Testing the initial collision geometry with Cu+Au collisions at RHIC

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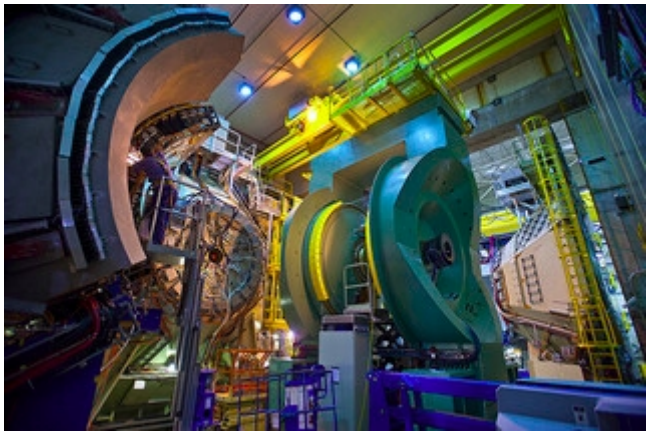


RHIC&AGS Annual Users' Meeting: Workshop on U+U and Cu+Au shape studies

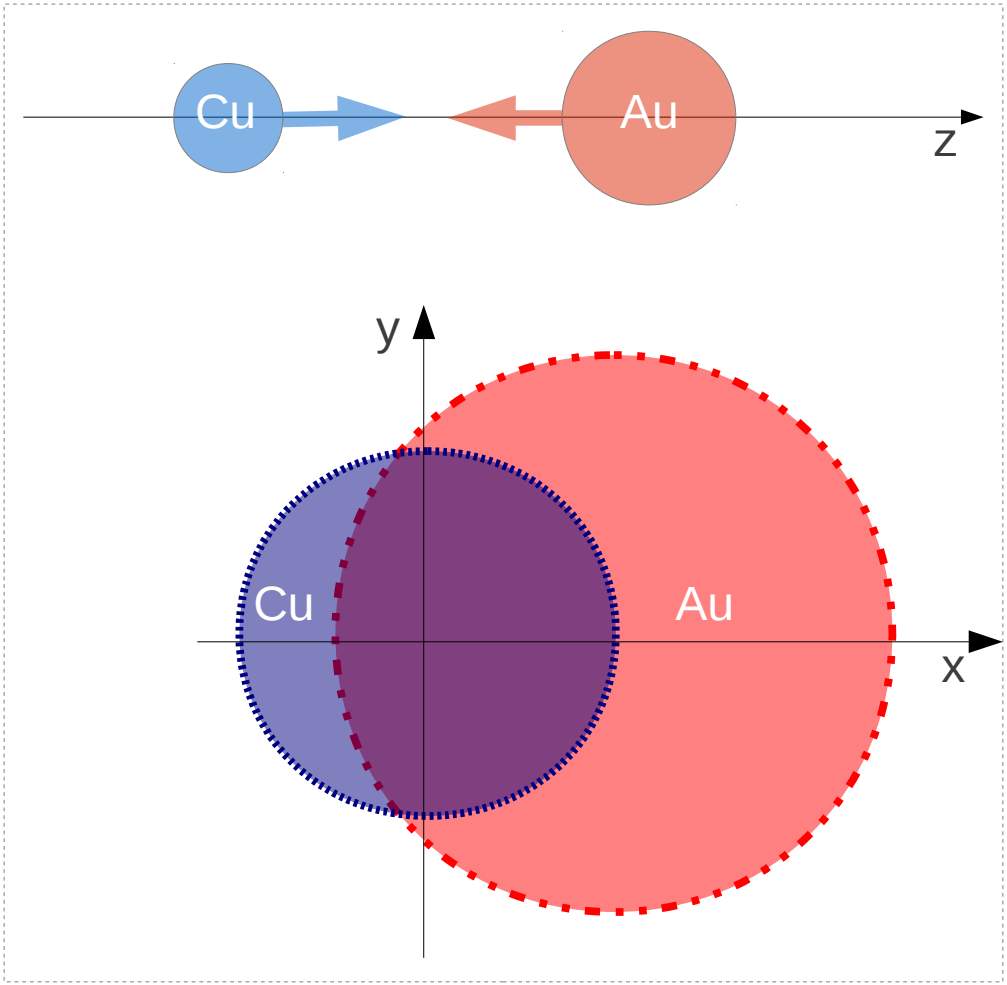
RHIC Run 12

- RHIC versatility – energy and species scans
  - Recent Improvements
    - EBIS source
    - Horizontal stochastic cooling in both beams
      (small beam size, high luminosity, low beam loss rates)
- Allows for unique collision environments
  - First U+U collisions at 193 GeV
  - First Cu+Au at 200 GeV

species	√s	wks	± 30 cm	± 10 cm	Events	motivation
U+U	193	2.9	171.2 μb-1	89.9 μb-1	1.2 B	explore geometry
Cu+Au	200	5.5	4.96 nb-1	2.47 nb-1	7.6 B	control geometry

CuAu: asymmetric system

- Forward/Backward asymmetry
  - Along the beam axes
- Left/Right asymmetry
  - In the initial geometry profile, perpendicular to the beam
  - Use as a control parameter



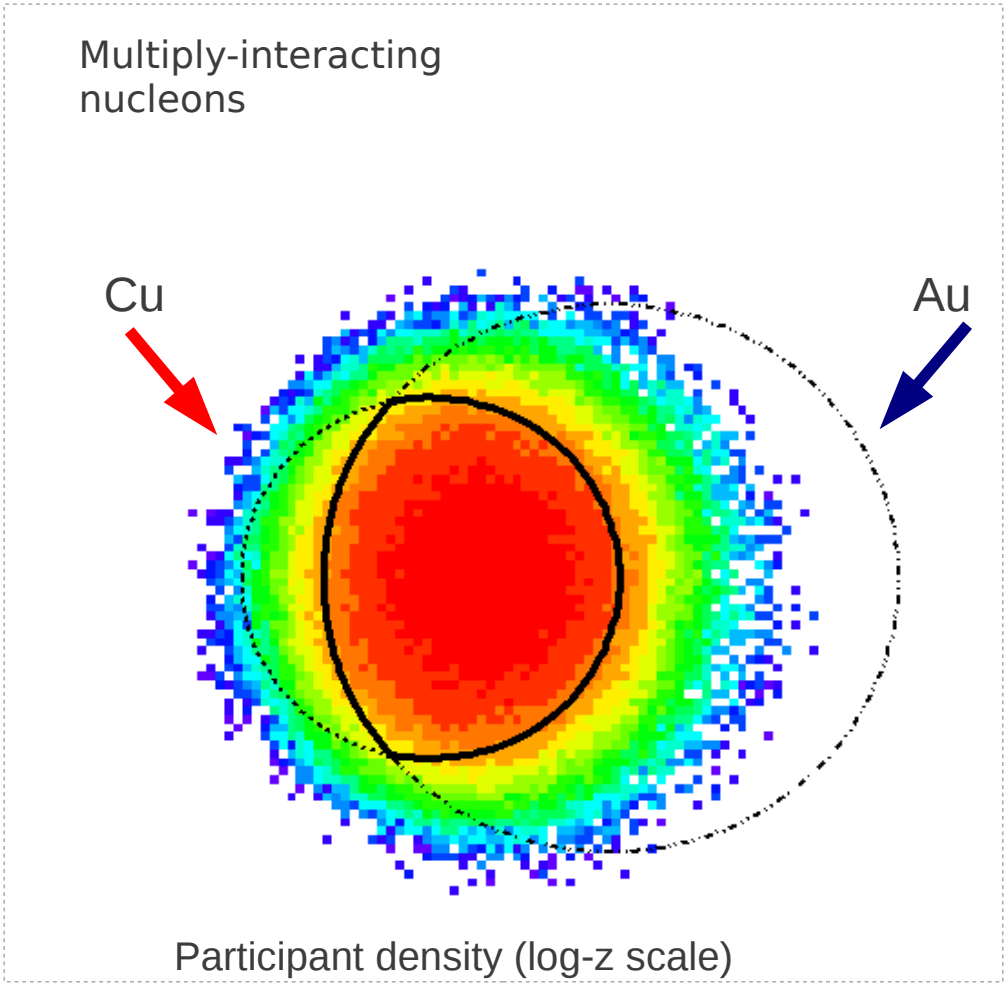
Test of the initial geometry

Left/Right asymmetry

- Core: asymmetric density profile
- Corona: larger on Au-side

Study

- Naturally arising odd harmonics
- Central collisions:
  - Cu completely swallowed no Cu-going corona



Glauber model CuAu, b=4fm

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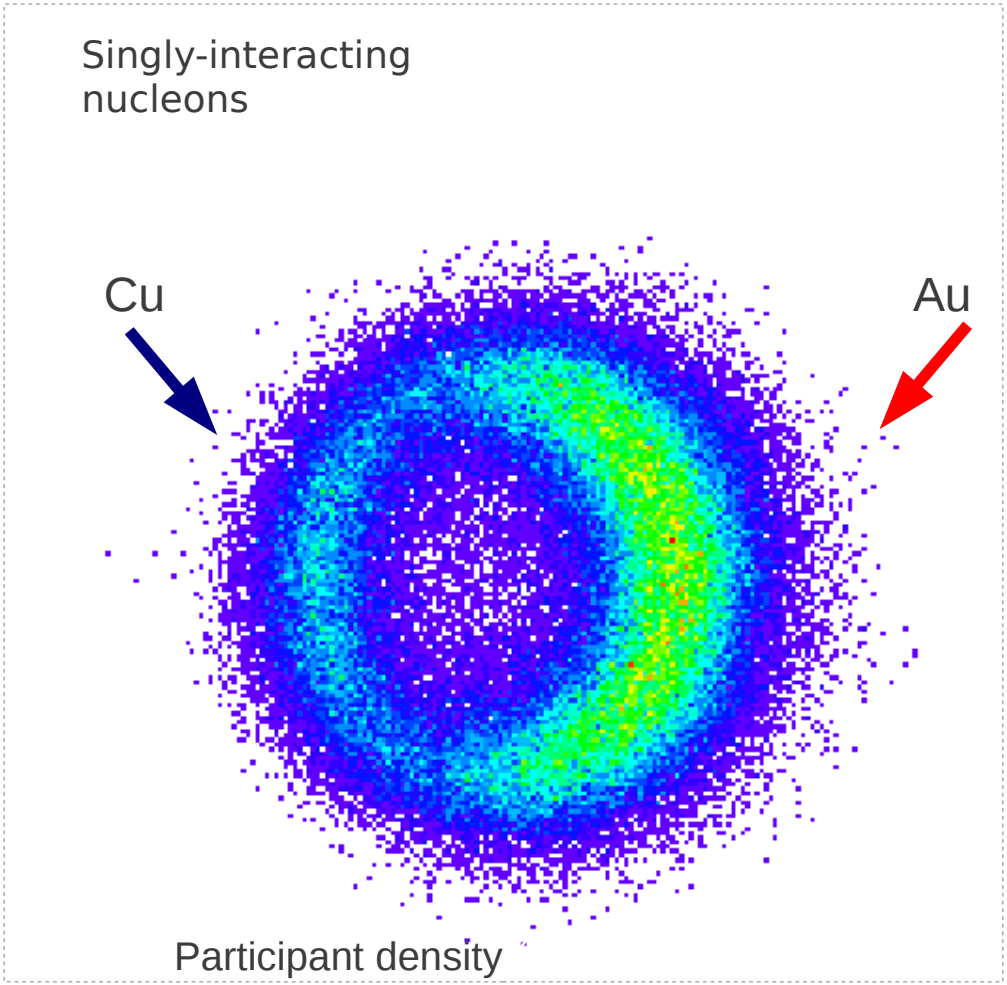

