PHENIX Results from the RHIC Energy Scan

Edward O'Brien

Quark Matter 2012

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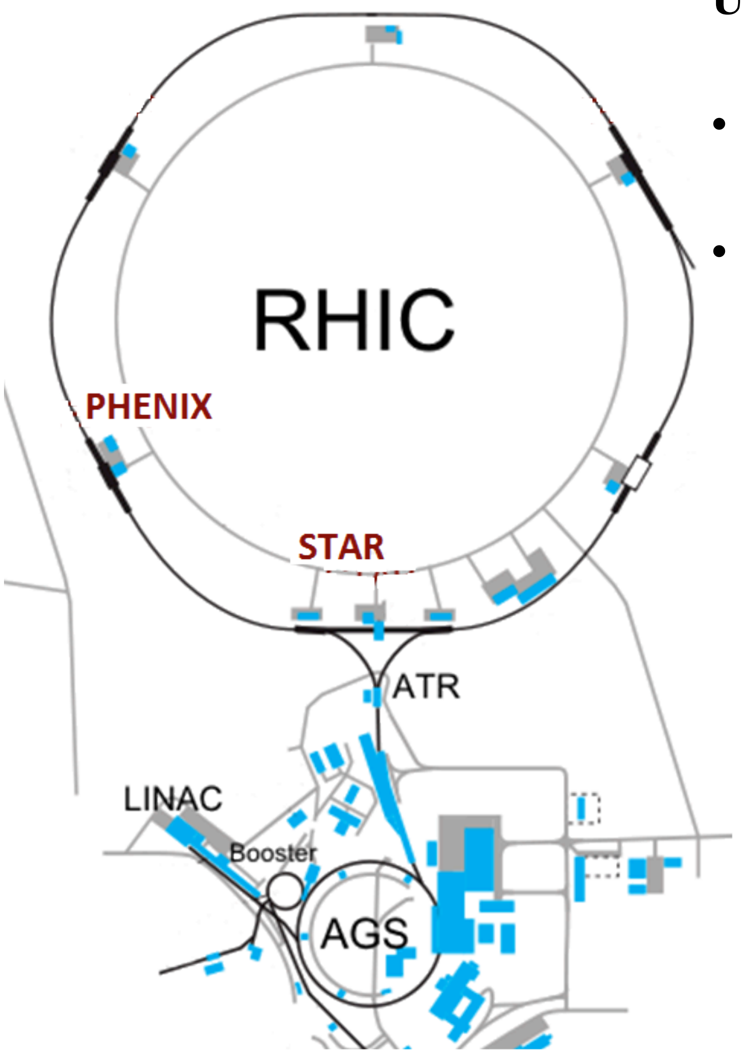
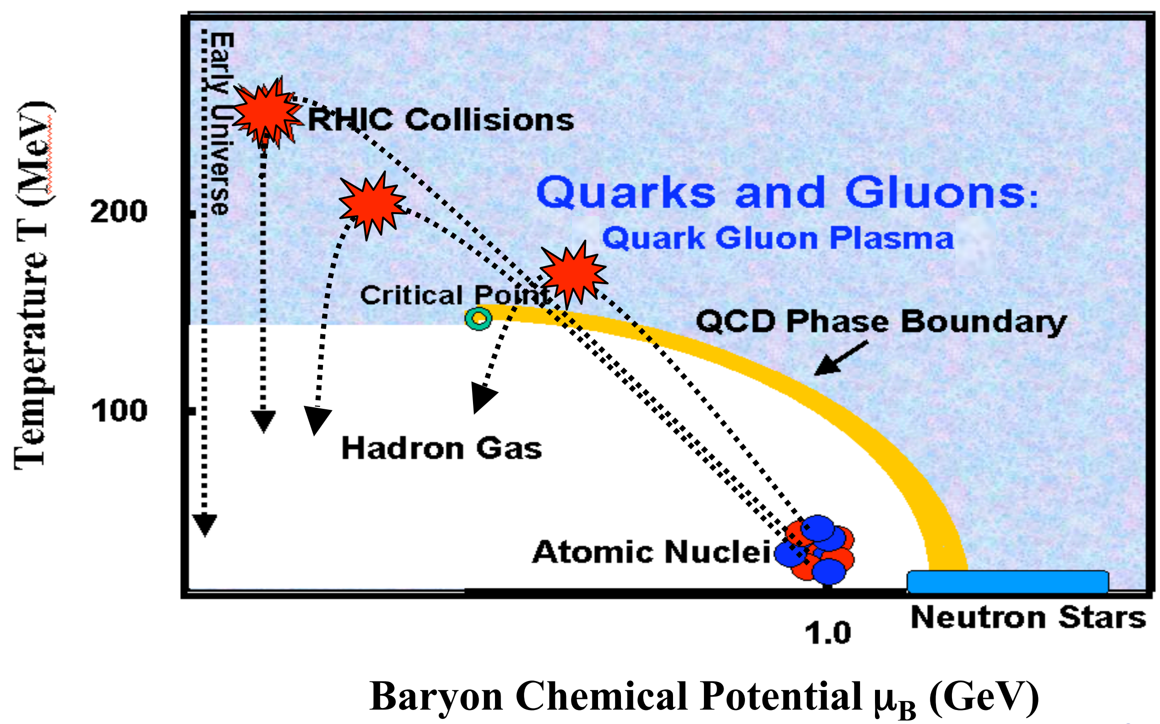
The Physics Motivation



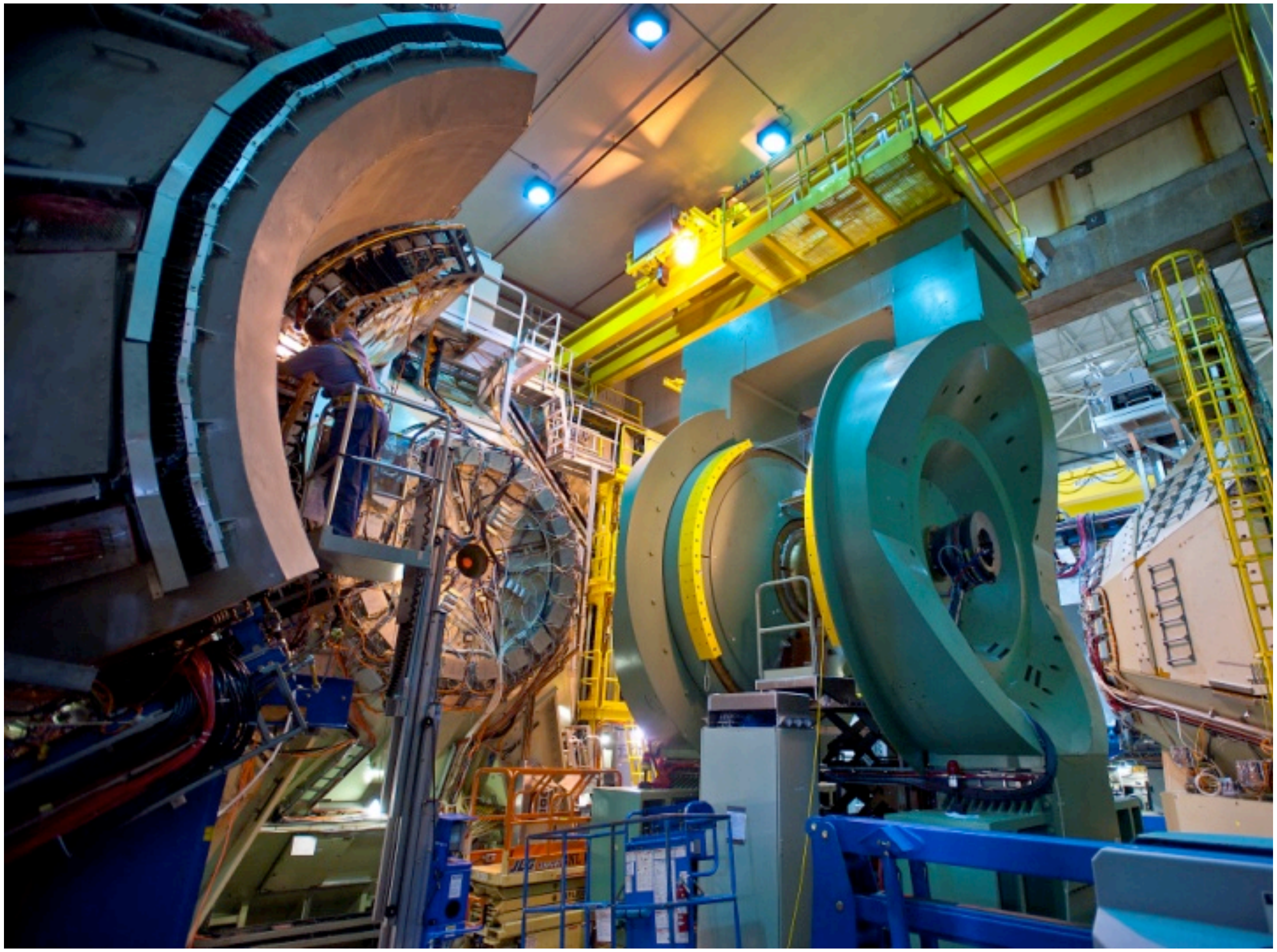
Use the flexibility of RHIC to carry out detailed energy and species scans with the point of determining:

- The evolution from partonic to hadronic matter through the QCD crossover region - QGP transition
- Location, if any, of a critical point on the QCD phase diagram



Physics Results of Energy and Species Scan

- Global variables
- R_{AA}
- Flow



RHIC Run History

12 Years, 12 Runs, 10 Energies, 6 Combination of Species

RHIC's exceptional flexibility has enabled a Physics program of broad scope

RHIC Run	Year	Species	Energy	Ldt
Run-1	2000	Au+Au	130 GeV	1 μb-1
Run-2	2001-2	Au+Au	200 GeV	24 μb-1
		Au+Au	19 GeV	
		p+p	200 Gev	150 nb-1
Run-3	2002/3	d+Au	200 GeV	2.74 nb-1
		p+p	200 GeV	0.35 nb-1
Run-4	2003/4	Au+Au	200 GeV	241 μb-1
		Au+Au	62.4 GeV	9 μb-1
Run-5	2005	Cu+Cu	200 GeV	3 nb-1
		Cu+Cu	62.4 GeV	0.19 nb-1
		Cu+Cu	22.4 GeV	2.7 μb-1
Run-6	2006	p+p	200 GeV	10.7 pb-1
		p+p	62.4 GeV	100 nb-1
Run-7	2007	Au+Au	200 GeV	813 μb-1
Run-8	2007/2008	d+Au	200 GeV	80 nb-1
		p+p	200 GeV	5.2 pb-1
		Au+Au	9.2 GeV	
Run-9	2009	p+p	200 GeV	16 pb-1
		p+p	500 GeV	14 pb-1
Run-10	2010	Au+Au	200 GeV	1.3 nb-1
		Au+Au	62.4 GeV	100 μb-1
		Au+Au	39 GeV	40 μb-1
		Au+Au	7.7 GeV	260 mb-1
Run-11	2011	p+p	500 GeV	27 pb-1
		Au+Au	200 GeV	915 μb-1
		Au+Au	27 GeV	5.2 μb-1
		Au+Au	19.6 GeV	13.7 M events
Run-12	2012	p+p	200 GeV	9.2 pb-1
		p+p	510 GeV	30 pb-1
		U+U	193 GeV	171 μb-1
		Cu+Au	200 GeV	4.96 nb-1

RHIC Run History

12 Years, 12 Runs, 10 Energies, 6 Combination of Species

Approximately half of RHIC's running time has contributed in to the energy and species scan studies

