Highlights from PHOBOS at Quark Matter 2008

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PHOBOS Collaboration

  

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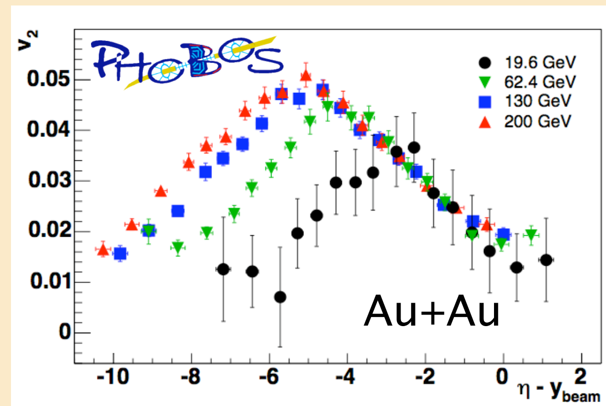
UNIVERSITY OF MARYLAND
BROOKHAVEN NATIONAL LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

9 Current Ph.D. Students

PHOBOS Philosophy

- Motivated by the history of heavy ion collisions
  - No smoking guns 
  - Every figure tells a story

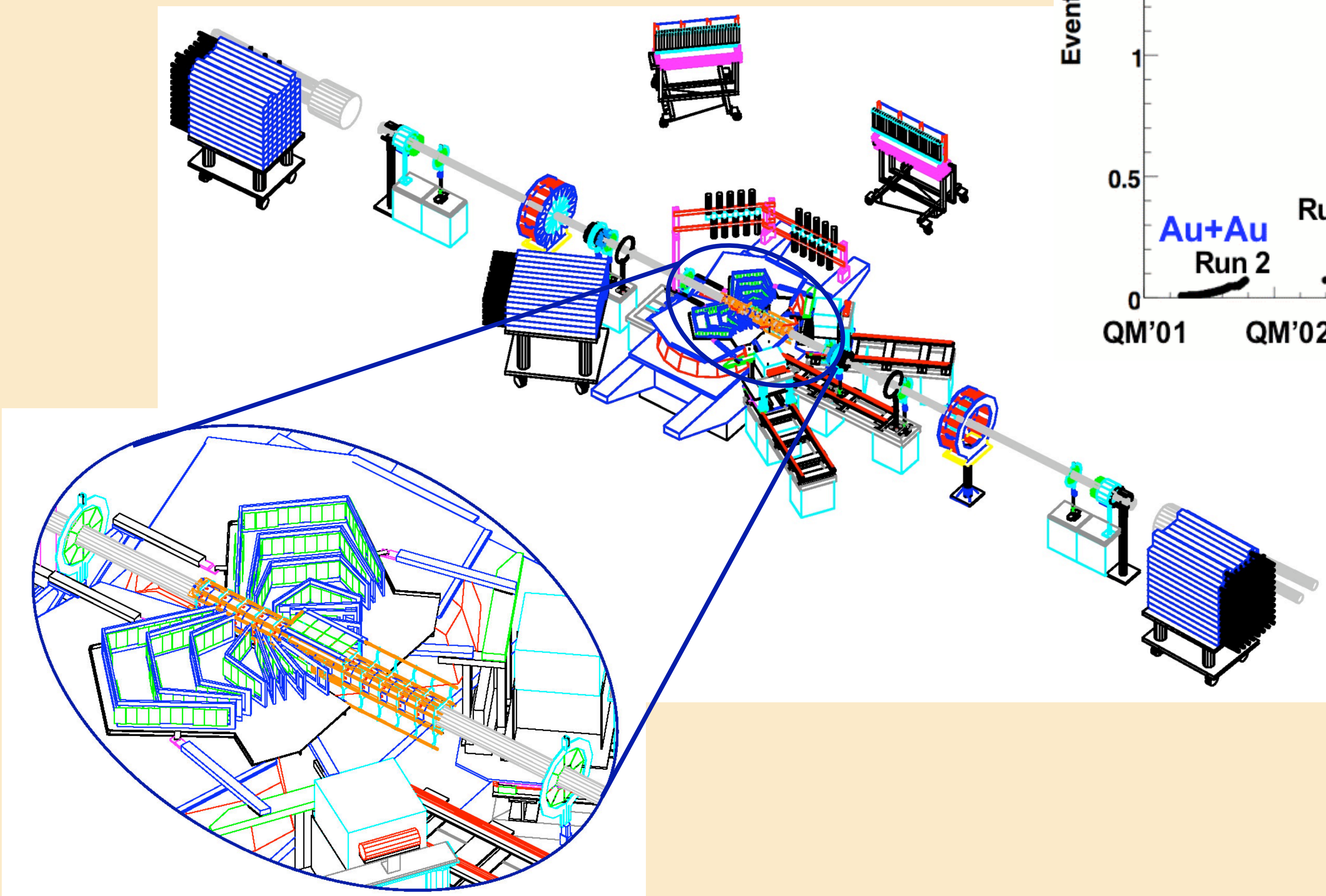


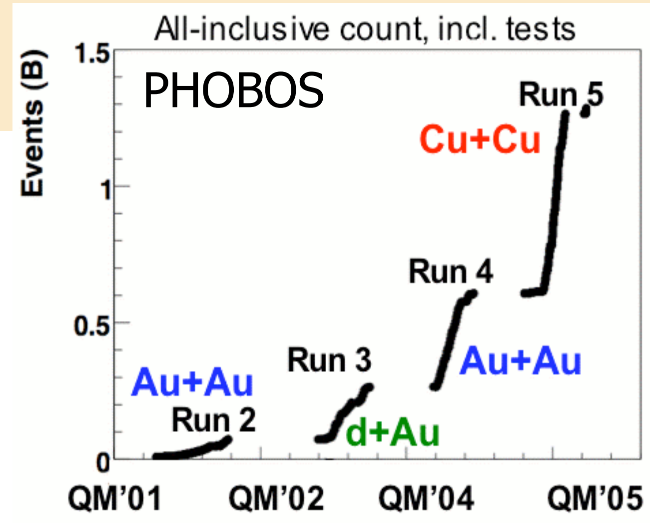
- Characterize particle production over as broad a range as possible in η ($\Delta\eta$), ϕ ($\Delta\phi$), p_T, particle species, energy density, system size & shape

Today's Talk

- More fun with PHOBOS
- Three big new questions
- Not just completing or expanding older analyses, these are new approaches
  - Are heavy ion collisions more social, i.e. do particles get produced in similar clusters?
  - Is "close in η" special, i.e. how far in $\Delta\eta$ do the interesting structures at $\Delta\phi$ ~0 and ~180^o extend?
  - What do so-called "flow fluctuation measurements" really measure and how can you tell?

PHOBOS Detector

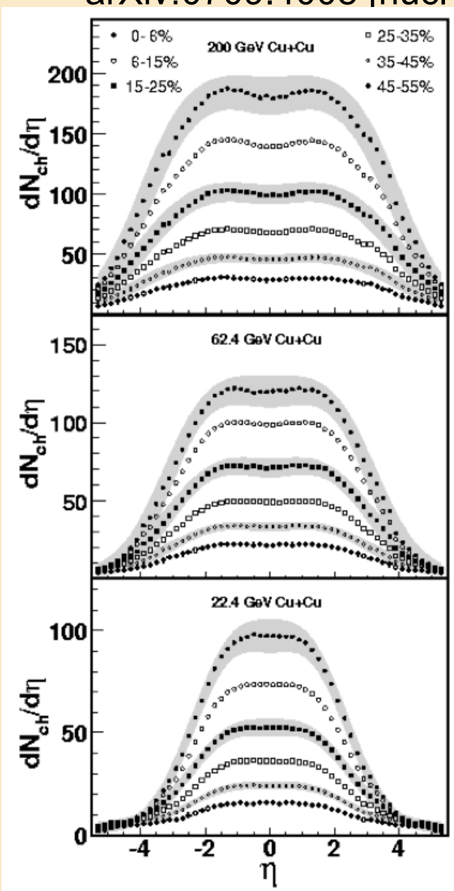




Systematic Studies: General

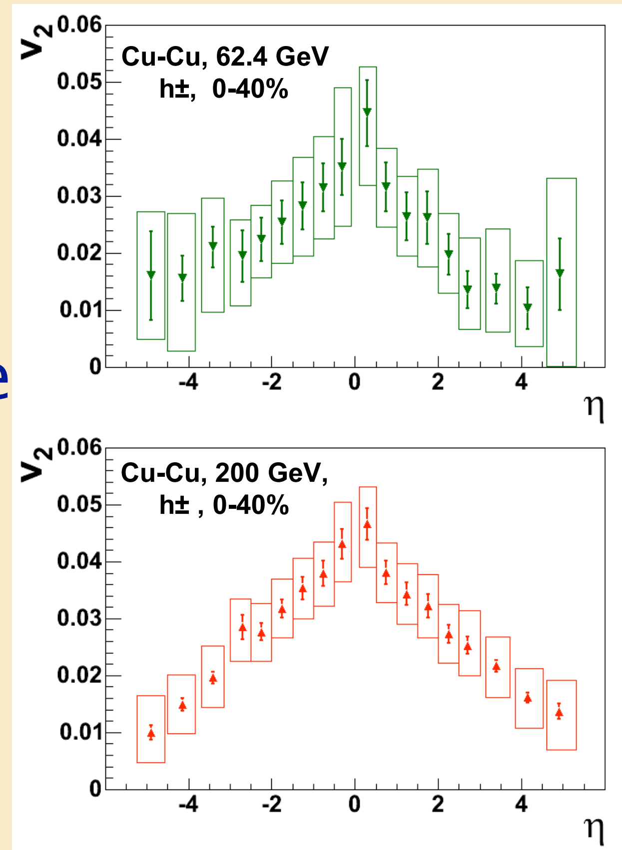
Global properties of charged particle production extensively characterized.

arXiv:0709.4008 [nucl-ex]



PHOBOS trademarks:
LARGE η coverage
BROAD centrality range

Phys. Rev. Lett. 98 (2007) 242302

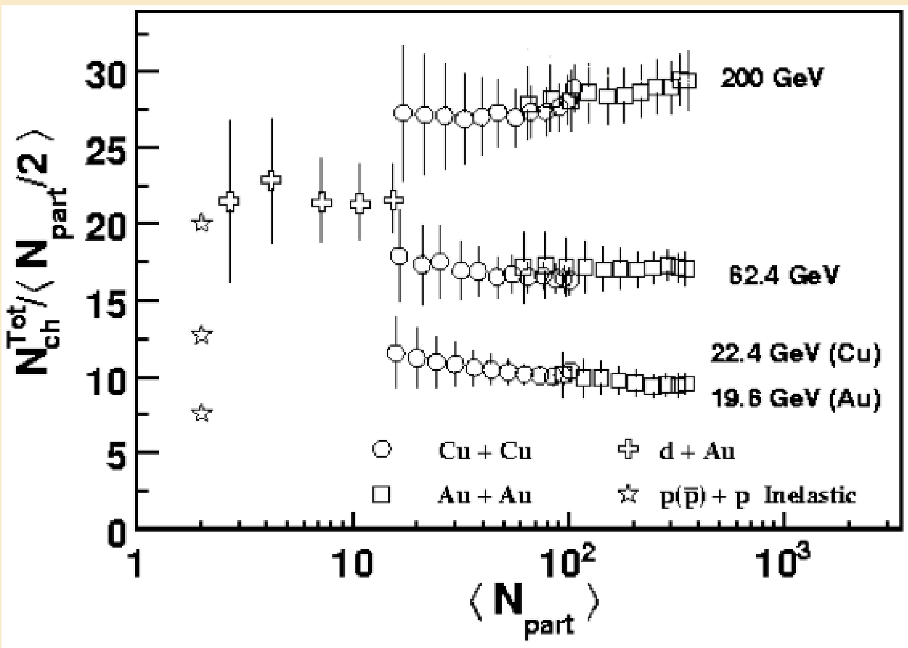


Systematic Studies: New Results

Charged particle production

N_{ch}^{Tot}

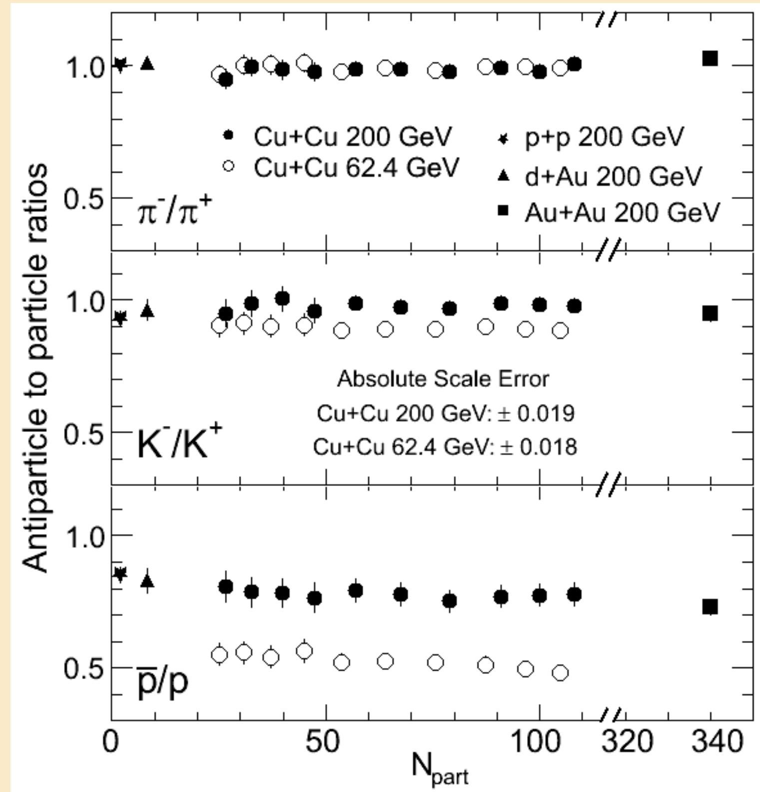
arXiv:0709.4008 [nucl-ex]



Total charged particle multiplicity scales with N_{part}

Antiparticle to particle ratios

arXiv:0802.1695 [nucl-ex]



