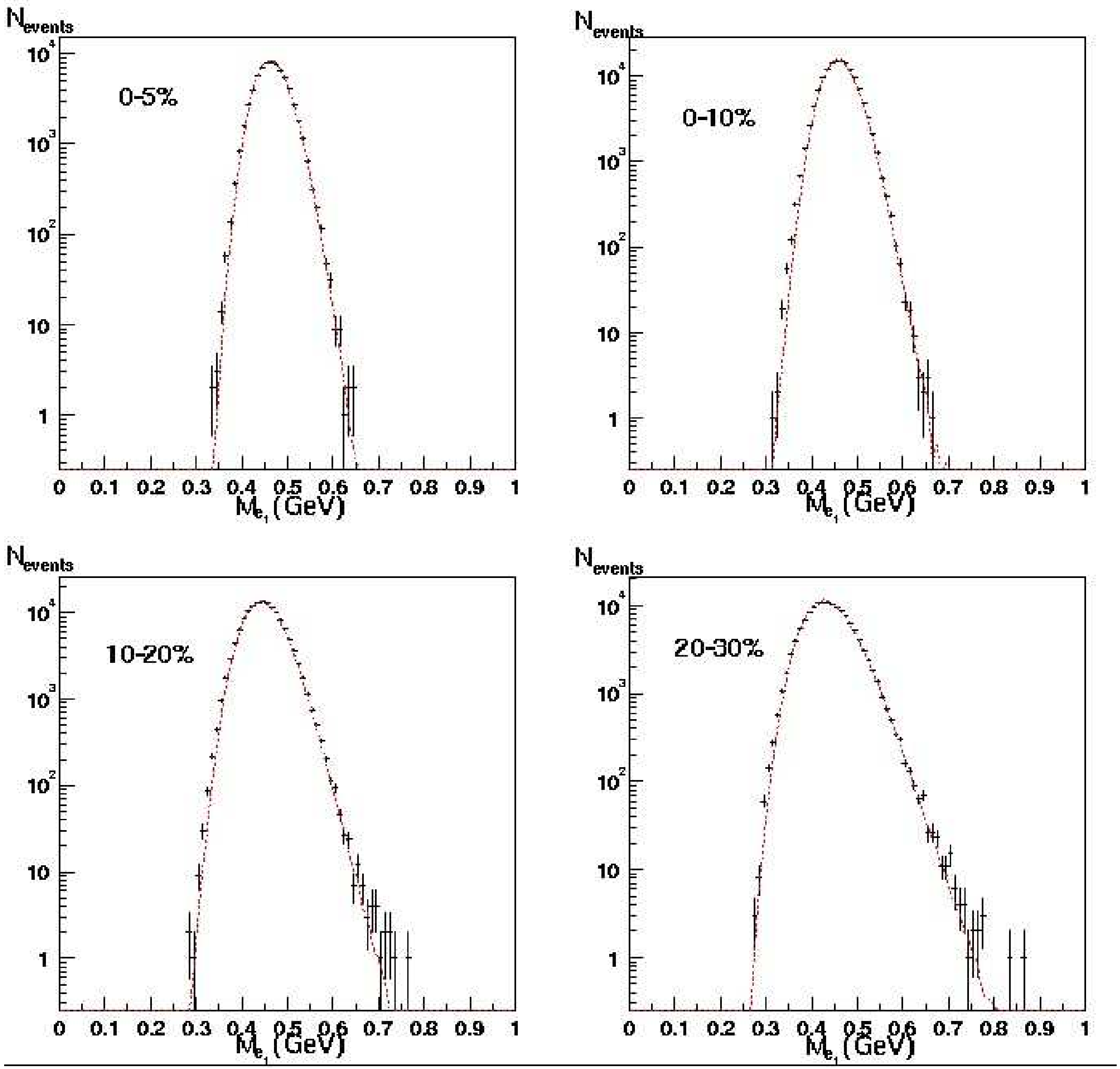




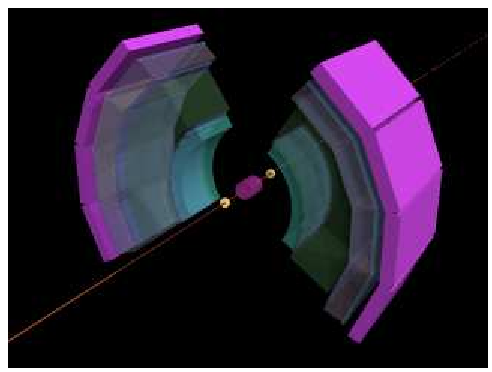
Mixed Event Distribution



Mean e_t Distributions



Mixed Event Distribution



Relating Semi-inclusive to Event-by-Event p_t and e_t Spectra

Calculation for Statistically Independent Particle Emission:

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

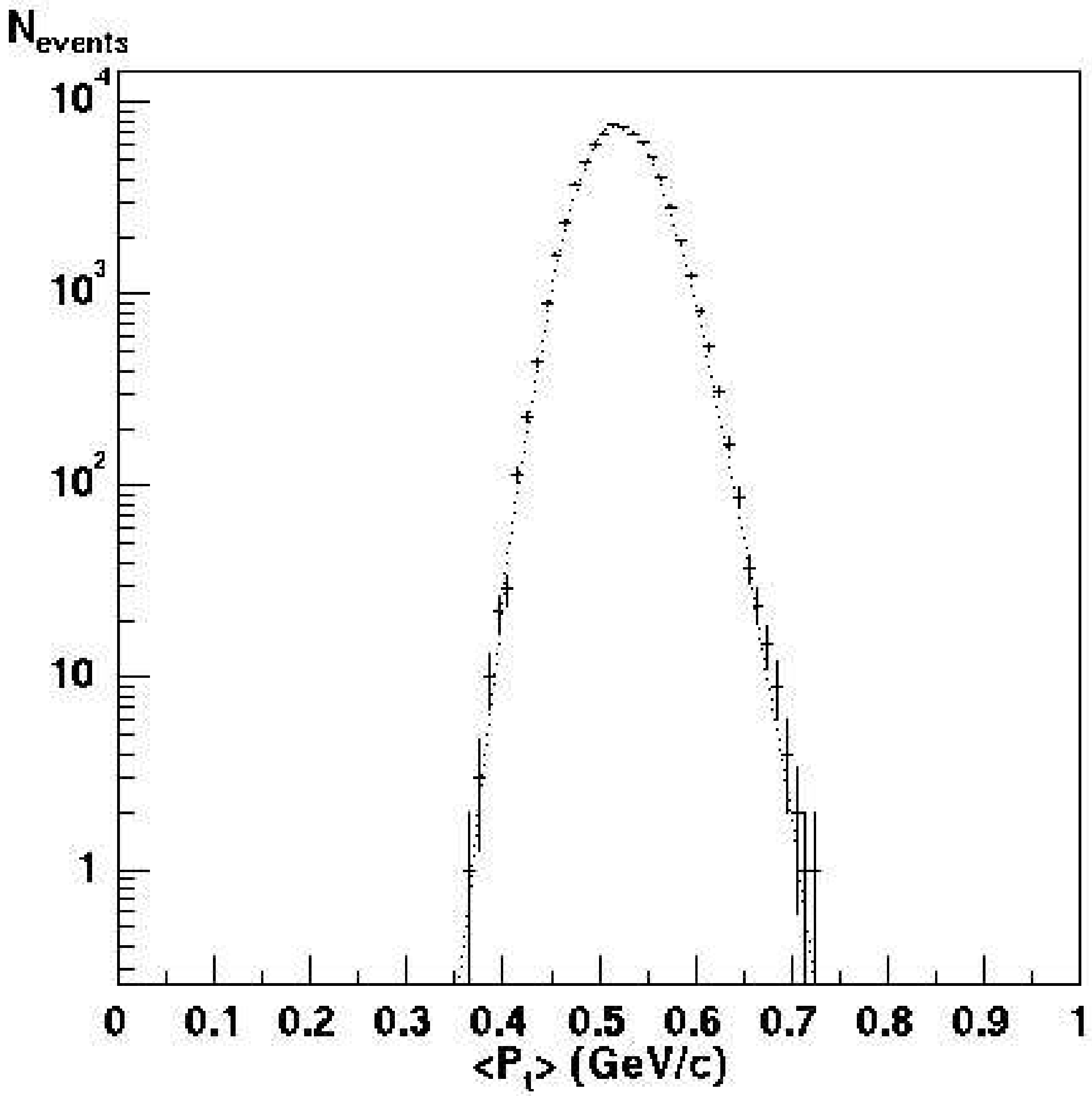
The random distribution is a gamma distribution, $f_\Gamma(M_X,np,nb)$, where

