Recent results from PHOBOS

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for the PHOBOS collaboration

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Strangeness in Quark Matter (SQM 2007),
June 24-29, 2007, Levoča, Slovakia

PHOBOS collaboration

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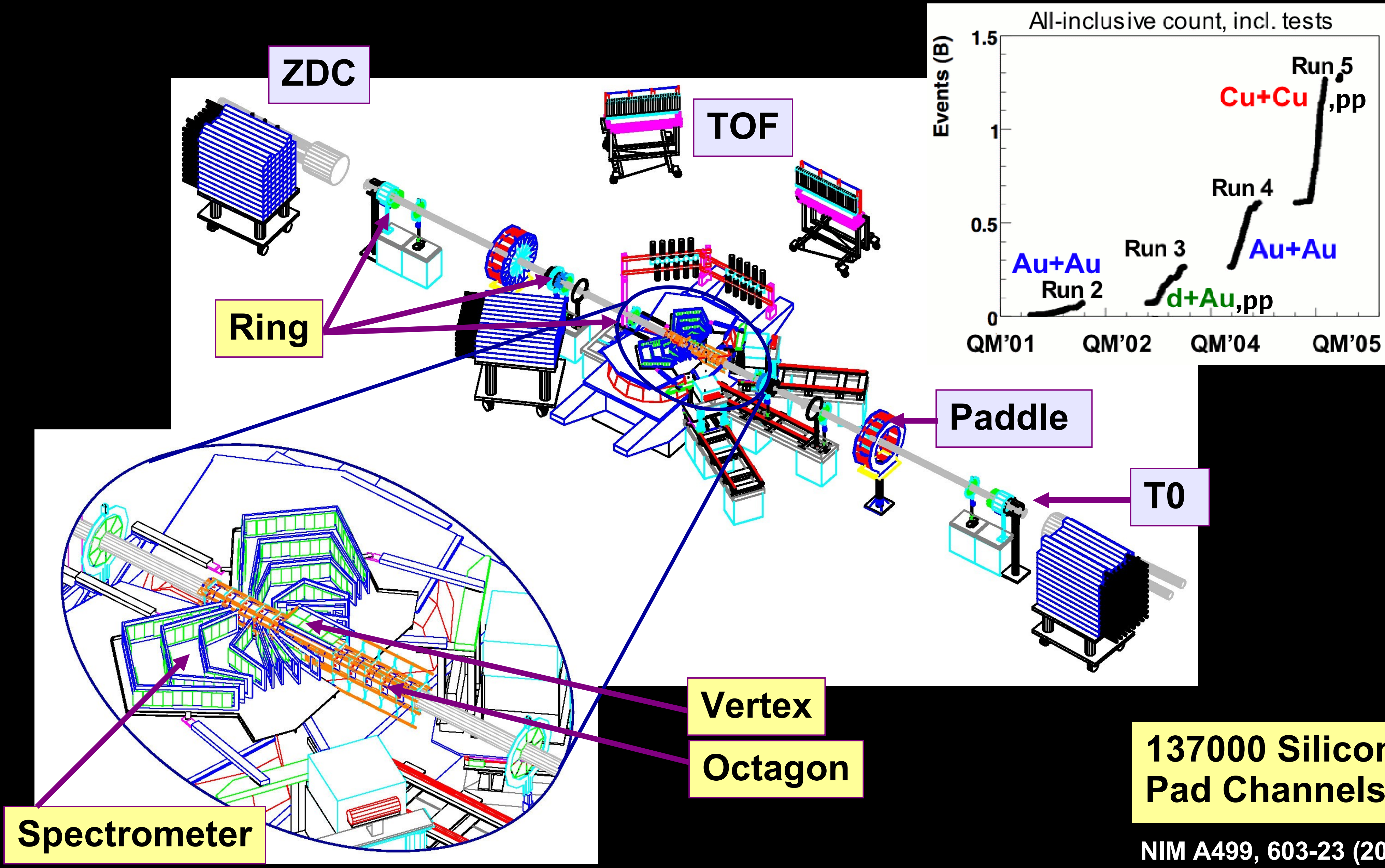
BROOKHAVEN NATIONAL LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

46 scientists, 8 institutions, 9 PhD students

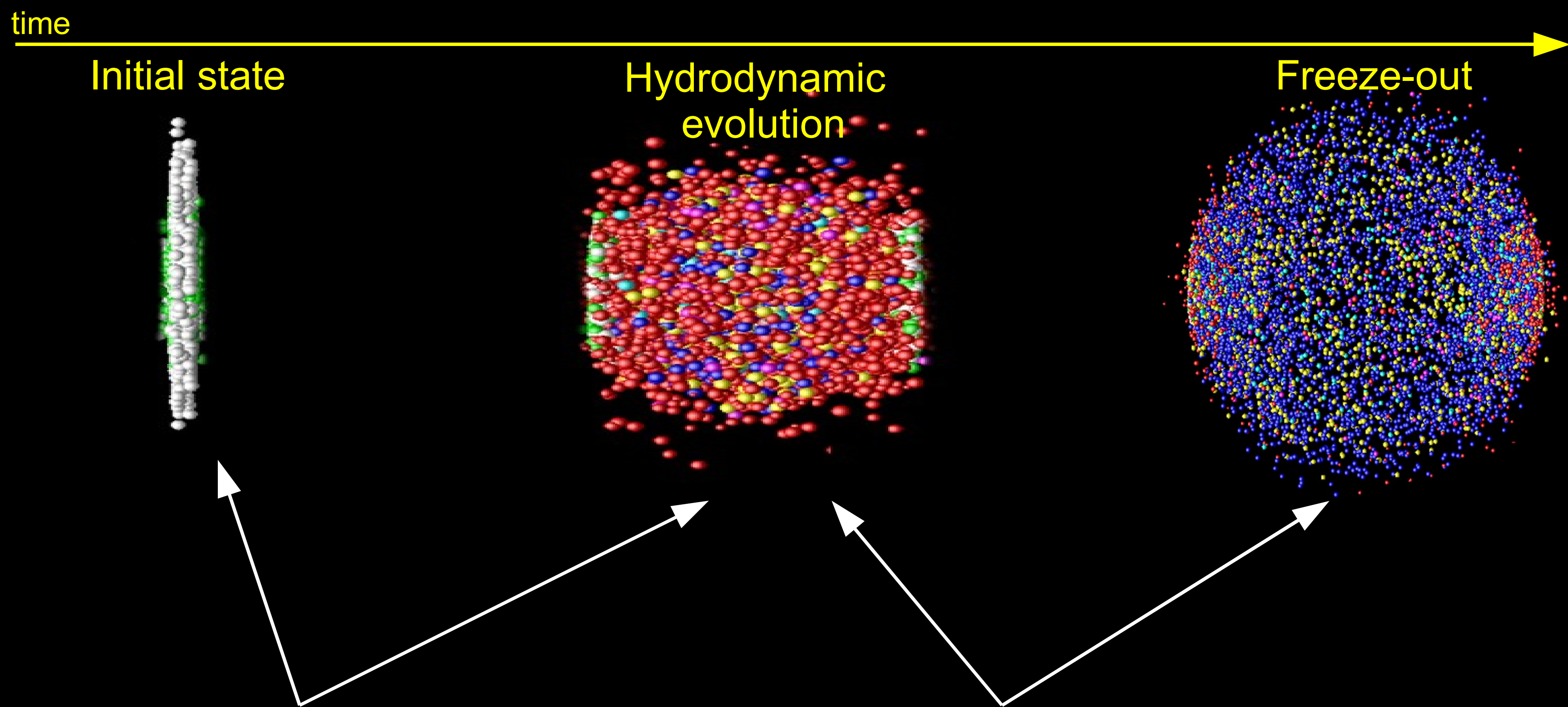
PHOBOS experiment



137000 Silicon Pad Channels

NIM A499, 603-23 (2003)

Outline

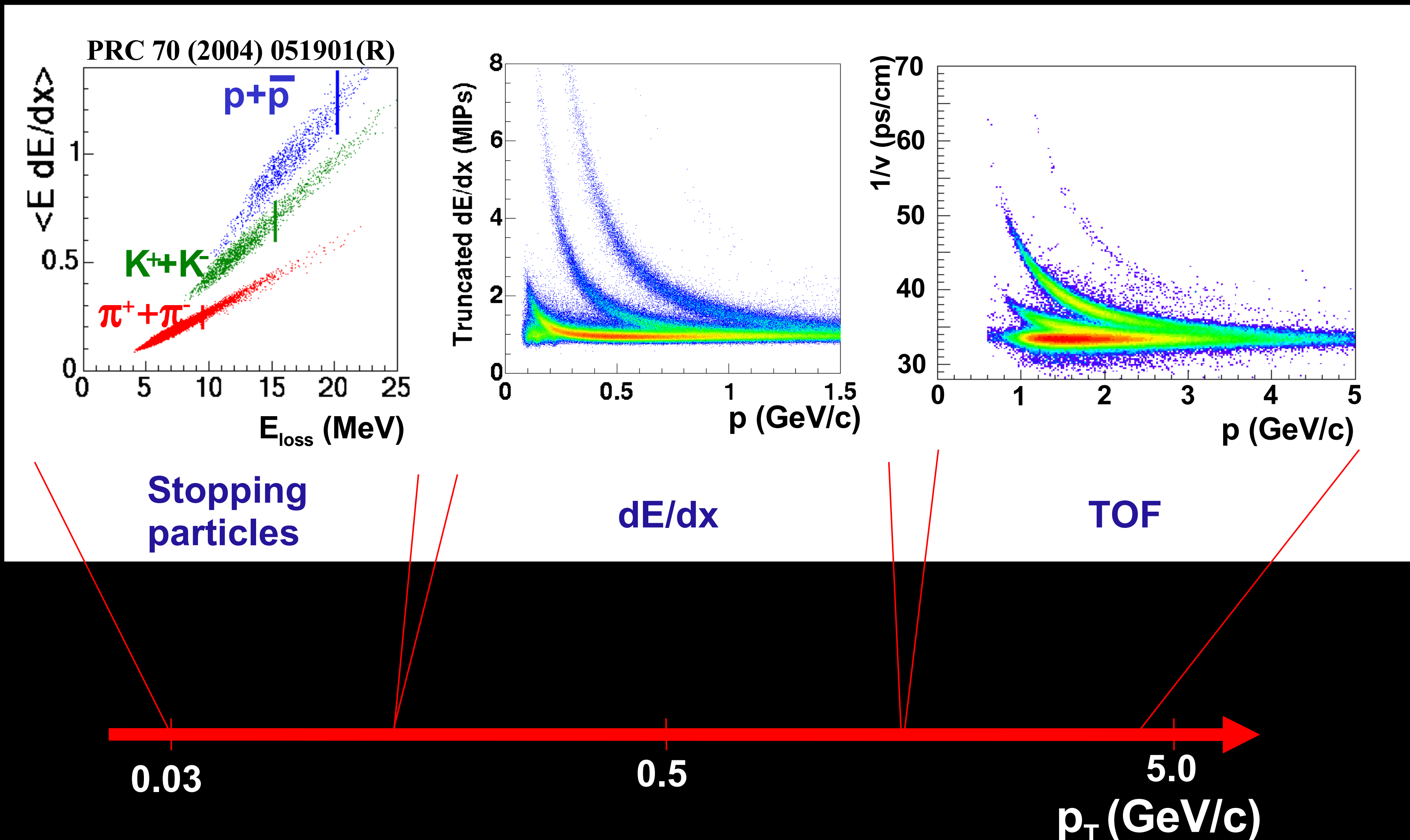


Elliptic flow
Initial state fluctuations
Elliptic flow fluctuations

Identified spectra
Anti-particle/particle ratios
Two particle correlations

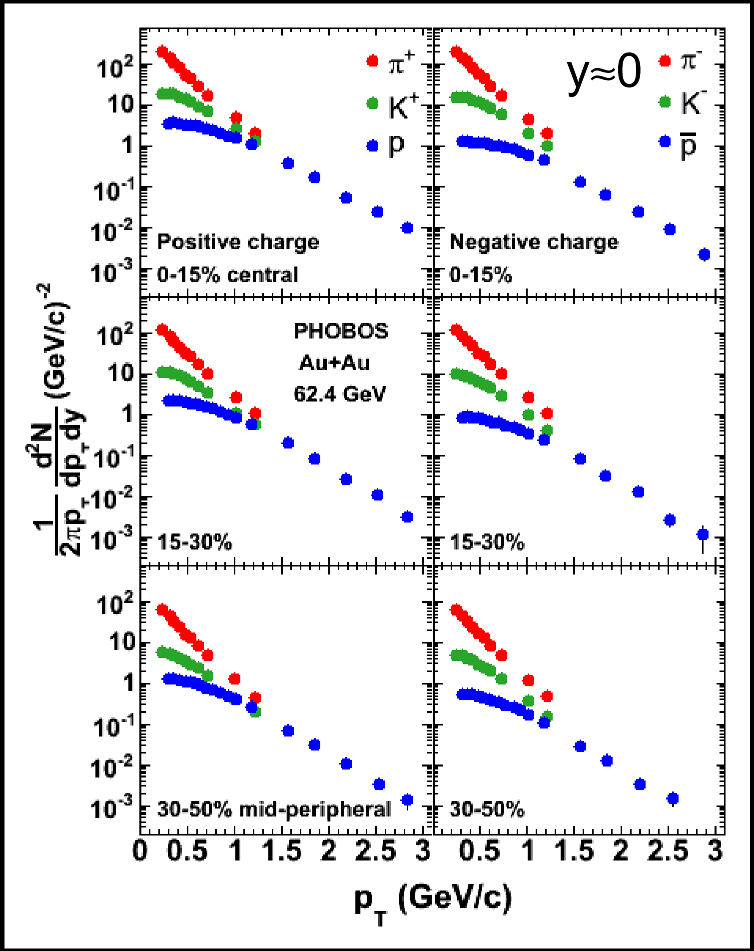
Recent results covered in this talk:
presented at QM06
preprint/publication since QM06