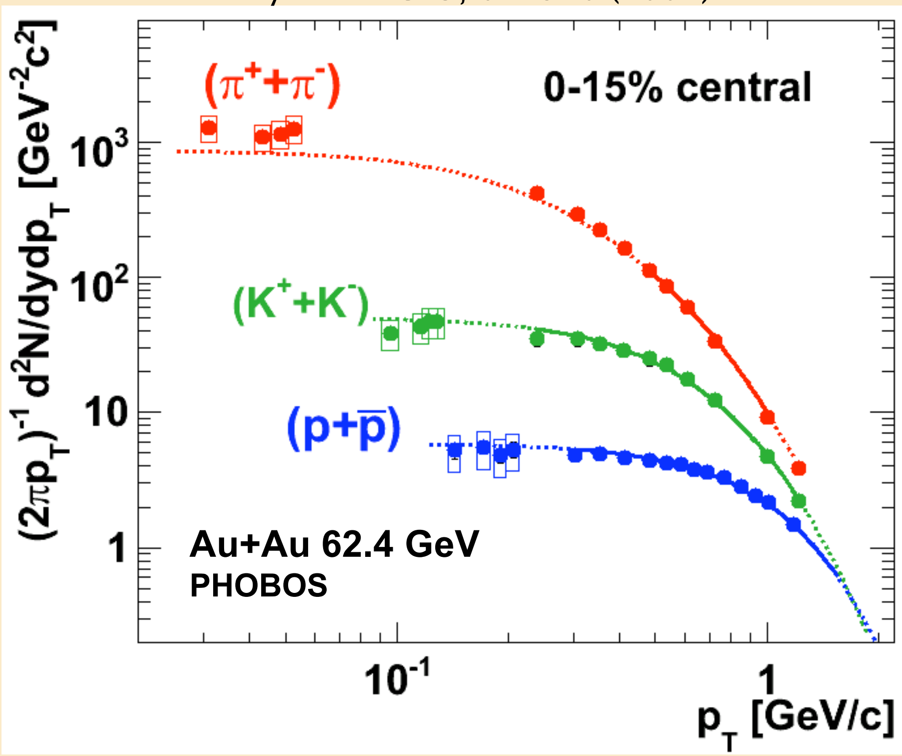
At most weak dependence on system size

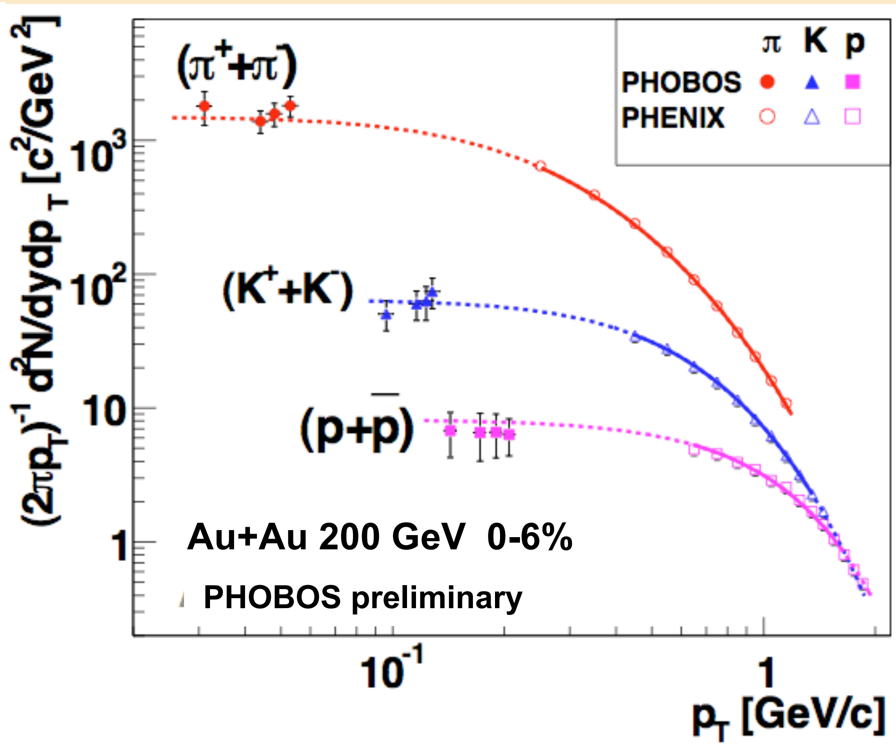
Systematic Studies: New Results

UNIQUE PHOBOS measurements:
Energy and centrality dependence of low-p_T spectra

Phys. Rev. C75, 024910 (2007)

New data





Dotted lines are extrapolated Blast-Wave fits to high p_T data
No anomalous low-p_T enhancement
Radial flow effects ⇒ breaking m_T scaling

Systematic Studies: Summary

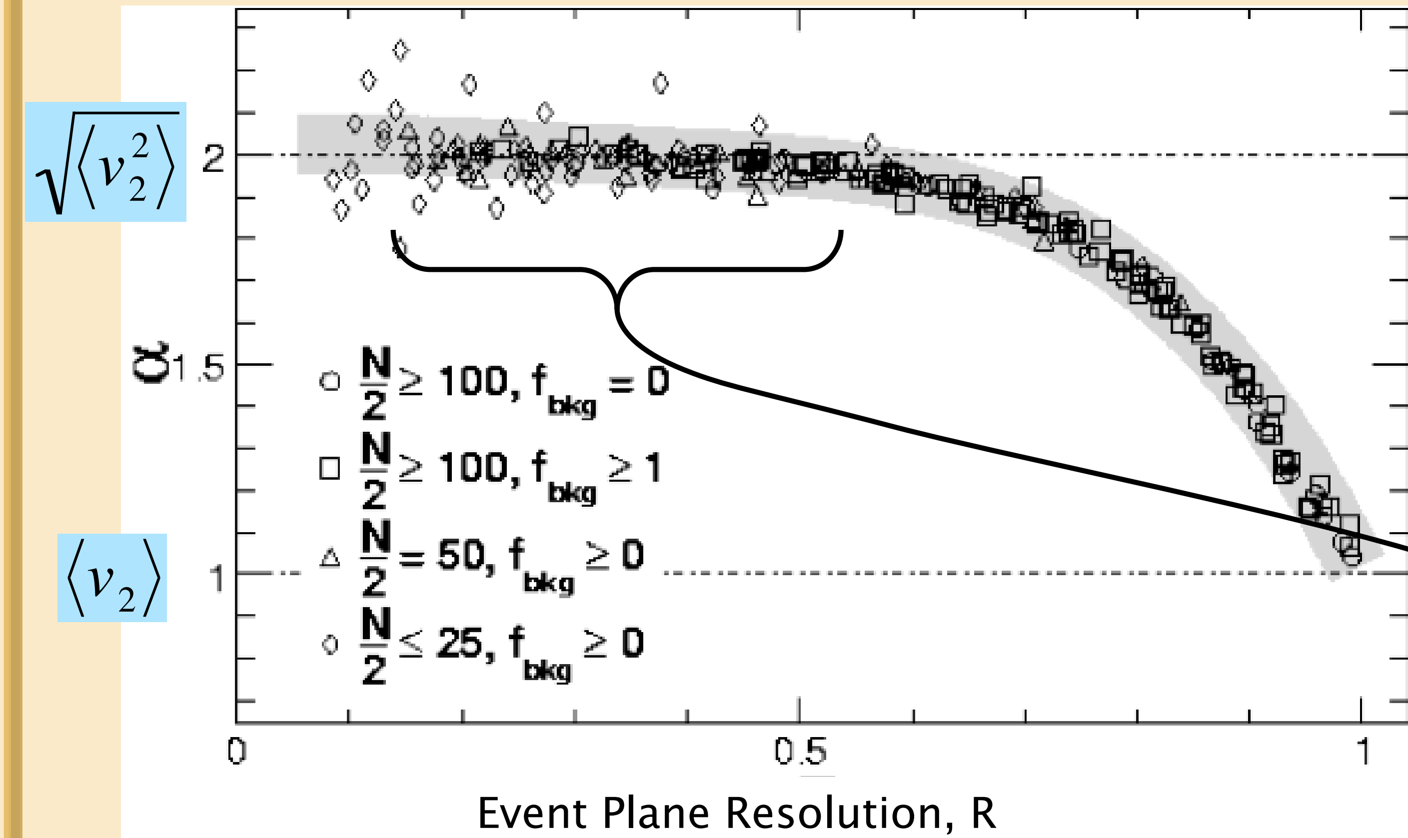
- Many properties of particle production can be described with a surprisingly small number of systematic dependencies.
  - N_{part} scaling of total N_{ch}; extended longitudinal scaling in the nucleus rest frame; factorization of energy and centrality dependencies.
- The collision geometry has a major impact on the dynamical evolution of the system.
- A consistent explanation of these features of the data in terms of the interplay of geometry, conservation laws, and QCD is eagerly awaited.
- These observations provide a tool for extrapolating RHIC data to LHC energies.

Geometry and elliptic flow

- What do various "v_2" measurements actually measure?
- Eccentricity, what eccentricity?
- Is the connection between geometry and flow "on average" or specifically event-by-event?

- Extensively studied with Monte Carlo Glauber approach which includes spatial correlations among participants arXiv:0711.3724 to be published in Phys. Rev. C

What does "v_2" measure?



$v_2\{EP\}$ fit to

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

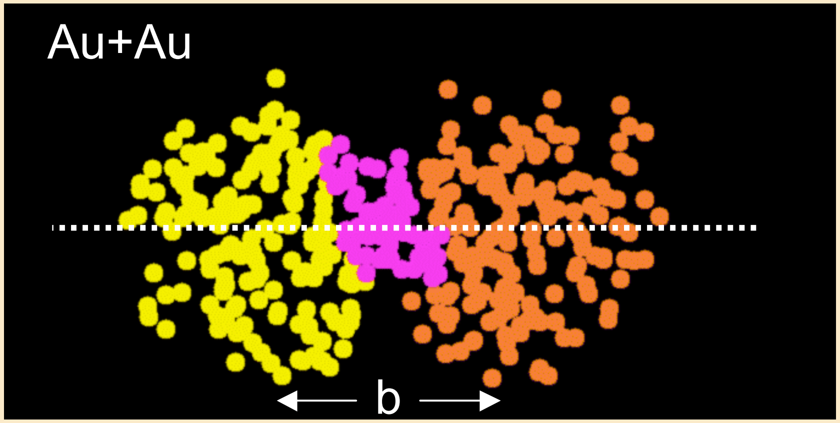
PHOBOS R:
0.13 – 0.55

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

Answer might be different for a different experiment
or a different flow extraction technique

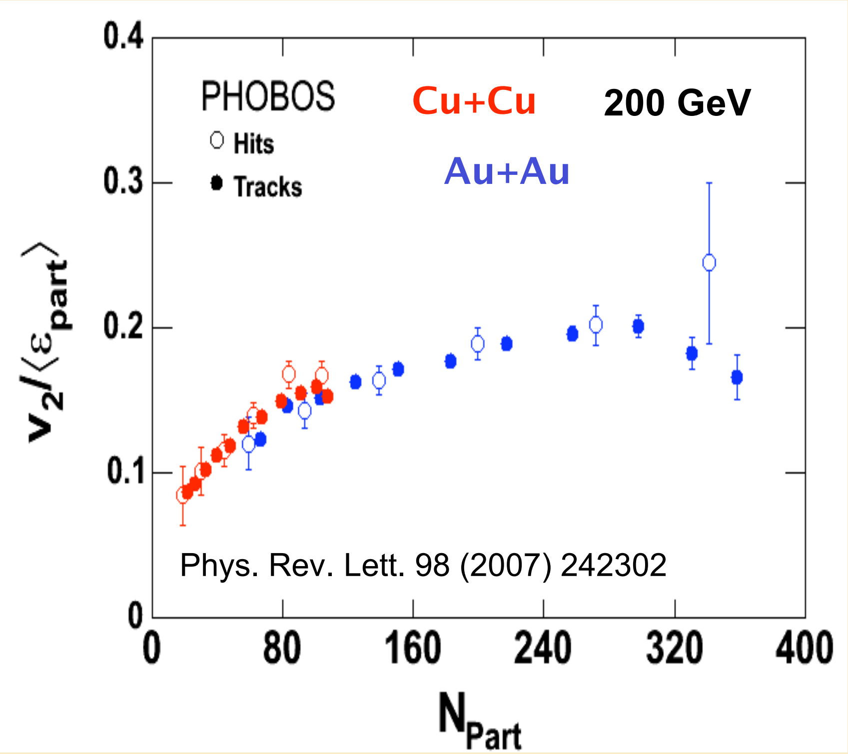
Eccentricity, what eccentricity?

Participant eccentricity



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

$\langle \epsilon_{part} \rangle$ **unifies** average v_2 in Cu+Cu and Au+Au



Eccentricity, what eccentricity?

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}

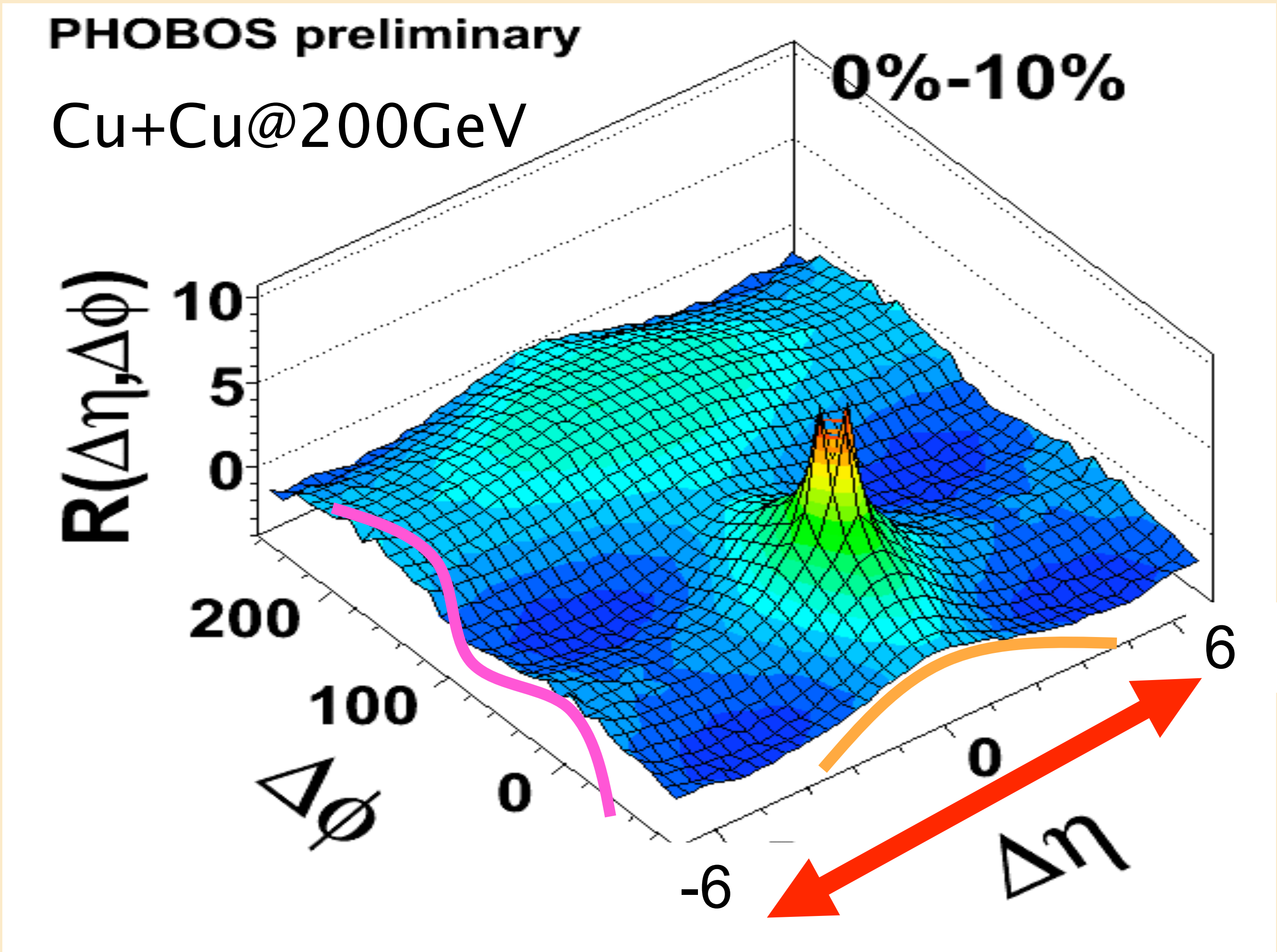
=> $<\varepsilon_{part}>$ is very robust!

