STAR measurements on charge-dependent correlations in 27 GeV Au+Au collisions to search for the Chiral Magnetic Effect

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for the STAR collaboration

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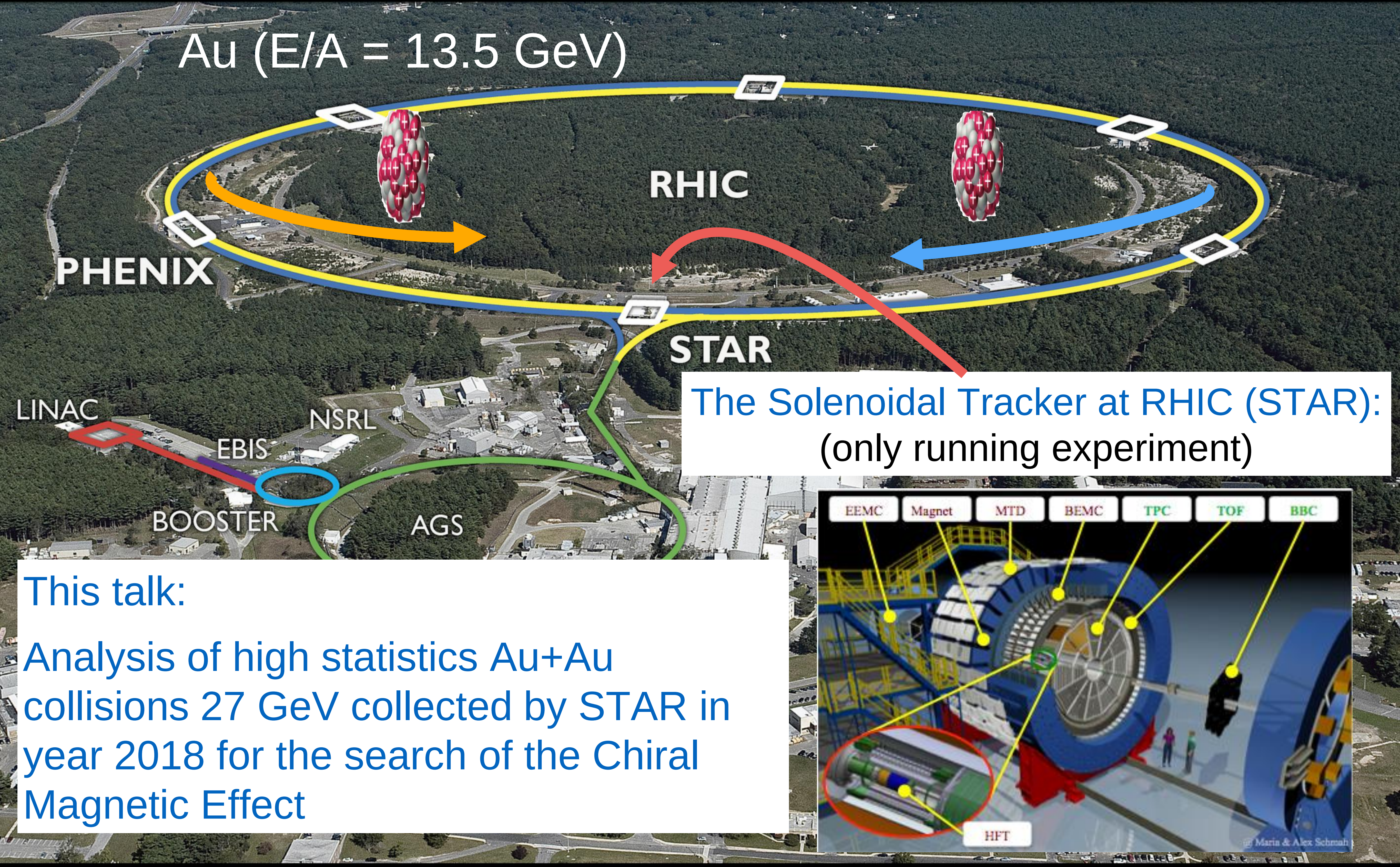
Outline



The Solenoidal Tracker at RHIC (STAR):
(only running experiment)

This talk:

Analysis of high statistics Au+Au collisions 27 GeV collected by STAR in year 2018 for the search of the Chiral Magnetic Effect

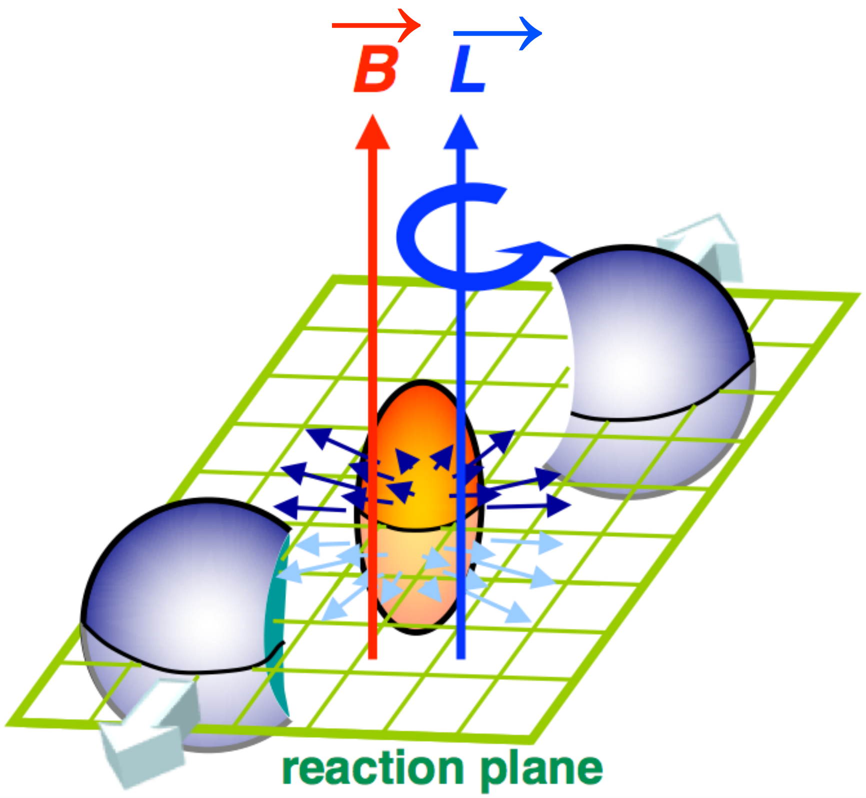
Strongest B-field in the Universe

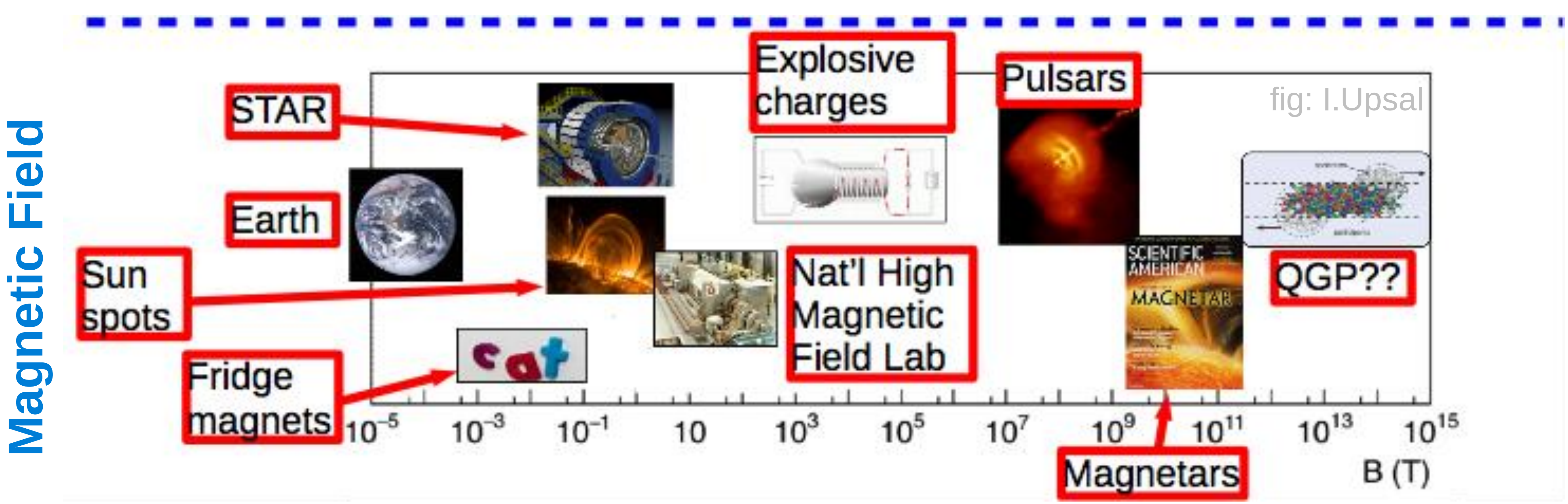
Collisions of two heavy ions create the strongest magnetic fields in the universe

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)

