News from PHOBOS

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Executive Summary

- The physics message remains the same, only broader, deeper, and more interesting.
- Very complex systems, potentially influenced by a broad suite of physics processes, display a surprising range of simply dependencies.
- The details of the geometry of the initial interaction points appears to drive the subsequent evolution of the system.

PHOBOS Collaboration

  

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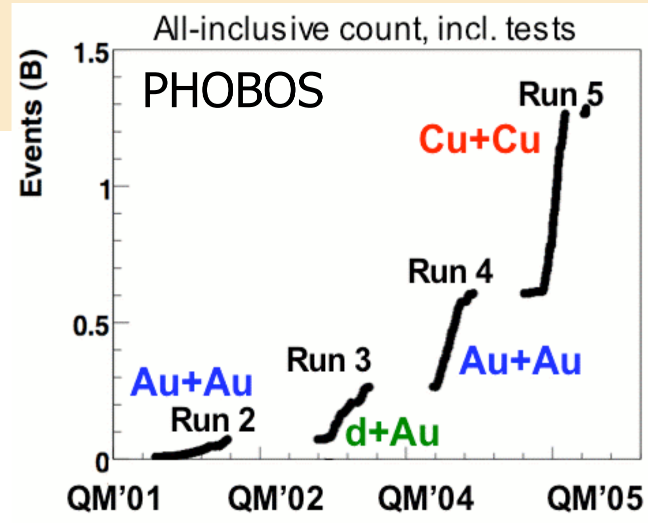
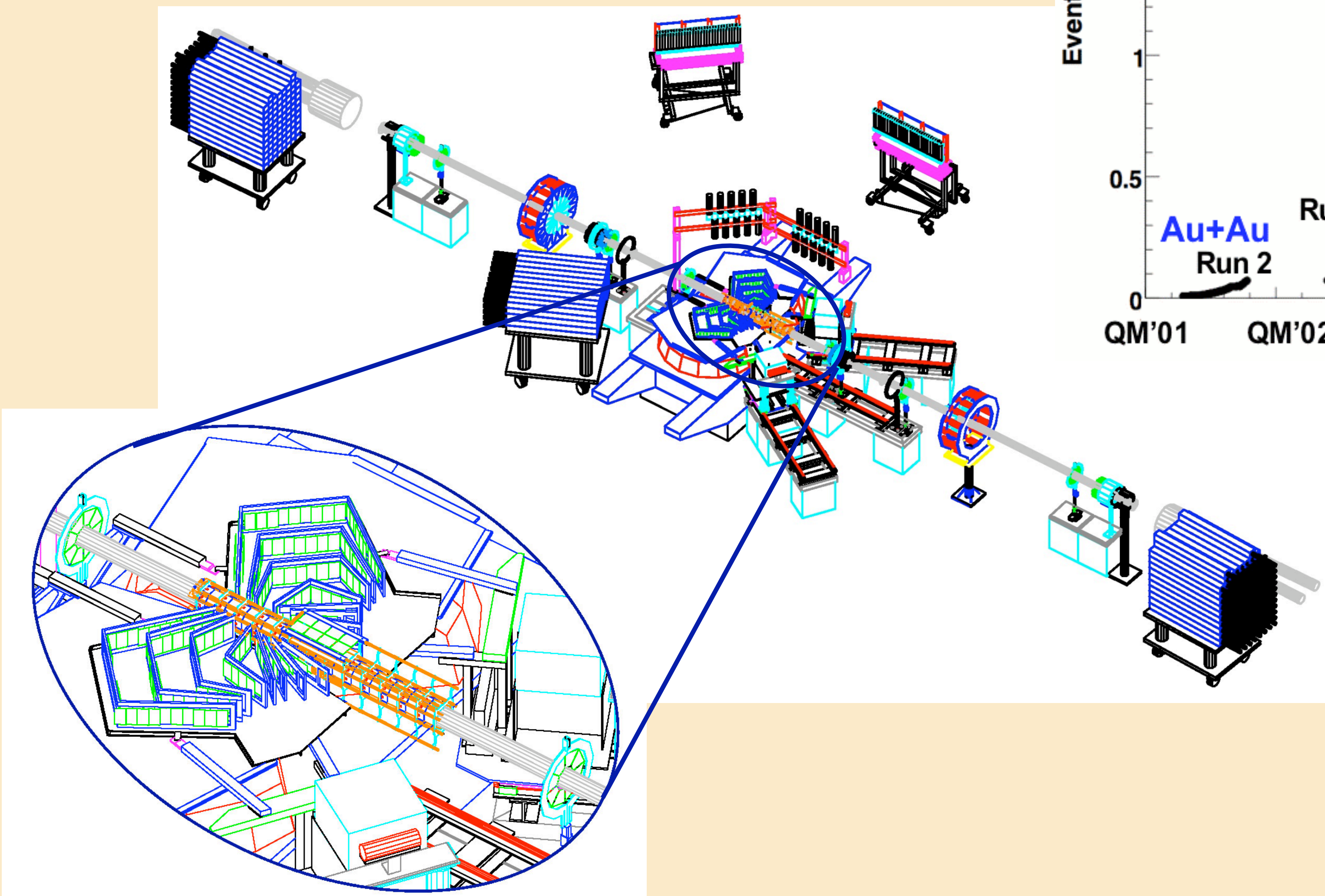
UNIVERSITY OF MARYLAND
BROOKHAVEN NATIONAL LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

9 Current Ph.D. Students

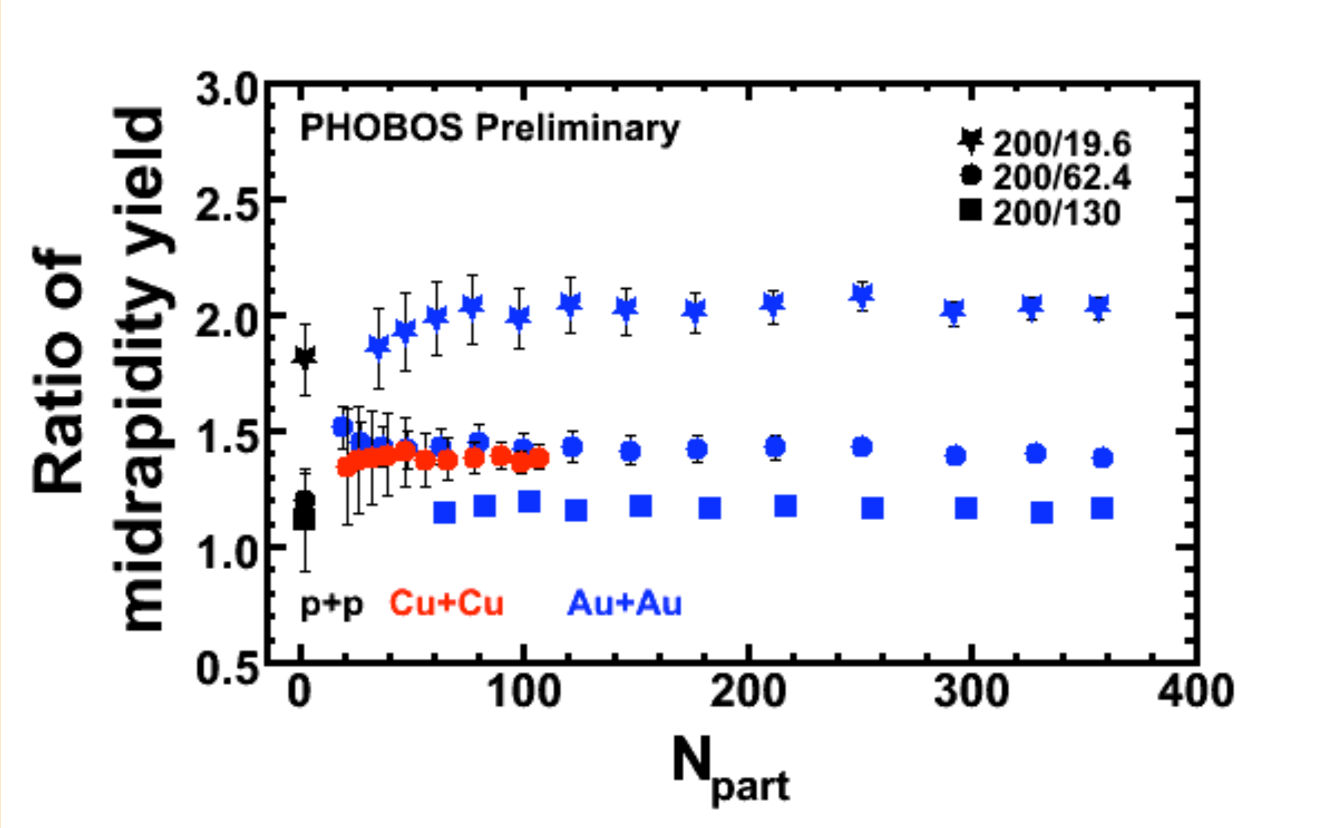
PHOBOS Detector





Simple Dependence: Example I

Midrapidity charged particles

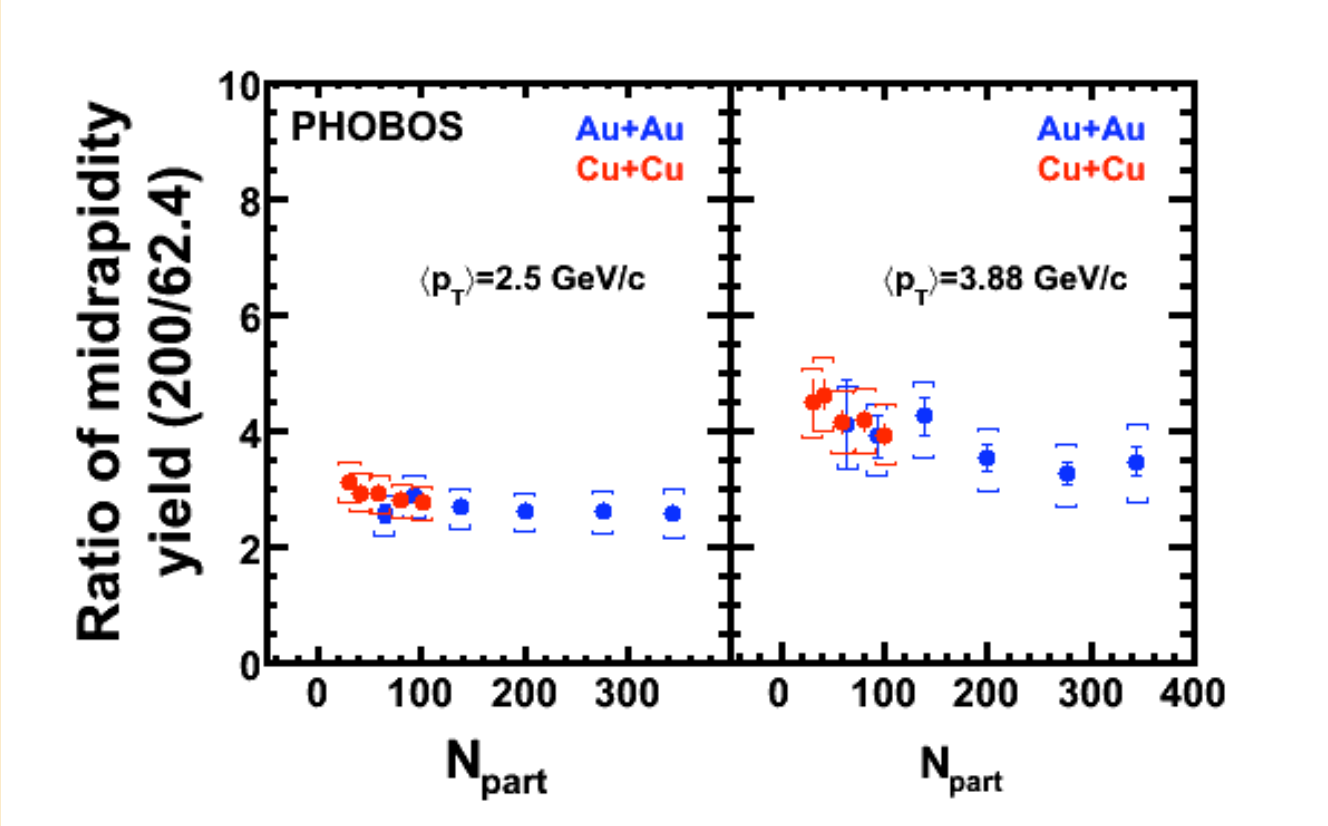


Phys.Rev. C74 (2006) 021901
Phys.Rev.Lett. 94 (2005) 082304
Nucl.Phys. A774 (2006) 113-128

Energy/Centrality factorization and “scaling laws” in global charged particle production

Simple Dependence: Example II

Midrapidity charged particle spectra



Phys.Rev. C74 (2006) 021901
Phys.Rev.Lett. 94 (2005) 082304
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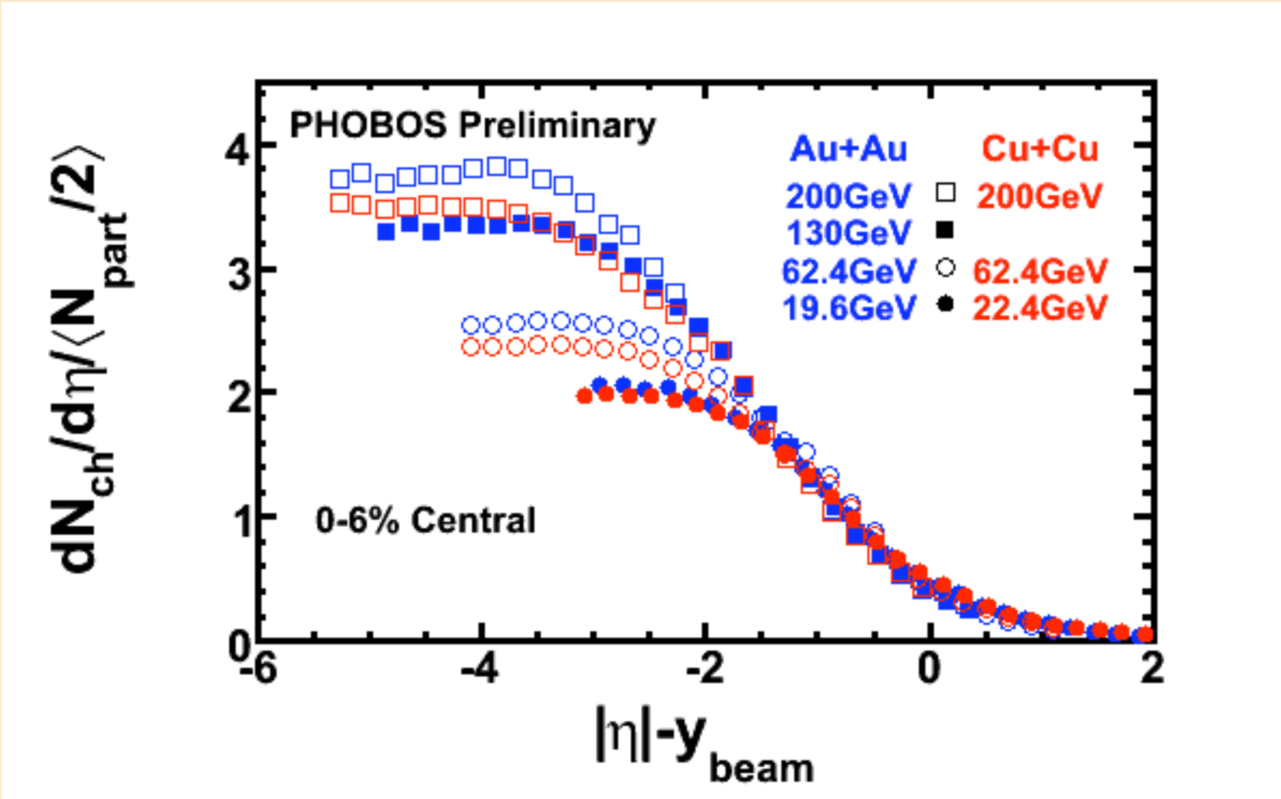
Energy/Centrality factorization and "scaling laws" in global charged particle production

