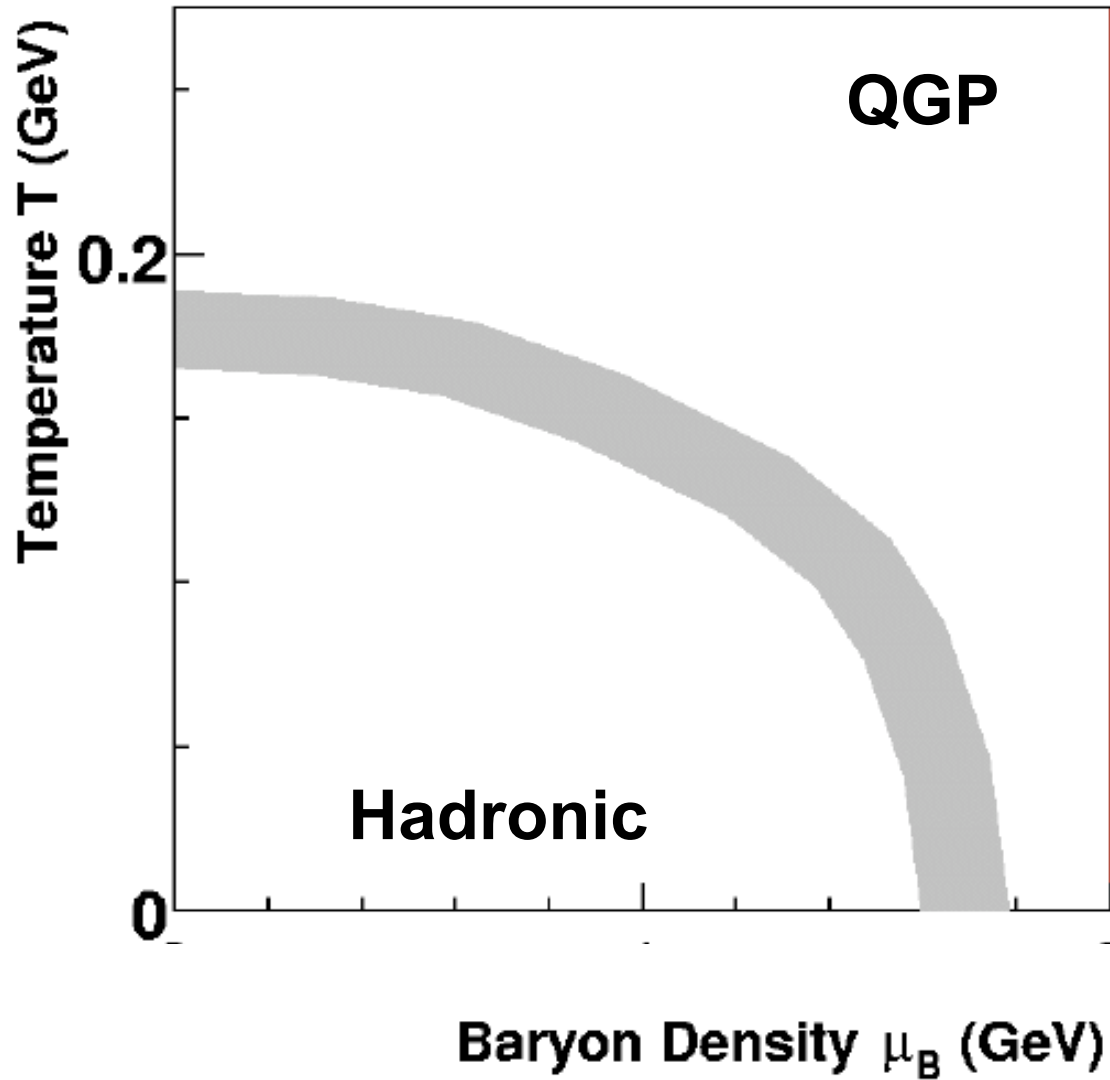


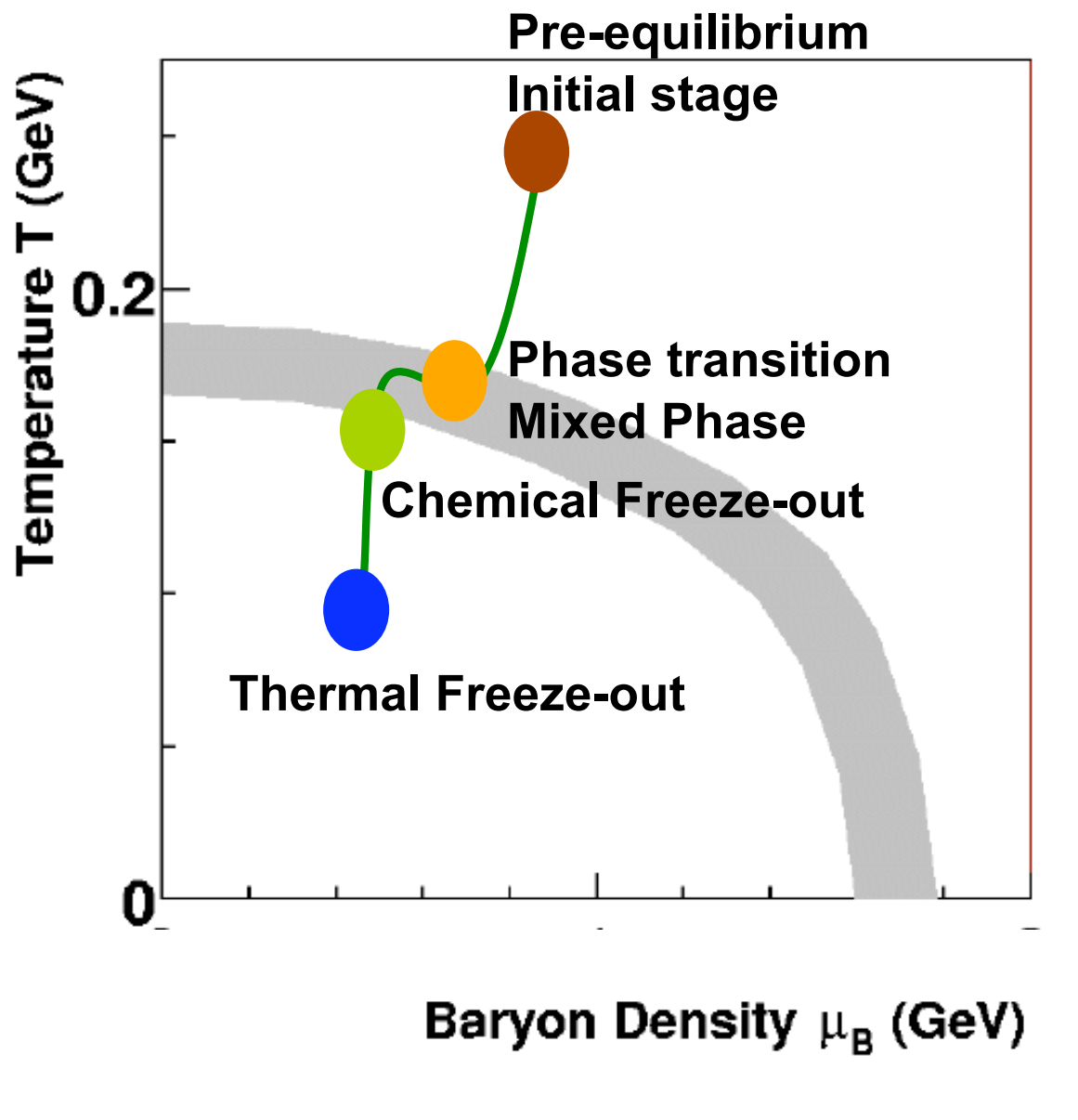
What have we learned from event-by-event fluctuations at RHIC?

