Event-by-Event Average p_T Fluctuations in s_{NN}=200 GeV Au+Au and p+p Collisions in PHENIX: Measurements and Jet Contribution Simulations

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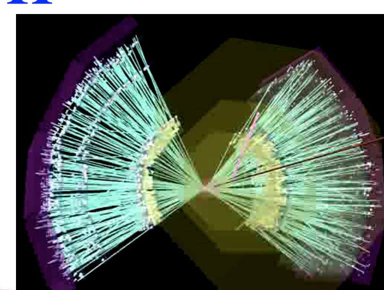
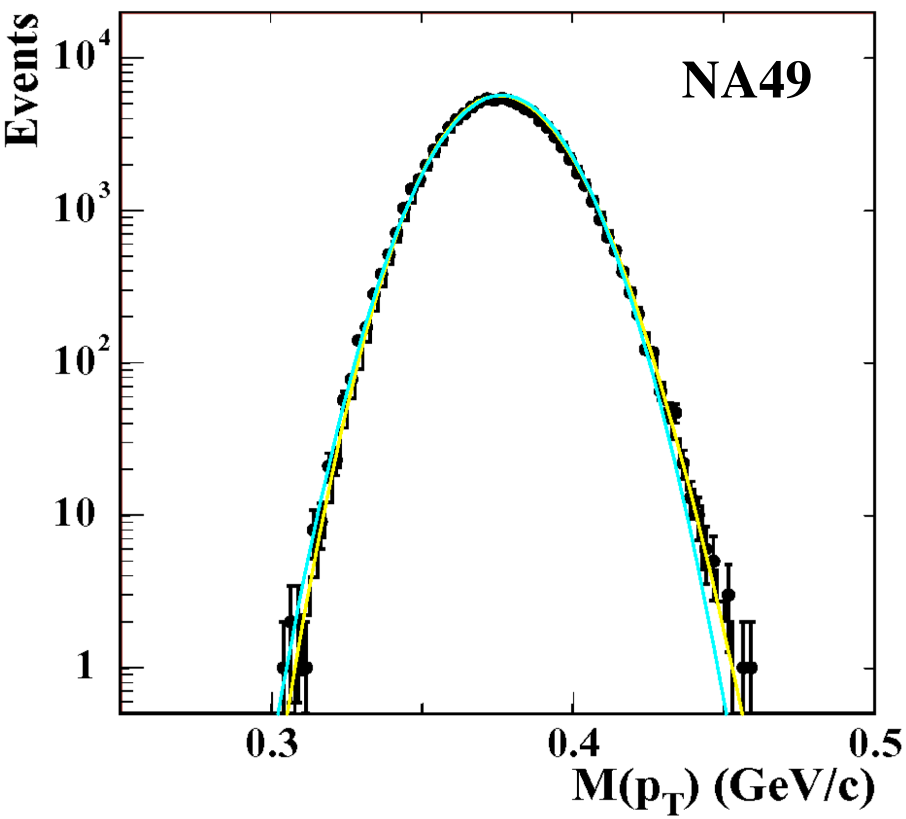


The Event by Event Average p_T (Mp_T) Distribution is not a gaussian, it's a gamma distribution!

- DEFINITION $$M_{p_T} = \overline{p_T}_{(n)} = \frac{1}{n}\sum_{i=1}^{n} p_{T_i} = \frac{1}{n} E_{Tc}$$ for events with n particles.

- For **statistically independent** emission (the sum of independent p_{T_i}) analytical formula



$$f(y) = \sum_{n=n_{\min}}^{n_{\max}} f_{\mathrm{NBD}}(n, 1/k, \langle n\rangle)\, f_\Gamma(y, np, nb)$$

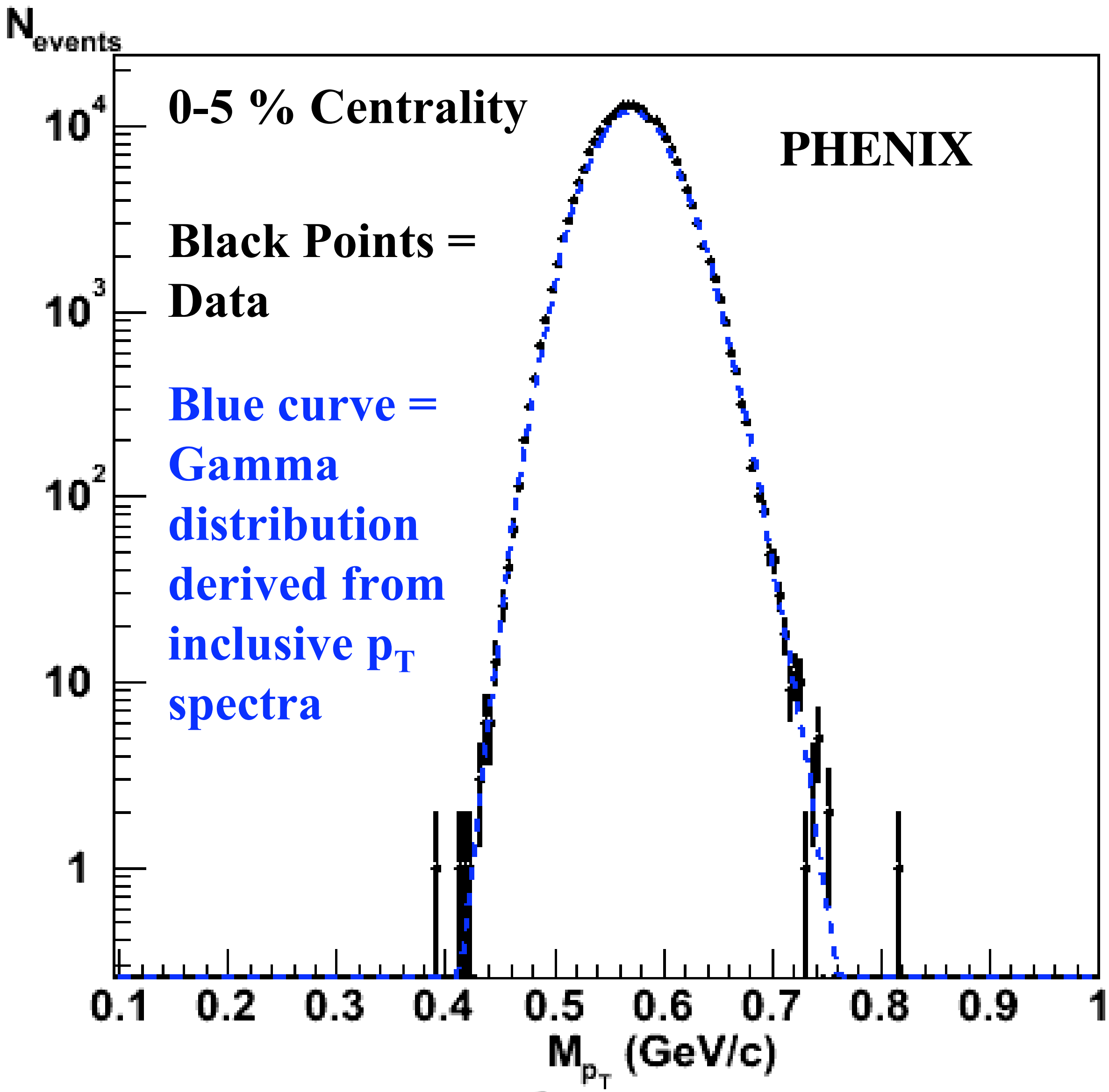
- Depends on the 4 semi-inclusive parameters
  - b, p of p_T distribution (Gamma),
  - <n>, 1/k of track multiplicity (NBD)

