Disentangling flow and signals of Chiral Magnetic Effect in U+U and Au+Au collisions

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(for the STAR Collaboration)

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STAR

Quark Matter 2017

U.S. DEPARTMENT OF ENERGY | Office of Science

Motivation : Separation of flow and CME

CME : QCD anomaly driven chirality imbalance leads to current along B-field

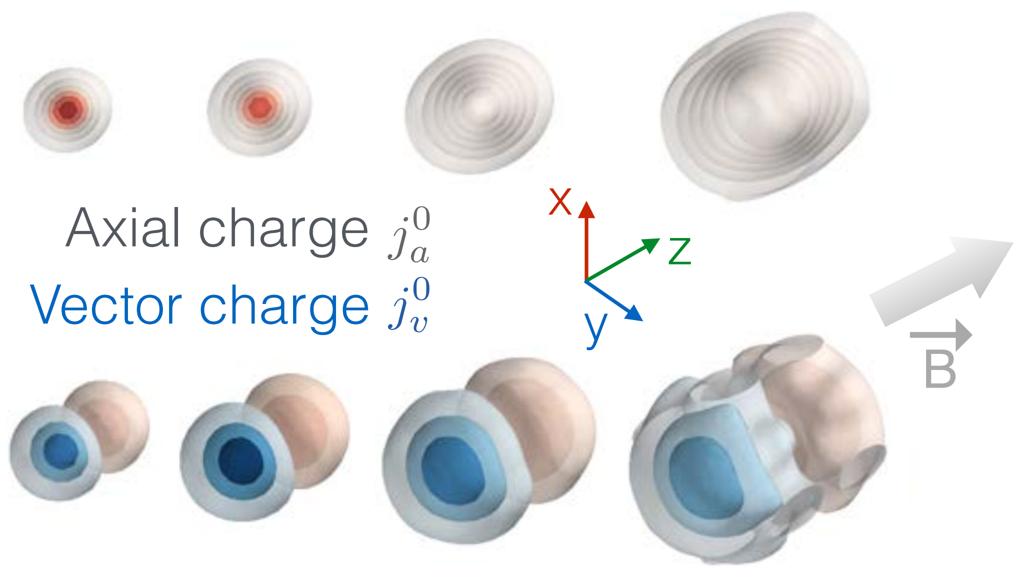
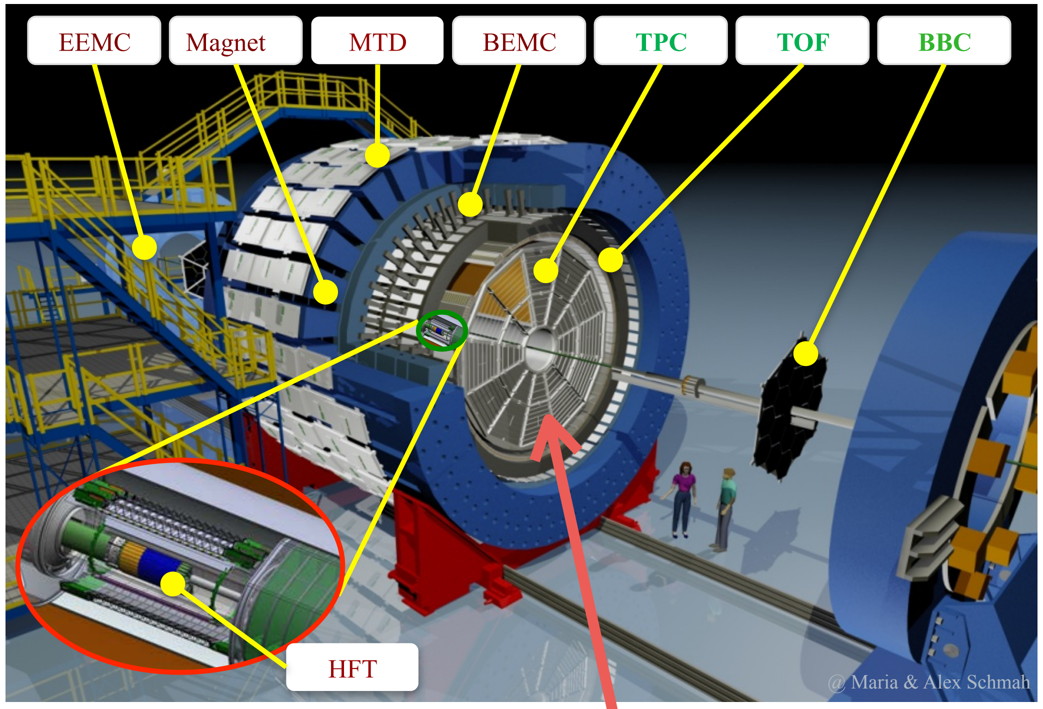


Fig: Muller, Schlichting, Sharma, PRL 117 142301 (2016)

STAR Detector



Time-Projection Chamber (used for this analysis)

Goal : Search for signals of CME & suppress flow driven background

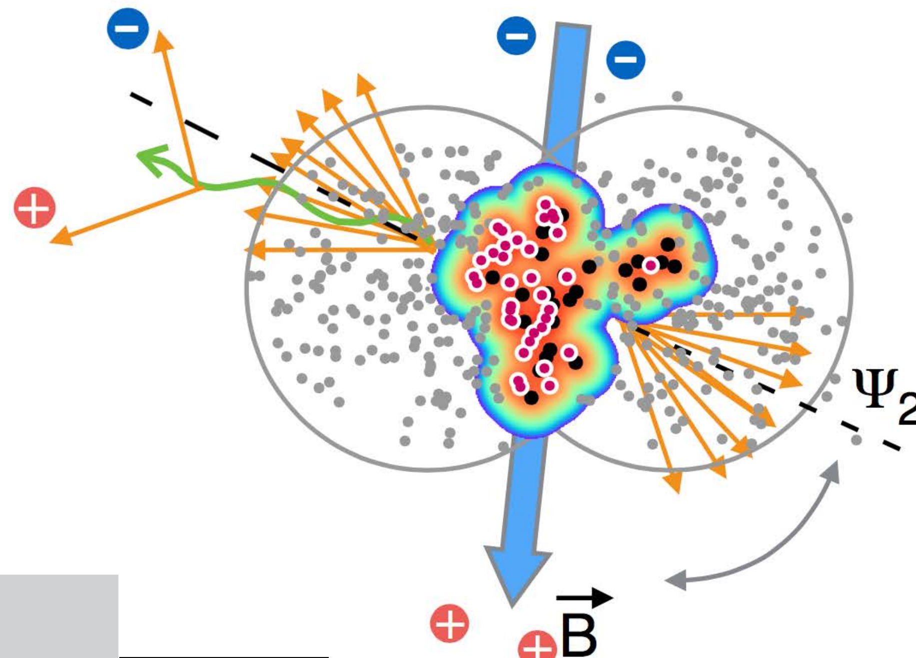
Observables :

Voloshin, PRC 70 (2004) 057901

Three particle correlator : $C_{112} = \langle \cos(\phi_1 + \phi_2 - 2\phi_3) \rangle$

LPV correlator : $\gamma^{a,b} \sim \dfrac{\langle \cos((\phi_1^a + \phi_2^b - 2\phi_3)) \rangle}{v_2\{2\}}$, $v_2\{2\}^2 = \langle \cos(2(\phi_1 - \phi_2)) \rangle$

Signal & Backgrounds of charge separation



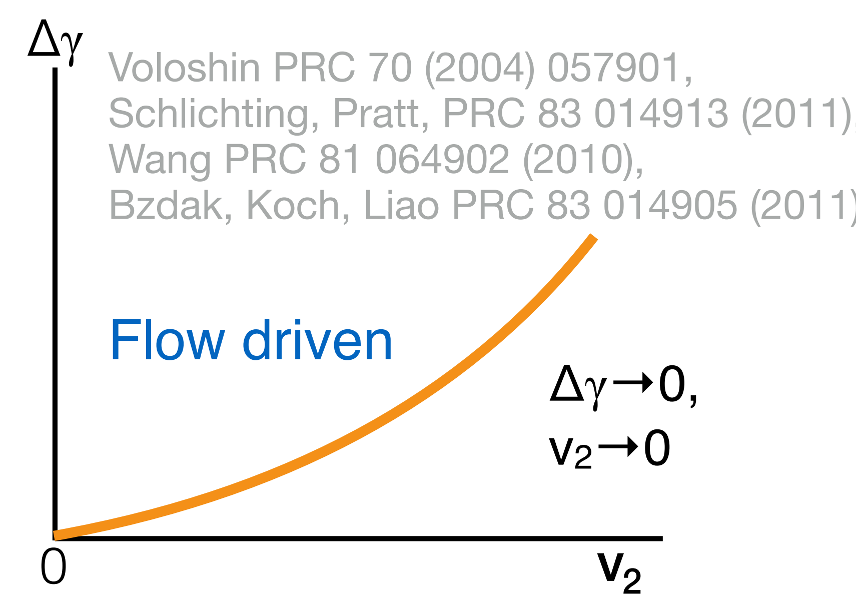
$$\gamma^{a,b} = \langle \cos(\phi_1^{\mathrm{a}} + \phi_2^{\mathrm{b}} - 2\Psi_2) \rangle$$

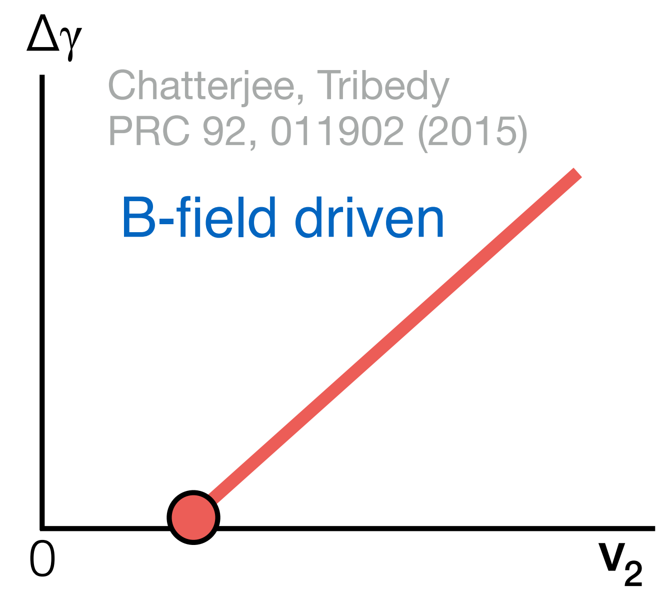
Charge separation (central-events)

Background

- HBT, Coulomb
- Flowing resonance
- Charge conservation
- Momentum conservation

→ v_2 $\approx \frac{v_2\{2\}}{N}$ →





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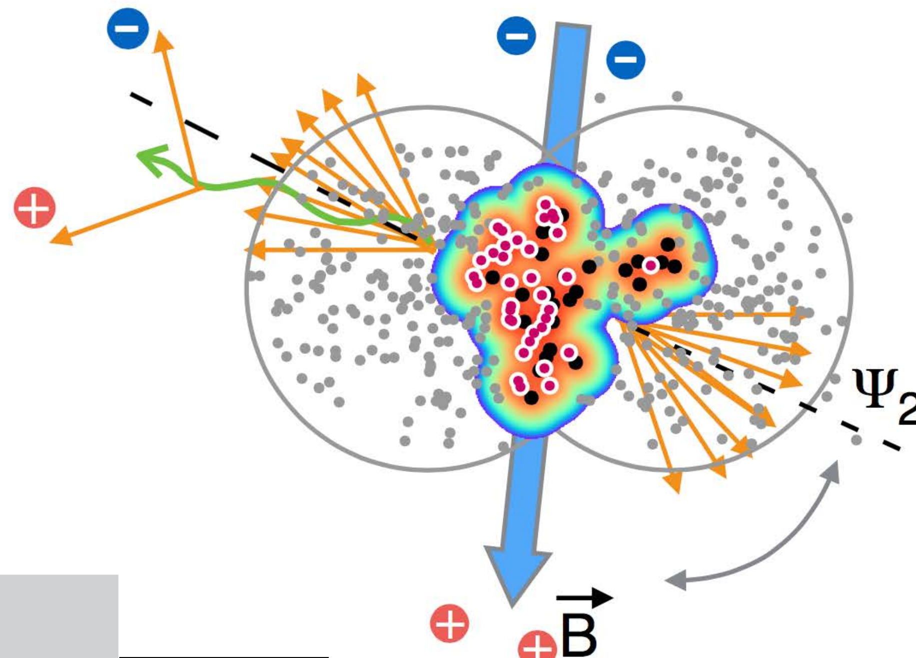

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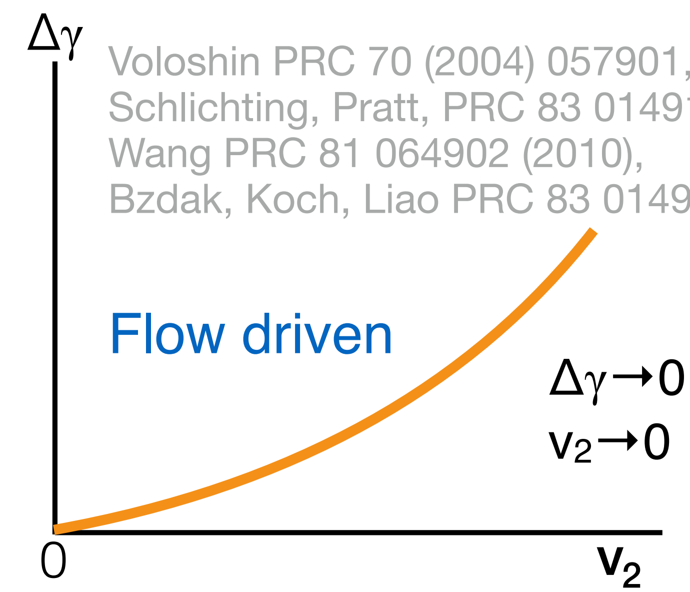
→ v_2 $\approx \frac{v_2\{2\}}{N}$

Signal

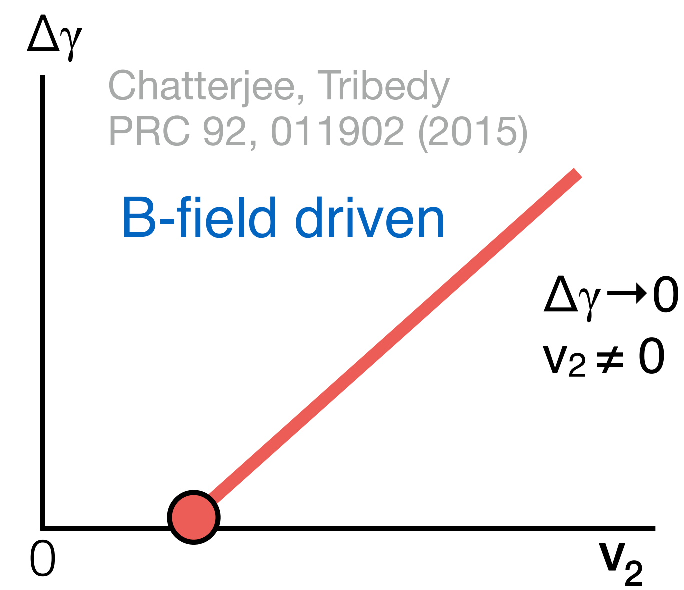
- Magnetic field

→ Ψ_2 $\approx \langle B^2 \cos(2(\Psi_B - \Psi_2)) \rangle$

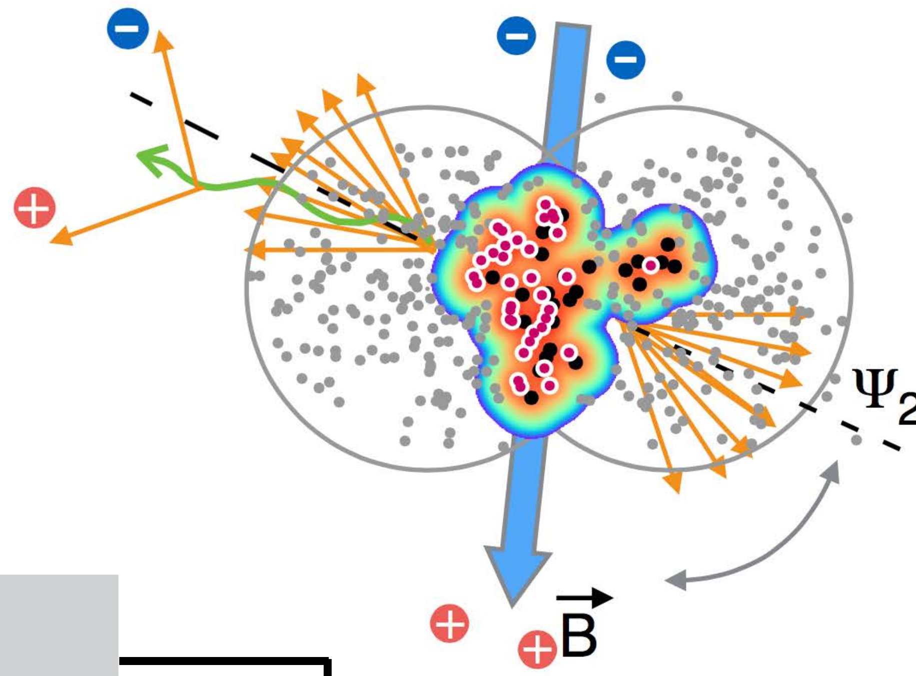
Voloshin PRC 70 (2004) 057901,
Schlichting, Pratt, PRC 83 014913 (2011),
Wang PRC 81 064902 (2010),
Bzdak, Koch, Liao PRC 83 014905 (2011)



Chatterjee, Tribedy
PRC 92, 011902 (2015)



Signal & Backgrounds of charge separation



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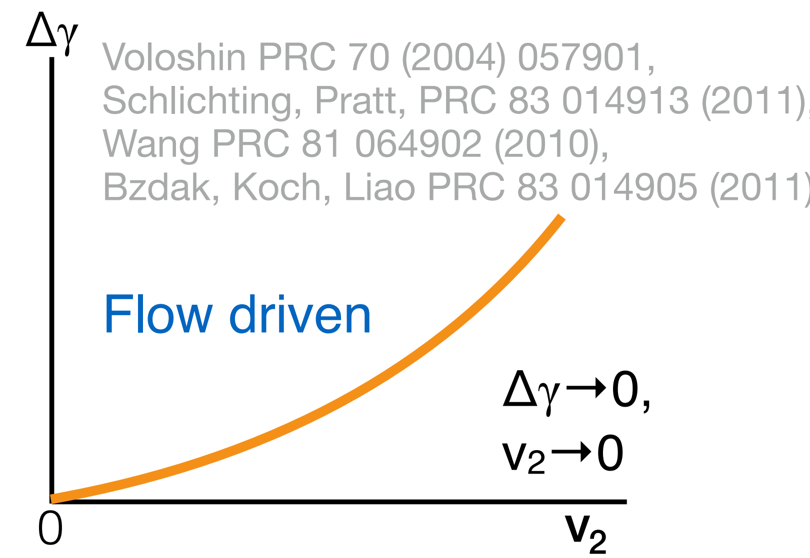


