Charge sensitive cumulants and flow in U+U collisions from STAR

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(for the STAR Collaboration)

BROOKHAVEN NATIONAL LABORATORY

QCD workshop on Chirality, Vorticity & Magnetic Field in Heavy Ion Collision

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STAR

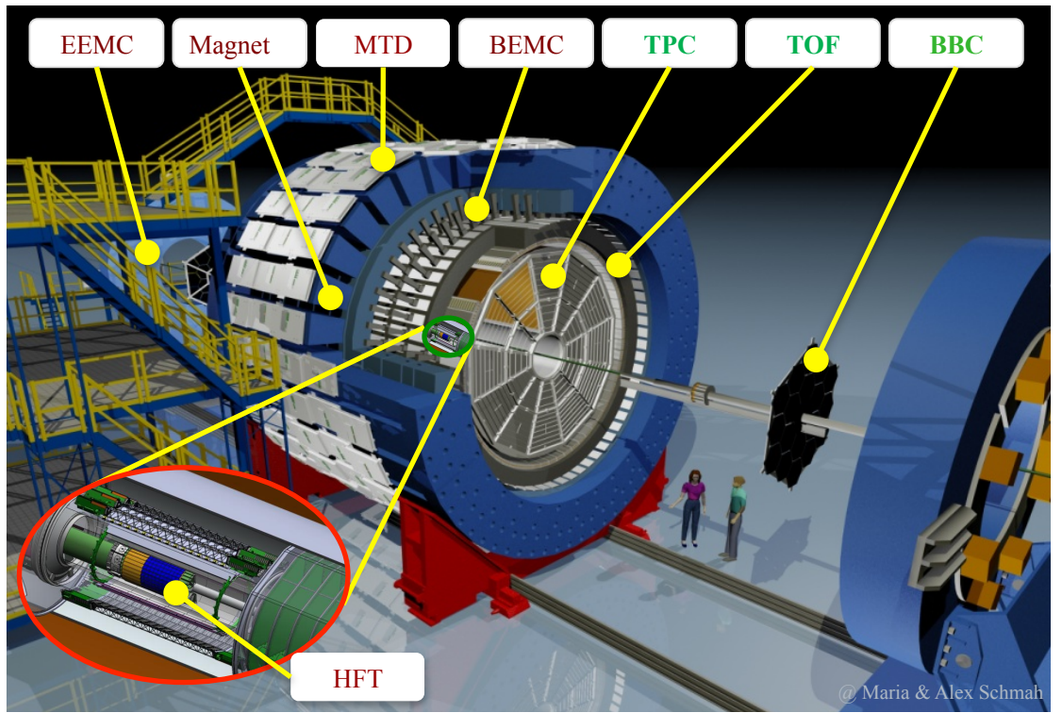
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Introduction
- Results of flow in U+U collisions from STAR
- Results of charge-dependent azimuthal correlations from STAR
- Challenges and outlook

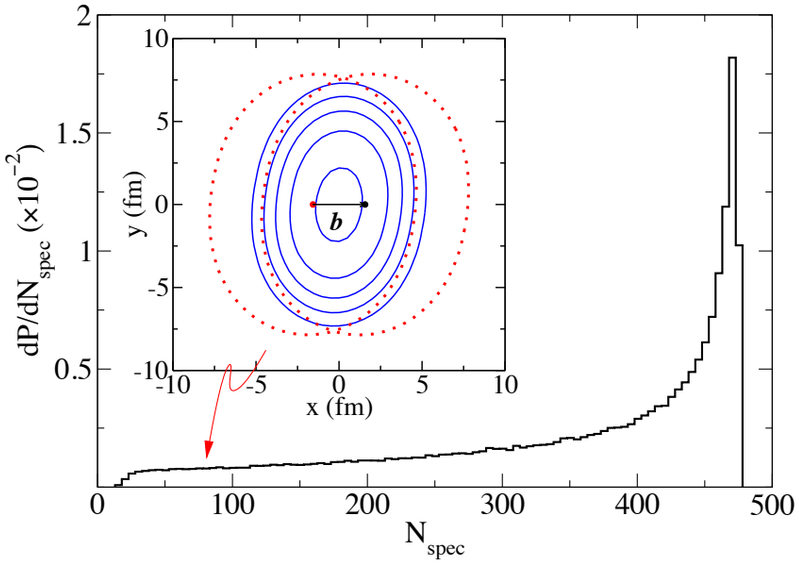
Flow is the dominant source of background for signals of CME

Can U+U collisions be used to disentangle the two effects ?

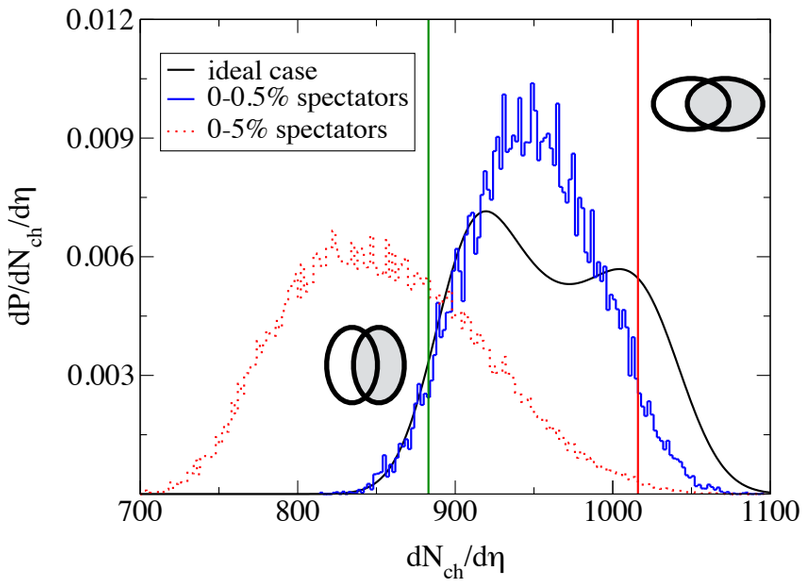


Motivations for U+U collisions at RHIC

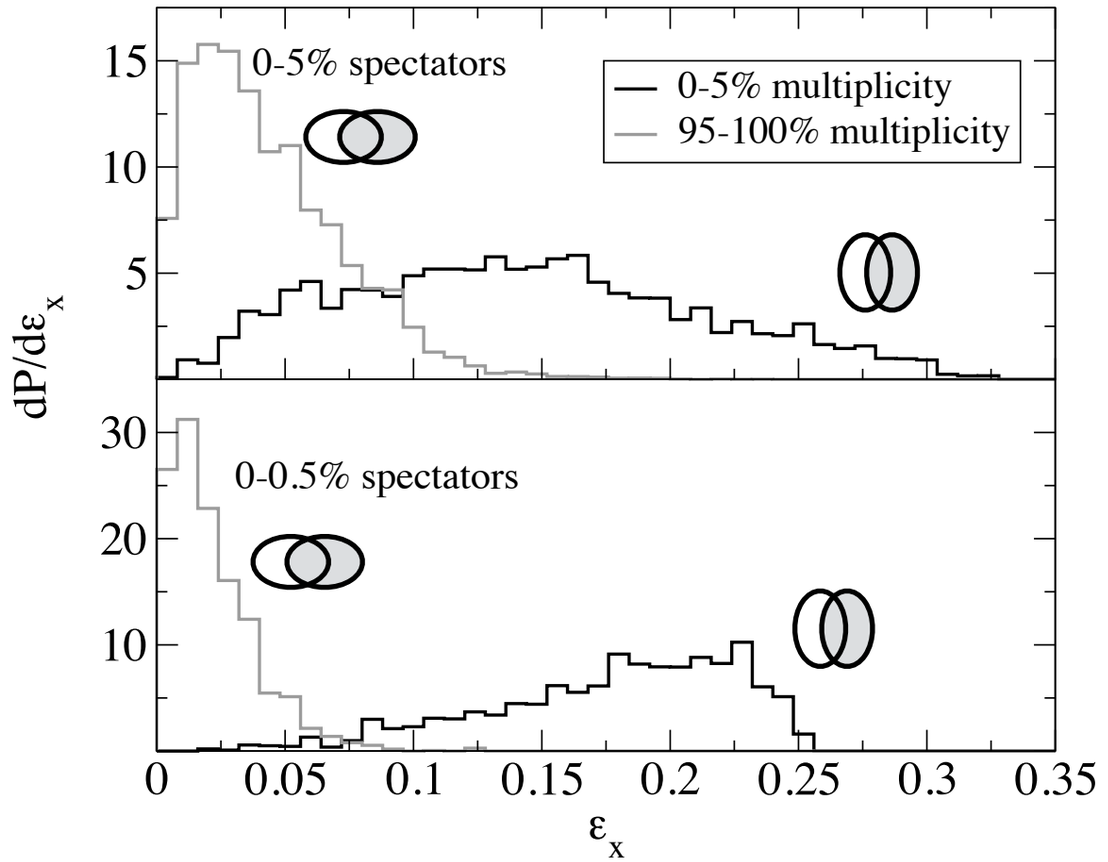
Trigger on spectators



Trigger on multiplicity



Kuhlman, Heinz, nucl-th/0411054, nucl-th/0506088



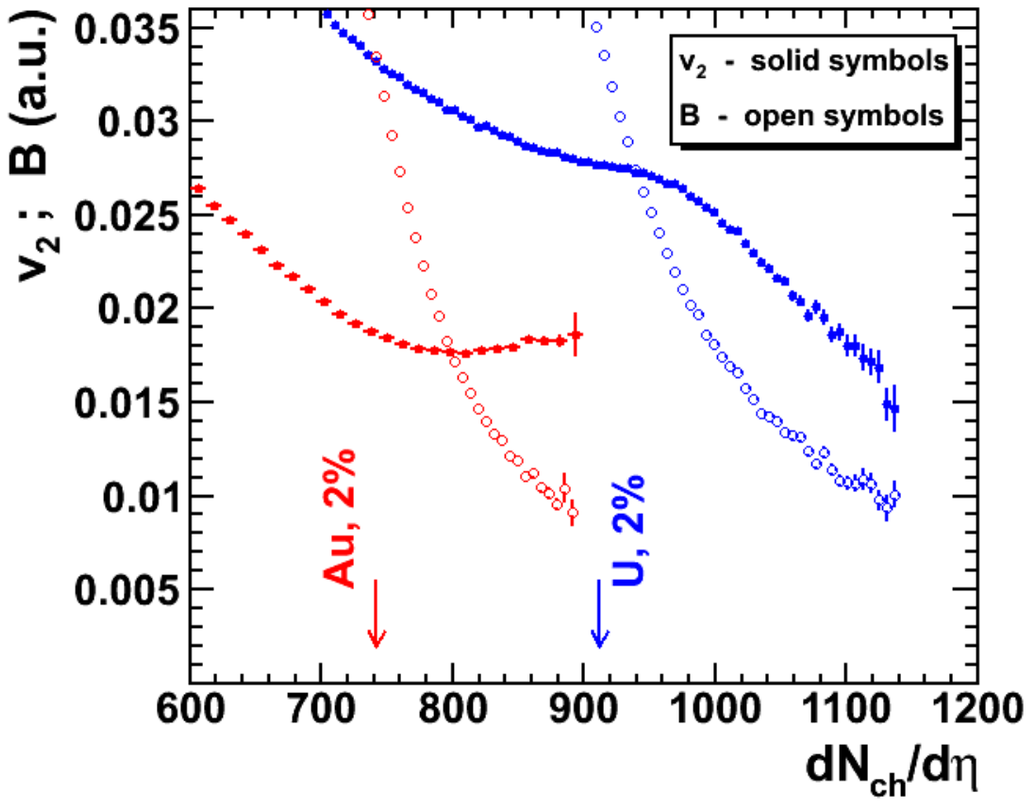
Triggering the spectators & multiplicity

