Latest Results from the PHOBOS Experiment

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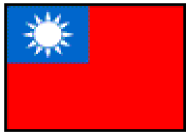
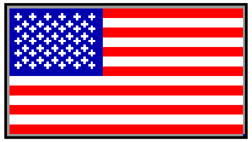
for the PHOBOS Collaboration

PHOBOS Collaboration

Burak Alver, Birger Back, Mark Baker, Maarten Ballintijn, Donald Barton, Russell Betts, Richard Bindel, Wit Busza (Spokesperson), Vasundhara Chetluru, Edmundo García, Tomasz Gburek, Joshua Hamblen, Conor Henderson, David Hofman, Richard Hollis, Roman Hołyński, Burt Holzman, Aneta Iordanova, Chia Ming Kuo, Wei Li, Willis Lin, Constantin Loizides, Steven Manly, Alice Mignerey, Gerrit van Nieuwenhuizen, Rachid Nouicer, Andrzej Olszewski, Robert Pak, Corey Reed, Christof Roland, Gunther Roland, Joe Sagerer, Peter Steinberg, George Stephans, Andrei Sukhanov, Marguerite Belt Tonjes, Adam Trzupek, Sergei Vaurynovich, Robin Verdier, Gábor Veres, Peter Walters, Edward Wenger, Frank Wolfs, Barbara Wosiek, Krzysztof Woźniak, Bolek Wysłouch

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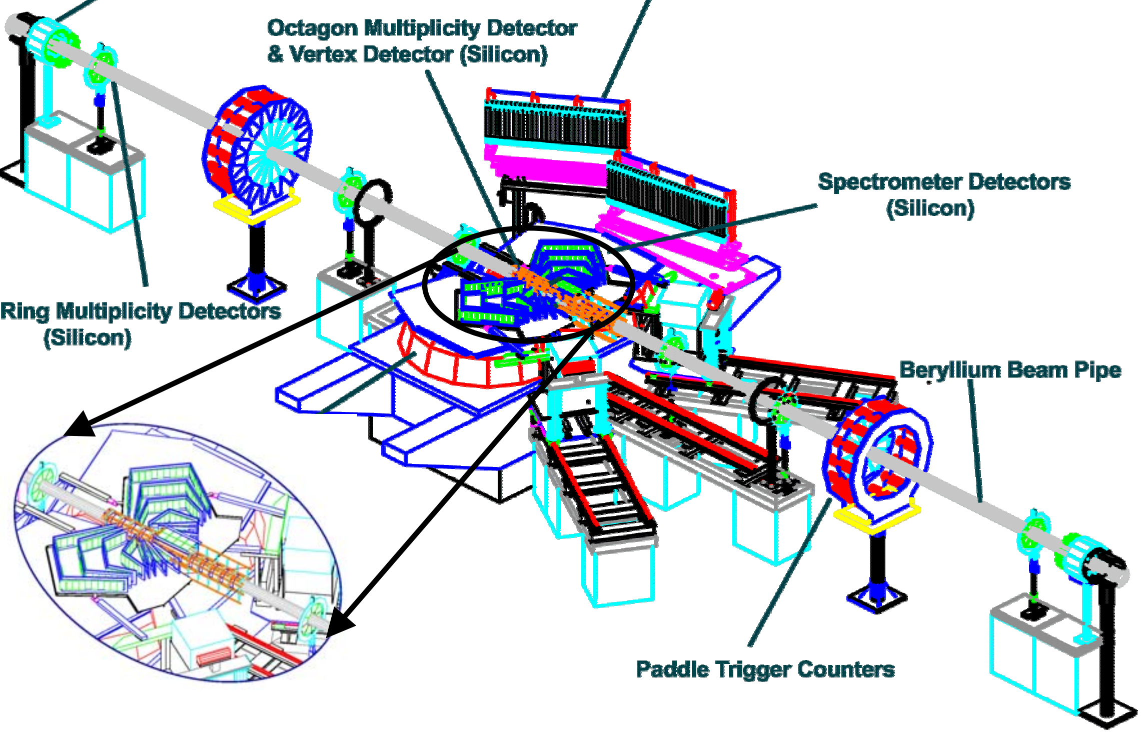
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

9 Ph.D. Students

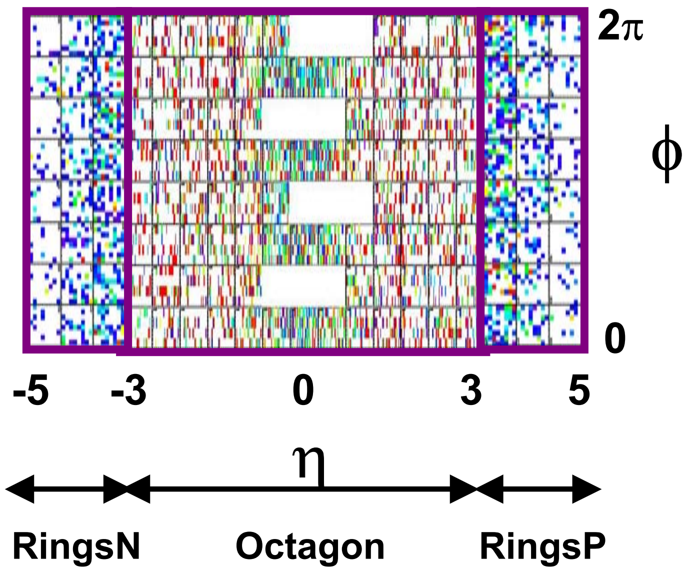
PHOBOS Detector



Large acceptance for N_{ch}

$-5.4 < \eta < 5.4$ $(0.5^o < \theta < 179.5^o)$

$0 < \phi < 2\pi$



Vertex+Spec fill the Octagon holes

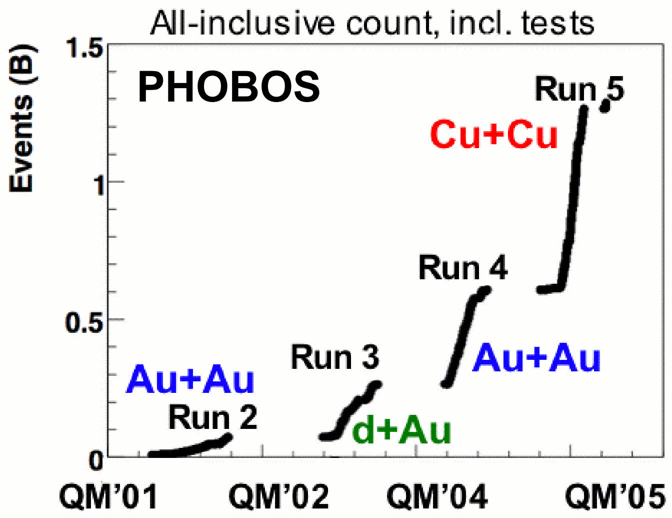
Unique low-p_T measurements

PHOBOS Research Program

I. **Systematic study of charged hadron production in p+p, d+Au, Cu+Cu, Au+Au**

II. **Comprehensive study of correlations and fluctuations**

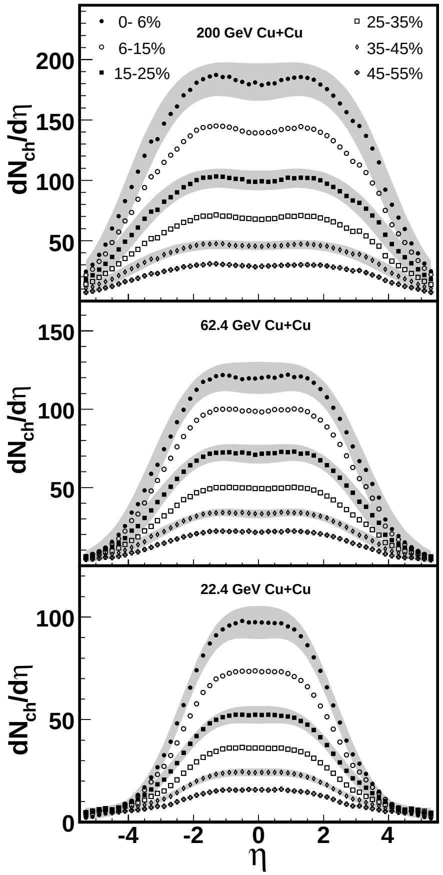
Analyses are based on data sets collected during the first 5 RHIC runs, exploiting the large coverage in η and ϕ.



Systematic Studies

The study of global properties of charged particle production in different collision systems is essentially completed.

arXiv:0709.4008 [nucl-ex]

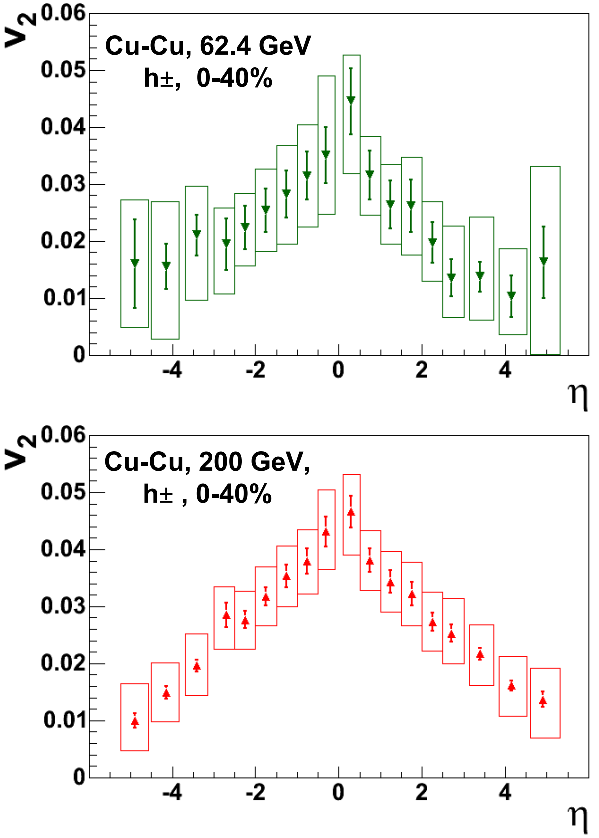


PHOBOS 'fingerprints':

LARGE η coverage

BROAD centrality range

Phys. Rev. Lett. 98 (2007) 242302

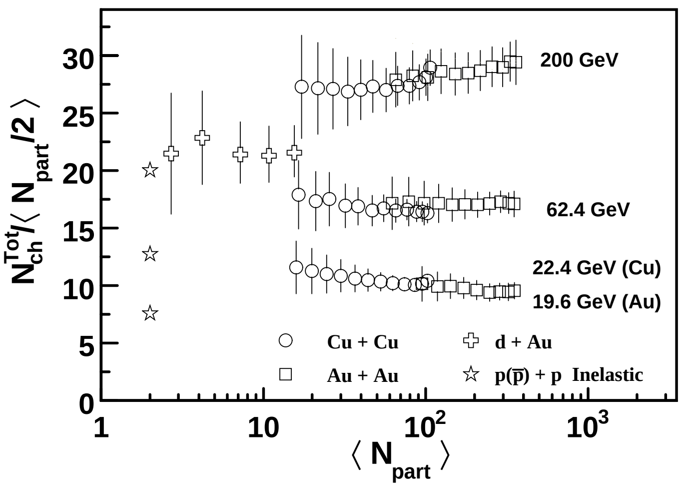


Systematic Studies: New Results

Charged particle production

N_{ch}^{Tot}

arXiv:0709.4008 [nucl-ex]