Gunther Roland/MIT

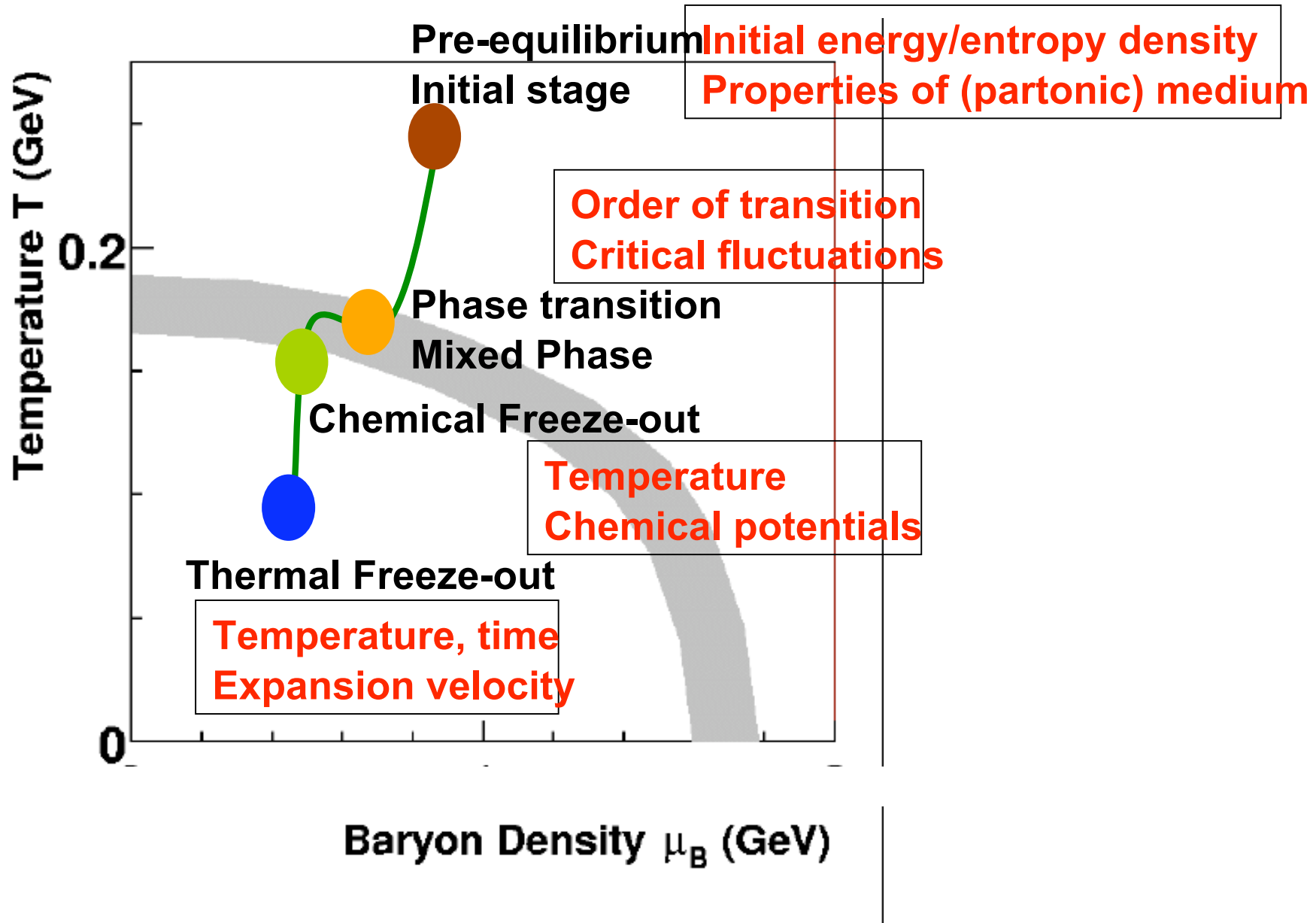
Exploring the QCD Phase Diagram



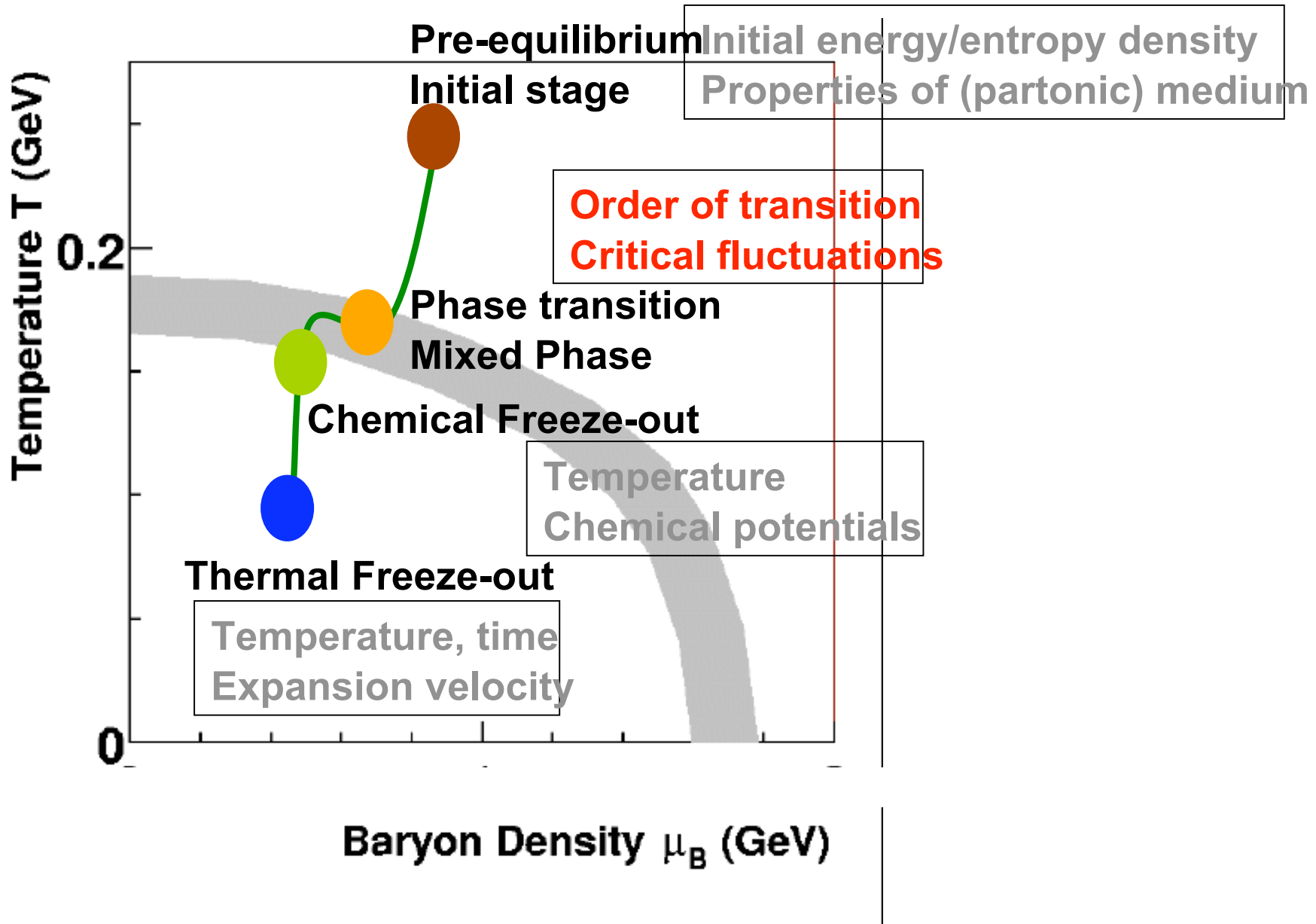
Exploring the QCD Phase Diagram



Exploring the QCD Phase Diagram



Exploring the QCD Phase Diagram



What can we learn from fluctuations?

- **Chiral Symmetry Restoration**

- Disoriented Chiral Condensates
- Charge/neutral event-by-event fluctuations

- **Deconfinement**

- Charge/DoF different in QGP vs Hadron gas
- N+/N-event-by-event fluctuations

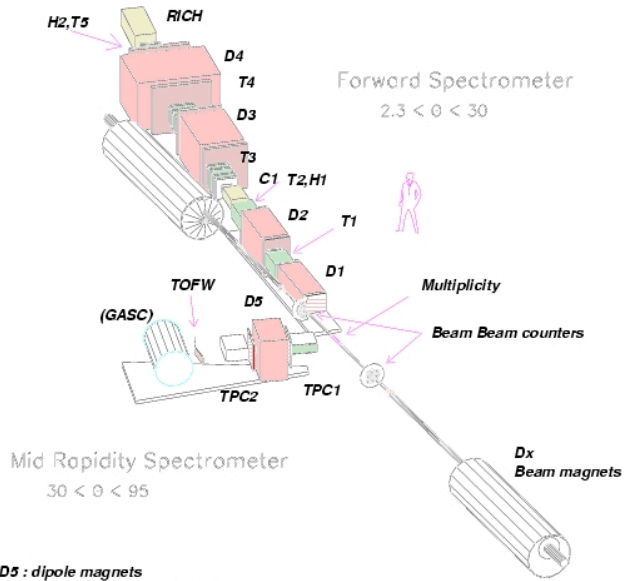
- **Critical fluctuations at phase transition**

- Critical endpoint in QCD phase diagram
 - 1.5-2% DT/T
- $\langle p_T \rangle$ event-by-event fluctuations

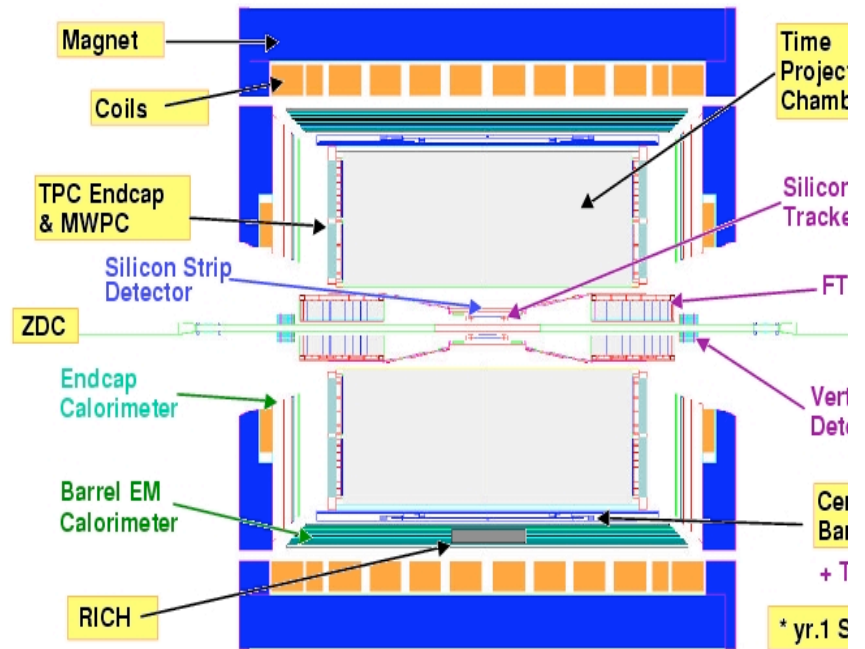
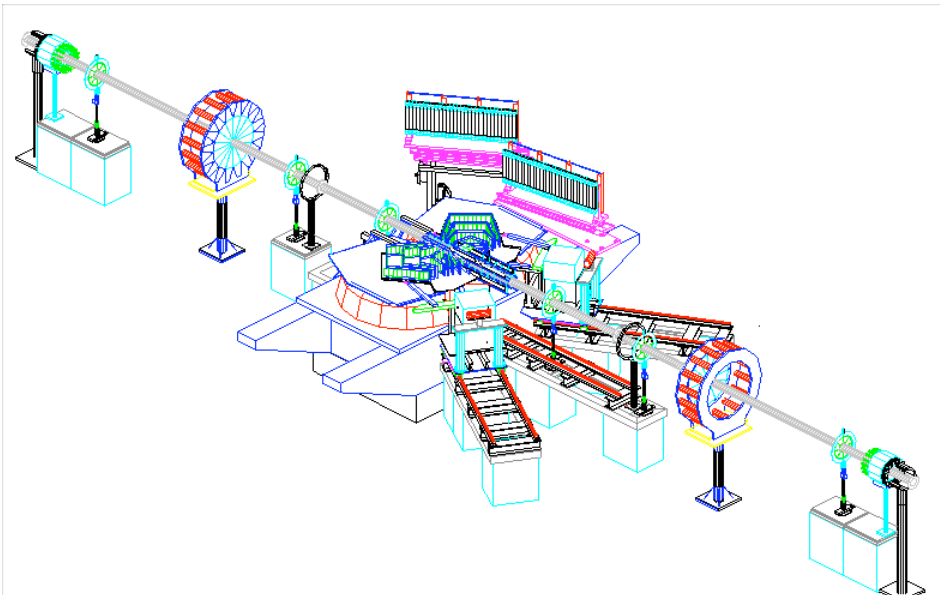
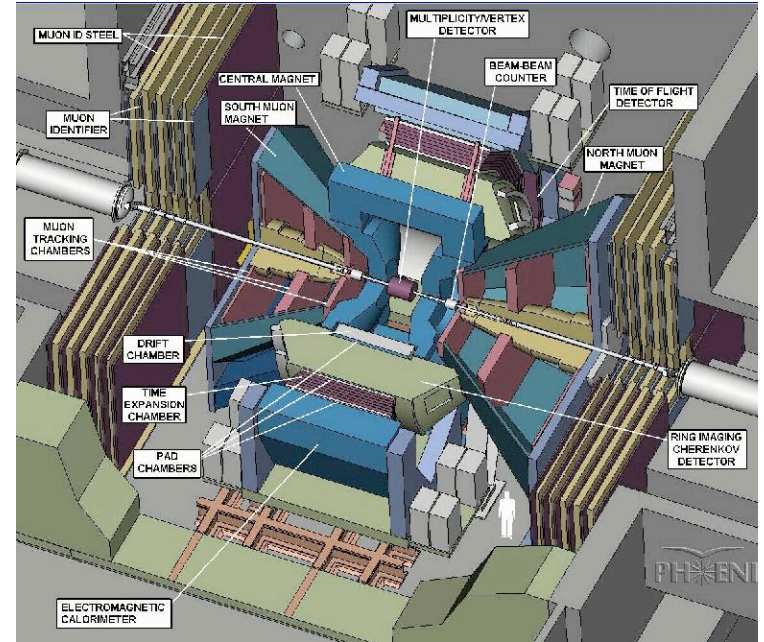
Experiments