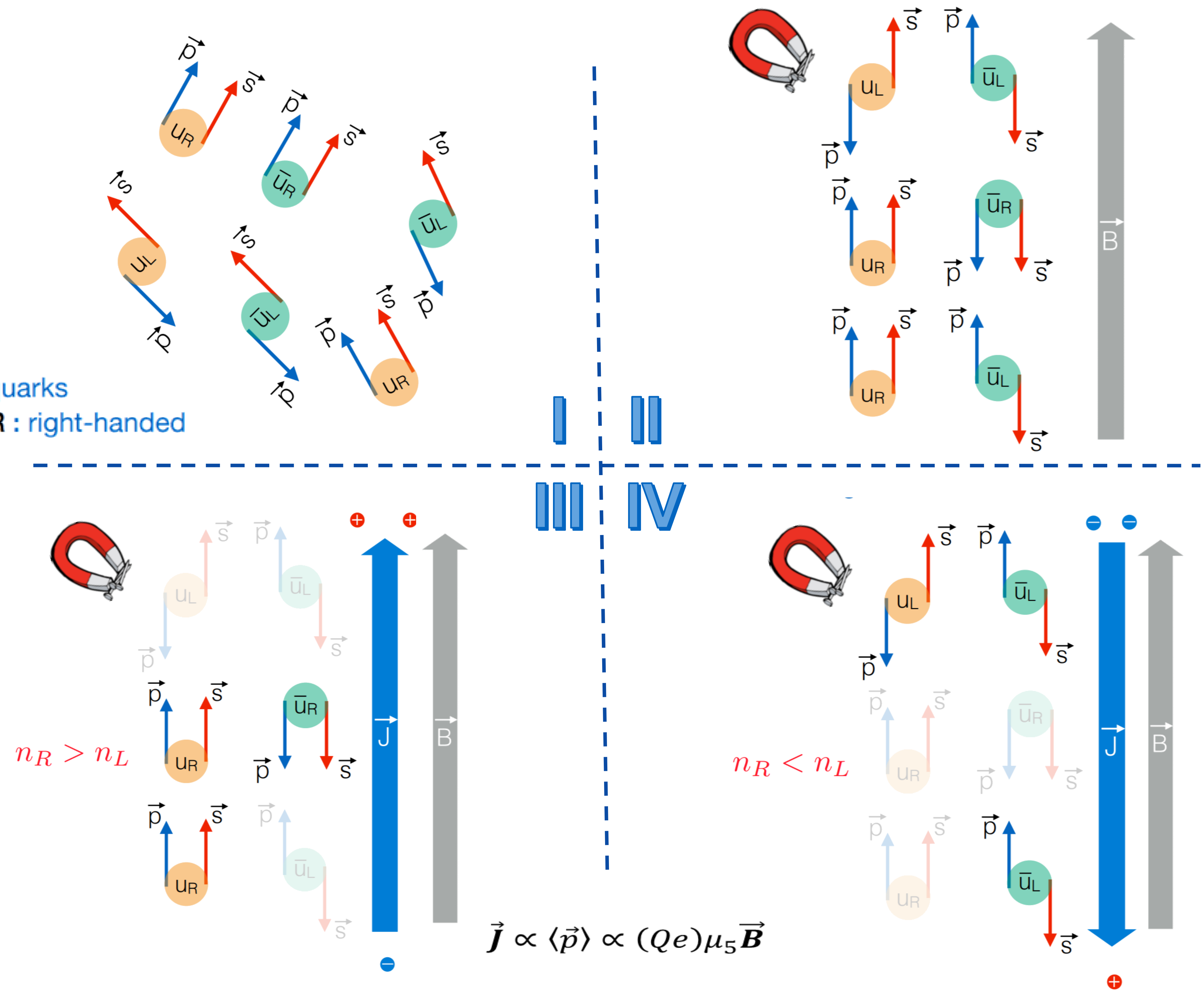




What is Chiral Magnetic Effect?

