The Ridge at High $\Delta\eta$ and Evidence of Clustering

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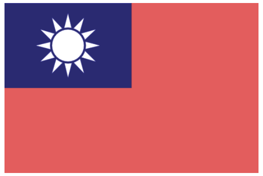
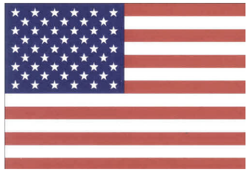
Massachusetts Institute of Technology

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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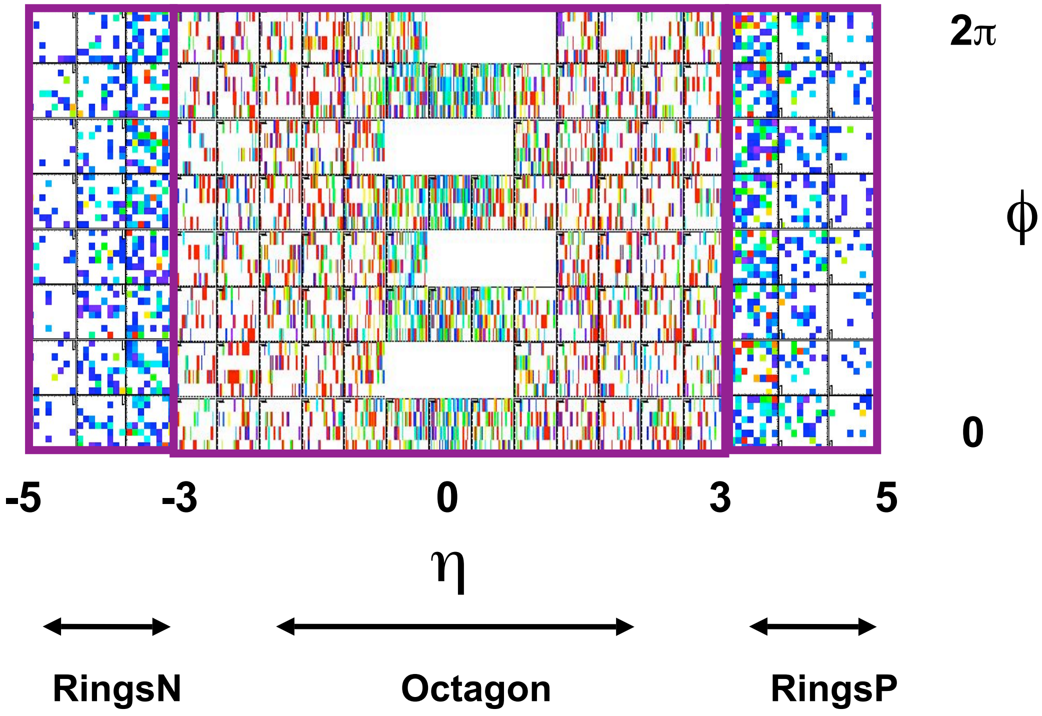
Correlations Studies with PHOBOS

Exploit large η- ϕ coverage of the PHOBOS detector

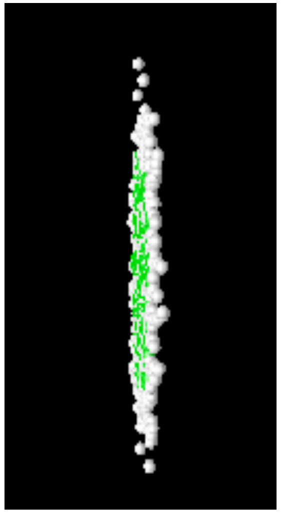
PHOBOS Acceptance – by far the largest of all RHIC experiments



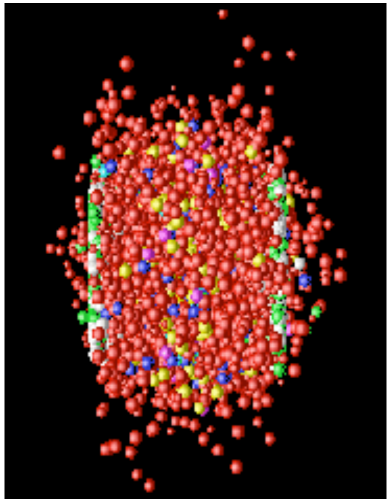
Vertex+Spec fill the Octagon holes

Goals

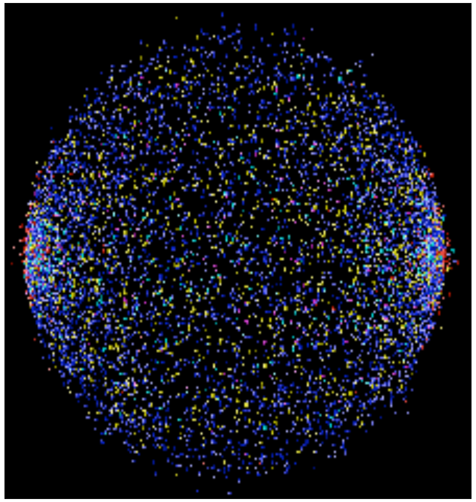
Insight into different stages of the system evolution



Initial state



Hydrodynamical evolution



Freeze-out

Medium response to initial hard scatterings

Hadronization of 'clusters'

Two Measurements

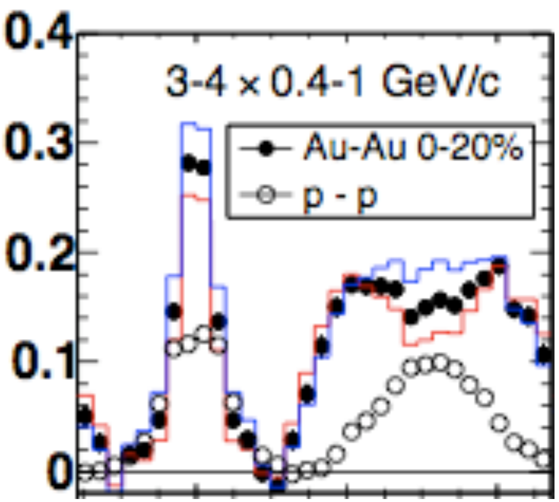
1. Two-particle correlations with high-p_T trigger for Au+Au

2. Two-particle correlations in $(\Delta\eta,\Delta\phi)$ for p+p, Cu+Cu, Au+Au

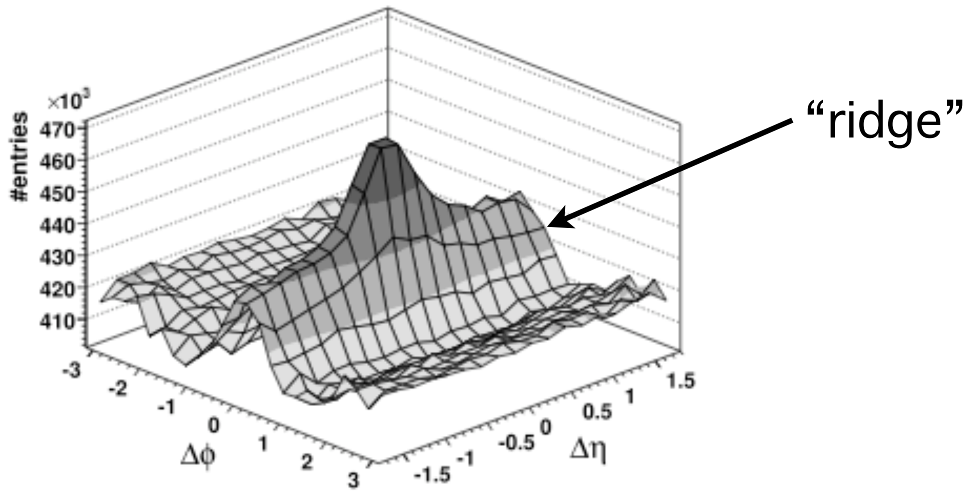
Previous Triggered Correlation Data

Medium response to high-p_T probes near mid-rapidity

PHENIX, arXiv:0705.3060v2



STAR, arXiv:nucl-ex/0701074v2



- ✓ broadening in Δφ of away-side compared to p+p
- ✓ enhanced correlation ("ridge") at Δφ=0 and large Δη

Experimental Setup

High p_T trigger tracks

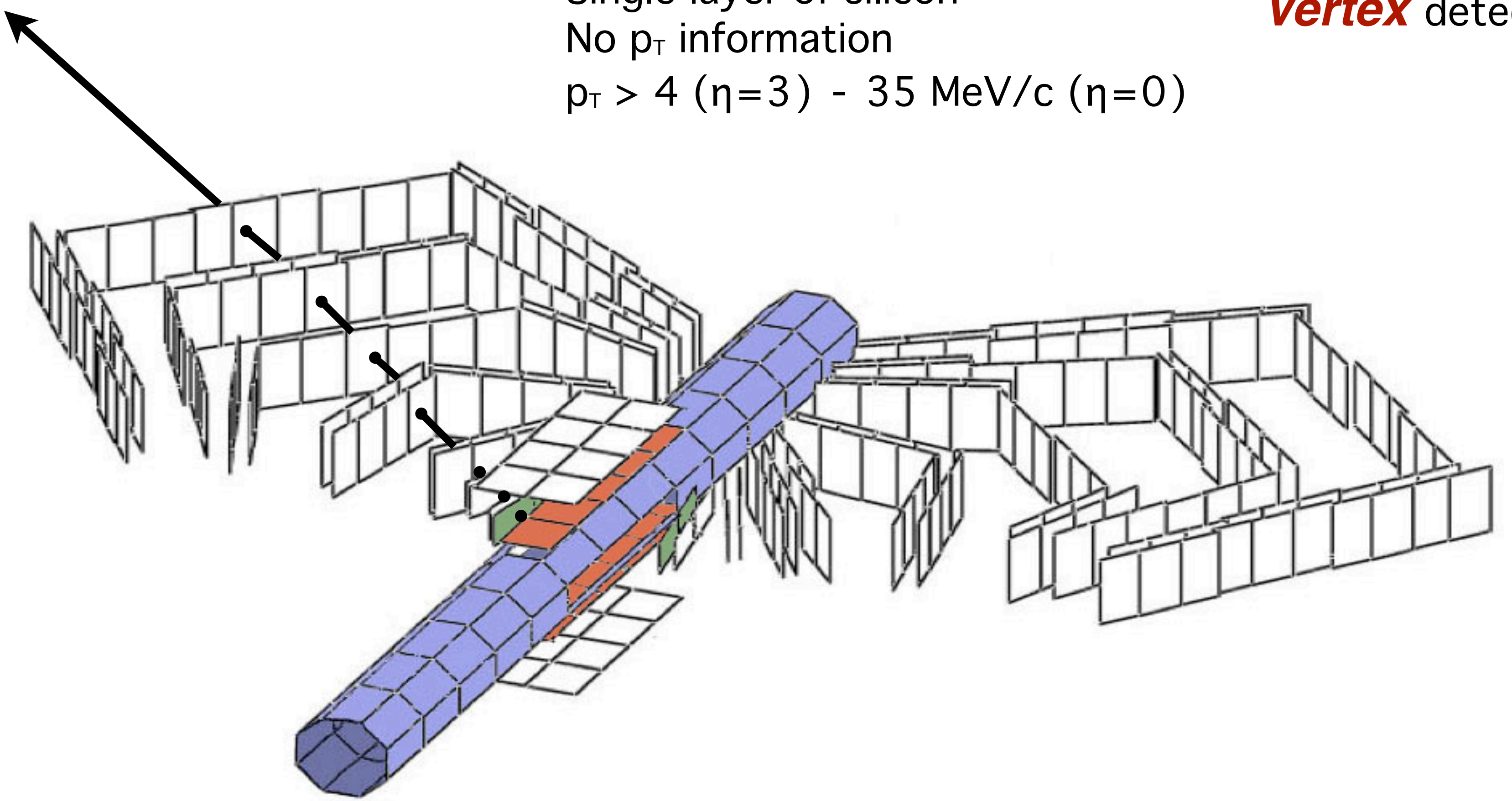
$p_T > 2.5$ GeV/c
$0 < \eta_{trig} < 1.5$

Associated hits

Full ϕ coverage
Broad η coverage ($-3<\eta<3$)

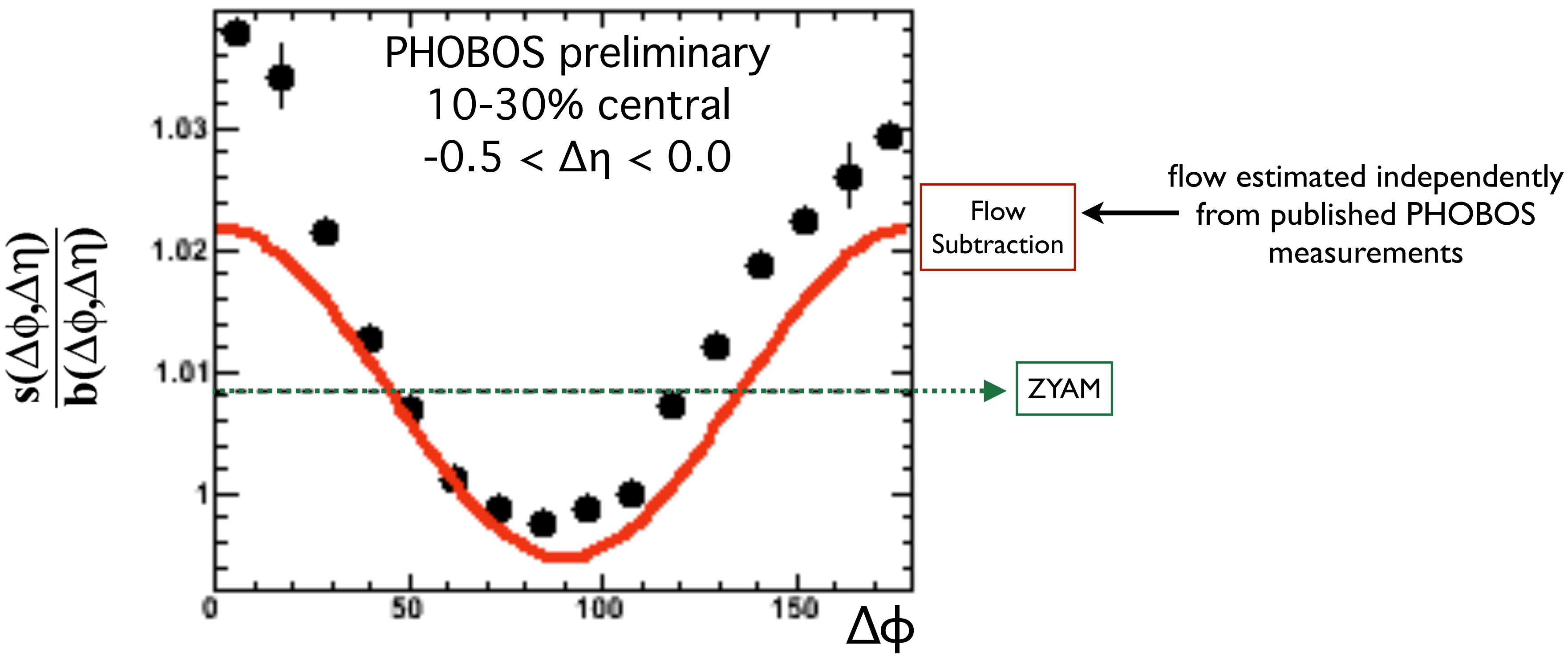
Single layer of silicon
No p_T information
$p_T > 4$ ($\eta=3$) - 35 MeV/c ($\eta=0$)

Octagon holes are filled using hits from the first layers of the ***Spectrometer*** and ***Vertex*** detectors



Flow Subtraction

$$\frac{1}{N_{trig}} \frac{d^2N_{ch}}{d\Delta\phi\, d\Delta\eta} = B(\Delta\eta) \left\{ \frac{s(\Delta\phi,\Delta\eta)}{b(\Delta\phi,\Delta\eta)} - a \left[\boxed{1 + 2V(\Delta\eta)\cos(2\Delta\phi)} \right] \right\}$$

