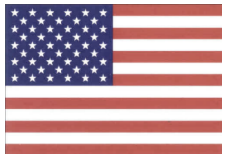
Long-range correlations in PHOBOS

Wei Li
(davidlw@mit.edu)
Massachusetts Institute of Technology
For the PHOBOS collaboration

Workshop on
Saturation, the Color Glass Condensate and Glasma, BNL
May 11th, 2010

PHOBOS Collaboration

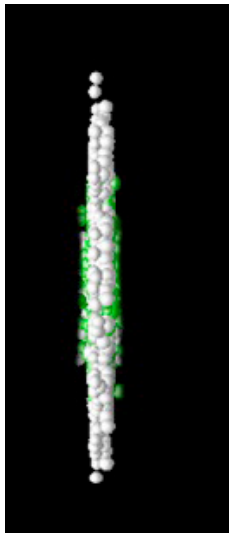


Burak Alver, Birger Back, Mark Baker, Maarten Ballintijn, Donald Barton, Russell Betts, Richard Bindel, Wit Busza (Spokesperson), Vasundhara Chetluru, Edmundo García, Tomasz Gburek, Joshua Hamblen, Conor Henderson, David Hofman, Richard Hollis, Roman Hołyński, Burt Holzman, Aneta Iordanova, Chia Ming 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

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

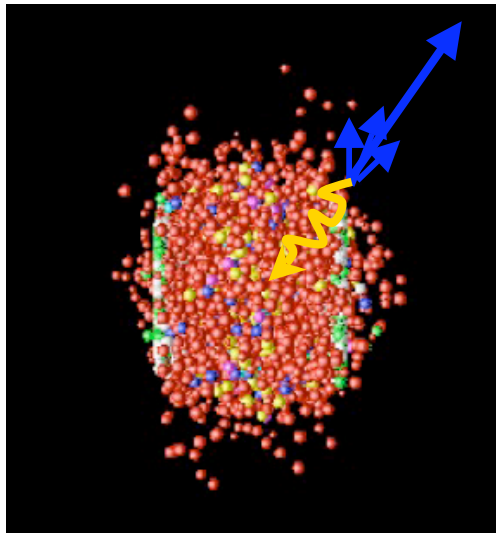
Overview

Initial state



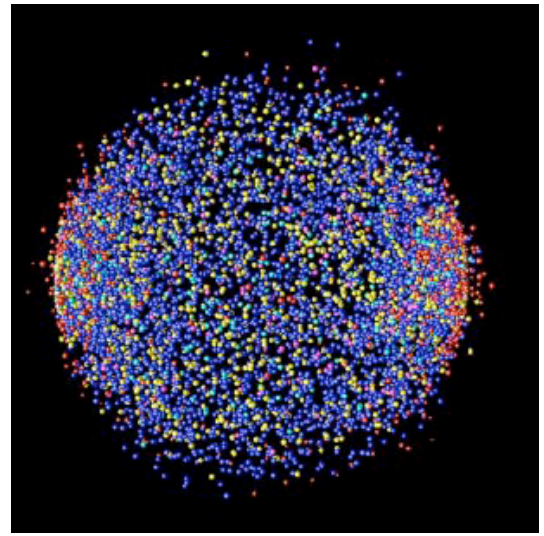
Elliptic flow

Hydrodynamic evolution



Jet-medium interactions

Hadronization



Hadronization via clusters

Studies of long-range correlations at PHOBOS probe different stages of the system evolution!

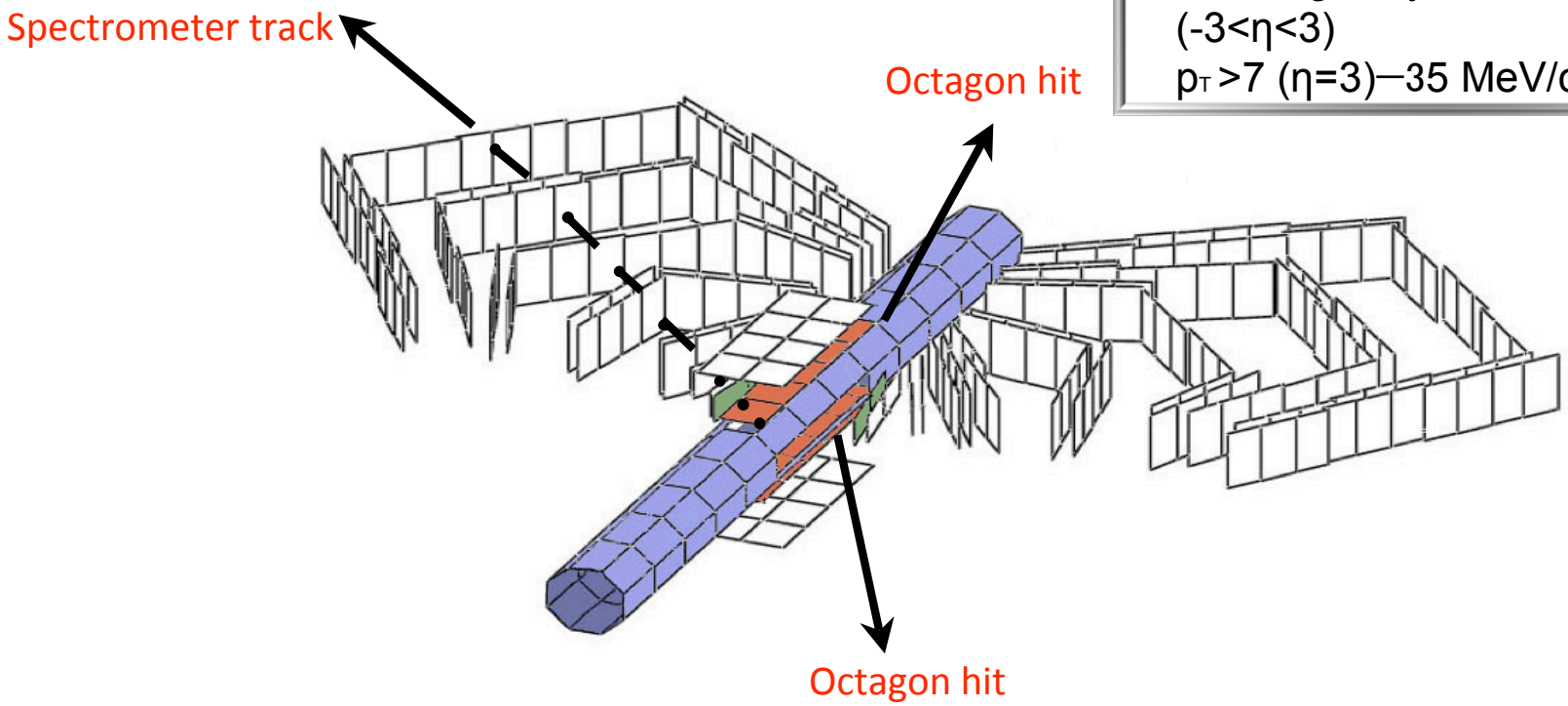
Correlation measurements at PHOBOS

Inclusive Correlations

- Pairs with all particles detected in a single layer of silicon ($-3<\eta<3$)
  pT >7 (η=3)—35 MeV/c (η=0)

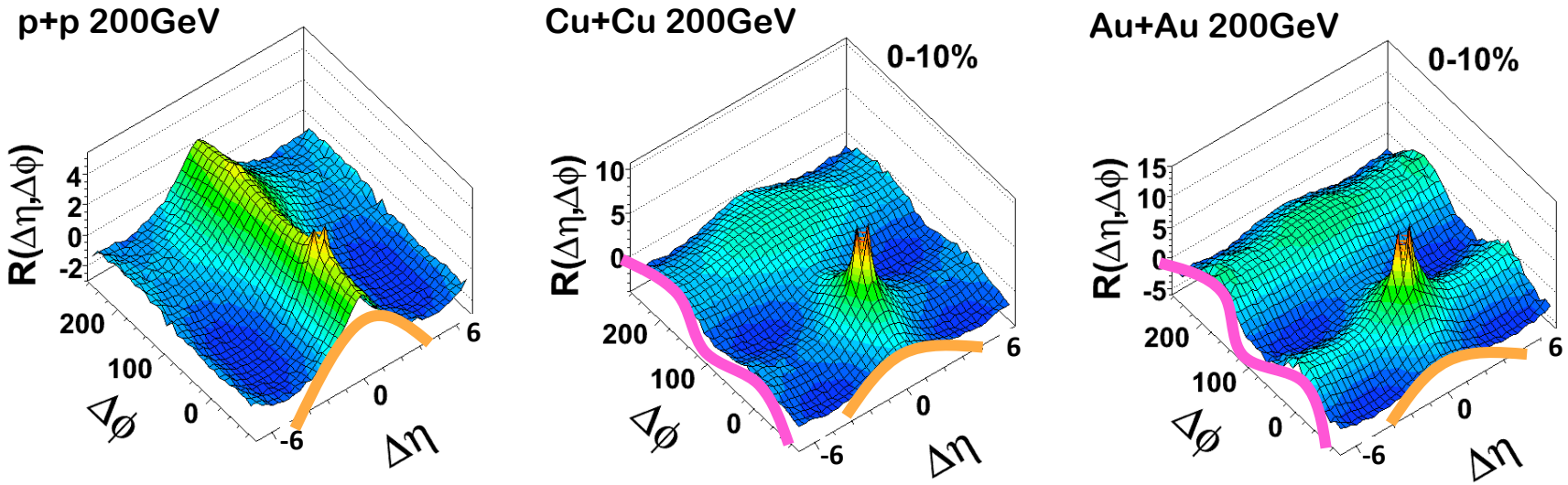
Triggered Correlations

- "Trigger" particles detected in the Spectrometer ($0<\eta<1.5$)
- Associated particles detected in a single layer of silicon ($-3<\eta<3$)
  p_T >7 (η=3)—35 MeV/c (η=0)



Inclusive two-particle correlations

PHOBOS



Phys. Rev. C75(2007)054913

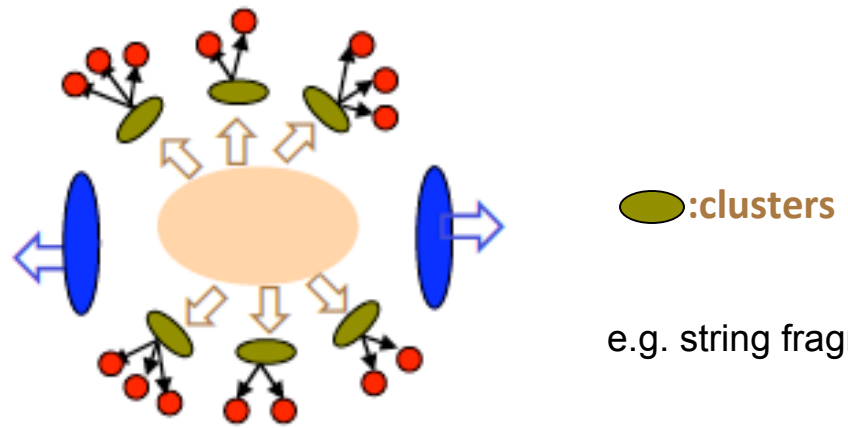
Phys. Rev. C81(2010)024904

$$R(\Delta\eta,\Delta\varphi) = < (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right) >_{evt}$$