J. Mitchell

BRAHMS



D1,D2,D3,D4,D5 : dipole magnets
 T1,T2,T3,T4,T5, TPC1 TPC2: tracking detectors
 H1,H2,TOFW : Time-of-flight detectors
 RICH, GASC : Cherenkov detectors



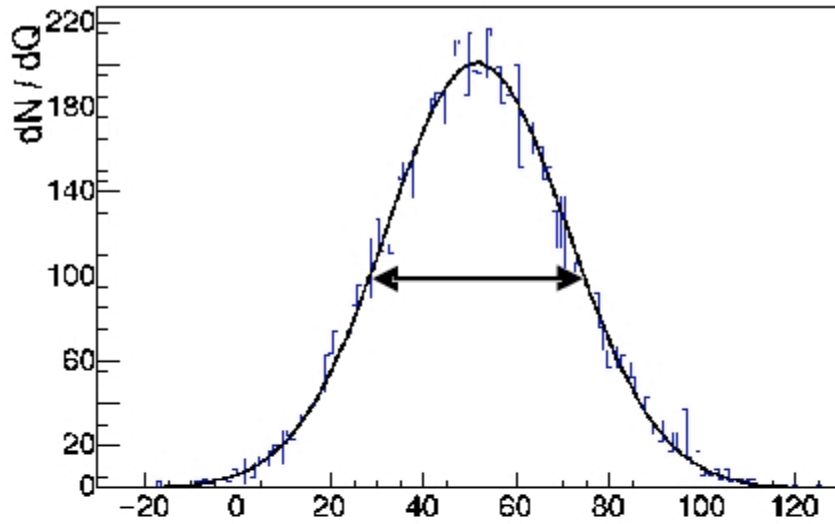
Observables at RHIC

- **Global/local multiplicity fluctuations**
 - Brahms/Phenix/Phobos/Star
- **Charge/neutral fluctuations**
 - Phenix/Star
- **$\langle E_T \rangle$, $\langle p_T \rangle$ fluctuations**
 - Phenix/Star
- **$\langle p_T \rangle$ subevent**
- **Charge ratio/difference fluctuations**
 - Phenix/Star
- **K/pi, pi/p fluctuation**
 - Star

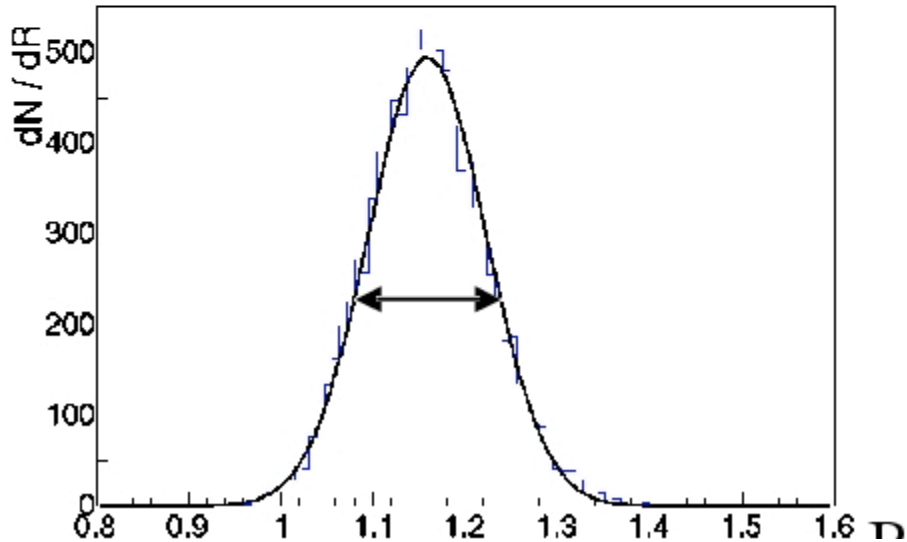
Observables at RHIC

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 - Star

Charge fluctuations



$$Q = N_+ - N_-$$



Define variables to measure variance of charge ratio and charge difference distribution

Charge fluctuations - D^{\sim}

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

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

$D^{\sim} \approx 1$ (or 2 Heinz) : frozen QGP fluctuations with global charge conservation

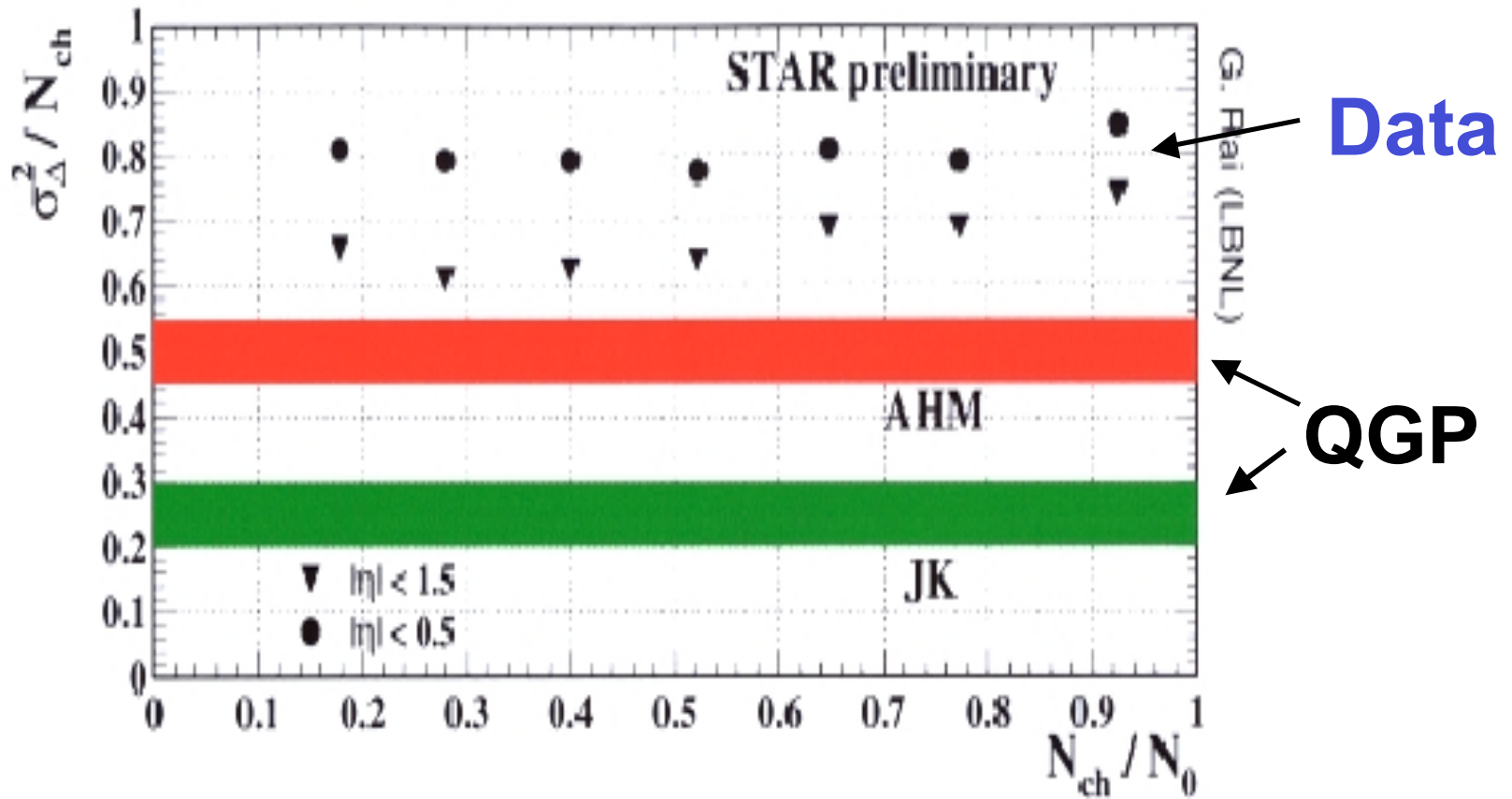
$D^{\sim} \approx 2.8$: gas with resonances and with global charge conservation
(if both particles fall in the acceptance, e.g. Δy window)