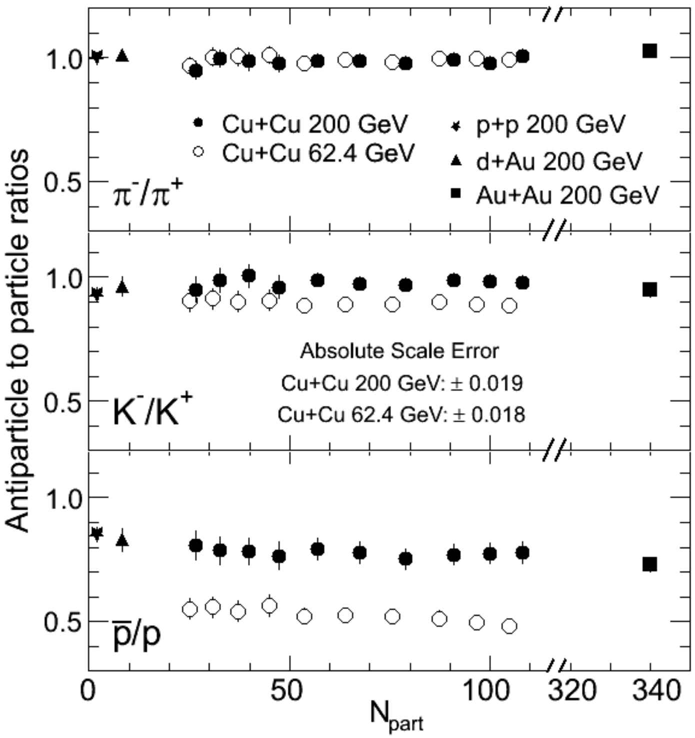


Total charged particle multiplicity scales with N_{part}

Poster by Gabor Veres

Antiparticle to particle ratios

submitted



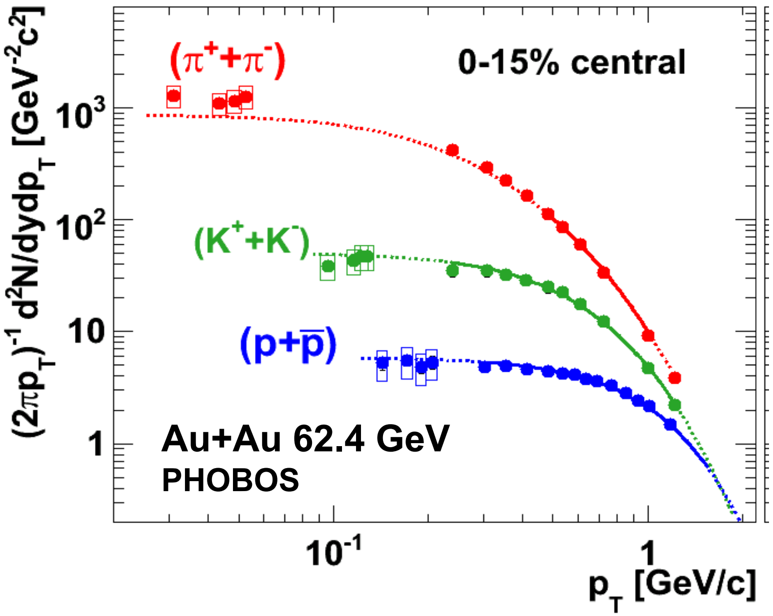
At most weak dependence on system size

Poster by Vasu Chetluru

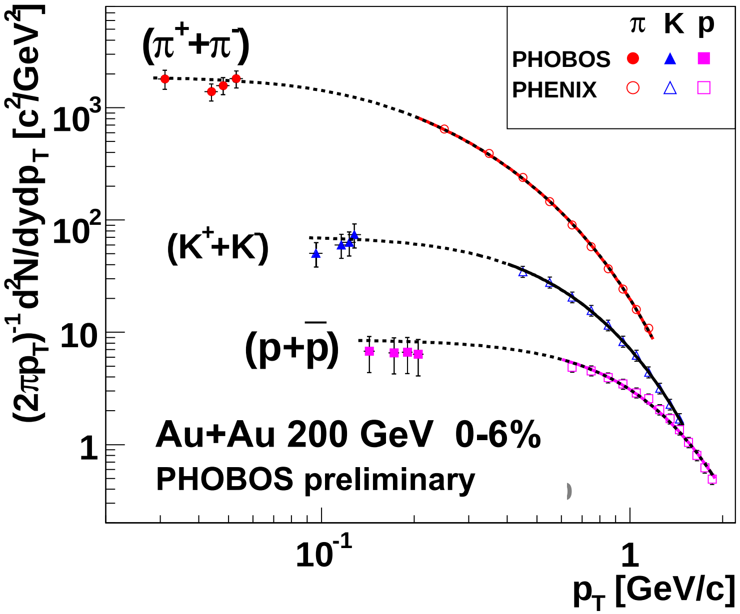
Systematic Studies: New Results

UNIQUE PHOBOS measurements on energy and centrality dependence of the low-p_T spectra

Phys. Rev. C75, 024910 (2007)



New data



No anomalous enhancement

Radial flow effects → breaking m_T scaling

Talk by Tomasz Gburek

Systematic Studies: Summary

- **Particle production in HI collisions is controlled by simple scaling rules**

  N_{part} scaling of total N_{ch}; extended longitudinal scaling in the nucleus rest frame; factorization of the energy and centrality dependencies

  – The collision geometry determines the dynamical evolution of the system

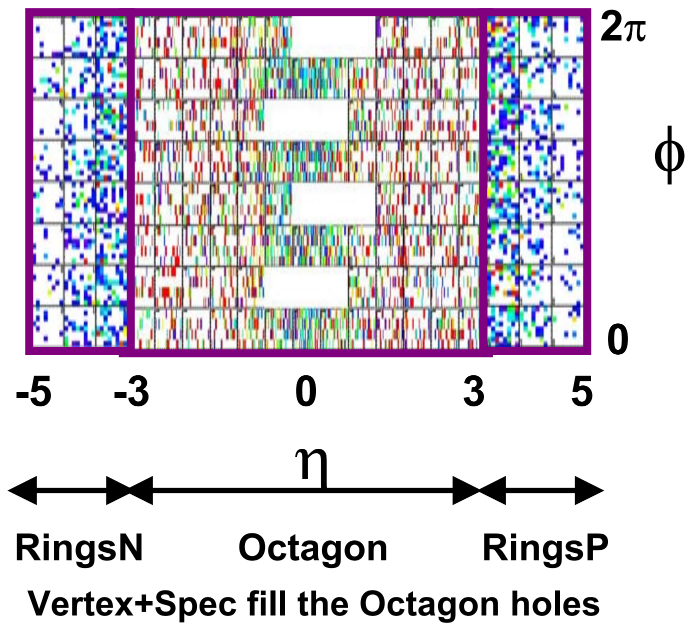
  – To date no theory/model can consistently explain the scaling rules

  – The observations provide a tool for extrapolating RHIC data to the LHC collisions

Correlation & Fluctuation Studies

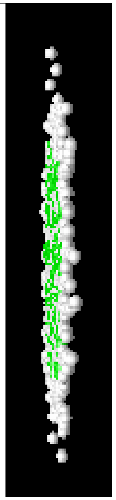
Exploit large η- ϕ coverage of the PHOBOS detector

PHOBOS Acceptance – by far the largest of all RHIC experiments

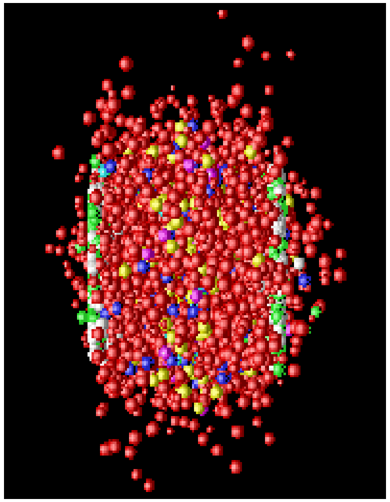


Correlation & Fluctuation Studies

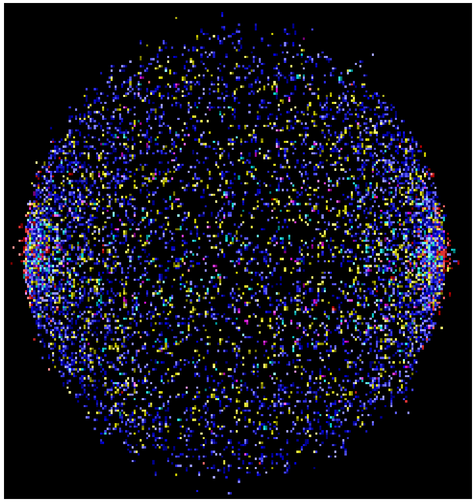
Insight into different stages of the system evolution



Initial state



Hydrodynamical evolution



Freeze-out

Fluctuations of the initial source geometry

Elliptic flow fluctuations

Medium response to high-p_T partons →p_T-triggered correlations

Hadronization → two-particle correlations

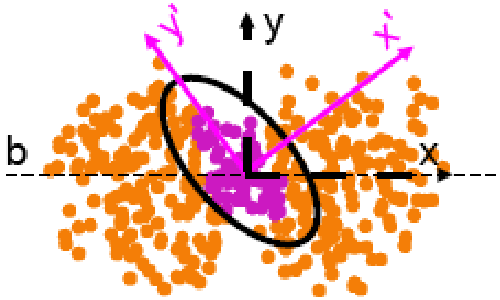
Correlation & Fluctuation Studies

New results from PHOBOS:

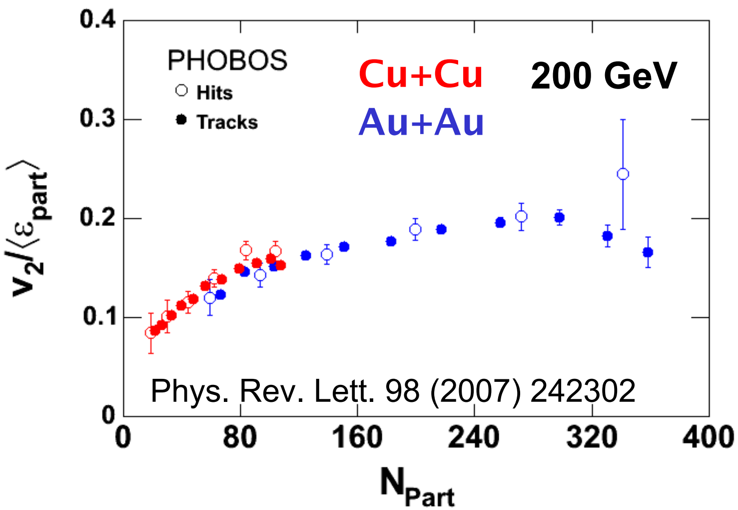
- ✓ Fluctuations of the initial source geometry from the Glauber Monte Carlo model
- ✓ Elliptic flow fluctuations corrected for non-flow effects
- ✓ Two-particle correlations with high-p_T trigger for Au+Au
- ✓ Two-particle correlations in $(\Delta\eta,\Delta\phi)$ for pp, Cu+Cu, Au+Au

Initial Source Eccentricity

Participant eccentricity



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



Monte Carlo Glauber (MCG) approach

arXiv:0711.3724 to be published in Phys. Rev. C

Robustness of $<\varepsilon_{part}>$:

Choice of the MCG parameters

- inter-nucleon separation
- nuclear radius
- nuclear skin depth
- σ_{NN}

MCG model assumptions

- binary collisions vs. participants
- local matter distribution (point-like/Gaussian/hard-sphere)