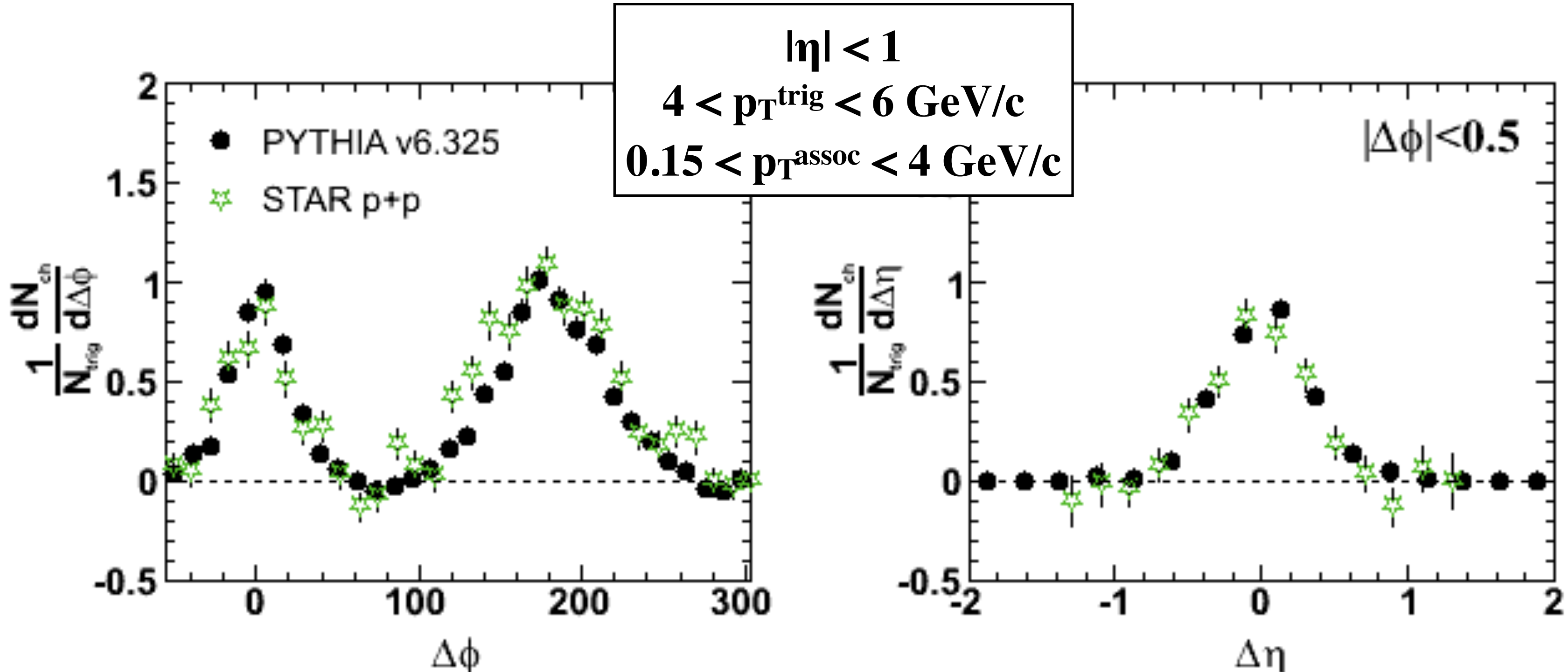


The scale factor, **a** , is calculated such that the yield after subtraction is zero at its minimum (ZYAM)

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

PYTHIA p+p reference

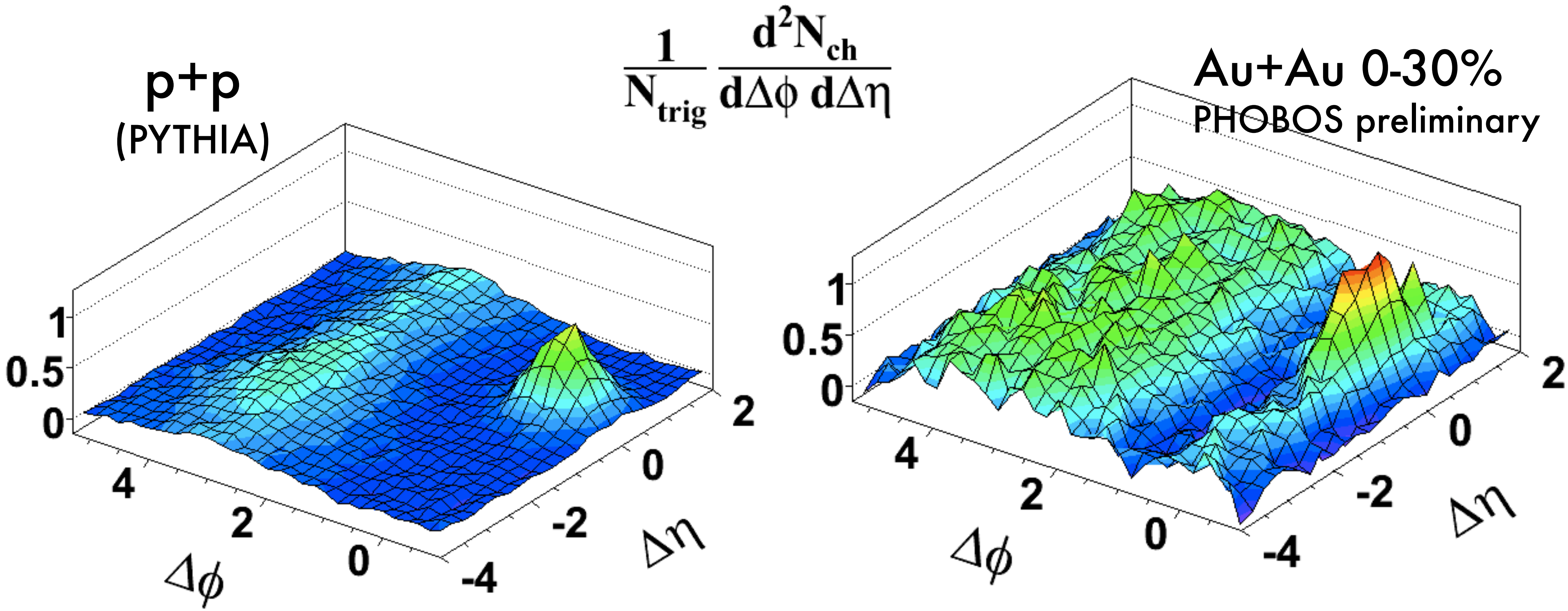
- PHOBOS is limited by statistics in p+p
- We will compare our Au+Au results to PYTHIA, which reasonably reproduces STAR p+p data



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

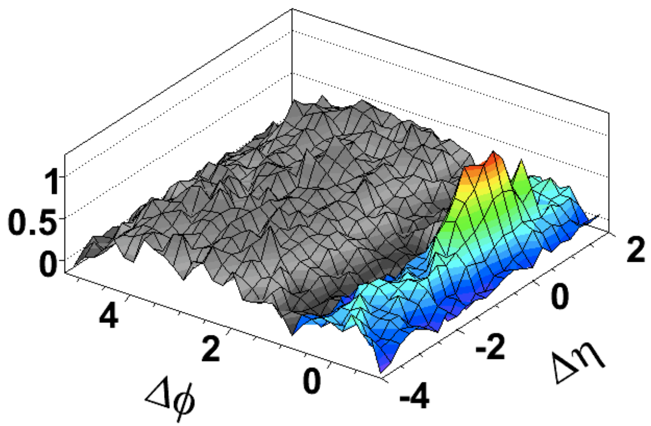
Comparison of Au+Au and p+p

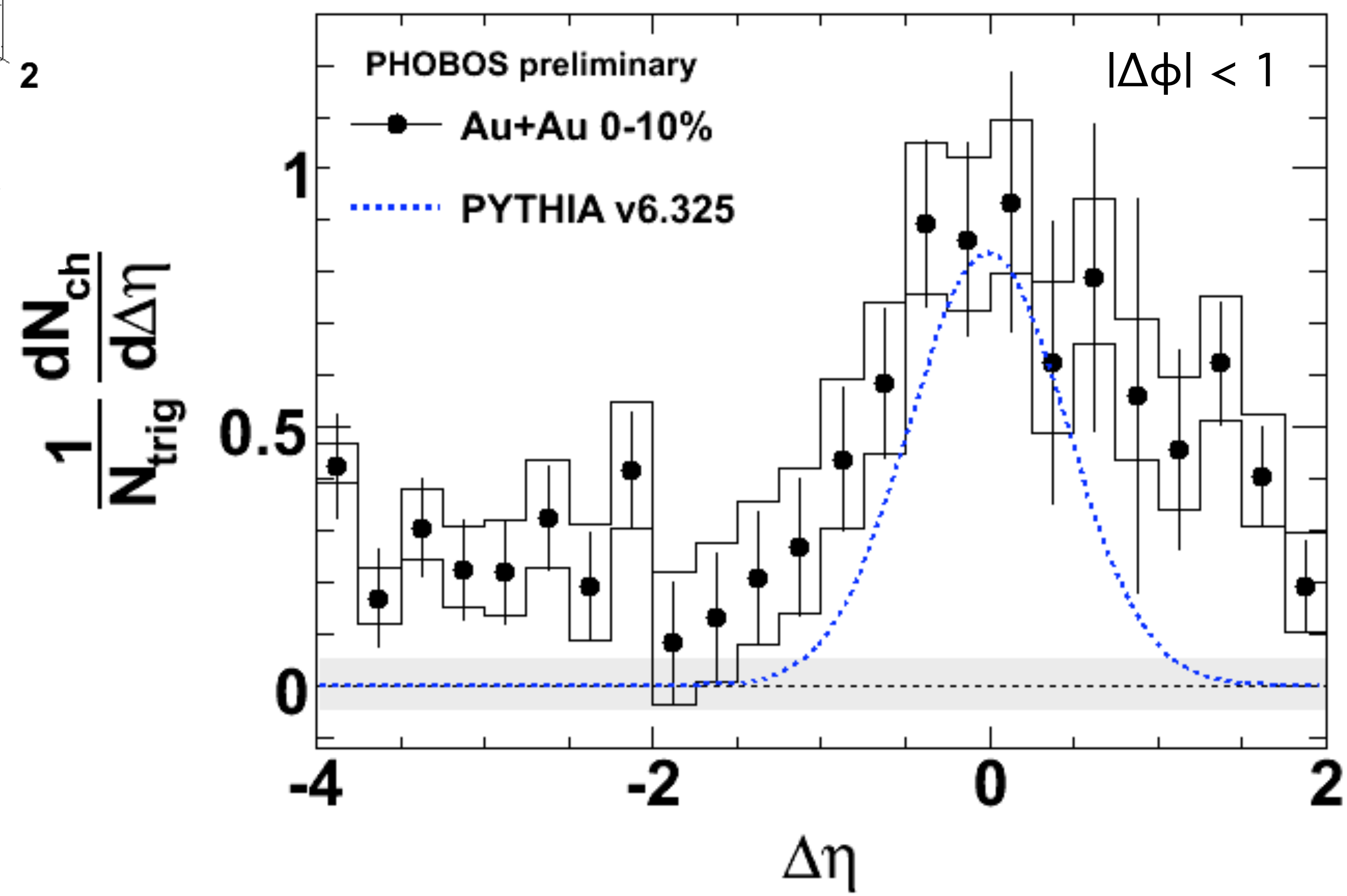
$p_T^{trig} > 2.5$ GeV/c
$p_T^{assoc} \gtrsim 20$ MeV/c



Ridge Extent in $\Delta\eta$

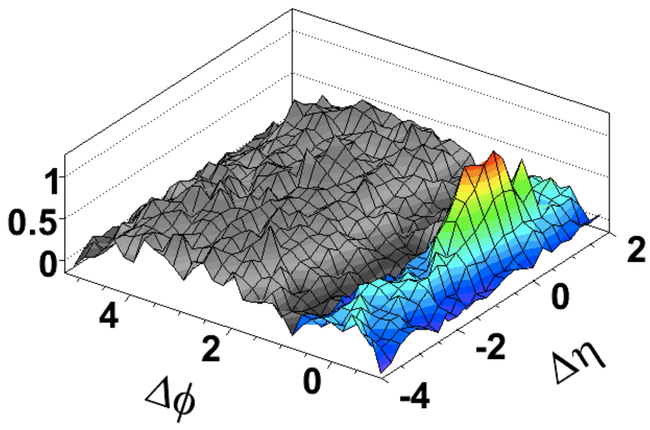
Correlated yield on near-side ($|\Delta\phi| < 1$):

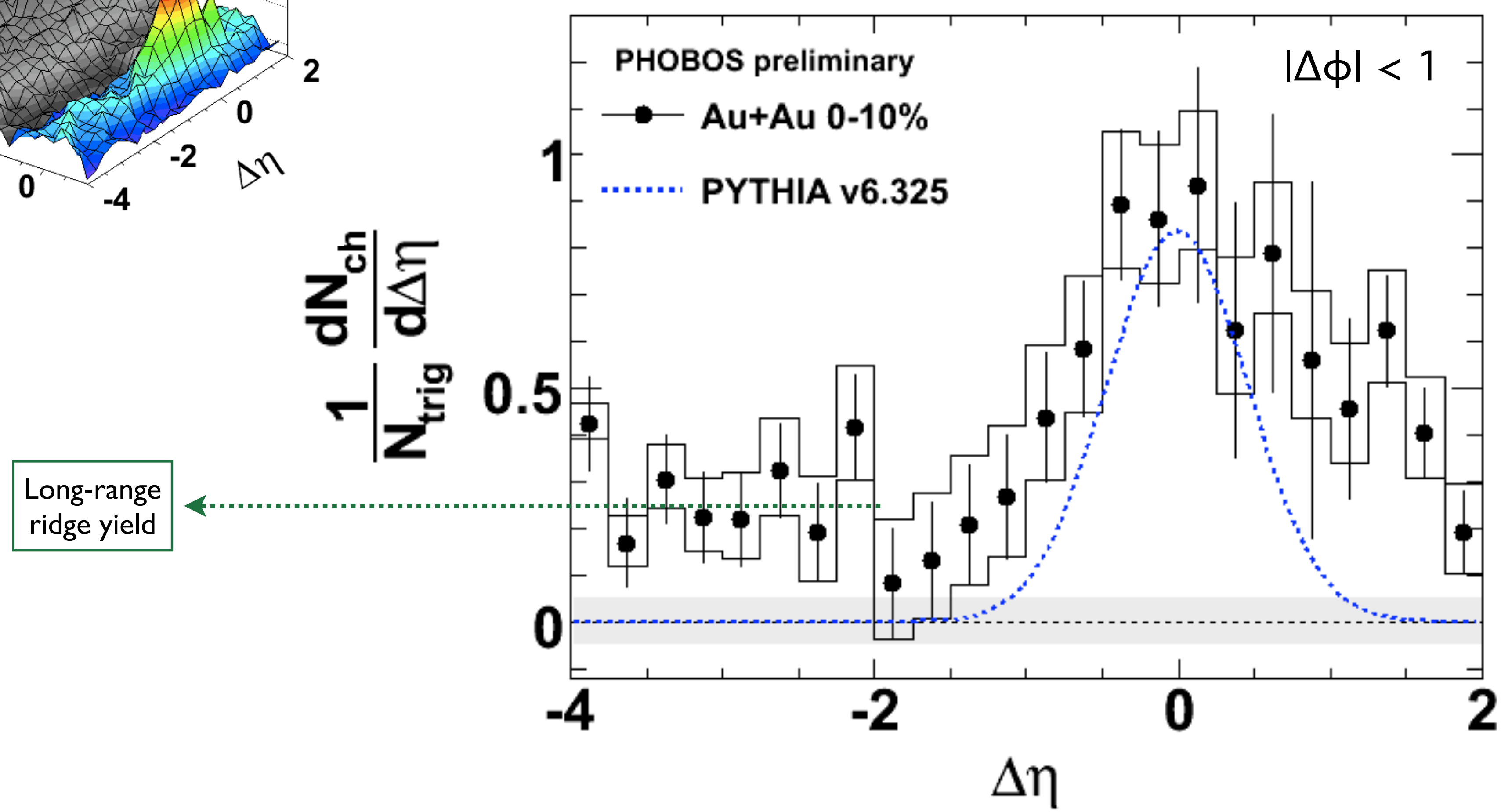




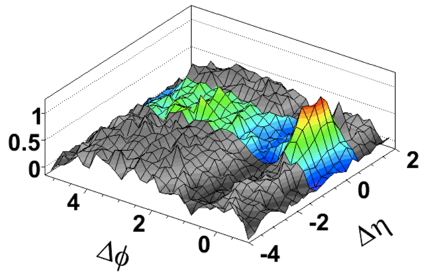
Ridge Extent in Δη

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

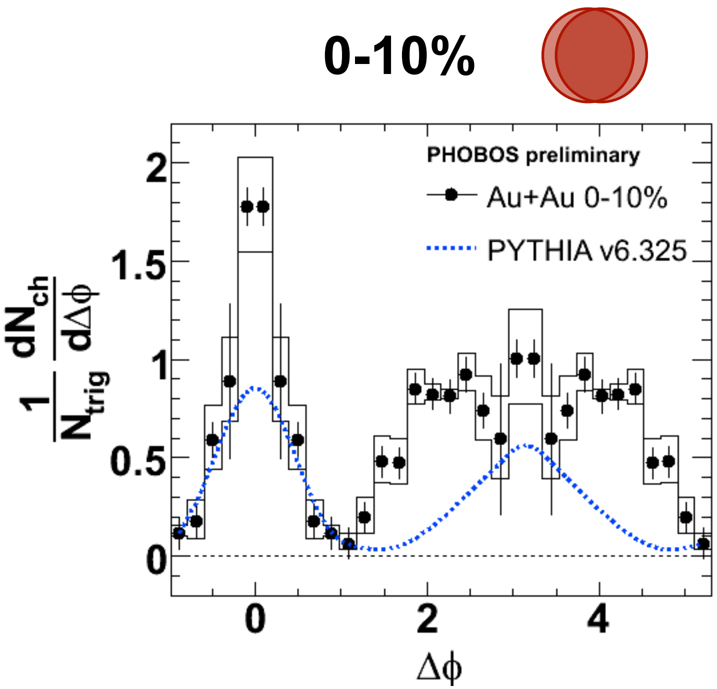


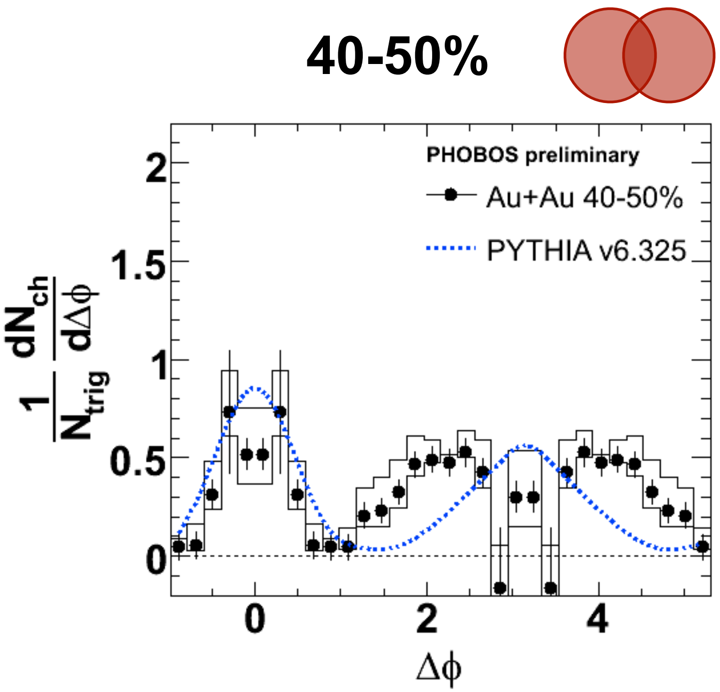


Triggered 2-particle correlations

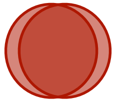
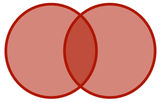


