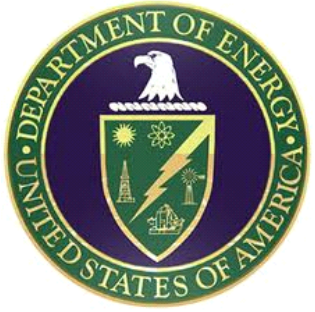
STAR Update Results for U+U Collisions at 193 GeV

Gang Wang (UCLA)
for the STAR Collaboration

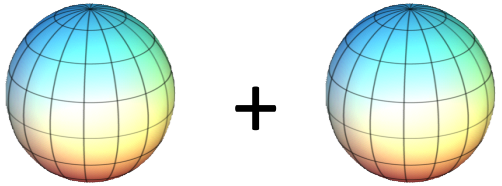


Motivation

The prolate shape of uranium nuclei provides the possibility to study

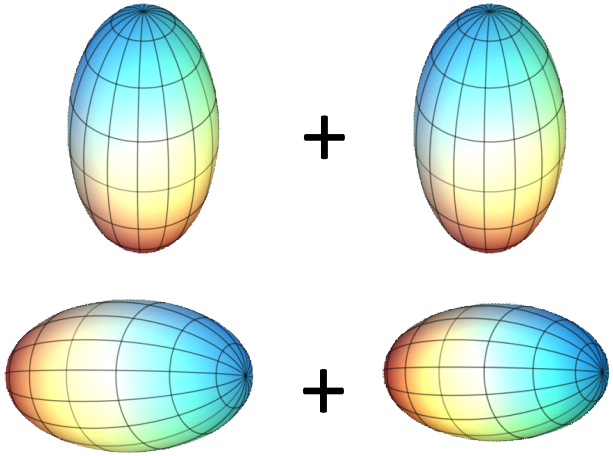
- Particle production mechanism
- Anisotropic flow
  - any difference between Au+Au and U+U?
  - separate body-body and tip-tip in U+U?
- Chiral Magnetic Effects
  - LPV signal induced by v_2?
- Path-length dependence of hard probes
  - heavy flavor

Au+Au Collisions



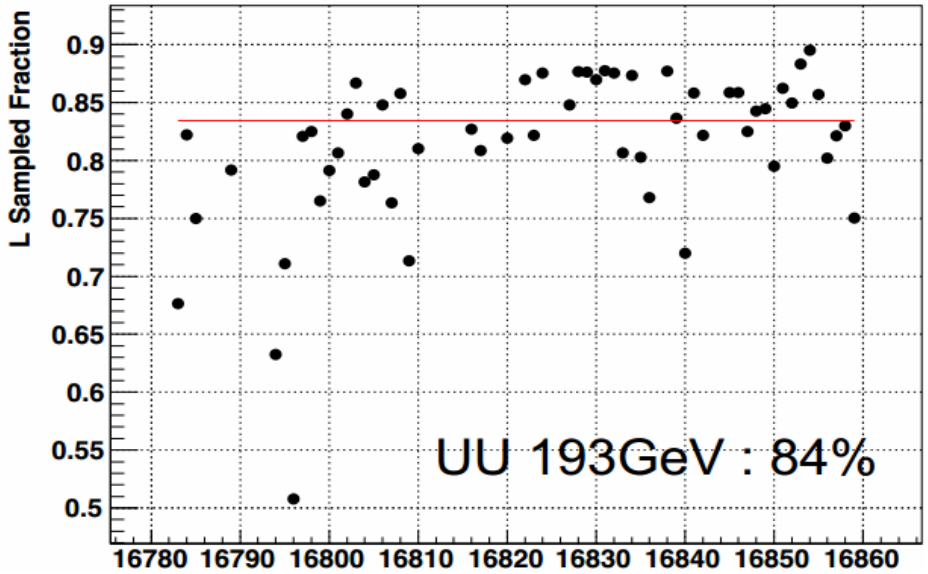
Oblate(on average)

U+U Collisions



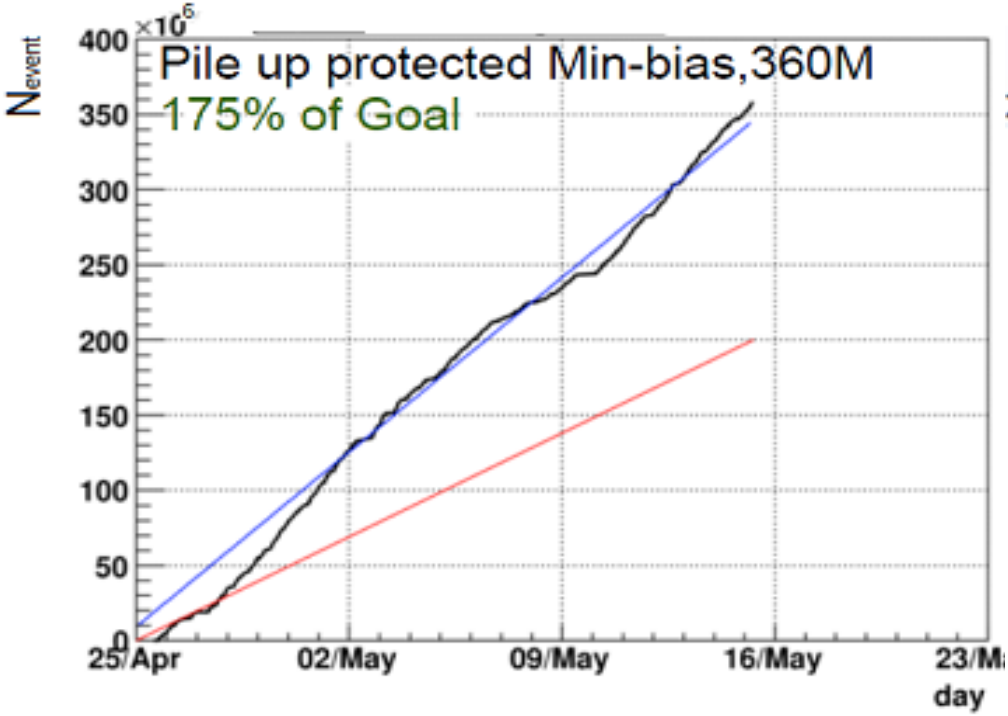
Prolate(on average)

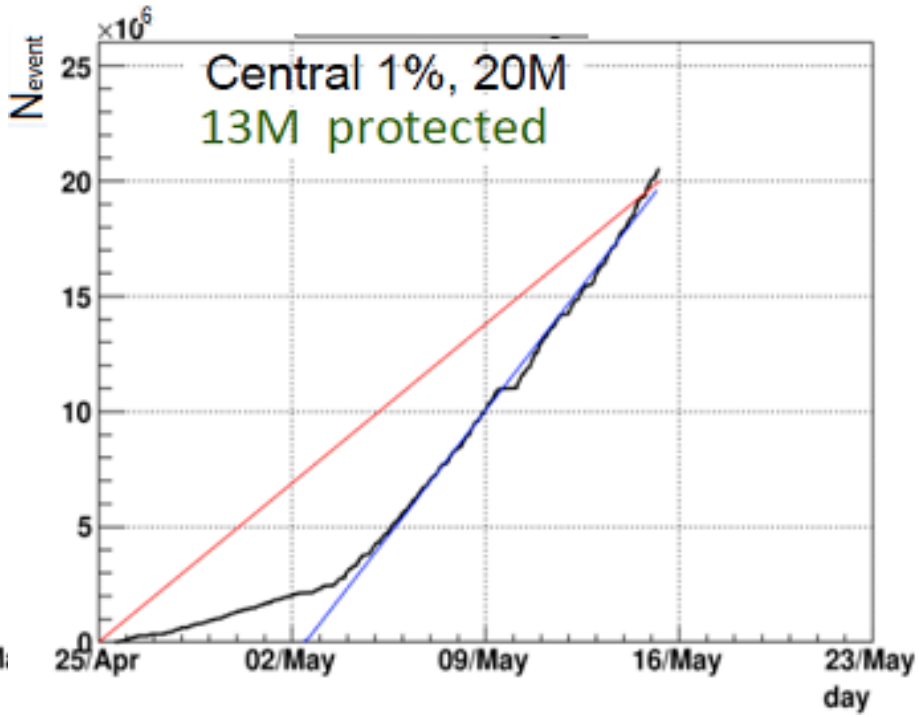
Successful data taking



- RHIC run12: 4 weeks of U+U
- Data taking efficiency: 84%
- Triggers with pile-up protection
- No major detector issues

Can we see any difference between Au+Au and U+U?





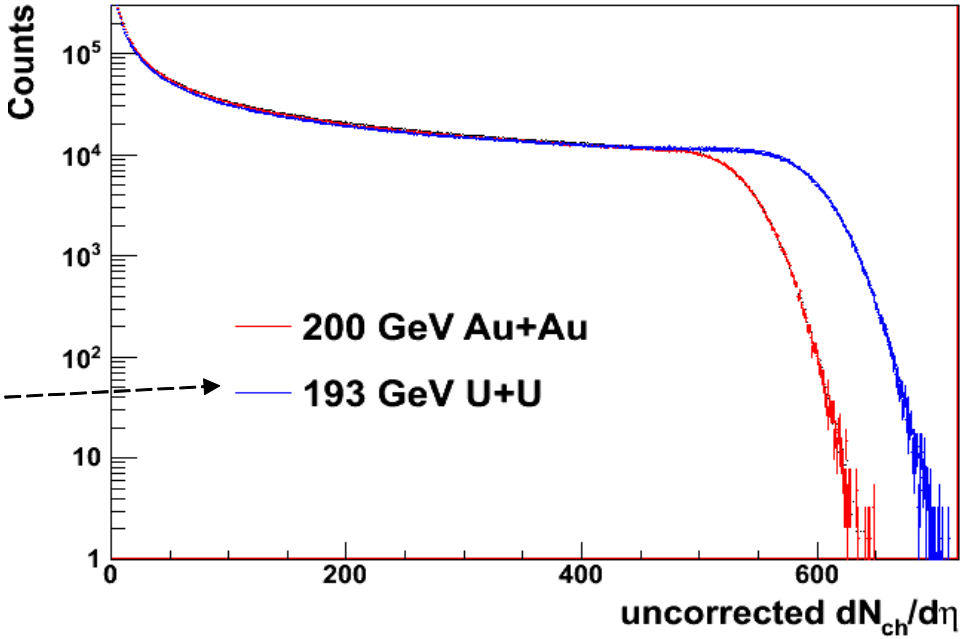
Can we see a difference between Au+Au and U+U?

We often assume multiplicity depends on both the number of participants and the number of binary collisions:

$N_{ch} = n_{pp}*[xN_{coll} + (1-x)N_{part}/2]$.

