New Results from the PHOBOS Collaboration

Structure and Fine Structure of Hadron Production at RHIC

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PHOBOS Collaboration



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BROOKHAVEN NATIONAL LABORATORY
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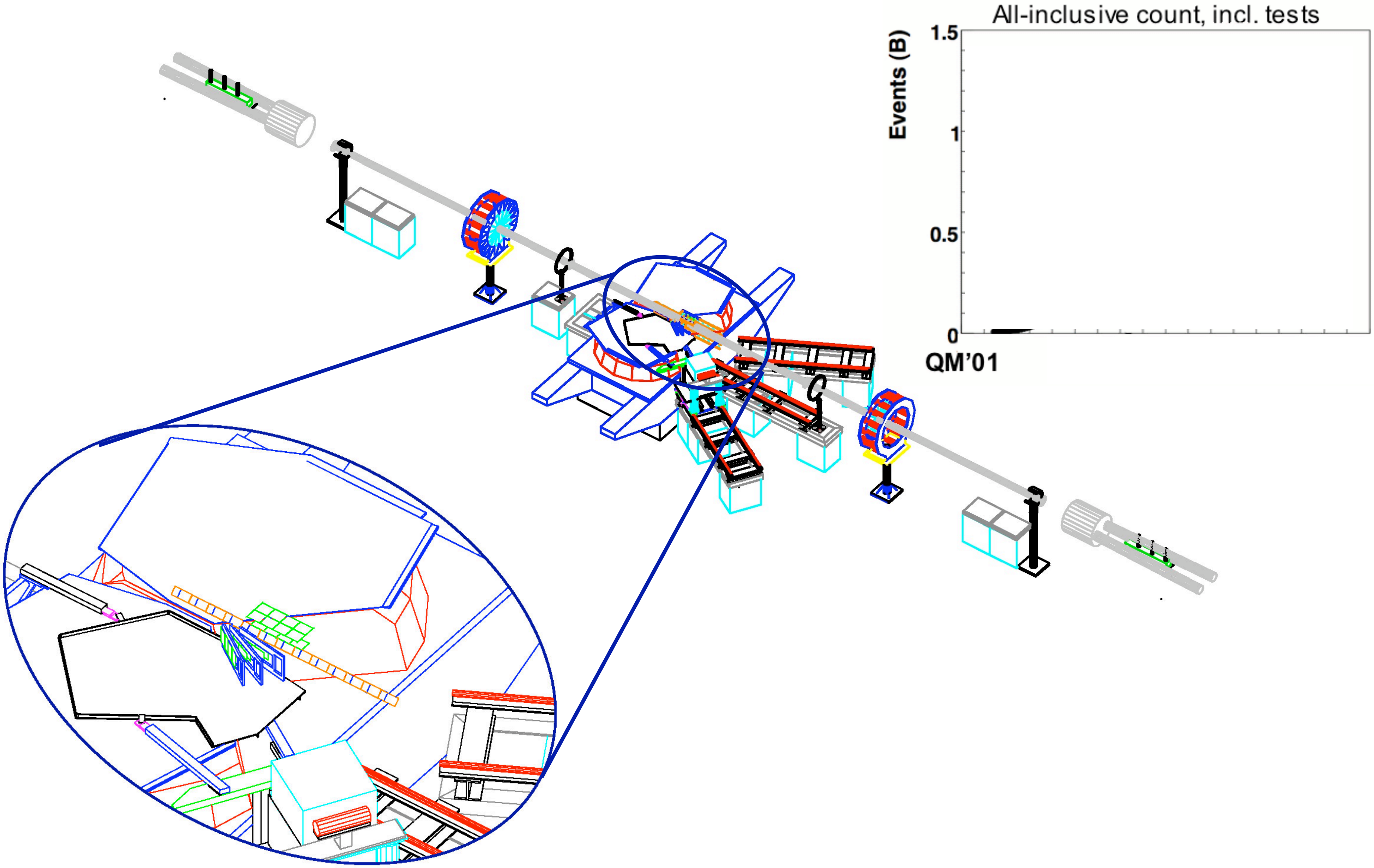
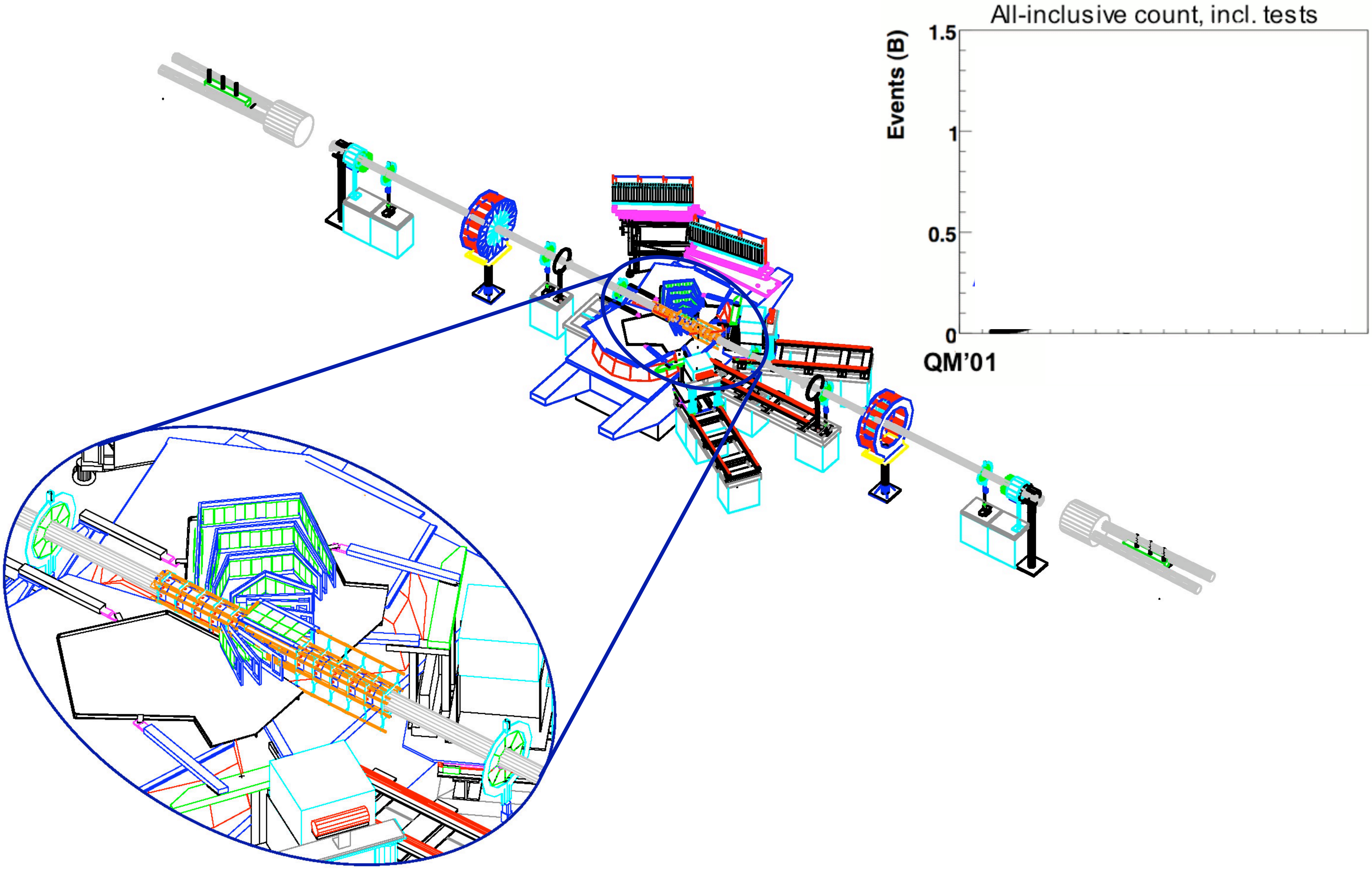
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF ROCHESTER

