New developments in CME search at low collision energies with the STAR detector

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for the STAR collaboration

BROOKHAVEN
NATIONAL LABORATORY

Workshop on the QCD Phase Structure at High Baryon Density Region

12-14 Nov 2019, CCNU, Wuhan, China

STAR

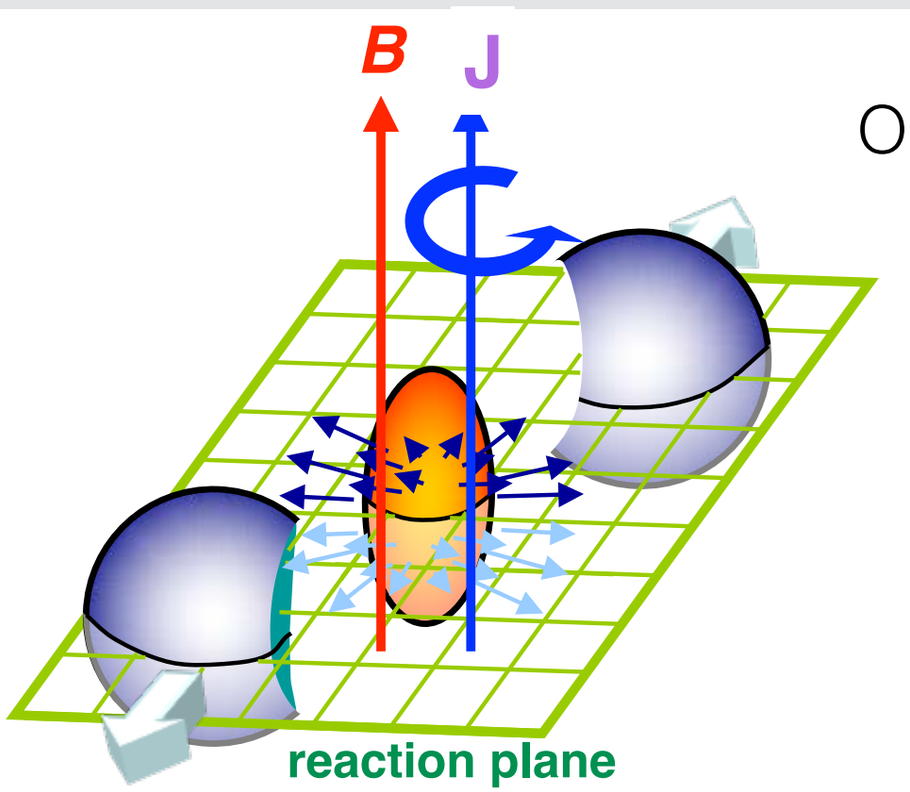
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

Strong magnetic field

$B \sim 10^{18}$ Gauss

D. Kharzeev, L. McLerran, and H. Warringa, Nucl.Phys.A803, 227 (2008)
McLerran and Skokov, Nucl. Phys. A929, 184 (2014)



Orbital angular momentum

$L \sim 10^{3} \hbar$

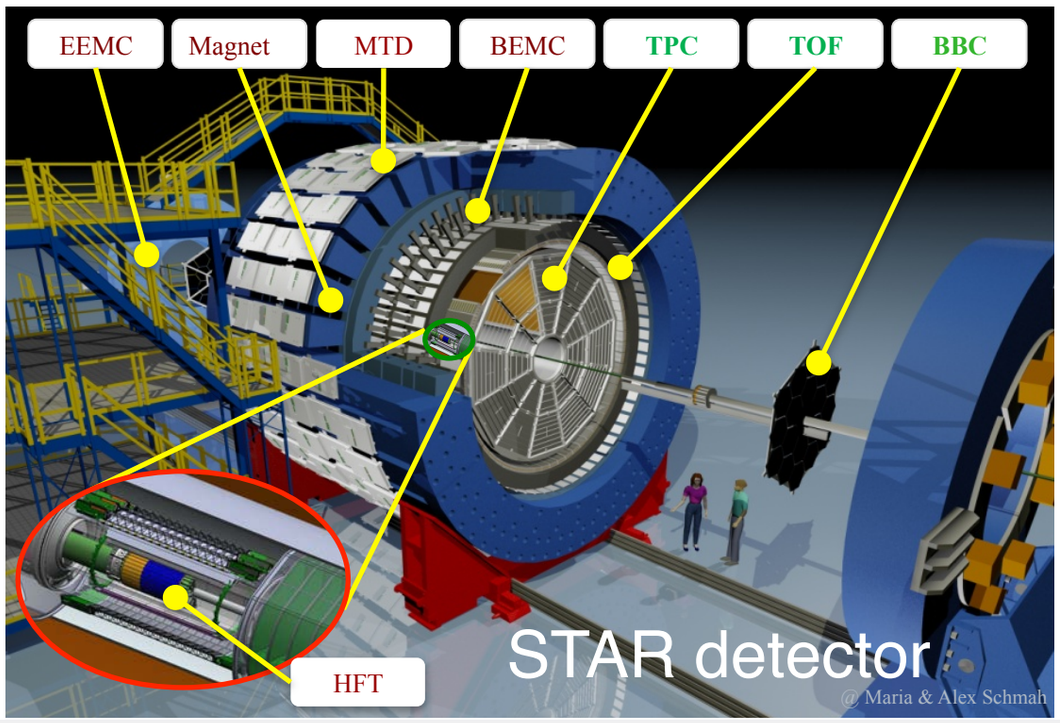
Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

Year 2018 Run of RHIC : dedicated to search for chiral & vortical effects:

Isobar Ru+Ru/Zr+Zr@200 GeV

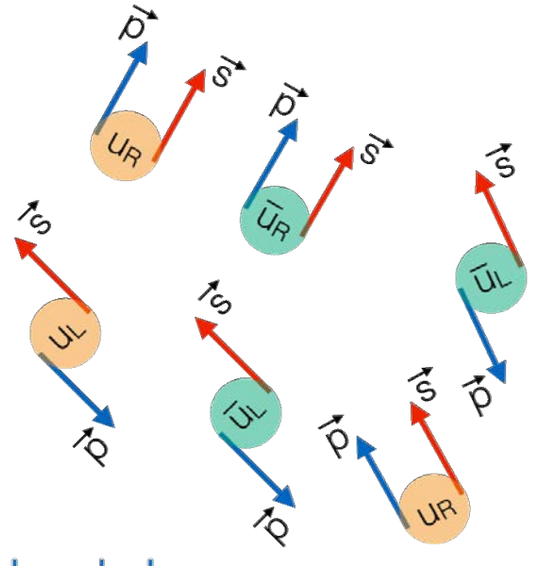
Au+Au @ 27 GeV

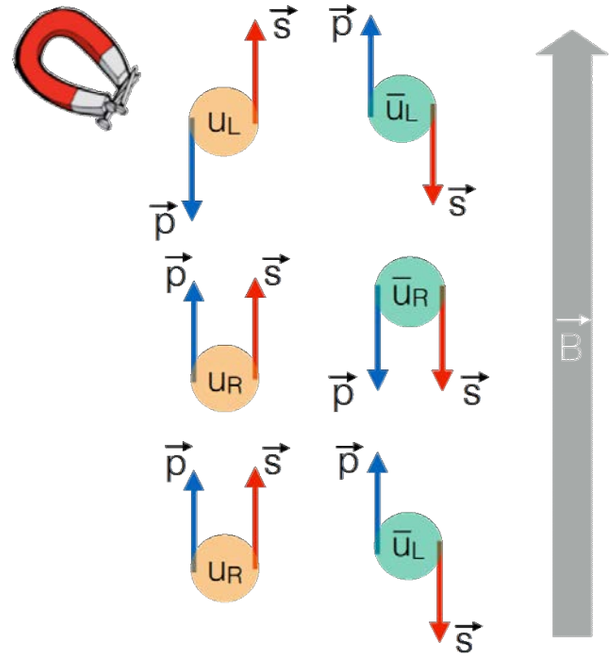
This talk: High statistics 27 GeV data with Event Plane Detector provides new capabilities for CME search at lower energy in STAR



The Chiral Magnetic Effect (CME)

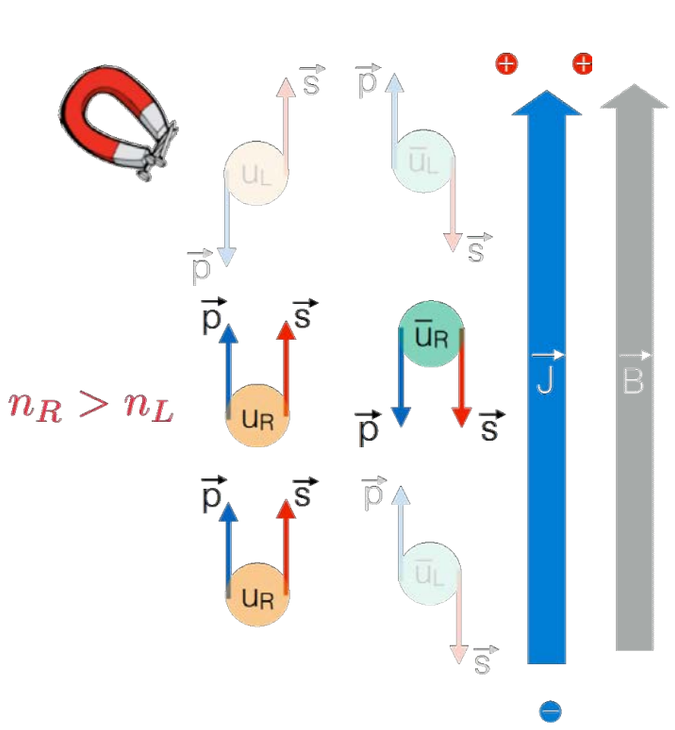
Quarks randomly oriented

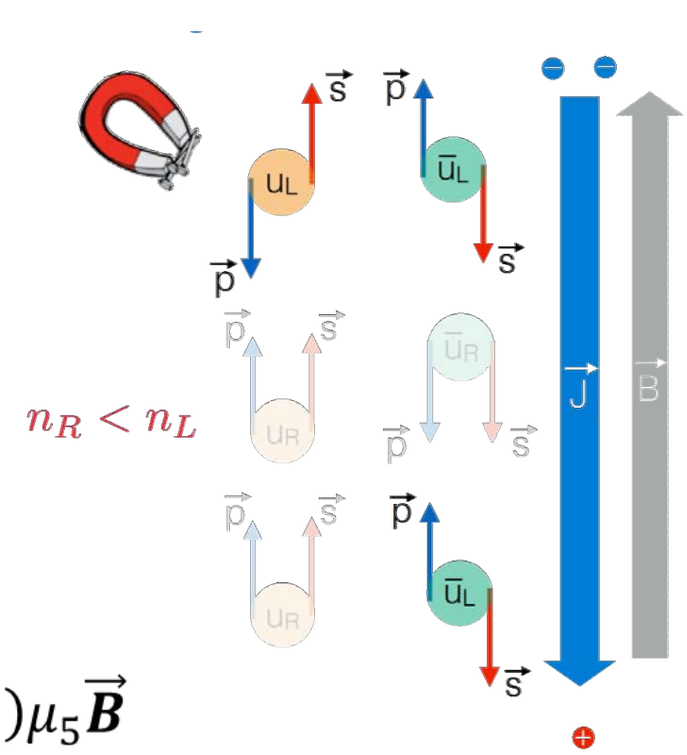




Quarks aligned along B

More right handed quarks J || B





More left handed quarks J || -B

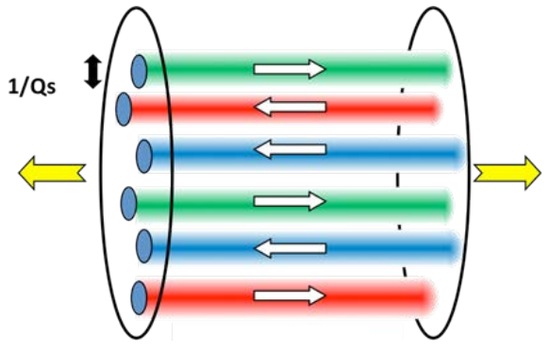
$$\vec{J} \propto \langle \vec{p} \rangle \propto (Qe)\mu_5 \vec{B}$$

