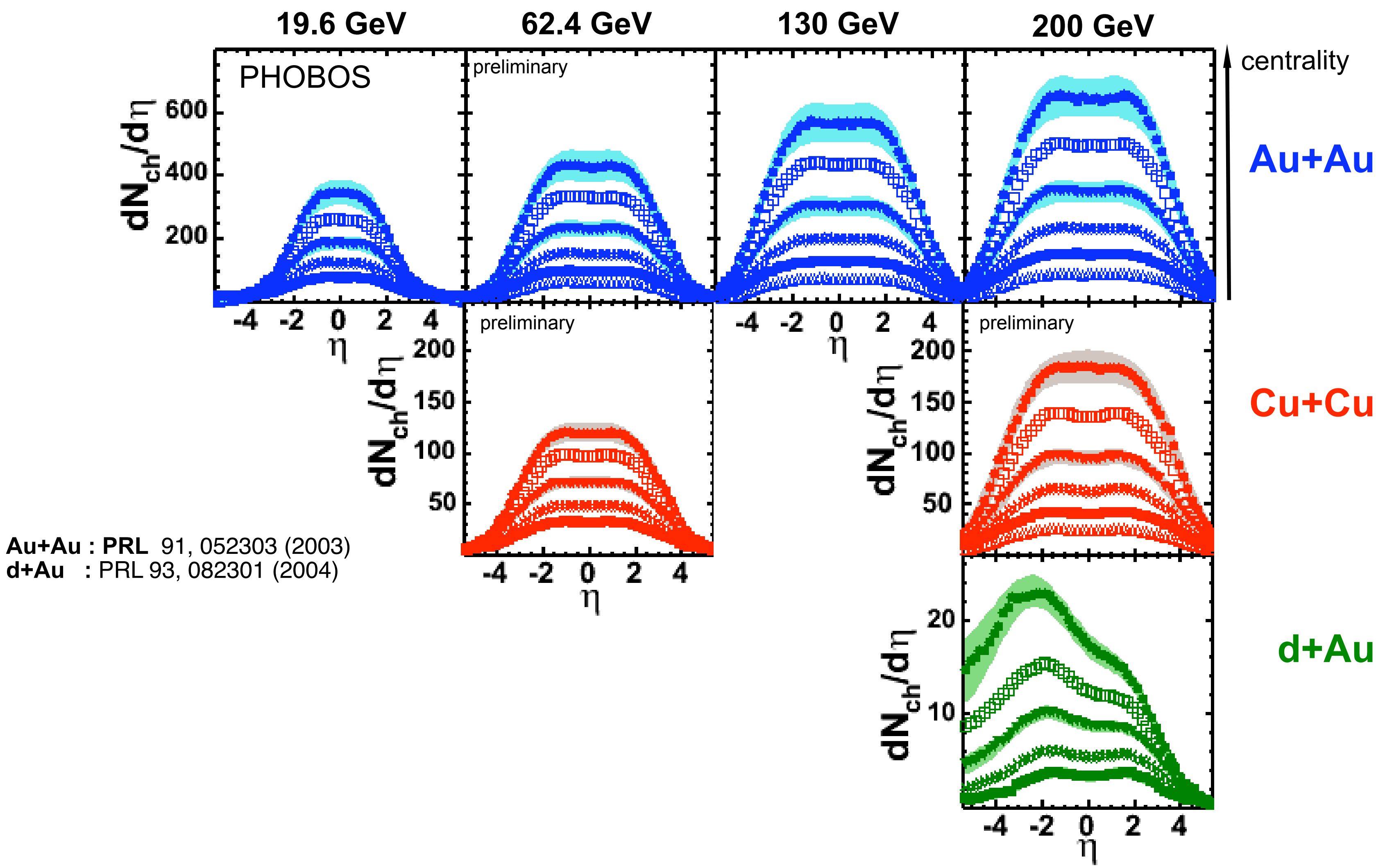
Multiplicity Fluctuations at RHIC

VI-SIM Workshop
May 19 2006

Gunther Roland

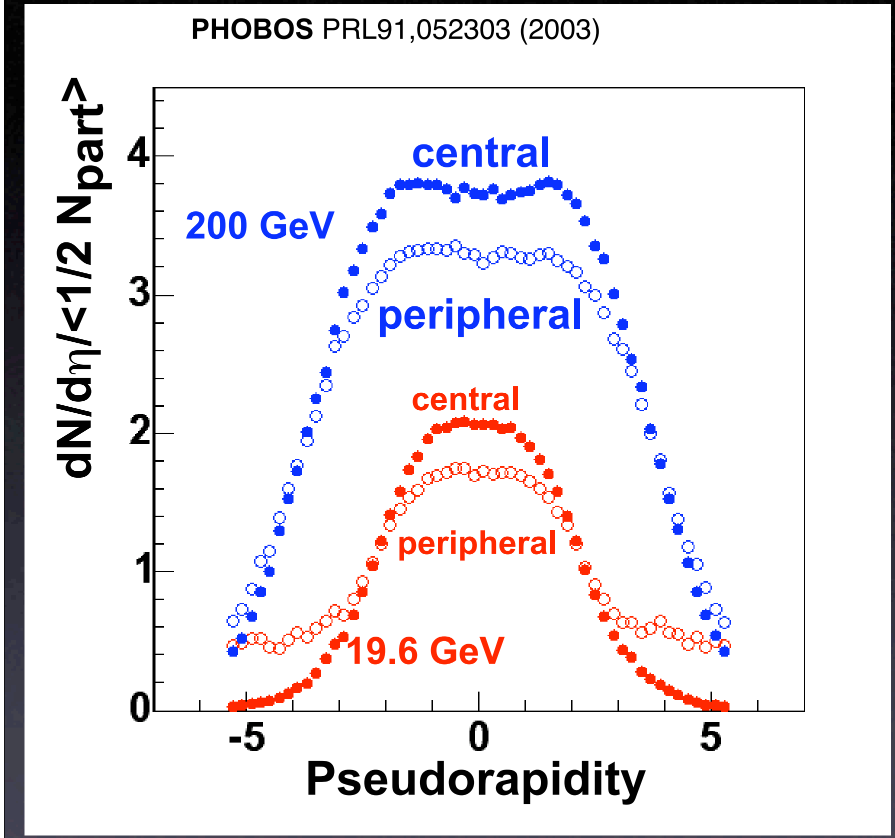
Charged hadron multiplicities at RHIC

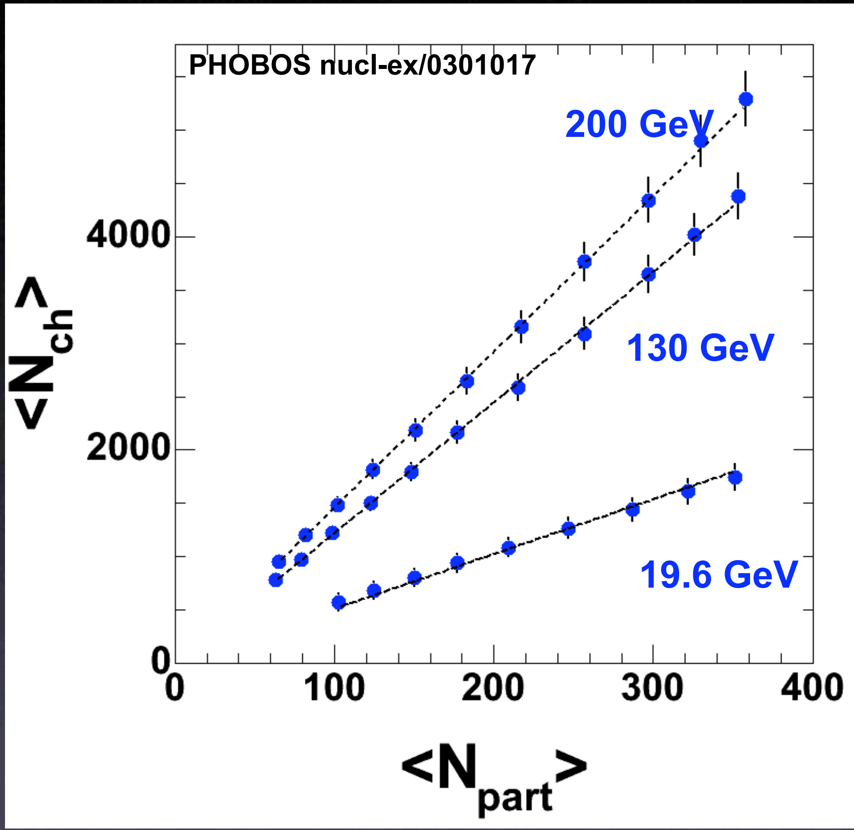


Charged hadron multiplicities at RHIC

- Rich p+p, p+A, A+A dataset on multiplicities
- “Scaling features”of hadron multiplicities in A+A
  - N_{part} scaling (also in p+A)
  - Limiting fragmentation (also in p+p, p+A, e+e-)
  - Factorization of energy/centrality dependence
  - Universality of total multiplicity in A+A, e+e-, p+p
- Seen over wide range in energy

Global constraints on multiplicity distributions





Centrality dependence of dN/dη shape

N_{part} scaling of total (4-π) multiplicity

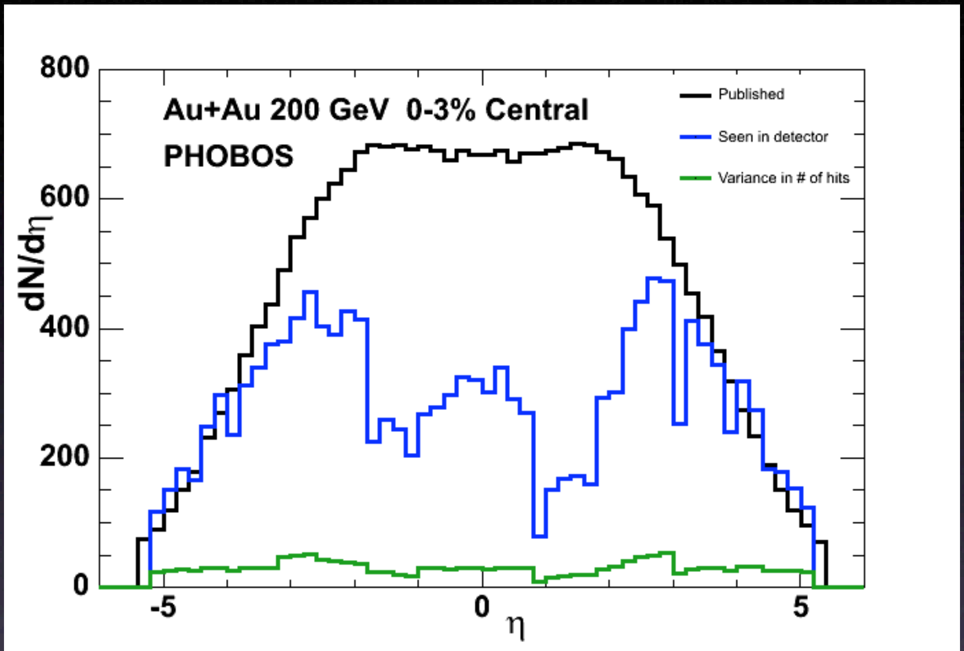
Charged hadron multiplicities at RHIC

- “Global constraints” on average $dN/d\eta$

Charged hadron multiplicities at RHIC

- “Global constraints” on average dN/dη
-
- What is the variation of large scale structure from event to event?
- What is the local structure of hadron production?
- **Study multiplicity correlations/fluctuations**

dN/dη seen by PHOBOS



Hit counting:
Occupancy ~ 1.6
near midrapidity

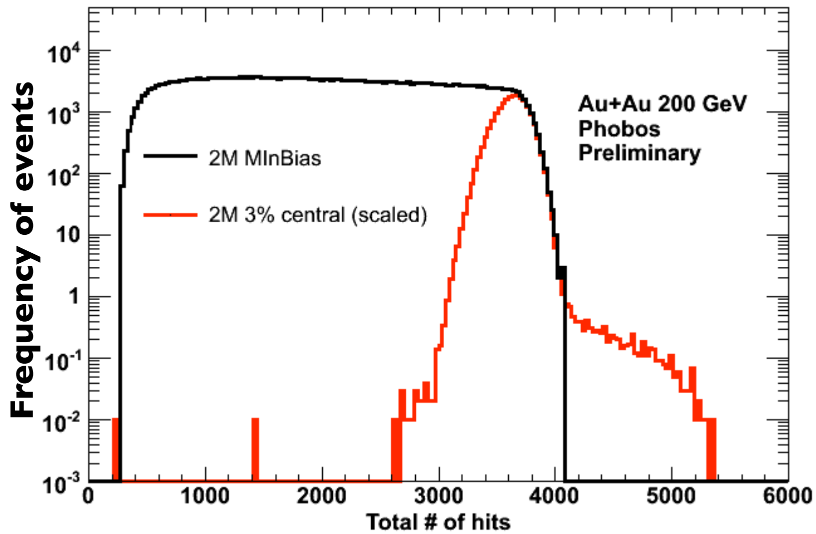
Search for large scale fluctuations:

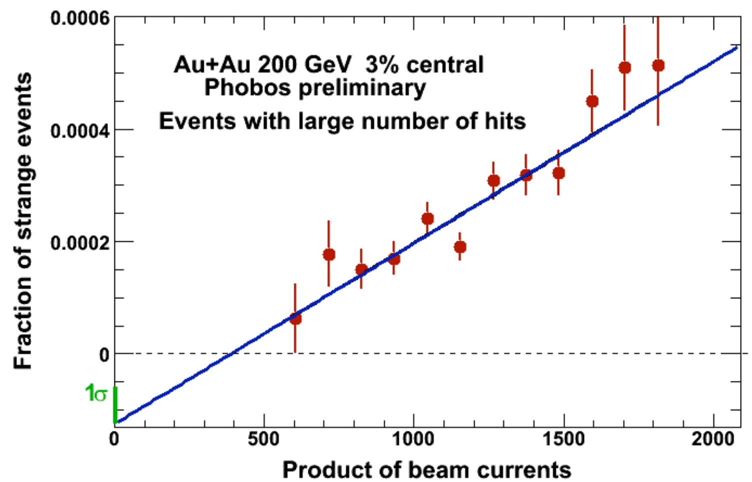
I. Multiplicity Fluctuations ↔ Integral of raw dN/dη

II. Shape Fluctuation ↔ χ^2 of single-event dN/dη vs average

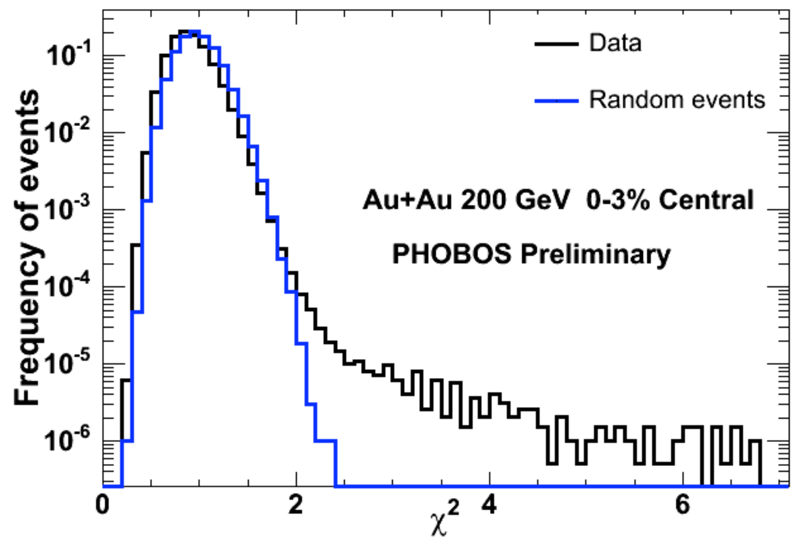
"Unusual" Events in Au+Au?

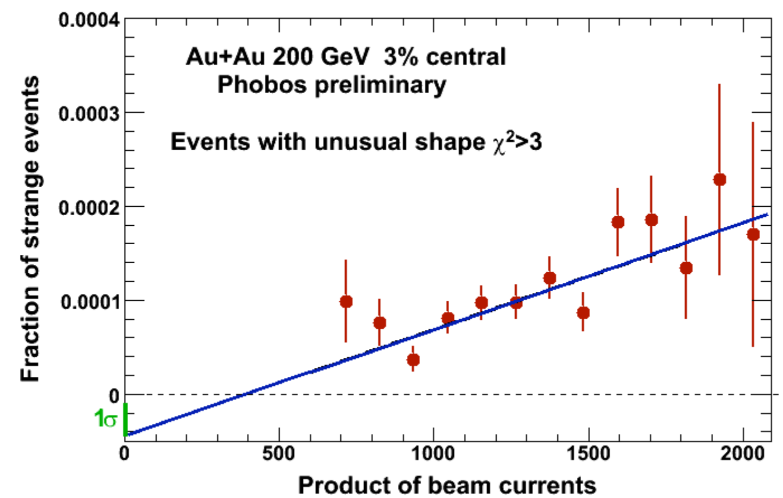
Total Multiplicity Fluctuations



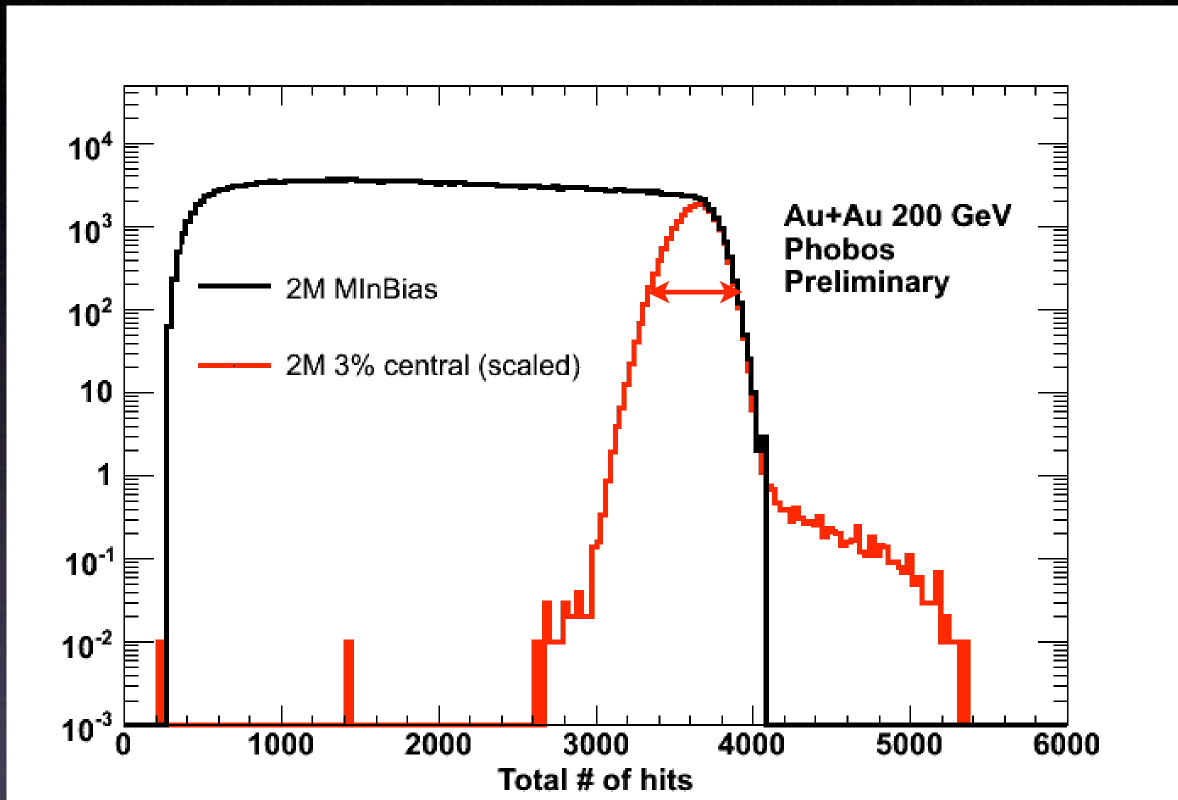


Shape Fluctuations





Understanding the width of multiplicity distributions

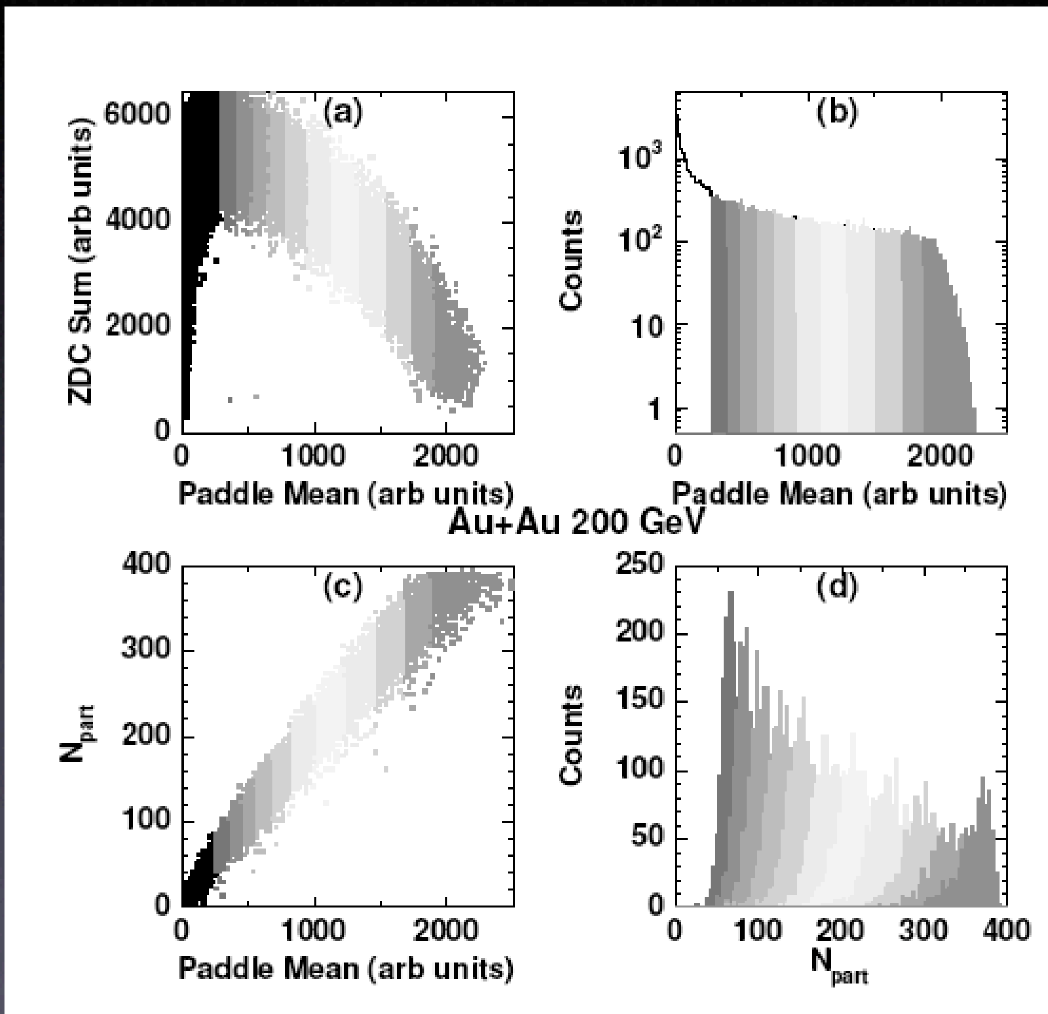


Variance of multiplicity distribution

$\leftrightarrow$

Variance of N_{part} distribution

Centrality determination and fluctuations



Recipe

(a) or (b): Select fractional x-section in 'multiplicity' N

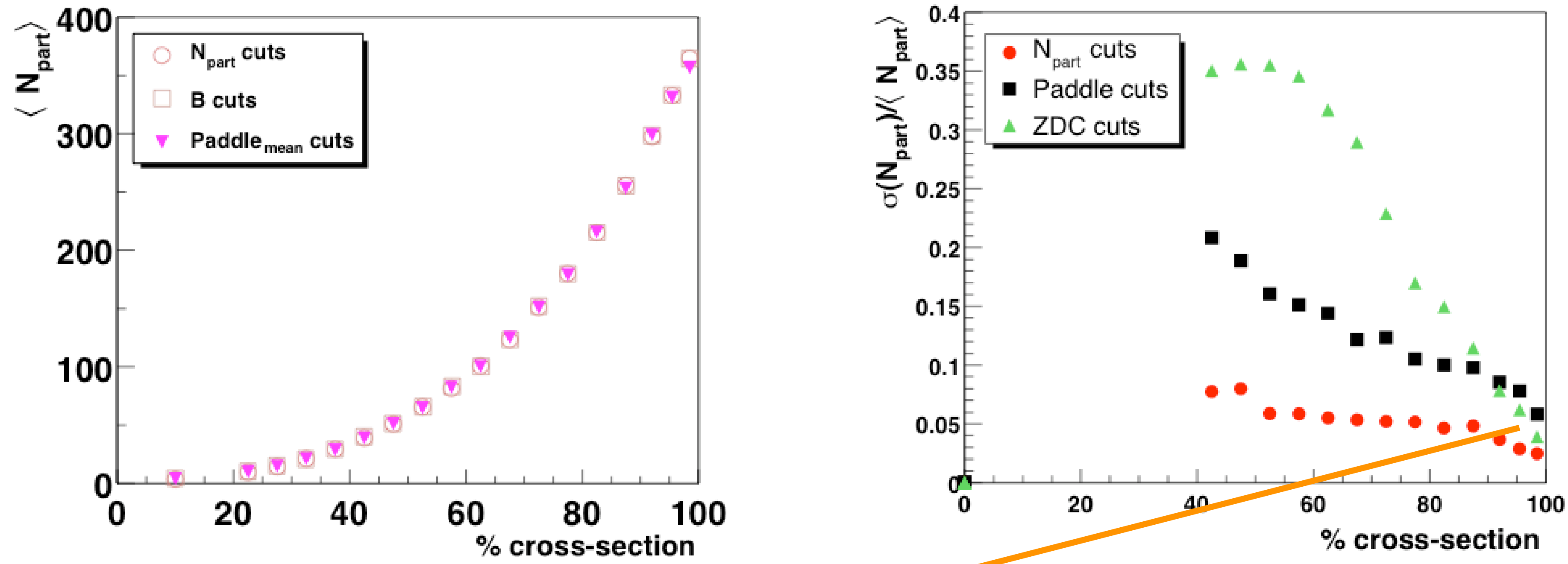
(c) Use MC to translate x-section bin in N to x-section in N_{part}

