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APS physics

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BROOKHAVEN NATIONAL LABORATORY

CME search at STAR using the Event Plane Detector

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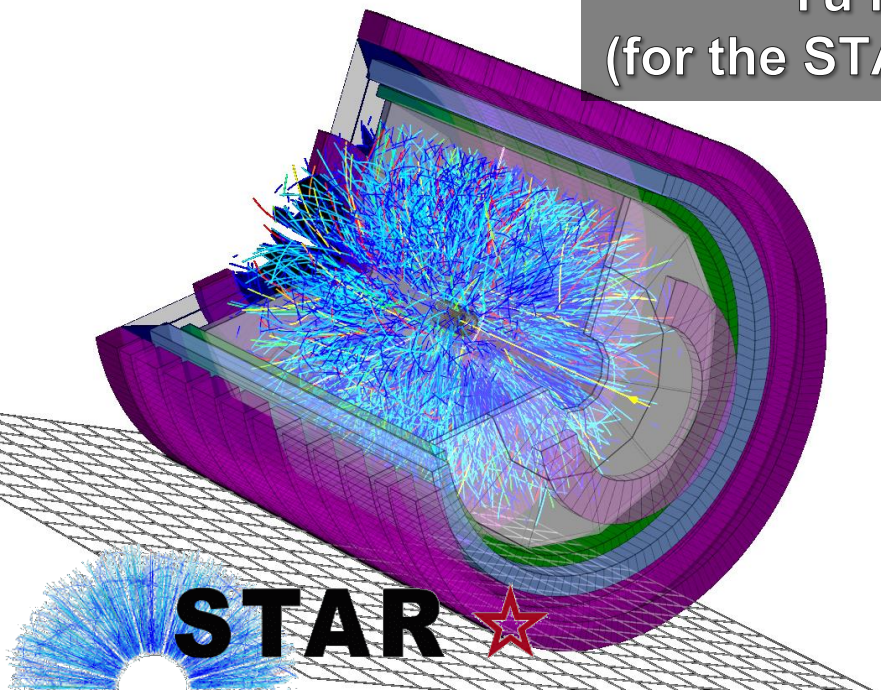
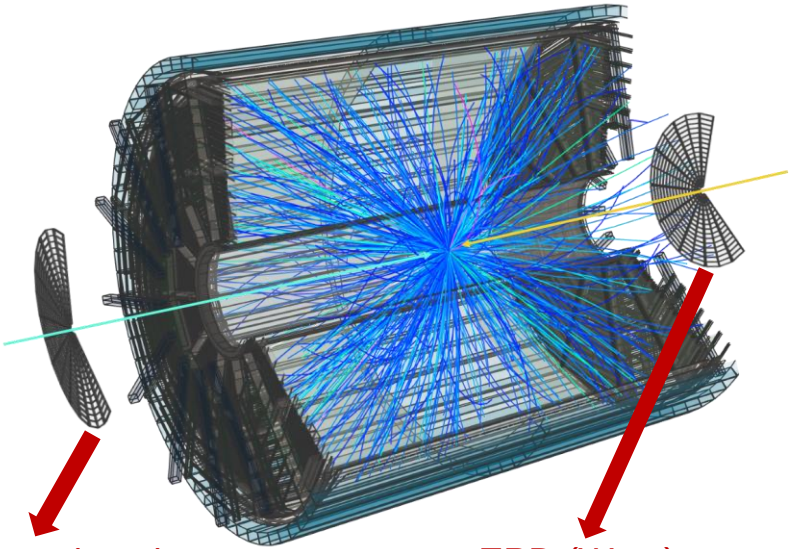
(for the STAR collaboration)



1. Fudan University
2. Brookhaven National Laboratory

Introduction

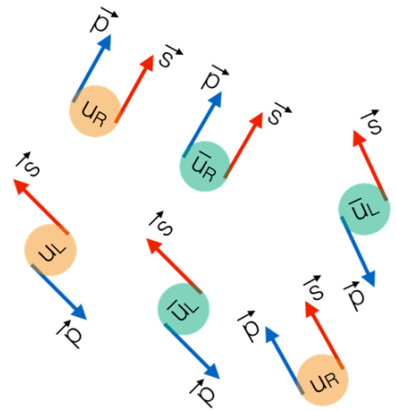
Solenoidal Tracker at RHIC (STAR)