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

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

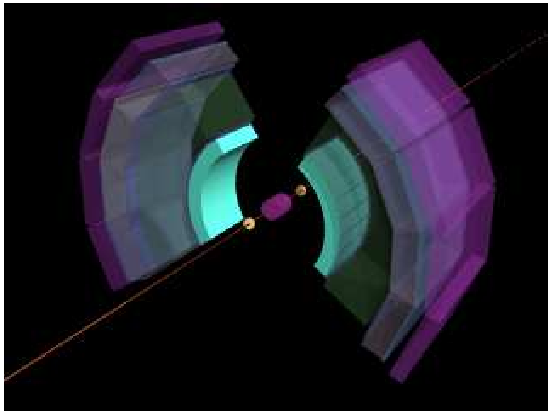
$$f(M_X) = \Sigma\, f_{NBD}(n,1/k,<n>)\, f_\Gamma(M_X,np,nb),$$

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



Mean p_t Distributions

Gamma Distribution <u>calculation</u> based upon semi-inclusive spectra



Quantifying the Fluctuations

Define the magnitude of a fluctuation, ω:

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

Define the fractional fluctuation difference from random, d:

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

Also commonly used is the variable, ϕ_{pt}:

$$\phi_{p_t} = \sqrt{< N >}\left(\sigma_{data} - \sigma_{random}\right) = d\mu\sqrt{< N >}$$

Fluctuation Results

Fluctuation Quantities for the M_{p_t} analysis.

Centrality class	ω (%)	d (%)	ϕ_{p_t} (MeV/c)
0 - 5 %	7.37 ± 0.10	0.14 ± 0.15	5.65 ± 6.02
0 - 10 %	7.85 ± 0.13	0.16 ± 0.19	6.03 ± 7.28
10 - 20 %	9.52 ± 0.14	0.19 ± 0.21	6.11 ± 6.63
20 - 30 %	11.7 ± 0.21	0.21 ± 0.35	5.47 ± 9.16

Fluctuation Quantities for the M_{e_t} analysis.

Centrality class	ω (%)	d (%)	ϕ_{e_t} (MeV/c)
0 - 5 %	7.32 ± 0.07	0.30 ± 0.09	11.5 ± 3.59
0 - 10 %	7.84 ± 0.08	0.37 ± 0.12	13.6 ± 4.23
10 - 20 %	9.58 ± 0.17	0.38 ± 0.20	11.1 ± 5.75
20 - 30 %	11.8 ± 0.26	0.40 ± 0.32	9.28 ± 7.34

Modelling a fluctuation

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

Define a model with 2 event classes, each at a different temperature parameter.

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

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

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

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

$$q = N_{events,fluctuating} / N_{events}$$

Modelling a fluctuation

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

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

$$f(p_t) = q \times \Gamma(p_t, b_1, p_1) + (q-1) \times \Gamma(p_t, b_2, p_2)$$

- For both distributions to have the same μ:

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

- Choose p_1 and q. Obtain p_2 using:

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

- Use the constant μ to extract b_1 and b_2.

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 <N> (Gaussian) distributions over the same ranges used to calculate Mean p_t and Mean e_t for the data.
- Generates Mean p_t, Mean e_t 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.

Determining the Fluctuation Sensitivity

Procedure

- **Start with identical <N> and semi-inclusive spectra as for the data.**
- **Scan over the fluctuation fraction *q*, and p_1.**
- **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 Mean p_t for all events. Calculate *d*.**