  derived from the quoted means and standard deviations of the semi-inclusive p_T and multiplicity distributions.
- The result is in excellent agreement with the NA49 Pb+Pb central measurement PLB **459**, 679 (1999)

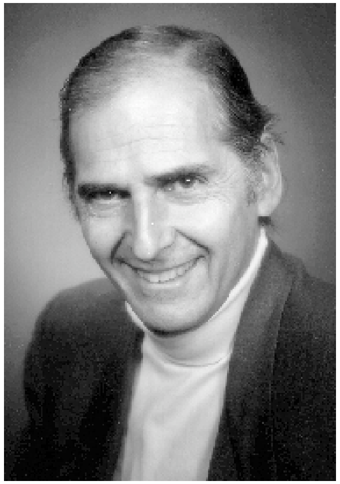
See M.J.Tannenbaum PLB **498**, 29 (2001)

From one of Jeff Mitchell's talks:

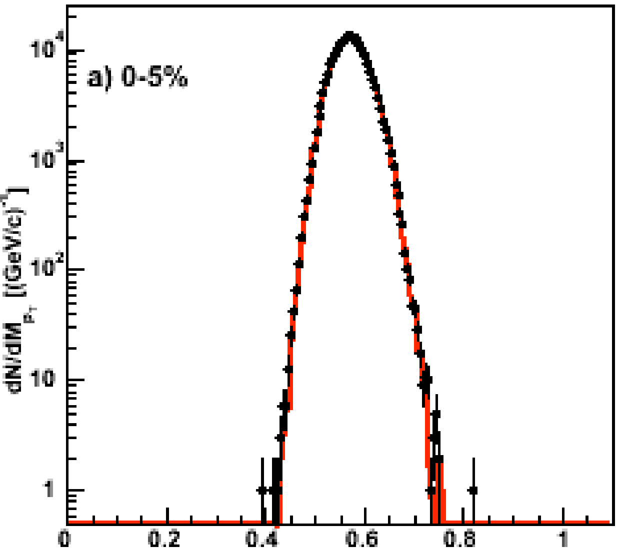
"Average p_T Fluctuations"



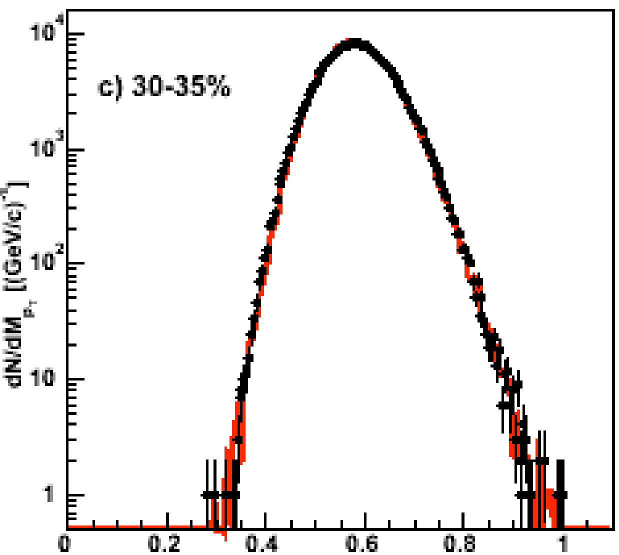
It's not a Gaussian…it's a Gamma distribution!



