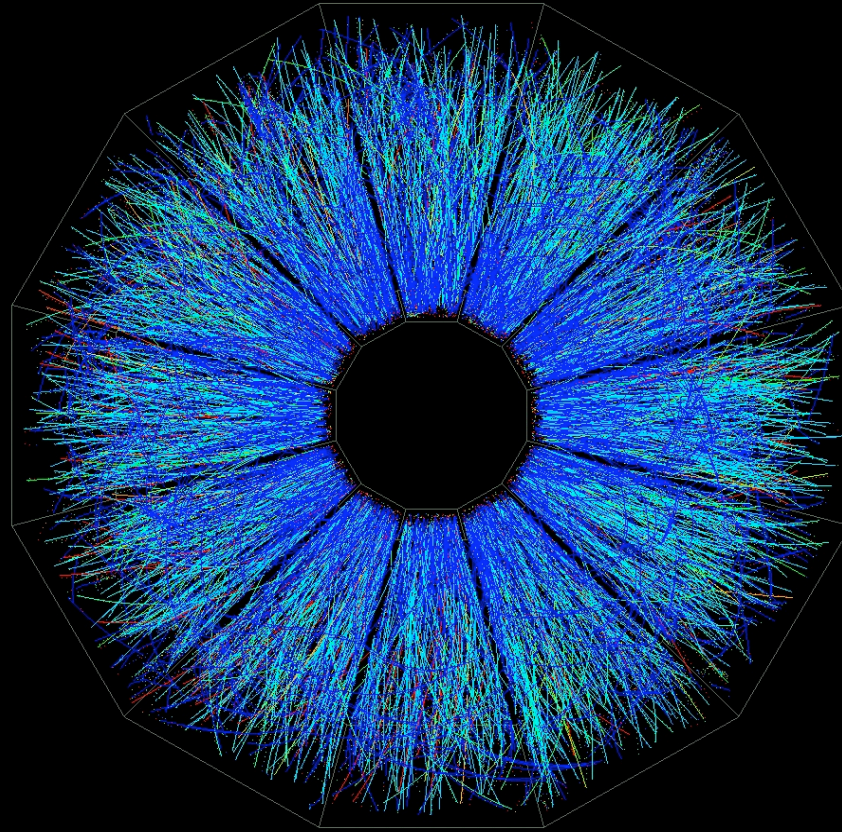


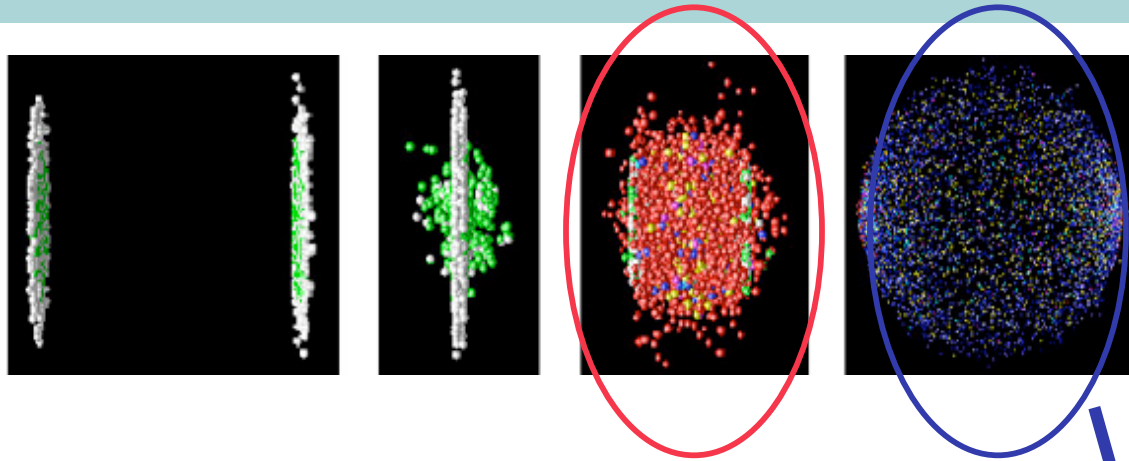
Bulk Matter at RHIC



Gunther Roland/MIT

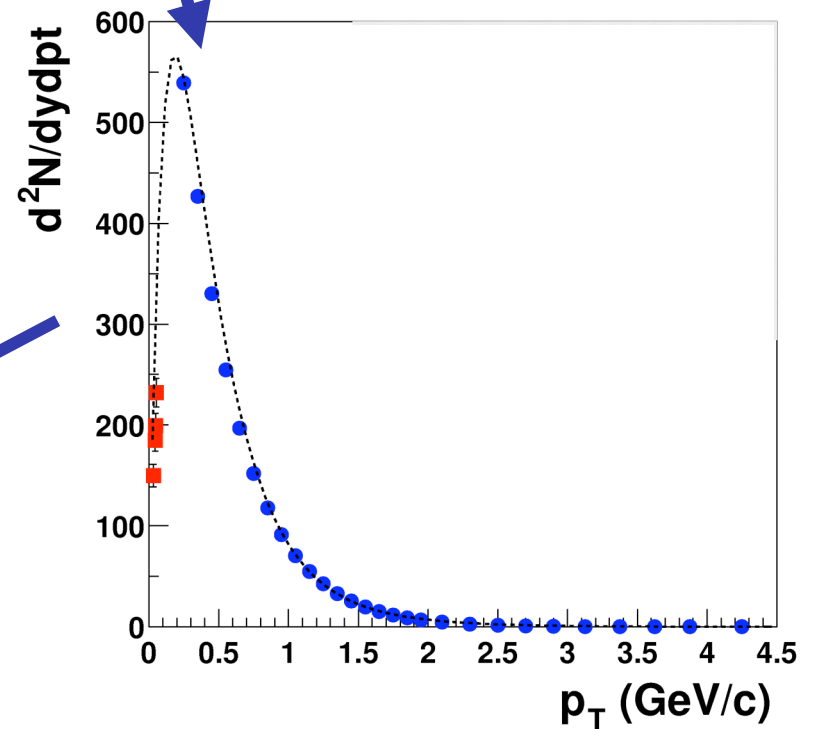


Bulk Matter at RHIC

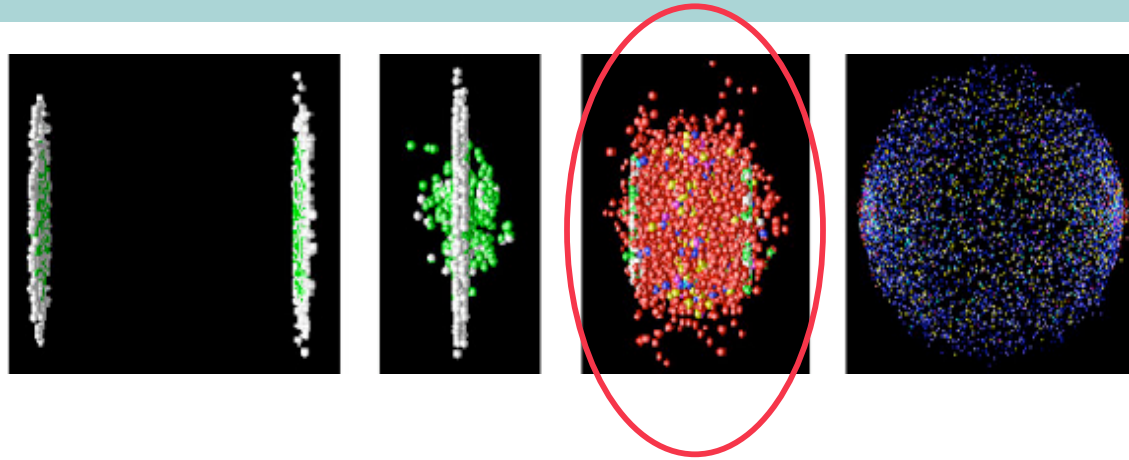


Bulk parameters

- $\langle N_{ch} \rangle$, dN/dh
- T_{ch} , m_B , l_s
- $\langle p_T \rangle$, $\langle E_T \rangle$
- $\langle b_T \rangle$, $\langle b_L \rangle$
- v_1 , v_2



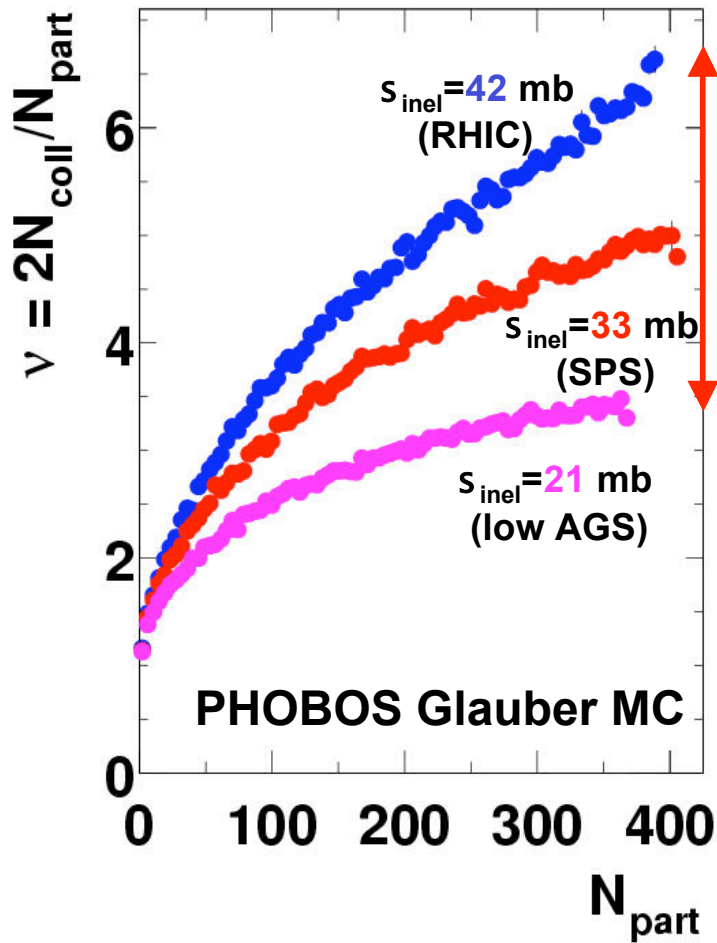
Bulk Matter at RHIC



- Developing consensus
 - High density ‘coherent’ initial state
 - Strongly interacting, expanding, ‘liquid’ medium
 - Very large opacity for fast colored objects
- Open questions
 - Nature of medium?
 - How is medium produced?

