Elliptic Flow Fluctuations
and
Non-Flow Correlations

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for the PHOBOS collaboration

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The 20th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions (Quark Matter 2008)

February 4-10, 2008, Jaipur, India

PHOBOS Collaboration

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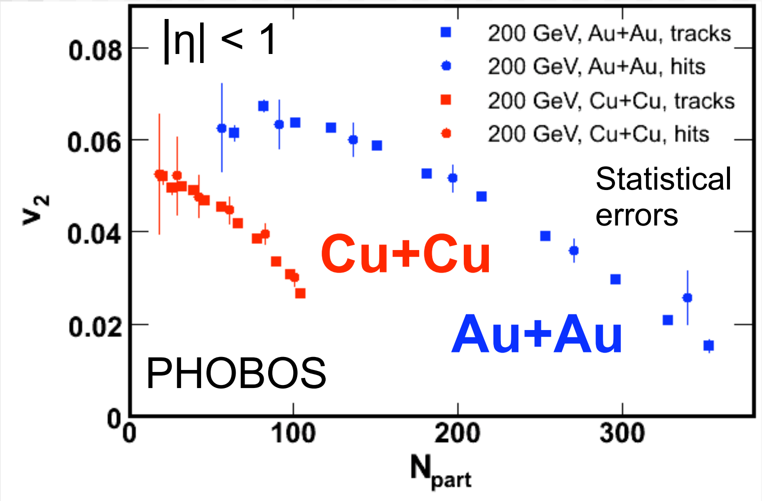
46 scientists, 8 institutions, 9 PhD students

ARGONNE NATIONAL LABORATORY
INSTITUTE OF NUCLEAR PHYSICS PAN, KRAKOW
NATIONAL CENTRAL UNIVERSITY, TAIWAN
UNIVERSITY OF MARYLAND

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

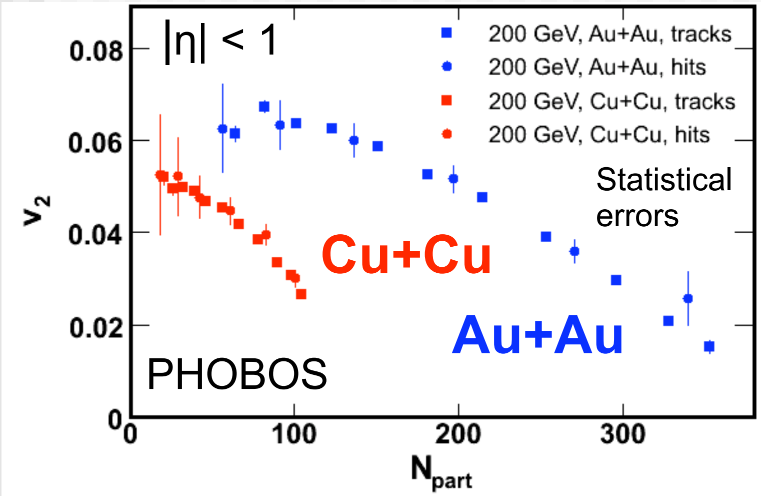
Quark Matter 2005

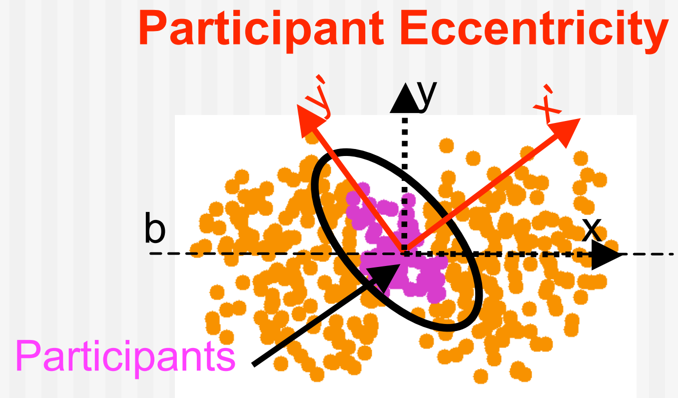


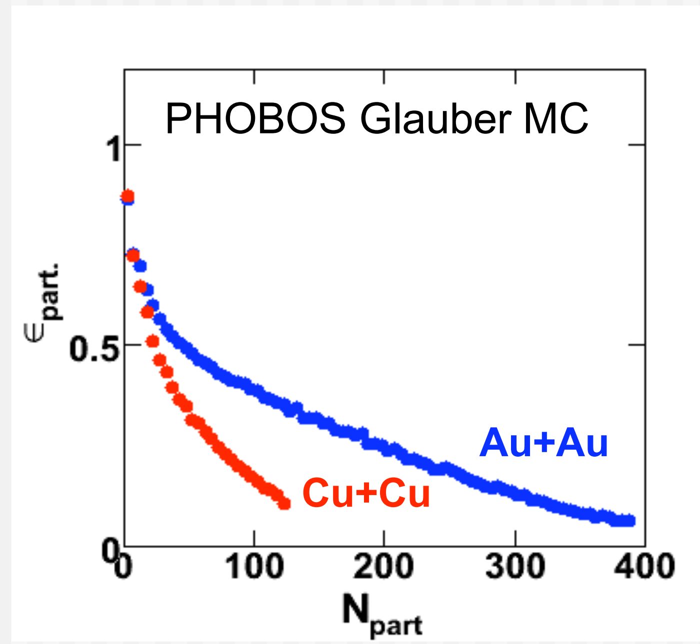
- High v_2 observed in Cu+Cu
  - Especially most central events

Au+Au, 200 PRL 94 122303 (2005)
Cu+Cu, 200 PRL 98 242302 (2007)

Quark Matter 2005



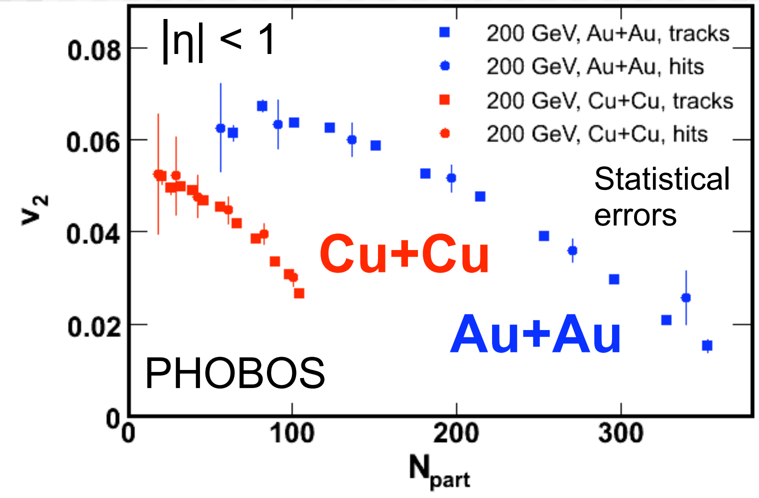


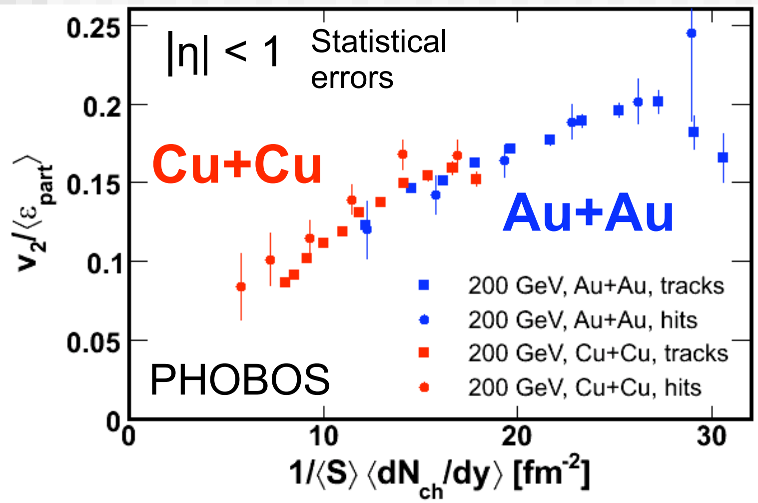


- High v_2 observed in Cu+Cu
  - Especially most central events
- Fluctuations in initial collision region can lead to large eccentricity

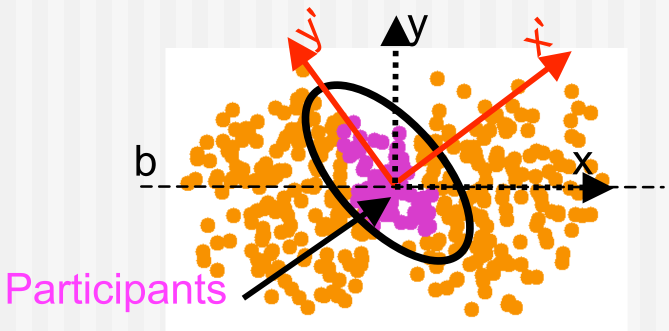
Au+Au, 200 PRL 94 122303 (2005)
Cu+Cu, 200 PRL 98 242302 (2007)

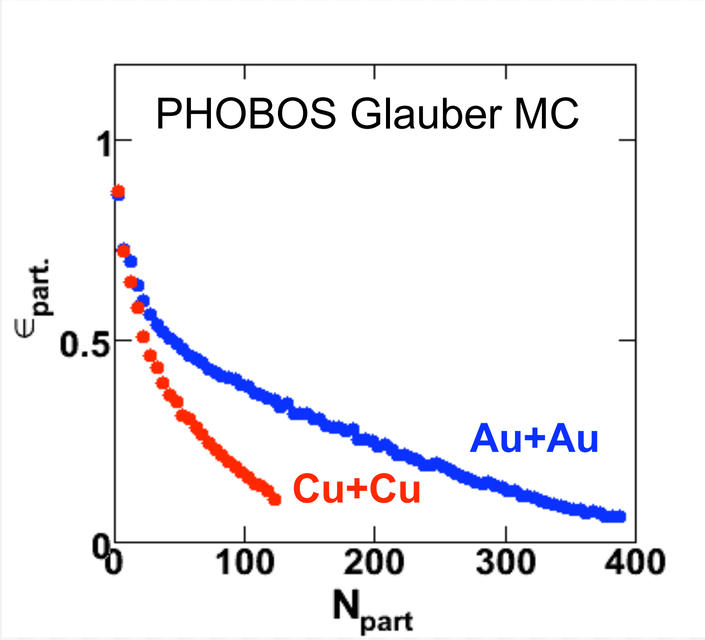
Quark Matter 2005





Participant Eccentricity

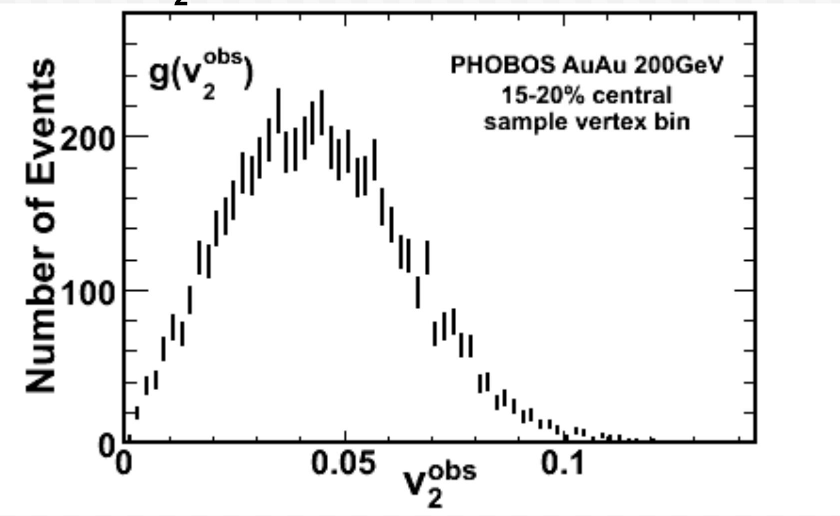




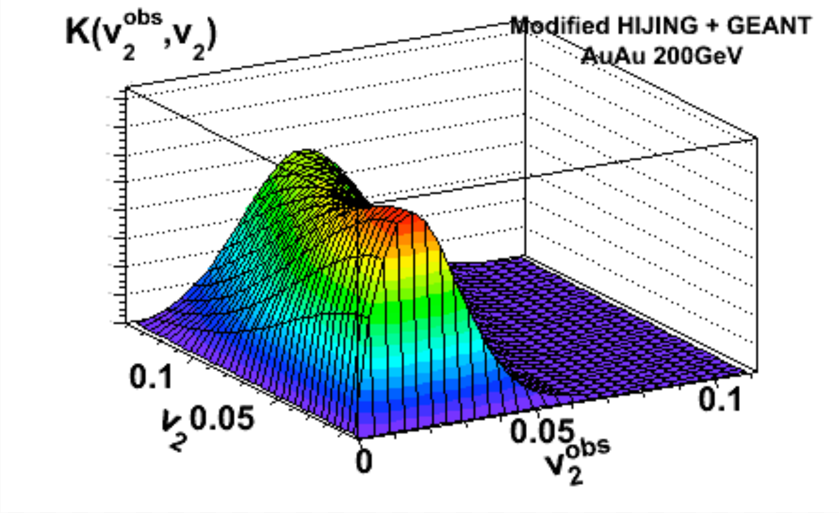
Au+Au, 200 PRL 94 122303 (2005)
Cu+Cu, 200 PRL 98 242302 (2007)

