

RHIC 25

A quarter century of
discovery

May 20-23, 2025

2025 RHIC/AGS ANNUAL
USERS' MEETING

STAR

**25
YEARS**



Brookhaven[®]
National Laboratory

Supported in part by



U.S. DEPARTMENT OF
ENERGY

Argonne
NATIONAL LABORATORY



S

Search for the Chiral Magnetic Effect from STAR Beam Energy Scan-II data

Zhiwan Xu

Argonne National Lab

May 22, 2025

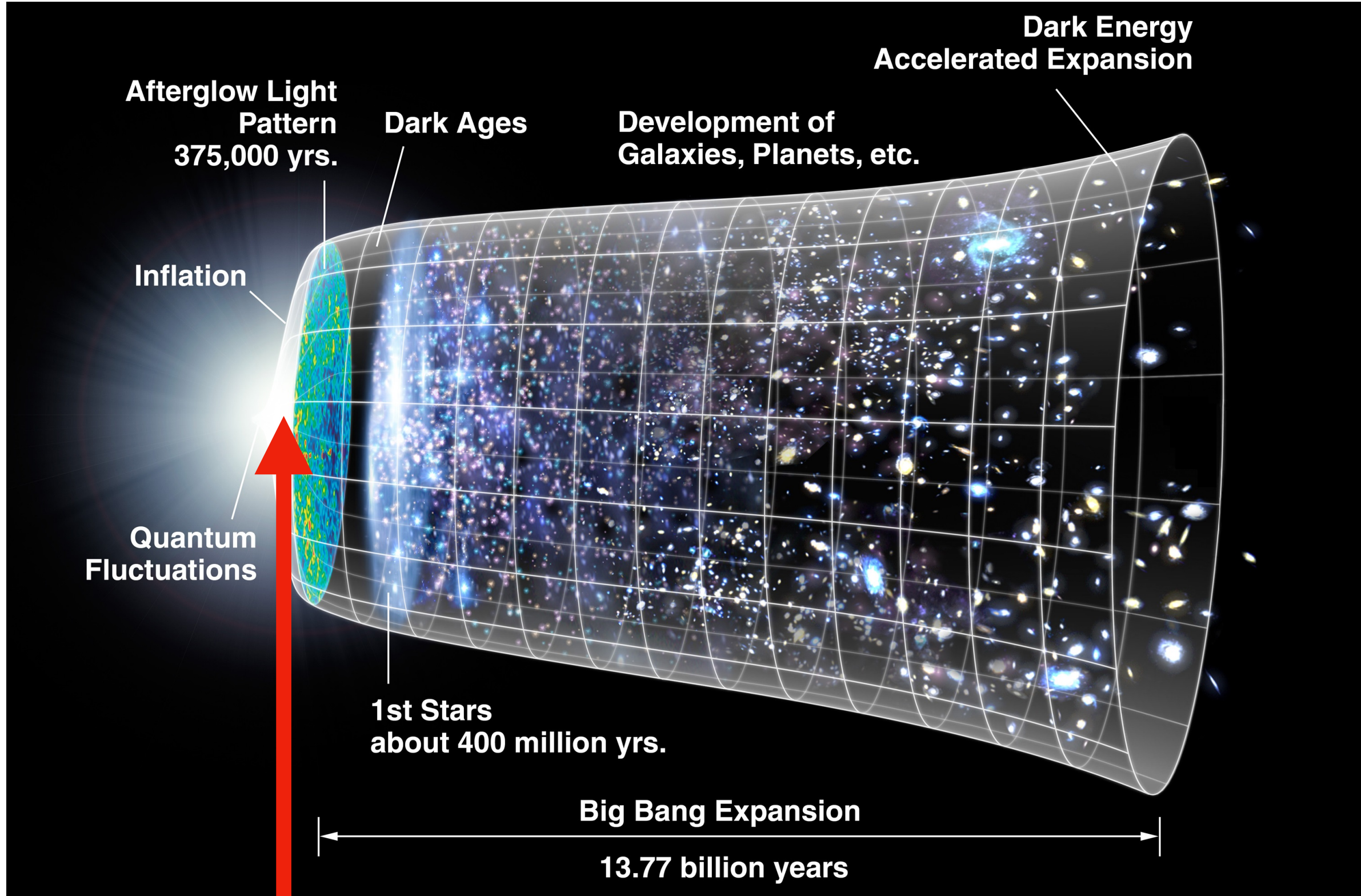
Brookhaven, NY



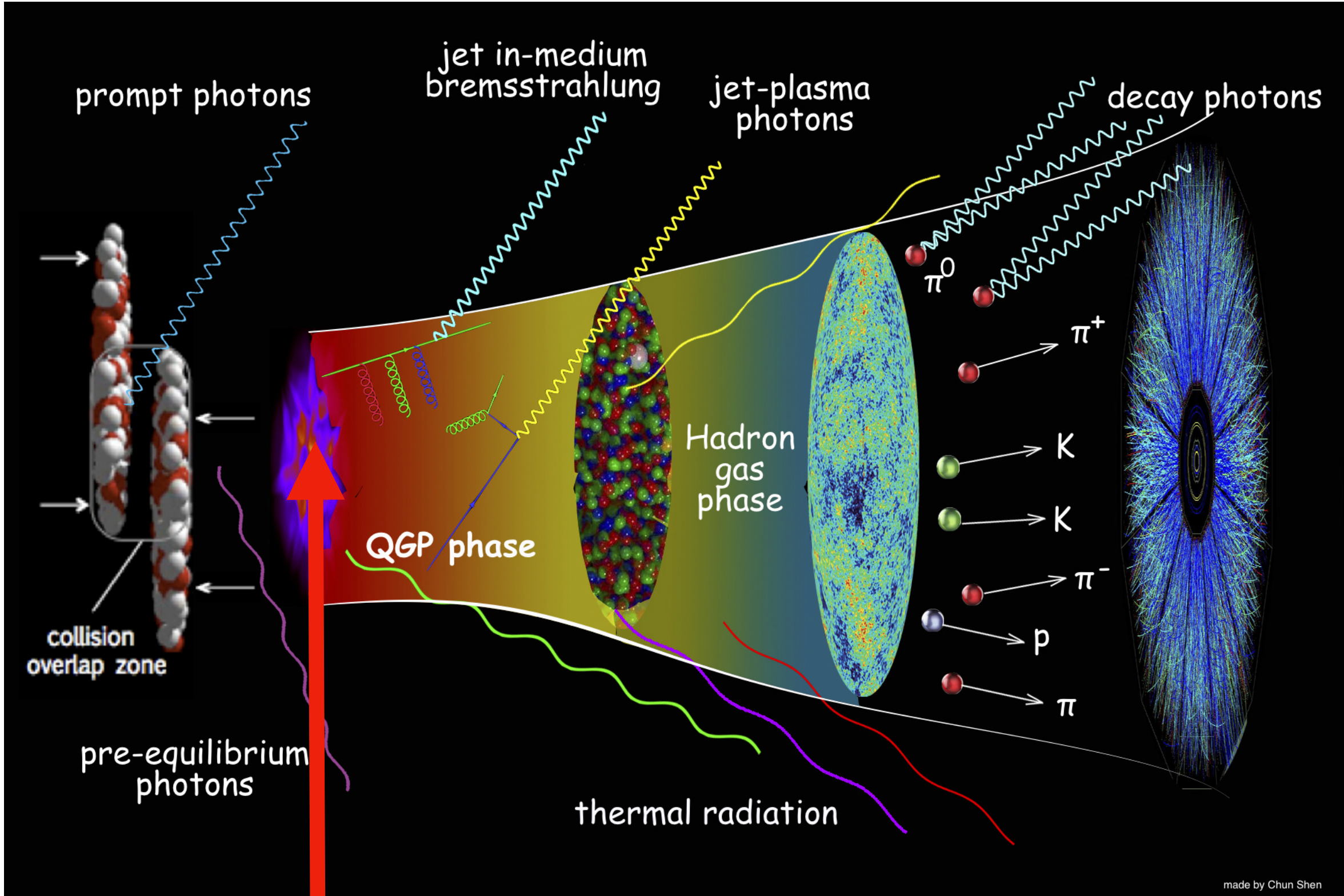
UCLA

Quark Gluon Plasma: the Small Bang

The Big Bang Theory

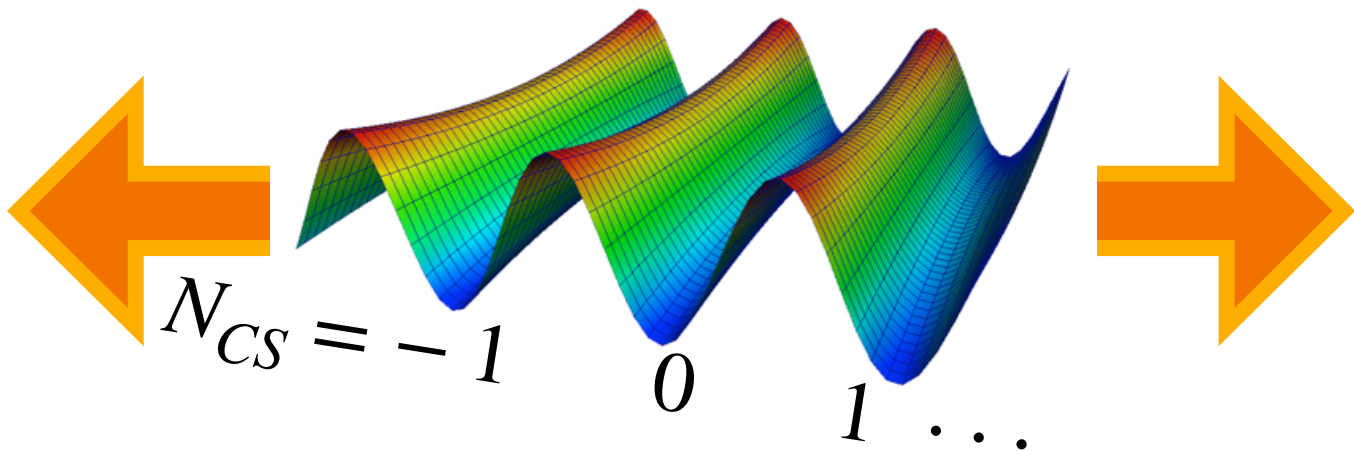


The “Small Bang” at RHIC



“Baryogenesis”