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

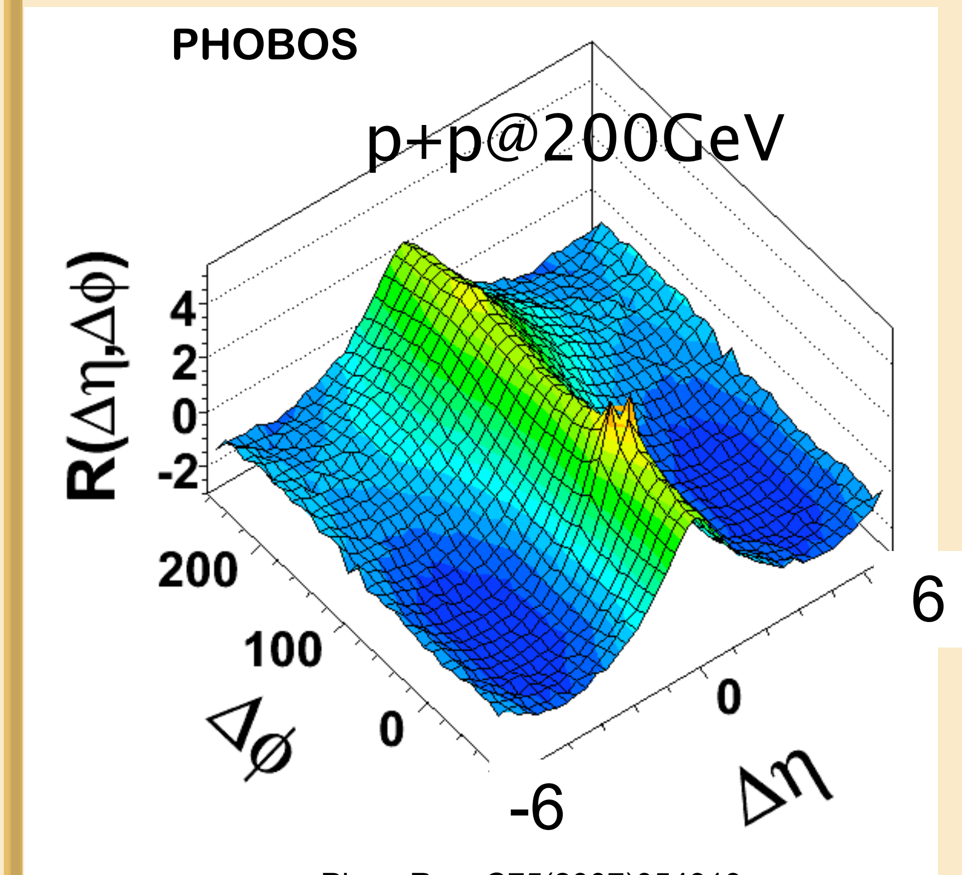
Three big new questions

- Are heavy ion collisions more social, i.e. do particles get produced in similar clusters?
  - 2-particle correlations
  - Inclusive (i.e. no p_T cut)
  - Data interpreted using a simple cluster model
  - Particles produced in groups of ~2.5 on average
- Is "close in η" special, i.e. how far in $\Delta\eta$ do the interesting structures at $\Delta\phi$ ~0 and ~180º extend?
- What do so-called flow fluctuation measurements really measure and how can you tell?

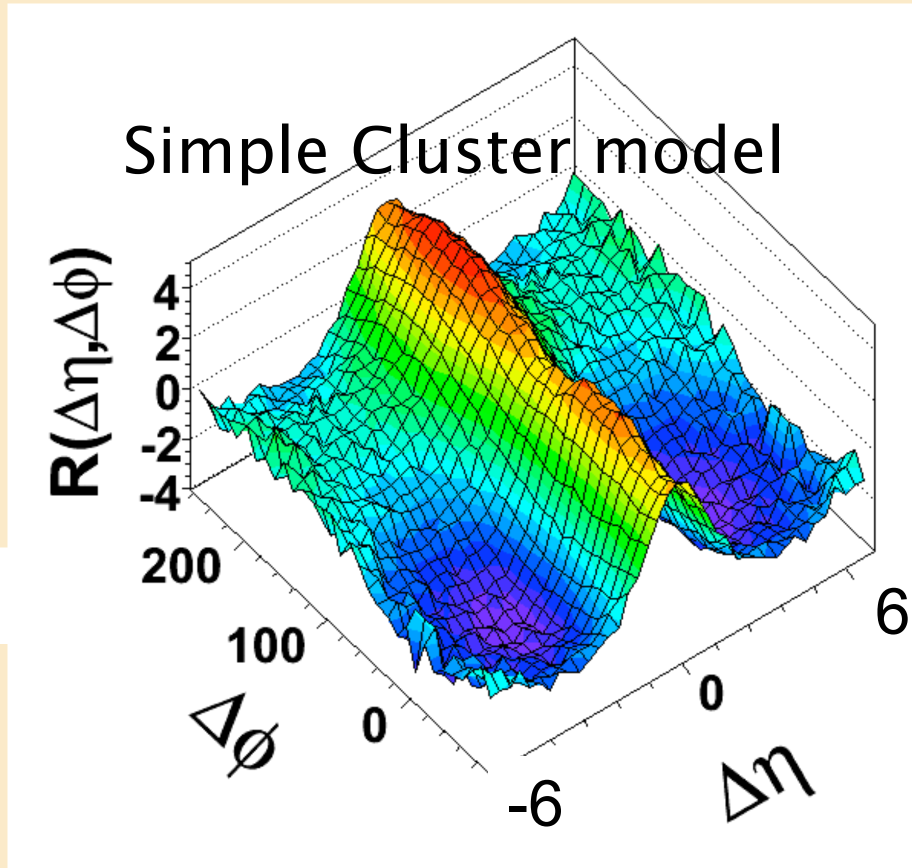
The PHOBOS Advantage: Large Coverage



Cluster-like Correlation Structure



Phys. Rev. C75(2007)054913

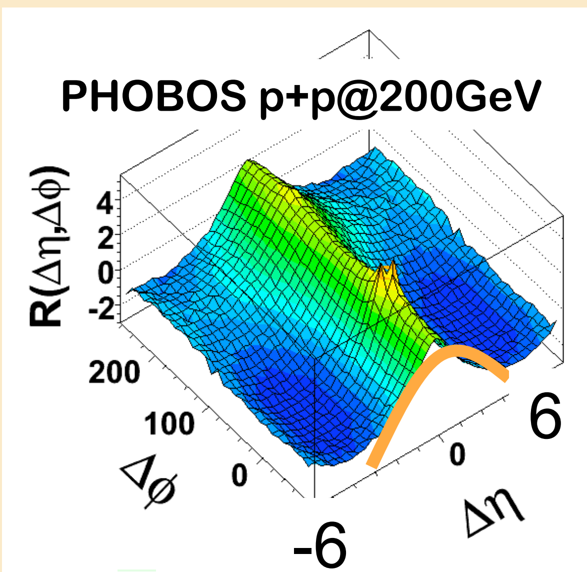


2-Particle Correlations

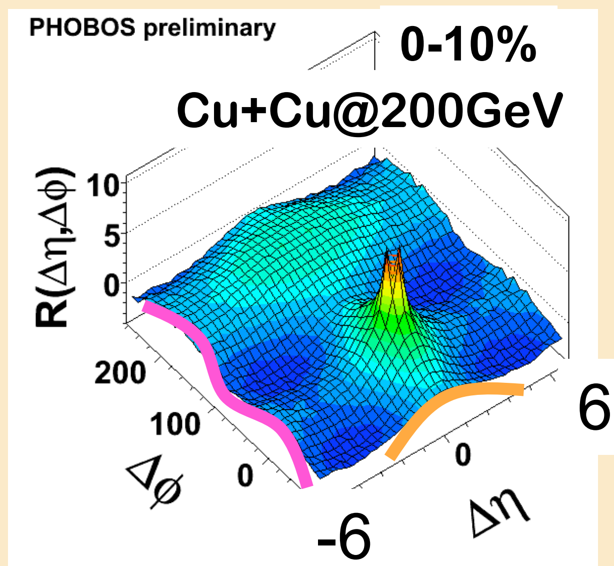
Multiplicity-independent
2-particle correlations

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

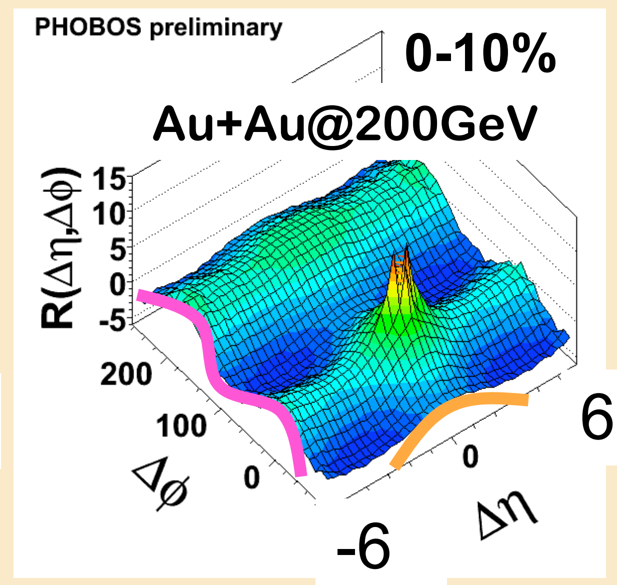
New



Phys. Rev. C75(2007)054913



J. Phys. G34(2007)s1005



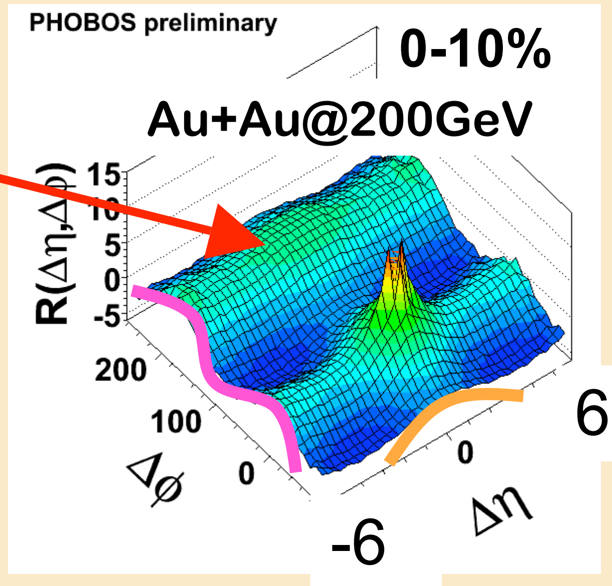
2-Particle Correlations

Multiplicity-independent
2-particle correlations

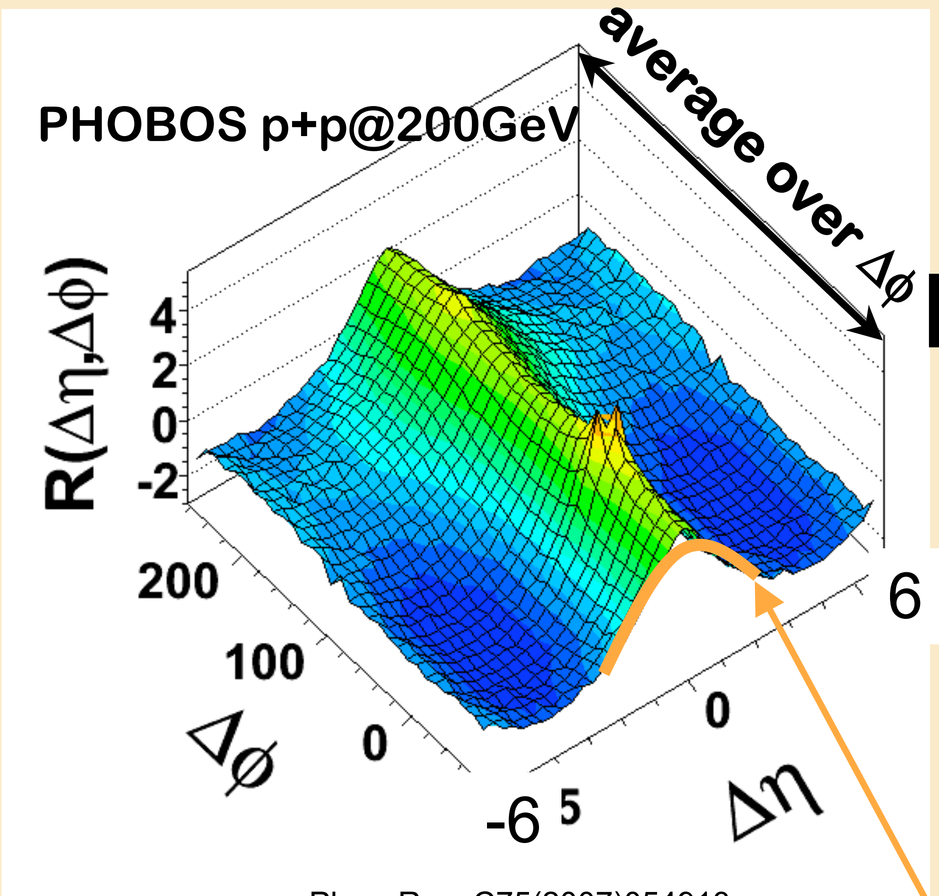
$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left[\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1\right]\right\rangle$$

Warning: Normalization “enhances” apparent flow signal in high multiplicity events

New

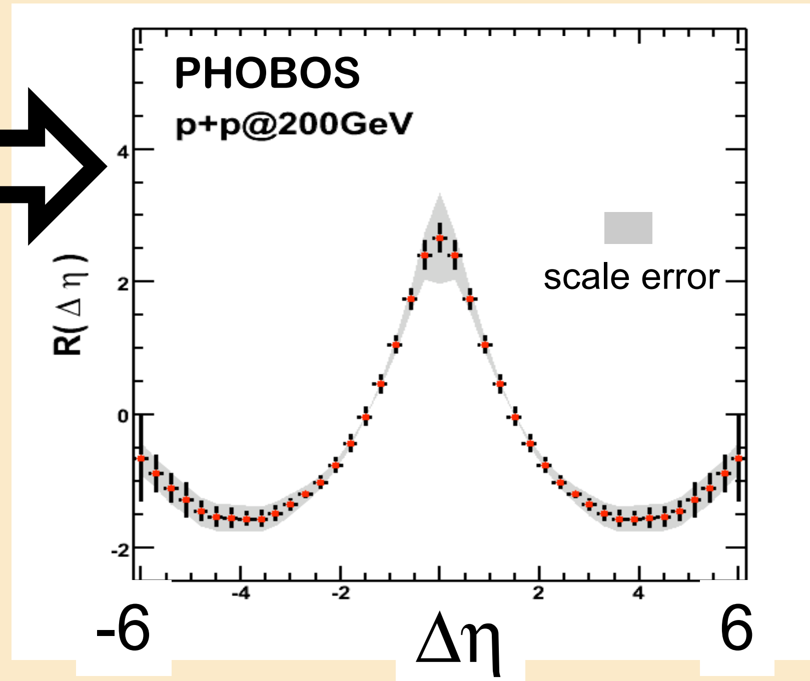


Parameterize cluster properties



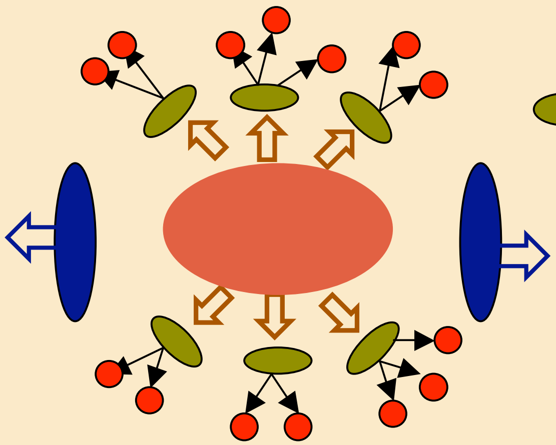
Phys. Rev. C75(2007)054913

Two-particle $\Delta\eta$ correlation function:



Study short-range rapidity correlations

2-Particle Correlations: Cluster Model



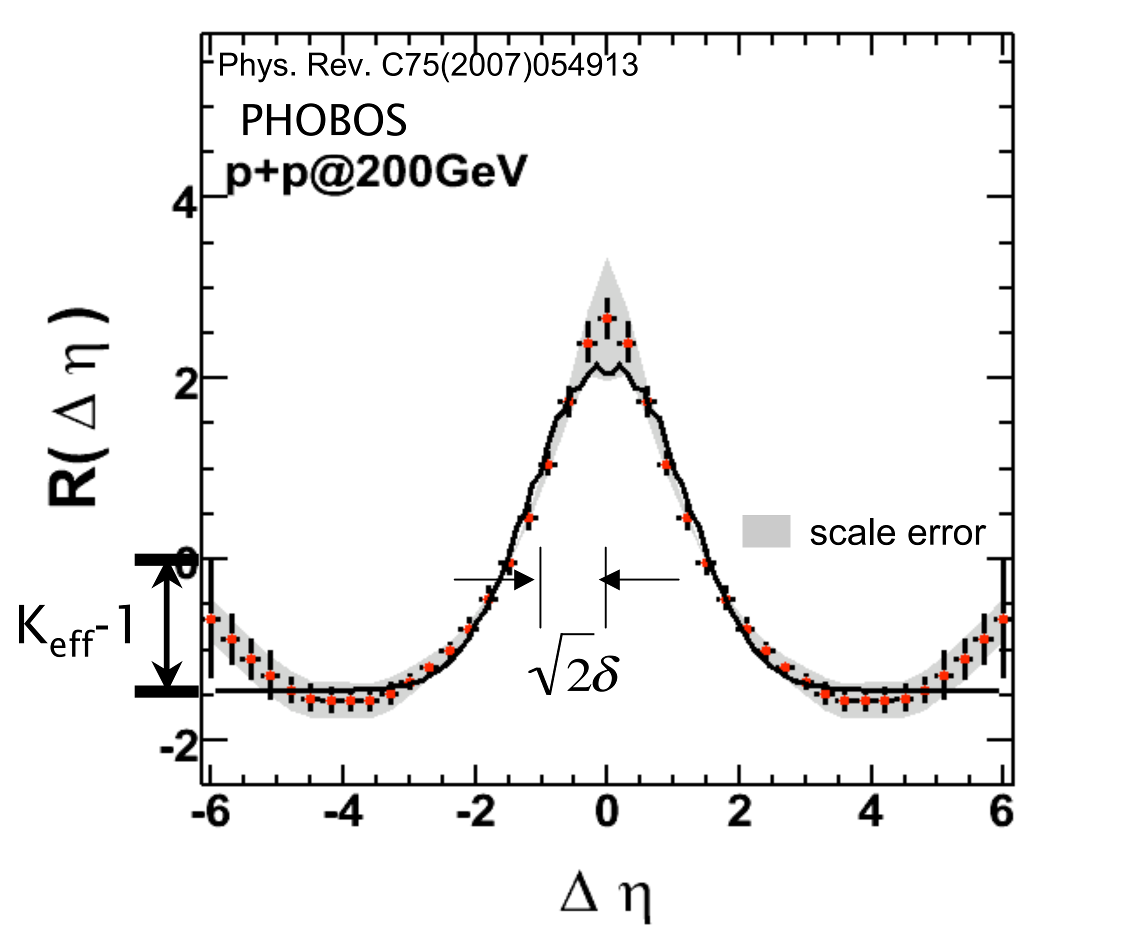
K_{eff} : effective cluster size

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

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

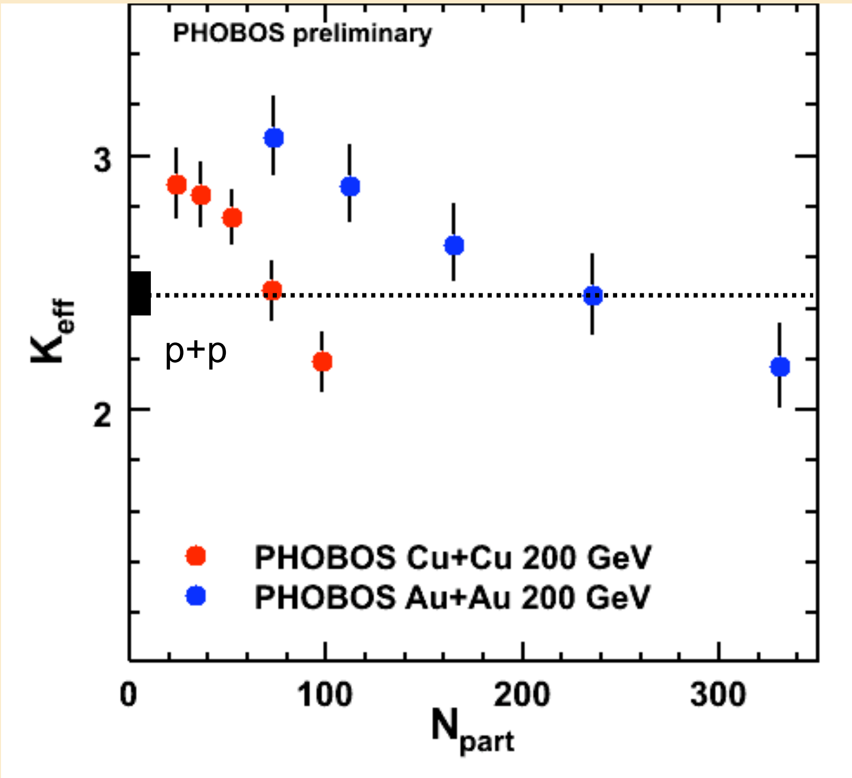
$$\Gamma(\Delta\eta) \propto \exp\left(-\frac{(\Delta\eta)^2}{4\delta^2}\right)$$

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

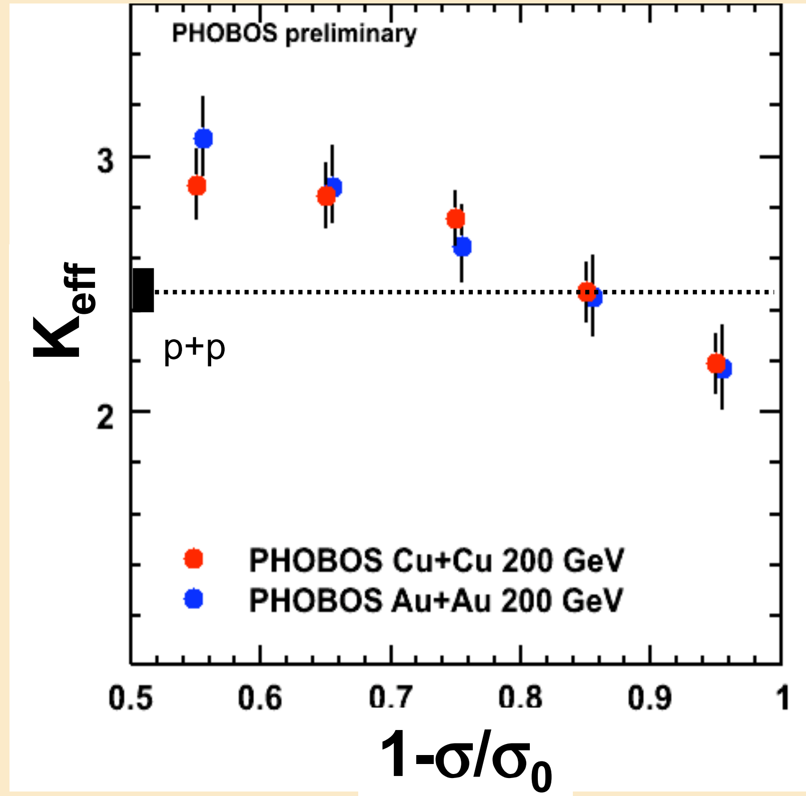


Comparing Cu+Cu to Au+Au

For the same Npart



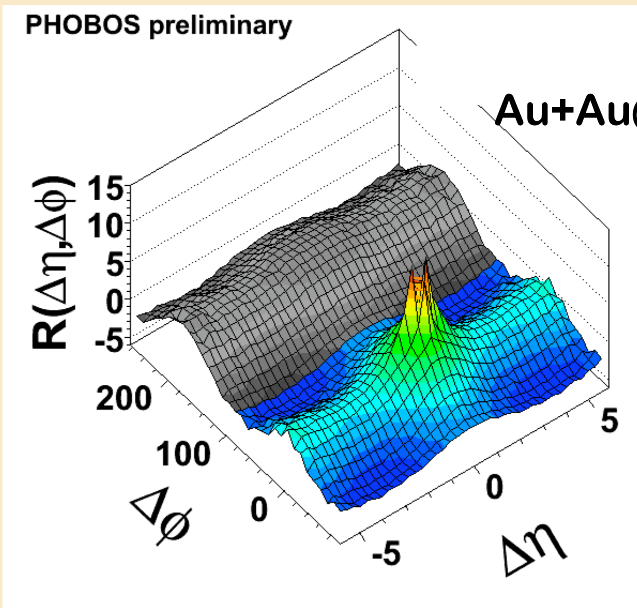
For the same fraction of the inelastic cross section σ/σ_0



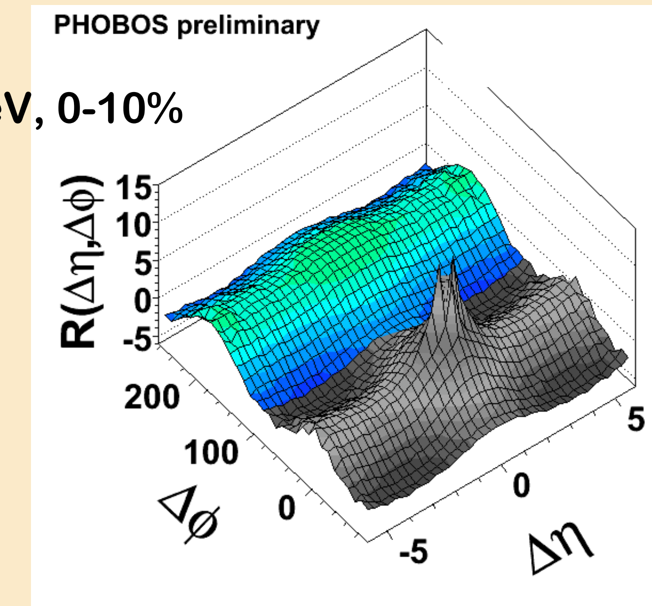
Cluster size in Au+Au is similar to that in p+p & Cu+Cu

Near- and Away-side clusters

Study cluster properties differentially in $\Delta\phi$



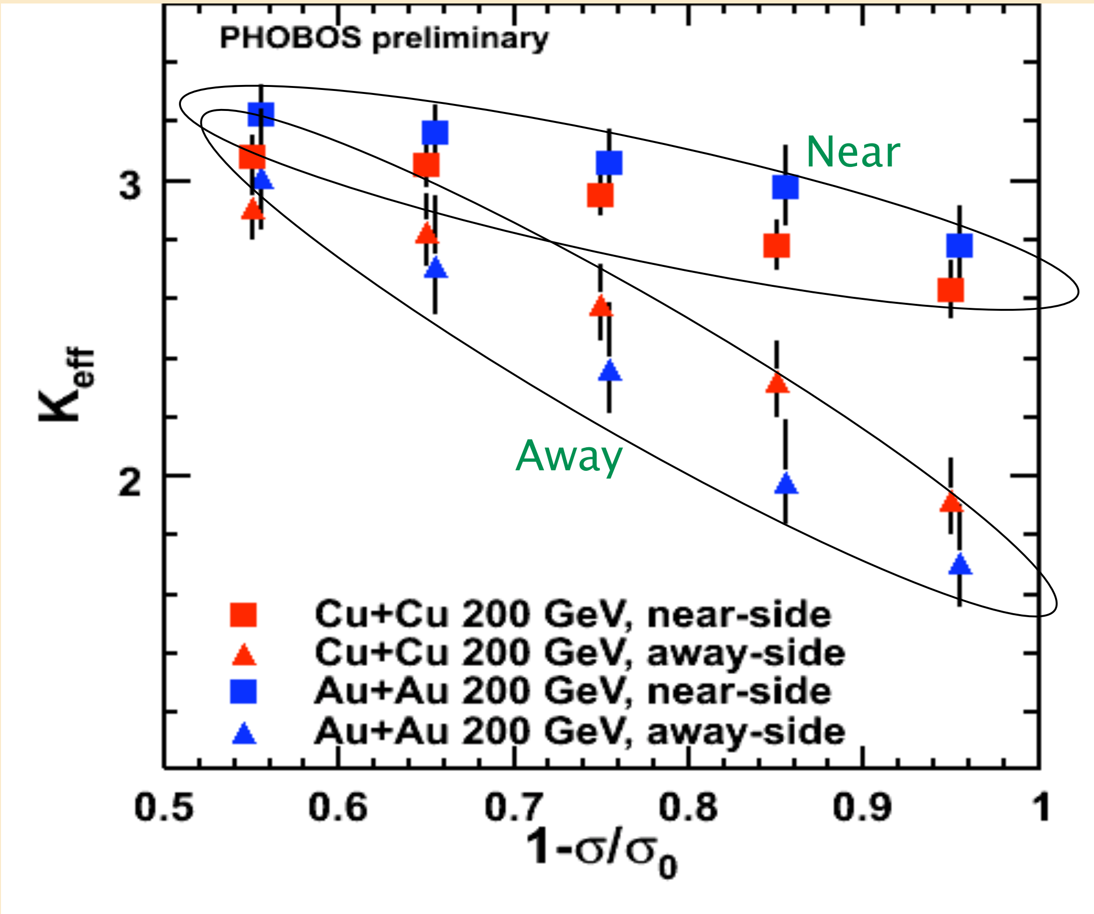
Near-side clusters:
$0^o < \Delta\phi < 90^o$
higher p_T



Away-side clusters:
$90^o < \Delta\phi < 180^o$
lower p_T

Elliptic flow is averaged out by construction.

Near- and Away-side clusters



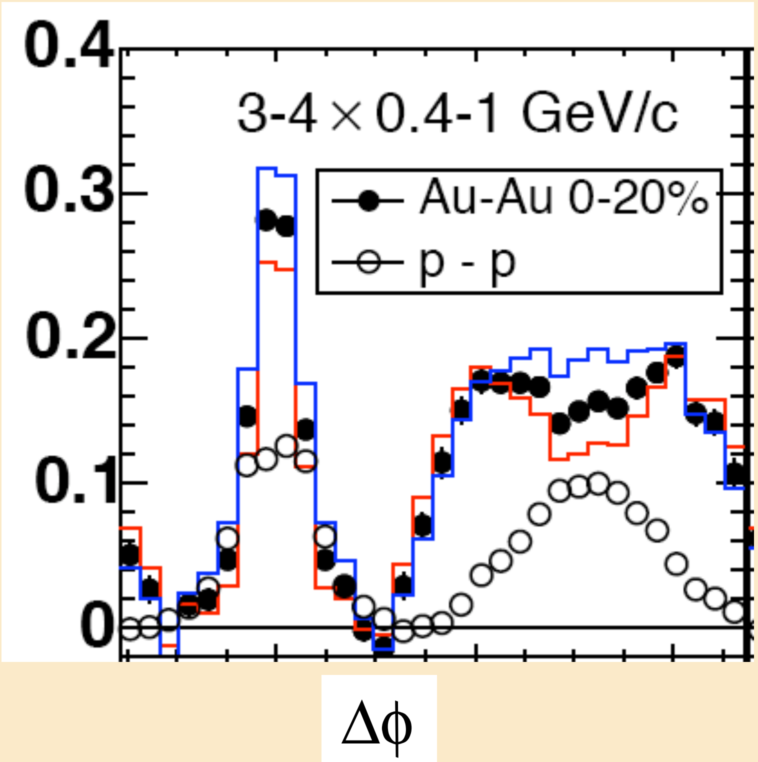
Away-side clusters are smaller and depend more strongly on centrality than near-side ones.