Quarks randomly oriented

Quarks aligned along B



quarks antiquarks

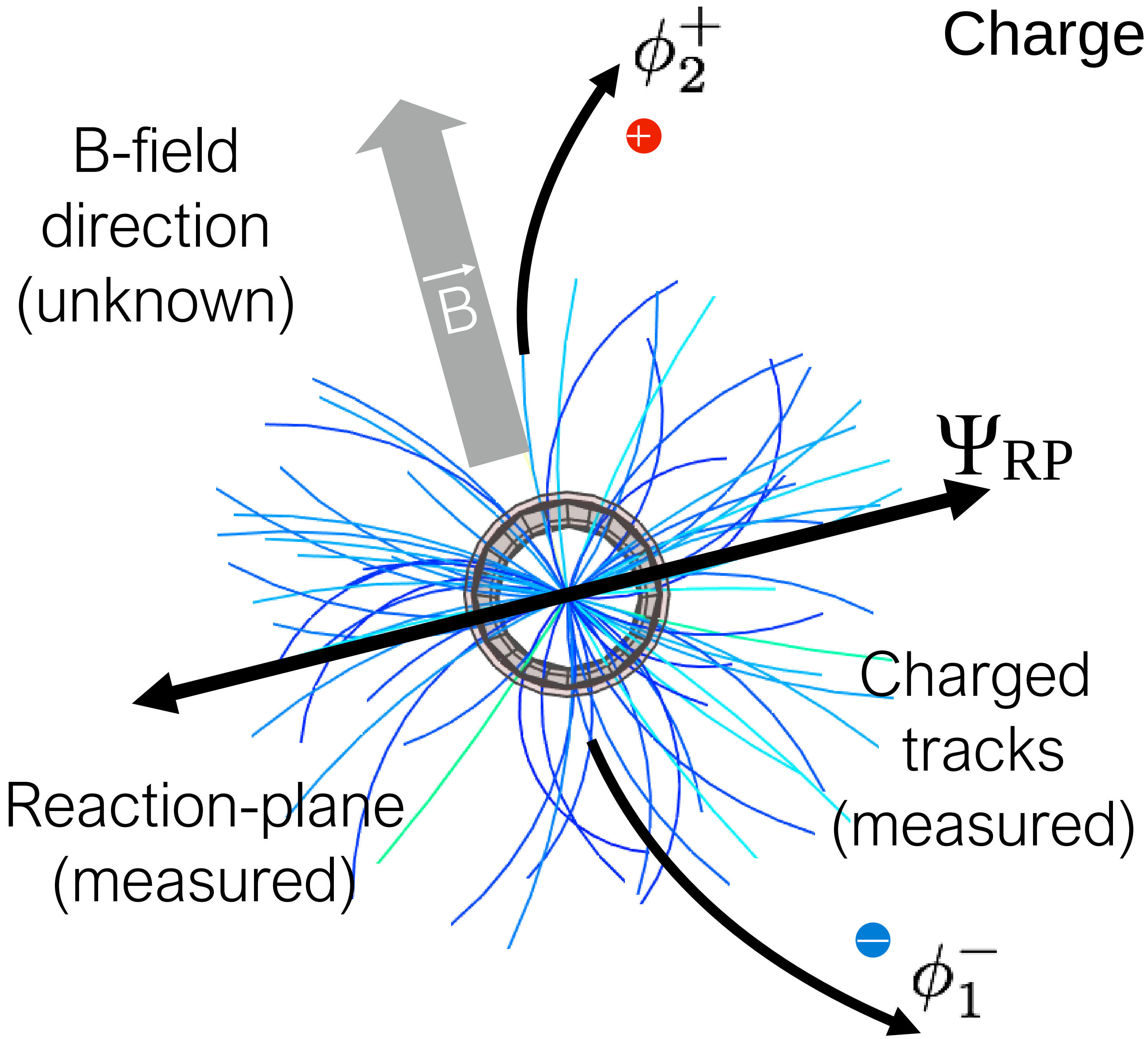
L : left-handed **R** : right-handed

More right-handed quarks J || B

More left-handed quarks J || -B

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

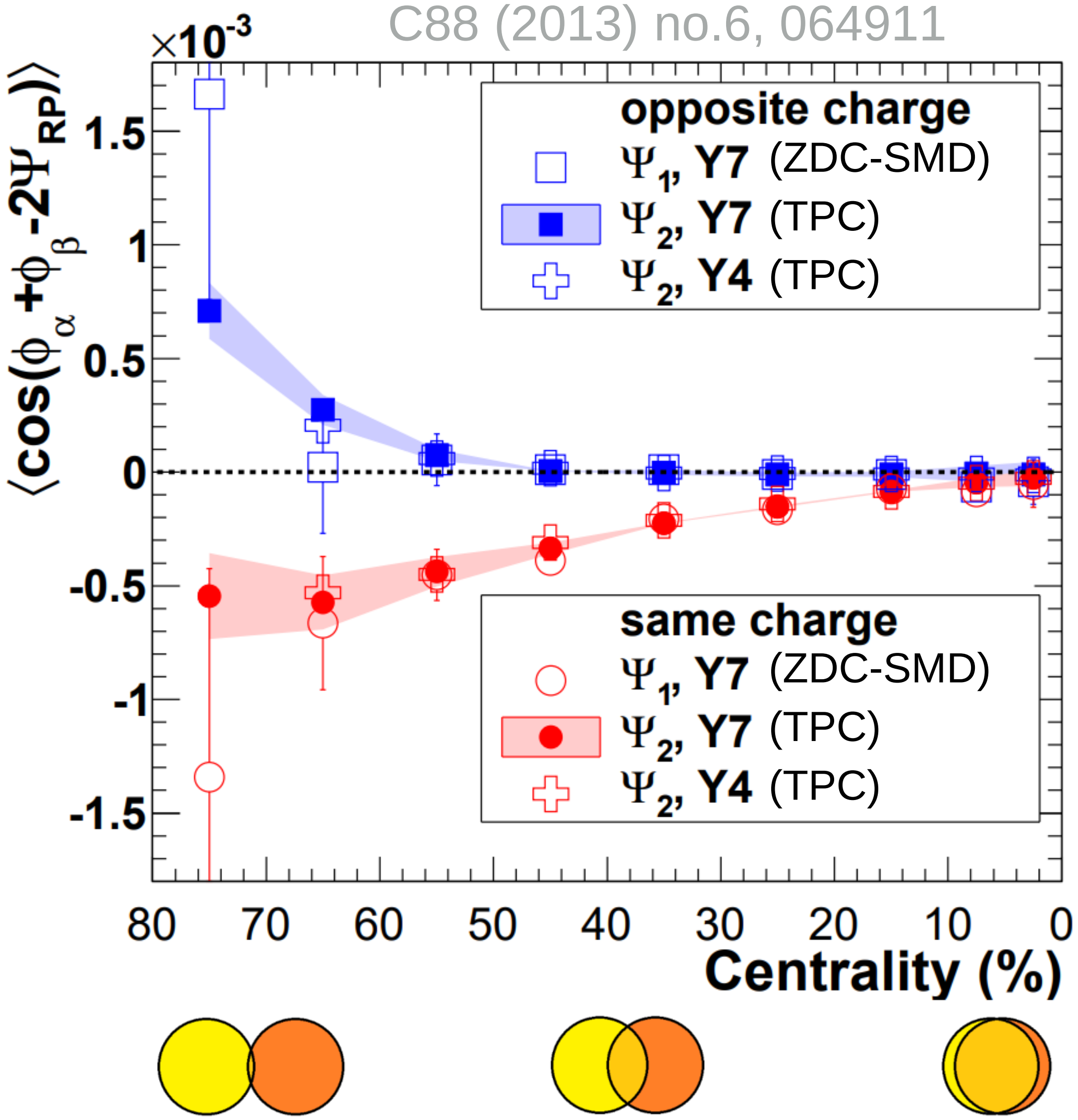
How to detect Chiral Magnetic Effect



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



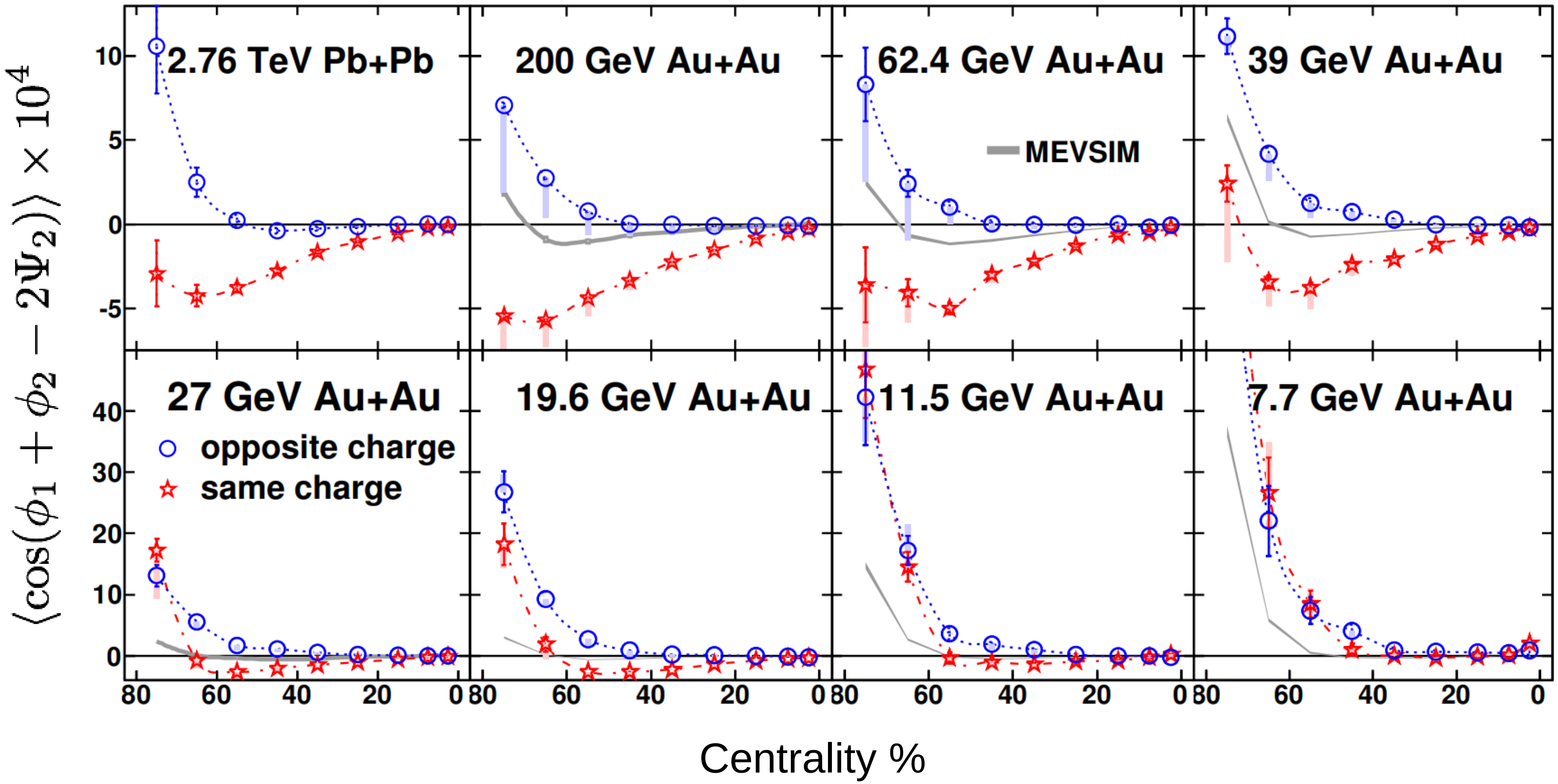
We measure the angular correlations of positive and negative particles across a plane (reaction plane) that is correlated to B-field directions.

CME search at lower energies

Motivation: √s dependence & BES-I data

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

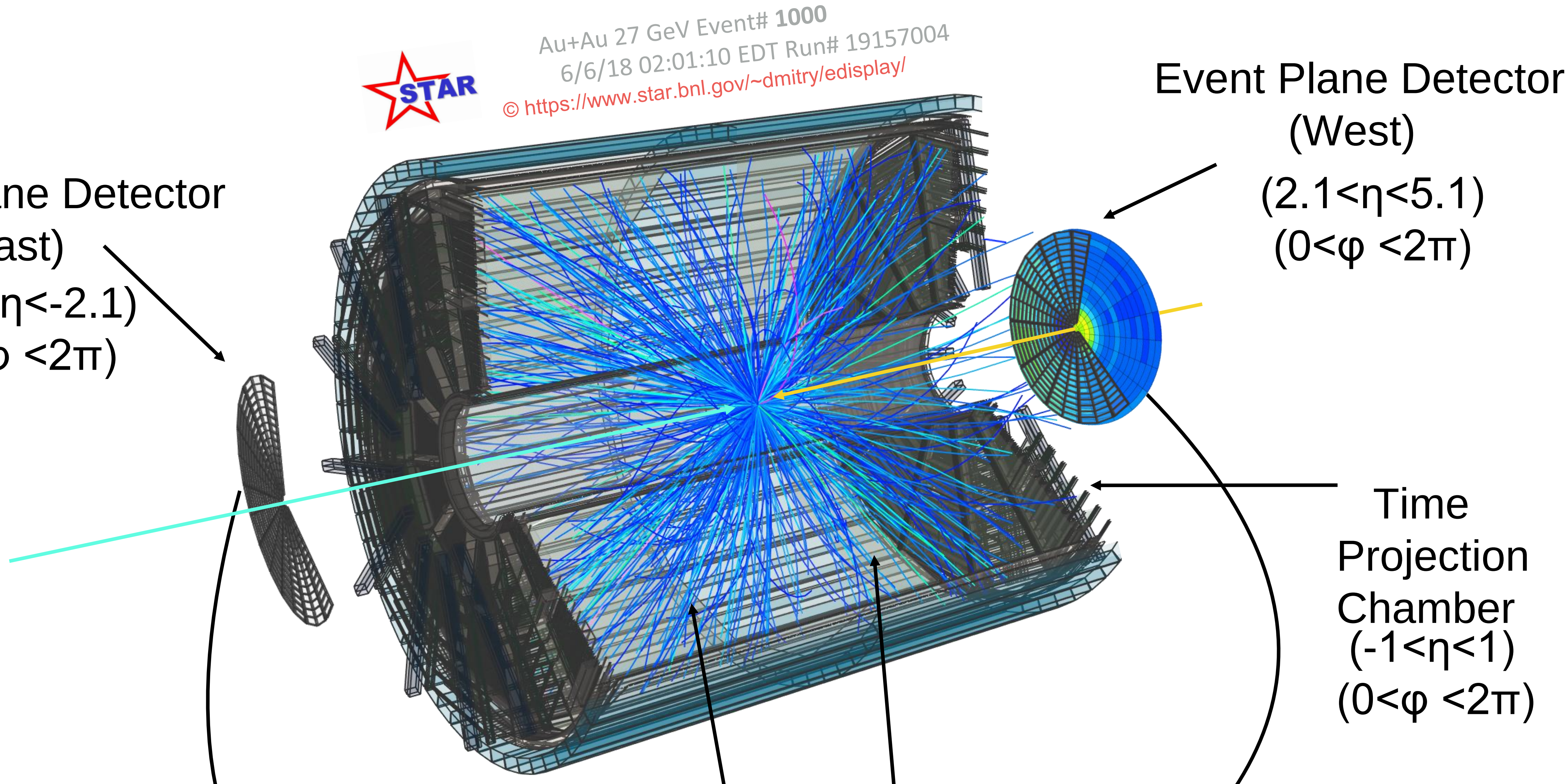
L. Adamczyk et al. (STAR Collaboration), PRL 113 (2014) 052302.