Imbalance of Left handed & Right handed Quarks + B-field = Electric Current

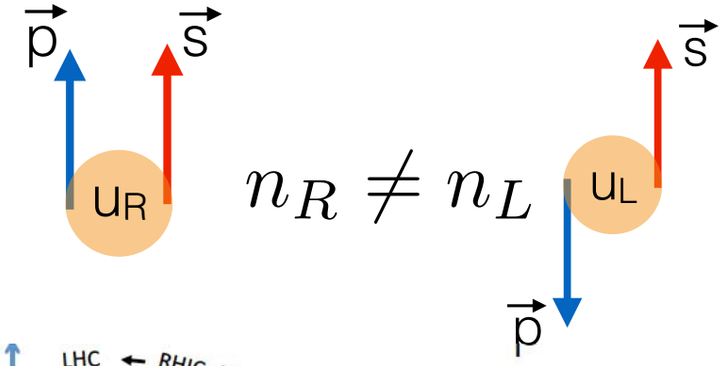
Observability of CME in heavy-ion collisions

#1: Non-conservation of chirality: Collisions generate fluctuating parallel chromo E & B fields

Kharzeev et al, hep-ph/0109253, Buividovich 0907.0494

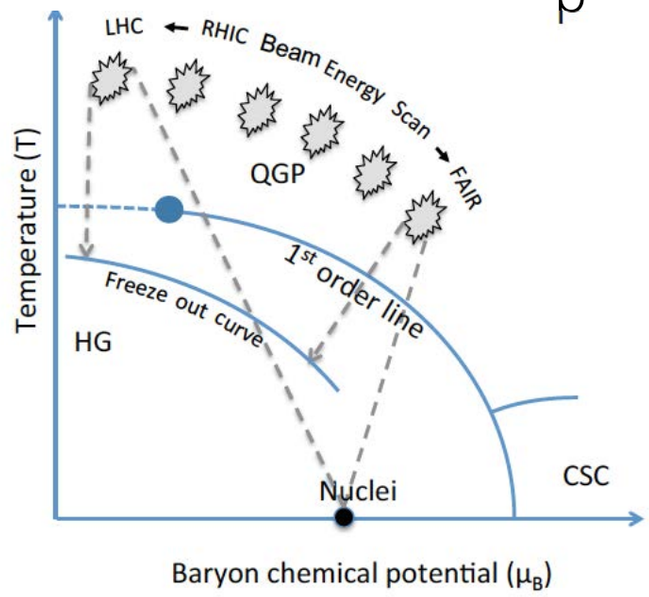


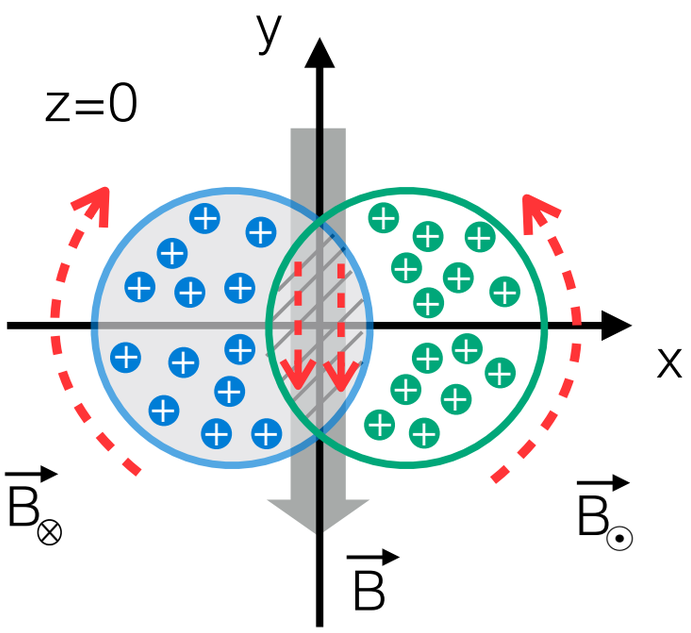
$$E \parallel B \parallel \hat{z} \quad \Rightarrow \quad dQ_5/dt \propto \mathbf{E}\cdot\mathbf{B}$$



#2: A deconfined medium of massless fermions (chiral symmetry restoration)

(Theme of this workshop)



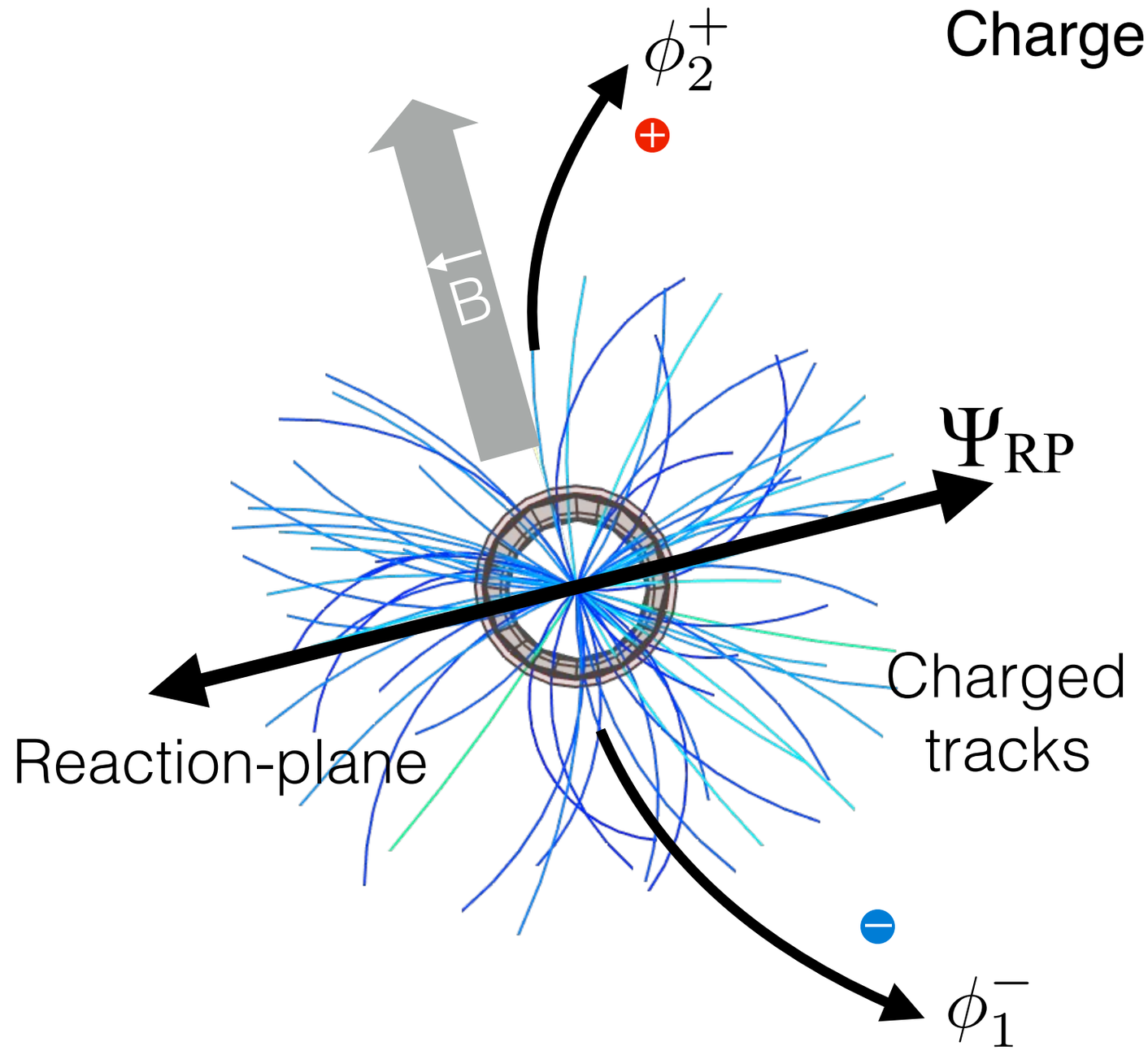


#3: Creation of strong magnetic field ~10^{18} Gauss

Kharzeev, McLerran, and Warringa 0711.0950, Skokov, Illarionov, Toneev 0907.1396, McLerran, Skokov, 1305.0774

All three conditions are strongly √s-dependent

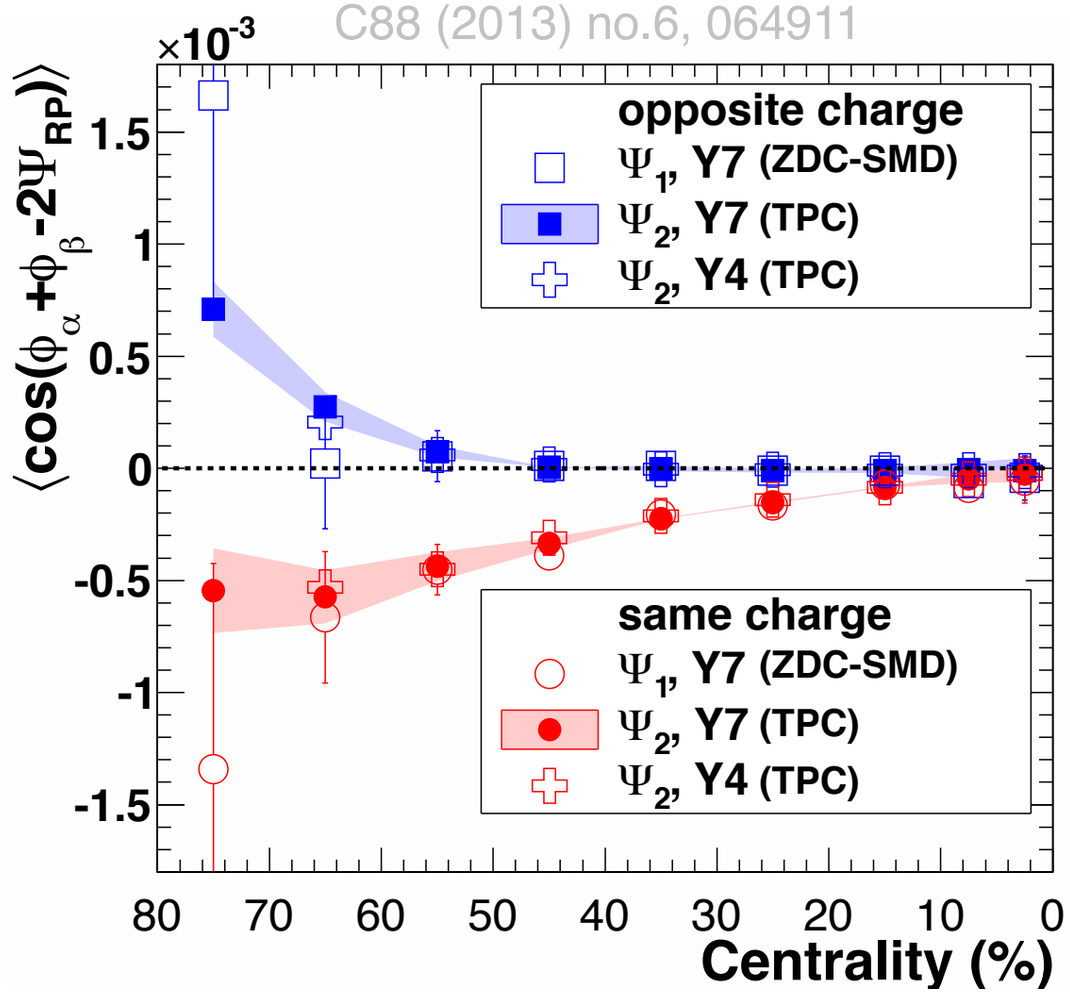
Observables for CME search : γ-correlator



Charge separation across reaction plane

$$\gamma^{\alpha,\beta} \equiv \left\langle \cos\left(\phi_a^\alpha + \phi_b^\beta - 2\psi_{\mathrm{RP}}\right)\right\rangle$$

STAR collaboration,
C88 (2013) no.6, 064911



STAR capability to measure CME using γ-correlator:

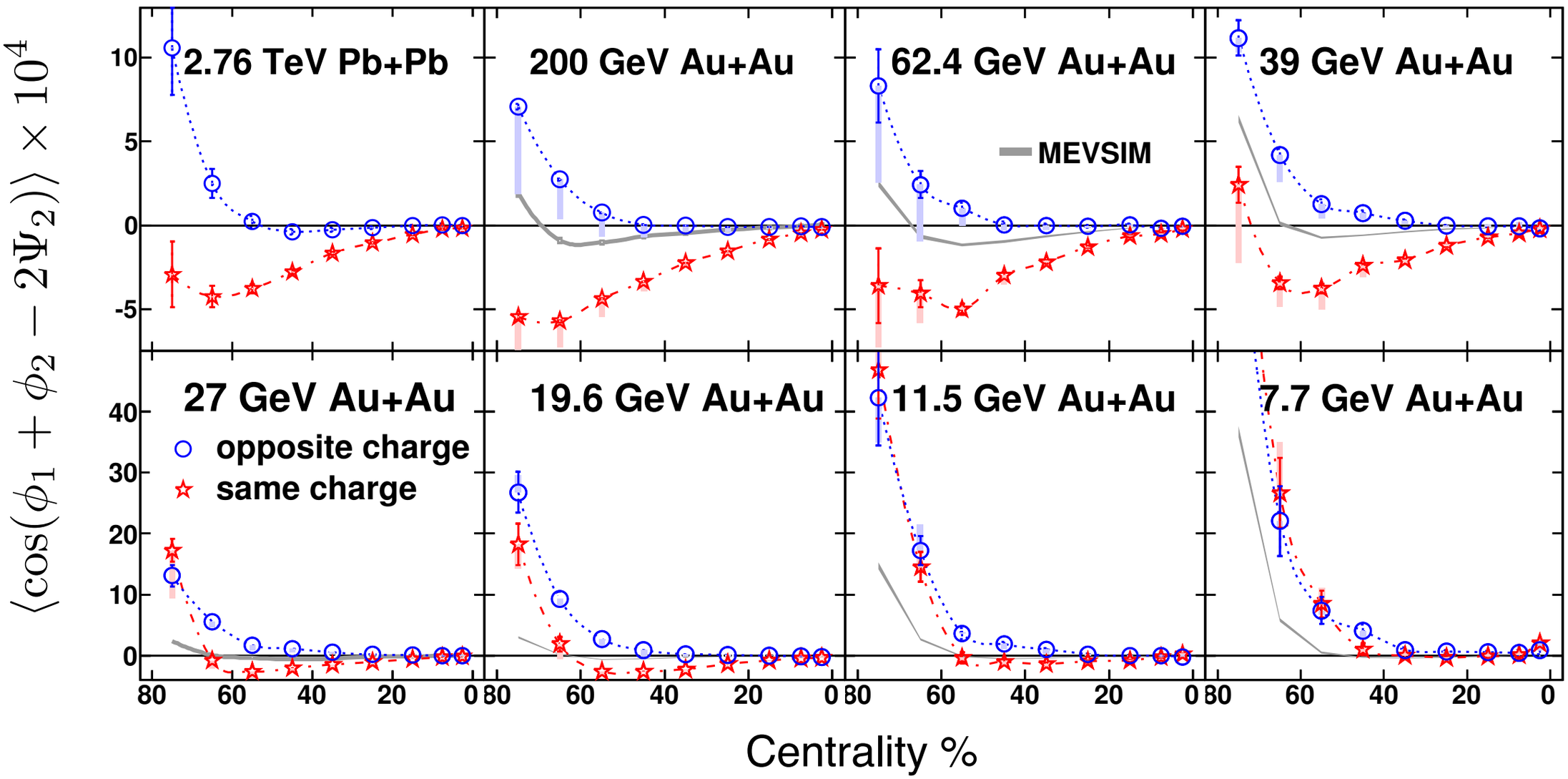
Charged tracks from TPC (-1<η<1)

Proxy for reaction planes: event-planes from ZDC-SMD, TPC & BBC

Motivation: √s dependence & BES-I data

Charge separation vanishes towards lower energy

L. Adamczyk et al. (STAR Collaboration), PRL 113 (2014) 052302.



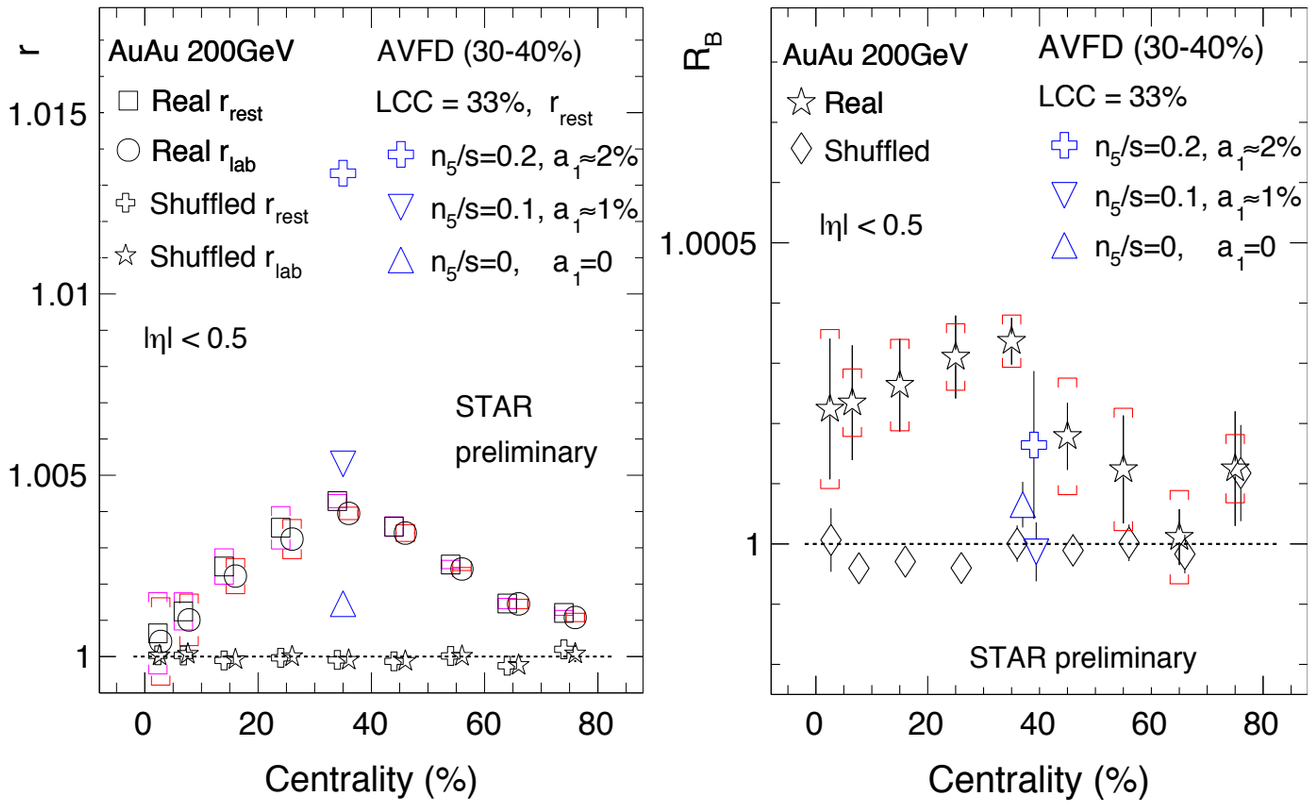
Why does charge separation disappear at lower √s ?
Is this because signal vanishes or background vanishes?

Many new insights since 2014 on how to handle background

New developments: CME search at high √s

CME search at top energy from STAR@QM 2019

Y. Lin , QM 2019



Use Signed Balance Function & compensate for boosted charge pairs:

r_{rest}(lab) & R_B >1 : small possible signal in data

Exploit system (U+U /Au+Au dependence & correlation of B-field with participants vs spectator planes :

Small CME fraction & dominance of background

J. Zhao,

CME search at top energy from STAR@QM 2019

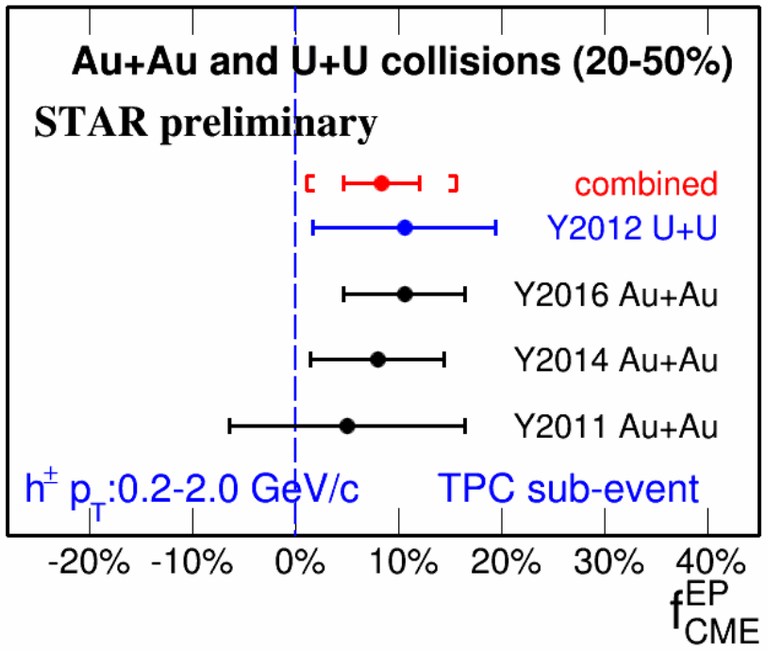
Use Signed Balance Function & compensate for boosted charge pairs:

r_{rest}

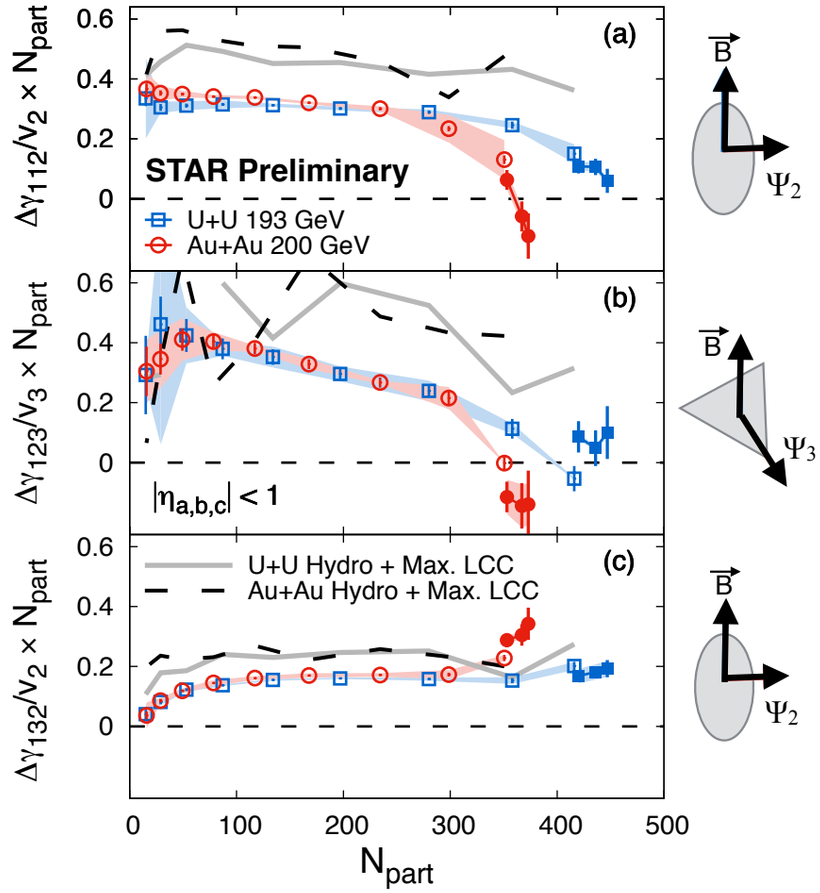
possible signal in data

Exploit system dependence (U+U /Au+Au) & correlation of B-field with participants vs spectator planes :