Three big new questions

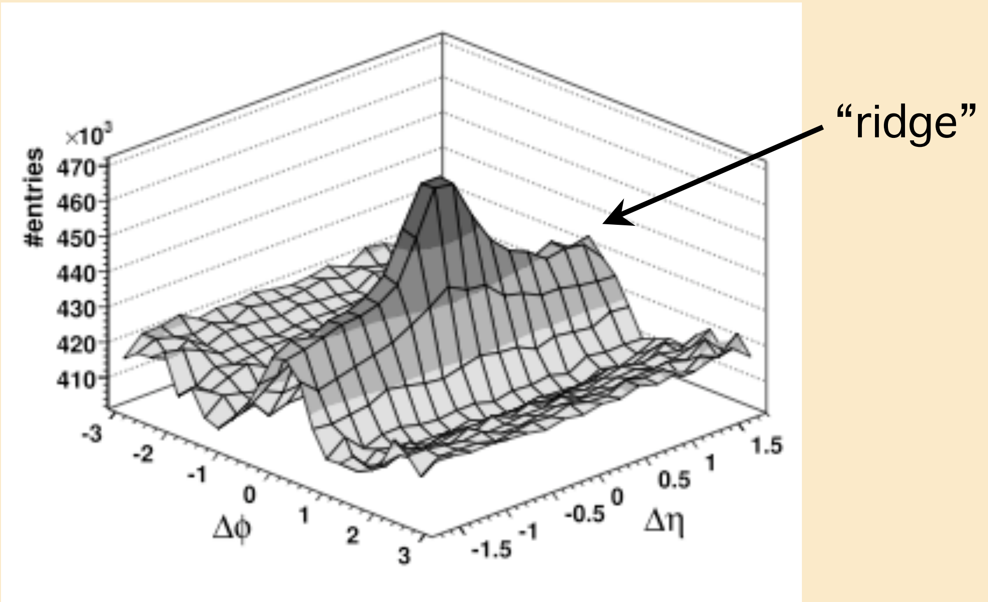
- Are heavy ion collisions more social, i.e. do particles get produced in similar clusters?
- Is "close in η" special, i.e. how far in $\Delta\eta$ do the interesting structures at $\Delta\phi$ ~0 and ~180^o extend?
  - 2 particle correlations with a high p_T trigger
  - At $\Delta\phi\approx 0$, study shape of correlation versus $\Delta\eta$
  - Primary motivation is to expand study of "ridge" seen in earlier measurements over limited $\Delta\eta$
  - Also study the $\Delta\eta$ dependence of the broadening in $\Delta\phi$ of the away side peak
- What do so-called flow fluctuation measurements really measure and how can you tell? Two $\Delta\phi$, or not two $\Delta\phi$?

Previous Triggered Correlation Data

PHENIX, arXiv:0705.3060v2

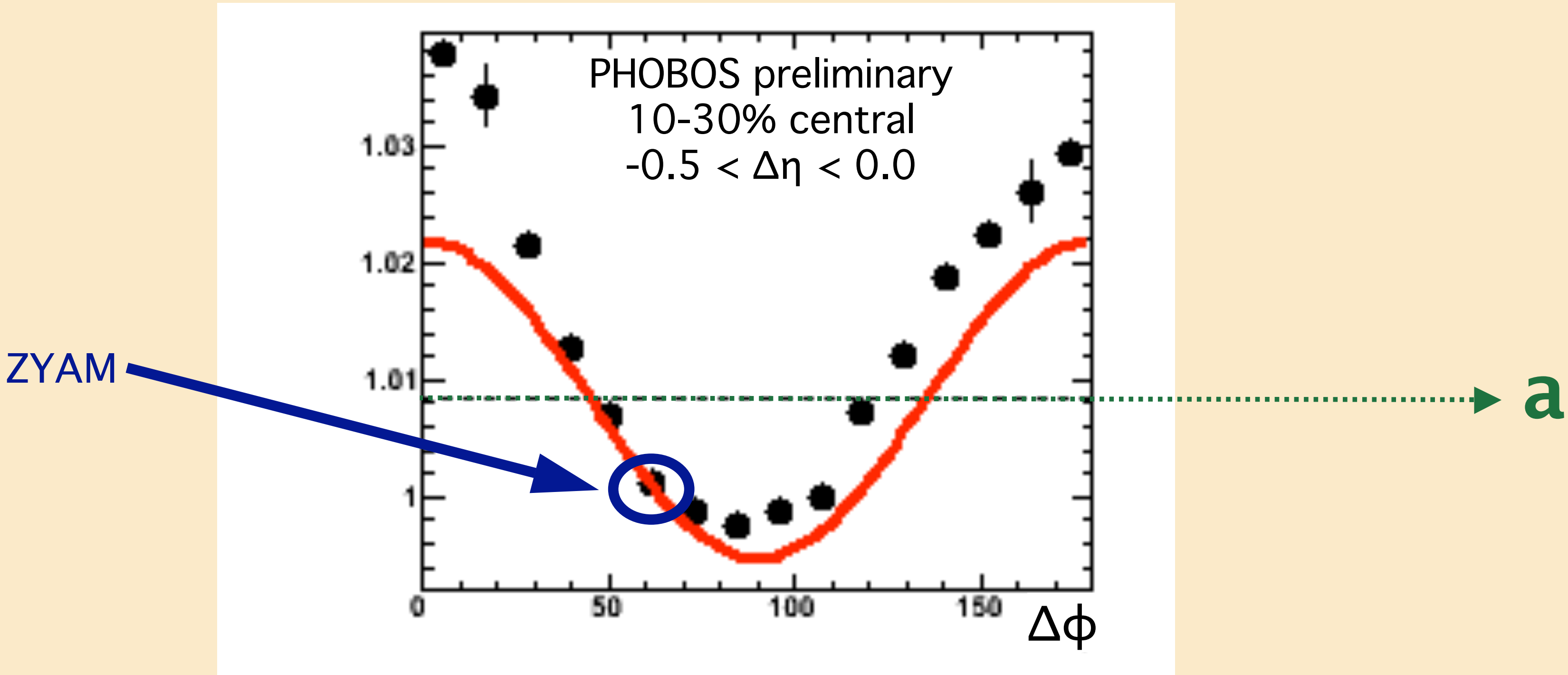


STAR, arXiv:nucl-ex/0701074v2



Flow subtraction

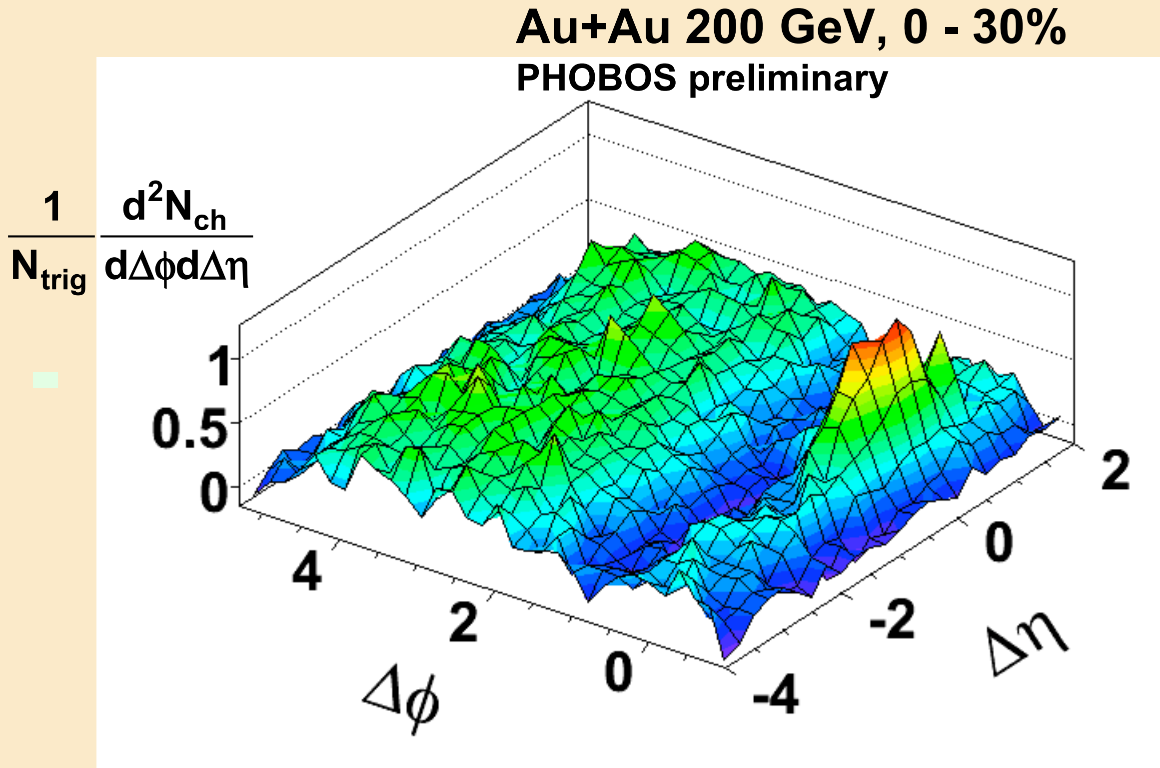
$$\frac{s(\Delta\phi,\Delta\eta)}{b(\Delta\phi,\Delta\eta)} - a\,[\,1 - 2V(\Delta\eta)\cos(2\Delta\phi)\,]$$



The scale factor, a (always ≈1), is calculated such that the yield after subtraction is zero at its minimum (ZYAM)

Ajitanand et al. PRC **72**, 011902(R) (2005)

Triggered Correlation Data



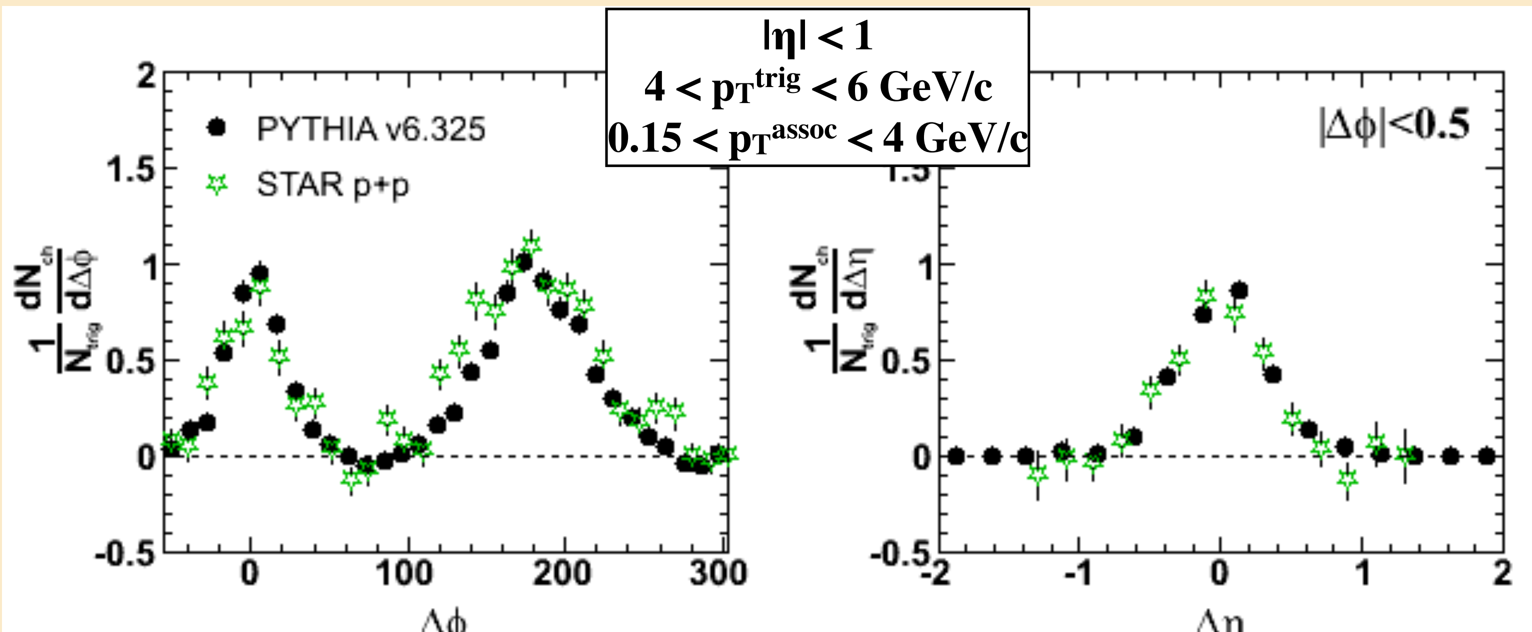
$$p_T^{trig} > 2.5 GeV/c \quad 0 < \eta^{trig} < 1.5$$

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

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

PYTHIA p+p reference

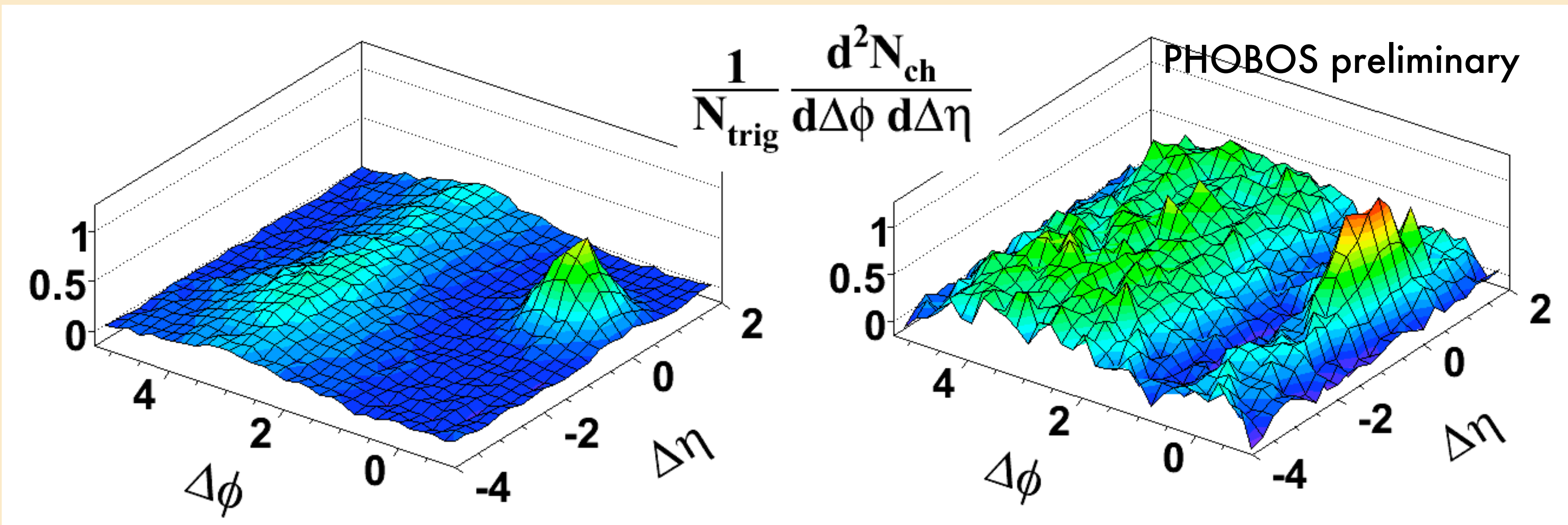
- PHOBOS is limited by statistics in p+p
- We will compare our Au+Au results to PYTHIA, which reproduces STAR p+p data reasonably well



