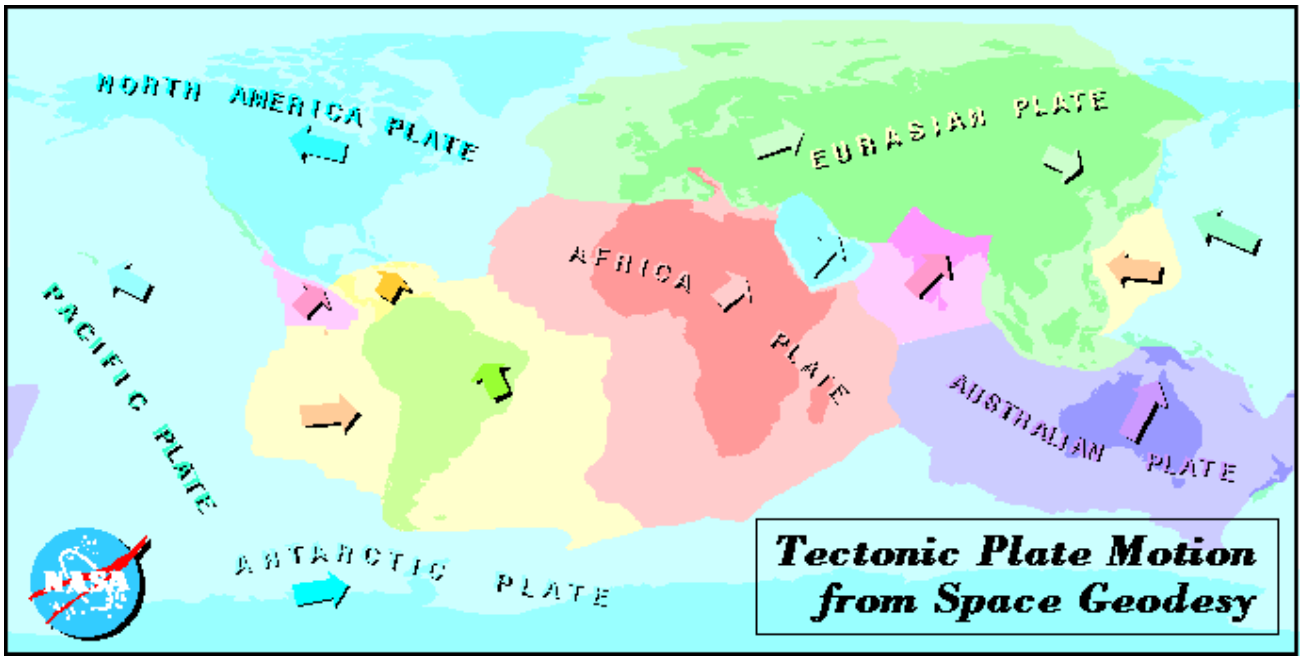
Rapporteur II: Global & Flow Observables

Peter Steinberg

Brookhaven National Laboratory

Global Flow



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BNL

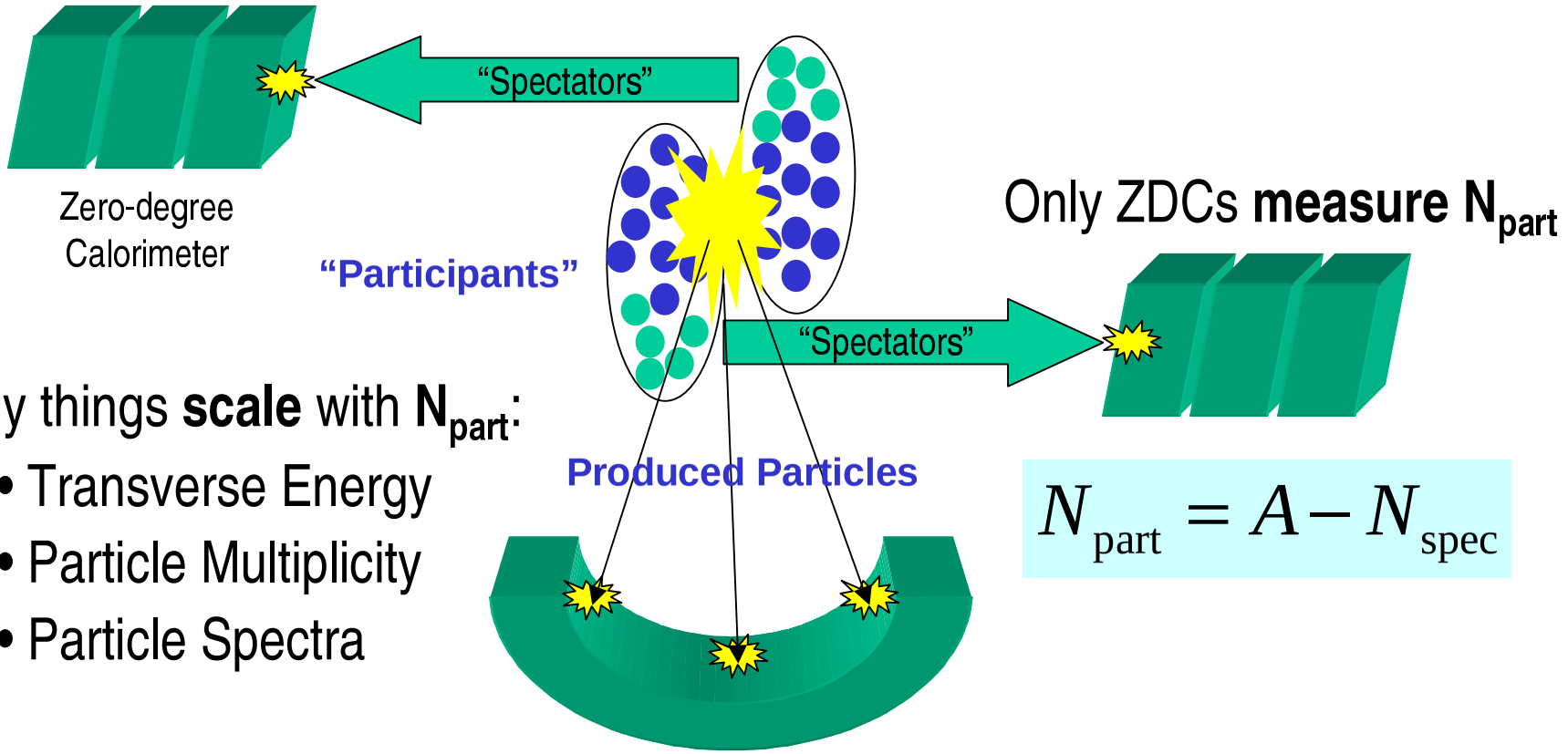
Outline

- **Global Variables**
  - Event shape
    - $dN/d\eta$
  - Centrality dependence
    - $dN/d\eta$
    - $dE_T/d\eta$
  - $\langle p_T \rangle$
  - Initial Energy density
- **"Flow"**
  - Event shape
    - $dN/d\phi$
  - Centrality dependence
    - $dN/d\phi$
    - Species
  - $v_1, v_2,$
  - Initial Pressure

- In principle, we are looking at two important pieces of the equation of state…

Centrality: Participants vs. Spectators

The collision geometry (i.e. the impact parameter) determines the number of nucleons that **participate** in the collision



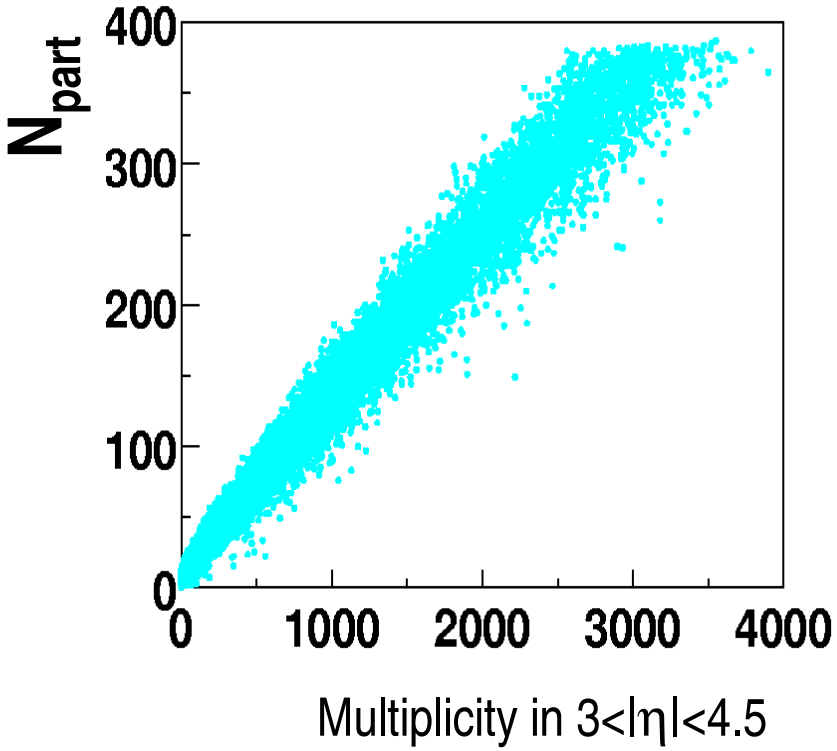
Only ZDCs **measure N_{part}**

Many things **scale** with **N_{part}**:

- Transverse Energy
- Particle Multiplicity
- Particle Spectra

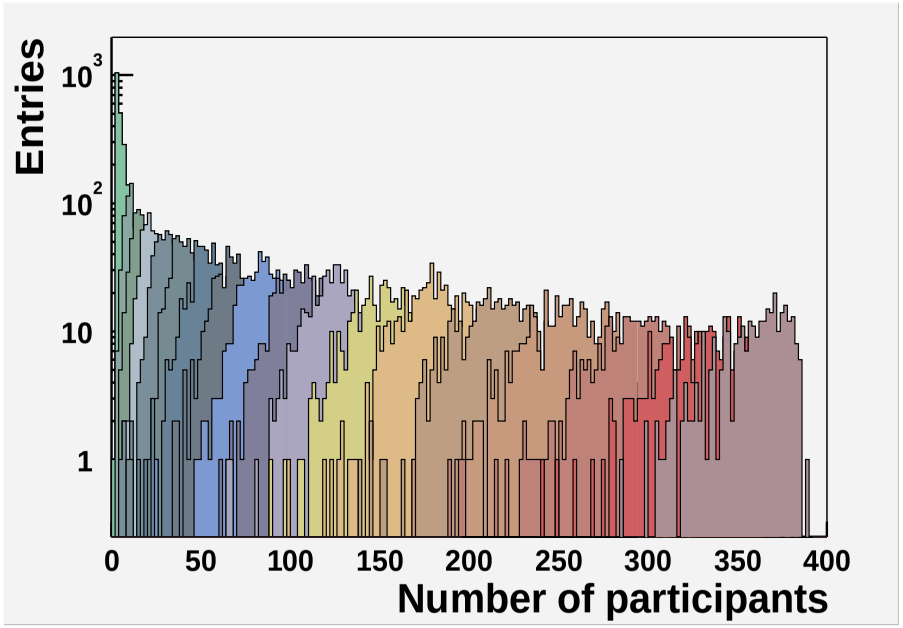
$$N_{\text{part}} = A - N_{\text{spec}}$$