PHENIX M_{p_T} vs centrality 200 GeV Au+Au nucl-ex/0310005



M_{p_T} (GeV/c)

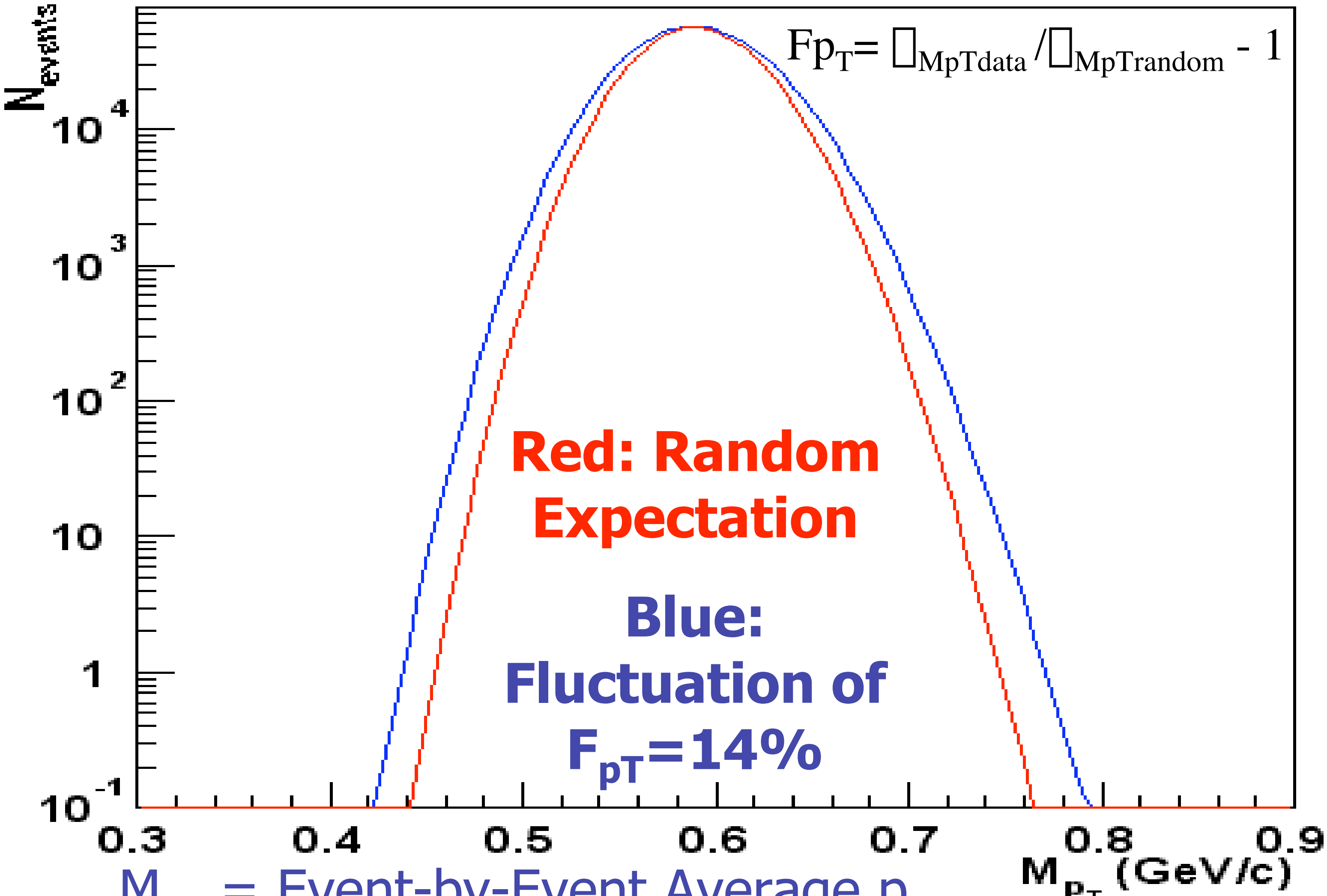


M_{p_T} (GeV/c)

- compare Data to Mixed events for random.
- Must use exactly the same n distribution for data and mixed events and match inclusive $\langle p_T \rangle$ to $\langle M_{p_T} \rangle$
- best fit of real to mixed is statistically unacceptable
- deviation expressed as:

F_{p_T}= □$_{M_{p_T}\text{data}}$/ □$_{M_{p_T}\text{mixed}}$ -1 ~ few %

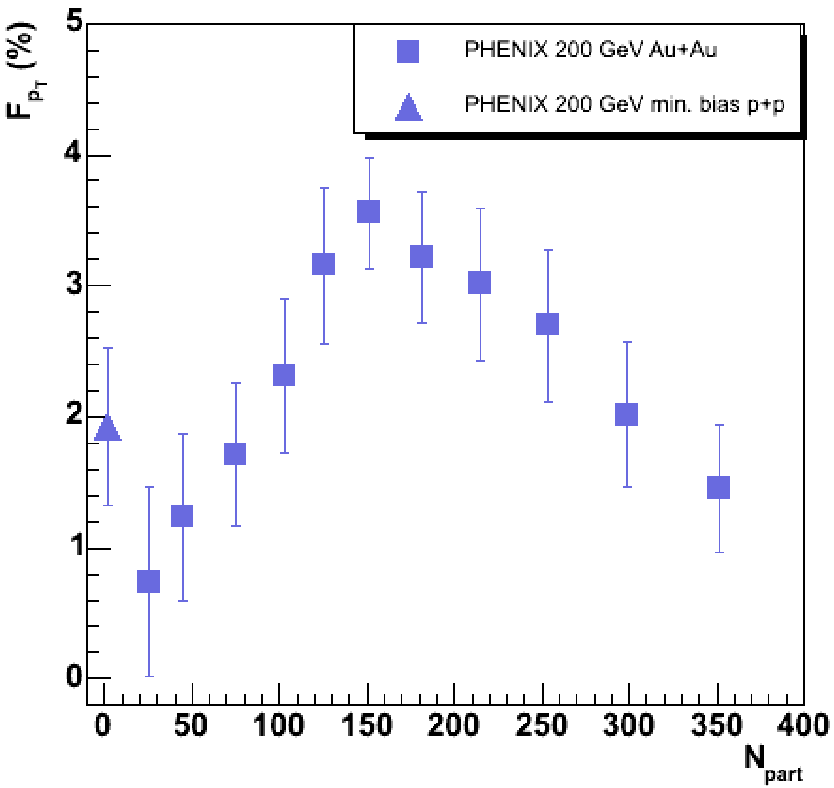
How To Measure a Fluctuation
$\langle M_{p_T} \rangle$ must stay the same only $\sigma_{M_{p_T}}$ varies

