Elliptic Flow Fluctuations in Heavy-Ion Collisions

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MIT

ISMD 2007, LBNL
7/5 - 7/9

Outline

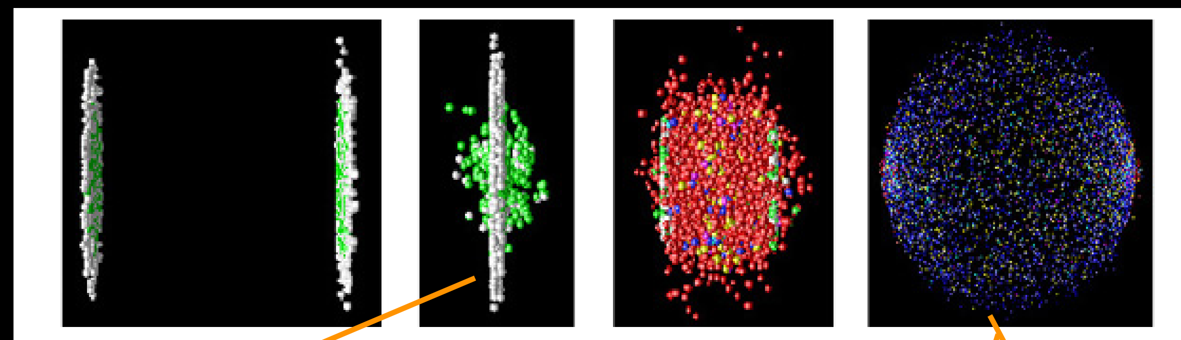
This talk has two parts

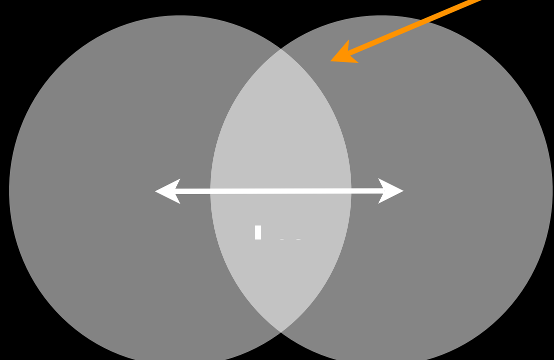
The first part gives an overview of many years of work

The second part summarizes developments in the last 3 weeks

Elliptic Flow

Time ⟶

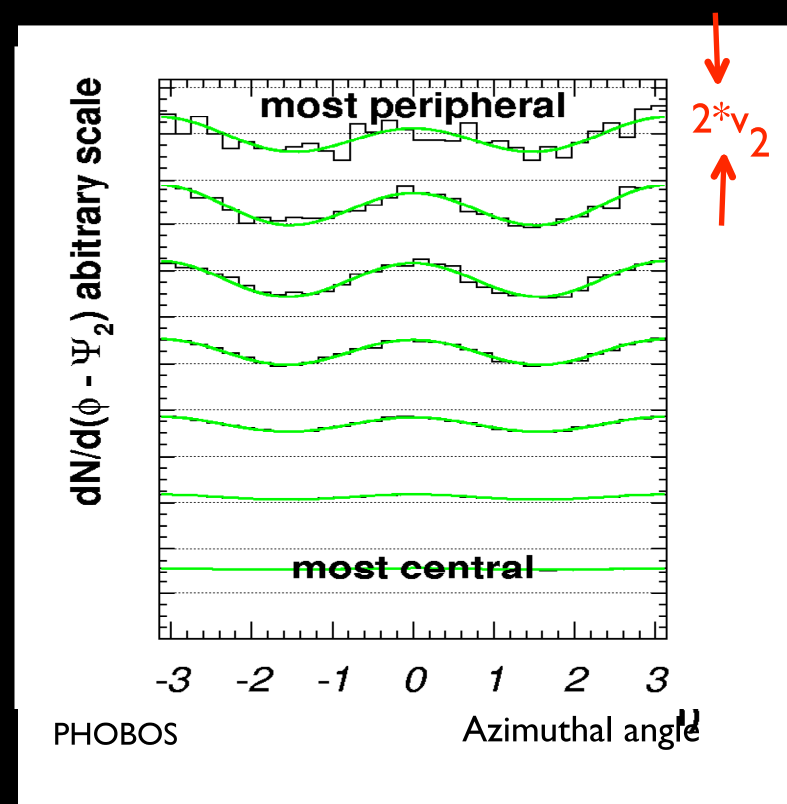




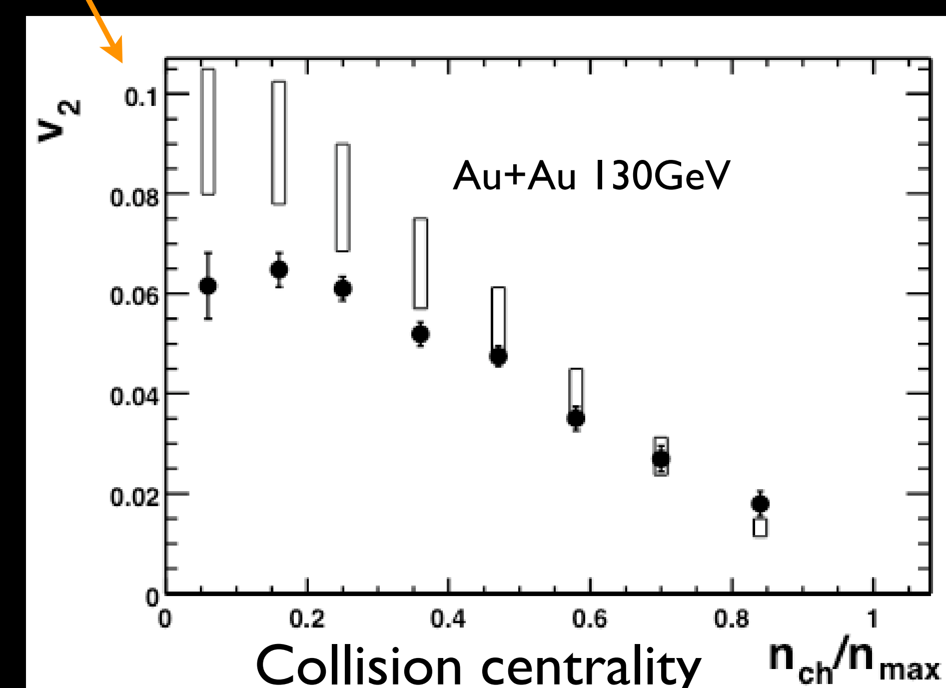
$$\epsilon_{std} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

Transverse view of
initial geometry
for a peripheral collision

Azimuthal distribution
dN/dφ = 1 + 2 v_2 cos(2(φ - φ0))



STAR PRL 2000

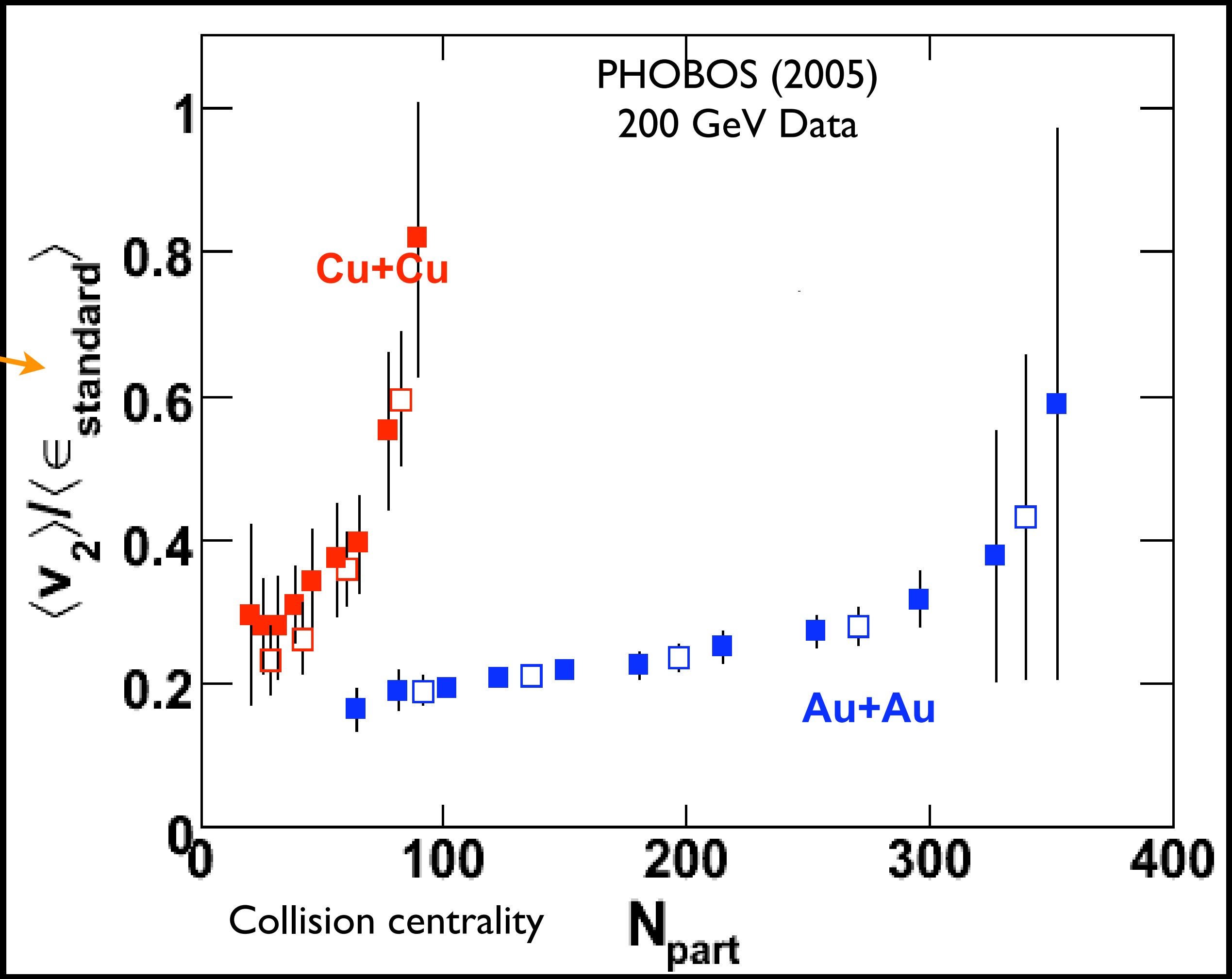


“1:1” translation of initial geometry
to final state azimuthal
particle distribution

“Perfect Fluid”

Challenge: System Size Scaling

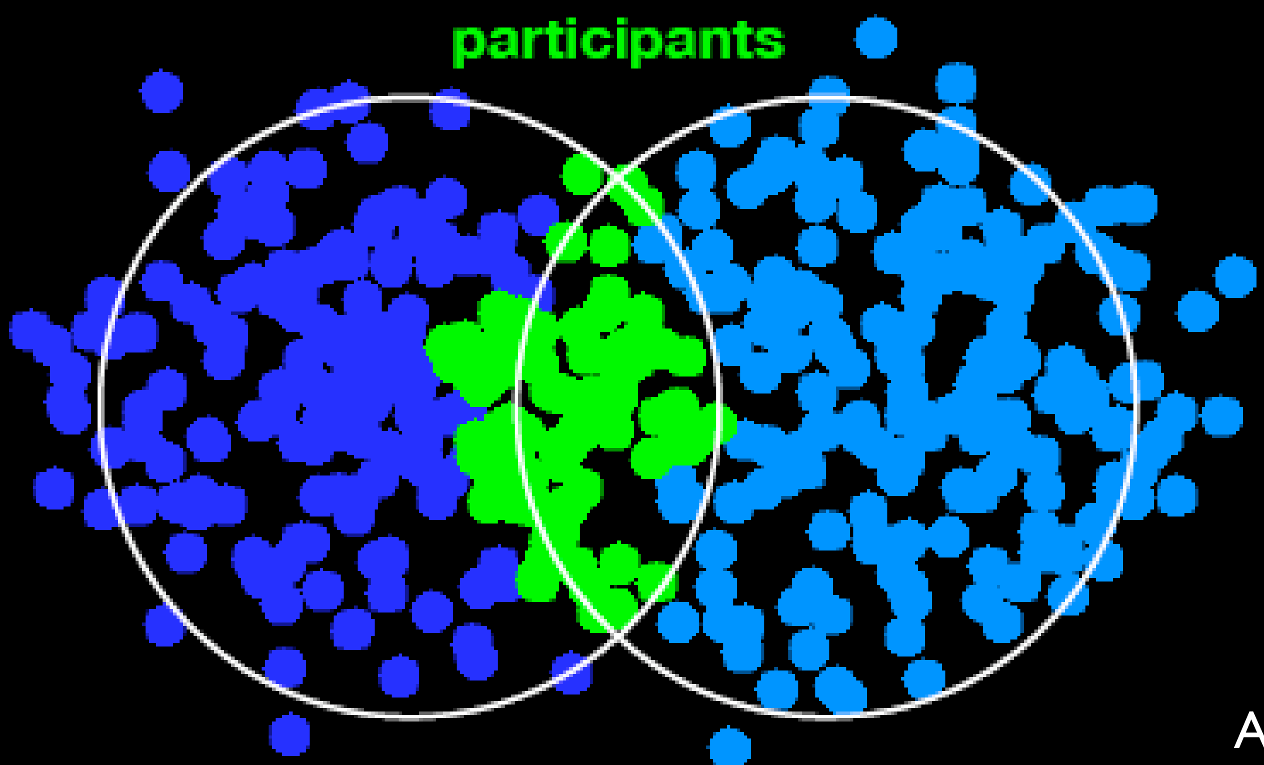
$$\epsilon_{std} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$



For same N_{part} (~ same initial density), v_2/ϵ_{std} is much larger in Cu+Cu than in Au+Au collisions

Re-thinking ϵ

At fixed *b*



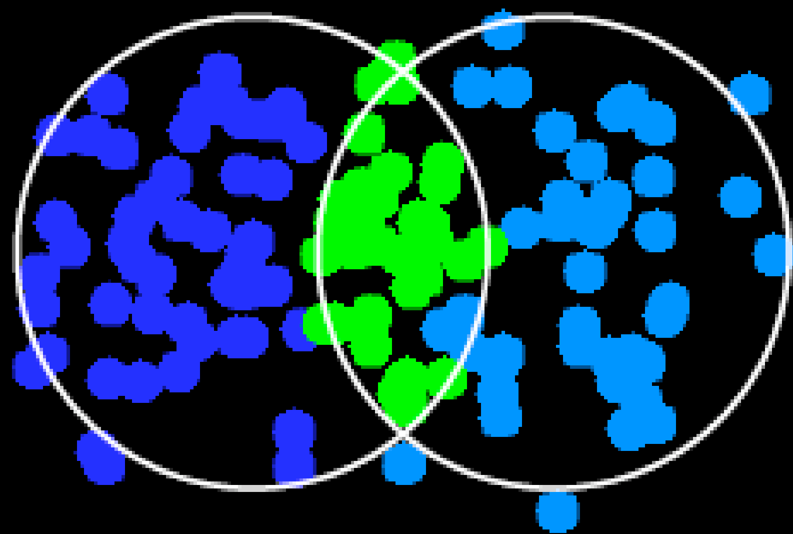
In Glauber MC model, geometry is sampled by finite number of nucleons

➞

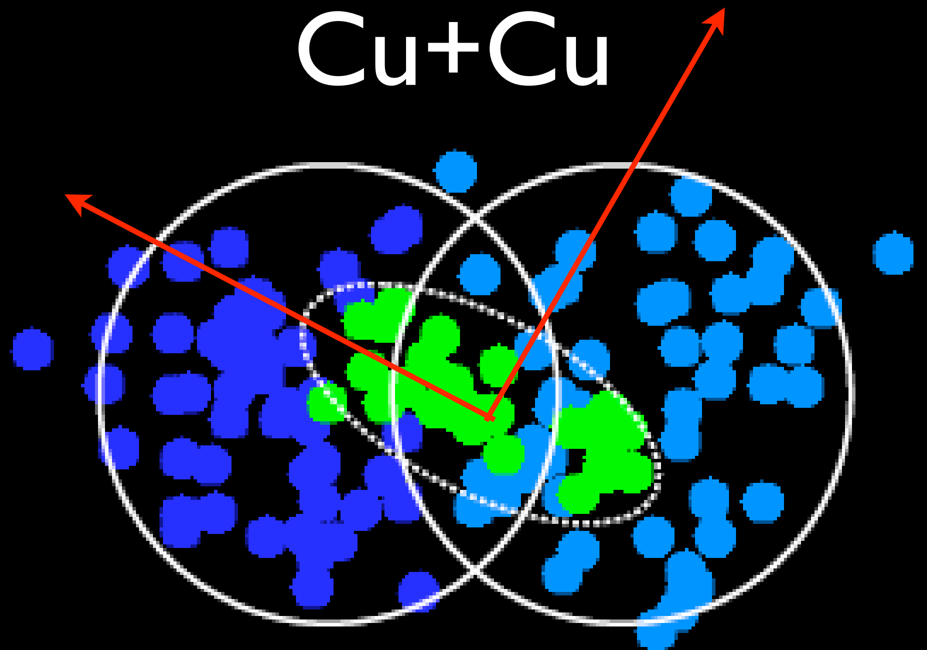
Geometry varies from event-to-event, even at fixed *b*

Aguiar, Hama, Kodama, Osada, hep-ph/0106266 (QM 2001)
Miller, Snellings, nucl-ex/0312008
(4 citations until 2005, 28 since then)
Broniowski et al, arXiv:0706.4266

Collision Geometry Fluctuations



Plots from Richard Bindel, Maryland, using PHOBOS Glauber MC



$$\epsilon_{part} = \frac{\sigma_y'^2 - \sigma_x'^2}{\sigma_y'^2 + \sigma_x'^2} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy}^2)^2}}{\sigma_y^2 + \sigma_x^2}$$

