

# Multiplicity Measurements and Empirical Extrapolations to LHC

*ECT\* Trento  
January 2007*

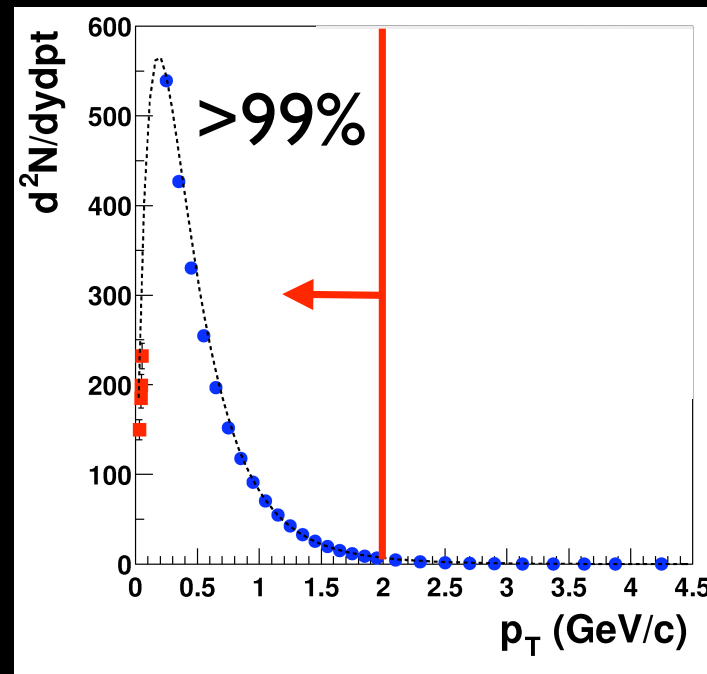
Gunther Roland  
MIT

# Key Features of Soft Particle Production in Heavy Ion Collisions

*ECT\* Trento  
January 2007*

Gunther Roland  
MIT

# “Soft Physics”



“Soft Physics”: Particle production with  $p_T < 2\text{GeV}/c$

# Summary

Soft particle production in heavy ion collisions is characterized by a number of scaling relationships  
(e.g.  $N_{\text{part}}$  scaling of  $N_{\text{ch}}$ , limiting fragmentation, factorization of energy/centrality dependence)

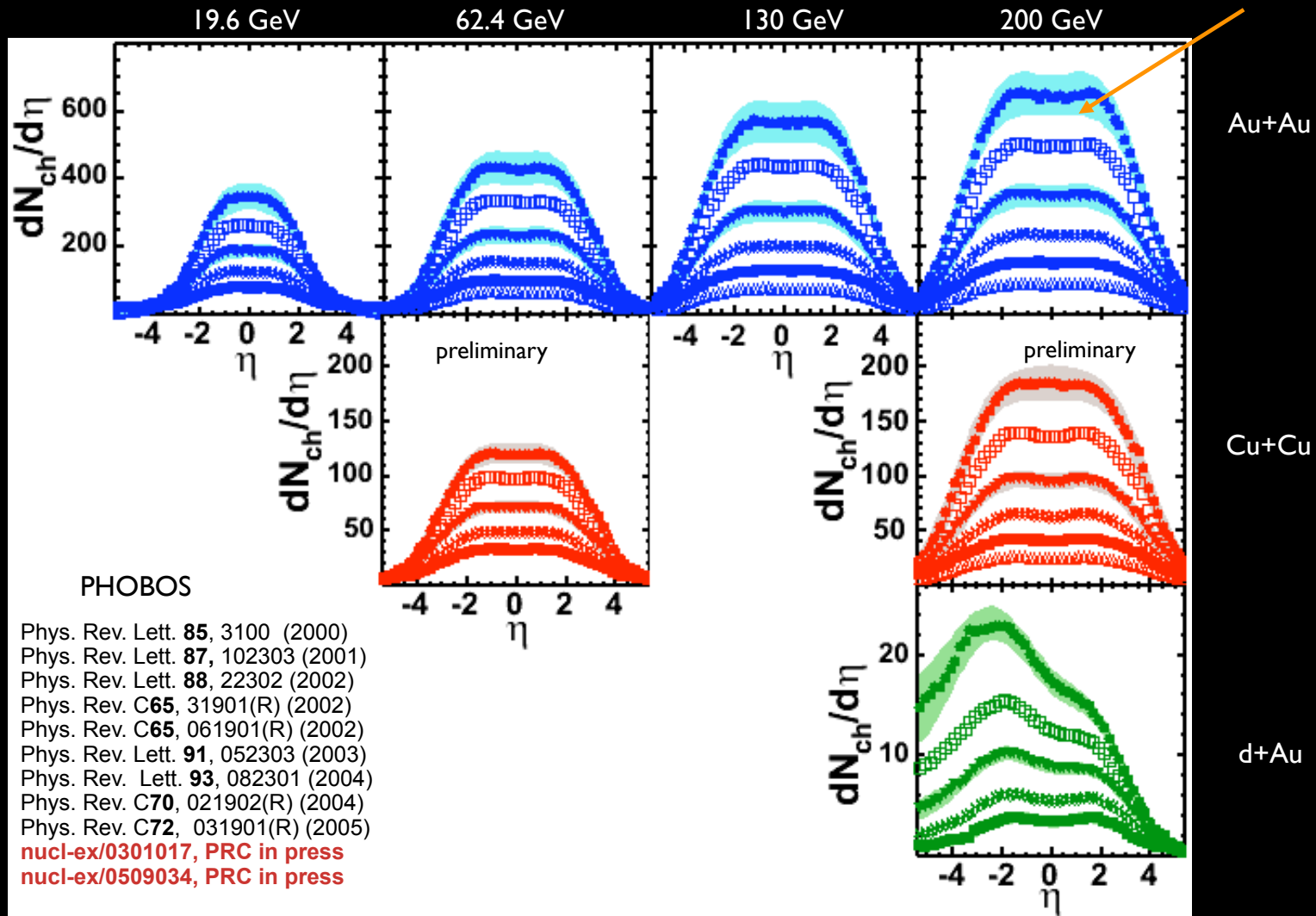
Ideally, these relationships should emerge naturally from our understanding of the collision process

Parton saturation/CGC may provide a framework for this understanding. Recent data provide new information and (maybe) a challenge

# Multiplicity Data

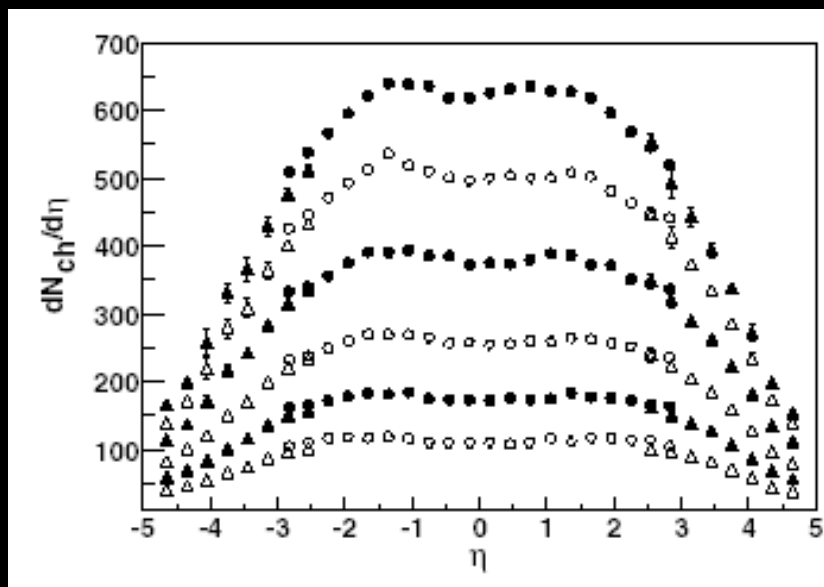
# PHOBOS Data

central events



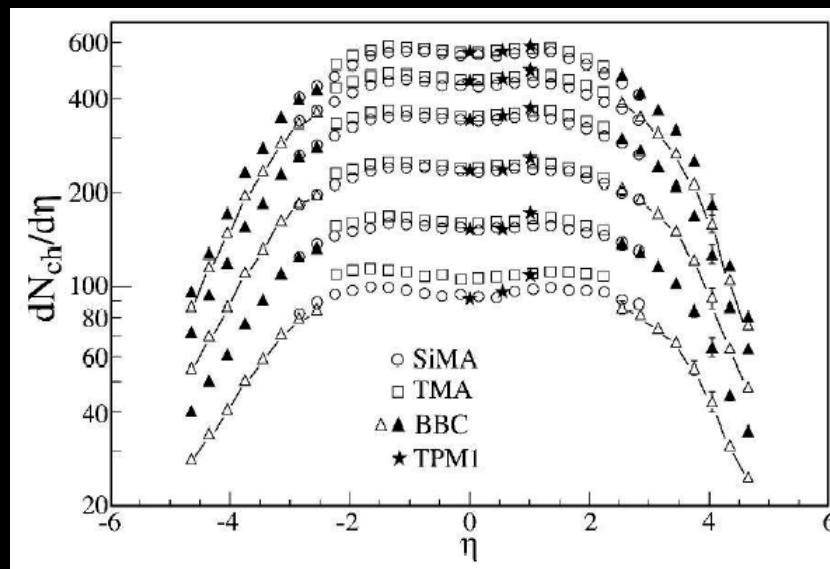
# BRAHMS Data

200 GeV Au+Au



Phys. Rev. Lett. 88, 202301(2002)

130 GeV Au+Au

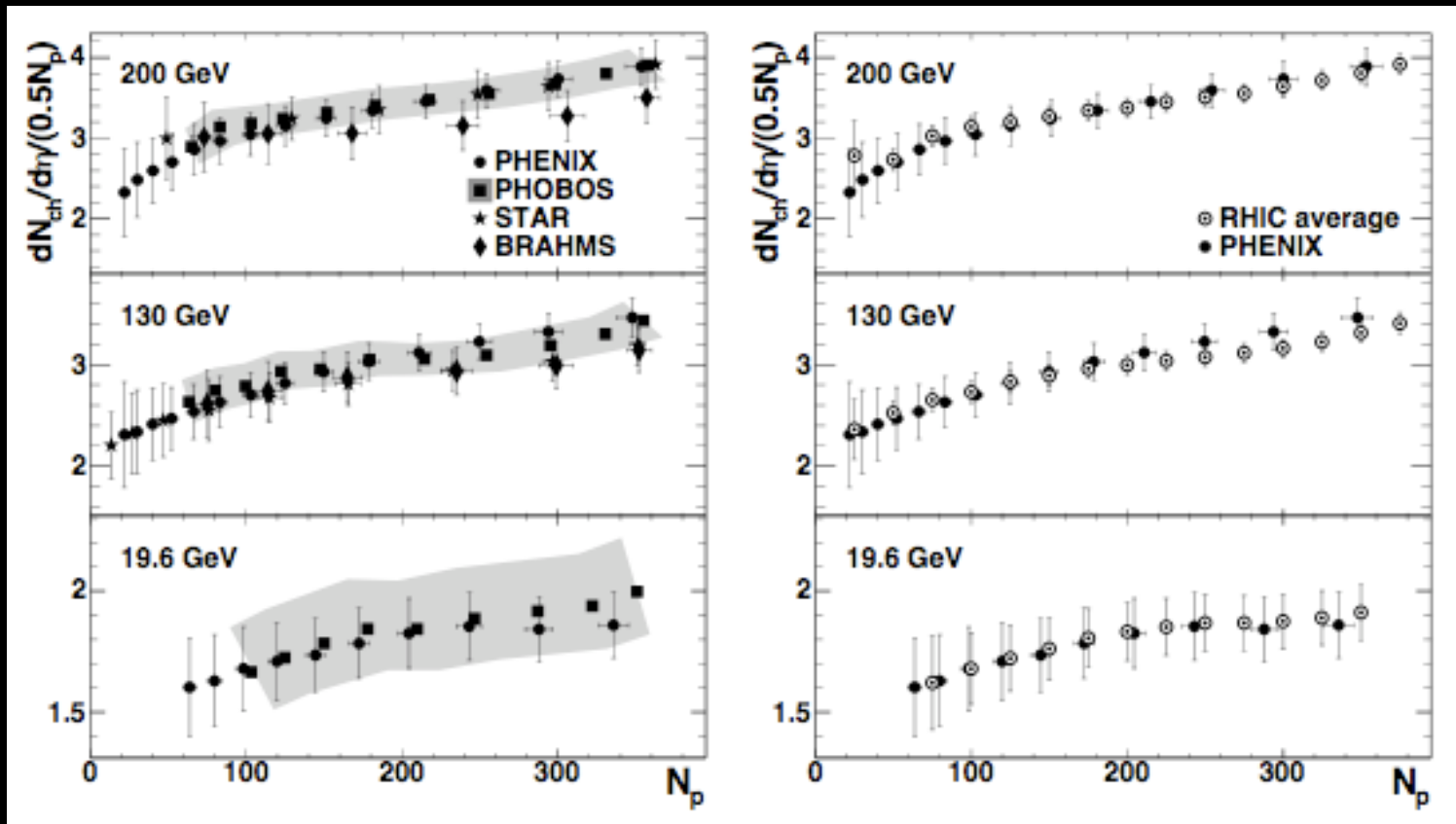


Phys. Lett. B 523 (2001) 227

Very good consistency between BRAHMS and PHOBOS in Pseudorapidity distributions

# PHENIX (+STAR) Data

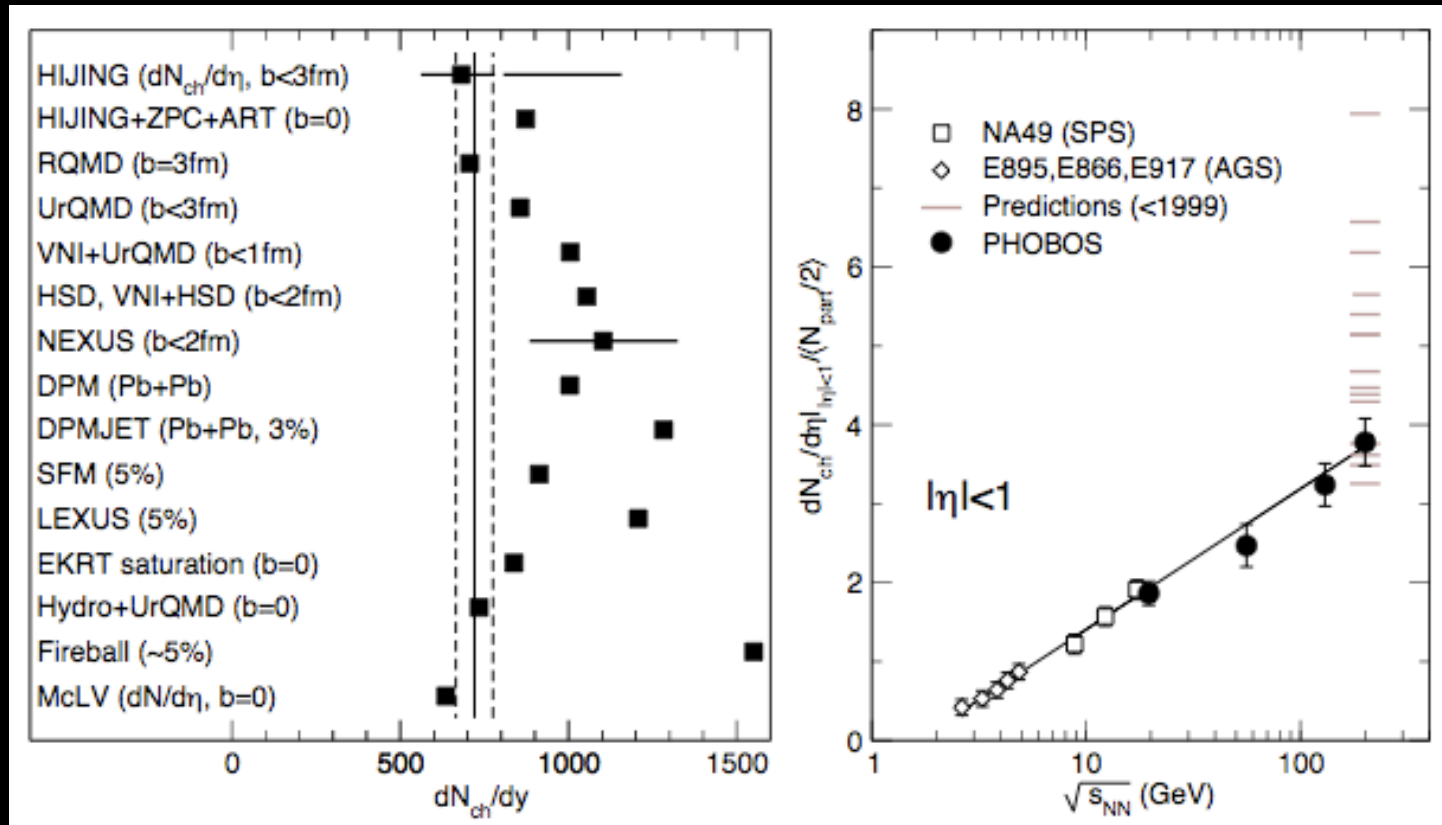
Au+Au, PHENIX nucl-ex/0409015, PRC



Again, very good agreement between experiments

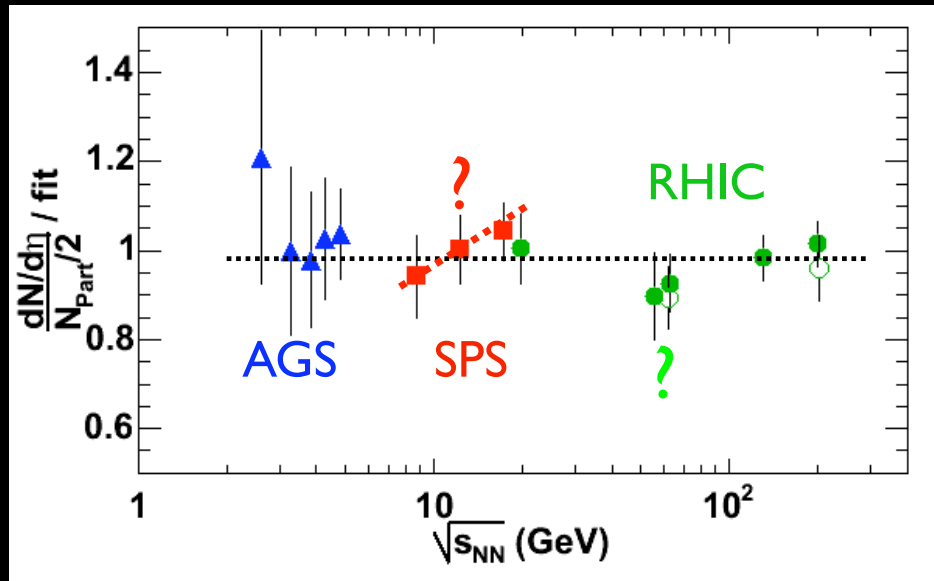
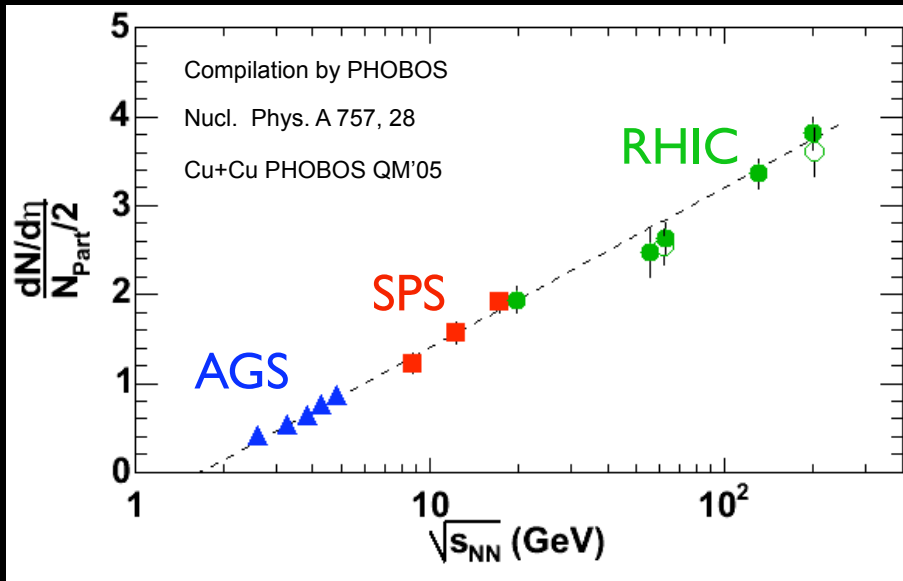
# Energy Dependence, Part I