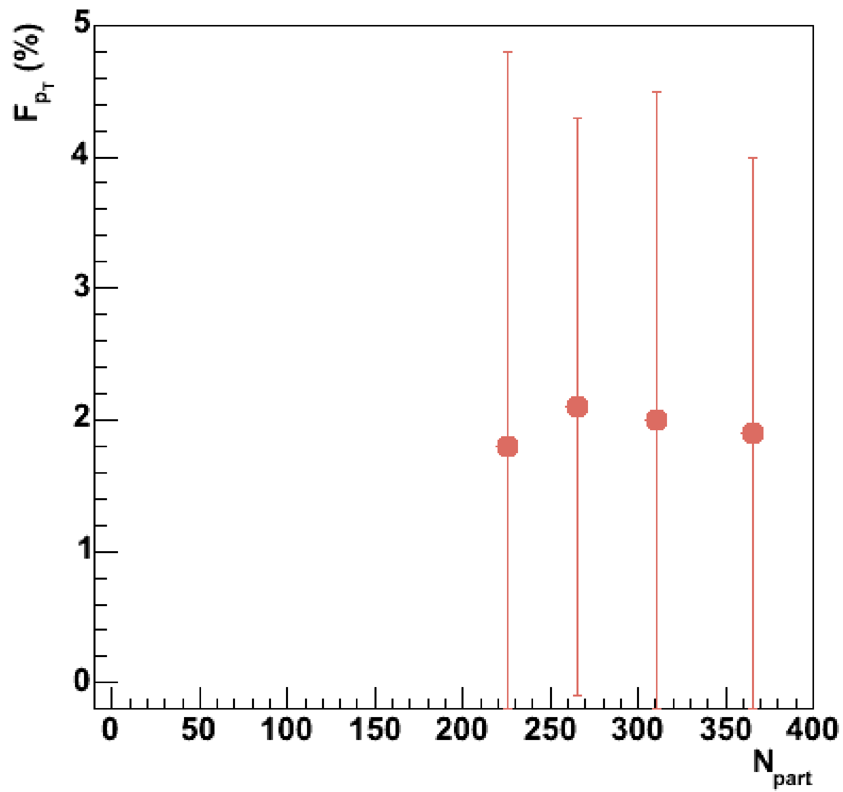


M_{pT} = Event-by-Event Average p_T

Large Improvement at $\sqrt{s_{NN}}$= 200 GeV Compared to $\sqrt{s_{NN}}$= 130 GeV results

nucl-ex/0310005 subm. PRL



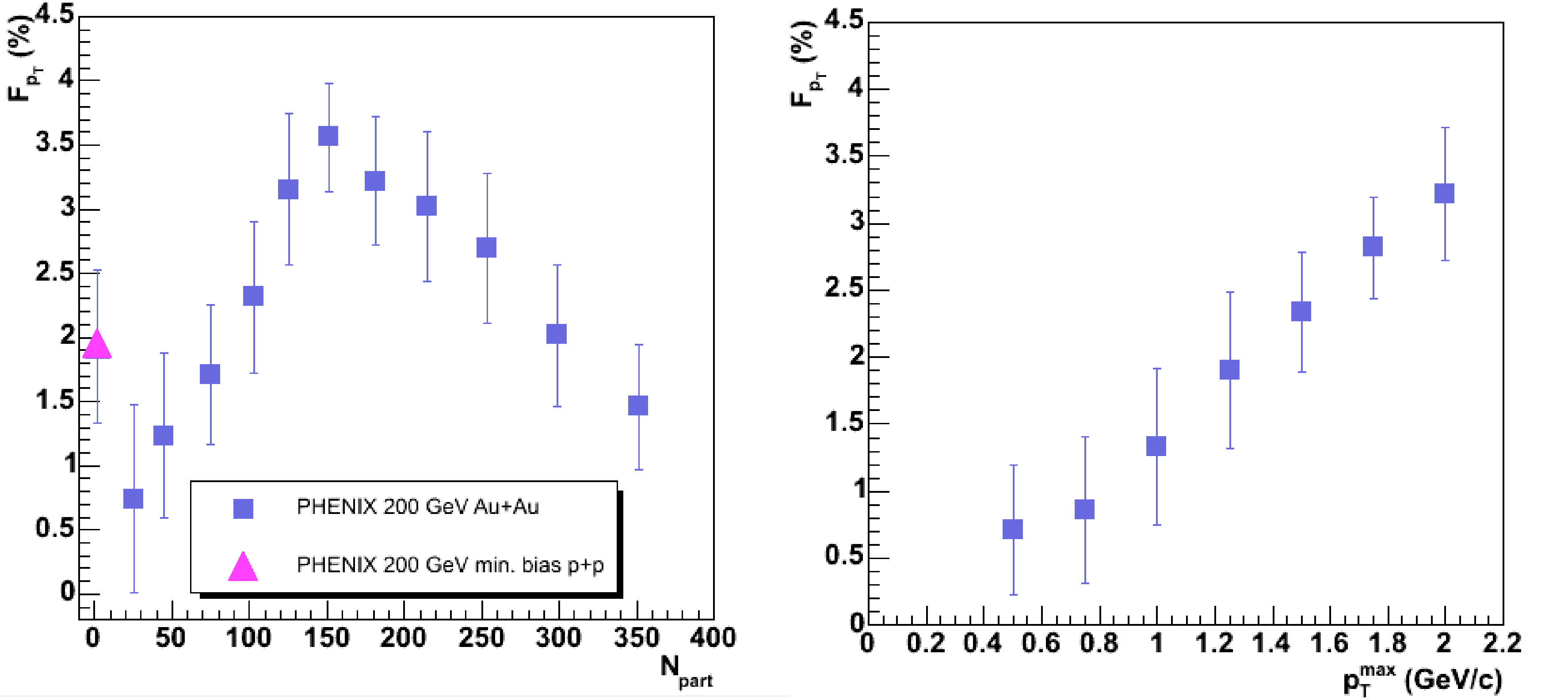


- 3 times larger solid angle
- better tracking
- more statistics

$\sqrt{s_{NN}}$=130 GeV
PRC **66** 024901 (2002)