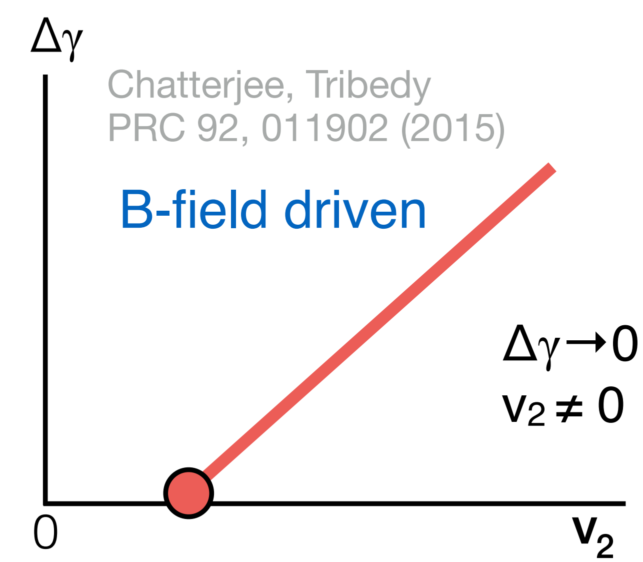
v_2 ↔ Ψ_2

Signal

- Magnetic field

→ Ψ_2 →

$$\approx \langle B^2 \cos(2(\Psi_B - \Psi_2)) \rangle$$

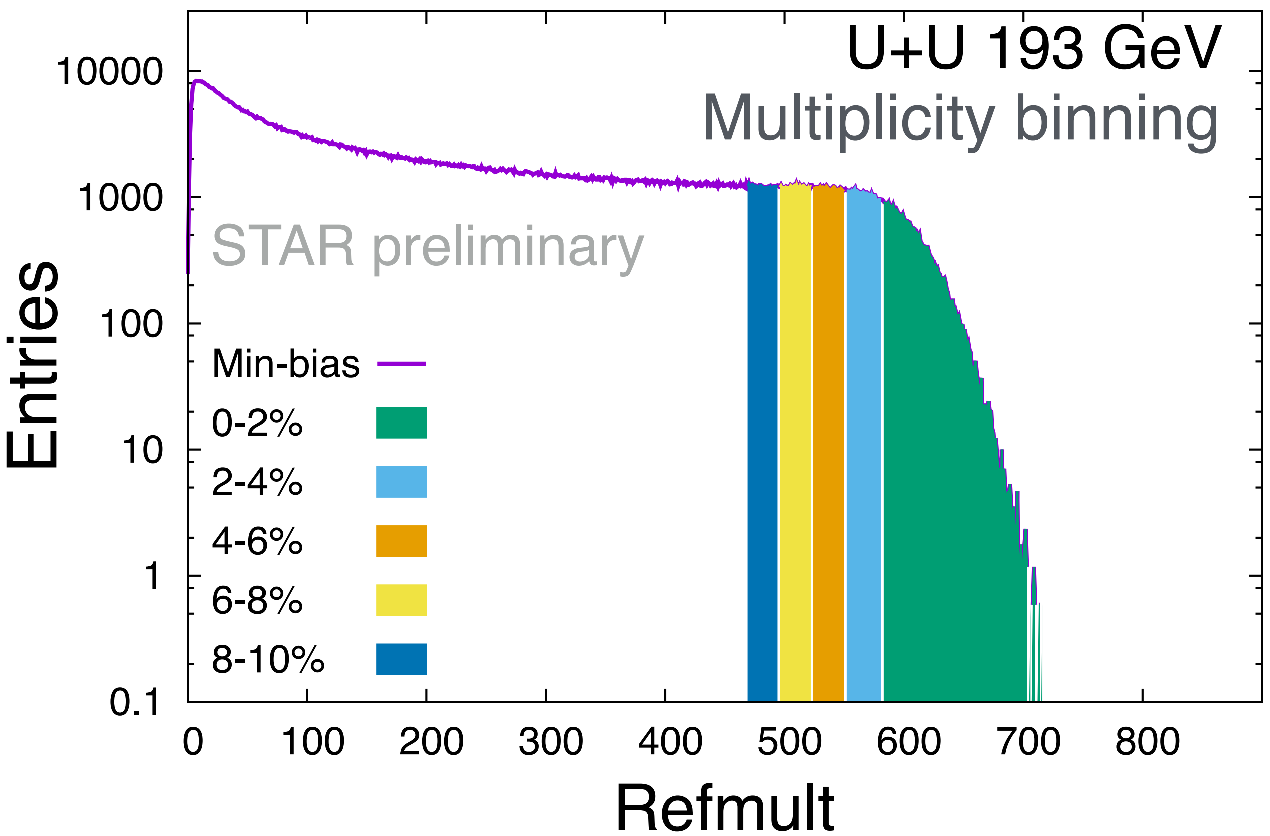


Strategy : look for vanishing $\Delta\gamma$ when v_2 is still non-zero

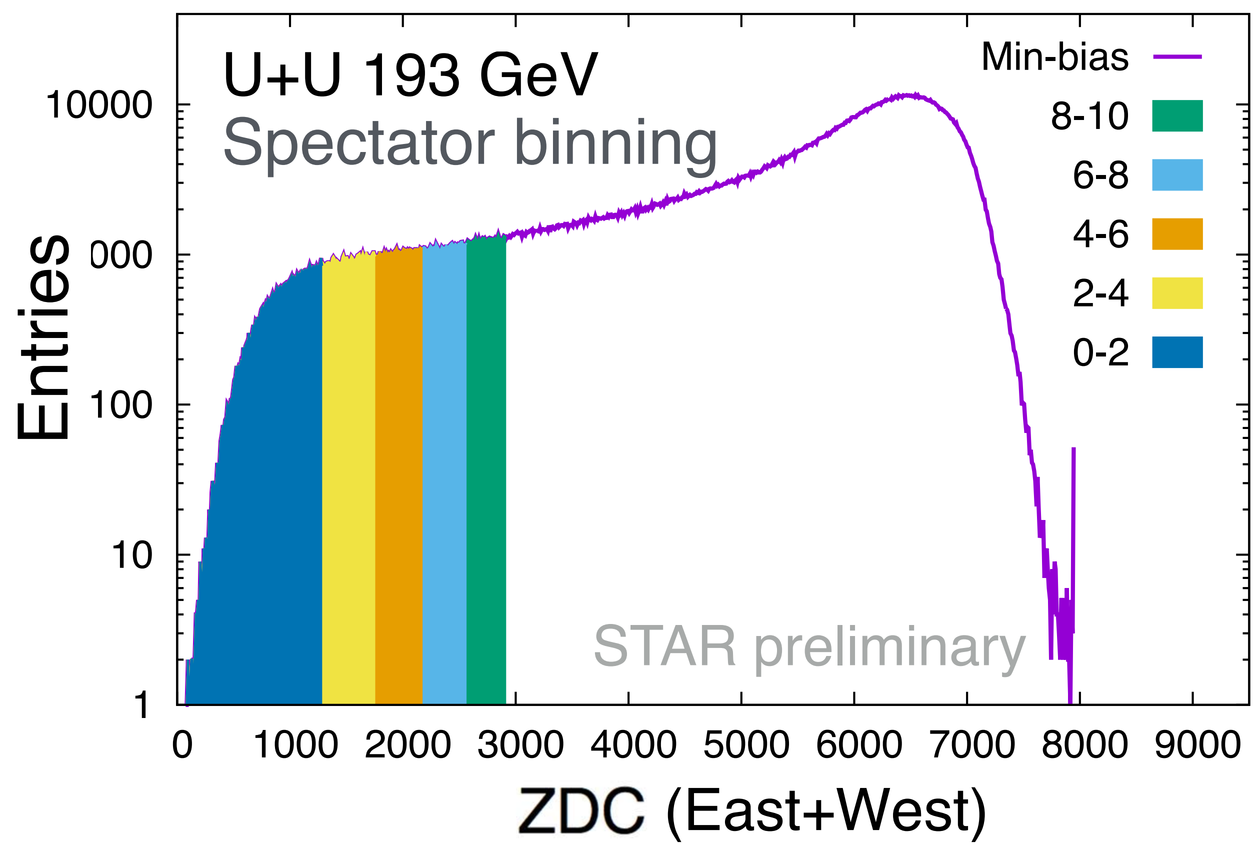
Analysis details

- **Data Set used :** U+U 193 GeV (Year 2012), Au+Au 200 GeV (Year 2011), p+Au 200 GeV (Year 2015)
- **Acceptance cuts :** $0<\phi<2\pi,\ |\eta|<1,\ p_T > 0.2$ GeV/c
- **Centrality :** Time Projection Chamber & Zero Degree Calorimeter

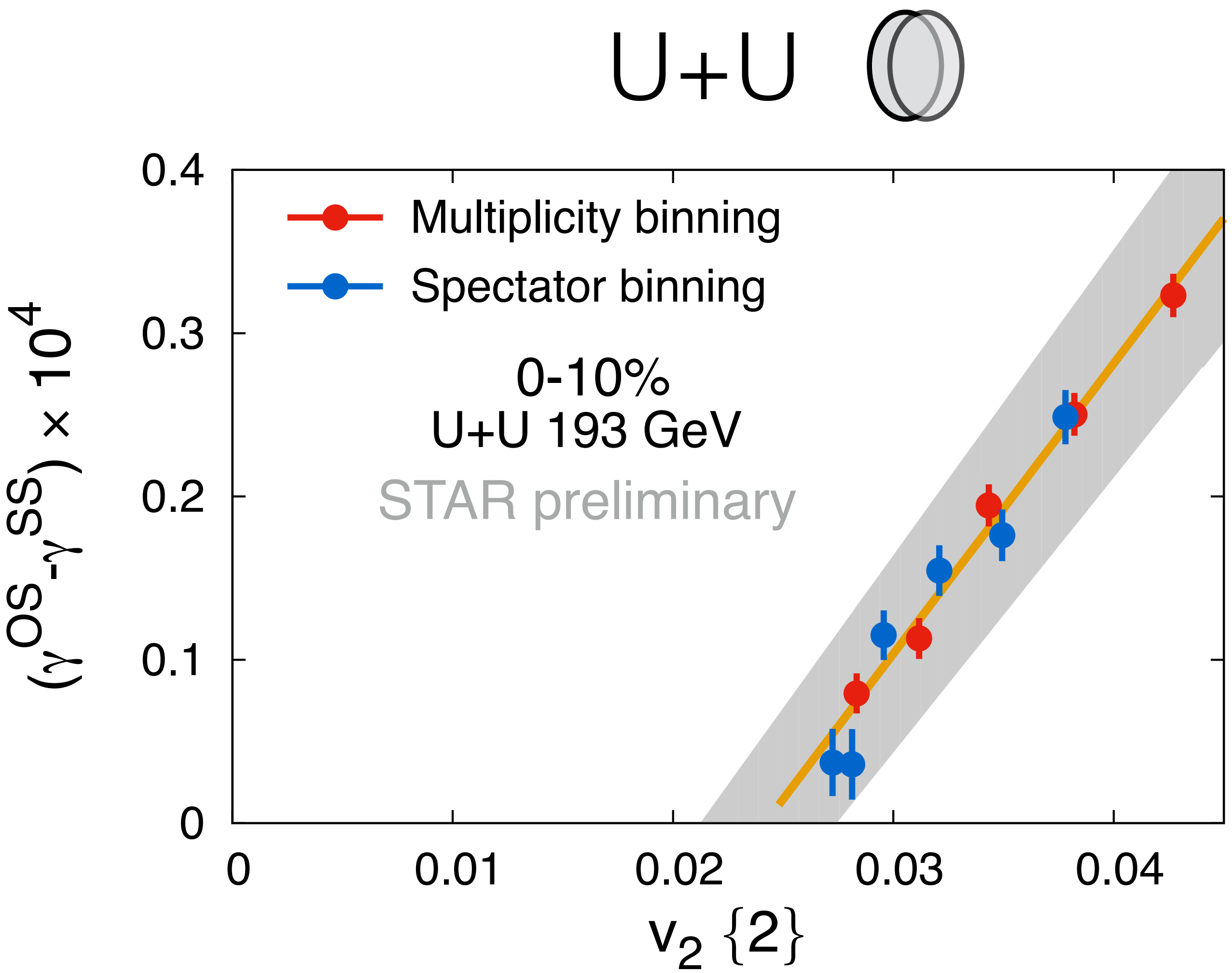
Uncorrected multiplicity in $|\eta|<0.5$

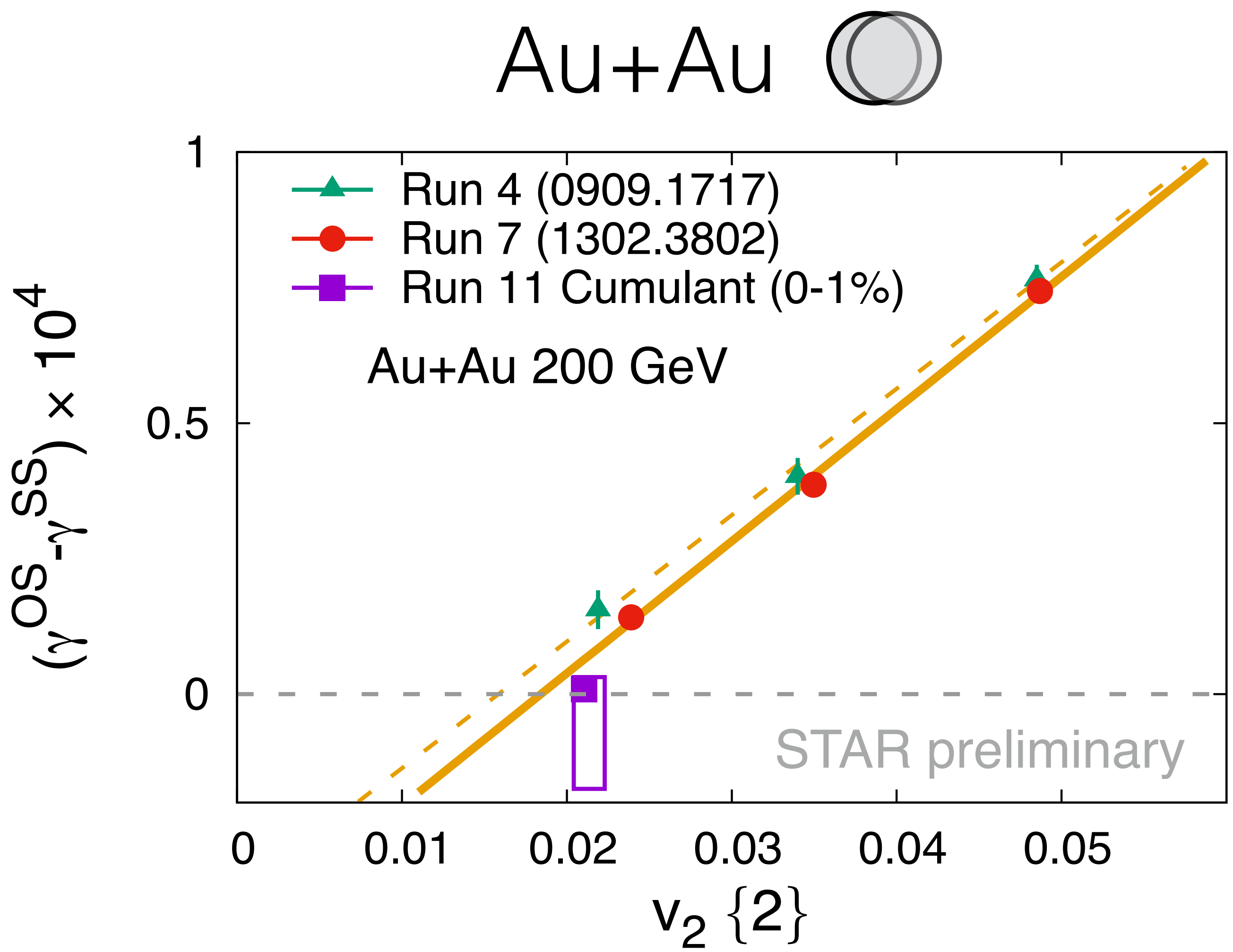


Neutron response of ZDCs



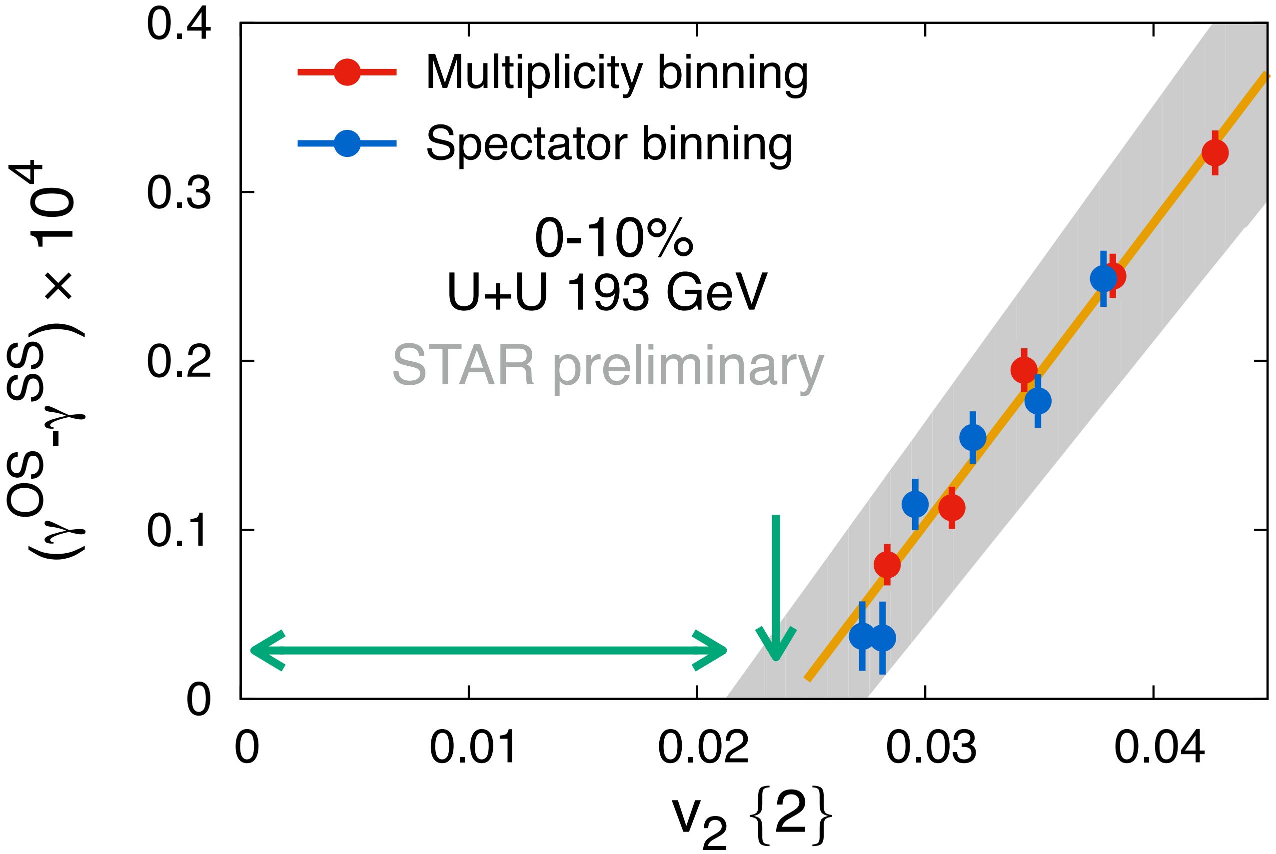
Results : Central and Ultra-central Collisions



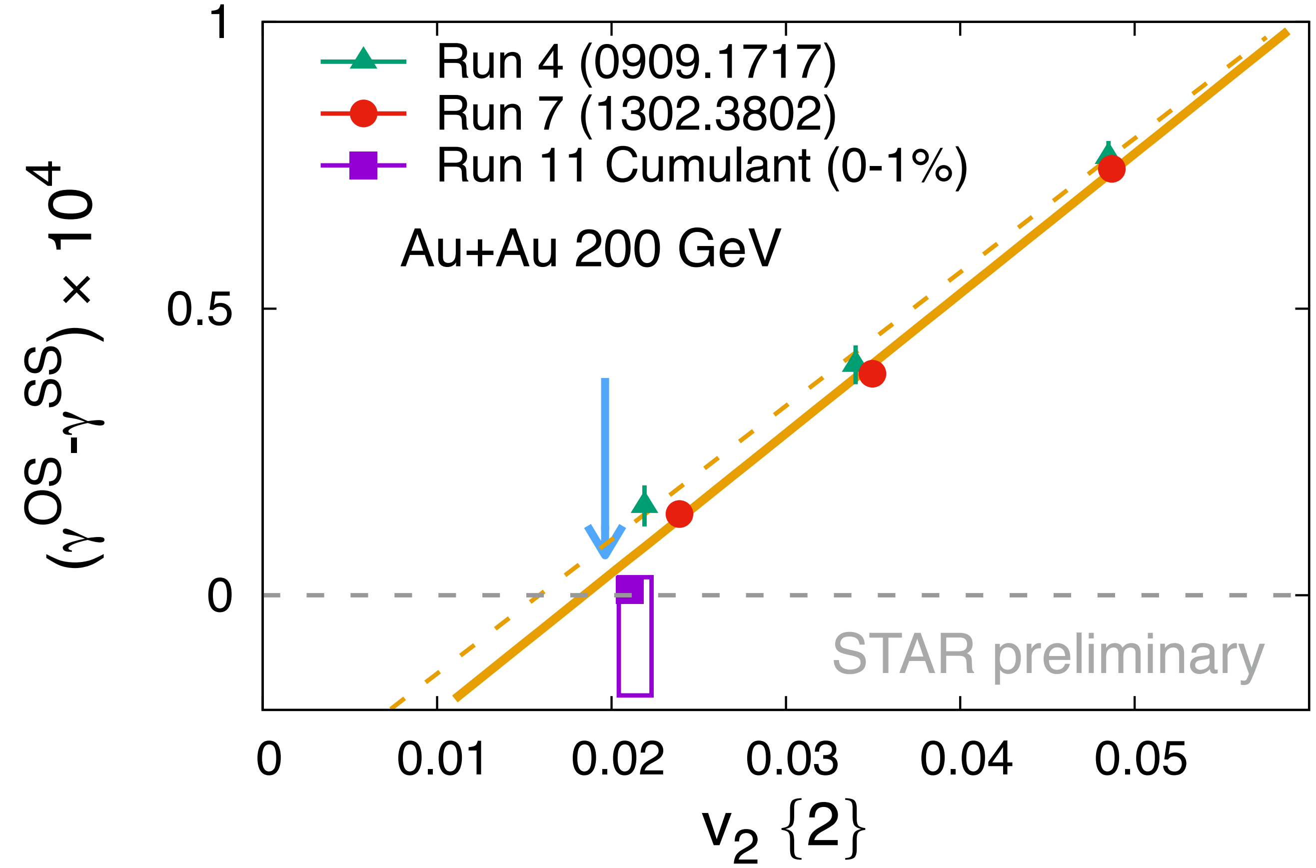


Results : Central and Ultra-central Collisions

U+U



Au+Au

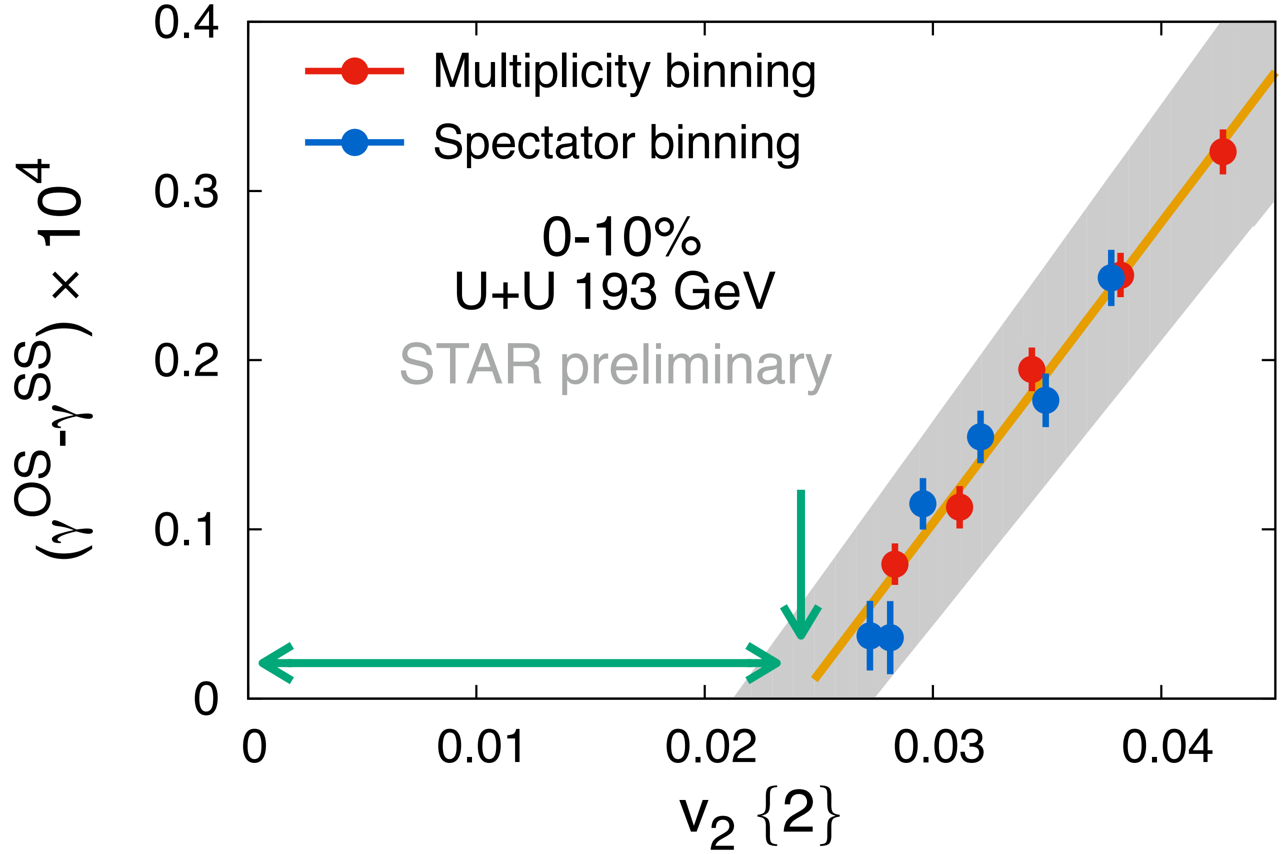


Data :

- Show vanishing charge separation for non-zero values of v_2 {2}
- Show linear growth with v_2 {2}
- Show larger v_2 {2} offset ($\Delta\gamma=0$) for U+U than Au+Au

