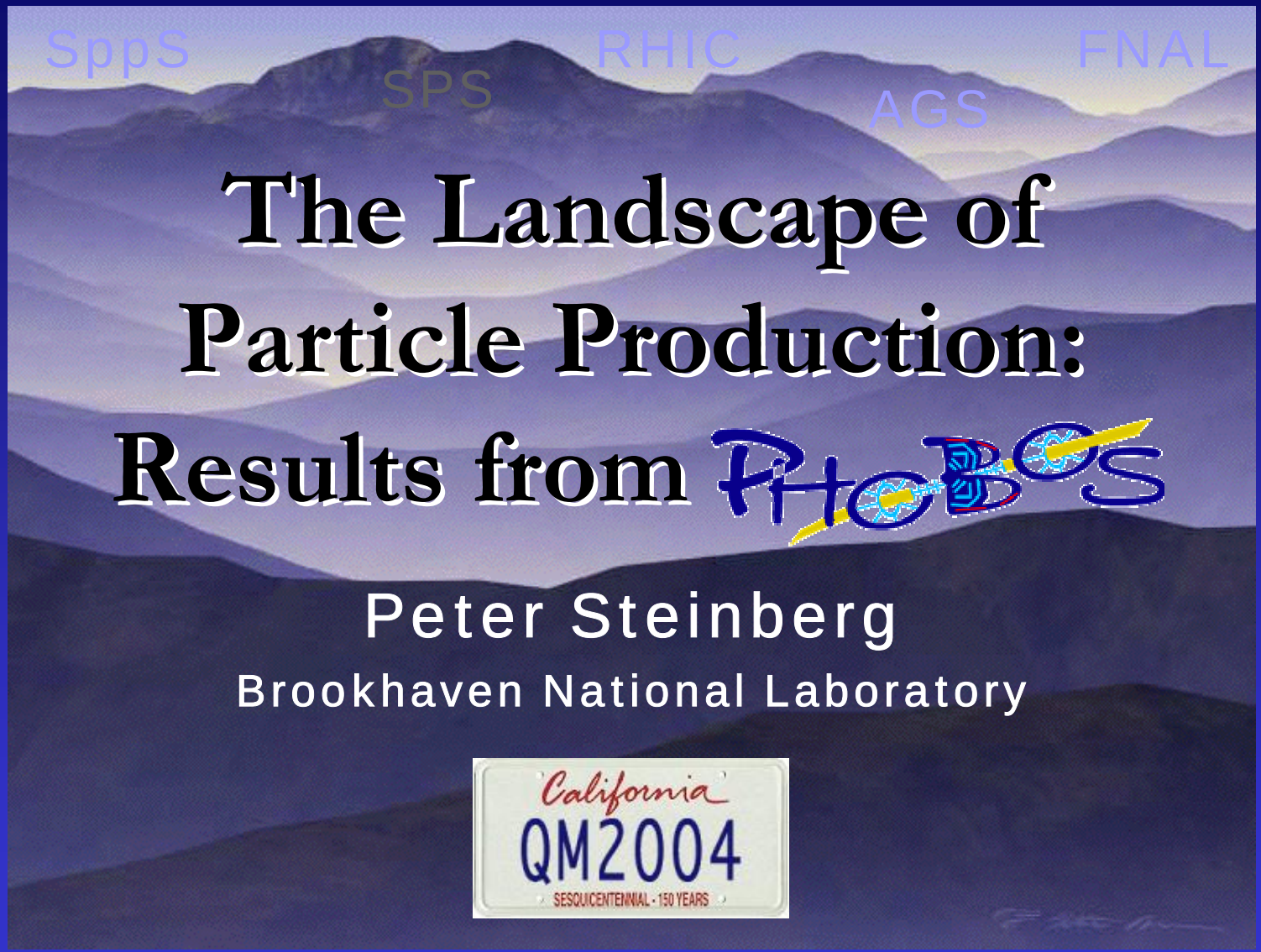


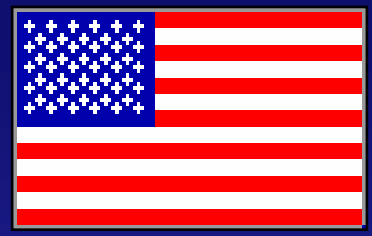
The Landscape of Particle Production: Results from PHOBOS

Peter Steinberg

Brookhaven National Laboratory

PHOBOS Collaboration 2004



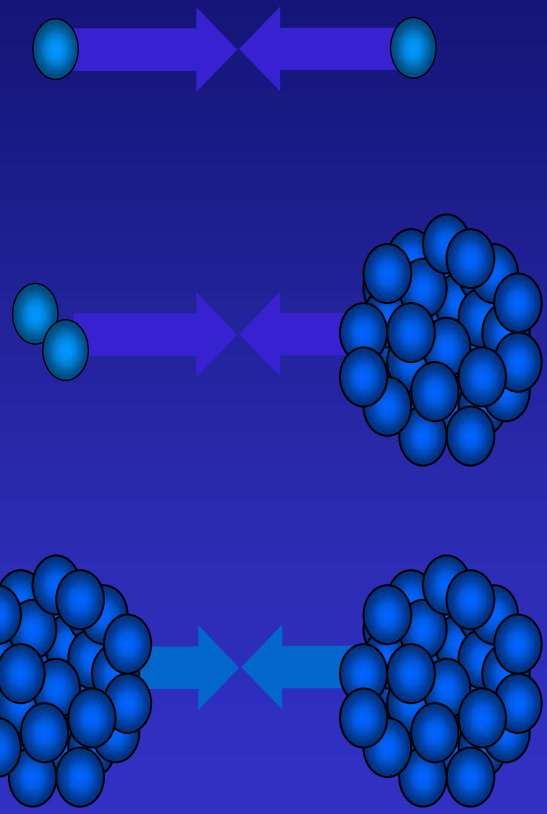


Birger Back, Mark Baker, Maarten Ballintijn, Donald Barton, Russell Betts, Abigail Bickley, Richard Bindel, Wit Busza (Spokesperson), Alan Carroll, Zhengwei Chai, Patrick Decowski, Edmundo Garcia, Tomasz Gburek, Nigel George, Kristjan Gulbrandsen, Stephen Gushue, Clive Halliwell, Joshua Hamblen, Adam Harrington, Conor Henderson, David Hofman, Richard Hollis, Roman Hołyński, Burt Holzman, Aneta Iordanova, Erik Johnson, 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, Iouri Sedykh, Wojtek Skulski, Chadd Smith, 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, Jinlong Zhang

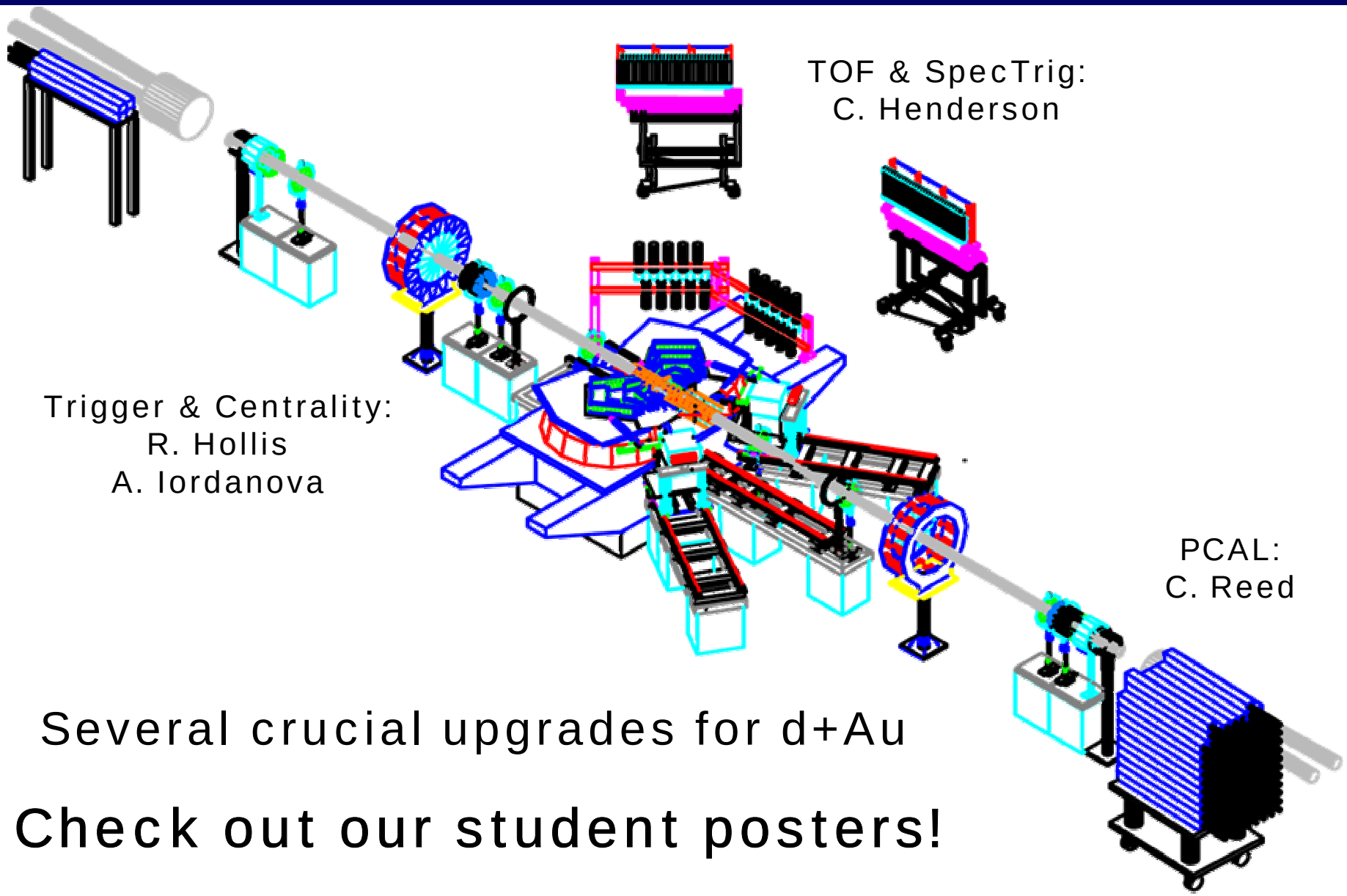
ARGONNE NATIONAL LABORATORY
INSTITUTE OF NUCLEAR PHYSICS, KRAKOW
NATIONAL CENTRAL UNIVERSITY, TAIWAN
UNIVERSITY OF MARYLAND
BROOKHAVEN NATIONAL LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

PHOBOS Highlights

- d+Au & p+p physics
  - Multiplicity
  - Inclusive Spectra
  - PID
- Multiparticle Physics in Au+Au



PHOBOS 2003



TOF & SpecTrig:
C. Henderson

Trigger & Centrality:
R. Hollis
A. Iordanova

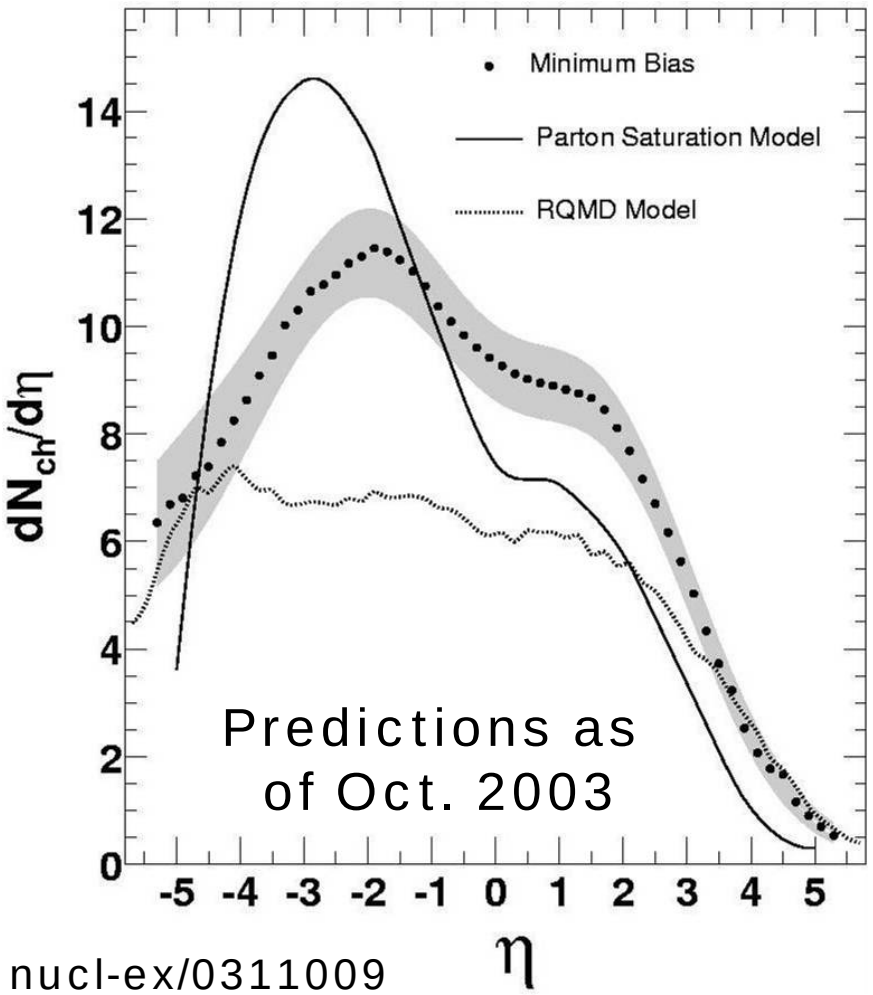
PCAL:
C. Reed

Several crucial upgrades for d+Au

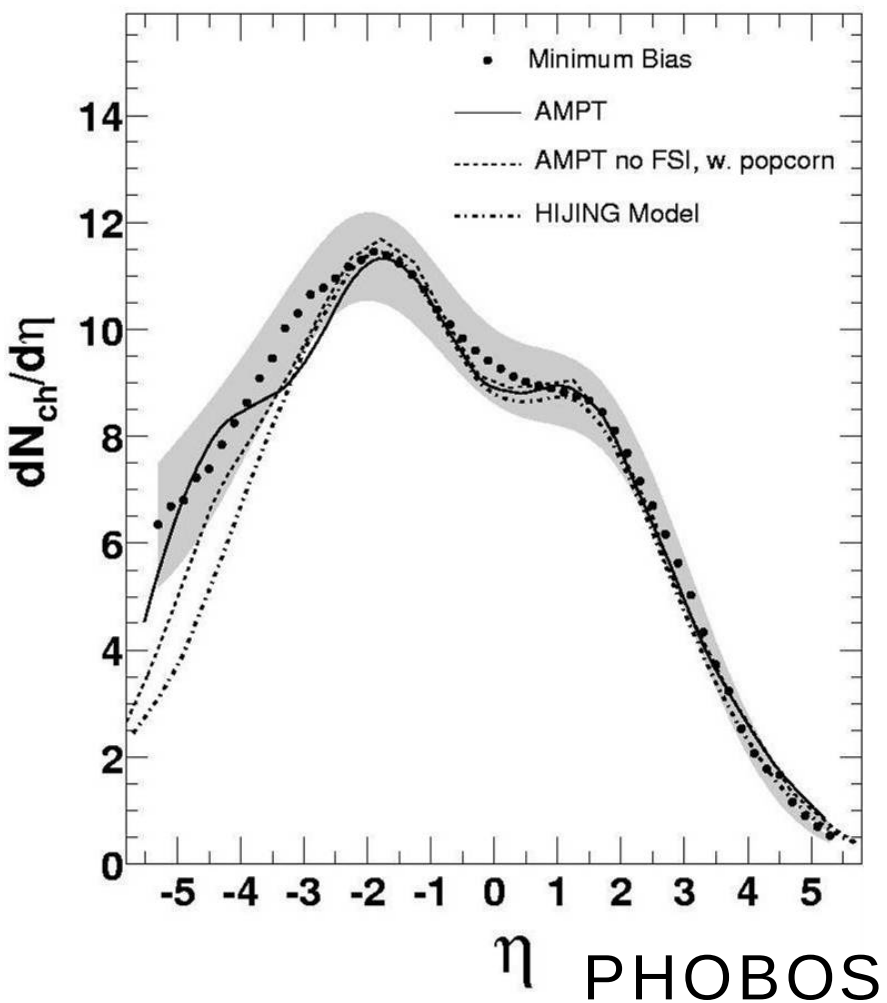
Check out our student posters!

Charged-Particle Multiplicities in p+p & d+Au

Minimum-bias d+Au

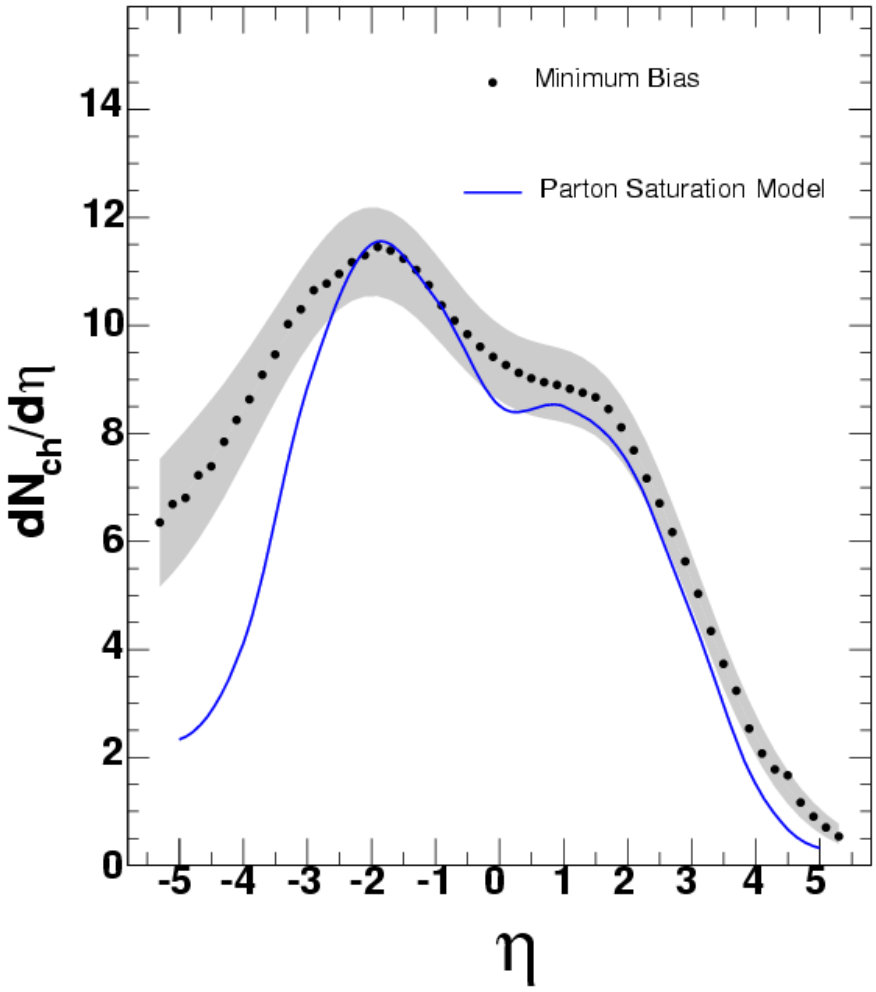


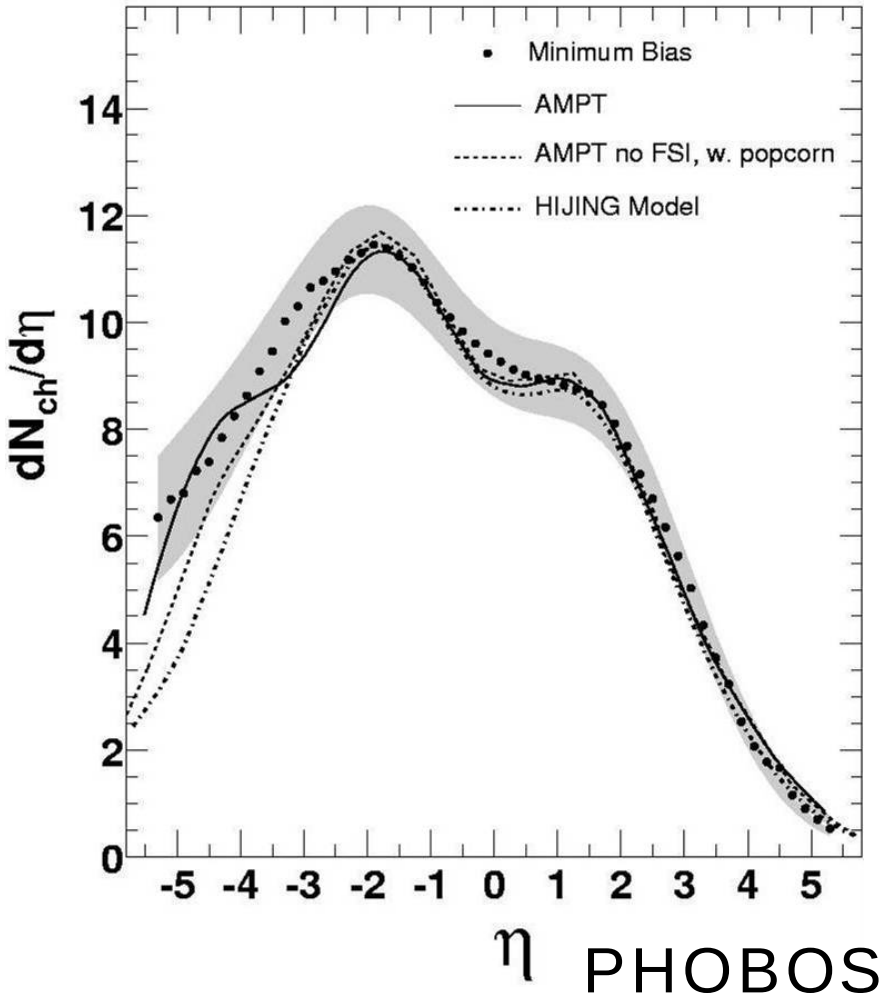
nucl-ex/0311009



See R. Nouicer's talk

Minimum-bias d+Au

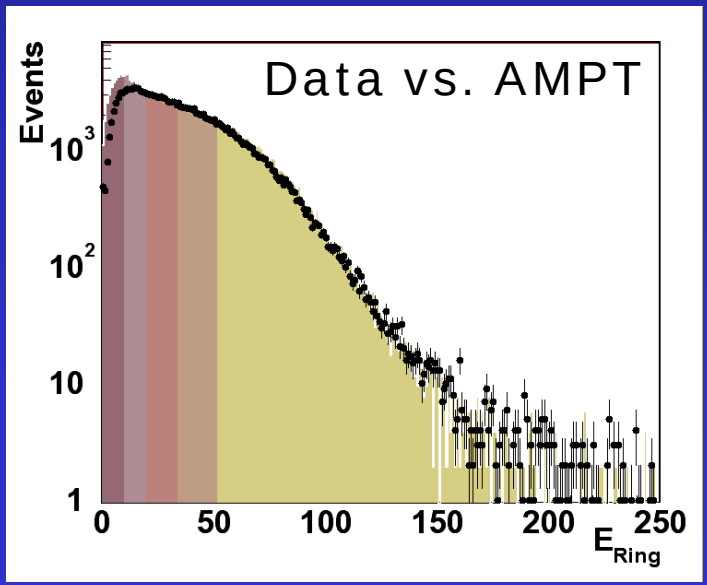


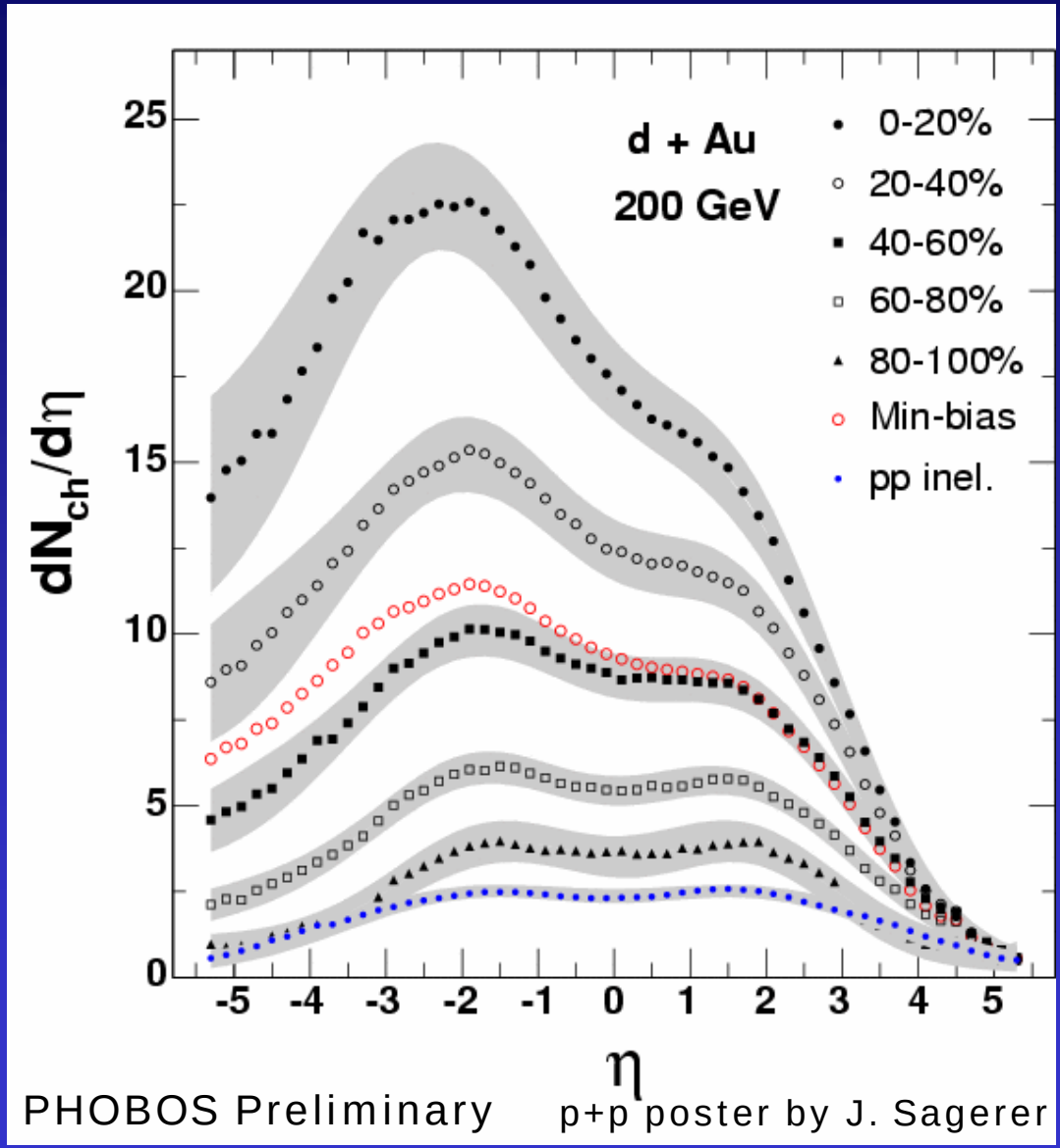


See R. Nouicer's talk

Centrality Dependence of d+Au

Centrality (%)	N_{part}	$N_{part}(Au)$	$N_{part}(d)$
0-20	15.5	13.5	2.0
20-40	10.8	8.9	1.9
40-60	7.2	5.4	1.7
60-80	4.2	2.9	1.4
80-100	2.7	1.6	1.1