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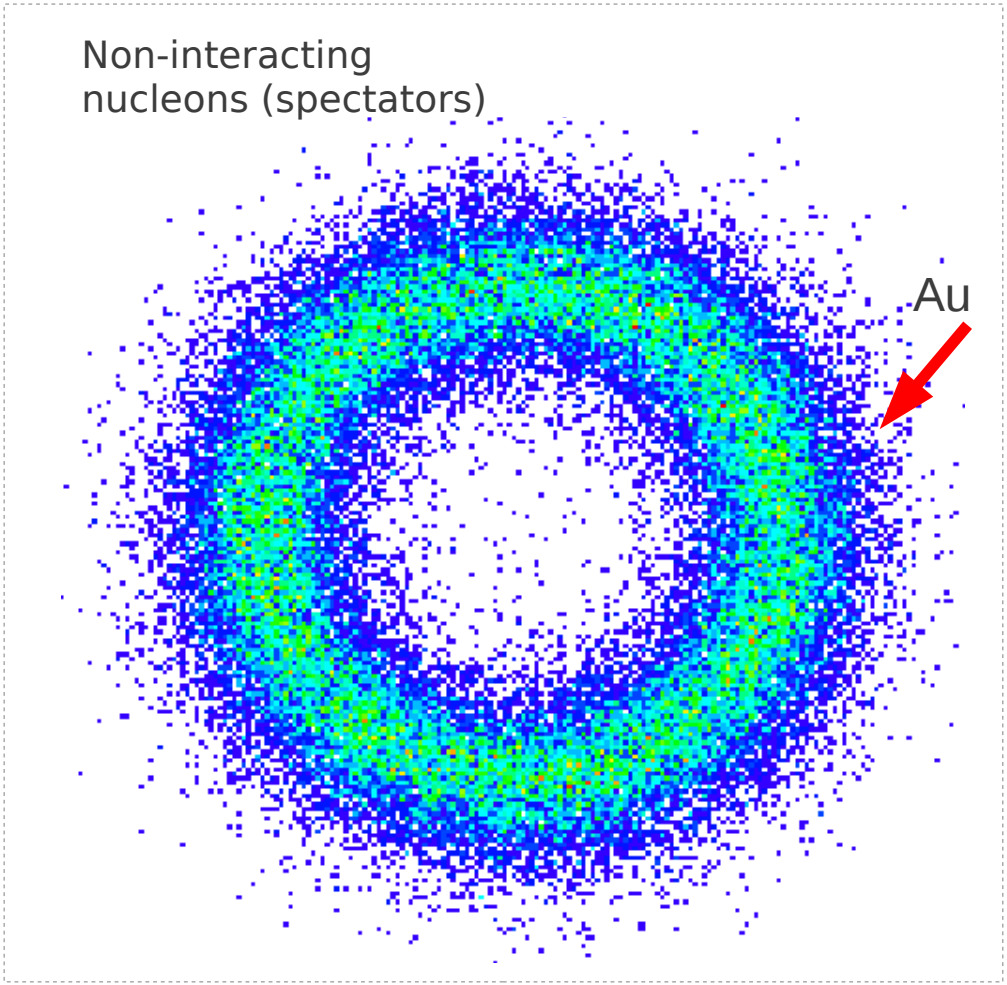
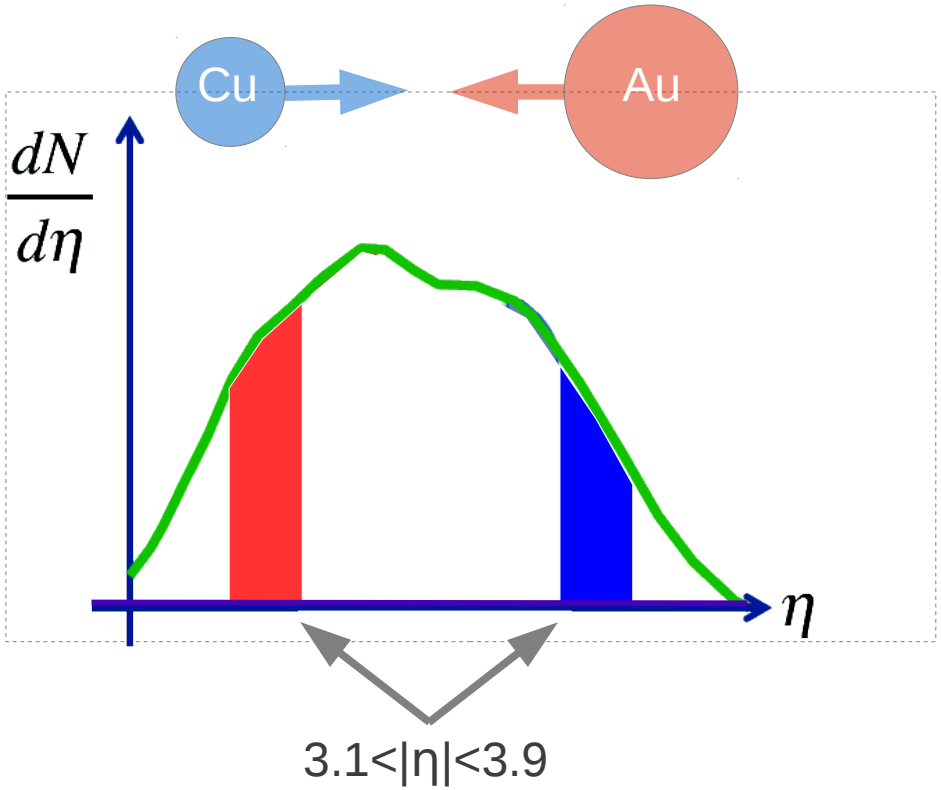