Central and Ultra-central Collisions

Data



Central and Ultra-central Collisions

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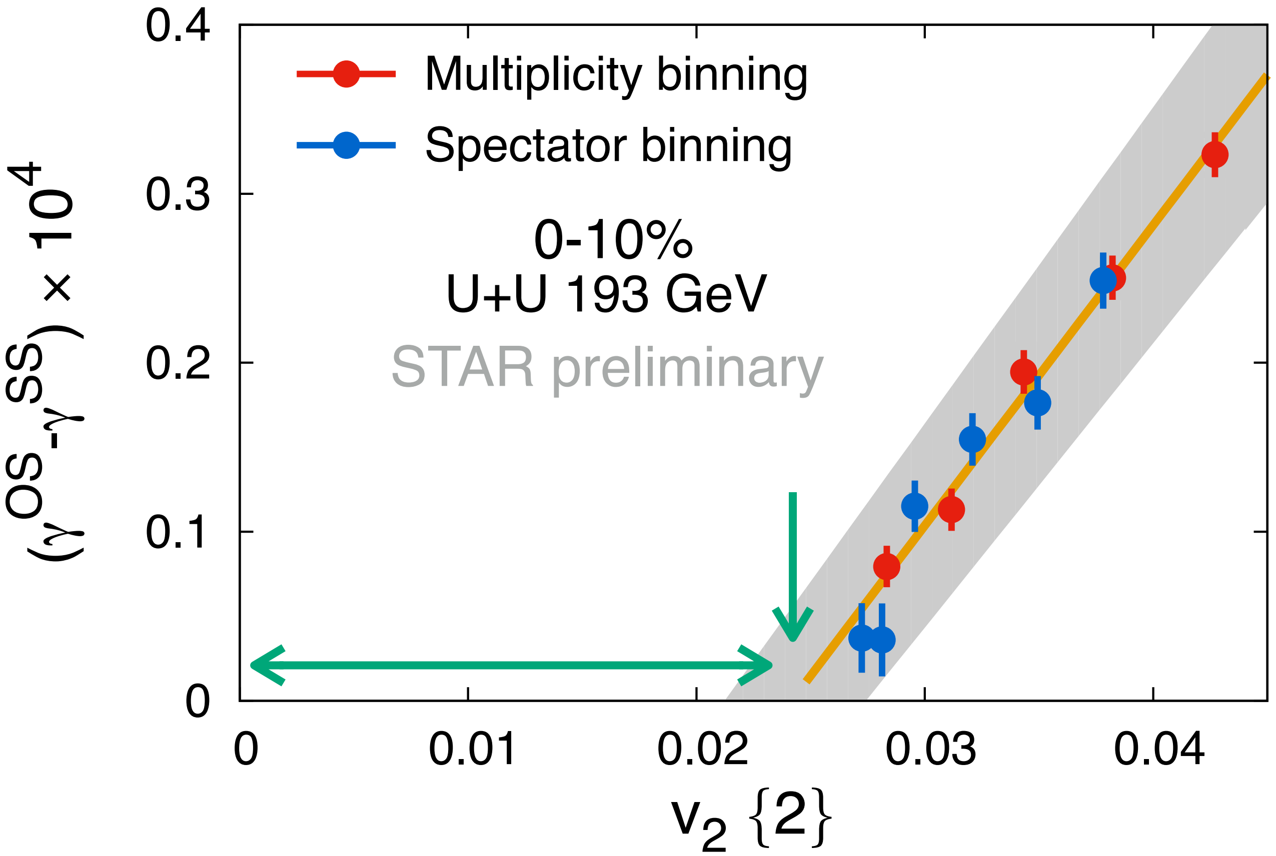
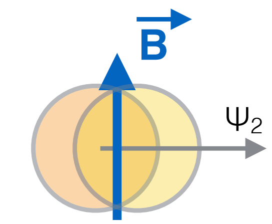
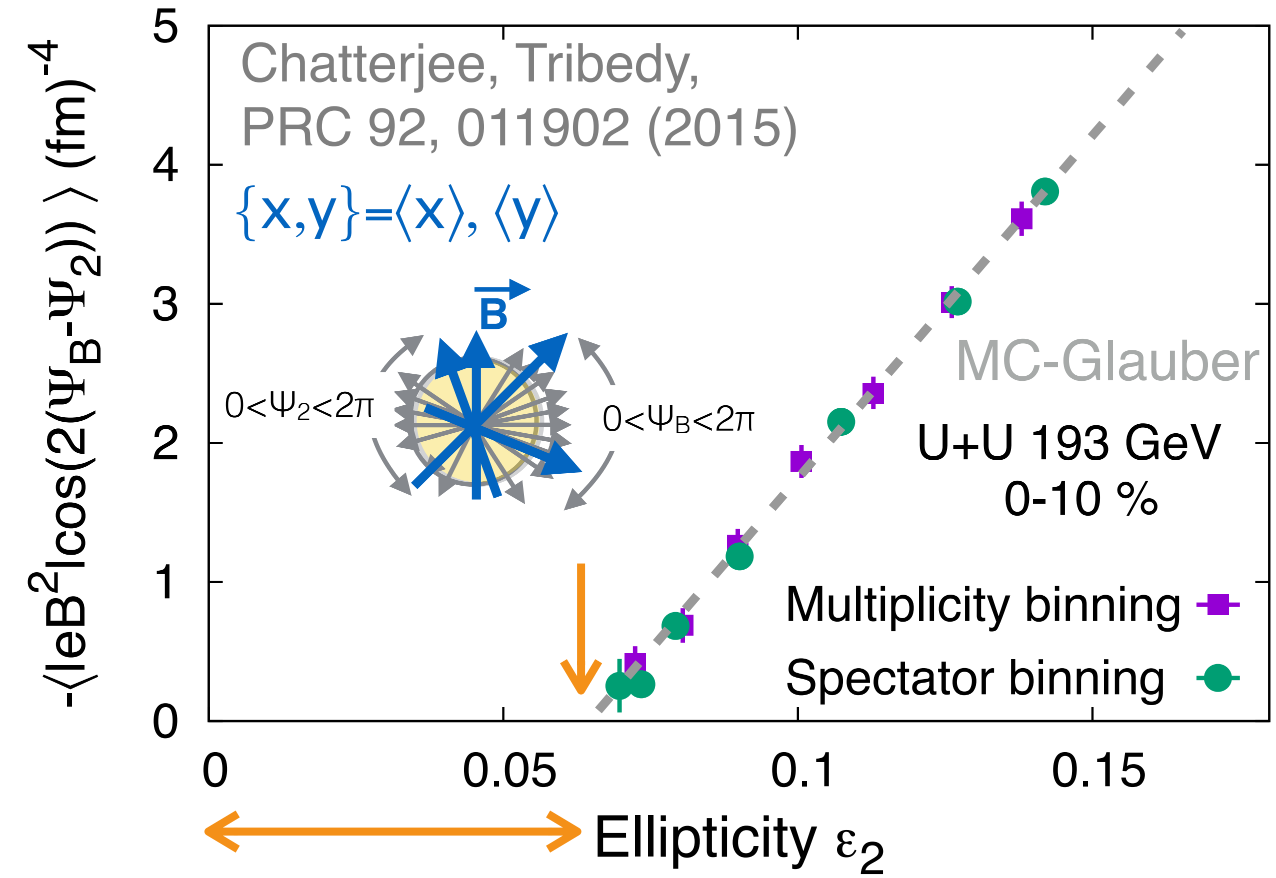


Projected B-field

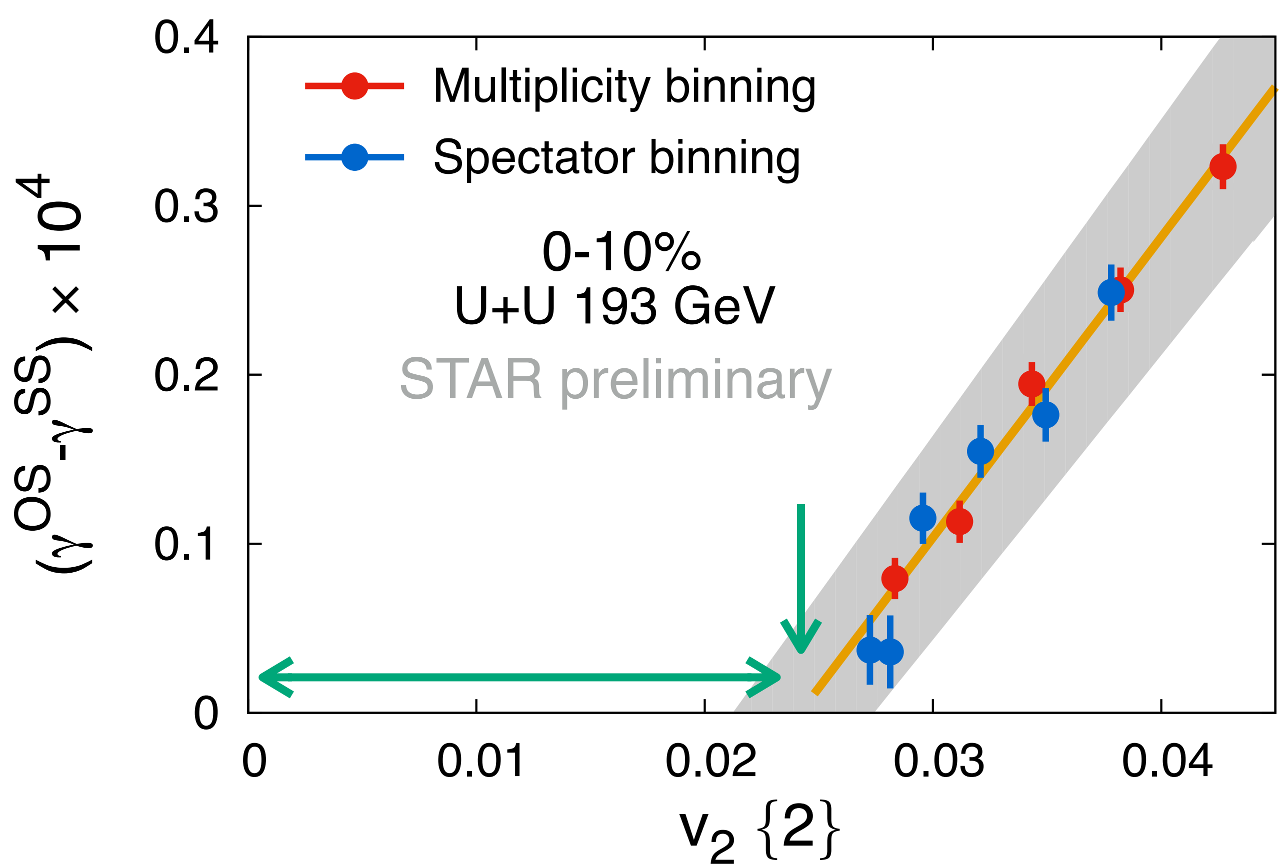




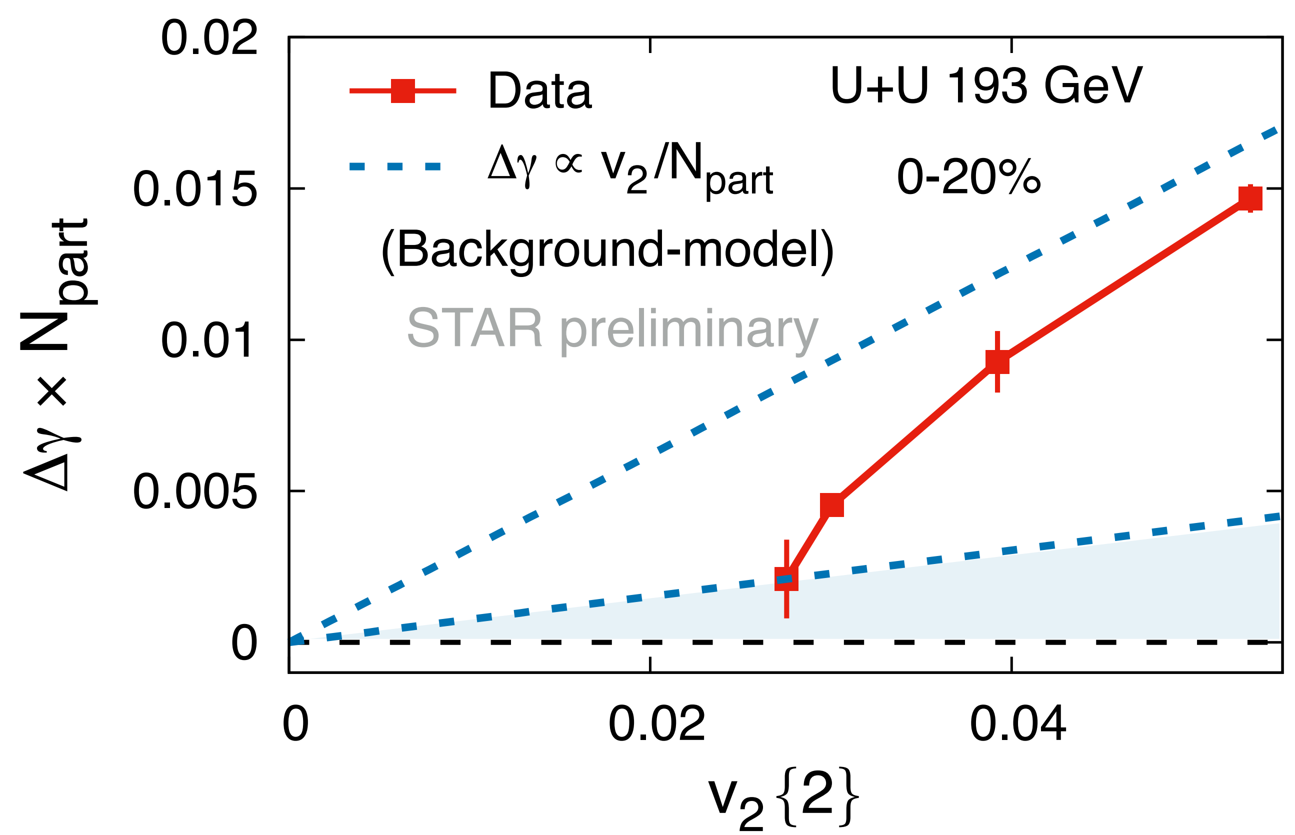
Projected B-field vs ε_2 can provide a natural explanation to the data

Central and Ultra-central Collisions

Data



Data & Background expectations

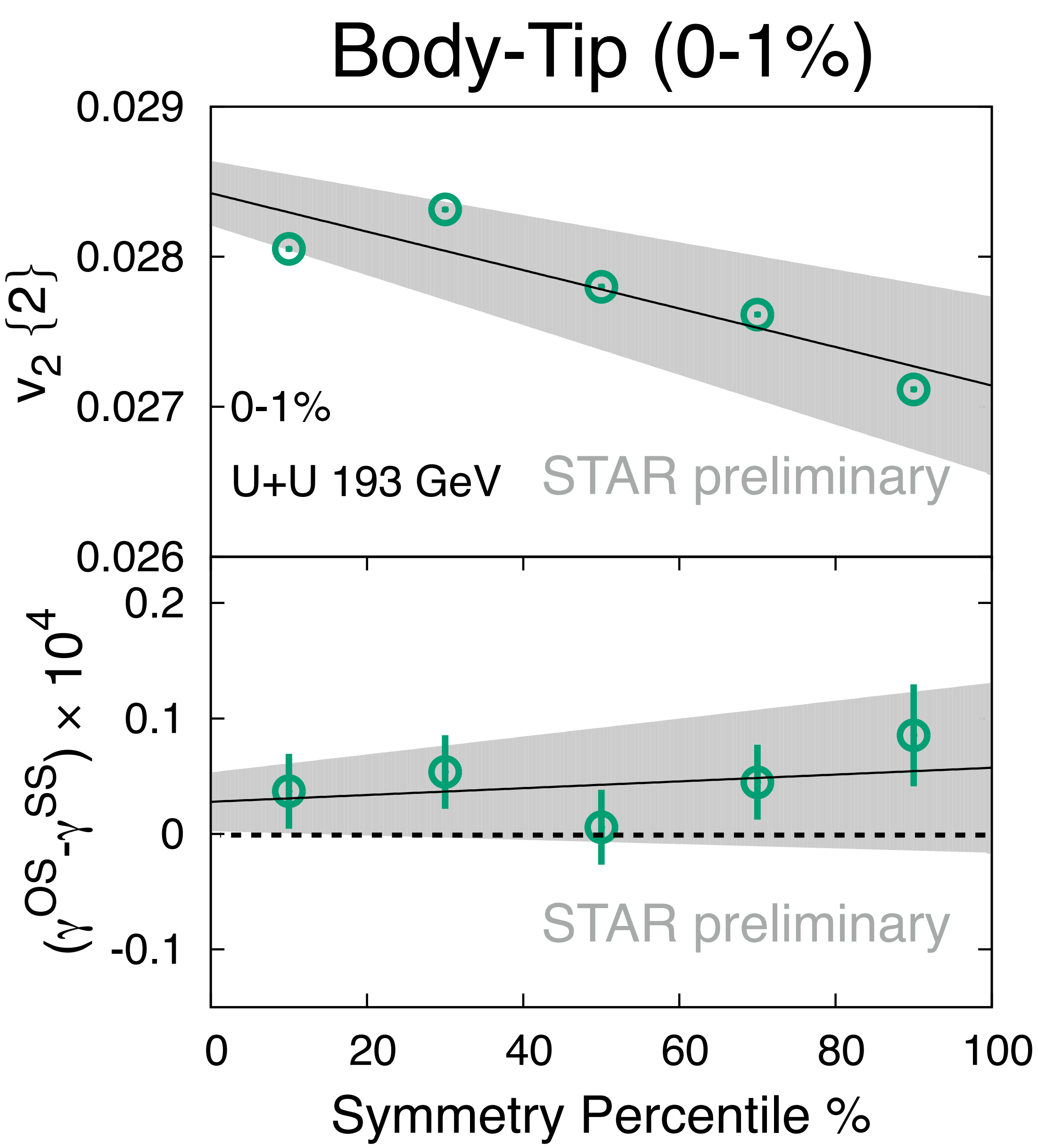


We need to see if a background model can explain data

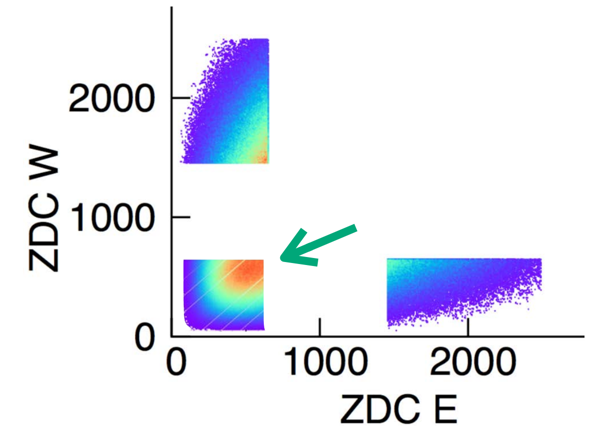
$$\Delta\gamma_{\text{Background}} = (\gamma^{OS} - \gamma^{SS})_{\text{Background}} \approx \frac{v_2\{2\}}{N} \Rightarrow \Delta\gamma_{\text{Background}} \times N \approx v_2\{2\}$$

Body-Tip Collisions (U+U)

Binning in spectator asymmetry → independent from centrality binning



Chatterjee, Tribedy, PRC 92, 011902 (2015)



Provides a way to trigger even smaller v_2 {2}

Body-Tip Collisions (U+U)