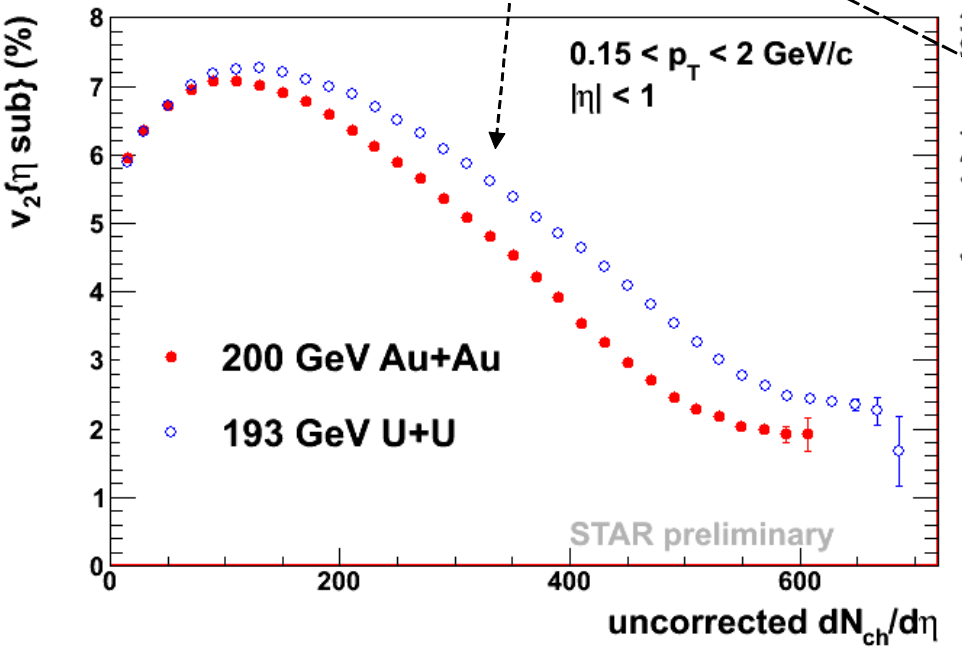
A larger system produces more particles?

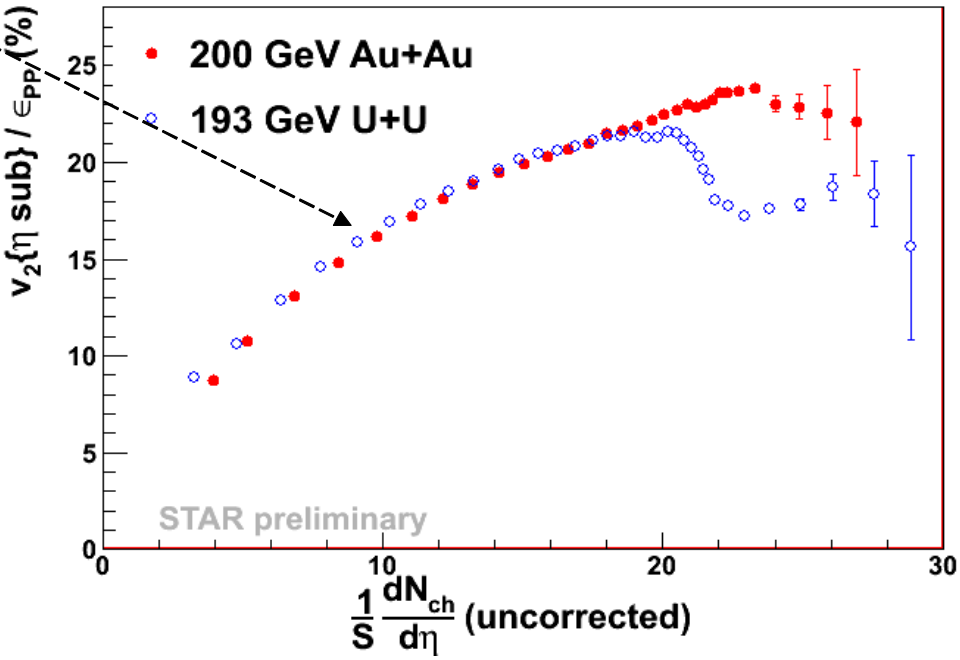
Yes! and well described by Glauber MC

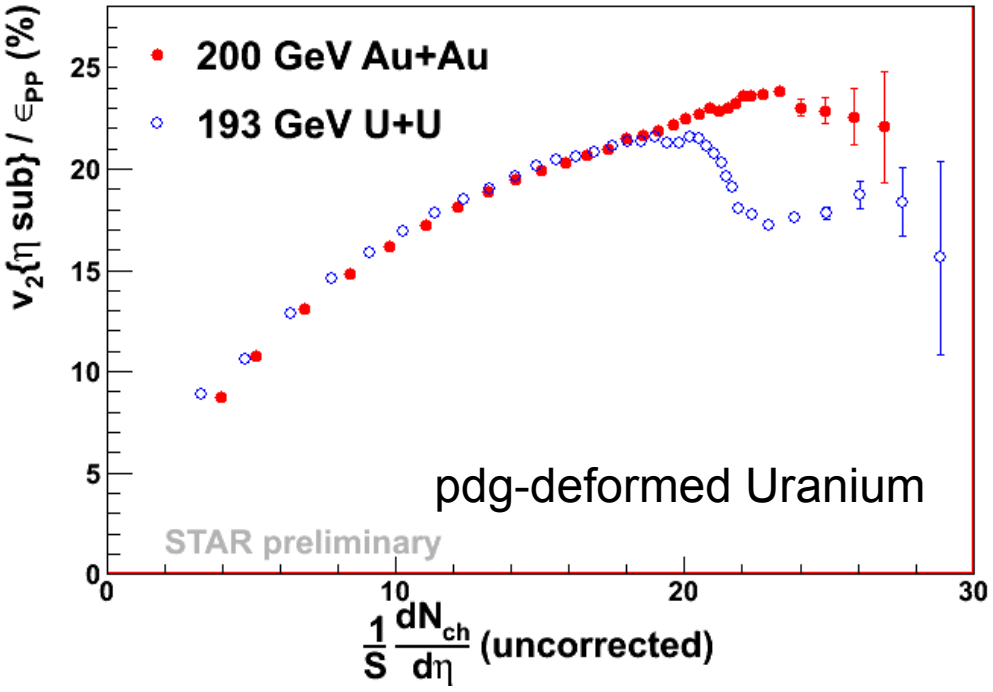


A more deformed system has larger v_2?

It depends on how you look at it...



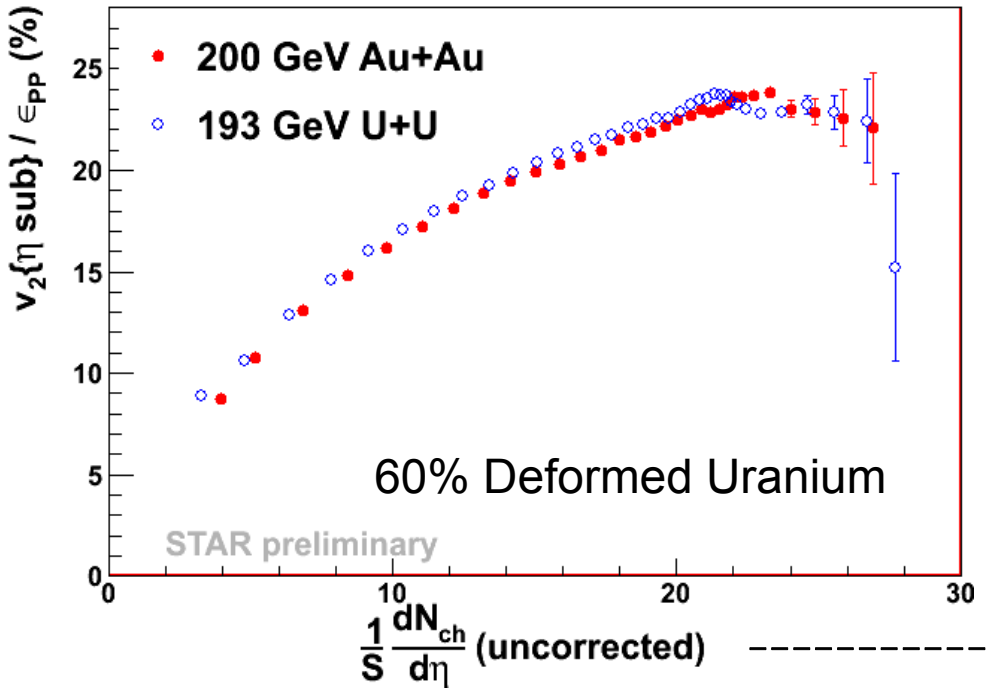


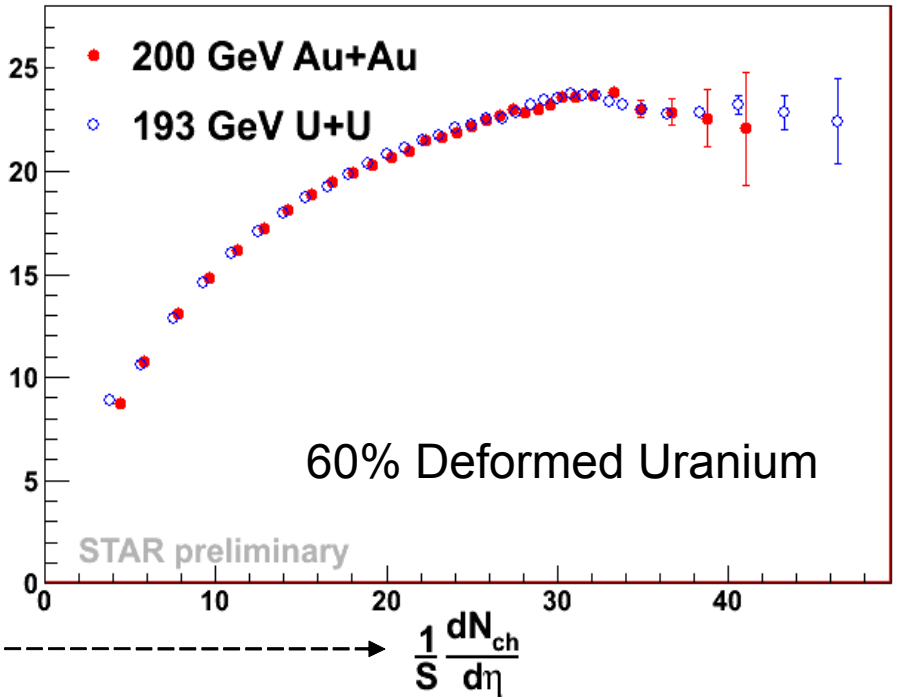


Deformation

How deformed do we need Uranium to be in Glauber?