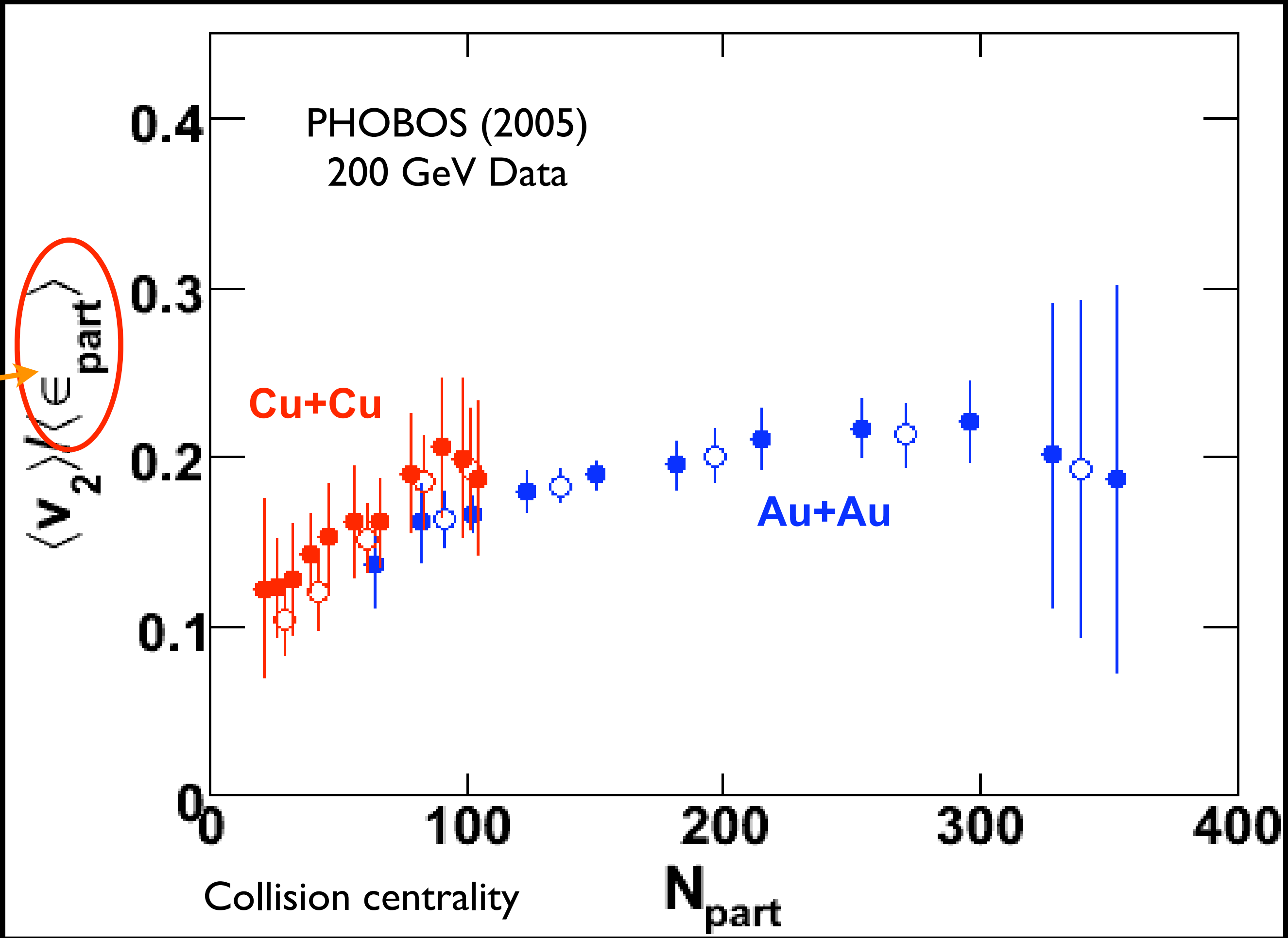
"Participant Eccentricity"

PHOBOS 2005, see also
Broniowski et al, arXiv:0706.4266

If flow is driven by initial matter distribution, the orientation (and shape) of that distribution should determine direction and magnitude of flow

System Size Scaling

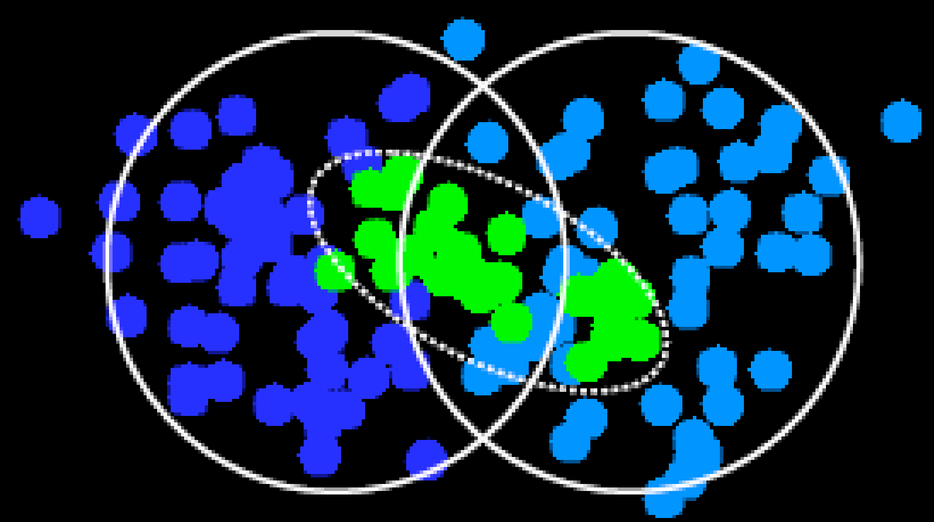
$$\epsilon_{part} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy}^2)^2}}{\sigma_y^2 + \sigma_x^2}$$



Re-interpretation of Glauber MC initial states yields v_2 scaling between Cu+Cu and Au+Au

Collision Geometry Fluctuations

Cu+Cu



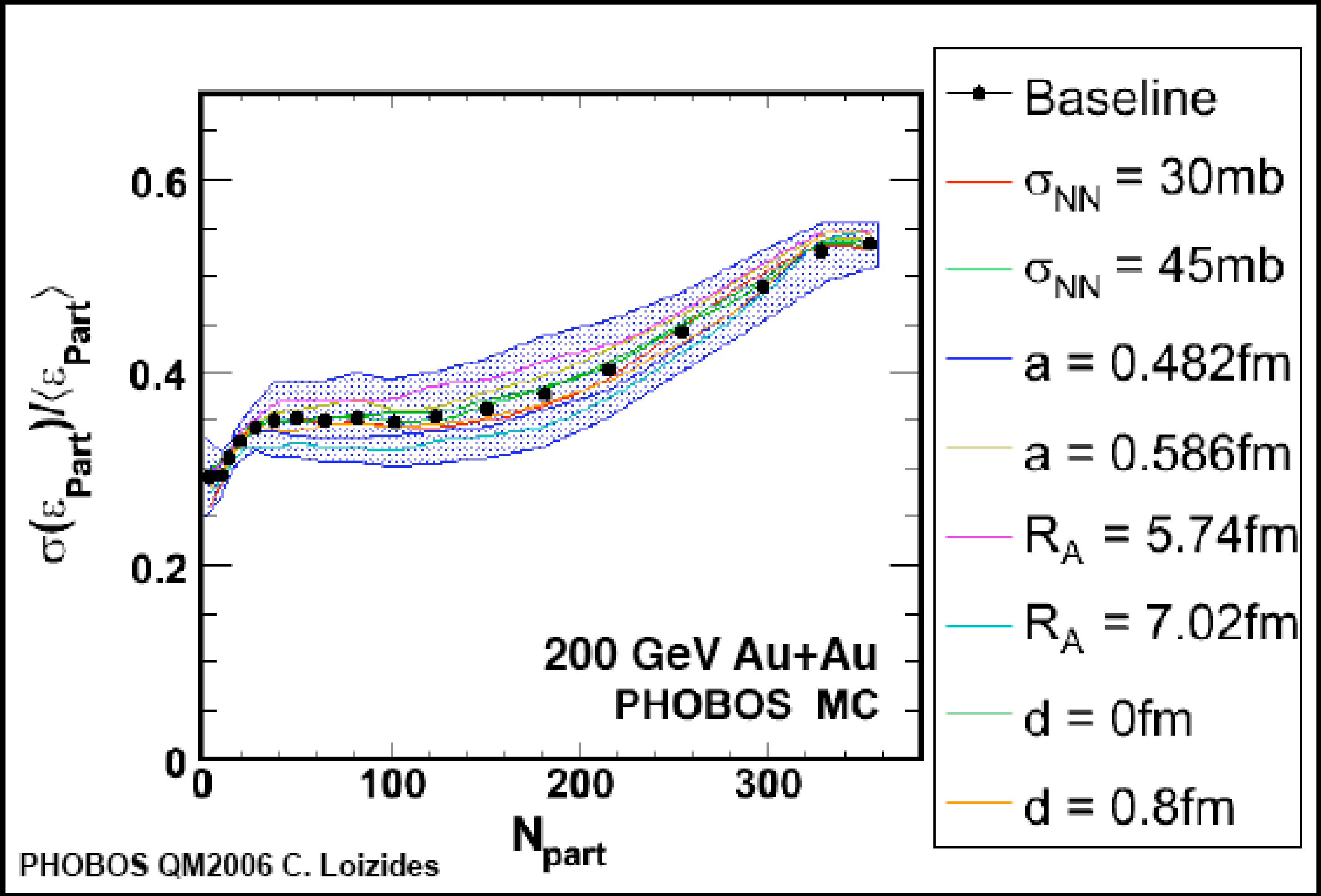
How do we know the Glauber shapes and shape fluctuations are real?

Measure them directly!
If $v_2 \propto \epsilon$, then:

$$\boxed{\frac{\sigma(v_2)}{\langle v_2 \rangle} = \frac{\sigma(\epsilon)}{\langle \epsilon \rangle}}$$

i.e. relative fluctuations in v_2 should be determined by relative fluctuations in ϵ

ϵ_{part} Fluctuations in Glauber MC

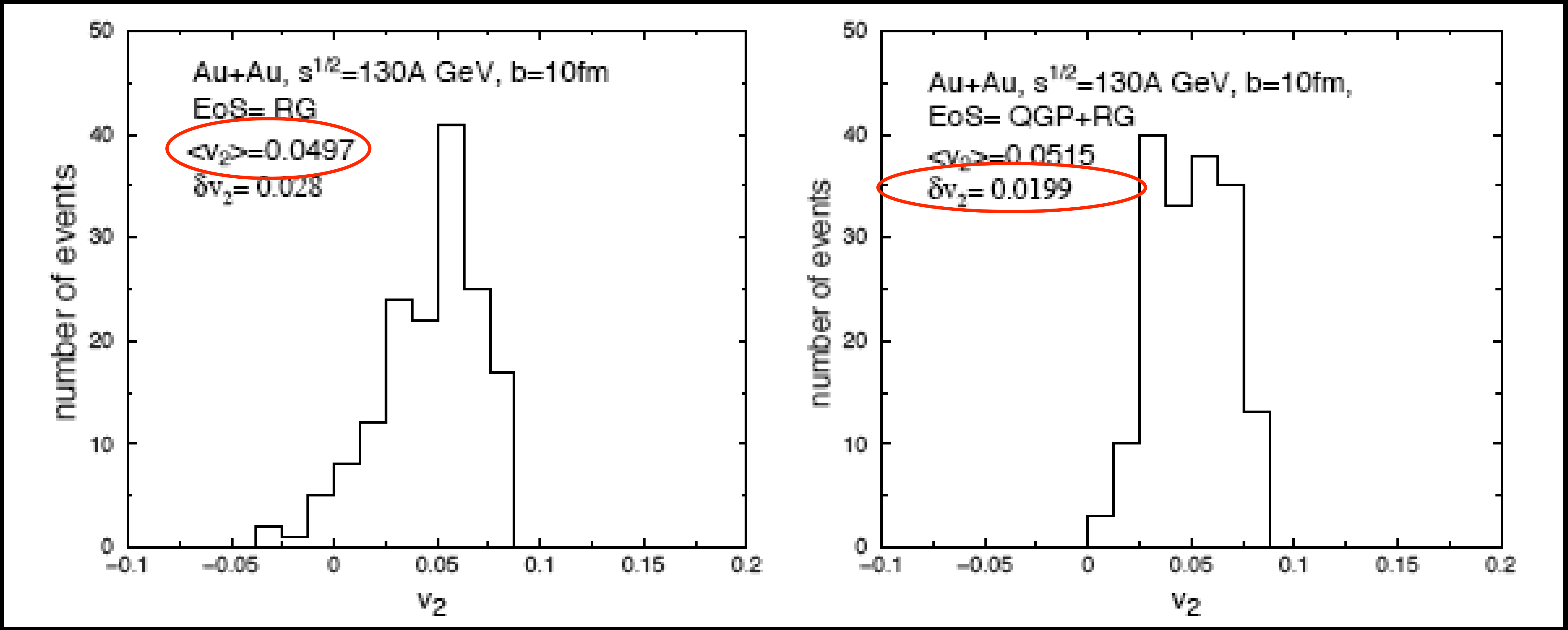


Large event-by-event variation of ϵ_{part} (~40%)

Robust against variation of Glauber MC parameters

MC Glauber Fluctuations and Hydro

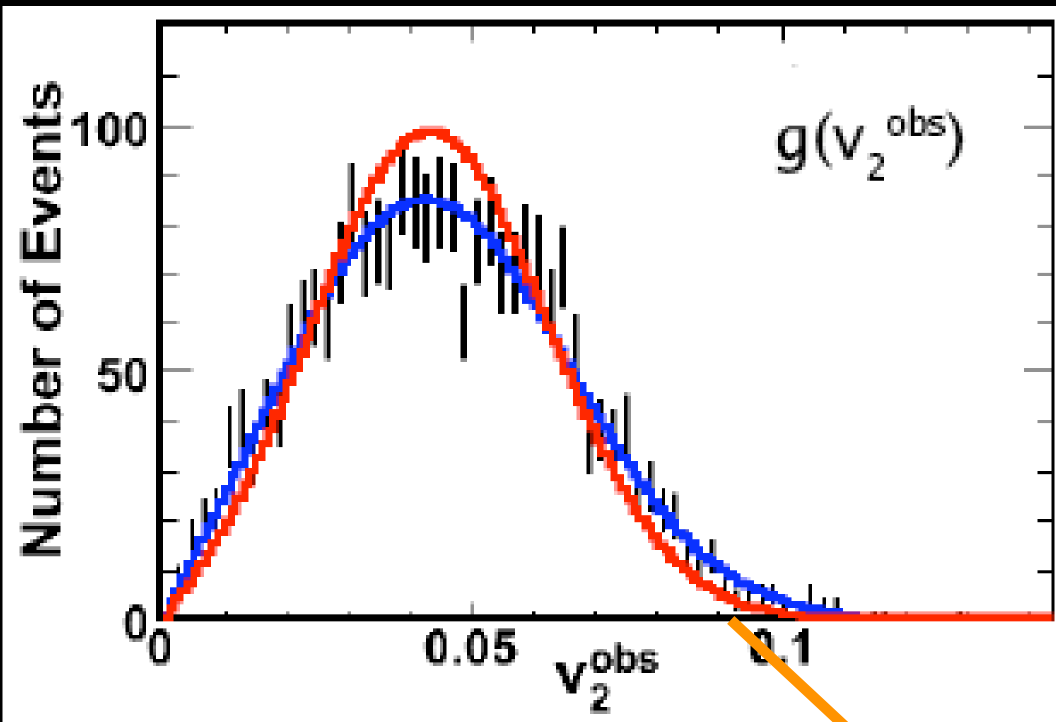
Aguiar, Hama, Kodama, Osada, hep-ph/0106266 (QM 2001)



Using Glauber MC initial conditions (NeXus) in Hydro

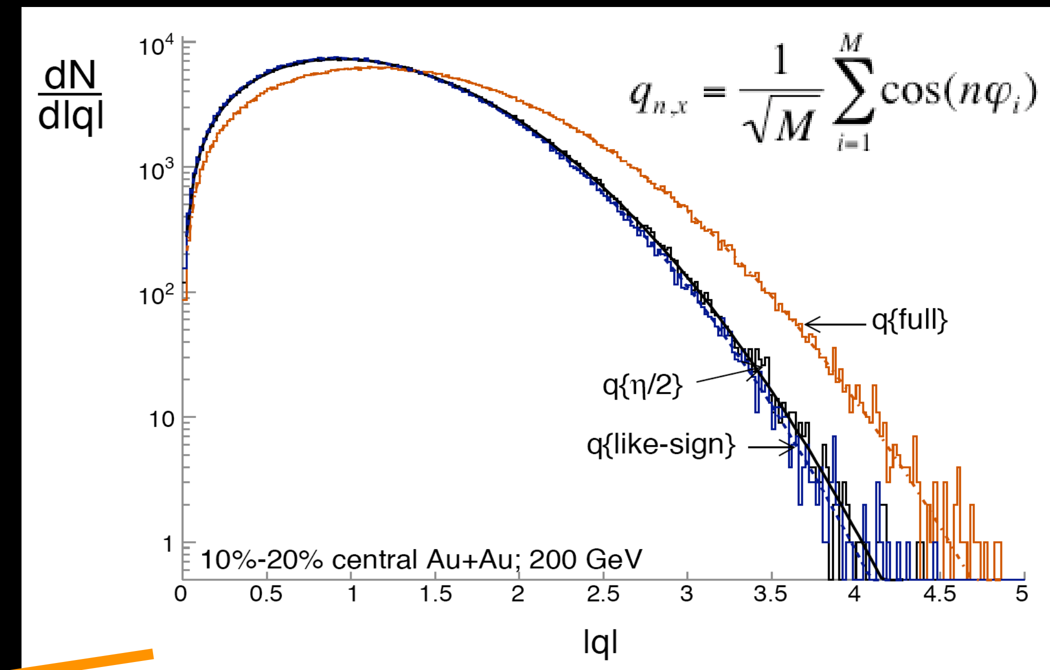
Sensitivity to EoS?