Simple Dependence: Example III

Extended longitudinal scaling

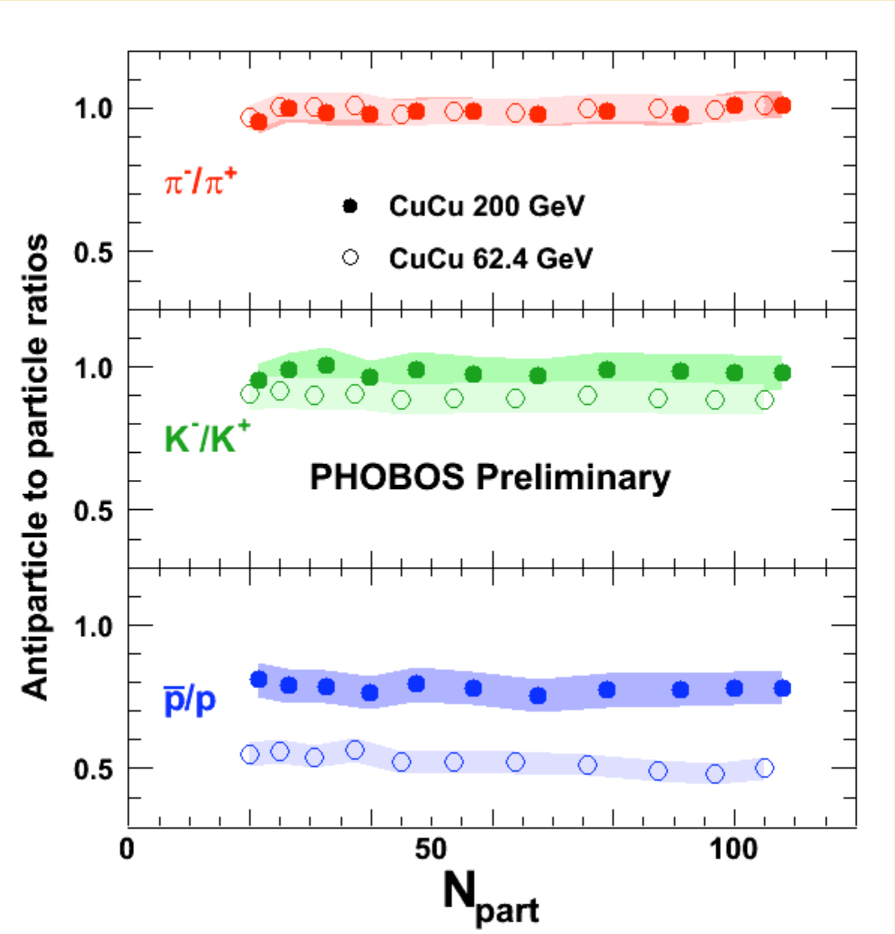


Phys.Rev. C74 (2006) 021901
Phys.Rev.Lett. 94 (2005) 082304
Nucl.Phys. A774 (2006) 113-128

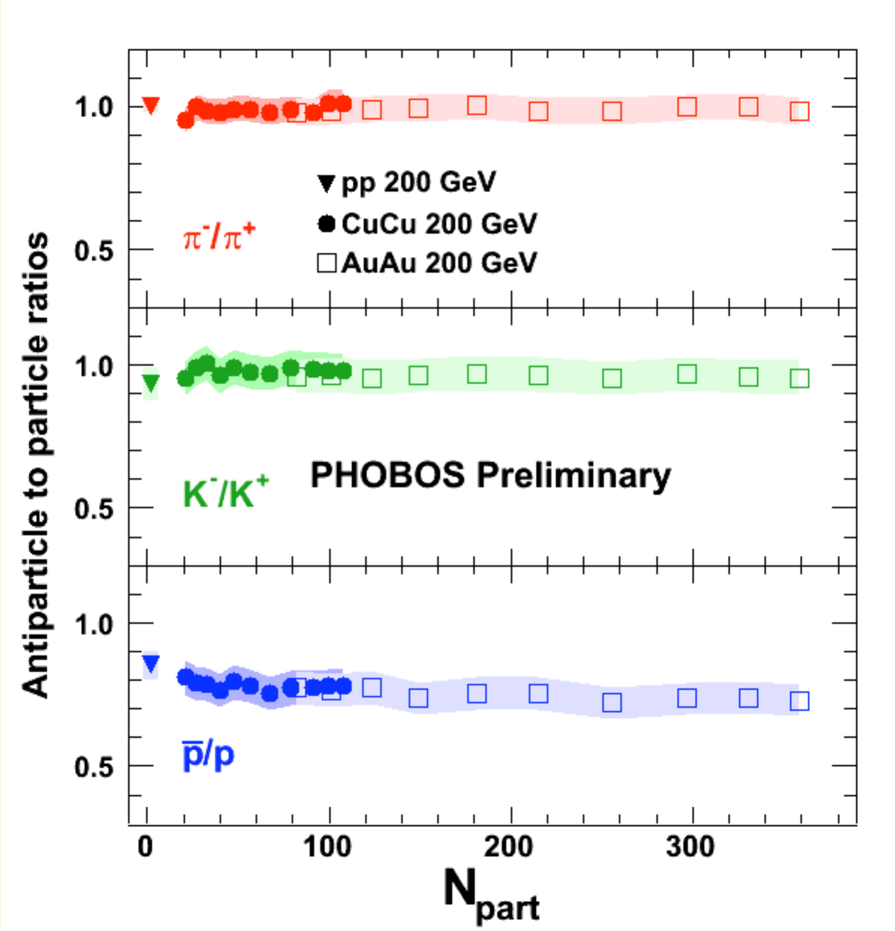
Energy/Centrality factorization and "scaling laws" in global charged particle production

Simple Dependence: Example IV

200, 62.4 GeV Cu+Cu



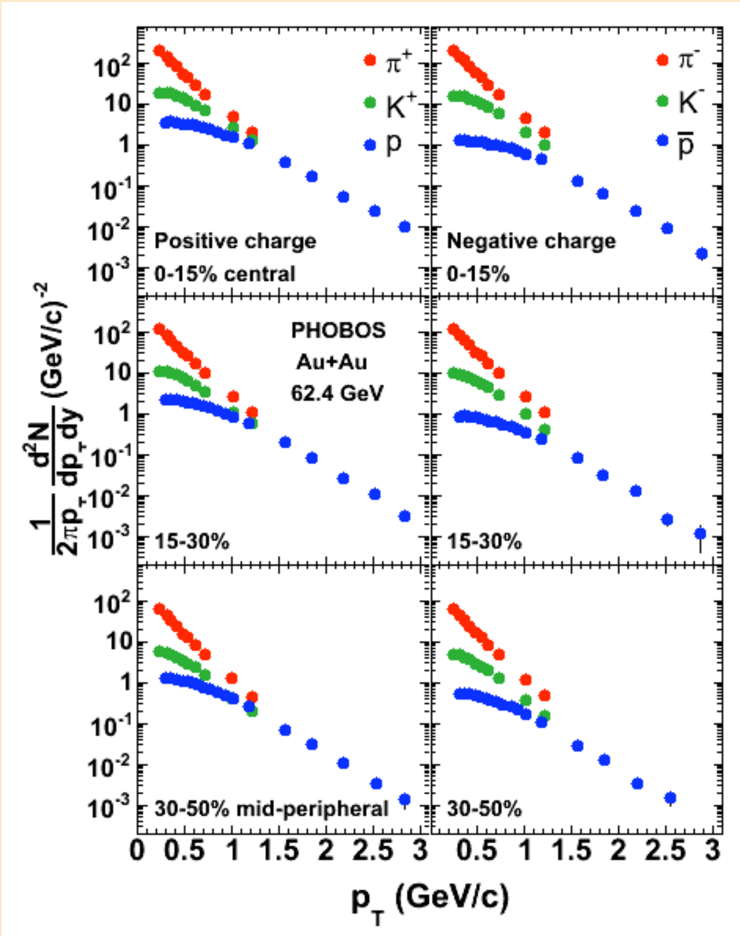
200 GeV p+p, Cu+Cu & Au+Au

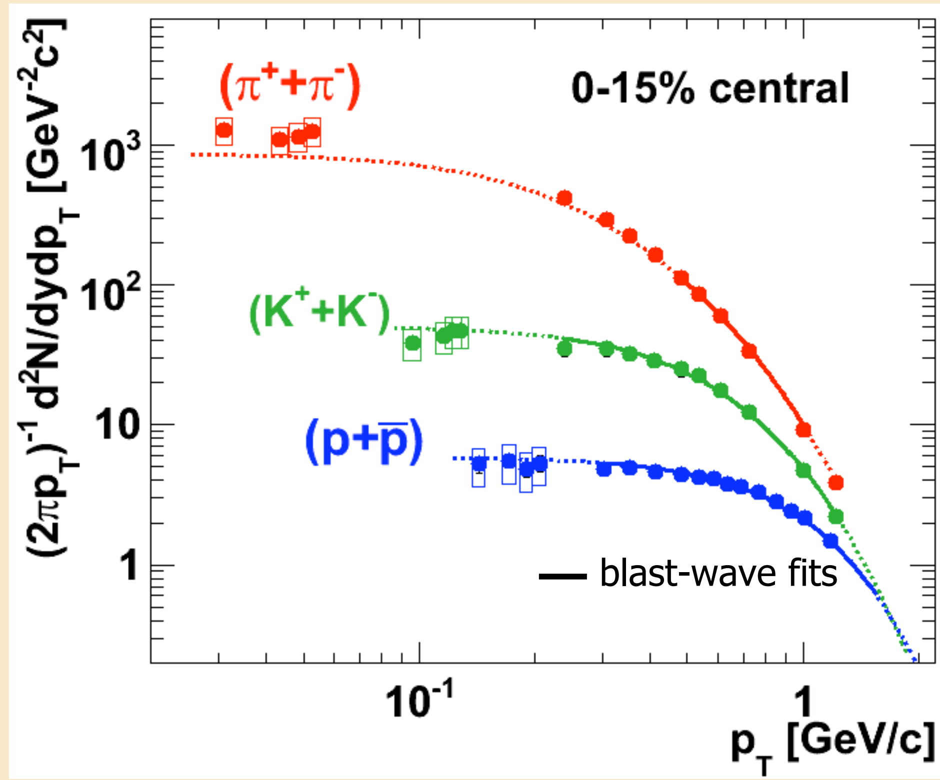


Midrapidity "chemistry" at most weakly dependent on system size

Simple Dependence: Example V (intro)

62.4 GeV Au+Au



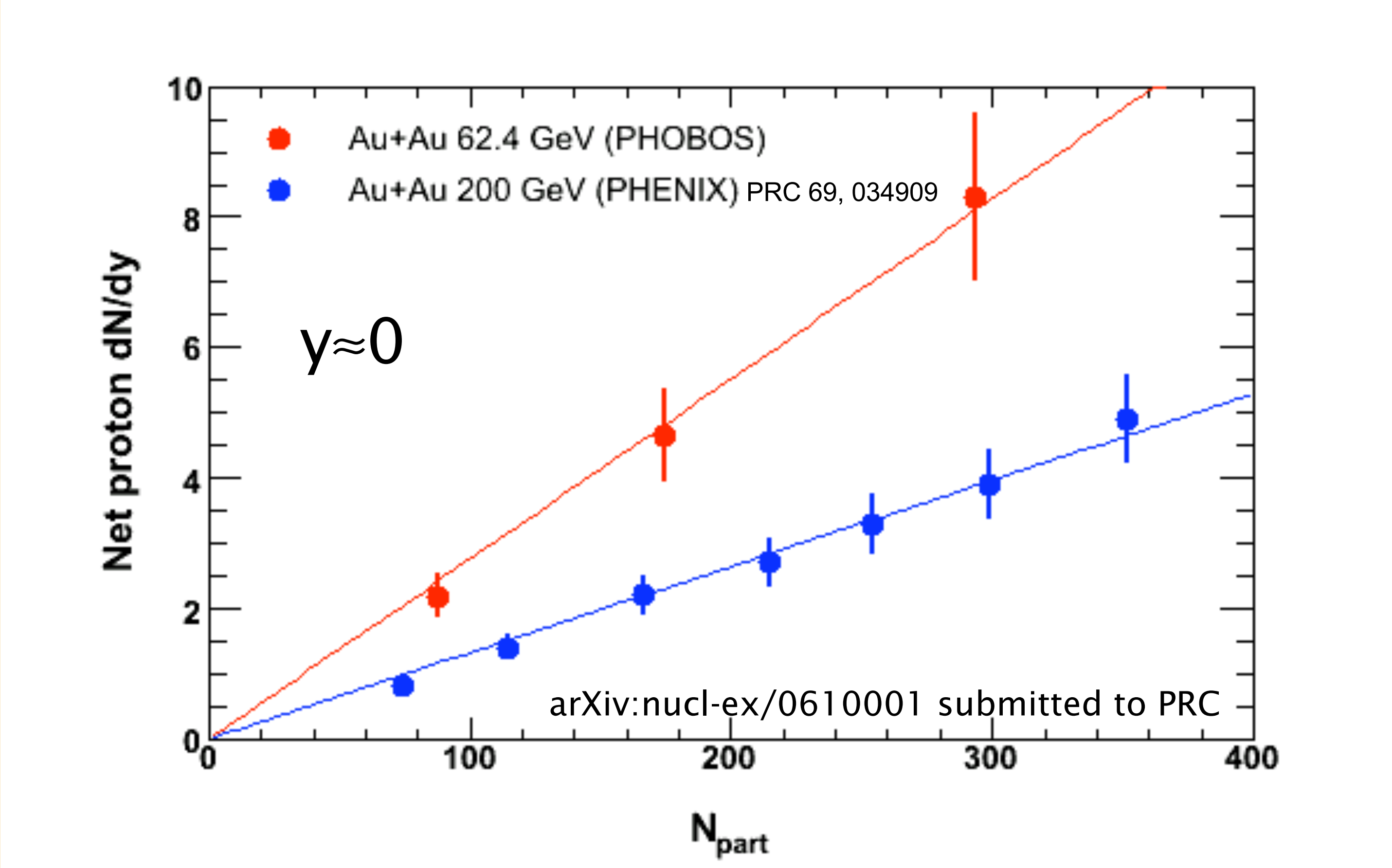


arXiv:nucl-ex/0610001submitted to PRC

First published identified spectra for 62.4 GeV Au+Au at RHIC (down to very low p_T, a unique PHOBOS measurement)

Simple Dependence: Example V

Net protons (p−p̄)



See parallel talk by Gábor Veres

The net proton yield is proportional to Npart!
p̄/p centrality independent ⇒ p and p̄ ∝Npart as well

Simple Dependence Summary

- Many properties of particle production can be described with a surprisingly small number of systematic dependencies.
- A consistent explanation of these features of the data in terms of the interplay of geometry, conservation laws, and QCD is eagerly awaited.
- {Personal opinion} The emergence of order out of random particle interactions is one hallmark of the creation of a form of "matter".