(d) Find $<N_{part}>$ and $\sigma(N_{part})$ for each x-section bin

Requires knowledge of
* trigger efficiency
* fluctuations/resolution in N

Fluctuations and centrality cuts

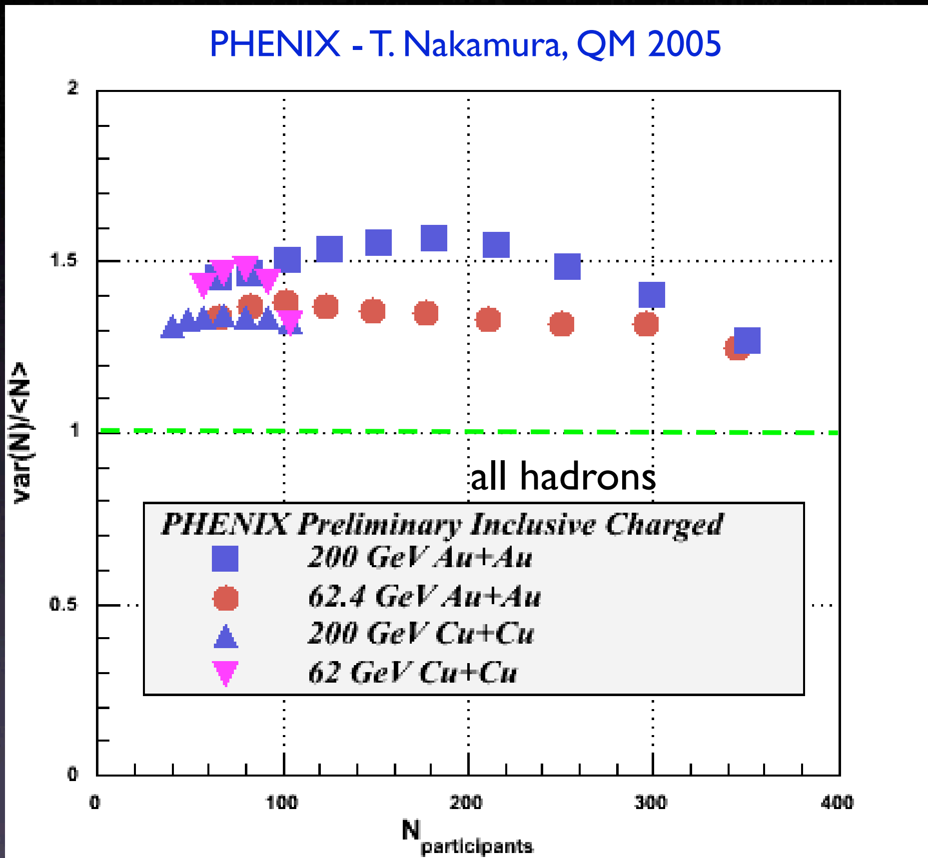
HIJING + GEANT

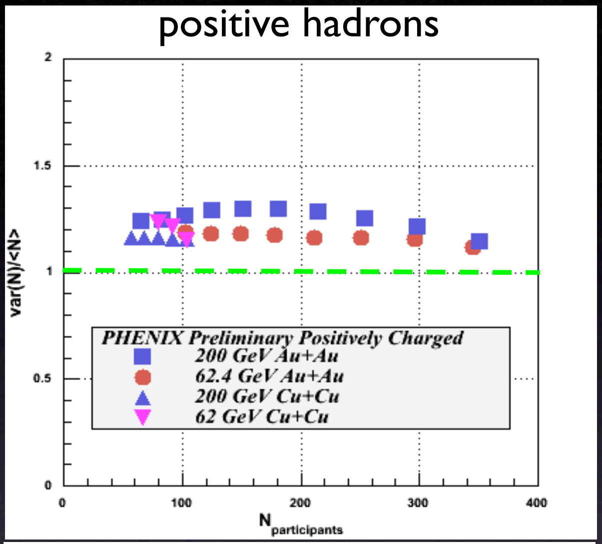


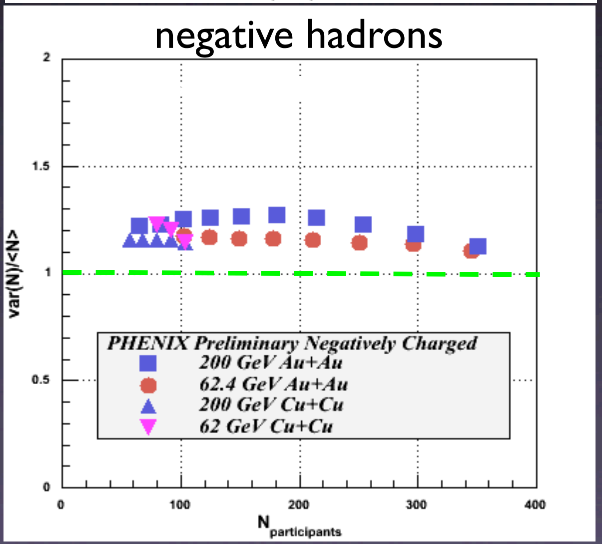
Large variation in N_{part} even for very fine (3%) x-section bins: 6%

(compare to Poisson multiplicity fluctuations ~ few %)

Normalized variance vs. participants

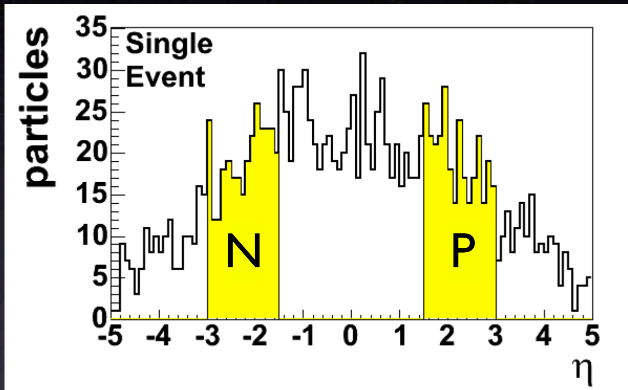






Deviation from Poisson
No charge dependence

Forward/backward multiplicity correlations



$$C = \frac{P - N}{\sqrt{P + N}}$$

Use variance σ^2_C

* Removes participant fluctuations

* Works for asymmetric bins

Particles produced independently:

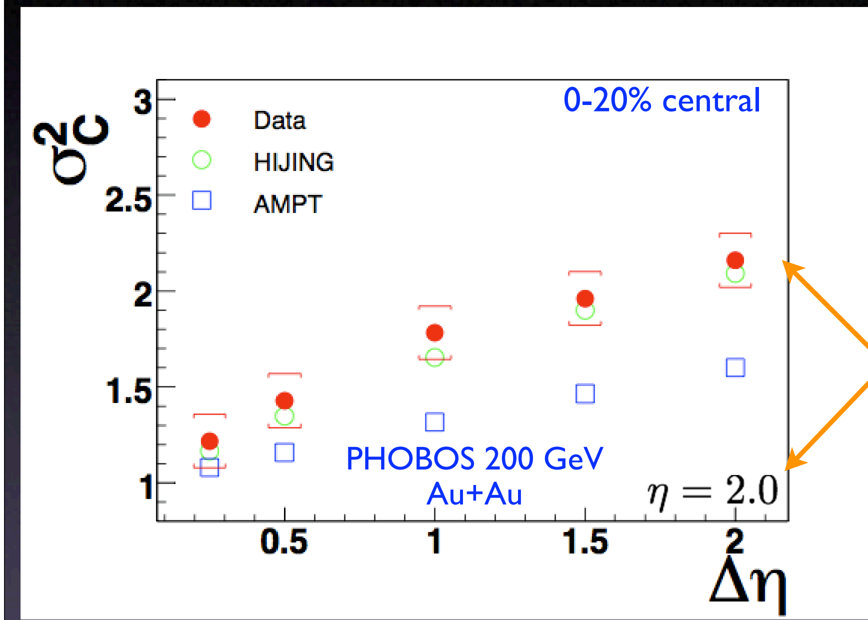
$\sigma^2_C = 1$

Particles produced in clusters of size *K*:

$$C \rightarrow \sqrt{K} C$$

$$\sigma^2_C \rightarrow K \sigma^2_C$$

Forward/backward multiplicity correlations



Particles produced independently:

$\sigma^2{}_C = 1$

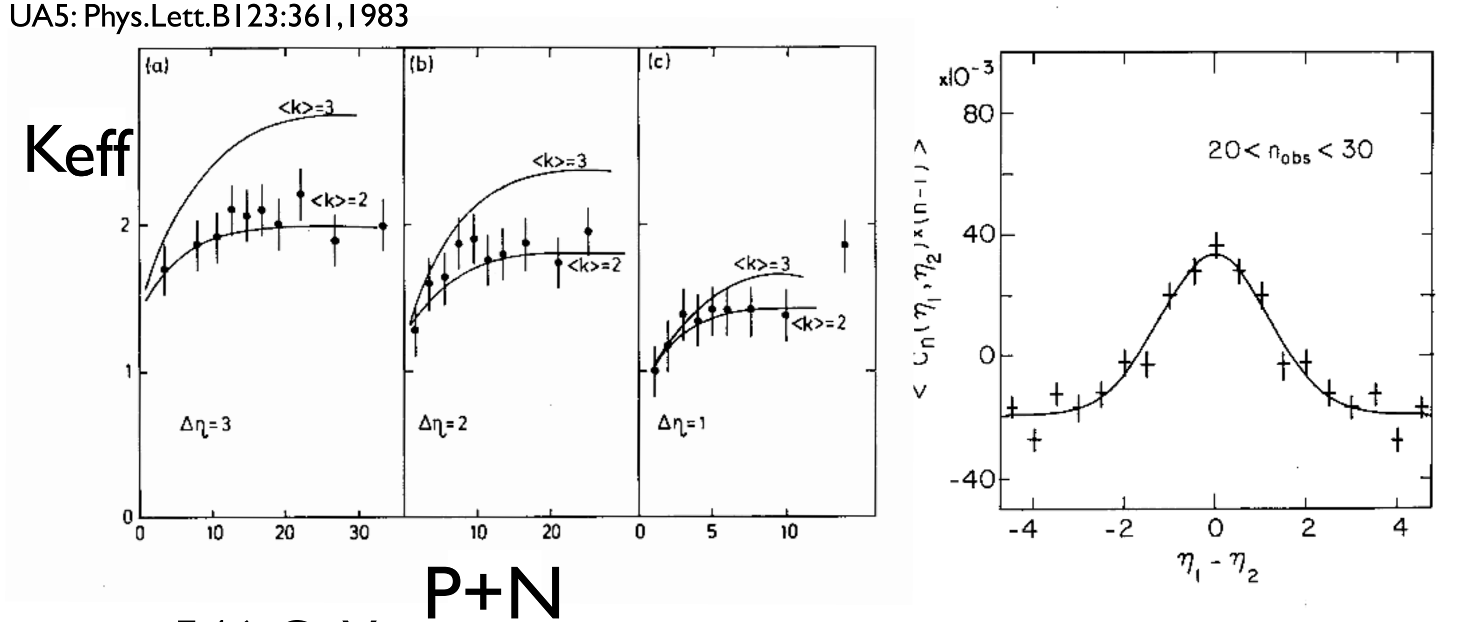
Particles produced in clusters of size *K*:

$$C \to \sqrt{K} C$$
$$\sigma^2_C \to K \sigma^2_C$$

effective cluster size ≈ 2-2.5
for 200 GeV Au+Au

Clusters in p+p

UA5: Phys.Lett.B123:361,1983



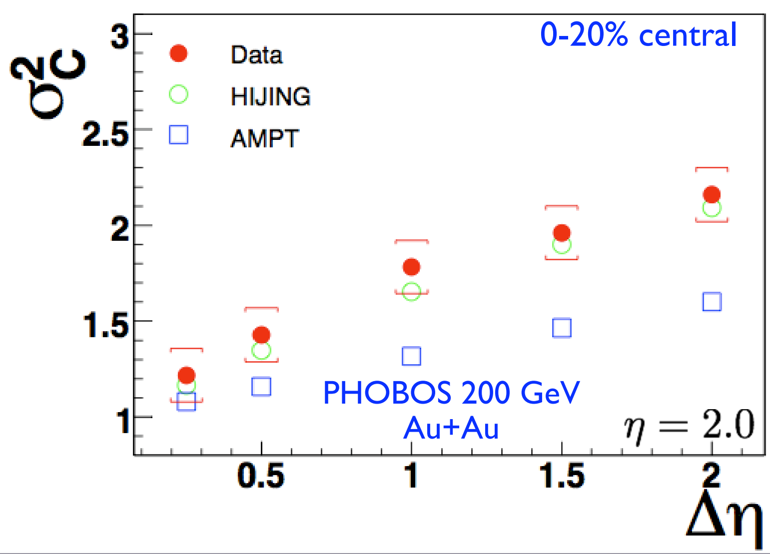
$\overline{p}+p$ 546 GeV

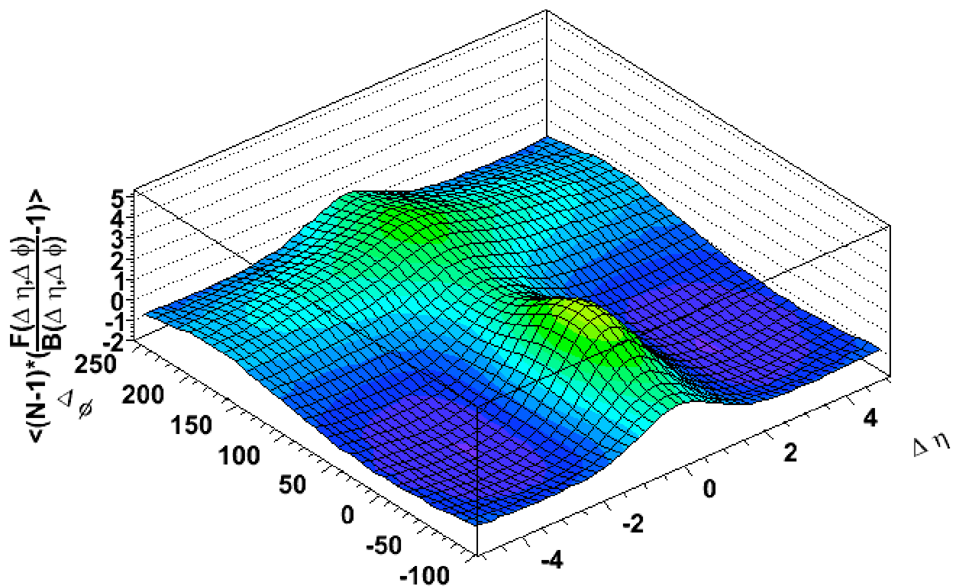
Clusters in Au+Au reminiscent of results from p+$\overline{\text{p}}$

Forward/backward multiplicity correlations

"Clusters" in A+A (and p+p) collisions

PHIOBOS QM'05



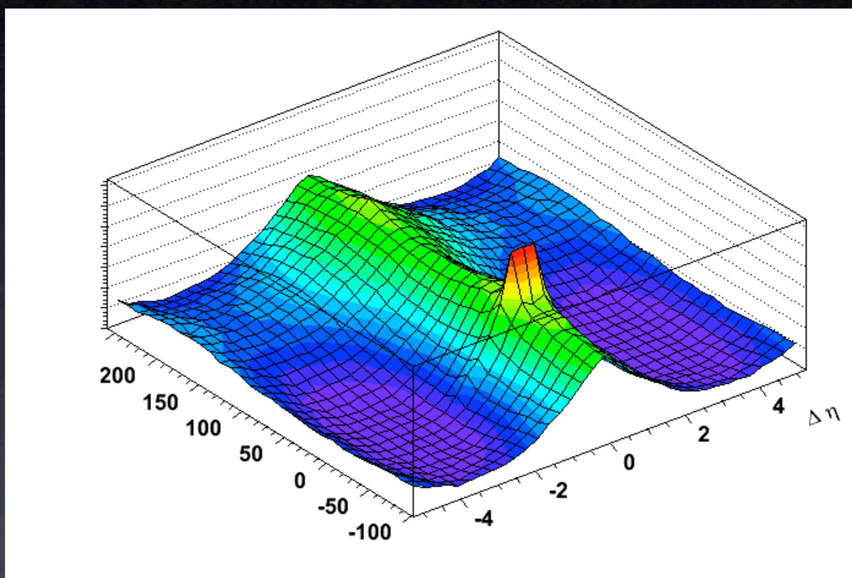


effective cluster size ≈ 2-2.5
for 200 GeV Au+Au

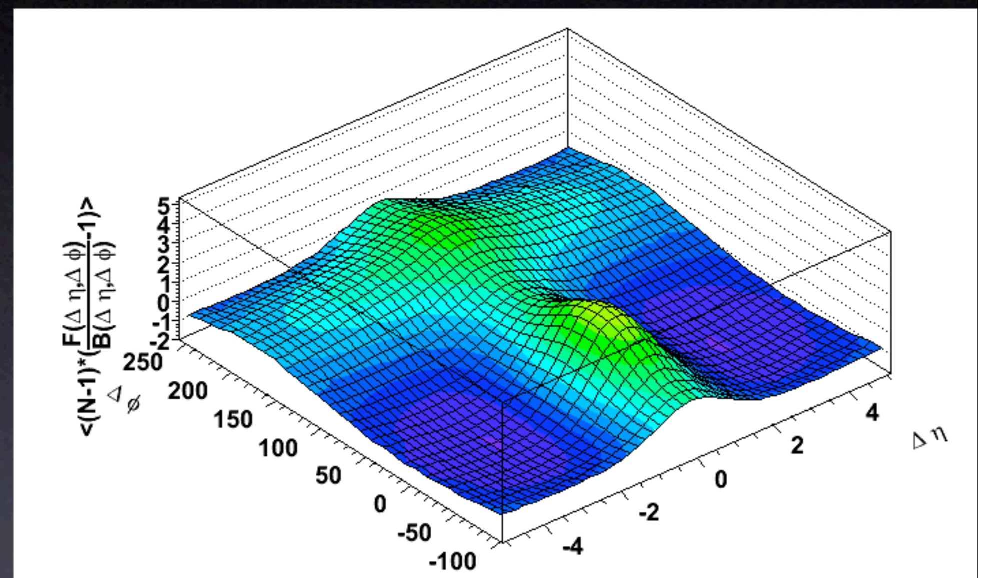
"Cluster" in Δη,Δφ space via
2-particle correlations
(pythia p+p @200 GeV, η<3)

Data vs MC

For illustration only!

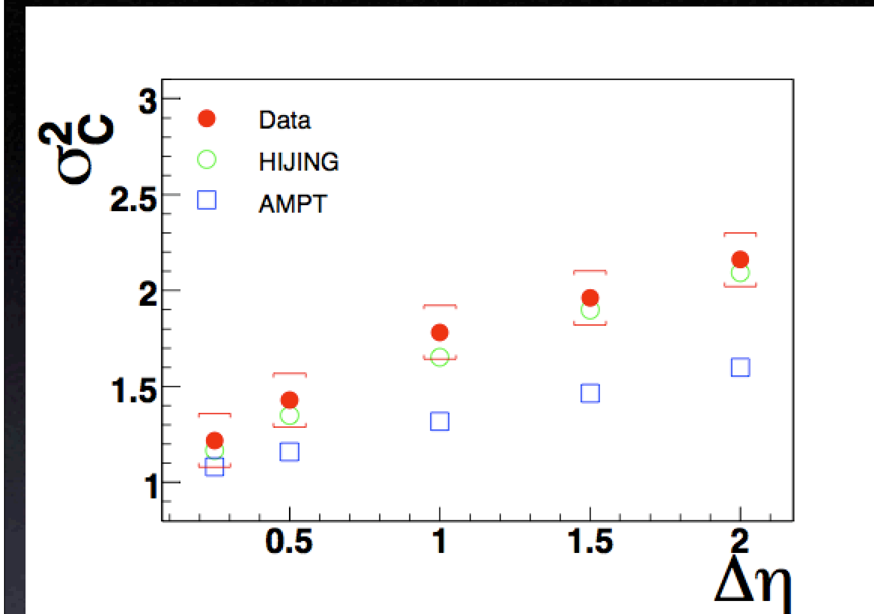


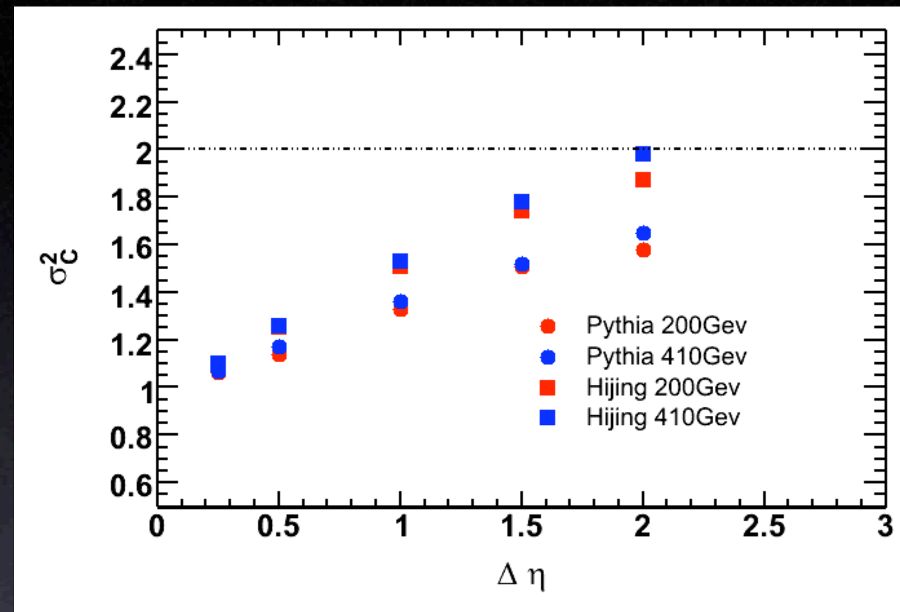
“Cluster” in Δη,Δφ space via 2-particle correlations (PHOBOS p+p @200 GeV, η<3)



“Cluster” in Δη,Δφ space via 2-particle correlations (pythia p+p @200 GeV, η<3)

Connection between σ^2_c and K





"Conjecture"