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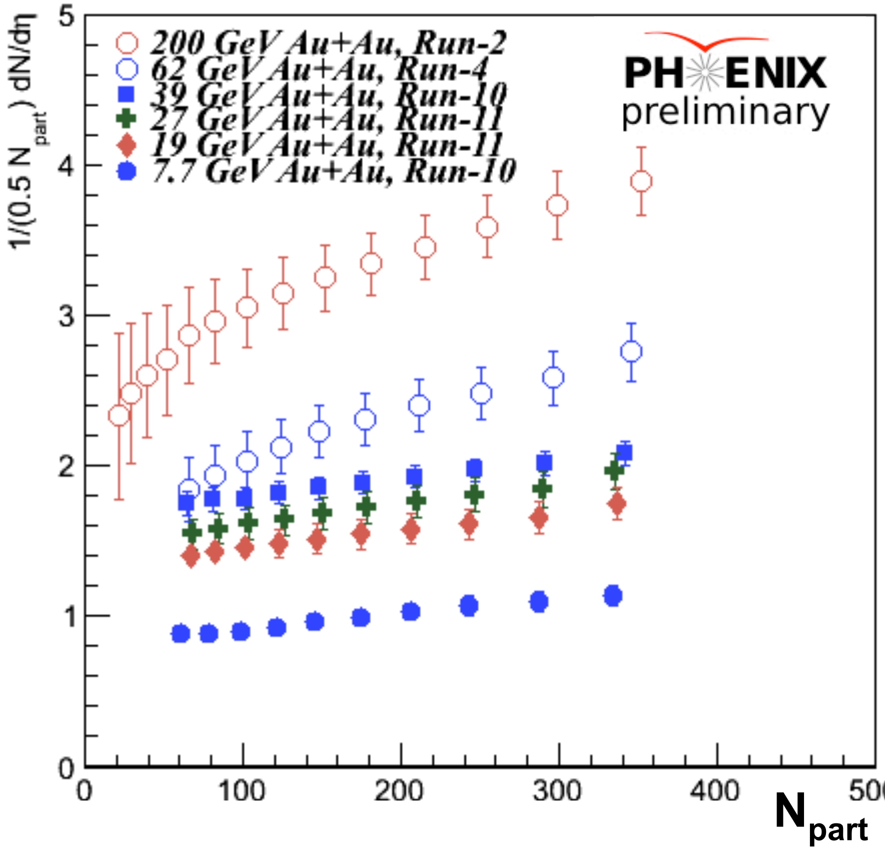
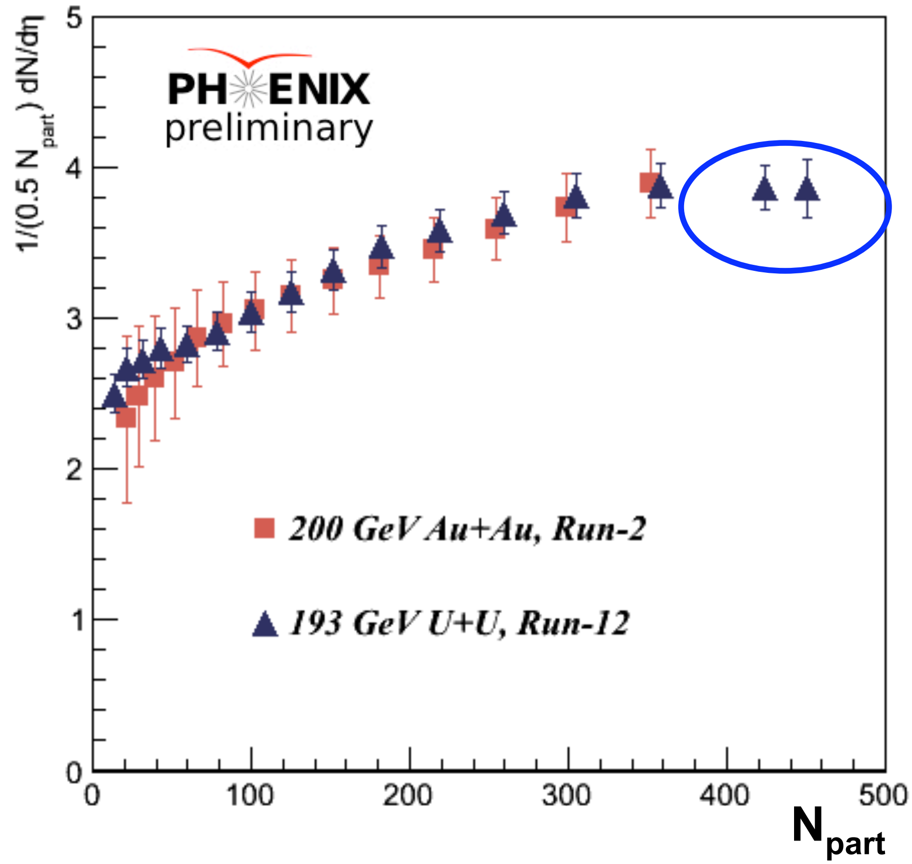
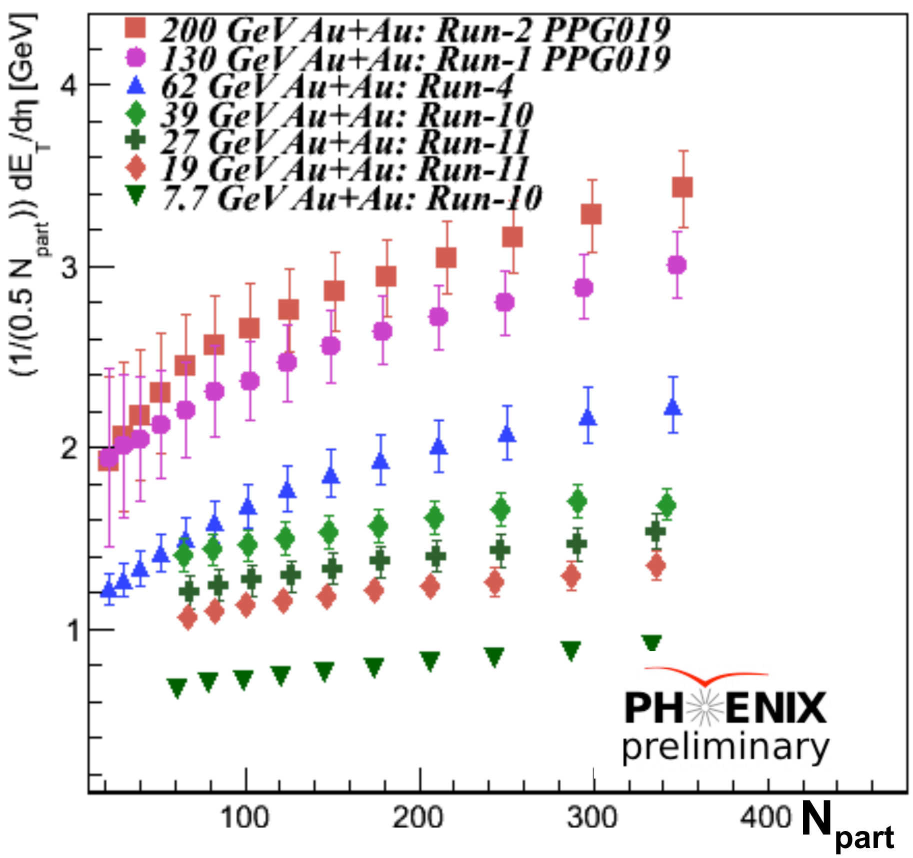
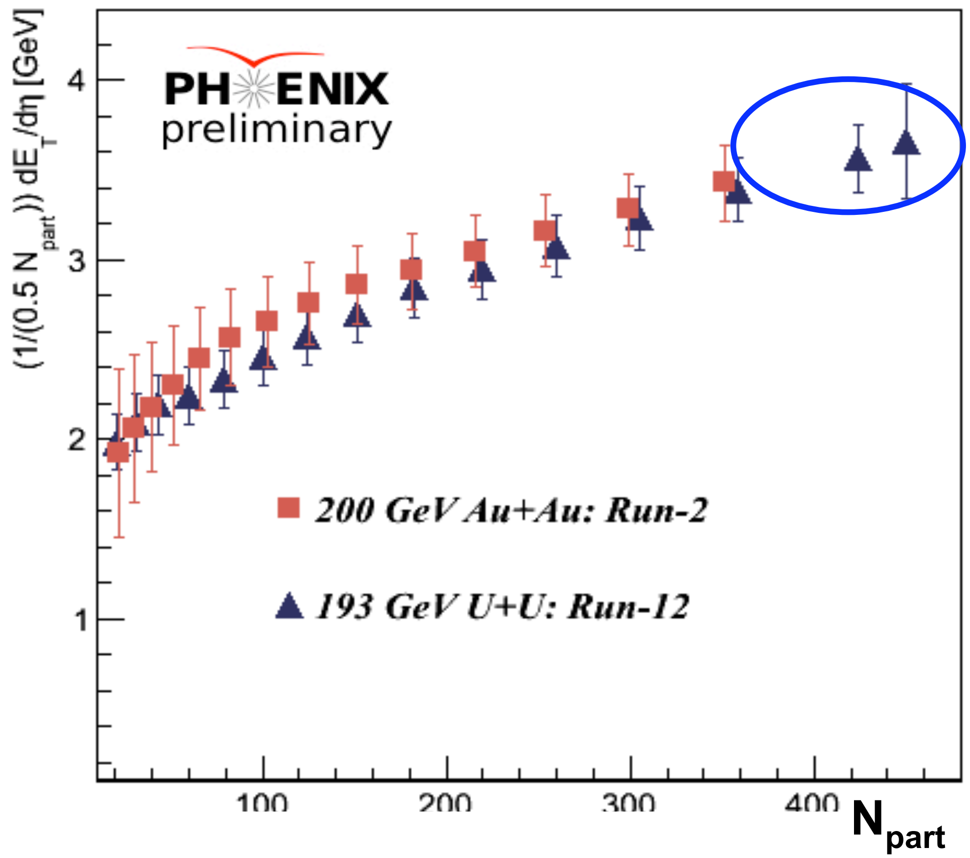
Global Variable dN/dη