Measuring Centrality



- Clearly, fluctuations affect your centrality estimator

- In principle, we could work with % of cross section



- Final measurement of Npart is best attempt to correct for facts of life

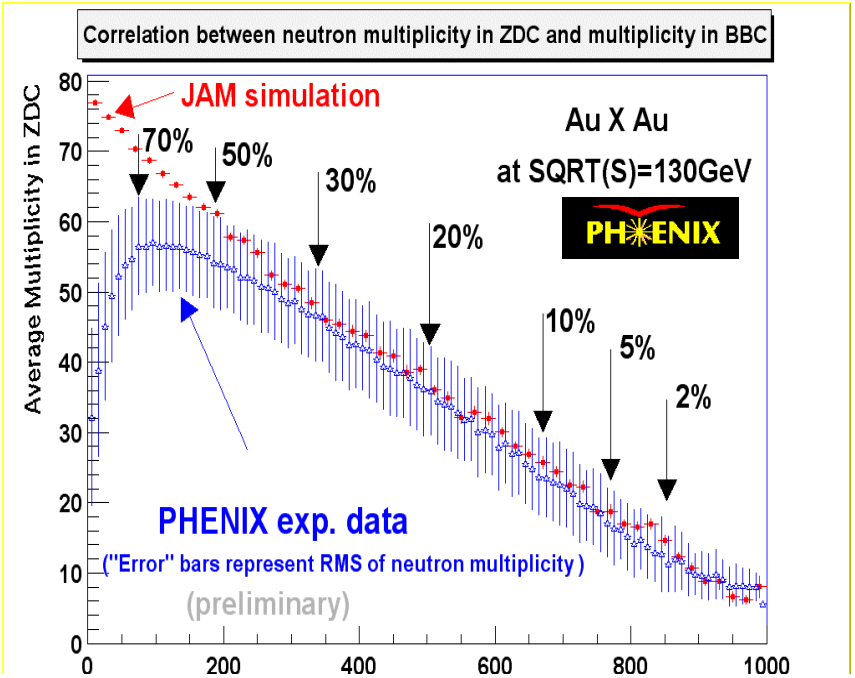
Why we should use N_{part}

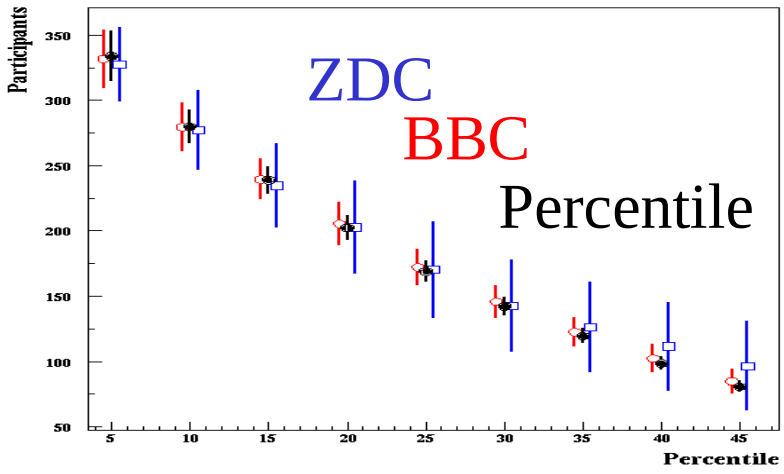
- Very difficult to compare experimental results without serious estimate of N_{part}
- Must incorporate fluctuations in the measurement of the centrality estimators
- OK, Glauber implementation is a real uncertainty

- Even if you don't "like" participants, the exercise is critical for inter-experiment comparisons

ZDC as centrality device

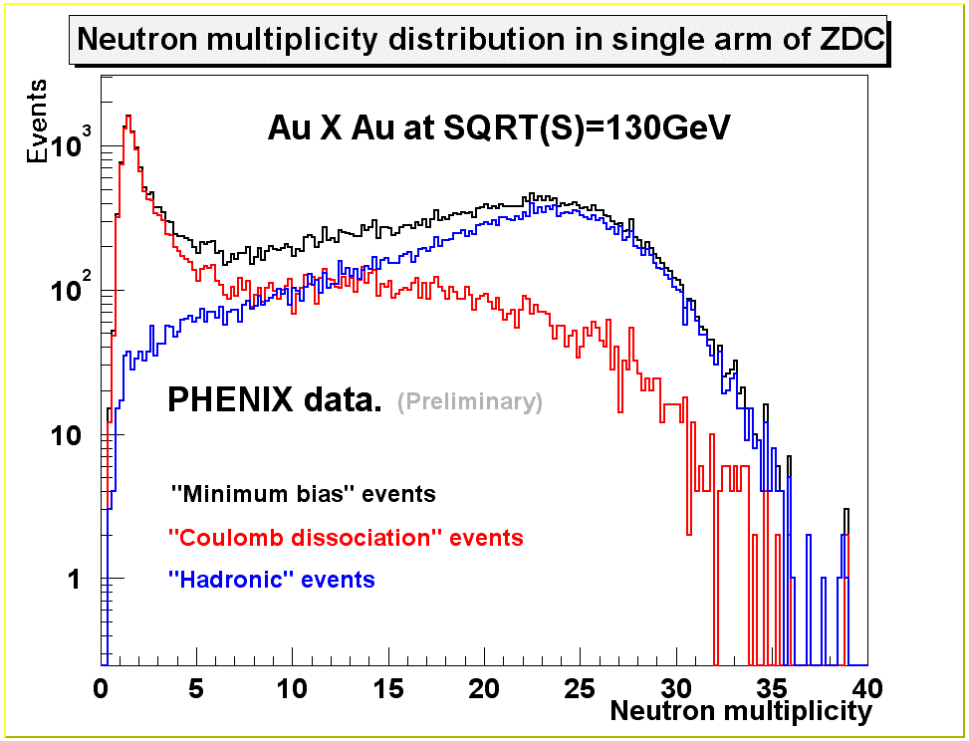
- Only shared detector
  - Rates: luminosity via well-known reference process
  - Timing: substantial background rejection
  - Pulse height: measures centrality
- Directly confirms monotonic relationship between participants with multiplicity

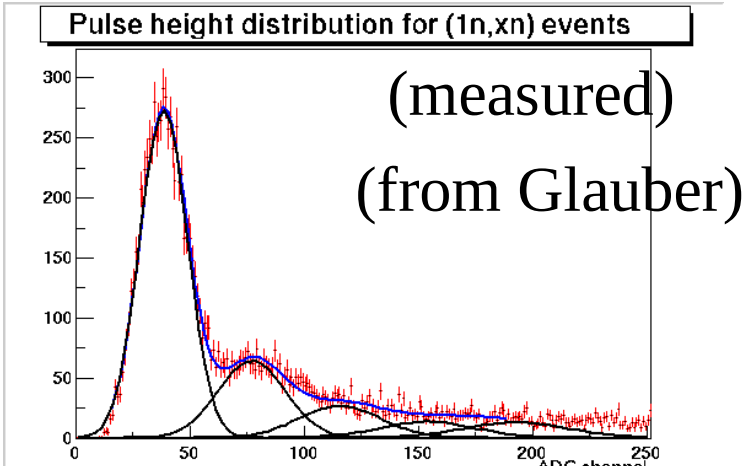


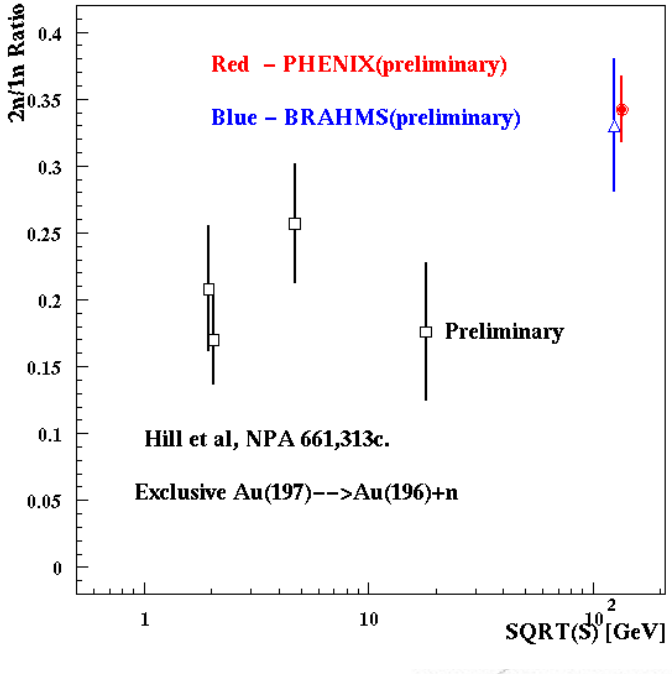


Mutual Coulomb Dissociation

- Reference: σ_{zdc} =10.7+/-0.5 b
- **Measurement: $(\sigma_{geo} / \sigma_{tot})_{exp}$ = $(N_{bbc}/ N_{tot})_{exp}/ \varepsilon_{bbc}$= (0.668 $\pm$ 0.022)**
  Theory: $\sigma_{geo} / \sigma_{tot}$ = (0.673 $\pm$ <0.034)



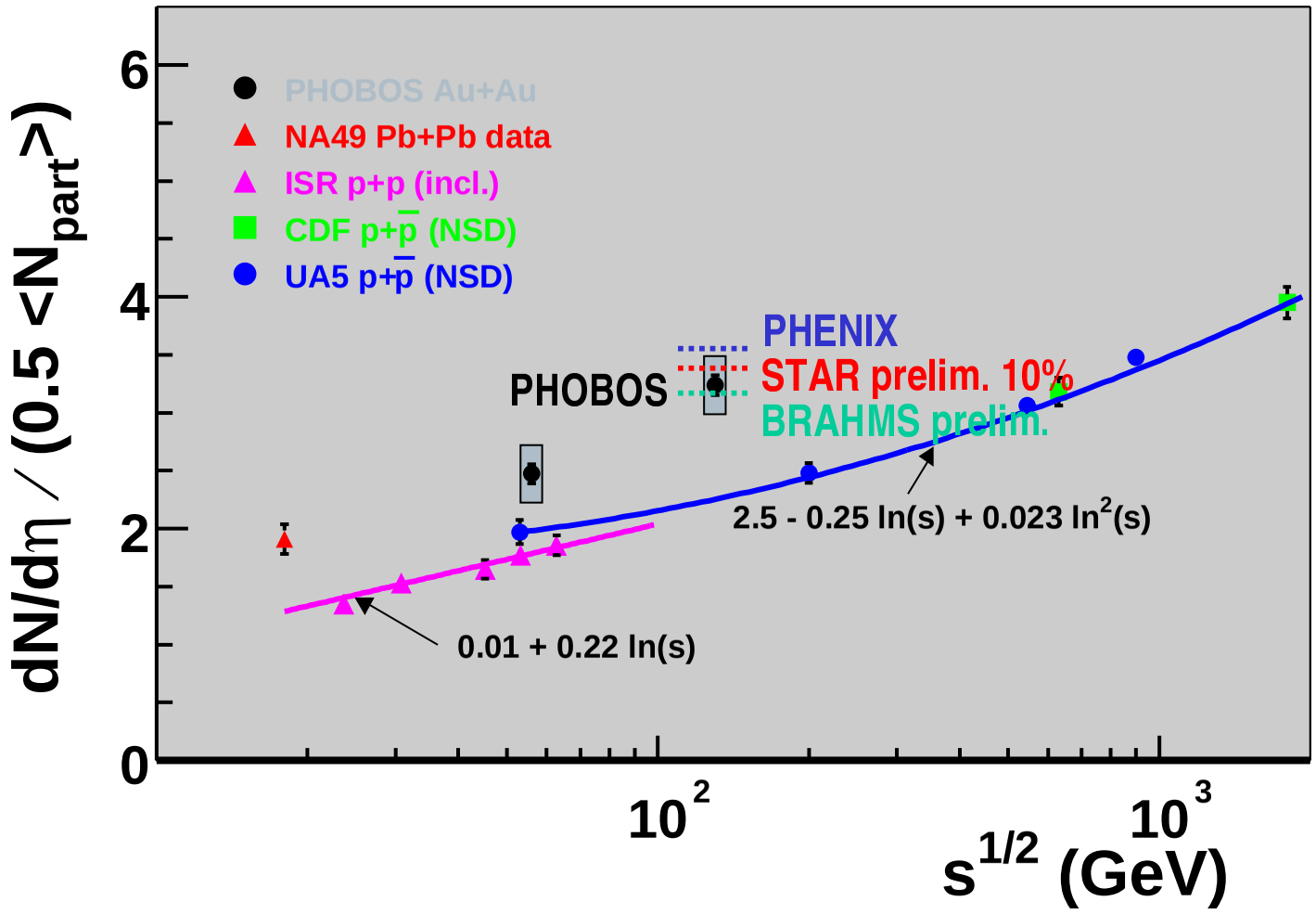




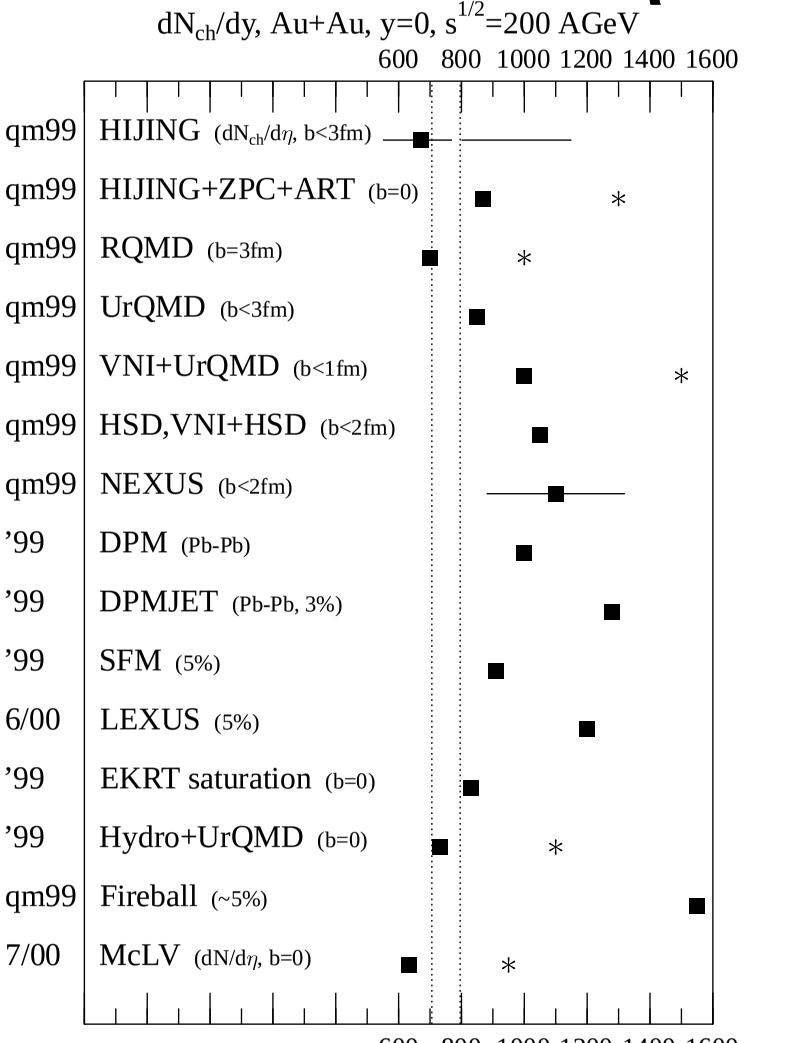
Multiplicity: what is learned

- Can the models get the “big picture” right?
  - However, let’s not ignore the details…
- Magnitude
  - Integral over energy density, stopping, shadowing, quenching, flow
- Centrality dependence
  - Study effect of system size (onset of interesting effects above critical volume)
  - Interplay between N_{part} and N_{coll}
- Shape
  - Stopping, Final state interactions