Fluctuation is a few percent of σ_{MpT}: Interesting variation with N_{part} and p_{Tmax}

Errors are totally systematic from run-run r.m.s variations



$n > 3 \quad 0.2 < p_T < 2.0$ GeV/c $\qquad$ 0.2 GeV/c $< p_T < p_T^{max}$

PHENIX nucl-ex/0310005 subm. PRL

Simulate of Fluctuations: I-Baseline Simulation

A **data-driven** simulation designed to simulate statistically independent particle production:

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

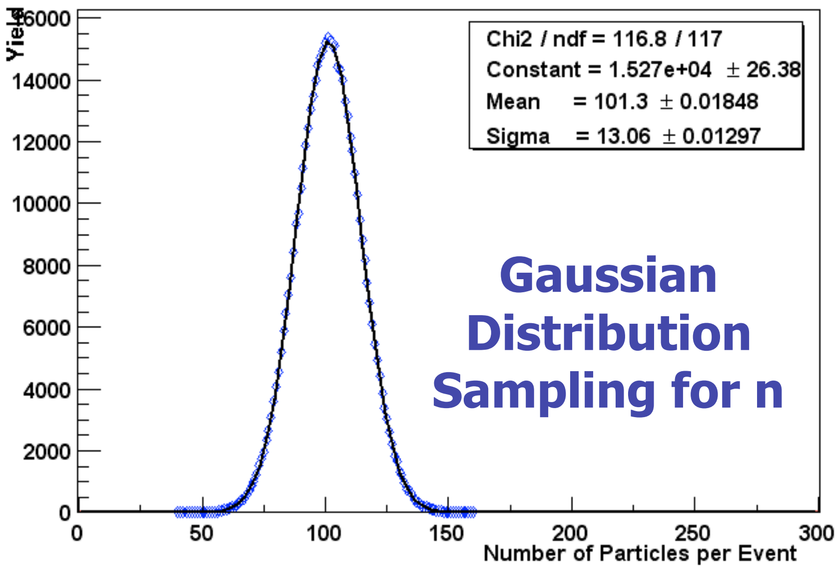
- Assign a p_T to each particle by sampling an m_T exponential distribution fit (or double exponential, or Gamma distribution) to the data inclusive p_T distribution.

- Calculates the event-by-event M_{pT}.

- Generates mixed events for calculation of fluctuation quantities.

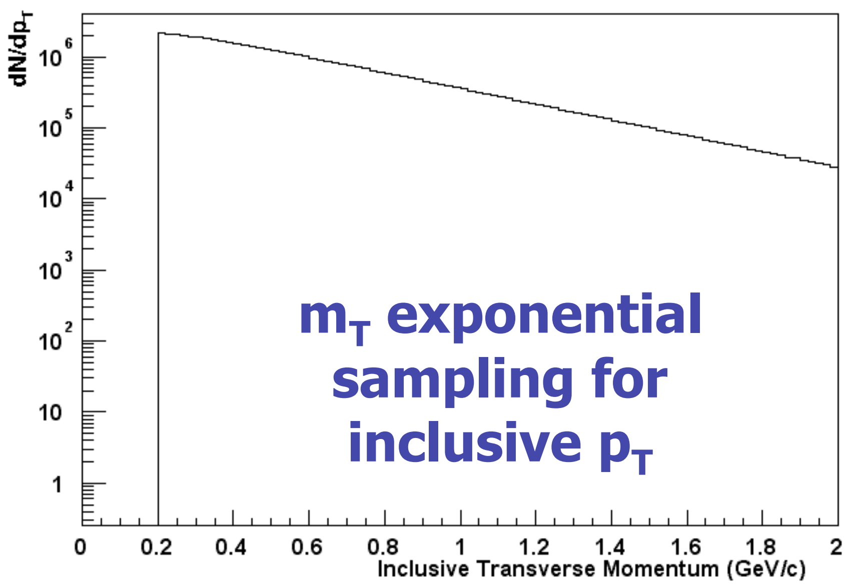
Input parameters include: $\langle n \rangle$, $\sigma_{\langle n \rangle}$, inclusive p_T function paramters, p_T range for $\langle p_T \rangle$ calculation.

Results from the Baseline Simulation with random p_T and n from measured distributions



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

Inclusive $\langle p_T \rangle$, σ_{pT}, $\langle n \rangle$, $\sigma_{\langle n \rangle}$ matched to the data for each centrality class.