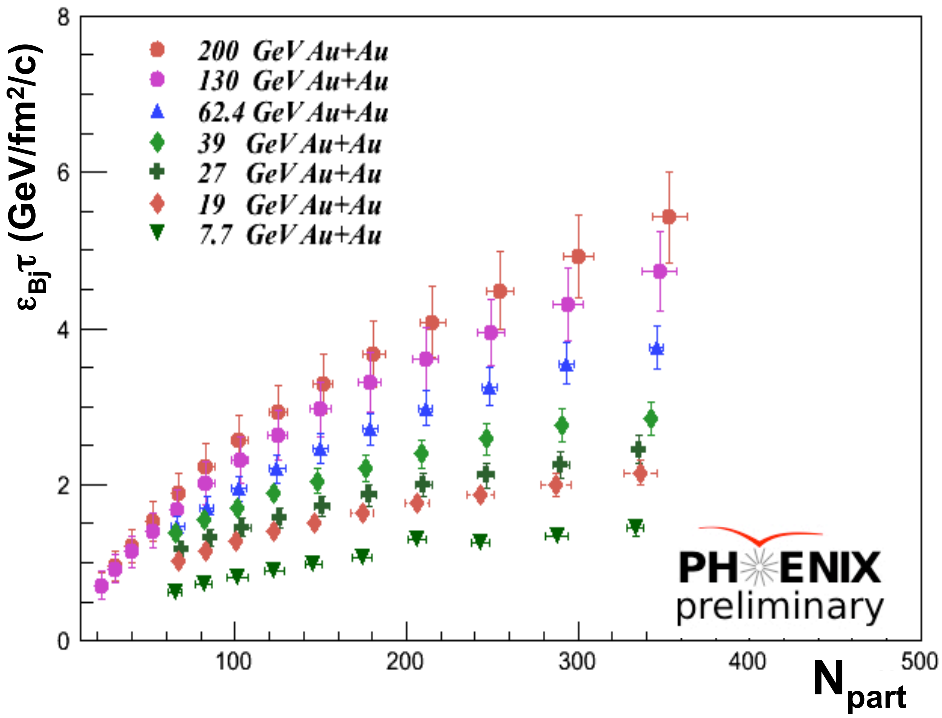
Global Variables $dE_T/d\eta$

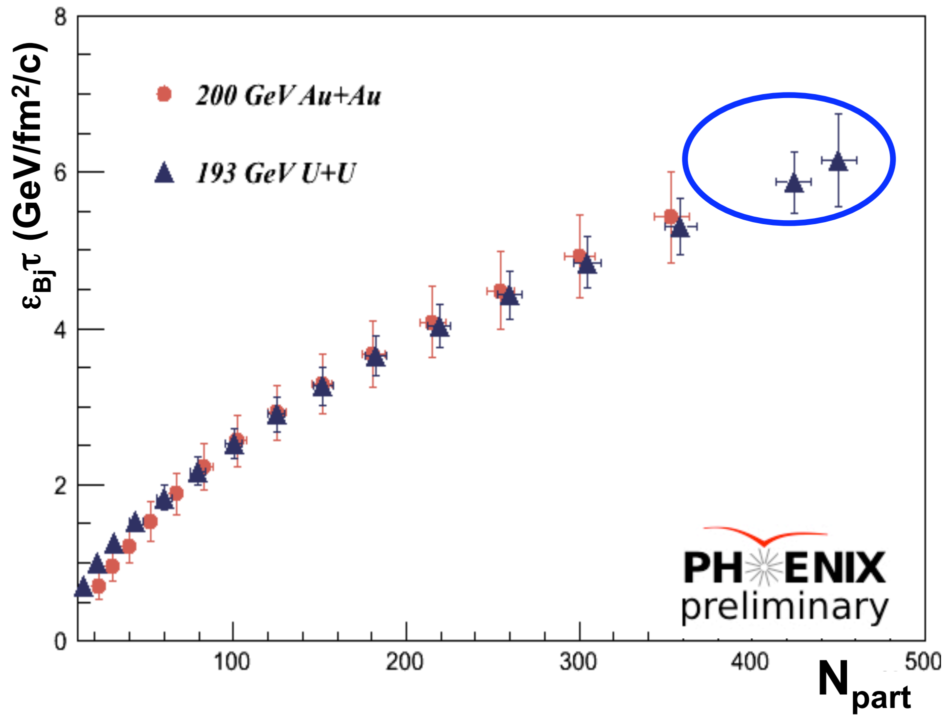




Global Variables $\varepsilon_{Bj}\ \tau$

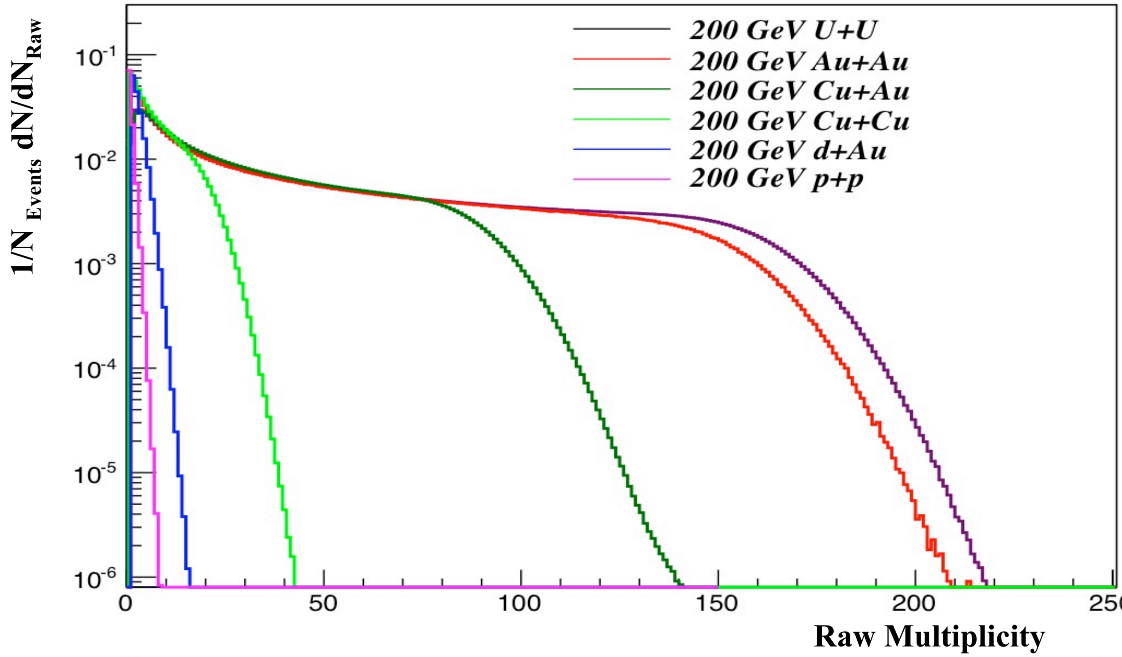
$\varepsilon_{Bj} = 1/A_{\perp}\tau(dE_T/dy)$

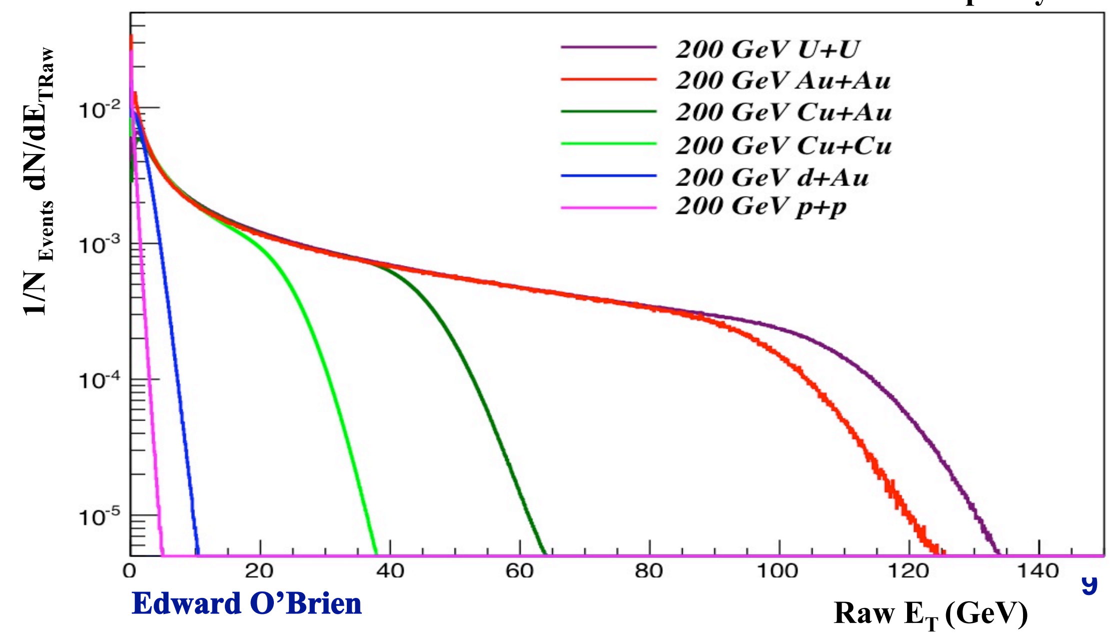




A Look at New “Raw” Data

Uncorrected multiplicity and E_T data for recent U+U and Cu+Au RHIC run superimposed on raw multiplicity and E_T distributions from pp, dAu, CuCu and AuAu data sets





J. Mitchell Friday 7B

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Fluctuations in Global Variables

HI collisions that pass close to a QCD critical point might demonstrate observable large fluctuations in correlation lengths of particular global variables.

Correlation length is ξ

Then

Variance : $\sigma^2 = <(\Delta \mathcal{N})^2> \sim \xi^2$

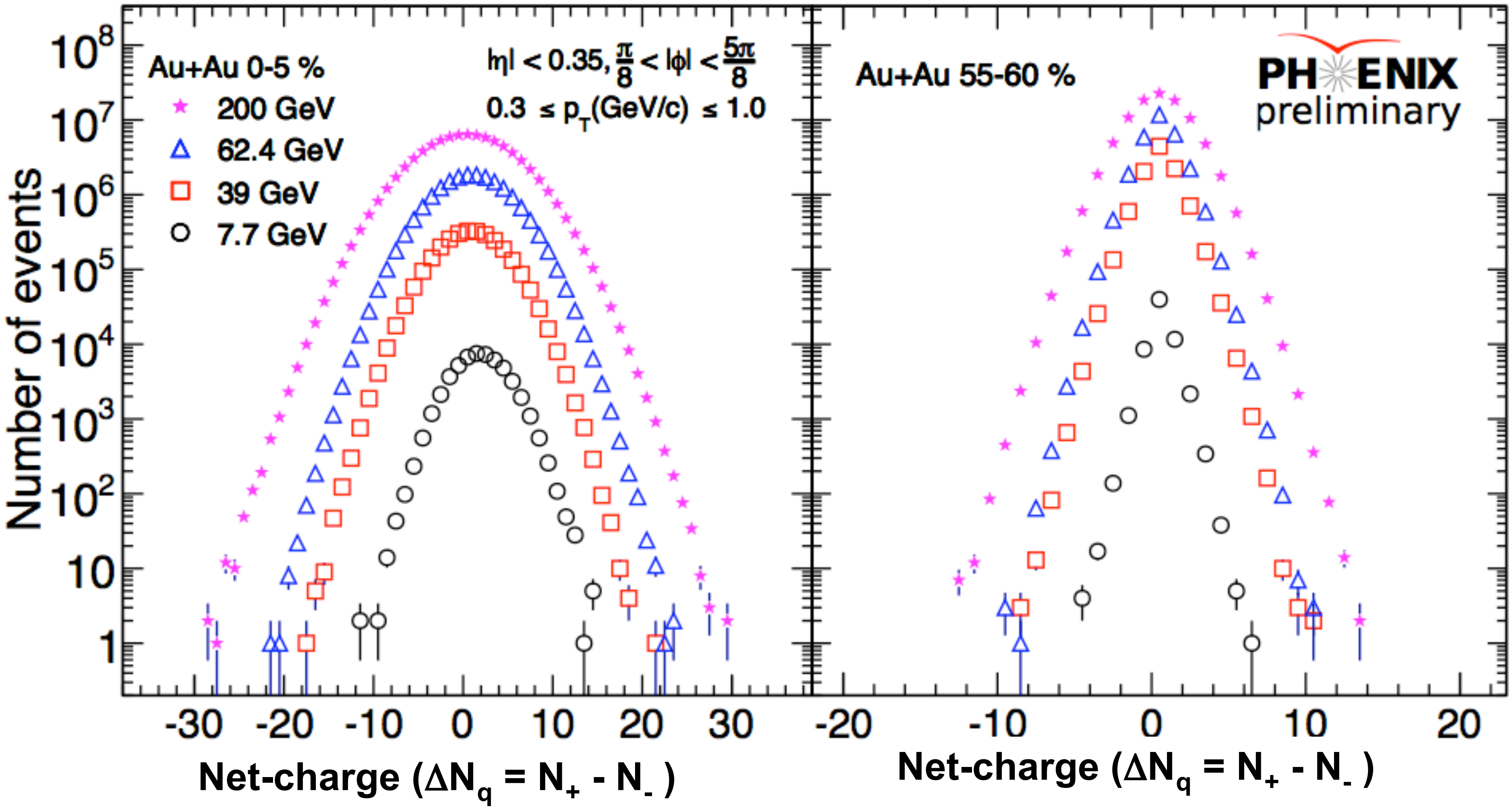
Skewness: $S = <(\Delta \mathcal{N})^3>/\sigma^3 \sim \xi^{4.5}$

Kurtosis: $K = <(\Delta \mathcal{N})^4>/\sigma^4 \sim \xi^7$

The strategy is to vary $\sqrt{s}$ and look for a sudden change in correlation length

Lattice calculations say we don't have to hit a bulls eye on the critical point. We just have to come close to see the fluctuations in ξ

Net Charge Distributions



- Correlation length related to moments of conserved quantities including net charge
- Correlation length should diverge at the critical point in the phase diagram