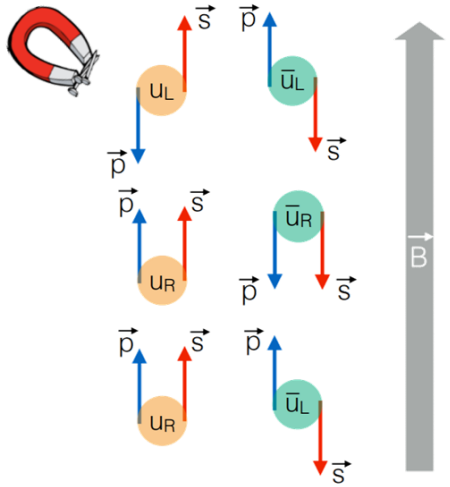


- RHIC has collided multiple ion species;
- Year 2018 was dedicated to search for effects driven by strong electromagnetic fields by STAR
- This analysis is about using the new detector EPD in STAR for CME search
- CME search @ Low energy
  - Au+Au @ 27 GeV
- CME search @ RHIC high energy
  - Isobar: Ru+Ru, Zr+Zr @ 200 GeV

The Chiral Magnetic Effect (CME)

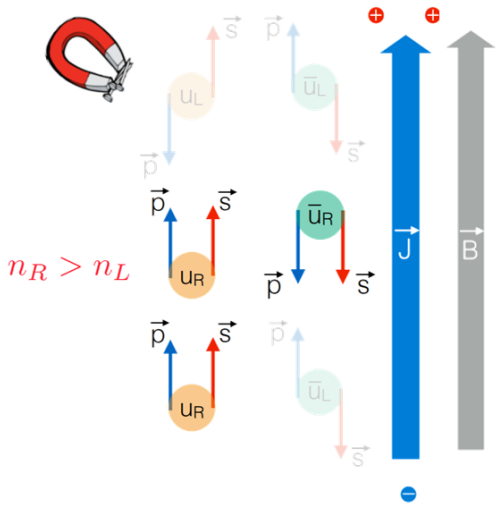