Extracting v_2 Fluctuations



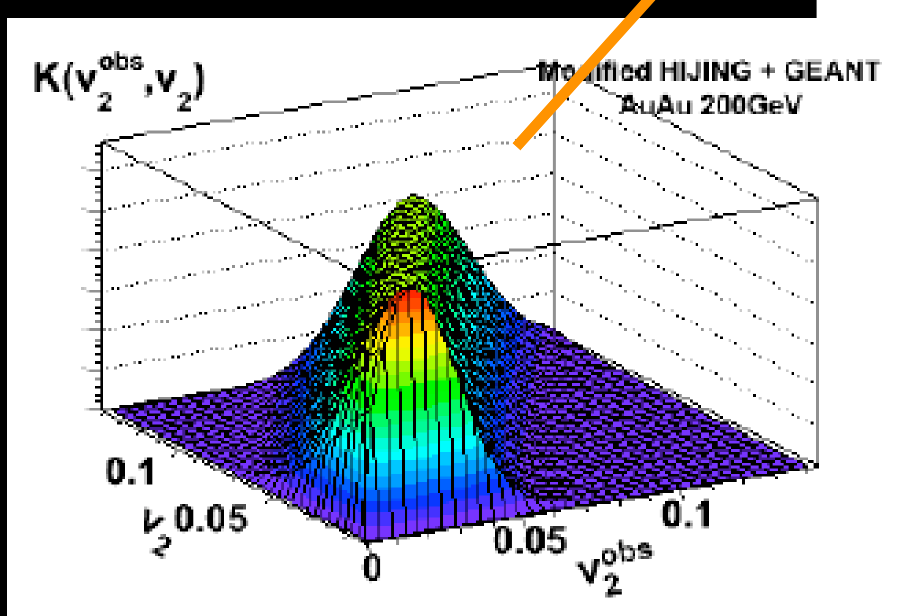
PHOBOS: event-by-event fit of (v_2,ϕ_0) over ~ 4π

Measured



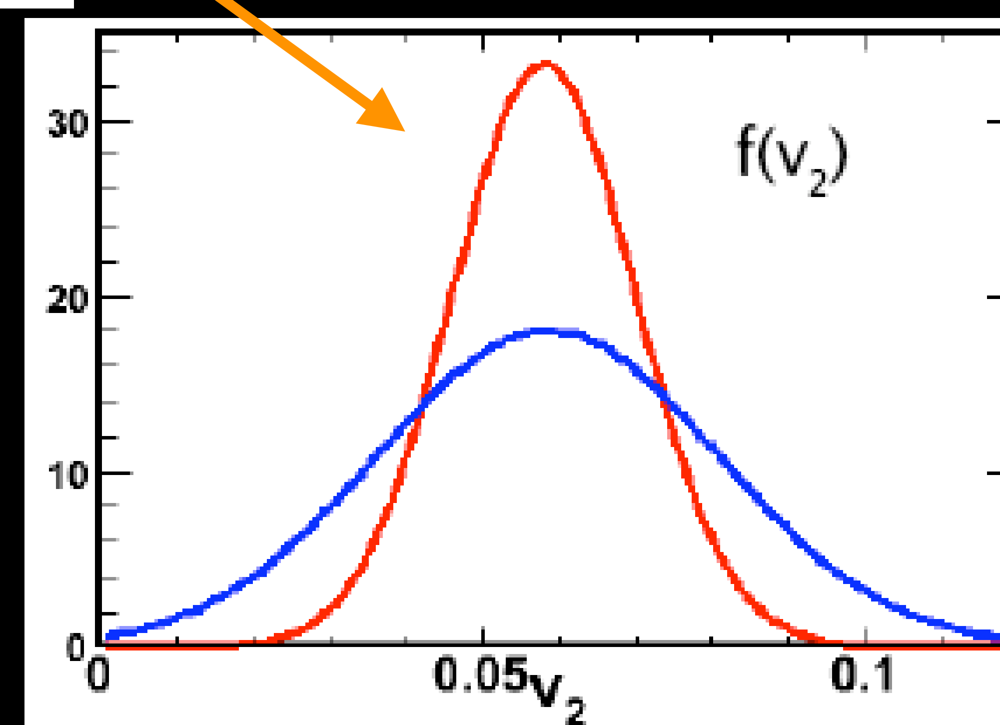
STAR: distribution of event-by-event Q-vector in -1 < η < 1

$$\underbrace{g(v_2^{obs})}_{\text{Measured}} = \int_0^1 \underbrace{K(v_2^{obs}, v_2)}_{\text{Constructed from MC}} \underline{f(v_2)}\, dv_2$$



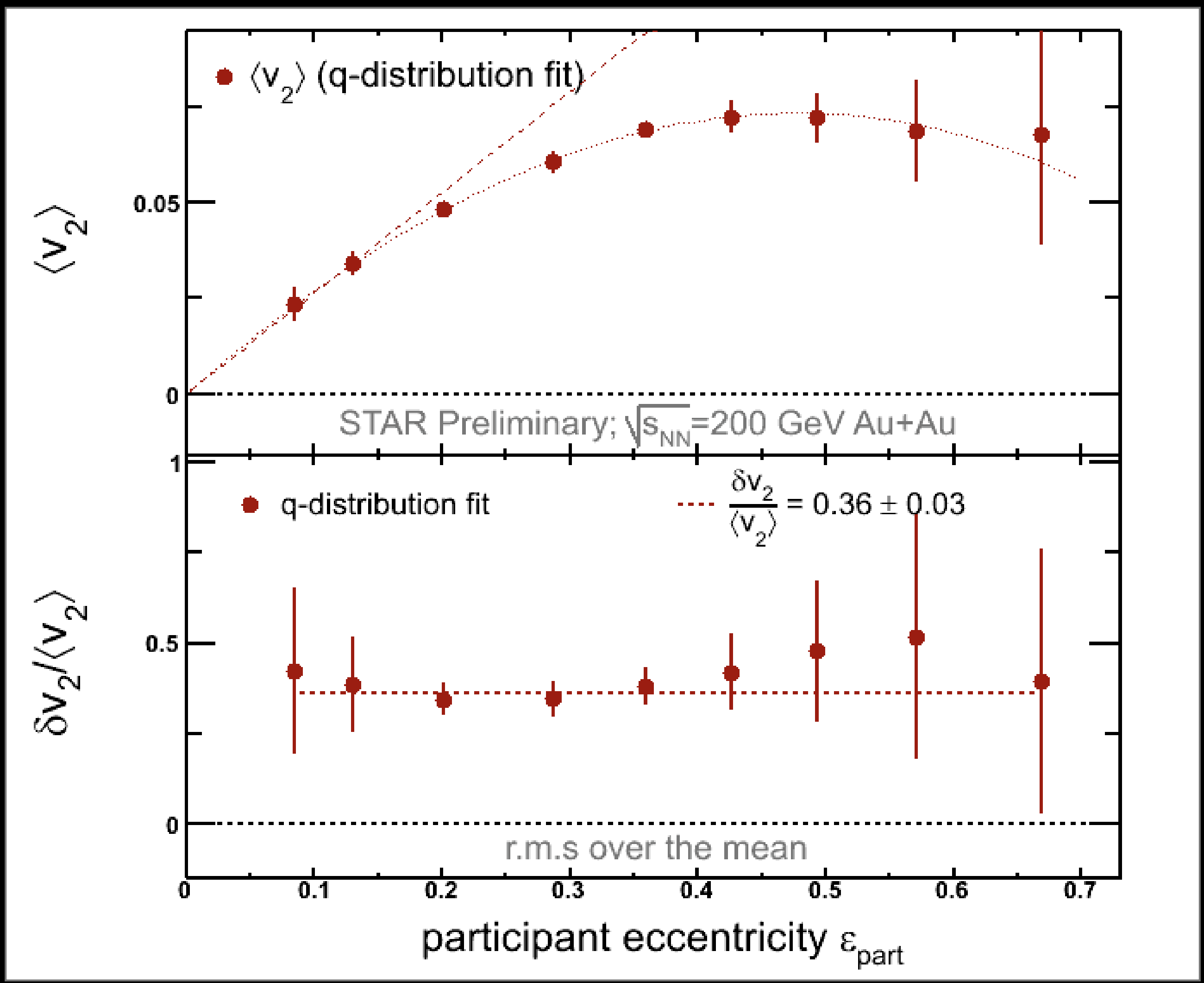
Correction function

Corrected

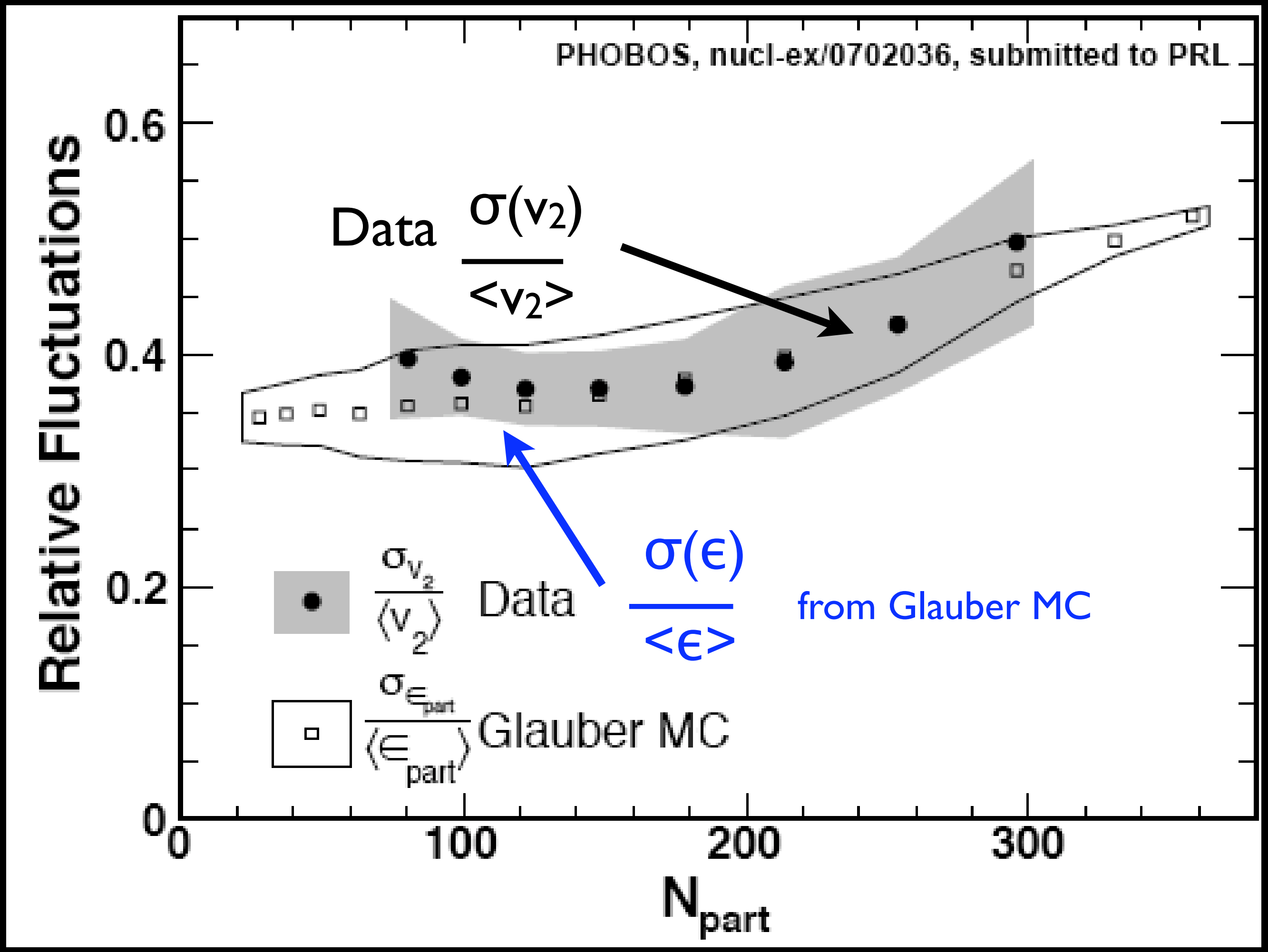


v_2 Fluctuations at QM 2006

STAR QM 2006



PHOBOS, QM 2006

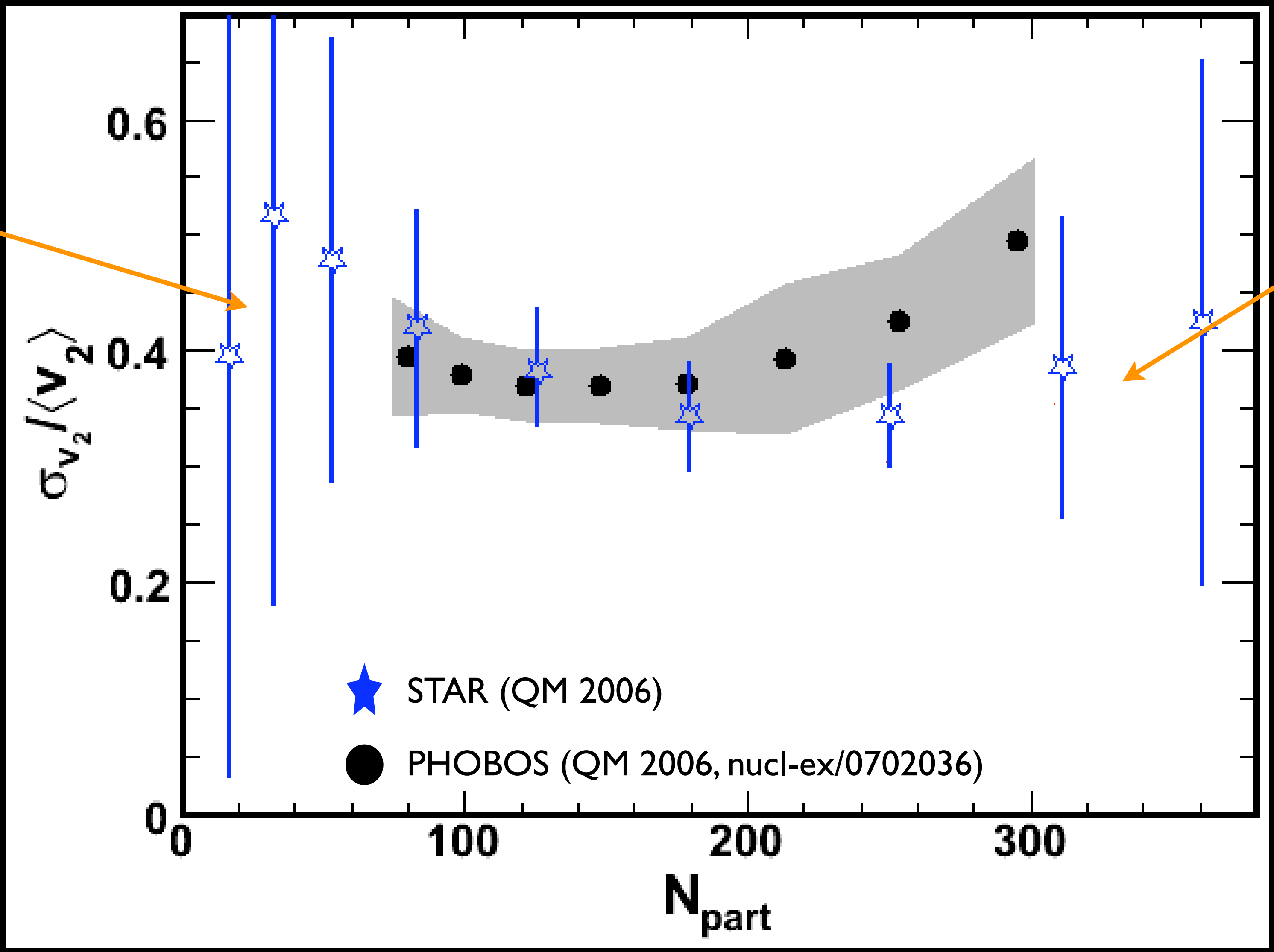


Both experiments observe event-by-event variation of v_2 by 40%

Weak dependence on collision centrality

v_2 Fluctuations at QM 2006

Small multiplicity



Small v_2

Both experiments observe event-by-event variation of v_2 by 40%
Weak dependence on collision centrality

A Twist...

arXiv.org > nucl-ex > arXiv:nucl-ex/0612021

Search o

Nuclear Experiment

Elliptic flow fluctuations in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV

Paul Sorensen (for the STAR Collaboration)

(Submitted on 19 Dec 2006 (v1), last revised 13 Jul 2007 (this version, v2))

Please note that after these results were reported at Quark Matter 2006 and posted on the preprint server it was found that what is reported here as \textit{elliptic flow fluctuations}, should rather be taken as an upper limit on the fluctuations. Further analysis has shown that fitting the multiplicity dependence of the q-distribution does not enable one to disentangle non-flow and fluctuations. The data from the q-vector distrubution does not, therefore, exclude the case of zero fluctuations. The remainder of these proceedings we leave as they were originally reported.

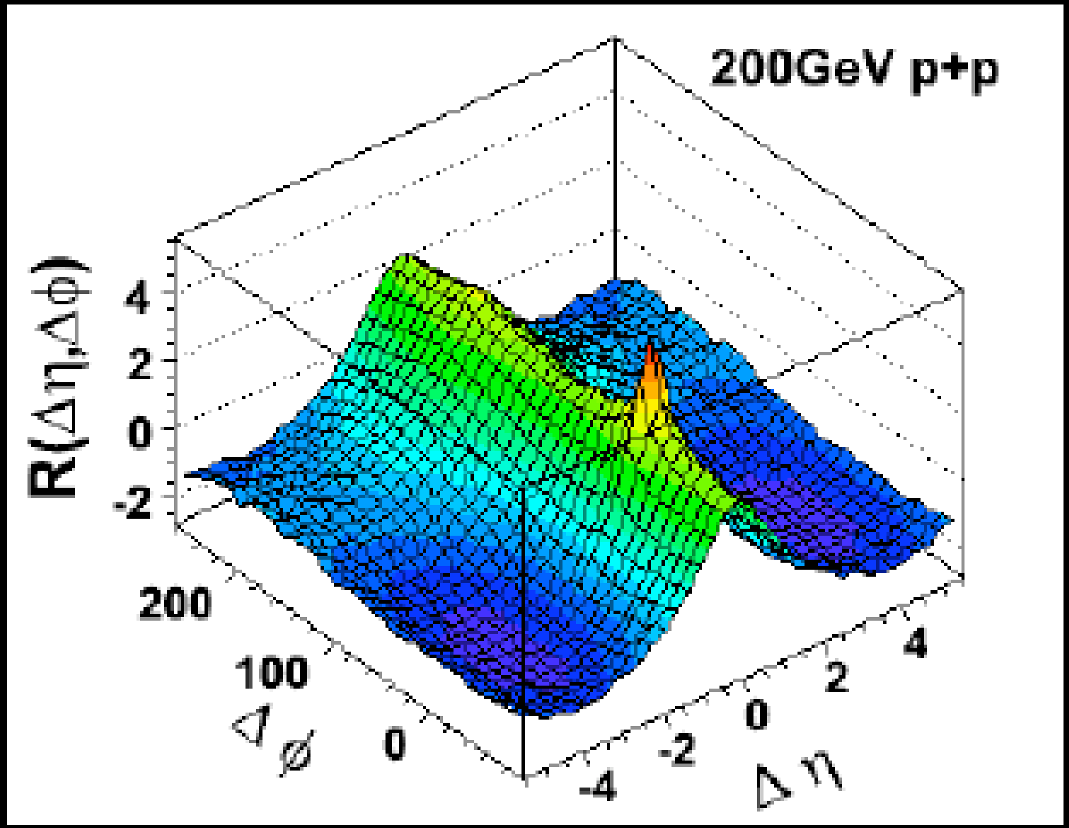
Comments: Statements regarding disentangling non-flow and fluctuations by examining the multiplicity dependence of the q-vector distributions are retracted: data presented here on elliptic flow fluctuations should be taken as an upper limit on the fluctuations

Subjects: **Nuclear Experiment (nucl-ex)**

Cite as: arXiv:nucl-ex/0612021v2

Non-Flow Effects

$$R(\Delta\eta) = \langle (n-1)\left(\frac{\rho(\eta_1-\eta_2)}{\rho_{mix}} - 1\right)\rangle$$