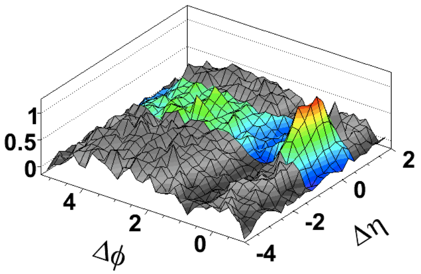
Short-range
$|\Delta\eta| < 1$



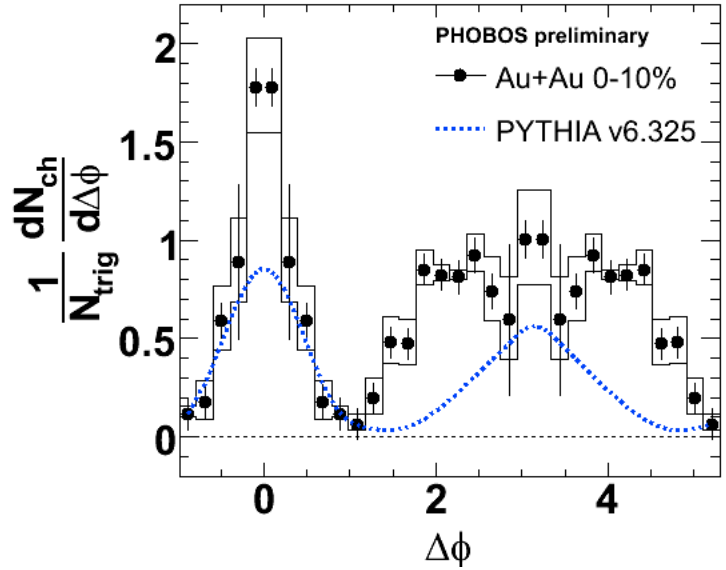


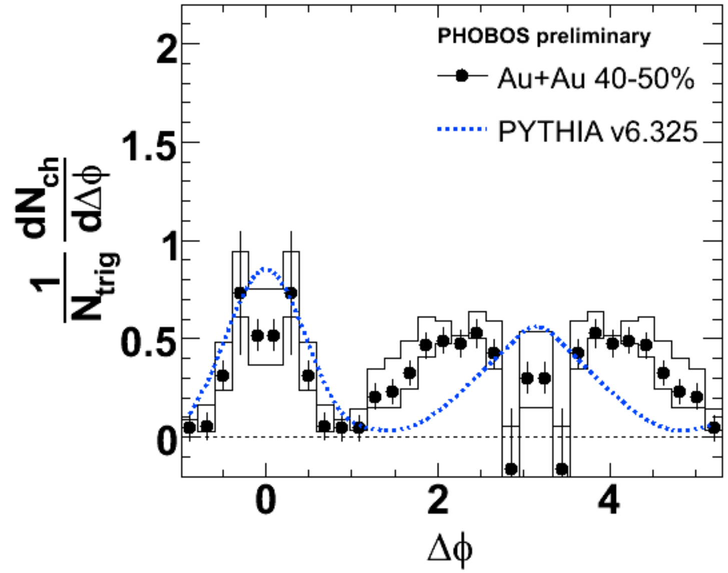
Triggered 2-particle correlations

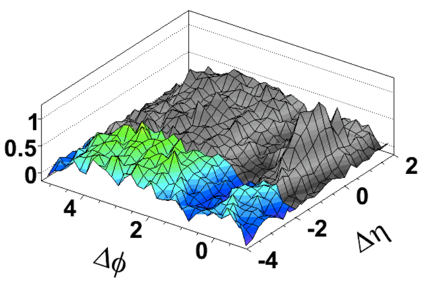
0-10%  **40-50%** 



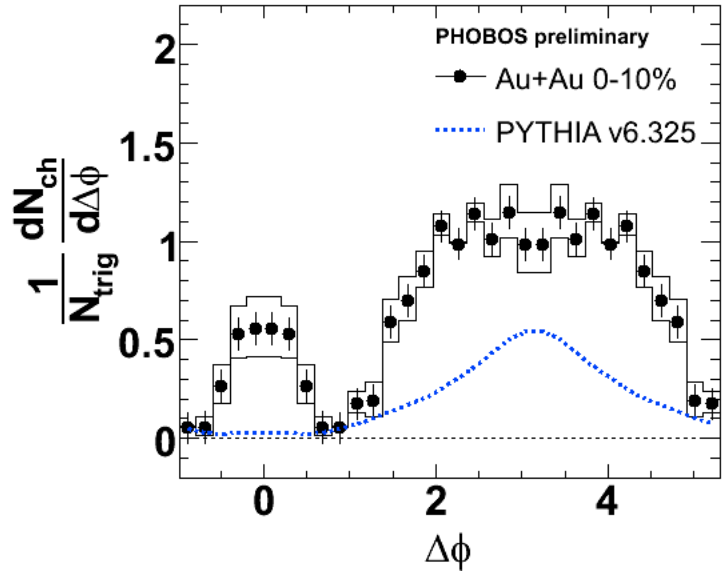
Short-range
|Δη| <1

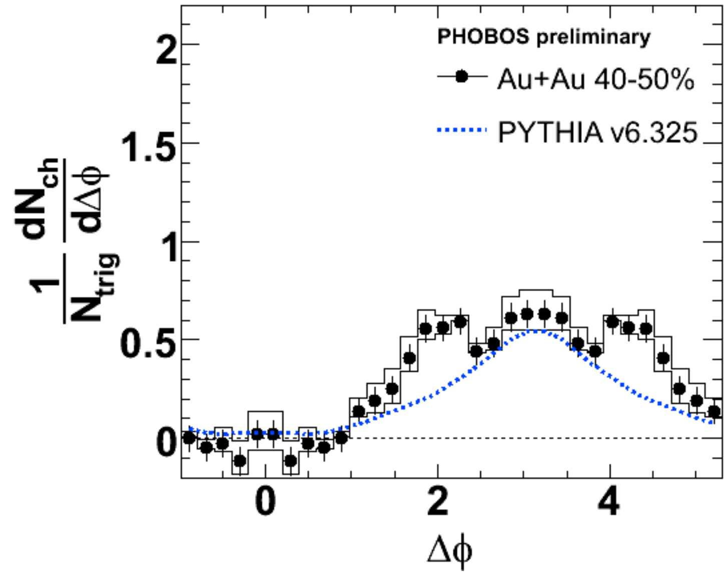






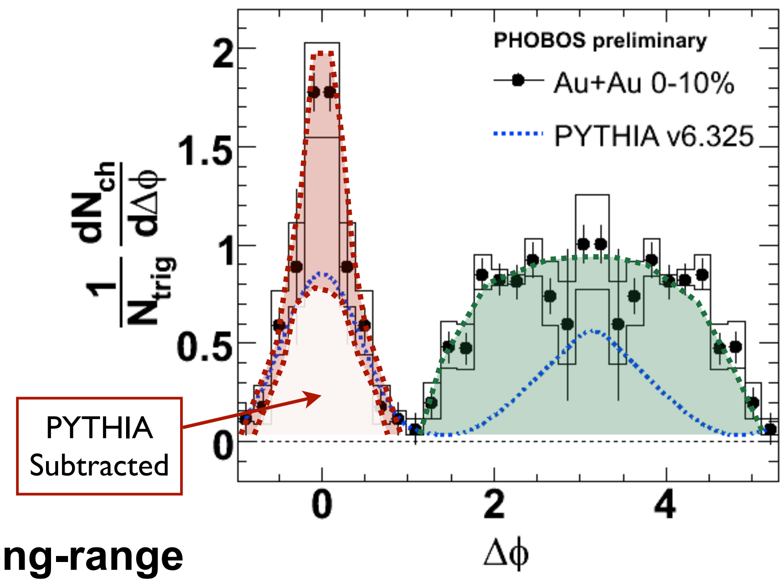
Long-range
–4< Δη <–2



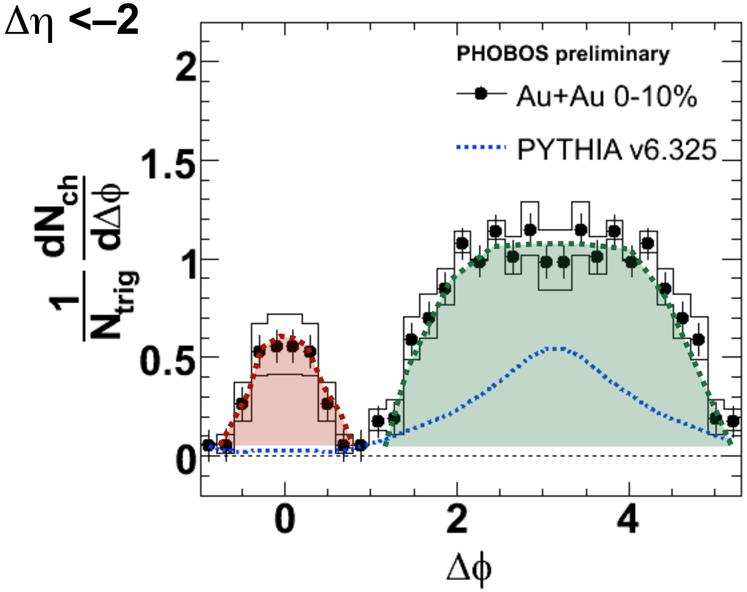


Integrated ridge yield

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

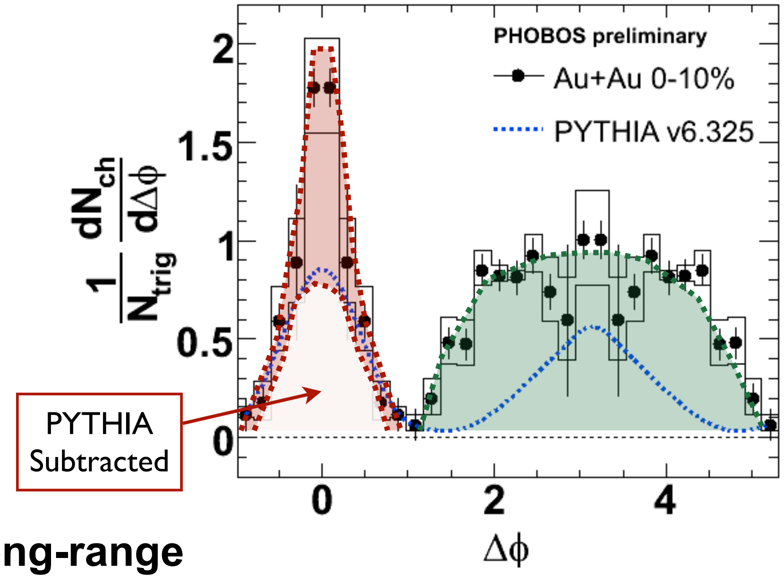


Long-range
$-4 < \Delta\eta < -2$

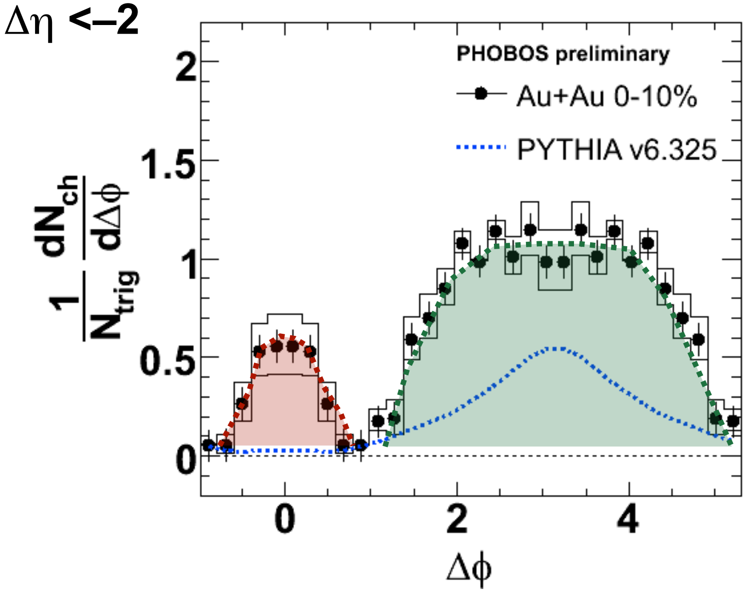


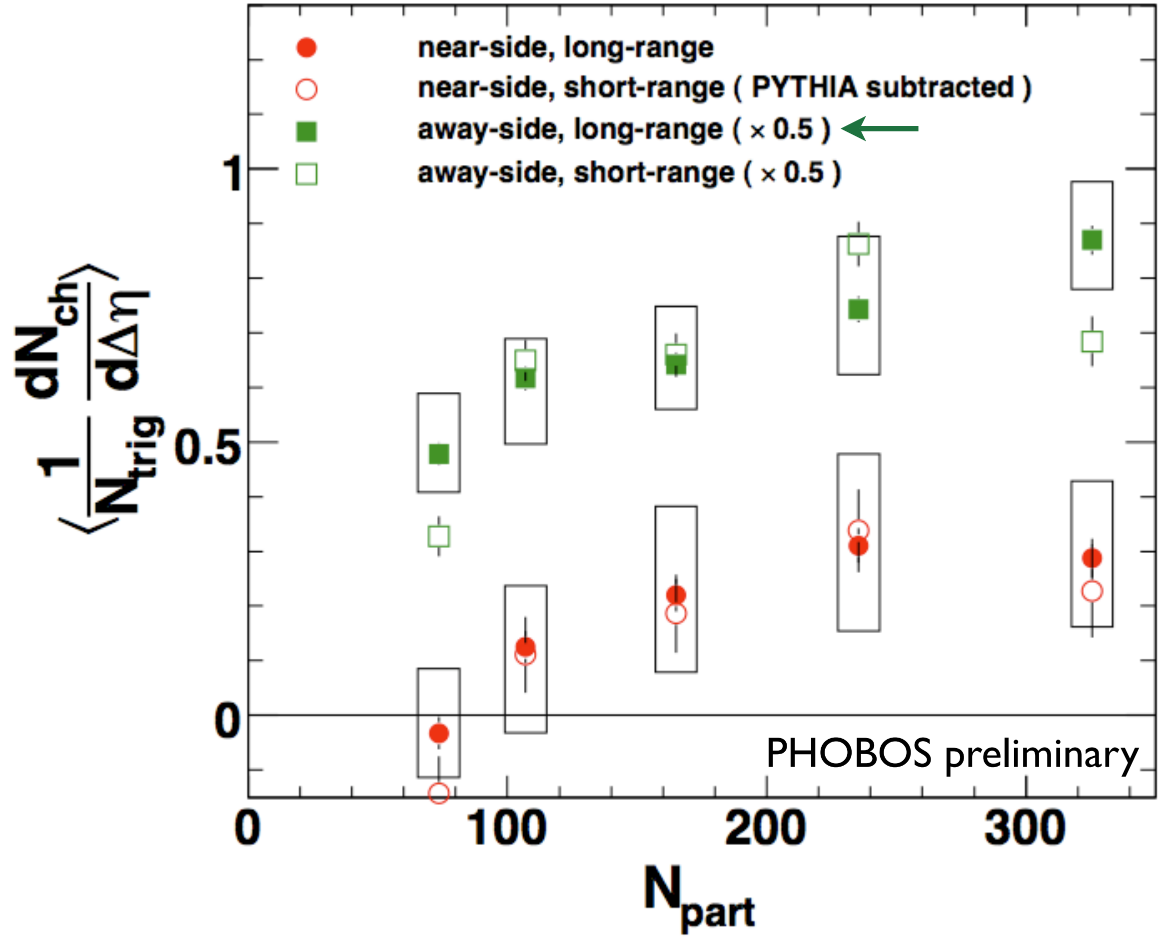
Integrated ridge yield

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



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





Summary

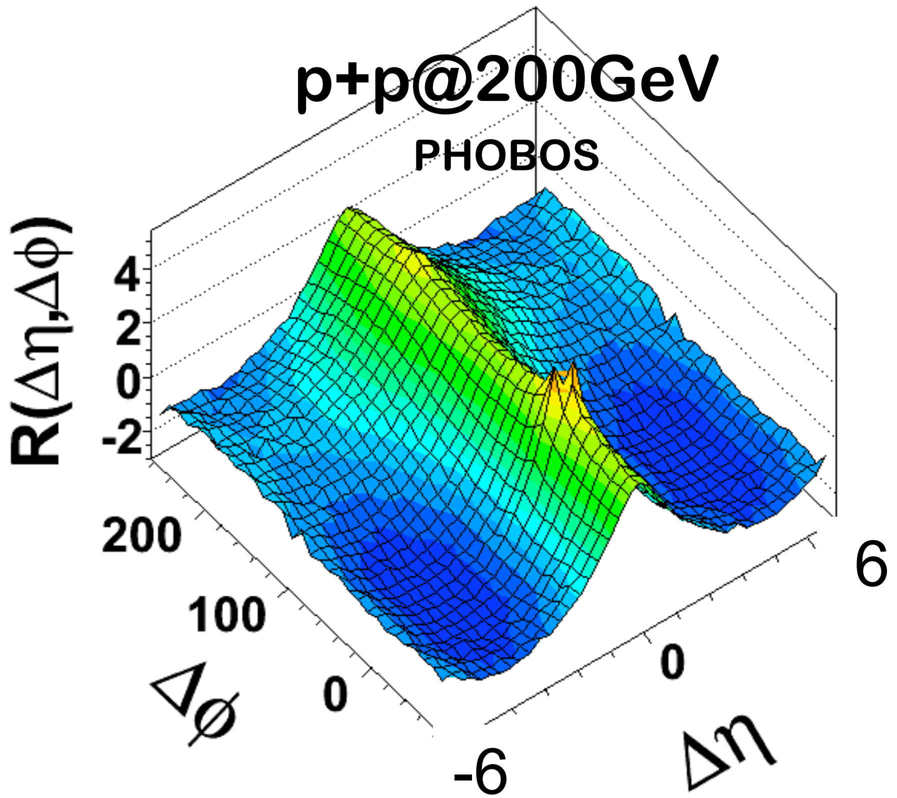
- Similar broadening of the away-side correlation in $\Delta\varphi$ relative to p+p over the full $\Delta\eta$ range