Interesting observation: charge separation disappears at lower energies

We revisit the 27 GeV analysis with new capabilities & high statistics data

STAR capability for CME search at low energies



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

We measure charge-dependent azimuthal correlator using TPC and EPD

EPD: new capability of CME search at STAR

STAR Event Plane detector acceptance: $2.1<|\eta|<5.1$

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

EPD detects both participants & spectators

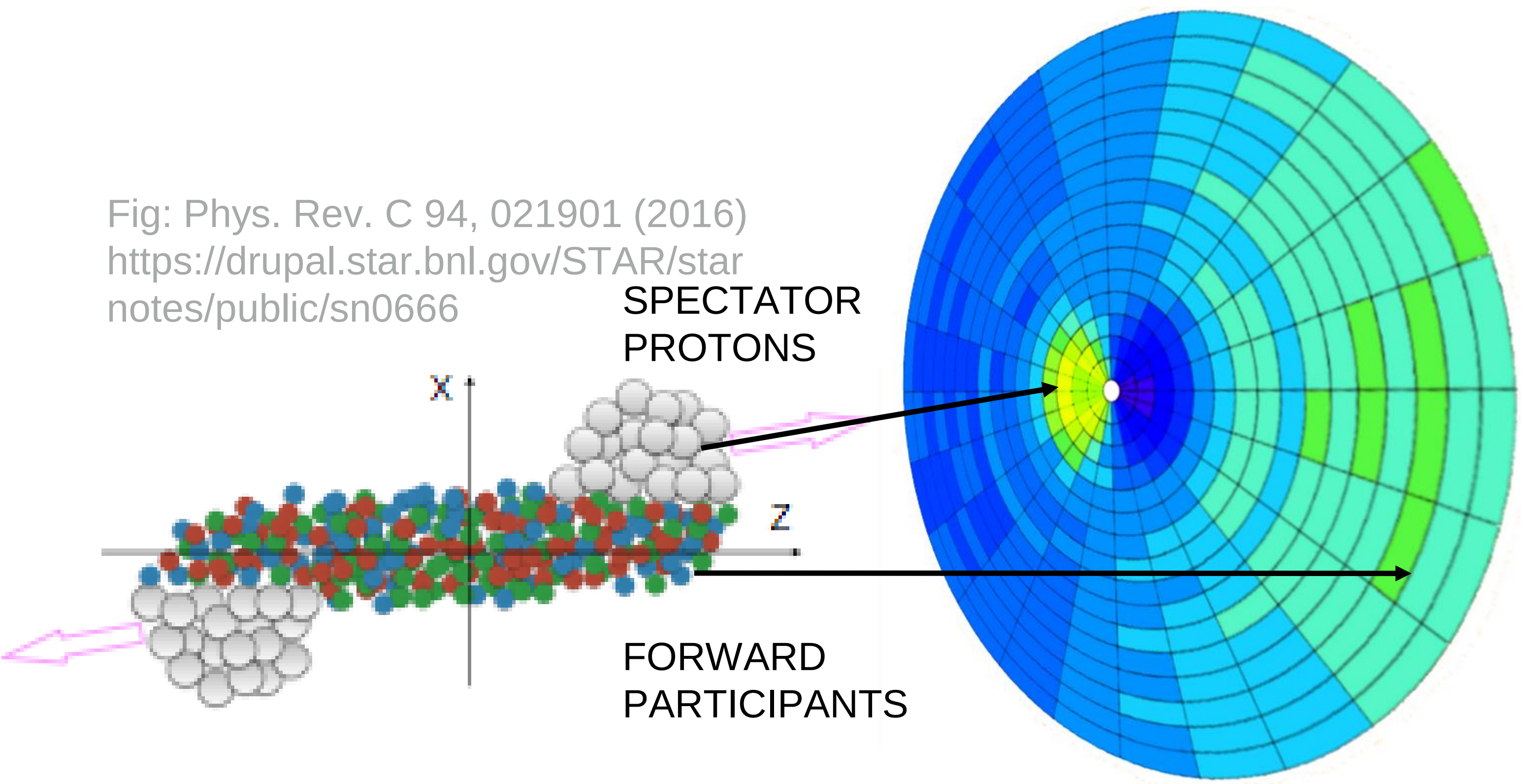
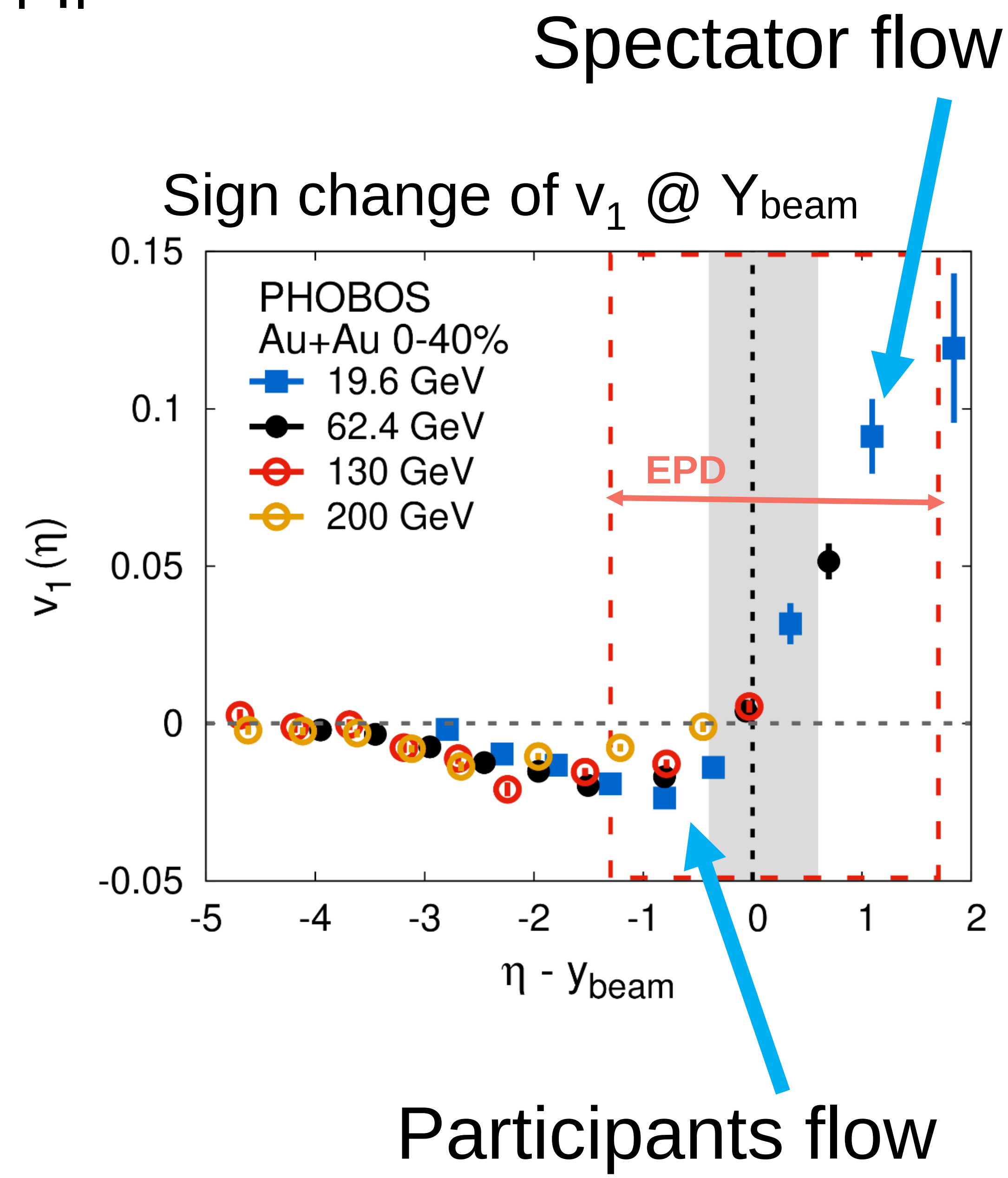