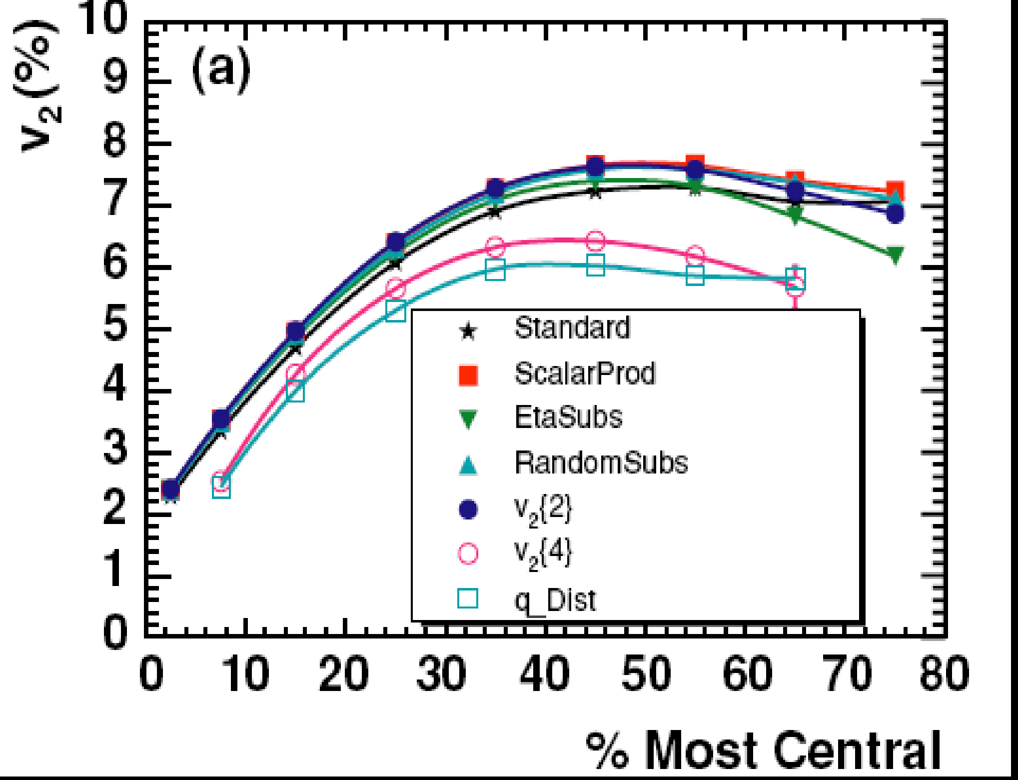


“Clusters”
“Mini-jets”
“Non-flow”

Particles are not produced independently

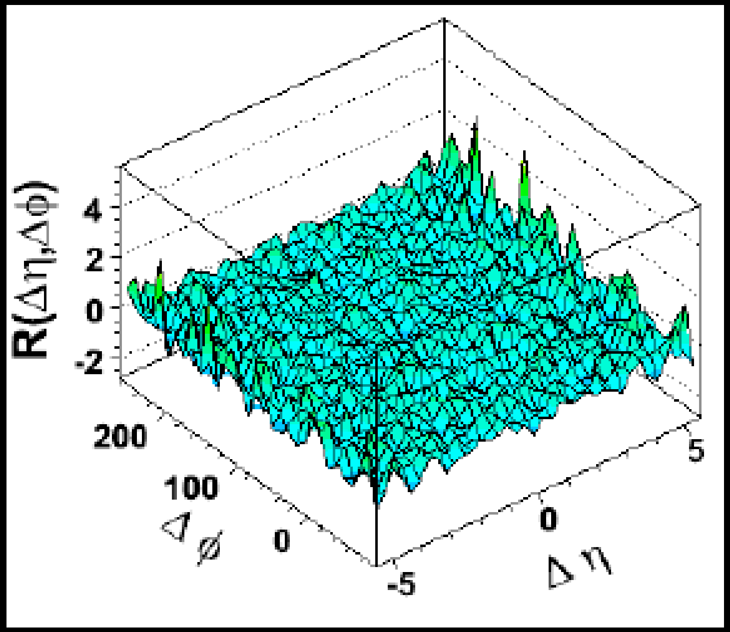
Δϕ structure of correlations can mimic flow and flow fluctuations

PHYSICAL REVIEW C **72**, 014904 (2005)

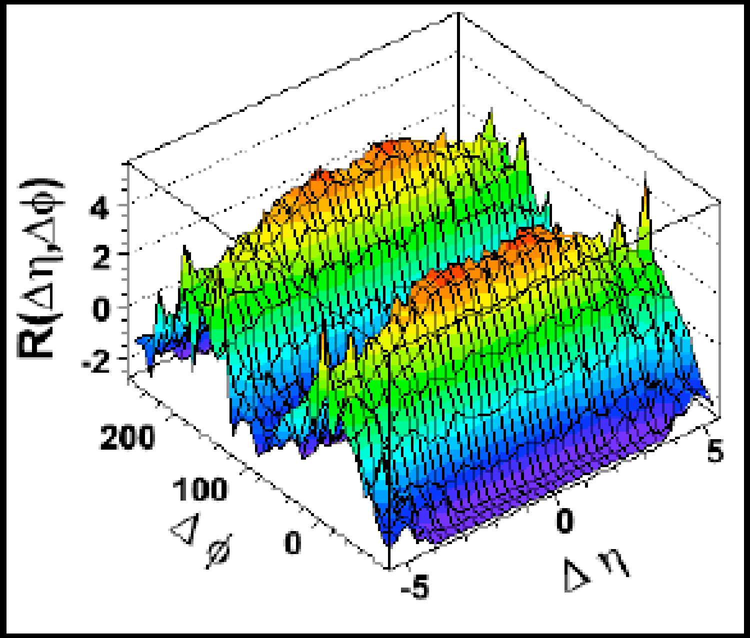


Angular Correlation Functions

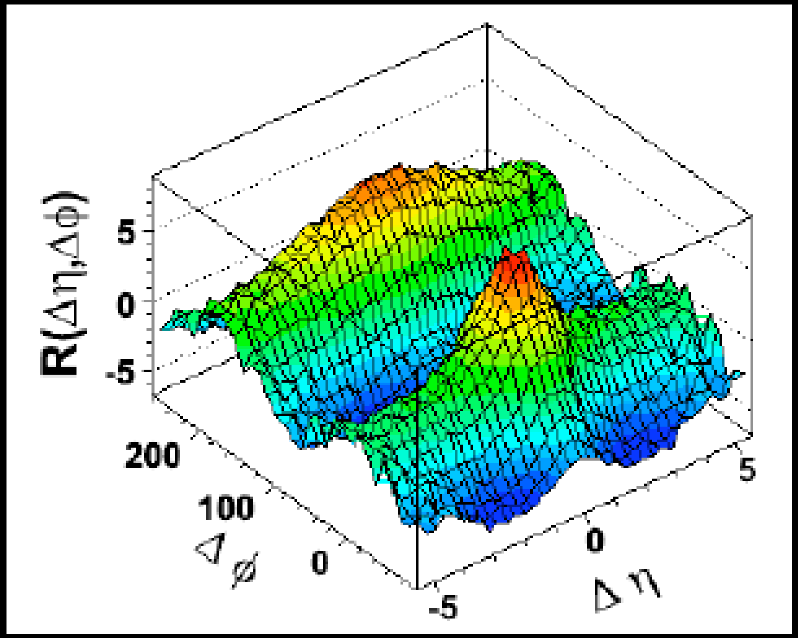
Plots from Burak Alver using cluster model MC



No flow
No correlations



flow
No correlations

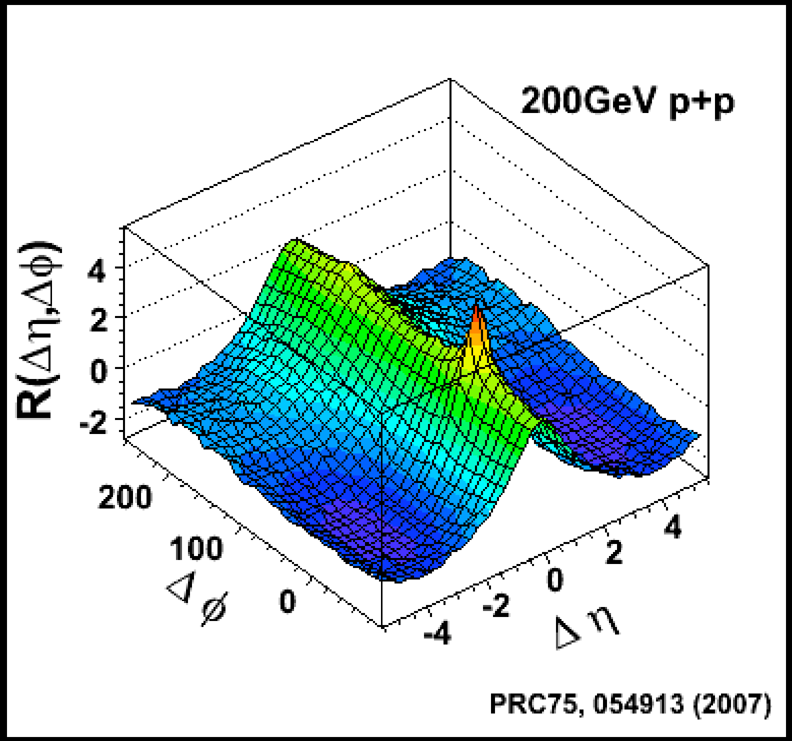


flow
cluster decay

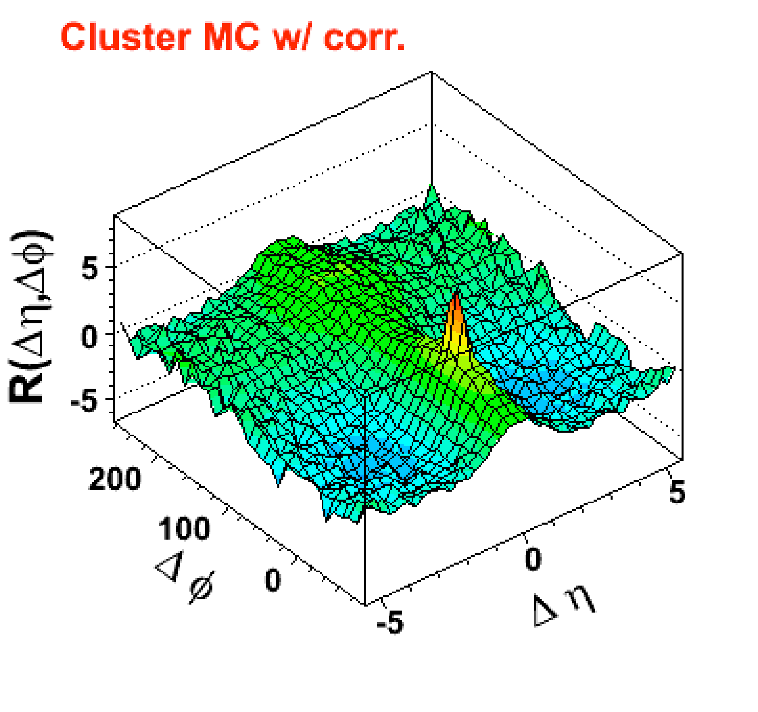
Can one disentangle effects of flow and non-flow correlations?

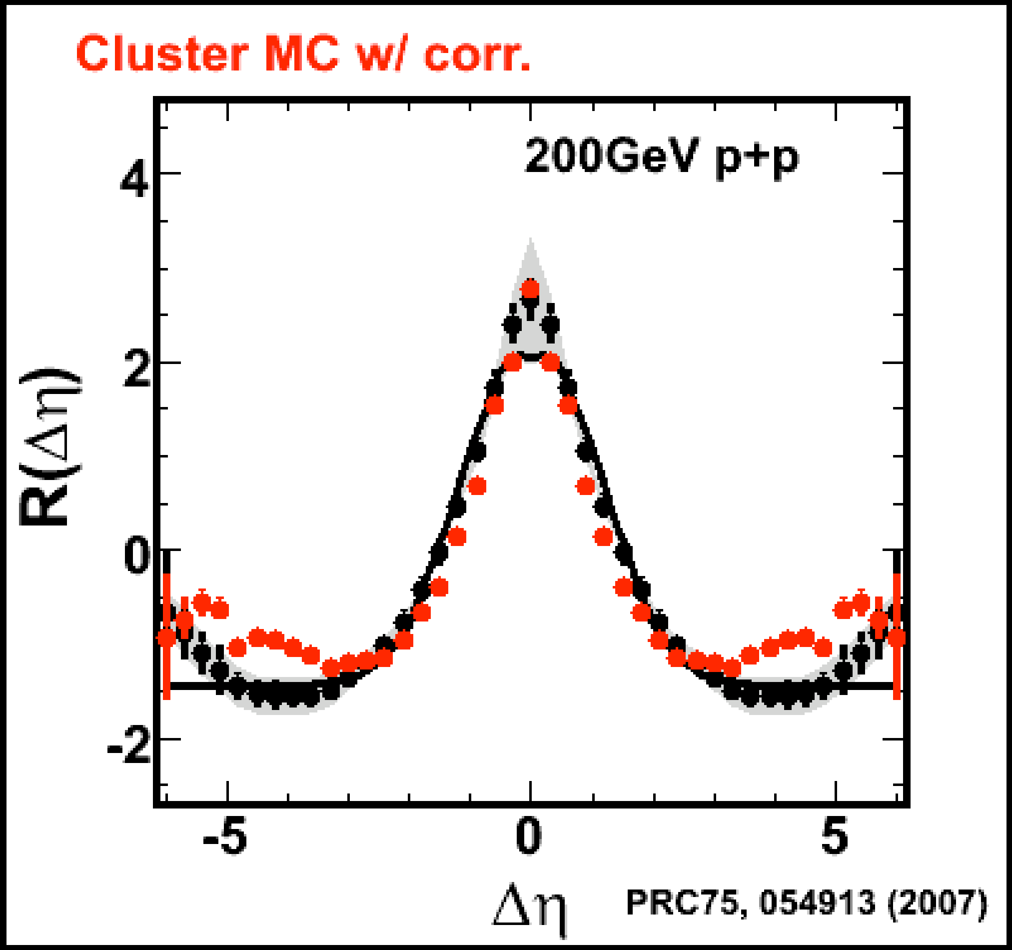
Model studies with flow, flow fluctuations and “clusters”

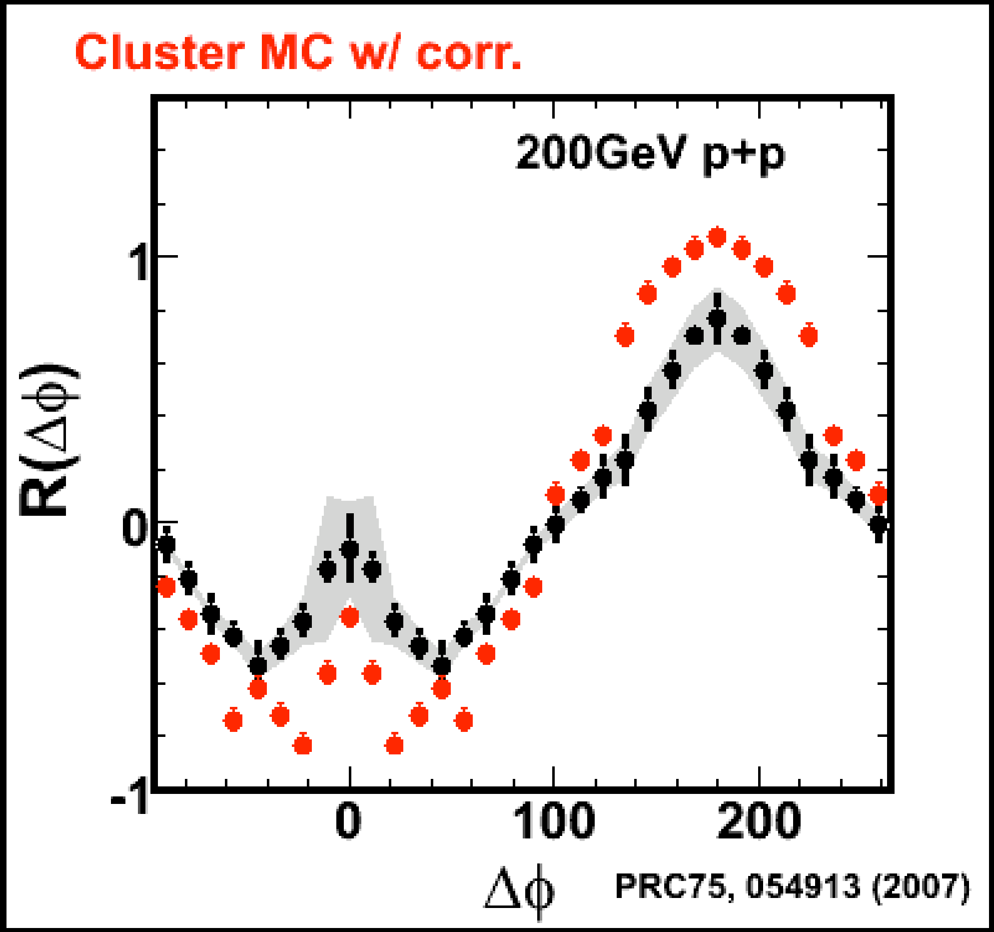
Cluster Model vs Data



Study by
Burak Alver (MIT),
Wei Li (MIT),
Krzysztof Wozniak (Krakow)
using cluster model MC

