

Two Types of Geometric Scaling in A+A



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Workshop on “RHIC & LHC: The Next Few Years”

Weizmann Institute, Rehovot, Israel

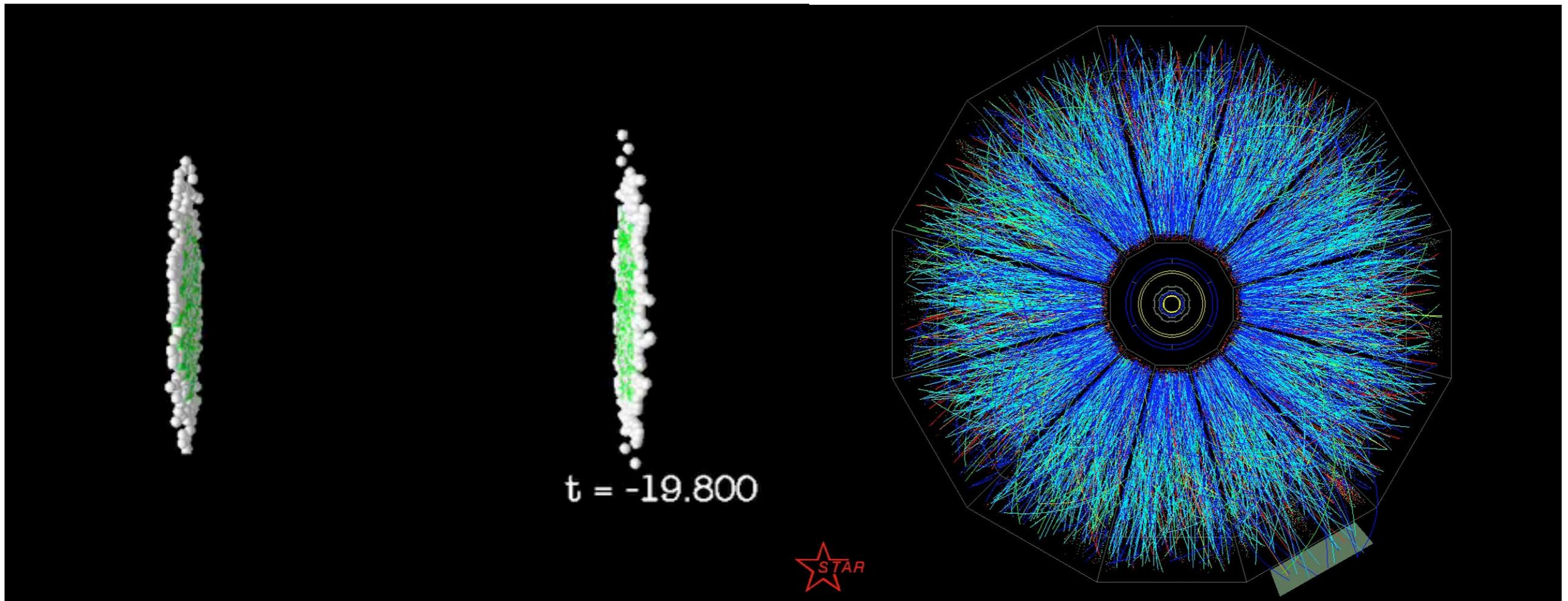
17 November 2008



RHIC Physics in a Nutshell

Collisions of Ions

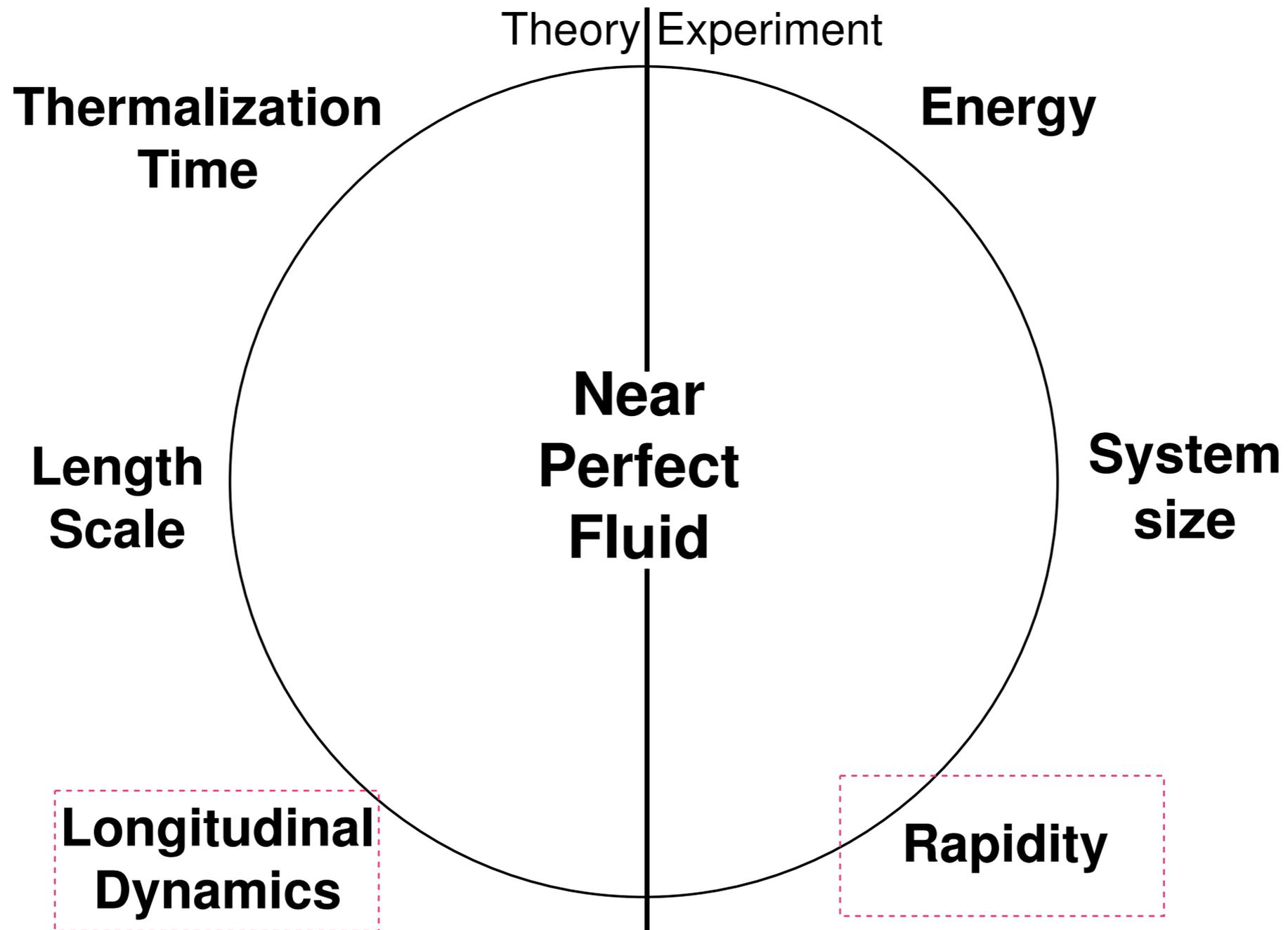
1000's of Particles



RHIC physics takes place in **space-time**
Need to “rewind” dynamical evolution to study
QCD at high temperature and density



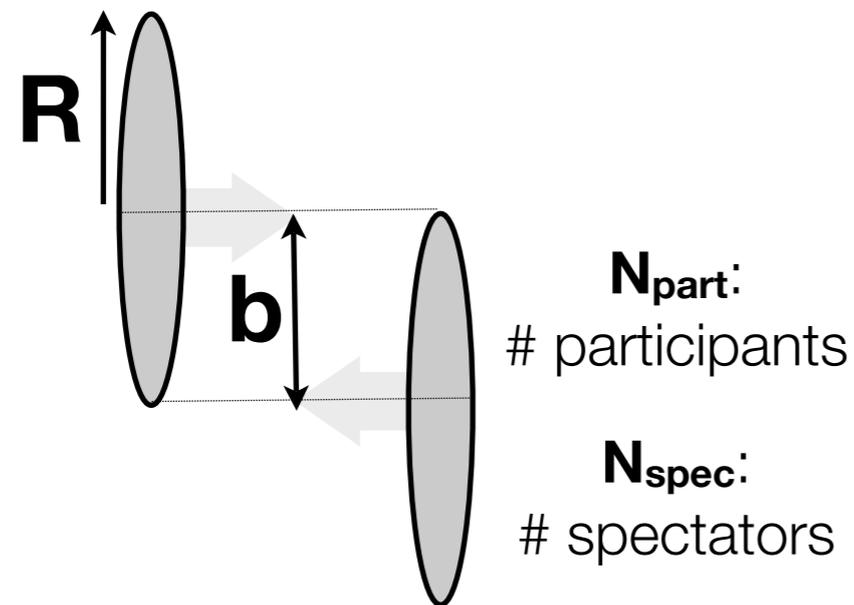
The Edge of Liquidity





Nuclear Geometry

Knowing collision geometry is essential for all heavy ion results

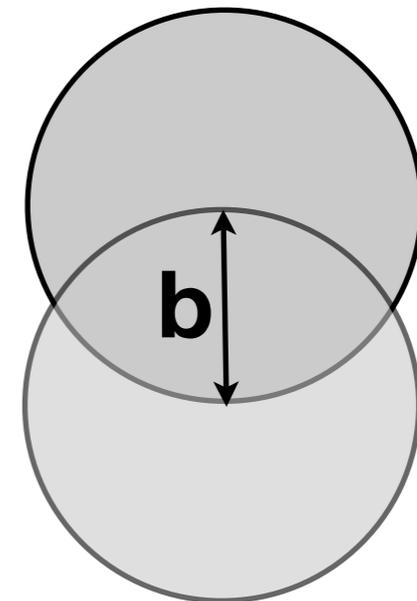


X-Z:

Longitudinal contraction ($1/\gamma$)

$$\epsilon = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

“eccentricity”



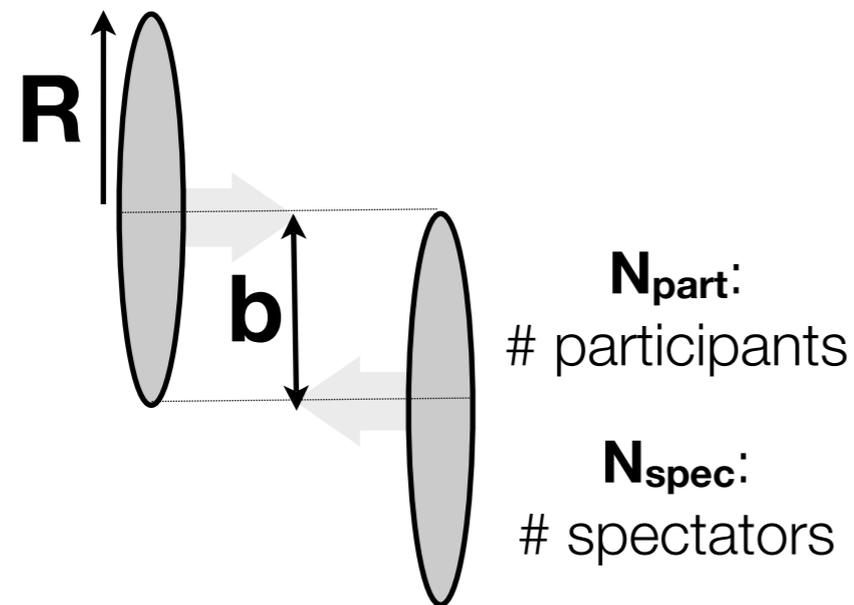
X-y:

Transverse overlap

Transverse and longitudinal scales are quite different:
spatial, temporal, momentum (via $\Delta p = h/\Delta R$)



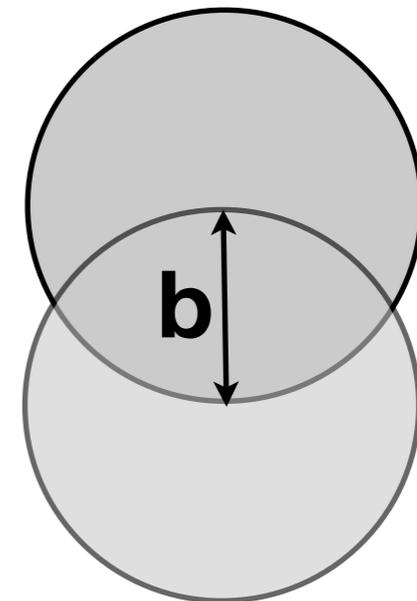
Momentum and Time Scales



Interactions at early times
can span full rapidity range

$$\Delta y \sim \log(\Delta p) \sim \log(\sqrt{s})$$

$$\epsilon = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

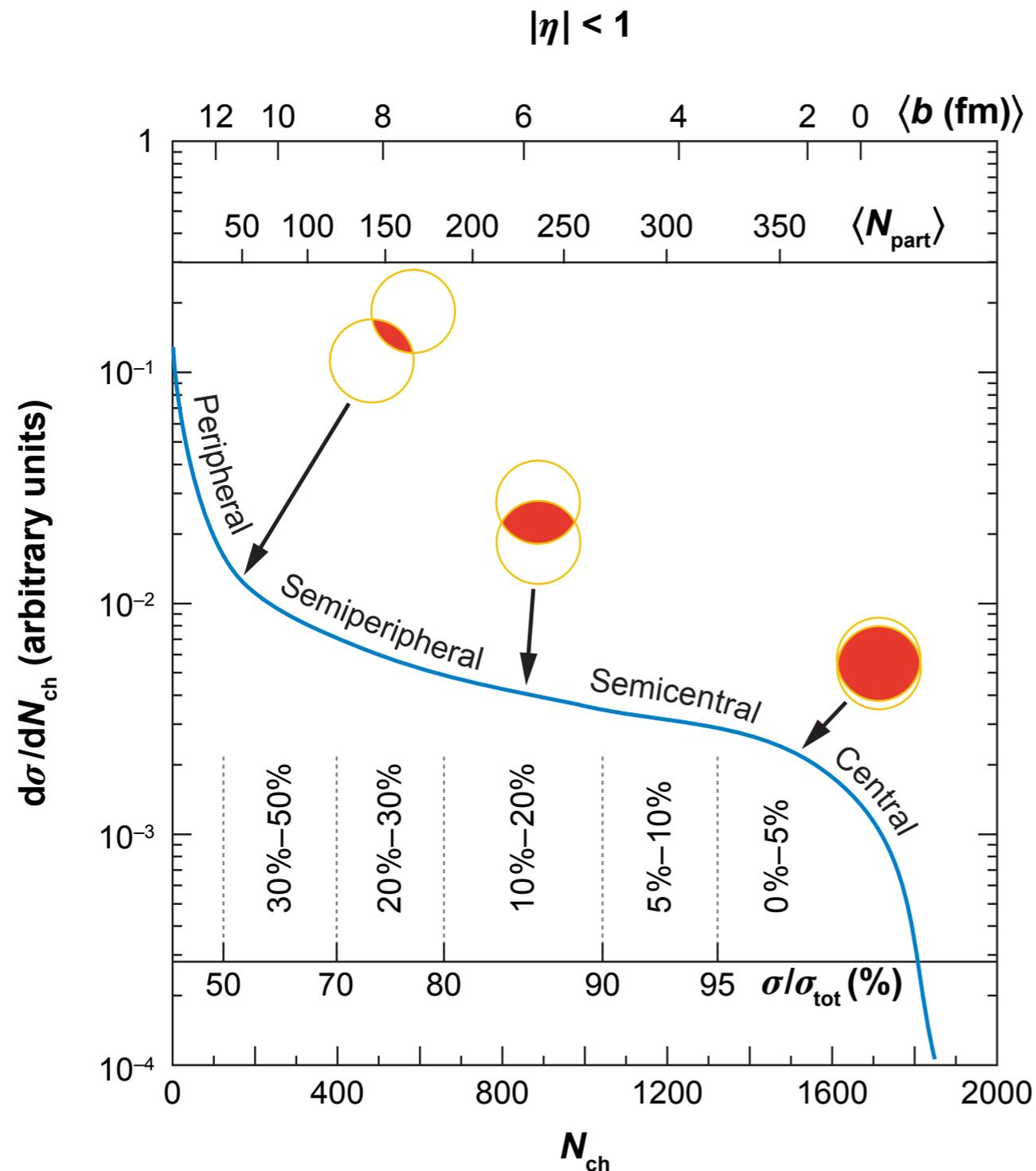


Interactions at later times
build up transverse flow,
become limited in rapidity

$$\Delta y \sim 1$$



“Centrality” (Fraction of Cross Section)



Cannot directly measure N_{part} , N_{spec} , b , ϵ , etc.

