Search for the chiral magnetic effect in U+U & Isobar collisions

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BROOKHAVEN NATIONAL LABORATORY

CME workshop, RHIC & AGS Annual Users' Meeting, June 7-10, 2016

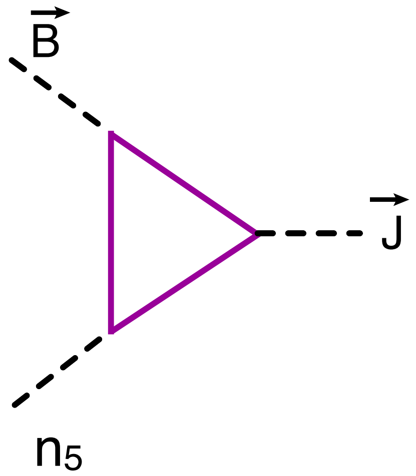
Brookhaven National Laboratory, Upton, NY,USA

STAR

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

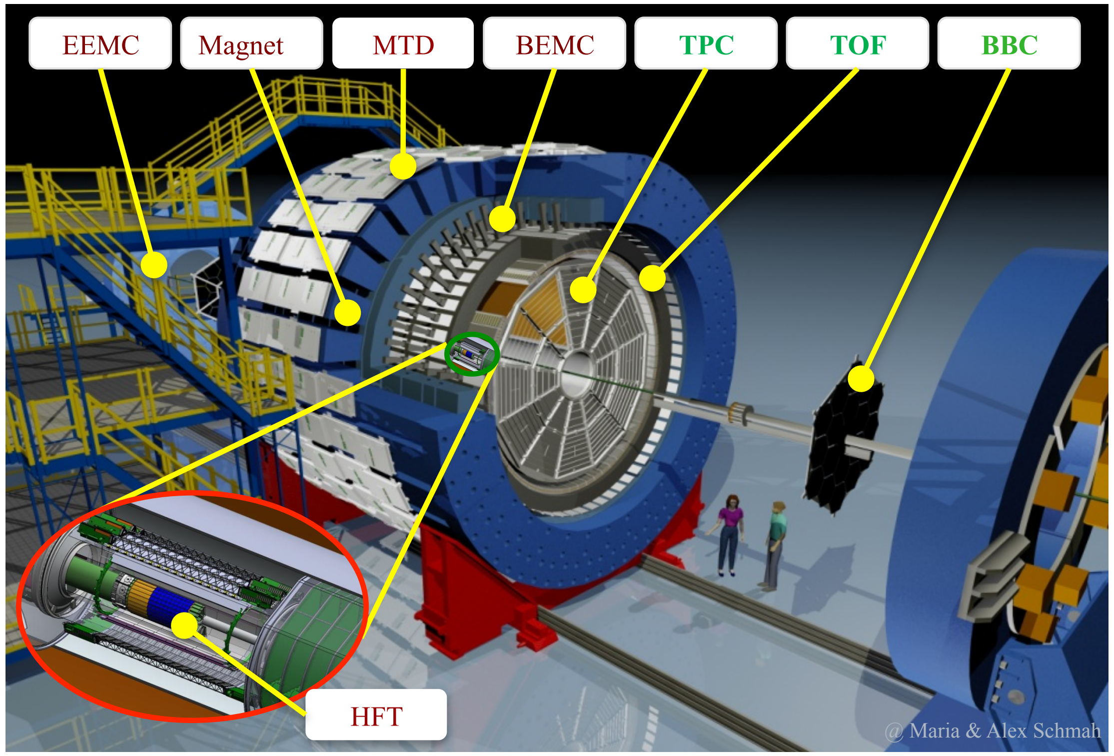
- Results for U+U & Au+Au collisions from STAR
- What else can we try with the existing data
- Outlook for collisions of Isobars @ RHIC



Flow is the dominant source of background for signals of CME

How can U+U collisions be used to disentangle the two effects ?

What else can we try : Isobars



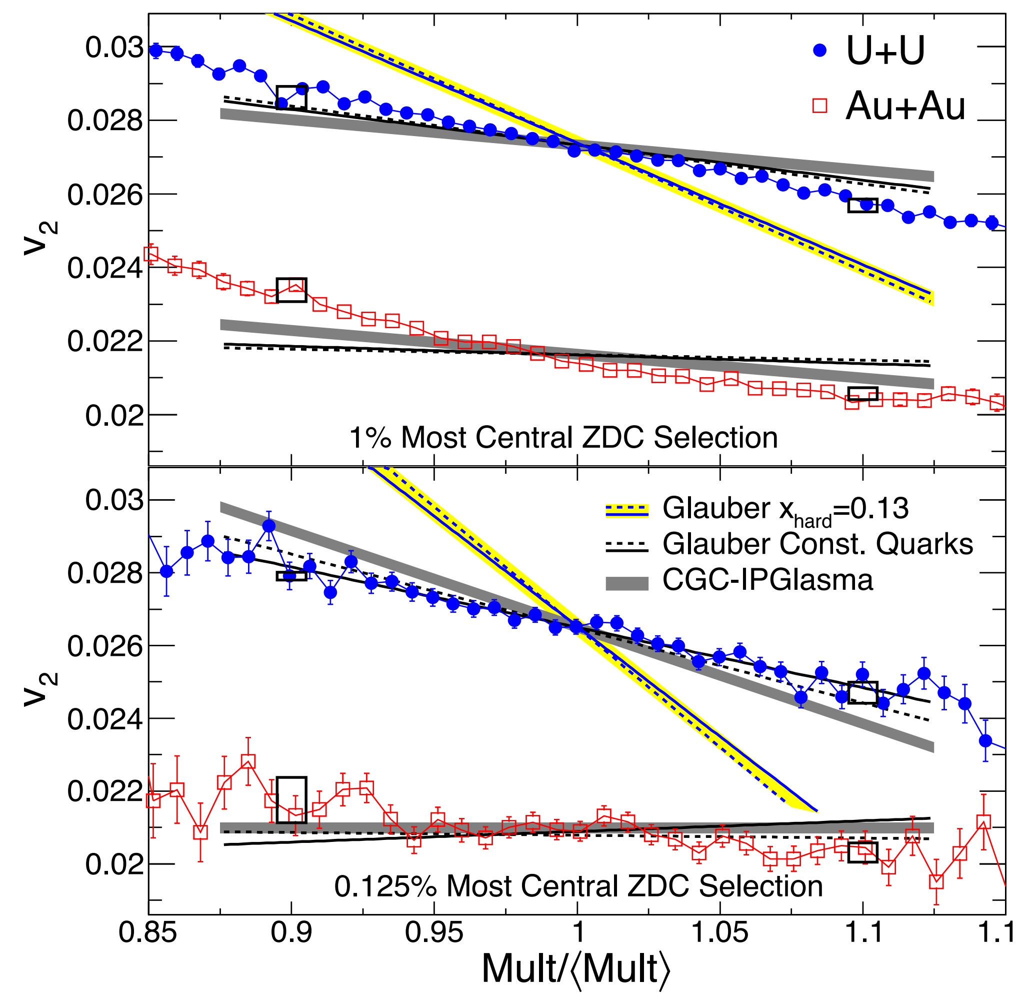
What have we learned from the U+U collisions at RHIC ?

- 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 :
  CGC —> Weak dependence of multiplicity on shape (Schenke, PT, Venugopalan 1403.2232)

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

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

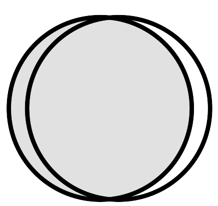


U+U data contradicts strong binary-collision dependence of multiplicity

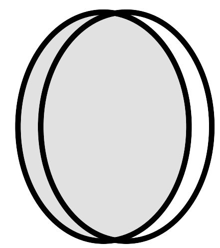
Next Step: Can we use U+U collisions to learn about CME ?

Qualitative picture

Correlation between B-field & eccentricity

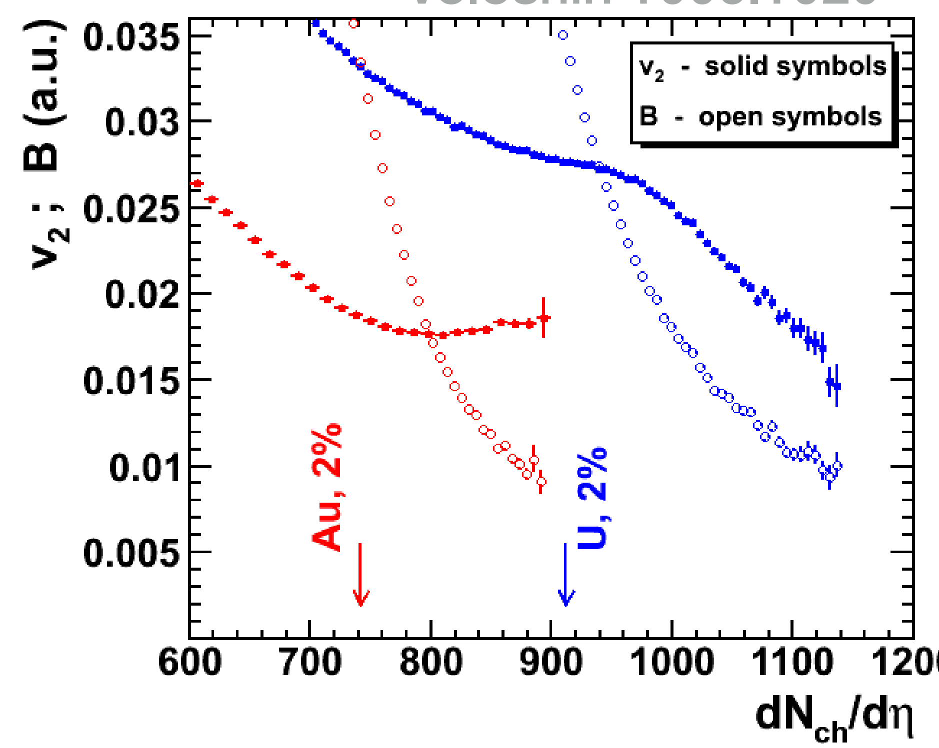


Au+Au (ultracentral)
$\varepsilon \sim 0$, $B \sim 0$

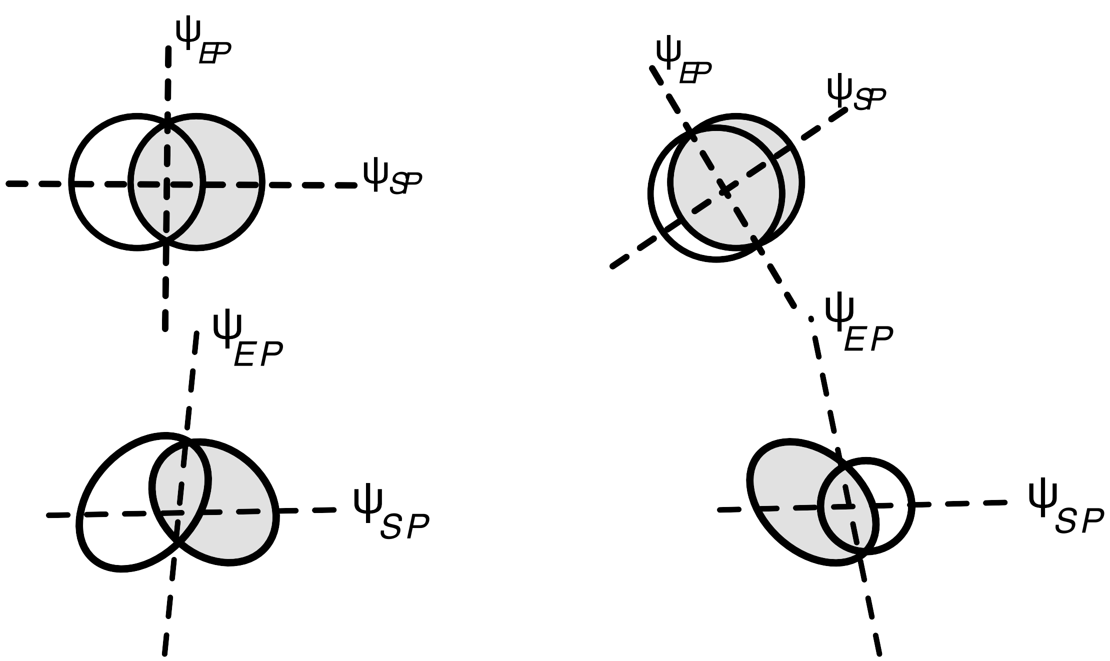


U+U (ultracentral)
$\varepsilon \neq 0$, $B \sim 0$

Voloshin 1006.1020



Search for non-zero v_2 & zero CME



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) correlator :

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

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

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

- The CME correlator :

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

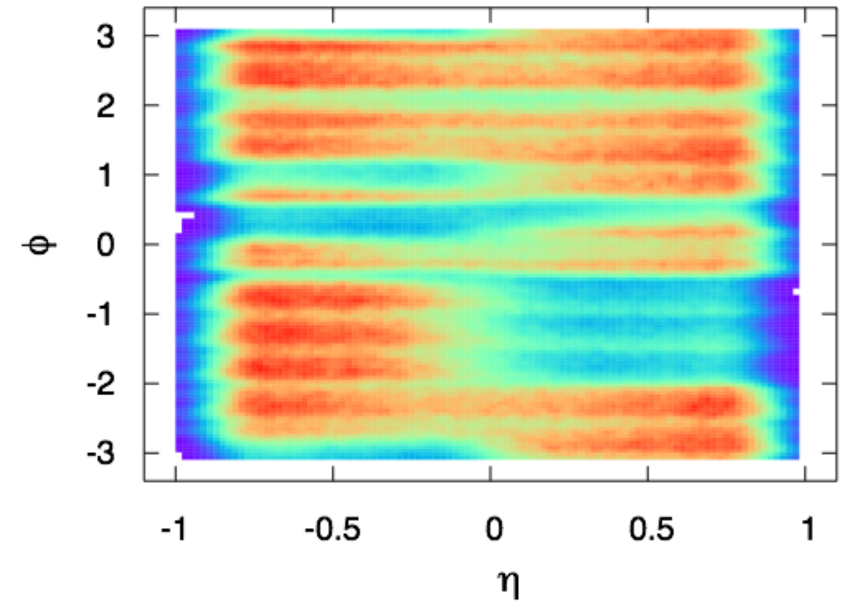
(3P-cumulant method) (event-plane method)

$$v_2\{2\}^2 = \langle \cos(2(\phi_1 - \phi_2)) \rangle$$

Details of the data set

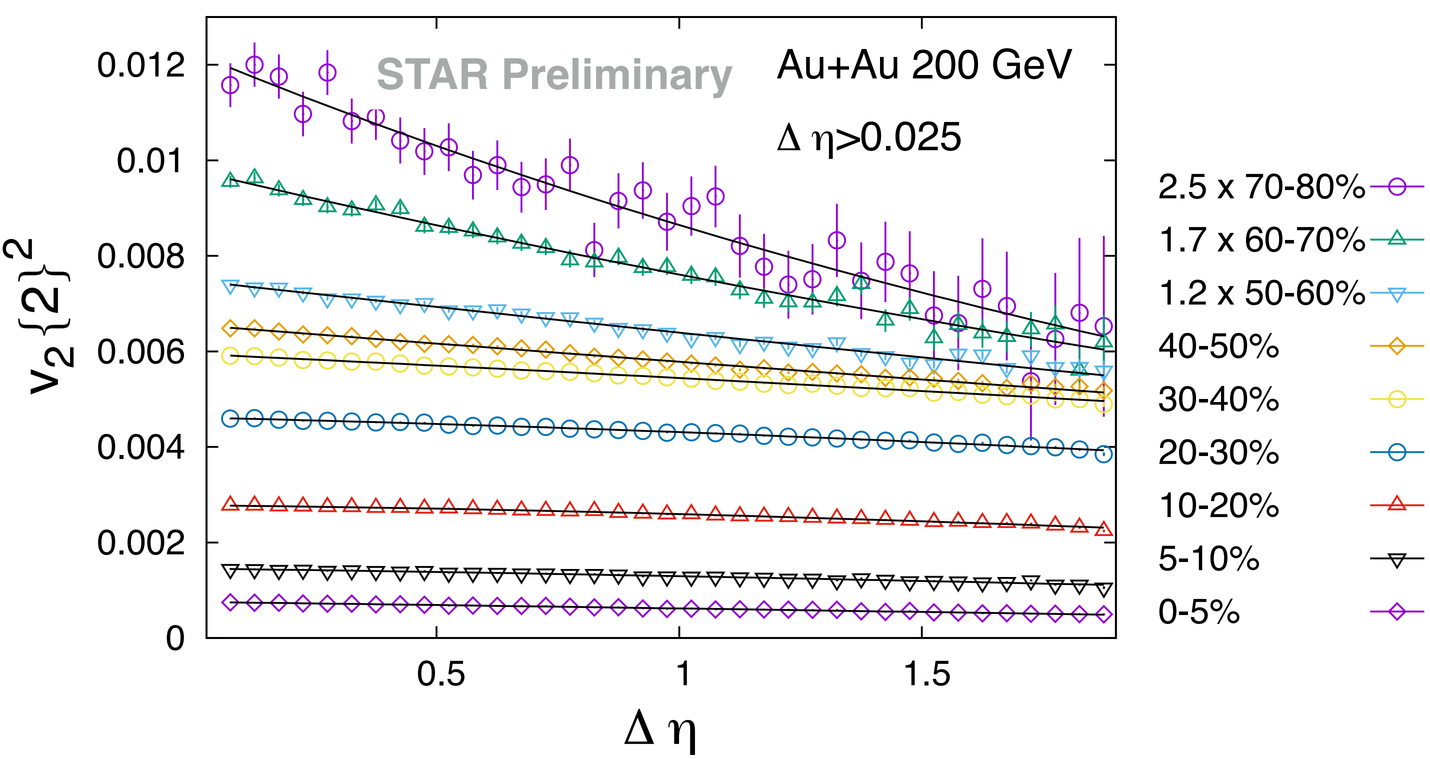
- U+U 193 GeV : Year 2012 **(Min-bias/ultra-central)**
- Au+Au 200 GeV : Year 2004, 2007 **(Min-bias)**, 2011 **(ultra-central)**
- Centrality selection :
  - TPC uncorrected multiplicity $|\eta|<0.5$
  - ZDC East & West ADC
- Common QA cuts :
  - $|V_r|<$ **2**, $|V_z| <$ **20**, $|V_z$ - $vpdV_z|<$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