V. Koch, S. Jeon, hep-ph / 0003168

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

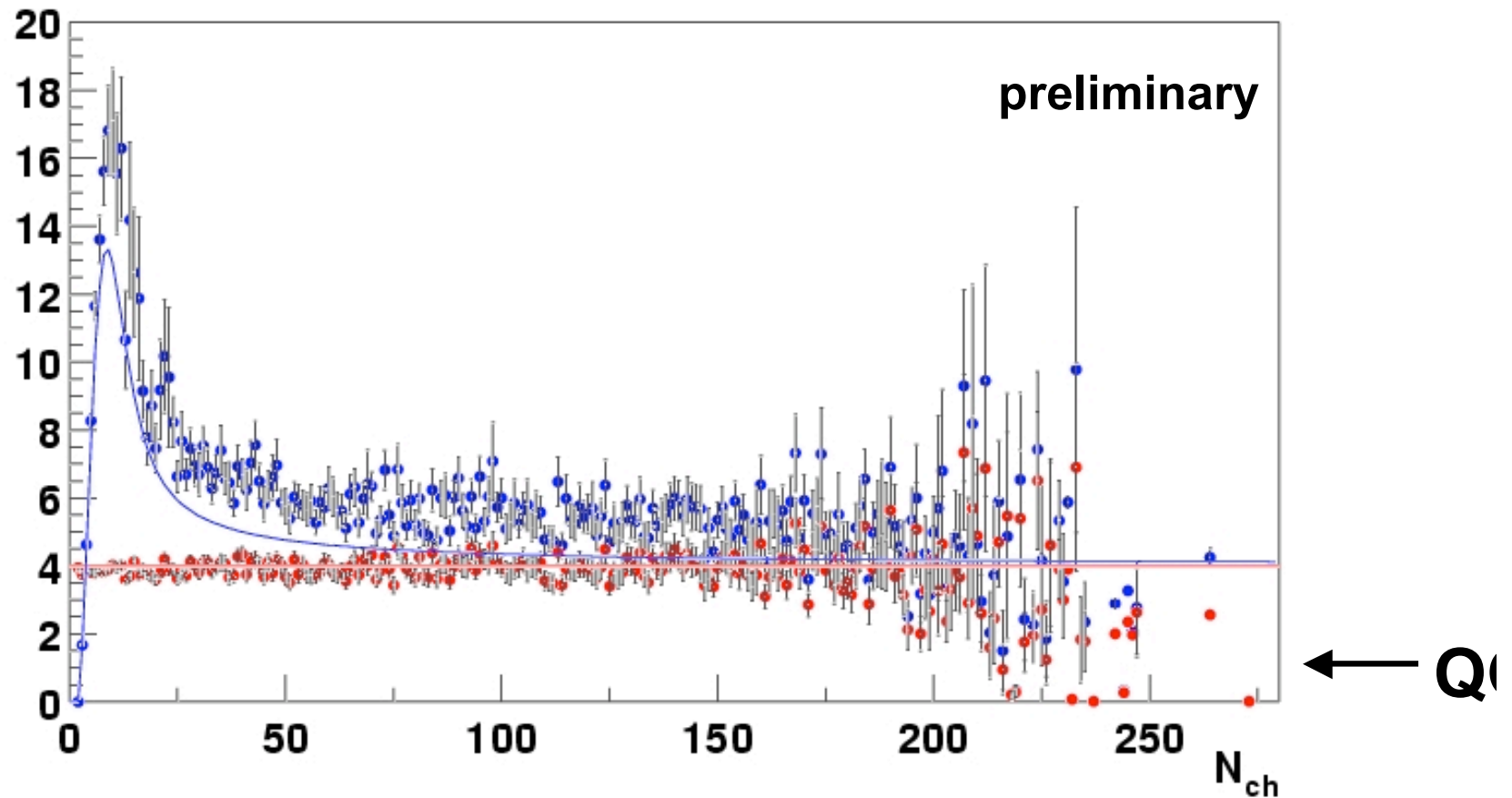
Charge fluctuations at RHIC - STAR

D*.25



No sign of QGP suppression of charge fluc

Charge fluctuations at RHIC - PHENIX

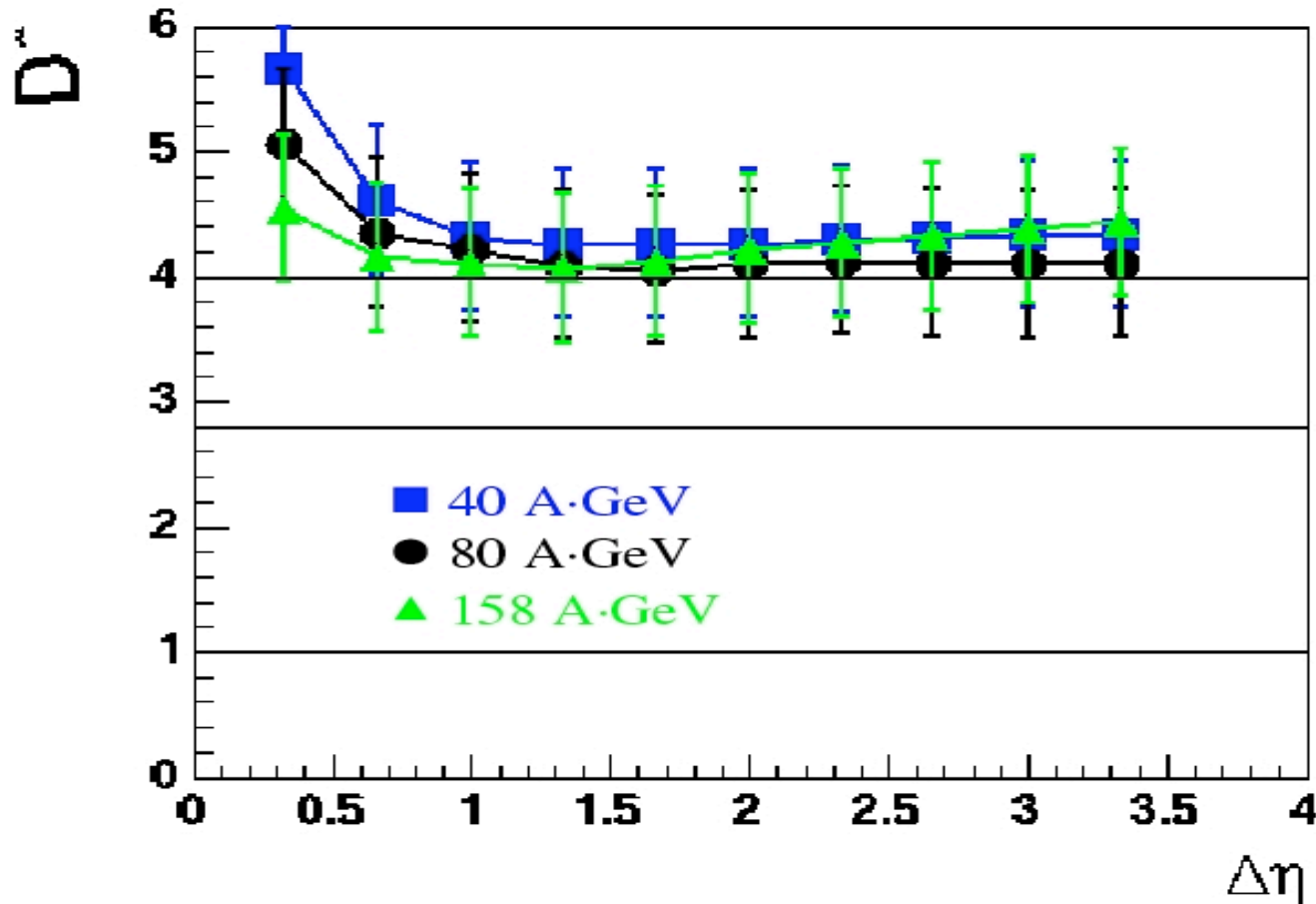


$$(\langle R^2 \rangle - \langle R \rangle^2) * N_{ch} \quad (R = N_+ / N_{ch})$$

$$4 (\langle Q^2 \rangle - \langle Q \rangle^2) / N_{ch} \quad (Q = N_+ - N_{ch})$$

No sign of QGP suppression of charge fluct

Charge fluctuations at SPS



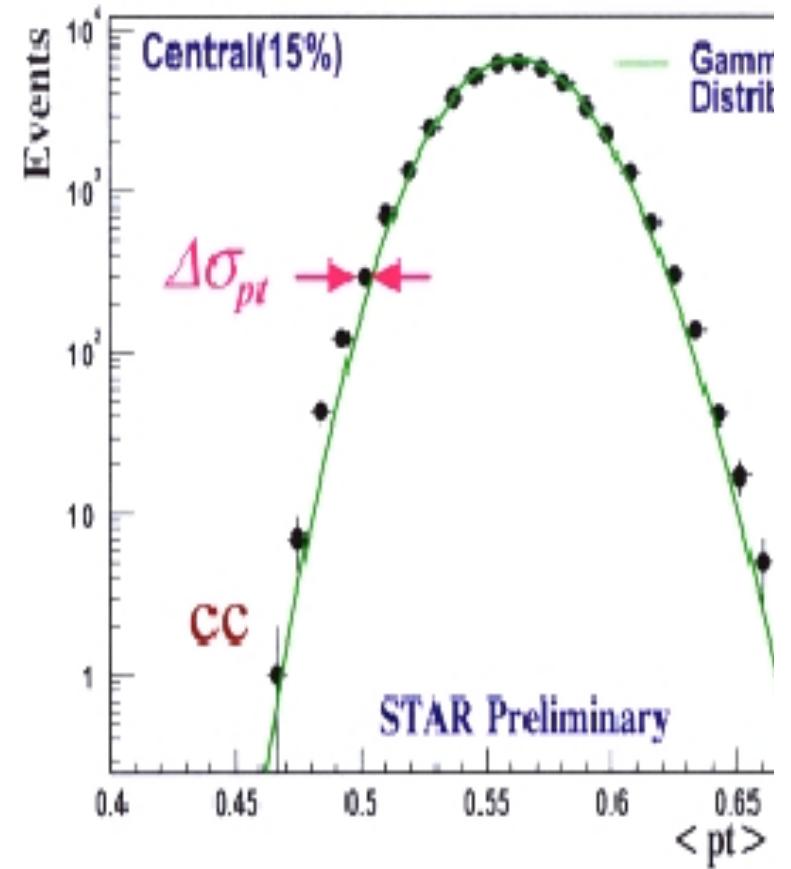
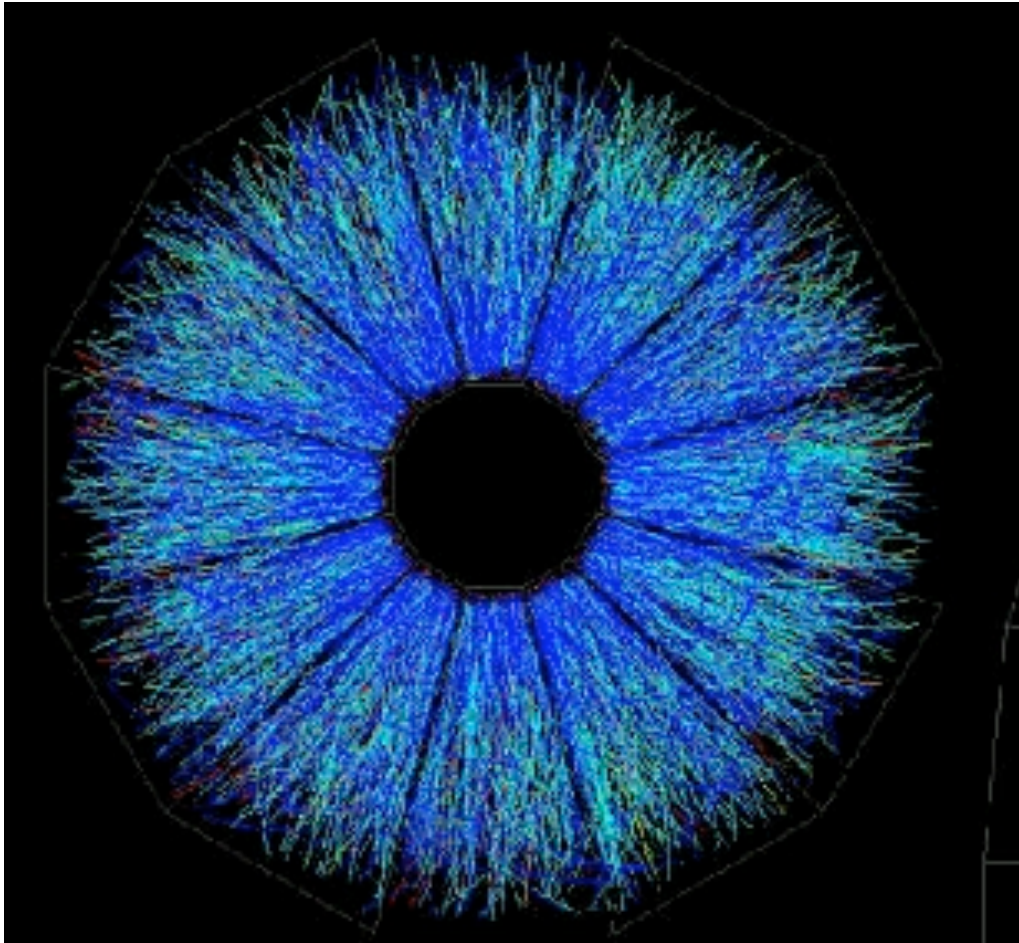
NA49

Consistent with RHIC results!