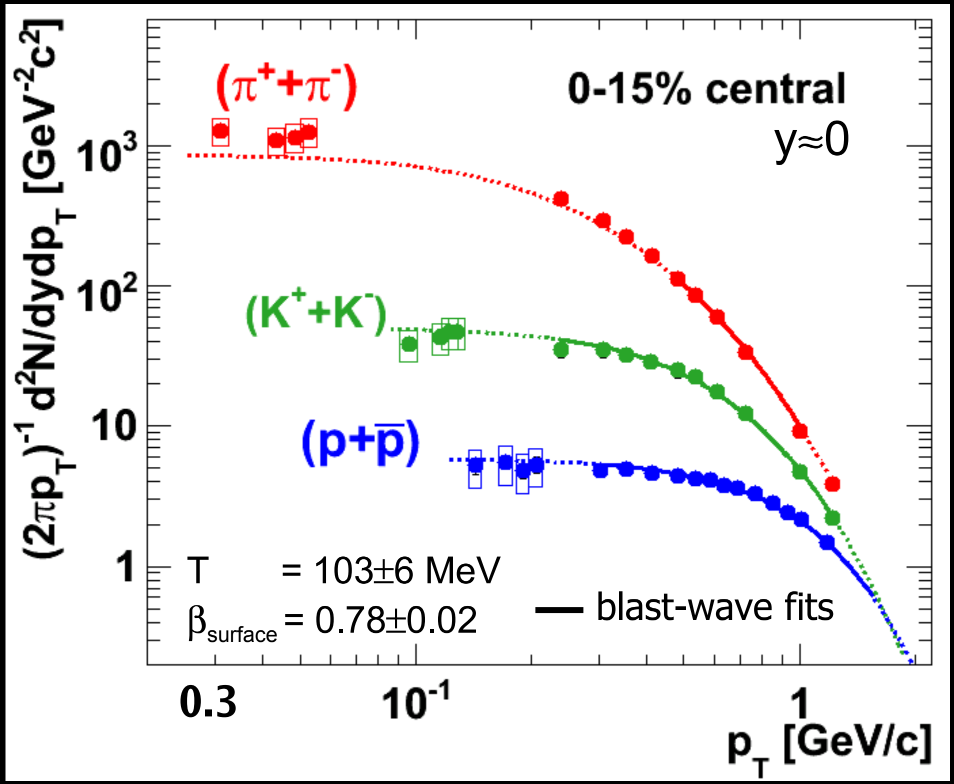
PHOBOS PID capabilities



Particle ID from very low to high p_T

Identified particle spectra at 62.4 GeV





First published identified spectra for 62.4 GeV Au+Au at RHIC

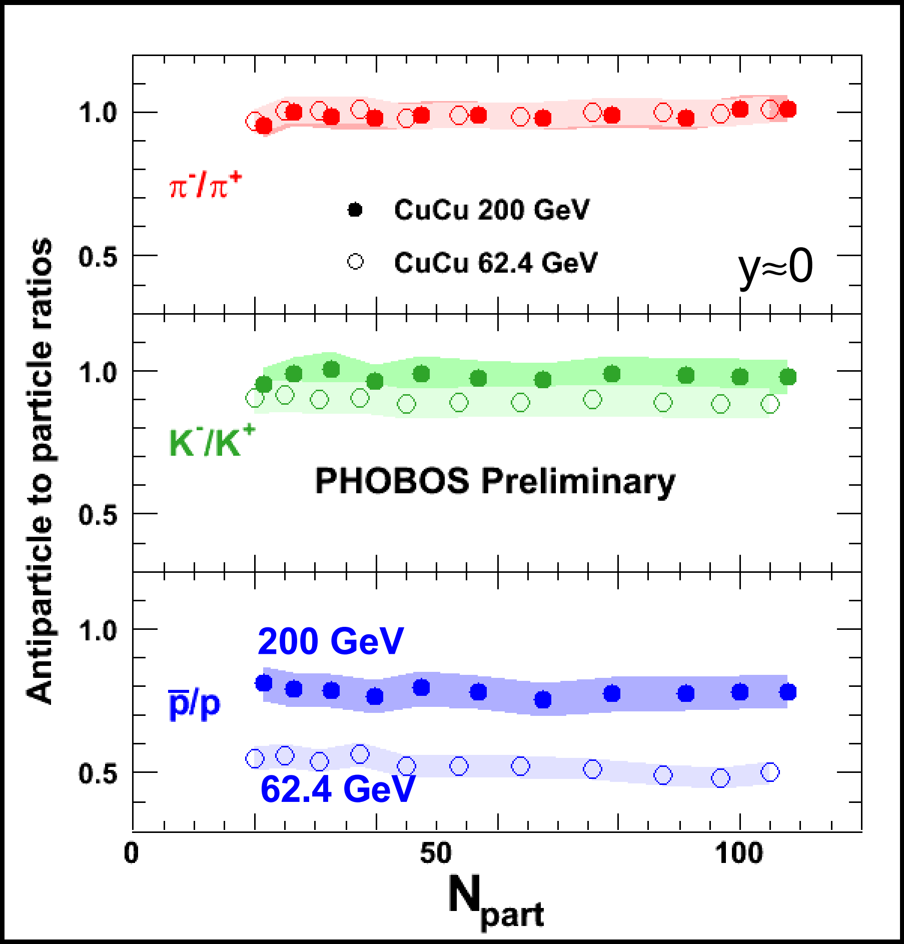
Down to very low p_T, a unique PHOBOS measurement: no anomalous enhancement is observed

(as one would expect for a large volume + weakly interacting system)

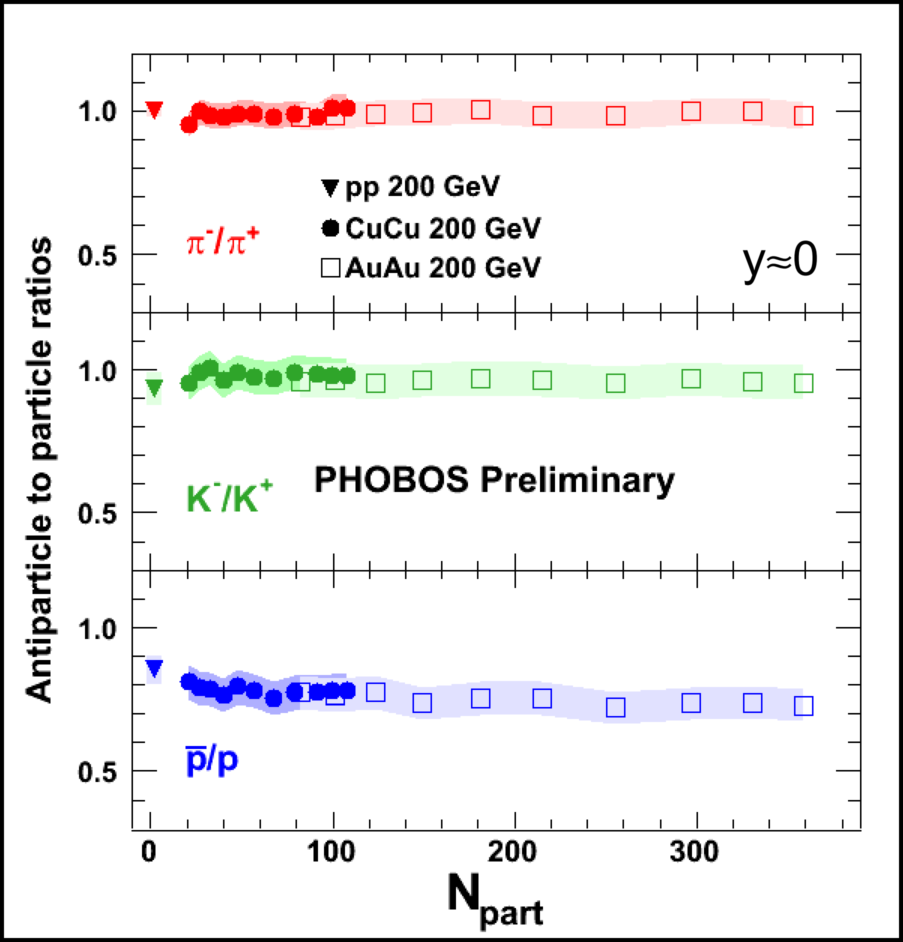
PRC 75 024910 (2007)

Anti-particle / particle ratios

200 and 62.4 GeV Cu+Cu



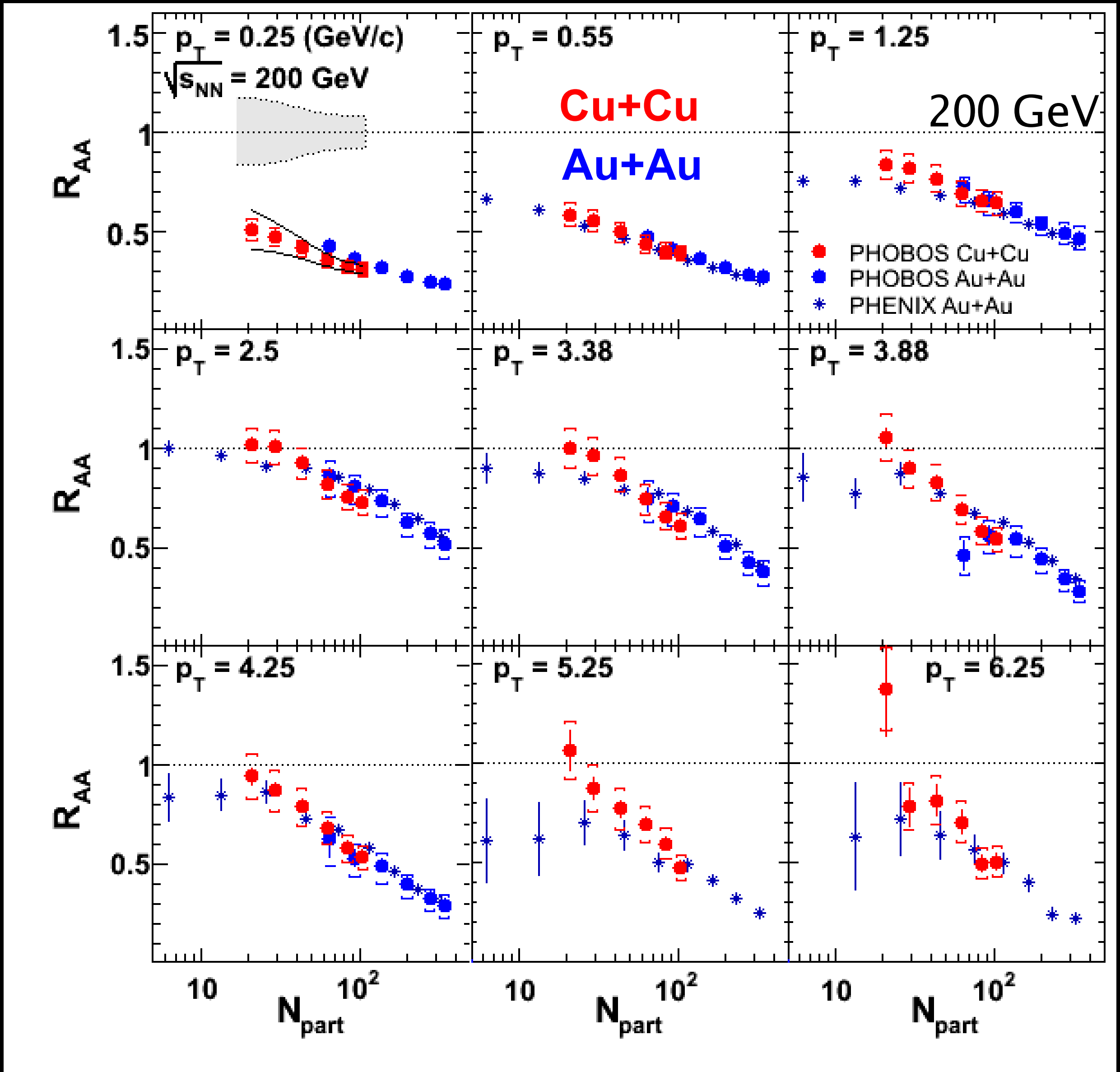
200 GeV Cu+Cu and Au+Au



At most weak centrality or system size dependence

prel. QM06, nucl-ex/070164

System size scaling



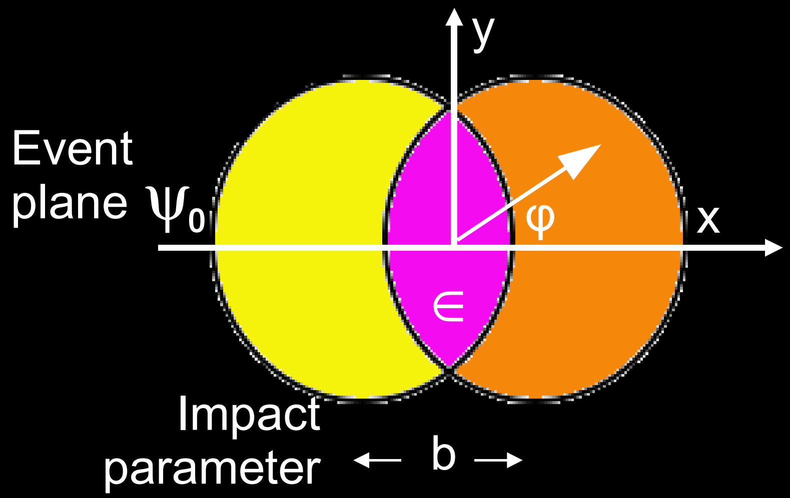
We have seen this before!

Au+Au: PRL 94, 082304 (2005), PLB 578, 297 (2004)
Phenix: PLB 561, 82 (2003), PRC 69, 034910 (2004)
Cu+Cu: PRL 96, 212301 (2006)
p+p: UA1 -2.5<η<2.5 (acc. correction with PYTHIA)

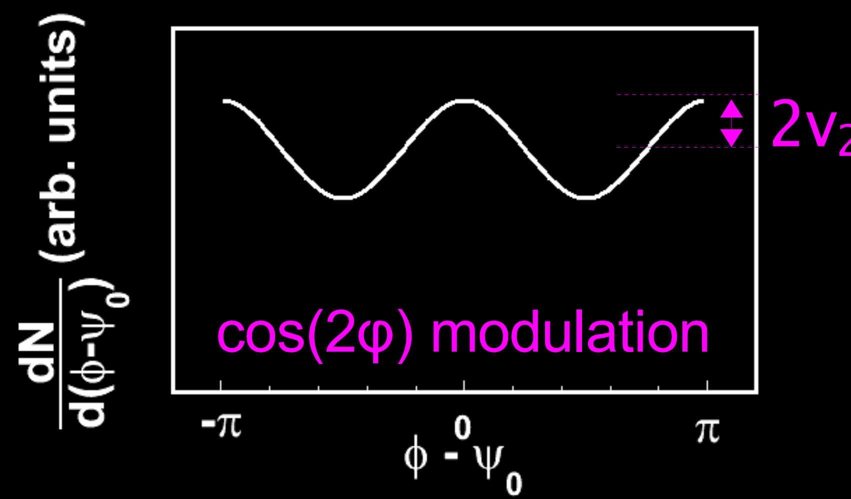
$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta}$$

