Bulk Observables in p-p, d-Au and Au-Au at RHIC

David Hofman
University of Illinois at Chicago

For the PHOBOS Collaboration

QCD and High Energy Hadronic Interactions
March 28 – April 4, 2004
XXXIXth Recontres de Moriond

PHOBOS Collaboration (February 2004)

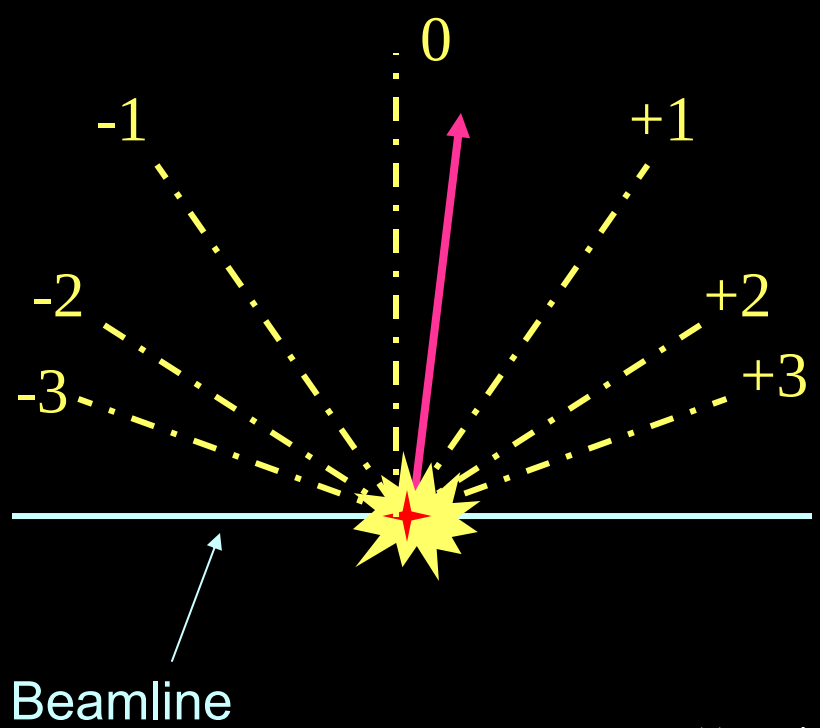
Birger Back, Mark Baker, Maarten Ballintijn, Donald Barton, Russell Betts, Abigail Bickley, Richard Bindel, Wit Busza (Spokesperson), Alan Carroll, Zhengwei Chai, Patrick Decowski, Edmundo García, Tomasz Gburek, Nigel George, Kristjan Gulbrandsen, Clive Halliwell, Joshua Hamblen, Adam Harrington, Michael Hauer, Conor Henderson, David Hofman, Richard Hollis, Roman Hołyński, Burt Holzman, Aneta Iordanova, Jay Kane, Nazim Khan, Piotr Kulinich, Chia Ming Kuo, Willis Lin, Steven Manly, Alice Mignerey, Gerrit van Nieuwenhuizen, Rachid Nouicer, Andrzej Olszewski, Robert Pak, Inkyu Park, Heinz Pernegger, Corey Reed, Michael Ricci, Christof Roland, Gunther Roland, Joe Sagerer, Helen Seals, Iouri Sedykh, Wojtek Skulski, Chadd Smith, Maciej Stankiewicz, Peter Steinberg, George Stephans, Andrei Sukhanov, Marguerite Belt Tonjes, Adam Trzupek, Carla Vale, Siarhei Vaurynovich, Robin Verdier, Gábor Veres, Edward Wenger, Frank Wolfs, Barbara Wosiek, Krzysztof Woźniak, Alan Wuosmaa, Bolek Wysłouch

ARGONNE NATIONAL LABORATORY
INSTITUTE OF NUCLEAR PHYSICS, KRAKOW
NATIONAL CENTRAL UNIVERSITY, TAIWAN
UNIVERSITY OF MARYLAND
BROOKHAVEN NATIONAL LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

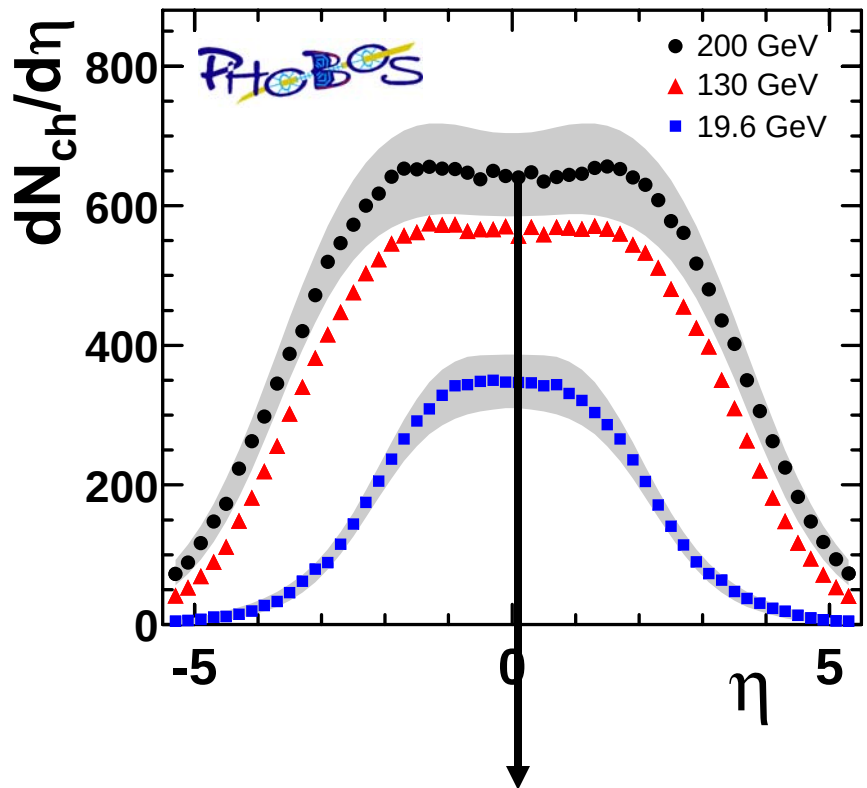
Charged Particle Production at RHIC

Pseudorapidity = η = Lorentz invariant angle with respect to the beampipe

$\eta = -\ln \tan \theta/2$



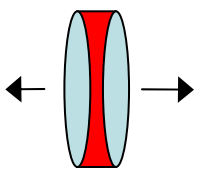
Central (head-on) Collisions

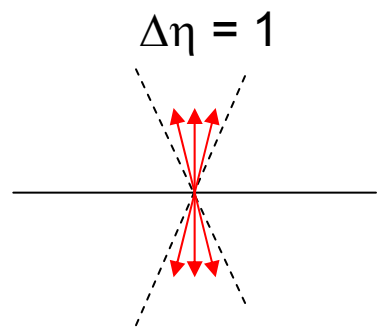


$$\frac{dN_{\mathrm{ch}}}{\mathrm{d}\eta} \approx 670$$ @ midrapidity 200 GeV

A “coffee napkin” Estimate of Energy Density at Midrapidity.

Look at all produced particles in a Central ‘Head-on’ Collision





$$\left(\frac{dN}{d\eta}\right)_{all} \sim 1000 \quad \langle E \rangle \sim 1 GeV$$

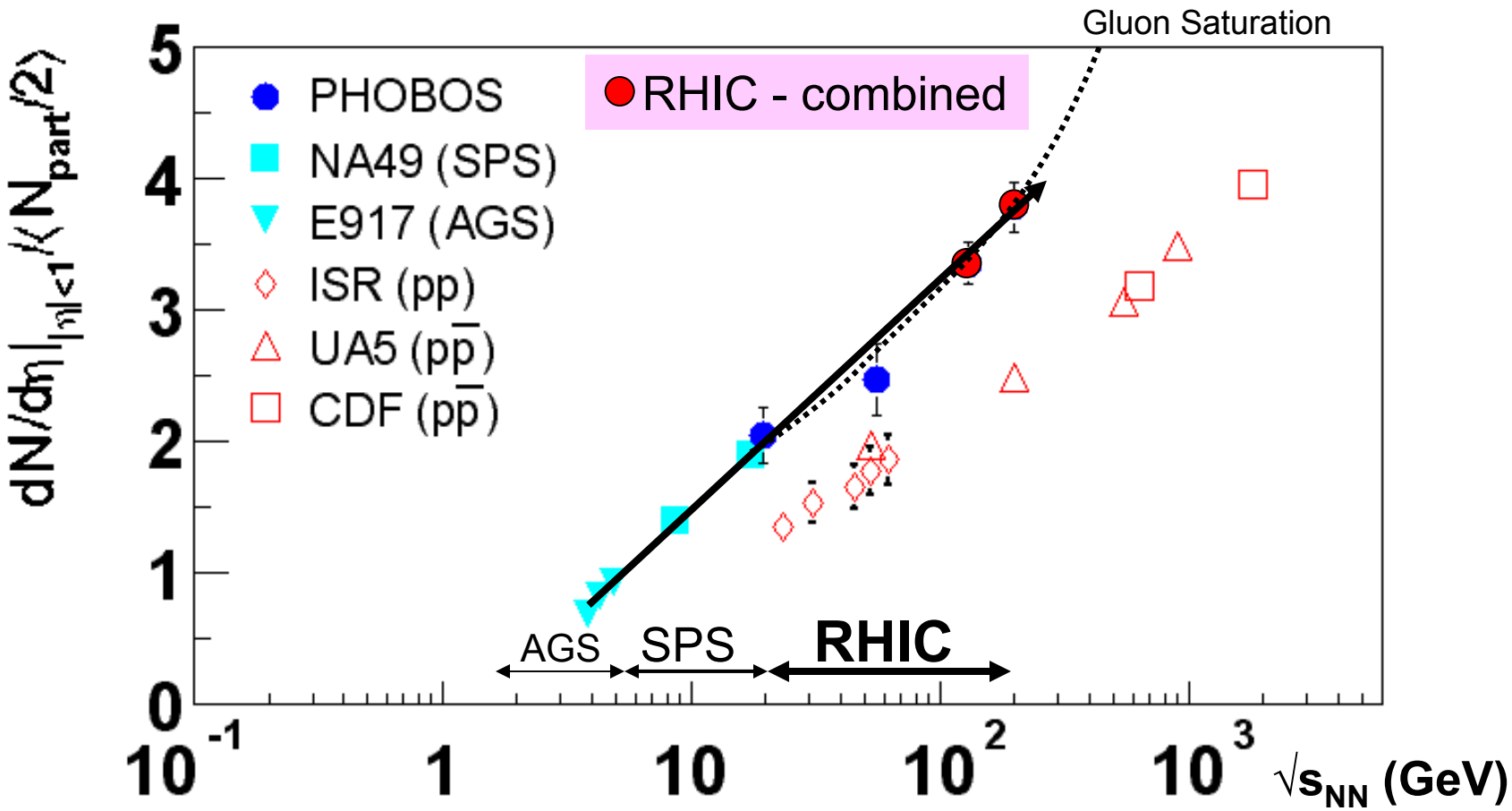
Total energy released in $\Delta\eta$=1 is ~ 1000 GeV