An example of a modelled large fluctuation

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

Red = Fluctuation distribution with

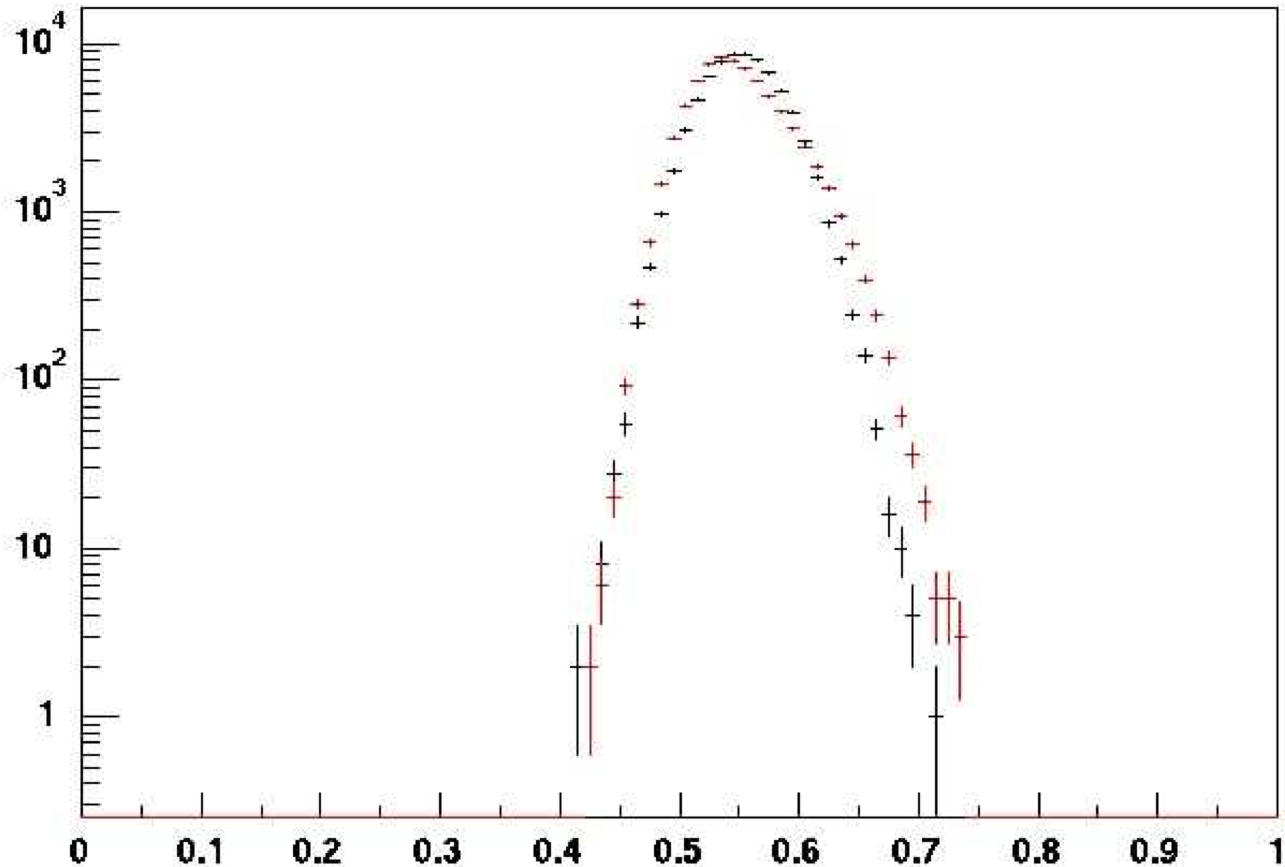
$q = 60\%$, $b_1 = 87.1$ MeV, $b_2 = 257$ MeV.