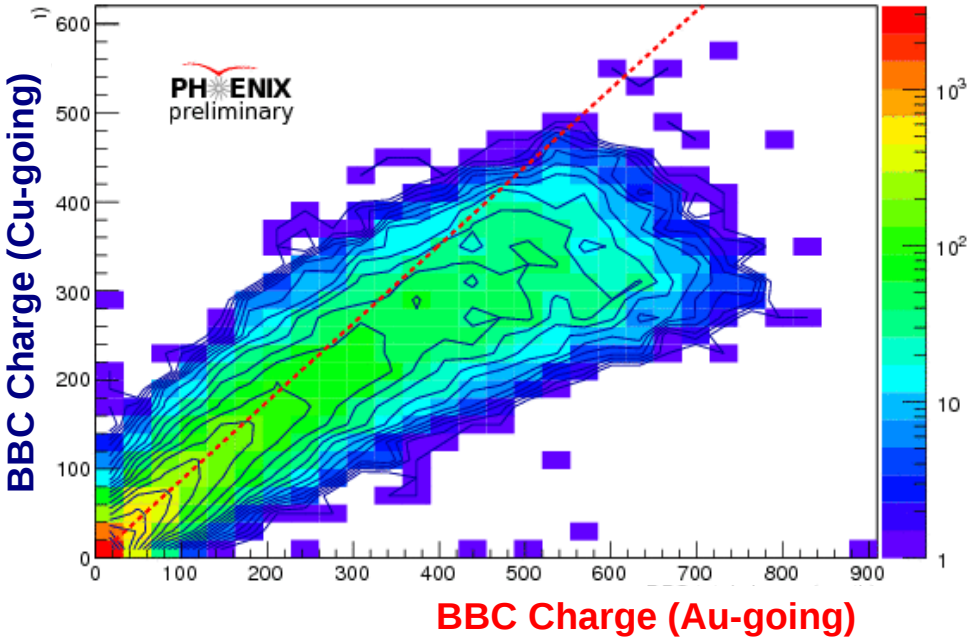
Glauber model CuAu, b=0fm

Global particle production

BBC charge distribution

- Initial forward/backward asymmetry → reflected in the particle production

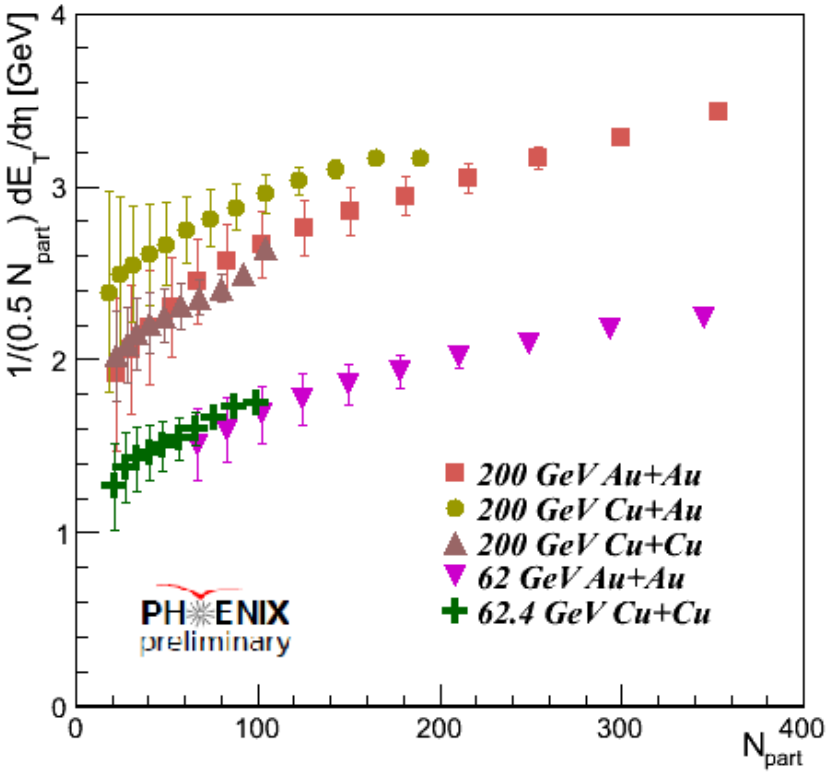




Transverse energy density, E_T

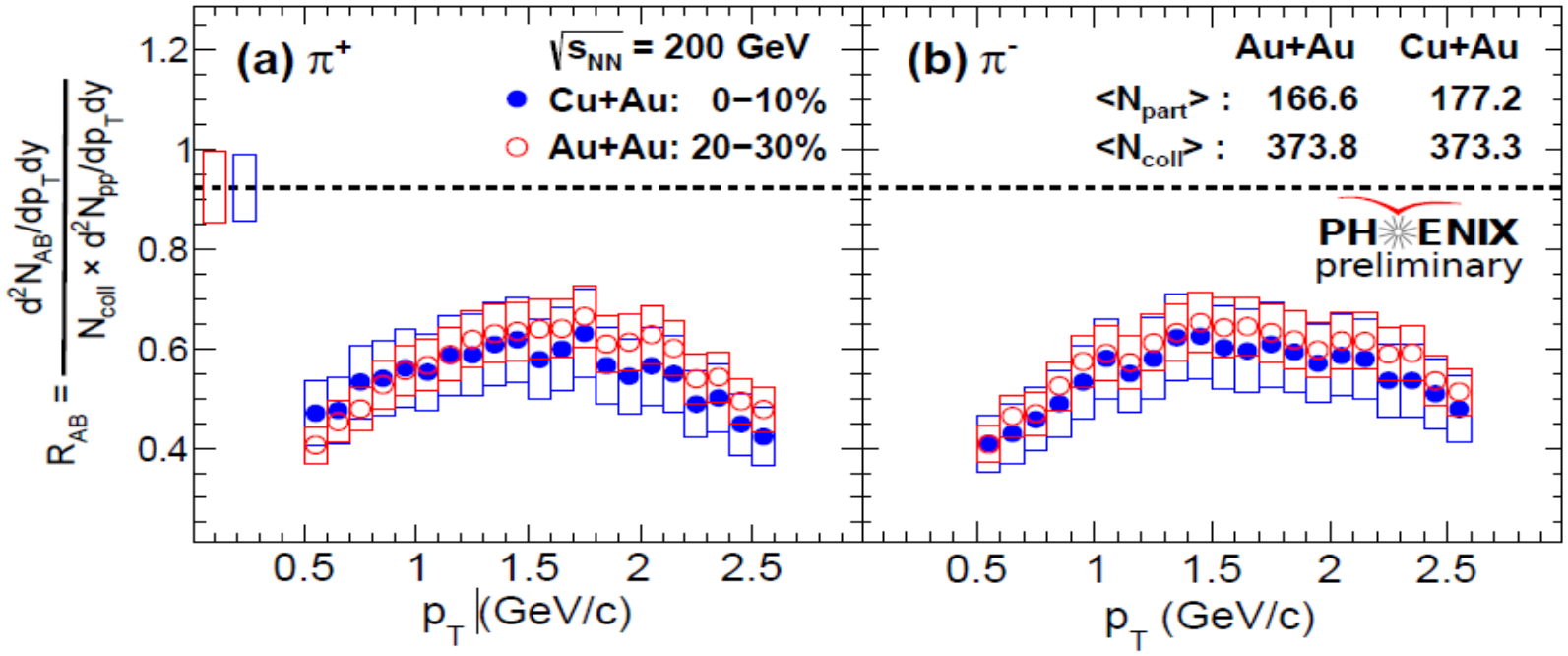
- E_T production is independent of the collision system
  - Similar E_T in Cu+Cu and Au+Au at the same N_{part}
  - Higher E_T in Cu+Au reflects larger core at the same N_{part}

Mid-rapidity
$|\eta| < 0.35$



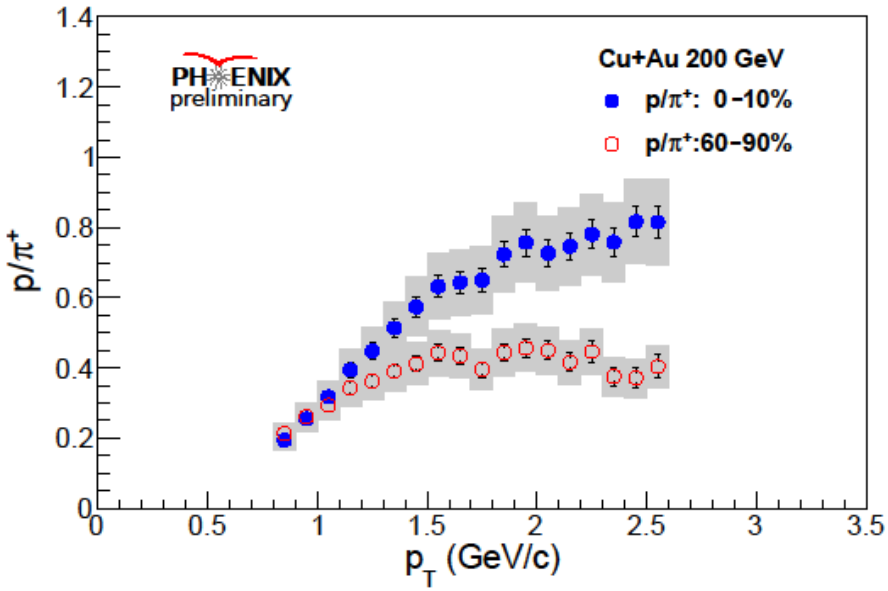
Charged particle spectra

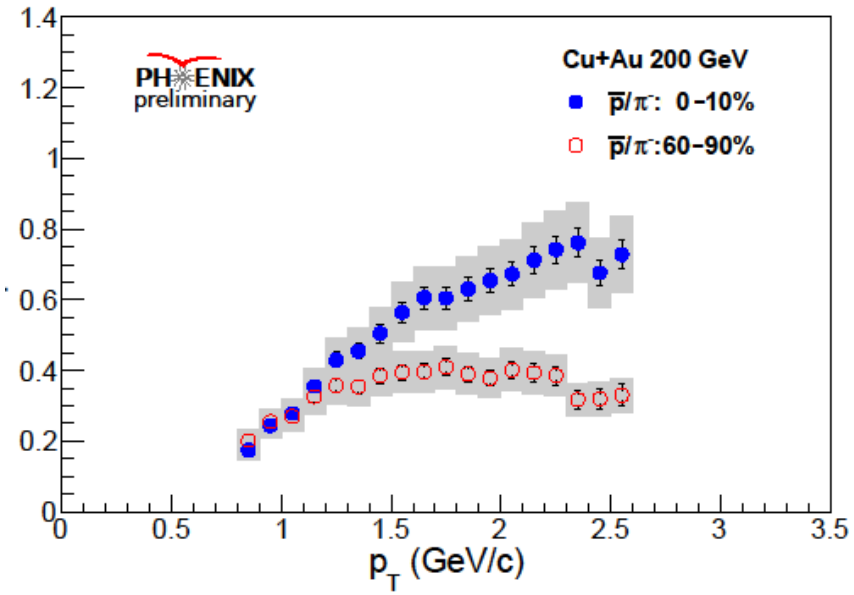
- Pion nuclear modification factor, R_{AB}
  - Cu+Au comparable to Au+Au at the same N_{coll} values.



Baryon to meson ratio

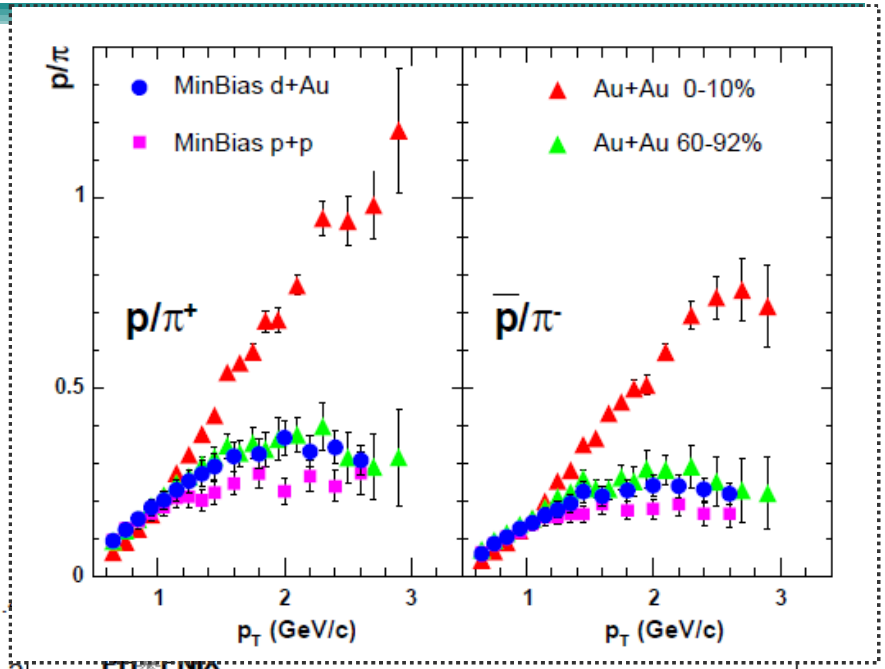
- Significant baryon enhancement in central collisions
  - For both positive and negative ratios.

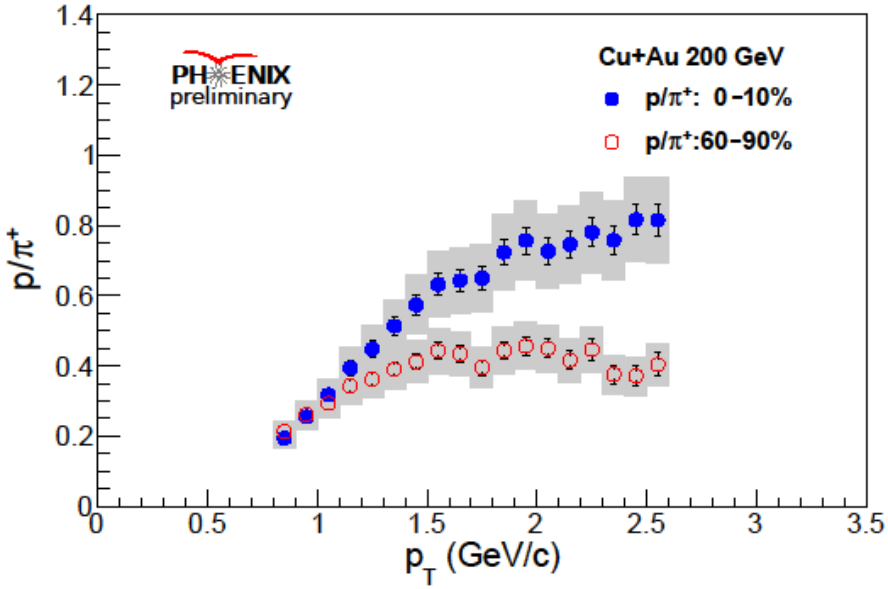


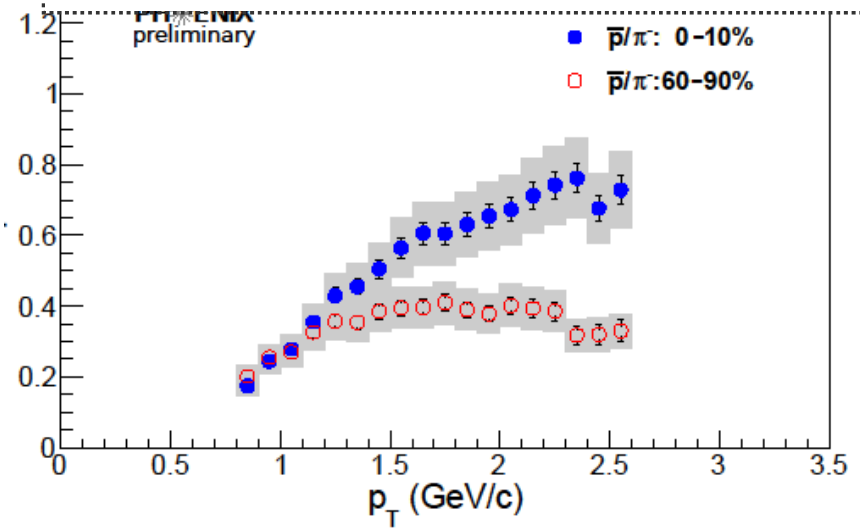


Baryon to meson ratio

- Significant baryon enhancement in central collisions
  - For both positive and negative ratios.
  - Similar to Au+Au and Cu+Cu at the same energy.