Max initial overlap volume $\sim \pi R^2 (1\,fm) \sim 200\,fm^3$

$\Rightarrow$ Initial Energy Density Estimate, $\varepsilon \sim$ **5 GeV/fm^3**

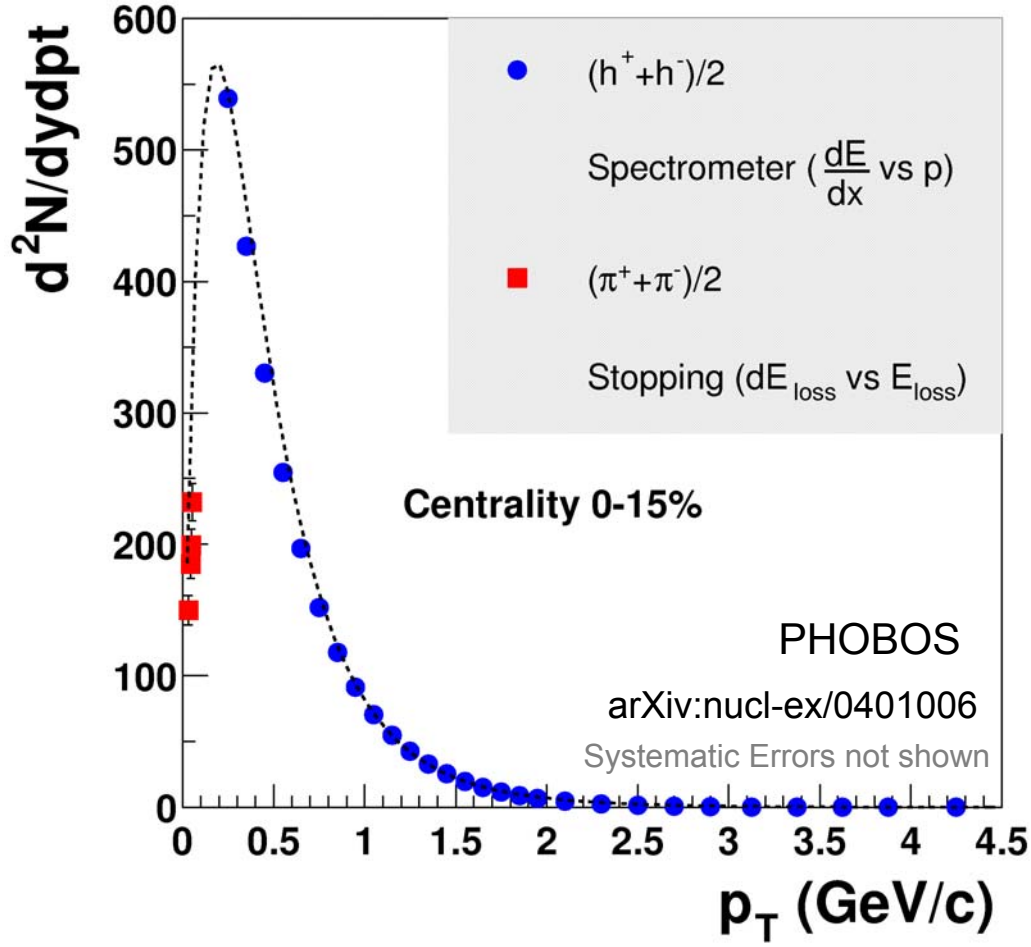
Charged Particle Density near Midrapidity

Central Collisions (for Heavy Ion data)



→ "Logarithmic Rise" for AA data, above pp baseline

‘PHOBOS’ Bulk Observables ≡ Low p_T



$$\frac{dN}{d\eta}(\text{charged particle yields in general})\ \text{"}measures\text{"}\ p_T < 2\,GeV/c$$

