System-size dependence and scaling features of observables measured with PHOBOS

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for the PHOBOS collaboration

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XLIst Recontres de Moriond

QCD and high energy hadronic interactions

La Thuile, Aosta Valley, Italy, March 19-25, 2006

PHOBOS collaboration (August 2005)



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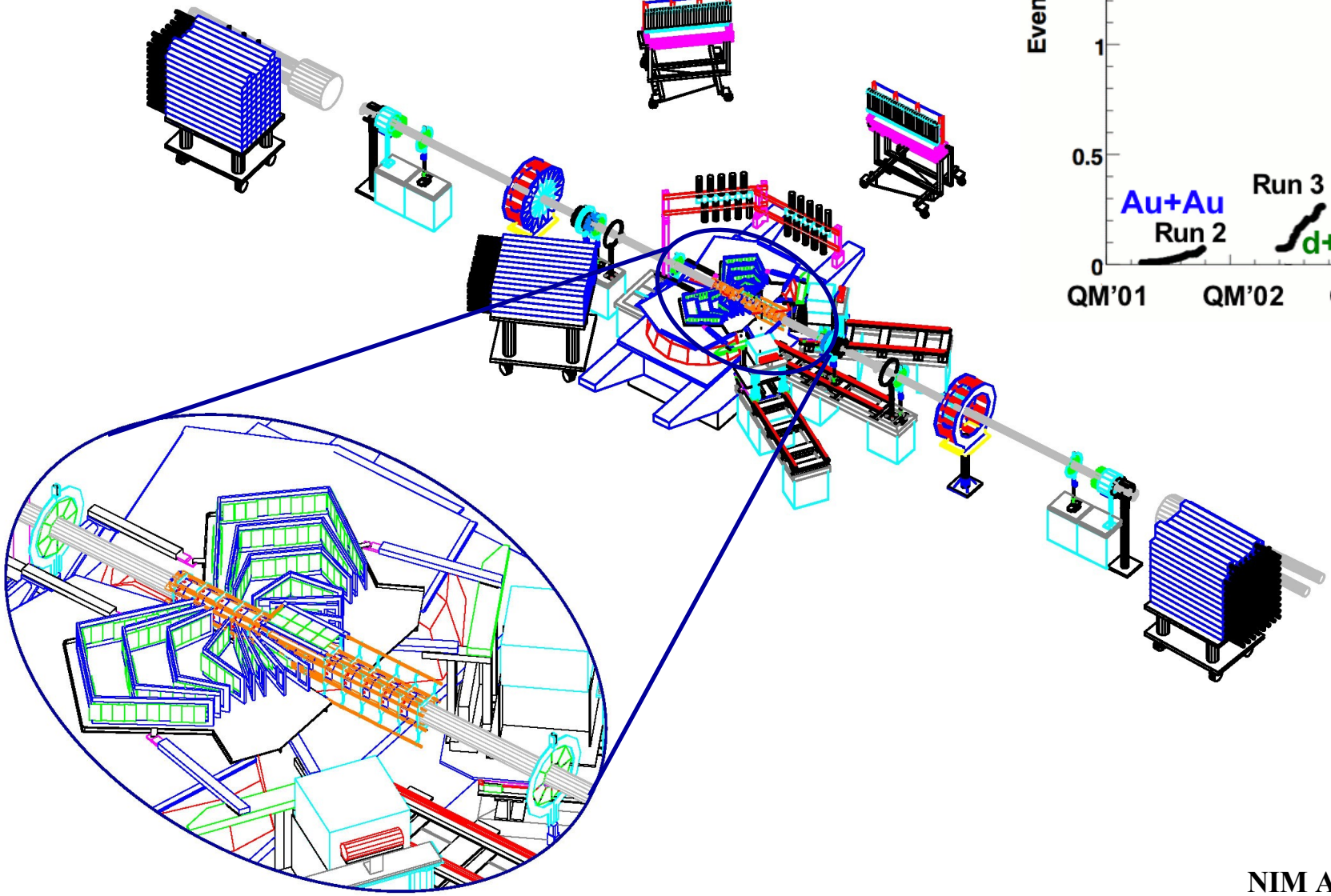
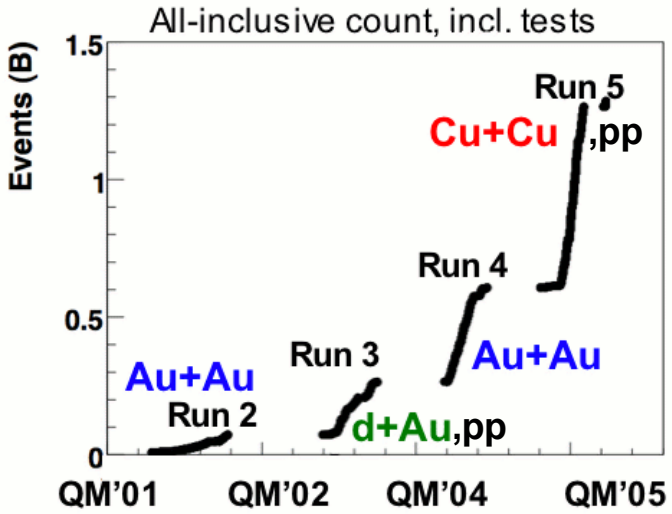
PHOBOS experiment

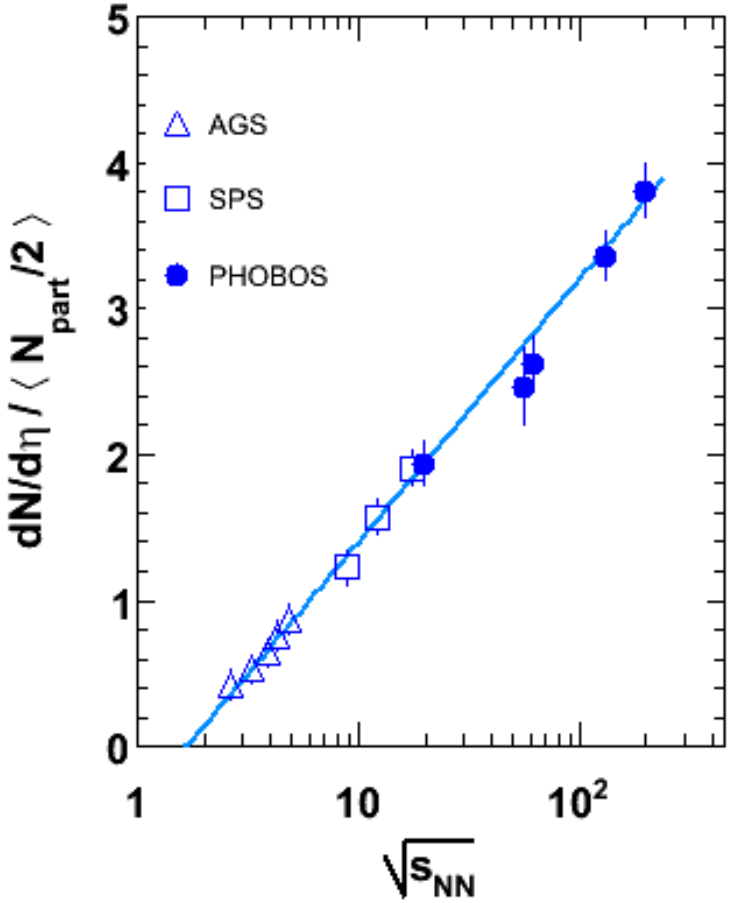


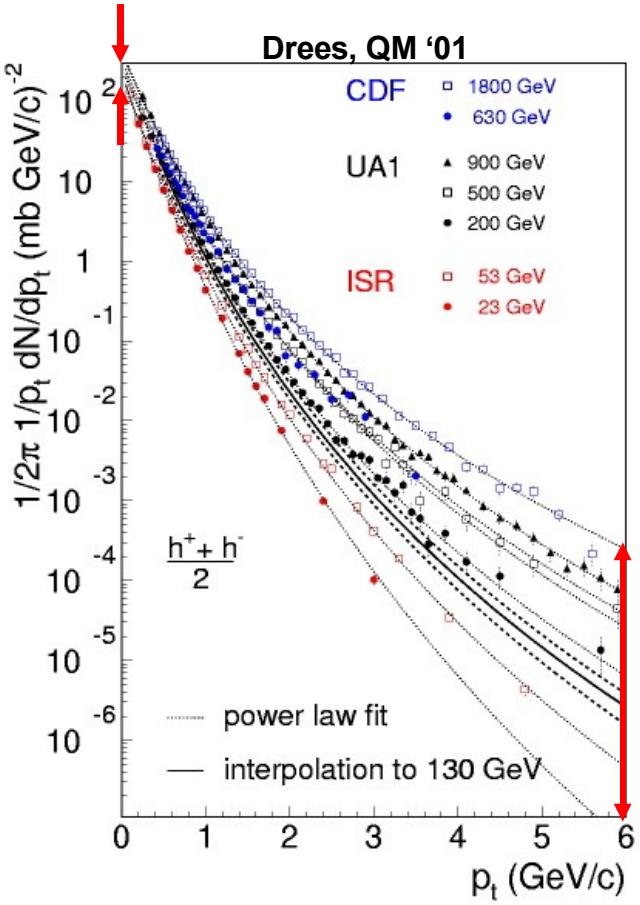


NIM A499, 603-23 (2003)

Control parameters: collision energy

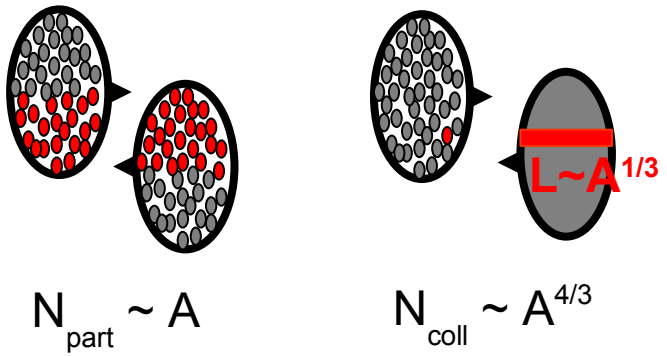
- Collision energy
  - mid-rapidity particle density
  - ratio of hard vs. soft processes