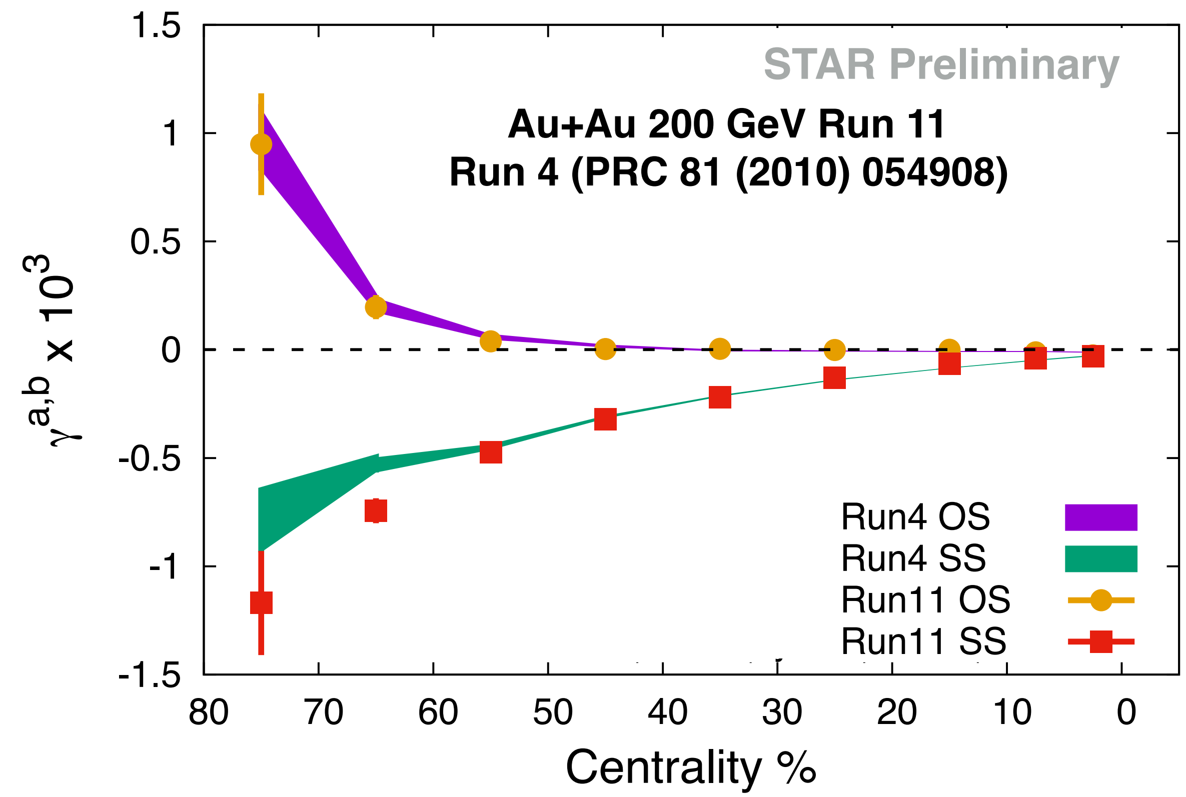
TPC acceptance
(used in this analysis)



Weight estimation :
bin in sagitta, η-ϕ

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

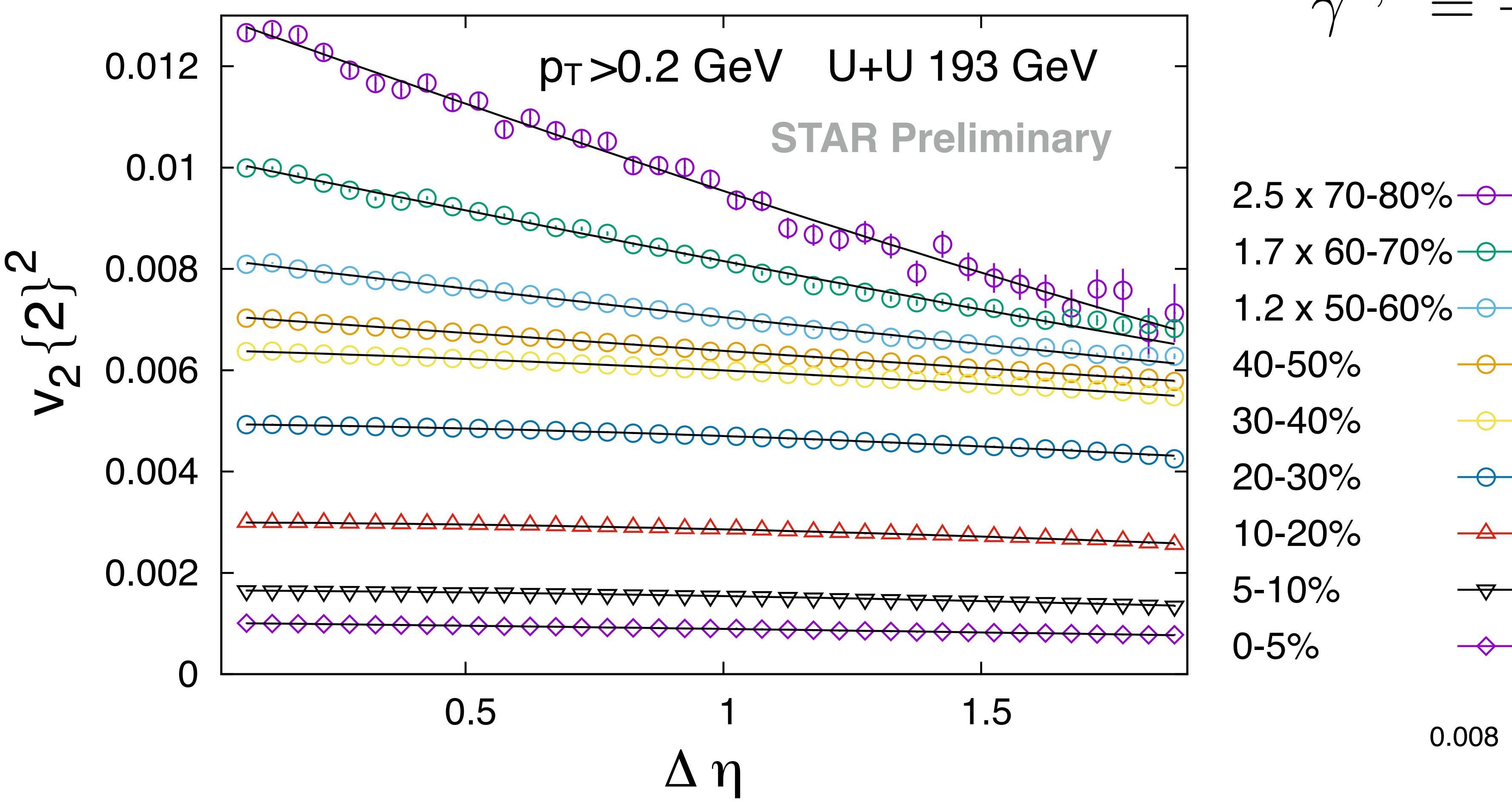


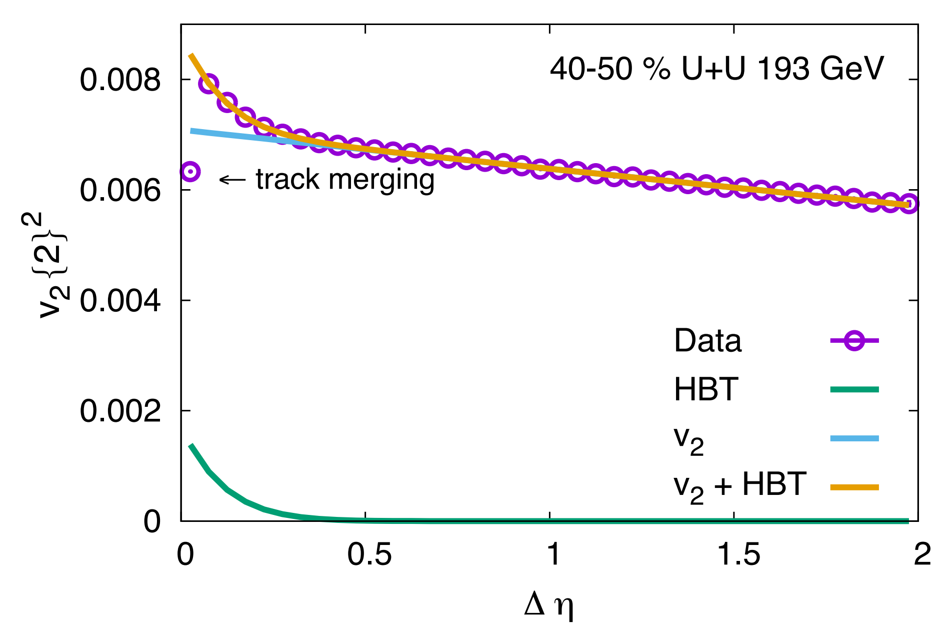


Au+Au results —> baseline for measurements in U+U

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

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

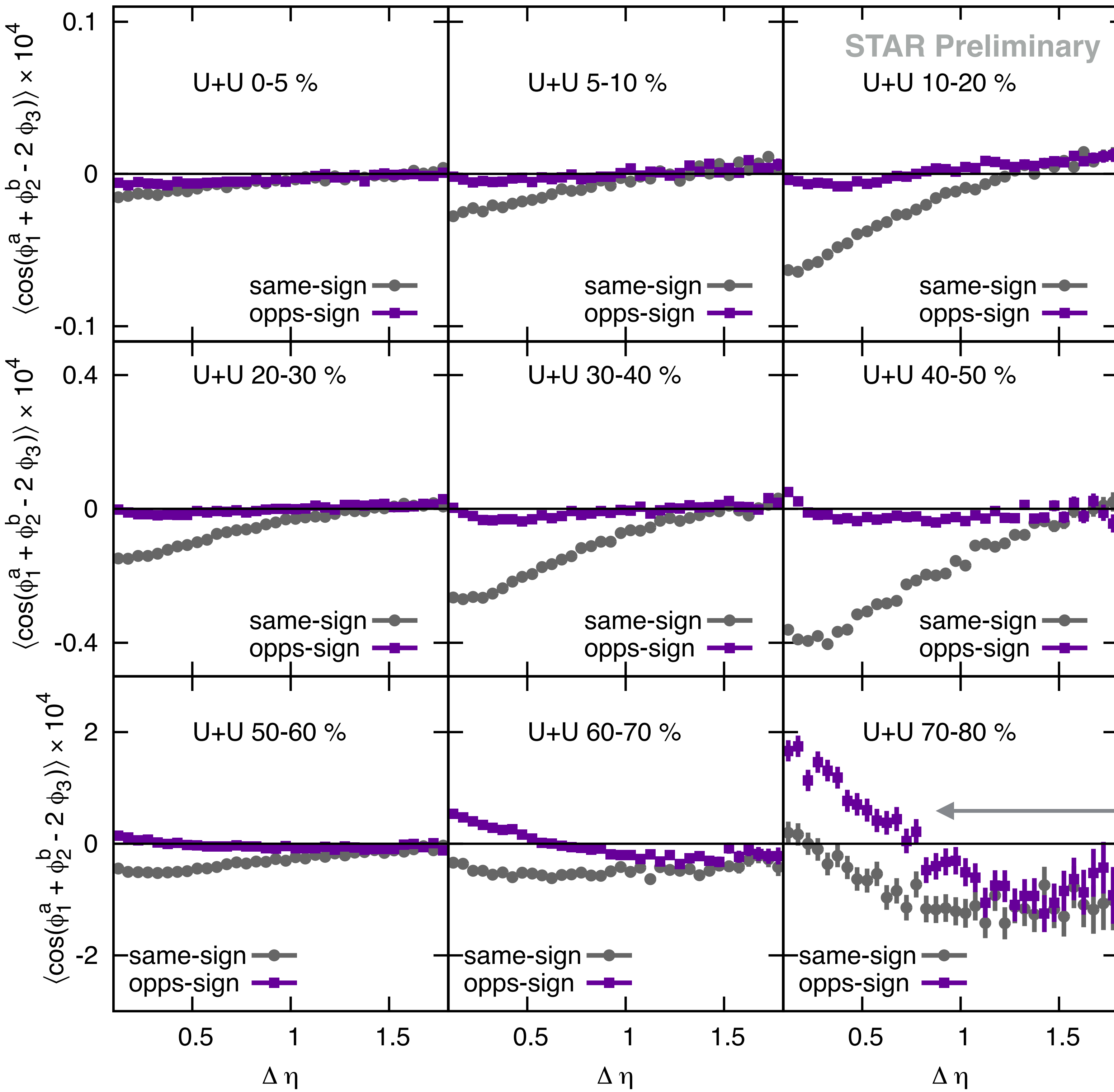




Removing two major artifacts:

- Track merging (apply Δη > 0.025)
- Short range -correlations (Gaussian fit)

Differential measurement of the C_{112} correlator



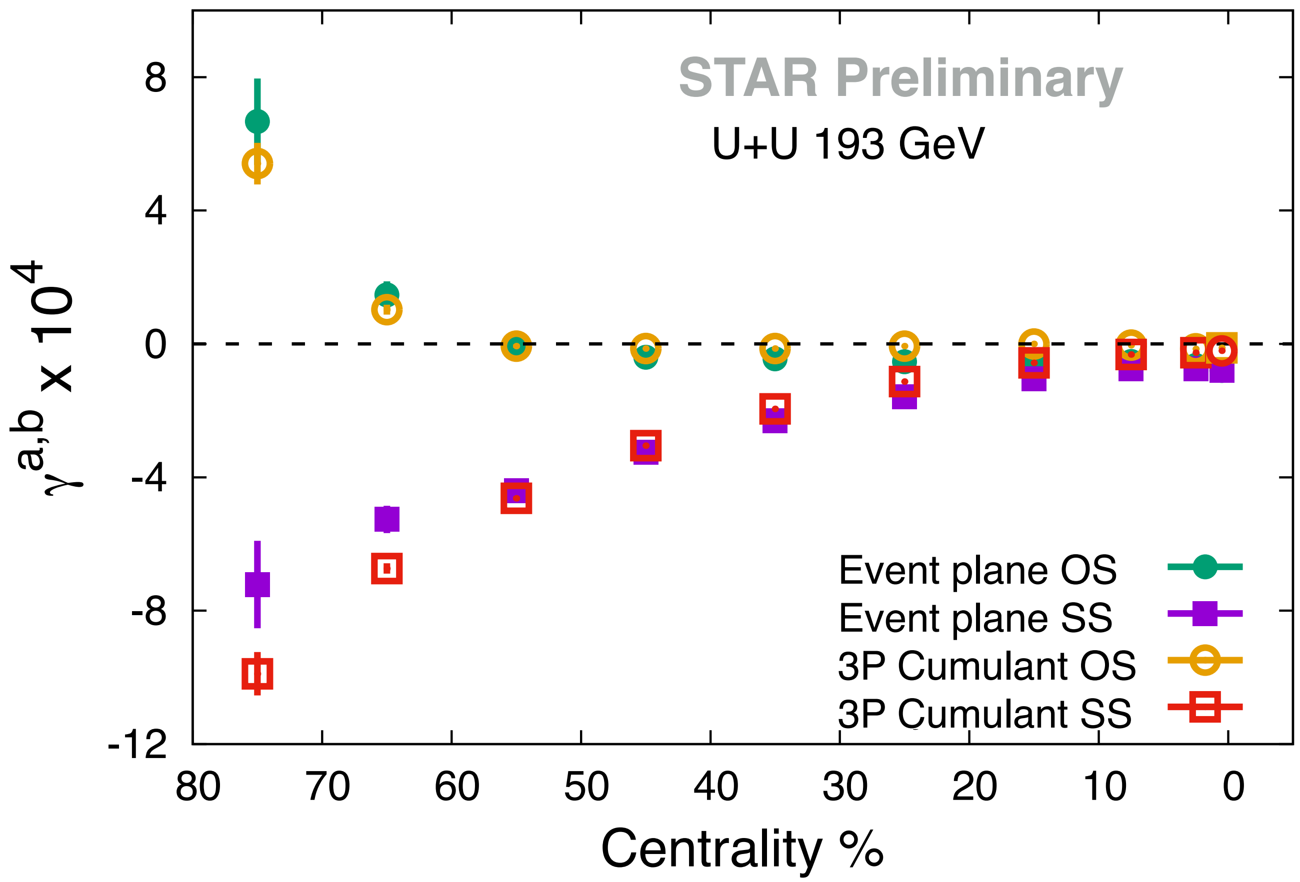
$$C_{112} =$$
$$\langle \cos(2(\phi_1^a + \phi_2^b - 2\phi_3)) \rangle$$
$$\Delta\eta = \Delta\eta_{1,2}$$