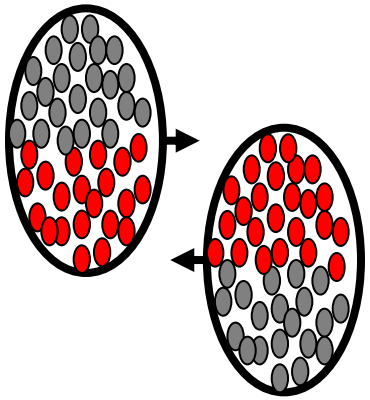
p + p Collisions

"Participant" Scaling

Au+Au Collisions

# of participating pairs of nucleons

$\equiv N_{part}/2$



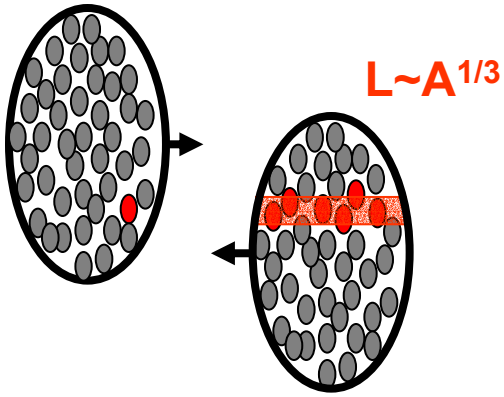
$N_{part}/2 = 1$

$N_{part}/2 \sim A$

Binary "Collision" Scaling

# of binary NN collisions

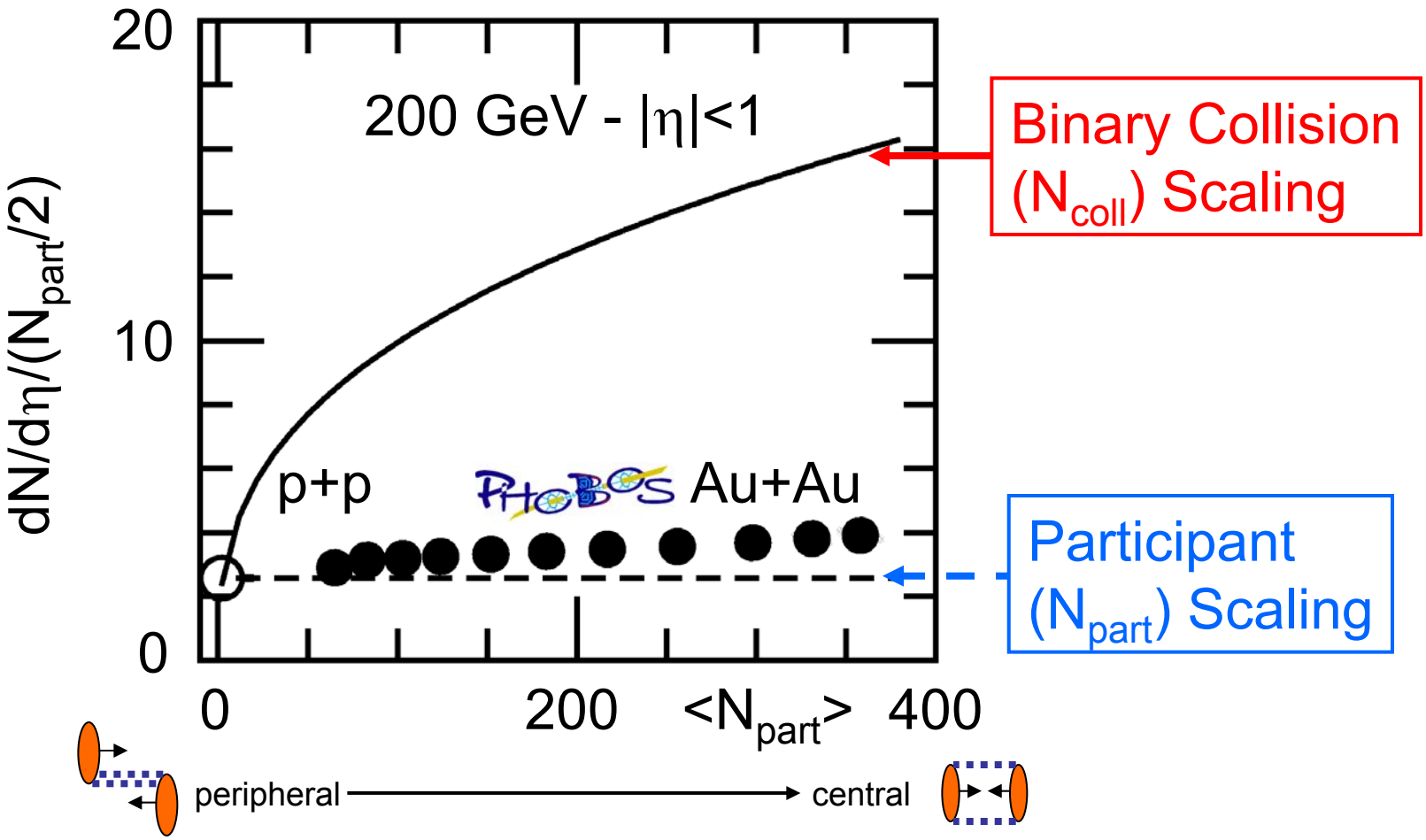
$\equiv N_{coll}$



$N_{coll} = 1$

$N_{coll} \sim A^{4/3}$

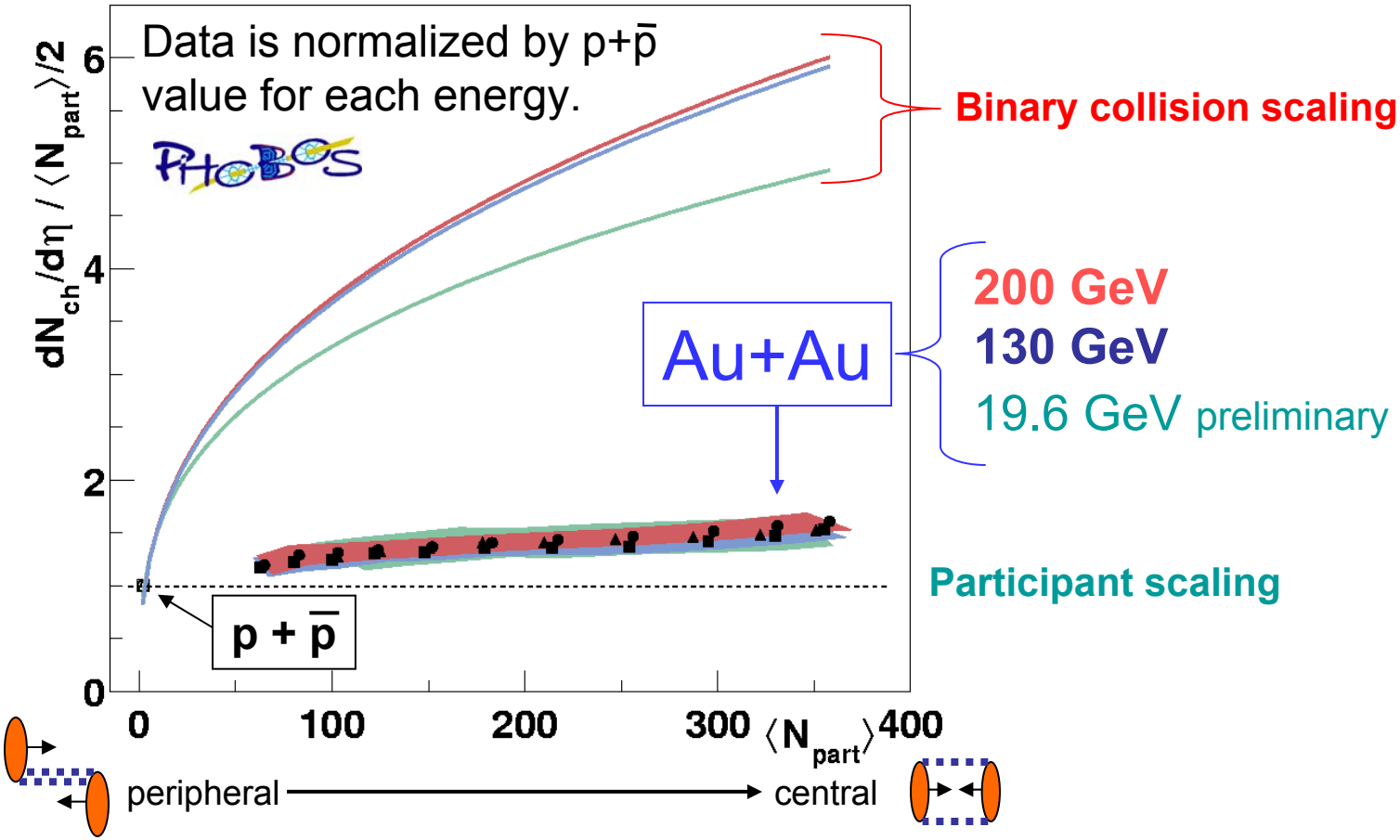
Centrality Dependence of Midrapidity Charged Particle Yields



→ Au+Au Centrality Dependence allows only about 10% N_{coll} Scaling

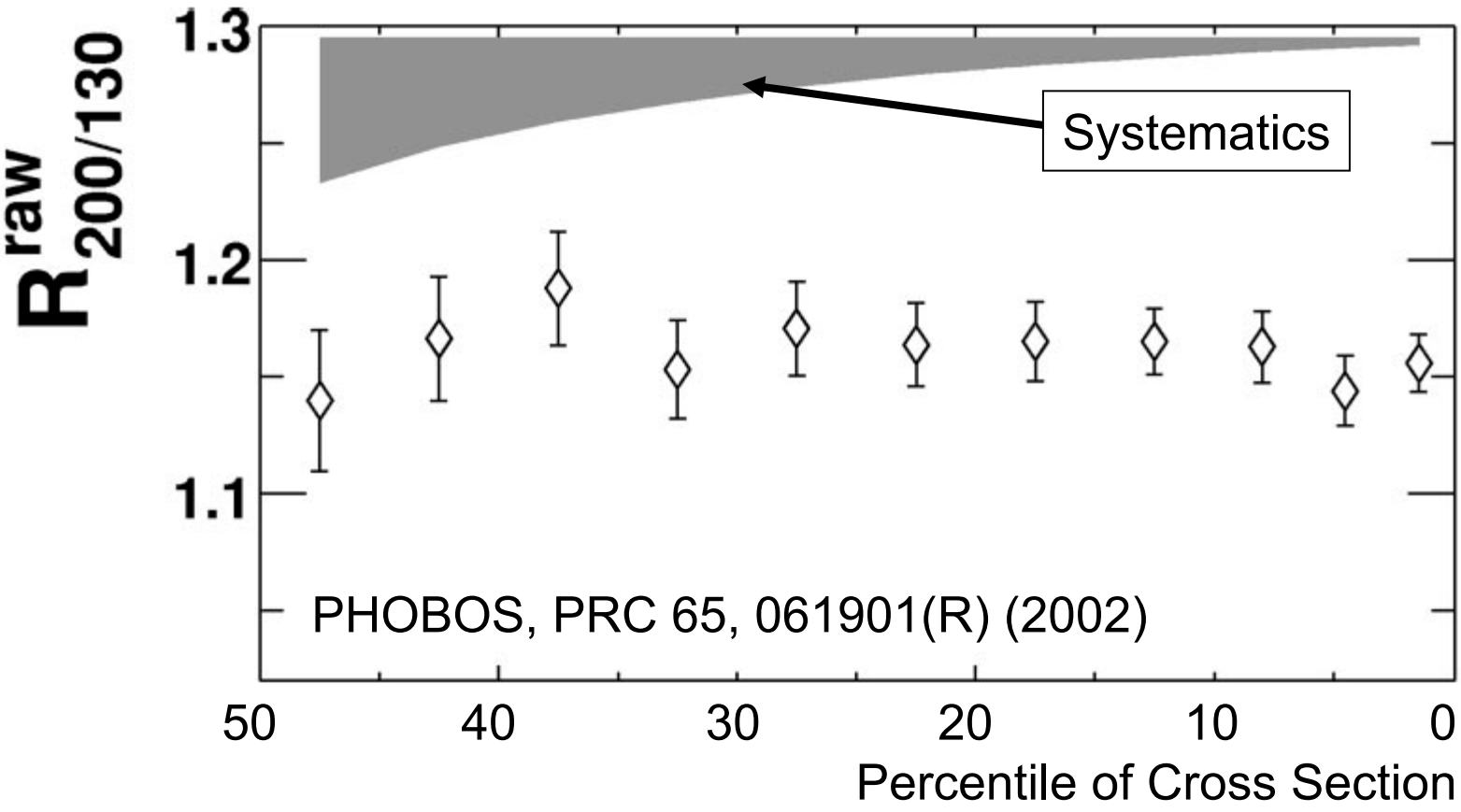
Charged Particle Production at Midrapidity

