Simulation Studies of Contributions to Event-by-Event Average p_T Fluctuations

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Outline:

- Data and Observables
- Description of the simulation
- Elliptic Flow Contributions?
- Jet Contributions at RHIC?
- Jet Contributions at CERN?
- Conclusions

$\langle p_T \rangle$ Fluctuations: Probing for Signs of a Phase Transition

Analogy: Critical Opalescence

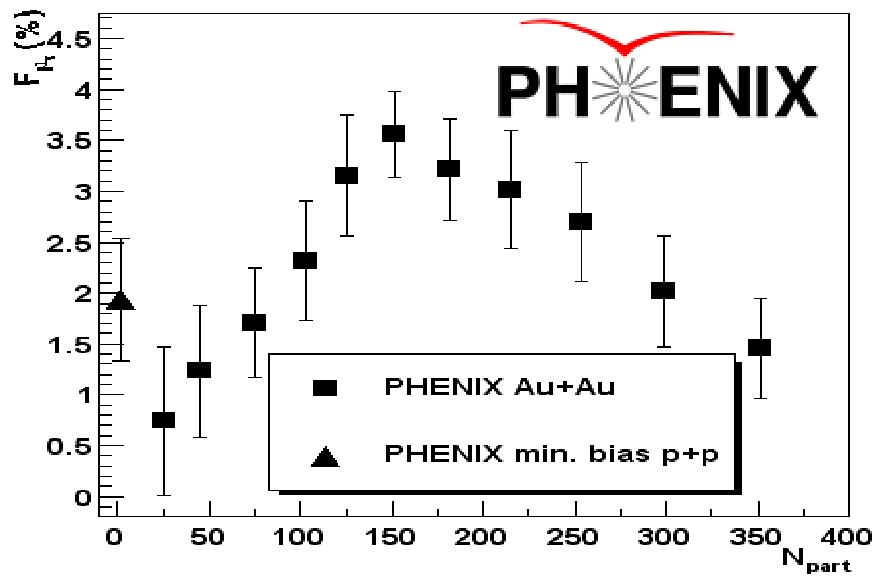
A sealed container containing freon on a hot plate at the critical point.
The image is projected onto a wall.

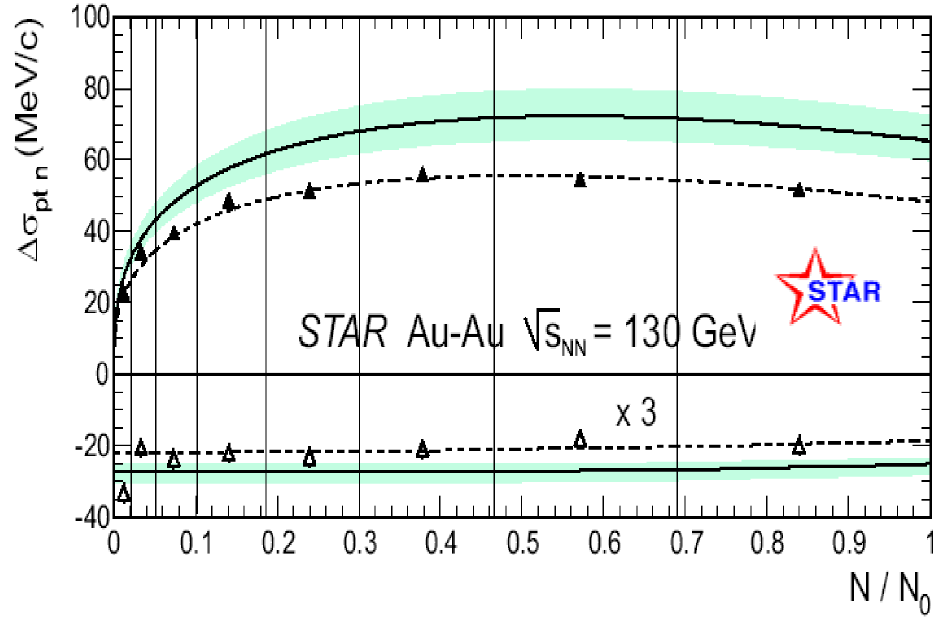
Movie by the University of Minnesota Physics Department

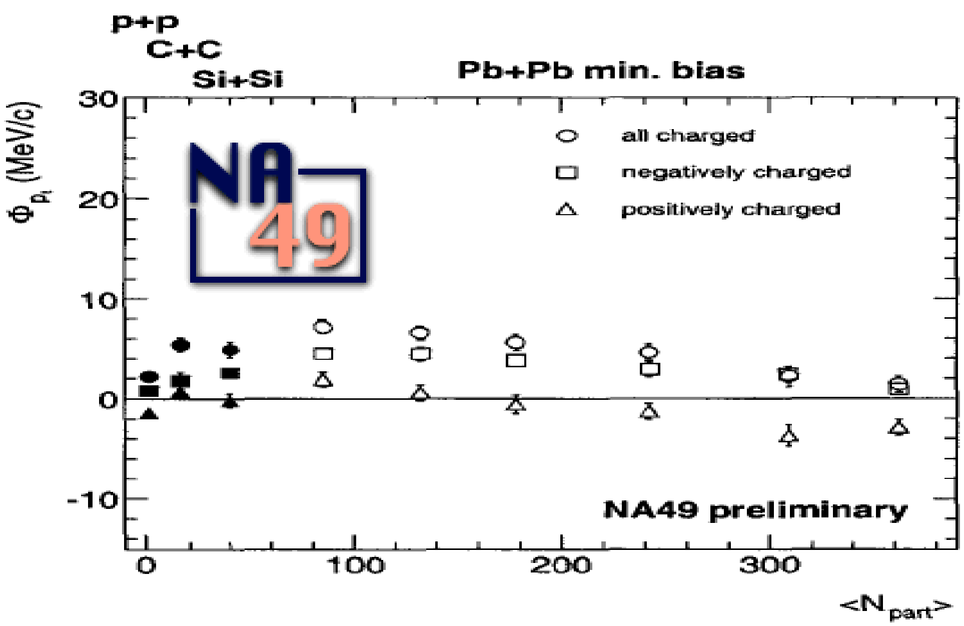
- ***S. Mrowczynski (see Phys. Lett. B314 (1993) 118.)*** **Instability of the plasma could be present, initiated as random color fluctuations. For some events, the fluctuations of particle transverse quantities would be magnified.**

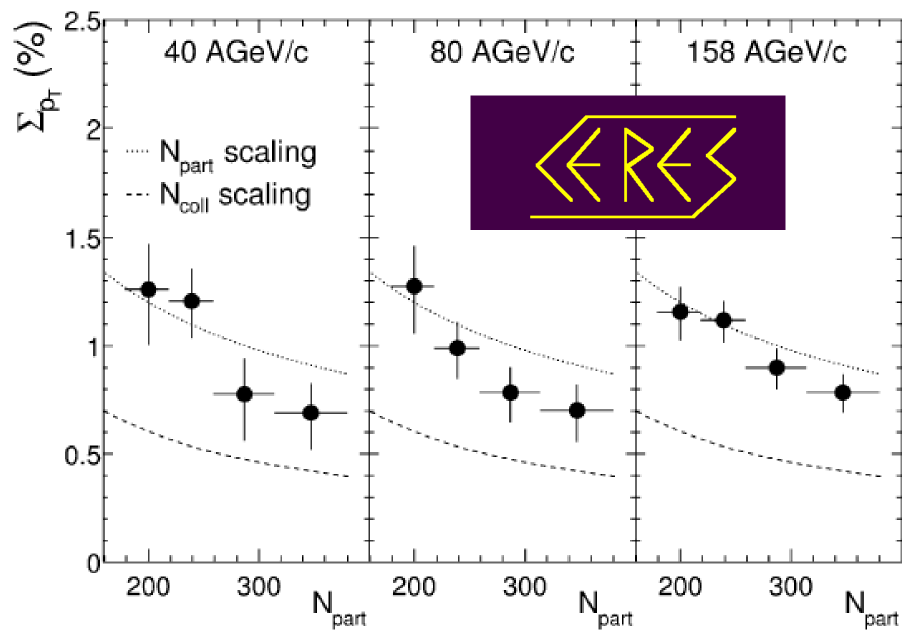
- ***M. Stephanov, et al. (see Phys. Rev. Lett. 81 (1998) 4816)*** **suggest that near a tri-critical point in the QCD phase diagram, the event-by-event fluctuations in p_T could increase significantly.**

Behold The Signal!