Measure distributions and assume they are monotonic with variable of interest

Bin data in “fractions of total inelastic cross section” (requires estimation of σ_{inel}) and relate to same bin in geometric distribution

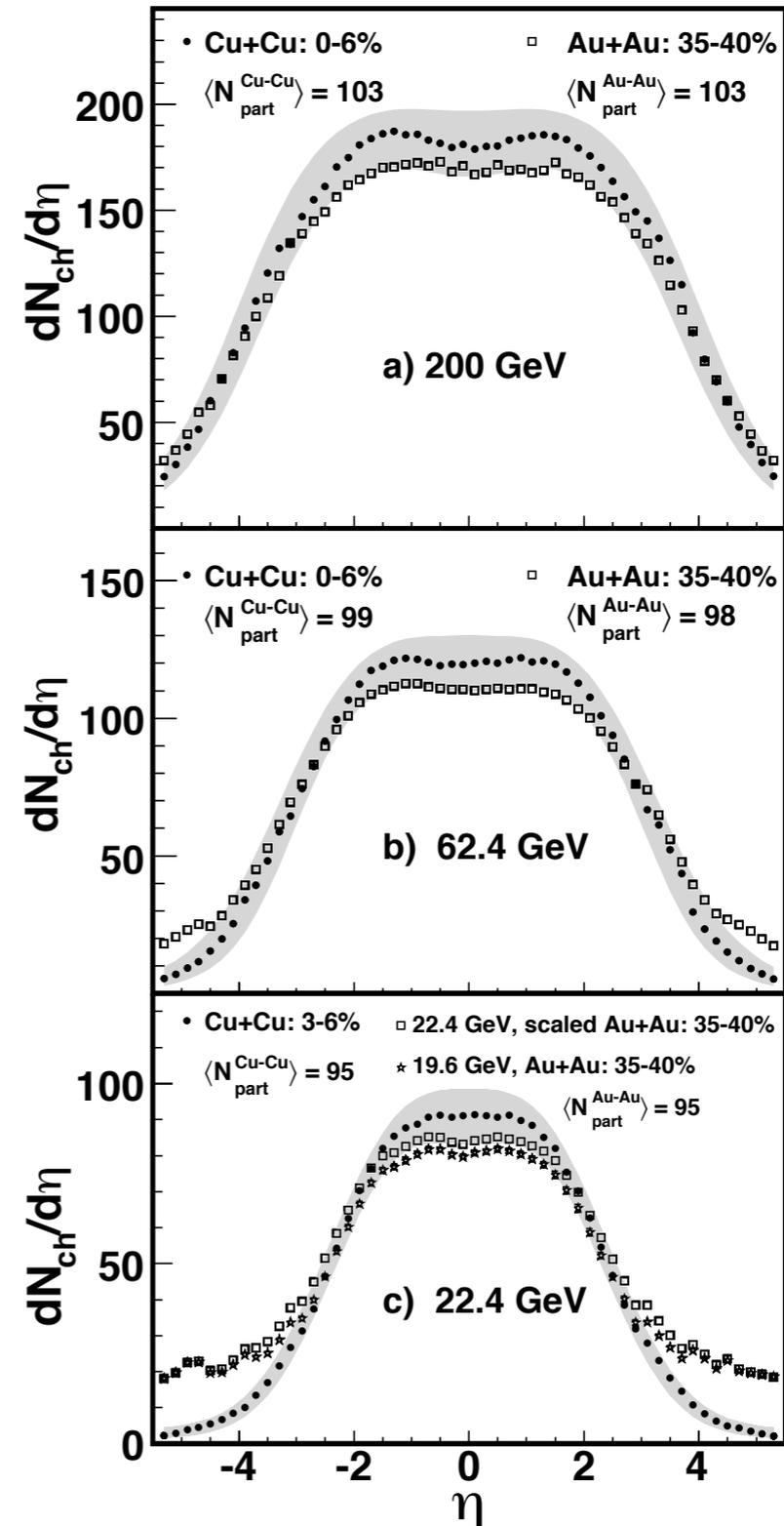
“Density” Scaling





$dN/d\eta$ in Au+Au and Cu+Cu at same N_{part}

At same N_{part} , overall scale of $dN/d\eta$ same for Au+Au and Cu+Cu, especially near $\eta \sim 0$



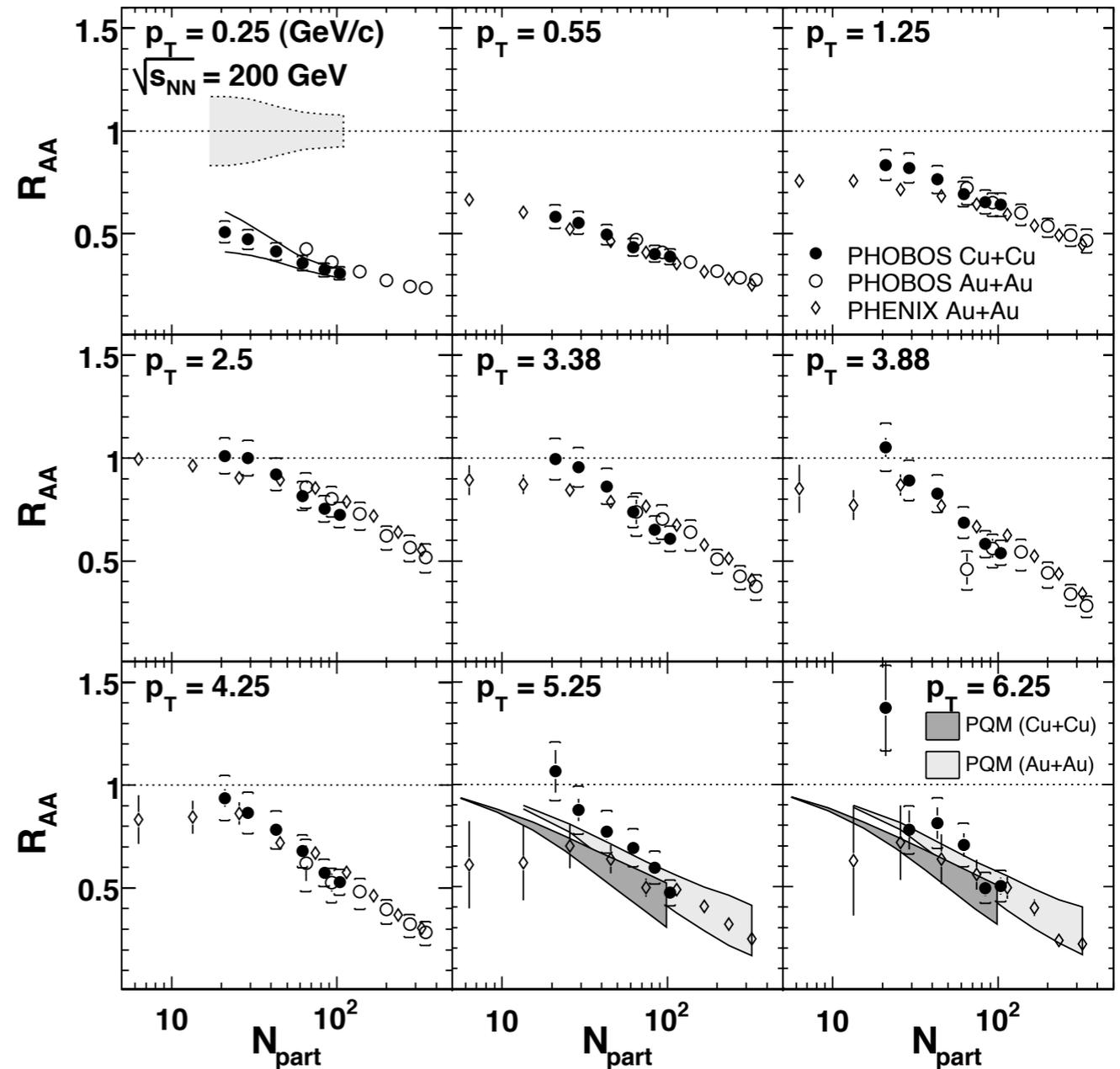


“Density” Scaling

PHOBOS did a comparison of inclusive charged spectra in Au+Au and Cu+Cu at 200 GeV and 62.4 GeV

R_{AA} found to scale between Au+Au and Cu+Cu when compared at the same N_{part}

Works all the way down to low p_T , i.e. soft domain

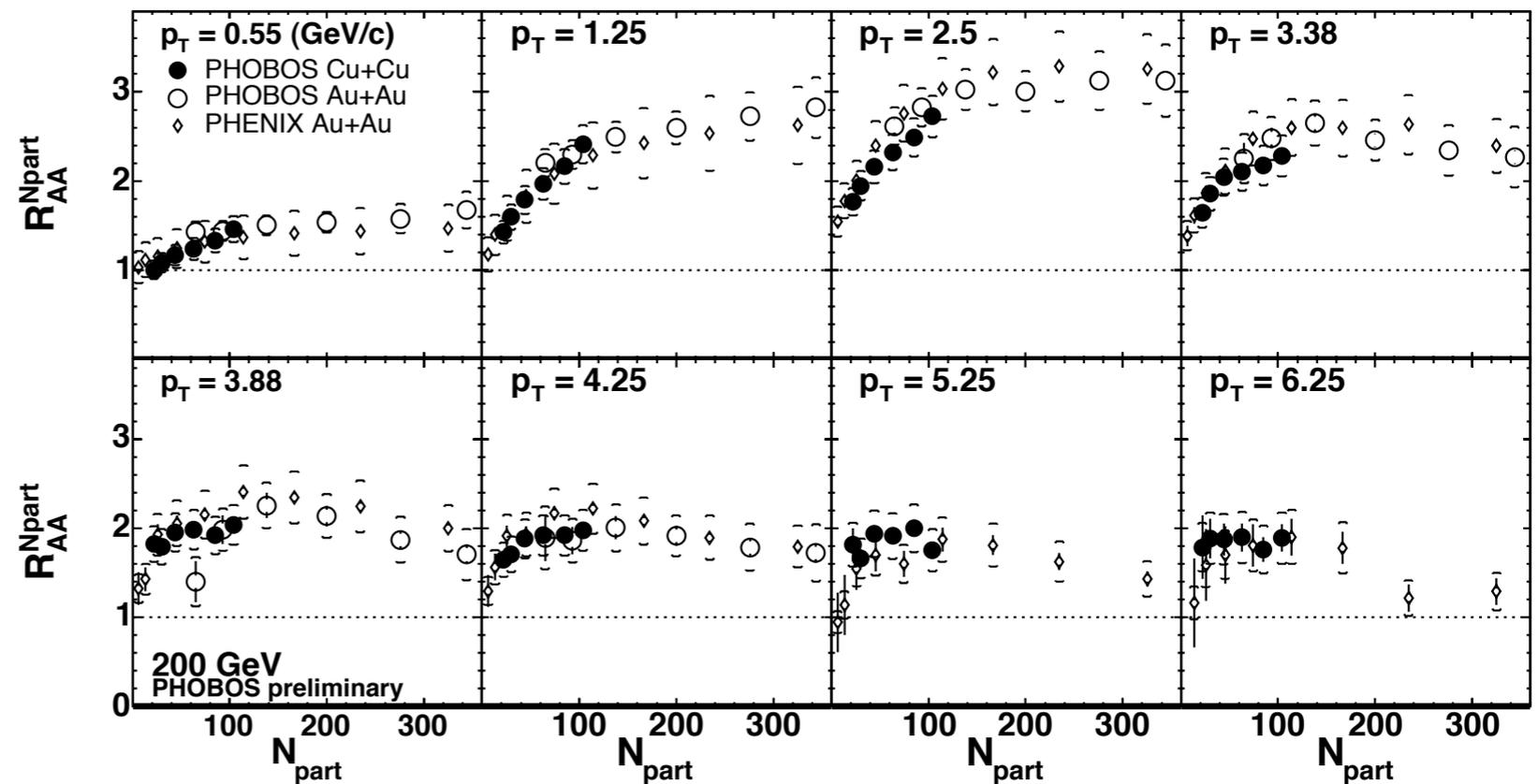




Nuclear Modification of dN/dp_T vs. N_{part}

$$R_{AA}^{N_{part}} = \frac{2}{N_{part}} \frac{\frac{dN^{A+A}}{dp_T}}{\frac{dN^{p+p}}{dp_T}}$$

Enhancement
of yield at $\eta \sim 0.8$
relative to p+p in
Au+Au and Cu+Cu
vs. N_{part}



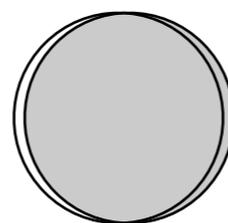
Bottom line, spectral modification only depends on N_{part} ,
which is main determinant of overall $dN/d\eta$