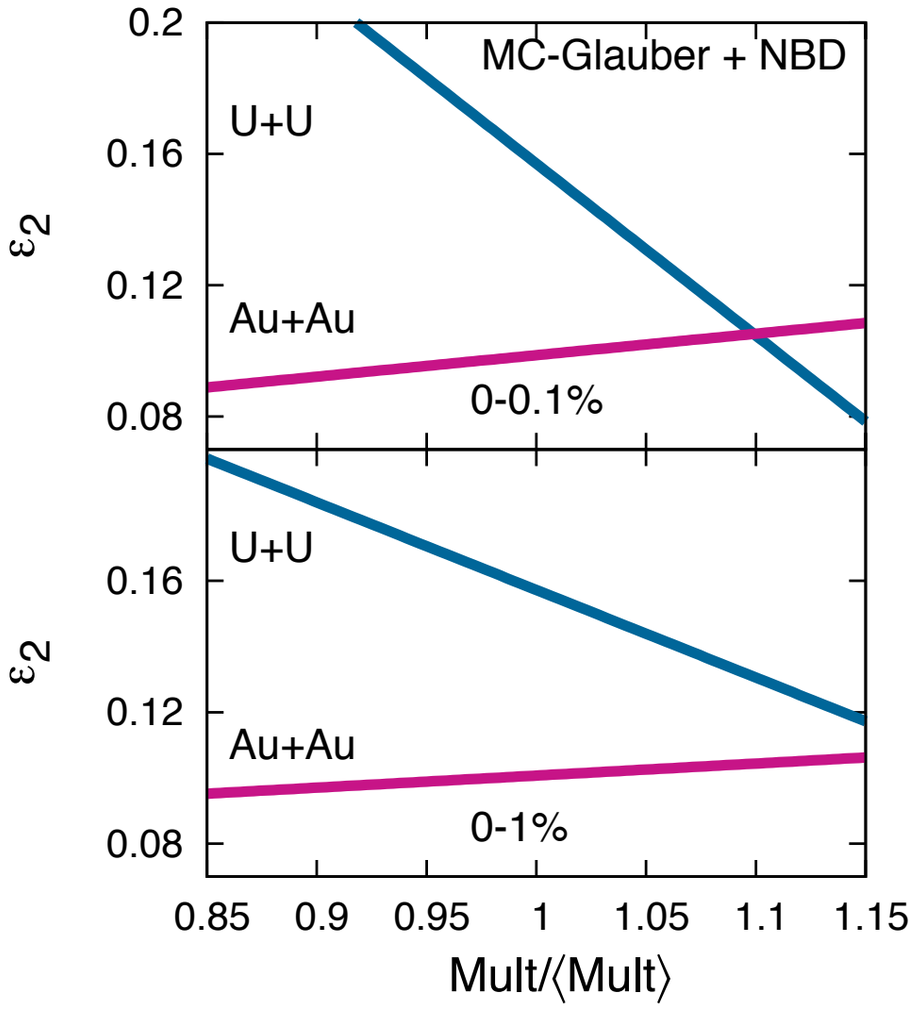
—> probe the shape of Uranium

(interesting collision geometries)

Motivations for U+U collisions at RHIC

Voloshin 1006.1020



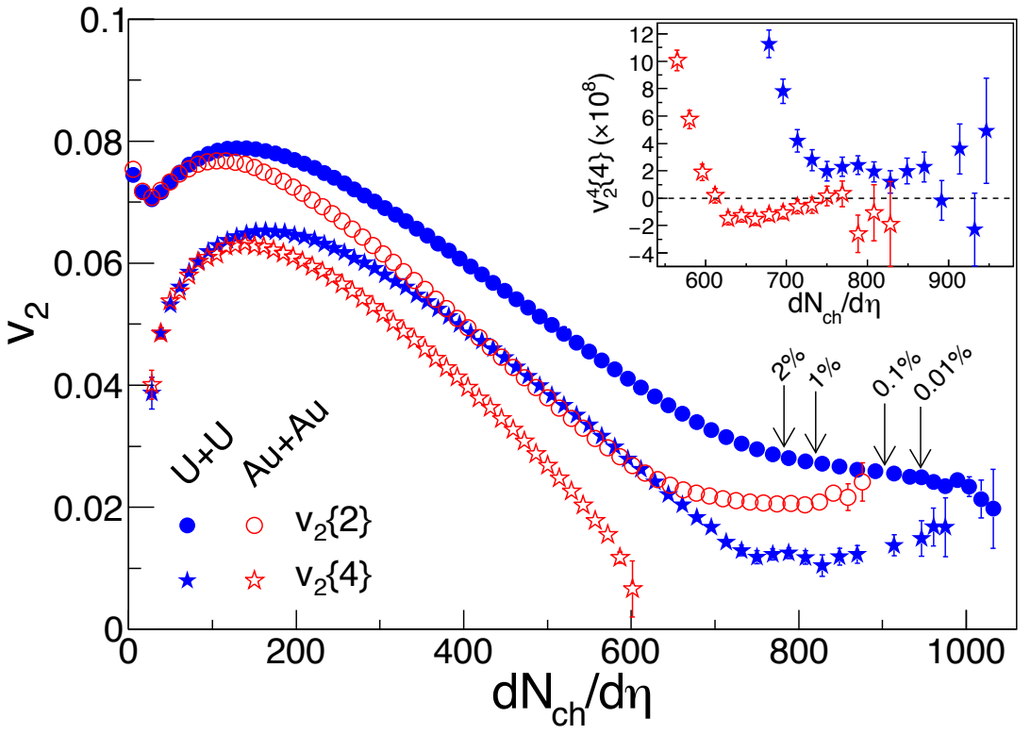


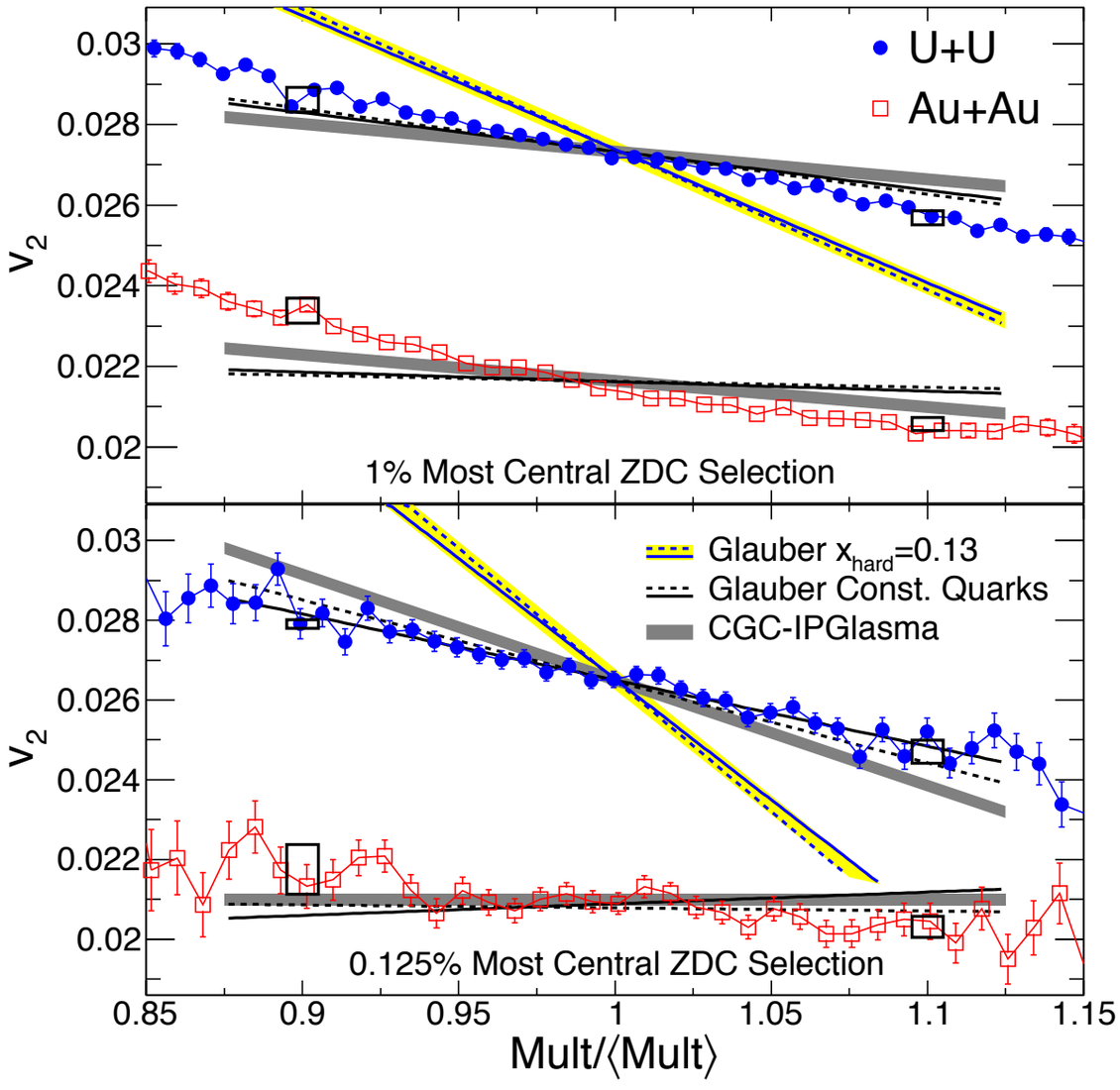
Ultra-central U+U—> Knee-structure, different from Au+Au (oblate)

—> probe of particle production mechanism & degree of coherence

First results on U+U collisions from STAR

L. Adamczyk et al. (STAR Collaboration)
Phys. Rev. Lett. 115, 222301 (2015)





- No Knee-like structure
- Sensitivity to shape <1% event
- Data contradicts strong binary-collision dependence of multiplicity
- IP-Glasma & Quark-Glauber —> better explain the ultra-central data.

What have we learned from the U+U collisions at RHIC ?

- Limitations of two-component model in MC-Glauber:
  Modifications : Quark-Glauber (nucl-th/0302071, 1509.06727), TRENTO (1412.4708), Shadowed Glauber (1510.01311)

- Evidence of color coherence : CGC like initial state

  Kuhlman, Heinz, Kovchegov, nucl-th/0604038v1
  Schenke, PT, Venugopalan (1403.2232)

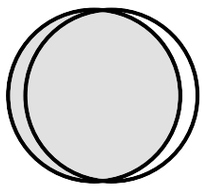
Weak dependence of multiplicity on shape is a prediction of CGC

- Dominance of fluctuations, small control in triggering shape
  35% variation in dN/deta —> 12% variation in v_2 in (<1% ZDC)

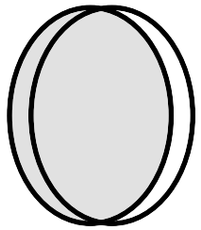
Next Step: Can we use U+U collisions to learn about CME ?

Qualitative picture

Correlation between B-field & eccentricity



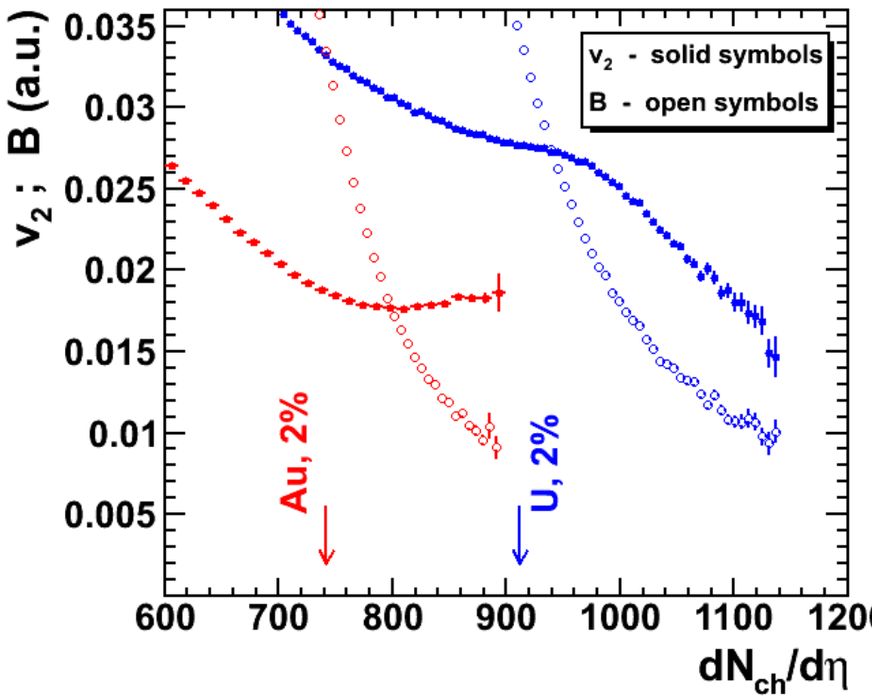
Au+Au (ultracentral)
ε~0, B~0

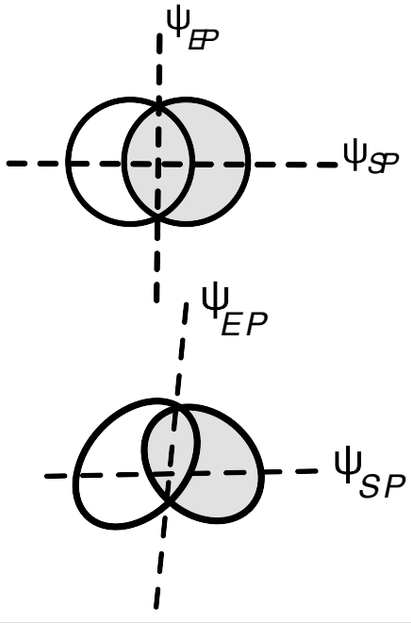


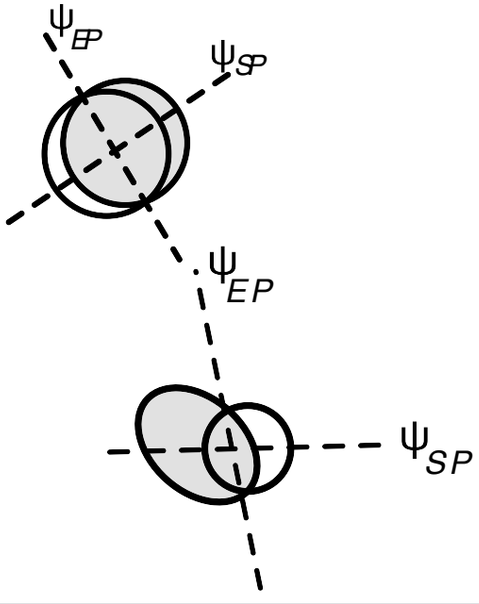
U+U (ultracentral)
ε≠0, B~0

Search for non-zero v_2 & zero CME

Voloshin 1006.1020







Reaction plane & B-field direction is strongly correlated in Au+Au—> Not true for U+U

Can U+U collisions disentangle flow & signals of CME ?