Role of initial collision geometry

Initial overlap region characterized by eccentricity

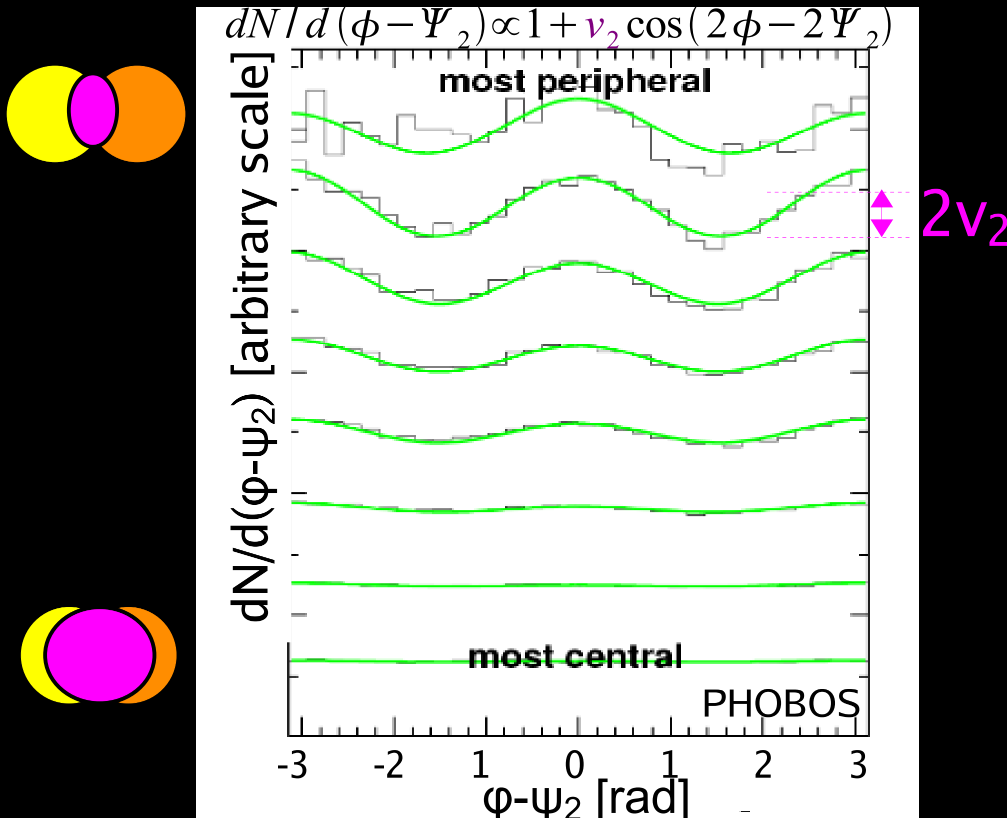


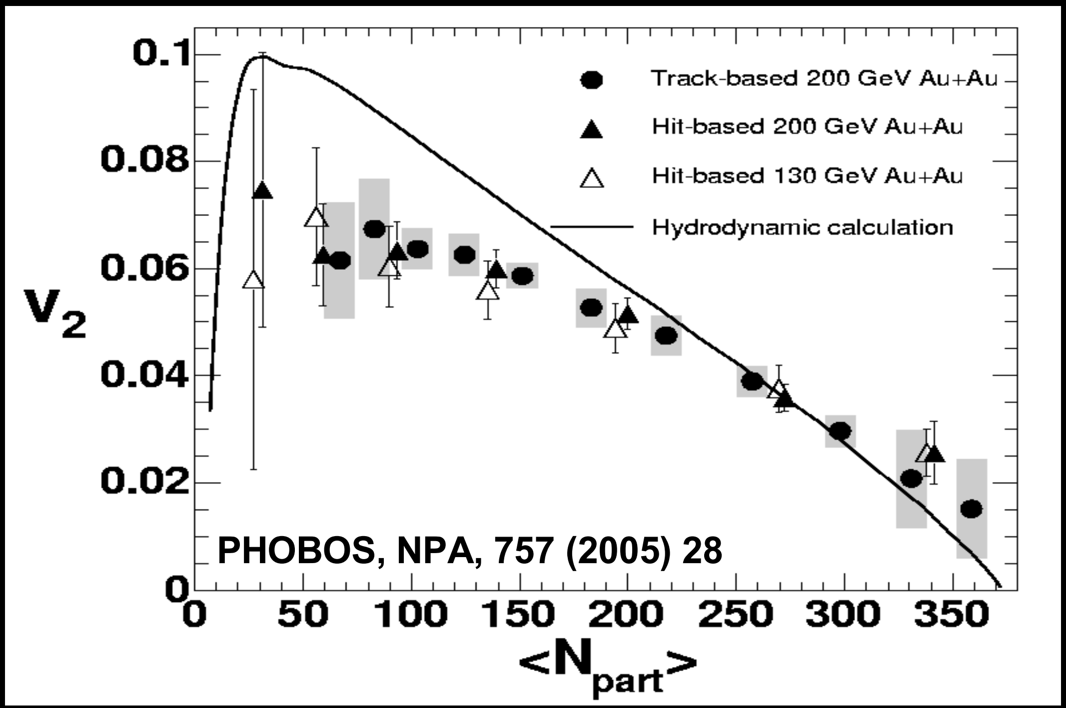
Visible in final particle azimuthal angular distribution

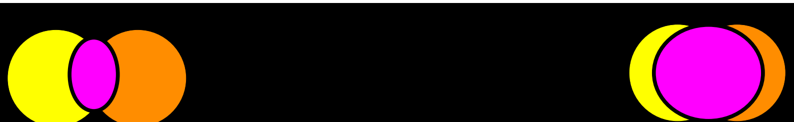


Initial eccentricity $\in$ → if produced matter interacts → v_2 Final particle distributions

Elliptic flow and hydrodynamics @ RHIC







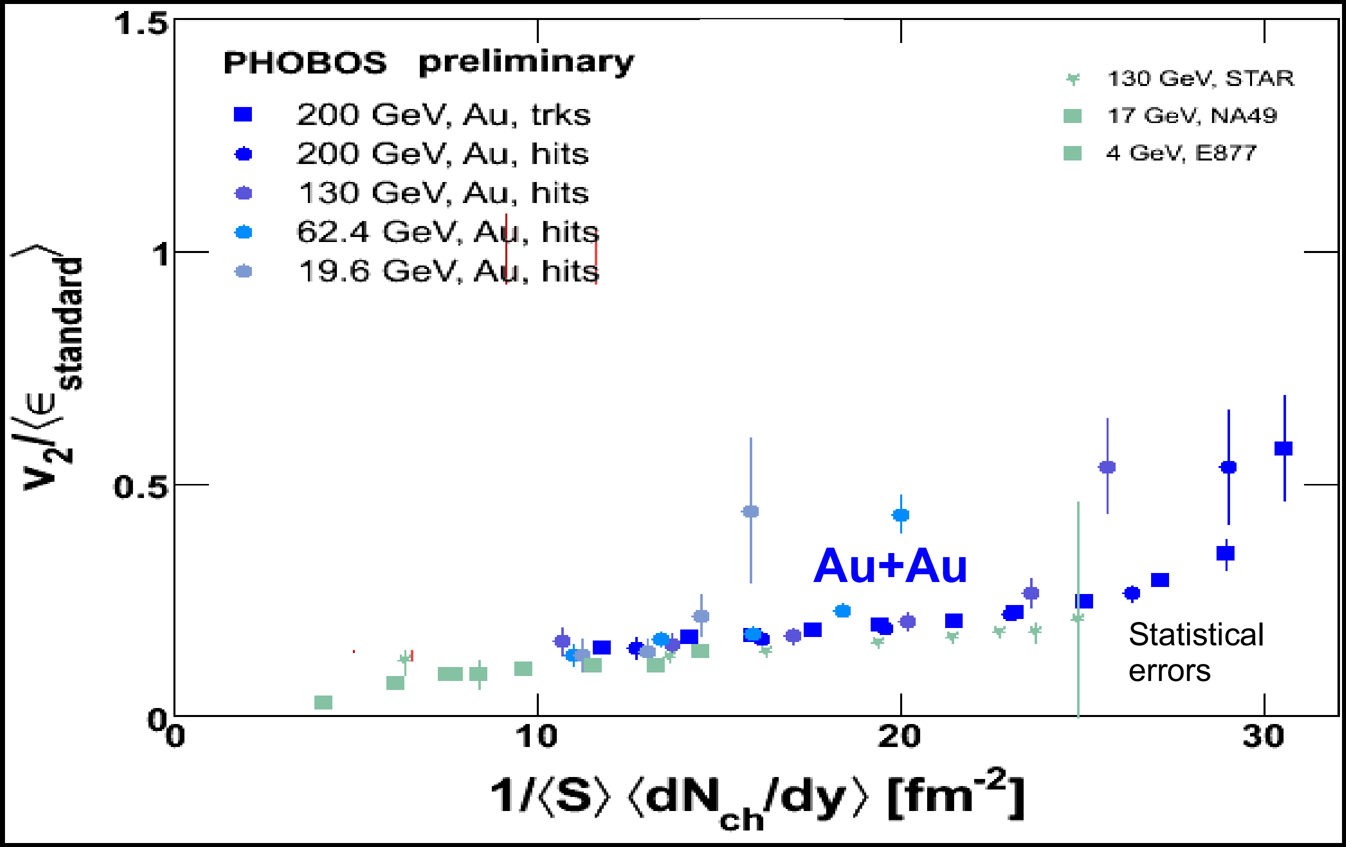
Initial eccentricity $\in$ —Ideal hydrodynamics→ v_2 Final particle distributions

$$v_2 \propto \epsilon f(n)$$

(n=density)

Bhalerao, Blaizot, Borghini, Ollitrault, PLB 627, 49 (2005)

Elliptic flow and collision geometry



Fine print

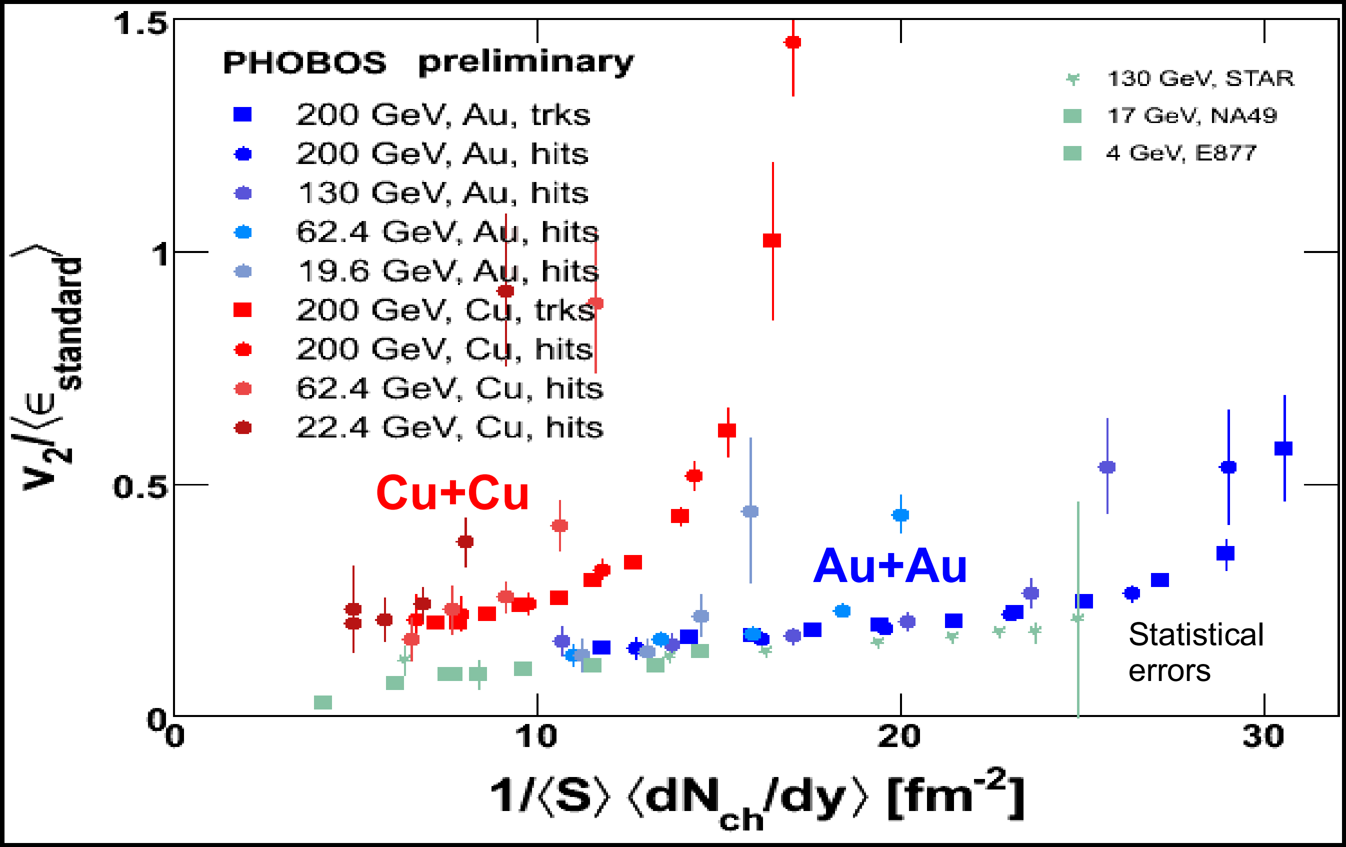
- Scale $v_2(\eta)$ to $v_2(y)$ (~10% lower)
- Scale $dN/d\eta$ to dN/dy (~15% higher)
- S is overlap area (MC Glauber)

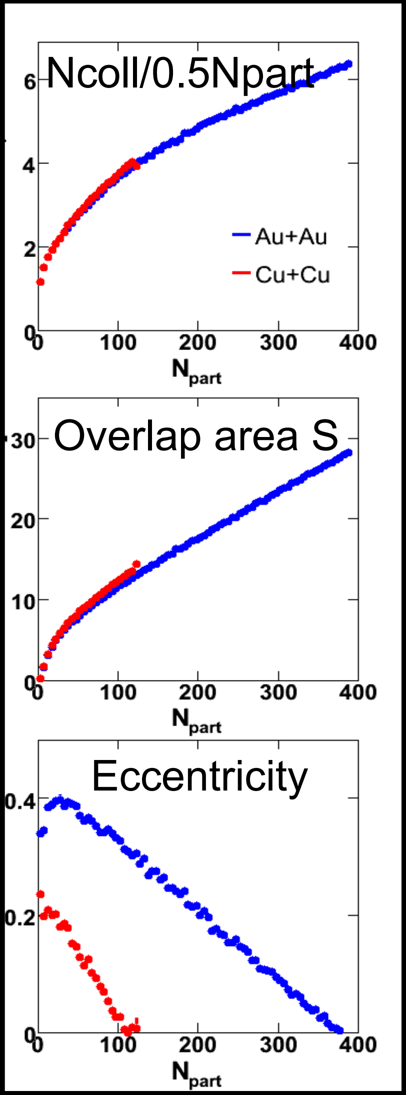
Expect $\frac{v_2}{\epsilon} \propto \frac{dN/dy}{S}$ (transverse area density)

Au+Au, 200,130,62.4+19.6 GeV: PRL 94 122303 (2005)

Heiselberg, Levy, PRC 59 2716, (1999)
Voloshin, Poskanzer, PLB 474 27 (2000)
STAR, PRC 66 034904 (2002)

Elliptic flow and collision geometry (2)





Expect $\frac{v_2}{\epsilon} \propto \frac{dN/dy}{S}$ (transverse area density)

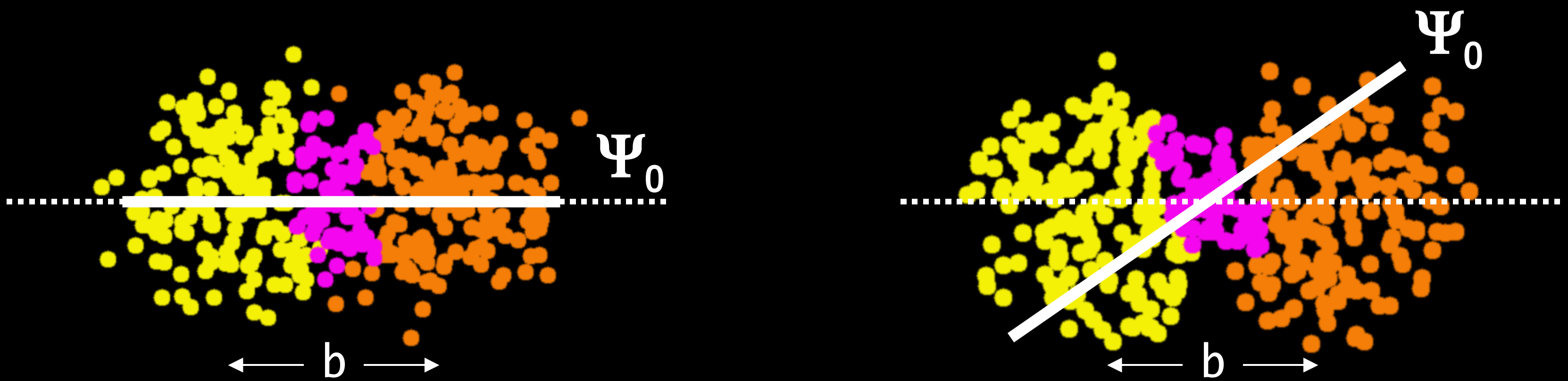
No scaling between Cu+Cu and Au+Au

Au+Au, 200,130,62.4+19.6 GeV: PRL 94 122303 (2005)
Cu+Cu, 200+62.4 GeV: PRL 98 242302 (2007)
Cu+Cu, 22.4 GeV: prel. QM06, nucl-ex/0701054

Heiselberg, Levy, PRC 59 2716, (1999)
Voloshin, Poskanzer, PLB 474 27 (2000)
STAR, PRC 66 034904 (2002)

What is the eccentricity to use?