# Energy Dependence of $dN/d\eta$ @ $\eta=0$



Slow (logarithmic) rise of multiplicity  
 Indication of saturation/coherence phenomenon  
 (vs  $p+p + N_{coll}$  scaling of hard contribution)

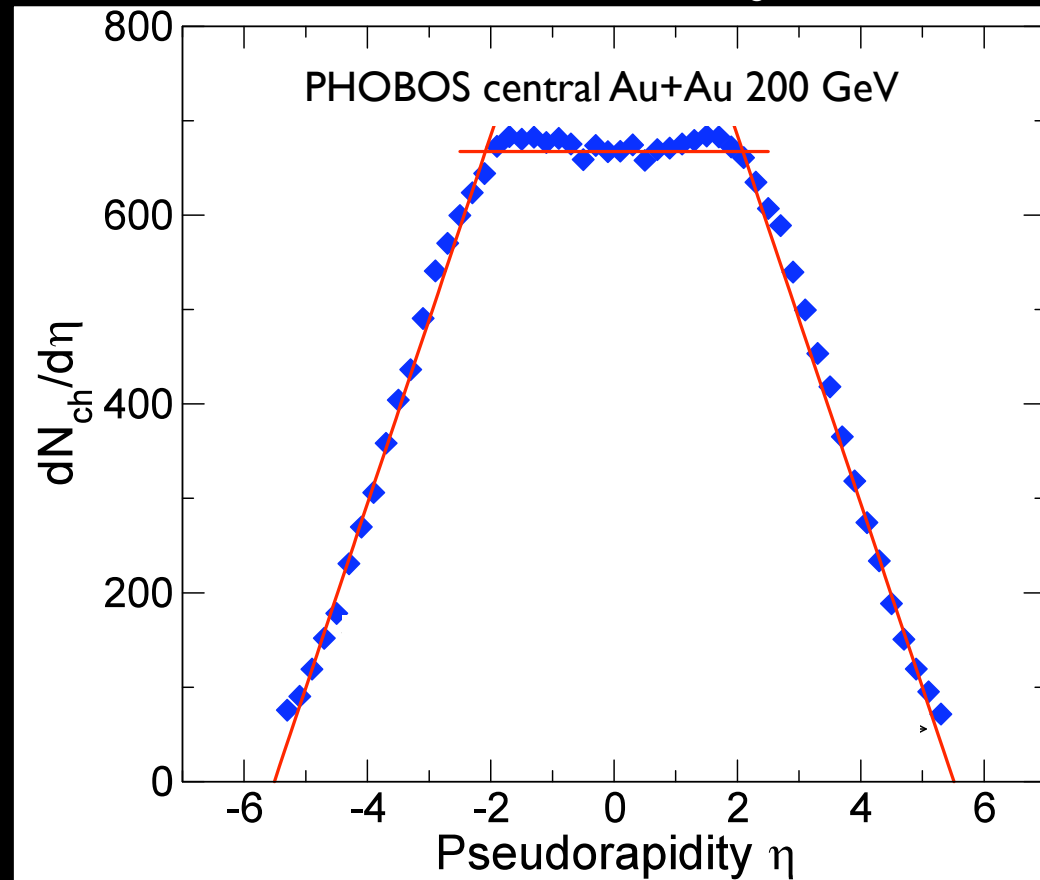
# Energy Dependence of $dN/d\eta$ @ $\eta=0$



- Logarithmic growth of mid-rapidity particle density
- Structure at SPS energy range and/or around  $\sqrt{s} \approx 60 \text{ GeV}$ ?
- Precision of  $\approx 5-10\%$  - better if doing relative scan in single experiment ( $\approx 3\%$ )?

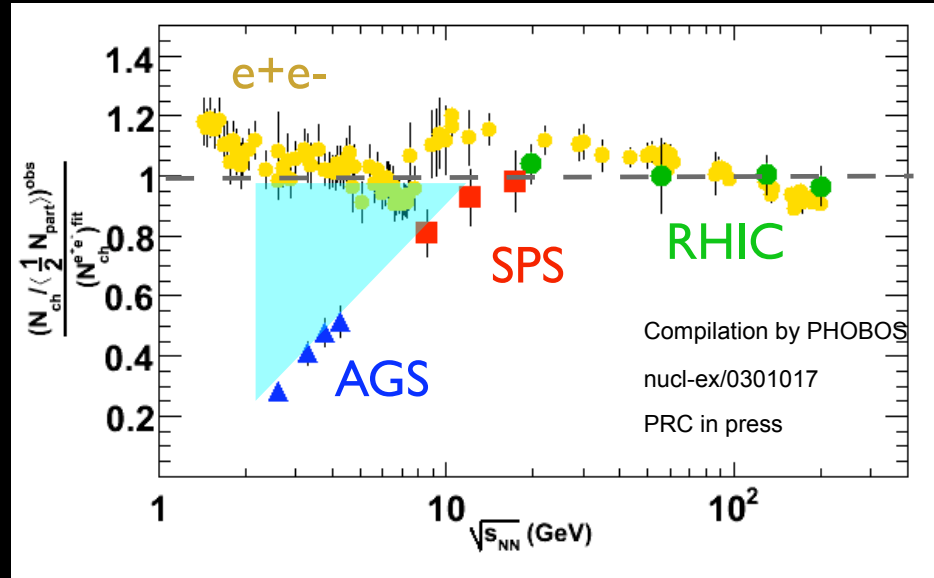
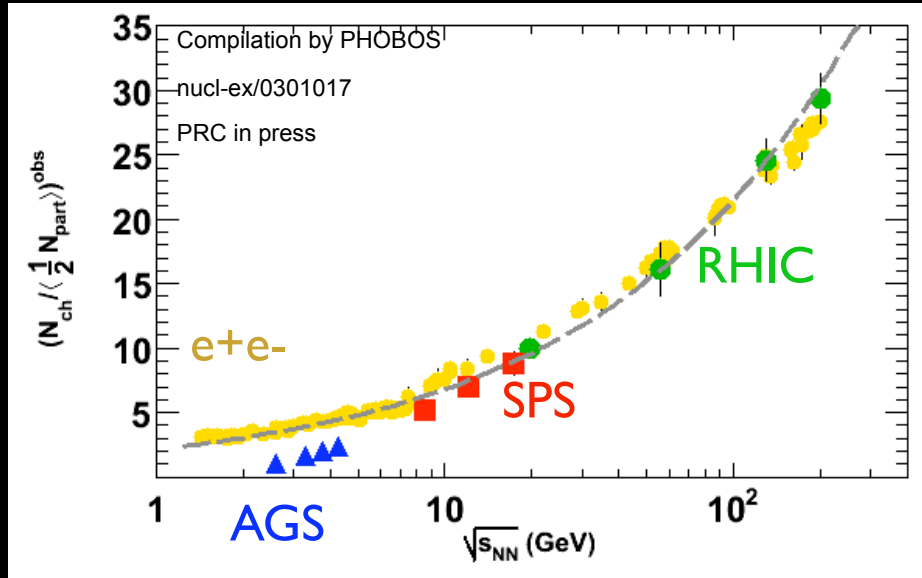
# Total multiplicity

Plot from Birger Back, Bari 2005



“Trapezoidal” shape of  $dN/d\eta$  distribution  
Integral  $\rightarrow N_{ch}$

# Total multiplicity

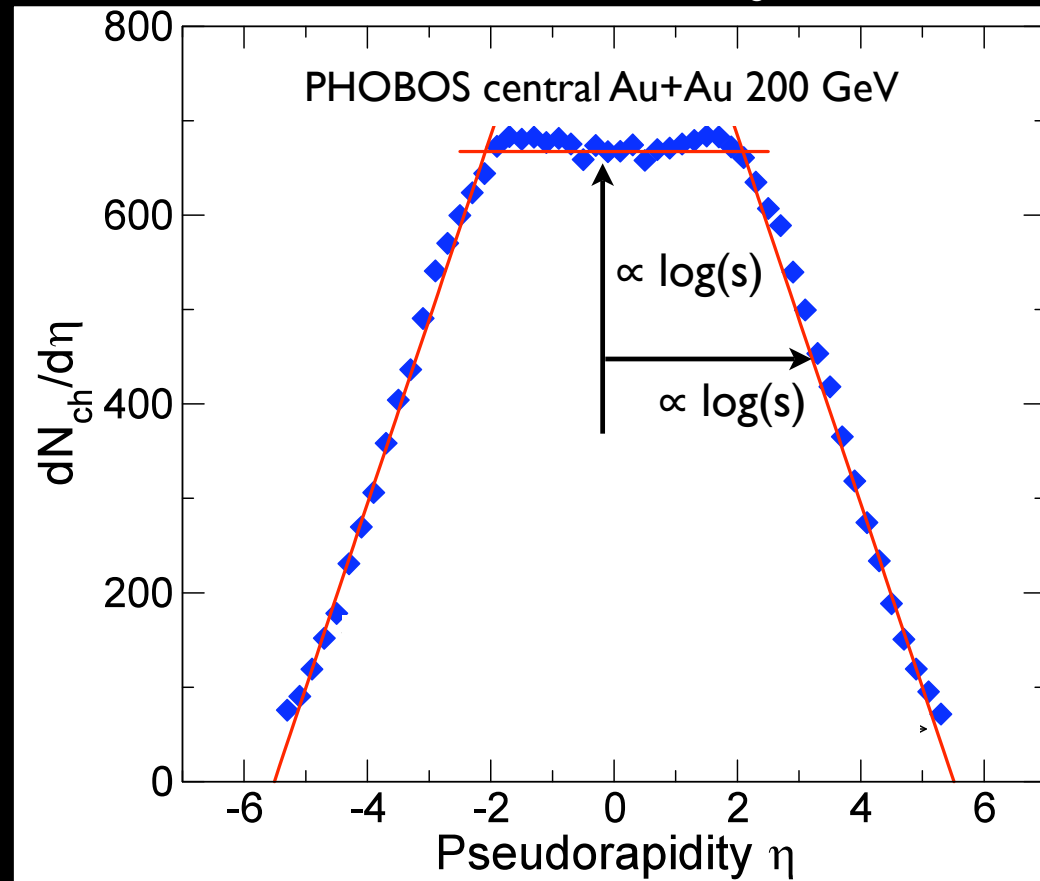


Energy dependence:  $N_{ch} \propto s^{1/4}$  (@RHIC)

$N_{ch} / (0.5 N_{part})$  for A+A coincides with  $e^+e^-$  data (@RHIC)

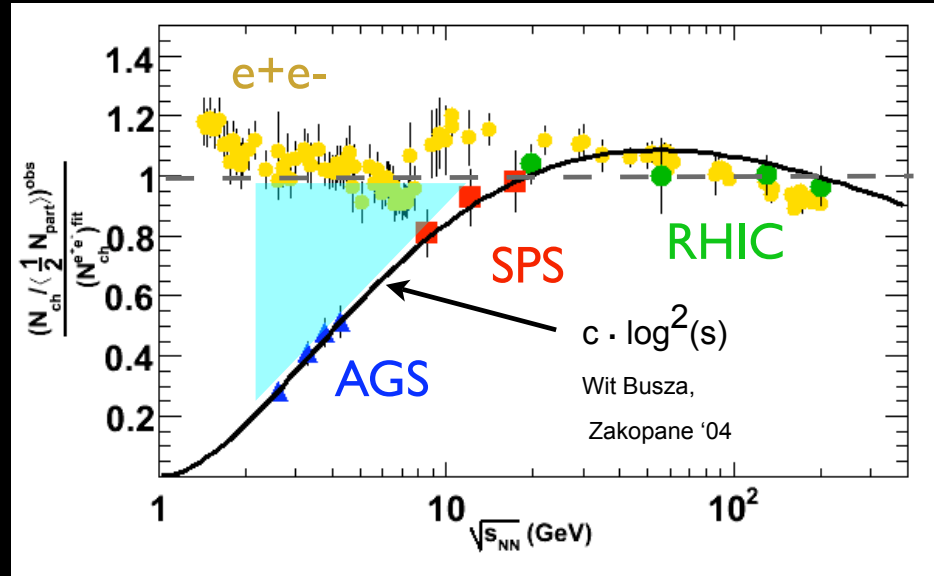
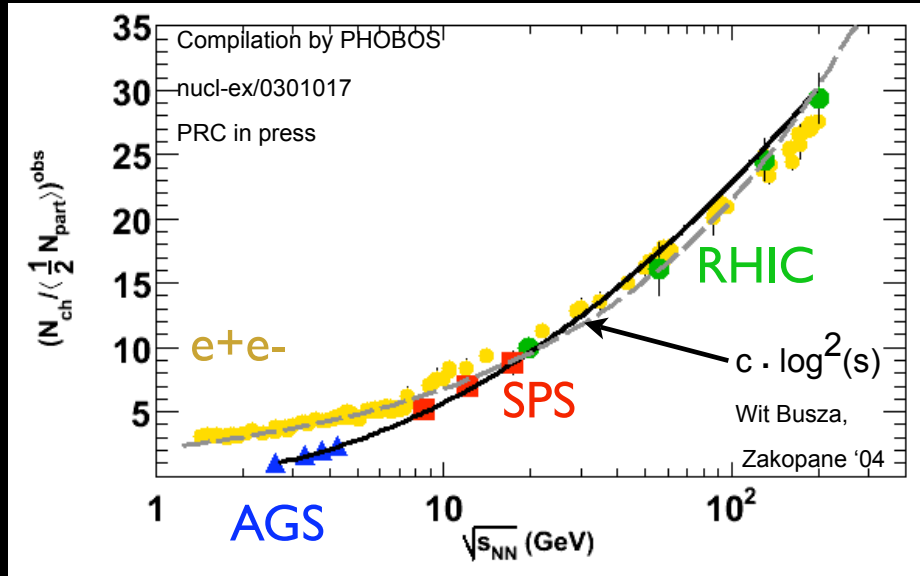
# Total multiplicity

Plot from Birger Back, Bari 2005



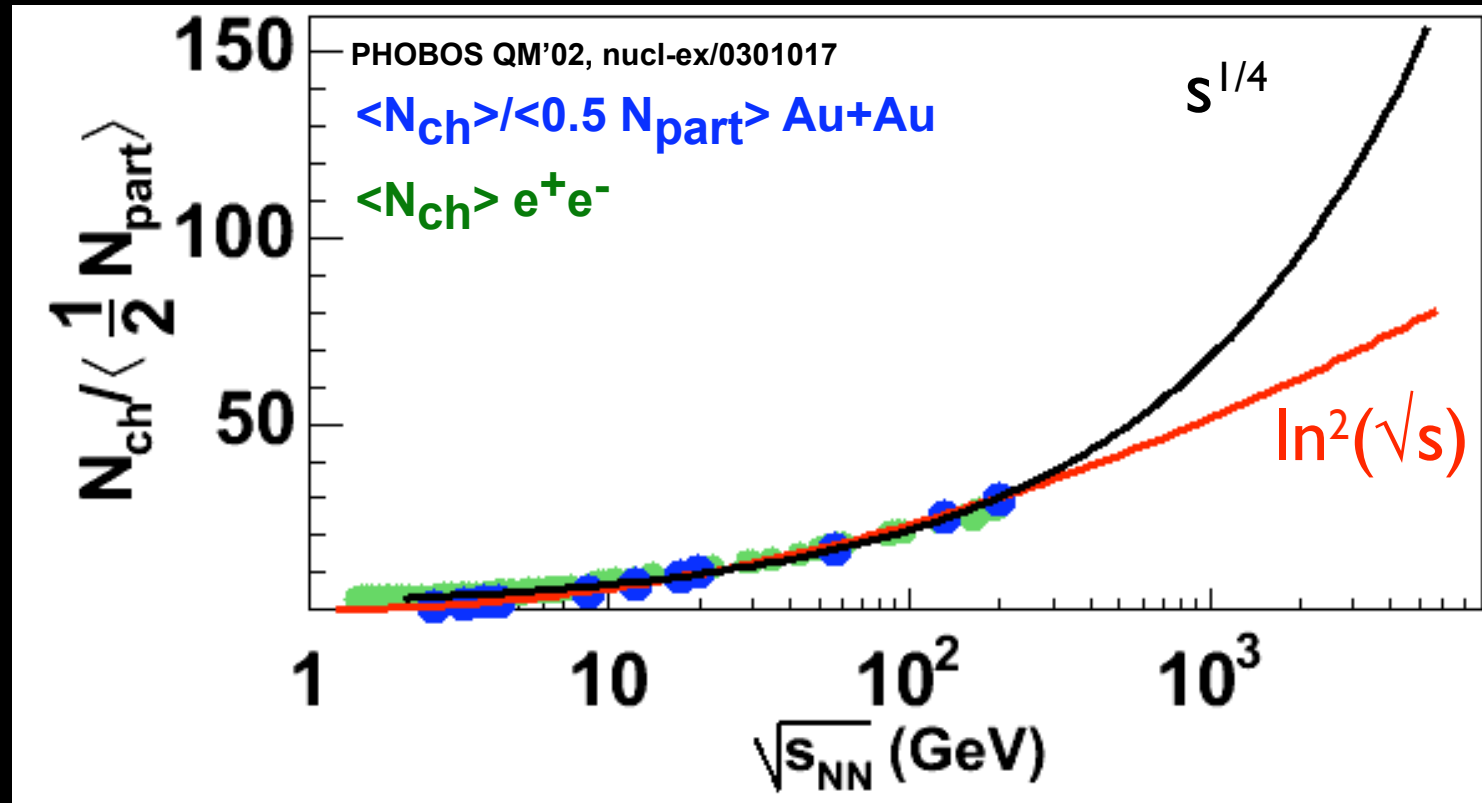
“Trapezoidal” shape suggests  $N_{ch} \propto \log^2(s)$