Observables for CME

- General (3-particle) cumulant :

$$\mathrm{C_{m,n,m+n}} = \langle \cos((\mathrm{m}\phi_1 + \mathrm{n}\phi_2 - (\mathrm{m}+\mathrm{n})\phi_3)) \rangle$$

- Lowest order (3-particle) **charge sensitive cumulant** :

$$\mathrm{C_{112}} = \langle \cos((\phi_1^{\pm} + \phi_2^{\mp} - 2\phi_3)) \rangle$$

- The CME correlator :

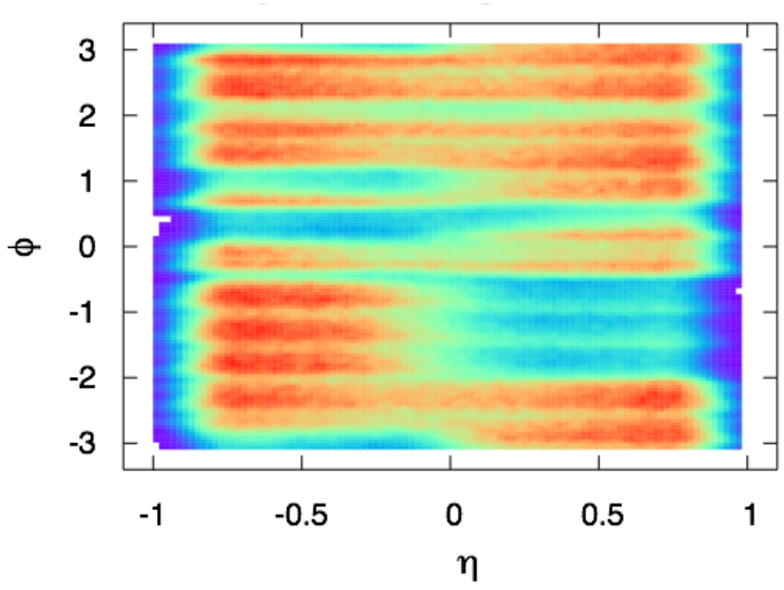
$$\gamma^{a,b} \sim \frac{\langle \cos(\phi_1^a + \phi_2^b - 2\phi_3) \rangle}{v_2\{2\}} \quad \sim \langle \cos(\phi^a + \phi^b - 2\Psi_{RP}) \rangle$$

(3P-cumulant method) (event-plane method)

Details of the data set

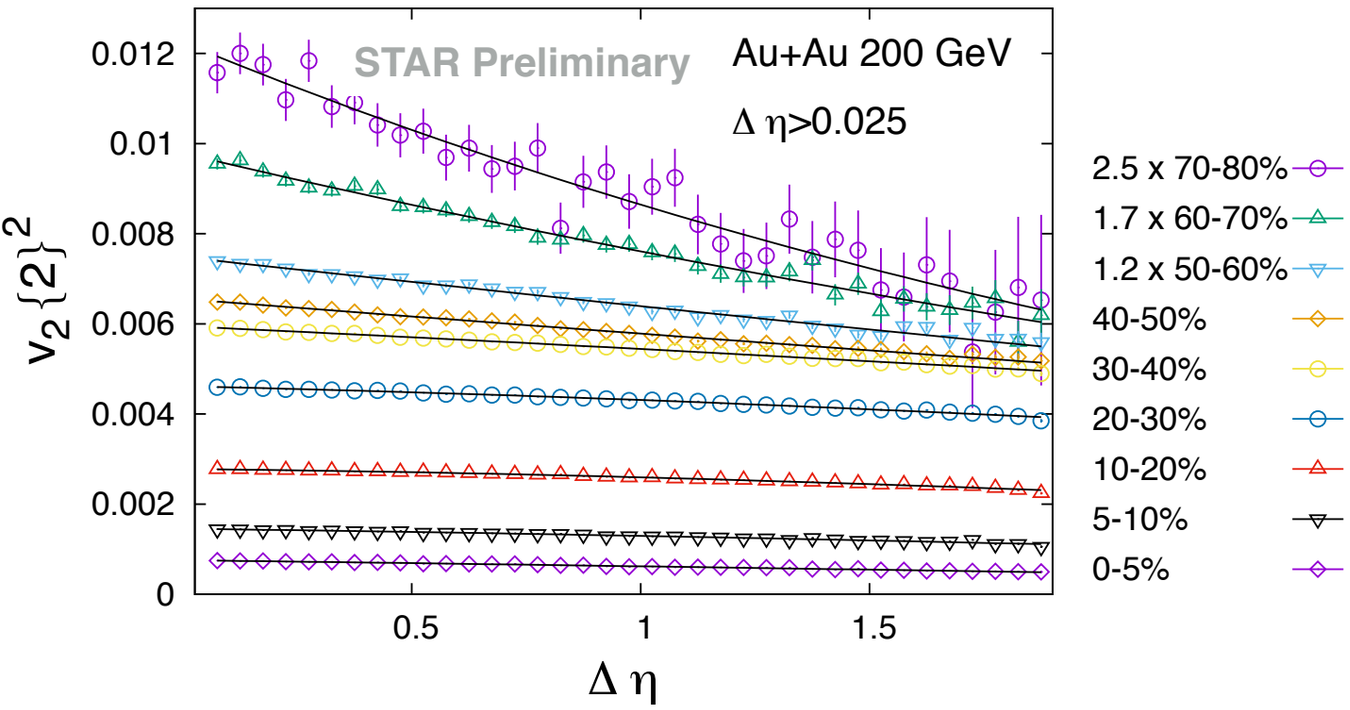
- U+U 193 GeV : Year 2012 (Min-bias/ultra-central)
- Au+Au 200 GeV : Year 2004, 2007 (Min-bias), 2011 (ultra-central)
- Centrality selection :
  - TPC uncorrected multiplicity $|\eta|<0.5$
  - ZDC East & West ADC
- Common QA cuts :
  - $|V_r|< 2$, $|V_z| < 20$, $|V_z - vpdV_z|< 2$ cm
- Acceptance cuts: $|\eta|<1$, 0.2 GeV/c$<|p_T|$

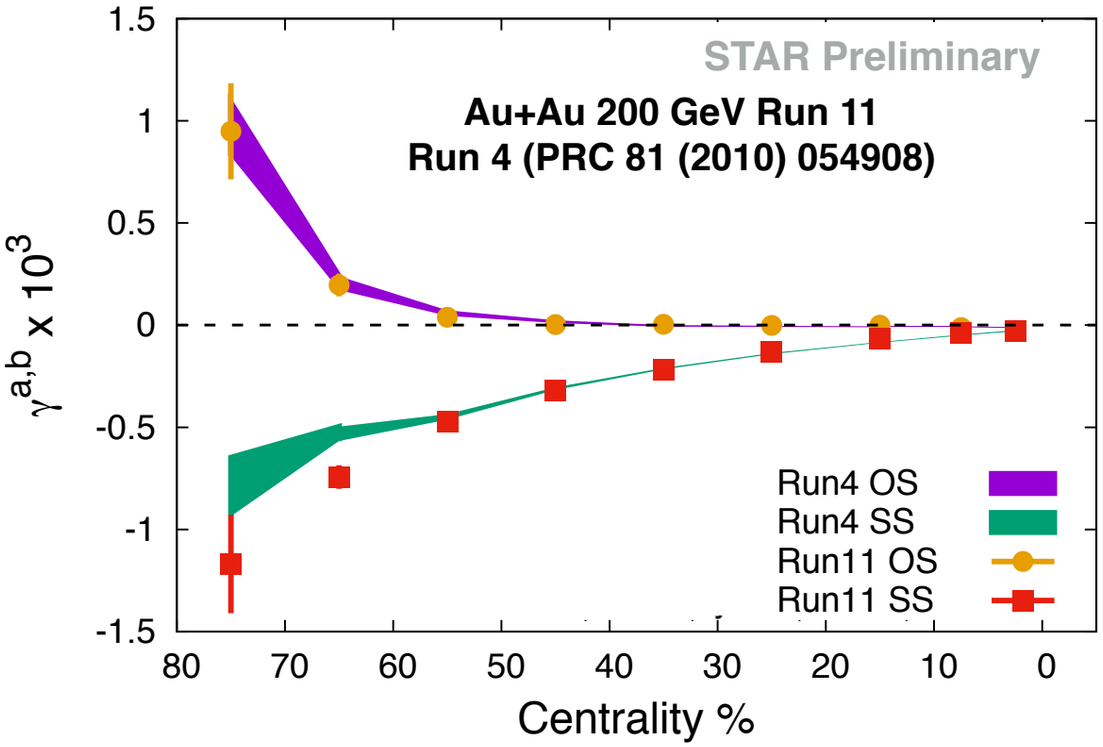
TPC acceptance
(used in this analysis)



Weight estimation :
bin in sagitta, η-ϕ

Measurement of $v_2\{2\}$ & γ^{ab} in Au+Au collisions

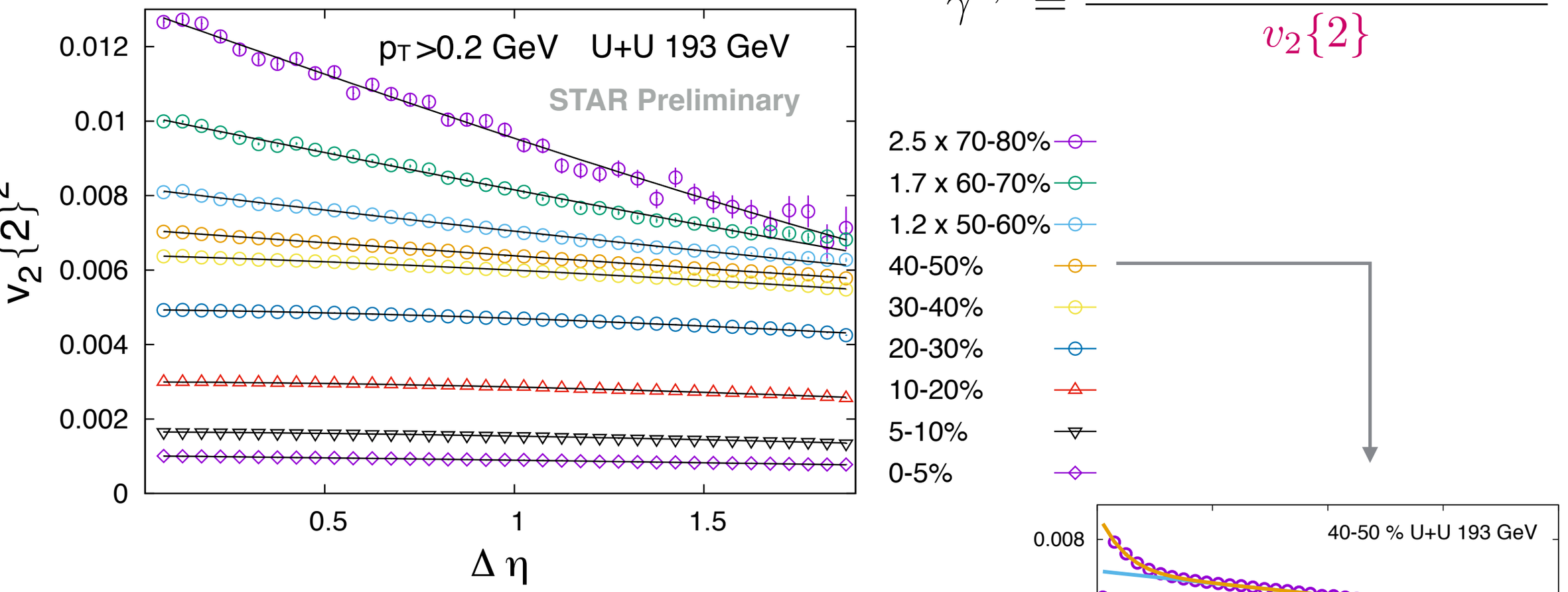


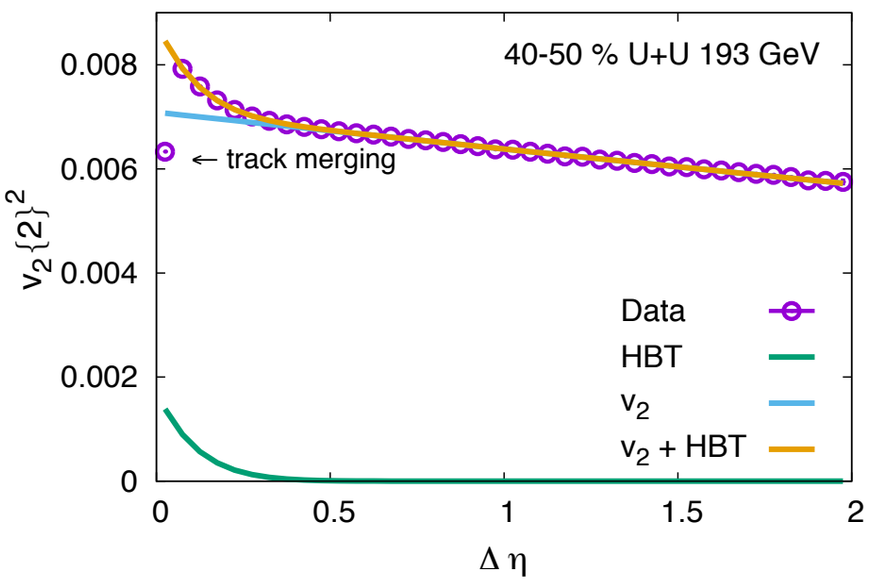


Au+Au results —> baseline for measurement in U+U

Measurement of $v_2\{2\}$ in U+U collisions

$$\gamma^{a,b} = \frac{\langle \cos(2(\phi_1^a + \phi_2^b - 2\phi_3)) \rangle}{v_2\{2\}}$$