Energy dependence



dN/dη: Predictions

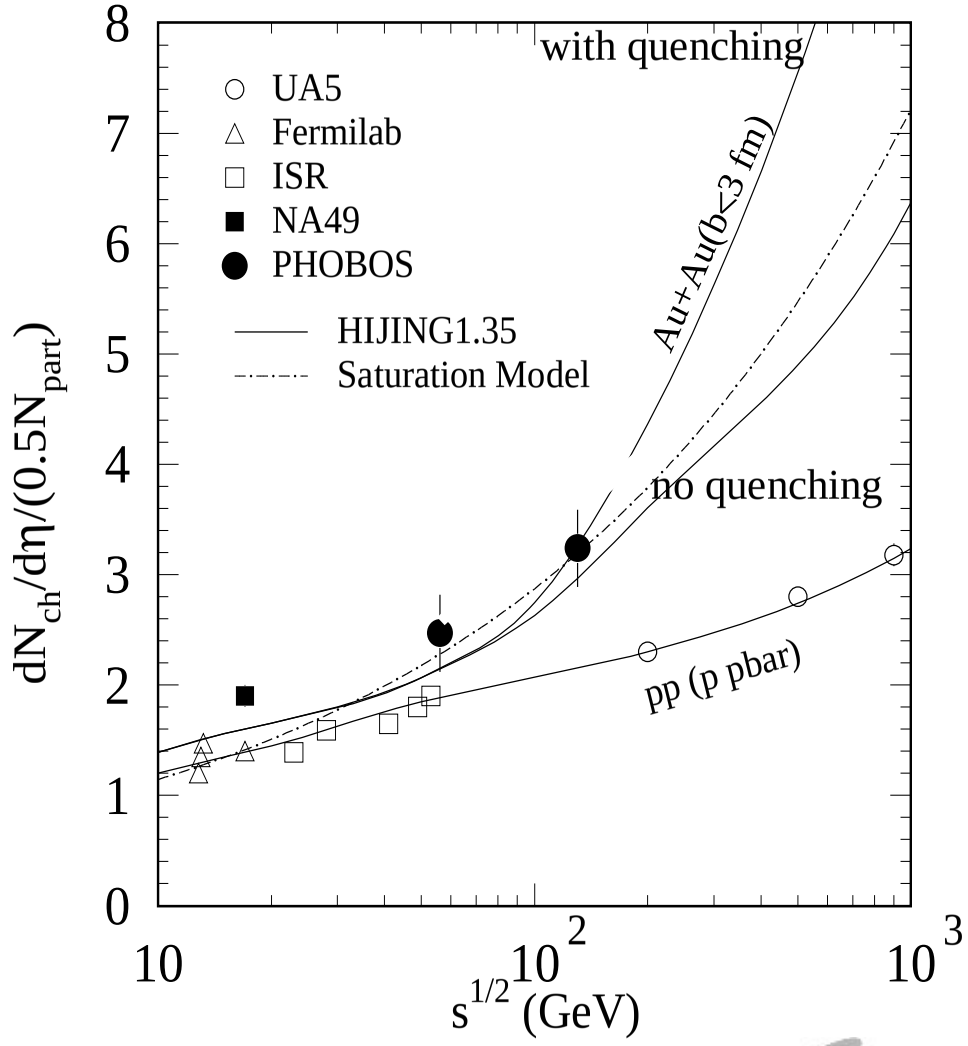


$\sim \frac{2}{3}: \quad N(*) \rightarrow N_{ch}$ ····· data $* (200/130)^{0.37} * 1.1$

$\sim 1.1: \quad \eta \rightarrow y$

$\sim 0.9: \quad b = 0 \rightarrow b \lesssim 3\,\mathrm{fm}(5\%)$

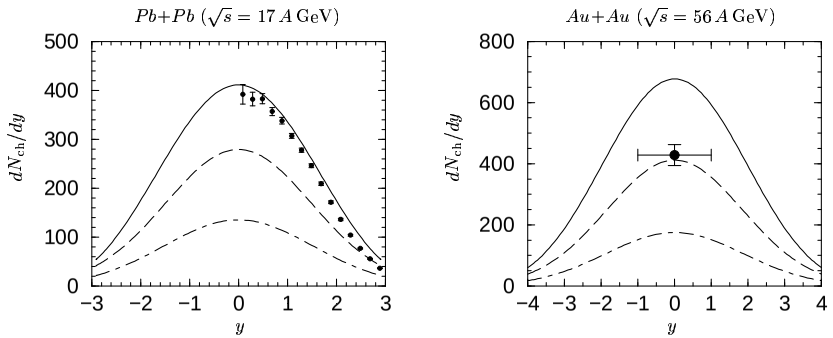
see [Armesto,Pajares, hep-ph/0002163]

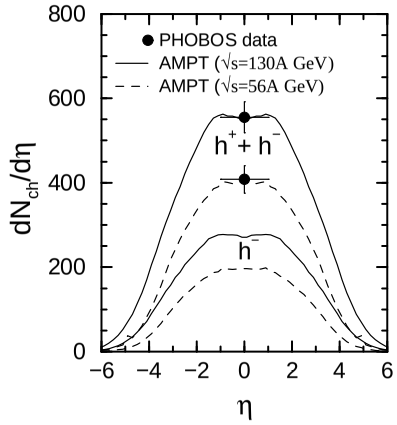


dN/dη: Post-dictions

- AMPT, LEXUS, DSM, HIJING, EKRT
- Please be careful about scaling y to η
  - Not boost invariant!
  - Not .9, .95 etc.
  - Jacobian depends on velocity: dy = β dη
  - Depends on species and mean $p_{T!}$
- Still not sure who gets the champagne…wait for 200 GeV