$\omega_{base} = 6.02\%$

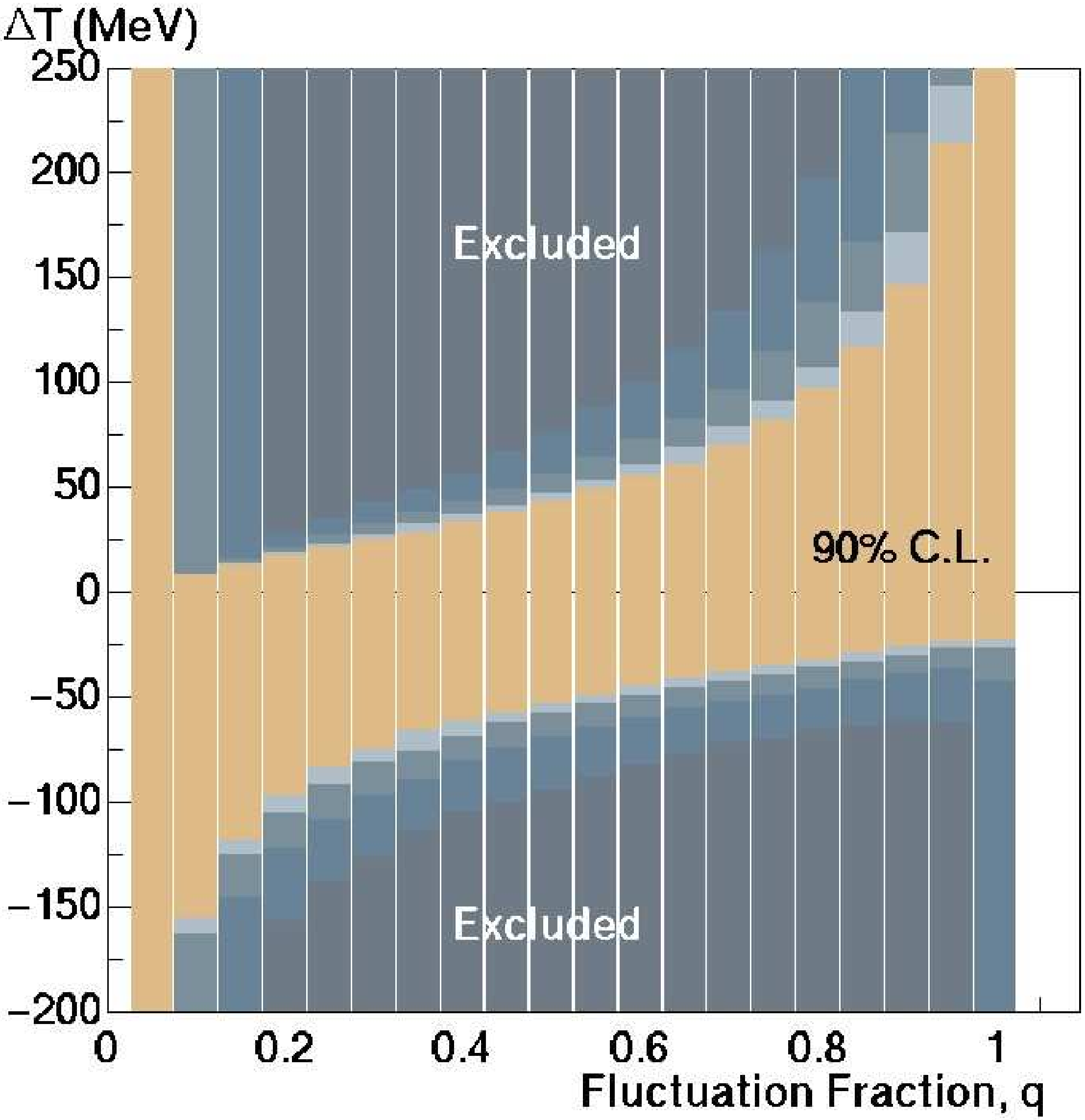
$\omega_{model} = 6.98\%$

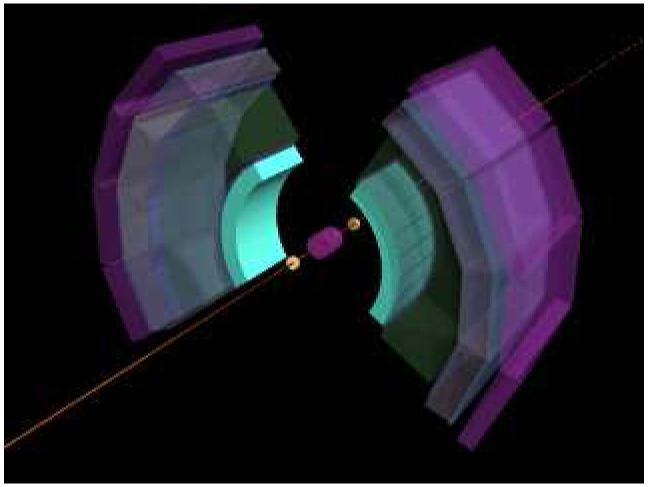
$d = 0.96\%$

$\phi = 38.7$ MeV

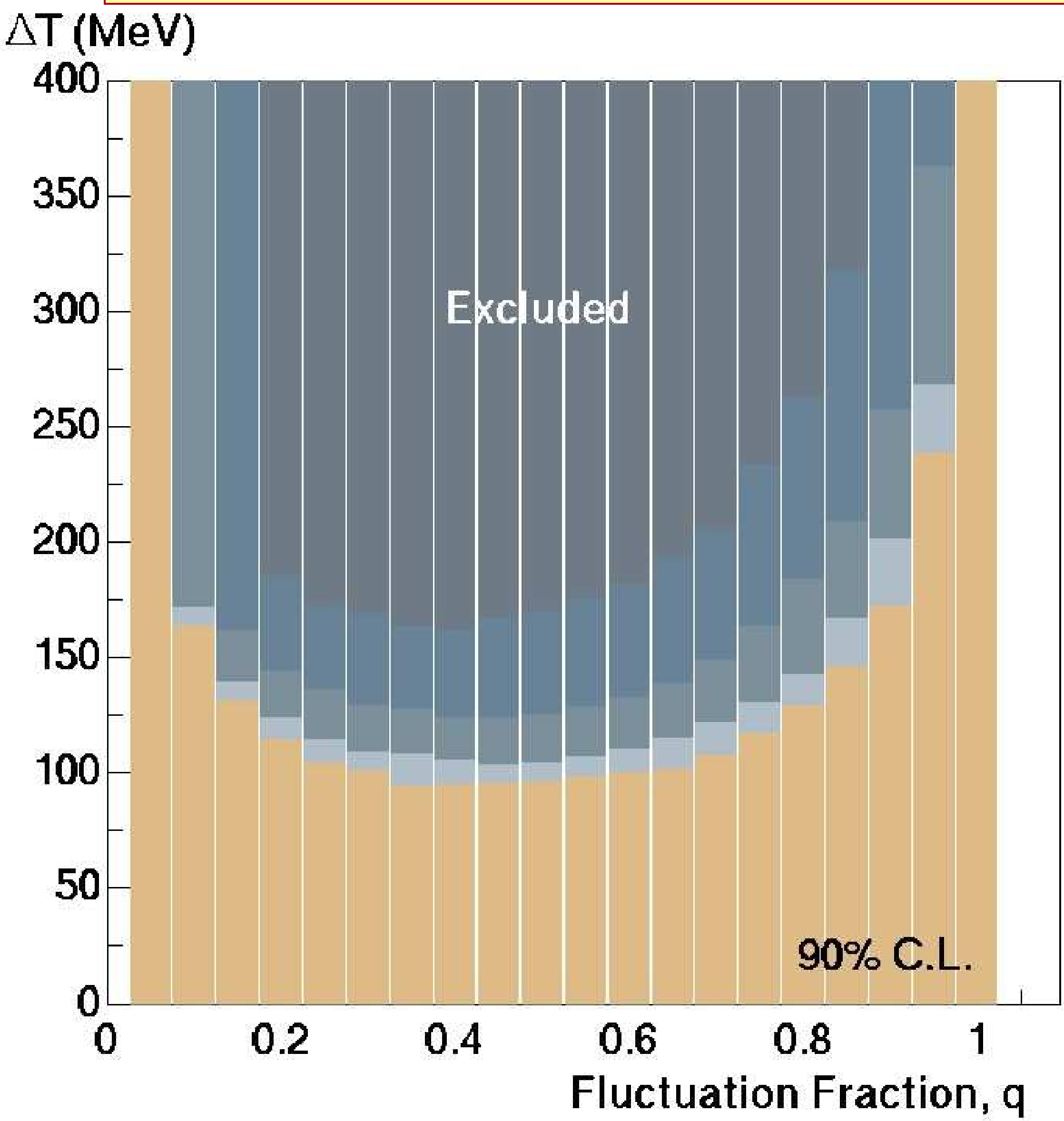


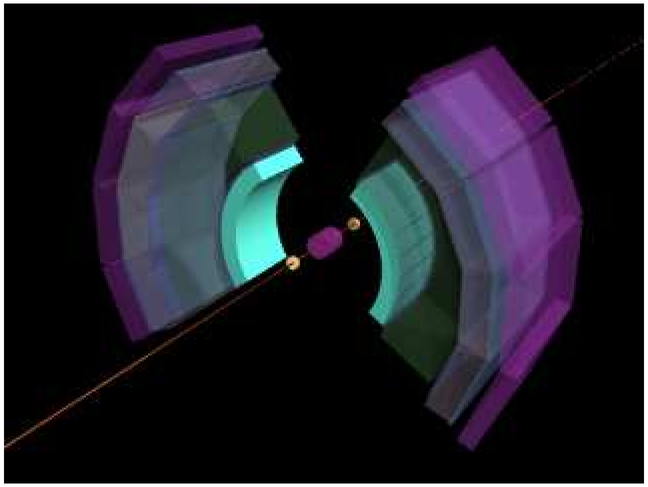
Mean p_t fluctuation Sensitivity





Mean p_t fluctuation Sensitivity

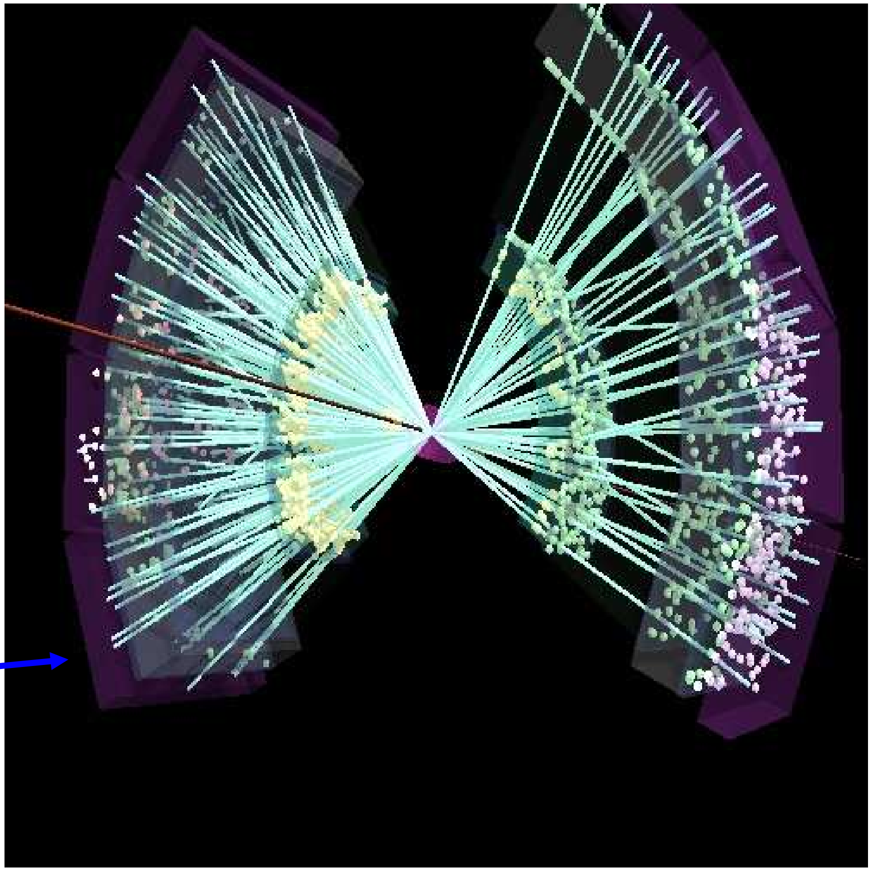




Conclusions and Outlook

Conclusions:

- There are no *significant* non-random fluctuations in Mean p_t or Mean e_t over the most 30% central $\gamma = 130$ Au+Au collisions within the PHENIX acceptance.