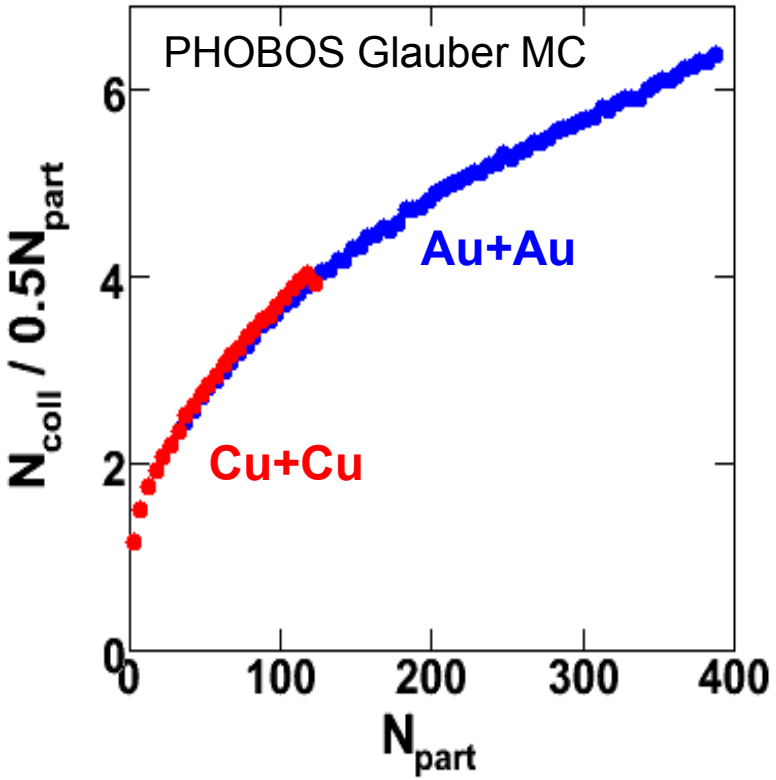




Control parameters: Collision centrality

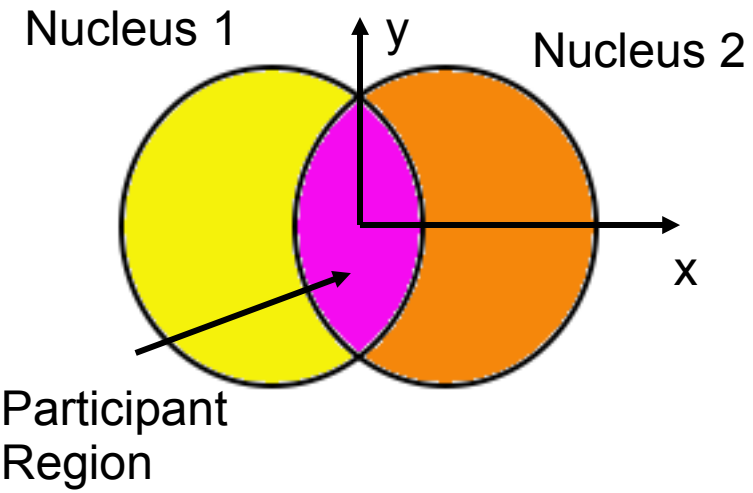
- Collision energy
  - mid-rapidity energy density
  - ratio of hard vs. soft processes
- Collision centrality
  - #Participants (N_{part})
  - #NN-collisions (N_{coll})

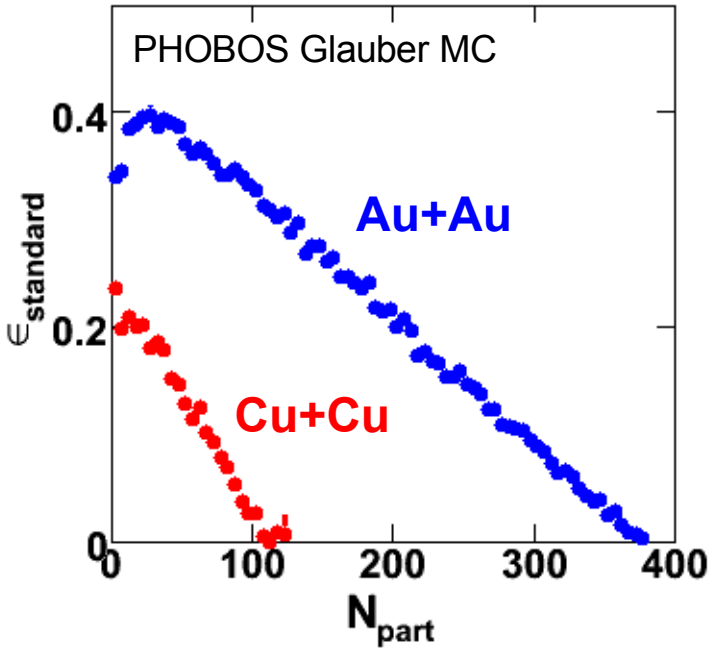




Control parameters: Transverse geometry

- Collision energy
  - mid-rapidity energy density
  - ratio of hard vs. soft processes
- Collision centrality
  - #Participants (N_{part})
  - #NN-collisions (N_{coll})
- Transverse geometry
  - Eccentricity (wrt reaction plane) $\epsilon = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$

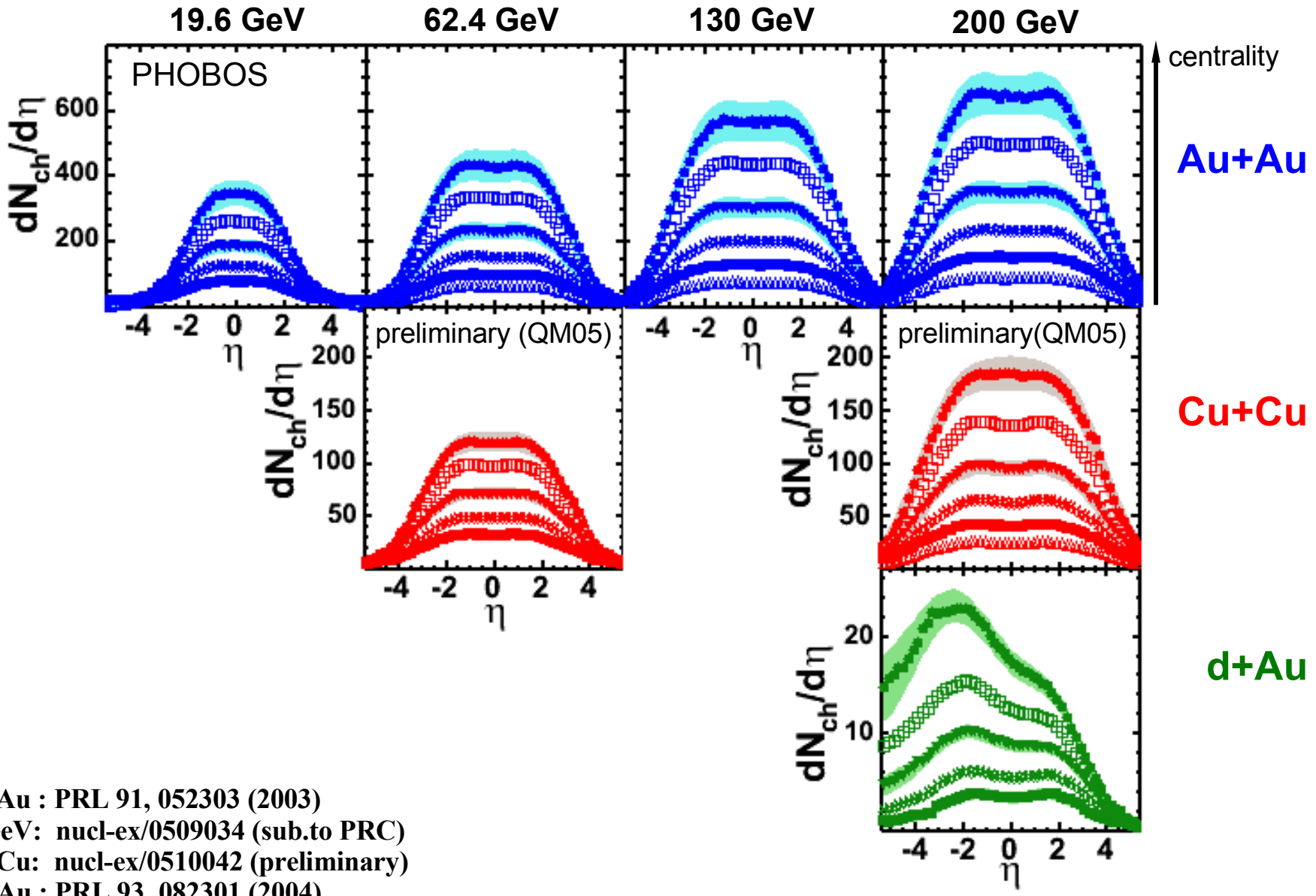




Control parameters: Species comparison

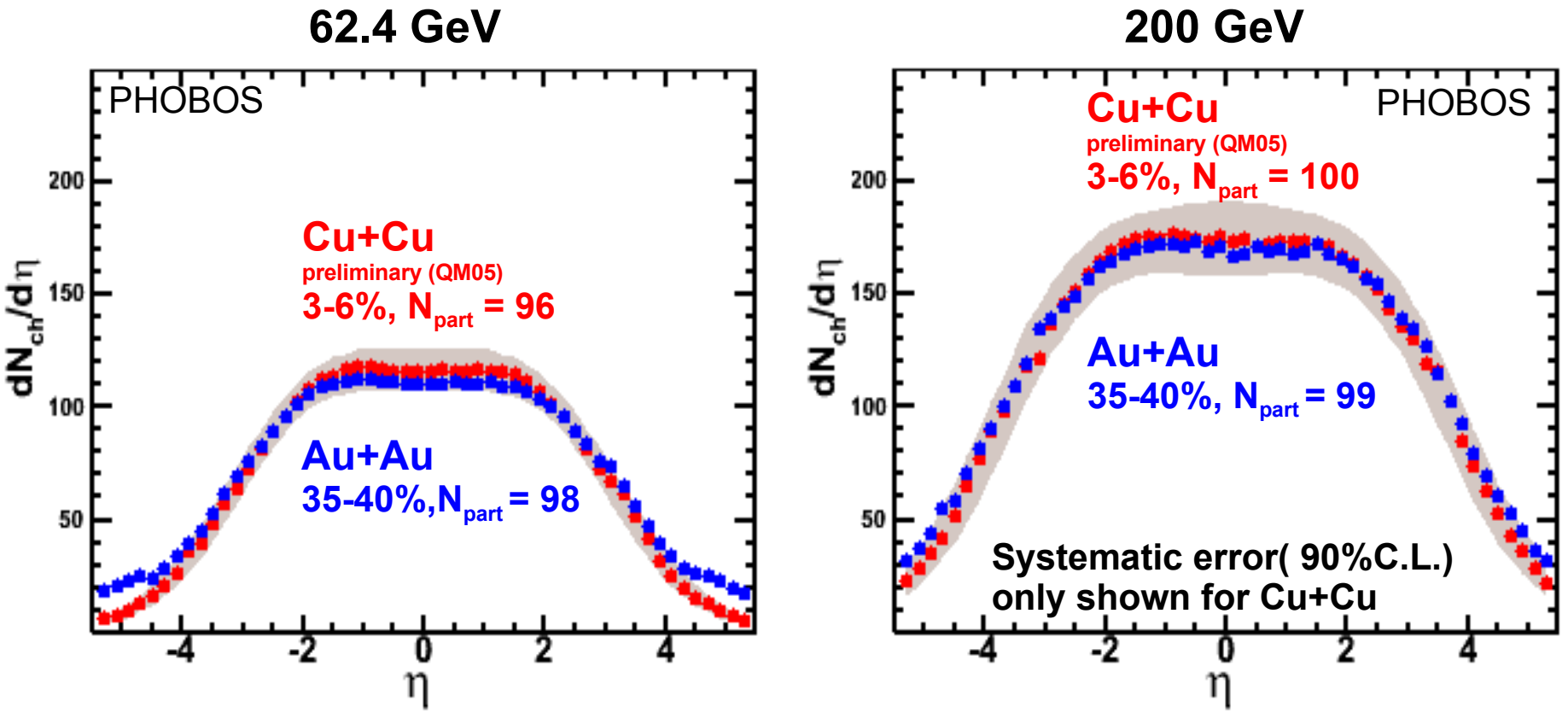
- Compare Au+Au vs Cu+Cu
  - Probe interplay of initial geometry and final-state particle density
  - Study consequences of early thermalization and collectivity
- **Emphasis on simple scaling features of the data**

Charged hadron dN/dη



Au+Au : PRL 91, 052303 (2003)
62 GeV: nucl-ex/0509034 (sub.to PRC)
Cu+Cu: nucl-ex/0510042 (preliminary)
d+Au : PRL 93, 082301 (2004)