Participant Eccentricity in Au+Au and Cu+Cu

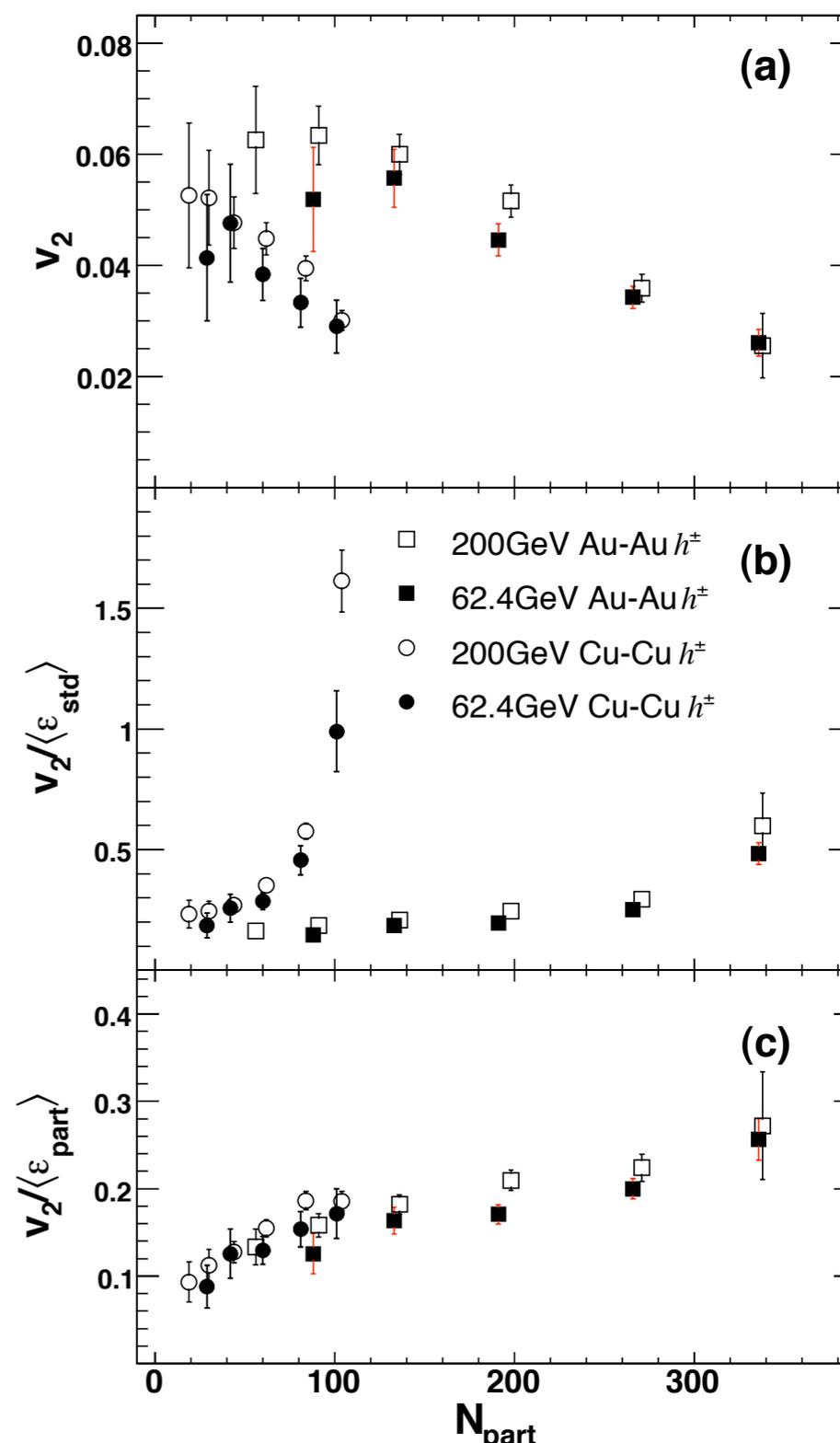
PHOBOS, Phys.Rev.Lett.98:242302,2007

$v_2 \not\rightarrow 0$ even when $b \rightarrow 0$



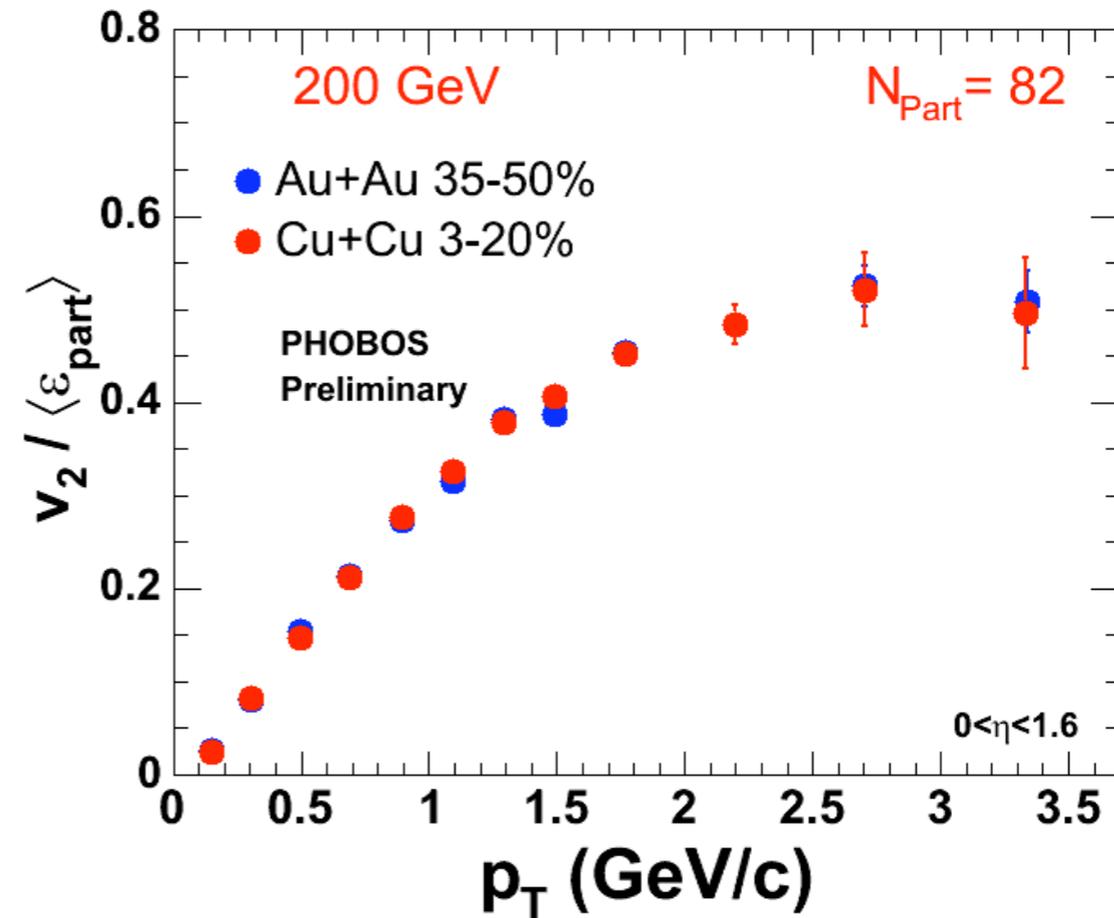
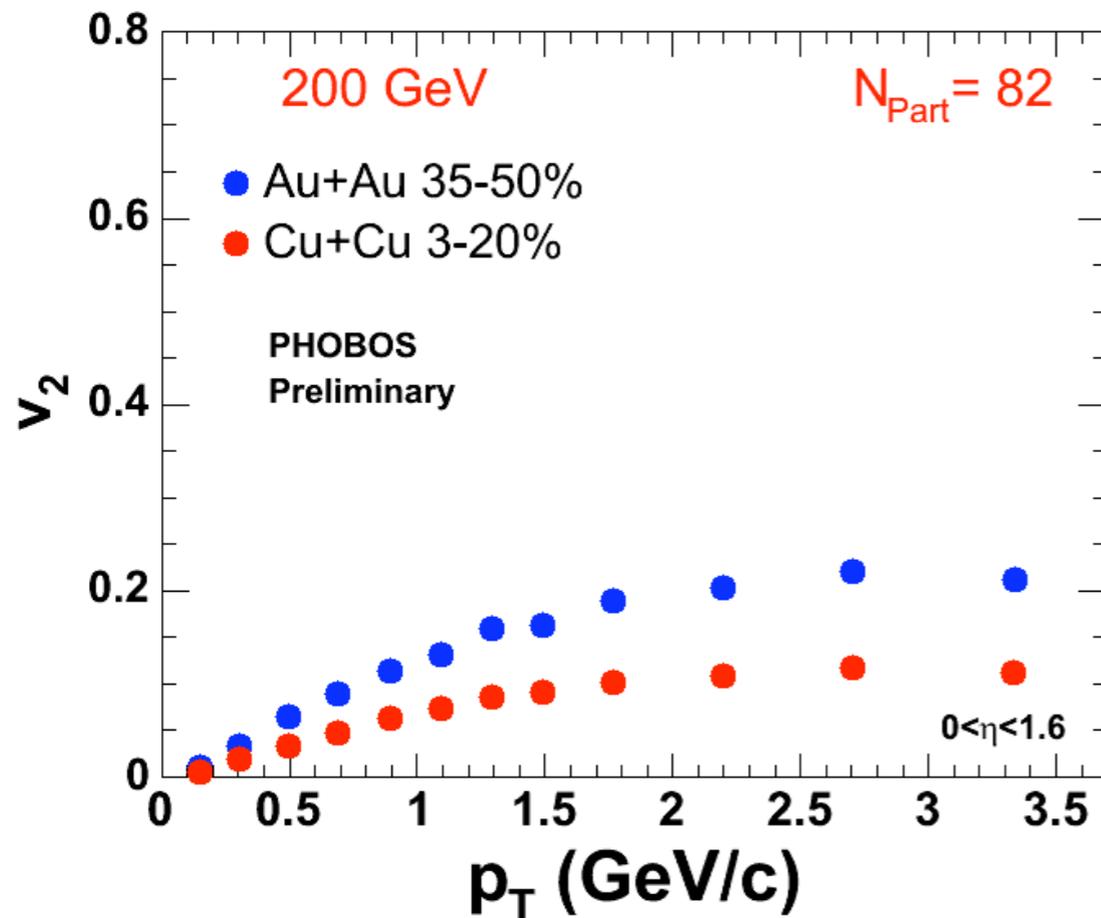
Since $\epsilon_{\text{std}} \rightarrow 0$, $v_2/\epsilon_{\text{std}}$ diverges
for central Cu+Cu events

$v_2/\epsilon_{\text{part}}$ scales for Au+Au and Cu+Cu:
Nucleon configuration
“**frozen-in**” very early (**small τ_0**)





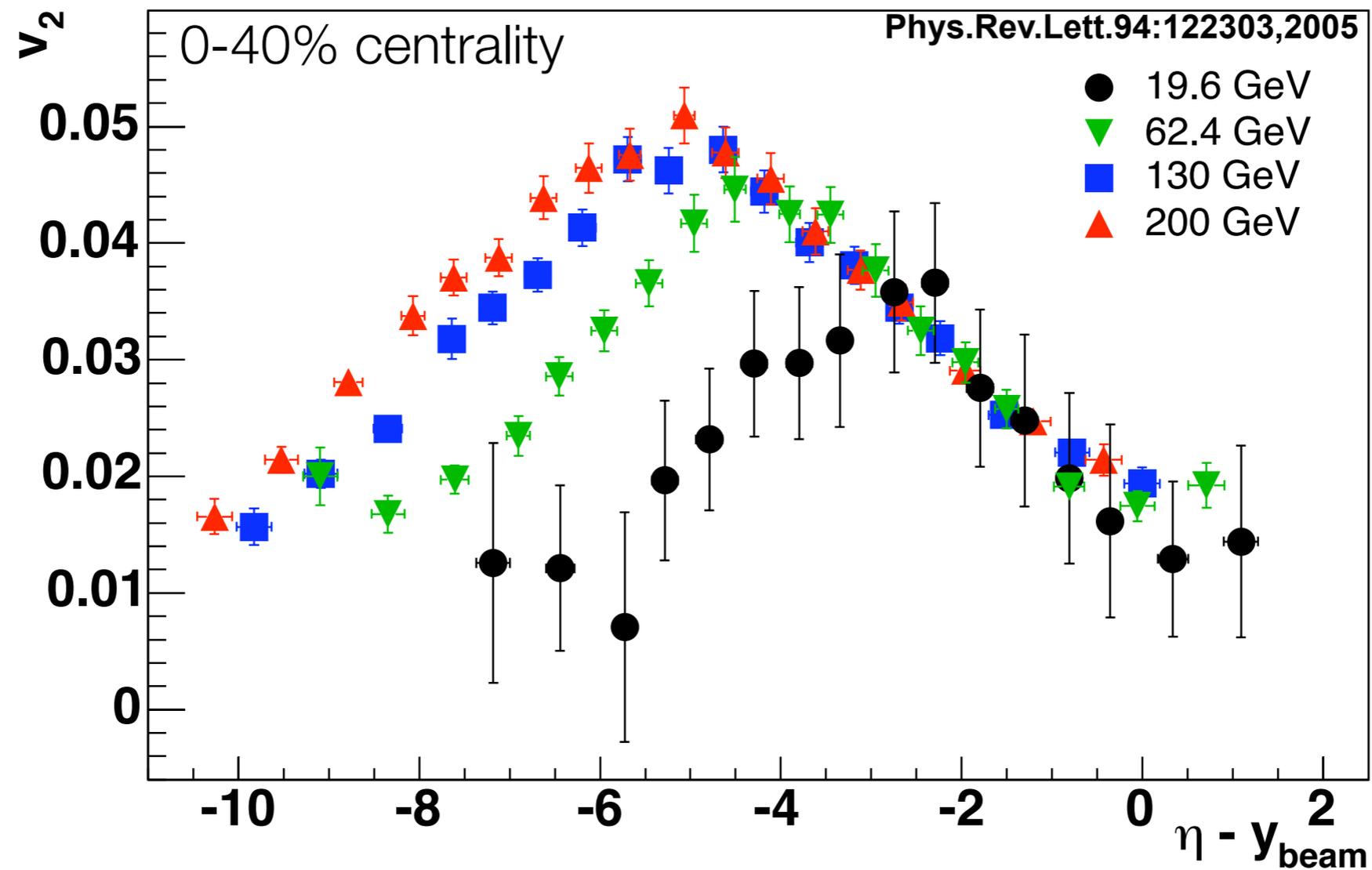
Density Scaling for $v_2(p_T)$



At same N_{part} , very precise ϵ_{part} scaling of $v_2(p_T)$ between Au+Au and Cu+Cu



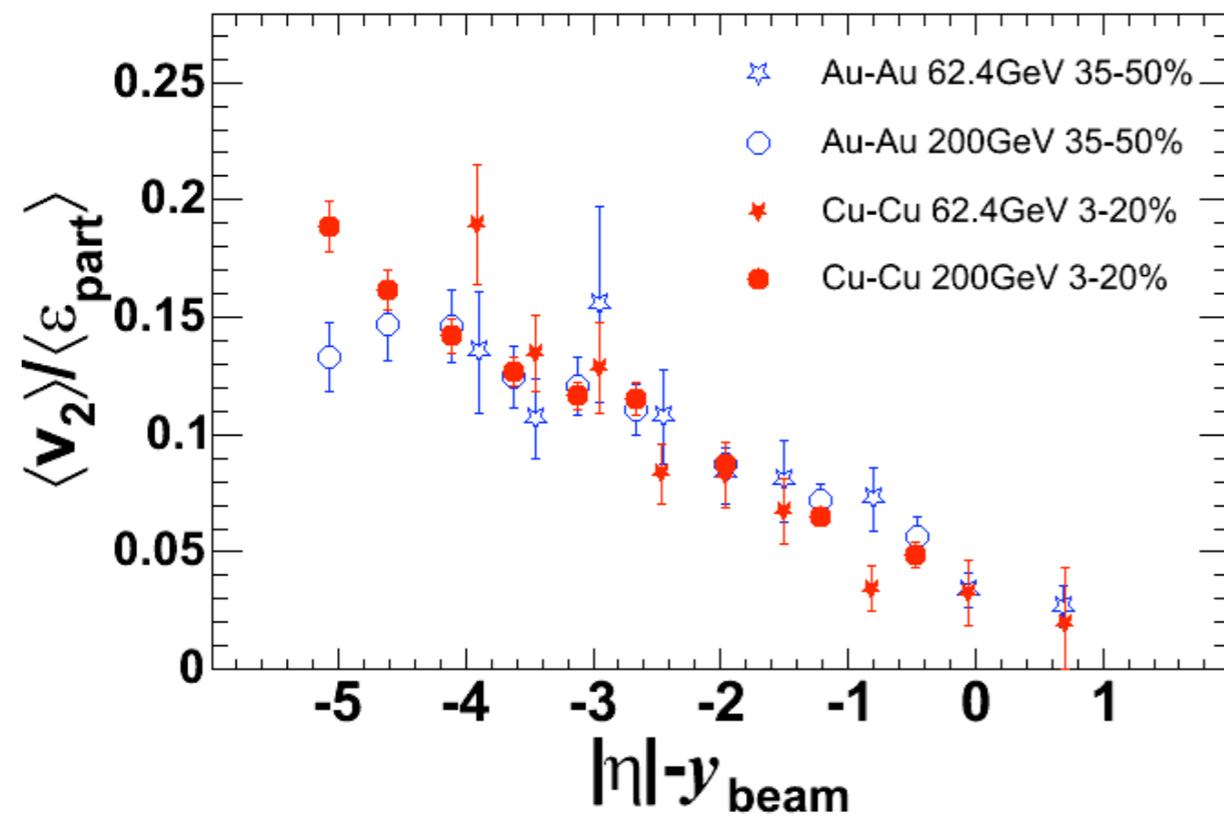
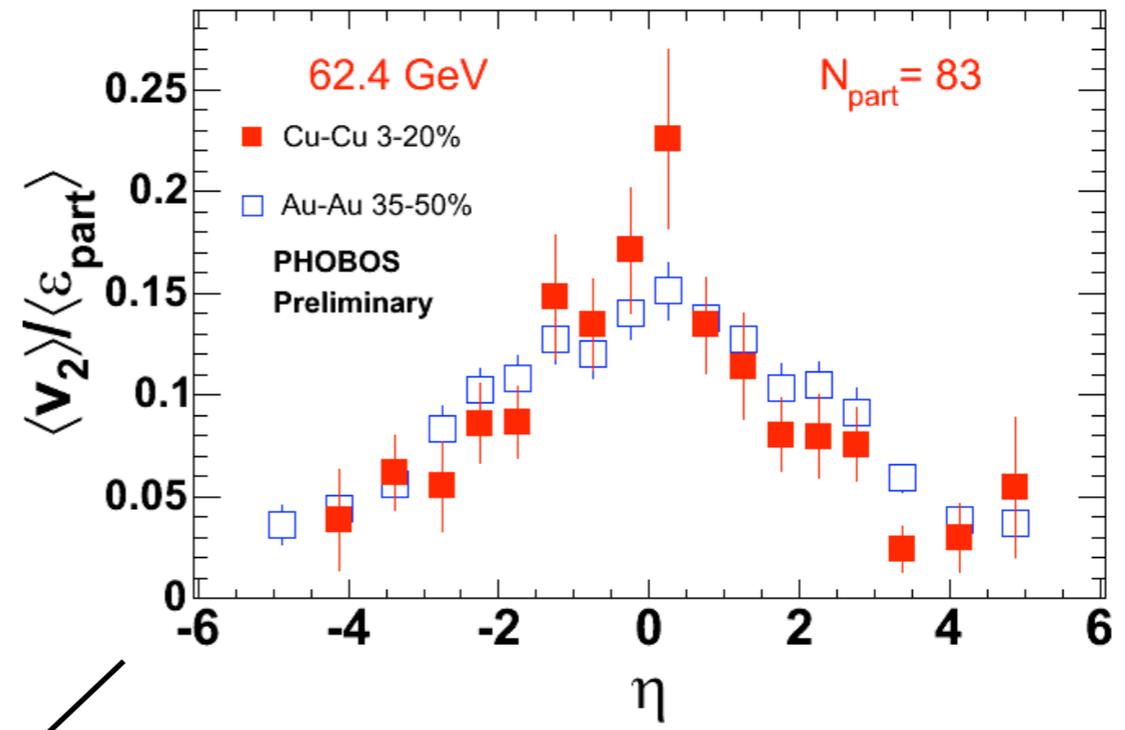
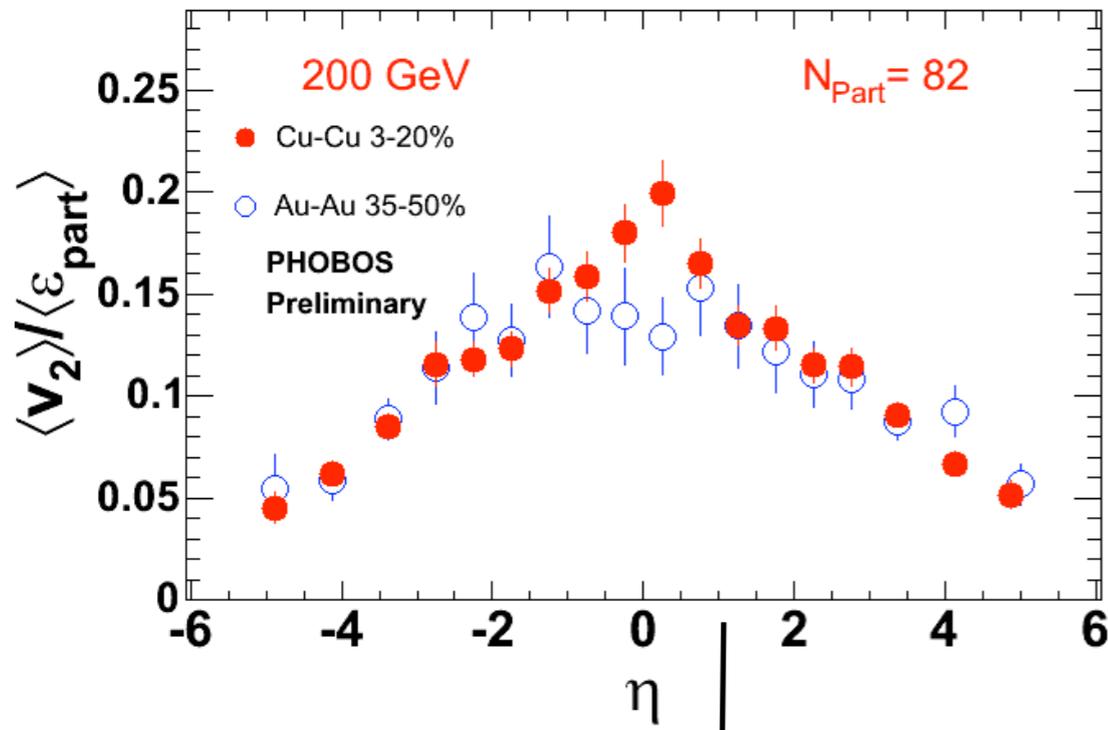
“Extended Longitudinal Scaling” of Elliptic Flow