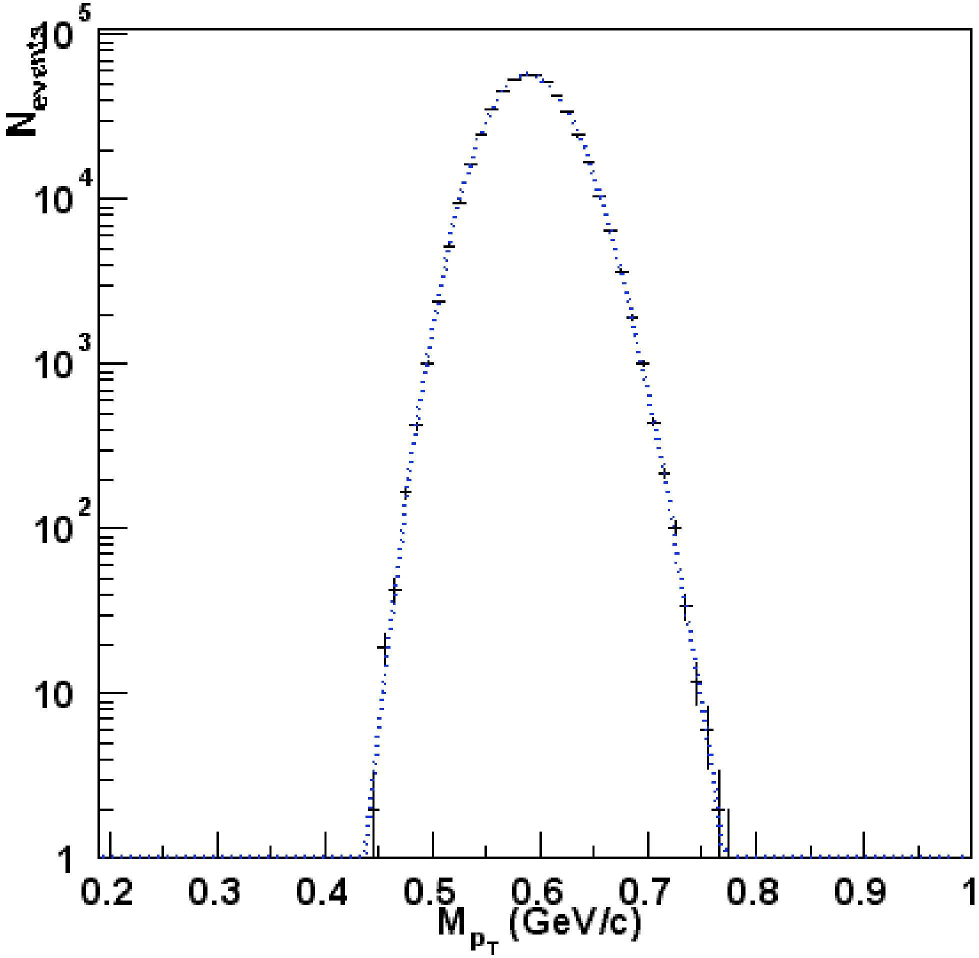


I-Results from the Baseline Simulation

Black points: Simulation Output

Blue curve: Gamma distribution calculation for statistically independent particle emission with input parameters taken from the inclusive spectra.

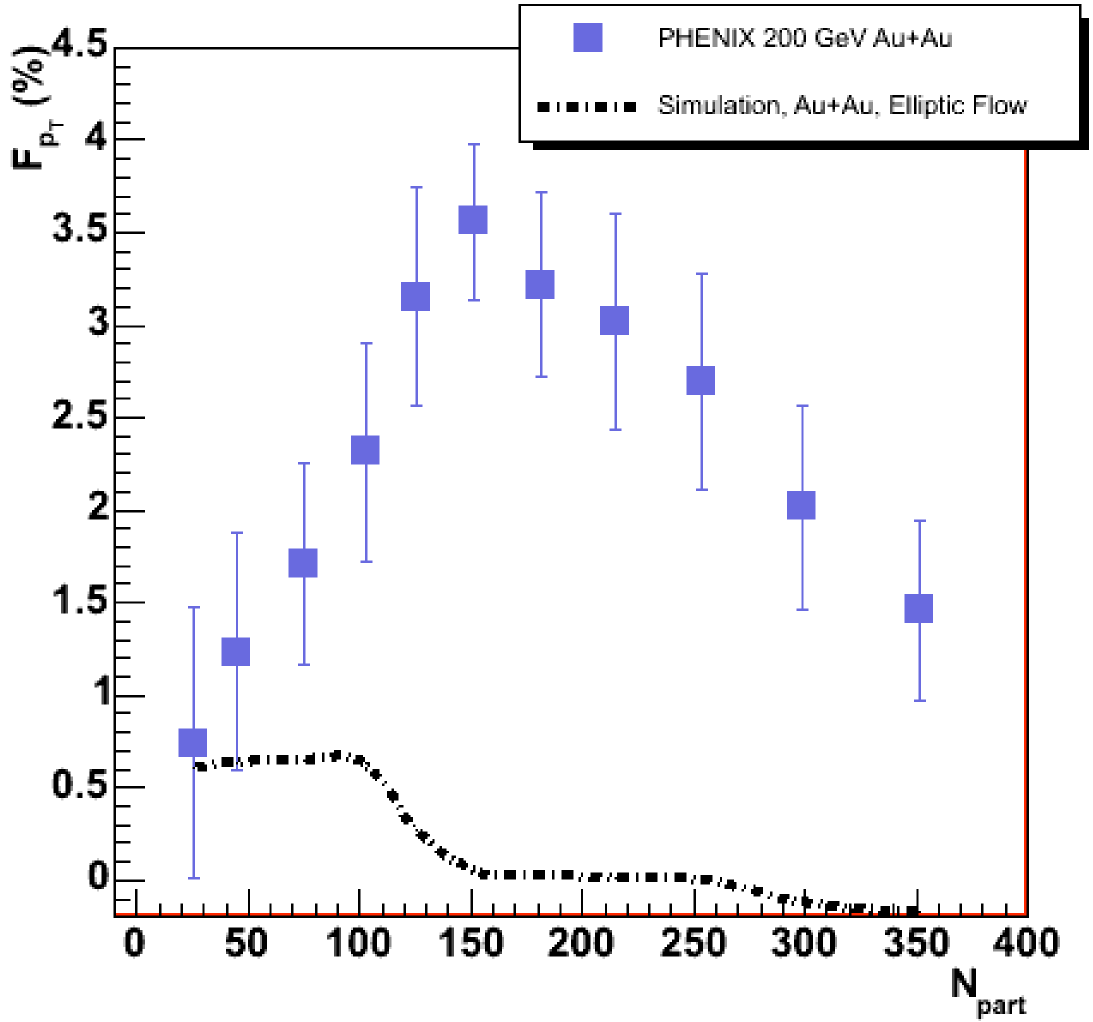
*My result (PLB**498**) is now a good check for statistical independence in the Monte Carlo or in the mixed events*



II-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.