Small CME fraction & dominance of background

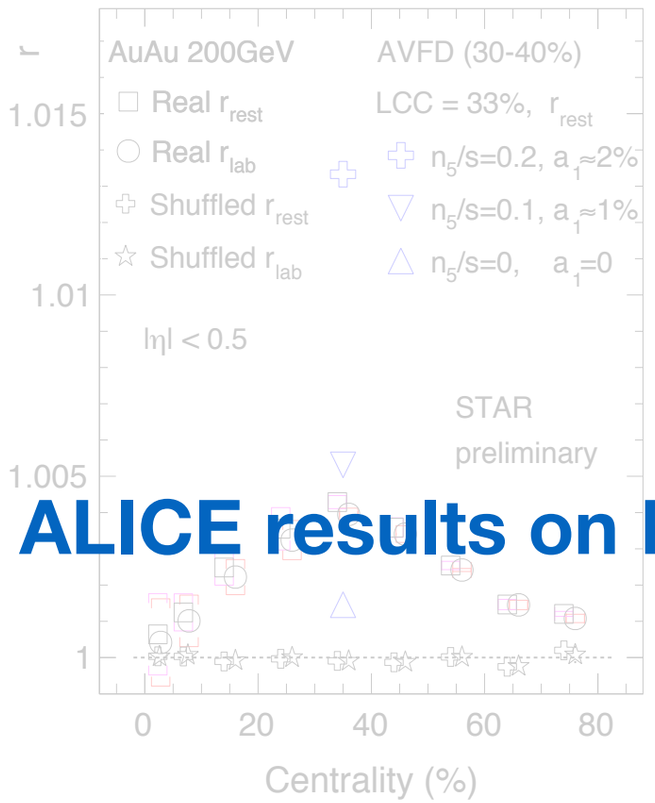


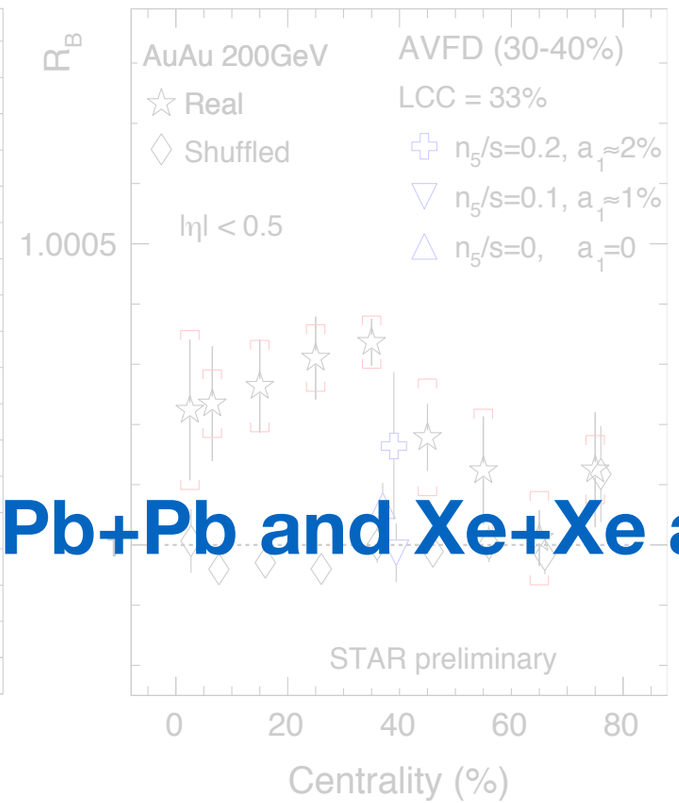
J. Zhao, QM 2019



CME search at top energy from STAR@QM 2019

Y. Lin ,





Exploit system dependence (U+U /Au+Au
B-field with participants vs spectator planes :
Small CME fraction & dominance of background

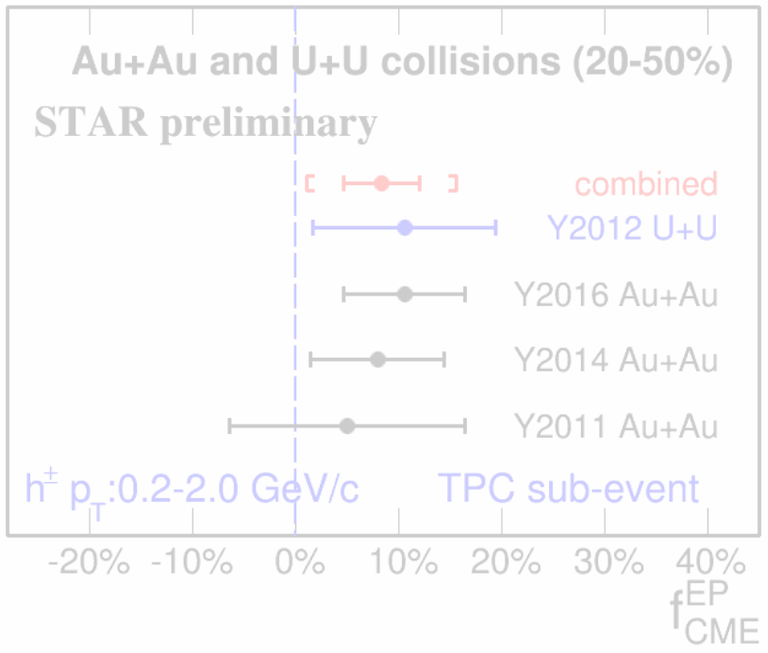
ALICE results on Pb+Pb and Xe+Xe also indicate small CME at LHC

J. Zhao,

Use Signed Balance Function & compensate for boosted charge pairs:

r_{rest}

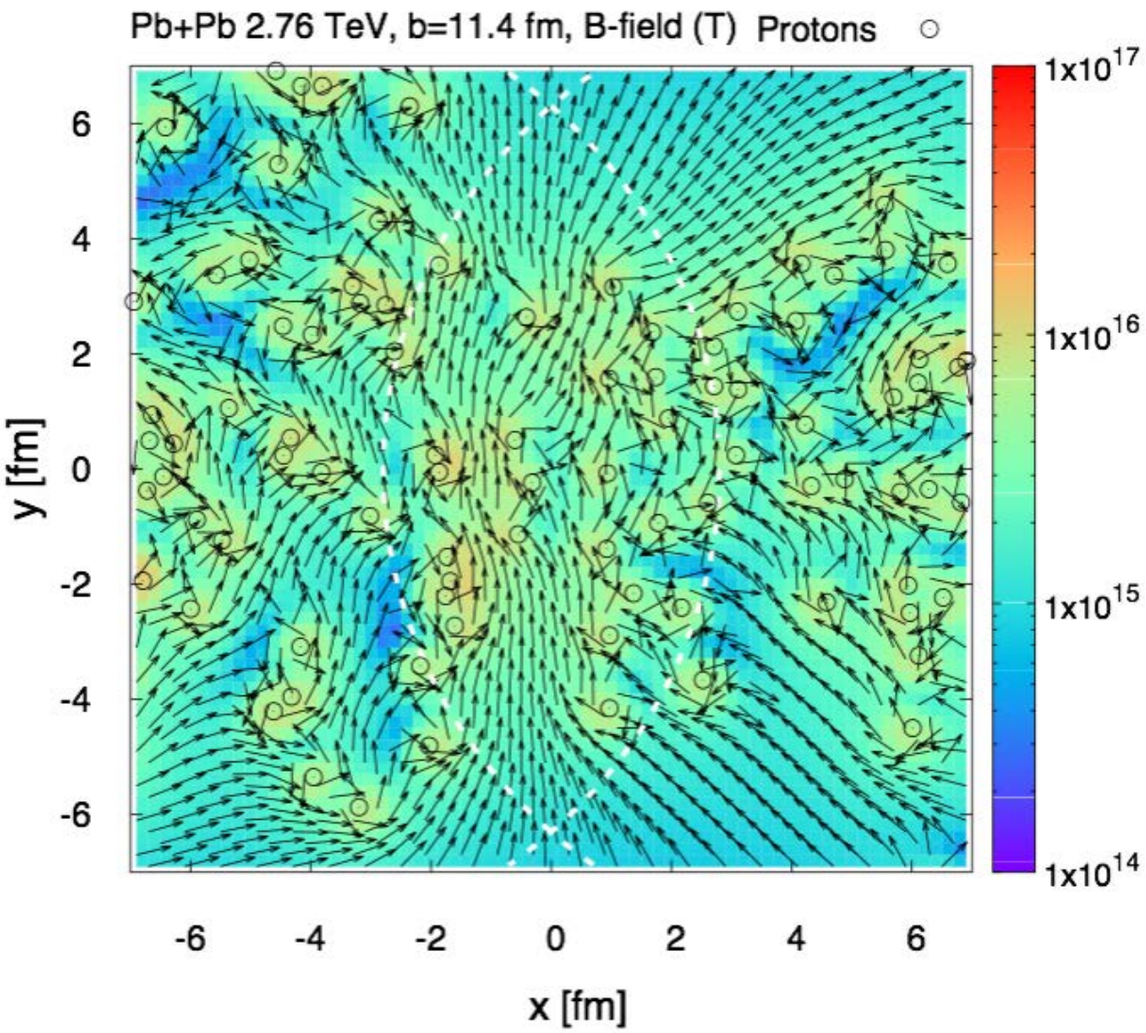
possible signal in data



New theory guidance : Complexity of a real event

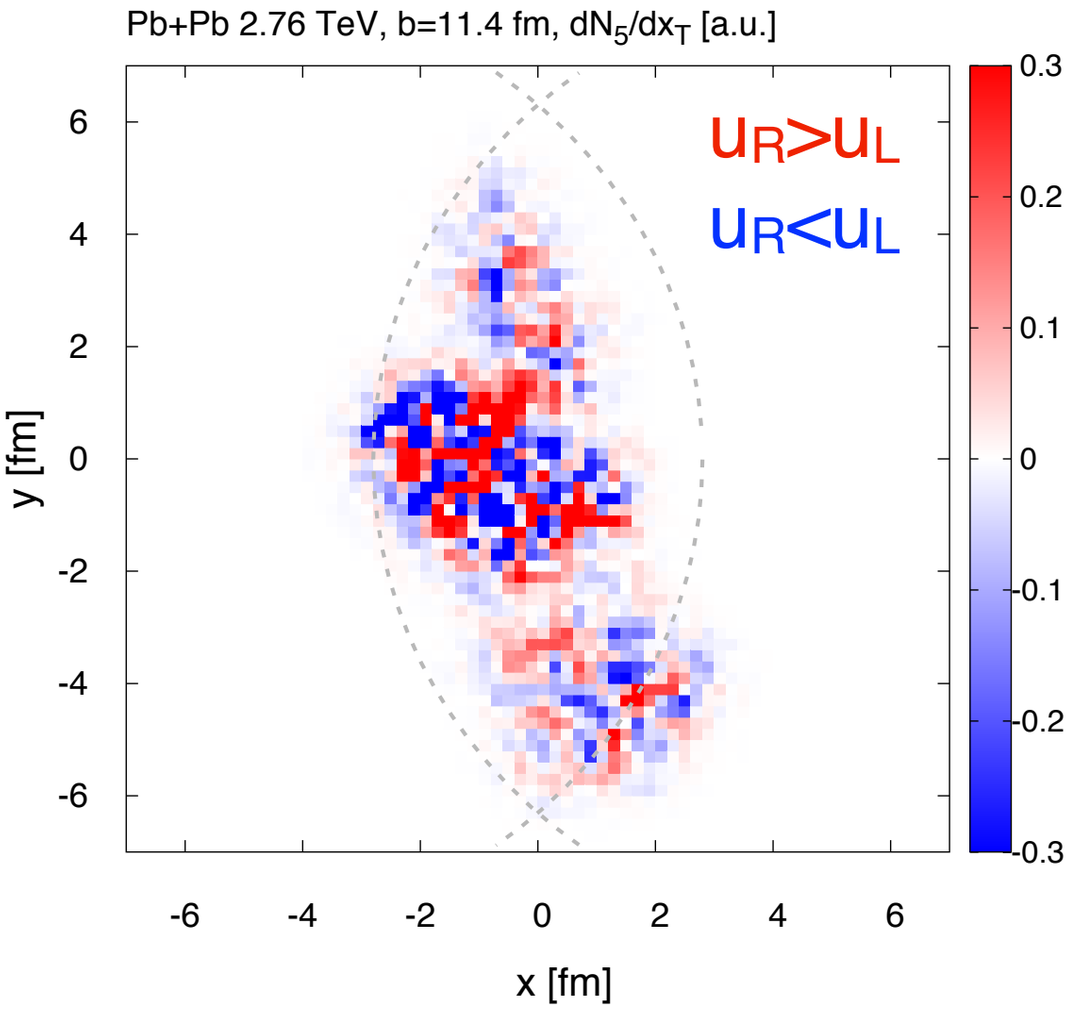
Magnetic field map

Pb+Pb @ 2.76 TeV
b=11.4 fm, N_{part}=56



Based on: Chatterjee, Tribedy, Phys. Rev. C 92, 011902 (2015)