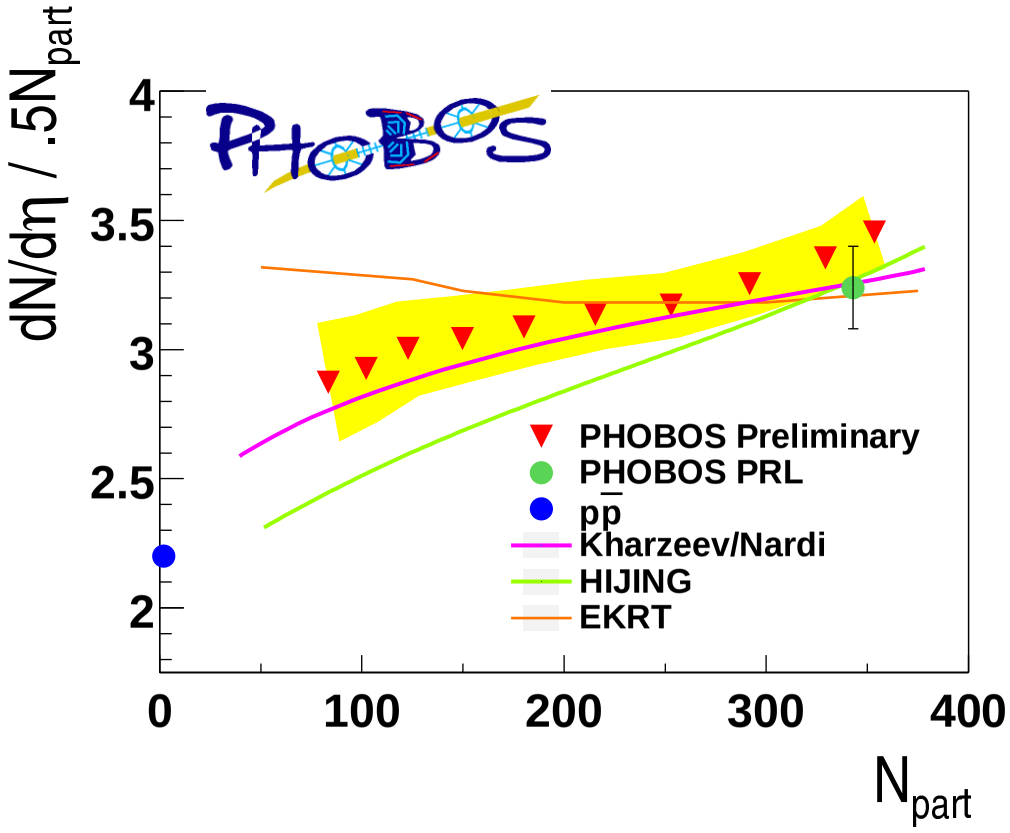
LEXUS

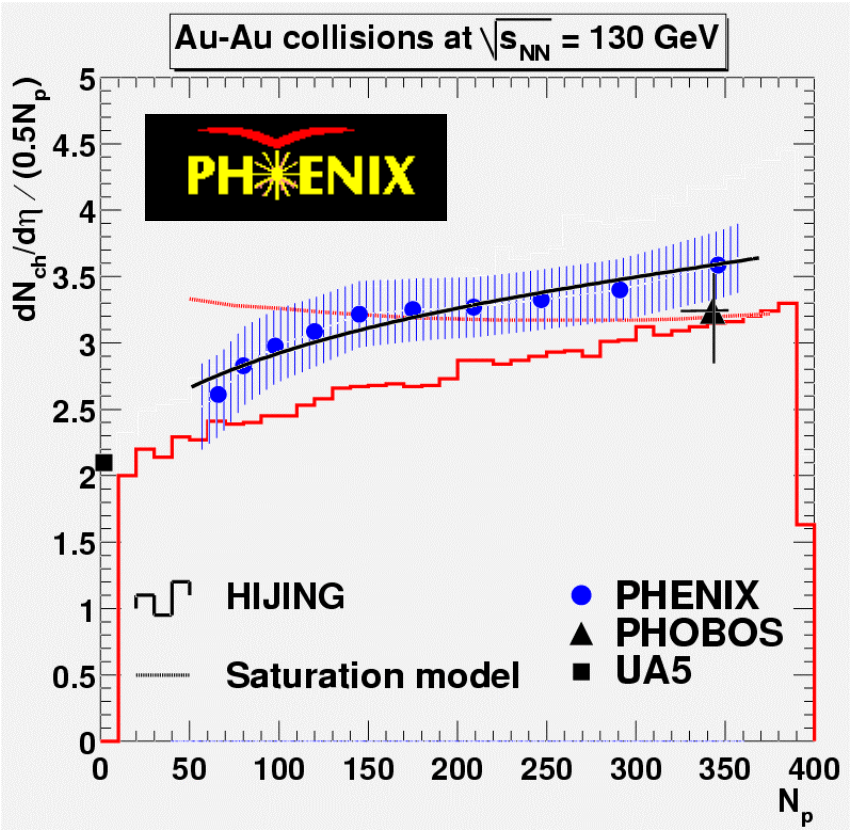




AMPT

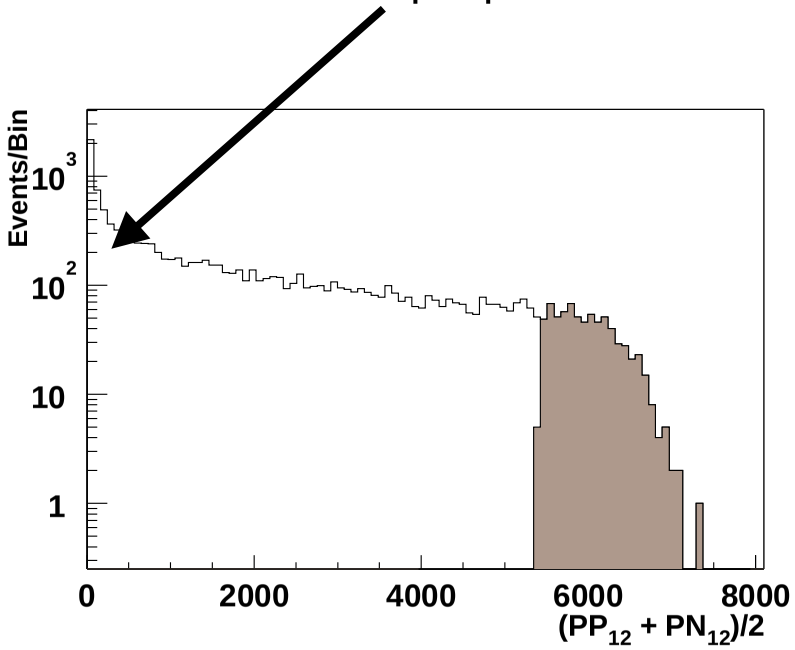
dN/dη vs Centrality at η=0

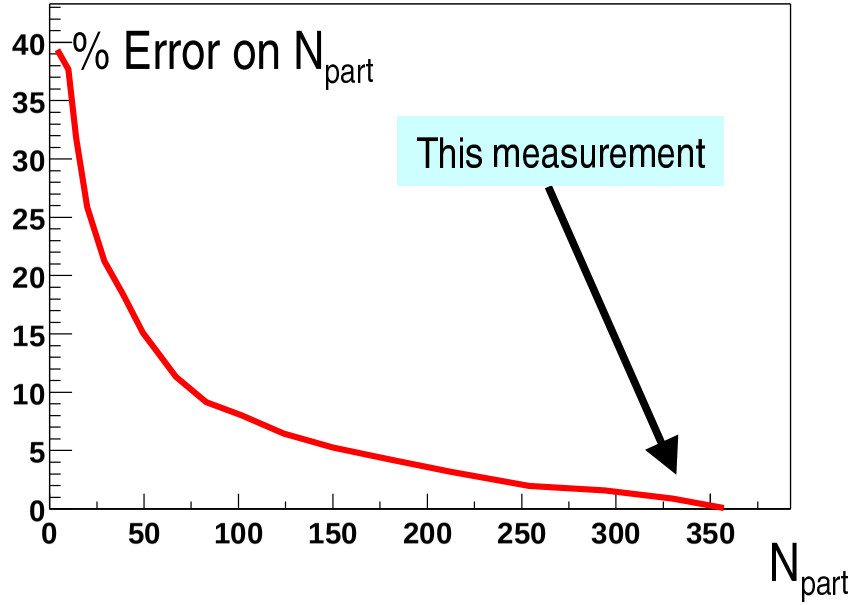




Uncertainty on N_{part}

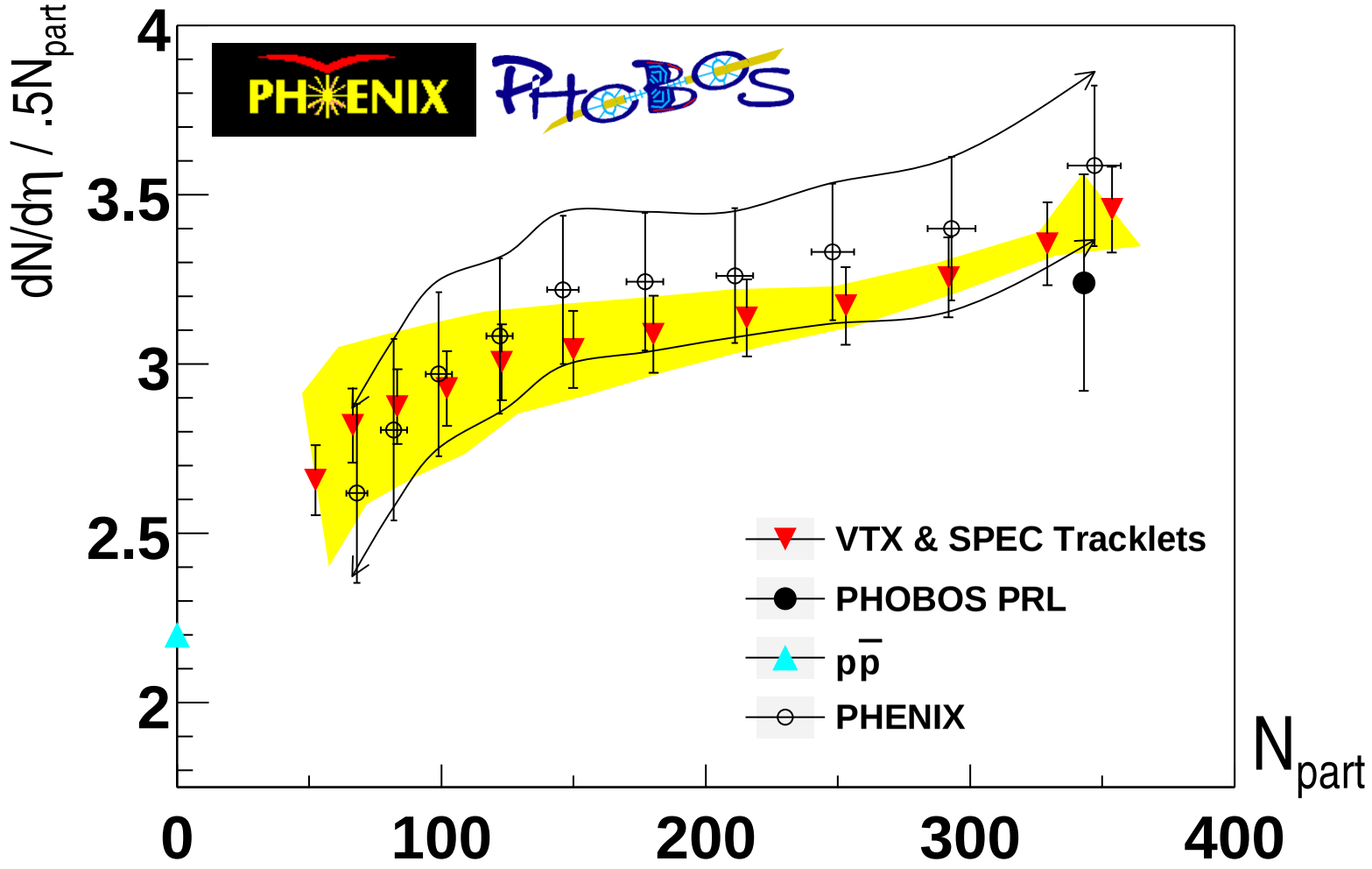
- Measurement sensitive to trigger bias
  - "Minimum-bias" still has bias
  - Affects most peripheral events



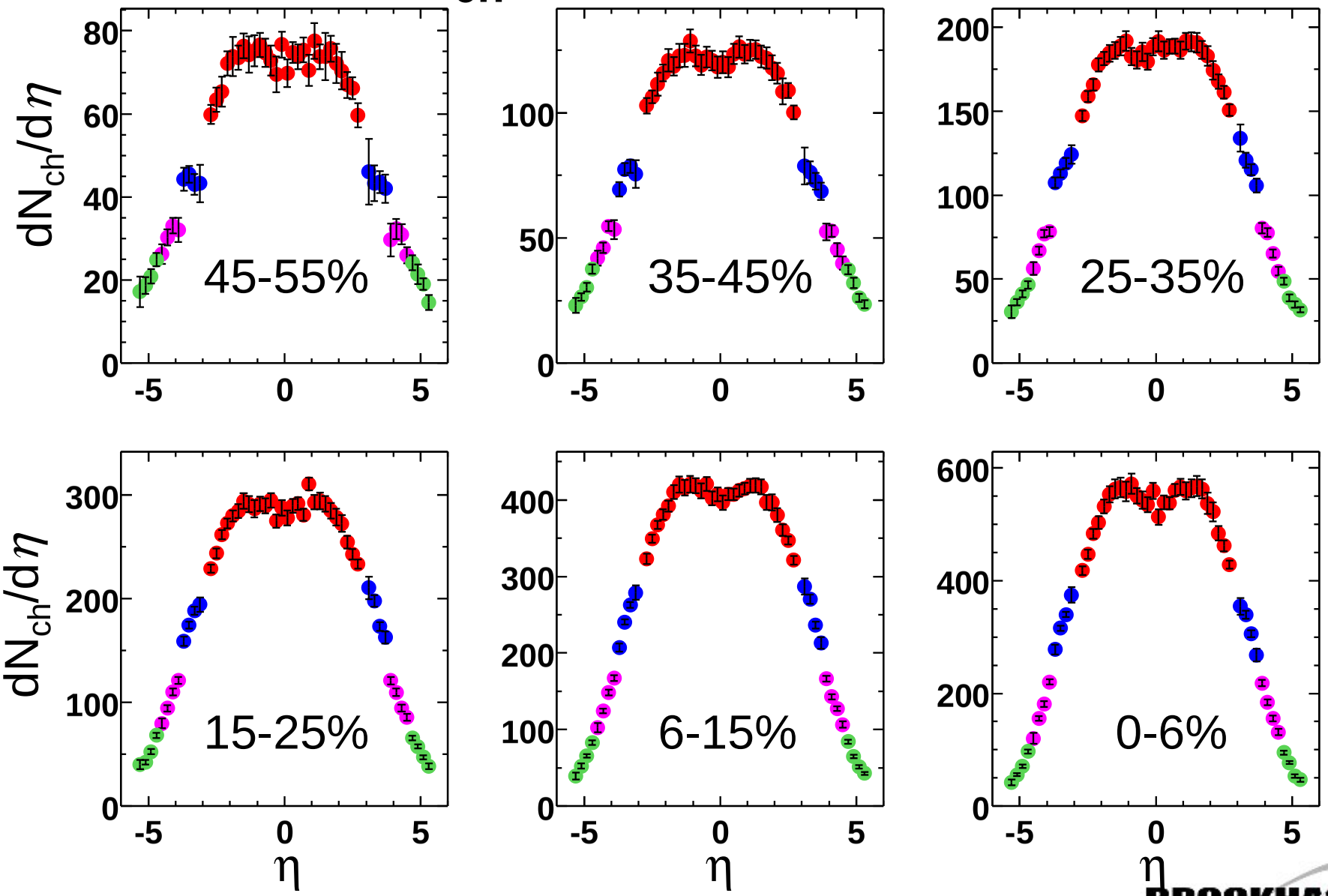


- Estimating 96% when really 90% overestimates N_{part}
- Creates "pivot point" at central events
- Hard to rule out EKRT…

