Review of PHENIX PPG027:

Measurement of nonrandom Event-by-Event Fluctuations of Average Transverse Momentum in 200 GeV Au + Au and p + p Collisions

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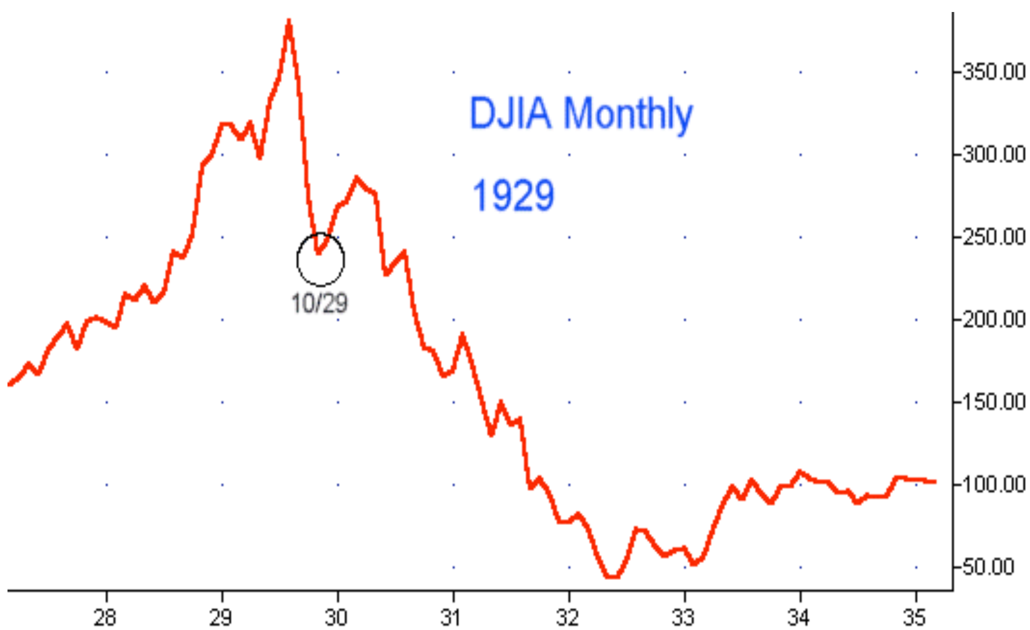
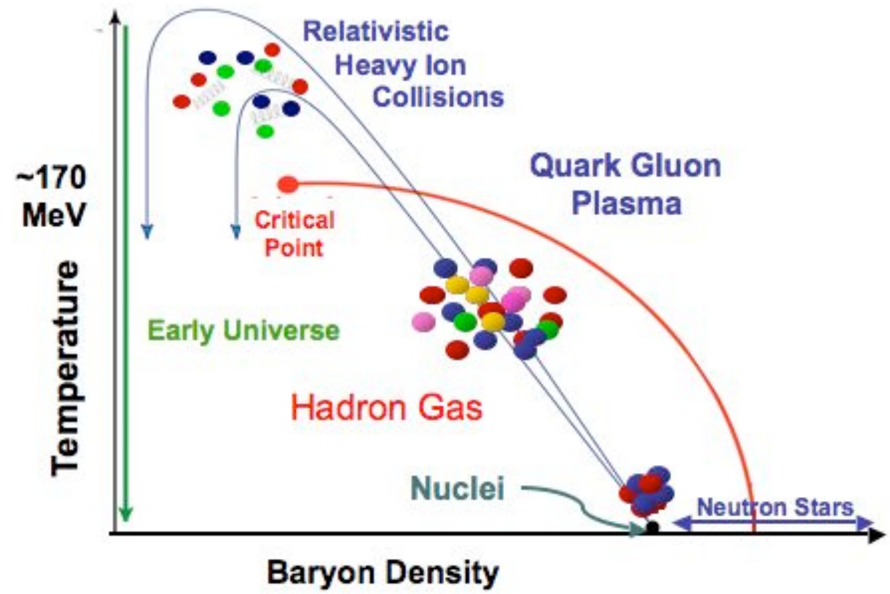
05/02/07

What is Nonrandom Event-by-Event Fluctuations?

- When fluctuations in the data cannot be explained by random statistical variations. Something else is influencing the produced particles.



Motivation



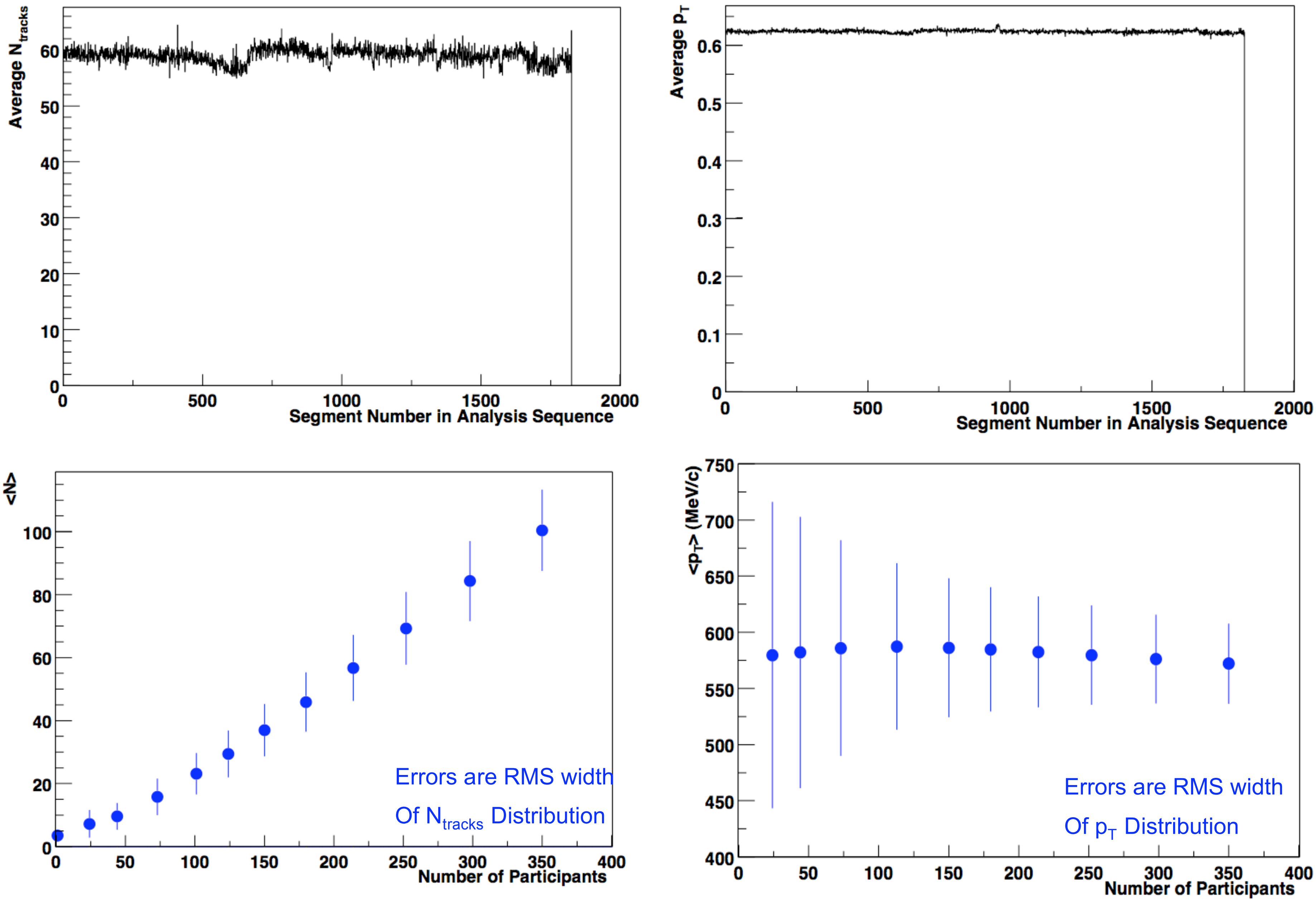
- Nonrandom fluctuations could provide information about
  - a phase transition - used as a probe for phase instabilities
  - thermalization of the system

Analysis: 2 Parts

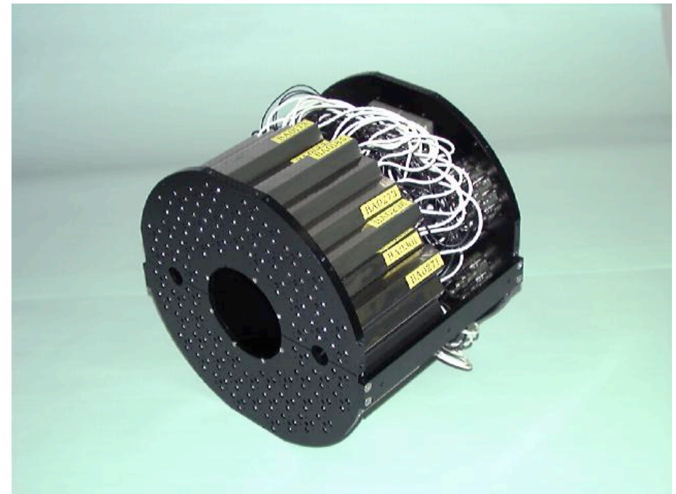
1. From microDST's apply cuts to events that produce custom nanoDST's that hold desired track information.
2. Apply further cuts to tracks and produce fluctuation plots from nanoDST's using a mixed event method.