Need to remove two major artifacts :

- Track merging
  - apply $\Delta\eta > 0.025$
- Short-range - correlations
  - do : (OS - SS)

Results using Cumulant and Event-plane methods

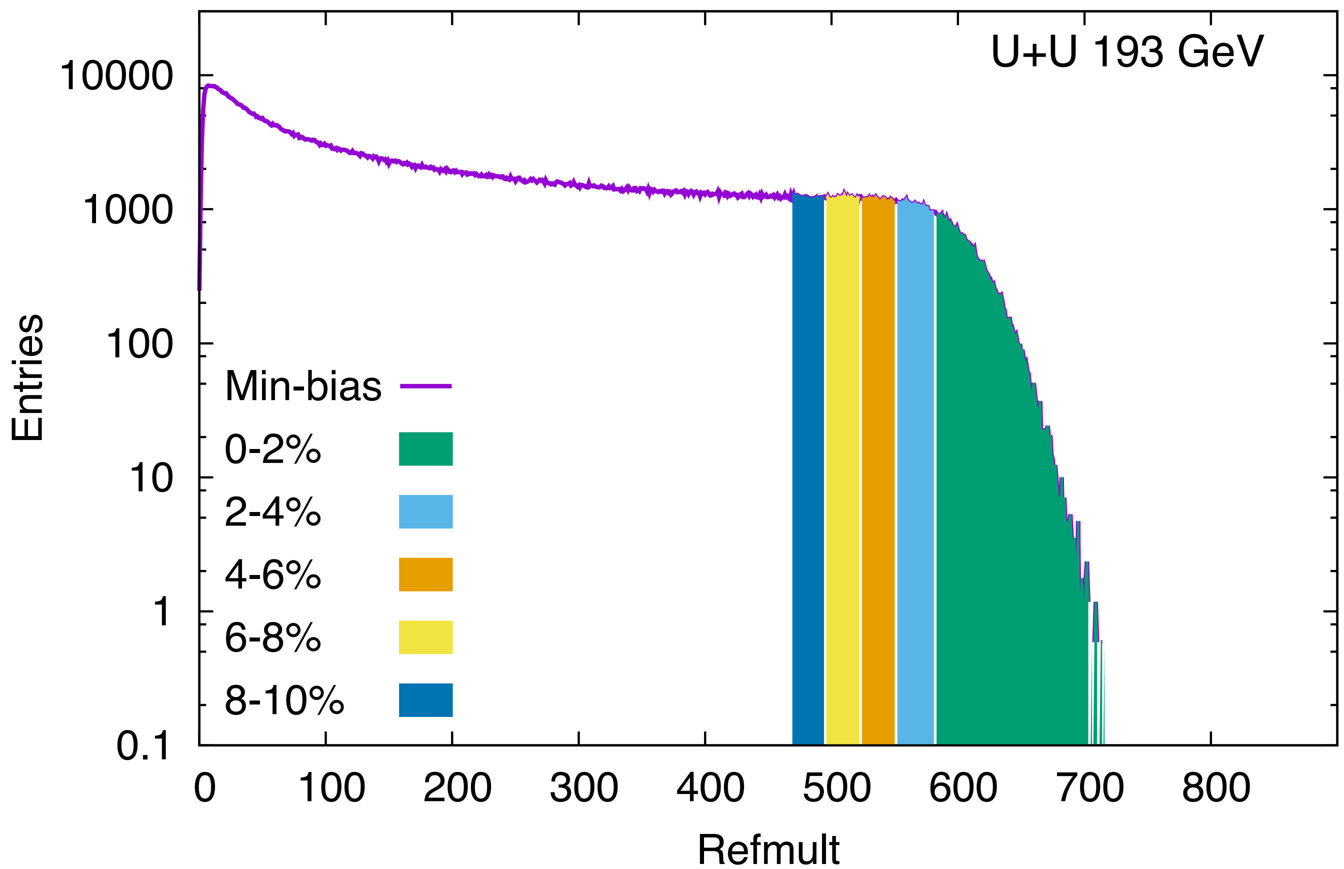
$$\gamma^{a,b} \sim \frac{\langle \cos(\phi_1^a + \phi_2^b - 2\phi_3) \rangle}{v_2\{2\}} \sim \langle \cos(\phi^a + \phi^b - 2\Psi_{RP}) \rangle$$



Centrality bins finer than 0-10% is needed to probe the shape of Uranium

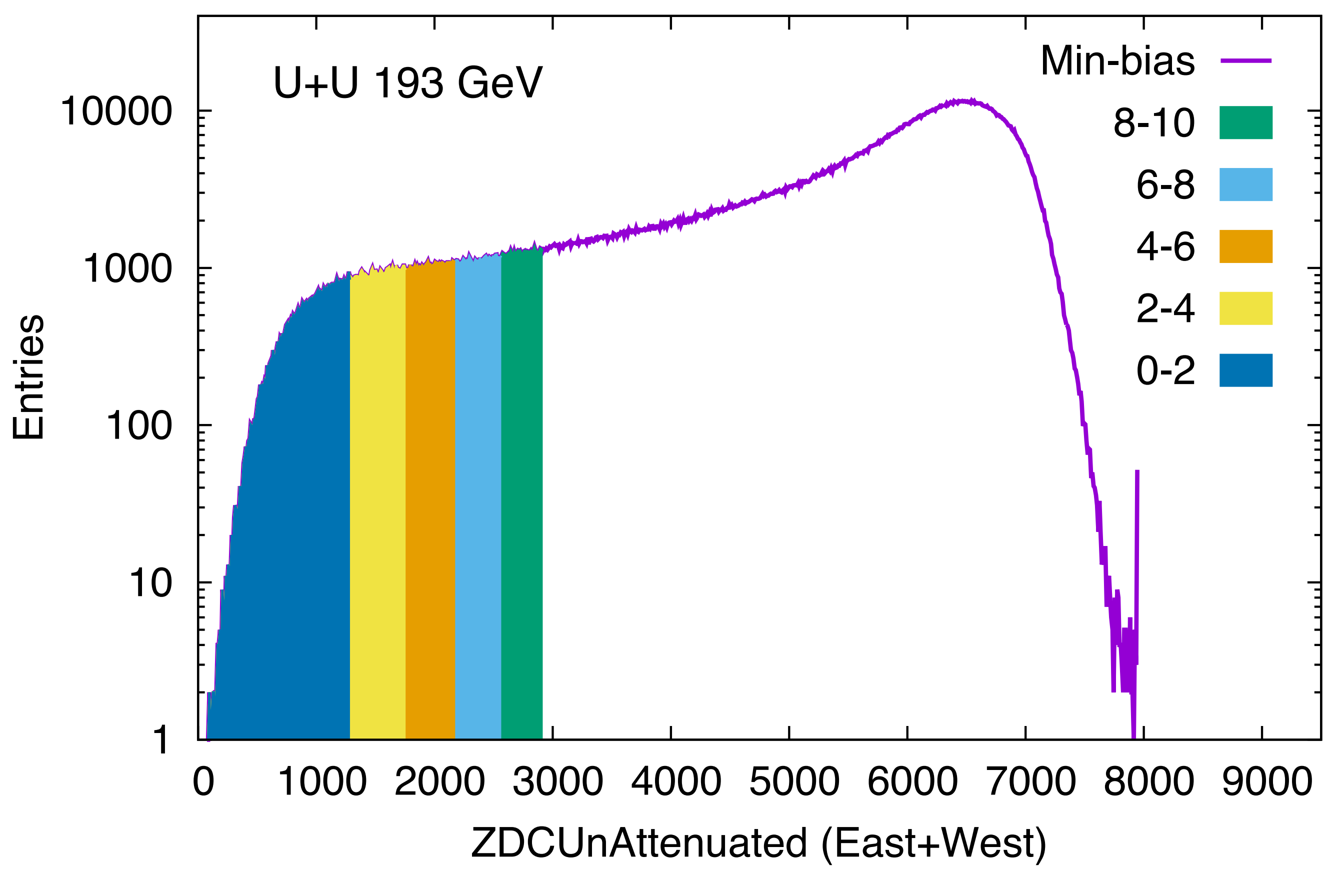
Centrality Selection in 0-10% events

-Method 1 (using RefmultCorr)



Binning on multiplicity

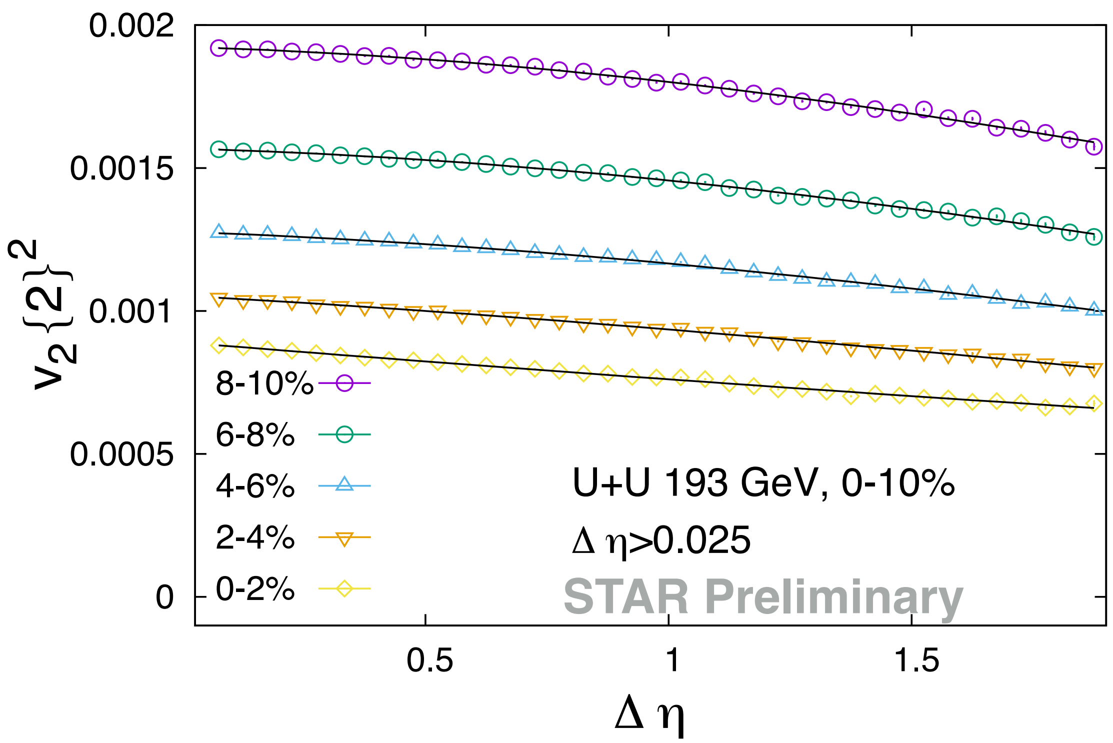
-Method 2 (using ZDCs)