Fig: Phys. Rev. C 94, 021901 (2016)
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666



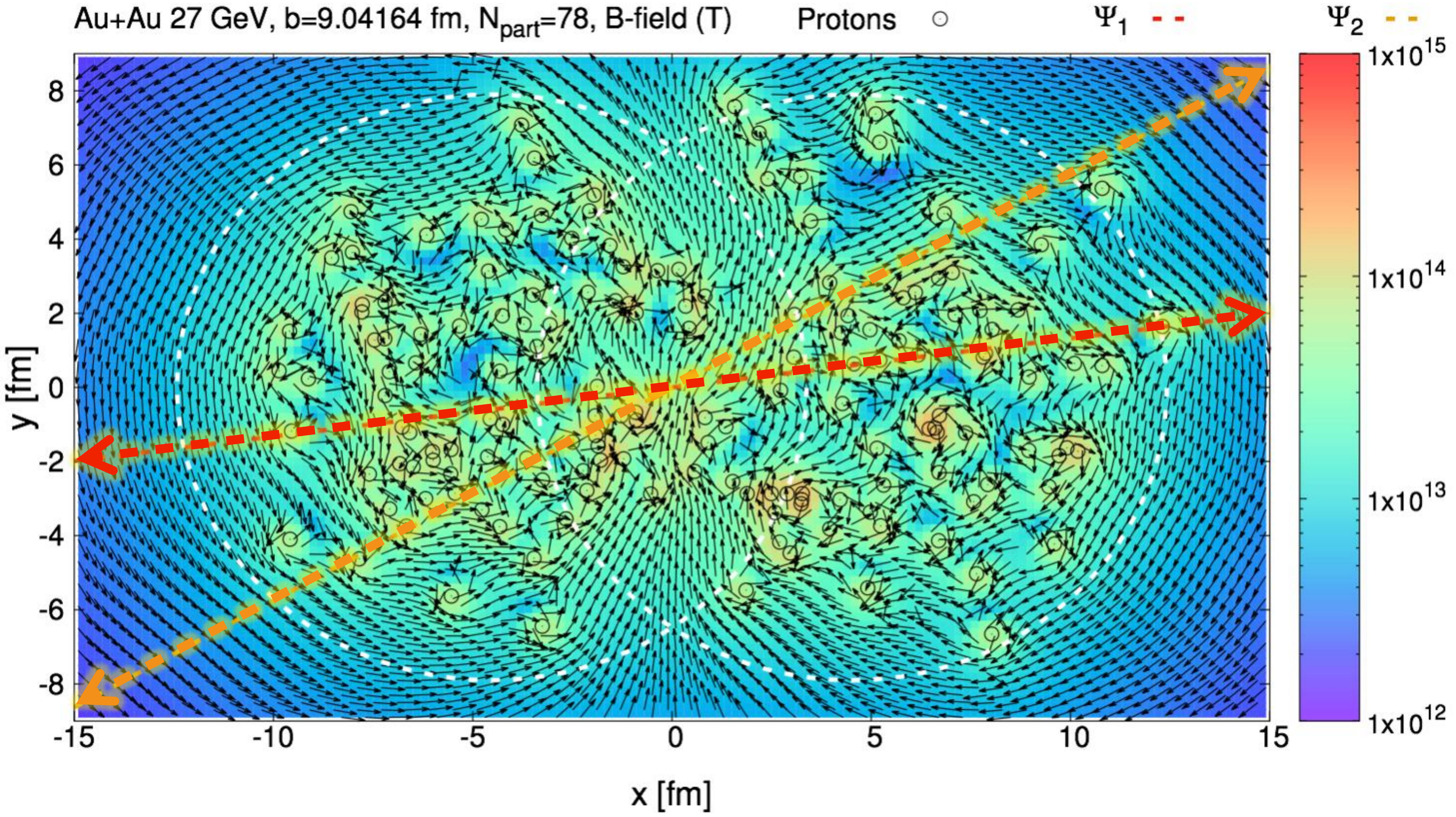
We use two planes from EPD as proxy for Ψ_{RP}

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

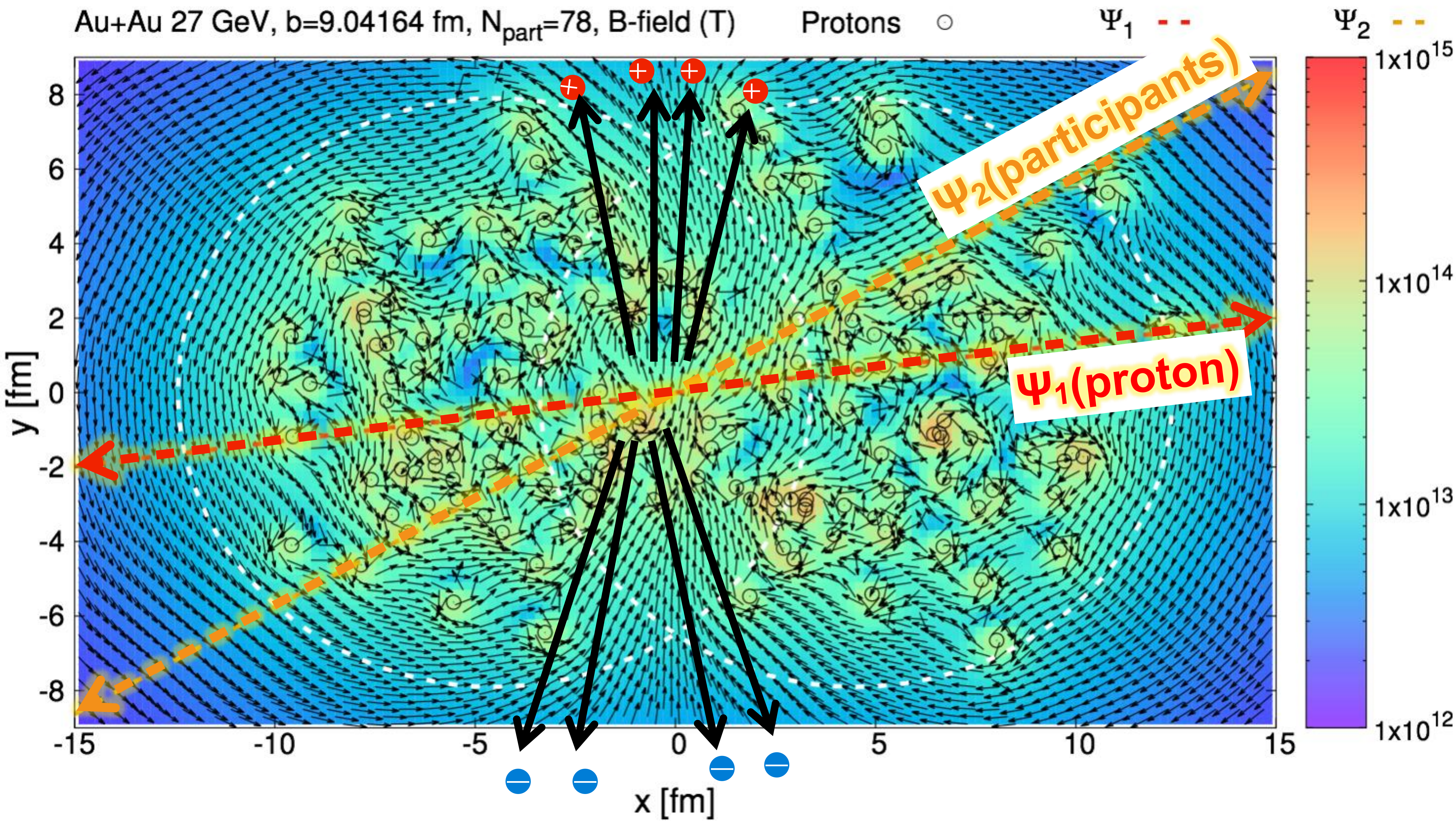
Ψ_2 ($\eta < Y_{beam}$): 2nd-order event plane of particles going in forward direction

