Energy Scan @ PHENIX

The 2012 RHIC/AGS Annual Users' Meeting
Frontiers of RHIC Physics

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Brookhaven National Laboratory

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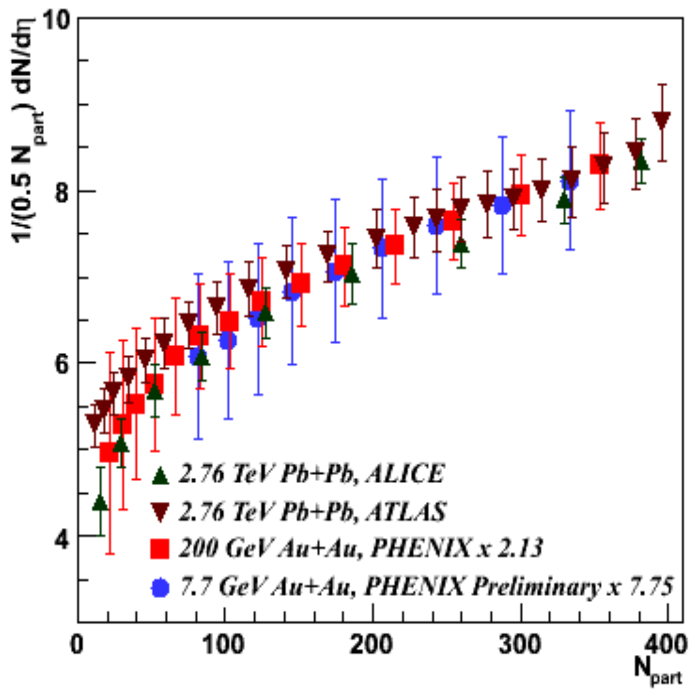
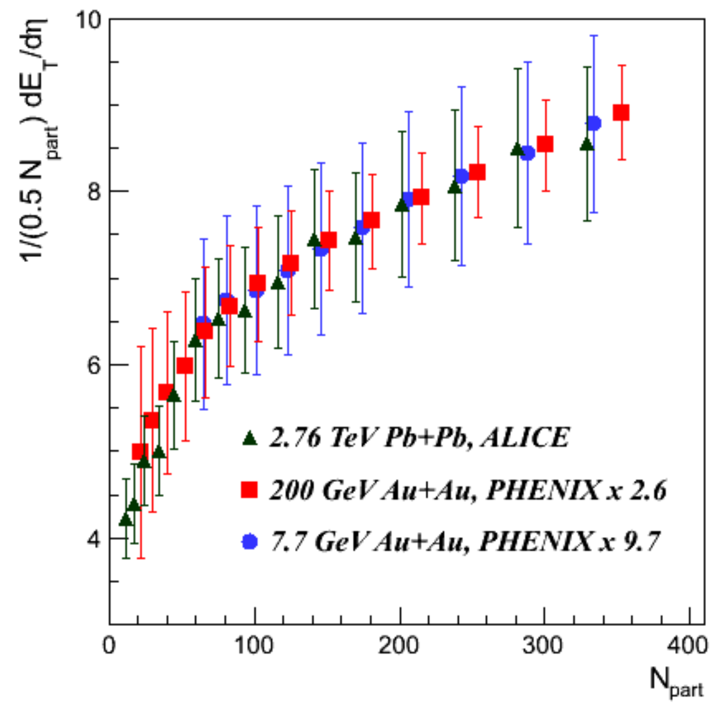
for PHENIX Collaboration

Contents

- RHIC is an extremely versatile collider:
  - Dial back the beam energy
  - Change the initial amount of stuff in collision
- Probe the QCD phase diagram with:
  - Global observables
  - Invariant yields
  - Nuclear modification factor
  - Higher flow moments
  - Fluctuations
- Search for dramatic effects, *e.g.*, phase boundary ending at the critical point

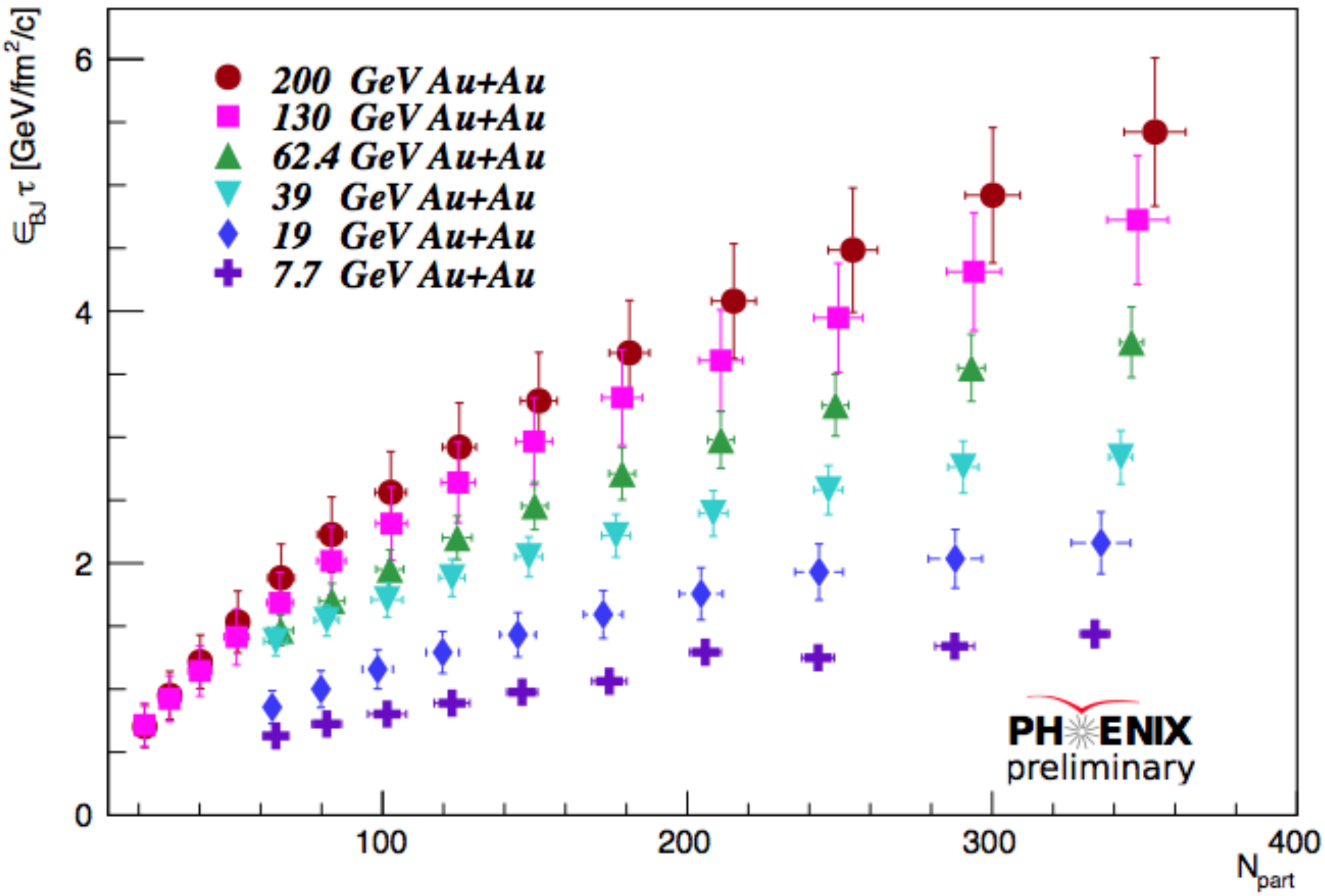
global observables: $dN/d\eta$ and $dE_T/d\eta$





No significant change in centrality dependence of $dN/d\eta$ and $dE_T/d\eta$ distributions in energy range of 7.7 GeV Au+Au to 2.76 TeV Pb+Pb, but a significant change in magnitude, *n.b.*, scaling factors

Bjorken energy density



$$\epsilon_{Bj} = \frac{1}{A_{\perp}\tau}\frac{dE_T}{dy}$$

$A_{\perp}$ = transverse overlap area of the nuclei determined from the Glauber model