Charged hadron dN/dη in Cu+Cu vs Au+Au



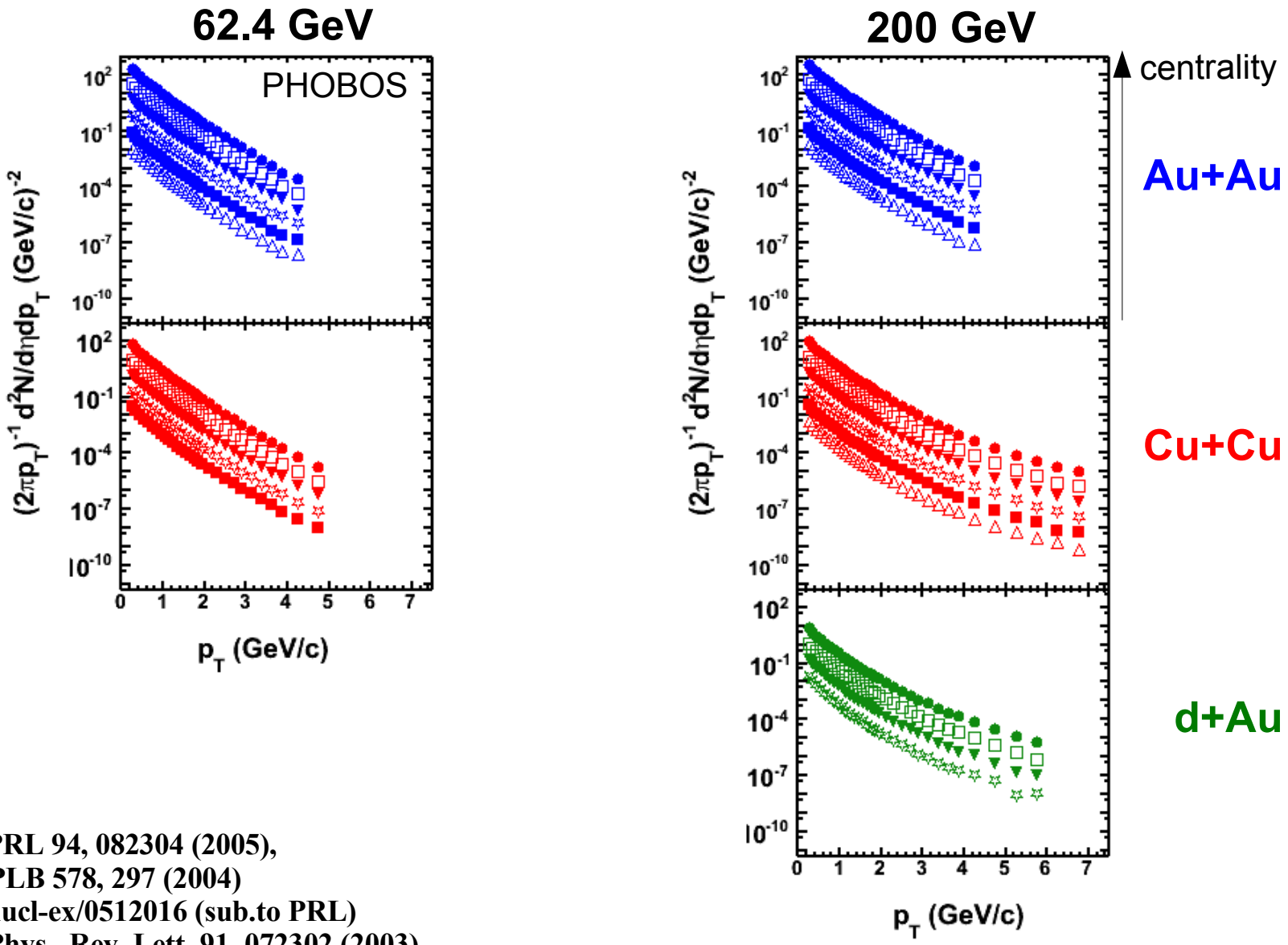
dN/dη very similar for Au+Au and Cu+Cu at same N_{part} without any other normalization

The same is true for mid-central Cu+Cu vs peripheral Au+Au (not shown)

See nucl-ex/0510042; nucl-ex/0601026

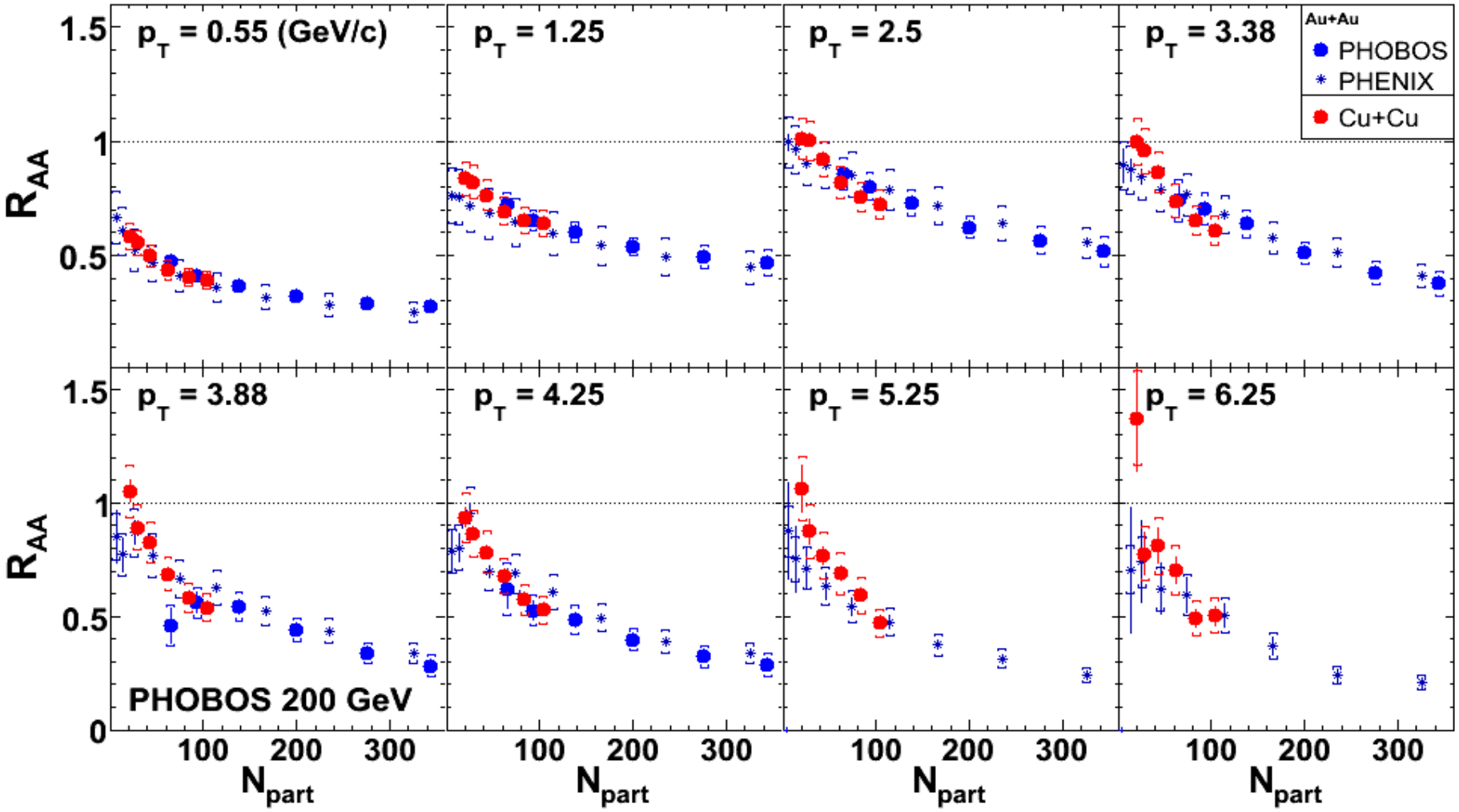
Charged hadron p_T-spectra (near mid-rapidity)

0.2<η<1.4



Au+Au: PRL 94, 082304 (2005),
PLB 578, 297 (2004)
Cu+Cu: nucl-ex/0512016 (sub.to PRL)
d+Au: Phys. Rev. Lett. 91, 072302 (2003)

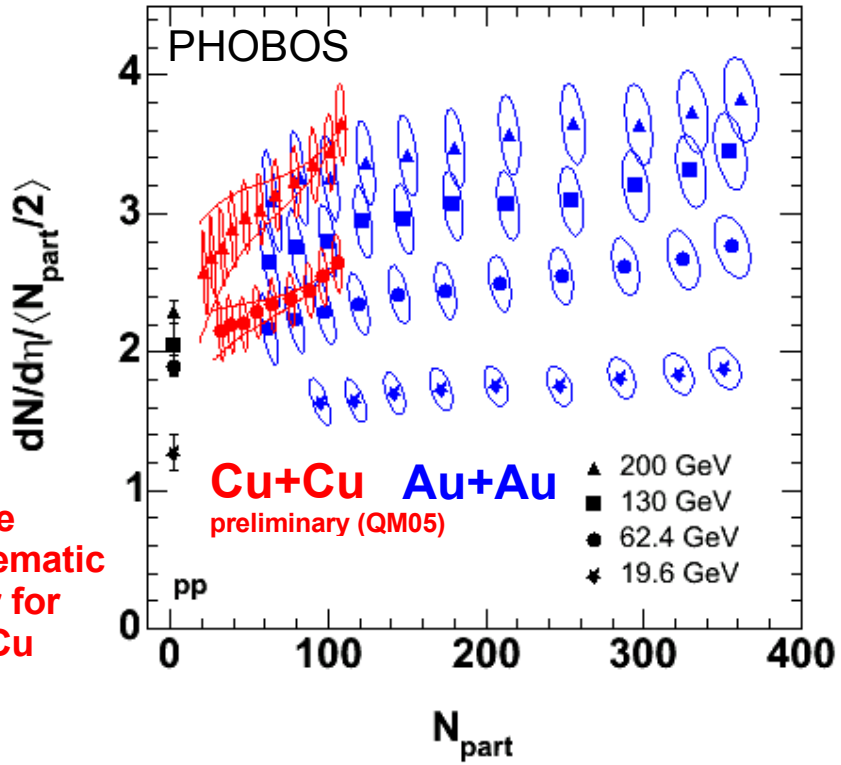
Yields vs N_{part} in Cu+Cu vs Au+Au at 200 GeV



Au+Au: PRL 94, 082304 (2005), PLB 578, 297 (2004)
Phenix: PLB 561, 82 (2003), PRC 69, 034910 (2004)
Cu+Cu: nucl-ex/0512016 (sub.to PRL)
p+p: UA1 -2.5<η<2.5 (acc. correction with PYTHIA)