The pdg values for Uranium are $\beta_2 = 0.28$ and $\beta_4 = 0.093$.
To match the Au+Au curve, I need to scale them down by ~40%.
(a very convenient way)

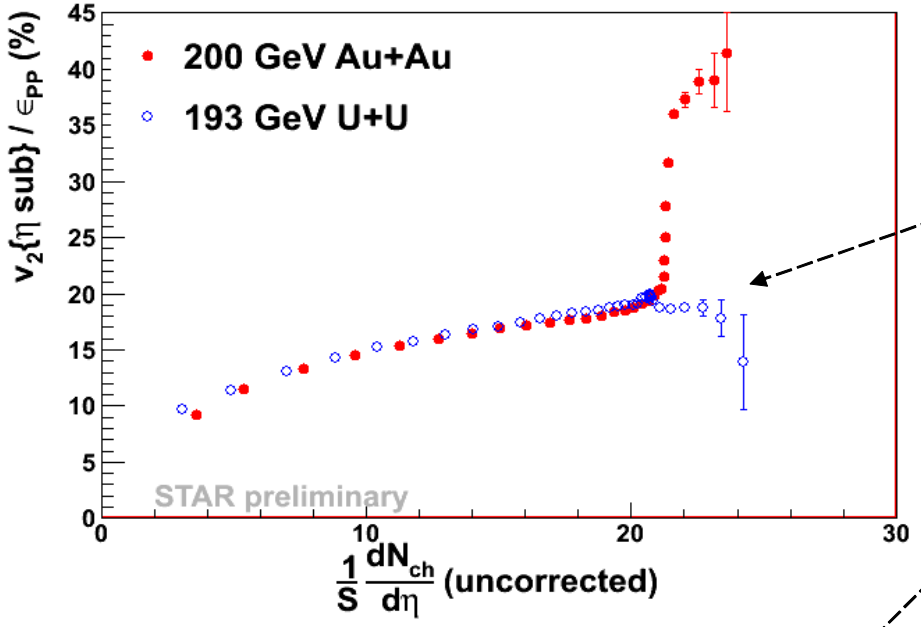


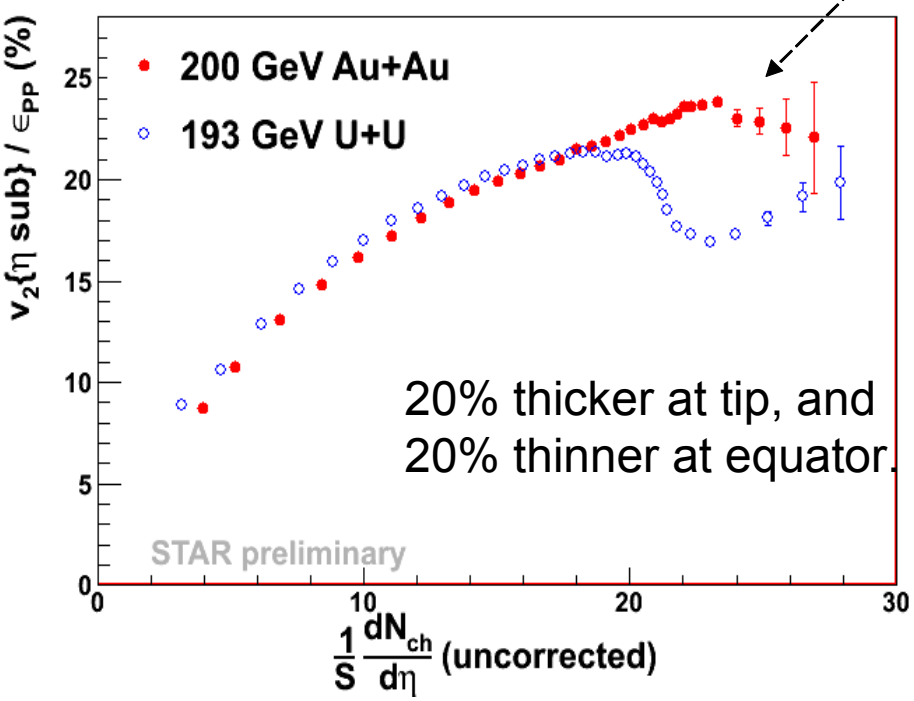


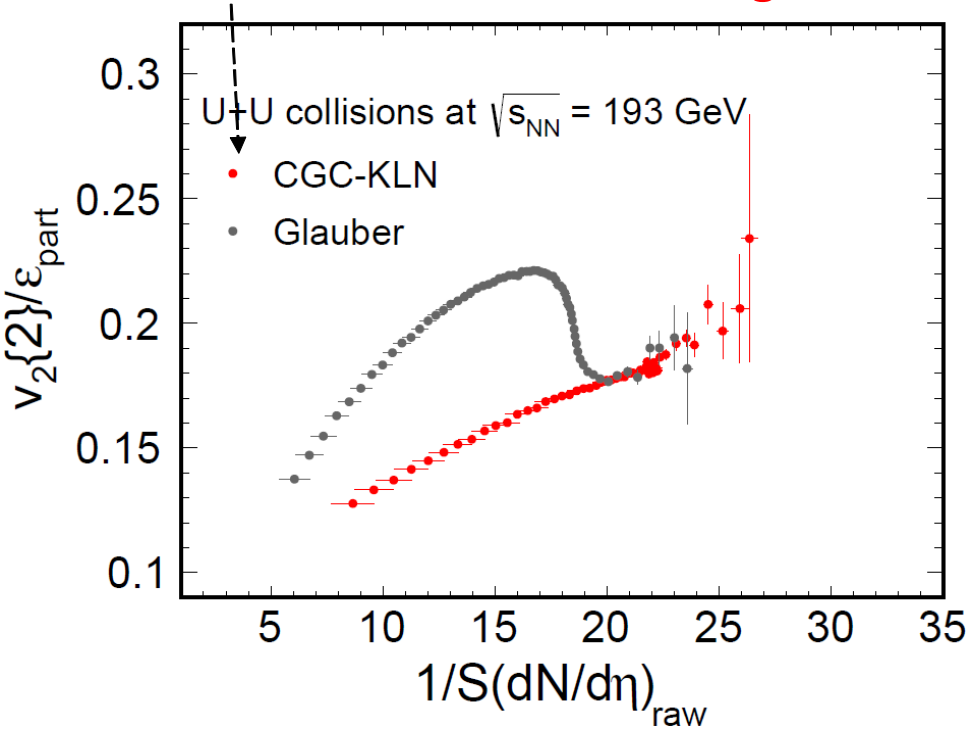
Other approaches

- Quark participants instead of nucleon participants
- Nucleon skin variation
- CGC-KLN instead of Glauber

Need more investigation!

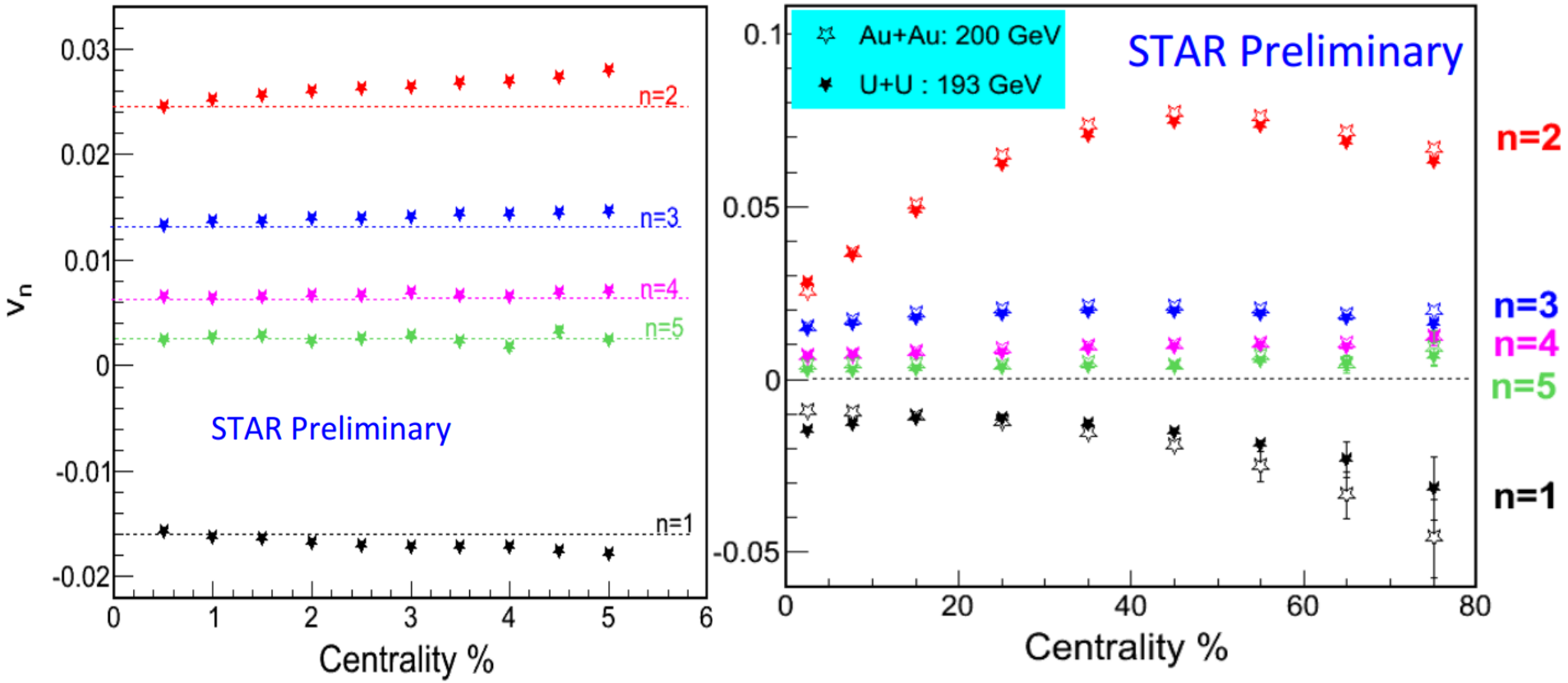






Other harmonics: v_n

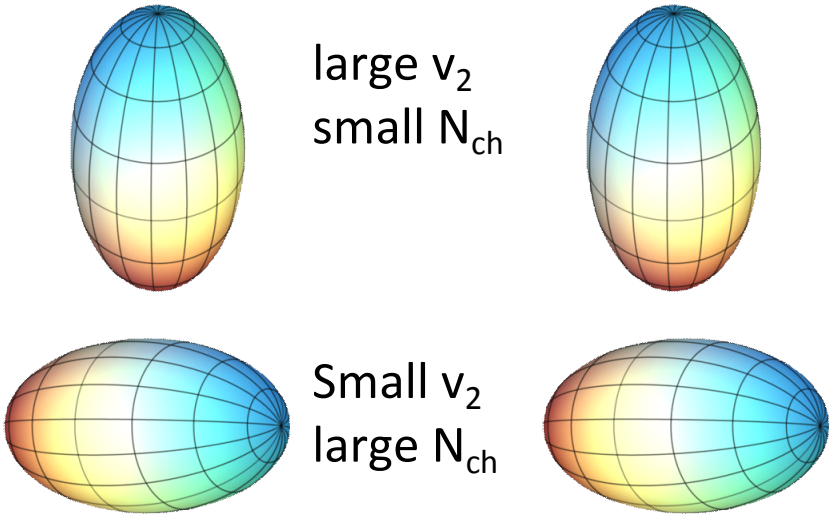
In central U+U, v_2 changes slightly, while other harmonics are almost constant.