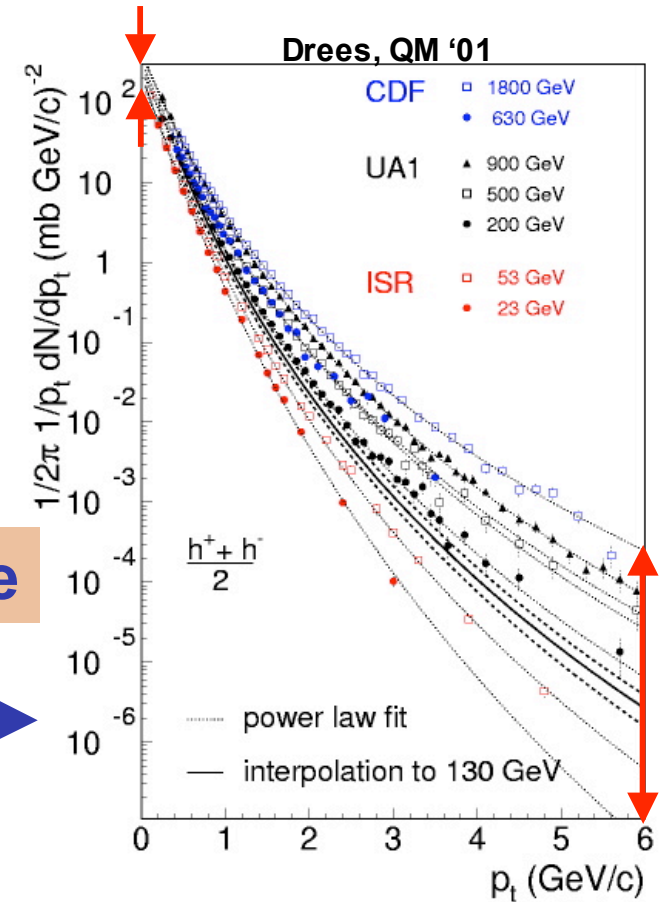


Control Parameters



System-Size

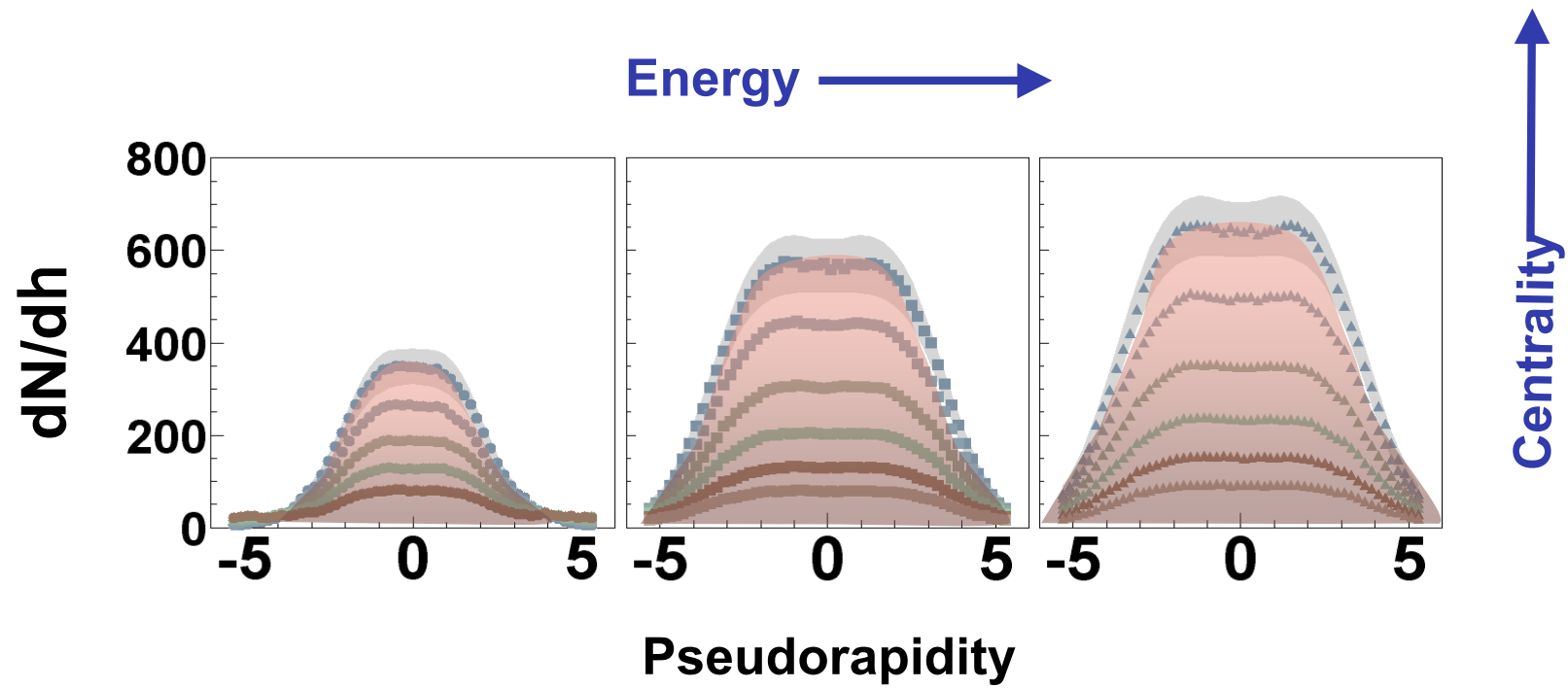
Energy



Also: Different systems (different nuclei, pp, pA, e⁺e⁻)



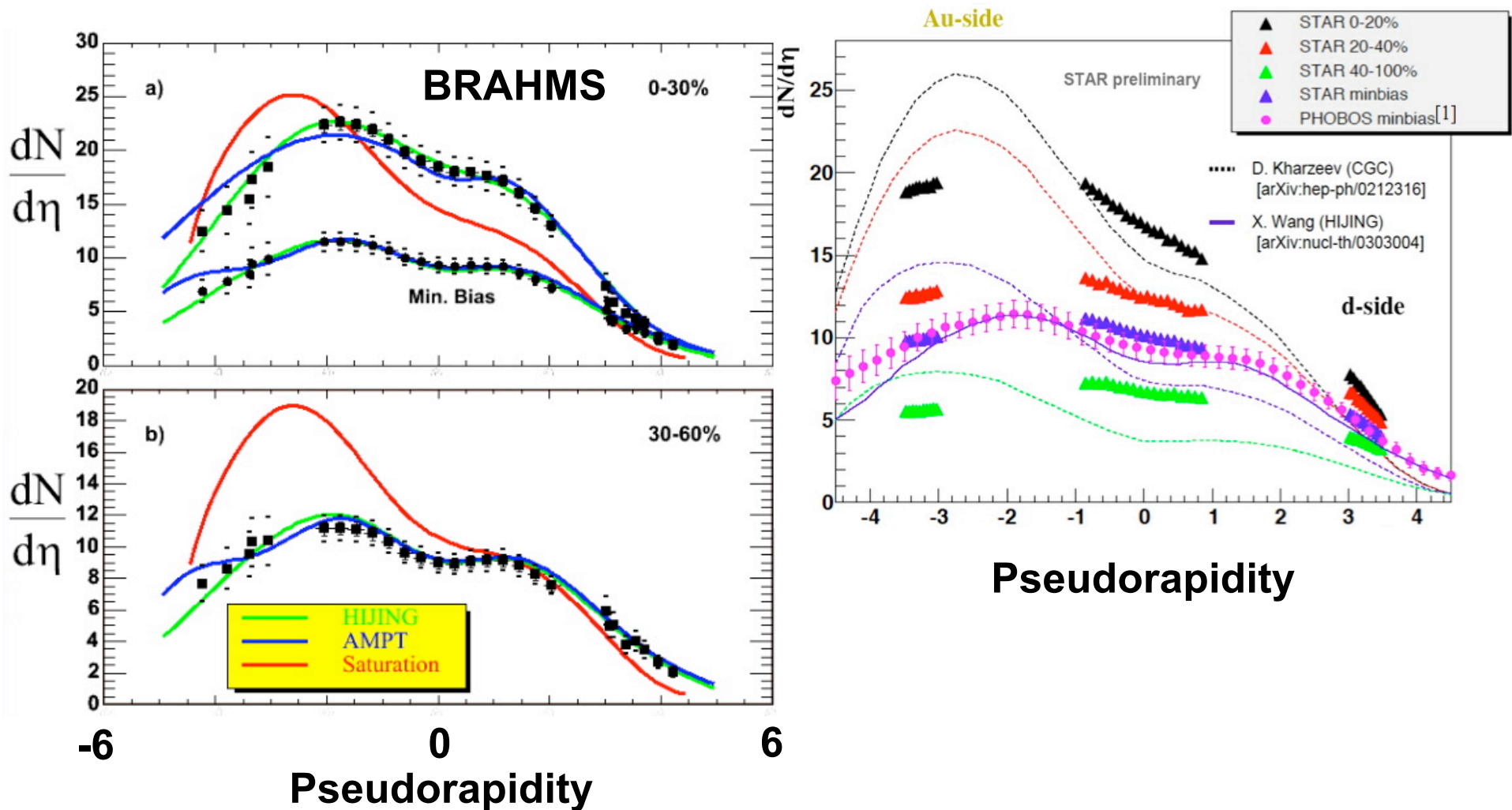
I. 4-p Multiplicity $\langle N_{ch} \rangle$



How does integral over 4-p, $\langle N_{ch} \rangle$,
change with Energy and Centrality?



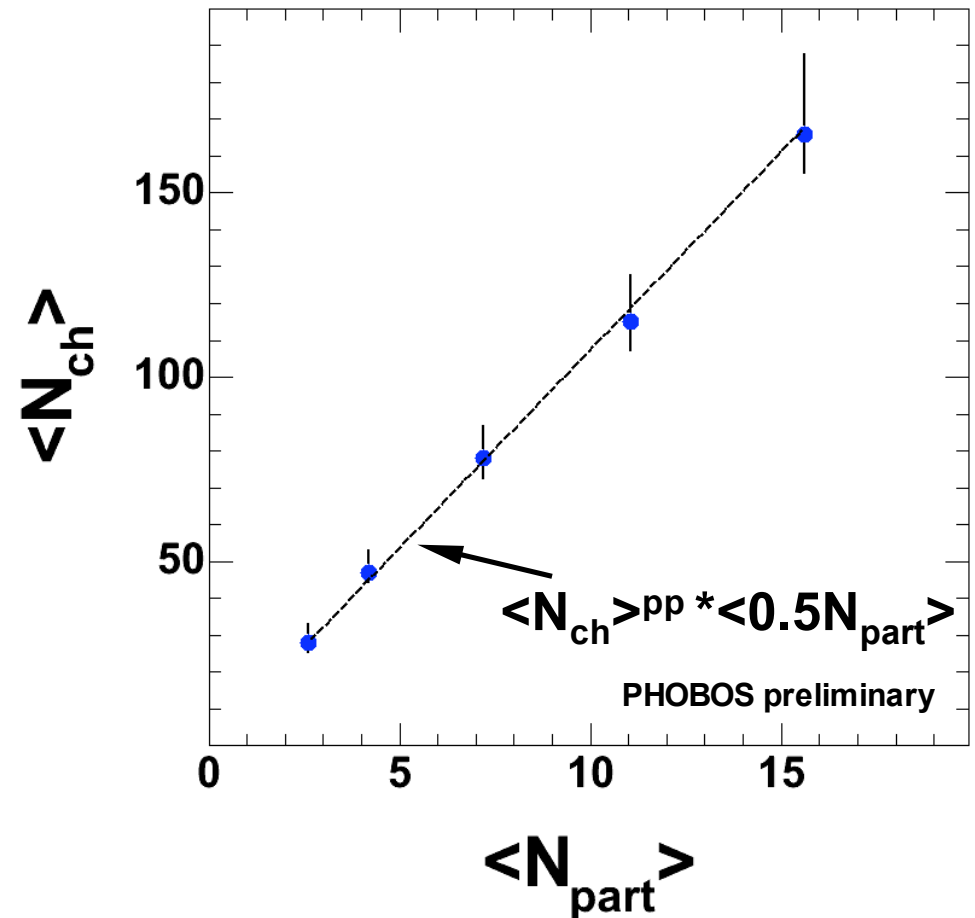
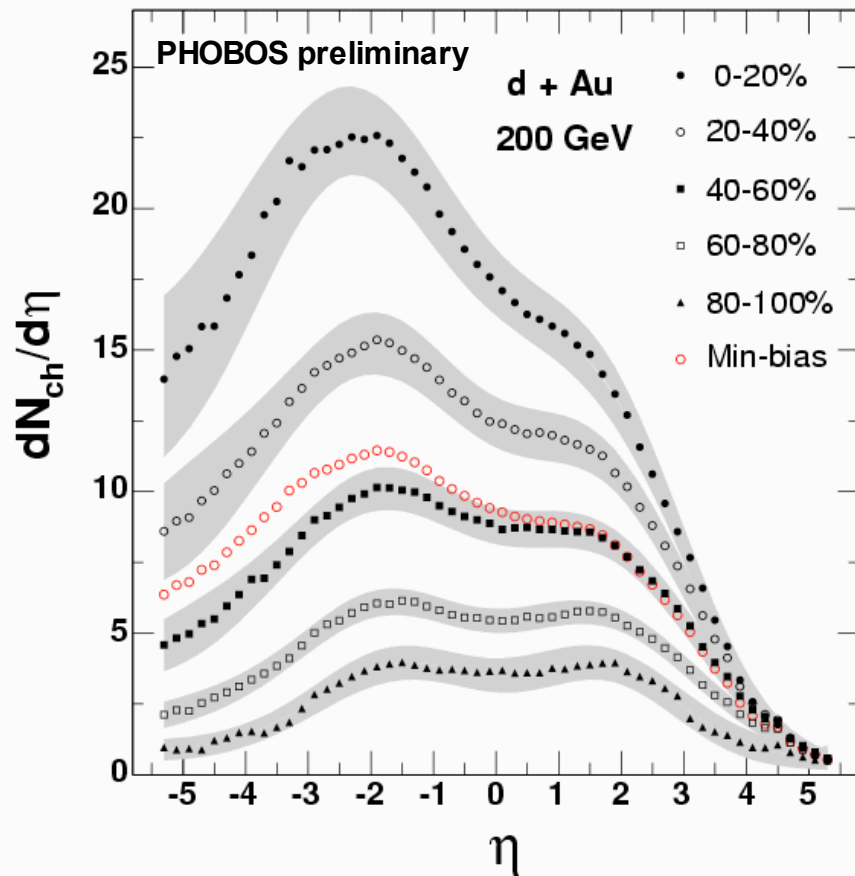
$\langle N_{ch} \rangle$ vs N_{part} in d+Au