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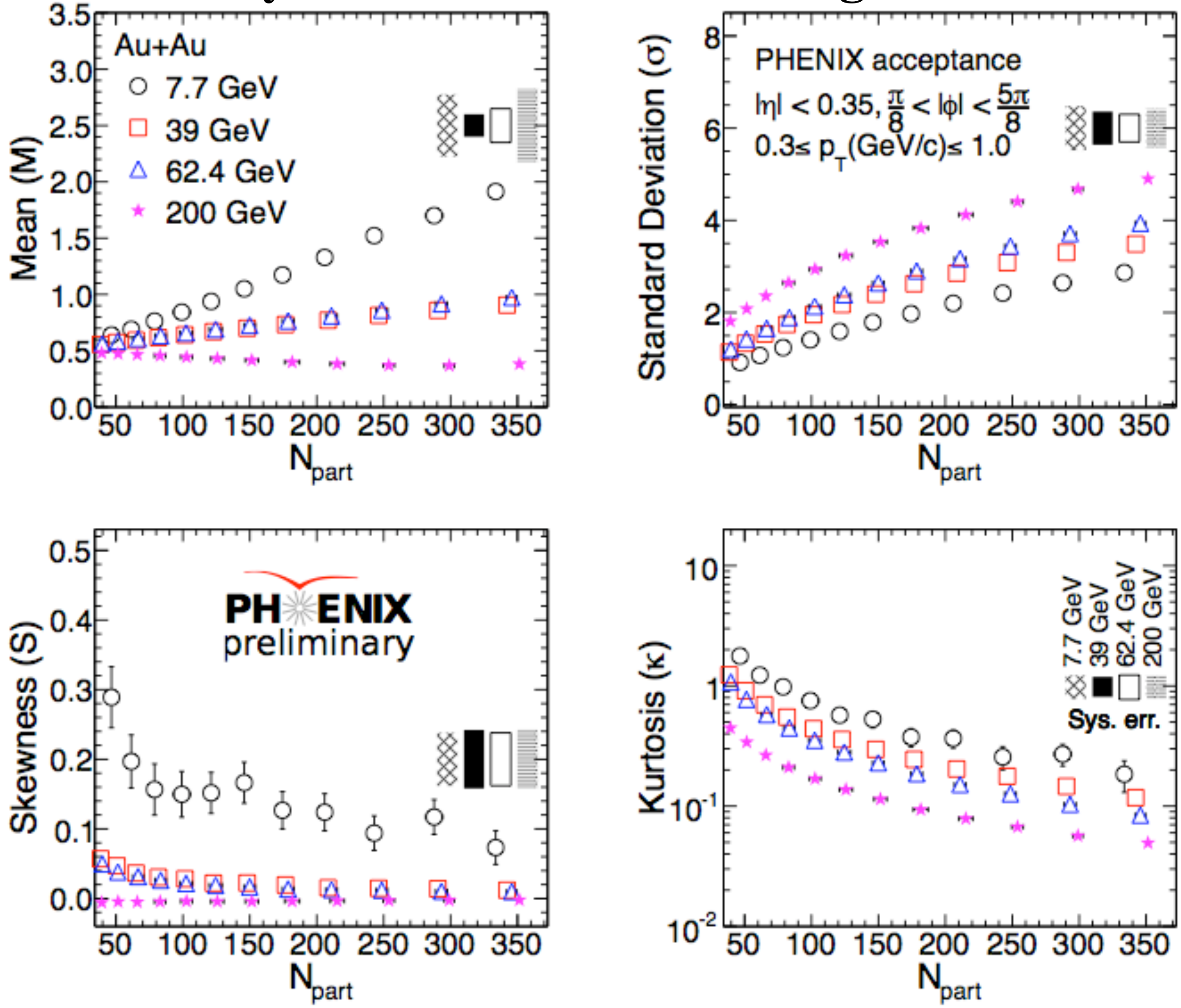
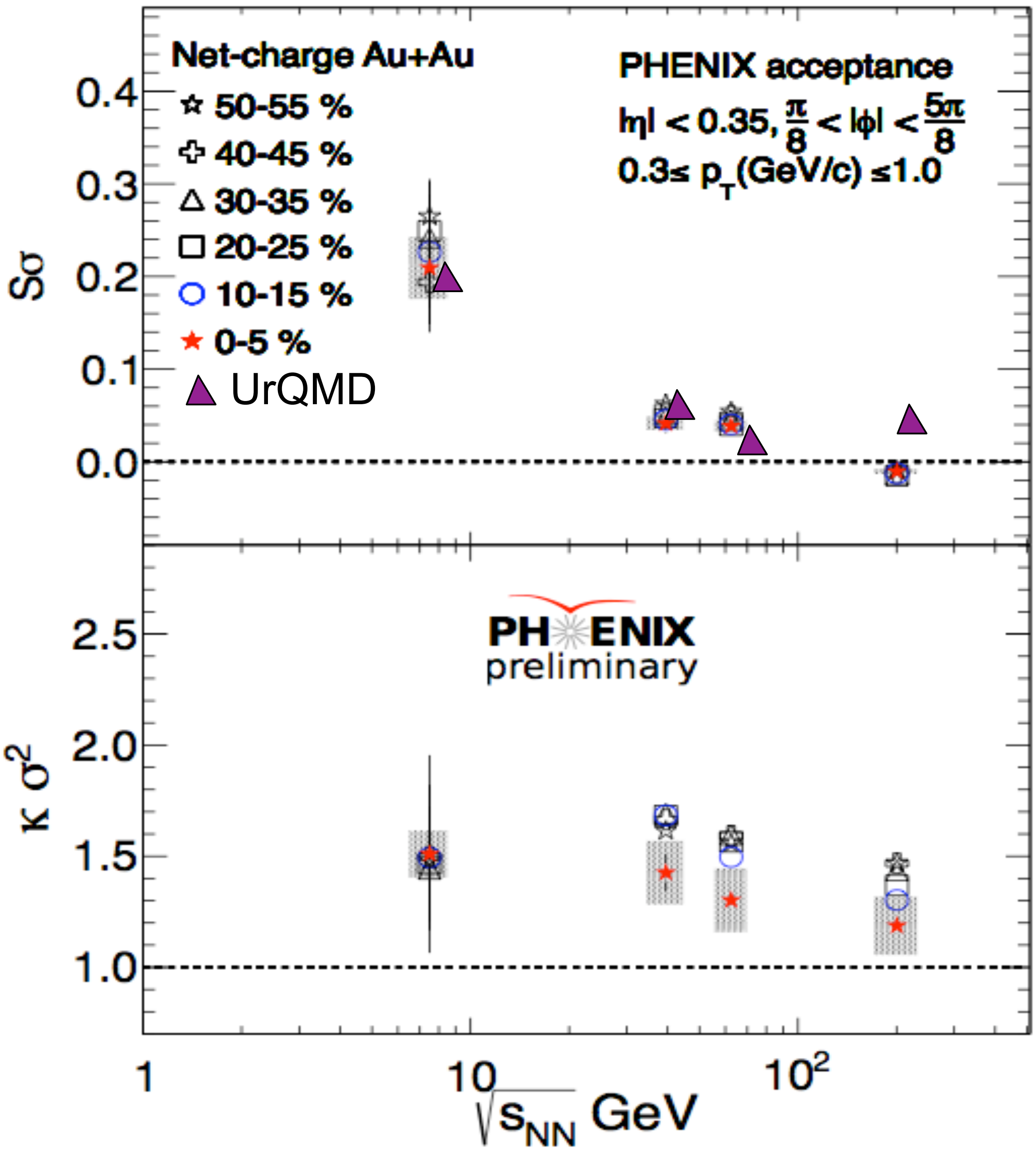
Net Charge Moments

They scale as correlation length



$\sqrt{s_{NN}}$ Dependence of Net Charge Fluctuations

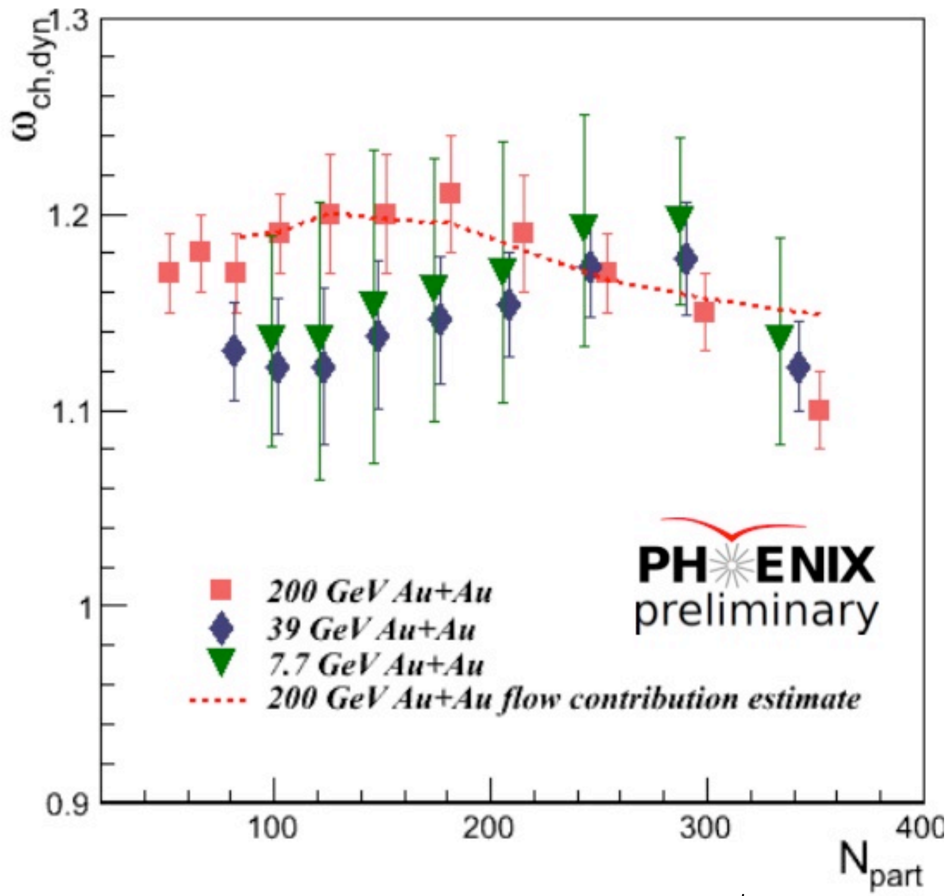


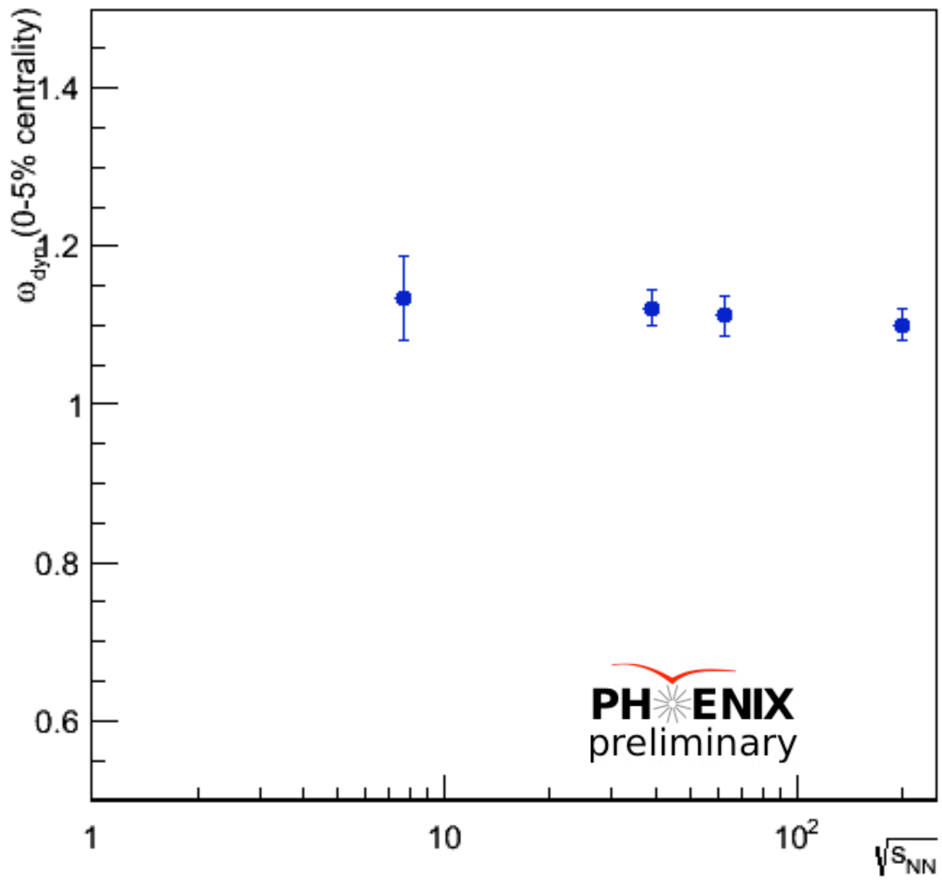
- Neither $\mathcal{K}$ nor S vary with centrality at 7.7, 39, 62.4 and 200 GeV
- Kurtosis vs energy is flat within errors
- Skewness tracks UrQMD prediction
- Analysis of data sets from $\sqrt{s}$ = 19.6, 27 GeV still to be completed