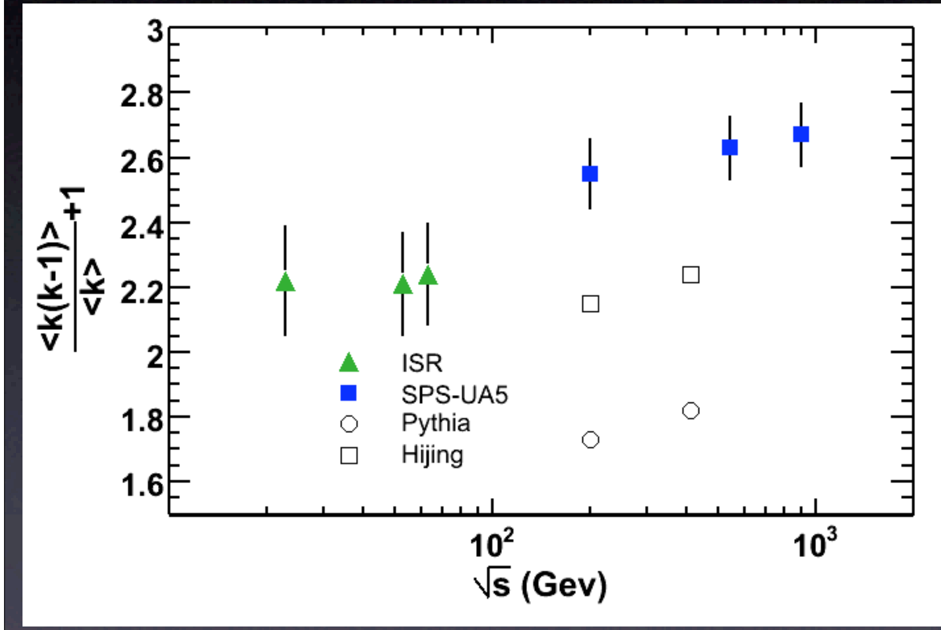
MC p+p $\Delta\eta,\Delta\phi$ correlations ~ p+p $\Delta\eta,\Delta\phi$ correlations

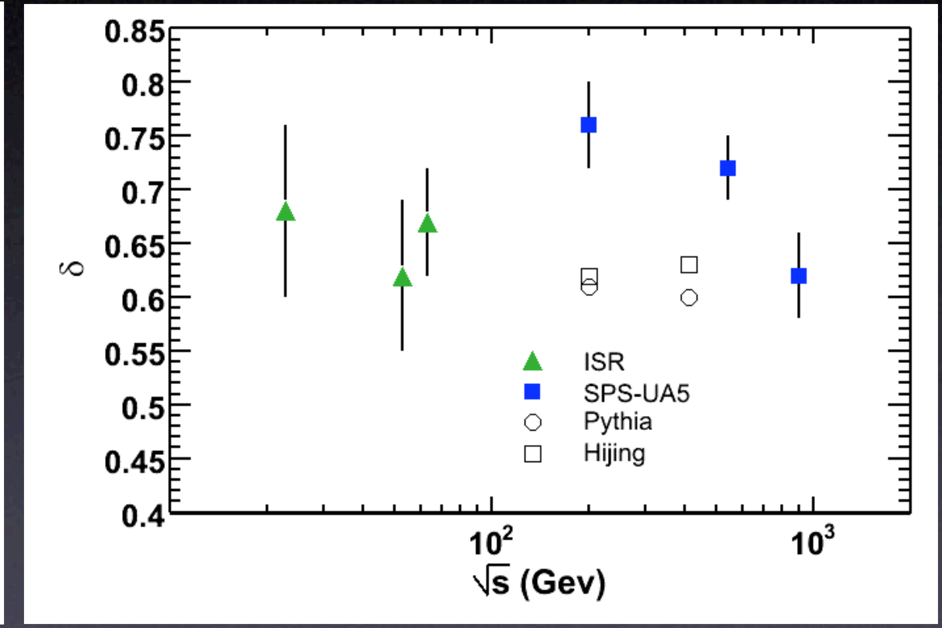
MC σ^2_C systematics ~ Au+Au σ^2_C systematics

⇒ clusters in Au+Au ~ clusters in p+p

p+p clusters vs √s

Origin of p+p clusters?

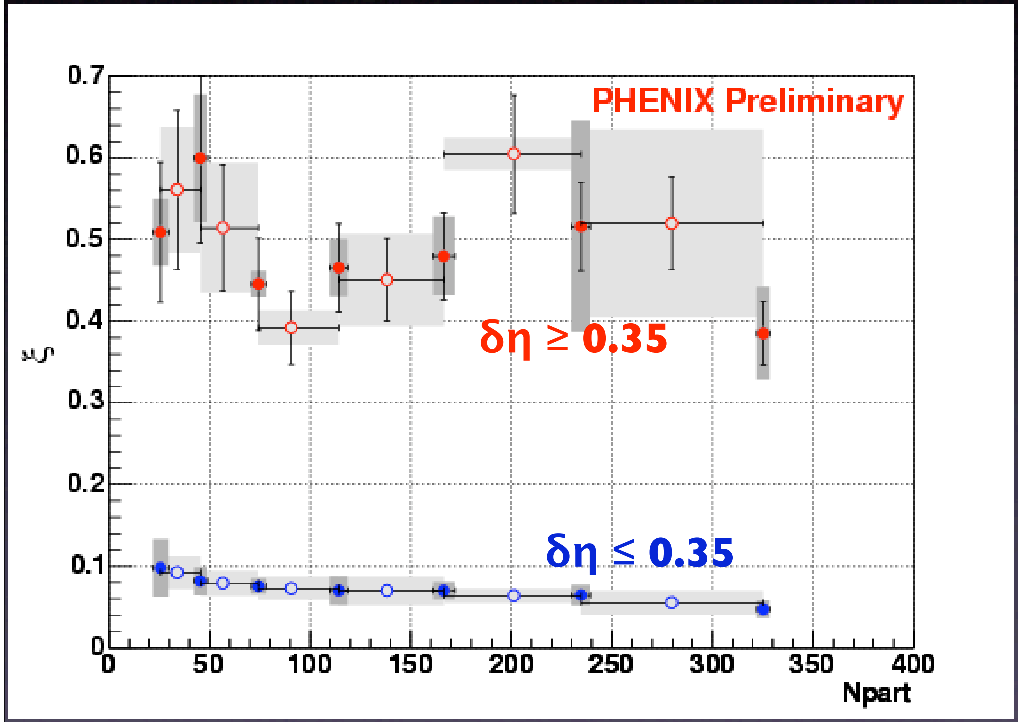




* Resonances?
* String fragmentation?
* (mini-) Jets?

Correlation length in Au+Au

Au+Au 200 GeV, no magnetic field
Δη<0.7, ΔΦ<π/2 rad



K. Homma and T. Nakamura (QM'05)

- **Fitting Range**

Blue: δη ≤ 0.35

Red : δη ≥ 0.35

- **Centrality**

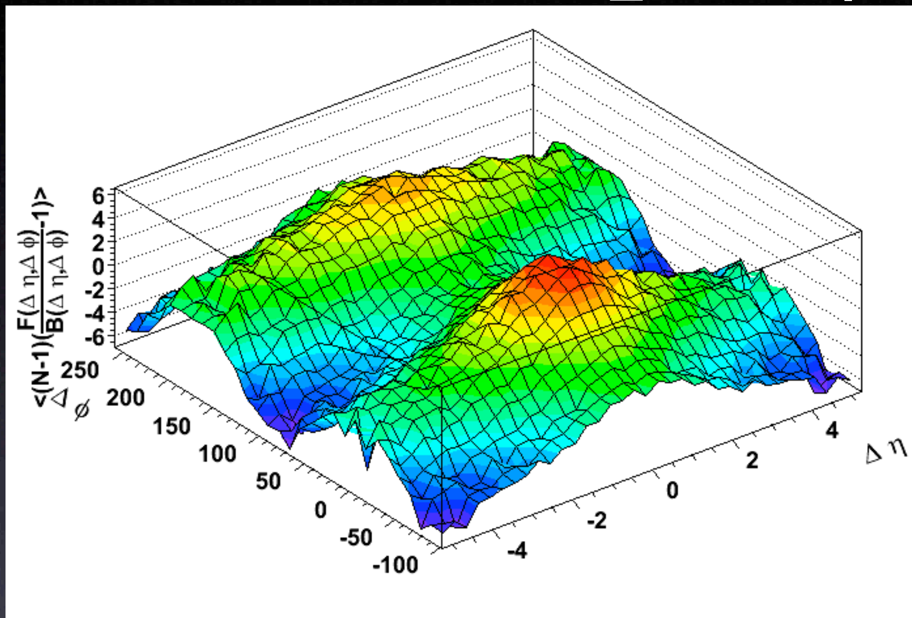
filled circle : 0-70 % (10% interval)

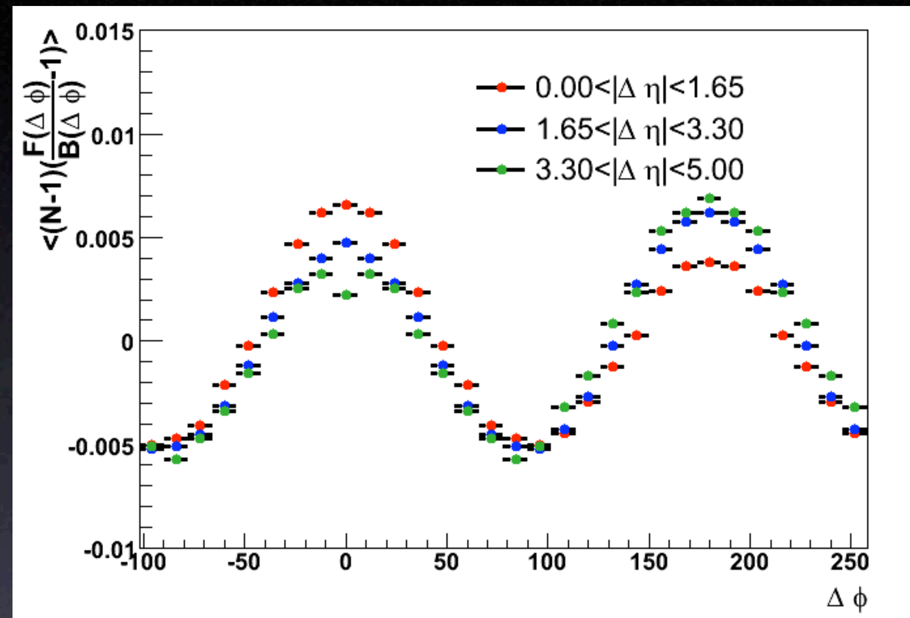
open circle : 5-65 % (10% interval)

"Different behaviors about the extracted correlation length (ξ) as a function of number of participants are observed in the different range of the pseudo rapidity gap. The correlation length at the range of large pseudo rapidity gap has a large fluctuation."

Angular correlations in A+A

Cu+Cu MC w/ v_2 and v_1

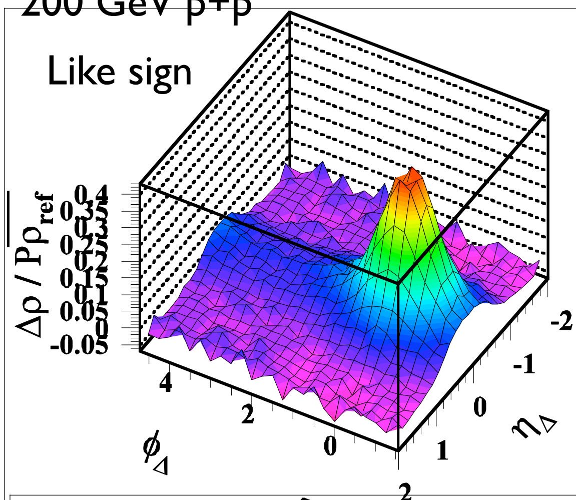


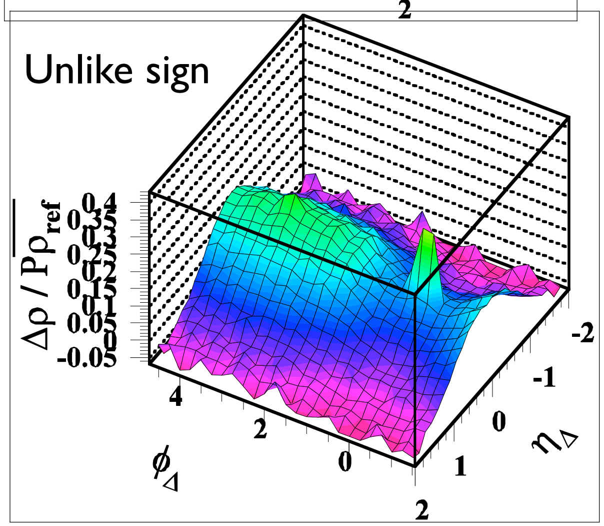


Much richer phenomenology in A+A
* study vs η, √s, species, centrality

Angular charge correlations

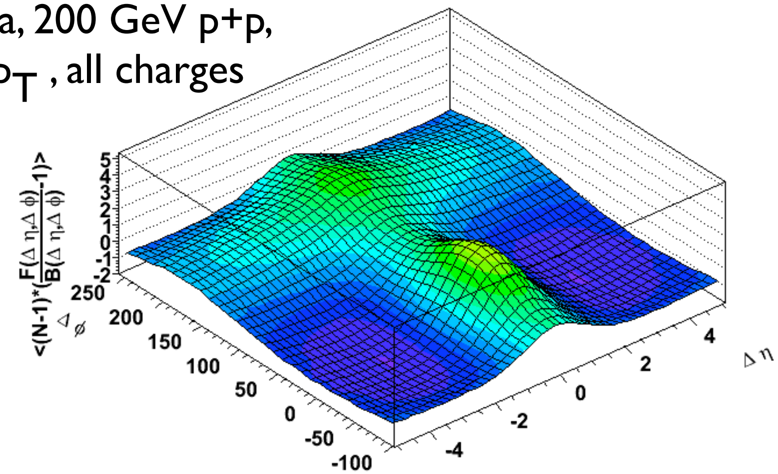
STAR
200 GeV p+p





Split sample

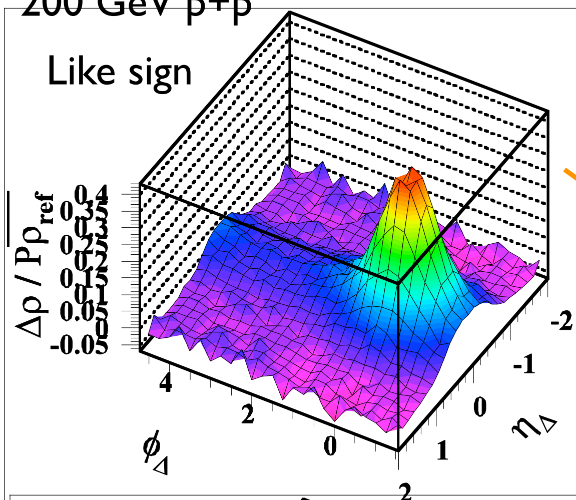
Pythia, 200 GeV p+p,
all p_T , all charges