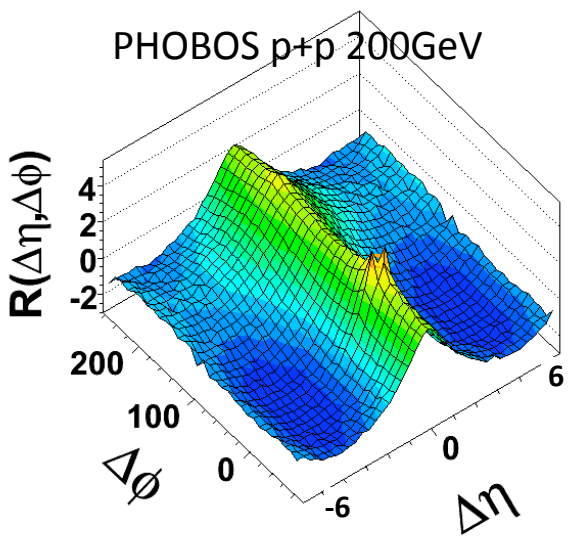
Similar structure in p+p, Cu+Cu and Au+Au collisions, in A+A collisions a clear trace of elliptic flow is visible

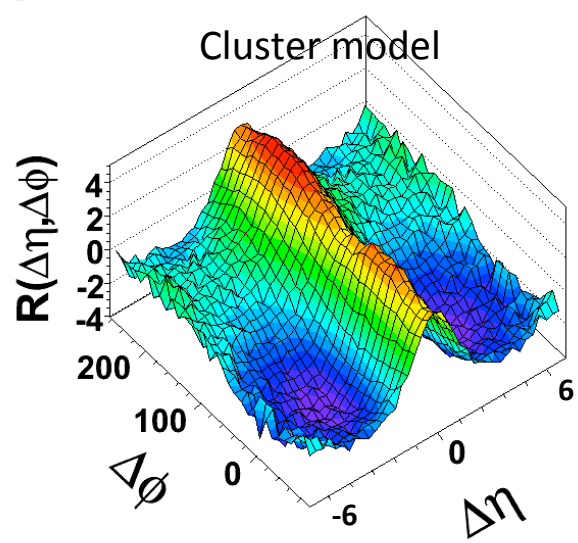
Clusters and two-particle rapidity correlations

Independent cluster emissions:



e.g. string fragmentations





Phys. Rev. C75(2007)054913

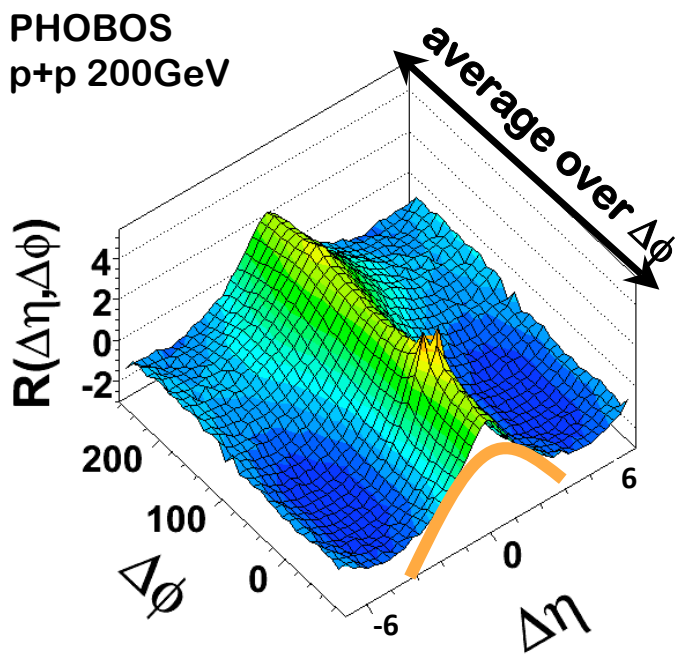
Quantify cluster properties

Cluster model:

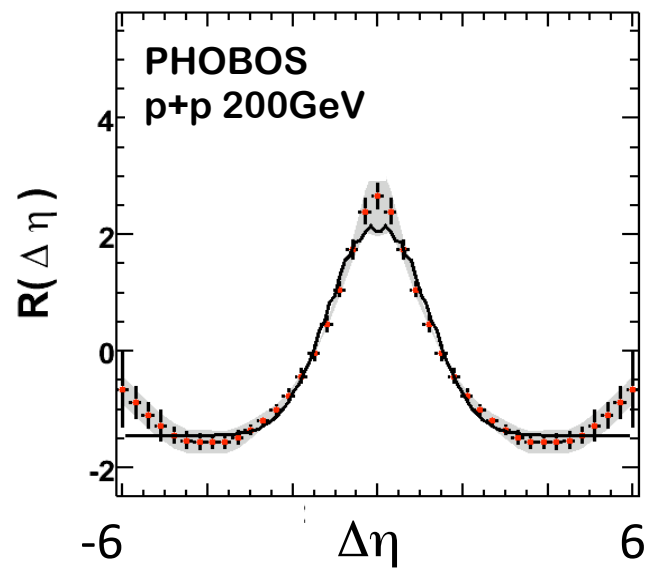
$$R(\Delta\eta) = (K_{eff} - 1)\left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right] \qquad \Gamma(\Delta\eta) \propto \exp\left(-\frac{(\Delta\eta)^2}{4\delta^2}\right)$$

Effective Cluster Size

Cluster Width



In A+A, the contribution from elliptic flow is averaged out

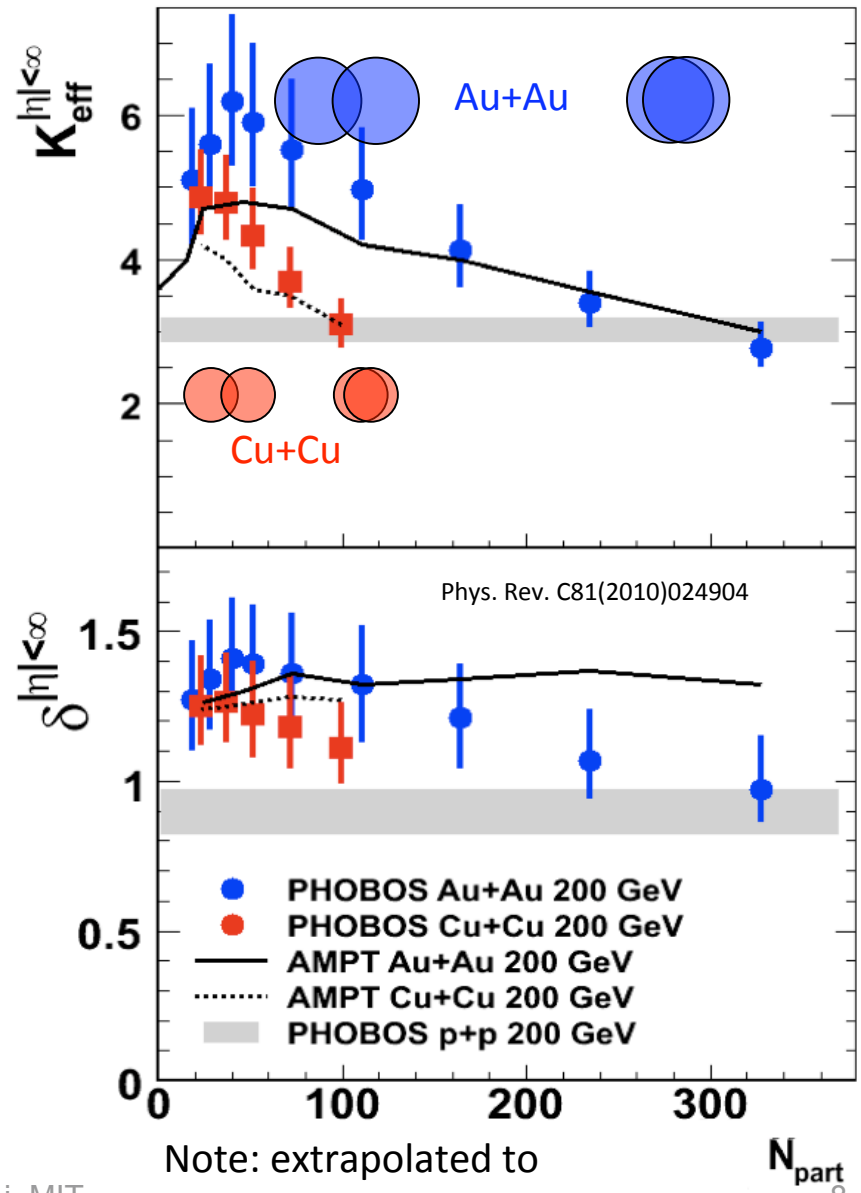


Phys. Rev. C75(2007)054913

Clusters in HI collisions

- Cluster size is large:
  (up to 6 charged particles
  – much more than predicted
  from known resonances)

- Cluster width exceeds that
  for isotropic decay at rest (~0.9)

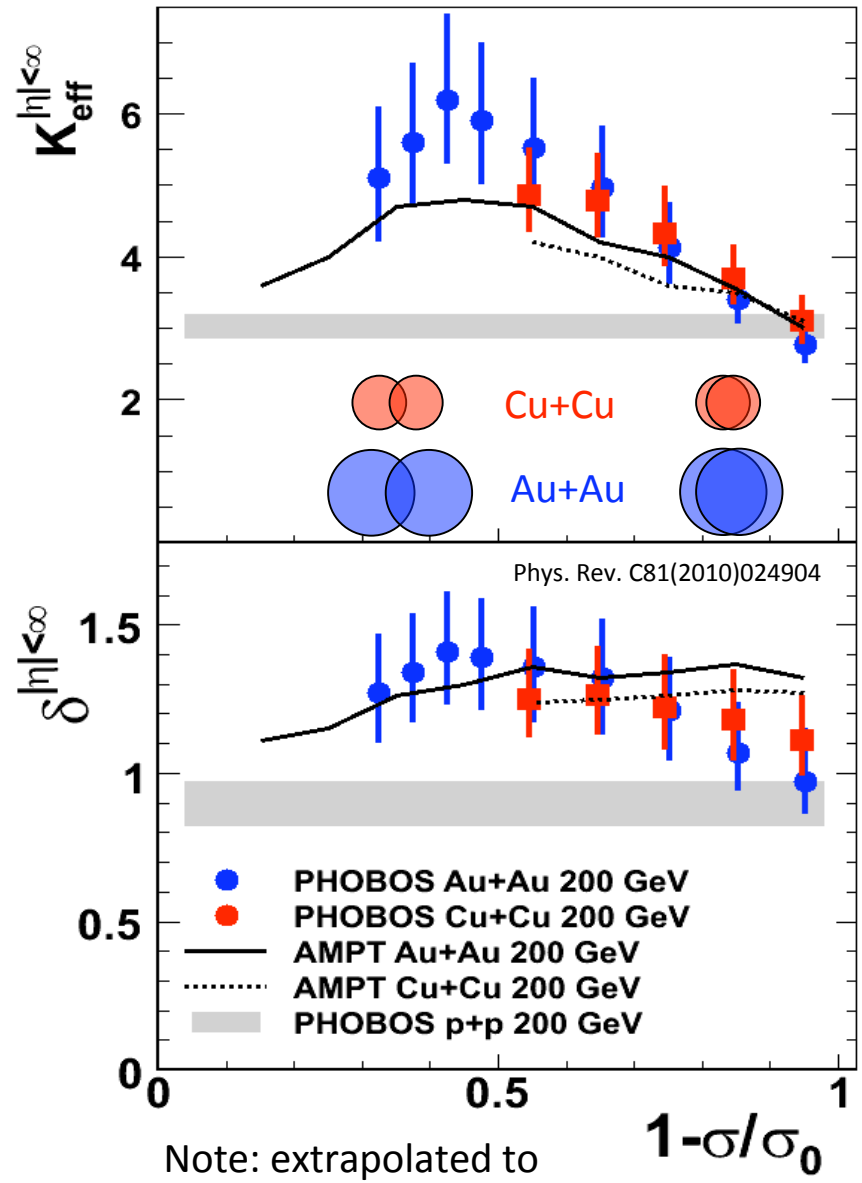


Note: extrapolated to
full phase space

Clusters in HI collisions

- Cluster size is large: (up to 6 charged particles – much more than predicted from known resonances)
- Cluster width exceeds that for isotropic decay at rest (~0.9)
- Cluster size and width very similar at the same centrality, defined as the same fraction of cross section.