Quark Matter 2006

v_2^{obs} distribution in "data"



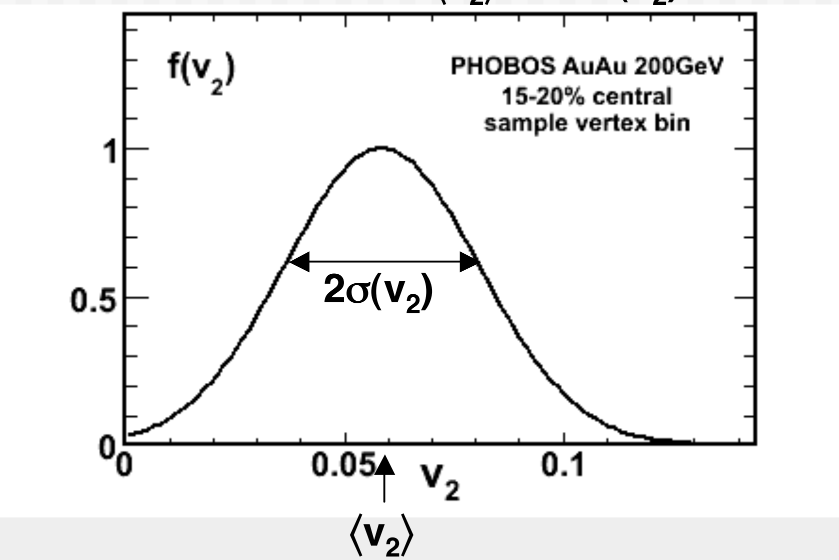
Kernel – Response Function



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

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

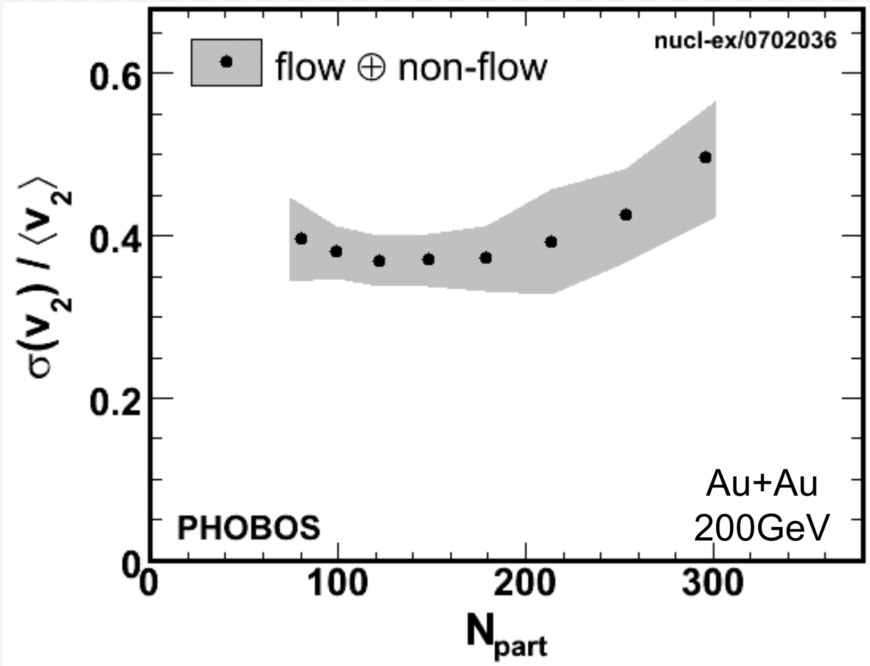
Extracted true $\langle v_2 \rangle$ and $\sigma(v_2)$



arXiv:nucl-ex/0702036

Quark Matter 2006

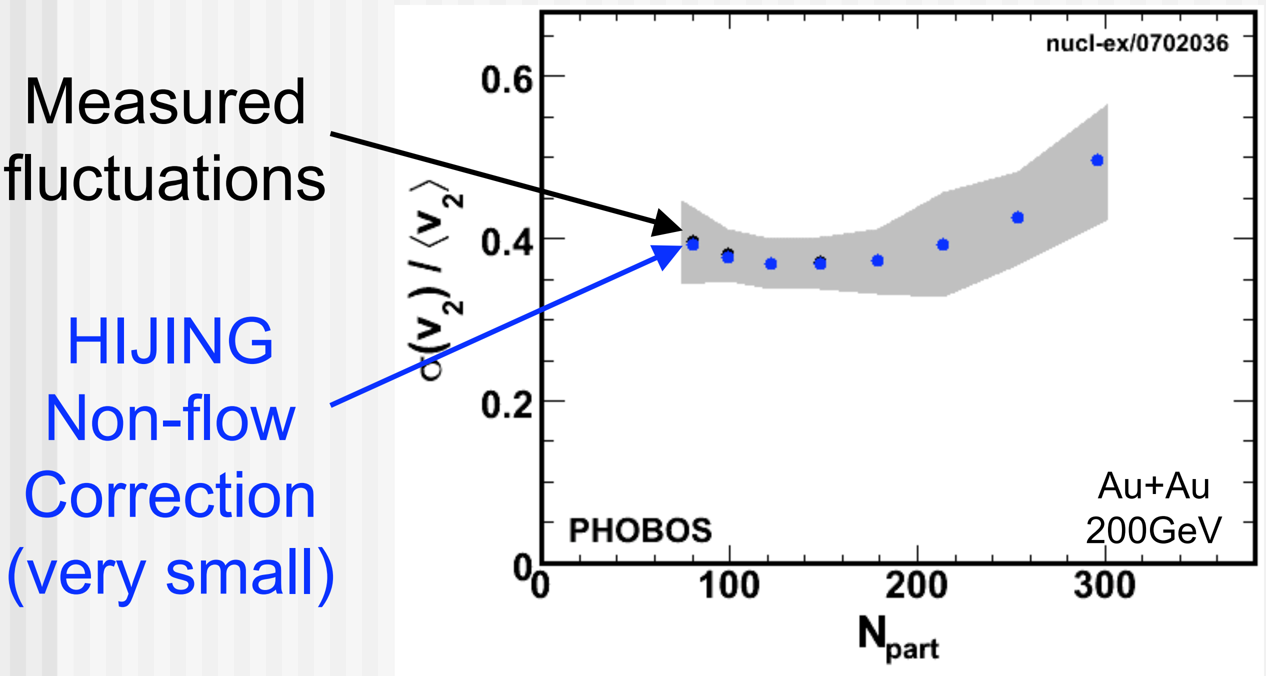
- Relative v_2 fluctuations of approximately 40%



- Correlated particle production (non-flow correlations) can broaden the v_2^{obs} distribution and affect the fluctuation measurement.

Quark Matter 2006

- Estimate non-flow contribution with HIJING



- We used response function calculated from HIJING with correlations preserved to estimate non-flow effect.

Quark Matter 2008

- We have made a data-based measurement of non-flow
  - Separating 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 - small $\Delta\eta$
  - Idea: Use unique acceptance of PHOBOS to do a systematic study of $\Delta\varphi$ correlations at different $\Delta\eta$ ranges.
- Finally: flow fluctuations corrected for non-flow correlations

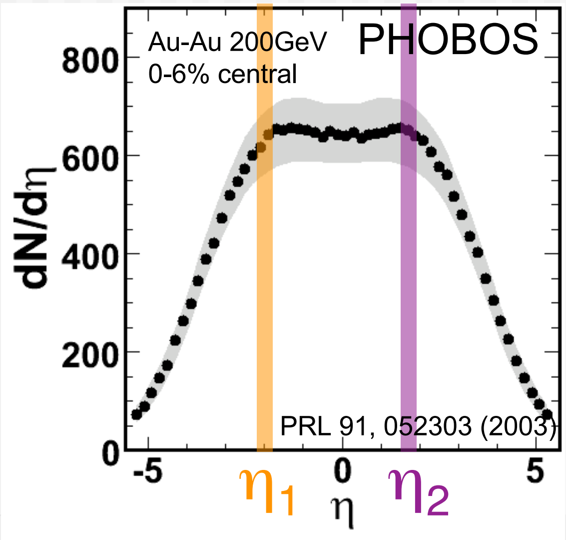
Correlation function R_n

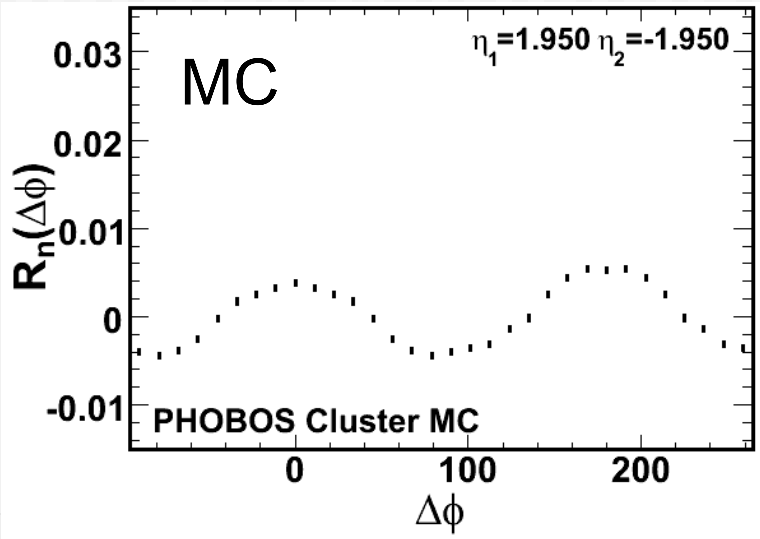
- Calculate $\Delta\varphi=\varphi_1-\varphi_2$ correlations between two particles at two η windows, η_1 and η_2.
  - Foreground: hit pairs in the same event
  - Background: hit pairs in mixed events

$$F(\Delta\varphi) = \frac{1}{n_{\mathrm{pairs}}^{\mathrm{same}}} \frac{d\,n_{\mathrm{pairs}}^{\mathrm{same}}}{d\Delta\varphi}$$

$$B(\Delta\varphi) = \frac{1}{n_{\mathrm{pairs}}^{\mathrm{mixed}}} \frac{d\,n_{\mathrm{pairs}}^{\mathrm{mixed}}}{d\Delta\varphi}$$

$$R_n(\Delta\varphi) = \frac{F(\Delta\varphi)}{B(\Delta\varphi)} - 1$$





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- Calculate $\Delta\varphi=\varphi_1-\varphi_2$ correlations between two particles at two η windows, η_1 and η_2.
  - Foreground: hit pairs in the same event
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$$F(\Delta\varphi) = \frac{1}{n_{\text{pairs}}^{\text{same}}} \frac{dn_{\text{pairs}}^{\text{same}}}{d\Delta\varphi}$$

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$$R_n(\Delta\varphi) = \frac{F(\Delta\varphi)}{B(\Delta\varphi)} - 1$$

Technical note: Correction for secondaries are done using $R(\Delta\varphi)$ which is not diluted by multiplicity.