# Total multiplicity

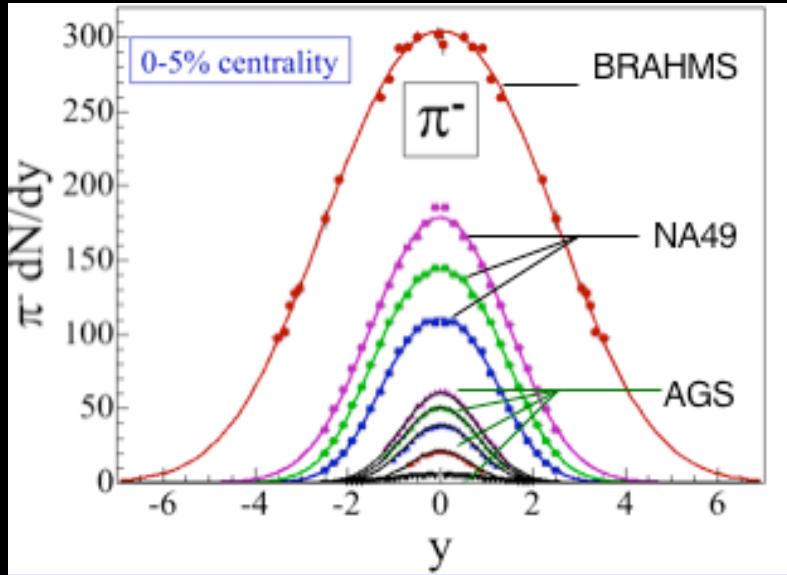


A+A by itself can be fit with  $\log^2(s)$   
Emergence of structure at low energy depends on context

# Extrapolating to LHC

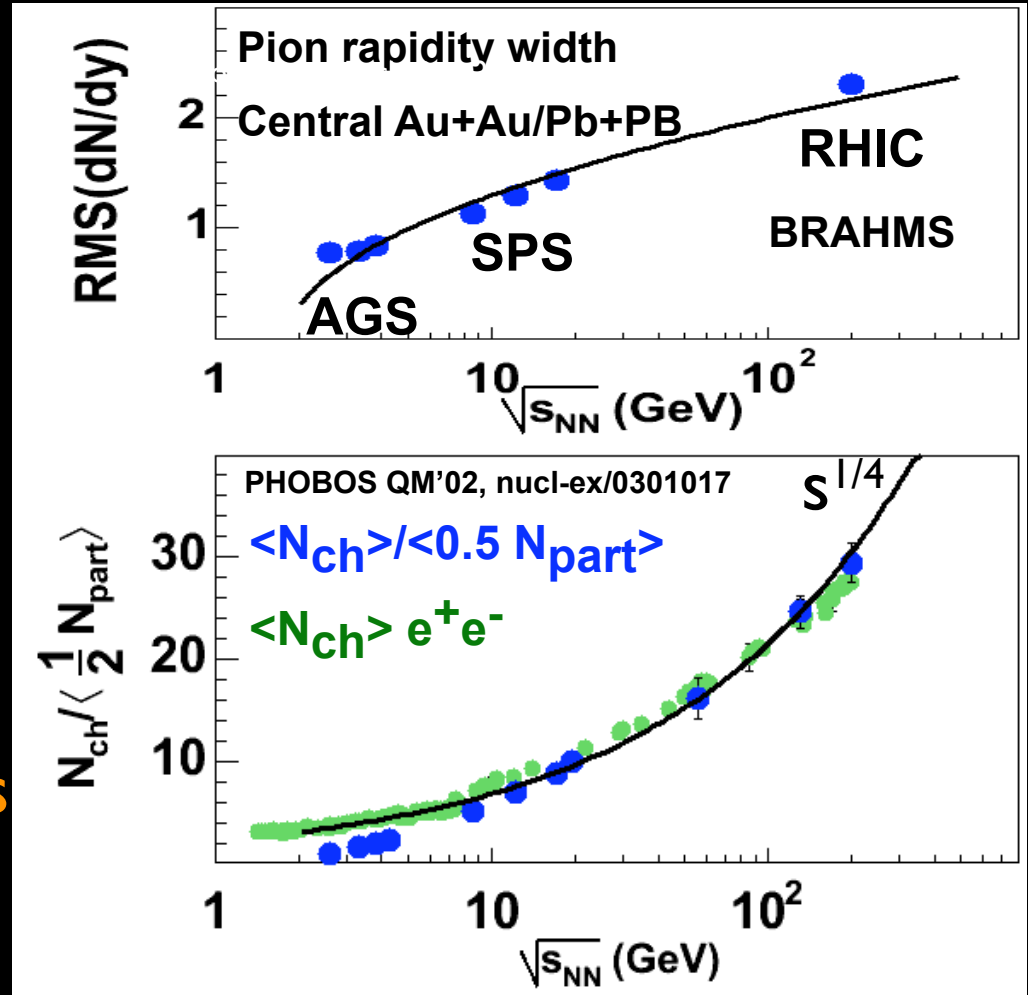


# Energy Dependence of $N_{ch}$



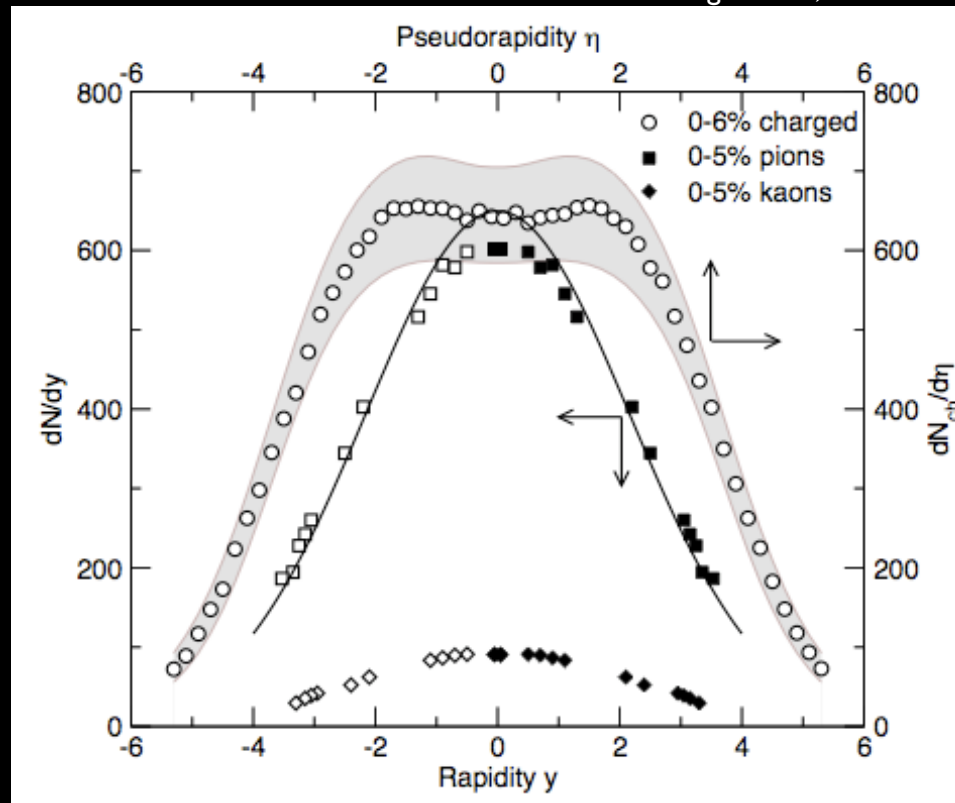
Plot from BRAHMS, QM'04

Meson rapidity distributions are approximately Gaussian - reminiscent of Landau?



# Comparison of $dN/dy$ and $dN/d\eta$

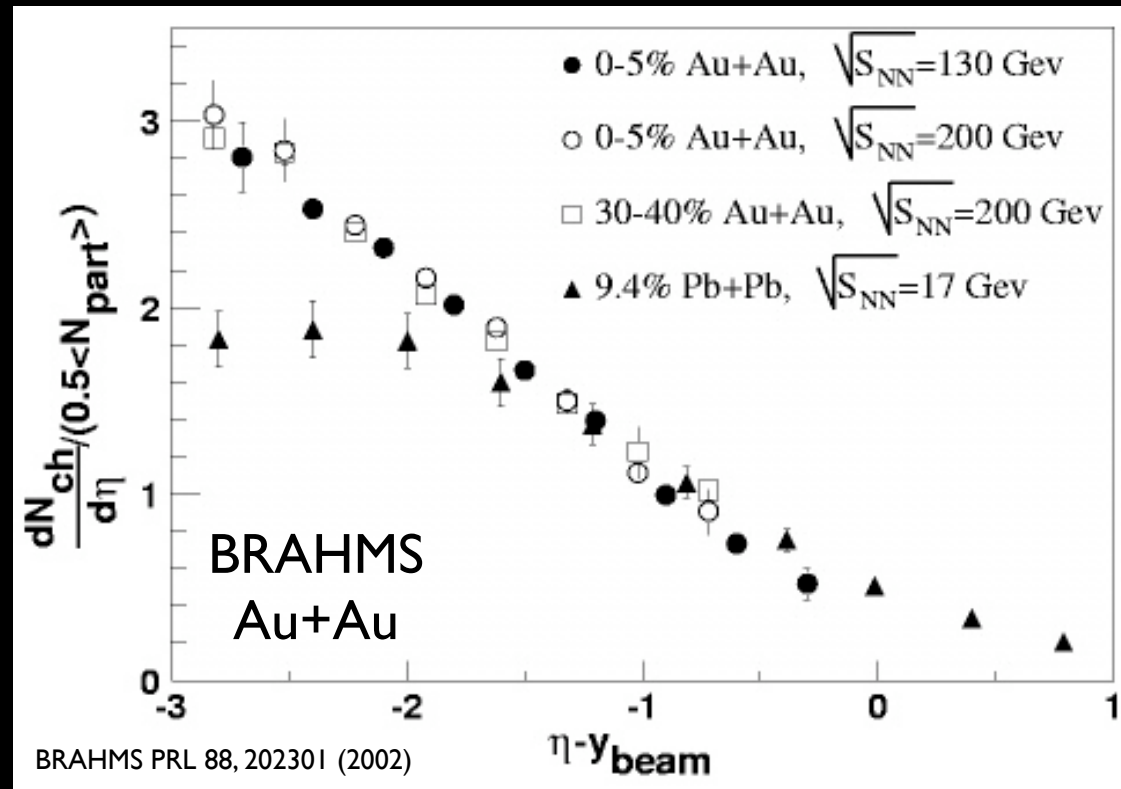
Plot from Birger Back, Bari 2005



After accounting for protons, Jacobians,  $p_T(y)$  etc:  
> 20% difference between direct  $dN/d\eta$  measurement  
and transformed  $dN/dy$

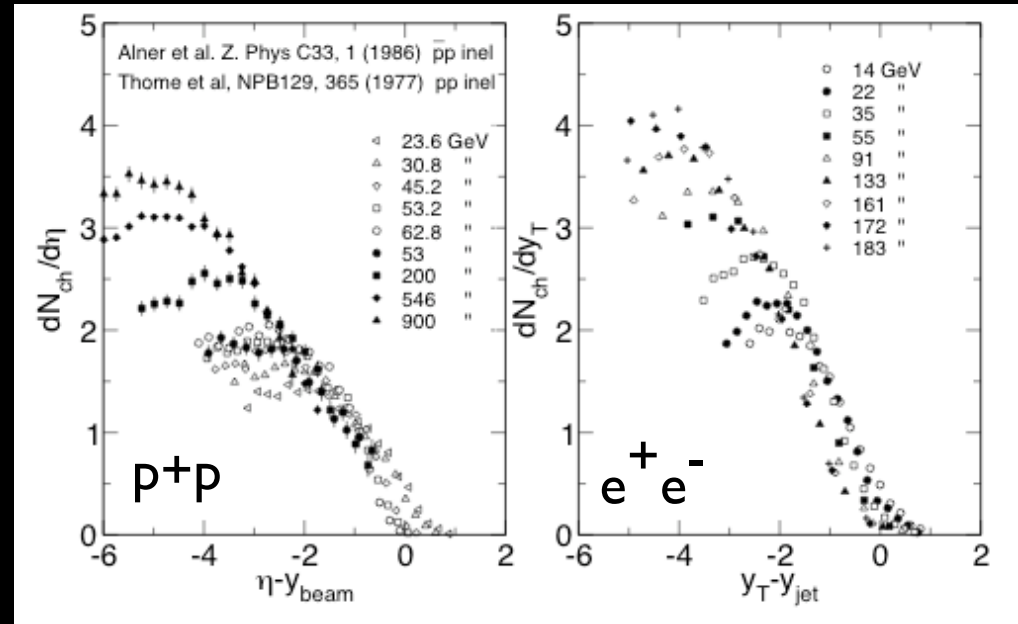
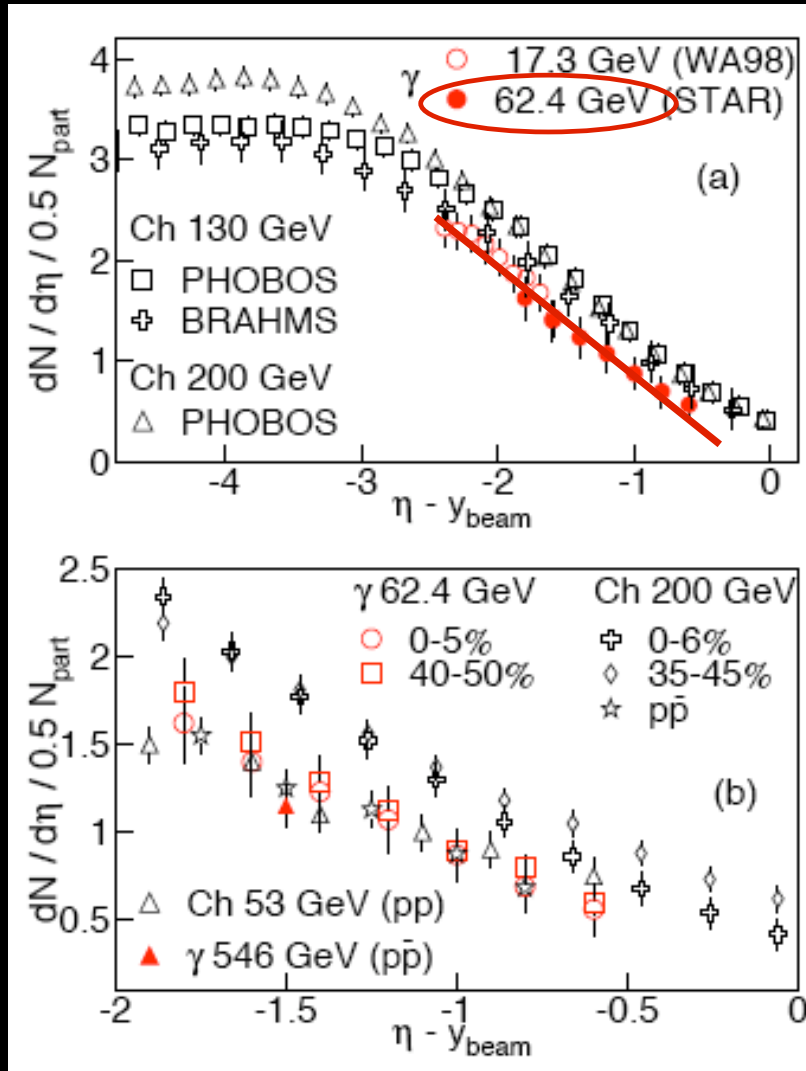
Energy Dependence,  
Part II:  
Limiting Fragmentation  
("Extended Longitudinal Scaling")

# Limiting Fragmentation in Au+Au



Yields at high rapidity are energy independent, when viewed in restframe of one of colliding nuclei

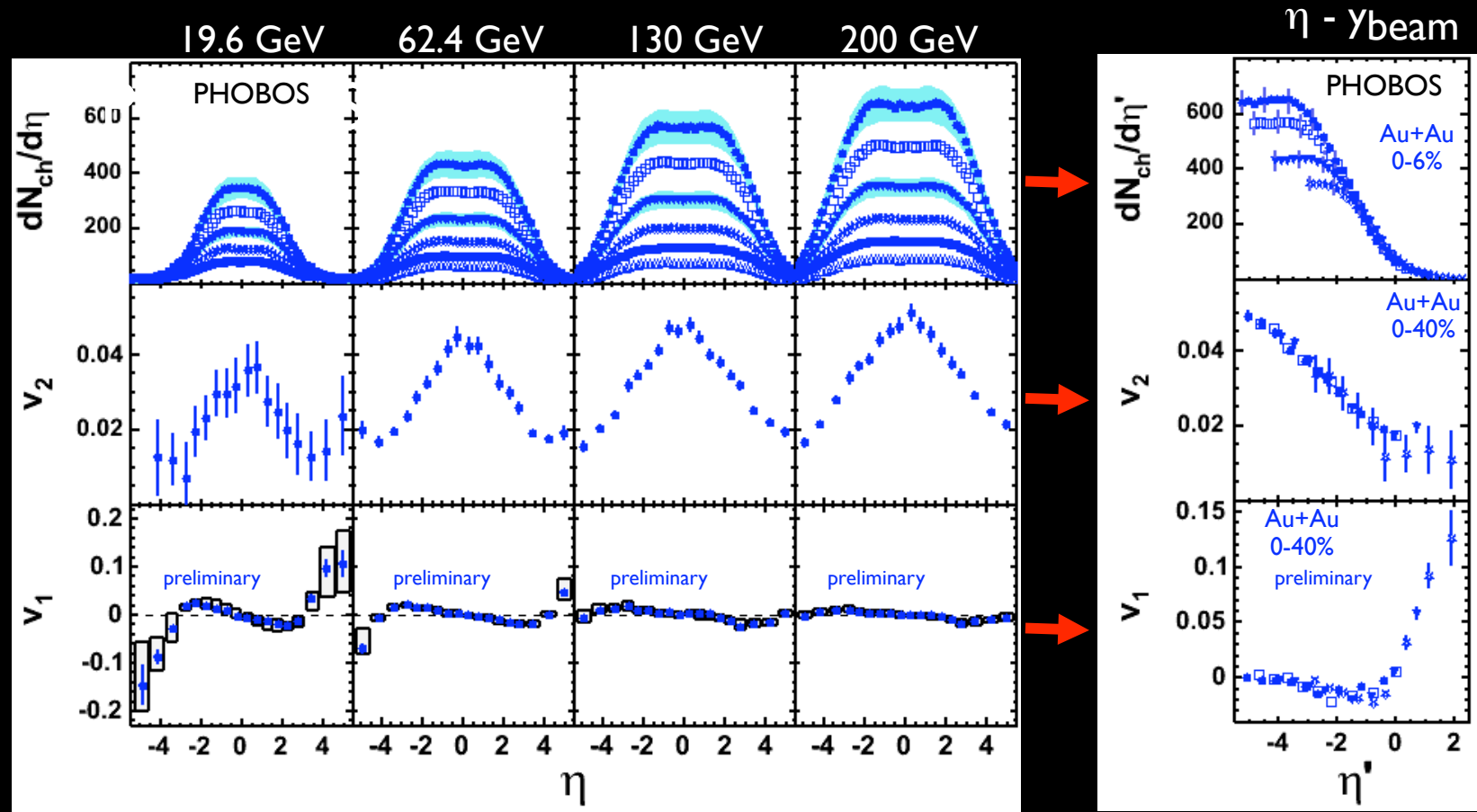
# Limiting Fragmentation: Universal phenomenon