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

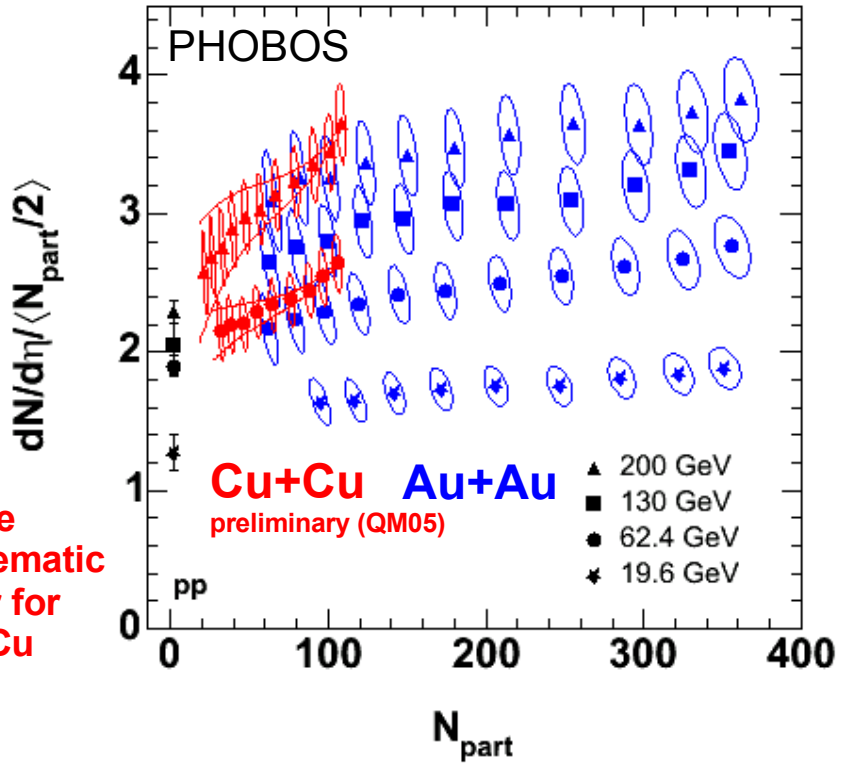
Factorization of energy and centrality



Large systematic error for Cu+Cu

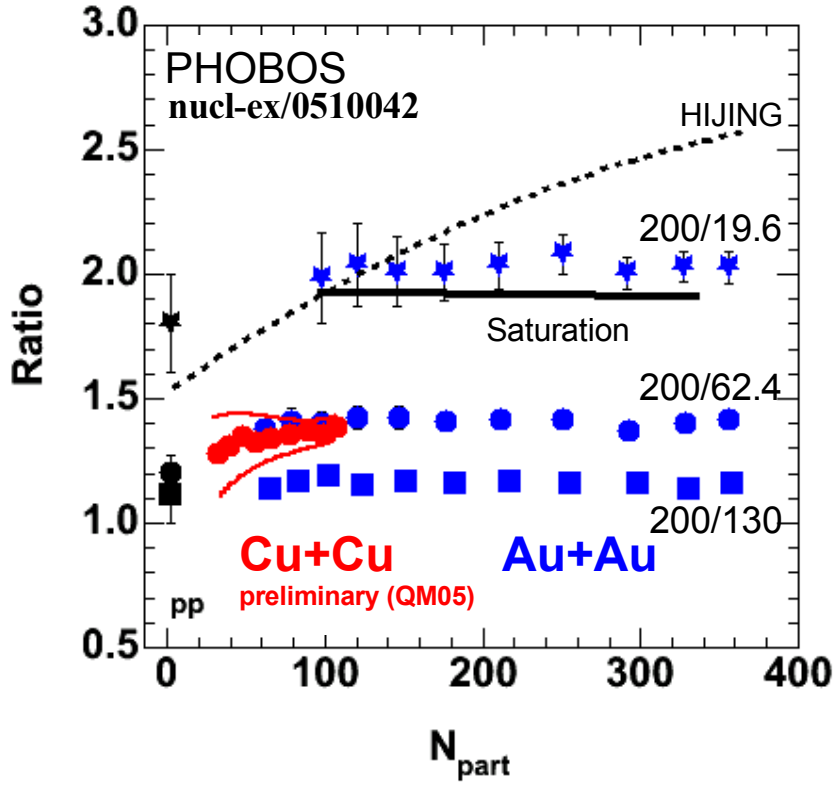
Au+Au: Phys. Rev. C70, 021902(R) (2004)
62.4 GeV: nucl-ex/0509034 (sub.to PRC)
Cu+Cu: nucl-ex/0510042 (preliminary)

Factorization of energy and centrality



Large systematic error for Cu+Cu

Ratio of dN/dη @ η=0 relative to 200 GeV vs centrality

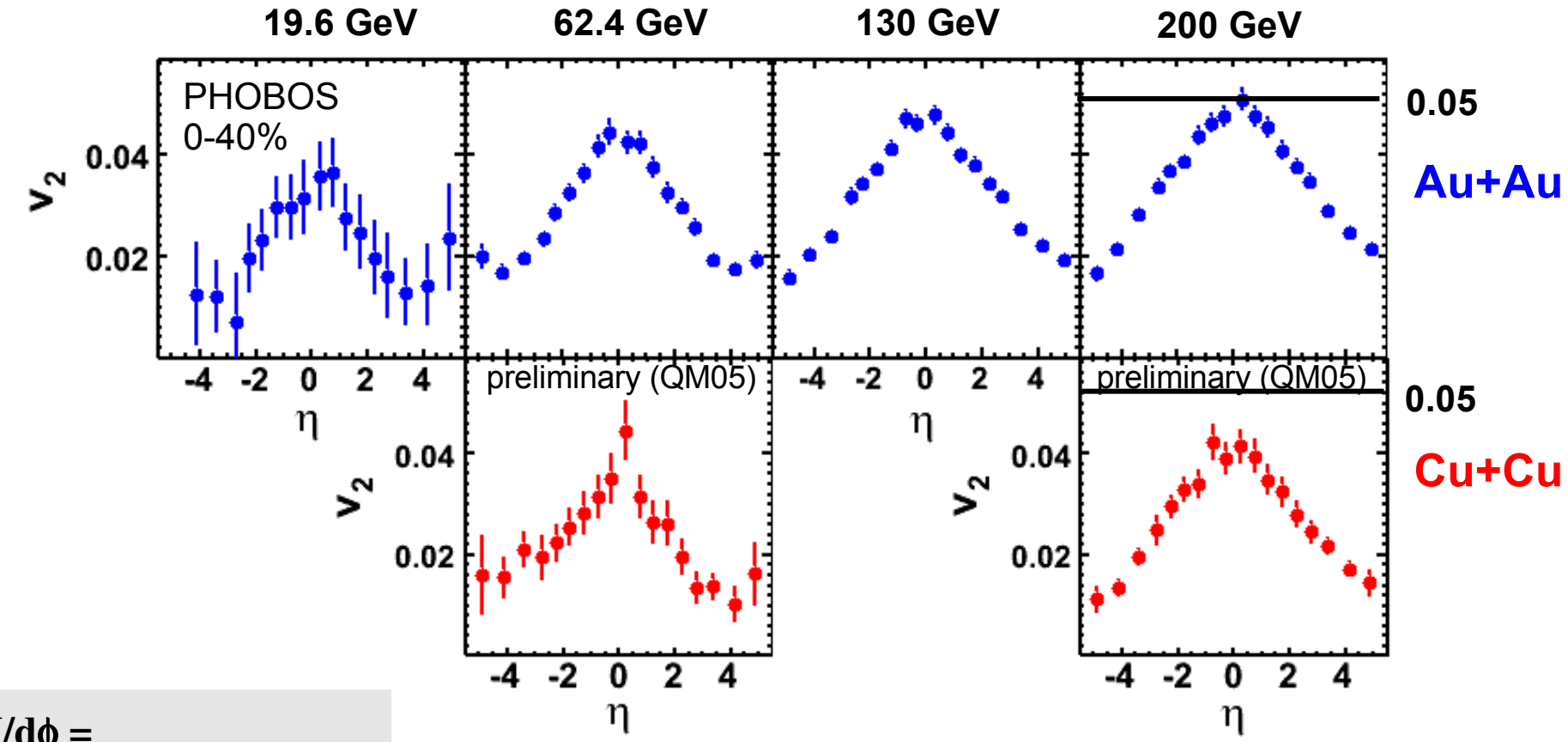


Factorization of energy and centrality due to initial state effect?

Also holds in bins of p_T up to $p_T \approx 4$ GeV/c for $N_{part} > 40$ (not shown)

Au+Au: Phys. Rev. C70, 021902(R) (2004)
62.4 GeV: nucl-ex/0509034 (sub.to PRC)
Cu+Cu: nucl-ex/0510042 (preliminary)

Elliptic flow (v_2)