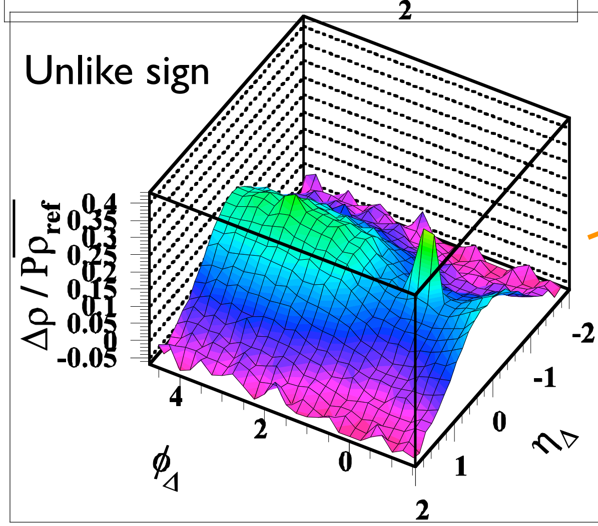


2-D angular correlation function

Angular charge correlations

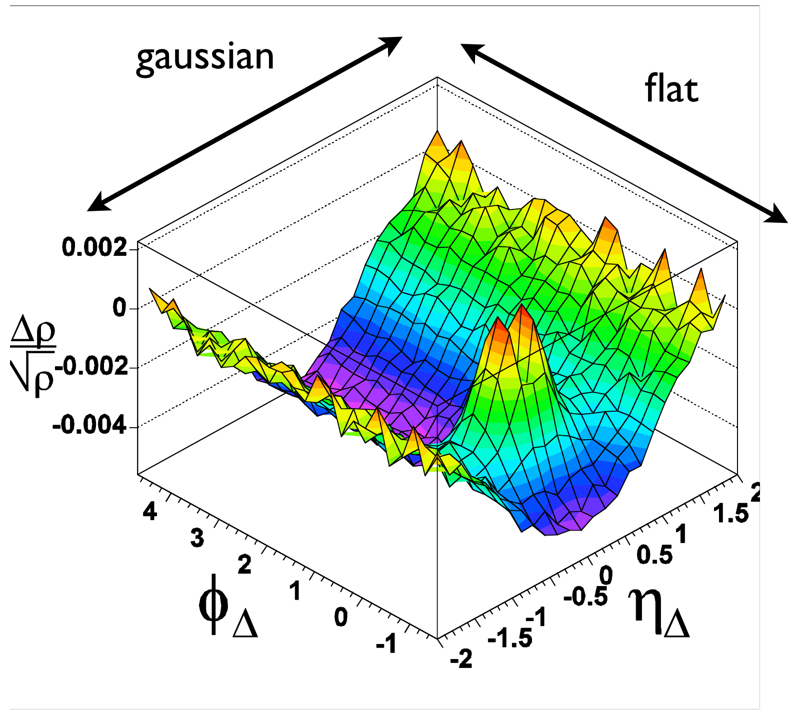
STAR
200 GeV p+p





subtract

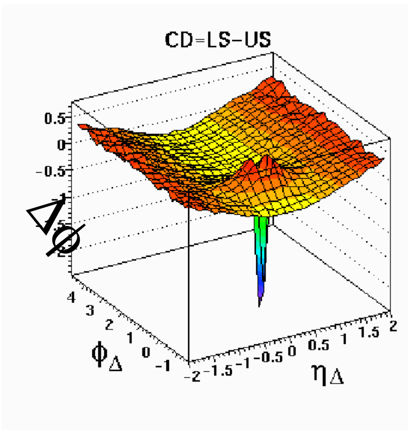
longitudinal charge ordering



"Charge Dependent (CD)" correlations

Charge Dependent Correlations

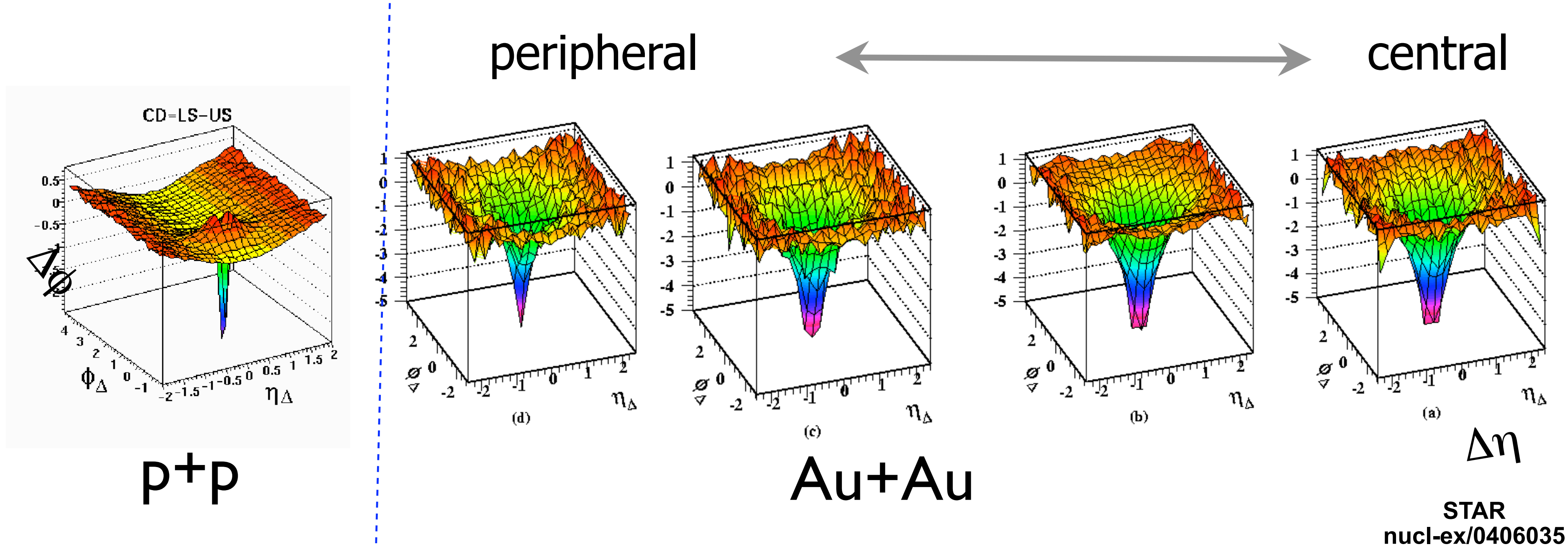
Difference of like-sign and unlike-sign 2-particle correlations:



p+p

Charge Dependent Correlations

Difference of like-sign and unlike-sign 2-particle correlations:



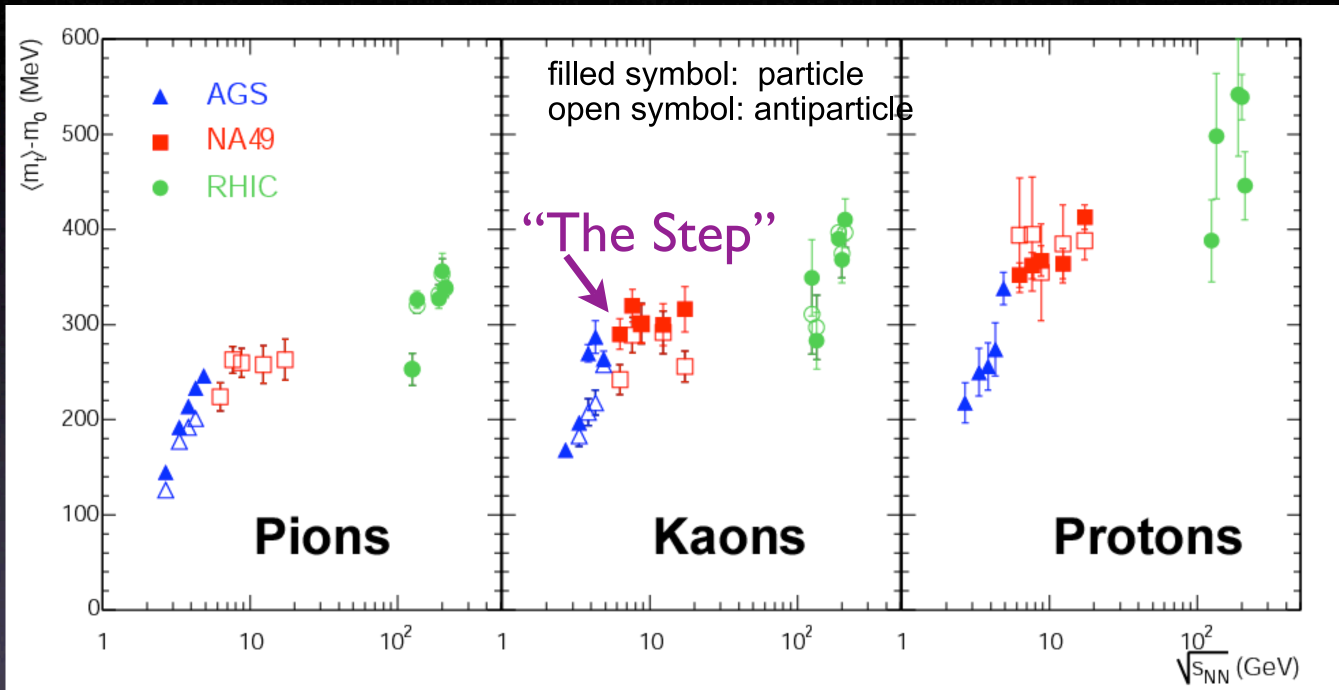
Evolution of "cluster" properties/charge correlations

Summary

- Studies of multiplicity fluctuations and correlations are emerging at RHIC
- Dominated by local correlations structures (”clusters”)
- Similarities to pp
  - Cluster-size, correlation length
- Evolution from pp to AA
  - 1D to 2D charge ordering
- Much more to come in AA