Energy and Centrality Dependence



→ All RHIC energies show a similar N_{part} dependence

Ratios to Help Cancel Systematics

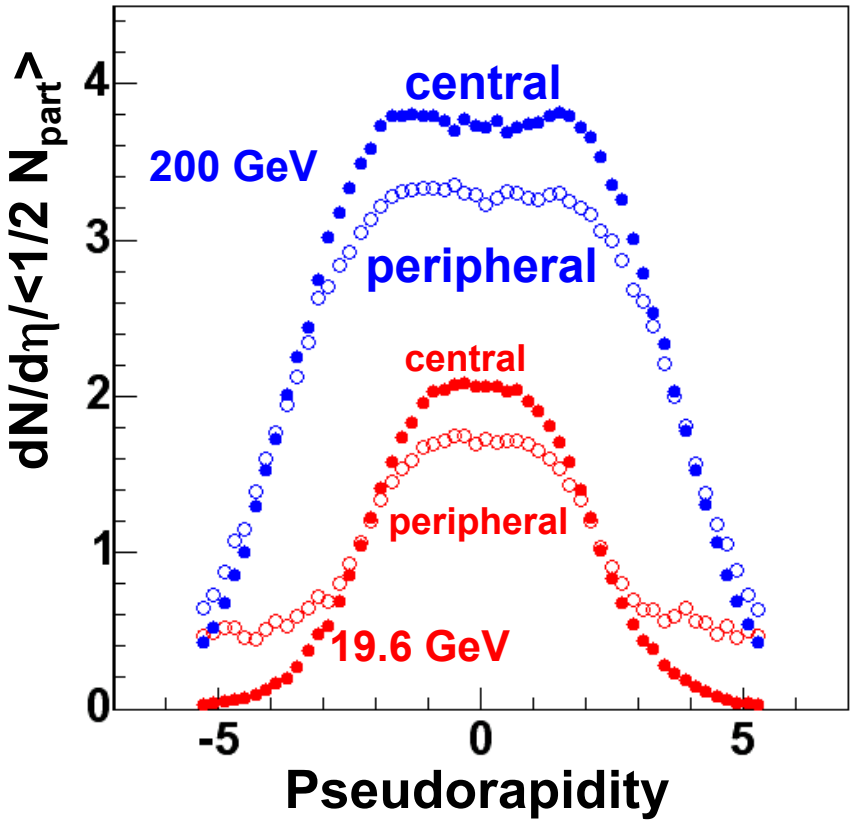


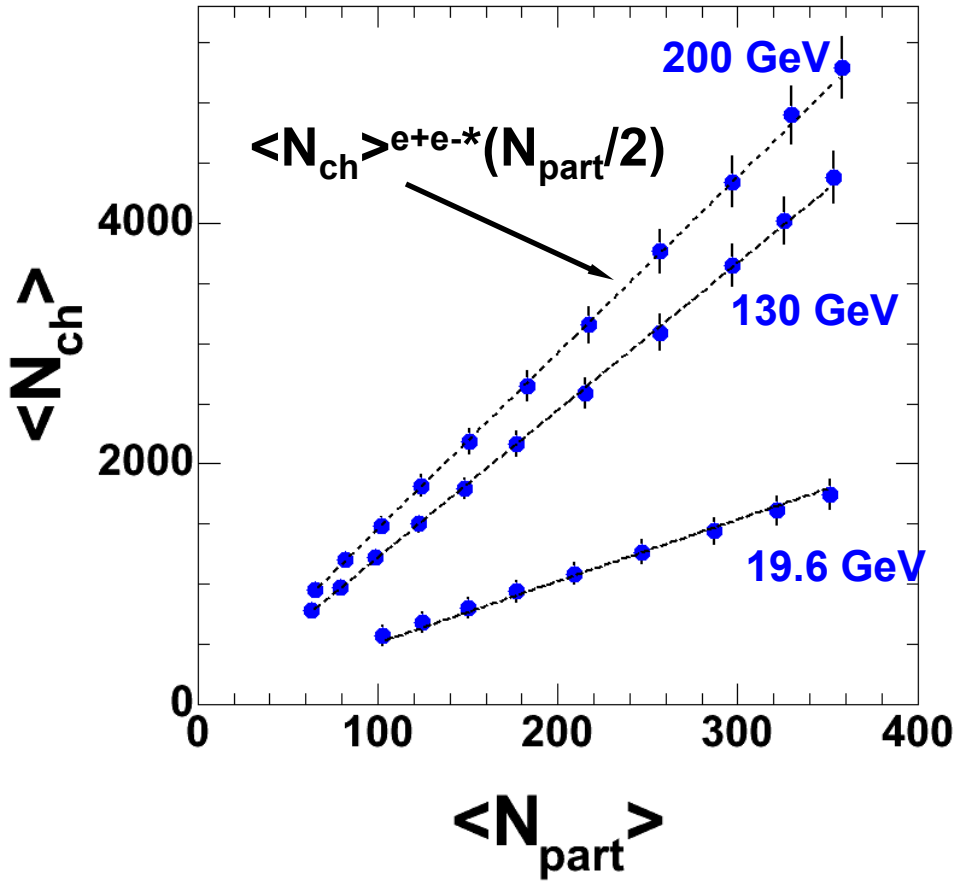
→Systematics Dominated by Trigger Efficiency/Centrality Determination

Ratio (200/130) = 1.14 ± 0.01 (stat) ± 0.05 (syst)

Centrality Dependence of Total Charged Particle Production $\langle N_{ch} \rangle$

Au+Au Collisions

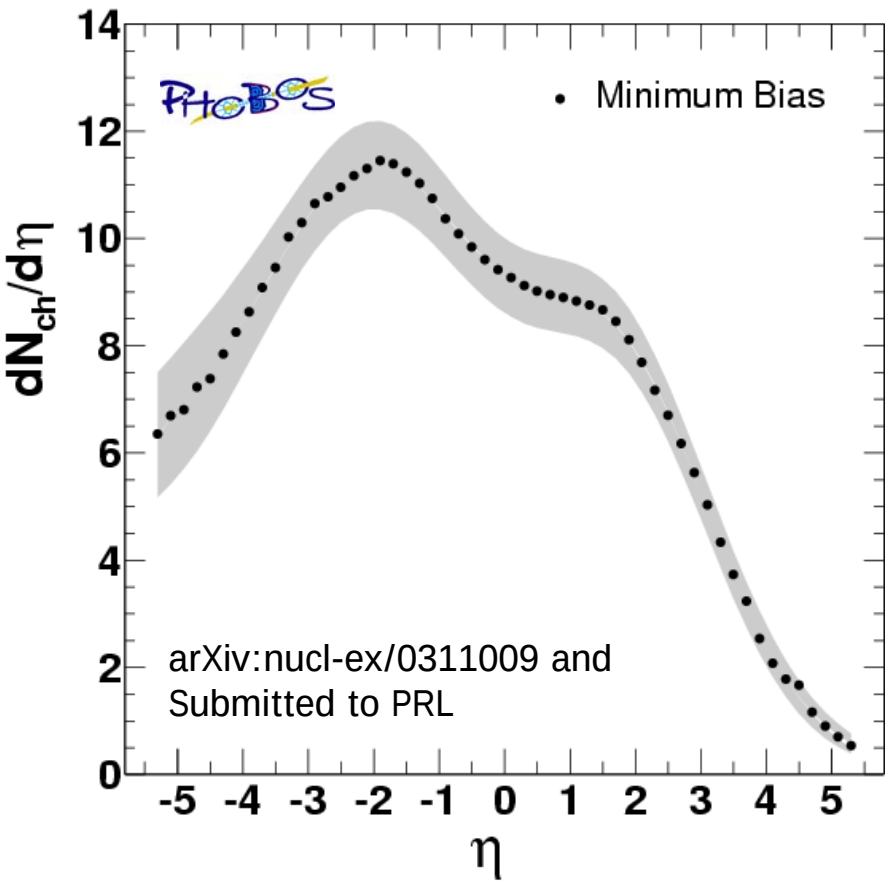




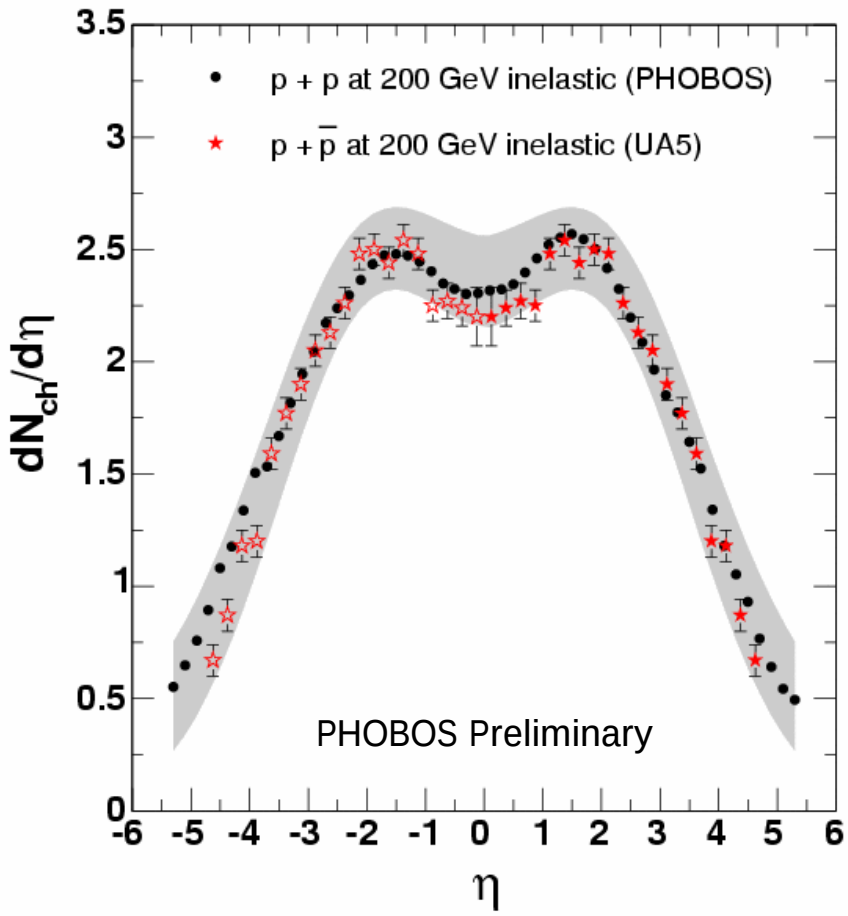
→ $N_{ch}(AuAu) = (N_{part}/2)\ N_{ch}(e^+e^-)$