First ever CME search of spectator proton plane

Magnetic field map in a single collision



Magnetic field map in a single collision

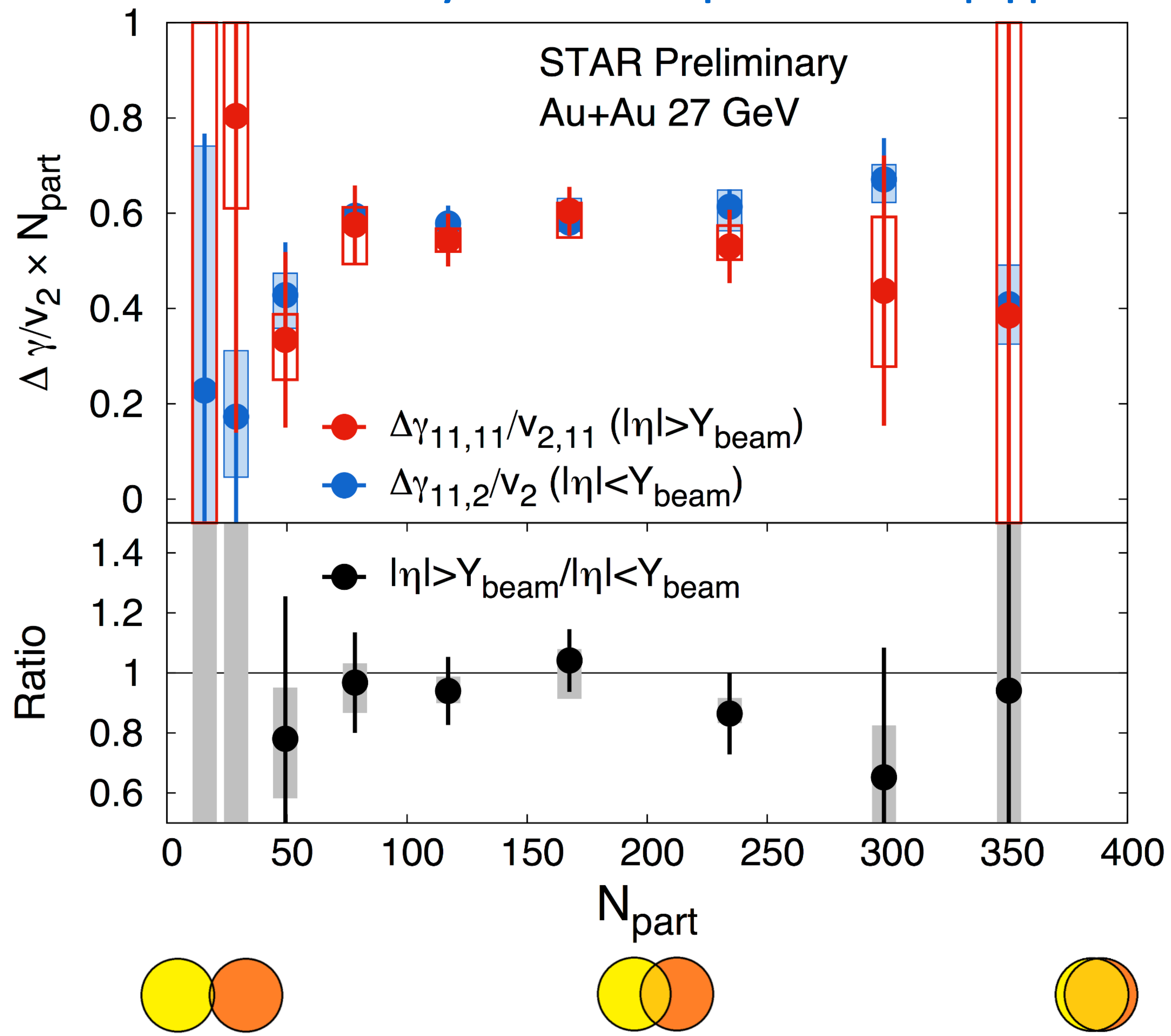


Ψ_1 (proton) is more correlated with Ψ_B than Ψ_2 (participants)

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

Measurement of charge separation

Charge separation normalized by v_2 w.r.t. planes at $|\eta|<Y_{beam}$ and $|\eta|>Y_{beam}$



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

Summary

- We utilized the unique combination of Au+Au 27 GeV data collected by STAR in the year 2018 of RHIC run and the newly installed Event Plane Detector to study charge separation w.r.t. spectator-proton & event planes at forward rapidity using the same detector.
- We see no significant difference of charge separation between the two scenarios.
- Our results will put strong constraints on CME search.

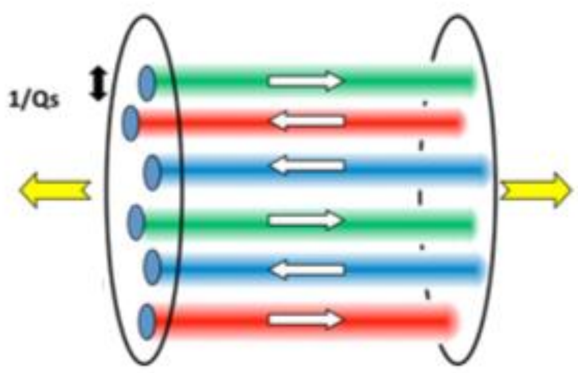
Thanks

Backup

Observability of CME in heavy-ion collisions

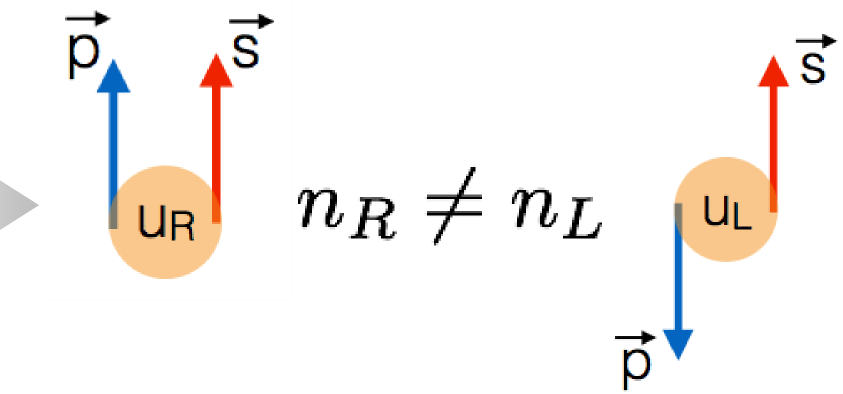
#1: Non-conservation of chirality: Collisions generate fluctuating parallel chromo E & B fields