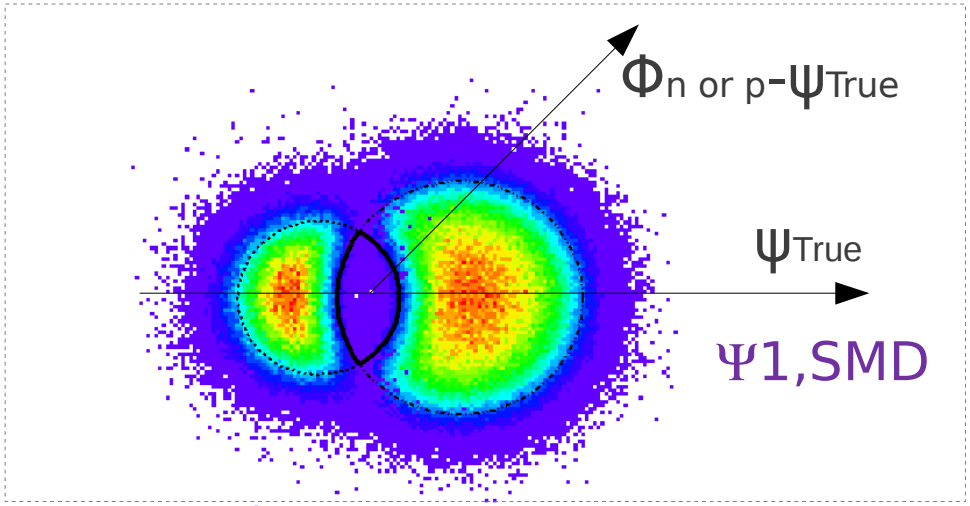


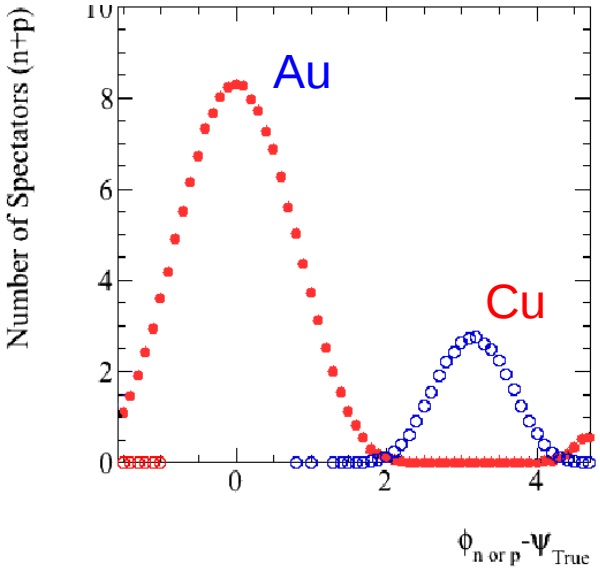


Azimuthal particle production

v_n measurements in Cu+Au

- Asymmetric density profile will lead to asymmetric pressure gradient
  - Measure particle production relative to the Spectator(true) reaction plane.
- In data
  - Use the shower max in the ZDC (neutron).
  - Direction decided by the Au spectators.
  - Ψ1,SMD: combination of ***Ψ1,SMDSouth*** with flipped ***Ψ1,SMDNorth***.





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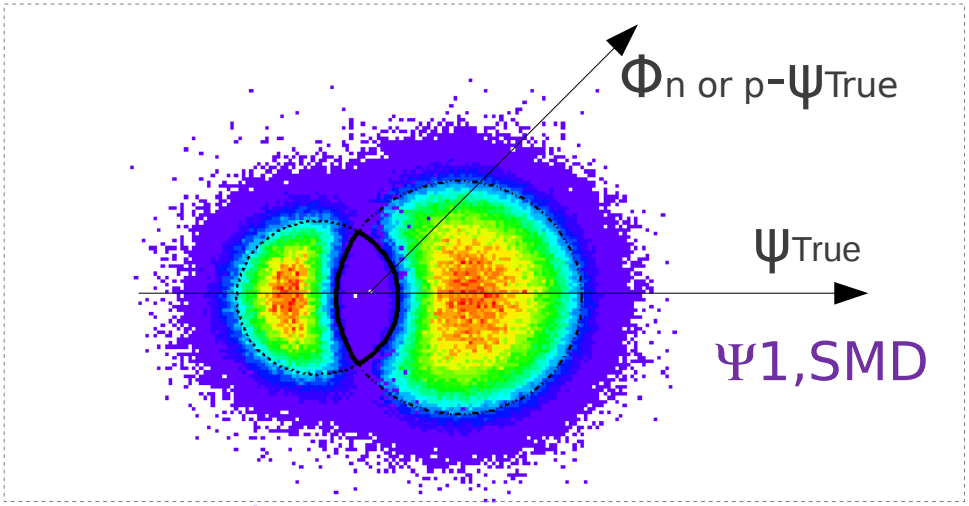
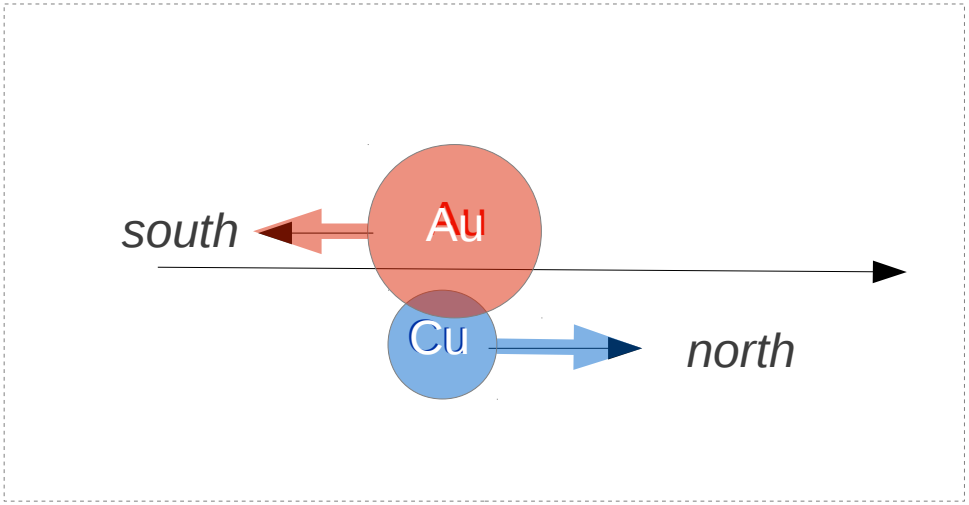
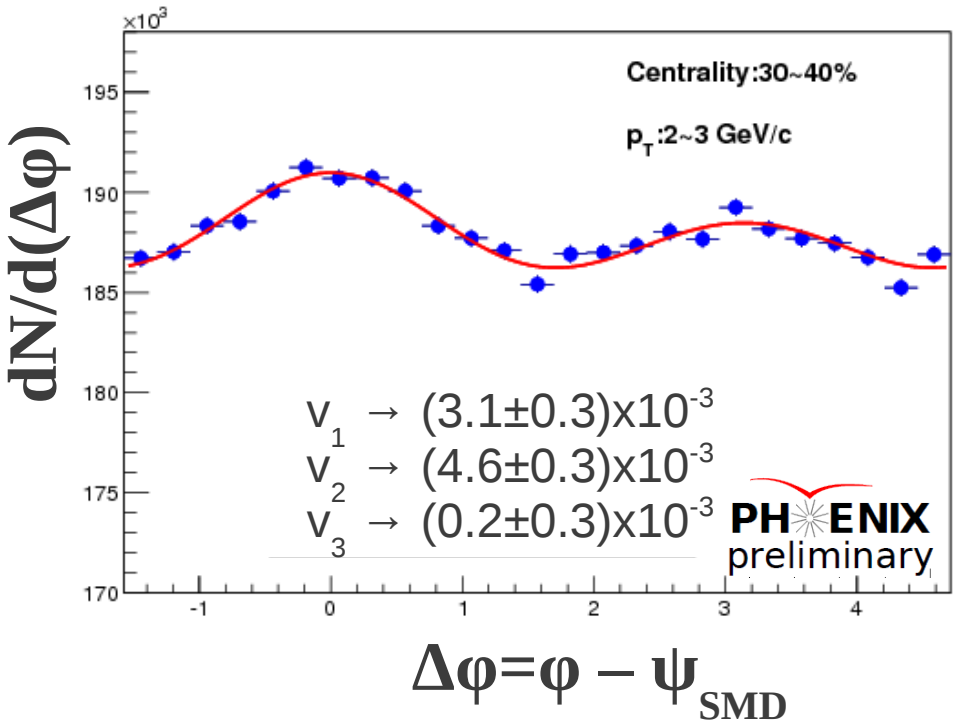