Pseudorapidity Distribution of Charged Particles in d + Au and p + p Collisions at 200 GeV

• d + Au at 200 GeV Min-Bias



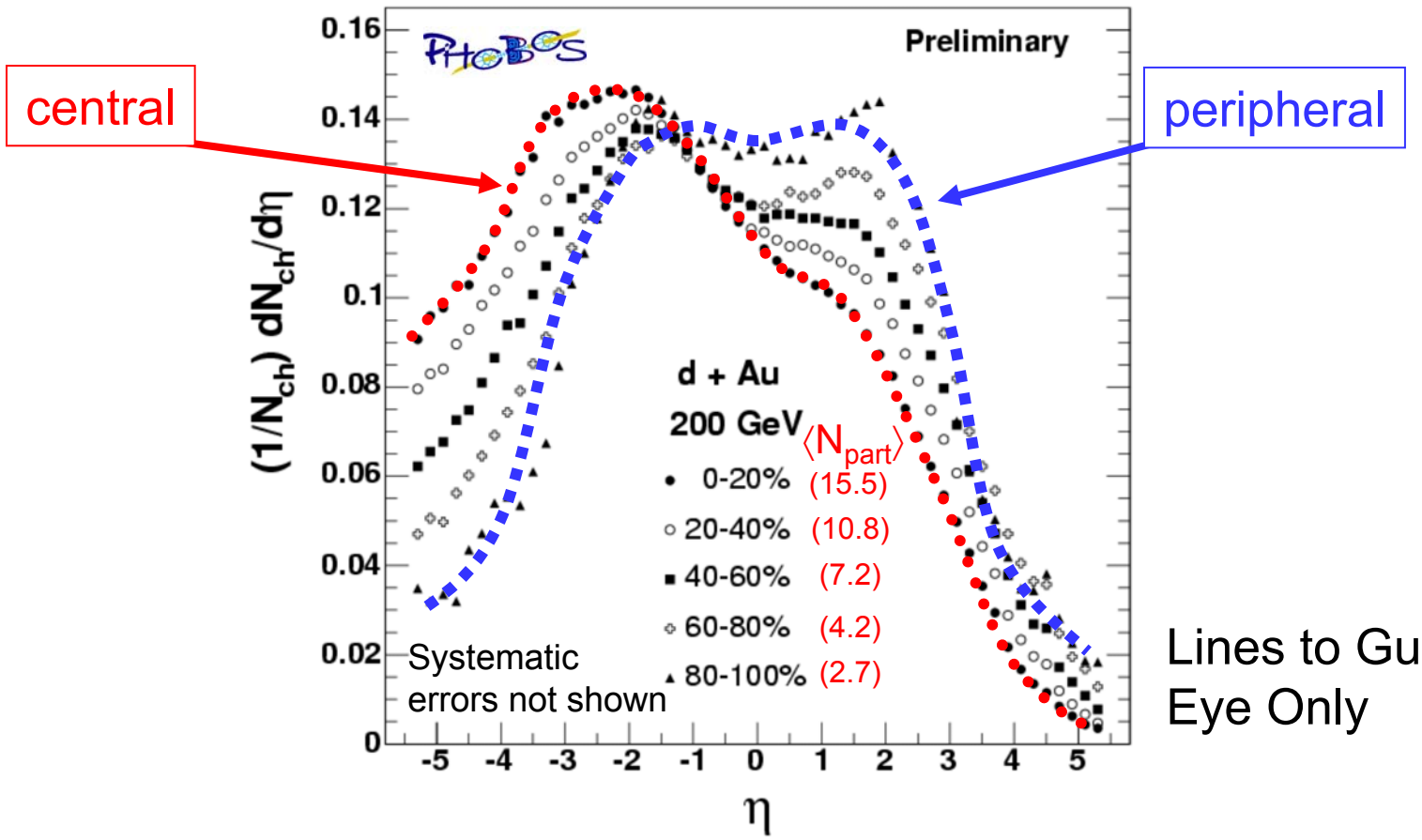
• p + p at 200 GeV



→ PHOBOS can measure down to very low multiplicities.

d+Au Centrality Dependence of $dN_{ch}/d\eta$ Shape

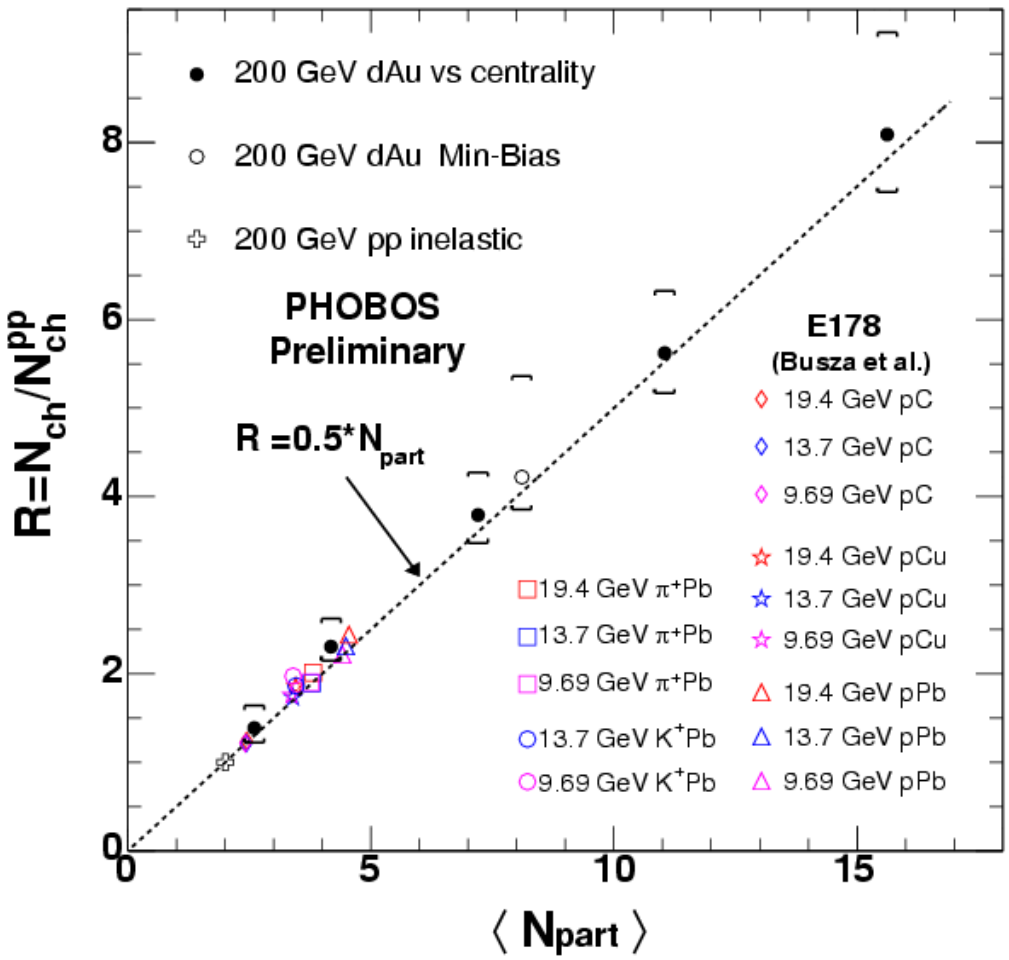
(Normalized to N_{ch} so can compare shape change)



Lines to Guide Eye Only

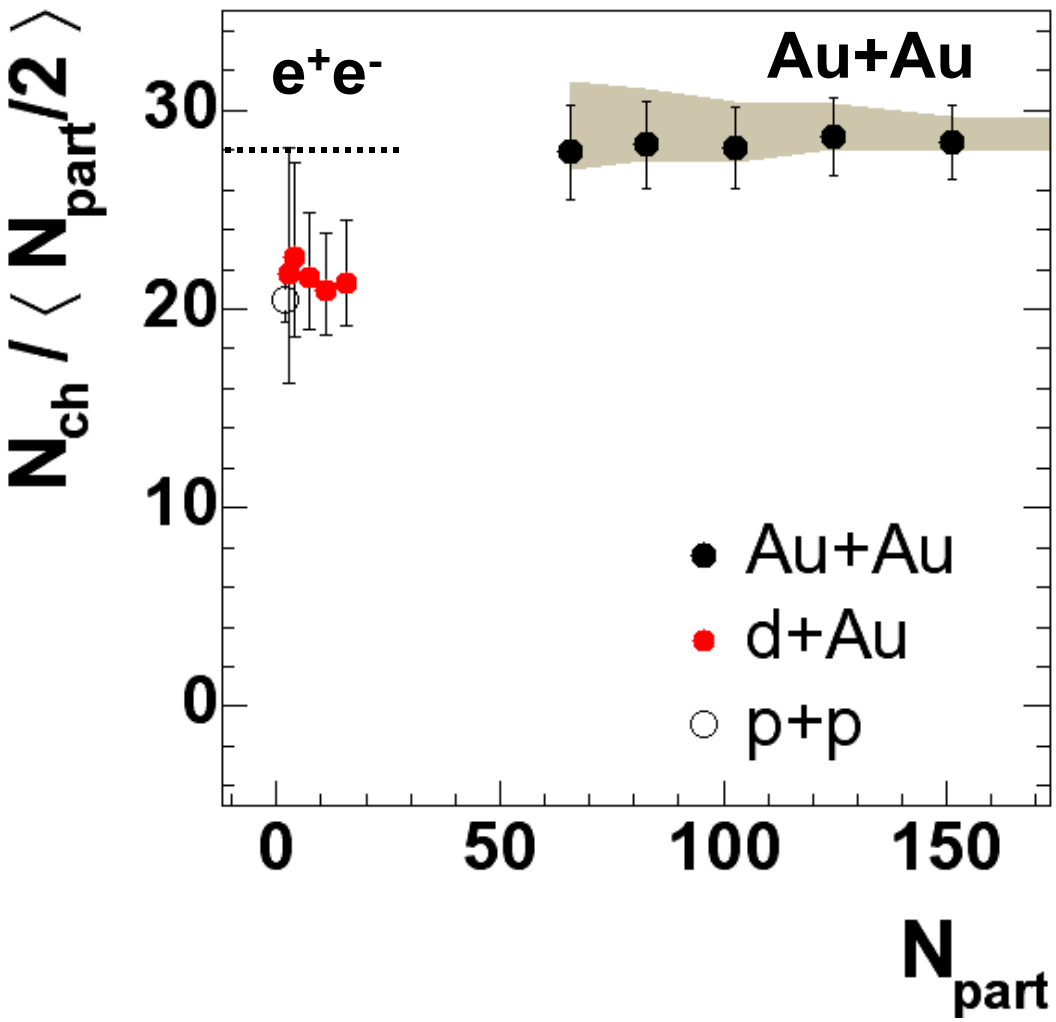
→ In dAu, particle production shifts to negative rapidity with increasing N_{part}.