Massless quarks randomly oriented

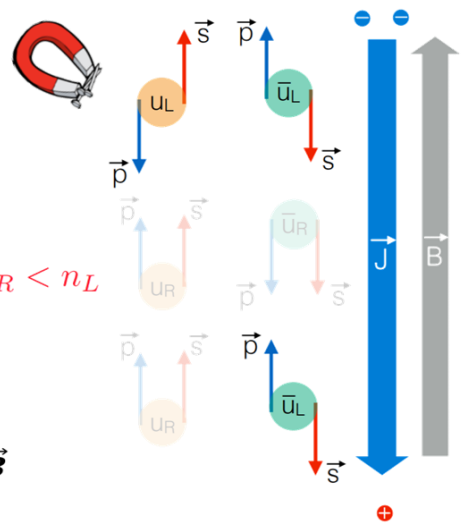




Quarks aligned along B

More right-handed quarks J || B



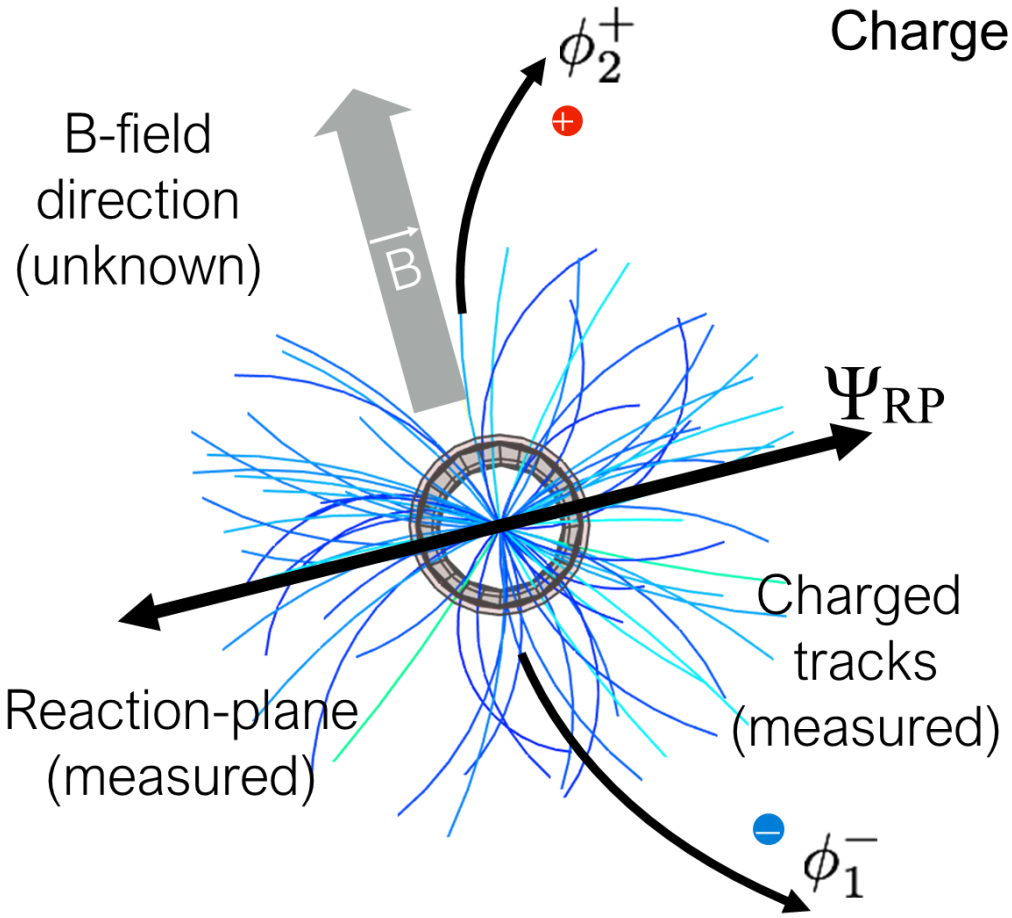


More left-handed quarks J || -B

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

Imbalance of left-handed & right-handed quarks + B-field = electric current

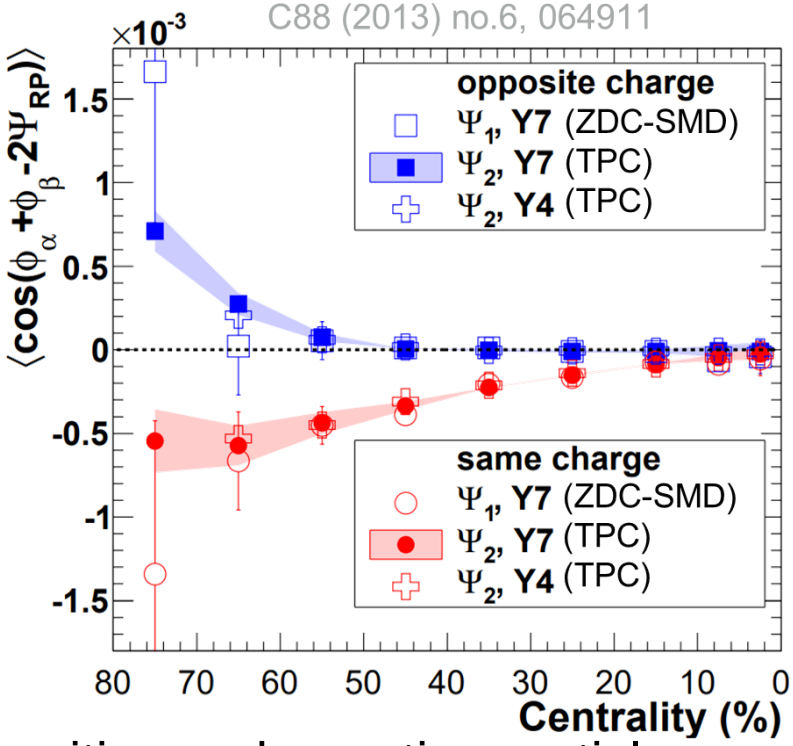
The Chiral Magnetic Effect (CME)