→ $<\varepsilon_{part}>$ is robust

Event-by-Event Fluctuations of ε_{part}

Calculation of the higher order cumulants

$\varepsilon_{part}\{2\}$, $\varepsilon_{part}\{4\}$

Poster by Richard Hollis

v_2 Fluctuations and Initial Geometry Fluctuations

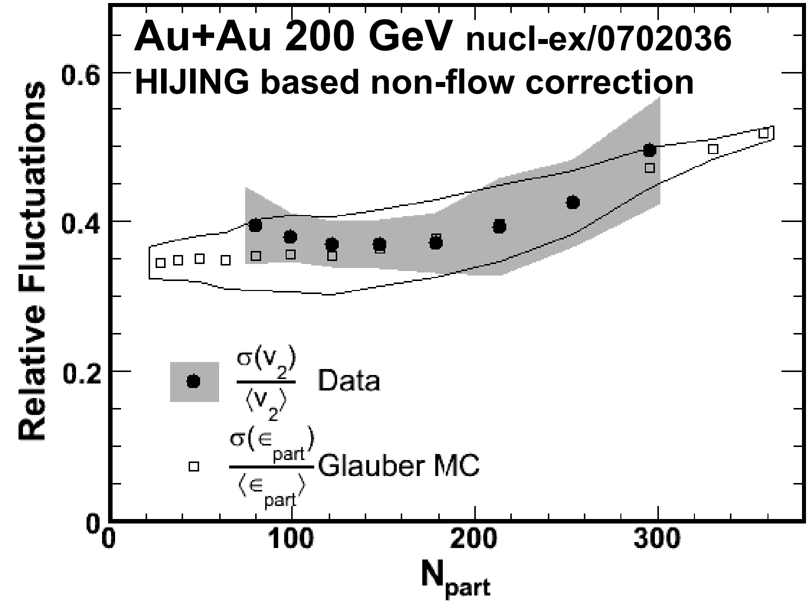
<u>Quark Matter 2006 Highlight:</u>

PHOBOS measured

large dynamical fluctuations of v_2

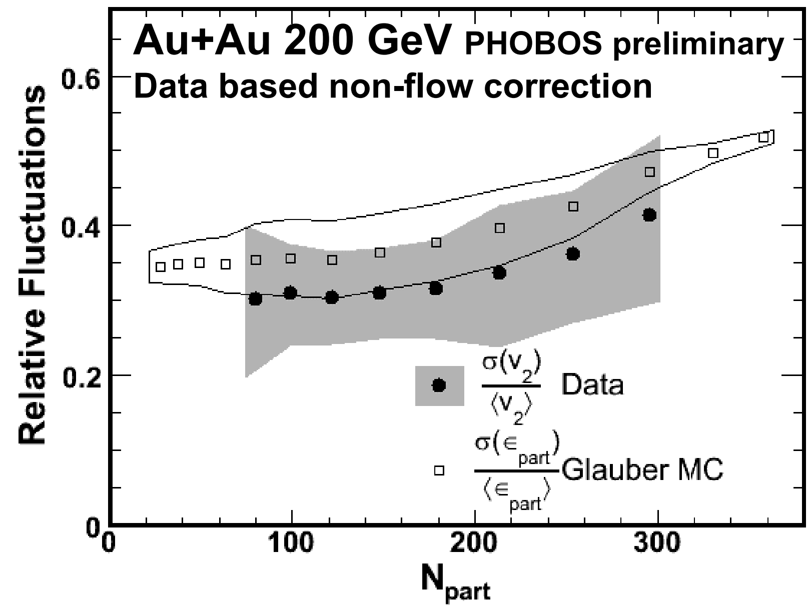
$$\frac{\sigma(v_2)}{<v_2>} \approx \frac{\sigma(\varepsilon_{part})}{<\varepsilon_{part}>}$$

This result was corrected for non-flow contribution estimated from the HIJING model (negligible, <2%)



<u>Quark Matter 2008:</u>

- **Non-flow contribution determined from data**
- **Relative v_2 fluctuations corrected for non-flow contribution →**



Determination of the Non-Flow Term δ

Non-flow term: $\delta = \langle\cos(2\Delta\phi)\rangle_{non\text{-}flow}$, $\Delta\phi=\phi_1-\phi_2$

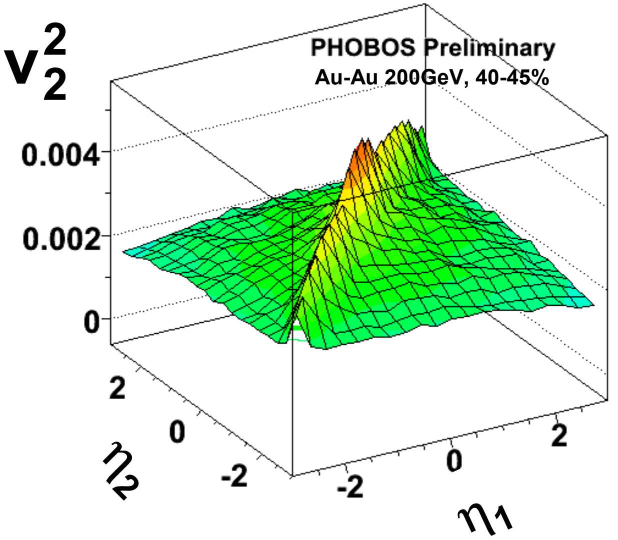
- **Non-flow component is dominated by short-range correlations in $\Delta\eta$**
- **Flow component depends on η and is present at all $\Delta\eta$ - all particles are correlated with the reaction plane**

→ This difference and the large PHOBOS acceptance in η allow us to disentangle the two effects

For each η_1 and η_2 measure the two-particle correlations in $\Delta\phi$:

$$R_n(\eta_1,\eta_2,\Delta\phi) \propto 2v_2^2(\eta_1,\eta_2)\cos(2\Delta\phi)$$

$$v_2^2(\eta_1,\eta_2) = \underbrace{v_2(\eta_1)\cdot v_2(\eta_2)}_{\text{flow component}} + \underbrace{\delta(\eta_1,\eta_2)}_{\text{non-flow term}}$$



flow ⊕ non-flow

Determination of the Non-Flow Term δ

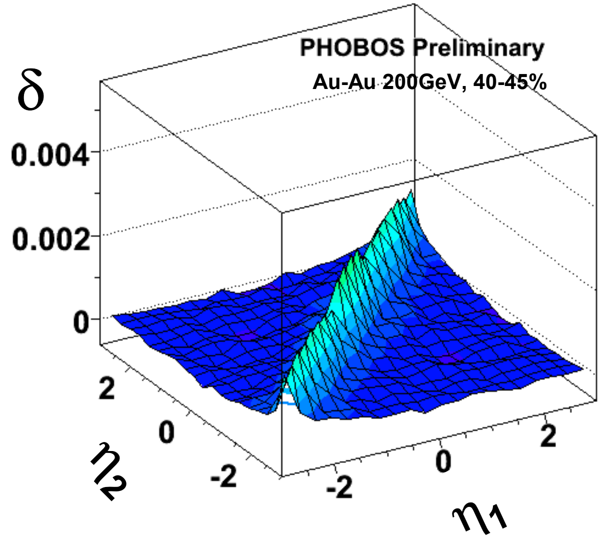
- **Assume that the non-flow component is small at large $\Delta\eta$**
- **Fit at large $\Delta\eta$ ($\Delta\eta$ > 2) to find the flow component of $v_2^2(\eta_1,\eta_2)$**

For large $\Delta\eta$: $v_2(\eta_1)\cdot v_2(\eta_2) \approx v_2^2(\eta_1,\eta_2)$

  - Right-side was corrected for a small non-flow effect at $\Delta\eta$>2, estimated from HIJING

- **Subtract the flow component from $v_2^2(\eta_1,\eta_2)$ to get $\delta(\eta_1,\eta_2)$**

$$\delta(\eta_1,\eta_2) = v_2^2(\eta_1,\eta_2) - v_2(\eta_1)\cdot v_2(\eta_2)$$



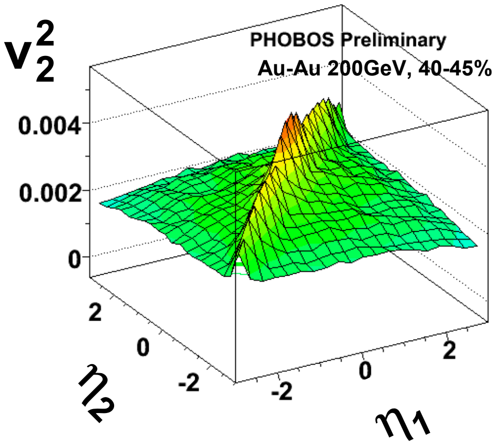
non-flow

- **Average over $dN/d\eta_1$, $dN/d\eta_2$**

$\langle\delta\rangle$

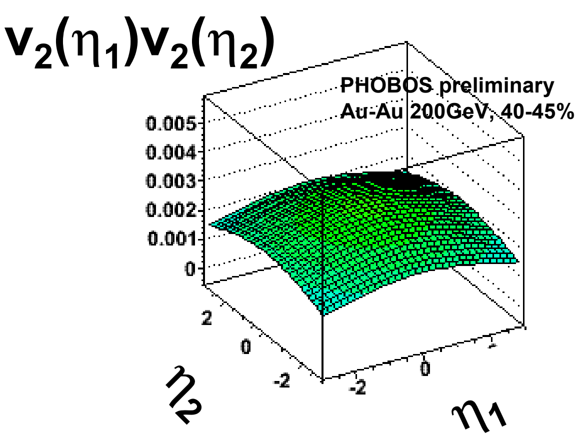
Determination of the Non-Flow Term δ

1. **Determine $v_2(\eta_1,\eta_2)^2$ from the correlations in $(\eta_1,\eta_2,\Delta\phi)$**



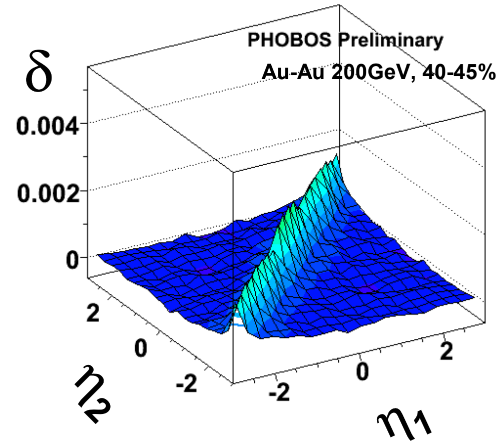
flow ⊕ non-flow

2. **Fit $v_2(\eta_1,\eta_2)^2$ at $\Delta\eta>2$ to get the flow component $v_2(\eta_1)v_2(\eta_2)$**



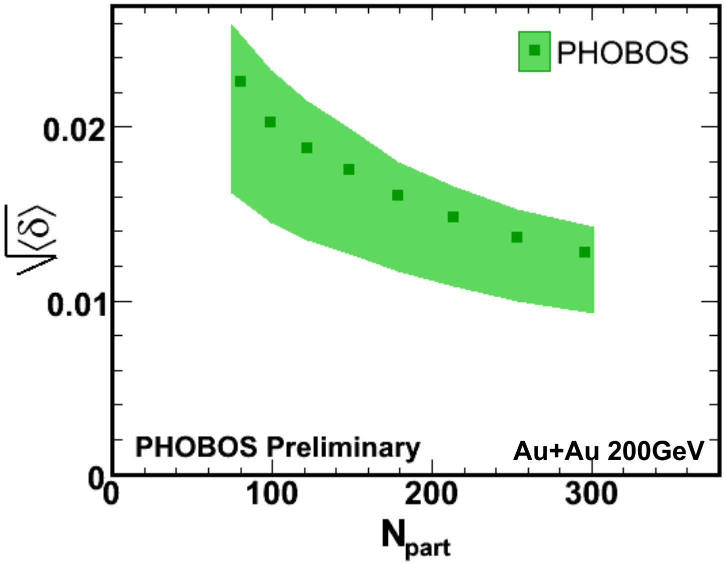
flow

3. **Subtract flow component from $v_2(\eta_1,\eta_2)^2$ to get $\delta(\eta_1,\eta_2)$**



non-flow

4. **Average over $dN/d\eta_1$, $dN/d\eta_2$**



<δ>

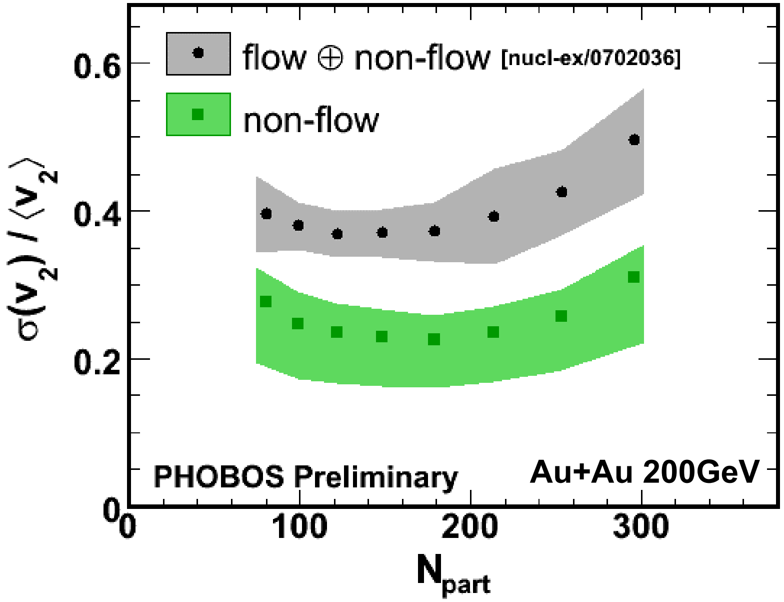
Elliptic Flow Fluctuations

$\sigma(v_2)$ – measured elliptic flow fluctuations (flow ⊕ non-flow)