Where's the QGP?

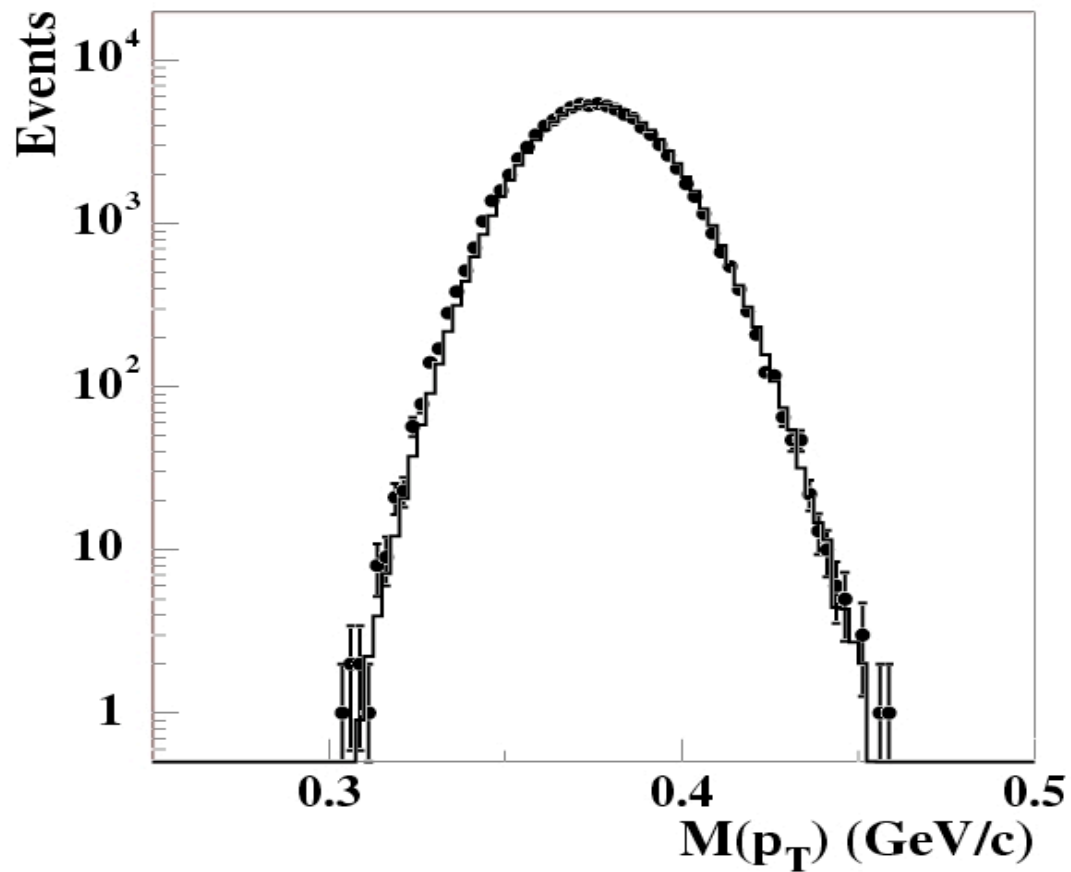
- **Results at RHIC (STAR, PHENIX) and SPS (NA49) >> QGP limit**
- **Diffusion wins? (Shuryak/Stephanov, hep-ph/00010100)**

Measuring $\langle p_T \rangle$ fluctuations



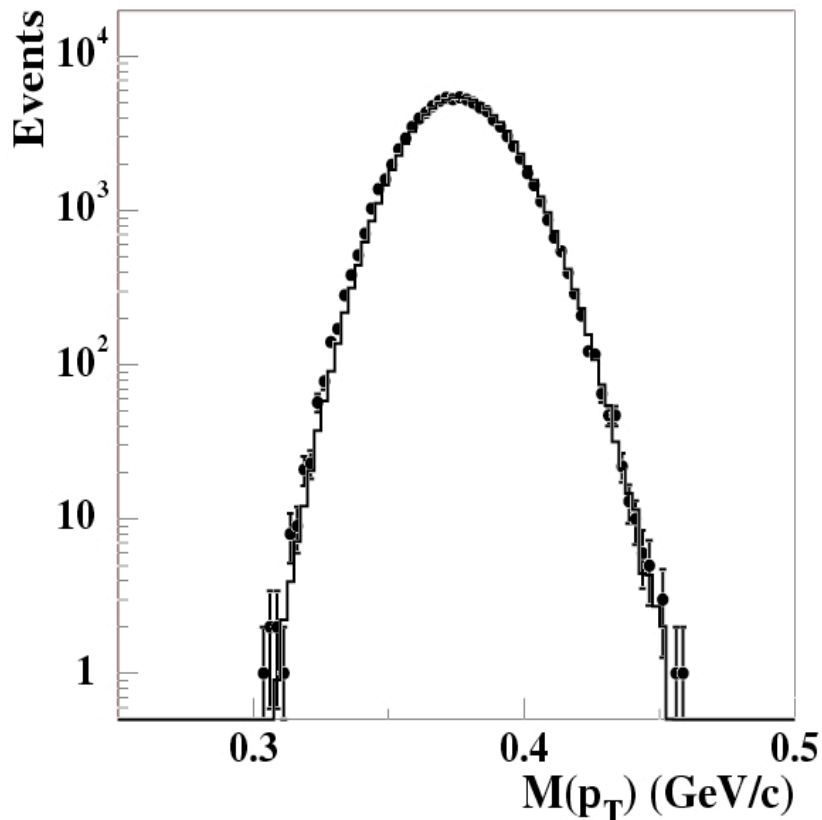
STAR single event

It's not a Gaussian...



...it's a Gamma-fur
(M. Tannenbaum, Phys.Lett.B 498(

Results on $\langle p_T \rangle$ -SPS, part I



$$\overline{N}\sigma_{\langle p_T \rangle}^2 - \sigma_{p_T}^2 \approx 2\sigma_{p_T} (\sqrt{\overline{N}}\sigma_{\langle p_T \rangle} - \sigma_{p_T}) \equiv 2\sigma_{p_T} \Delta\sigma_{p_T}$$

↑
↙
↓

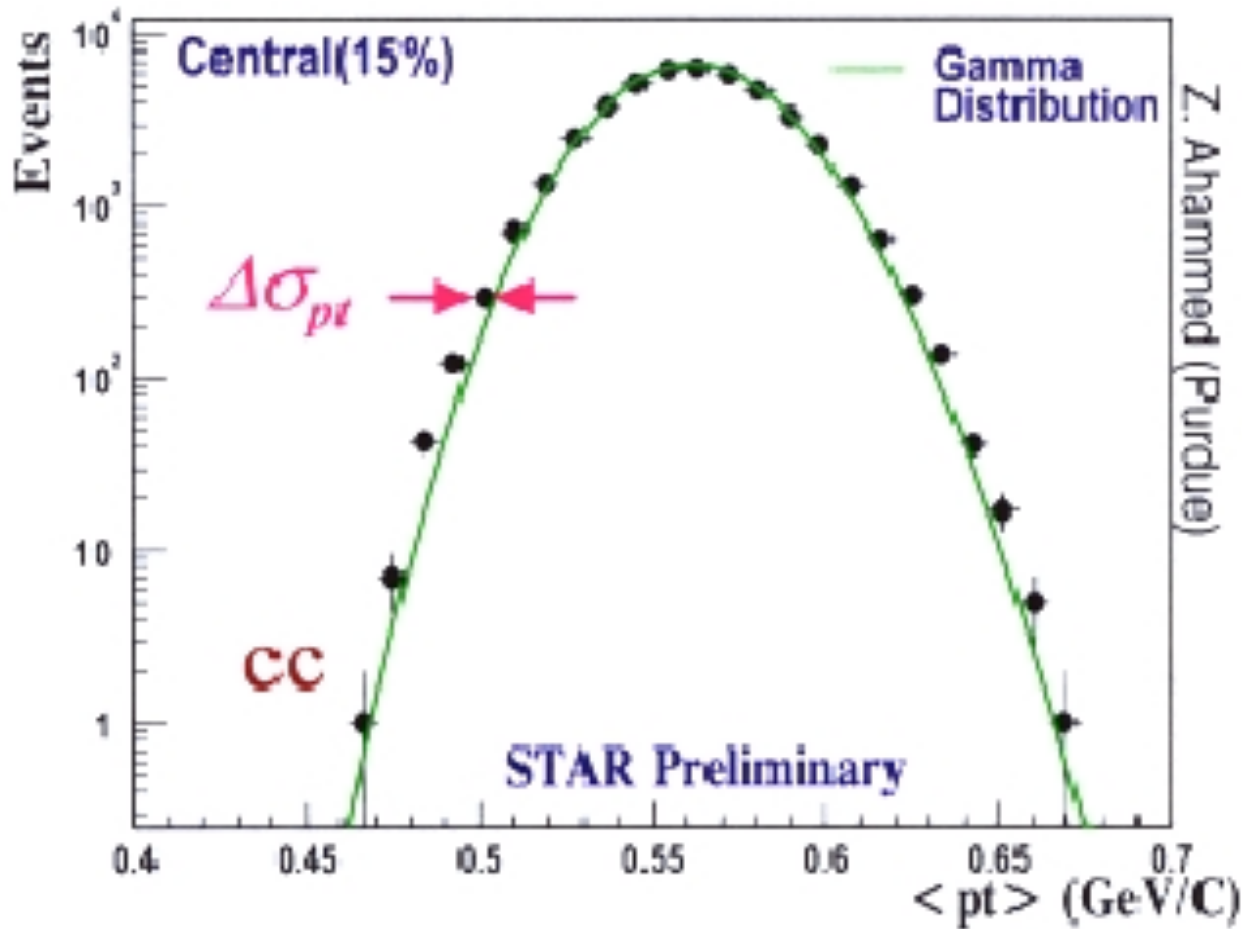
Inclusive Event-by-event f_{p_T}

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
$\overline{p_T}$	$376.75 \pm 0.06 \text{ MeV}/c$
$(\overline{p_T^2} - \overline{p_T}^2)^{\frac{1}{2}}$	$282.2 \pm 0.1 \text{ MeV}/c$