Expanding our probe of the particle production mechanism

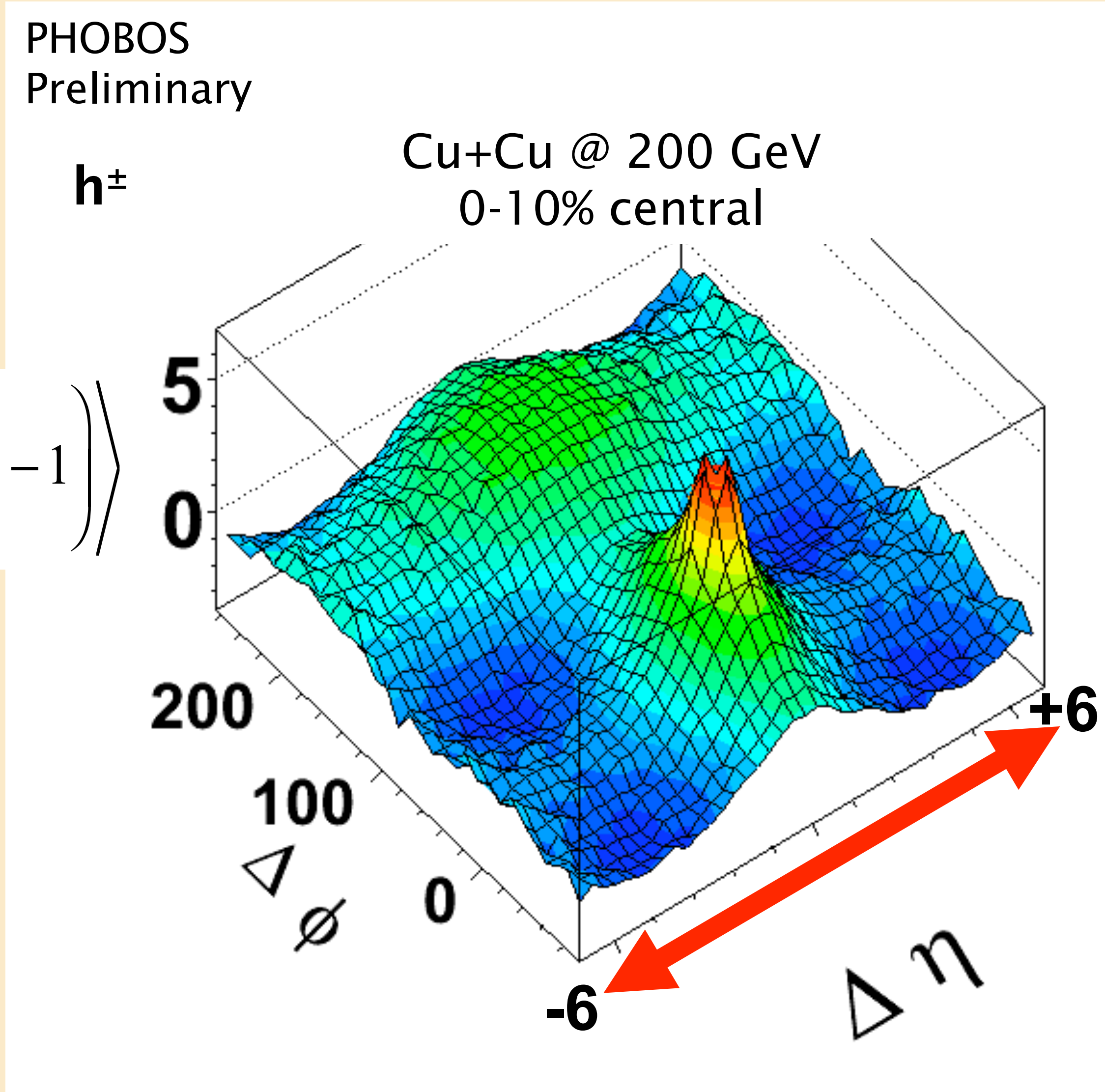
One example: 2-particle correlations

See parallel talk by Wei Li

The PHOBOS Advantage: Large Coverage

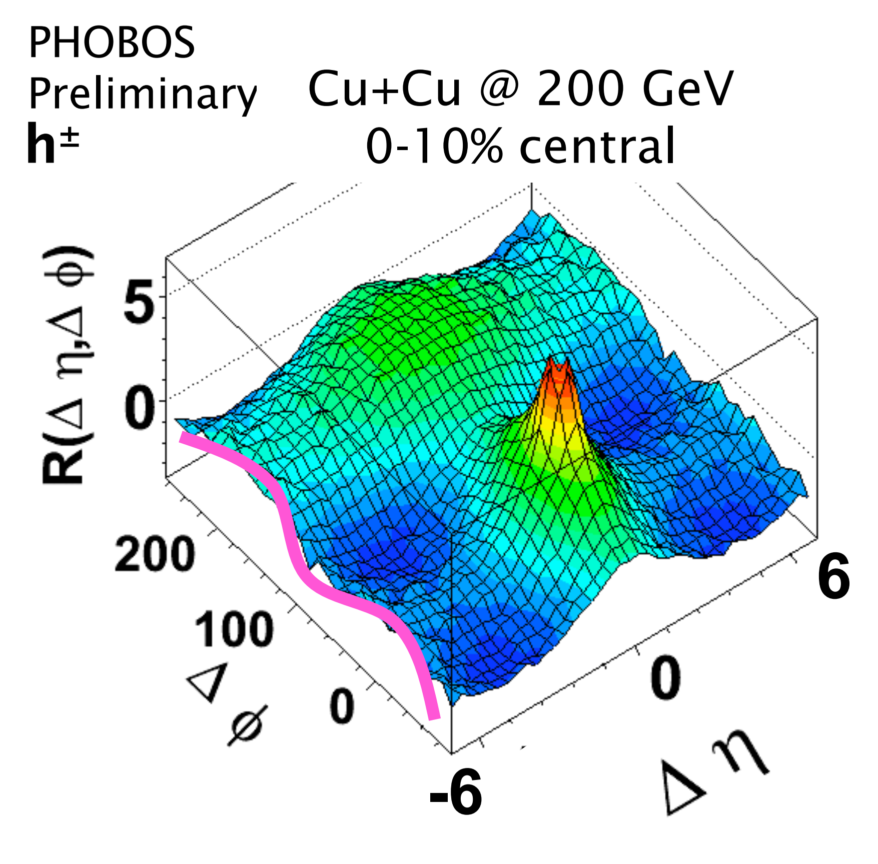
$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left(\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle$$

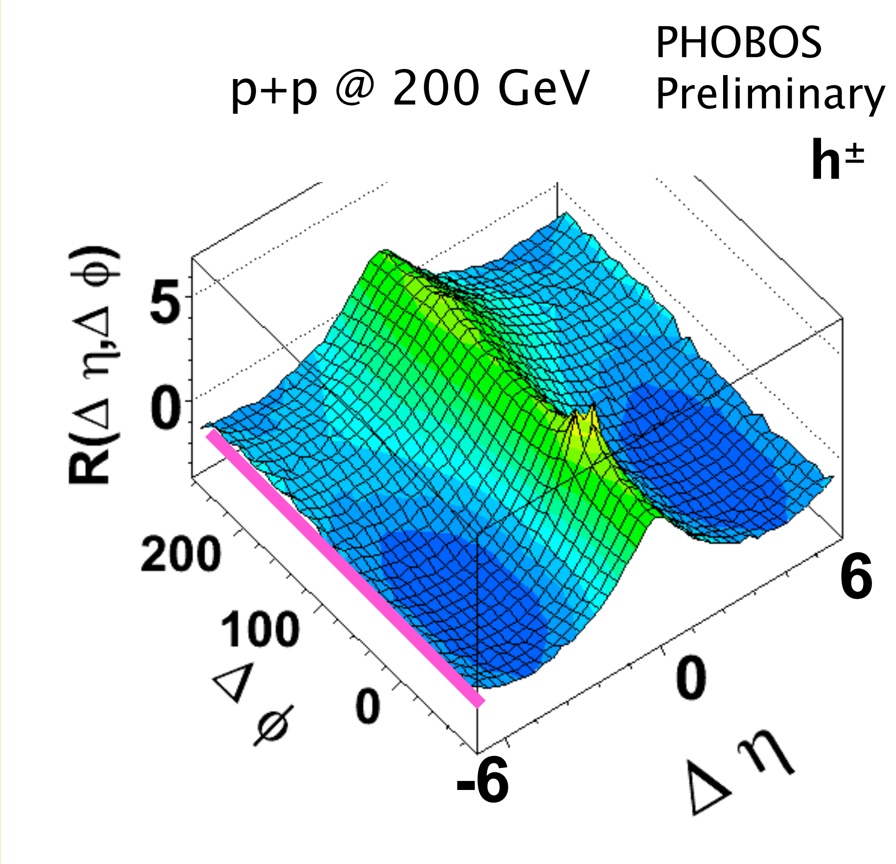
Range expandable to **±10-11 units** using the Ring detectors



2-Particle Correlations

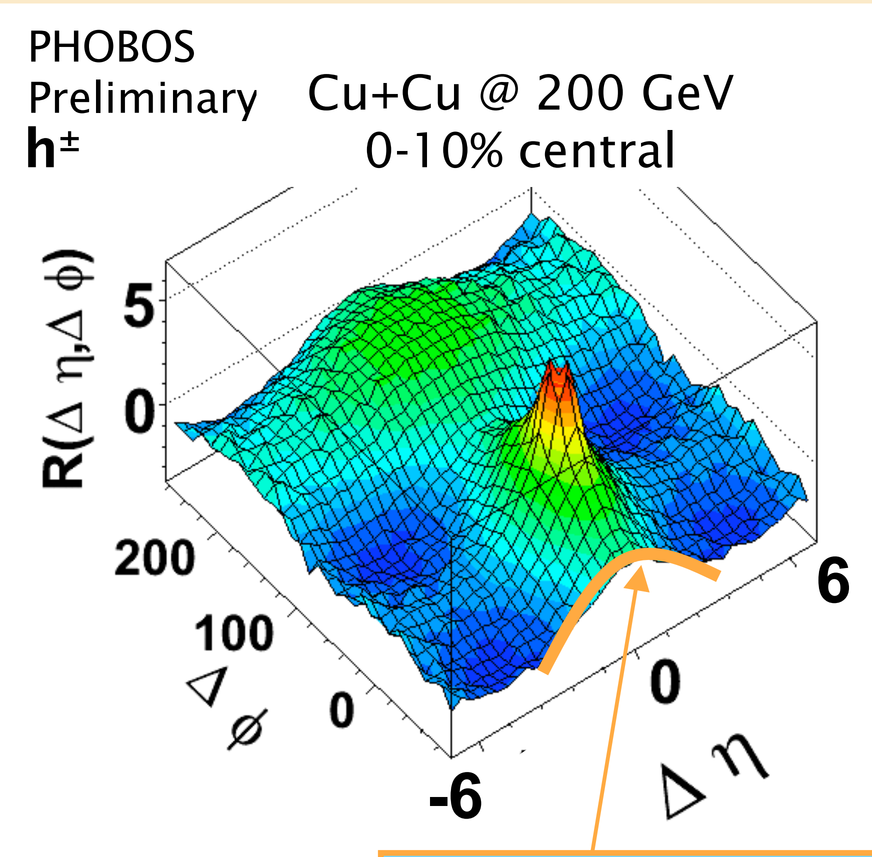
$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left(\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1 \right) \right\rangle$$

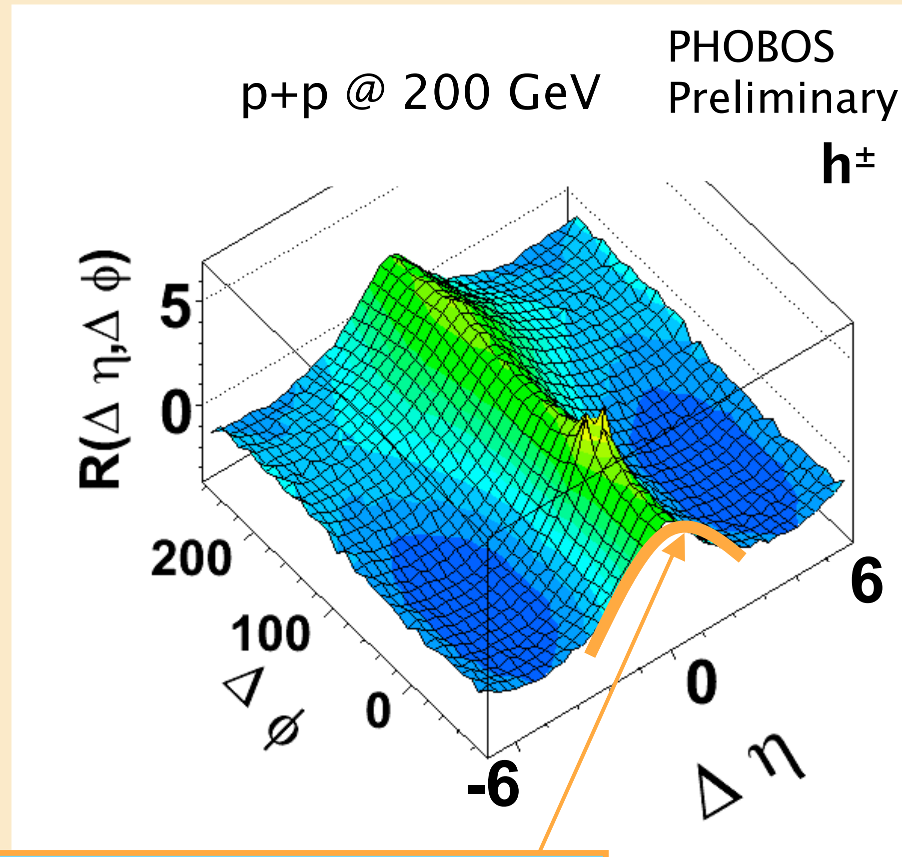




2-Particle Correlations: First Step

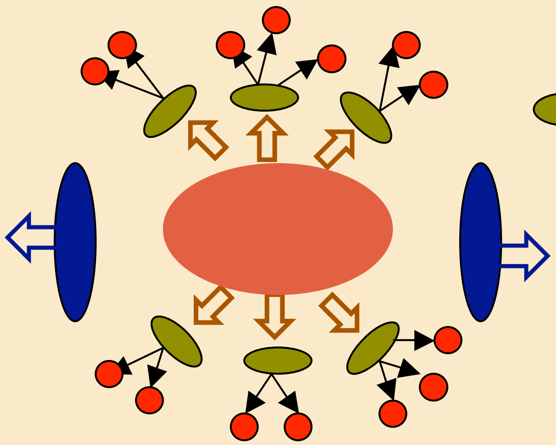
$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left(\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1 \right) \right\rangle$$





Study the short-range rapidity correlations

2-Particle Correlations: Cluster Model

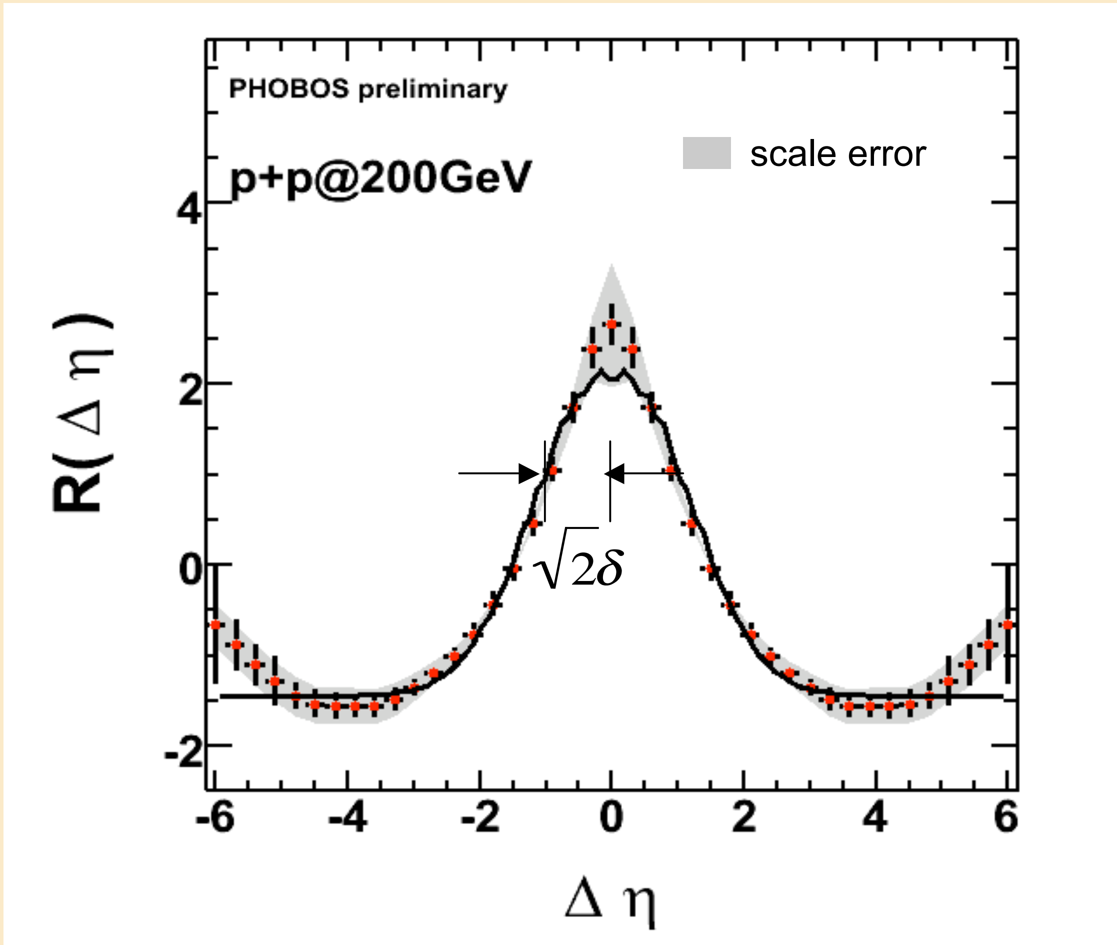


$$R(\Delta\eta) = \alpha\left(\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right)$$