The spatial distribution of
the interaction points of participating nucleons
for the same b will vary from event-to-event



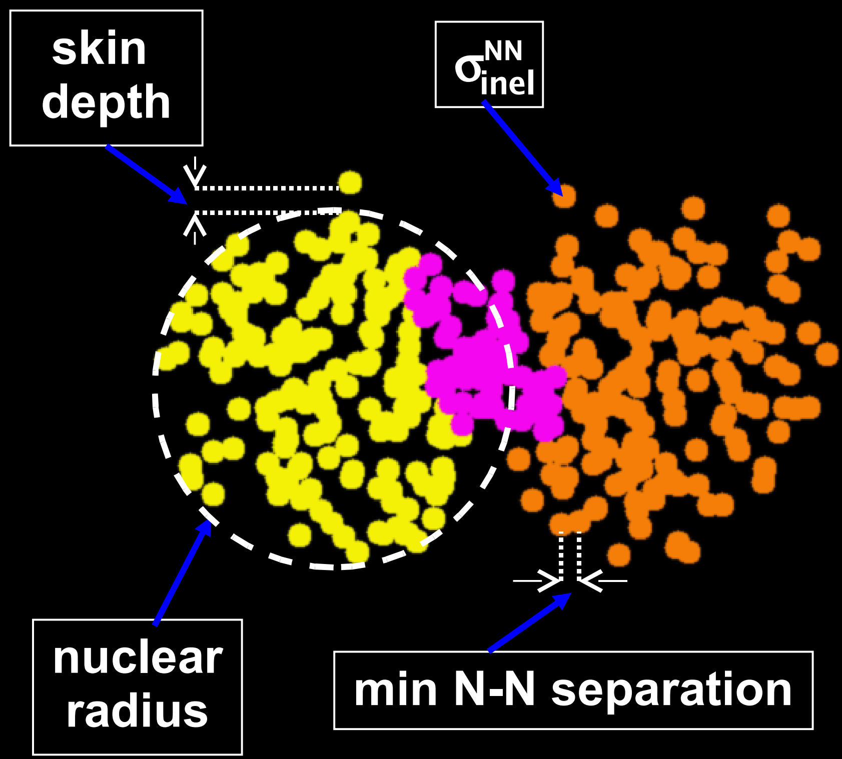
If hydro is at work, then what matters for flow is the shape of the produced matter. Thus, the relevant eccentricity for elliptic flow should vary event-by-event

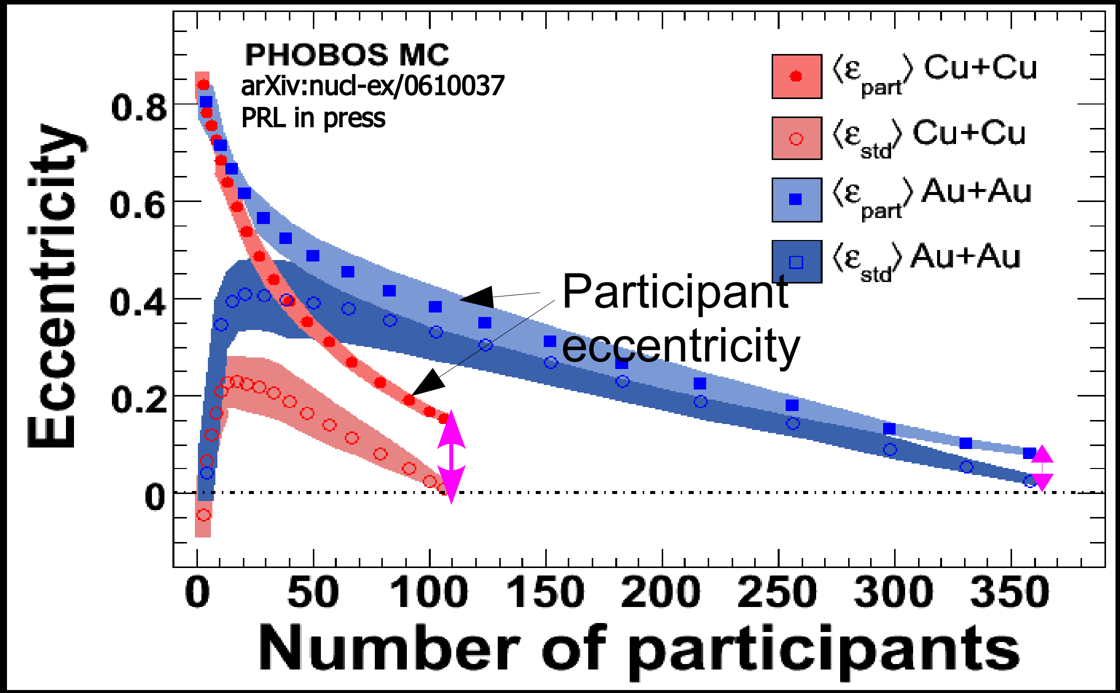
Participant eccentricity

$$\epsilon_{part} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2} \quad (0 < \epsilon_{part} \leq 1)$$

Introduced at QM05,
PRL 98 242302 (2007)

Standard vs participant eccentricity





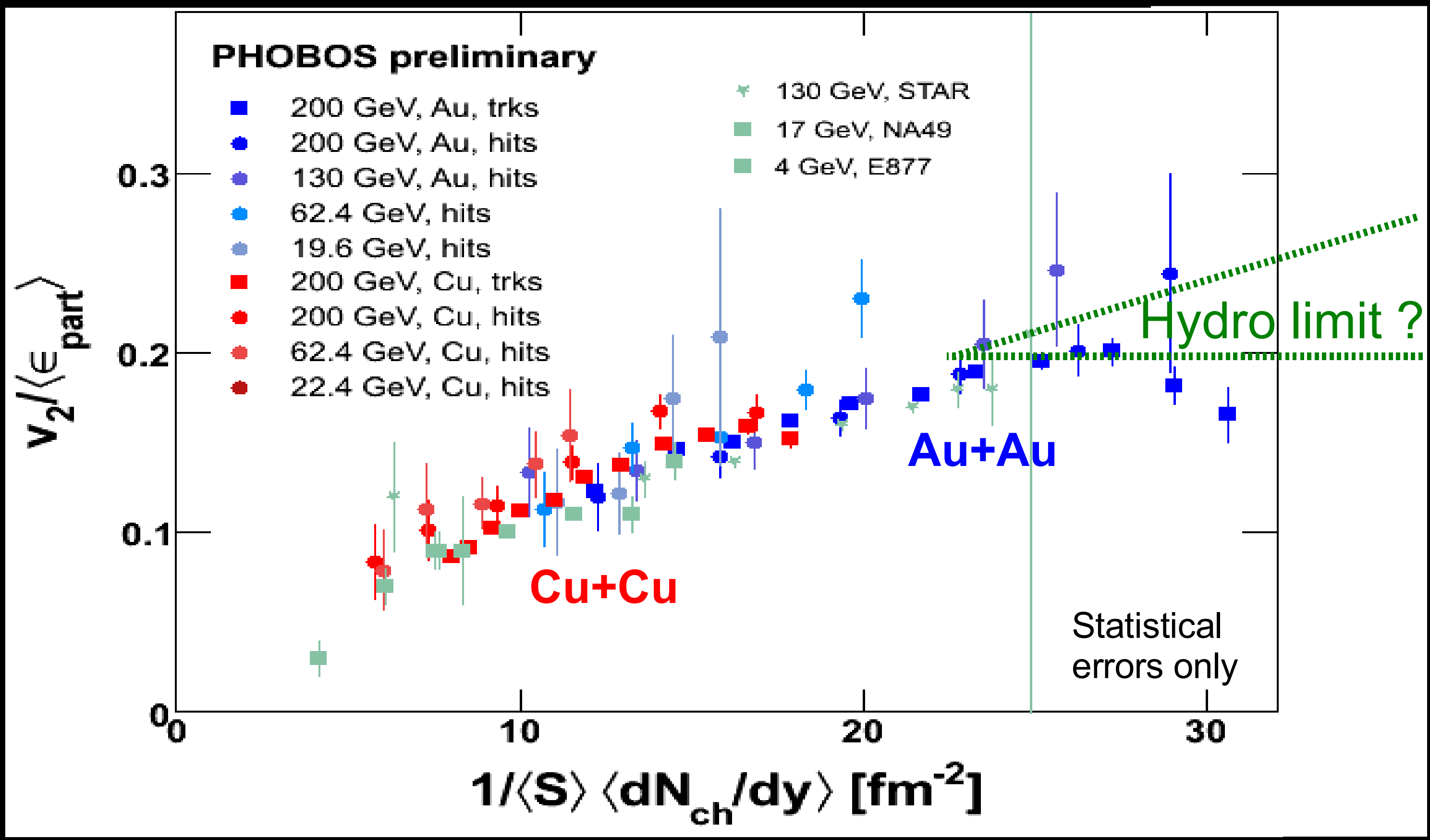
Studied variations to obtain 90% CL bands on calculation and no significant effect was found.

Participant eccentricity

Increasingly important for smaller systems (and most central collisions)

Introduced at QM05,
PRL 98 242302 (2007)

Elliptic flow and fluctuating initial geometry



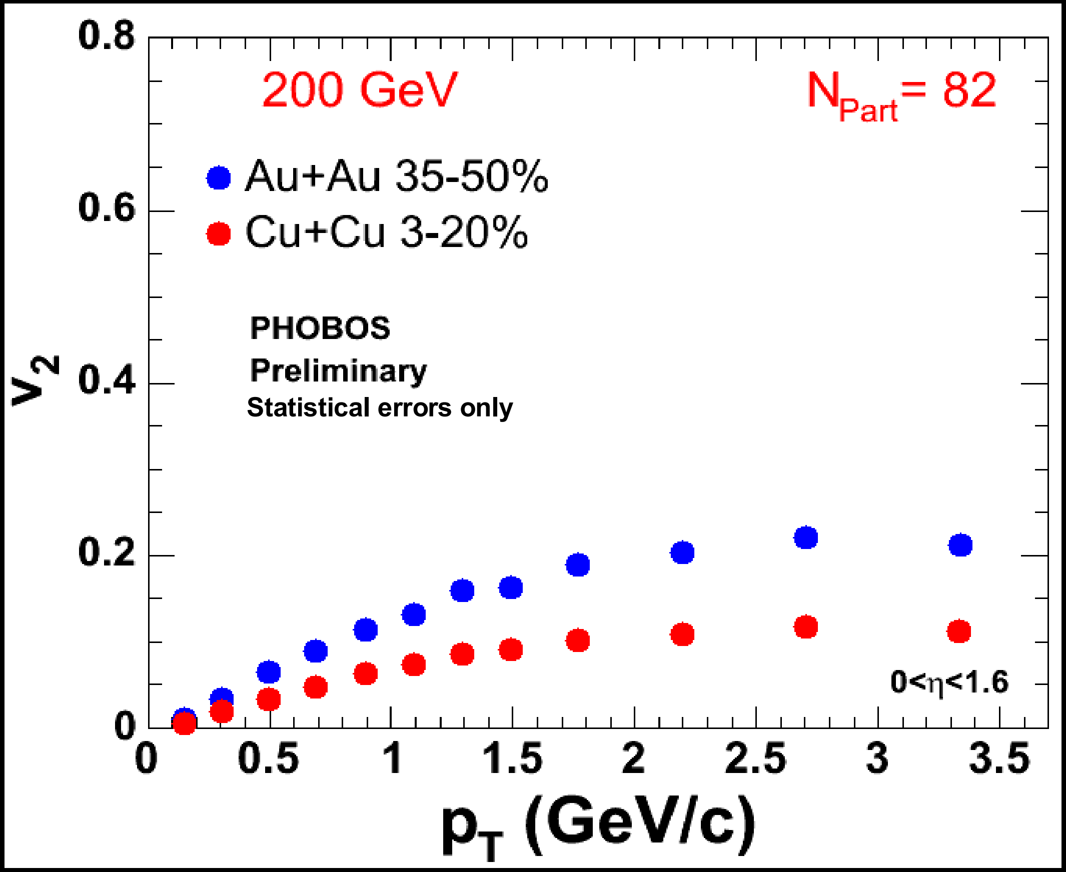
Fine print

- Scale $v_2(\eta)$ to $v_2(y)$ (~10% lower)
- Scale dN/dη to dN/dy (~15% higher)
- S is overlap area (MC Glauber)

Participant eccentricity unifies average flow in Cu+Cu and Au+Au

Au+Au, 200,130,62.4+19.6 GeV: PRL 94 122303 (2005)
Cu+Cu, 200+62.4 GeV: PRL 98 242302 (2007)
Cu+Cu, 22.4 GeV: prel. QM06, nucl-ex/0701054