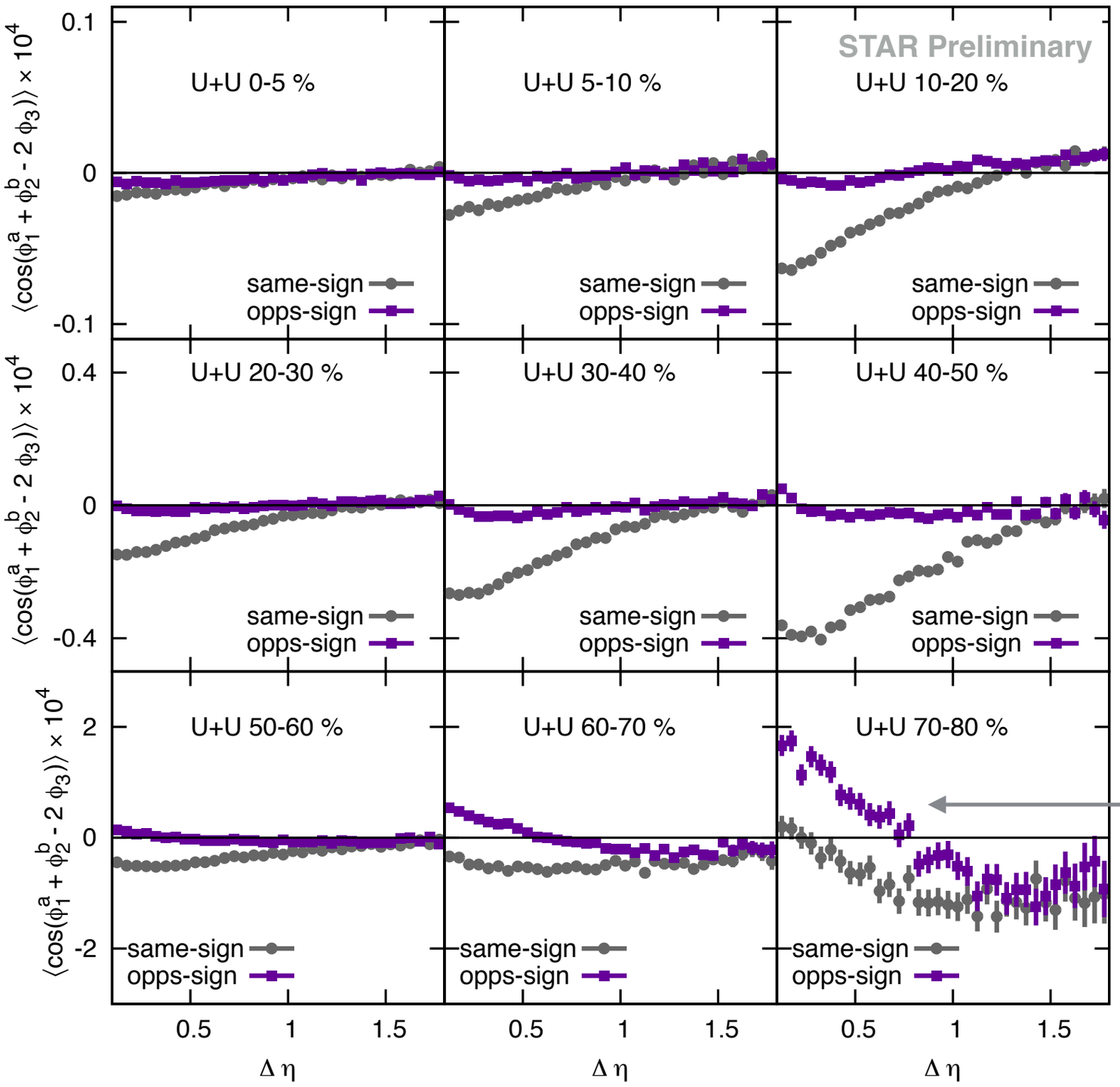




Removing two major artifacts:

- Track merging (apply $\Delta\eta > 0.025$)
- HBT -correlations (Gaussian fit)

Differential measurement of the C_{112} correlator



$$C_{112} = \langle \cos(2(\phi_1^a + \phi_2^b - 2\phi_3)) \rangle$$

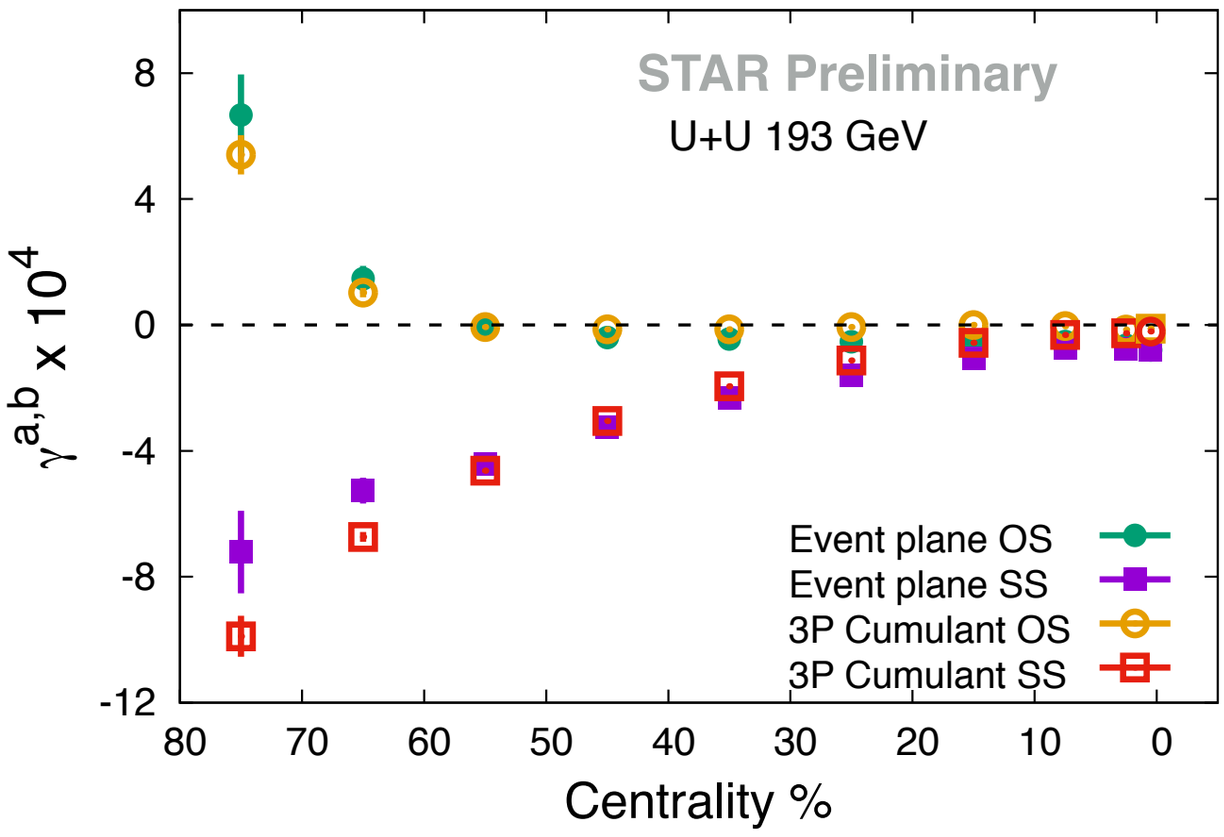
$$\Delta\eta = \Delta\eta_{1,2}$$

Need to remove two major artifacts :

- Track merging
  - apply Δη > 0.025
- HBT -correlations
  - do : (OS - SS)

Results using Cumulant and Event-plane methods

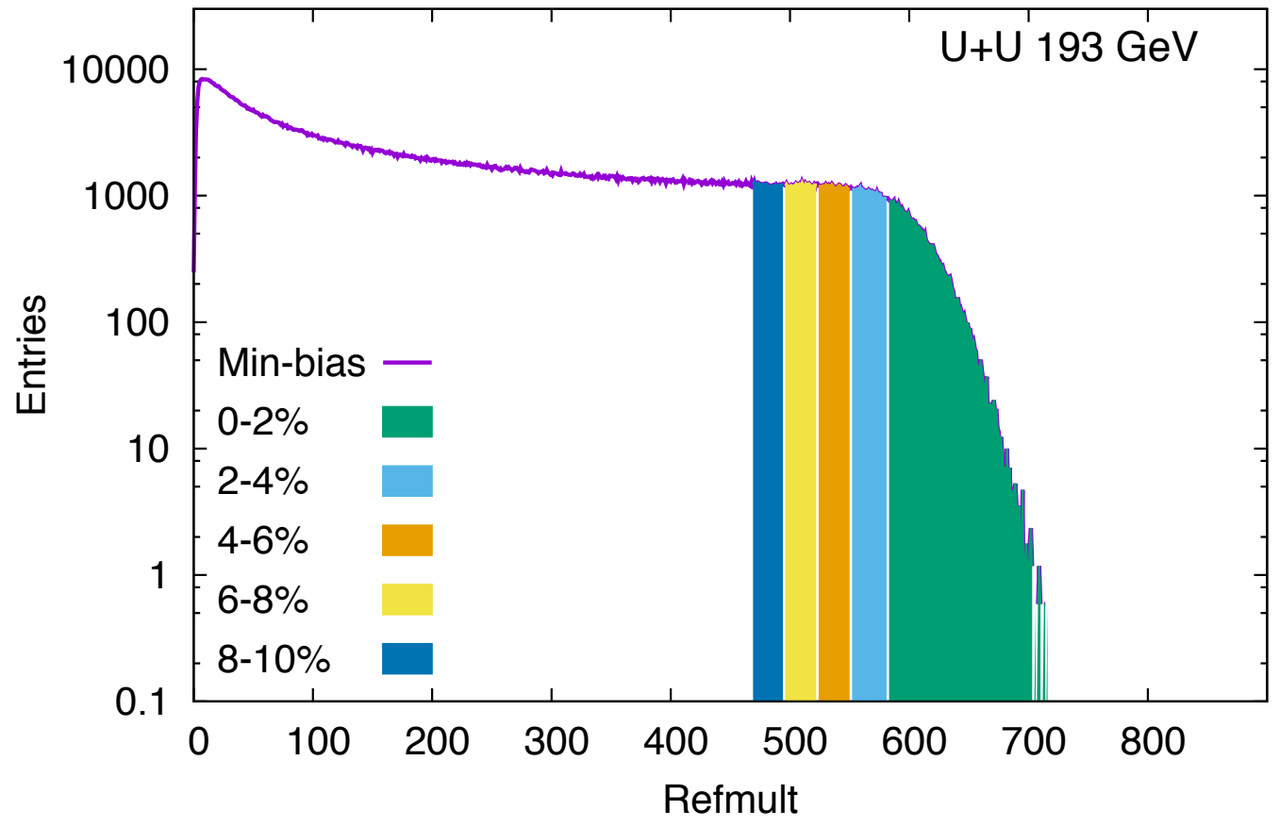
$$\gamma^{a,b} \sim \frac{\langle \cos(\phi_1^a + \phi_2^b - 2\phi_3) \rangle}{v_2\{2\}} \quad \sim \langle \cos(\phi^a + \phi^b - 2\Psi_{RP}) \rangle$$



A tighter centrality selection in 0-10% events is needed to probe the shape of Uranium