Participant Scaling in d+Au



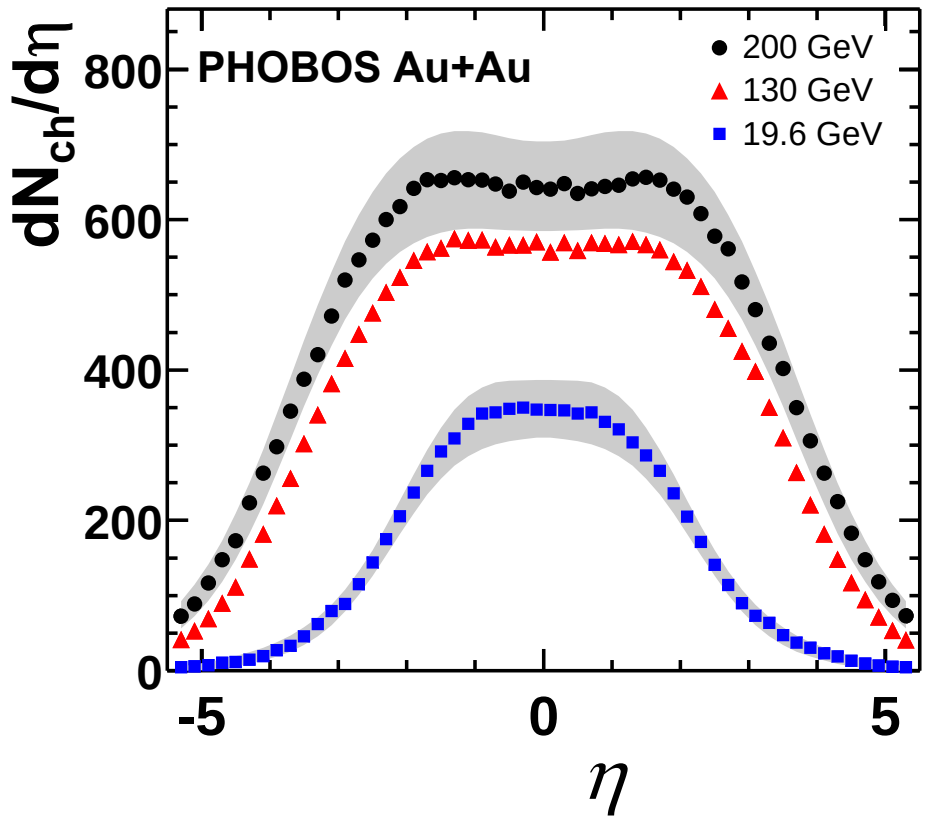
→ $N_{ch}(dAu) = (N_{part}/2)\, N_{ch}(pp)$

$\langle N_{ch} \rangle$ in Au-Au vs. p-p and d-Au @ 200 GeV



→ Difference in total charged particle production between Au+Au (e^+e^-) vs. d+Au (pp) at same collision energy

Features of the Data at High Pseudorapidity (η).

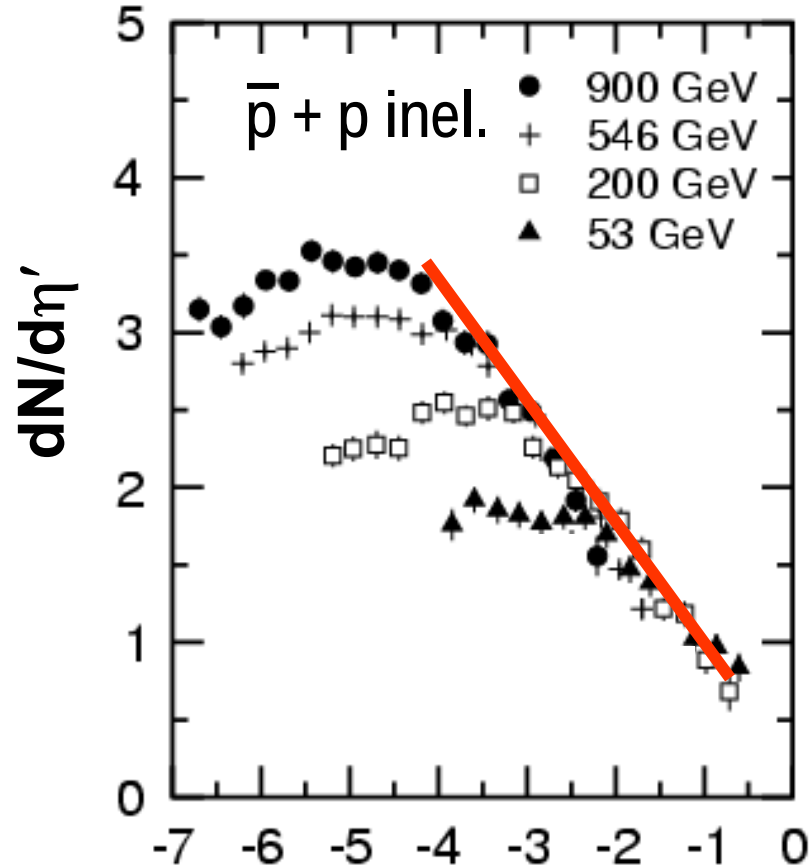


→ Move to rest frame of one nucleus: i.e. $\eta' = \eta - y_{beam}$.

Reminder: Limiting Fragmentation in $\bar{p}$+p

Ansatz:
Benecke, Chou, Yang, Yen,
Phys. Rev. 188, 2159 (1969)

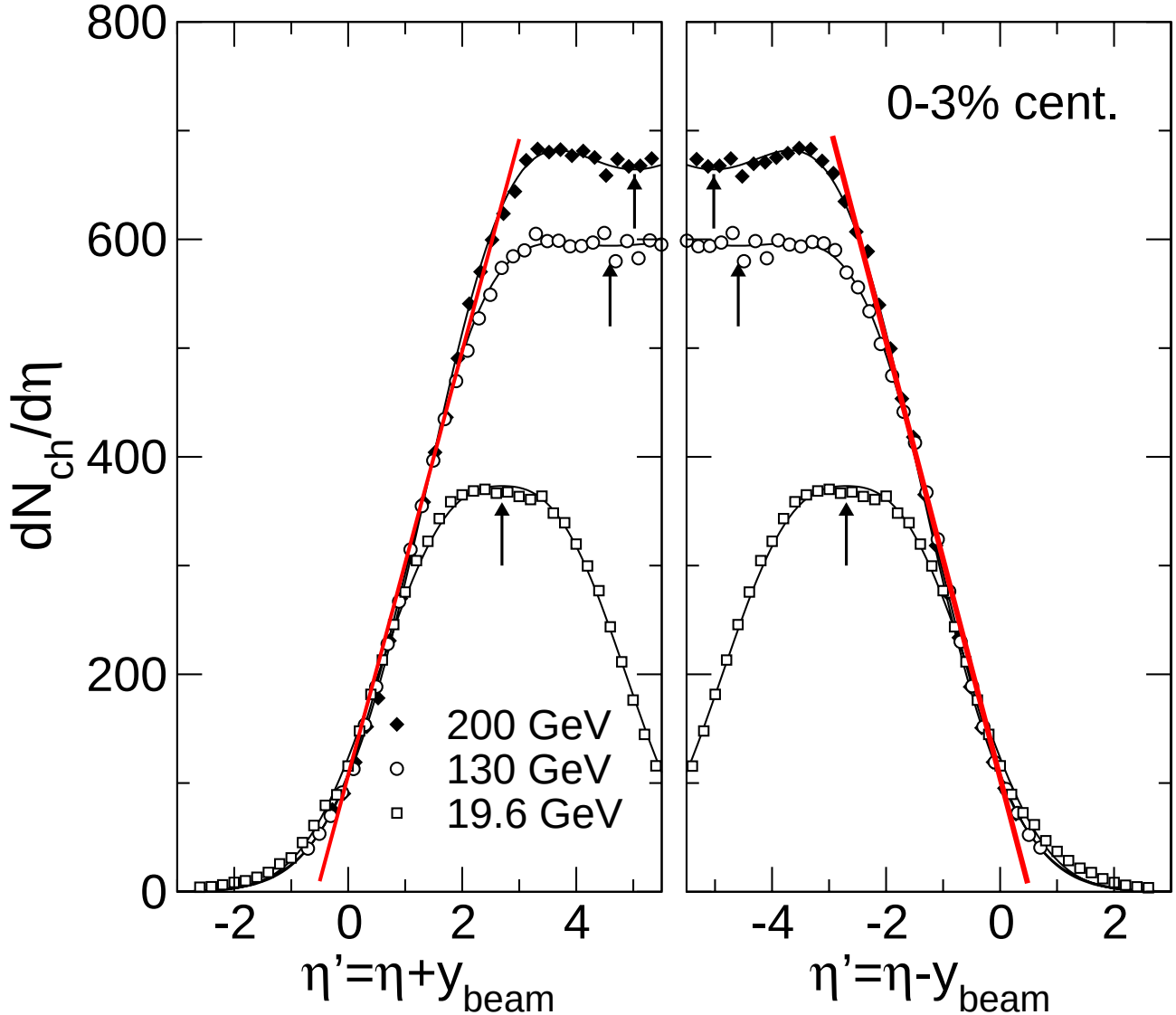
Data:
UA5 (Alner *et al.*),
Z.Phys.C33, 1 (1986)



$$\eta' \equiv \eta - y_{beam}$$

→ Ansatz: At high collision energy, $d^2N/dy'dp_T$ and particle mix, reach a limiting value and become independent of energy around beam rapidity.