- Correlation at $\Delta\varphi=0$ and large $\Delta\eta$ ('ridge') persists to $\Delta\eta=4$
- Ridge yield at large $\Delta\eta$ disappears as one goes to peripheral collisions, similar to excess yield over PYTHIA at small $\Delta\eta$

Inclusive 2-particle correlations

multiplicity independent
2-particle correlations

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

No high p_T trigger!
(soft physics)



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Inclusive 2-particle correlations

multiplicity independent
2-particle correlations

No high p_T trigger!
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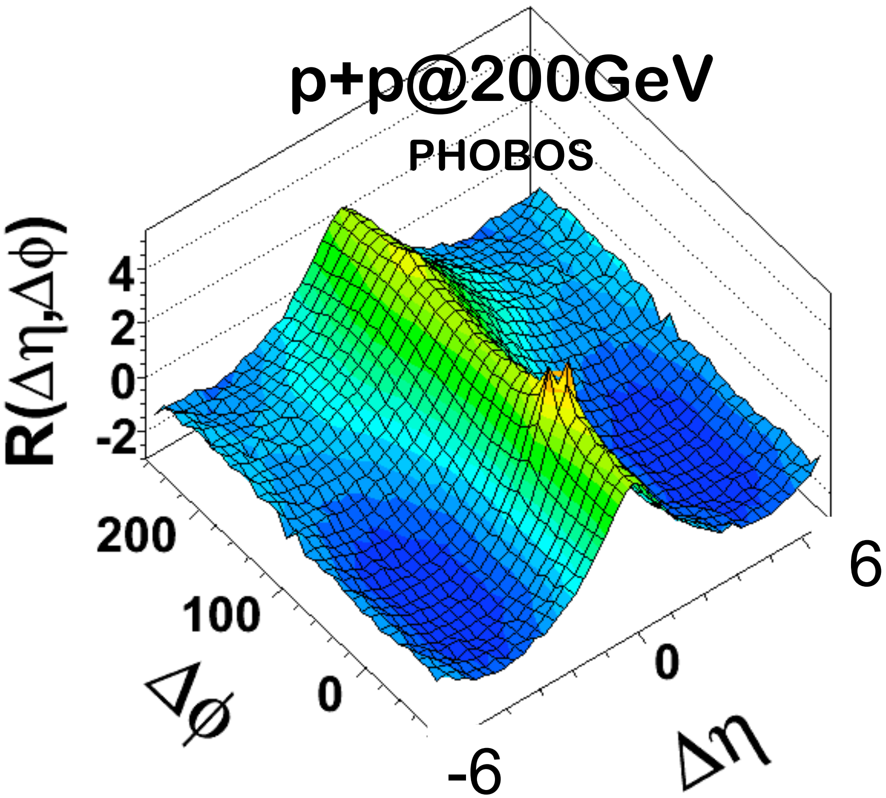
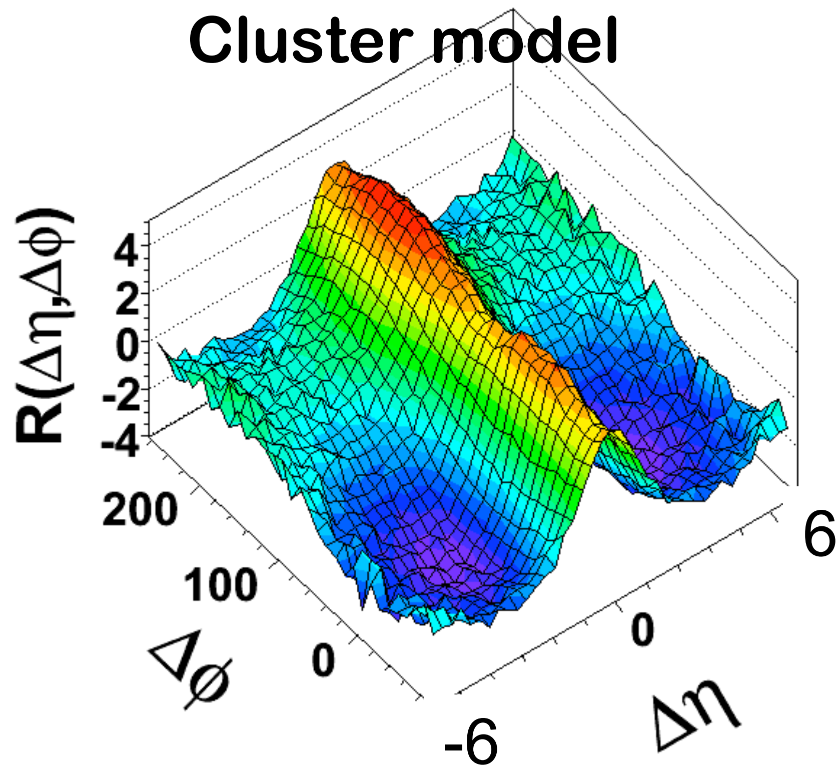


Phys. Rev. C75(2007)054913



Inclusive 2-particle correlations

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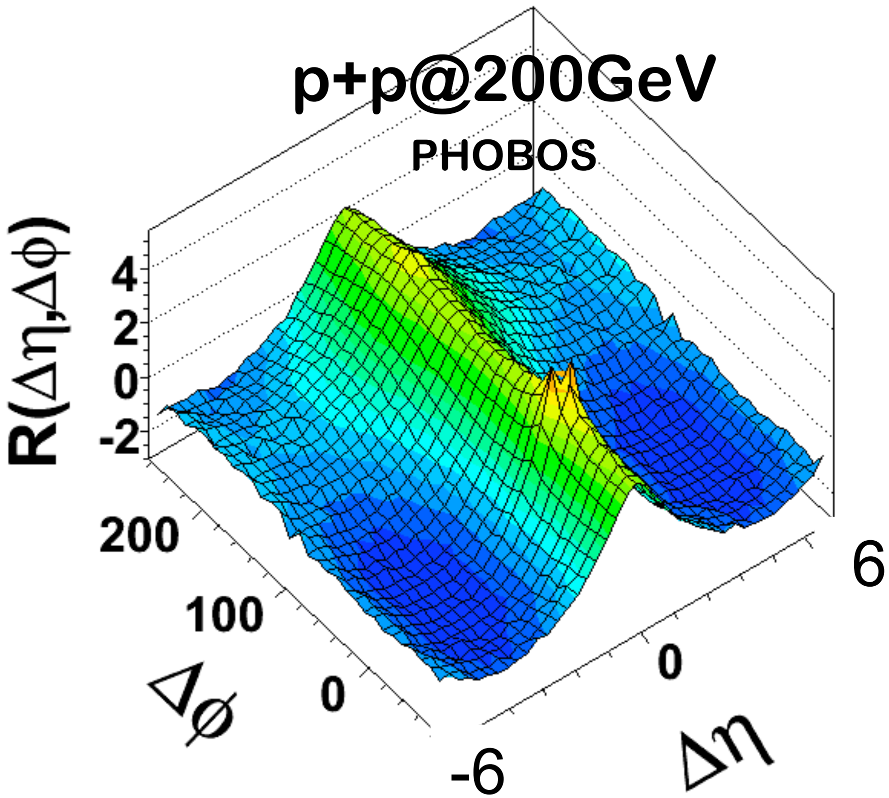

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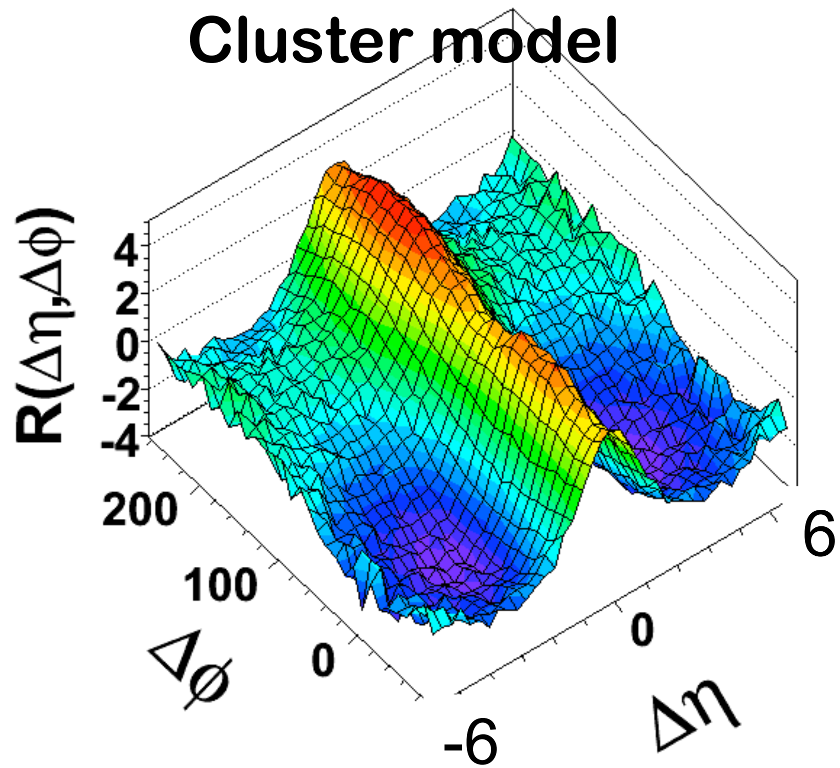
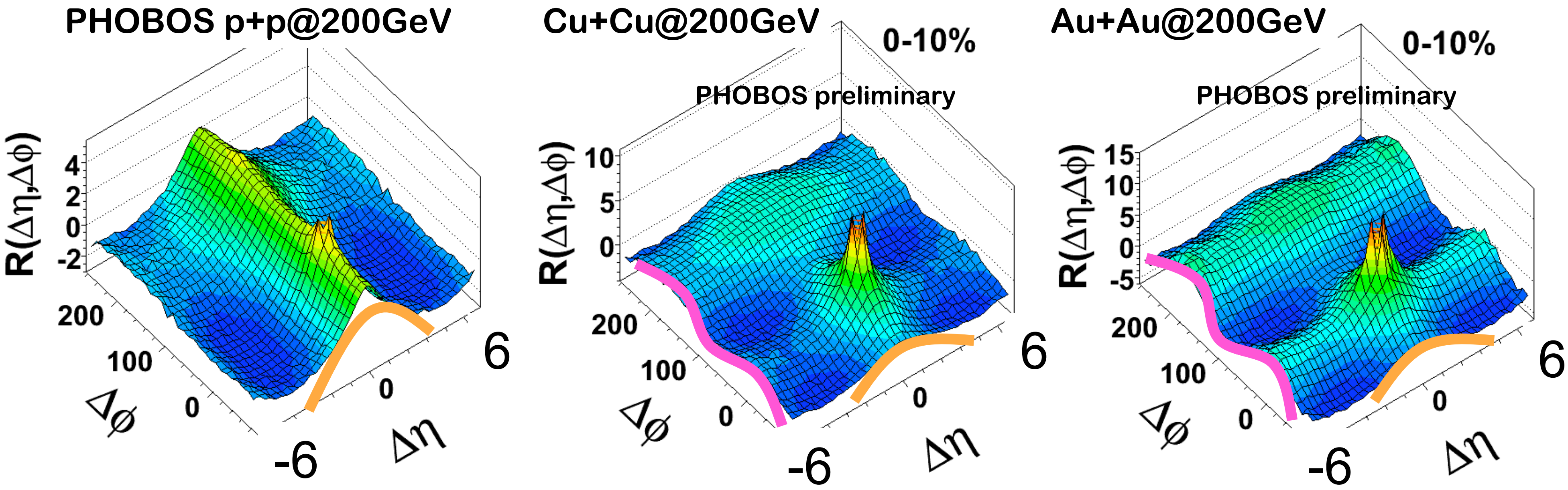