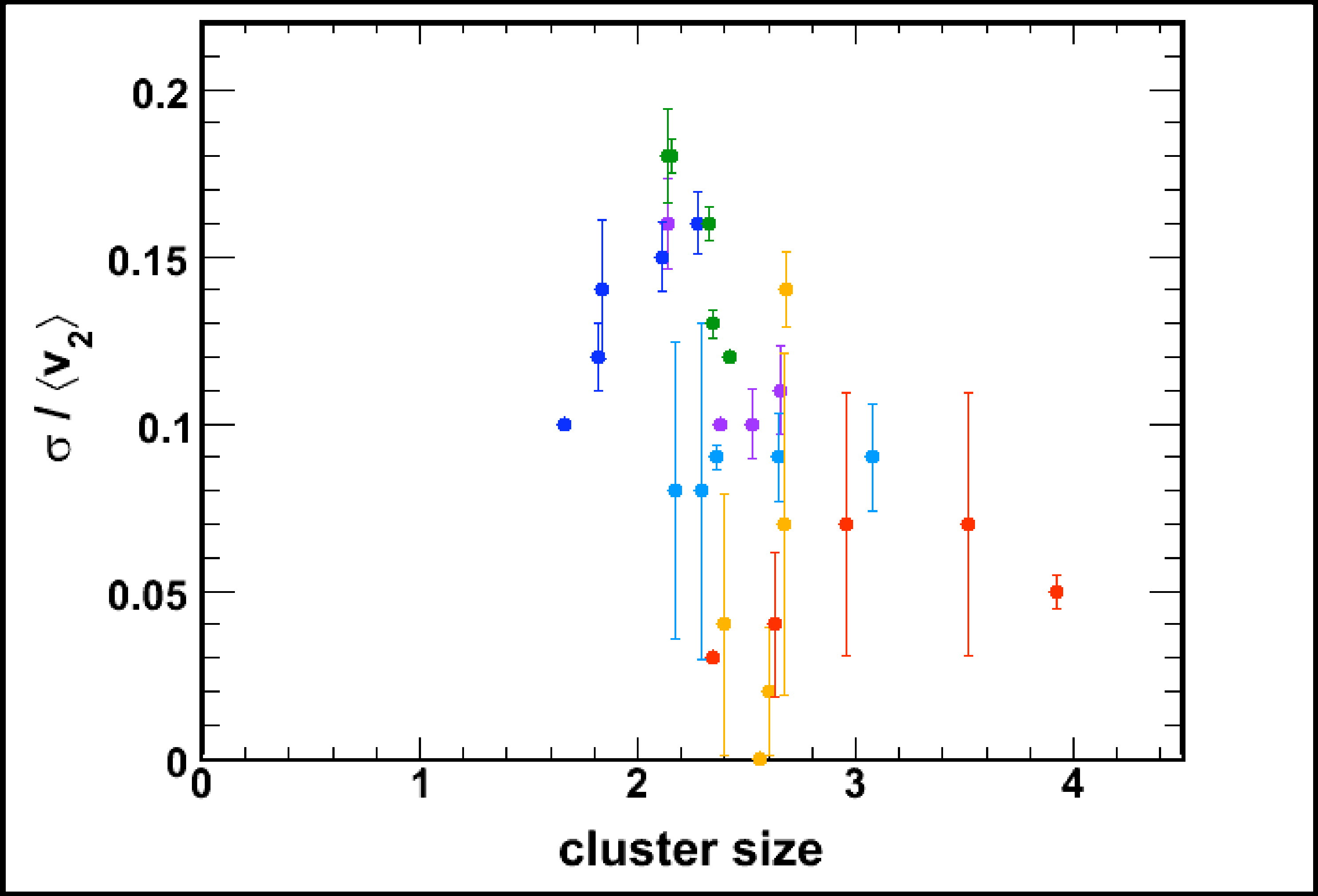






v_2 Fluctuations from Clusters

Study by
Burak Alver (MIT) using cluster
model MC



Cluster models with *constant* “true” v_2 yield significant v_2 fluctuations

But “cluster size” is not the correct scaling parameter

v_2 Fluctuations from Clusters

Paul Sorensen (STAR),
HIC Montreal July 2007

Multiplicity

$$\sigma^2 \approx \frac{1}{2}\left(1 + v_4 - 2v_2^2 + M\left(\delta_2 + 2\sigma_{v_2}^2\right)\right)$$

$$\delta_2 = \left\langle \cos 2\left(\varphi_1 - \varphi_2\right)\right\rangle$$

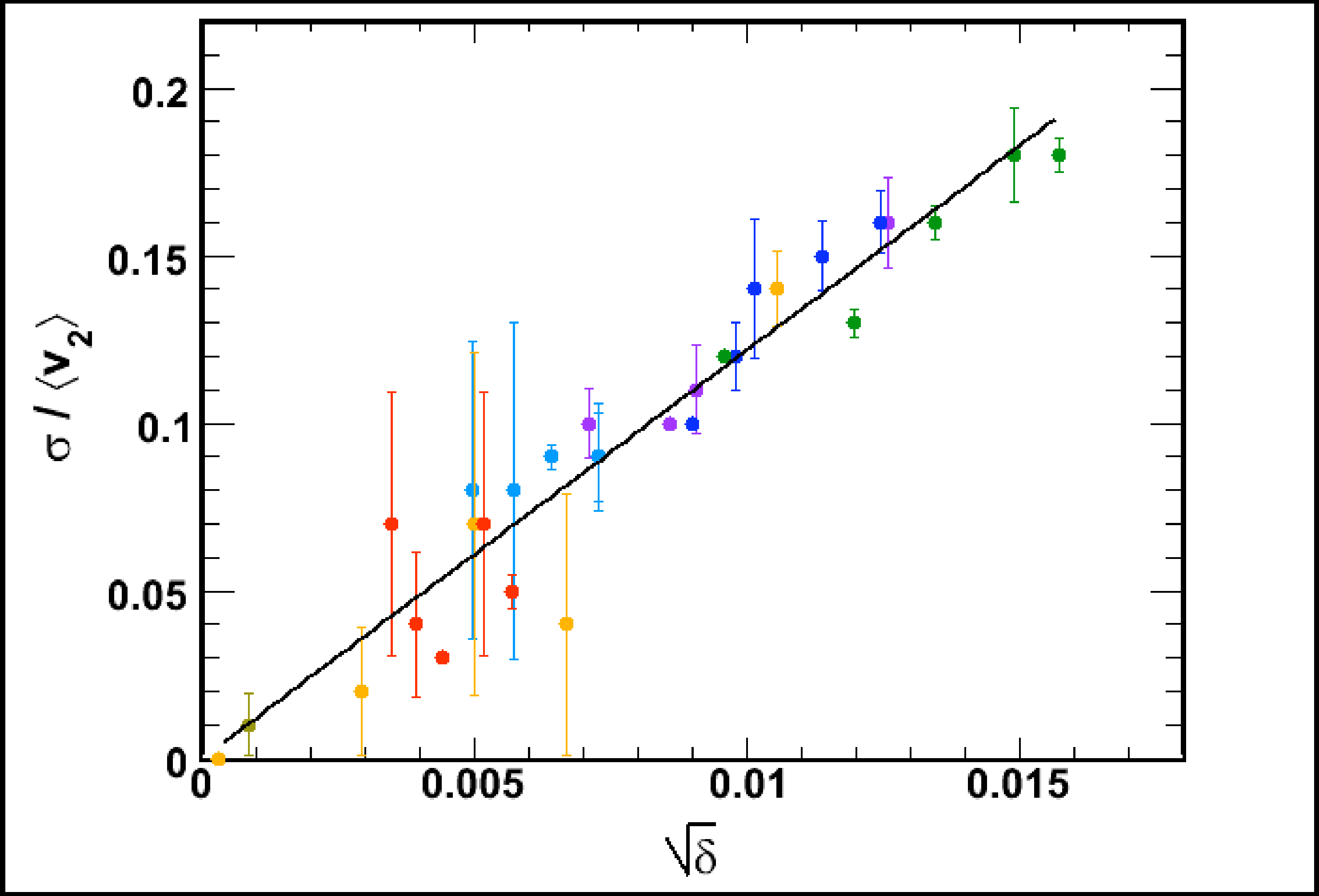
Fluctuations of
q-vector distribution

$\Delta\phi$

The cluster (non-flow) contribution to fluctuations scales with the flow-like $\langle\cos(2\,\Delta\phi)\rangle$ term of the cluster correlation functions

v_2 Fluctuations from Clusters

Study by
Burak Alver (MIT) using cluster model MC



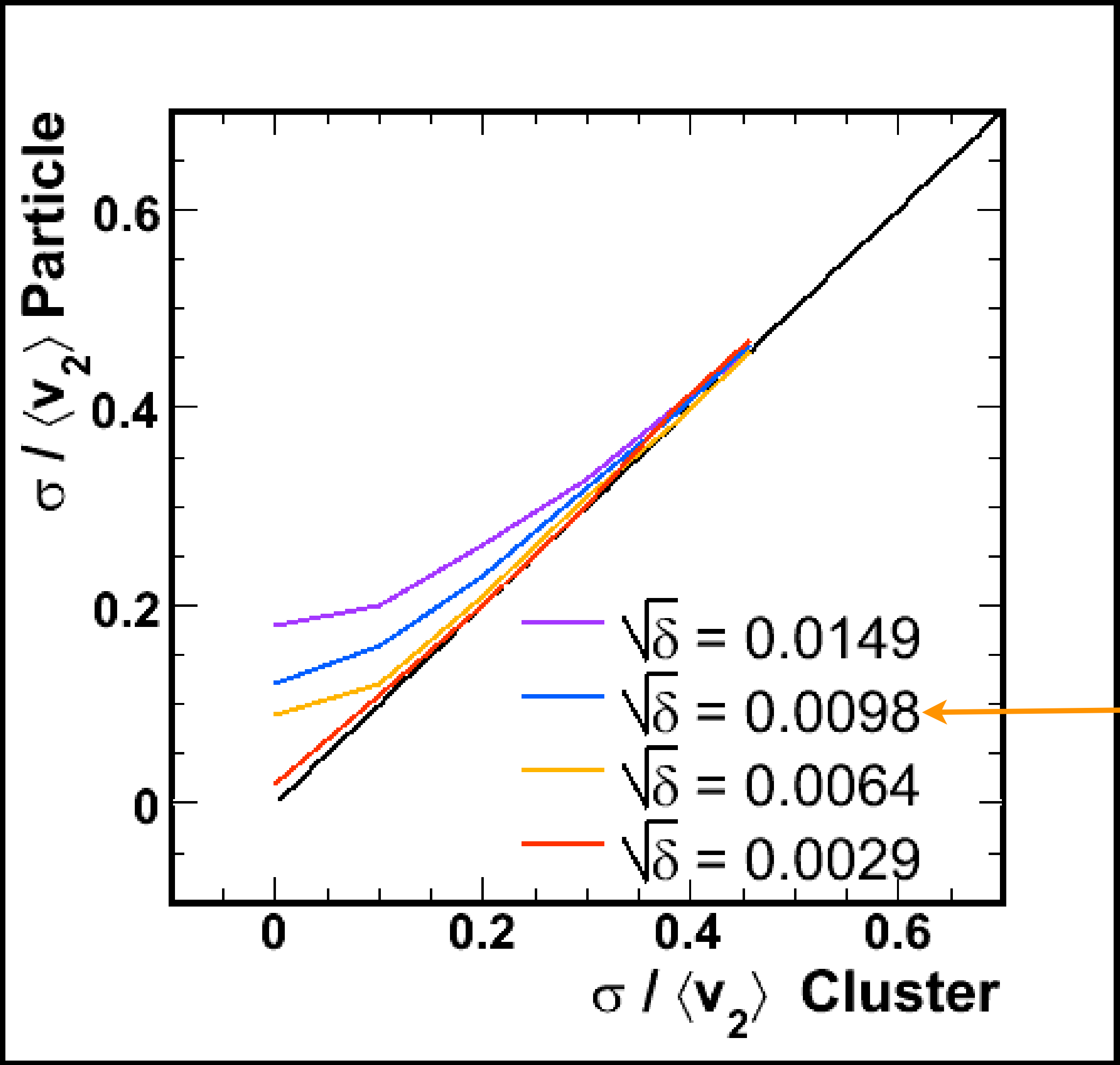
Clusters models with constant cluster v_2

"δ" indeed appears to be the correct parameter characterizing v_2 fluctuations from clusters

How big is the contribution in the data?

v_2 Fluctuations from Clusters

Study by
Burak Alver (MIT) using cluster model MC

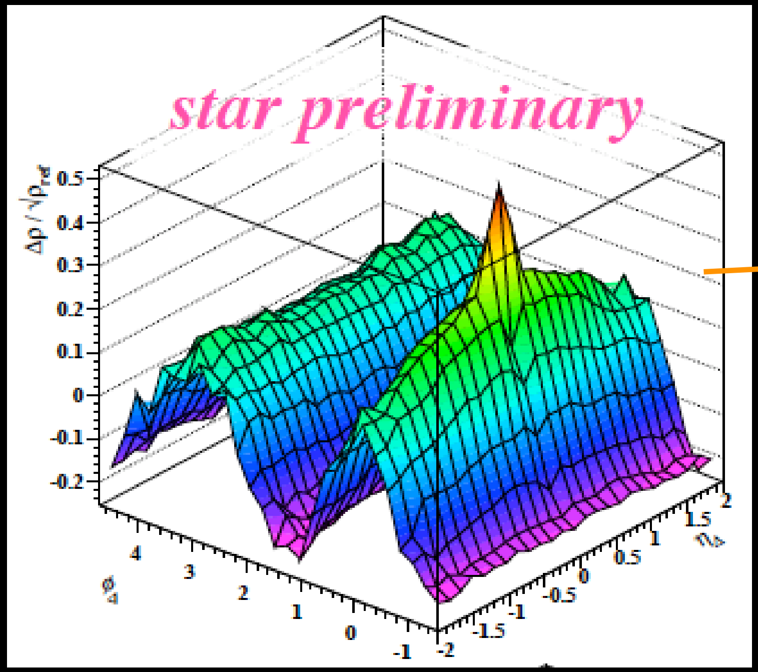


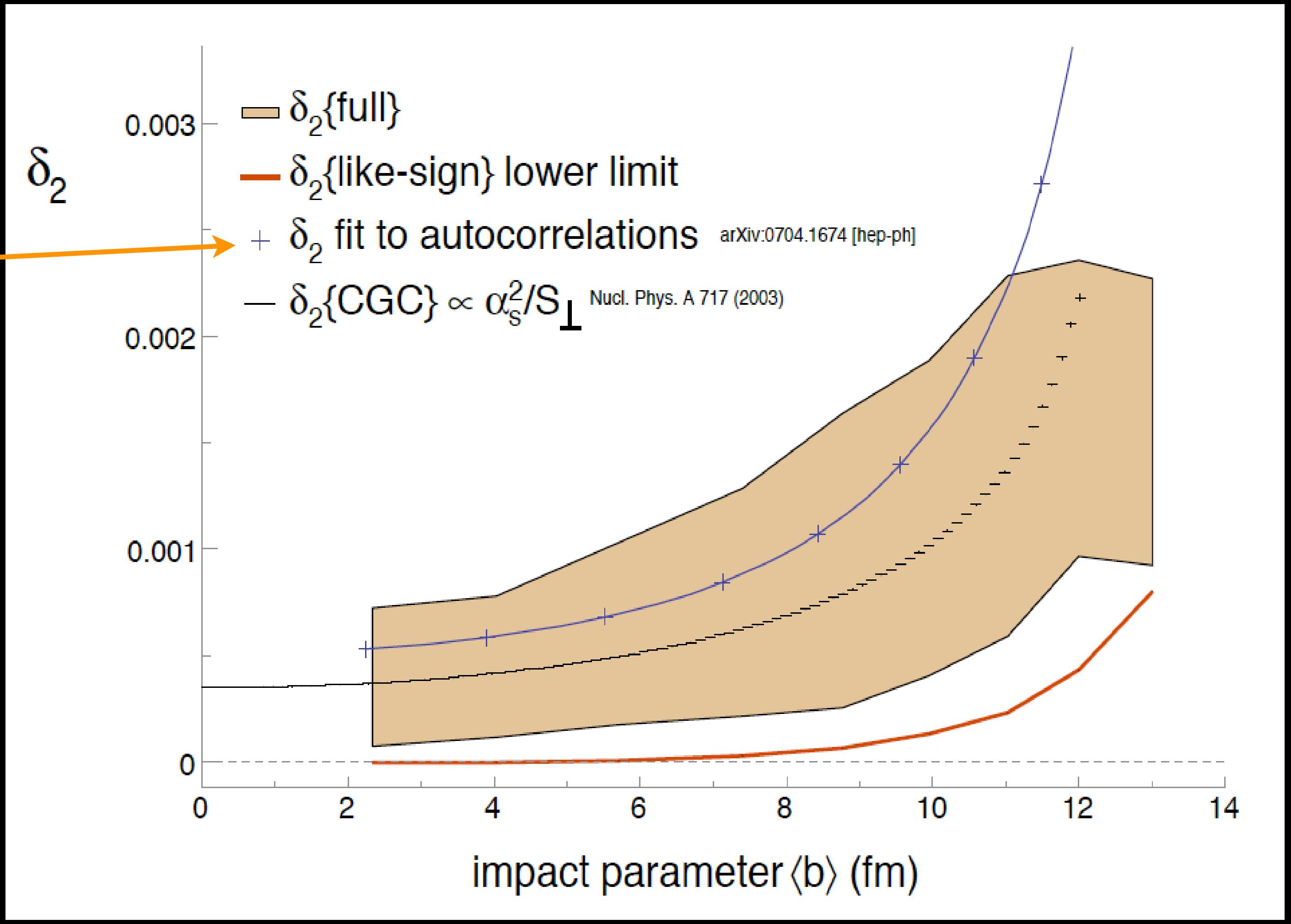
HIJING/p+p data
in PHOBOS acceptance

To explain full fluctuation result using non-flow correlations would require much stronger correlations than seen in p+p