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

hep-ex/9904014 (PLB)

Results on $\langle p_T \rangle$ -STAR



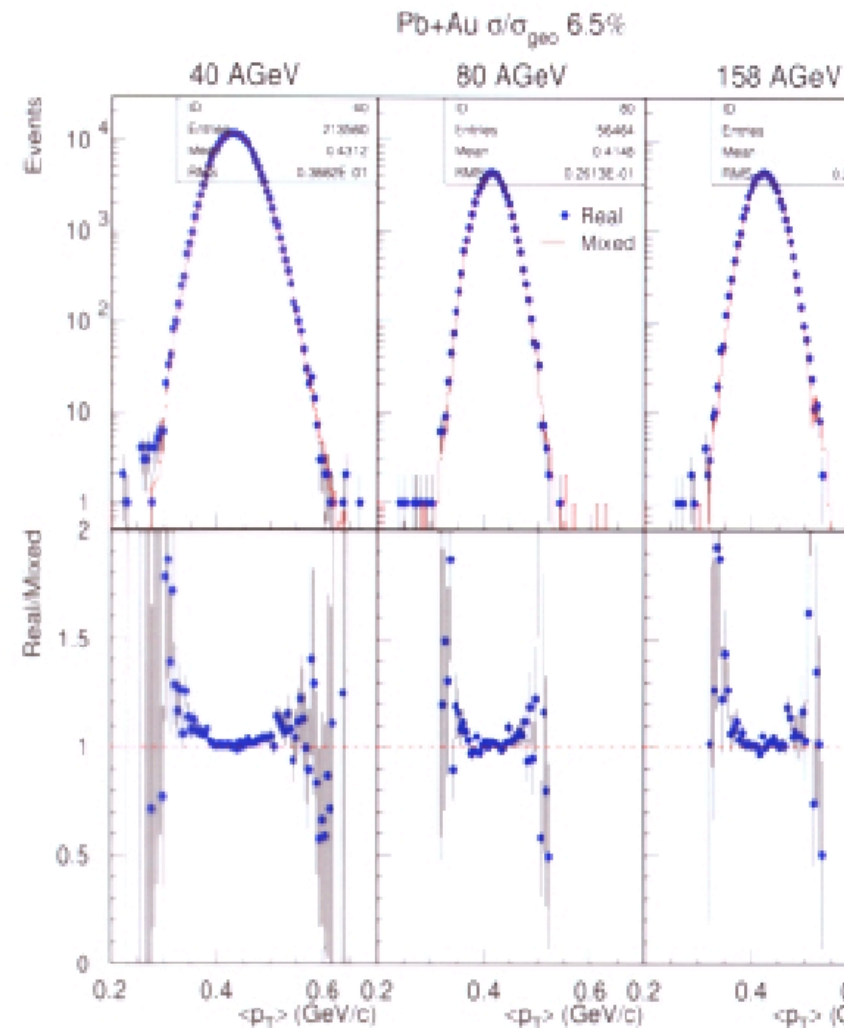
$$\Delta\sigma_{pt} \sim 35 \text{ MeV}$$

Results on $\langle p_T \rangle$ -SPS, part II

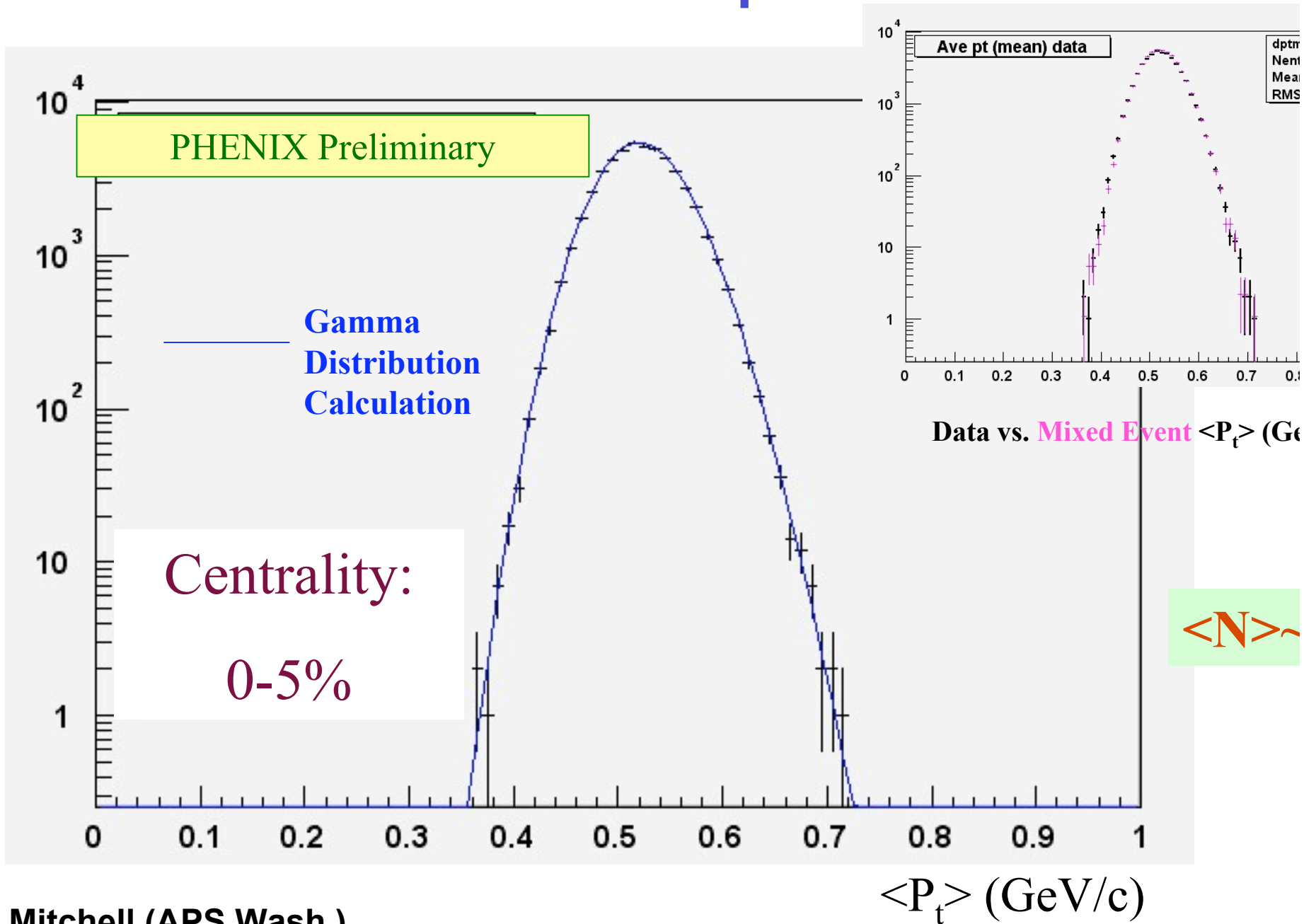
Results from CERES TPC for central Pb+Pb

	N_{events}	$\langle N_{\text{tracks}} \rangle$	$\Phi_{p_T \text{ real}} \text{ (MeV)}$	$\Phi_{p_T \text{ mix}} \text{ (MeV)}$
40 AGeV	216881	77.8	5.5 ± 0.7	0.0 ± 0.2
80 AGeV	56464	128.7	3.7 ± 0.9	-0.5 ± 0.8
158 AGeV	57819	129.4	7.8 ± 0.9	1.0 ± 0.9