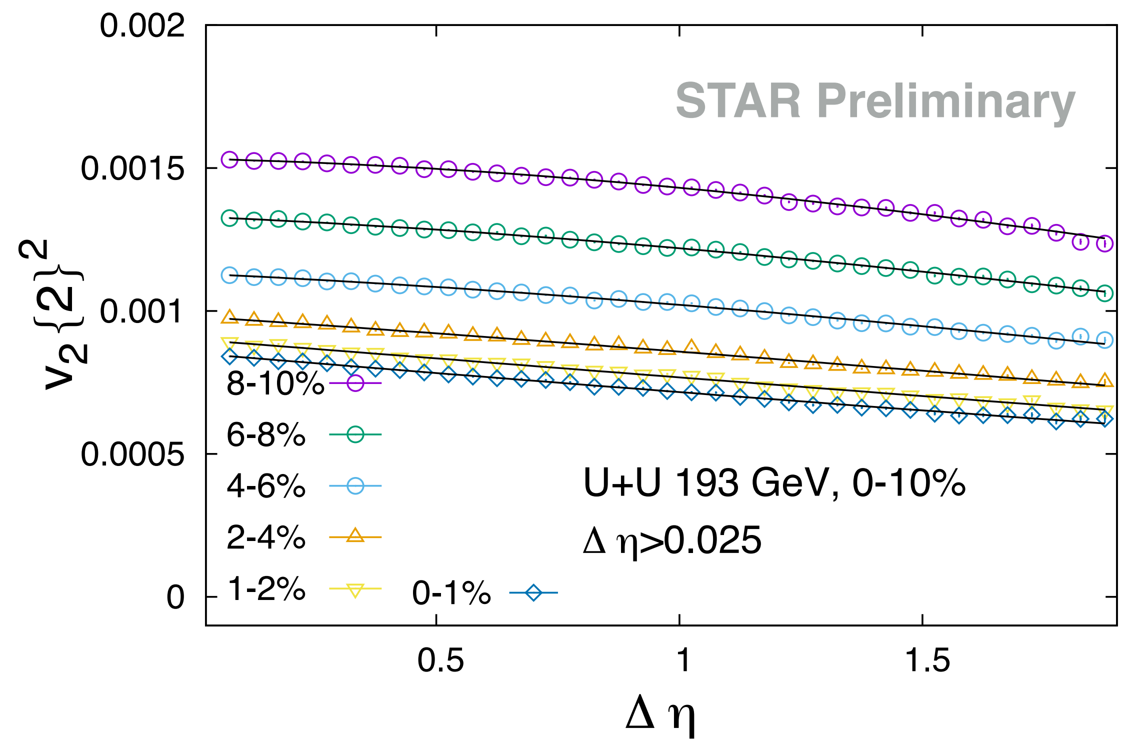
Binning on spectators

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

After removing track merging and HBT peak



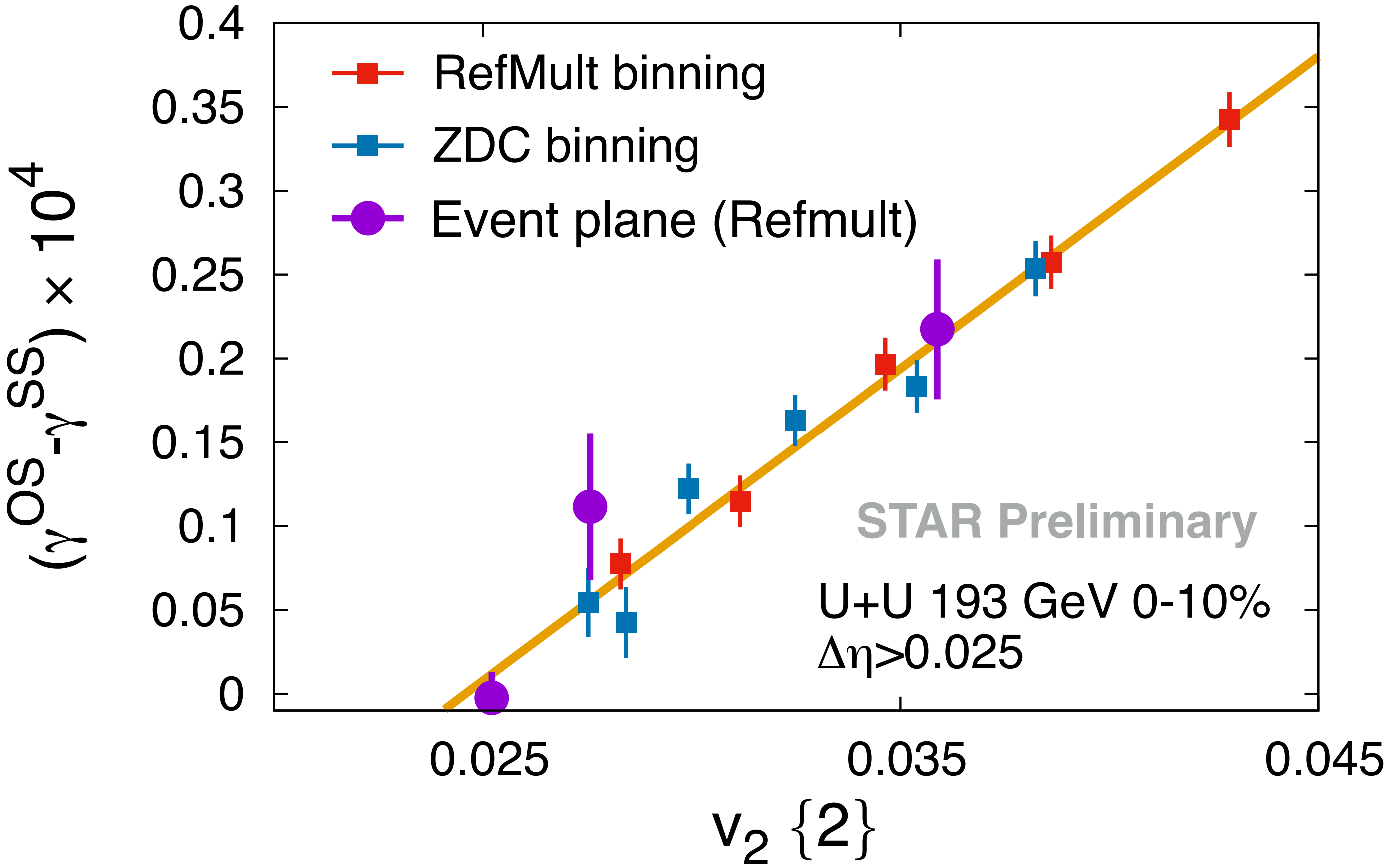
Refmult bins



ZDC bins

Stronger variation of v_2 with multiplicity compared to spectators

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

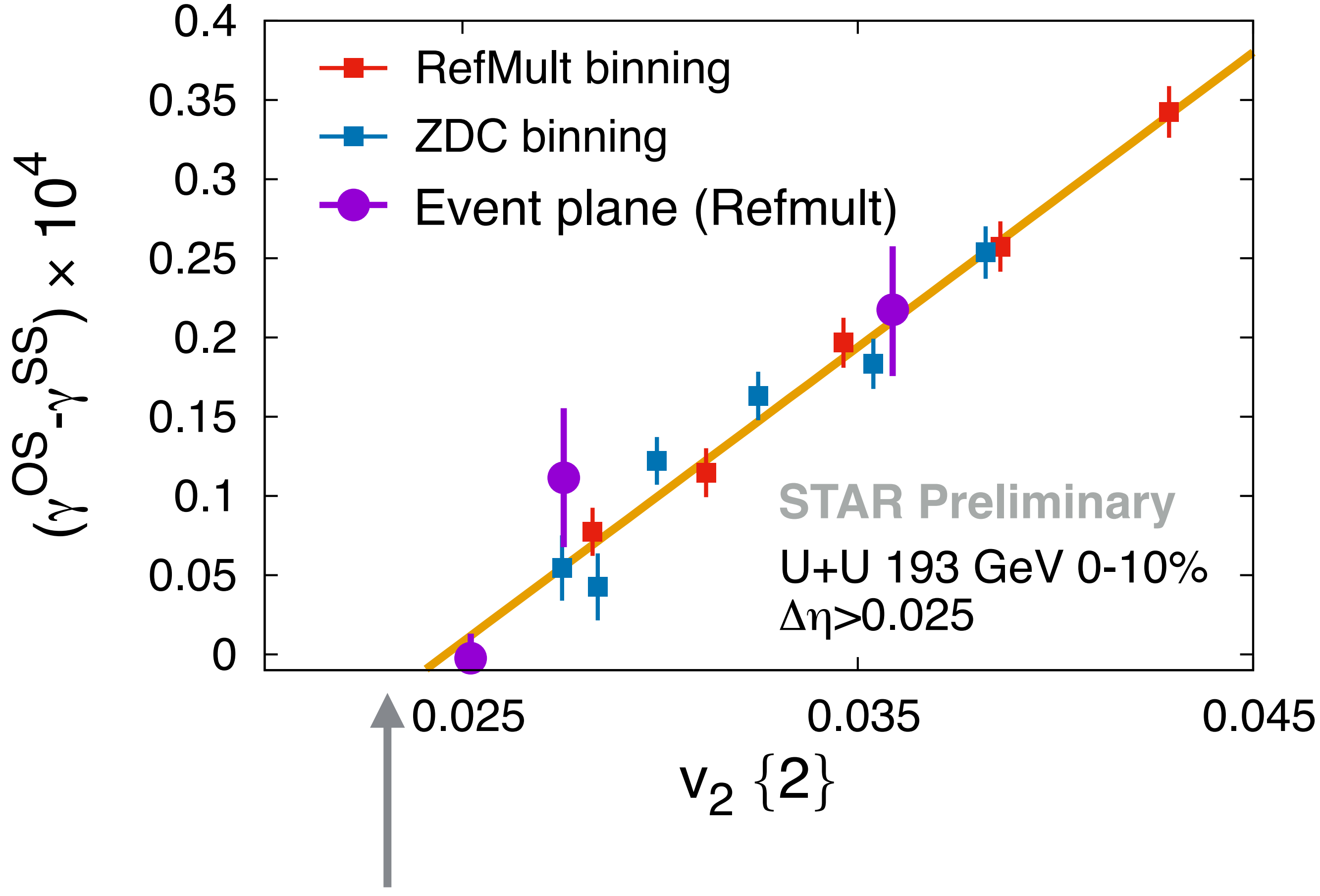


Observations in 0-10%:

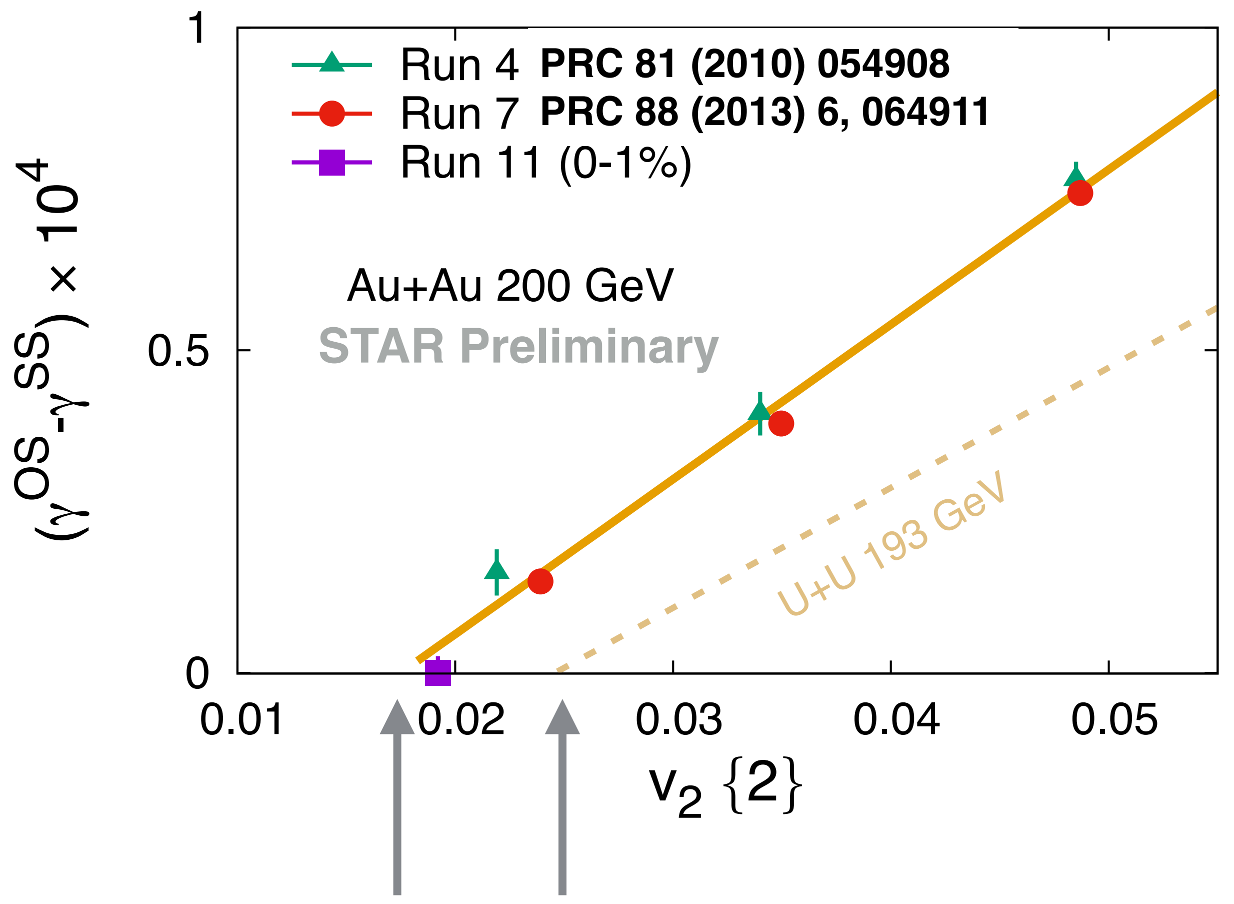
- Strong correlation : **nearly linear dependence** between γ^{ab} & v_2
- γ^{ab}~0 for $v_2 \neq 0$

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

U+U collisions



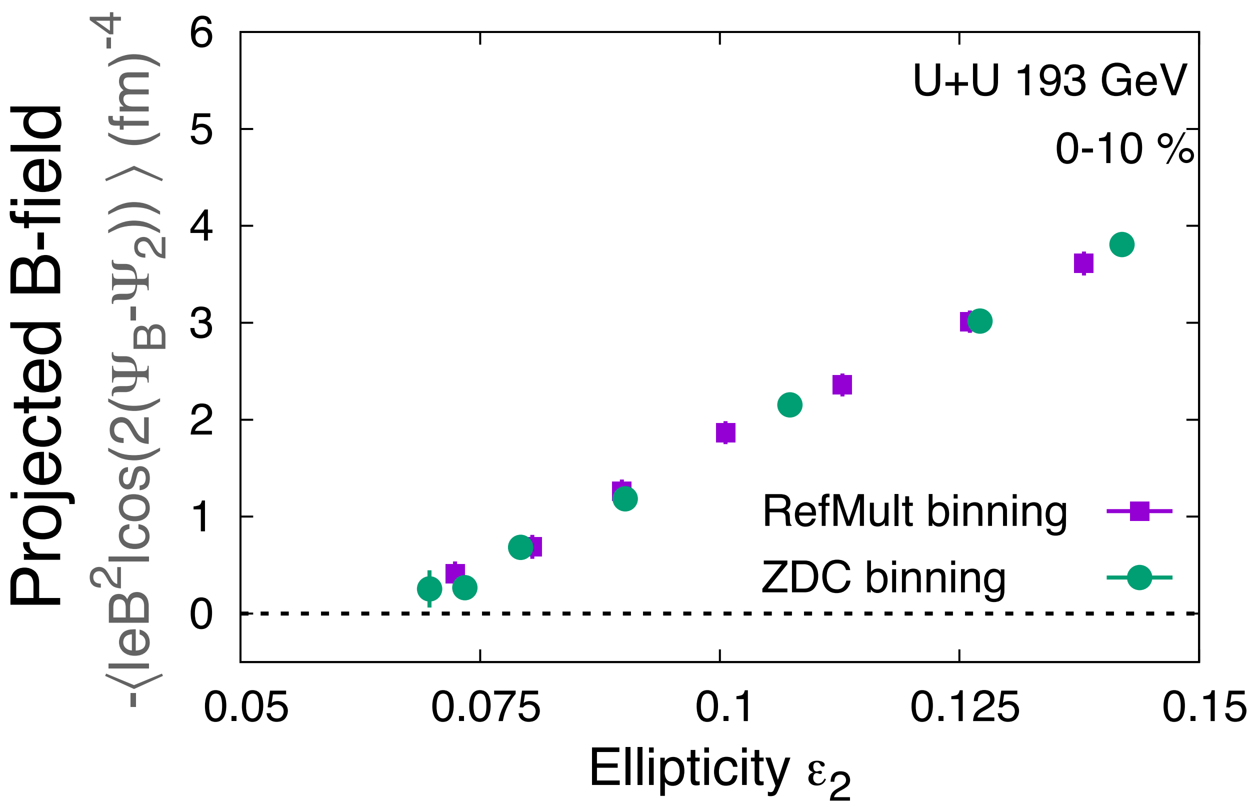
Au+Au collisions



- Observation-I : linear dependence ($\Delta\gamma$-v_2)
- Observation-II : $\Delta\gamma = (\gamma^{OS} - \gamma^{SS}) \sim 0$ for non-zero v_2

Can model calculations provide some insights ?

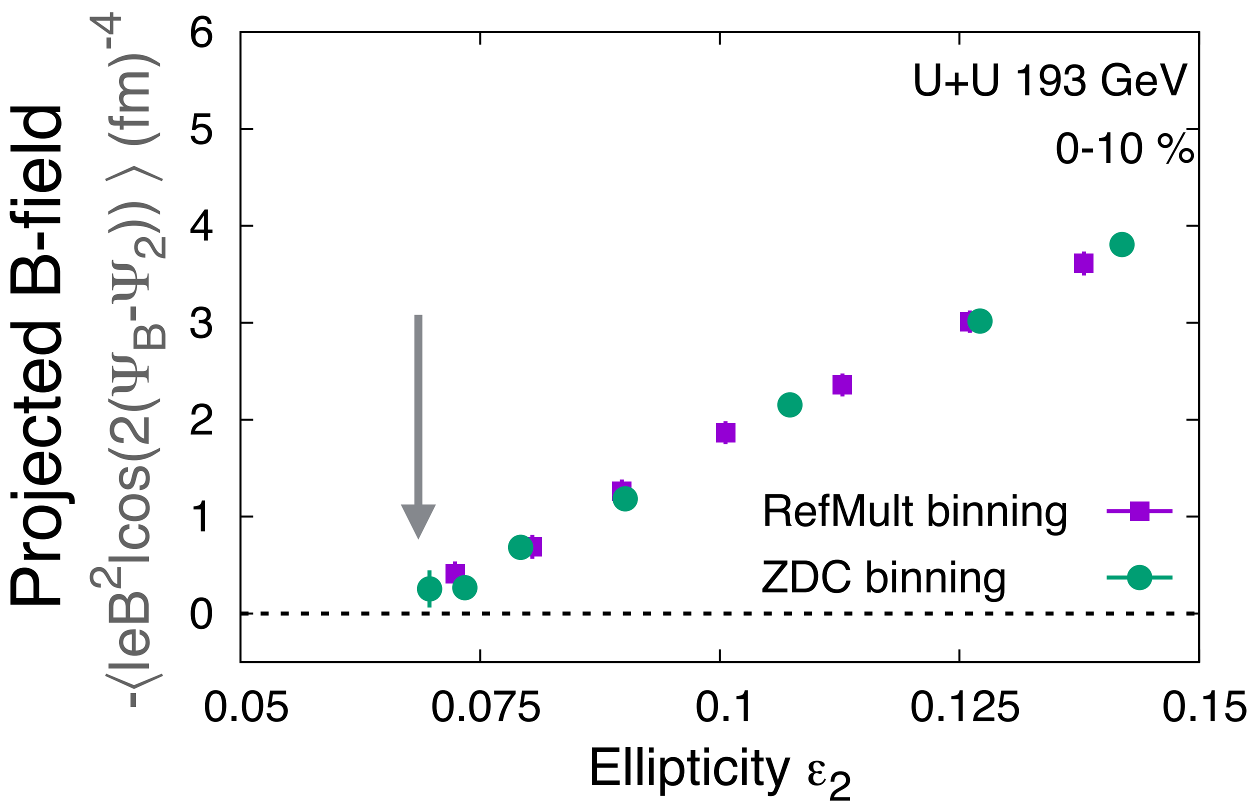
Proxy for γ^{ab} & $\mathbf{v_2}$ —> MC-Glauber model simulation

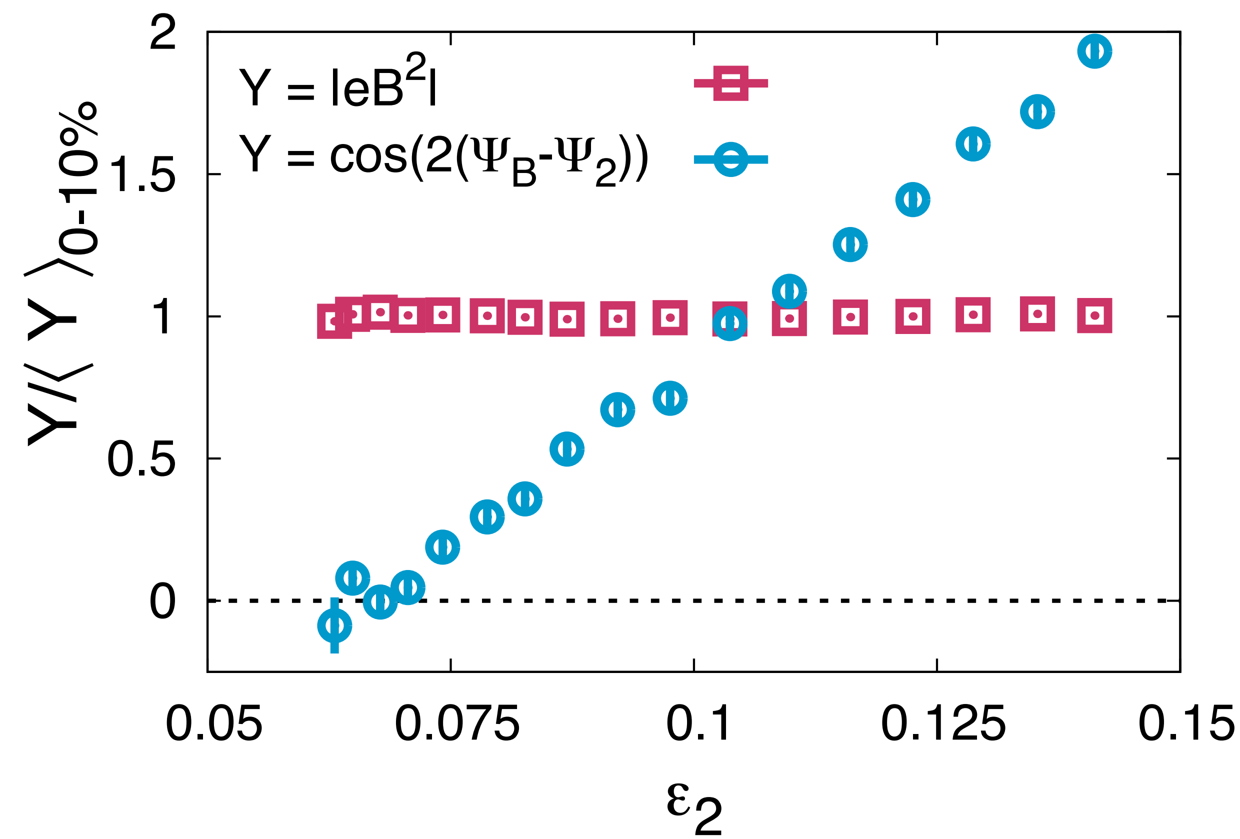


Linear dependence ($\Delta\gamma$-v_2) + offset ⟶ also seen in model (B-ε_2)

Can model calculations provide some insights ?