$<\delta>$ – non-flow term determined from the data

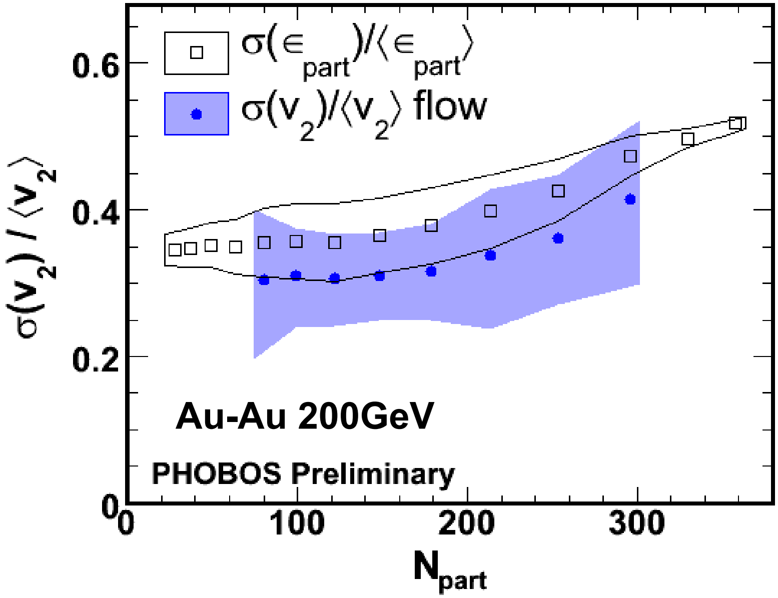
Contribution from non-flow to $\sigma(v_2)$

$\sigma_\delta(\overline{v_2}) = \sqrt{<\delta>/2}$ (arXiv:07080800)



Relative flow fluctuations corrected for non flow contribution and compared to the eccentricity fluctuations

Within systematic errors the magnitude of v_2 fluctuations is in agreement with ε_{part} fluctuations



Talk by Burak Alver

p_T - Triggered Two-Particle Correlations

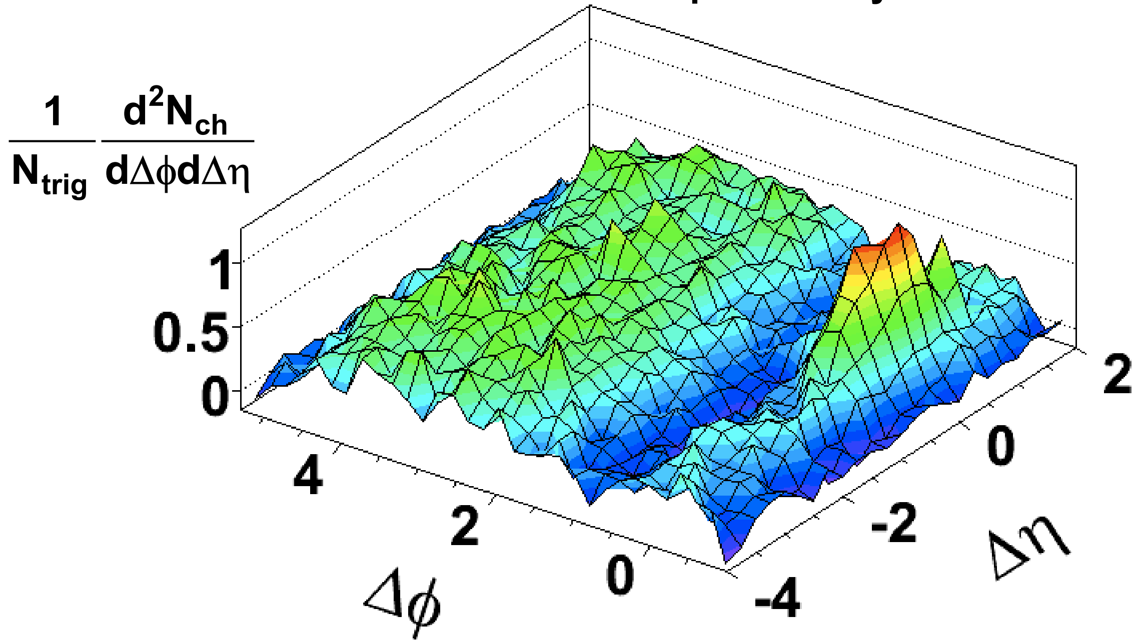
Motivation: medium response to high-p_T partons tests the presence of long-range $\Delta\eta$ correlations at near- and away-sides

$$p_T^{trig} > 2.5\text{GeV}/c \qquad 0 < \eta^{trig} < 1.5$$

$$p_T^{assoc} - \text{no cut} \qquad -3 < \eta^{assoc} < 3$$

For pions p_T > 35 MeV/c at η~0
p_T > 4 MeV/c at η~4-5

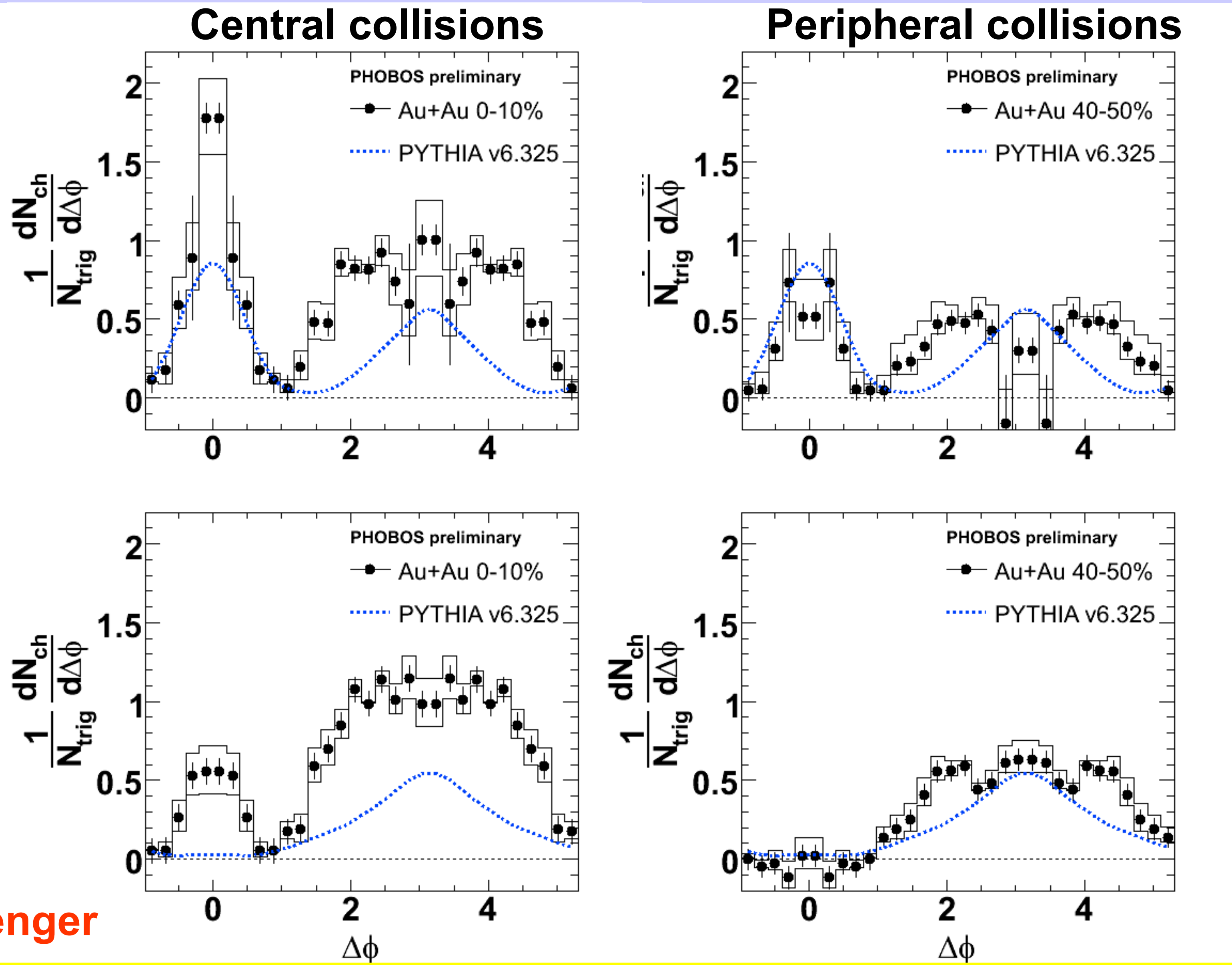
Au+Au 200 GeV, 0 - 30%
PHOBOS preliminary



p_T - Triggered Two-Particle Correlations

Short-range $|\Delta\eta| < 1$

Long-range $-4 < \Delta\eta < -2$



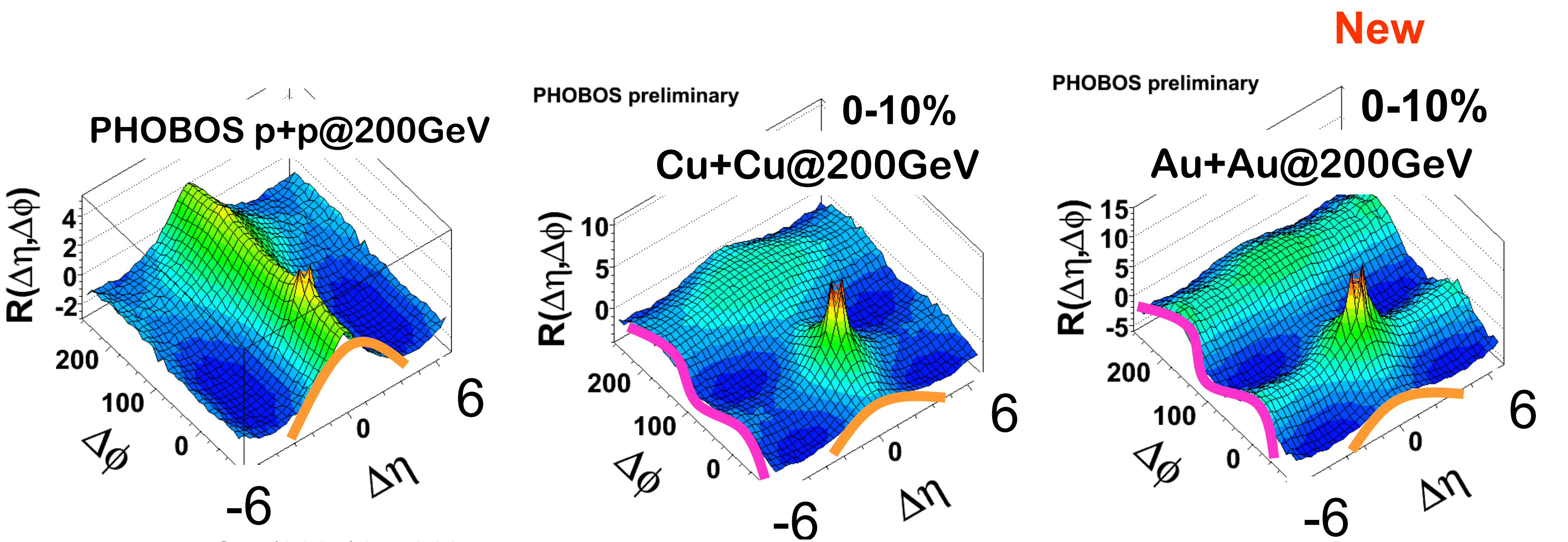
Talk by Ed Wenger

Two-Particle Correlations

How are hadrons produced at freeze-out?