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

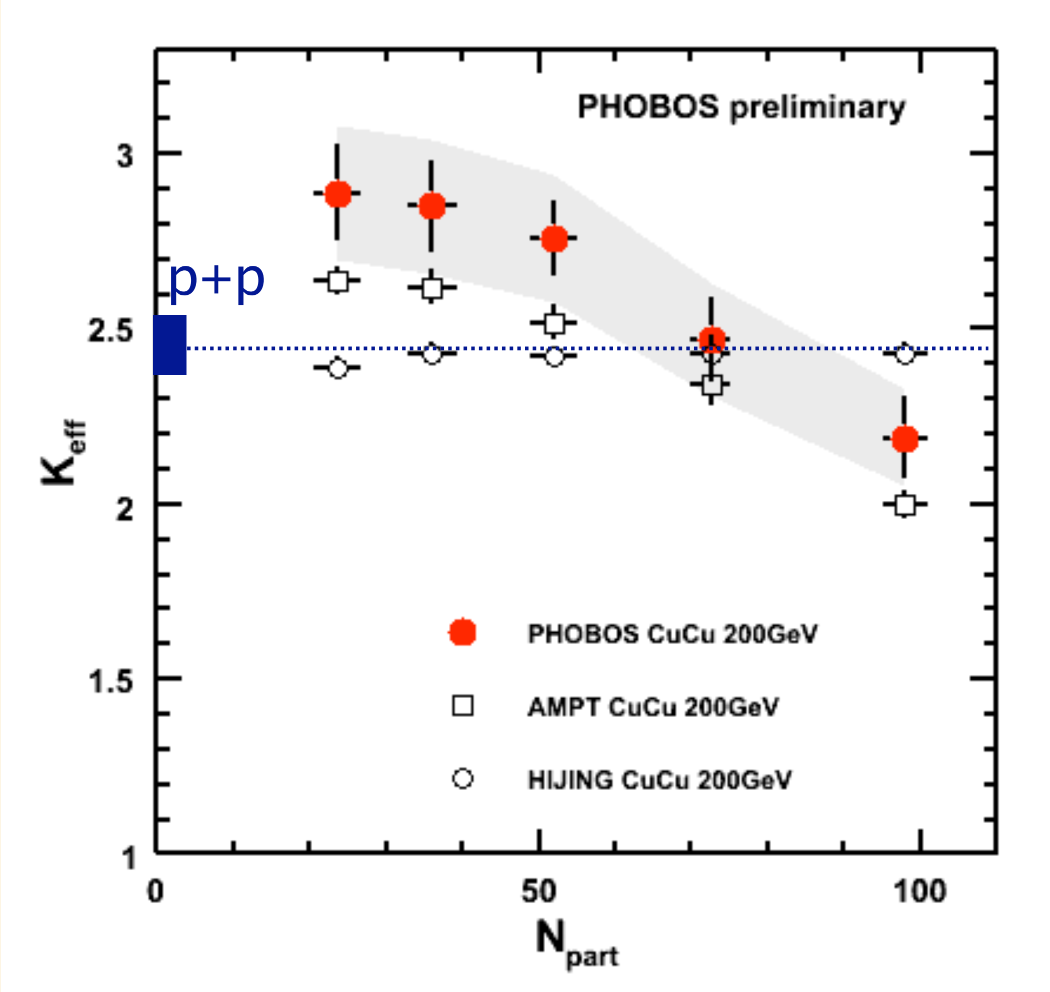
$$K_{eff} = \alpha + 1 = \frac{< k(k-1) >}{< k >} + 1$$

K_{eff}: effective cluster size



2-Particle Correlations: Results

K_{eff} = **effective cluster size**



Particles tend to be produced in clusters with an average **size of 2-3**.
Interesting centrality dependence – can compare to other systems

More detailed study of geometry and elliptic flow

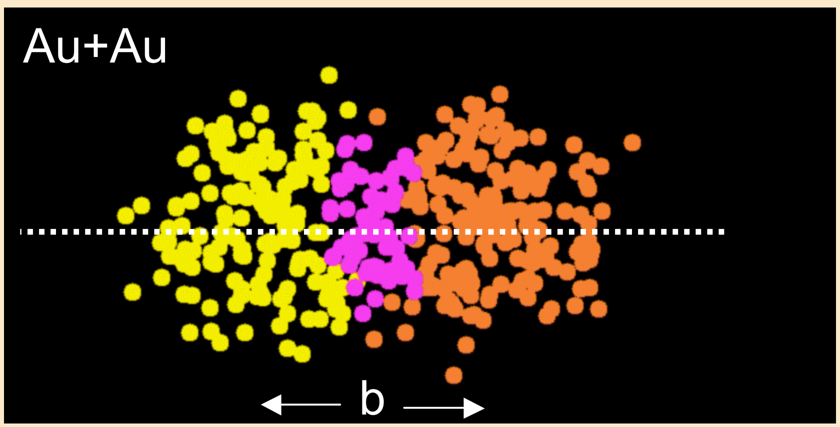
Is the connection "on average" or specifically event-by-event?

See parallel talk by Rachid Nouicer

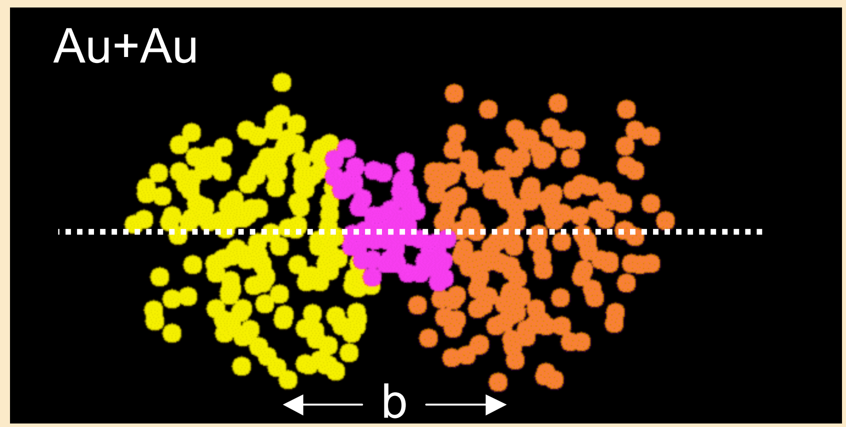
Event-by-Event Variation in Geometry

Basic idea: In a MC Glauber model, the detailed shape and orientation of the interaction region of two nuclei can vary event-to-event. Does this make a difference?

Event 1

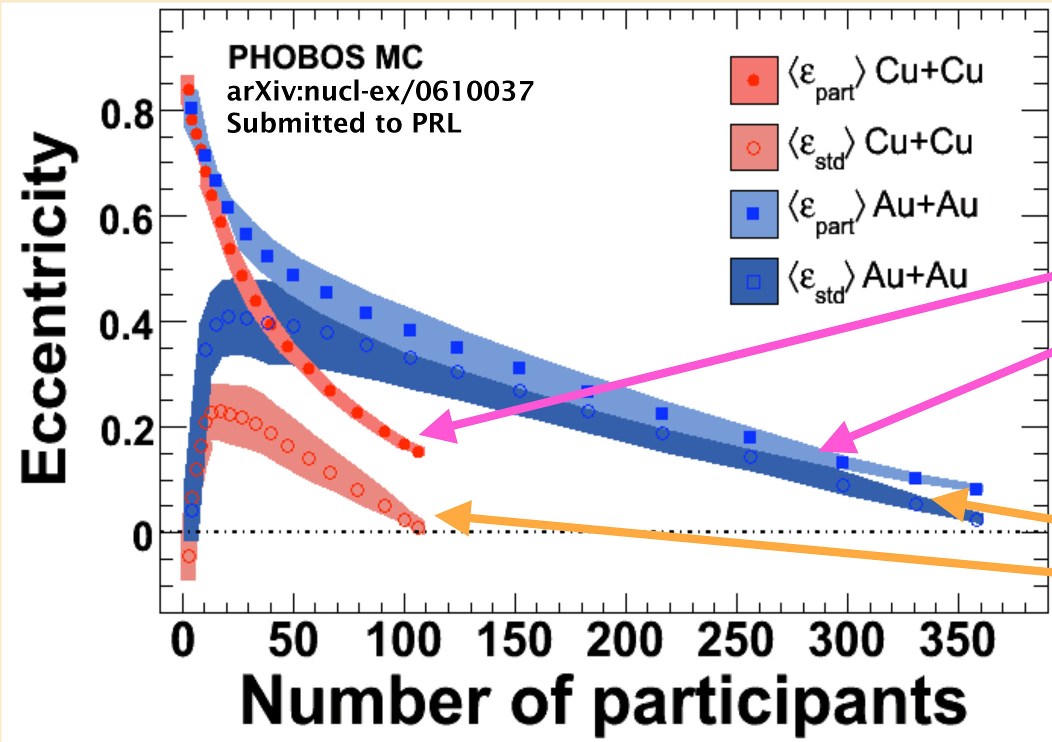


Event 2



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

Quantitative Comparison of Eccentricities



$<\varepsilon_{part}>$
"participant" nucleons
event-by-event calculation

$<\varepsilon_{std}>$
"standard" calculation

The two calcuations **do** differ significantly, more so for smaller systems.

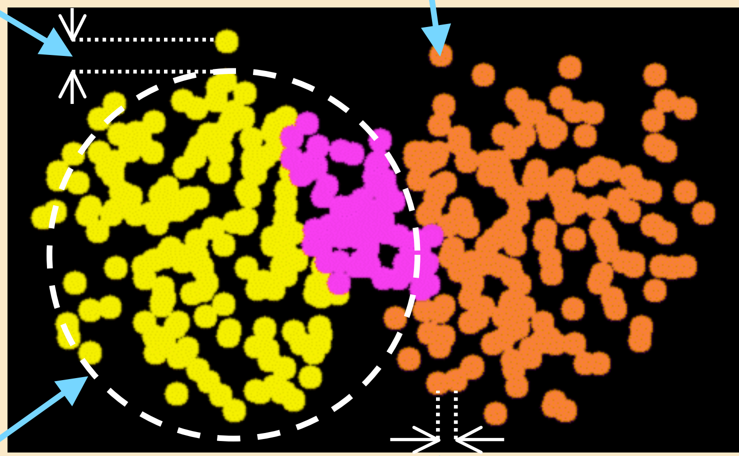
Variability in Calculated Eccentricities

Studied variations in:

σ_{NN}

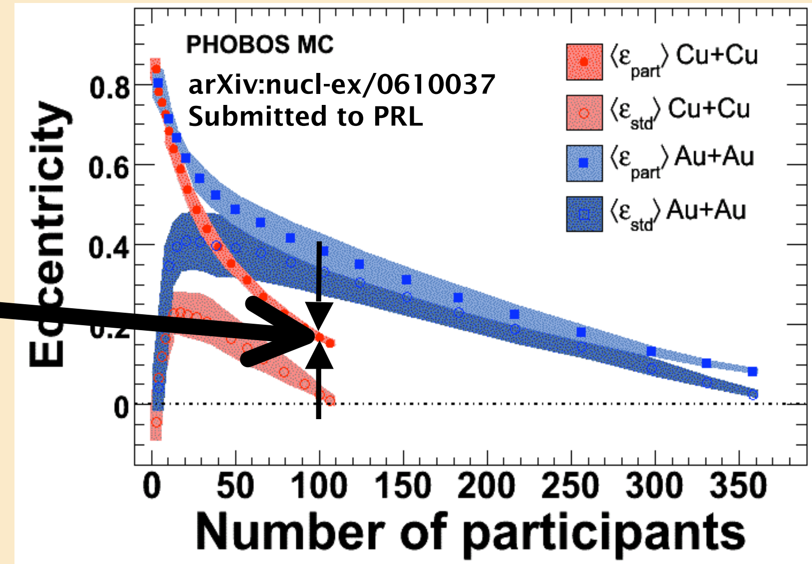
skin depth

nuclear radius



min N-N separation

90% CL bands on calculation



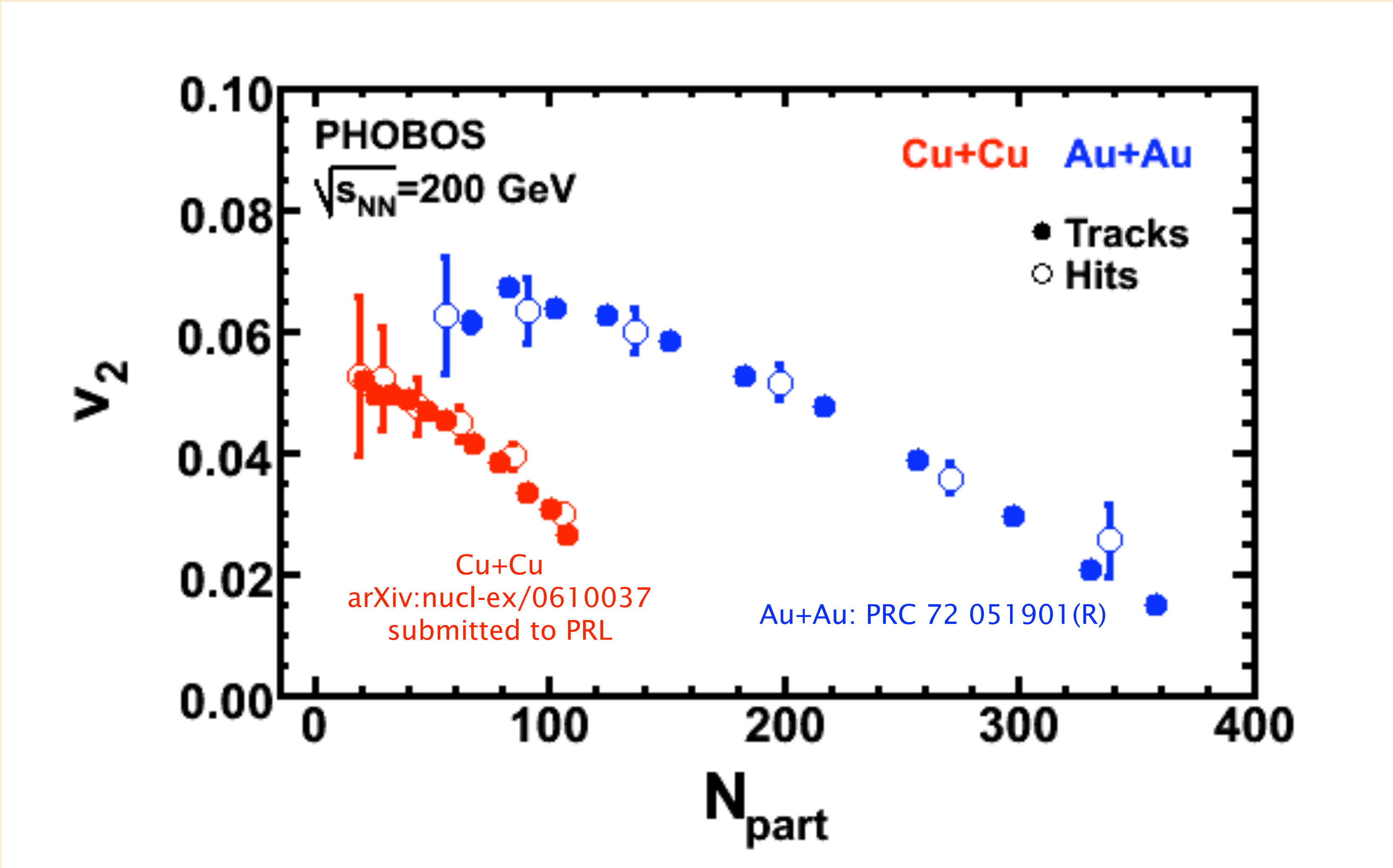
More recent studies in collaboration with Ulrich Heinz have included variations in individual nucleon density profiles and different N_{part} and N_{coll} weighting.

$$\sqrt{\langle \epsilon^2_{\mathrm{part}} \rangle} \approx \langle \epsilon_{\mathrm{part}} \rangle$$

Results of PHOBOS Glauber MC
Motivated by work of:
Bhalerao, Ollitrault – PLB641 260, (2006)
Ollitrault – private communications (2006)

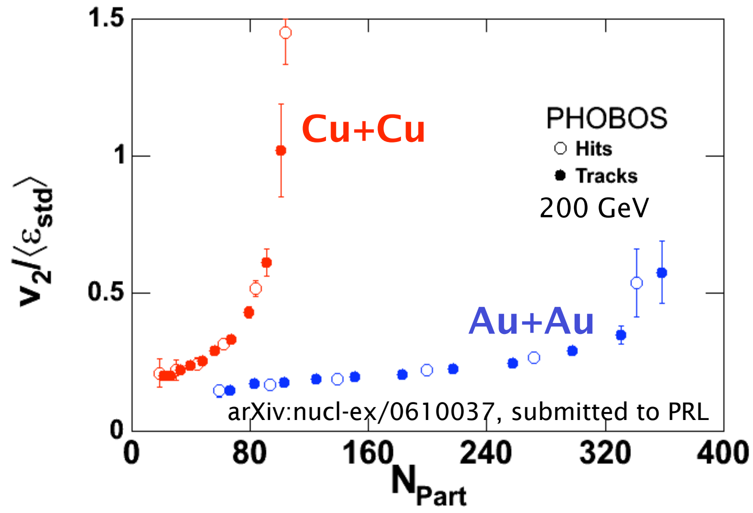
$\langle \epsilon_{\mathrm{part}} \rangle$ calculation from Glauber MC is **robust**