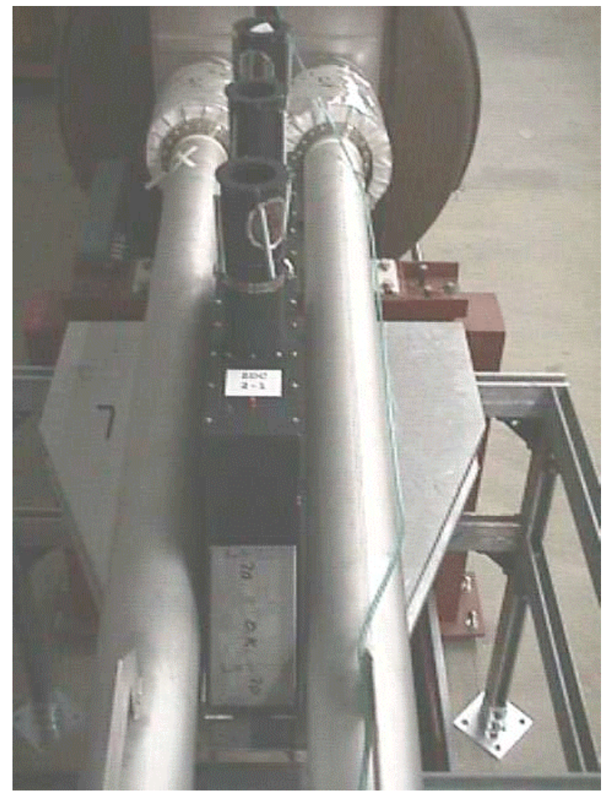
Analysis: Part 1

Quality of Dataset



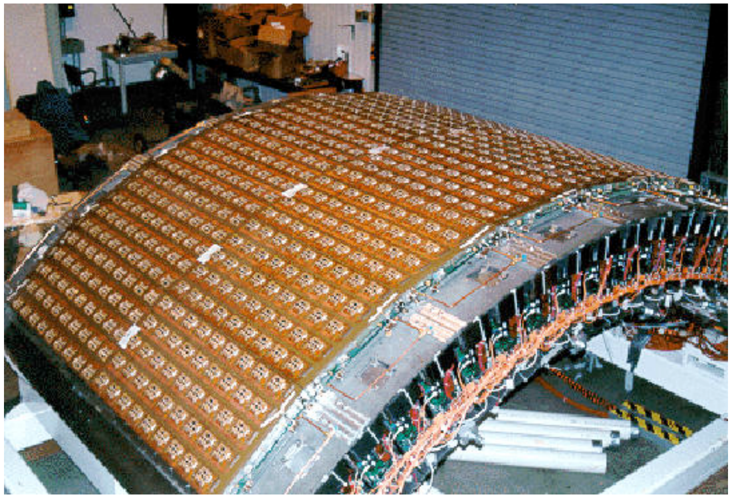
Creating nanoDST's

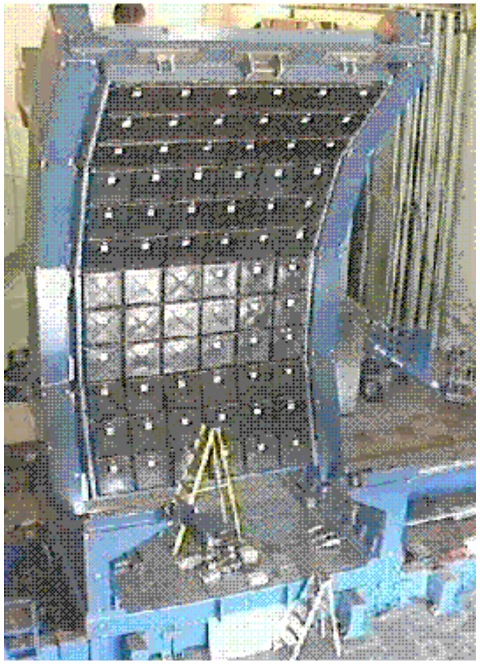




- Using BBC and ZDC, events must
  - Be a minimum bias event
  - Be within ±5cm of zero vertex position
- Using Drift Chamber, Pad Chamber, EMCal events must
  - Have at least 5 tracks that pass track cuts

Track Cuts





- Drift chamber quality of 31 or 63
- Track has more than 2 X1 and 2 X2
- Pass a momentum reconstruction quality
- The track projection from DC must match within 3 standard deviations in PC3 or EMCal. This helps reduce background.
- Track proximity cut - If two tracks are located within 0.02 radians in azimuth and 1cm in z then one of the tracks is randomly removed from analysis. Done before mixing events.
- Tracks restricted to between ±60cm to avoid background scattering
- 0.2 GeV/c < p_T < 2.0 GeV/c

If an event doesn't have 3 tracks that pass these cuts it is rejected

Analysis: Part 2

Quantify Fluctuation

$$\omega_{p_T} = \frac{\sigma_{p_T}}{< M_{p_T} >} \times 100\%$$

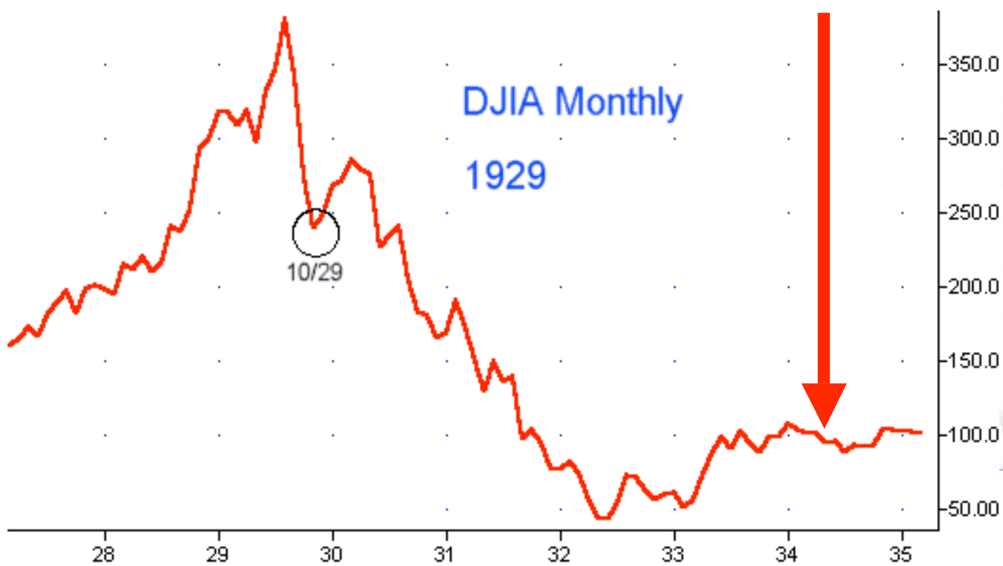
$$F_T = \frac{(\omega_{(p_T,data)} - \omega_{(p_T,mix)})}{\omega_{(p_T,mix)}} \times 100\%$$