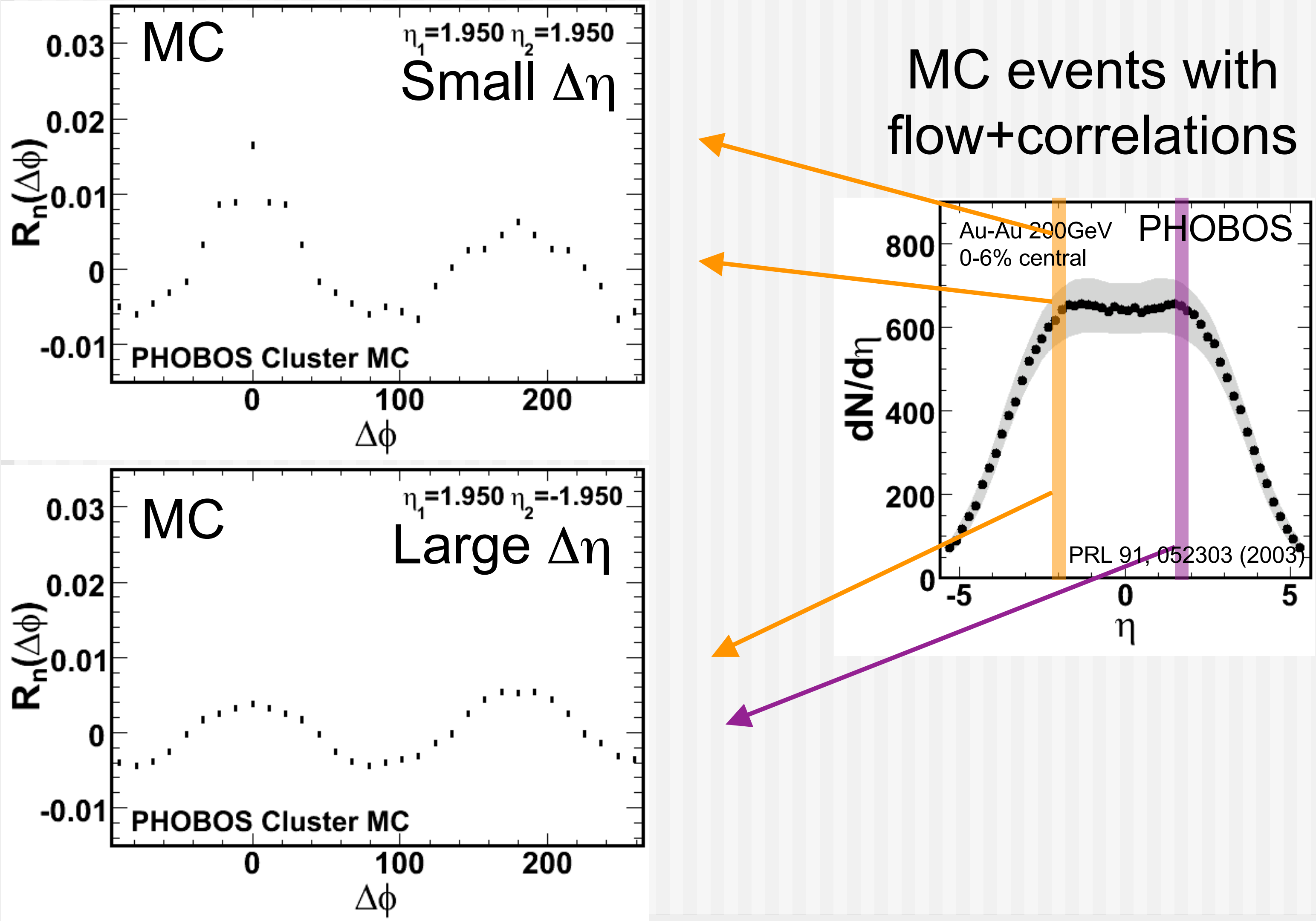
$$R(\Delta\varphi) = \left\langle (n-1)\left(\frac{F(\Delta\varphi)}{B(\Delta\varphi)} - 1\right)\right\rangle$$

n=number of hits

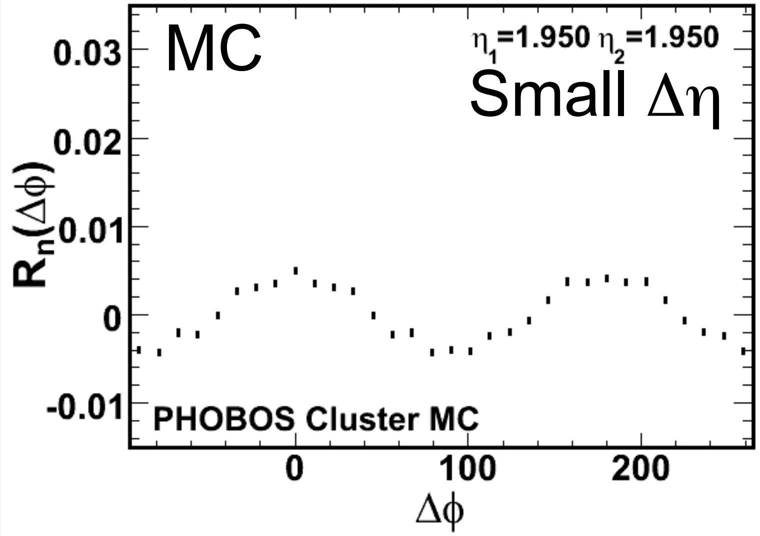
PRC 75 054913 (2007)

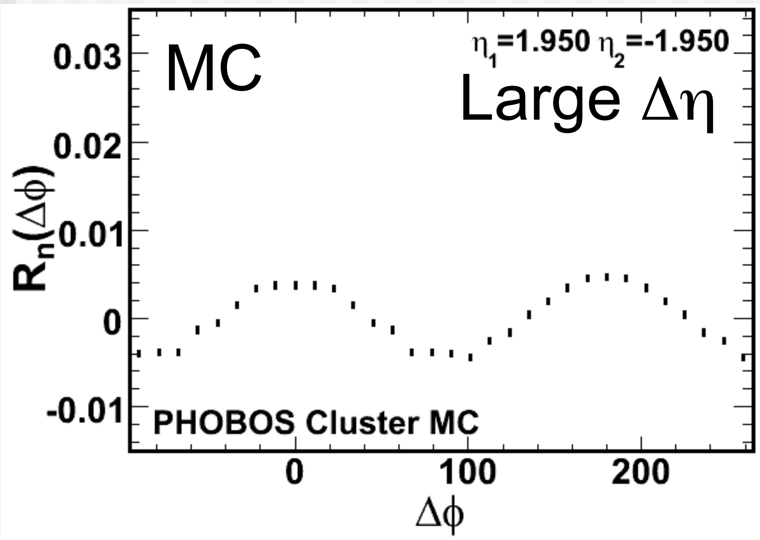
See Wei Li's talk for details at session XIX

Short and long range correlations

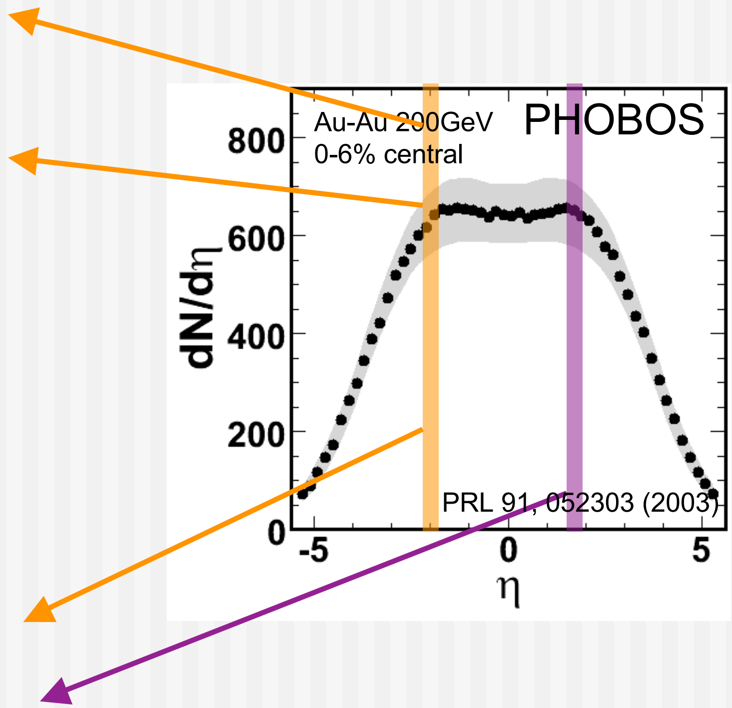


Flow

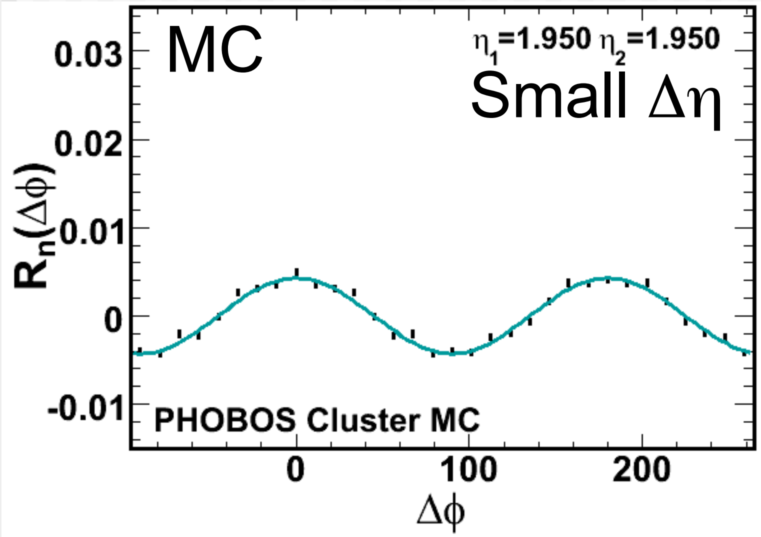


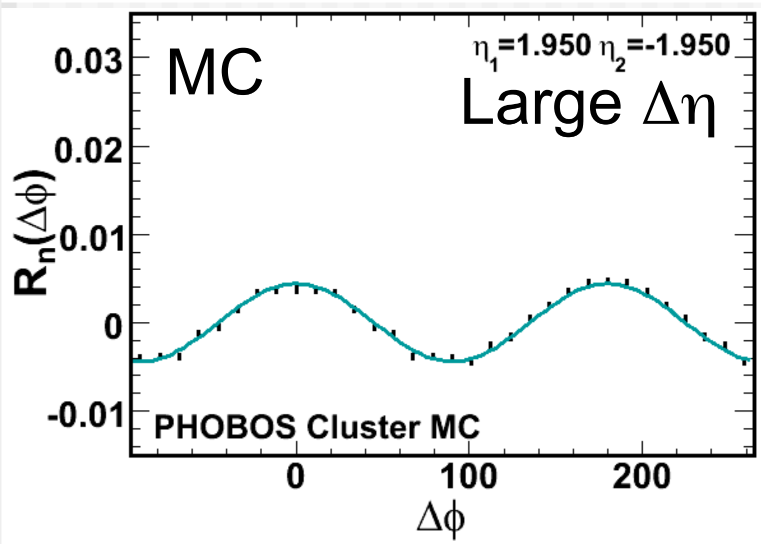


MC events with <u>only flow</u>



Calculating $v_2^2(\eta_1,\eta_2)$



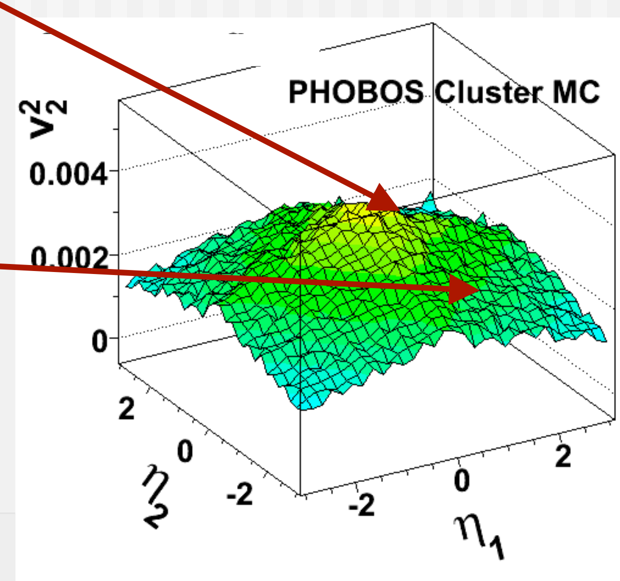


Calculate 2nd Fourier coefficient of $R_n(\Delta\varphi)$:

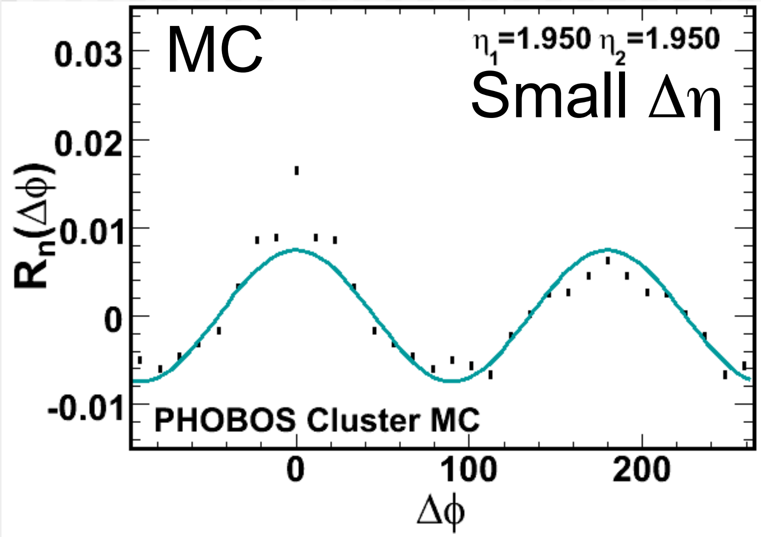
$$R_n(\Delta\varphi) = 2v_2^2\cos(2\Delta\varphi)$$

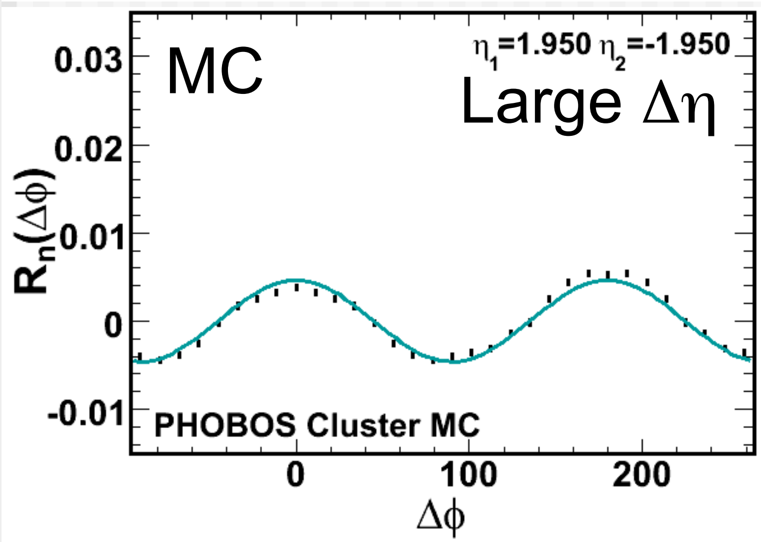
If there is no non-flow:

$$v_2^2(\eta_1,\eta_2) = v_2(\eta_1)\times v_2(\eta_2)$$



Calculating $v_2^2(\eta_1,\eta_2)$

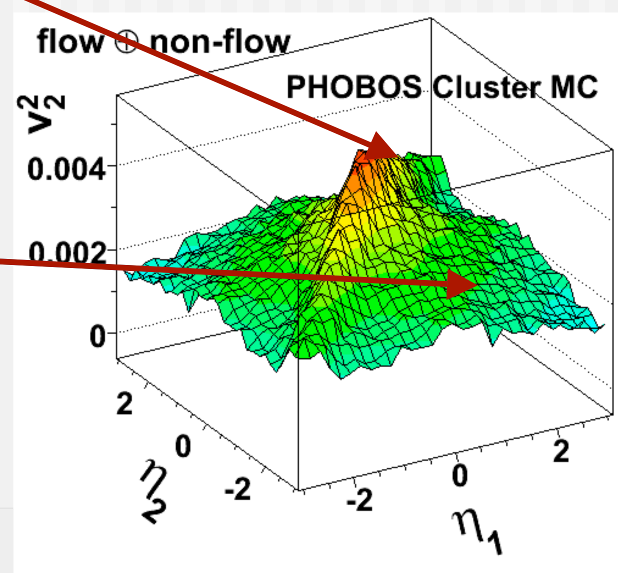




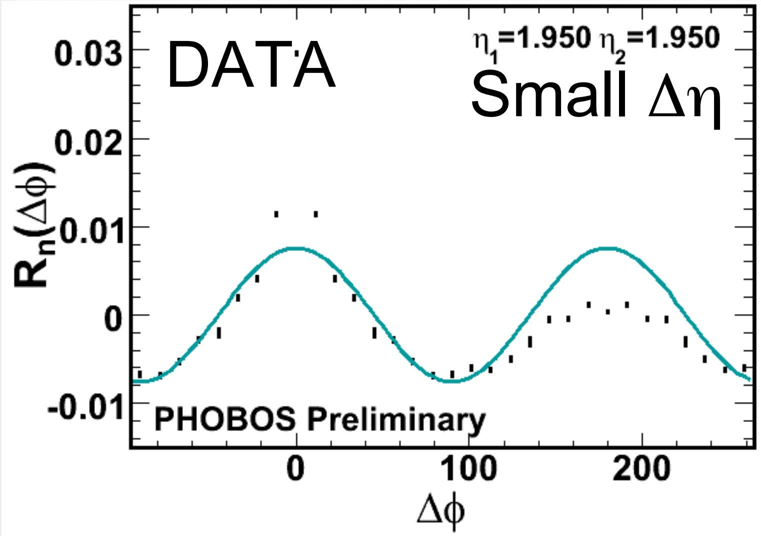
$$R_n(\Delta\varphi) = 2v_2^2\cos(2\Delta\varphi)$$

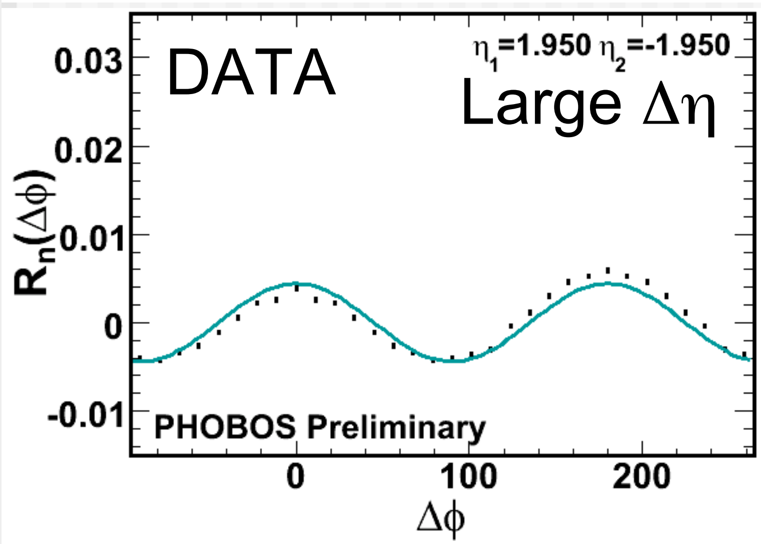
In general:

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



Calculating $v_2^2(\eta_1,\eta_2)$





$$R_n(\Delta\varphi) = 2v_2^2\cos(2\Delta\varphi)$$

In general:

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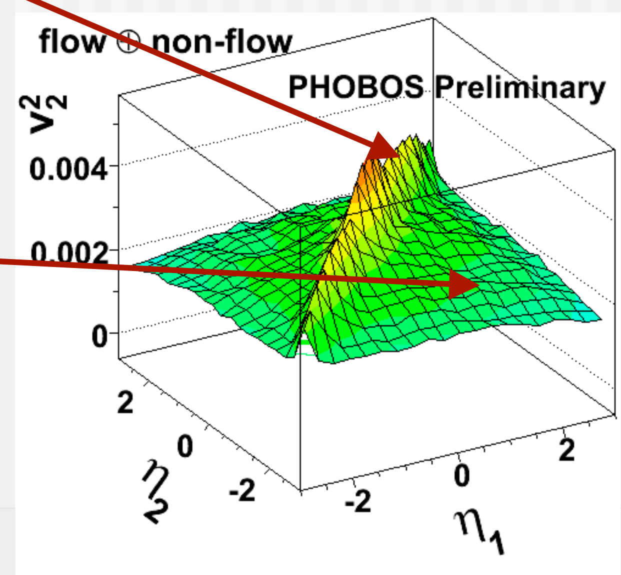
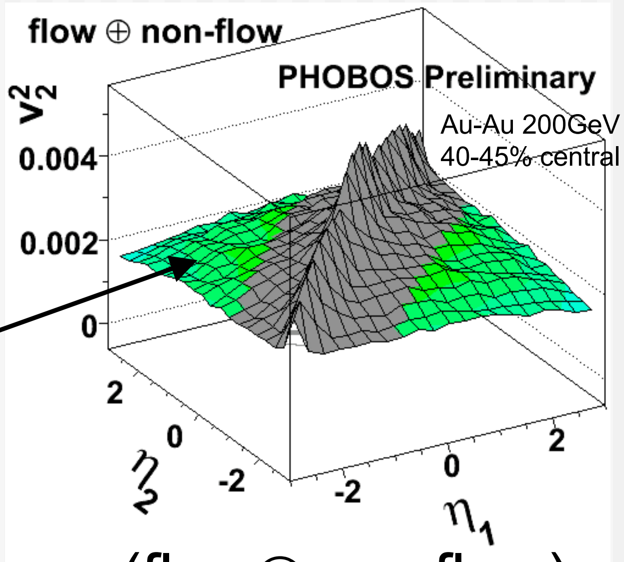


Separating flow and non-flow

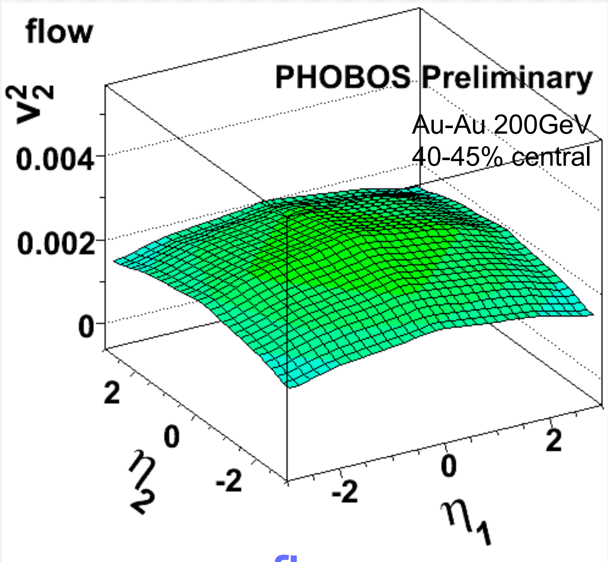
- Assume non-flow is small for $|\eta_1 - \eta_2| > 2$
  - Residual $\delta(\eta_1,\eta_2)$ in data estimated using HIJING
- Fit to find flow component of v_2^2:

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

Fit here



(flow⊕non-flow)

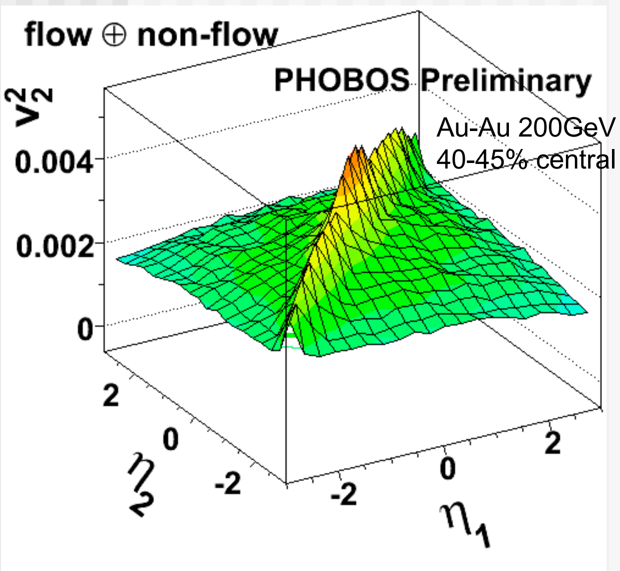


flow

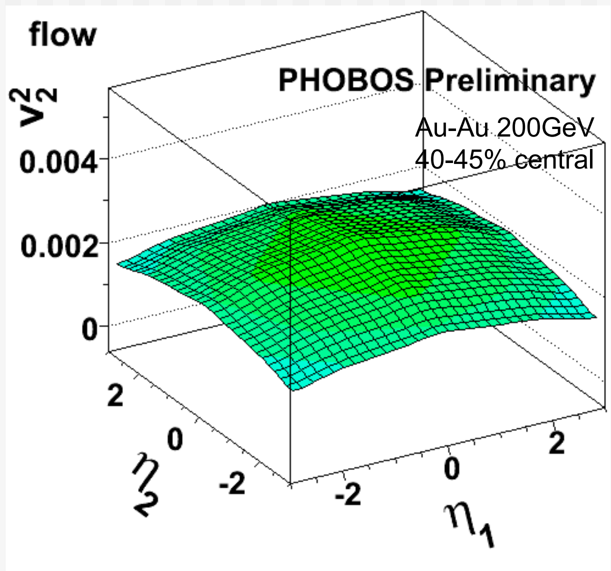
Separating flow and non-flow

- Subtract to find $\delta(\eta_1,\eta_2)$ at all ranges:

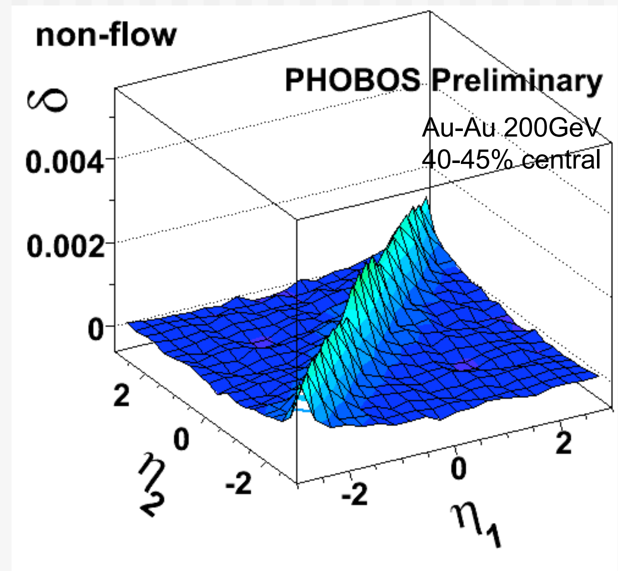
$$\delta(\eta_1,\eta_2) = v_2^2(\eta_1,\eta_2) - v_2(\eta_1) \times v_2(\eta_2)$$



flow⊕non-flow



flow

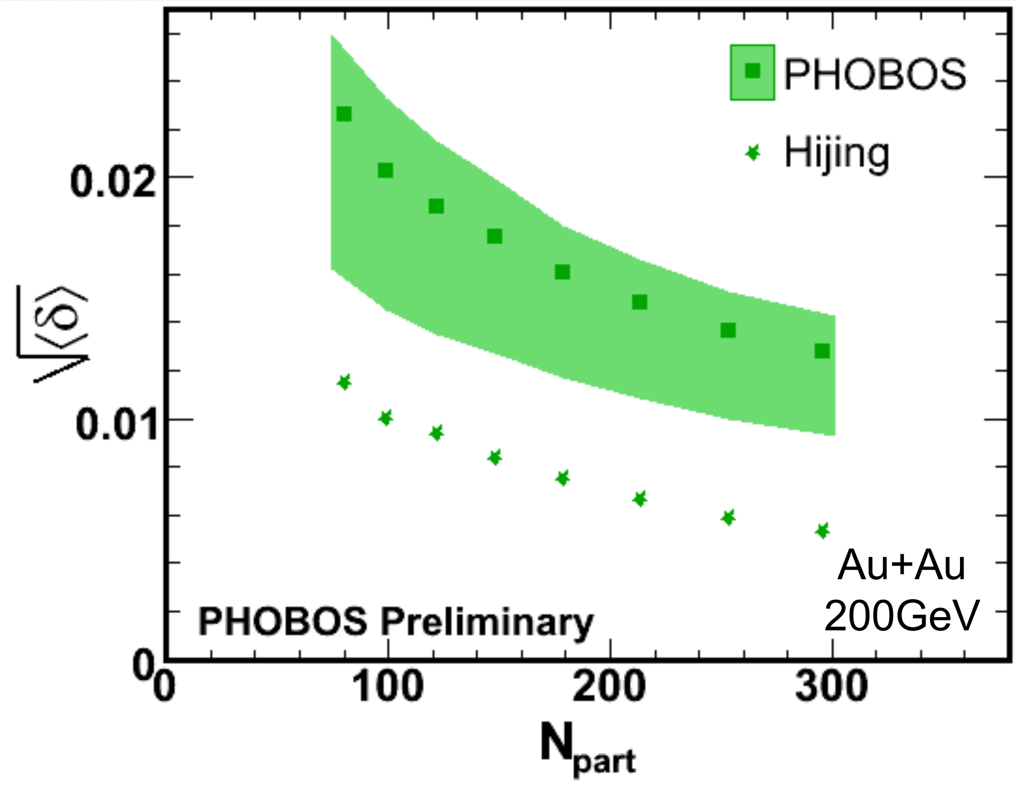


non-flow

δ as a function of centrality

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

$$\langle\delta\rangle = \frac{\int \delta(\eta_1,\eta_2)\frac{dn}{d\eta_1}\frac{dn}{d\eta_2}d\eta_1 d\eta_2}{\int \frac{dn}{d\eta_1}\frac{dn}{d\eta_2}d\eta_1 d\eta_2}$$



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

Non-flow effect on fluctuations

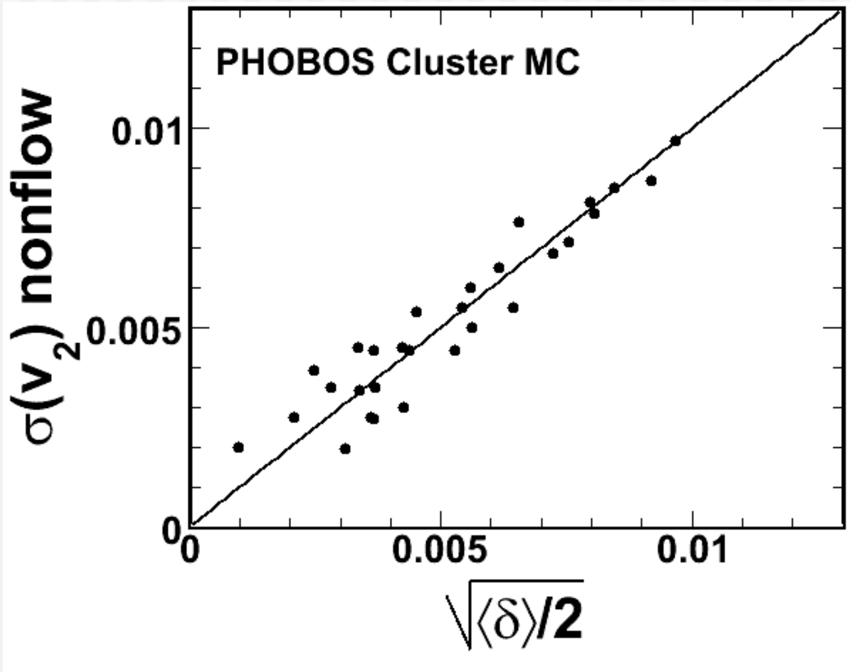
- Non-flow correlations are quantified by δ

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

arXiv:0708.0800

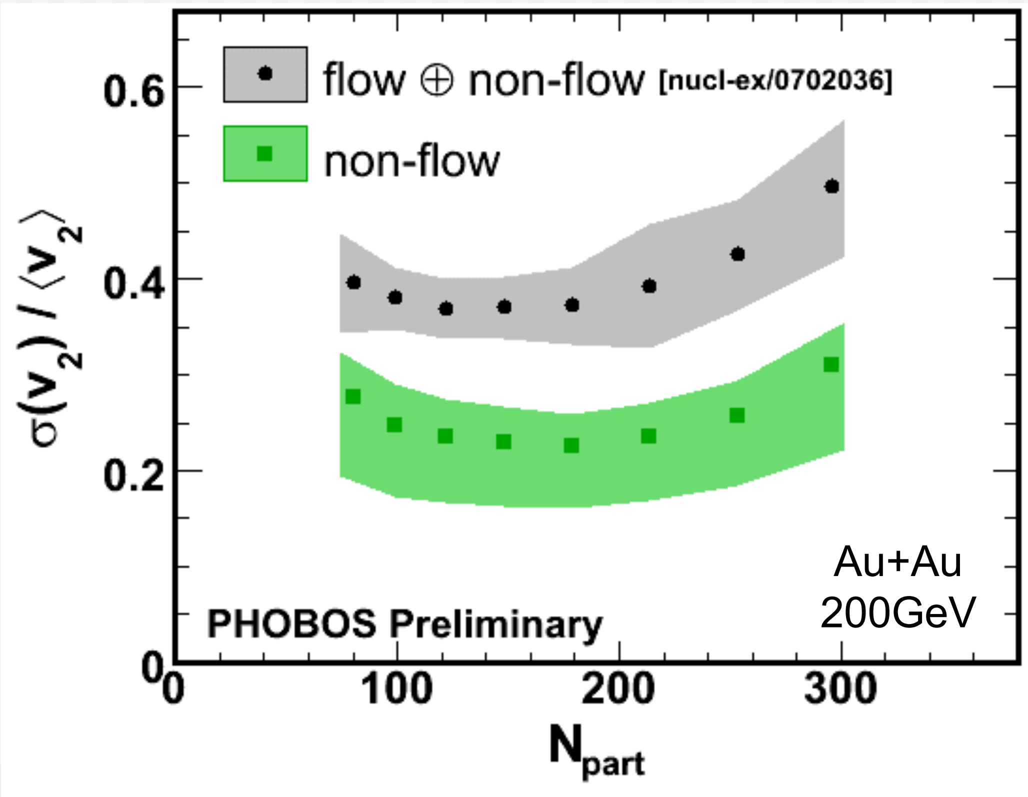
  - Verified in MC studies

Fluctuations measured in events with constant flow →



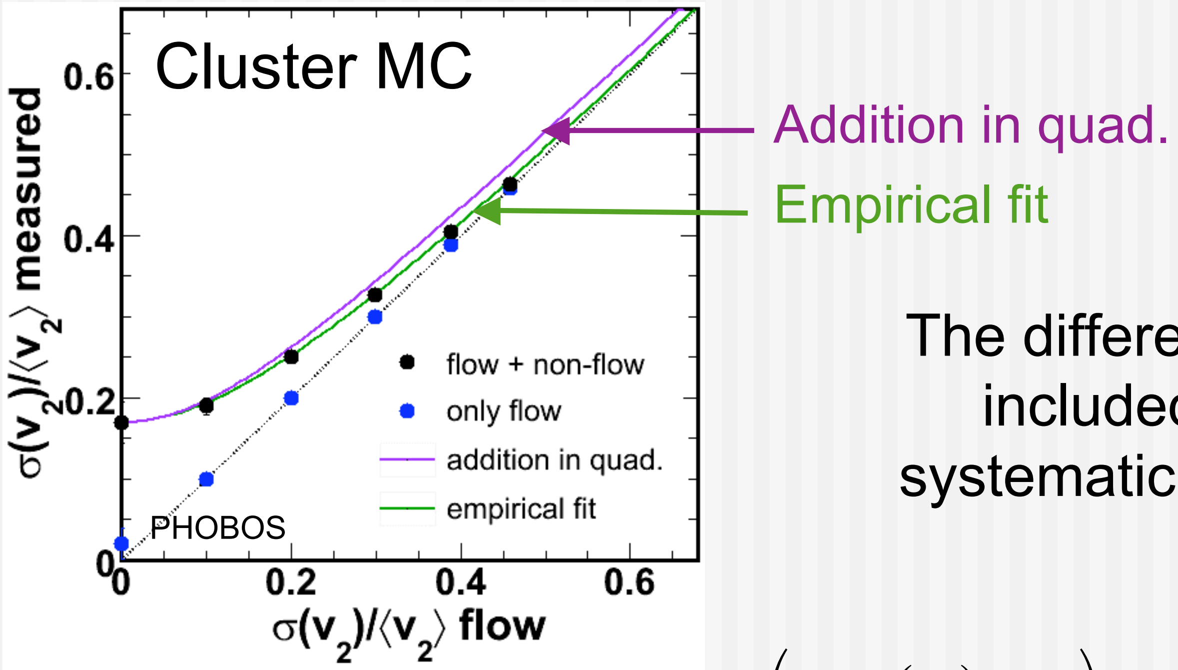
Expected fluctuations from non-flow

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



Subtracting non-flow

- How do non-flow and fluctuations add?
  - Empirical fit matches MC results better than addition in quadrature.