Multiplicity independent two-particle correlation function:

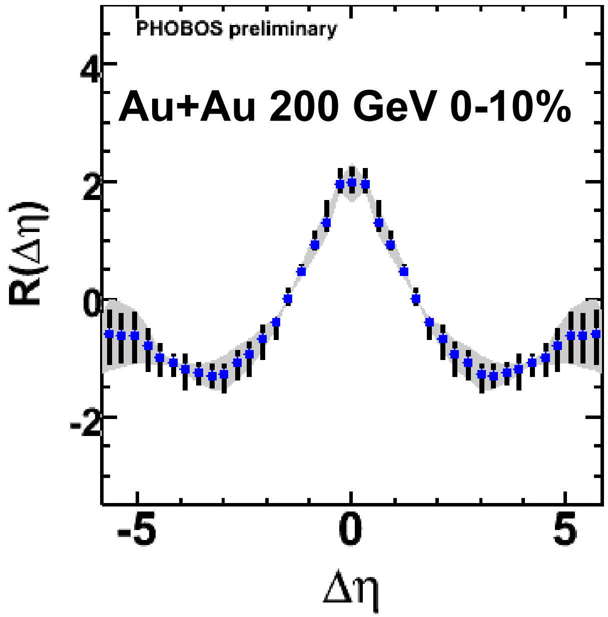
$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left[\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1\right]\right\rangle$$



Phys. Rev. C75(2007)054913

J. Phys. G34(2007)s1005

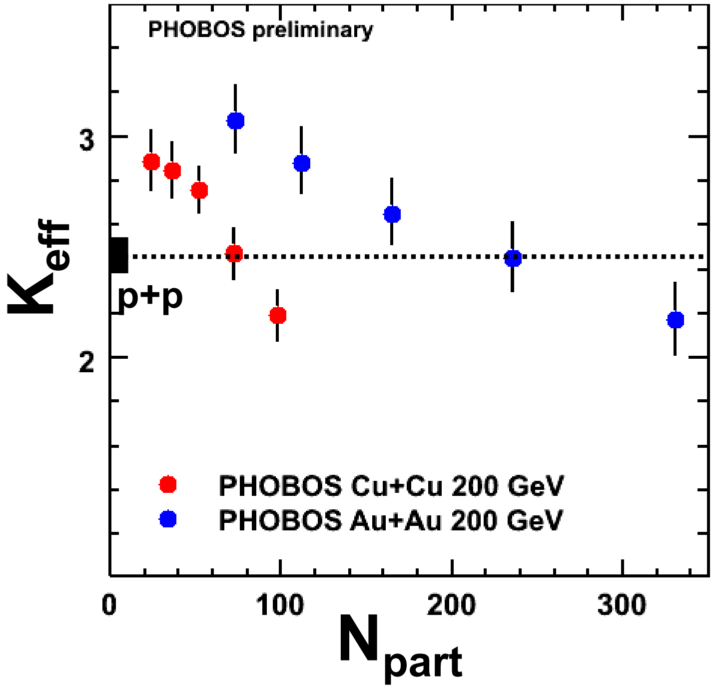
Two-Particle Correlations



After averaging over $\Delta\phi$, $R(\Delta\eta)$ shows short-range correlations, which can be explained in terms of clusters:

K_{eff} : effective cluster size

$\sqrt{2}\ \delta$: cluster decay width



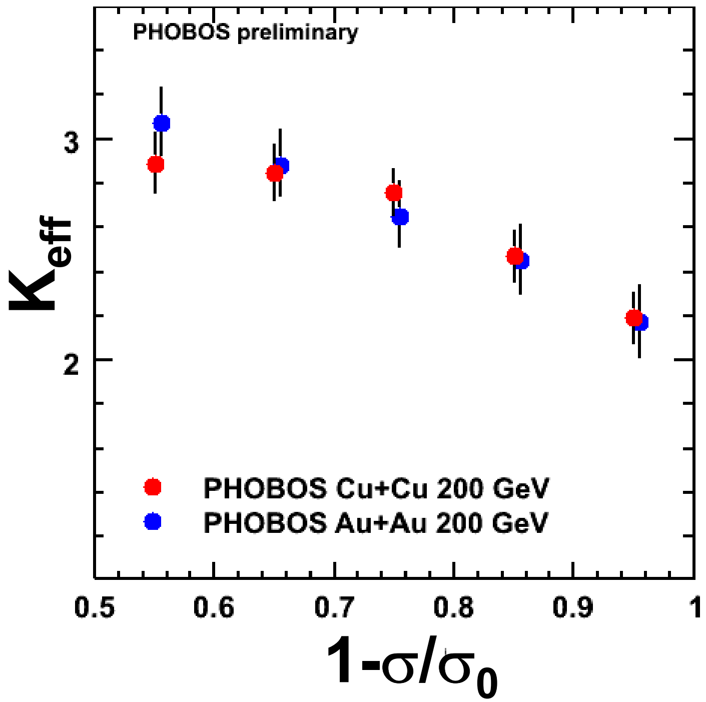
Effective cluster size in Cu+Cu and Au+Au

- Cluster size decreases with centrality
- All cluster sizes are larger than extracted from models with resonances (~1.7)
- For the same N_{part}:

  Au+Au clusters > Cu+Cu clusters

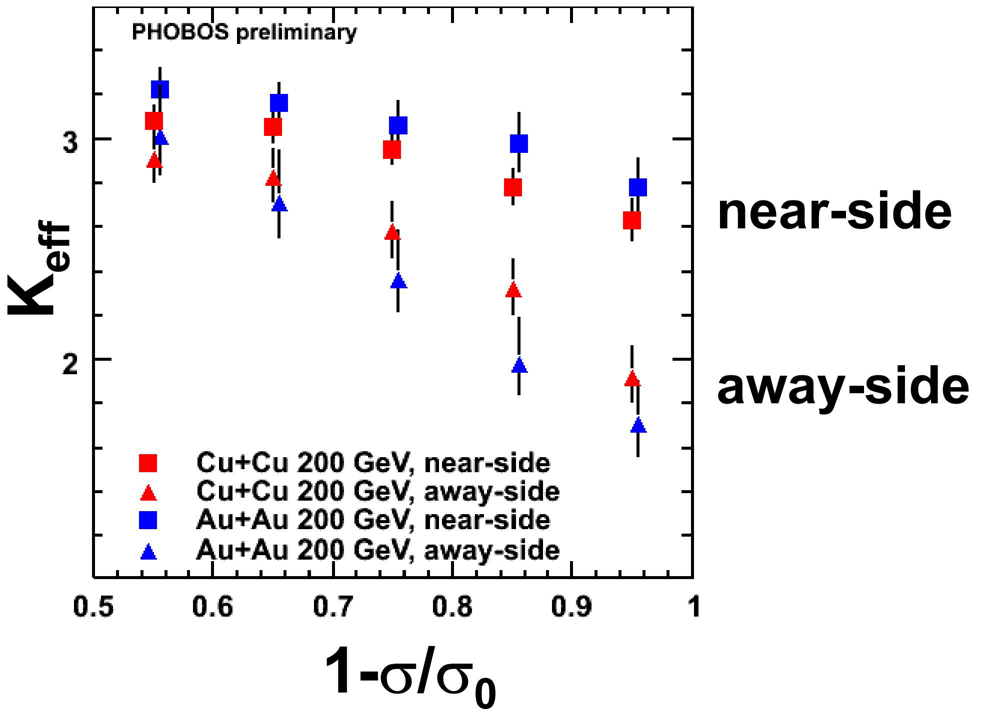
Two-Particle Correlations

Comparison of Au+Au and Cu+ Cu for the same fraction of the inelastic cross section σ/σ_0



Size of the clusters in Au+Au is similar to that in Cu+Cu

Near- and away-side clusters

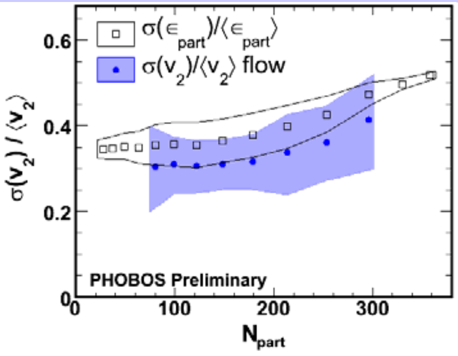


Away-side clusters are smaller and depend more strongly on centrality than near-side ones.

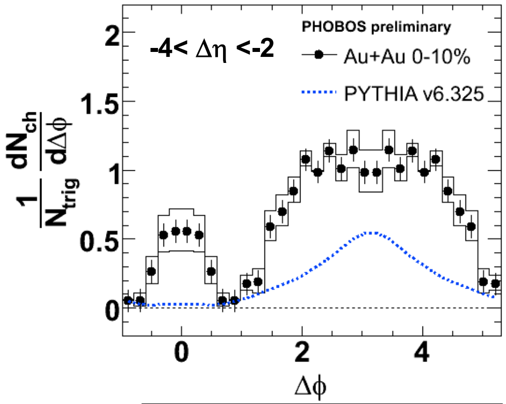
Talk by Wei Li

Correlation & Fluctuation Studies: Conclusions

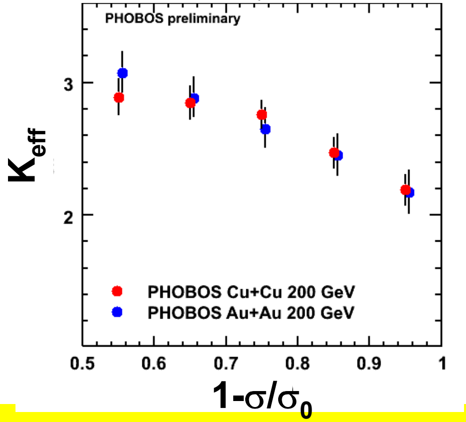
➢ Fluctuations of the initial source geometry are imprinted in the final distributions of particles → system thermalizes very rapidly



➢ Ridge effect persists up to $\Delta\eta$ = 4 in central Au+Au collisions



➢ Effective cluster size shows intriguing system size dependence



PHOBOS at Quark Matter 2008

- **TALKS:**

Ed Wenger – High-p_T triggered correlations in Au+Au collisions

Tuesday, parallel session VIII, 16:10

Burak Alver – Measurement of non-flow correlations and elliptic flow fluctuations in Au+Au collisions at RHIC

Friday, parallel session XII, 14:00

Tomasz Gburek – Energy and centrality dependence of particle production at very low p_T

Saturday, parallel session XVII, 14:40

Wei Li – System size dependence of two-particle correlations in p+p, d+Au, Cu+Cu and Au+Au

Saturday, parallel session XIX, 15:20

- **POSTERS (Wednesday) :**

Gabor Veres – System size, energy, centrality and pseudorapidity dependence of charged-particle density in Au+Au and Cu+Cu collisions at RHIC

Vasu Chetluru – Antiparticle to particle ratios using the PHOBOS detector

Richard Hollis – The importance of correlations and fluctuations on the initial source eccentricity in high energy nucleus-nucleus collisions.