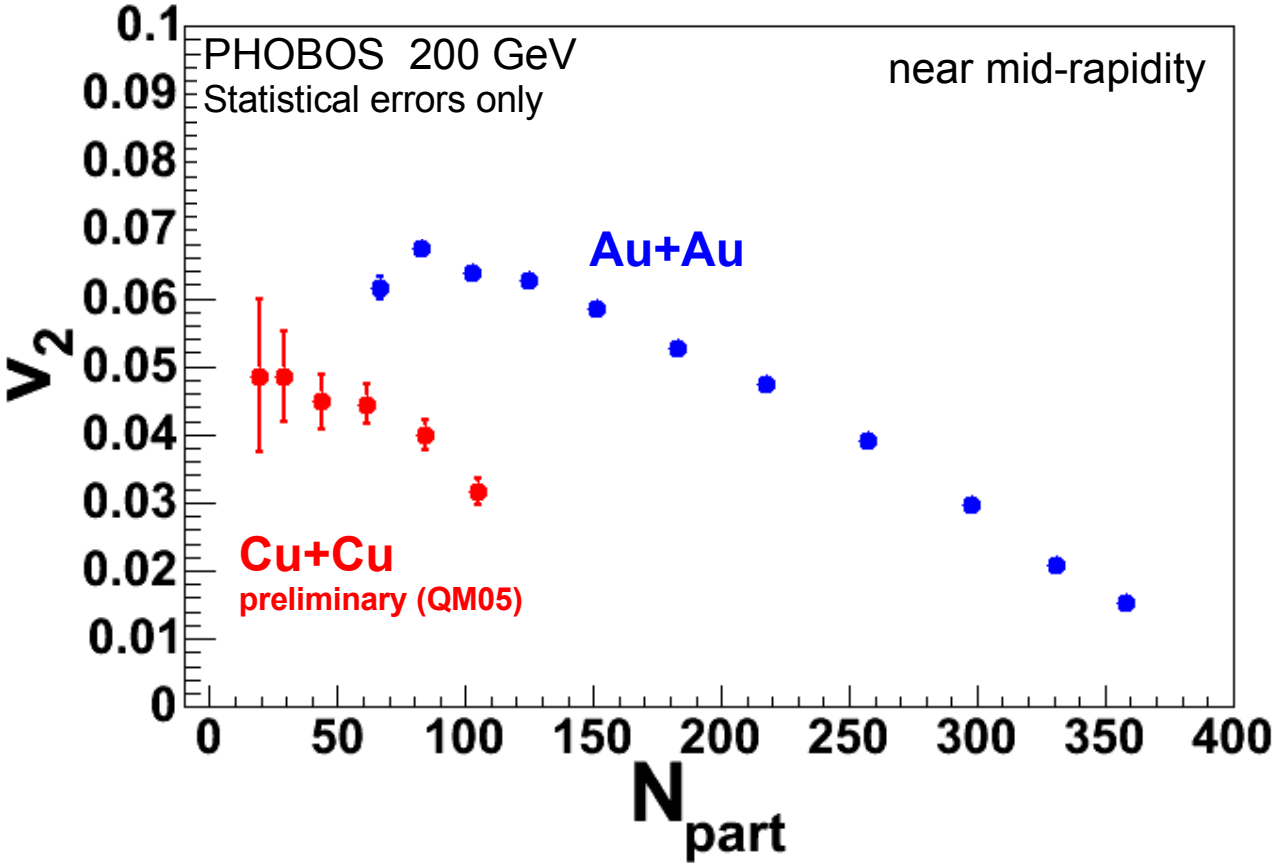
$dN/d\phi =$

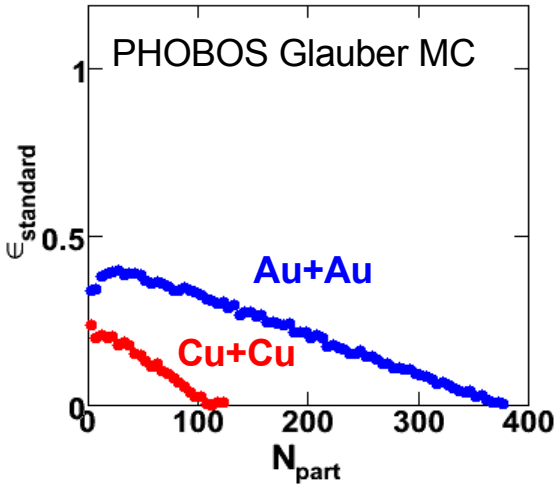
$N_0 (1 + 2v_1 \cos\phi +$

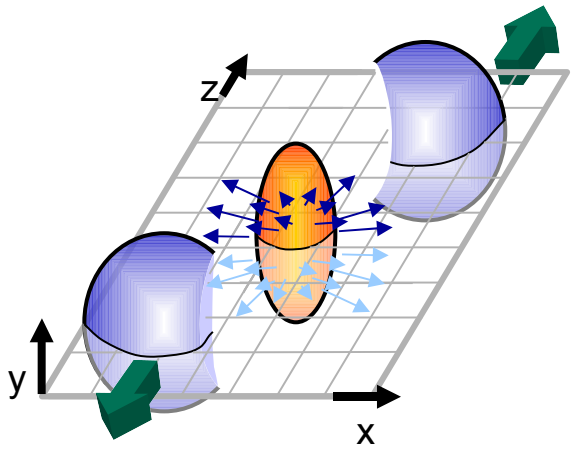
$2v_2 \cos(2\phi) + \ldots)$

Au+Au: PRL 94 122303 (2005)
Cu+Cu: nucl-ex/0510031 (preliminary)

Elliptic flow vs N_{part}

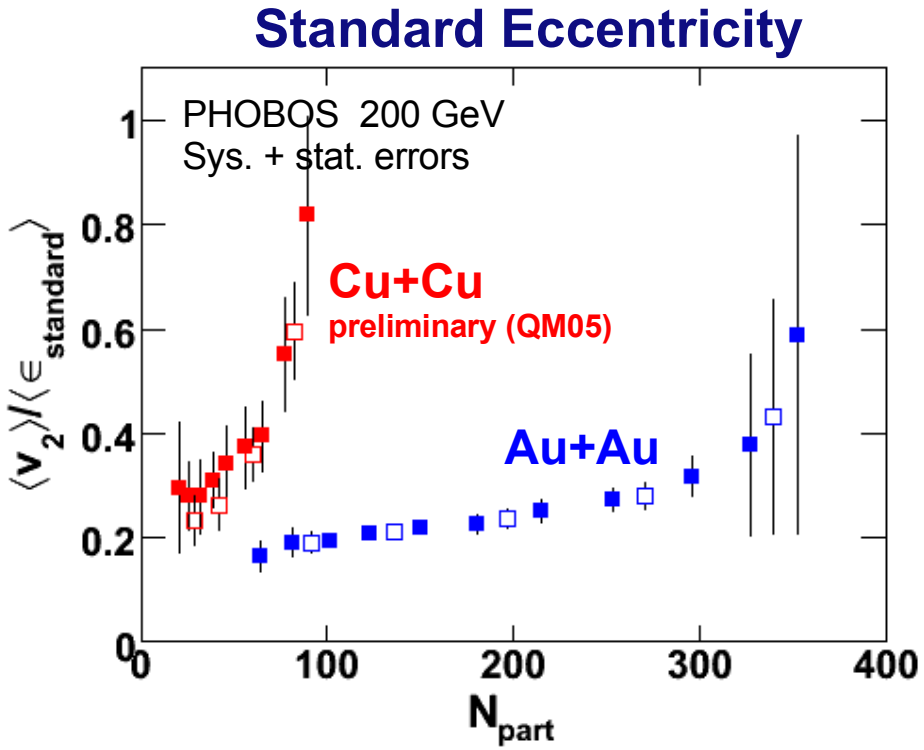


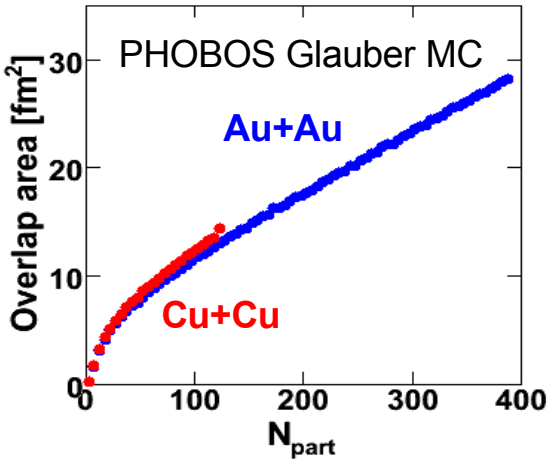




Substantial v_2 even for most central bin in Cu+Cu

Scaled elliptic flow vs N_{part}

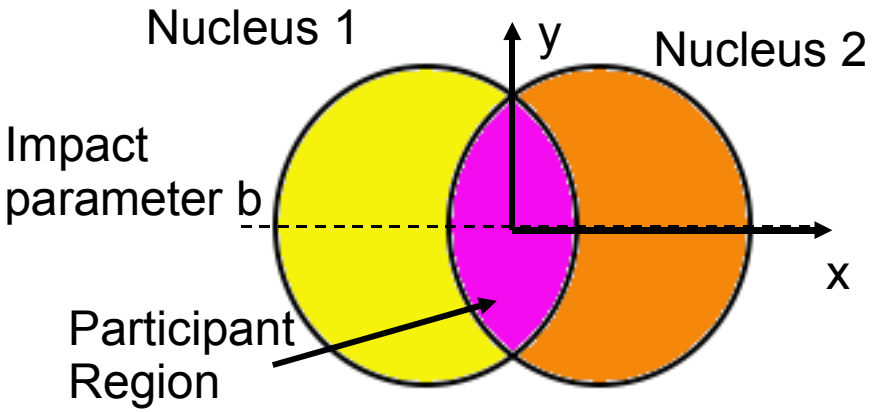


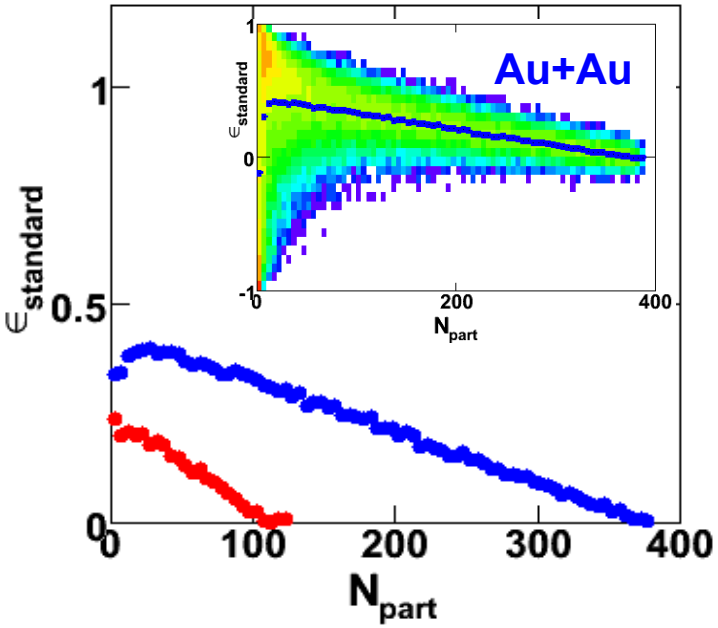


Dividing v_2 by the standard eccentricity shows no connection between the two species

Eccentricity calculation (reexamined)

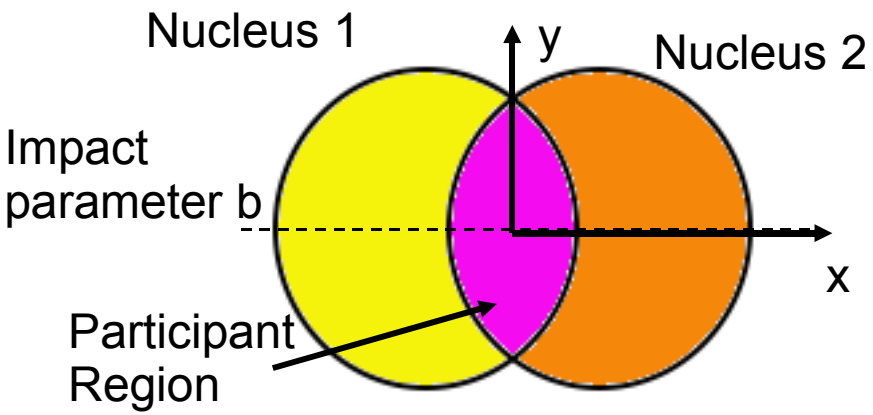
Standard Eccentricity



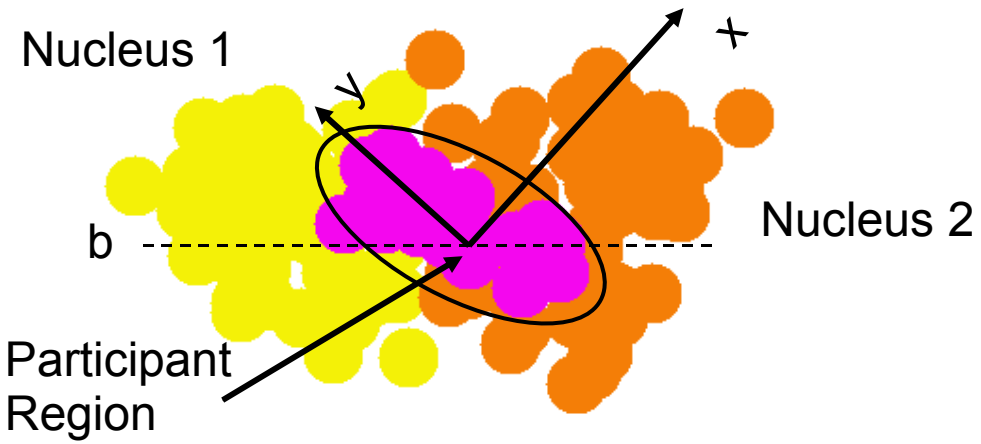


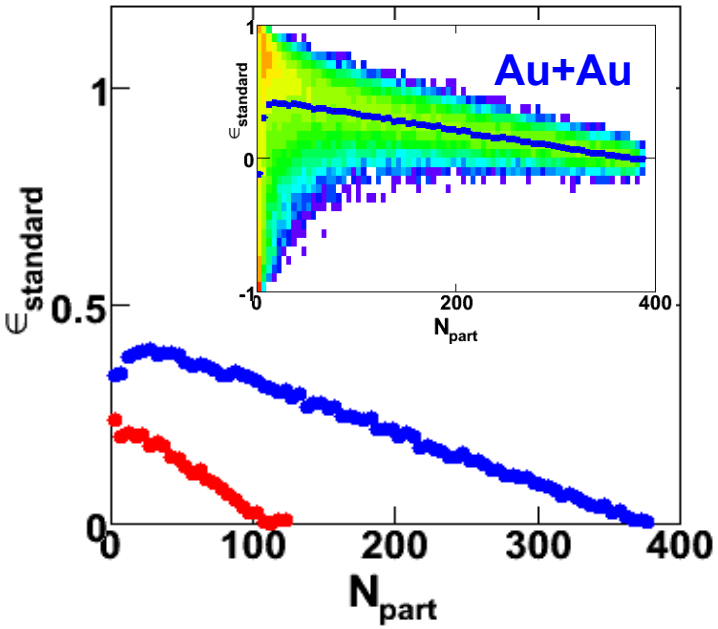
Eccentricity calculation (reexamined)

