Fluctuations: Experiment

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MIT

QCD in the RHIC Era
-
ITP/UCSB April 8-12 2002

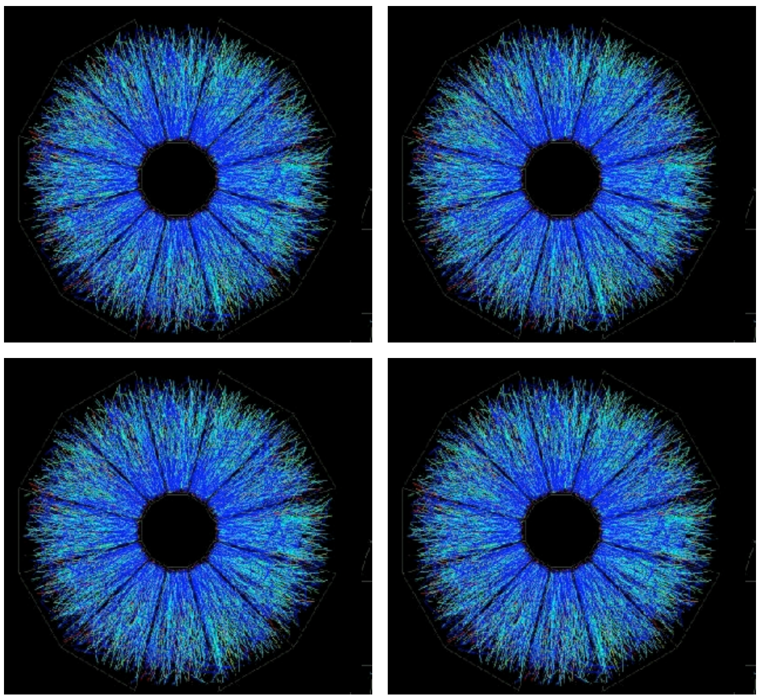
Fluctuations: Experiment

- Survey of experimental results
  - Global fluctuations of intensive variables
  - Energy and centrality dependence

- Some mild Speculation

Event-by-Event Fluctuations

Are these events '*different*' or '*the same*'?



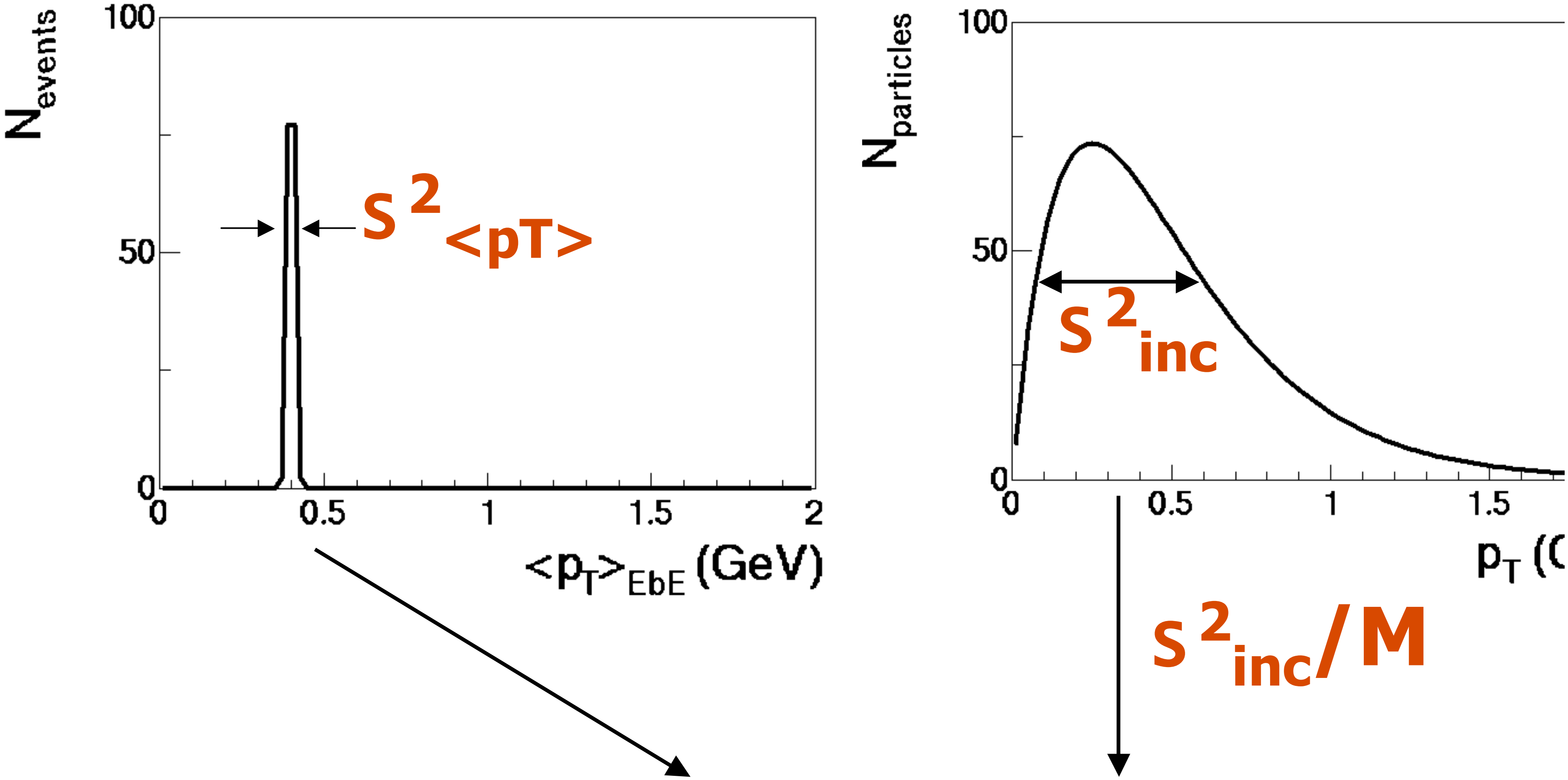
- What do we mean by 'different'?
- What physics would make them more 'different' or more 'the sam
- What does the data tell us?

Global Dynamical Fluctuations

Example: $\langle p_T \rangle_{EbE}$ Fluctuations ($\langle p_T \rangle_{EbE} = \Sigma\, p_{Ti}$)

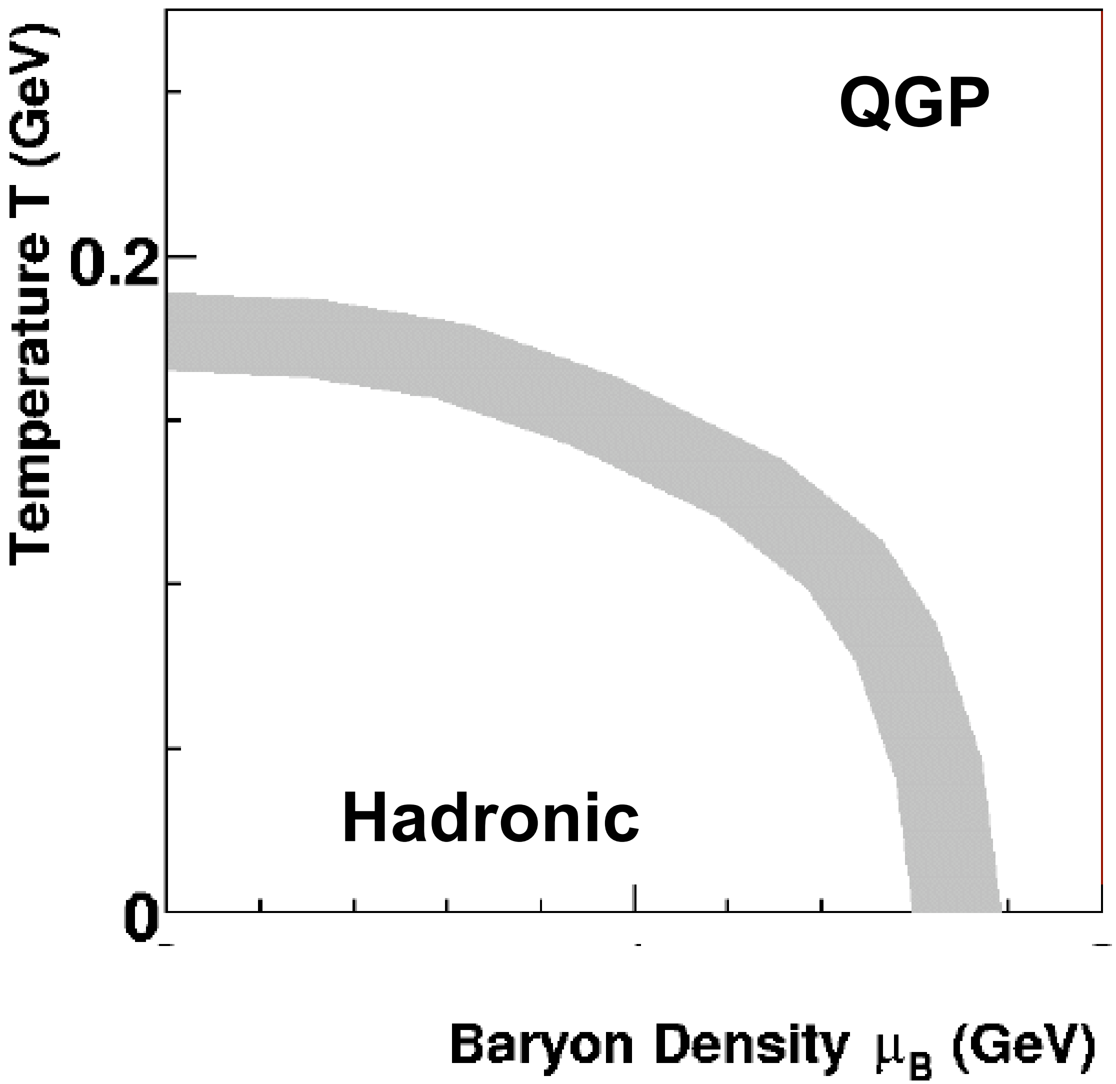
- **Global**: Study variation of $\langle p_T \rangle_{EbE}$ from event to event
- **Dynamical**: Study $\boldsymbol{\sigma^2_{\langle pT \rangle EbE}}$ relative to statistical reference