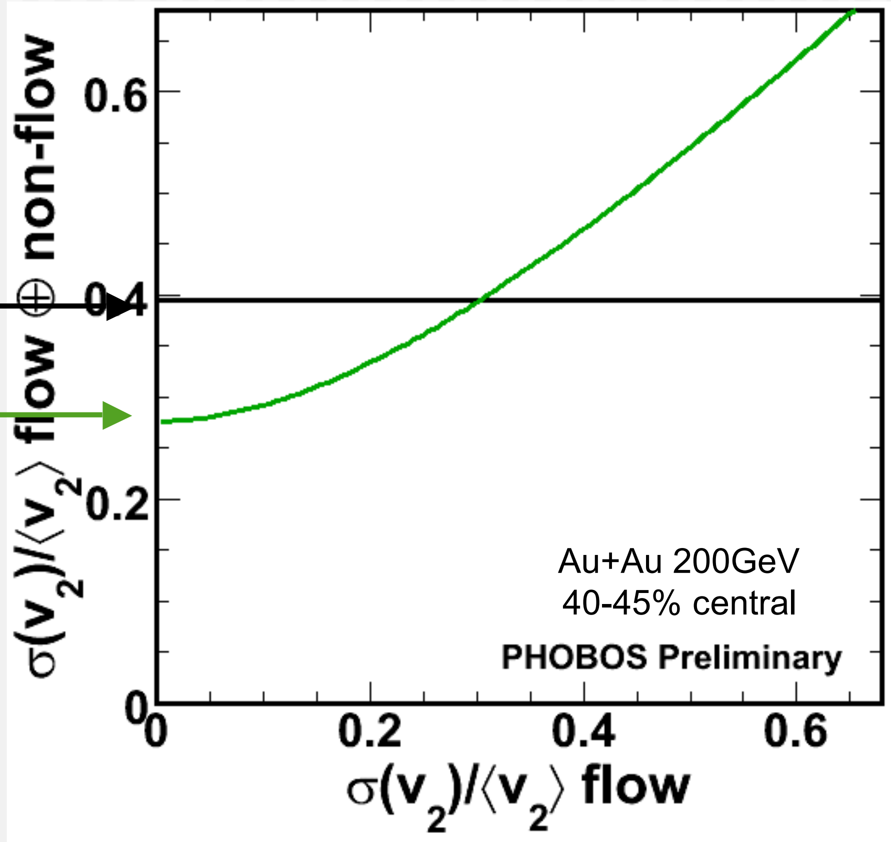
The difference is included in systematic errors

$$\sigma(v_2)_{\text{total}} = \sigma(v_2)_{\text{flow}} + \sigma(v_2)_{\text{non-flow}} \times \exp\left(-\frac{\sigma(v_2)_{\text{flow}}}{\sigma(v_2)_{\text{non-flow}}}\right)$$

Subtracting non-flow in data

$\sigma(v_2)$ flow⊕non-flow

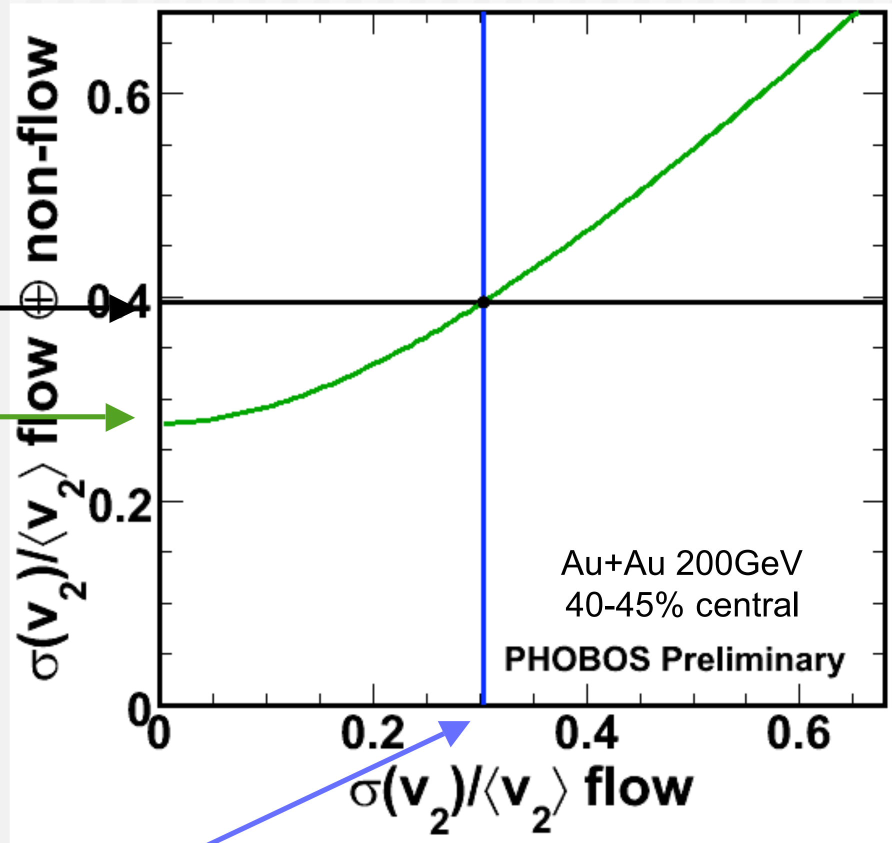
$\sigma(v_2)$ non-flow



Subtracting non-flow in data

$\sigma(v_2)$ flow⊕non-flow

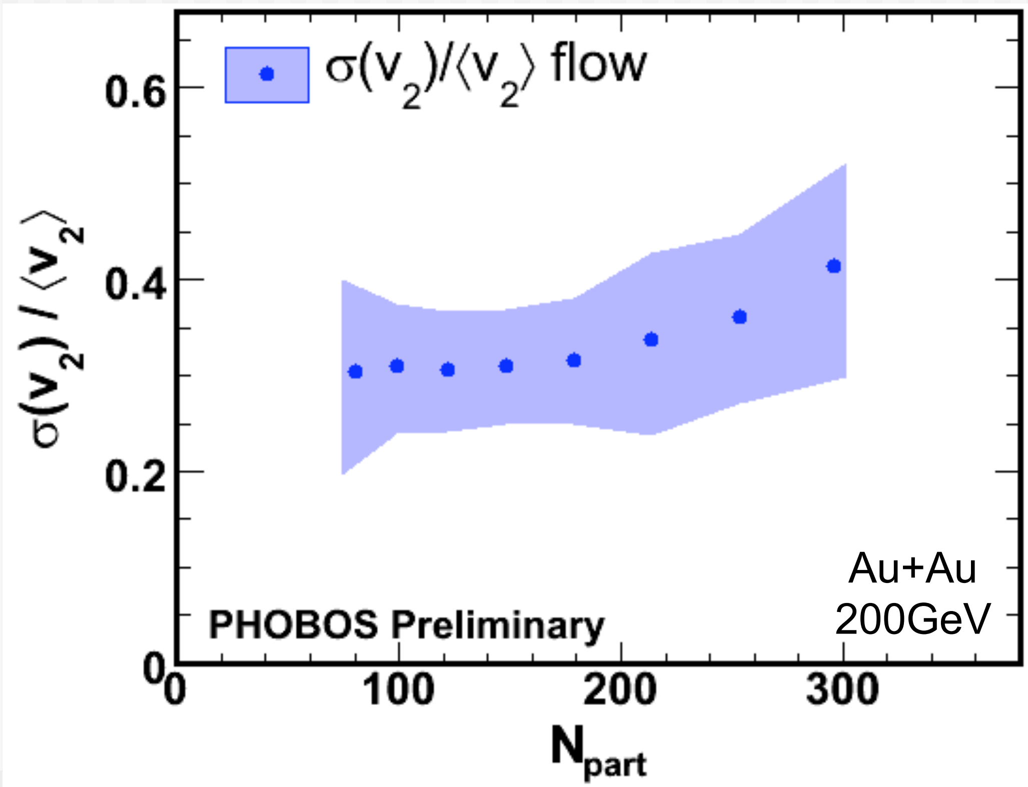
$\sigma(v_2)$ non-flow



$\sigma(v_2)$ flow extracted

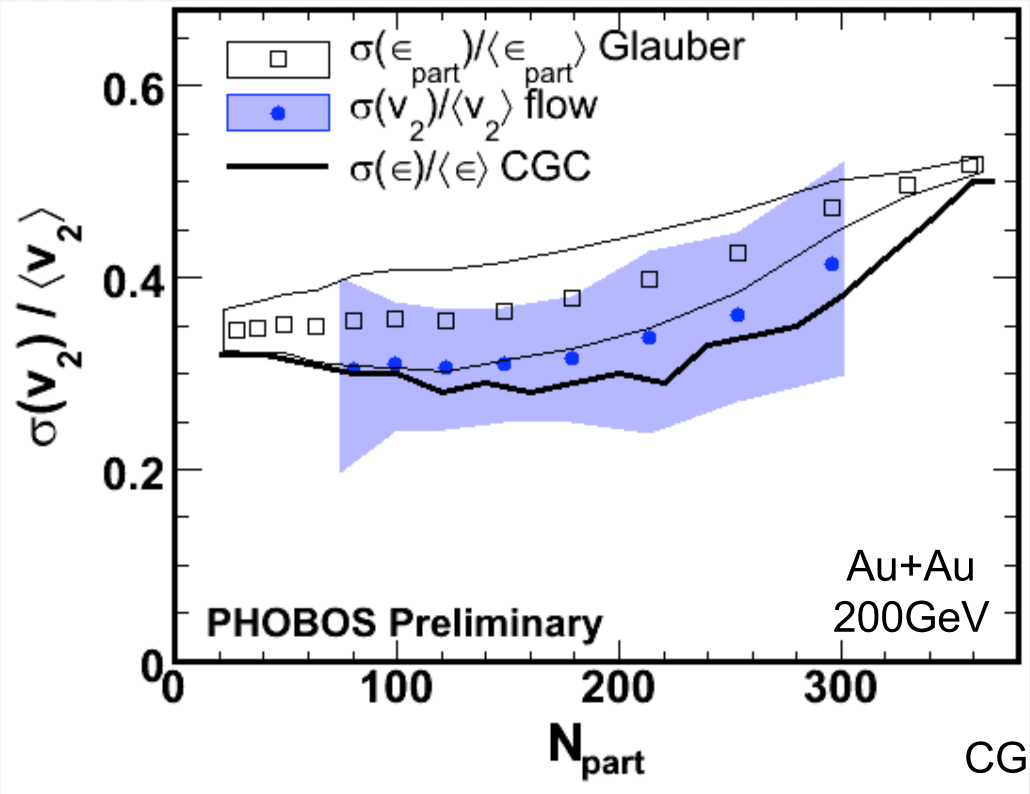
Flow fluctuations

- First results of flow fluctuations corrected for non-flow correlations measured in data.