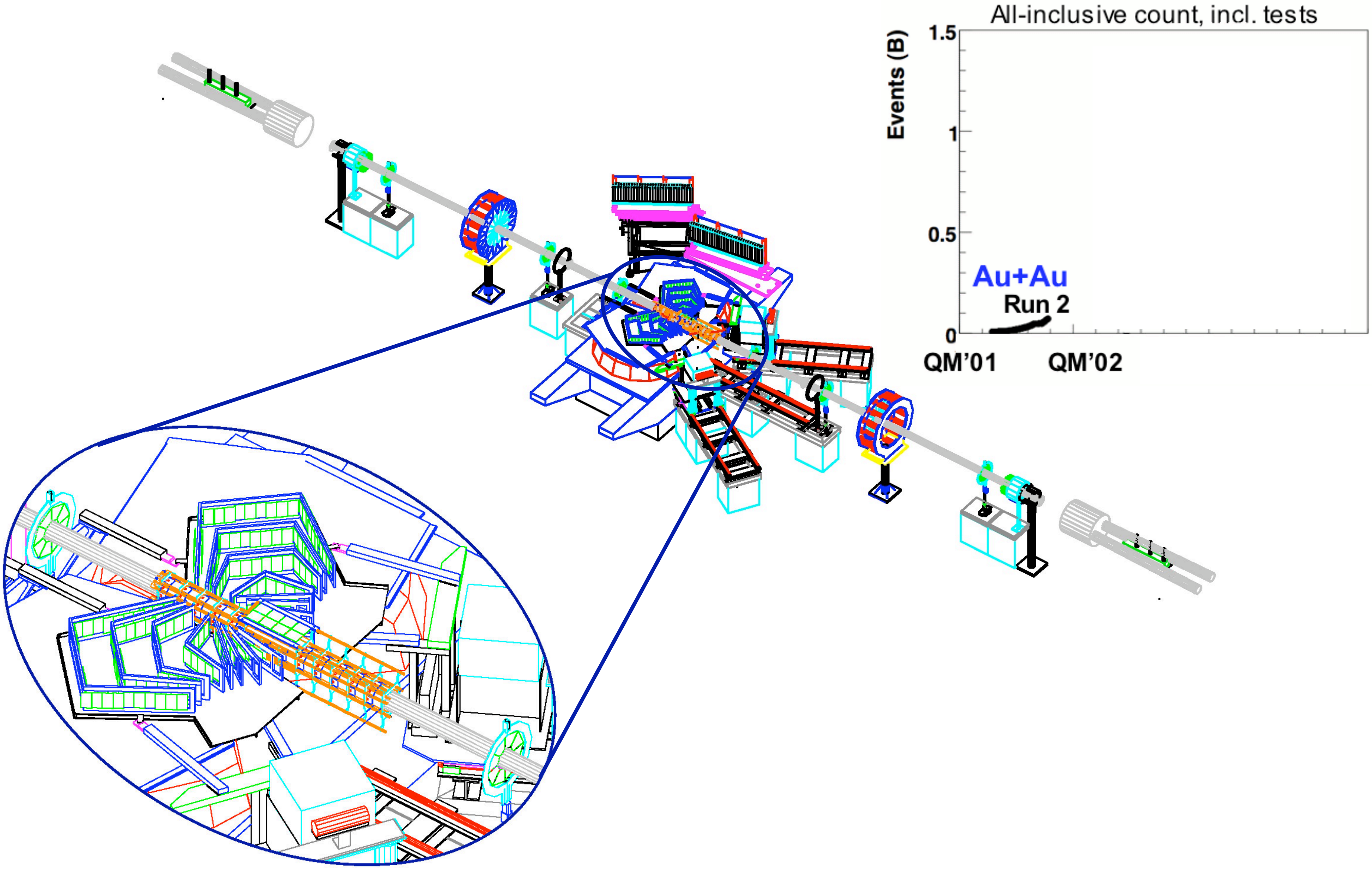
PHOBOS Experiment - Commissioning Run



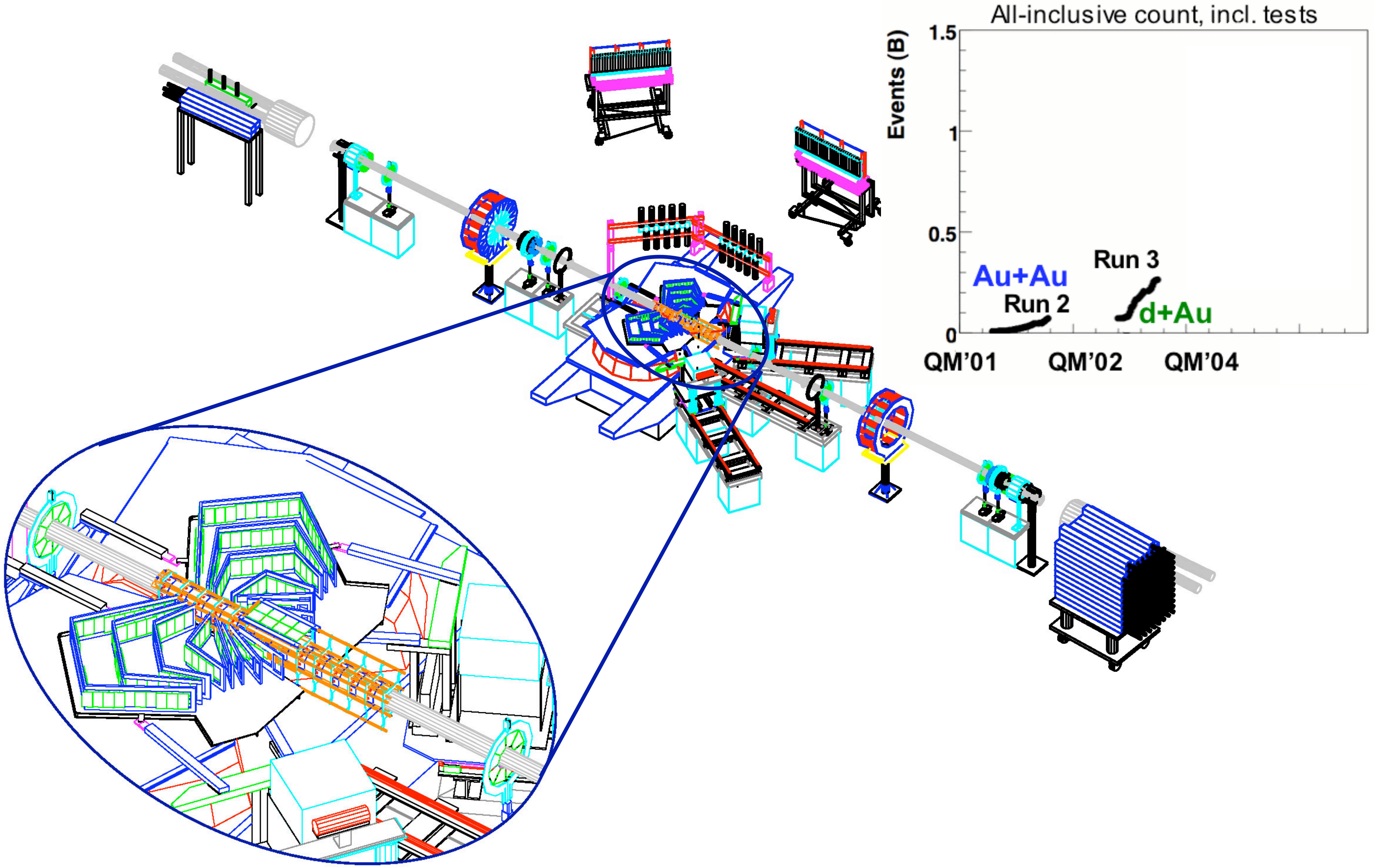
PHOBOS Experiment - Run 1



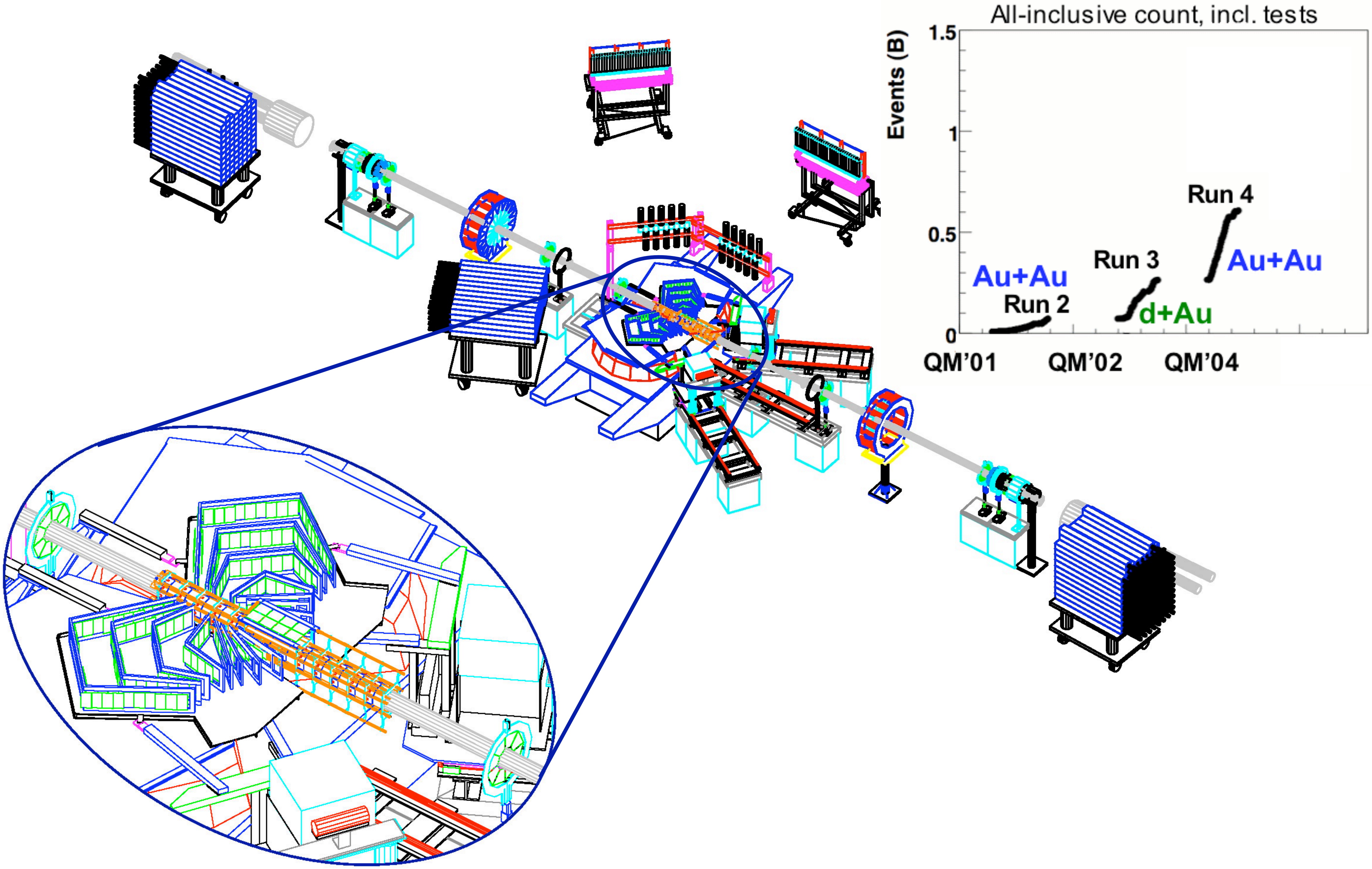
PHOBOS Experiment - Run 2



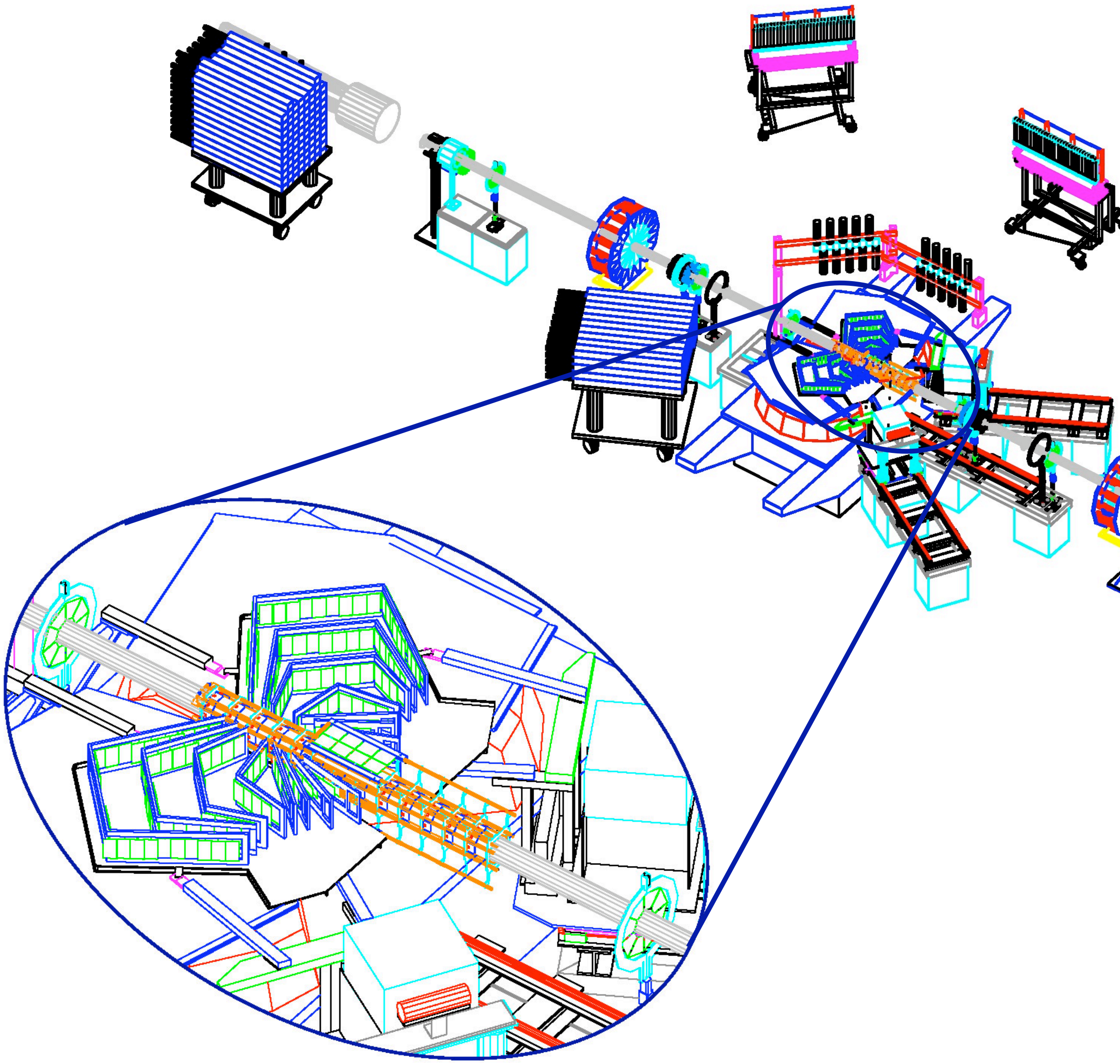
PHOBOS Experiment - Run 3

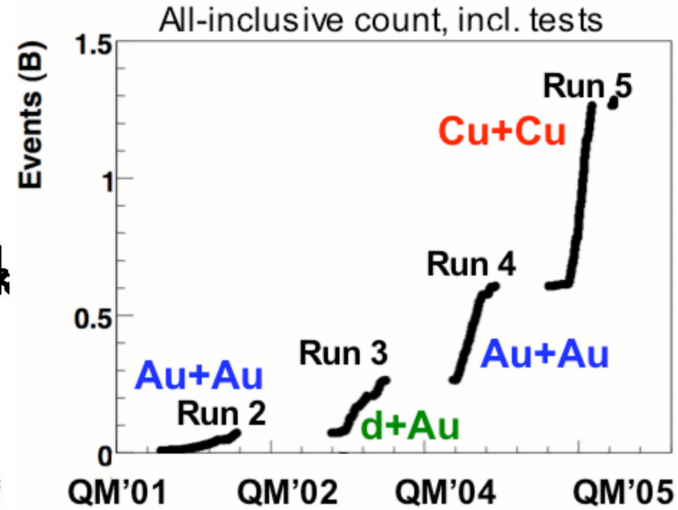


PHOBOS Experiment - Run 4

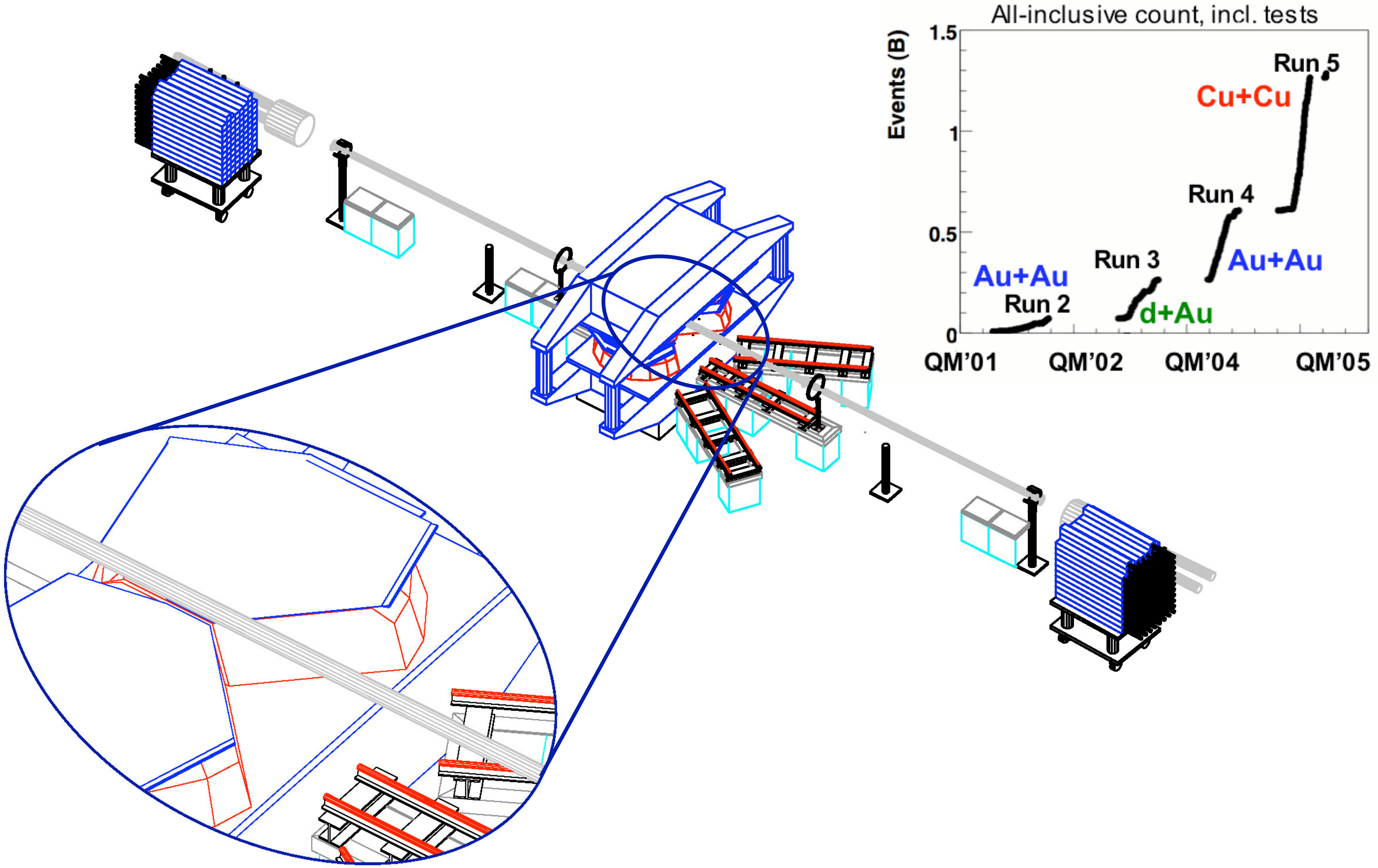


PHOBOS Experiment - Run 5





PHOBOS Experiment - Run 6



Number of Events to Tape

[in millions]

GeV \ system	p+p	d+Au	Cu+Cu	Au+Au
410	20			
200	100	150	400	250
130				4.3
62.4			110	22
55.9				1.8
22.5			20	
19.6				~1

[shaded box] = shown in this talk

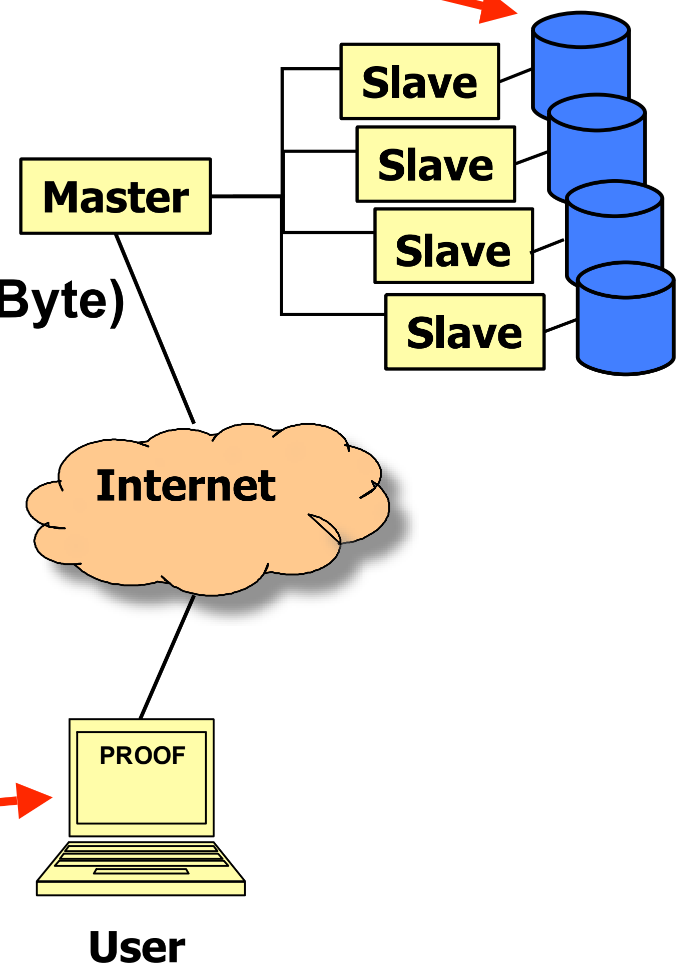
PHOBOS Computing Architecture

Distributed disks
- 100 TByte, fast access
- ALL physics data is stored on disks!

CatWeb – data management (650k files, 400 TByte)
- Easy www interface to stage HPSS→RCF
- API for access to functionality from ROOT/PhAT

AnT – Analysis Tree DST format
- ROOT Tree based, fast access to subsets of data
- Well structured, links hits to tracks etc.

PROOF – Parallel ROOT Facility
- Transparent, parallel interactive analysis,
- over x100 speed-up!
- Co-exist with regular batch usage



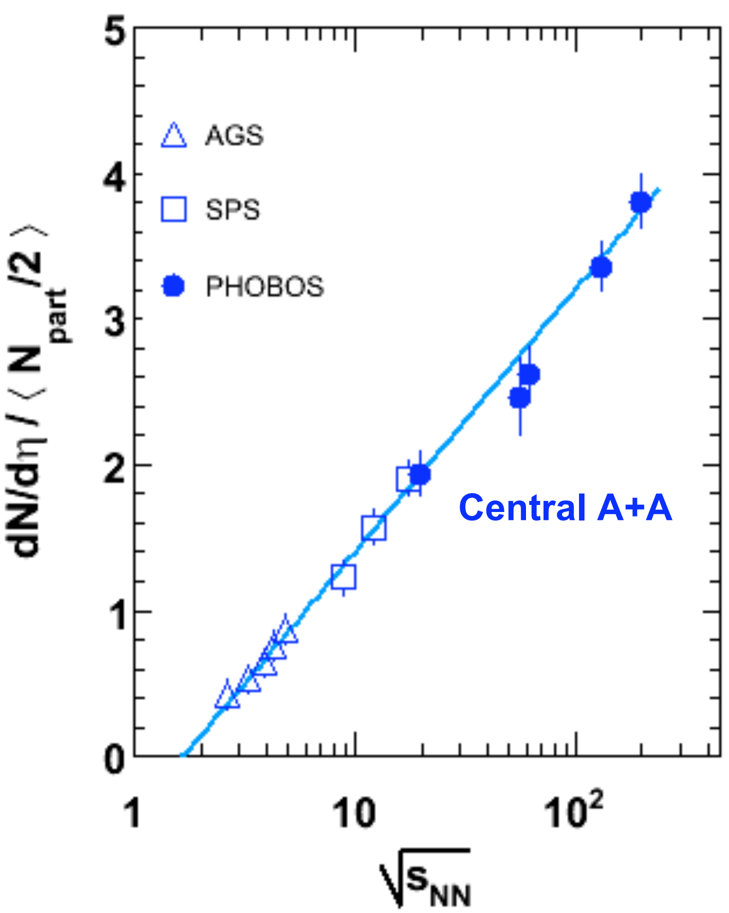
See poster by Maarten Ballintijn

Mission Statement

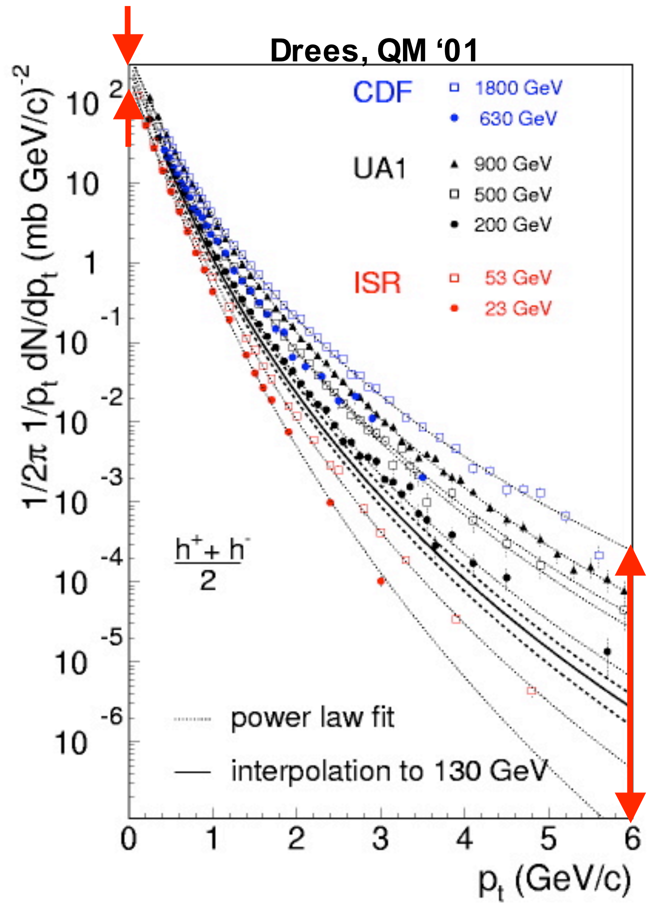
- Systematic study of charged hadron production
- Search for
  - Organizing principles (Scaling laws, Sum rules)
    - Common features with elementary systems
    - Collective effects

Collision Energy

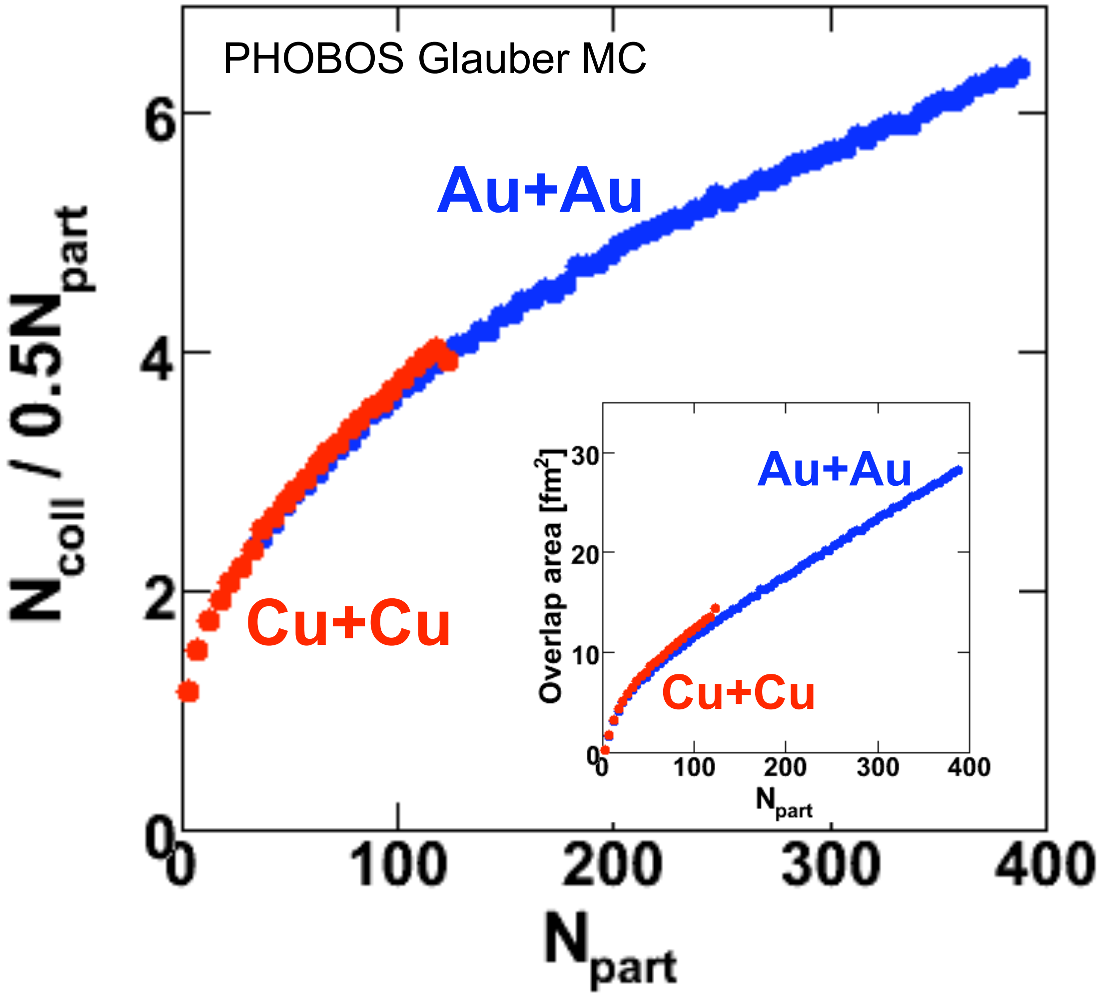
Energy Density



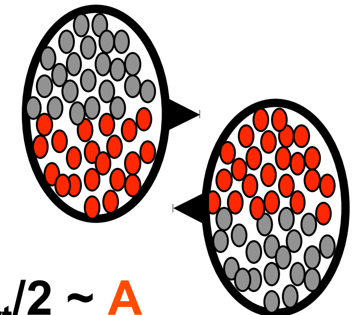
Balance of 'Hard' vs 'Soft' Particle Production



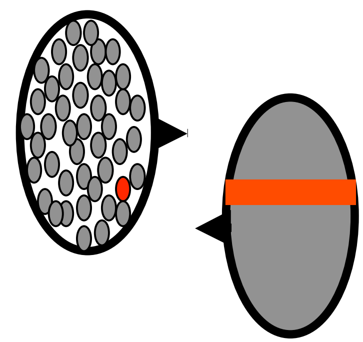
Collision Geometry



"Participants"



$N_{part}/2$ ~ A

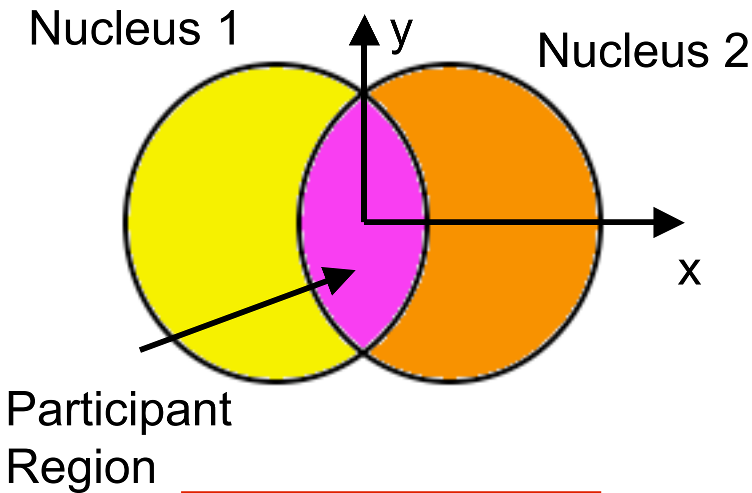


L~$A^{1/3}$

N_{coll}= # of NN collisions: ~$A^{4/3}$

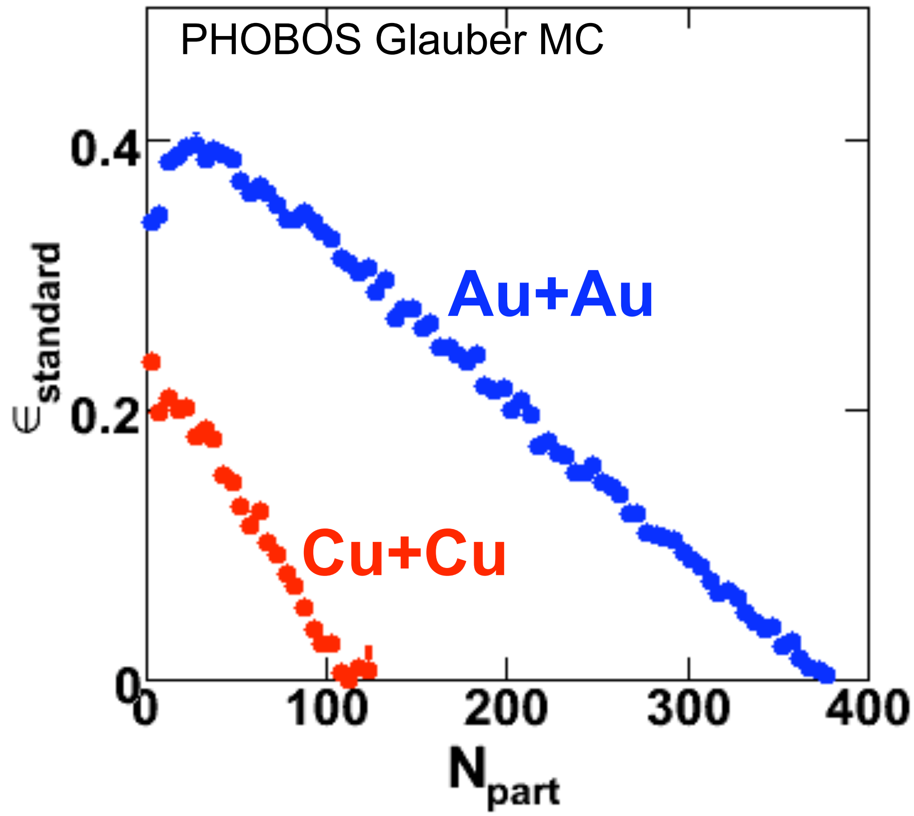
"Collisions"

Transverse Geometry



$$\varepsilon = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

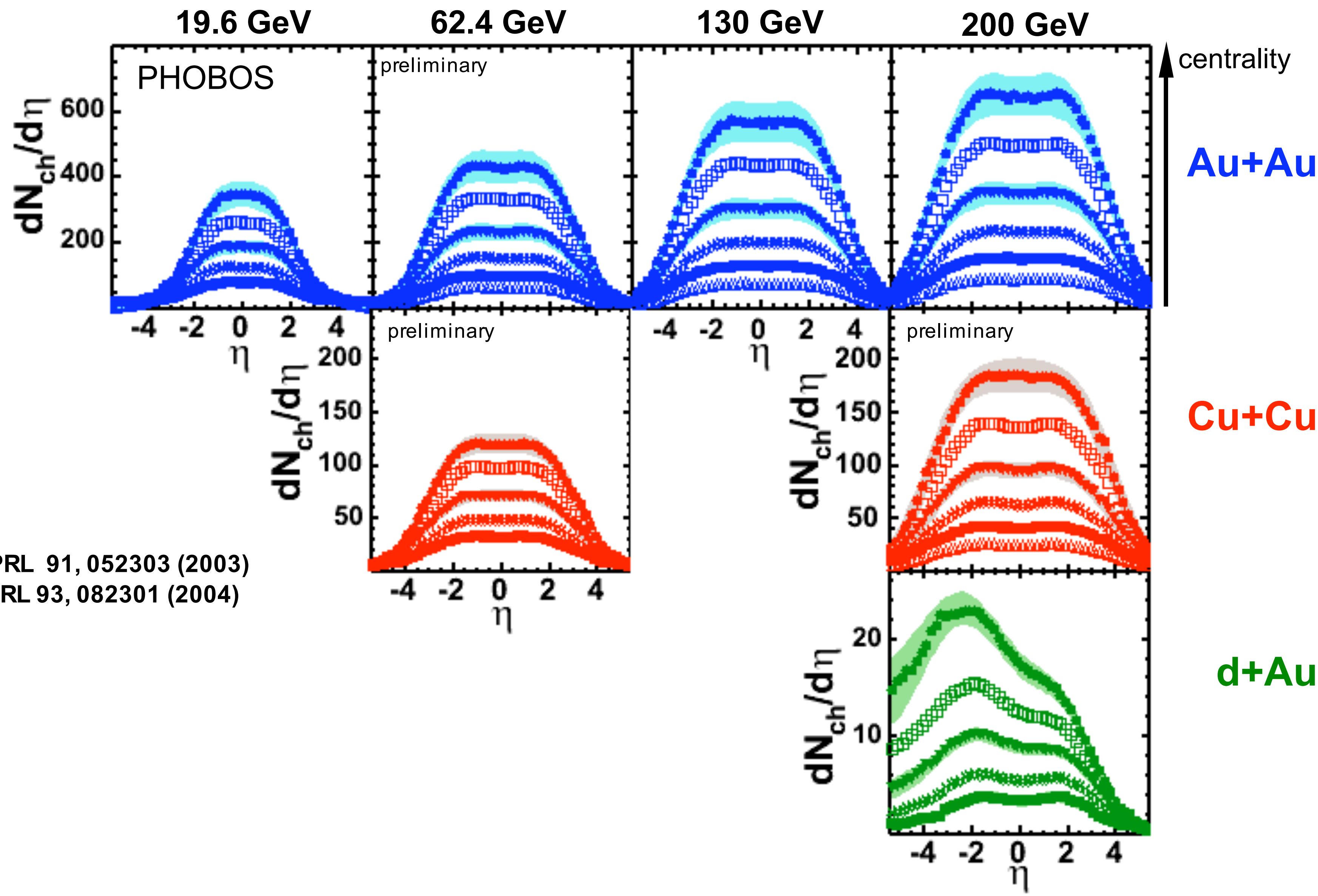
wrt reaction plane



- **Au+Au vs Cu+Cu**
  - **Interplay of initial geometry and initial density**
  - **Test ideas of early thermalization and collectivity**