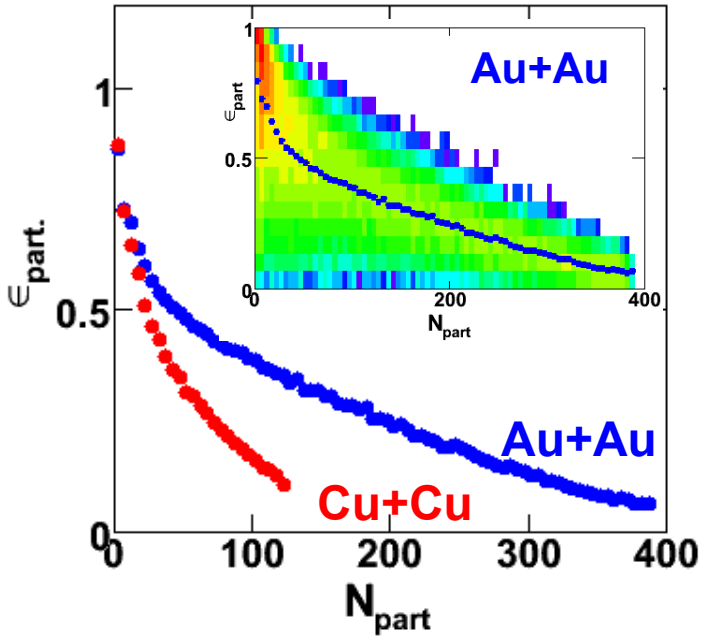
Standard Eccentricity



Participant Eccentricity

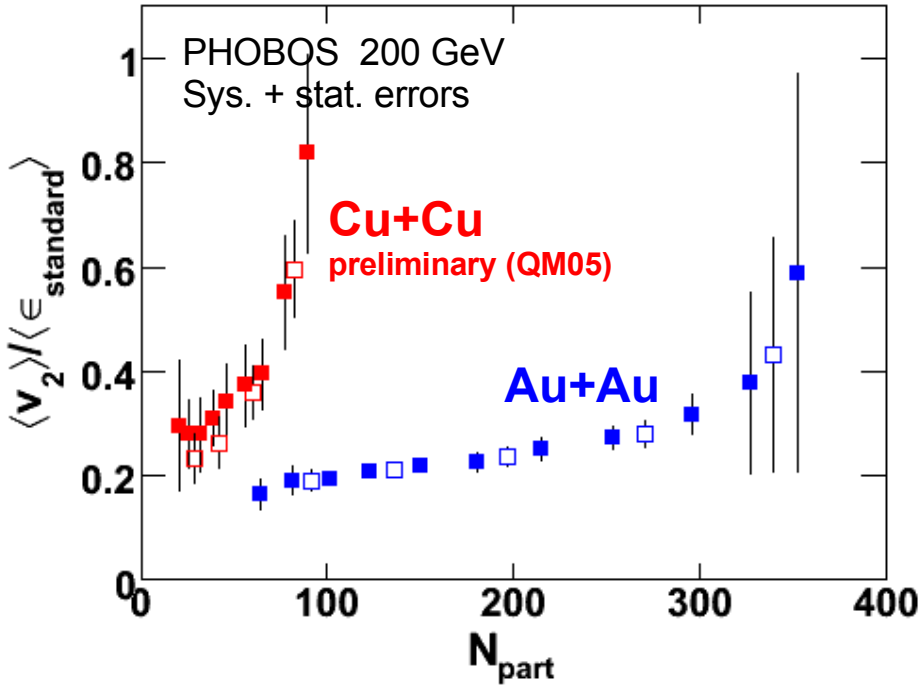




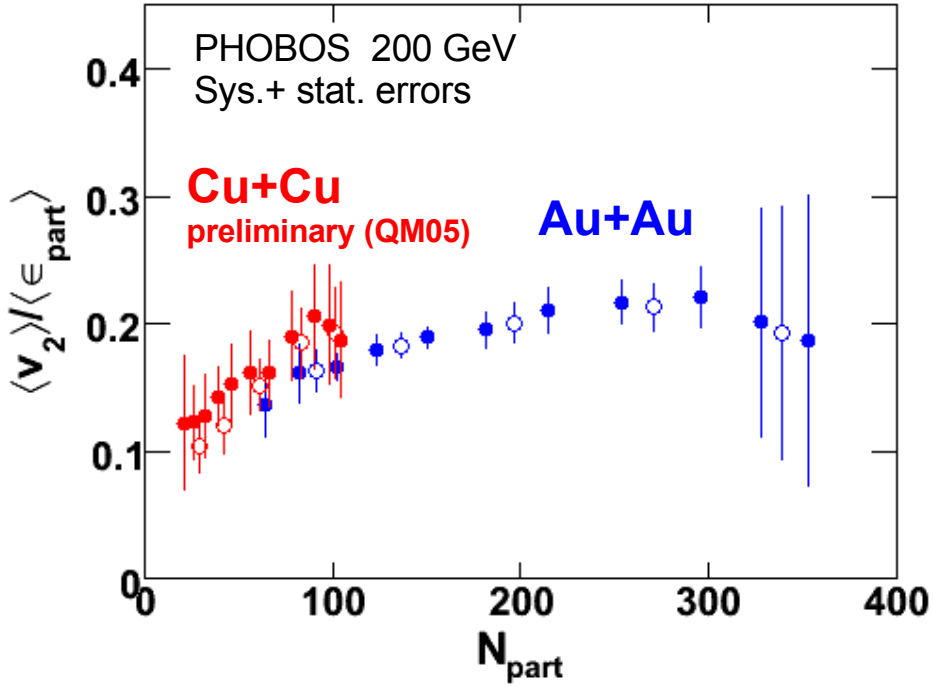


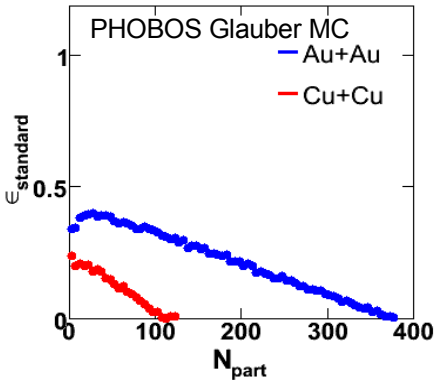
Scaled elliptic flow vs N_{part} (2)

Standard Eccentricity

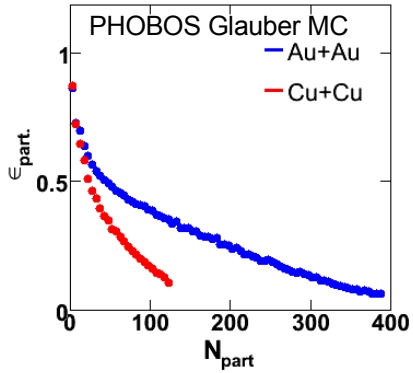


Participant Eccentricity





"Participant Eccentricity" allows v_2 scaling from Cu+Cu to Au+Au



Summary

- PHOBOS has large data sets on nucleus-nucleus collisions for various species and energies
- Probe interplay of initial geometry and final particle density
  - For the same N_{coll}/N_{part} ratio Au+Au and Cu+Cu show similar features ($dN/d\eta$ vs η, dN/dp_T vs p_T)
  - Factorization of energy/centrality found in Au+Au and Cu+Cu
    - Rules out N_{part}-and-N_{coll} two-component model
- Study consequences of early thermalization using elliptic flow
  - At the same Npart, Cu+Cu has larger elliptic flow than Au+Au
  - Elliptic flow may be determined by distribution of participant nucleons, not reaction plane

Backup

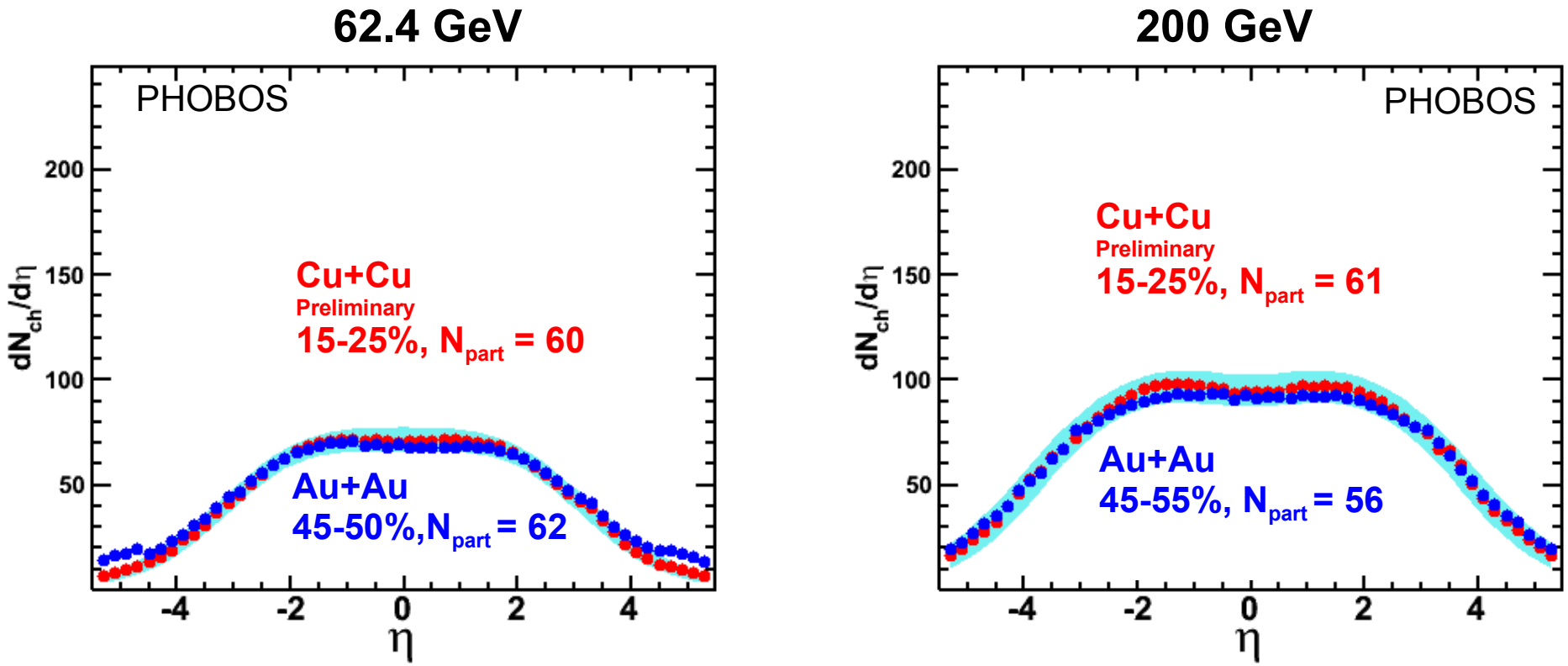
PHOBOS experiment (2)

Recorded data sets on tape [in millions]

GeV \ system	p+p	d+Au	Cu+Cu	Au+Au
410	20			
200	100	150	400	250
130				4.3
62.4			110	22
55.9				1.8
22.5			20	
19.6				~1