Evolution of shape with centrality



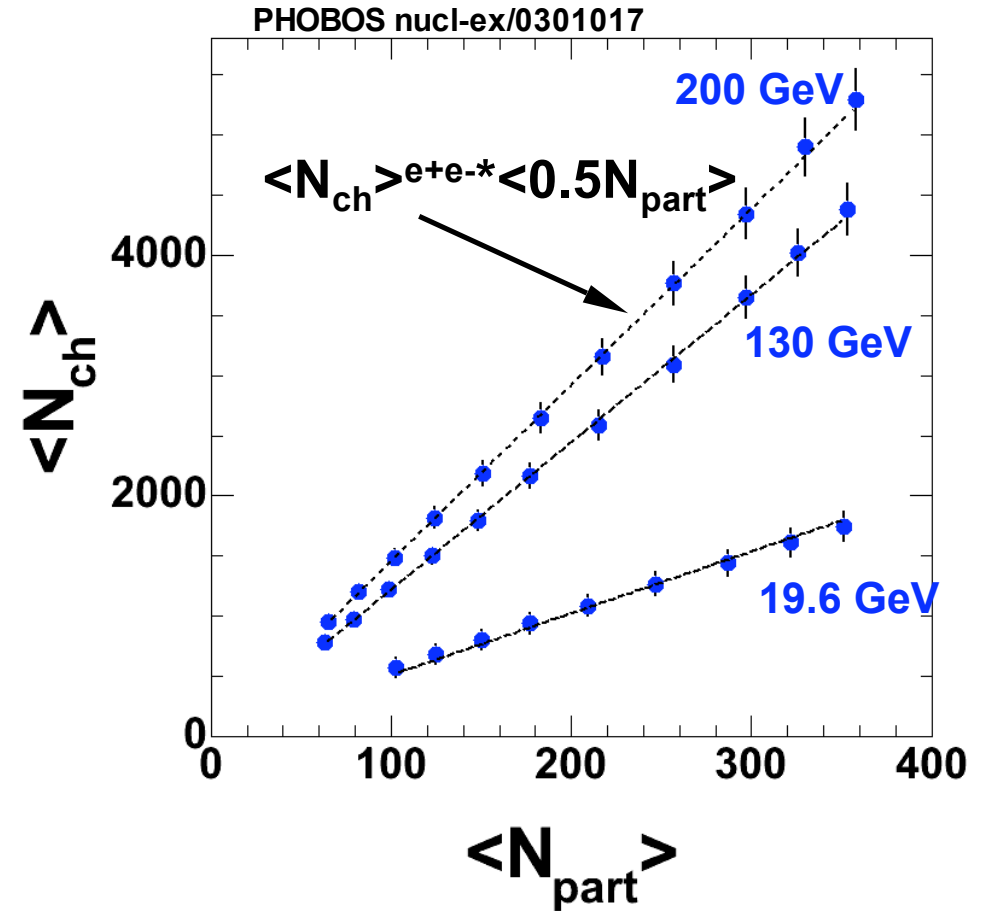
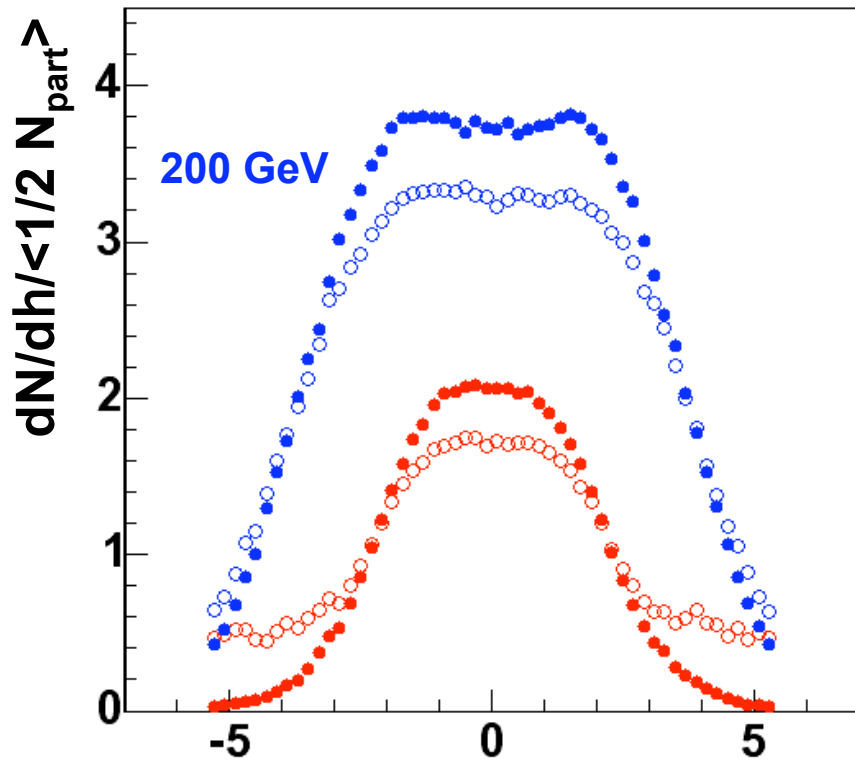
$\langle N_{ch} \rangle$ vs N_{part} in d+Au



$$\langle N_{ch} \rangle \text{ in d+Au} = \langle N_{ch} \rangle \text{ in p+p} * 0.5 \langle N_{part} \rangle$$



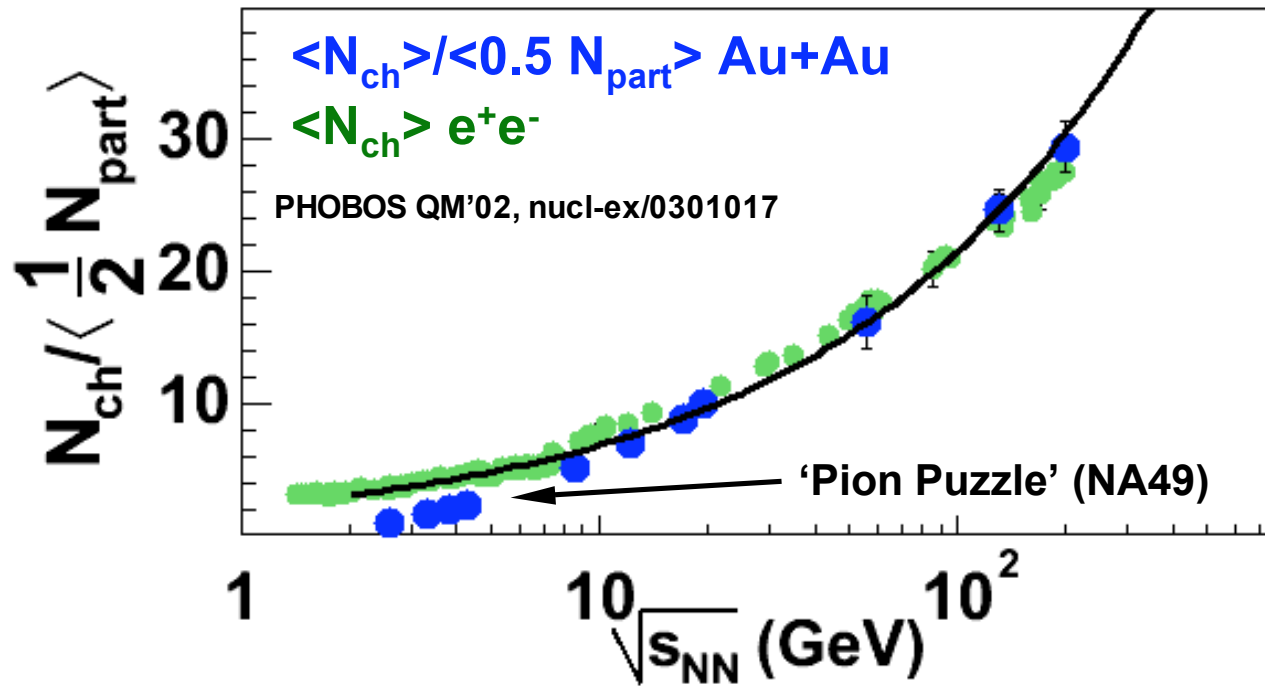
$\langle N_{ch} \rangle$ vs N_{part} in Au+Au



$\langle N_{ch} \rangle$ in Au+Au proportional to N_{part}

Gunther Roland
GRC 2004

$\langle N_{ch} \rangle$ vs \sqrt{s}

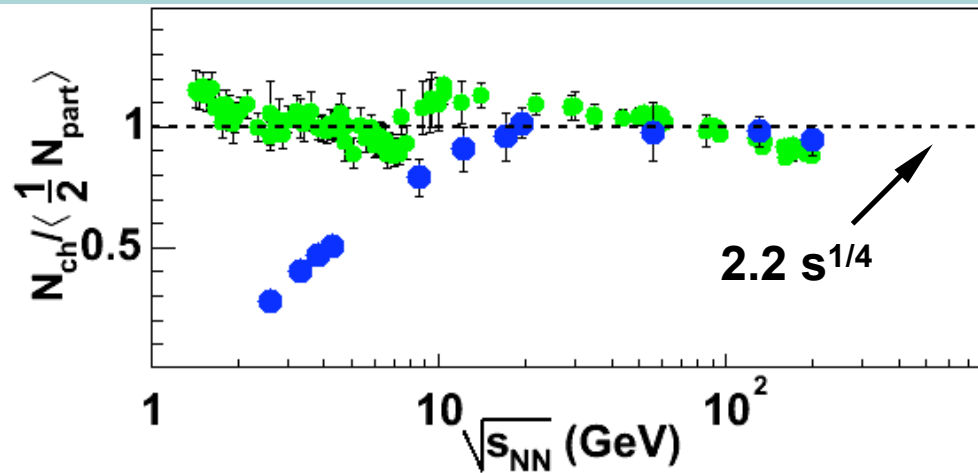


Secondly, we wish to stress that as a function of *available energy* W_{had} the hadronic multiplicity varies as $N \approx 2.2 W_{had}^{1/2}$ over a vast range of initial energies.²⁵

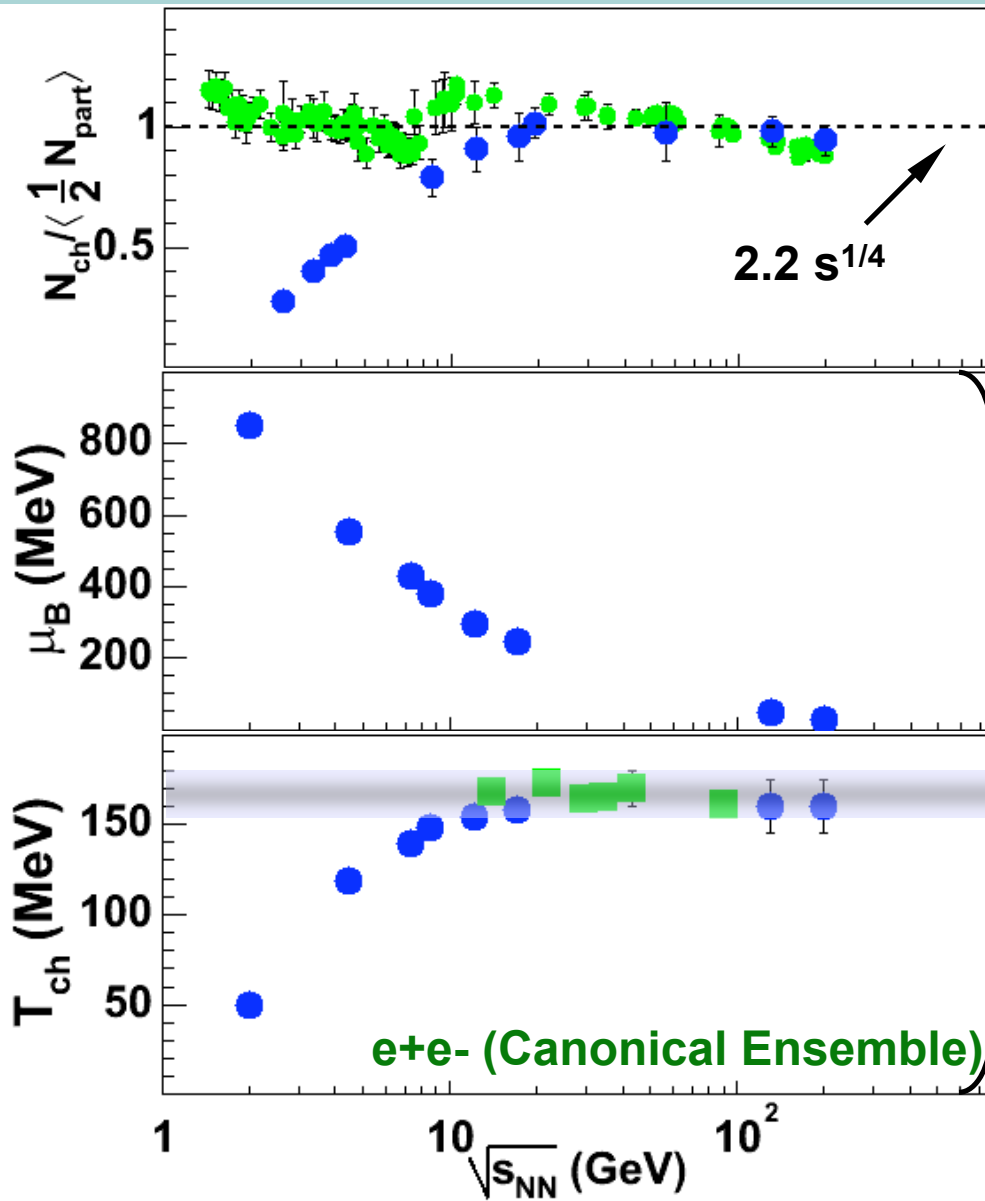
Carruthers, Duong-Van on pp and e⁺e⁻ data in 1983