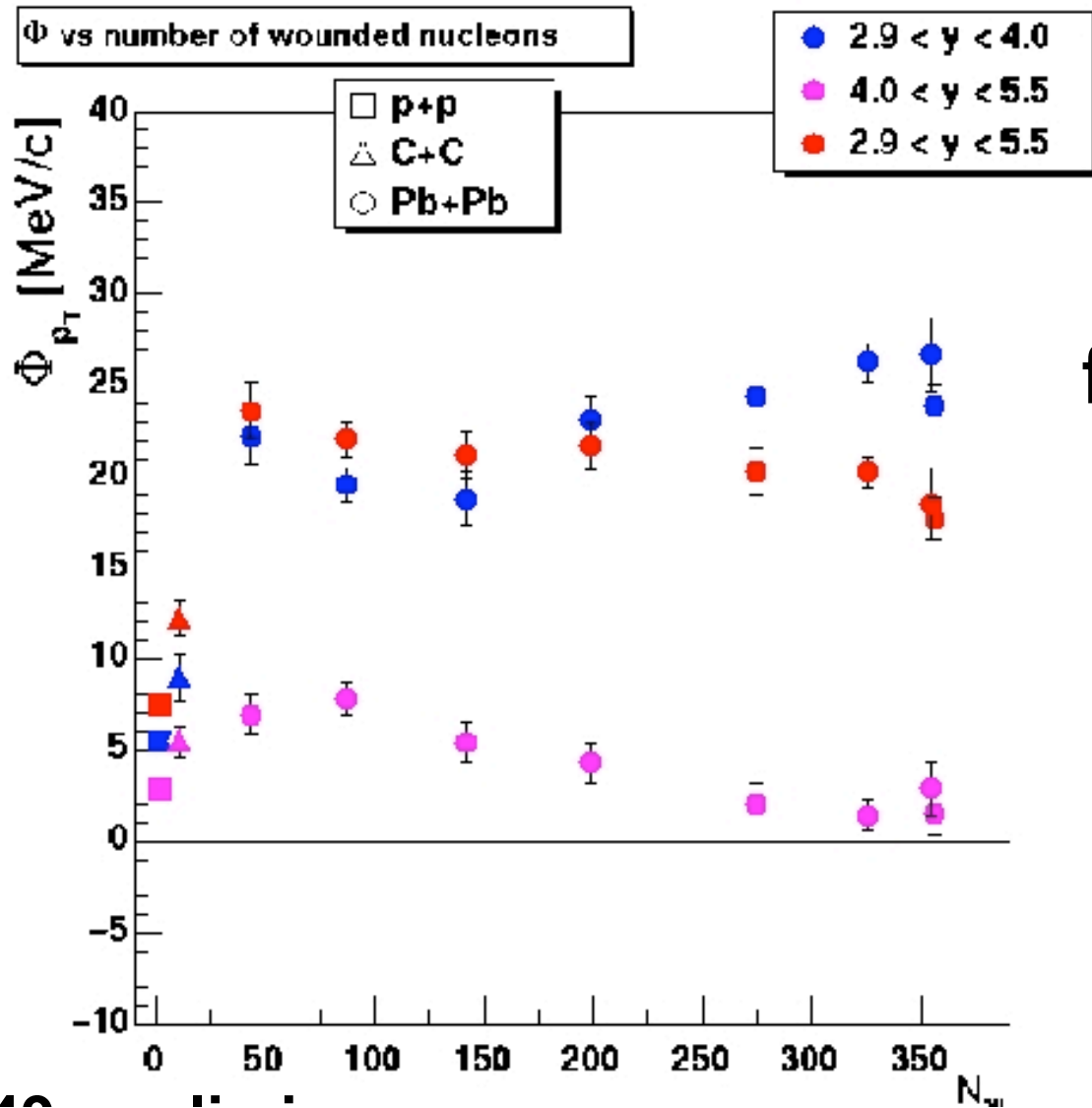
$0.05 < p_T < 1.5 \text{ GeV}$



Results on $\langle p_T \rangle$ -PHENIX



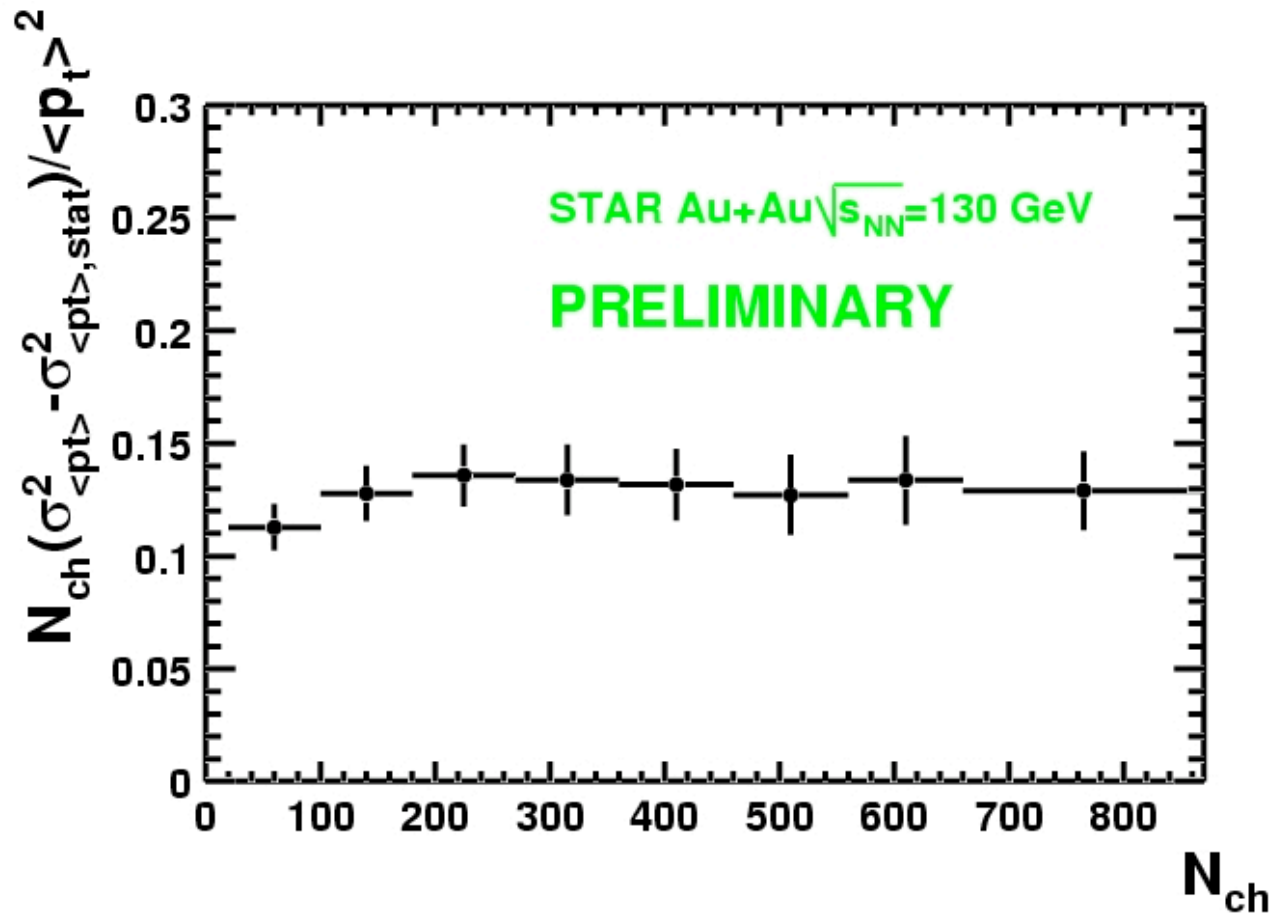
Results on $\langle p_T \rangle$ -SPS, part III



$f_{pT} = 25$ MeV near $y=0$

$f_{pT} = 1$ MeV near $y=1$

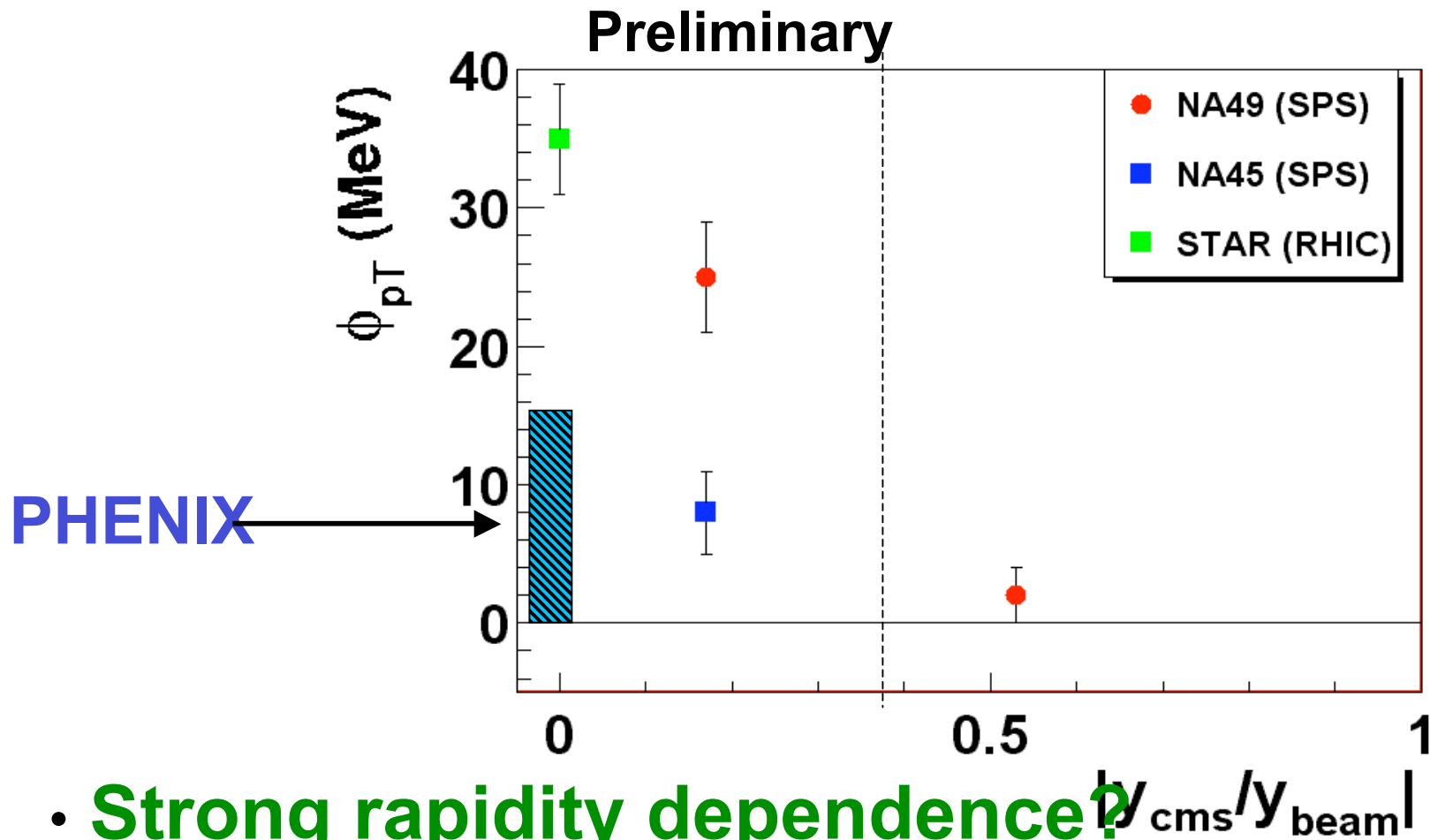
Results on $\langle p_T \rangle$ -STAR, part II



S. Voloshin (INPC 2001)

Centrality dependence small (similar to SPS)

Summary E-by-E $\langle p_T \rangle$



- Strong rapidity dependence?
- Small centrality dependence in Au+Au
- Different azimuthal coverage – (SPS) results

Experimental summary

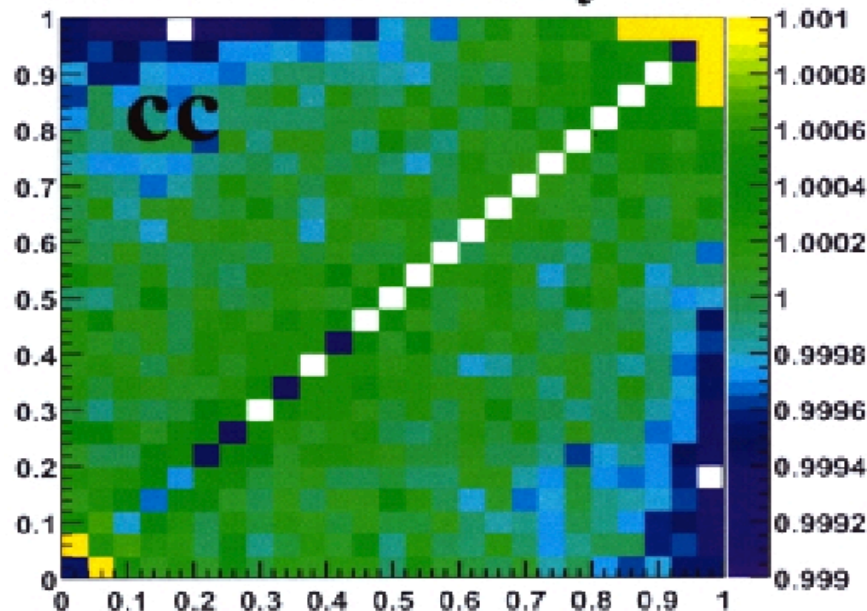
- No sign for QGP-suppression of charge fluctuations
 - consistent at RHIC (STAR/PHENIX) and SPS (NA45, NA49)
- Large $\langle p_T \rangle$ fluctuations near mid-rapidity
 - $DT/T \sim 1-1.5\%$
 - Seen at RHIC (STAR) and SPS (NA45, NA49)
 - Magnitude comparable
 - But not compatible with PHENIX data
- $\langle p_T \rangle$ fluctuations small in forward region at SPS

What have we really learned from fluctuations at RHIC?