Axial charge profile



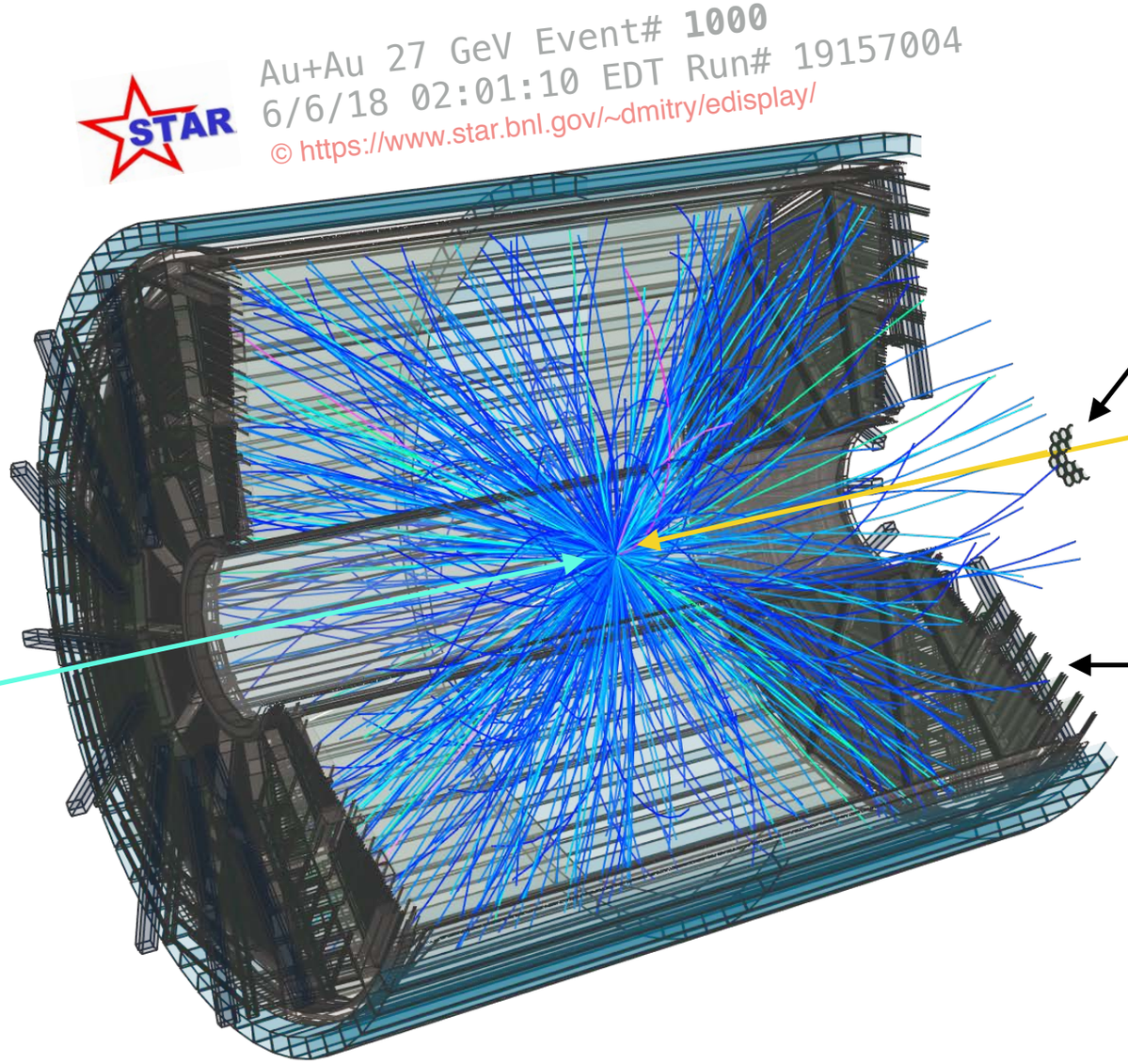
Based on: Lappi, Schlichting, Phys. Rev. D 97, 034034 (2018)

Going beyond cartoon picture: 1) Fluctuations dominate e-by-e physics, 2) B-field & domain size of axial-charge change with √s

Time to revisit CME search at low √s

New developments: CME search at low √s

STAR capability for CME search at low energy

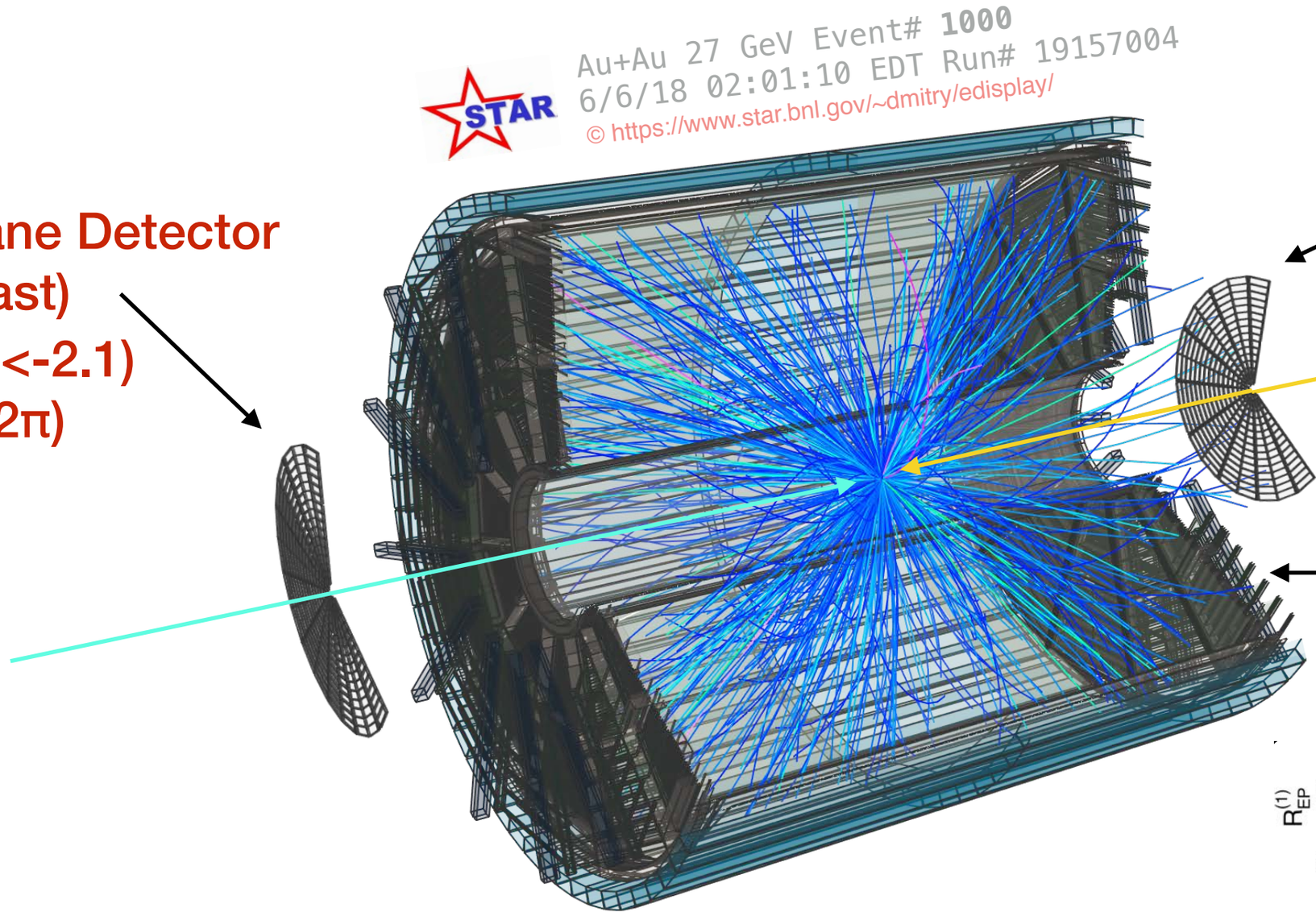


Beam Beam Counter (East) (-5.1<η<-3.3) (0<ϕ<2π)

Beam Beam Counter (West) (3.3<η<5.1) (0<ϕ<2π)

Time Projection Chamber (-1<η<1) (0<ϕ <2π)

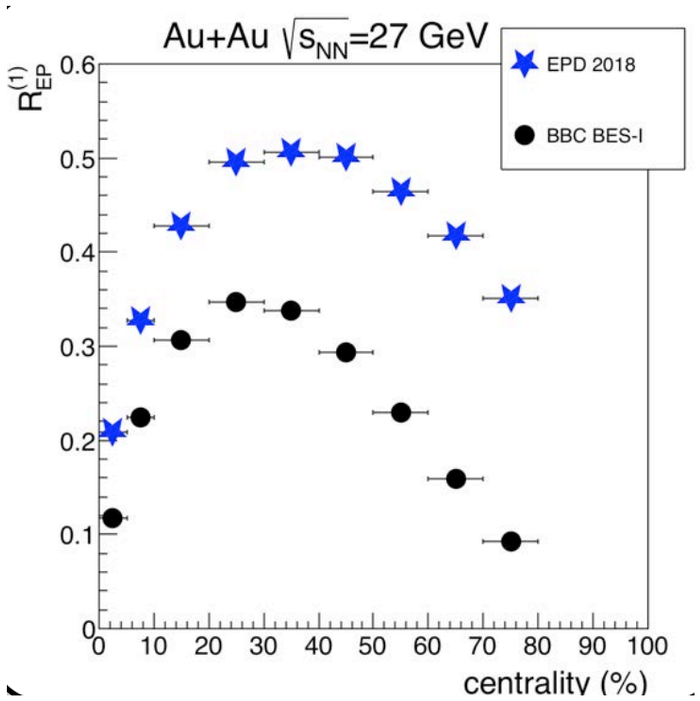
STAR capability for CME search at low energy



Event Plane Detector
(East)
(-5.1<η<-2.1)
(0<ϕ<2π)

Event Plane Detector
(West)
(2.1<η<5.1)
(0<ϕ<2π)

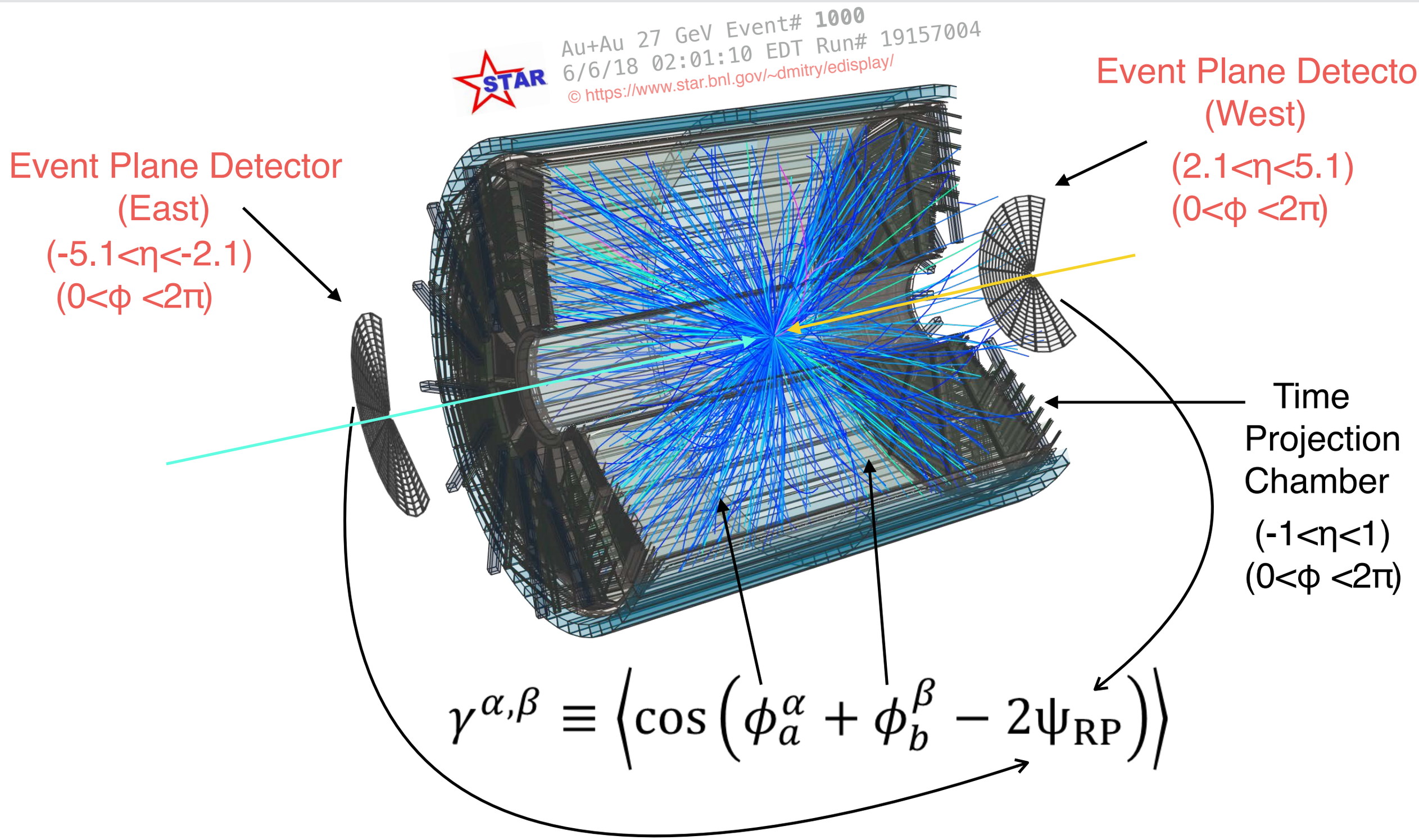
Time
Projection
Chamber
(-1<η<1)
(0<ϕ <2π)