Global Dynamical Fluctuations

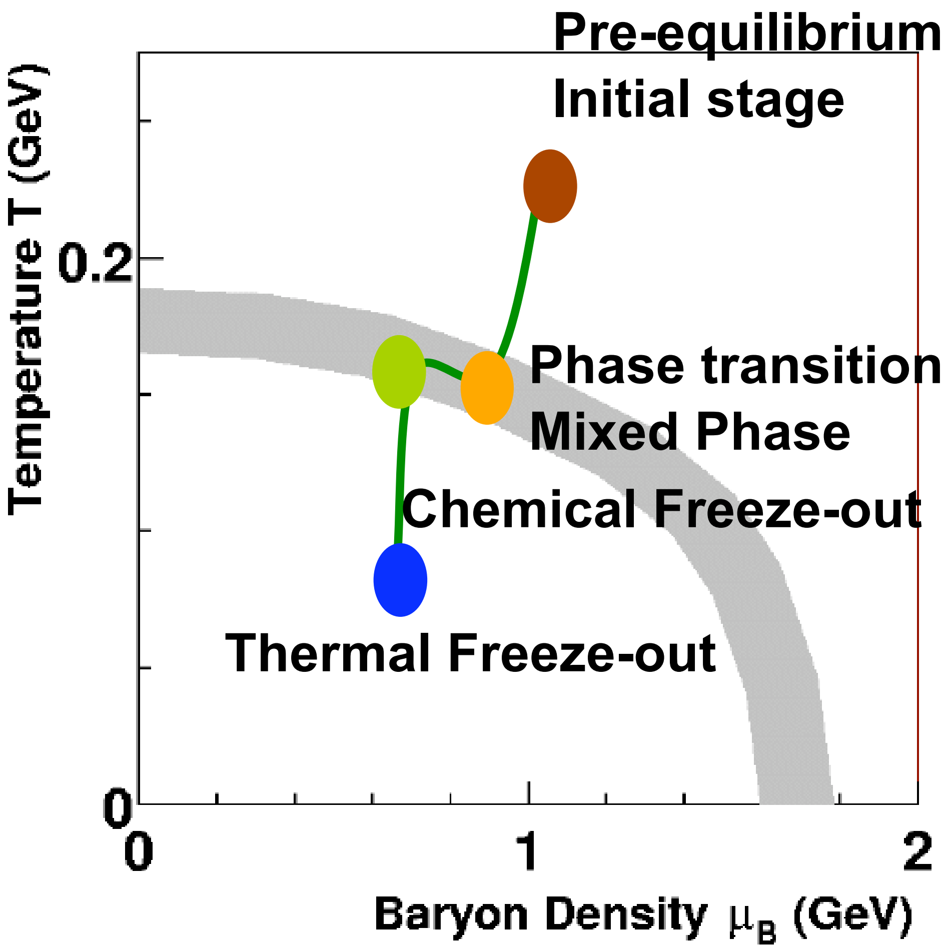


$$s^2_{p_T,dyn} = s^2_{<p_T>} - s^2_{p_T,stat}$$

Exploring the QCD Phase Diagram



Fluctuations and the QCD Phase Diagra



Chiral Symmetry Restoratio

- Formation of DCC's
- Charge/Neutral Fluctuations

Order of Transition/Latent H

- Supercooling
- Droplet formation
- K/p Fluctuations
- <pT> Fluctuations

Location of Critical Point

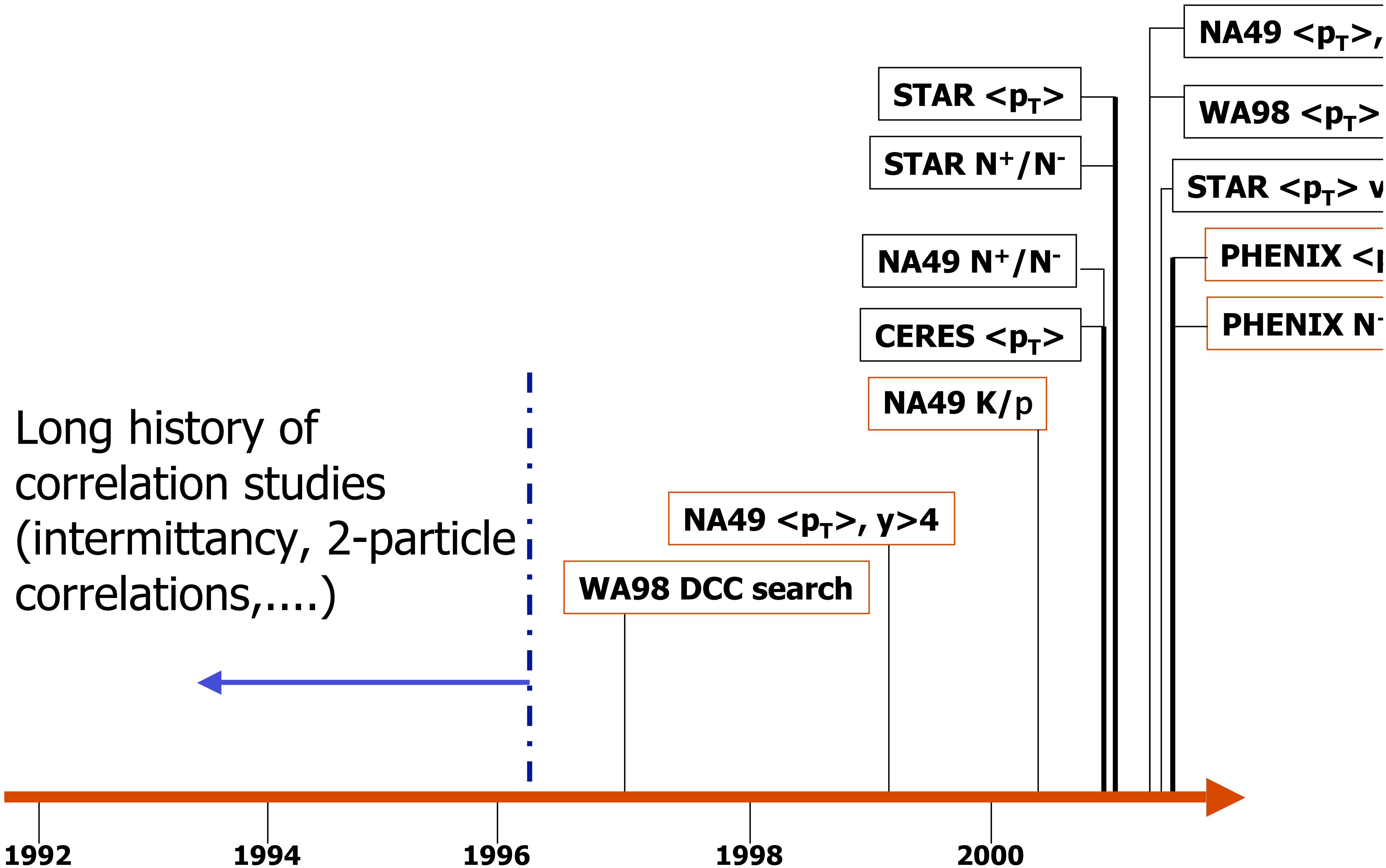
- $\langle p_T \rangle$ Fluctuations

Deconfinement

- Charge/DoF
- N^+/N^- Fluctuations

A Brief History of Global Fluctuation

Long history of correlation studies (intermittancy, 2-particle correlations,....)

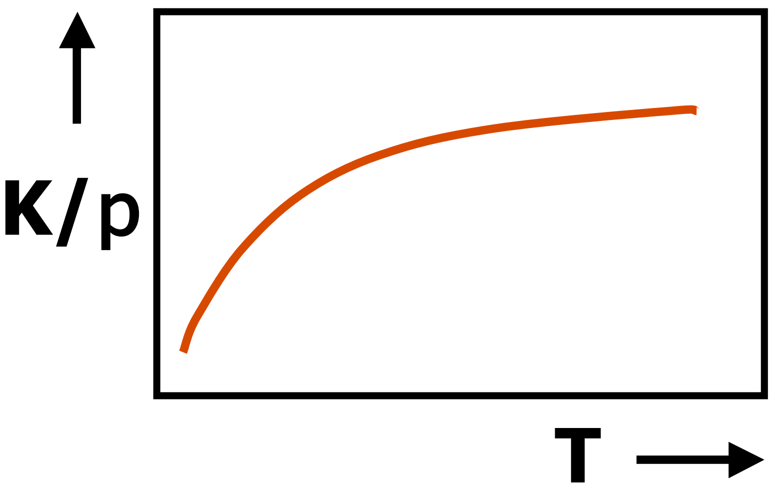


Look at Event-by-Event Fluctuations in

- K/p ratio
- N^+,N^- multiplicities
- $\langle p_T \rangle$

E-by-E fluctuations in the K/p ratio

- Is strangeness enhanced in every event?
- Can we see signs of super-cooling below T_{crit}?



E-by-E fluctuations in the K/p ratio

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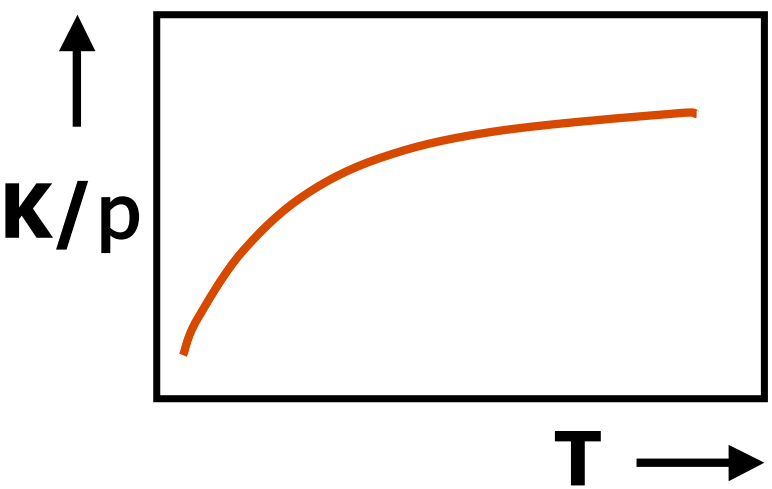
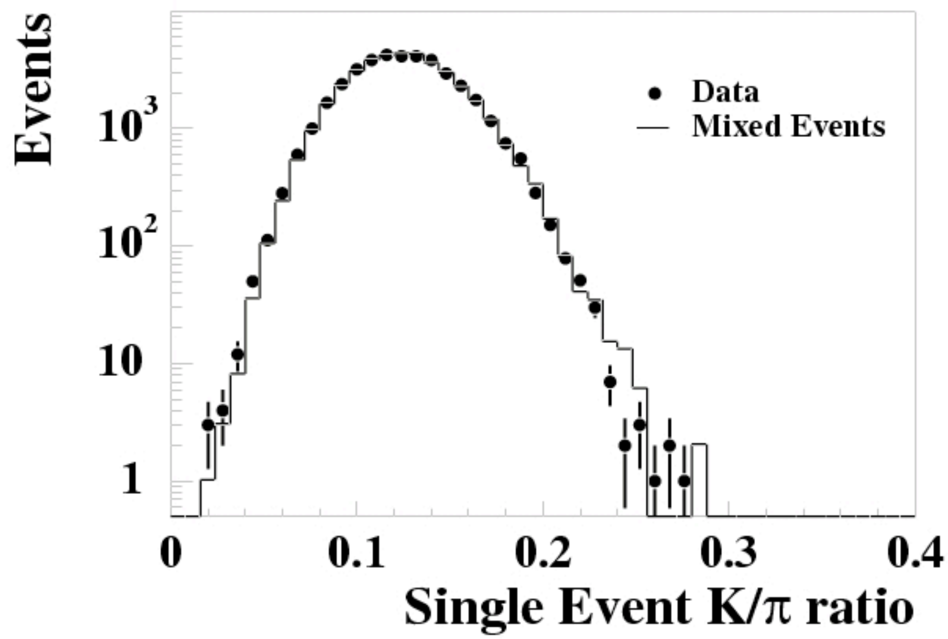


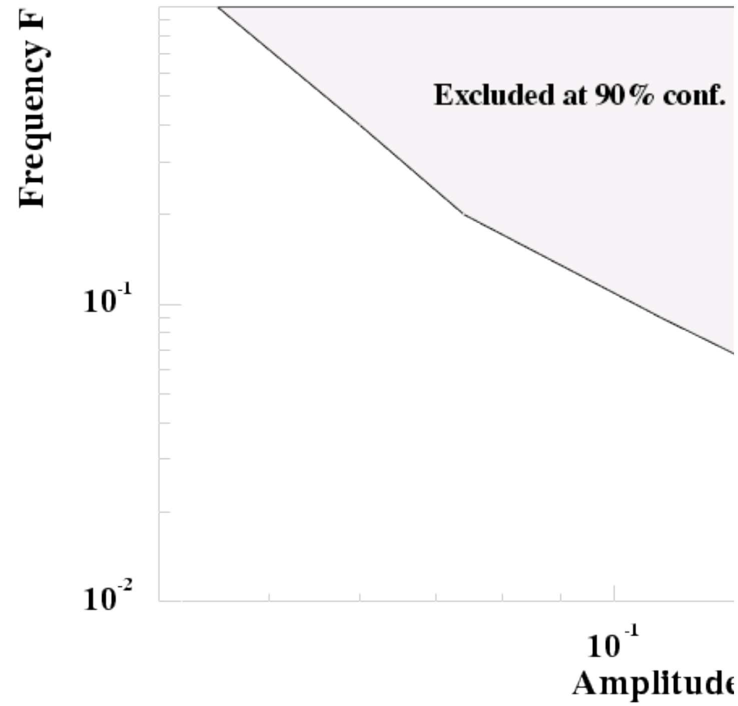
NA49 Measurement

- Use dE/dx to identify p,K,p event-by-event
- Do Max Likelihood fit to extract K/p ratio ev by-event
- Required 2 years of detector calibation to eliminate dE/dx – multiplicity correlation