Add little detector cartoon

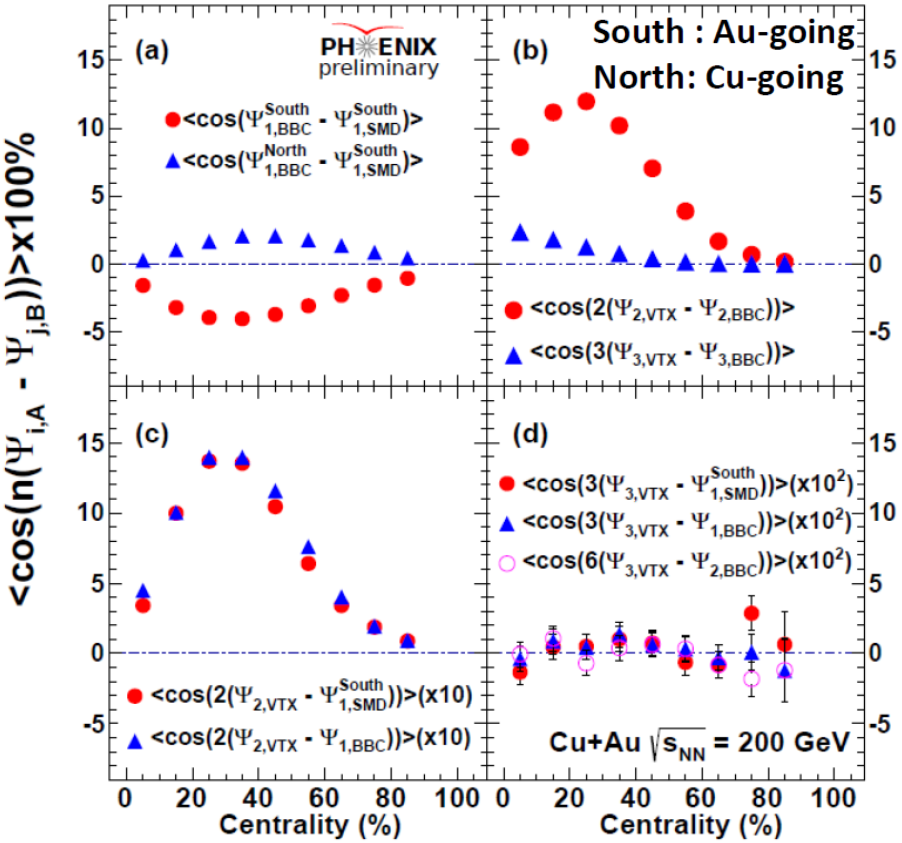
Hadron v_n

- An asymmetric $dN/d\Delta\phi$ distribution is observed with Ψ_1,SMD
  - more particles emitted from the Au side than from the Cu side.
- Hadrons at mid-rapidity exhibit large v_1 (not observed in Au+Au) and v_2 .
- Not consistent with a large v_3.



Event plane correlations

- Correlation ($\Psi_{1,BBC}$: $\Psi_{1,SMD}$)(S) stronger than ($\Psi_{1,BBC}$: $\Psi_{1,SMD}$)(N)
  - v_1 larger on Au-going side
- Ψ_3 expected to correlate with Ψ_1 and Ψ_2 from the initial asymmetric geometry
  - very weak raw correlation seen in data

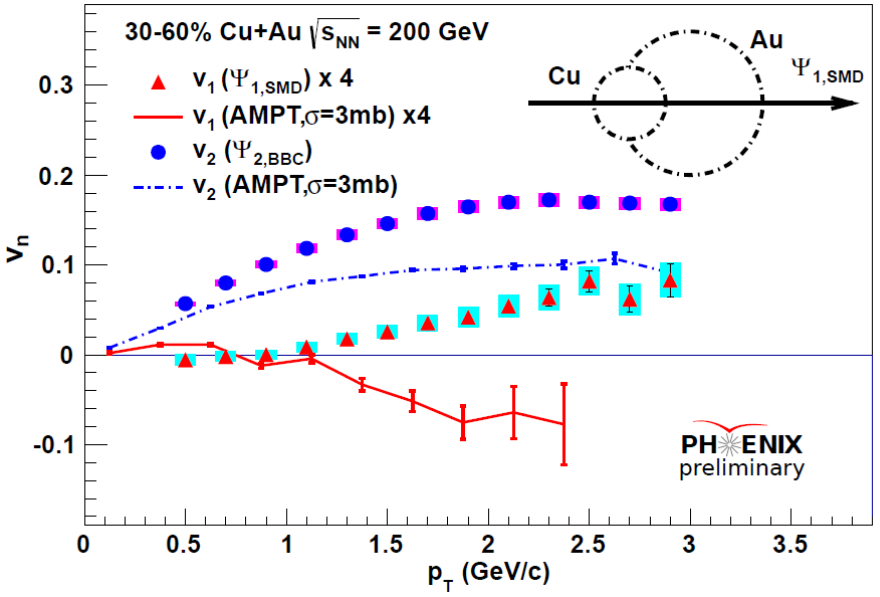


Modeling v_n

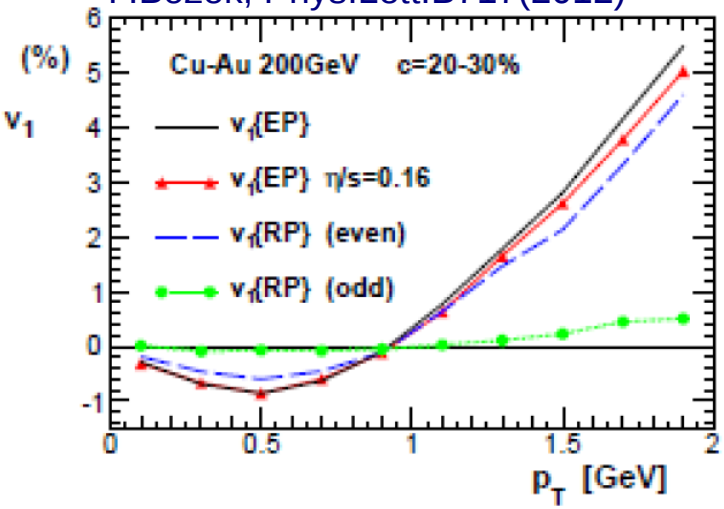
- Comparison with AMPT at mid-rapidity
  - v_2 observed trends are expected.
  - Stronger v_1 (zero in AuAu)
    - Wrong sign.
    - Naively explained by the corona.

- New models (E-by-E hydro) attempt to reproduce the v_1 sign in data.

AMPT (v1.21) calculations by H. Ruiz and J. Nagle with string melting cross section (σ) of 3 mb



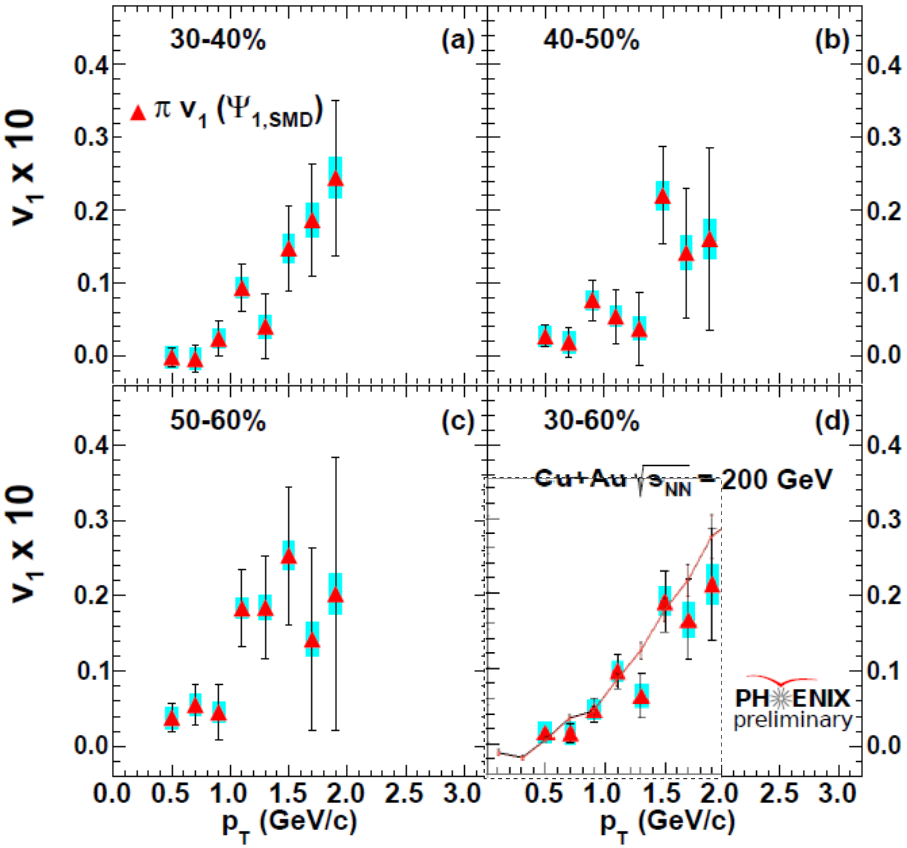
P.Bozek, Phys.Lett.B717(2012)



Hadron v_1

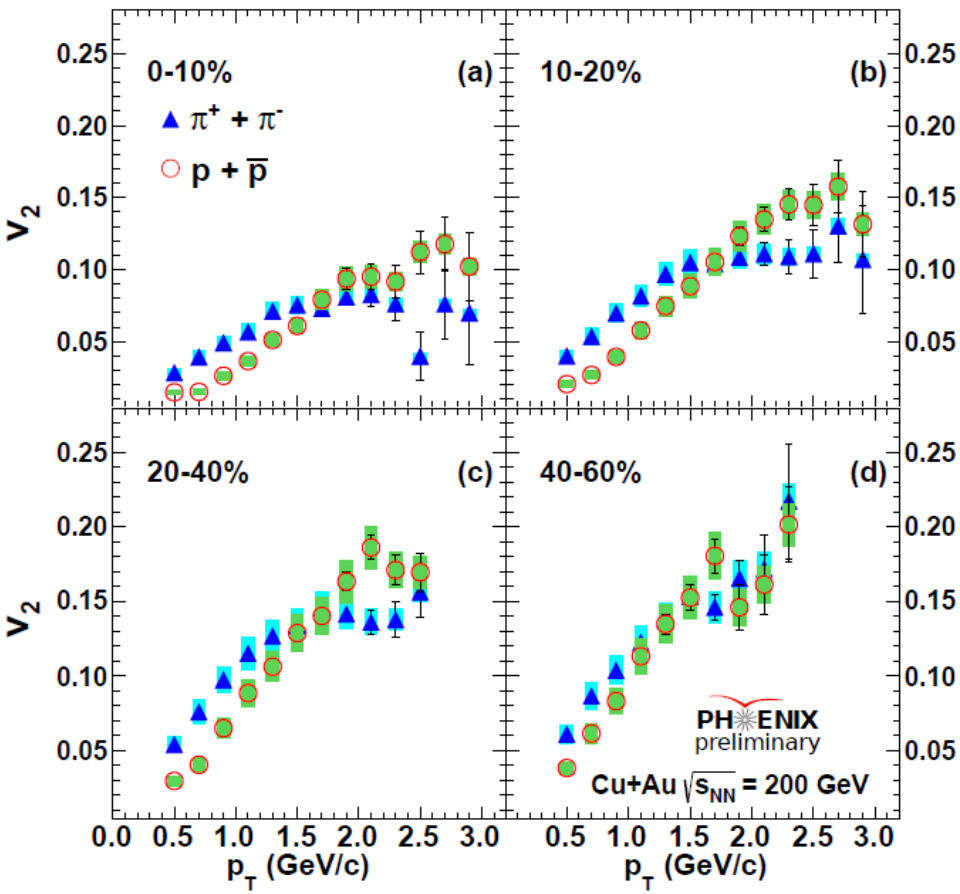
- Sizable positive pion v_1 is observed at p_T > 1GeV/c at mid-rapidity
  - Increases with p_T.
  - Observed in all centrality bins.
  - May be due to asymmetric density profile.
  - Need more statistics for proton.