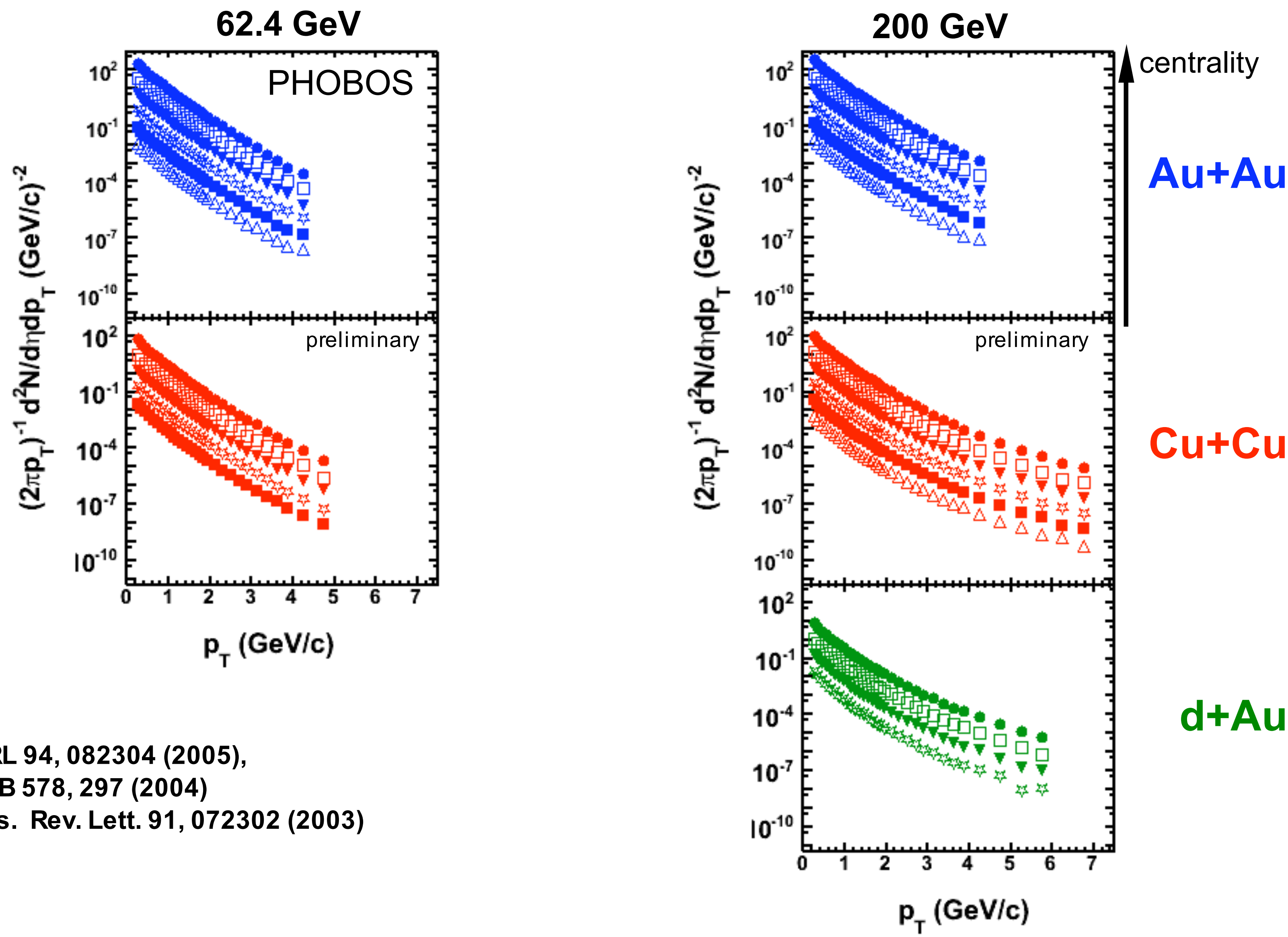
PHOBOS Data

Charged Hadron dN/dη



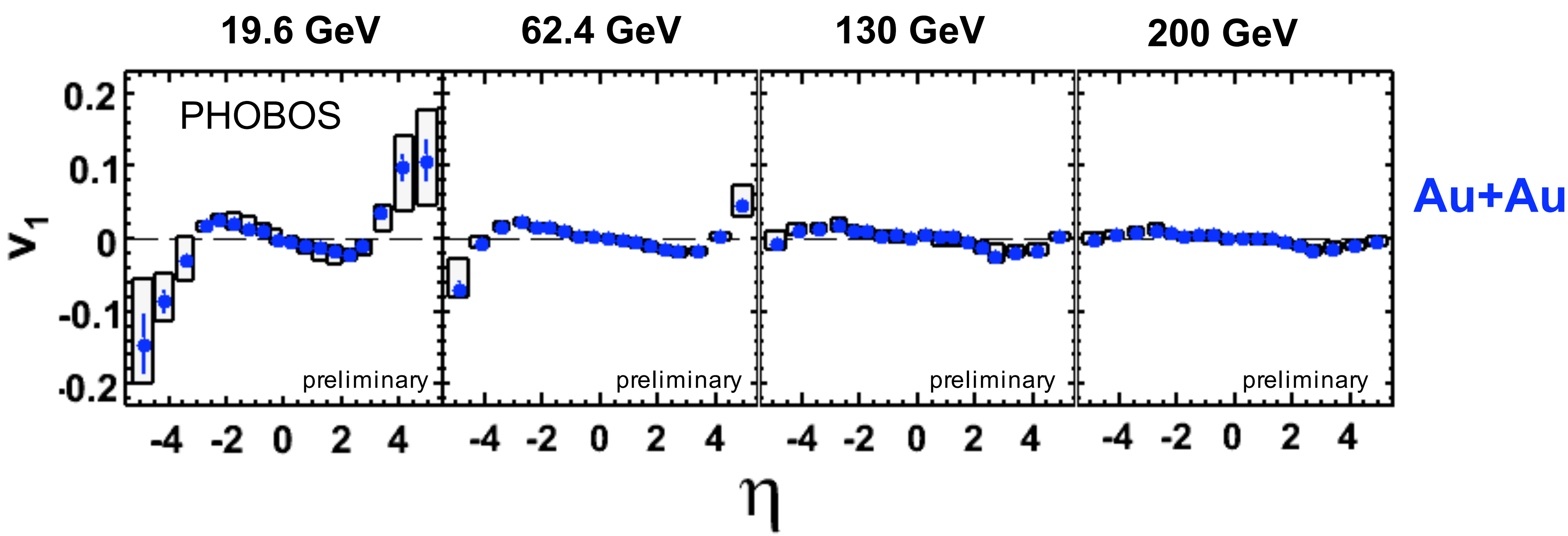
Au+Au : PRL 91, 052303 (2003)
d+Au : PRL 93, 082301 (2004)

Charged Hadron p_T Spectra



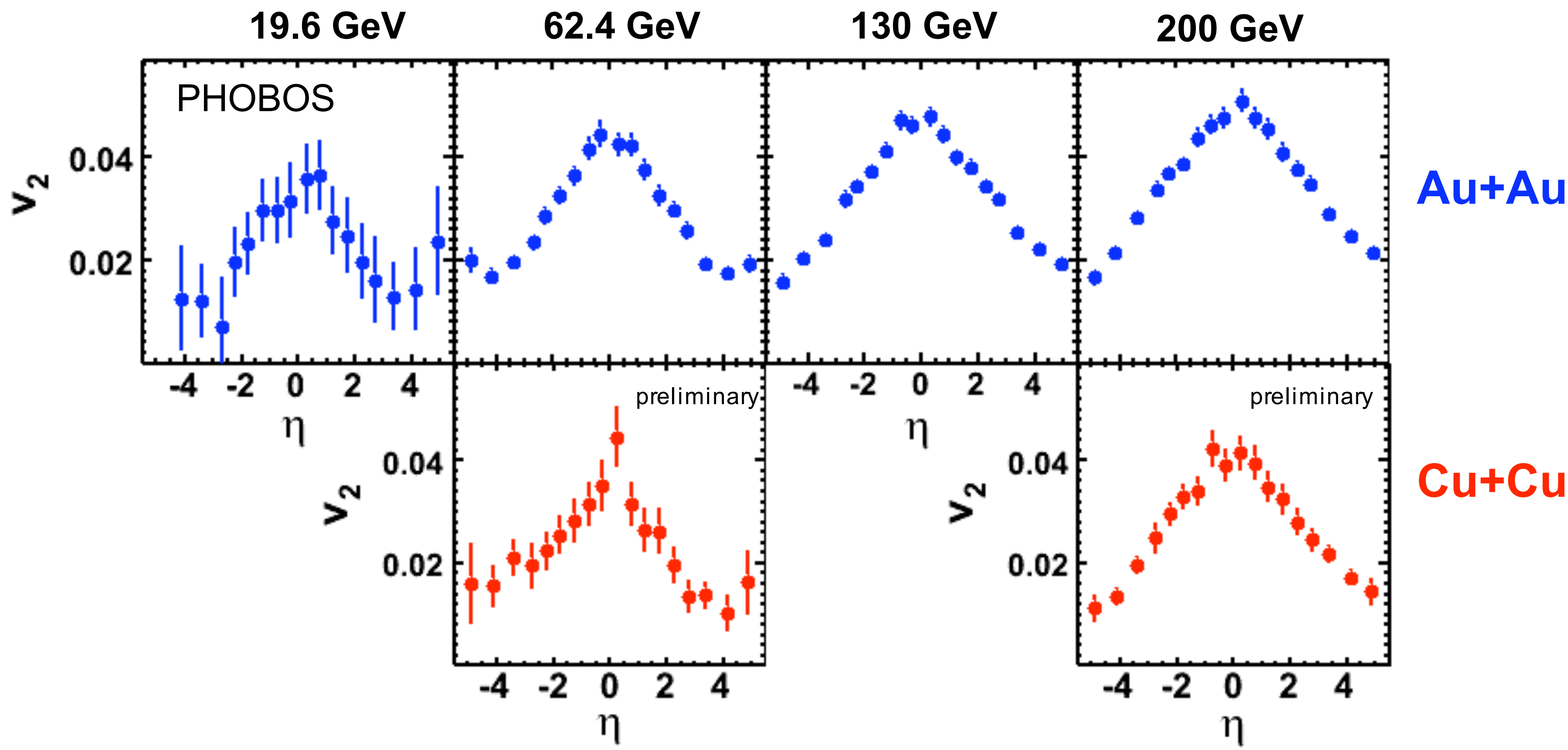
Au+Au: PRL 94, 082304 (2005),
PLB 578, 297 (2004)
d+Au: Phys. Rev. Lett. 91, 072302 (2003)

Directed Flow



See poster by Alice Mignerey

Elliptic Flow



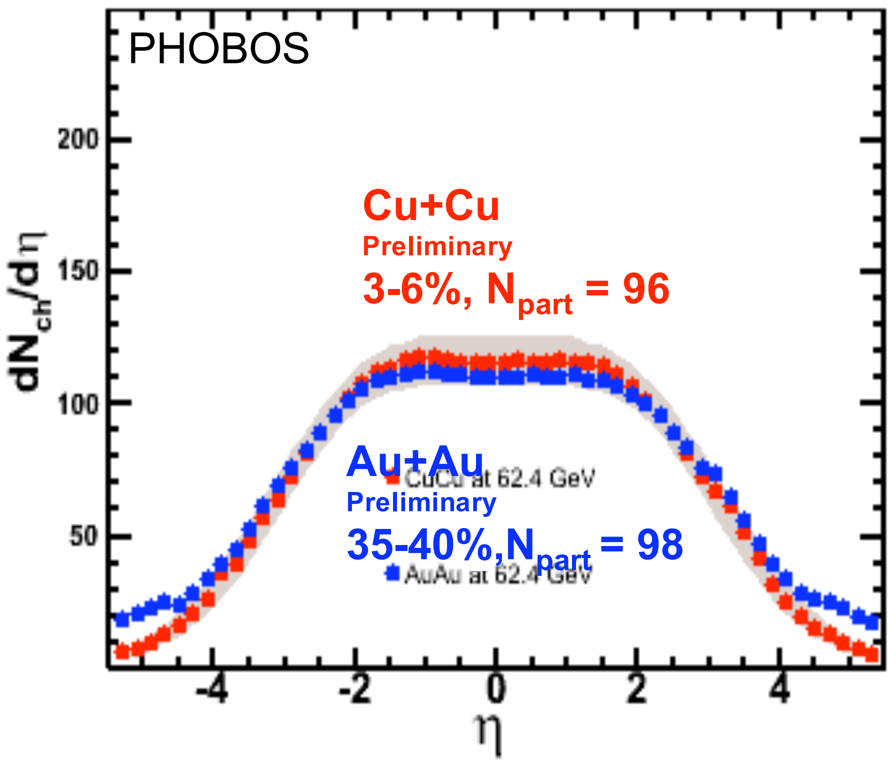
Au+Au: PRL 94 122303 (2005)

Yields in Cu+Cu vs Au+Au

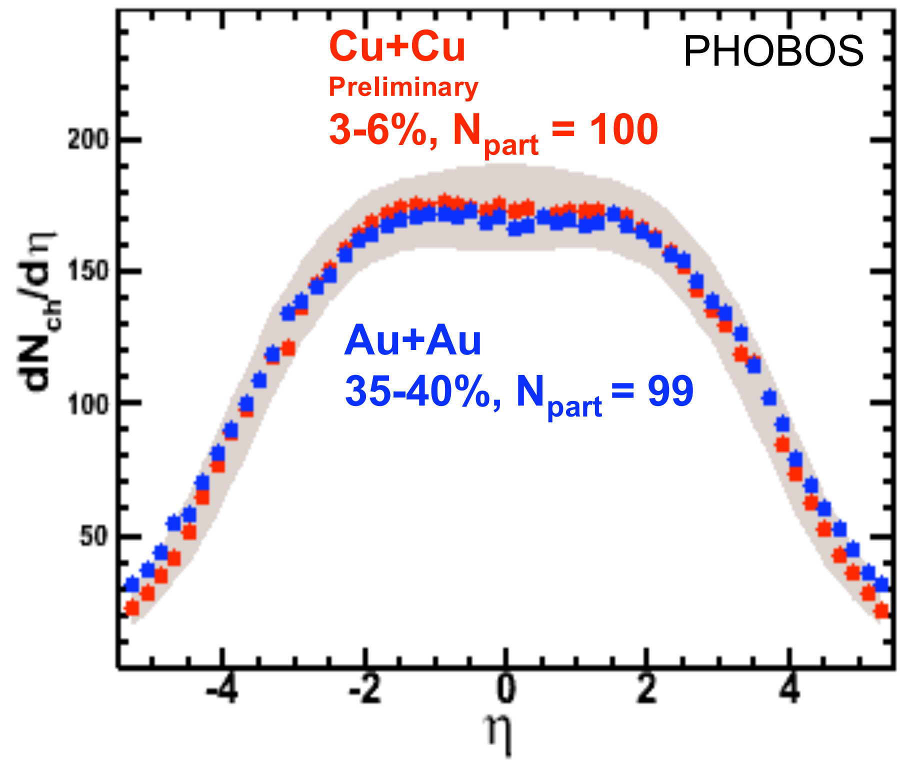
Q: How does charged hadron production in Cu+Cu compare to Au+Au?