“Thermal Fit” Parameters and Multiplicity vs sqrt(s)



“Thermal Fit” Parameters and Multiplicity vs sqrt(s)



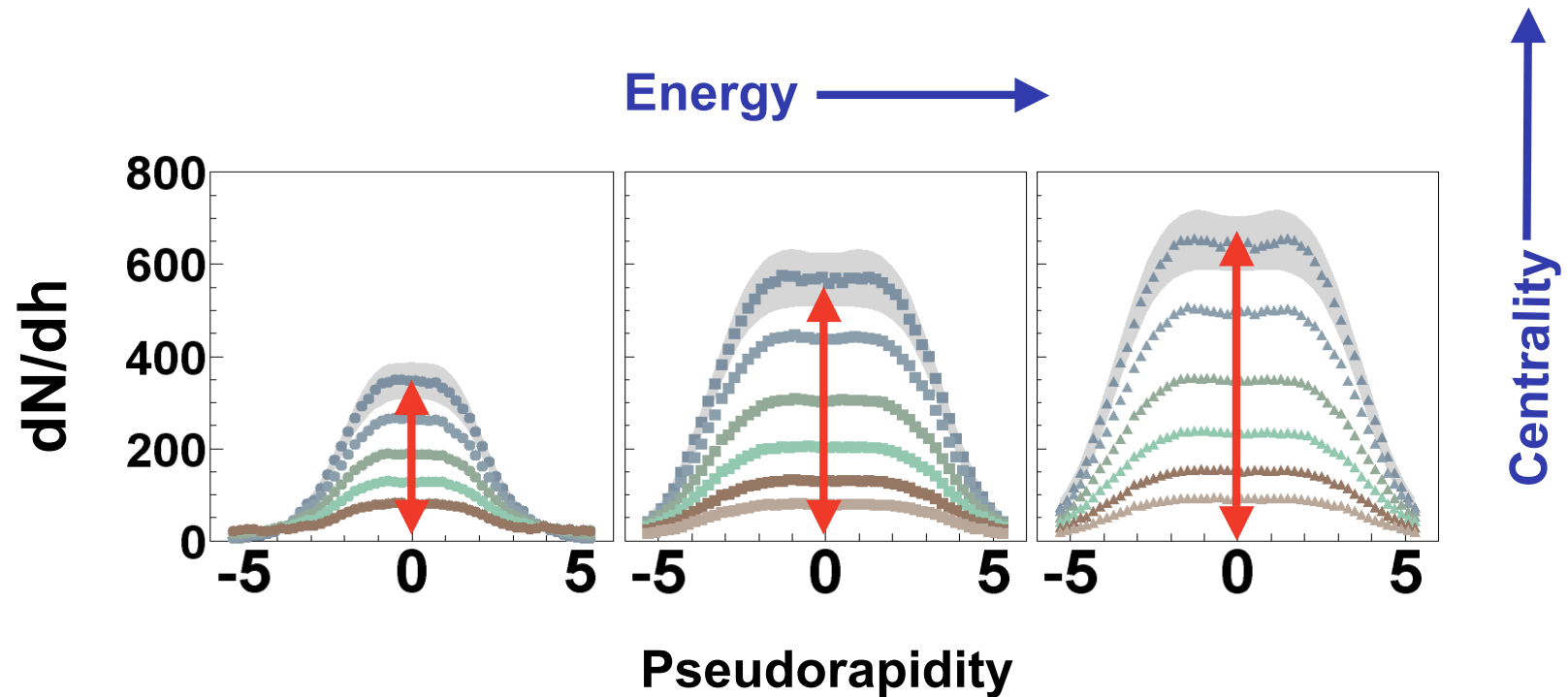
Thermal Model Fits:

Becattini et al (e^+e^- , AGS/SPS)

Braun-Munzinger et al (RHIC)



II. Particle Density near Mid-Rapidity



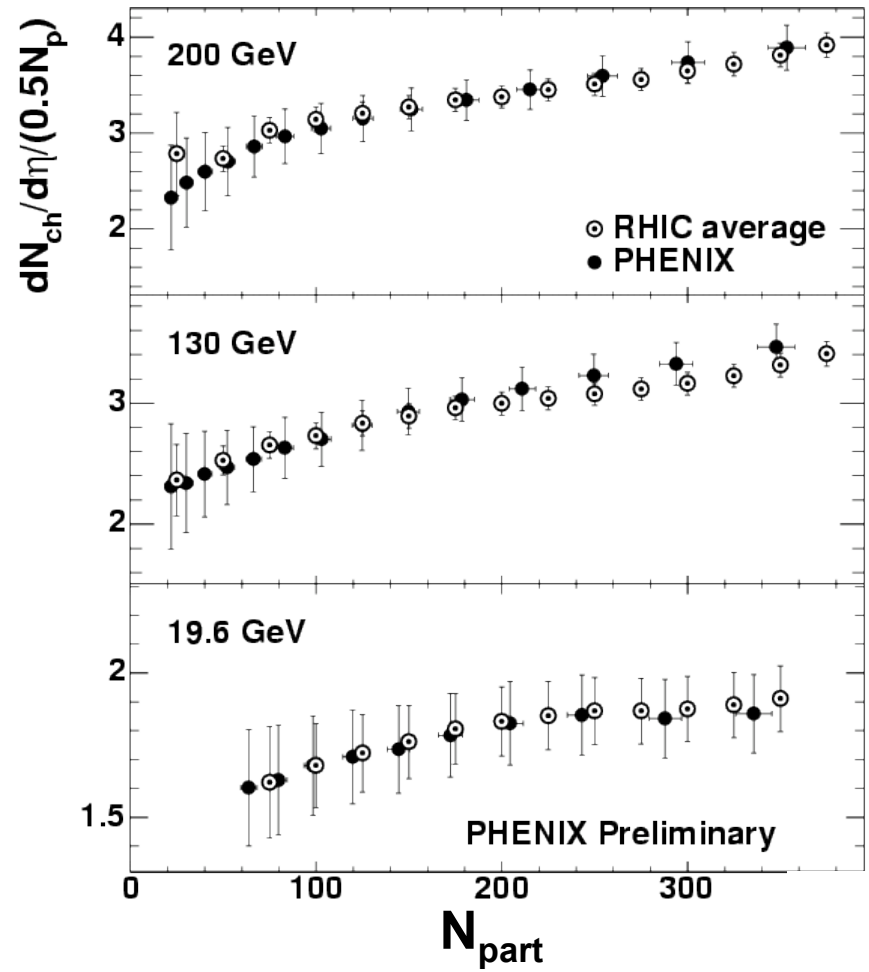
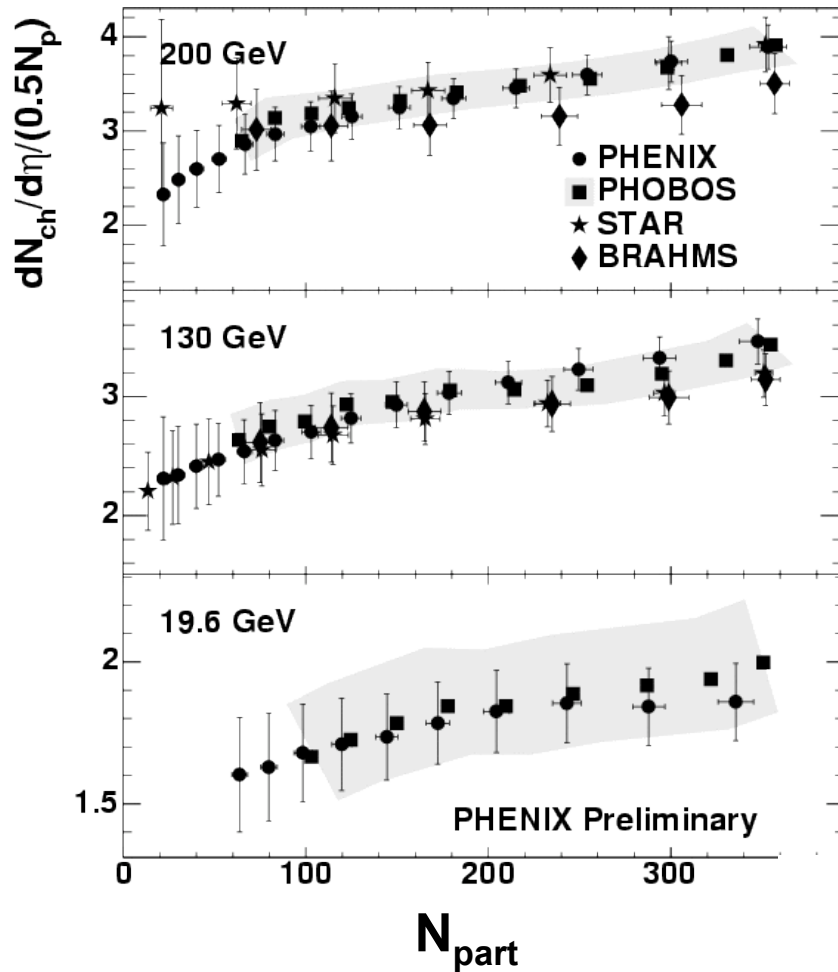
How does Density at 90° change
with Energy and Centrality?