E-by-E fluctuations in the K/p ratio

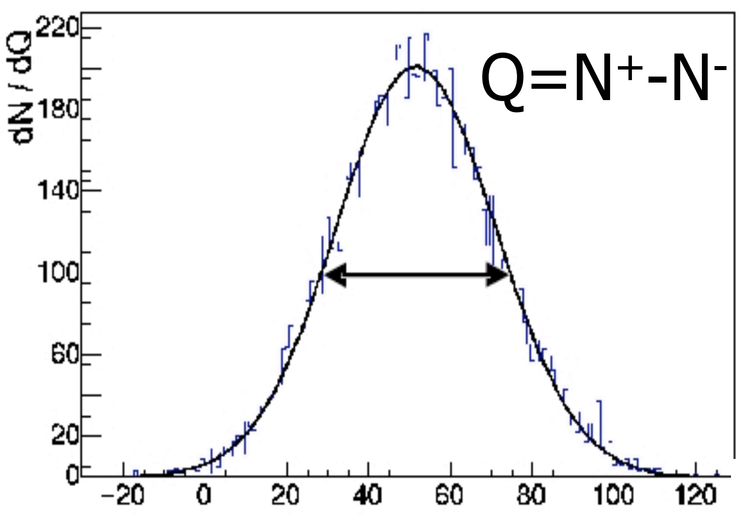
NA49, PRL 86 (2001) 1965

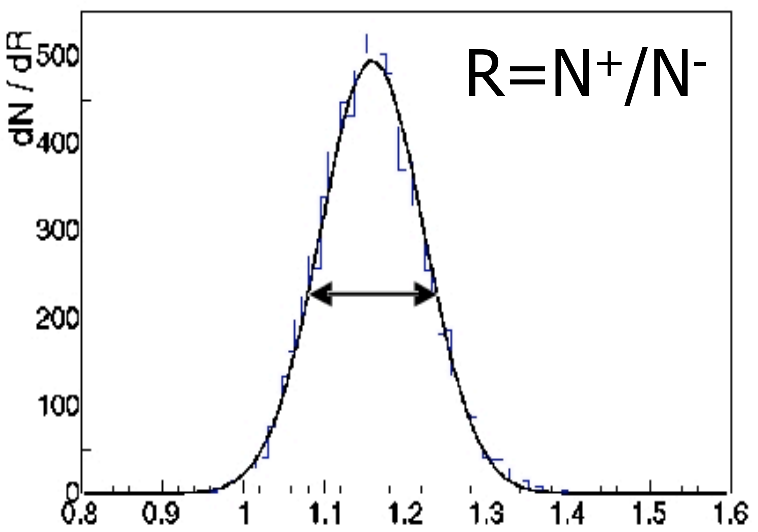




- Dynamical fluctuations are small (< ~5%)
- Compatible with resonance gas (Jeon, Koch; nuclth/9906074)
- Strangeness enhancement in every event
- Chemical freeze-out at same T in every event

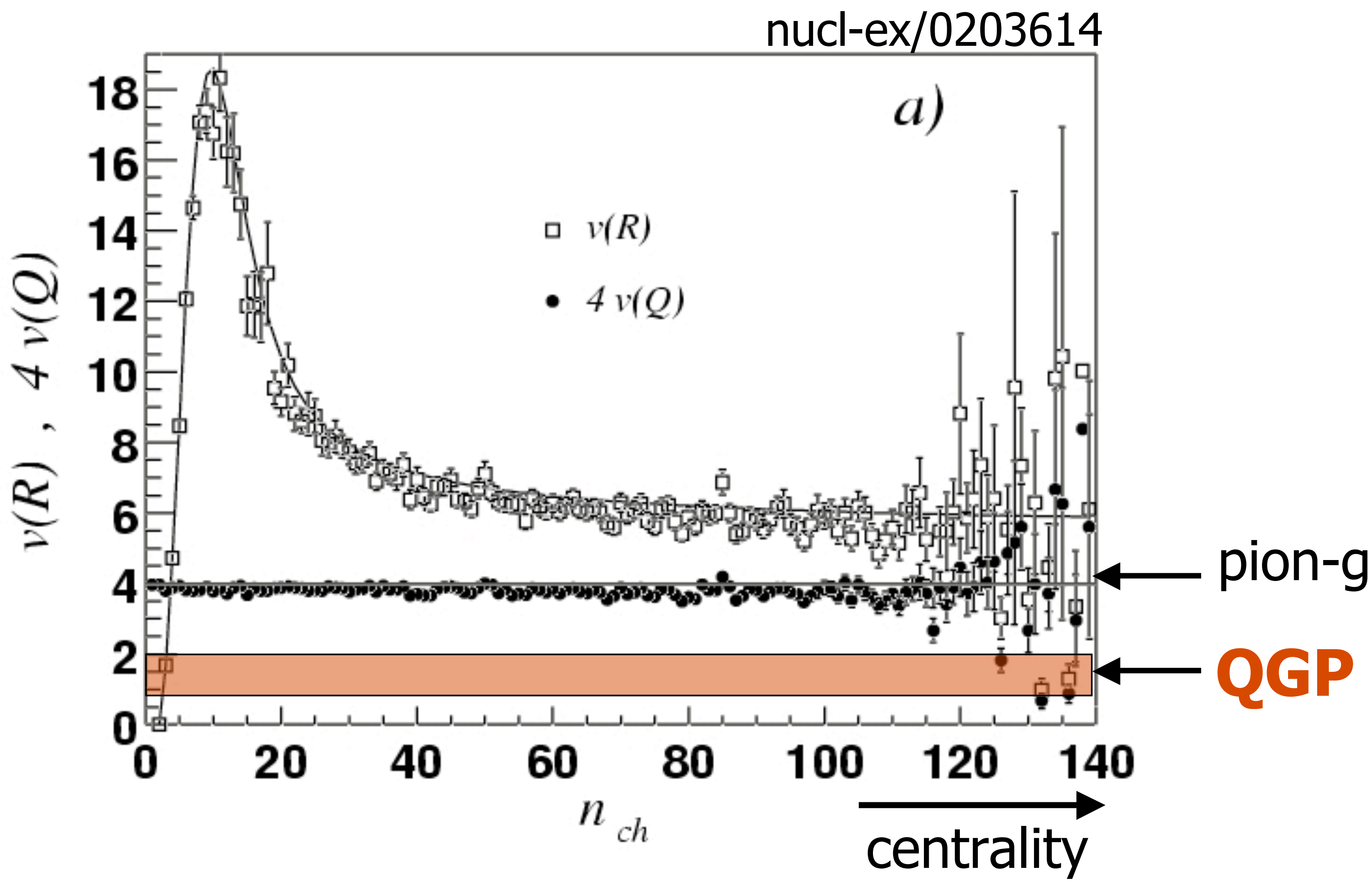
Charge fluctuations





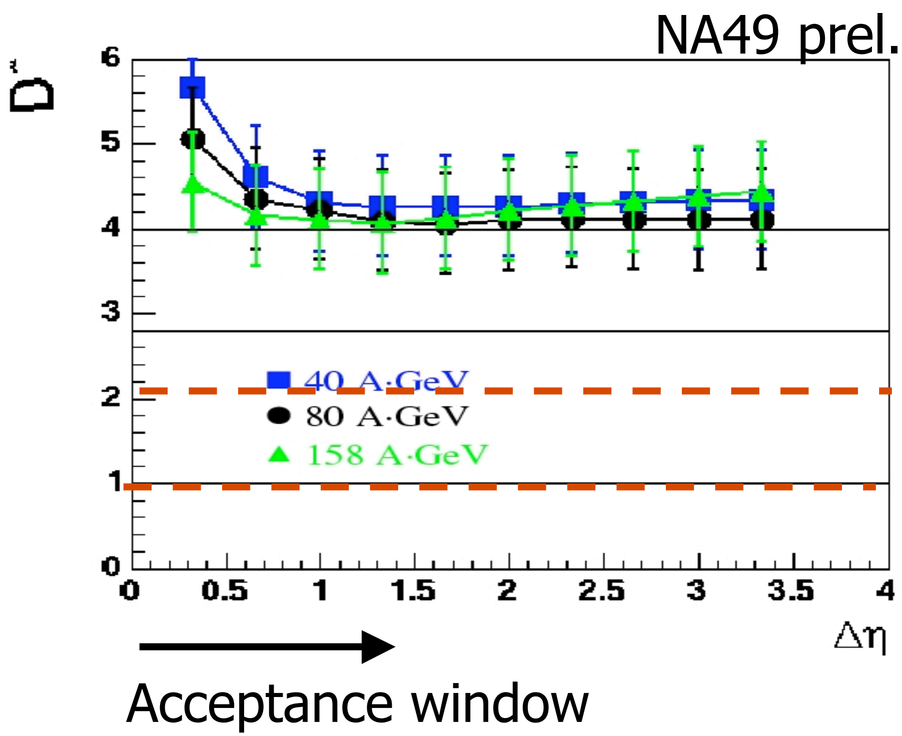
- Net Charge/Dy Fluctuations <-> Charge/DoF
  - Jeon, Koch hep-ph/0003168
  - Asakawa, Heinz, Mueller hep/ph/0003169
  - Change from 1-2 (QGP) to 4 (Pion G
- Fluctuations frozen b/c charge conservation
  - Diffusion vs Expansion timescale
- Fluctuations of N^+/N^- ratio or N^+-difference vs statistical reference

Charge fluctuations at RHIC: PHENI

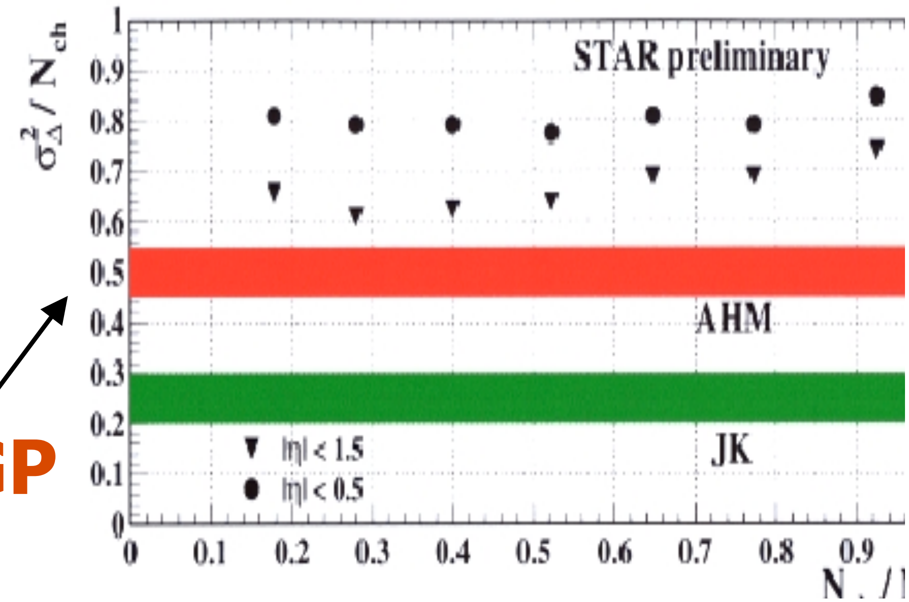


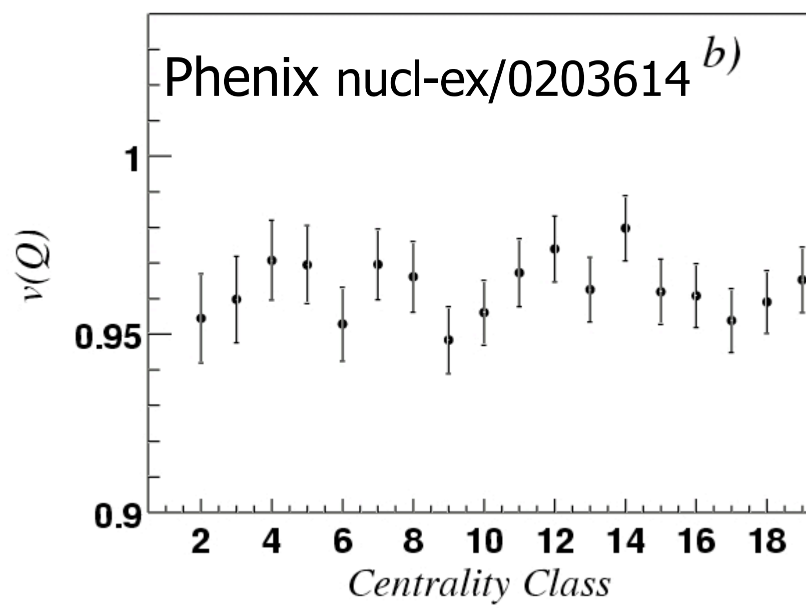
No sign of QGP suppression of charge fluctuatior

More results



QGP





- Excellent consistency at RHIC
- No centrality dependence
- No energy dependence from sqrt(s) 10 to 130 GeV

Charge Fluctuations

- Fluctuations close to resonance gas prediction
- Little/no energy or centrality dependence
- Where's the QGP?
  - Diffusion wins?
  - Dilution by late stage resonance formation (Zaranek, NA49 simulations)
  - Quark coalescence (Bialas, hep-ph/0203047)

$\langle p_T \rangle_{EbE}$ Fluctuations

- p_T - simple observable (supposedly...)
- High statistical precision: $s_{pT,EbE}/\langle pT \rangle_{inc} < 0.1\%$
- Sensitive to many interesting scenarios
    - Criticial endpoint
    - DCC production
    - Droplet formation
    - Jets
    - Any non-statistical, momentum-localized process

(Too?) Many ways to measure p_T Fluctuations

$f_{pT} = (<Z>/<M>)^{1/2} - \overline{z}^{1/2}$, w/ $z = p_T - <p_T>$, $Z = Sz$

(Gazdzicki, Mrowczynski)