Charge separation across reaction plane

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

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

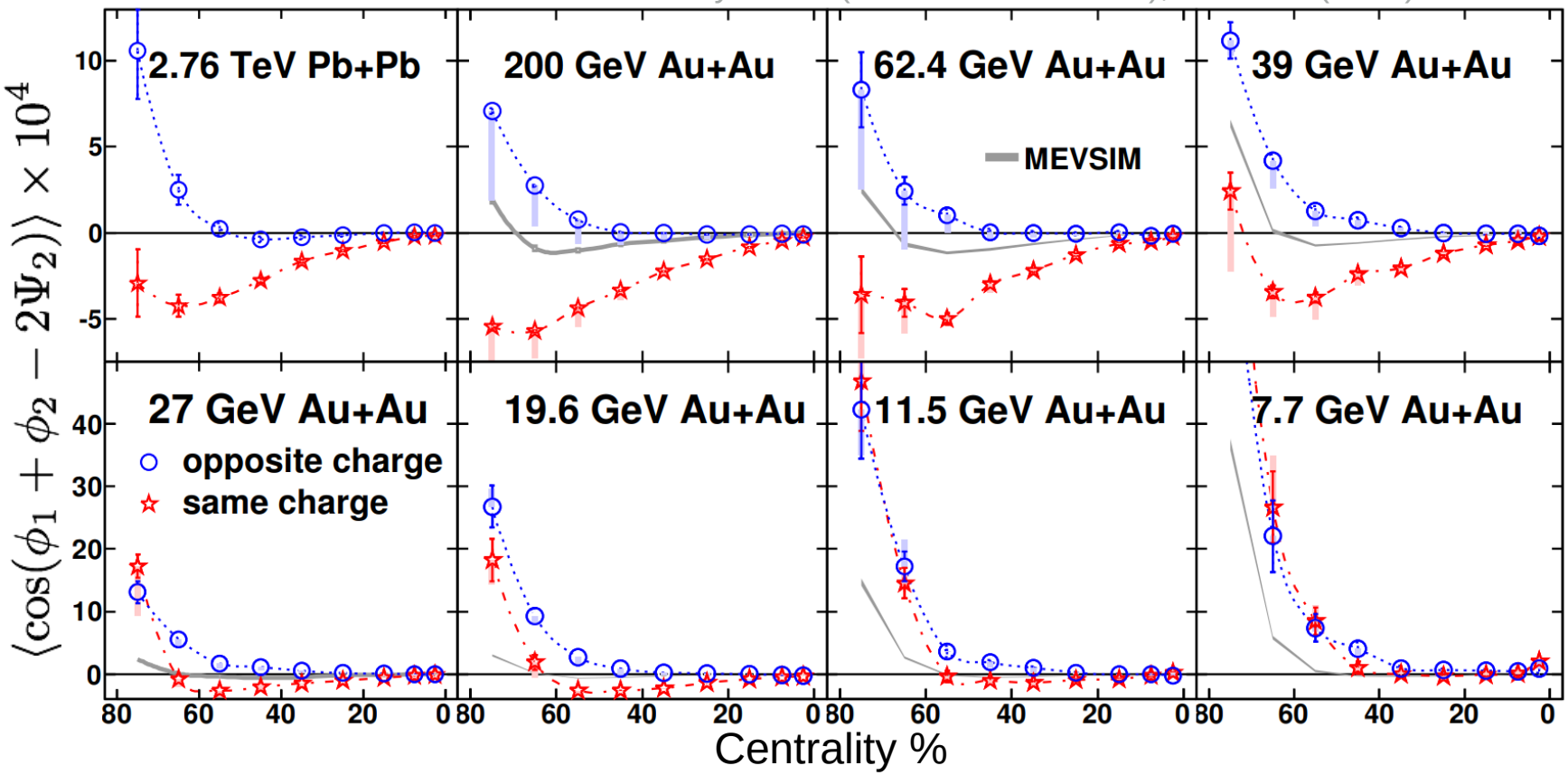


We measure the angular correlations of positive and negative particles across a plane (reaction plane) that is correlated to B-field directions.

CME search at low RHIC energy

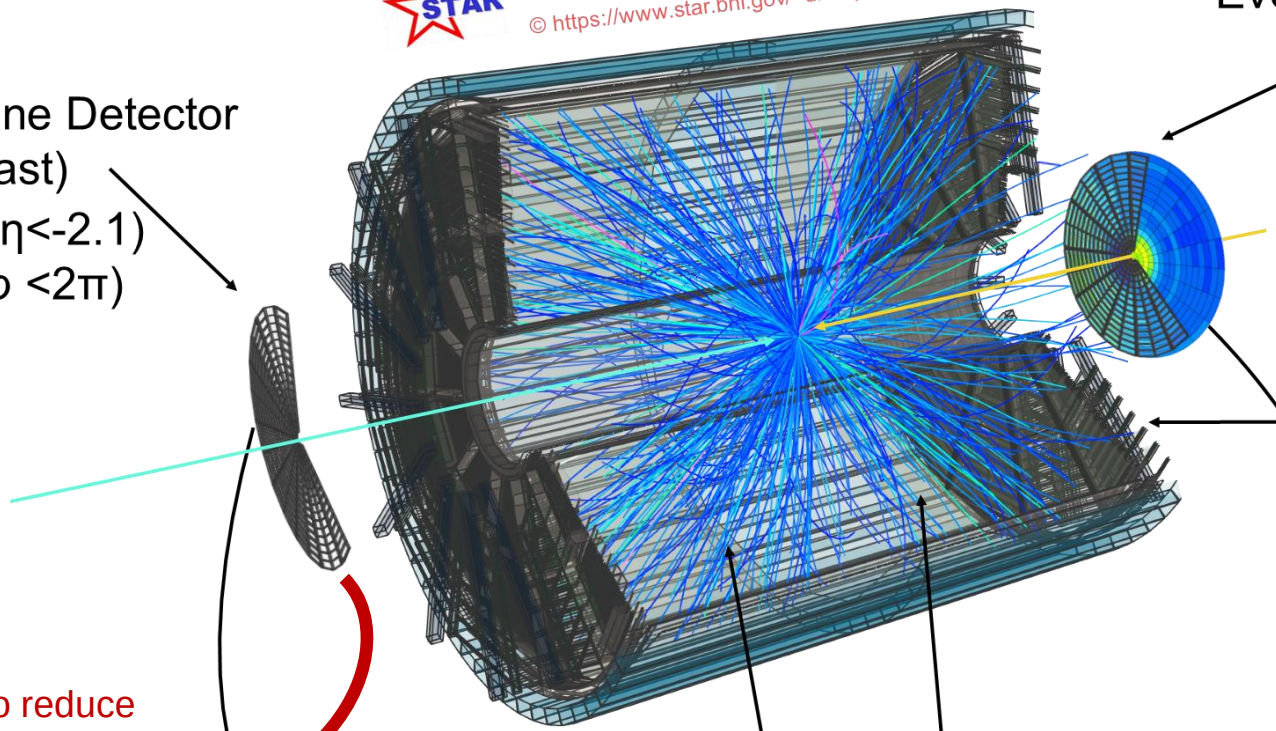
The STAR collaboration has measured charge separation over a wide range of collision energies