In p+p, particles tend to be produced in correlated fashion

2-particle correlations

multiplicity independent
2-particle correlations

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



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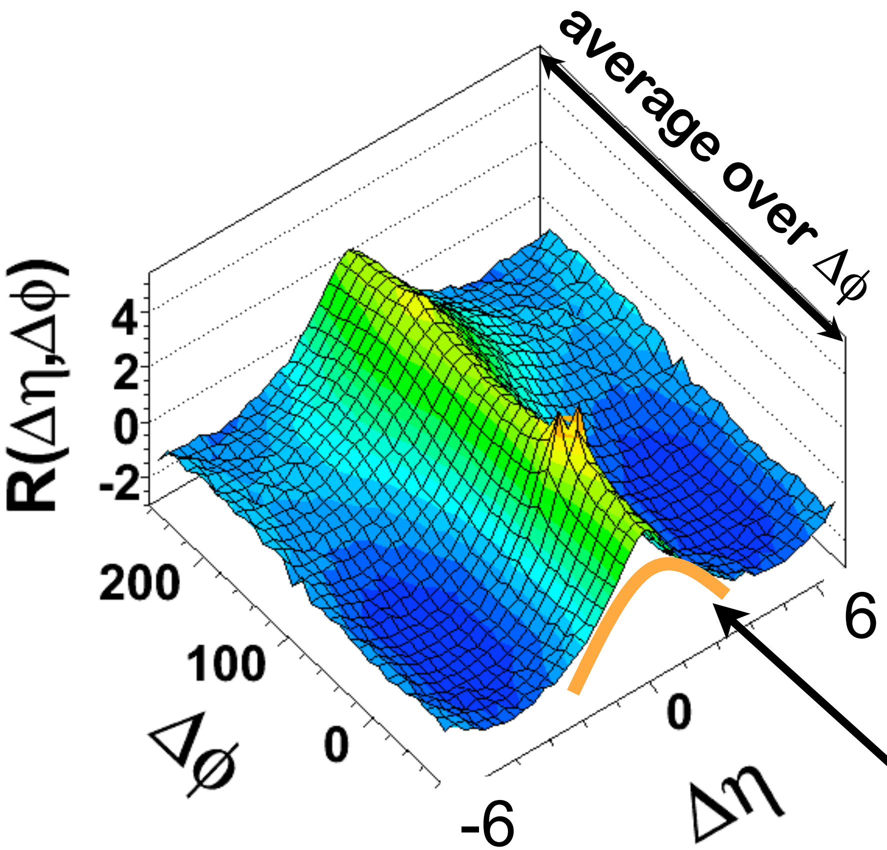
J. Phys. G34 (2007) s1005

v_2 component: $<2(n-1)v_2^2>$

Parameterize Cluster Properties



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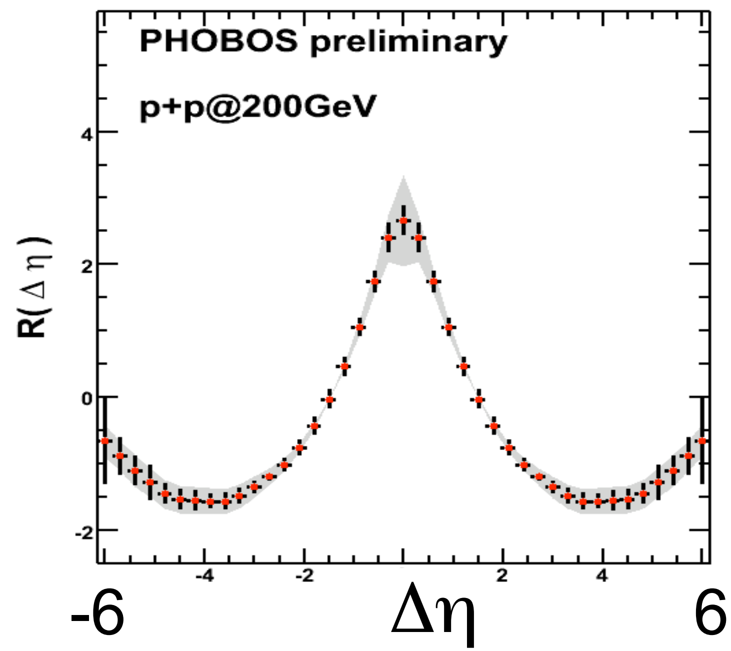
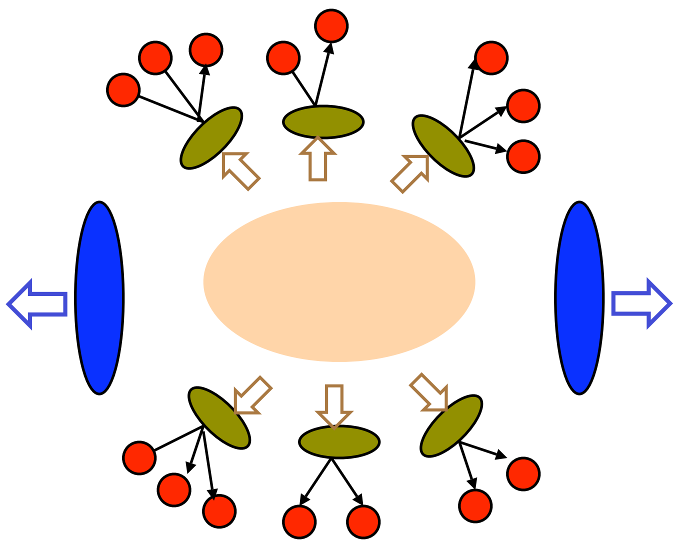
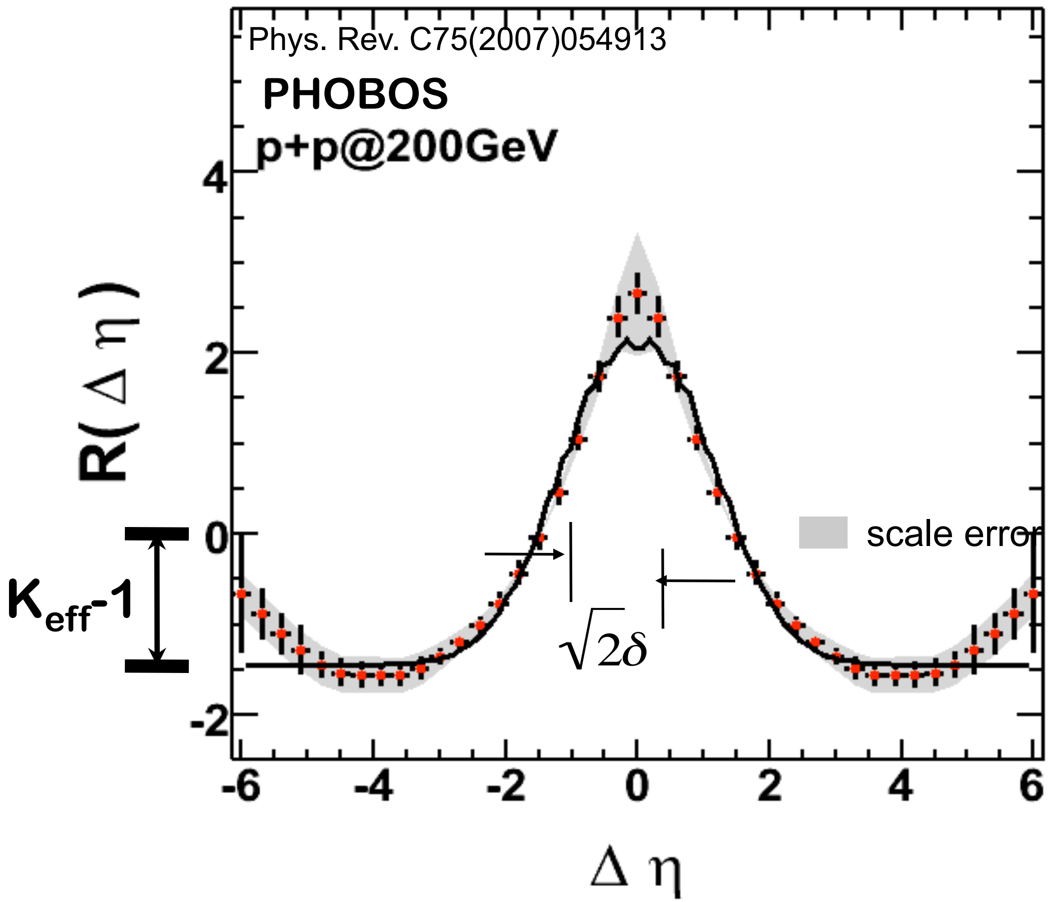


focus on short-range $\Delta\eta$ correlations

Cluster Size and Decay Width

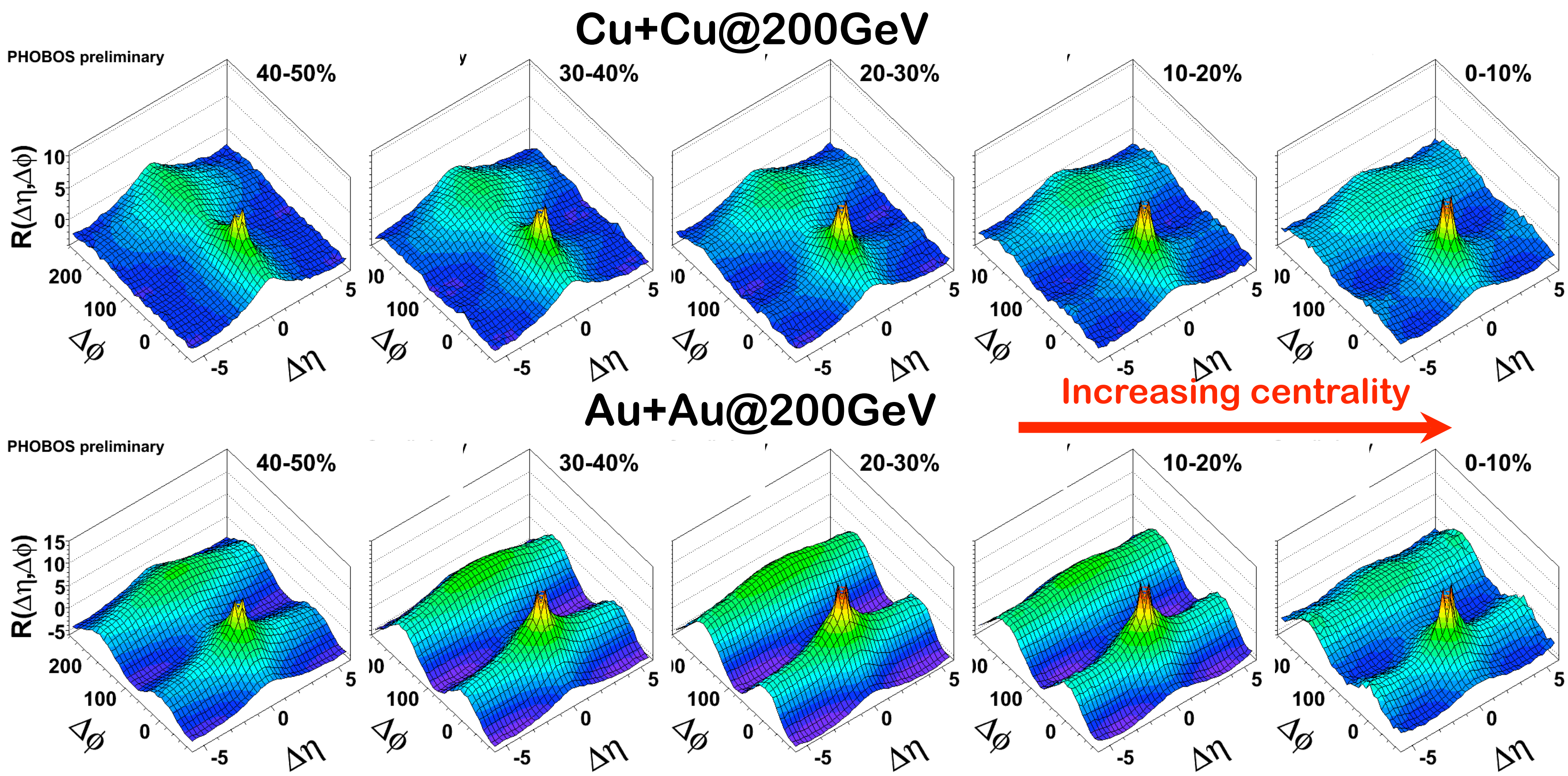




K_{eff} : effective cluster size

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

2-particle correlations in Cu+Cu and Au+Au

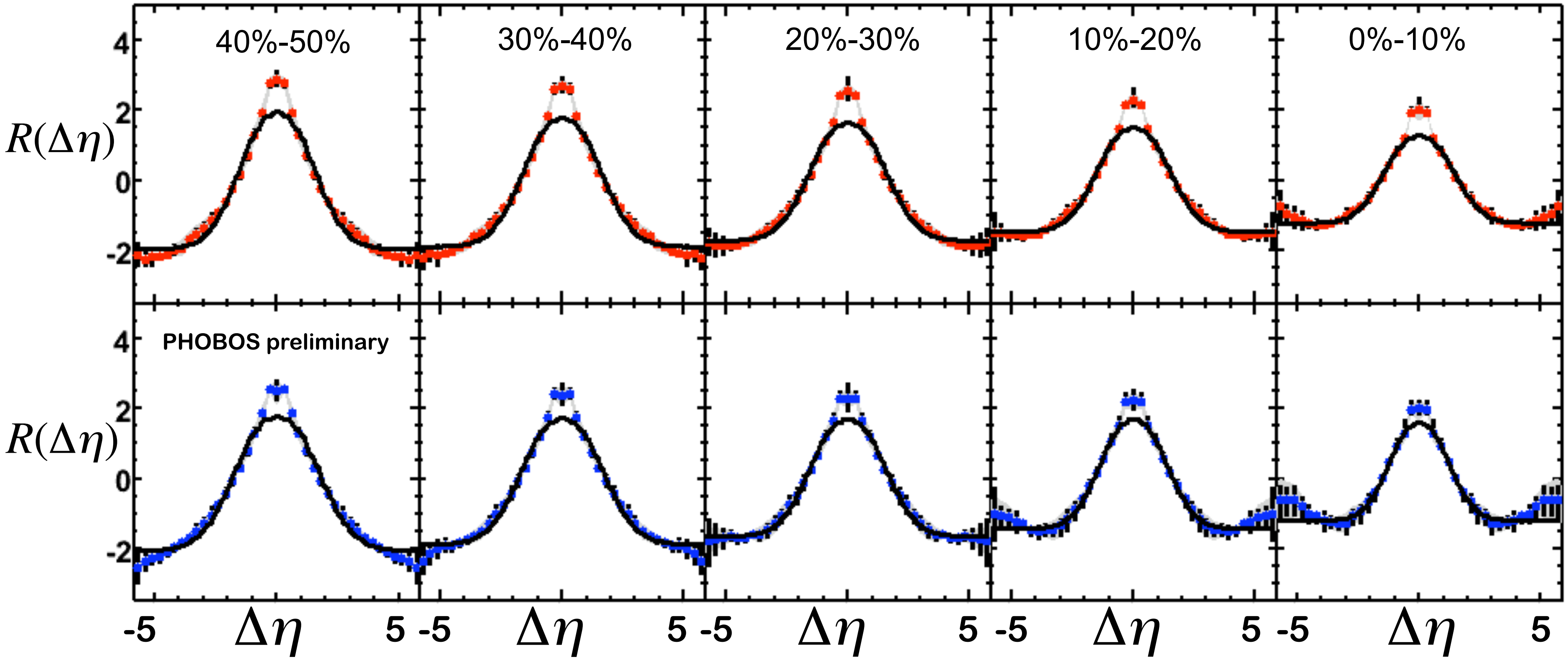


v_2 component: $<2(n-1)v_2^2>$

Extracting Cluster Parameters

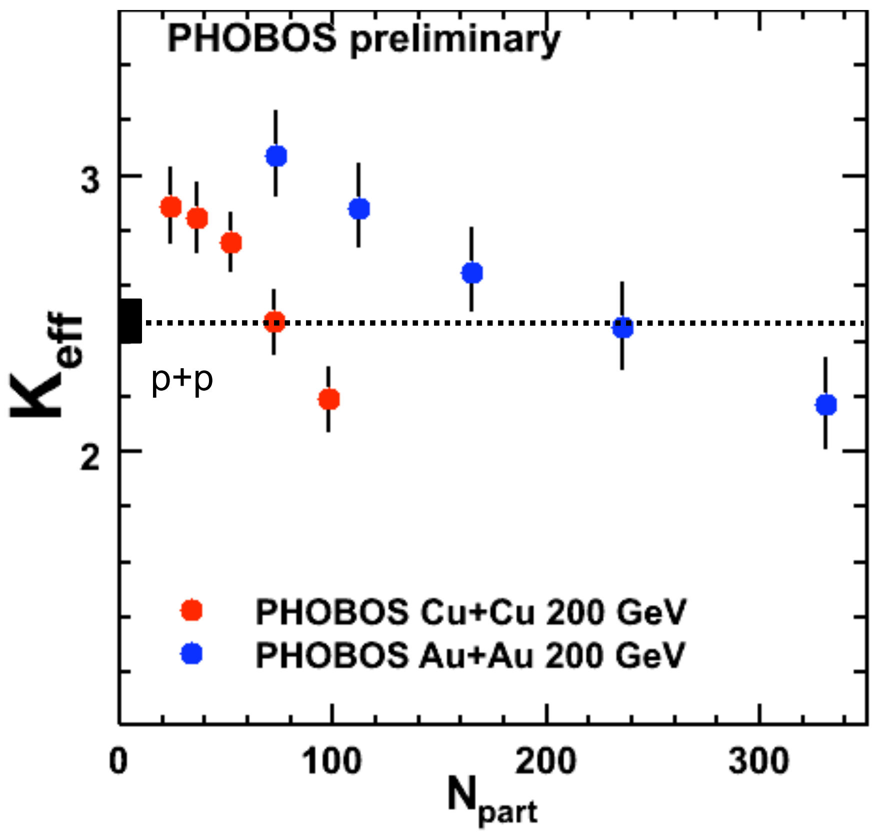
Extracting cluster parameters from
two-particle Δη correlation function
(scale errors are shown as grey bands)