$s^2_{dyn} = (s^2_{EbE} - s^2_{inc} /<M>) \times <M>/(<M>-1)$

(Voloshin)

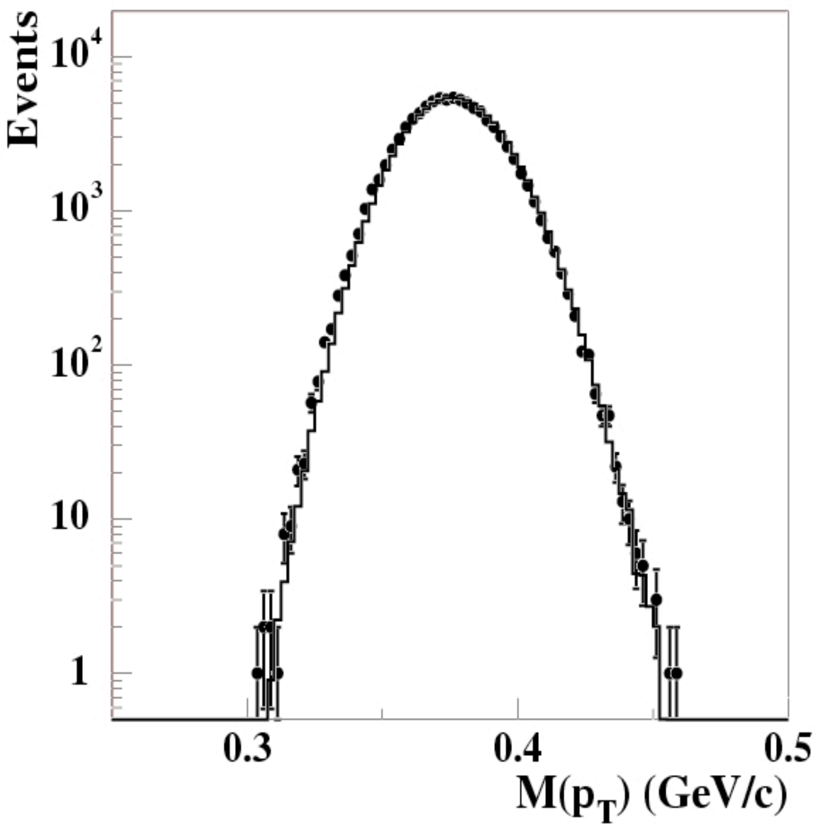
$Ds^2 = \overline{M \times (<p_T>_{inc} - <p_T>)^2} - s^2_{EbE}$

(Trainor)

Direct model comparison (NA49, WA98, PHENIX)

Global <p_T> fluctuations at SPS

NA49, Phys Lett B459 (1999) 679

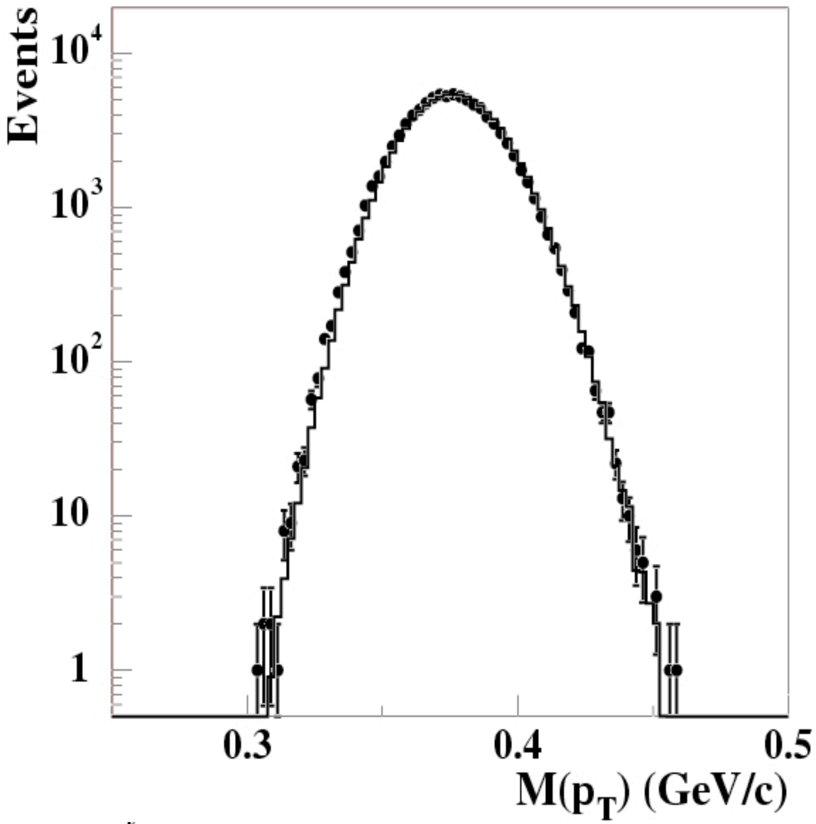


- Charged particles, $4 < y_p < 5$

$$\Phi_{p_T} = 0.6 \pm 1.0 \text{ MeV}/c$$

- Result consistent with statistical fluctuations only
  - Expect +5 MeV from HBT
  - Canceled by –5MeV from two-track resolution

Global <p_T> fluctuations at SPS



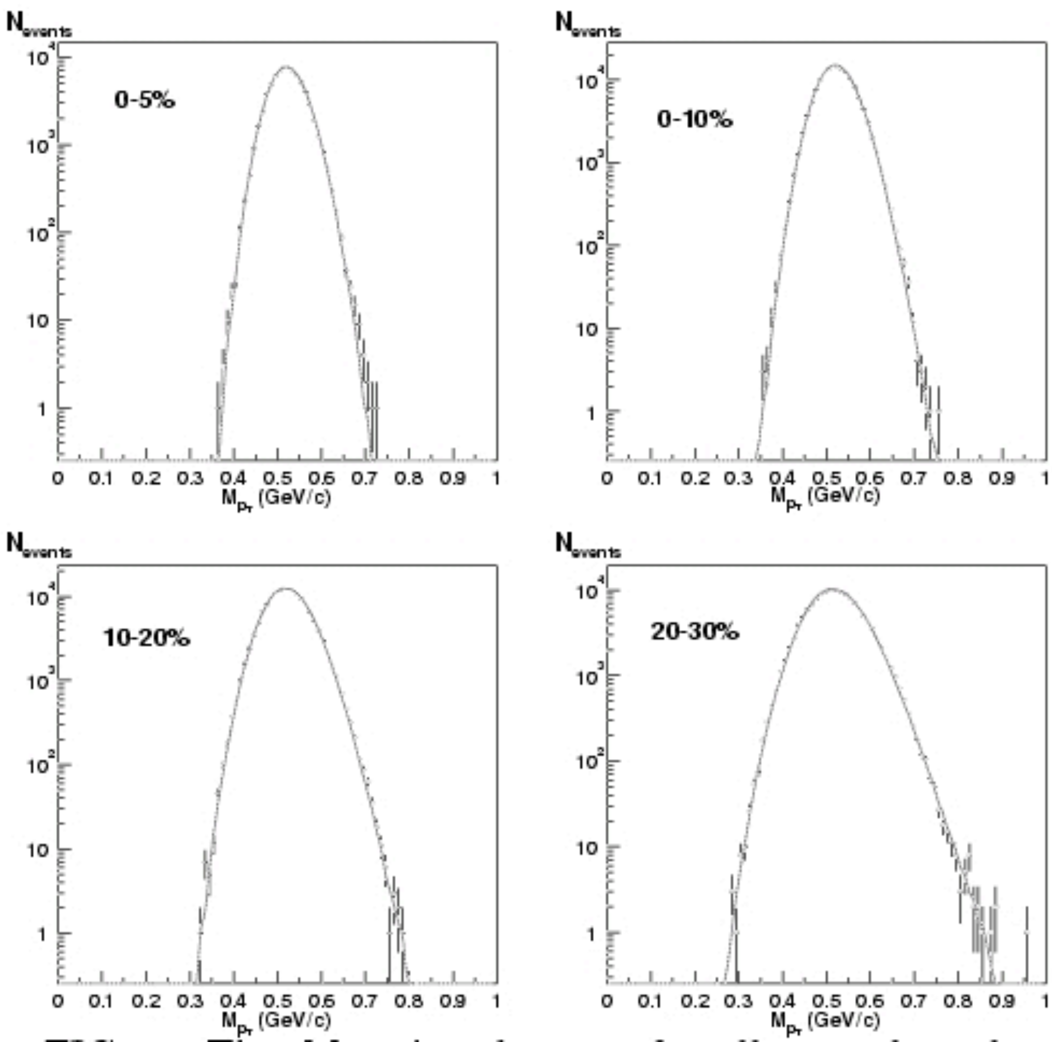
No. of events	98426
$\langle N \rangle$	270.13 ± 0.07
$(\langle N^2 \rangle - \langle N \rangle^2)^{\frac{1}{2}}$	23.29 ± 0.05
$\overline{p_T}$	376.75 ± 0.06 MeV/c
$(\overline{p_T^2} - \overline{p_T}^2)^{\frac{1}{2}}$	282.2 ± 0.1 MeV/c

It's not a Gaussian....