Scaling also observed for $v_2(\eta)$: related to $dN/d\eta$?



Longitudinal Scaling of $v_2(\eta)$ follows Density



Limiting fragmentation holds in smaller centrality bins only if compared at same N_{part}

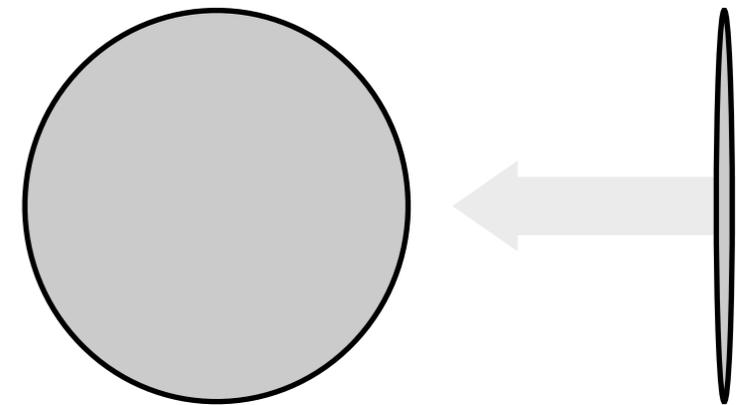
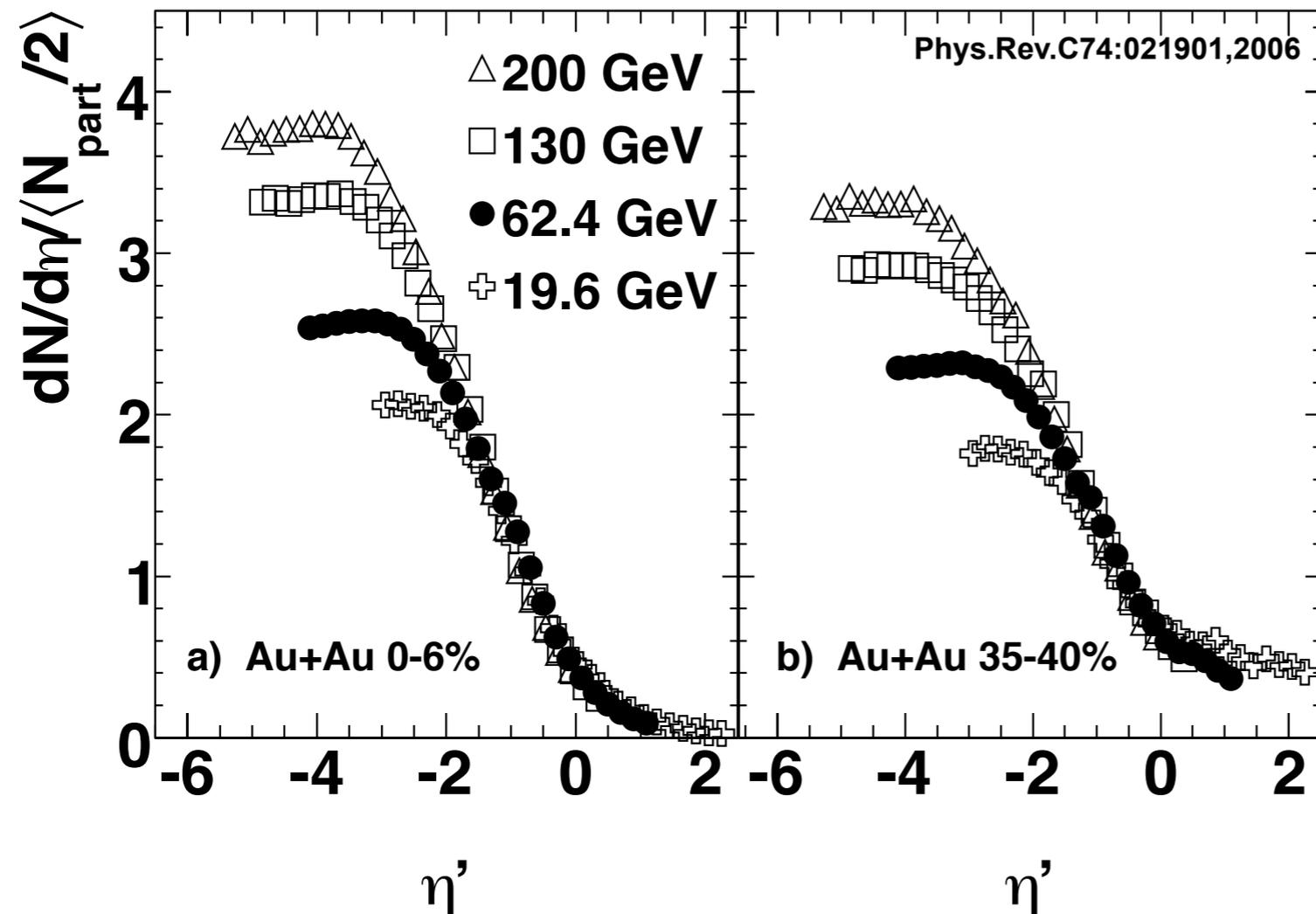
“Fractional” Scaling





Extended Longitudinal Scaling of $dN/d\eta$

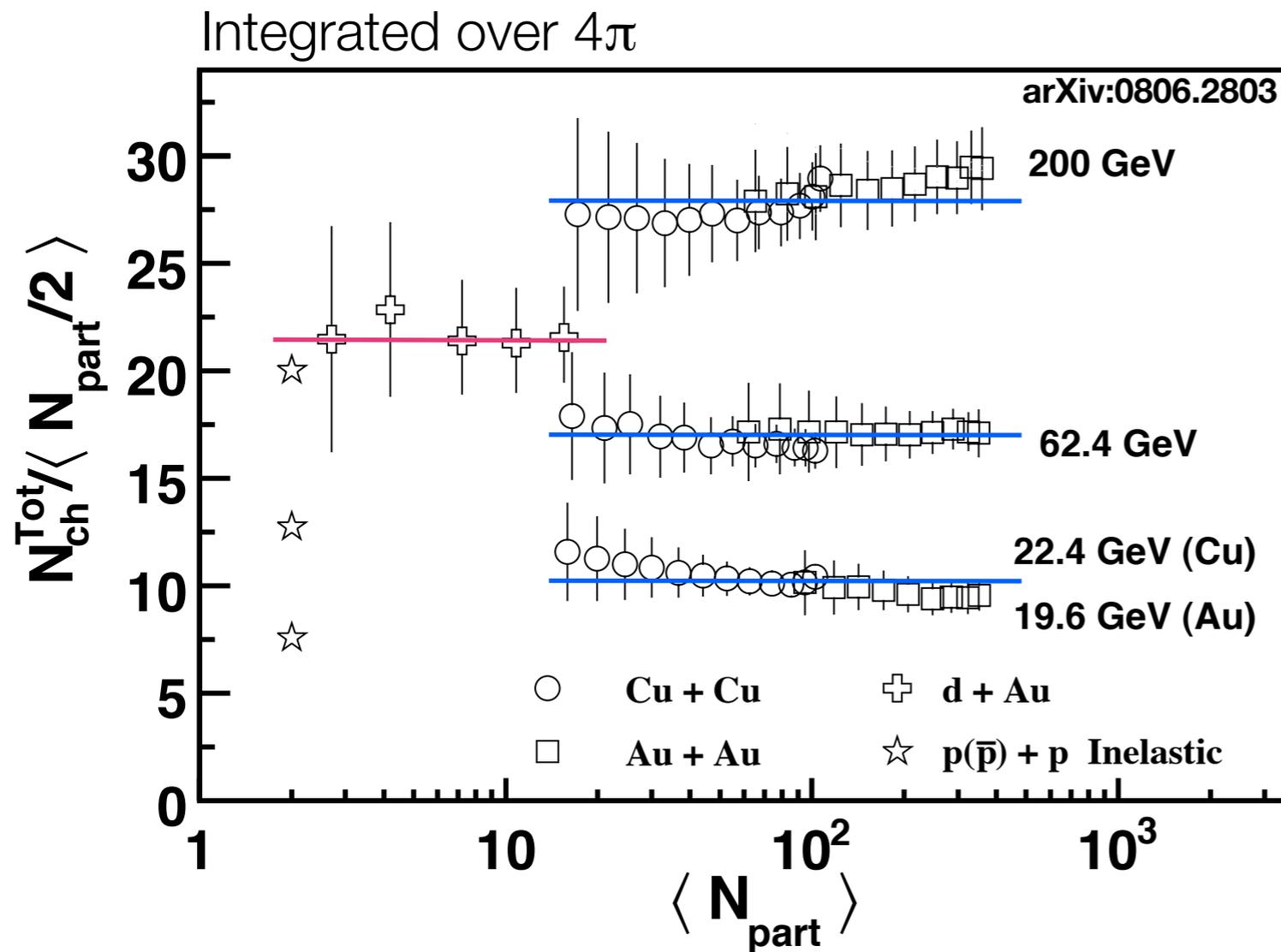
- From rest frame of one projectile: yields invariant at fixed geometry (i.e. same $b/2R$ or $N_{\text{part}}/2A$)



Most theoretical approaches assume (or require) that dN/dy is established very early in collision -- and remains unchanged



N_{part} Scaling of Total Multiplicity



Total multiplicity (4π) shows “wounded nucleon” scaling to $N_{part}=20$ in both Au+Au and Cu+Cu

Suggests no change in overall degrees of freedom with **system size**

Suggests no additional entropy in system evolution

$$S \propto sV \propto N_{tot} \propto N_{part}$$

(Fermi-Landau model)

(p+p/d+Au \rightarrow A+A explained by “leading-particle” effects)

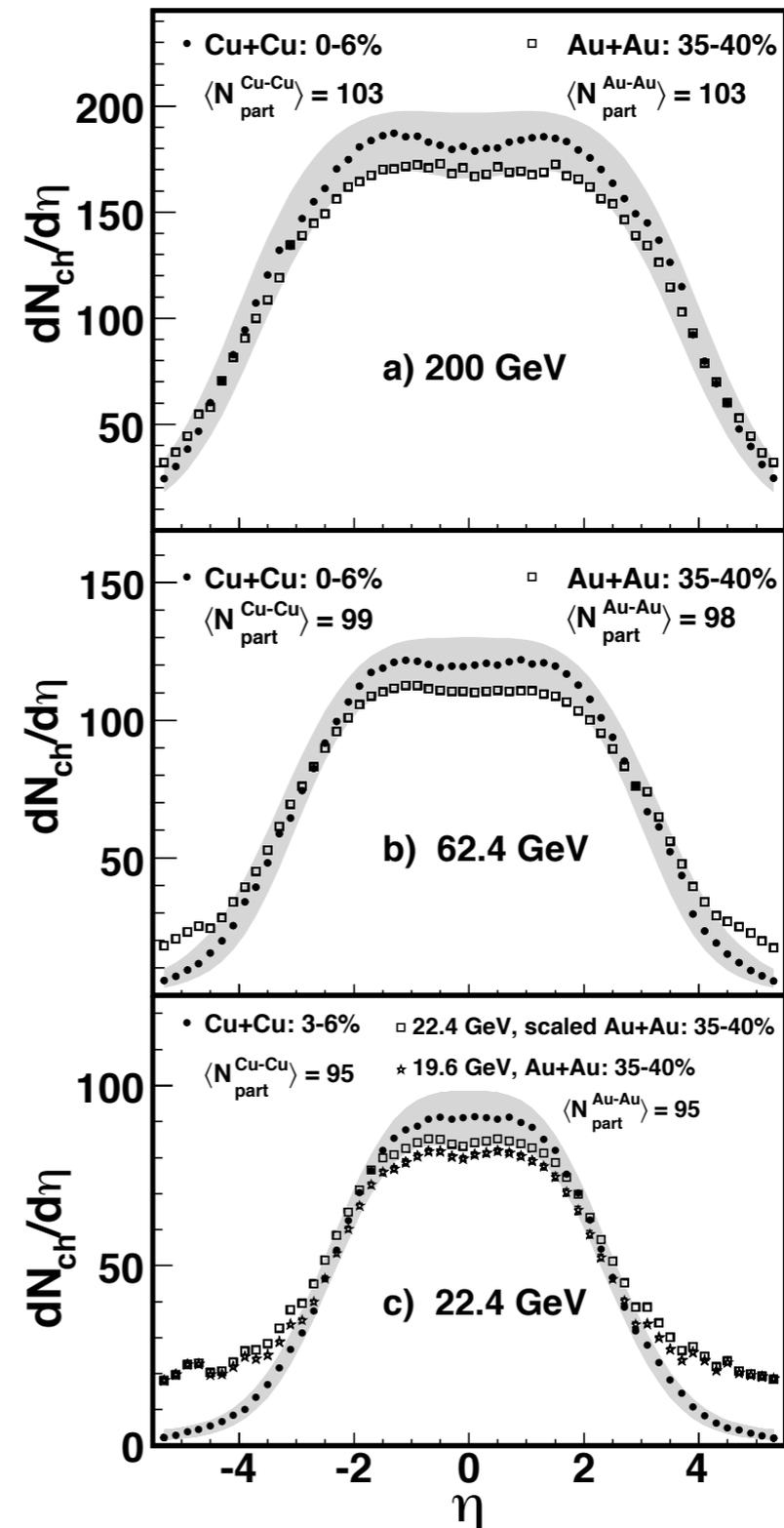


$dN/d\eta$ in Au+Au and Cu+Cu at same N_{part}

At same N_{part} , overall scale of $dN/d\eta$ same for Au+Au and Cu+Cu

In detail, shape is different:
More central events taller,
more peripheral events wider