= shown in this talk

Charged hadron dN/dη in Cu+Cu vs Au+Au

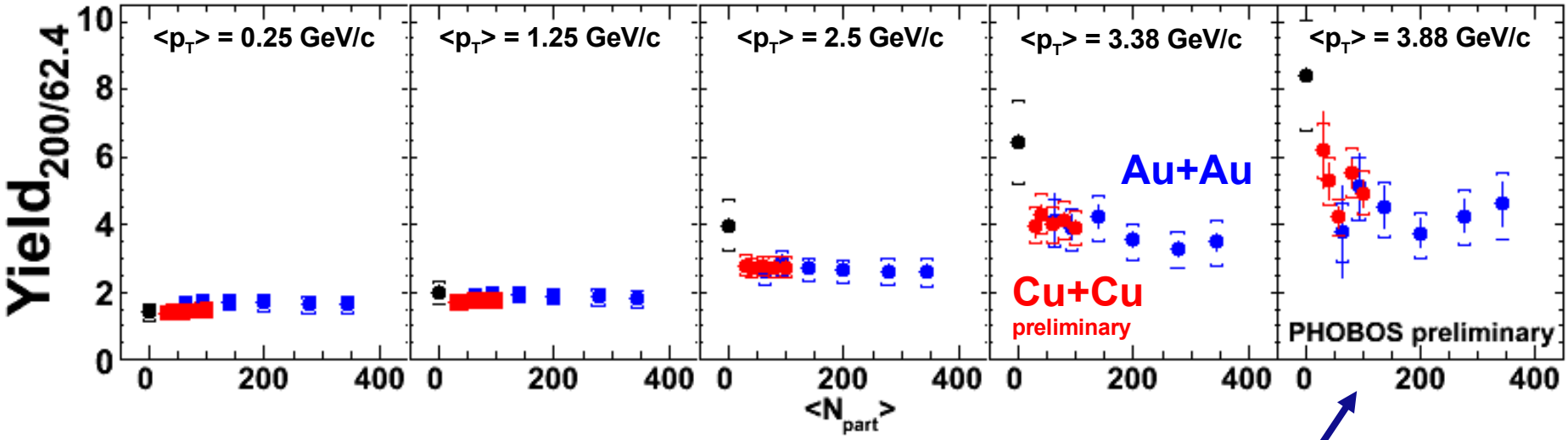


Also true for mid-central Cu+Cu vs peripheral Au+Au

Unscaled dN/dη very similar for Au+Au and Cu+Cu at same N_{part}

Factorization of energy and centrality in bins of p_T

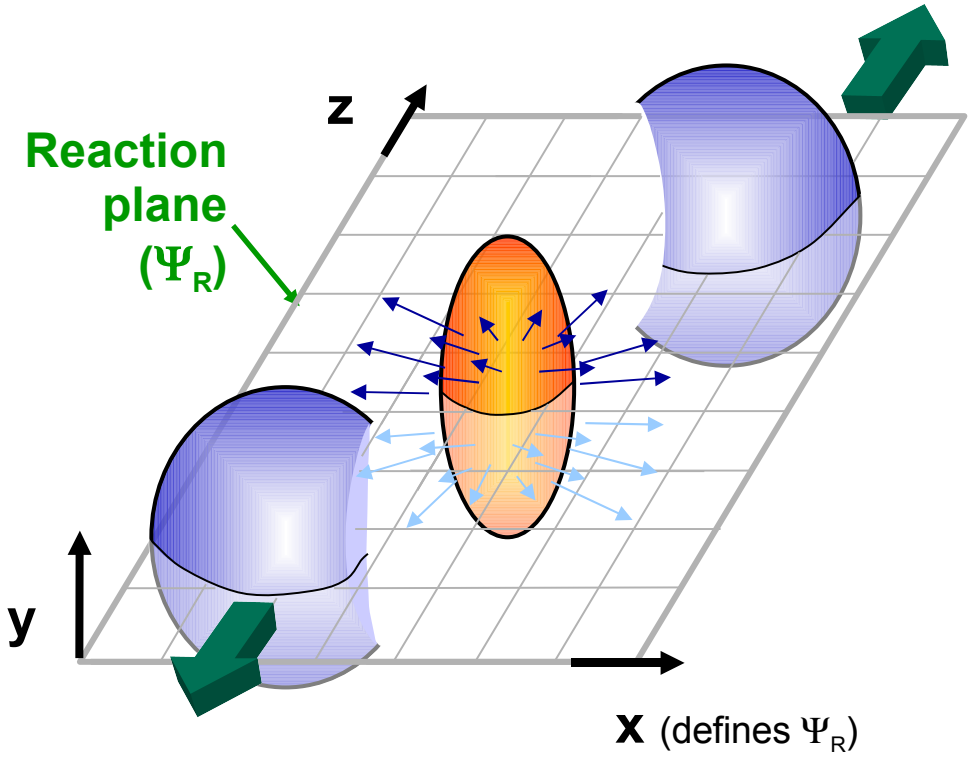
Ratio of charged hadron yields in 200 GeV to 62 GeV

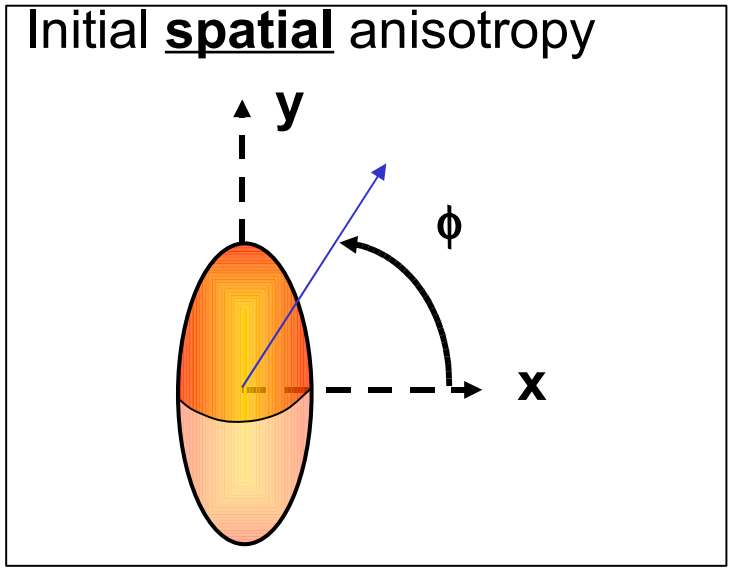


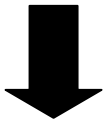
Energy/centrality factorization up to $p_T \approx 4$ GeV/c for $N_{part} > 40$

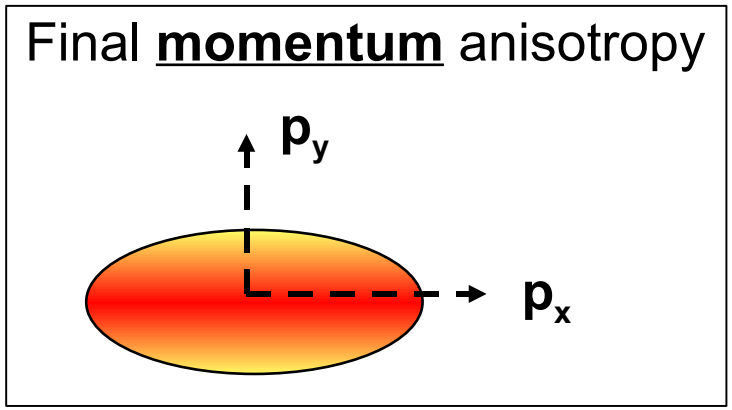
Au+Au: PRL 94, 082304 (2005)