- New models (E-by-E hydro) attempt to reproduce the v_1 sign in data
  - Hashimoto, Murase and Hirano, JPS13



Hadron v_2

- The v_2 of pions and protons are measured as a function of p_T and centrality
  - The v_2 measured from Ψ_1 and Ψ_2 are consistent with each other (Ψ_{BBC}).



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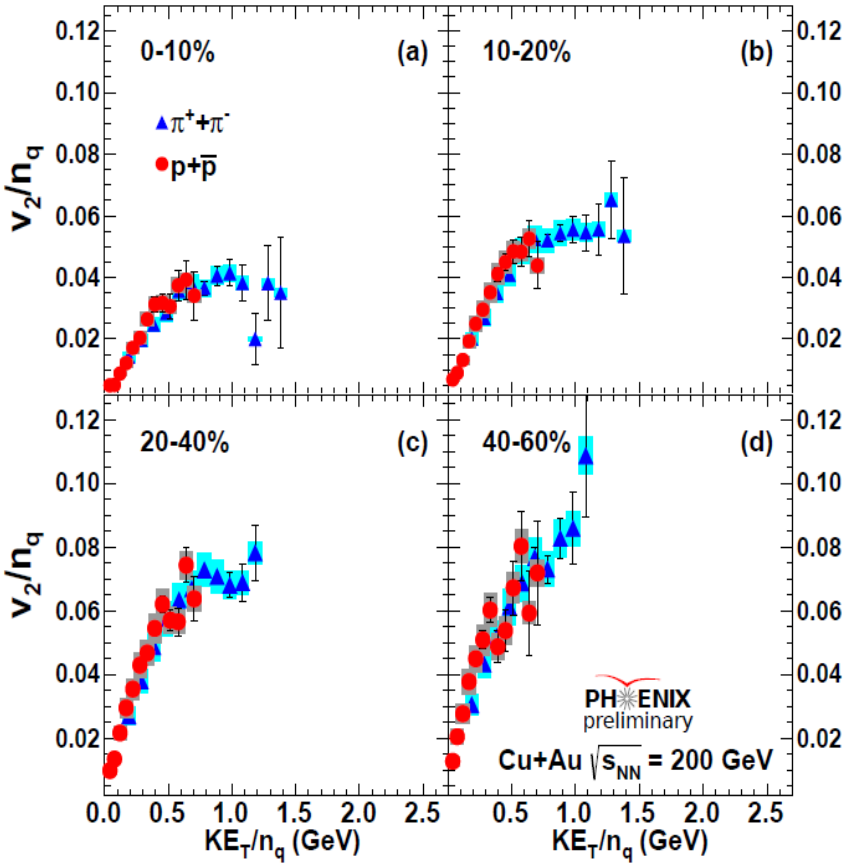
  - The v_2 measured from Ψ_1 and Ψ_2 are consistent with each other (Ψ_{BBC}).
  - n_q scaling holds in Cu + Au collisions at 200 GeV.



Hard probes – J/ψ

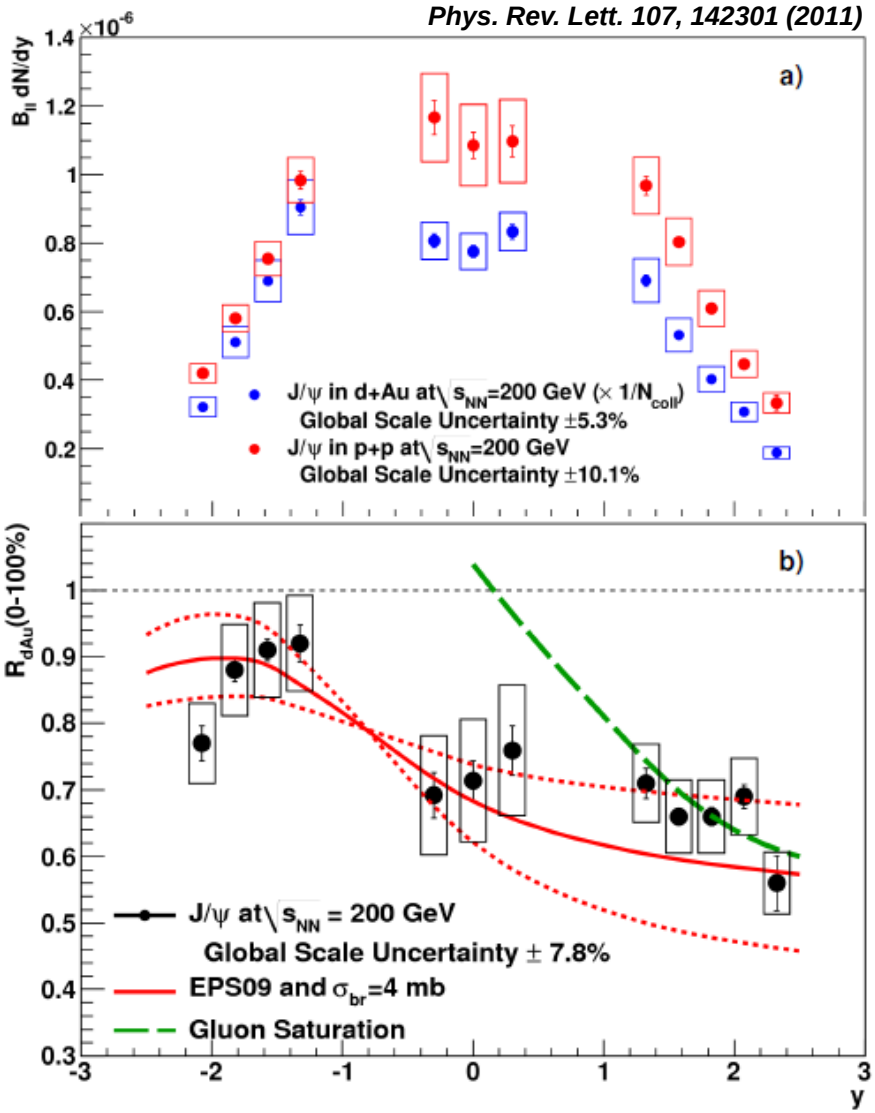
- Do the observed initial geometrical effects in charged hadrons hold for hard probes?

J/ψ production

- d+Au → cold nuclear matter effect
  - Forward/backward asymmetry
  - “suppression” at forward rapidity

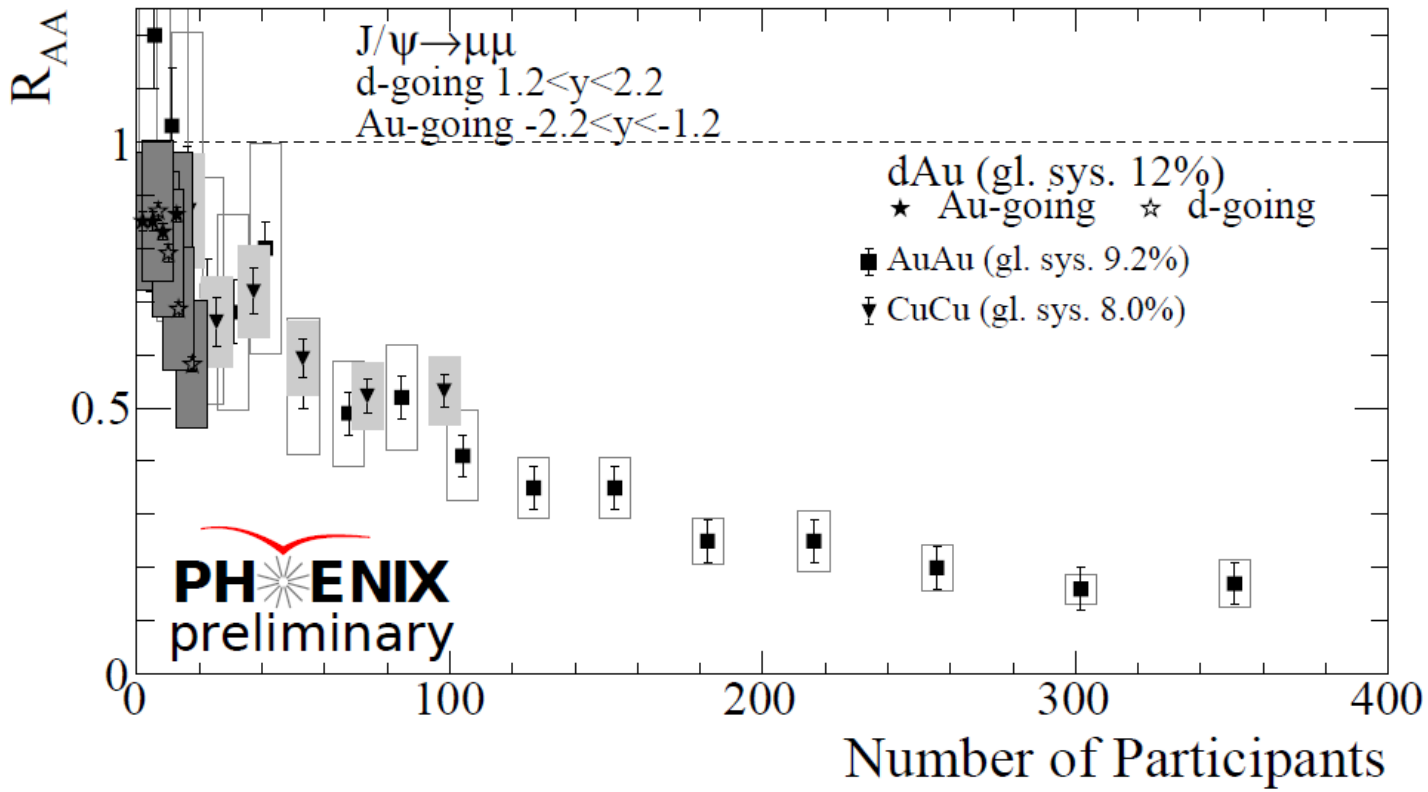
- Add more variation to the initial geometry …
- Cu+Au
  - Forward/backward momentum asymmetry like d+Au, but also includes hot nuclear matter
  - Left-right asymmetry – test of possible core/corona effects