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



Interesting observation: charge separation effects seem to disappear at lower energies. We revisit the 27 GeV analysis with new capabilities & high statistics data

STAR capability for CME search @ low energies



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)

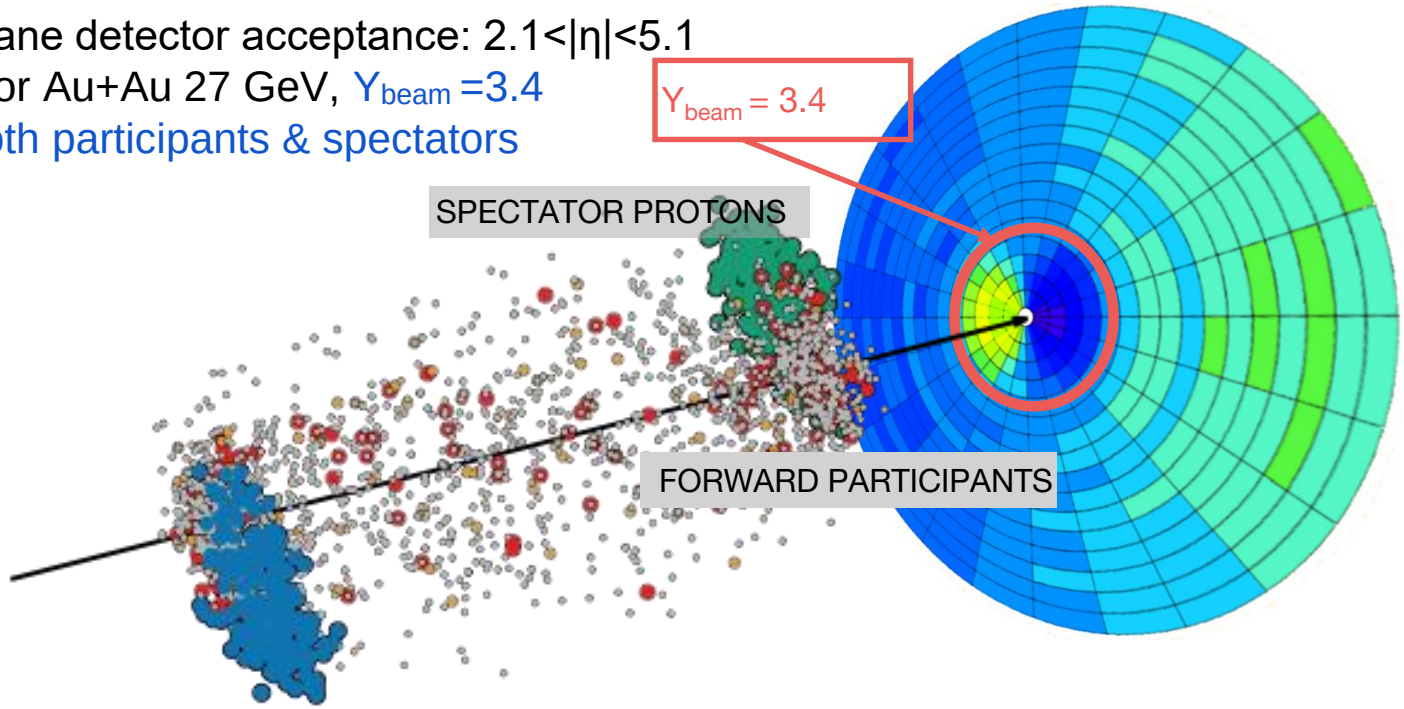
It helps to reduce non flow and at lower energies this help to measure spectator rich event plane

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

We measure charge-dependent azimuthal correlator using TPC and EPD

Unique for 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



The cartoon above shows that the inner region of EPD detects spectator protons, whose direct flow signal has opposite direction compared to the outer sector that are dominated by the participants.