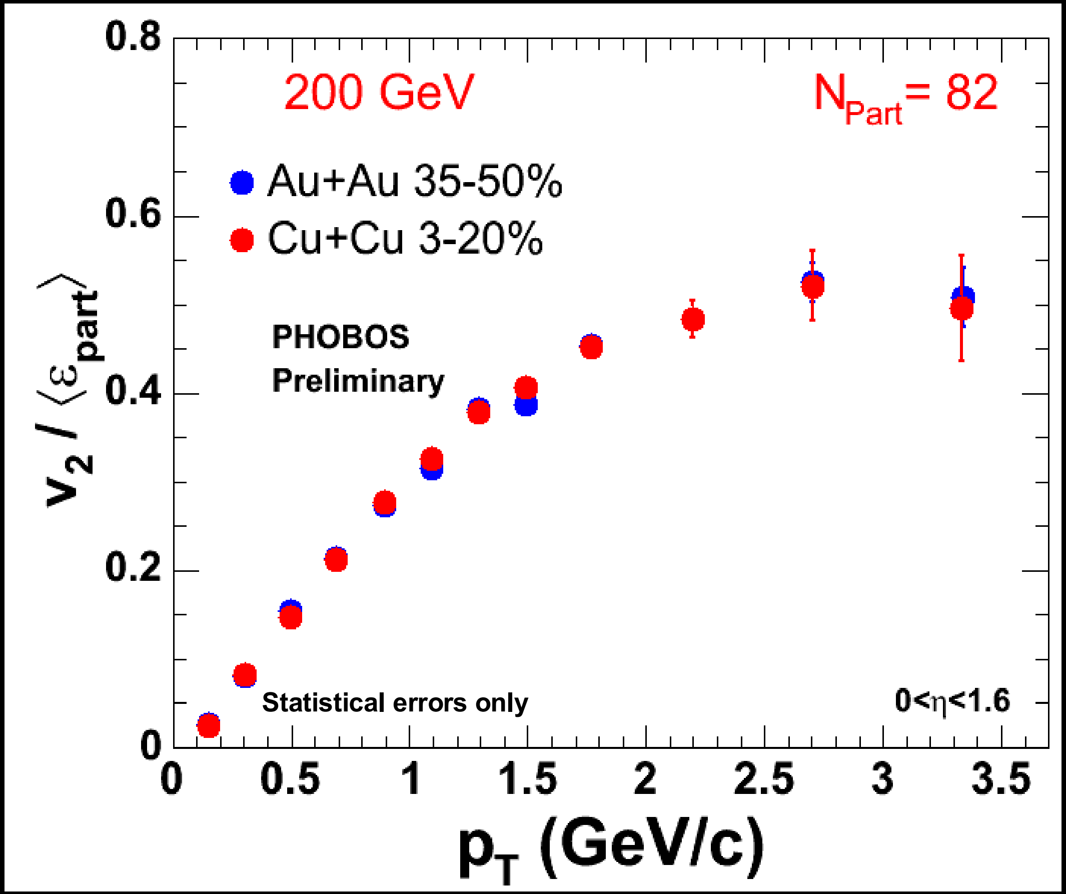
Transverse momentum dependence



Choose two bins with same Npart (~ same area density at fixed energy)

QM06, nucl-ex/0701054

Transverse momentum dependence

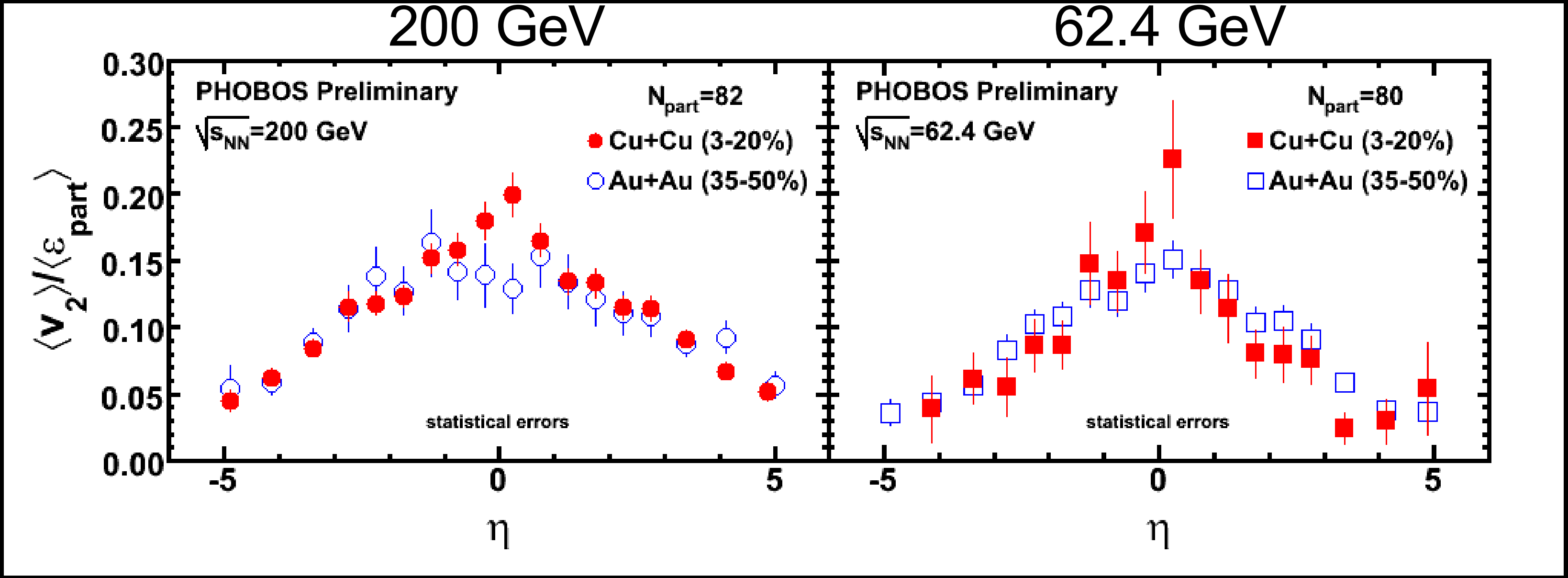


Participant eccentricity unifies midrapidity $v_2(p_T)$ between Cu+Cu and Au+Au

(at same Npart or density)

QM06, nucl-ex/0701054

Rapidity dependence



Participant eccentricity unifies Cu+Cu and Au+Au at same Npart, at all pseudorapidities: source shape does not change with η

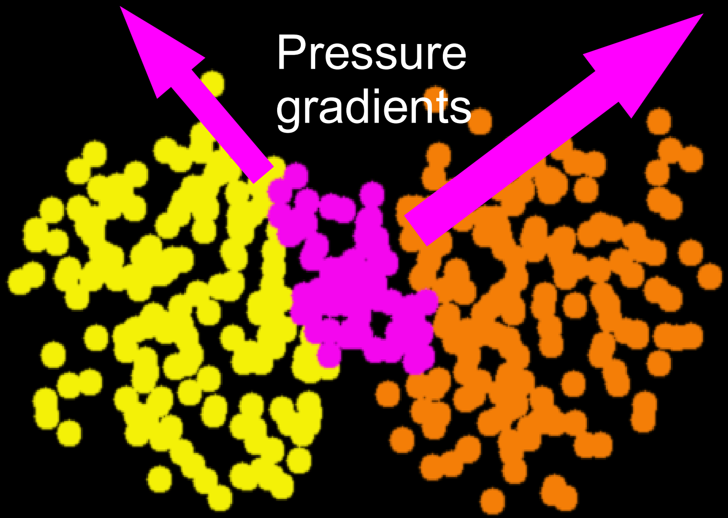
(matched N_{part} ~81)

QM06, nucl-ex/0701054

Flow fluctuations

Event-by-event initial state geometry appears relevant: It is transmitted to particles at all rapidities and p_T

This should lead to measurable effects on elliptic flow

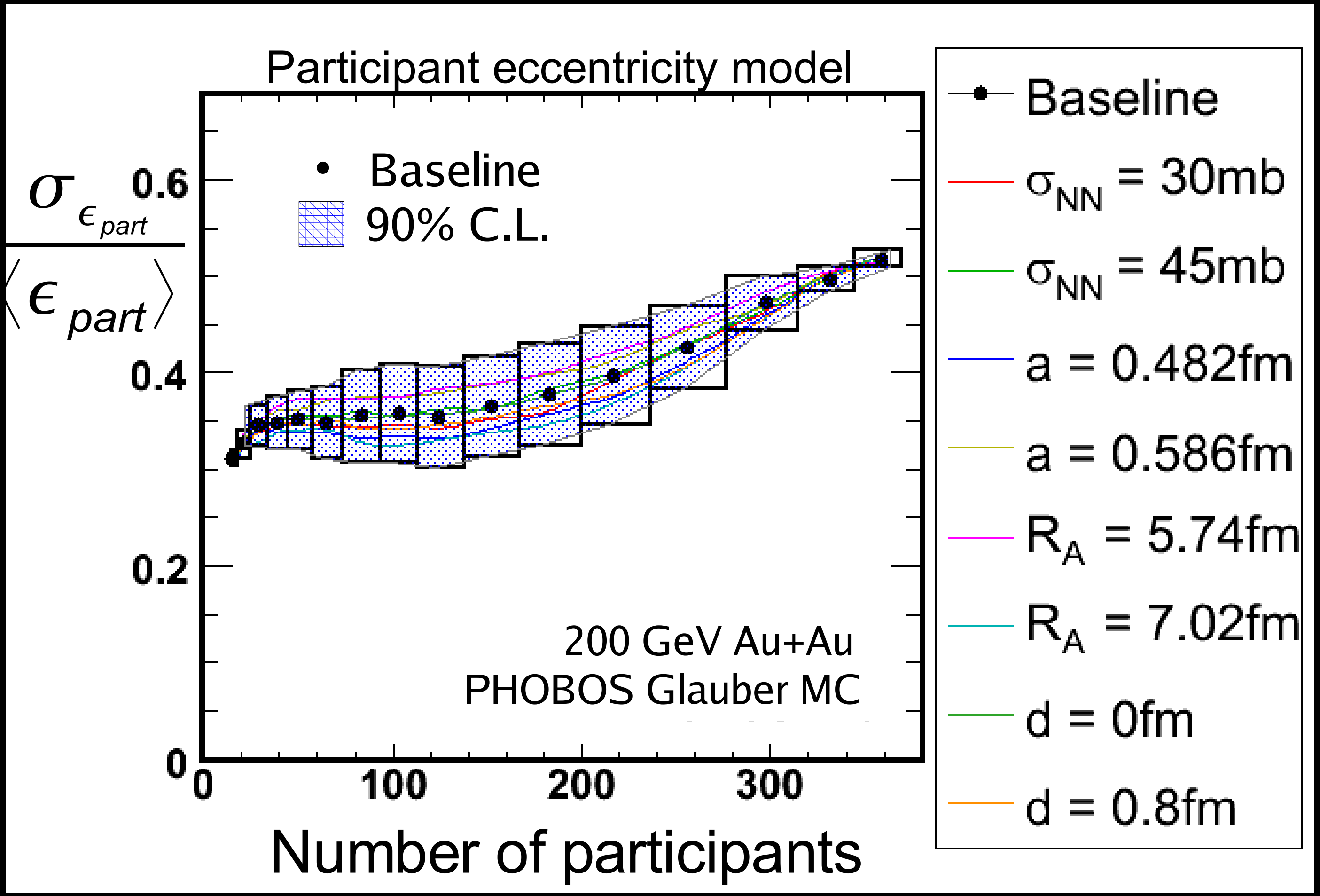


if $v_2 \sim \epsilon_{part}$

event-by-event, **then**

$$\frac{\sigma_{v_2}}{\langle v_2 \rangle} = \frac{\sigma_{\epsilon_{part}}}{\langle \epsilon_{part} \rangle}$$

Expected relative magnitude of fluctuations

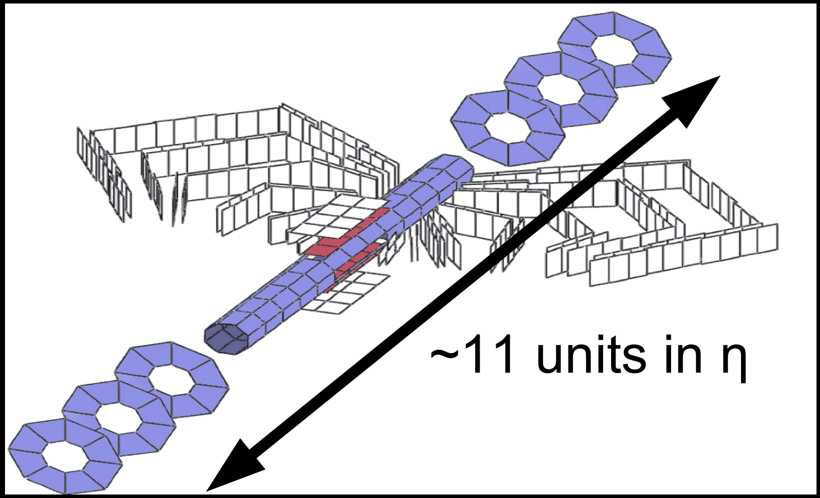


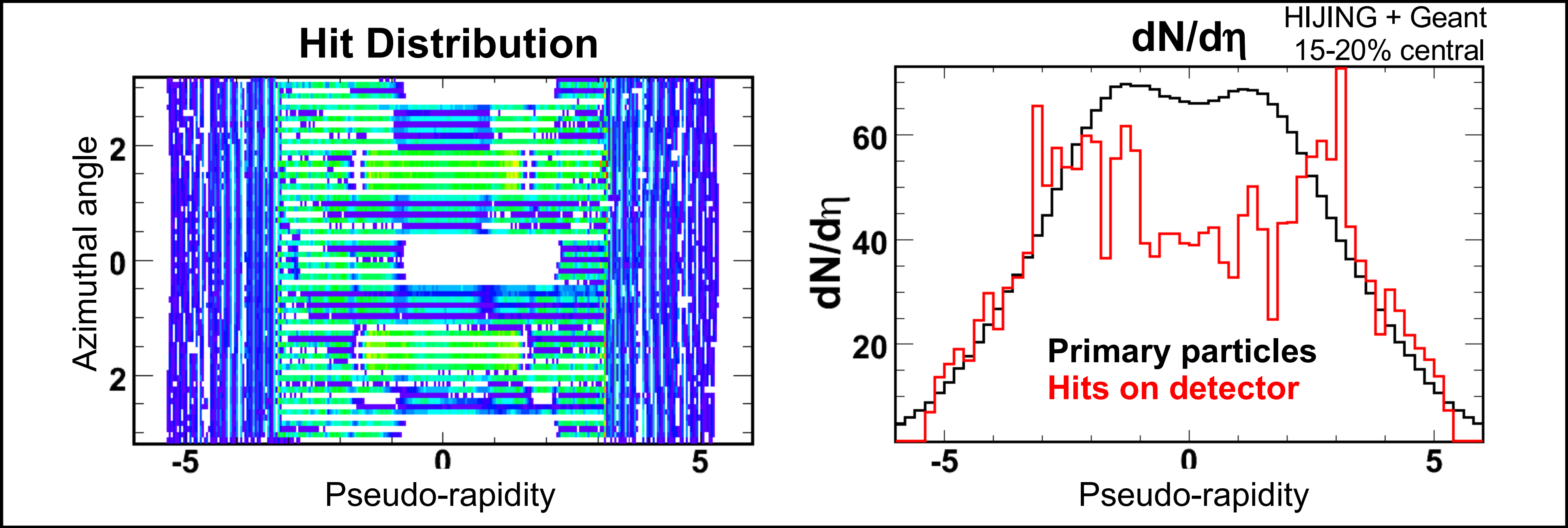
NB: Npart fluctuations have been removed

Glauber MC approach makes a definite prediction for relative event-by-event fluctuations of about 40% and robust against variation of Glauber parameters