dN/dη in Cu+Cu vs Au+Au

62.4 GeV



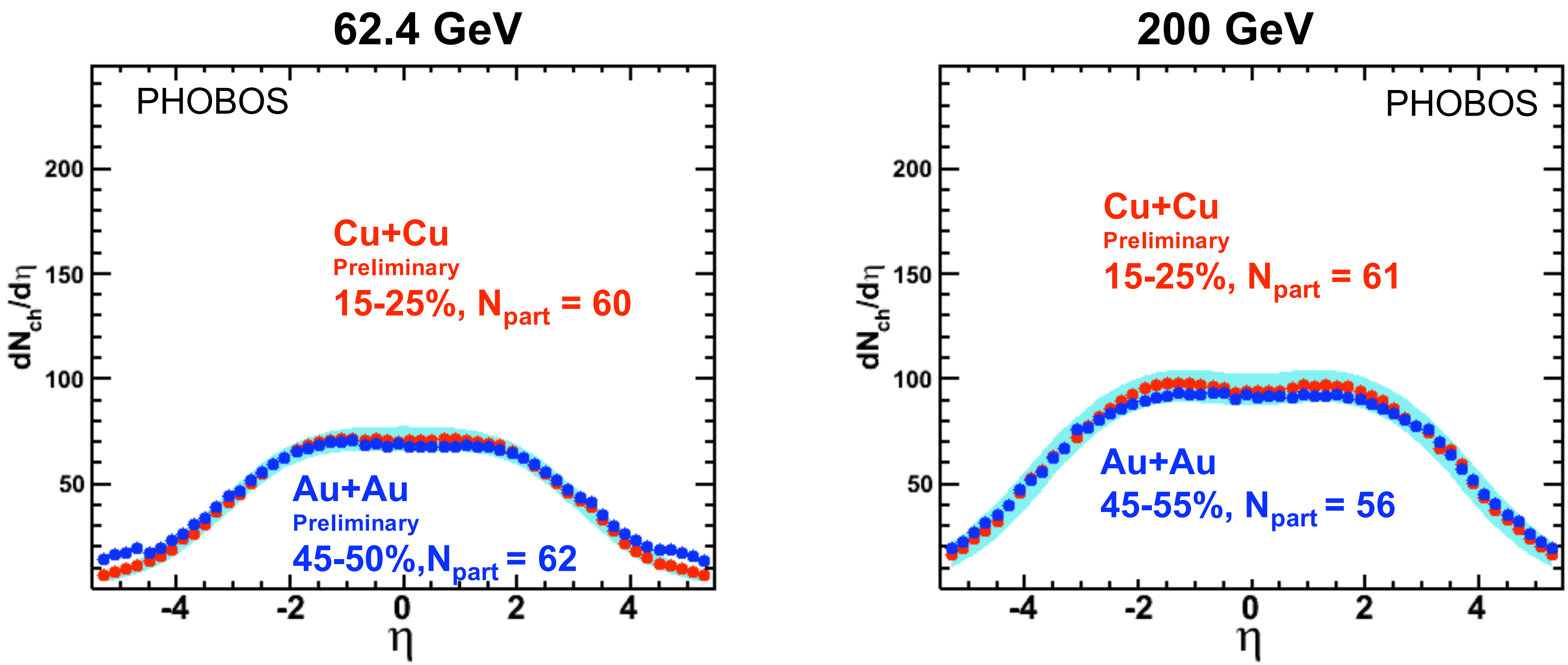
200 GeV



<u>Unscaled</u> dN/dη very similar for Au+Au and Cu+Cu at same N_{part}

See poster by Richard Hollis

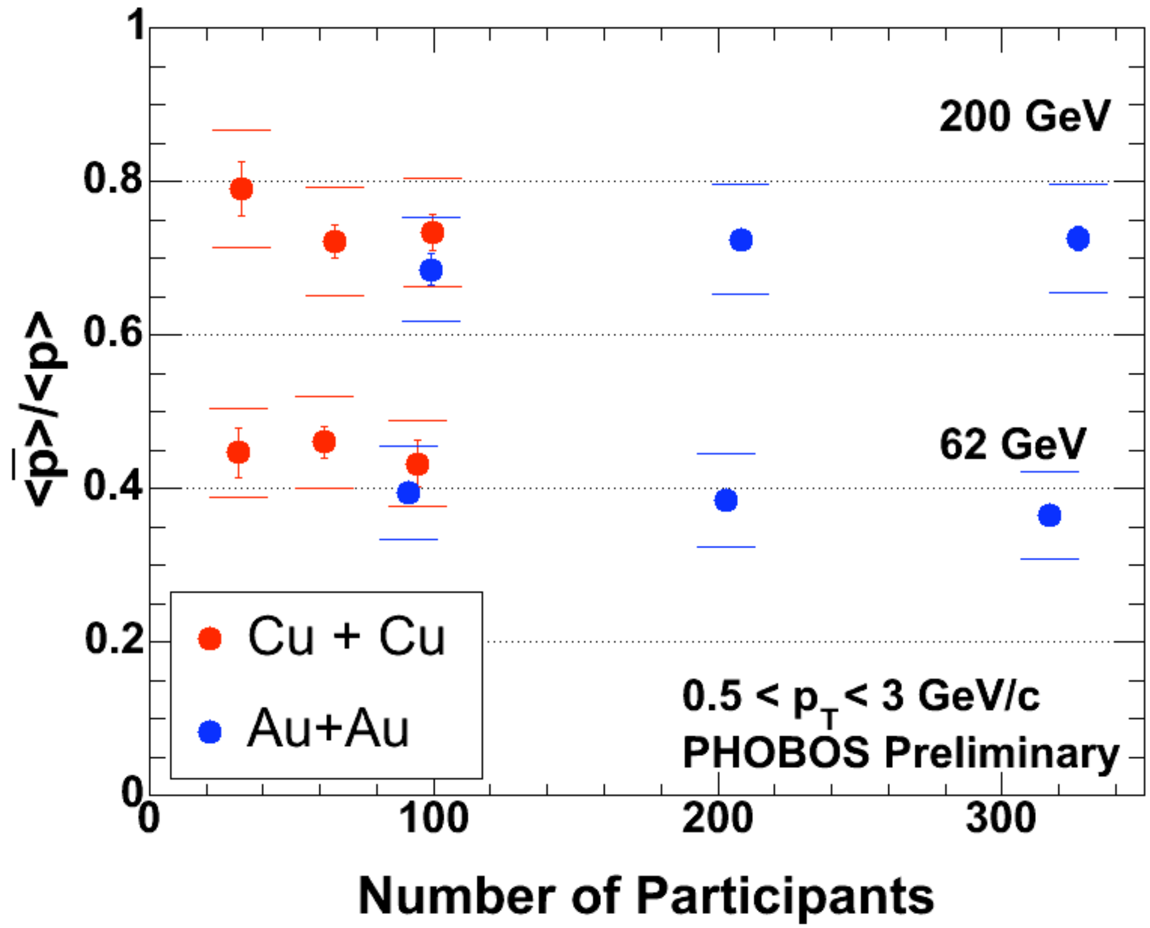
dN/dη in Cu+Cu vs Au+Au



Also true for mid-central Cu+Cu vs peripheral Au+Au

<u>Unscaled</u> dN/dη very similar for Au+Au and Cu+Cu at same N_{part}

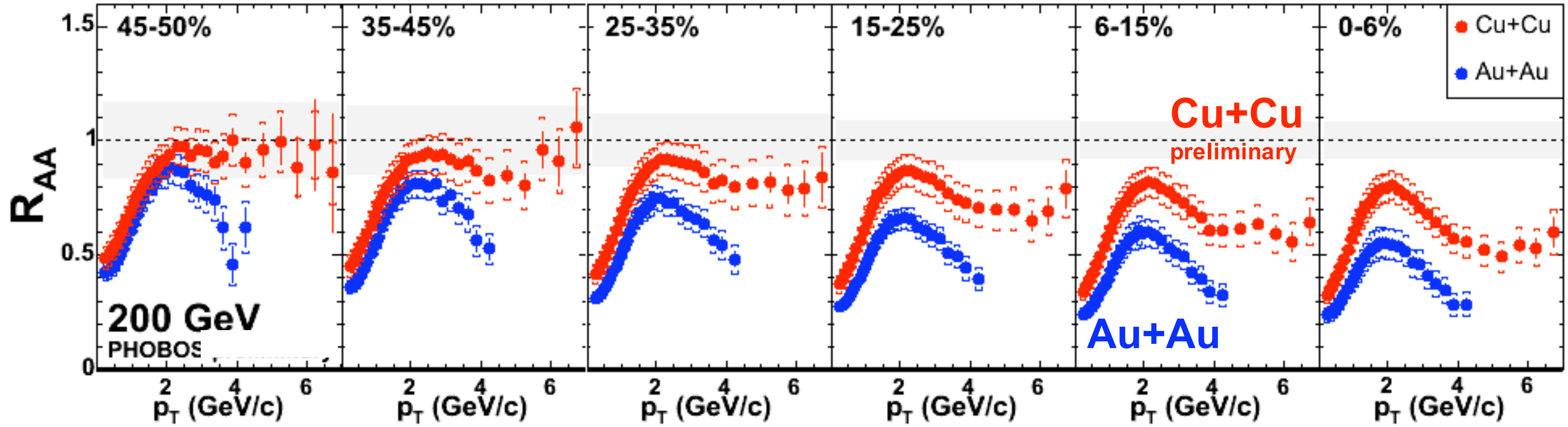
Anti-proton/proton ratio



$\bar{p}$/p ratio very similar in Cu+Cu and Au+Au

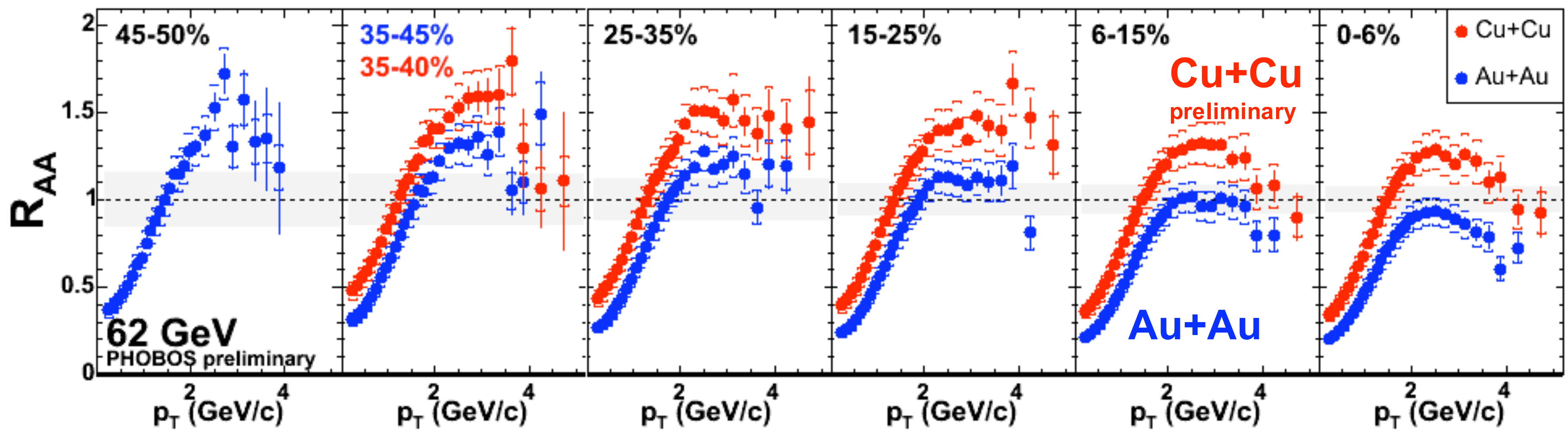
See poster by Vasu Chetluru

Particle Production vs p_T

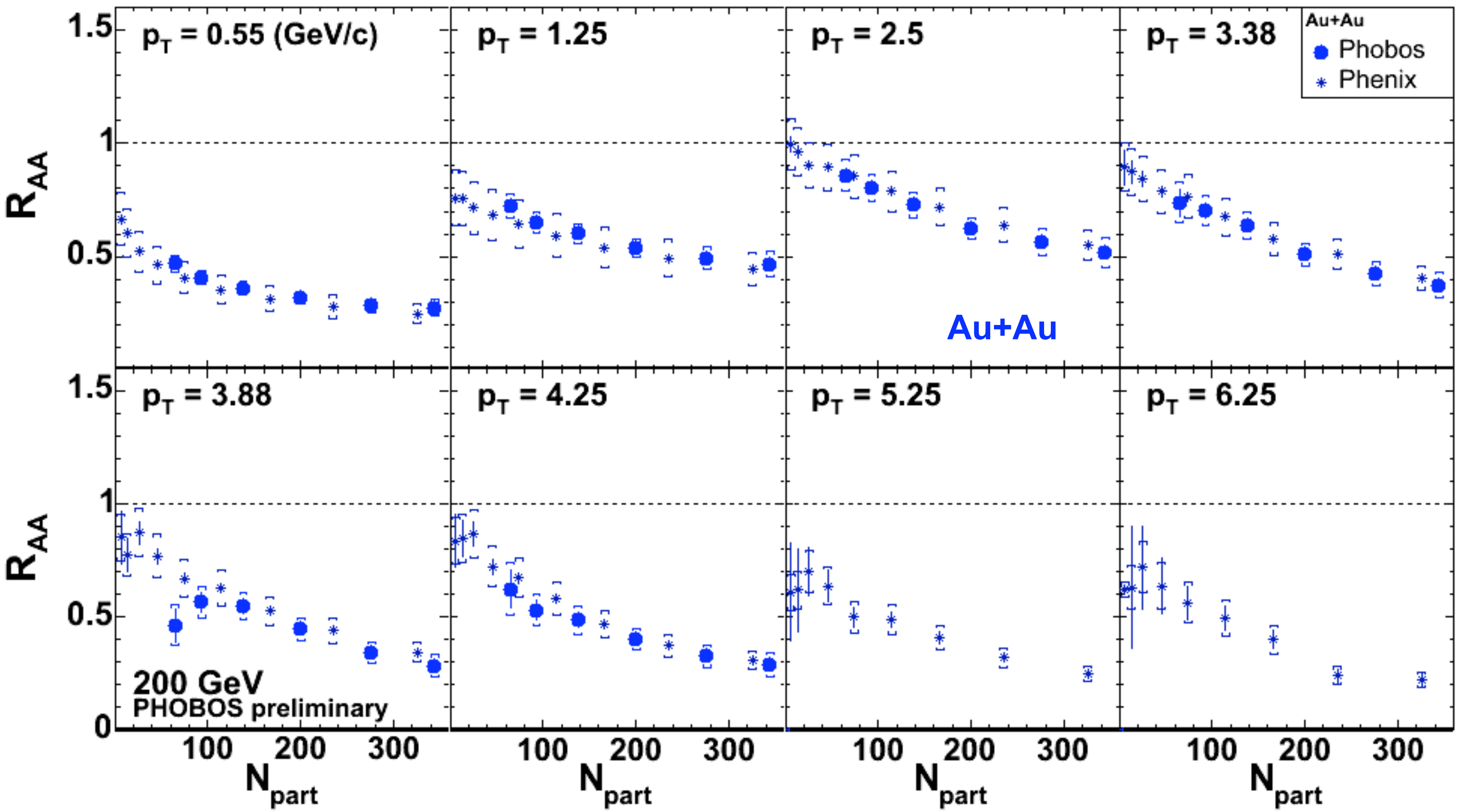


Charged hadron R_{AA} ↖ **200 GeV** **63 GeV** ↘

Au+Au: PRL 94, 082304 (2005), PLB 578, 297 (2004)



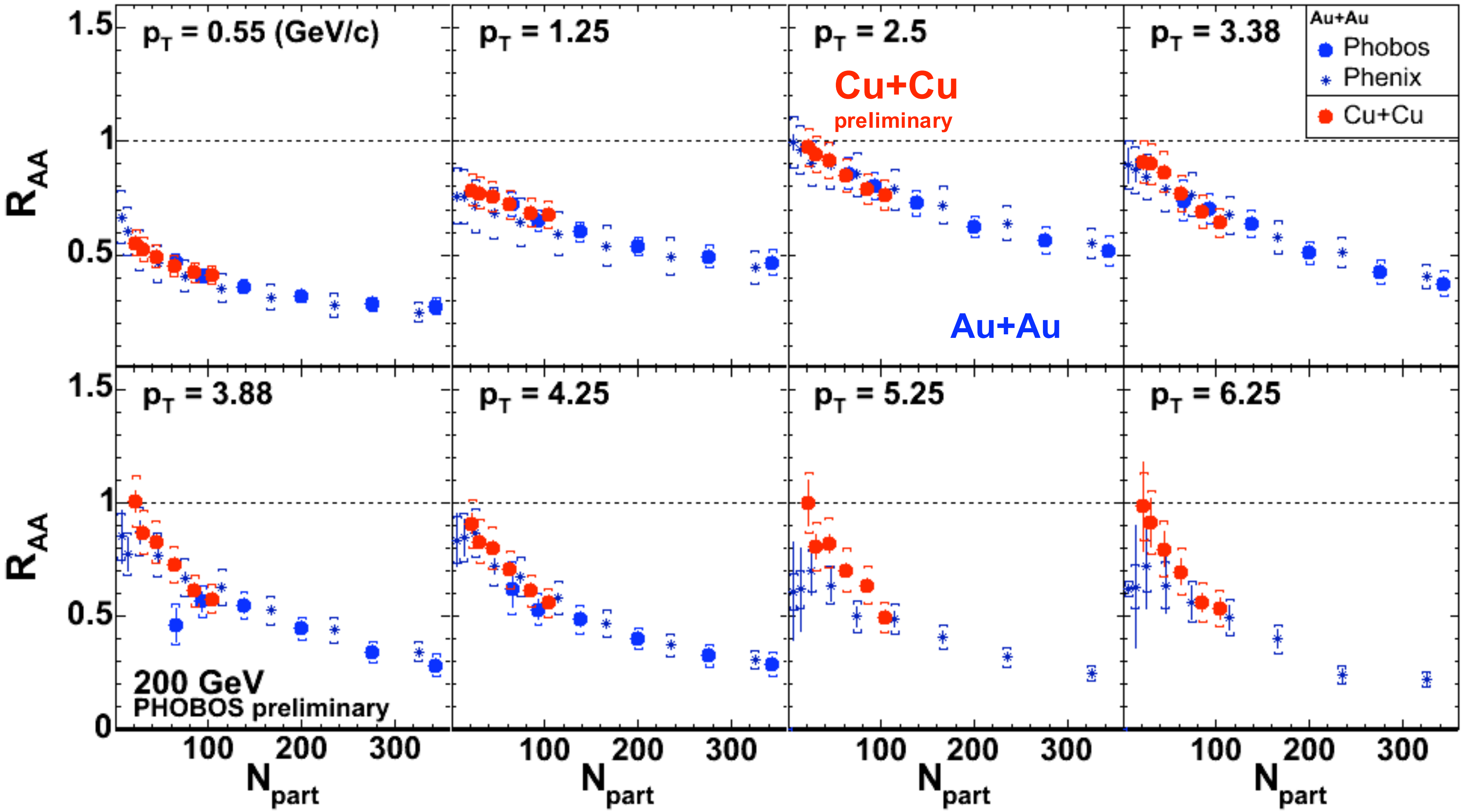
Yields vs N_{part}, 200 GeV



Au+Au: PRL 94, 082304 (2005), PLB 578, 297 (2004)

See poster by Gerrit van Nieuwenhuizen

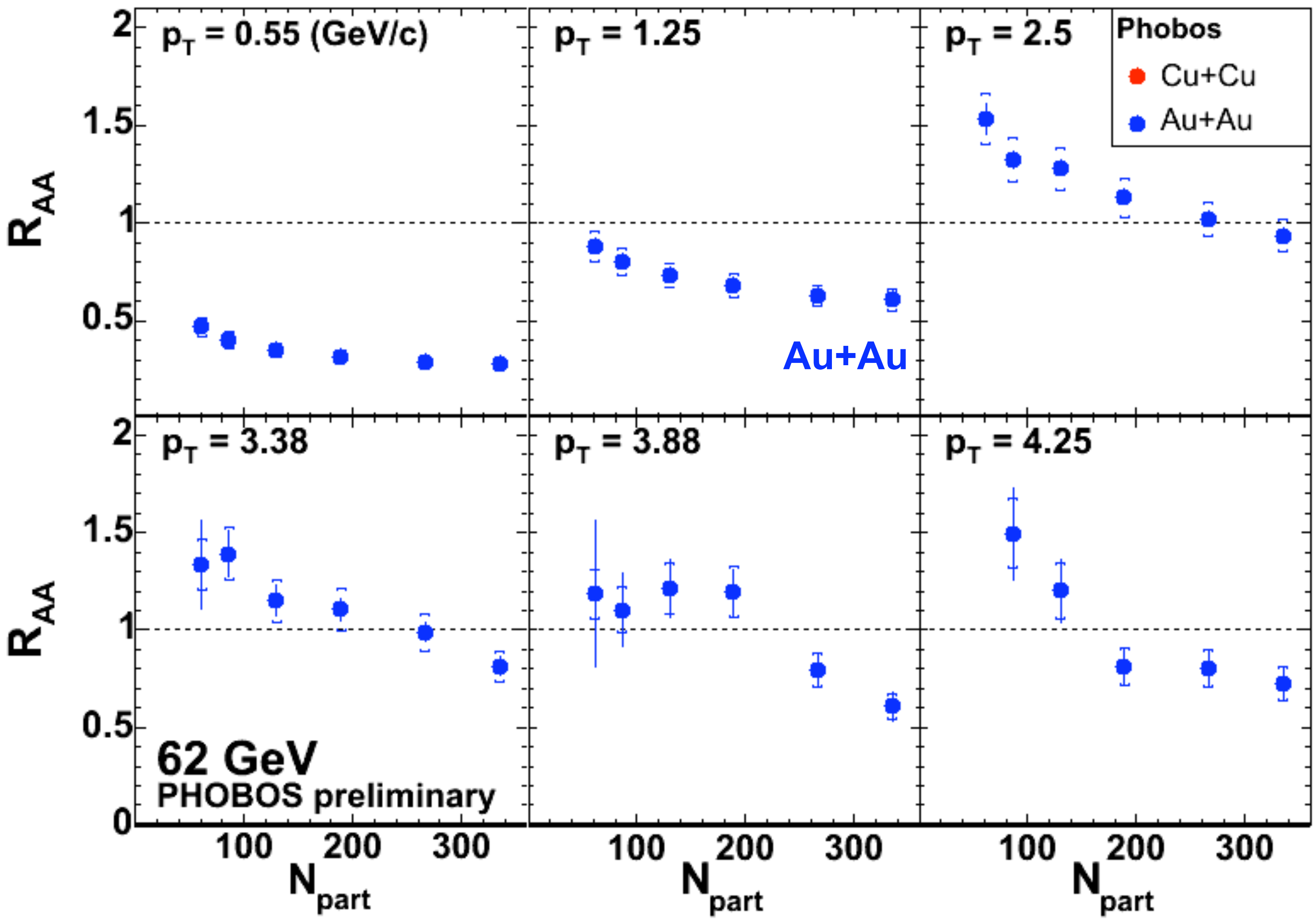
Yields vs N_{part}, 200 GeV



Au+Au: PRL 94, 082304 (2005), PLB 578, 297 (2004)

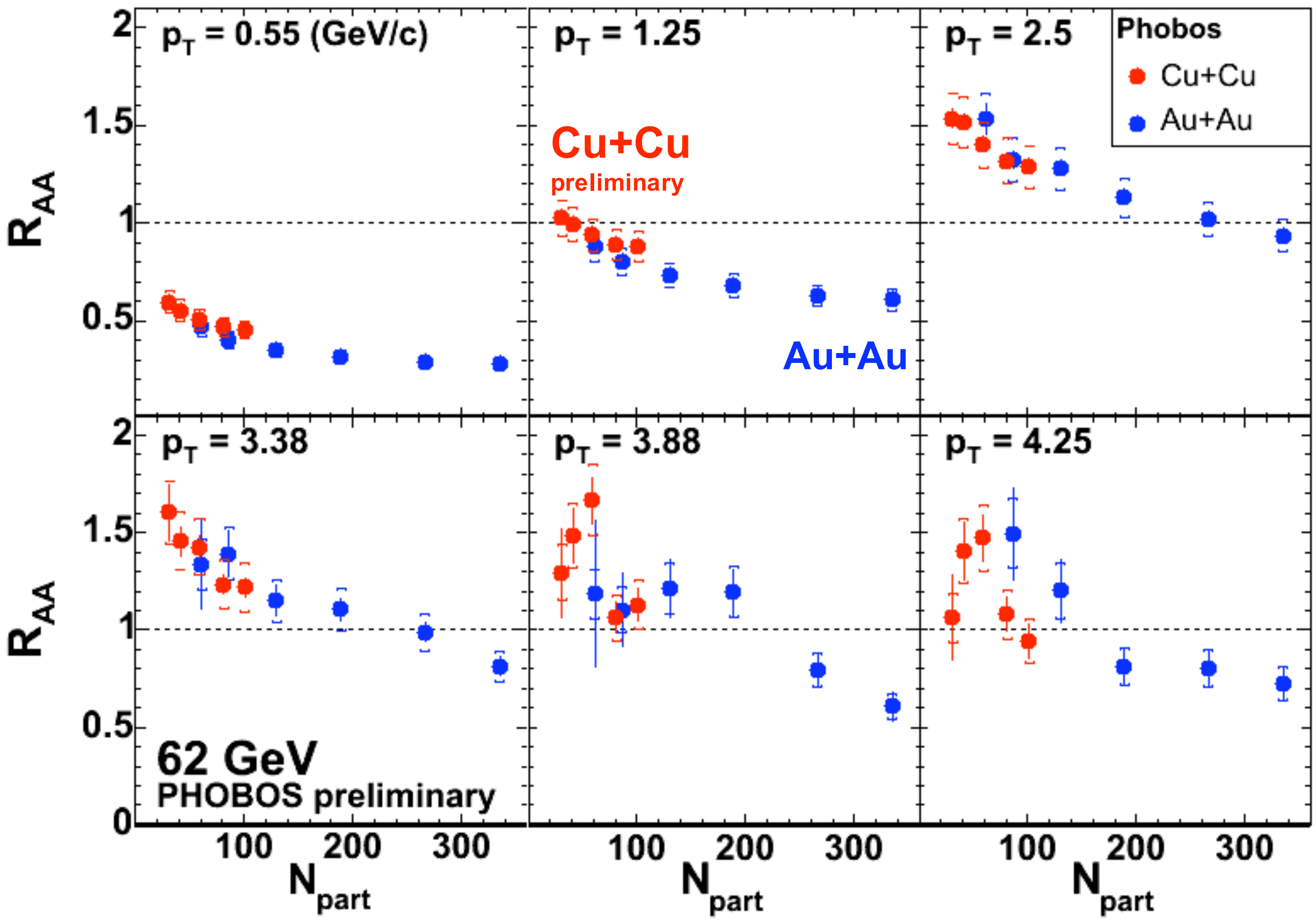
See poster by Gerrit van Nieuwenhuizen

Yields vs N_{part}, 62 GeV



Au+Au: PRL 94, 082304 (2005)

Yields vs N_{part}, 62 GeV



Au+Au: PRL 94, 082304 (2005)

Yields in Cu+Cu vs Au+Au

Q: How does charged hadron production in Cu+Cu compare to Au+Au?

A: For same system size (N_{part}, N_{coll}), Cu+Cu and Au+Au are very similar:

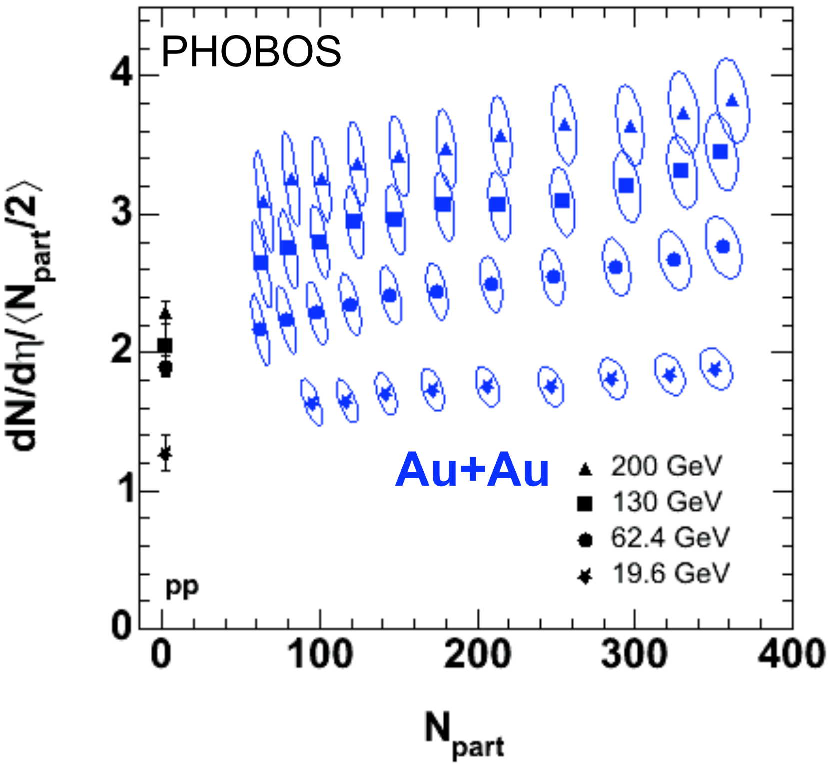
- **Total multiplicity**
- **Mid-rapidity $dN/d\eta$**
- **$\bar{p}/p$**
- **$dN/d\eta$ vs η**
- **dN/dp_T (R_{AA})**

Geometry and Energy

Q: What is the interplay between collision centrality (geometry) and collision energy?

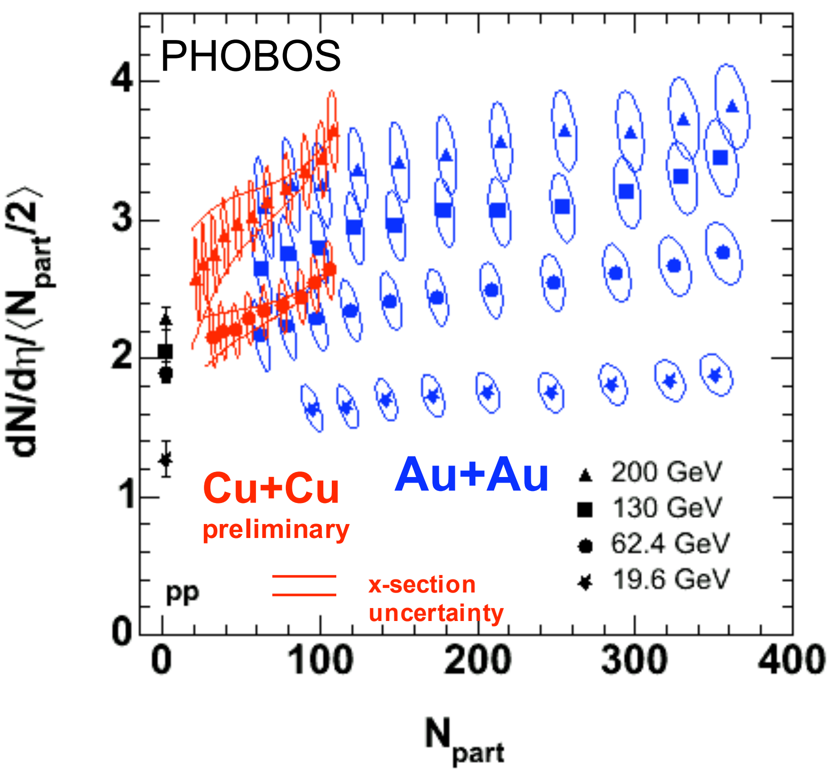
⟶ Balance of hard/soft processes

Energy/Centrality Factorization

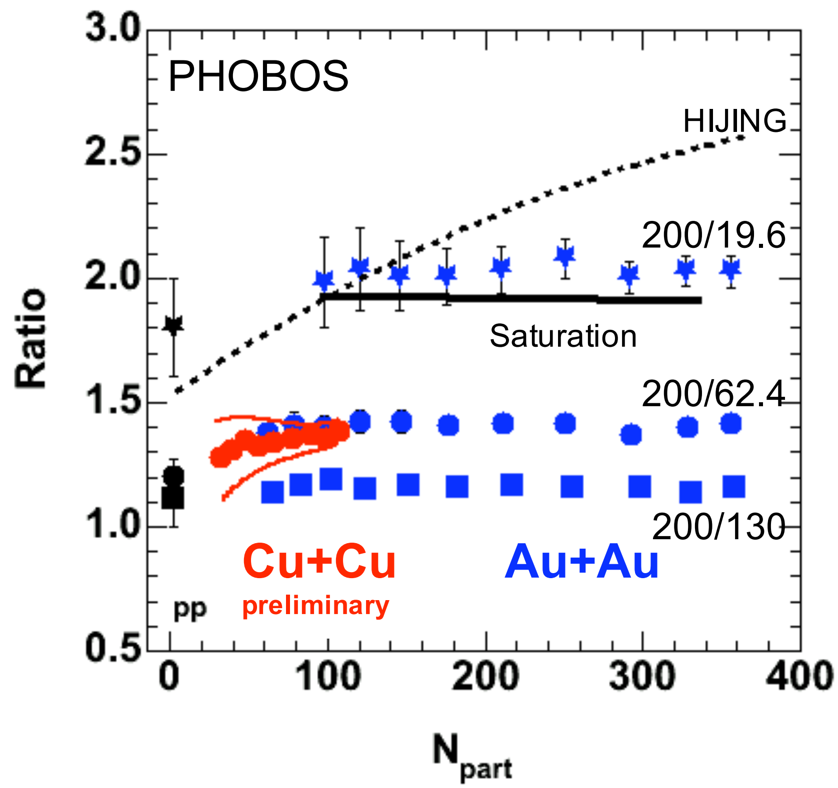


Au+Au: Phys. Rev. C70, 021902(R) (2004) + prel. 62.4 GeV

Energy/Centrality Factorization



Ratio of dN/dη @ η=0 relative to 200 GeV vs centrality



Factorization of energy and centrality dependence

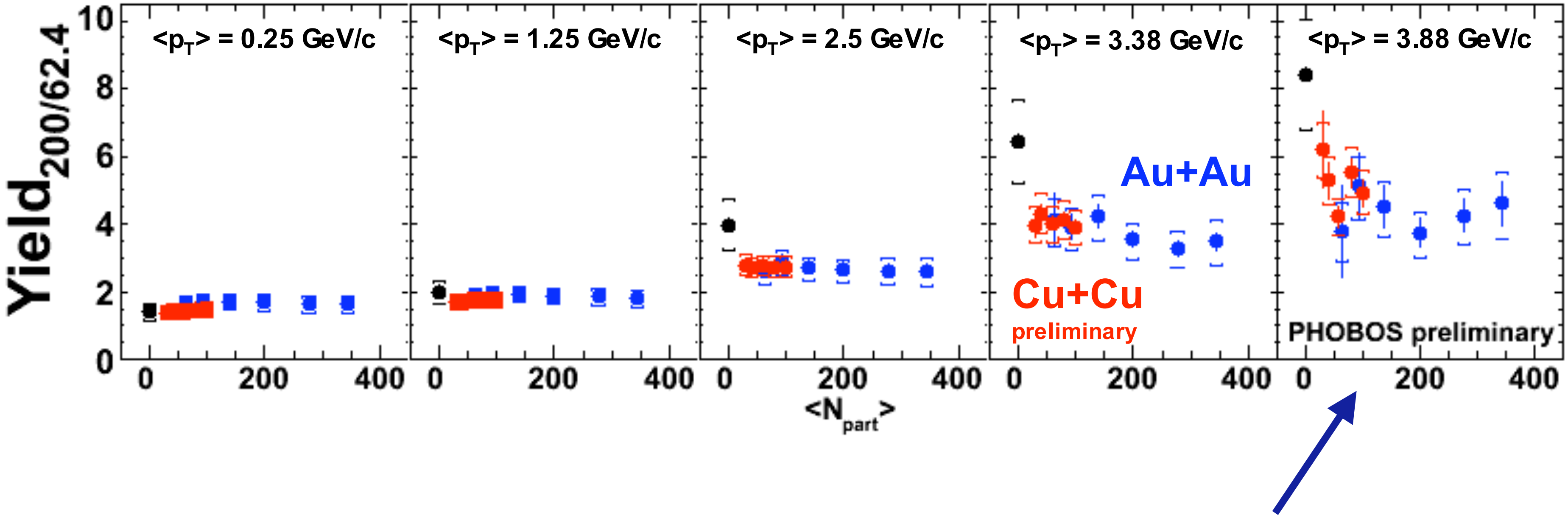
Initial state effect?