v_2 Fluctuations from Clusters

Paul Sorensen (STAR),
HIC Montreal July 2007



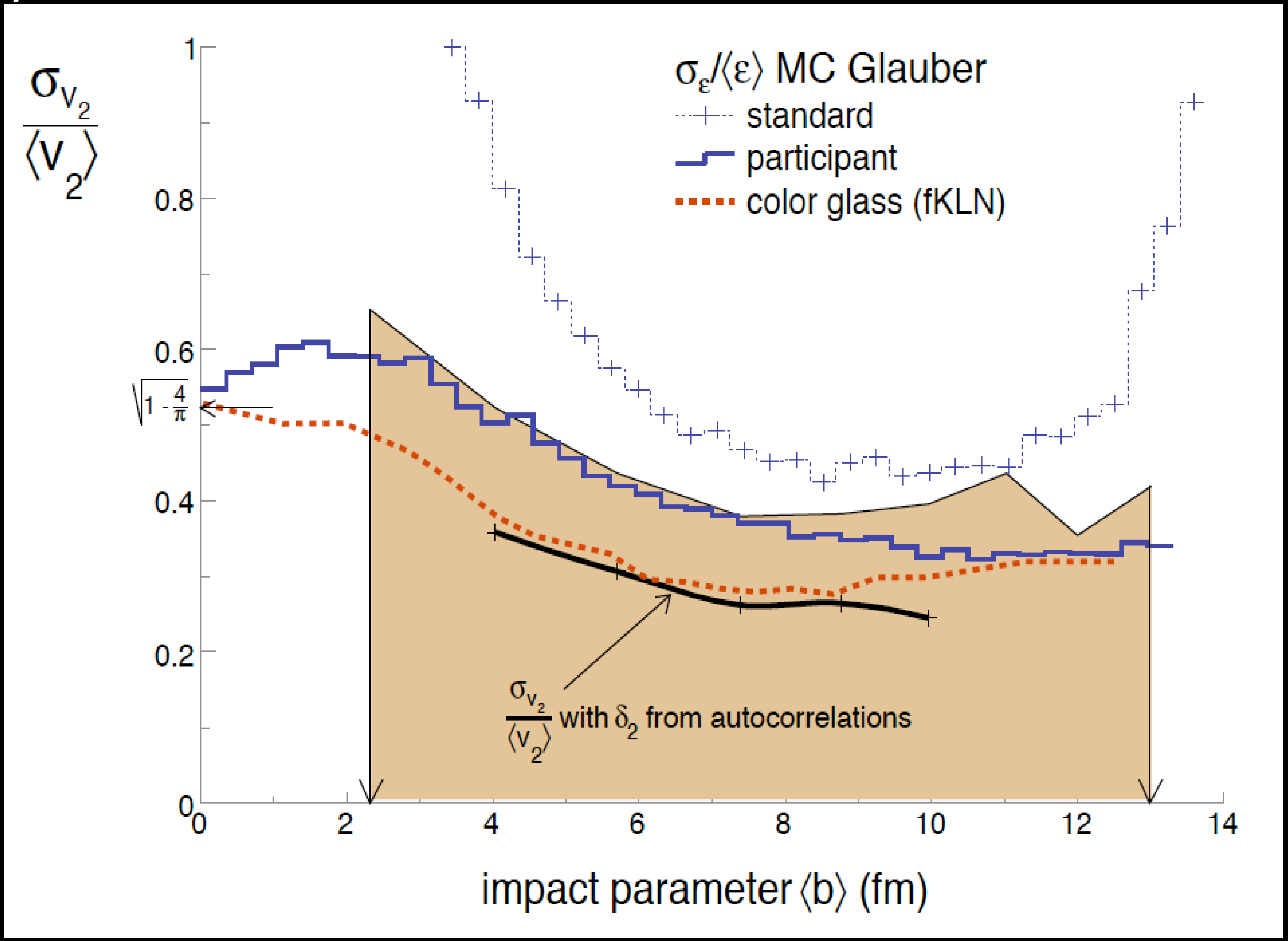


Decompose* observed two-particle correlations to estimate δ

*it is not clear if this can be done in a model independent way

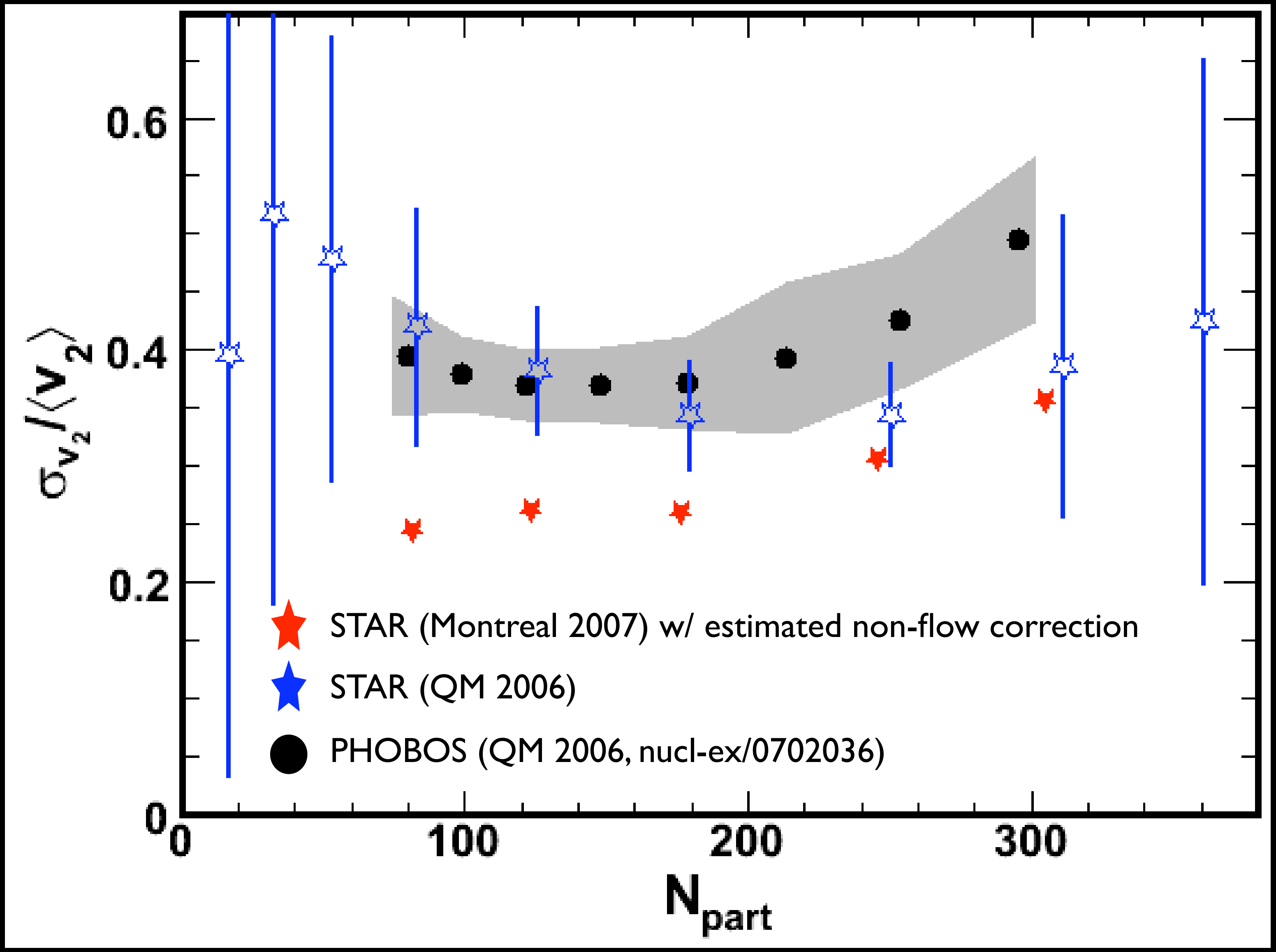
Results revisited

Paul Sorensen (STAR),
HIC Montreal July 2007



Significant change from observed
final state v_2 fluctuations to estimated “true” flow fluctuations

Results revisited



Significant change from observed final state v_2 fluctuations to estimated "true" flow fluctuations

Summary I

- STAR and PHOBOS have observed large fluctuations of *final state hadron* v_2
  - This statement is correct regardless of contribution of non-flow (cluster, mini-jet, etc) correlations
- *Interpretation* of data requires quantitative understanding of correlations
  - Relevant term looks like flow

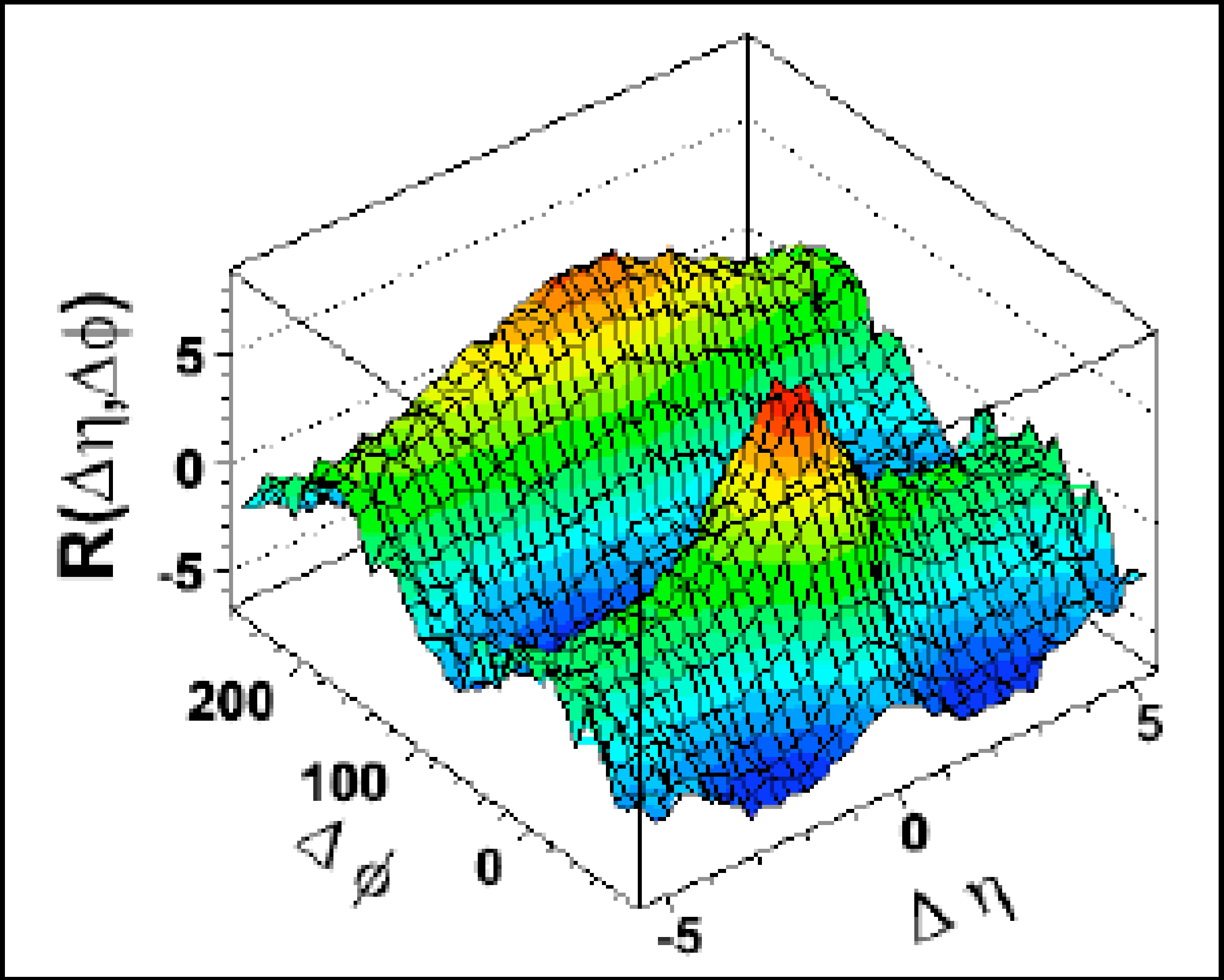
Summary II

- Efforts to correct for non-flow contribution underway
  - Based on two-particle correlation measurement
  - Factor x2 difference in estimated δ between STAR and PHOBOS
    - Result of different acceptance ($|\eta| < 1$ vs $|\eta| < 5.4$)?
  - *Is there enough independent information to distinguish flow fluctuations and non-flow correlations?*
- Interpretation of observed correlations
  - Resonances
  - Mini-jets: Remnants of initial semi-hard scattering?
  - Clusters formed at hadronization?

Summary III

- Can we win the case for flow fluctuations based on circumstantial evidence?
- Need to consider all information available
  - Two-particle correlations in p+p, Cu+Cu, Au+Au
  - Energy, centrality and rapidity dependnce
  - Flow measurements in Cu+Cu and Au+Au
- Challenge and opportunity

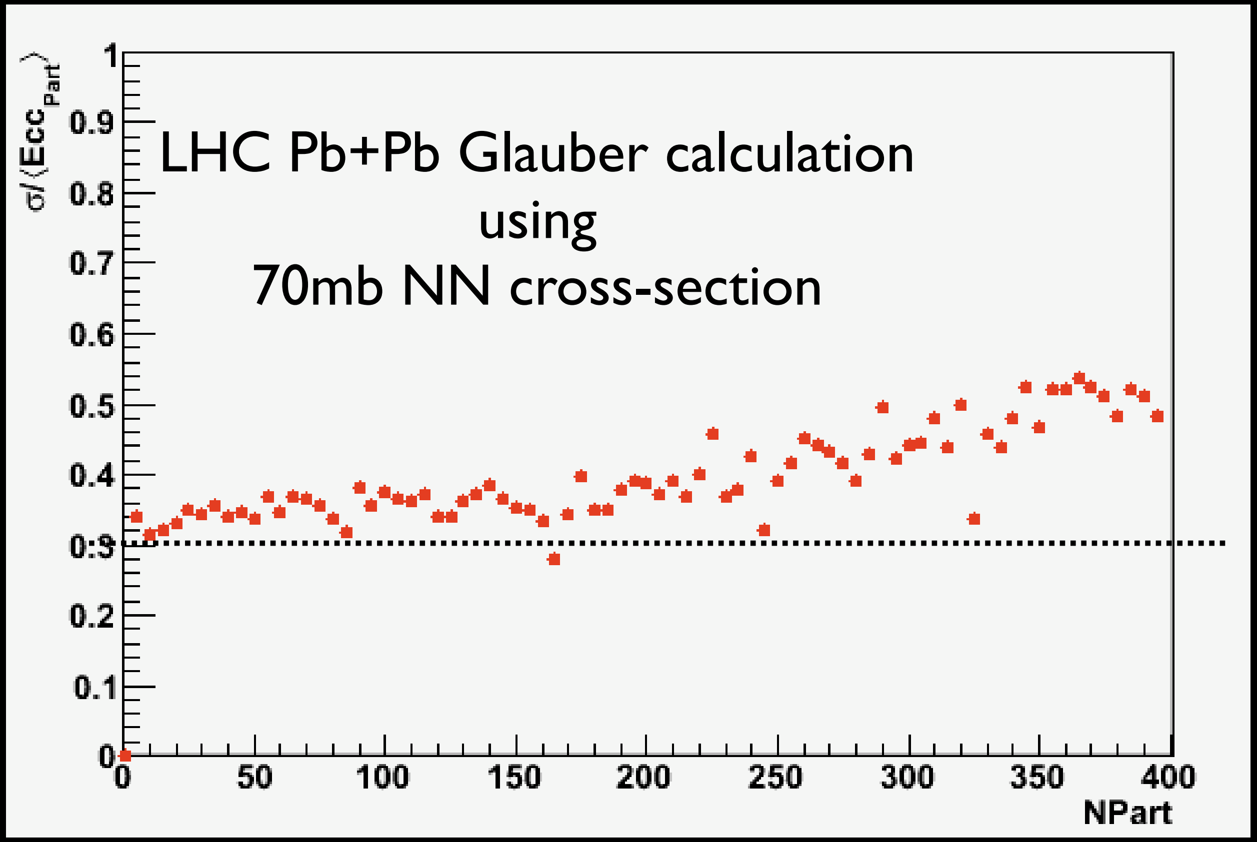
Flow and Clusters

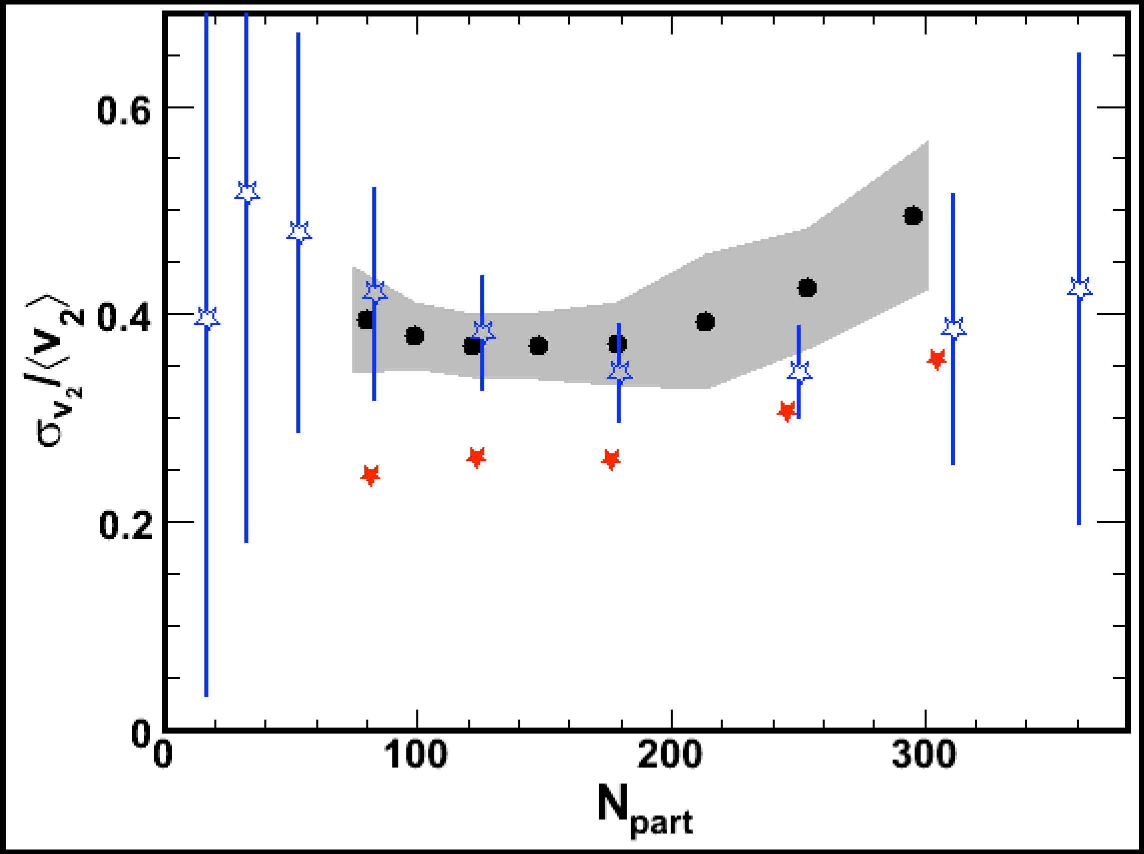


Flow (and flow fluctuations) is a long-range phenomenon
Clusters/non-flow/mini-jets have limited correlation length

(Caveat: Rapidity dependence of flow poorly understood)