Model comparison

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



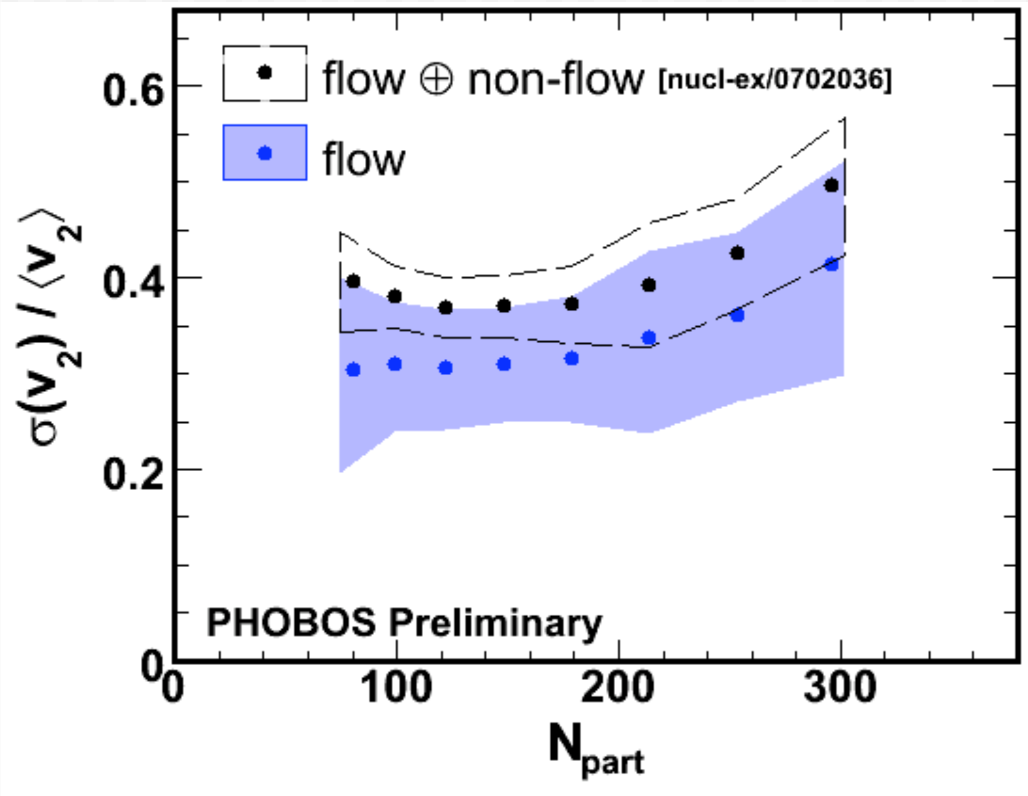
CGC: arXiv:0707.0249

Conclusions

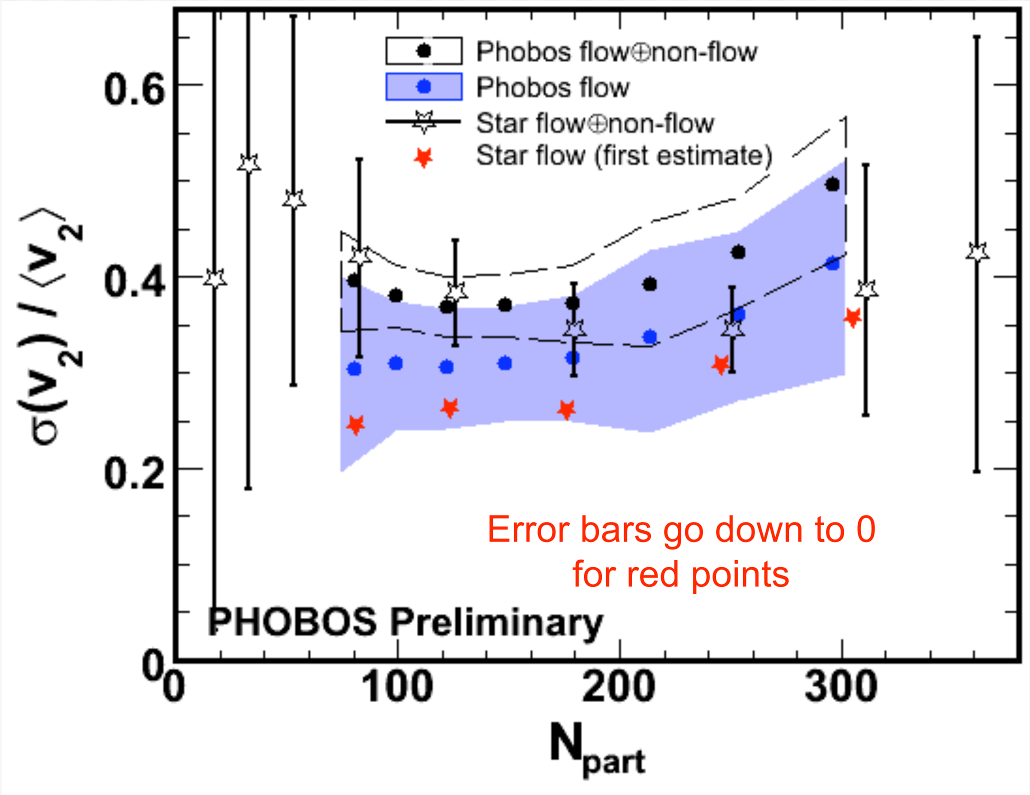
- We have performed a systematic measurement of $\Delta\varphi$ correlations at different $\Delta\eta$ ranges allowing the separation of flow and non-flow correlations.
- We have presented the first measurement of flow fluctuations corrected for non-flow.
- Our results agree both with the participant eccentricity and with CGC calculations of initial geometry fluctuations within errors.

Backups

Comparison to total fluctuations

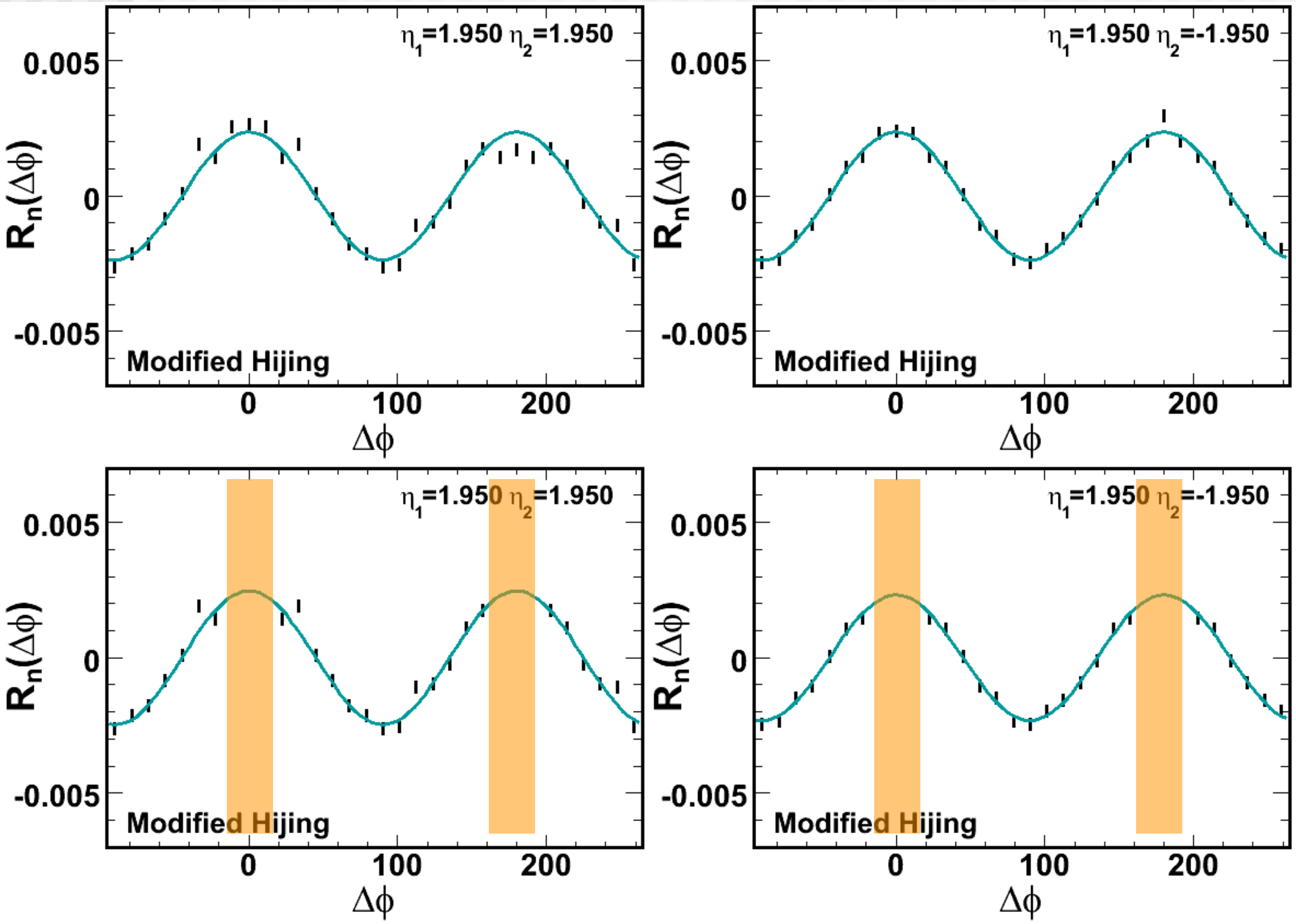


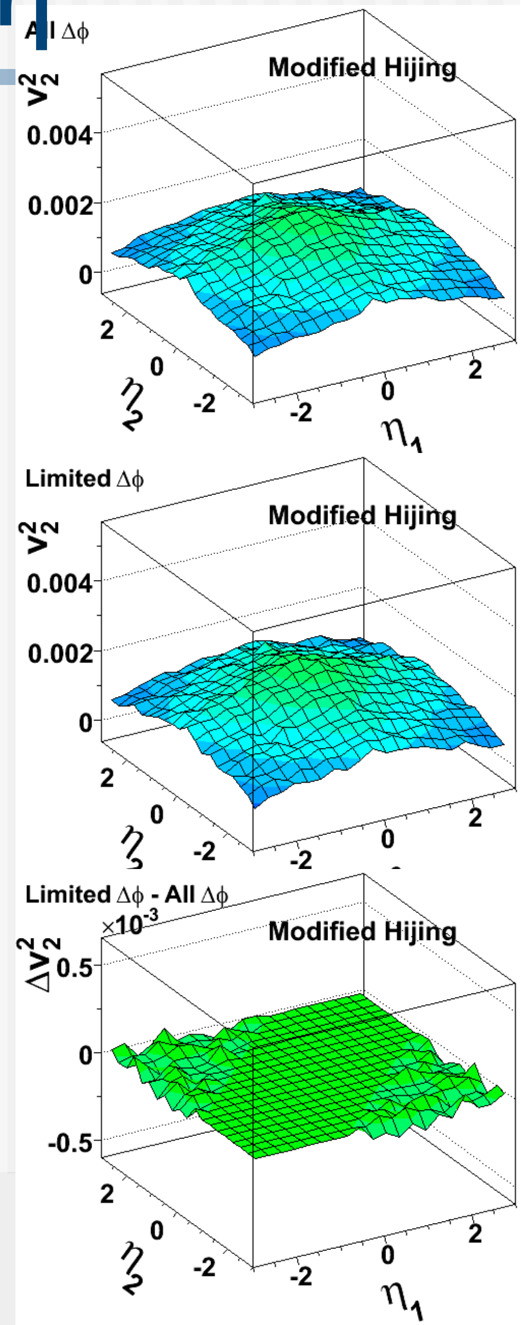
Comparison to STAR



Estimating δ for large Δη

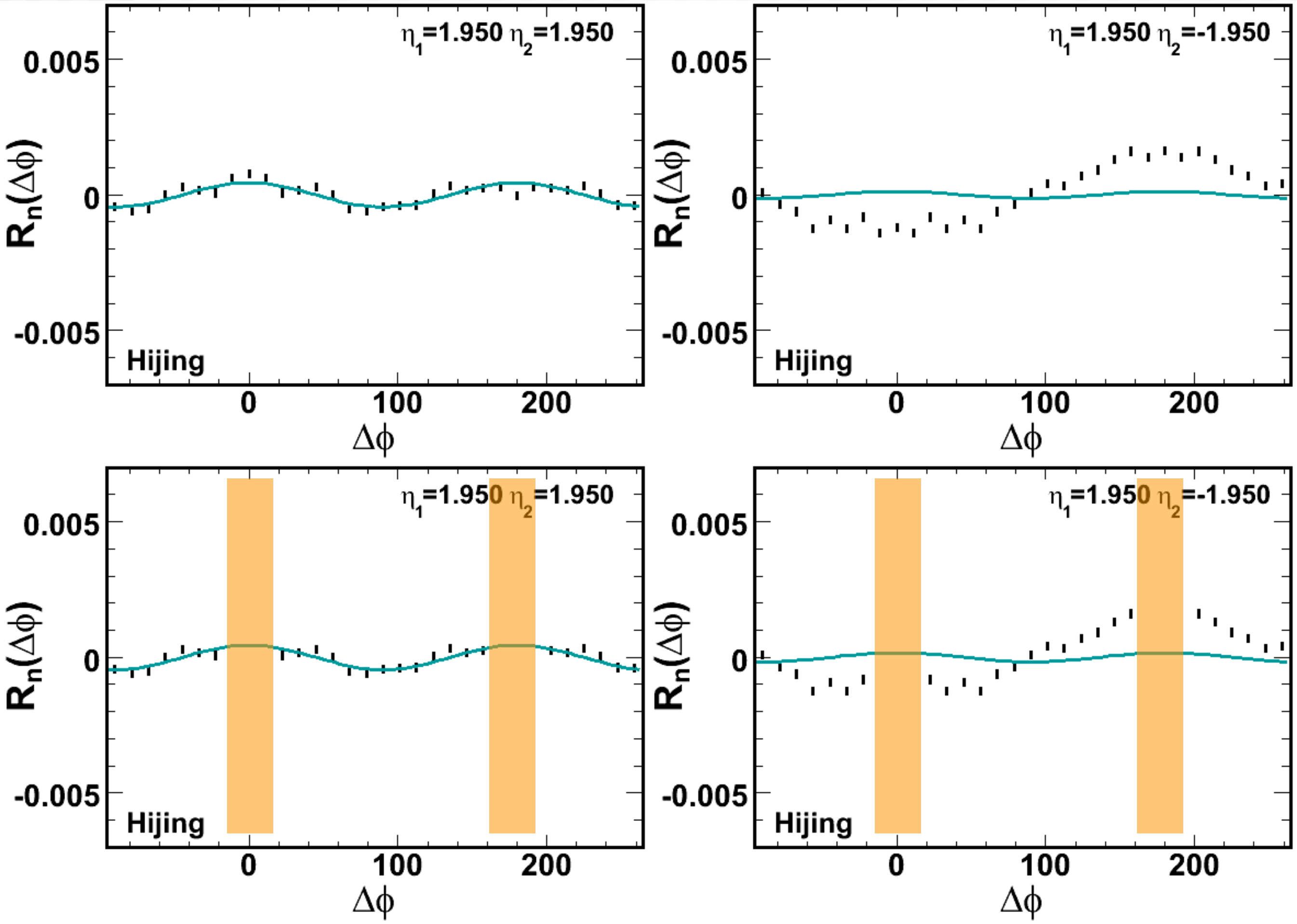
If there is no non-flow, ignoring bins in a fit does not change results