PHOBOS Preliminary

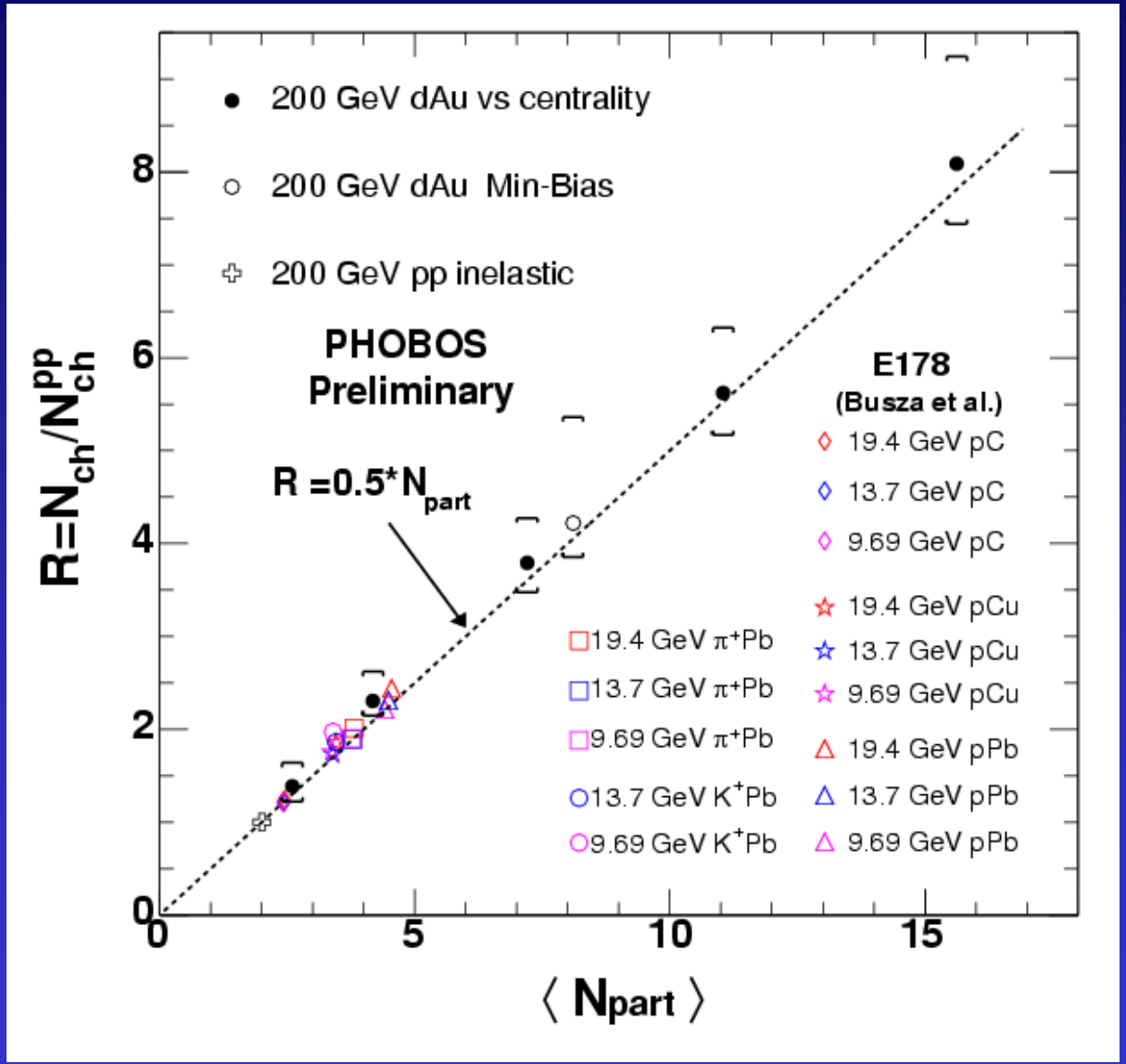
p+p poster by J. Sagerer

Participant Scaling?

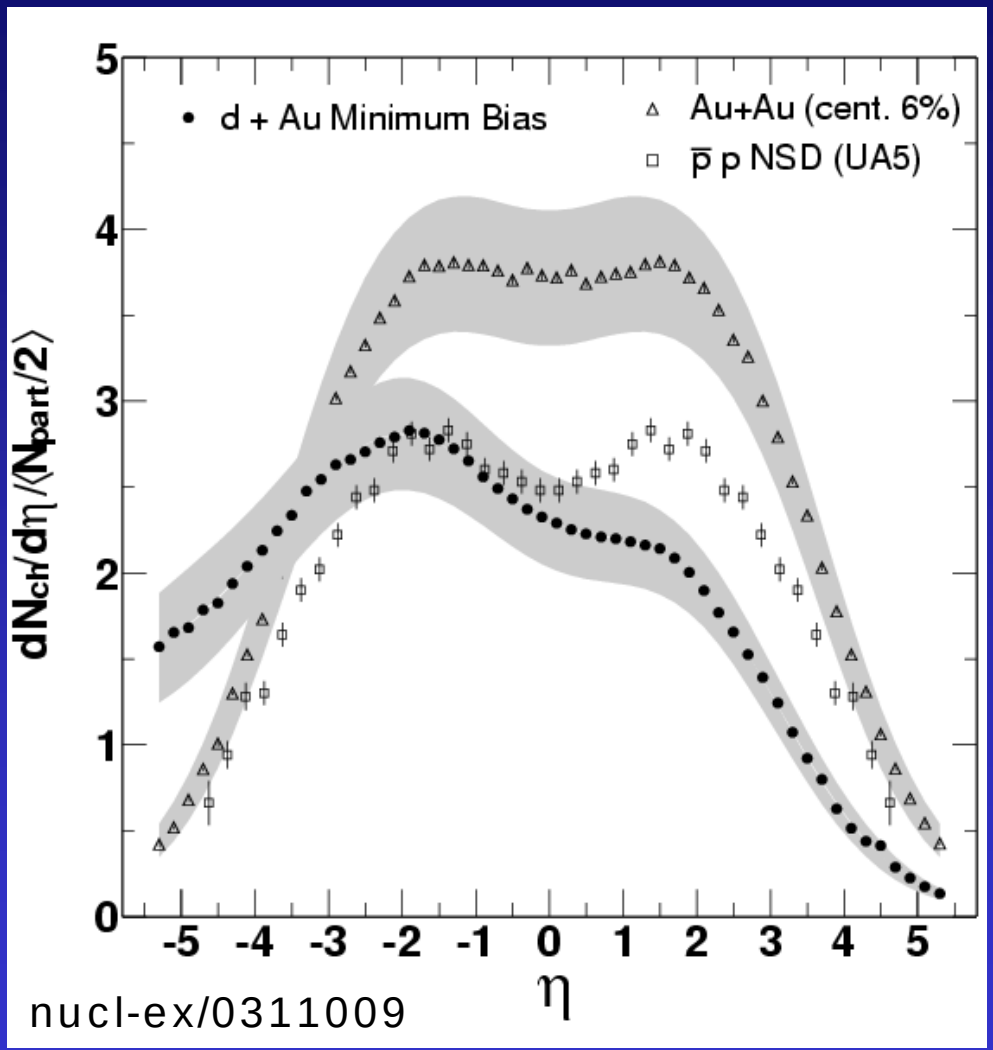
Multiplicity extrapolated to 4π

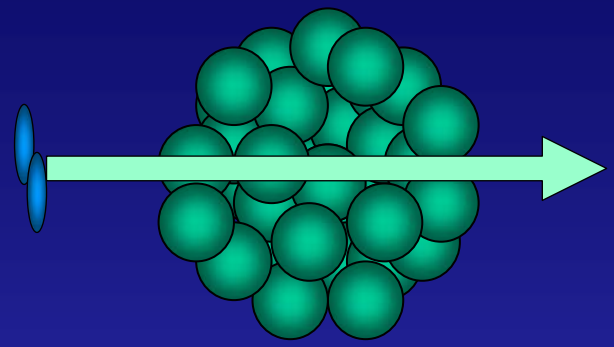
Relative to p+p multiplicity at same energy, scales with $N_{part}/2$

No modification with
- Beam energy
- Nuclear thickness



Is N_{part} Fundamental?





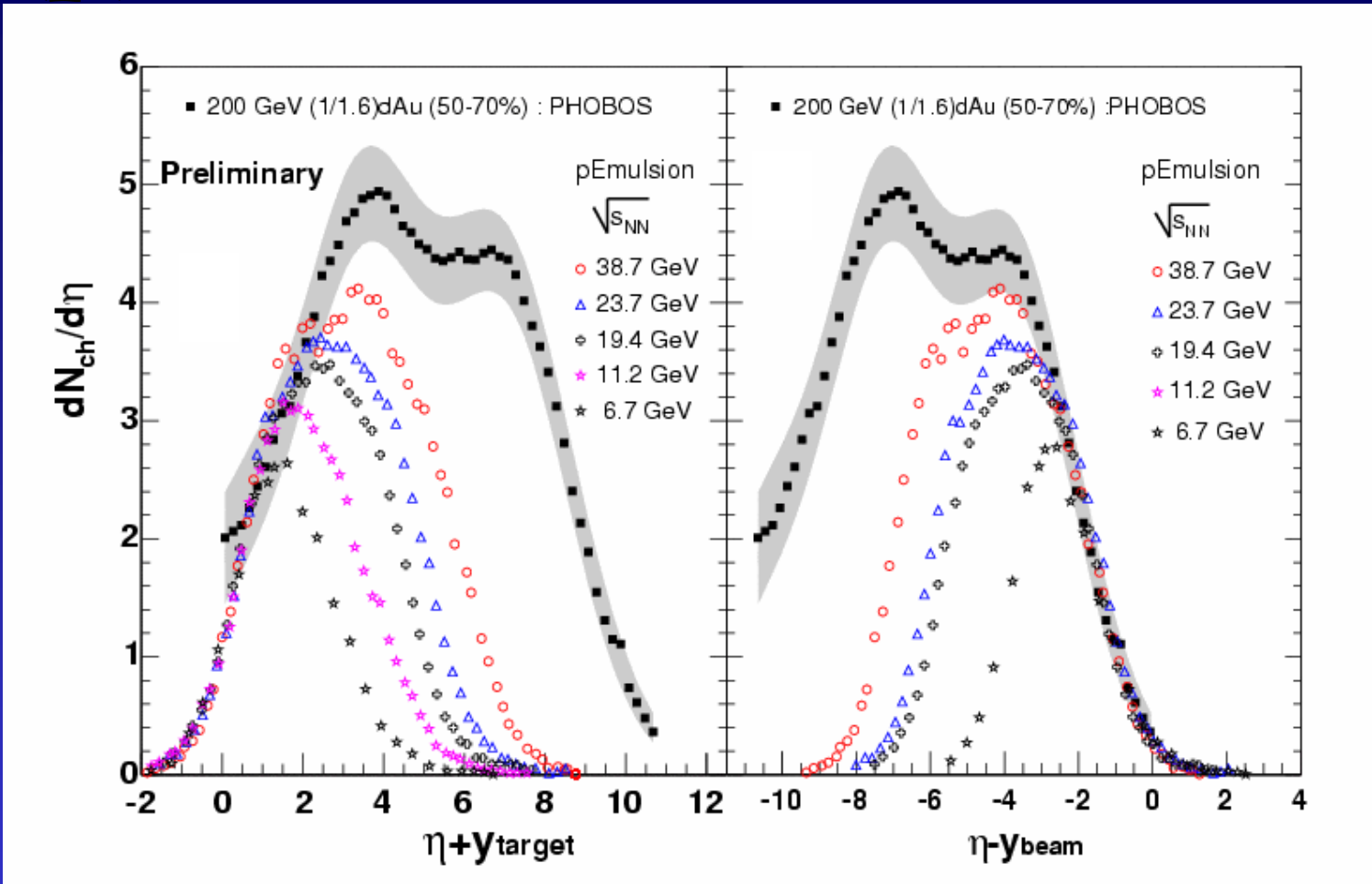
Expectations:
"stopping" in d direction
"cascading" in Au direction

Why do they add up to N_{part} scaling so robustly?

Same effect in Au+Au

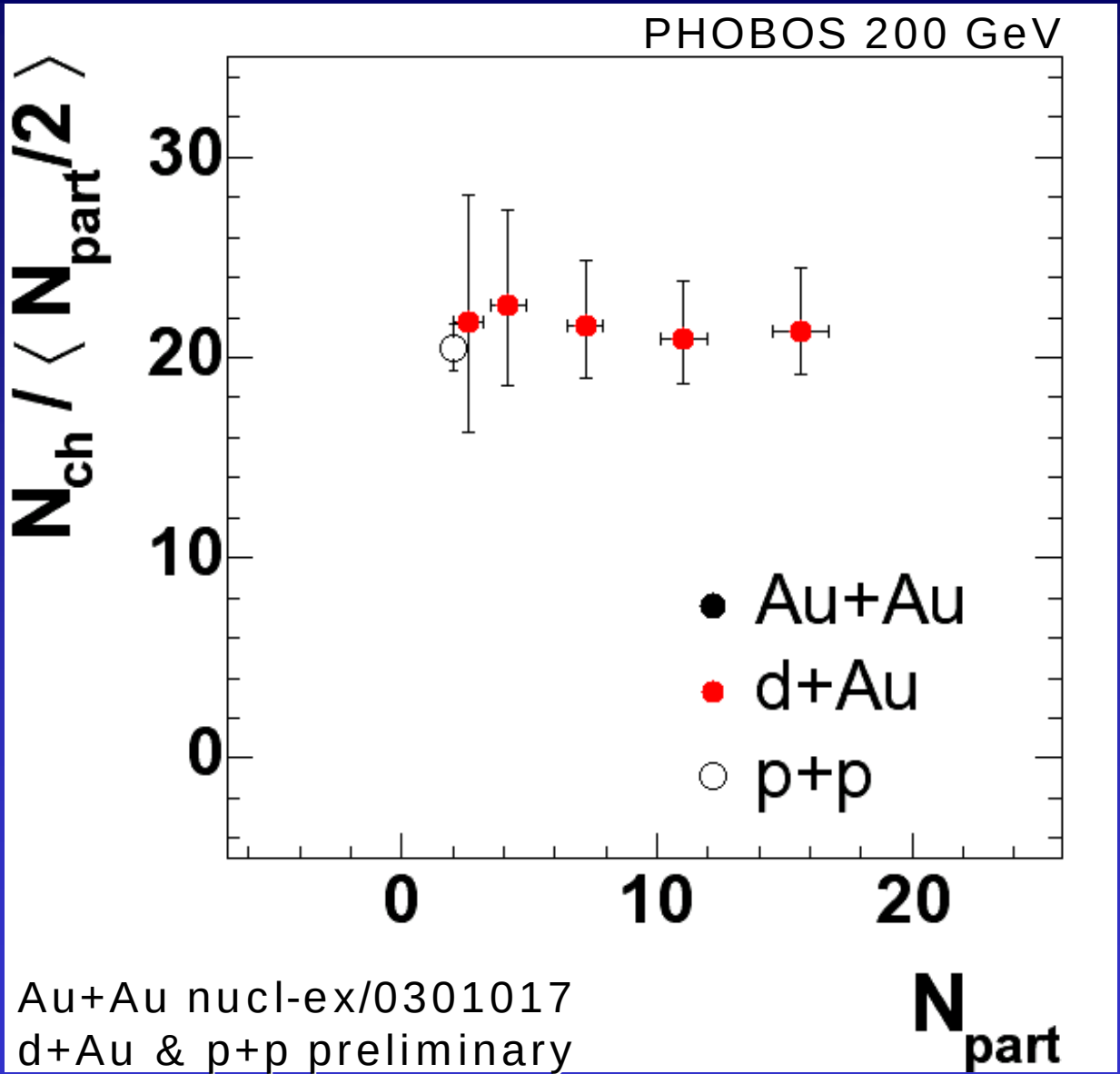
"Long-range" correlation?

(p)d+Au in Different Frames



As with Au+Au, "limiting fragmentation region" grows with energy.
Shape appears to be constrained by lower-energy p+A data.
Surprising over 1.5 orders of magnitude in collision energy.

Can we build Au+Au with p+p/d+Au?



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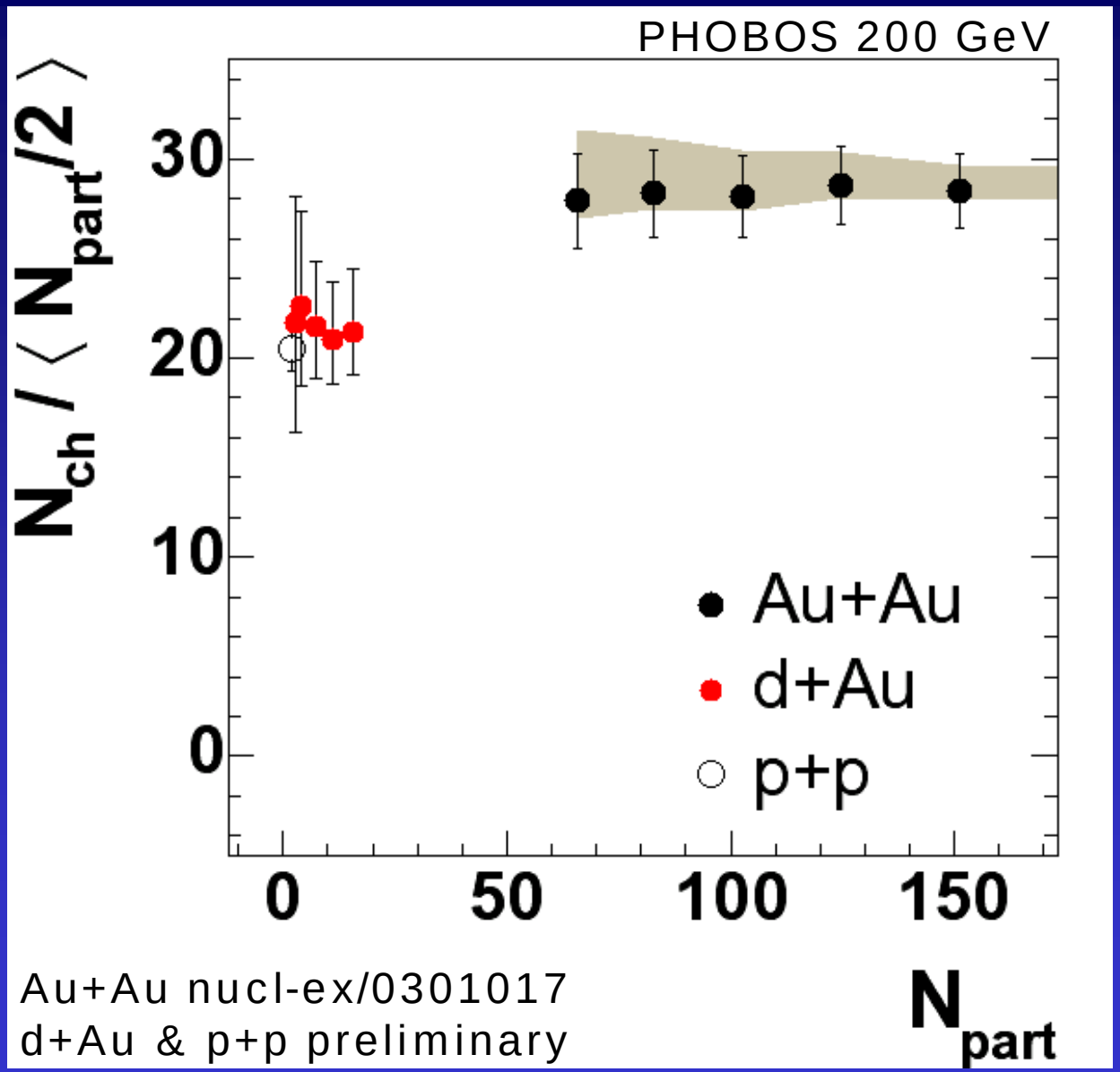

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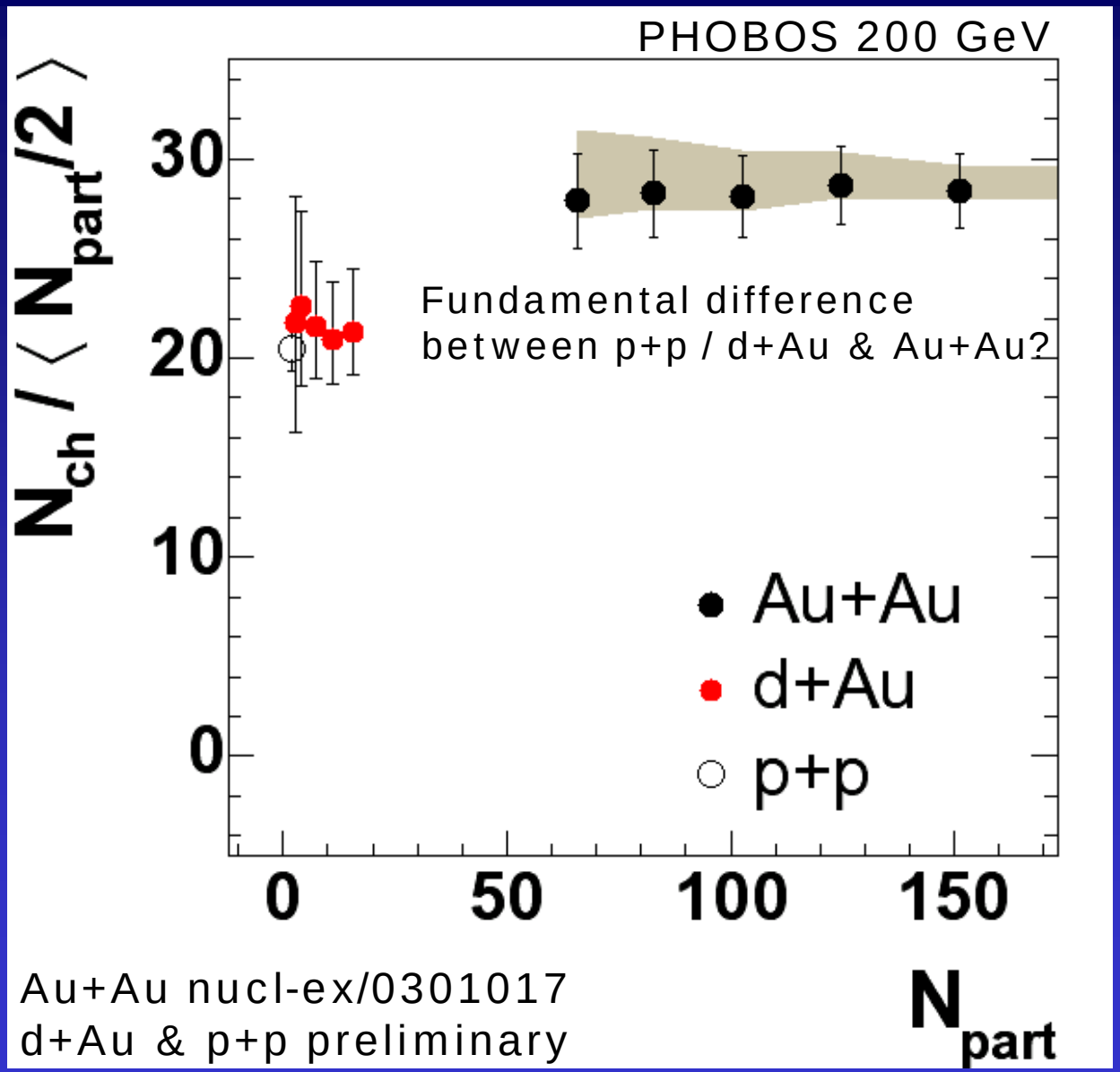

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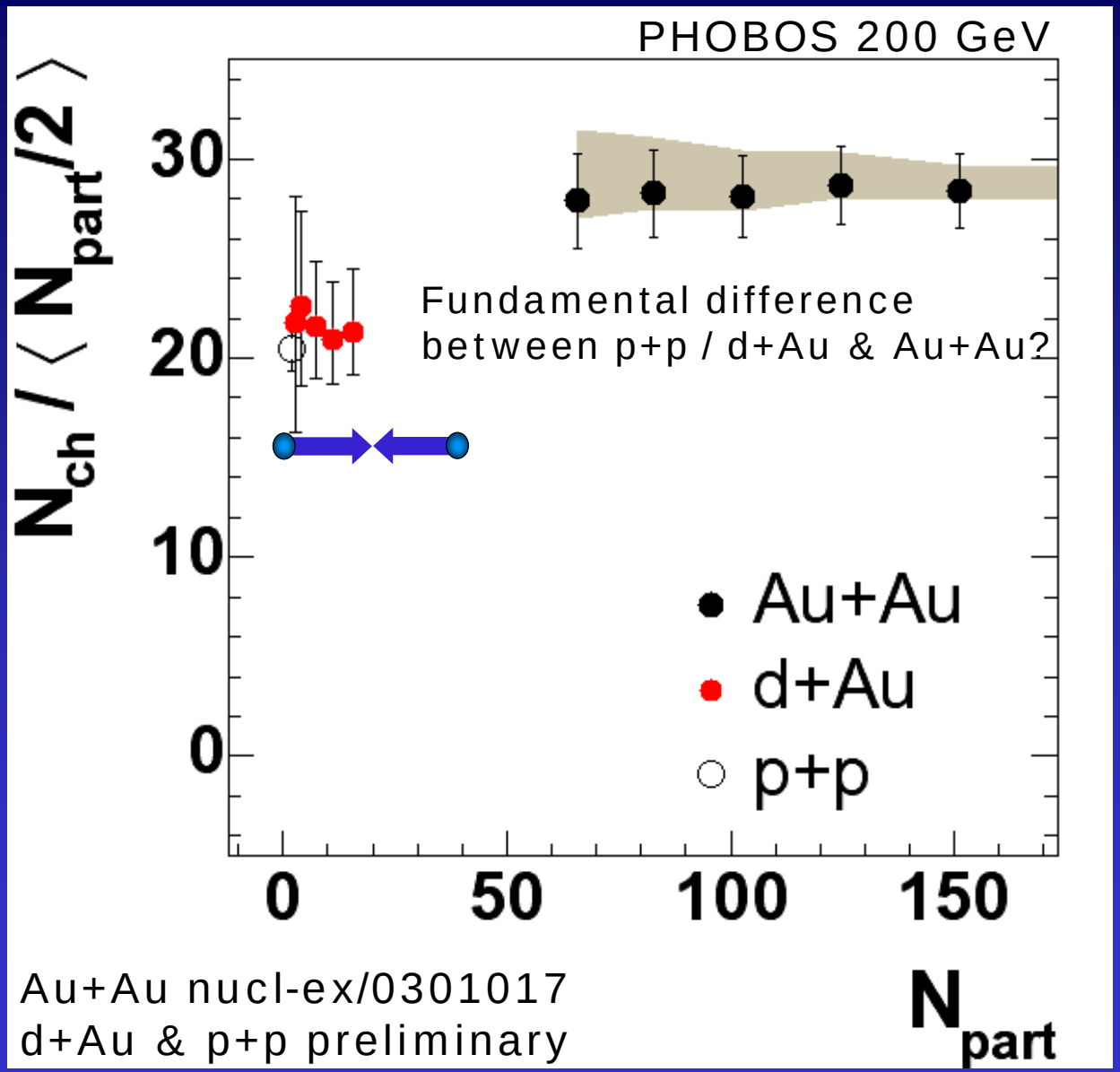