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

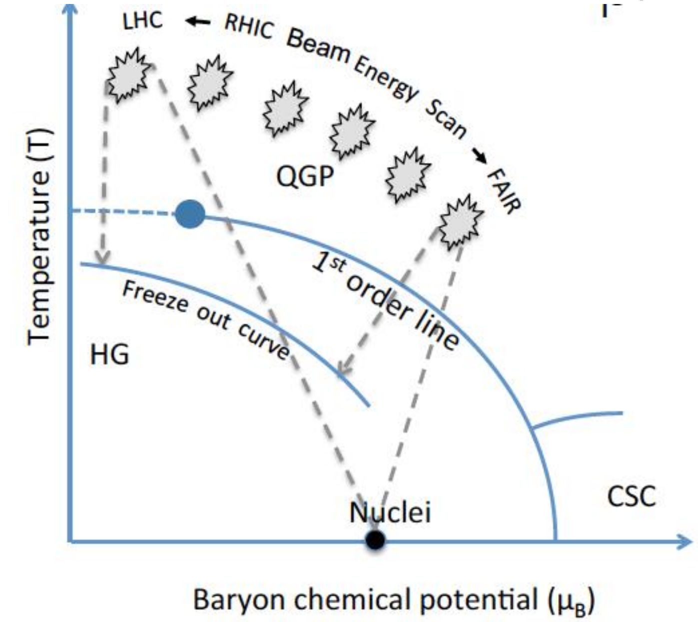


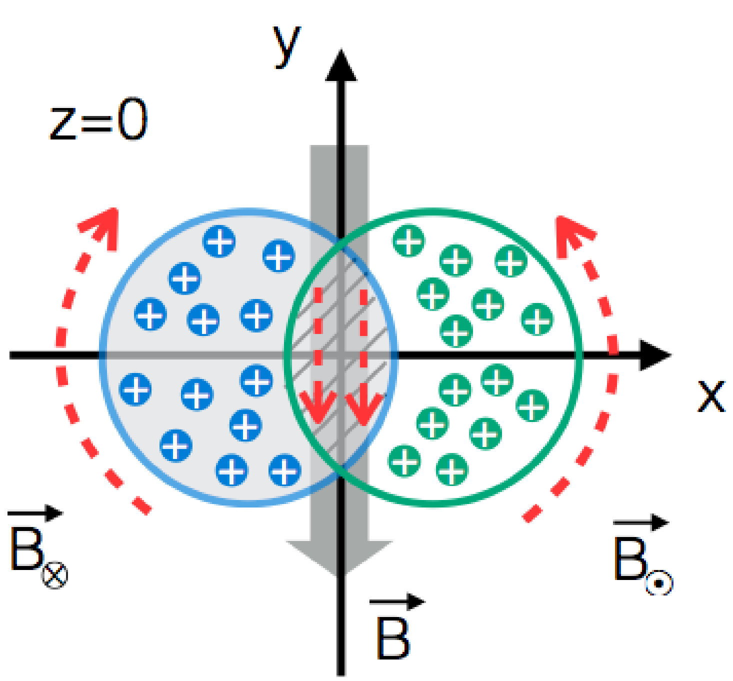
$E \parallel B \parallel \hat{z}$

$$dQ_5/dt \propto \mathbf{E}\cdot\mathbf{B}$$



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





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

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

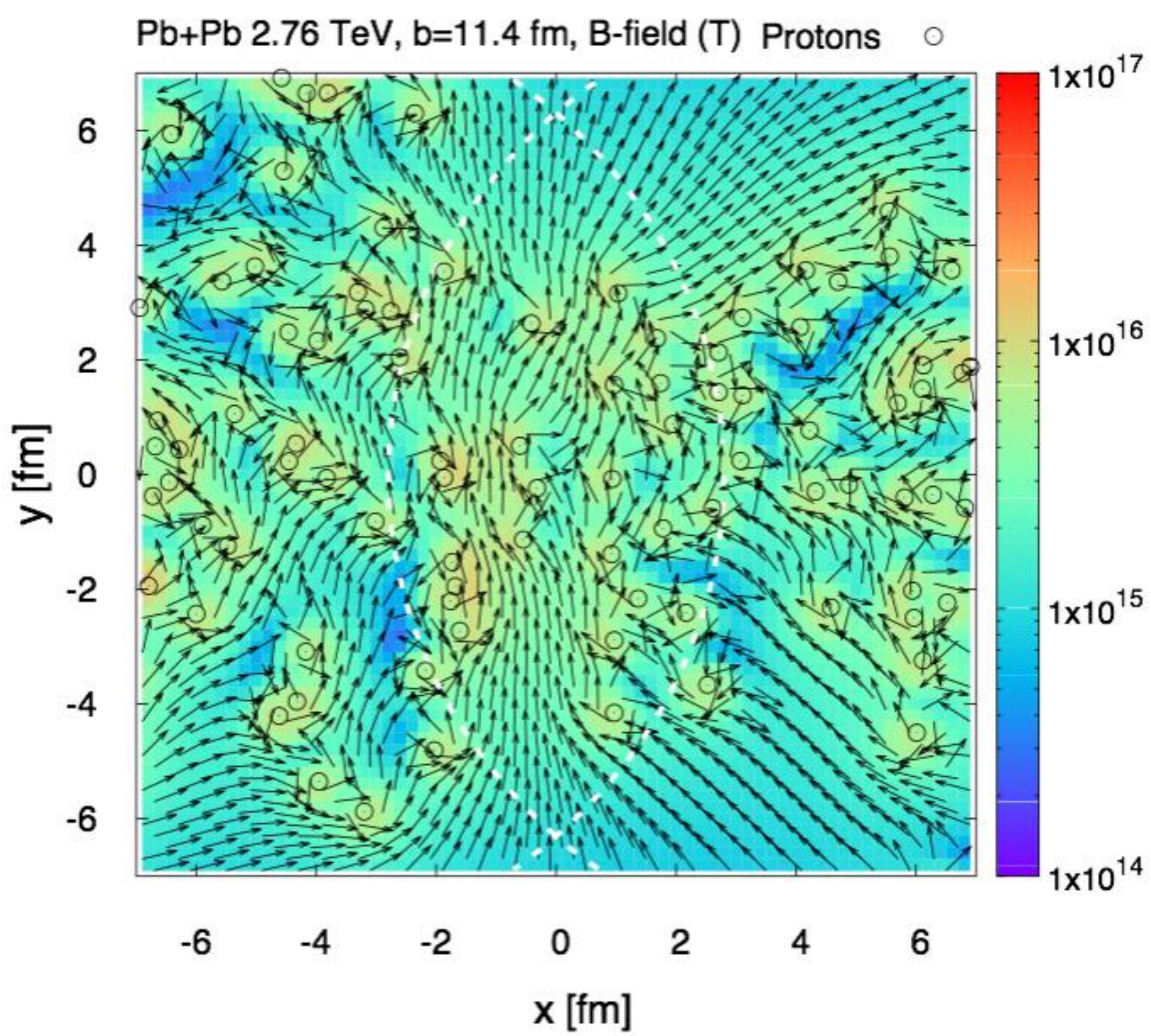
All three conditions are strongly √s-dependent

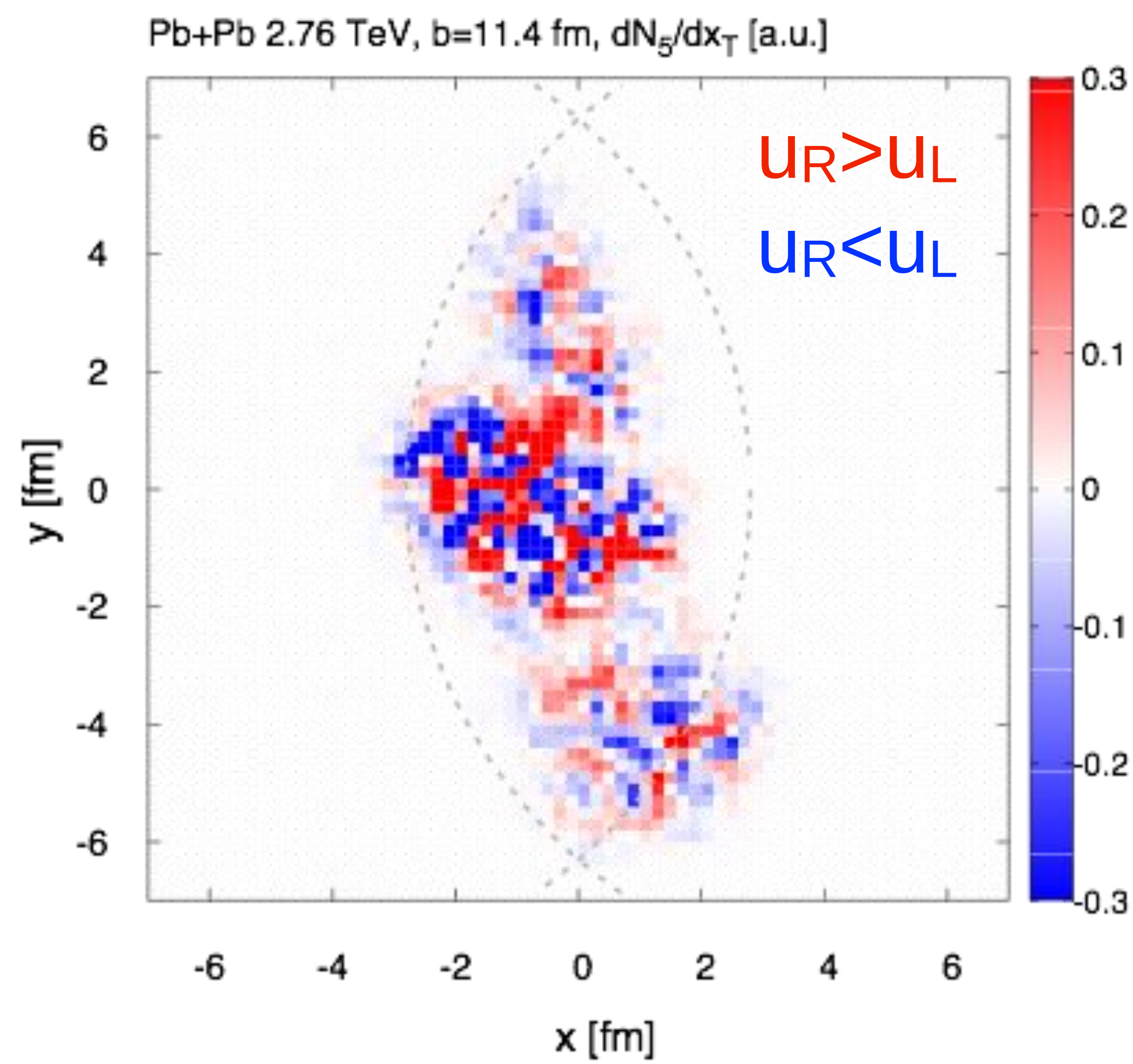
Complexity of a real event

Magnetic field map

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

axial charge





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

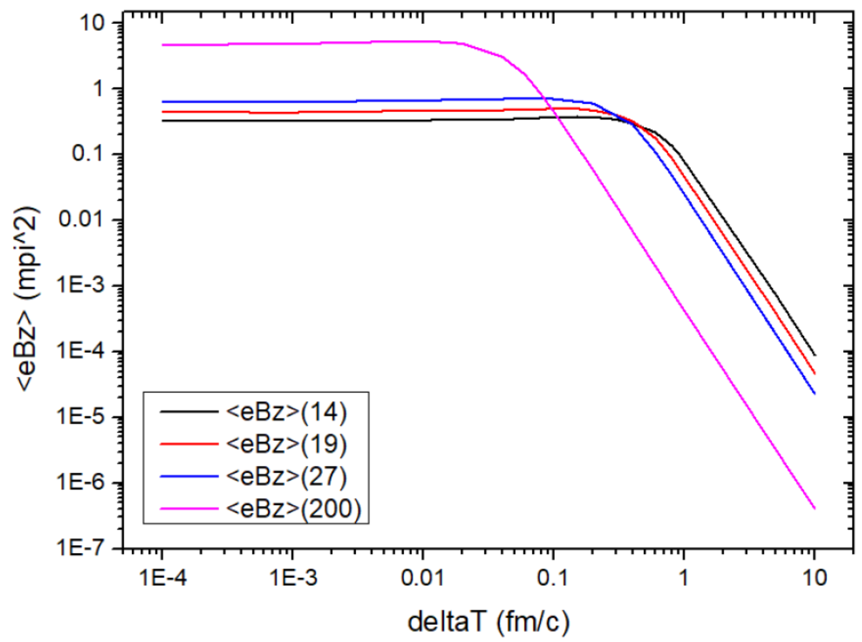
Based on: Lappi, Schlichting, Phys. Rev. D 97, 034034 (2018)

Going beyond cartoon picture: fluctuations dominate e-by-e physics

Both B-field & domain size of axial-charge change with √s

Why choose 27 GeV?