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

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

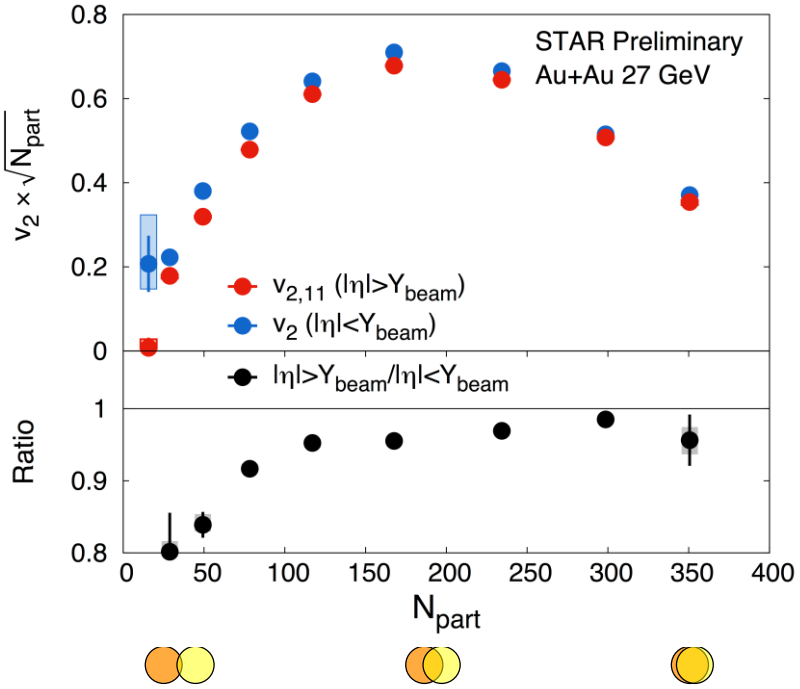
Ψ_2 ($\eta < Y_{beam}$): 2nd-order event plane for particles going in forward direction

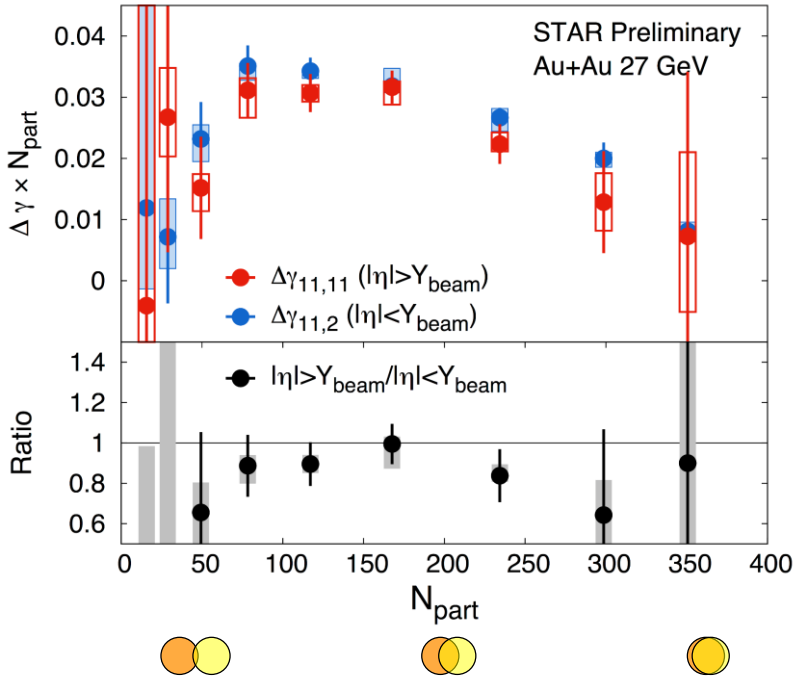
Fraction of CME signal can be estimated using SP and PP plane measurement as proposed in:

H-j Xu et al. Chin. Phys. C42 (2018) 084103
Voloshin, Phys. Rev. C 98, (2018) 054911
Jie Zhao for the STAR collaboration, arXiv:2002.09410

Elliptic flow & Δγ w.r.t different planes

We measure the elliptic flow and the charge separation, using γ correlator (Δγ=γ(OS)-γ(SS)), w.r.to TPC-EPD-inner first harmonic planes and the TPC-EPD-outer second harmonic plane.