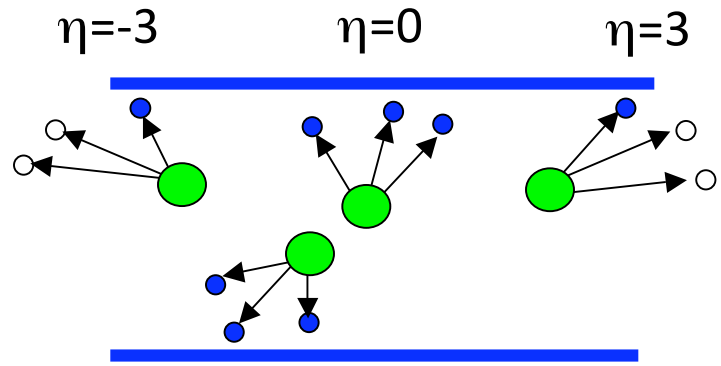
The geometry of the interaction area determines the properties of hadronization?



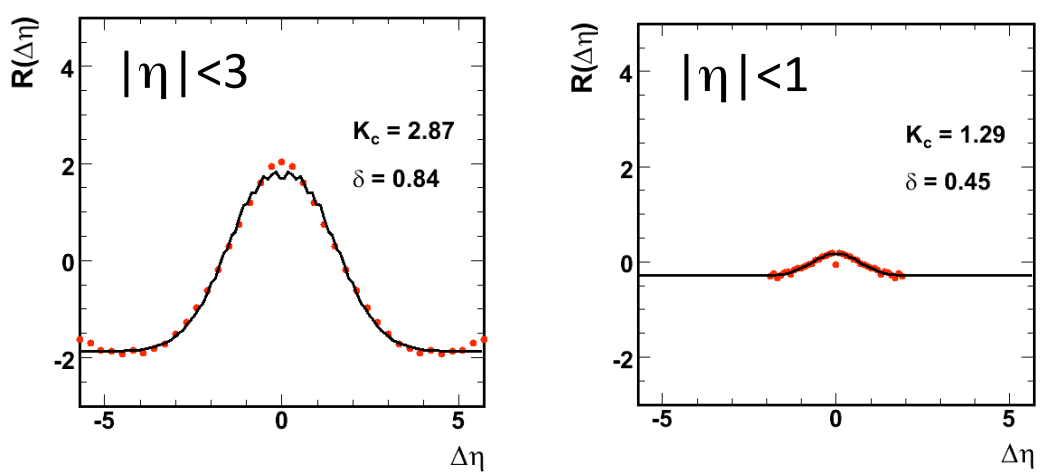
Note: extrapolated to full phase space

Acceptance effects

Clusters are partially lost at the edge of the acceptance



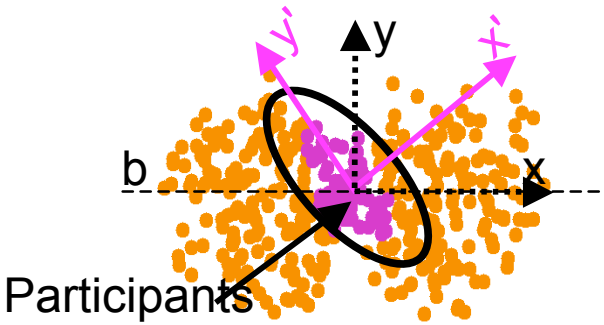
Same cluster model inputs (K=4)



Large phase space coverage is important!

Initial state fluctuation

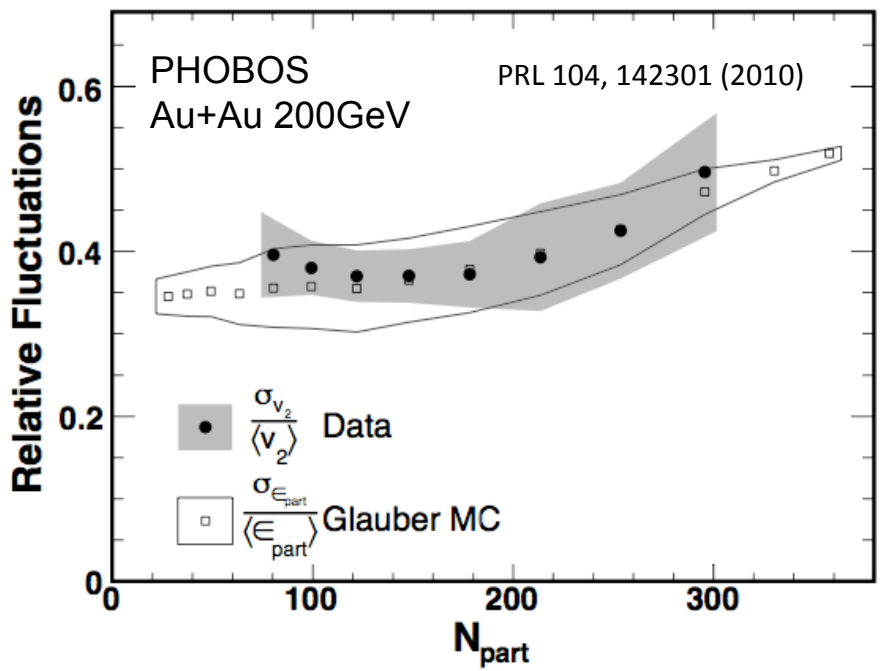
Participant Eccentricity



Phys. Rev. C77, 014906 (2008)

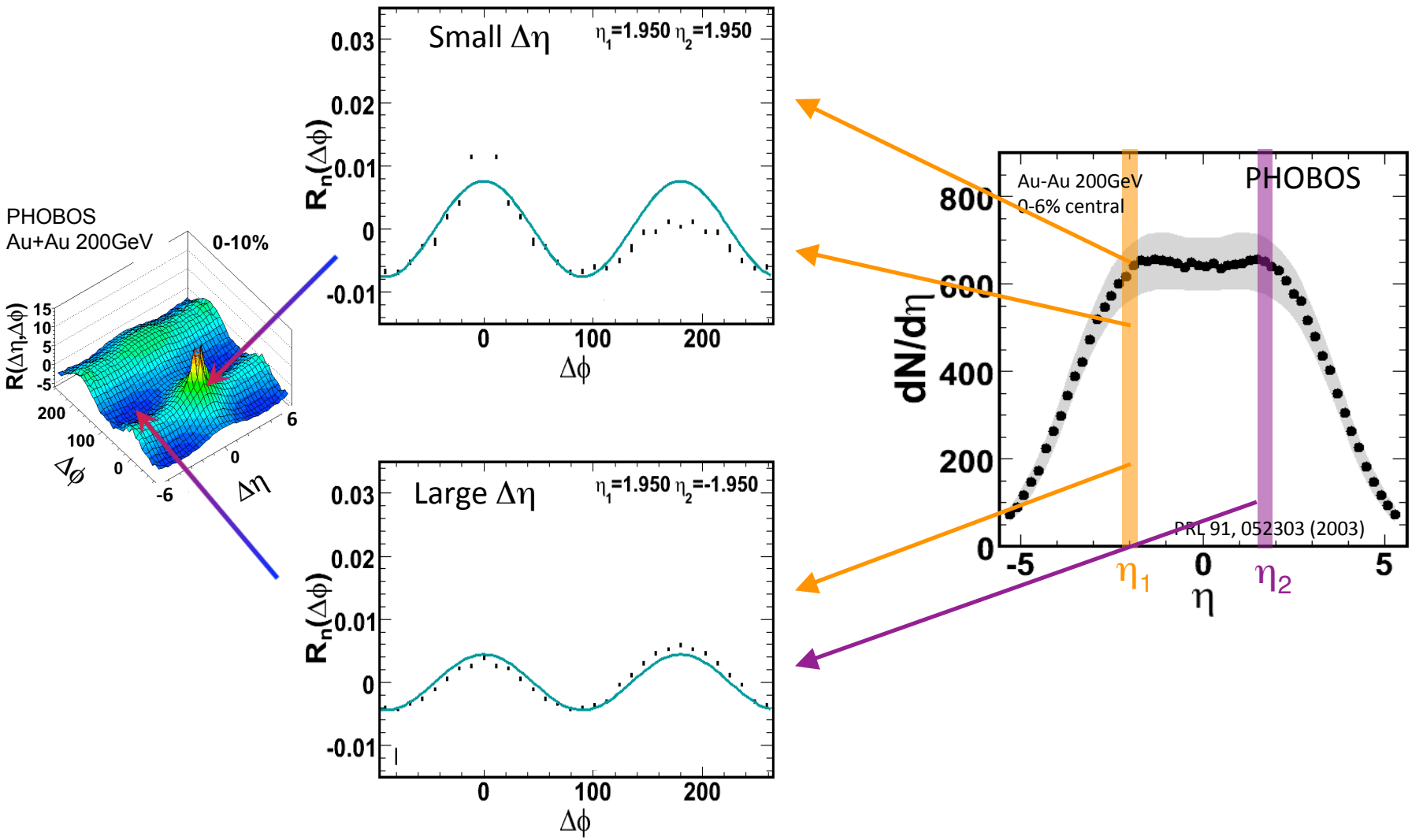
$$\langle \epsilon_{\rm part} \rangle = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{(\sigma_y^2 + \sigma_x^2)}$$

Elliptic flow fluctuation



Non-flow correlations not corrected

Short and long range correlations

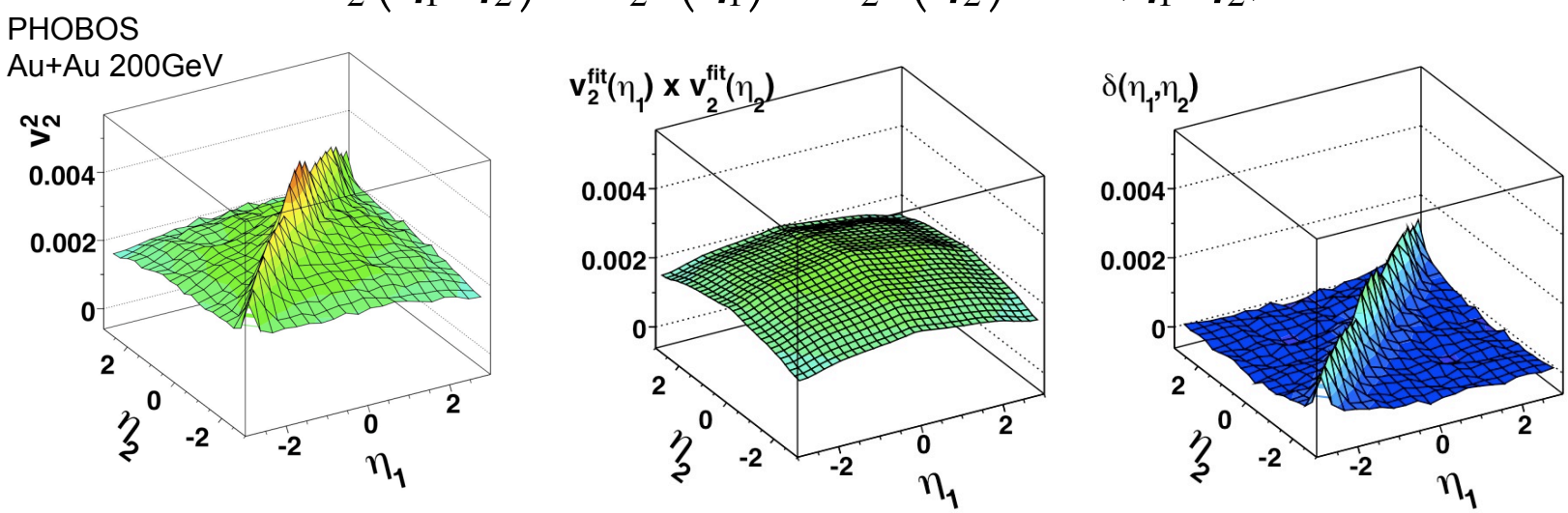


Separate non-flow correlations

- Flow is long range in η, correlating all particle via impact parameter b
- Non-flow is dominated by short-range correlations (small $\Delta\eta$)