Matter > Anti-matter



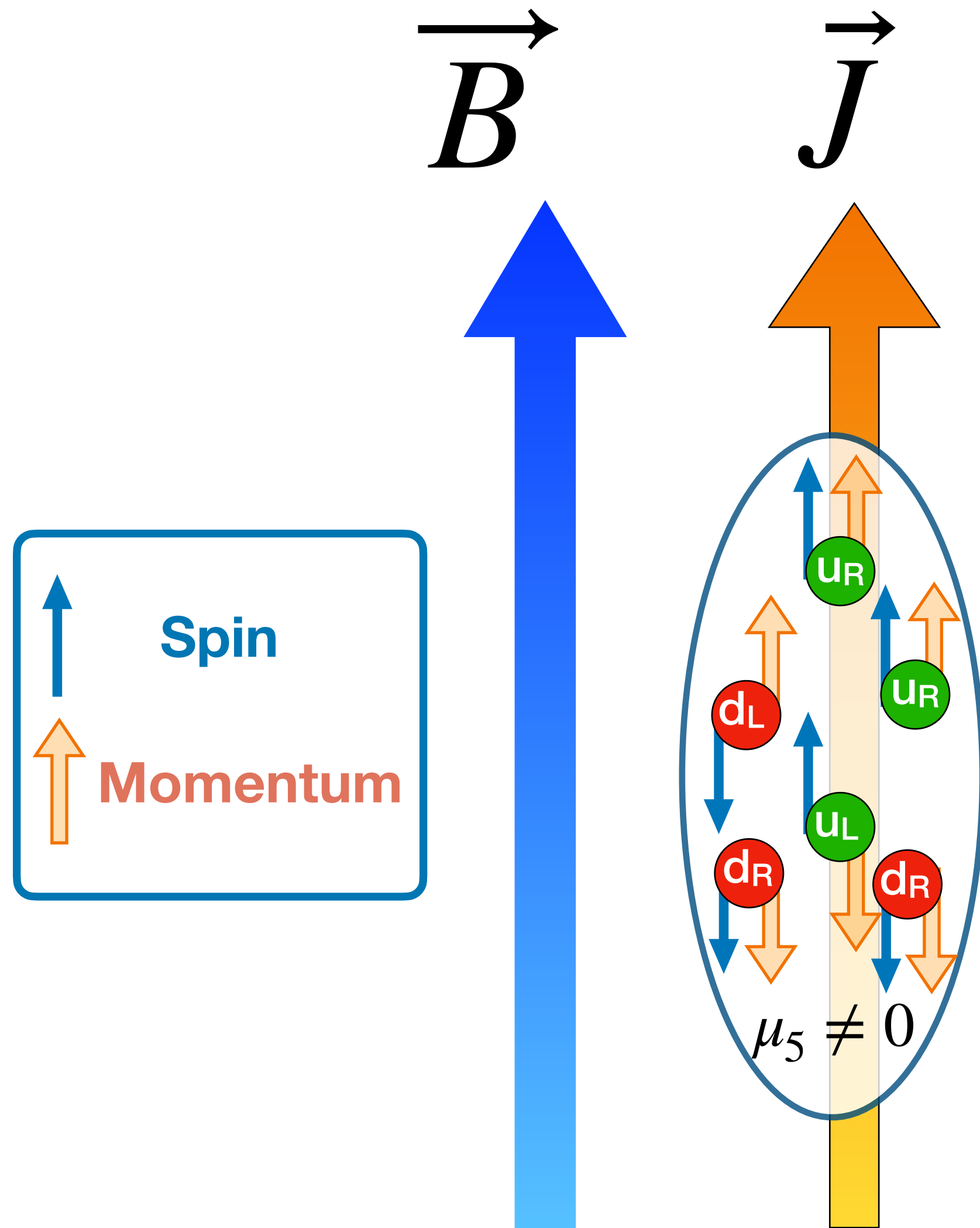
“Chirogenesis”

More LH>RH (RH>LH) in local domain

<https://www.bnl.gov/newsroom/news.php?a=11795>



Chiral Magnetic Effect



Magnetic field ($\vec{B}$) can induce charge separation ($\vec{J}$) for quarks with chirality imbalance (μ_5): CME.

$$\vec{J} \propto \mu_5 \vec{B}$$

Manifestly violate **local** P and CP symmetries.