Excitation Function: Momentum Spectra

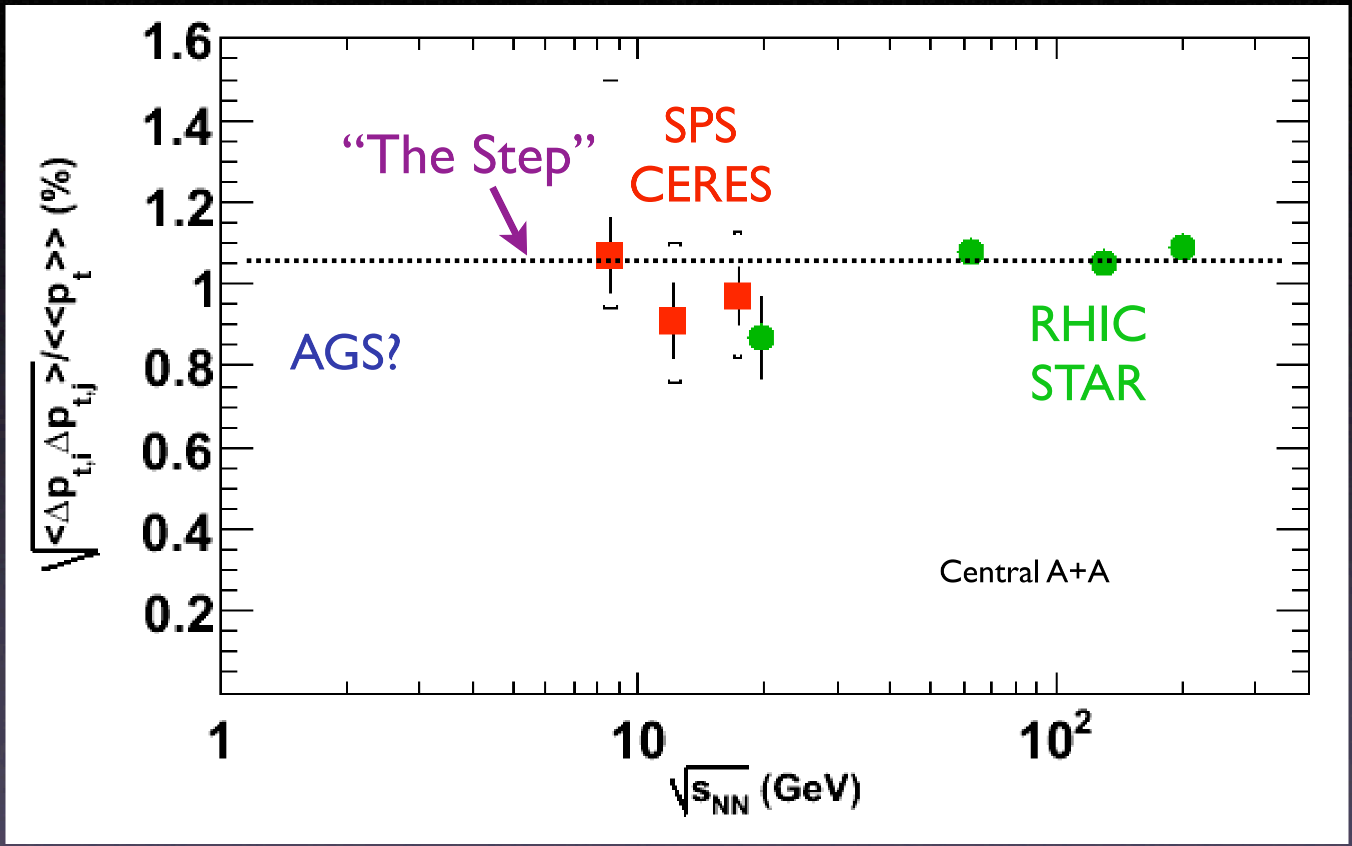
Compilation by NA49
Plot from Claudia Hoehne, QM'05



- Structure in energy dependence of <mT>
- Reminiscent of Van Hove's T vs ϵ prediction (1982)
- Surprisingly difficult measurement
    - Decay corrections, PID acceptance

Excitation Function: Momentum Fluctuations

Compilation by STAR
STAR PRC 72 044902 (2005)

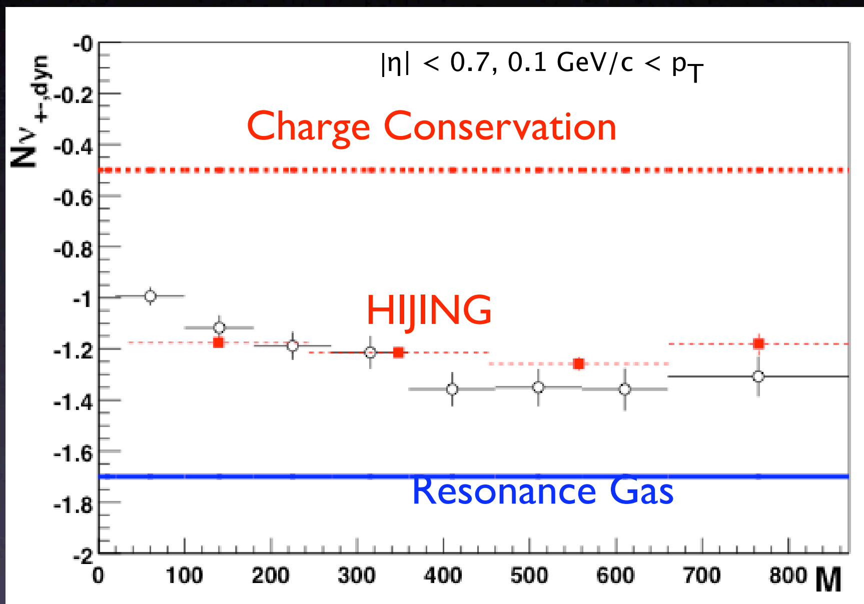


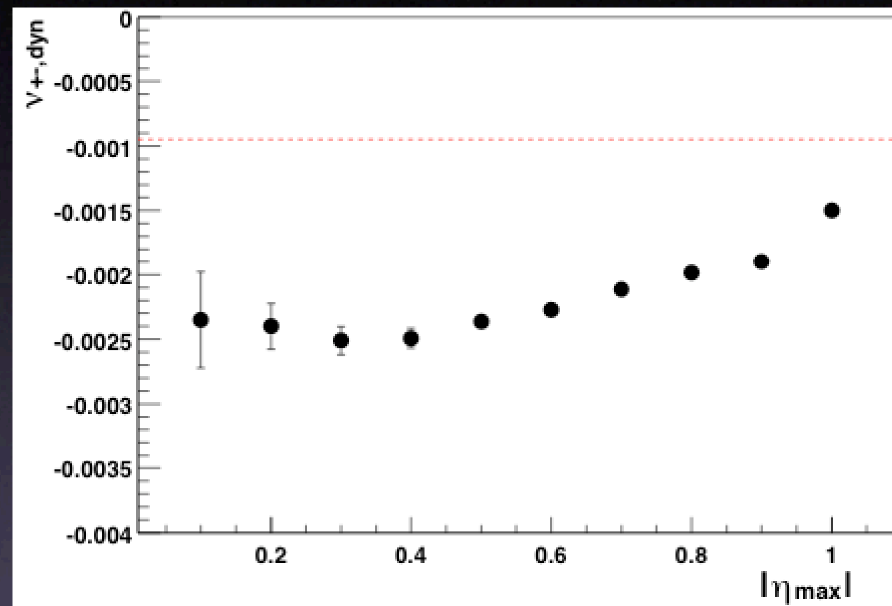
Monotonic energy dependence over measured range
No results near "step" region

Results from STAR

Acceptance: $\Delta y \approx 2$, $\Delta\Phi = 2\pi$

STAR PRC 68 (2003)



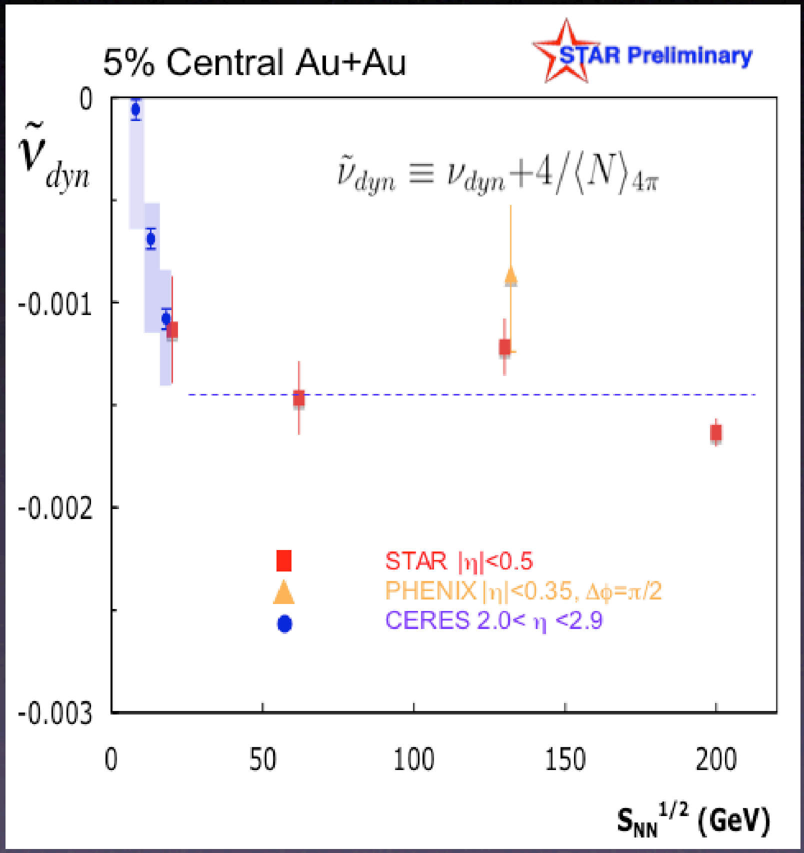


Fluctuations agree with stochastic distributions of *Hadrons*

Excitation Function: Charge Fluctuations

NA49, PRC 70 064903 (2004)

Plot from Claude Pruneau
RHIC Users meeting workshop '04
PHENIX: PRL 89 082301 (2002)

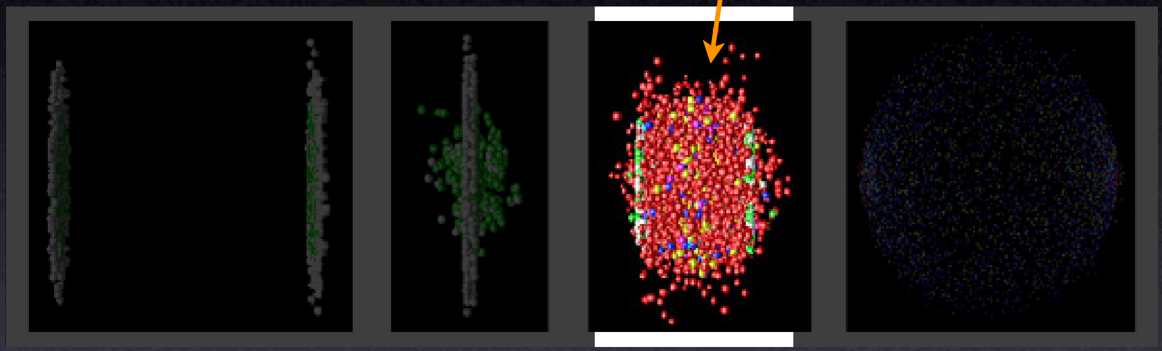


QGP

Little (no) √s dependence of charge fluctuations

What have we learned from Charge fluctuations?

DoF of Medium?



Net charge fluctuations large (~ hadron gas)

Small/no $\sqrt{s}$ dependence

→

Quark coalescence?

Property of Hadronization?

Diffusion?

Bound states?