Centrality and Energy Evolution

$-1 < h < 1$

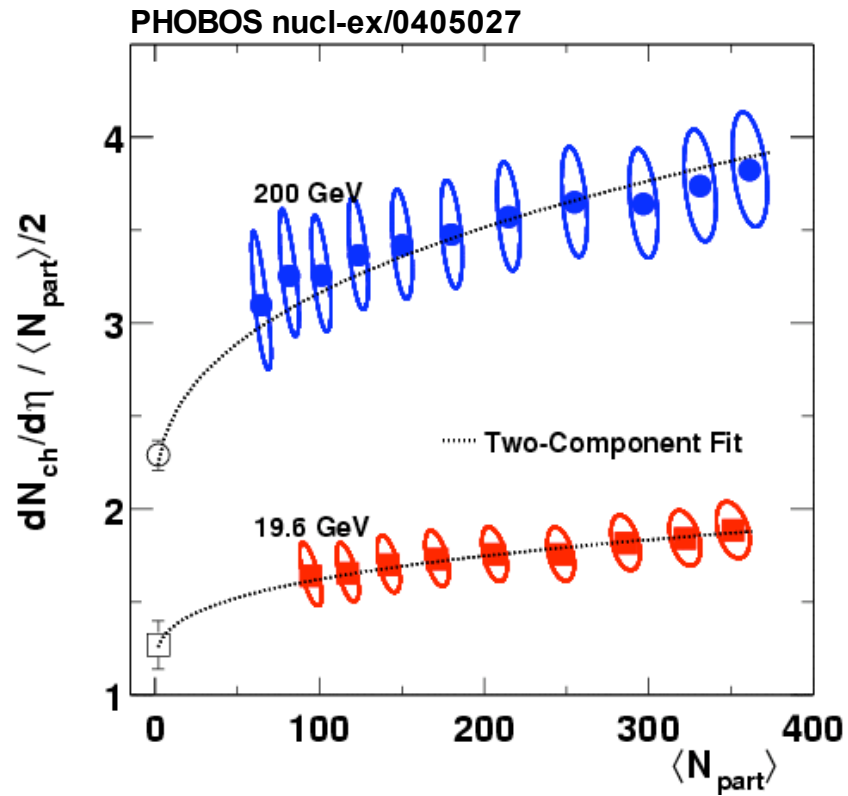
Compilation: Sasha Milow/QM'04



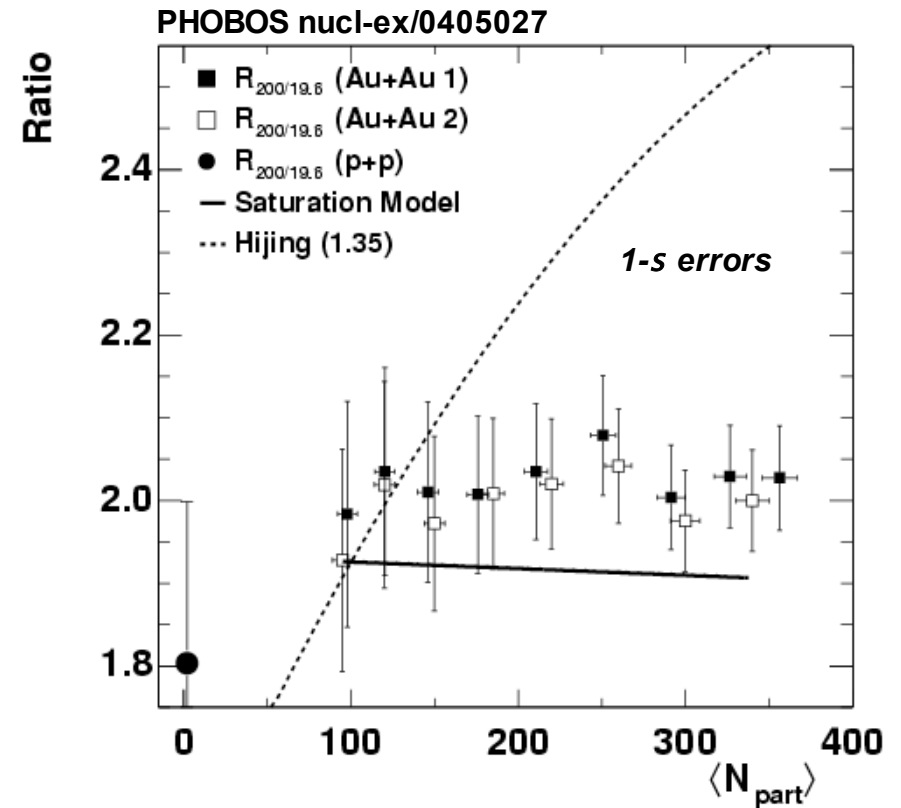
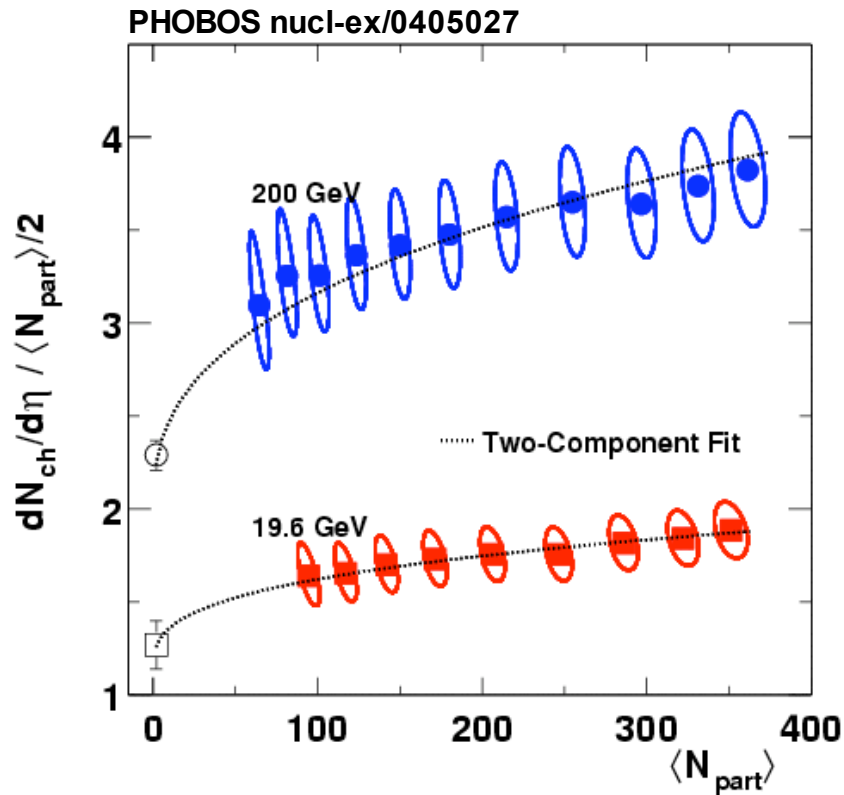
Consistent data set from all experiments



Centrality and Energy Evolution



Factorization

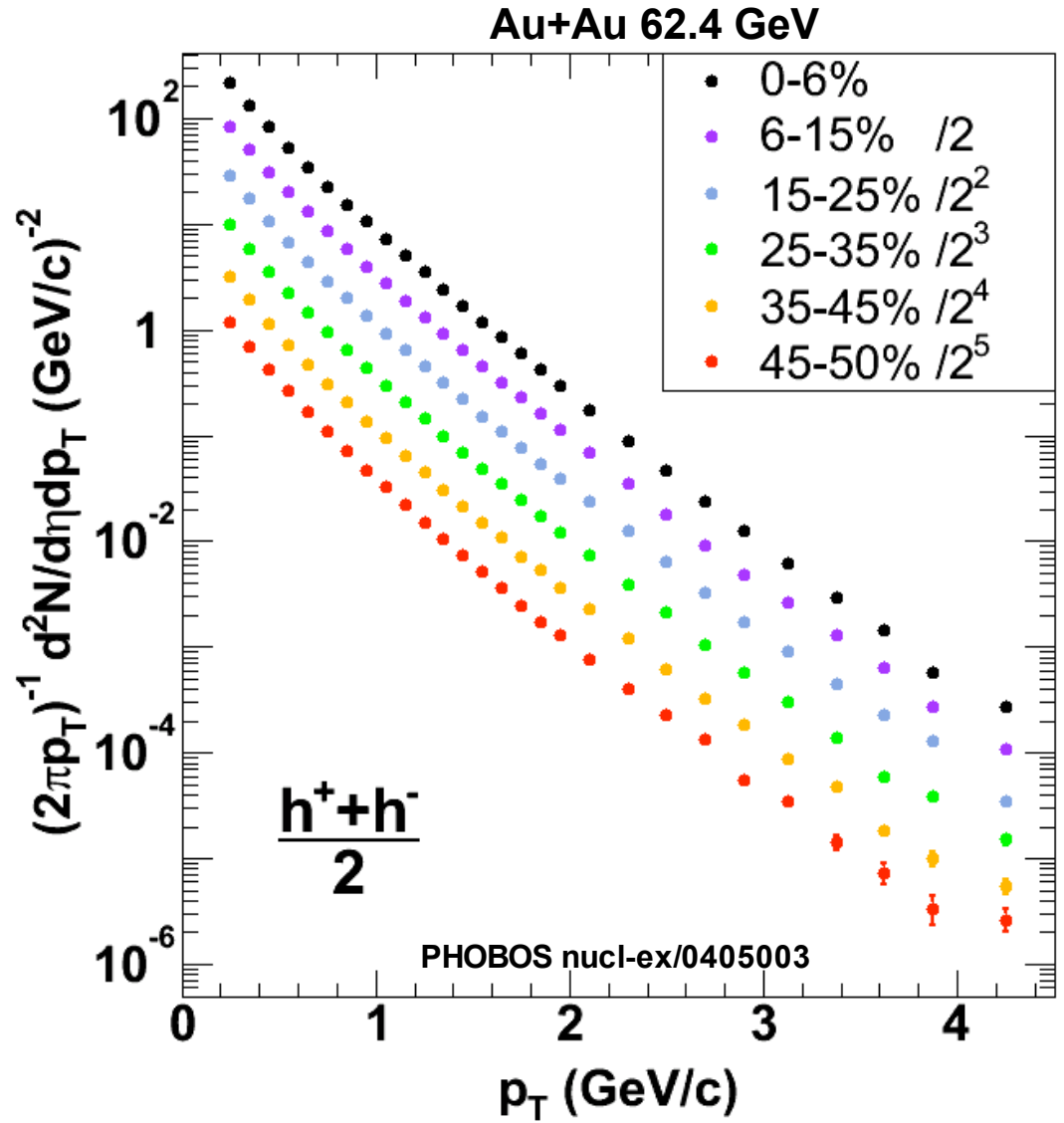
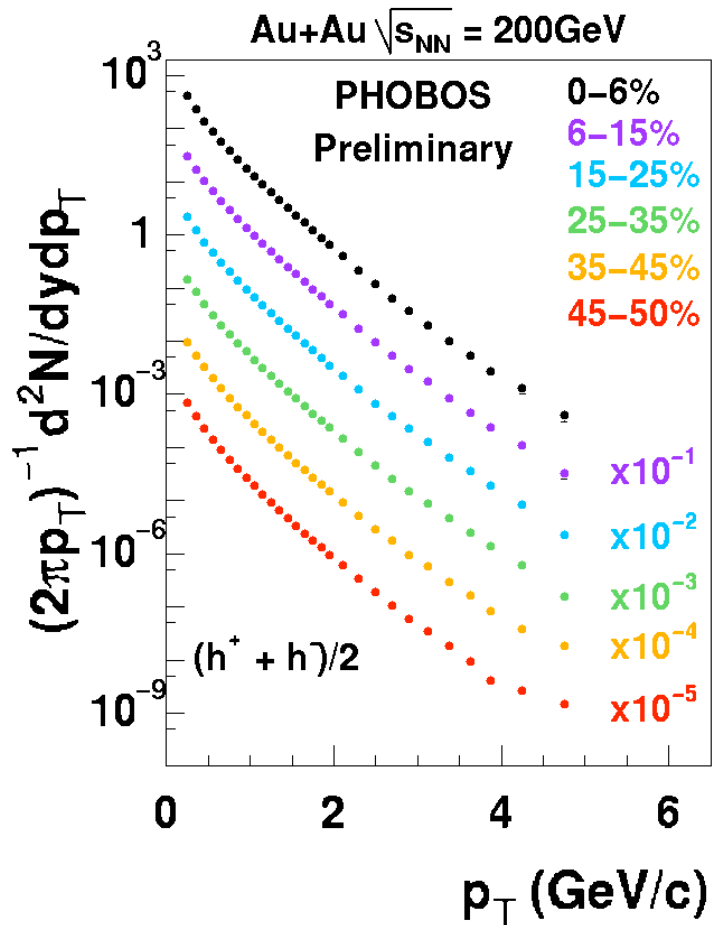


- $dN/dh / \langle N_{part} \rangle / 2$ changes with \sqrt{s} , $\langle N_{part} \rangle$
- Energy and Centrality Dependence Factorize