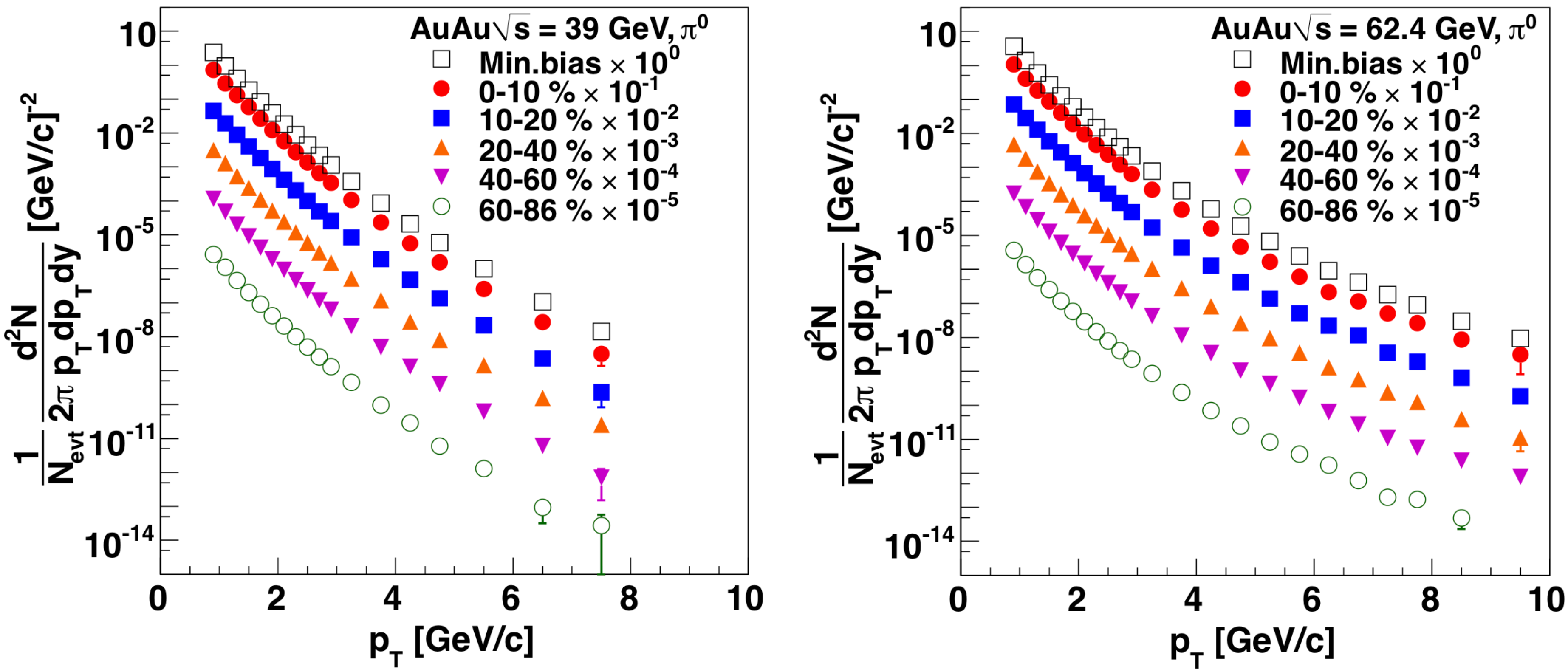
τ = formation time

n.b., $dE_T/d\eta$ is multiplied by 1.25 to obtain dE_T/dy at SPS energies

ε_{Bj} increases by a factor of 3.8 (11.1) going from 7.7 to 200 GeV (2.76 TeV)

π^0 invariant yields

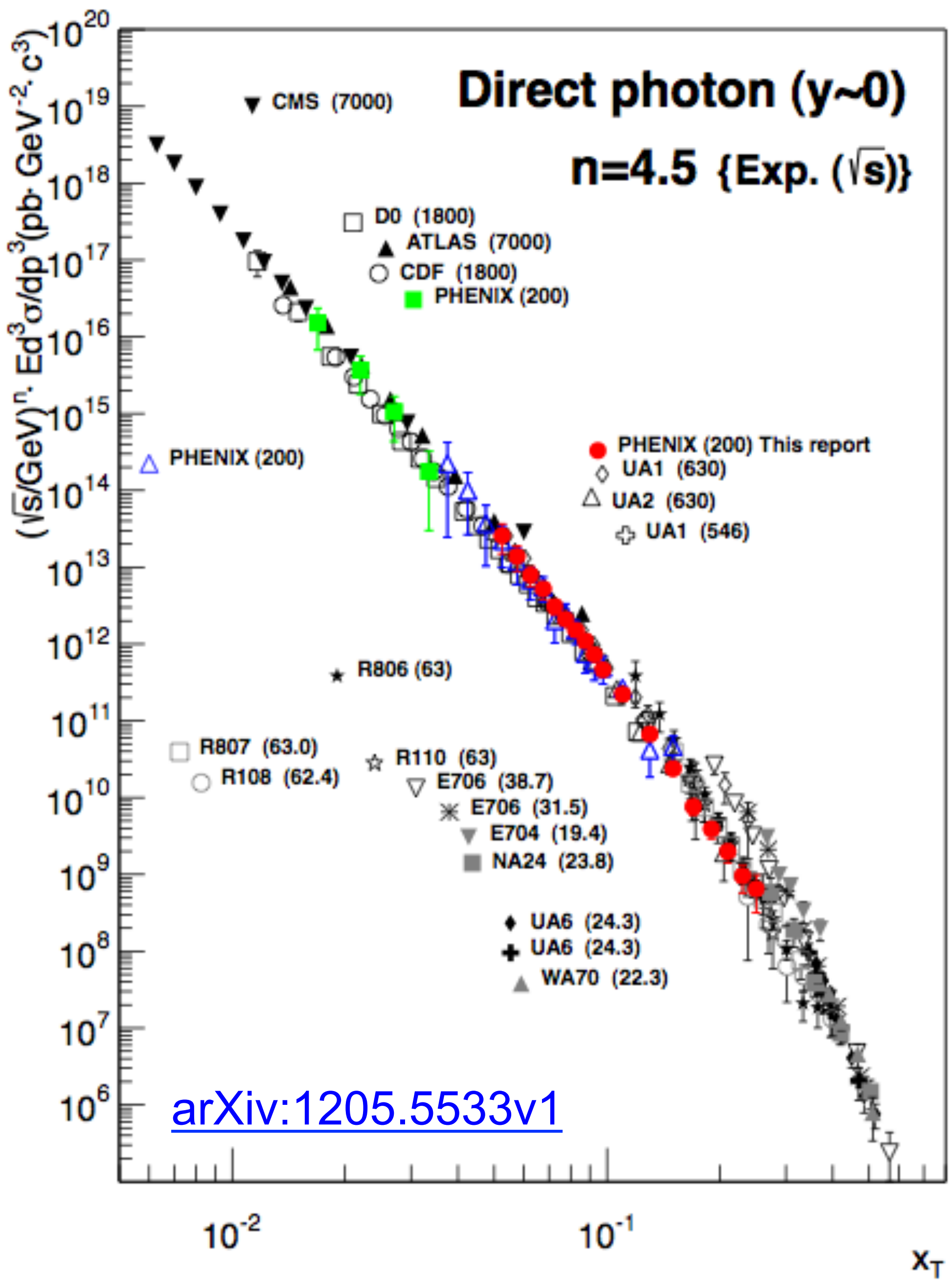
arXiv:1204.1526v1



from power-law fits to minimum bias spectra (for p_T > 4 GeV/*c*):

$$f(x) = \frac{A}{(p_T)^n},$$

n_{200GeV}	=	-8.06	± 0.01
n_{62GeV}	=	-10.60	± 0.03
n_{39GeV}	=	-13.04	± 0.08



$x_T = 2p_T/\sqrt{s}$ scaling

In hard scattering region:

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^{\,n_{eff}(x_T,\sqrt{s})}} G(x_T)$$

universal scaling function

For isolated photons from p+p collisions in Bjorken's parton model:

n_{eff} = constant = 4.0

x_T scaling (cont)

In pQCD contributions from:

- running $\alpha_s(Q^2)$
- PDF (and FF) evolution

Other effects:

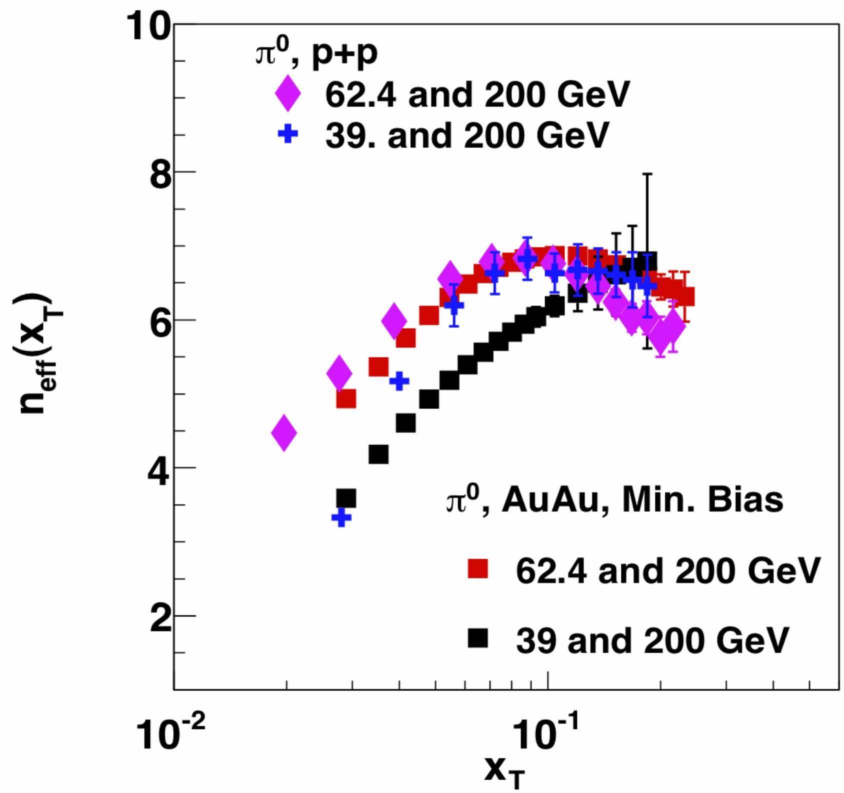
- k_T smearing
- higher-twist phenomena

So n_{eff} not constant, rather:

$$n_{eff}(x_T) = \frac{\log\left(Yield\left(x_T,\sqrt{s_1}\right)/Yield\left(x_T,\sqrt{s_2}\right)\right)}{\log\left(\sqrt{s_2}/\sqrt{s_1}\right)}$$

to compare different beam energies.