Au+Au: Phys. Rev. C70, 021902(R) (2004) + prel. 62.4 GeV

c.f. Armesto, Salgado, Wiedemann hep-ph/0407018

Factorization in p_T, I

Ratio of charged hadron yields in 200 GeV to 62 GeV

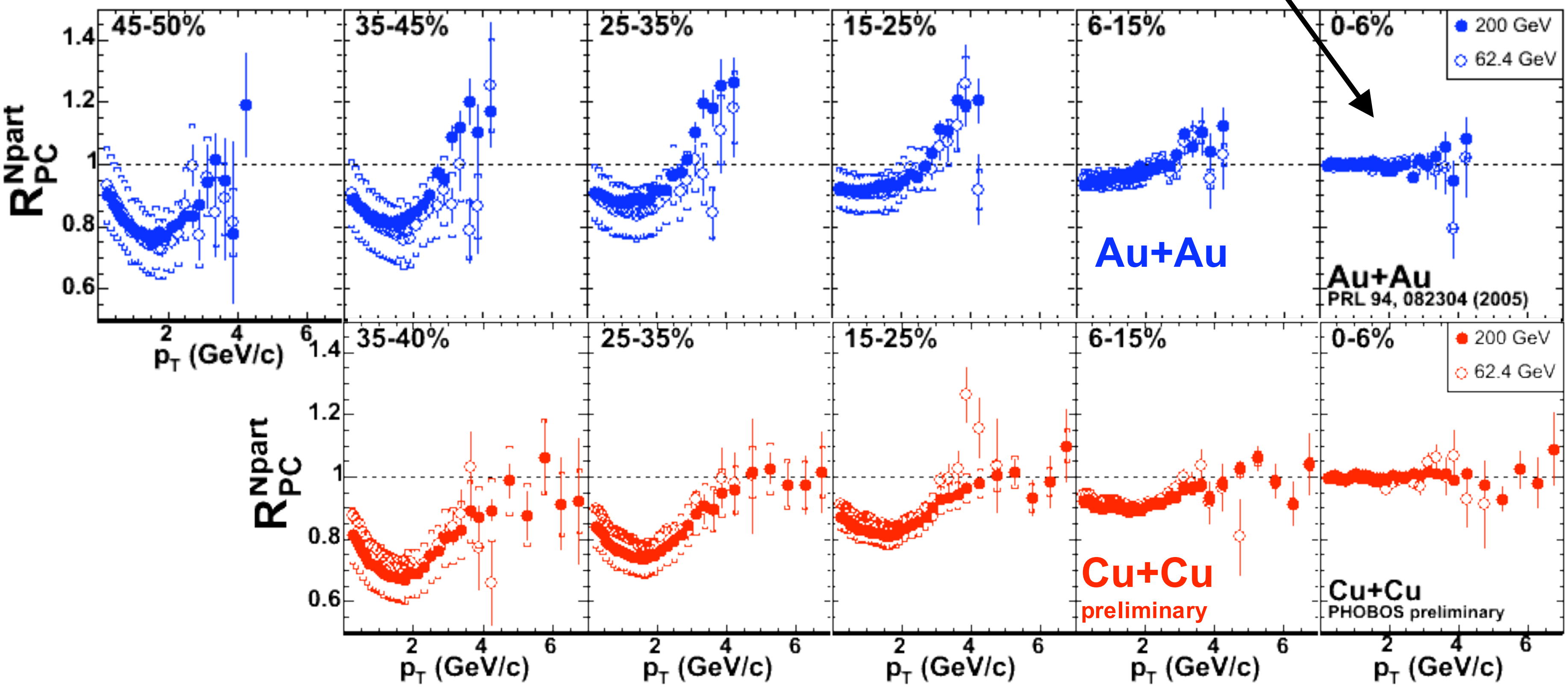


Energy/centrality factorization up to $p_T \approx 4$ GeV/c for $N_{part} > 40$

Au+Au: PRL 94, 082304 (2005)

Factorization in p_T, II

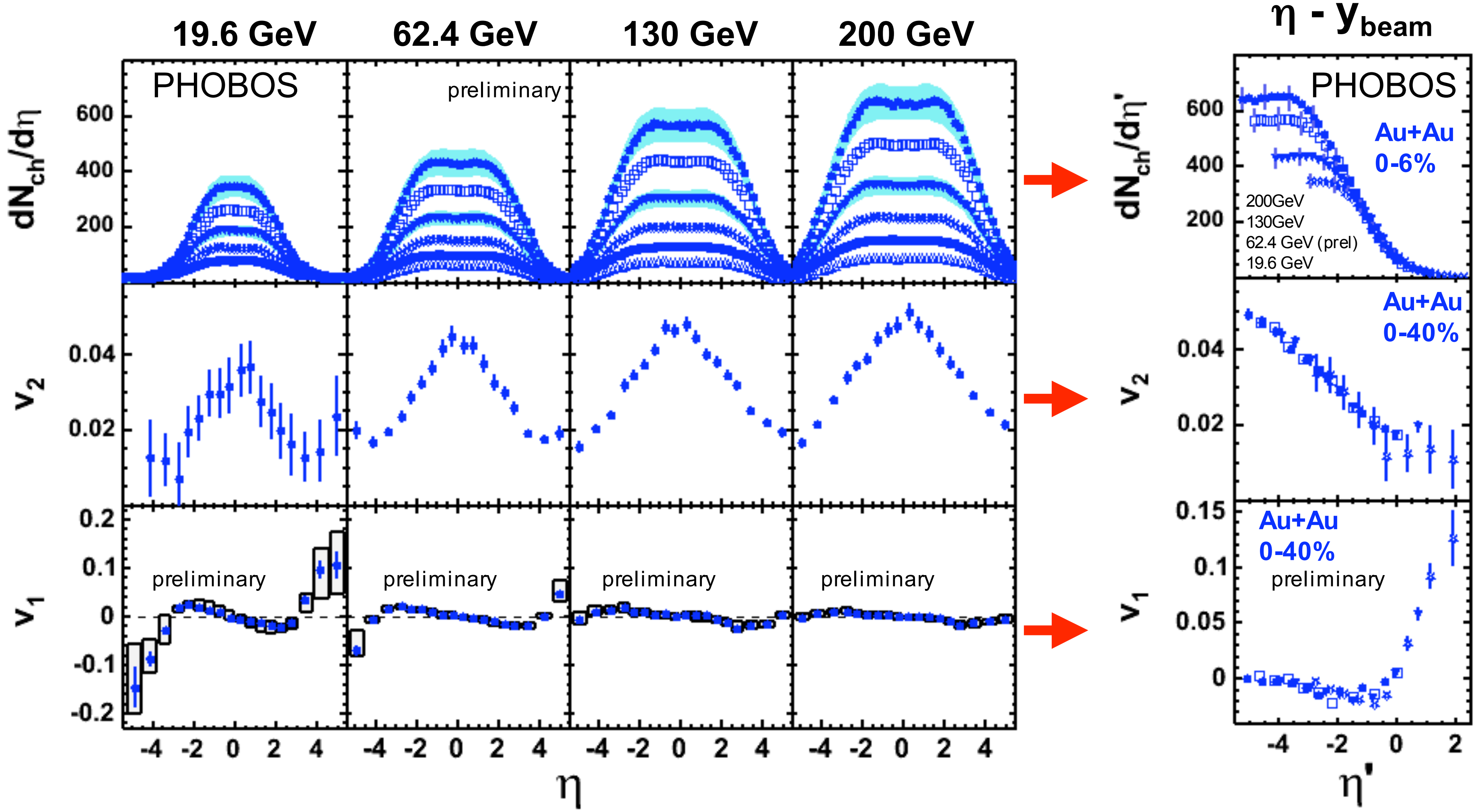
Normalized for central events



Same shape evolution from central to peripheral at 200 GeV and 62 GeV

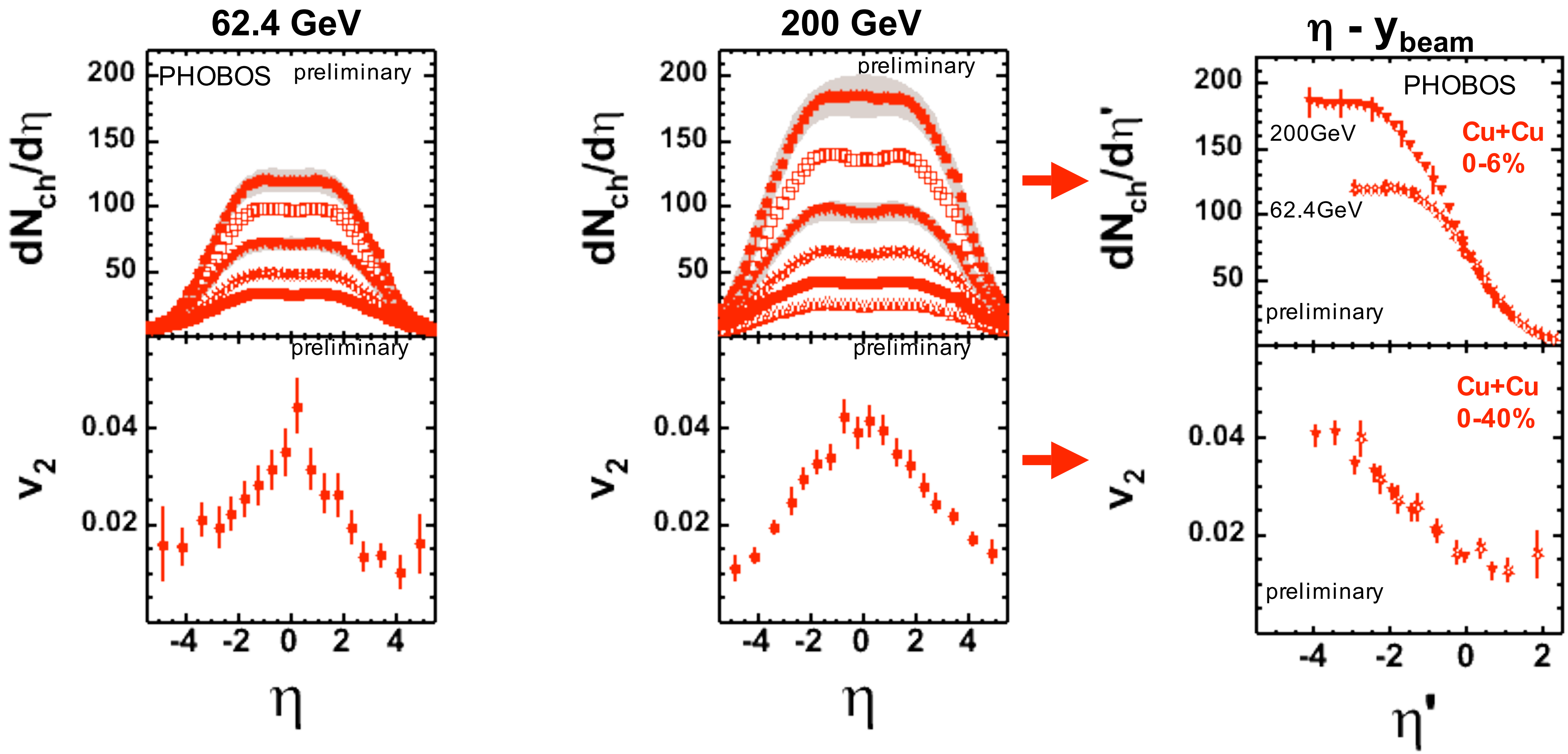
Au+Au: PRL 94, 082304 (2005)

Limiting Fragmentation (Au+Au)



"Extended Longitudinal Scaling" of all longitudinal distributions

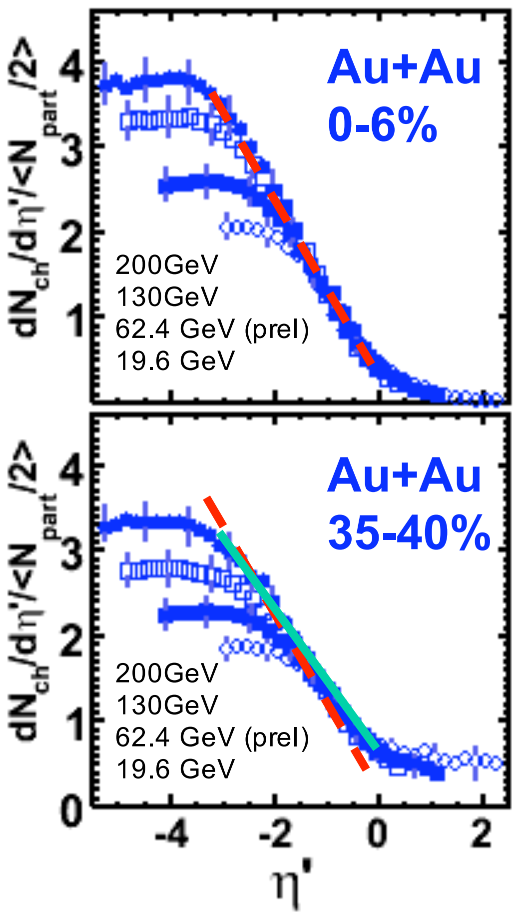
Limiting Fragmentation (Cu+Cu)

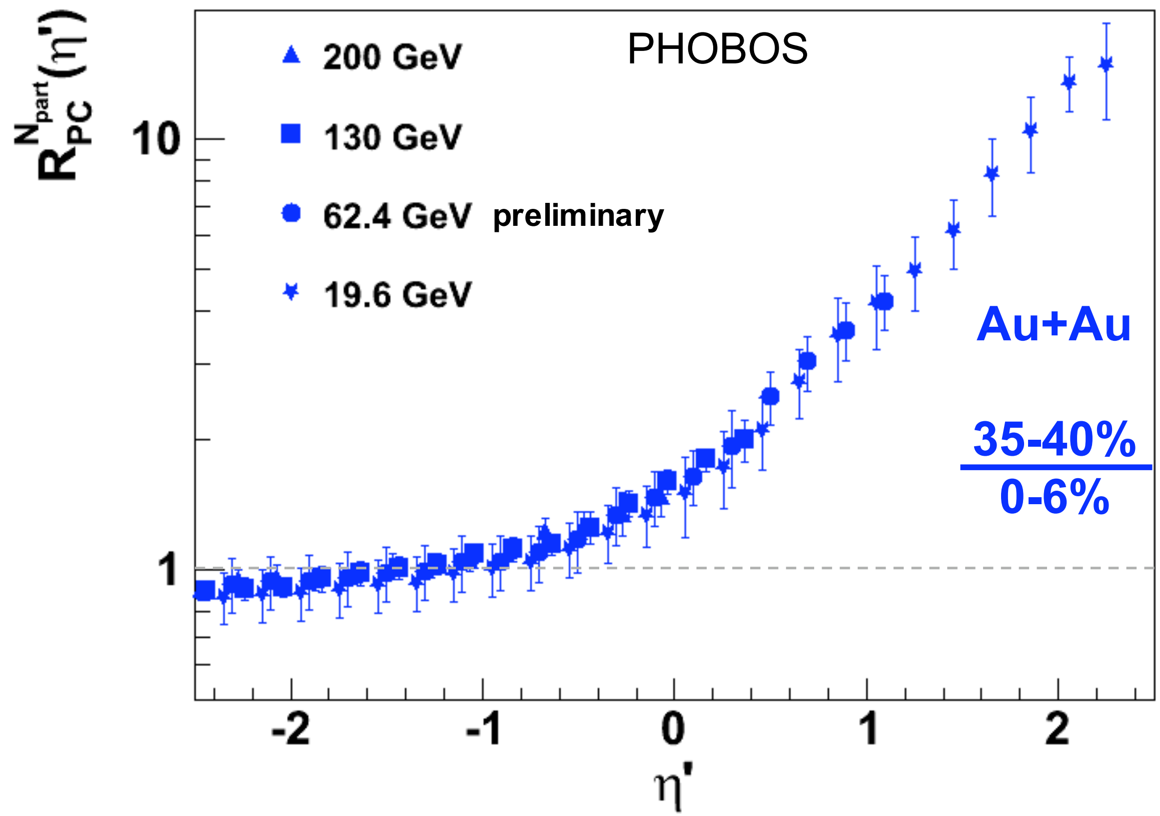


'Extended Longitudinal Scaling' also seen in Cu+Cu
Persists from p+p to Au+Au over large range in η'

$R_{PC}^{N_{part}}$ is energy independent

Ratio of 0-6% and 35-40% centrality bins, each normalized by N_{part}





Geometry and Energy

Q: What is the interplay between collision centrality (geometry) and collision energy?

→ **Balance of hard/soft processes**

A: Factorization of geometry and energy dependence is observed:

- N_{part} scaling
- $dN/d\eta$ @ $\eta=0$
- Limiting fragmentation
- p_T spectra

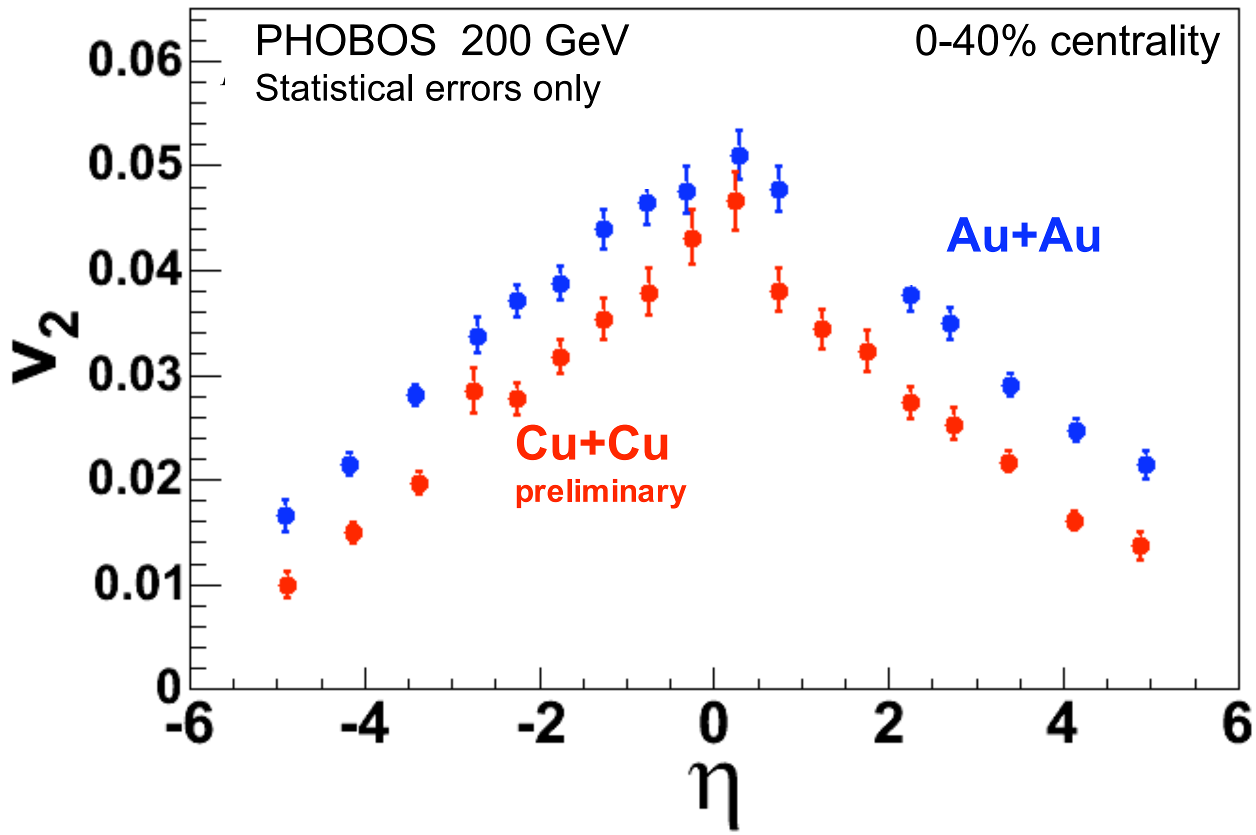
Rules out N_{part}/N_{coll} two-component picture

Dominance of geometry?

Elliptic Flow, Geometry & Density

Q: How does elliptic flow scale with geometry and density?