New & Old Data: v_2 in Au+Au, Cu+Cu



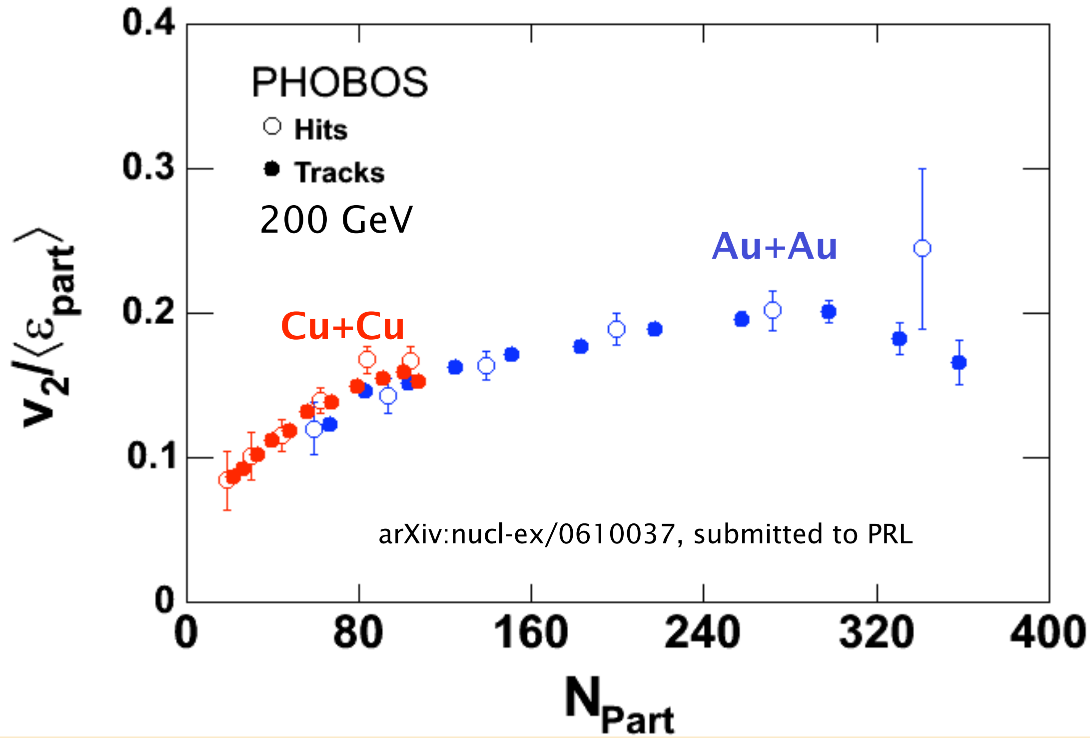
Scaling v_2 by Eccentricity

Standard Eccentricity

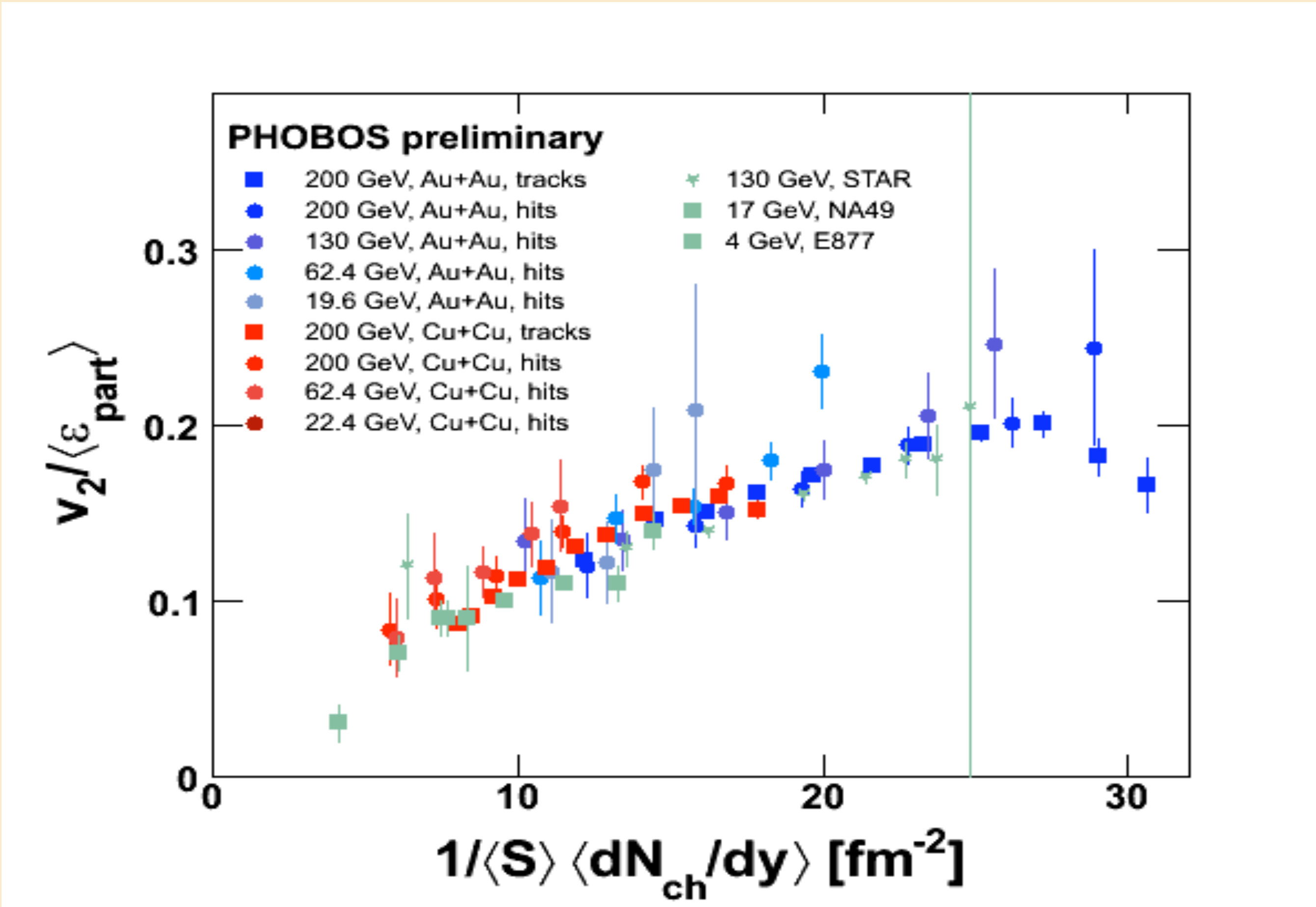


$\langle\epsilon_{\mathrm{part}}\rangle$ **unifies** average v_2 in Cu+Cu and Au+Au

Participant Eccentricity

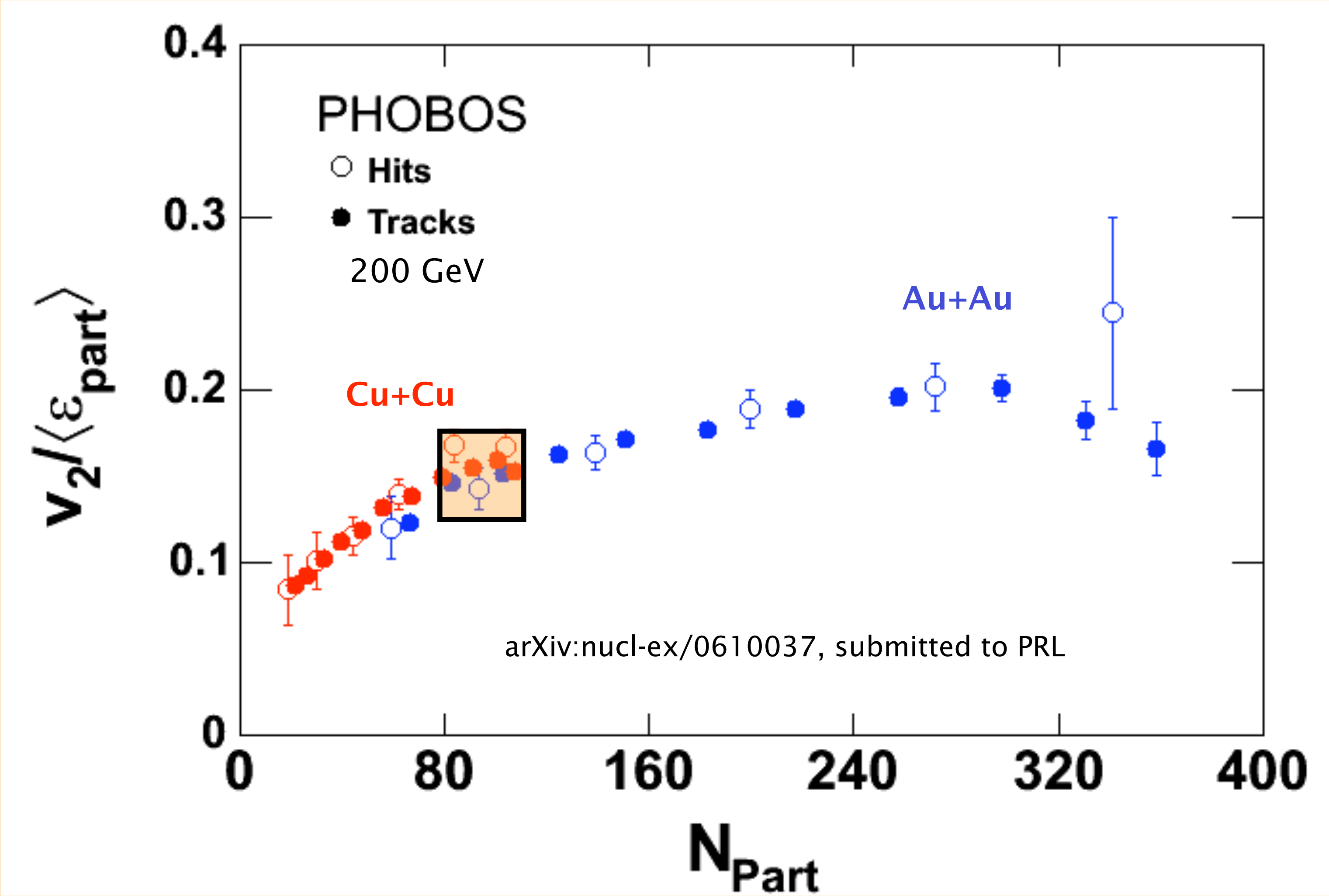


Scaling v_2 by Eccentricity and Particle Density

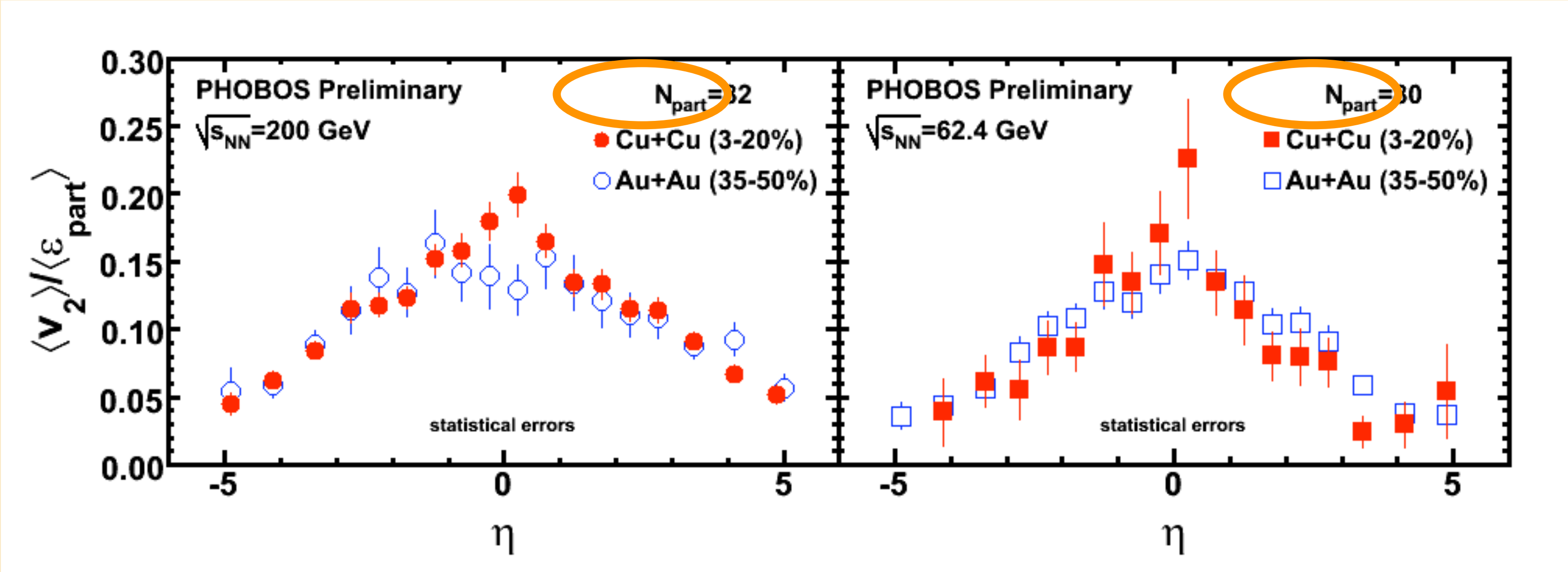


Voloshin, Poskanzer, PLB 474 27 (2000); Heiselberg, Levy, PRC 59 2716, (1999)

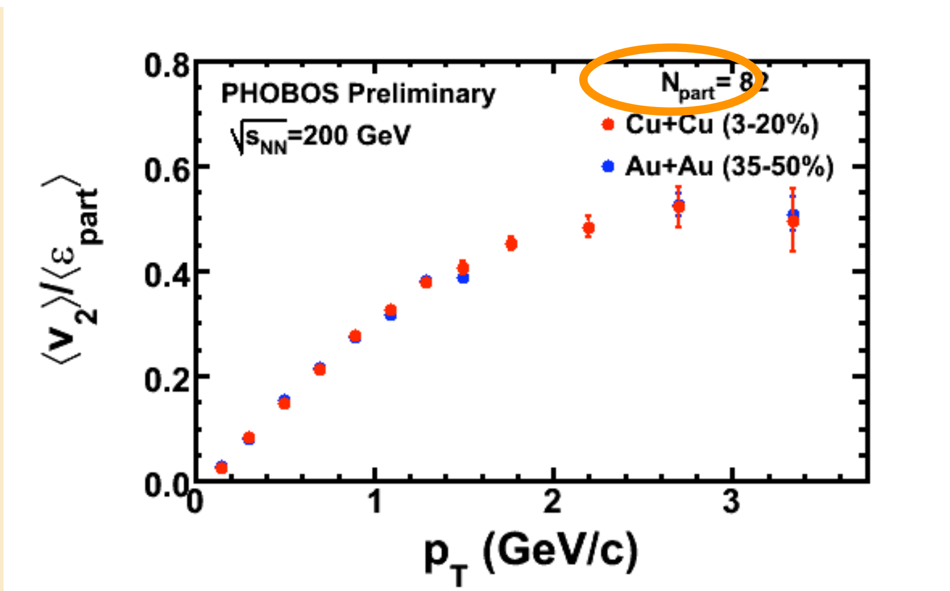
Study v_2 More Differentially



Study v_2 More Differentially



Au+Au & Cu+Cu
at matched N_{part}
Also similar
(1/S)dN/dy



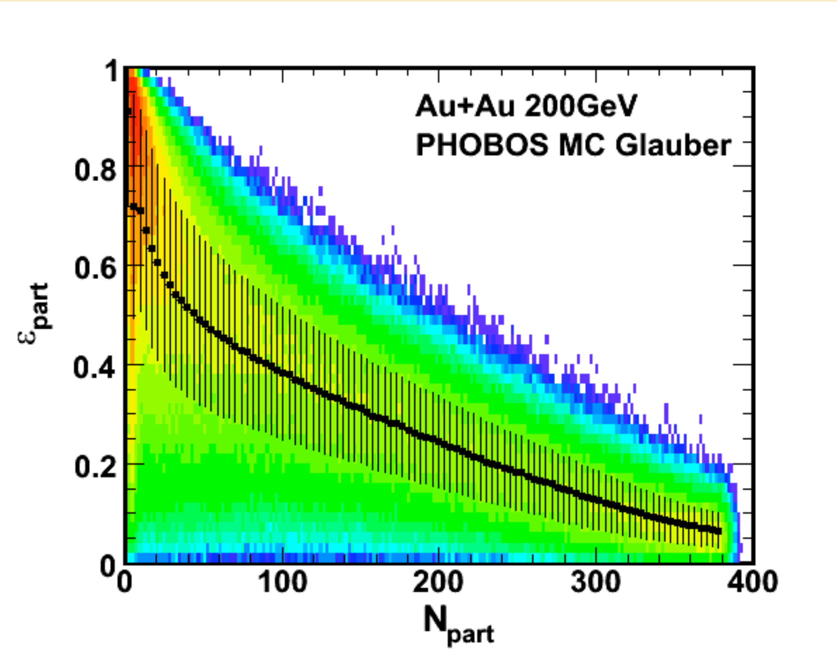
But, does the event-by-event variation matter?