ω Multiplicity fluctuations

$\omega_{ch,dyn}$ = <N>/var(N) corrected for impact parameter fluctuations

Mean multiplicity fluctuation flat for these 4 collision energies





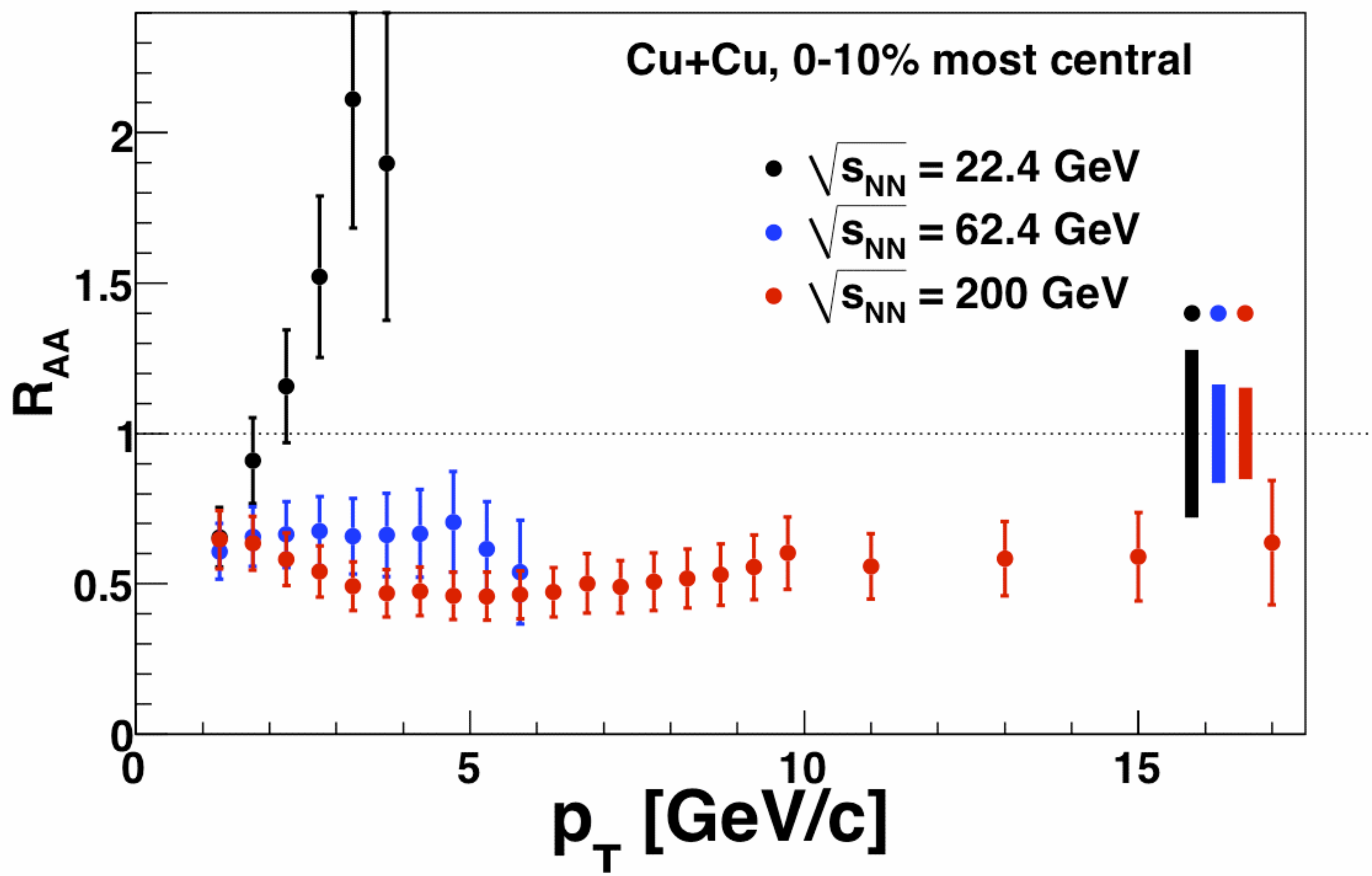
Analysis of data sets from √ s = 19.6, 27 GeV still to be completed

Global Variable Summary

- **Global analysis of $dN/d\eta$, $dE_T/d\eta$ and ε_{Bj} vs. centrality performed for data sets at $\sqrt{s}$ = 200, 130, 62.4, 39, 27, 19.6 and 7.7 GeV**
  - Gradual evolution of the quantities with centrality and $\sqrt{s}$ has been observed
  - No obvious non-monotonic behavior at these collision energies
  - U+U data @ $\sqrt{s}$ = 193 GeV shows ~20% higher $dE_T/d\eta$ and ε_{Bj} than Au+Au 200 GeV data at the most central collisions.
  - Maximum U+U $dN/d\eta$ shows no increase over Au+Au $dN/d\eta$
- **Fluctuation analyses have been performed for net charge and multiplicity fluctuations at $\sqrt{s}$ = 200, 62.4, 39 and 7.7 GeV**
  - No obvious non-monotonic behavior at these collision energies
  - Analysis of data sets from 27 and 19.6 GeV are on the way

