Limiting Fragmentation Observations at PHOBOS

Richard S Hollis

University of Illinois at Chicago

For the PHOBOS Collaboration

PHOBOS Collaboration (April 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, 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, Sergei Vaurynovich, Robin Verdier, Gábor Veres, Peter Walters, Edward Wenger, Frank Wolfs, Barbara Wosiek, Krzysztof Woźniak, Alan Wuosmaa, Bolek Wysłouch

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

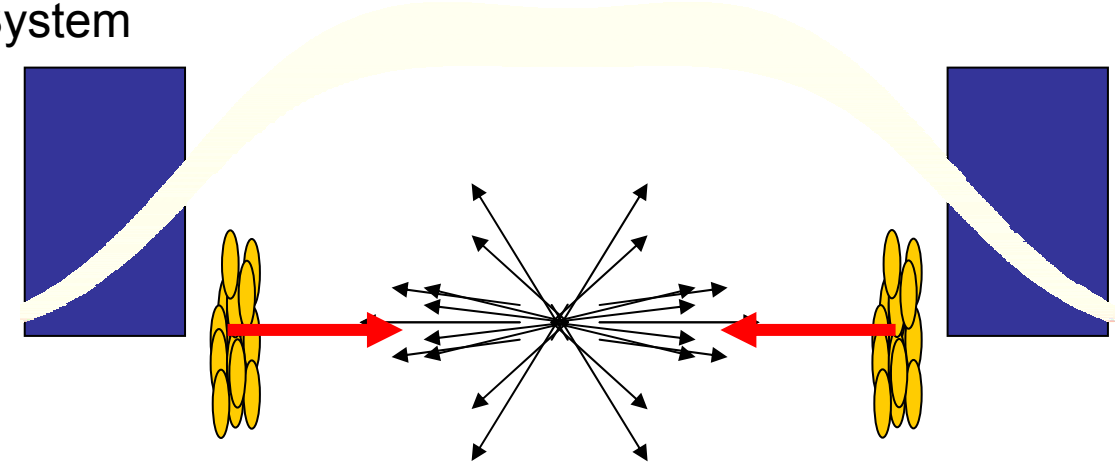
Outline

- PHOBOS
  - Detector
  - Multiplicity Measurement Technique
- Multiplicity measurements
  - *Au+Au*
  - *p+p*
  - *d+Au*
- Flow measurements

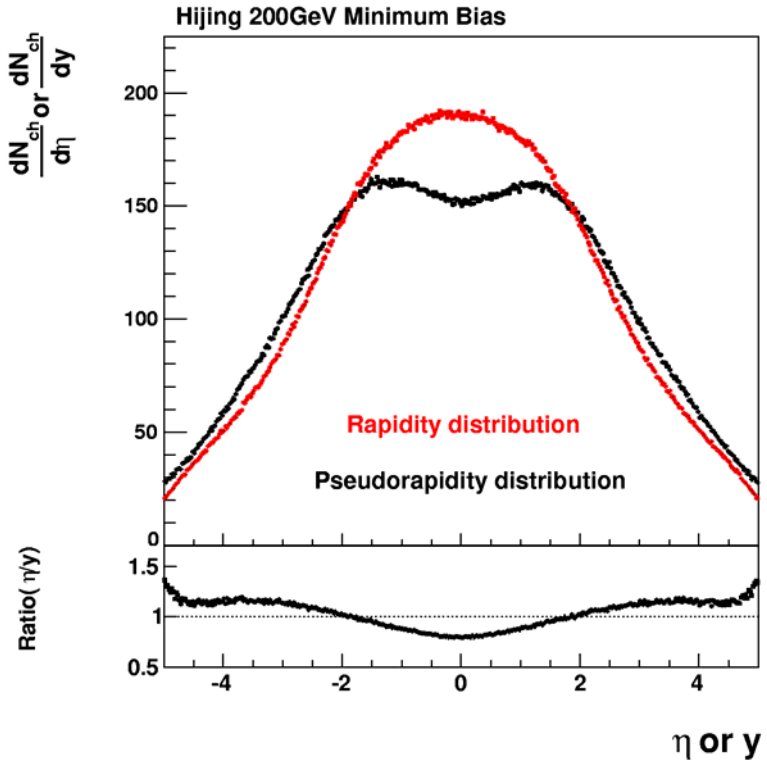
Limiting Fragmentation

- Term for particles produced at high η.
  - Particles produced close to the beam rapidity of one of the colliding nuclei
  - Same “Limiting” distribution of charged-particles in this region independent of energy

Center-of-mass System



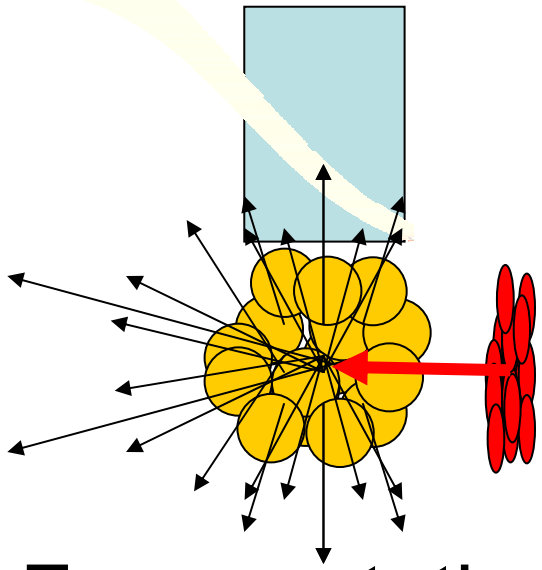
Rapidity and Pseudorapidity



- |y|<2
  - significant deviation between y and η
- |y|>2
  - Shape is similar
  - η distribution is wider
  - Approximation y ≈ η
- y shifts under a longitudinal boost
  - dN/dy is not distorted
- ***Shift*** to target rest frame by y_{beam}
  - For both η and y