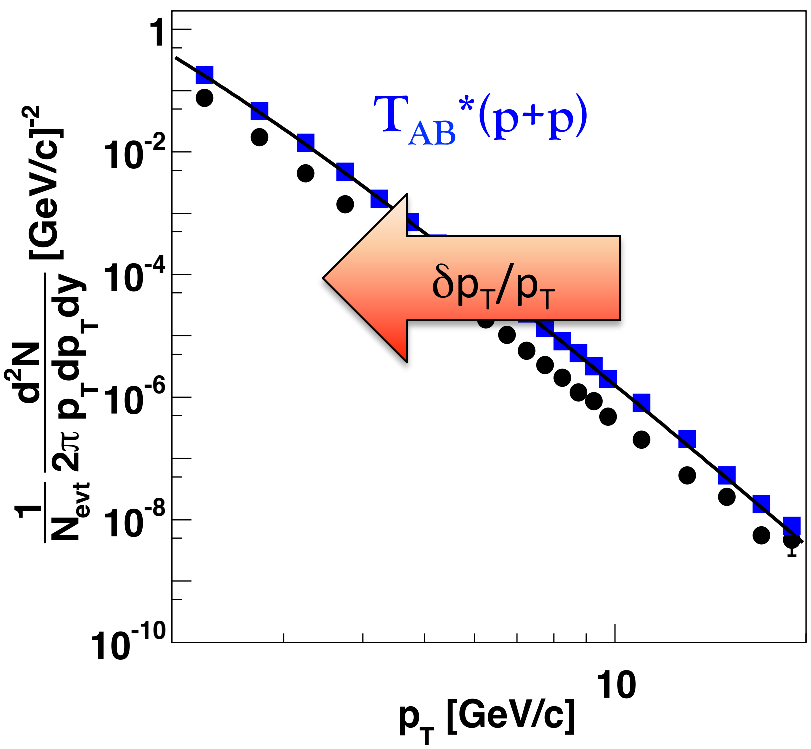
arXiv:1204.1526v1

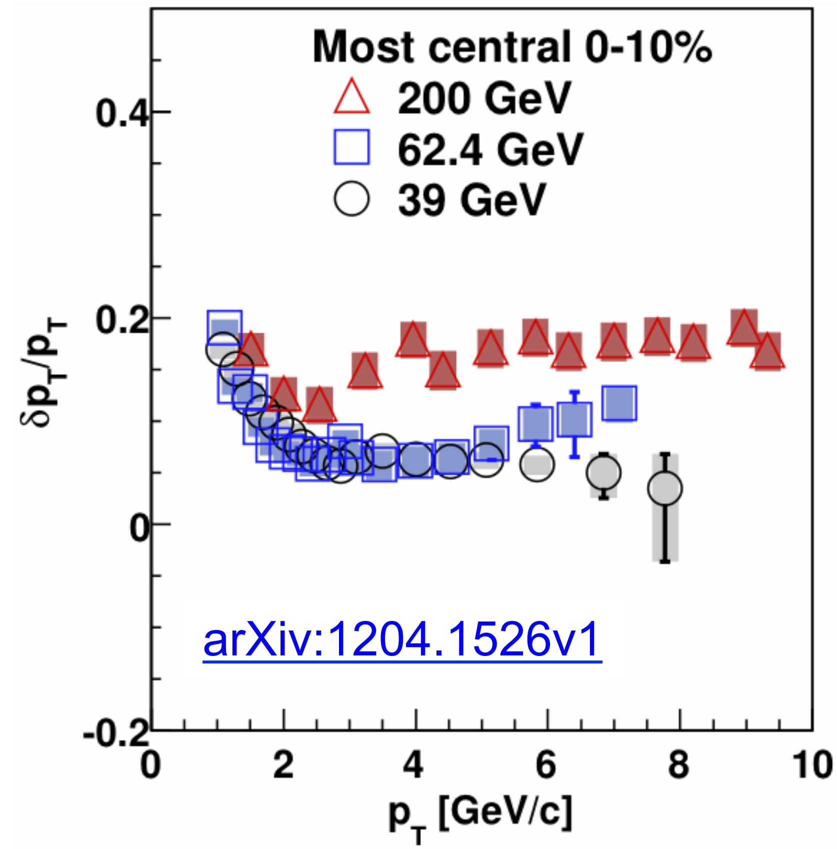


Largest deviation for 39 and 200 GeV Au+Au comparison ⟶ hard scattering not dominant source of high p_T π^0 in 39 GeV Au+Au collisions

fractional momentum shift

Horizontal shift of T_{AB}-scaled p+p towards Au+Au spectrum:

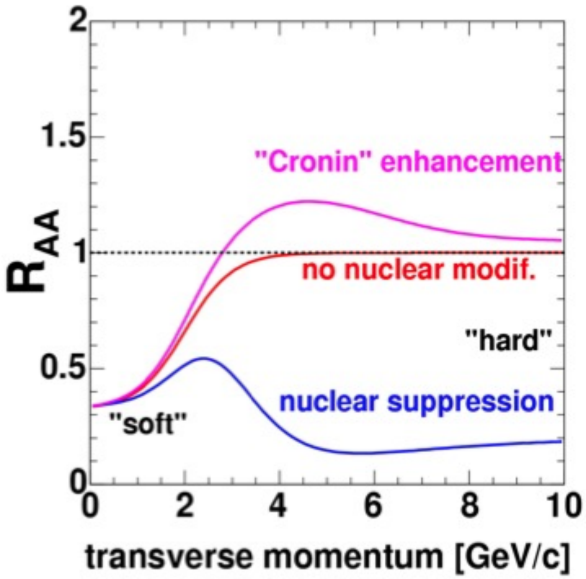


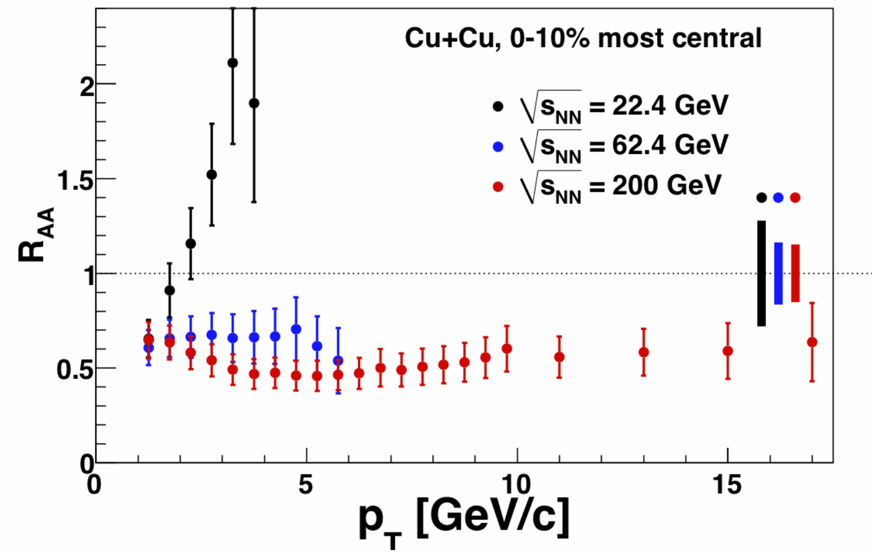


Partons in 200 GeV collisions suffer largest average momentum loss

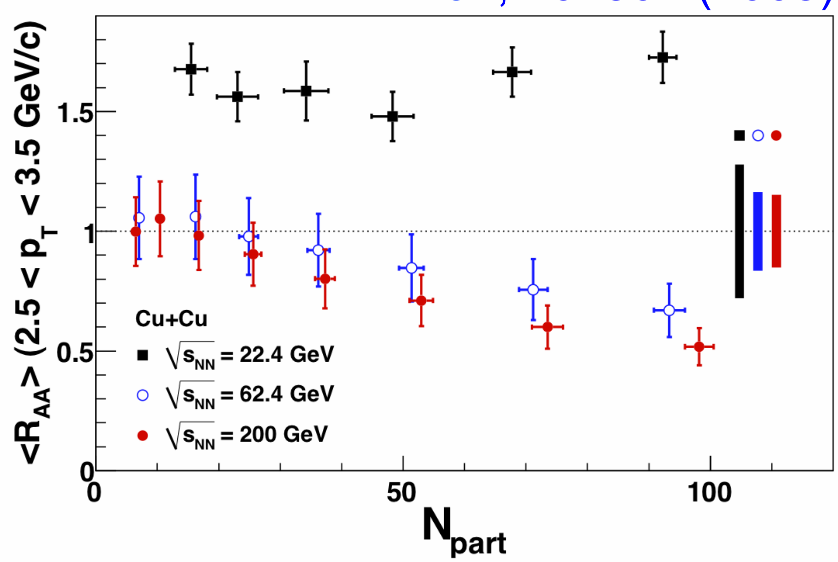
nuclear modification factor - R_{AA}

$$R_{AA}(p_T) = \frac{(1/N_{AA}^{evt}) d^2N_{AA}/dp_T dy}{\langle N_{coll}\rangle / \sigma_{pp}^{inel} \times d^2\sigma_{pp}/dp_T dy}$$



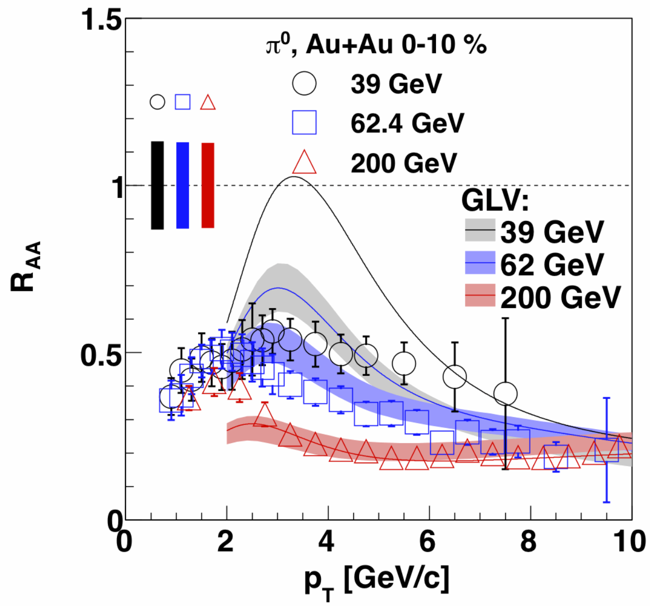


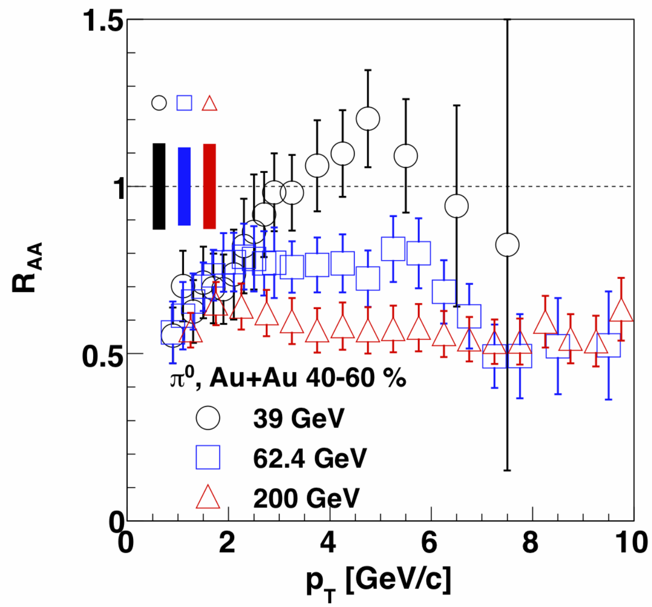
PRL **101**, 162301 (2008)



n.b., R_{AA} requires p+p reference data at corresponding √s.