Limiting Fragmentation in Au+Au

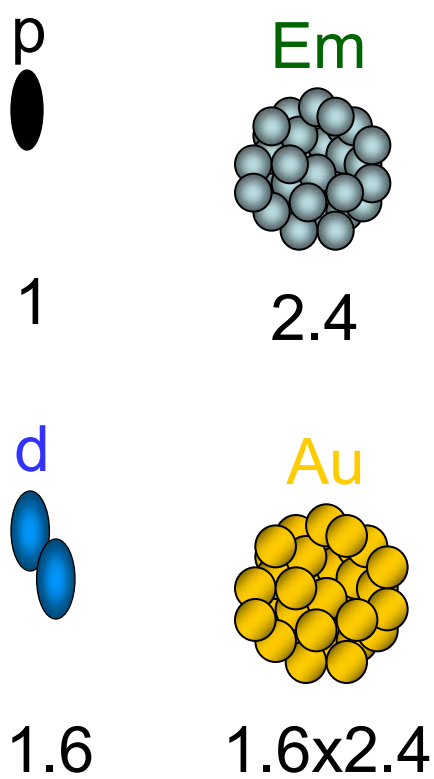


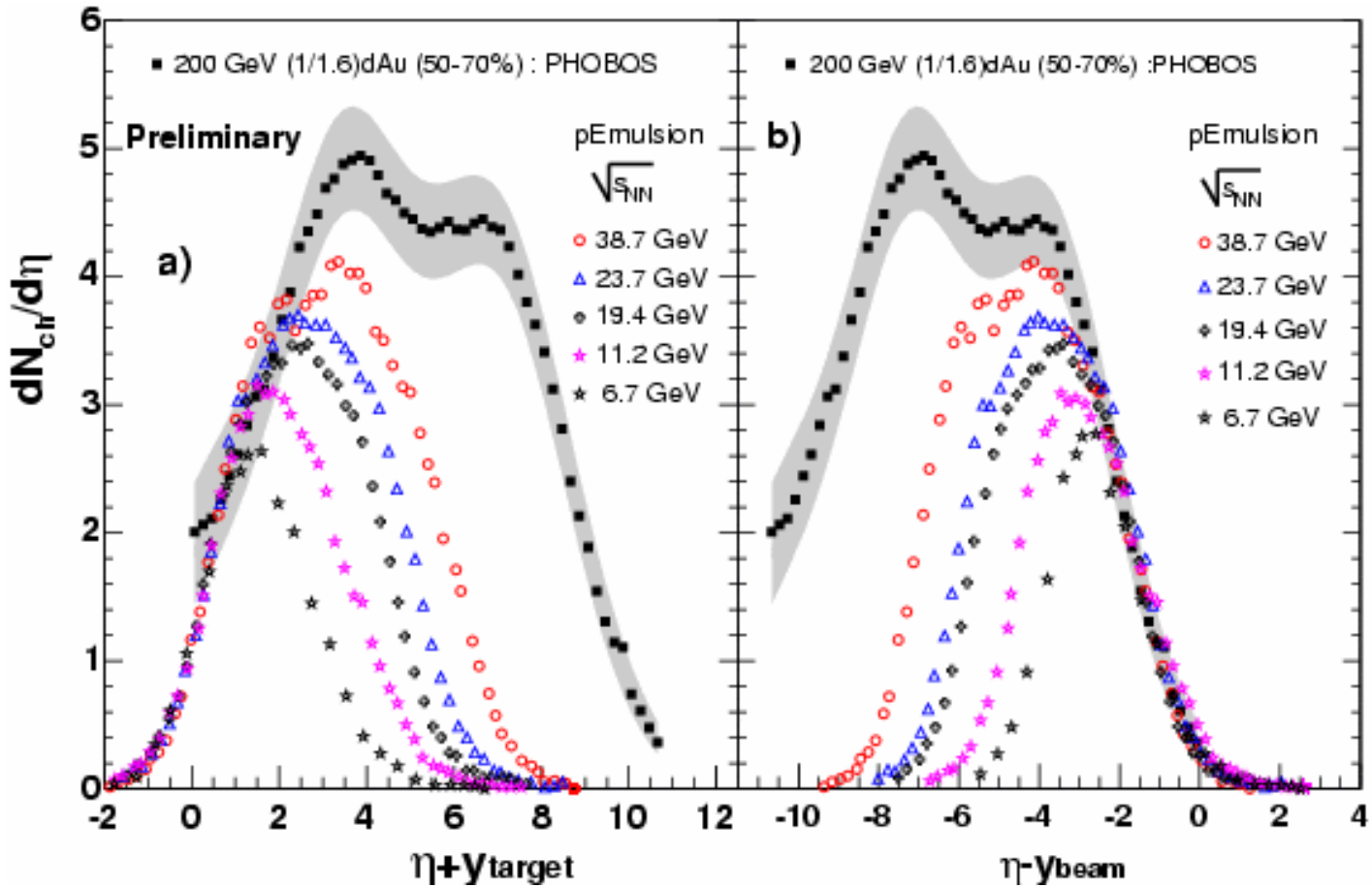
→ Growth of the Fragmentation Region with $\sqrt{s_{NN}}$

Limiting Fragmentation in dAu and pEmulsion Data

dAu & pEmulsion per incident nucleon and approx. same N_{part}

N_{part} Selection:

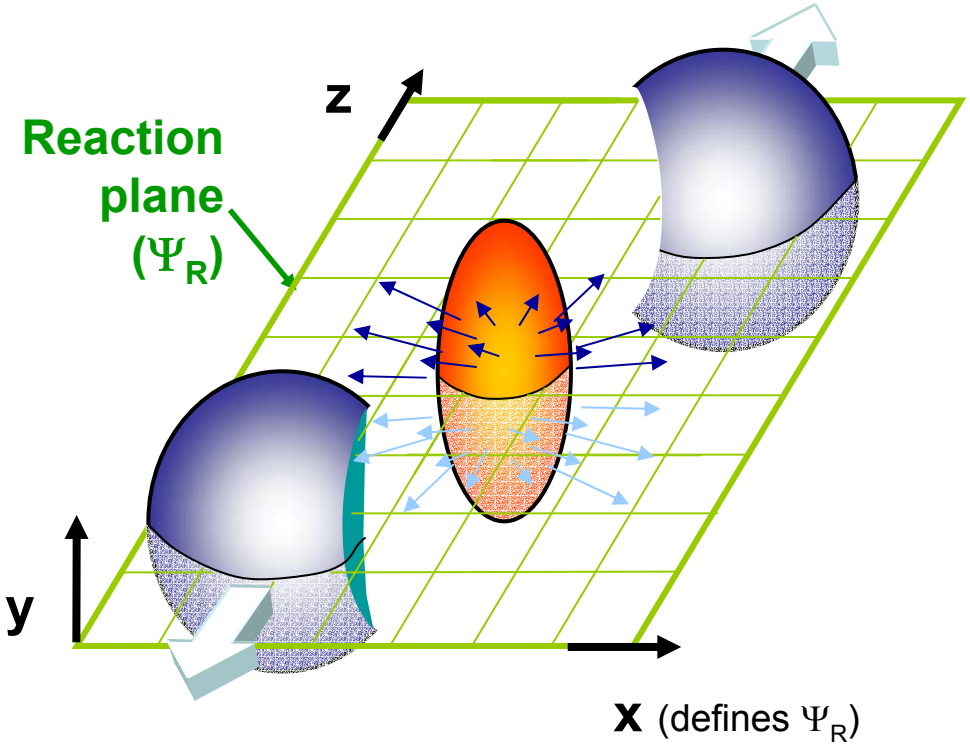




→ Growth of the Fragmentation Region with $\sqrt{s_{NN}}$ in d+Au and pEm

R. Nouicer, QM '04

Charged Particle "Flow": A Bulk Collective Effect

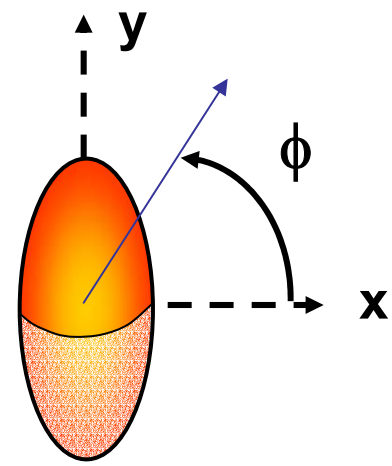


Directed Flow: v_1

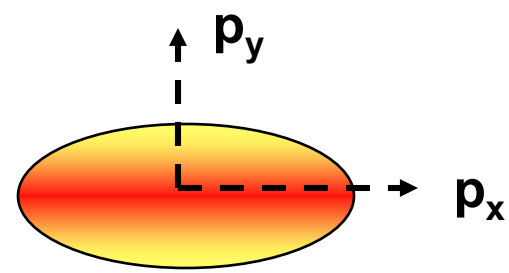
$$dN/d(\phi - \Psi_R) = N_0 (1 + 2v_1 \cos(\phi - \Psi_R) + 2v_2 \cos(2(\phi - \Psi_R)) + \ldots)$$