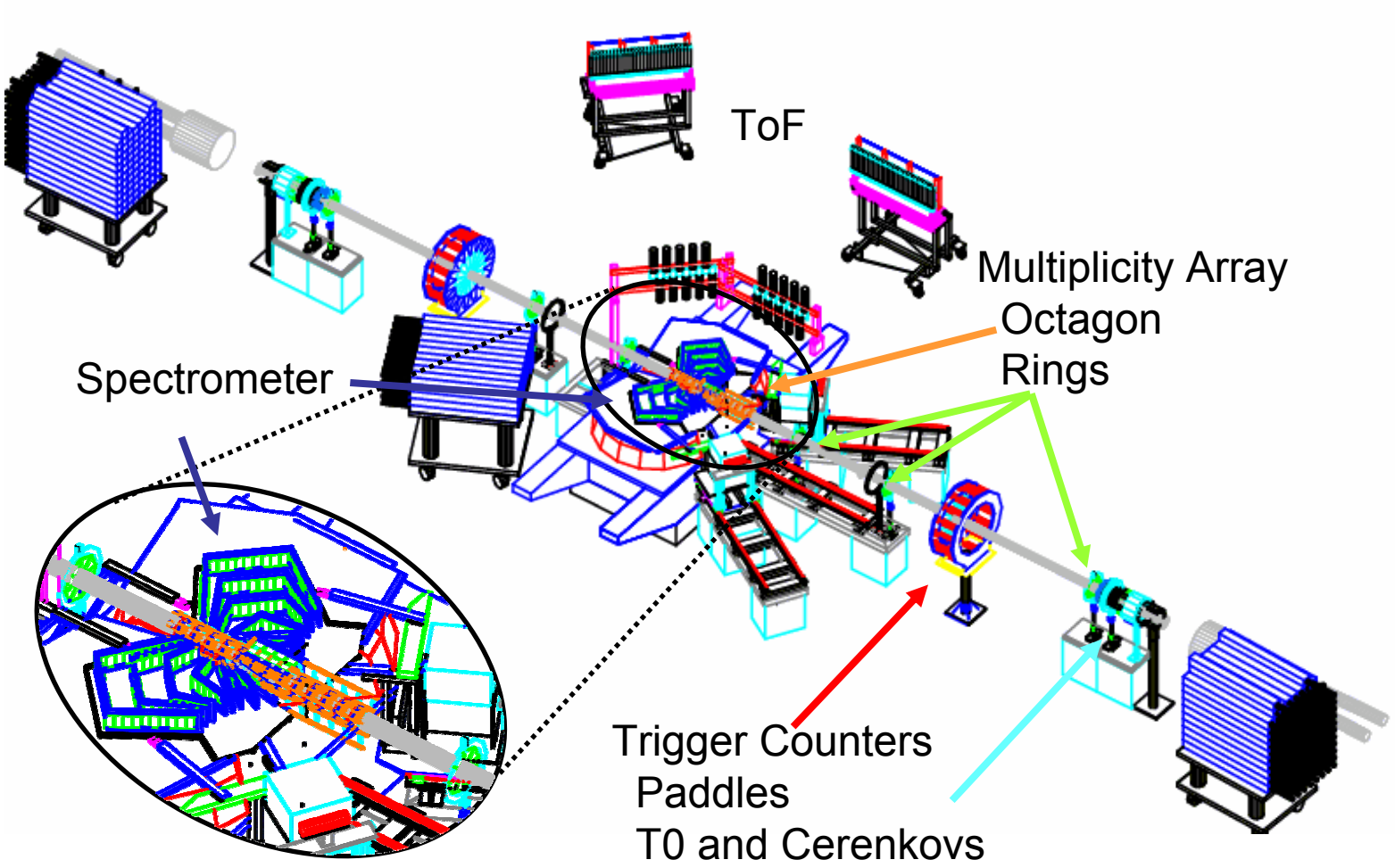
Limiting Fragmentation

Target rest frame



- Expected → a ***narrow*** Fragmentation Region
- Observed → “Extensive Longitudinal Scaling”

PHOBOS Detector

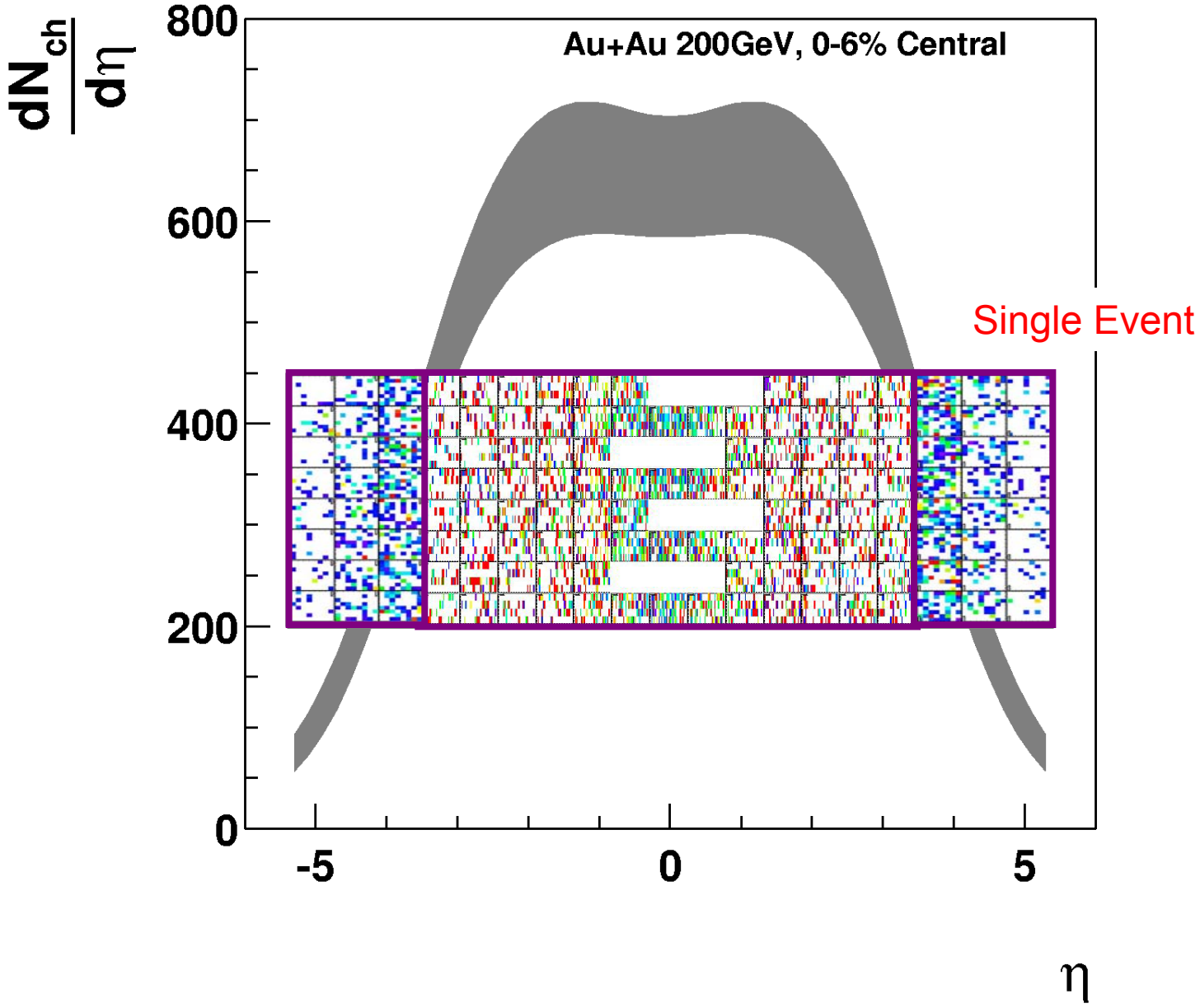


Multiplicity Detectors

- Octagon:
  - Mid-rapidity ($|\eta| < 3.2$)