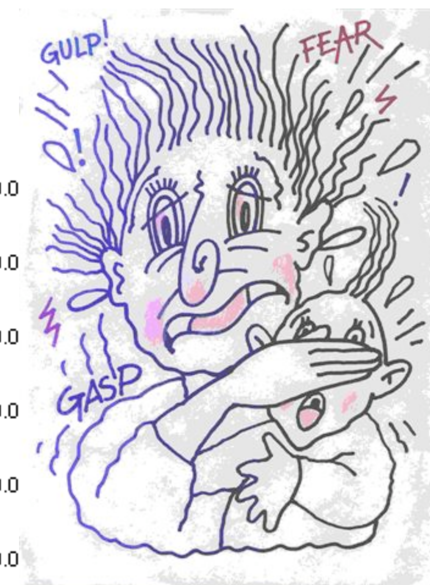
ω_{p_T} = Magnitude of the fluctuation width

σ_{p_T} = Standard deviation of the distribution of average transverse momentum

M_{p_T} = Mean p_T

F_T = Percentage of fluctuation not due to random fluctuation

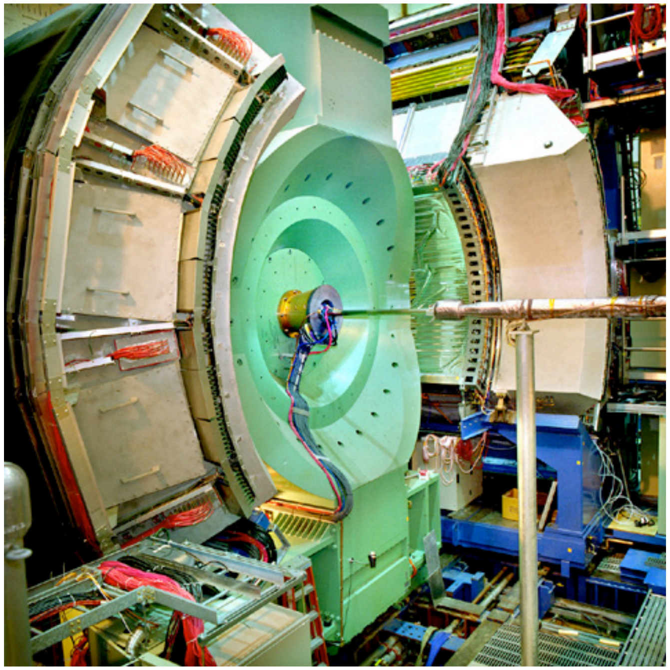




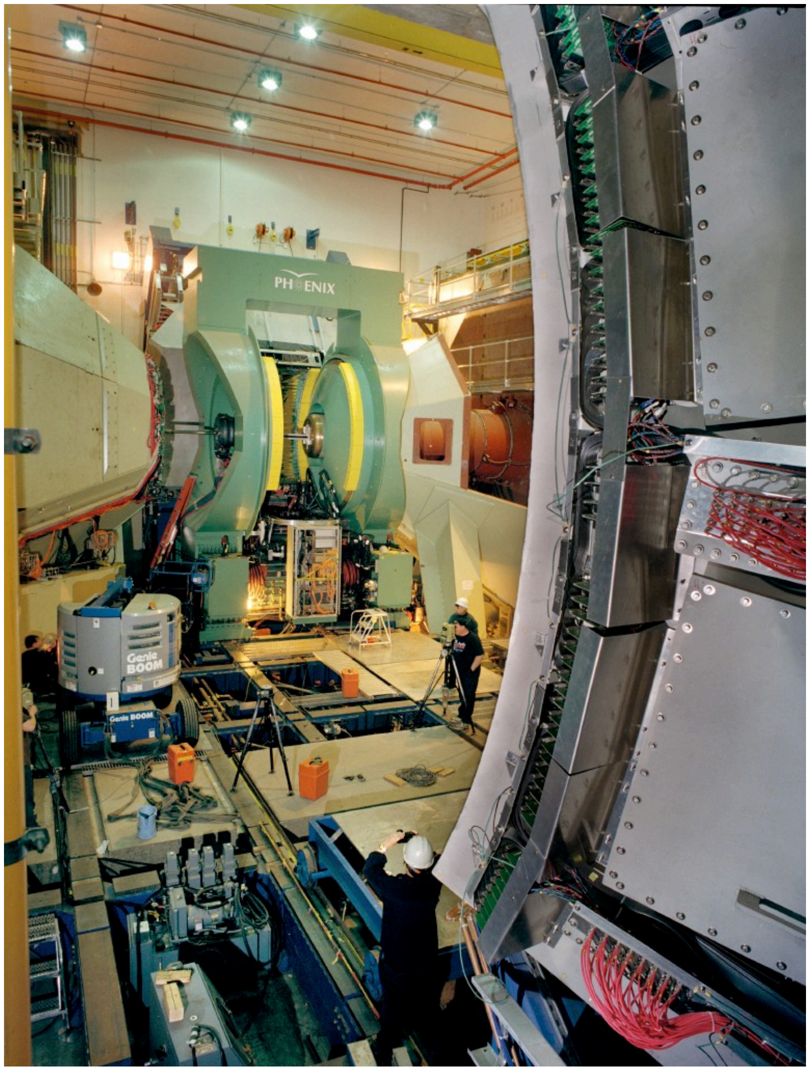
Crash!!!

Mixed Events

- Serves as baseline for random fluctuations ($\omega_{(pT,\ mix)}$).
- Because ω_{pT} is dependent on N_{tracks} there needs to be an identical N_{tracks} distribution between data events and mixed events.
- Therefore, the number of mixed events having a certain number of tracks is predetermined to match distribution from data events.

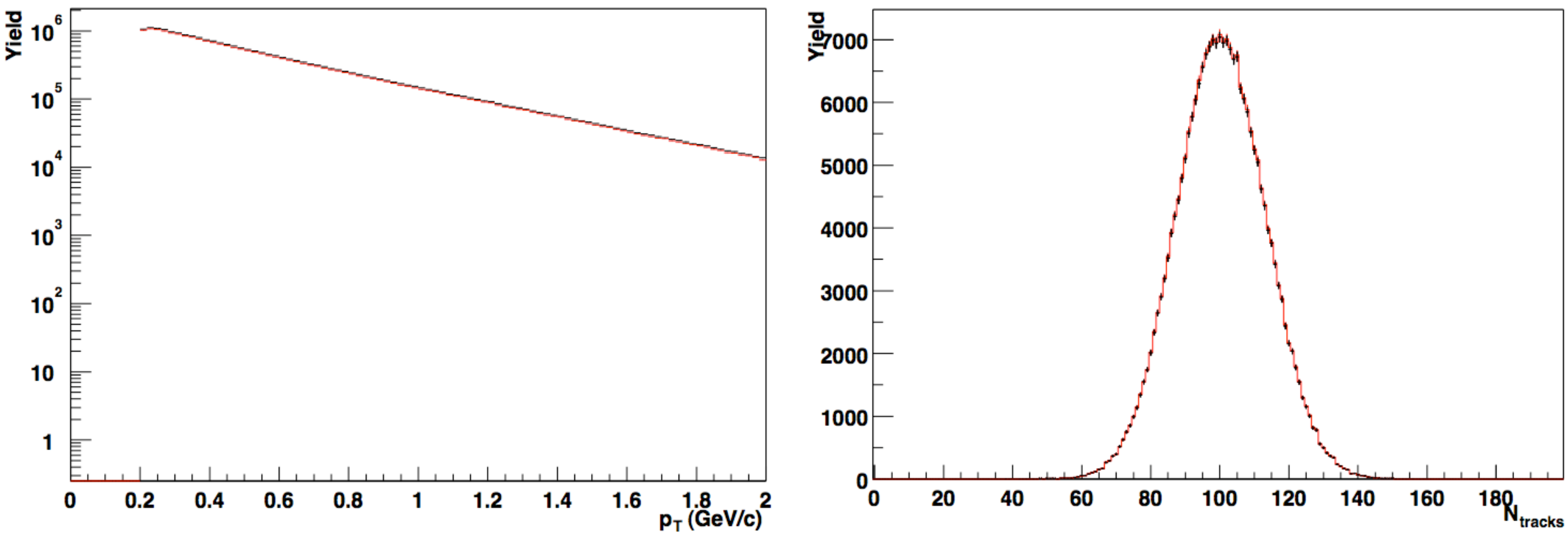


Mixed Event Method



- Uses a buffer containing constantly updated tracks from real data events
- Randomly samples tracks from these data events and if they pass the track cuts they are stored in mixed events
- When mixed event is filled its event quantities and calculated and stored
- Mixed event is then cleared of its contents and assigned a new number of tracks
- 500 mixed events are stored in memory
- No mixed event will contain two tracks from the same data event