- All event-by-event spectra are well described by the semi-inclusive spectra accounting for known detector effects.
- Given a simple dual event class 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 azimuthal 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.

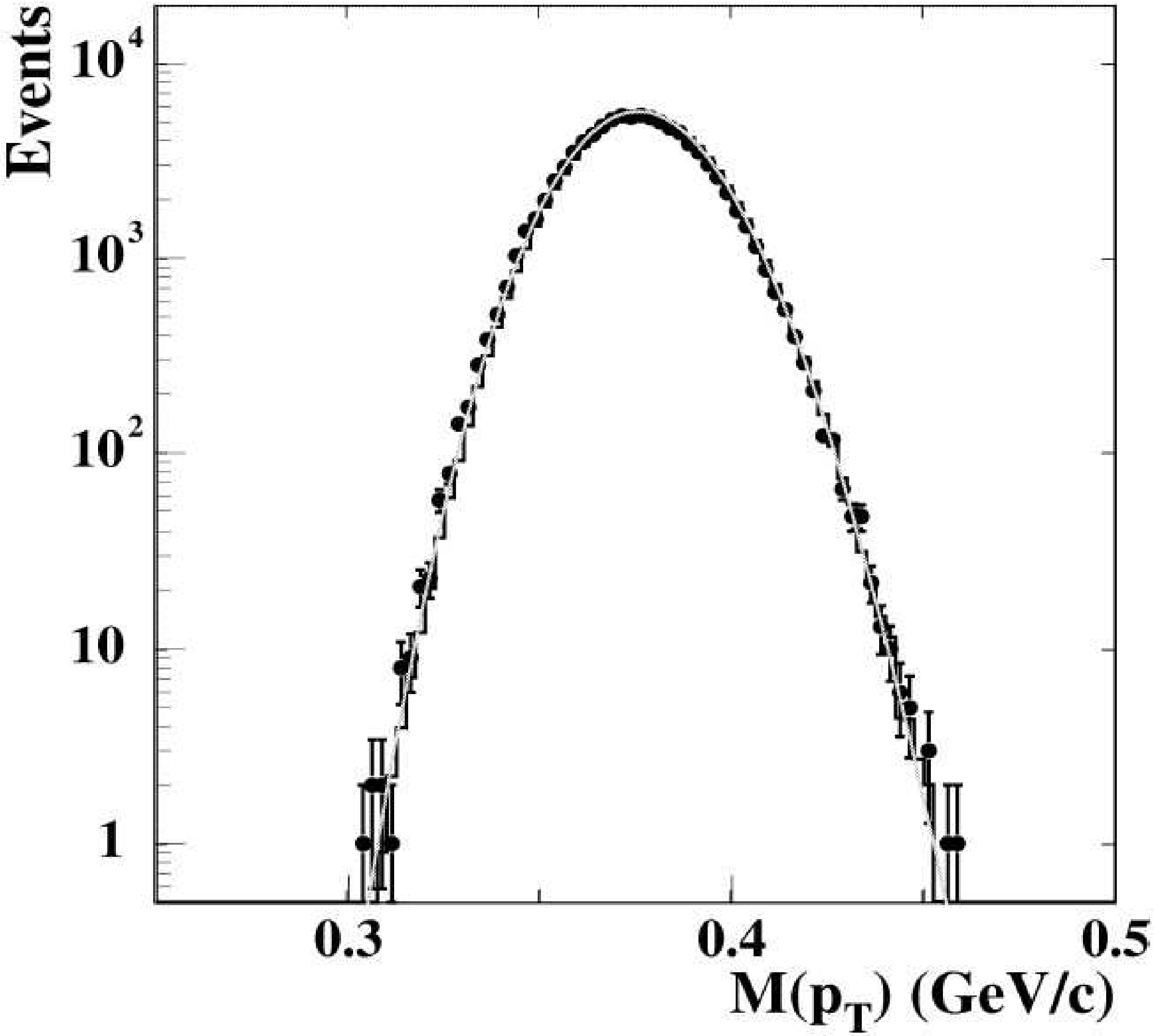
- Since the π is massive, the σ cannot immediately decay. It must wait for the density to decrease and for its mass to rise towards the vacuum value.

- 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 $\langle N_\sigma\rangle$.