- Rings:
  - Forward detectors ($3.0 < |\eta| < 5.4$)

Multiplicity Array



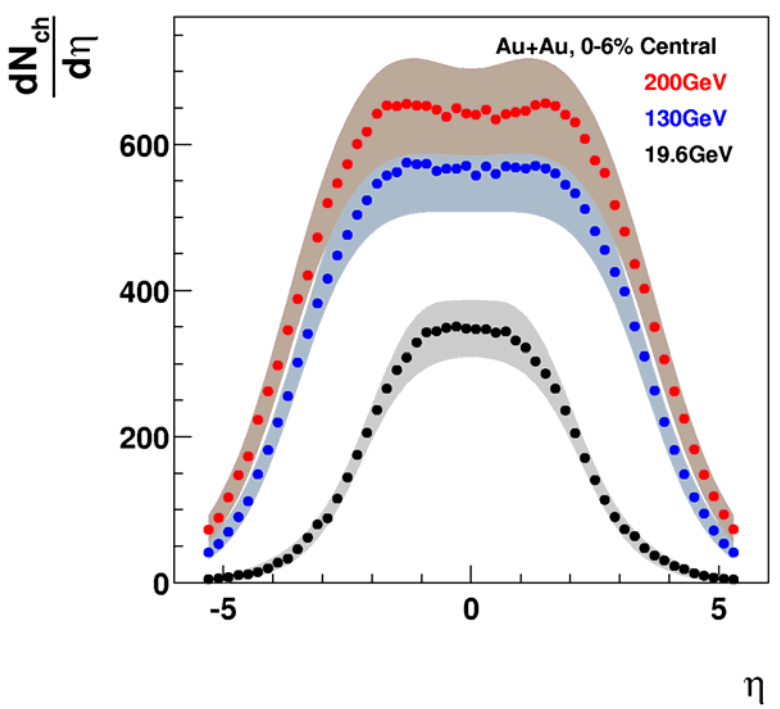
Multiplicity Reconstruction

- Hit Counting
  - Basic
    - Count digital hit pads
  - Hit density correction
    - Count digital unoccupied pad
    - Assume Poisson statistics
    - Determine mean occupancy → Apply correction
  - Occupancy corrections derived from data
- Analogue
  - Correction Applied
    - Energy deposition spectra
    - A fit to this determines the relative multi-hit contribution

Au+Au $dN_{ch}/d\eta$ vs η

- Multiplicity
  - Almost all Phase space covered
  - 3 energies
    - $\sqrt{s}$ = 19.6 to 200 GeV
  - Large range of collision geometries

Total Number of Charged Particles

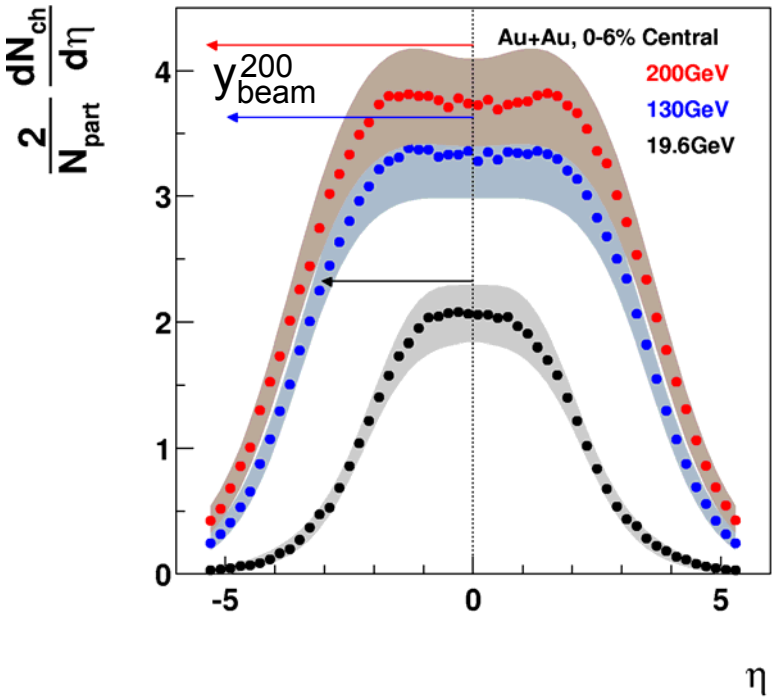


Data from PRL **91** 052303 (2003)

Au+Au $dN_{ch}/d\eta$ vs η

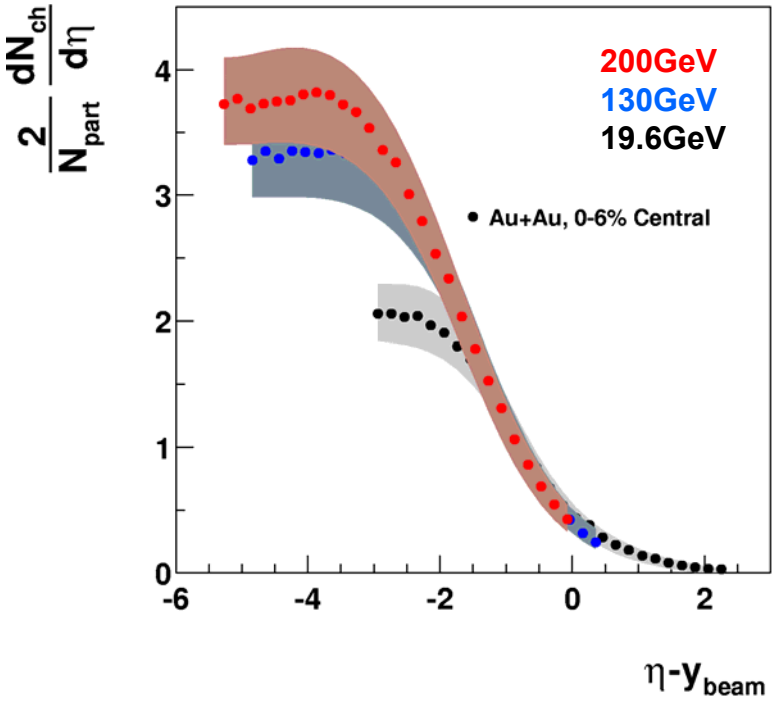
- Scaling by $N_{part}/2$
  - Distributions are relatively the same
  - $<N_{part}>$ is almost the same for each energy
- y_{beam} grows with energy
- Shift each η by y_{beam}