Phys. Rev. Lett. 107, 142301 (2011)



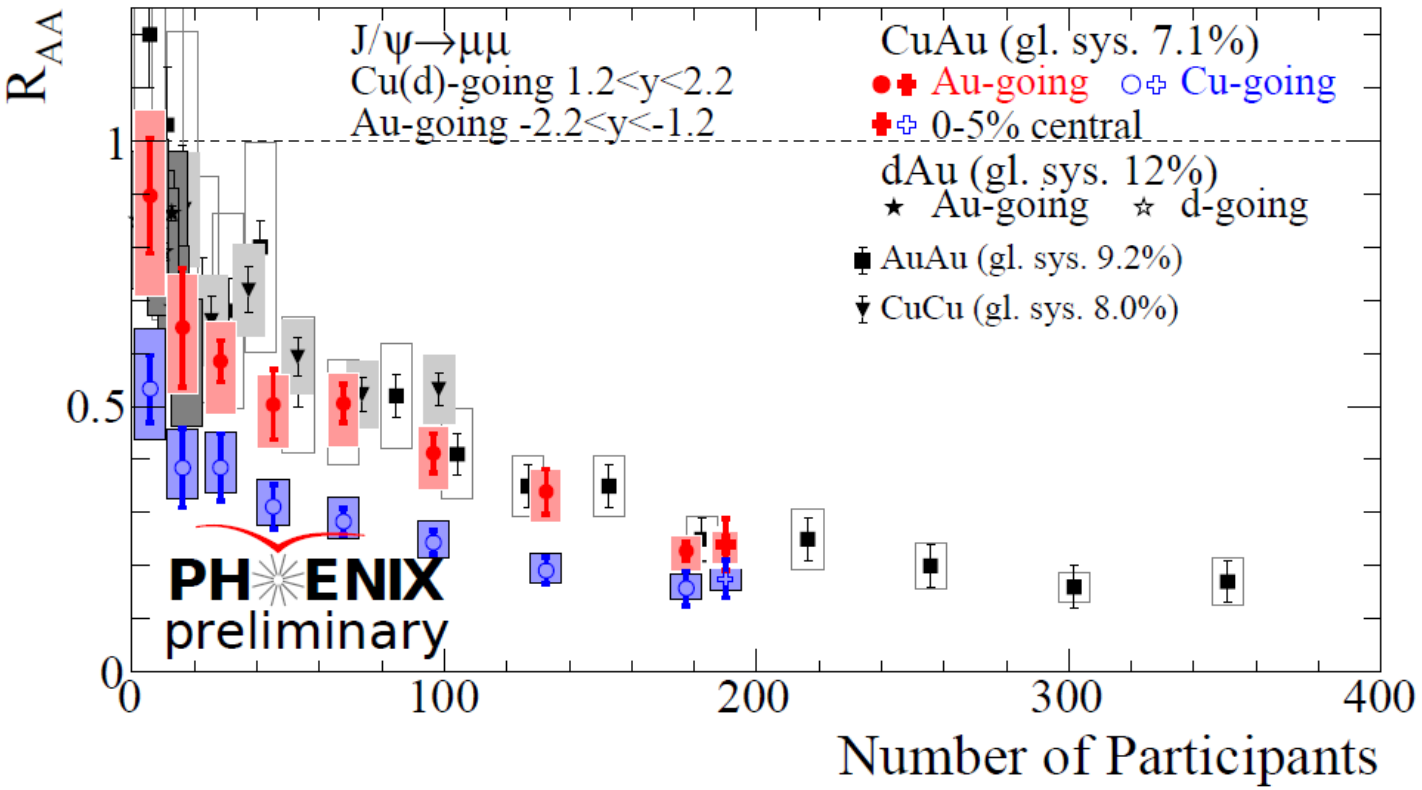
J/ψ Nuclear Modification Factor (R_{AA})

- Cu+Cu and Au+Au → CNM and final-state effects
  - Suppression observed
  - Independent of collision system



J/ψ R_{AA} in Cu+Au

- Same suppression as Au+Au/Cu+Cu measured in the Au-going direction
- More suppressed in the Cu-going direction
- J/ψ not significantly more suppressed in completely swallowed-Cu (top 5%)



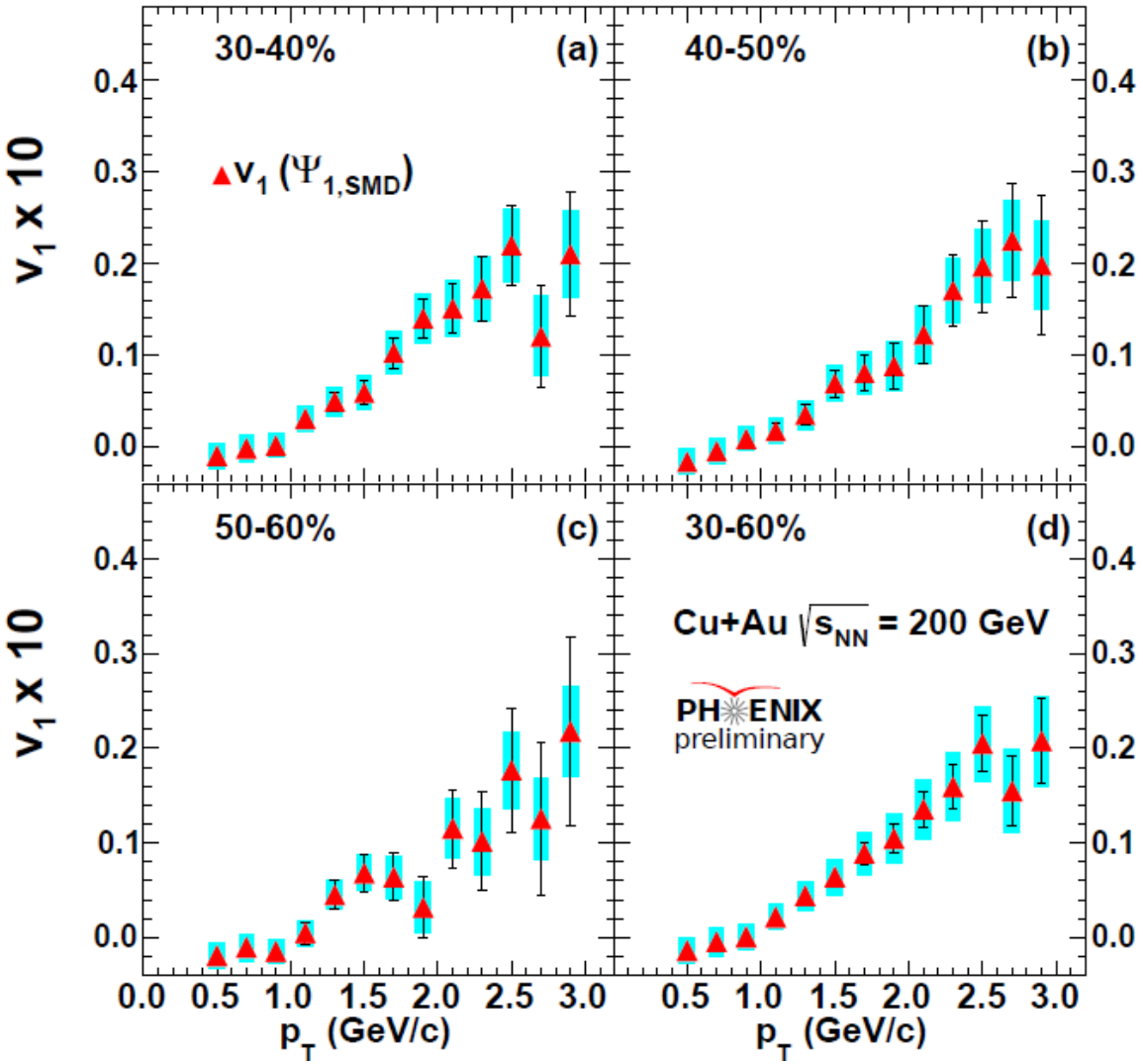
Outlook

- Cu+Au, as an asymmetric system, provides the unique opportunity to test the relation between the initial collision geometry and the final particle production

- Some undergoing and near-term planned analyses:
  - π^0 spectra to high p_T
  - direct photons
  - heavy quark flow
  - J/ψ side-to side production
  - jet production
- New detectors: VTX and FVTX

Backup

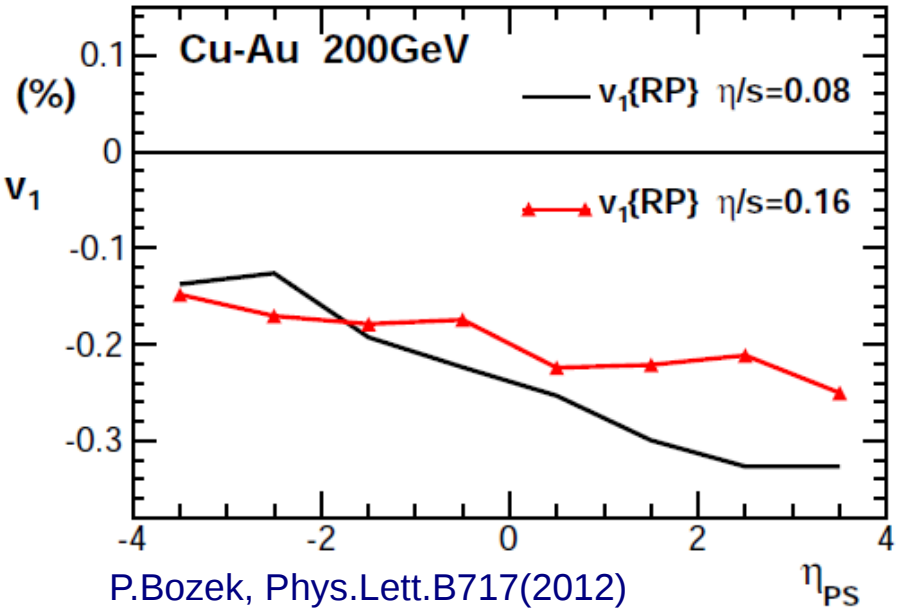
Hadron v1


30-40%
(a)
40-50%
(b)
50-60%
(c)
30-60%
(d)
v_1 ($\Psi_{1,SMD}$)
Cu+Au $\sqrt{s_{NN}}$ = 200 GeV
PHENIX
preliminary
v_1 x 10
p_T (GeV/c)
0.0
0.1
0.2
0.3
0.4
0.5
1.0
1.5
2.0
2.5
3.0

v_1 models

- The direction of ψ_{1RP} is in the direction of the Au nucleus
  - At mid-rapidity v_1 is negative → more particles flow in the direction of the Cu half of the plane.
- Measurable v_3