PHOBOS whitepaper

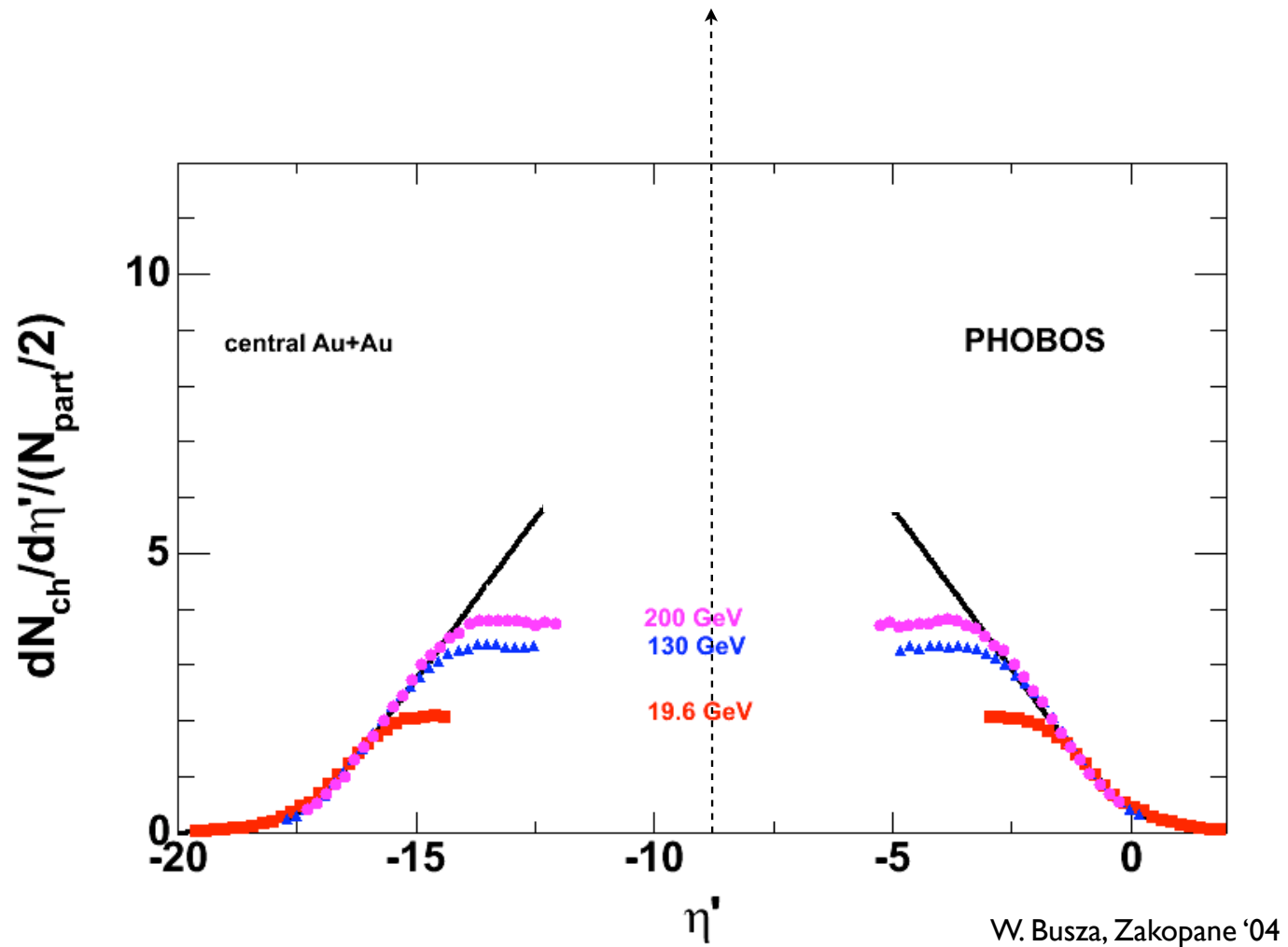
STAR nucl-ex/0502008

# Extended longitudinal scaling

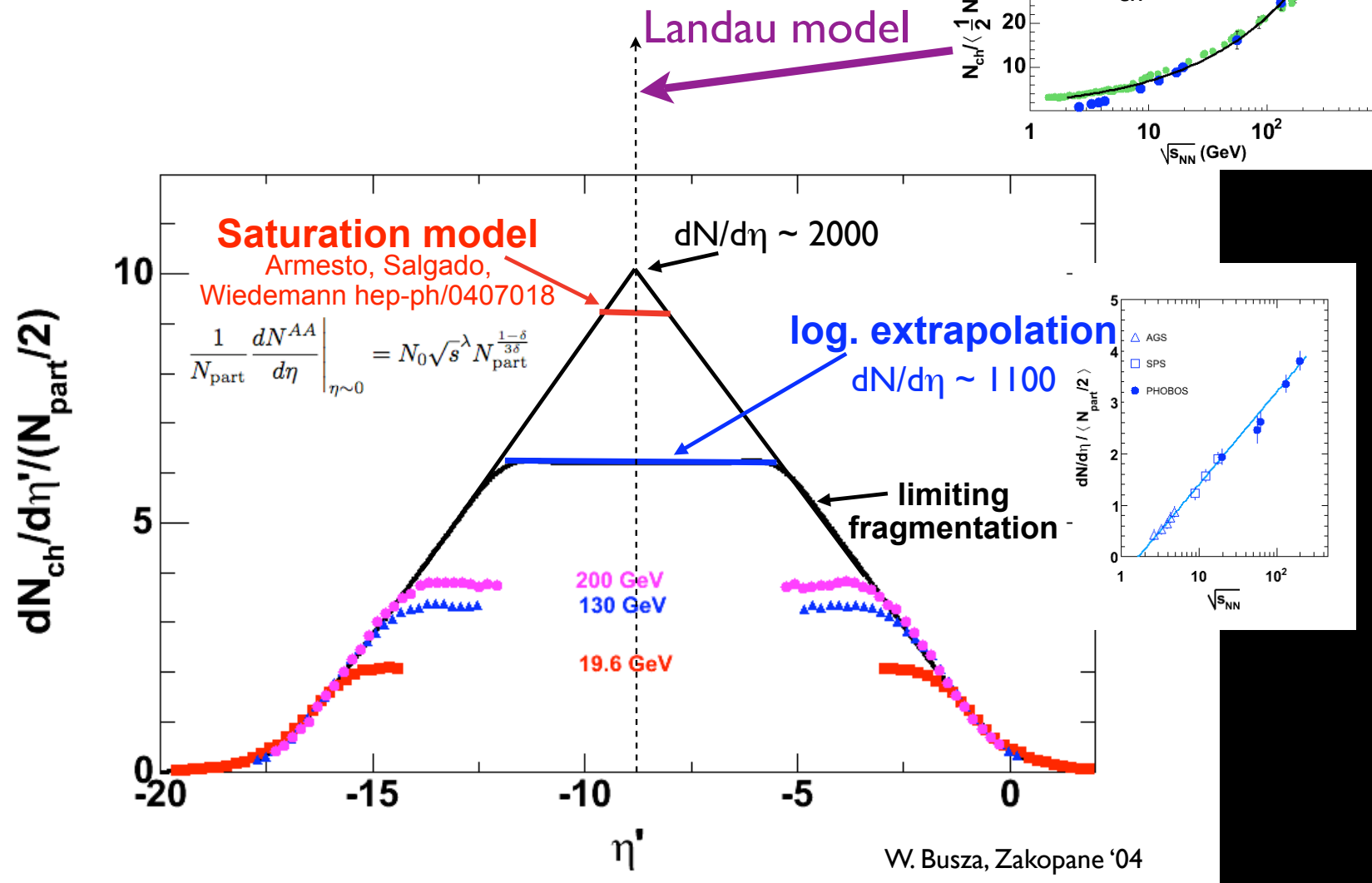


“Extended longitudinal scaling” (aka limiting fragmentation)  
of all longitudinal distributions