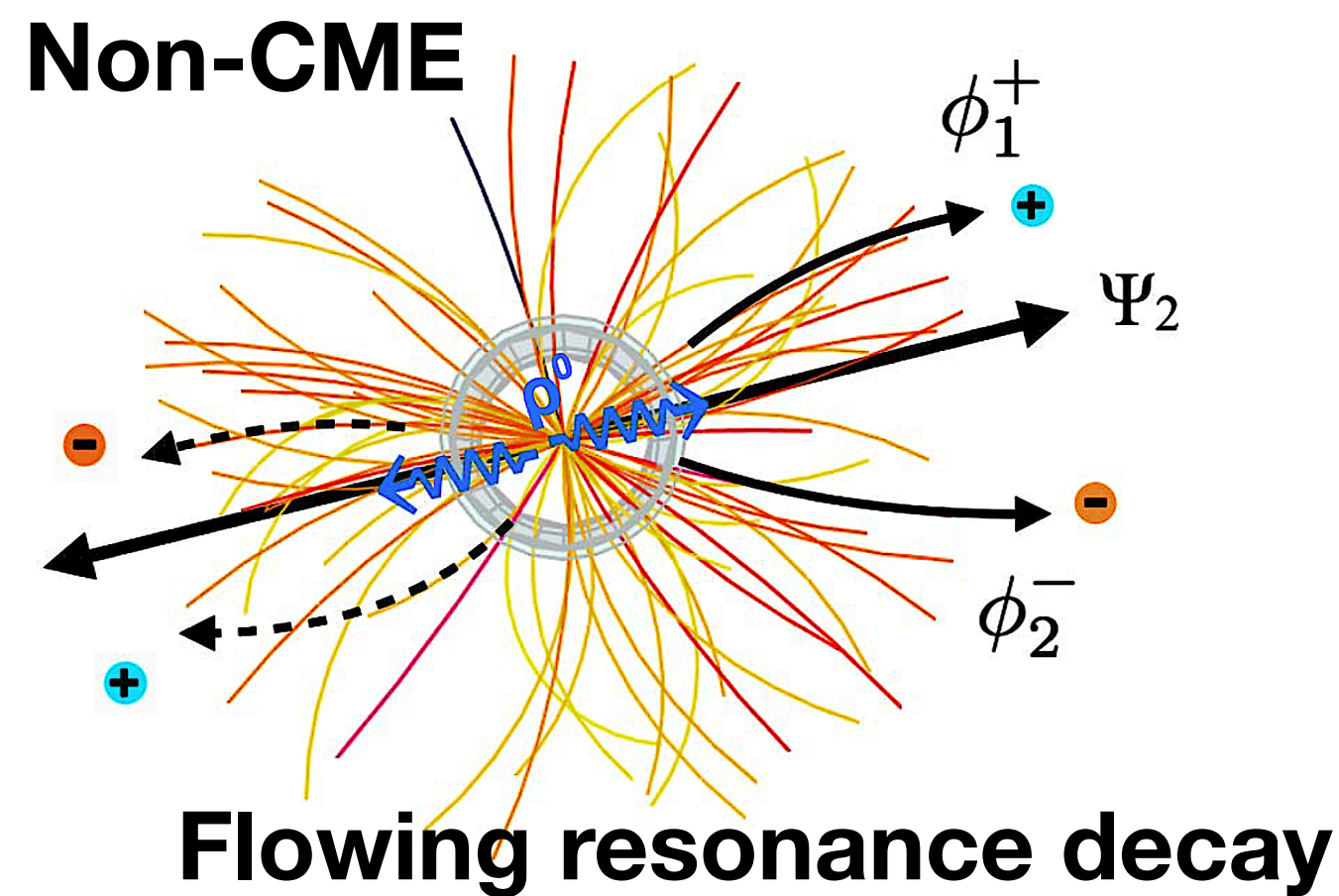
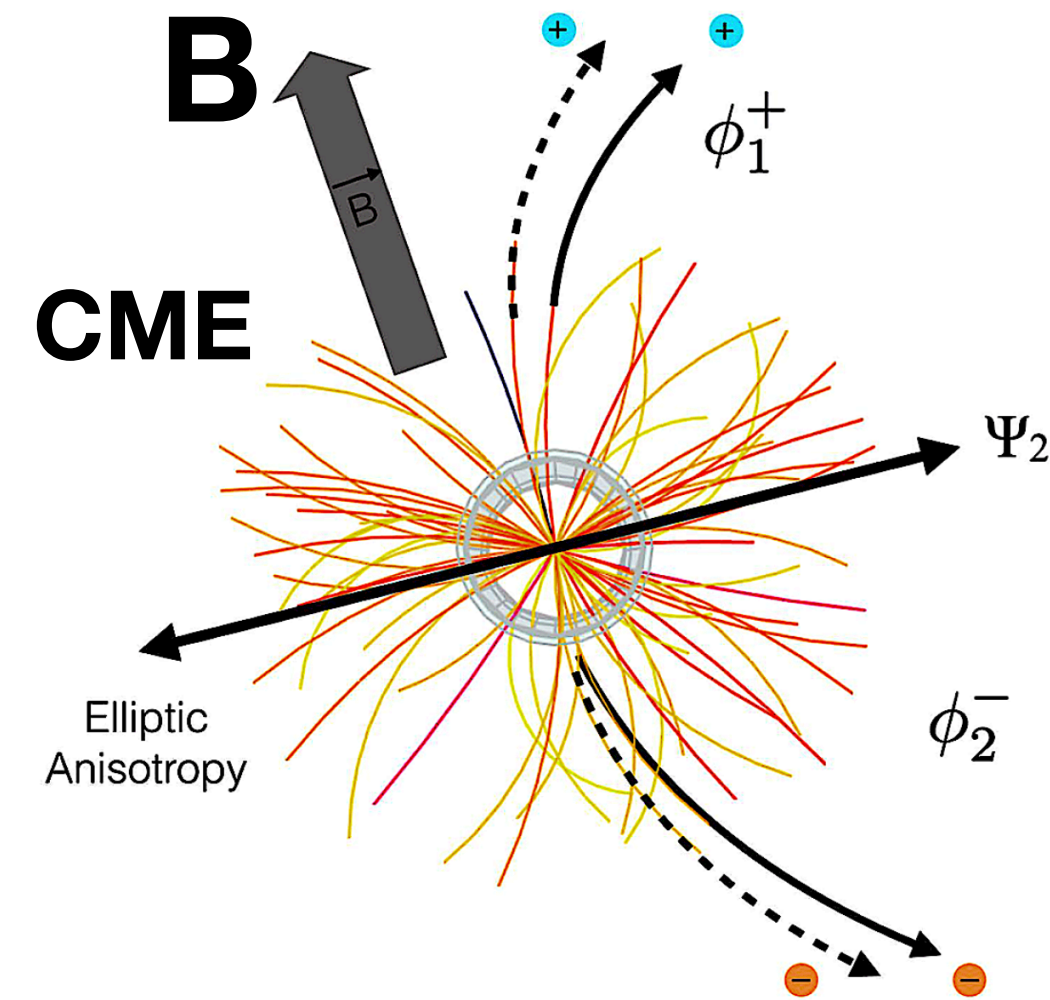
↑ *odd parity* ↑ *even parity*