Total Number of Charged Particles divided by half N_{part}



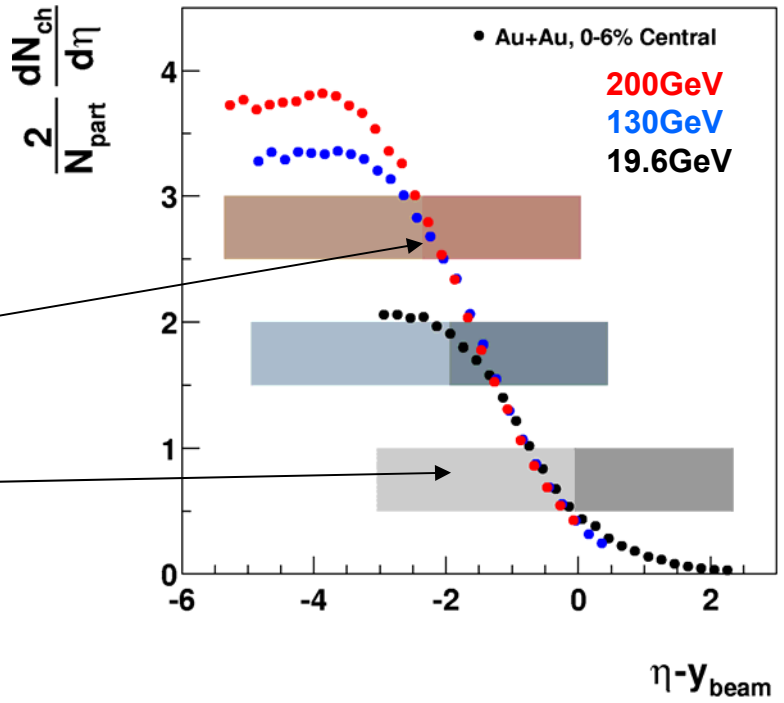
Au+Au $dN_{ch}/d\eta$ vs $\eta - y_{beam}$

- Region of 'overlap'
  - For each energy
  - Close to rapidity of one projectile
- Expected
  - Narrow fragmentation region
- Observed
  - Extensive longitudinal scaling
- Fragmentation Region
  - Grows with energy

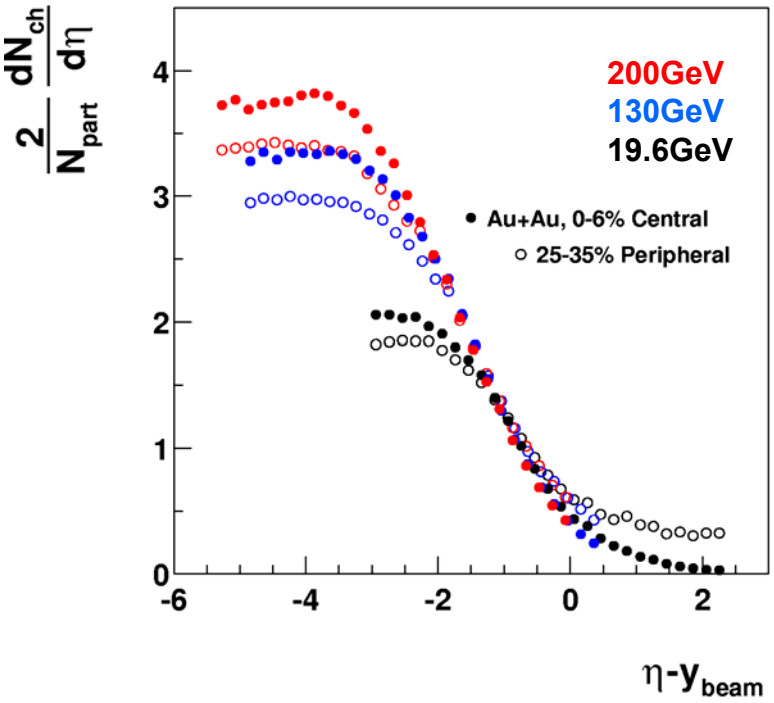


Au+Au $dN_{ch}/d\eta$ vs $\eta - y_{beam}$

- Region of overlap
  - Also covered by an overlap in detector-space
  - $-1 < \eta - y_{beam} < 0$
    - Covered by Rings for 200GeV
    - Covered by Octagon for 19.6GeV
- This is not a 'detector' effect!!