The Pentagon of Fluctuations

Goal of the observables:

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

F_{pT} PHENIX

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

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

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

$$\sigma^2_{p_T,dyn} \cong \frac{2\Phi_{p_T}\sqrt{\overline{\Delta p_T^2}}}{\langle N\rangle} \qquad \Delta\sigma_{p_T,n} \cong \sqrt{\left(\Phi_{p_T}+\sigma_{p_T,incl}\right)^2 - \sigma^2_{p_T,incl}}$$

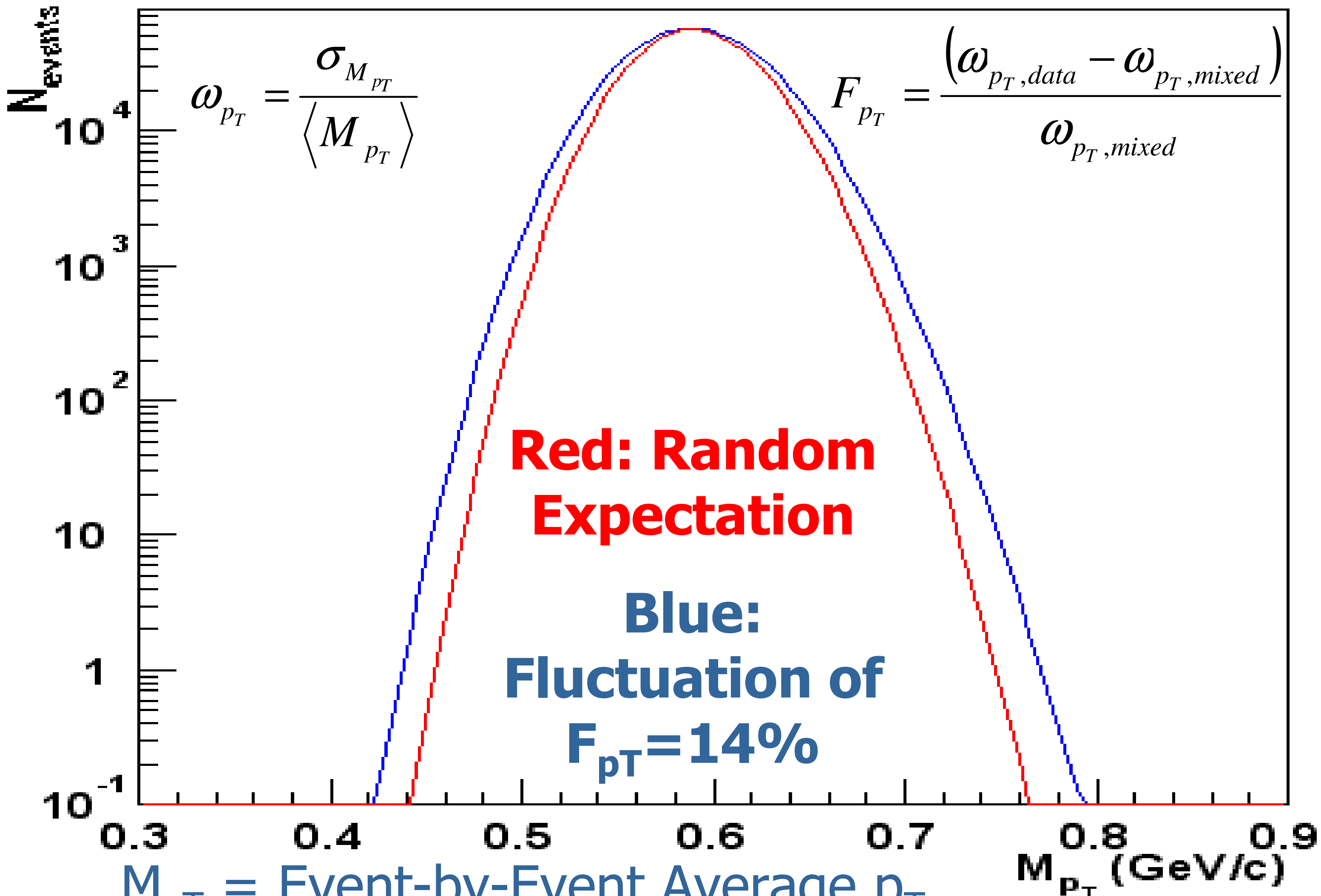
$$\sigma_{p_T,incl.} = \sqrt{\langle p_T^2\rangle - \langle p_T\rangle^2} \qquad \overline{\Delta p_T^2} \equiv \overline{p_T^2} - \overline{p_T}^2$$

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

NA49 Φ_{pT}

CERES Σ_{pT}

How To Measure A Fluctuation



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

How To Simulate a Fluctuation: 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.

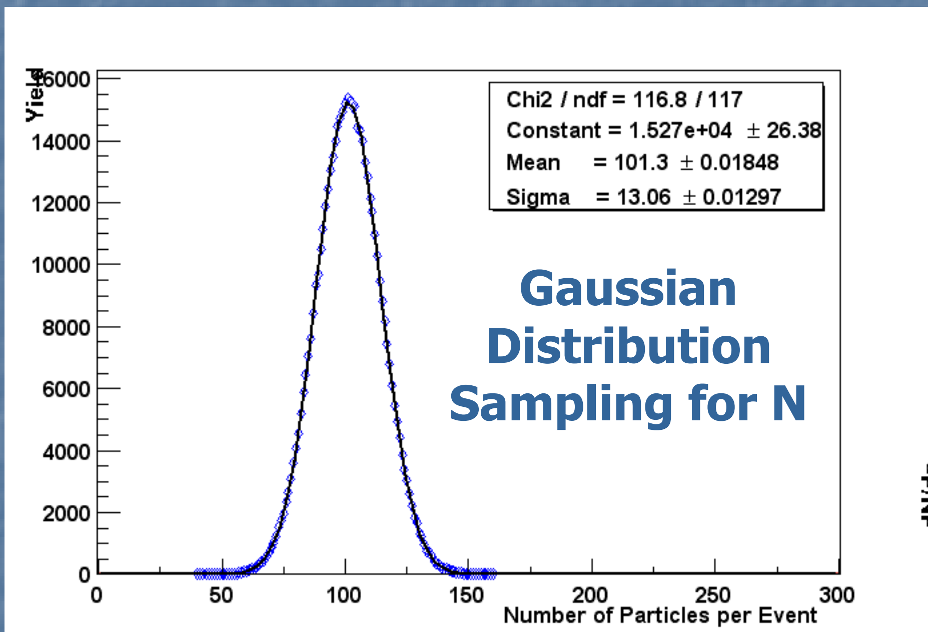
- Assign a p_T to each particle by sampling an m_T exponential distribution fit (or double exponential, or Gamma distribution) to the data inclusive p_T distribution.