Study $v_2^2(\eta_1,\eta_2) \equiv < \cos(2\Delta\phi) > (\eta_1,\eta_2)$

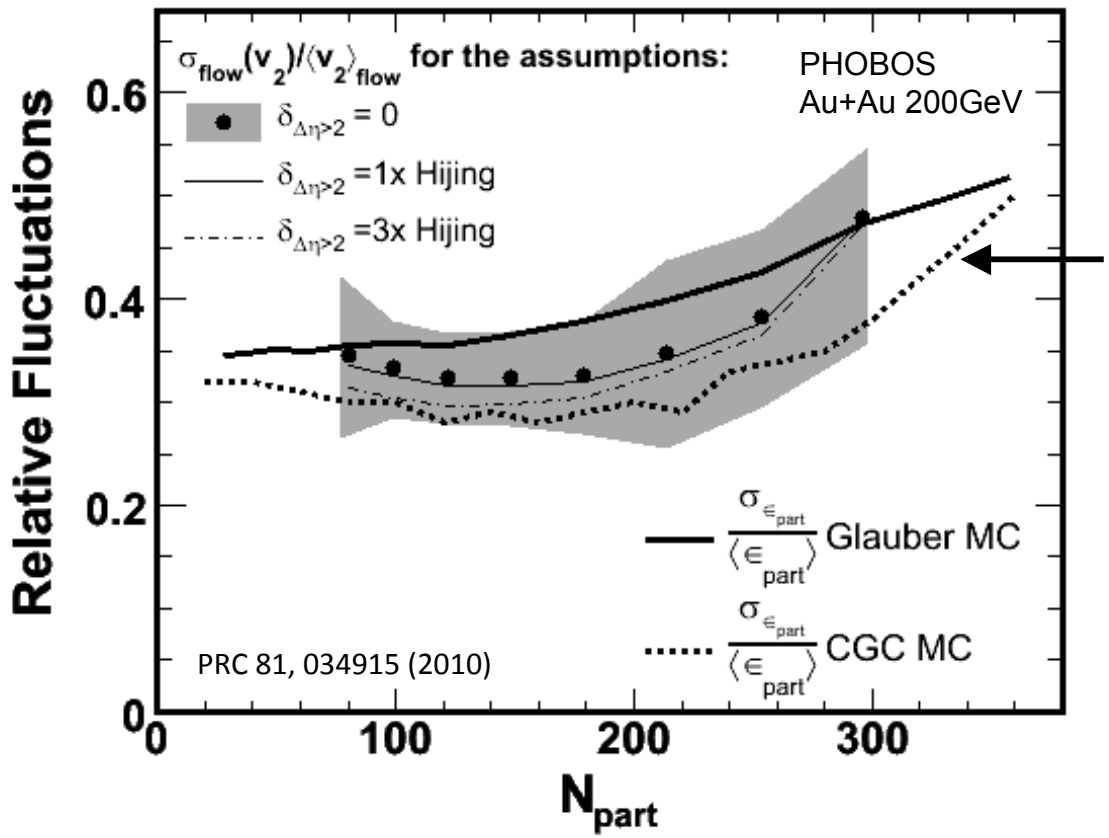
$$v_2^2(\eta_1,\eta_2) - v_2^{fit}(\eta_1) \times v_2^{fit}(\eta_2) = \delta(\eta_1,\eta_2)$$



flow⊕non-flow flow non-flow

PRC 81, 034915 (2010)

Corrected Flow Fluctuation Result



CGC-MC (fKLN)
Drescher, Nara,
PRC 76 (2007) 41903

Better constraint on the initial state fluctuation after taking out short-range non-flow effects

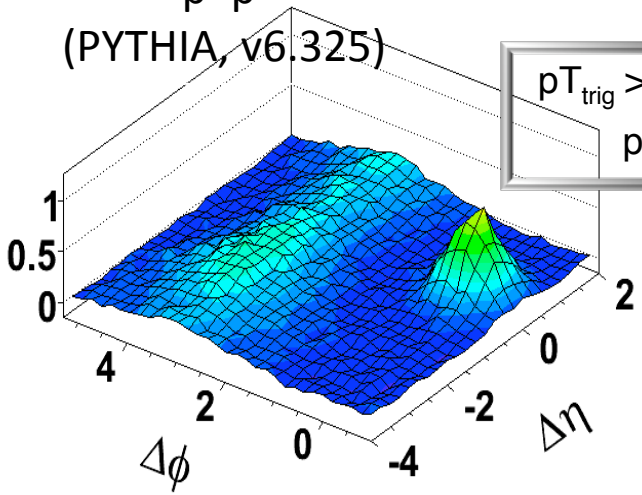
High p_T triggered correlations

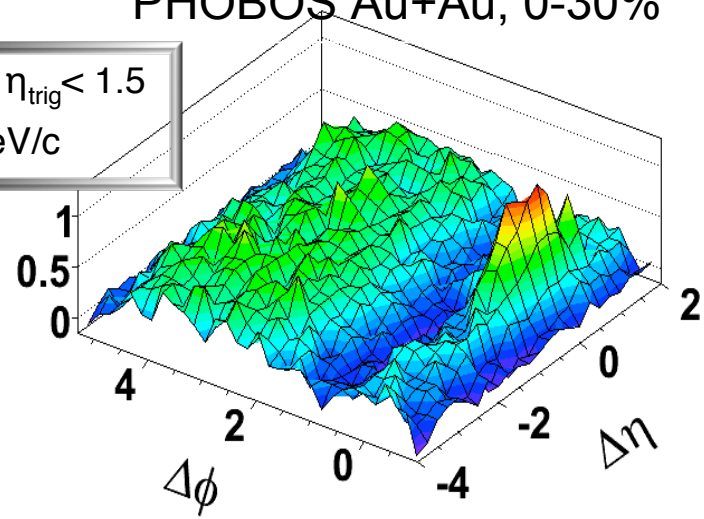
$$\frac{1}{N_{trig}} \cdot \frac{d^2 N_{ch}}{d\Delta\phi\, d\Delta\eta}$$

p+p
(PYTHIA, v6.325)

$pT_{trig} > 2.5$ GeV/c, $0 < \eta_{trig} < 1.5$
$pT_{assoc} > 4$-35 MeV/c

PHOBOS Au+Au, 0-30%





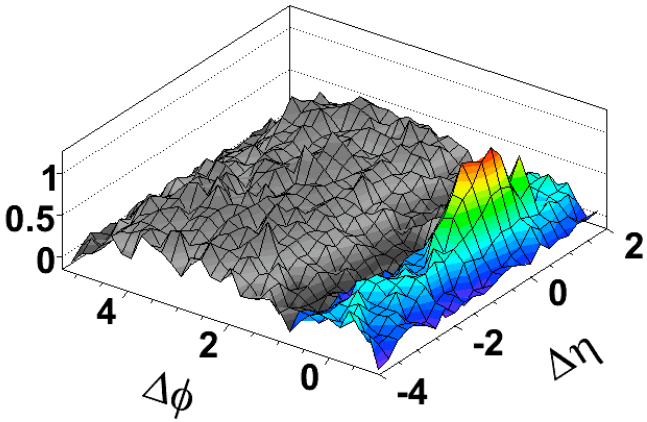
Note: PYTHIA agrees with STAR at midrapidity for a similar set of p_T cuts

PRL 104, 062301 (2010)

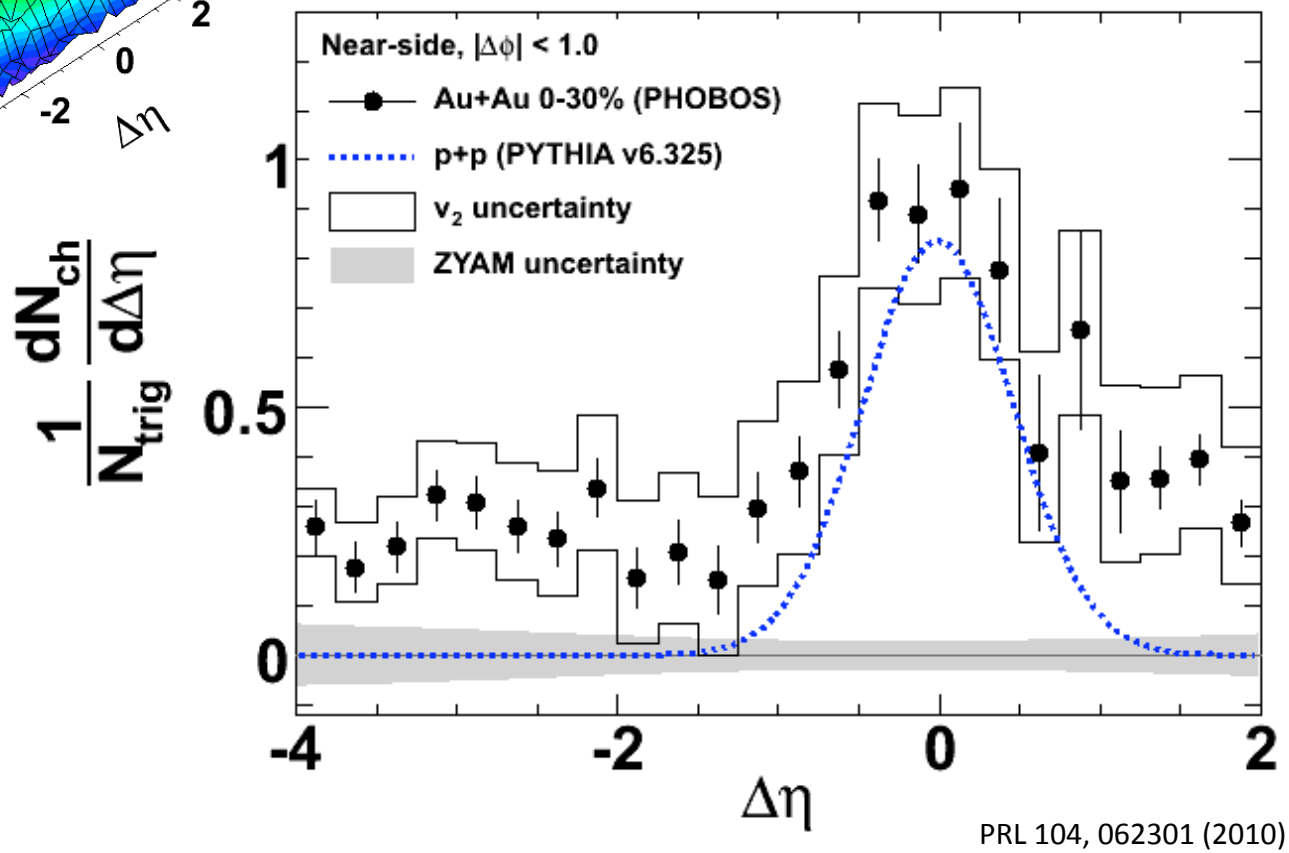
$$\frac{1}{N_{trig}} \cdot \frac{d^2 N_{ch}}{d\Delta\phi\, d\Delta\eta} = B(\Delta\eta)\left\{\frac{s(\Delta\phi,\Delta\eta)}{b(\Delta\phi,\Delta\eta)} - a(\Delta\eta)\left[1 + 2V_2(\Delta\eta)\cos(2\Delta\phi)\right]\right\}$$