Charged Hadron Spectra at 200 and 62.4 GeV

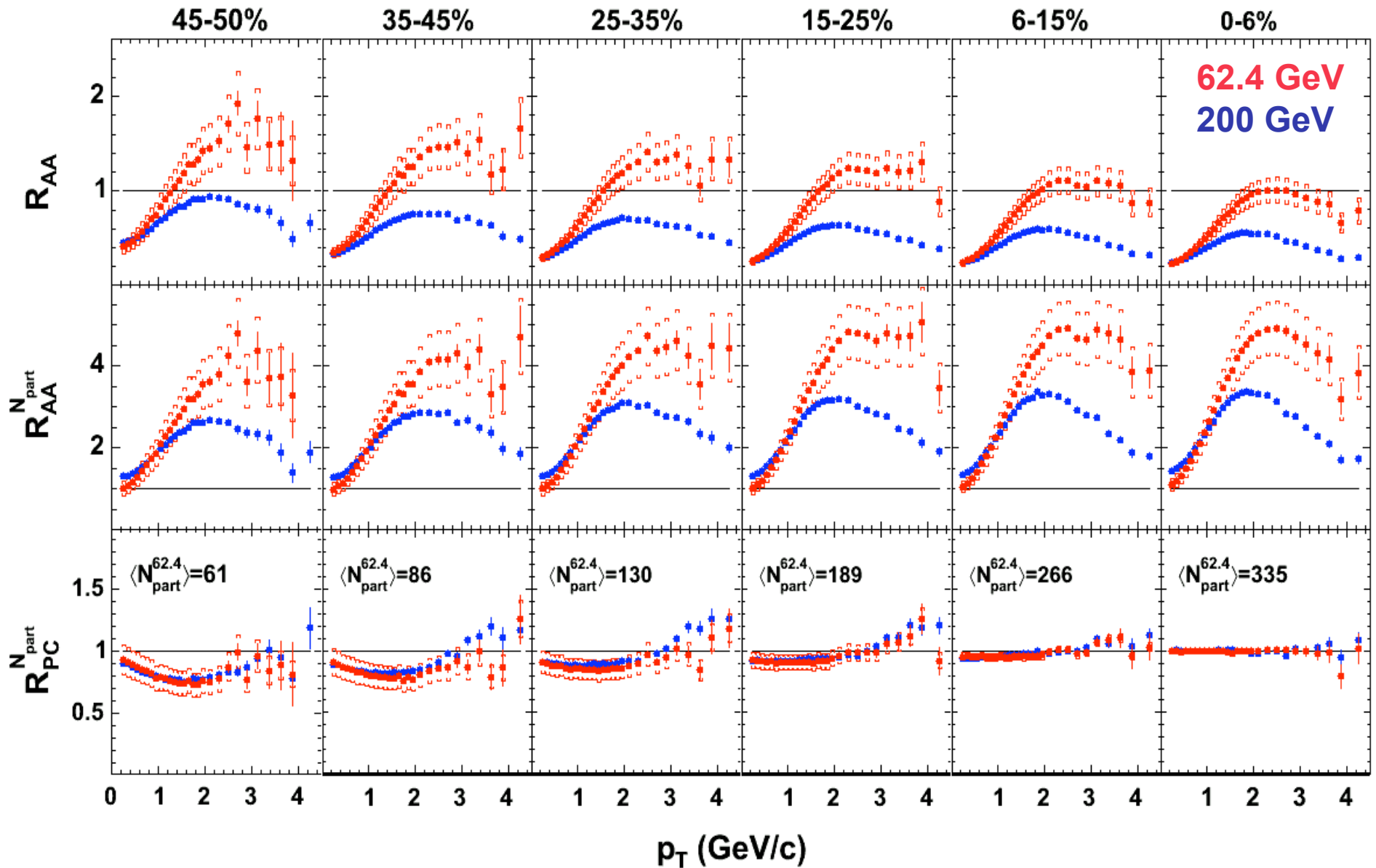
Phys.Lett. B 578 (2004) 297



Güntner Roland
GRC 2004

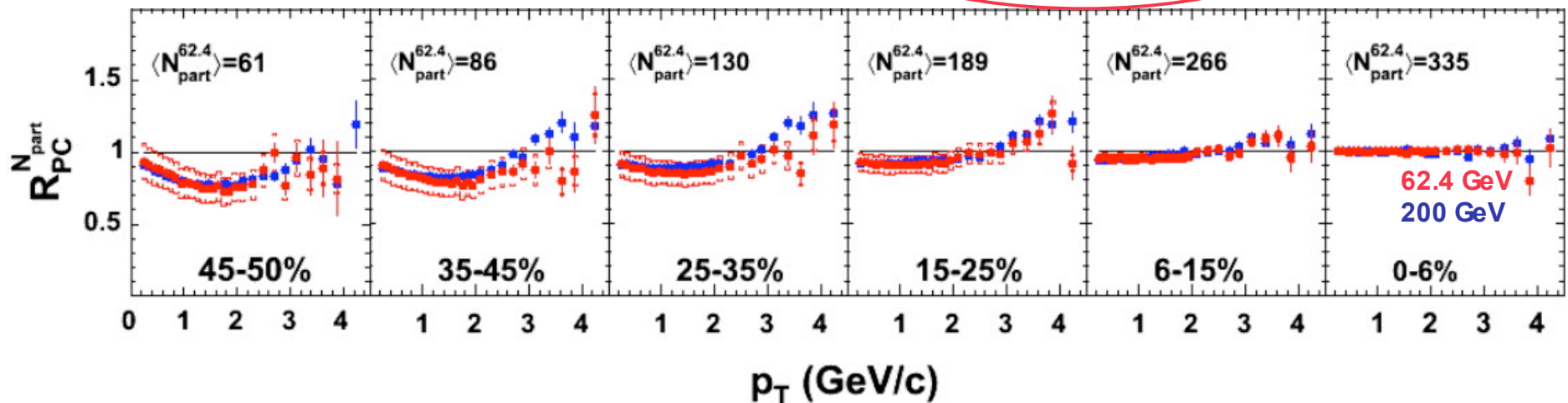


Centrality and Energy Evolution



Factorization

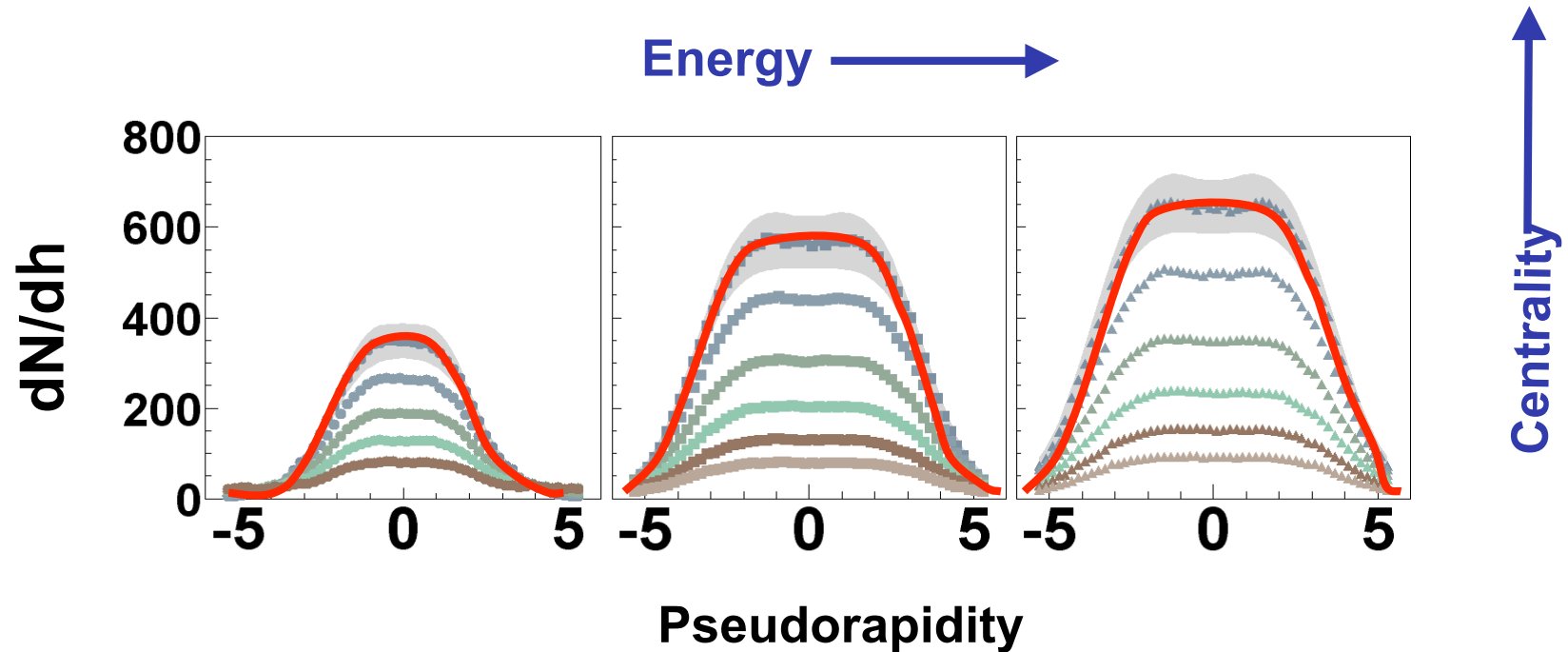
$$R_{PC}^{N_{part}} = \frac{\langle N_{part}^{0-6\%} \rangle}{\langle N_{part} \rangle} \frac{d^2 N_{AA} / dp_T d\eta}{d^2 N_{AA}^{0-6\%} / dp_T d\eta}$$



- Yield/participant changes by less than 25% for all p_T
- Factorization of energy and centrality dependence



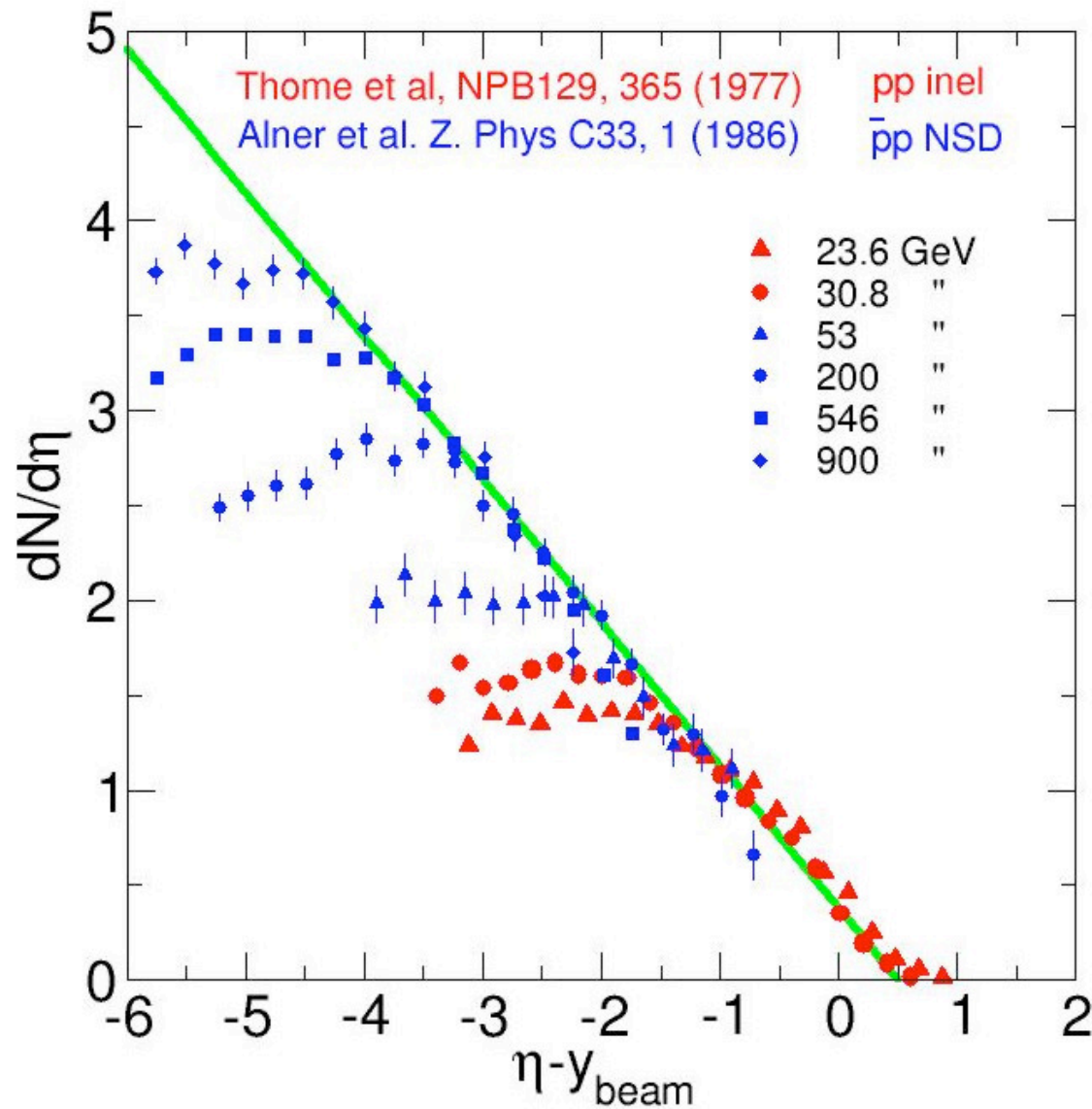
III. Shape of dN/dh Distributions



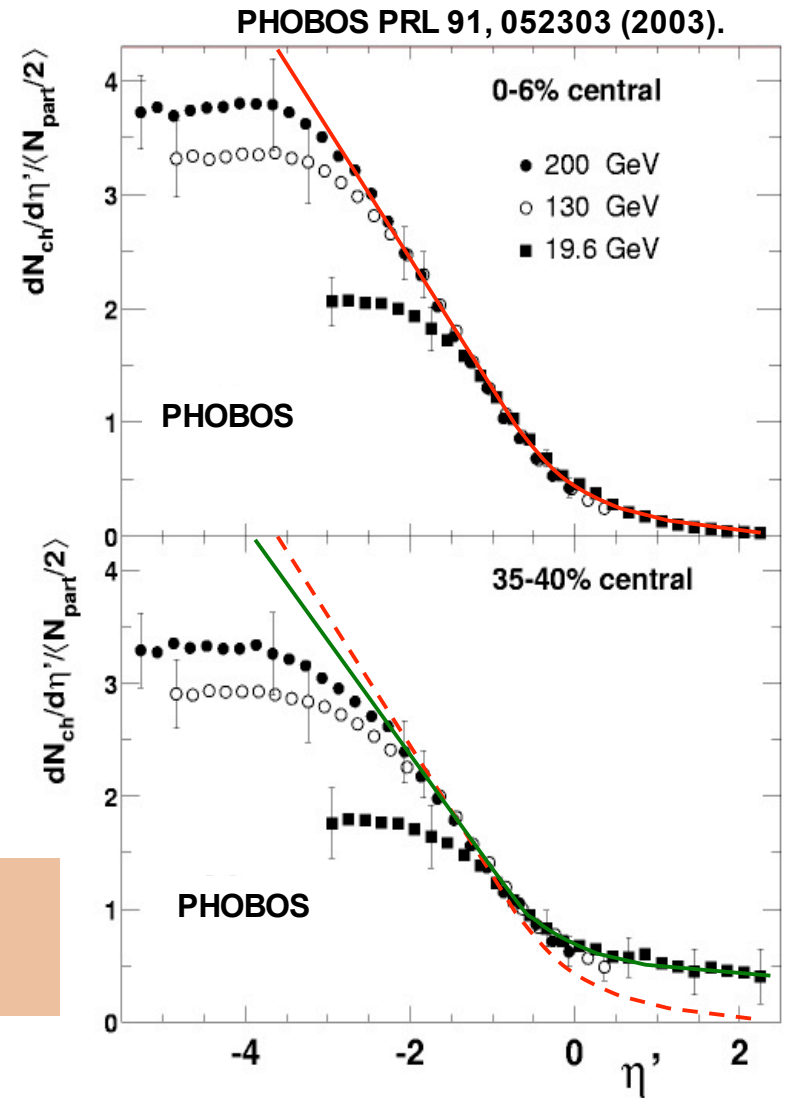
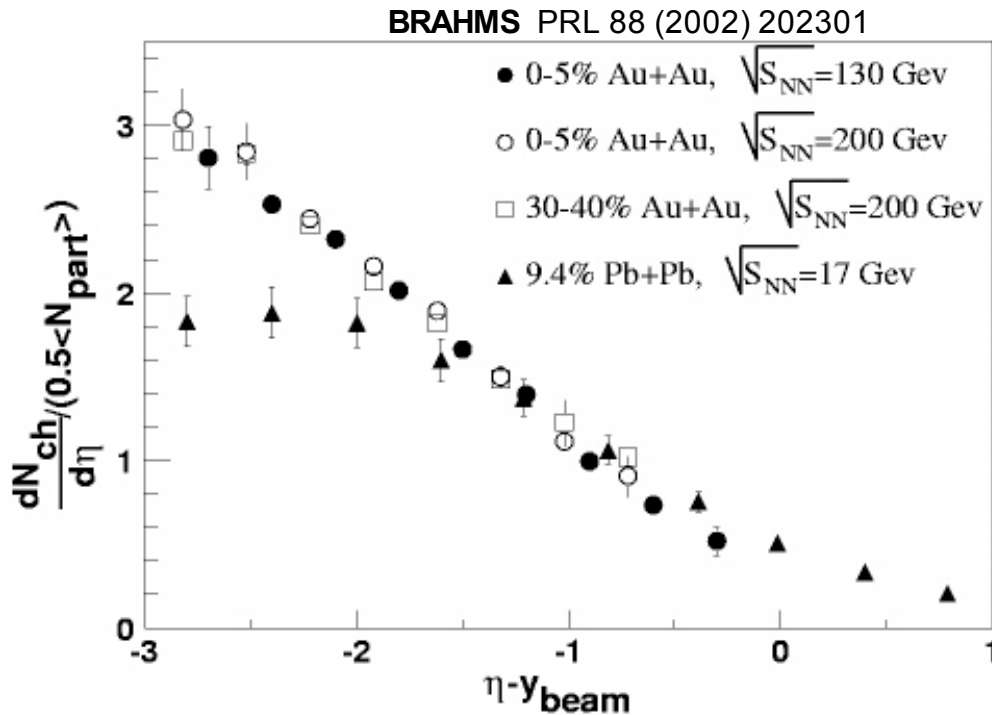
How does shape of dN/dh (dN/dy)
change with Energy?