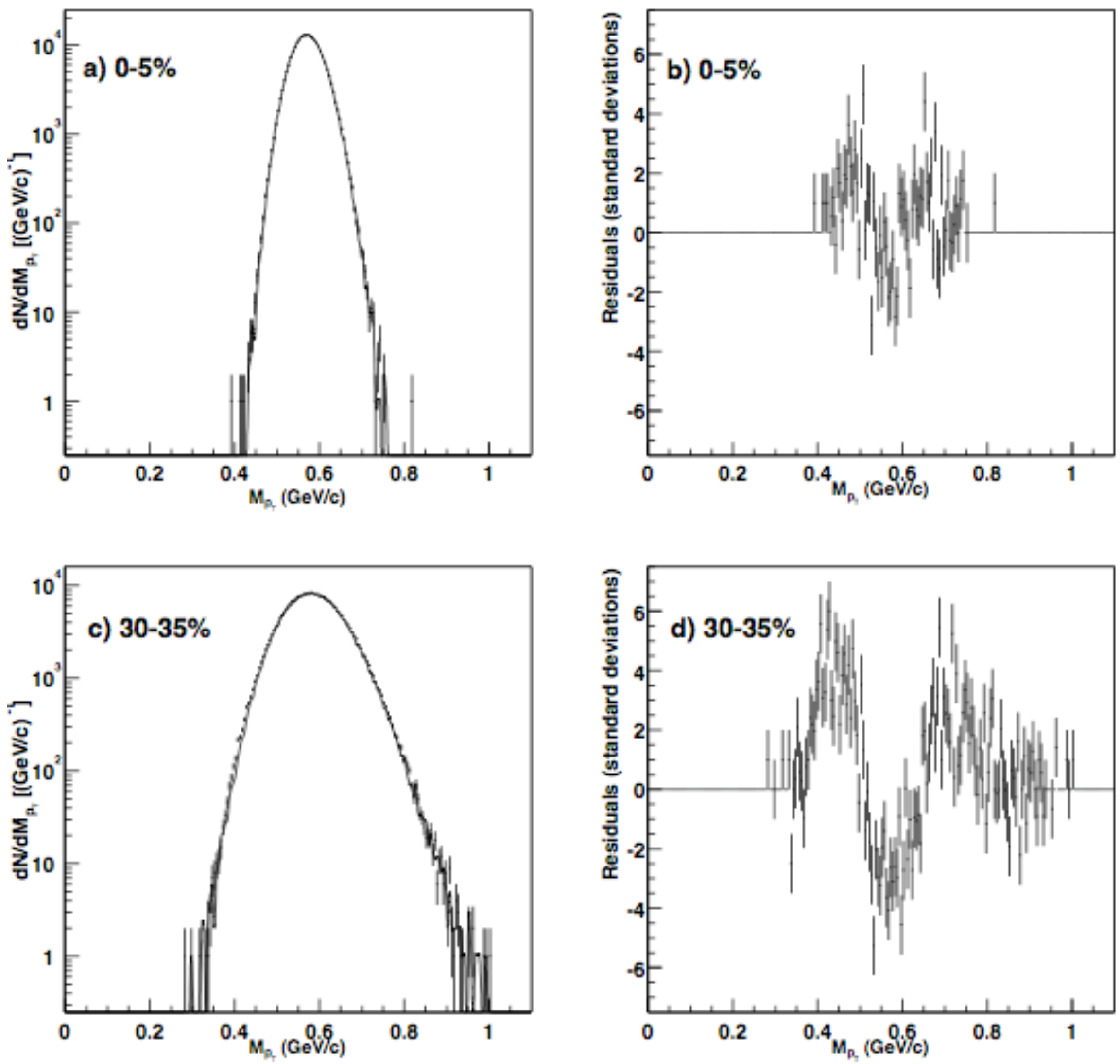
Quality of mixed events



0-5% Centrality
+ Data Distribution
-- Scaled Mixed Event Distribution

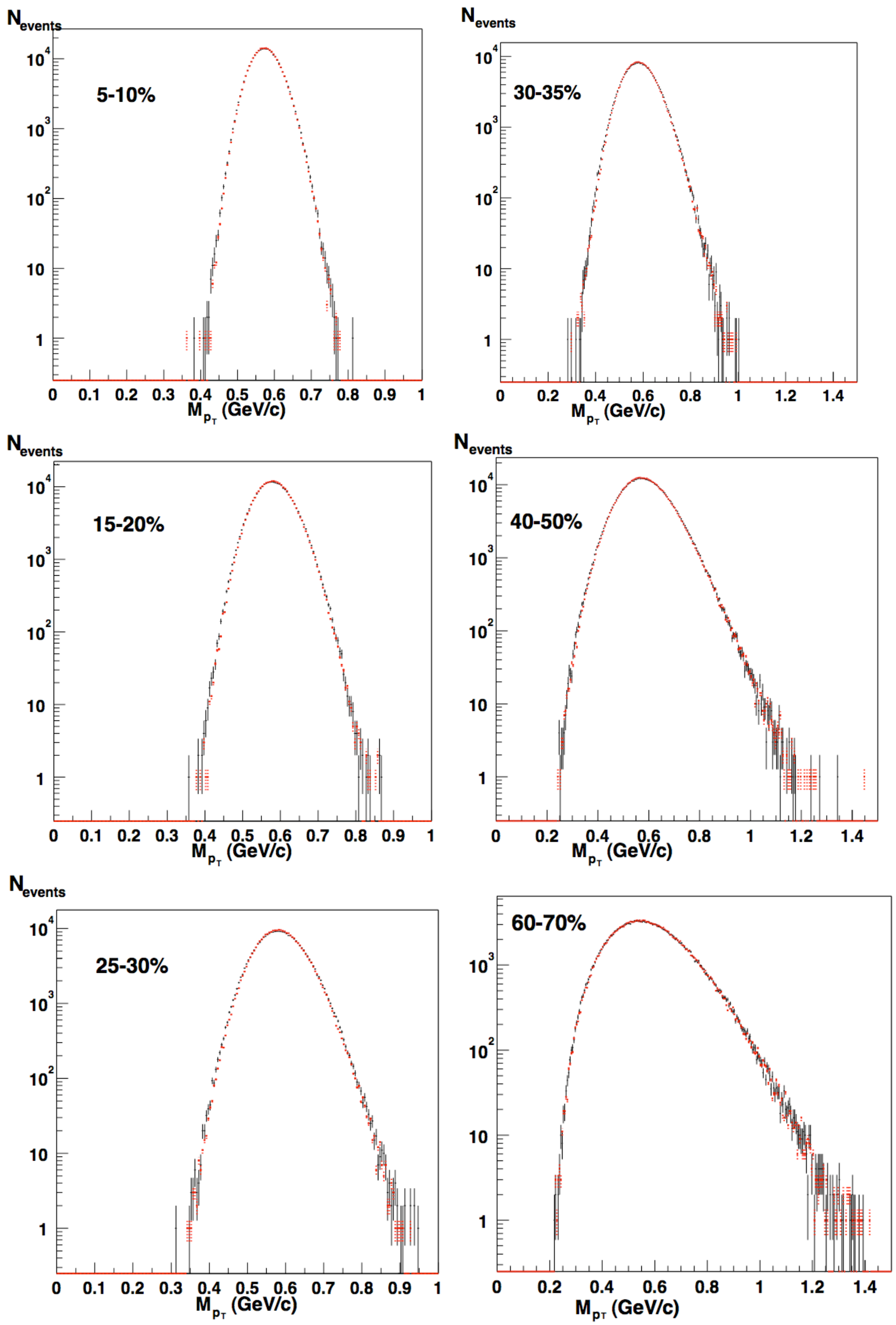
Comparison of data and mixed events

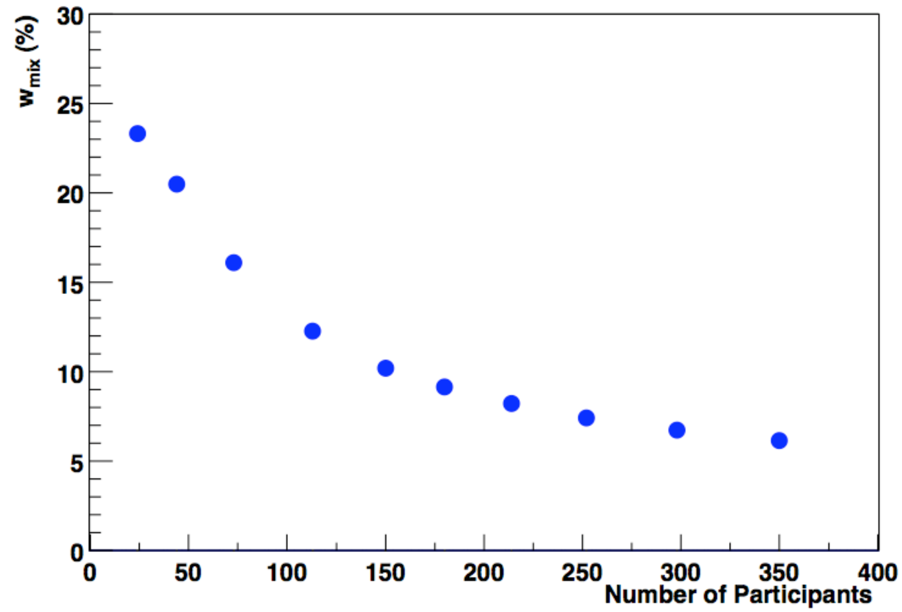
Overlay | Residuals



- Residuals shown as difference btw data and mixed event distributions in standard deviations of data points
- Double-peak is artifact from normalization procedure and the data and mixed events having different widths
- ω_{pT} increases with decreasing centrality