Normalization | Raw | Scale factor | Elliptic flow

Near-side "Ridge": extent in $\Delta\eta$

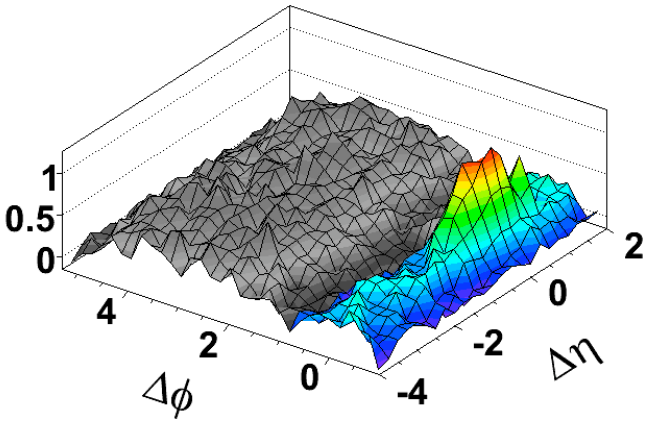


Near-side correlation for $|\Delta\phi|<1$

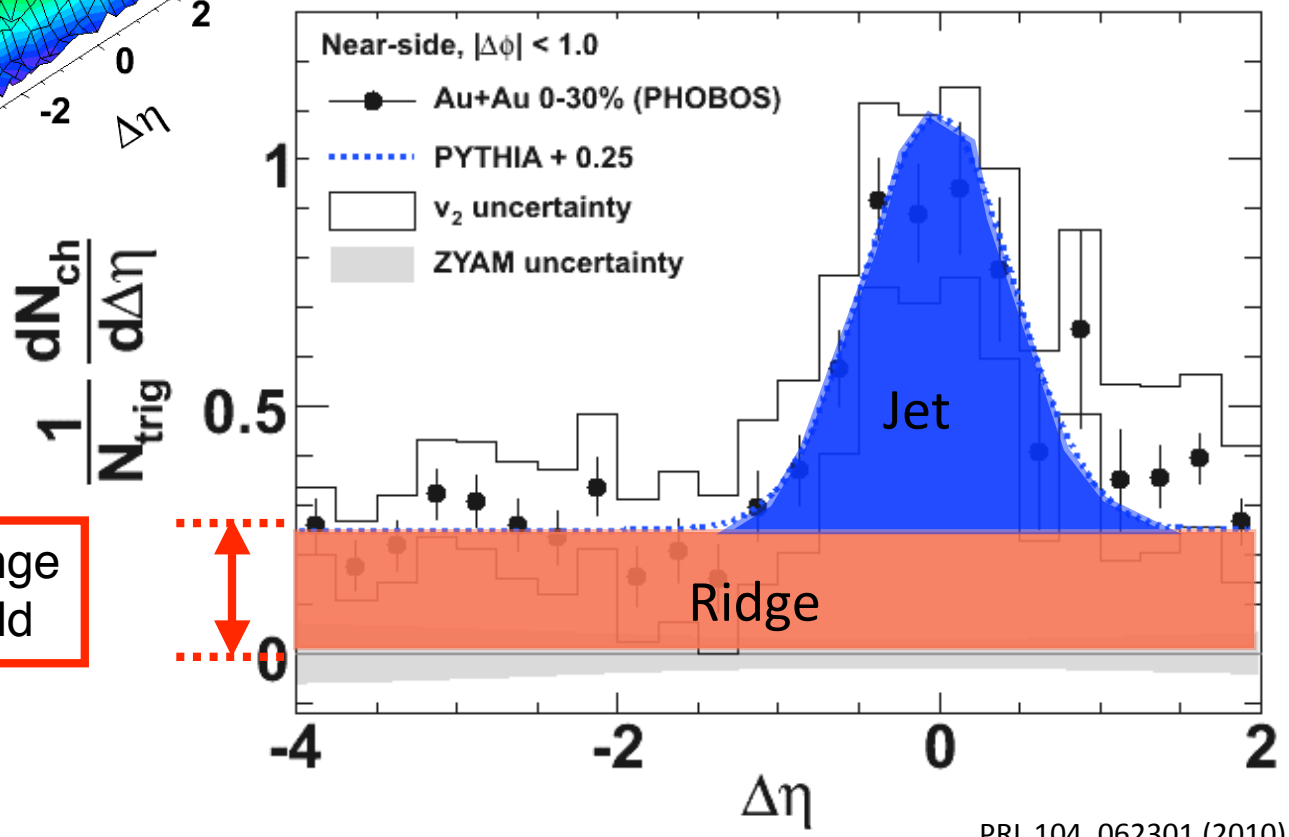


PRL 104, 062301 (2010)

Near-side "Ridge": extent in $\Delta\eta$



Near-side correlation for $|\Delta\phi|<1$

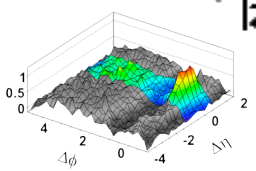


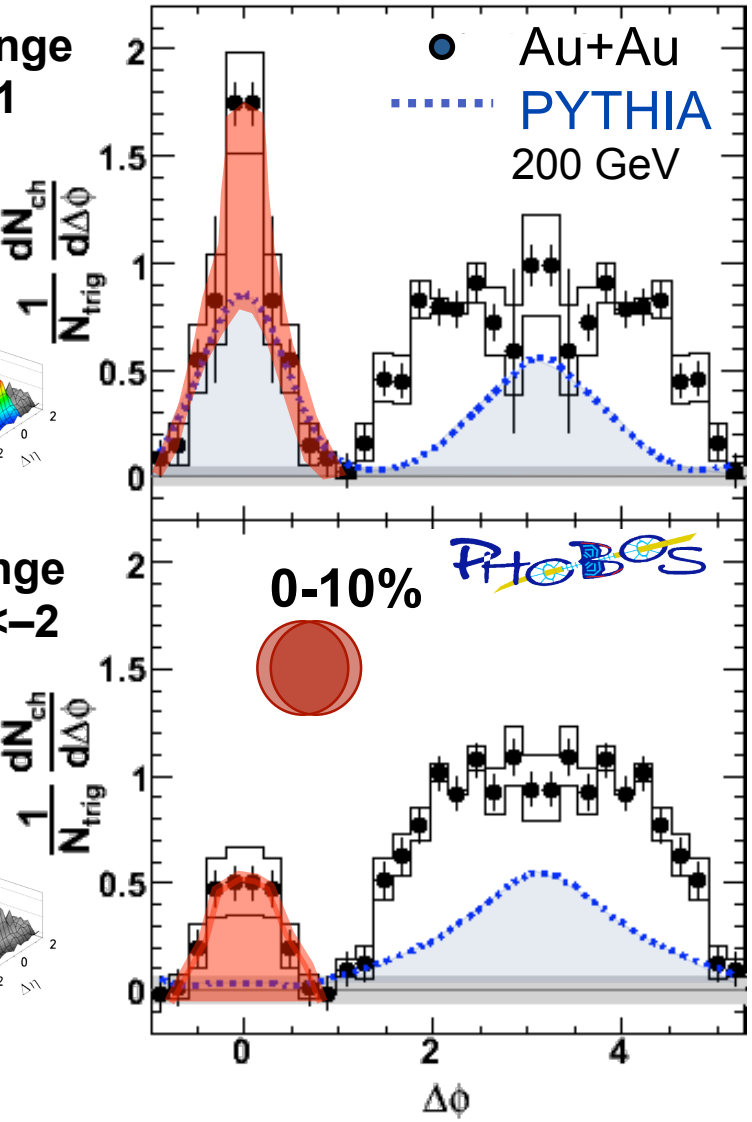
Long-range ridge yield

PRL 104, 062301 (2010)

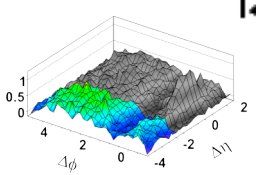
Centrality dependence

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

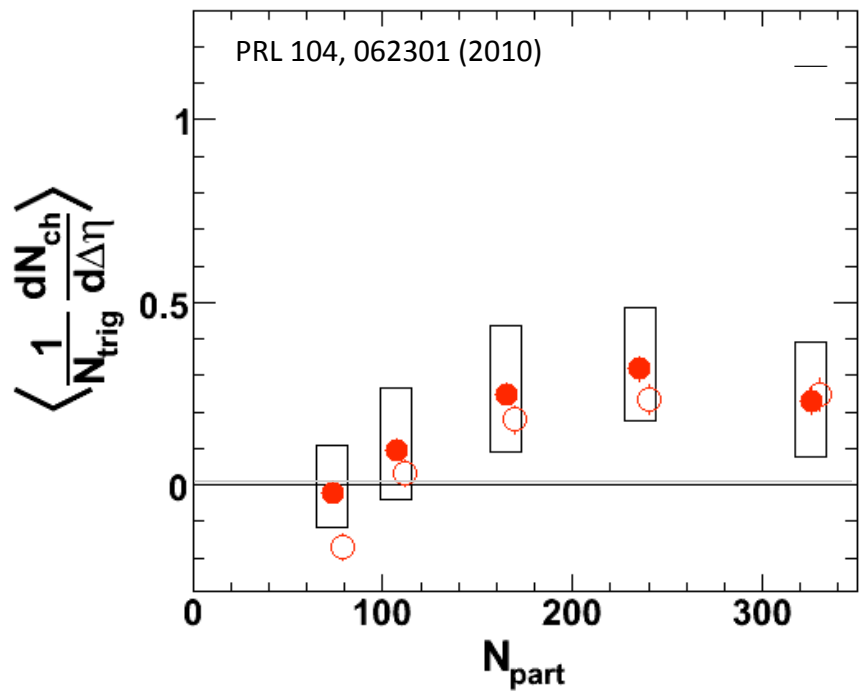




Long-range
$-4< \Delta\eta <-2$

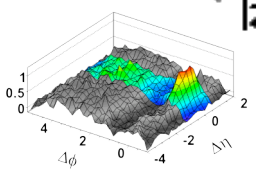


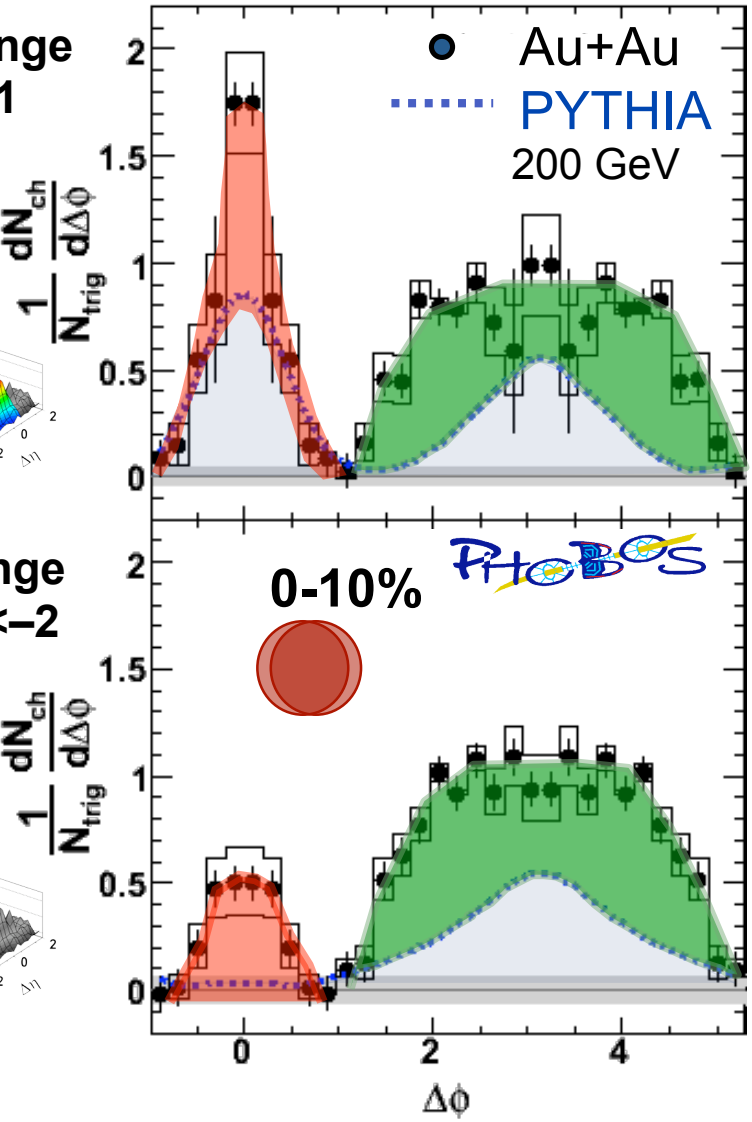
Near side:
- ● Short-range minus PYTHIA
- o Long-range (PYTHIA≈0)