Integrated pt, 20-30%



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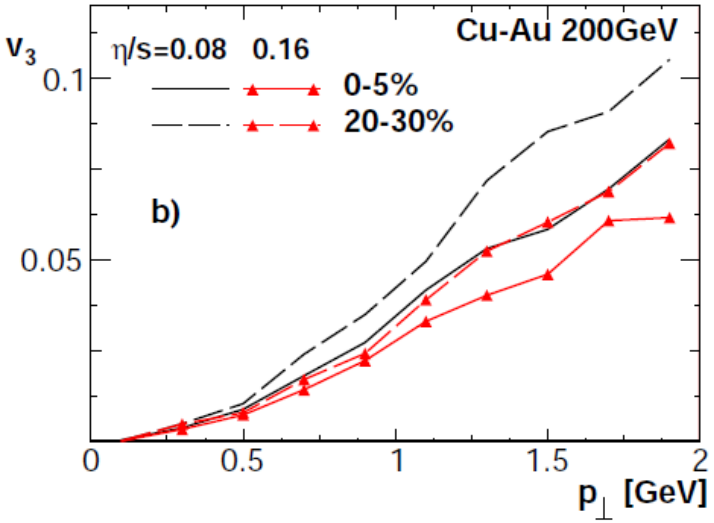
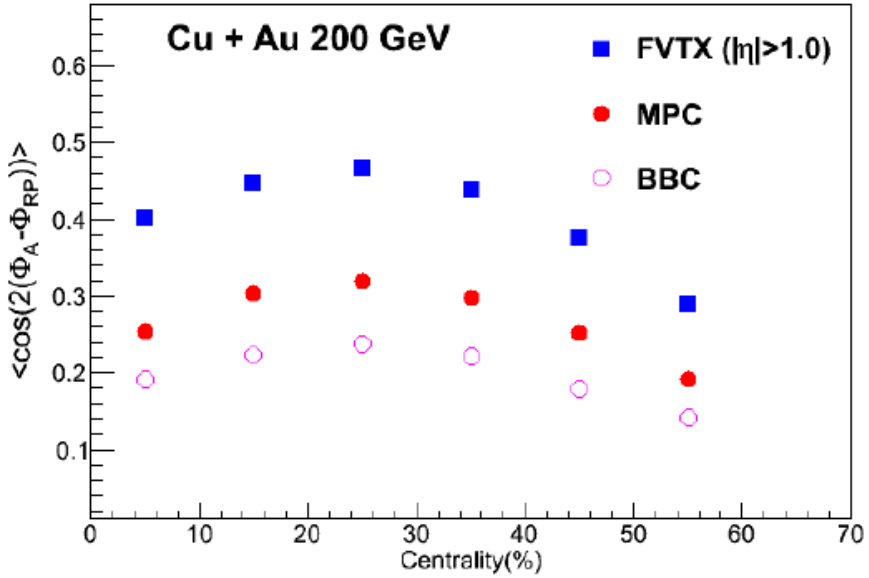
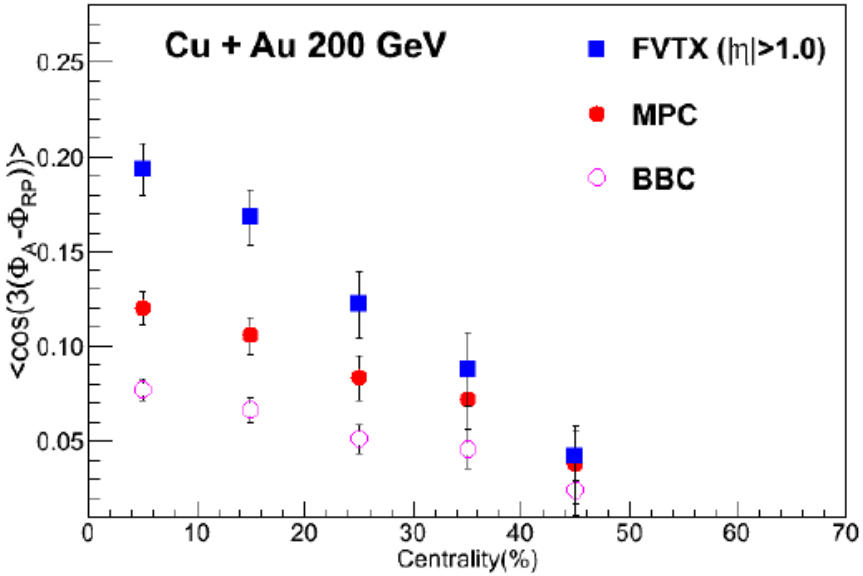
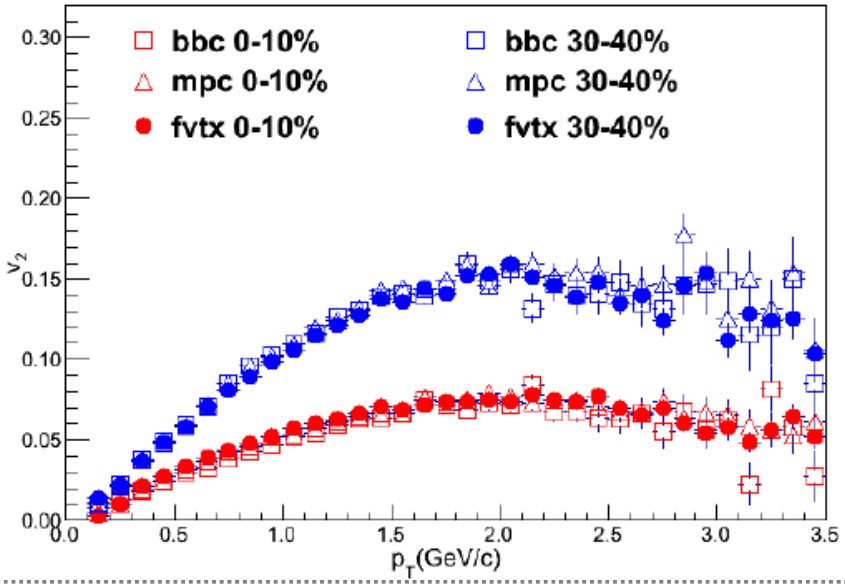


FVTX Event Plane





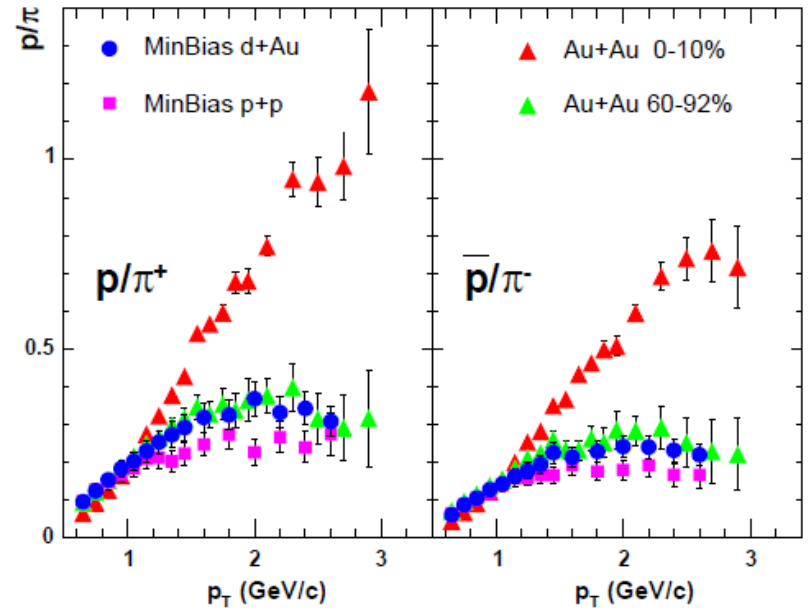


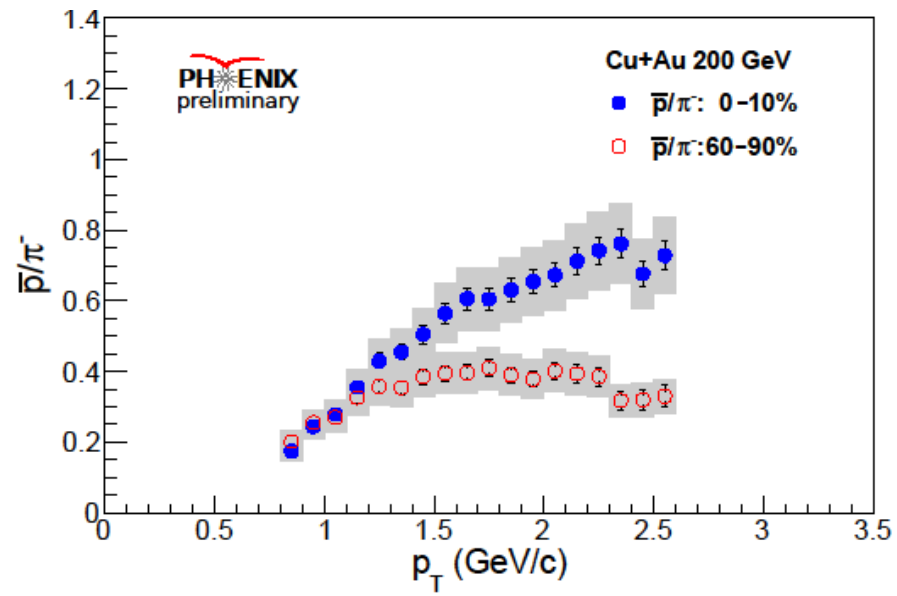
1.Event plane resolutions are significantly improved by FVTX detector for Ψ_2 and Ψ_3

2. The measurements of v_3 and v_4 in CuAu will come out soon with FVTX EP and full statistics

Baryon to meson ratio

- Pbar/p ratio
  - ***in symmetric systems*** depends on √s, with small centrality and p_T dependence
    - 200 GeV ~ 0.8
    - 62.4 GeV ~0.5
  - in Cu+Au at 200 GeV ?
    - Need feed down corrections





RHIC ions – 6 species and 15 energies to date

$^{238}U^{92+}$–$^{238}U^{92+}$ ♑ first time in 2012, 3 weeks physics, complete

96.4 GeV/nucleon

$^{197}Au^{79+}$–$^{197}Au^{79+}$

3.85, 4.6, 5.75, 9.8, 13.5, 19.5, 27.9, 31.2, 65.2, 100.0 GeV/nucleon

$^{63}Cu^{29+}$–$^{197}Au^{79+}$ ♑ first time in 2012, 5 weeks, under way

99.9/100.0 GeV/nucleon

$^{63}Cu^{29+}$–$^{63}Cu^{29+}$

11.2, 31.2, 100.0 GeV/nucleon

d–$^{197}Au^{79+}$

100.7/100.0 GeV/nucleon

p⇝–p⇝

31.2, 100.2, 204.9, 249.9, 254.9 GeV

Can collide any species from protons (polarized) to uranium – with each other or with another species