3 conditions of CME

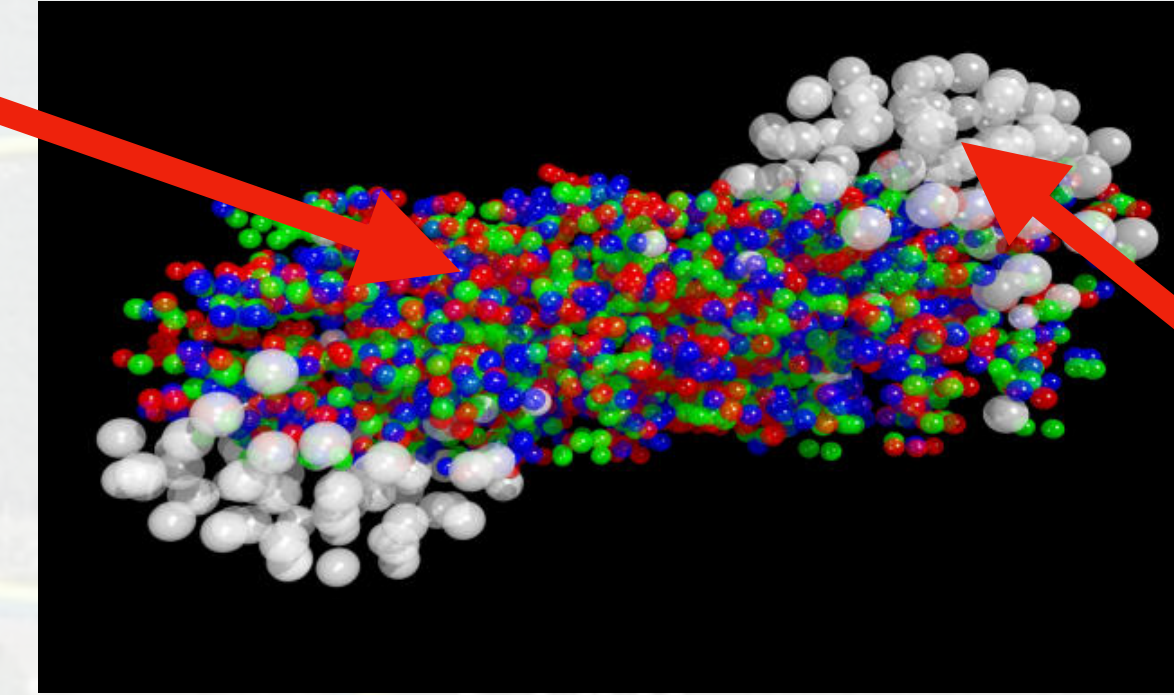
- Chiral Symmetry Restoration $m_q \rightarrow 0$
- Topological Vacuum Transition $\mu_5 \neq 0$
- A strong B field **The key condition**

Kharzeev, Liao, Tribedy, International Journal of Modern Physics E, Vol. 33, No. 09, 2430007 (2024)

CME Observables



Participants (QGP):
Quarks liberated
Excited gluons probe
QCD vacuum



Spectator protons
carry “+” charges:
Create B field

$$\frac{dN_{\pm}}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos(n\phi - n\Psi_{\text{RP}}) + 2a_1^{\pm} \sin(\phi - \Psi_{\text{RP}}) + \dots$$

What we measure:

$$\gamma^{112} = \langle \cos(\phi_1 + \phi_2 - 2\Psi_{\text{RP}}) \rangle = \langle v_1 v_1 \rangle - \langle a_1 a_1 \rangle + \text{BG}(v_2^{\text{cl}})$$

CME observable: $\Delta\gamma^{112} = \gamma^{\text{OS}} - \gamma^{\text{SS}}$

BKG indicator: $\gamma^{132} = \langle \cos(\phi_1 - 3\phi_2 + 2\Psi_{\text{RP}}) \rangle \rightarrow \Delta\gamma^{132}$

S.A. Voloshin, Phys. Rev. C, 70, 057901 (2004)