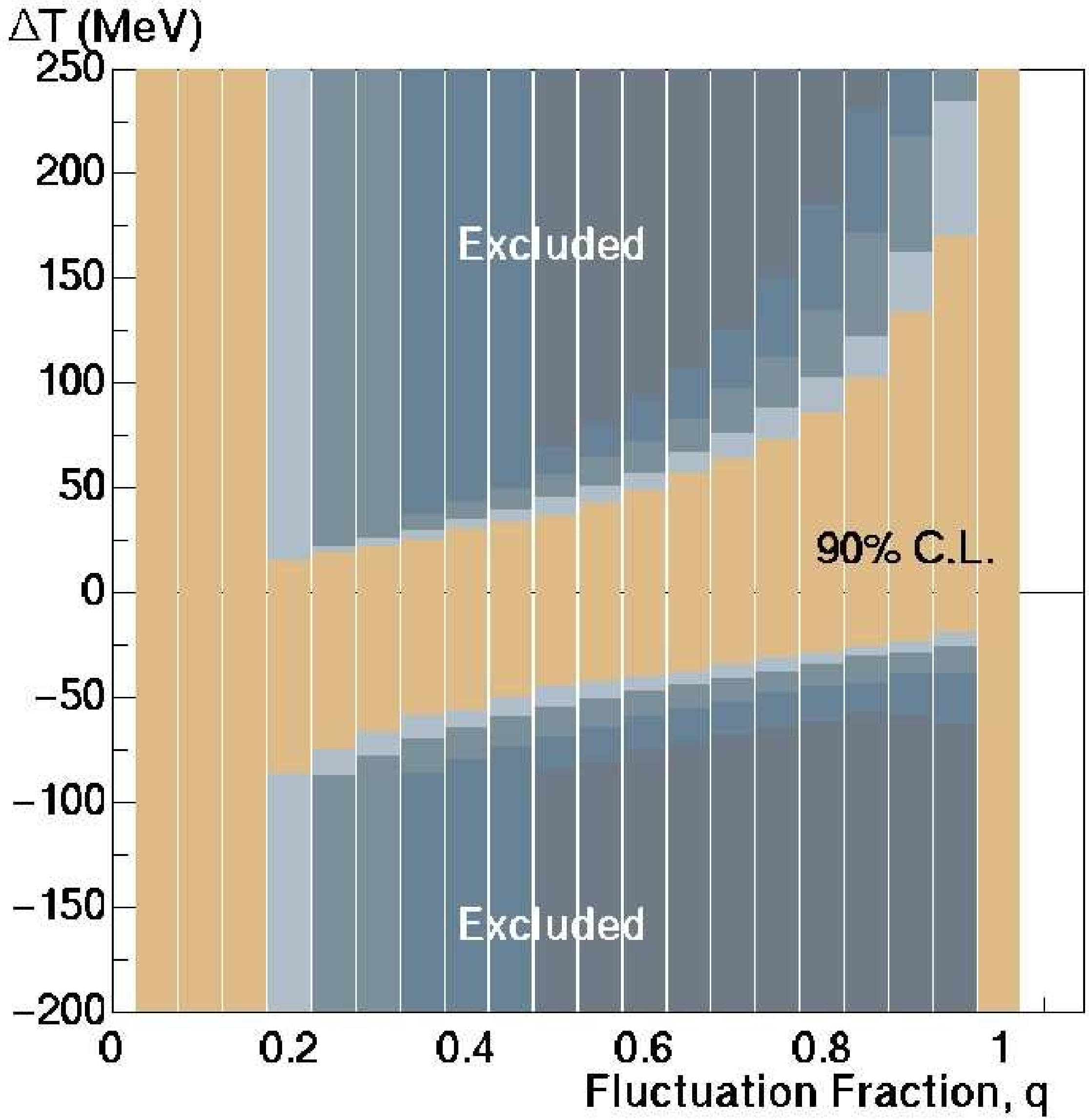
- Therefore, large event-by-event fluctuations could be expected in N_π and $\langle p_t\rangle$.

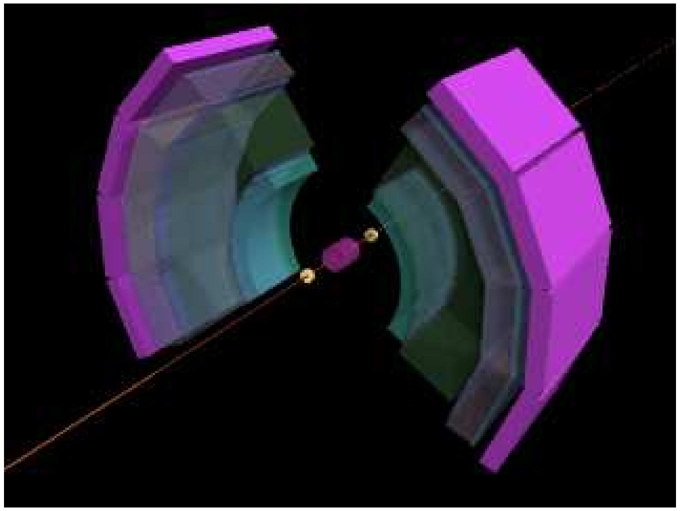
$\langle P_t \rangle$ Measurement from CERN Experiment NA49



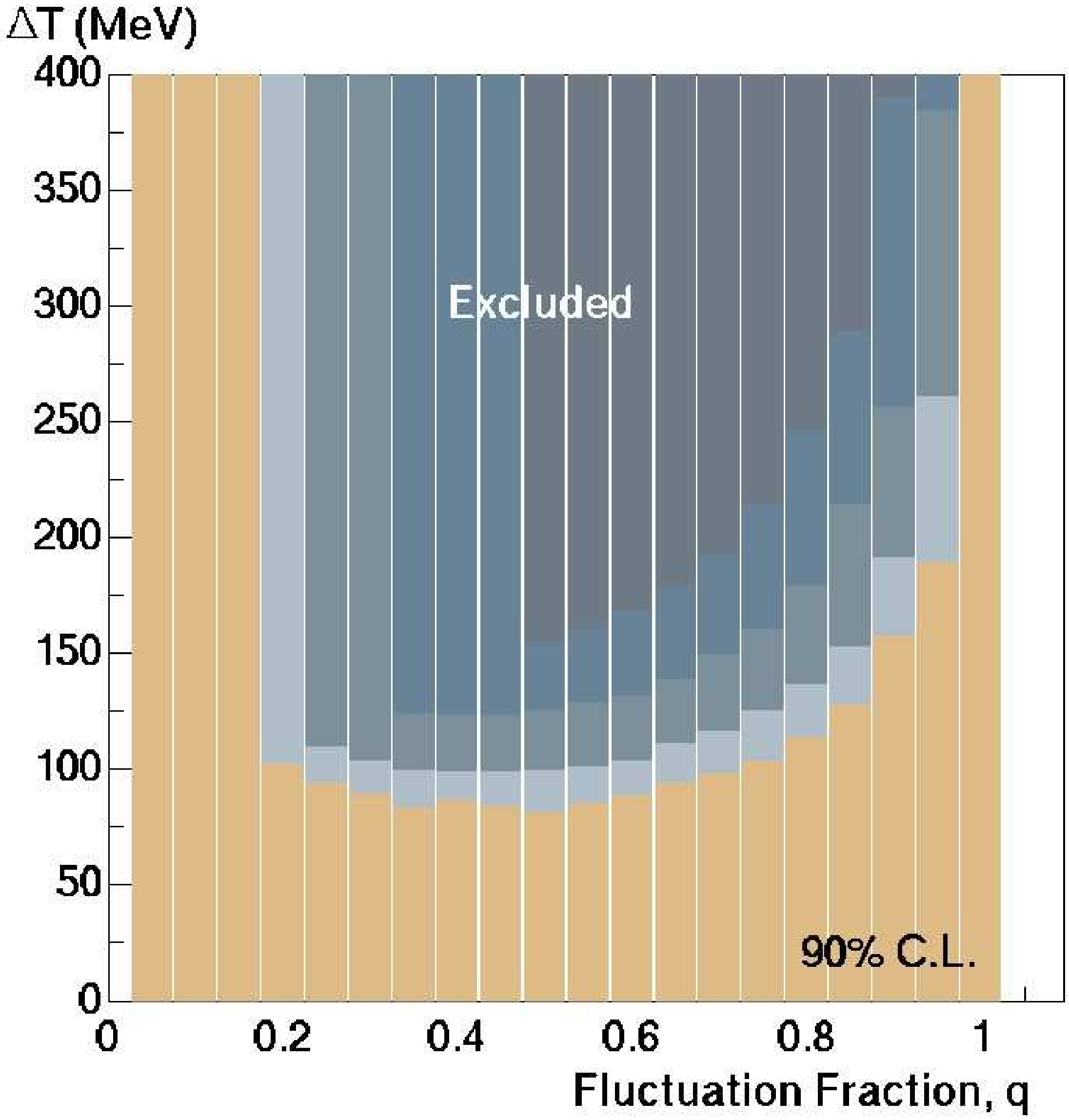
- See H. Appelshauser, et. al., Phys. Lett. B459 (1999) 679.
- Distribution is compatible with independent particle production.