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

Comparison of 2D Au+Au to p+p

p+p PYTHIA v6.325 | Au+Au 0-30% central

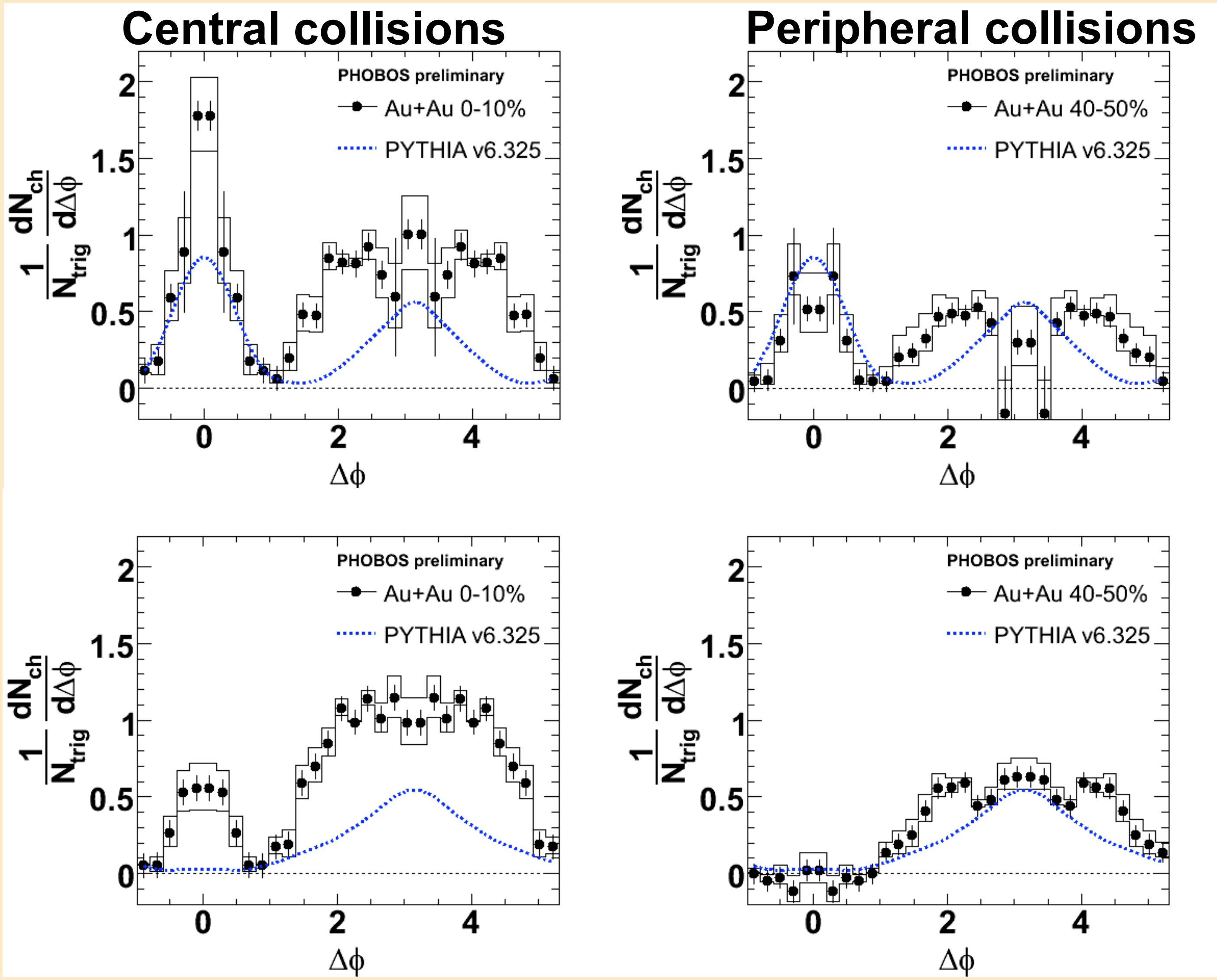


$p_T^{trig} > 2.5$ GeV/c
$p_T^{assoc} \gtrsim 20$ MeV/c

Far-Side Peak vs Δη and Centrality

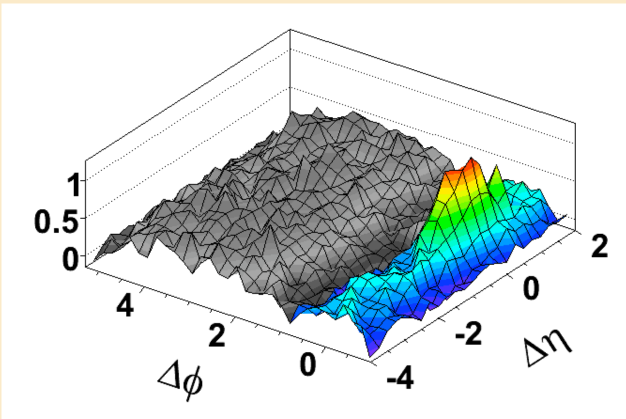
Short-range
|Δη| <1

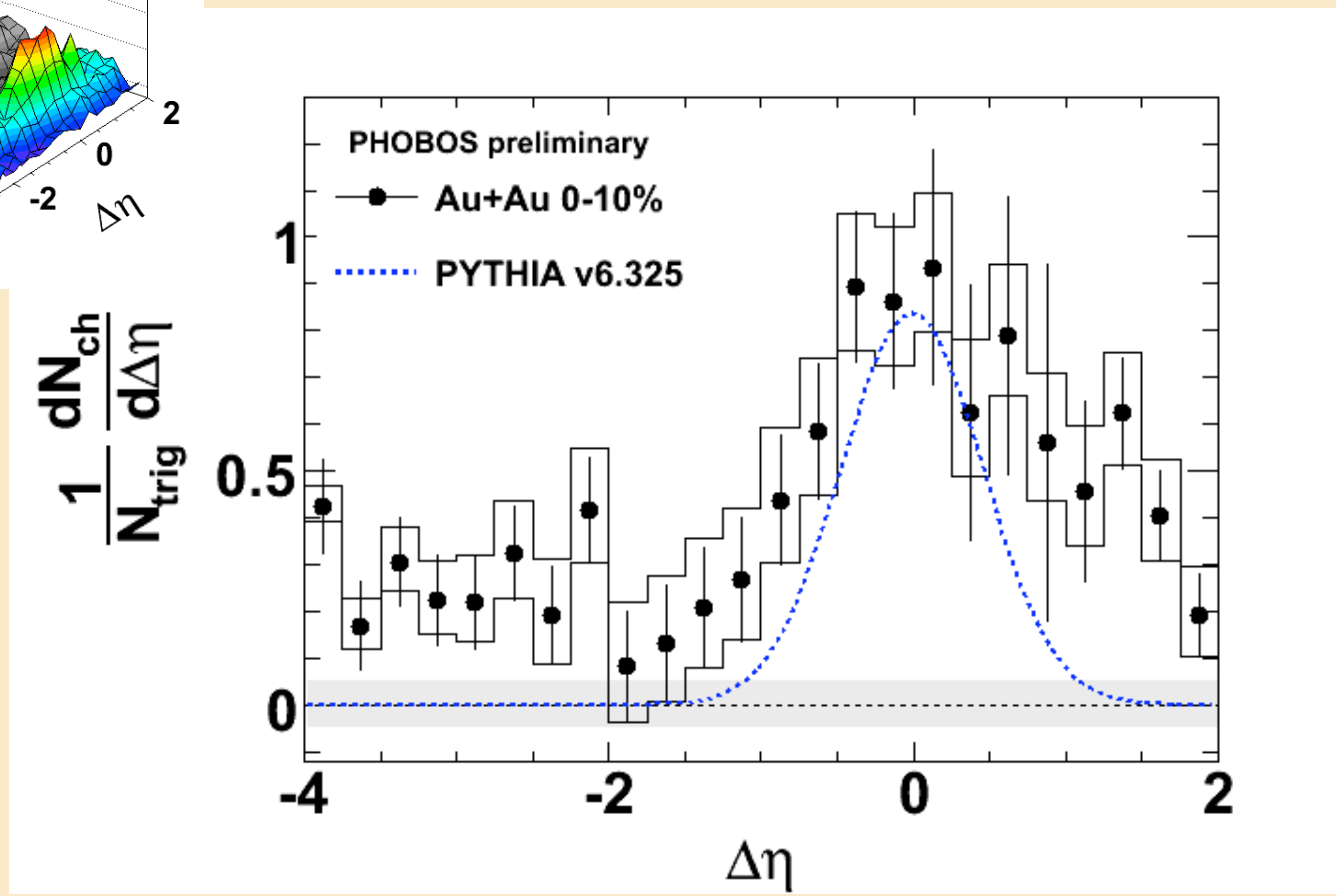
Long-range
–4< Δη <–2



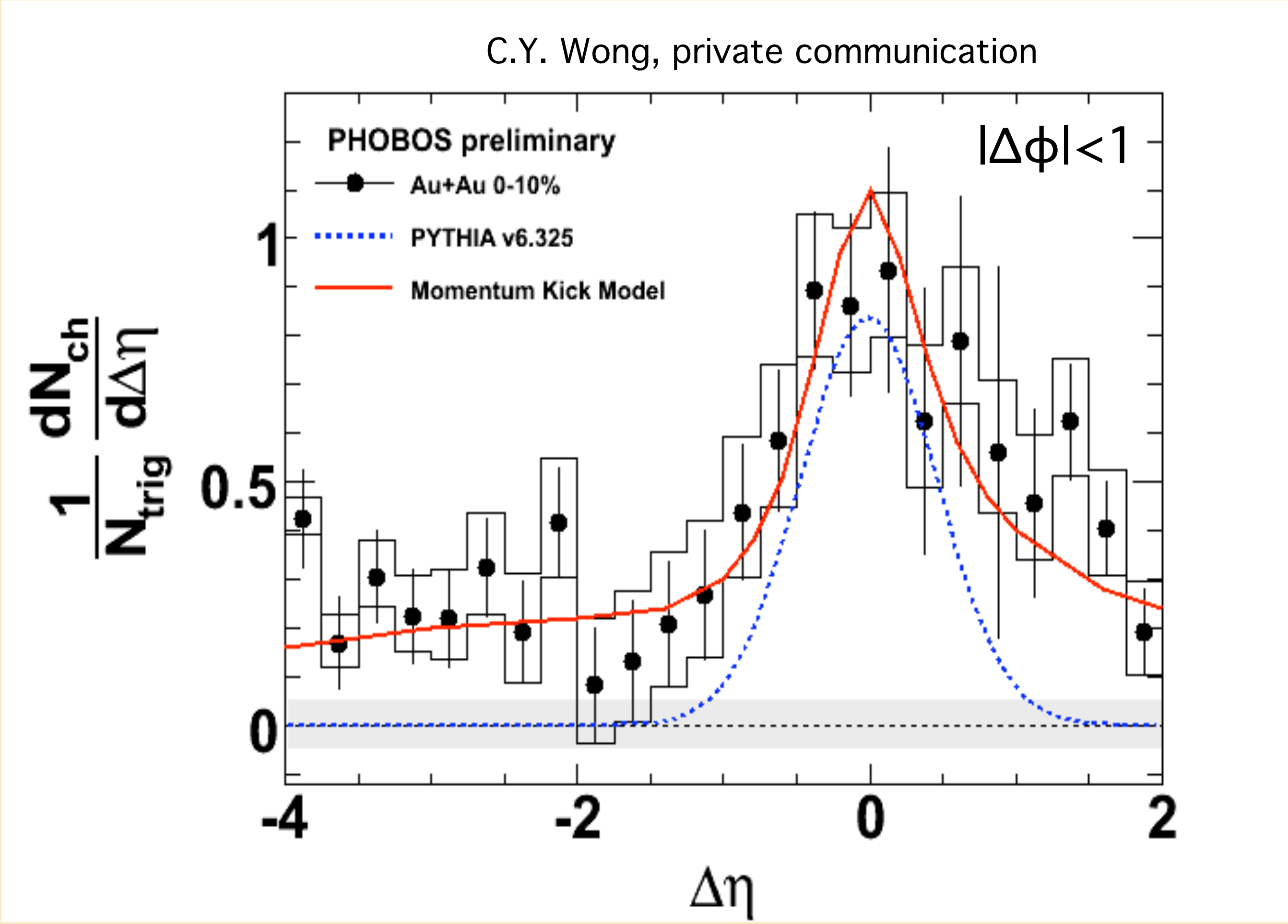
Extent in Δη of small Δϕ Ridge

Correlated yield on near-side (|Δϕ| < 1):





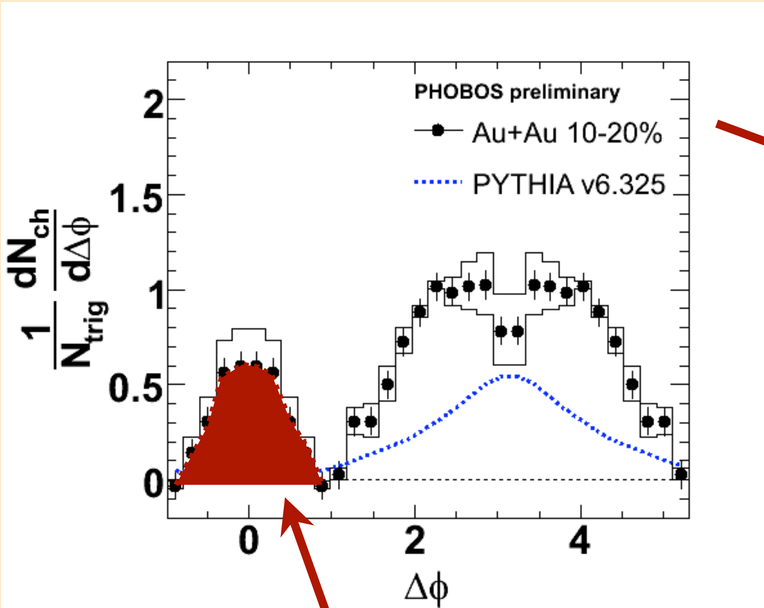
Comparison to Predictions



C.Y. Wong, PRC **76**, 054908 (2007)