- Calculates the event-by-event $\langle p_T \rangle$, M_{pT}.

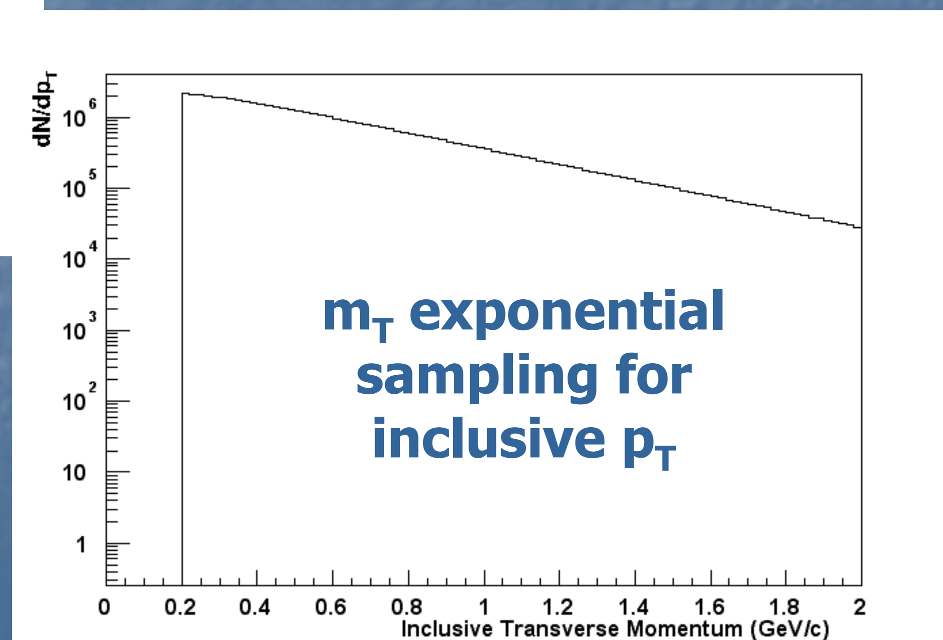
- Generates mixed events for calculation of fluctuation quantities.

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



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

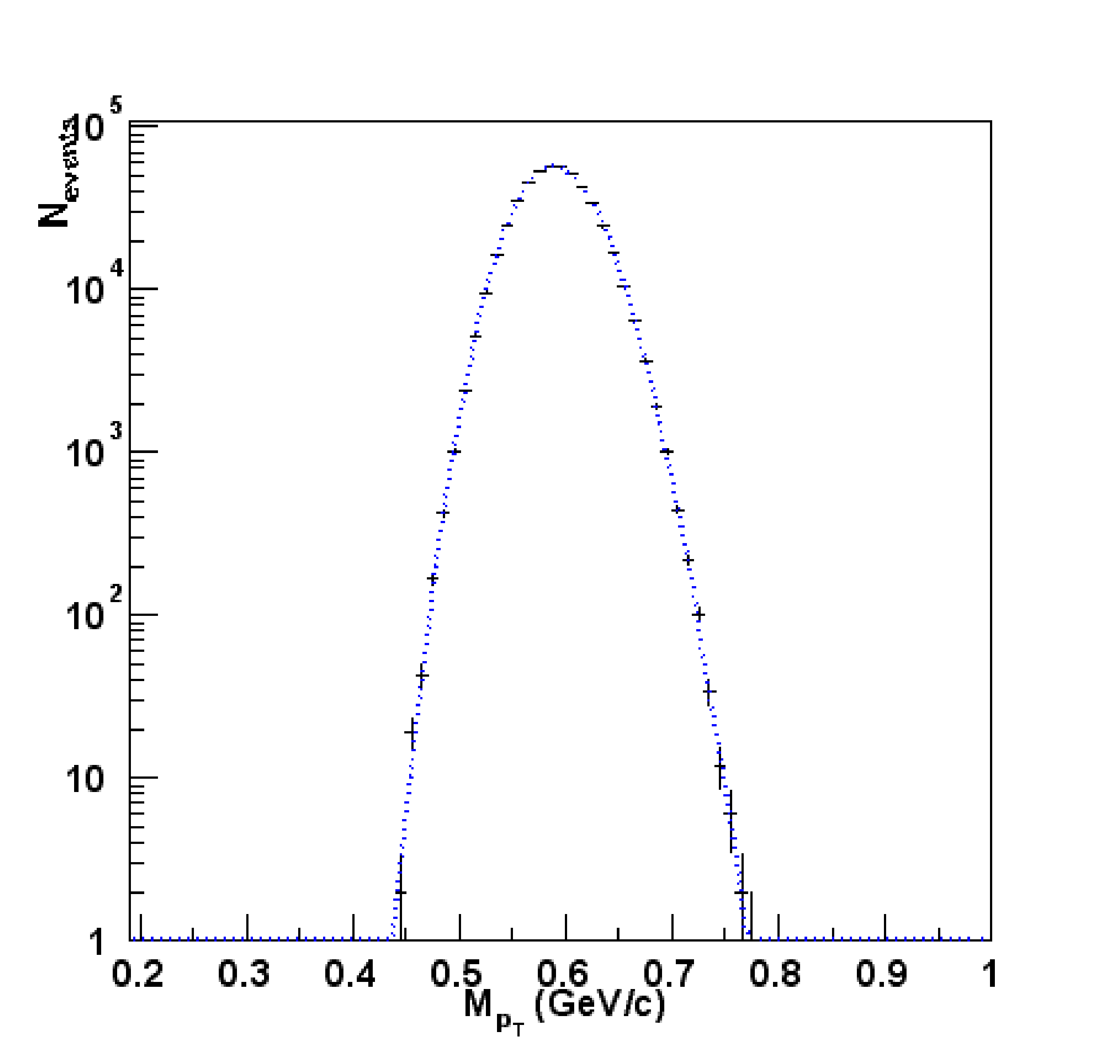


Inclusive $\langle p_T \rangle$, σ_{pT}, $\langle N \rangle$, $\sigma_{\langle N \rangle}$ matched to the data for each centrality class.