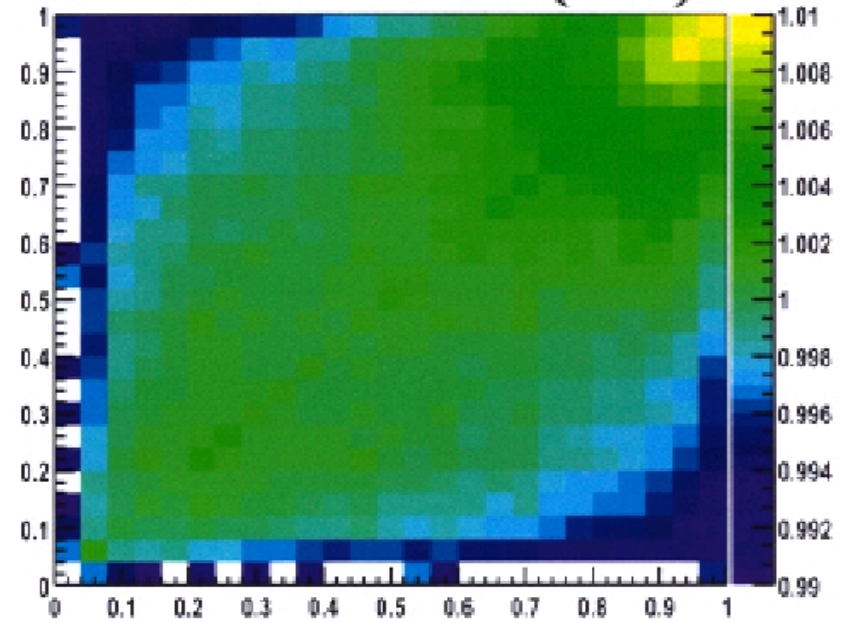
- Assume $DT/T \sim 1\%$ true
- Residual correlations from pp?
 - Thermalization (elliptic flow)
 - Forward data at SPS
 - pp at SPS
- (Mini-) Jets?
 - No change between SPS mid-y and RHIC
- Critical point?
 - m_B (RHIC) ~ 45 MeV vs 270 at SPS
- Difficult measurement!
 - More experimental studies

What does it mean?

STAR Preliminary Data



*mevsim** Monte Carlo:
1/T fluctuations (5%)



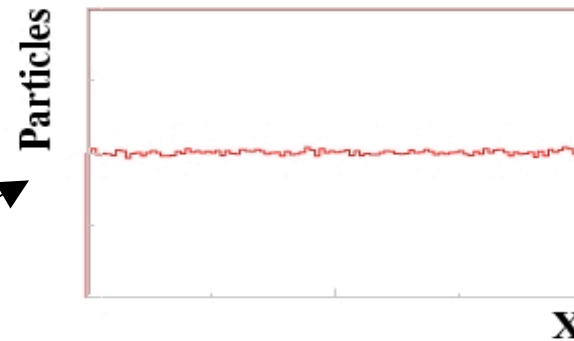
- Data consistent with **dynamical-fluctuations** simulation

*L. Ray (UTA) and R. Longacre (BNL)

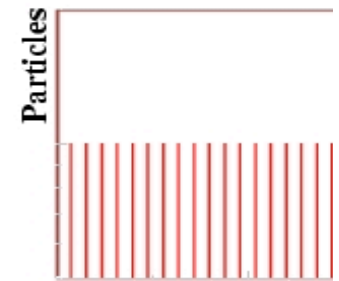
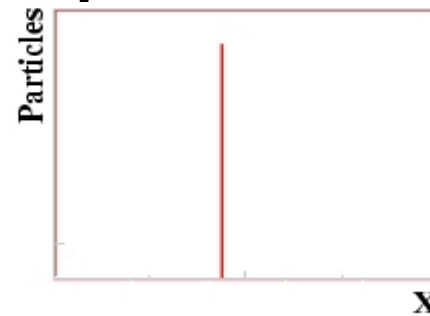
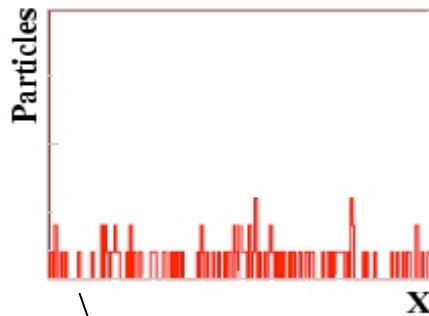
Non-statistical variation in temperature $\sim 1.2\%$

Fluctuations and Correlations

Same parent distribution



Different particle correlations

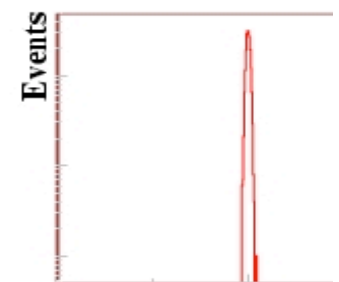
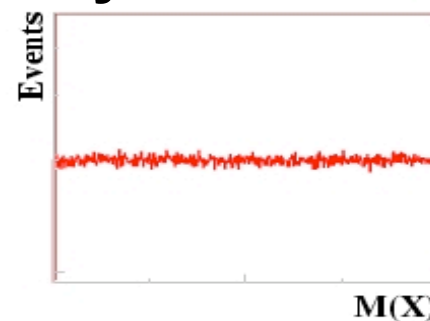
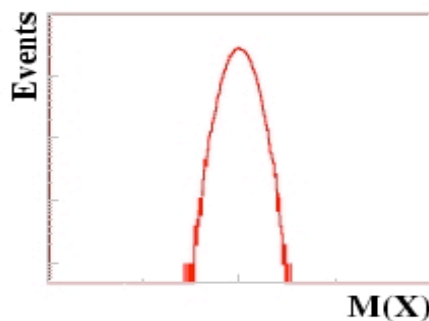


Independent production:

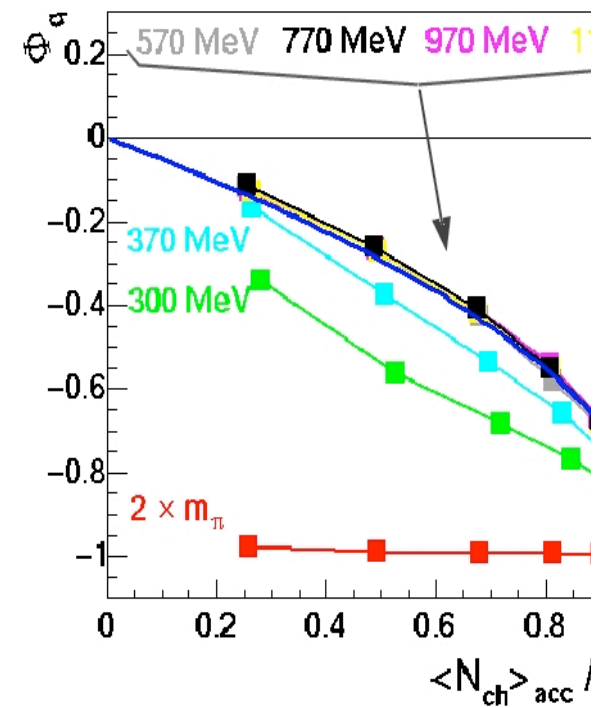
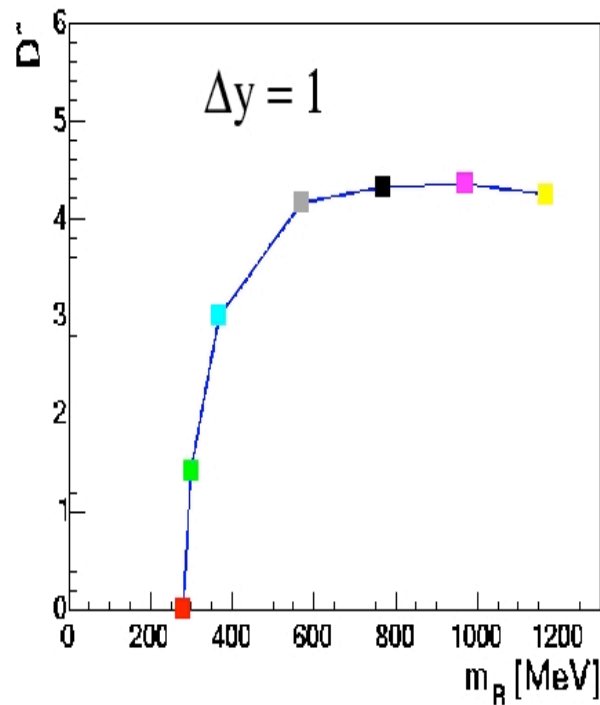
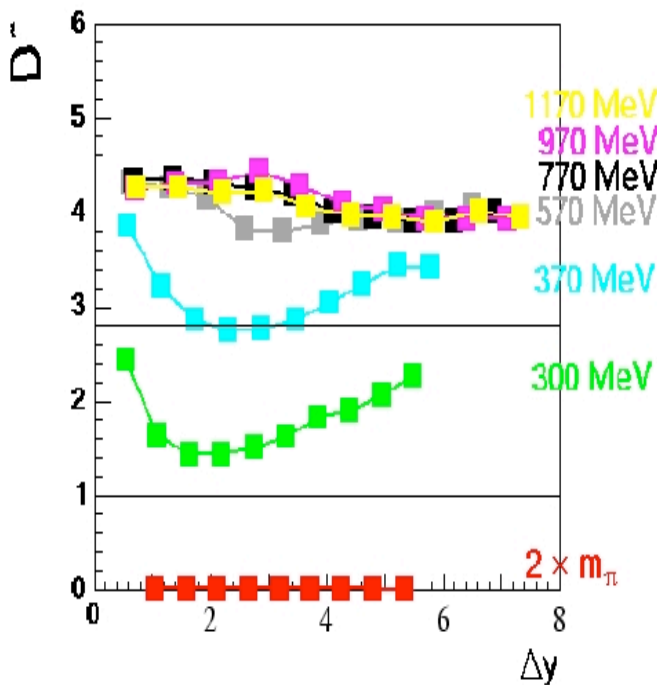
$$\text{RMS}_{\text{e-by-e}} = \text{RMS}_{\text{parent}} / \sqrt{N}$$

Central limit theorem

Different event-by-event mean distributions:



Where are the resonances?



Heavy resonances (>500 MeV) invisible in 'small' acceptance

What have we really learned from fluctuations at RHIC?

- **Search for non-statistical fluctuations**
- **Relative to a reference (CLT)**
 - Usually mixed event distributions
- **Many 'equivalent' techniques**
 - E-by-E mean values
 - Subevent correlations
- **Detector effects hard to simulate**
 - Can't use 'embedding'
 - Measurements very sensitive
 - Physics dependent