$$\omega_{p_T} = \frac{\sigma_{p_T}}{< M_{p_T} >} \times 100\%$$



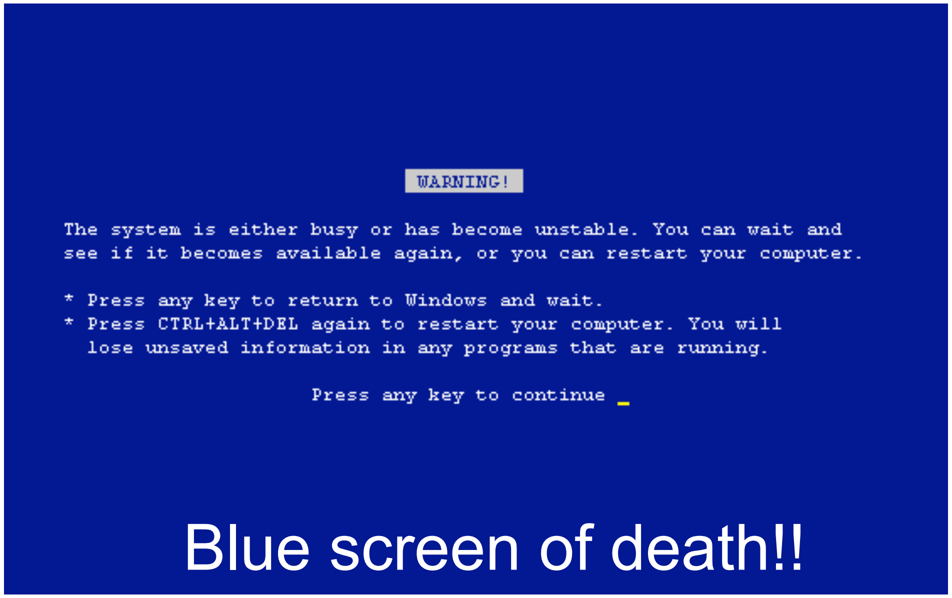


$$\omega_{p_T} = \frac{\sigma_{p_T}}{< M_{p_T} >} \times 100\%$$

$$F_T = \frac{(\omega_{(p_T,data)} - \omega_{(p_T,mix)})}{\omega_{(p_T,mix)}} \times 100\%$$