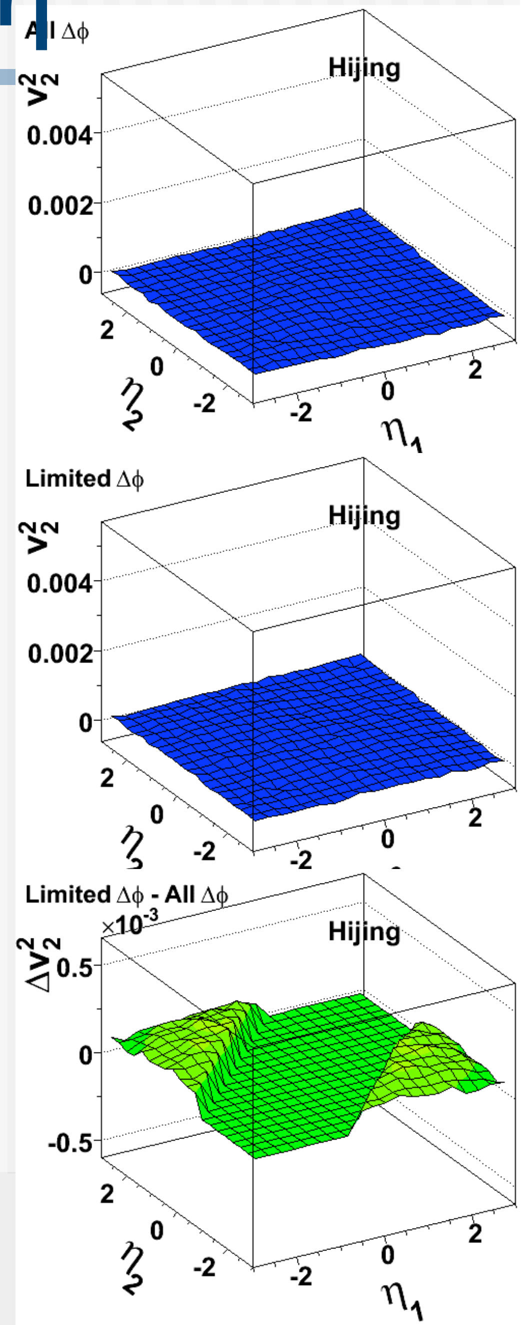




Estimating δ for large Δη

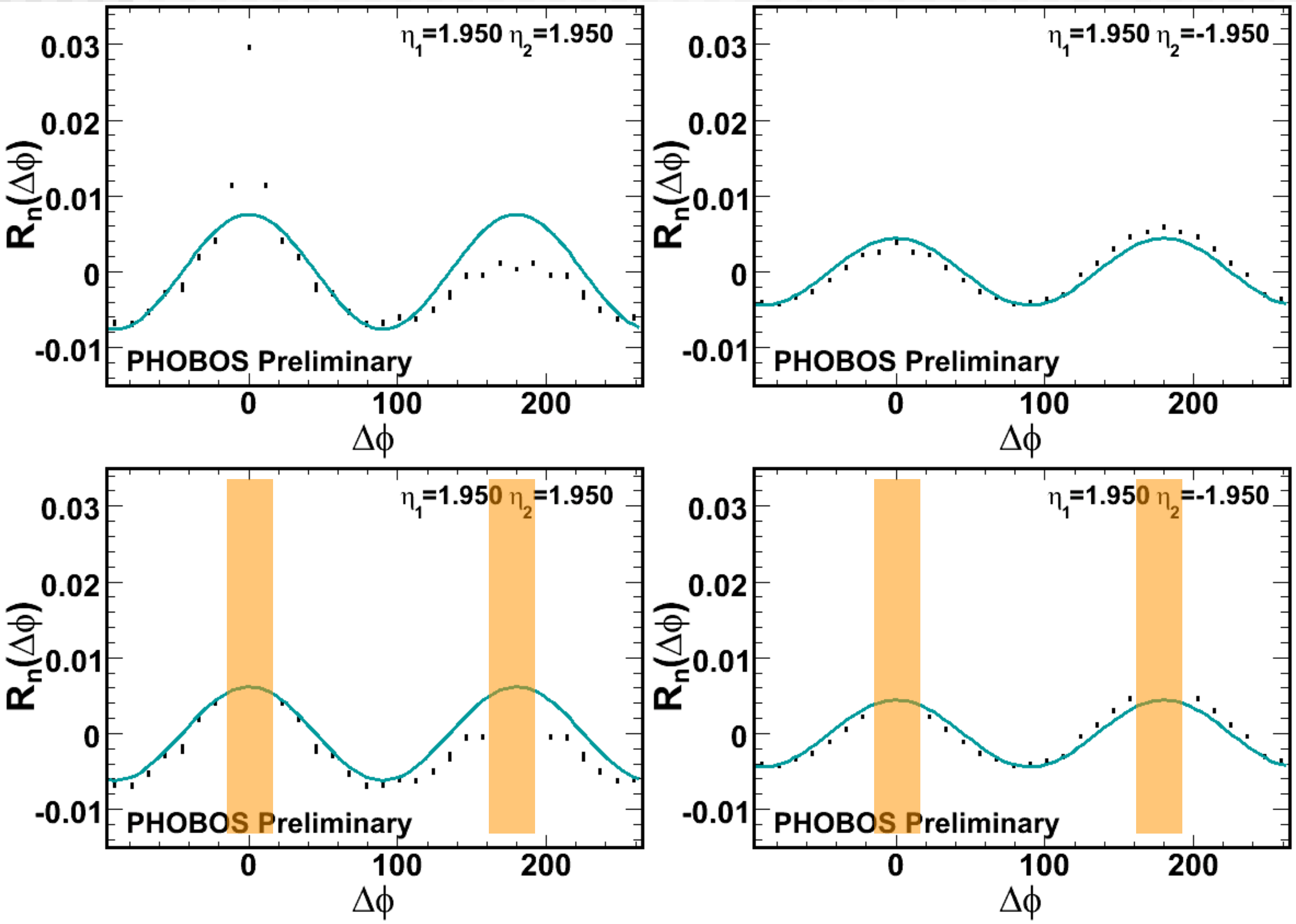
For HIJING, ignoring bins in fit changes results

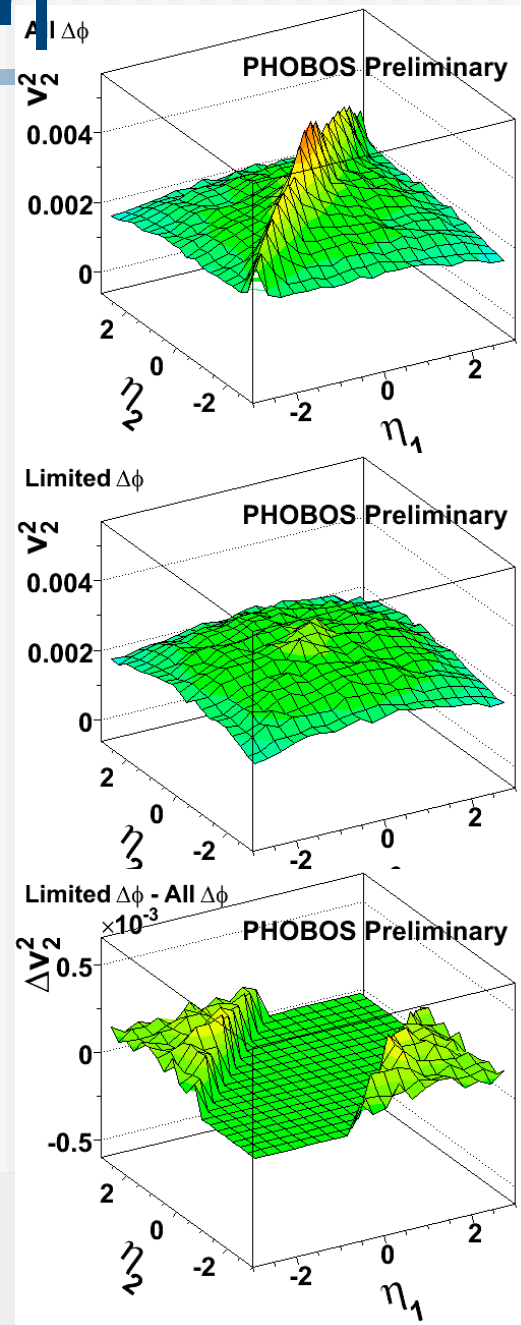




Estimating δ for large Δη

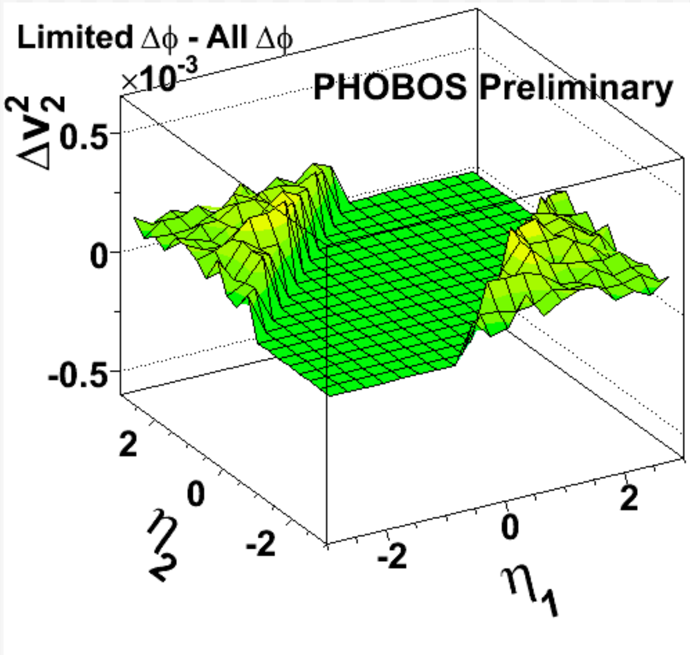
For Data, ignoring bins in fit changes results, similar to HIJING

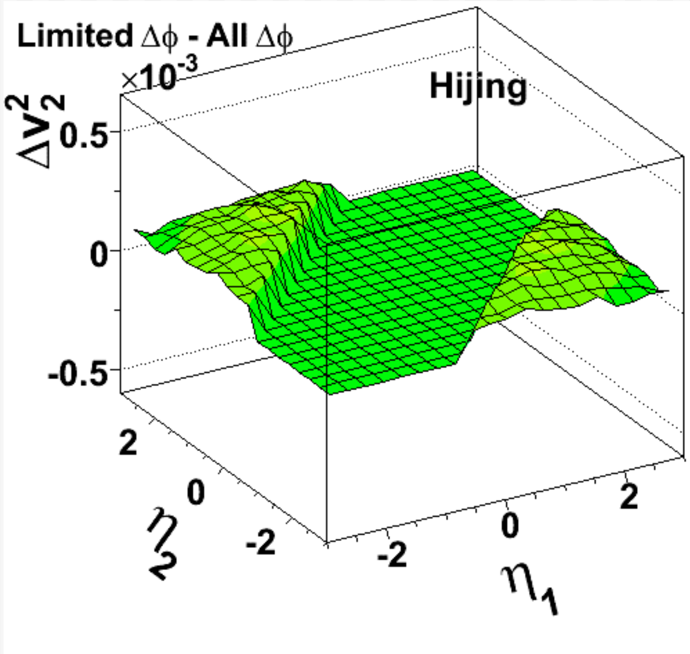




Estimating δ for large Δη

Comparing the effect of fit in limited range in data and HIJING, we estimate data has ~1.6 times non-flow compared to HIJING for $|\eta_1 - \eta_2| > 2$





Estimating δ for large Δη

We use: $\delta_{data}(\eta_1,\eta_2) = 1.6 \times \delta_{hijing}(\eta_1,\eta_2) \quad |\eta_1 - \eta_2| > 2$

Values of $\sqrt{\langle\delta\rangle}$ change by at most 12%
if the coefficient is changed to 0 or 3.2