Proxy for γ^{ab} & $\mathbf{v}_2$ —> MC-Glauber model simulation



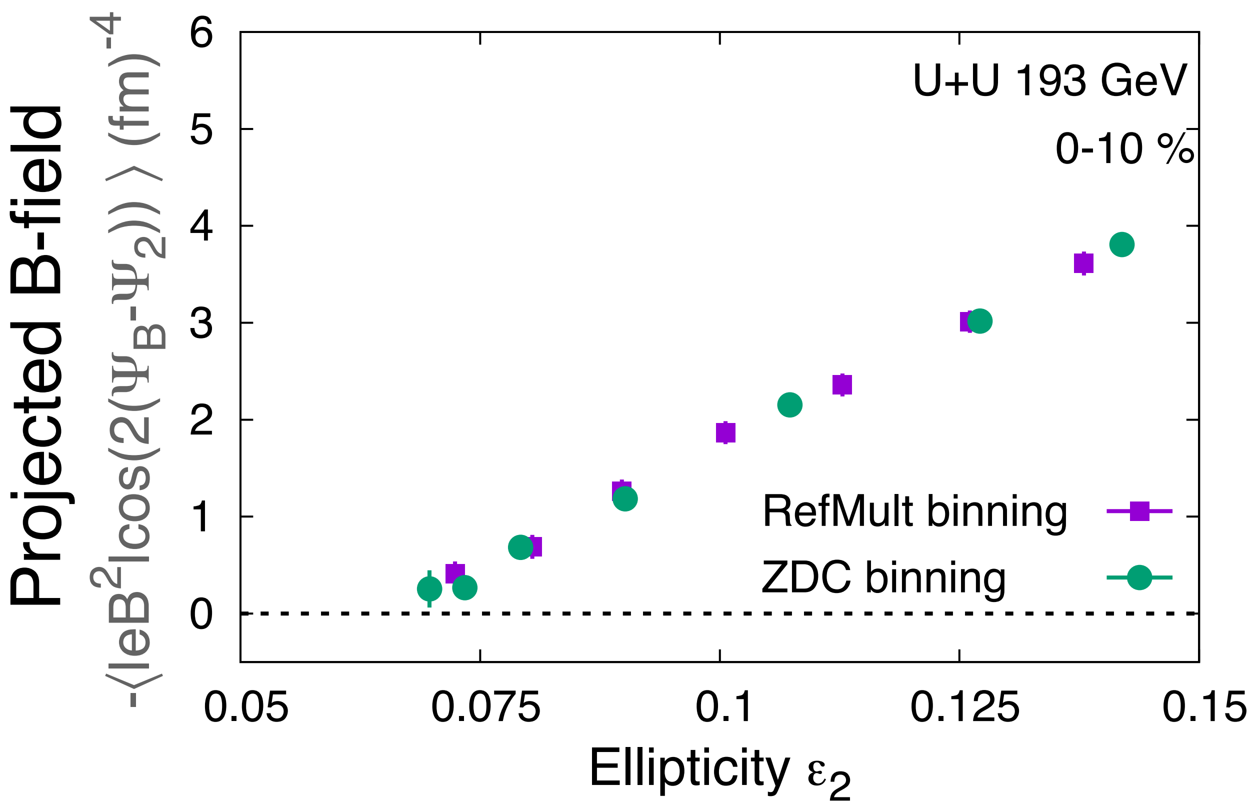


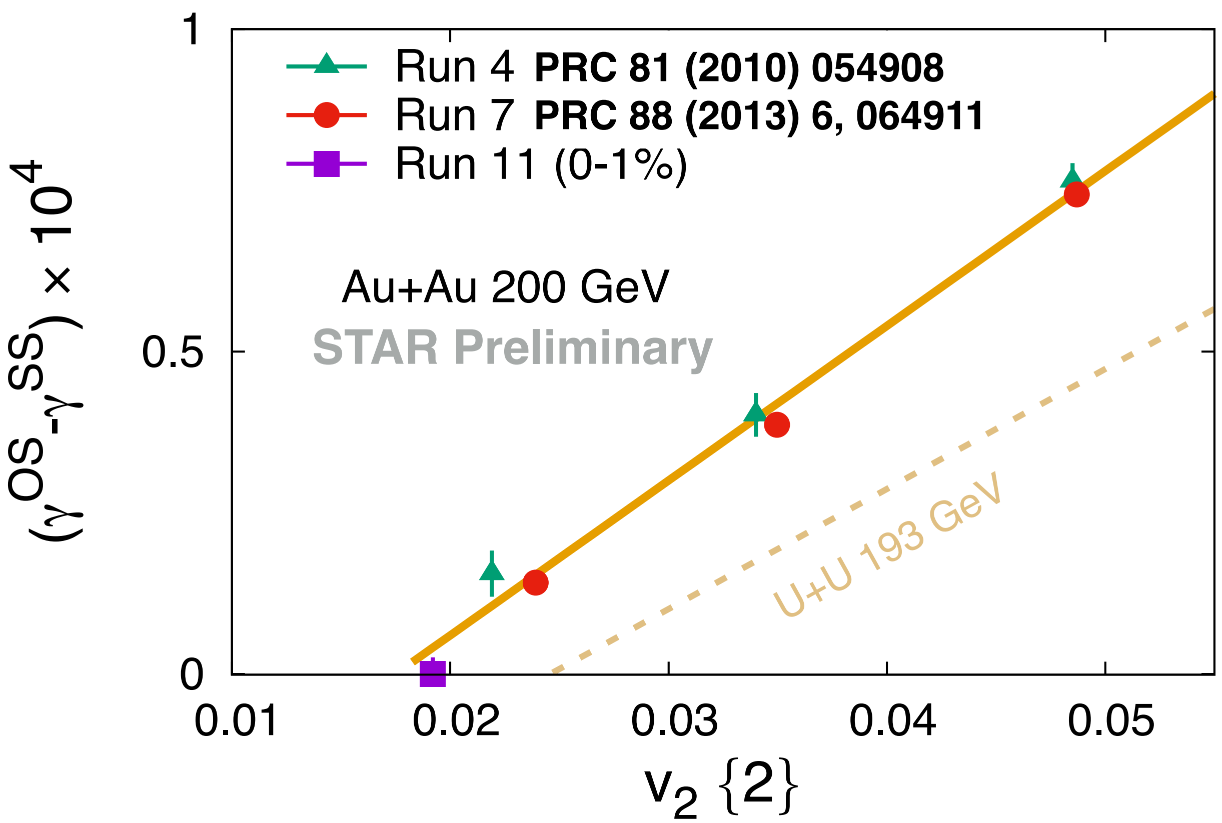
Linear dependence ($\Delta\gamma$-v_2) + offset ⟶ also seen in model ($\vec{B}$-ε_2)

Central events —> direction of $\vec{B}$ de-correlates with event-plane

Can model calculations provide some insights ?

Proxy for γ^{ab} & v_2 ⟶ MC-Glauber model simulation





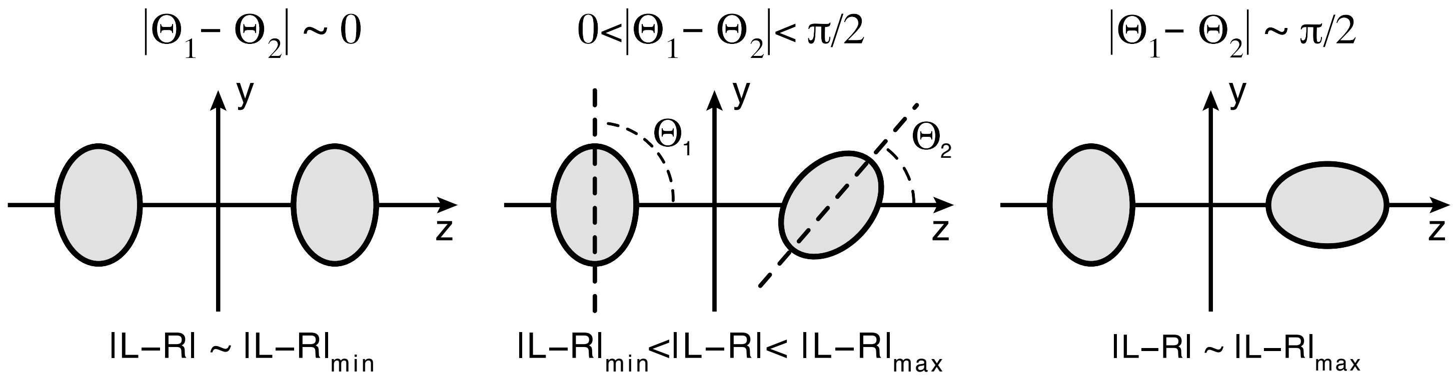
Background driven scenario : $\Delta\gamma \rightarrow 0$ when $v_2 \rightarrow 0$

B-field driven scenario : $\Delta\gamma \rightarrow 0$ when $\cos(\Psi_B-\Psi_2) \rightarrow 0$ even if $v_2 \neq 0$

New challenge for 100% background driven models

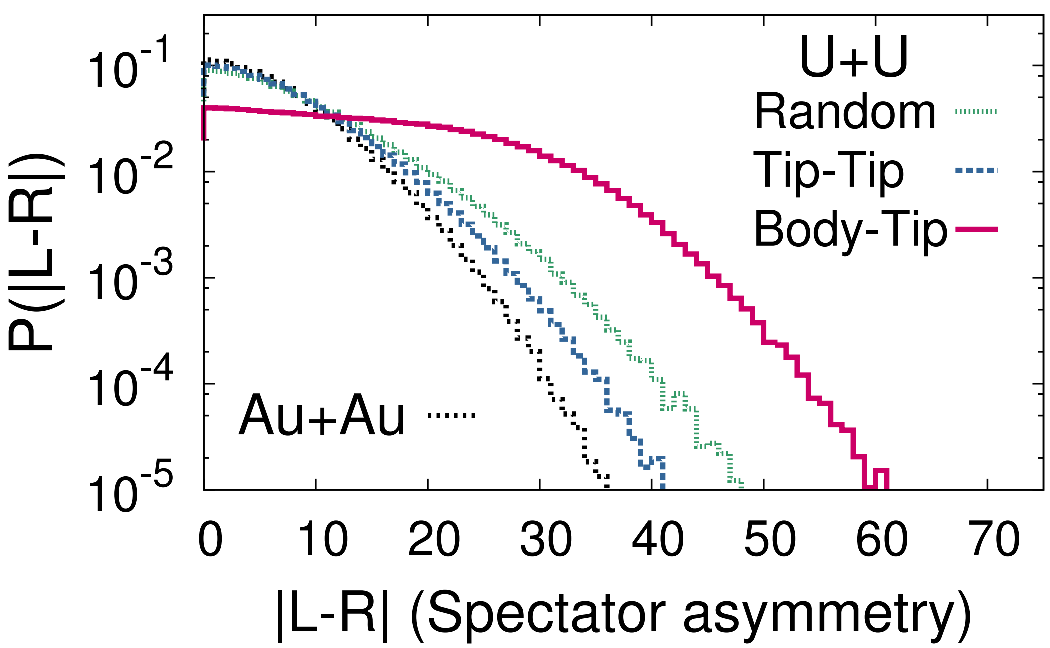
What else can we try with the existing U+U data ?

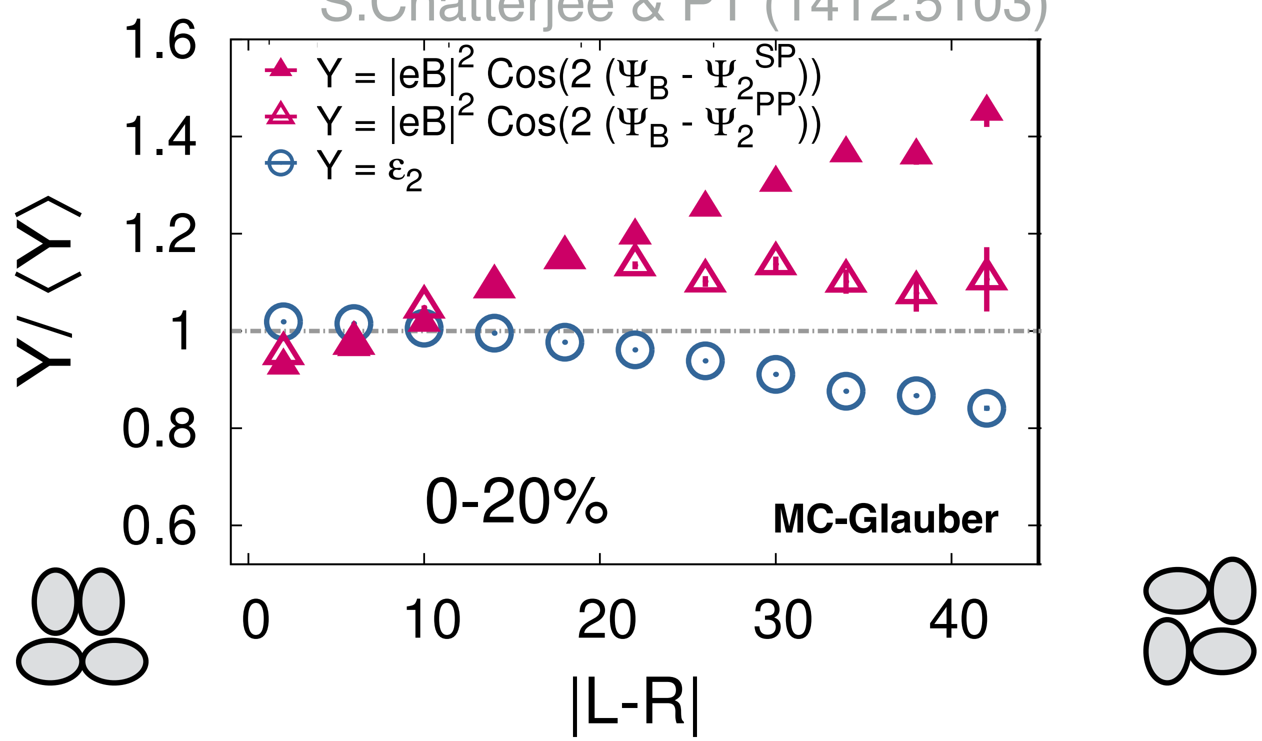
A new tuning parameter to disentangle ε_2 and B-field