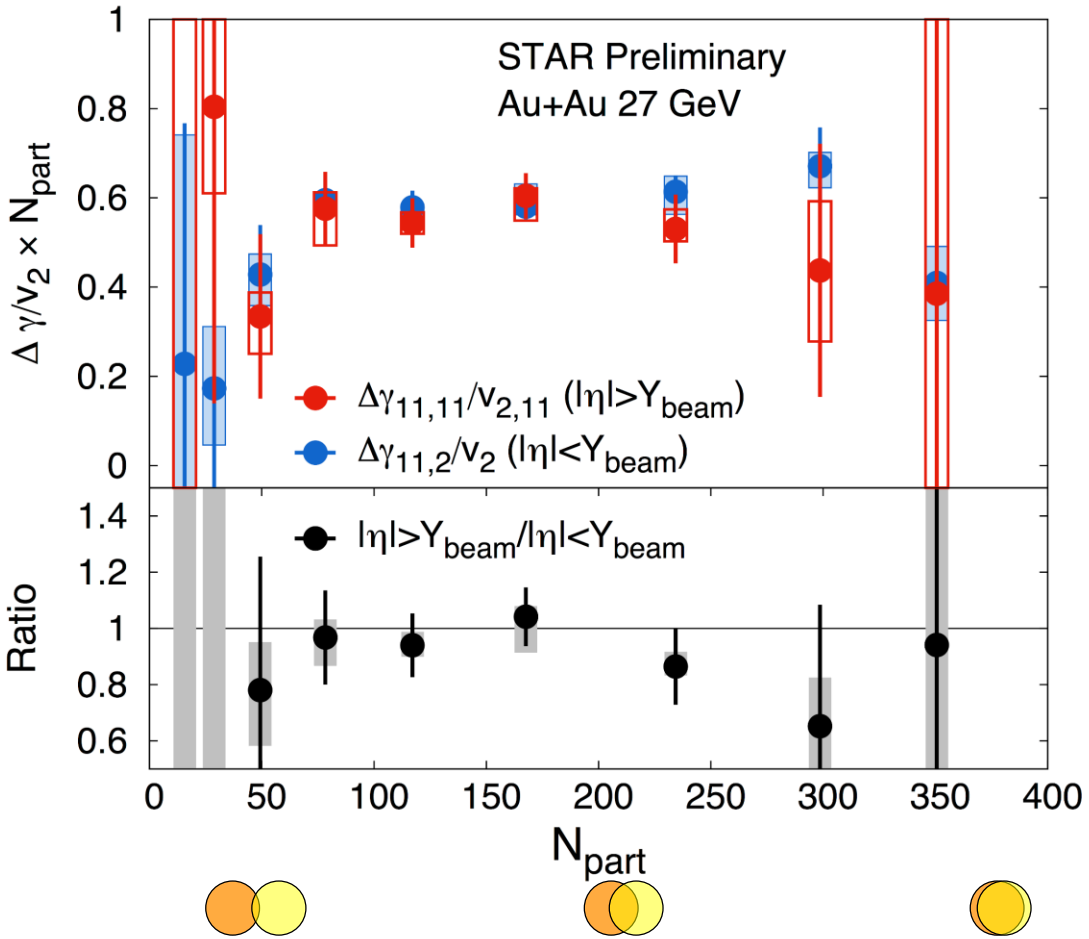




The ratio shows the elliptic anisotropy drops due to reduction in non-flow, de-correlation & change in flow fluctuations with pseudorapidity.

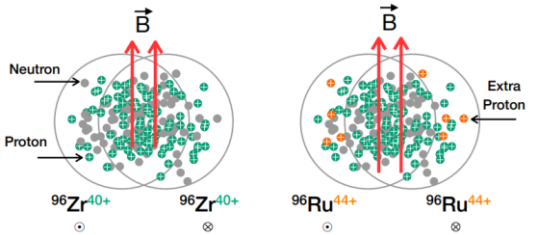
In mid-central events the charge separation w.r.t different planes are consistent with each other. In central and peripheral events spectator planes hint weaker charge separation although uncertainties dominate.