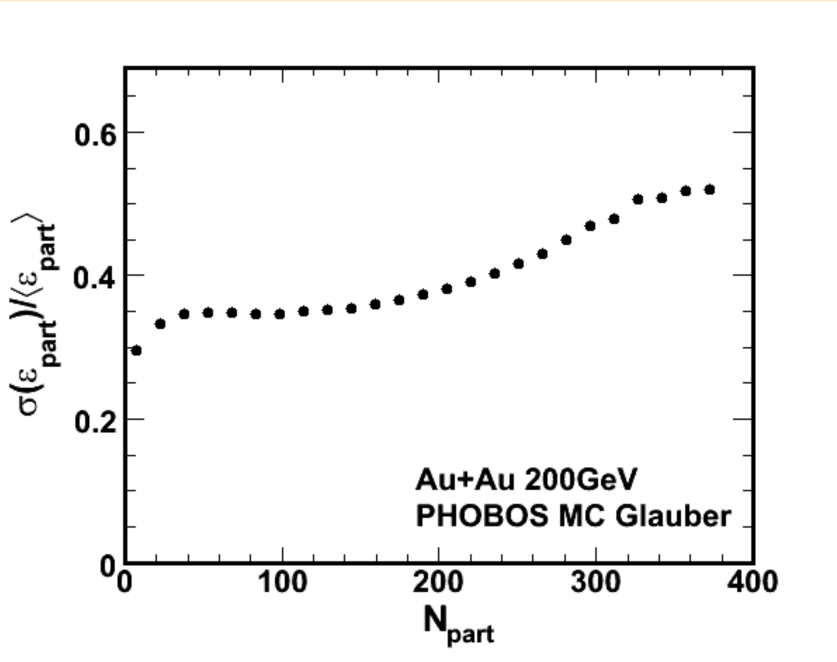
See parallel talk by Constantin Loizides

Fluctuations in Eccentricity

What magnitudes of fluctuations are expected?

Quantify with $\sigma(\varepsilon_{part})/<\varepsilon_{part}>$



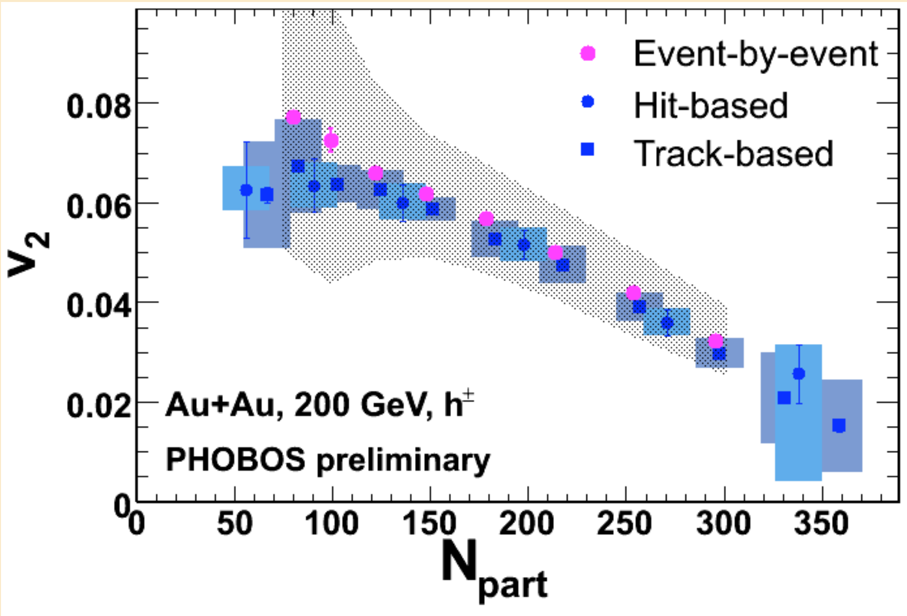


Fluctuations are **large**: ~30-50%

Elliptic Flow **Event-by-Event**

- Utilize full coverage of PHOBOS ($|\eta|<5.4$, $\Delta\phi\sim2\pi$).
- Detailed modeling of detector response, statistical fluctuations and multiplicity dependence.
  - Method is described in arXiv:nucl-ex/0608025
- Measure v_2 on an event-by-event basis.
- Average event-by-event result to compare to our other results.

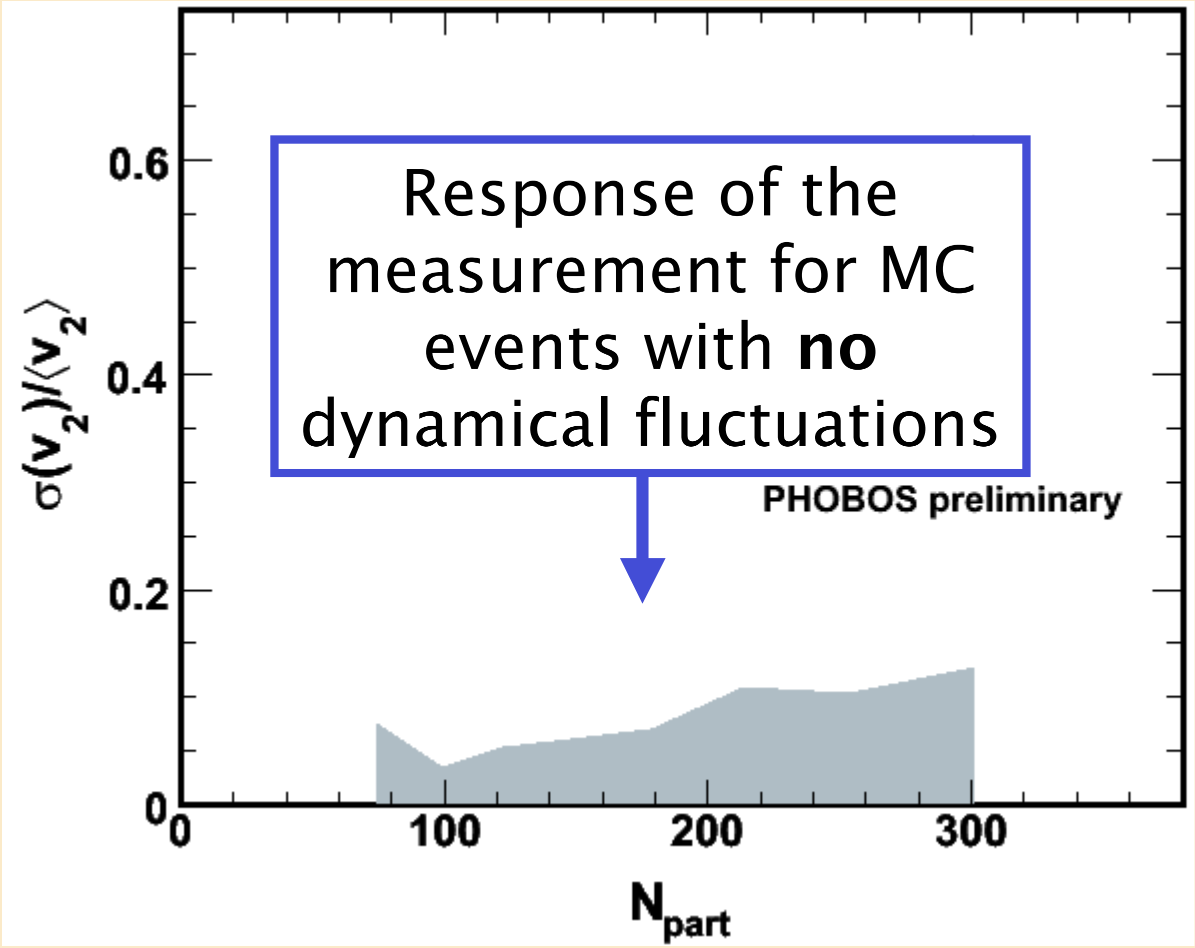
200 GeV Au+Au



$\langle v_2 \rangle$ measured event-by-event is **in agreement** with event averaged results, both hit and track based.

Elliptic Flow **Fluctuations**

$\sigma(v_2)/\langle v_2\rangle$ in 200 GeV Au+Au Collisions

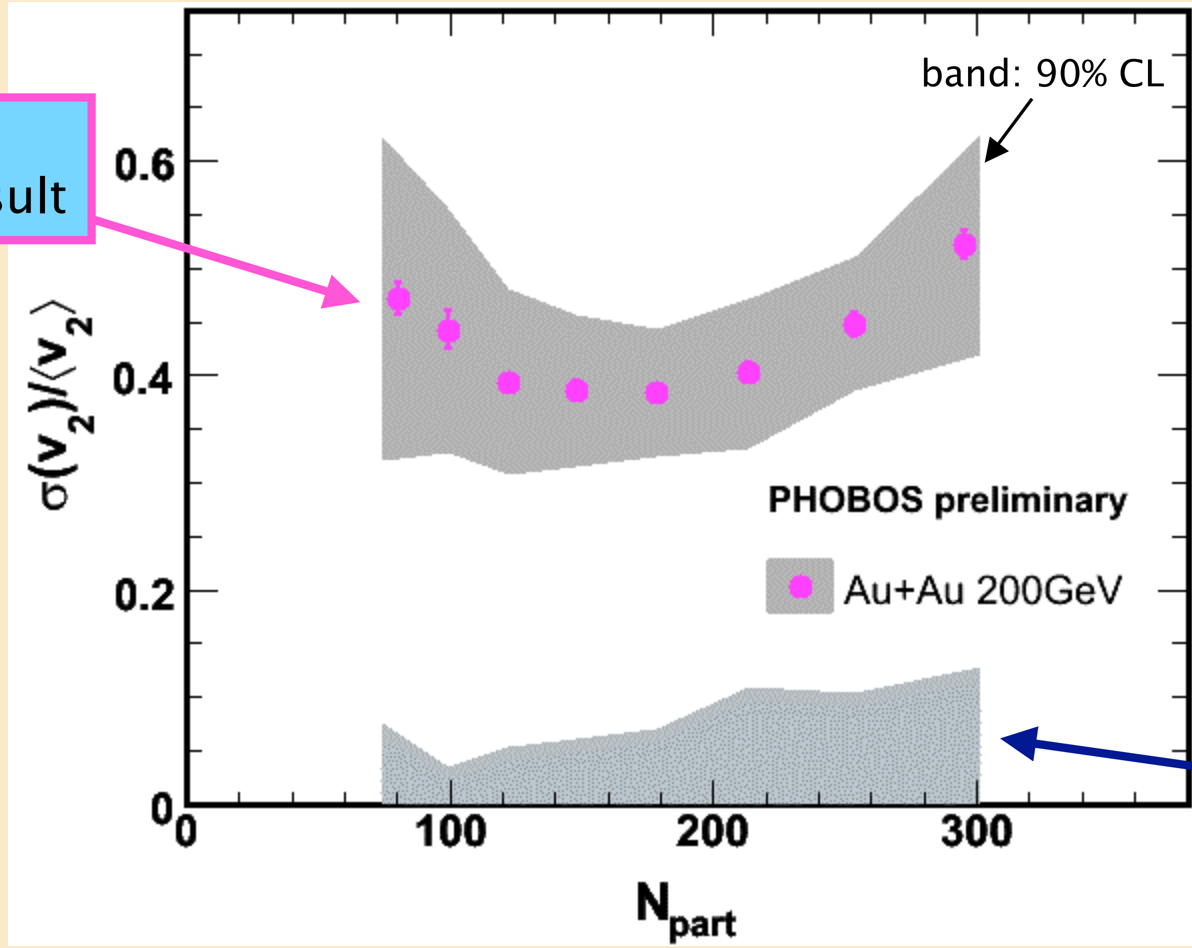


Reminder: this analysis corrects for detector and multiplicity effects as well as statistical fluctuations

Elliptic Flow **Fluctuations**

$\sigma(v_2)/\langle v_2\rangle$ in 200 GeV Au+Au Collisions

PHOBOS $\sigma(v_2)/\langle v_2\rangle$ result

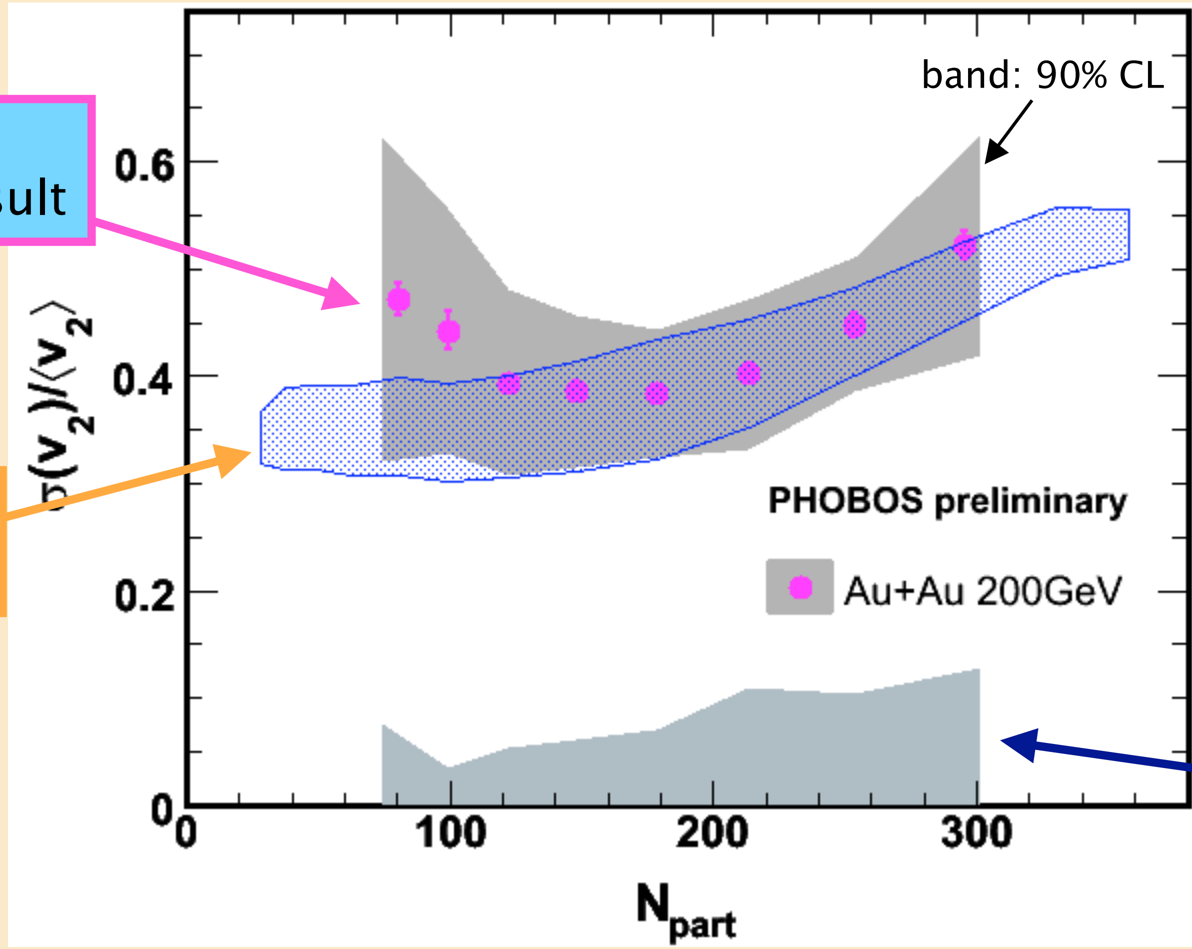


MC with no fluctuations

The data show **significant** dynamical v_2 fluctuations

Elliptic Flow **Fluctuations**

$\sigma(v_2)/<v_2>$ in 200 GeV Au+Au Collisions



PHOBOS $\sigma(v_2)/<v_2>$ result

PHOBOS ε_{part} prediction

MC with no fluctuations

Fluctuations in v_2 are **very similar** to ε_{part} variations

Event-by-Event Elliptic Flow Summary

- Previous evidence: The average azimuthal asymmetry in particle yield is correlated with event centrality in a suggestive way.
- New evidence: The azimuthal asymmetry in a **given** event depends in a suggestive way on the **detailed** shape and orientation of the interaction points of the particles in **that** event.
- {Personal opinion} The evidence that we are observing the evolution of individual “drops” of some form of fluid is increasingly strong.