# Extrapolation to LHC

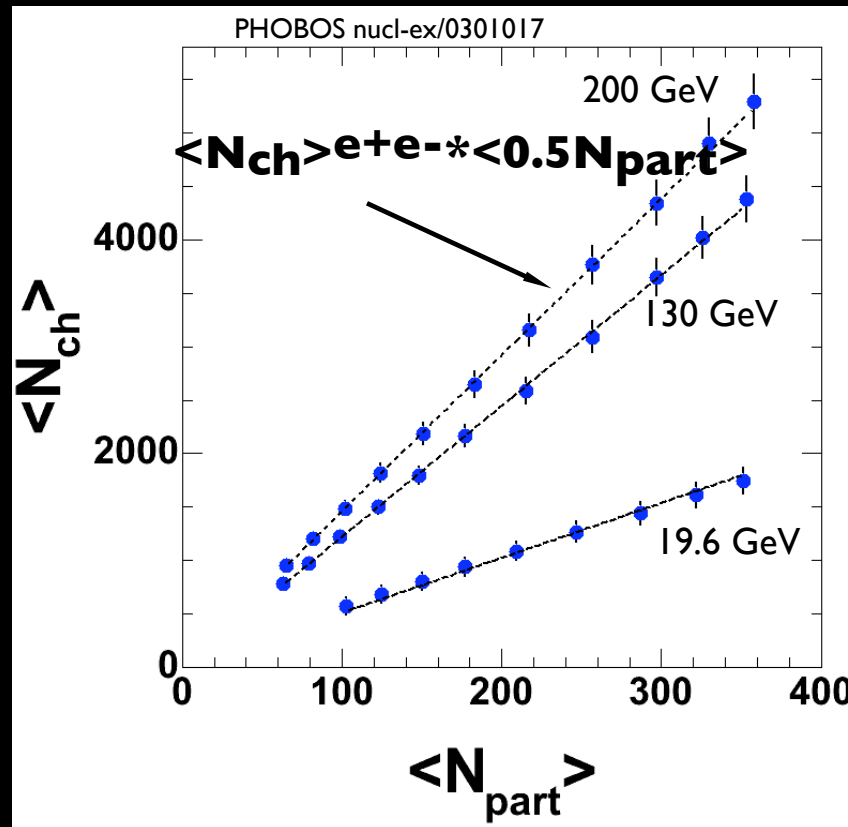


# Extrapolation to LHC



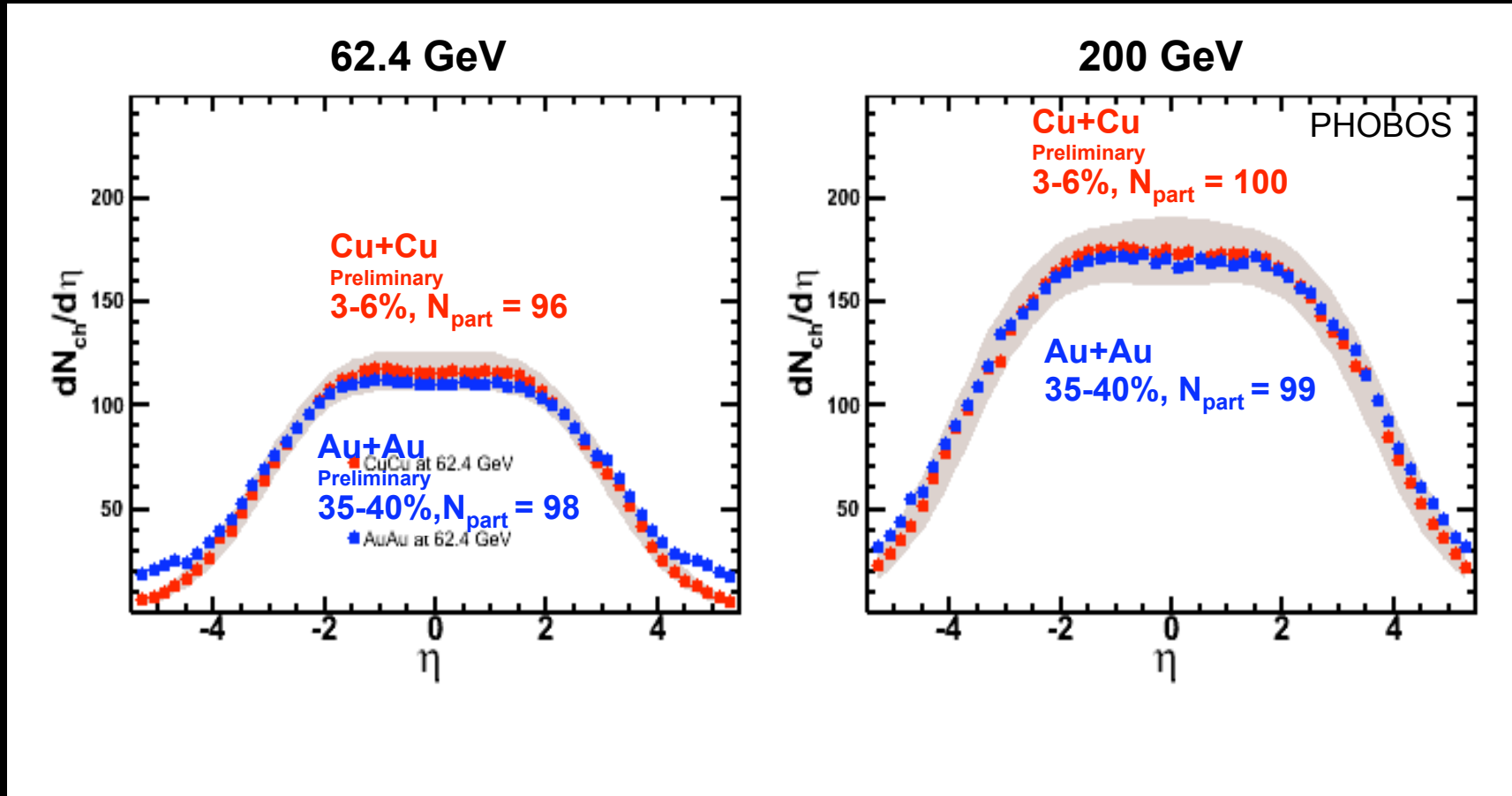
# Centrality Dependence

# Centrality Dependence



Total multiplicity in A+A collisions is proportional to  $N_{part}$

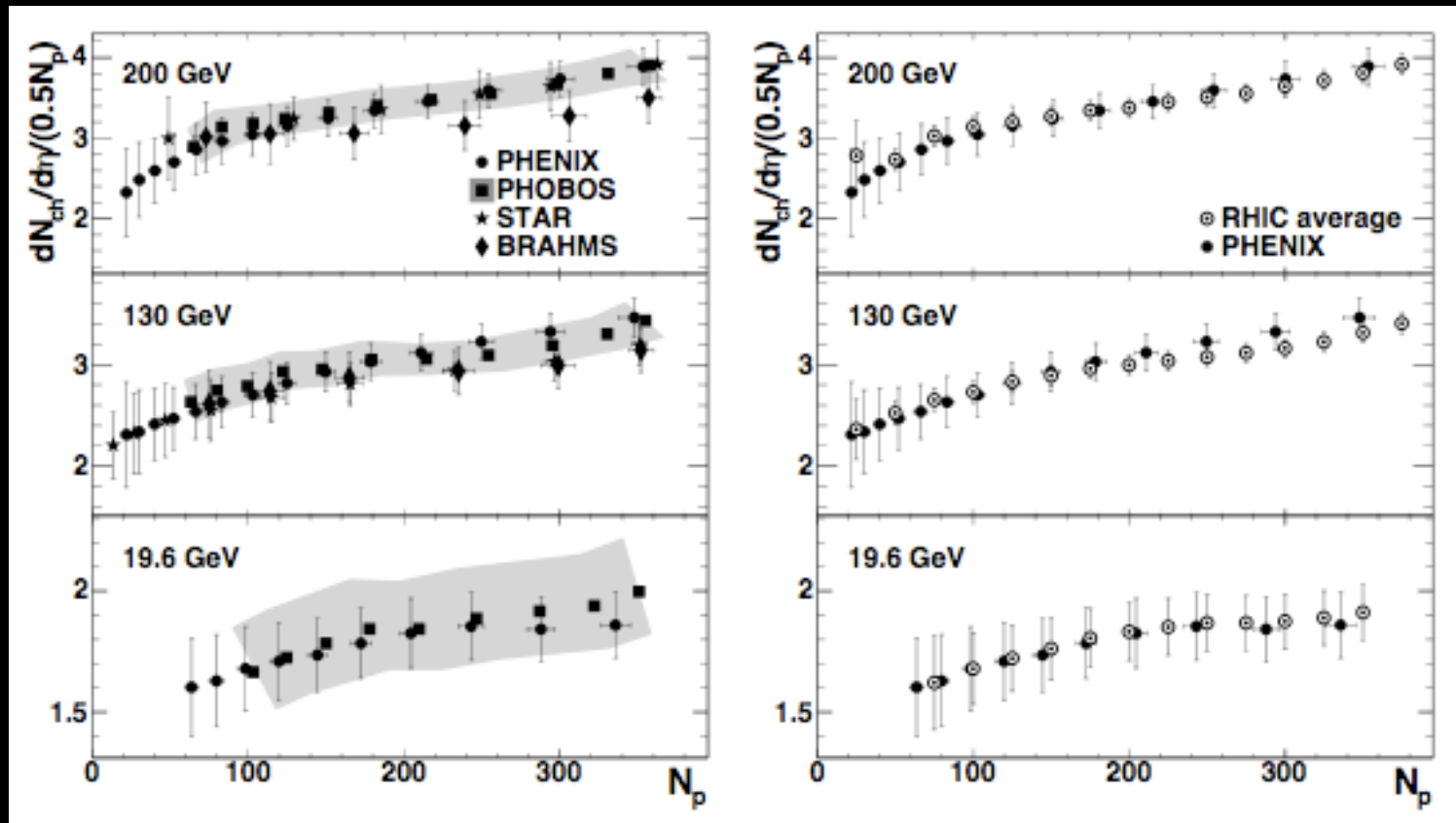
# Au+Au vs Cu+Cu



Similar  $dN/d\eta$  for same  $N_{part}$  in Au+Au vs Cu+Cu

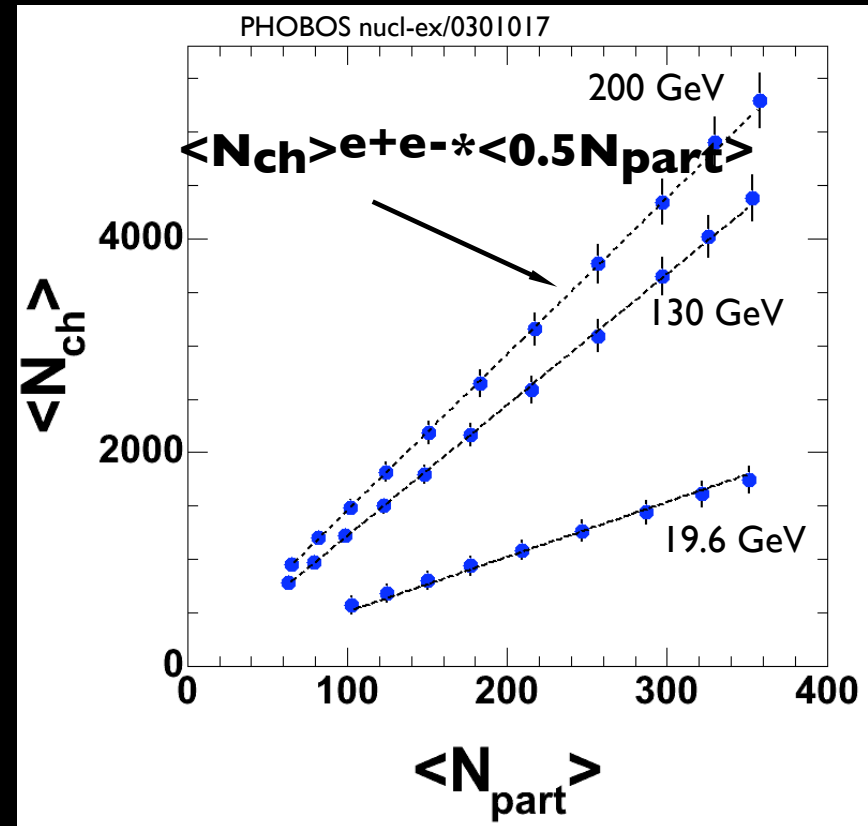
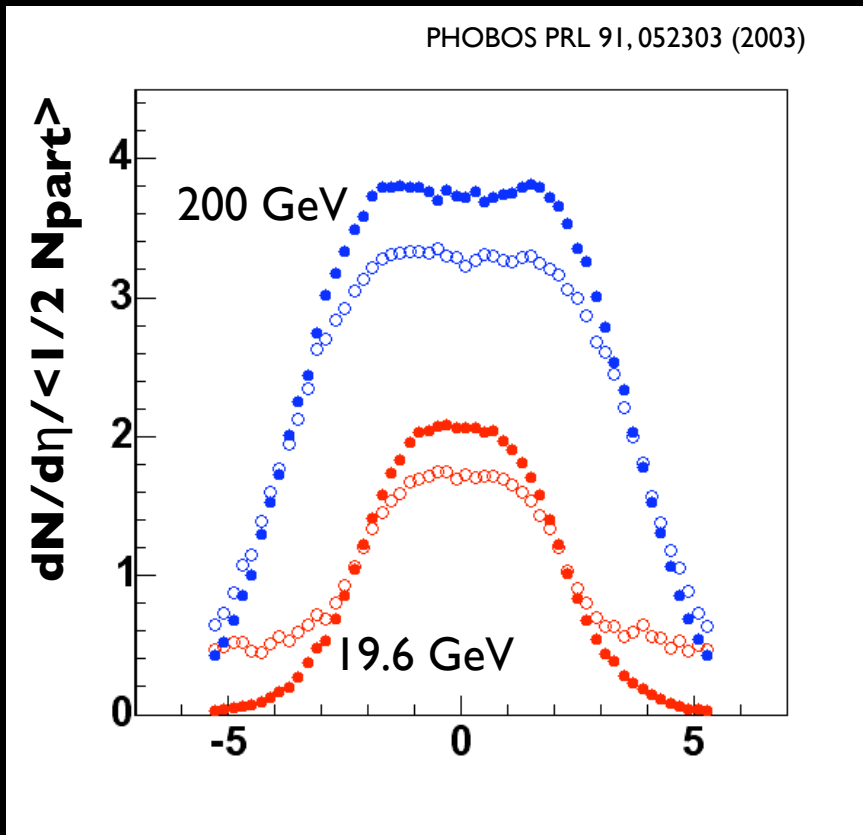
# PHENIX (+STAR) Data

PHENIX nucl-ex/0409015, PRC



Mid-rapidity yields per participant increase  
by  $\sim 30\%$  over same centrality range

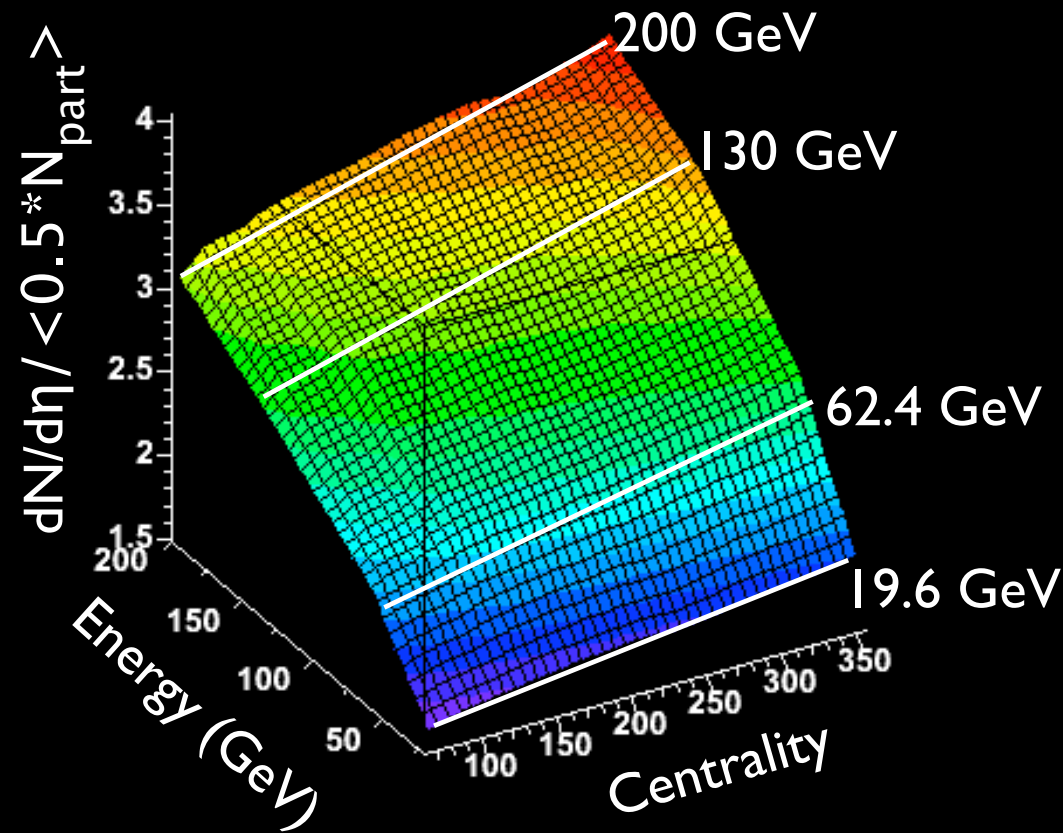
# Centrality Dependence in Au+Au



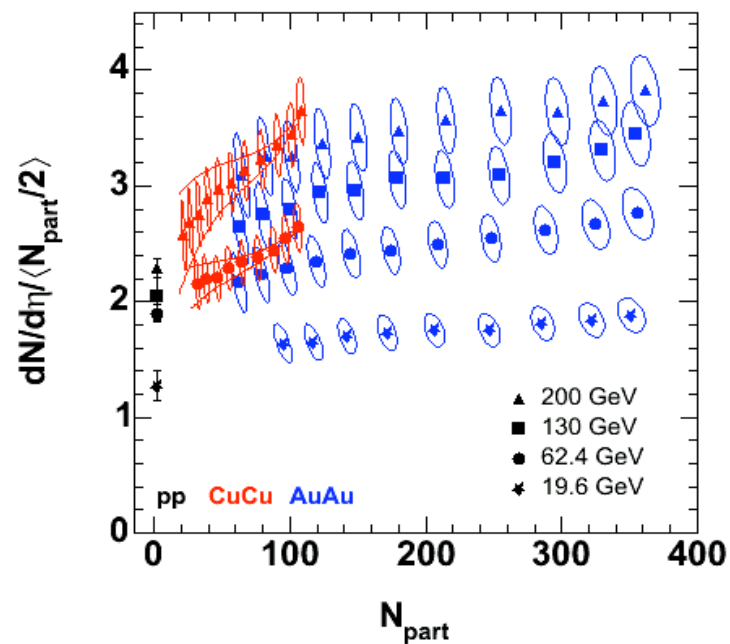
Shape changes vs centrality, while  $N_{ch}/N_{part}$  stays constant

# Centrality *and* Energy Dependence

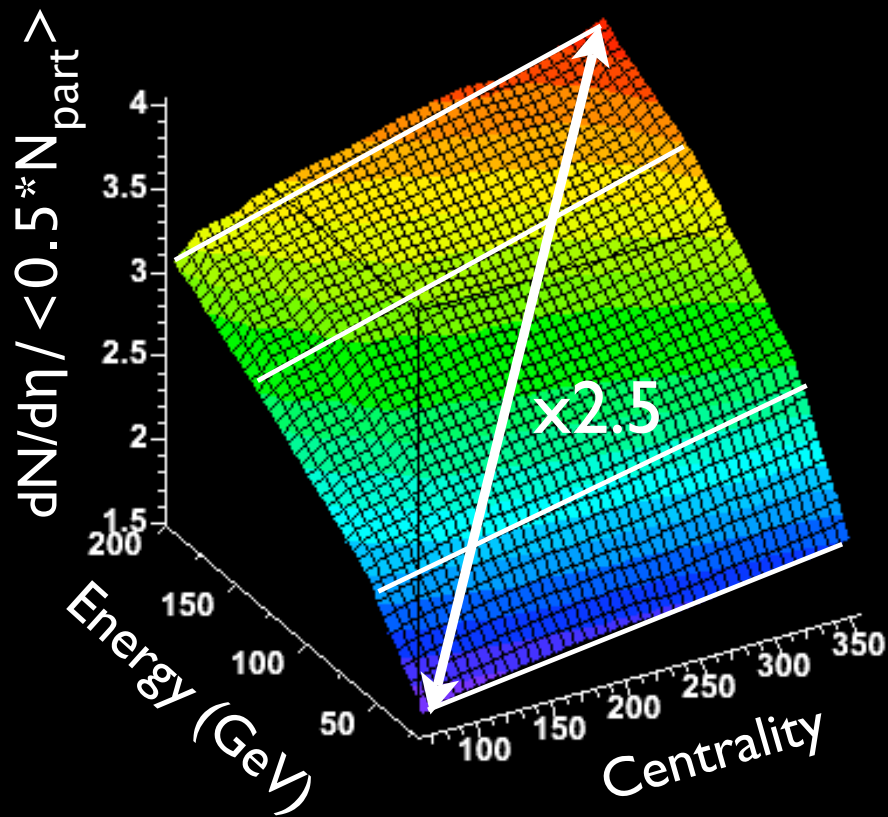
# Mid-rapidity $dN/d\eta$ vs $\sqrt{s}$ and $N_{part}$



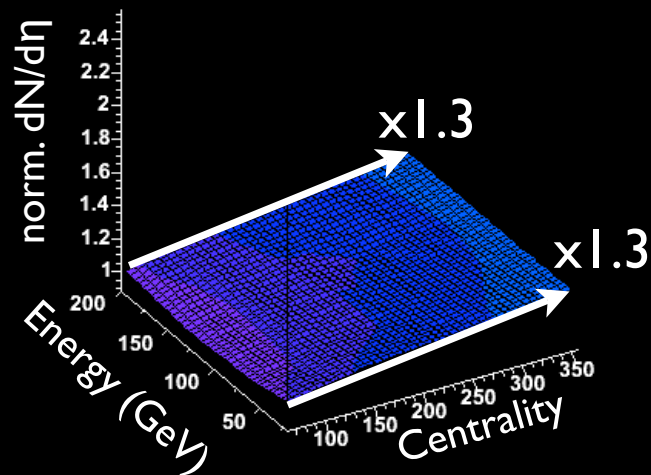
PHOBOS QM'05



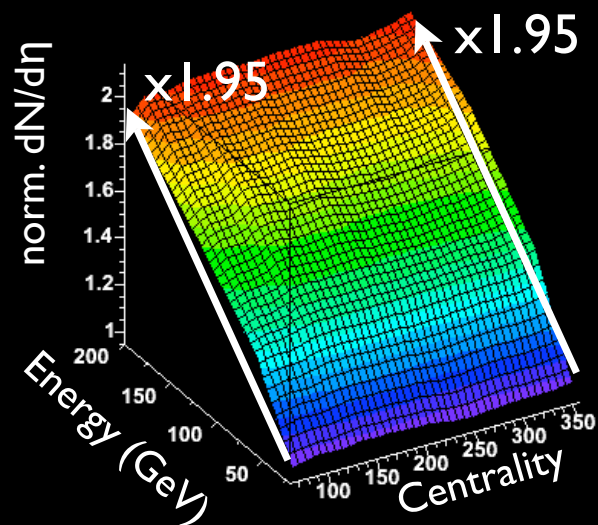
# Mid-rapidity $dN/d\eta$ vs $\sqrt{s}$ and $N_{\text{part}}$



||



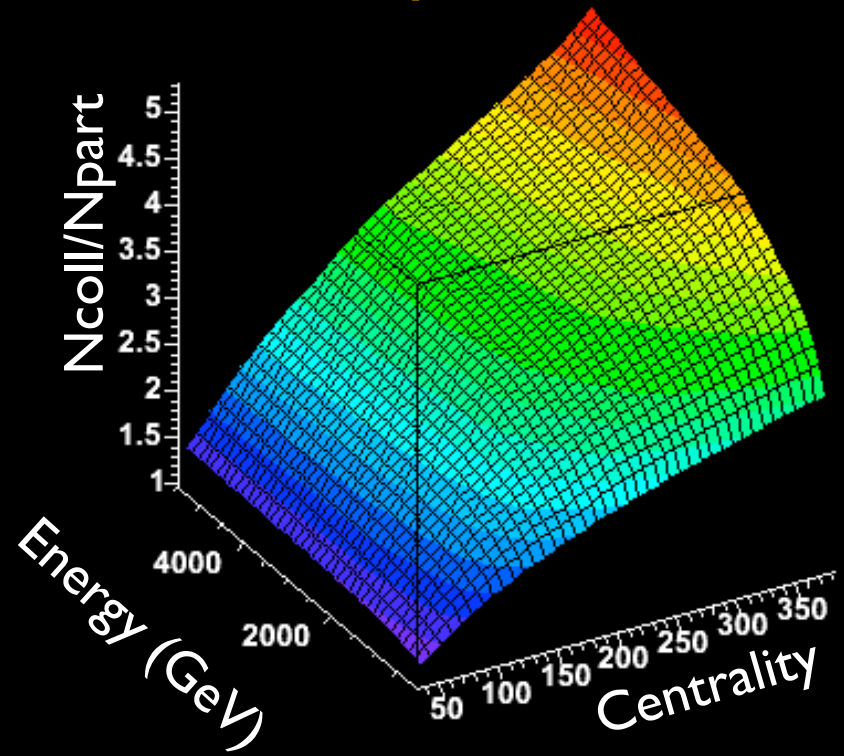
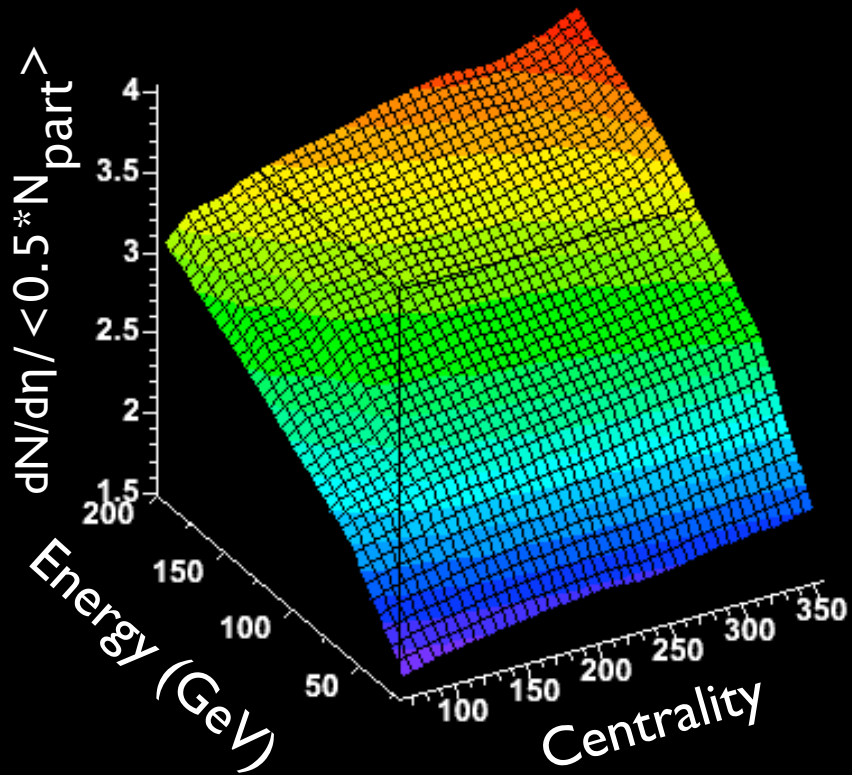
⊗