Event Shape Selection

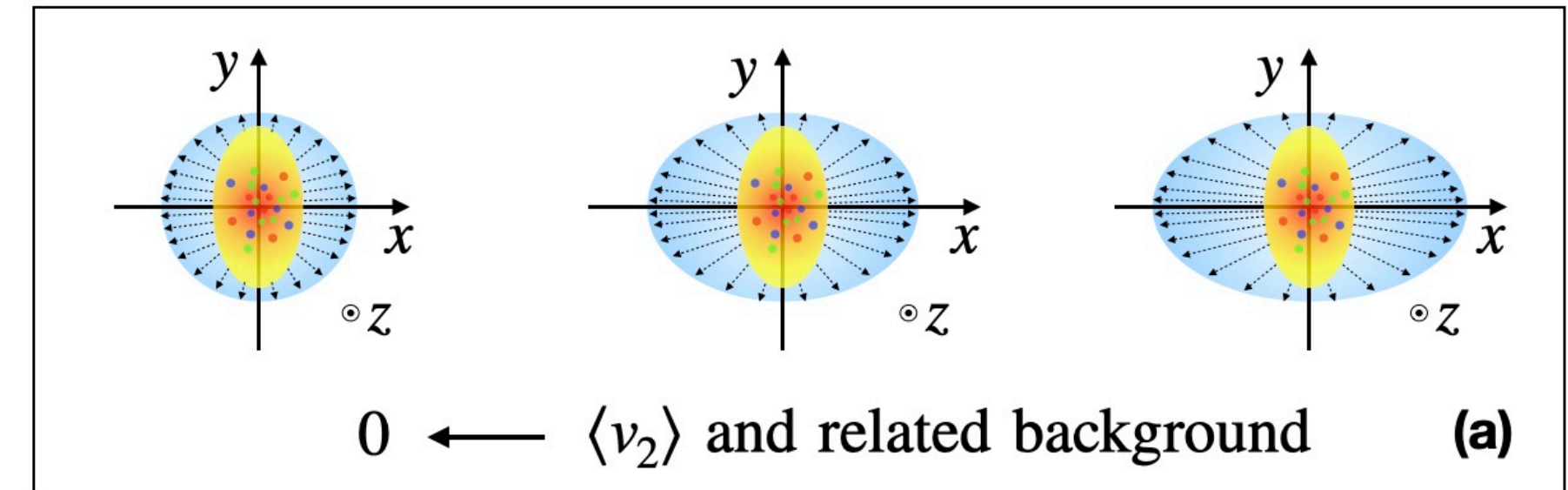
Z. Xu et al, PLB 848(2024)138367
Z.Xu et al Phys. Rev. C 107, L061902

- To control emission pattern fluctuation, we utilize **event shapes of same kinematic region**

1. Categorize events

Flow vector with higher-order normalization

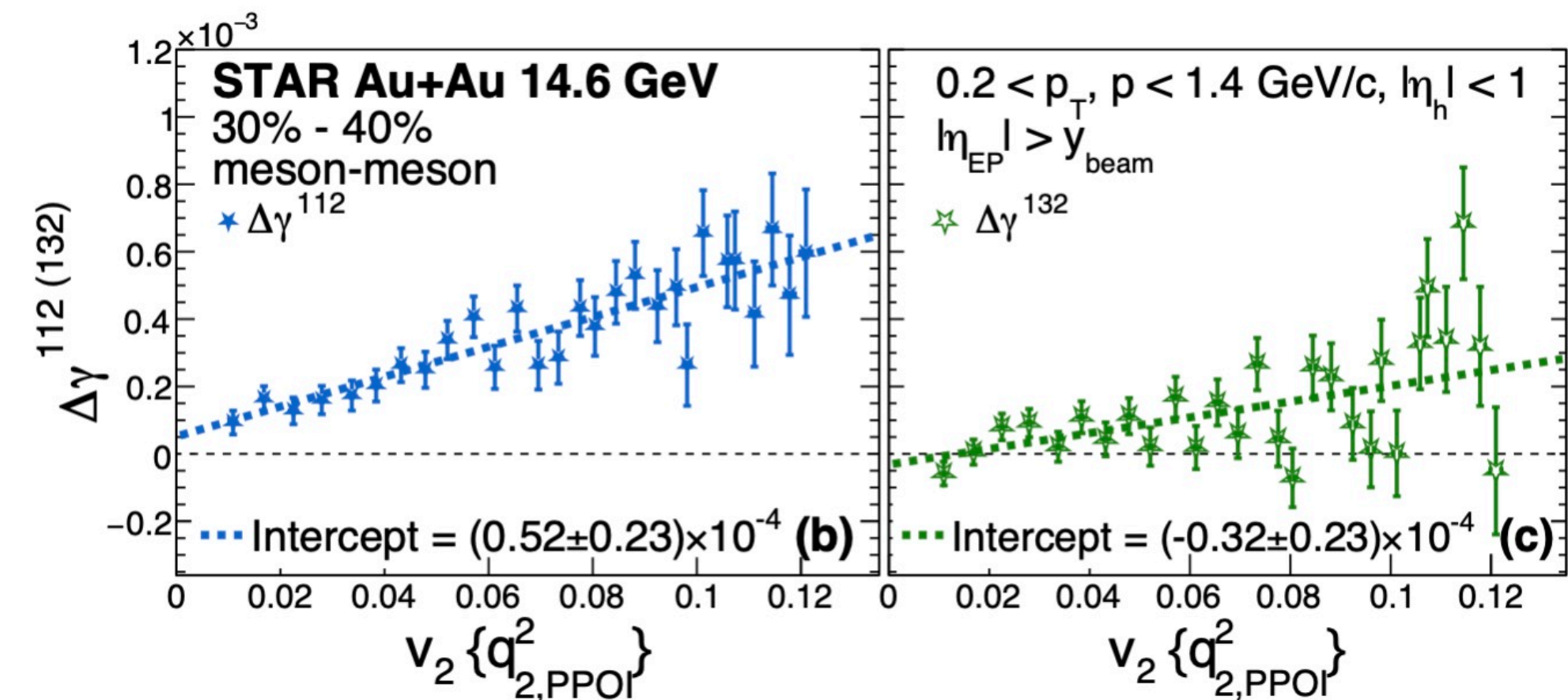
$$q_2^2 = \frac{(\sum_{i=1}^N \sin 2\varphi_i)^2 + (\sum_{i=1}^N \cos 2\varphi_i)^2}{N(1 + N\langle v_2 \rangle)}$$



2. Measure the $\Delta\gamma$ Observable & v_2 flow

pair q_2 (PPOI) **ESS** single v_2 (POI)