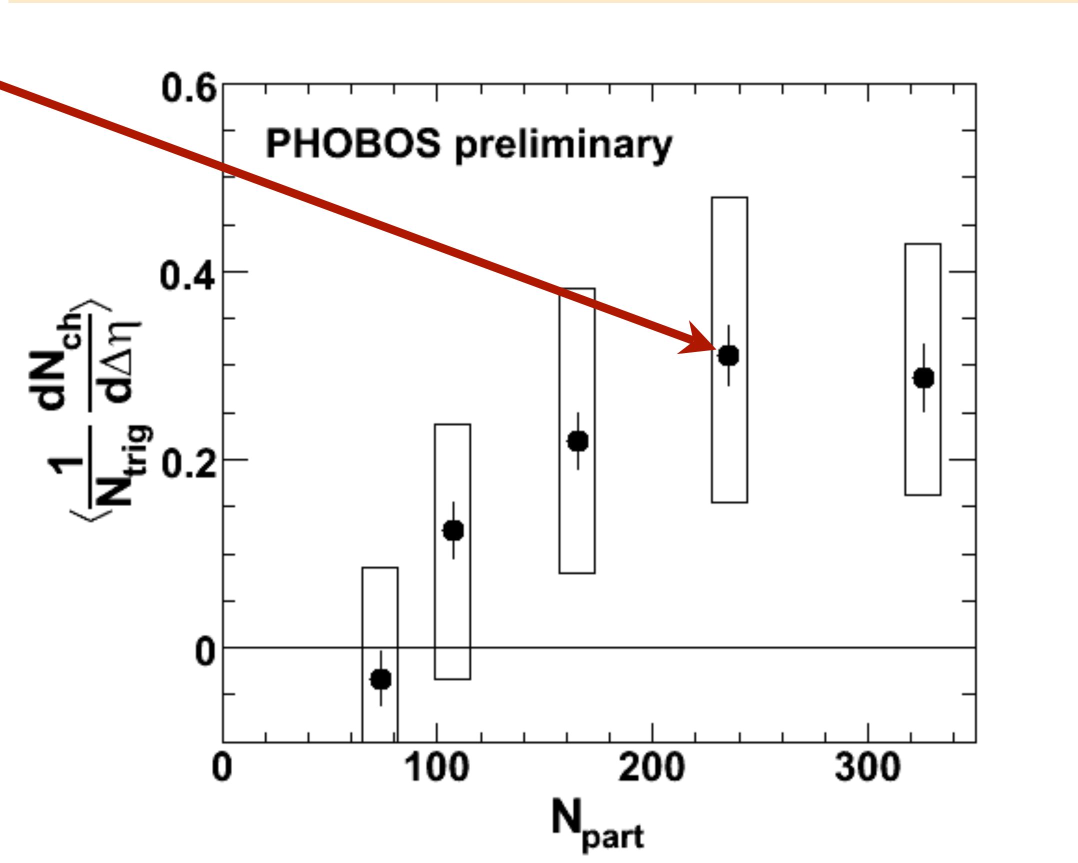
Small Δφ Ridge Yield vs Centrality

-4 < Δη < -2



Integrate ridge over |Δφ| < 1

|Δφ| < 1



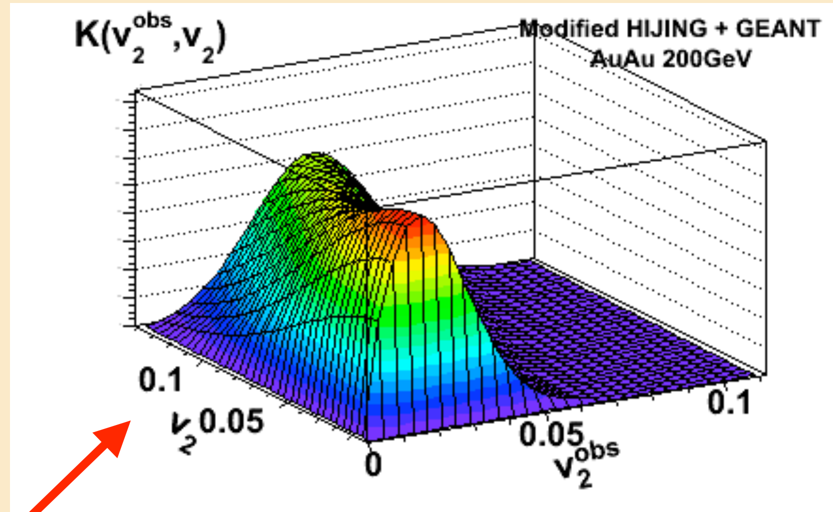
Three big new questions

- Are heavy ion collisions more social, i.e. do particles get produced in similar clusters?
- Is "close in η" special, i.e. how far in $\Delta\eta$ do the interesting structures at $\Delta\phi$ ~0 and ~180º extend?
- What do so-called flow fluctuation measurements really measure and how can you tell?
  - Event-by-event flow fluctuations were a prediction based on the ε_{part} explanation of Cu+Cu & Au+Au average flow values
  - Analysis is sensitive to any non-flow effects which have a ϕ asymmetry which affects $\langle\cos(2\Delta\phi)\rangle$ (These effects largely cancel in event-averaged analysis)
  - New data-based technique developed to correct for non-flow
  - Note that flow fluctuation results cannot be connected to eccentricity or easily interpreted without this correction

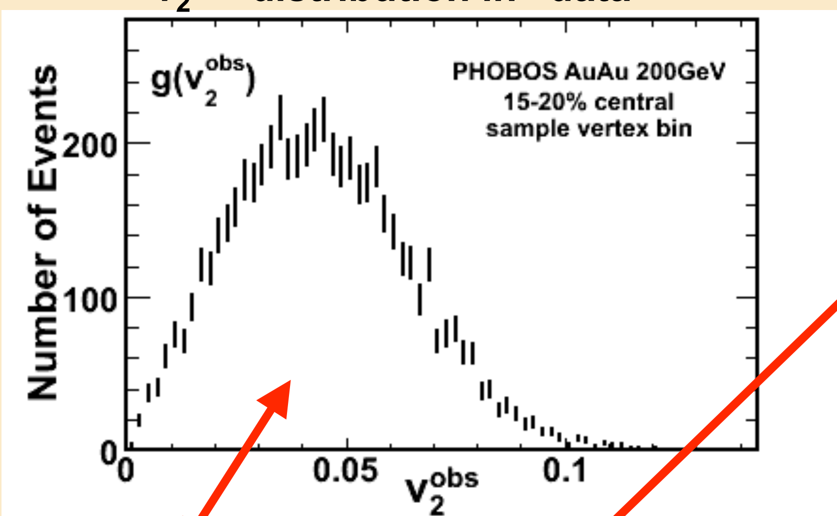
Overview of E-by-E Technique

- Event-by-event measurement
- Determination of response in MC
- Extraction of true $\langle v_2 \rangle$ and $\sigma(v_2)$

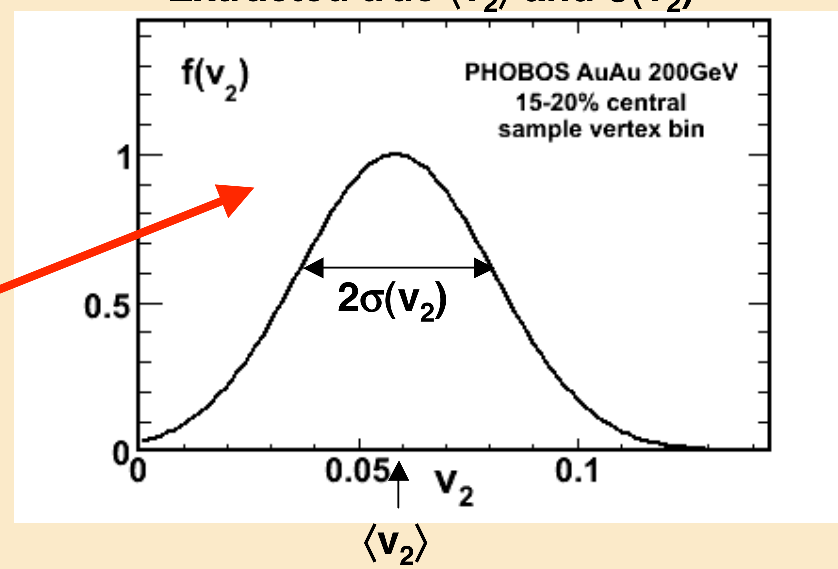
Kernel – Response Function



v_2^{obs} distribution in "data"



Extracted true $\langle v_2 \rangle$ and $\sigma(v_2)$



$$g(v_2^{obs}) = \int K(v_2^{obs}, v_2) f(v_2) \, dv_2$$

arXiv:nucl-ex/0702036

New Corrections for Non-Flow

- Uses on a data-based measurement of the combined effects of flow and non-flow
  - Flow magnitude is a function of η
  - Flow correlates particles at all $\Delta\eta$ ranges
  - Non-flow is dominated by short range correlations, so it is biggest at small $\Delta\eta$
  - Use large acceptance of PHOBOS to do a systematic study of $\Delta\varphi$ correlations at different $\Delta\eta$ ranges.
- Final result: Flow fluctuations corrected for non-flow correlations

Non-flow effect on fluctuations

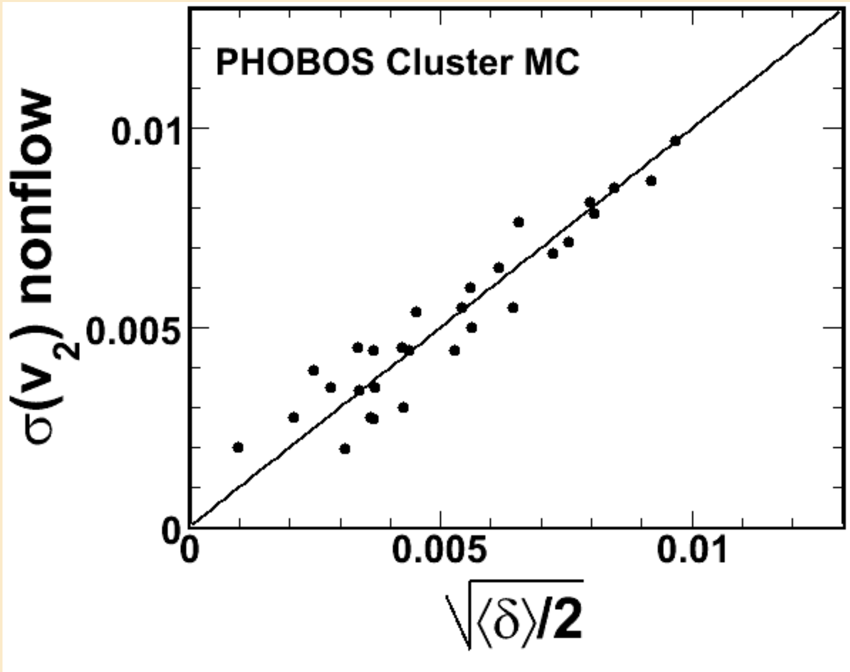
- Non-flow correlations are quantified by δ

$$\sigma_\delta(v_2) = \sqrt{\langle\delta\rangle/2} \qquad \delta = \langle\cos(2\Delta\varphi)\rangle$$

arXiv:0708.0800

  - Verified in MC studies

Fluctuations measured in events with constant flow →

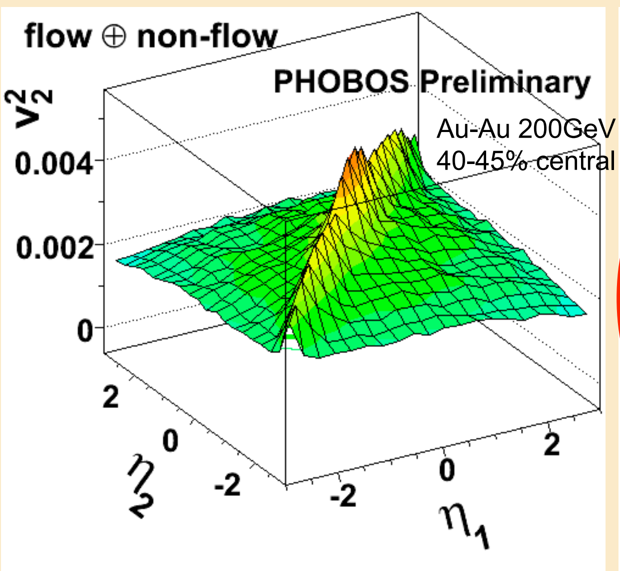


Separating flow and non-flow

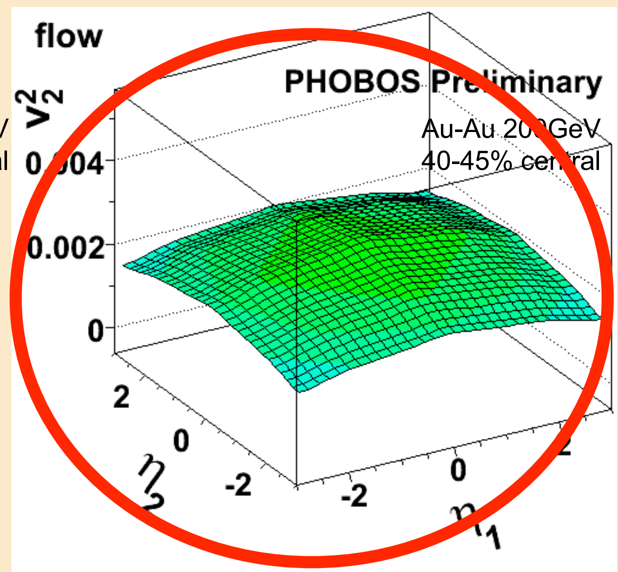
The goal is to subtract the flow contribution to $\langle \cos(2\Delta\varphi) \rangle$ in order to find $\delta(\eta_1,\eta_2)$ at all ranges:

For each η_1 and η_2 measure the two-particle correlations in $\Delta\phi$: $R_n(\Delta\varphi) = 2v_2^2\cos(2\Delta\varphi)$

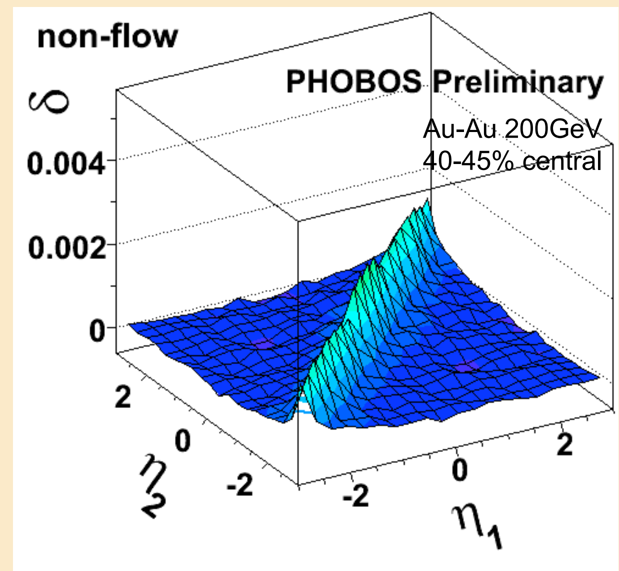
$$\delta(\eta_1,\eta_2) = v_2^2(\eta_1,\eta_2) - v_2(\eta_1) \times v_2(\eta_2)$$ HOW???