R: right going spectator neutrons

L: left going spectator neutrons

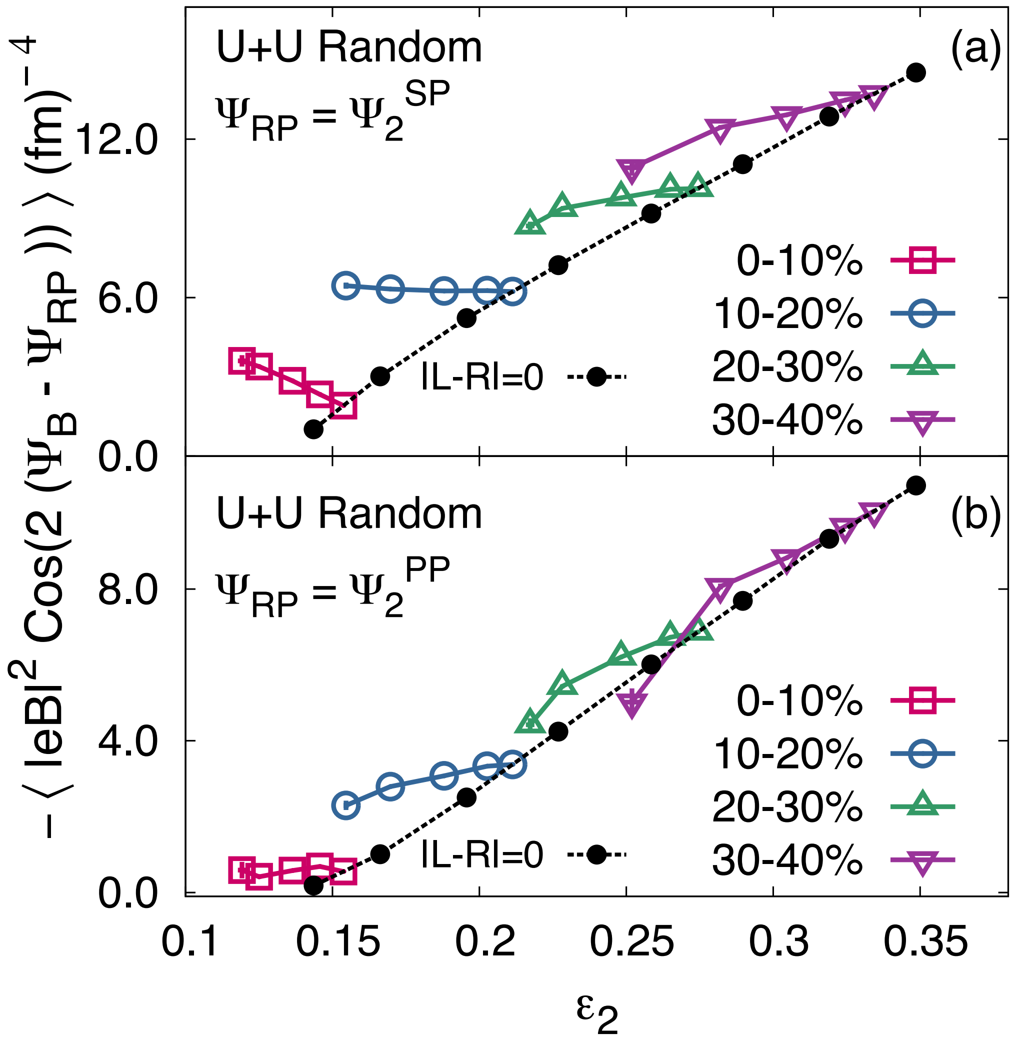


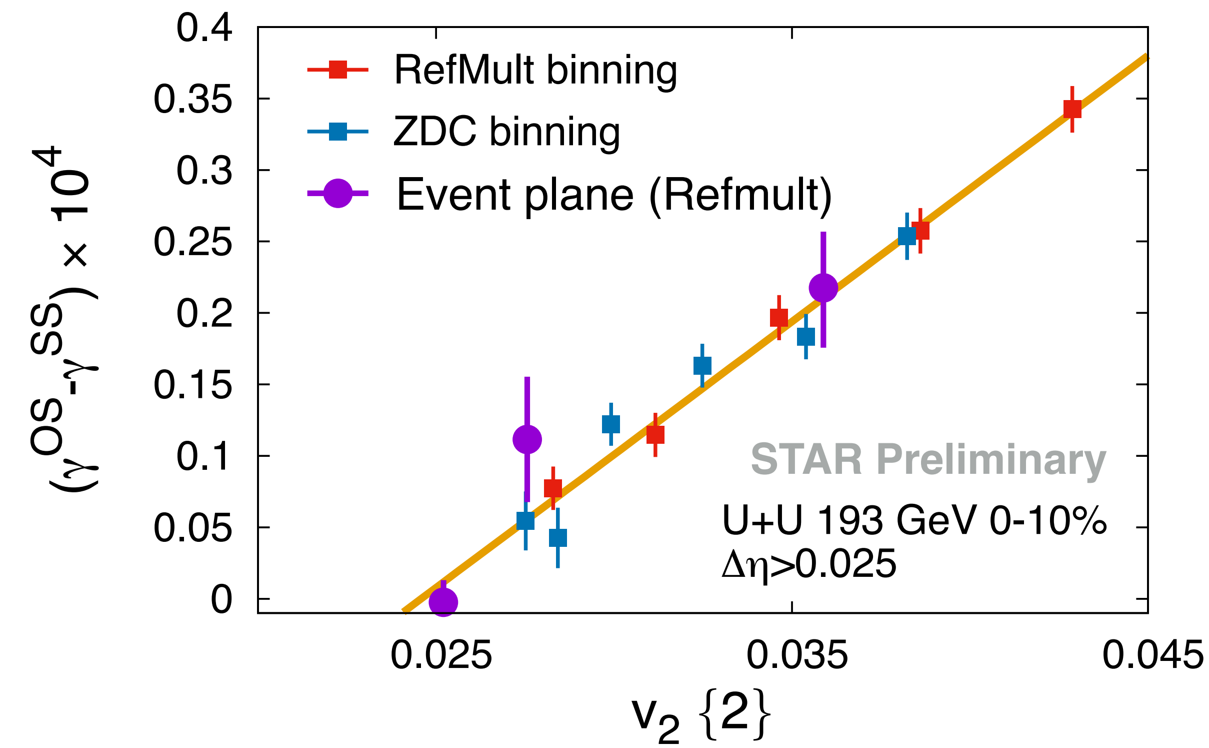


Binning in |L-R| it is possible to trigger body-tip events : B ↑ ε_2 ↓

Spectator asymmetry in U+U to disentangle $\Delta\gamma$ & v_2

S.Chatterjee & PT (1412.5103)





Spectator asymmetry —>
Triggers event with different B but same ε_2 & vice-versa

Look for similar trend between $\Delta\gamma$ & v_2 with **ZDC asymmetry**

Analysis under progress (challenges : ZDC response to neutrons)

Outlook for Isobar collisions at RHIC

Idea is to change B-field without changing background

$${}_{44}^{96}\mathrm{Ru} + {}_{44}^{96}\mathrm{Ru} \xleftrightarrow[\sqrt{s}=200\ \mathrm{GeV}]{} {}_{40}^{96}\mathrm{Zr} + {}_{40}^{96}\mathrm{Zr}$$

Different B-field with same flow background is expected

e-A scattering experiment

	Zr	Ru
R0	5.05	5.13
a(d) [fm]	0.45	0.45
β2	0.18	0.03
β4	0.01	0.009

(Woods-Saxon parameters)

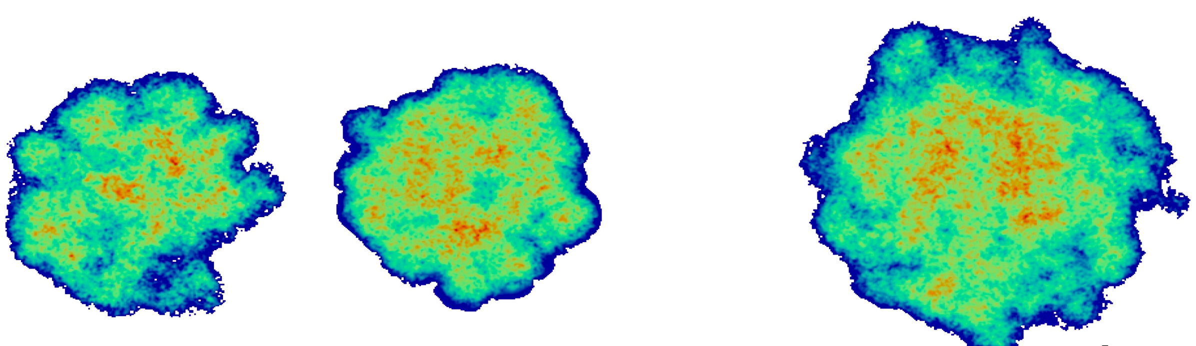
Q. Y. Shou *et al* arXiv:1409.8375

comprehensive model deduction

	Zr	Ru
R0	5.07	5.14
a(d) [fm]	0.48	0.46
β2	0.06	0.13
β4	0	0

Ref: Gang Wang, QCD Chirality workshop '2016

http://starmeetings.physics.ucla.edu/sites/default/files/gang_wang.pdf

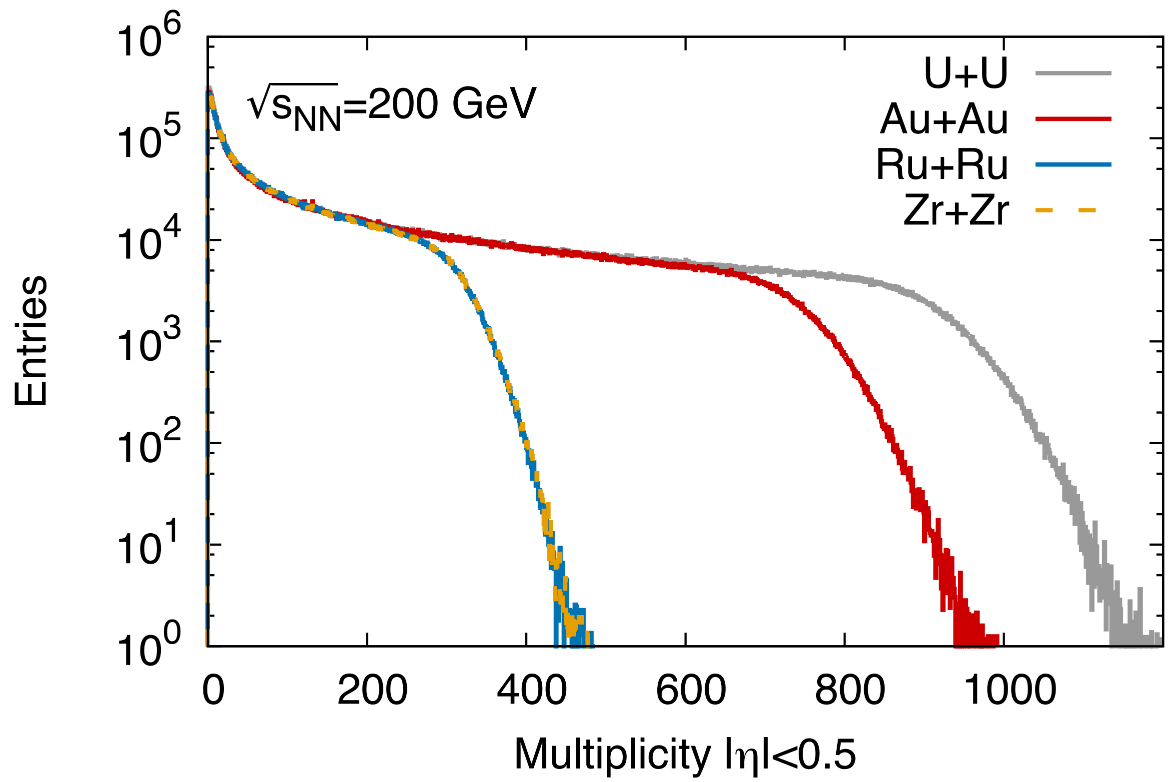


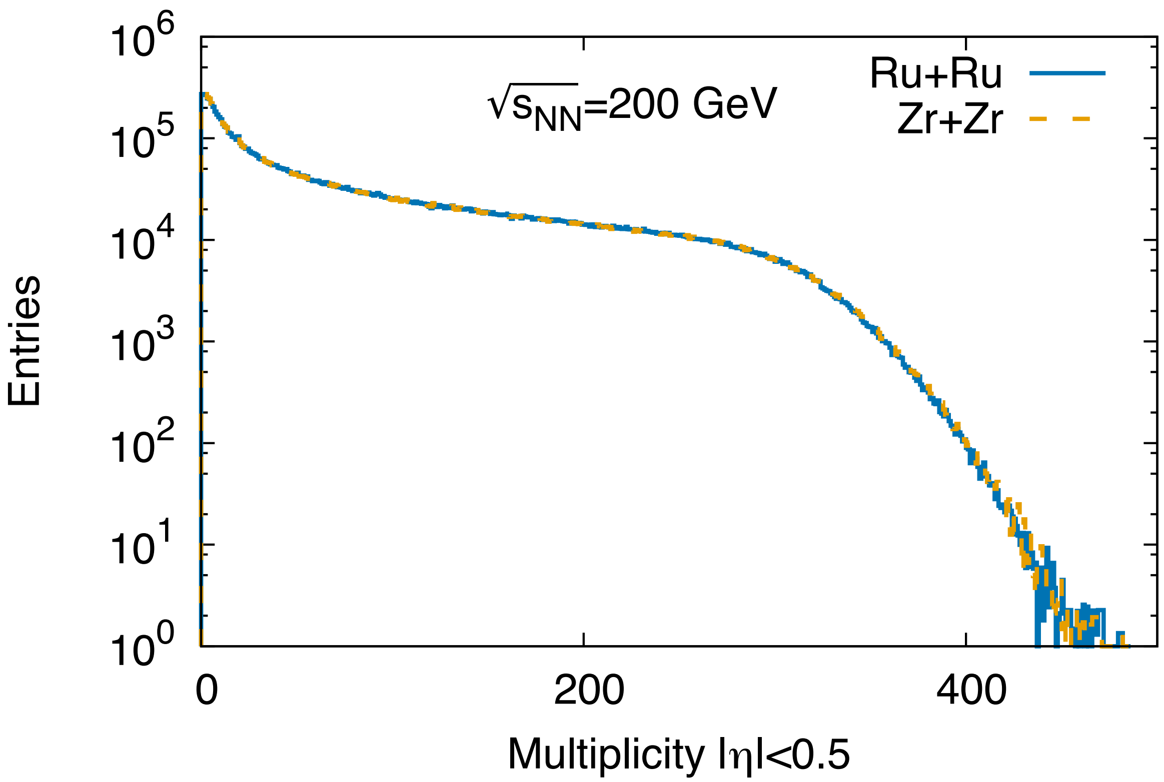
Zr +Zr　Ru +Ru　Au +Au

Single collision in IP-Glasma model (b=0)

Comparisons of multiplicities for centrality estimation

- Two component MC-Glauber corrected dN/dη
- Using parameters compatible to e-A scattering data

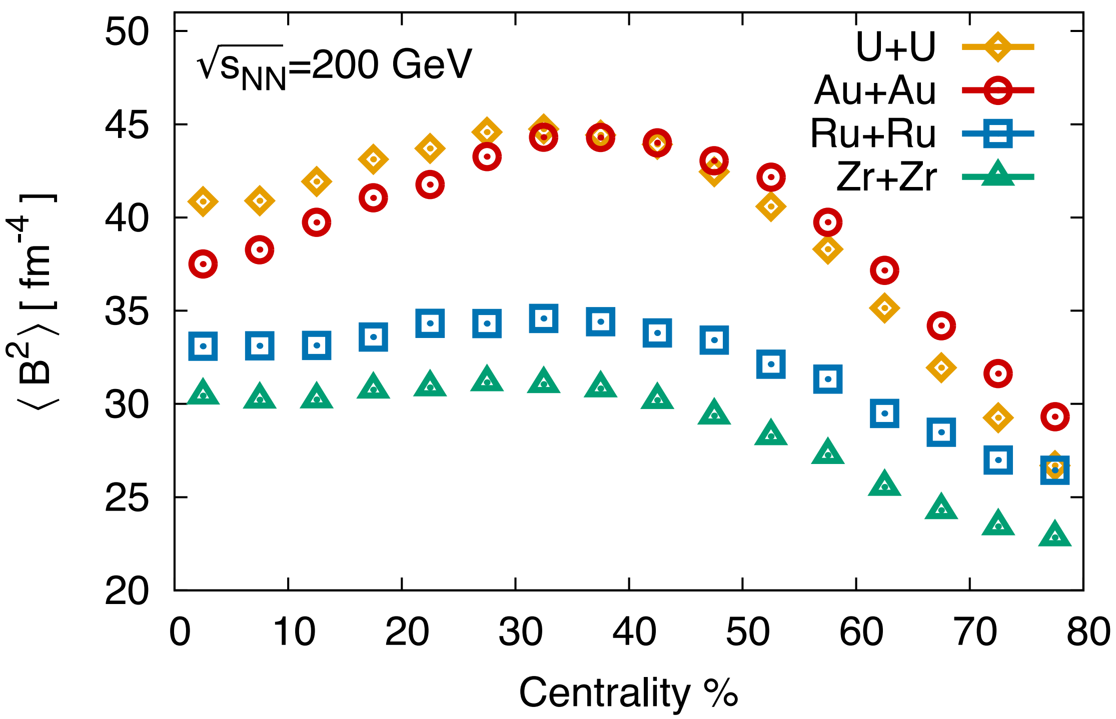




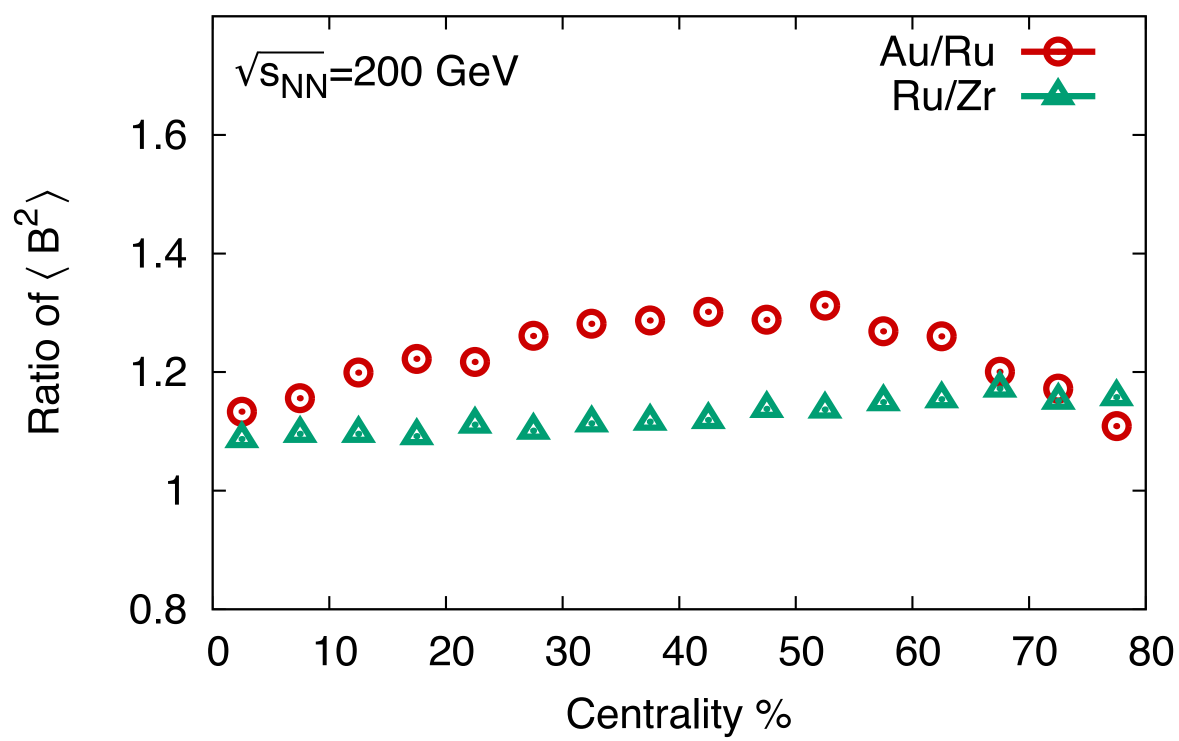
Comparison between different systems —> Zr+Zr & Ru+Ru similar

Comparisons of the magnetic fields

Estimation of B-field —> t=0, center of participant zone (in vacuum)