Challenges of event-by-event measurement

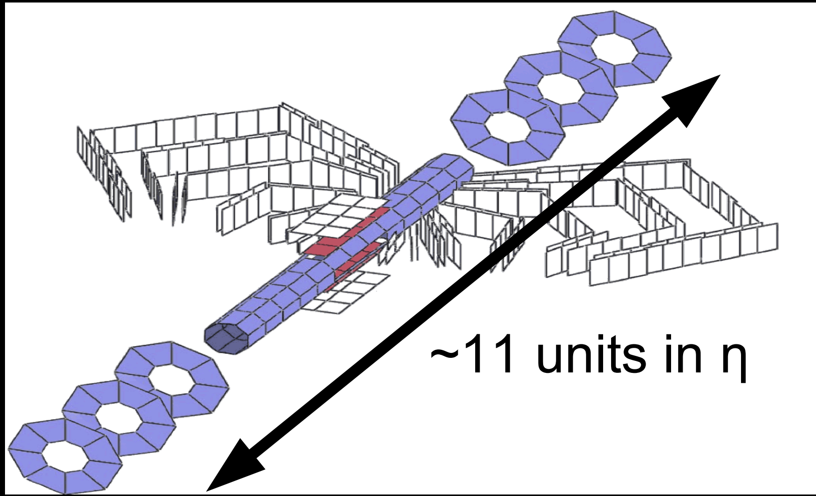
- PHOBOS Multiplicity Array
  - $-5.4<\eta<5.4$ coverage
  - Holes and granularity differences

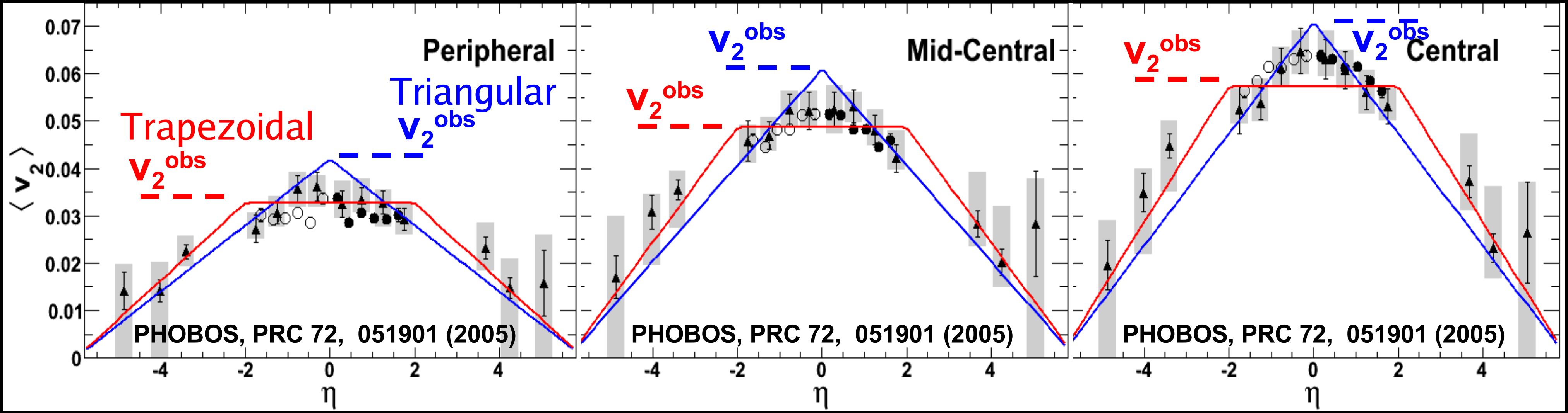




Event-by-event fit to parameterized shape

- Usage of all available information in event to determine event-by-event a single value for v_2^{obs}
- Use triangular or trapezoidal shape for pseudo-rapidity dependence of v_2^{obs}

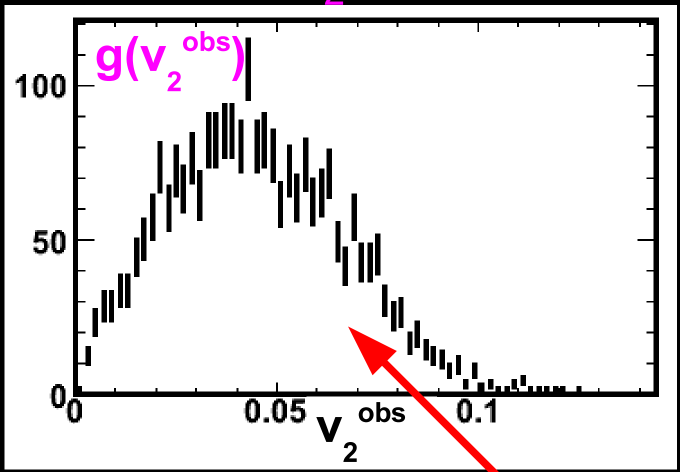




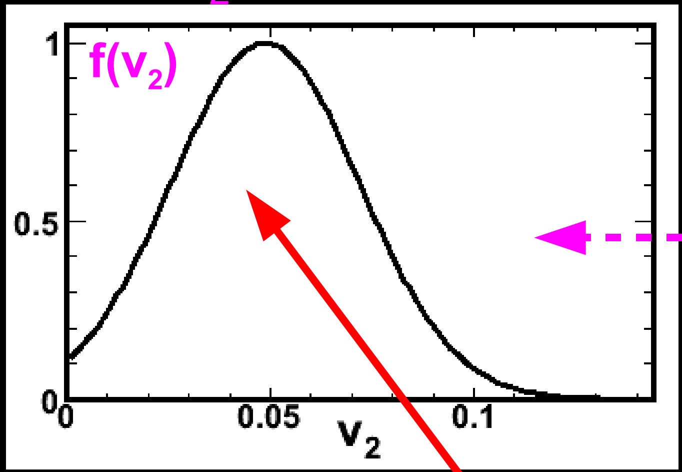
$$P(\eta,\phi;\ v_2^{obs},\phi_0)=p(\eta)[1+2\underline{v_2(\eta)}\cos(2\phi-2\phi_0)]$$

Measuring elliptic flow fluctuations

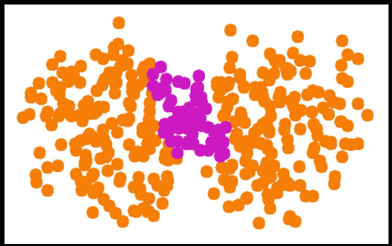
Observed v_2 distribution



True v_2 distribution



Source of v_2 fluctuation



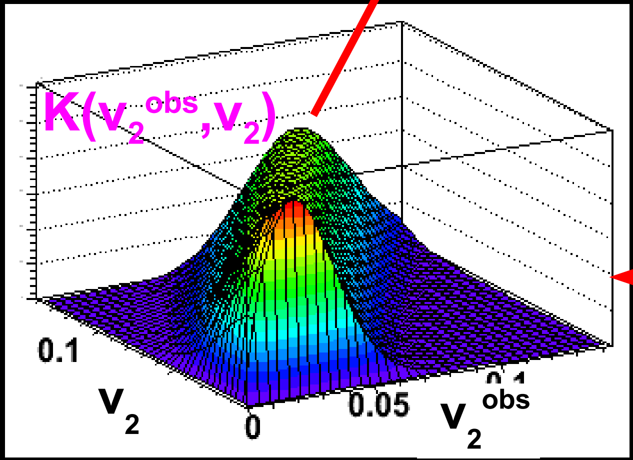
Event-by-event
LL-Fit to PDF

LL-Fit to assumed
true v_2 distribution

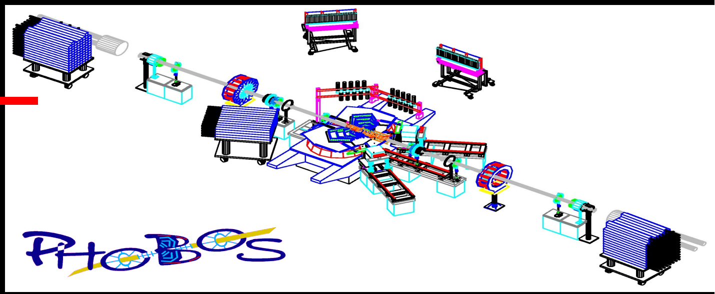
$$g(v_2^{obs}) = \int_0^1 K(v_2^{obs}, v_2)\, f(v_2)\, dv_2$$

Kernel

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



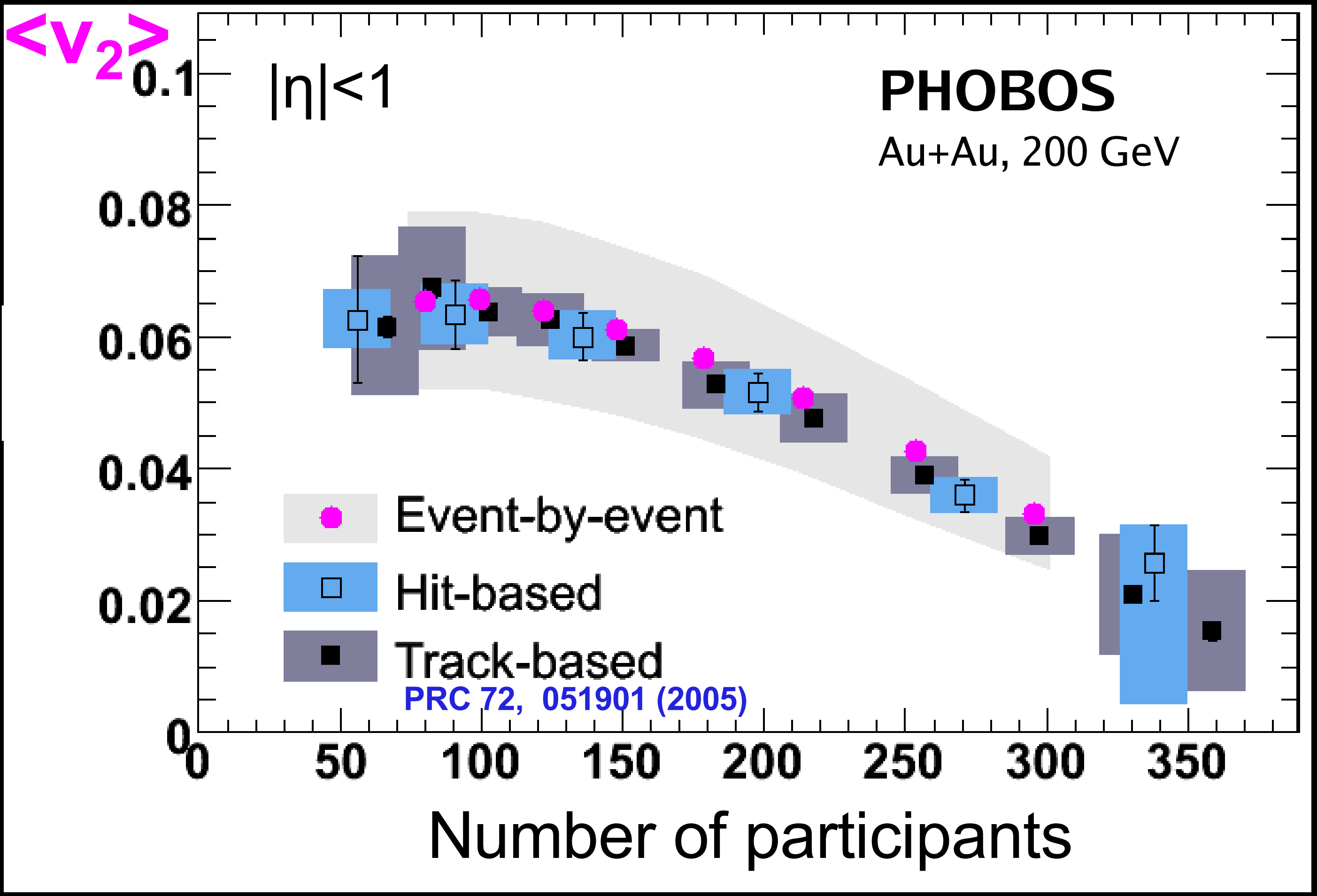
Detector response



nucl.-ex/0702036 (sub.to PRL)

Event-by-event mean v_2 vs published results

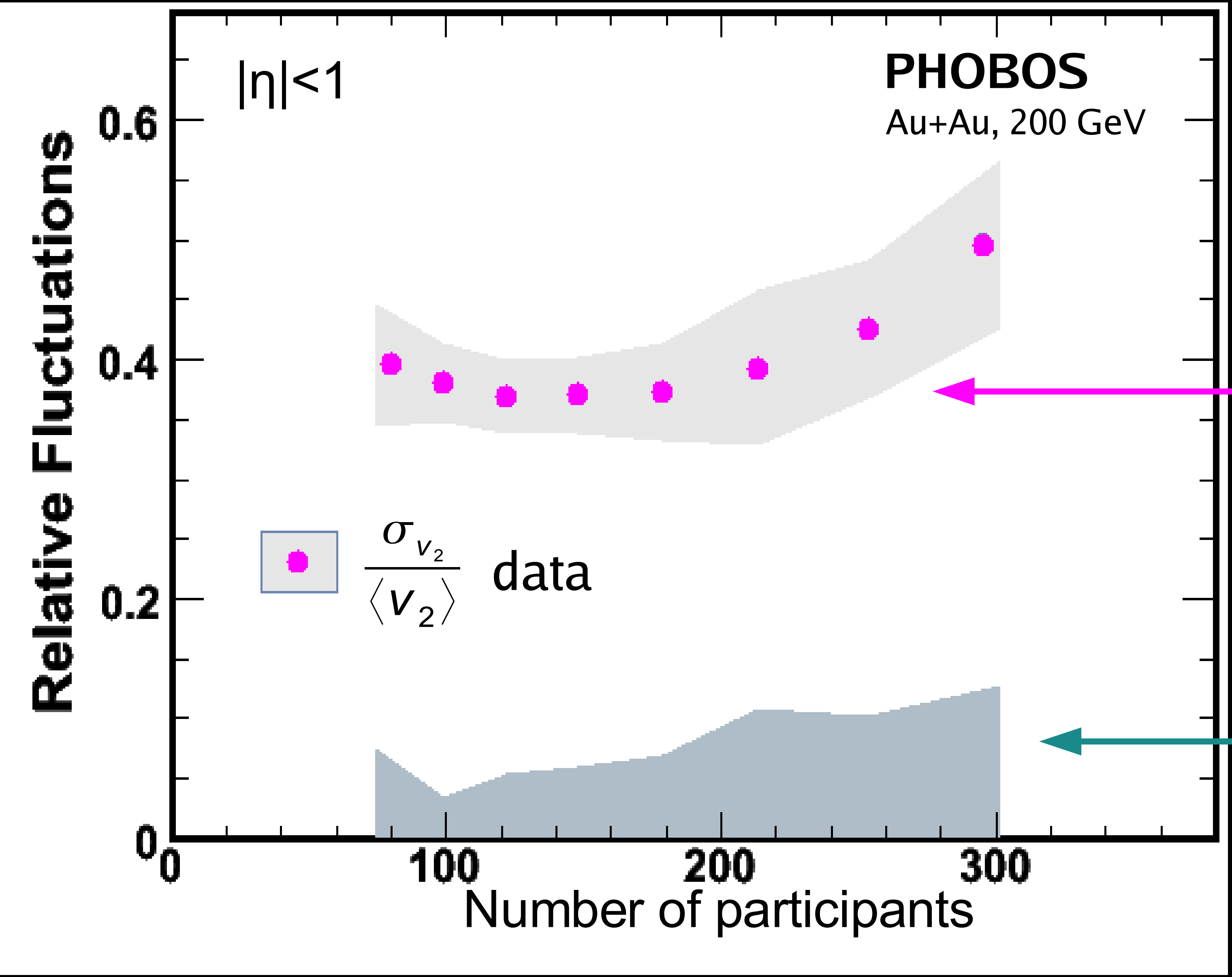
- Standard methods
  - Averaged over events to measure the mean
  - Hit- and track-based
  - Use reaction plane sub-event technique