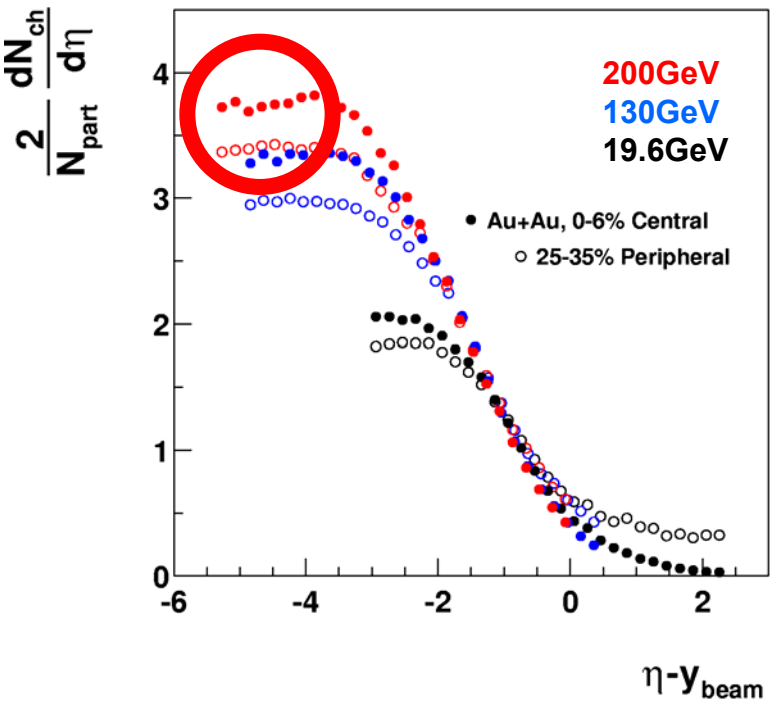


Centrality Dependence



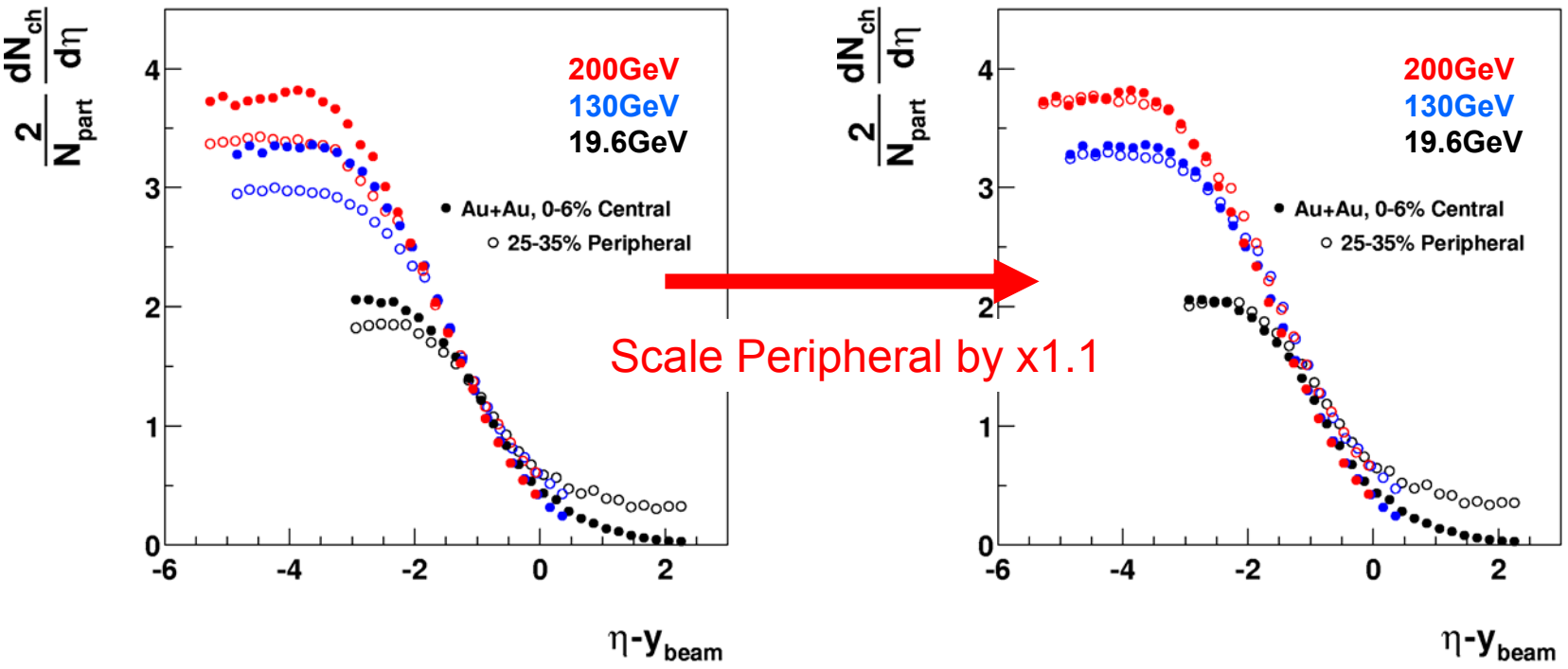
- Centrality
  - Data divided into distinct multiplicity bins
- Central 0-6%
  - N_{part} ~ 340
- Peripheral 25-35%
  - N_{part} ~ 140
- Not too peripheral
  - Restricted by the 19.6GeV data

Centrality + Energy Dependence



- Observations
  - Reduction at $\eta \sim 0$
  - Increase at $\eta - y_{beam} > 0$
  - Important observation for the total yield
- Measure the yield at $\eta \approx 0$ for 200GeV
  - Central/Peripheral≈1.1

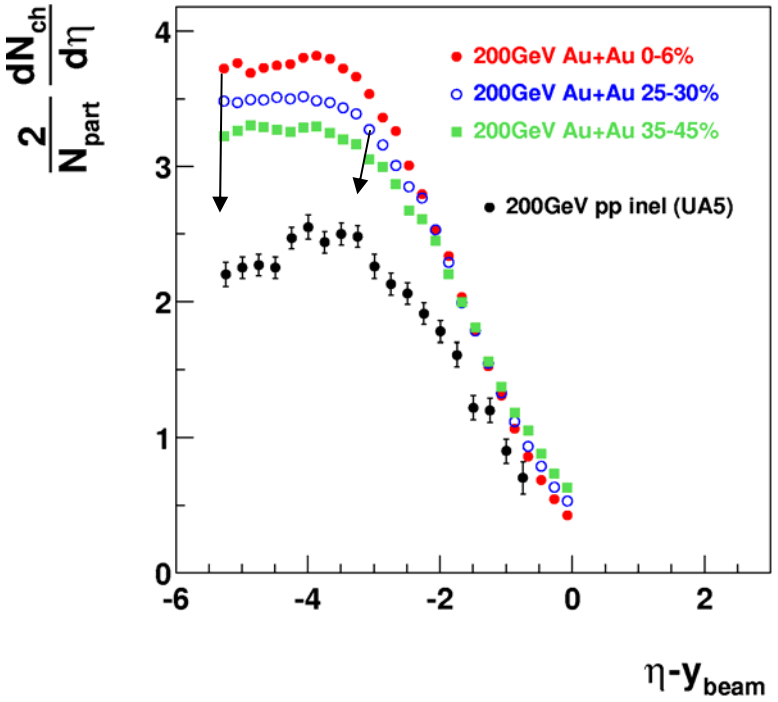
Departure Point from Limiting Curve



Same ‘relative’ departure point

Centrality dependence at 200GeV

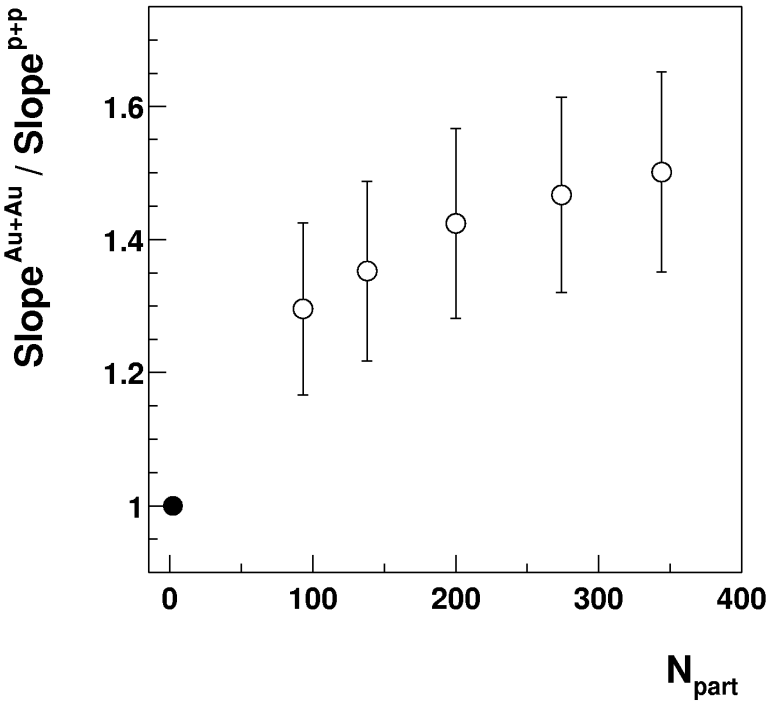
- Evolution from Central to peripheral
  - Slope decreases
- Can measure slope
  - From η-y_{beam}~-2 and 0
    - For each centrality
- Parameterize *p+p*
  - extract the slope