Event Plane Detector : A major upgrade for BES-II, fully installed in 2018

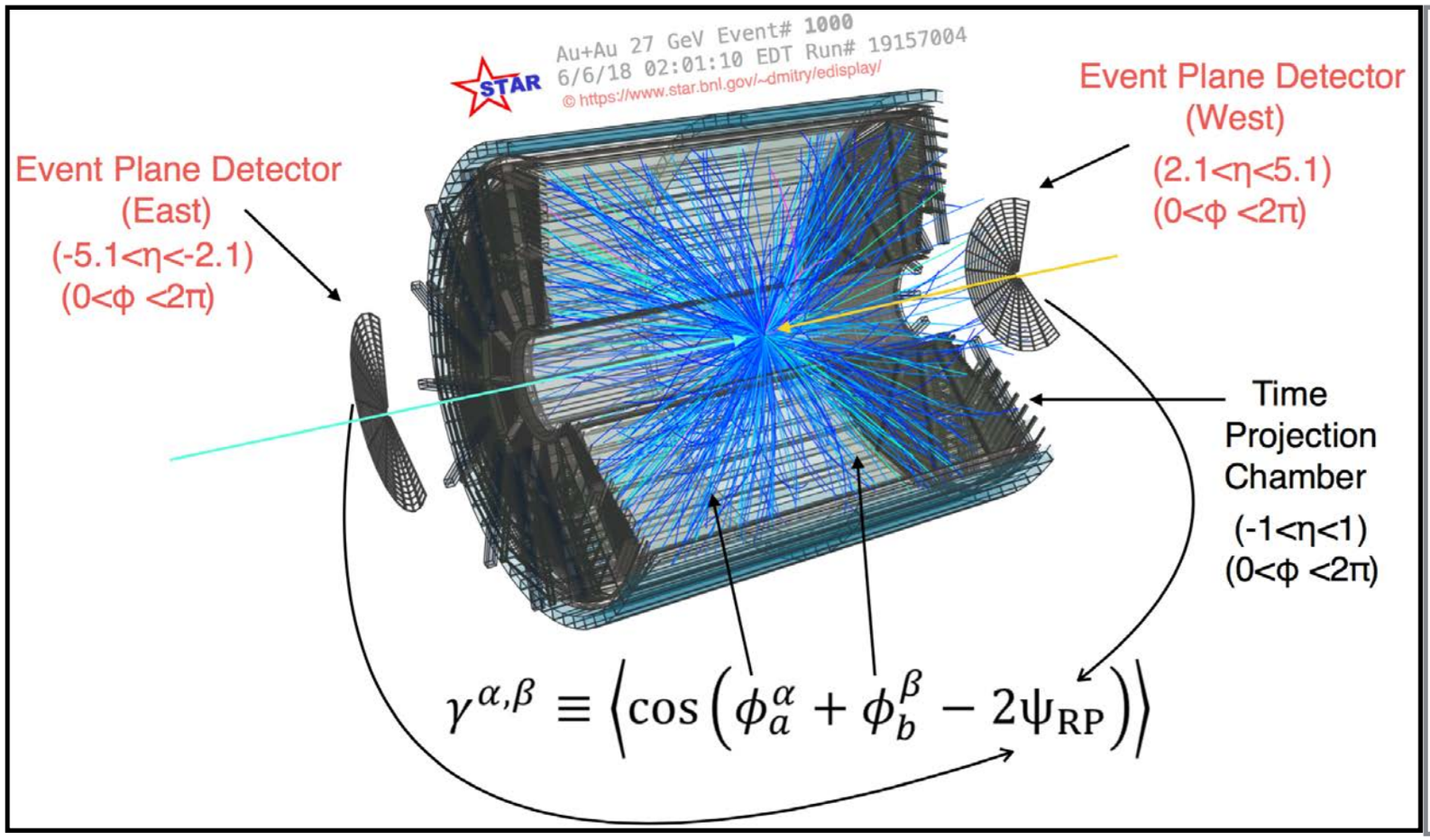
A factor of two increase in event-plane resolution

STAR capability for CME search at low energy



We measure charge-dependent azimuthal correlators using TPC and EPD

Details of our analysis



Observables:

$$\gamma^{\alpha,\beta} \equiv \left\langle \cos\left(\phi_a^\alpha + \phi_b^\beta - 2\psi_{\mathrm{RP}}\right)\right\rangle$$

$$\Delta\gamma = \gamma^{\pm,\mp} - \gamma^{++,--}$$

Elliptic anisotropy

$$v_2 = \langle \cos(2\phi - 2\Psi_{\mathrm{RP}})\rangle$$

We use scalar product method

Analysis details:

ϕ_a & ϕ_b all charge tracks from TPC: $0.2 < p_T < 2$ GeV, $|\eta| < 0.8$

Centrality : TPC uncorrected tracks $|\eta| < 0.5$ Ψ_{RP} : EPD with $2.1 < |\eta| < 5.1$

Systematics uncertainty: Variations in event & track selection criteria, tracking efficiency, acceptance, luminosity, run, and trigger conditions.

Unique advantage of EPD at 27 GeV

STAR Event Plane detector acceptance: 2.1<|η|<5.1

Beam rapidity for Au+Au 27 GeV, Y_{beam} =3.4

EPD detects both participants & spectators

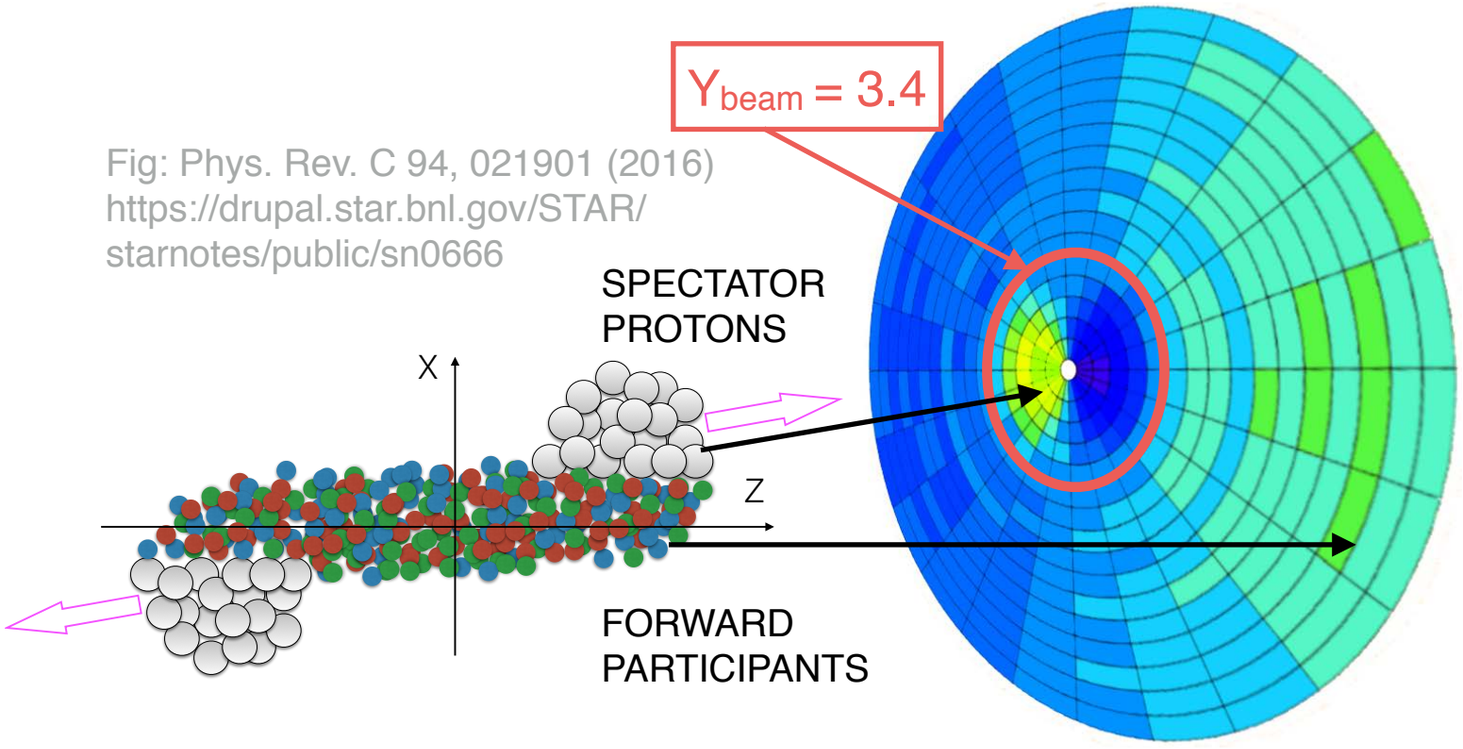
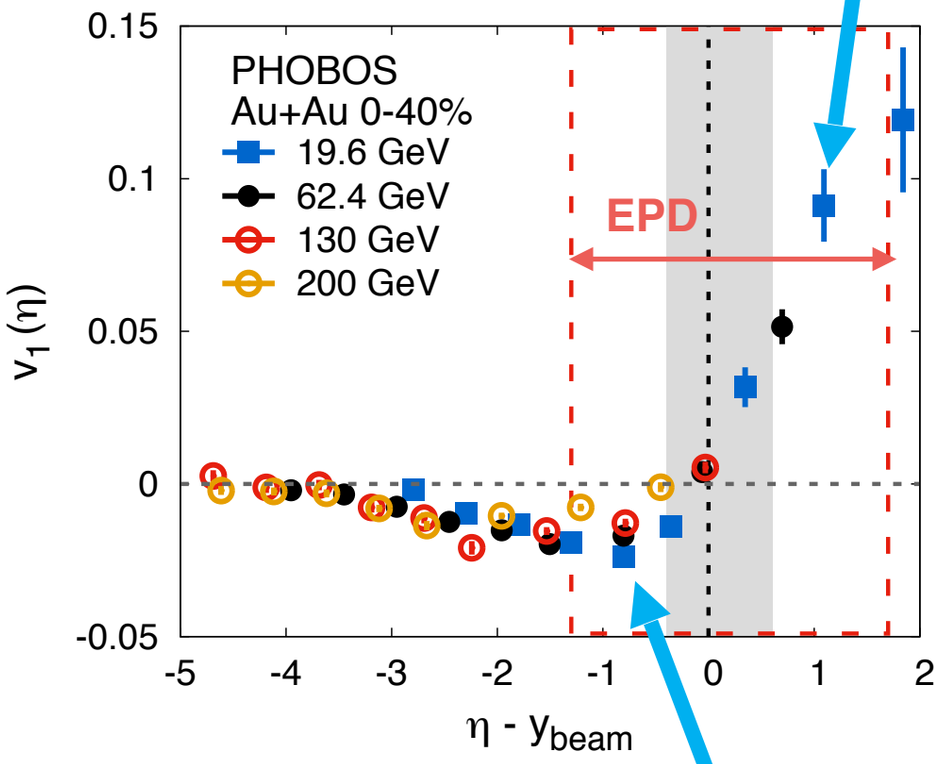


Fig: Phys. Rev. C 94, 021901 (2016)
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666