Backups

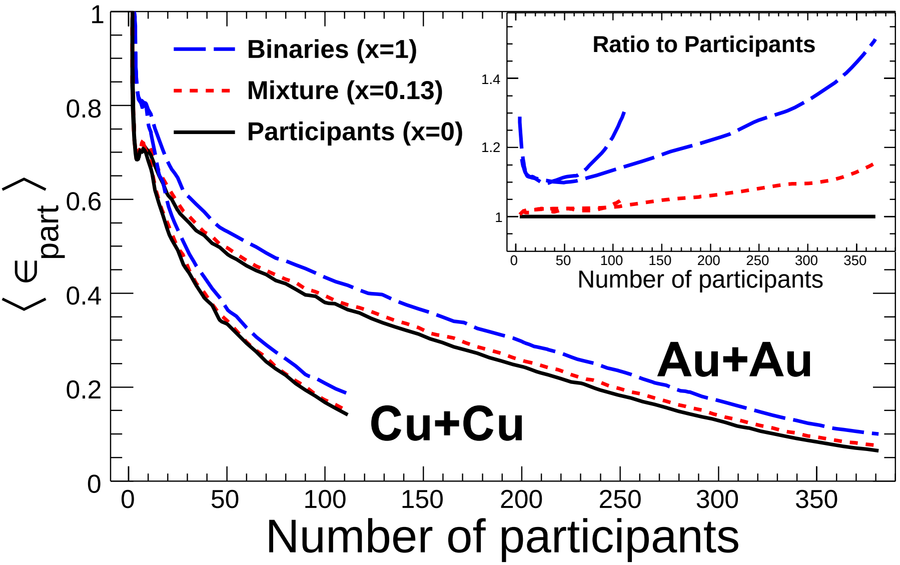
Initial Source Eccentricity

Monte Carlo Glauber (MCG) approach

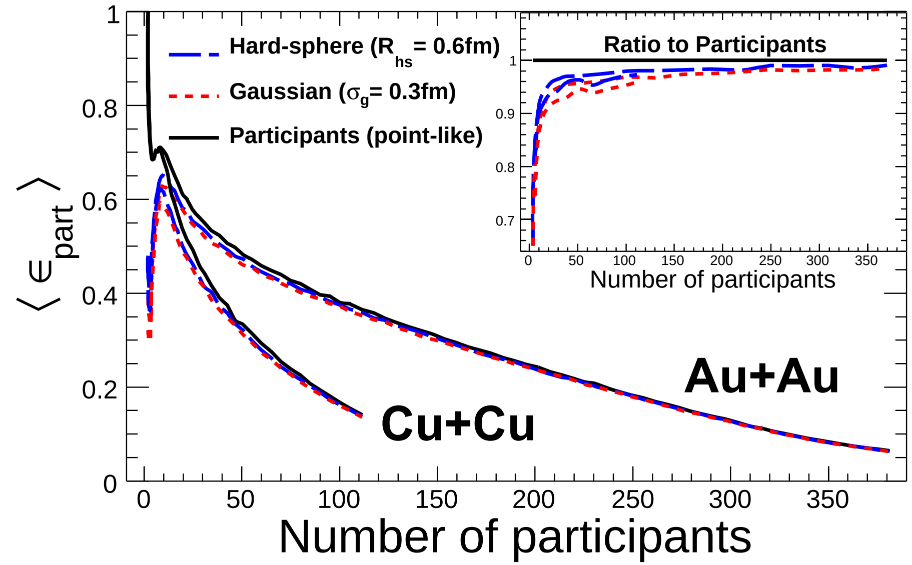
arXiv:0711.3724 to be published in Phys. Rev. C

Study of the robustness of $<\varepsilon_{part}>$:

Binary collisions vs. participants



Local matter distributions



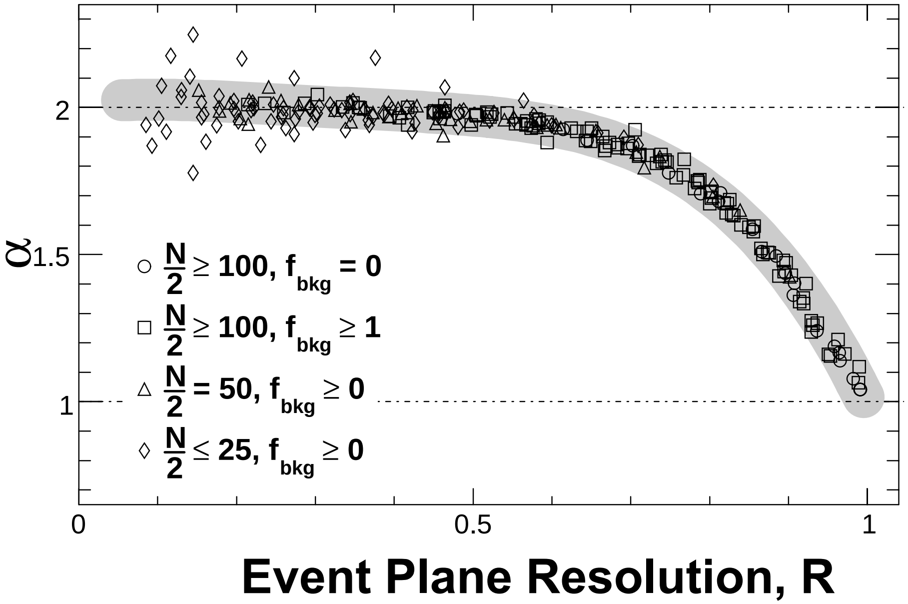
Participant eccentricity is robust to the Glauber model assumptions

Fluctuations of the Initial Source Eccentricity

Full MCG approach: includes spatial correlations among participants

arXiv:0711.3724 to be published in Phys. Rev. C

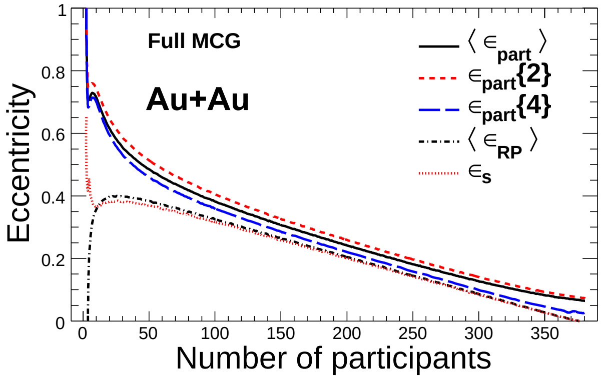
$$<< v_2^{\alpha} >>^{1/\alpha} = v_2\{EP\}$$

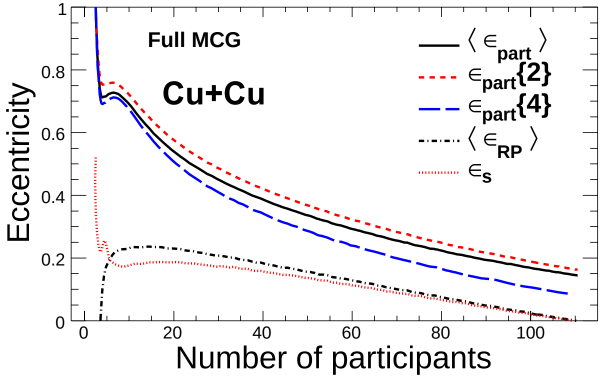


PHOBOS R: 0.13 – 0.55

$$v_2\{EP\} = \sqrt{< v_2^2 >}$$

higher order cumulants

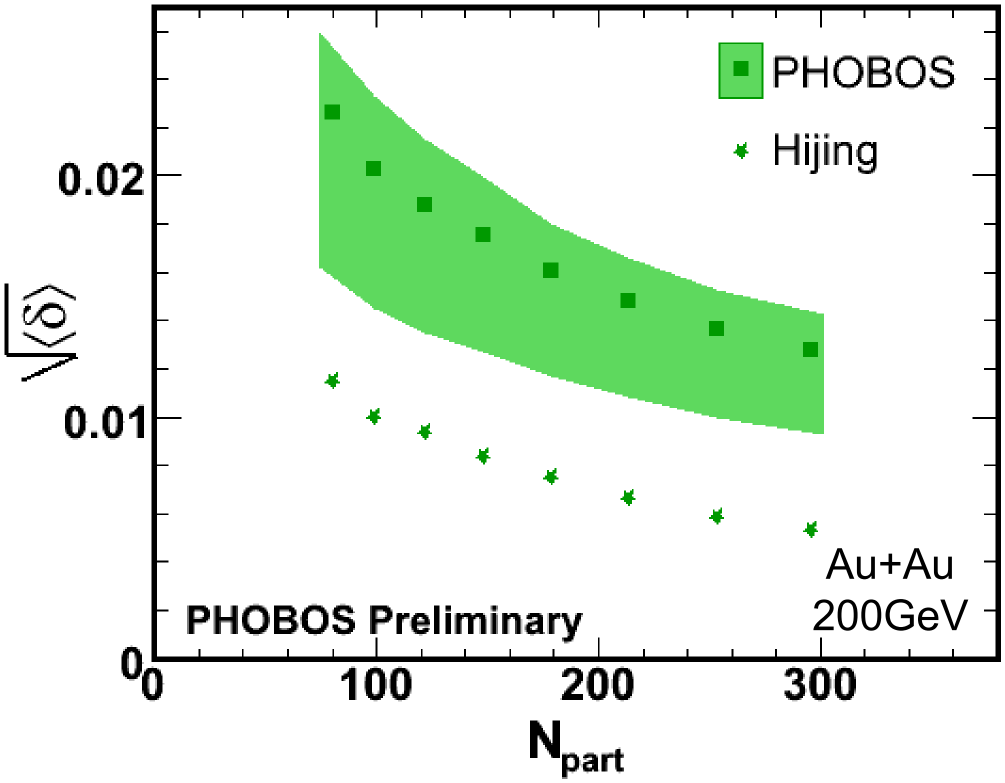




Poster by Richard Hollis

δ as a function of centrality

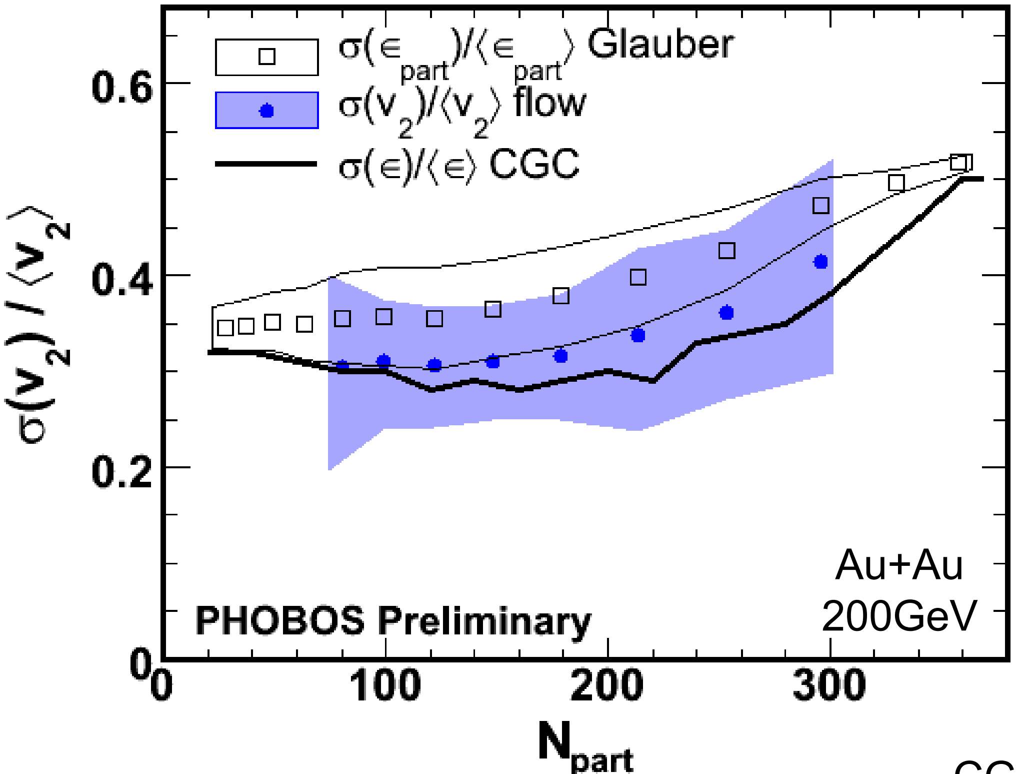
- Average $\delta(\eta_1,\eta_2)$ over all hit pairs



- Non-flow in data is larger than in HIJING
- These values are valid for PHOBOS geometry