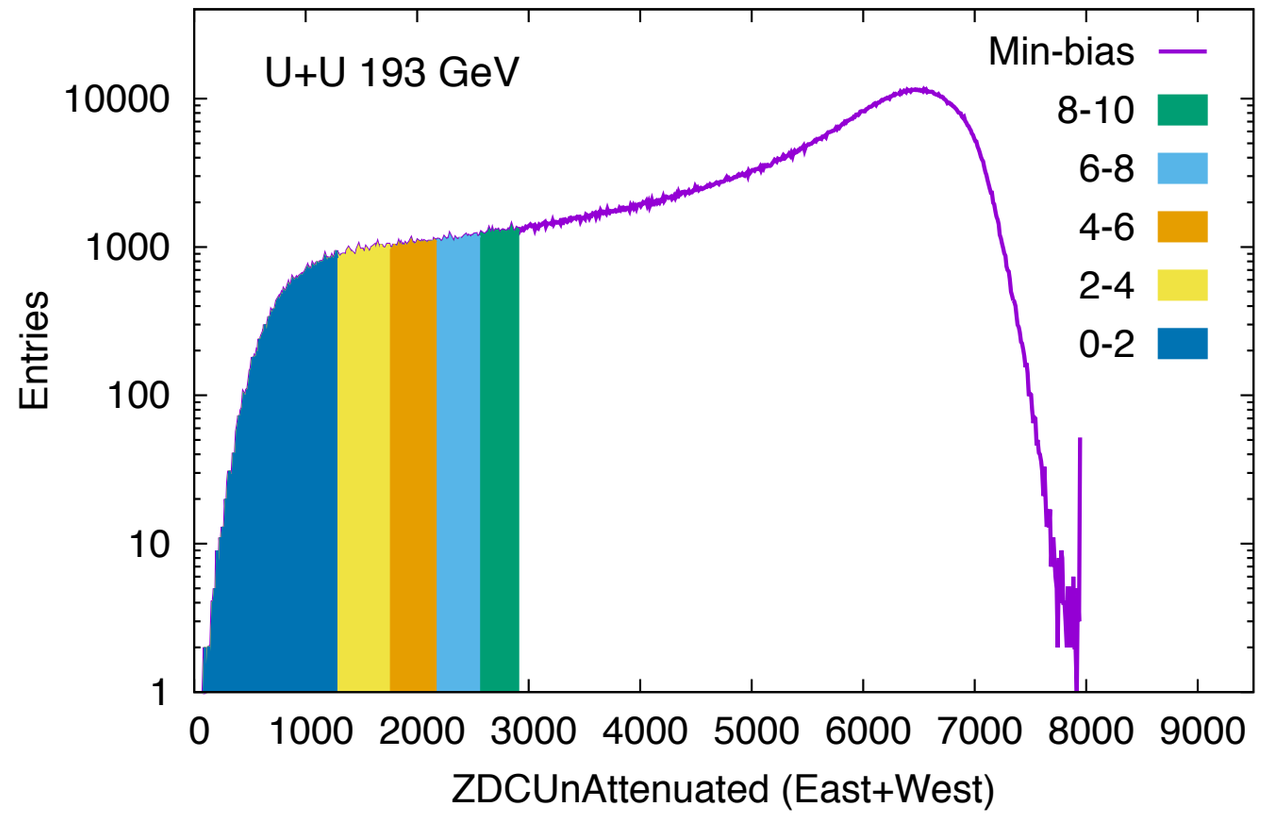
Centrality Selection in 0-10% events

-Method 1 (using RefmultCorr)



Binning on multiplicity

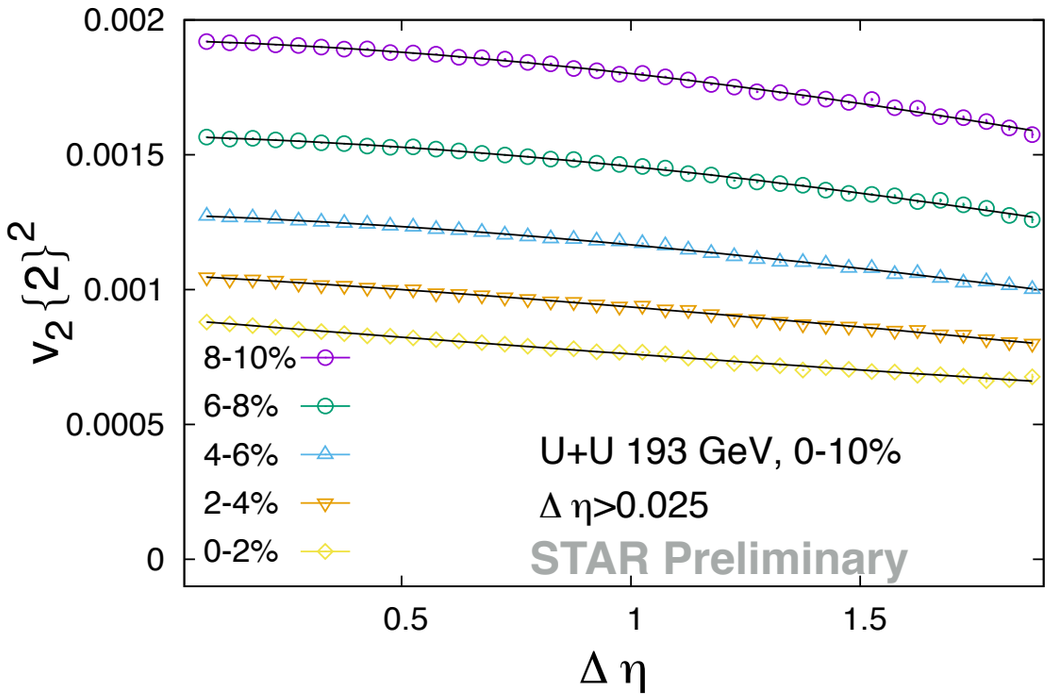
-Method 2 (using ZDCs)



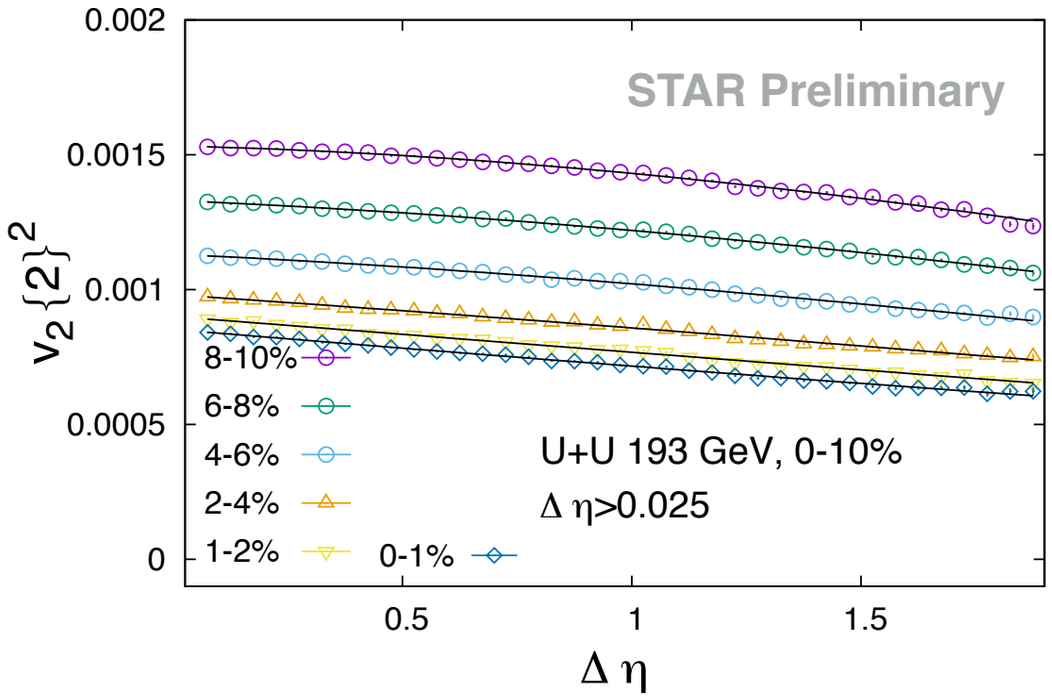
Binning on spectators

Estimation of $v_2\{2\}$ (varying multiplicity & spectators)

After removing track merging and HBT peak



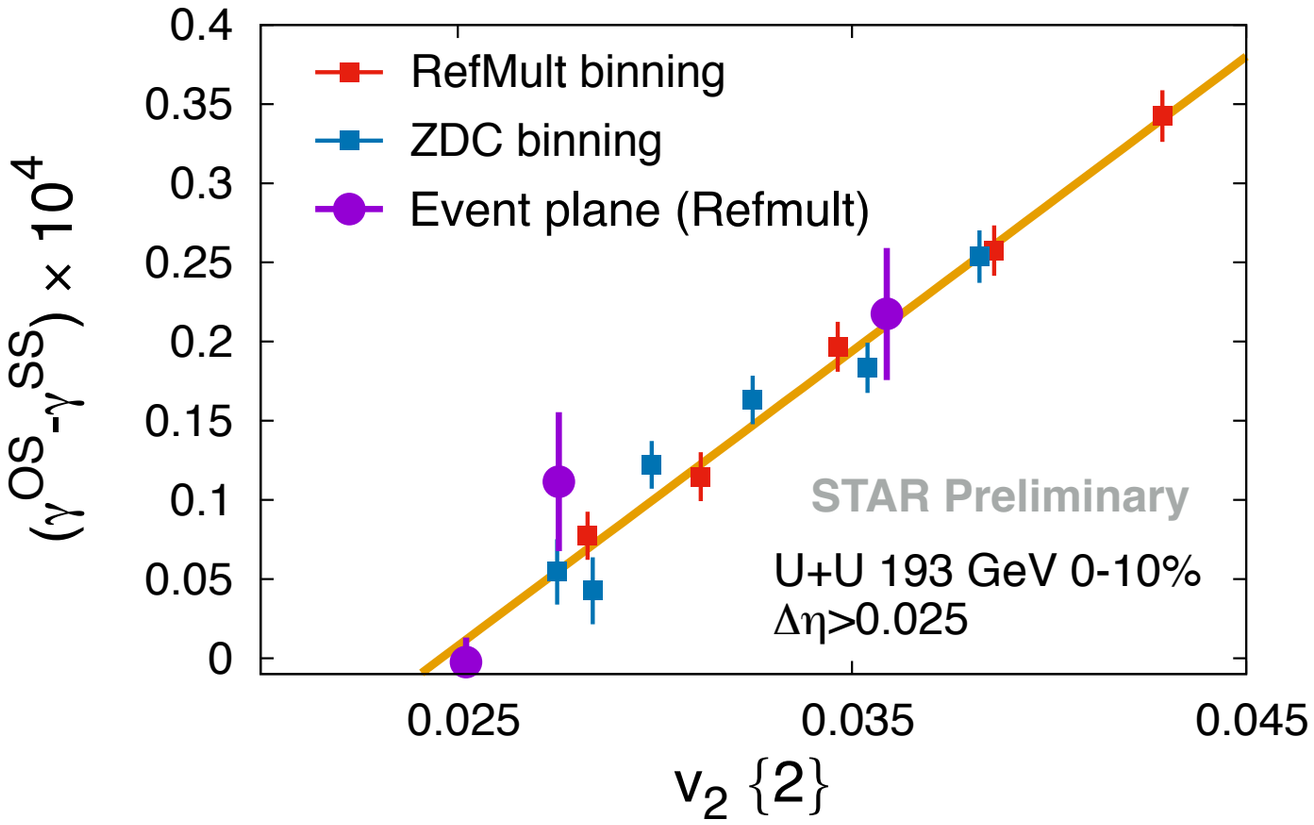
Refmult bins



ZDC bins

Stronger variation of v_2 with multiplicity compared to spectators

γ^{ab}-v_2 correlations (varying multiplicity & spectators)