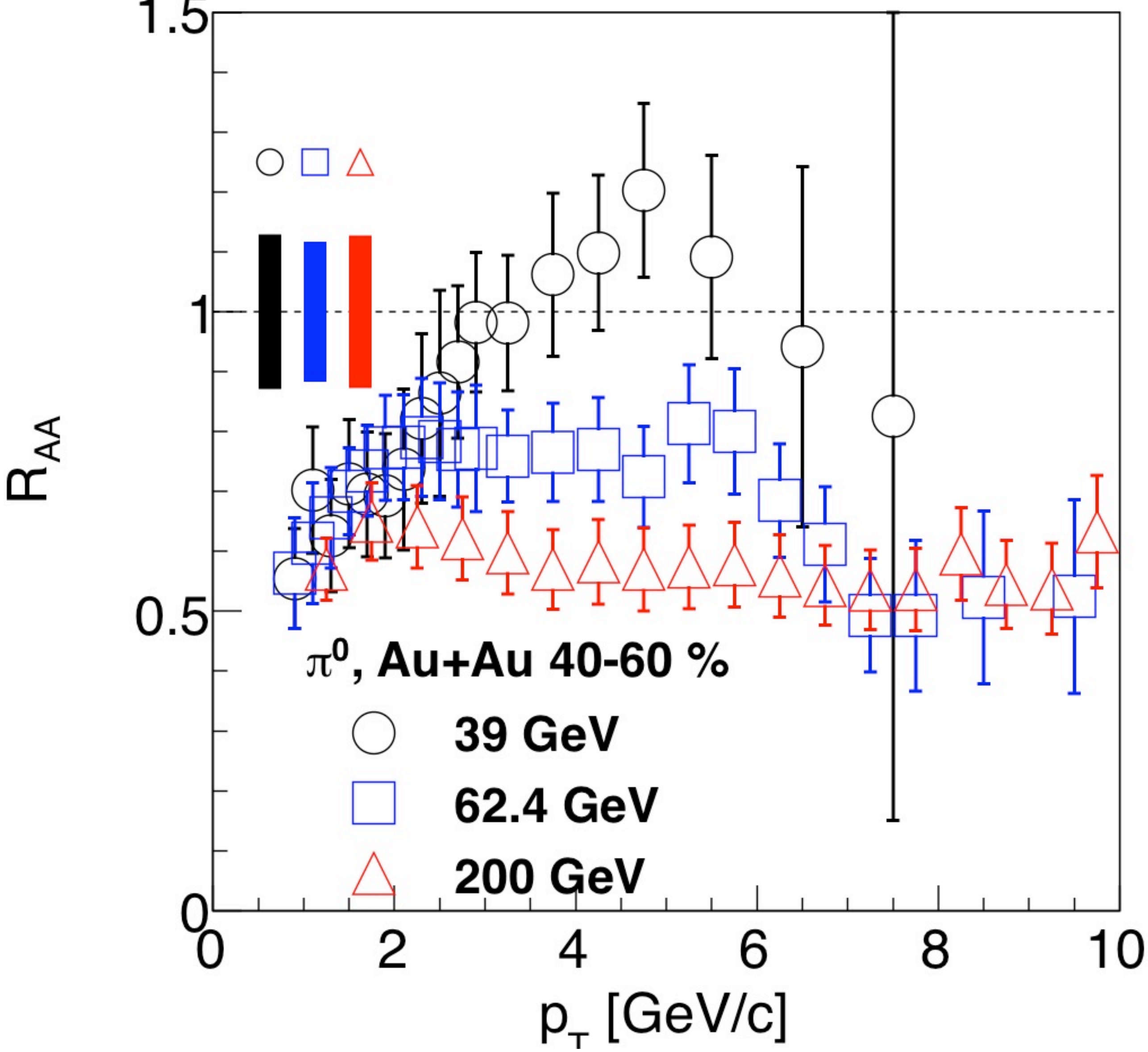
R_{AA} $\pi 0$

From our 2008 paper PRC 101, 162301



R_{AA} π0

Submitted to PRL arXiv:1204.1526v1



R_{AA} $\pi 0$

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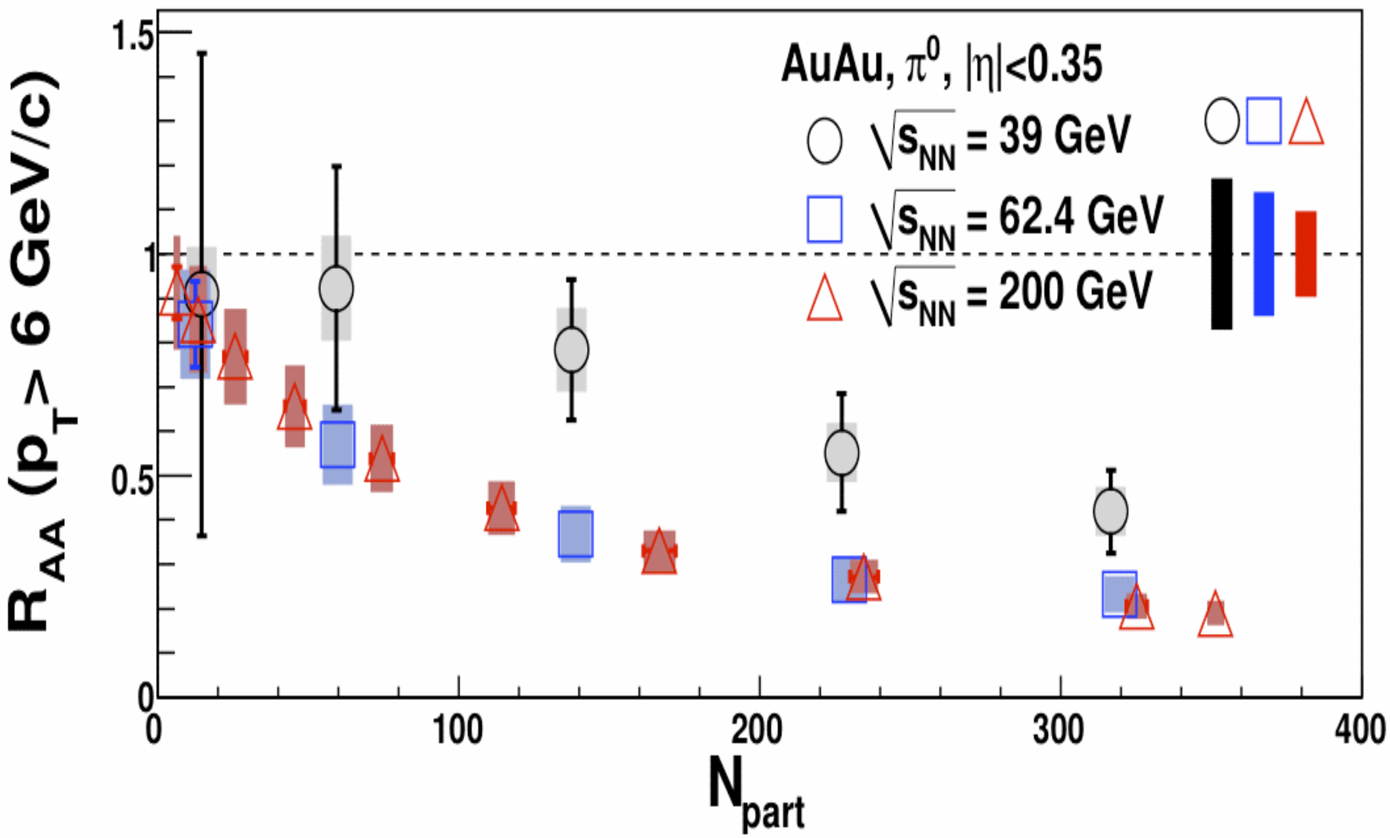
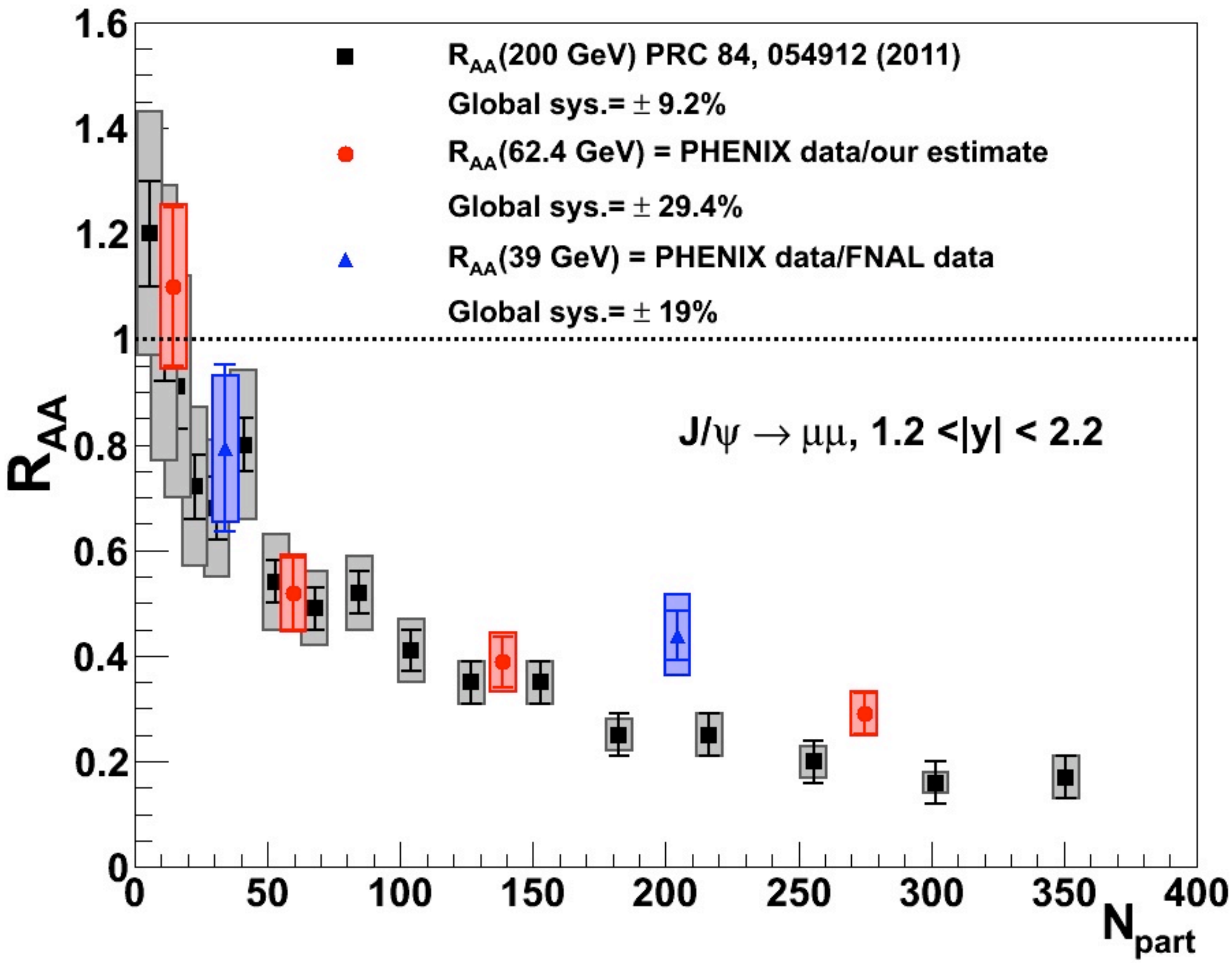


R_{AA} analysis of 27 GeV data is underway

R_{AA} J/ψ

Submitted to PRC arXiv:1208:2251

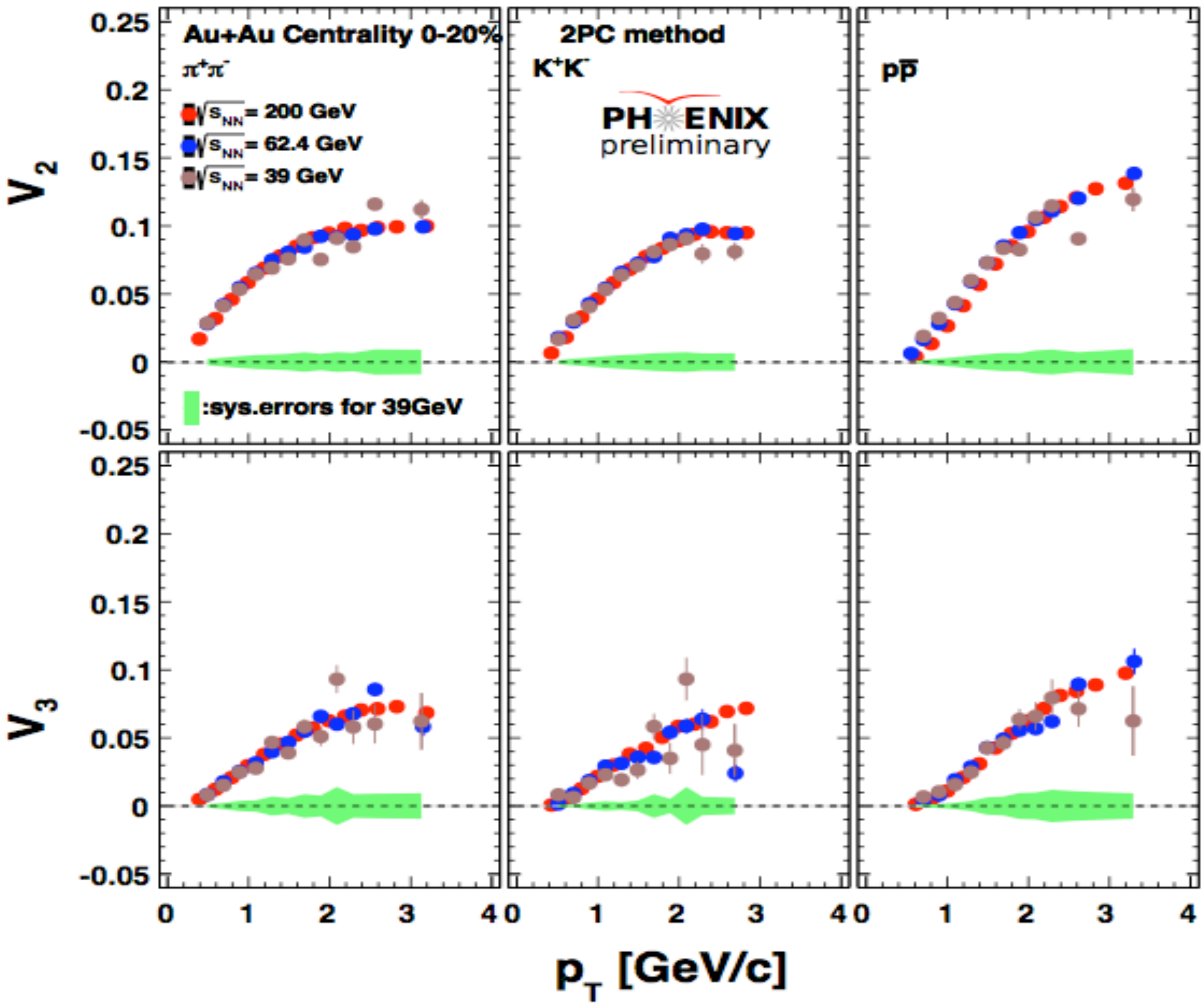


R_{AA} Summary

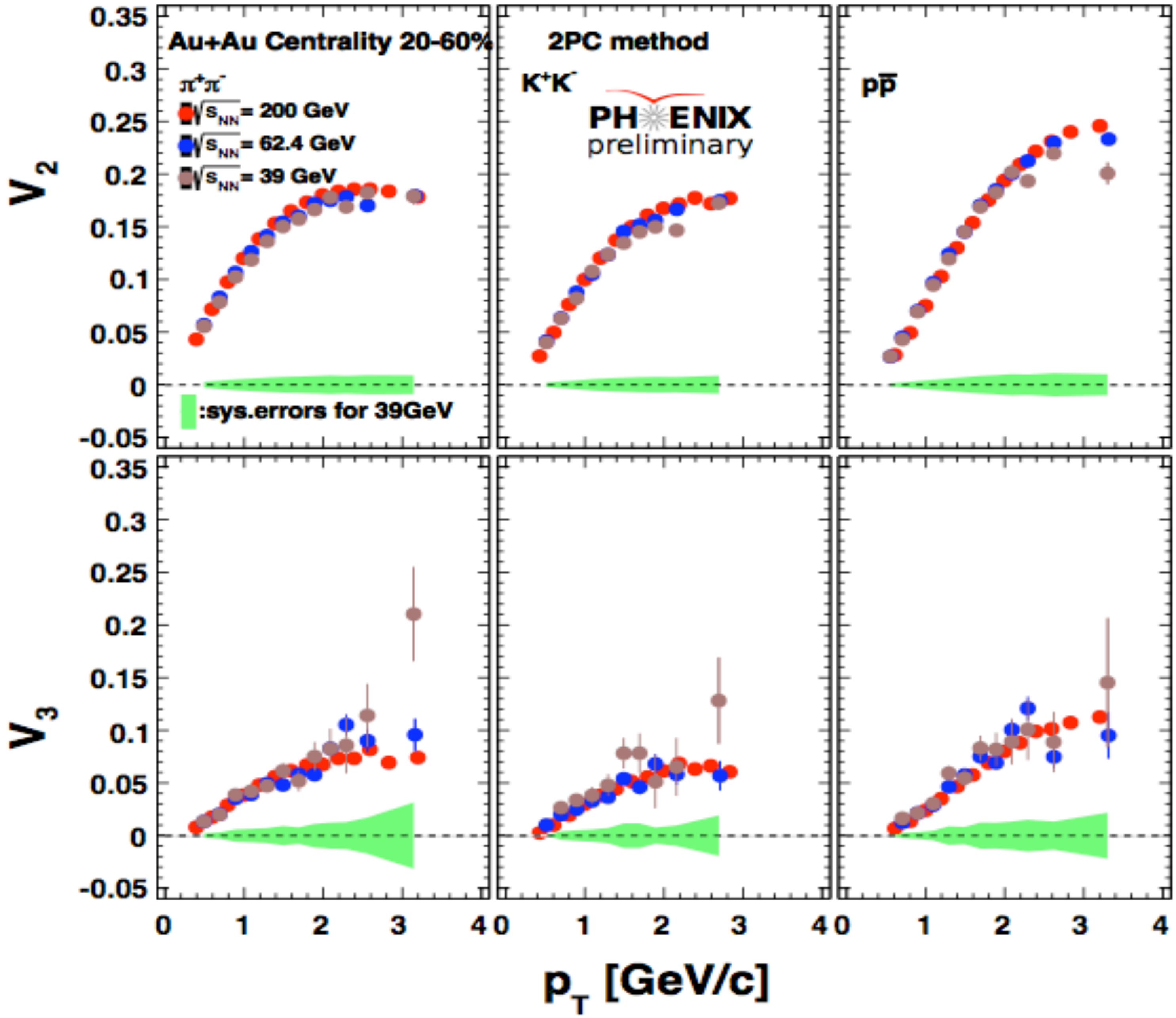
- **Jet quenching observed in central Au+Au collisions at $\sqrt{s}$ = 39, 62.4 GeV is similar to but not as strong as R_{AA} seen in Au+Au 200 GeV data**
  - Less suppression as a function of $\sqrt{s}$ vs p_T and centrality
  - $R_{AA} \sim 1$ for mid-peripheral (40-60%) Au+Au 39 GeV
  - Analysis of π^0 R_{AA} for 27 GeV Au+Au is underway

- **J/psi suppression is very similar at all N_{part} for particles produced in collisions of 200, 62.4 and 39 GeV (1.2 < |y| < 2.2)**