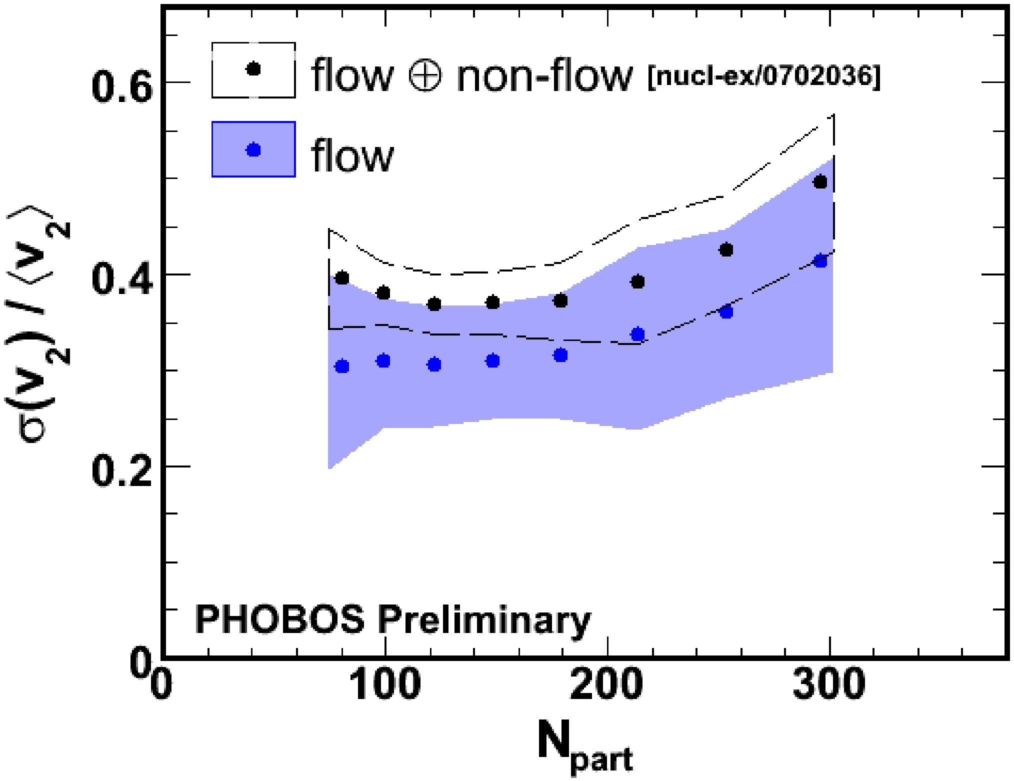
Model Comparison

- Results are in agreement with both Glauber and CGC calculations within errors

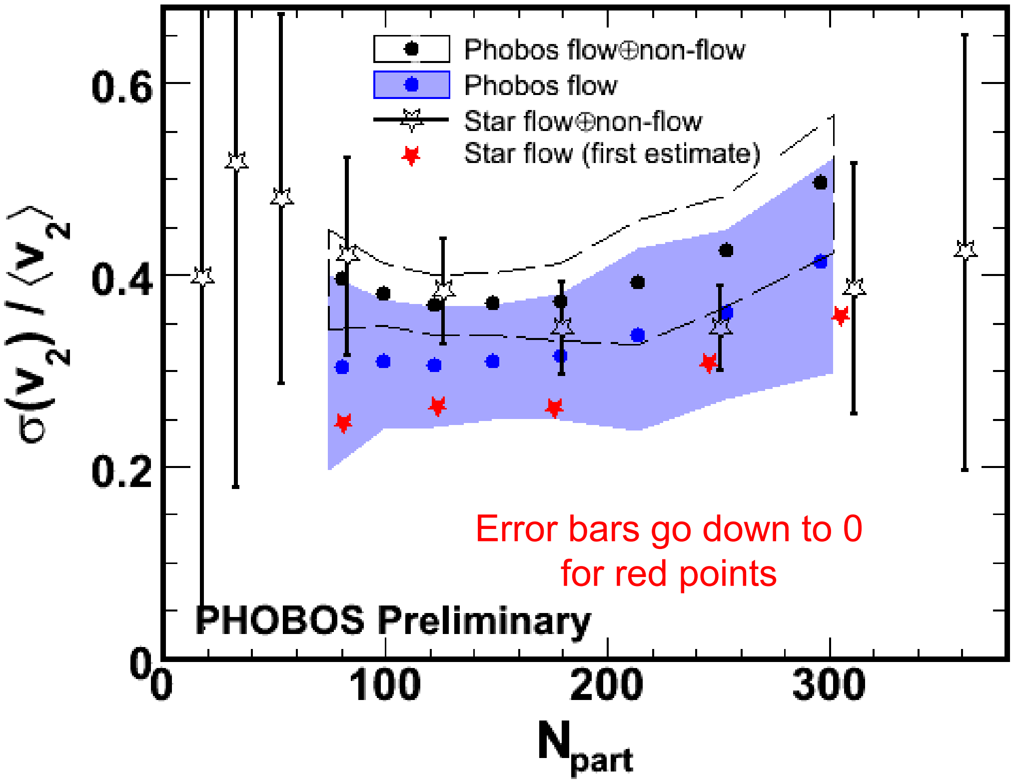


CGC: arXiv:0707.0249

Comparison to Total Fluctuations

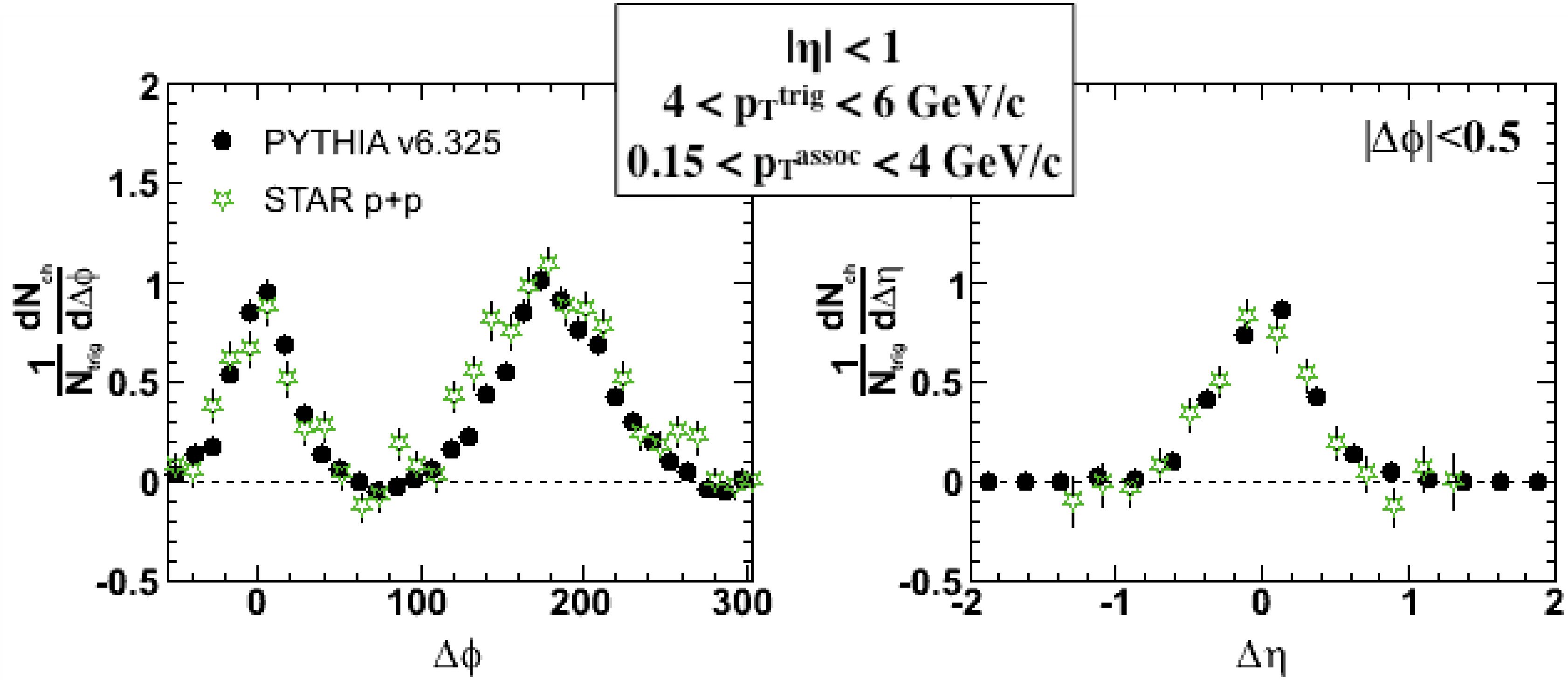


Comparison to STAR



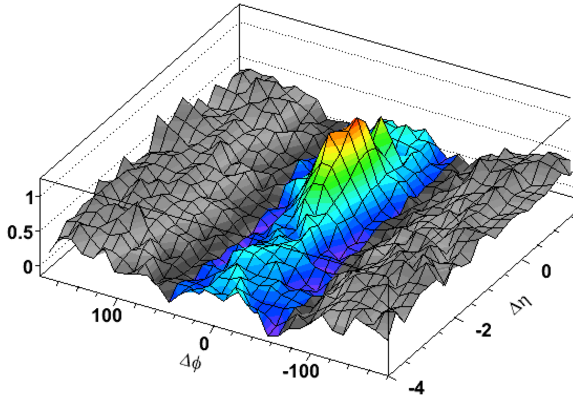
PYTHIA p+p Reference

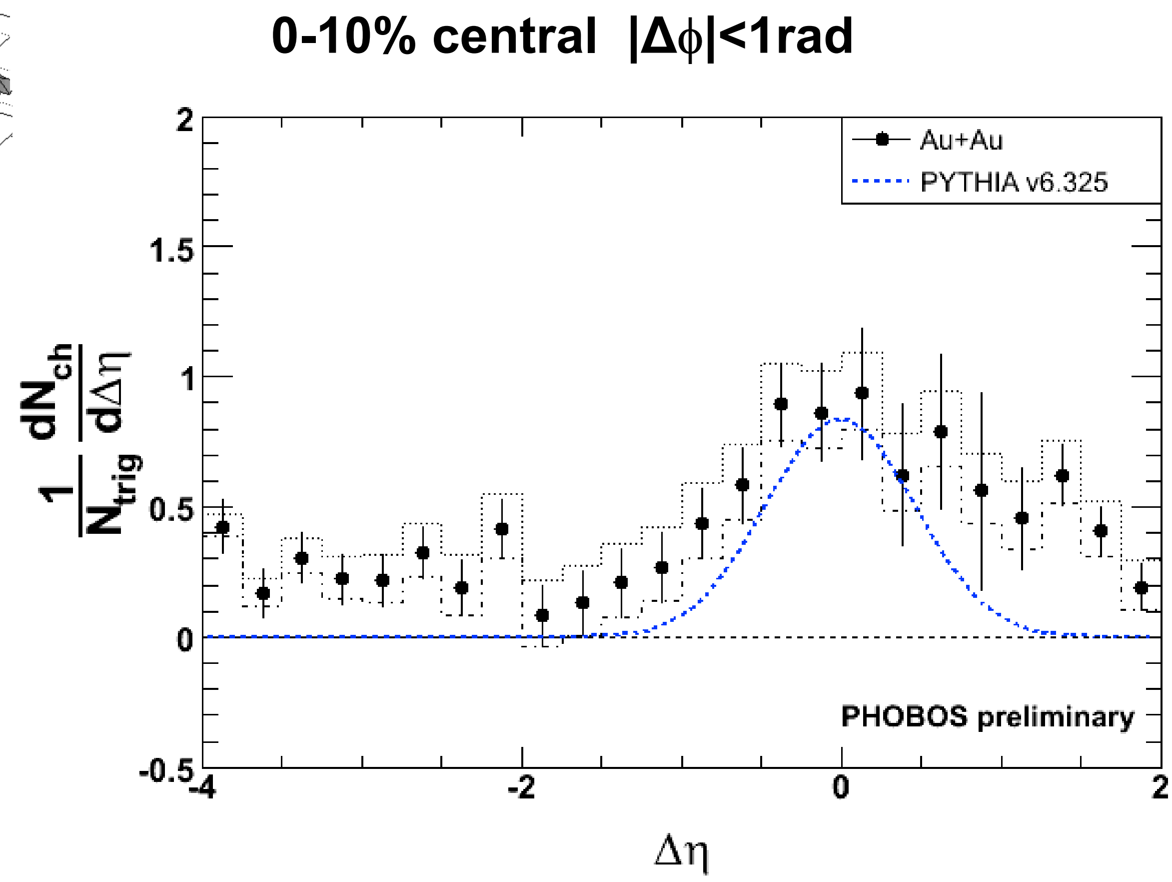
- PHOBOS is limited by statistics in p+p
- Compare our Au+Au results to PYTHIA, which reasonably reproduces STAR p+p



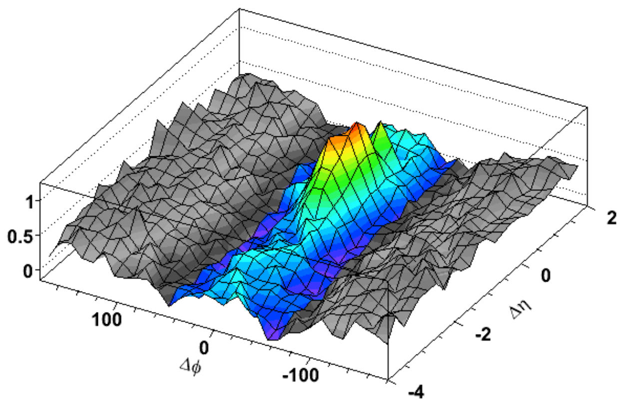
STAR, PRL **95**, 152301 (2005)