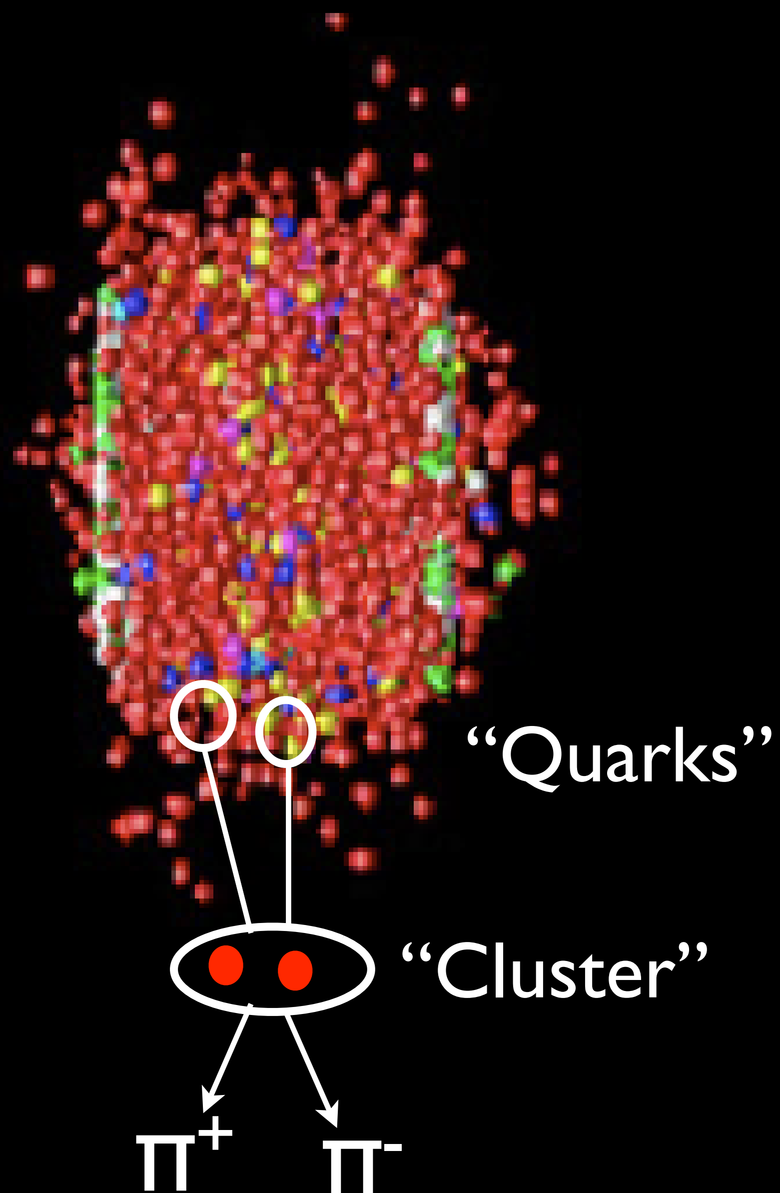
Elliptic Flow Fluctuations at LHC



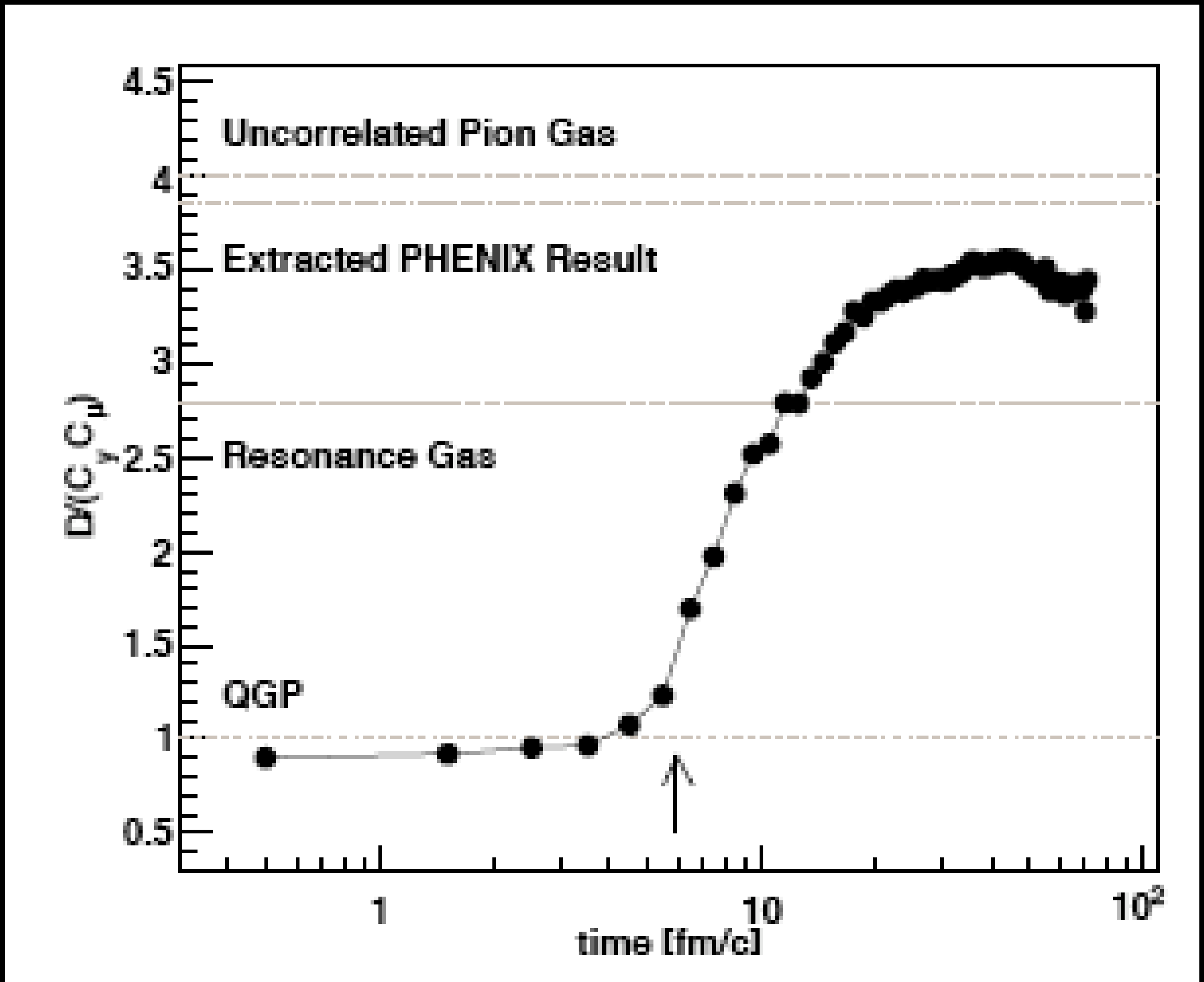


If "Glauber+ideal fluid" interpretation is true, the LHC plot shows expected fluctuations

Hadronization via Recombination

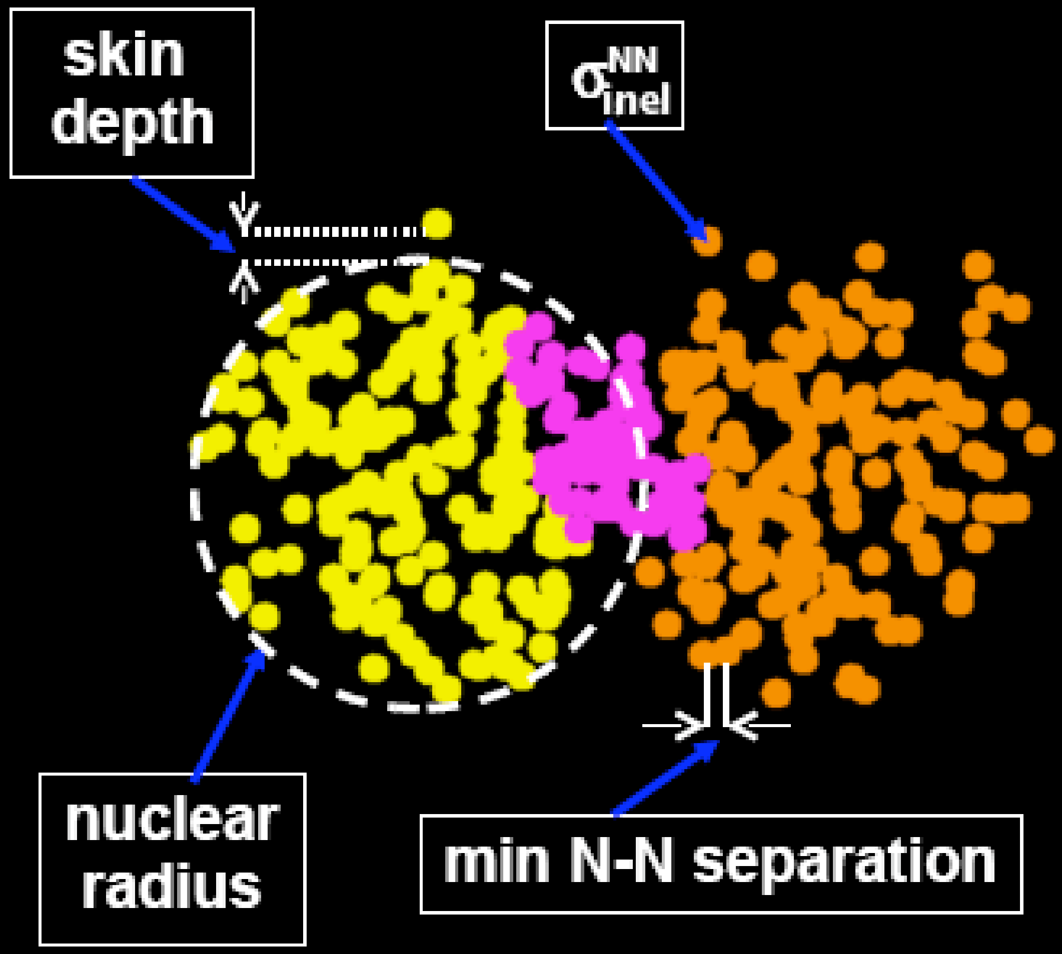


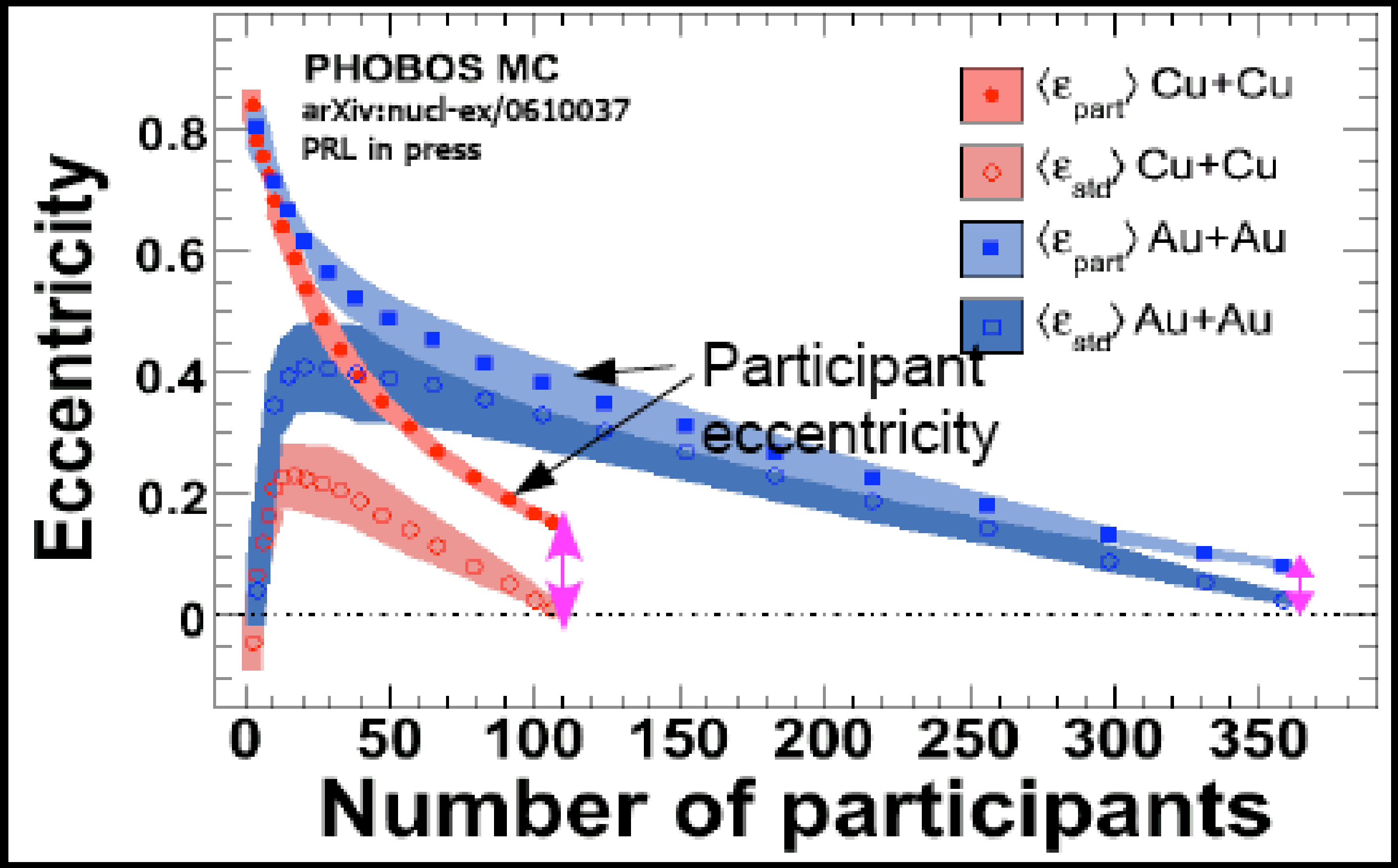
Haussler, Scherer, Bleicher, hep-ph/0702188



Recombination of "quarks" into "clusters" and subsequent decay of clusters provides redistribution of charges

Glauber MC Systematics



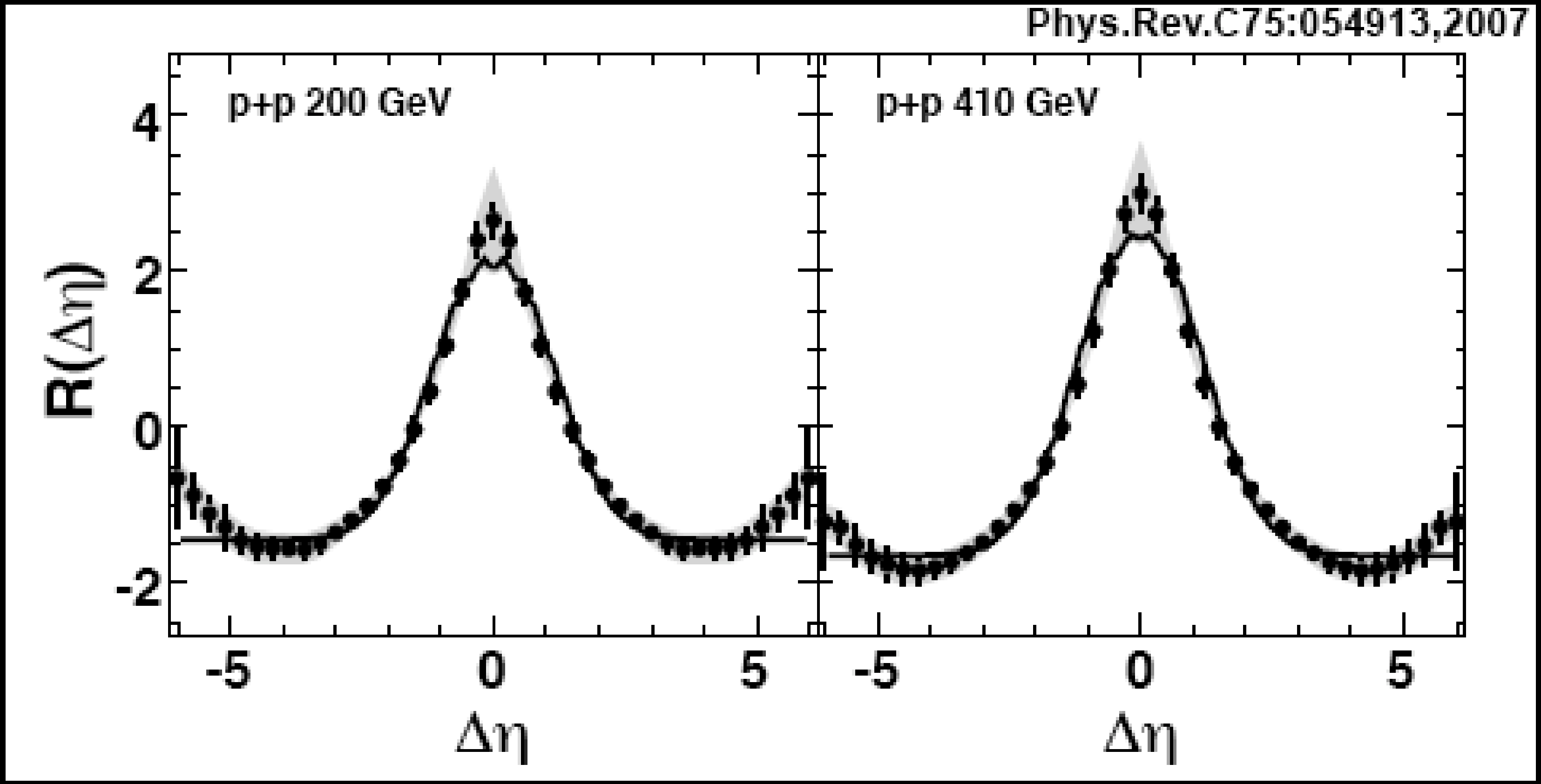


Studied variations to obtain 90% CL bands on calculation and no significant effect was found.

Participant eccentricity

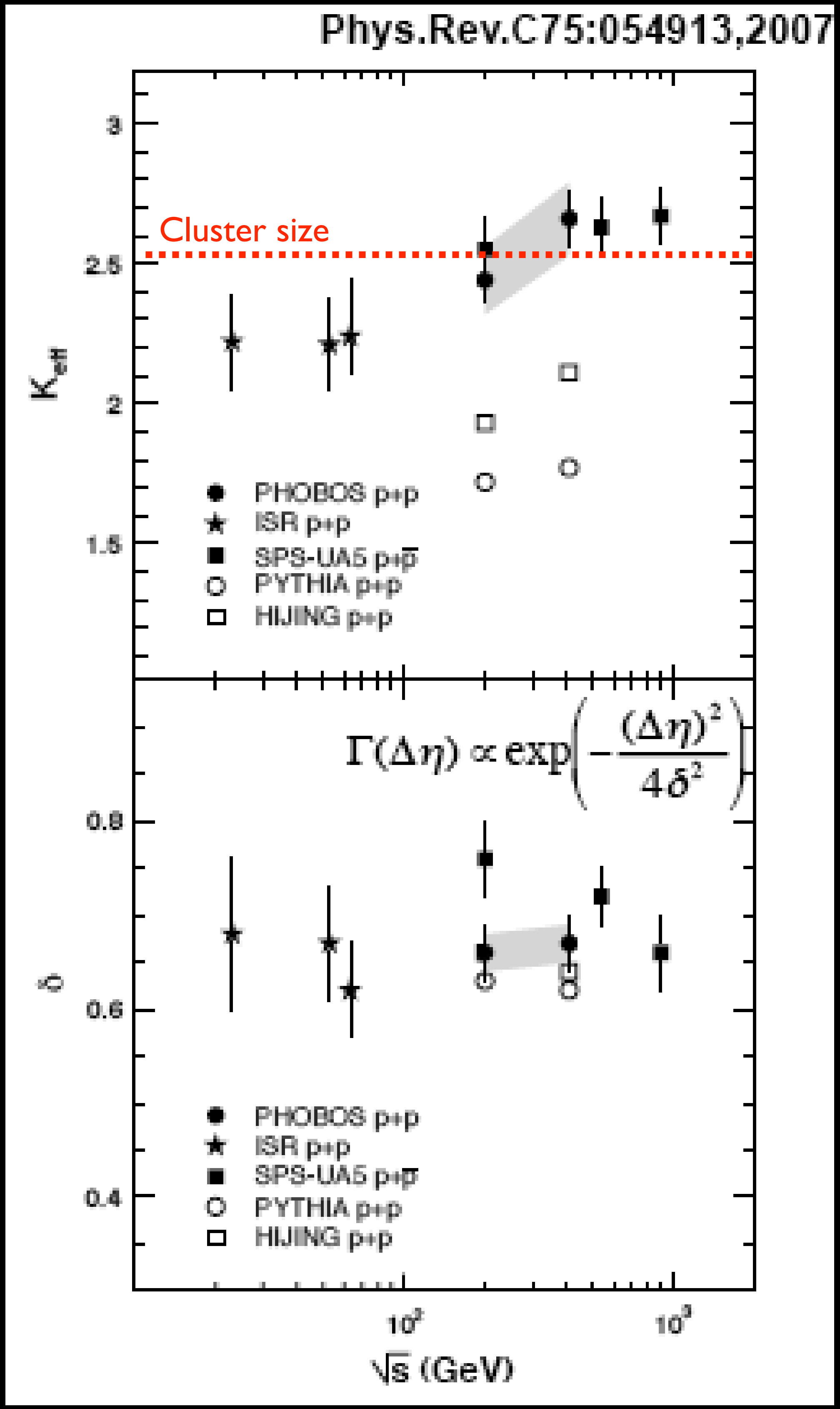
Increasingly important for smaller systems (and most central collisions)