PH: OBOS vs. ENIX



$dN_{ch}/d\eta$ vs. Centrality



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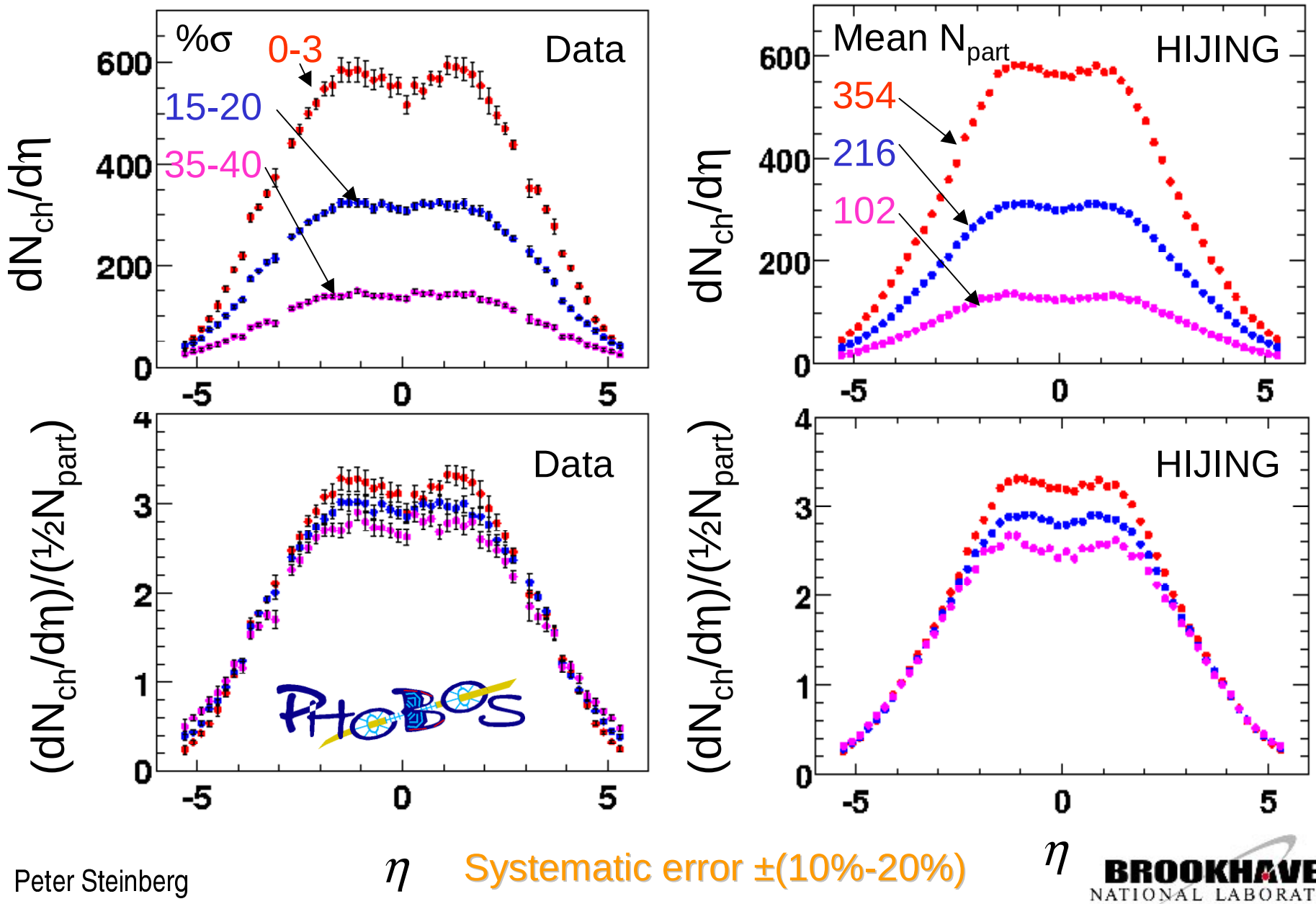
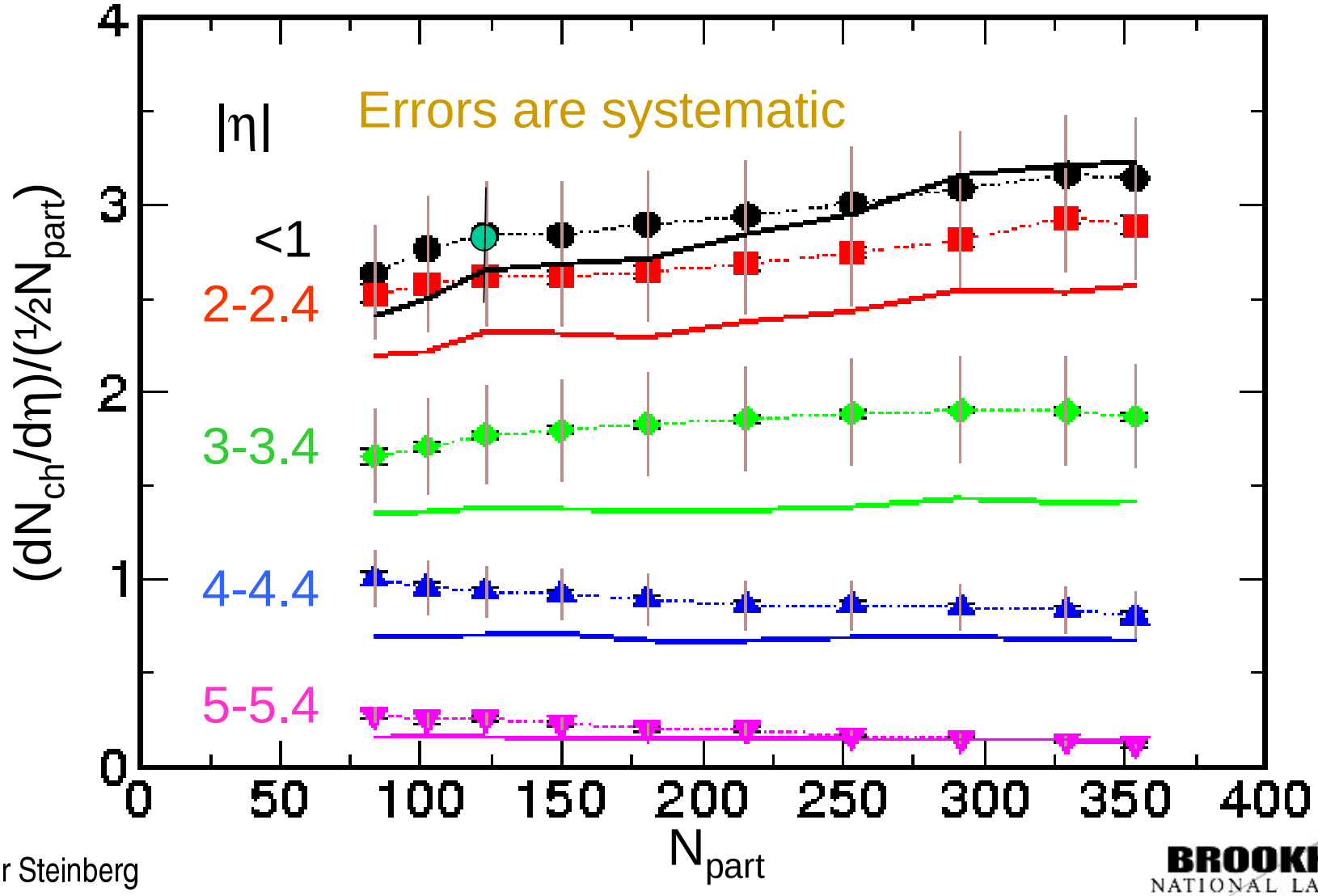
BROOKHAVEN NATIONAL LABORATORY

Shapes of $dN_{ch}/d\eta$ for different N_{part}

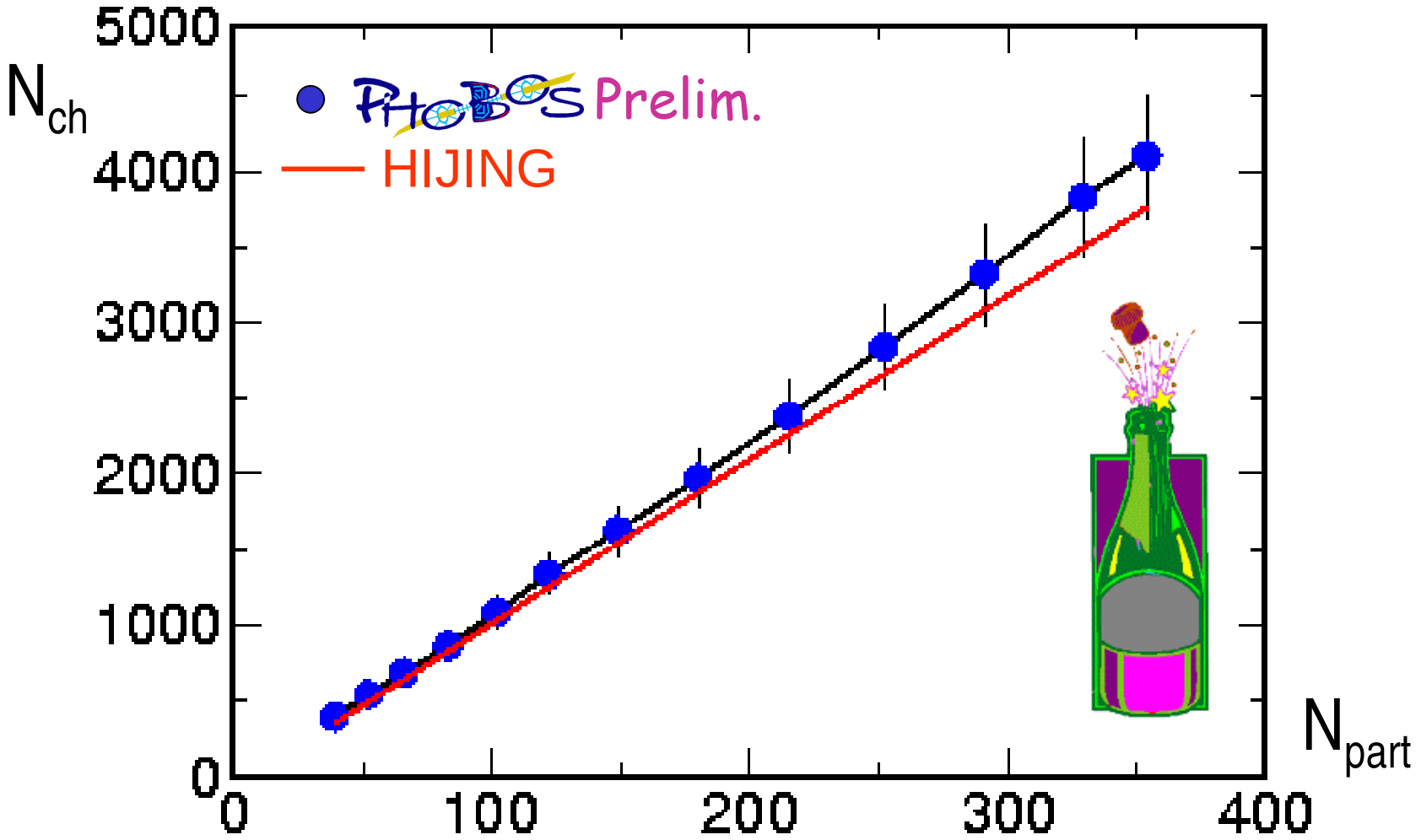


Centrality dependence of $dN_{ch}/d\eta|_{\eta}$

Symbols: PHOBOS Prelim. Solid lines: HIJING



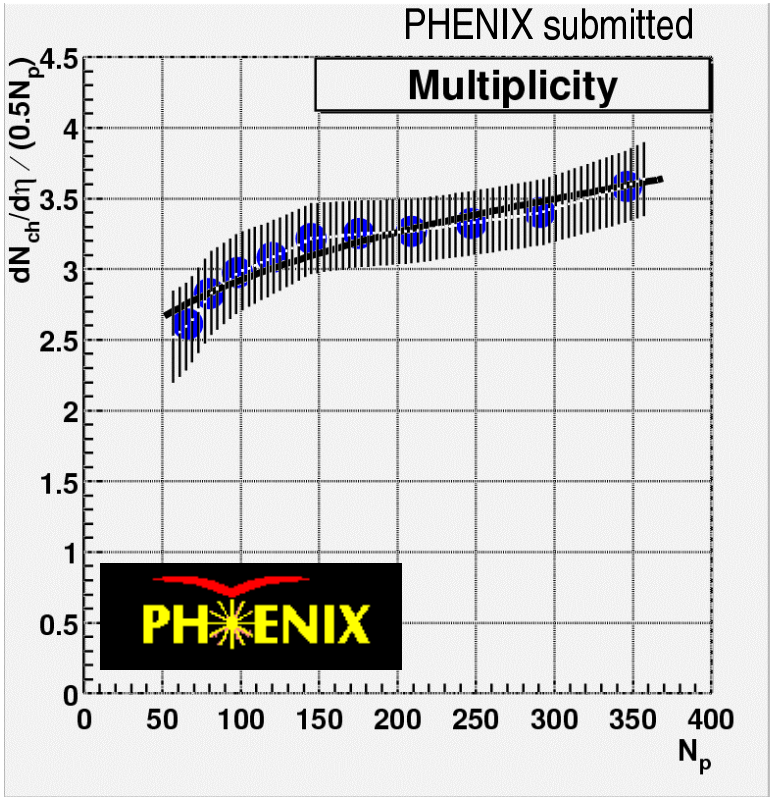
Total Multiplicity (|η|<5.4)