$\sqrt{s_{NN}}$ dependence of R_{AA} for π^0 in Au+Au collisions





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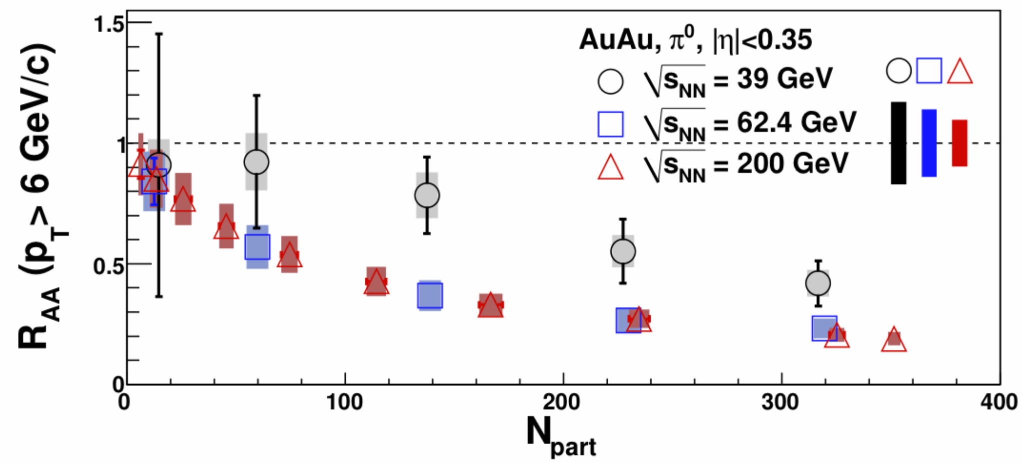
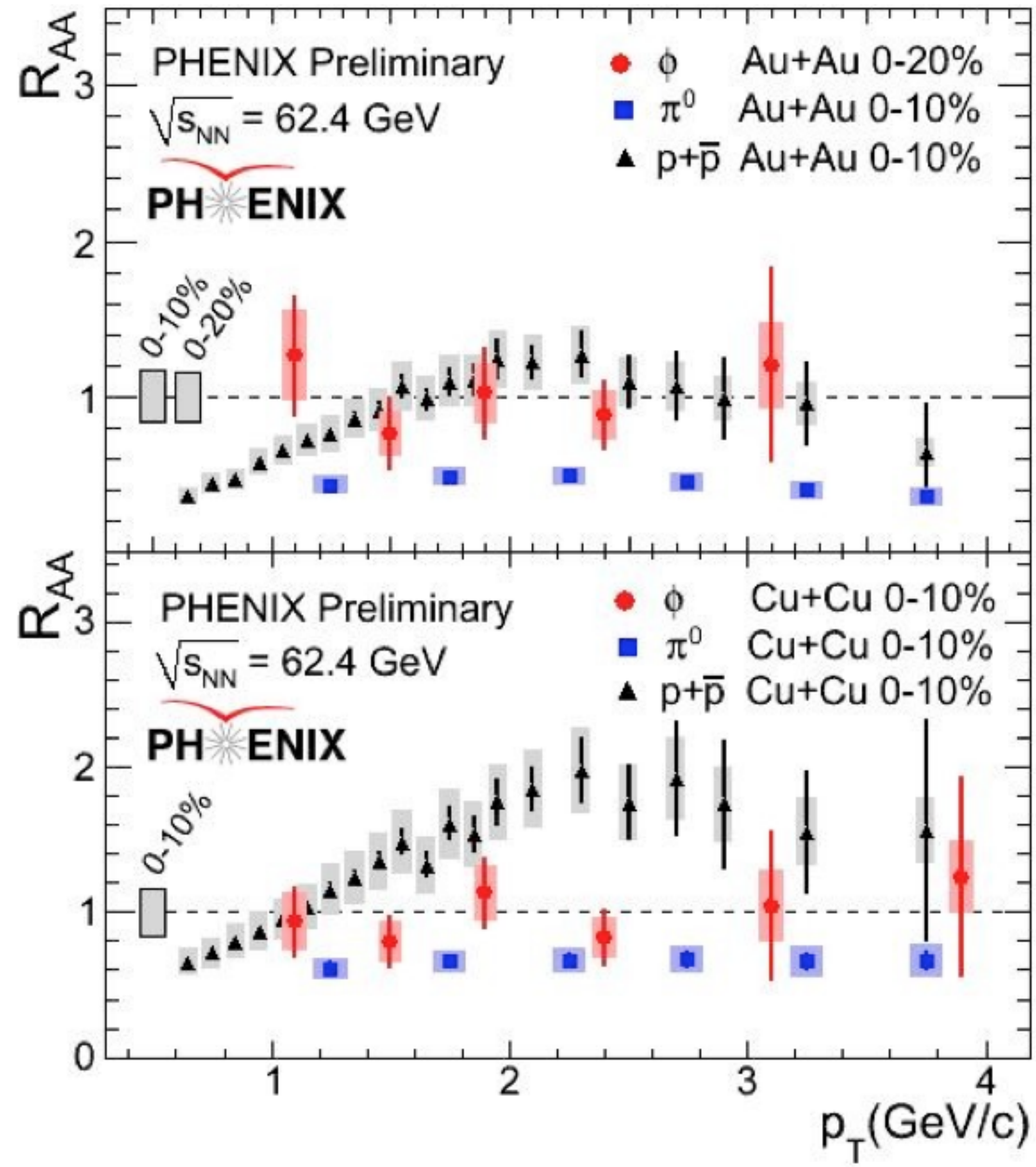


- 39 GeV data shows suppression for higher centrality only ($N_{part} > 100$)
- For $p_T > 6$ GeV/*c* the 62.4 and 200 GeV data points are comparable
- Increased initial-state parton mean free paths for better agreement with data



particle species dependence of R_{AA}

protons are enhanced
ϕ (similar mass) is not in Cu+Cu or Au+Au at $\sqrt{s_{NN}}$ = 62.4 GeV

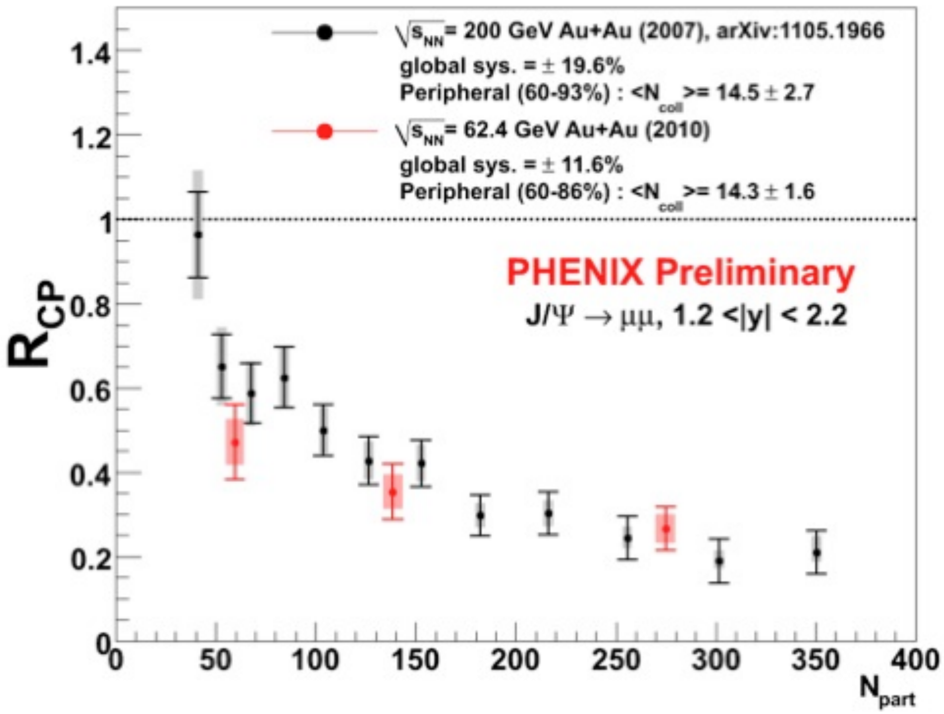
flavor dependent suppression persists at lower beam energy