Ridge Extent in Δη



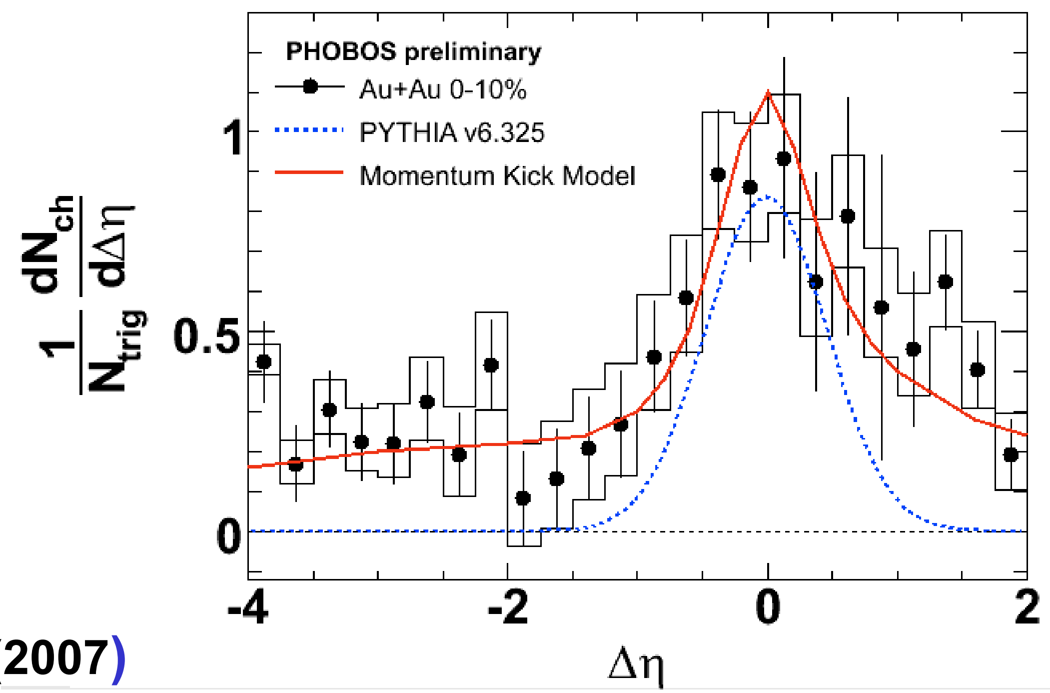


Comparison to Predictions



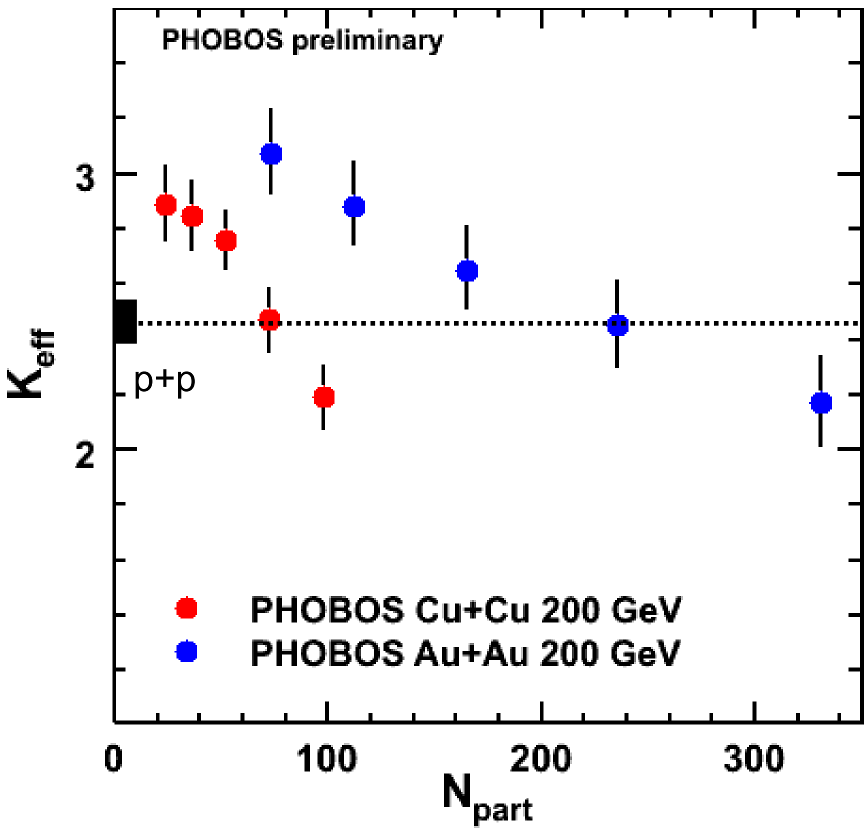
0-10% central |Δφ|<1rad

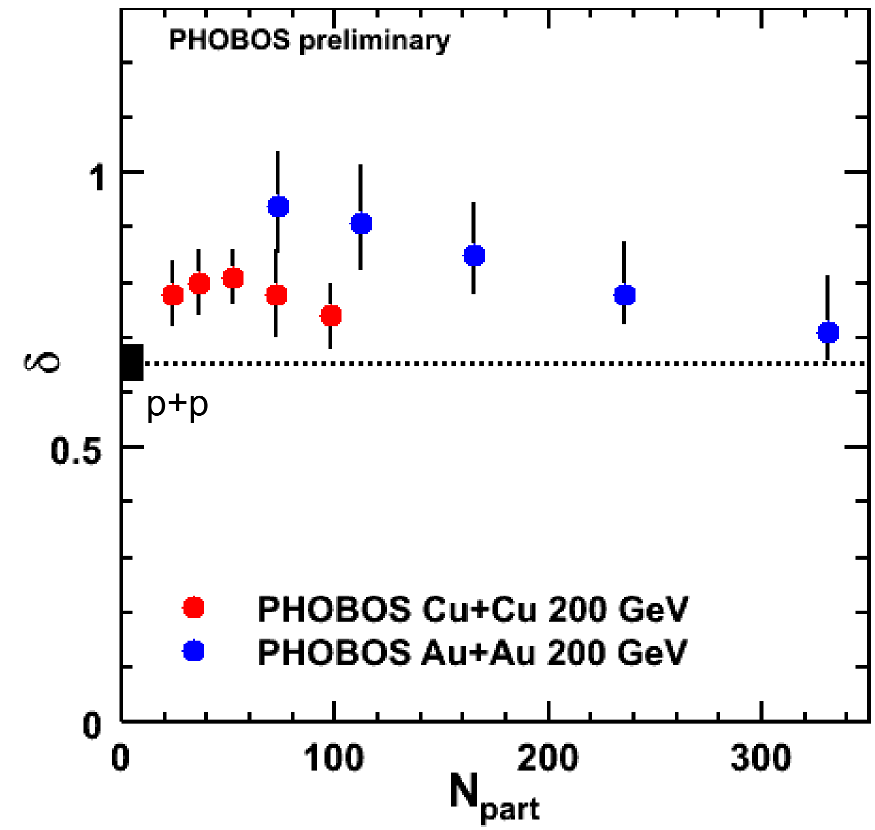
C.Y. Wong, private communication



C.Y. Wong PRC76, 054908 (2007)

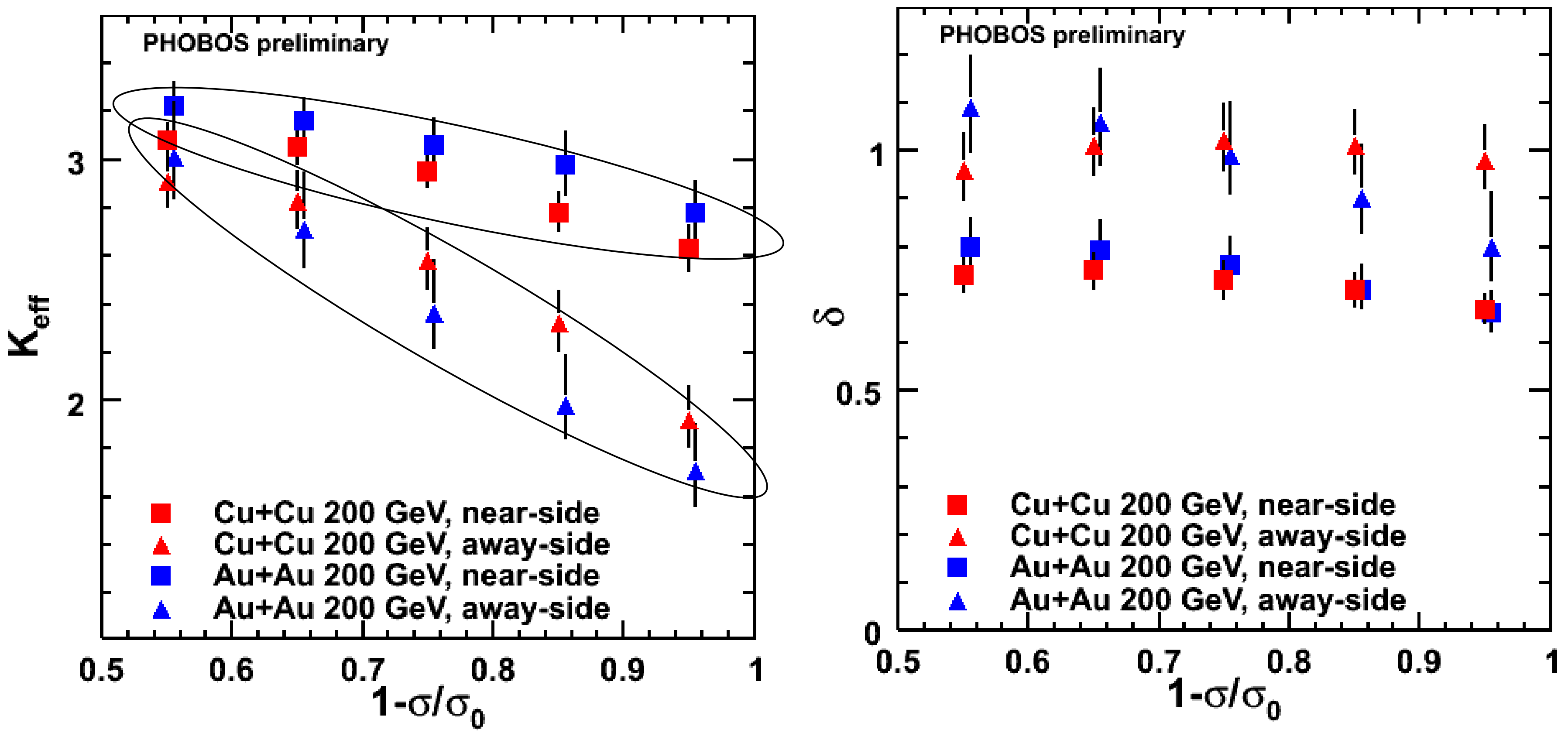
Clusters in Cu+Cu and Au+Au





- Cluster size decreases with N_{part} in A+A, but not monotonically.
- Enhancement of cluster from p+p to peripheral A+A.
- No strong dependence on N_{part} for cluster decay width.

Near- and Away-Side Clusters



Cluster Model

K. Eggert et al.,
Nucl. Phys. B 86:201, 1975

correlations between particles from one cluster

$$\Gamma(\Delta\eta) \propto \exp\left(-\frac{(\Delta\eta)^2}{4\delta^2}\right)$$

Two-particle rapidity correlation function:

Decay width: $\sqrt{2}\,\delta$

$$R(\Delta\eta) = \alpha\left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right]$$

k: cluster size

$$K_{eff} = \alpha + 1 = \frac{<k(k-1)>}{<k>} + 1 = <k> + \frac{\sigma_k^2}{<k>}$$

Keff : effective cluster size

$B(\Delta\eta)$ **: background distribution**