# Mid-rapidity $dN/d\eta$ vs $\sqrt{s}$ and $N_{\text{part}}$

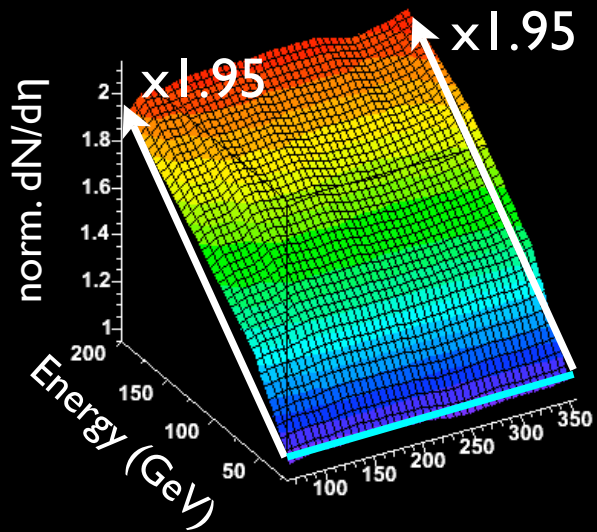
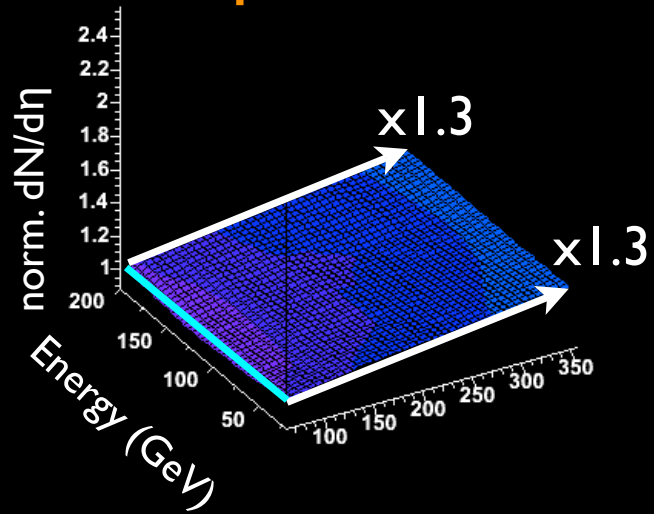
$dN/d\eta$  (Data)

$N_{\text{coll}}/N_{\text{part}}$  (MC)

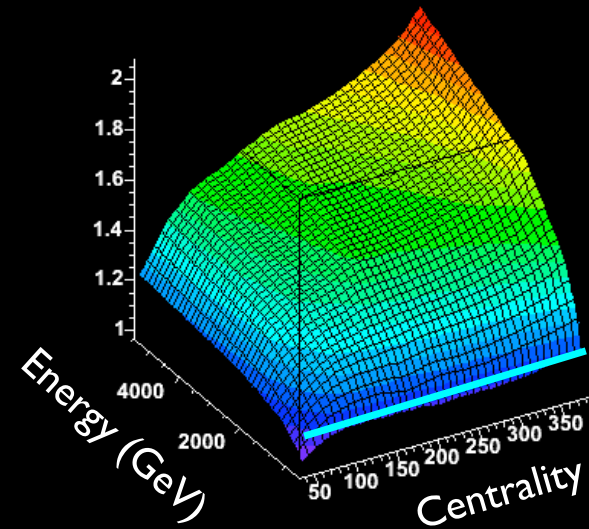
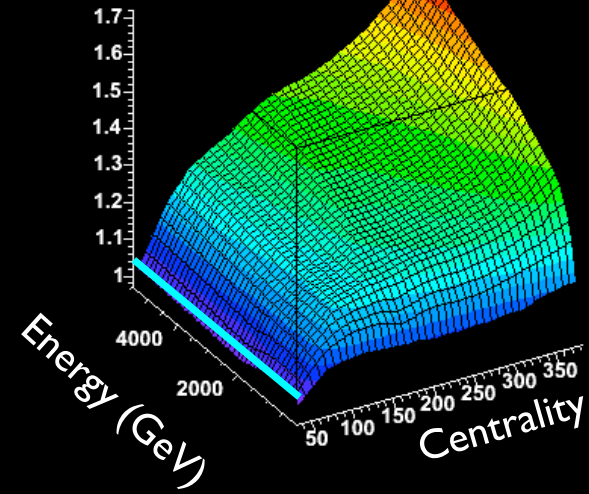


Factorization in a hard/soft picture?

$dN/d\eta / N_{\text{part}}$  (Data)

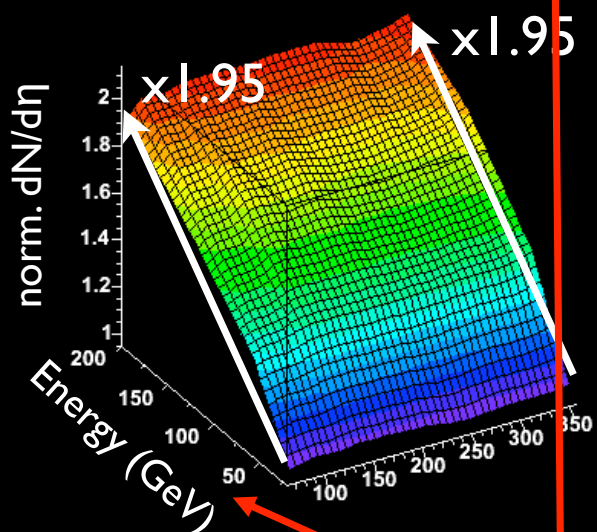
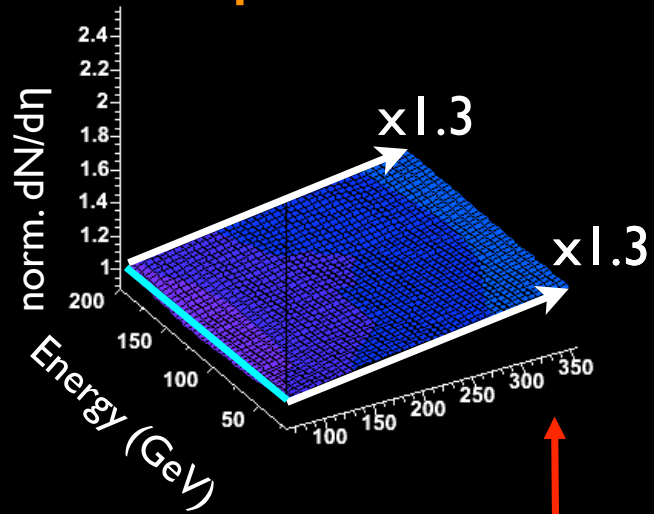


$N_{\text{coll}} / N_{\text{part}}$  (MC)

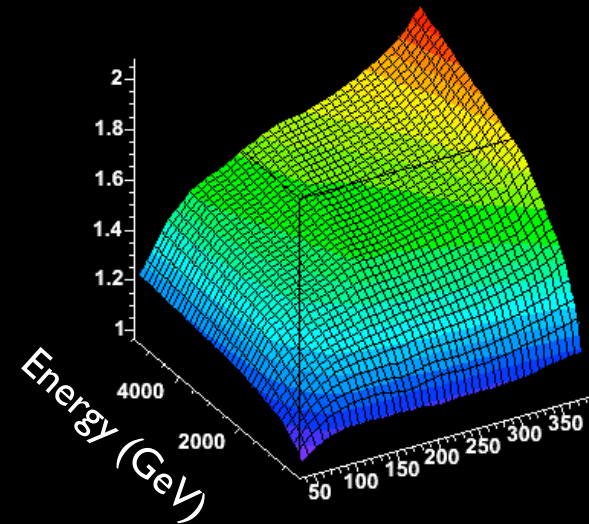
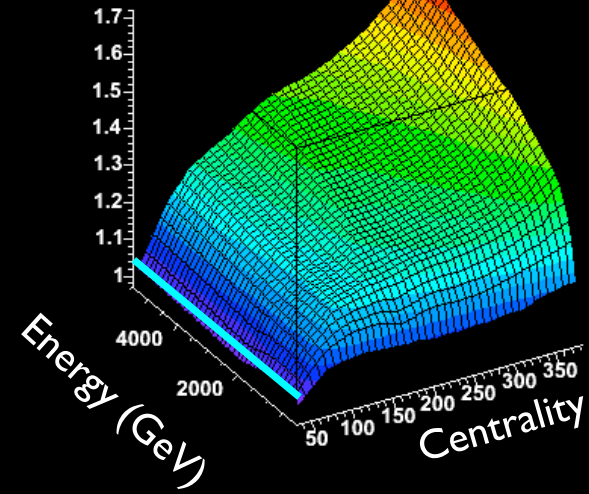


Contribution  $\propto N_{\text{coll}}$  breaks factorization

# $dN/d\eta / N_{\text{part}}$ (Data)



# $N_{\text{coll}} / N_{\text{part}}$ (MC)

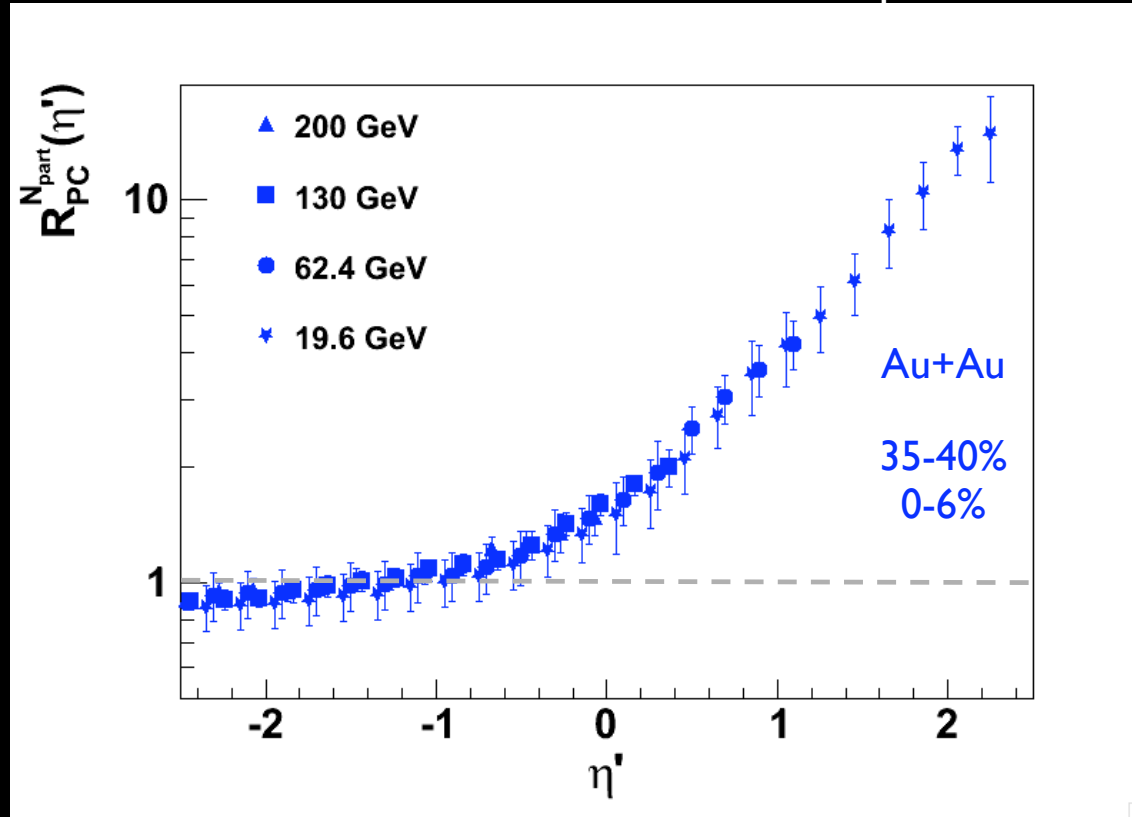
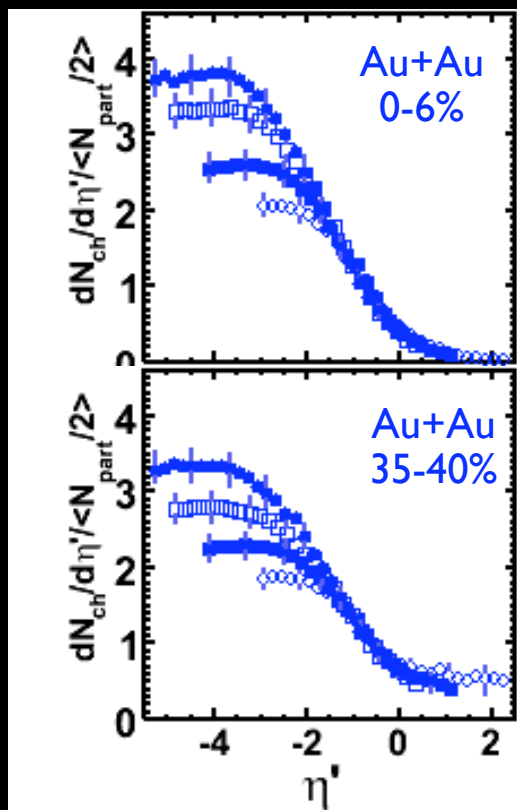


$$\frac{1}{N_{\text{part}}} \left. \frac{dN^{AA}}{d\eta} \right|_{\eta \sim 0} = N_0 \sqrt{s}^\lambda N_{\text{part}}^{\frac{1-\delta}{3\delta}}$$

Armesto, Salgado, Wiedemann hep-ph/0407018

# Factorization of Longitudinal Dynamics

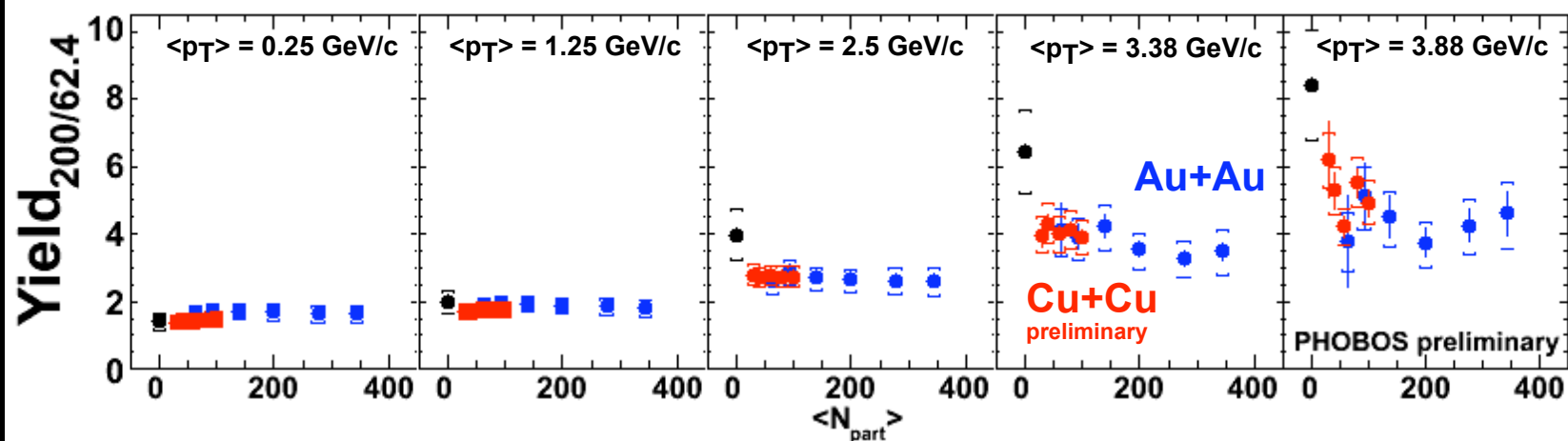
Ratio of 0-6% and 35-40% centrality bins, each normalized by  $N_{\text{part}}$



Dominance of Collision Geometry?

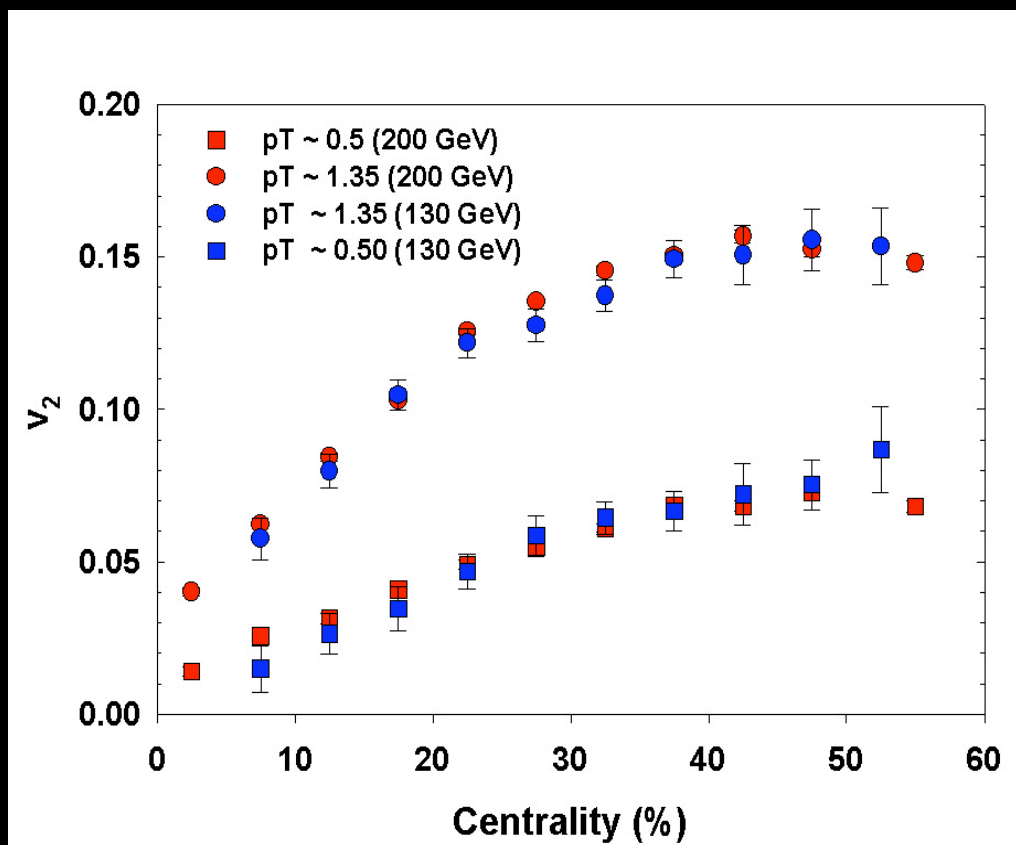
# Factorization of Transverse Dynamics

Ratio of yields in bins of  $p_T$   
between 200 and 62 GeV



Dominance of Collision Geometry?