Ongoing/Future PHOBOS Physics Topics

- Rare events, multiplicity fluctuations, and comparisons to cluster models
- More dynamical flow fluctuations
- Two-particle correlations using high-p_T trigger particles measured in the spectrometer.
- Identified particles at low p_T in 200 GeV Au+Au as a detailed function of centrality
- Spectator breakup in the fragmentation region
- Charged particle yields in 200 & 410 GeV p+p
- ϕ-meson production

Monty PHOBOS and the Holy Grail

I'm not dead yet…

In fact, I just had another idea…

Image from http://www.intriguing.com/mp/

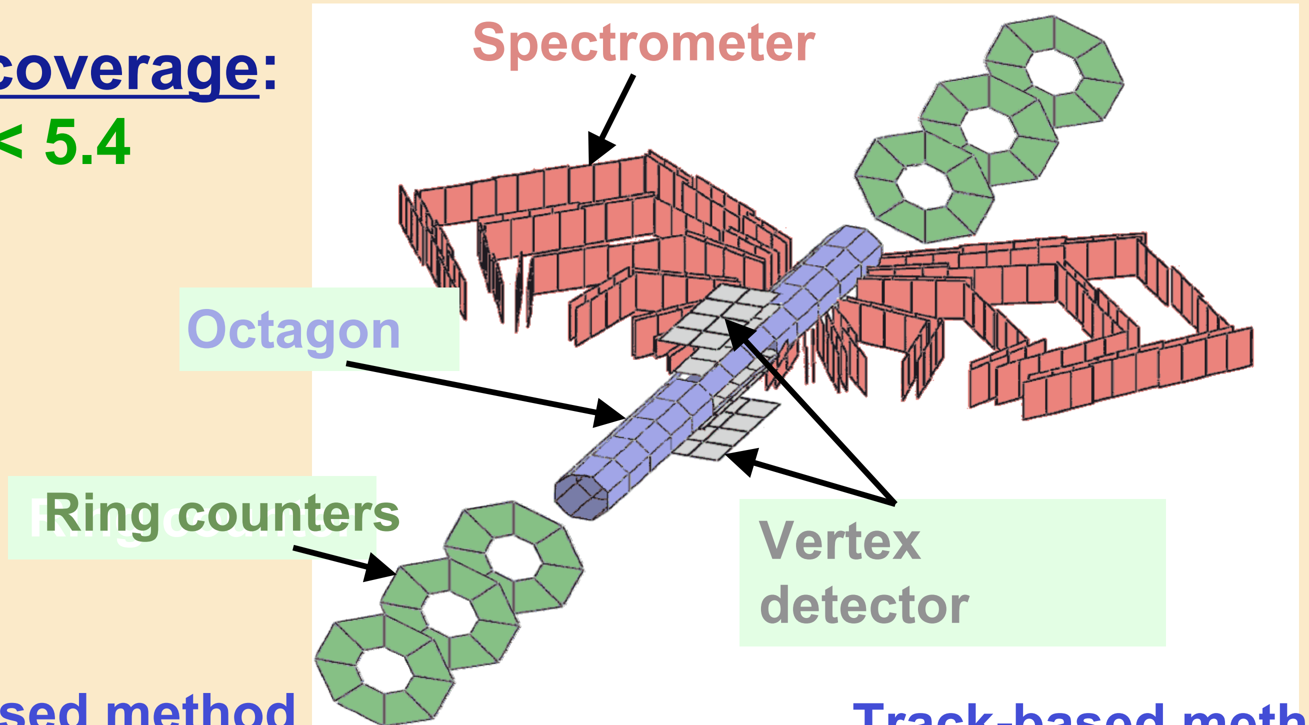
Summary of Backup Slides

- From R. Nouicer's talk (Flow)
  - 44 Measuring flow in PHOBOS
  - 45 Track-based method details
  - 46 Moments of ε_{part}
- From C. Loizides' talk (v_2 fluct.)
  - 47 Overview e-by-e v_2 meas.
  - 48 Methodology
  - 49 Glauber overview
  - 50 Glauber Robustness
- From W. Li's talk (2-part. corr.)
  - 51 Methodology
  - 52 Cluster size parameterization
- From G. Veres' talk (ident. part.)
  - 53 PHOBOS PID capability
  - 54 Particle ratios measurement

Measuring Flow in PHOBOS

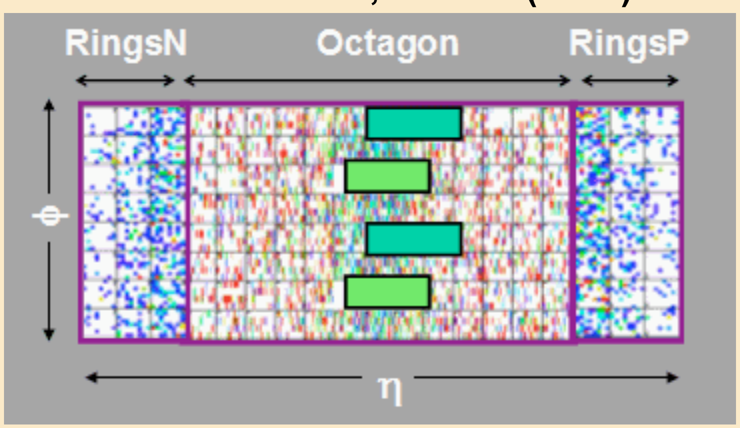
Large coverage:

$|\eta| < 5.4$



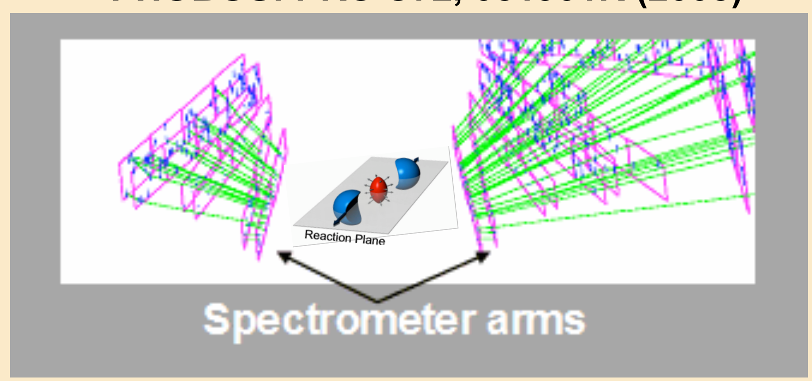
Hit-based method

PHOBOS: PRL 89, 222301 (2002)



Track-based method

PHOBOS: PRC C72, 051901R (2005)

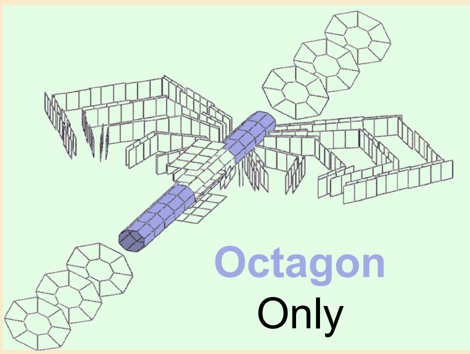


Track-based method: Robustness of Measurements of v_2 vs. p_T

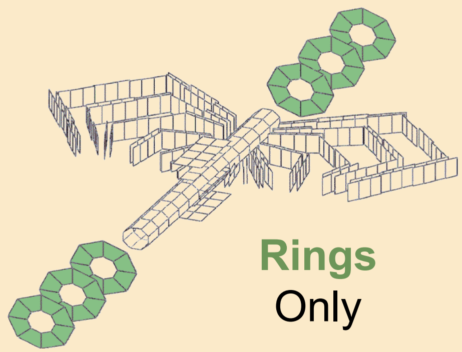
The large separation on η between the reaction plane subevents and the measured region reduces the non-flow correlations in track-based (hit-based) method.

- **Reaction plane subevents**

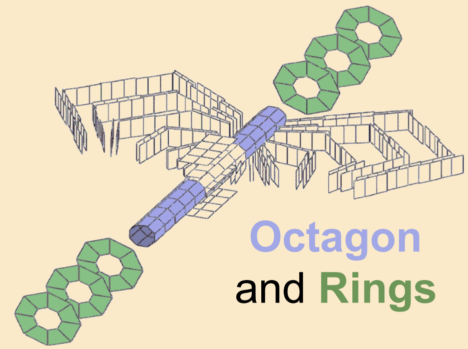
1) $2.0 < |\eta| < 3.2$



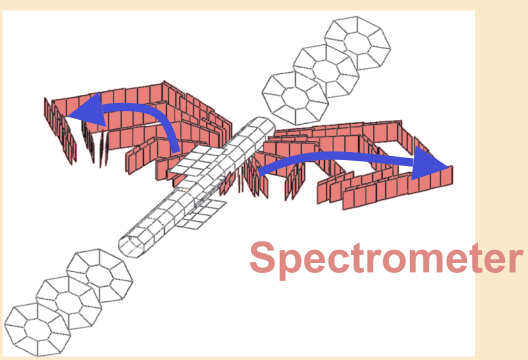
2) $3.0 < |\eta| < 5.4$



3) $2.0 < |\eta| < 5.4$

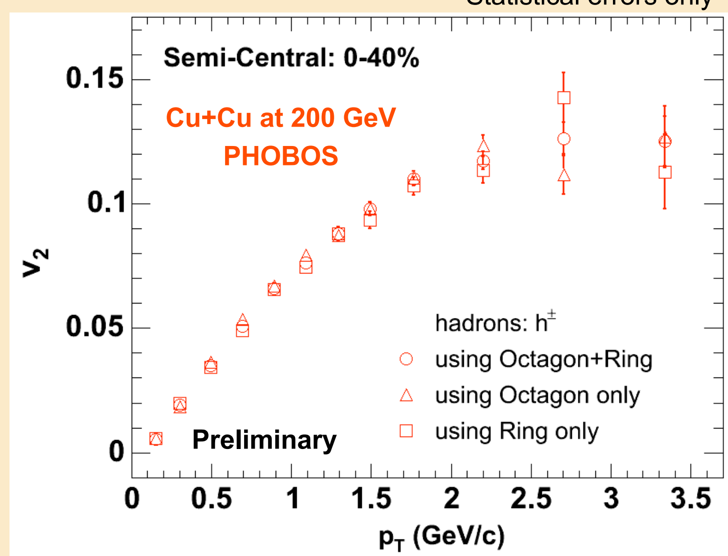


- **$v_2(p_T)$ measured in $0 < \eta < 1.6$**



Track-based method

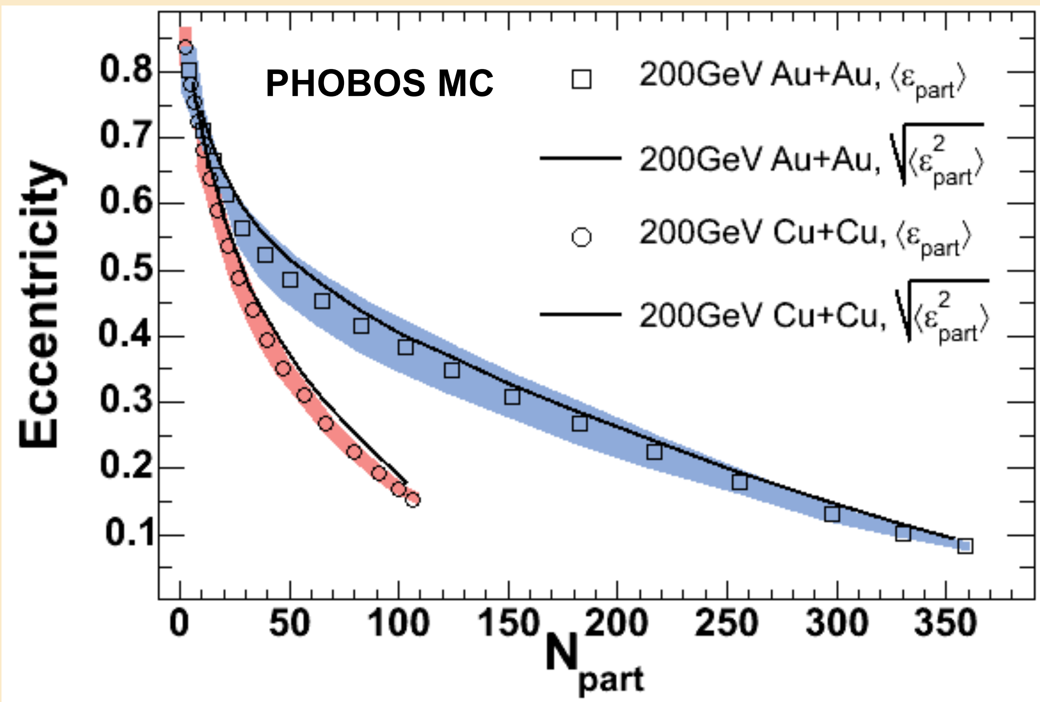
Statistical errors only



Theorists & PHOBOS since QM2005

It has been suggested that v_2 may scale as $\sqrt{\langle \varepsilon_{part}^2 \rangle}$ instead of $\langle \varepsilon_{part} \rangle$

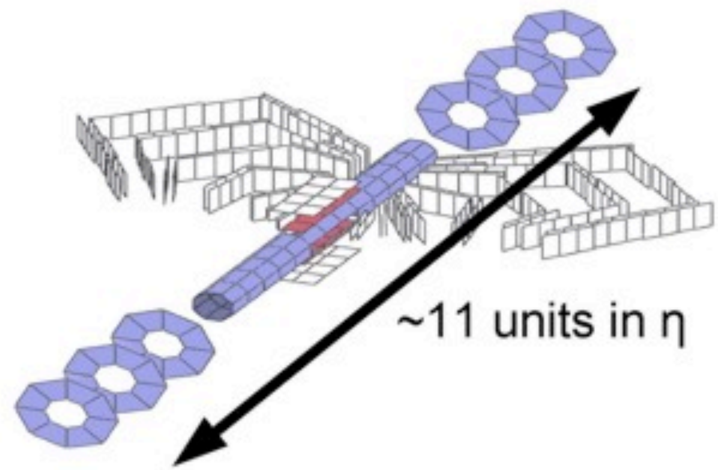
- Bhalerao, Ollitrault – PLB 641, 260 (2006)
- Ollitrault – private communications (2006)

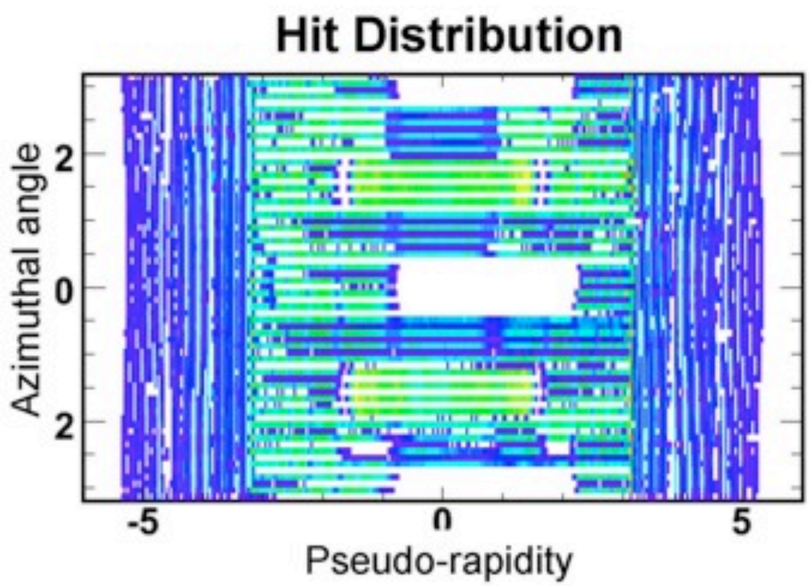


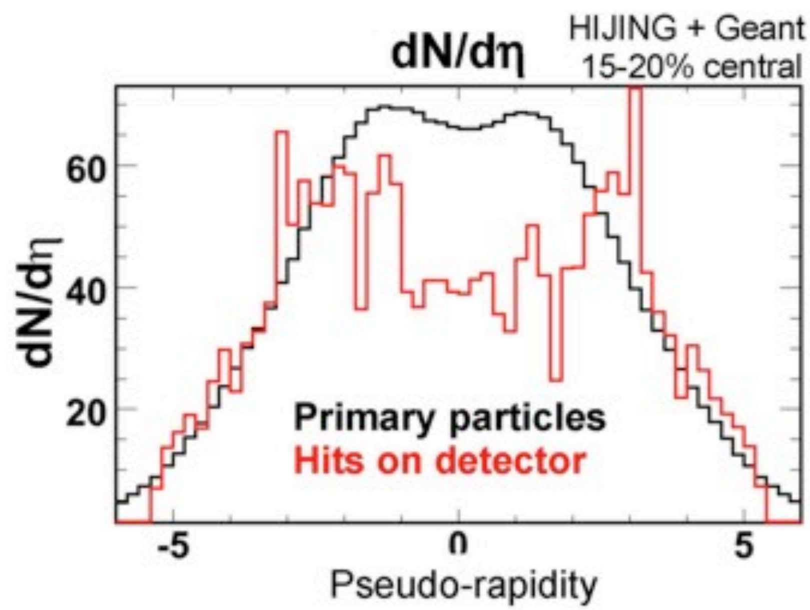
- In Collaboration with Ulrich Heinz

Event-by-event measurement of v_2^{obs}

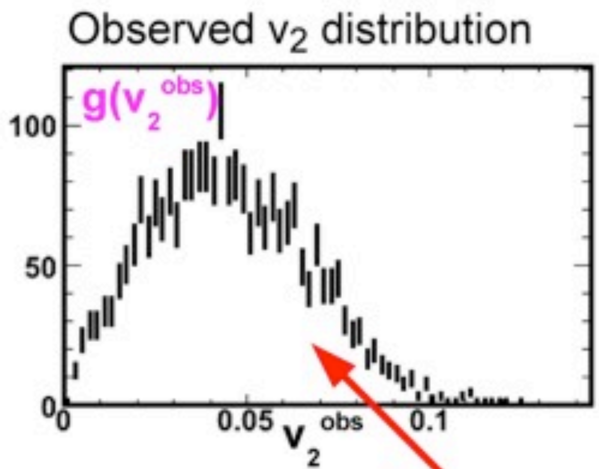
- PHOBOS Multiplicity Array
  - $-5.4<\eta<5.4$ coverage
  - Holes and granularity differences
- Usage of all available information in event to determine event-by-event a single value for v_2^{obs}