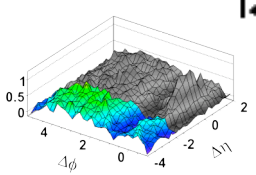
Centrality dependence

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



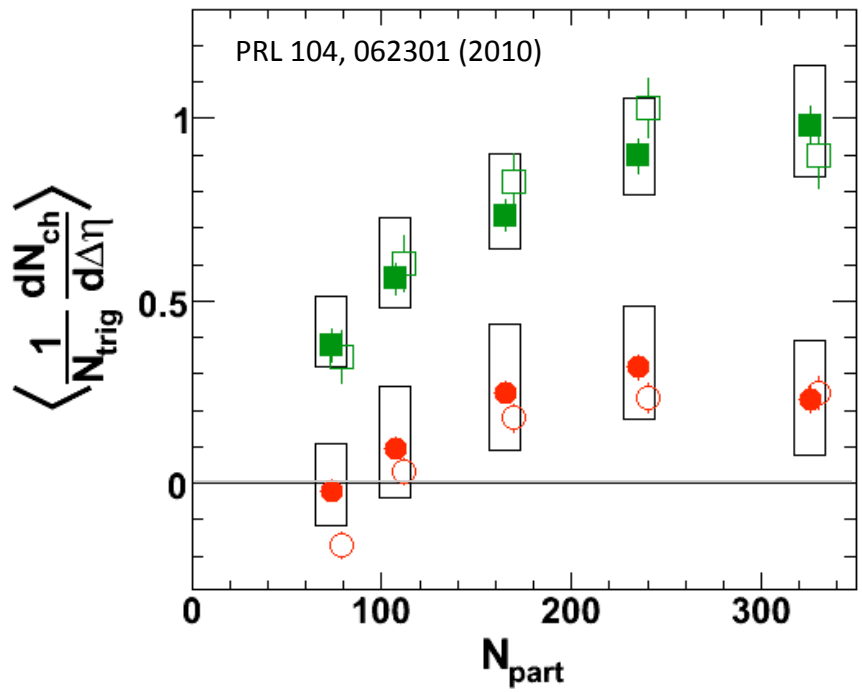


Long-range
$-4< \Delta\eta <-2$



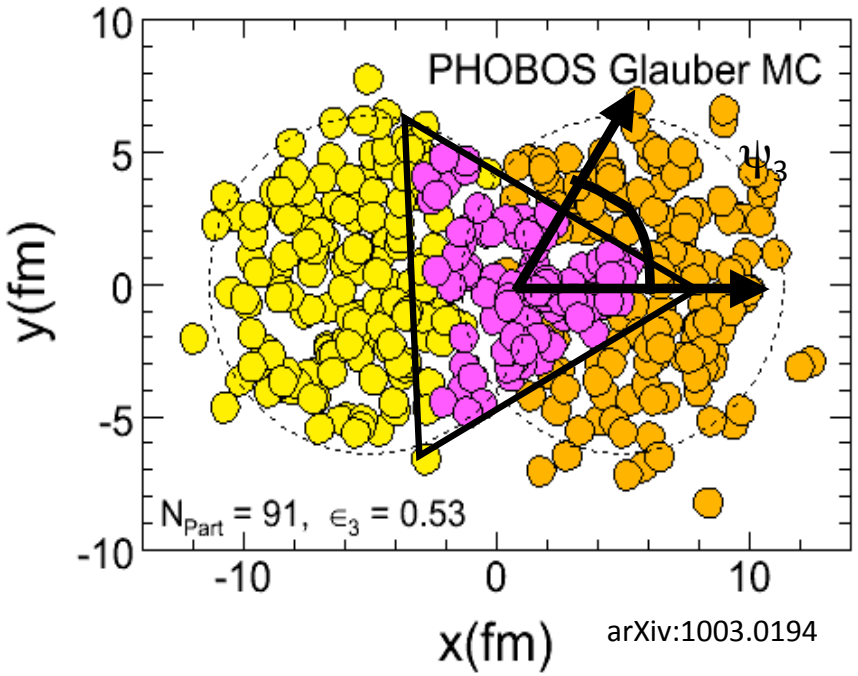
Near side:
- ● Short-range minus PYTHIA
- ○ Long-range (PYTHIA≈0)

Away side:
- □ ■ short, long-range both minus PYTHIA



Ridge and triangular flow

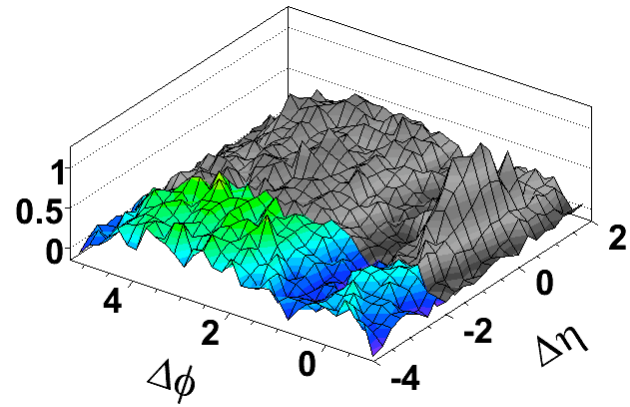
Triangular eccentricity

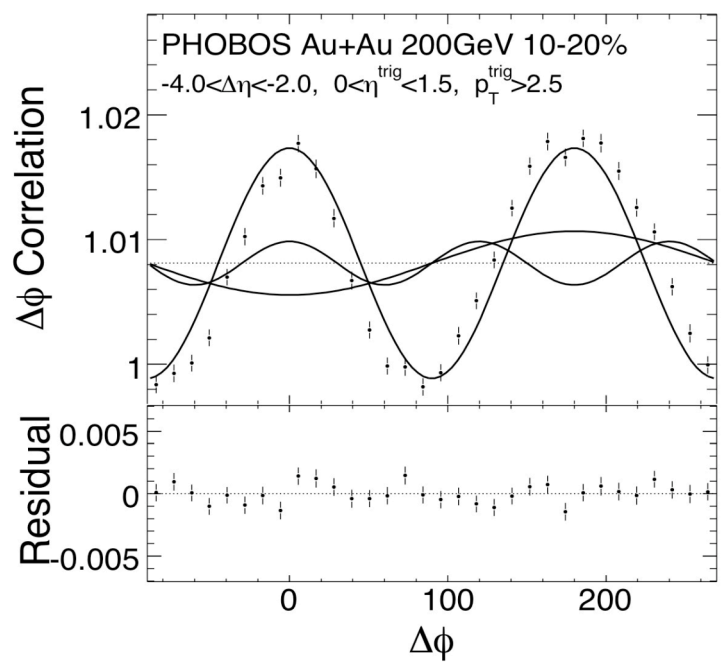


arXiv:1003.0194

$$v_3 = \langle \cos(3(\phi - \psi_3)) \rangle$$

See B. Alver's talk next





Long range correlations are well described by 3 Fourier Components

Conclusion

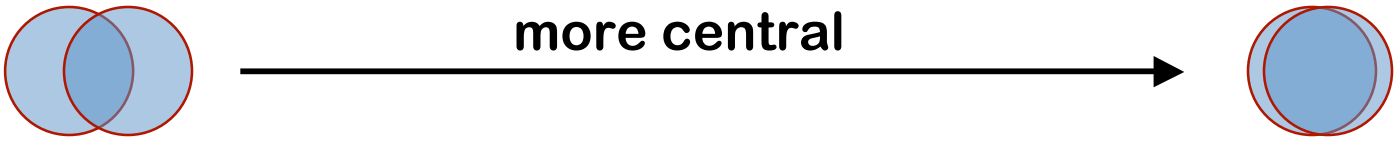
- Strong cluster-like correlations are observed in A+A collisions. Cluster size and width scale with the fractional cross section

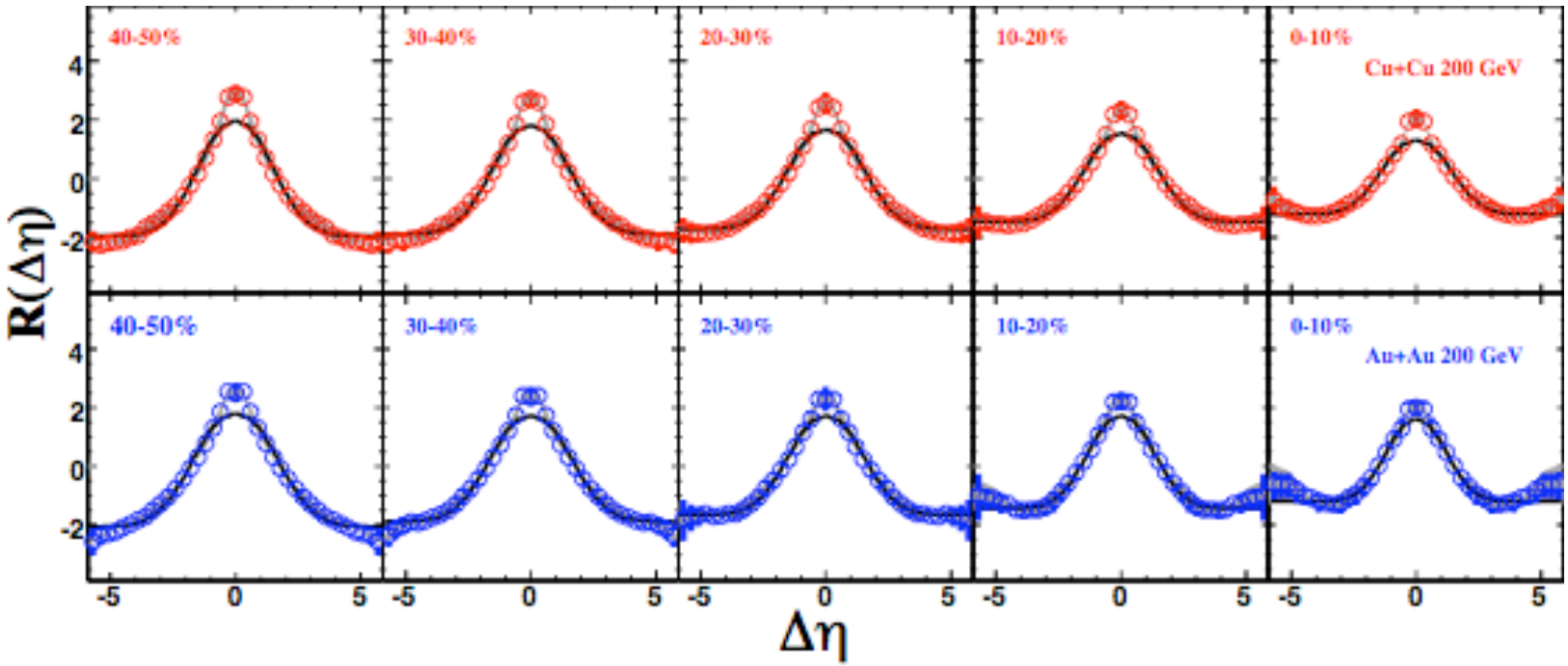
- Contributions from short-range non-flow correlations (~10%) have been determined and were found to be a small contribution to the event-by-event elliptic flow fluctuation measurement

- Near-side correlations of associated particles with high $p_T > 2.5$ GeV/c particle extend at least 4 units in pseudo-rapidity and diminish for a system with $N_{part} \sim 80$.