- adding momenta of two POI particles
~ mimic resonance decay



2. Plot $\Delta\gamma$ against v_2 to extrapolate $\Delta\gamma_{ESS}^{112}$

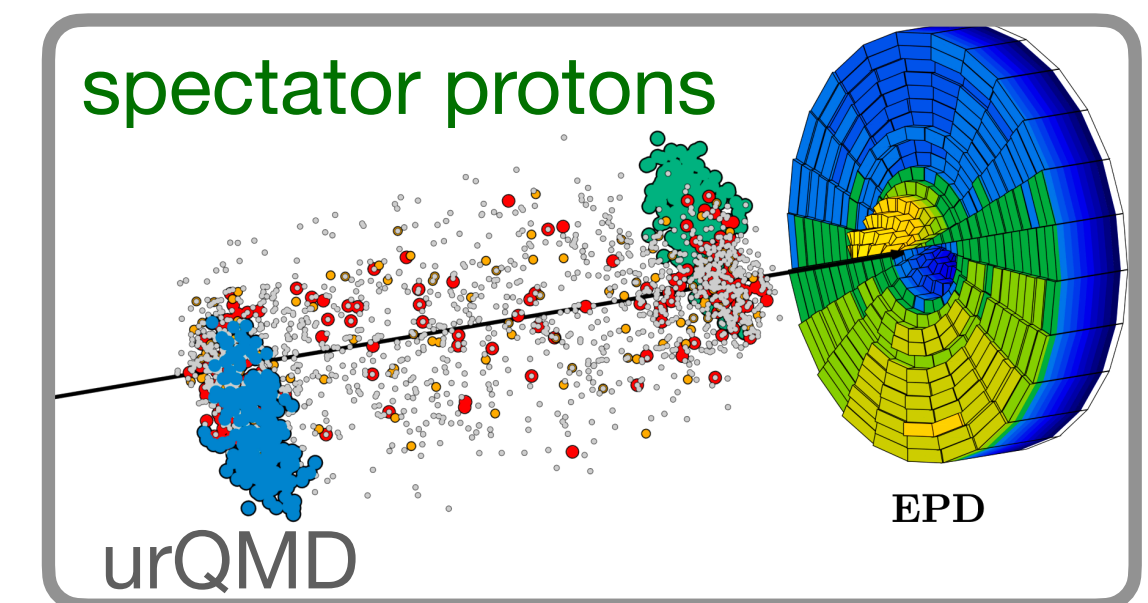
$$\Delta\gamma^{112} = \Delta\gamma^{CME} + k \frac{v_2}{N} + \Delta\gamma^{nonflow}$$

Signal **ESS** Ψ_1 Background

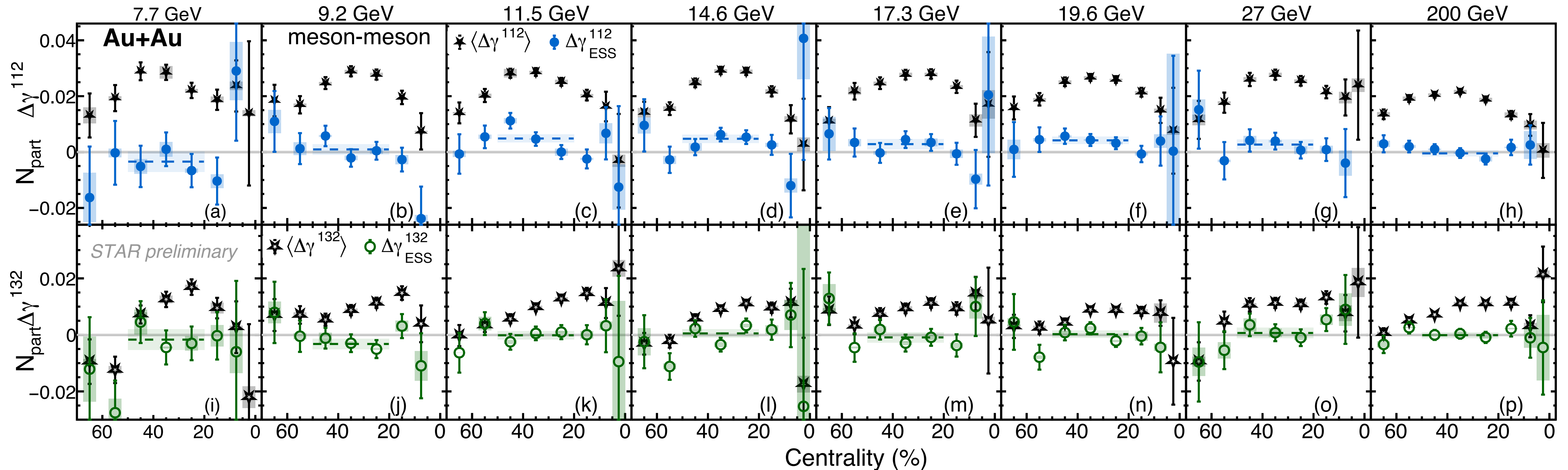
$$\Delta\gamma_{ESS}^{112} = \text{Intercept} \times (1 - v_2)^2$$