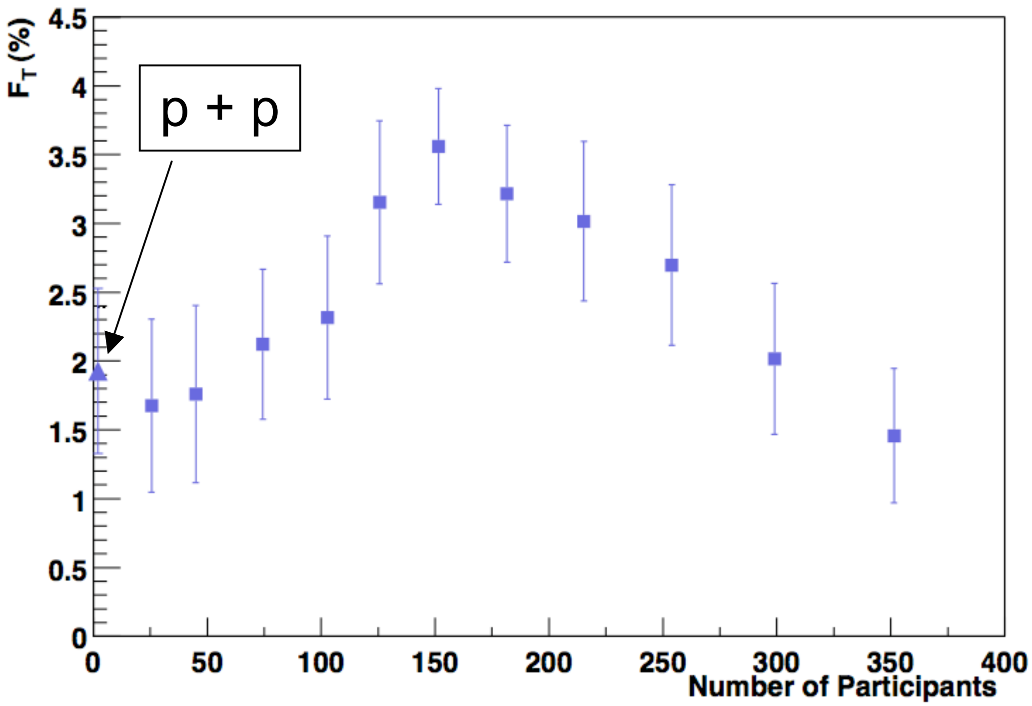
Results

Errors

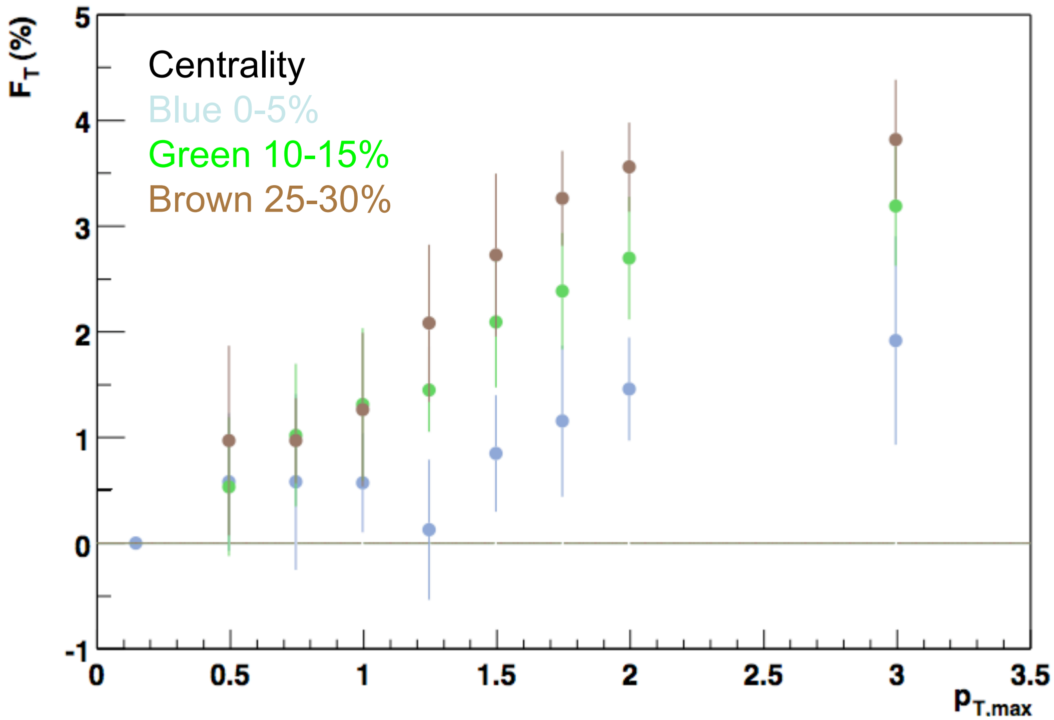


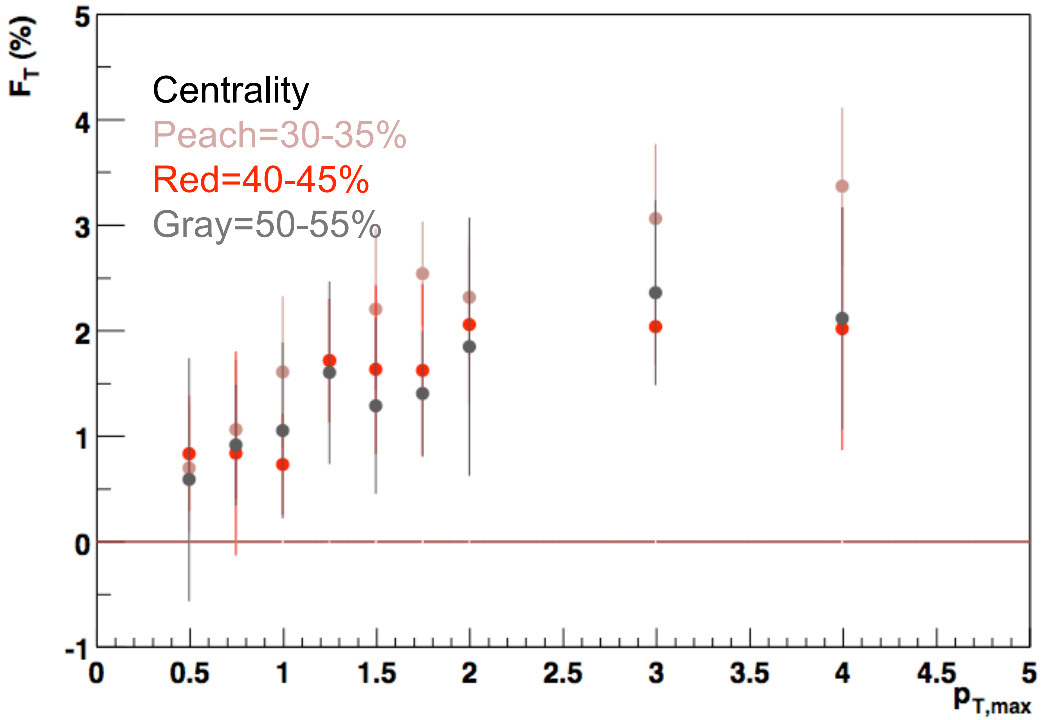
- Dominated by systematic errors from time-dependent detector variations
- Errors minimized by time dependent cuts on mean and standard deviations of p_T and N_{tracks} distributions
- Errors determined by
  - dividing data into 10 equally sized subsets
  - Fluctuation quantities are determined
  - Error calculated from variance of quantities from subsets
- Comparatively statistical errors are negligible (F_T=0.05%)

F_T vs Centrality



- Significant fluctuation signal seen
- Peaks at mid-central collisions

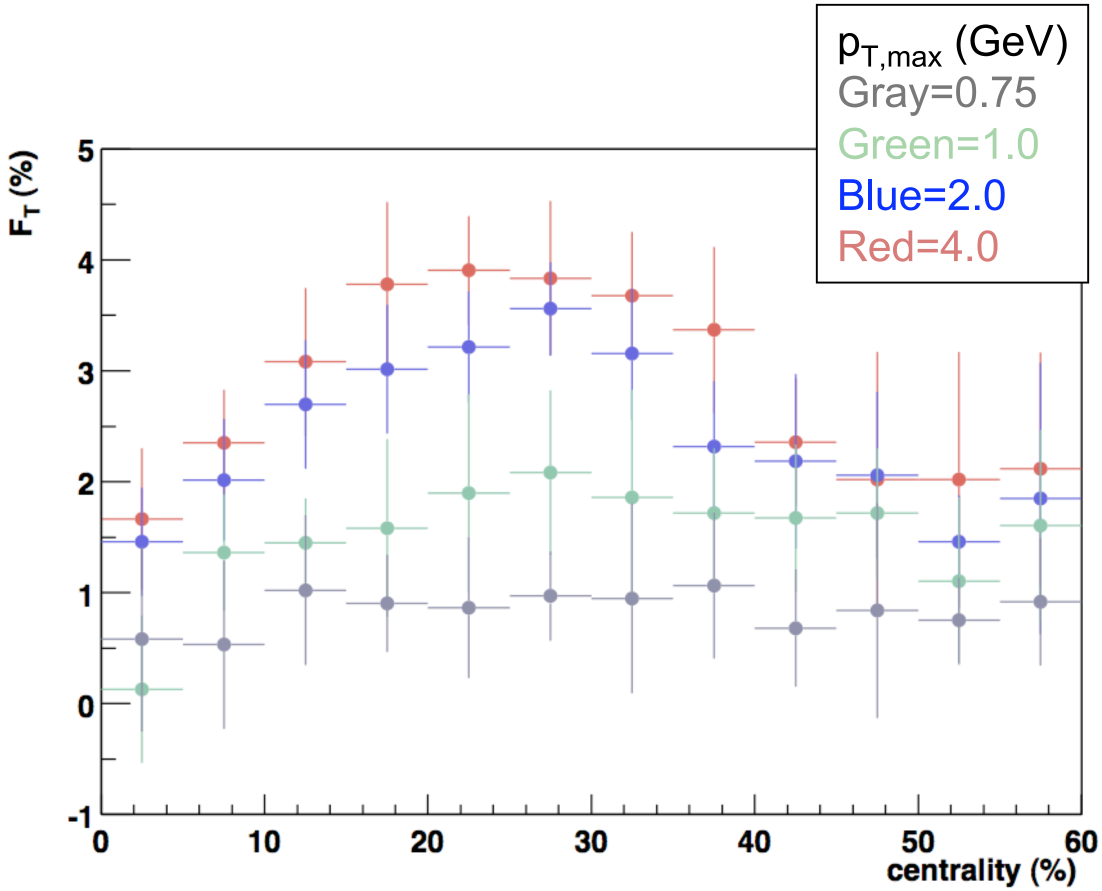




F_T vs p_T

- Significant fluctuation signal
- Largest signal for mid-central events
- Signal dramatically increases with a p_T > 1 GeV/c

F_T vs Centrality with p_T Bins

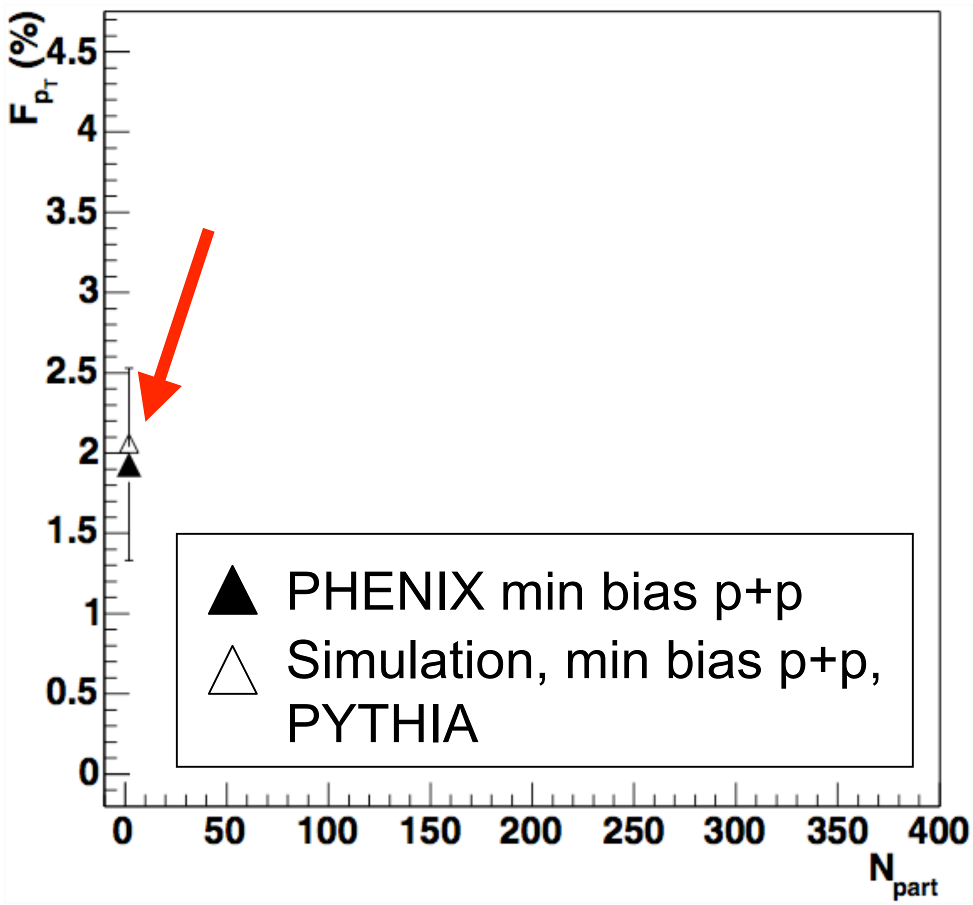


- Fluctuation peaks at mid-central collisions
- The higher the p_T the larger the fluctuation signal
- Large portion of fluctuation signal can be attributed to high p_T particles

Results indicate the fluctuation signal comes from high p_T particles (jets)?