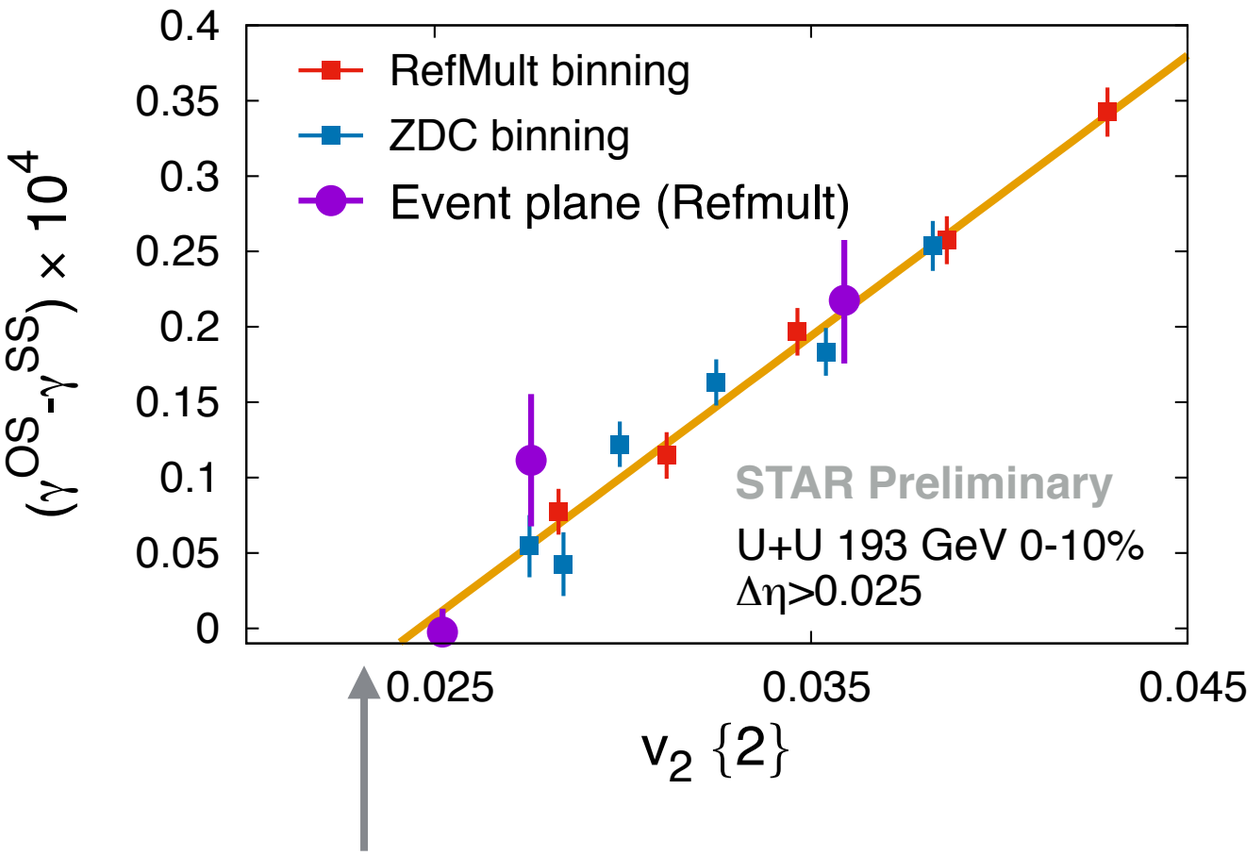


Observations in 0-10%:

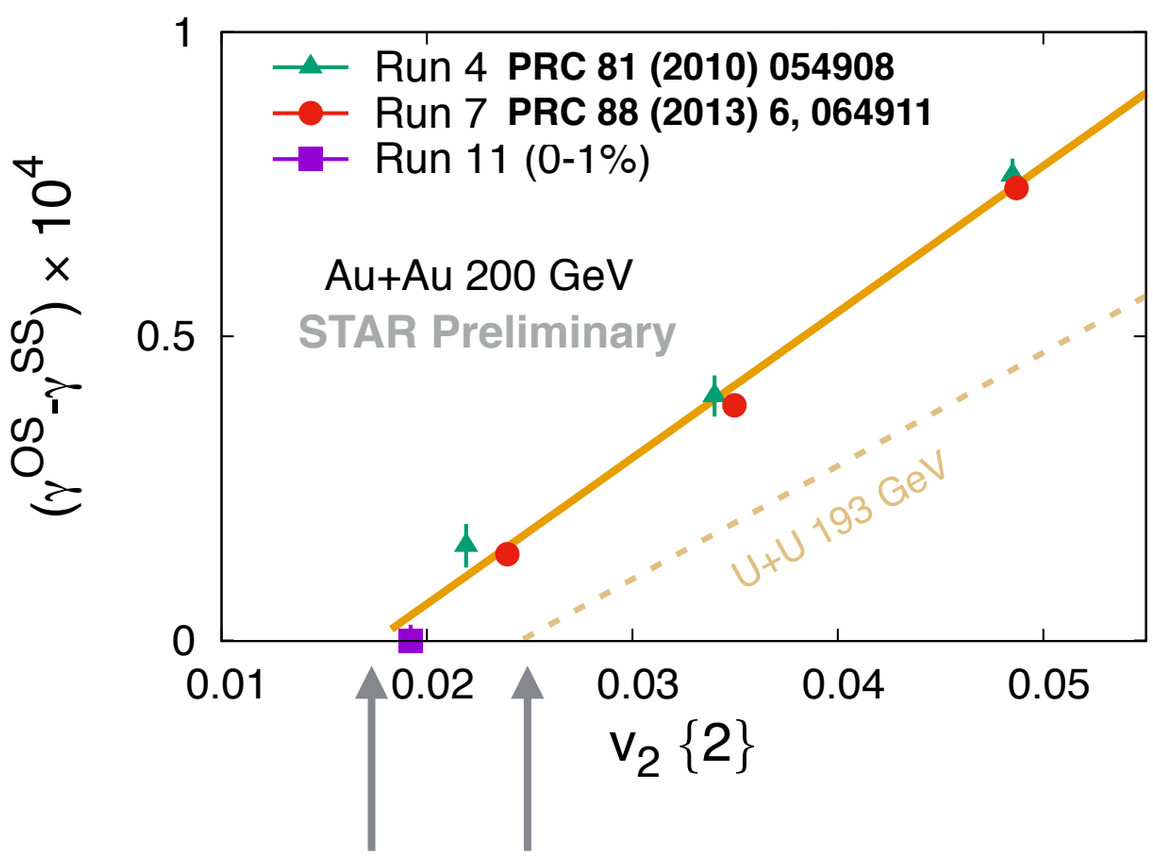
- Strong correlation : nearly linear dependence between γ^{ab} & v_2
- $\gamma^{ab} \sim 0$ for $v_2 \neq 0$

γ^{ab}-v_2 correlations (varying multiplicity & spectators)

U+U collisions



Au+Au collisions

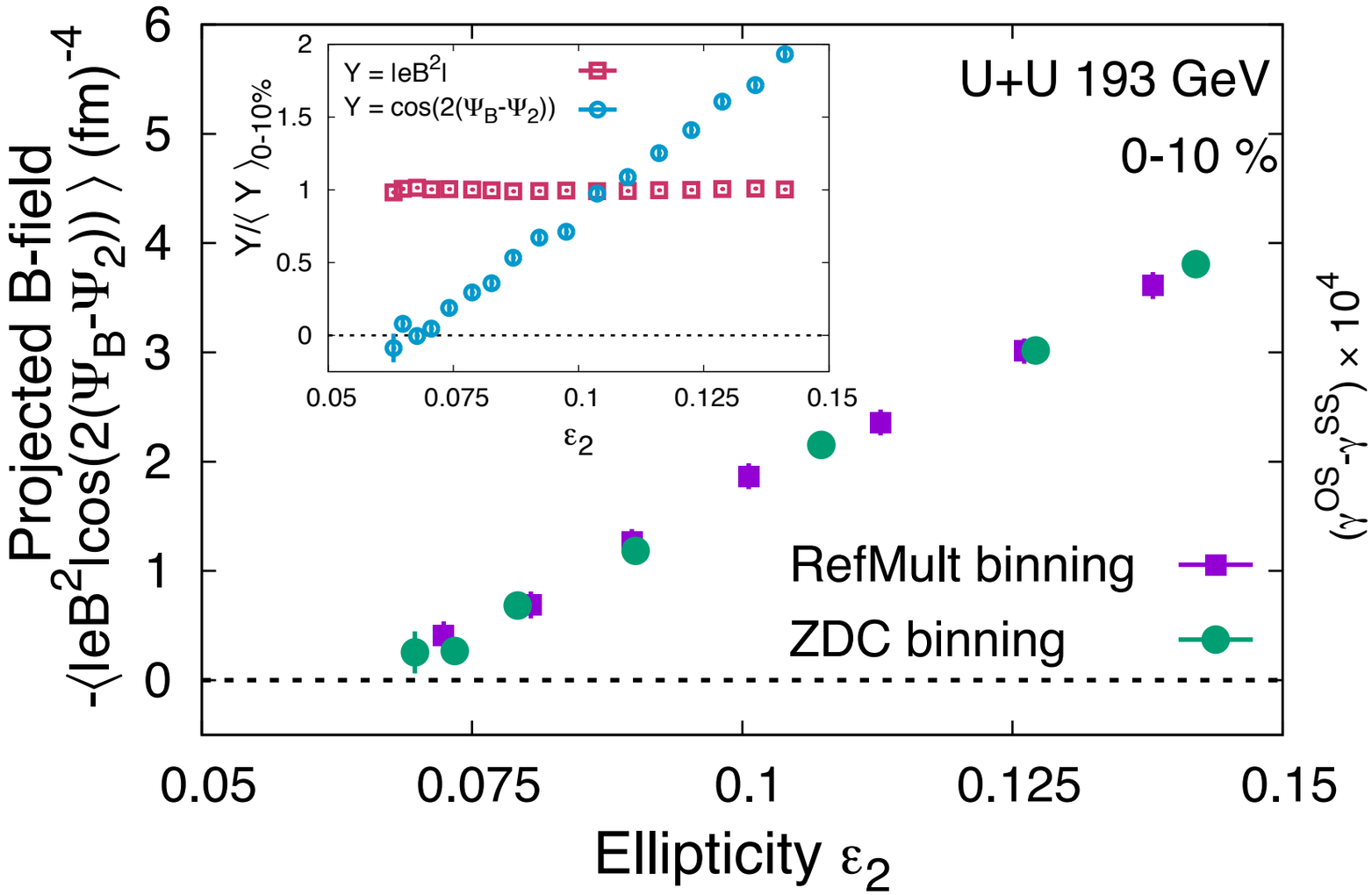


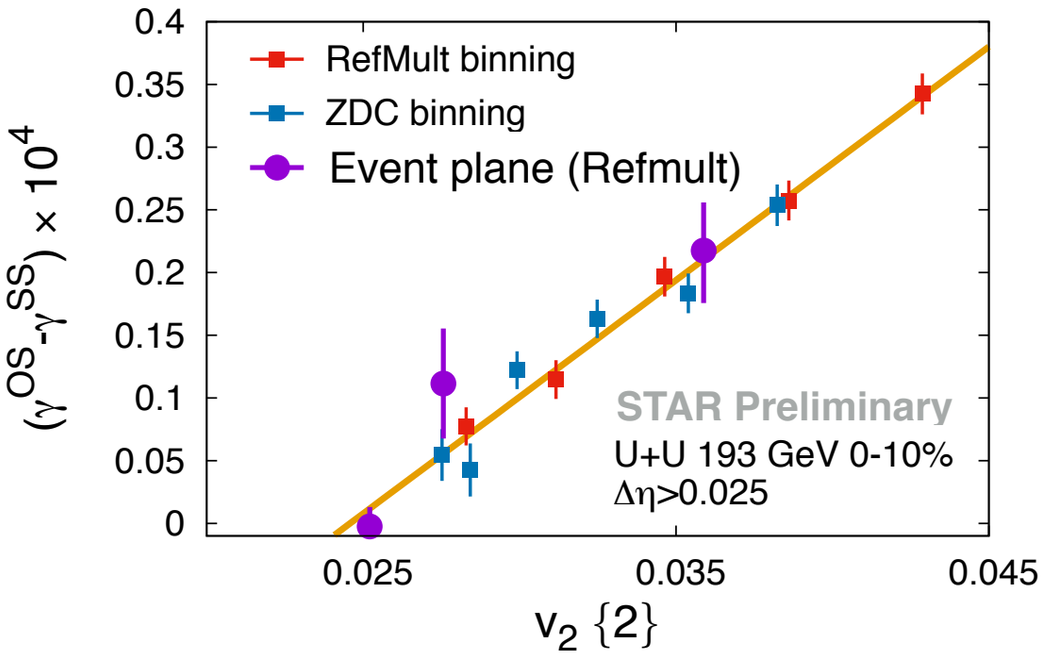
$(\gamma^{OS}-\gamma^{SS})\sim 0$ in both Au+Au and U+U for non-zero v_2