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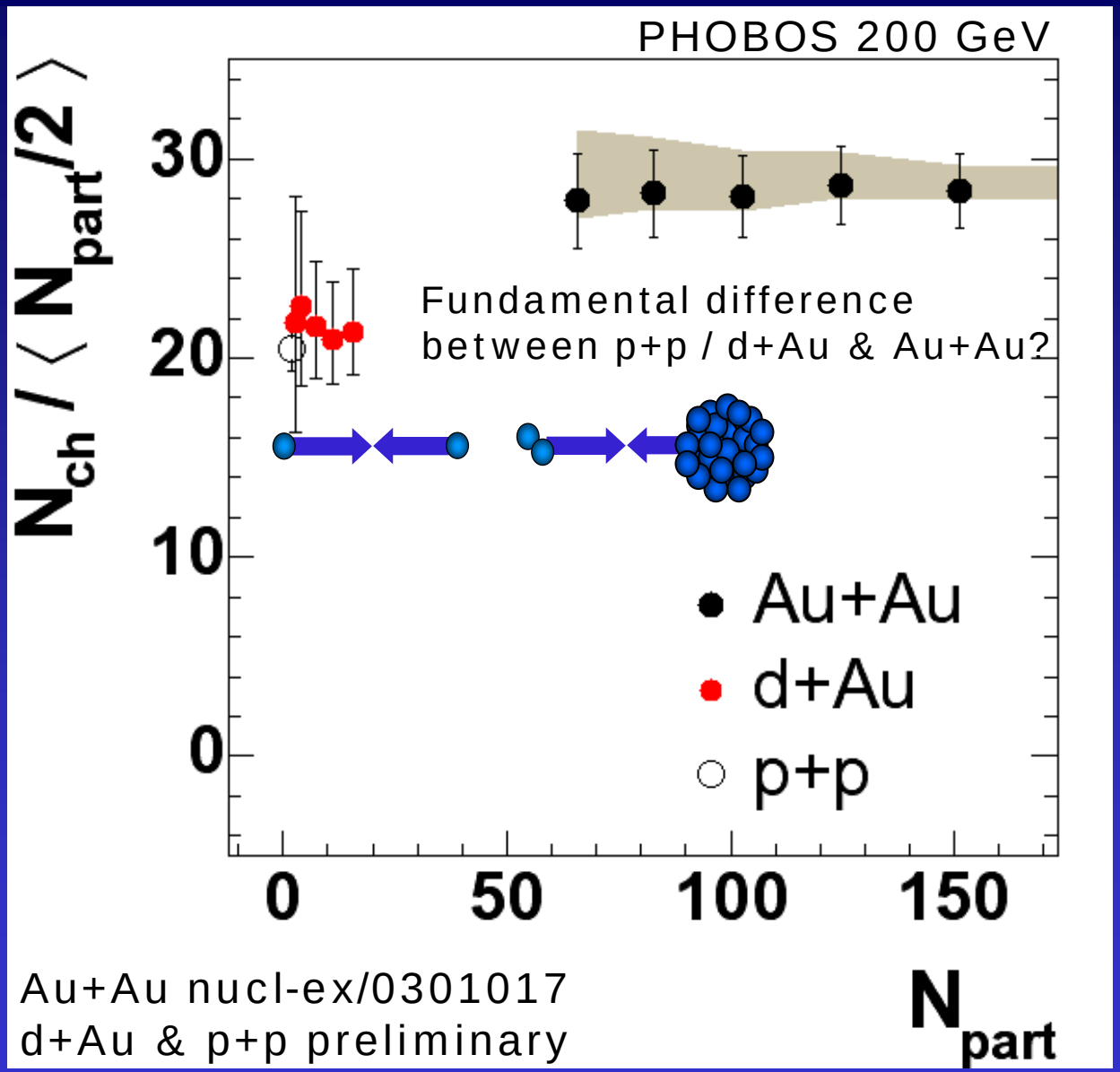
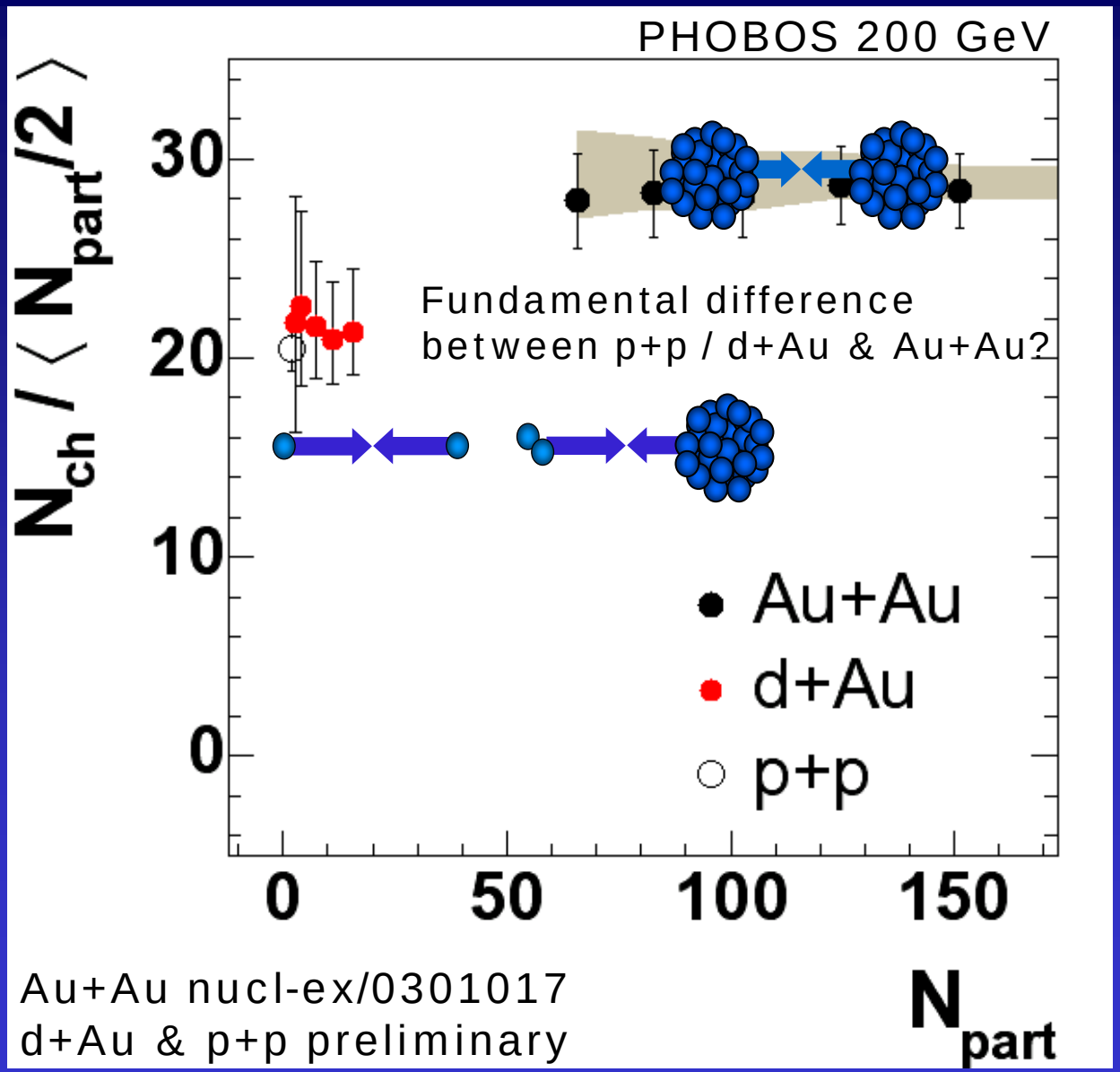


Can we build Au+Au with p+p/d+Au?



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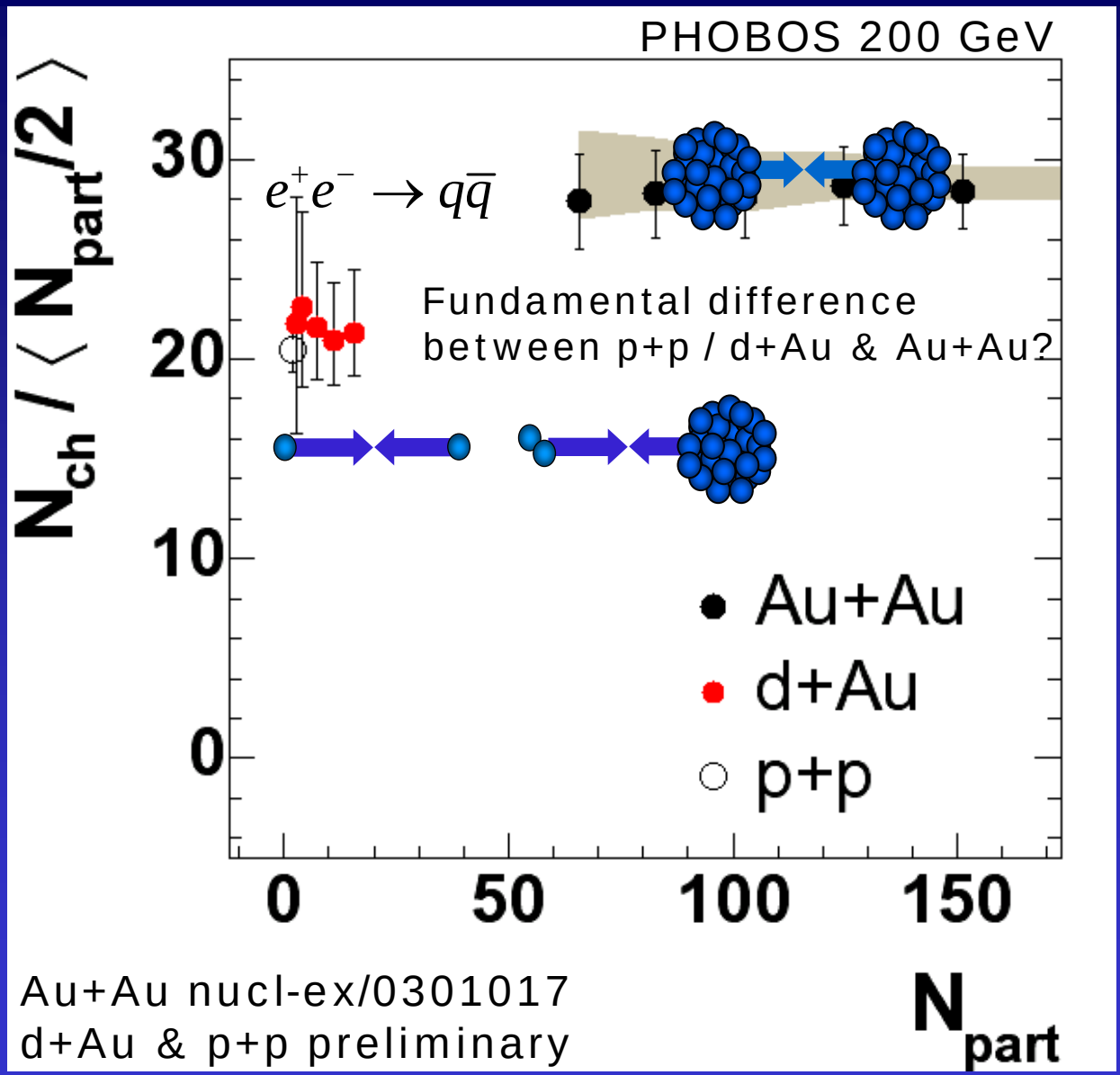


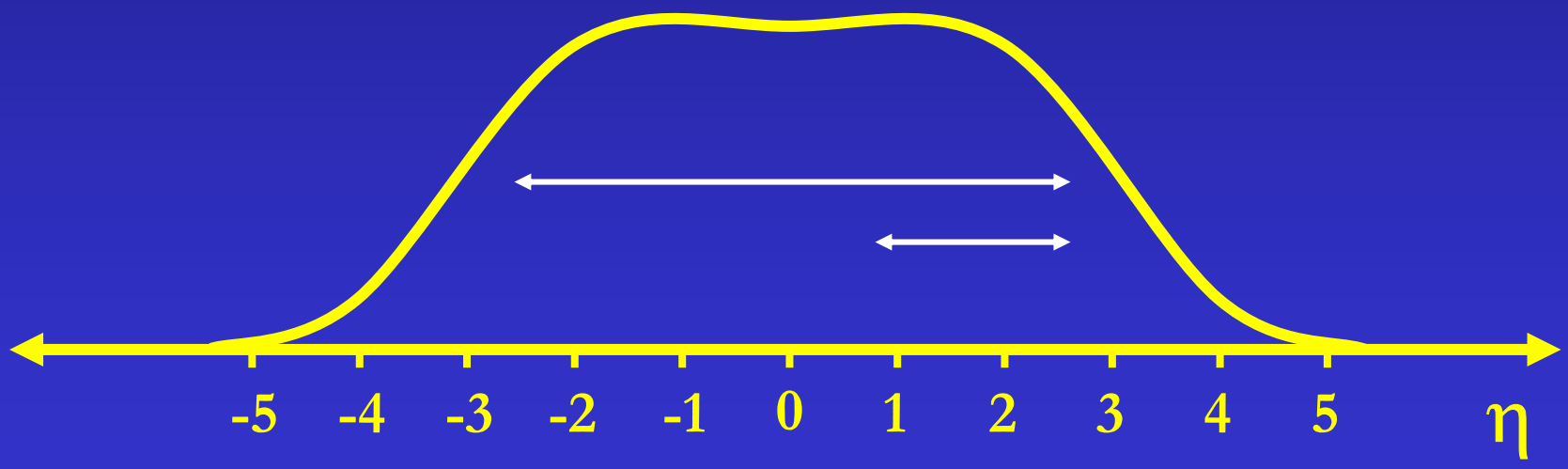
Multiparticle Physics: Fluctuations, HBT, Flow

Forward Multiparticle Physics in Au+Au

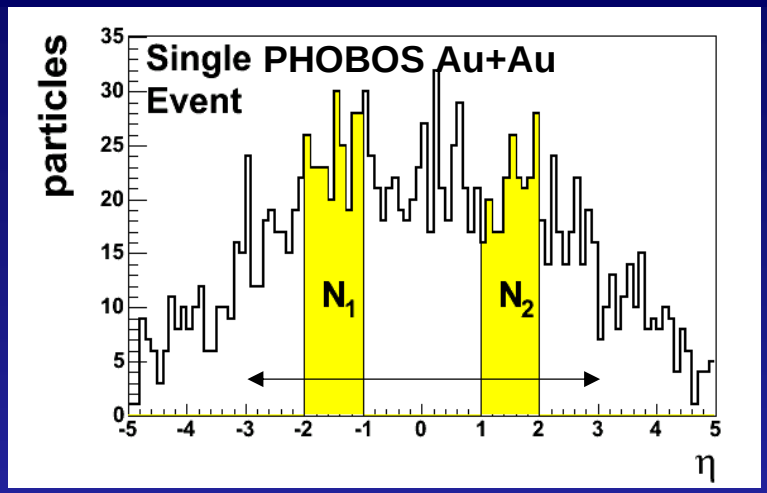
4π multiplicity measurements show long-range correlation

- Fluctuations & Correlations
- HBT Correlations
- Azimuthal asymmetries

} Long-Range vs. Short-Range effects



Forward-Backward Correlations

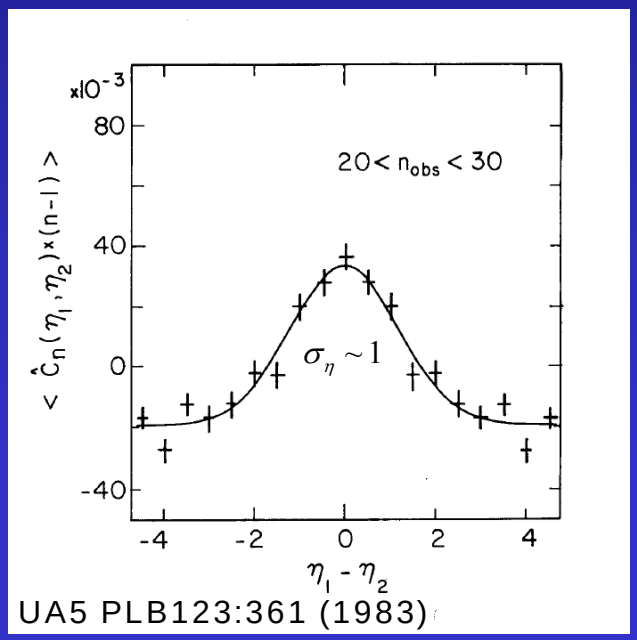


PHOBOS study for Au+Au:

$$C = \frac{F - B}{\sqrt{F + B}} \Rightarrow \sigma(C) = \sqrt{\kappa}$$

K. Wozniak talk

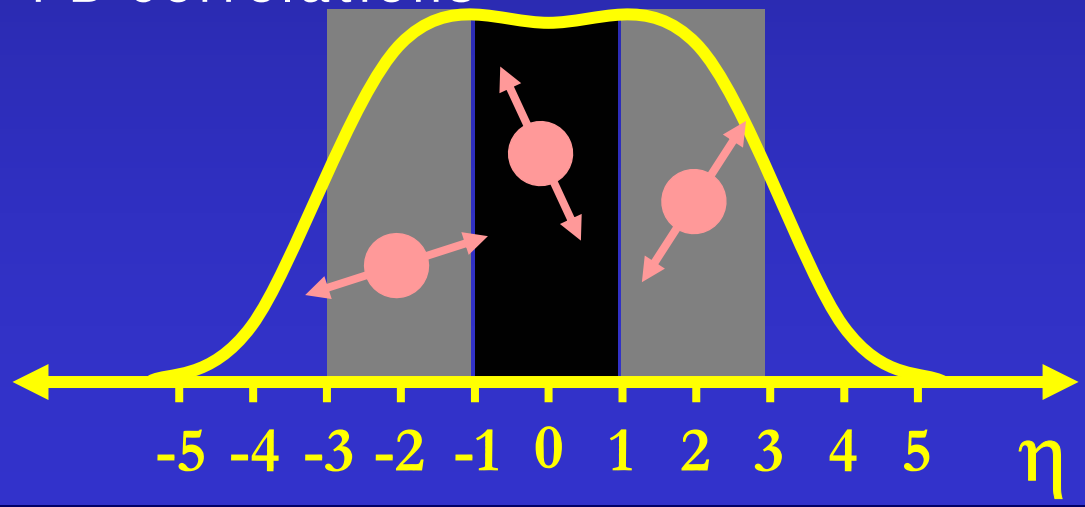
- Correlations consistent w/ UA5
- Weak rapidity dependence from $1<|\eta|<3$



UA5 PLB123:361 (1983)

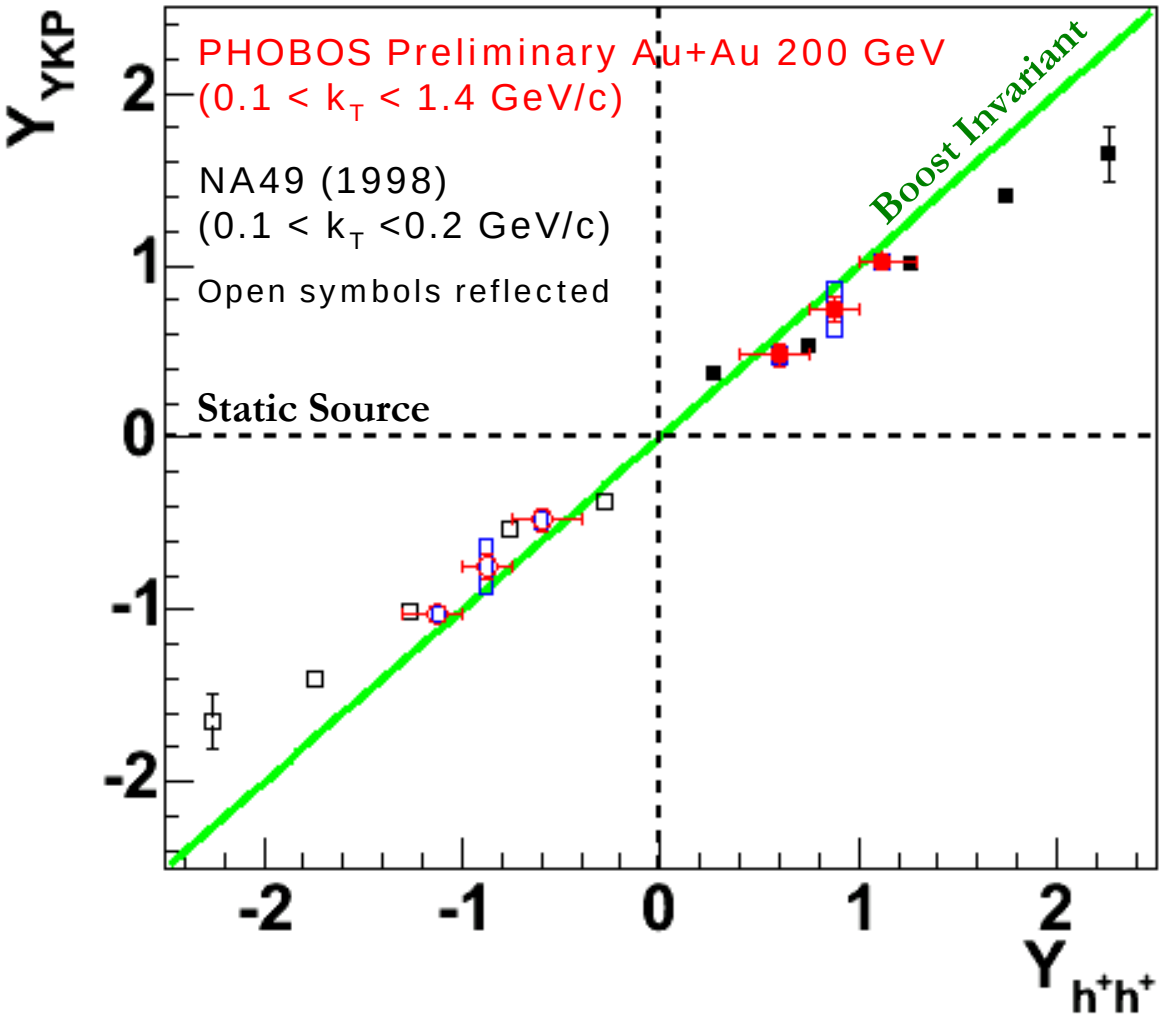
UA5 $\bar{p}$+p: 2-particle clusters explain

- Short-range correlations in η
- FB correlations



Longitudinal Dynamics with HBT

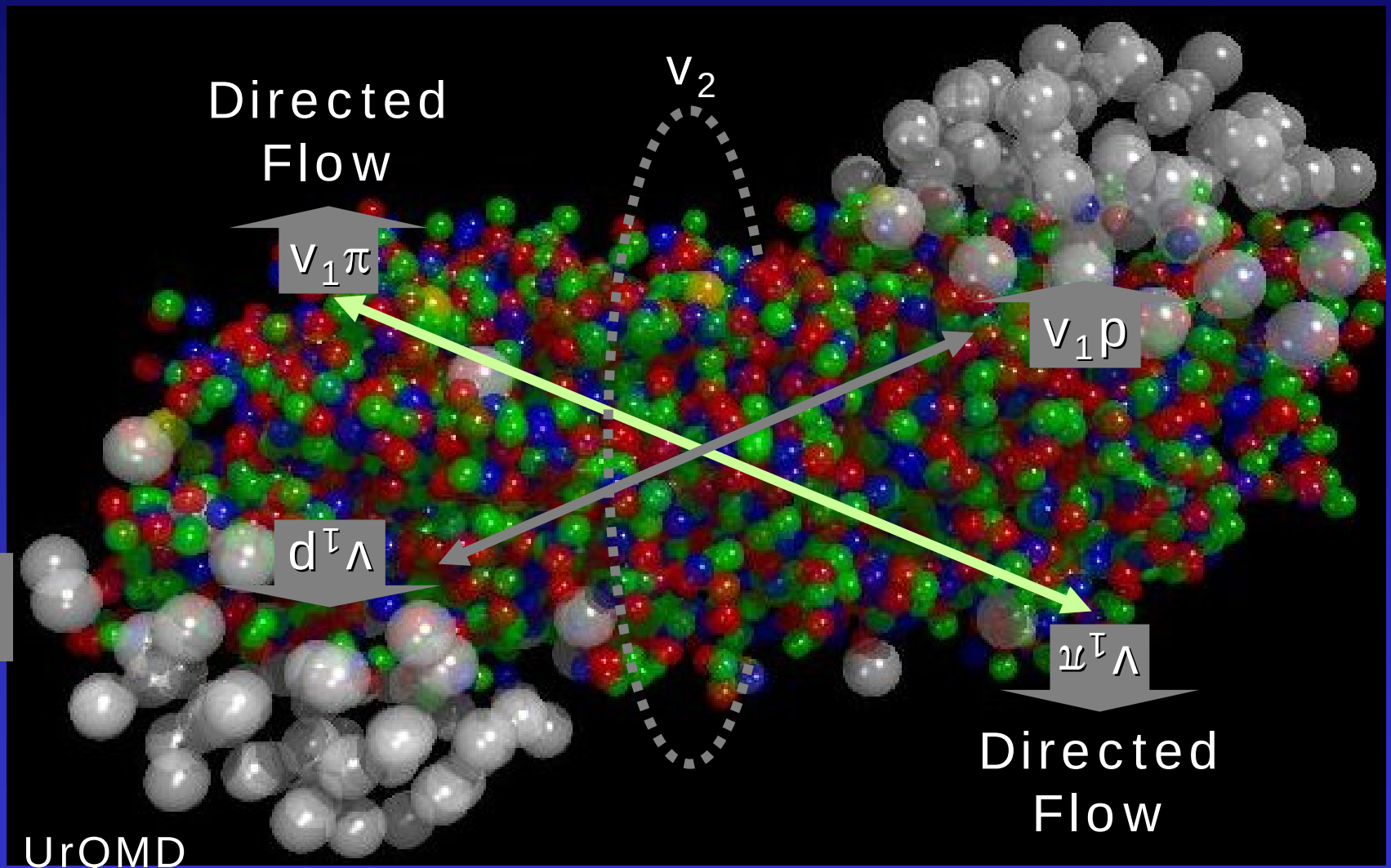
See talk by B. Holzman, poster by C.M.Kuo