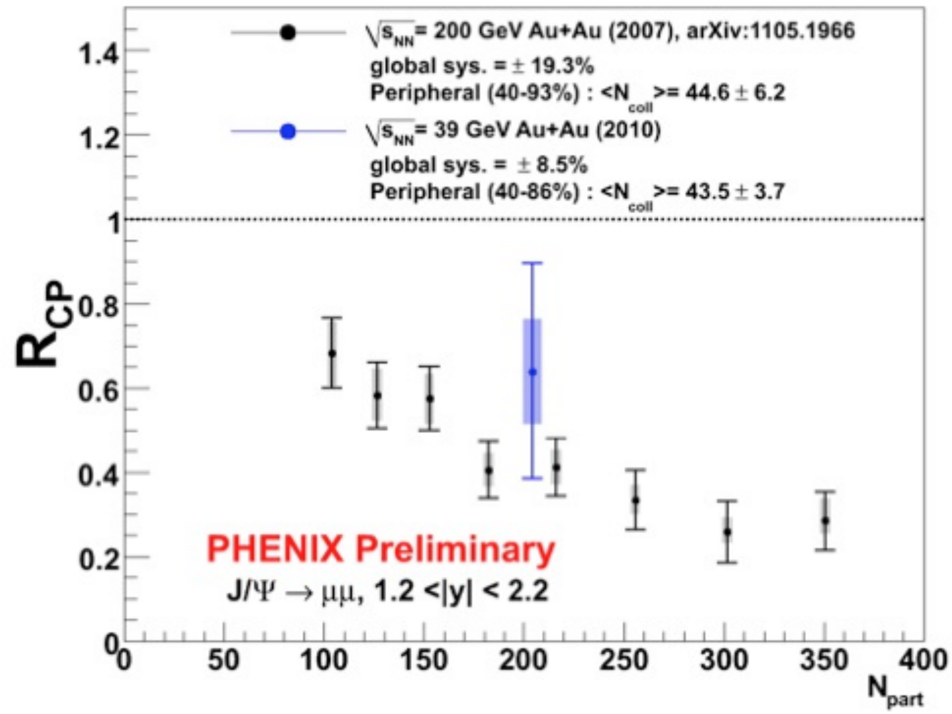
$\sqrt{s_{NN}}$ dependence of R_{CP} for J/ψ

$\sqrt{s_{NN}}$ = 62.4 GeV

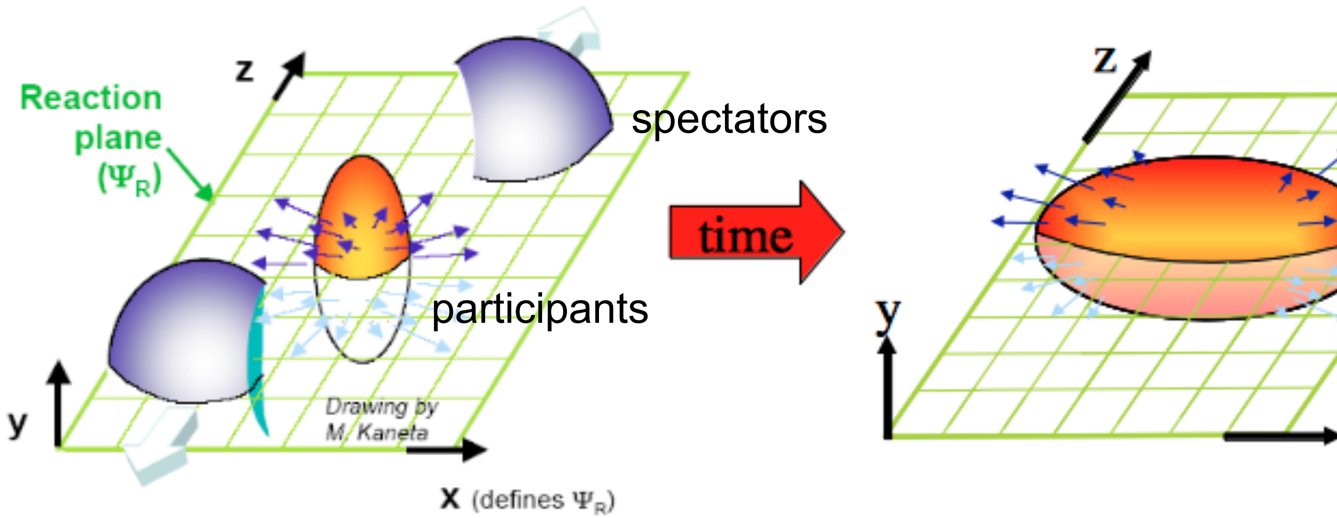
J. Phys. G: Nucl. Part. Phys. 38 124108

$\sqrt{s_{NN}}$ = 39 GeV



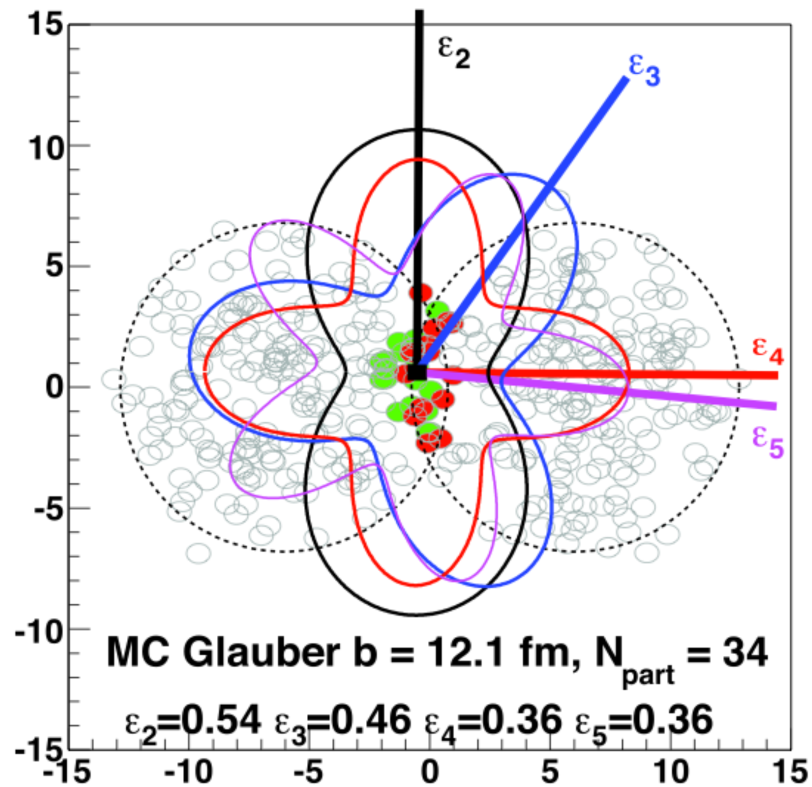


n.b., CP denotes ratio of central to peripheral (not p+p) data



$$v_n = \left\langle e^{in(\phi_p - \Psi_R)} \right\rangle$$

Fig. from PRC **83**, 044908 (2011)



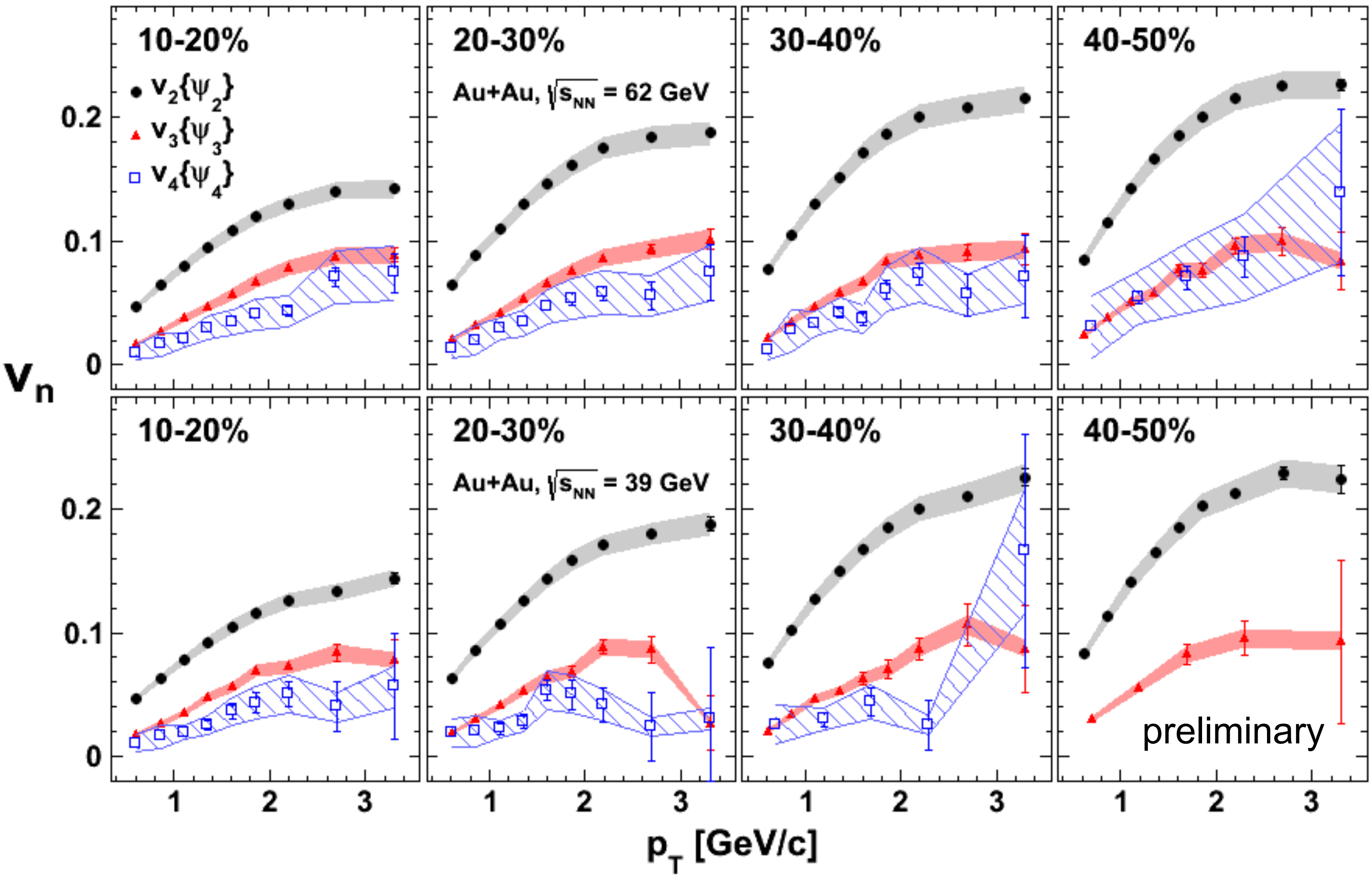
More recently:

- Generalized eccentricities for higher flow moments:

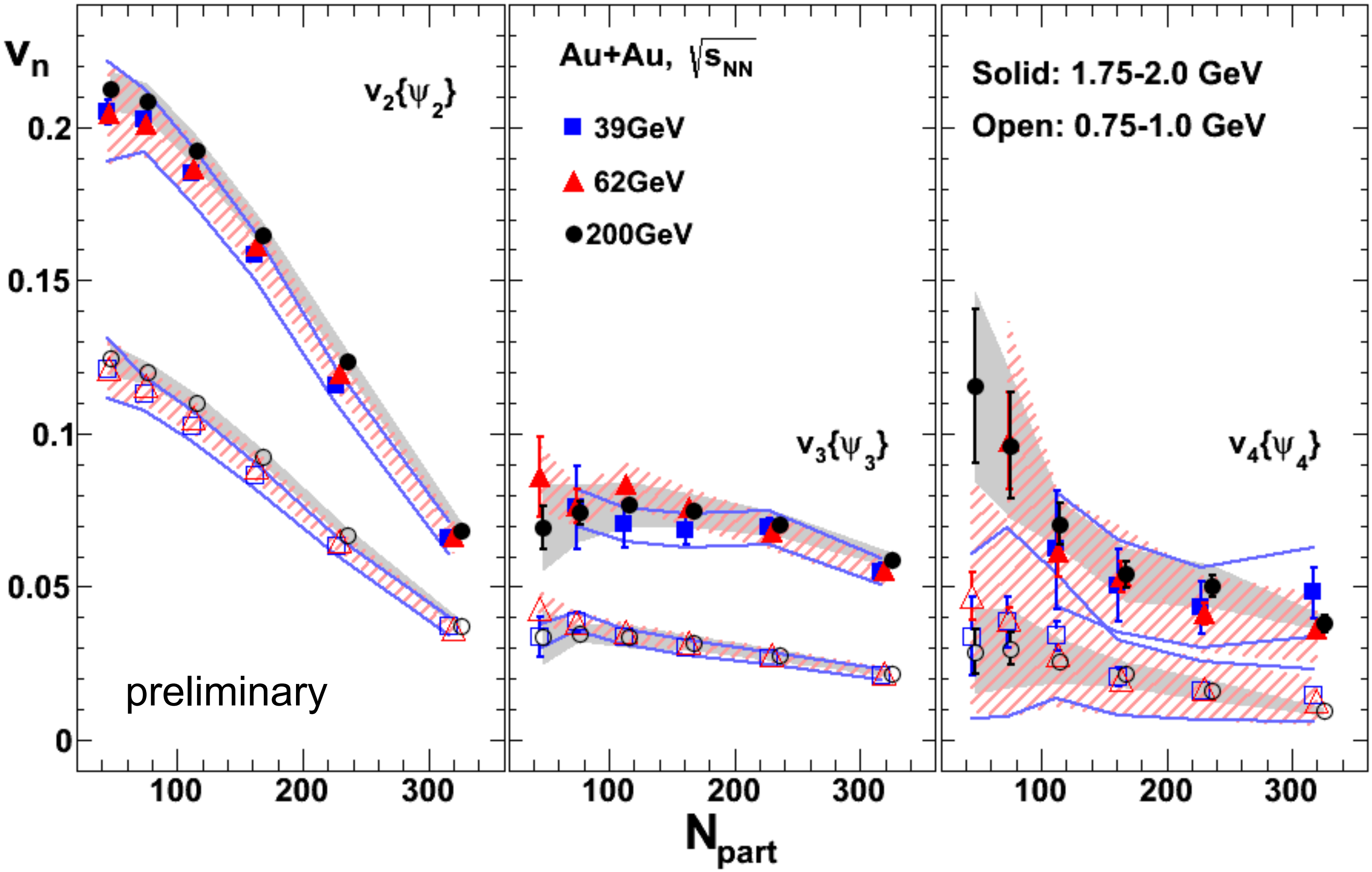
$$v_n = \left\langle e^{in(\phi_p - \Psi_n)} \right\rangle$$

- For smooth profile:
  Odd harmonics cancel out
- For "lumpy" profile:
  Odd harmonics persist