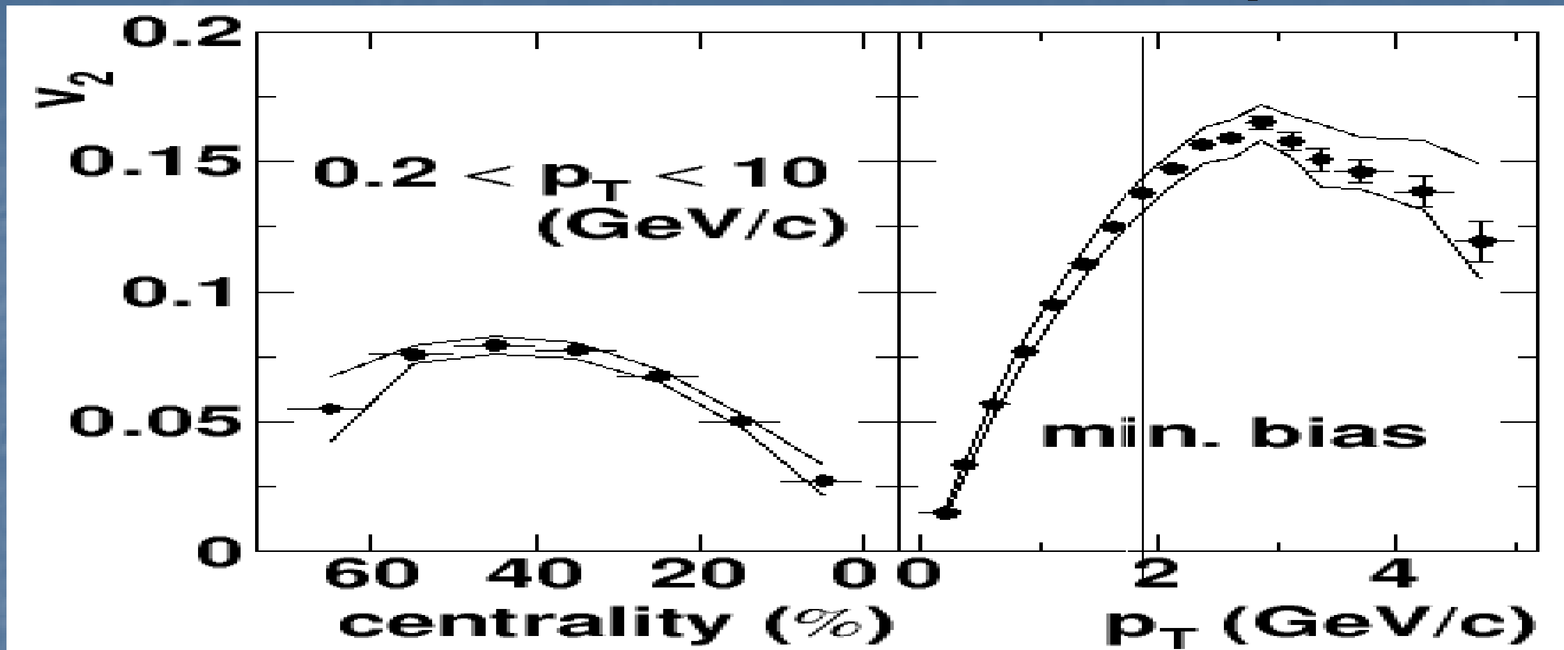
Results from the Baseline Simulation

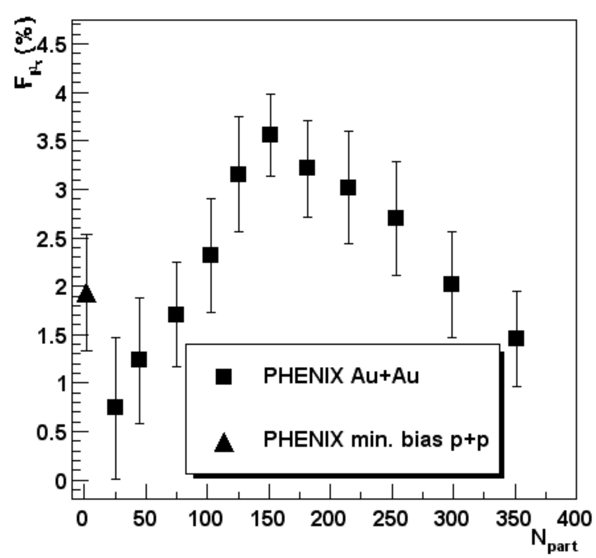
Black points: Simulation Output

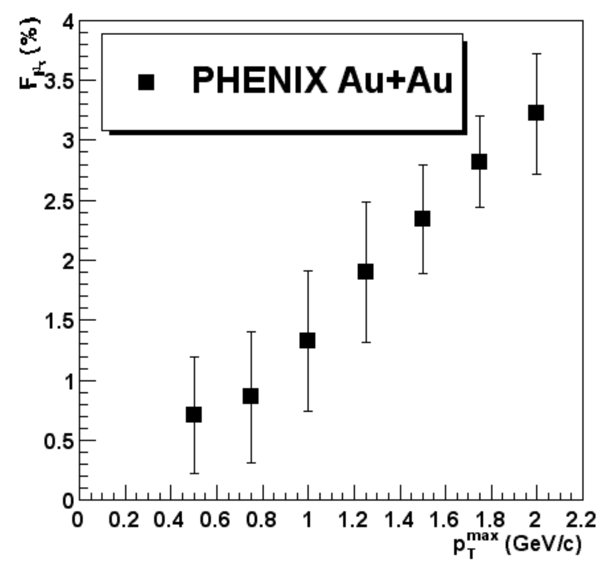
Blue curve: Gamma distribution calculation for statistically independent particle emission with input parameters taken from the inclusive spectra. *See M. Tannenbaum, Phys. Lett. B498 (2001) 29.*