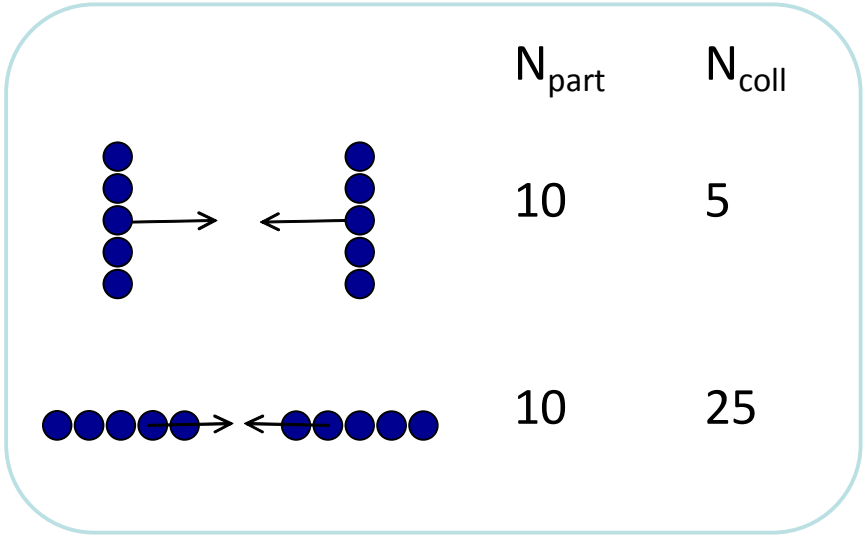


- For n = 3, 4,and 5, v_n in U+U is similar to that in Au+Au.
- For v_1 and v_2, the difference appears in central collisions (where we try to separate body-body and tip-tip).

Can we separate body-body and tip-tip?

We often assume multiplicity depends partially on the number of participants and partially on the number of binary collisions: $N_{ch} = n_{pp}*[xN_{coll} + (1-x)N_{part}/2]$.



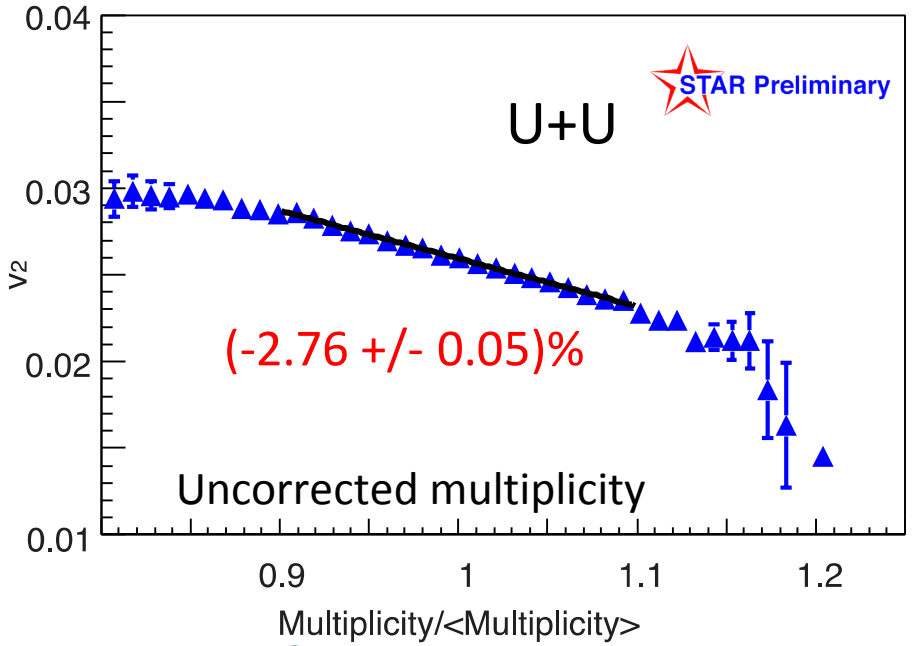


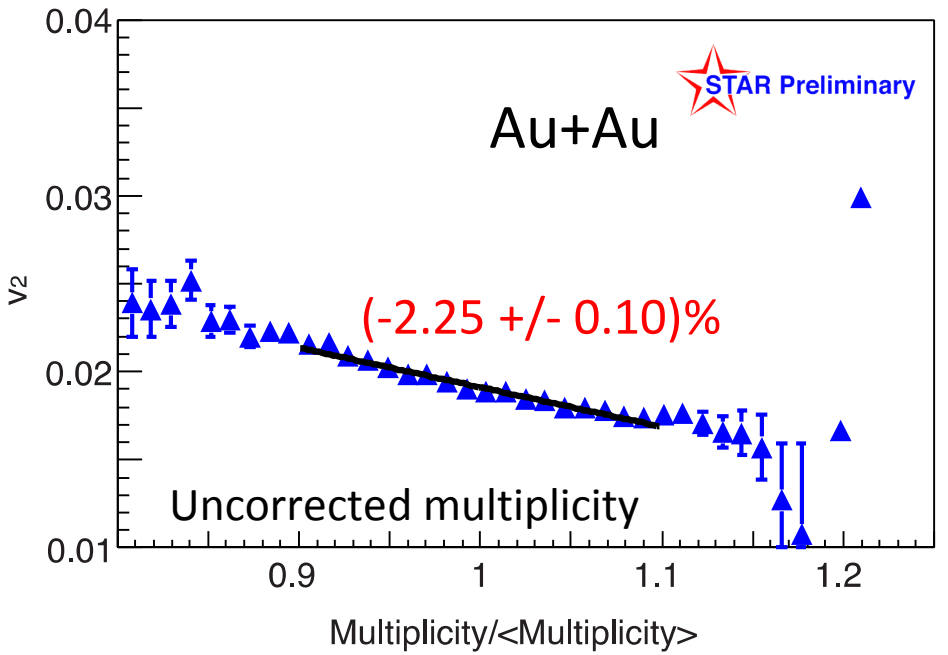
Zero Degree Calorimeters (ZDC) were used to trigger on spectator neutrons.

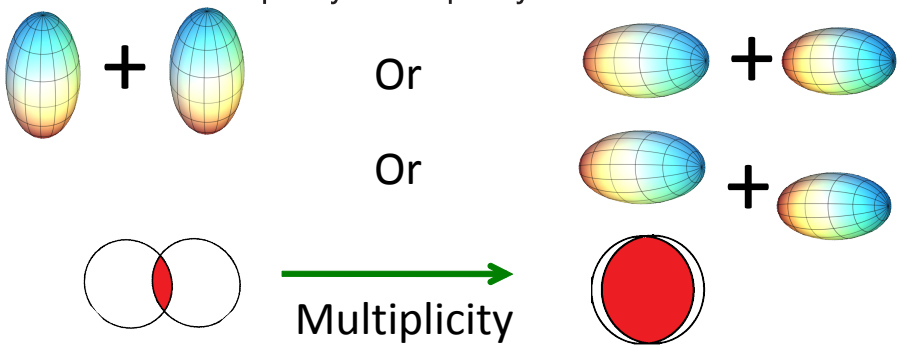
Central U+U collisions, ideal testing ground for particle production:

Is larger v_2 associated with lower N_{ch}?

Very central: 1% ZDC

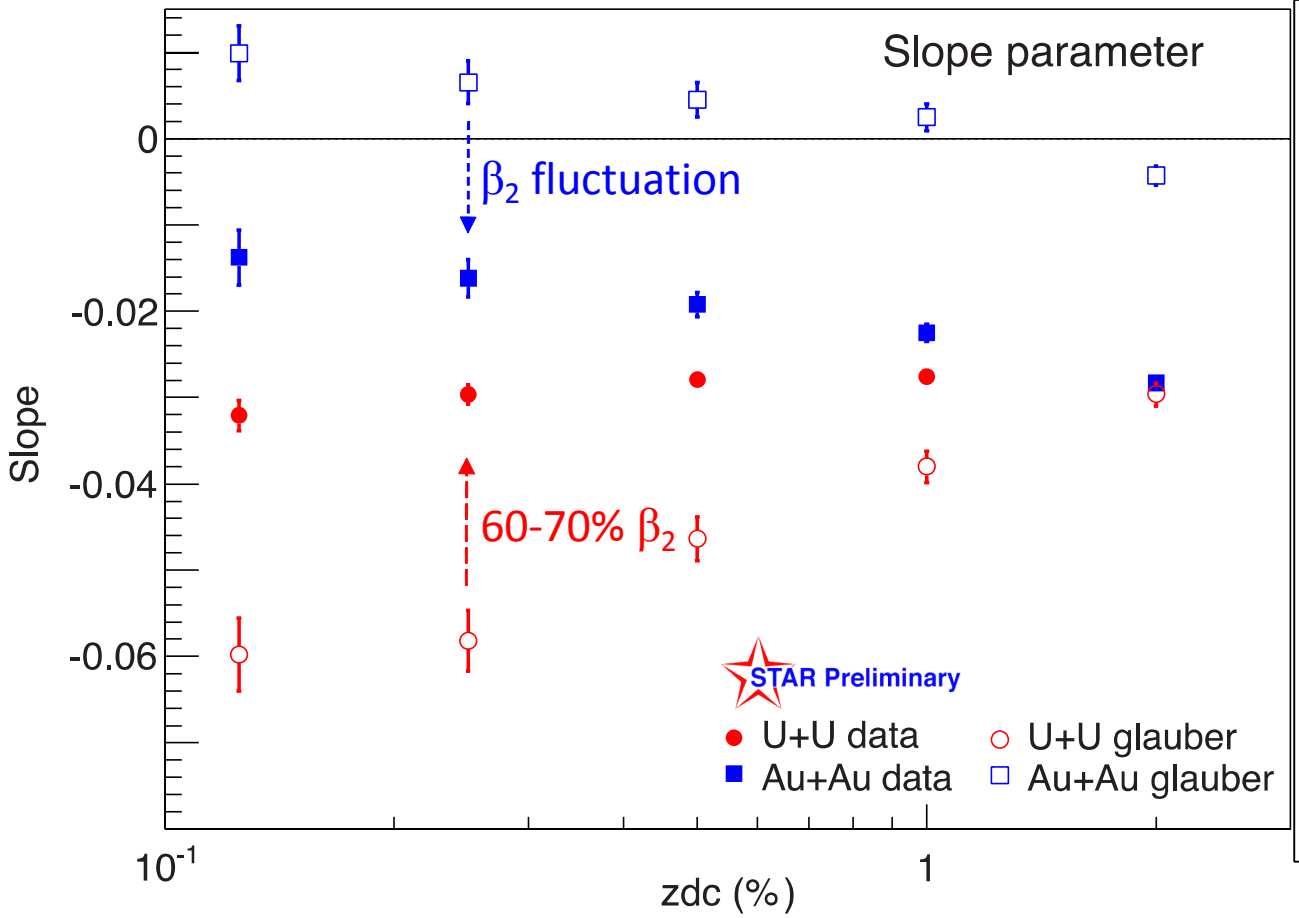






- Use normalized multiplicity to cancel out multiplicity independent efficiency
- Apply a linear fit to extract multiplicity dependence of $v_{2,}$ the slope parameter