flow⊕non-flow

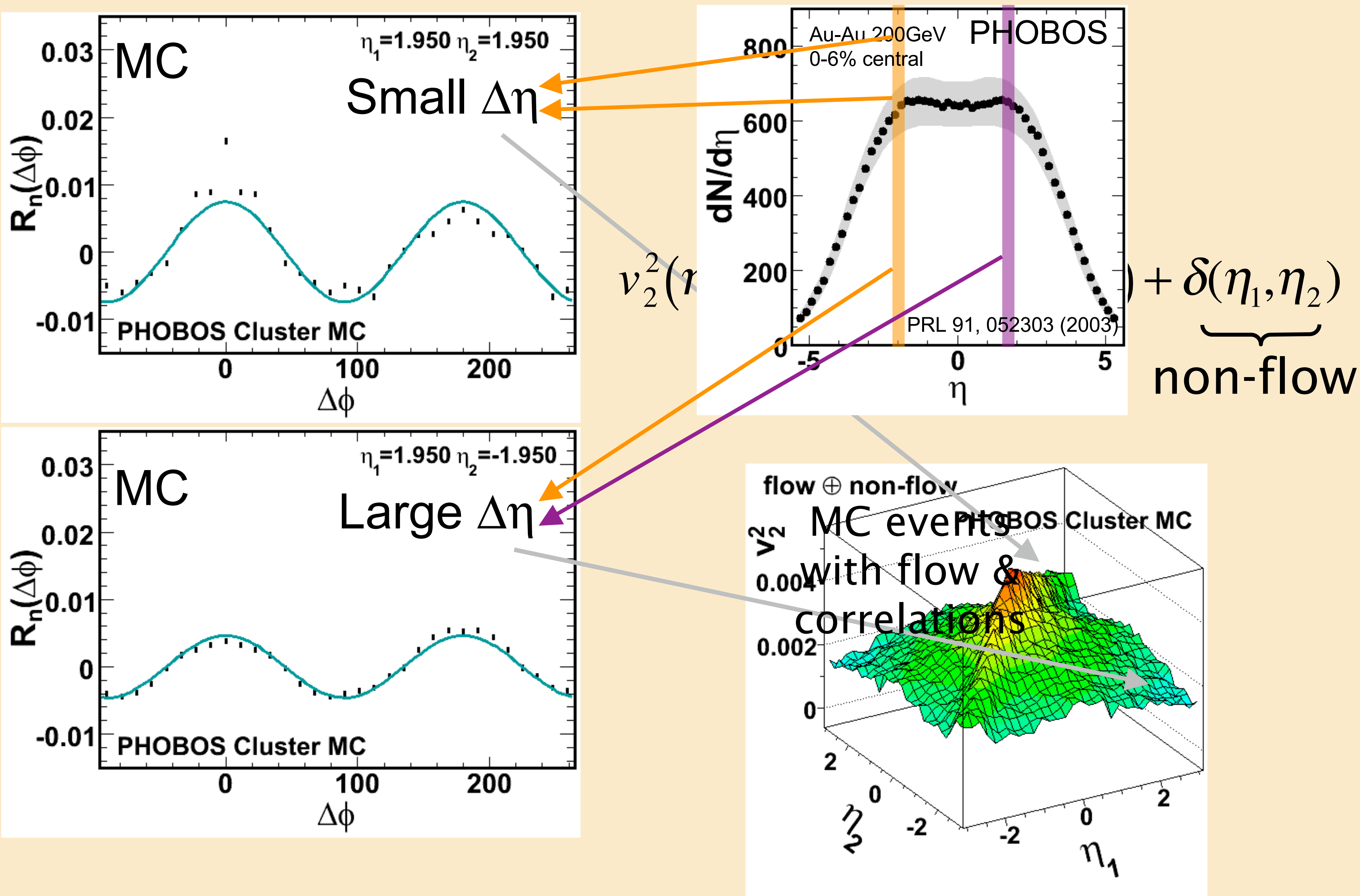


flow



non-flow

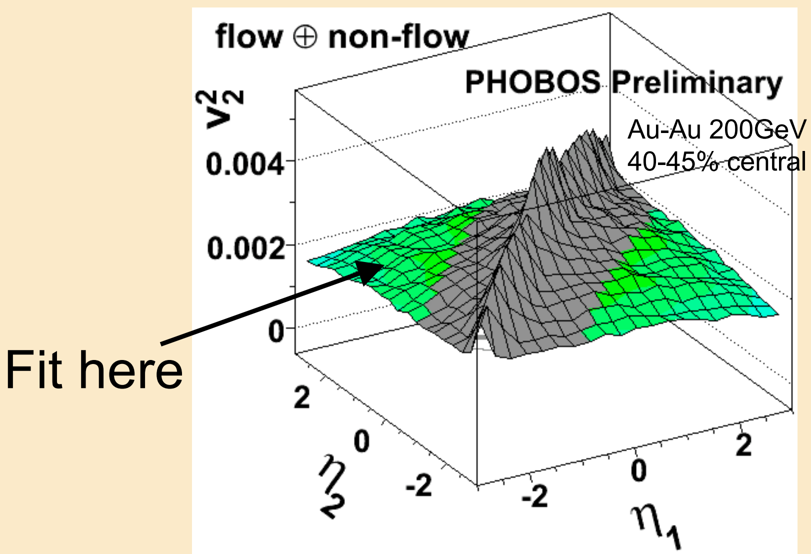
Short and long range correlations



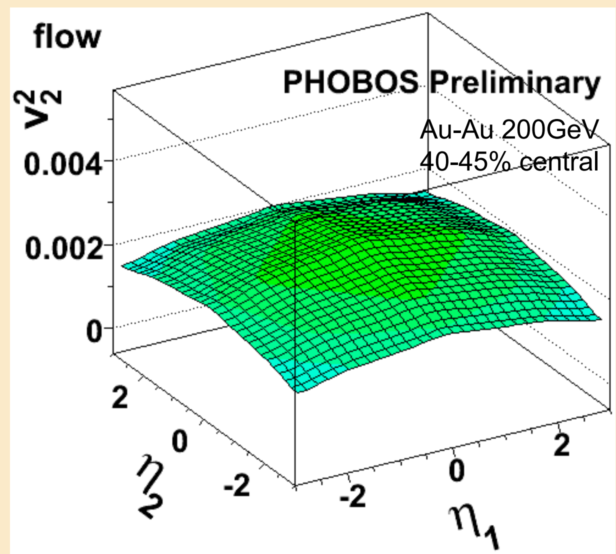
Separating flow and non-flow

- Assume non-flow is small for $|\eta_1 - \eta_2| > 2$
  - Residual $\delta(\eta_1,\eta_2)$ in data estimated using HIJING
- Fit to find flow component of v_2^2:

$$v_2(\eta_1) \times v_2(\eta_2) = v_2^2(\eta_1,\eta_2) - \delta(\eta_1,\eta_2) \quad |\eta_1 - \eta_2| > 2$$



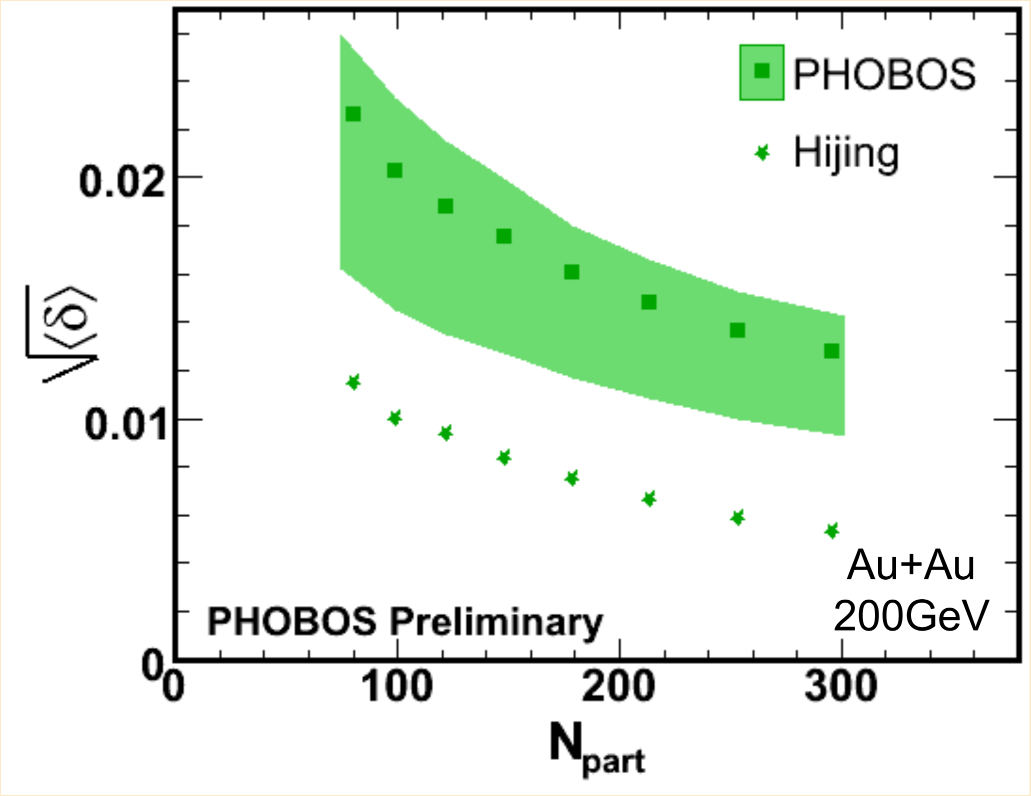
(flow⊕non-flow)



flow

δ as a function of centrality

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

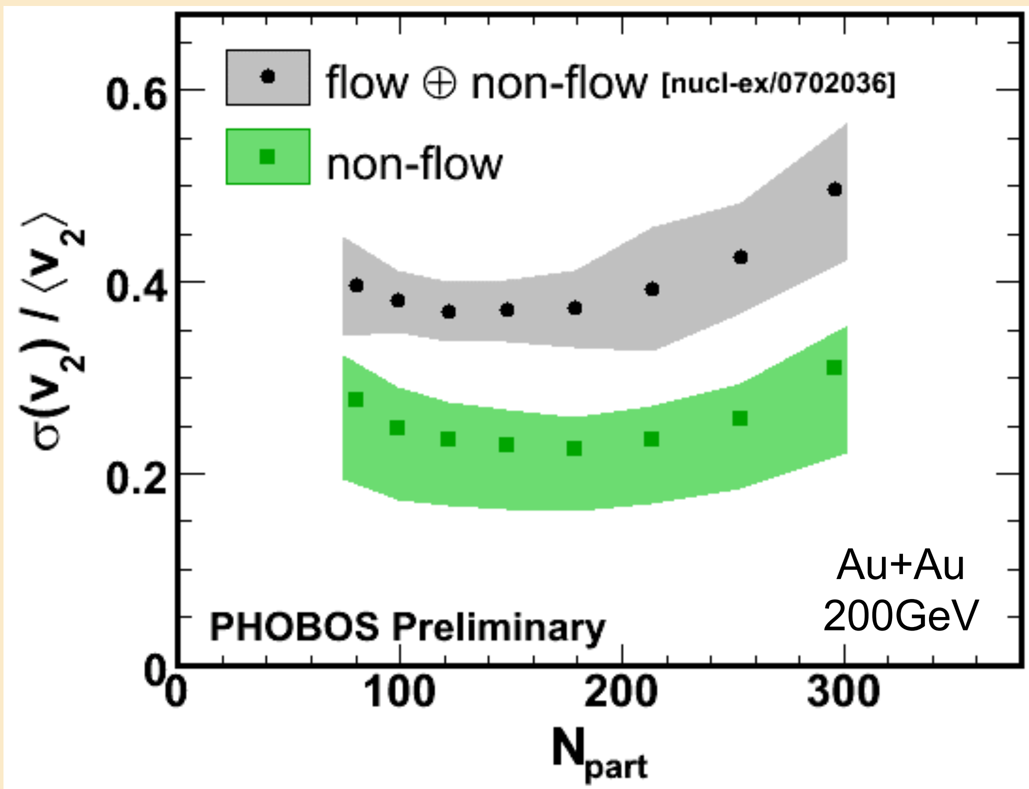


Non-flow in data is larger than in HIJING

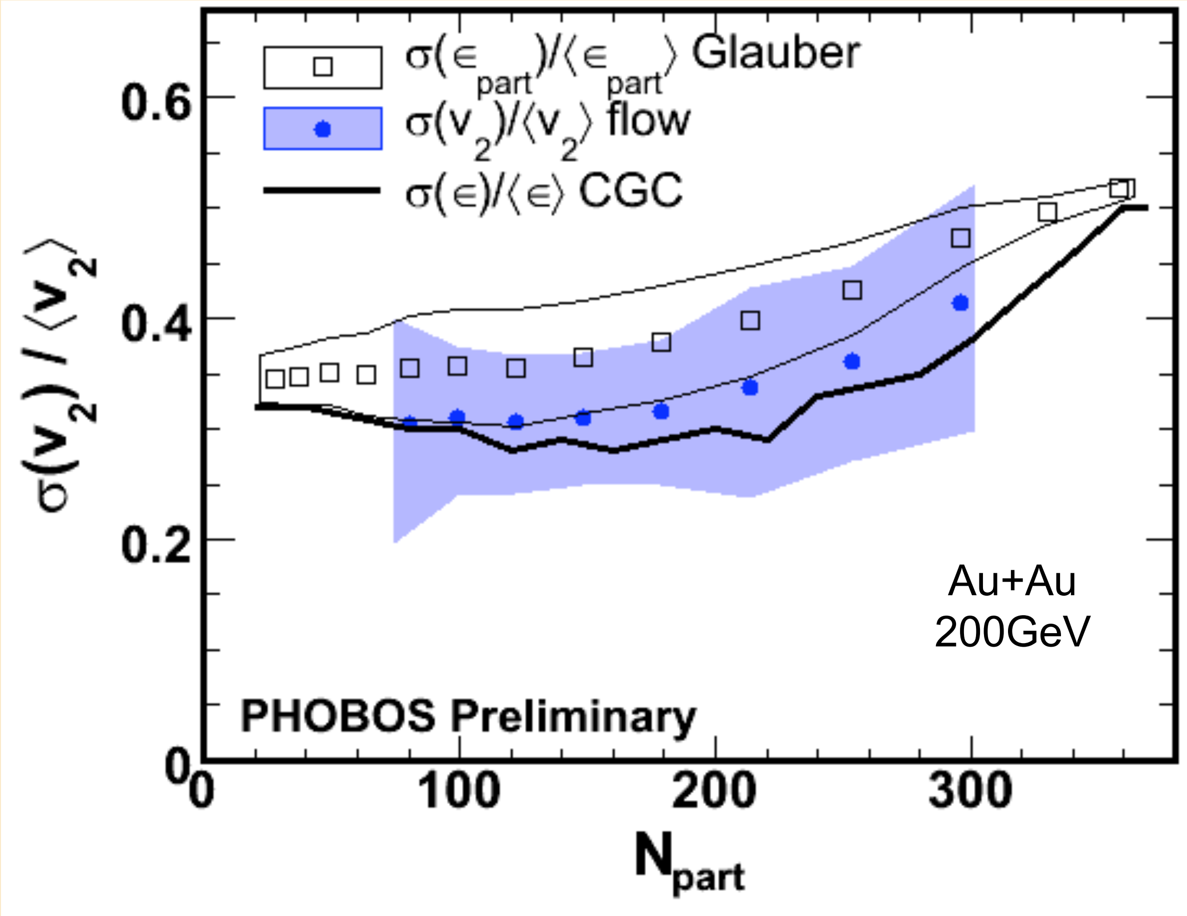
These values are valid for PHOBOS geometry

Expected fluctuations from non-flow

- Calculate expected fluctuations: $\sigma_\delta(v_2) = \sqrt{\langle\delta\rangle/2}$
- Scale with $\langle v_2 \rangle$ to match fluctuation results



Corrected Flow Fluctuation Result



In agreement with both Glauber and CGC calculations within errors

CGC: arXiv:0707.0249

Three big new questions

- 2 particle inclusive correlations
  - Particles in heavy ion collisions are created in clusters close in size to those in p+p collisions
  - Cluster size decreases with centrality, appears to depend on the fraction of total cross-section, not N_{part}
  - Significant differences between near and away side clusters
- p_T triggered correlations
  - Broadening of the away-side correlation in $\Delta\phi$ relative to p+p persists over the complete $\Delta\eta$ range
  - Correlation at $\Delta\phi=0$ and large $\Delta\eta$ (ridge) persists to $\Delta\eta = 4$
  - Ridge yield at large $\Delta\eta$ disappears as one goes from central to peripheral Au+Au collisions
- Flow fluctuations
  - New data-driven technique developed to subtract non-flow contributions to event-by-event flow fluctuations
  - Corrections are non-negligible but don't change the conclusion that event-by-event flow appears to track event-by-event eccentricity

PHOBOS Conclusions

- Many results from on-going and new analyses
- "Simple" systematic trends in data expanded
- New correlation and fluctuation analyses are revealing even more intriguing dependencies
- As always, more to come…