Fluctuation Trends and Elliptic Flow





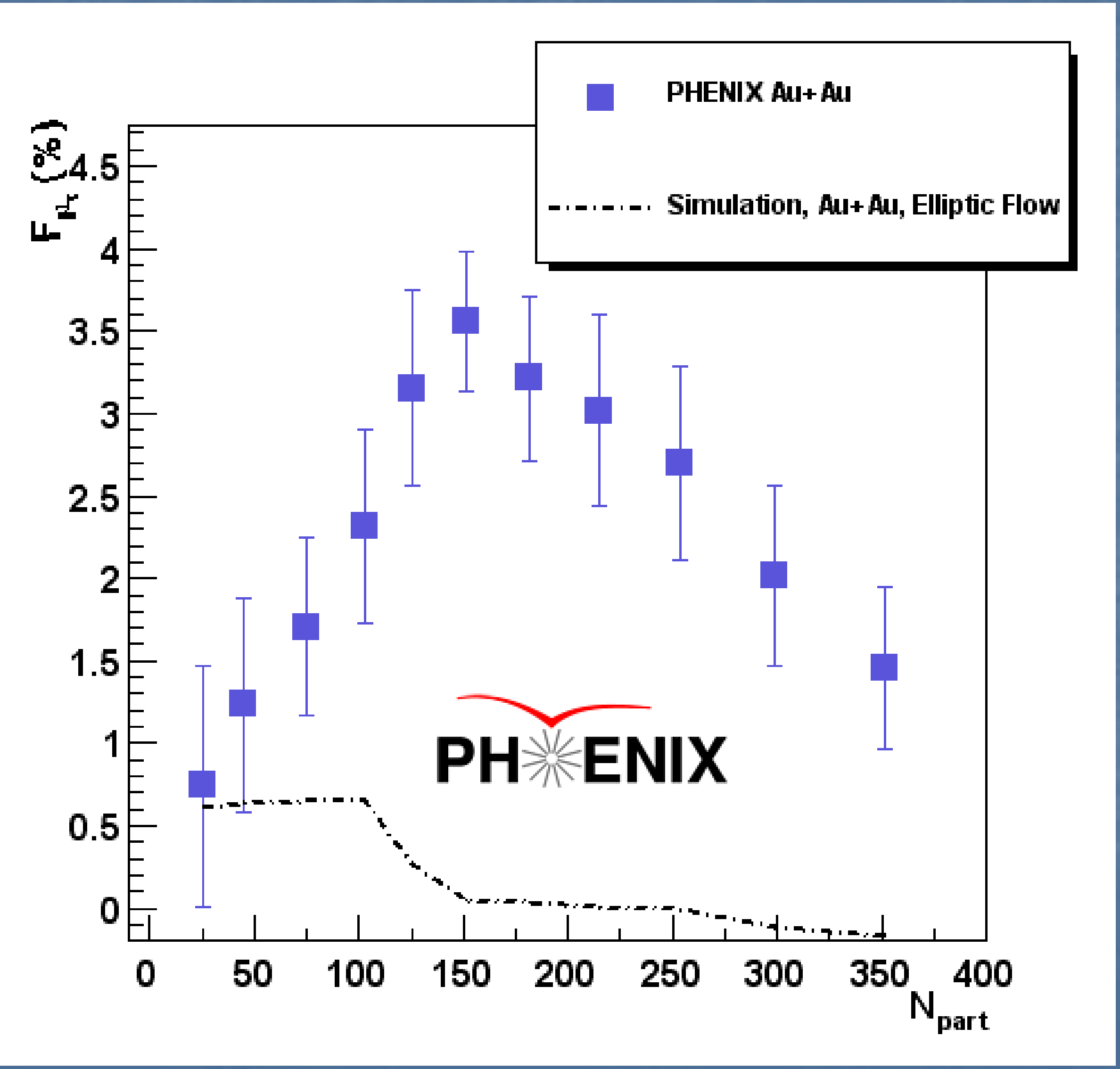


Similar properties observed in PHENIX.

Elliptic Flow Contribution Simulation

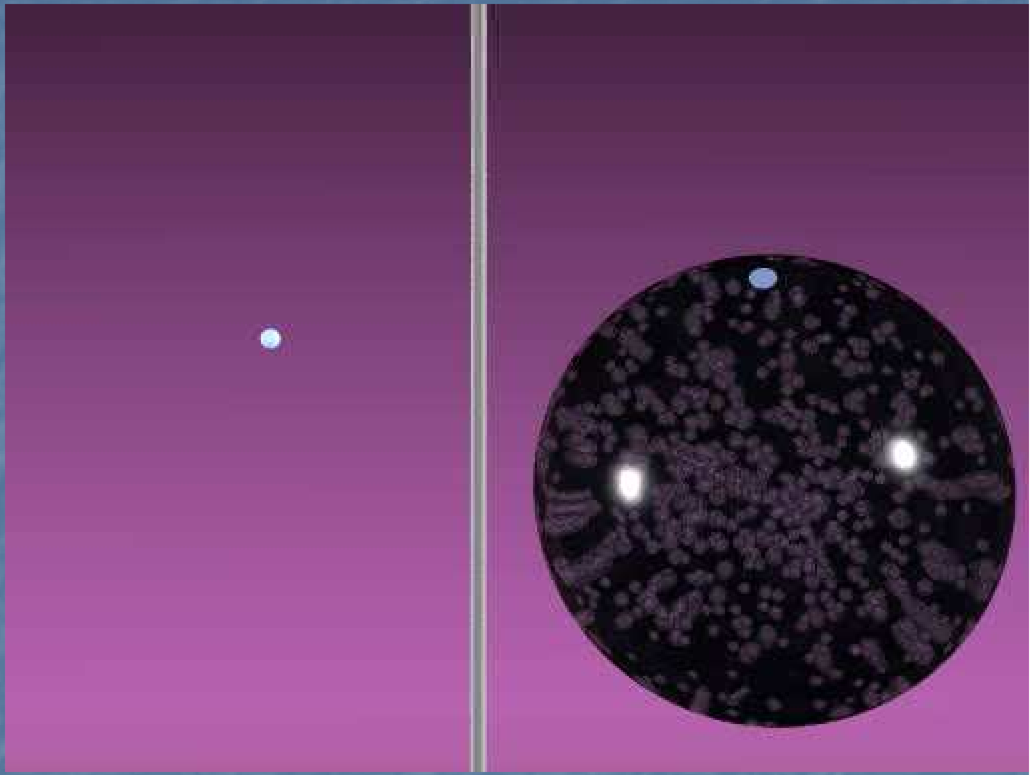
Algorithm: Particles are assigned an azimuthal coordinate based upon the PHENIX measurement of v_2 (wrt the reaction plane) as a function of centrality and p_T. Only particles within the PHENIX acceptance are included in the calculation of M_{pT}.

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



Fluctuations: A Jet Contribution?

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

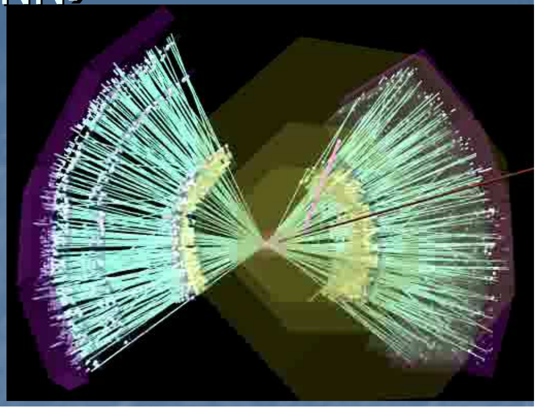


A single varying parameter is defined: A hard scattering probability factor, S_{prob}, is randomly tested for each thrown particle. If the test is true, a single PYTHIA event is embedded into the baseline event after applying experimental acceptance criteria.

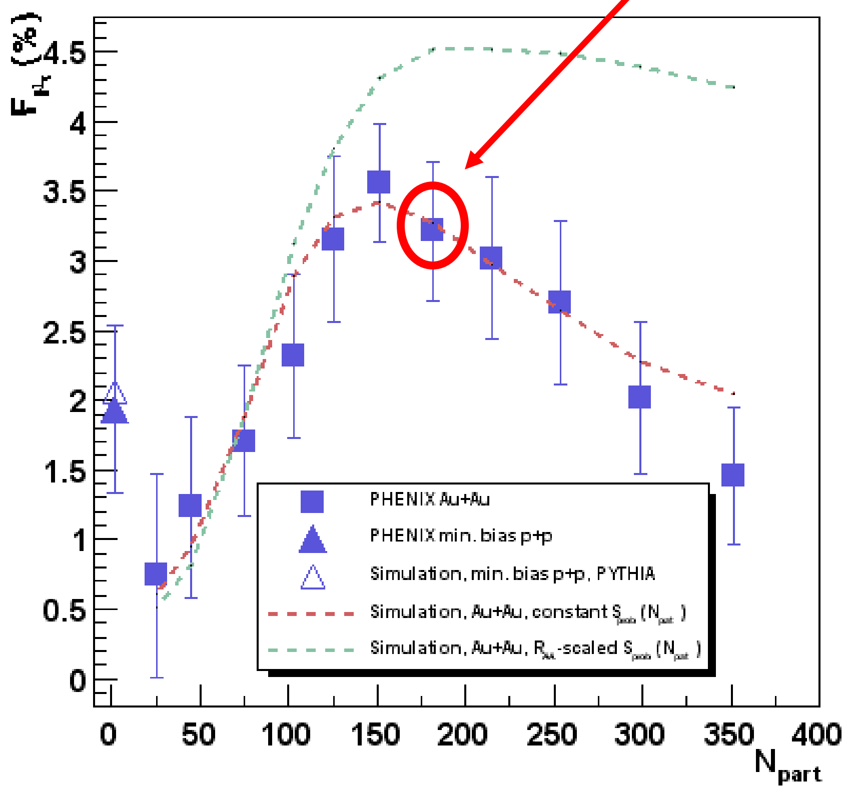
To mock up jet suppression, S_{prob} is scaled by the experimentally measured value of the nuclear modification factor, R_{AA}, as a function of centrality.