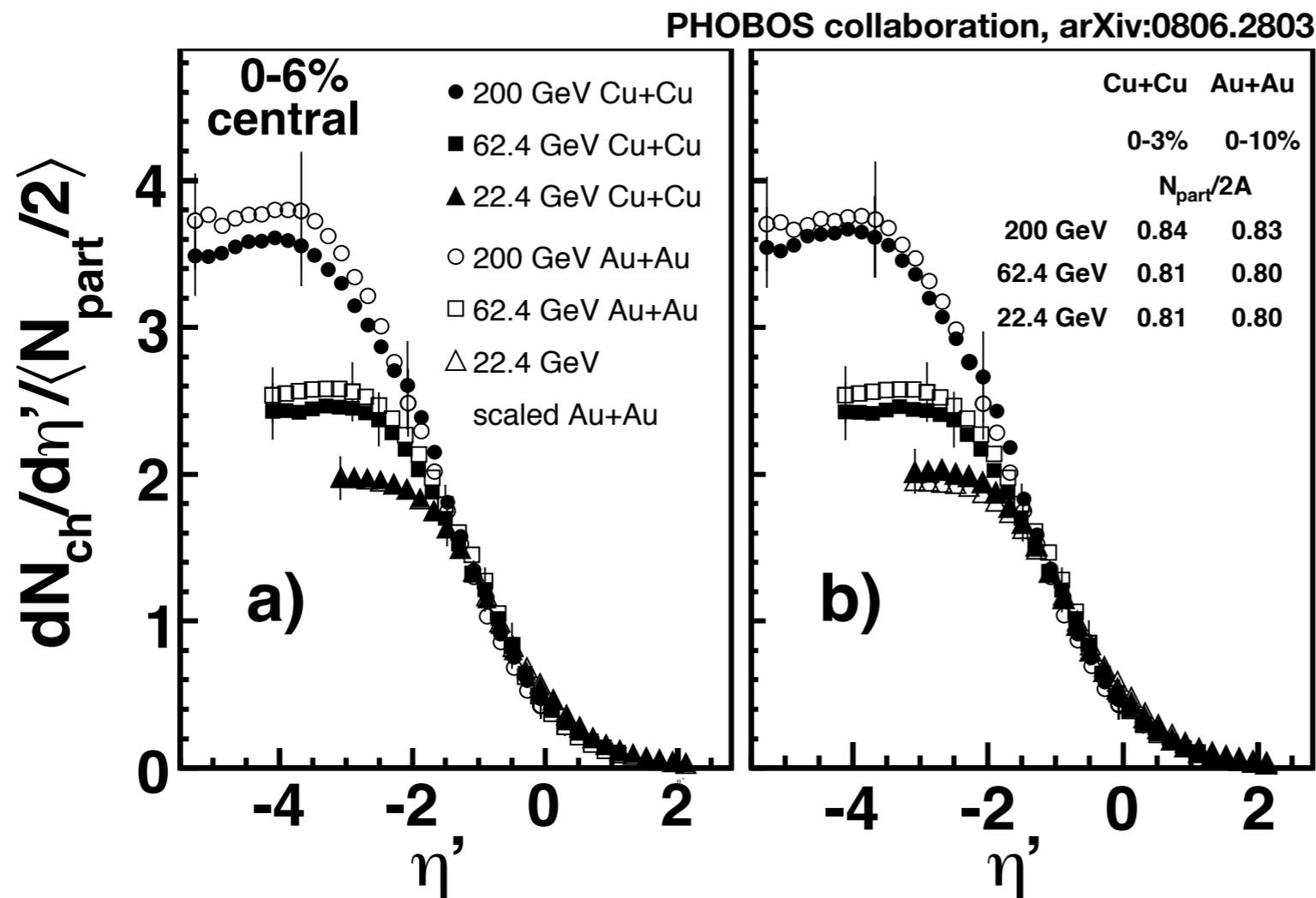
Difference becomes more acute as the energy decreases





“Fractional” Scaling in $dN/d\eta'$

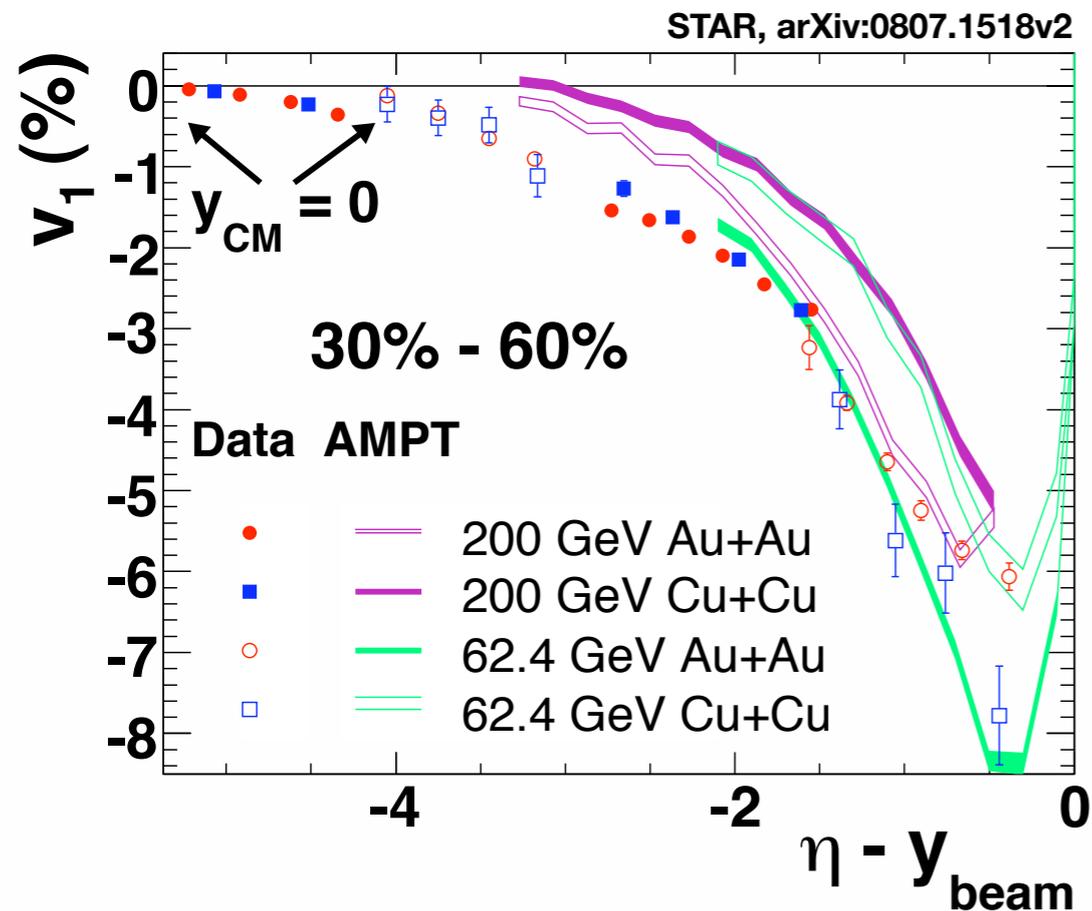
- No change in shape moving from Au+Au \rightarrow Cu+Cu



Change the nuclear size by x3: Au+Au \rightarrow Cu+Cu
No change in shape for same fraction of cross section ($b/2R$)



“Fractional” Scaling in Directed Flow

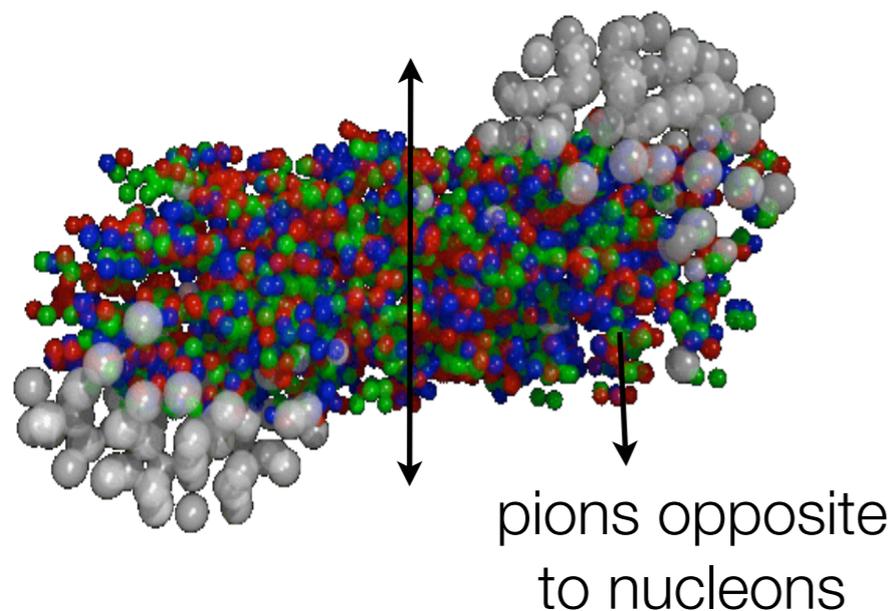


“Directed” flow (v_1) also scales with the fraction of cross section ($b/2R$) and not rapidity density, and shows longitudinal scaling

Change energy & size by x3 and all data collapses

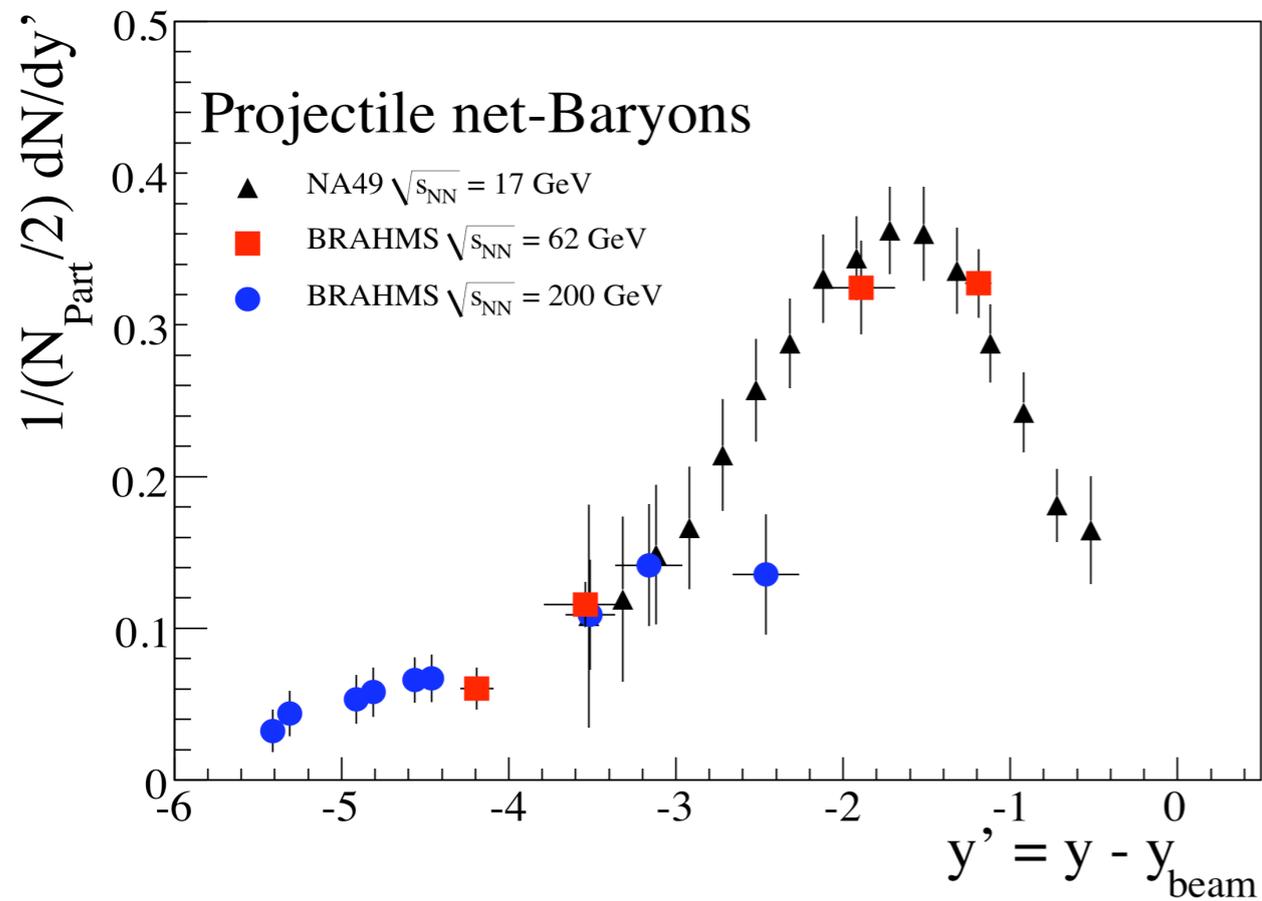
STAR’s explanation:

“At large η (in the fragmentation region), the directed flow is believed to be generated during the nuclear passage time ($2R/\gamma \sim 0.1 \text{ fm}/c$) [Sorge]”



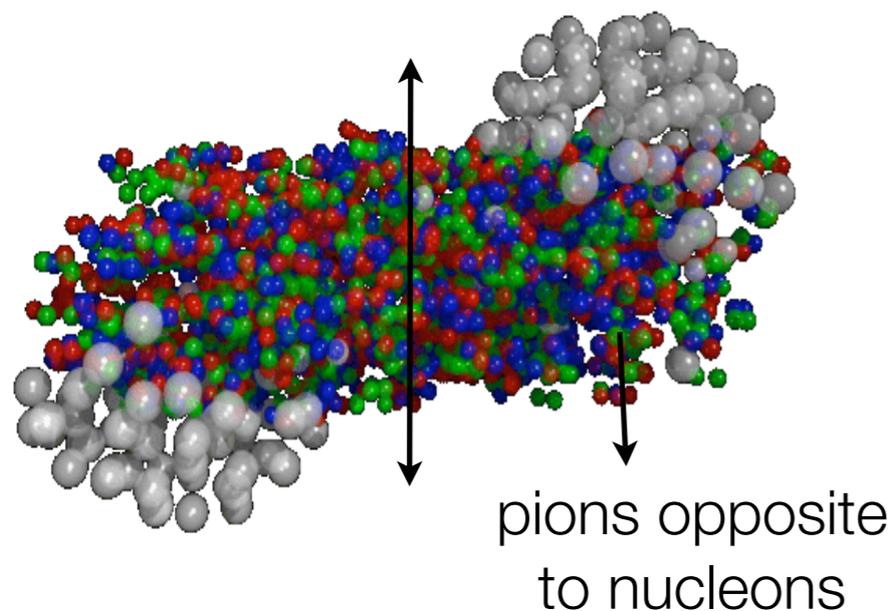


What about Nucleons?