• Cu+Cu@200GeV
• Au+Au@200GeV

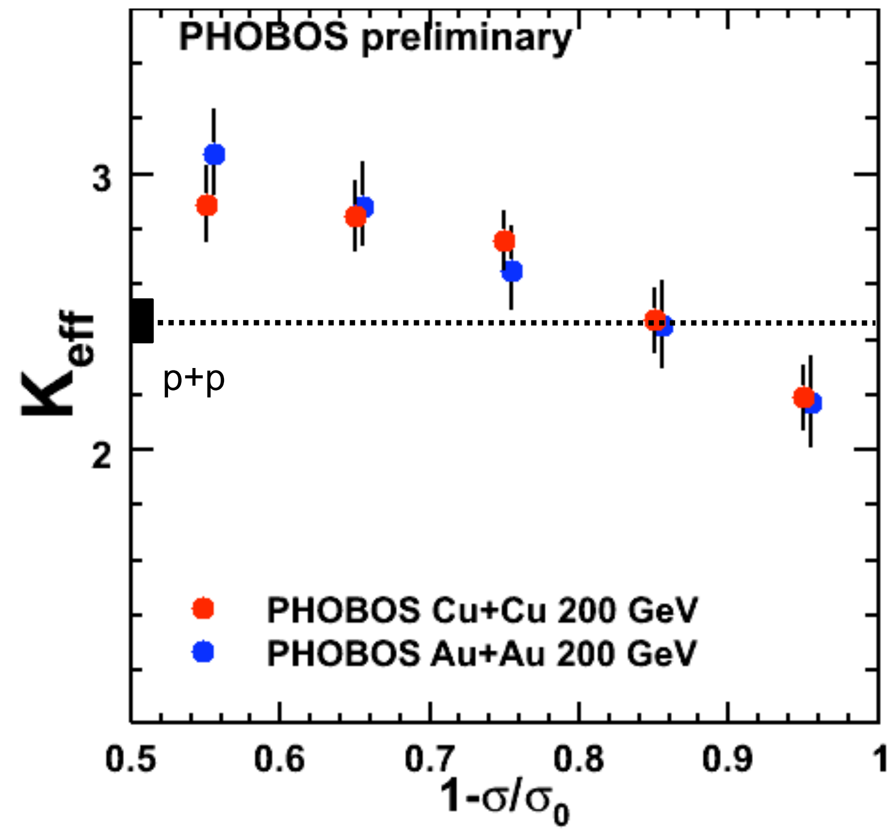


Comparing Cu+Cu to Au+Au

For the same N_{part}

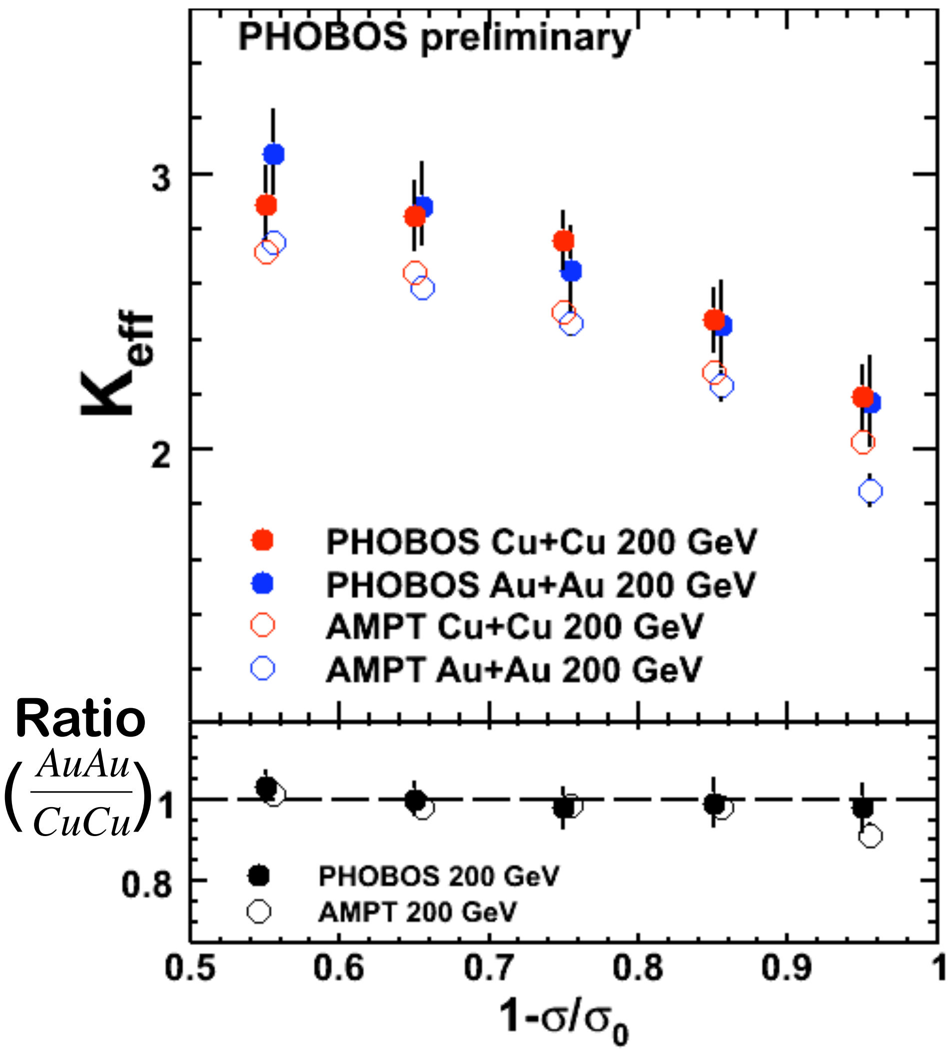


For the same fraction of inelastic cross-section



- Cluster size decreases with centrality in A+A
- Cluster size scales with geometry!

Centrality dependence of clusters



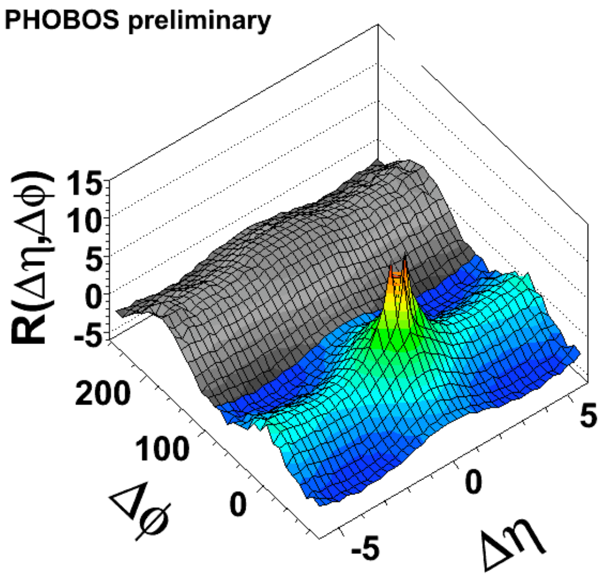
Model comparison:

- **Intriguingly, AMPT shows similar geometry scaling of cluster size.**
- **The decrease of cluster size with centrality in AMPT is related to hadronic re-scattering processes.**

Near- and away-side clusters

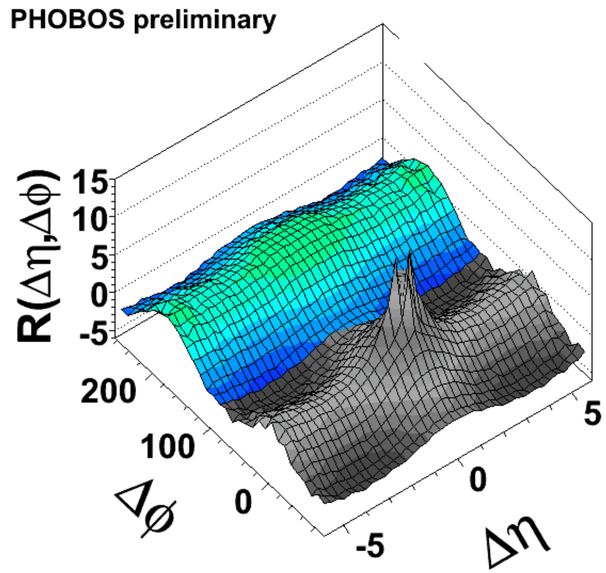
Study cluster properties differentially in $\Delta\phi$

Au+Au@200GeV, 0-10%



Near-side clusters:

- **$0^o < \Delta\phi < 90^o$**
- **higher p_T**

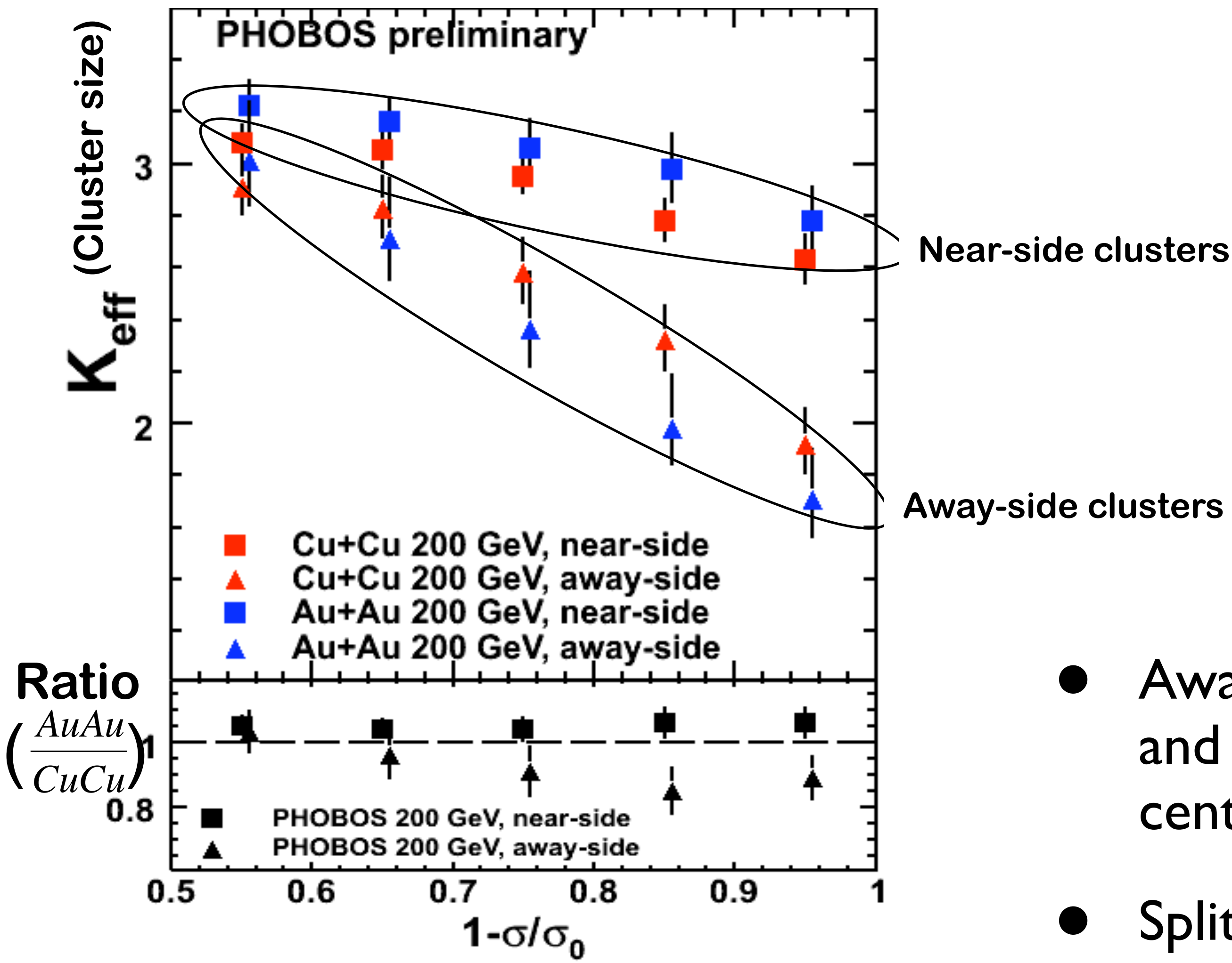


Away-side clusters:

- **$90^o < \Delta\phi < 180^o$**
- **lower p_T**

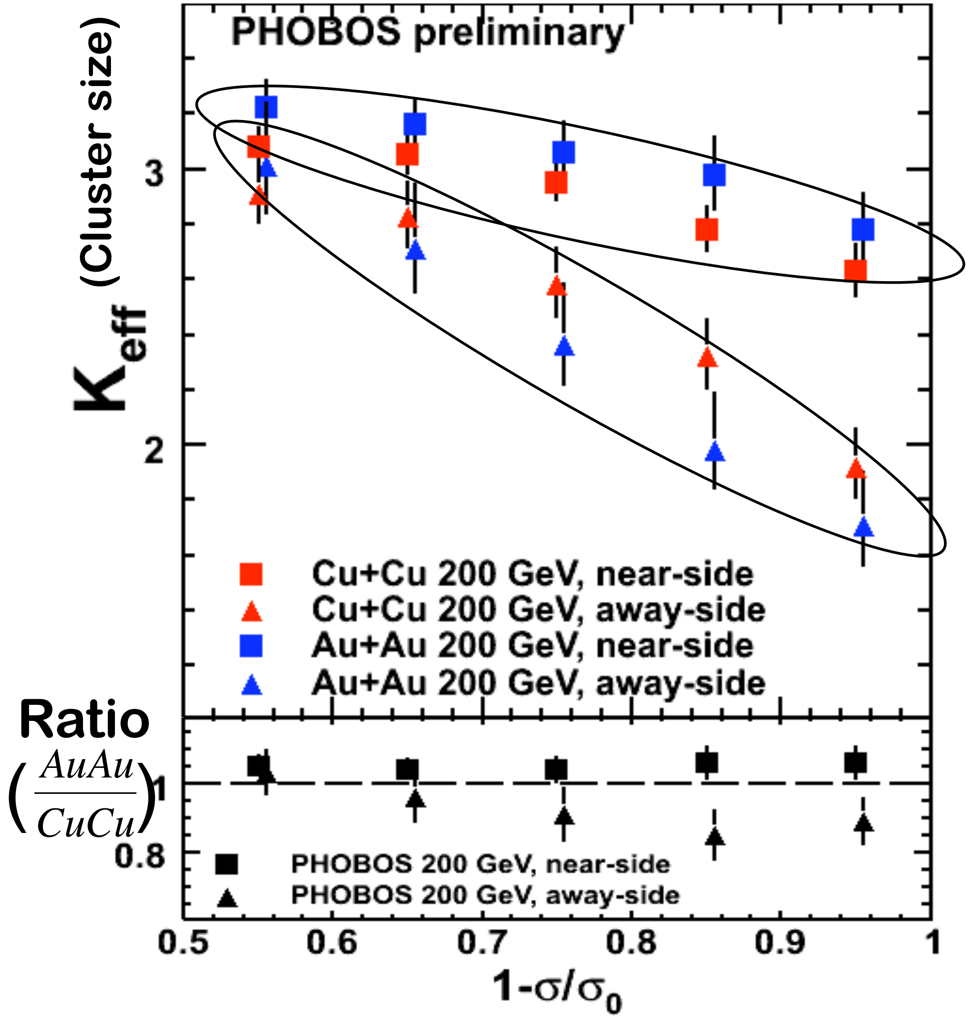
Elliptic flow is averaged out by construction.