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

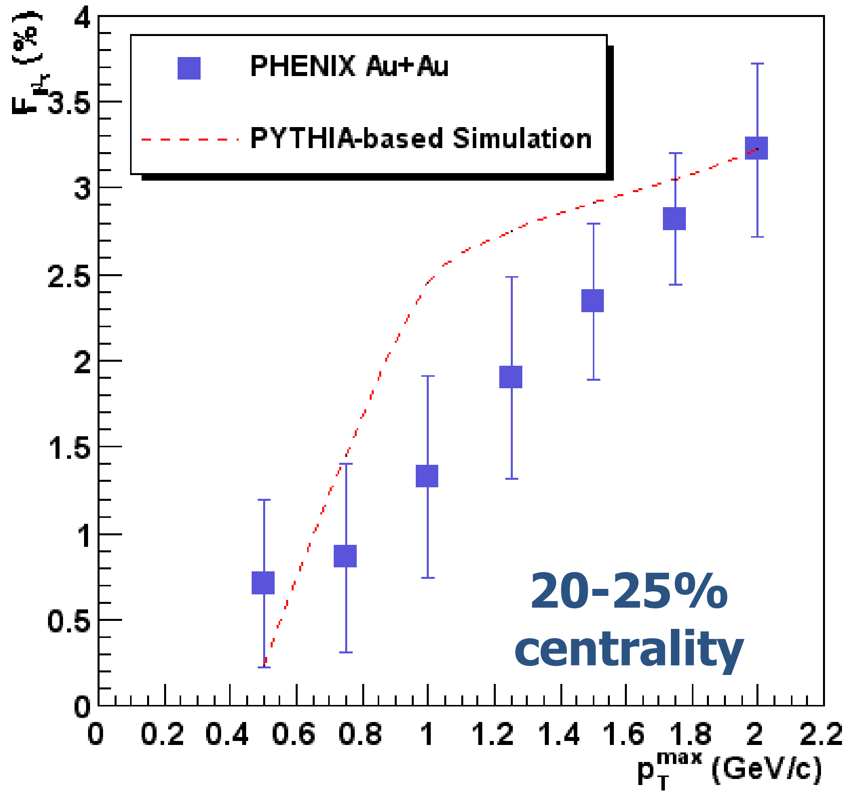
Jet Simulation Results: PHENIX at sqrt(s_{NN}) = 200 GeV



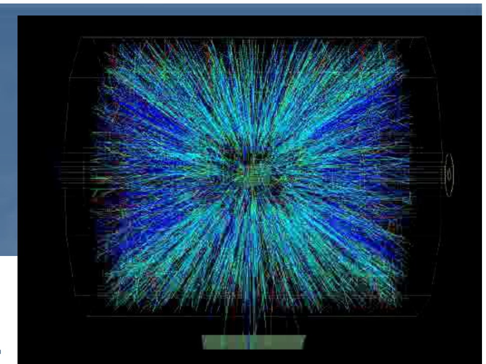
The S_{prob} parameter is initially adjusted so that F_{pT} from the simulation matches F_{pT} from the data for 20-25% centrality.



PHENIX Data: nucl-ex/0310005



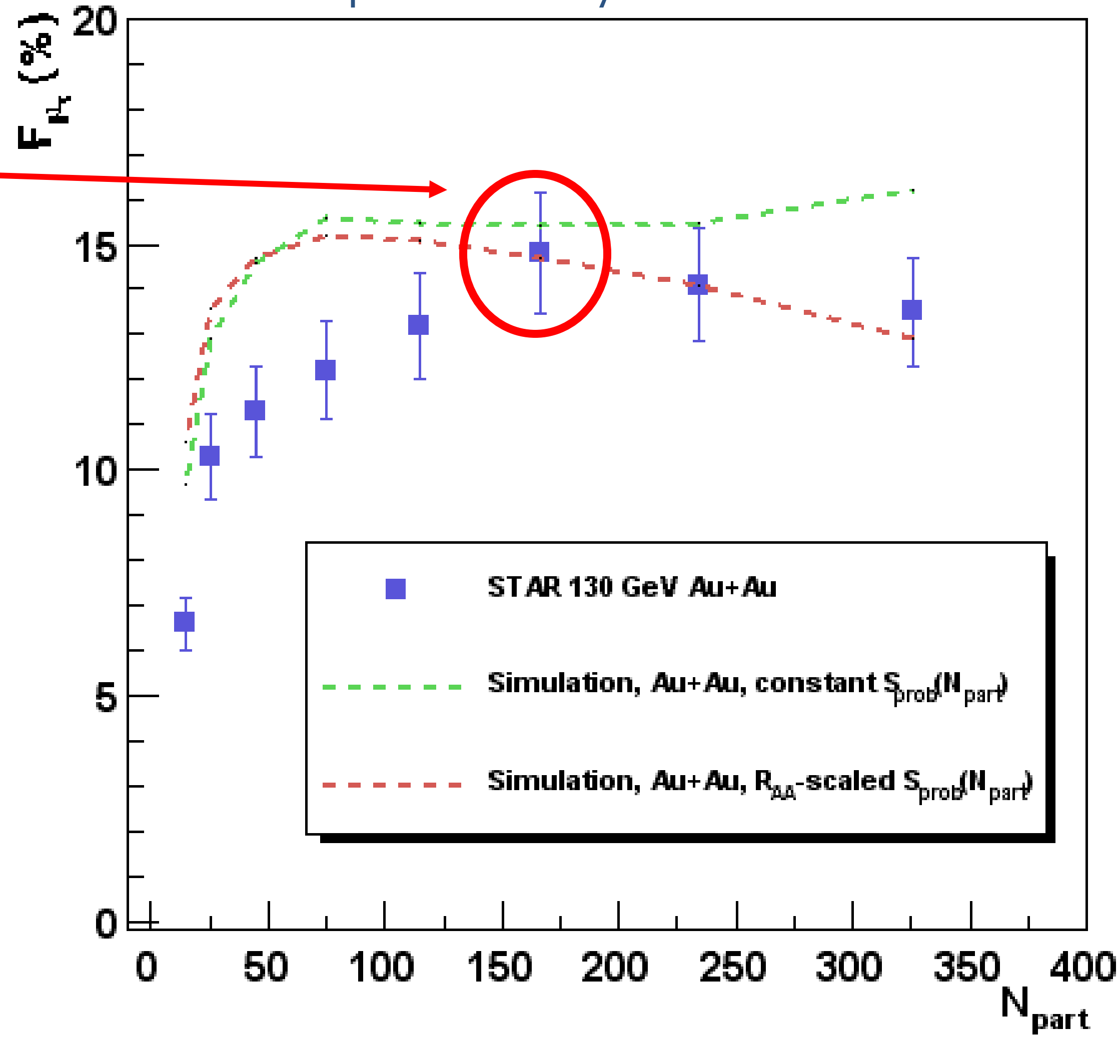
Jet Simulation Results:
STAR at sqrt(s_{NN}) = 130 GeV



These results use the initial value of S_{prob} that matches the PHENIX data with the PYTHIA events filtered through the increased STAR acceptance. The measured STAR value of F_{pT} for 20-30% centrality is reproduced.