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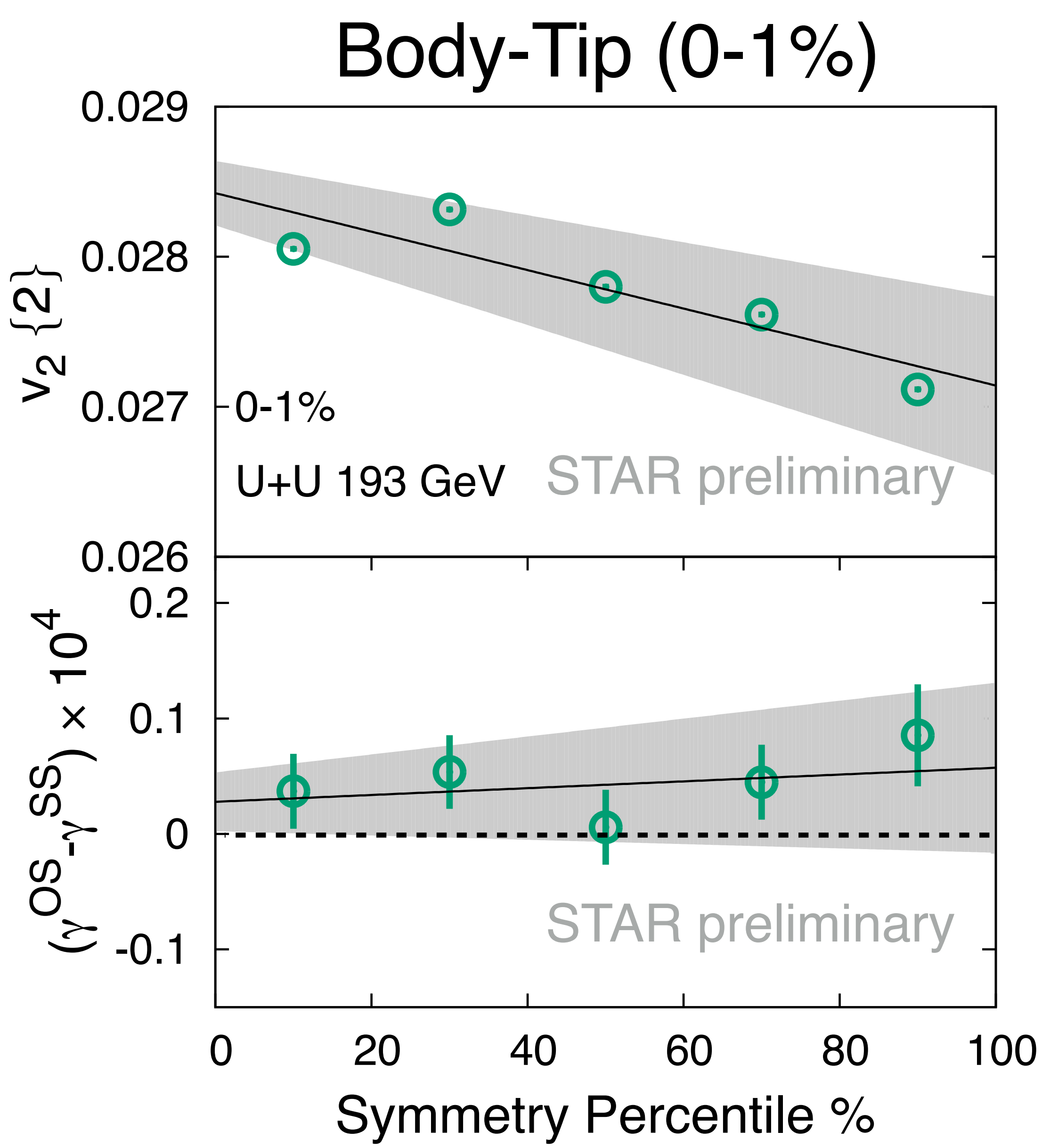
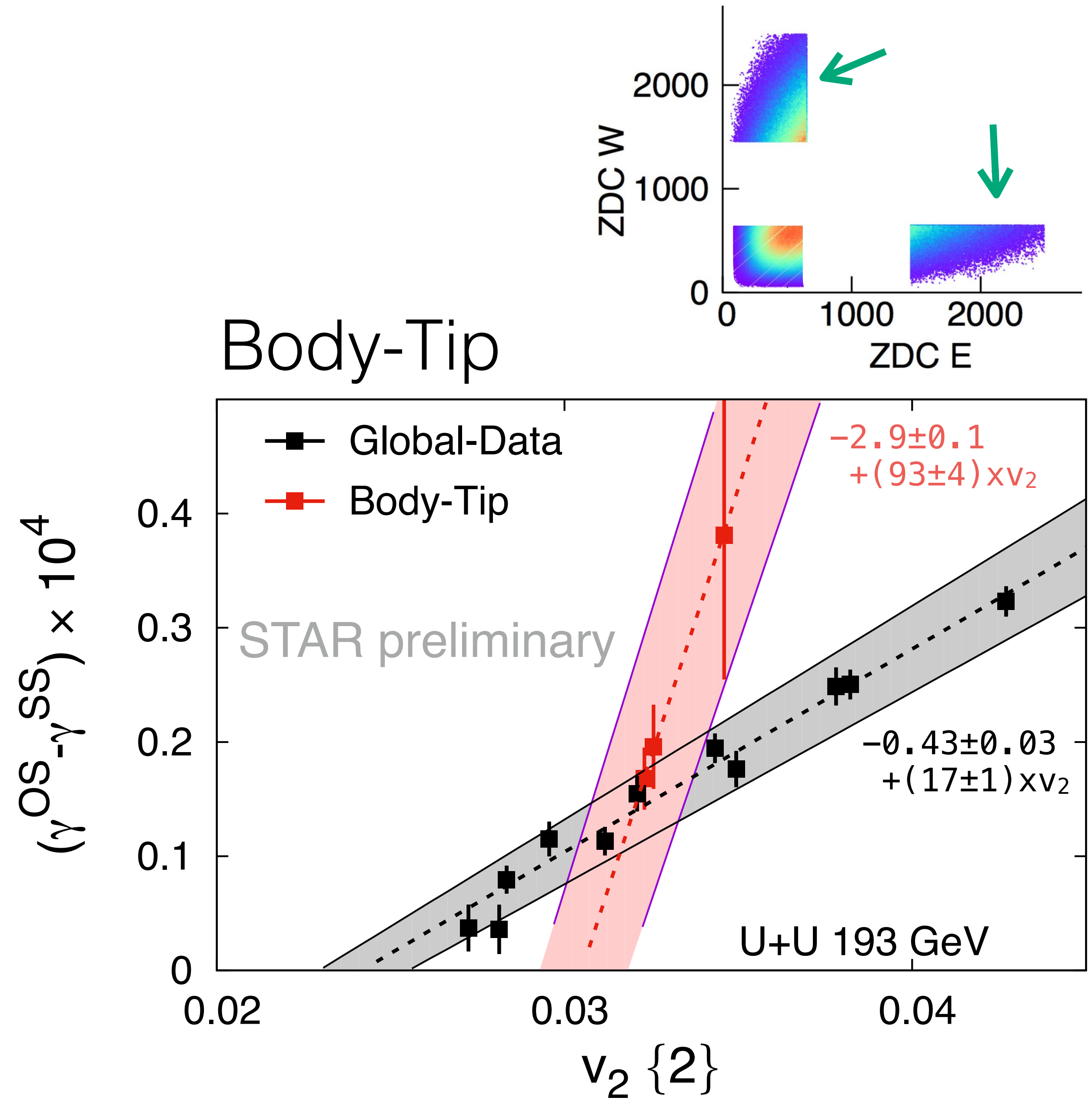
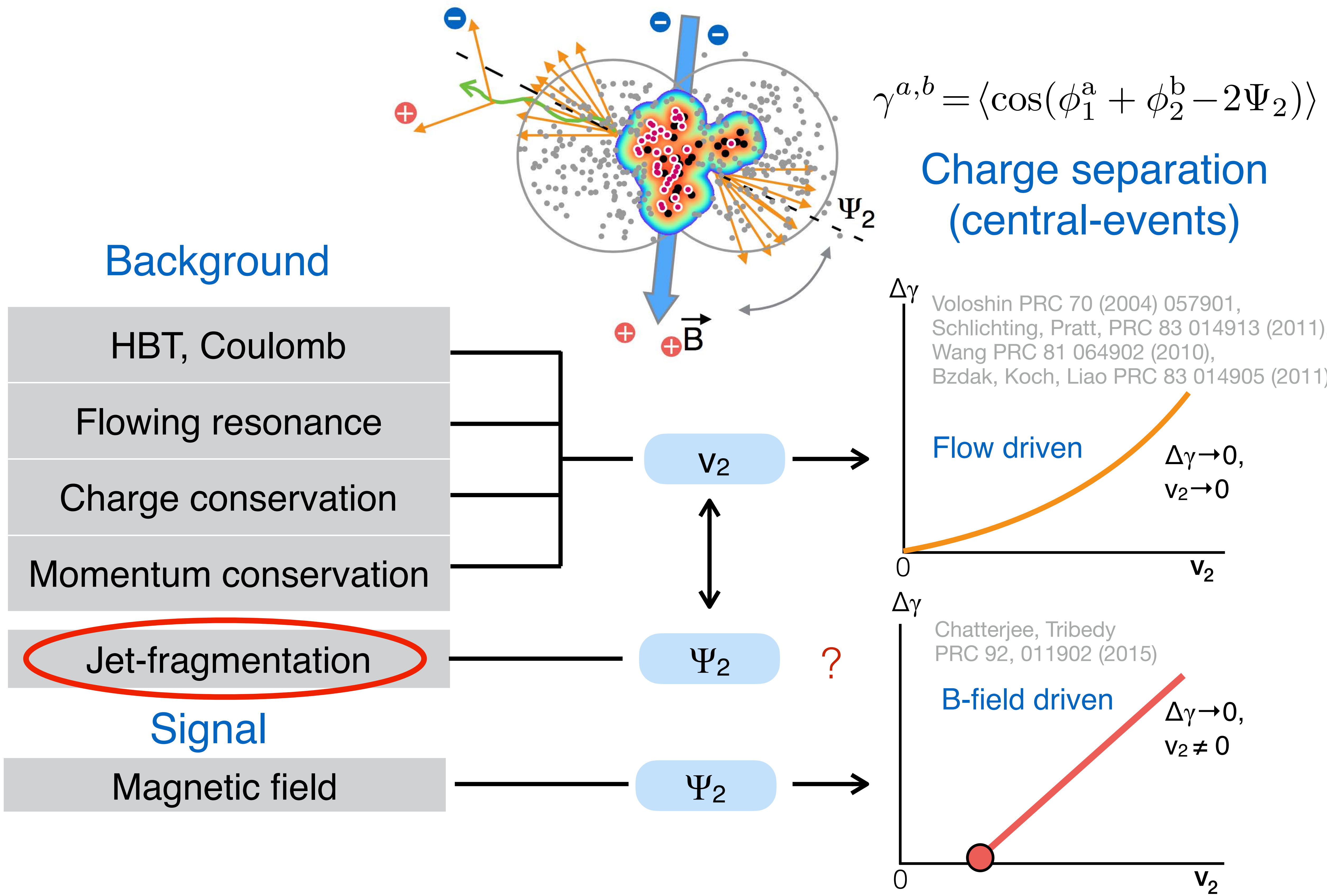




Provides a way to trigger even smaller $v_2\{2\}$

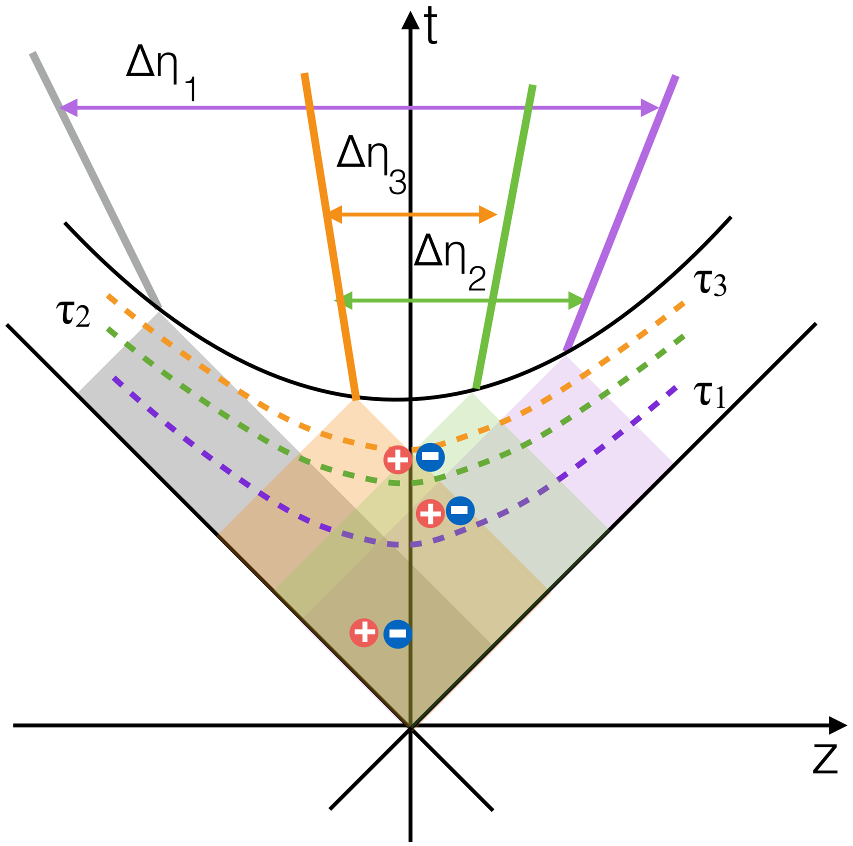
Different trend than conventional centrality binning

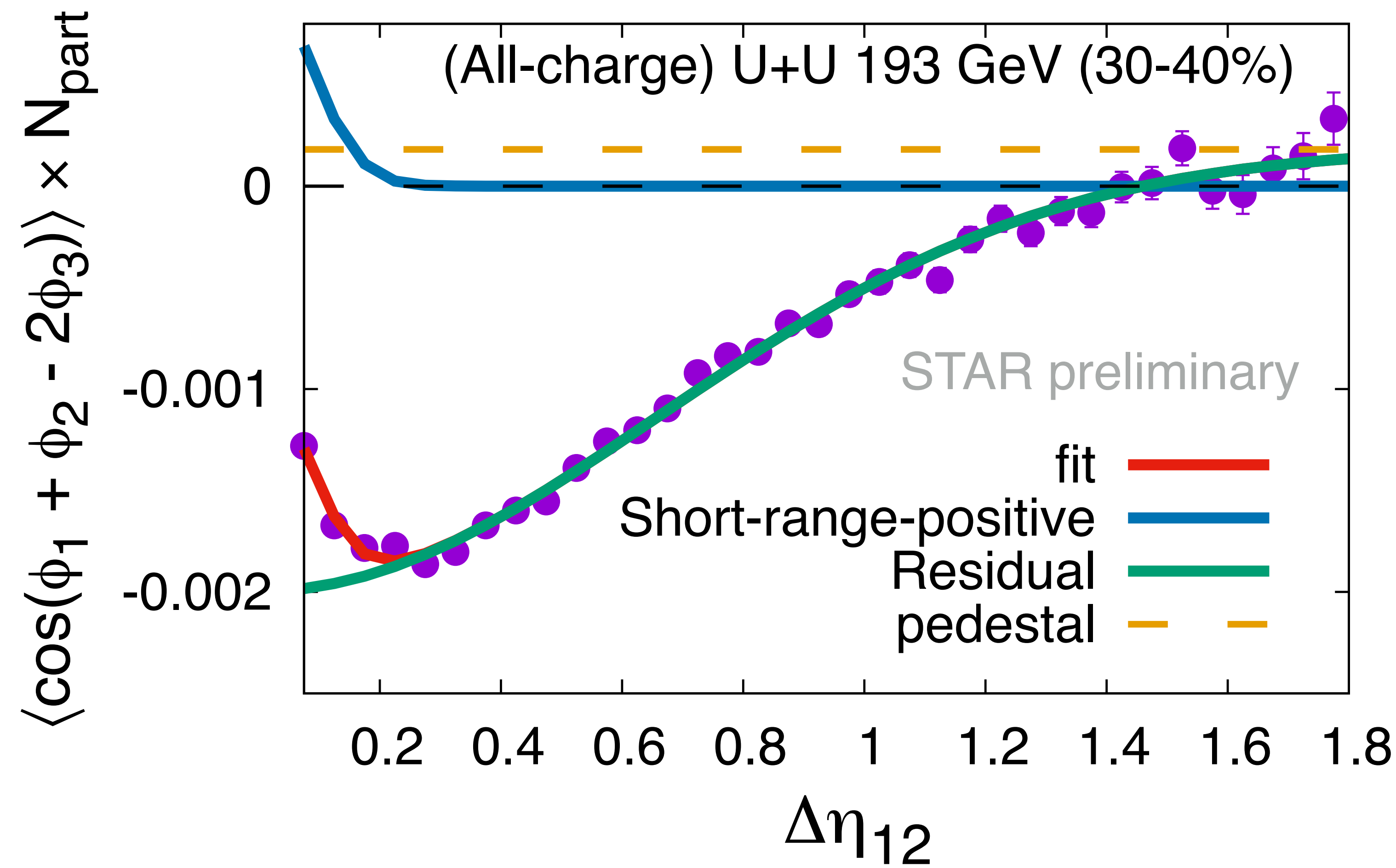
Signal & Backgrounds of charge separation



Anatomy of three-particle correlations

Search of early time charge separation → should be long-range in $\Delta\eta$





$$C_{112}(\Delta\eta_{12}) = A^{+}_{SR} e^{-(\Delta\eta)^2/2\sigma^2_{SR}} - A^{-}_{IR} e^{-(\Delta\eta)^2/2\sigma^2_{IR}} + A_{LR}$$

Anatomy of three-particle correlations

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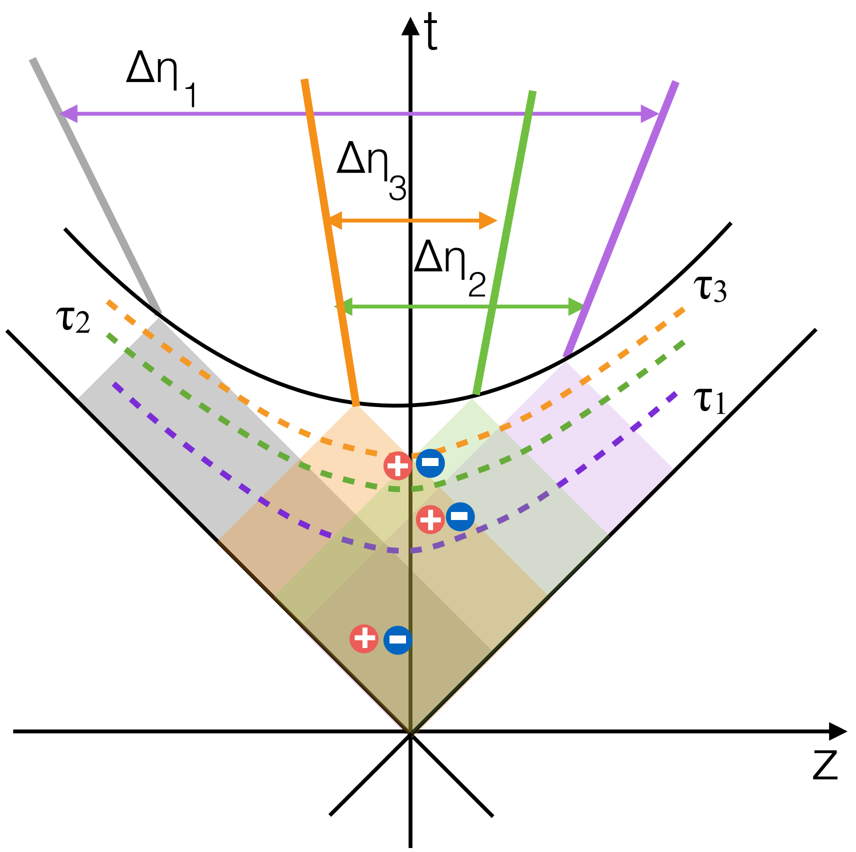
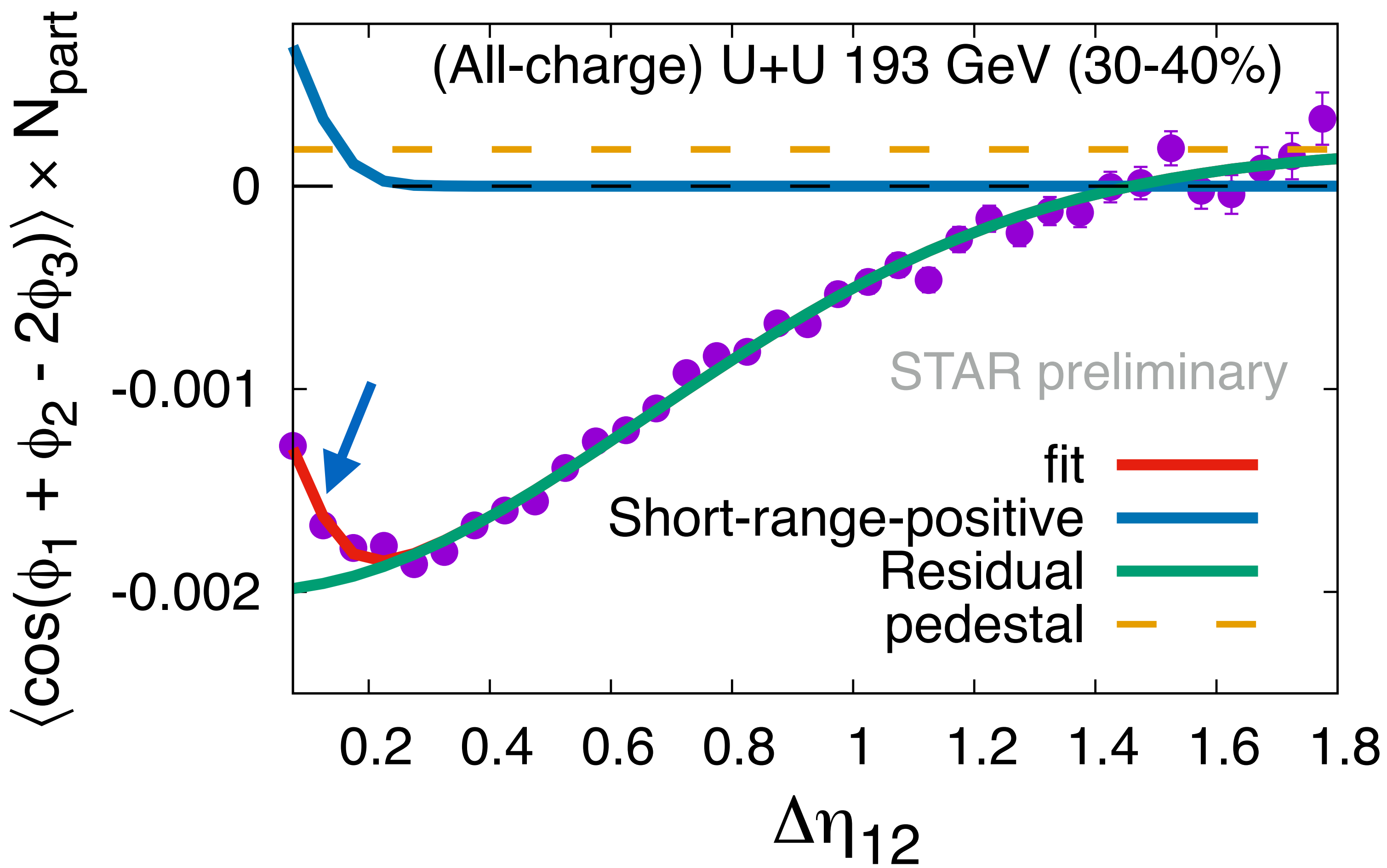




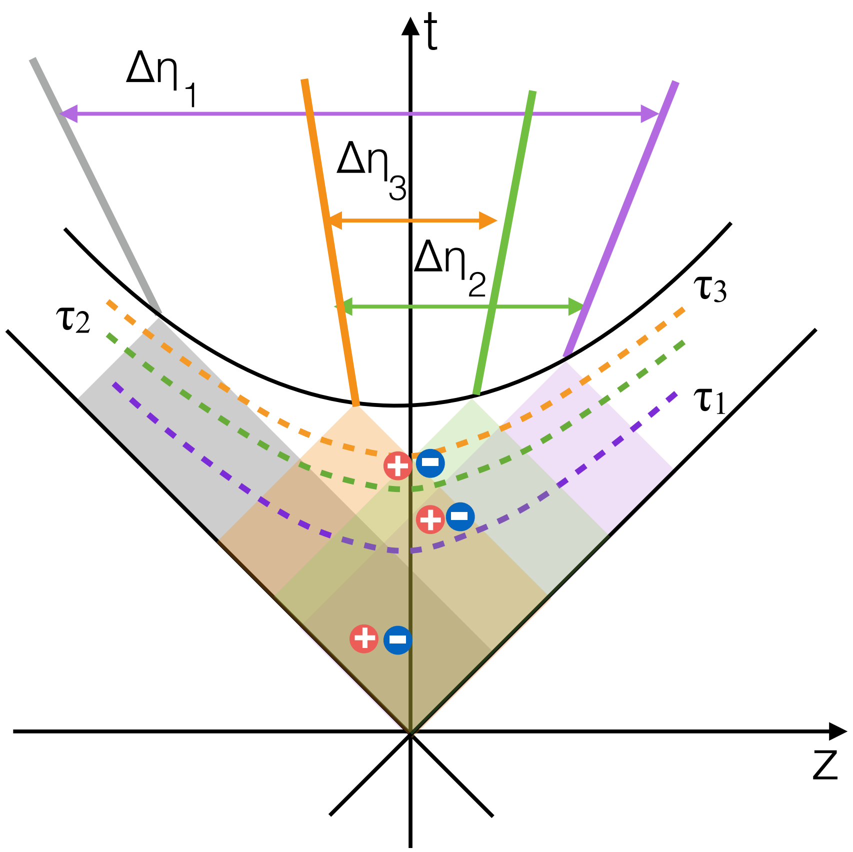
Short-range limit : $\Delta\phi \to 0, \Delta\eta \to 0 : C_{112} = \langle\cos(\phi_1(\eta_1)+\phi_2(\eta_2)-2\phi_3)\rangle \geq 0$