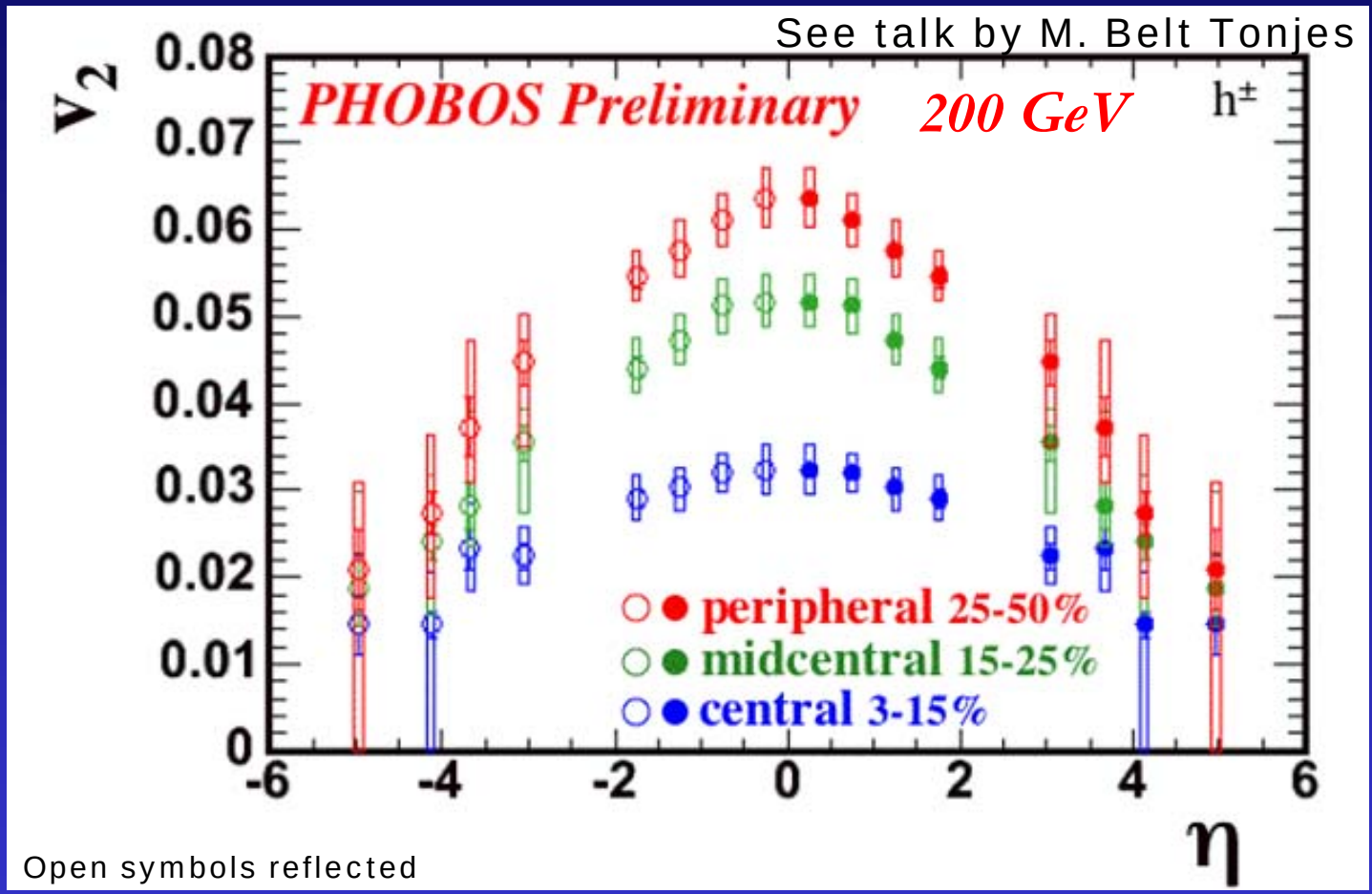
Particles at a given rapidity are correlated with a source at the same rapidity

Similar to FB result: correlations are local in rapidity.

Directed and Elliptic Flow



Elliptic Flow vs. Centrality

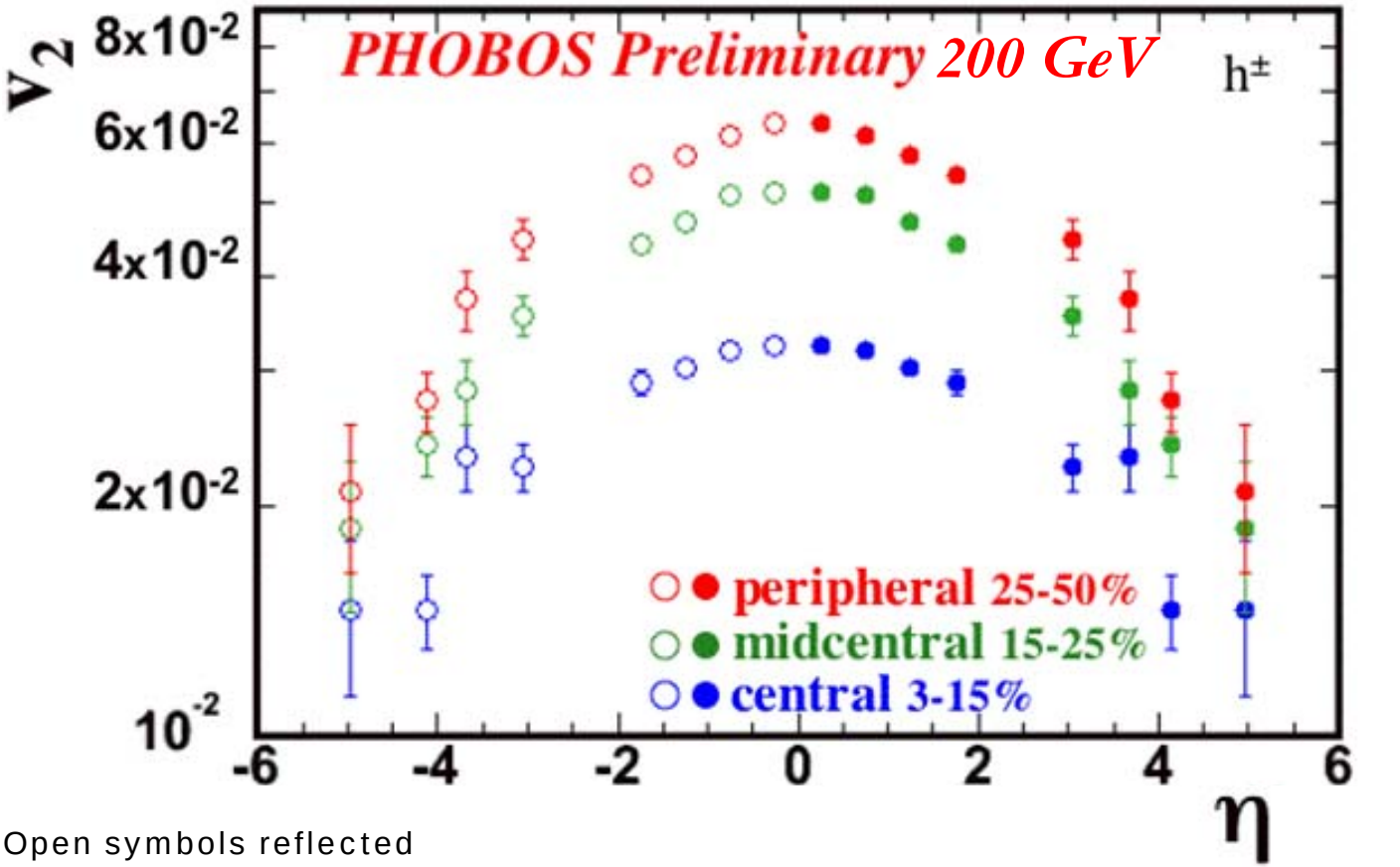


$$v_2^{central}(\eta) \propto v_2^{peripheral}(\eta)$$

Overall shape simple, but still unexplained

Elliptic Flow vs. Centrality

See talk by M. Belt Tonjes

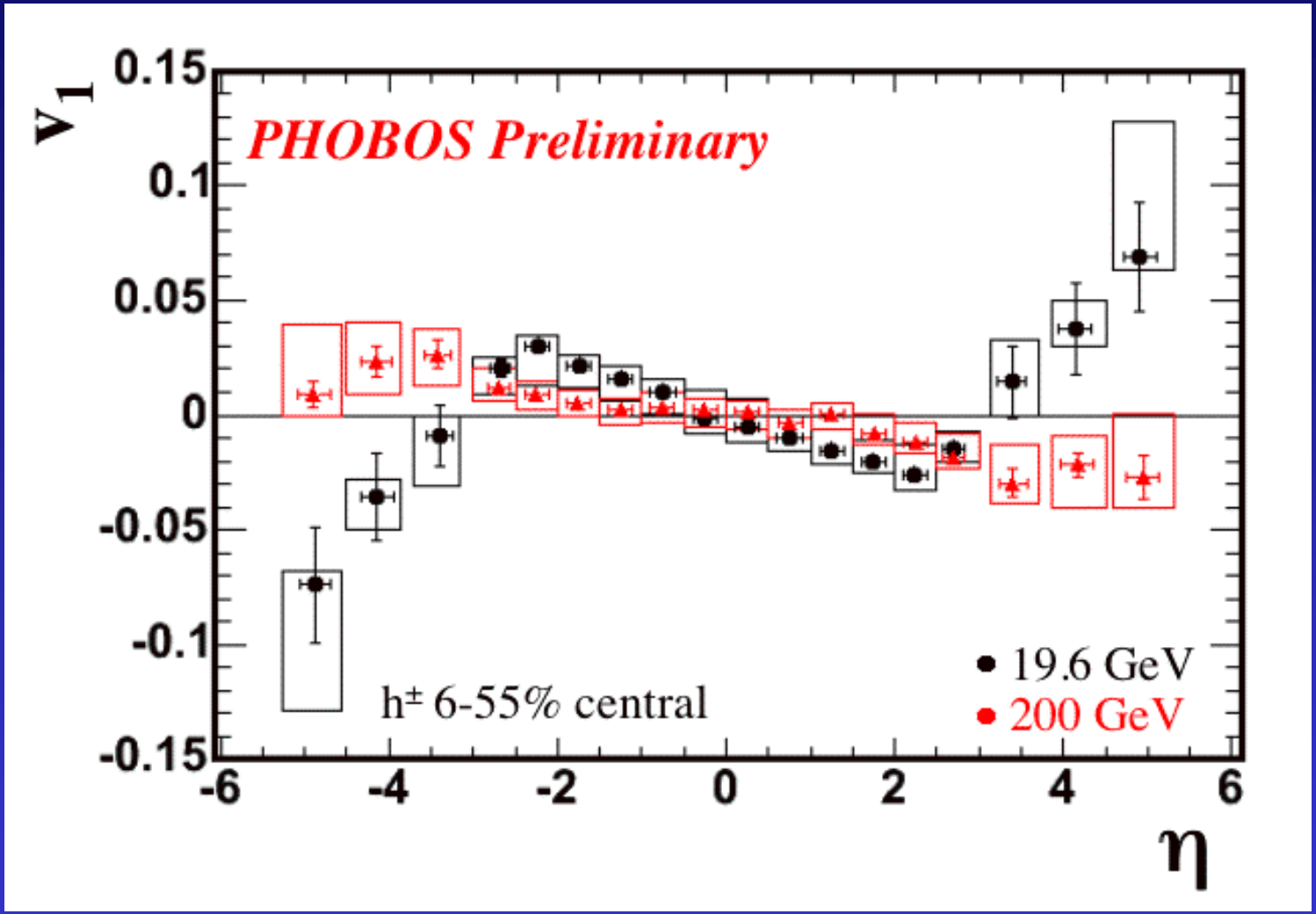


Open symbols reflected

$$v_2^{central}(\eta) \propto v_2^{peripheral}(\eta)$$

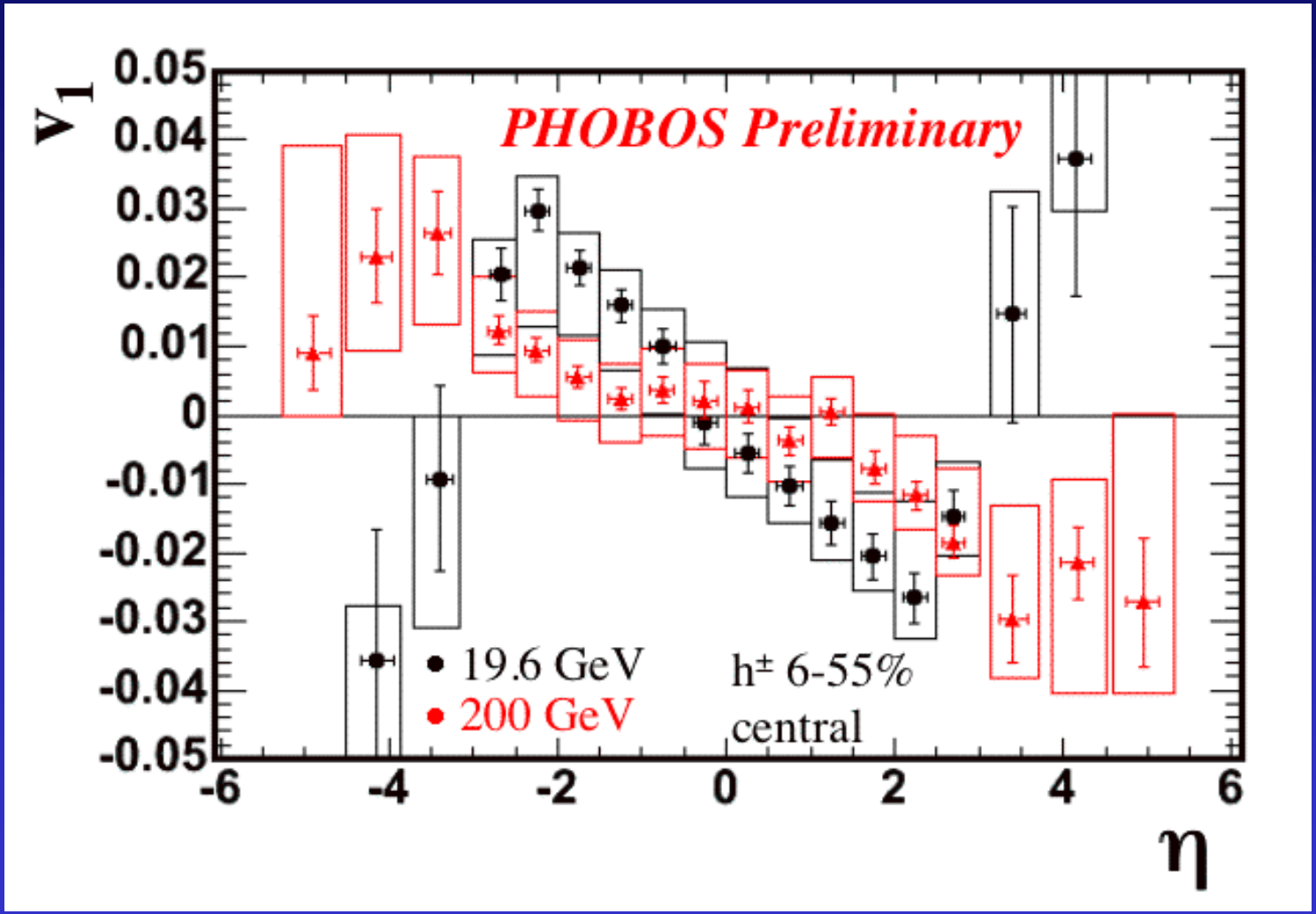
Overall shape simple, but still unexplained

Directed Flow vs. Energy



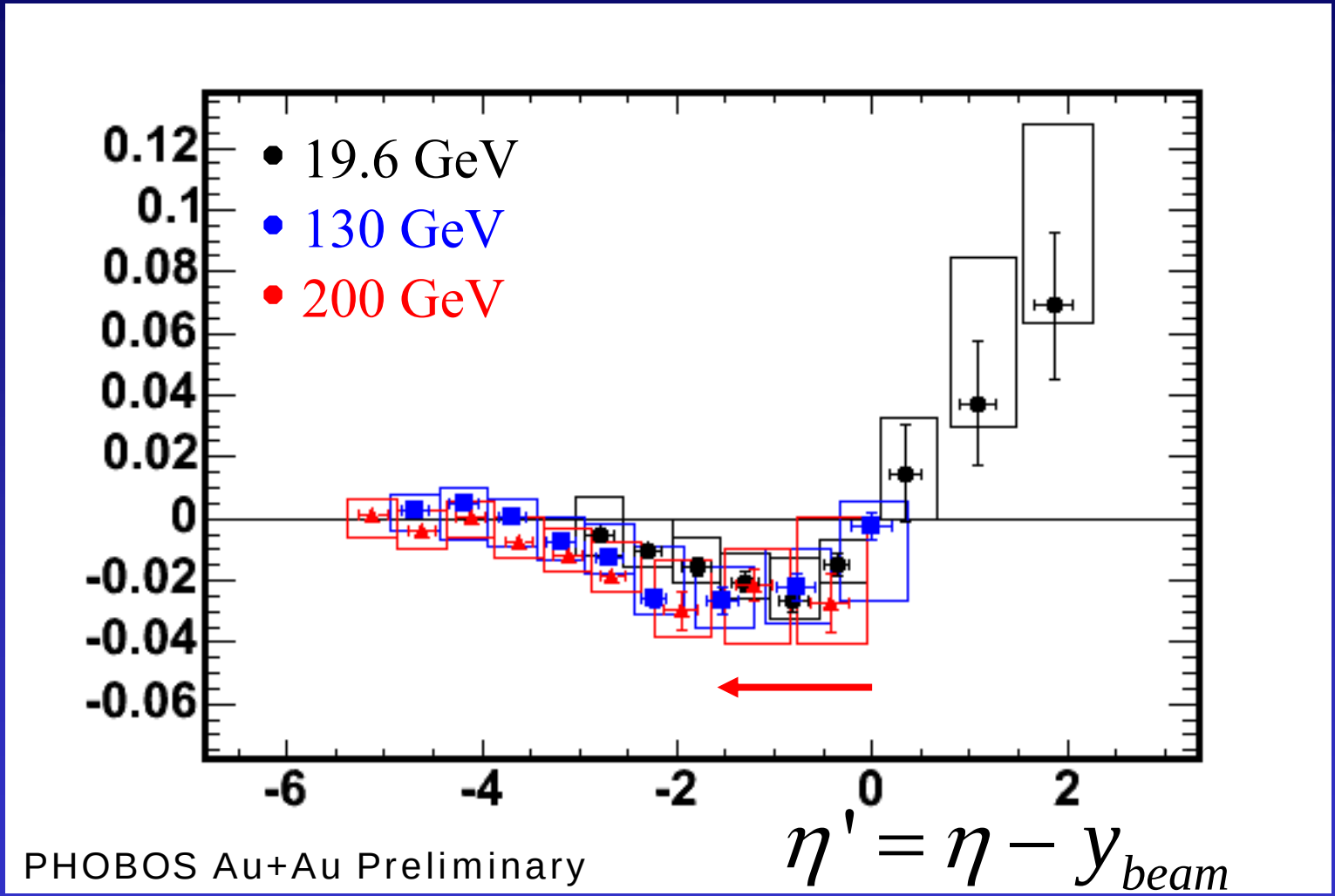
Dramatic change of directed flow near η=0

Directed Flow vs. Energy



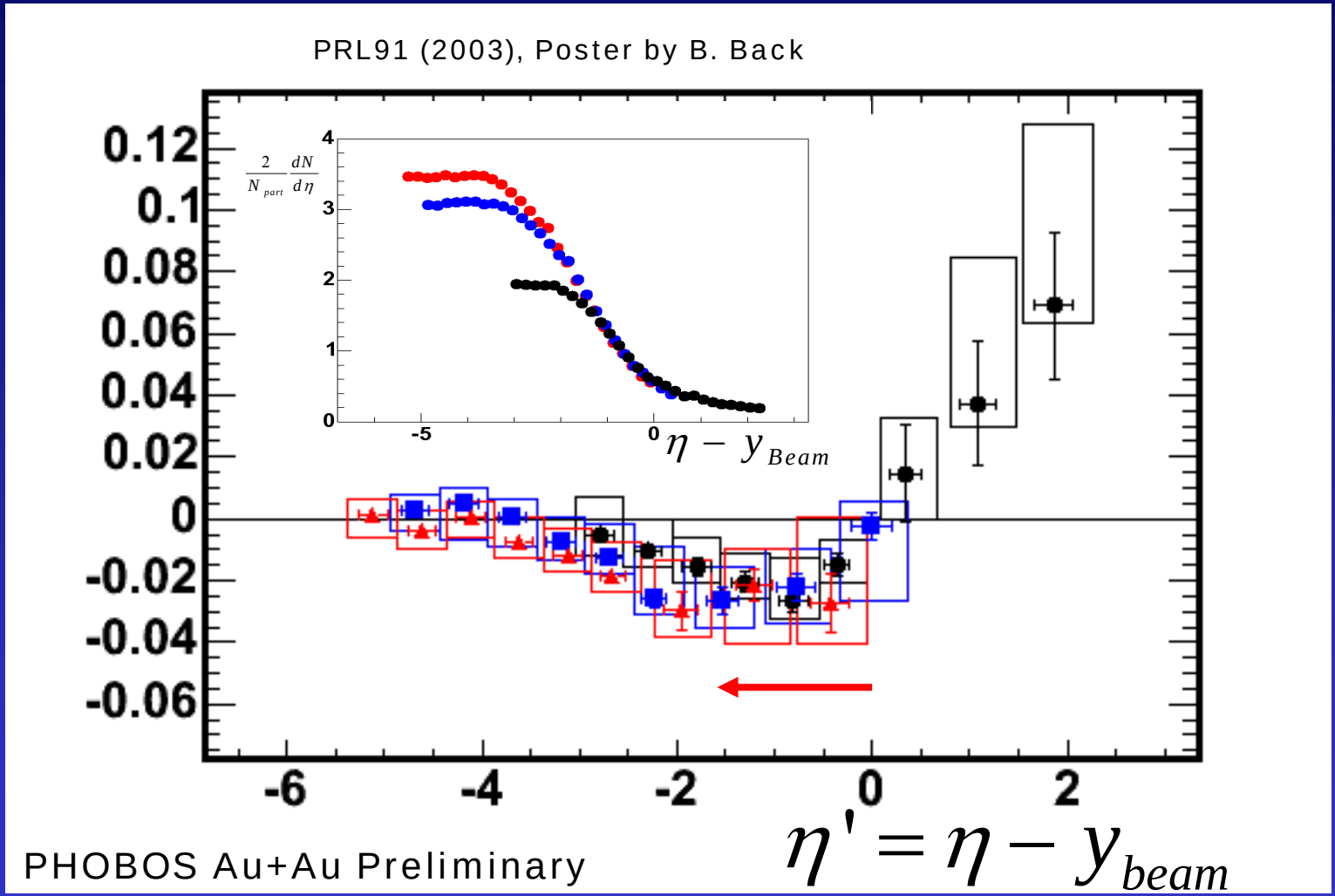
Dramatic change of directed flow near $\eta=0$

"Limiting Fragmentation" of v_1



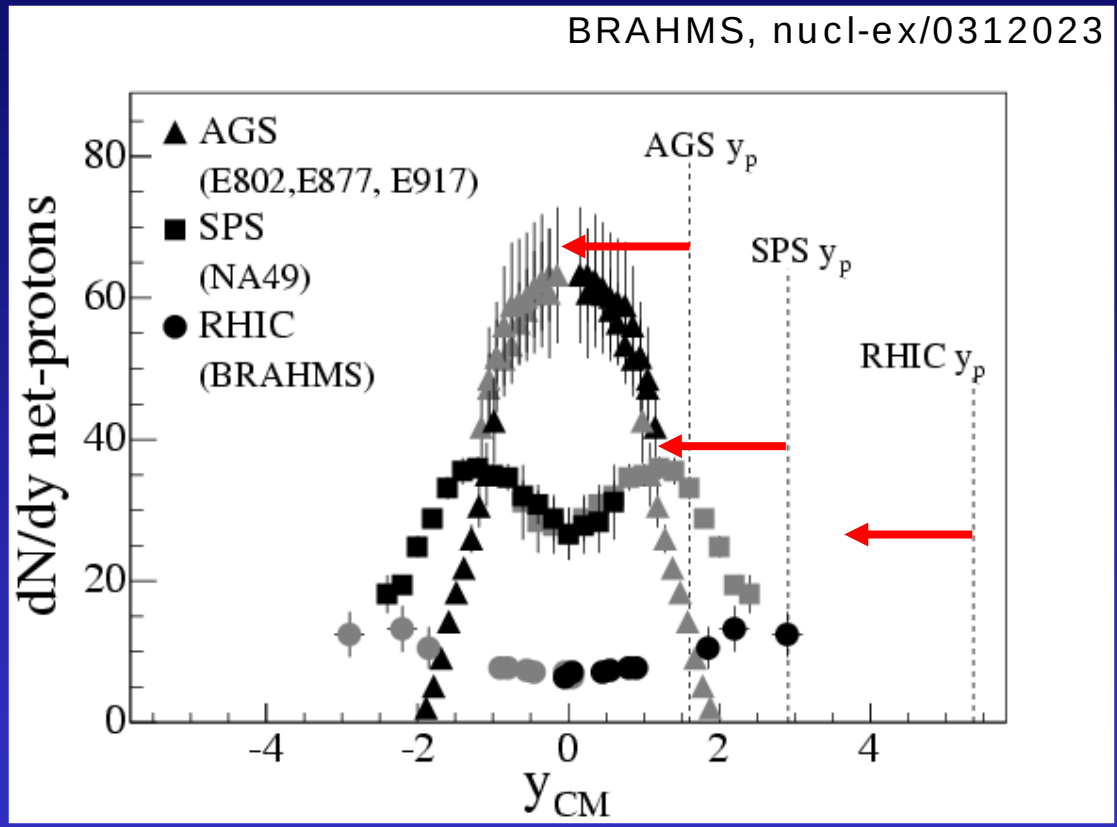
Similar directed flow relative to beam rapidity