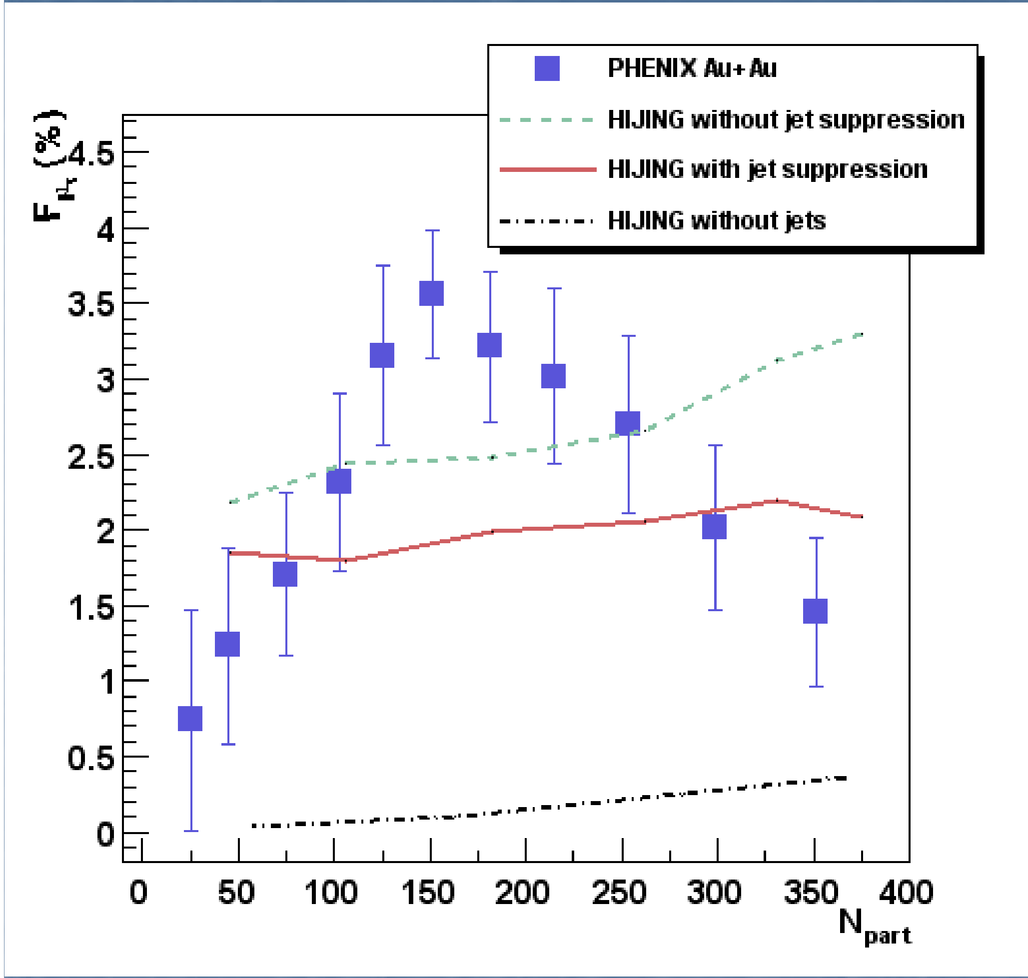
STAR data: nucl-ex/0308033

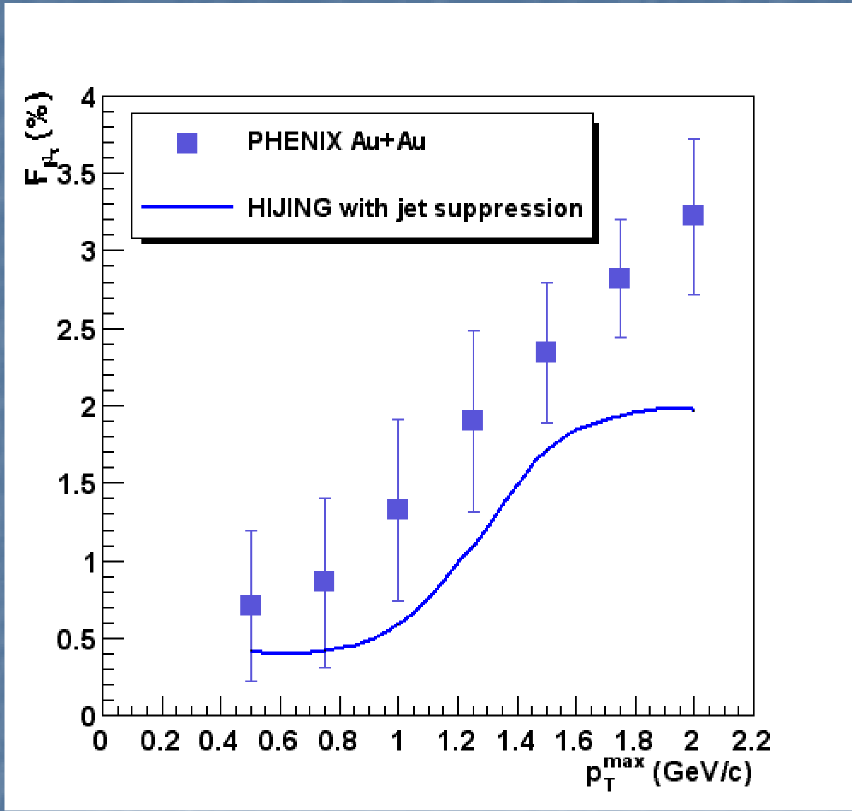
Error bars are the quoted total systematic error.



PREDICTION: The STAR values of F_{pT} should increase by ~20% for centralities 0-40% at sqrt(s_{NN})=200 GeV.

Fluctuations According to HIJING





HIJING cannot reproduce the centrality dependence of the fluctuations.

One problem is that <N> changes depending on the HIJING settings – not matched to the observed dataset.

Example for 0-5% centrality: <N> = 93.0 for jet suppression, 76.6 without suppression, and 51.2 without jets.