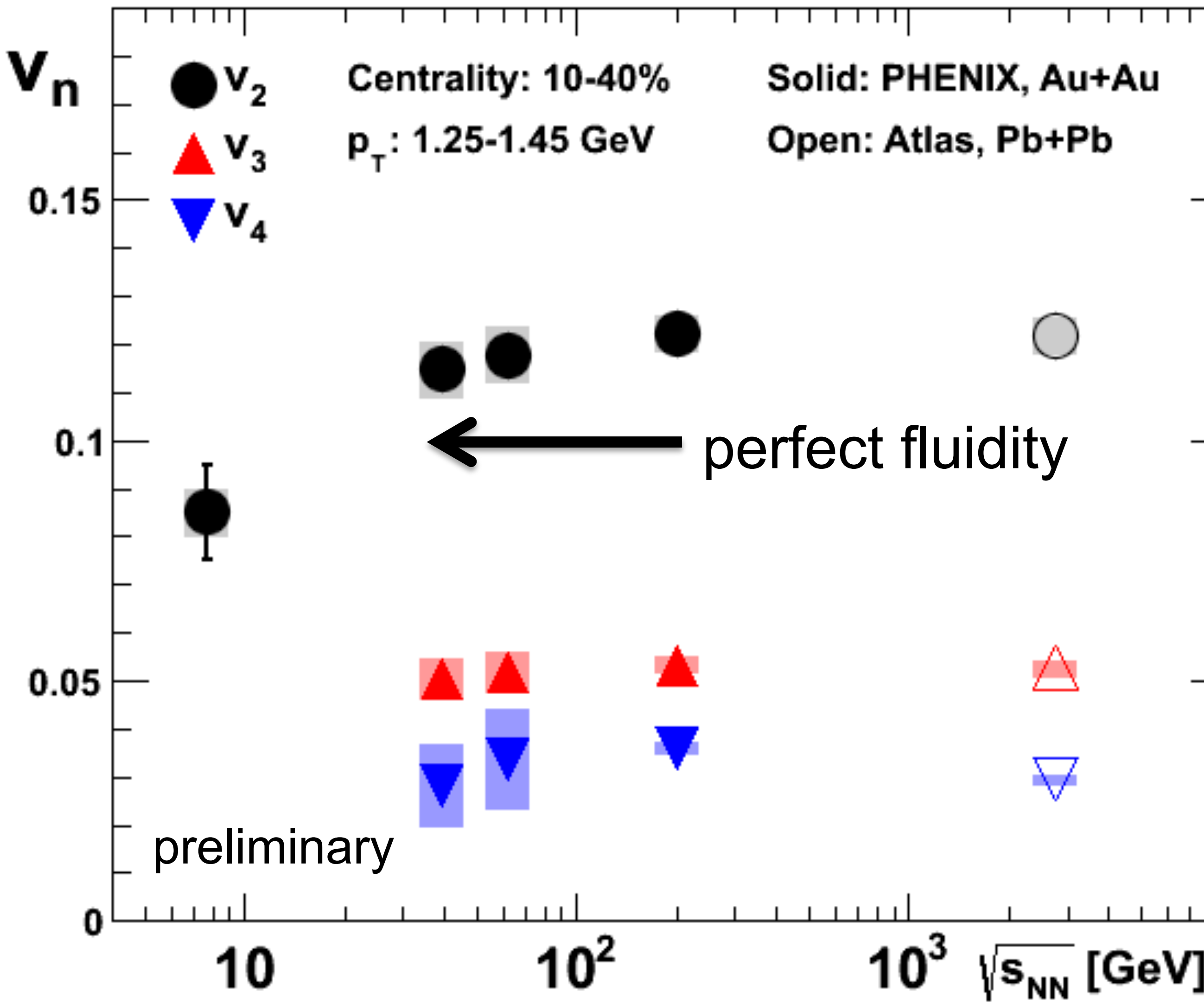
$v_n\{\Psi_n\}$ for charged hadrons



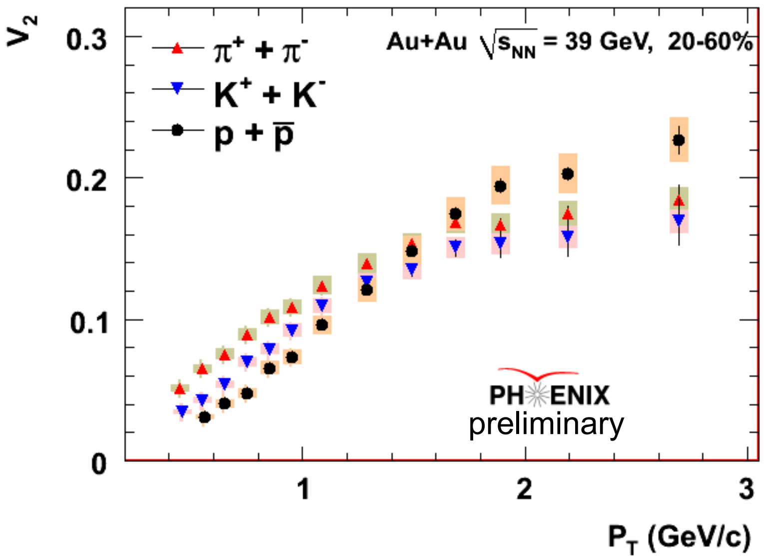
$v_n\{\Psi_n\}$ for charged hadrons

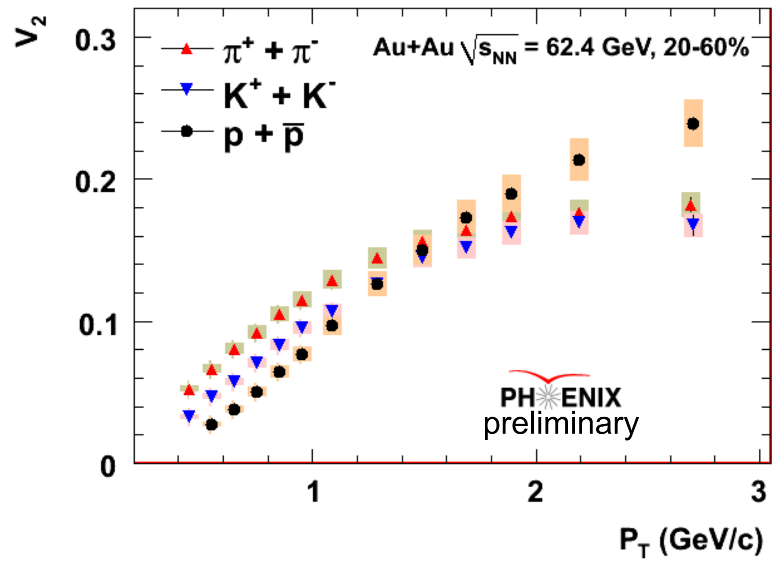


$\sqrt{s_{NN}}$ dependence of $v_n\{\Psi_n\}$ for charged hadrons

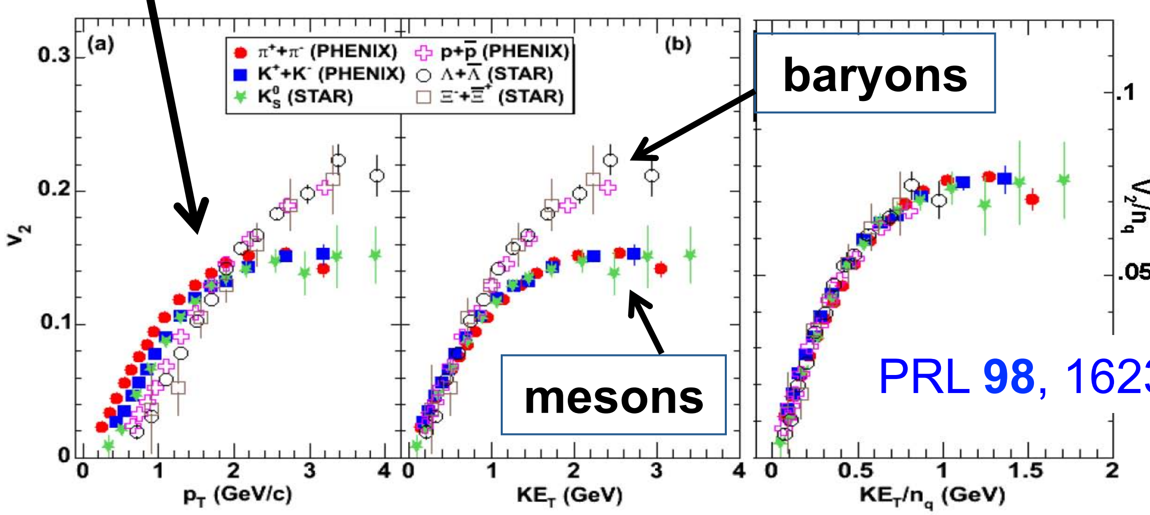


$\sqrt{s_{NN}}$ dependence of PID v_2



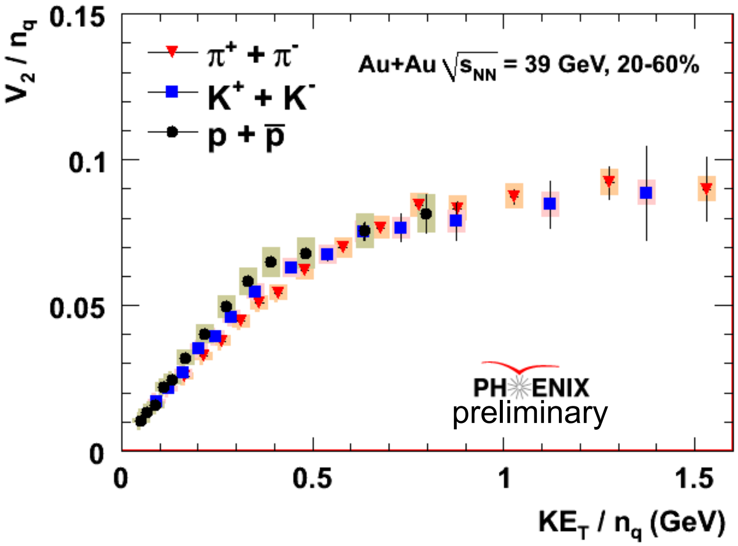


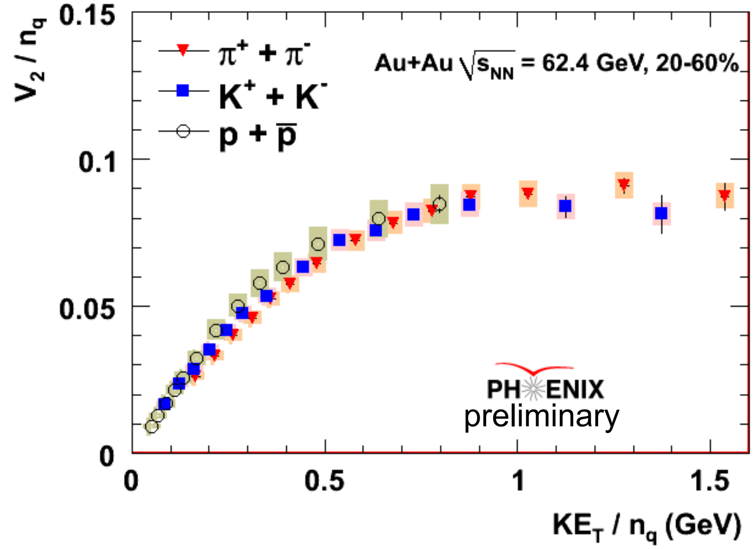
same mass scaling pattern as seen in 200 GeV Au+Au collisions



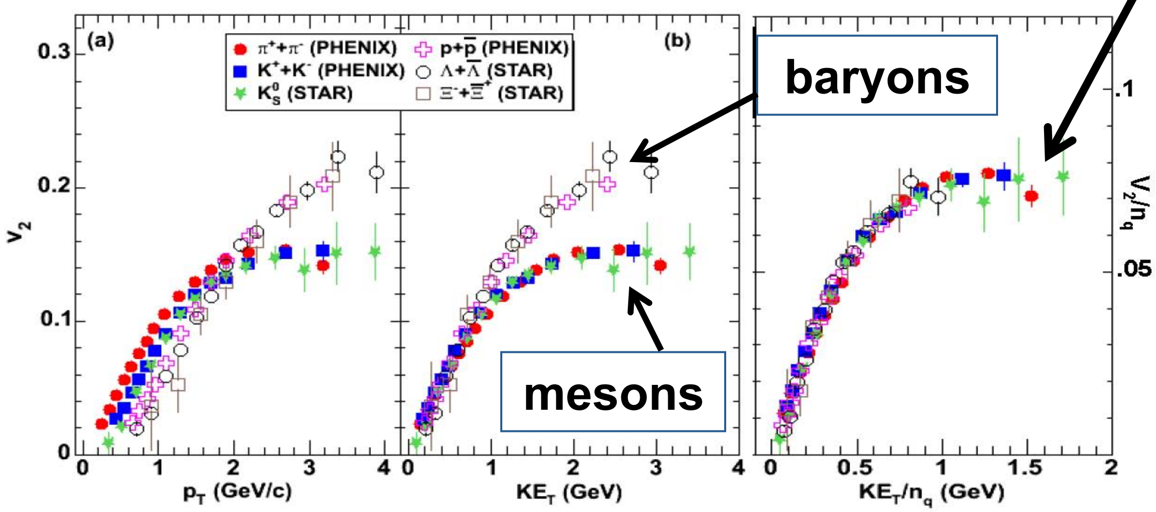
PRL **98**, 162301 (2007)