Direct (v_1) and elliptic (v_2) flow



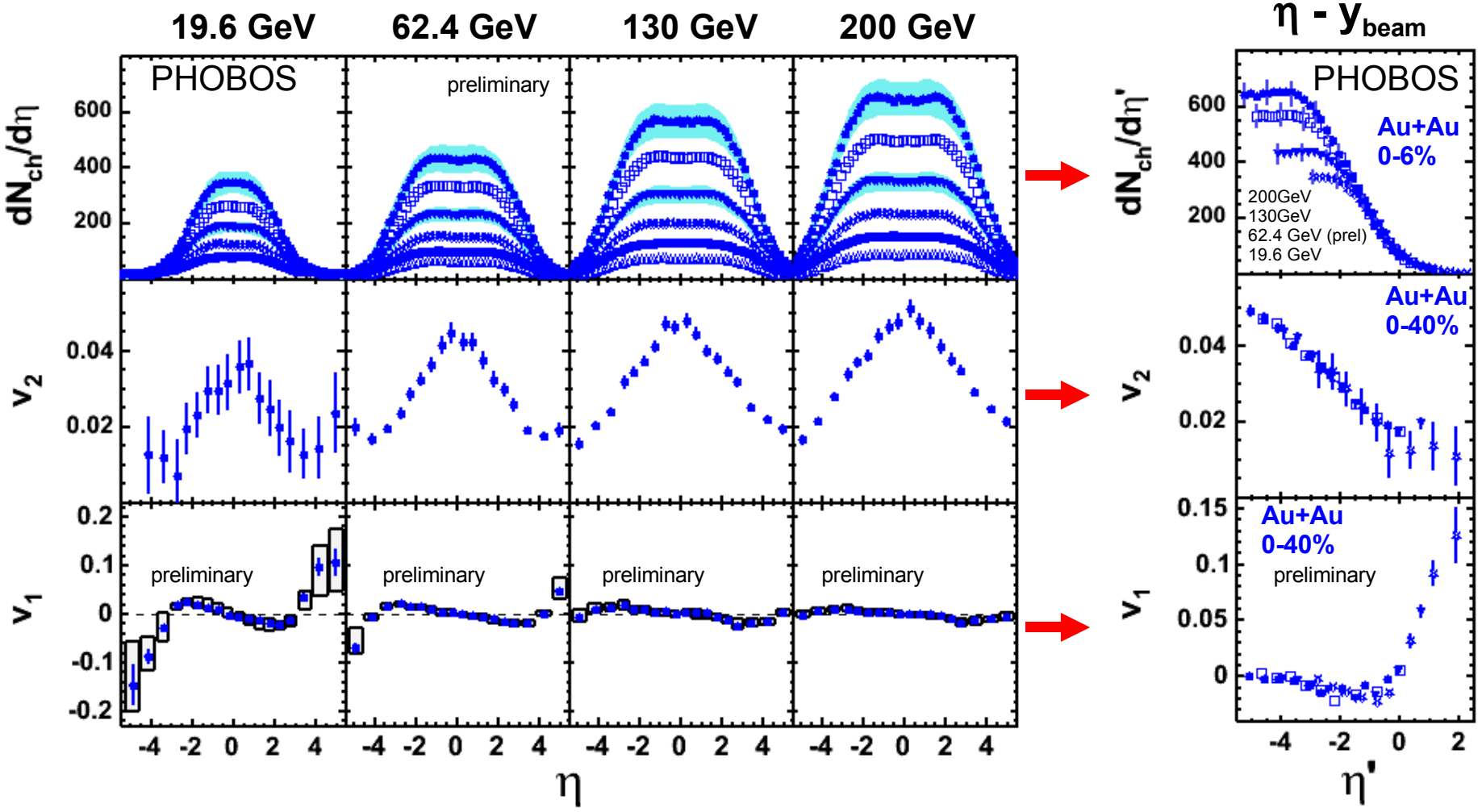






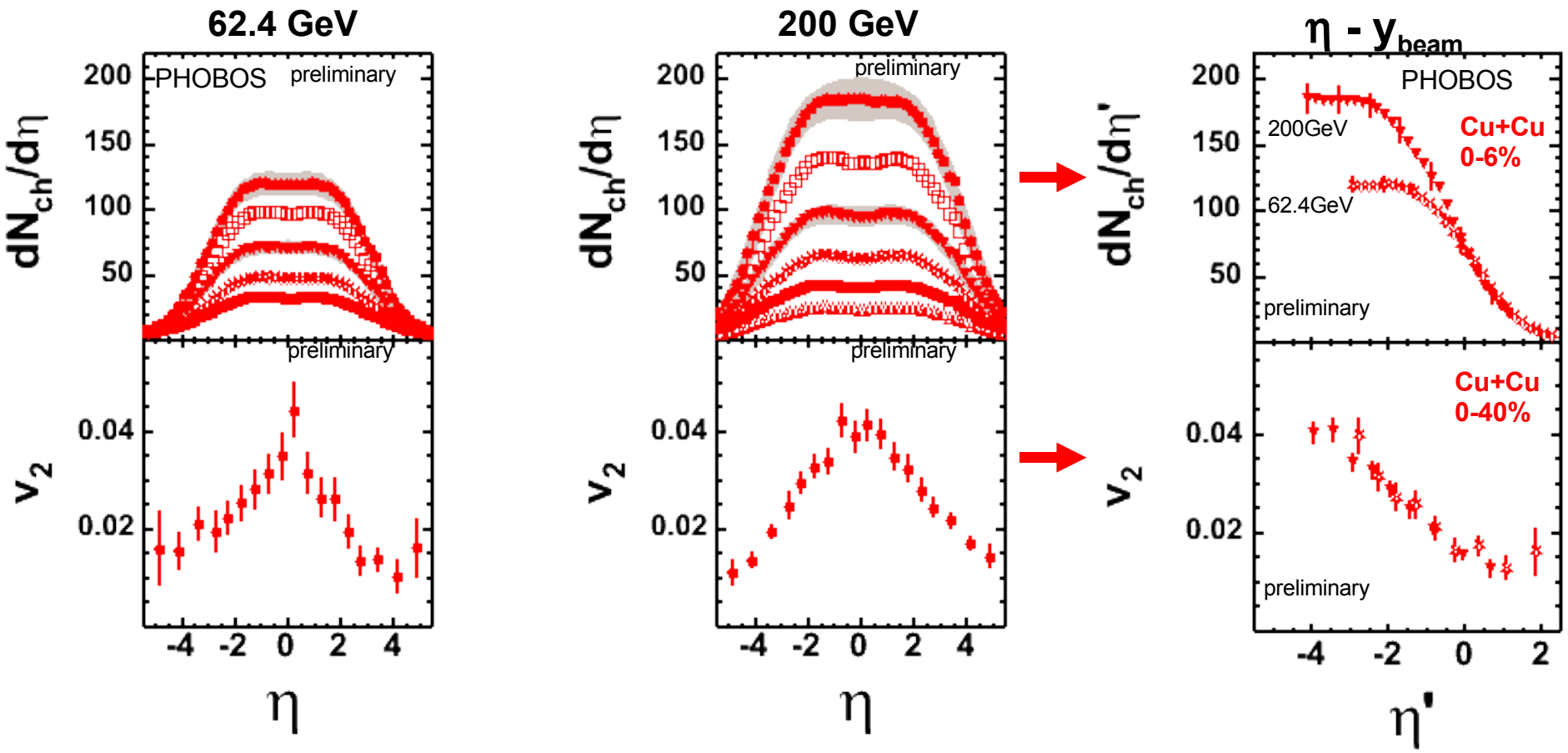
$$dN/d(\phi - \Psi_R) = N_0 (1 + 2v_1 \cos(\phi - \Psi_R) + 2v_2 \cos(2(\phi - \Psi_R)) + \dots)$$

Limiting fragmentation (Au+Au)



"Extended Longitudinal Scaling" of all longitudinal distributions

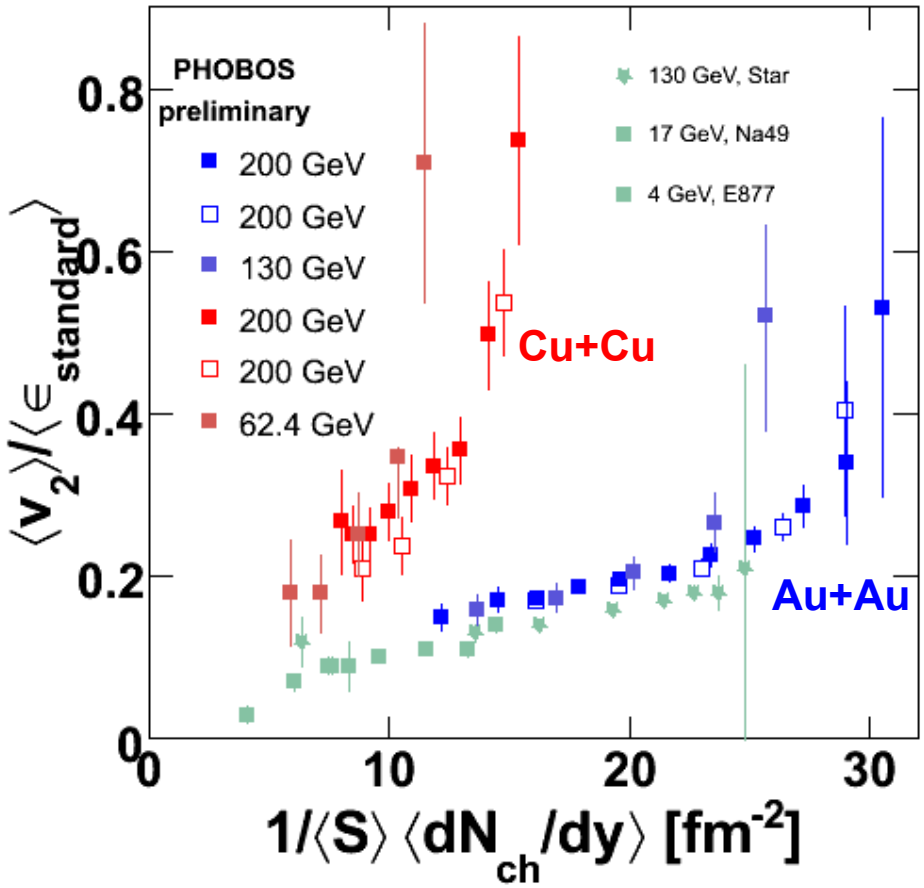
Limiting fragmentation (Cu+Cu)



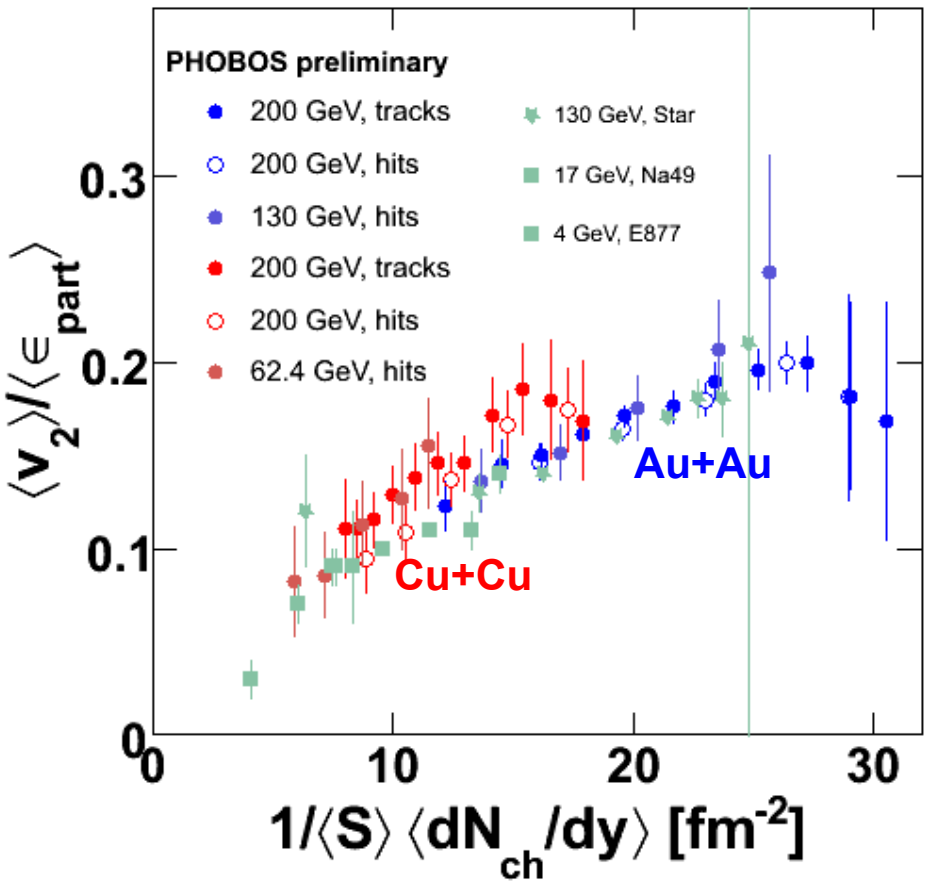
'Extended Longitudinal Scaling' also seen in Cu+Cu
Persists from p+p to Au+Au over large range in η'

“Low density limit” scaling

Standard Eccentricity



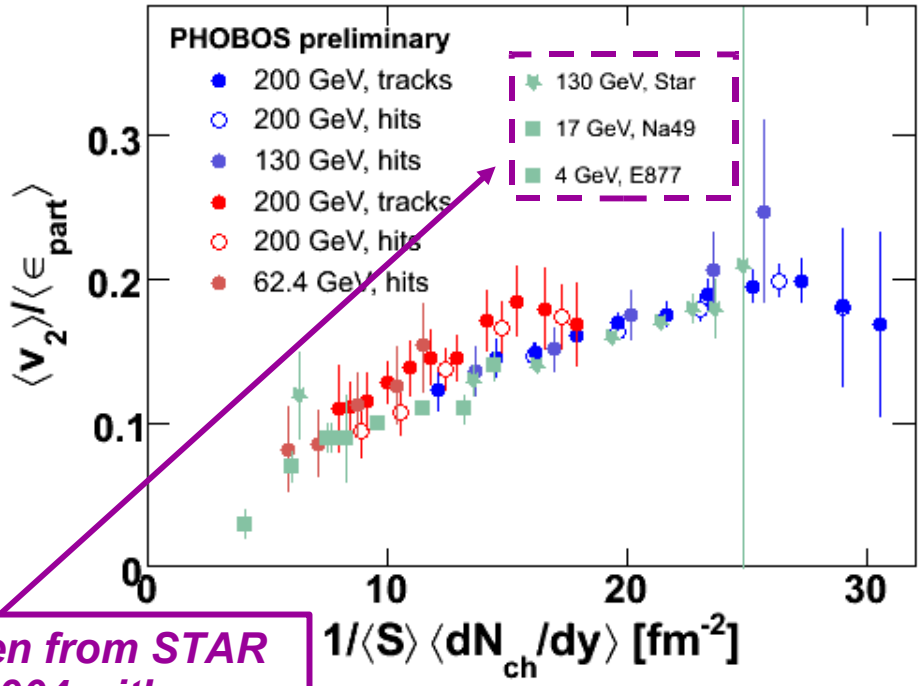
Participant Eccentricity



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

Low-density limit scaling

- **Caution:** we used ε_{part} for PHOBOS data. Important for Cu-Cu, less critical for Au-Au.
- Scale $v_2(\eta)$ to ~$v_2(y)$ (10% lower)
- Scale $dN/d\eta$ to be ~dN/dy (15% higher)



Points for STAR, NA49 and E877 data taken from STAR Collaboration, Phys.Rev. C66 (2002) 034904 with no adjustments

Approximate "LDL" scaling observed.