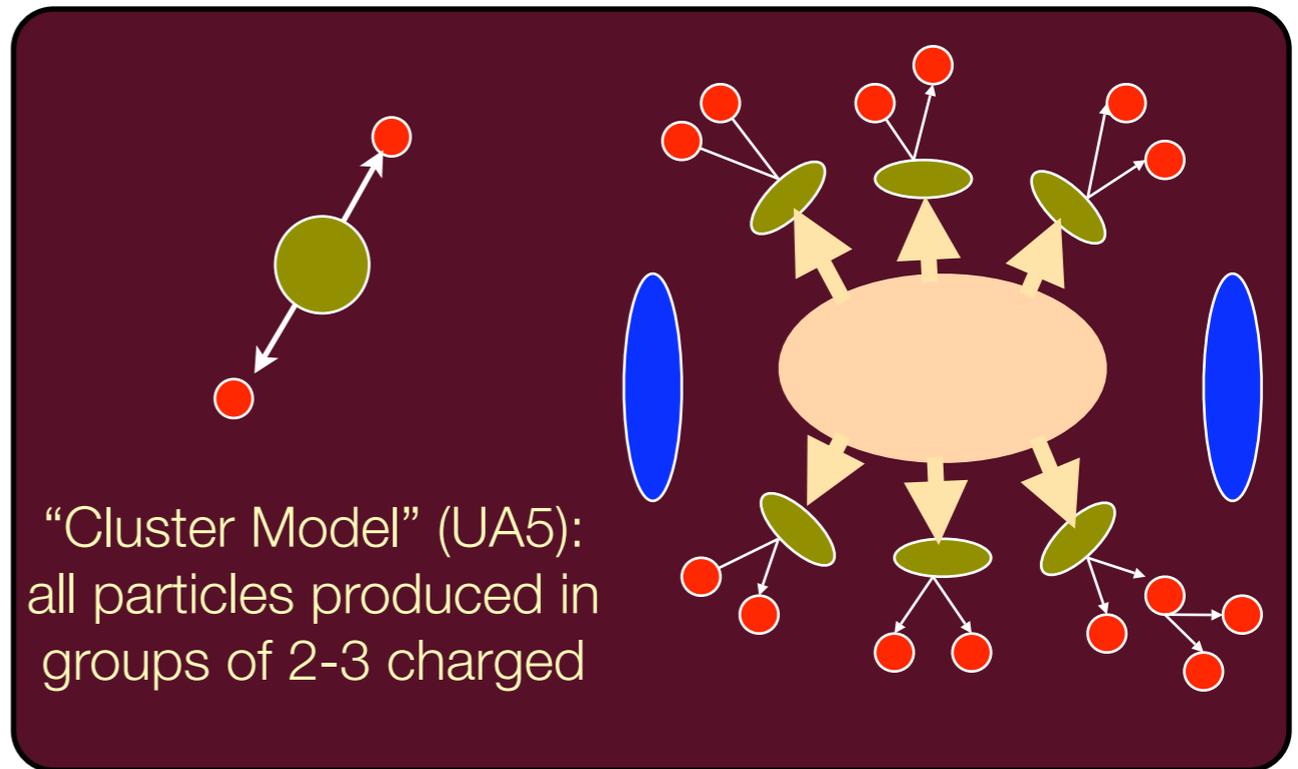
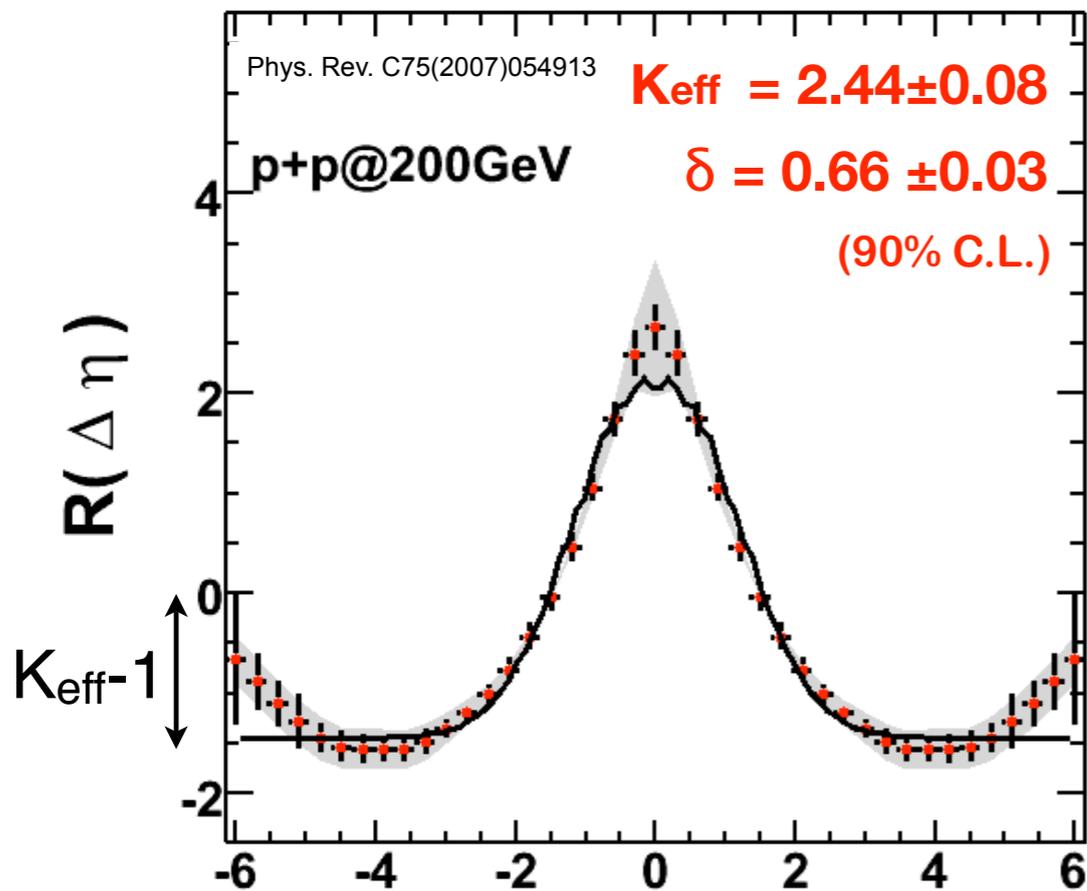
Interesting to compare the directed flow data with BRAHMS extraction of dN/dy of net baryons.

Also “fractional” in nature?





Two Particle Correlations in p+p (PHOBOS)



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

↑
“equal multiplicity”

K_{eff} = “cluster size”
 δ = “cluster width”

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

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

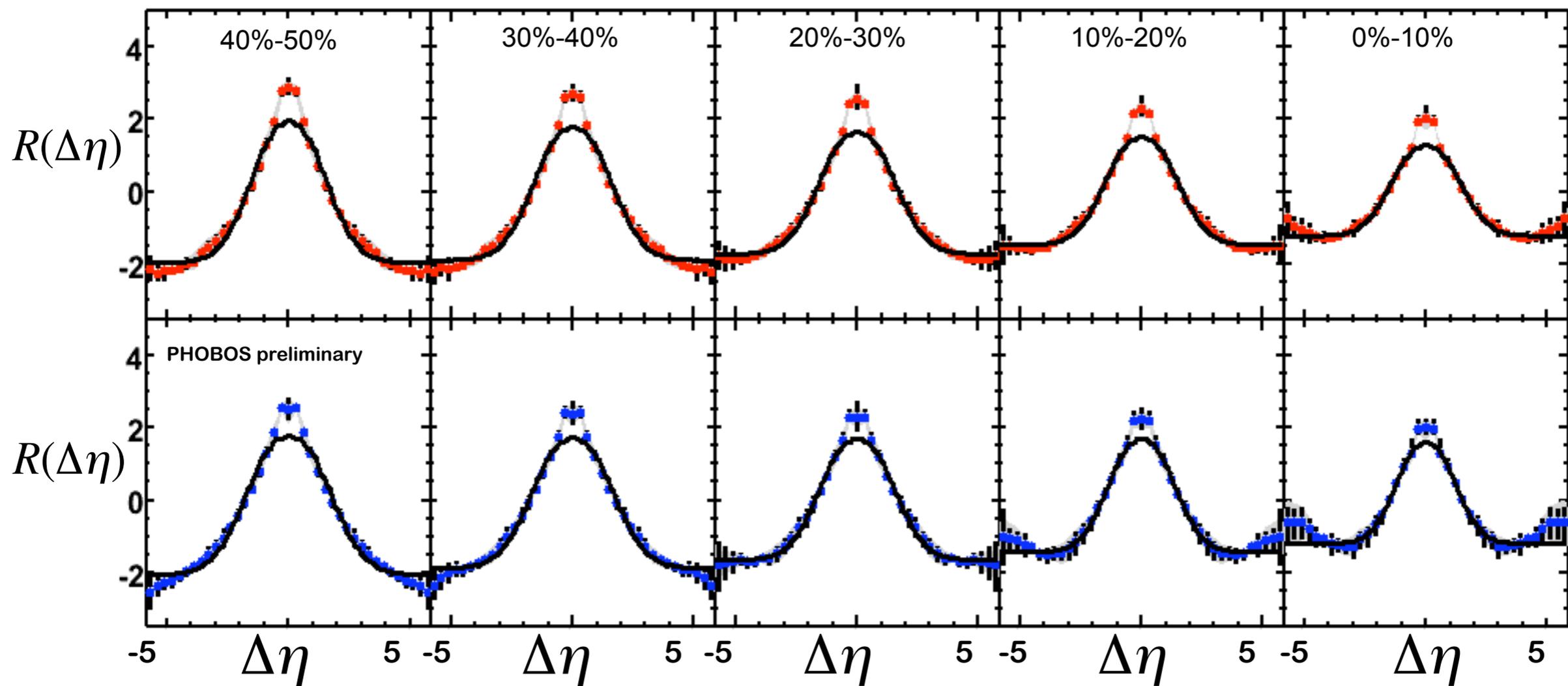
$$K_{eff} = \alpha + 1 = \frac{\langle k(k-1) \rangle}{\langle k \rangle} + 1 = \langle k \rangle + \frac{\sigma_k^2}{\langle k \rangle}$$



Two Particle Correlation Function in Au & Cu

Two-particle $\Delta\eta$ correlation function
(scale errors are shown as grey bands)

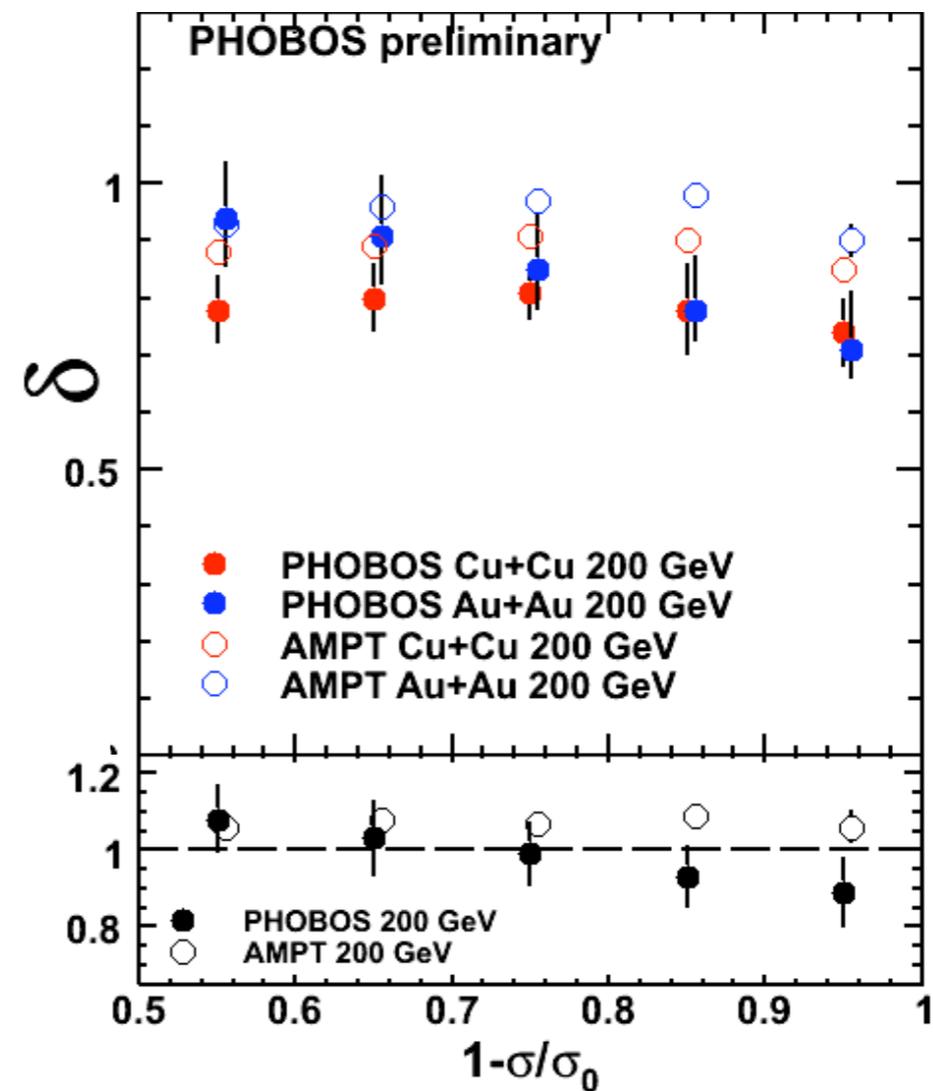
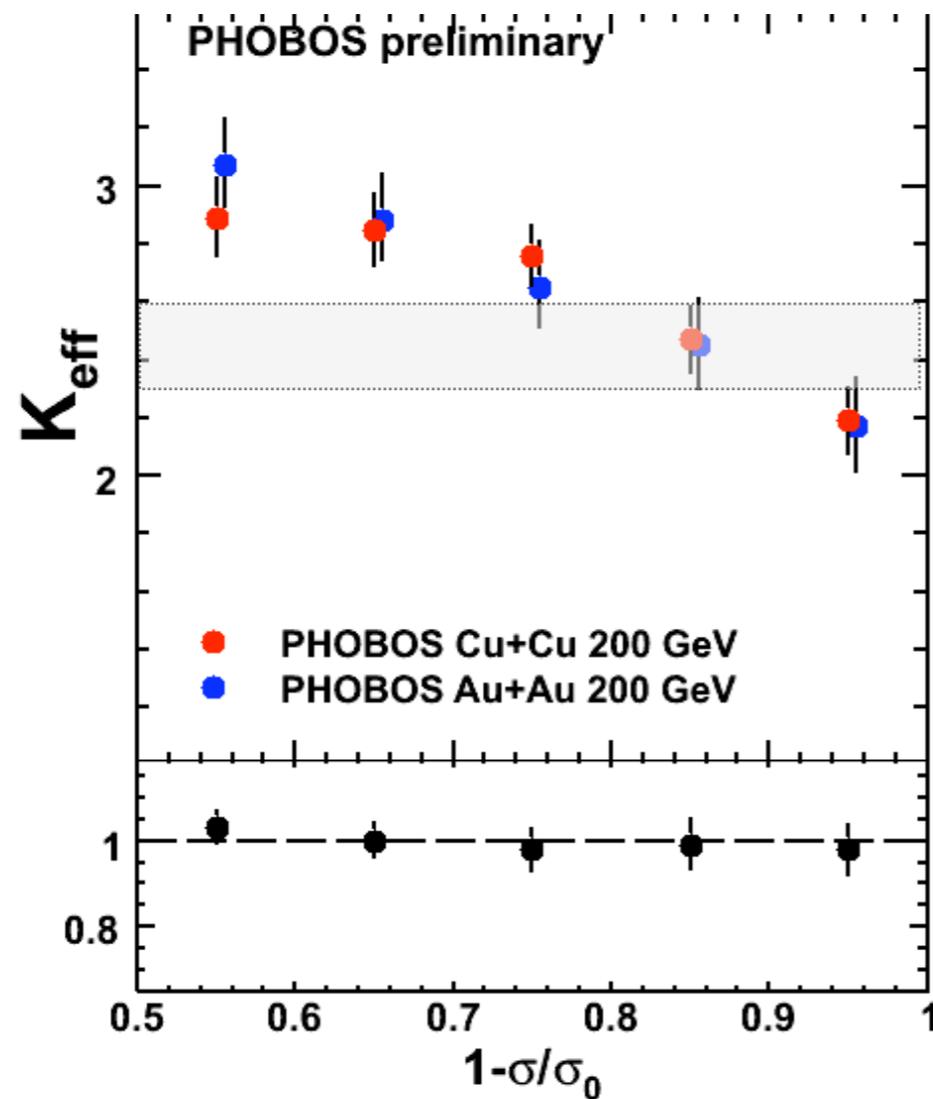
- **Cu+Cu@200GeV**
- **Au+Au@200GeV**



PHOBOS Preliminary



“Clusters” in Au+Au and Cu+Cu

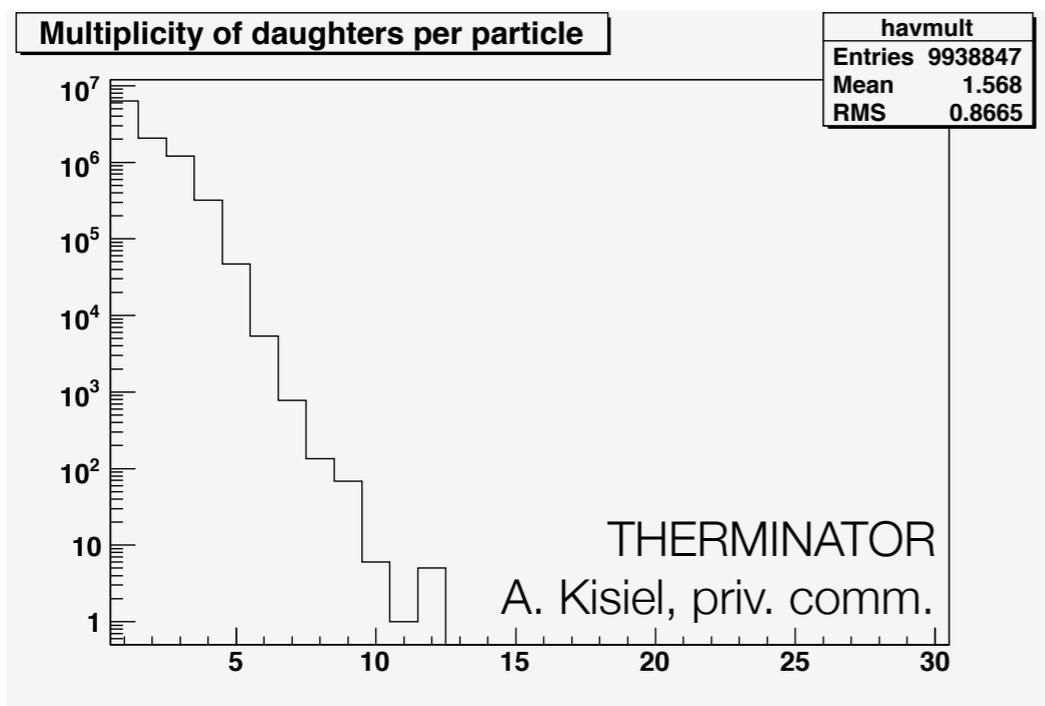


Again, fractional scaling -- for “cluster size” in Au+Au & Cu+Cu[!]