Very good agreement of the event-by-event measured mean v_2 with the hit- and tracked-based, event averaged, published results

nucl.-ex/0702036 (sub.to PRL)

Relative elliptic flow fluctuations



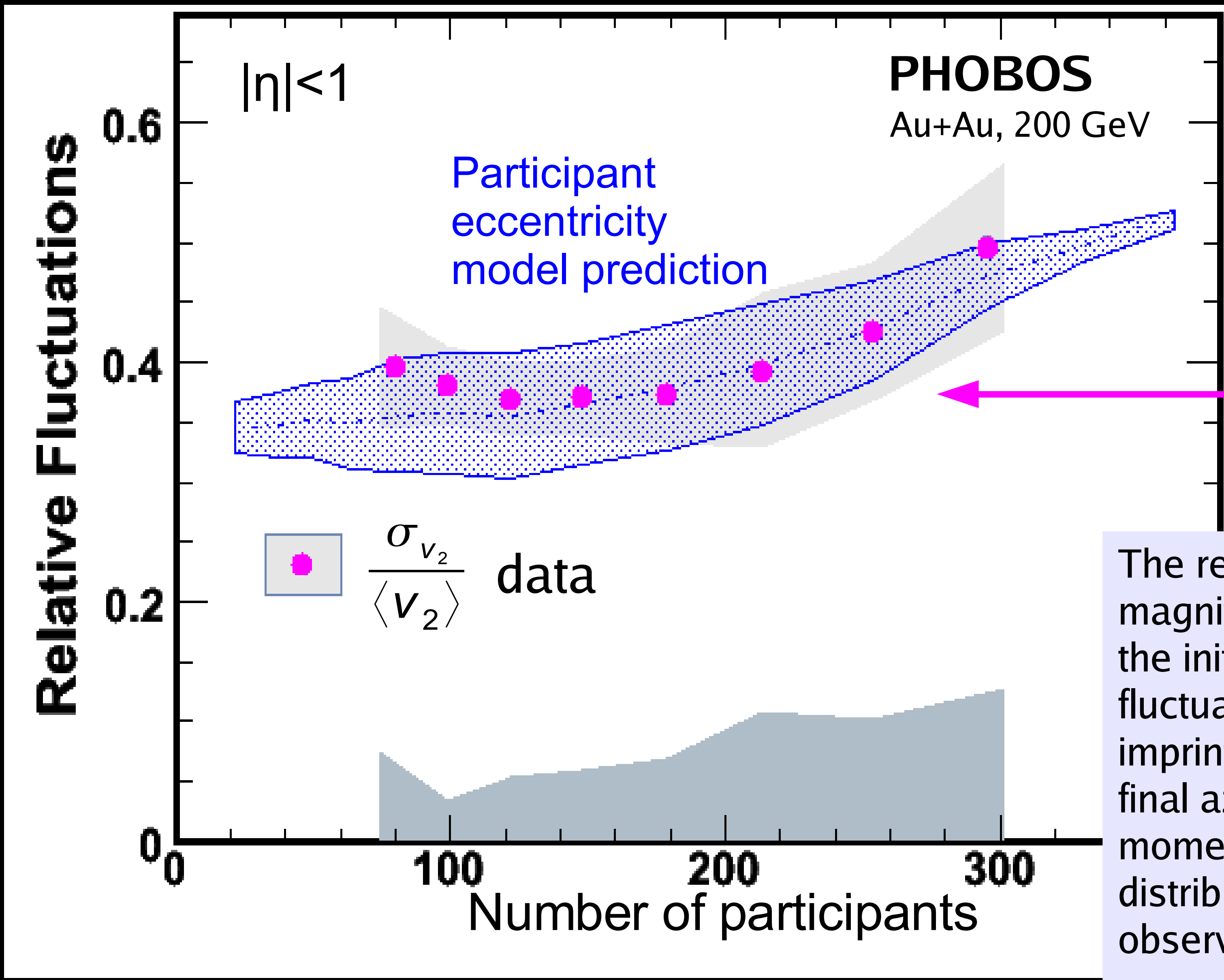
Observe significant dynamical v_2 fluctuations

MC with no dynamical fluctuations (included in the sys.error)

NB: All trivial (incl. Npart) fluctuations have been removed

nucl.-ex/0702036 (sub.to PRL)

Relative elliptic flow fluctuations



Observe significant dynamical v_2 fluctuations

The relative magnitude of the initial state fluctuations are imprinted in the final azimuthal momentum distribution of the observed particles

NB: All trivial (incl. Npart) fluctuations have been removed

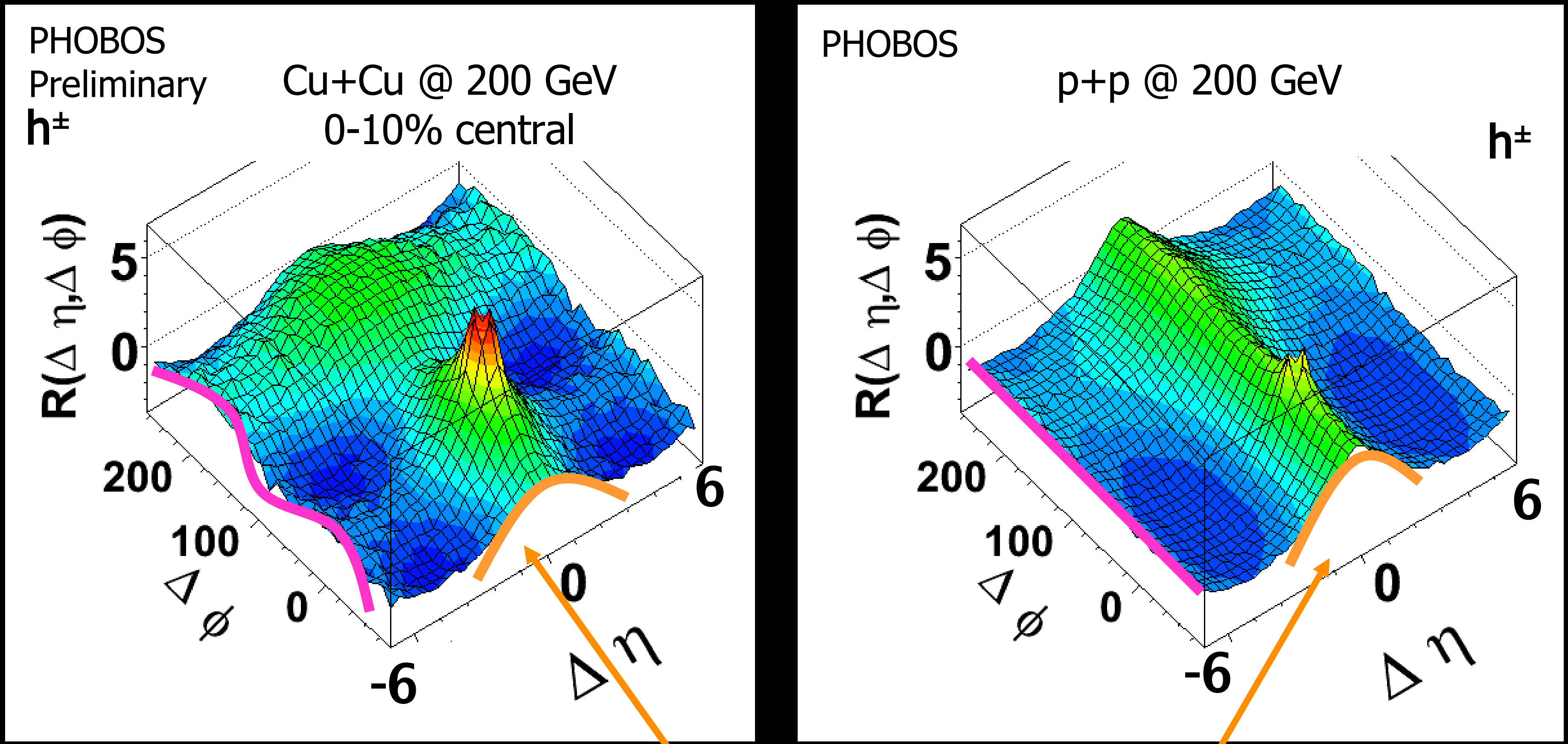
nucl.-ex/0702036 (sub.to PRL)

One subtlety: Non-flow correlations

- Non-flow correlations mimic dynamical fluctuations and contribute to the width of the v_2 distribution
- Kernel could compensate for non-flow effects if they are correctly described by the MC used to make the kernel
- Develop new MC and/or tune MC on data
  - Use two-particle correlation measurements to disentangle the different contributions

Non-flow correlations generally are all multi-particle correlations other than flow (such as jets, HBT, momentum conservation, resonance decays, ...)

Two particle correlations



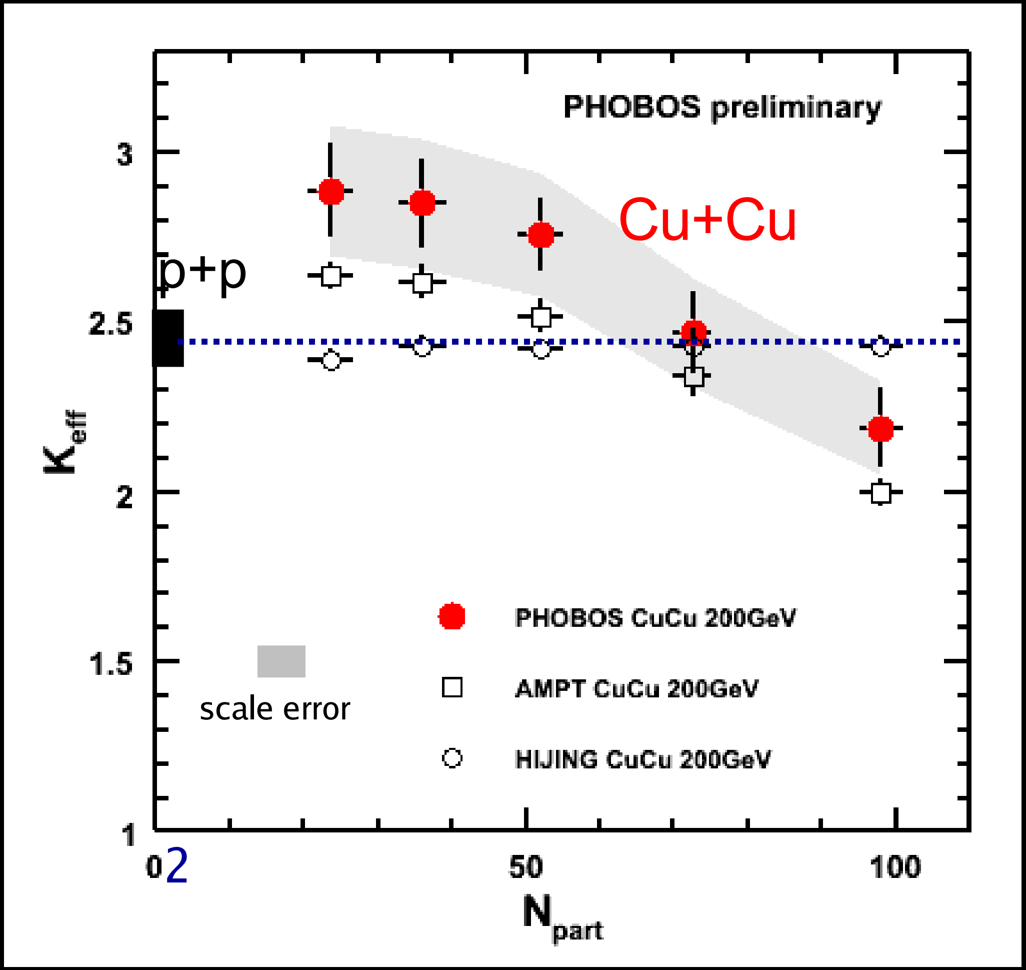
Study the short-range rapidity correlations

$$R = \langle (n-1)(\frac{F_n}{B_n} - 1) \rangle$$

Use both features to improve understanding of non-flow effects that induce artificial flow fluctuations

p+p: PRC 75 054913 (2007)
Cu+Cu: prel. QM06, nucl-ex/0701055

Extract effective cluster size



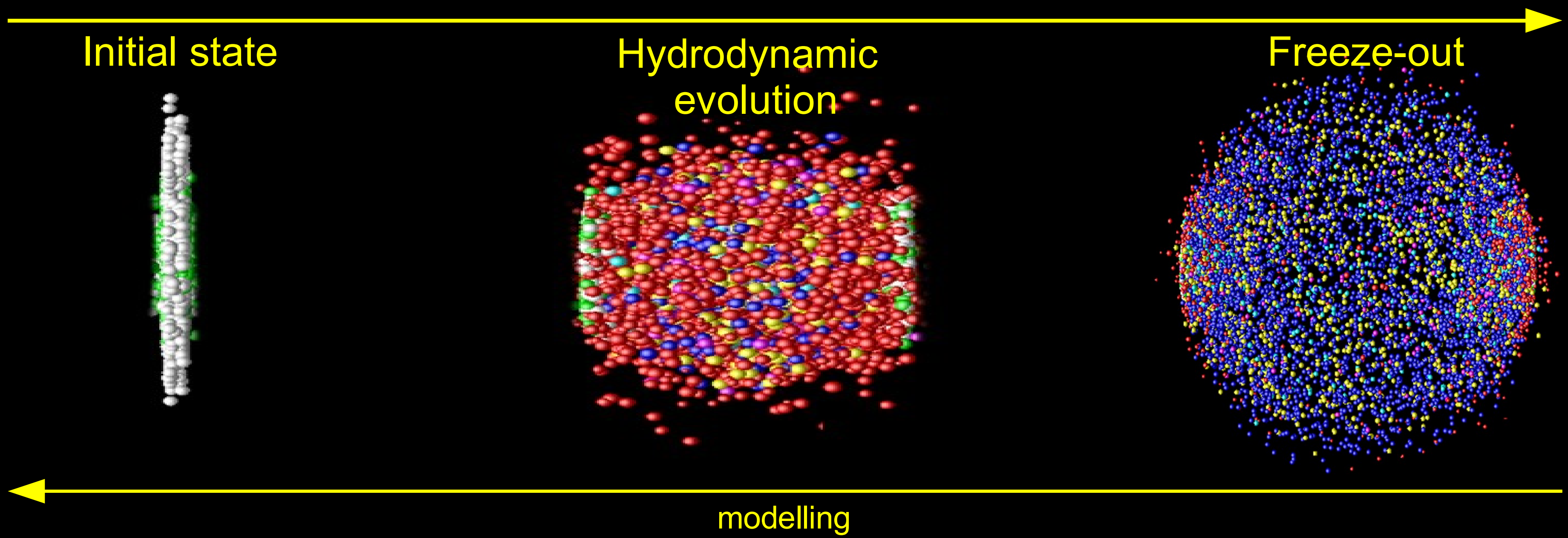
On average, particles production in clusters with a size of 2-3, with a perhaps interesting centrality dependence for Cu+Cu

p+p: PRC 75 054913 (2007)
Cu+Cu: prel. QM06, nucl-ex/0701055

Summary

- Extended (and published) existing analyses
  - Anti-particle / particle ratios in Cu+Cu
  - Identified spectra in 62.4 GeV Au+Au, including uniquely low p_T
  - Participant eccentricity scaling of v_2 differentially in p_T and η
- New two particle correlations analysis
  - Particles tend to be produced in clusters with a size of 2-3.
  - Study of non-flow contribution to flow fluctuations
- New flow fluctuation analysis
  - Large dynamical v_2 fluctuations of 40% in Au+Au at 200 GeV
  - The participant eccentricity predictions for the magnitude of the relative fluctuations are in striking agreement with the measurement
  - This suggests that the initial state thermalizes very rapidly, taking a detailed snapshot , which is preserved and propagated by the subsequent hydrodynamic evolution