UA5 data from Z.Phys.C **43** (1989) 1

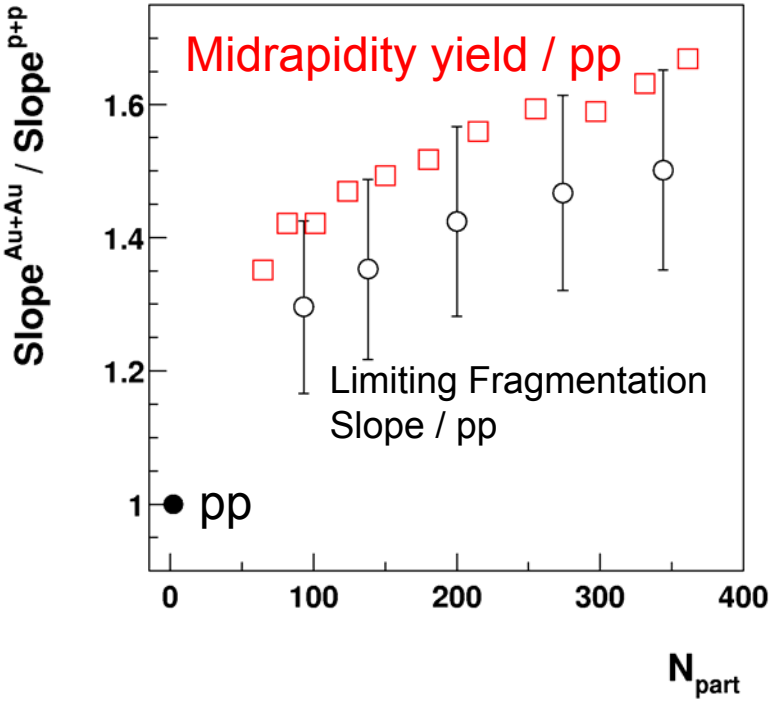
Centrality dependence of the slope

- As expected
  - Slope trend declines
  - Systematically higher than *p*+*p*
- A more peripheral measurement is needed



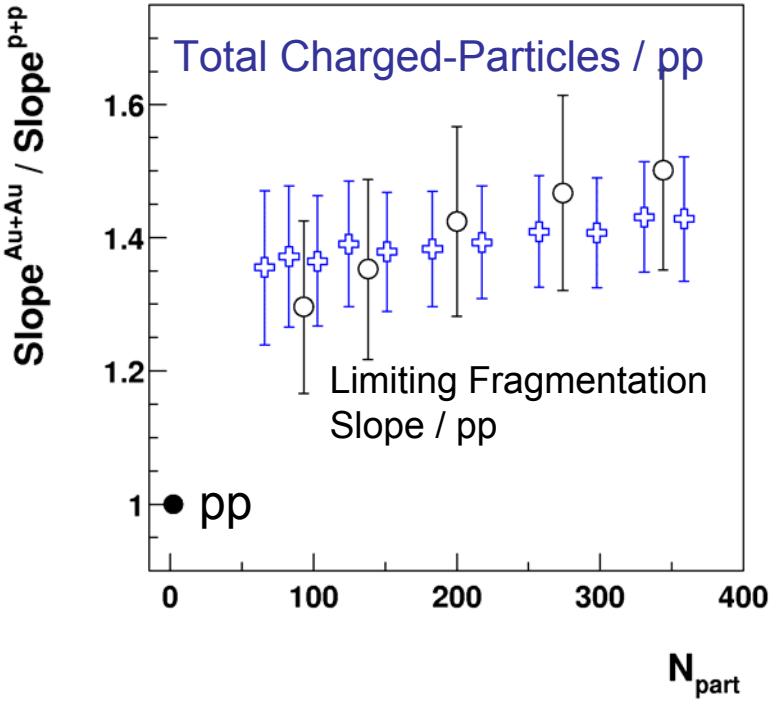
Slope and Midrapidity yield

- As expected
  - Slope trend declines
  - Systematically higher than *p+p*
- Same trend seen at midrapidity



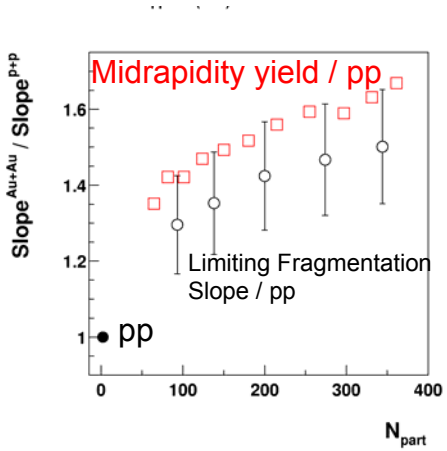
Slope and Total charged-particles

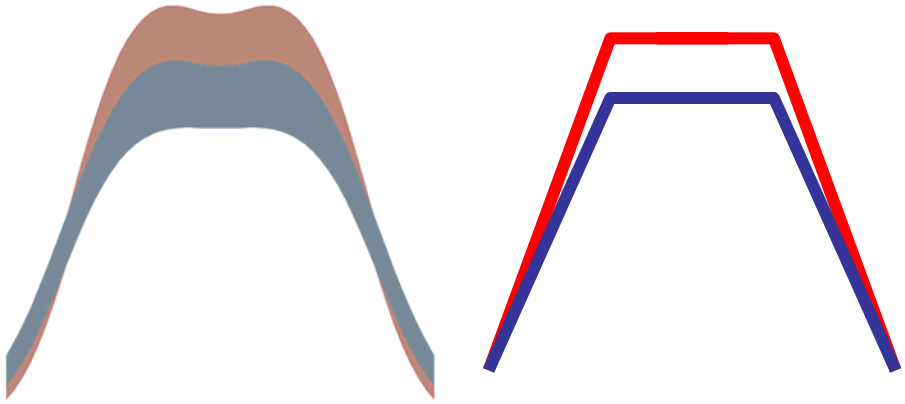
- As expected
  - Slope trend declines
  - Systematically higher than *p+p*
- Same trend seen at midrapidity
- Total yields ‘flat’
  - For increasing centrality
    - Midrapidity rise
    - Decrease for $\eta - y_{beam} > 0$
  - Effects cancel each other



Slope and Midrapidity yield

- Same trend seen at midrapidity
  - Not Surprising
    - dN/dη ~ trapezoid
  - Midrapidity α slope