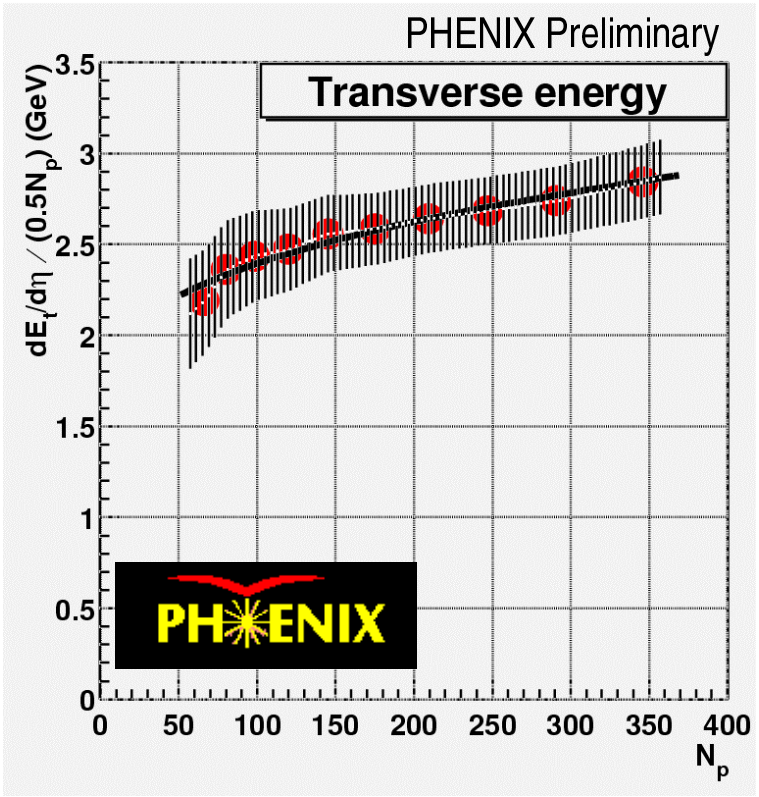


Multiplicity Results

- EKRT, HIJING disfavored by both PHENIX & PHOBOS
- Initial state saturation looks like modified Glauber
  - No way to resolve using N_{ch} alone
- What about E_T?
  - Hydro does *p dV* work during longitudinal expansion, decreases $dE_T/d\eta$
  - Eskola: "E_T will be more efficient model killer"…
- So far, few papers predicting E_T, but surely on the way
  - PHOBOS got 9 in two months after the first paper…

Centrality dependence of E_T

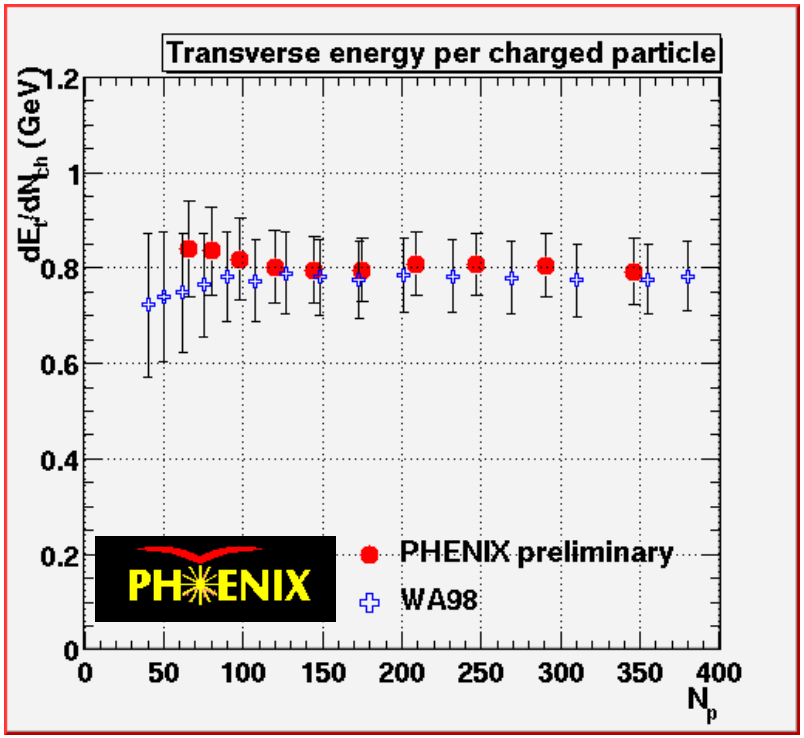




- E_T and charged particles appear to vary in lockstep
- Fits are a modified WNM, possibly allow extraction of fraction of hard production (NB. ambiguities persist…)

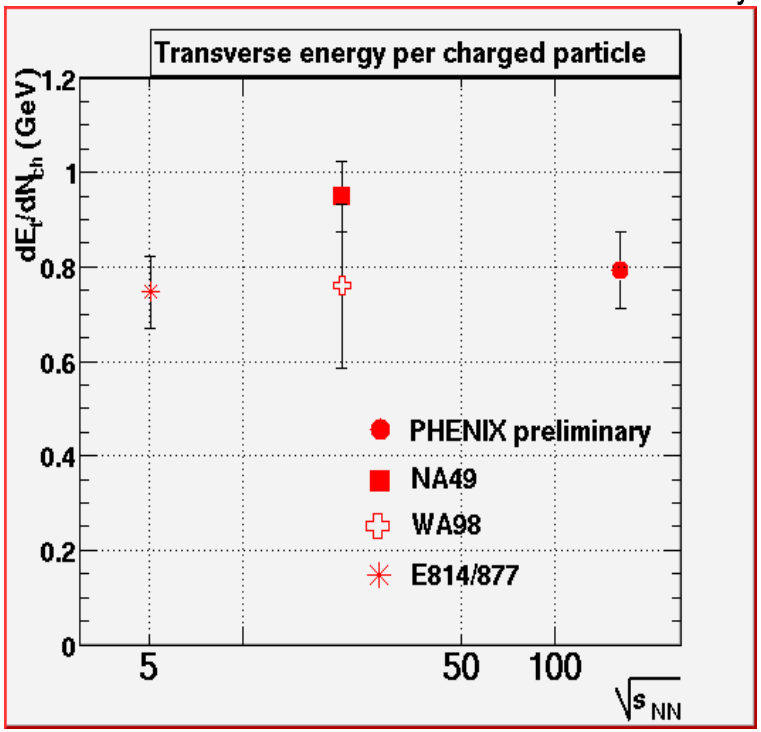
E_T per charged particle

PHENIX Preliminary



- Independent of centrality
- Appears to be same as WA98 (@SPS)

PHENIX Preliminary



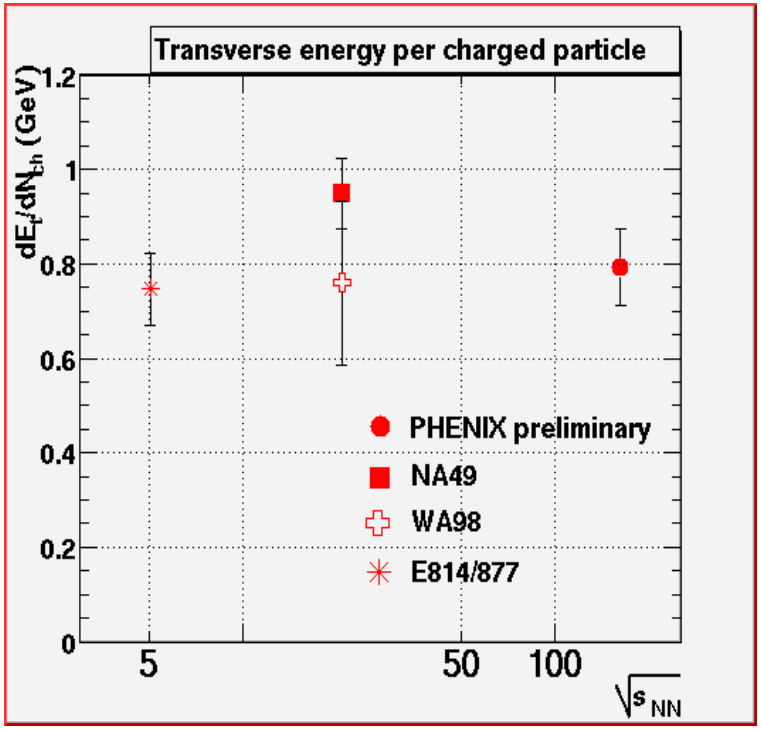
- Energy dependence
- Possible 20% discrepancy betw. NA49/WA98
- Where is the increased <p_T> seen by STAR/PHENIX?

"So what's the Energy Density?"

- Sorry, I won't tell you…
- Implication of PHENIX
  - Constant E_T/charged particle
  - Energy density (via Bj formula) simply scales with multiplicity!

$$\varepsilon = \frac{\frac{dE_T}{d\eta}}{\pi R^2 \tau} = \frac{\frac{dN_{ch}}{d\eta}\frac{E_T}{N_{ch}}}{\pi R^2 \tau}$$

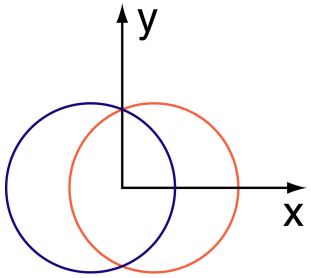
  - (Even PHOBOS can do it!)
  - ~50% higher than SPS…

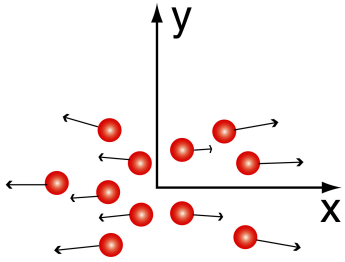


- Ambiguities persist
  - Formation time might be substantially less

“Flow”

- Radial flow
  - Not seen in angular distributions
  - Use HBT, spectra ($T = T_o + m\langle\beta^2\rangle$ - Nu Xu)
- Directed flow
  - Forward rapidities
  - Not measured yet
    - Sensitivity estimated at PHOBOS/STAR
  - Interesting predictions for phase transition…
- Elliptic flow
  - Early time push, hydrodynamic evolution
  - Strongest at midrapidity





$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \langle \cos 2\phi \rangle$$

$$\phi = \operatorname{atan} \frac{p_y}{p_x}$$

v_2 from azimuthal correlations

- Method used by PHENIX

$$C(\Delta\phi) = \frac{R(\Delta\phi)}{B(\Delta\phi)}$$

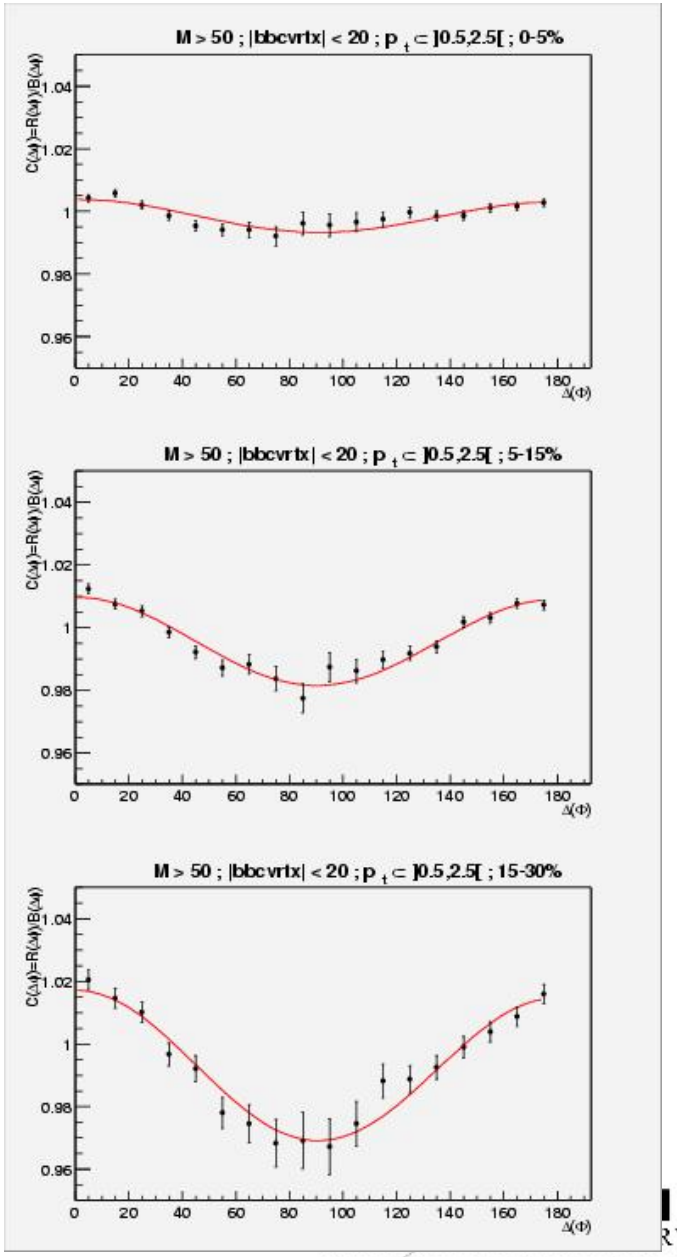
- Similar information content as Fourier method

$$C(\Delta\phi) \sim 1 + v_2^{\,2} \cos(2\Delta\phi)$$

- OK for partial acceptance
- Sensitive to other correlations
  - Jets (at 180°) , HBT (at 0°)

➢ But is that bad?