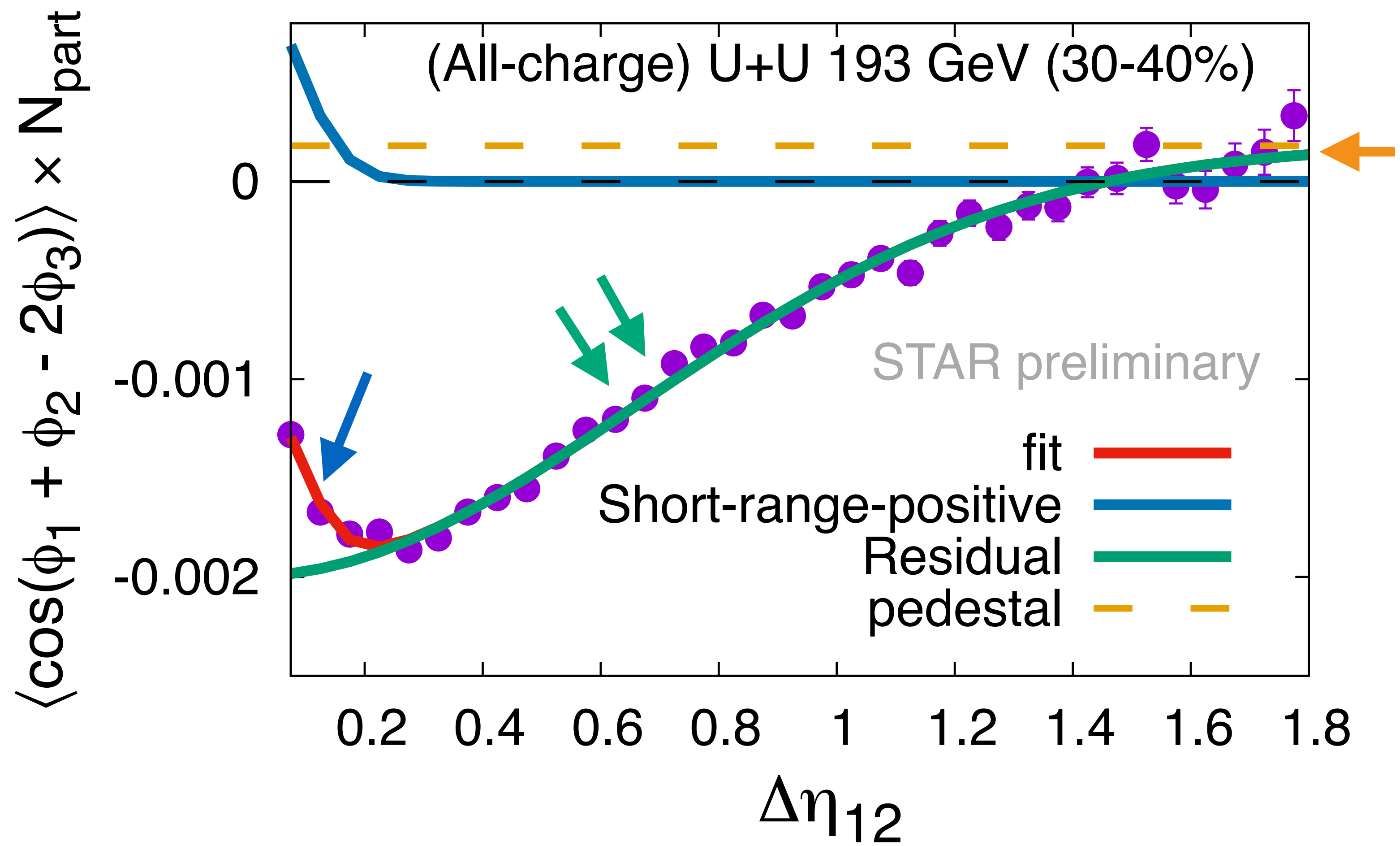
$$C_{112}(\Delta\eta_{12}) = \boxed{A^{+}_{SR} e^{-(\Delta\eta)^2/2\sigma^2_{SR}}} - A^{-}_{IR} e^{-(\Delta\eta)^2/2\sigma^2_{IR}} + A_{LR}$$

Short-range-positive

Anatomy of three-particle correlations

Search of early time charge separation → should be long-range in $\Delta\eta$





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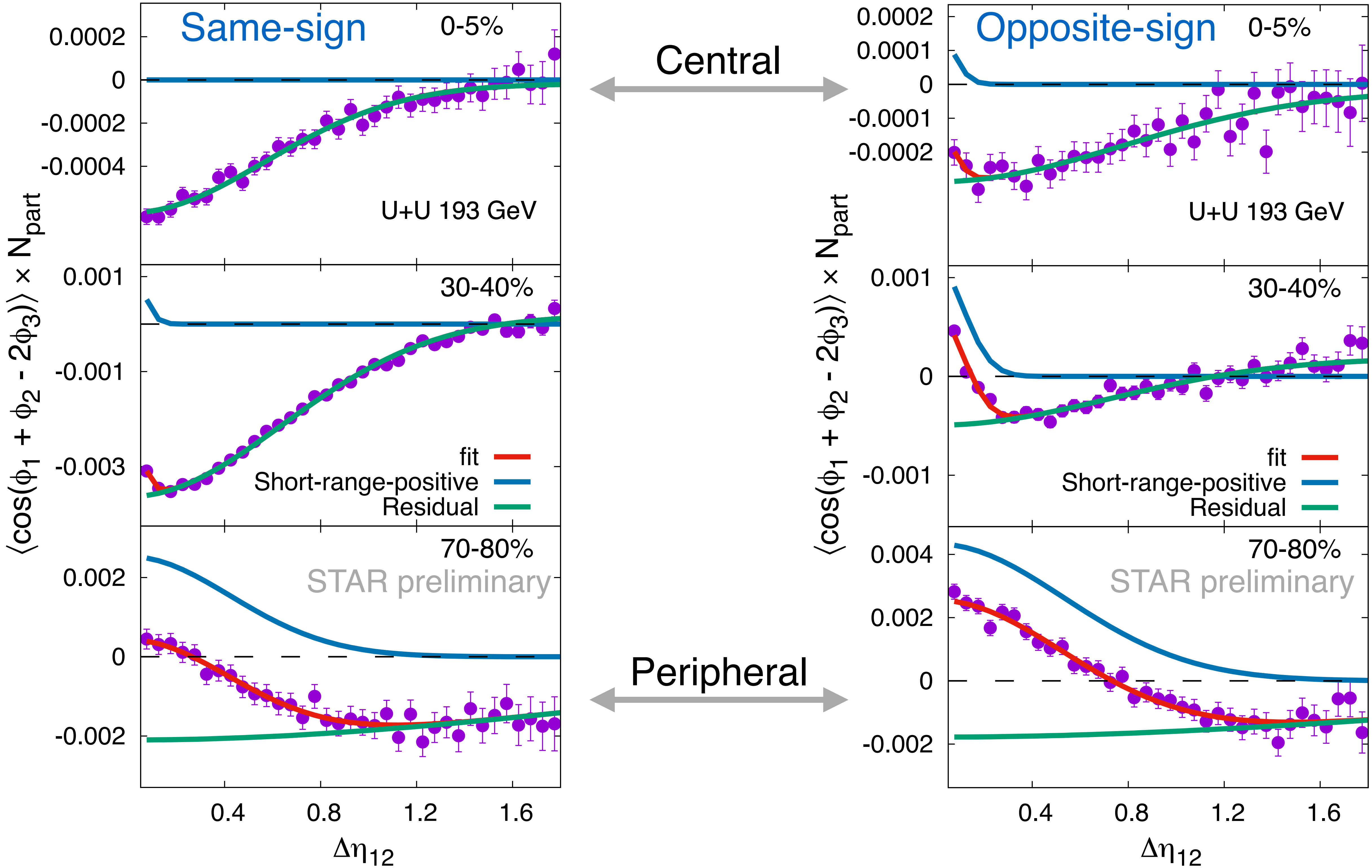
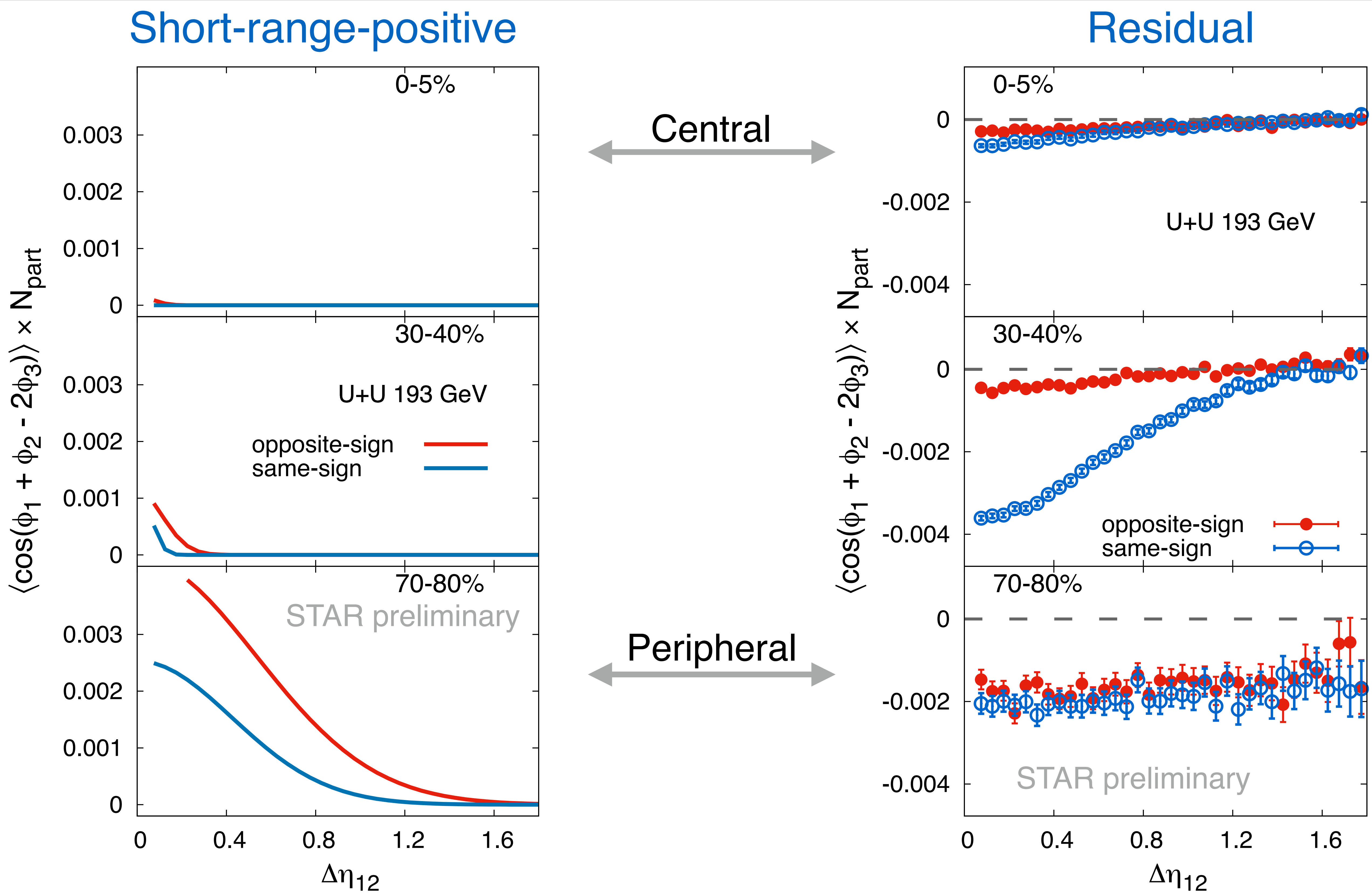
Short-range-positive Residual

Comparison between U+U centralities



Very different trend between central and peripheral events

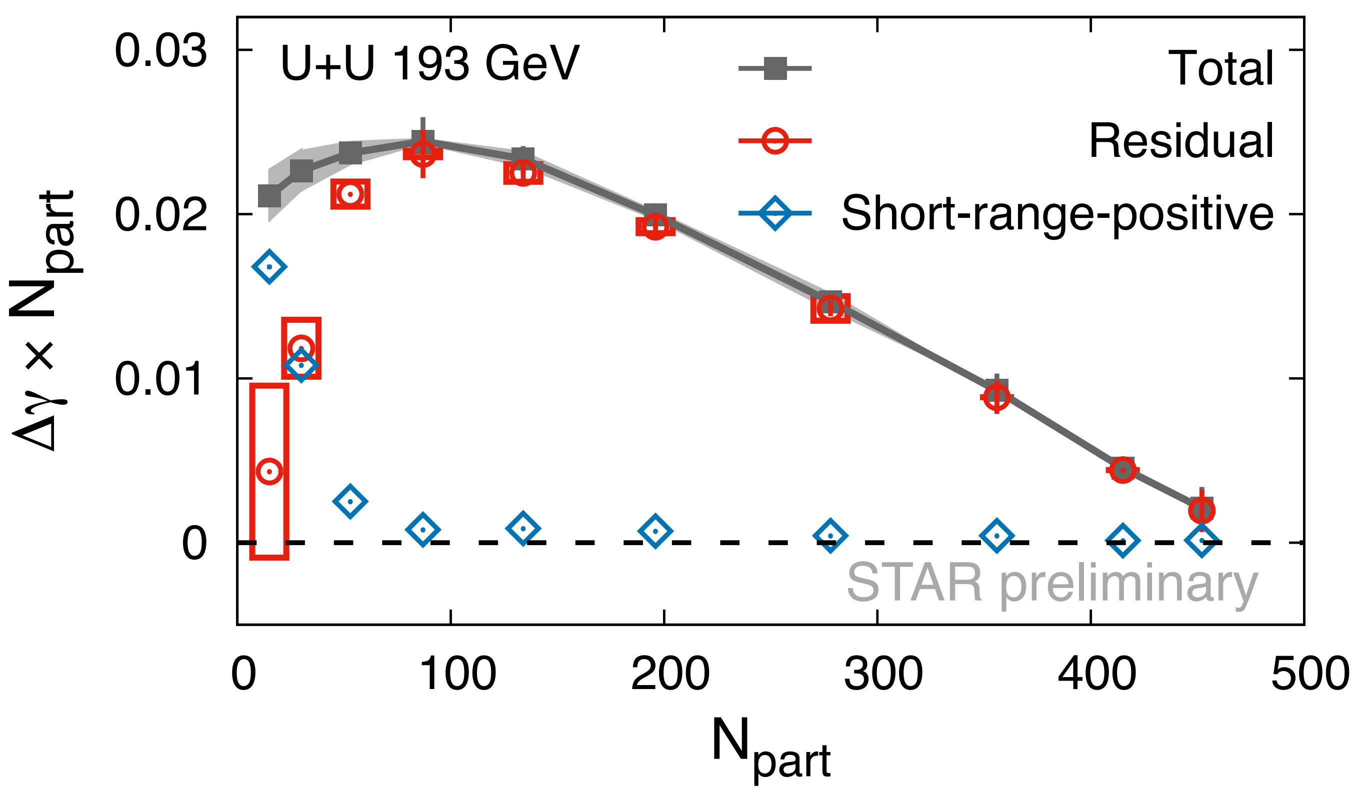
Comparison between U+U centralities



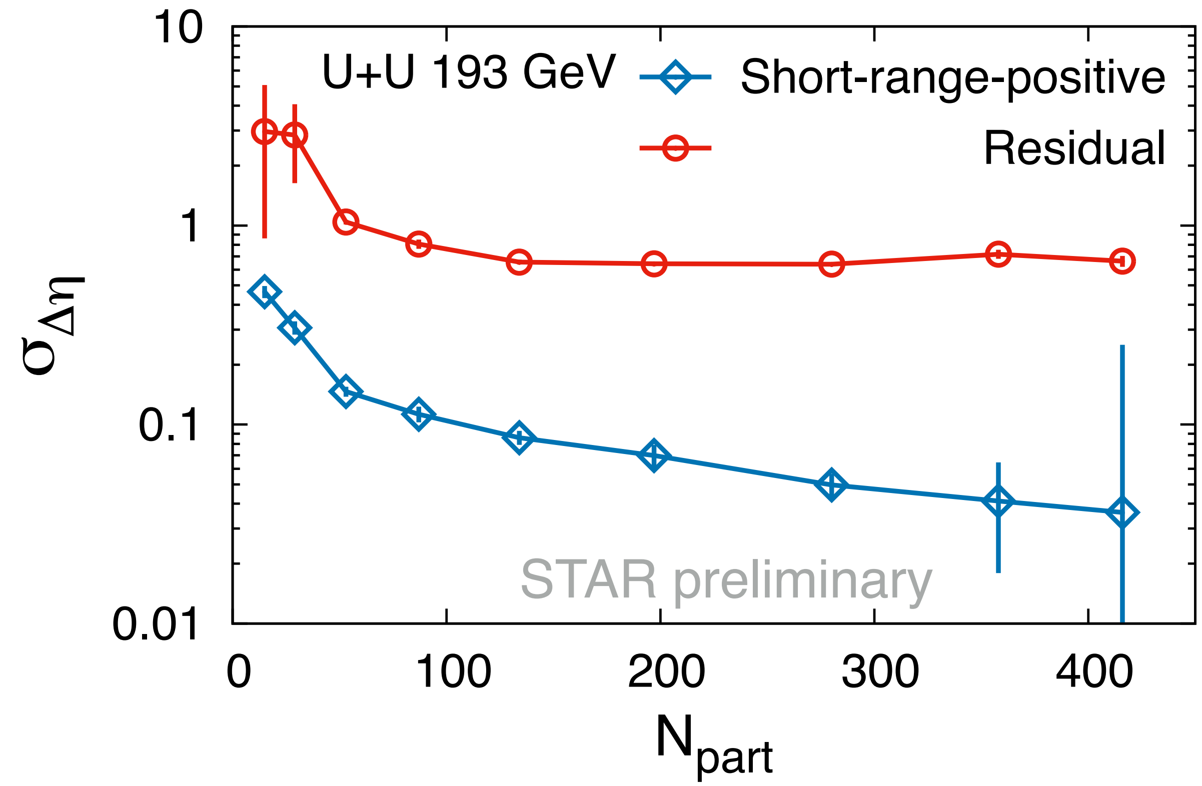
Centrality dependence of charge separation

Charge separation : $\gamma^{a,b} \sim \frac{\langle \cos((\phi_1^a + \phi_2^b - 2\phi_3)) \rangle}{v_2\{2\}} \rightarrow \Delta\gamma = \gamma^{OS} - \gamma^{SS}$

Magnitudes of different components



Widths of different components



After short-range-positive subtraction, $\Delta\gamma \rightarrow 0$ for small & large N_{part}

Short-range positive component:

Likely HBT, Coulomb & jet-fragmentation in peripheral events

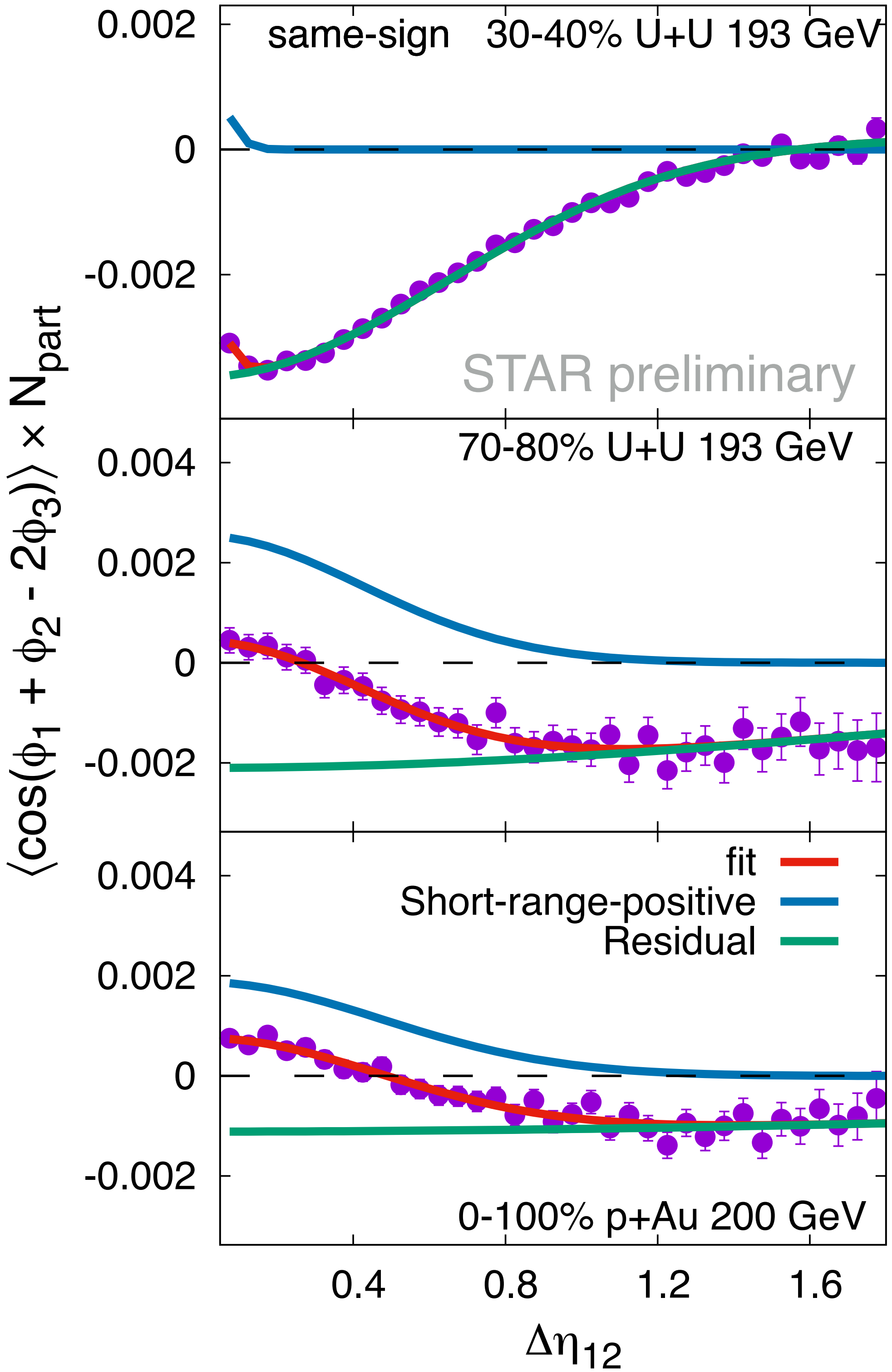
Only HBT, Coulomb in central events.