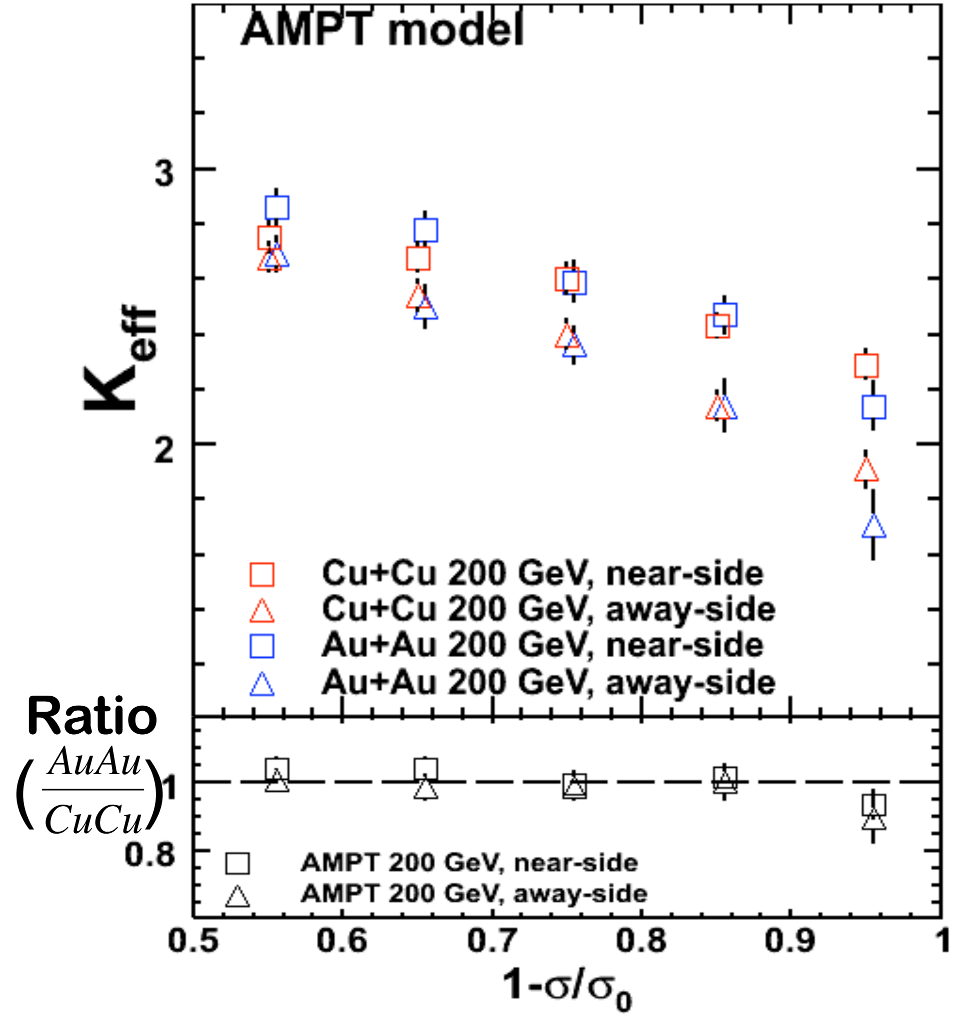
Near- and away-side clusters



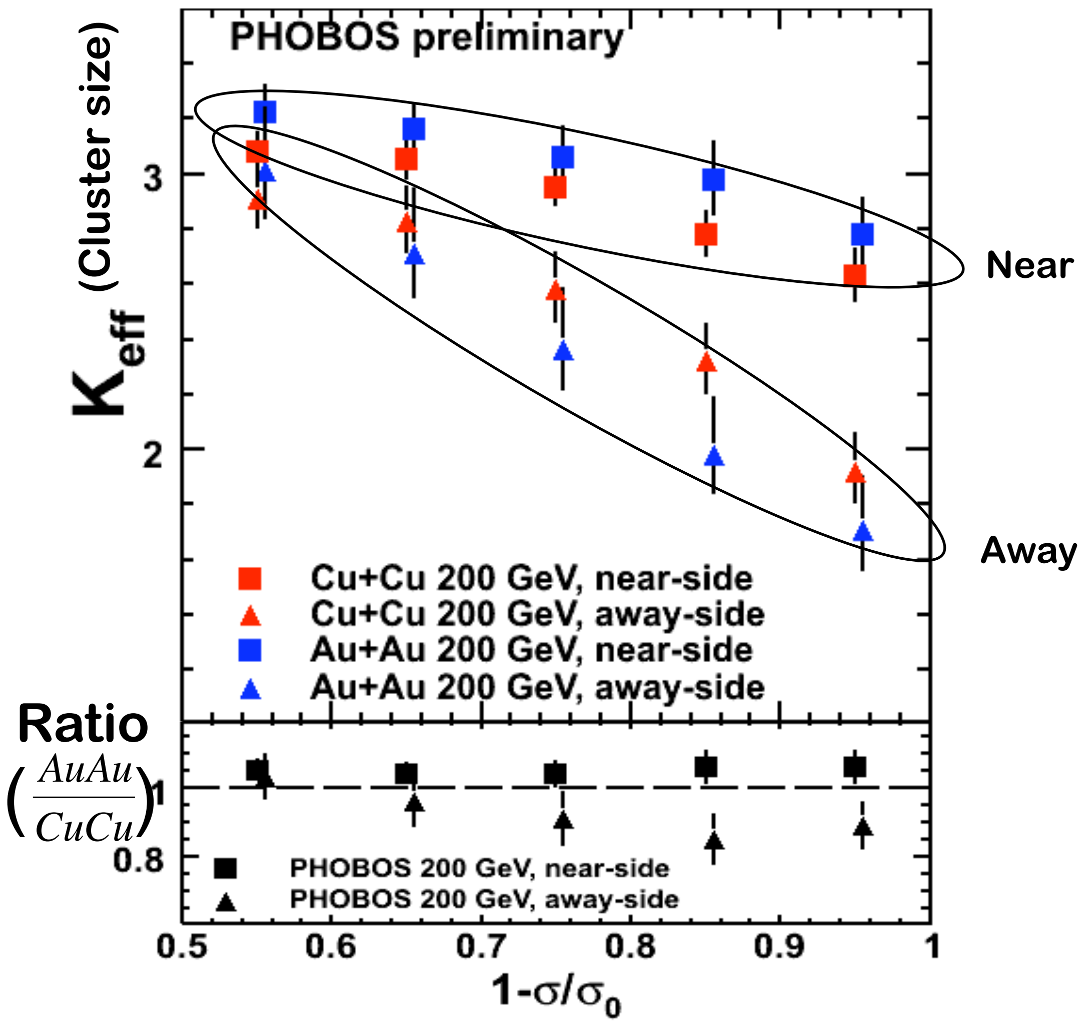
- Away-side clusters are smaller and depend more strongly on centrality than near-side ones
- Splitting between near- and away-side is more pronounced for Au+Au than Cu+Cu collisions

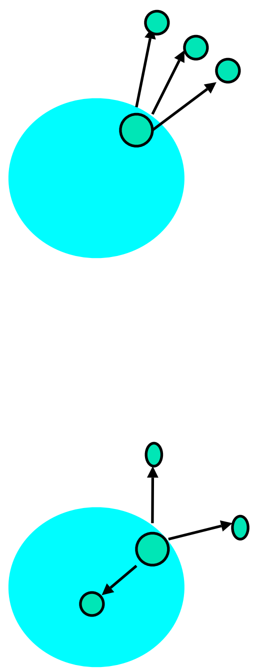
Near- and away-side clusters





Near- and away-side clusters





One possible explanation:

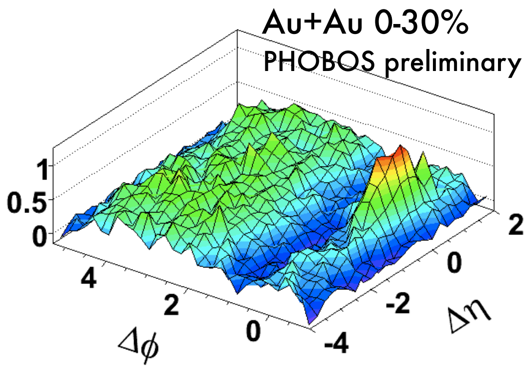
Absorption of cluster decay products?

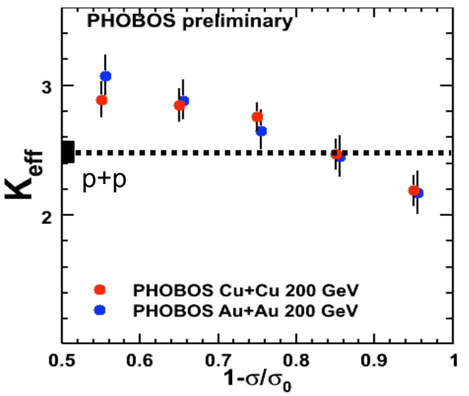
Summary

- 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 fraction of cross-section, not N_{part}
- Significant differences between near- and away-side clusters

Final Summary

- PHOBOS can measure correlations at large Δη
- 'Ridge' correlation extends over very large pseudorapidity range
- Hadrons are not produced independently but rather in 'clusters' whose properties scale with collision geometry

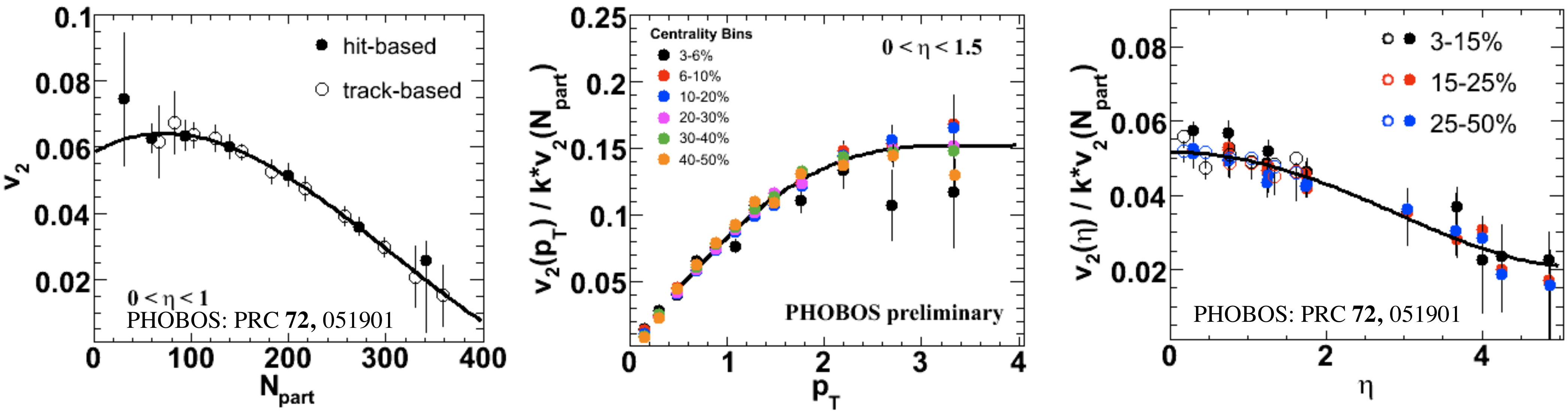




Backup Slides

Estimating the Flow Term

- Parameterize published PHOBOS measurements as $v_2(N_{part}, p_T, \eta) = A(N_{part})\, B(p_T)\, C(\eta)$



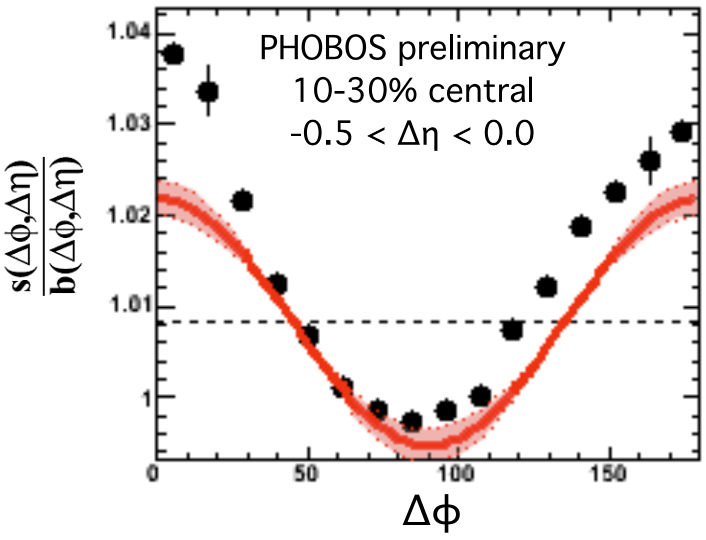
- Correct $v_2(N_{part}, \langle p_T^{trig} \rangle, \eta_{trig})$ for occupancy and $v_2(N_{part}, \langle p_T^{assoc} \rangle, \eta_{assoc})$ for secondaries

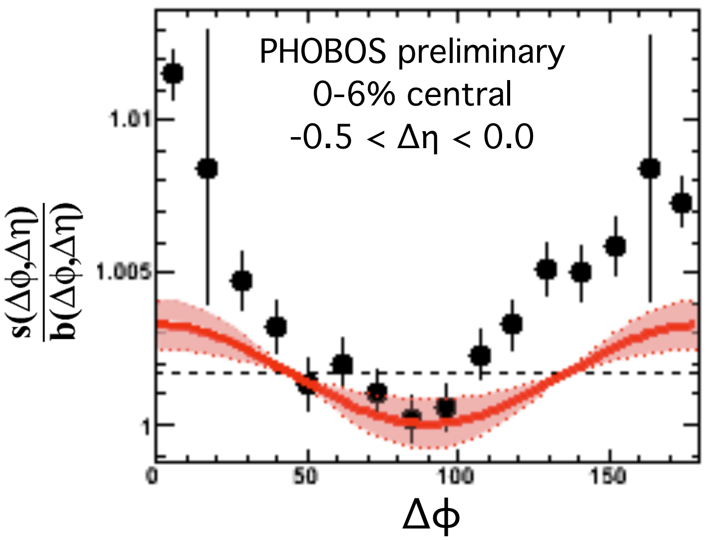
$$1 + 2V(\Delta\eta)\cos(2\Delta\phi)$$

$$V = \langle v_2^{trig} \rangle \langle v_2^{assoc} \rangle$$

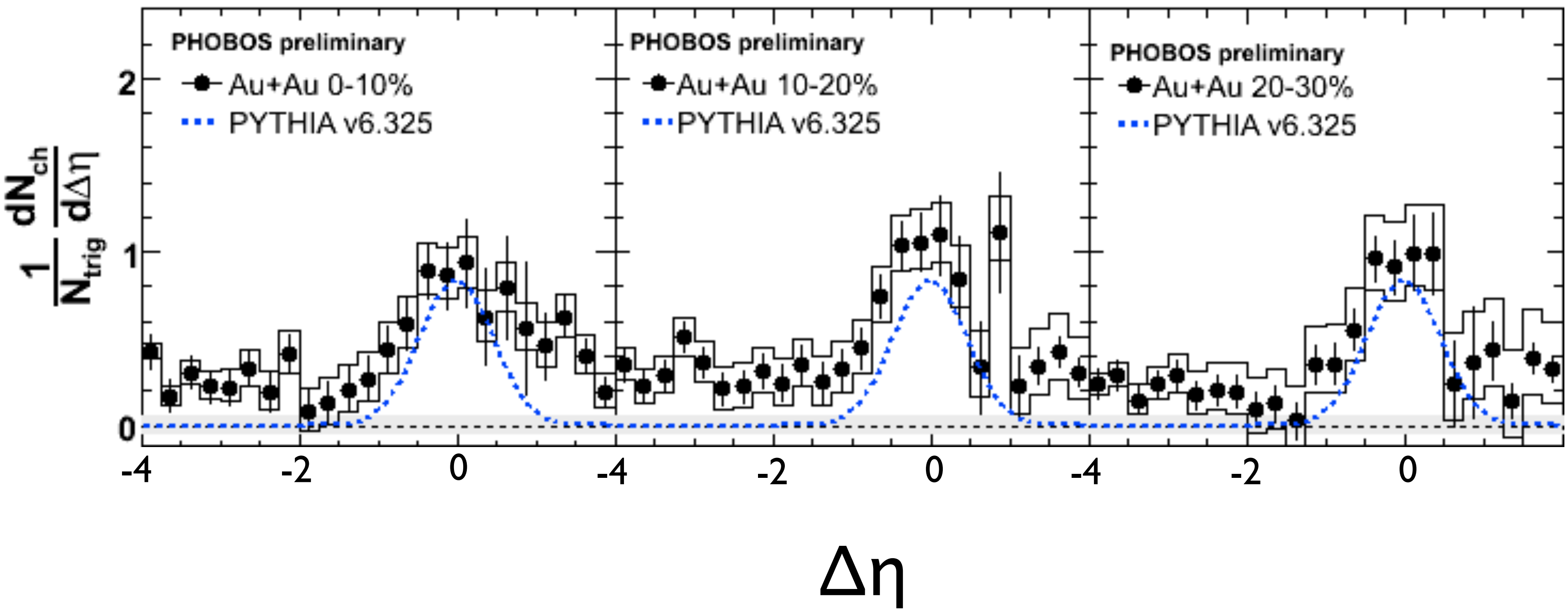
v2 Subtraction Systematics

- The dominant systematic error in this analysis is the uncertainty on the magnitude of $v_2^{trig} v_2^{assoc}$
  - ~14% error on $v_2^{trig} v_2^{assoc}$ (η=0)
  - ~20% error on $v_2^{trig} v_2^{assoc}$ (η=3)
  - In the most central collision -- where flow is small compared to the correlation -- the error on $v_2^{trig} v_2^{assoc}$ can exceed 50%.