Cluster parameterization in Cu+Cu and Au+Au

Two-particle $\Delta\eta$ correlation function

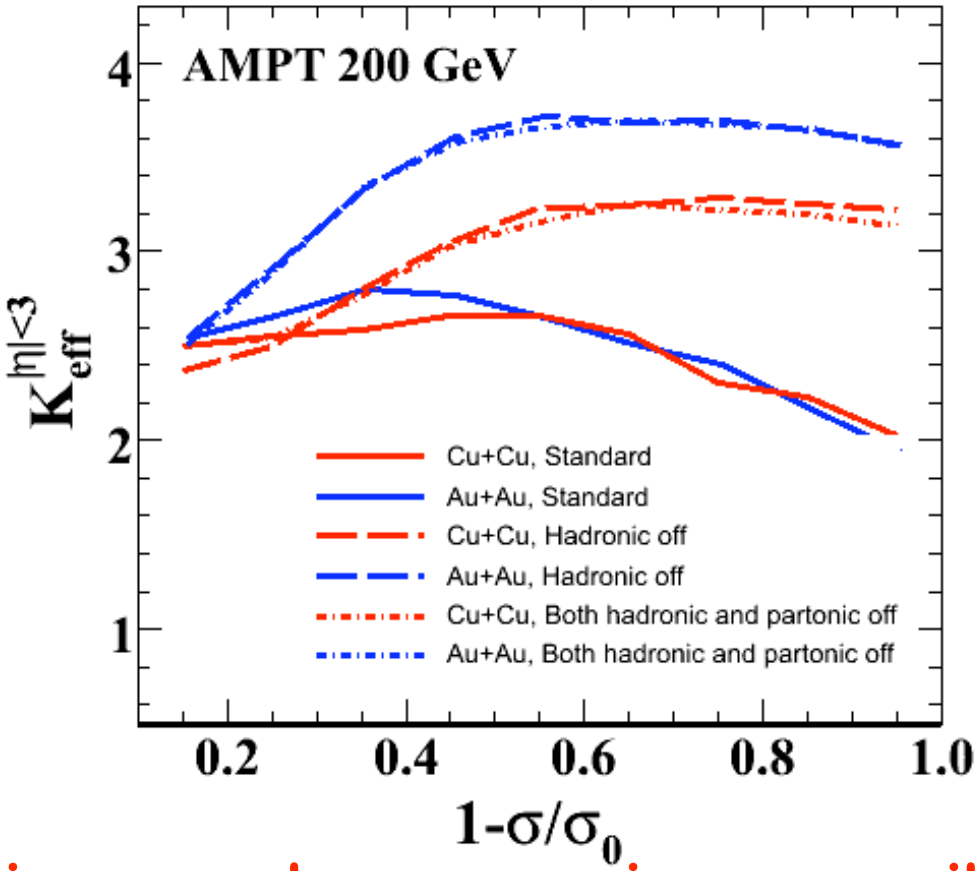




Clear centrality dependence of cluster properties!

AMPT model

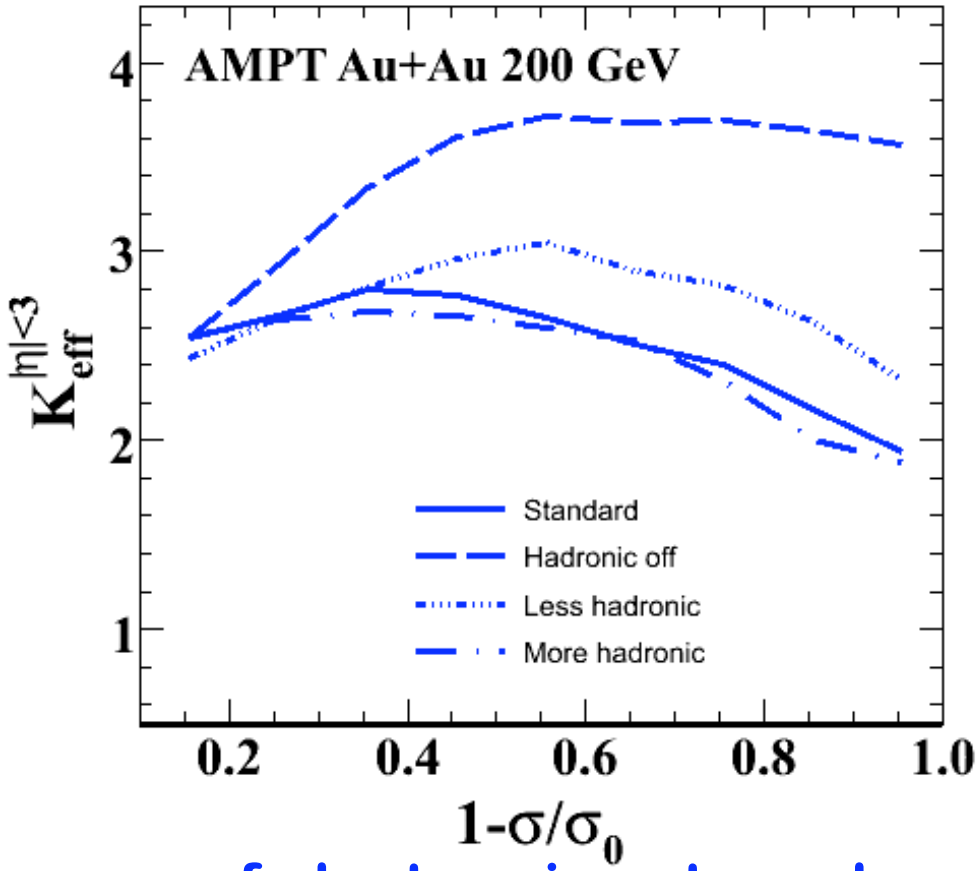
Switch on and off various processes



Hadronic cascade process is responsible for the decrease of cluster size toward central collisions.

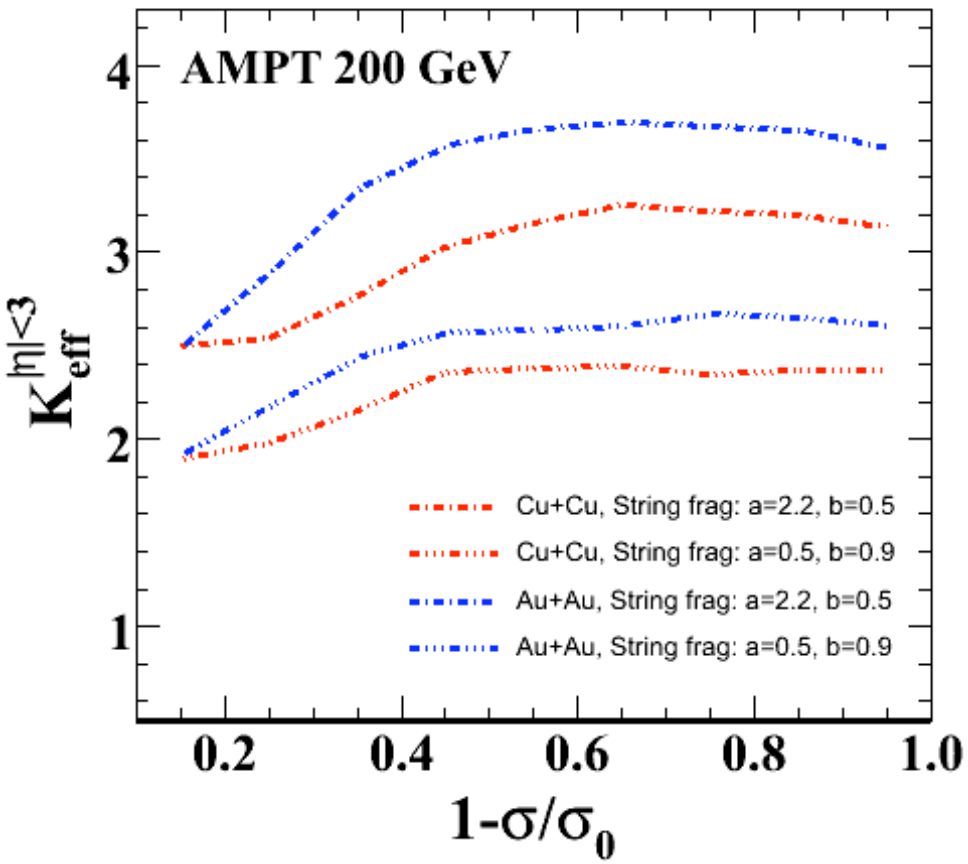
AMPT model

Varying the time length of hadronic cascade



Decrease of cluster size strongly correlates with the duration of hadronic cascade.