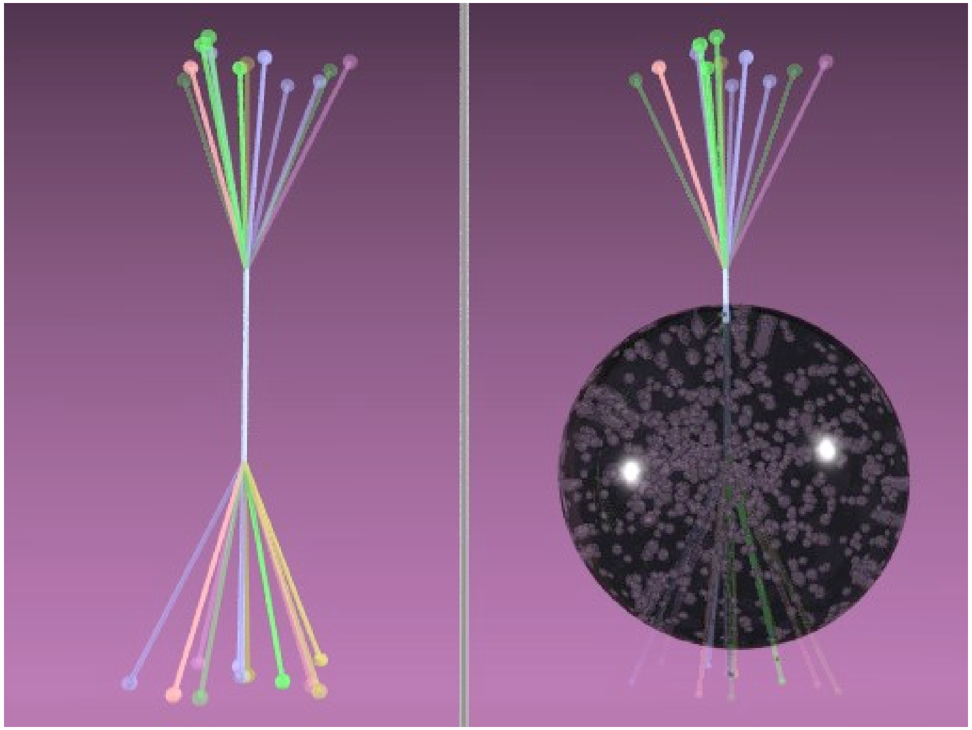


III-A Jet Contribution?

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.

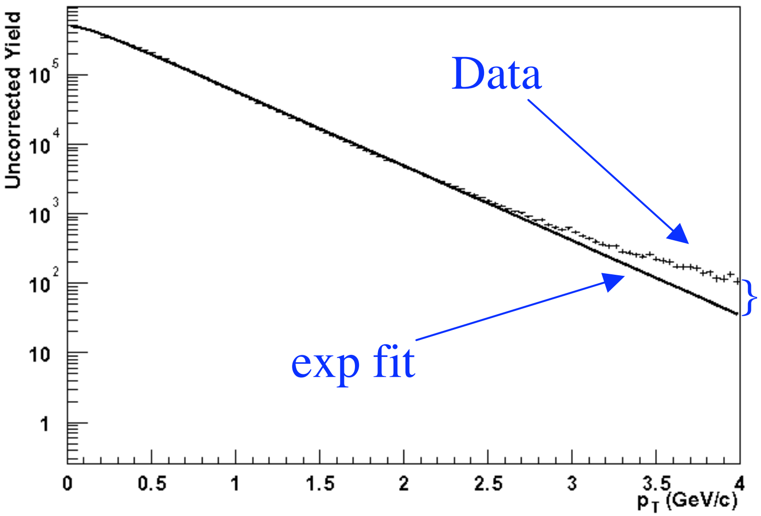
NOTE: The n distribution is preserved in this simulation. The inclusive $<p_T>$ and □(p_T) are affected by less than 1%.



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.