Elliptic Flow in Cu+Cu vs Au+Au

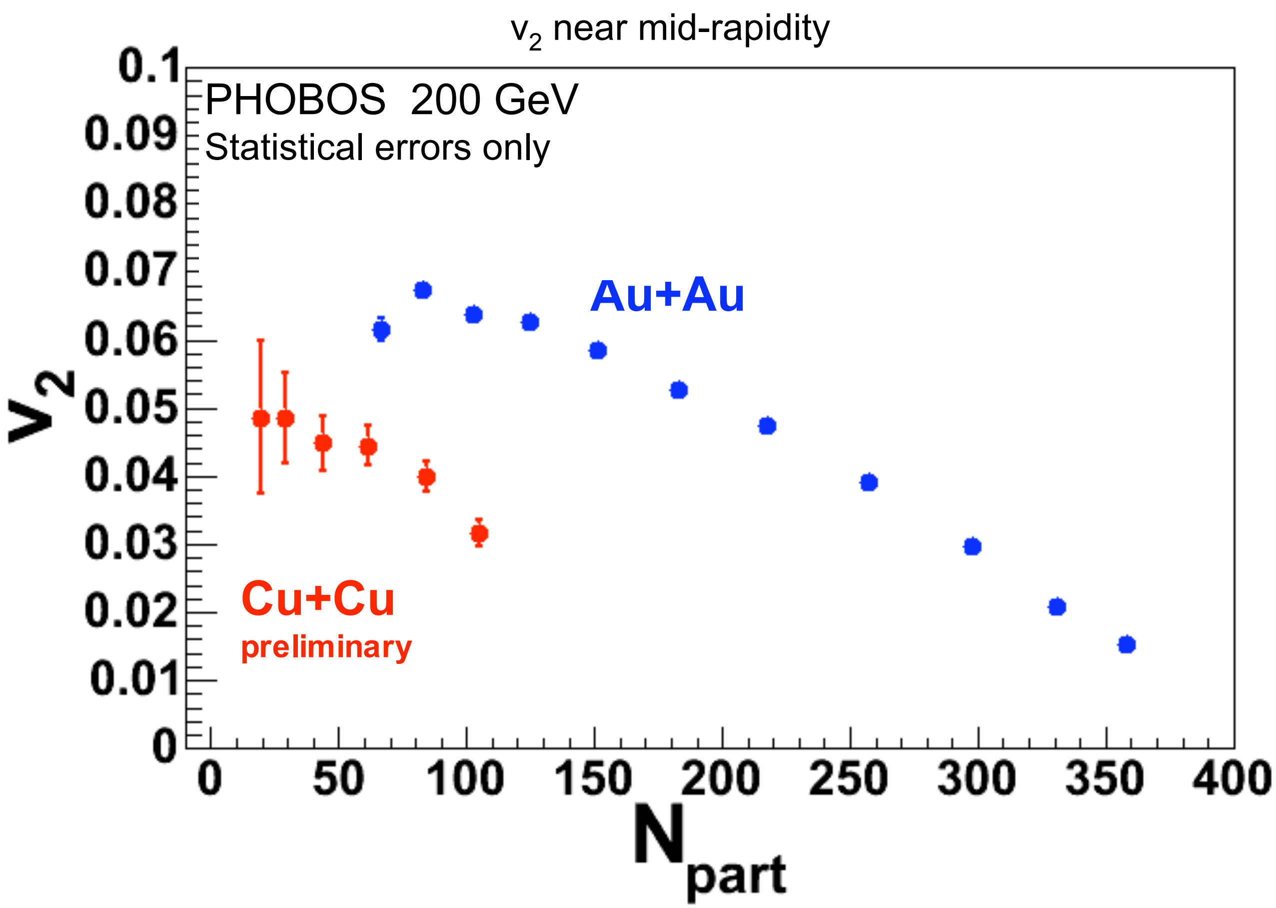


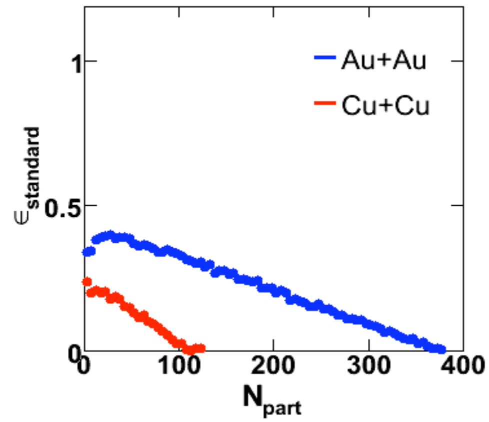
Sizable v_2 for Cu+Cu

Much larger than transport-model predictions

See talk by Steve Manly

Elliptic Flow vs N_{part}

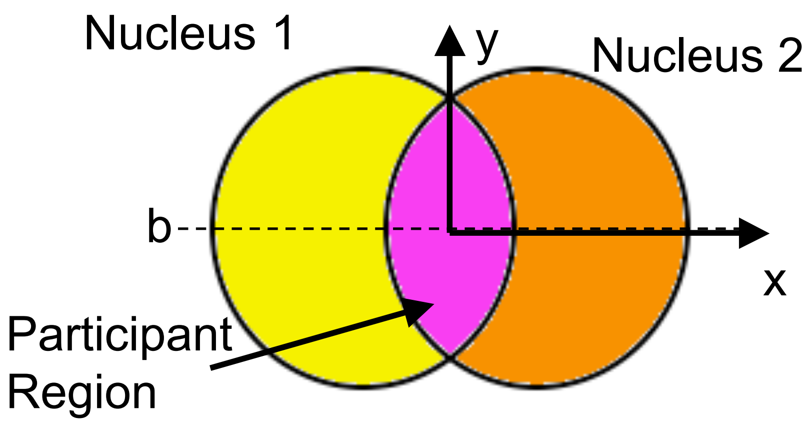




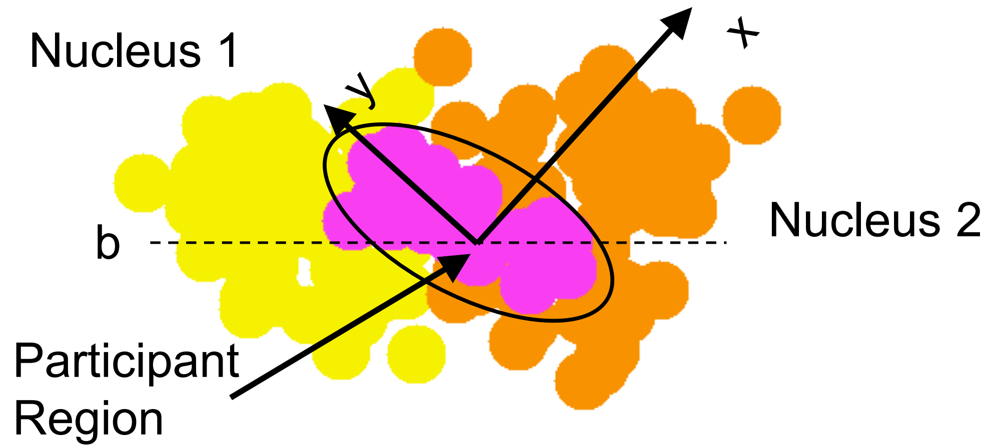
Substantial v_2 even for most central bin in Cu+Cu

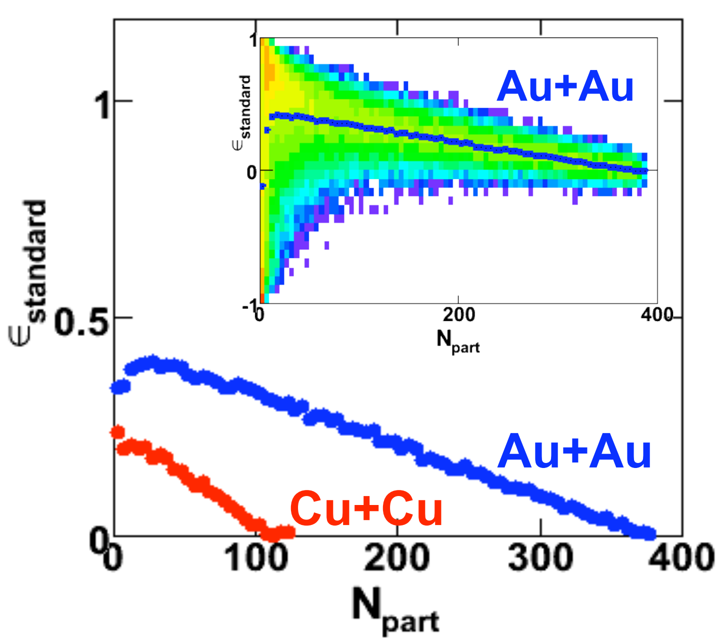
Eccentricity Calculation

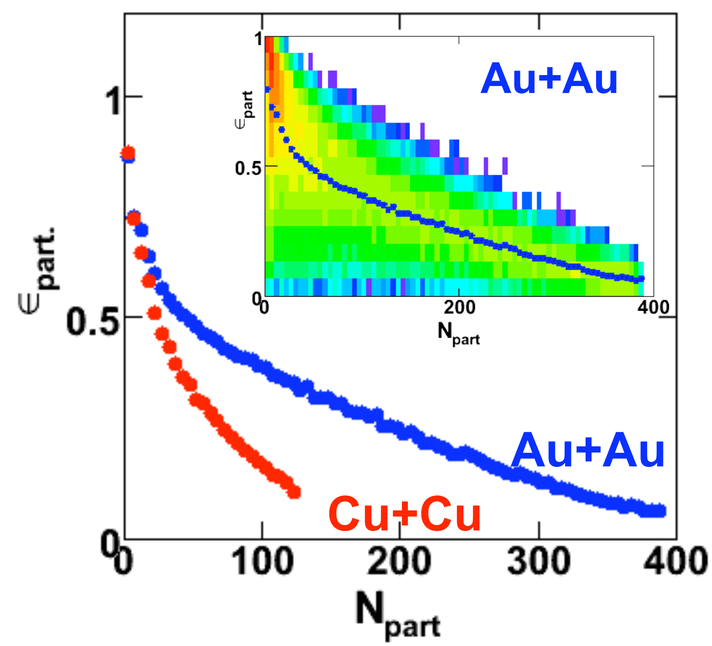
Standard Eccentricity



Participant Eccentricity

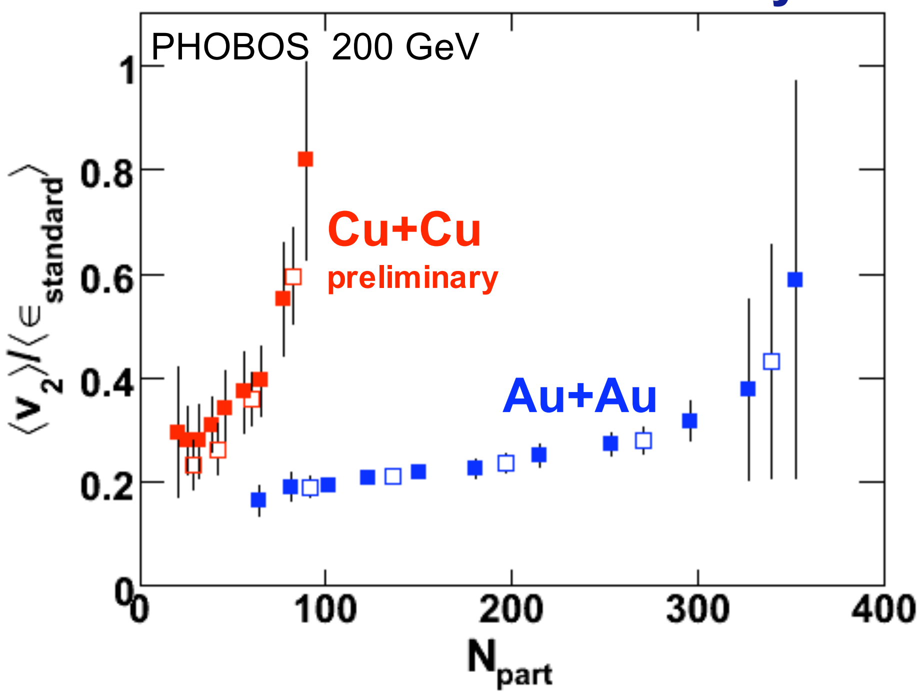




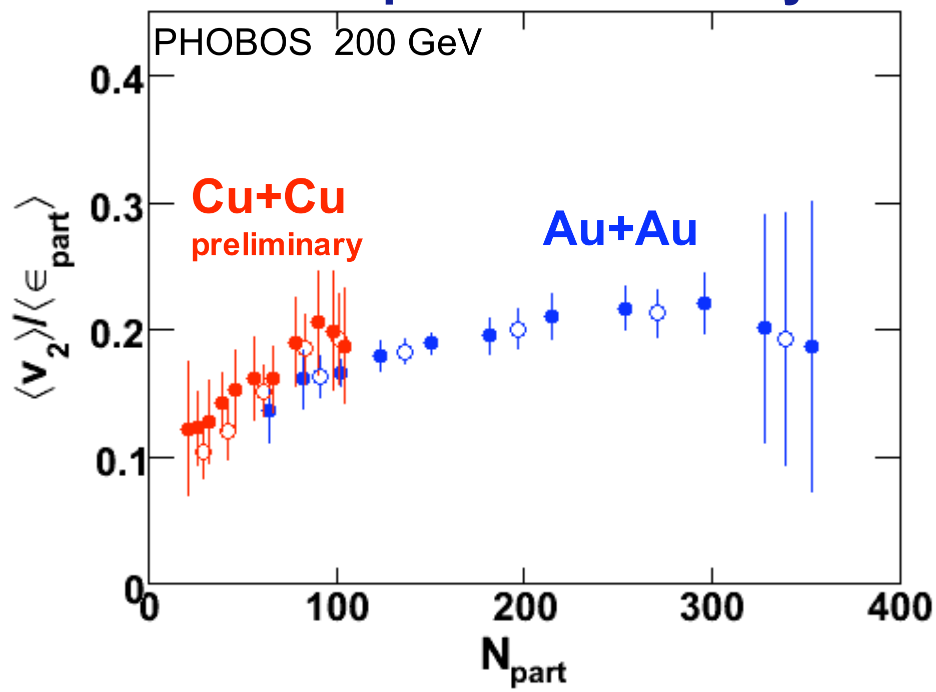


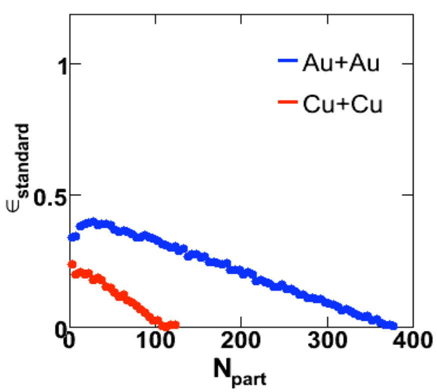
Elliptic Flow vs N_{part}, II

Standard Eccentricity

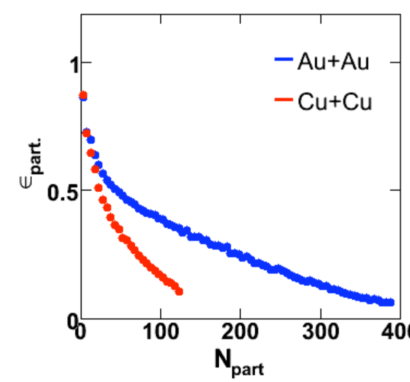


Participant Eccentricity



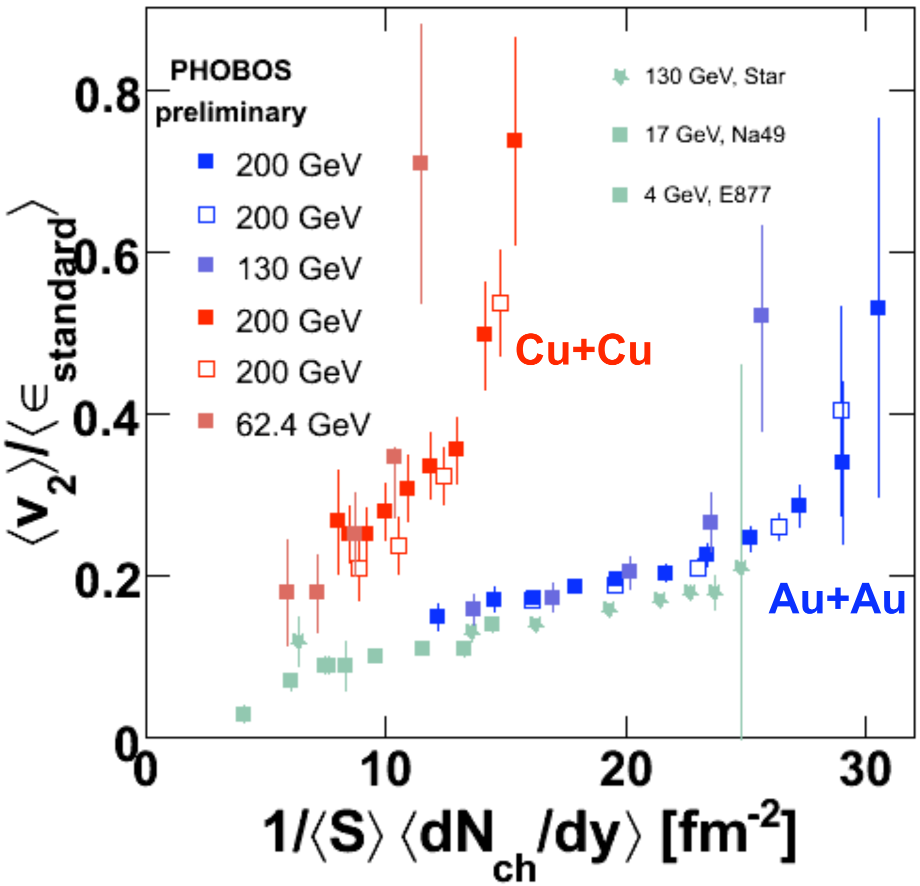


"Participant Eccentricity" allows v_2 scaling from Cu+Cu to Au+Au

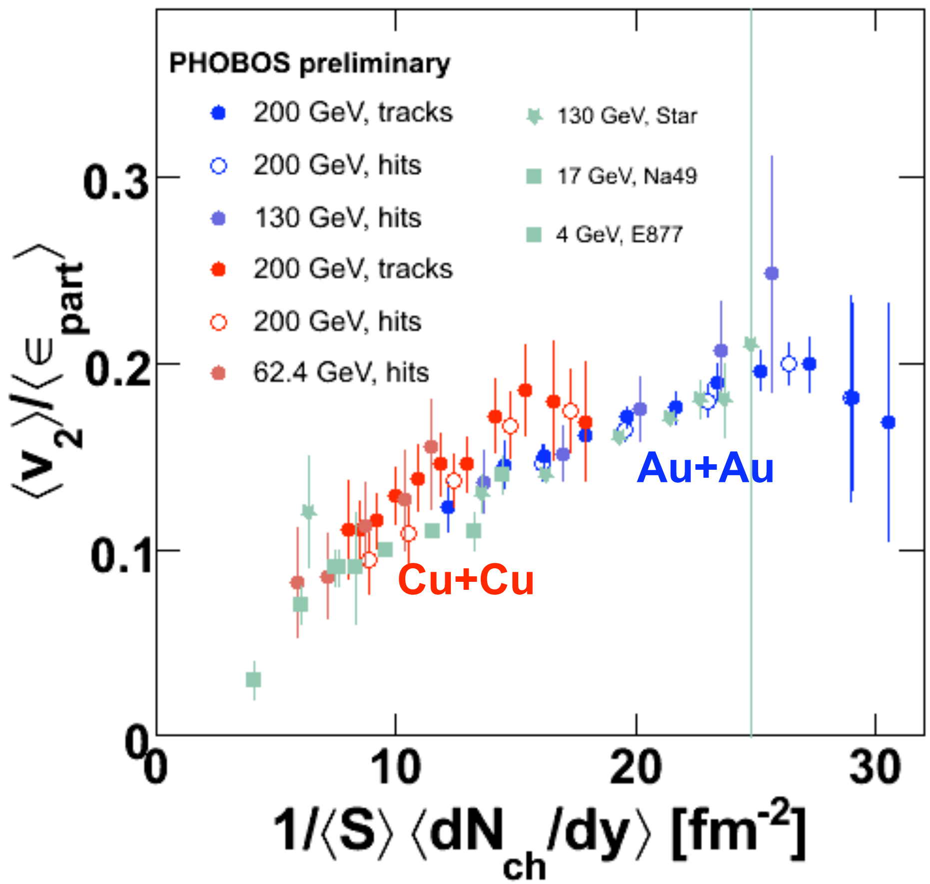


‘Low Density Limit’-Scaling

Standard Eccentricity



Participant Eccentricity



Low Density Limit:
STAR, PRC 66 034904 (2002)
Voloshin, Poskanzer, PLB 474 27 (2000)
Heiselberg, Levy, PRC 59 2716, (1999)

Elliptic Flow, Geometry & Density

Q: How does elliptic flow scale with geometry and density?

A: Large elliptic flow observed in Cu+Cu

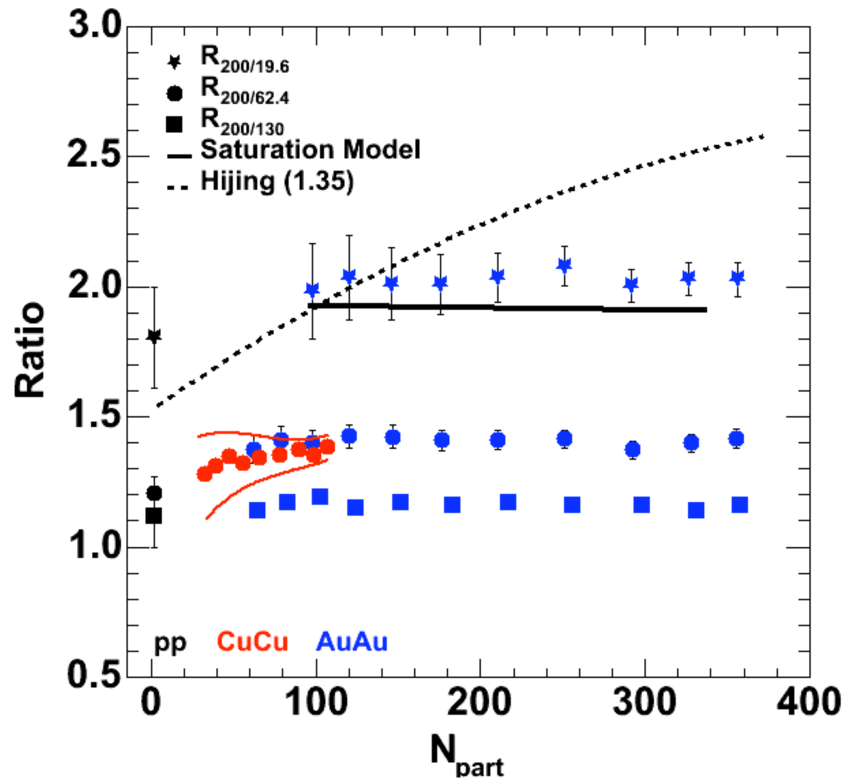
- Non-vanishing $\langle v_2 \rangle$ for central events
- "Non-flow" effects?
- Expansion driven by participant eccentricity?

Physics Lessons, I

Q: What Physics Lessons have we learned?

A1: Energy/Centrality factorization implies suppression/saturation of initial particle production

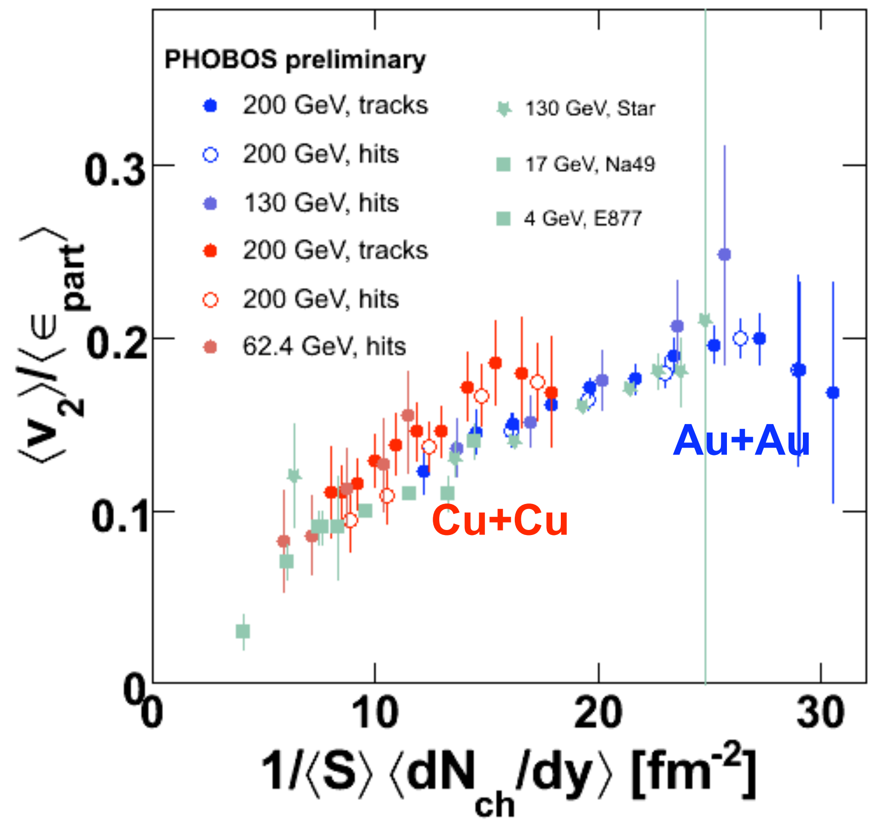
If this persists at LHC, underlying physics will dominate HIC at LHC



Physics Lessons, II

Q: What Physics Lessons have we learned?