Residual component:

May still have short-range backgrounds in mid-central events

Comparison between U+U and p+Au

Same-sign



Central

A+A

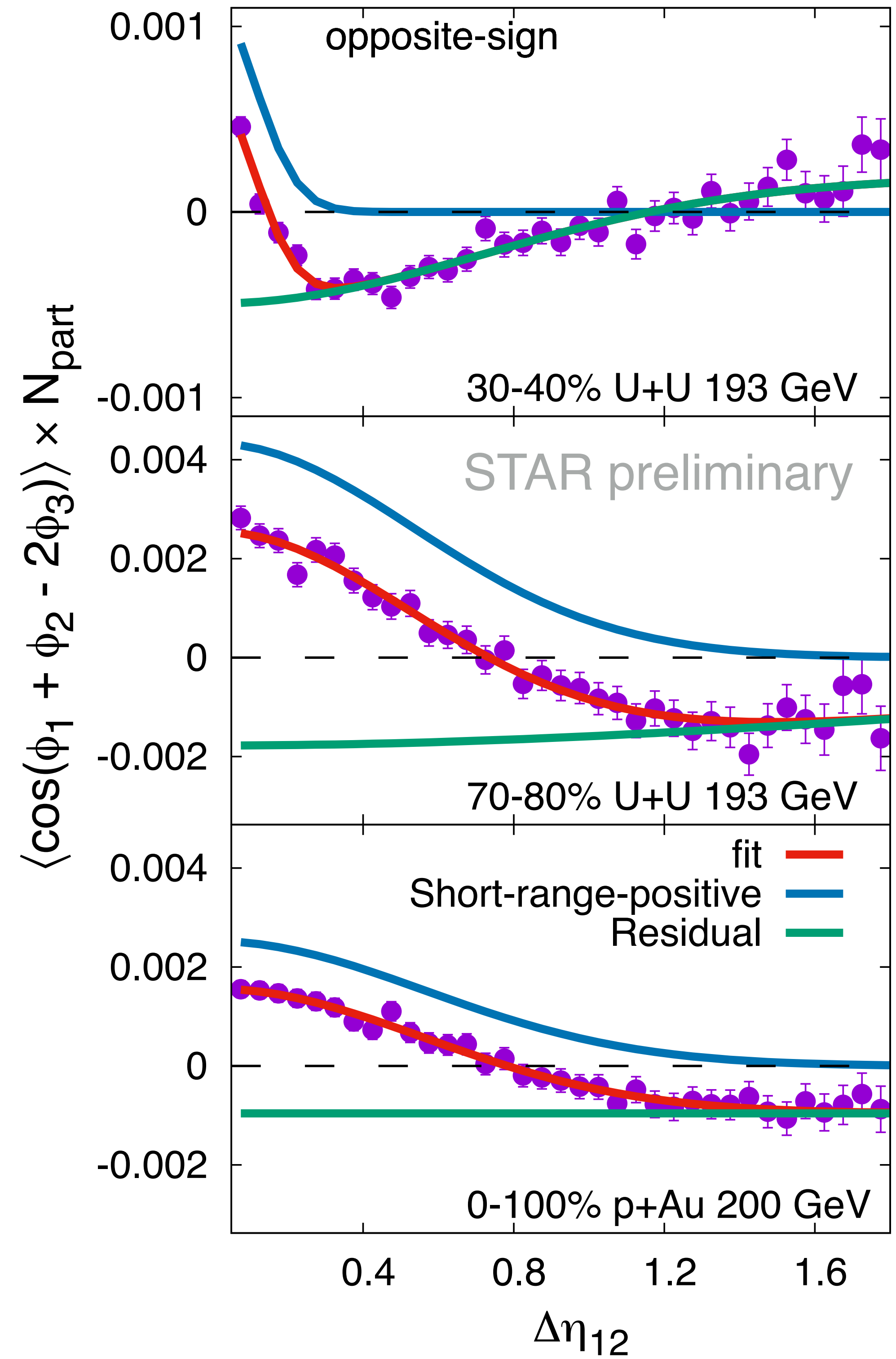
Peripheral

A+A

Min-bias

p+A

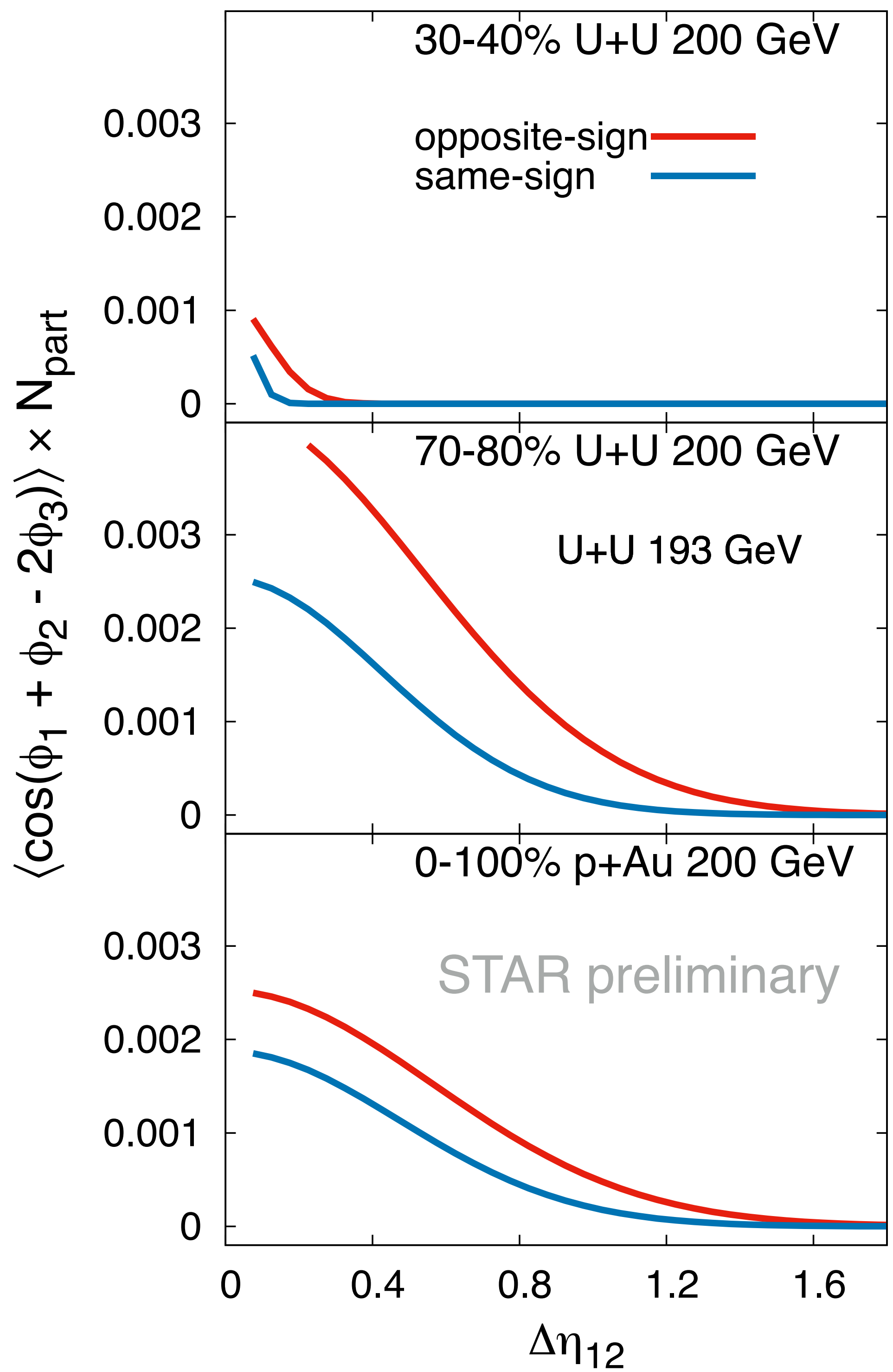
Opposite-sign



p+Au data are consistent with peripheral U+U

Comparison between U+U and p+Au

Short-range-positive



Central

A+A

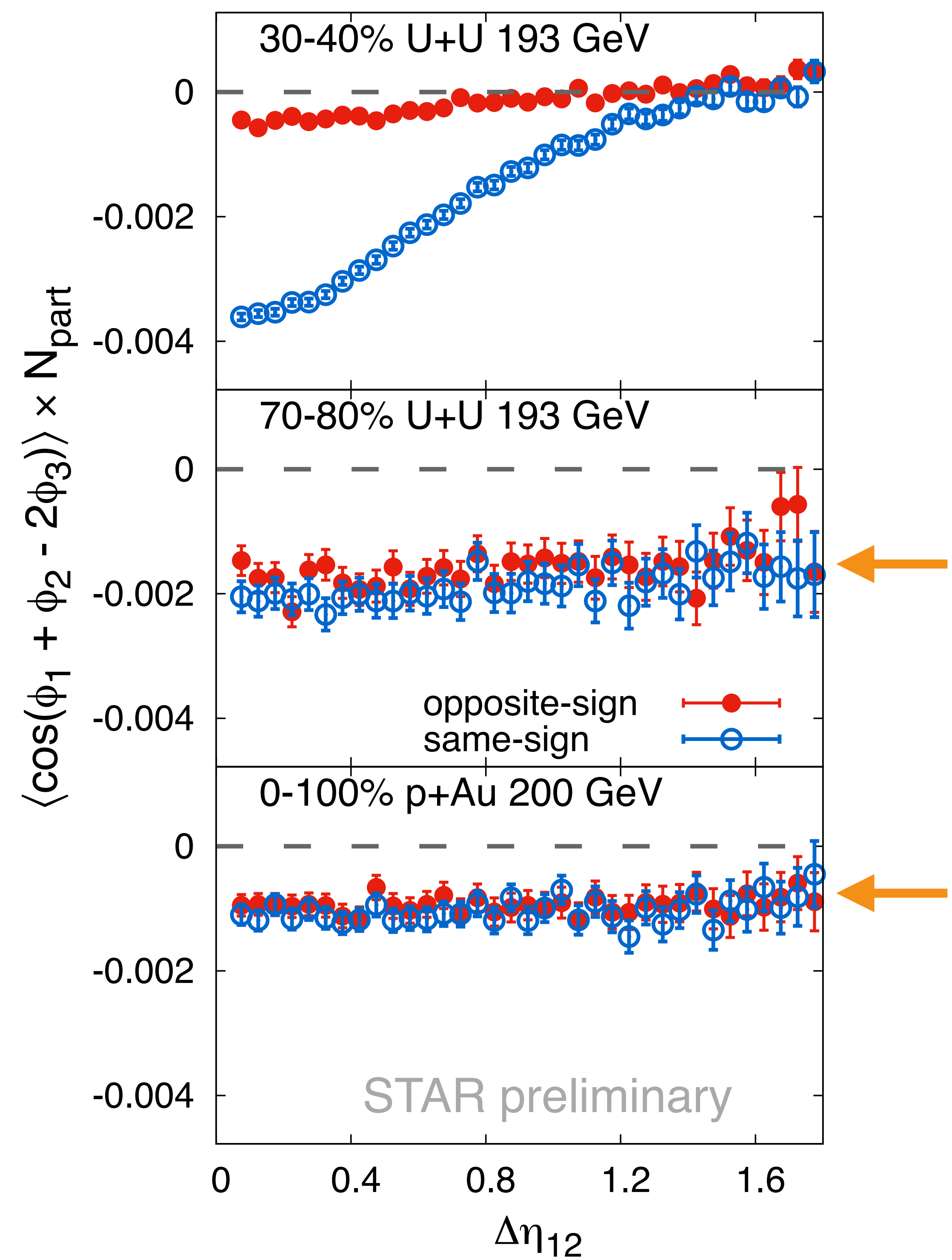
Peripheral

A+A

Min-bias

p+A

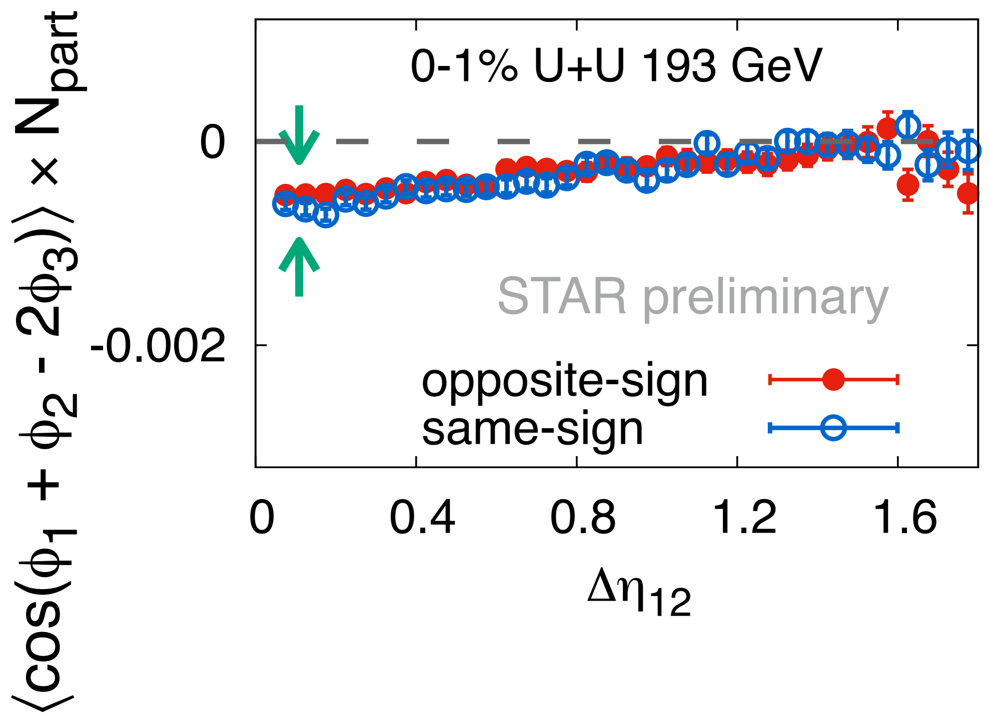
Residual



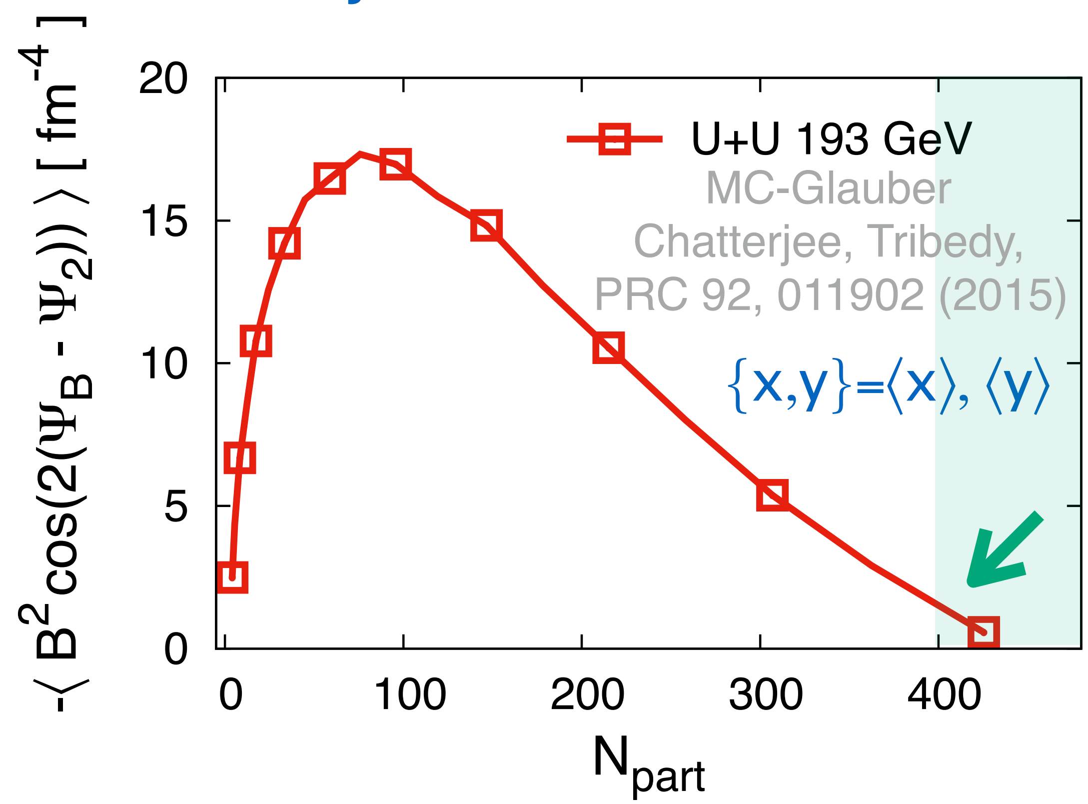
Short-range subtracted component vanishes in p+Au

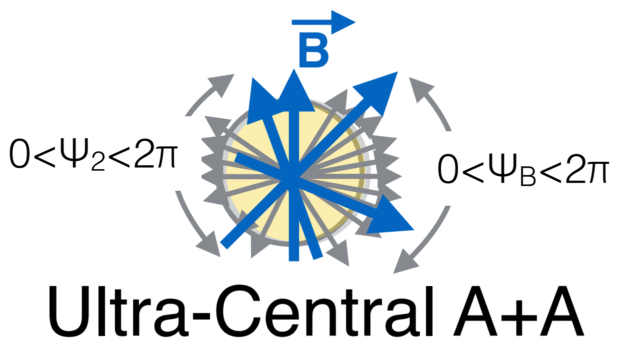
Comparison between U+U and p+Au

Data (short-range-positive subtracted)



Projected B-field in A+A





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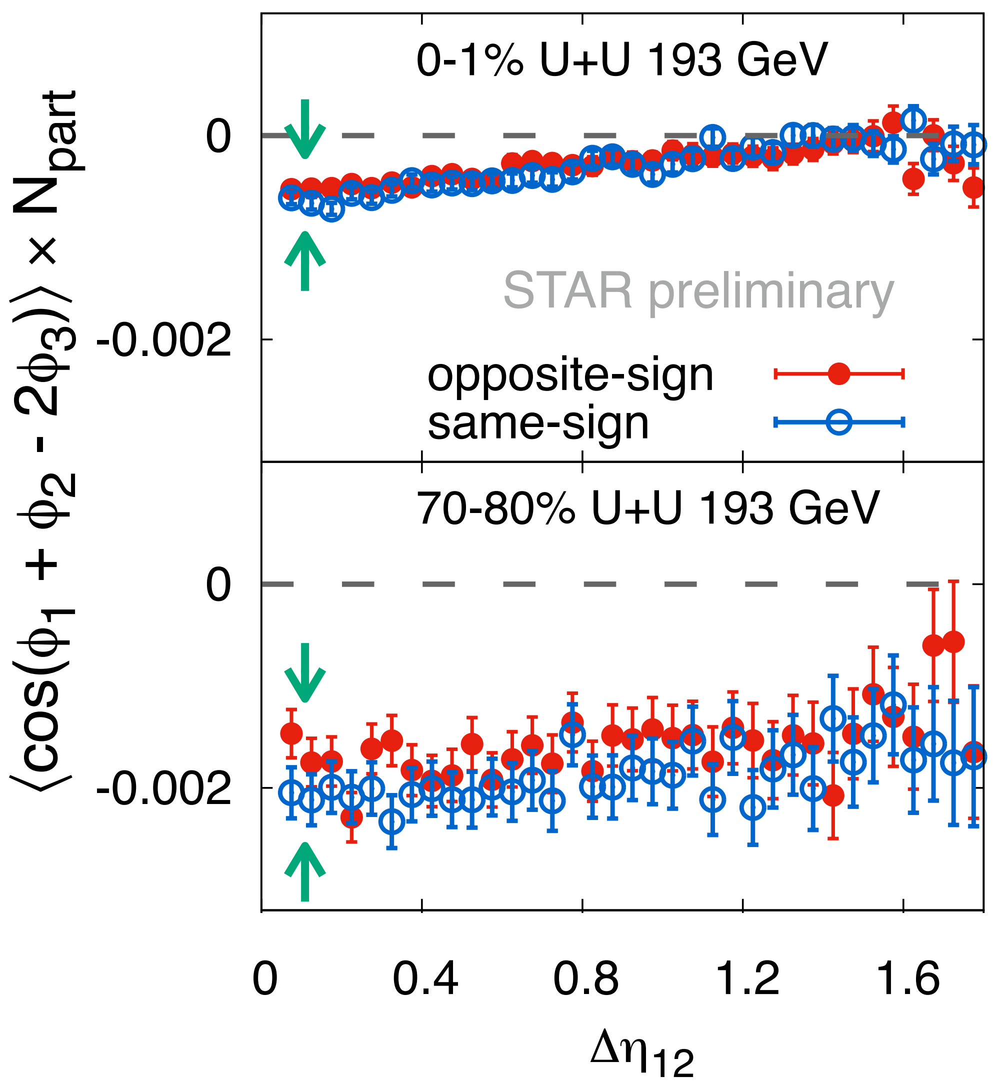

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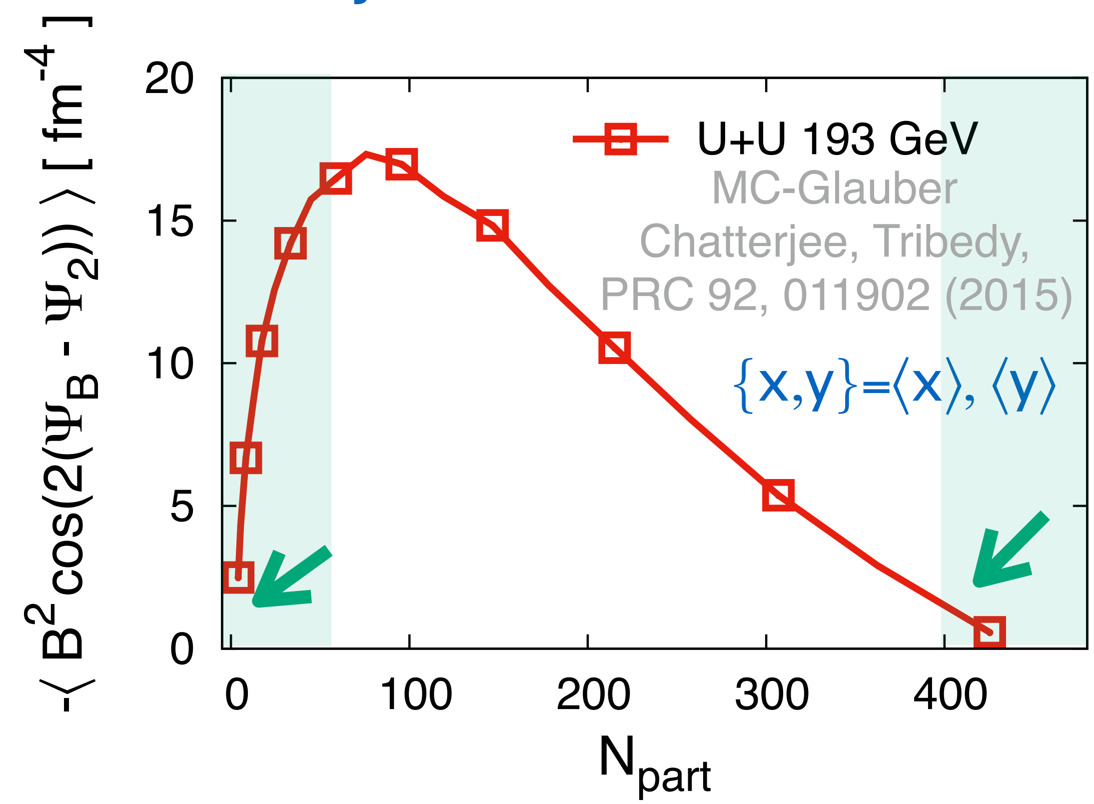