Peripheral has larger cluster size (3 vs. 2) and width (0.9 vs 0.75) than central collisions (or p+p)



Resonances set scale

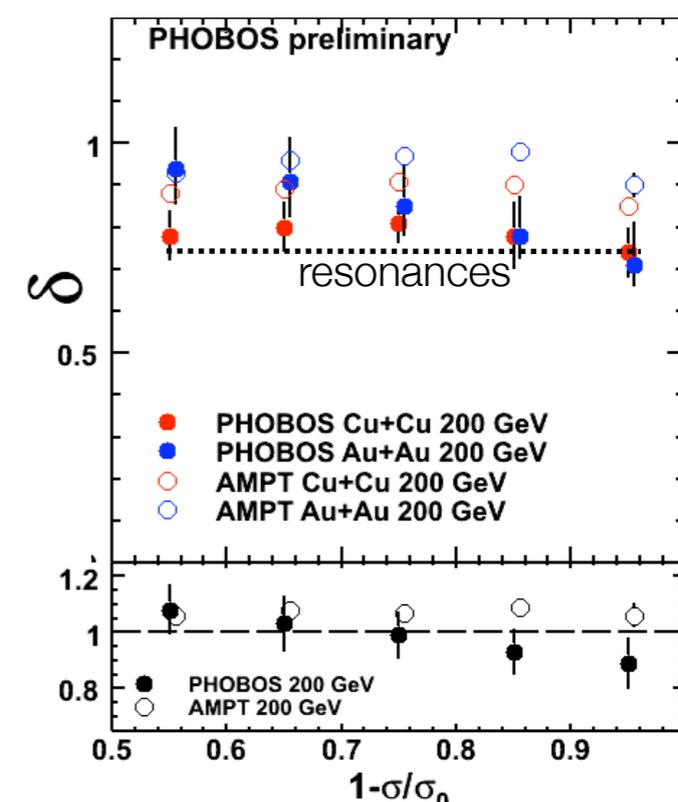
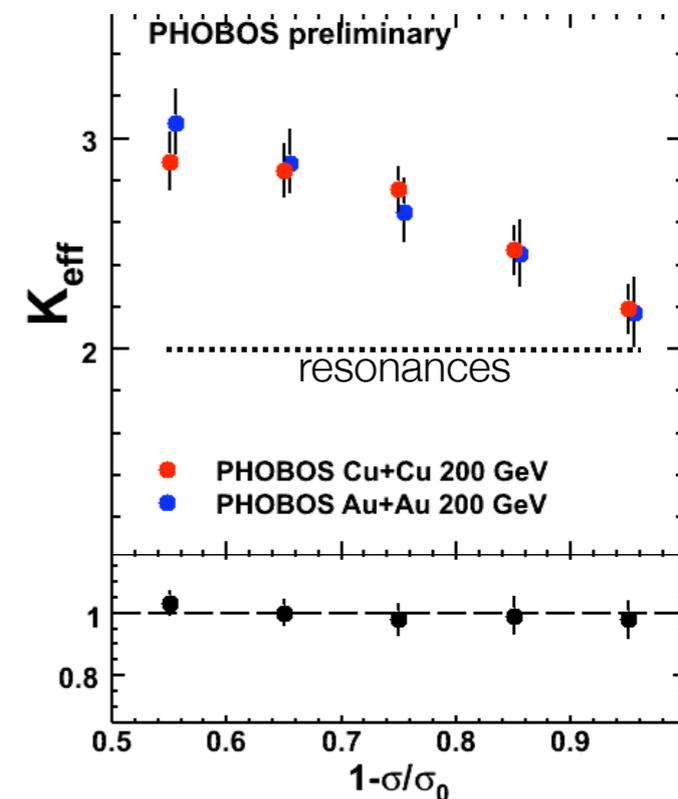


$$K_{eff} = \mu + \sigma^2 / \mu \sim 2$$

Resonances give
“predictable” answer of
 $K_{eff} \sim 2$, $\delta \sim 0.75$
(isotropic decay)

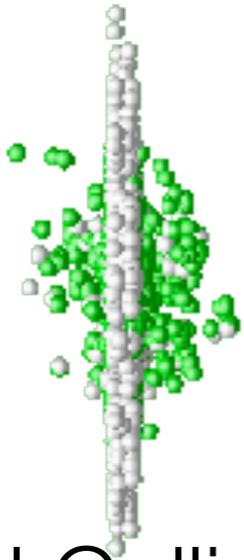
“huge” clusters
in peripheral events

“wide” clusters
in peripheral events
(at least for Au+Au...)

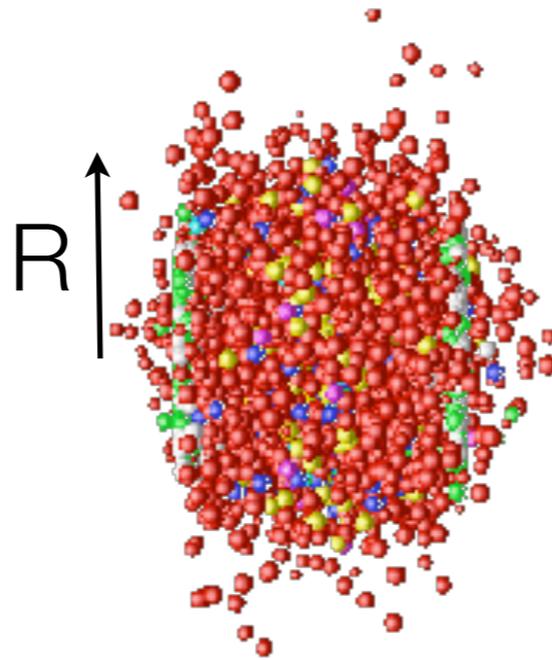




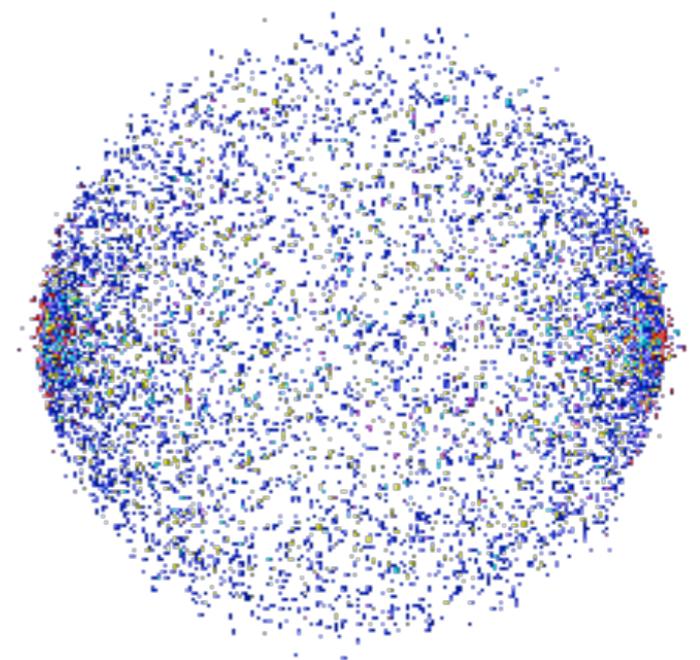
Putting it All Together



Initial Collisions
(Nuclear geometry,
Baryon stopping)



Dynamical evolution
 $\tau \sim O(R)$



Freezeout
(Hadronization)

$$dN/d\eta$$

$$v_1(\eta)$$

$$K_{\text{eff}} > 2$$

Fractional Scaling

$$dN/dp_T$$

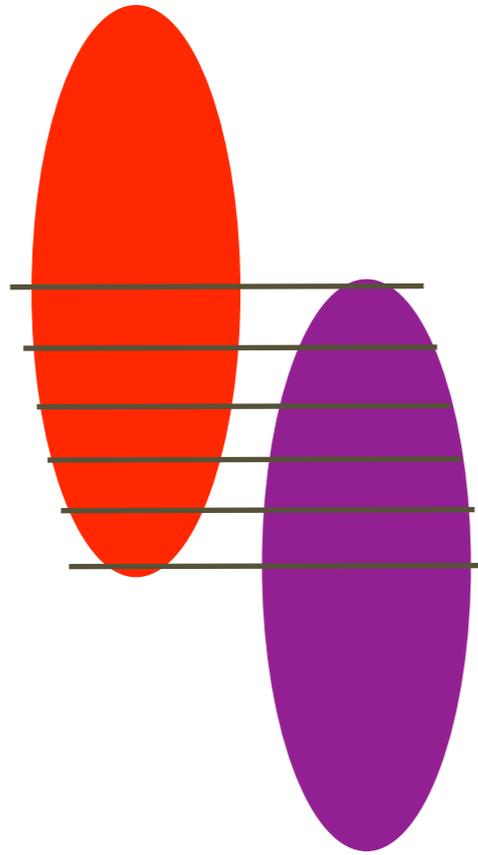
$$v_2(p_T, \eta)$$

Density Scaling

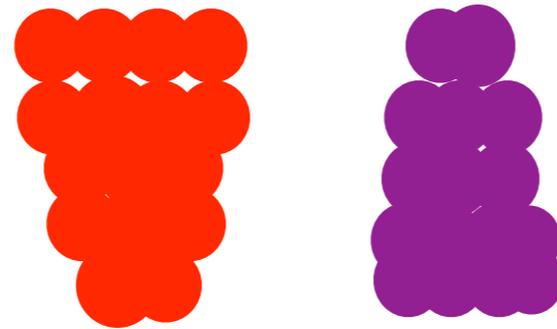
$$K_{\text{eff}} \sim 2$$



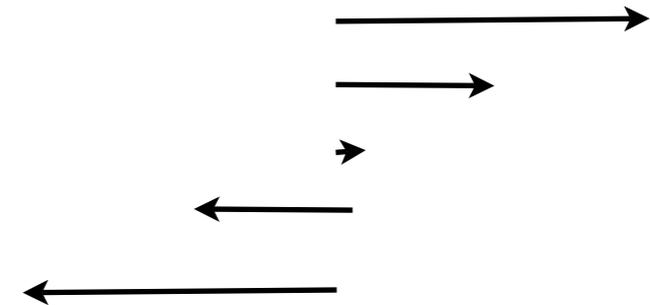
The “Shift” *ansatz*



Longitudinal slice



Decompose into
colliding tubes



$$\Delta y = \frac{1}{2} \ln \left[\frac{N_A}{N_B} \right]$$

not an original idea: discussed in terms of hydro (Voloshin, Lisa),
firestreak model, collective tube model, etc...



The “shift” *ansatz* on d+Au

A simple model of $dN/d\eta$
 PHOBOS minbias d+Au

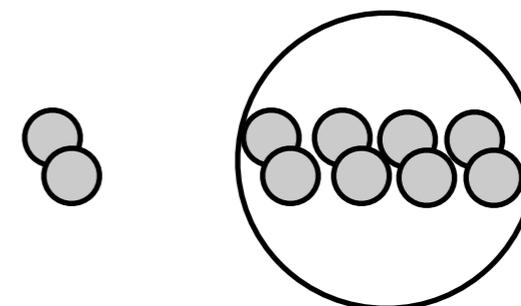
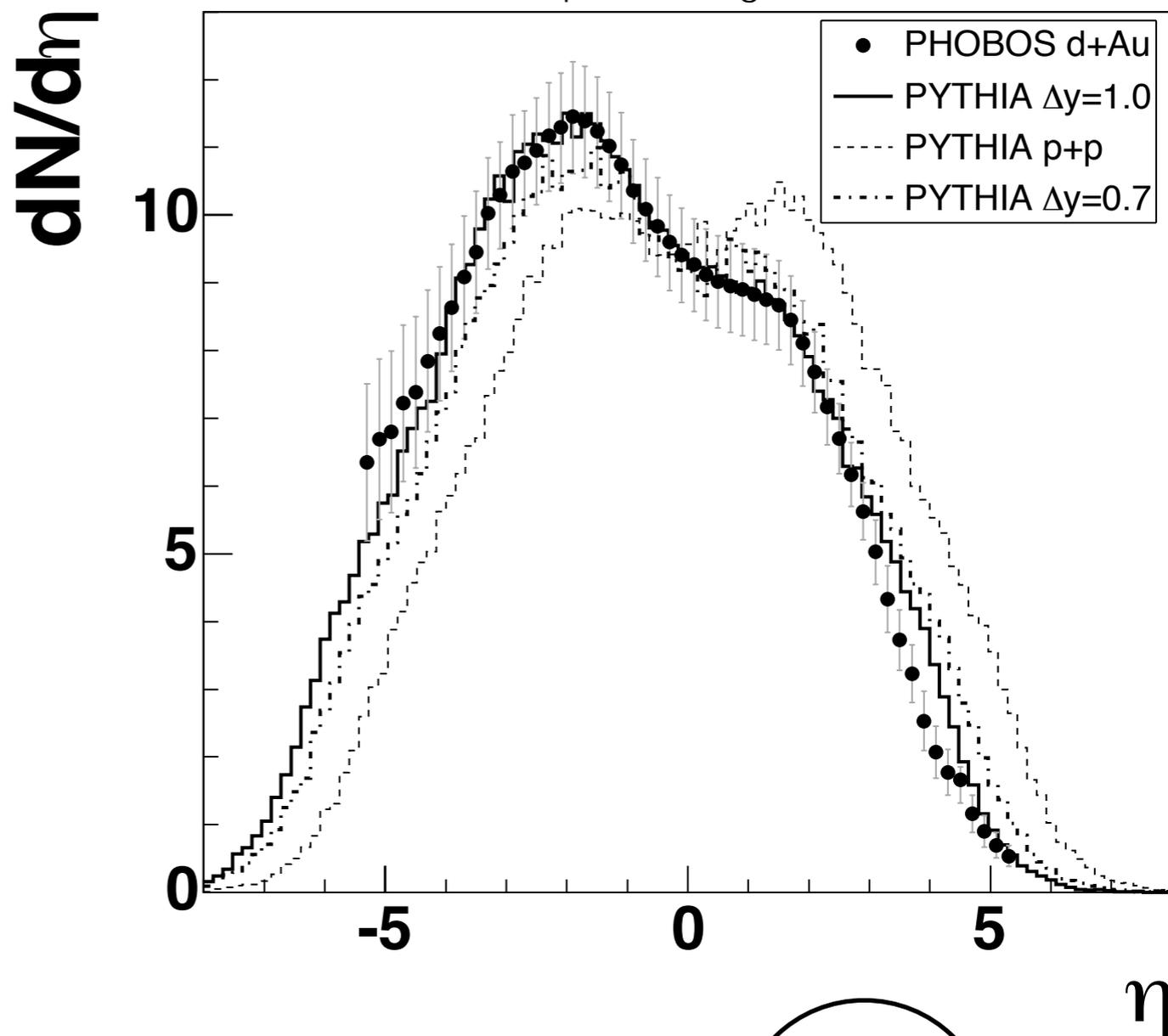
Take PYTHIA p+p 200 GeV
 Scale it up by $N_{\text{part}}/2$
 Shift rapidity by Δy
 Recalculate $dN/d\eta$ '

Reproduces shape in both
 forward and backward
 hemispheres.