Approach based on
arXiv:1111.1949 & arXiv:1412.5103

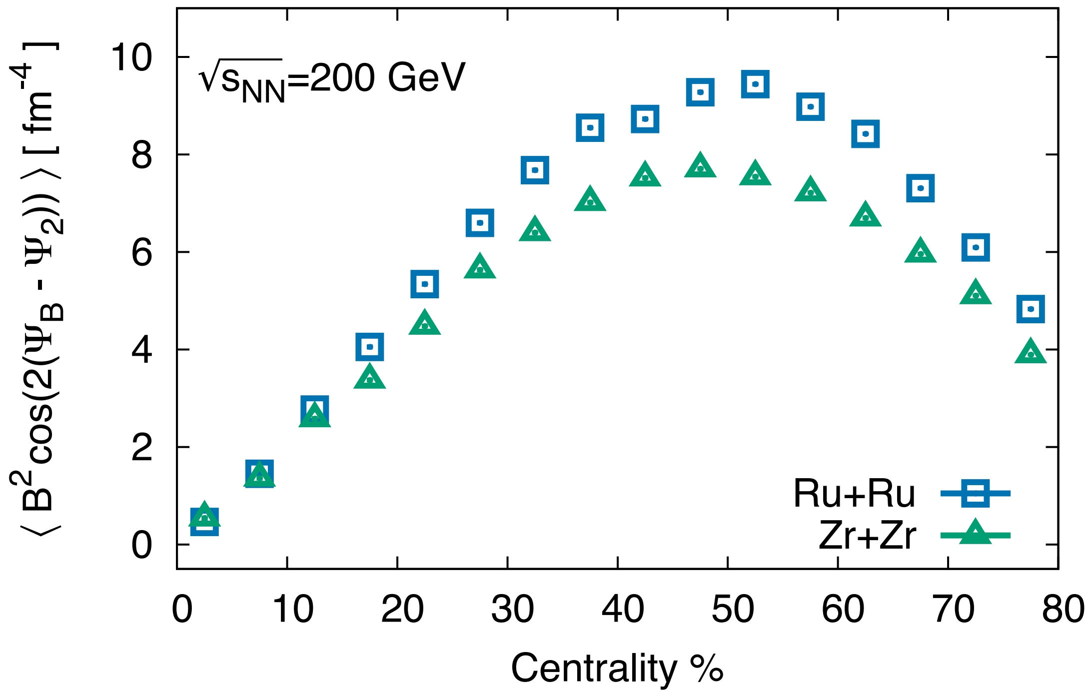


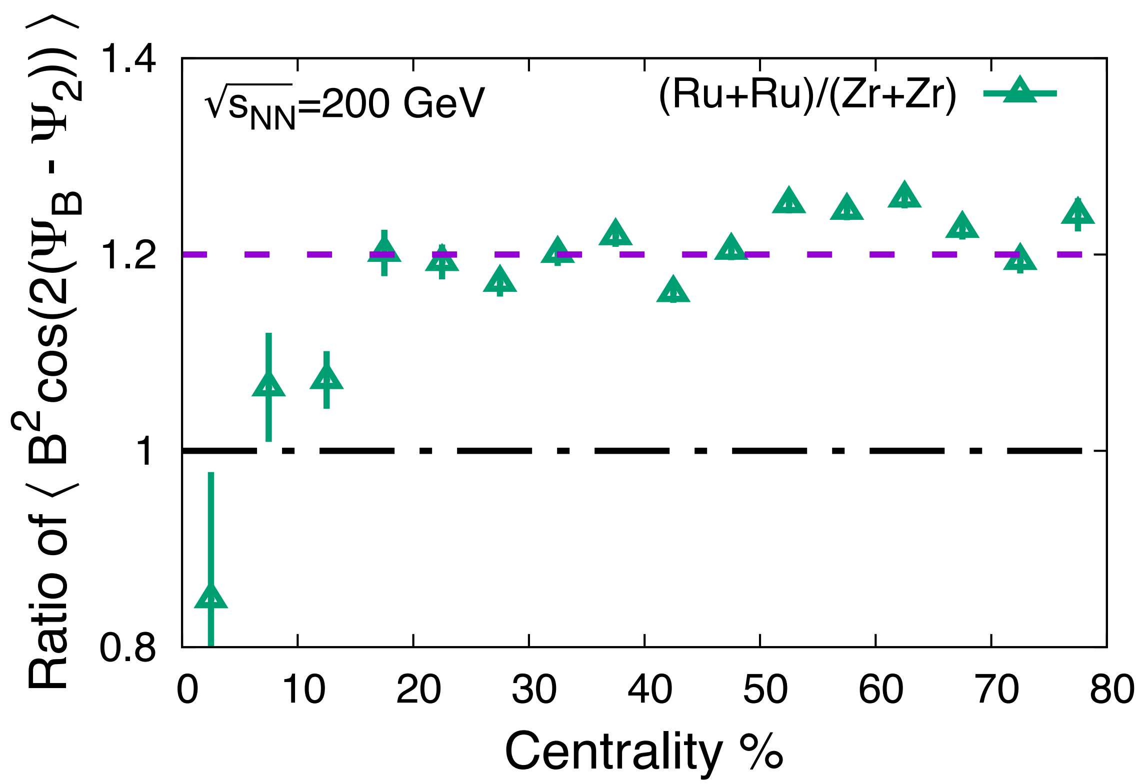
Estimation of B-field —> not affected by nuclear deformation

Vladimir Skokov : QCD Chirality workshop ‘2016
http://starmeetings.physics.ucla.edu/sites/default/files/vladimir_skokov.pdf

Comparisons of the projected magnetic fields

CME signal depends on both |B| and direction Ψ_B





- Signal strength ~ $|B^2|\cos(2(\Psi_B-\Psi_2))$ —> Projected field
- About 20% difference in Ru+Ru vs Zr+Zr

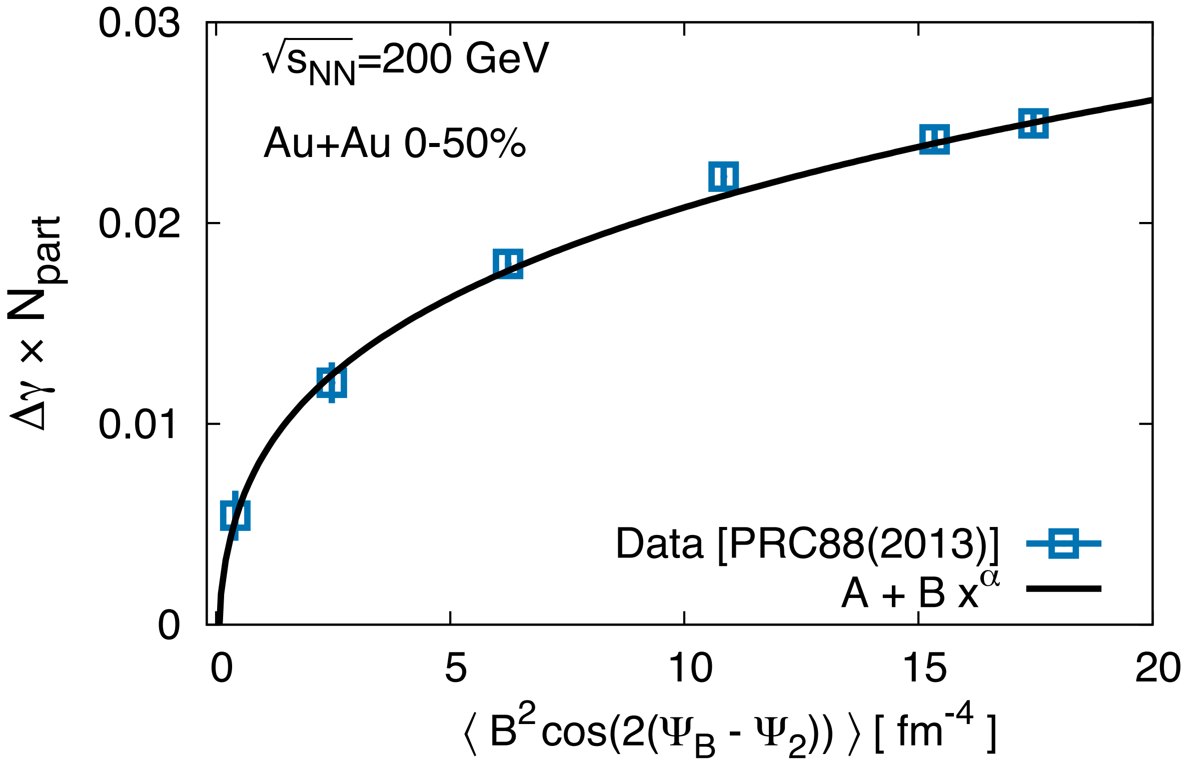
Projection for CME correlator in Isobar collisions

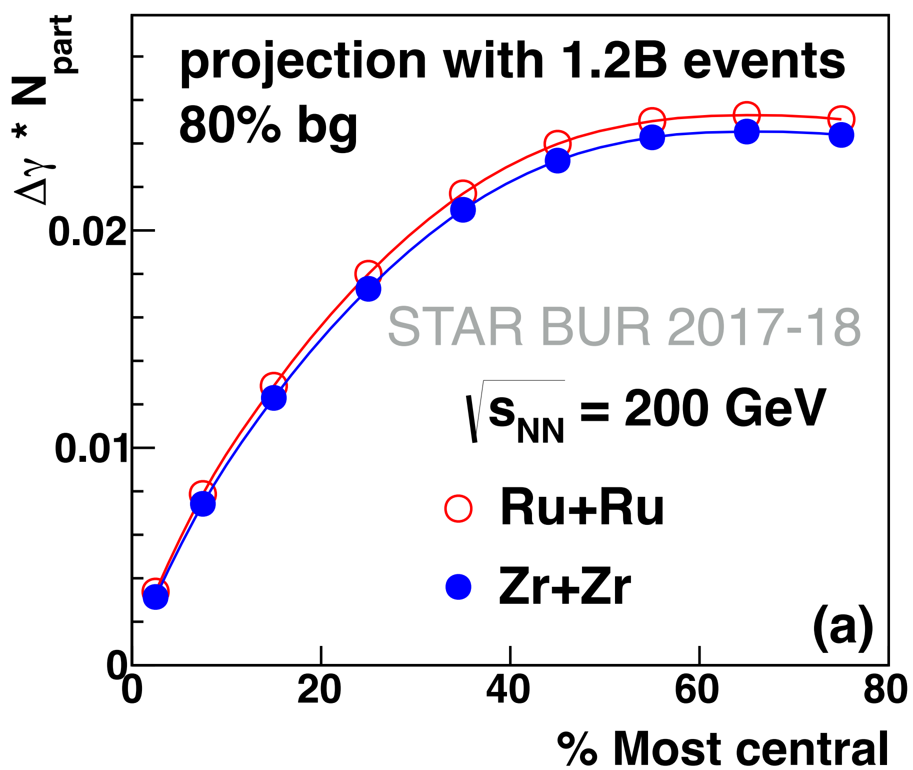
- Step-I —> parameterize Au+Au data in terms of B

$$Y = \Delta\gamma \times N_{\text{part}} = \alpha + \beta \langle B^2 \cos(2(\Psi_B - \Psi_2)) \rangle^{\lambda}$$

- Step-II —> make projections for Ru+Ru & Zr+Zr

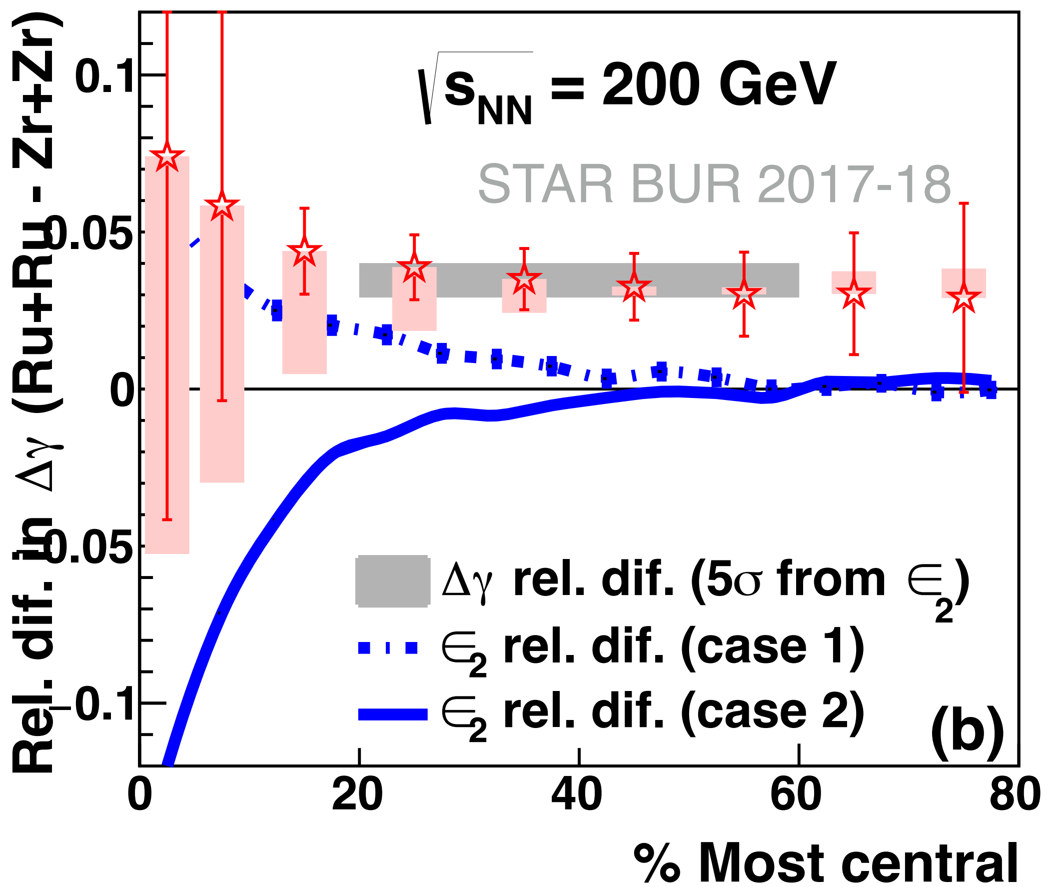
Contribution from the background has to be incorporated

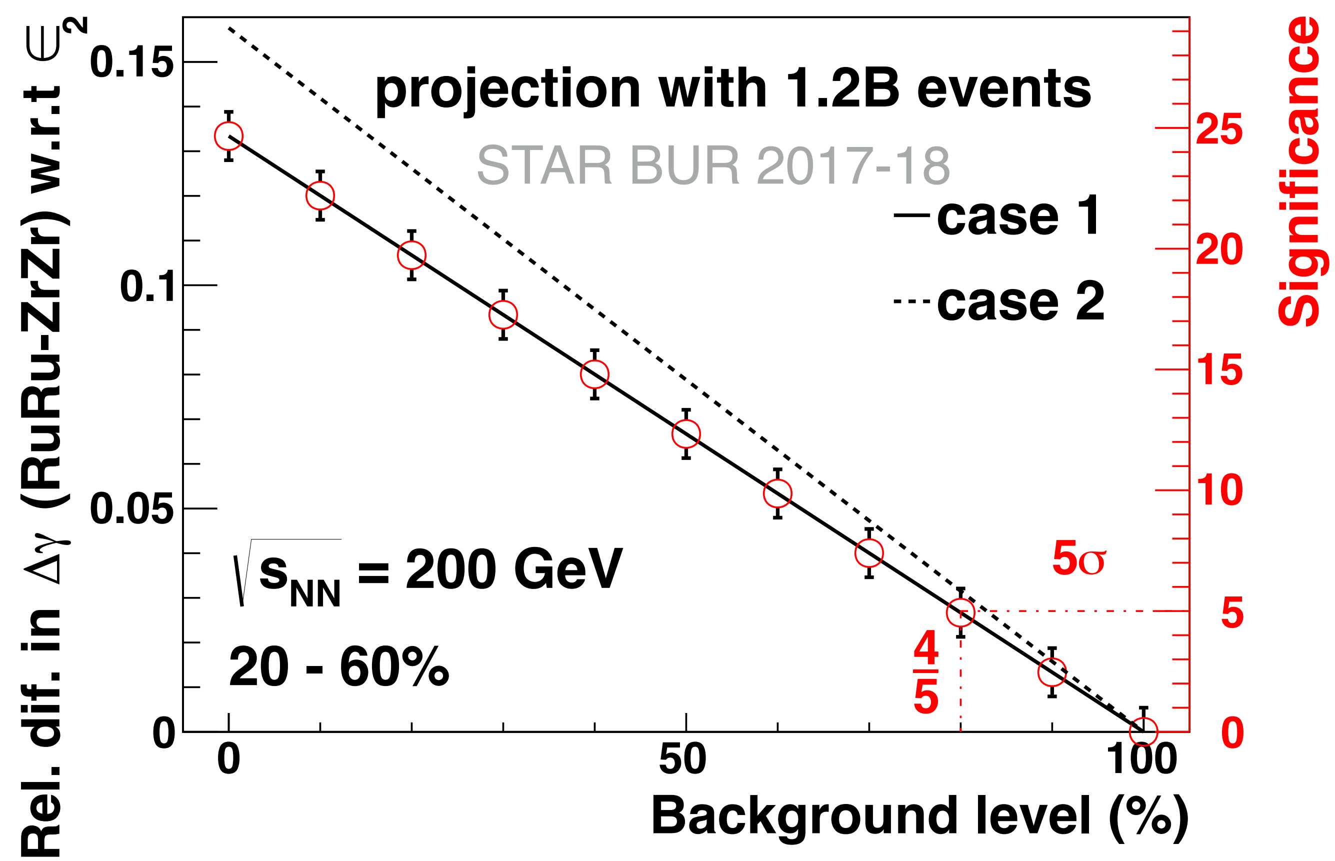




Significance of the expected signal in Isobar collisions

Ref: https://drupal.star.bnl.gov/STAR/system/files/STAR_BUR_Run1718_v19.pdf





Isobar ratio gives maximum 5σ (1.2 B) if CME is ~ 20% B-field driven

Equivalent running of RHIC : 3.5-weeks for each species (STAR proposal for BUR in Runs 18)