Slope vs ZDC



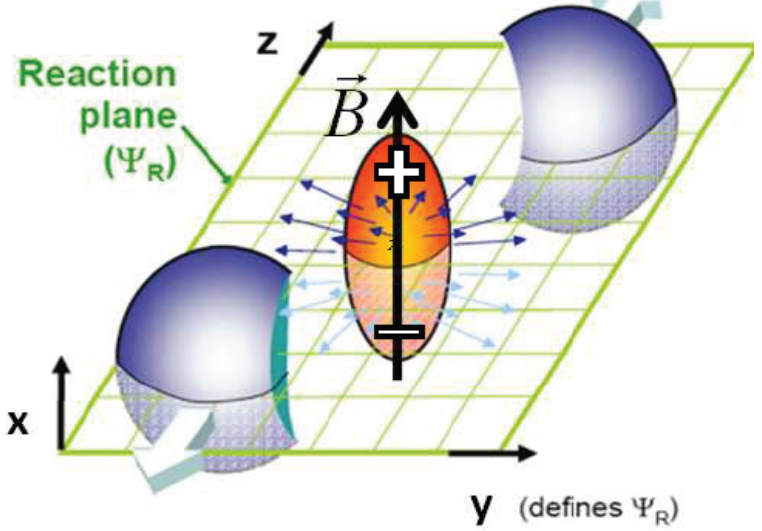
- A clear difference between U+U and Au+Au
- The ability to separate body-body and tip-tip collisions is enhanced when we go more central.
- Work in progress

- Compare with eccentricity calculated from Glauber simulations
  - β_2 fluctuation will pull the Glauber slopes to negative for Au+Au
  - (Again) 60-70% β_2 will match the data for U+U
- Glauber results are scaled down to match the experimental v_2
  - Scale factor is 0.2 for U+U, 0.25 for AuAu

Local Parity Violation + CME

$$\frac{dN_{\pm}}{d\phi} \propto 1 + 2a_{\pm} \cdot \sin\left(\phi^{\pm} - \Psi_{RP}\right)$$

CME + Parity-odd domain,
=> charge separation across RP



A direct measurement of the *P*-odd quantity *"a"* should yield *zero.*

$$\gamma = \left\langle \cos(\phi_\alpha + \phi_\beta - \psi_{RP}) \right\rangle$$

$$= \left[\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle + B_{in} \right] - \left[\left\langle a_\alpha a_\beta \right\rangle + B_{out} \right]$$

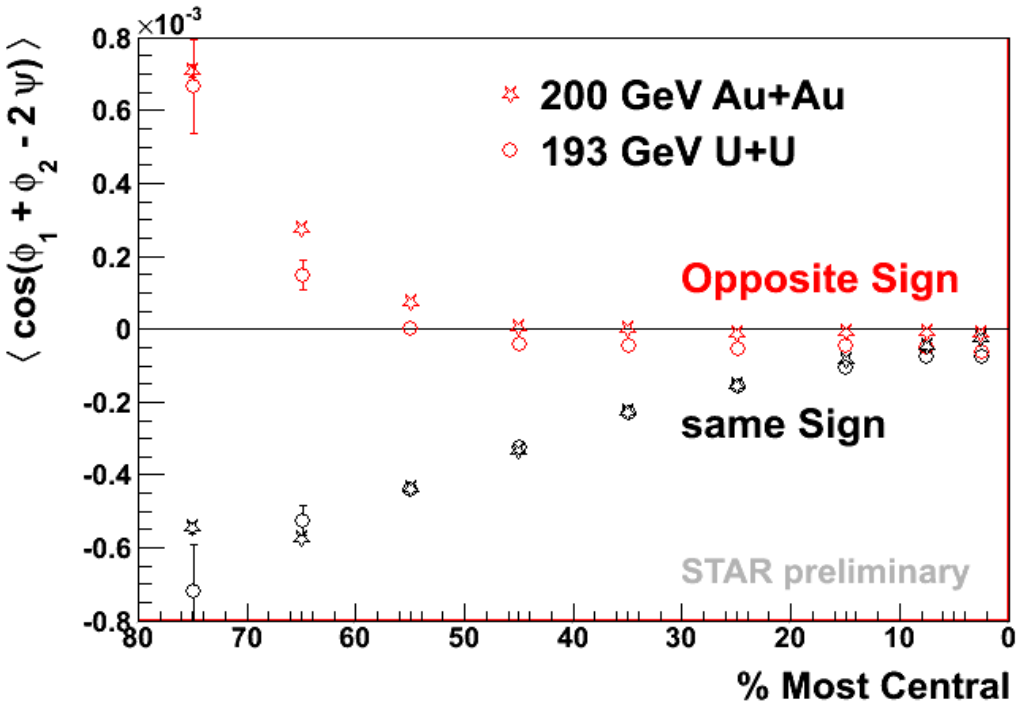
S. Voloshin, PRC 70 (2004) 057901

Non-flow/non-parity effects: largely cancel out

Directed flow: expected to be the same for SS and OS

P-even quantity: still sensitive to charge separation

LPV correlator in U+U



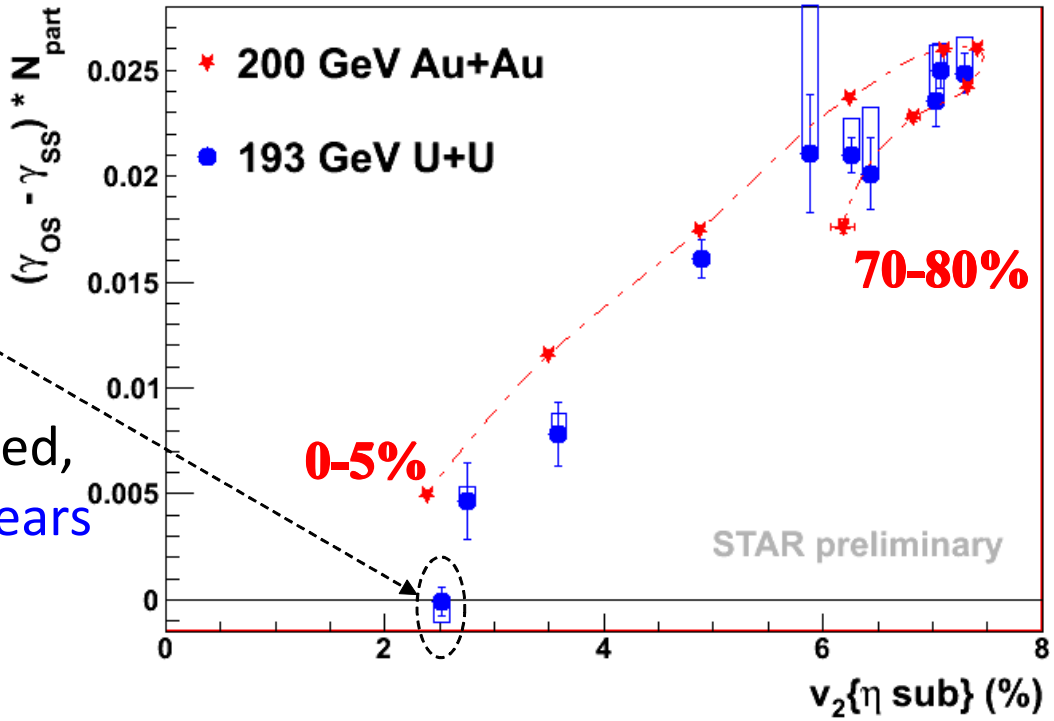
❖ The difference between OS and SS is still there in U+U, with similar magnitudes to Au+Au.

❖ Consider OS-SS to be the signal

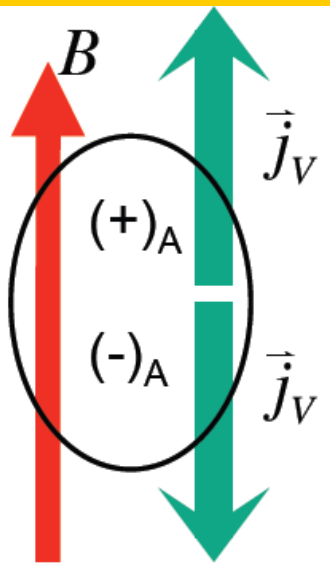
❖ N_{part} accounts for dilution effects

❖ A dedicated trigger with 0-1% spectator neutrons.

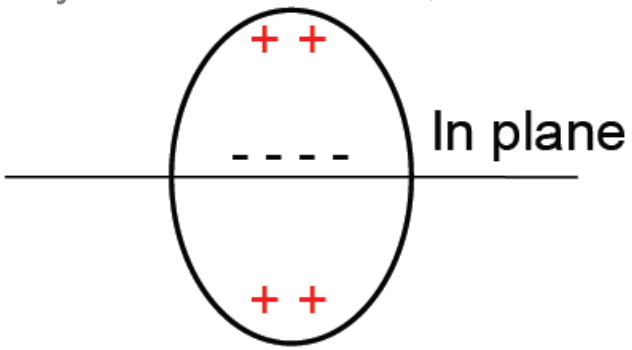
❖ With the magnetic field suppressed, the charge separation signal disappears (while v_2 is still ~ 2.5%).