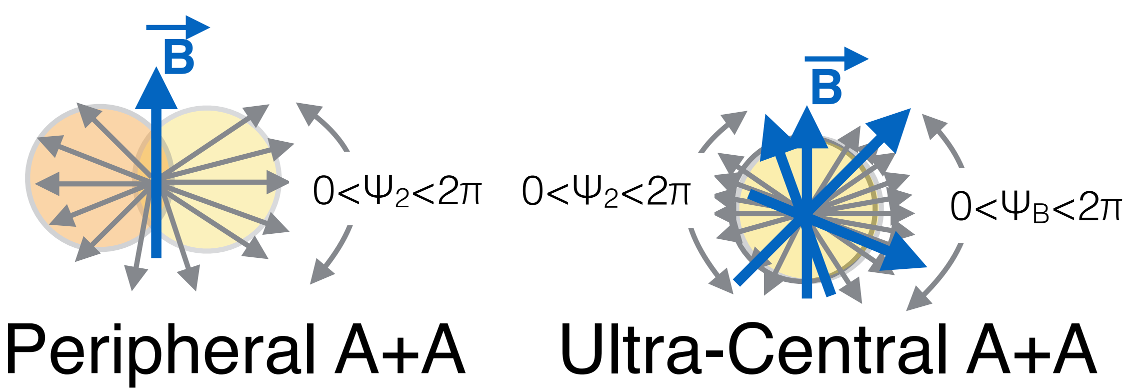

Comparison between U+U and p+Au

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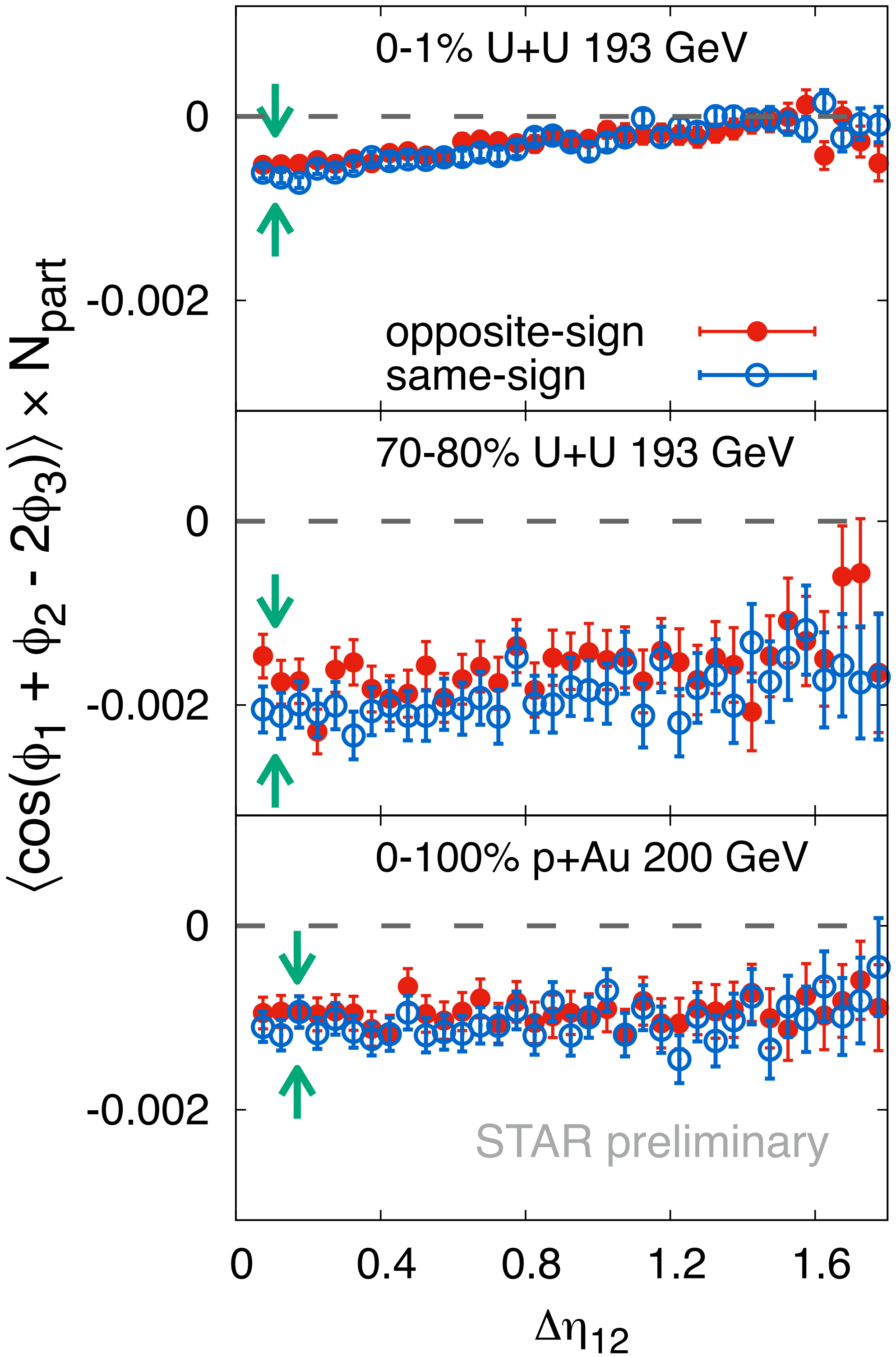
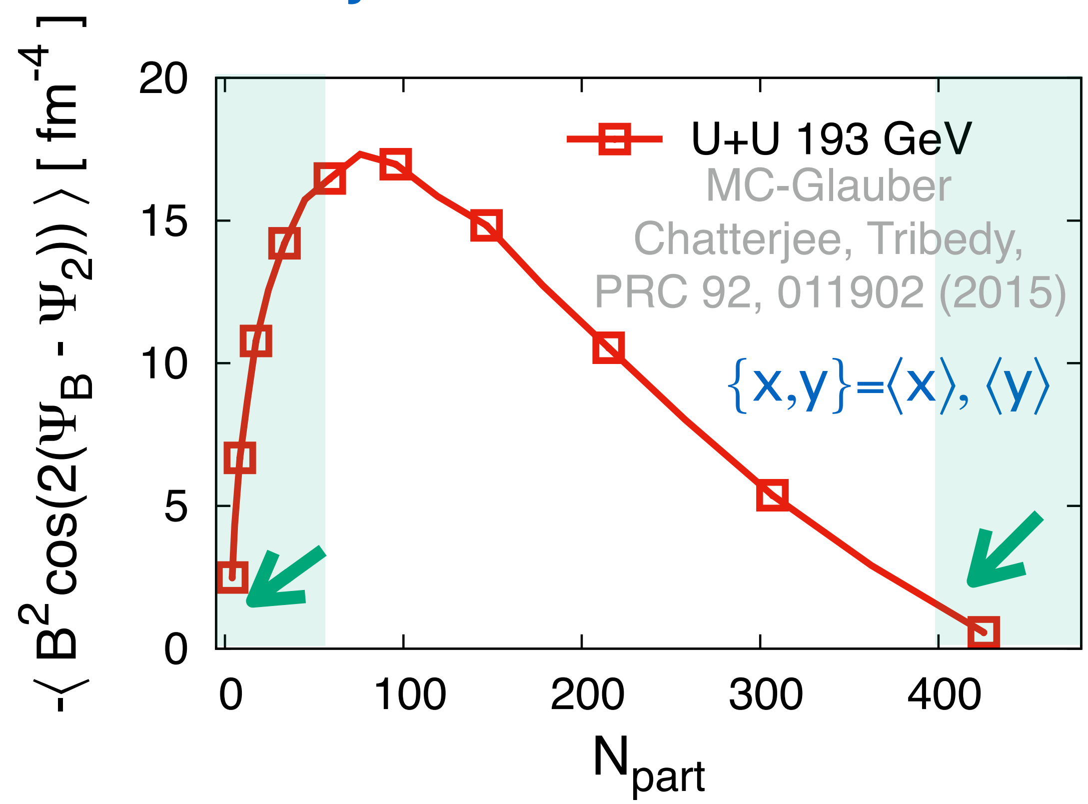
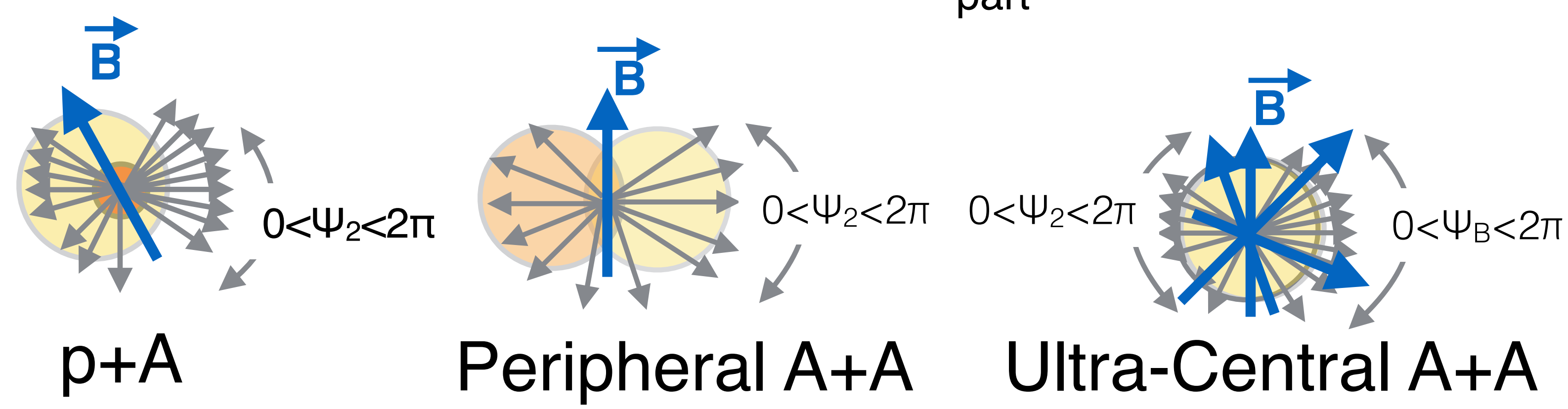


Projected B-field in A+A

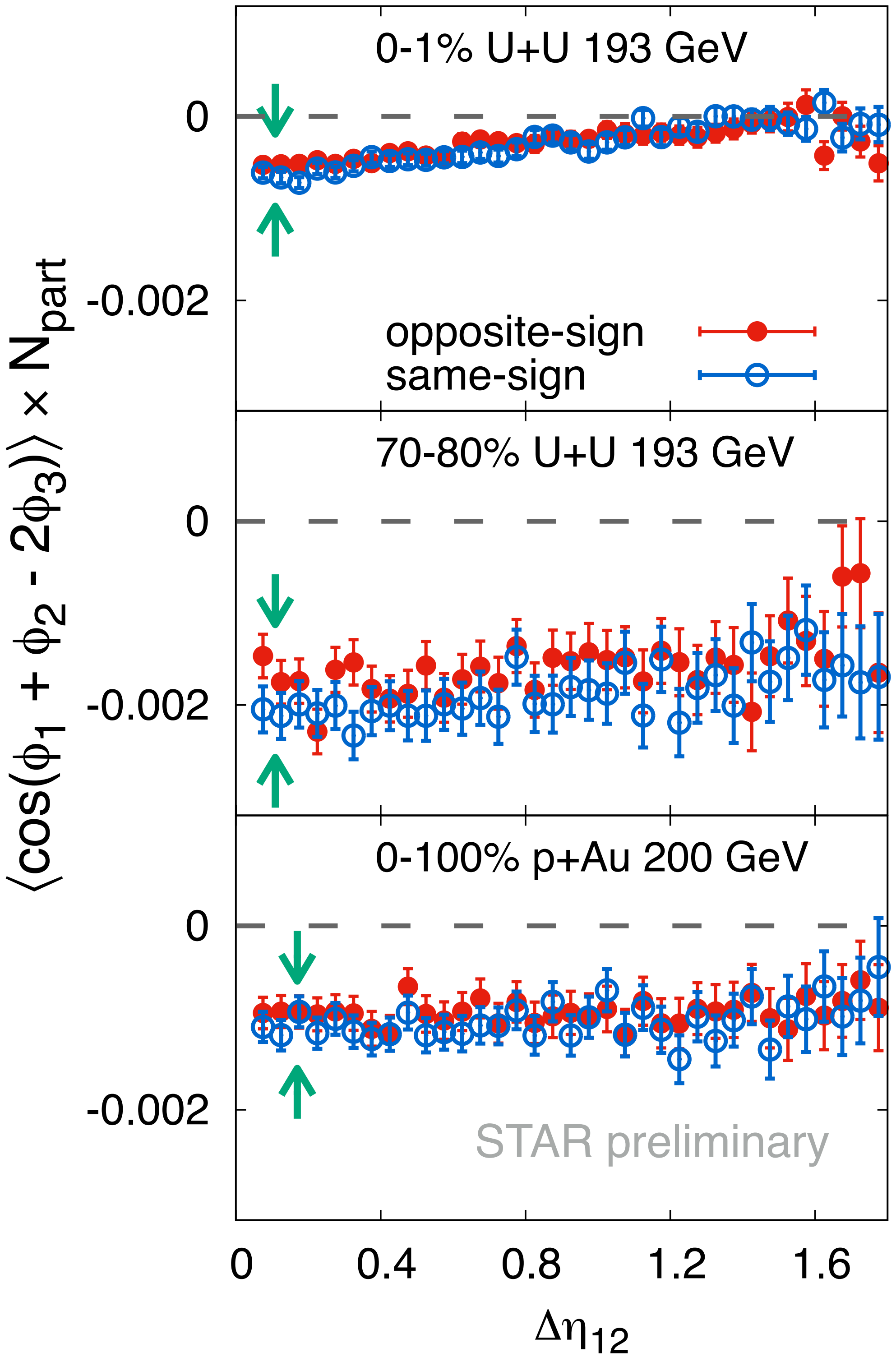




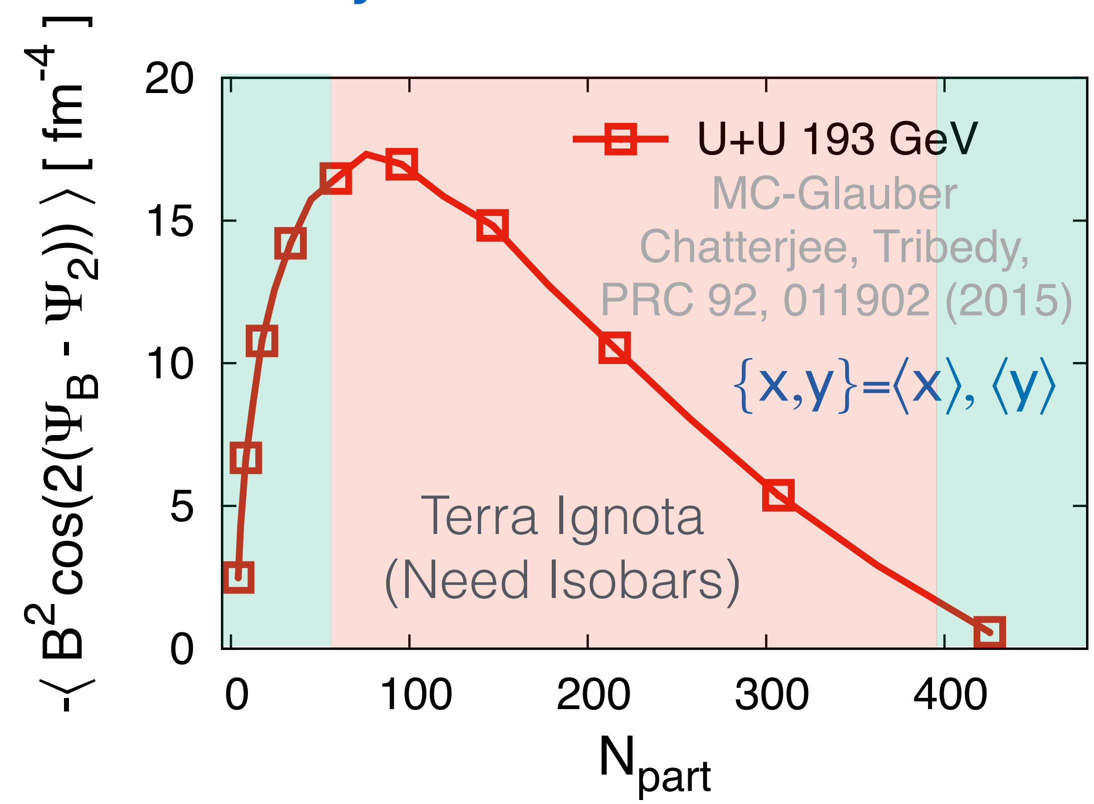
Belmont, J.L. Nagle 1610.07964

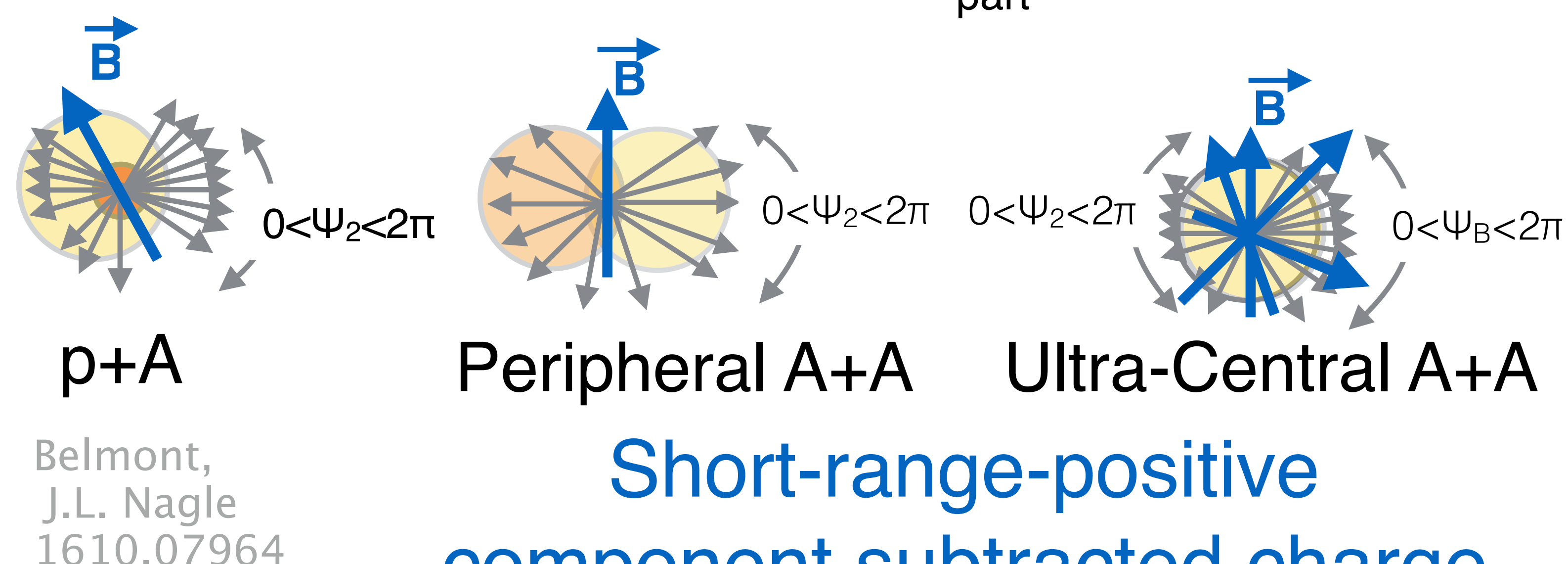
Comparison between U+U and p+Au

Data (short-range-positive subtracted)



Projected B-field in A+A





Short-range-positive component subtracted charge separation vanishes the same way as projected B-field

Summary

– Ultra-central U+U and Au+Au show $\Delta\gamma \sim 0$, $v_2 \neq 0$

- $\Delta\gamma$ vs v_2 consistent with B-field vs ε_2, constrain for background models of charge separation

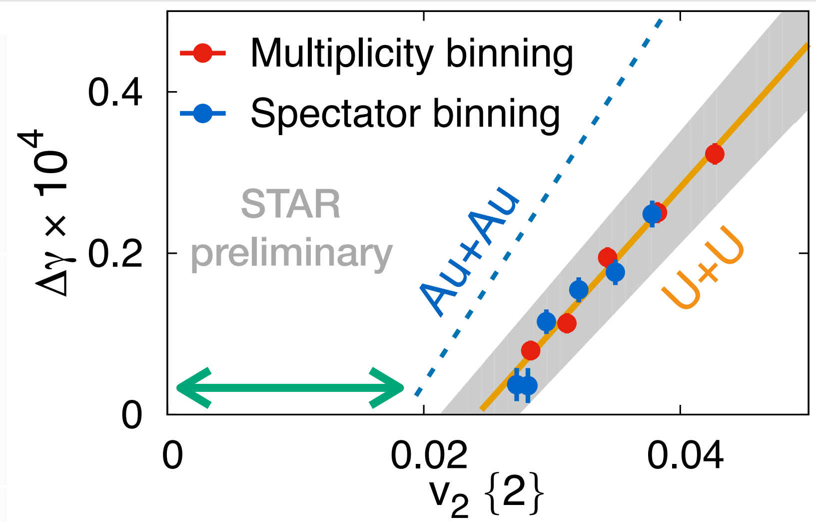
– Short-range-positive component (A^{+}_{SR}) subtracted charge separation vanishes in central & peripheral events

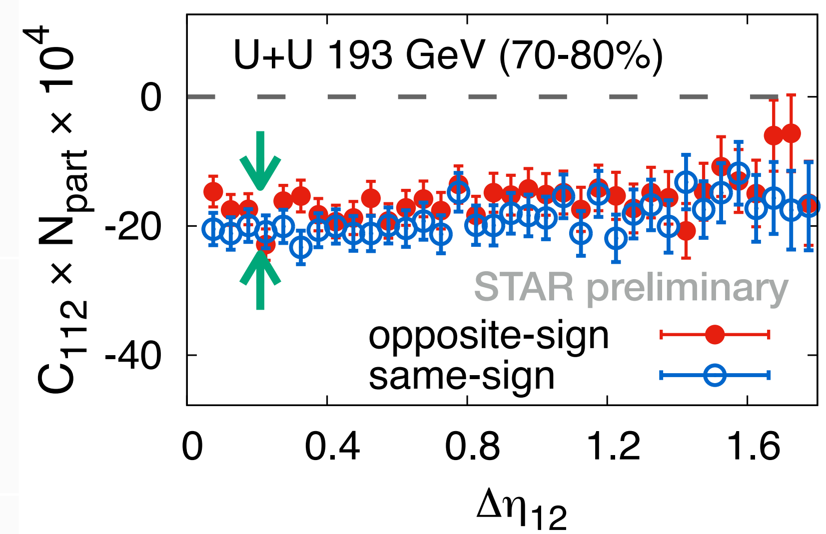
– p+Au data show no A^{+}_{SR} subtracted charge separation, consistent to peripheral A+A

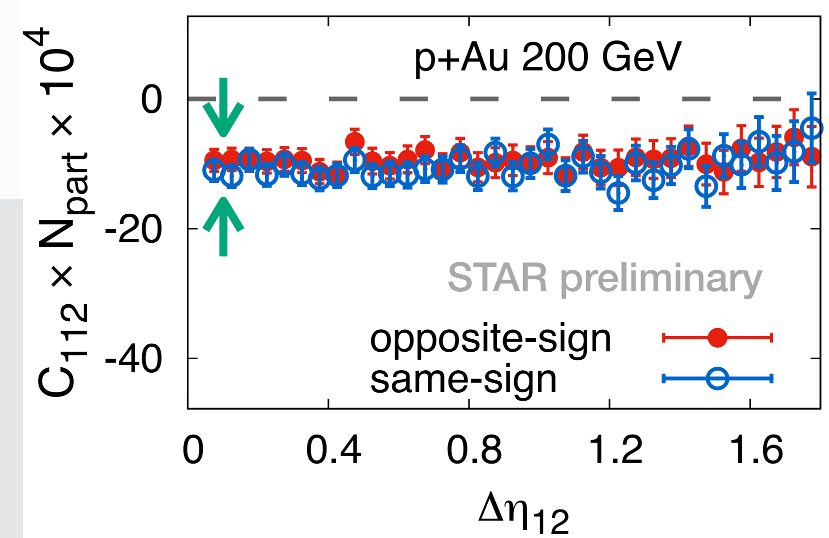
- A^{+}_{SR} subtracted signal follow projected B-field in central, peripheral A+A & in p+Au

Current data helped to disentangle signal/background in the limits of vanishing projected B-field.