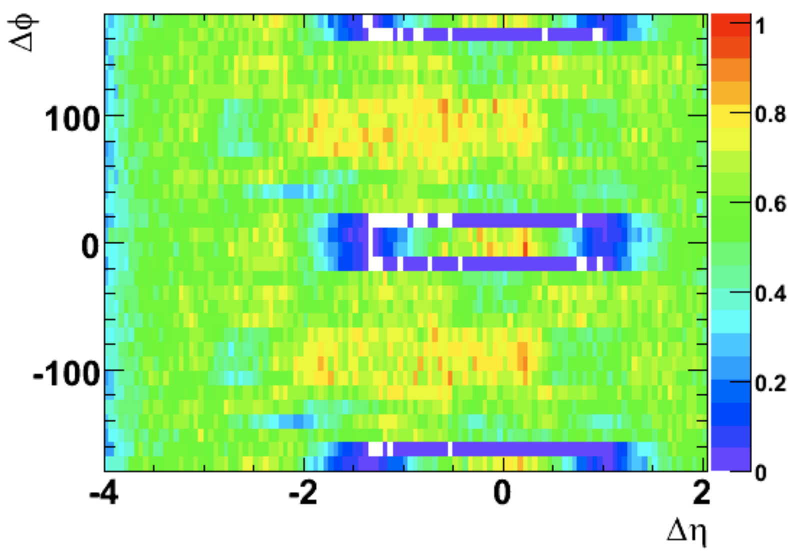


More centrality bins



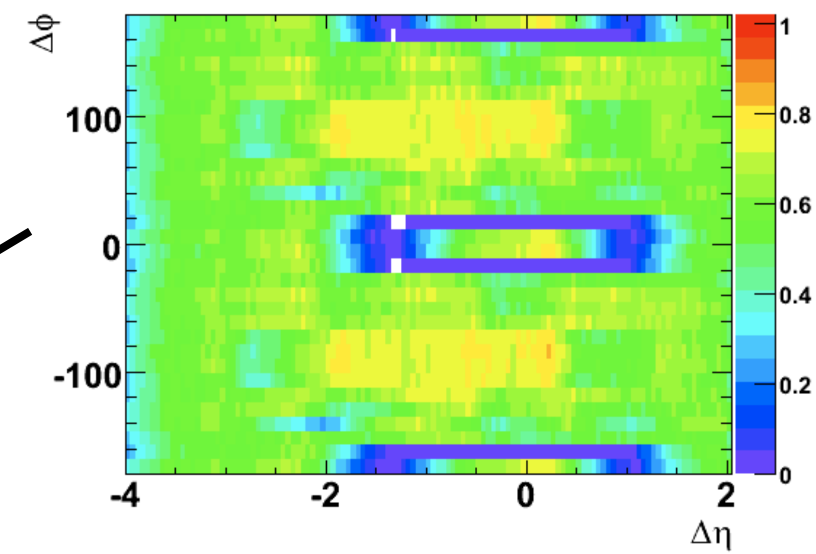
Pair acceptance

$s(\Delta\phi,\Delta\eta)$

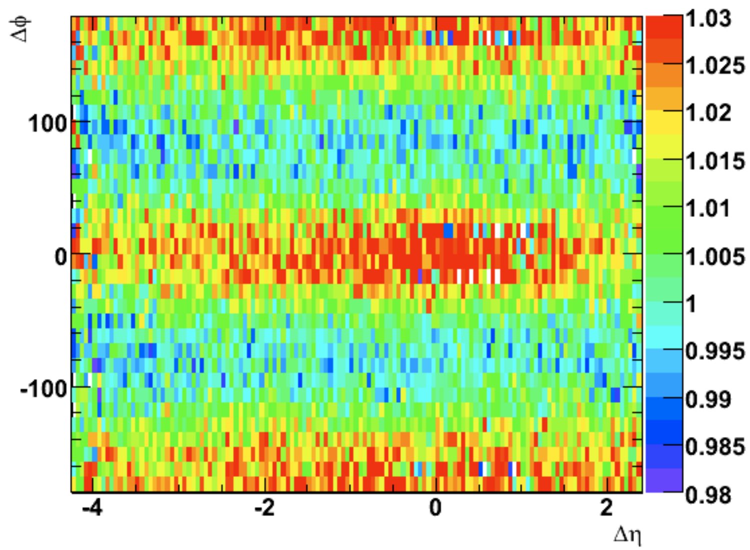


15-20% central
3mm < v_z < 4mm

$b(\Delta\phi,\Delta\eta)$

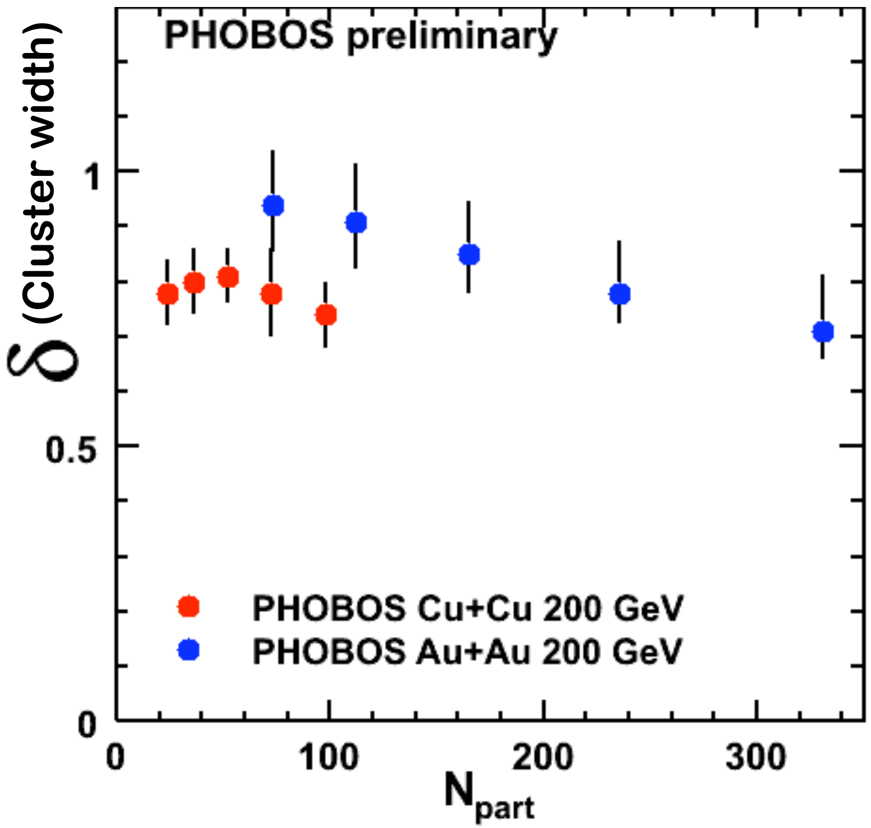


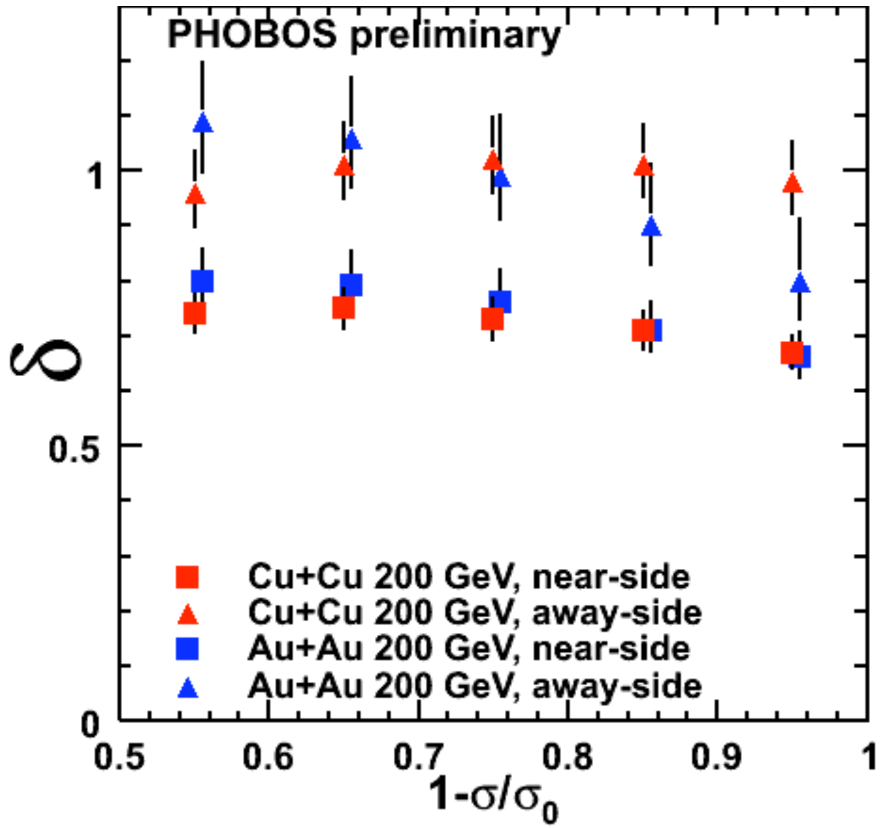
$$\frac{s(\Delta\phi,\Delta\eta)}{b(\Delta\phi,\Delta\eta)}$$



averaged over
-15cm < v_z < 10cm

Cluster Width





Methodology

Two-particle correlation function:

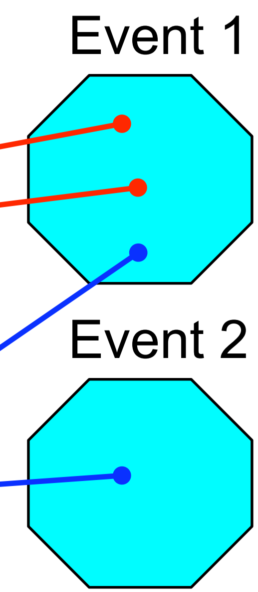
$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left(\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle$$

Foreground:

$$F_n(\Delta\eta,\Delta\phi) \sim \rho_n^{II}(\eta_1,\eta_2,\phi_1,\phi_2) = \frac{1}{n(n-1)\sigma_n}\frac{d^4\sigma_n}{d\eta_1 d\eta_2 d\phi_1 d\phi_2}$$

Background:

$$B_n(\Delta\eta,\Delta\phi) \sim \rho_n^{I}(\eta_1,\phi_1)\rho_n^{I}(\eta_2,\phi_2) = \frac{1}{n\sigma_n}\frac{d^2\sigma_n}{d\eta_1 d\phi_1} \bullet \frac{1}{n\sigma_n}\frac{d^2\sigma_n}{d\eta_2 d\phi_2}$$



Cluster Model Details

correlations between particles from one cluster

Two-particle rapidity correlation function:

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

Decay width: δ

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

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

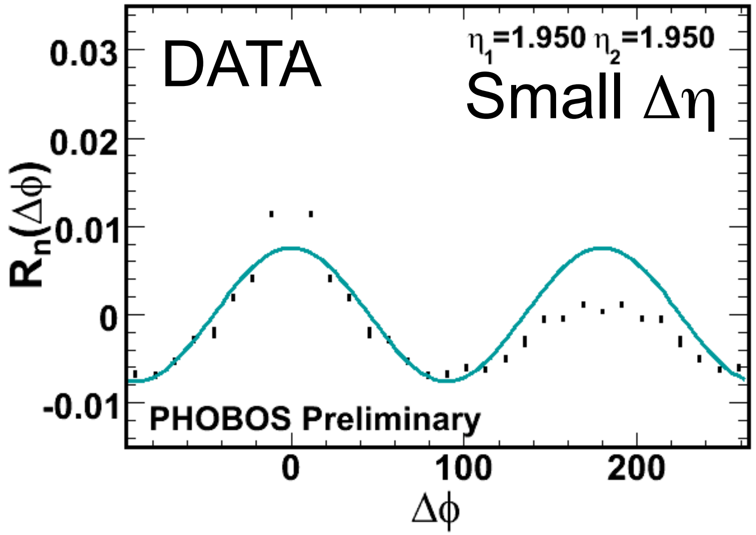
k: cluster size

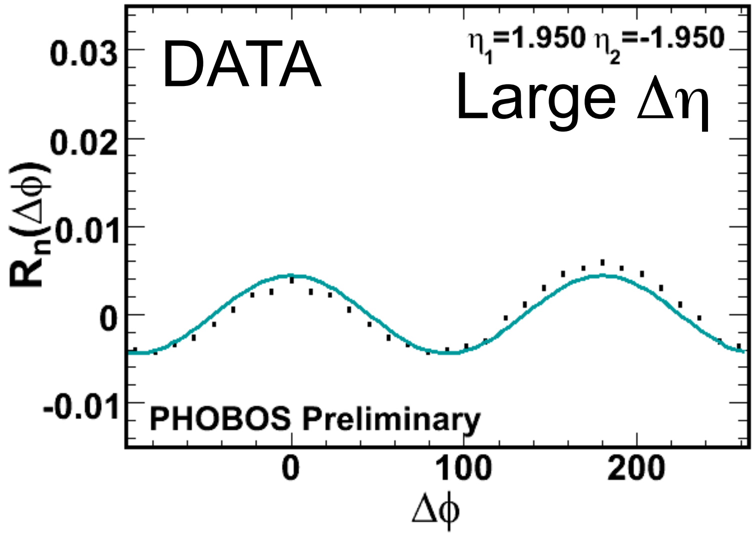
$$K_{eff} = \alpha + 1 = \frac{<k(k-1)>}{<k>} + 1 = <k> + \frac{\sigma_k^2}{<k>}$$

K_{eff} : effective cluster size

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

Separating flow and non-flow

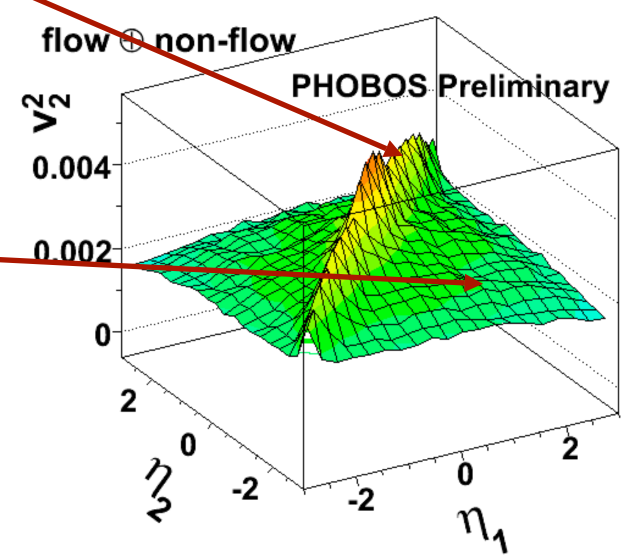




$$R_n(\Delta\varphi) = 2v_2^2\cos(2\Delta\varphi)$$

In general:

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



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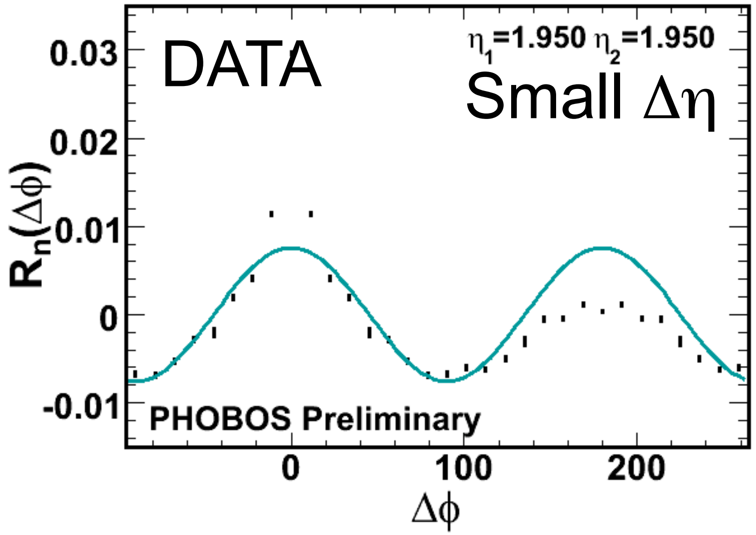

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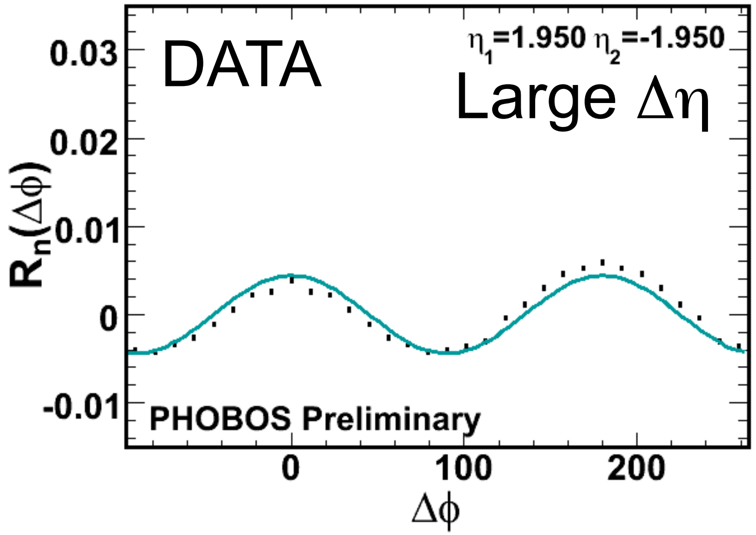

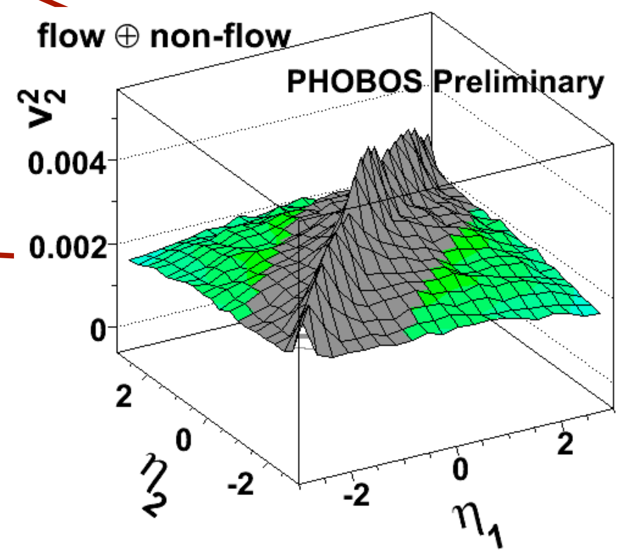

Estimating δ for large $\Delta\eta$

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