Elliptic Flow: v_2

Initial **spatial** anisotropy

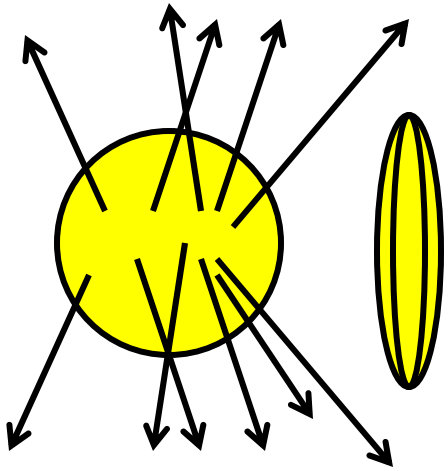


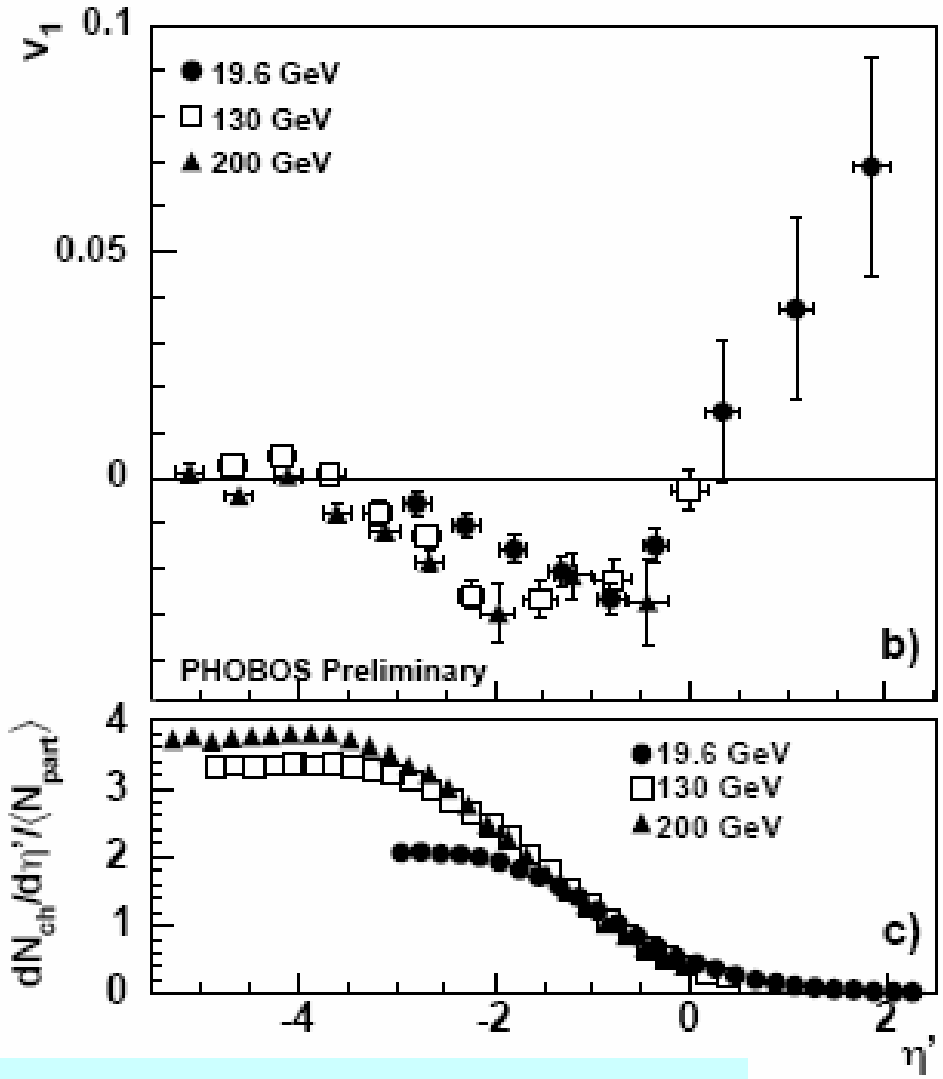
Final **momentum** anisotropy



Directed Flow (v_1) In Beam Rest Frame

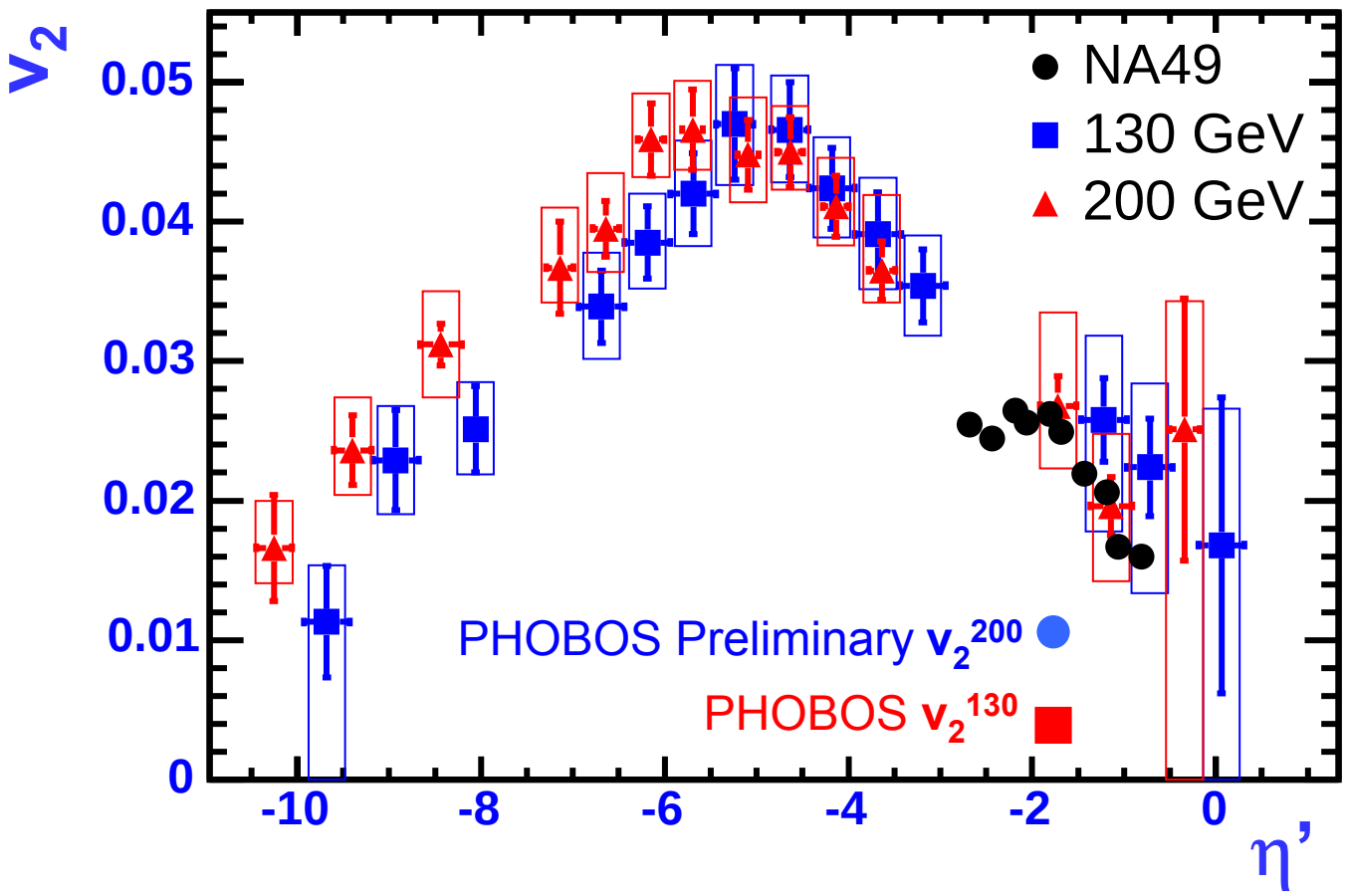
In target frame of reference, directed flow exhibits signal consistent with limiting fragmentation





→ Limiting Fragmentation Behavior in Directed Flow

Elliptic Flow (v_2) In Beam Rest Frame



→ Limiting Fragmentation Behavior in Elliptic Flow

Experimental Summary

Bulk (charged particle) Observables at RHIC

- Scaling of multiplicity data with $N_{part}/2$ in Au+Au and d+Au.
- Per participant pair, Au+Au reaches e^+e^- total particle production level at RHIC energies. d+Au reaches p+p level (at the same collision energy).
- "Limiting fragmentation" of charged particle multiplicity yields ($dN/d\eta$) observed in Au+Au and d+Au at RHIC.
- "Limiting fragmentation" of azimuthal angular distribution of charged particles (v_1 and v_2) observed at RHIC.