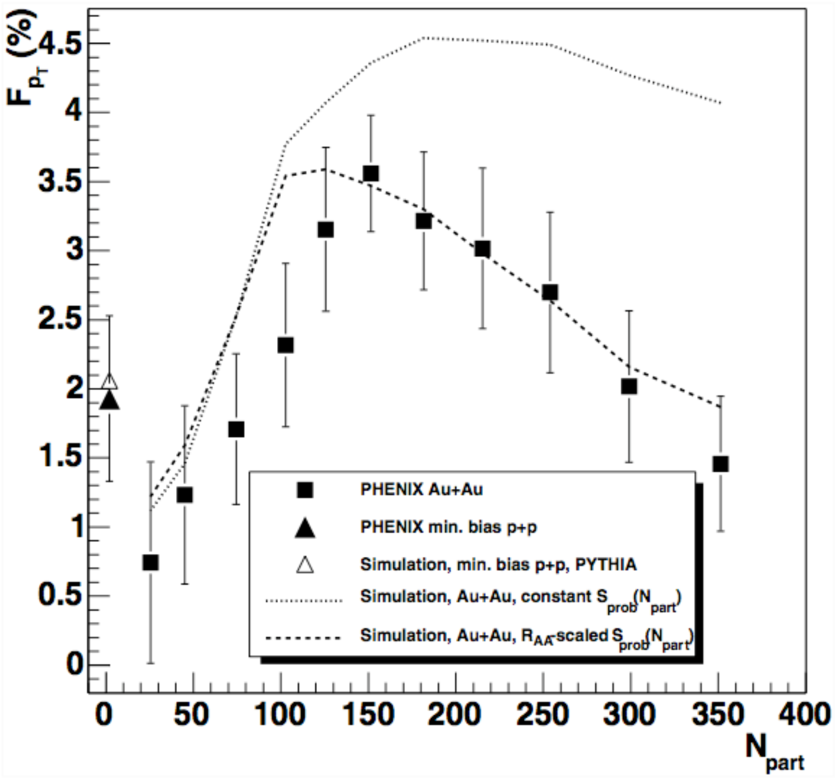
A simulation study was done to test this theory

Simulation: p+p



- Monte Carlo simulation
  - Gaussian distribution of N_{track}
  - Hard processes occur proportionally with increasing generated particles
  - 100,000 PYTHIA events yield a F_T of 2.06% (1.9% for data).

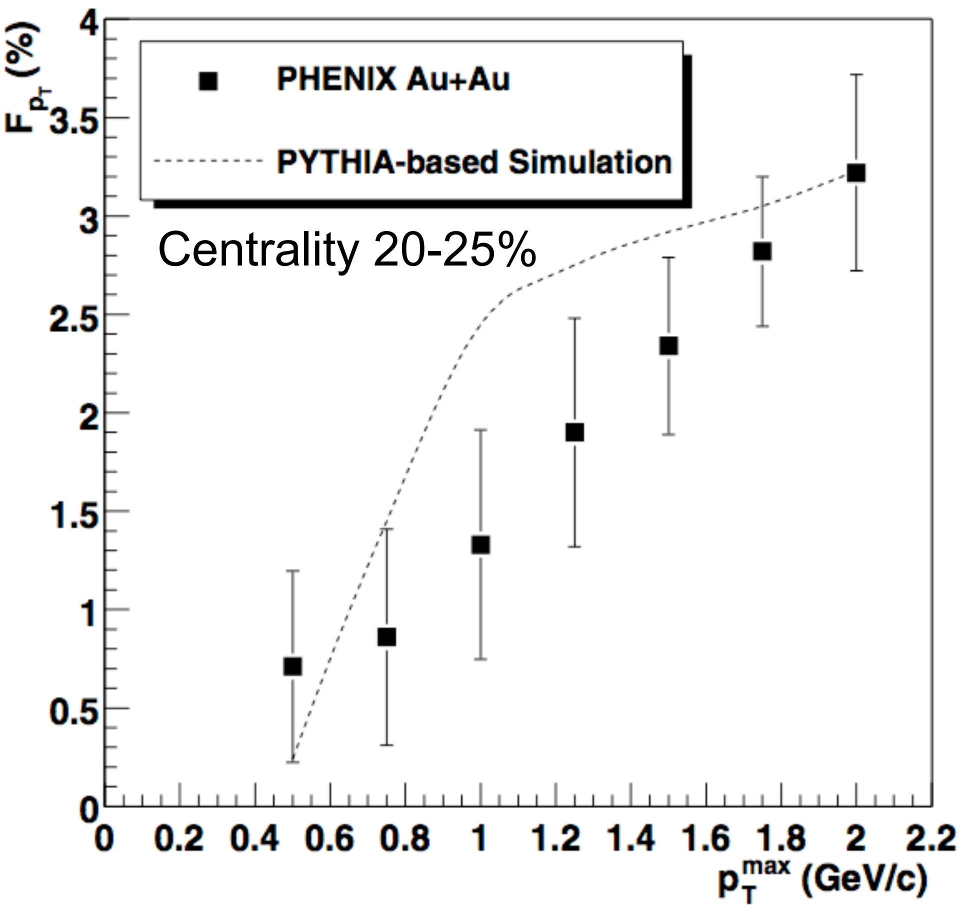
Simulation: Centrality Dependence



- Monte Carlo simulation
- As Au+Au events are being generated, p+p hard scattering events are embedded
- Two scenarios
  - ··· Probability of jets constant for all centralities
  - --- Probability of jets is scaled by R_{AA}
- Both include v_2 contribution

- F_T decrease for peripheral collisions due to small signal strength relative to fluctuations
- F_T decrease for central collisions is from suppression of jets due to nuclear medium

F_T vs P_T simulation



- Same Monte Carlo simulation
- Includes R_{AA} scaling
- Contribution from elliptic flow is negligible

Thoughts on results

- Fluctuations increase with increasing p_T
- F_T vs Centrality and F_T vs p_T both show a smooth behavior across spectrum (not sporadic)
- Simulations that include jet particles with R_{AA} suppression can model results well
- Therefore the fluctuations are caused by high p_T particles

But could the fluctuations be caused by something else?

Phase Transition?

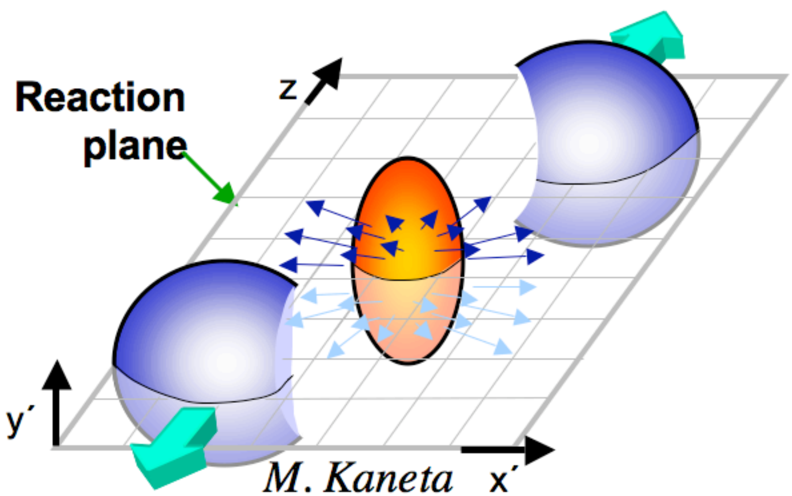
From Analysis Note

"The cause of the signal must be an effect that is present at all centralities at some level, even in the most peripheral collisions. This particular behavior goes against the expected behavior from instabilities prompted by a phase transition. If that were the cause, the signal would most likely only be seen in some, but not all, centrality bins."