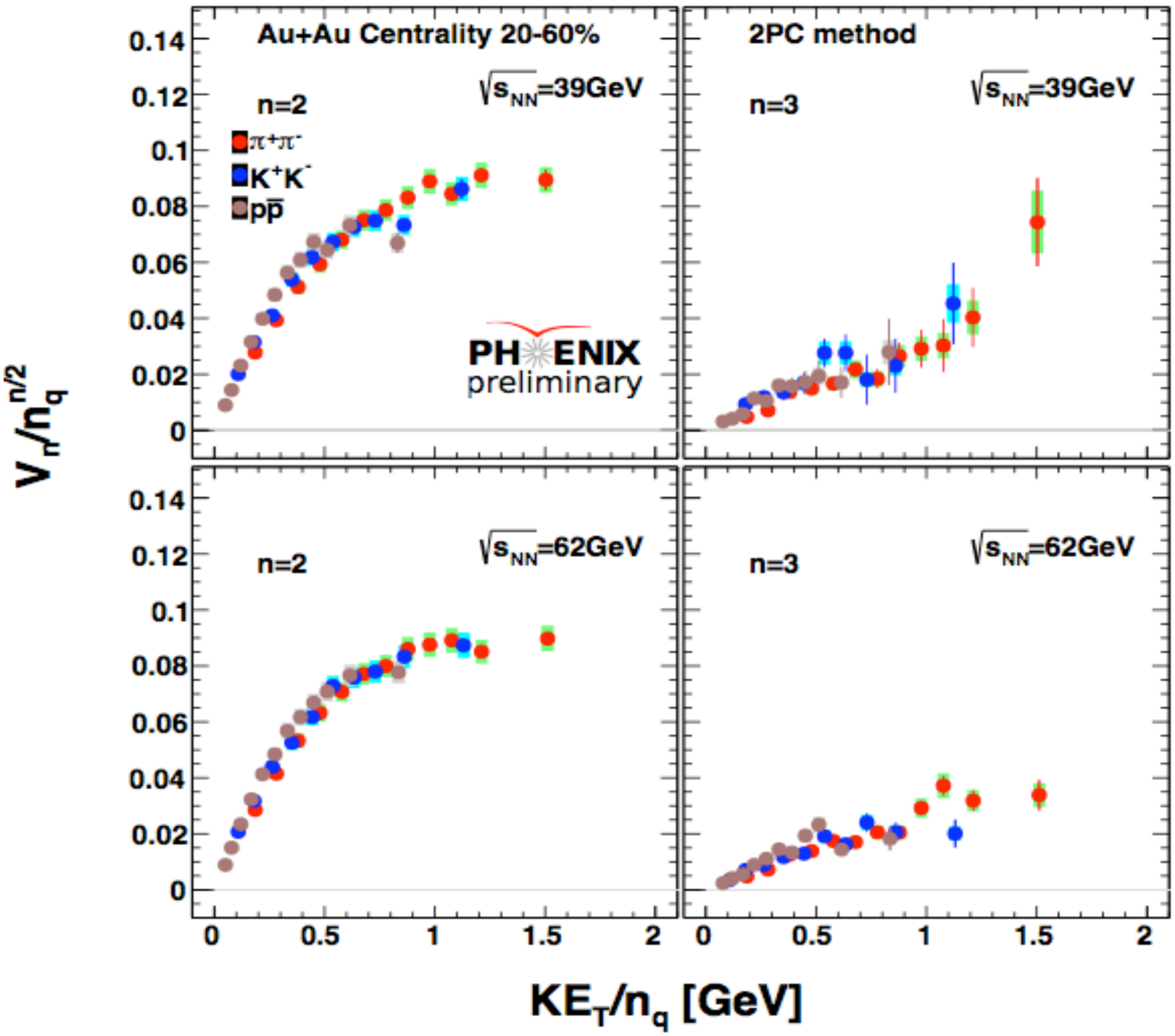
Flow v2, v3 π, K, p



Flow v2, v3 π, K, p



NCQ scaling of v2, v3



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Flow Summary

- **New v2 and v3 with PID have been measured in 62.4 and 39 GeV Au+Au data**

- **200, 62.4 and 39 GeV PID data shows the same v2, v3 values. Observed flow is saturated in this energy range**

- **NCQ scaling of v_n for identified charged hadrons, $KE_T/n_q < 1$ GeV observed for the beam energy range of 39–200 GeV confirms partonic flow down to 39 GeV**

Conclusions - 1

- **A large fraction of the extensive RHIC data set contributes to the energy and species scan**
- **Data has been analyzed at 7.7, 19.7, 27, 39, 62.4, 130, 193 and 200 GeV**
  - A gradual evolution for $dN/d\eta$, $dE_T/d\eta$ and ε_{Bj} vs $\sqrt{s}$ and N_{part}
  - ε_{Bj} of U+U ~ 20% higher than Au+Au
  - No significant increase in the $dN/d\eta$ seen in U+U
- **Net charge and multiplicity fluctuation analyses have been performed at 7.7, 39, 62.4 and 200 GeV**
  - No non-monotonic behavior observed within sensitivity.
  - Additional data at 27 and 19.6 GeV to be analyzed
- **Energy loss similar to that observed in 200 GeV Au+Au R_{AA} is seen in 62.4 and 39 GeV data**
  - The energy loss weakens as we decrease $\sqrt{s}$ and centrality
- **J/ψ suppression is very similar at all N_{part} for particles produced in collisions of 200, 62.4 and 39 GeV ($1.2 < |y| < 2.2$)**

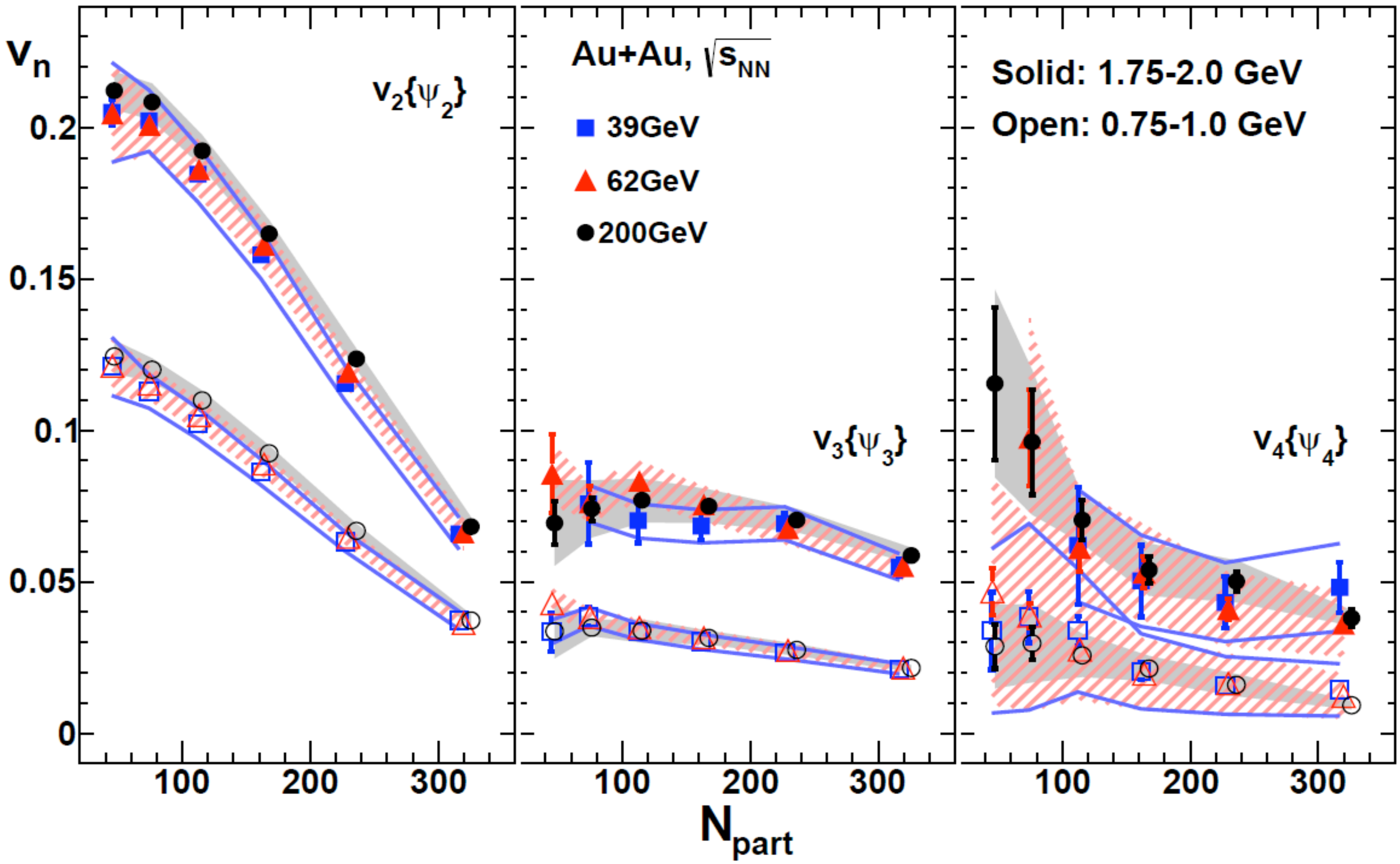
Conclusions - 2

- 200, 62.4 and 39 GeV PID data shows the same v2, v3 values
- NCQ scaling of v_n seen for π, K, p observed in range 39–200 GeV confirms partonic flow down to 39 GeV

Thank You

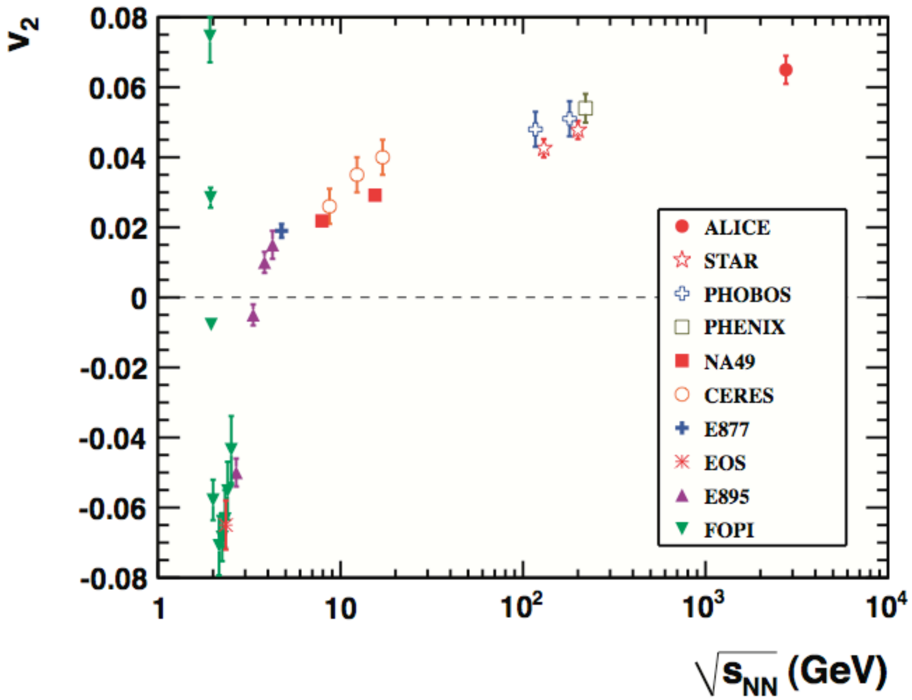
Back Up

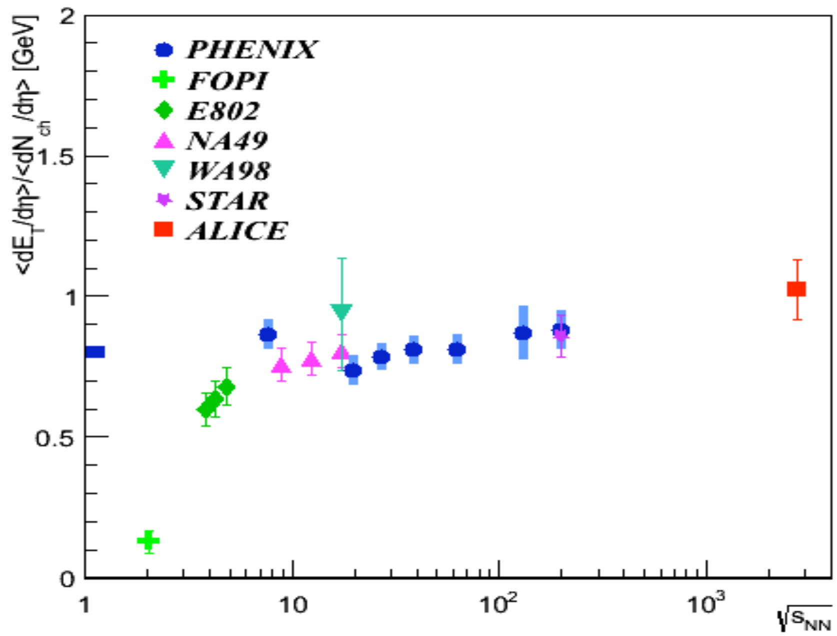
$v_{2,3,4}$ of Charged Hadrons vs $\sqrt{s}$