Limiting Fragmentation in p+p



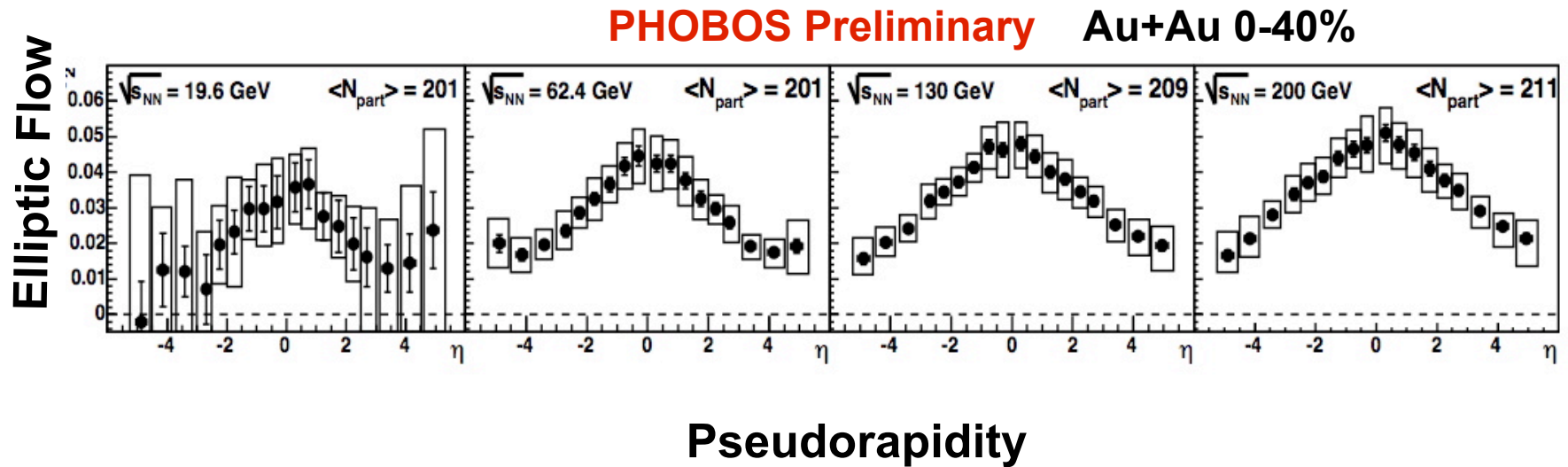
Limiting Fragmentation



Centrality-dependent Limiting Fragmentation in Au+Au at RHIC



Elliptic flow away from $h=0$

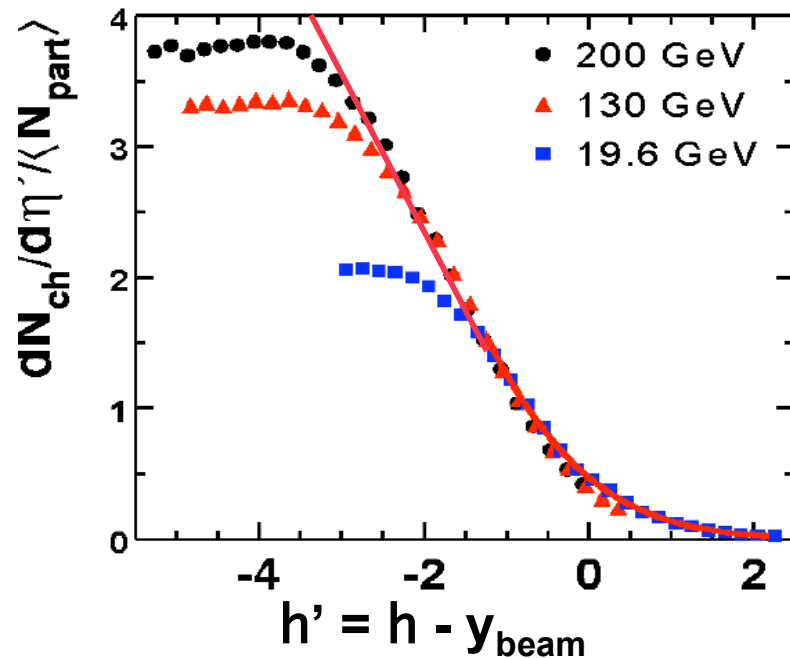


Strong h dependence of v_2 over full
RHIC energy range (19.6 - 200 GeV)

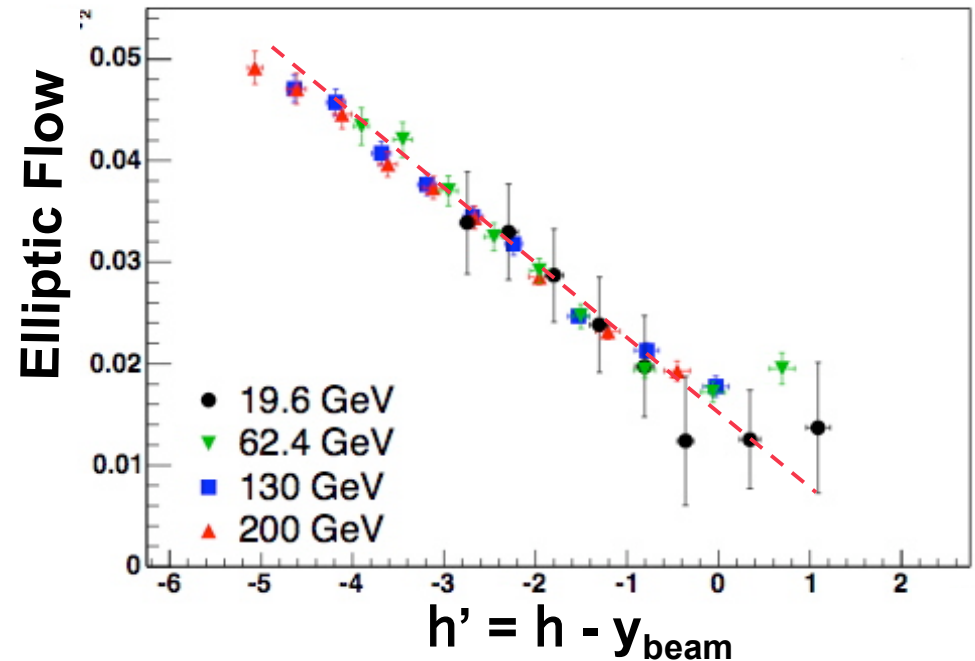


“Limiting Fragmentation”

PRL 91, 052303 (2003)



PHOBOS Preliminary



$v_2(h')$ is energy-independent

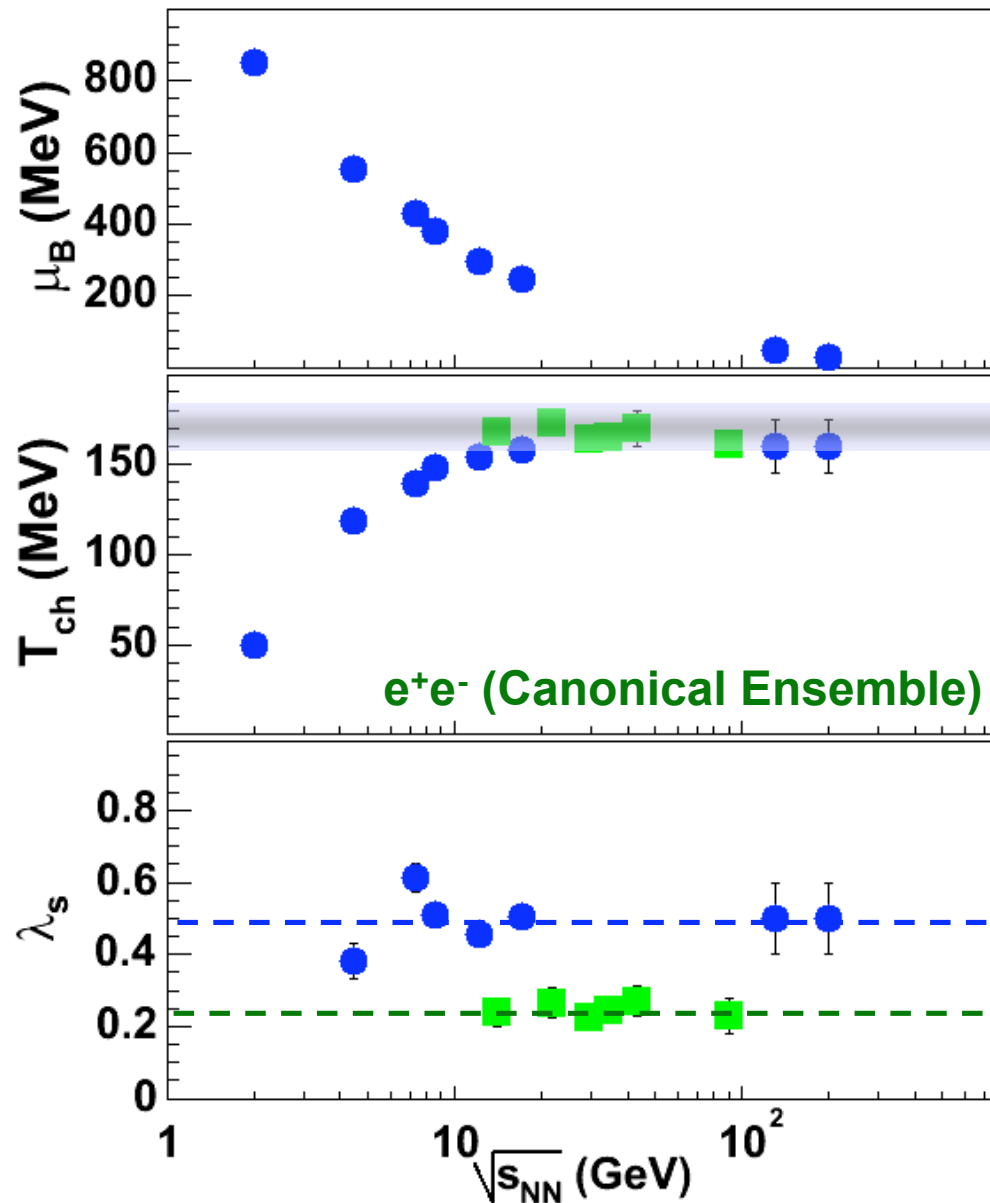


Summary

- **RHIC data (and surprises) continue to appear at high rate**
- **Data exhibit surprising simplicity**
 - **Success of statistical and hydro-like models**
 - **N_{part} scaling of total multiplicity**
 - **correspondence with elementary collisions**
 - **Factorization of energy and centrality dependence**
 - **Universality of dN/dh and v_2 in restframe of participating nucleus**
- **Dynamical (?) origin still to be understood**



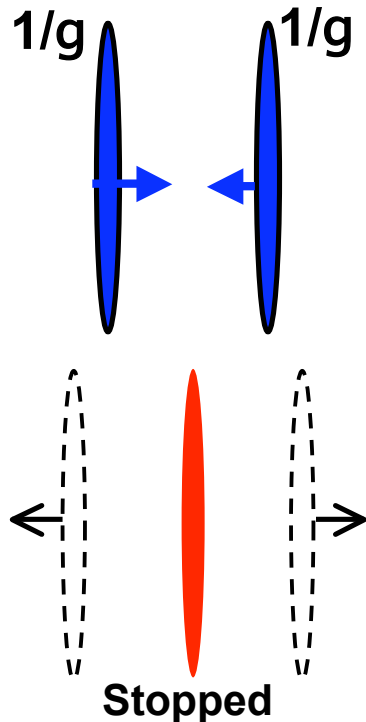
“Thermal Fit” Parameters vs sqrt(s)



e^+e^- hadronizes at same T_{ch}
Are we looking at a *local*
or *global* property?