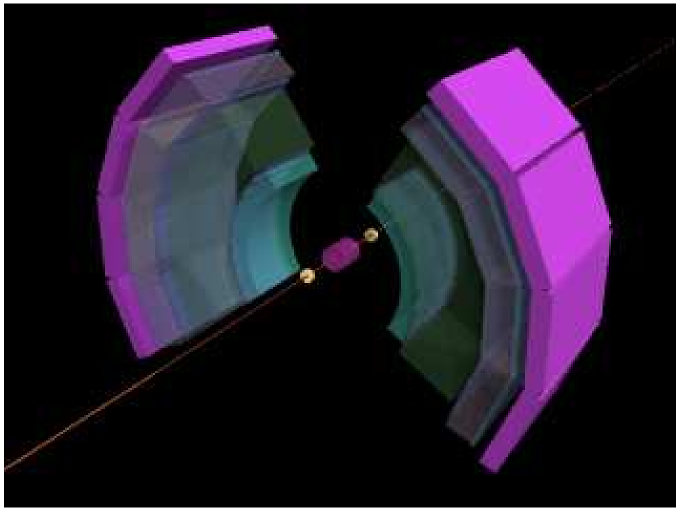
Mean e_t fluctuation Sensitivity



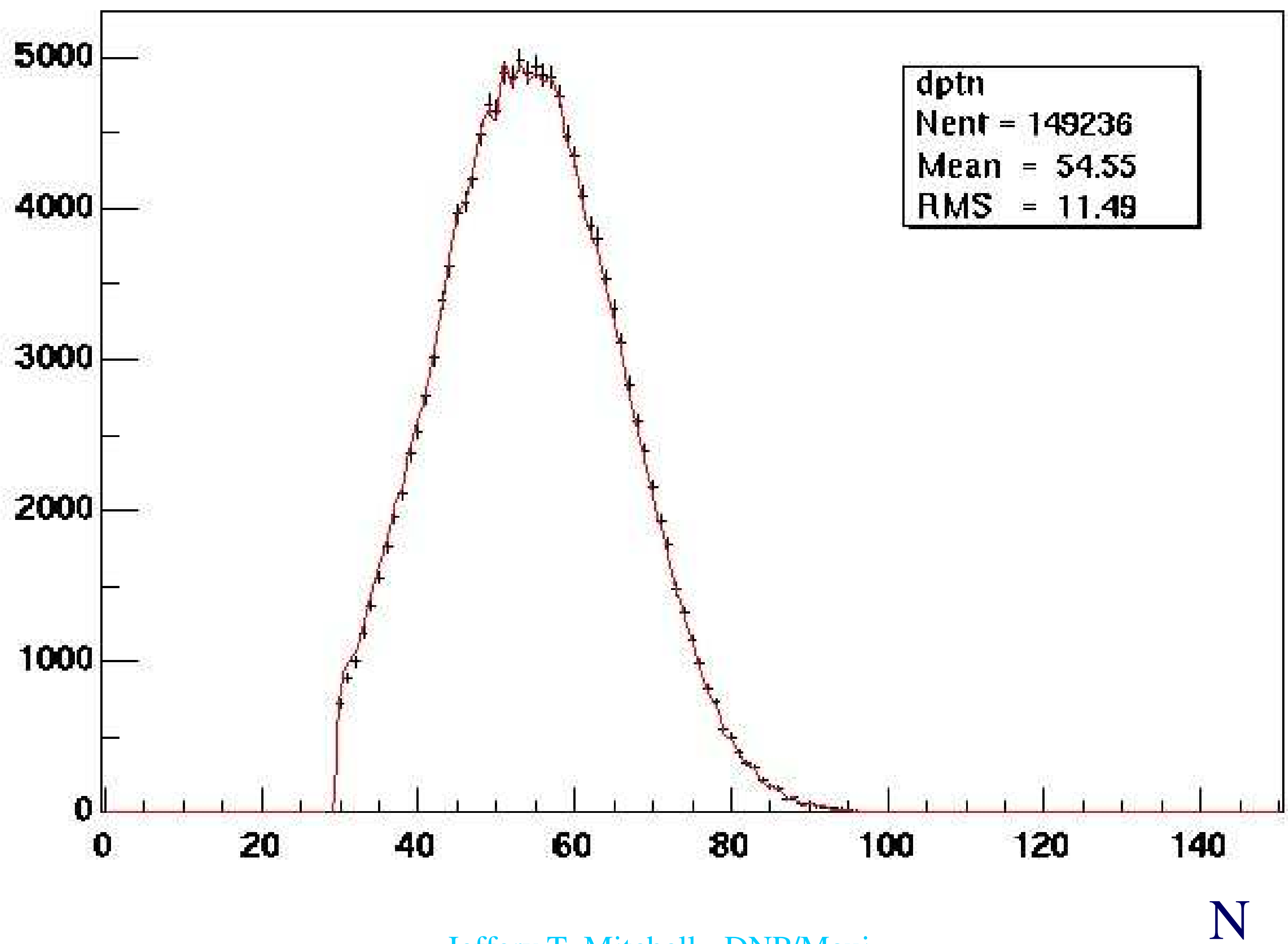


Mean e_t fluctuation Sensitivity





Comparison of data and mixed N distributions



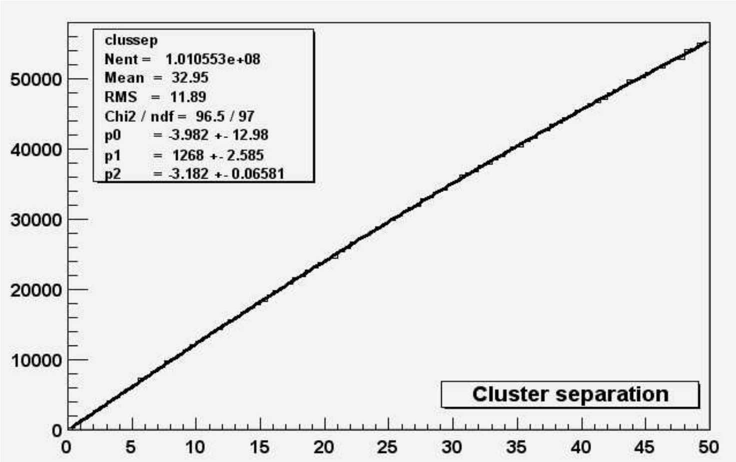
PbSc Mean Et: Cluster Merging Introduces Correlations.

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

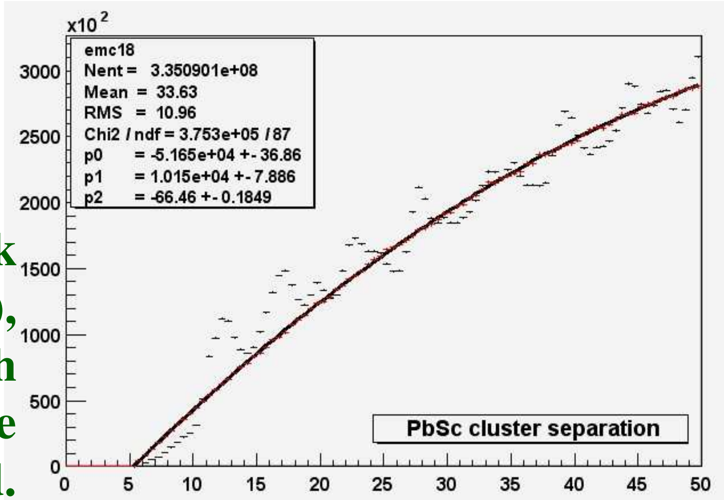