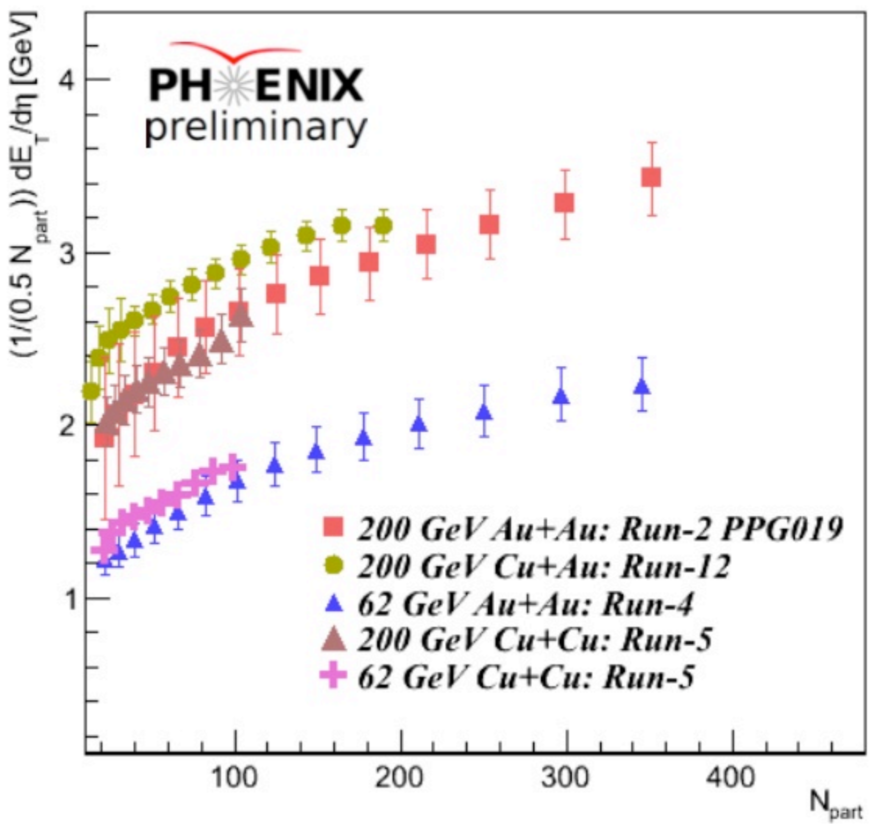
- Charged hadron results for v_2, v_3 and v_4 consistent with saturation of identified charged particles v_n for beam energies of 39-200GeV

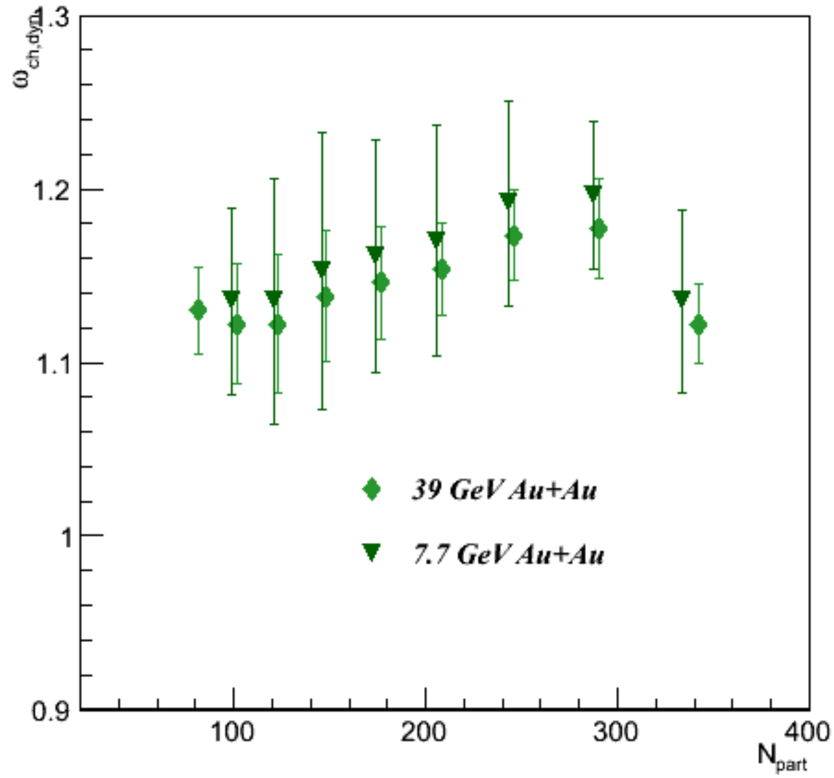
Excitation plot of v2 and E_T/particle





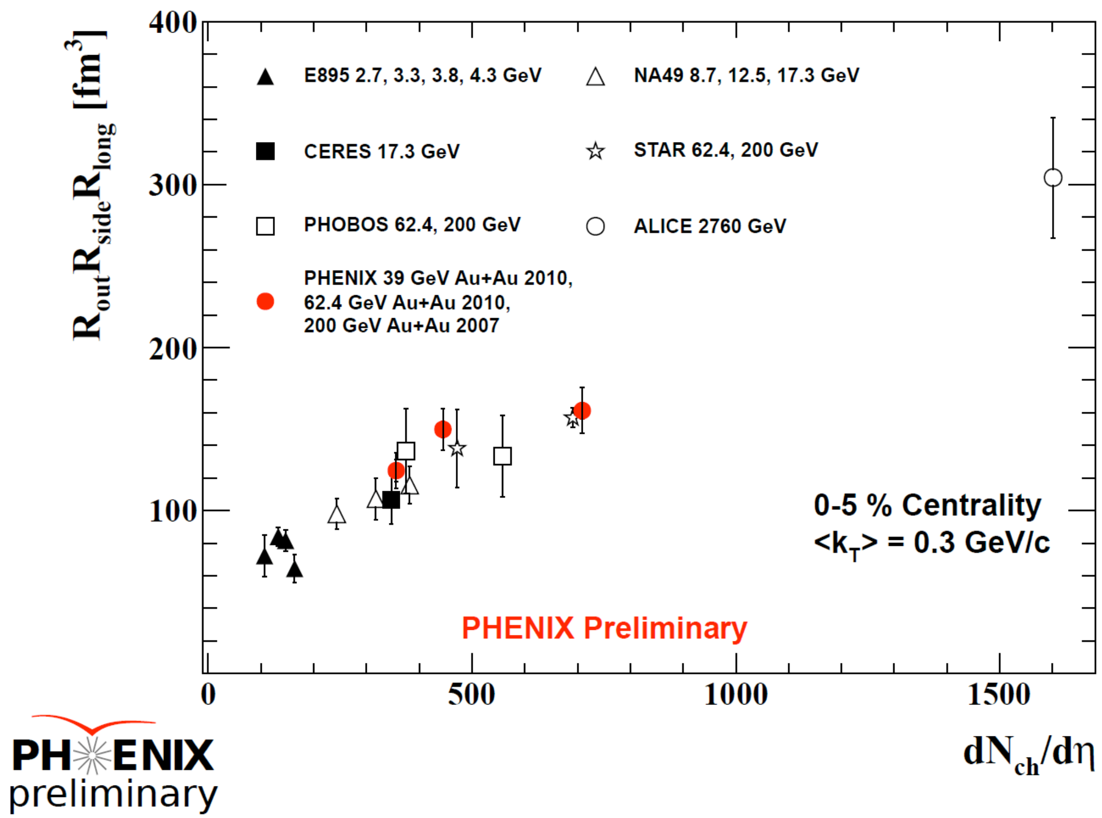
Global Variables $dE_T/d\eta$



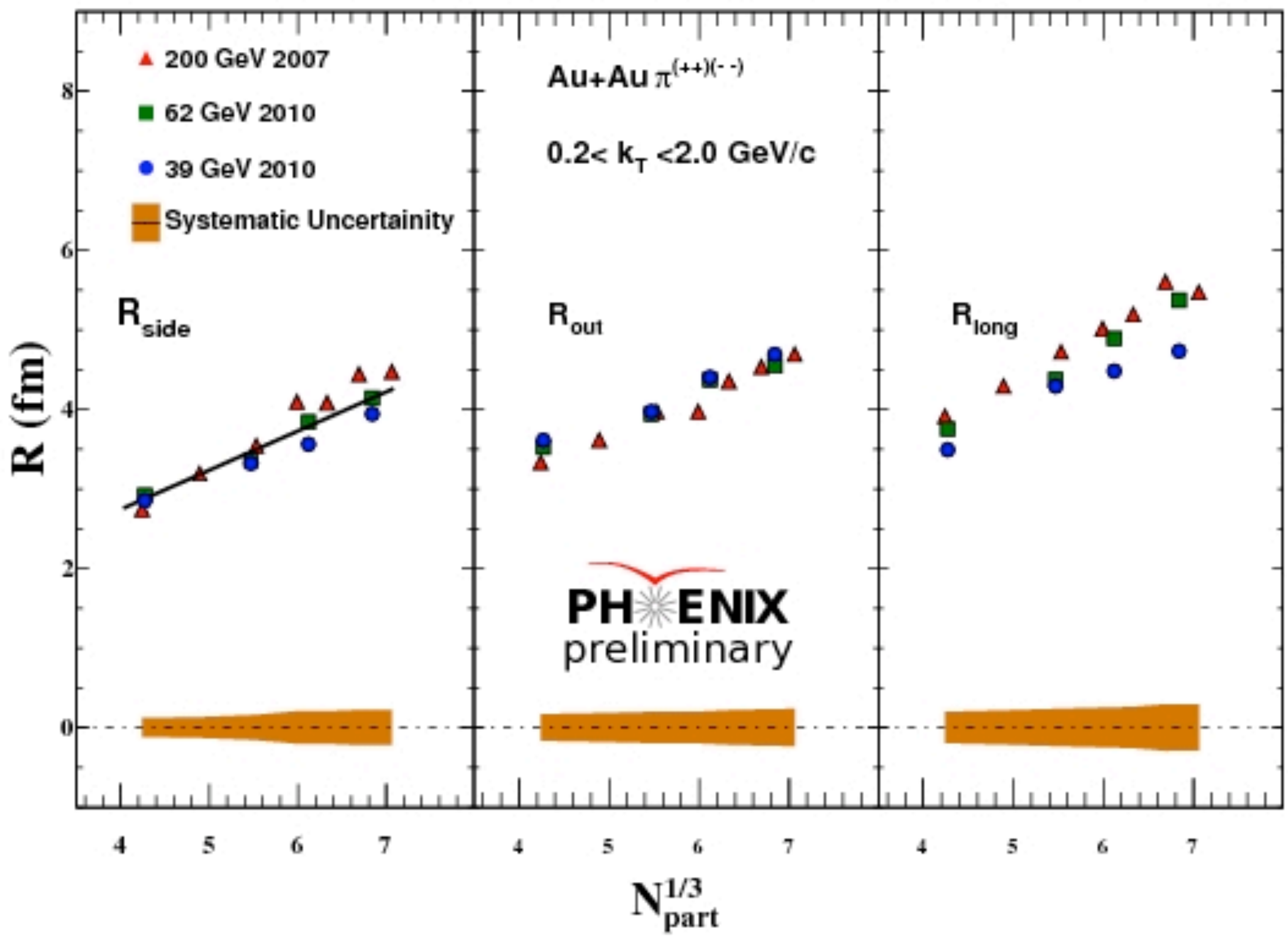


Initial geometry HBT systematics

- System volume from 3D HBT as a analysis function of entropy density
- PHENIX data follow the global linear trend



HBT


200 GeV 2007
62 GeV 2010
39 GeV 2010
Systematic Uncertainity
Au+Au $\pi^{(++)(--)}$
0.2< k_T <2.0 GeV/c
R_{side}
R_{out}
R_{long}
PHENIX preliminary
R (fm)
$N_{part}^{1/3}$