  - CERES data

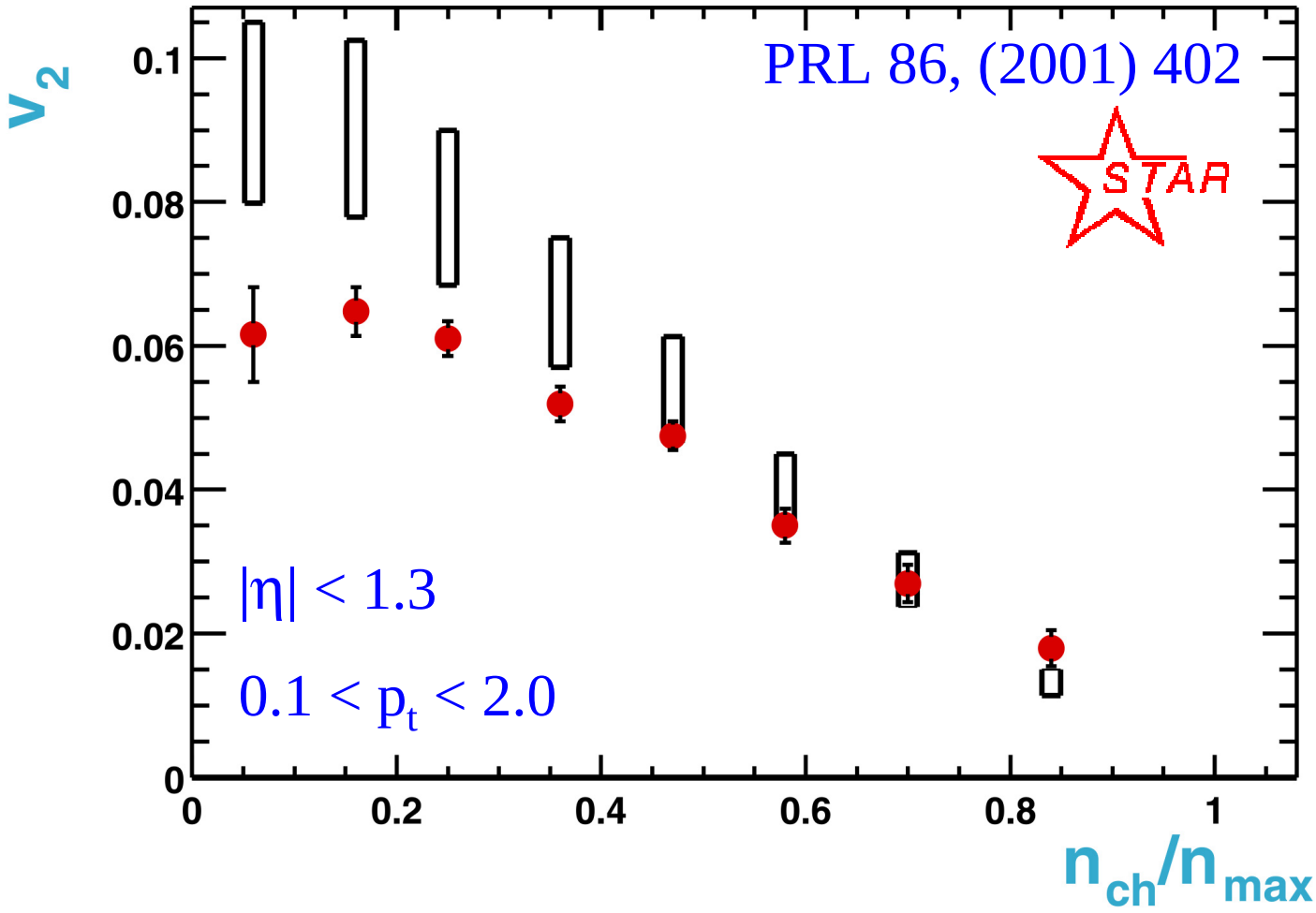


0-5%

5-15%

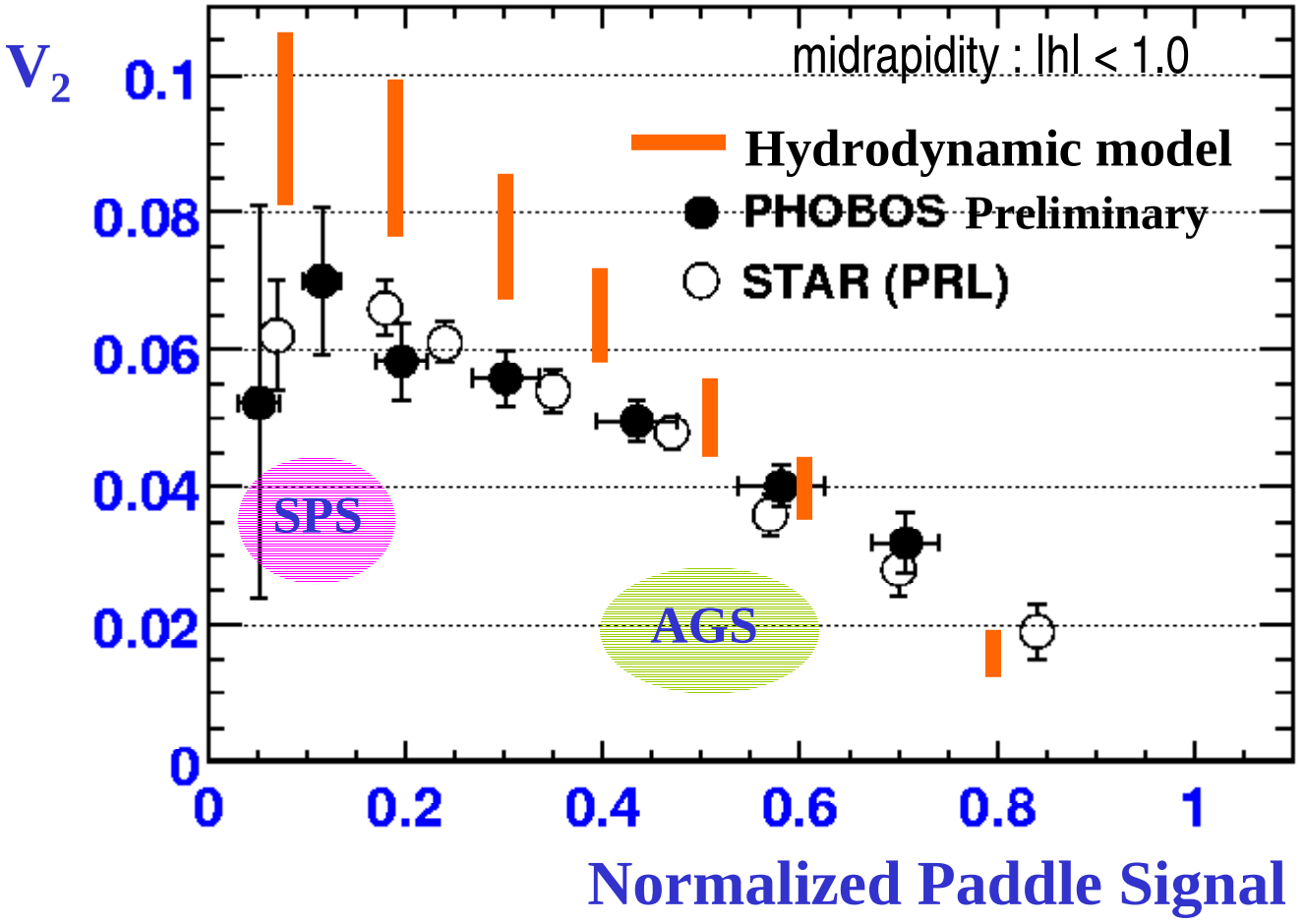
15-30%

v_2 versus centrality

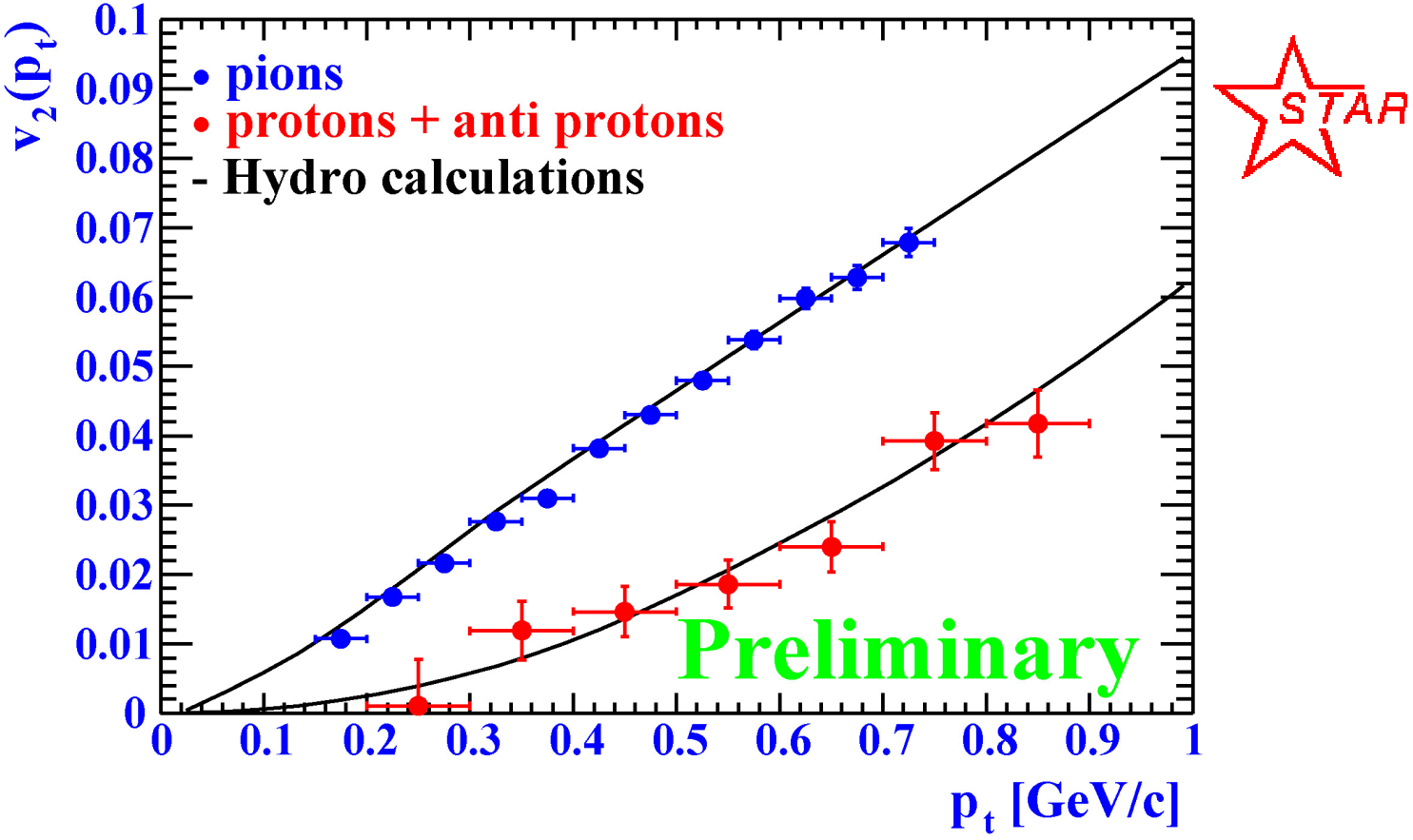


- Boxes show "initial spatial anisotropy" ε scaled by 0.19-0.25

Centrality Dependence

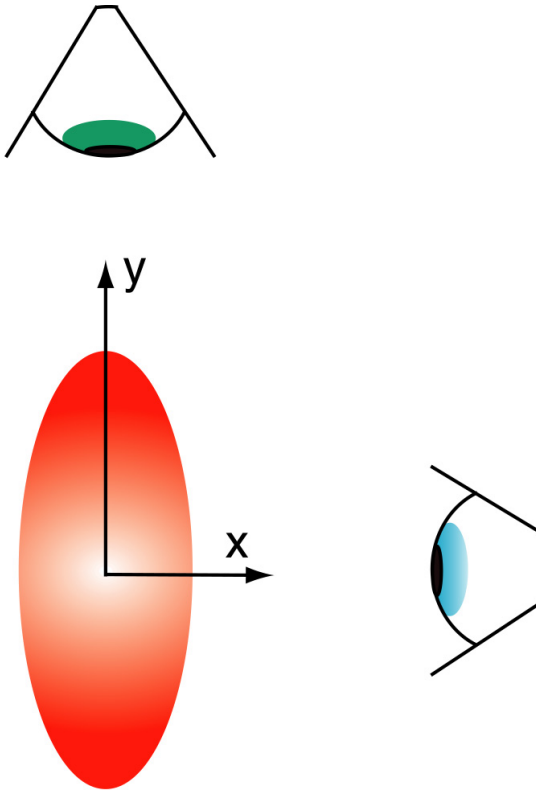


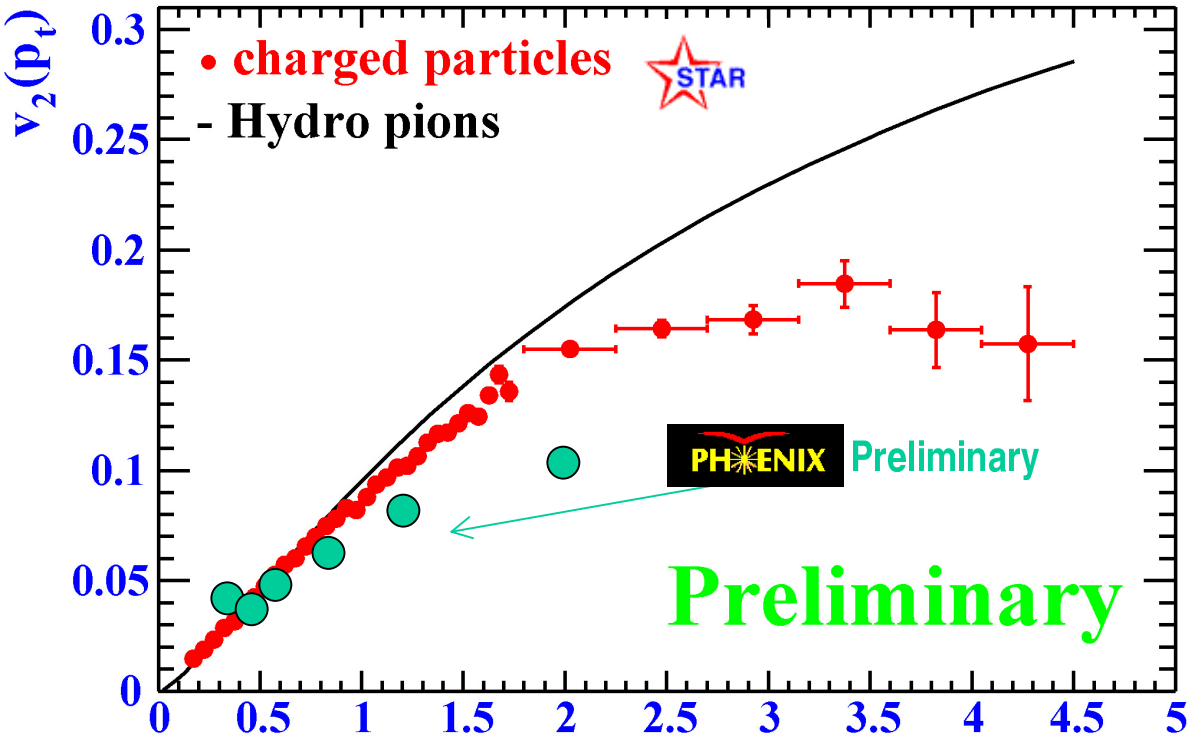
p_T dependence for π,p



- Hydro calculations: P. Huovinen, P. Kolb and U. Heinz

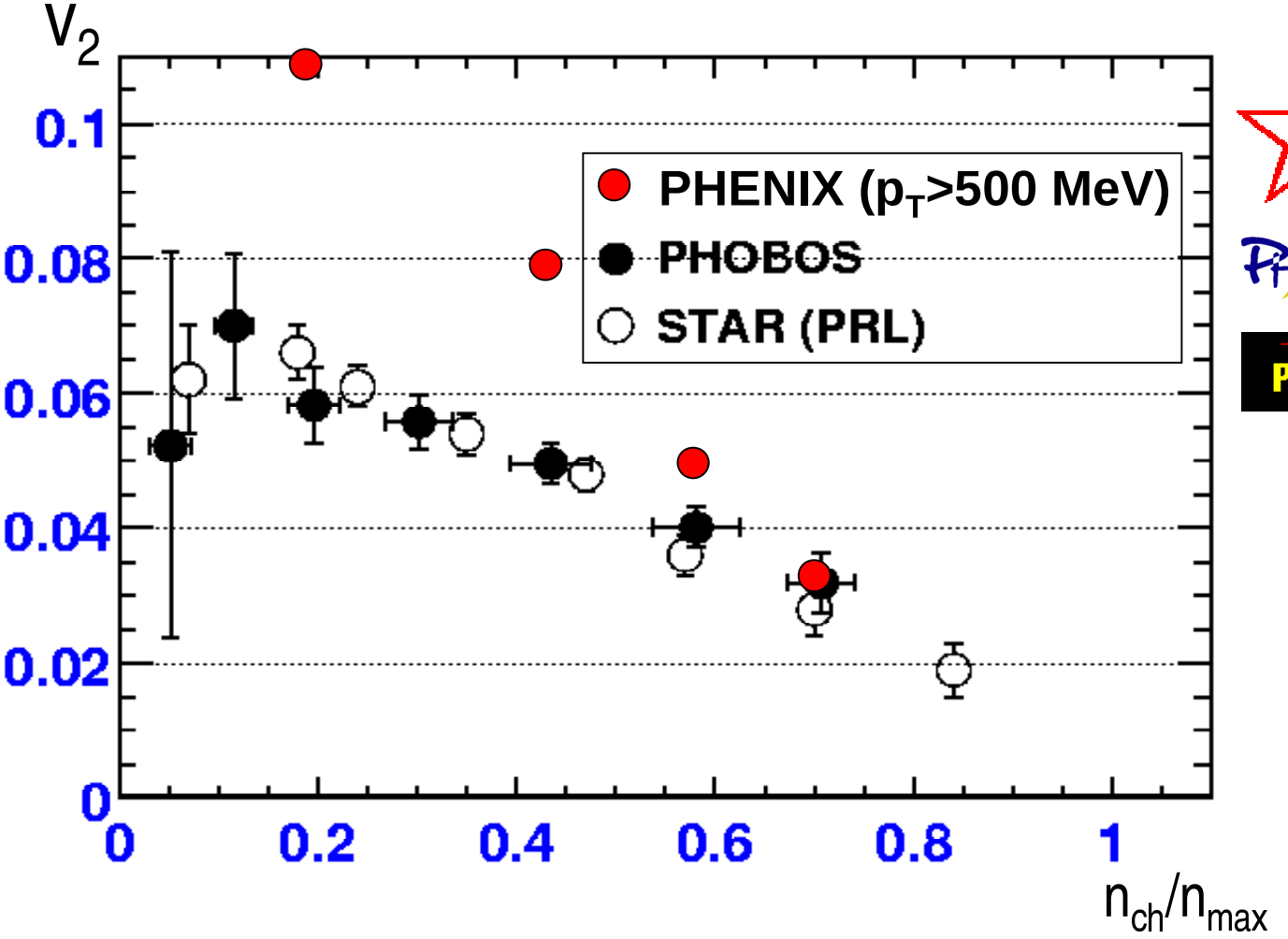
v_2 at high p_T



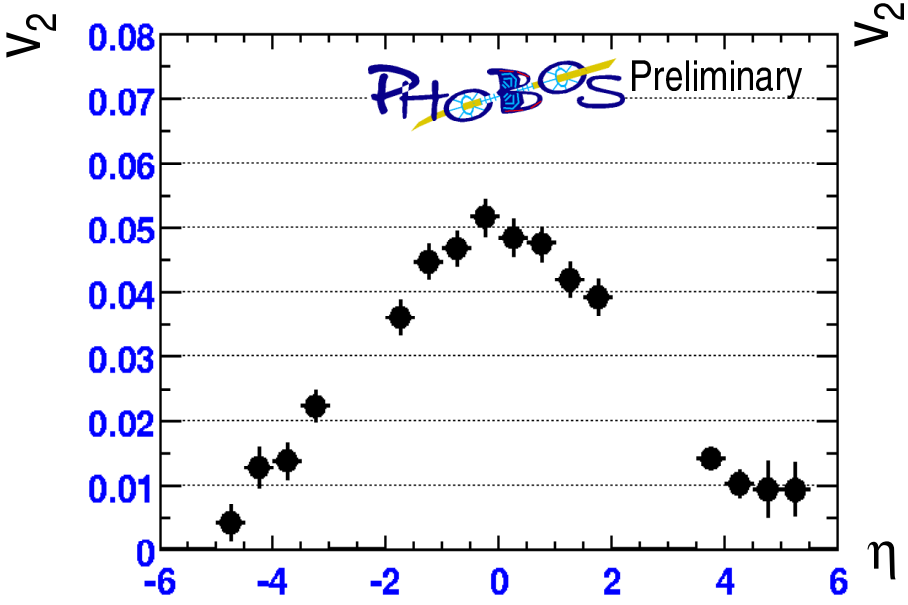