Isobar collisions at RHIC will help clarify the origin of charge separation in the regime of finite B-field.



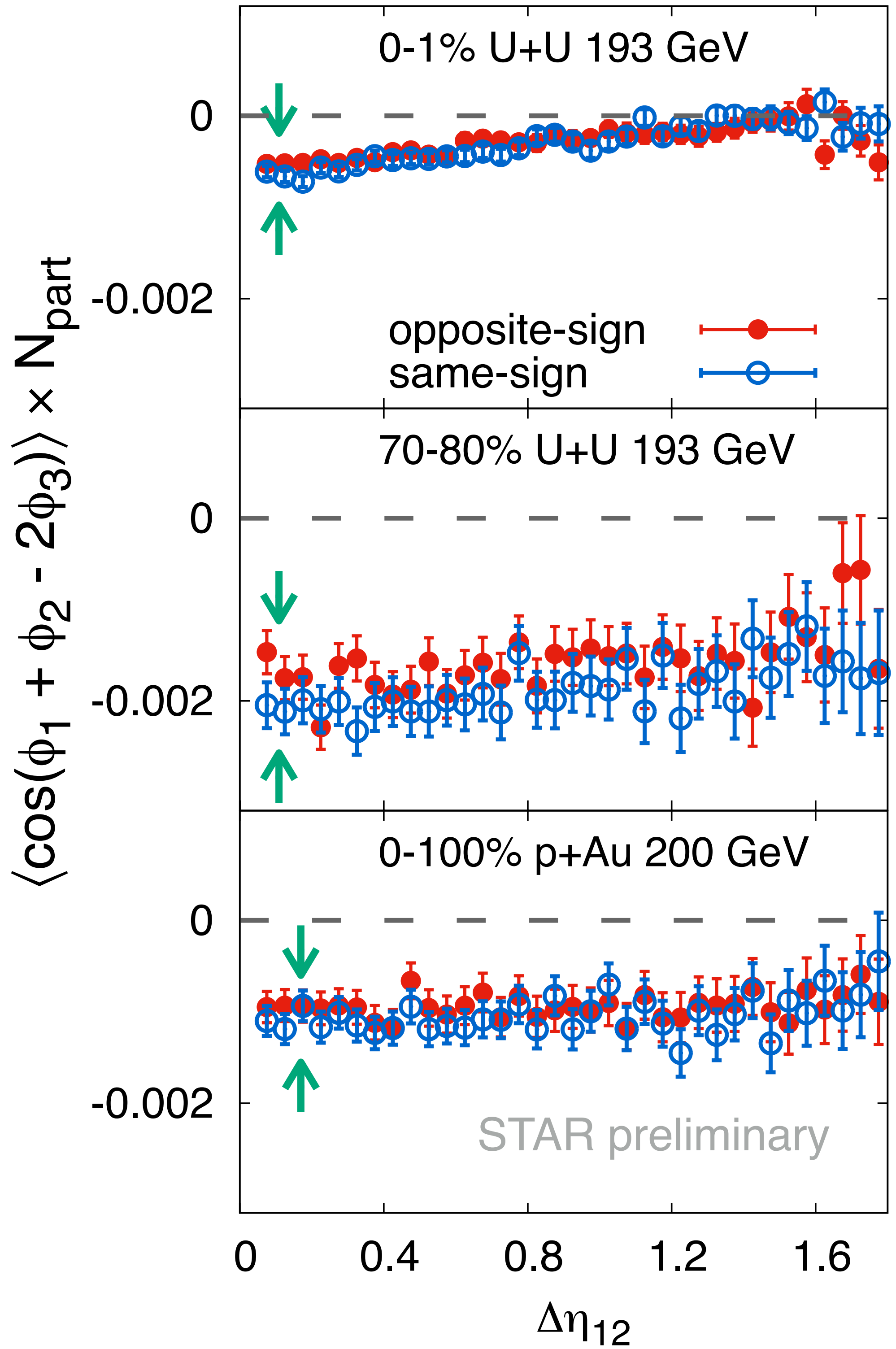




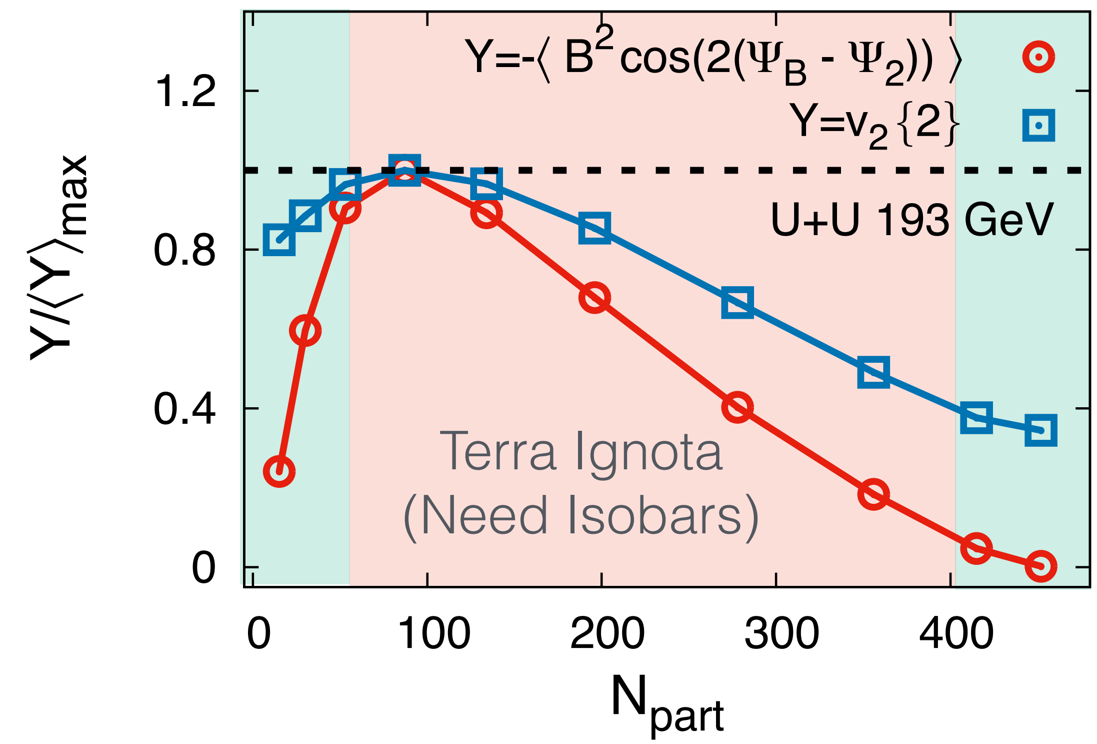
backup slides

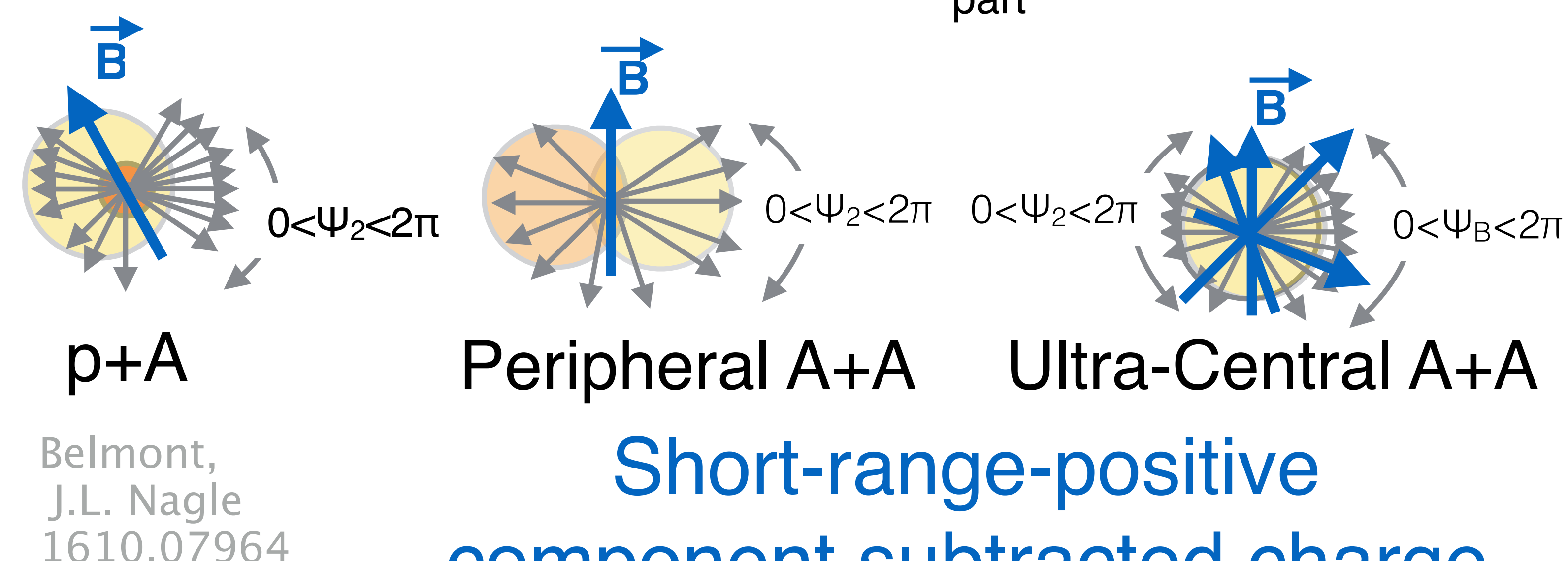
Comparison between U+U and p+Au

Data (short-range-positive subtracted)



Projected B-field in A+A





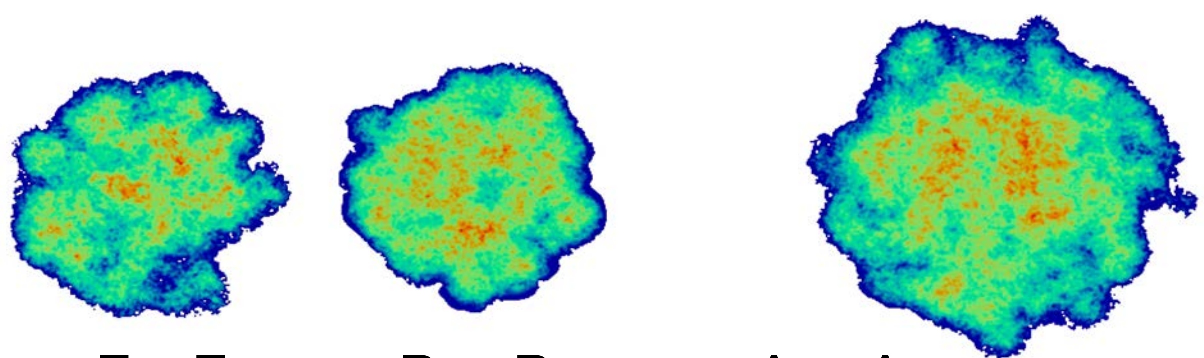
Short-range-positive component subtracted charge separation vanishes the same way as projected B-field

Outlook for Isobar collisions at RHIC

Idea is to change B-field without changing background

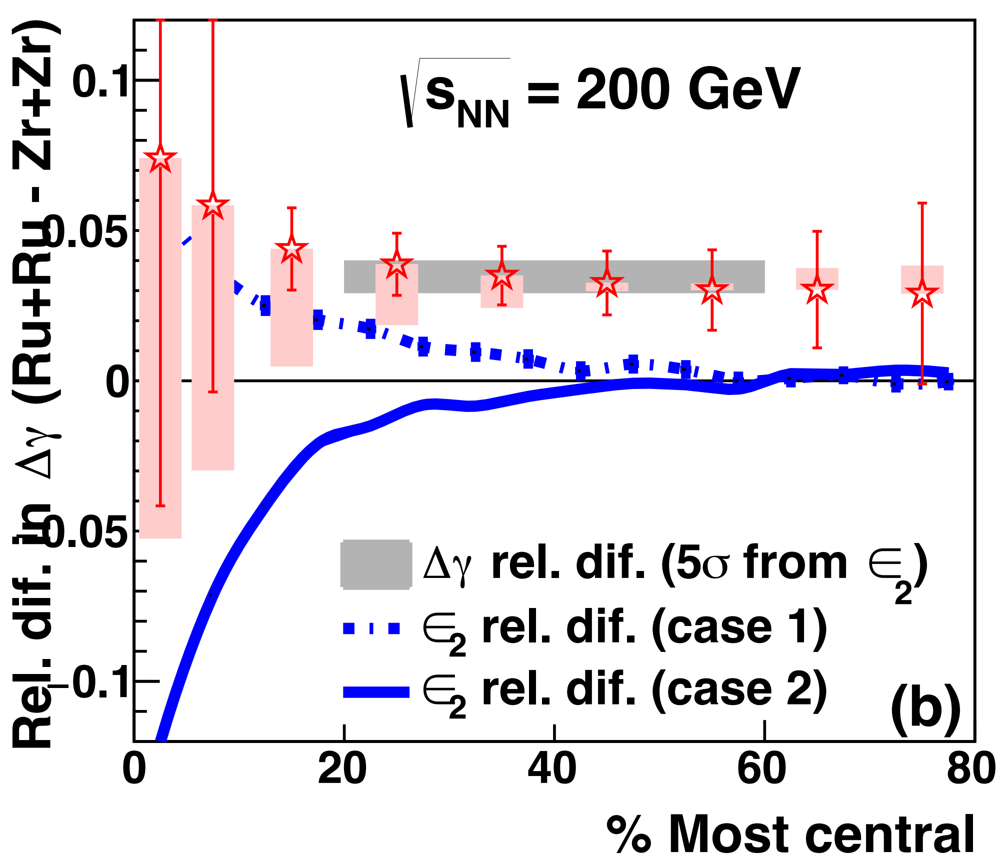
$^{96}_{44}Ru + ^{96}_{44}Ru \longleftrightarrow ^{96}_{40}Zr + ^{96}_{40}Zr$ ($\sqrt{s}$ =200 GeV)

Different B-field with same flow background is expected



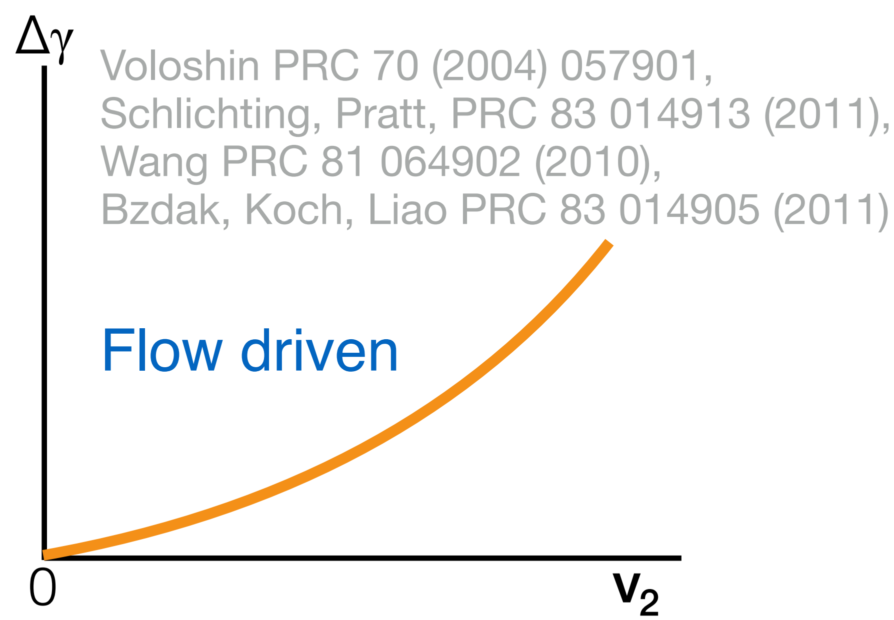
Single collision in IP-Glasma model (b=0)

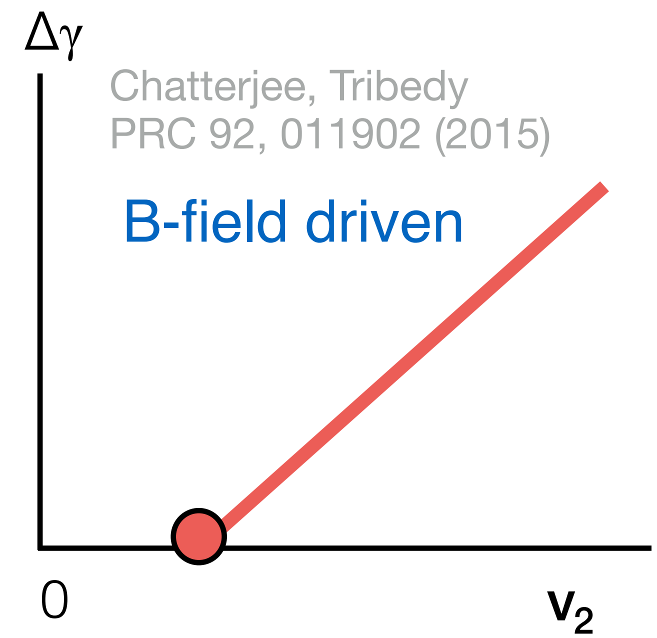
Gang Wang, QCD Chirality workshop '2016, Deng et al PRC 94, 041901 (2016), Skokov et al, 1608.00982



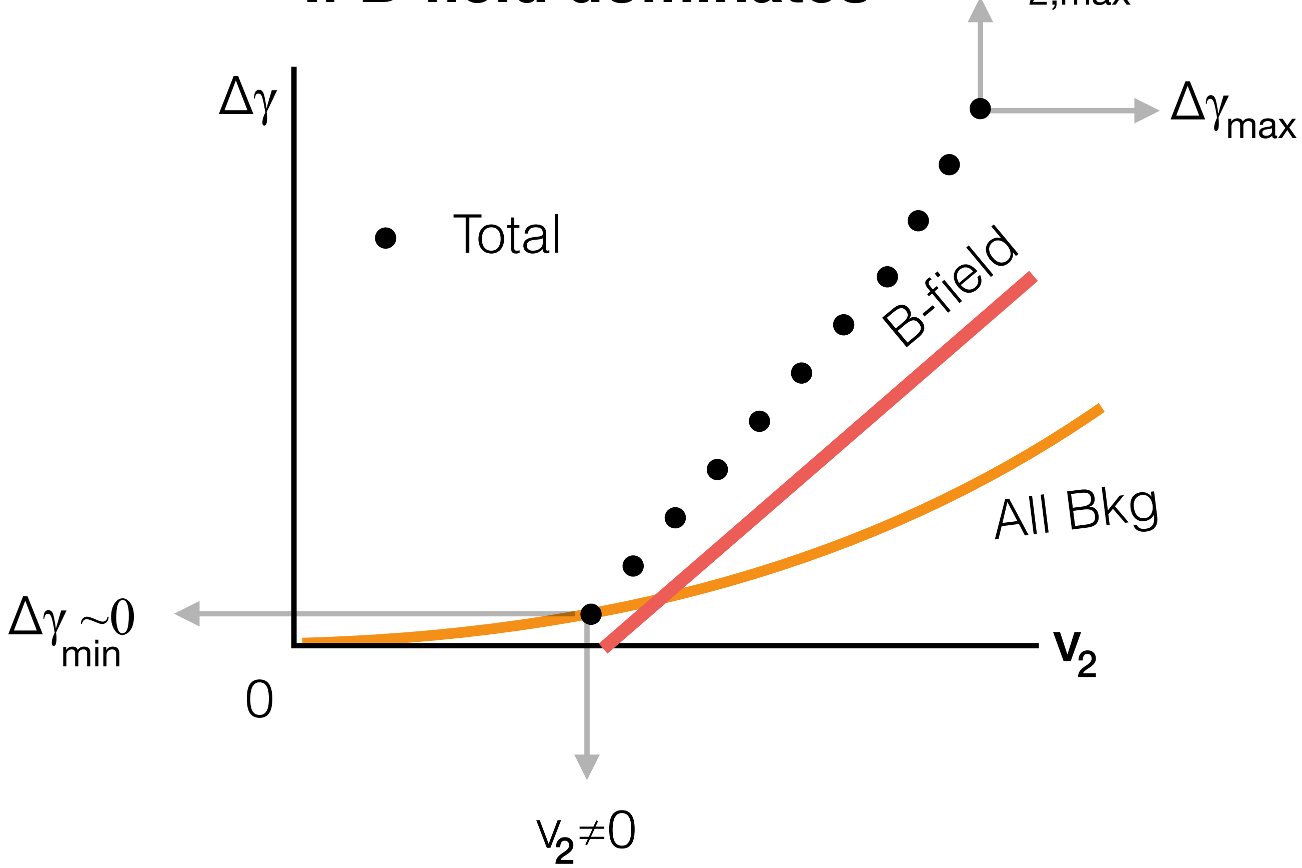
3.5 weeks of running with about 1.2 B events can provide about 5σ confidence of signal/bkg.

Signal and background of CME





If B-field dominates



If Background dominates