Dominance of fluctuations of the participants and spectators

Simulations including detector effects

MC-Glauber model with response of ZDC & TPC —> proxy for γ^{ab} & v_2

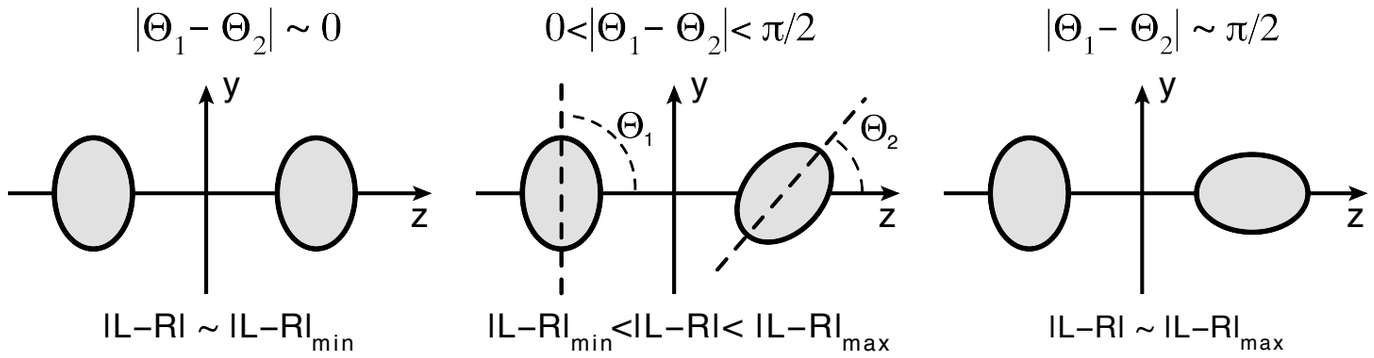




A pattern similar to data : γ depends on both $|B^2|$ & its alignment with the participant plane —> Participant & spectator fluctuations can't be neglected —> difficult to disentangle γ^{ab} & v_2

Spectator asymmetry in U+U collisions

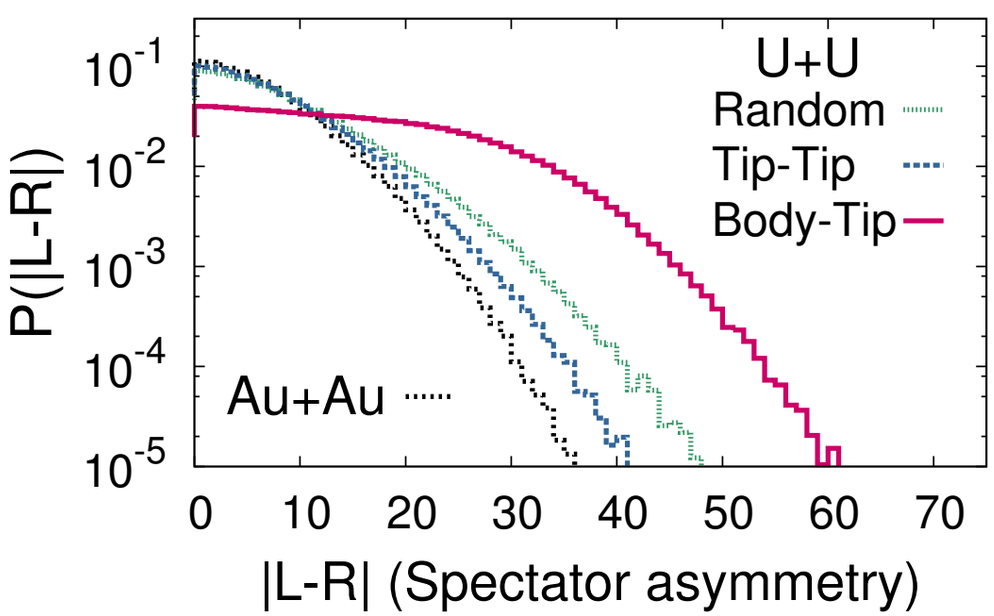
A new tuning parameter to disentangle ε_2 and B-field

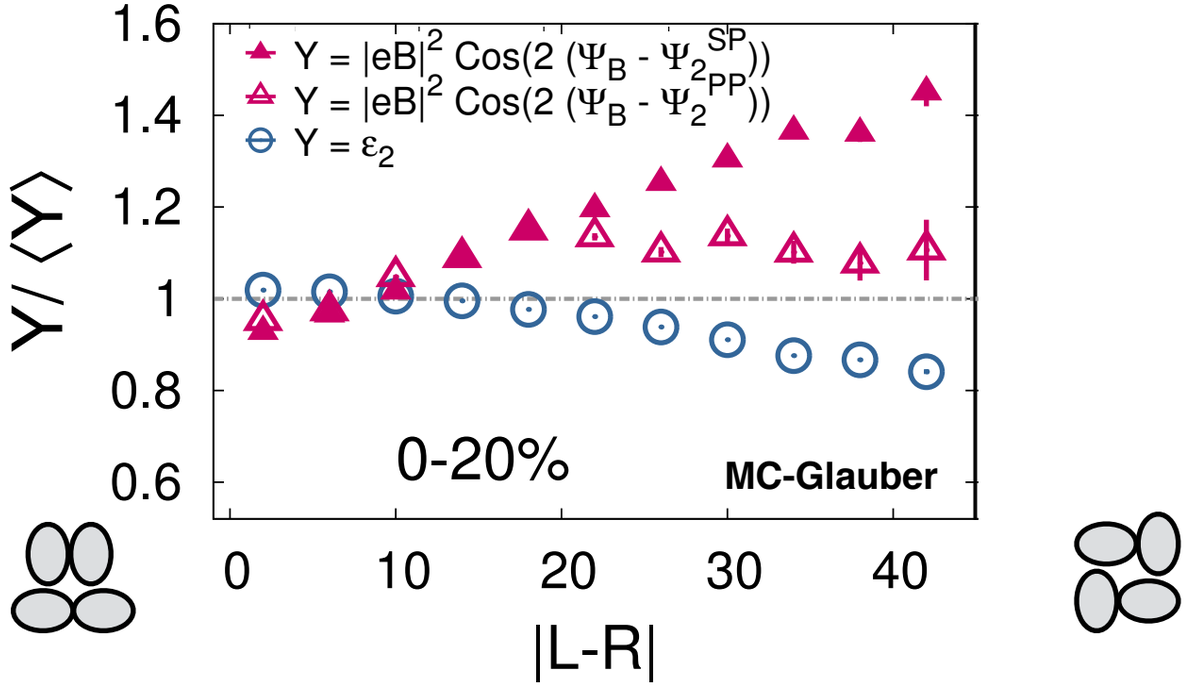


R: right going spectator neutrons

L: left going spectator neutrons

S.Chatterjee & PT (1412.5103)

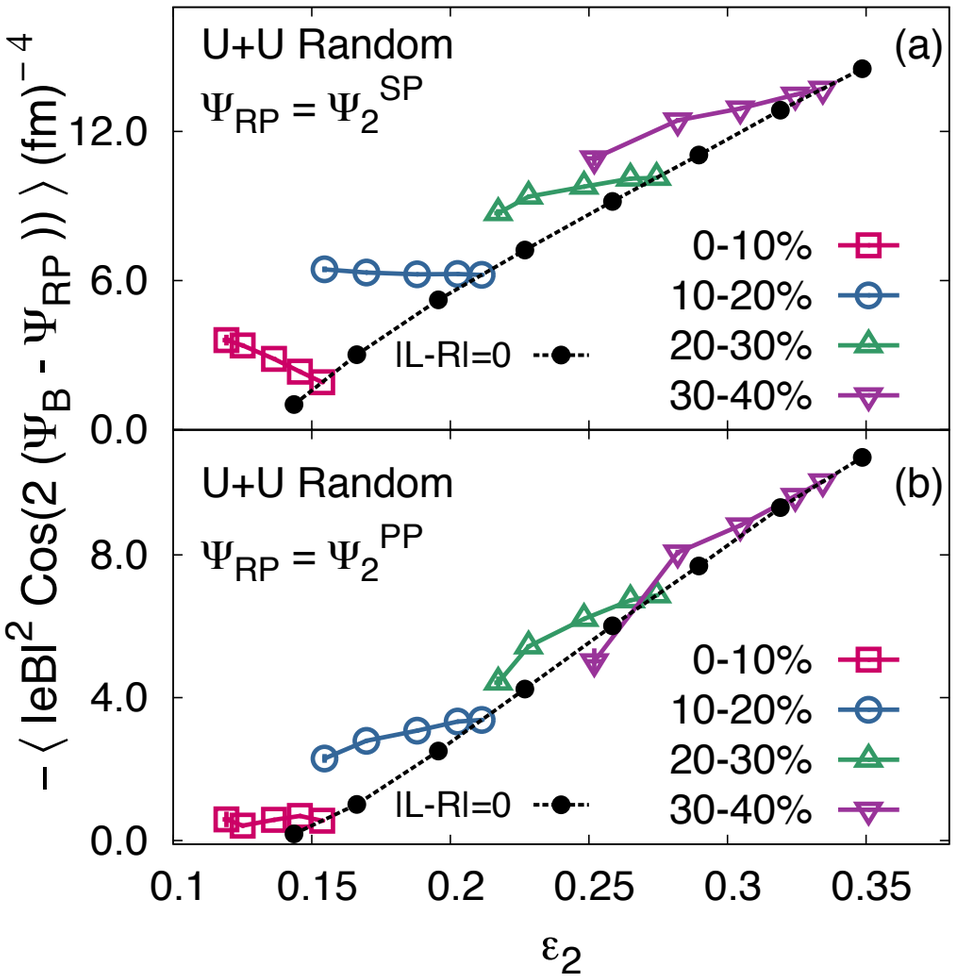


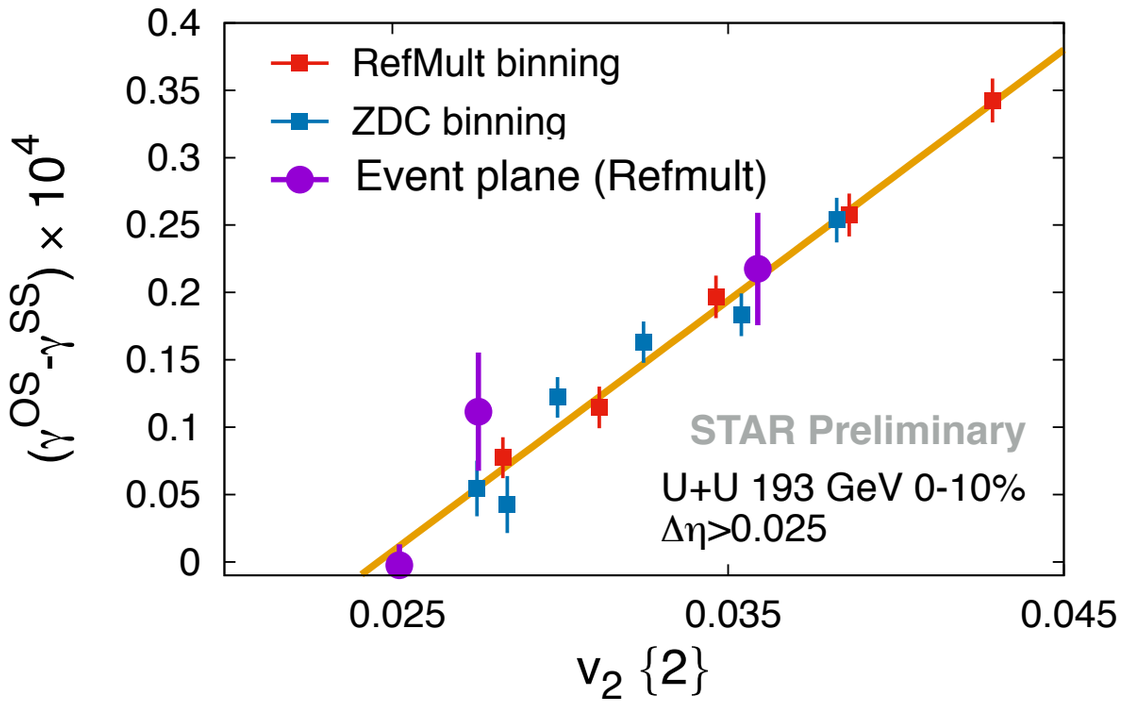


Binning in |L-R| it is possible to trigger body-tip events : B ↑ ε_2 ↓

Spectator asymmetry in U+U collisions

S.Chatterjee & PT (1412.5103)



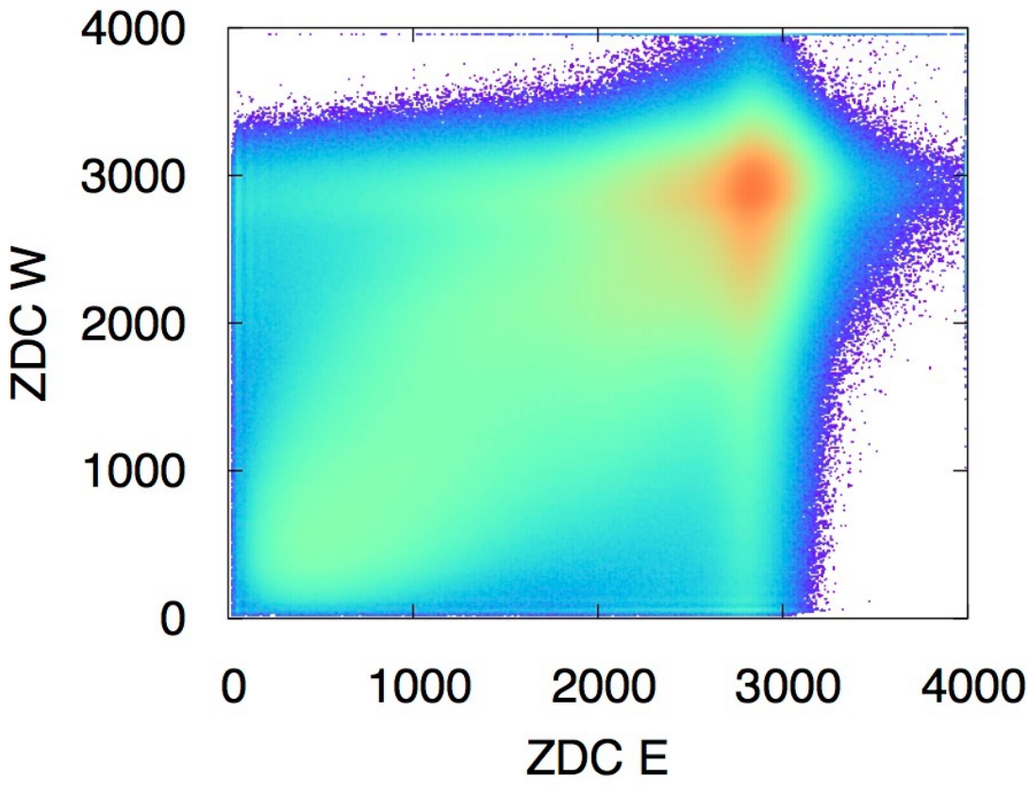


Spectator asymmetry —> triggers event with two different values of B-field but the same ε_2 & vice-versa

Next Step: Bin events in ZDC asymmetry & look for **similar trend between γ^{ab} & v_2**

Spectator asymmetry in U+U collisions

Body-Tip events are experimentally triggered by asymmetry of ZDCs



Experimental challenges :

- Response of ZDC to neutrons
- Clustering of nucleons that introduces artificial de-correlation

Analysis in this direction (separating signals of flow & CME) and systematic studies are under progress

Summary / Outlook

- Results on azimuthal correlations in U+U collisions at RHIC have constrained models of initial conditions.