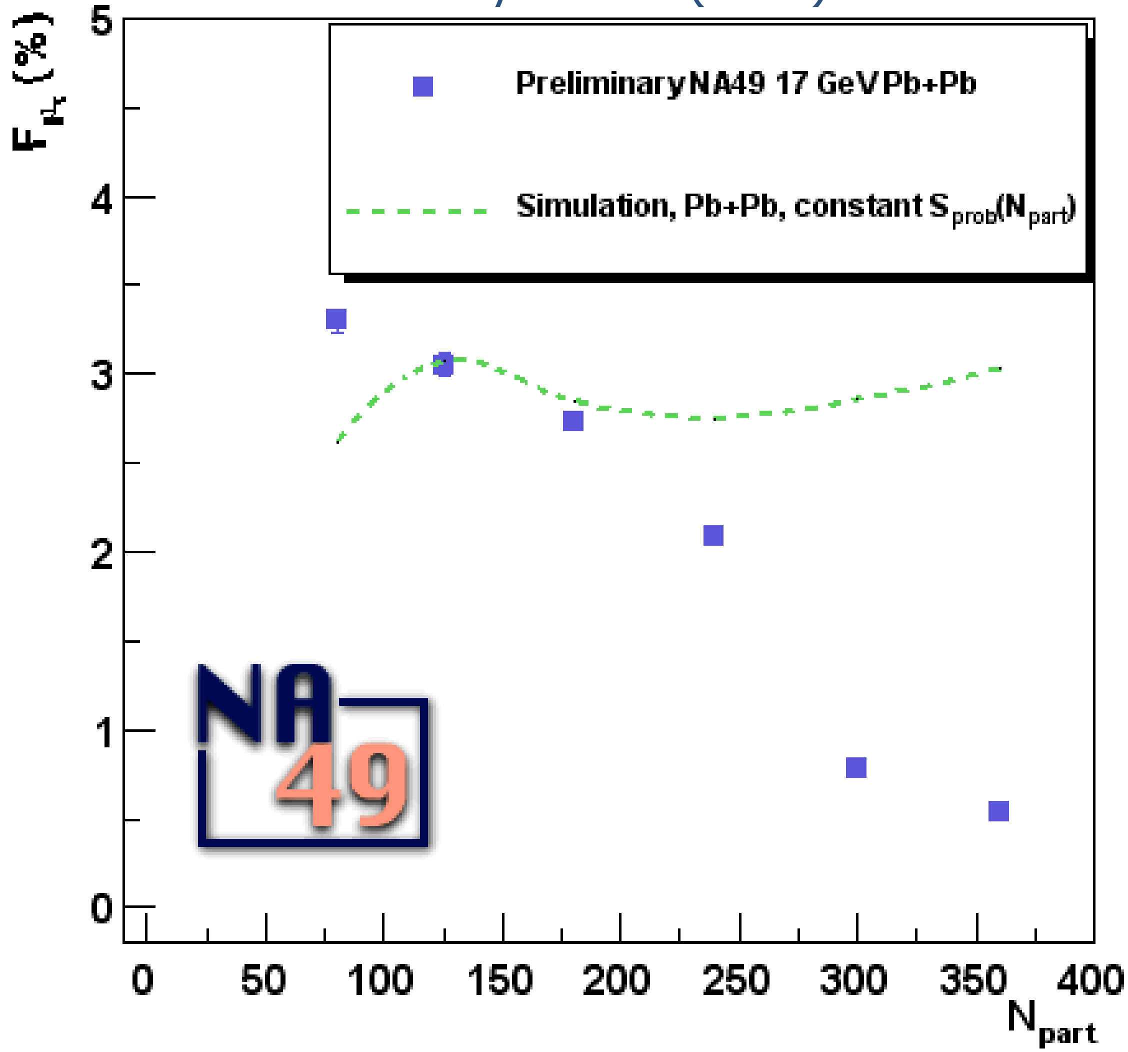
Jet Simulation Results: NA49 at sqrt(s_{NN}) = 17 GeV

Minimum bias p+p Data (NA49 Published, Phys. Lett. B459 (1999) 679): F_{pT} = 1.3% +/- 0.26%

From PYTHIA min. bias p+p alone: F_{pT} = 2.3%

S_{prob} must be scaled down by a factor of 3.63 to match the most central data point.

NA49 Preliminary Data: C. Blume, et al., Nucl. Phys. A715 (2003) 55c.



Jet Simulation Results:
CERES at sqrt(s_{NN}) = 17 GeV

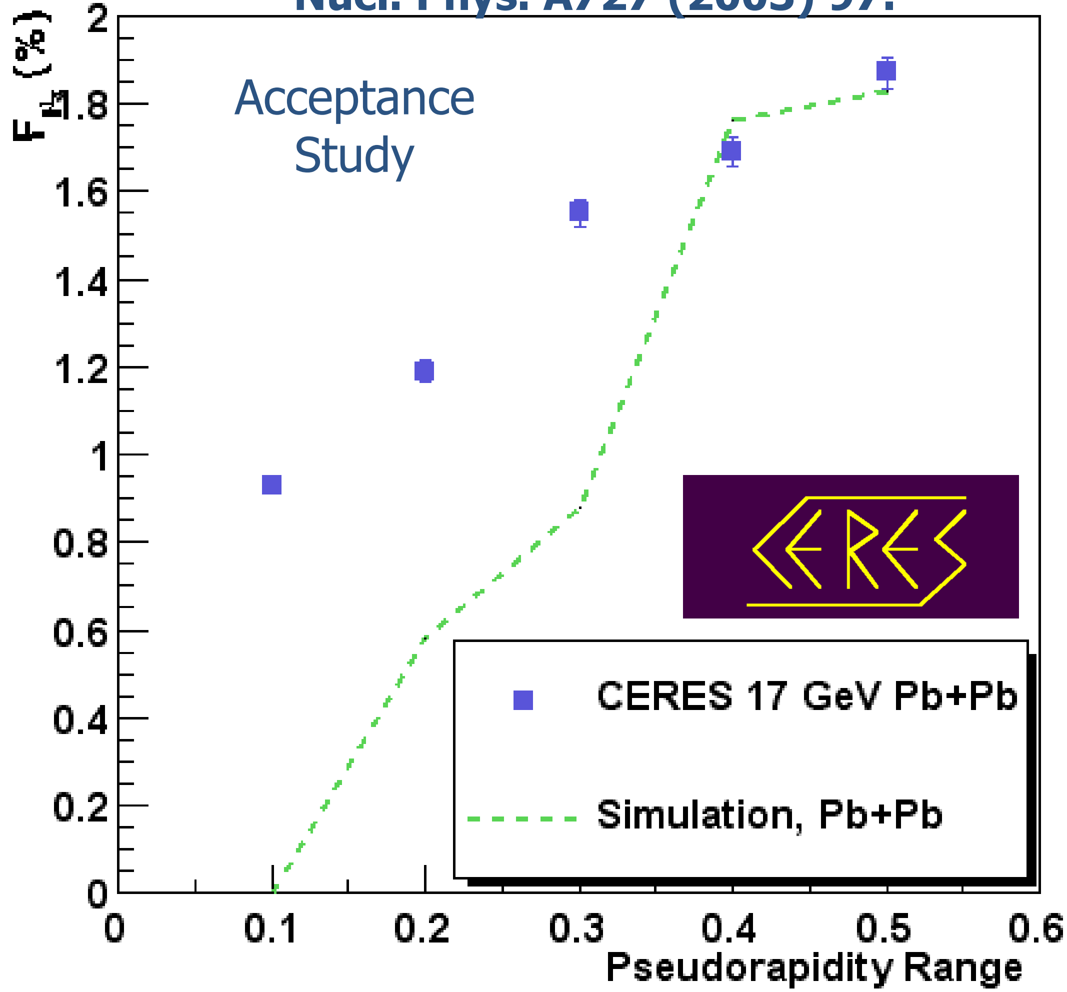
Energy dependence study:

CERES data:
F_{pT}(80 A GeV/c)/F_{pT}(158 A GeV/c) = 0.72

Simulation:
F_{pT}(80 A GeV/c)F_{pT}(158 A GeV/c) = 0.72

Averaged over 0-30% centrality.

CERES Data: D. Adamova, et al., Nucl. Phys. A727 (2003) 97.



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

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

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	0.6%	2.6%

Conclusions

- A simulation for studying the sources of event-by-event average p_T fluctuations has been described.
- A hybrid simulation using PYTHIA events to simulate hard process products can well reproduce the trends in fluctuation data at RHIC energies.
- The hybrid simulation predicts ~20% increase in non-random fluctuations measured by STAR at 200 GeV compared to the 130 GeV results.
- The hybrid simulation can describe the energy dependence of the CERN data, but fails to describe the centrality- or pseudorapidity-acceptance-dependence.
- Estimates of the remaining signal available for temperature fluctuations are less than 2% for both RHIC and CERN energies.