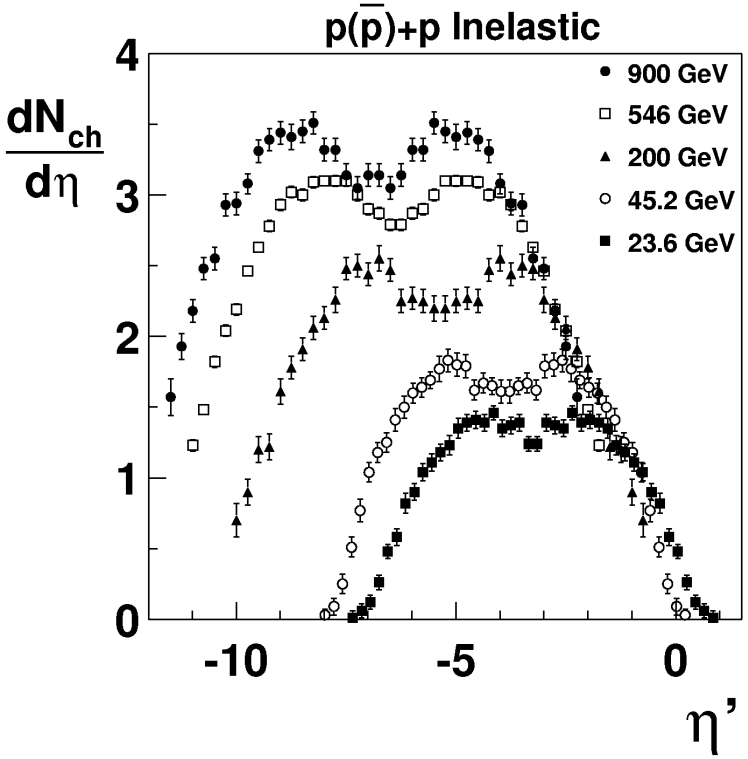




Smaller systems

- This measurement is not peculiar to *Au+Au*
  - First observed in *p+p*
  - Also in *d+Au*
- All exhibit the similar features

p+p



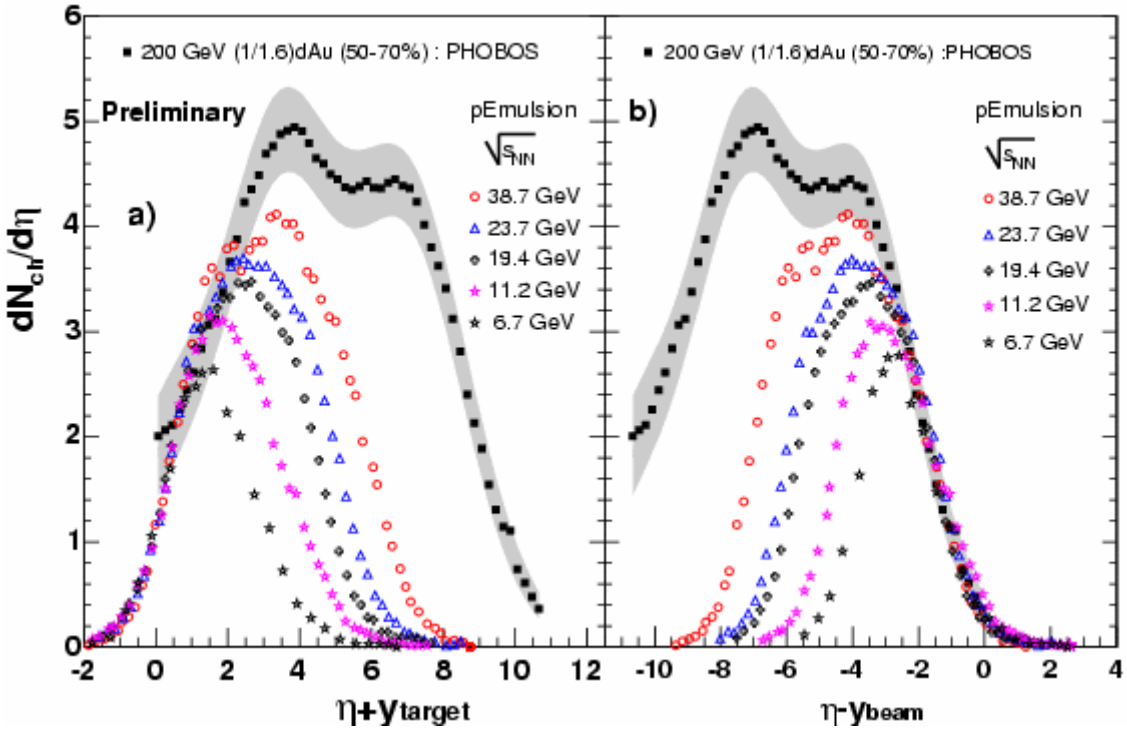
- Collection of many data over a factor of ~50 in $\sqrt{s}$
  - Reasonable Limiting Fragmentation agreement!

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

UA5 (200-900) → Z.Phys.C **43** (1989) 1
ISR (23.6,45.2) → Nucl.Phys **B129** 365 (1977)

d+Au

50-70% Centrality, PHOBOS data

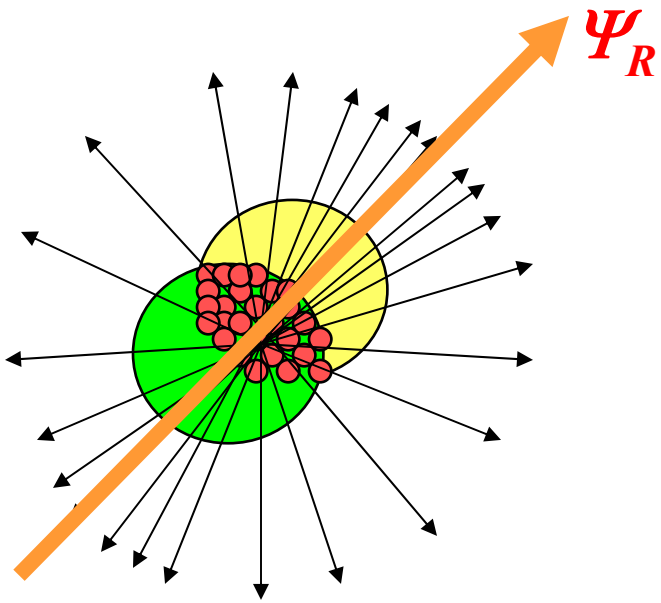


d+Au data from nucl-ex/0409021
p+Em referenced therein

d+Au

- Limiting fragmentation in both
  - Projectile rest frame
  - Target rest frame
- Centrality dependence
  - Systematic comparison with lower energy data
  - No need to change species
    - All measured in same collision system
  - Limiting fragmentation in each centrality bin