"Limiting Fragmentation" of v_1



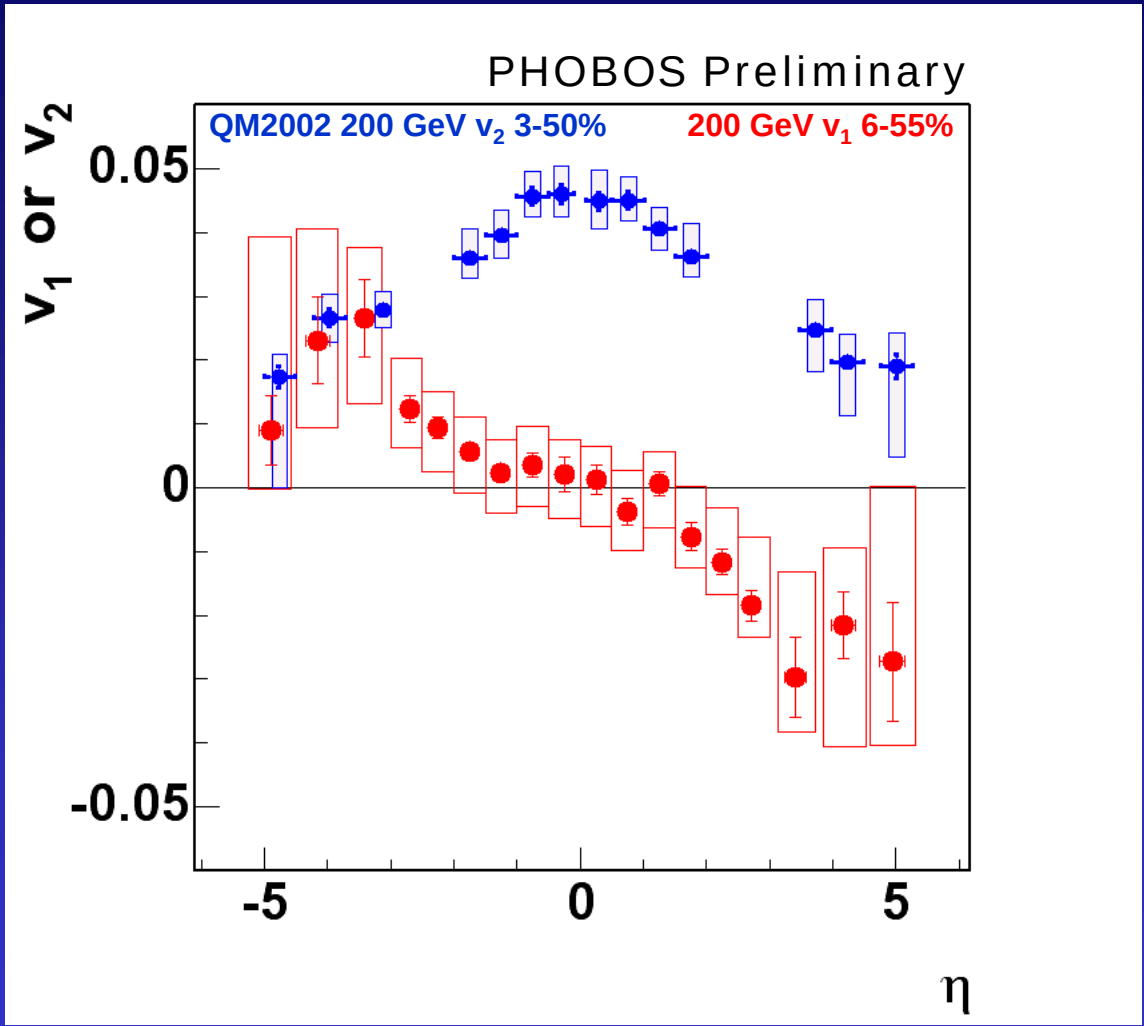
Similar directed flow relative to beam rapidity

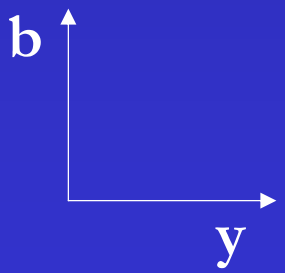
Connection with Net Baryons?



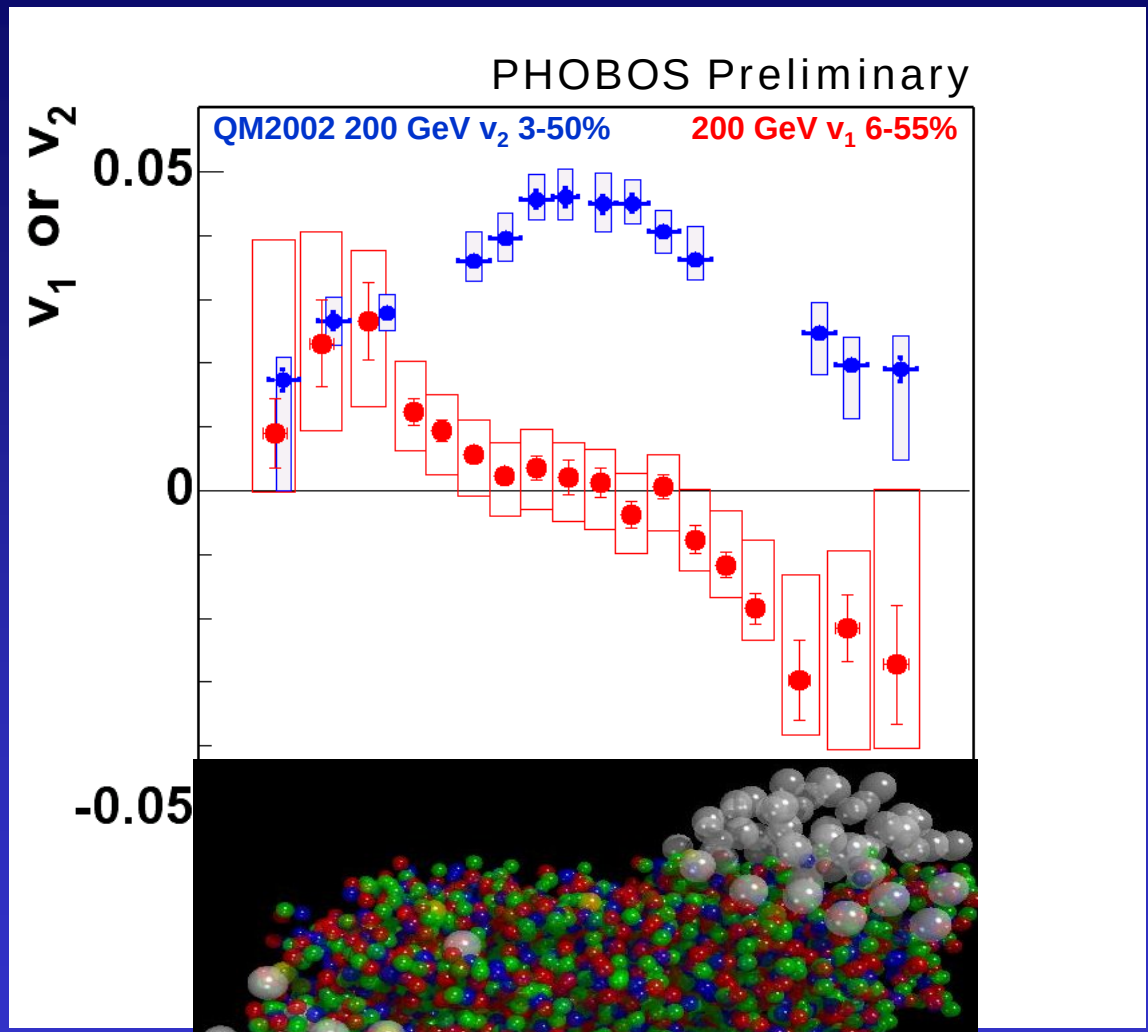
Peak of baryon density at AGS/SPS at η'~-1.5
(Busza & Goldhaber '84)

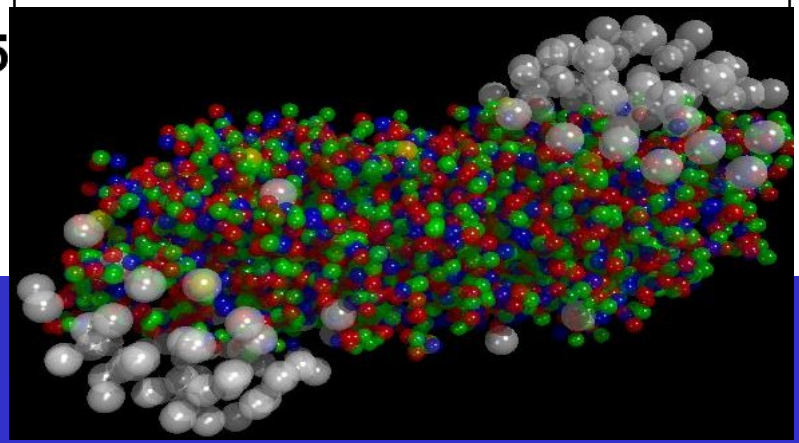
Directed & Elliptic Flow

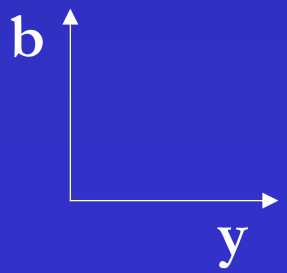




Directed & Elliptic Flow



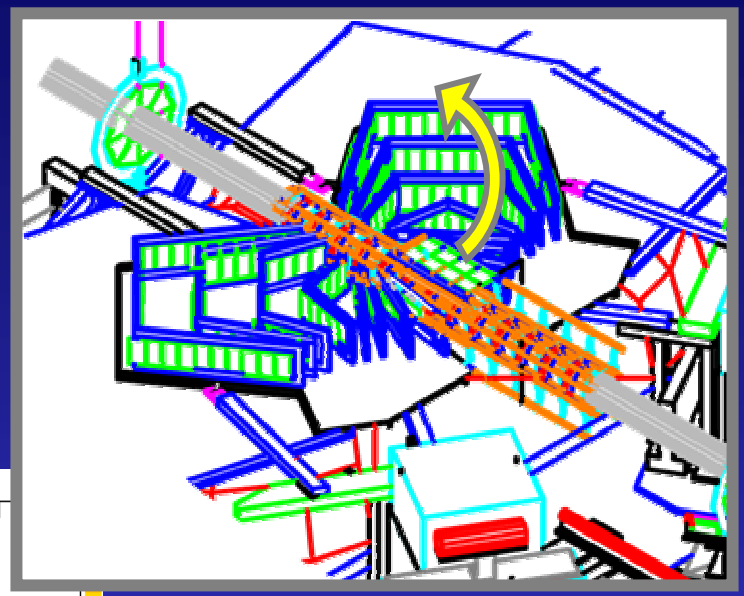


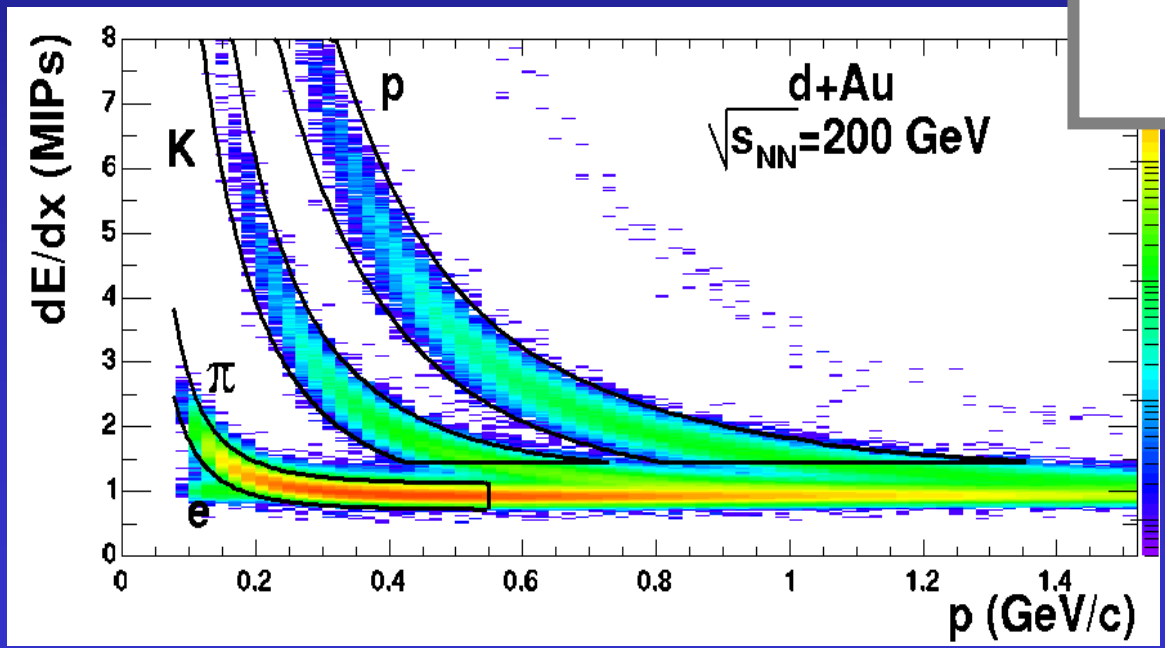


Identified Particles in d+Au

Ratios with dE/dx PID

A “classic” PHOBOS measurement:
Two charge signs,
two bending directions...





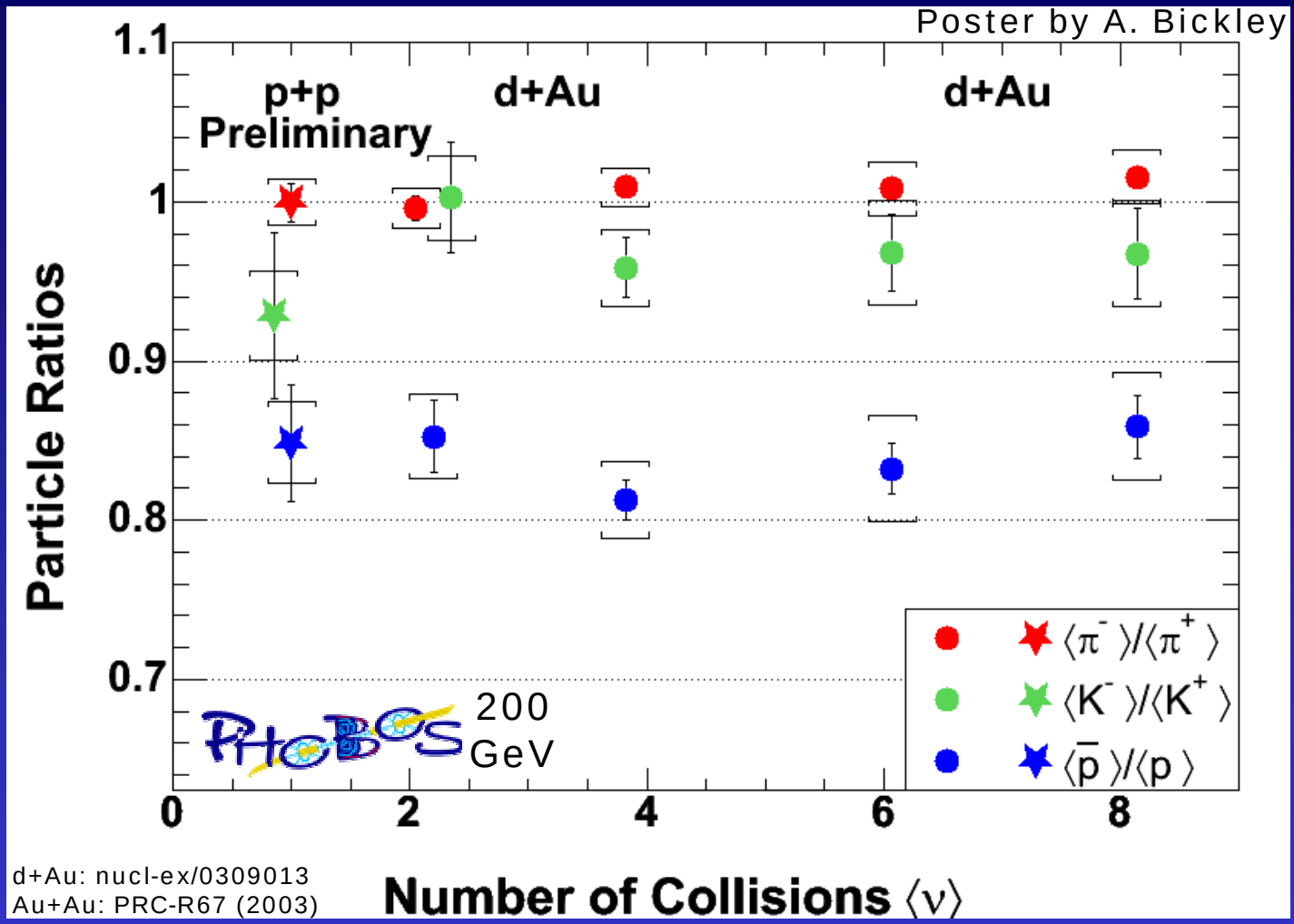
...but now we have

p+p

d+Au

Au+Au

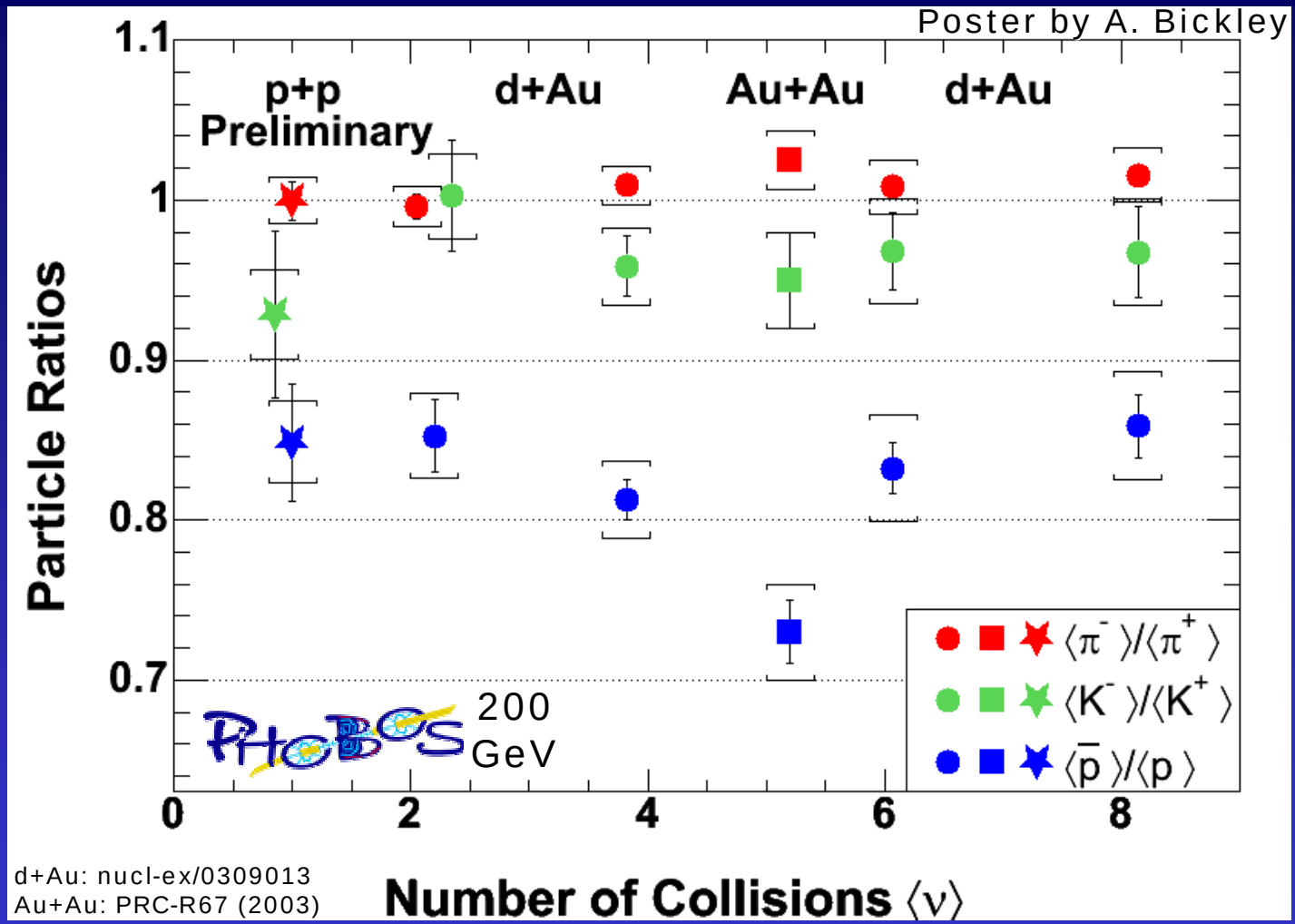
Identified Particle Ratios



p+p → d+Au : No modification (cf. multiplicity)

Au+Au: Additional net-baryons near η=0

Identified Particle Ratios



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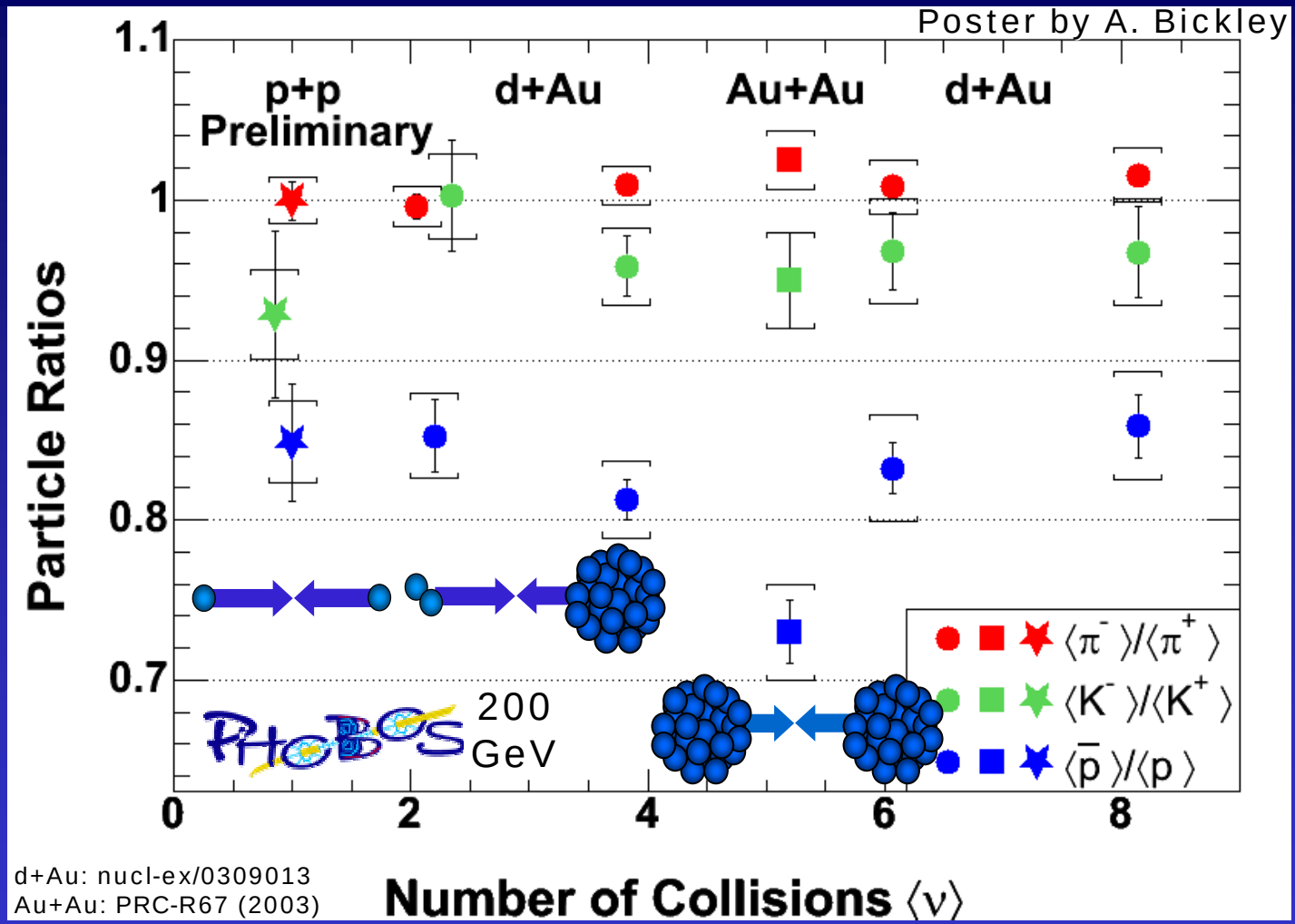
Identified Particle Ratios