Chiral Magnetic Wave



Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

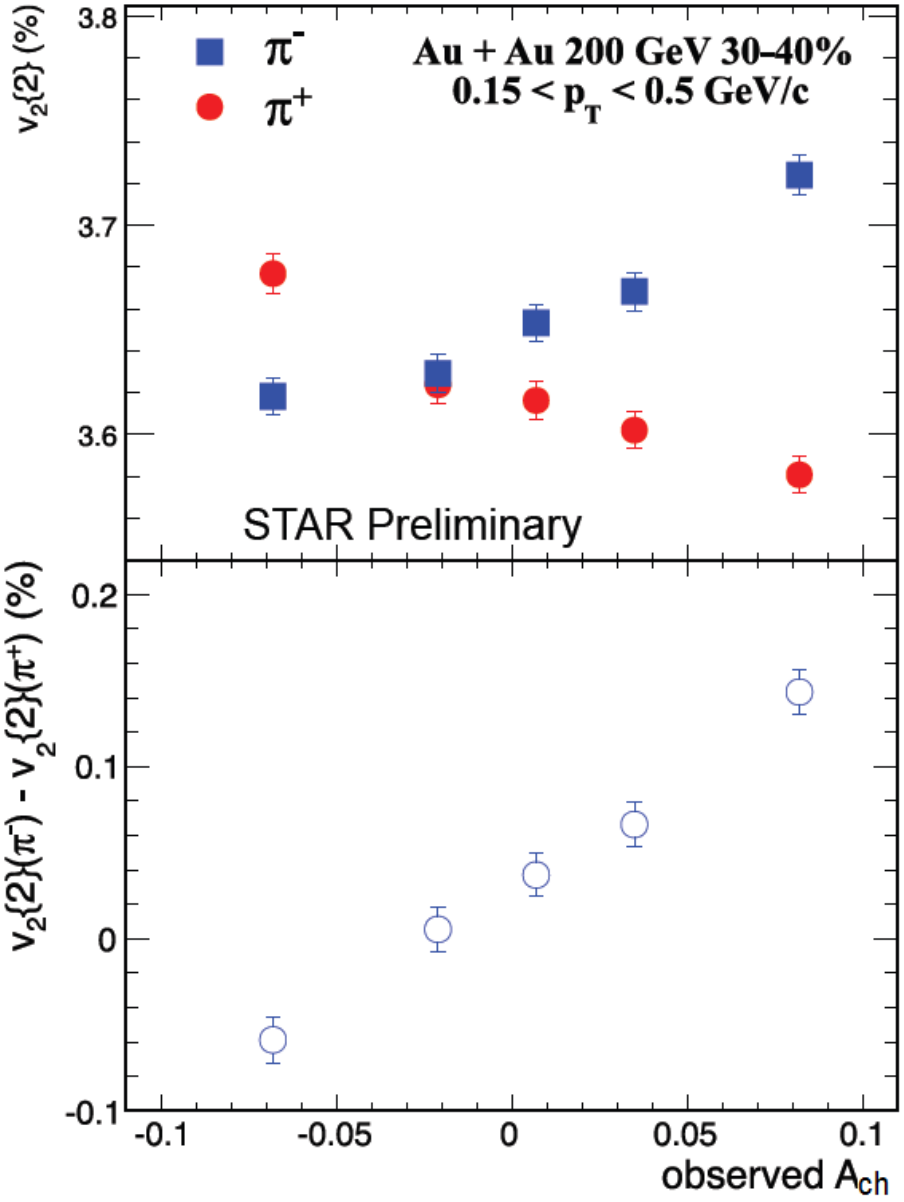


Formation of electric quadrupole: $v_2^{\pm} = v_2 \mp (\frac{q_e}{\rho_e}) A_{ch}$,

where charge asymmetry is defined as $A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$.

Then π^- v_2 should have a positive slope as a function of A_{ch},
and π^+ v_2 should have a negative slope with the same magnitude.
The integrated v_2 of π^- is not necessarily bigger than π^+: (other physics)
only the A_{ch} dependency matters for CMW testing.

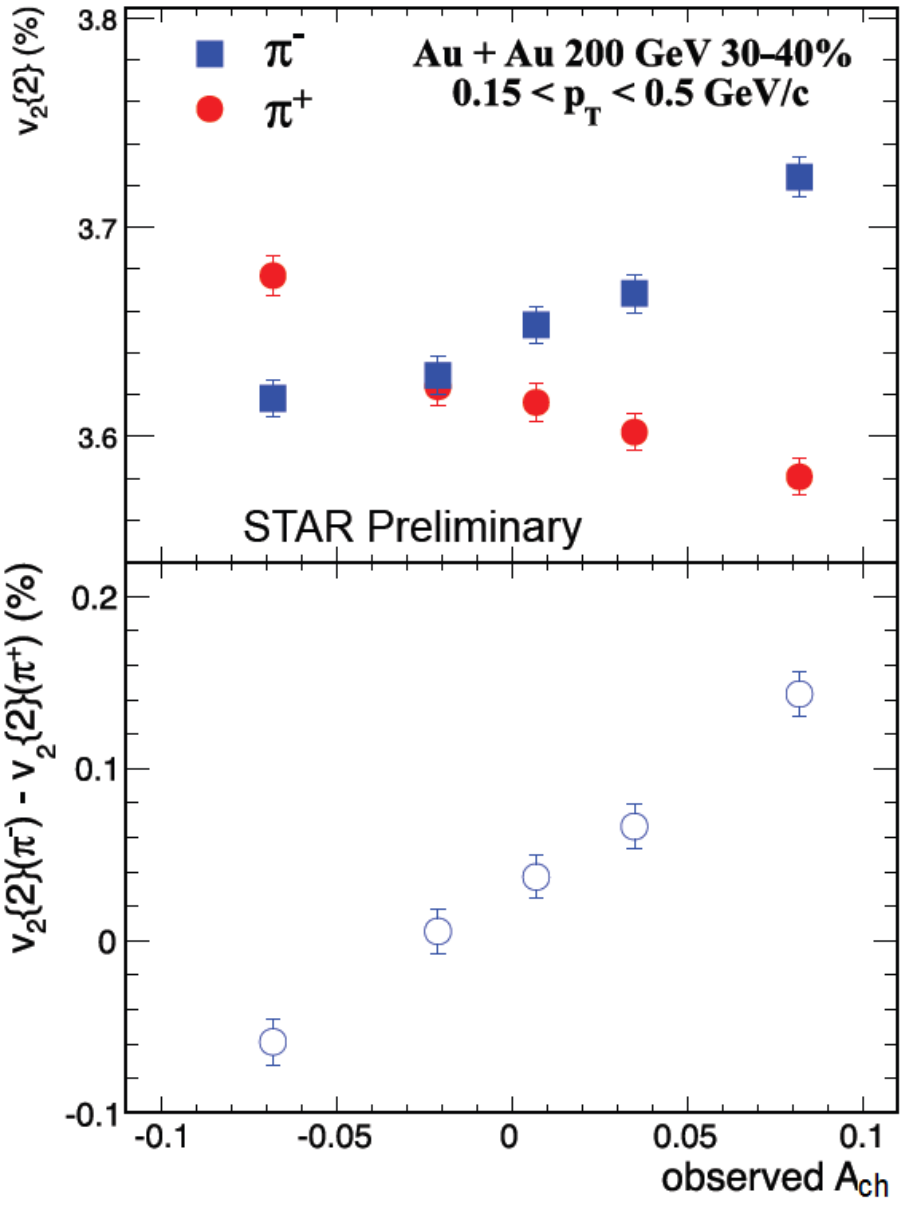
Charge asymmetry dependency

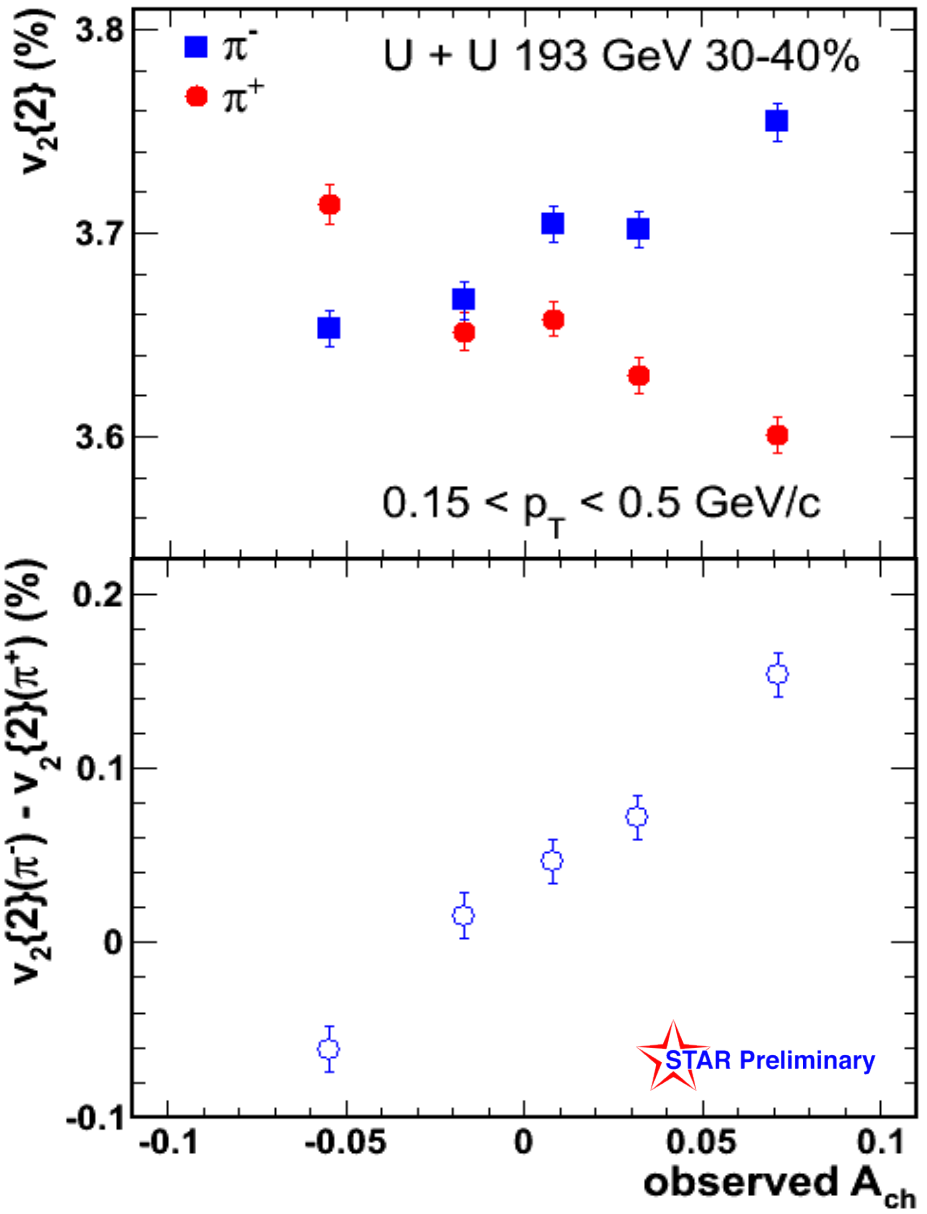


- v_2 was measured with the Q-cumulant method.
- Clear A_{ch} dependency
- $v_2(A_{ch})$ slopes for $\pi^{\pm}$:
  - opposite sign
  - similar magnitude
- v_2 difference vs A_{ch} may have a non-zero intercept: other physics?