AMPT model



AMPT

HIJING

Large fraction of clusters in AMPT are originated from strings

$$K(v_2^{obs}, v_2, n) = BG(v_2^{obs}, v_2, \sigma_n), \quad \sigma_n = 1/\sqrt{2n}$$

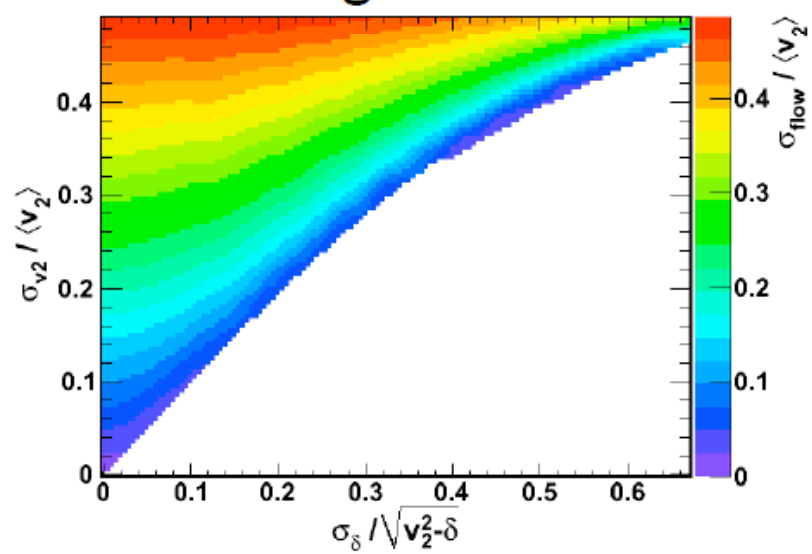
$$K_\delta(v_2^{obs}, v_2, n) = BG(v_2^{obs}, v_2, \sqrt{\sigma_n^2 + \sigma_\delta^2}), \quad \sigma_n = 1/\sqrt{2n}, \sigma_\delta = \sqrt{\delta/2}$$

$$g(v_2^{obs}) = \int K_\delta(v_2^{obs}, v_2, n)\, f_{flow}(v_2)\, \mathrm{d}v_2$$

$$g(v_2^{obs}) = \int K(v_2^{obs}, v_2, n)\, f(v_2)\, \mathrm{d}v_2$$

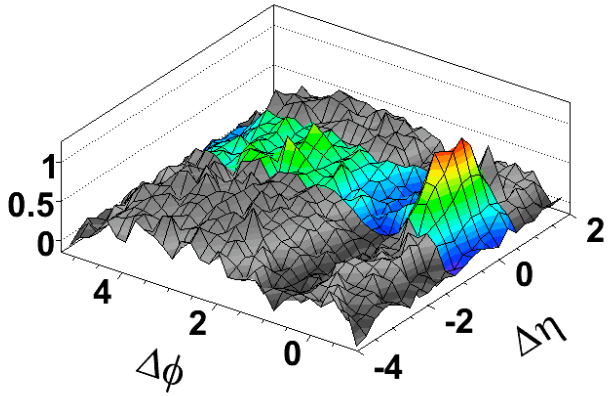
Generate $g(v_2^{obs})$ using this

Do a fit using this

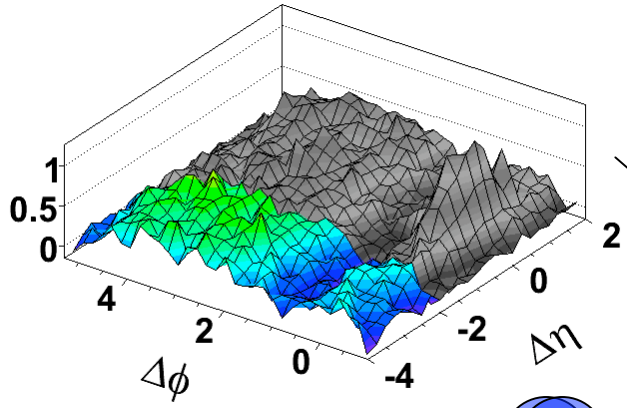


Centrality dependence

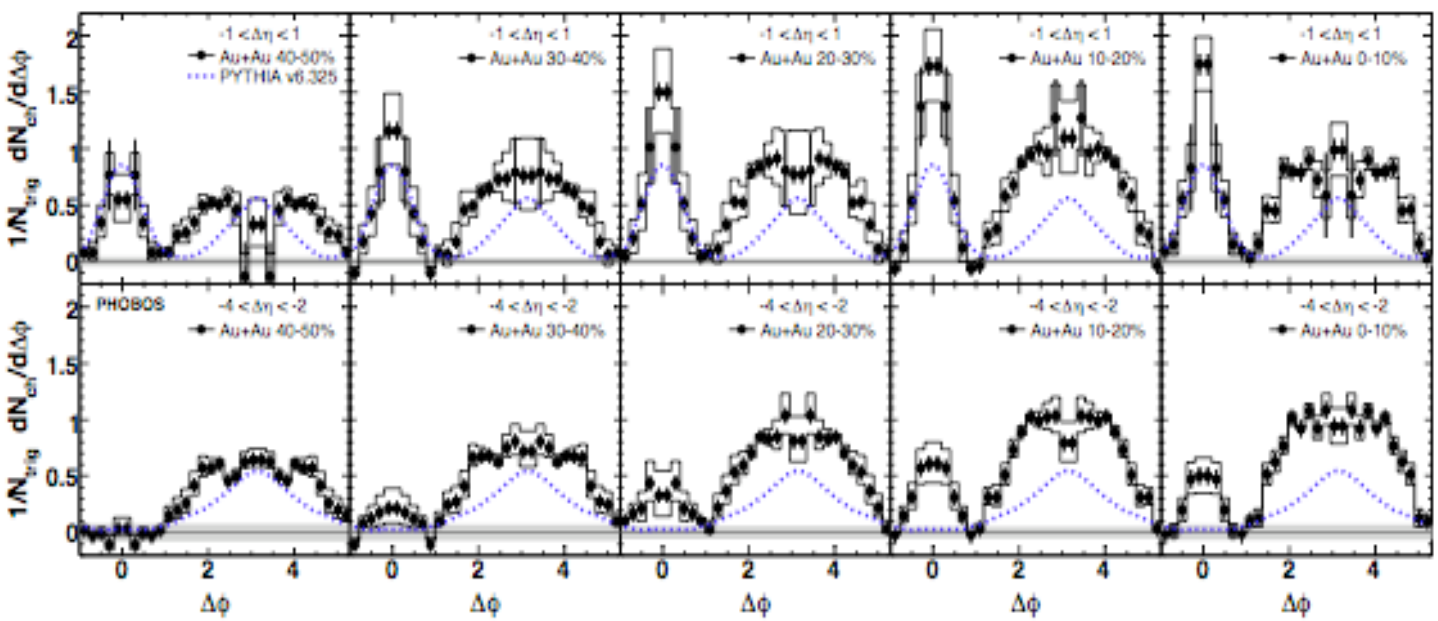
Short-range |Δη| <1



Long-range -4 < Δη < -2



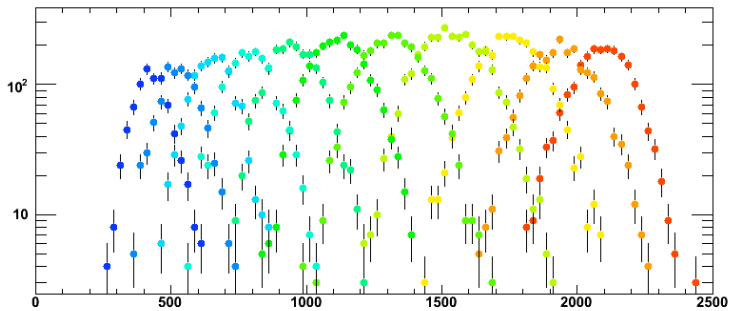
Projection in Δϕ:



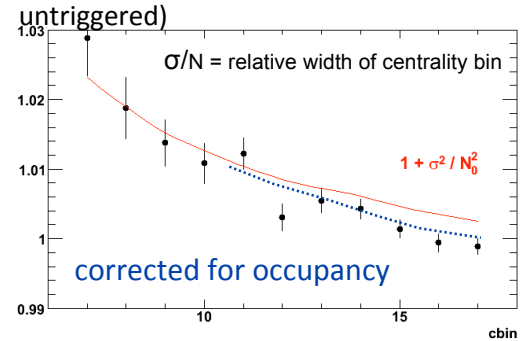
PRL 104, 062301 (2010)

ZYAM = "trigger bias" + "Δη correlations"

Number of octagon hits distribution for different centralities



Ratio of octagon hit multiplicities (triggered / untriggered)



Events with a trigger particle have higher average multiplicity than events without one, therefore the number of signal pairs per event is higher than the number of background (mixed events) pairs per event by the same factor, creating a "trigger bias", which does not depend on Δη.

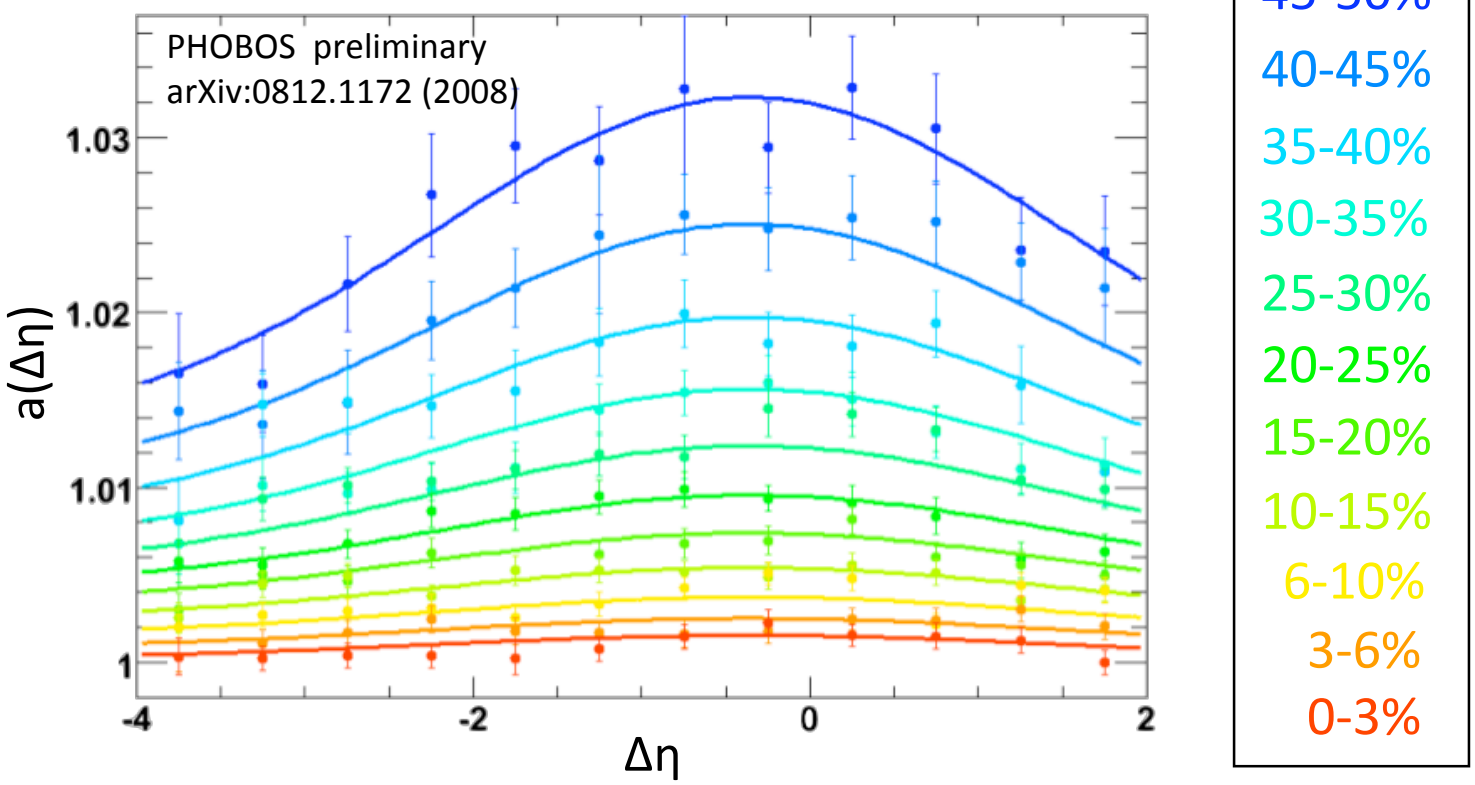
$$R(\Delta\eta,\Delta\varphi) = \left\langle (n-1)\left(\frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle$$

$$a(\Delta\eta) = \min_{\Delta\varphi}\left(\frac{s(\Delta\eta,\Delta\varphi)}{b(\Delta\eta,\Delta\varphi)} \cdot \frac{1}{1+2V(\Delta\eta)\cos(2\Delta\varphi)}\right)$$

ZYAM parameter is expected to have Δη dependence similar to the one of inclusive angular correlation function, i.e. Gaussian.

Implementation of ZYAM factors

ZYAM factors from 2D-fit in Δη and N_{part}



Constant trigger bias term has expected N_{part} dependence

Gaussian term: width/amplitude/N_{part}-dependence same as inclusive correlations