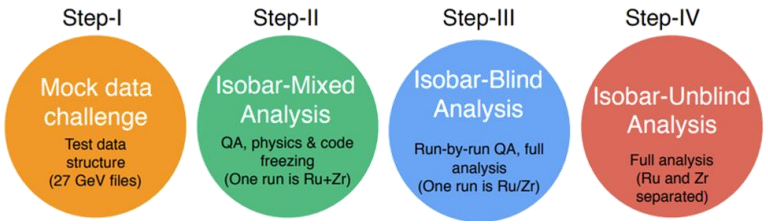
Measurement of charge separation



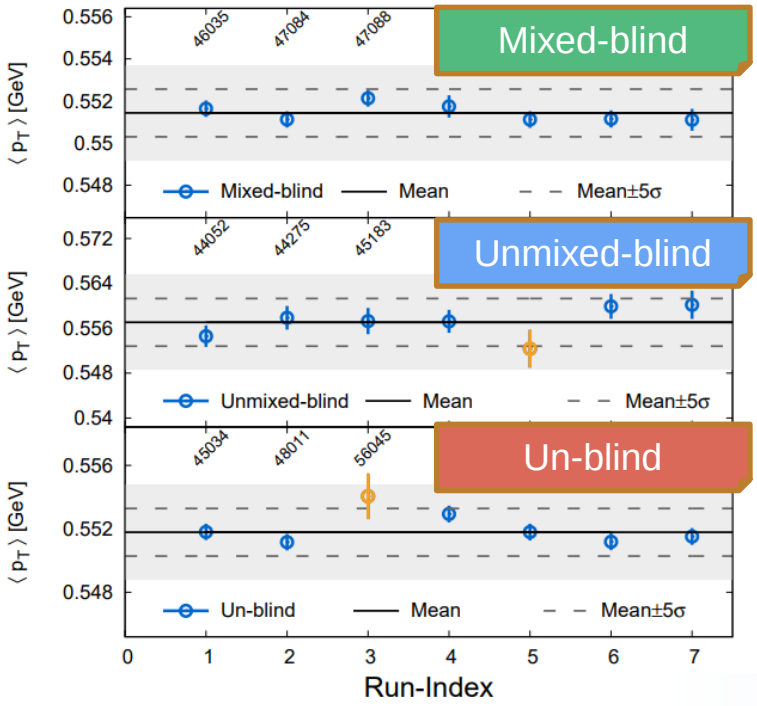
The quantity ($\Delta\gamma=\gamma(OS)-\gamma(SS)$) scaled by v_2 using different harmonic planes should be the same in case of background only scenario. The ratio of $\Delta\gamma/v_2$ between spectator proton rich EPD Ψ_1 plane and participant dominated Ψ_2 plane is presented — CME driven correlations will make this ratio >1.

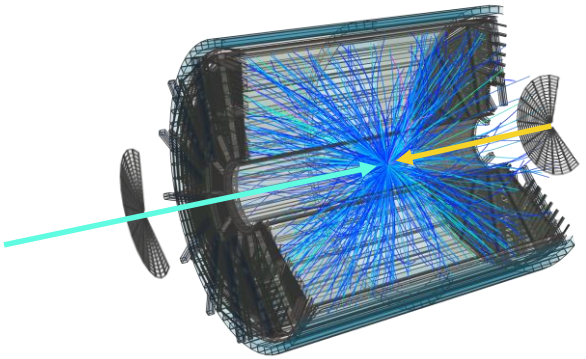
Decisive Tests Of CME Using Isobar Collisions

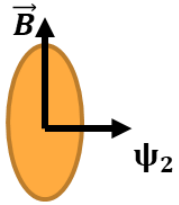
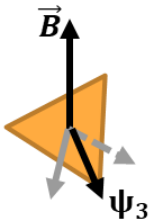




STAR collaboration, arXiv:1911.00596





	
$\gamma_{112} = \left\langle \cos\left(\phi_1^{\alpha} + \phi_2^{\beta} - 2\psi_2^{EPD}\right)\right\rangle$	$\gamma_{123} = \left\langle \cos\left(\phi_1^{\alpha} + 2\phi_2^{\beta} - 3\psi_3^{EPD}\right)\right\rangle$
Signal+background	Only background
Case for CME:	
$(\Delta\gamma_{112}/v_2)^{Ru+Ru}/(\Delta\gamma_{112}/v_2)^{Zr+Zr} > 1$	
$(\Delta\gamma_{112}/v_2)^{Ru+Ru}/(\Delta\gamma_{112}/v_2)^{Zr+Zr} > (\Delta\gamma_{123}/v_3)^{Ru+Ru}/(\Delta\gamma_{123}/v_3)^{Zr+Zr}$	

Summary

- At lower energies, the EPD acceptance ($2.1<|\eta|<5.1$) covers the region where particle production is accompanied by a large directed flow of beam fragments, stopped protons and spectators. Therefore, the EPD can measure the event plane associated with the spectators, strongly correlated to the magnetic field, with good precision.
- From the ratio of $\Delta\gamma/v_2$, we see no significant difference in the scaled charge separation w.r.t spectator proton & produced particle event planes.
- The isobar data taking was a success, bind analysis is ongoing by STAR.

Thank you!