Measuring global charge fluctuations

“Clustersize” Δy≈2

SPS

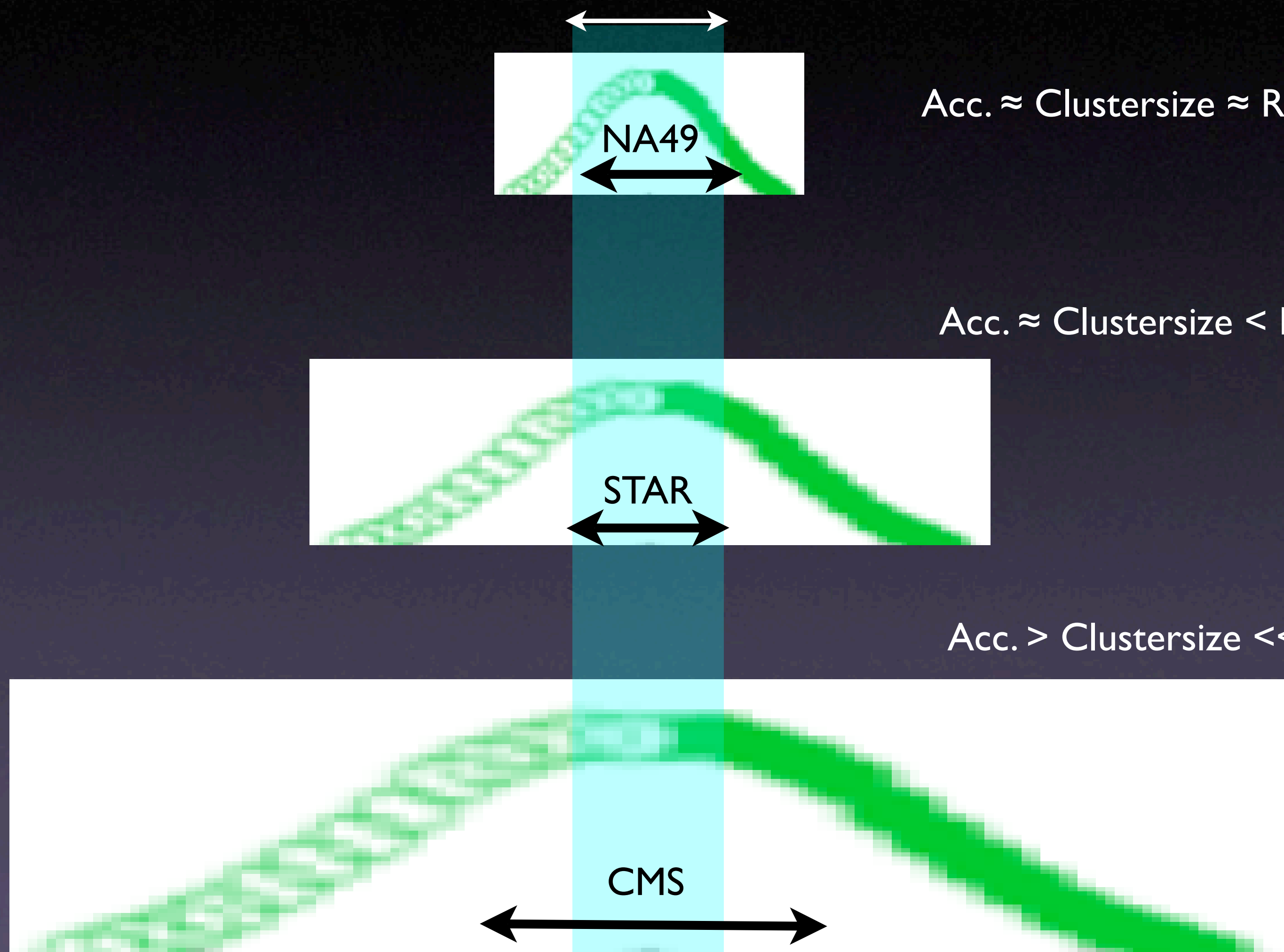
Acc. ≈ Clustersize ≈ Rapidity gap

RHIC

Acc. ≈ Clustersize < Rapidity gap

LHC

Acc. > Clustersize << Rapidity gap



Extraction of two particle correlation

Normalized correlation function

$$R(y_1, y_2) = \frac{C_2(y_1, y_2)}{\rho_1(y_1)\rho_1(y_2)} = \frac{\rho_2(y_1, y_2)}{\rho_1(y_1)\rho_1(y_2)} - 1$$

$\rho_1(y)$: inclusive single particle density

$\rho_2(y_1, y_2)$: inclusive two-particle density

$C_2(y_1, y_2)$: two-particle correlation function

Relation with NBD k

$$\frac{1}{k(\delta\eta)} = F_2 - 1 = K_2 = \frac{\int^{\delta\eta} C_2(y_1, y_2) dy_1 dy_2}{\int^{\delta\eta} \rho_1(y_1)\rho_1(y_2) dy_1 dy_2}$$

Used in E802 : PRC, 44 (1991) 1629

$$R_2 = R_0 e^{-|y_1 - y_2|/\xi} \quad : \quad \frac{1}{k(\delta\eta)} = F_2 - 1 = \frac{2R_0\xi^2[\delta\eta/\xi - 1 + e^{-\delta\eta/\xi}]}{\delta\eta^2}$$

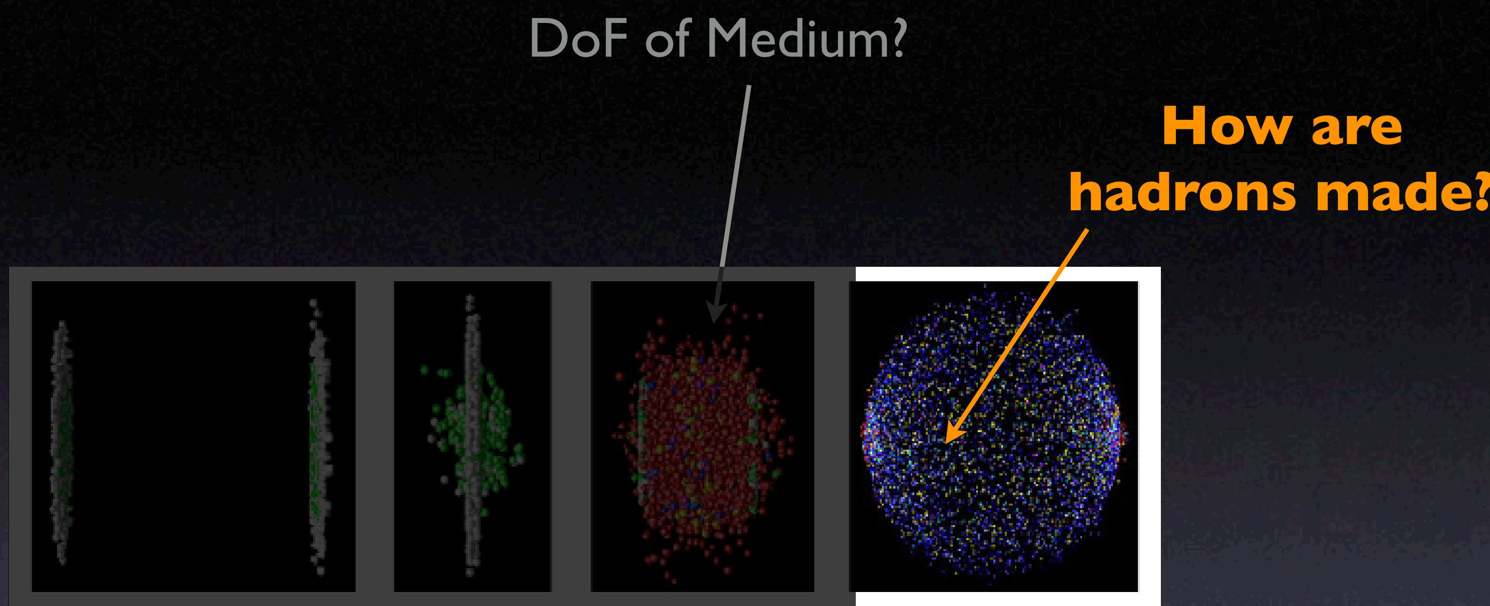
Two component model

$$R_2 = e^{-|y_1 - y_2|/\xi} + b \quad : \quad \frac{1}{k(\delta\eta)} = F_2 - 1 = \frac{2\xi^2[\delta\eta/\xi - 1 + e^{-\delta\eta/\xi}]}{\delta\eta^2} + \frac{b}{2}$$

ξ : Two particle correlation length

b : Strength of long range correlation

What have we learned from Charge fluctuations?



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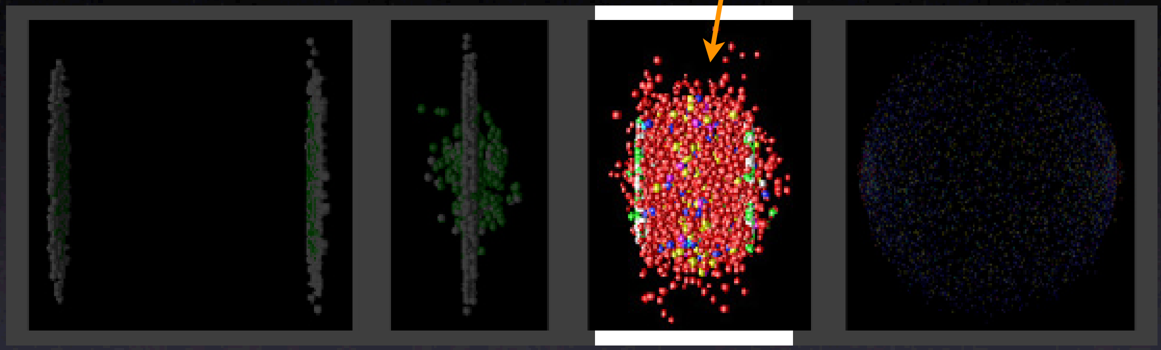
Diffusion?

Bound states?

Net Charge Fluctuations and the QGP

DoF of Medium?

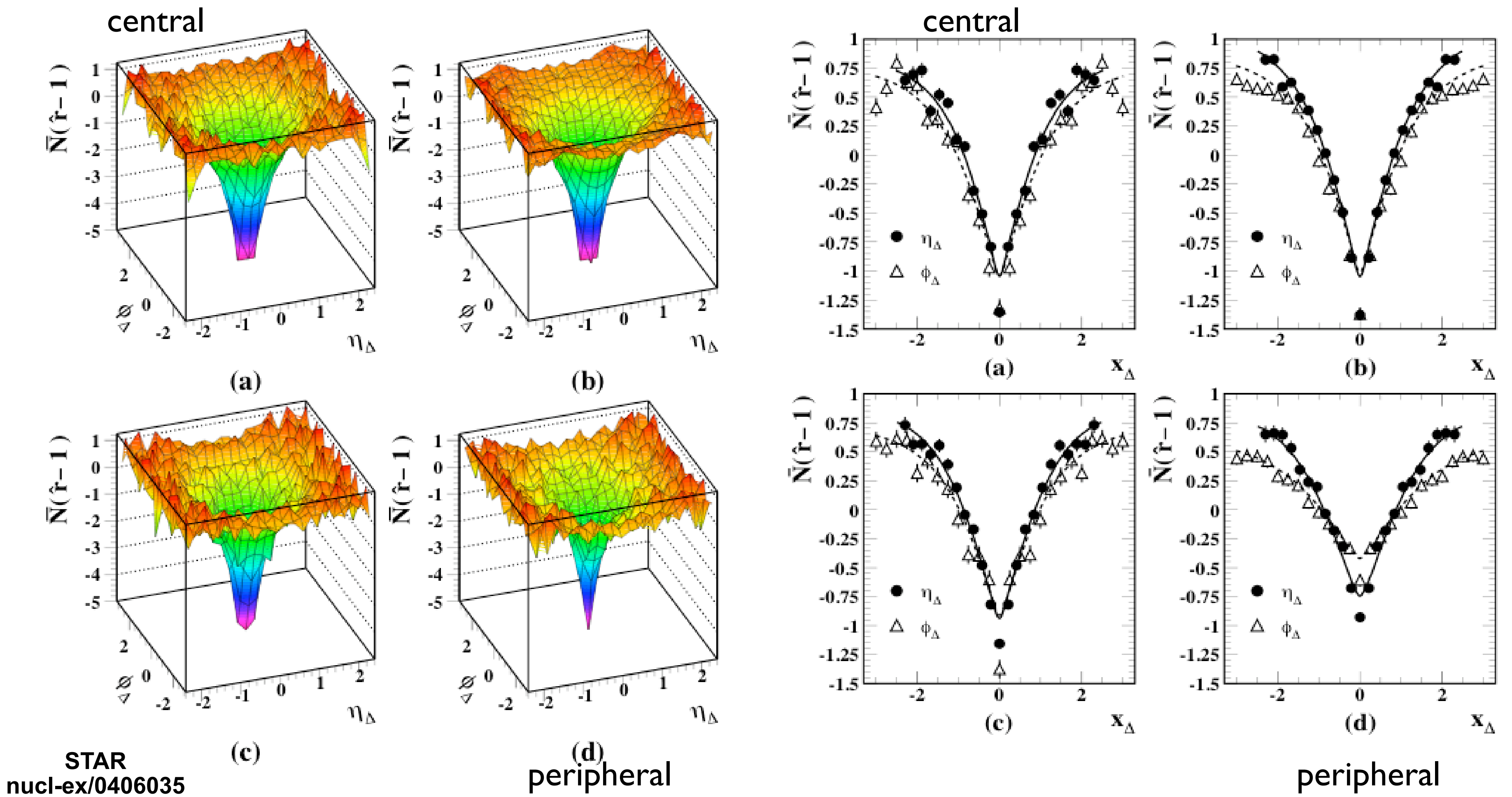
Jeon, Koch PRL (2000) hep-ph/0003168
Asakawa, Heinz, Mueller PRL (2000) hep-ph/0003169



- Net Charge/Δy Fluctuations ⇔ Charge/DoF
  - Fluc's change from 1-2 (QGP) to 4 (Pion Gas)
- Fluctuations frozen b/c charge conservation
  - Diffusion vs Expansion timescale

Note:
* Similar for net baryon number
* Connection to quark number susceptibilities
* Connection to Critical point

Charge Dependent Correlations



Centrality evolution in Au+Au