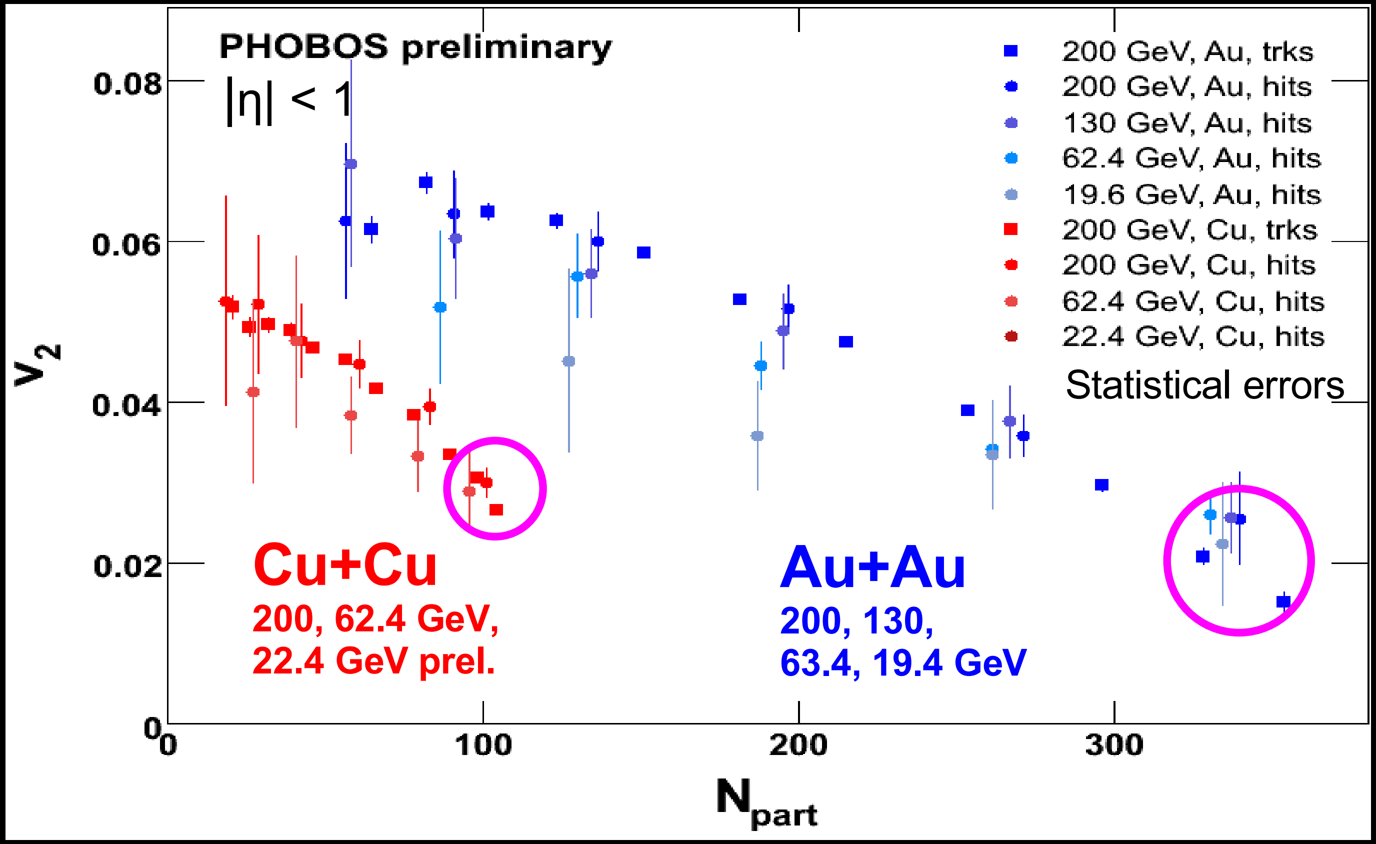
Summary

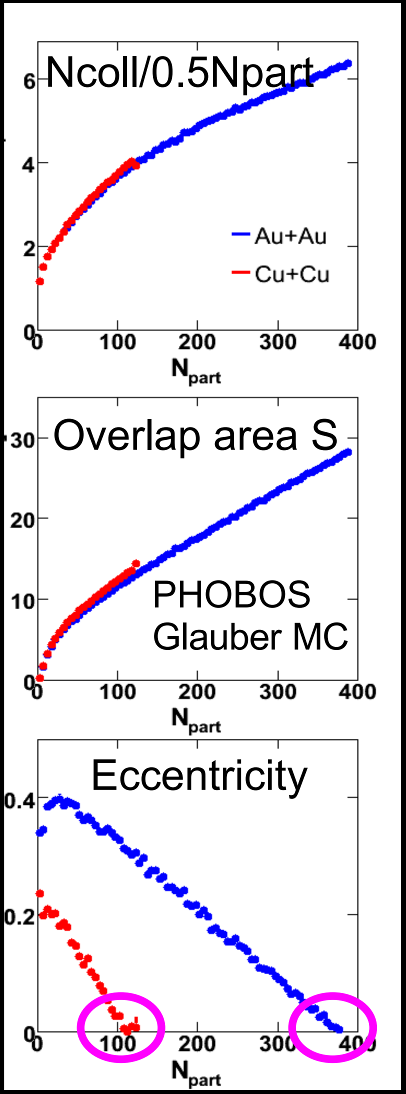


- New flow fluctuation analysis
  - Large dynamical v_2 fluctuations of 40% in Au+Au at 200 GeV
  - The participant eccentricity predictions for the magnitude of the relative fluctuations are in striking agreement with the measurement
  - This suggests that the initial state thermalizes very rapidly, taking a detailed snapshot , which is preserved and propagated by the subsequent hydrodynamic evolution

Backup slides

Elliptic flow and collision geometry (3)

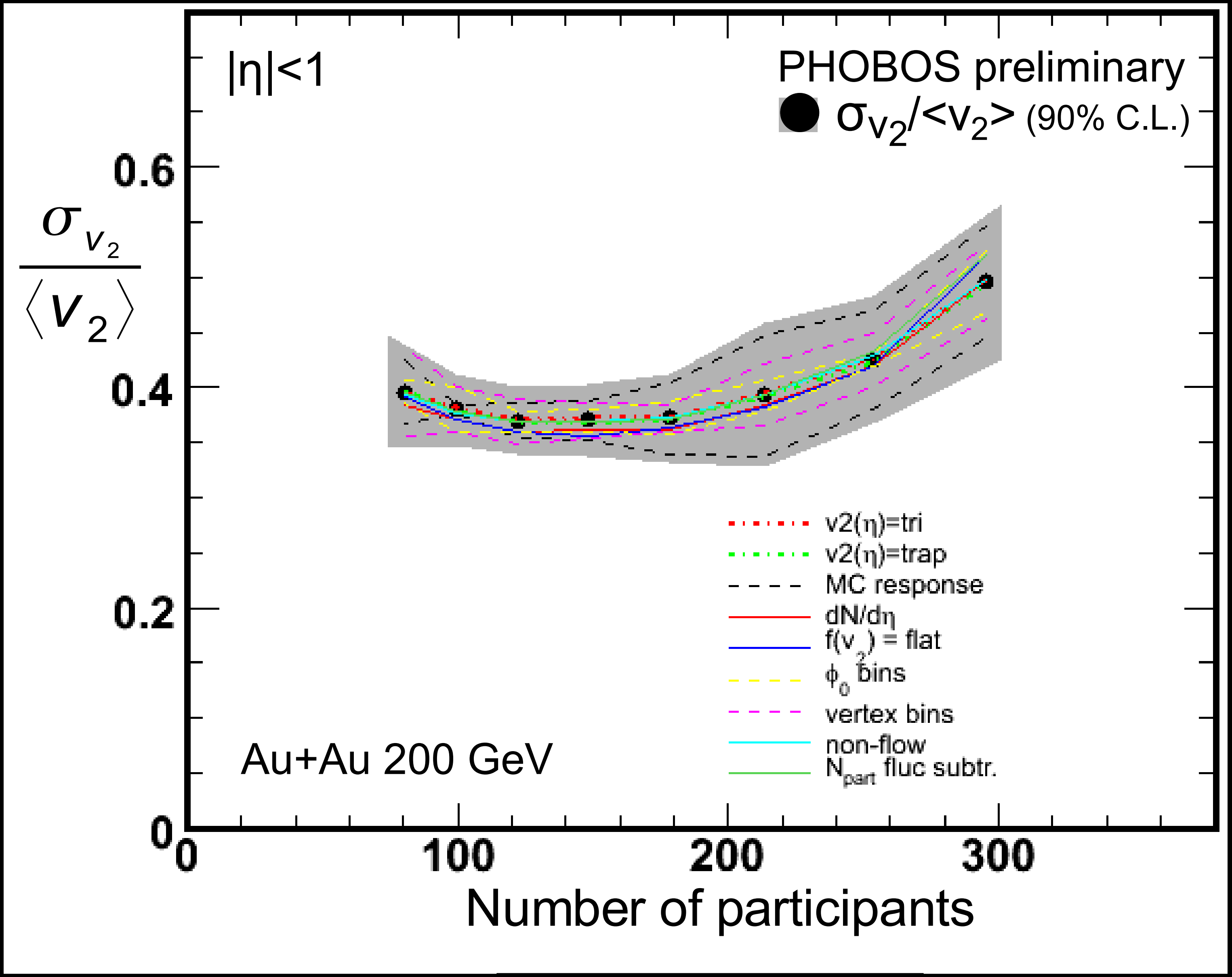




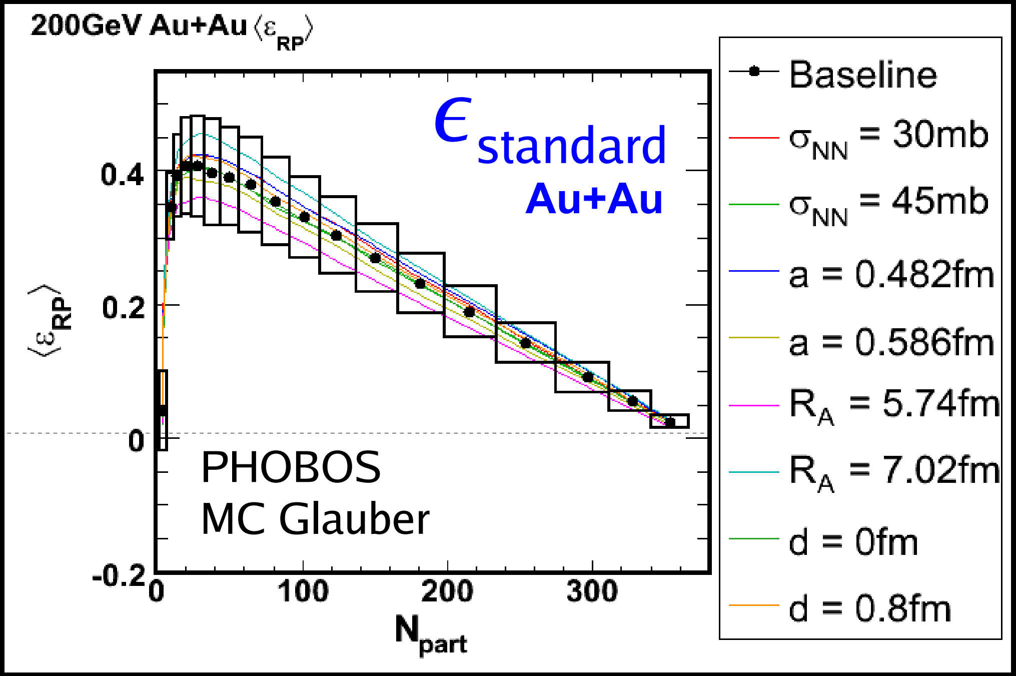
System comparison between Cu+Cu and Au+Au

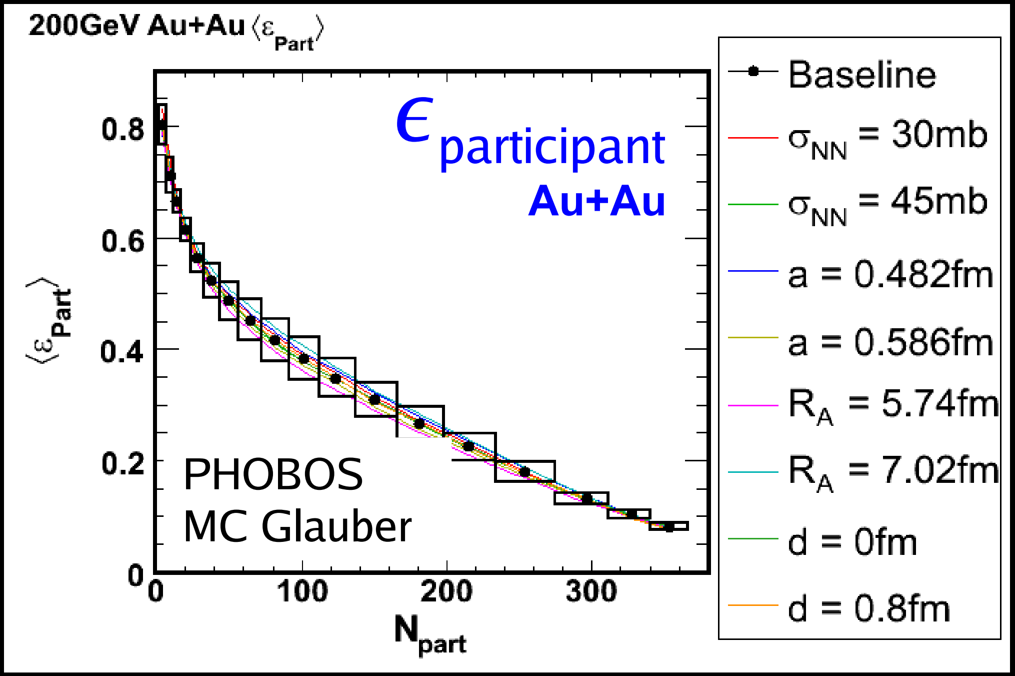
Au+Au, 200,130,62.4+19.6 GeV: PRL 94 122303 (2005)
Cu+Cu, 200+62.4 GeV: PRL 98 242302 (2007)
Cu+Cu, 22.4 GeV: prel. QM06, nucl-ex/0701054

Systematic error sources



Robustness with geometry variables





Variation of

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

- 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)

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

Expected elliptic flow fluctuations