Summary / Outlook

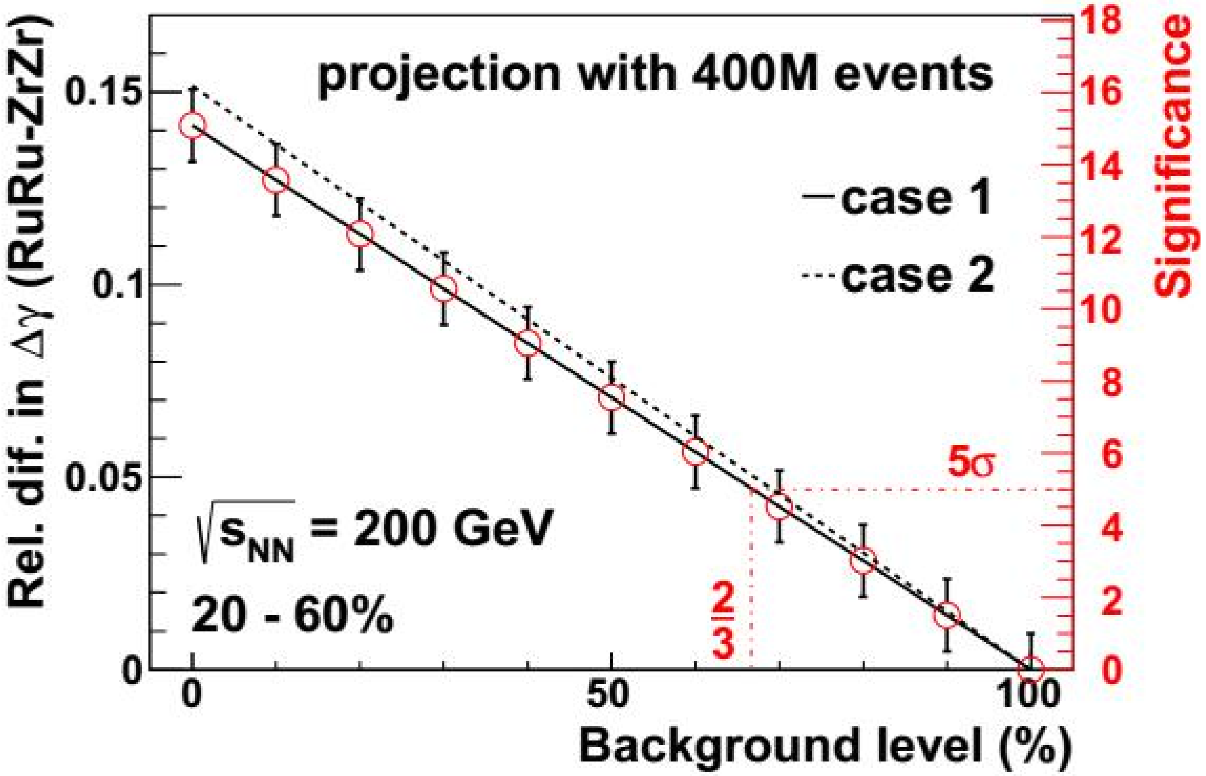
- Charge dependent azimuthal correlations have been studied in U+U & compared to Au+Au results.
- Strong correlation between γ^{ab} & v_2 observed in central events (<10%) with **γ^{ab} ~0 for v_2>0** in both U+U and Au+Au collisions.
- New analyses under way to use U+U data to disentangle CME signal from backgrounds (specifically using spectator asymmetry).
- Collisions of Isobar look very promising : **(3.5 x 2) weeks** of running with about (1.2 x 2) B events can provide about **5σ** confidence of signal/bkg.

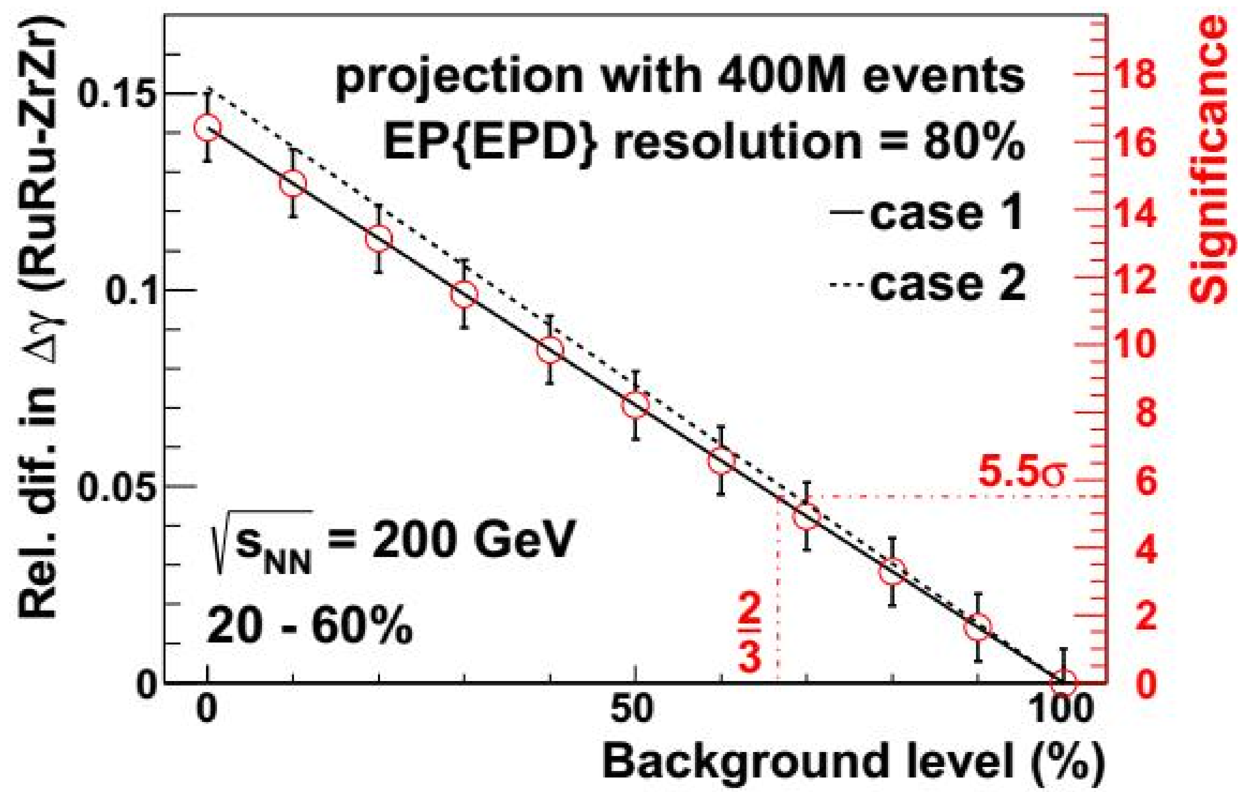
backup

Significance of the expected signal in Isobar collisions

Projection for 400M events

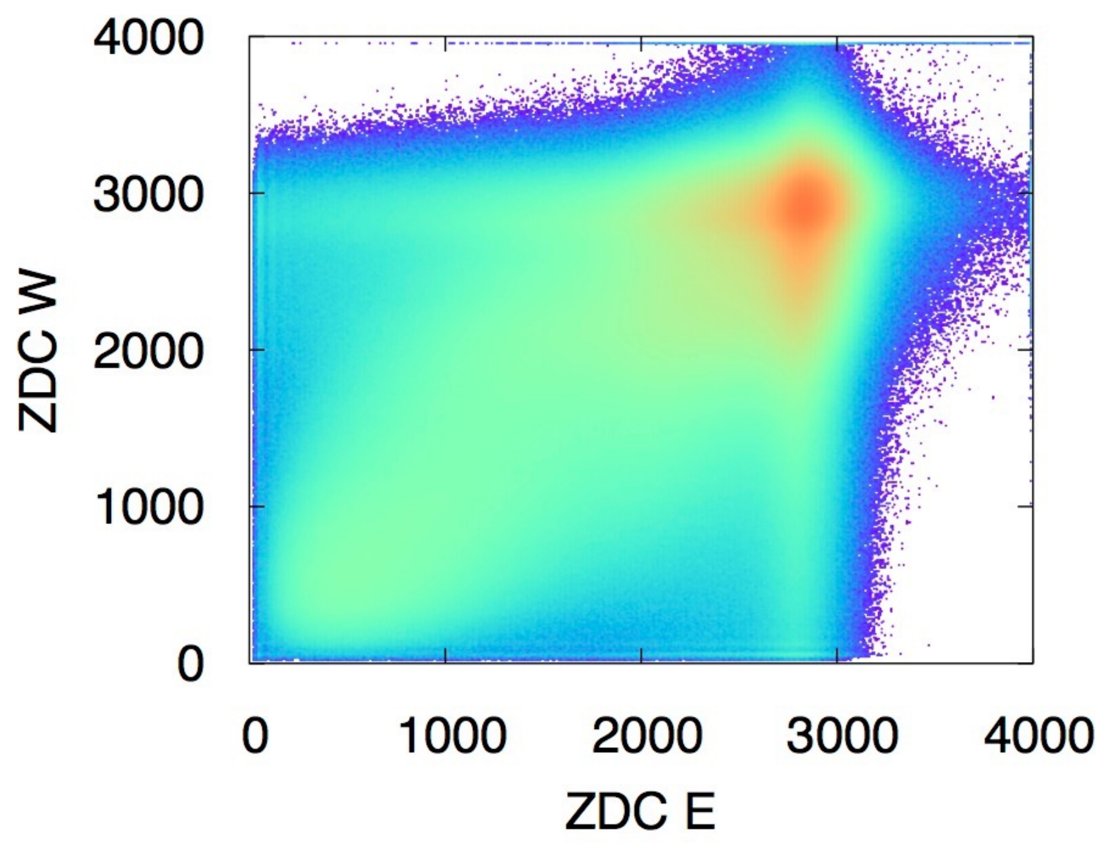
Study done by Gang Wang





Spectator asymmetry in U+U collisions

Body-Tip events are experimentally triggered by asymmetry of ZDCs

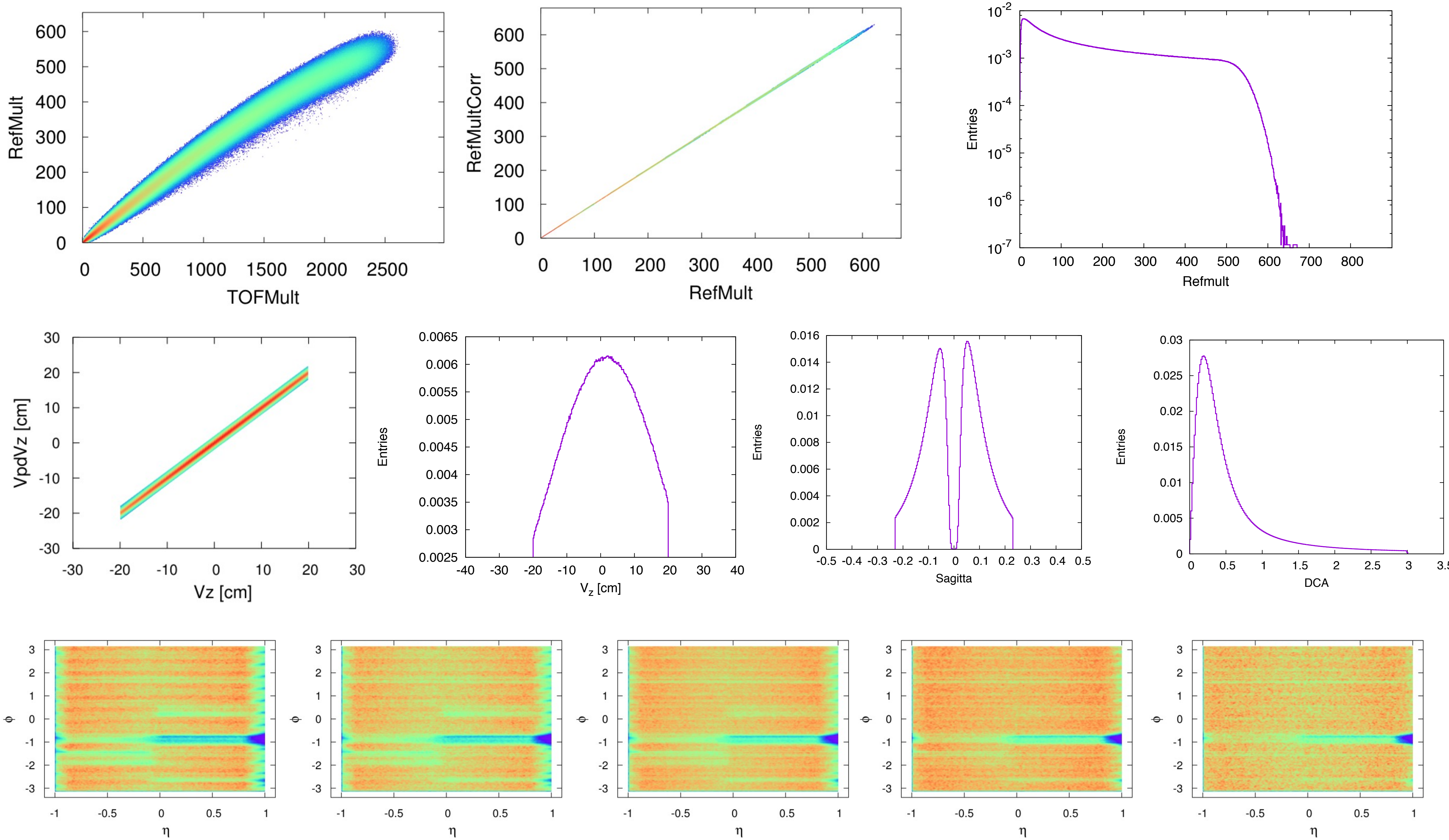


Experimental challenges :

- 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

A few QA plots



Weight estimation for cumulant calculations

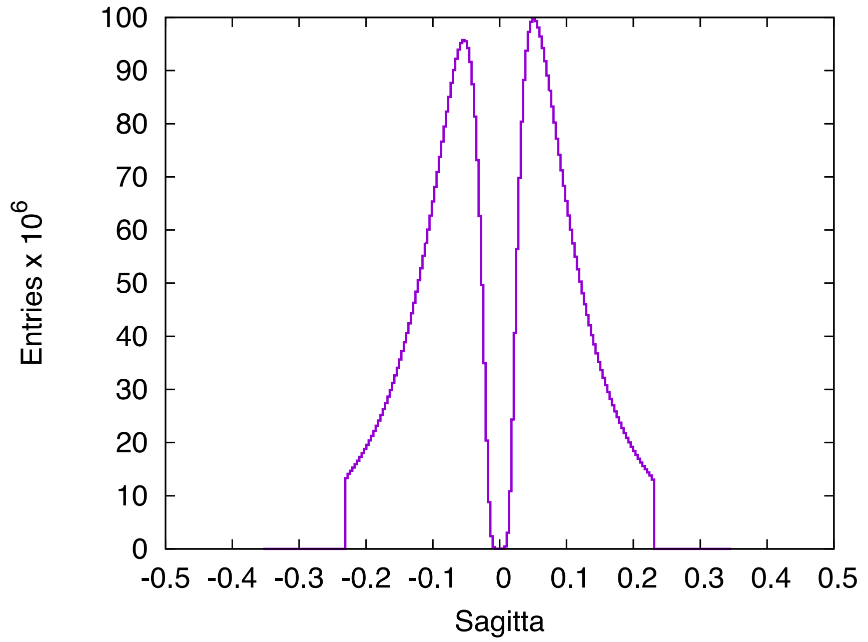
- Acceptance binning for weight calculation :

Sagitta = charge*((20.*p_T/3.) - √((20.*p_T/3.)^2 - 0.75^2))

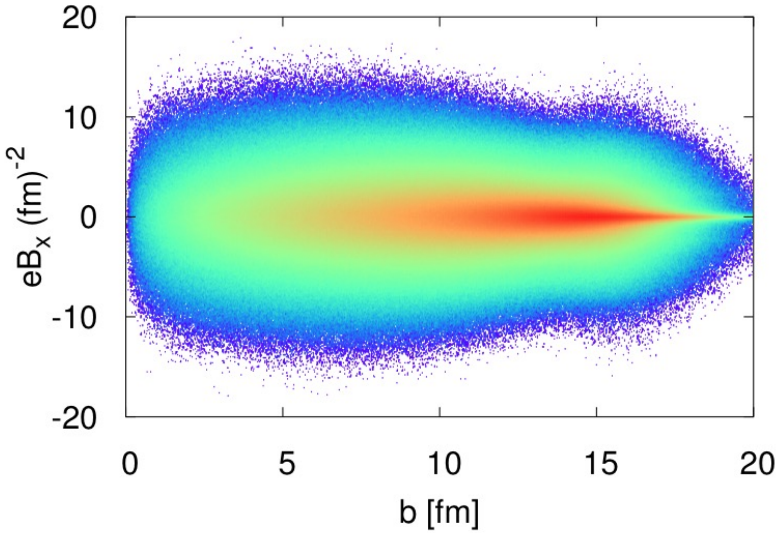
Weight = 1/(entries in η-ϕ) * 1/ϵ

The tracking efficiency :

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



B-field simulations : Dominance of fluctuations



t=0, x=<x>, y=<y>, z=0, U+U collisions