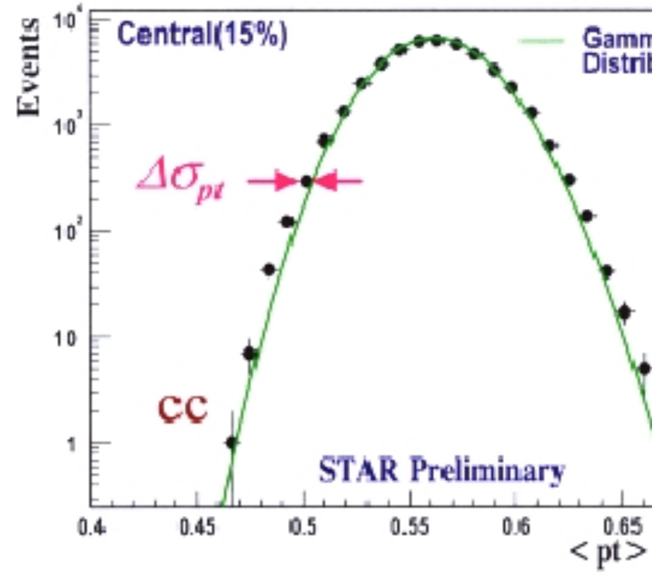
...it's a Gamma-Distribut

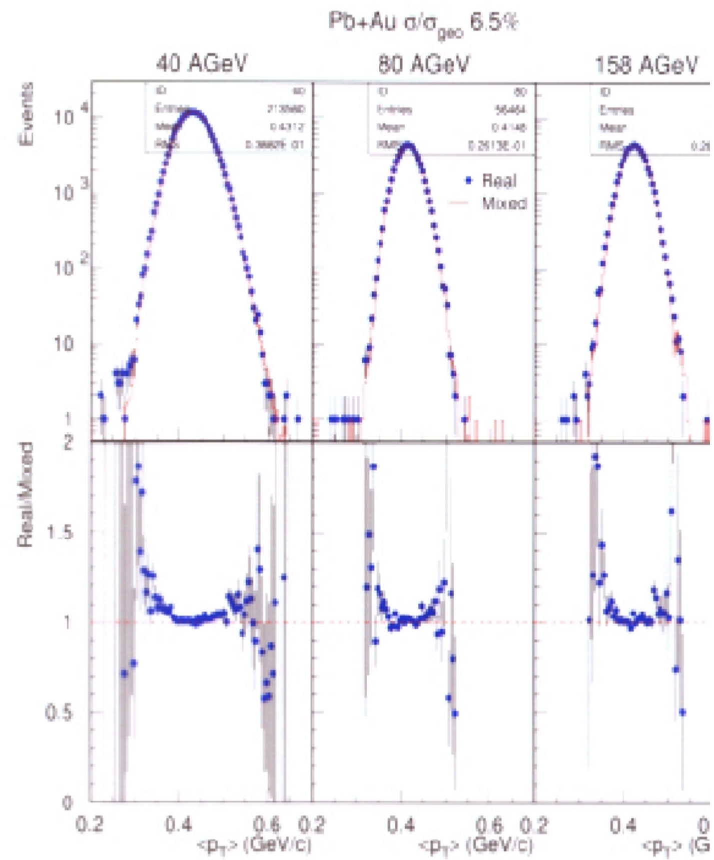
(M. Tannenbaum, Phys.Lett.B 498(

New Measurements



PHENIX nucl-ex/0203015





CERES QM'01

Look at $\langle p_T \rangle$ Fluctuations vs

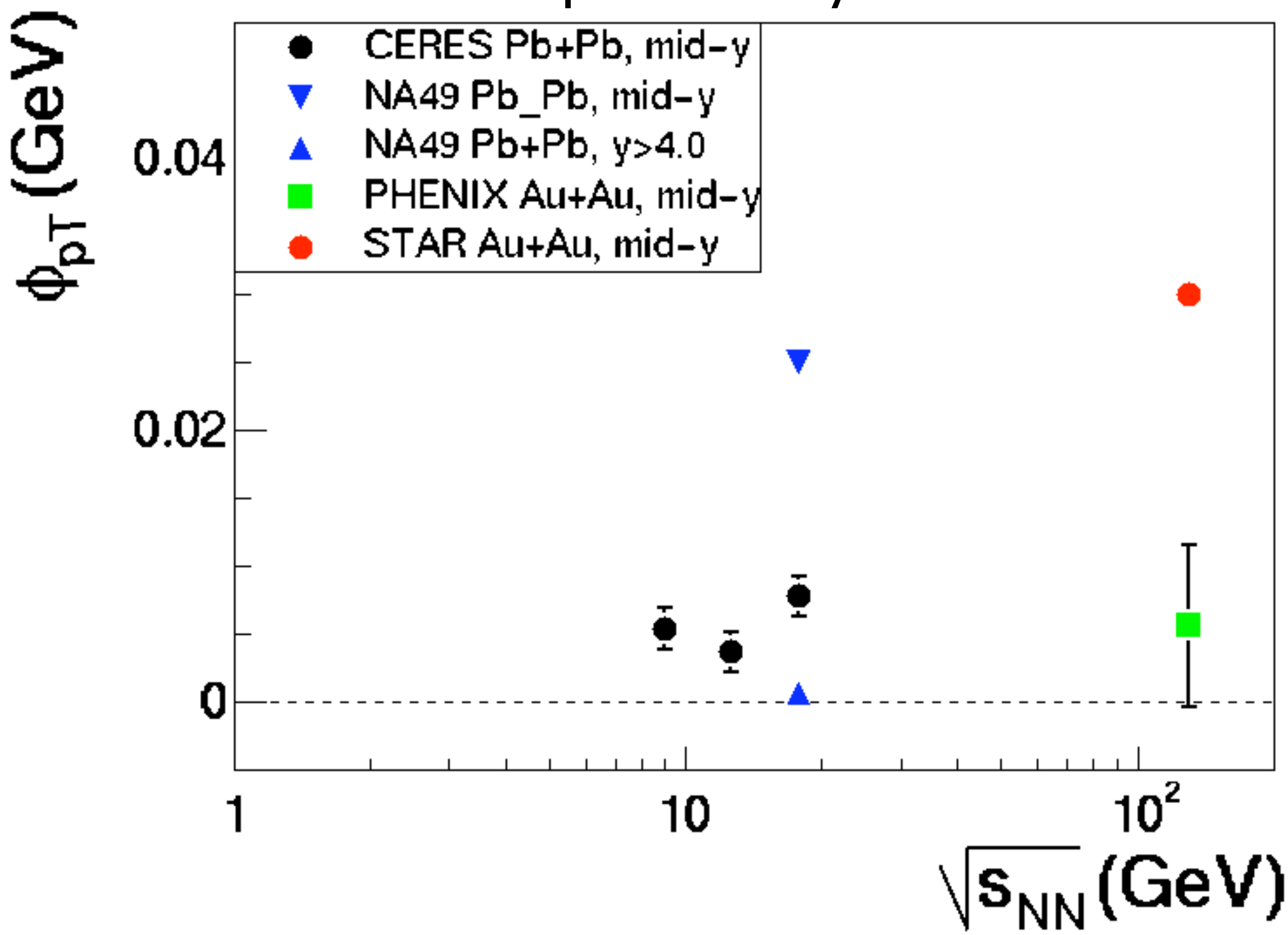
- Collision Energy
  - Critical point
- Centrality
  - Reaction mechanisms

$\langle p_T \rangle_{EbE}$ Fluctuations vs sqrt(s)

- Systematics not straightforward
  - Different acceptance
  - Different variables
  - Different phase-space region
- Here
  - Translate to $\mathbf{f}_{pT}$
  - Correct for acceptance assuming $y_{corr} >> y_{acc}$

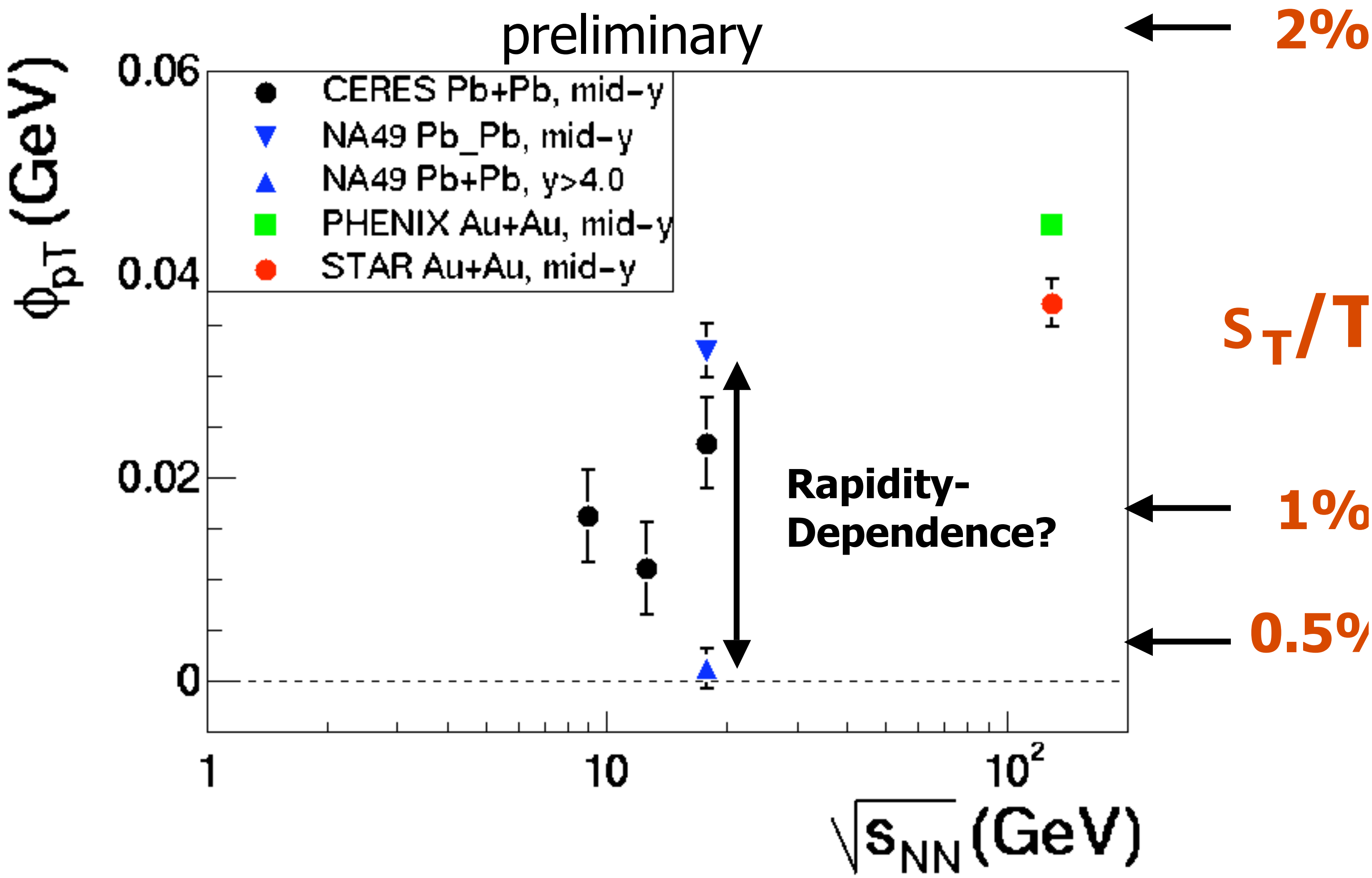
$\langle p_T \rangle_{EbE}$ Fluctuations vs sqrt(s)

preliminary



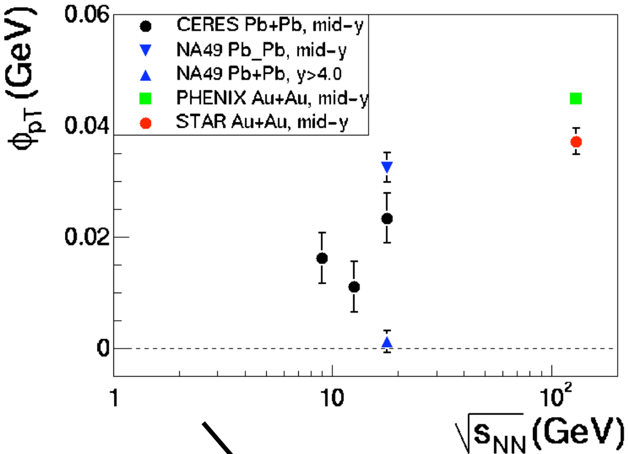
This is confusing....

$<p_T>_{EbE}$ Fluctuations vs sqrt(s)



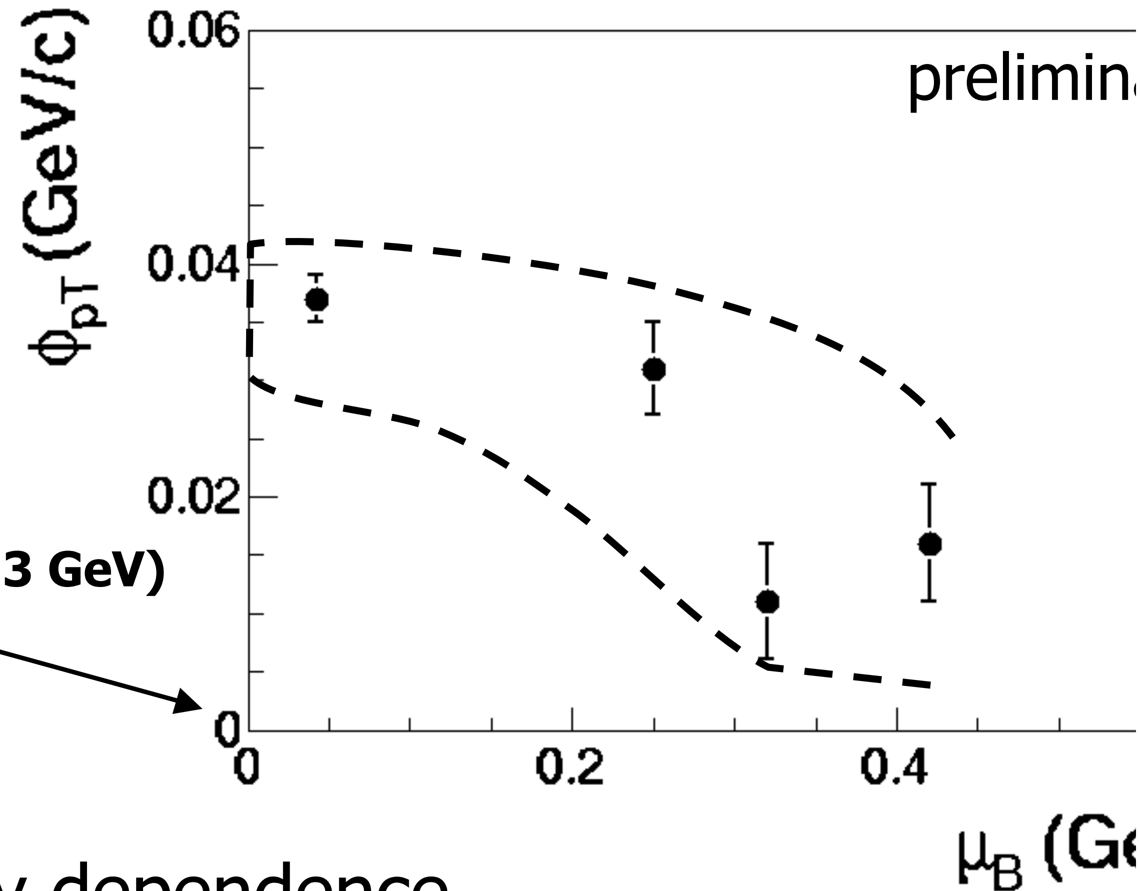
After correction for acceptance (good to ~ 25%