Strangeness enhancement
unique to AA
Global (or at least large
correlation volume)

Landau Hydrodynamics



Carruthers, Duong-Van on pp data in 1973:

surprisingly well described by Landau's energy-dependent **Gaussian rapidity distribution** [see Eq. (2.1) for the definition of y]

$$\frac{1}{\sigma_{\text{in}}} \frac{d\sigma}{dy} = \frac{dN}{dy}$$

$$= N \exp(-y^2/2L)/(2\pi L)^{1/2}, \quad (1.5)$$

where the parameter L is

$$L = \frac{1}{2} \ln(s/4m_p^2), \quad (1.6)$$

where s is the squared total c.m. energy.

y vs. η

Get a suppression in the spectra which is largest at low p_t and small $|\eta|$. It vanishes at large $|\eta|$ and high p_t .

Gives the famous dip in multiplicity distribution.

If integrating v_2 over p_t , get suppression of the lower p_t part (where v_2 is small) and the signal should rise.

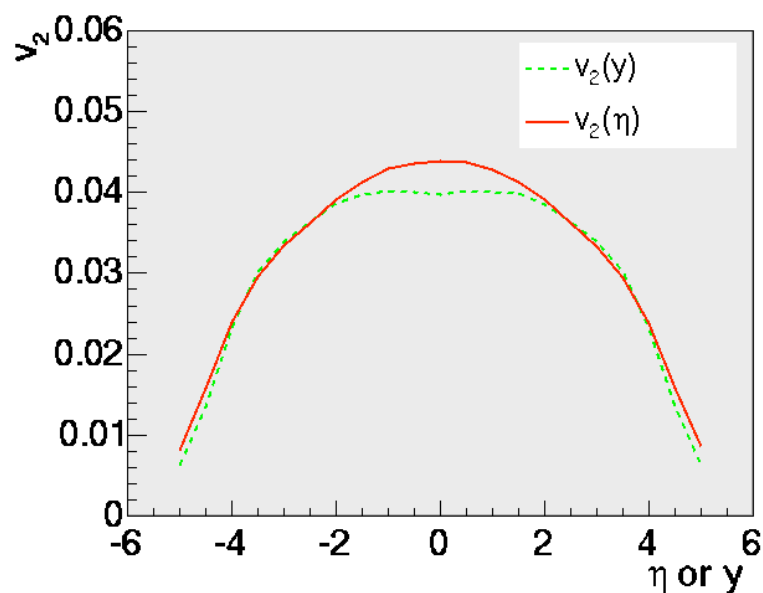
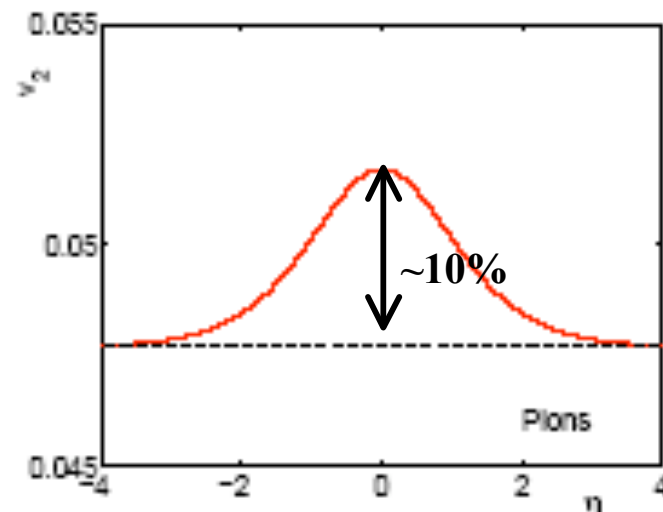


P. Kolb, Proc. of 17th Winter Workshop on Nuclear Dynamics (2001)

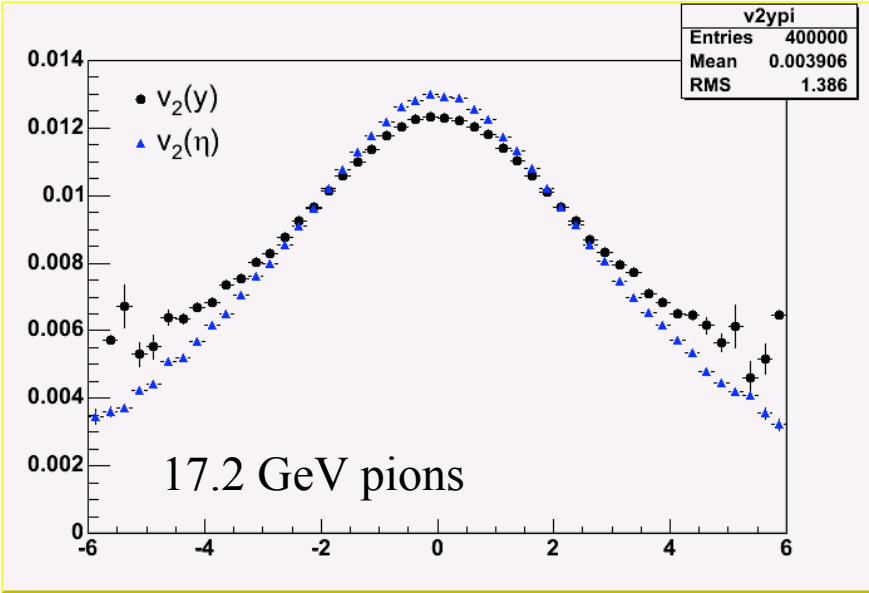
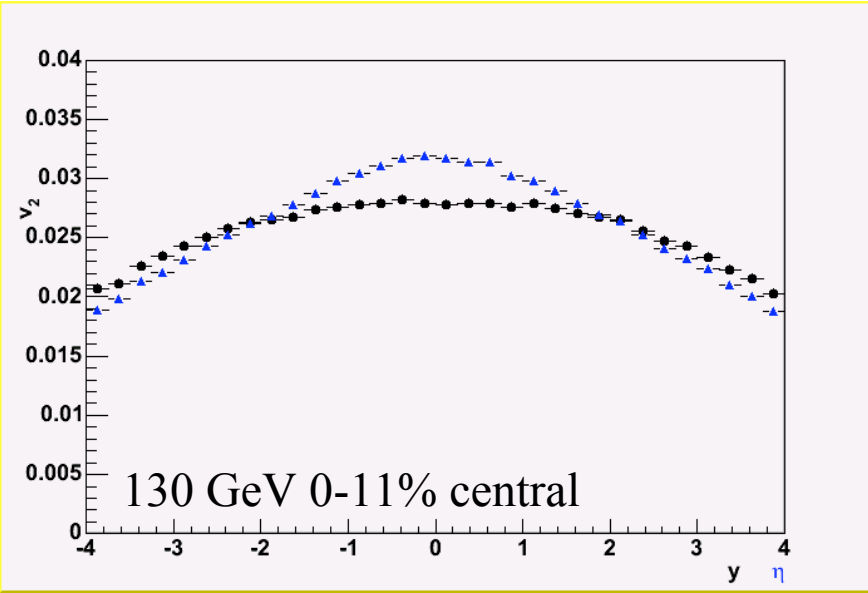
Transformation of spectra from η to y leads to suppression of multiplicity at low p_t and low $|\eta|$

This leads to an enhancement of inclusive v_2 at mid- η

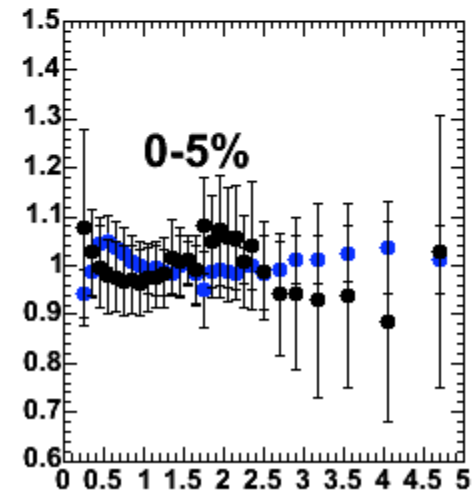
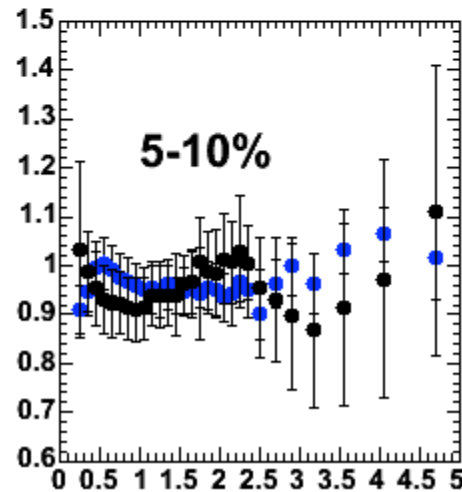
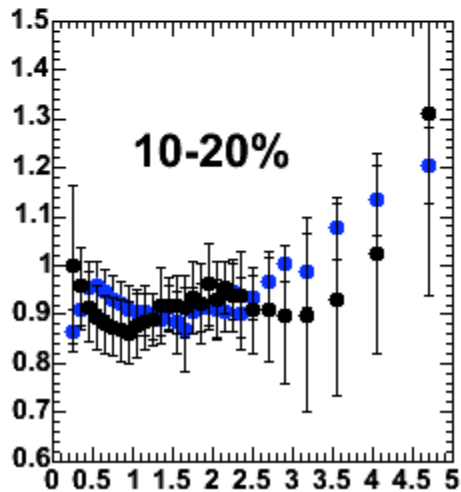
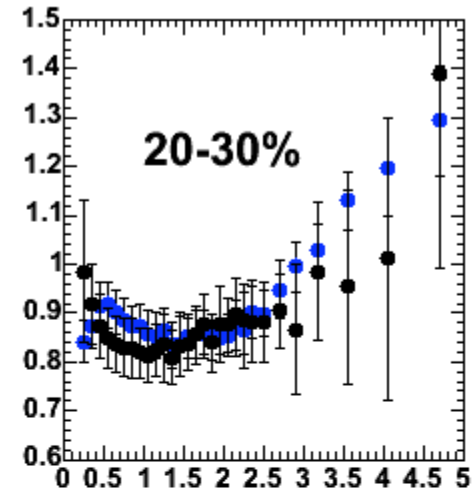
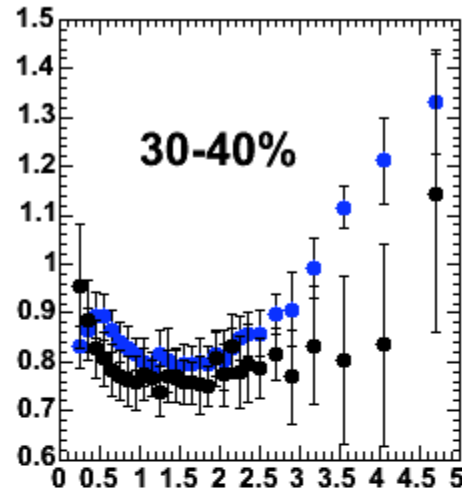
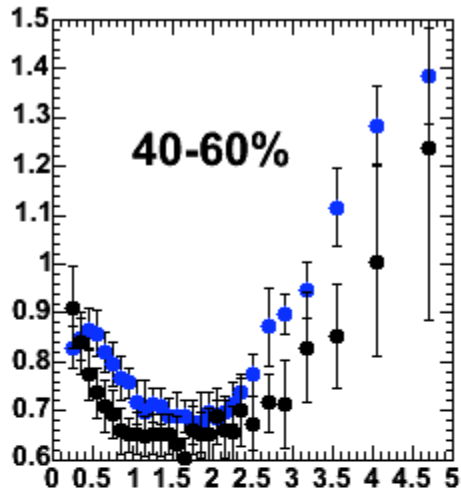
T. Hirano, BNL-Riken Workshop on Collective Flow and the QGP (Nov. 2003)



PHOBOS simulations - Preliminary



R_{PC} vs. p_T , STAR 130 and 200 GeV



PRL 89, 202301, 2002

PRL 91, 172302, 2003



Gunther Roland
GRC 2004