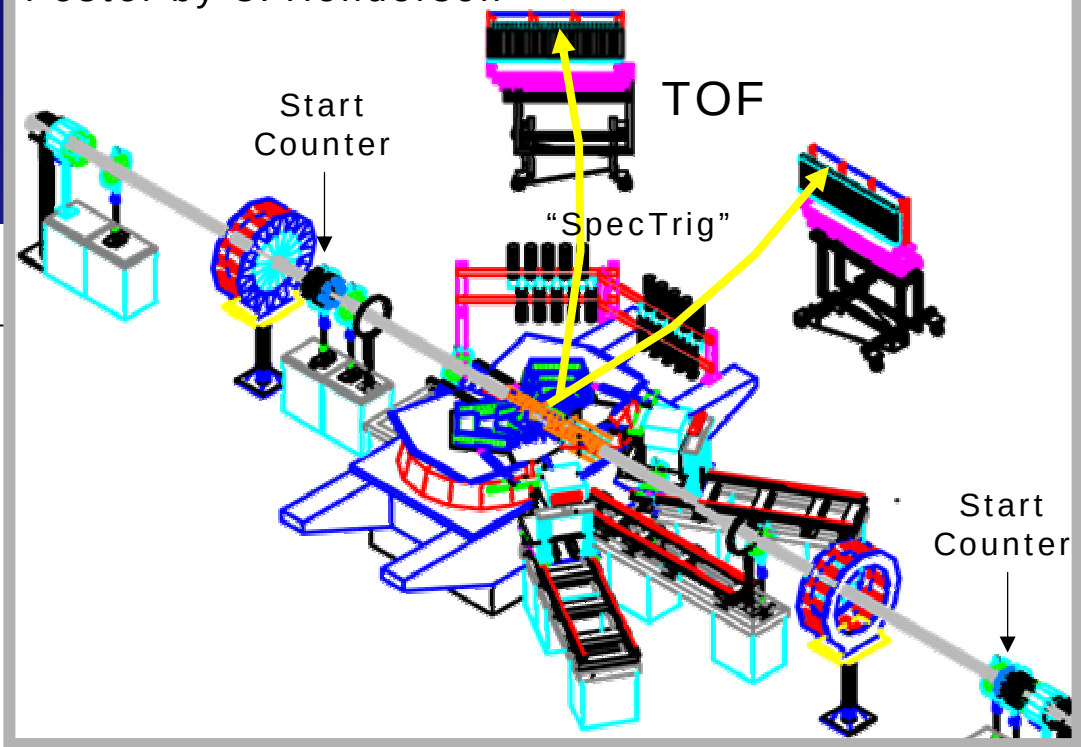


p+p → d+Au : No modification (cf. multiplicity)

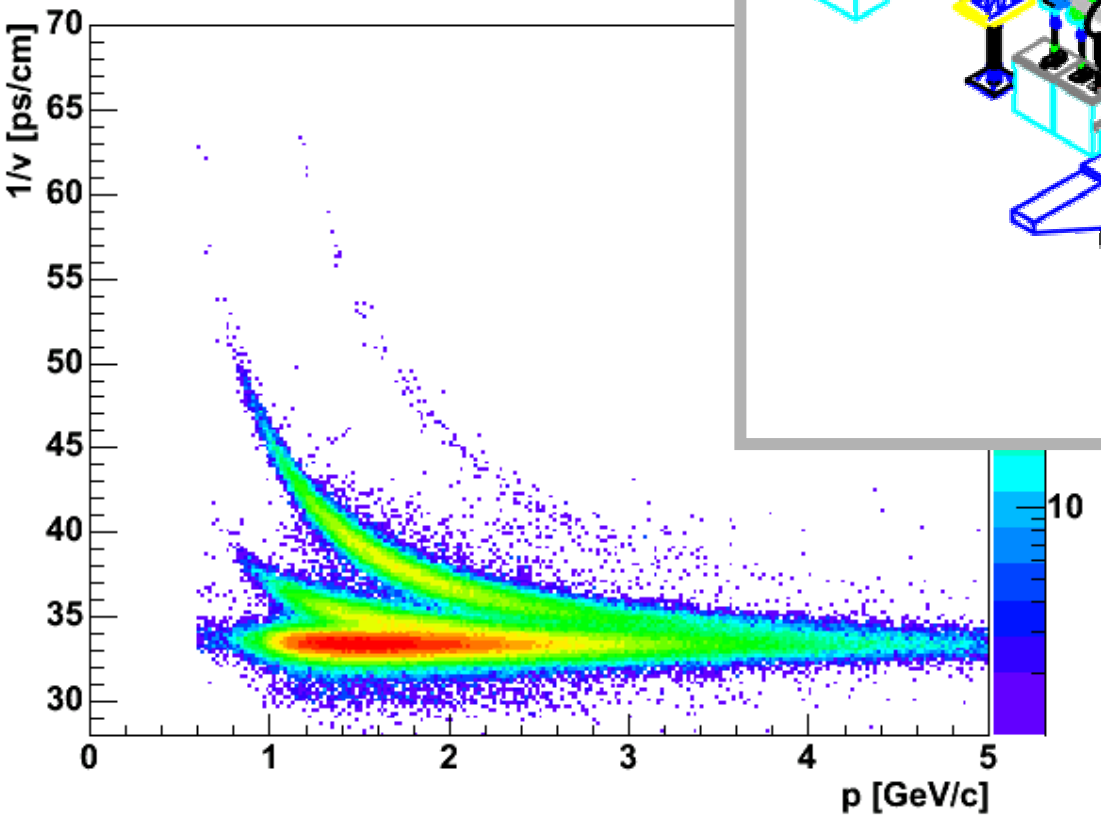
Au+Au: Additional net-baryons near η=0

PHOBOS TOF PID

Poster by C. Henderson

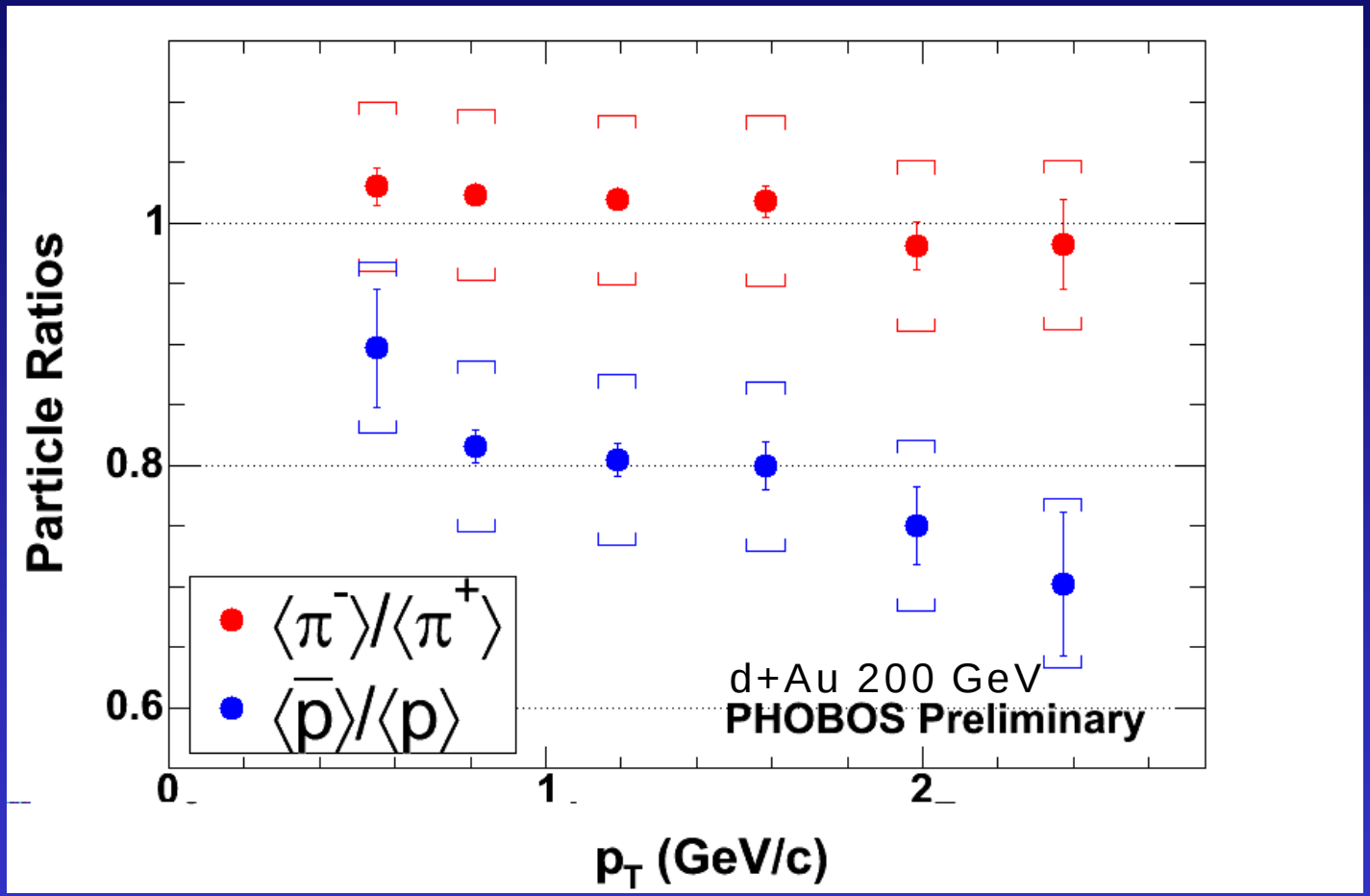


See talk by G.Veres



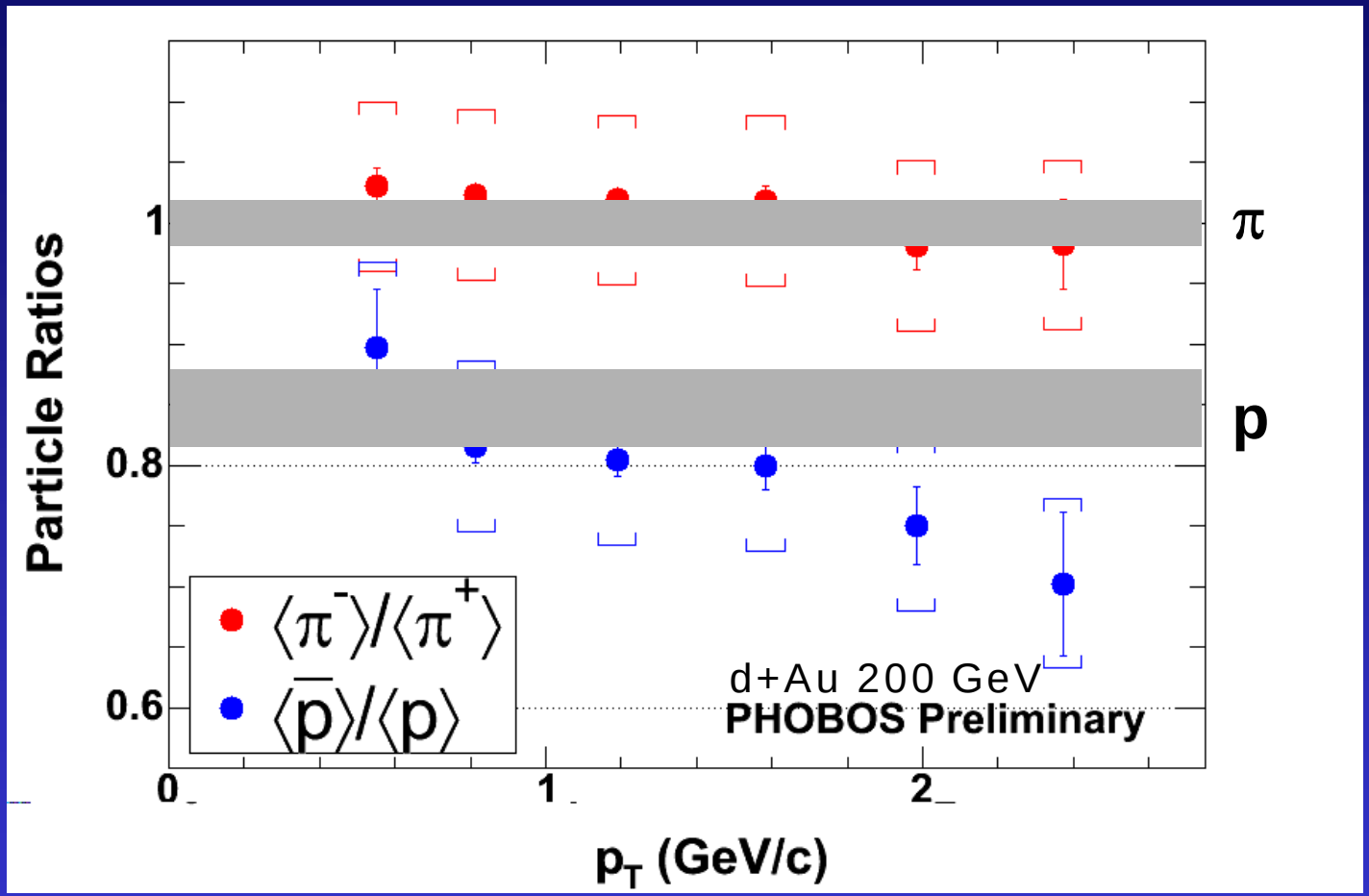
Spectrometer trigger enriched d+Au data set

Particle Ratios at High-p_T



Main difference between p and $\bar{p}$ is overall yield.
Spectral shape only slightly modified vs. p_T

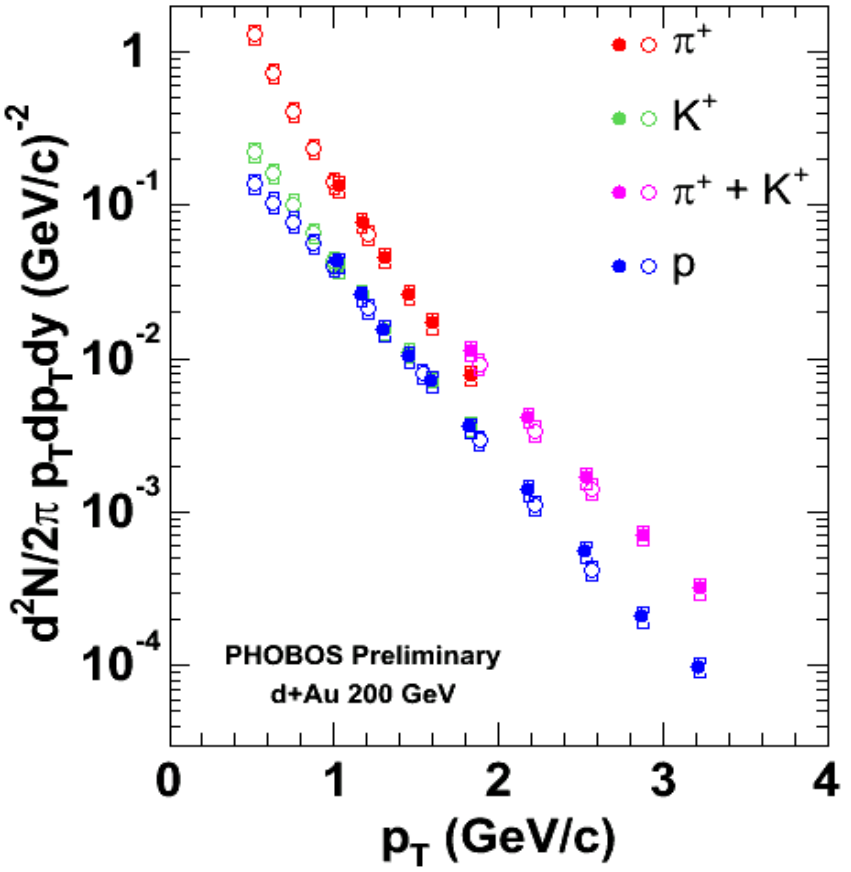
Particle Ratios at High-p_T

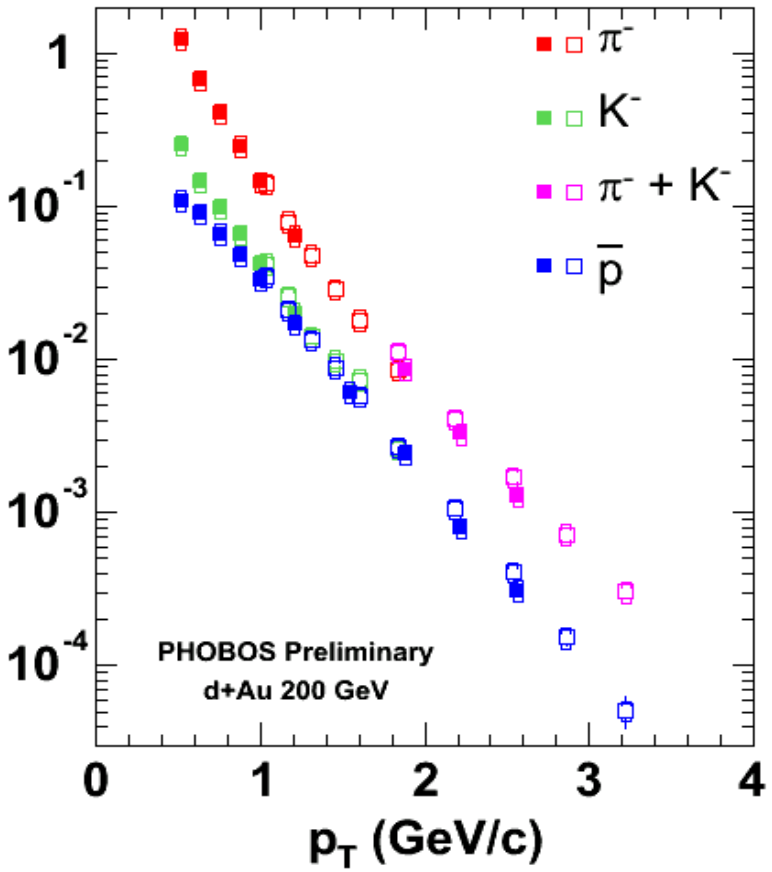


Main difference between p and $\bar{p}$ is overall yield.
Spectral shape only slightly modified vs. p_T

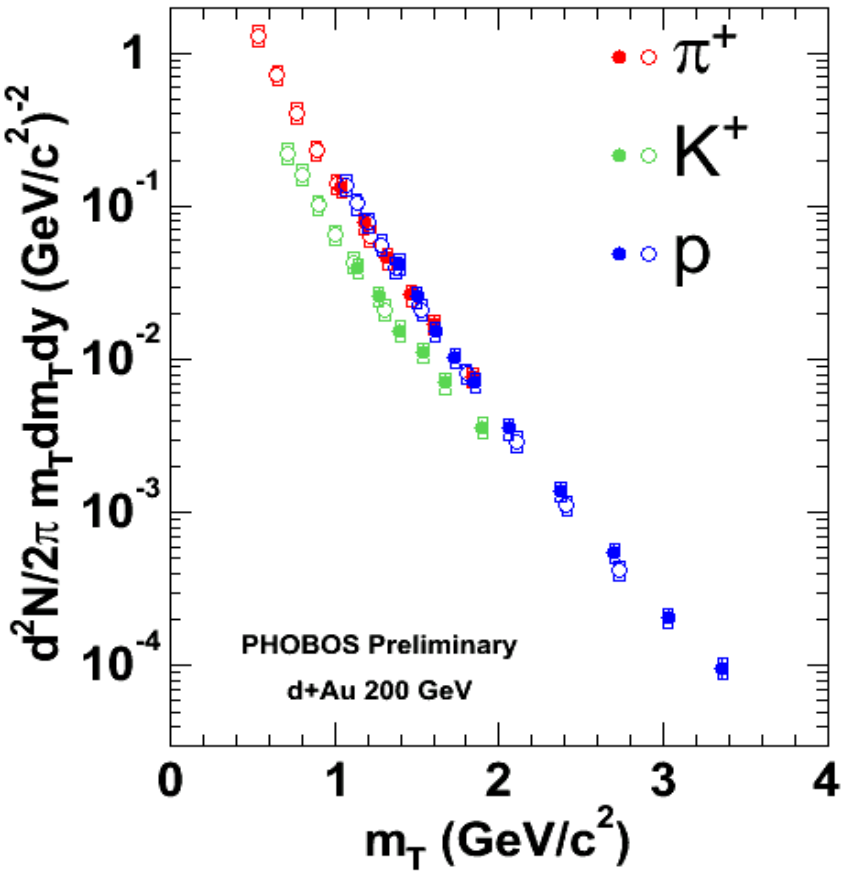
TOF PID Spectra d+Au

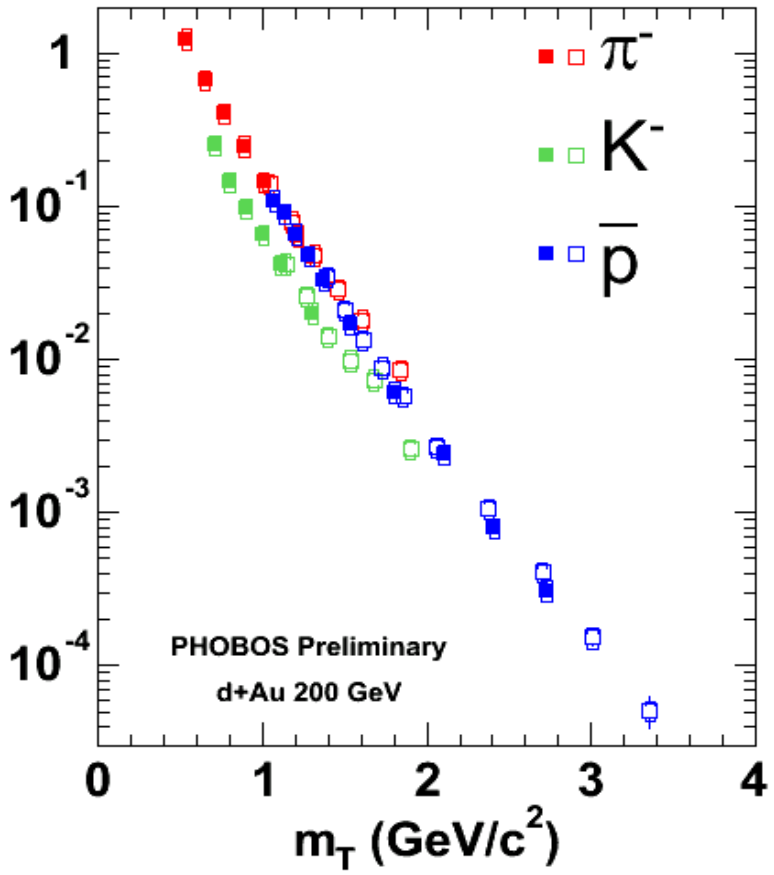
Pending weak-decay correction





m_T Scaling in d+Au and Au+Au





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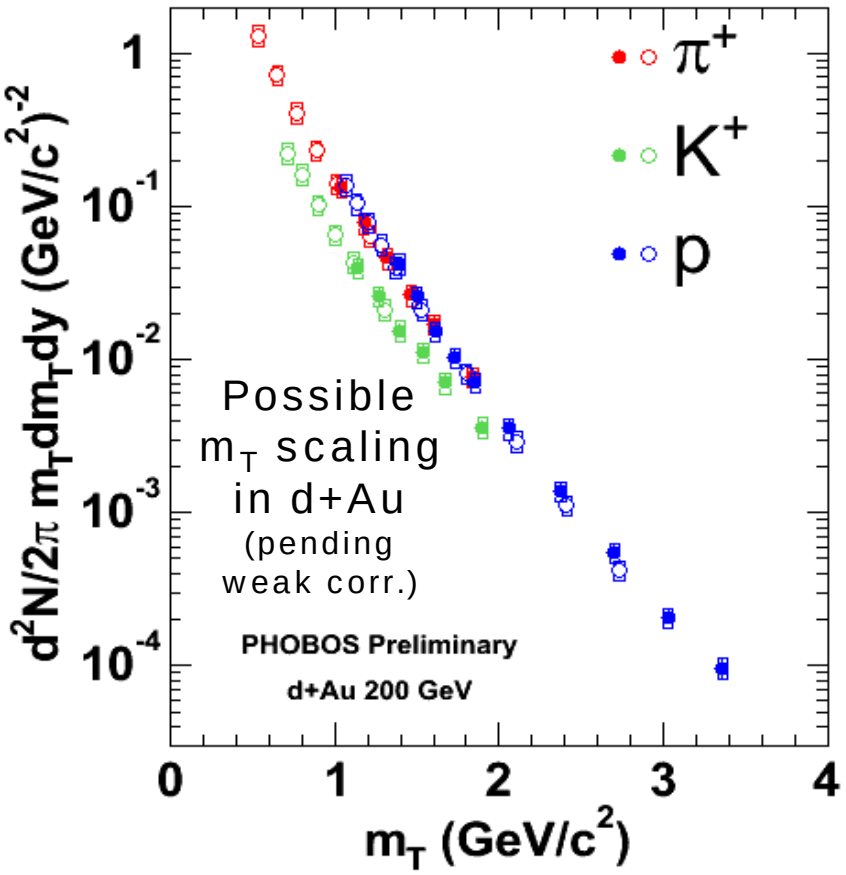