$\langle p_T \rangle_{EbE}$ Fluctuations vs m_B



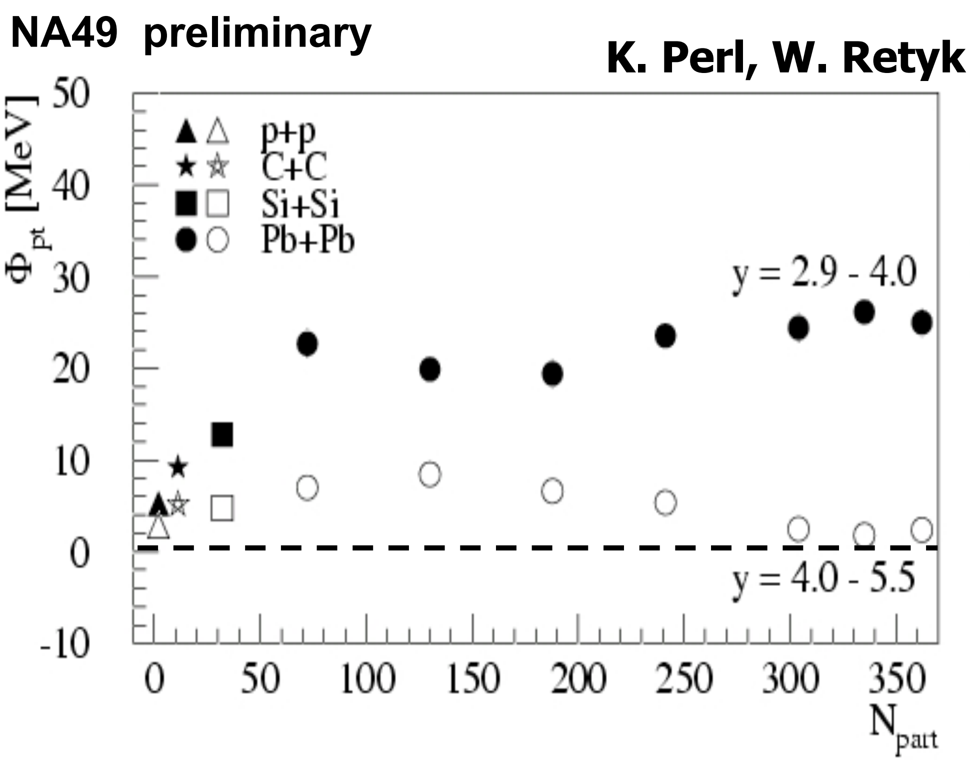
$m_B(s)$ = 1.27 GeV/(1 + sqrt(s)/4.3 GeV)

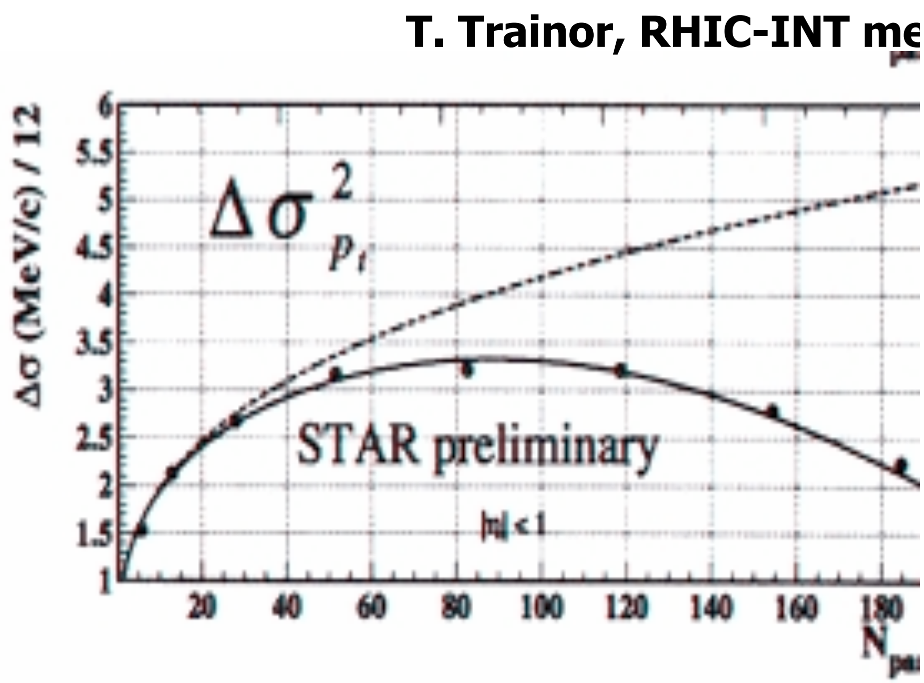
pbm et al (hep-ph/0106066)



- Indication of energy dependence
- Critical point not visible yet
- Wanted: (Final) data from CERES/NA49:20, 40, 80 Ge including pt-dependence

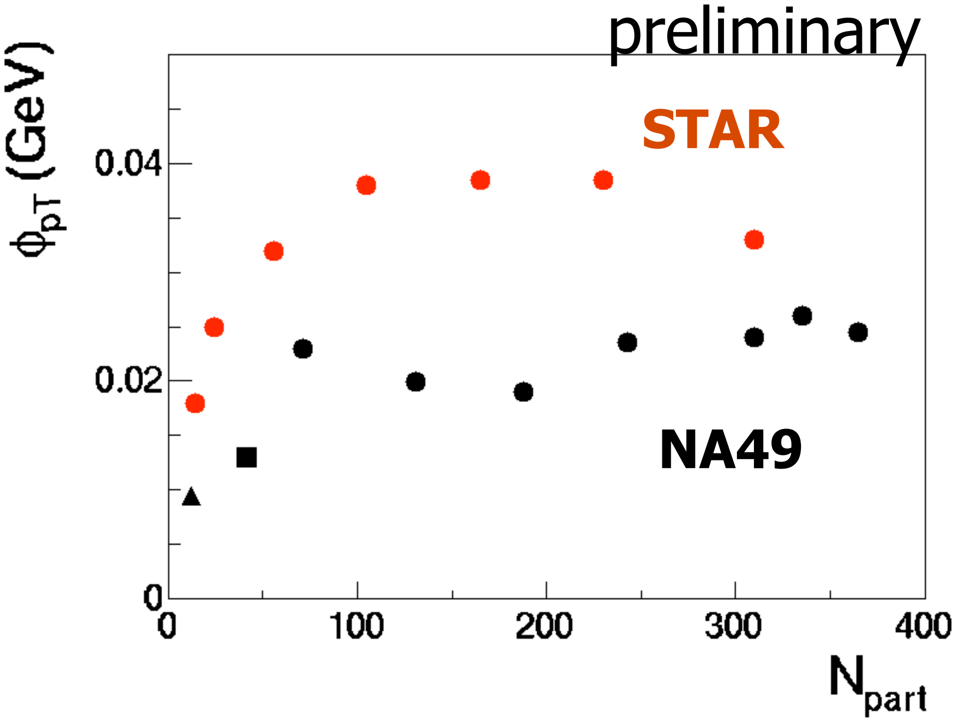
$\langle p_T \rangle_{EbE}$ Fluctuations vs Centrality

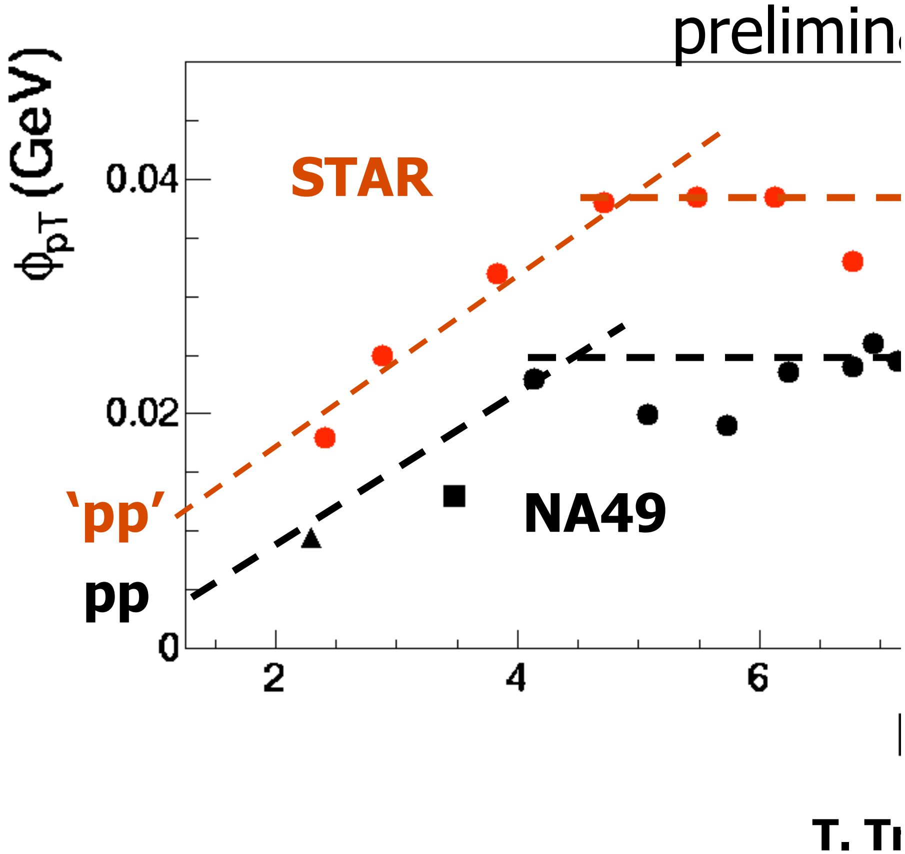




- Common trend?

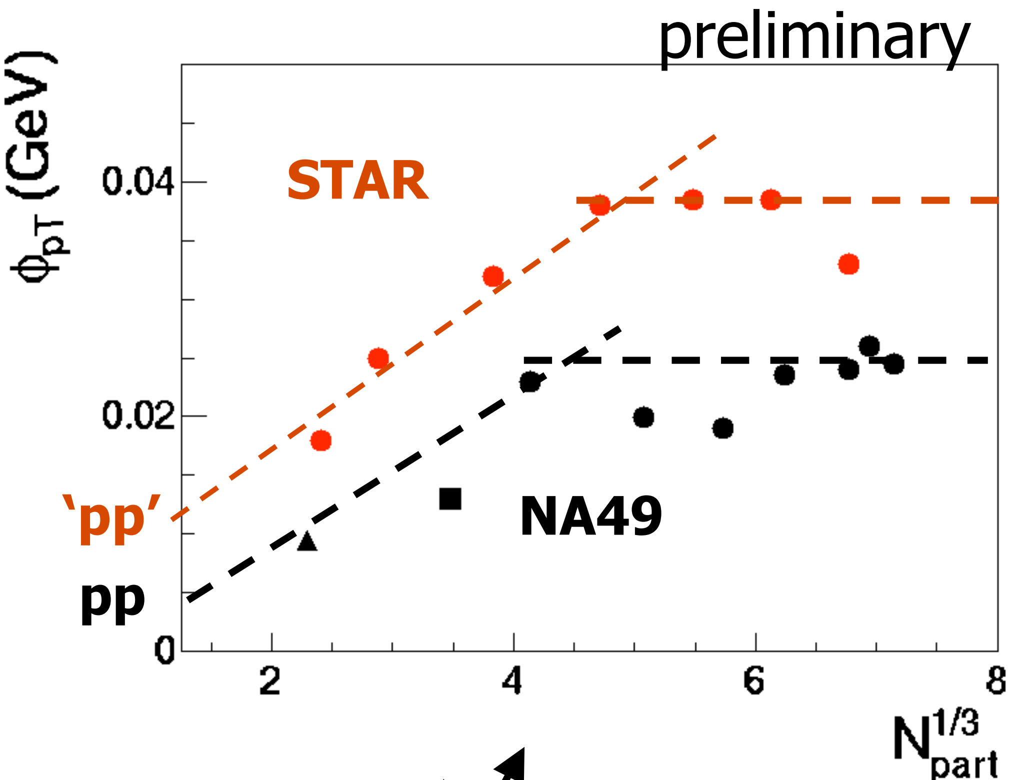
$\langle p_T \rangle_{EbE}$ Fluctuations vs Centrality