PID v_2/n_q

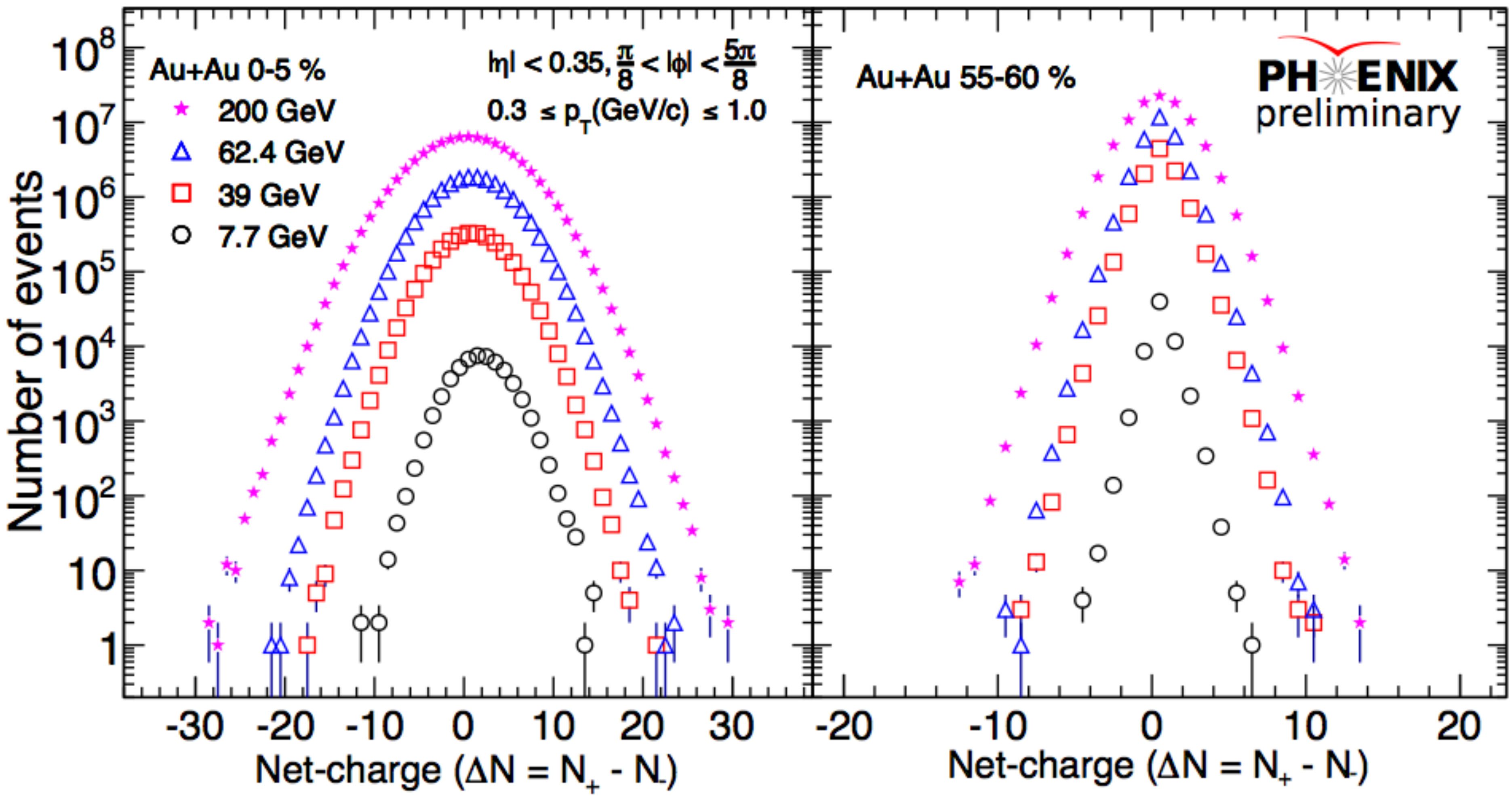




quark number (n_q) scaling indicates partonic collective flow down to 39 GeV



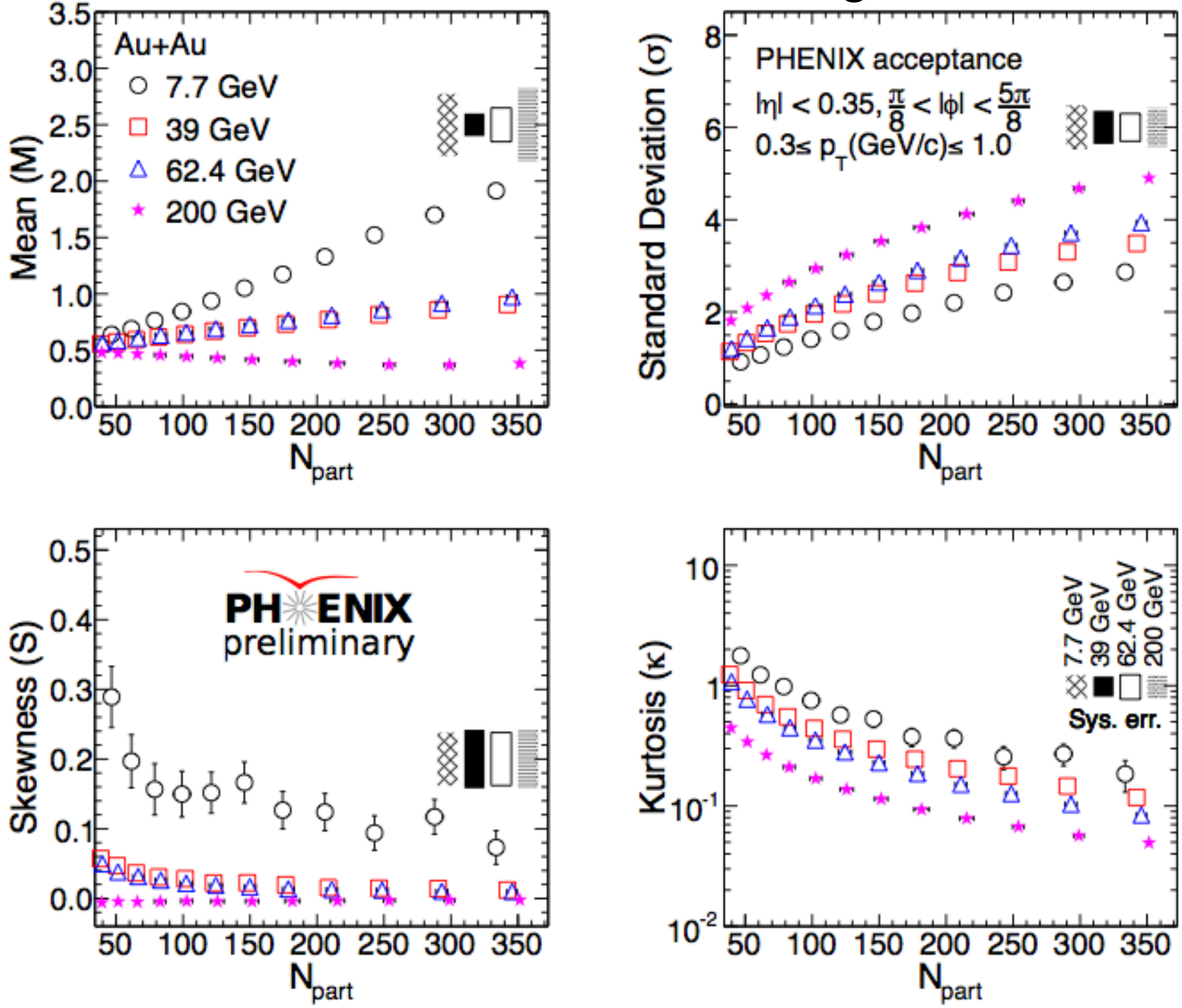
net charge distributions



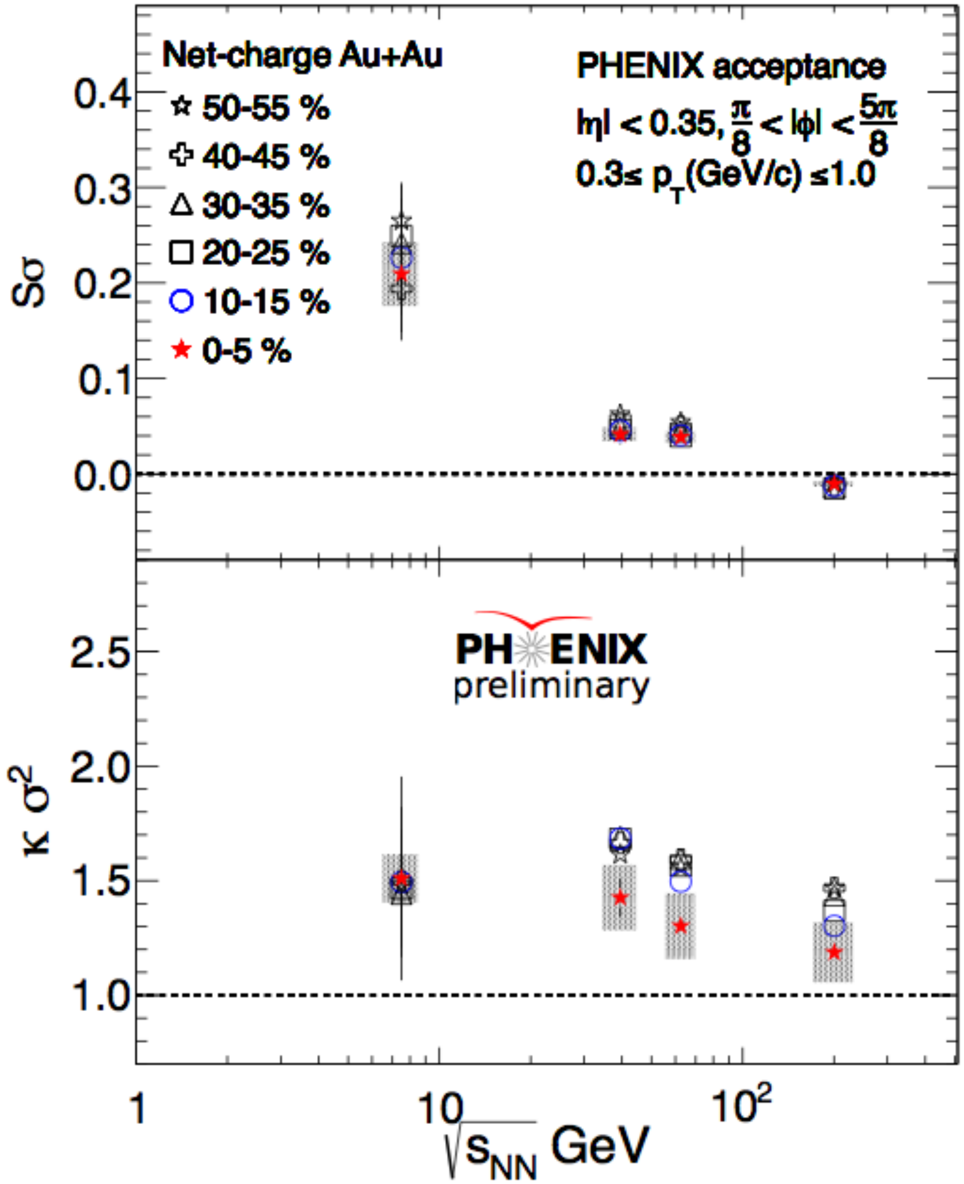
correlation length related to moments of conserved quantities including net charge
correlation length should diverge at the critical point in the phase diagram

net charge moments

scale as correlation length



$\sqrt{s_{NN}}$ dependence of net charge fluctuations



Prediction that products of moments will exhibit non-monotonic behavior near the critical point is not (yet) observed

Summary

- Smooth increase in global observables vs $\sqrt{s_{NN}}$
- Onset of hard processes at high p_T from invariant yields at each beam energy
- Onset of suppression from nuclear modification factor vs $\sqrt{s_{NN}}$
- From collective flow in Au+Au collisions:
  - Higher moments indicate initial state fluctuations
  - Partonic flow with perfect fluidity down to 39 GeV
- No excess fluctuations observed in the net charge