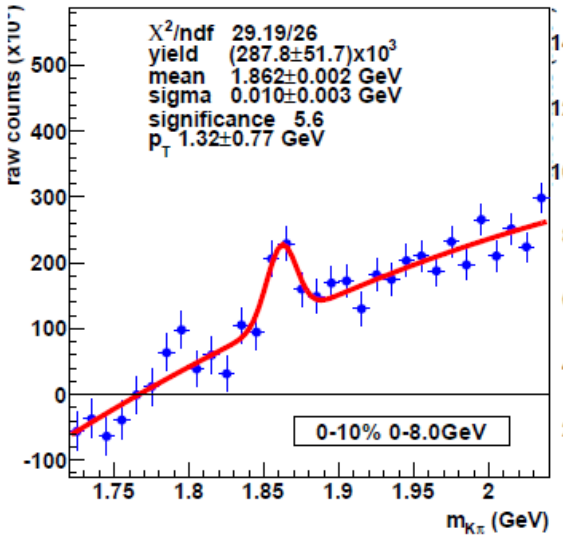
$$v_2^{\pm} = v_2 \mp \left(\frac{q_e}{\rho_e}\right) A_{ch}$$

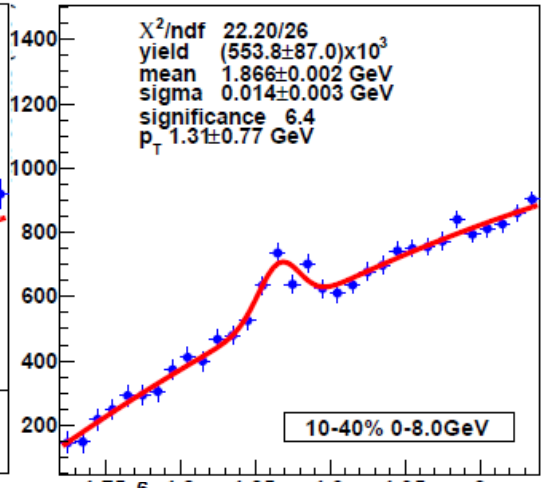
Confirmed in U+U

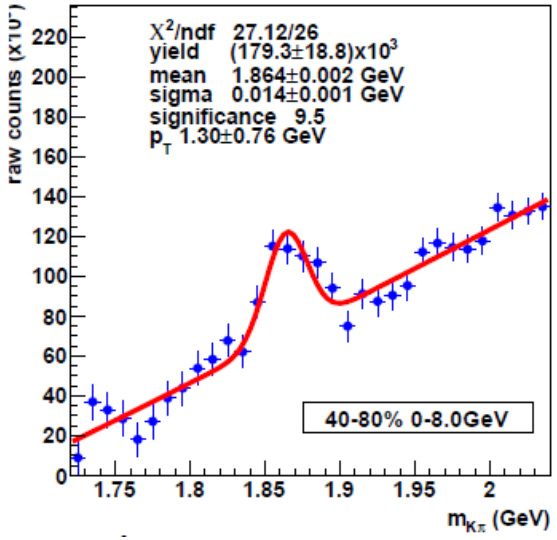


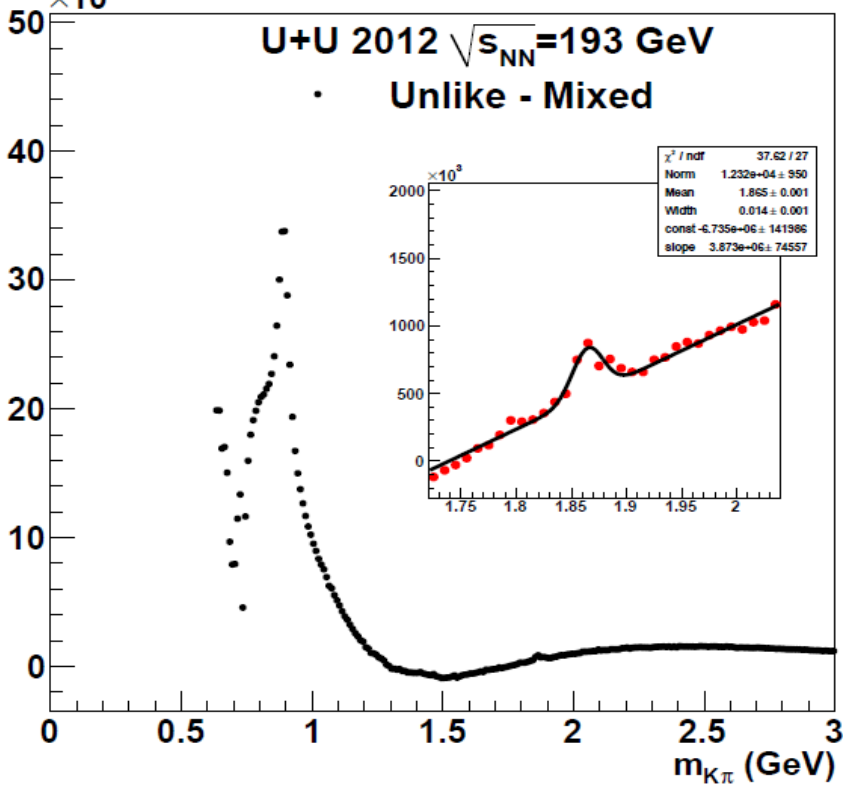


Hard probes: D^0







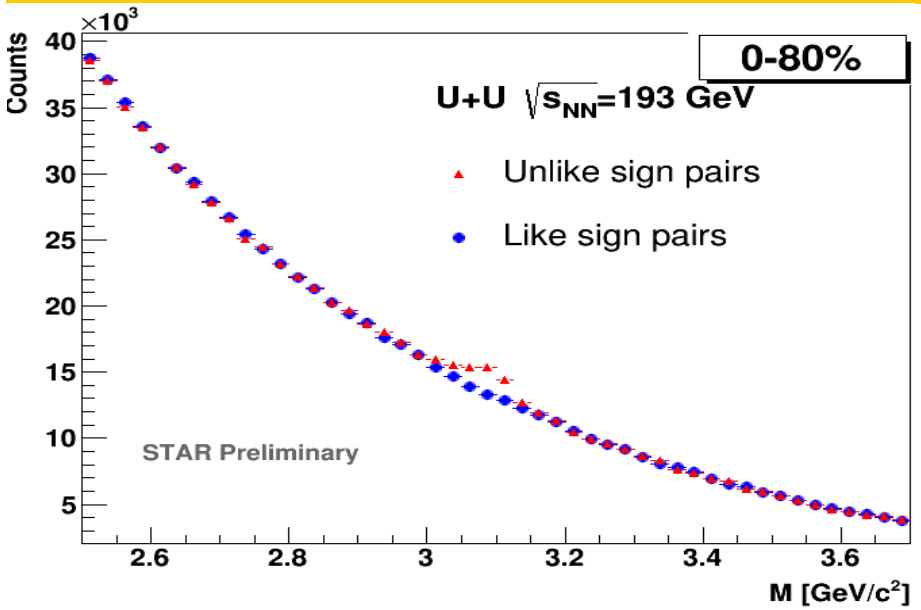


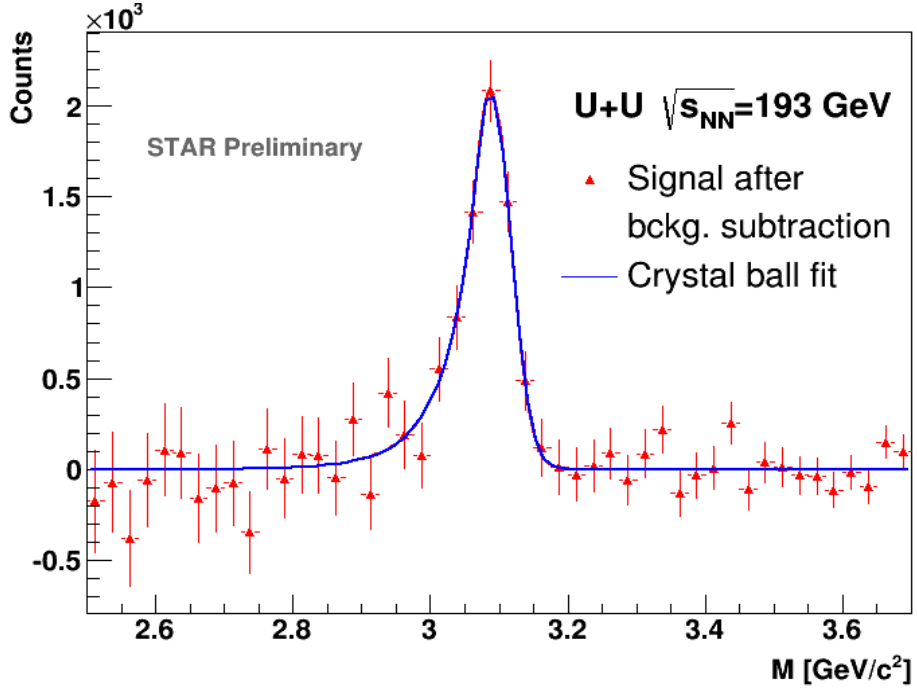
The study of the path-length dependence of hard probes has been initiated from the heavy flavor production in U+U.

Over 90% of charm quarks go into open charm production.