Elliptic Flow

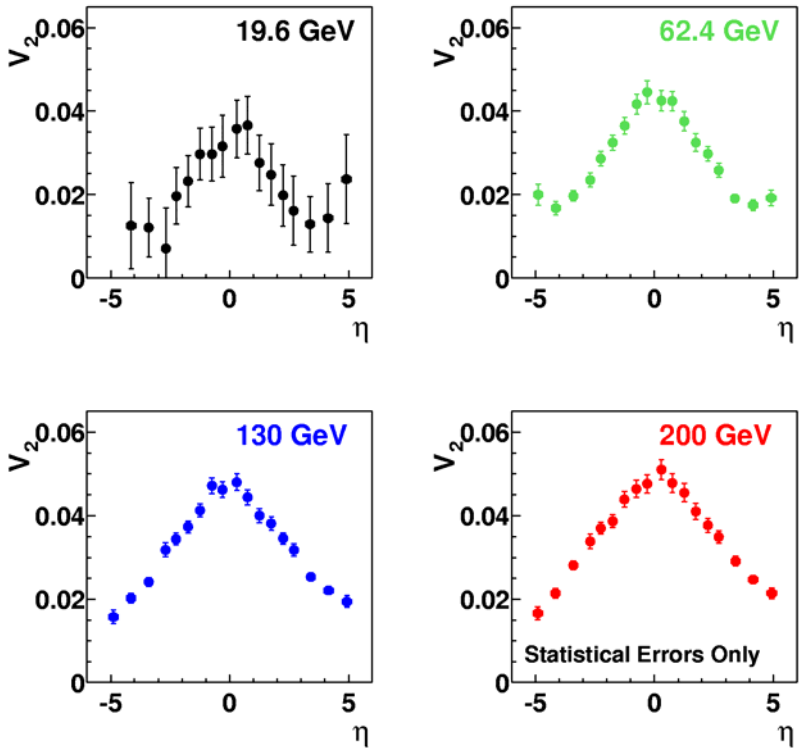


- The effect of the geometrical asymmetry
  - Non-central collisions
- Procedure
  - Measure the angle for the highest yield (Ψ_R)
    - Relative to the detector
    - "Reaction Plane"
  - Measure all particles relative to this angle
    - $2V_2 cos\ (2(\phi - \Psi_R)$

$$dN/d(\phi - \Psi_R) = N_0 (1 + 2V_1 cos\ (\phi - \Psi_R) + 2V_2 cos\ (2(\phi - \Psi_R) + \ldots)$$

Flow Results

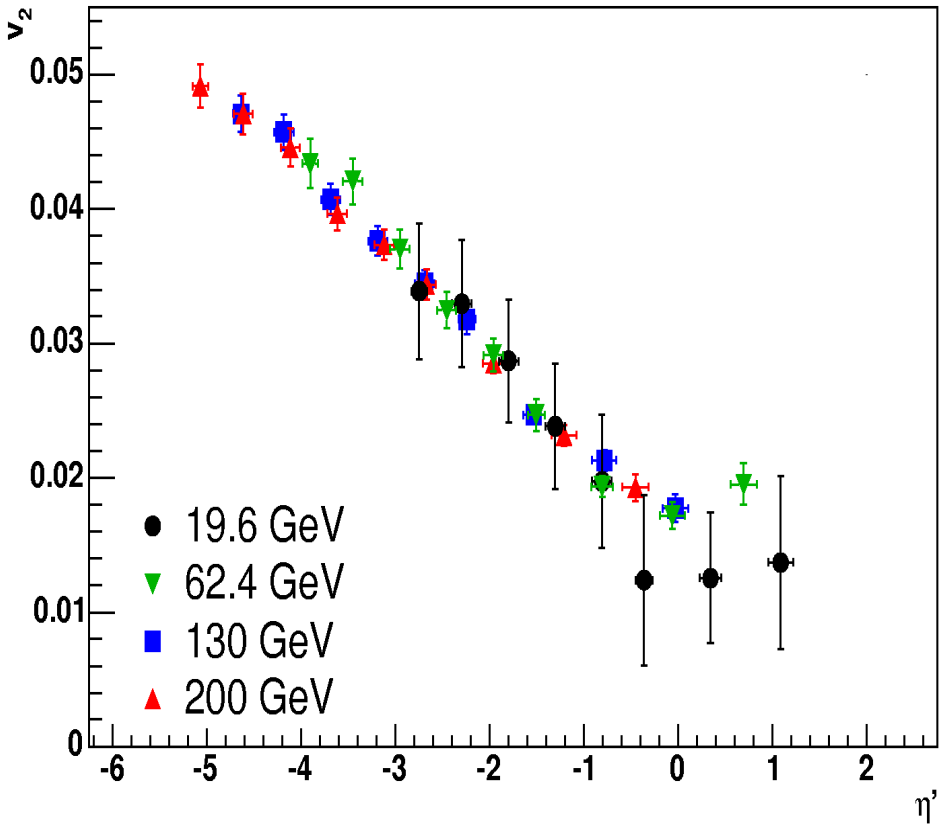
- Elliptic flow results
  - Statistical errors only
- Shift by y_{beam} again



Data from nucl-ex/0406021

Flow Results

- Elliptic flow results
  - Statistical errors only
- Shift by y_{beam} again
  - Fold and average signals

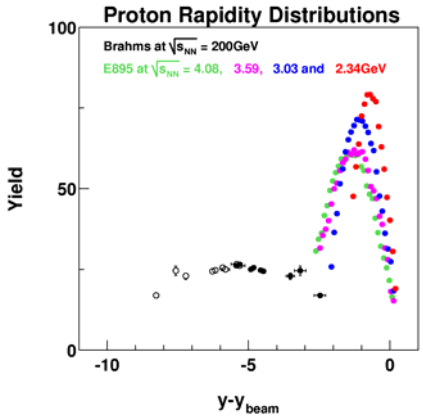


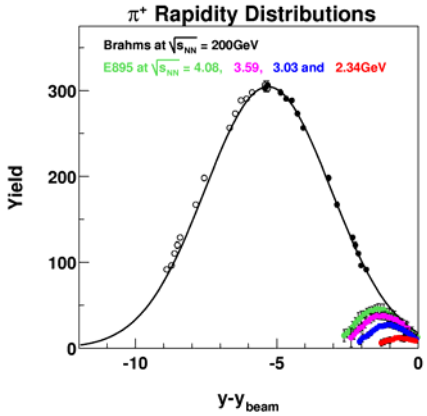
Data from nucl-ex/0406021

Outlook

- Several questions remain
  - Centrality dependence for whole range
  - Collision species dependence
    - Will *Cu+Cu* fit into *Au+Au* data?
  - Is this observation specific to η?
    - Original hypothesis was for rapidity distributions
  - Does each particle species exhibit the same features?
    - PHOBOS cannot identify particles away from midrapidity

Particle Species





- Lots of data available
  - Pions, Protons
  - Large rapidity and energy coverage

Brahms (200) → PRL 91 072305 (2003) (protons)
arXiv:nucl-ex/0403050 (mesons)
E895 (others) → PR **C66** 054905 (2003)

Summary

- PHOBOS has measured multiplicity and flow at high-η.
  - Large systematic dataset
  - $-5.4<\eta<5.4$
  - 2 to 360 participants
  - $\sqrt{s}$ = 19.6 to 200 GeV
- In the target rest frame
  - Multiplicity exhibits a common yield curve close to the beam rapidity of one nucleus
    - Extensive longitudinal scaling observed in
      - *Au+Au*, *d+Au* and *p+p*
  - Flow exhibits similar type behavior