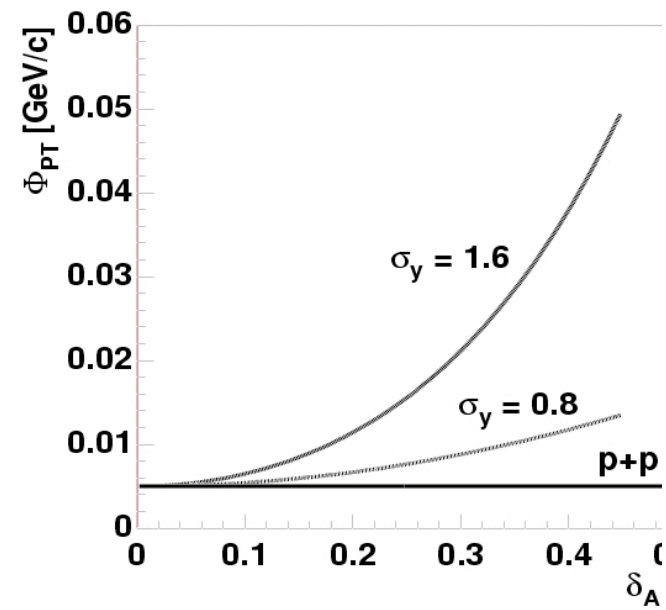


- Rapid rise, then saturation
- Lot's of experimental difficulties

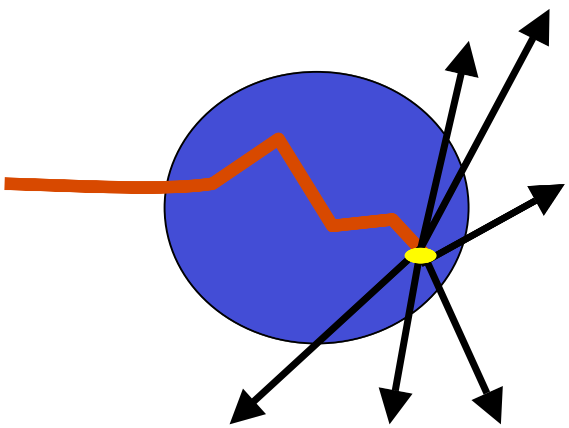
$\langle p_T \rangle_{EbE}$ Fluctuations vs Centrality



Initial state scattering (Trainor



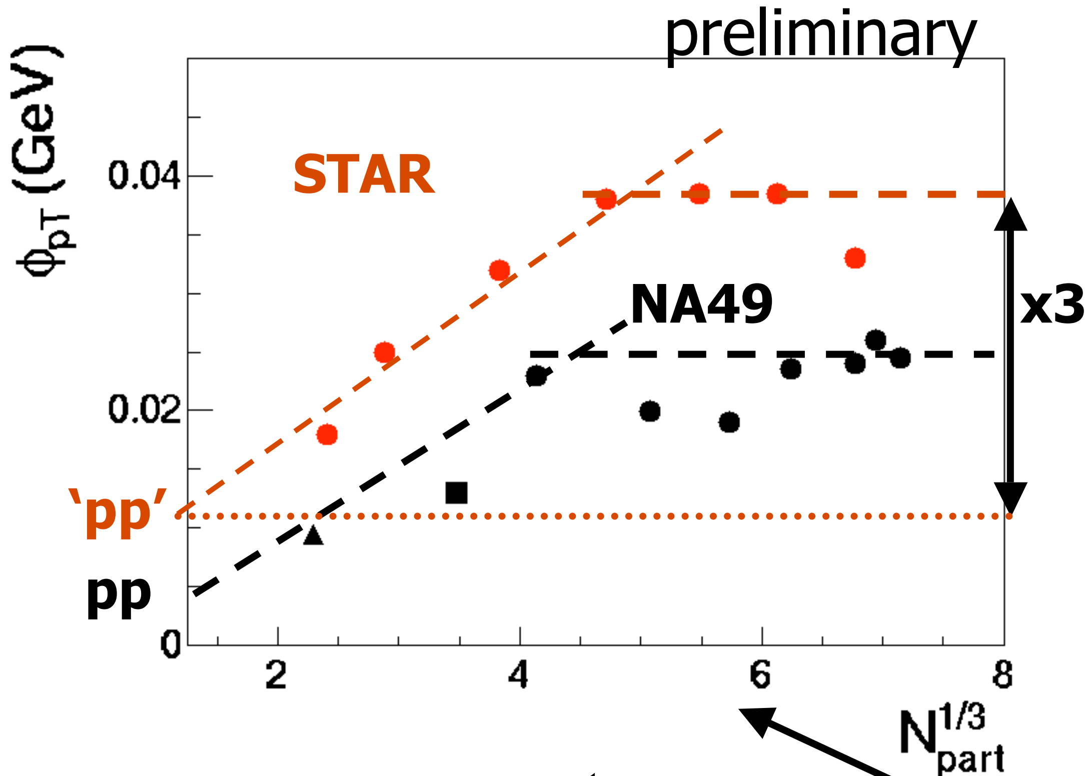
Gazdzicki, Leonidov, GR hep-ph/9711422

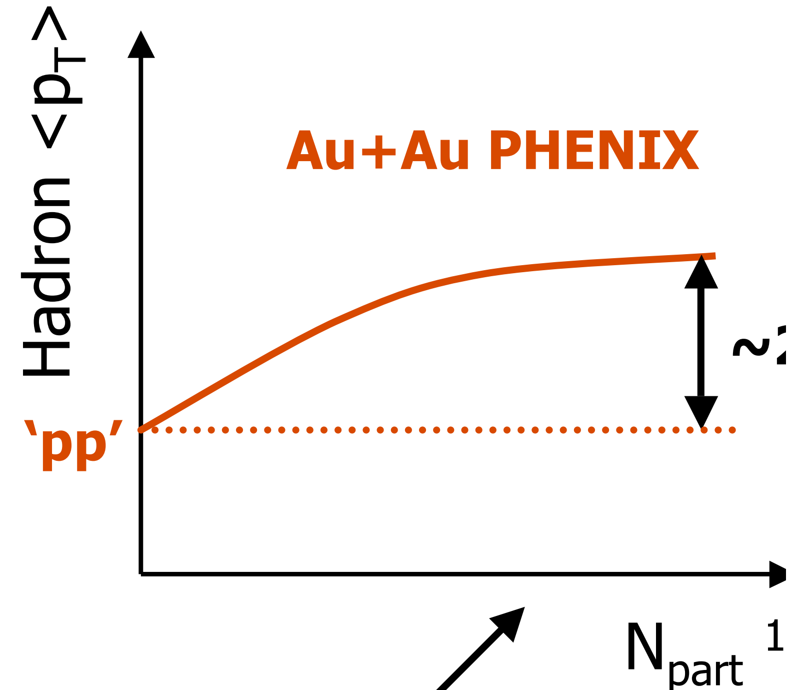


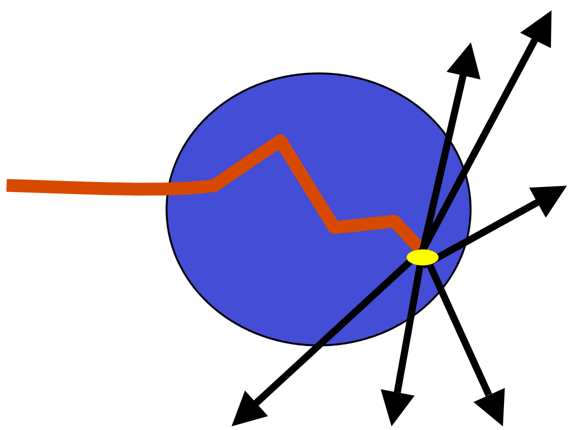
Leonidov, Nardi, Satz (Nucl. Phys. A610 (1996) 24)

Random walk in transverse rapidity

$\langle p_T \rangle_{EbE}$ Fluctuations vs Centrality





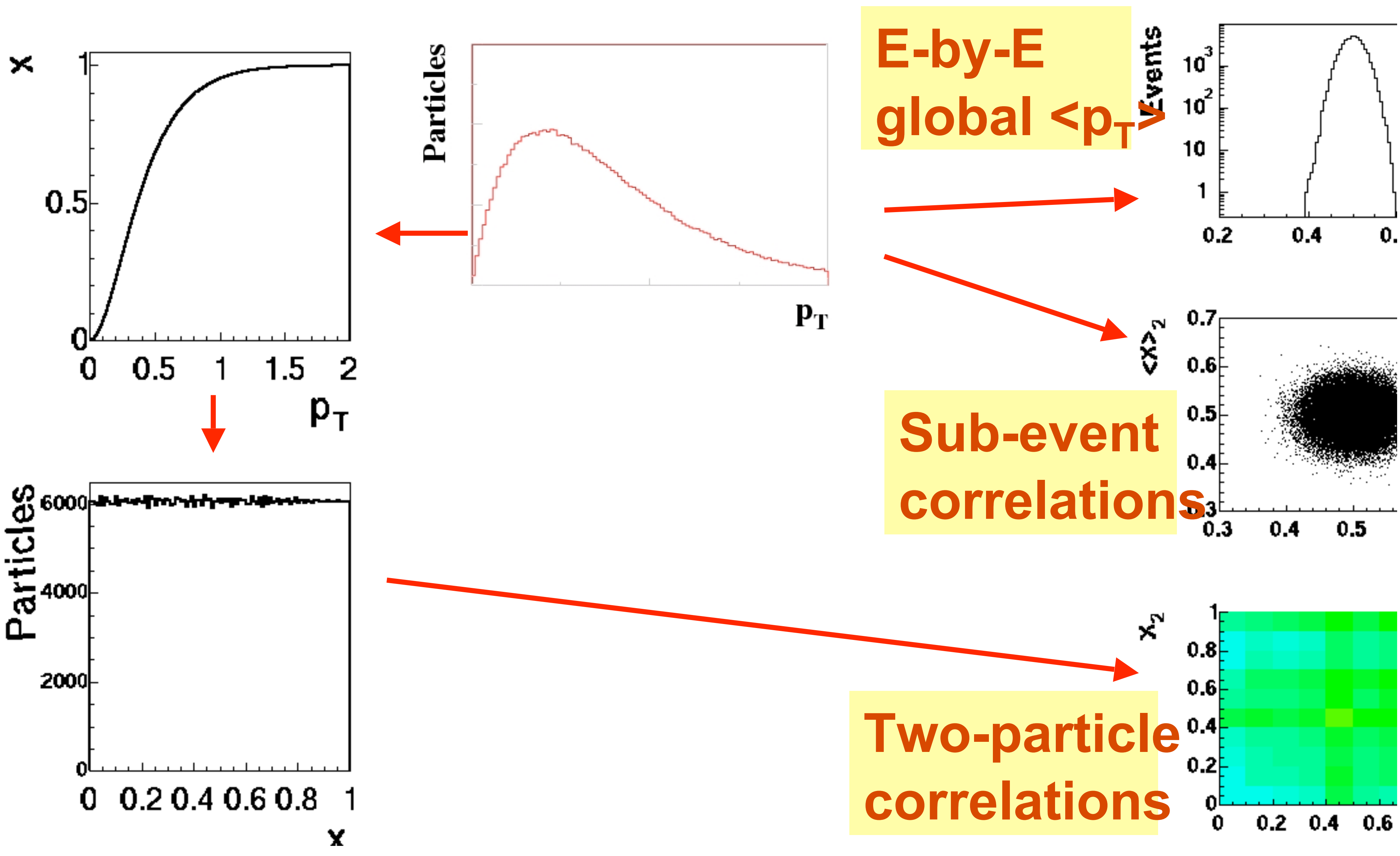


How does one prove that this is
not related?