A2: Strong collective flow observed in Cu+Cu emphasizes the need for understanding of early thermalization/pressure build up

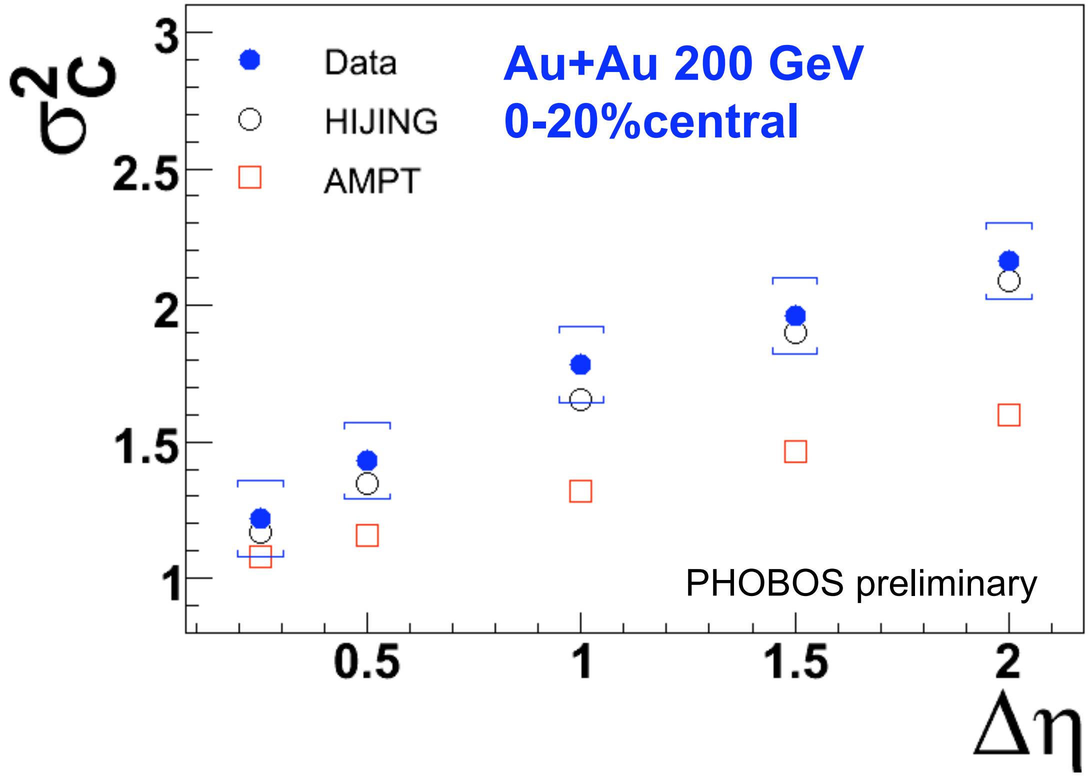


Continuing Physics Program

Q: What is the current and future physics program for PHOBOS?

Multiplicity Fluctuations

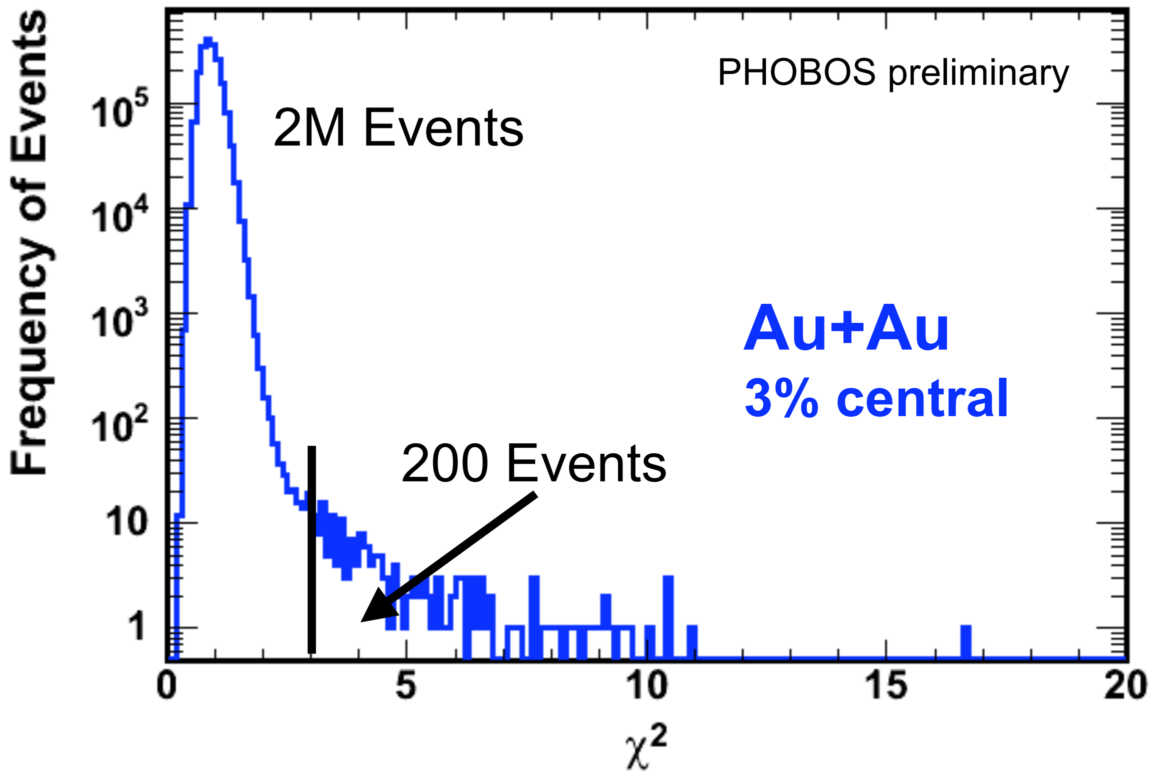
Effective cluster size



Correlated particle emission in 'clusters'

Extract cluster size from forward/backward multiplicity correlations See talk by Peter Steinberg

Search for Rare Events



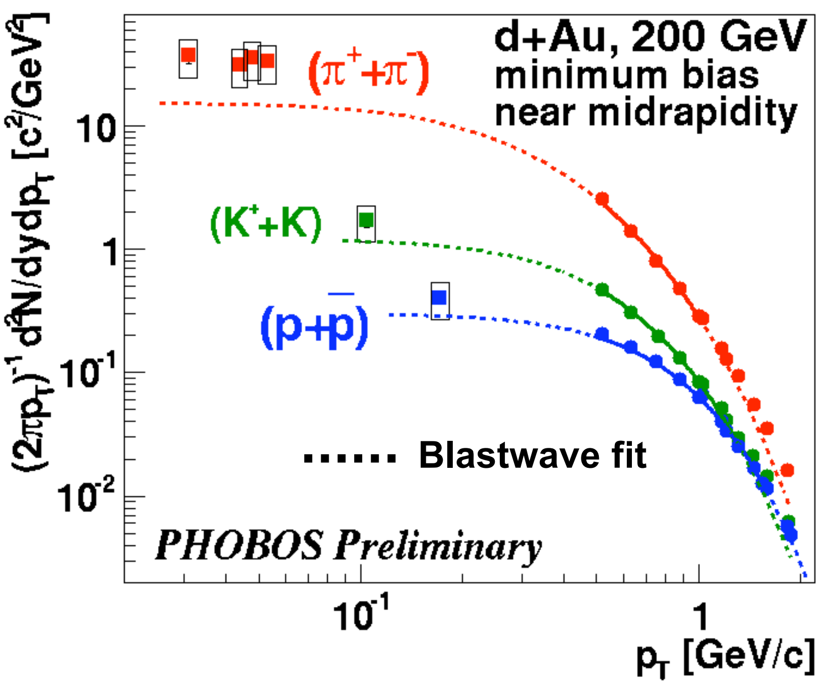
Search for 'unusual' events

Understand tails (≈10^{-4}) in terms of known backgrounds

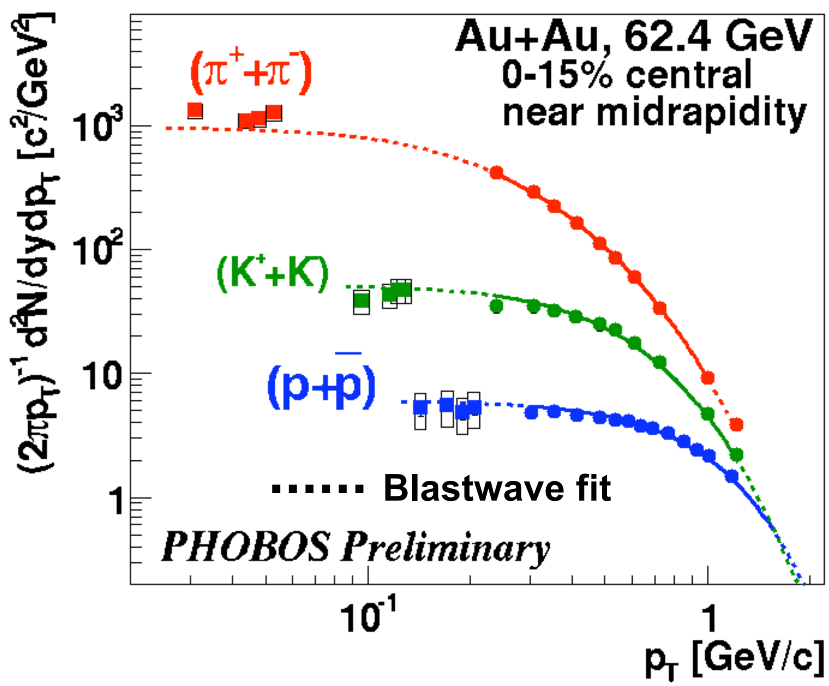
See talk by George Stephans

Particle Production at Low p_T

200 GeV d+Au (min bias)



62.4 GeV Au+Au (15% central)



Unique measurements at low p_T

See talk by Adam Trzupek (spectra) and poster by Siarhei Vaurynovich(Phi)

Continuing Physics Program

Q: What is the current and future physics program for PHOBOS?

A: We still have a long way to go

- **Complete systematics of hadron production and anisotropic flow**
- **Comprehensive studies of correlations over full acceptance**
- **Comprehensive study of charged hadron and ϕ production at very low p_T**

Make full use of the large Au+Au and Cu+Cu datasets

PHOBOS Talks

Adam Trzupek “Particle production at very low and intermediate transverse momenta in Au+Au and d+Au collisions” (Fri, 15:00 Rm #0.83)

Steve Manly “System-size and energy dependence of elliptic flow” (Fri, 16:20, Rm #0.81)

Peter Steinberg “Charged hadron multiplicity fluctuations in Au+Au collisions at RHIC” (Sat, 17:00, Globe Hall)

George Stephans “Two-particle angular correlations in d+Au collisions” (Mon, 16:00, Globe Hall)

PHOBOS Posters

Alice Mignerey “Systematic study of directed flow at RHIC”

Gerrit van Nieuwenhuizen “Charged Hadron spectra in Cu+Cu and Au+Au collisions at RHIC”

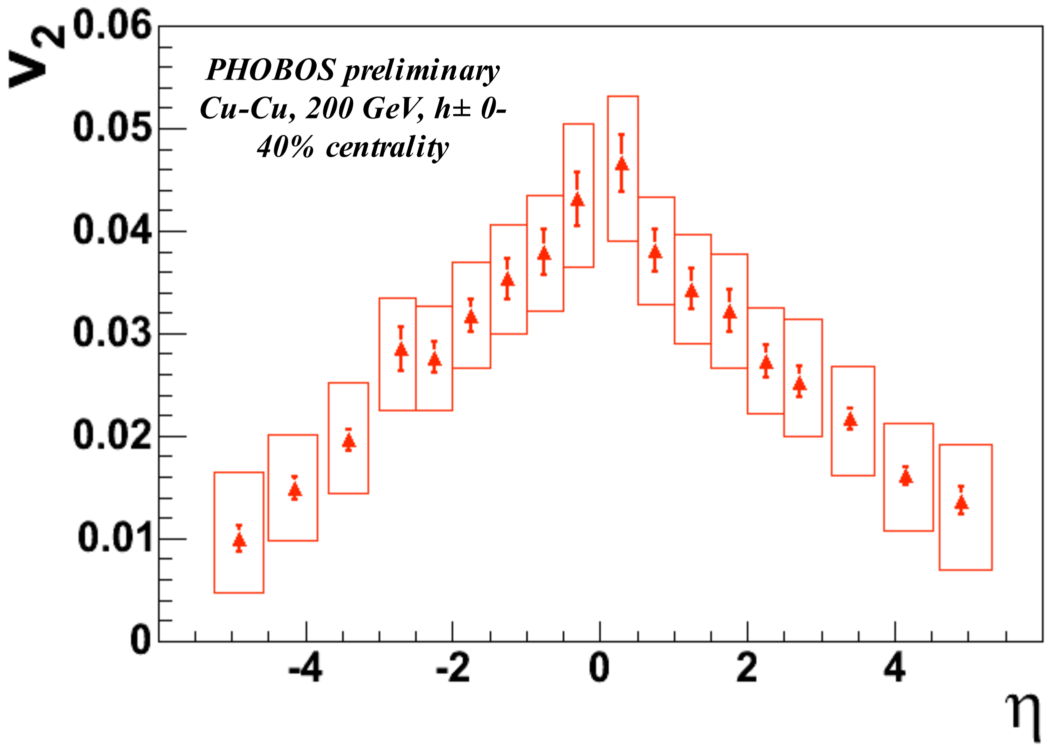
Richard Hollis “Charged particle multiplicities from Cu+Cu, Au+Au and d+Au collisions at RHIC”

Vasundhara Chetluru “Particle ratios in Cu+Cu collisions at RHIC

Siarhei Vaurynovich “Measurement of phi mesons with the PHOBOS detector”

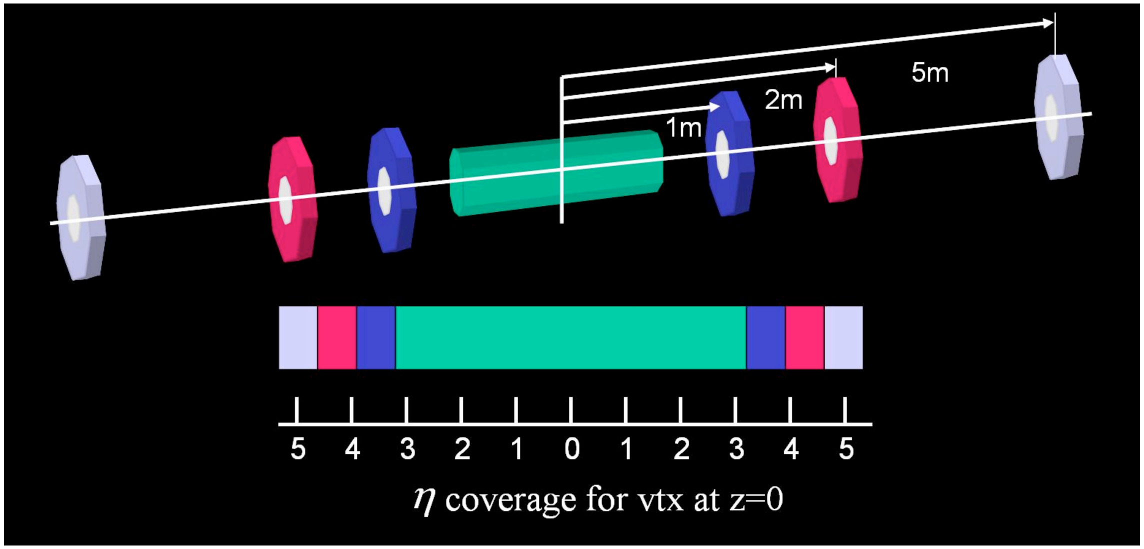
Maarten Ballintijn “The PHOBOS interactive computing architecture at RHIC”

Backup

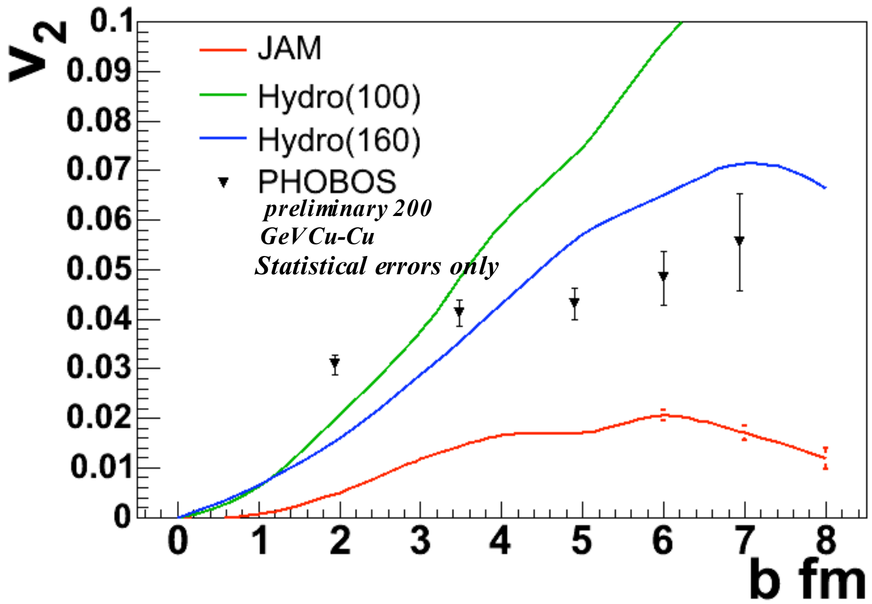


PHOBOS preliminary
Cu-Cu, 200 GeV, h± 0-40% centrality
v_2
0.06
0.05
0.04
0.03
0.02
0.01
0
-4
-2
0
2
4
η

Backup



Backup



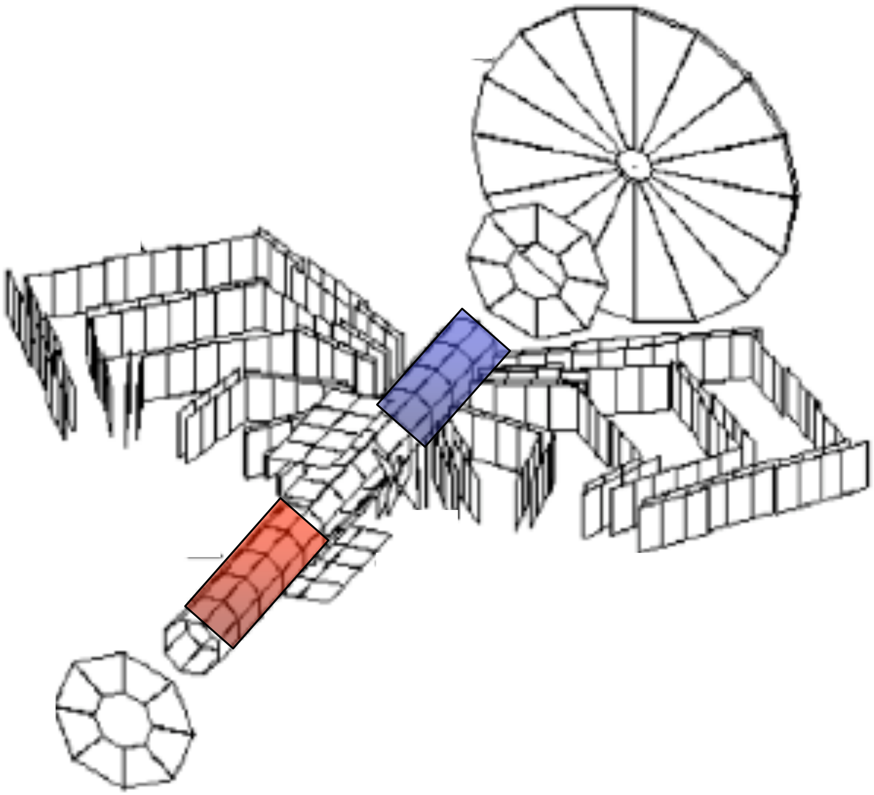
v_2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
JAM
Hydro(100)
Hydro(160)
PHOBOS
preliminary 200
GeV Cu-Cu
Statistical errors only
0
1
2
3
4
5
6
7
8
b fm

Backup

Regions used to determine reaction plane and resolution.

Cu-Cu, 200 and 62.4 GeV and Au-Au, 19.6, 62.4, 130 and 200 GeV:
$0.1<|\eta|<3.0$

(use $0.5<|\eta|<3.0$ and $1.0<|\eta|<3.0$ for systematic studies)



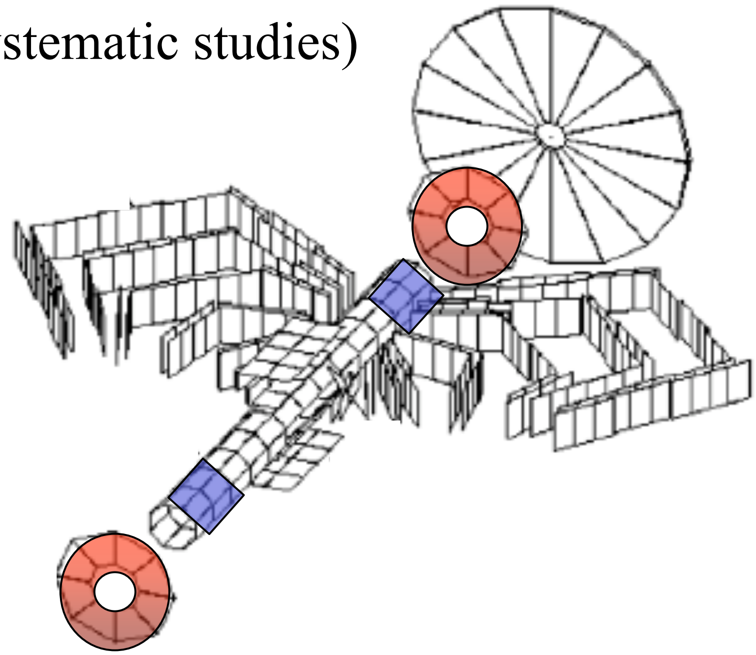
Backup

Regions used to determine reaction plane and resolution.