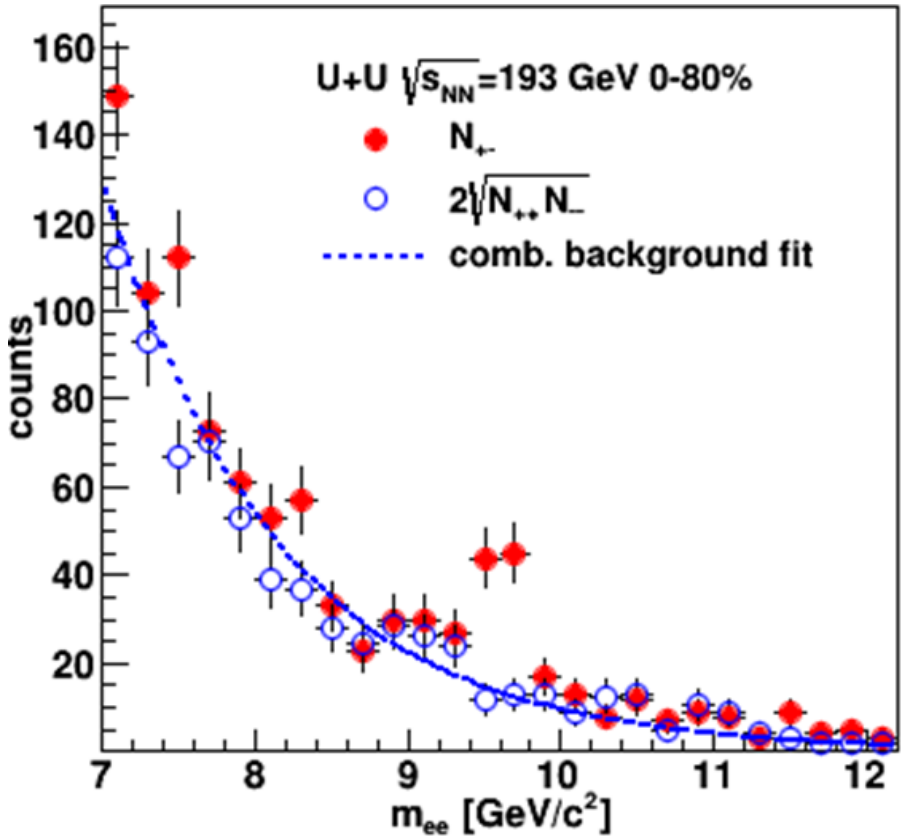
Signals even more significant will be expected with the incoming Heavy Flavor Tracker (HFT)!

Hard probes: J/ψ and γ





Clear signals for quarkonia in U+U.

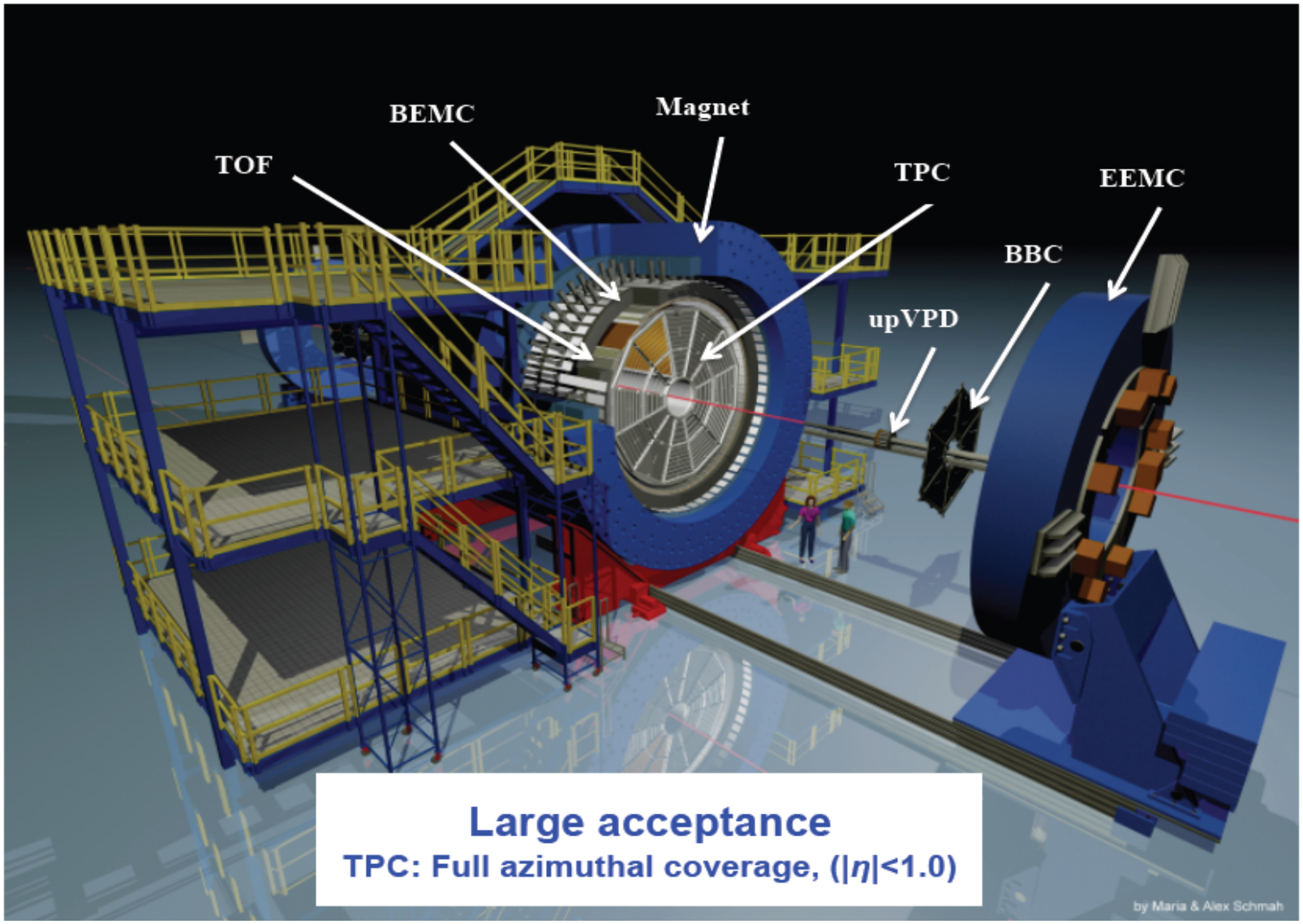


Summary

- Flow
  - v_2 difference between Au+Au and U+U appears in central collisions.
  - For Glauber to work, Uranium needs to be less deformed than pdg.
  - The separation of body-body and tip-tip is in progress...
- Chiral Magnetic Effects
  - An imporant systematic check for LPV correlator was carried out in U+U.
  - The Electric Quadrupole signal was qualitatively confirmed by U+U.
- Hard probes
  - Significant signals were seen for D^0, J/ψ and γ
  - Path-length dependence to be studied...
- We are taking full advantage of the U+U data: interesting features needs further investigation and calls for interpretation...

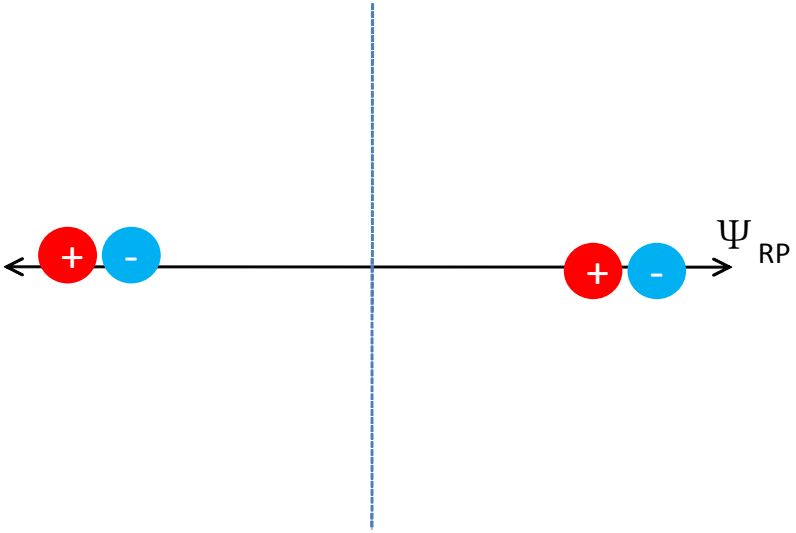
Backup slides

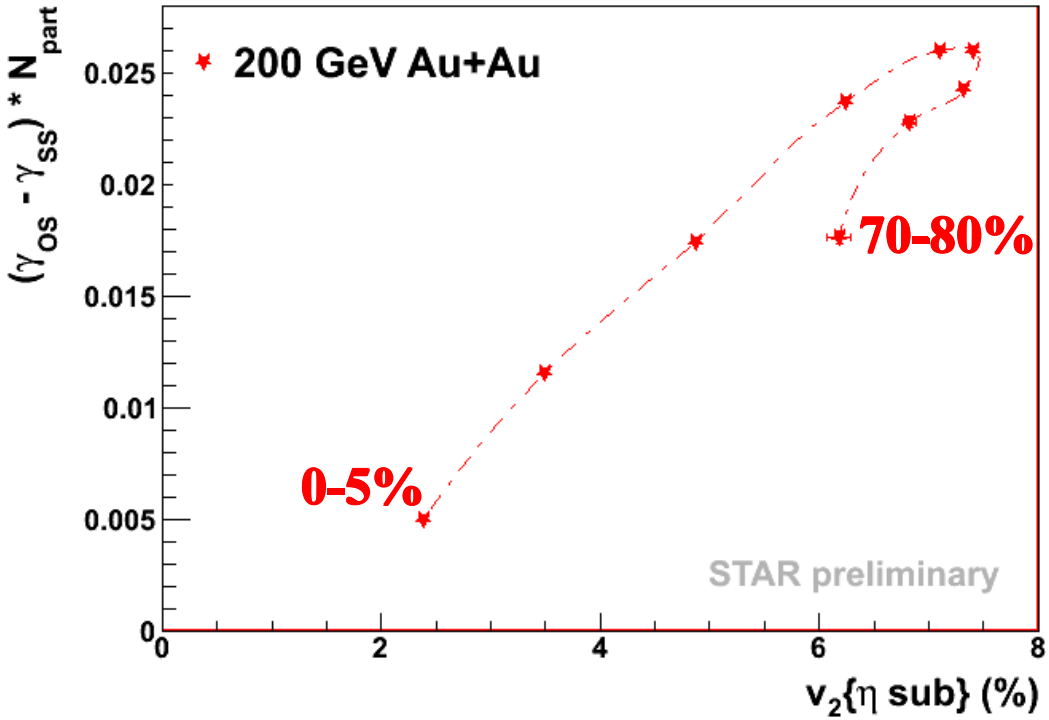
STAR


TOF
BEMC
Magnet
TPC
EEMC
BBC
upVPD
Large acceptance
TPC: Full azimuthal coverage, (|η|<1.0)
by Maria & Alex Schmah

Possible physics background

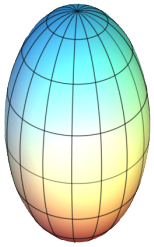
charge conservation/cluster + v_2 Pratt, Phys.Rev.C83:014913,2011





$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$
$$= \langle \cos((\phi_\alpha + \phi_\beta - 2\phi_{res}) + 2(\phi_{res} - \Psi_{RP})) \rangle$$
$$\approx \frac{f_{res} \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_{res}) \rangle \, v_{2,res}}{N_{ch}}$$

STAR, Phys. Rev. C72 (2005) 014904



Seemingly correlated!

Can we disentangle the relationship with U+U?

RHIC run2012, we took 350M minbias events and 14M central trigger events.