Energy dependence of cluster size

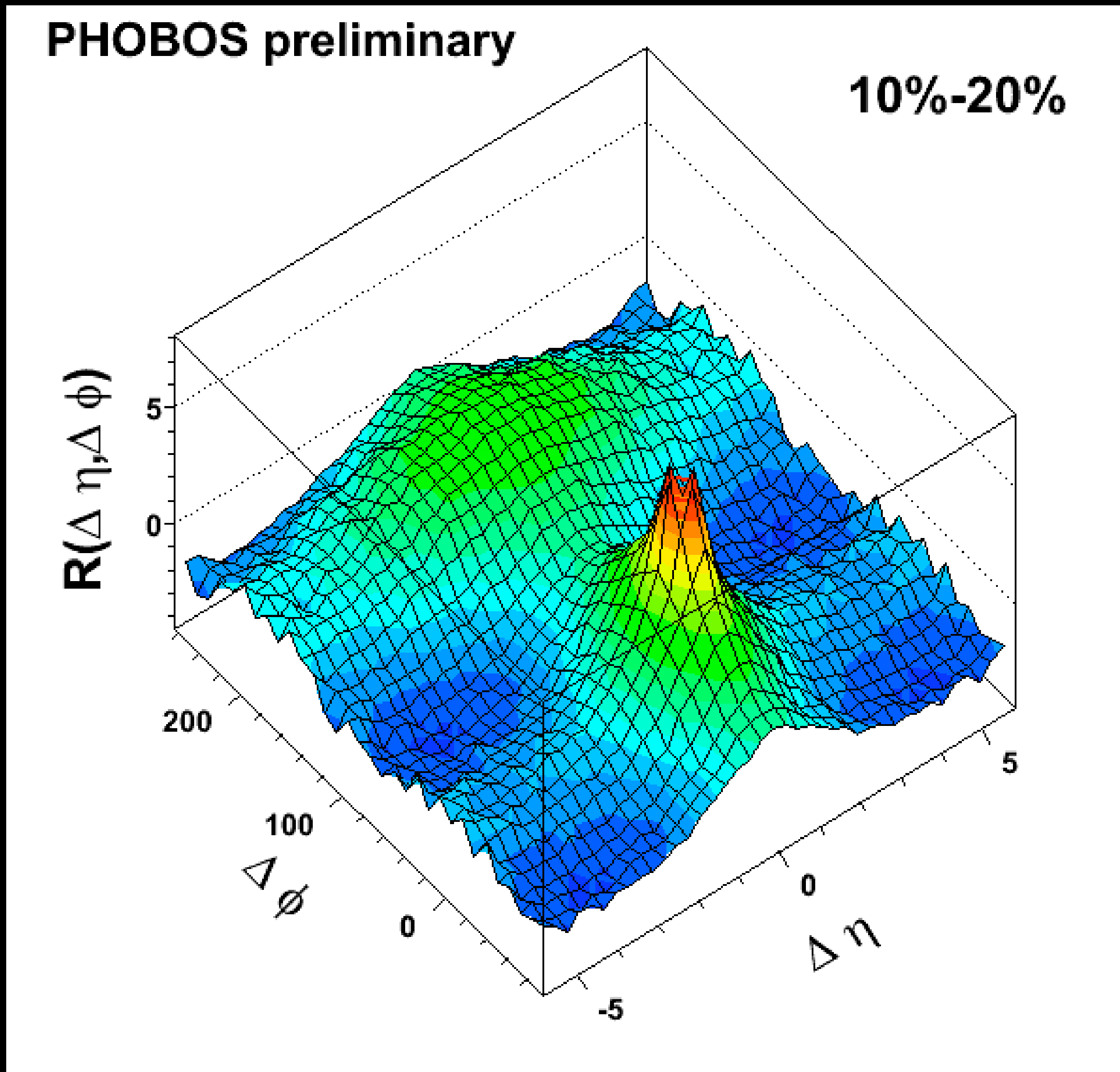


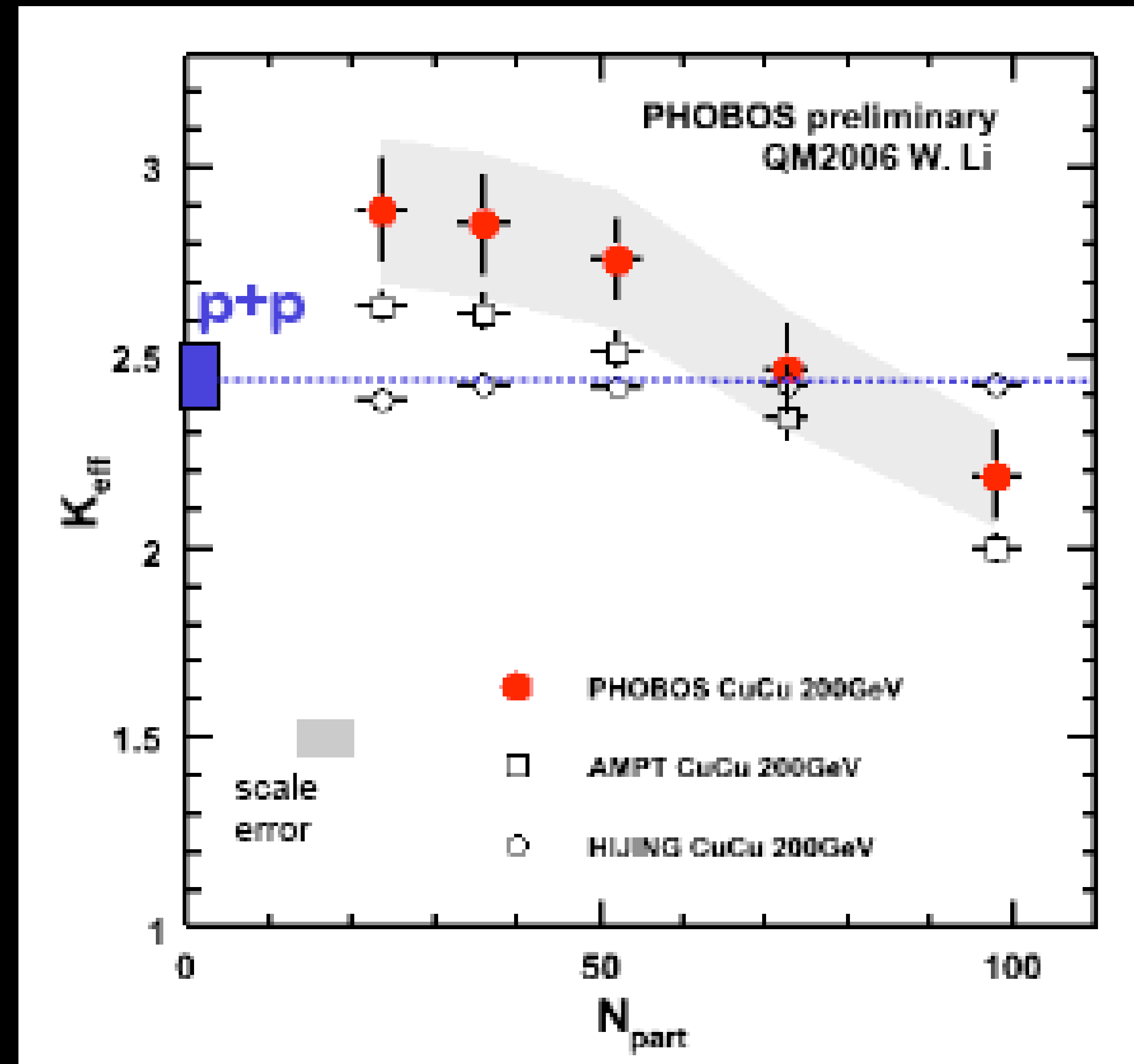
$$R(\Delta\eta) = \langle (n-1)\left(\frac{\rho(\eta_1-\eta_2)}{\rho_{mix}} - 1\right)\rangle$$

- ~ 2.5 particles per cluster
- Not dominated by "mini-jets"
- Effect of hadronization
- Not exhausted by resonances



Clusters in Cu+Cu collisions



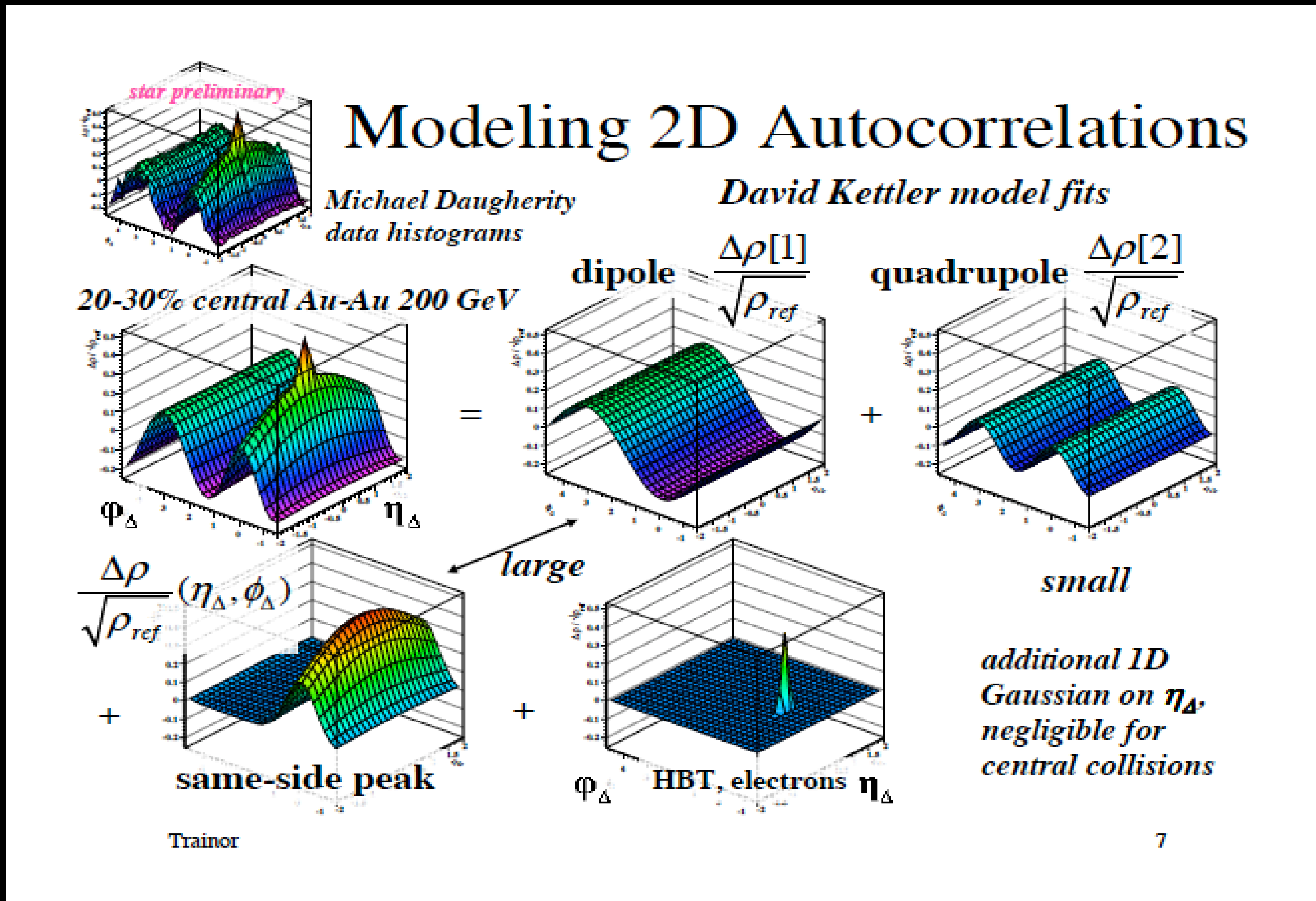


Clusters size in Cu+Cu comparable to p+p

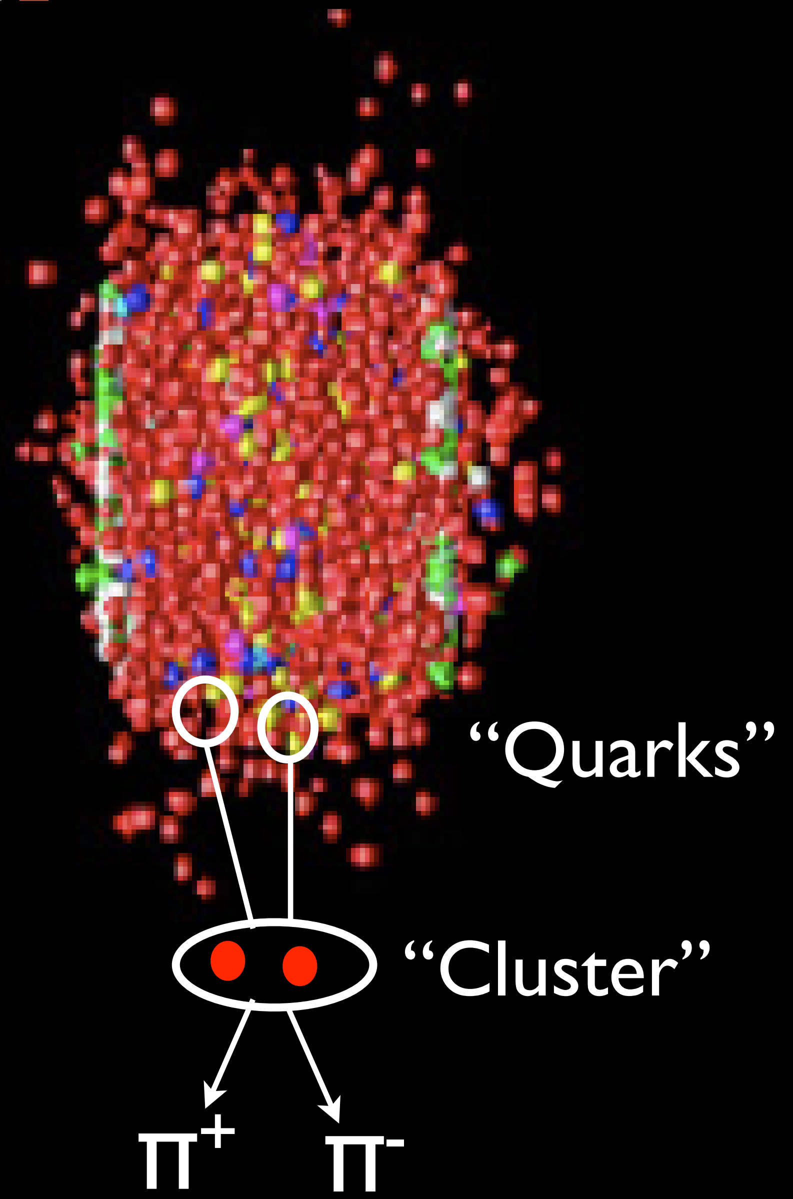
Non-trivial centrality dependence

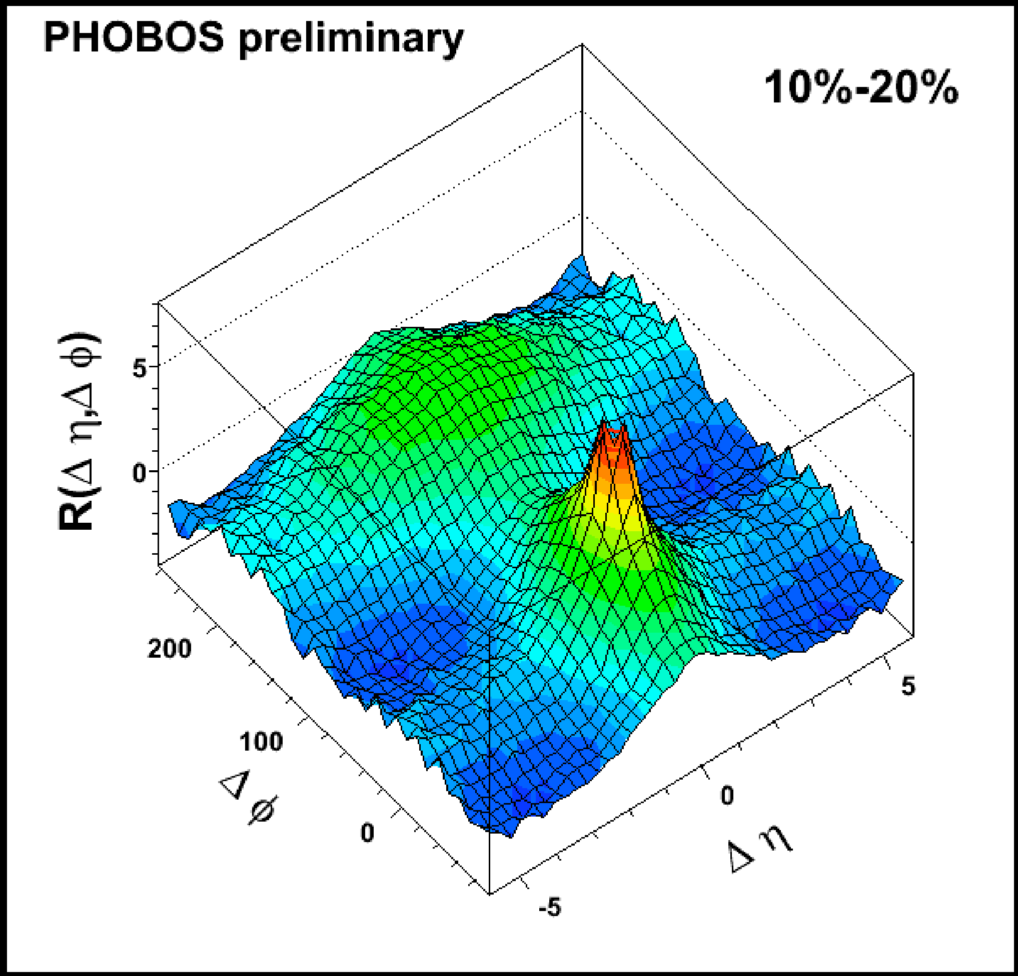
Constraint on reco/hadronization models?

Decomposing Correlations



Flow Fluctuations and Clusters





How are flow and flow fluctuations modified by decay of clusters?

Strategy: Add flow+flow fluctuations to cluster model that reproduce single particle momentum distributions and two particle correlation functions

Preliminary result: $\sigma(v_2)/<v_2>$ (almost) invariant vs cluster decays for $\sigma(v_2)/<v_2> \sim 0.4$