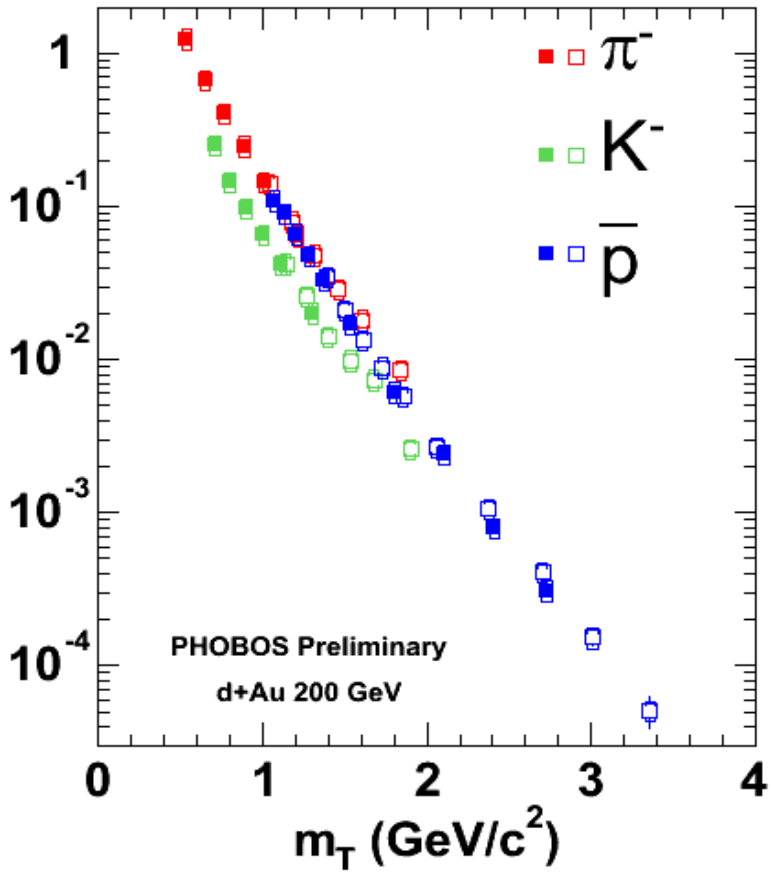

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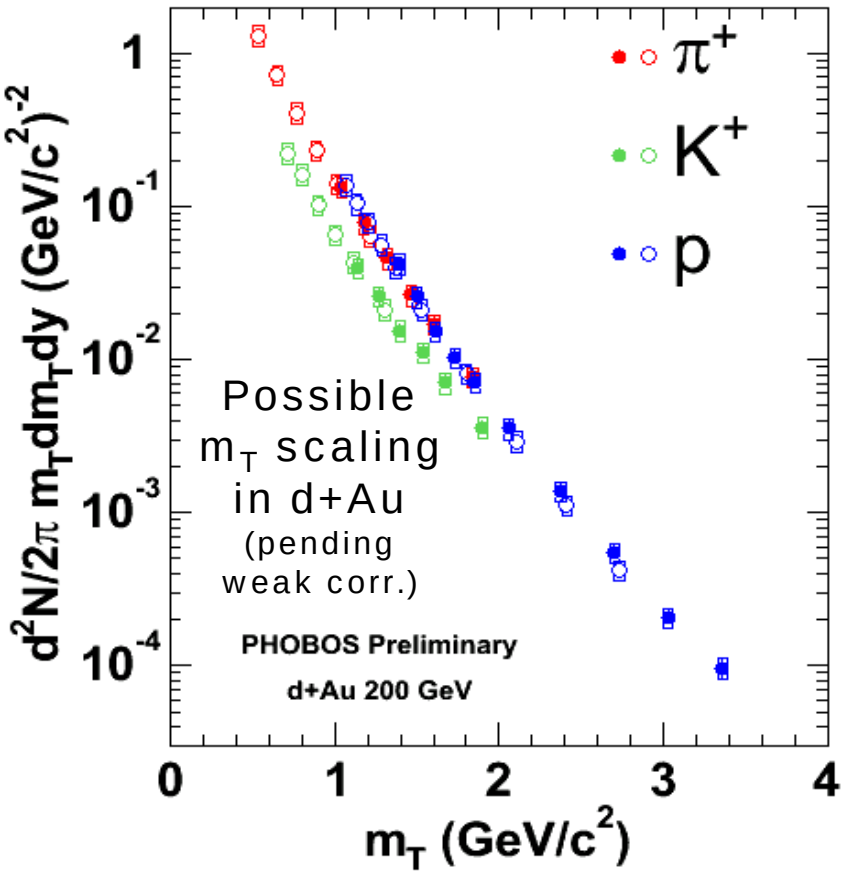
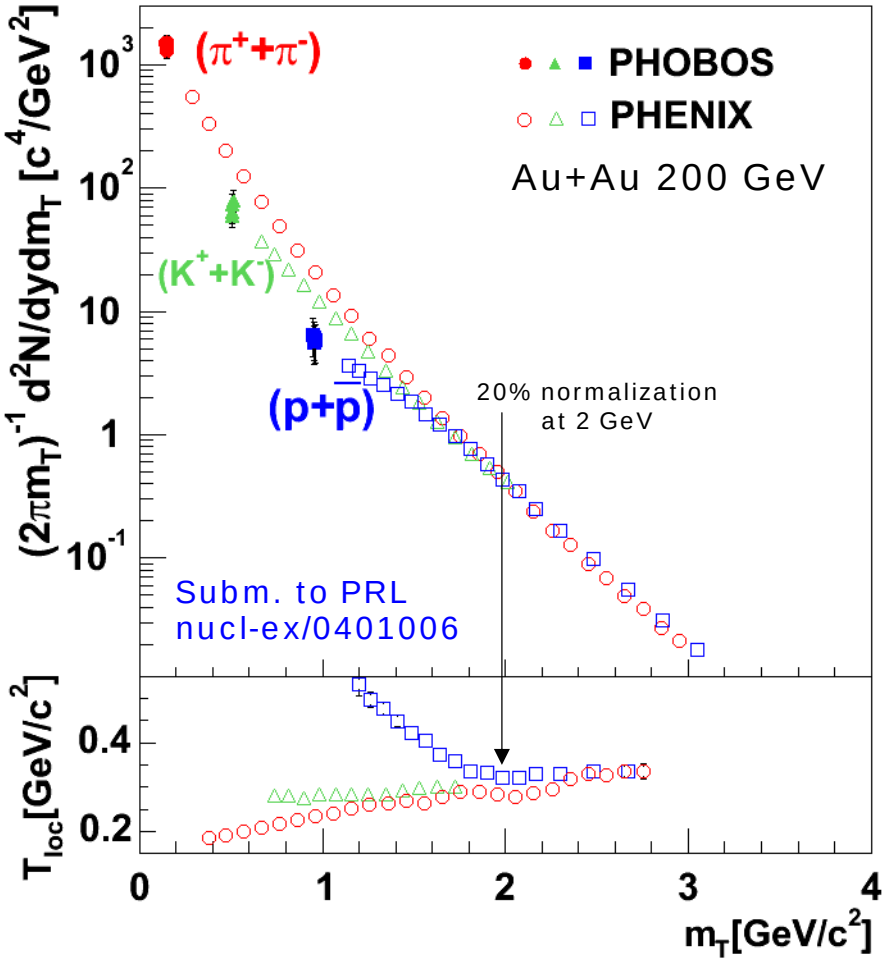




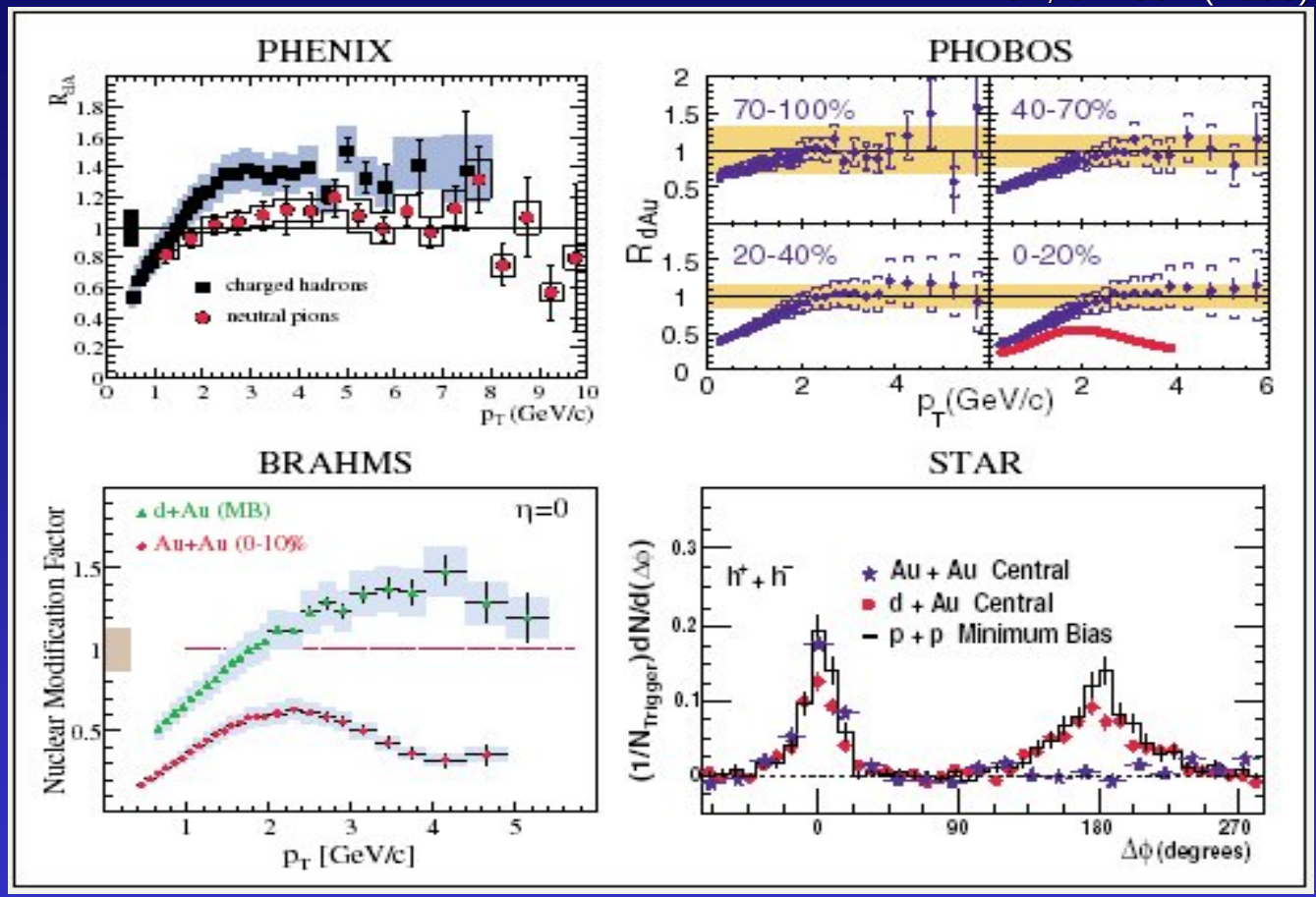
d+Au Inclusive Spectra vs. η

Inclusive Charged Hadrons in d+Au

PRL91, 072302 (2003)

Au+Au and d+Au scale differently relative to N_{coll}

$$R_{d+Au} = \frac{1}{N_{coll}} \frac{dN^{d+Au}/dp_T}{dN^{p+p}/dp_T}$$



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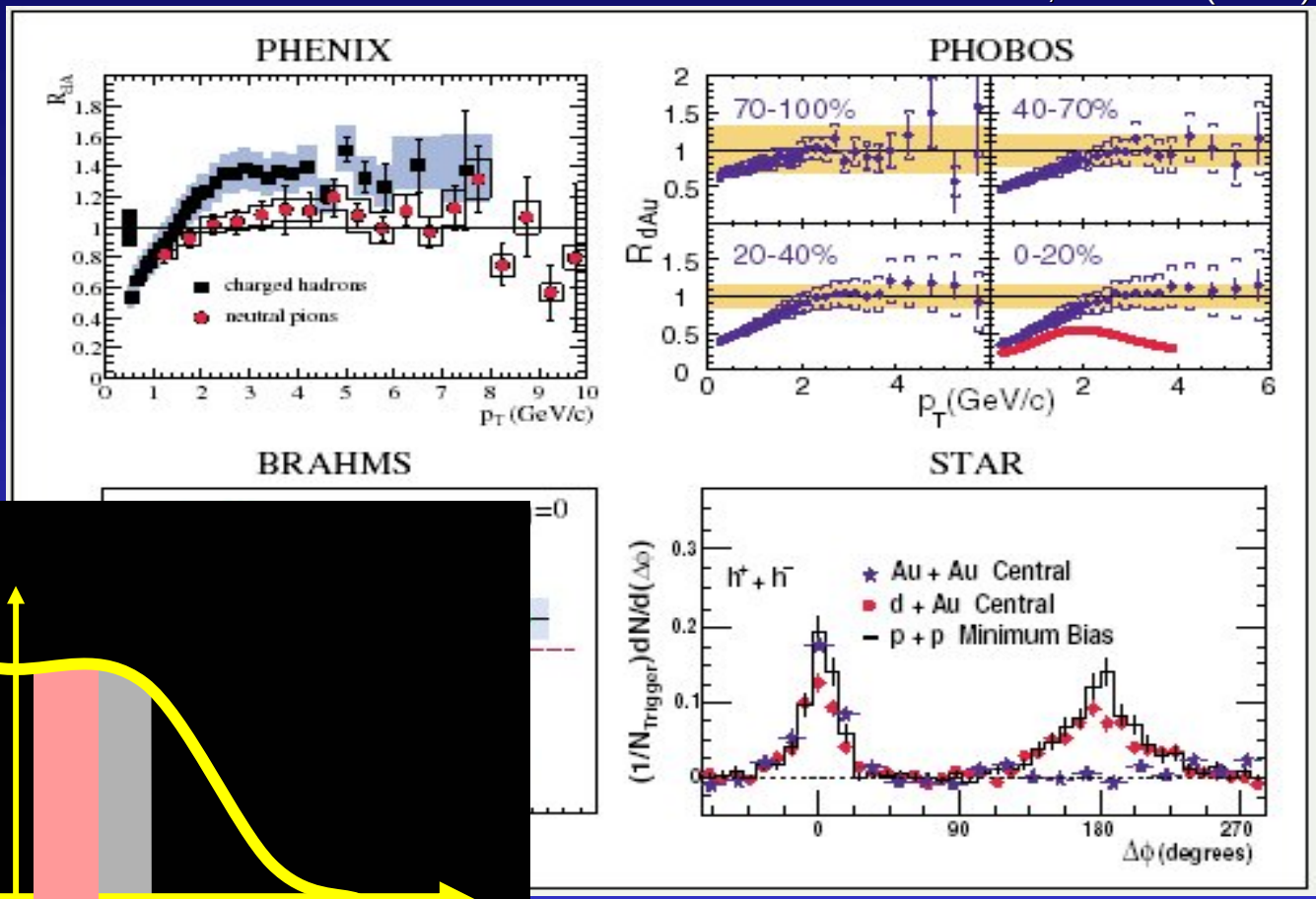
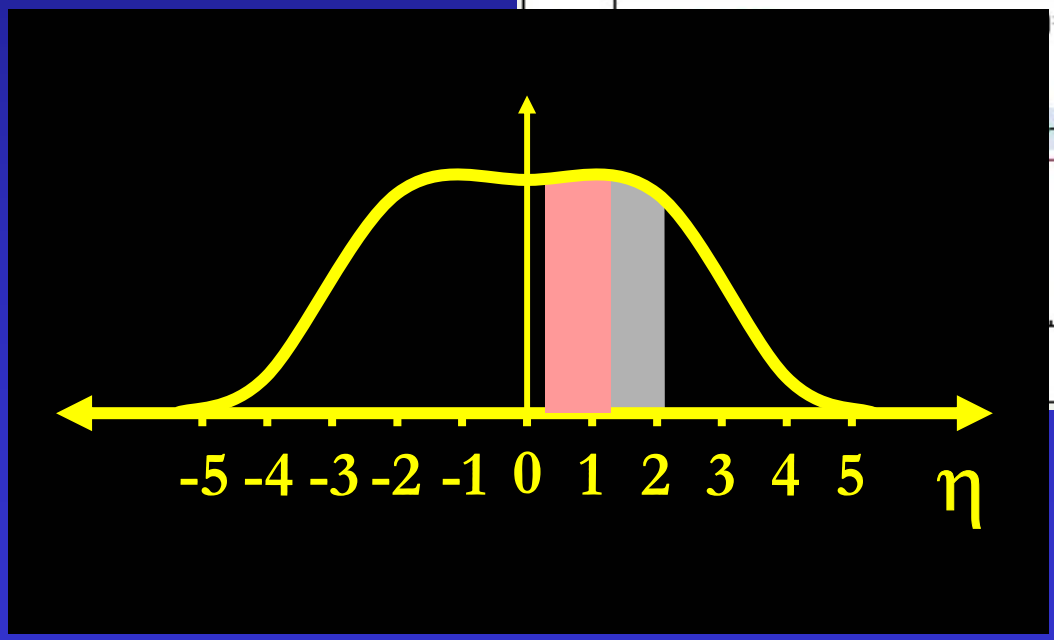
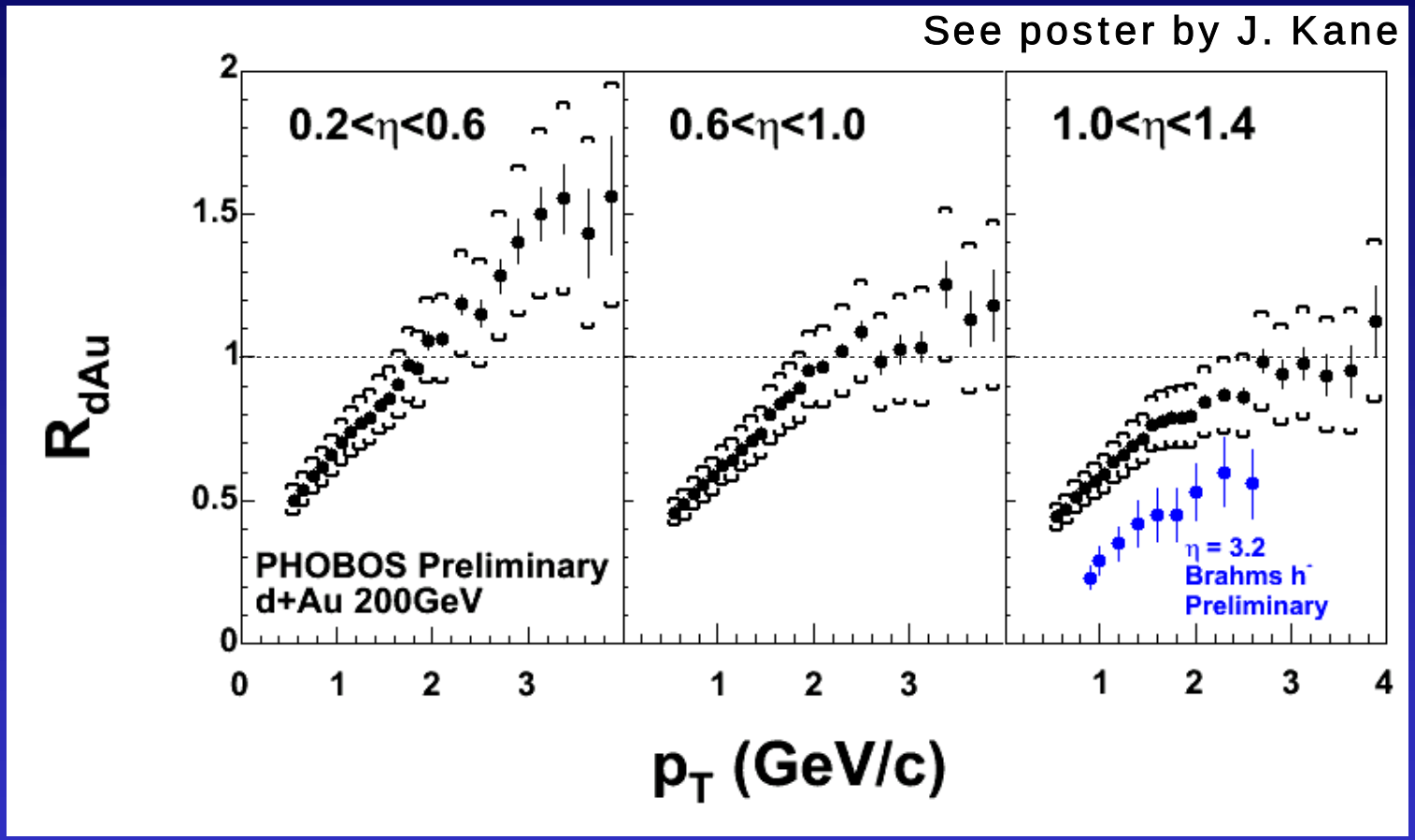




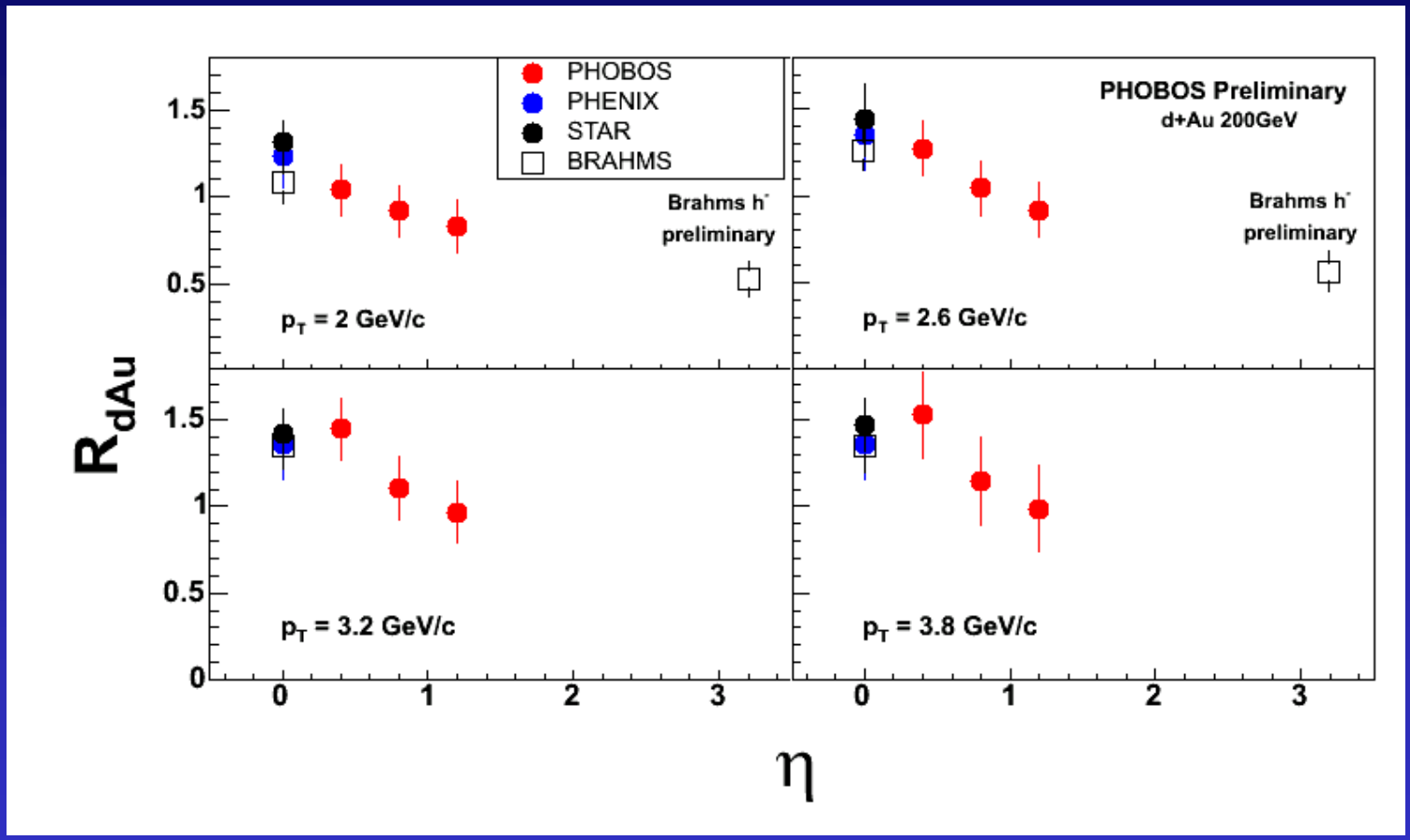
PHOBOS has a "forward" acceptance (& more in the future!)

Spectra in d+Au for η>0



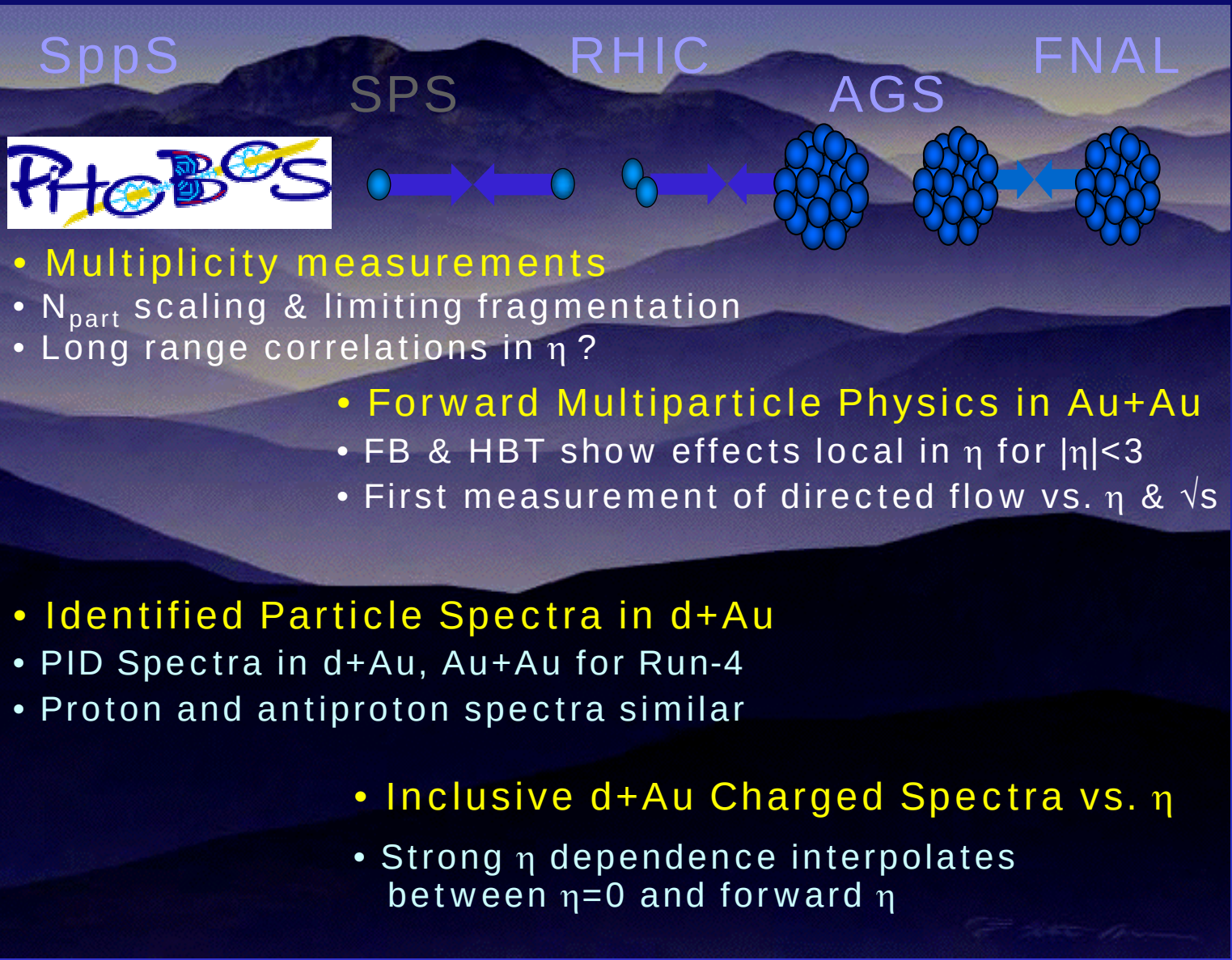
Systematic decrease in R_{d+Au} with increasing η
Saturation of ratio also occurs at a lower p_T

η-Dependence of R_{d+Au}



Monotonic evolution from mid-rapidity to forward rapidities.
BRAHMS data is a continuation of trends starting at η=0

The Landscape of Particle Production



- Multiplicity measurements
- N_{part} scaling & limiting fragmentation
- Long range correlations in η ?