Better description $\delta y \sim 0.3 \dots$

$$\Delta y = \frac{1}{2} \ln \left[\frac{N_{Au}}{N_d} \right] + \delta y$$

<http://arxiv.org/abs/nucl-ex/0703002v1>





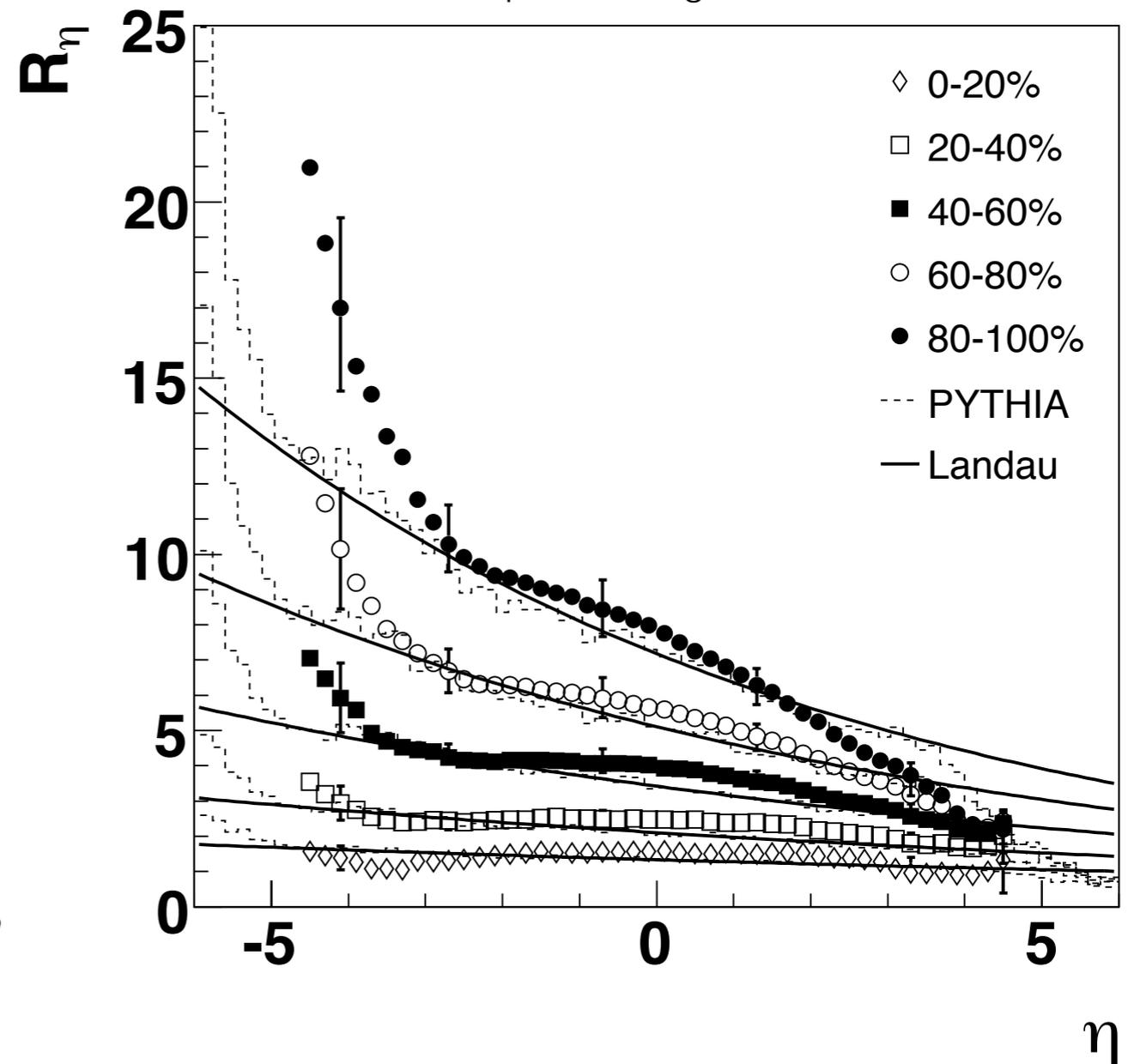
Shift ansatz vs. Centrality

PYTHIA: same as before

Landau: use Gaussian
dN/dy from Landau hydro
(and treat $y=\eta$)

$$R_{dA} = \frac{N_{part}}{2} \frac{e^{-(\eta+\Delta y)^2/2L}}{e^{-\eta^2/2L}}$$
$$= \frac{N_{part} e^{-(\Delta y^2)/2L}}{2} e^{-\frac{\Delta y}{L} \eta}$$

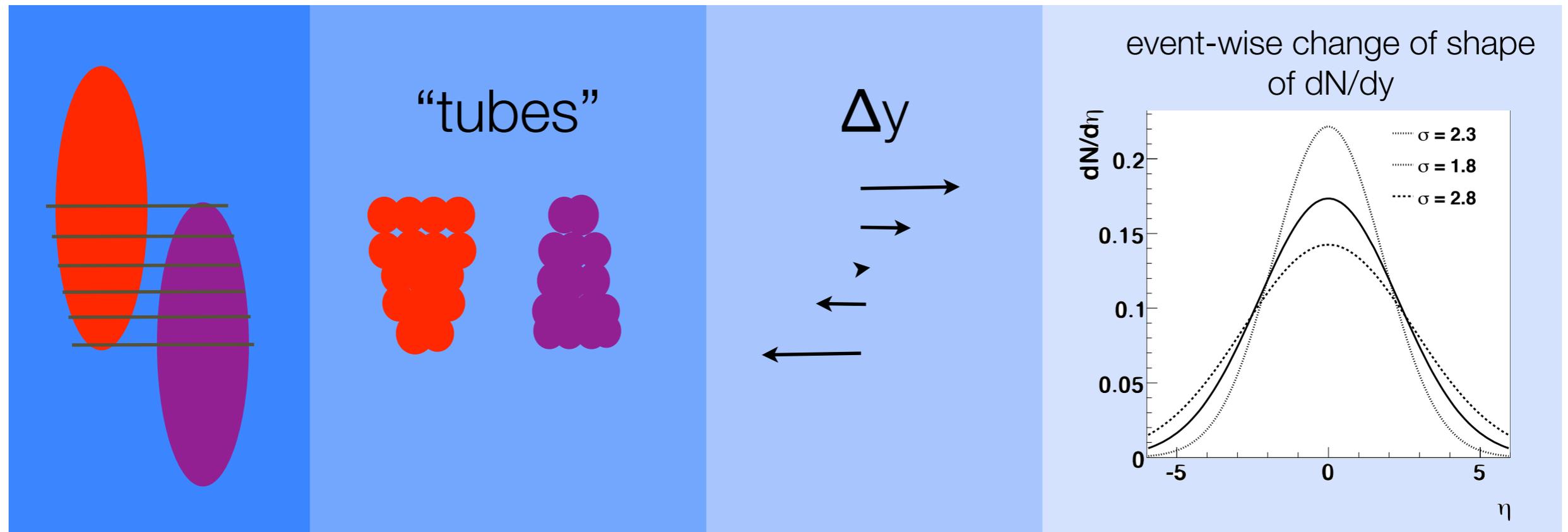
<http://arxiv.org/abs/nucl-ex/0703002v1>



Reasonable description, nearly parameter free ($\delta y=0.3$)

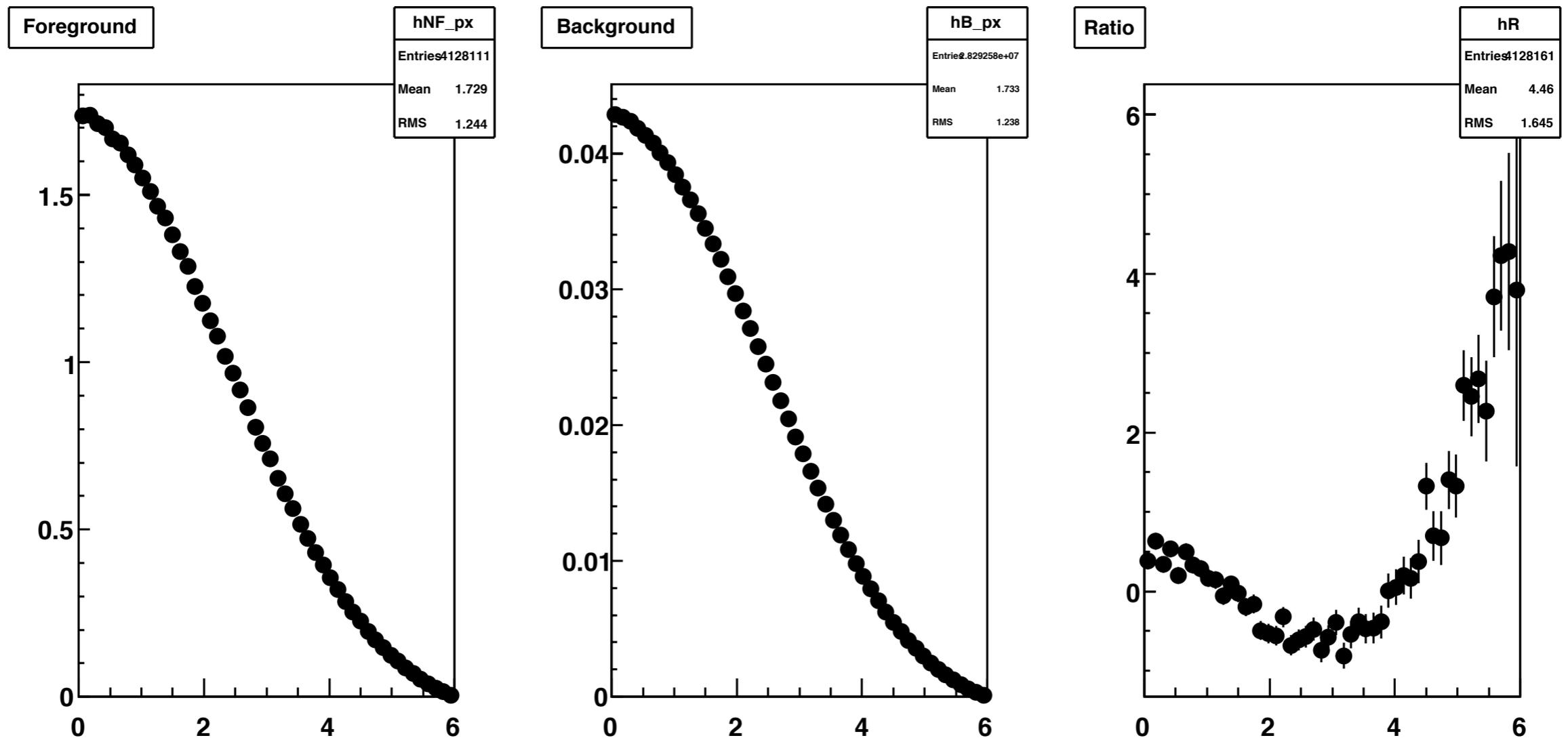


A Sketch of a Solution



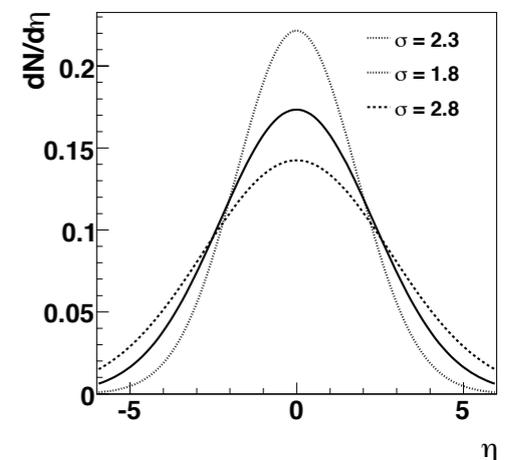
Bottom line: just as transverse geometry freezes in early, longitudinal geometry probably freezes in even earlier ($\Delta t \sim R/\gamma$)
asymmetric peripheral events make wider $dN/d\eta$, v_1 , long-range two particle “clusters”
symmetric central events are narrower, have no v_1 , and emit resonance-like clusters

Adding fluctuations to toy $dN/d\eta$ w/ no clusters



$n=50, k=1, \delta=1, \sigma_s=0.5, |\eta|<3$

Additional “cluster” near $\Delta\eta=0$ and “wings”





Discuss!



Thanks to organizers for a fantastic time at PANIC08, Weizmann, and in Israel!

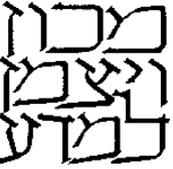


Petra 1950's
photo by my grandfather



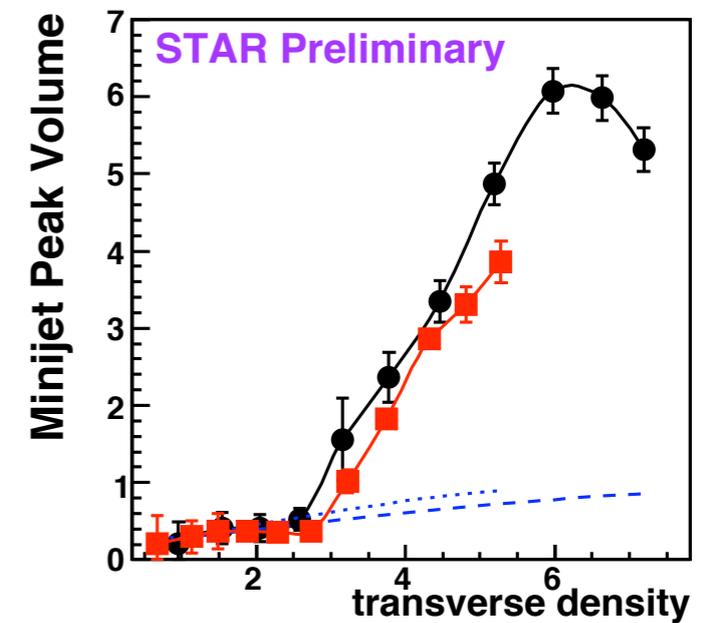
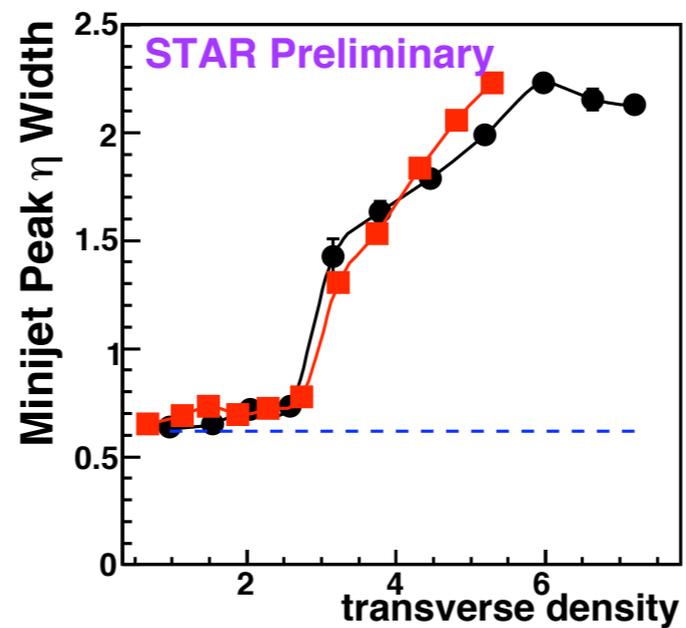
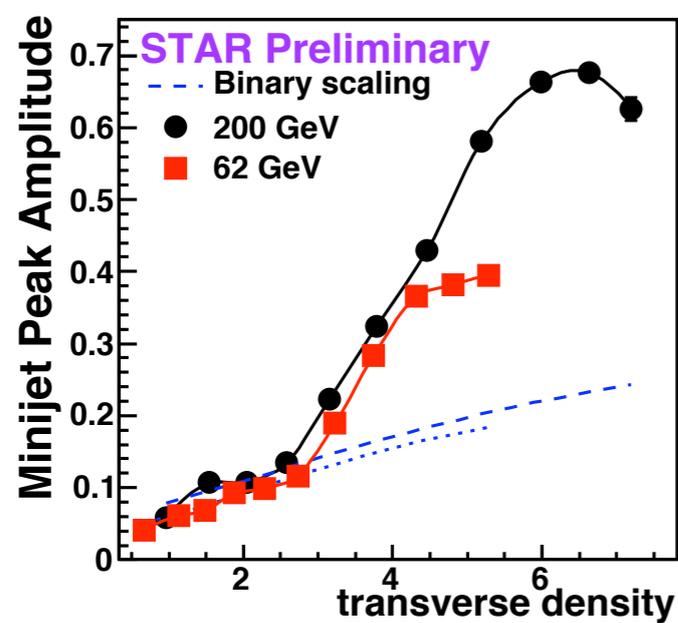
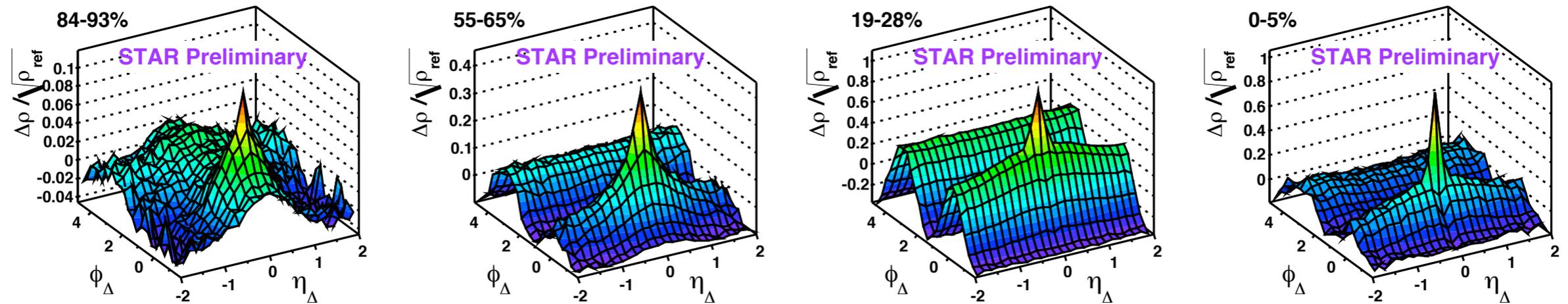
Petra 2008
photo by me







Minijets from Two Particle Correlations?





Total Multiplicity Systematics