Procedure: Generate clusters one at a time using the same prescription as used for M_{pt}.

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.

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.)

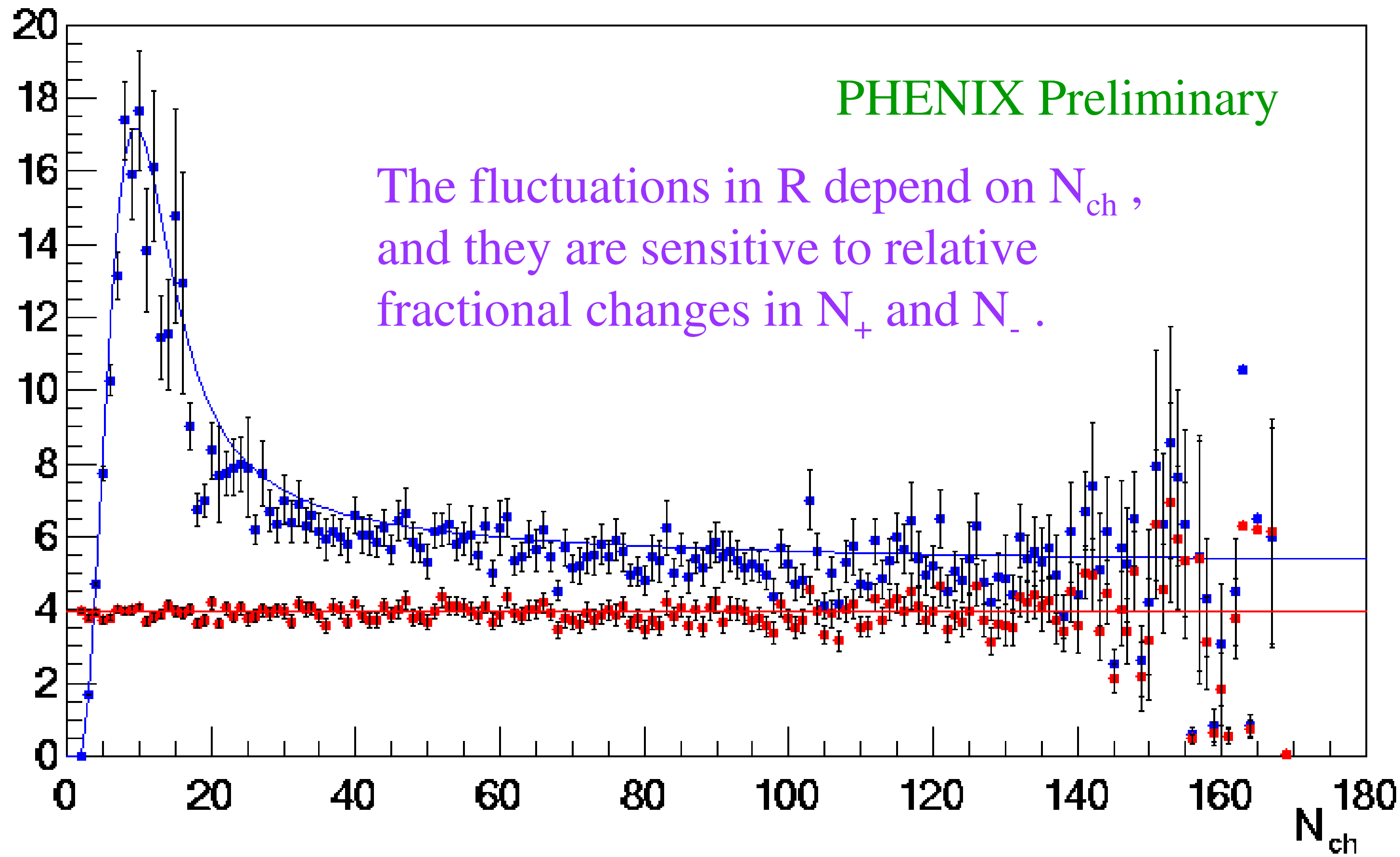
QGP : $$\frac{<Q^2>}{<N_{ch}>} \approx 0.20 - 0.25$$ (S. Jeon & V. Koch PRL 85(2000)2076)

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



$(<R^2> - <R>^2) * N_{ch}$ $(R = N_+/N_-)$

$4 (<Q^2> - <Q>^2) / N_{ch}$ $(Q = N_+ - N_-)$