v_1 baseline Au-Au, 19.6, 62.4, 130 and 200 GeV: 1.5<|η|<3.0 and 3.0<|η|<5.0

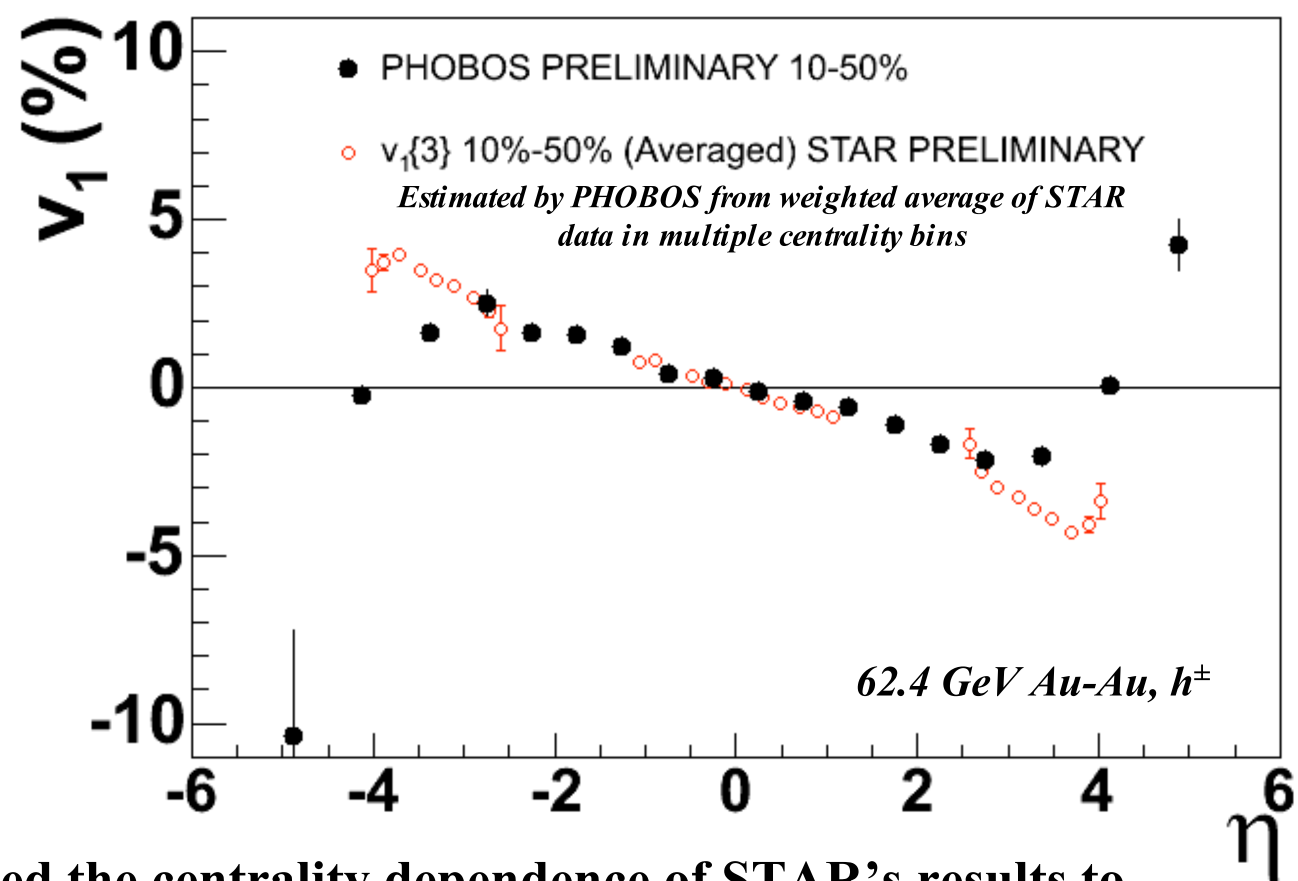
(use 1.5<|η|<2.5 and 3.5<|η|<5.0 for systematic studies)

v_1 mixed harmonic Au-Au, 19.6, 62.4, 130 and 200 GeV: 1.5<|η|<3.0 and 3.0<|η|<5.0 for the first harmonic part and 0.1<|η|<3.0 for the second harmonic part



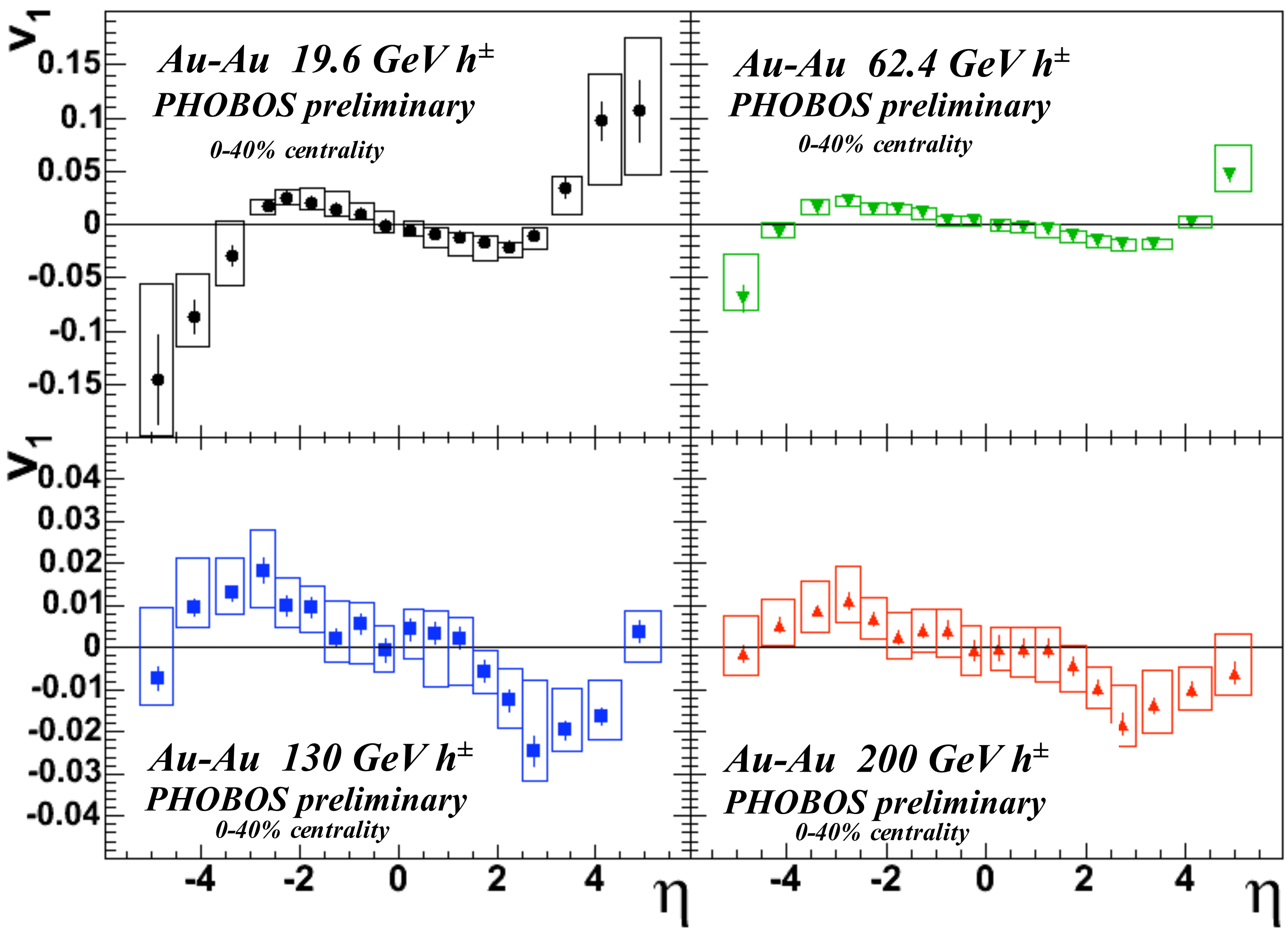
Comparison of directed flow results at 62.4 GeV

Discrepancy at high η possibly due to differences in low momentum cutoff?



We used the centrality dependence of STAR's results to estimate the STAR results in the 10-50% centrality bin

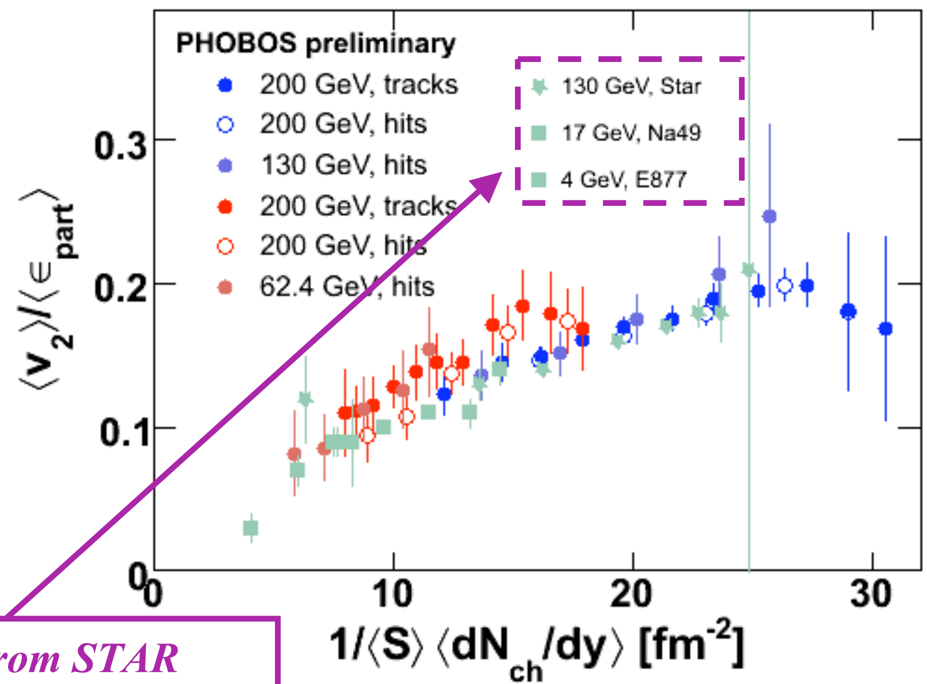
Backup



v_1
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Au-Au 19.6 GeV $h^{\pm}$
PHOBOS preliminary
0-40% centrality
Au-Au 62.4 GeV $h^{\pm}$
PHOBOS preliminary
0-40% centrality
v_1
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Au-Au 130 GeV $h^{\pm}$
PHOBOS preliminary
0-40% centrality
Au-Au 200 GeV $h^{\pm}$
PHOBOS preliminary
0-40% centrality
-4
-2
0
2
4
η

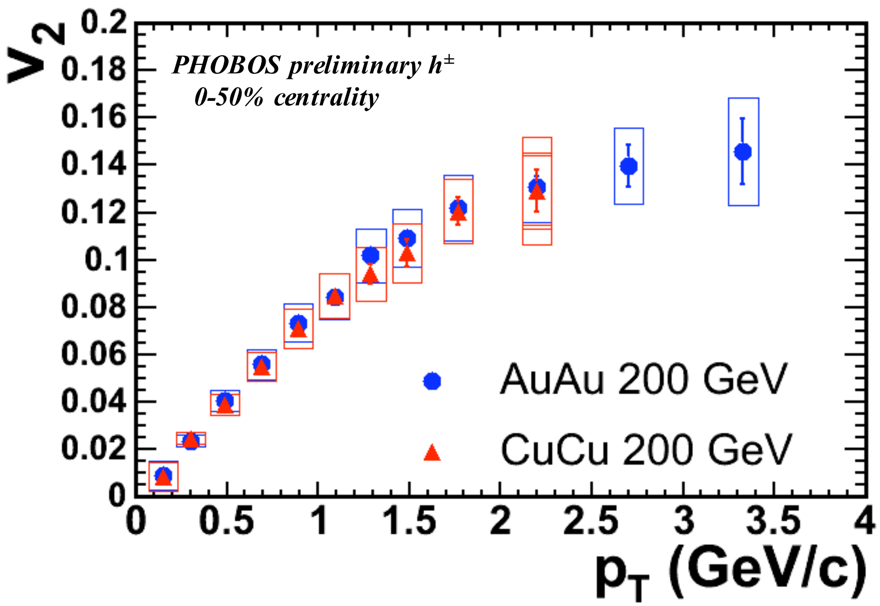
Backup

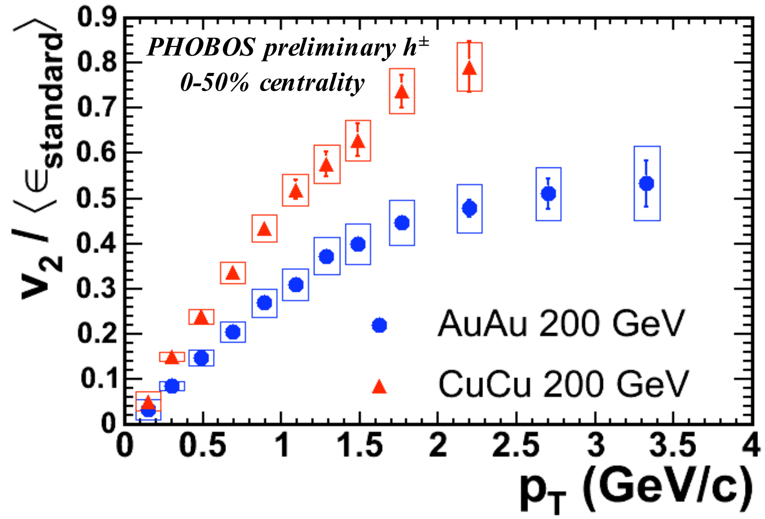
- **Caution:** we used ε_{part} for PHOBOS data. Important for Cu-Cu, less critical for Au-Au.
- Scale $v_2(\eta)$ to $\sim v_2(y)$ (10% lower)
- Scale $dN/d\eta$ to be ~dN/dy (15% higher)

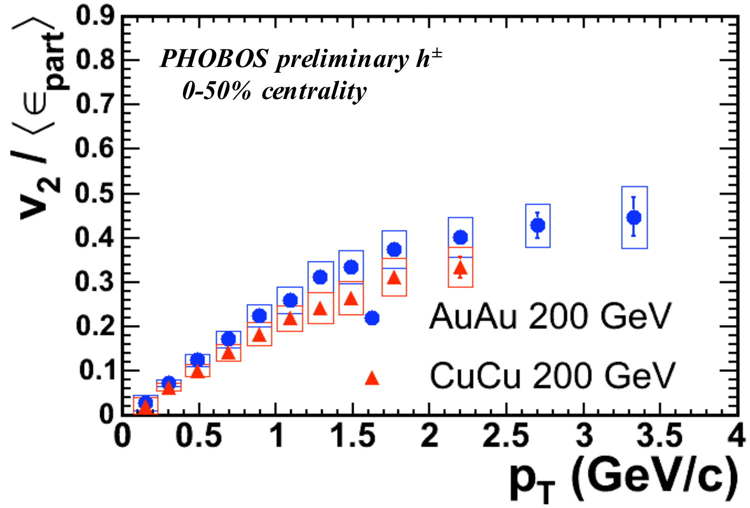


Points for STAR, NA49 and E877 data taken from STAR Collaboration, Phys.Rev. C66 (2002) 034904 with no adjustments

Approximate "LDL" scaling observed.







Eccentricity difference is important for same centrality selection.

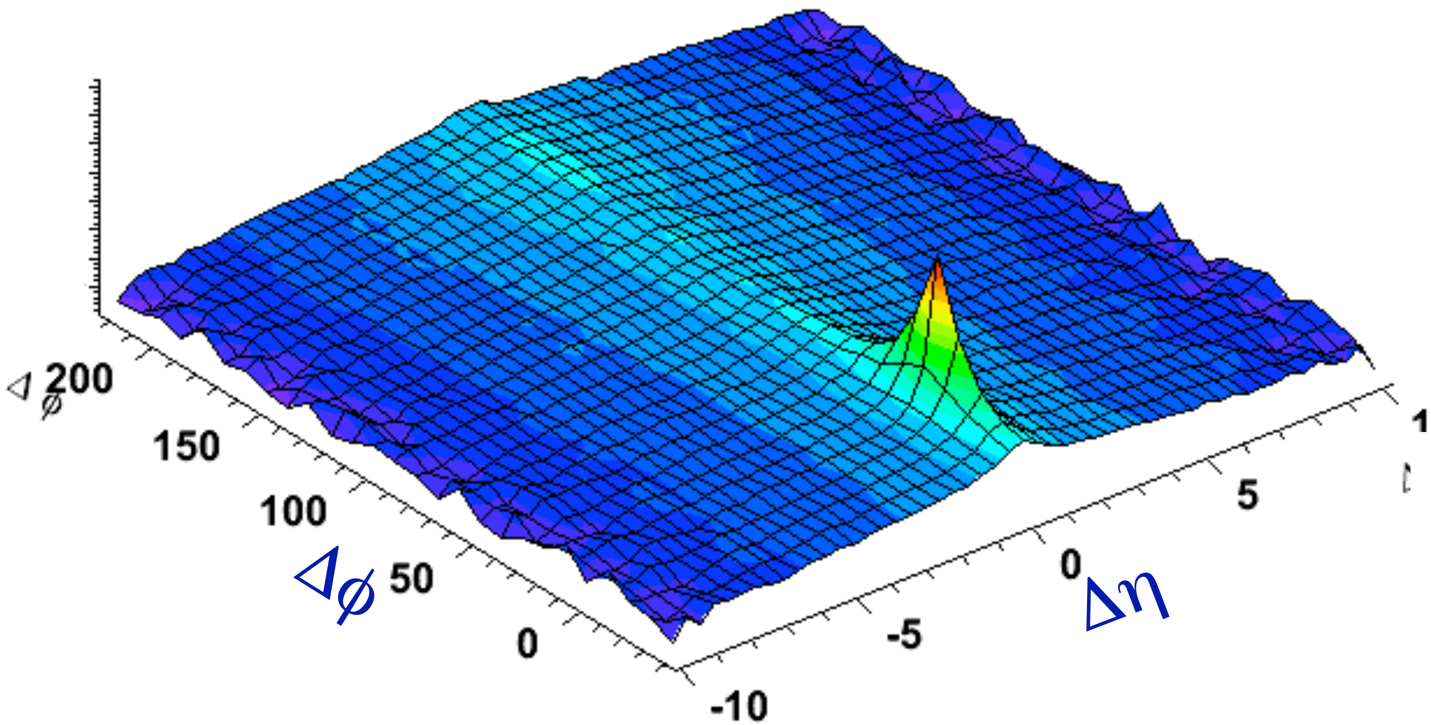
$V_2(p_T)$ for Cu-Cu is similar $v_2(p_T)$ for Au-Au when scaled by ε_{part}

Backup

Two particle correlation function of minbias dAu 200Gev

$$C(\Delta\eta, \Delta\phi) = \frac{N_{real}(\Delta\eta, \Delta\phi)}{N_{mixed}(\Delta\eta, \Delta\phi)}$$

Raw data



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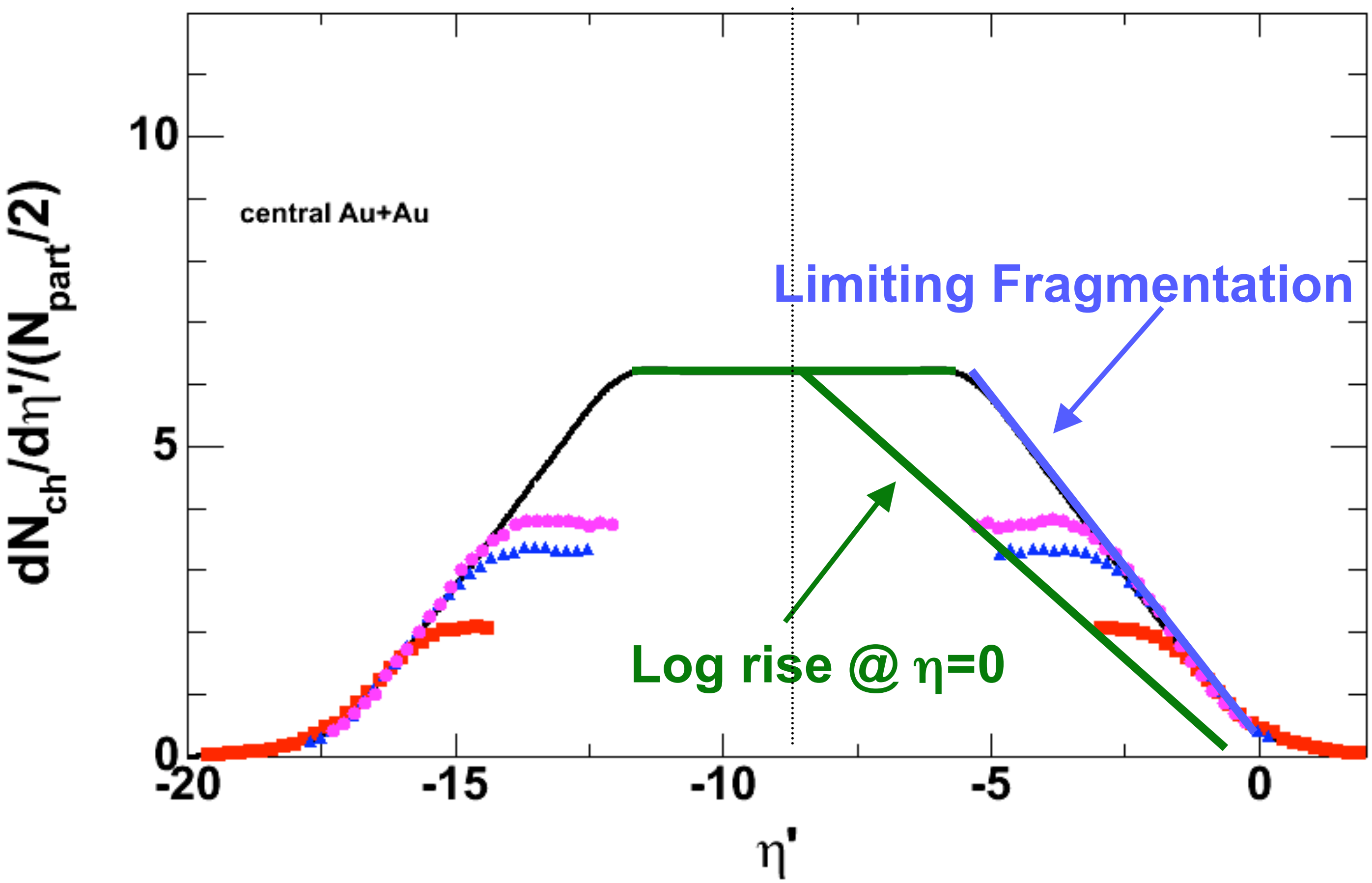
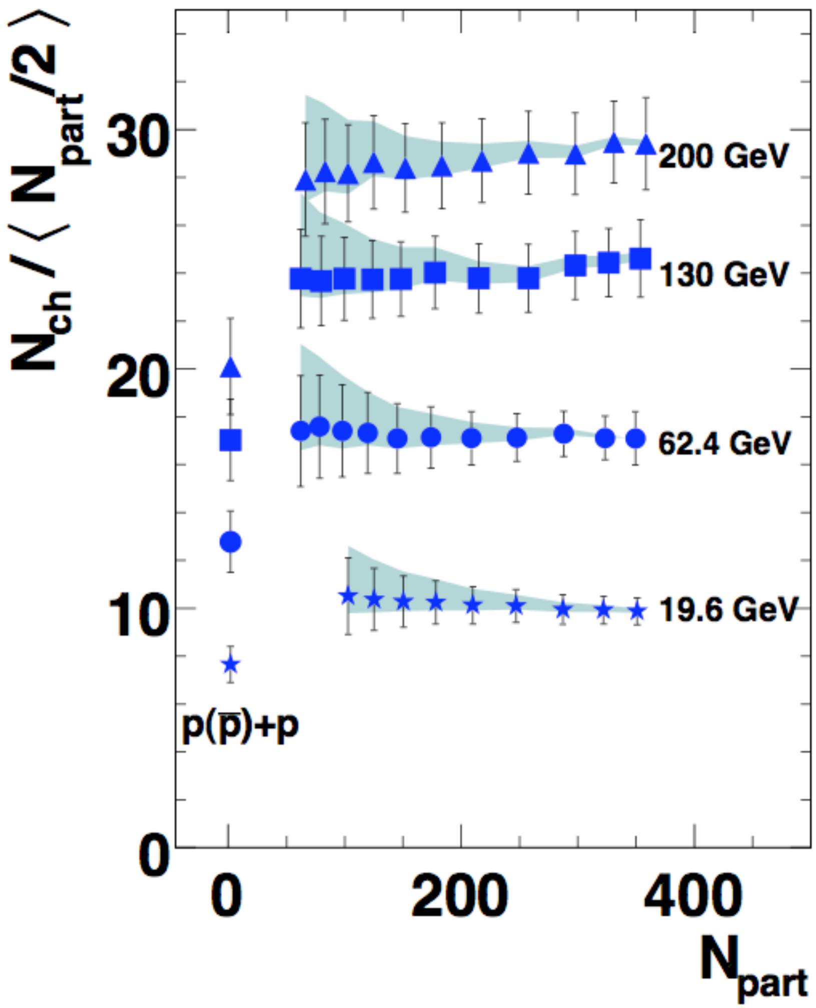


central Au+Au
Limiting Fragmentation
Log rise @ η=0
dNch/dη'/(Npart/2)
η'
10
5
0
-20
-15
-10
-5
0

Backup



$N_{ch} / \langle N_{part}/2 \rangle$
30
20
10
0
200 GeV
130 GeV
62.4 GeV
19.6 GeV
p(p̄)+p
0
200
400
N_{part}

Backup

Armesto, Salgado, Wiedemann hep-ph/0407018

$$\left.\frac{1}{N_{\mathrm{part}}}\frac{dN^{AA}}{d\eta}\right|_{\eta\sim 0} = N_0 \sqrt{s}^{\lambda} N_{\mathrm{part}}^{\frac{1-\delta}{3\delta}}$$