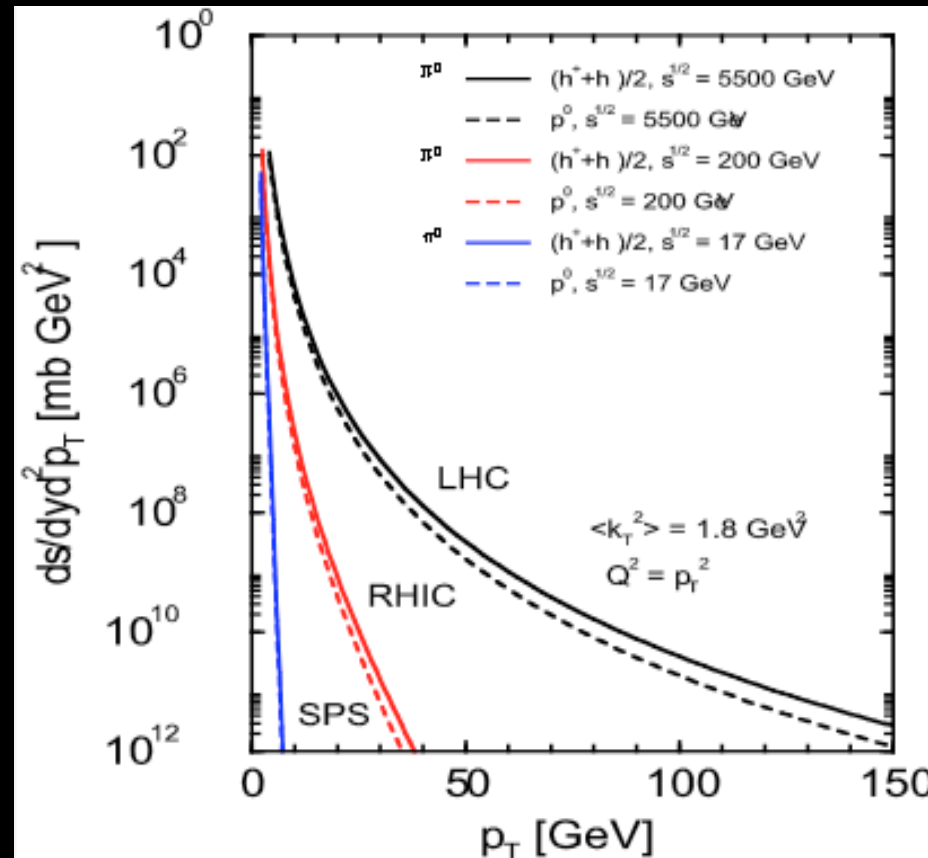
# Energy independence of $v_2(p_T, N_{\text{part}})$



**Factorization!**

**Dominance of Collision Geometry?**

# Particle Production at LHC

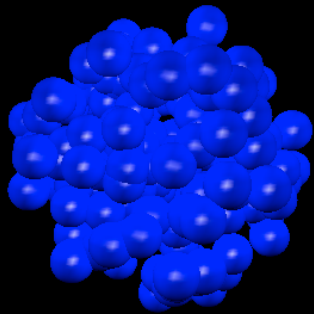


What will happen at the LHC?  
Will particle production from hard processes  
break energy/centrality factorization?

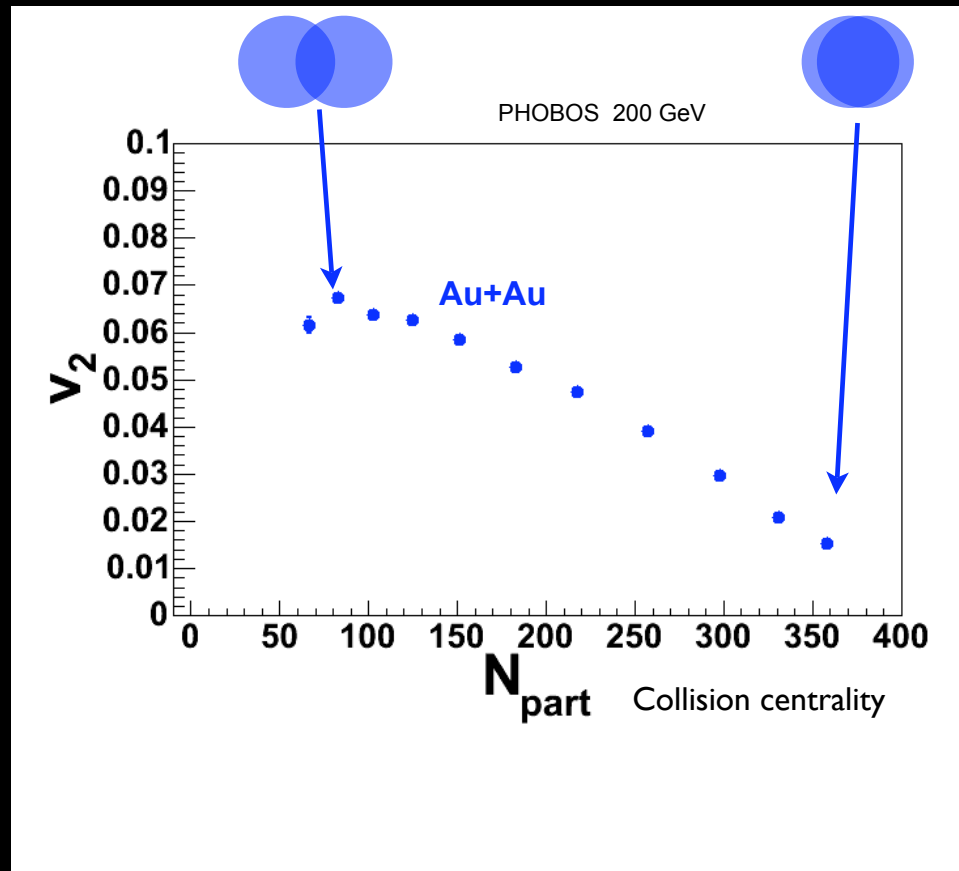
Another look at  
the initial geometry

# Elliptic Flow and Geometry, I

Test connection between geometry and elliptic flow  
by comparing Au+Au to Cu+Cu

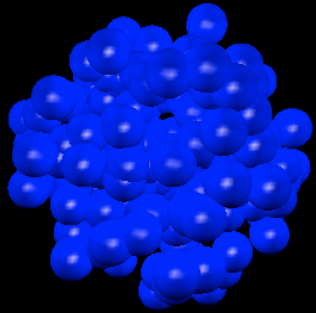


Gold  
 $A=197$

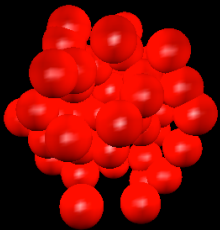


# Elliptic Flow and Geometry, I

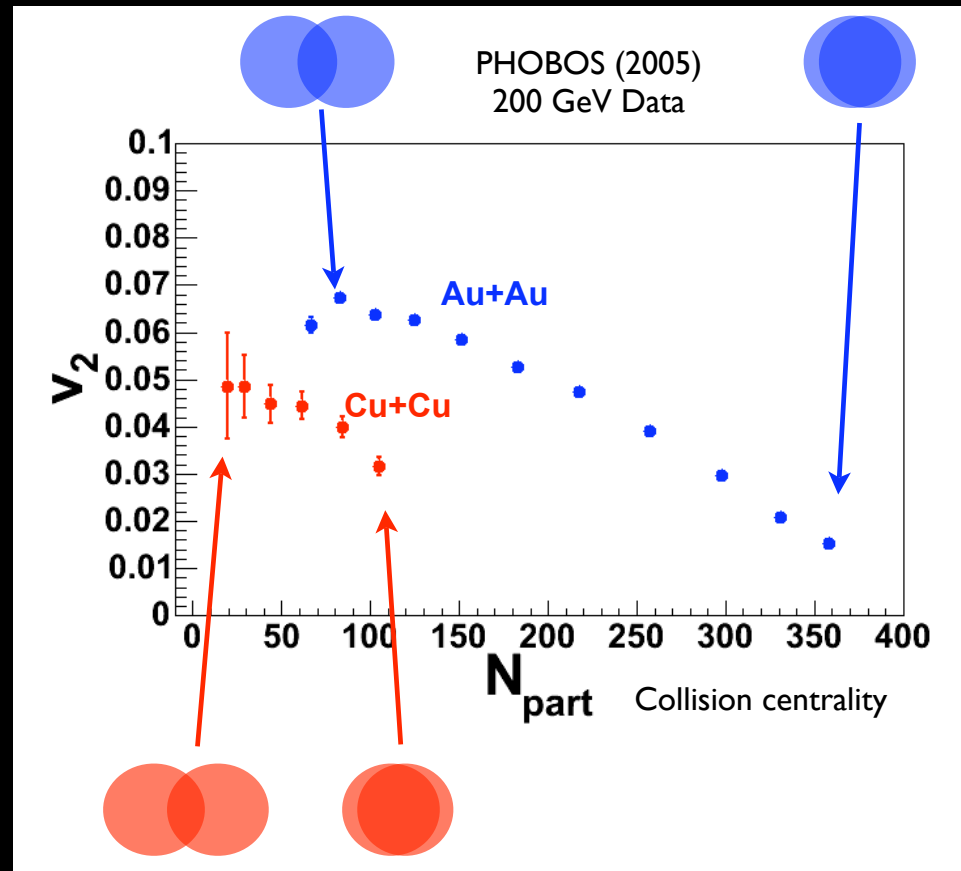
Test connection between geometry and elliptic flow  
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Gold  
A=197

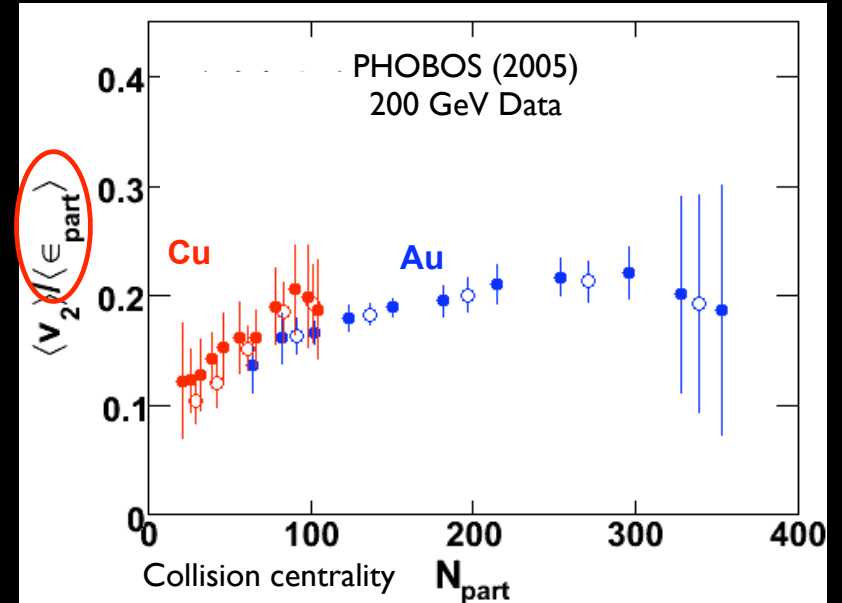
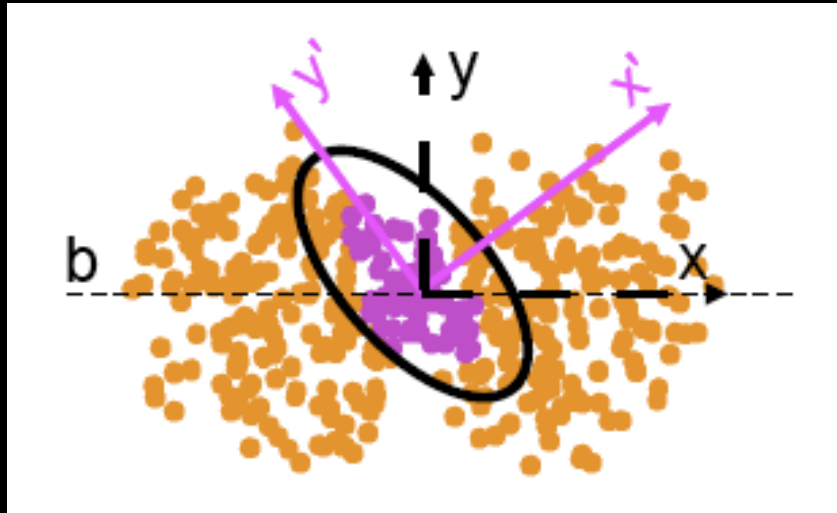


Copper  
A=64



$v_2$  is large even for central Cu+Cu

# Elliptic Flow and Geometry, II



Take into account fluctuations in shape and orientations of overlap zone relative to impact parameter from event to event

“Participant Eccentricity”

Estimated using Glauber MC calculation of nuclear overlap region

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

# Elliptic Flow and Geometry, III

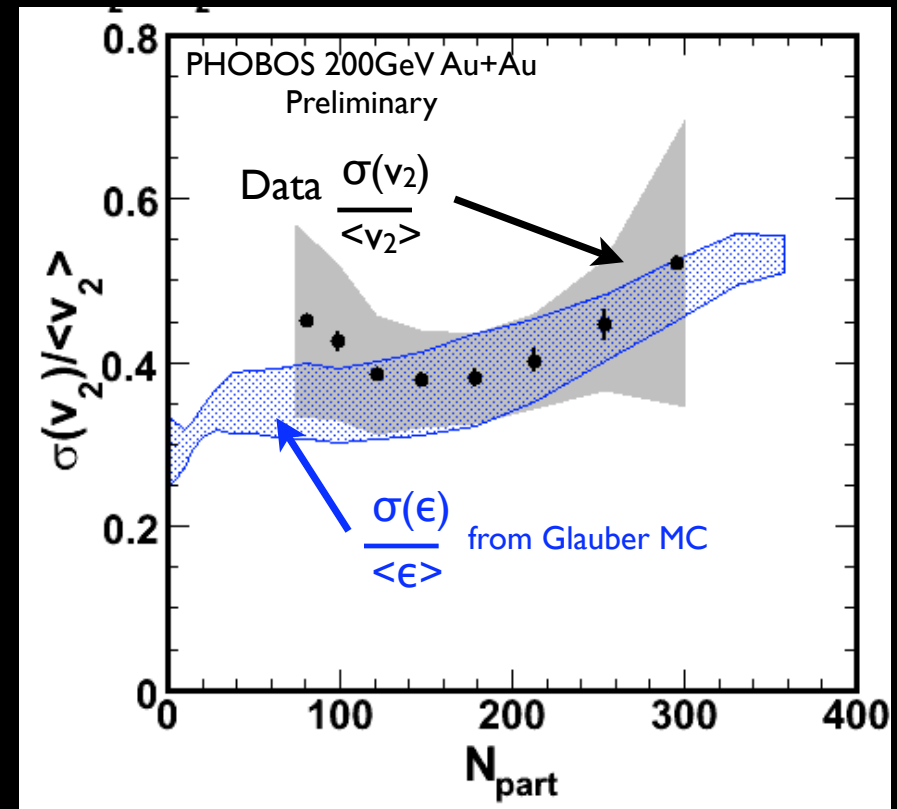
How do we know these  
fluctuations are real?

Measure them directly!  
If  $v_2 \propto \epsilon$ , then:

$$\frac{\sigma(v_2)}{\langle v_2 \rangle} = \frac{\sigma(\epsilon)}{\langle \epsilon \rangle}$$

i.e. relative fluctuations in  $v_2$  are determined  
by relative fluctuations in  $\epsilon$

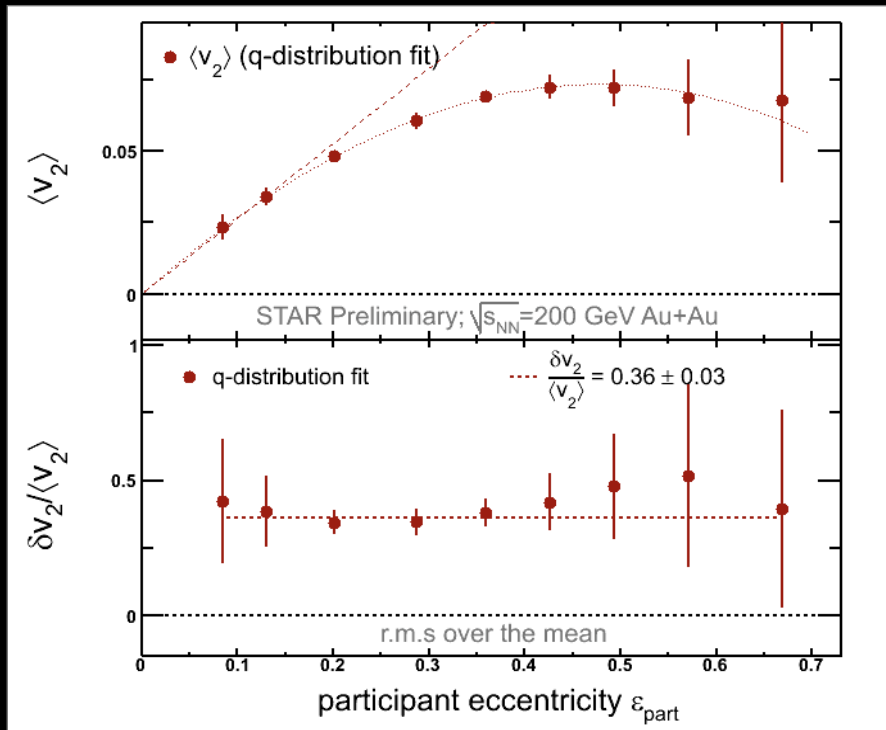
PHOBOS QM 2006



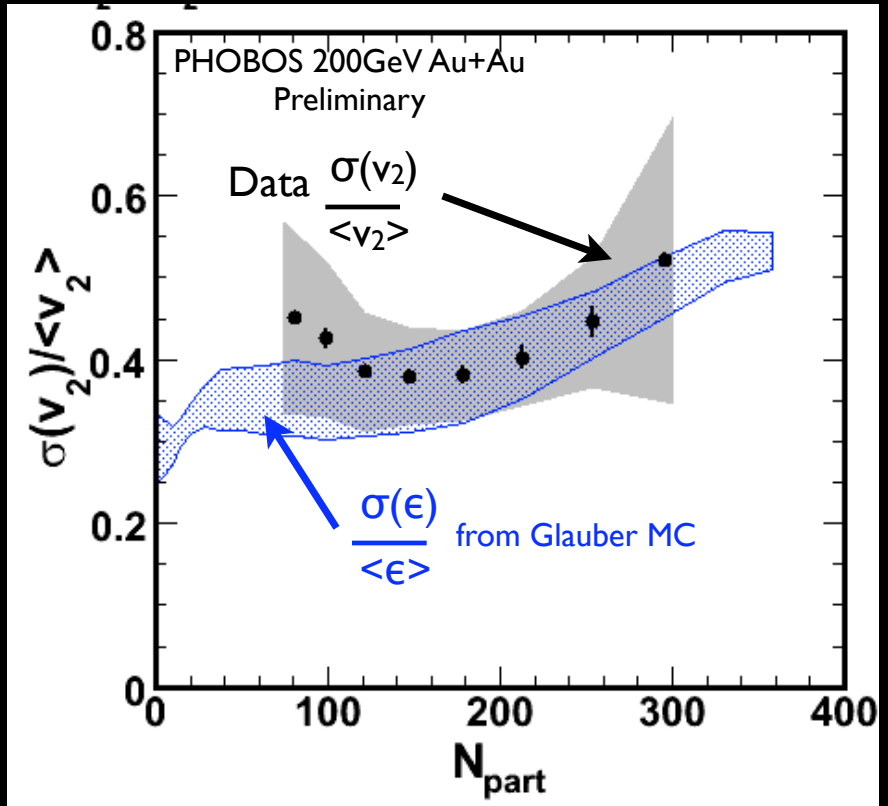
It appears that elliptic flow is indeed driven by event-by-event shape  
of interaction zone, as presumed in hydro calculations