Learning more

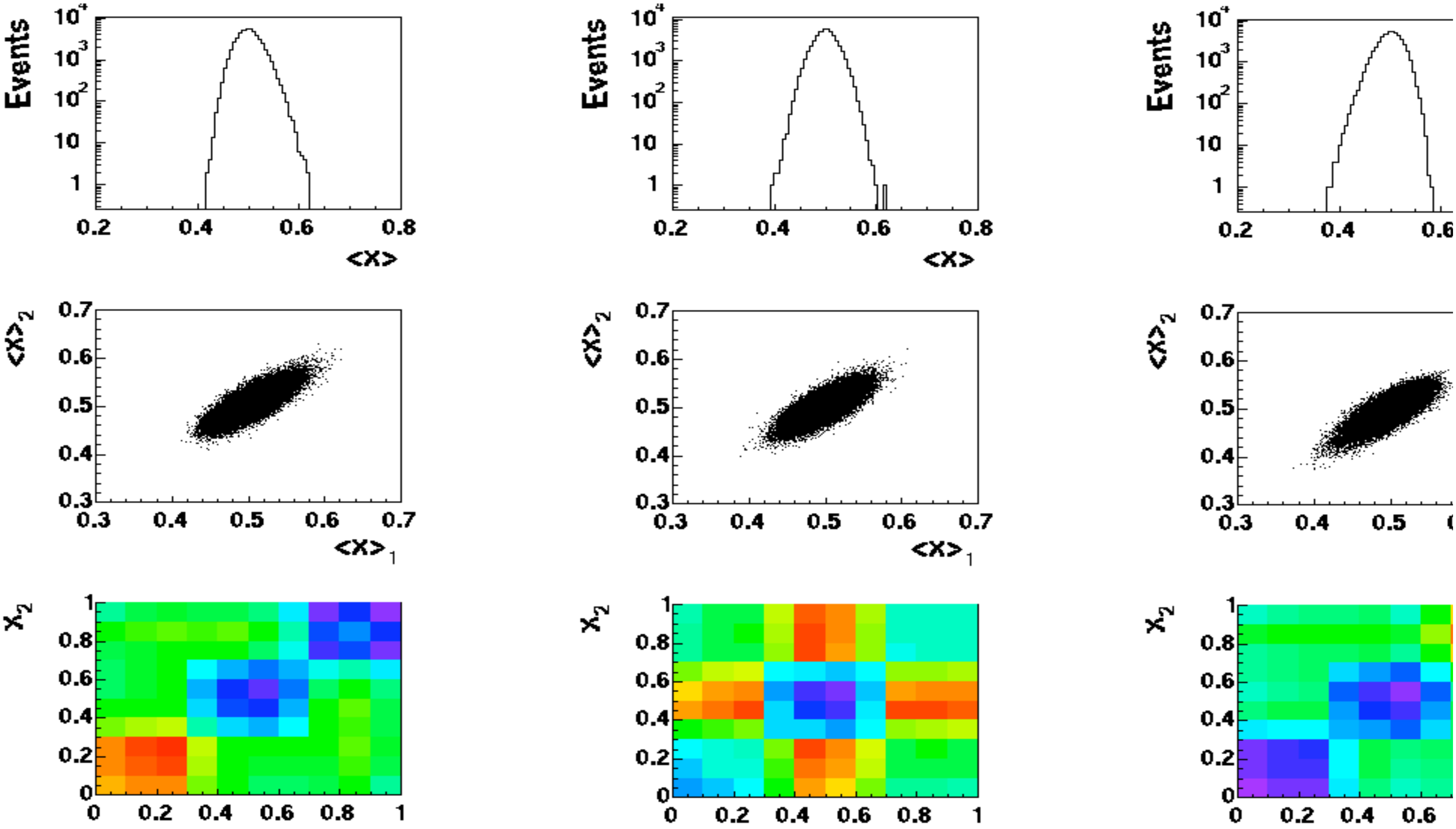
- Look at p+p and p+A data
  - Connection between ‘radial flow’ and fluctuations
  - p+A centrality dependence
- Look at more differential measures
  - Fluctuations at low/high pT
  - 2-particle correlators

Differential measures of p_T Fluctuatio



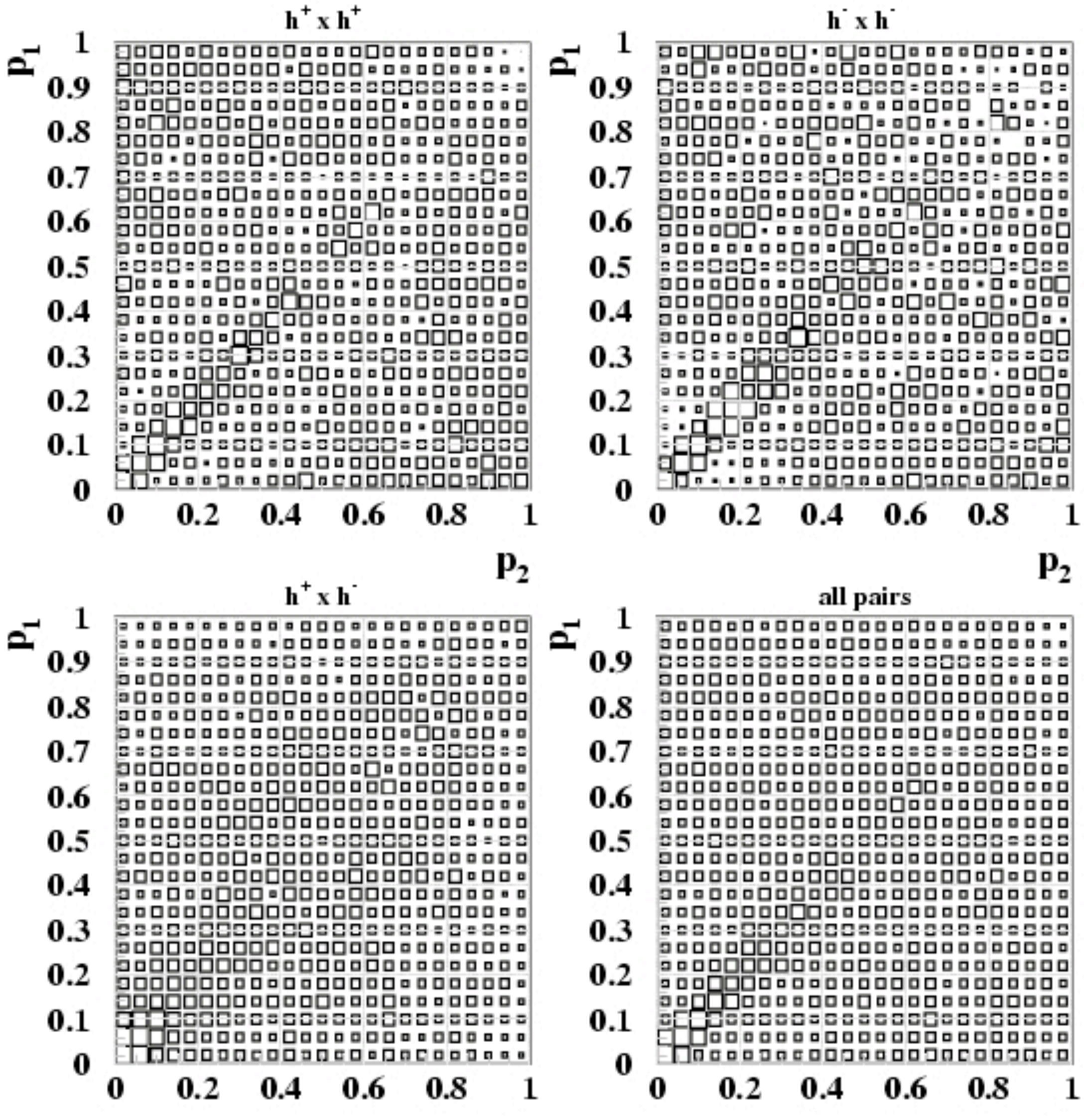
Beyond $<p_T>$

"Critical endpoint" | "T-Fluctuations" | "Jets'



Looking in more detail

J. Reid, QM'99



- Substructure fror different charge combinations
- Physics
  - HBT
  - Coulomb
  - Protons
- Detector effects

Summary

- Charge and K/p fluctuations look like resonance gas
  - No indication for strong first order transition
  - What happens to QGP charge fluctuations?
- $<p_T>$ fluctuations small (~1%)
  - Non-zero near mid-rapidity
  - Not suggestive of critical point
  - Possible Energy and centrality dependence
  - Are we seeing initial state scattering?
  - Alternative look at issues of ‘radial flow’ and ‘jet quenching’

CLT Variance Comparison Measures

$\Delta\sigma^2_{p_t}$ $\quad (\Delta\sigma^2_{p_t} \equiv 2\sigma_{\hat{p}_t}\Delta\sigma_{p_t})$

difference factor ~ Φ_{pt}

$\sigma^2_{p_t,dynamical}$

'dynamical' == observed - 'statistical'

δx –> a (single-particle 'bin'): $\quad \overline{m} \to \hat{m}$

N(Δx) - total multiplicity in acceptance

bin contents: $m(\delta x)$, $n(\delta x) = N(\Delta x) / M(\Delta x.\delta x)$; $<m(\delta x)> = m(\delta x) / n(\delta x)$

$$\Delta\sigma^2_m(\delta x) \equiv \overline{(m - n\hat{m})^2 / n} - \sigma^2_{\hat{m}}$$
$$\equiv \overline{n(<m> - \hat{m})^2} - \sigma^2_{\hat{m}}$$
$$\equiv \overline{(N-1)\{ <m_i \cdot m_j>_{i \neq j} - \hat{m}^2 \}}$$
$$\equiv \overline{\{ \Sigma^2_m(\delta x) - \Sigma^2_m(a) \} / N(\Delta x)}$$

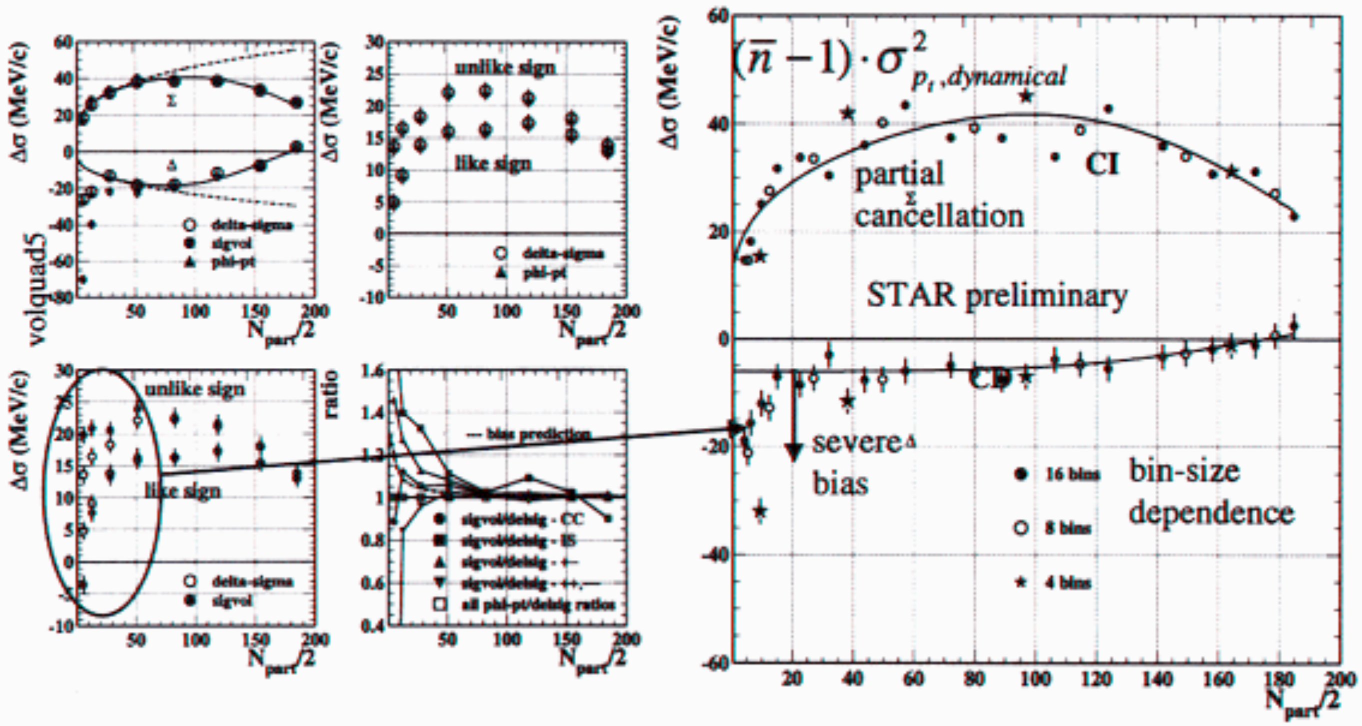
scale variation of total variance

⟷

$$\sigma^2_{m,dynamical} \equiv \overline{(<m> - \hat{m})^2} - \sigma^2_{\hat{m}} / \overline{N} \quad \text{earlier}$$
$$\equiv \overline{\{ N(<m> - \hat{m})^2 - \sigma^2_{\hat{m}} \} / (N-1)}$$
$$\equiv \overline{<m_i \cdot m_j>}_{i \neq j} - \hat{m}^2 \quad \text{later}$$

These two variance comparisons *seem* algebraically similar, yet are the subjects of strongly conflicting statements as to performance

Measure Bias Observed with Data



precision ABC test - J.G. Reid

Charge fluctuations - D~

$$\tilde{D} = (\langle \delta R \rangle^2 \cdot \langle N_{ch} \rangle_{acc}) / (C_y \cdot C_\mu)$$

$\tilde{D} = 4$: pion gas with global charge conservation

$\tilde{D} \approx 1$ (or 2 Heinz) : frozen QGP fluctuations with global charge conservatior

$\tilde{D} \approx 2.8$: gas with resonances and with global charge conservatic

(if both particles fall in the acceptance, e.g. Δy window)

V. Koch, S. Jeon, hep–ph / 0003168
M. Bleicher, V. Koch, S. Jeon, hep–ph / 0006201

Exploring the QCD Phase Diagram