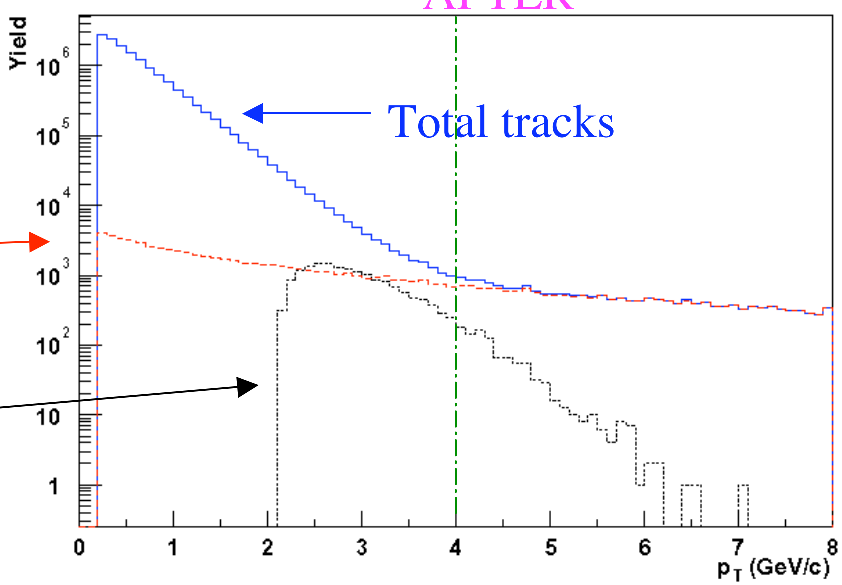
How Jets are Inserted

BEFORE



} Take pythia jet

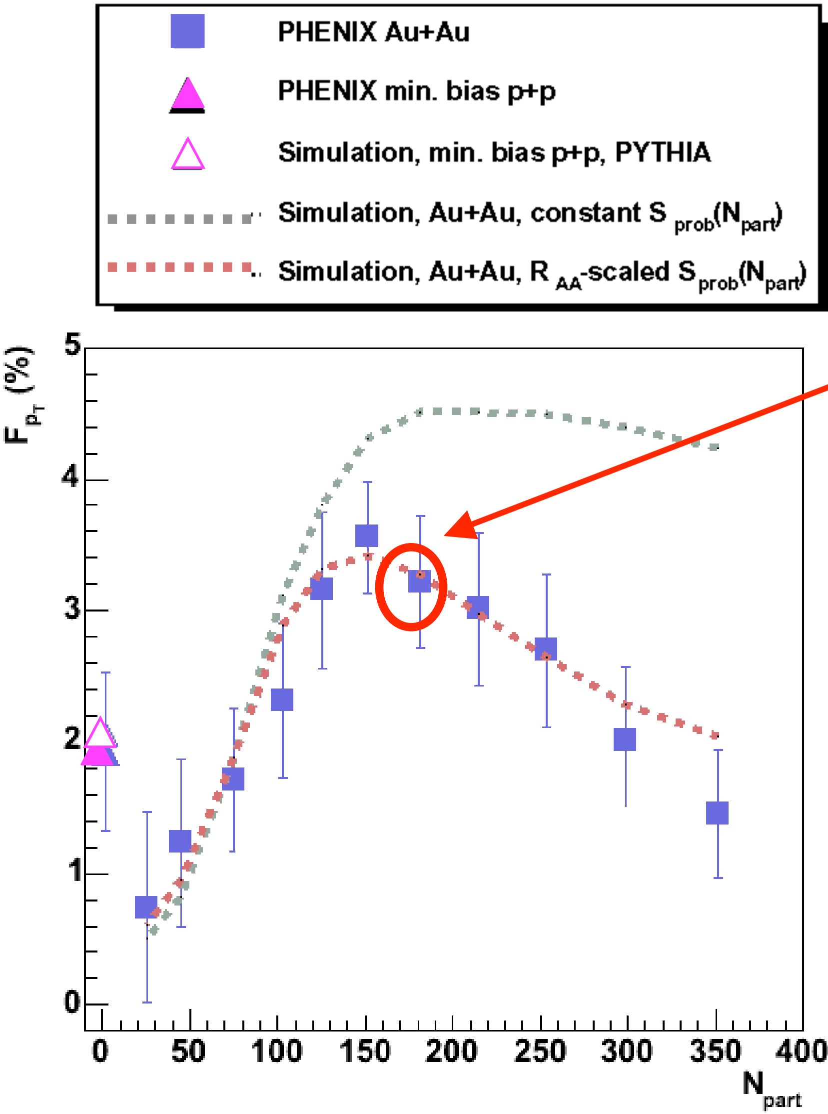
AFTER



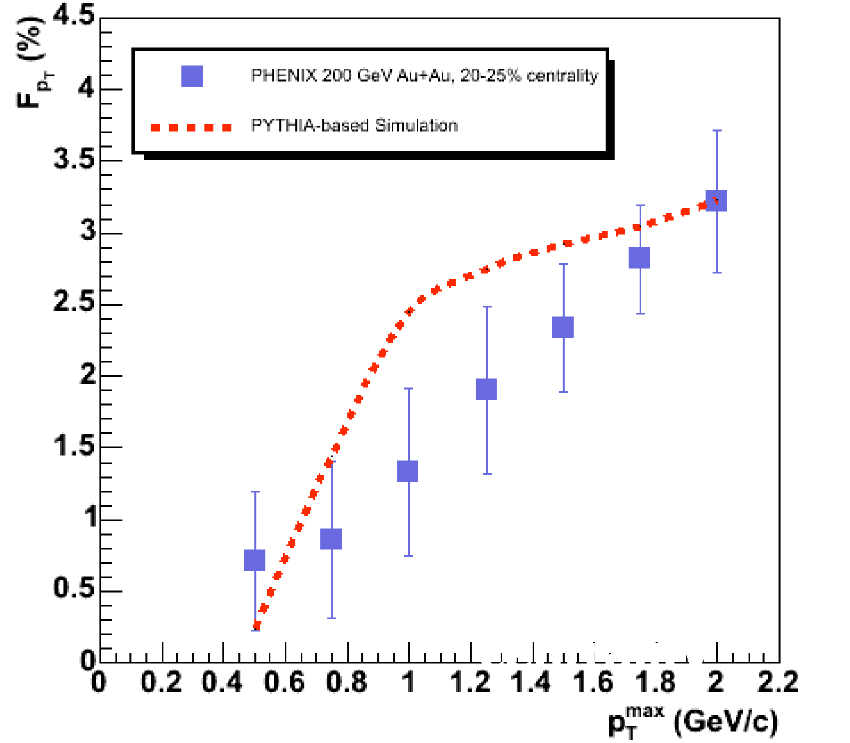
Tracks from pythia jets

Tracks generated with original exp fit

III-Jet Simulation Results
PHENIX at s_{NN} = 200 GeV



The S_{prob} x R_{AA} parameter is initially adjusted so that F_{pT} from the simulation matches F_{pT} from the data for 20-25% centrality.



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

$$\frac{\sigma_T}{< T >} = \sqrt{\frac{2F_{p_T}}{(p=0.8)\times(< n > -1)}}$$

R. Korus and S. Mrowczynski,

Phys. Rev. C64 (2001) 054908.

Measurement	s_{NN}	σ_T/<T> Most central	σ_T/<T>, At the peak Fp_T
PHENIX	200	1.8%	3.7%
STAR	130	1.7%	3.8%
CERES	17	1.3%	2.2%
NA49	17	0.6%	2.6%

See Jeff Mitchell's talk for more detailed comparisons of Expt's

Conclusions

- PHENIX event-by-event Mp_T data at s_{NN}=200 GeV show a significant positive non-random fluctuation---with striking variation with centrality and maximum p_T of tracks included.
- The increase of F_{pT} with increasing p_T implies that the majority of the fluctuation is due to correlated high p_T particles.
- A hybrid simulation using PYTHIA events to simulate hard-scattering products can well reproduce the PHENIX fluctuation data at s_{NN}=200 GeV when the measured jet suppression is included.
- Even if the entire fluctuation were due to event-by-event temperature fluctuations, these are less than 2 % for central collisions at both RHIC and CERN energies.
- Where are the critical-fluctuations that were expected ?