# Elliptic Flow and Geometry, III

## STAR QM 2006



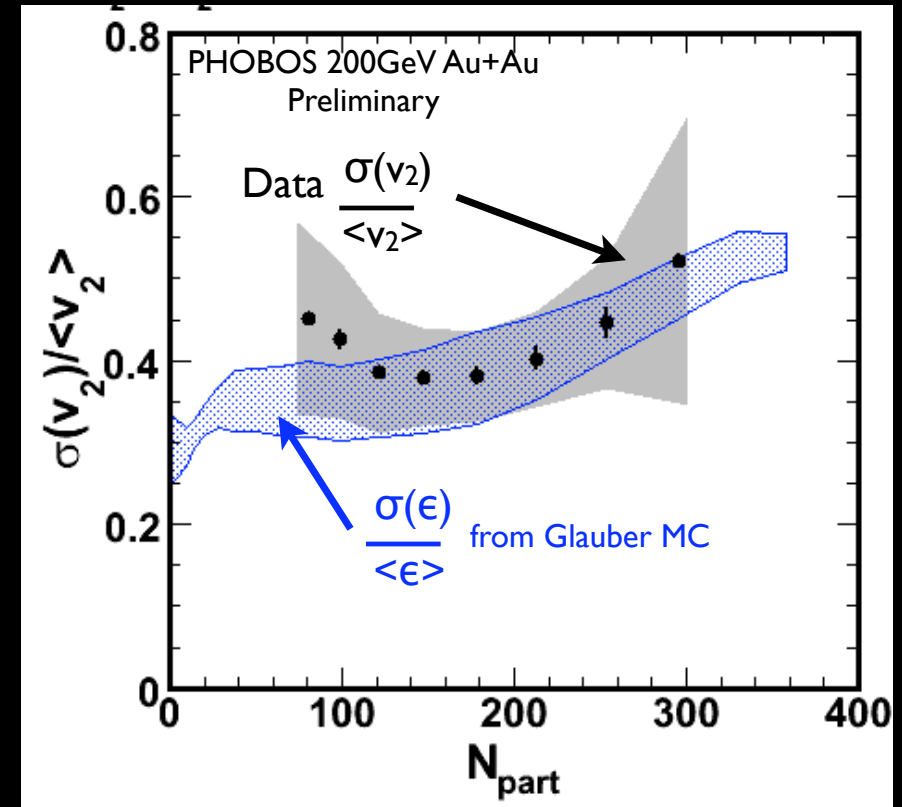
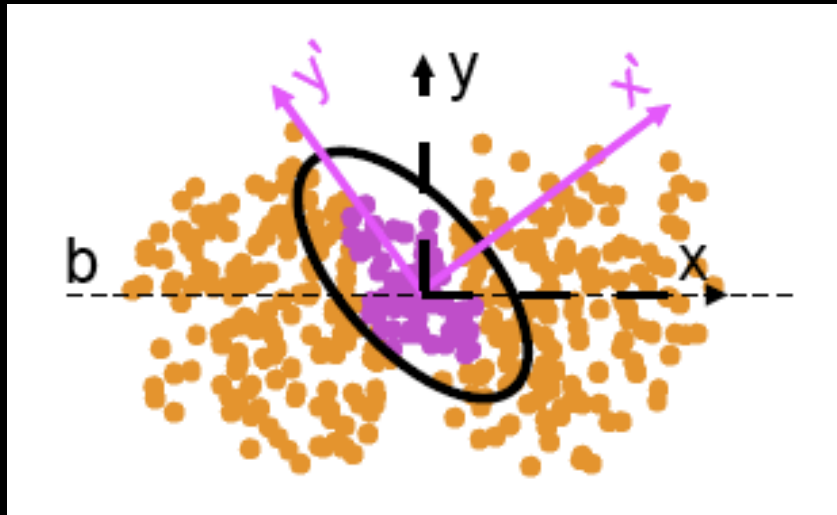
## PHOBOS QM 2006



Once again, good agreement between experiments

# Elliptic Flow and Geometry, III

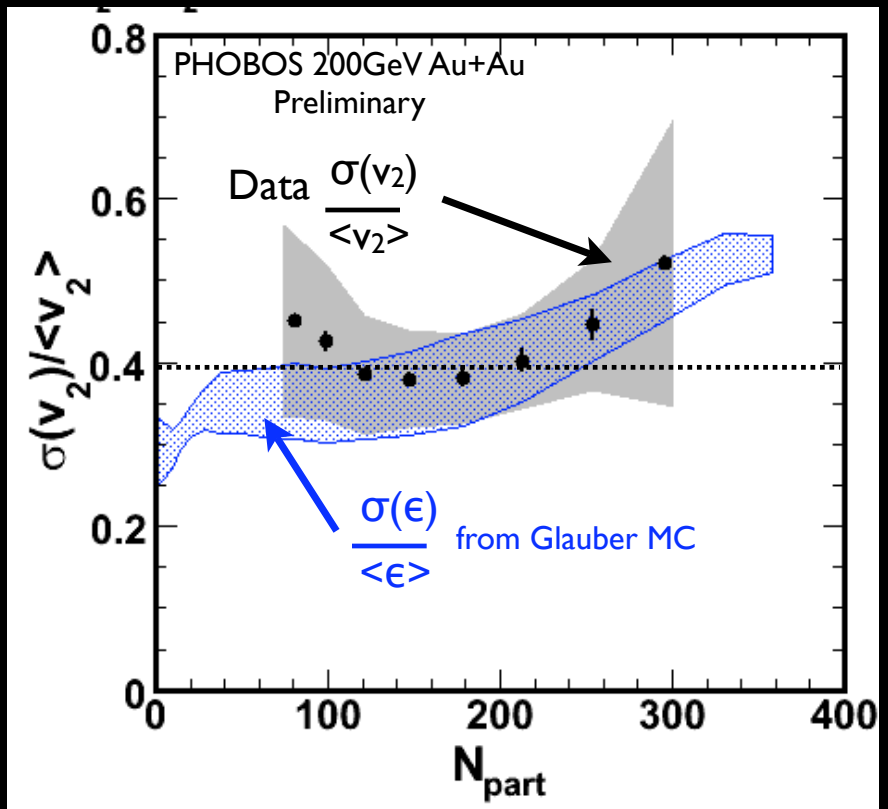
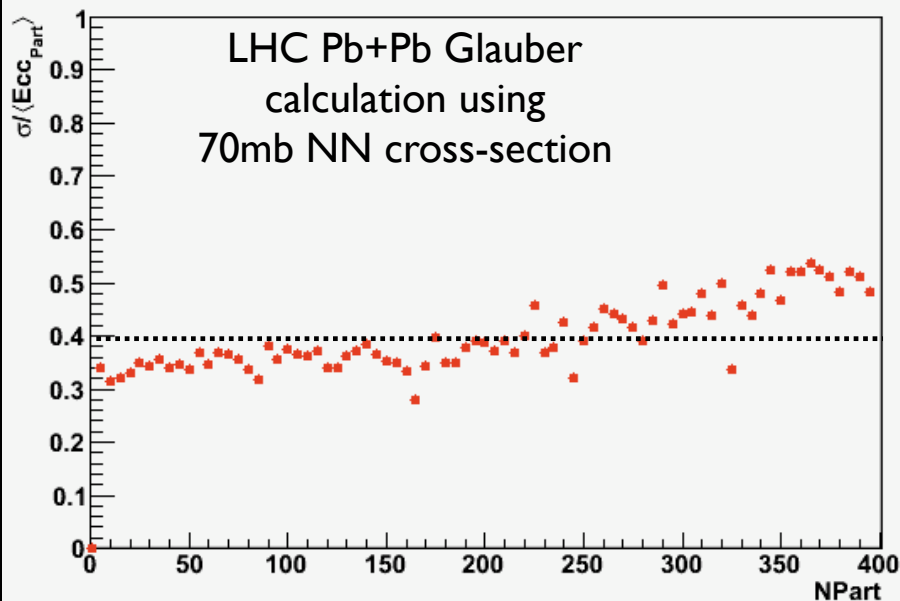
PHOBOS QM 2006



“Granularity” of overlap zone/initial geometry determined by nucleons!?

# Elliptic Flow and Geometry, III

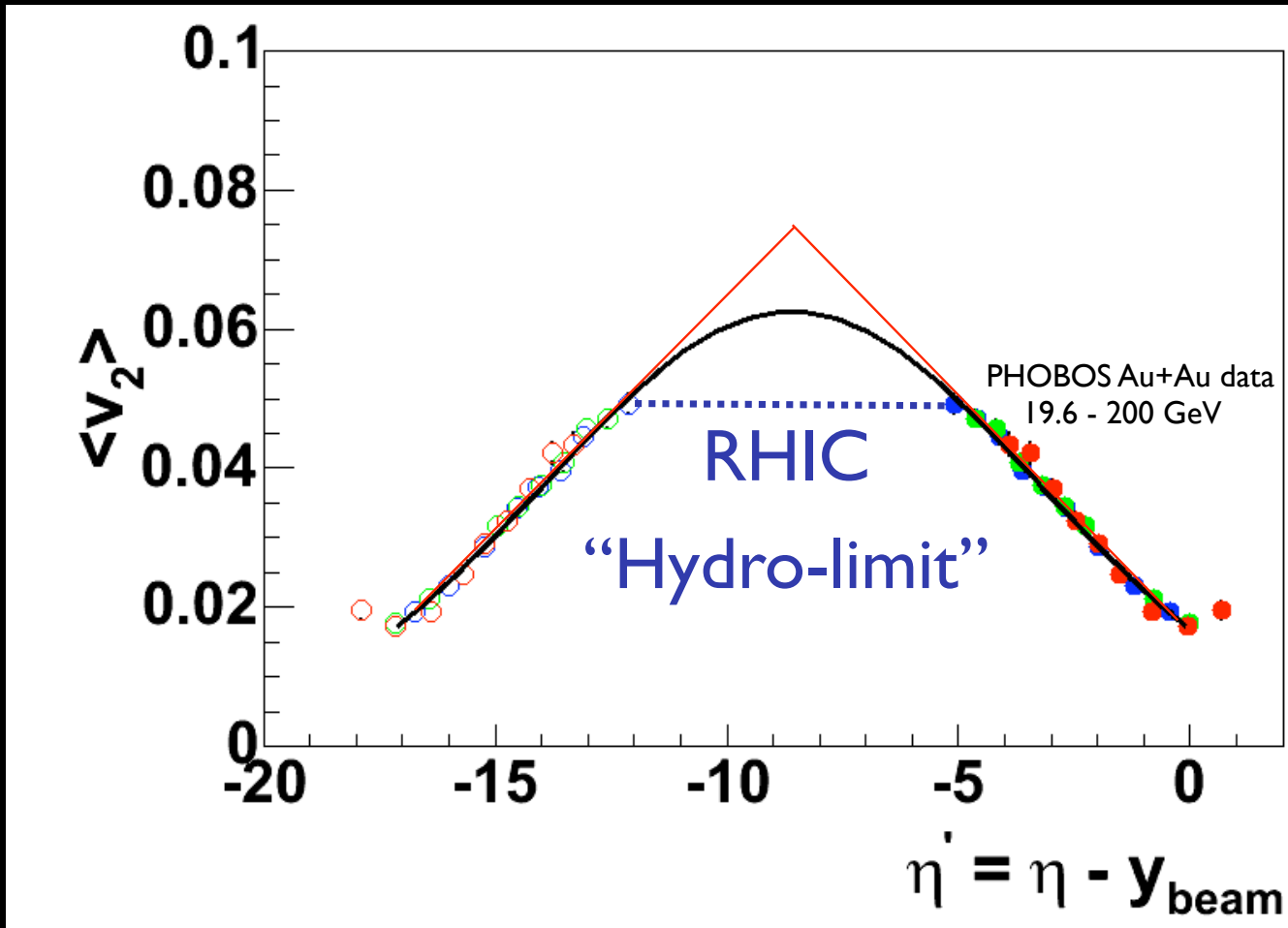
PHOBOS QM 2006



If “Glauber+ideal fluid” interpretation is true, the LHC plot shows expected fluctuations

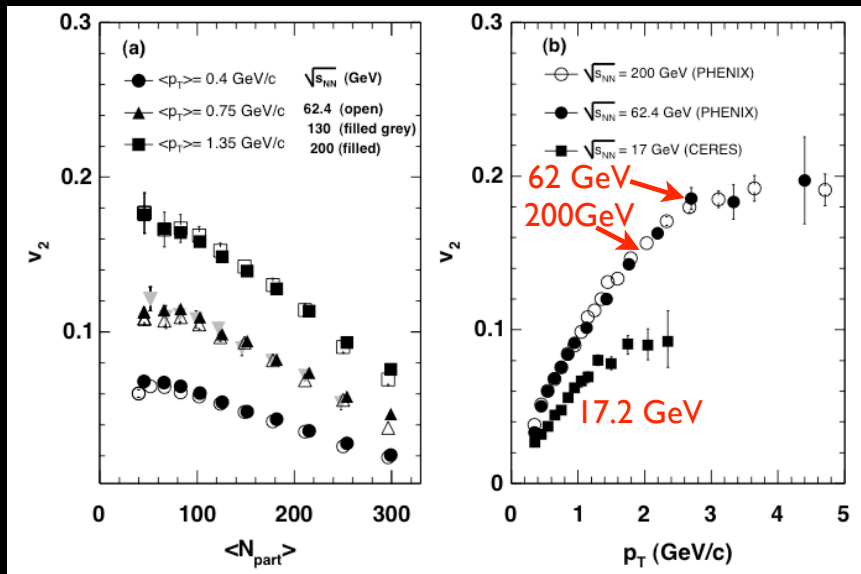
# Connections

# Elliptic Flow at LHC

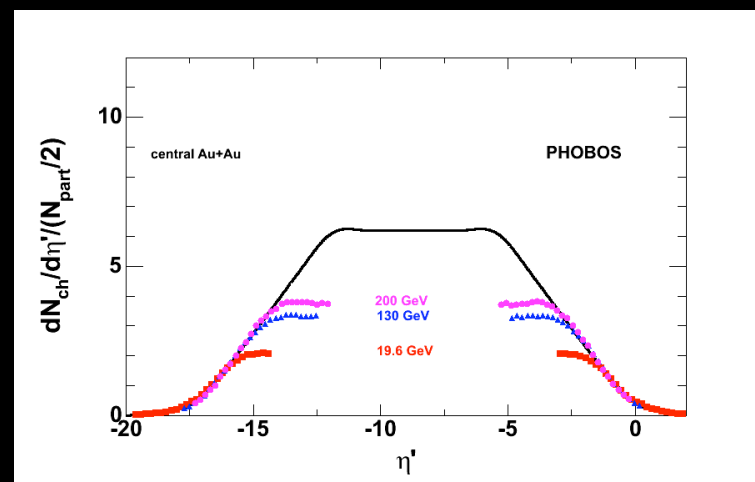
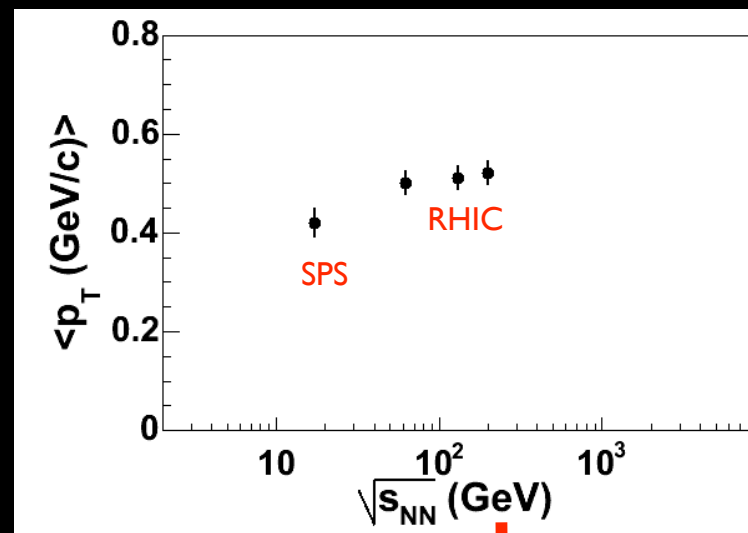


# $v_2$ vs $p_T$

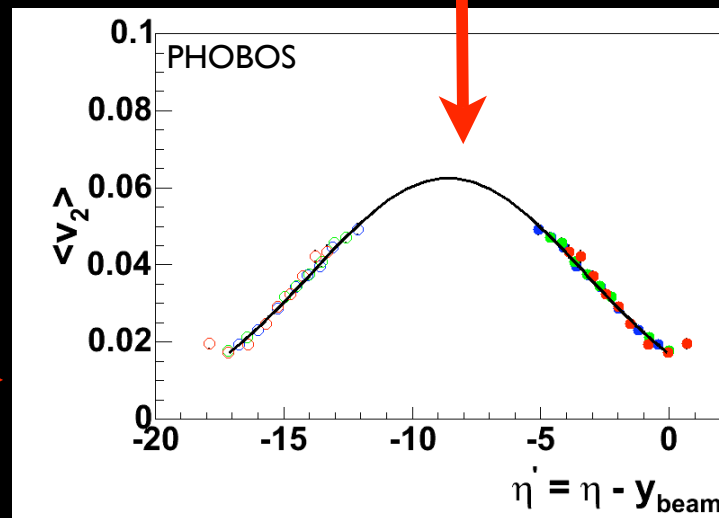
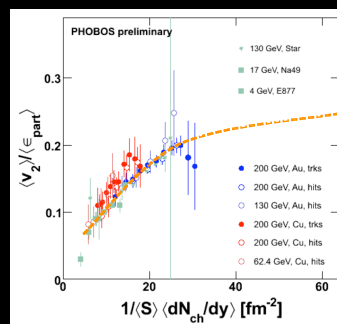
PHENIX nucl-ex/0411040



# $\langle p_T \rangle$ vs $\sqrt{s}$



# $dN/d\eta'$ vs $\sqrt{s}$



# $v_2(\eta')$ vs $\sqrt{s}$

# Summary

Soft particle production in heavy ion collisions is characterized by a number of scaling relationships (e.g.  $N_{part}$  scaling of  $N_{ch}$ , limiting fragmentation, factorization of energy/centrality dependence)

Ideally, these relationships should emerge naturally from our understanding of the collision process

Parton saturation/CGC may provide a framework for this understanding. Recent data provide new information and (maybe) a challenge