- At low collision energies the magnetic field is smaller than at high energies, but also has longer lifetime.
- New higher statistics low energies data.
- CME search at the LHC and top RHIC energy indicates the dominance of background. What happens at lower energy is of prime interest where the physics-driving signal and background are different.



The magnetic decay at different energies by a multiphase transport (AMPT) model simulation

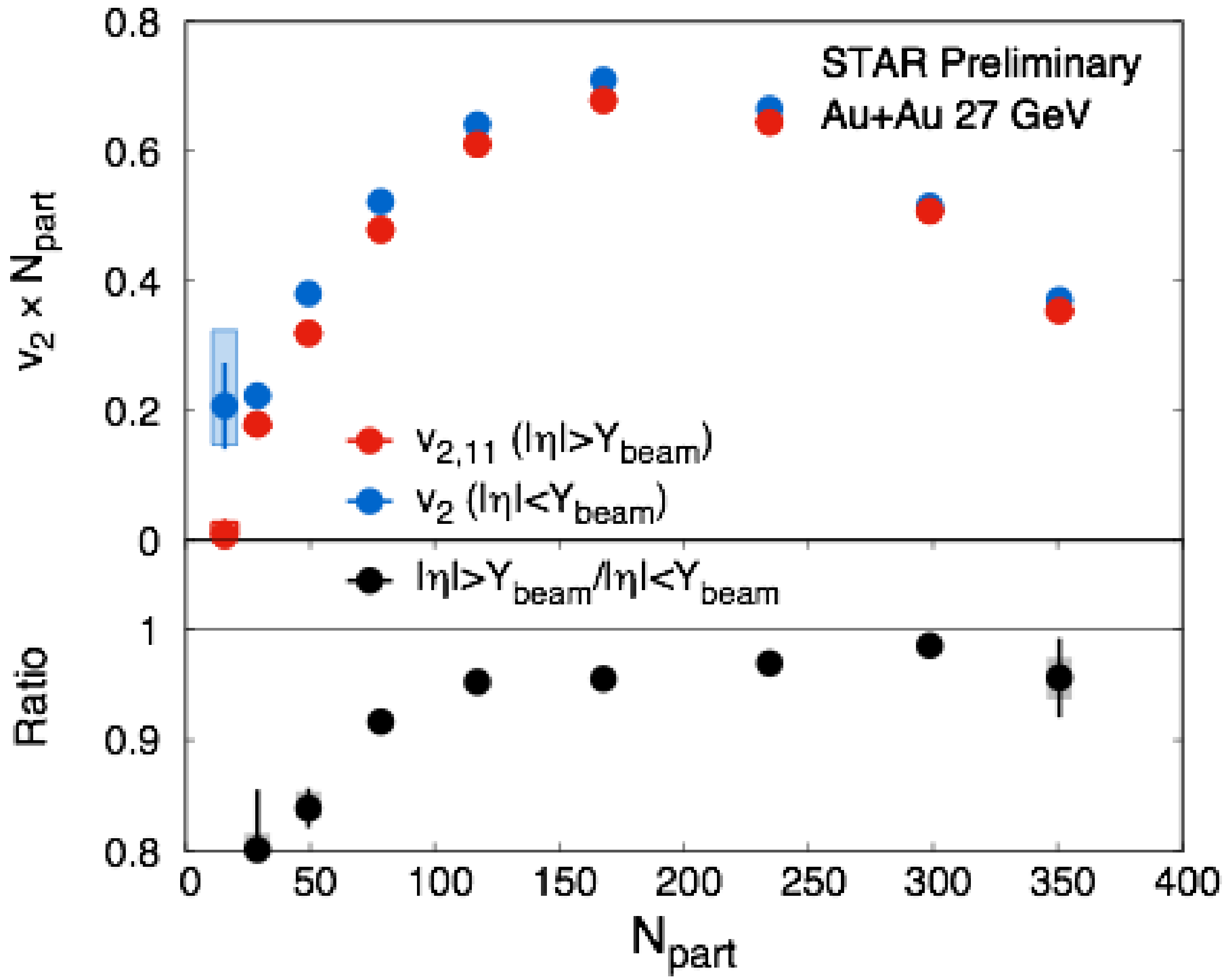
First step : Measurement of Elliptic anisotropy

Elliptic anisotropy w.r.t. the plane constructed from 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.t. the plane constructed from spectator protons $|\eta|>Y_{beam}$

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



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

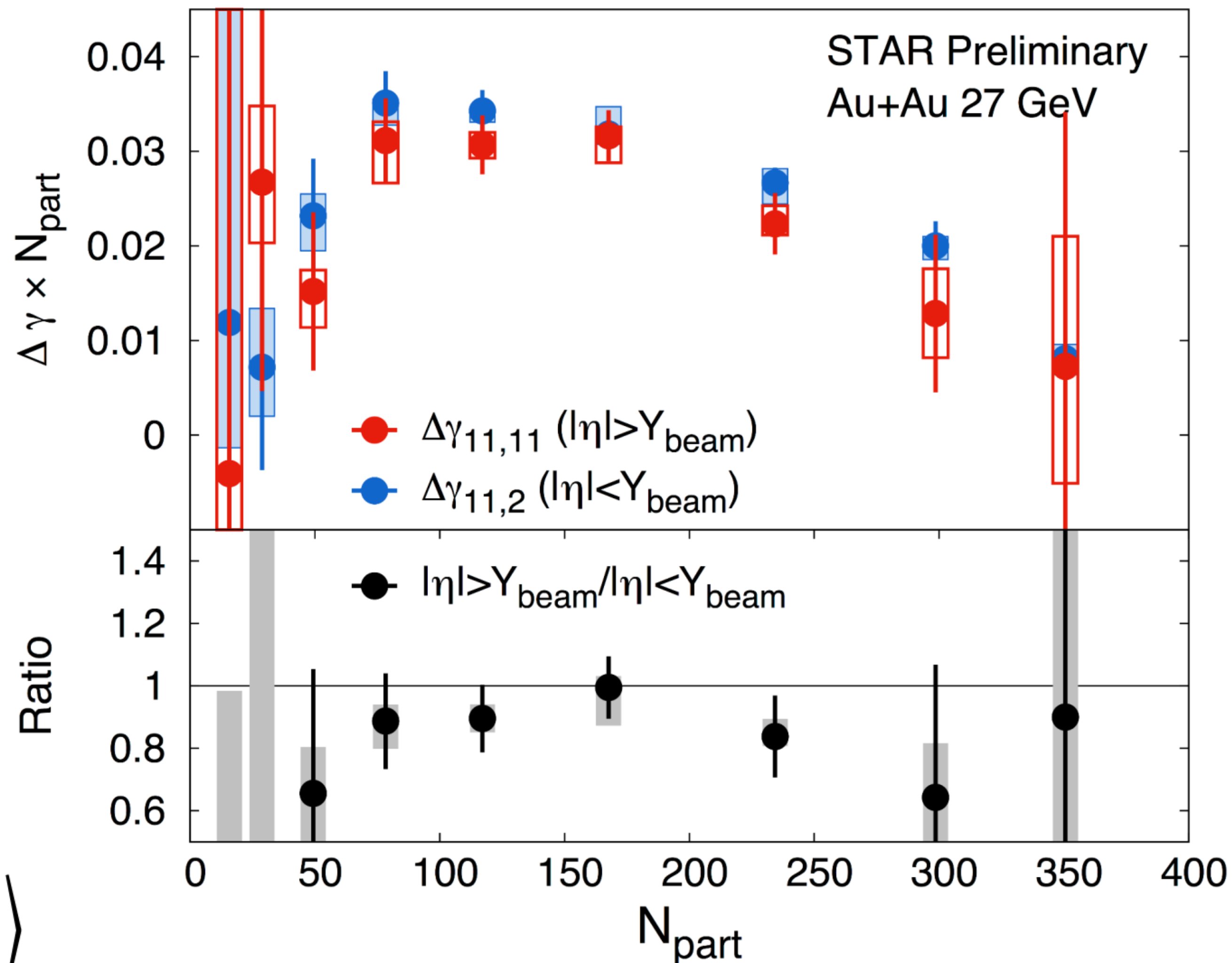
First step: Measurement of charge separation

Charge separation w.r.t. the plane constructed from 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. the plane constructed from 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.