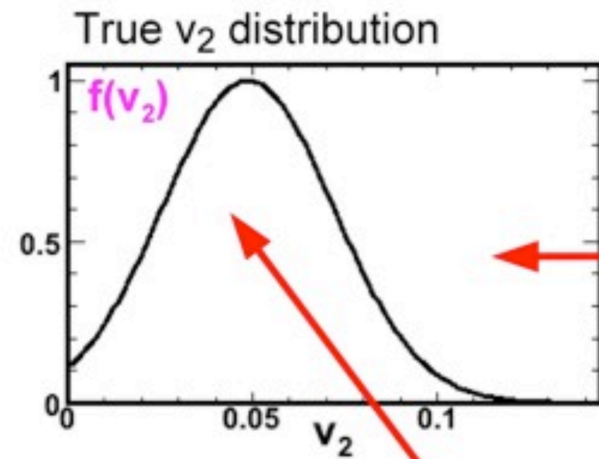


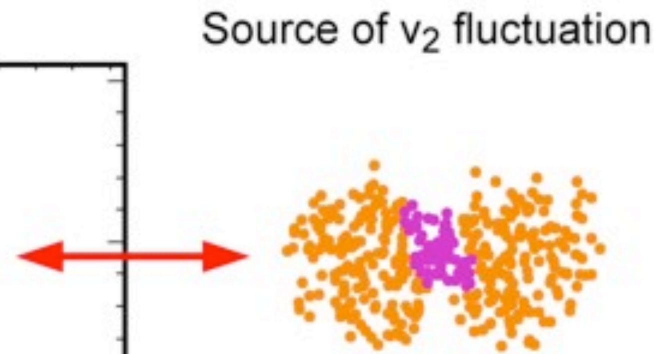




Measuring elliptic flow fluctuations



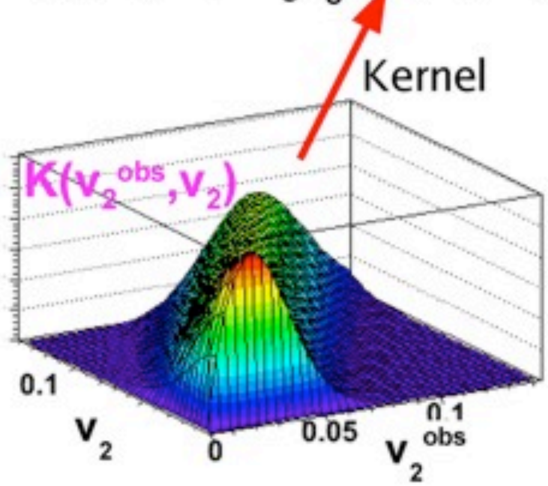




$$g(v_2^{obs}) = \int_0^1 K(v_2^{obs}, v_2) f(v_2) dv_2$$

Kernel

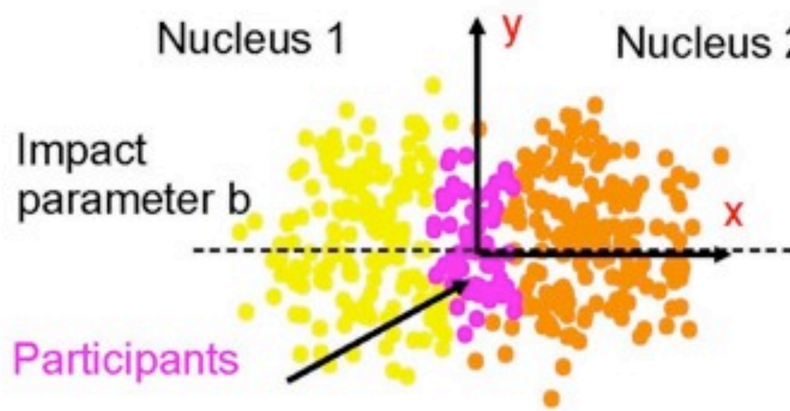
- Detector and acceptance effects
- Finite-number fluctuations
- Multiplicity fluctuations



Glauber MC

- Glauber Monte Carlo
  - Radial distribution of nucleons (in nucleus) drawn from Wood-Saxon distribution
  - Isotropic angular distribution
  - Separate by impact parameter
  - Nucleons travel on straight-line paths and interact inelastically when

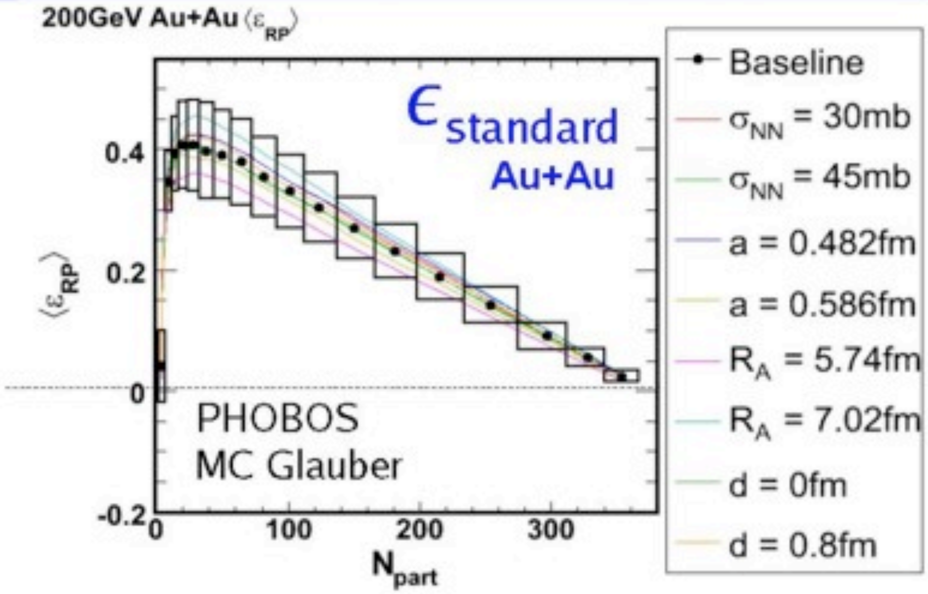
$$d=\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}<\sqrt{\sigma_{NN}/\pi}$$

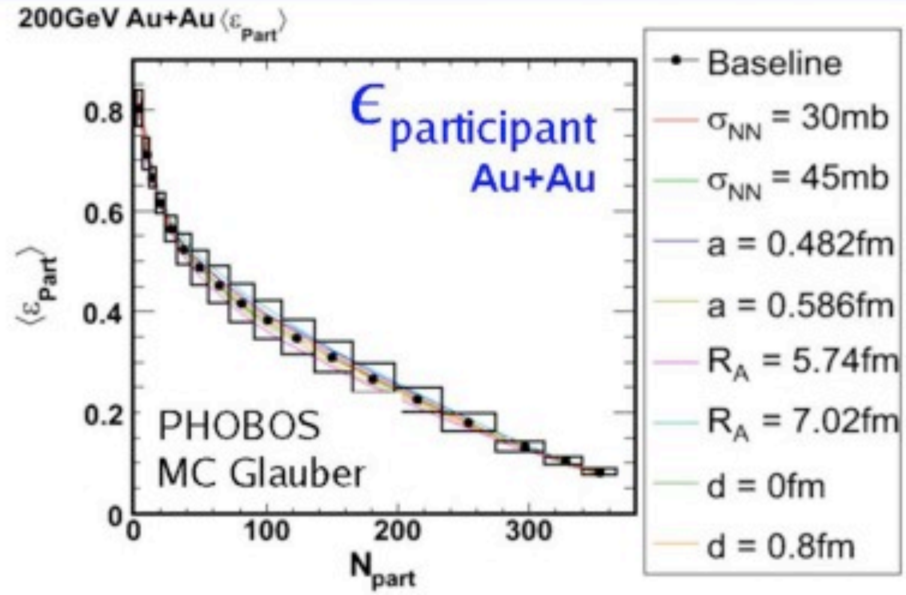


- Centrality of collision
  - #Participants
    - Nucleons that interact at least once
  - Related to cross section and impact parameter range
- Eccentricity of collision zone
  - Given by participants position distributions

Eccentricity: $\epsilon_{std}=\frac{\sigma_y^2-\sigma_x^2}{\sigma_y^2+\sigma_x^2}$

Robustness with geometry variables





- Variation of
  - Nucleon-nucleon cross section (30-45mb)
  - Nuclear radius (±10% from the nominal value)
  - Skin depth (0.482-0.586fm)
  - Minimum separation distance between nucleons (d=0-0.8fm)

$$\rho(r) = \frac{\rho_0}{1+\exp((r-R)/a)}$$

$\epsilon_{participant}$ even slightly more robust than $\epsilon_{standard}$

Methodology

Two-particle correlation function:

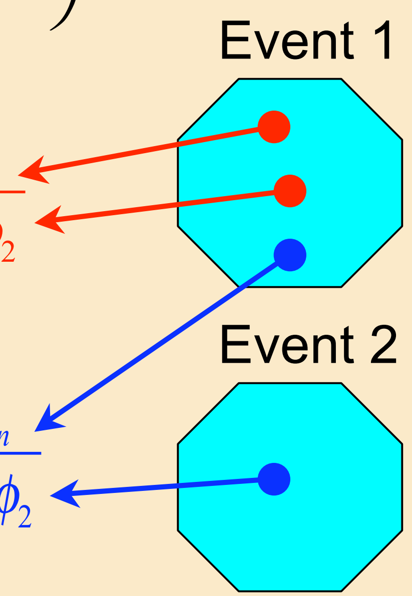
$$R(\Delta\eta,\Delta\phi) = < (n-1)\left(\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1\right) >$$

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:

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



Parameterize cluster size (multiplicity)

Quantitatively understand cluster phenomena

Two-particle rapidity correlation function:

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

correlations between particles from one cluster

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

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

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

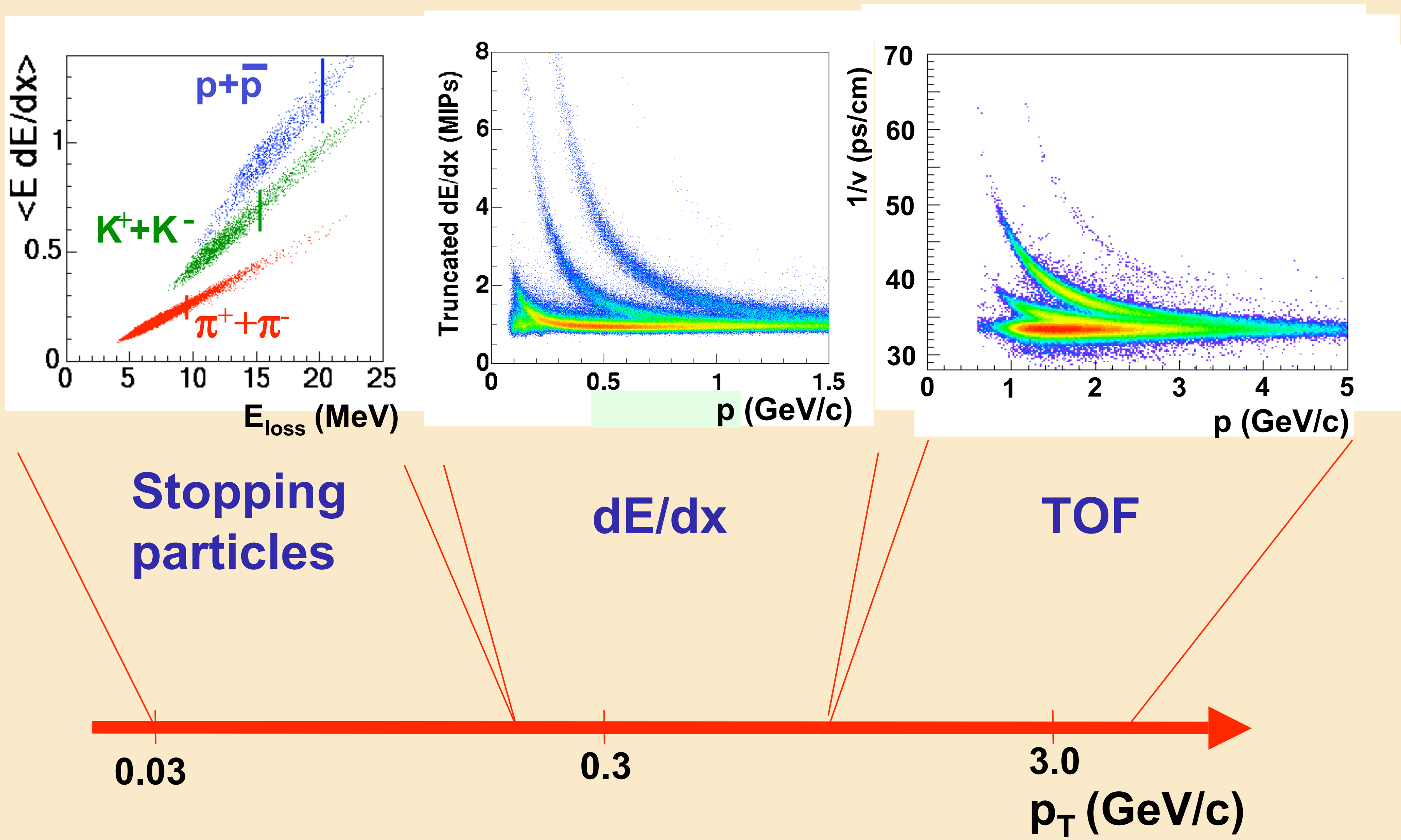
k: cluster size

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

K_{eff} : effective cluster size

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

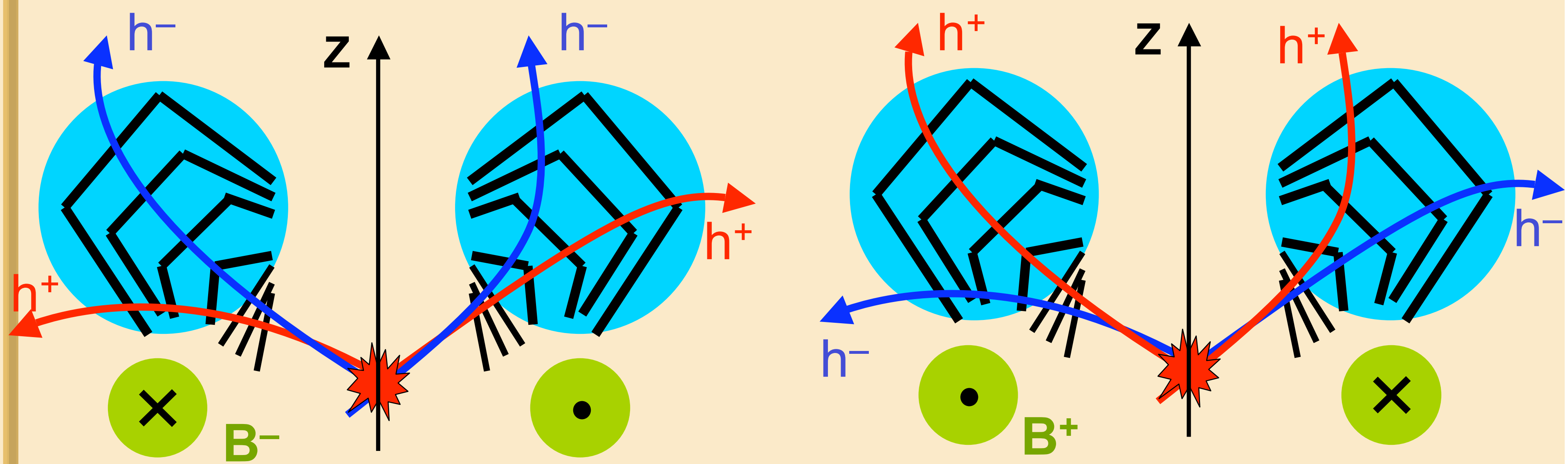
PHOBOS PID Capabilities



Particle ID from low to high p_T

Controlling systematic uncertainties

by changing the polarity of the magnetic field



Geometrical *a*cceptance drops out of the ratios:

$$a(p_{B^+}) = a(\overline{p}_{B^-})$$

$$a(p_{B^-}) = a(\overline{p}_{B^+})$$

Ratios measured independently for different:

- bending directions
- spectrometer arms