Spectator flow

Sign change of v_1@Y_{beam}



Participants flow

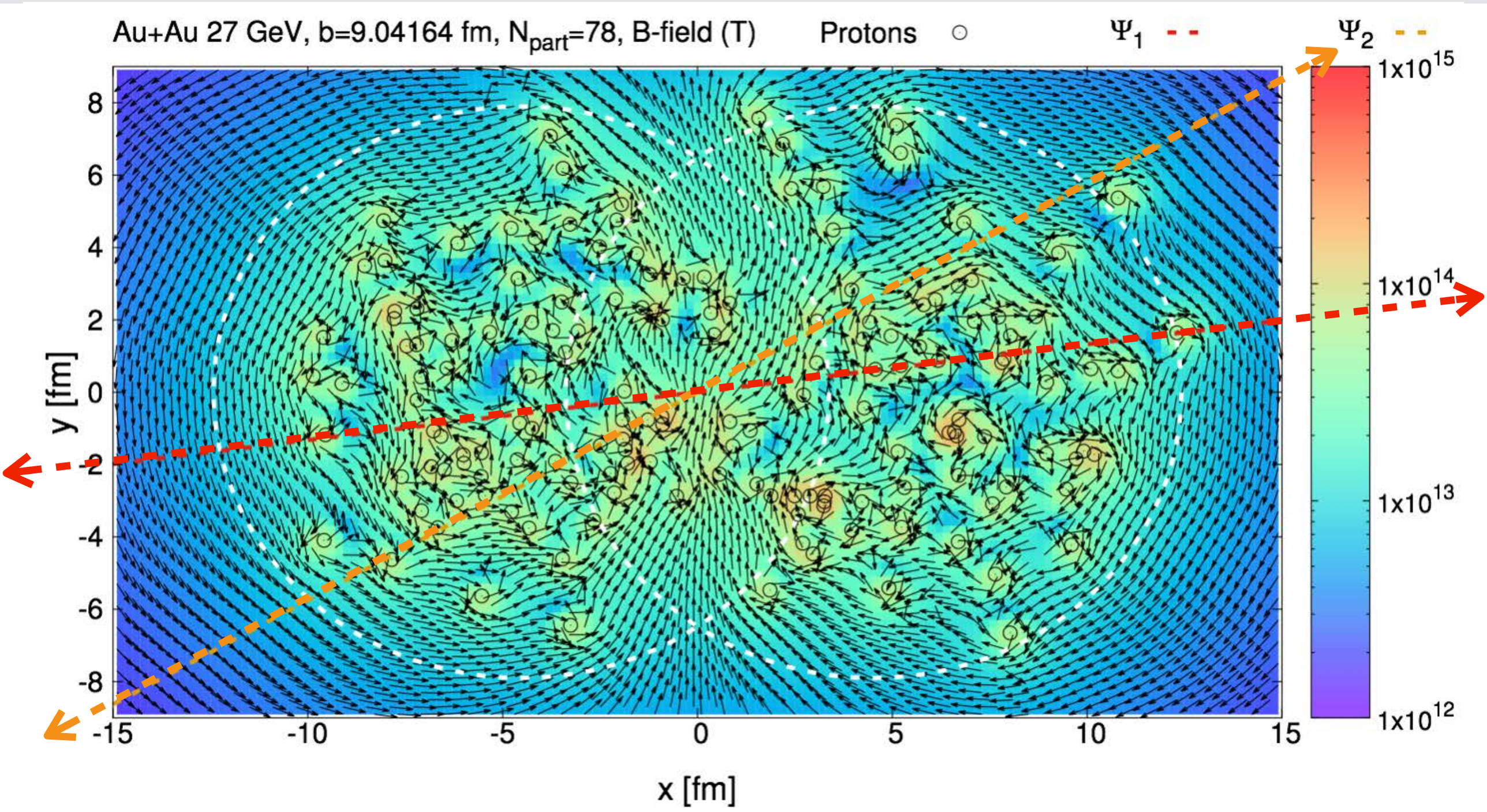
We use two planes from EPD as proxy for Ψ_{RP}

Ψ_1 ($\eta > Y_{beam}$): 1st-order plane, rich with spectator protons

Ψ_2 ($\eta < Y_{beam}$): 2nd-order plane of forward produced particle

First ever measurement of CME using spectator proton plane

Model expectations : a tale of two planes



Ψ_1 (proton) is more correlated to Ψ_B than Ψ_2 (participants)

We want to see if there is any difference in charge separation

First step : Measurement of Elliptic anisotropy

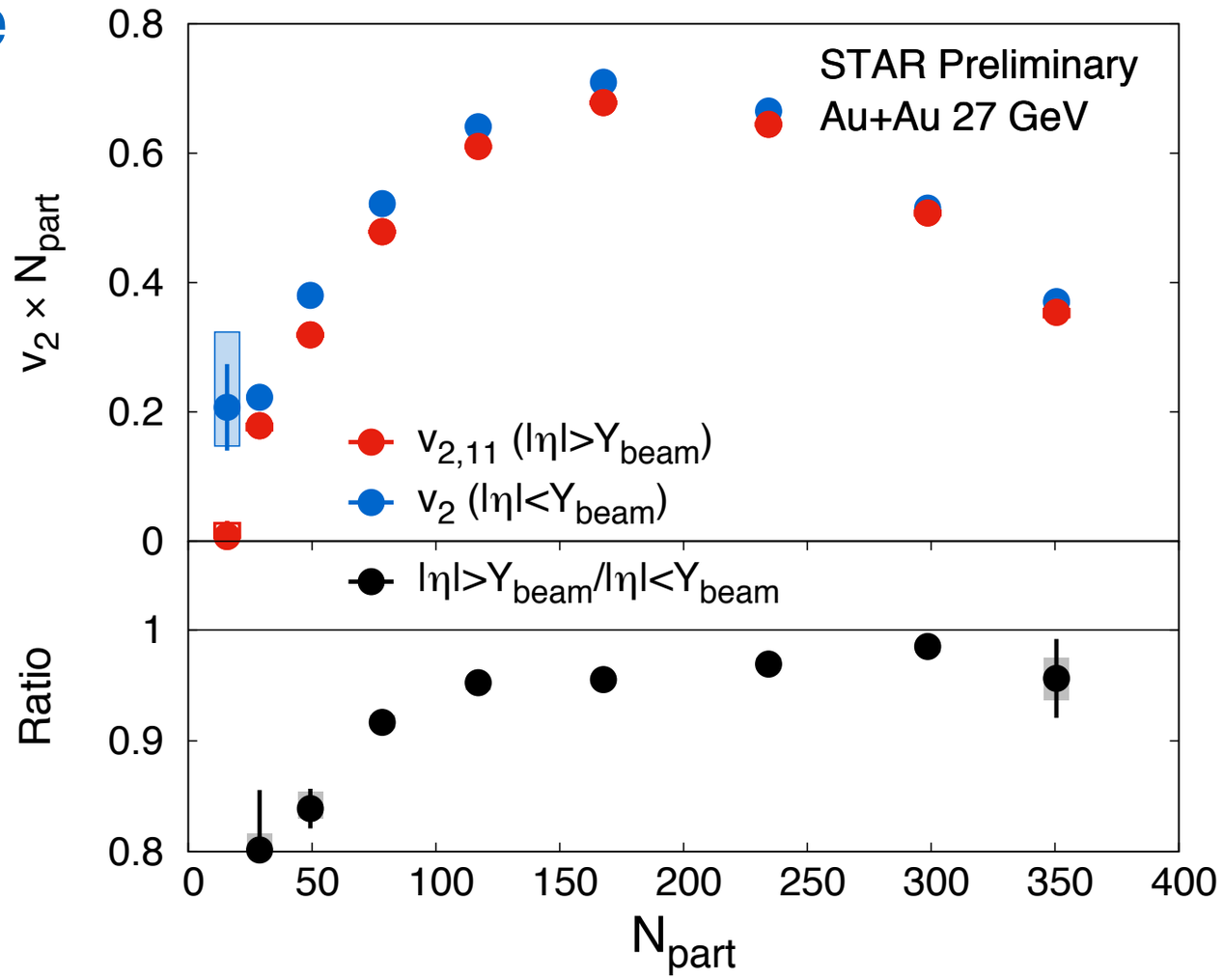
We take tracks from TPC & measure anisotropy w.r.t two planes

Elliptic anisotropy w.r.t the plane of the produced particles $|\eta|<Y_{beam}$

$$v_{2,2} \equiv \left\langle \cos\left(2\phi - 2\psi_2^{|\eta|<Y_{beam}}\right)\right\rangle$$

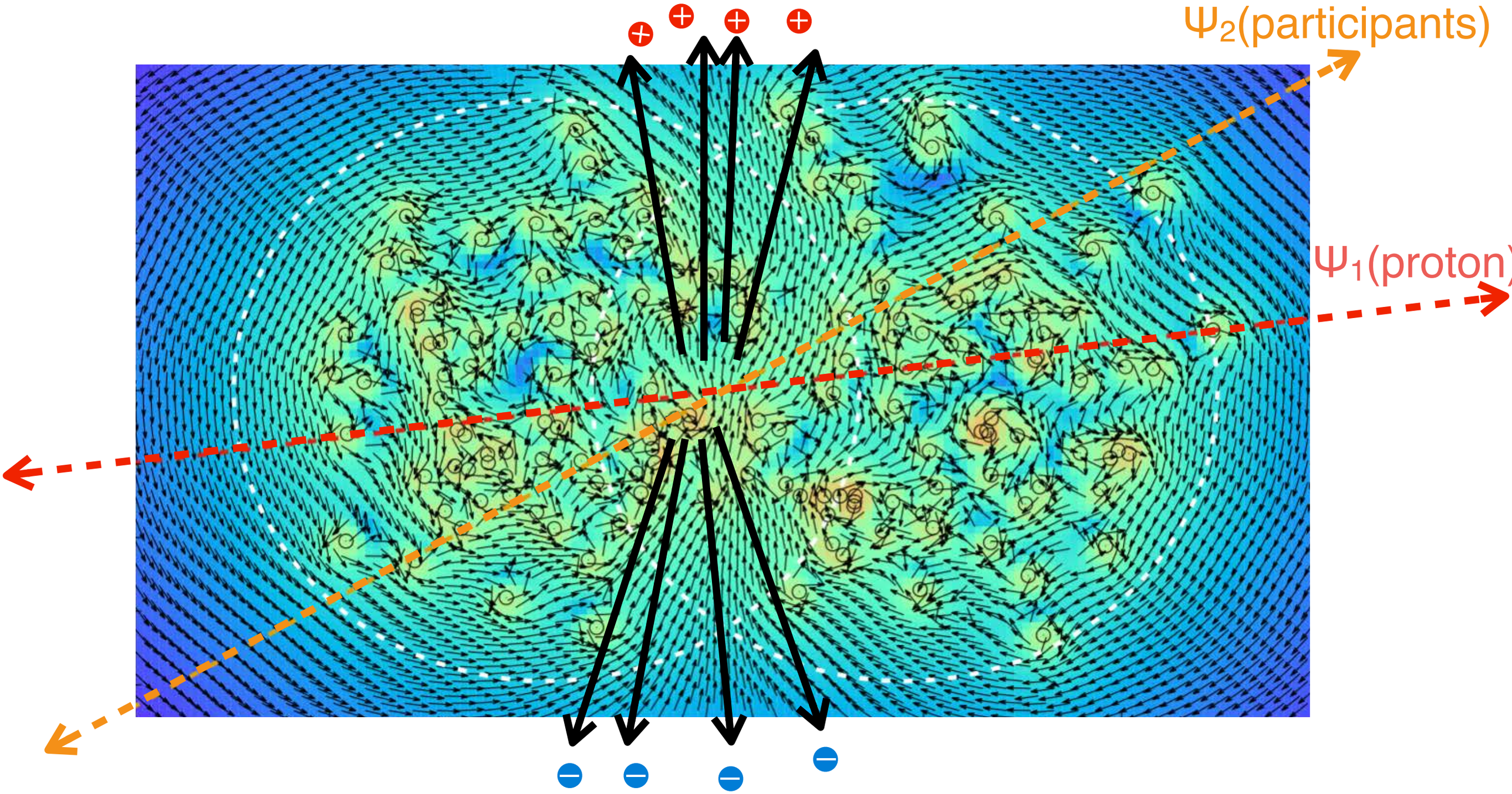
Elliptic anisotropy w.r.to the plane of the spectator protons $|\eta|>Y_{beam}$

$$v_{2,1,1} \equiv \left\langle \cos\left(2\phi - \psi_1^{\eta>Y_{beam}} - \psi_1^{-\eta<-Y_{beam}}\right)\right\rangle$$



Elliptic anisotropy drops by 20% w.r.t spectator proton plane due to decorrelation and difference in flow fluctuations w.r.t two planes