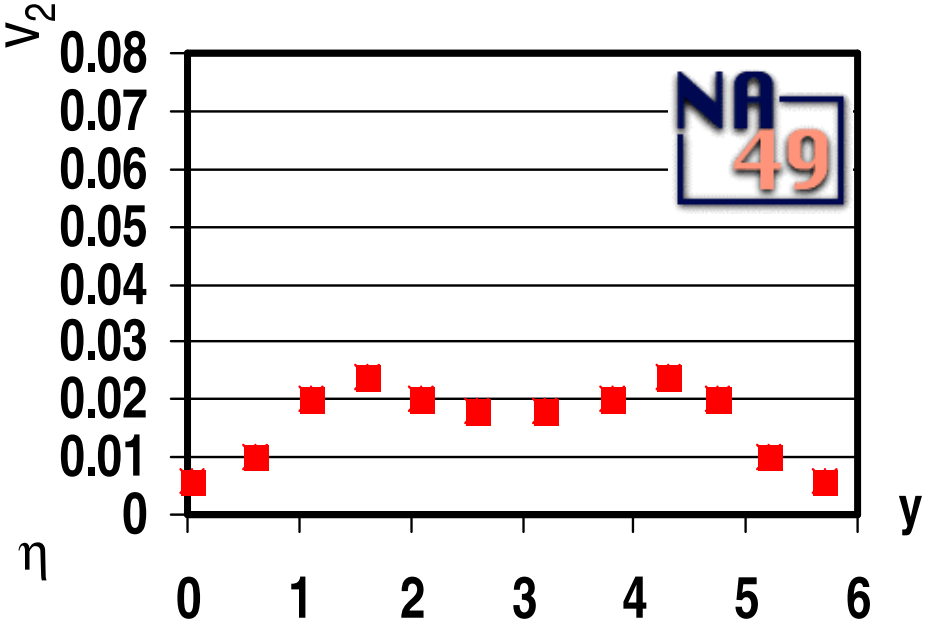
- Hydro fails at large transverse momentum
- Possible interpretations suggested by jet quenching (wait for A. Drees talk)
- However, perhaps composition is a critical part of this effect…

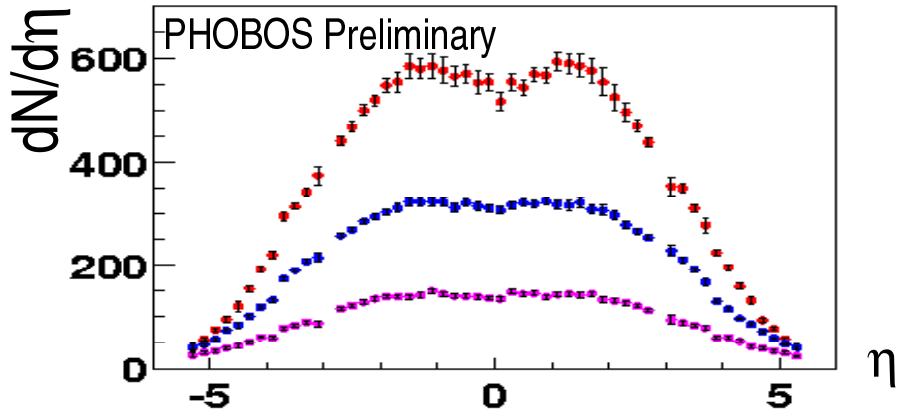
Comparison of all v_2 results



v_2 vs. (pseudo)rapidity







- NA49 (y), PHOBOS(η) (mainly pions)
- Different shape at midrapidity
- PHOBOS shape similar to dN/dη!
  - Low-density limit?? $\mathbf{v_2 \sim \varepsilon\ dN/dy}$
- However, v_2 appears to fall faster than multiplicity

Conclusions