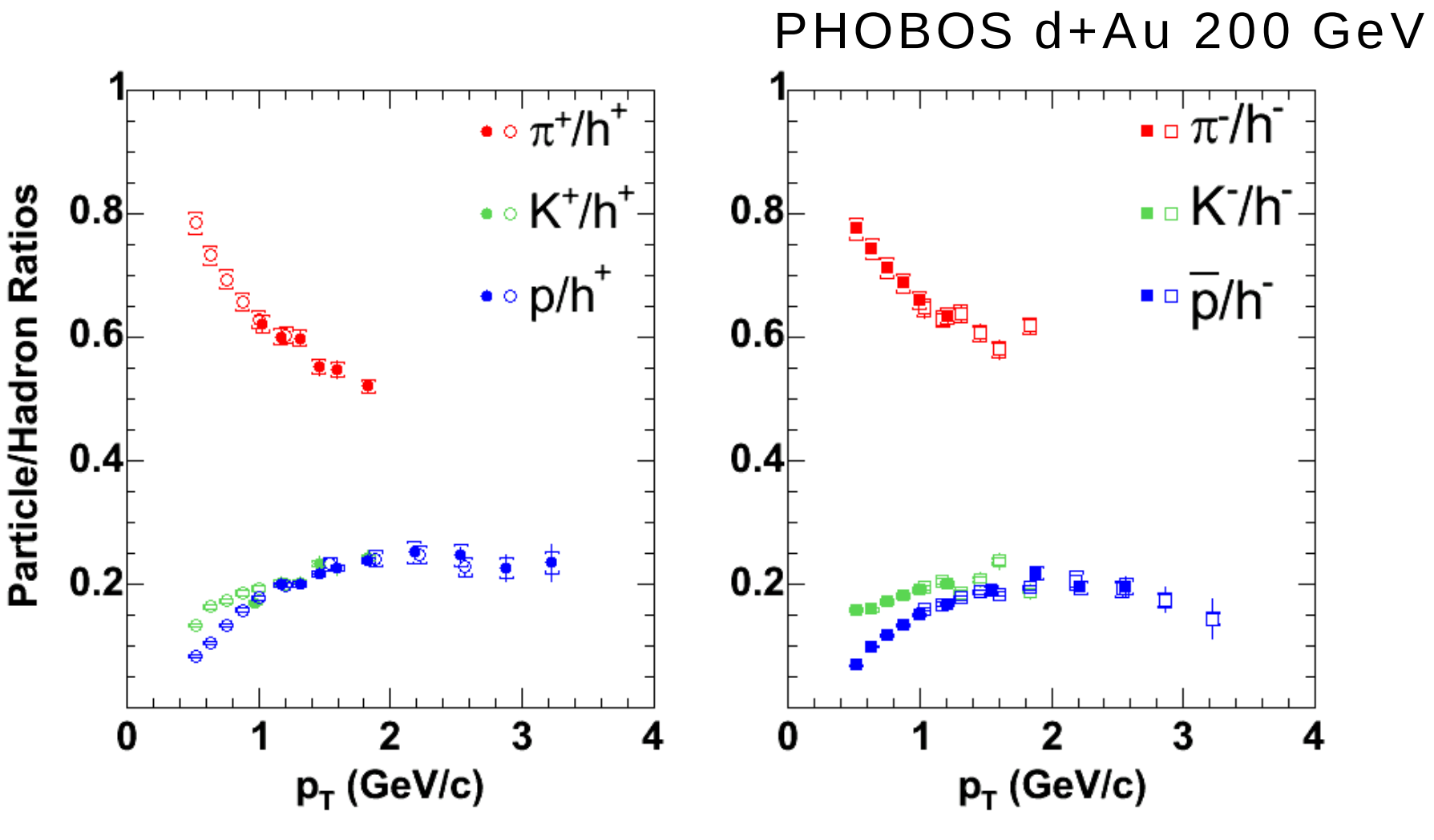
- Forward Multiparticle Physics in Au+Au
- FB & HBT show effects local in η for $|\eta|<3$
- First measurement of directed flow vs. η & $\sqrt{s}$

- Identified Particle Spectra in d+Au
- PID Spectra in d+Au, Au+Au for Run-4
- Proton and antiproton spectra similar

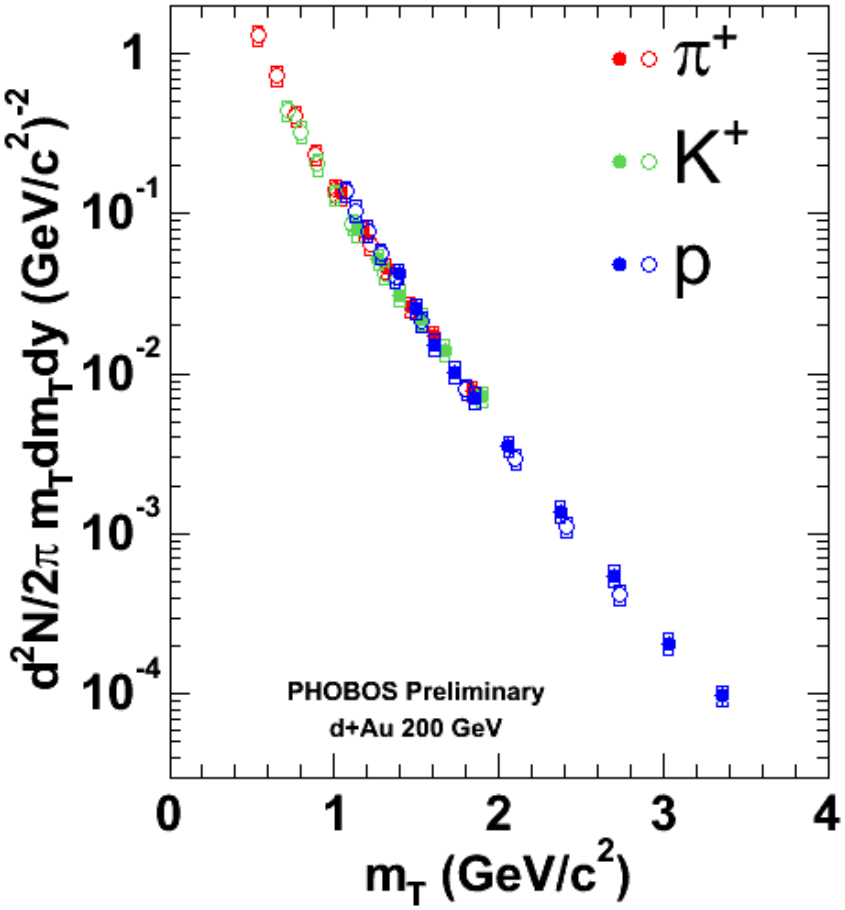
- Inclusive d+Au Charged Spectra vs. η
- Strong η dependence interpolates between η=0 and forward η

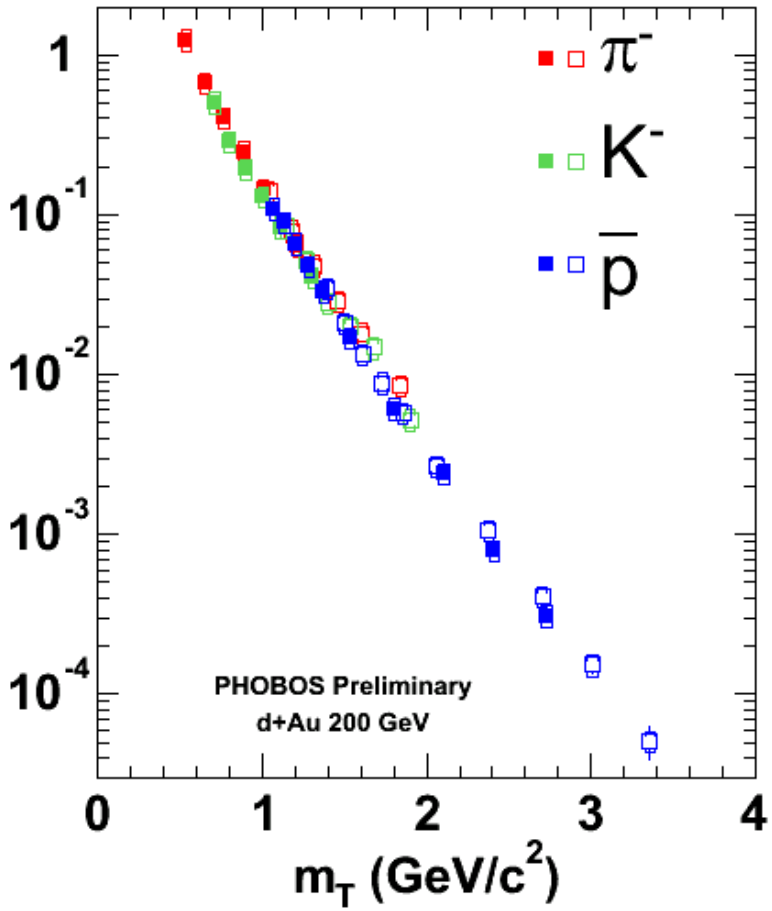
Backup Slides

Relative Yields vs. p_T



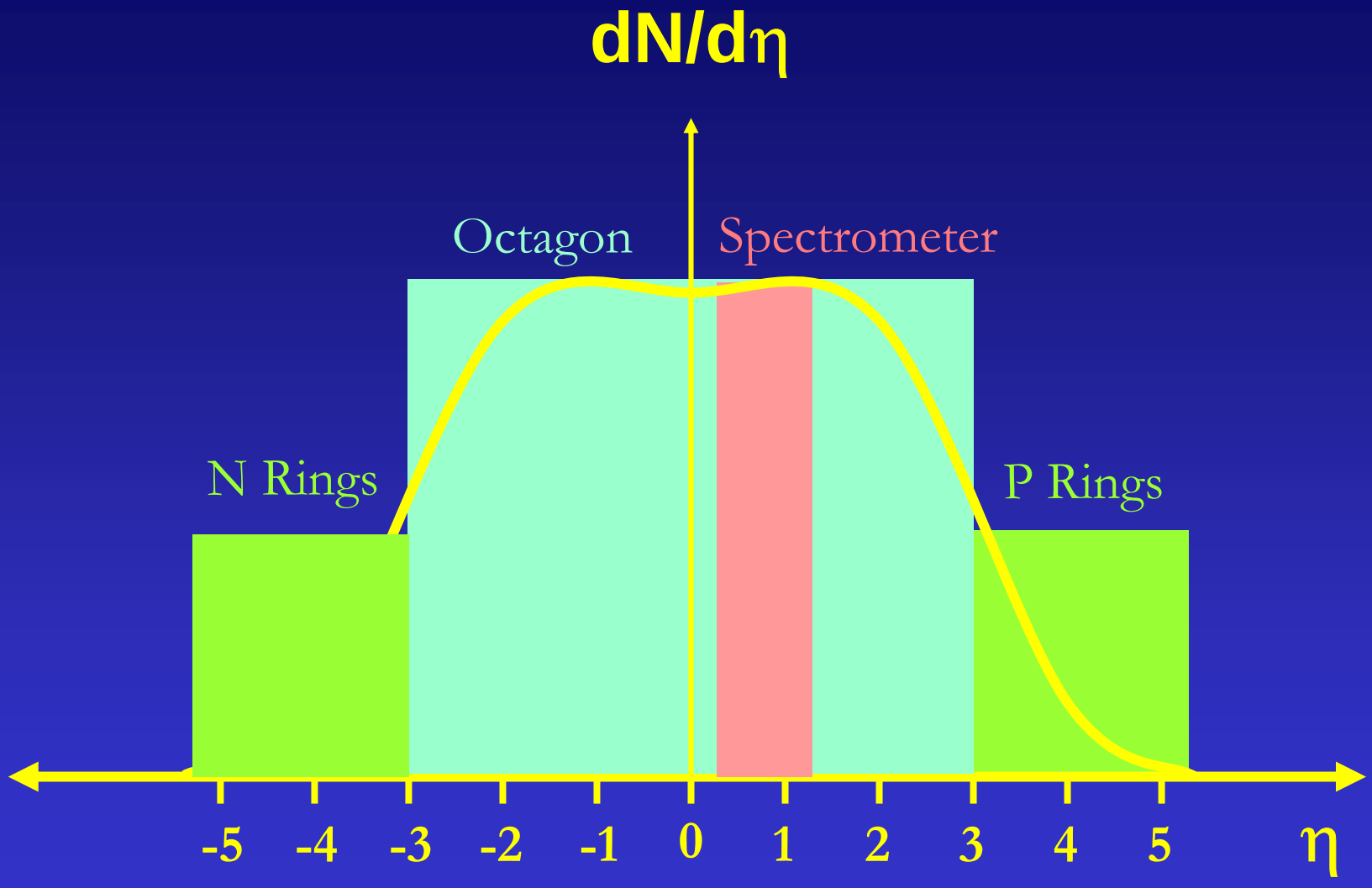
m_T Scaling and Strangeness





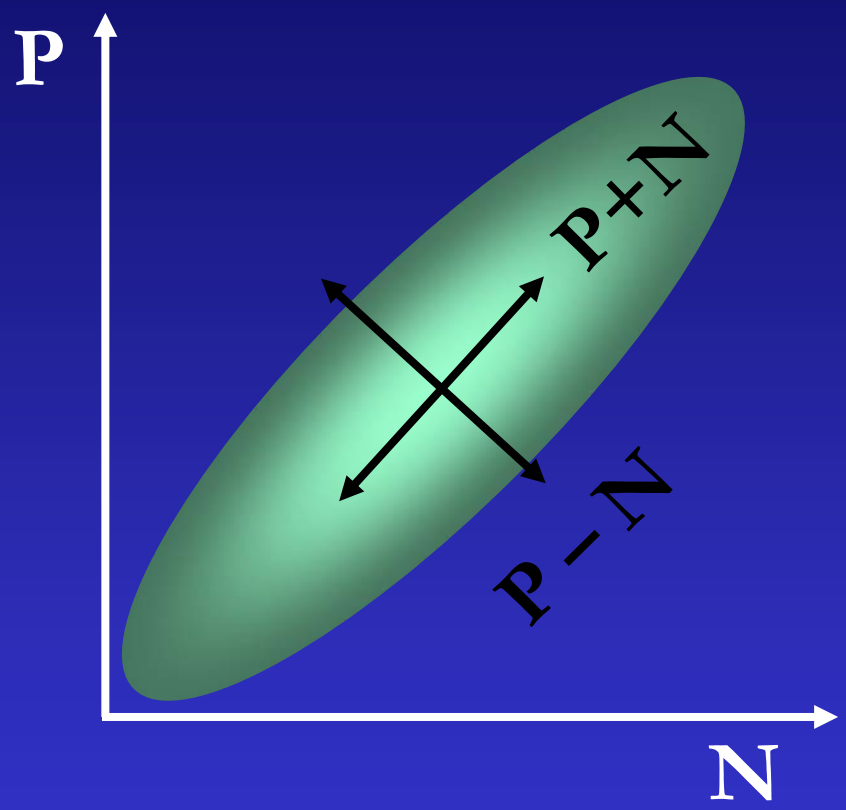
Factor of 2 brings K's into line (γ_s ~ 0.5 in pp)

PHOBOS Coverage



Nowhere to hide!

Principal Axes



Heavy-ion collisions dominated by N_{part} fluctuations

Decouple total from relative fluctuations

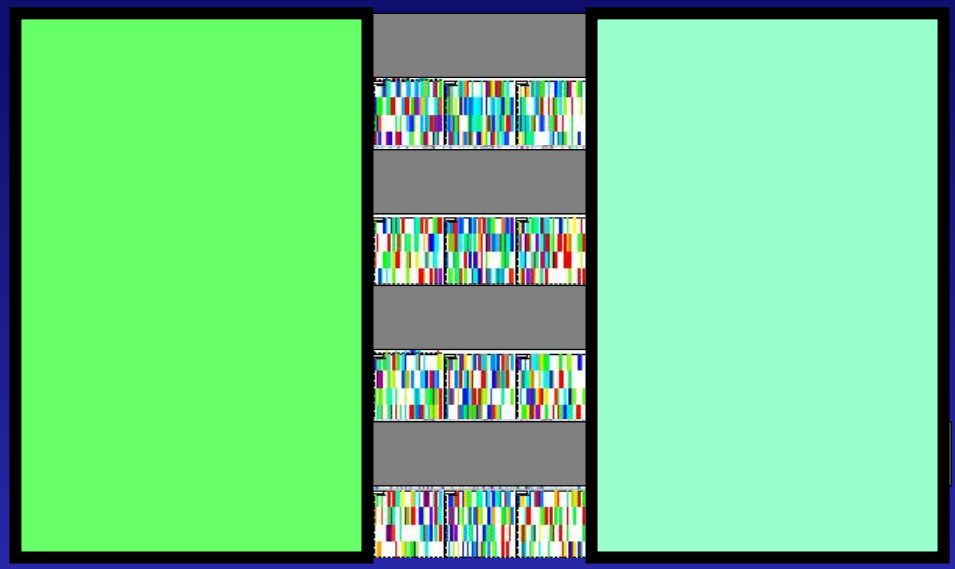
$$C = \frac{P - N}{\sqrt{P + N}}$$

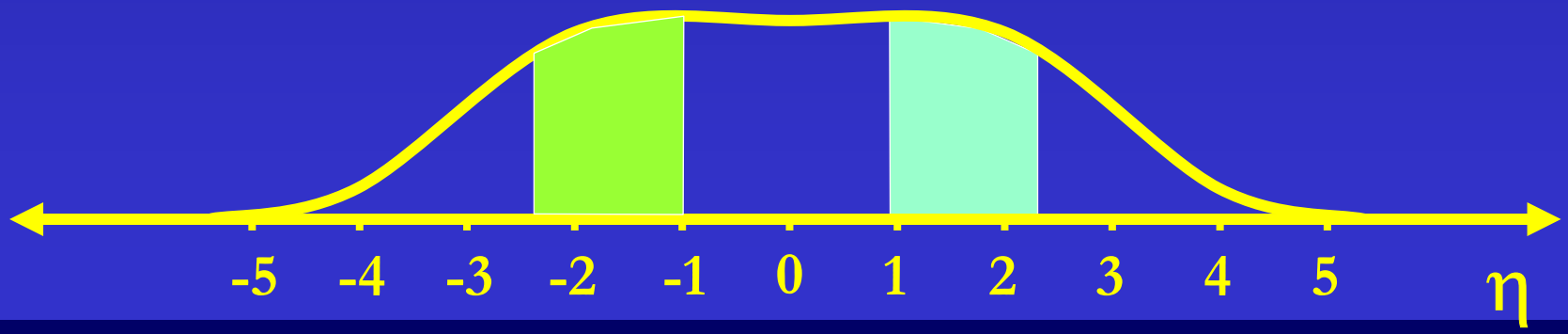
Independently partitioned between P & N

$$\sigma(C) = 1$$

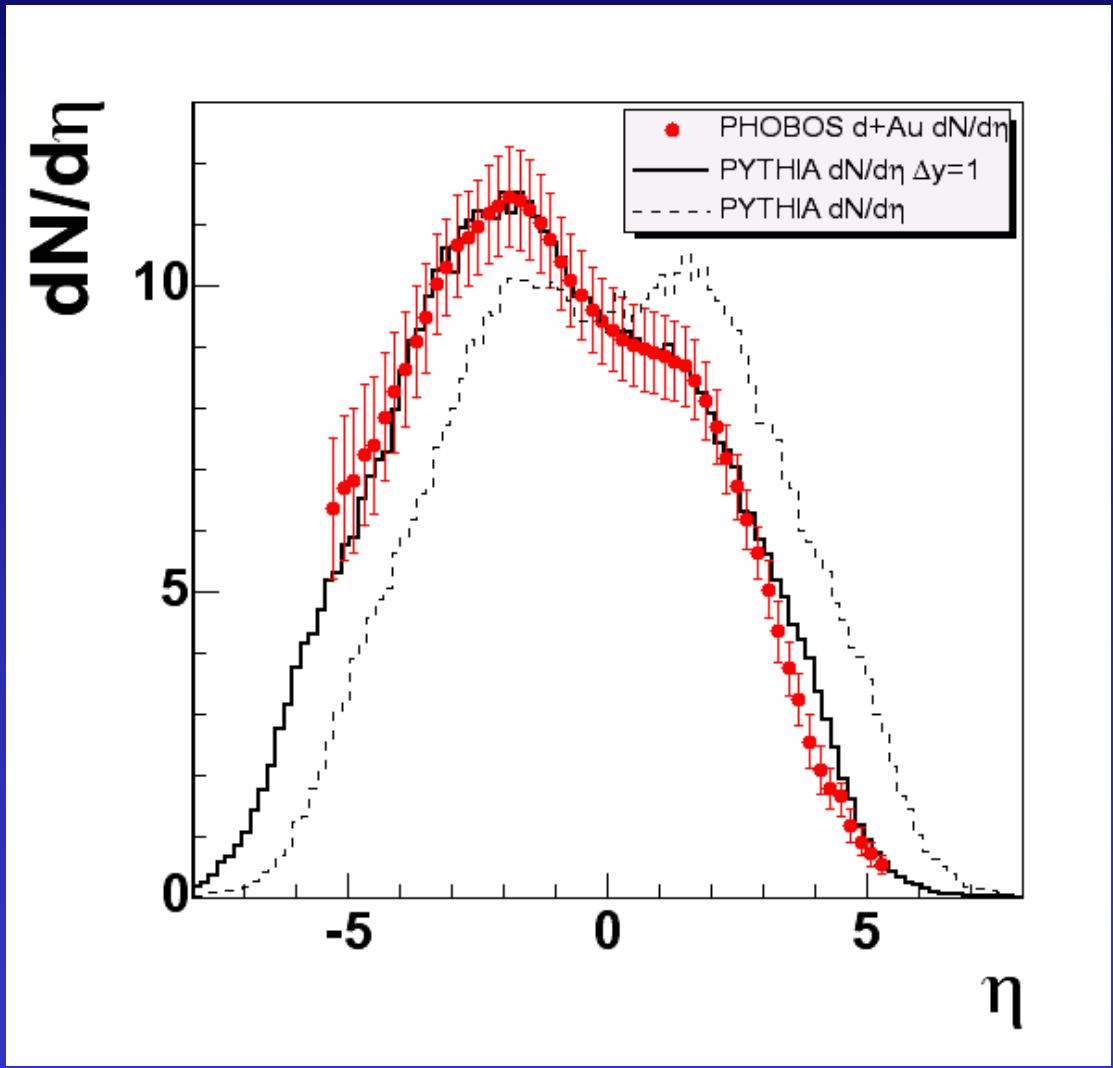
(flipping a coin, random walk…)

Forward-Backward Correlations





Simple Exercise



Let's play a game:

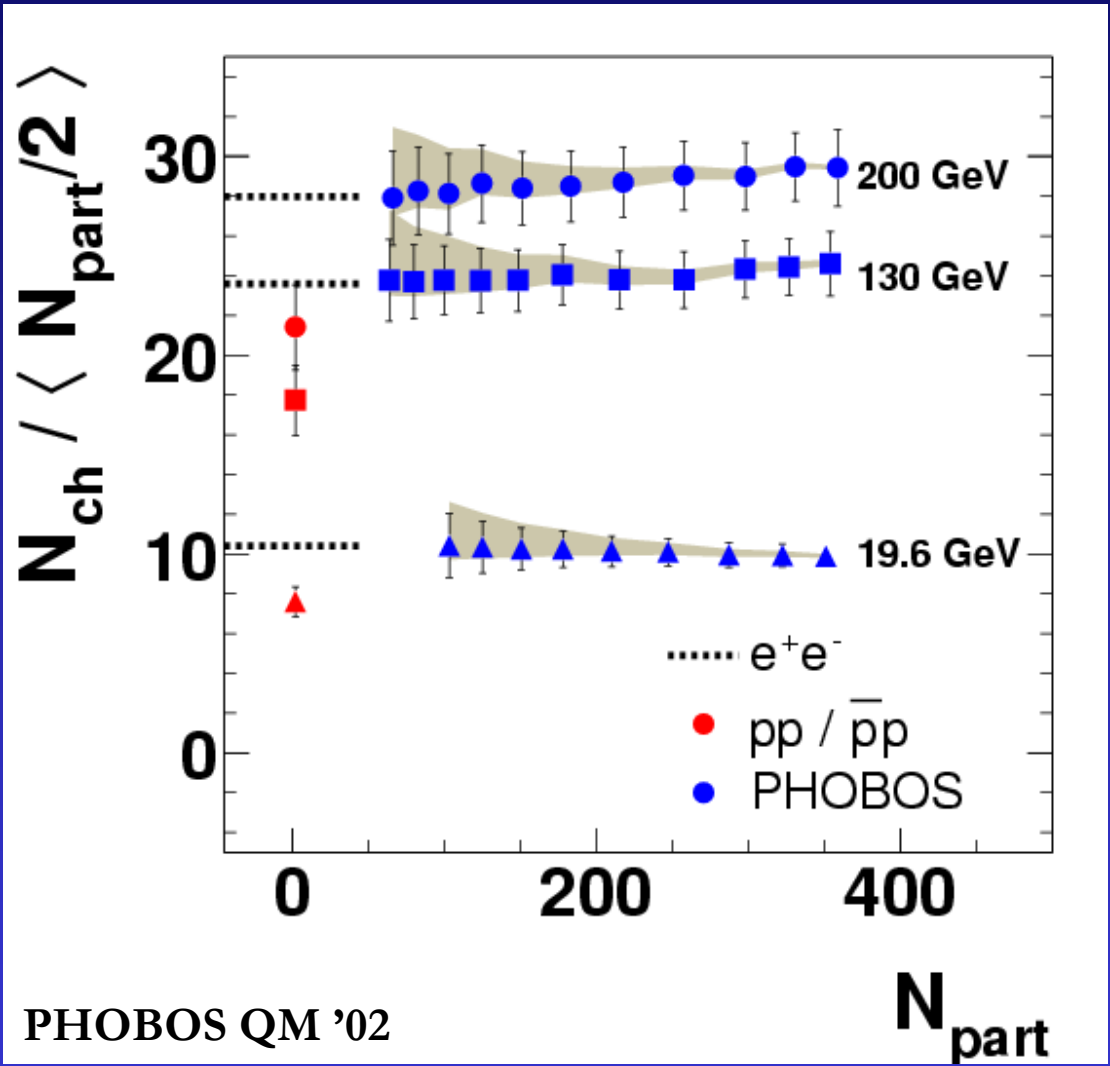
Shift PYTHIA dN/dy by $\Delta y = 1$

Scale up by $N_{part}/2$

Recalculate dN/dη

Similar shapes (violates energy conservation ☹)

Participant Scaling



Wounded Nucleon "Scaling"

$=$

$\frac{1}{2} N_{part} \times N_{e+e-}$

$\neq$

$\frac{1}{2} N_{part} \times N_{pp}$

Transition to d+Au