Model expectations : a tale of two planes

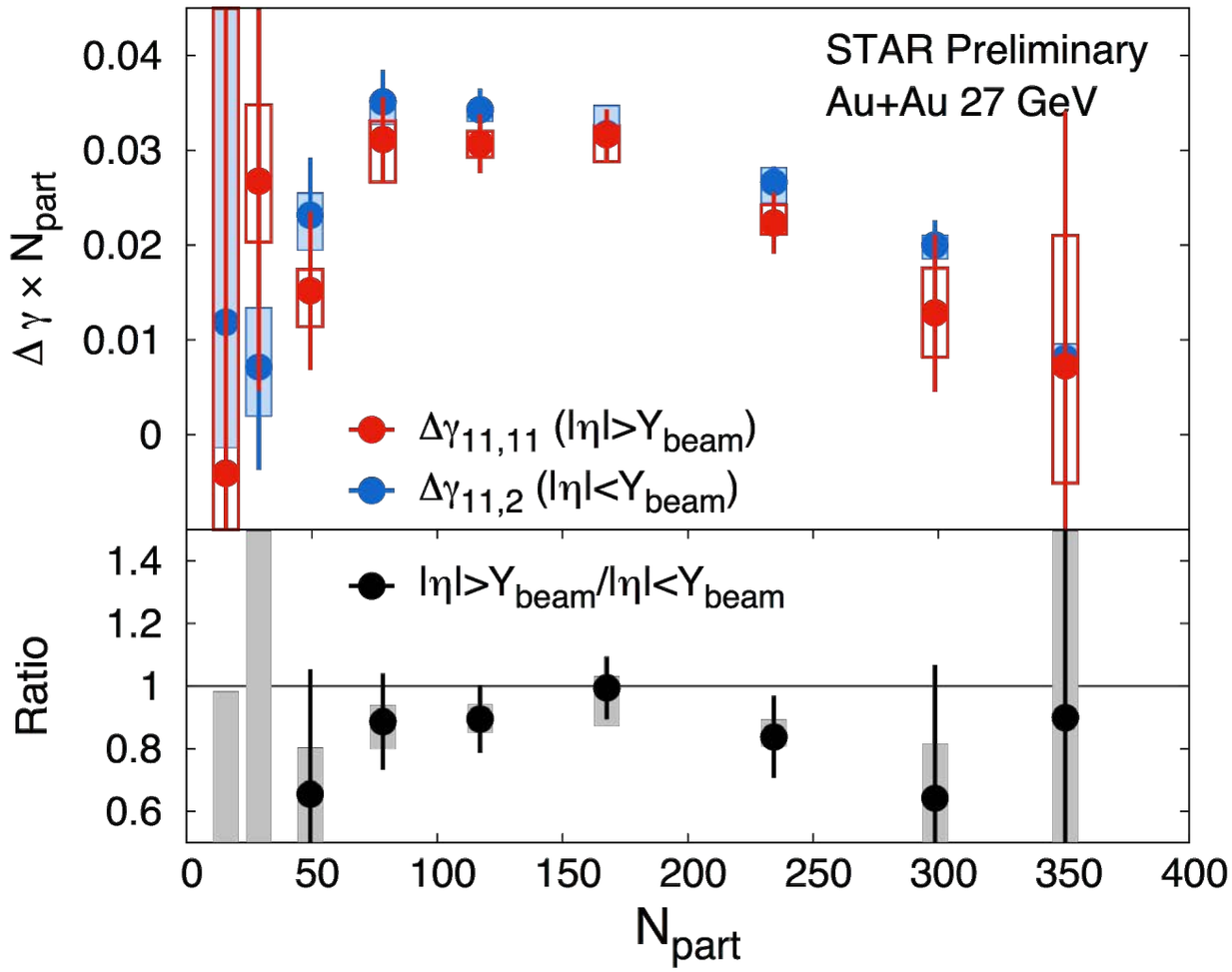


So which plane shows more charge separation?

Second step: Measurement of charge separation

Charge separation w.r.t planes of the produced particles $|\eta|<Y_{beam}$

$$\gamma_{1,1,2}^{\alpha,\beta} = \left\langle \cos\left(\phi_a^{\alpha} + \phi_b^{\beta} - 2\psi_2^{|\eta|<Y_{beam}}\right)\right\rangle$$



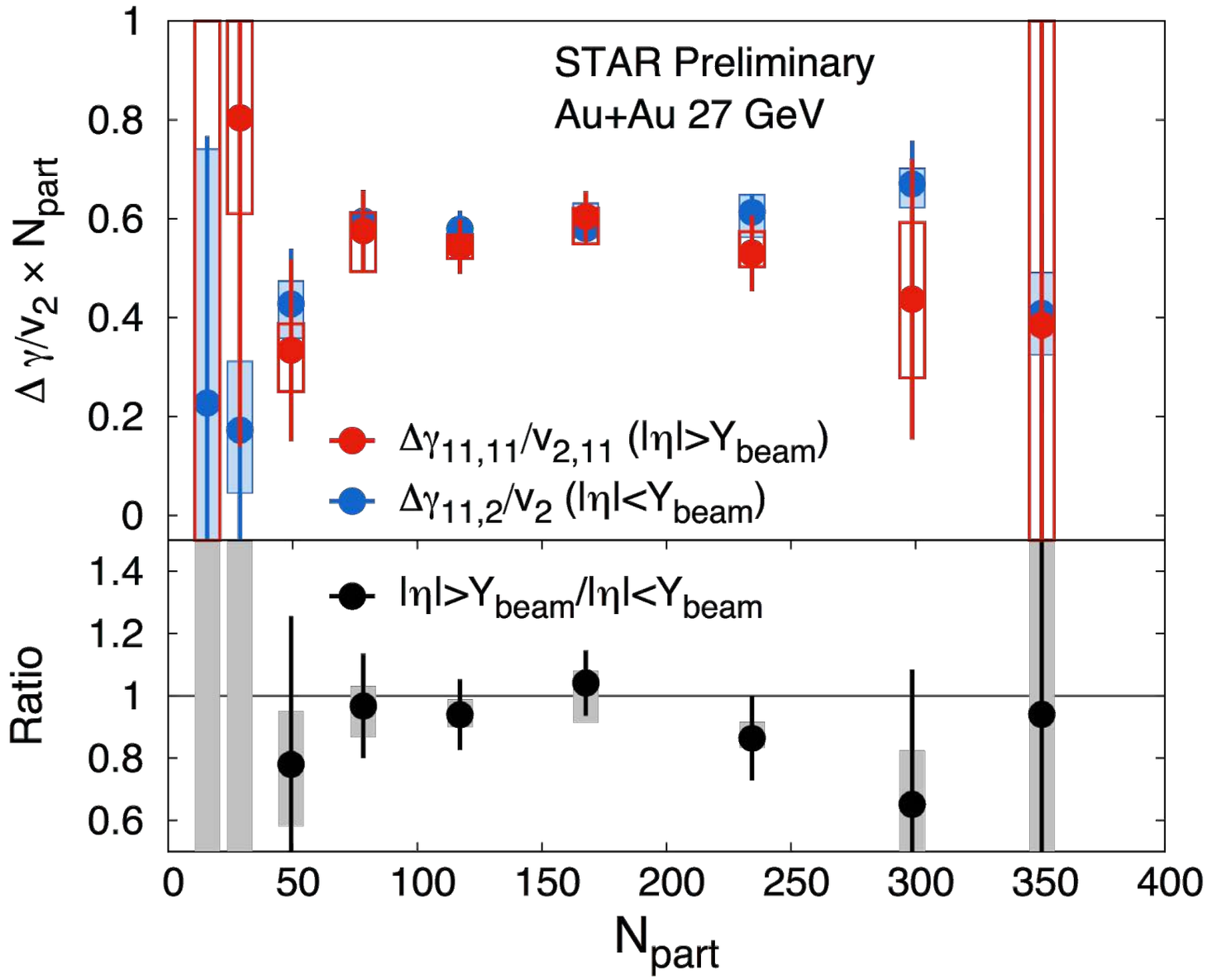
Charge separation w.r.t planes of the spectator protons $|\eta|>Y_{beam}$

$$\gamma_{1,1,1,1}^{\alpha,\beta} = \left\langle \cos\left(\phi_a^{\alpha} + \phi_b^{\beta} - \psi_1^{\eta>Y_{beam}} - \psi_1^{-\eta<-Y_{beam}}\right)\right\rangle$$

No significant difference in the charge separation w.r.t spectator proton & produced particle event planes

Measurement of charge separation

Charge separation normalized by v_2 for planes at $|\eta|<Y_{beam}$ & $|\eta|>Y_{beam}$

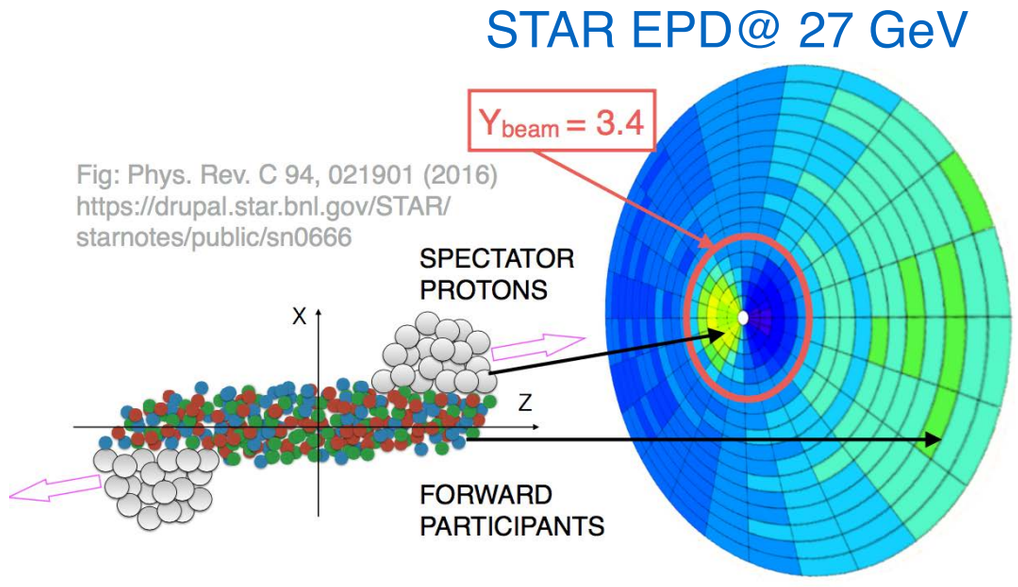


No significant difference in the scaled charge separation w.r.t spectator proton & produced particle event planes.

Summary

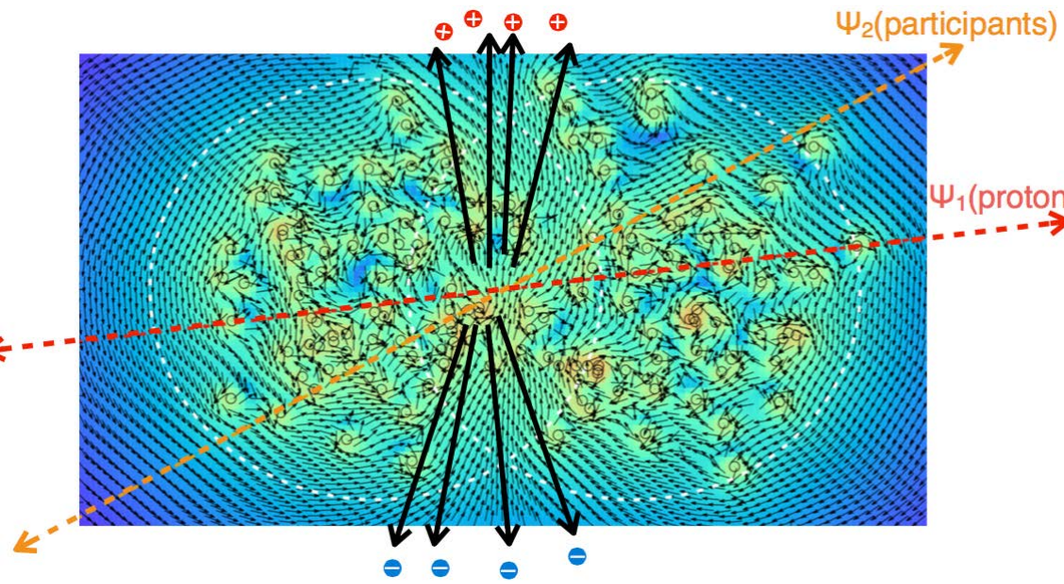
What did we try:

- We utilized the unique STAR capability at Au+Au 27 GeV with the newly installed Event Plane Detector to study charge separation w.r.t spectator proton plane and event plane at forward rapidity using the same detector.



What did we find:

- We found no significant difference of charge separation between the two scenarios
- Our results will provide valuable constraints on the observability of CME search at low energies



Thank You