- As a next step charge dependent azimuthal correlations have been studied in U+U & compared to Au+Au results.

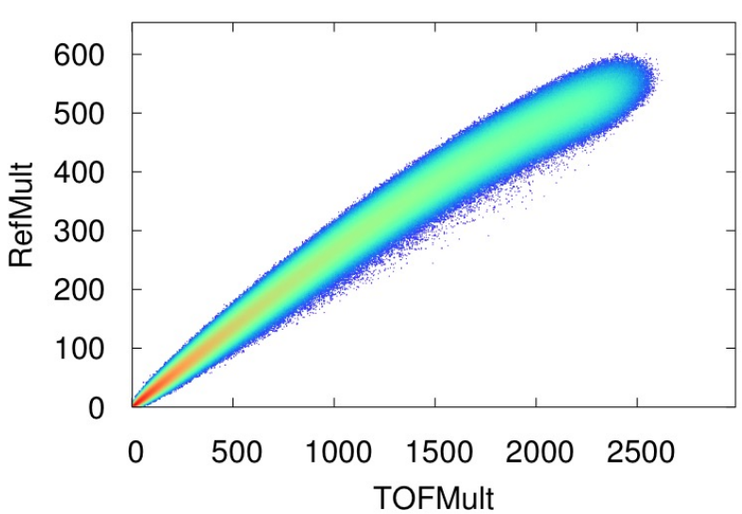
- Strong correlation between γ^{ab} & $\mathbf{v_2}$ observed in 0-10% with γ^{ab} **~0 for v_2>0** in both U+U and Au+Au collisions.

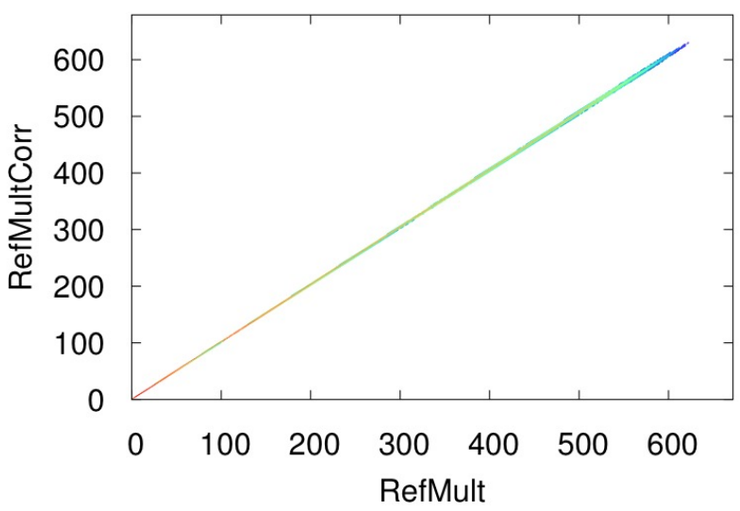
- Smaller than expected variation of v_2 with multiplicity in central U+U reduces lever arm for studying dependence of γ^{ab} on $\mathbf{v_2}$

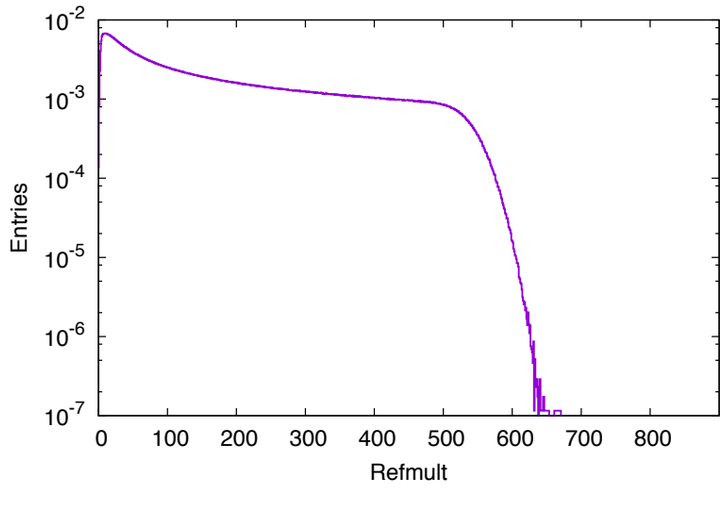
- New analyses under way to use U+U data to disentangle CME signal from backgrounds (specifically using spectator asymmetry).

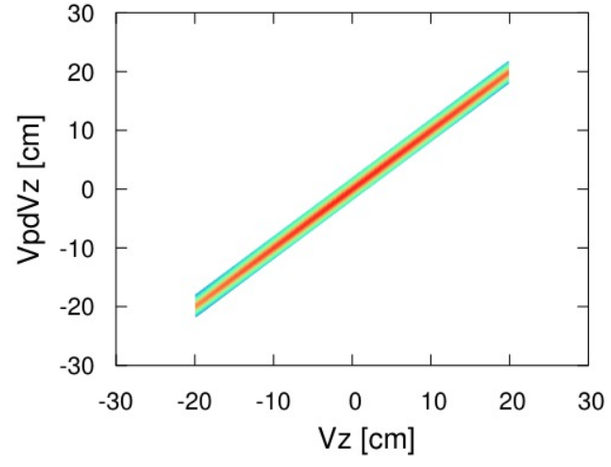
backup

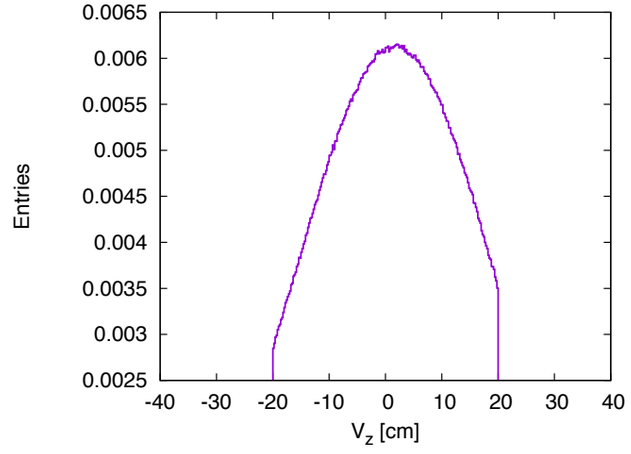
A few QA plots

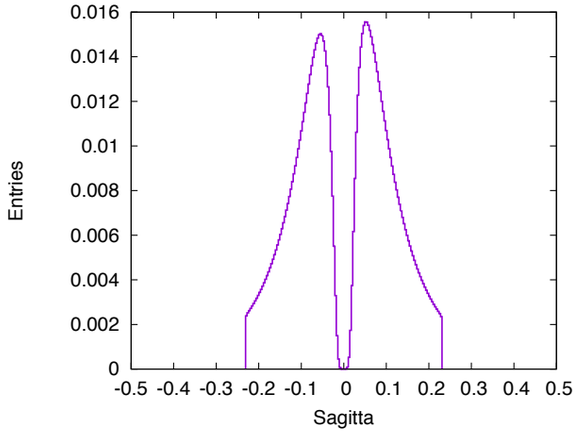


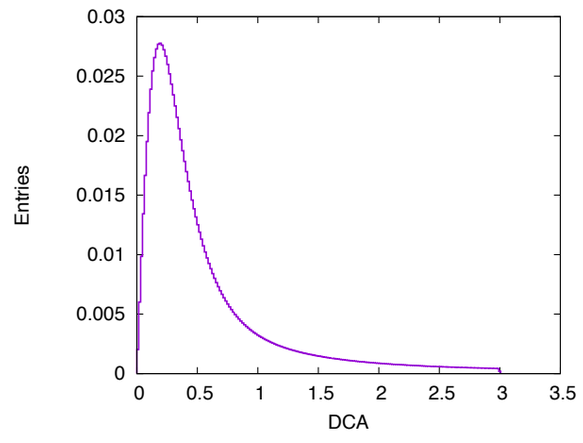


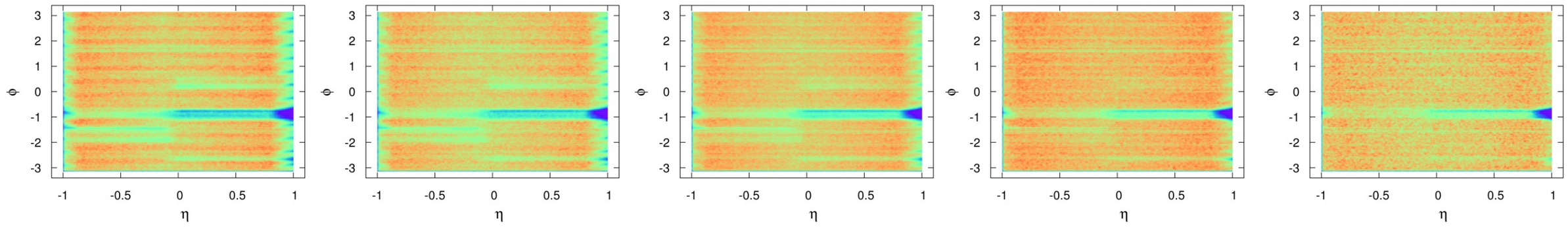












Weight estimation for cumulant calculations

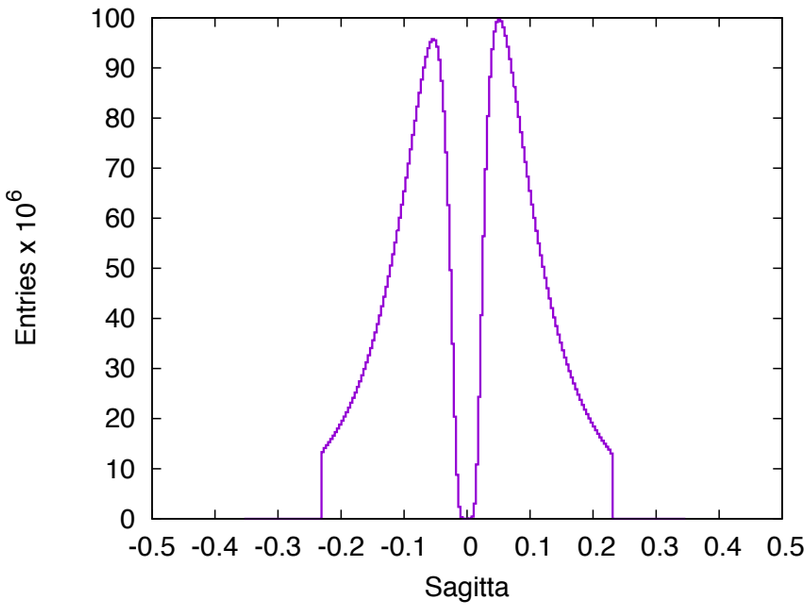
- Acceptance binning for weight calculation :

Sagitta = charge*((20.*p_T/3.) - $\sqrt{((20.*p_T/3.)^2 - 0.75^2)}$)

Weight = 1/(entries in η-ϕ) * 1/ϵ

The tracking efficiency :

$$\epsilon = \frac{C}{(1. + \exp(-(p_T + 0.1)/0.15))}$$



B-field simulations in U+U collisions

t=0, x=<x>, y=<y>, z=0