Using spectator plane Ψ_1

- construct B field
- suppress nonflow BKG

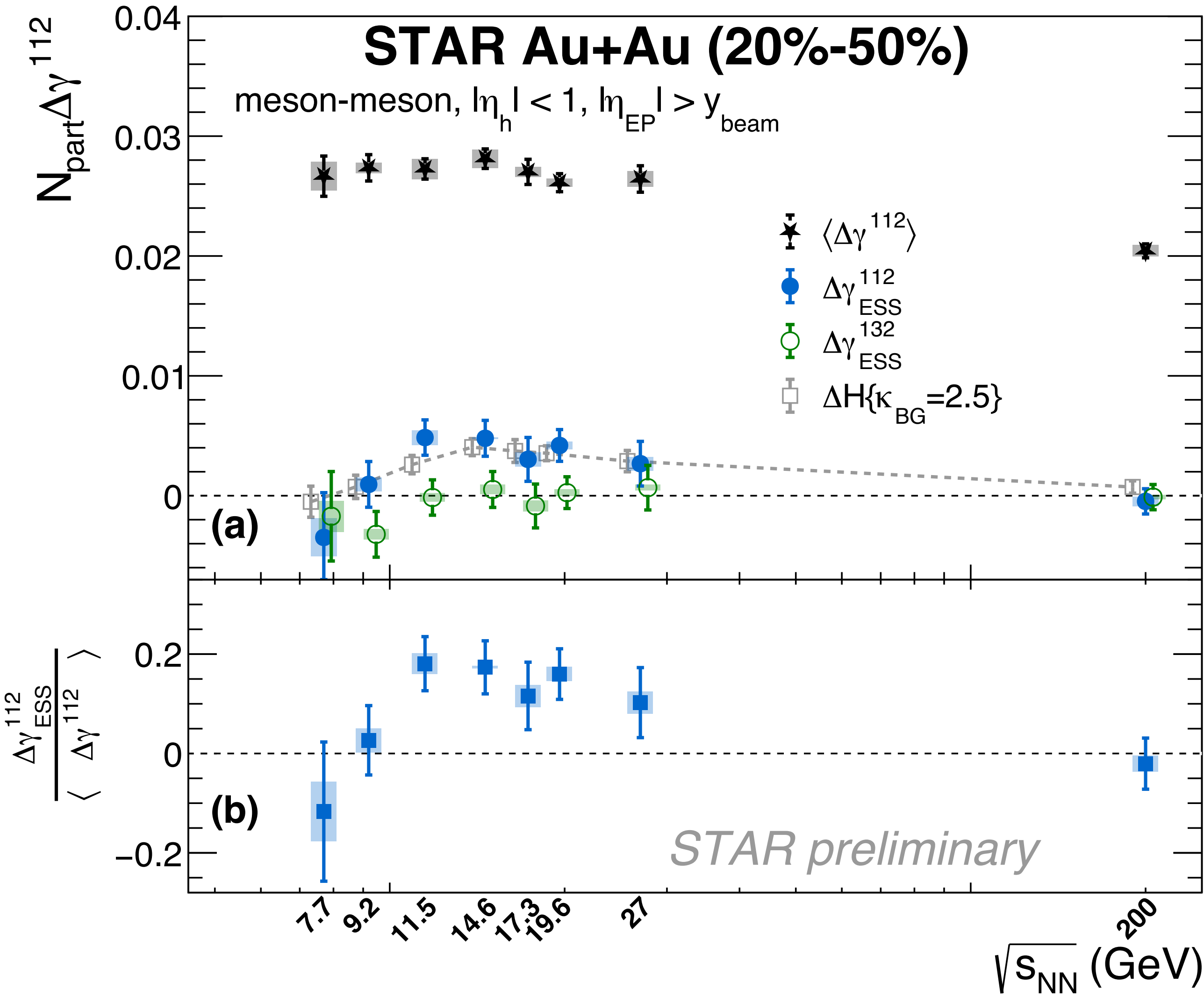


Beam Energy Scan-II results



- $\Delta\gamma_{ESS}^{112}$: a rise-and-fall trend. We observe residual charge separation after BKG suppression, at 19.6, 14.6 and 11.5 GeV, a finite $\Delta\gamma_{ESS}^{112}$ (3σ significance) in the 20-50% centrality.
- $\Delta\gamma_{ESS}^{132}$ is consistent with zero: verifies that ESS successfully suppresses the background.

Beam Energy Scan II results



$\sqrt{s_{NN}}$ (GeV)	Significance
7.7	Consistent with 0
9.2	Consistent with 0
11.5	3σ
14.6	3.1σ
17.3	1.6σ
19.6	3.5σ
27	1.3σ
200	Consistent with 0

- The ESS method identifies that at least 80% of $\langle \Delta\gamma^{112} \rangle$ is from the flow-related background.
- Rise and fall trend in energy dependence:
- Residual charge separation is over 5σ significance when combining 10-20 GeV, assuming similar physics conditions.
- At 200 GeV, result is well consistent with zero, aligned with the finding in Isobar blind analysis.



Summary and Acknowledgement

- The search for the CME in heavy-ion collision probes the intrinsic properties of QCD.
- We used the novel Event Shape Selection (ESS) to suppress flow-related backgrounds, and spectator plane from Event Plane Detector (EPD) to suppress non-flow backgrounds.
 - At each of 11.5, 14.6 and 19.6 GeV, we observed a positive finite residual charge separation($>3\sigma$). Over 5σ if combined.
 - How to link this residual charge separation to CME needs further investigations in the community

Acknowledgement

*I would like to thank the committee for this honor, and would like to take this opportunity to express my special gratitude to my supervisor, **Prof. Huan Huang**, and my friends and colleagues, **Gang Wang**, **Oleg Tsai** from UCLA, and **Aihong Tang** from BNL.*

I also want to thank all the collaborators at STAR especially folks of the CME focus group.

I am now at Argonne National Lab as a postdoc, thank you all for helping build my career!