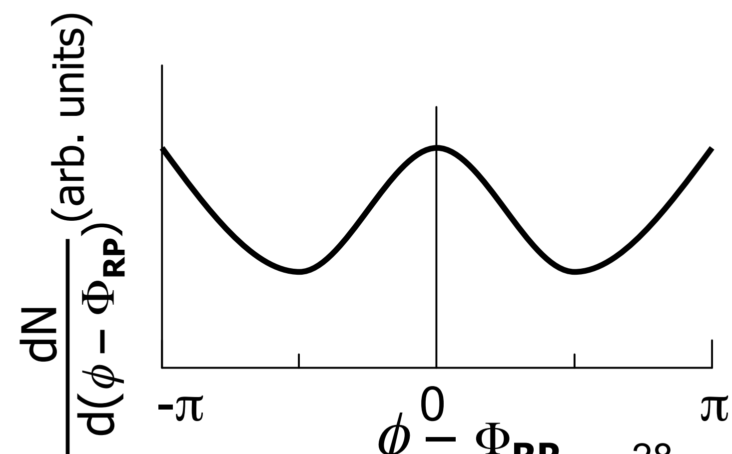
Conclusion: Fluctuations are NOT from a phase transition

Elliptic Flow?

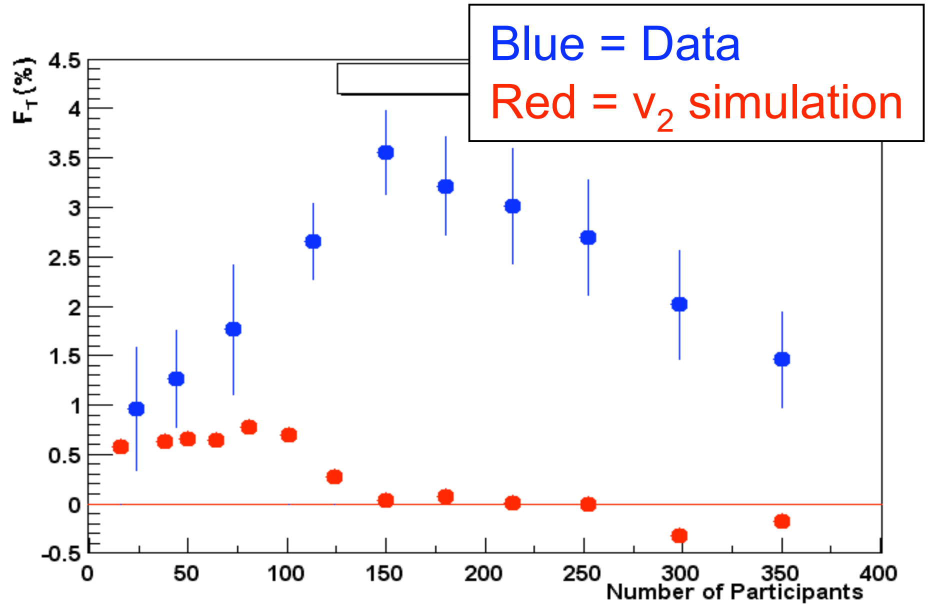
F_T exhibits a similar behavior with elliptic flow as a function of centrality and p_T



- Test with Monte Carlo simulation
  - Gaussian distribution of N_{tracks} fit to data
  - Random reaction plane angle
  - Independent particle distribution generated according to the function $\frac{dN}{d(\phi-\Phi)} = 1 + 2v_2\cos[2(\phi-\Phi)]$, where ϕ is angle of particle, Φ is reaction plane angle, and ν_2 is strength of elliptic flow signal
  - Generated particles follow PHENIX v_2 measurements regarding pT and centrality
  - Only generated particles that lie within PHENIX acceptance are included in M_{pT} calculation

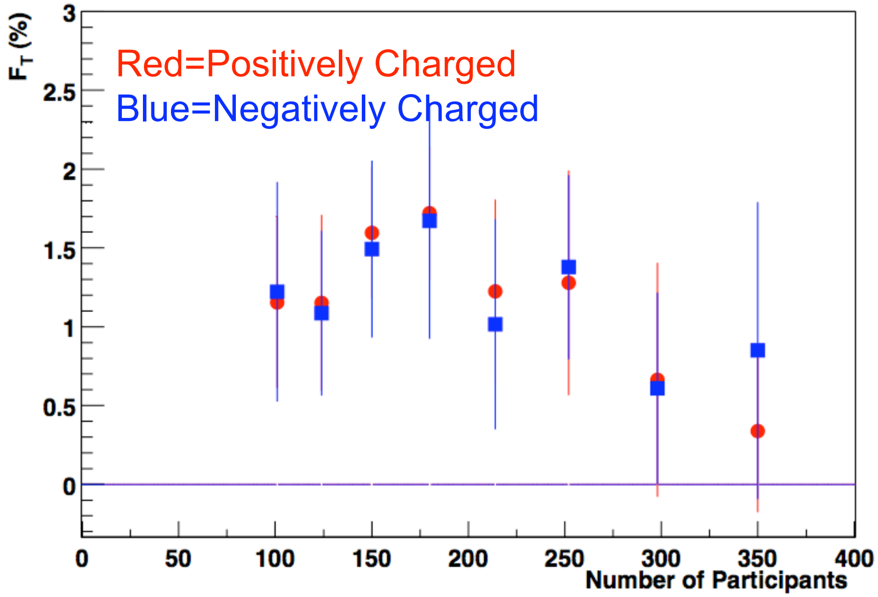


Simulation Results



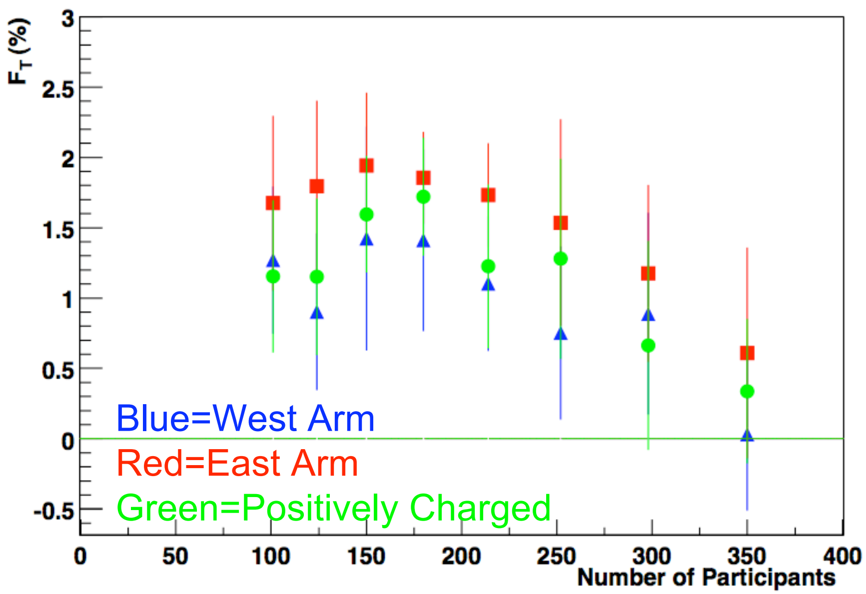
- Elliptic flow contribution to F_T is estimated to be 0.1% for N_{part}>150 and maxing at 0.6% for N_{part}<100
- Elliptic flow contribution to F_T is mostly canceled out by having mixed events sample tracks from data, which transfer's any v_2 effects in the data to mixed events, which eventually cancels out v_2 contribution
- Also, F_T is not zero for p + p collisions (1.9%, as seen earlier) where elliptic flow isn't present

- Conclusion: Elliptic flow does not significantly contribute to F_T signal.



Charge Dependence?

- Signal reduced due to smaller statistics, but still present



Tracking Anomalies?

- Signal reduced due to smaller statistics, but still present
- Differences can be attributed to differences in number of N_{tracks} from inefficiencies

Conclusion: Charge dependence and tracking anomalies do not significantly contribute to measured fluctuation.

Final Conclusions

- A significantly positive event-by-event F_T vs p_T signal is observed
- Fluctuations can be attributed to high p_T particles (jets) as shown by simulation
- Fluctuations are not caused by instabilities in effective temperature due to a phase transition (smooth behavior)
- Signal contribution from v_2 is small
- p+p collisions exhibit a non zero fluctuation showing signal is still seen without v_2