

Search for Chiral Vortical Effect at STAR

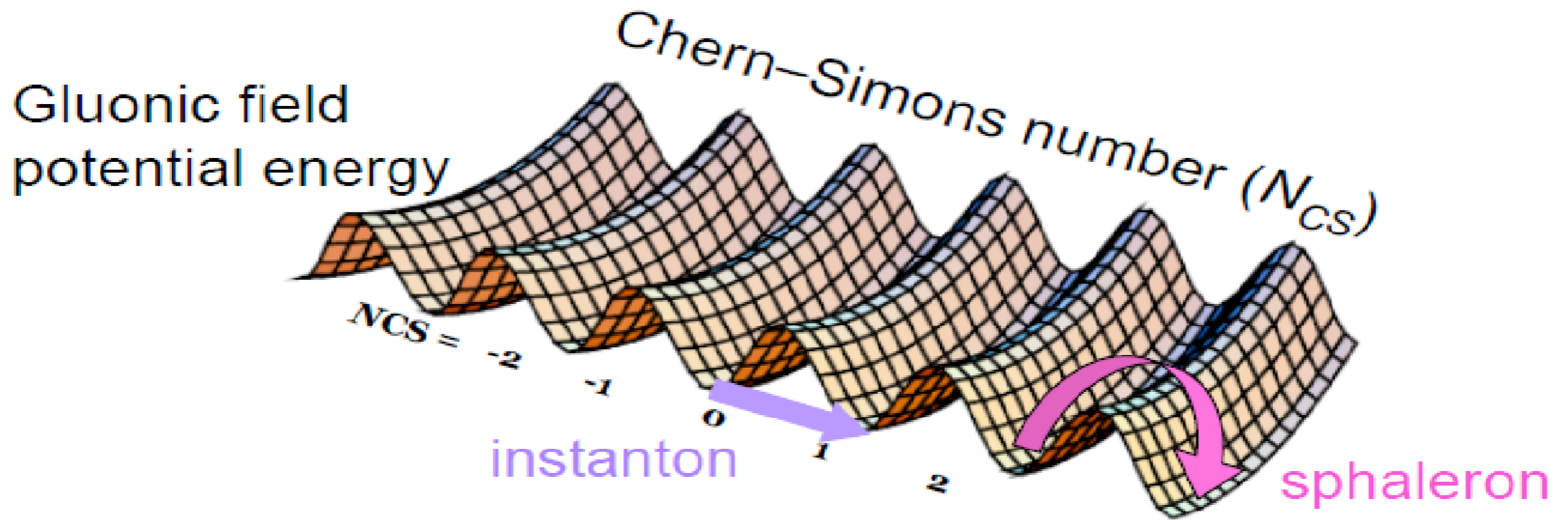
Liwen Wen(UCLA)
for the STAR Collaboration



Outline

- ▶ Physics Motivation
- ▶ STAR Experiment
- ▶ Preliminary Results on Search for CVE @ STAR
- ▶ Summary
- ▶ Outlook

QCD Vacuum Transition

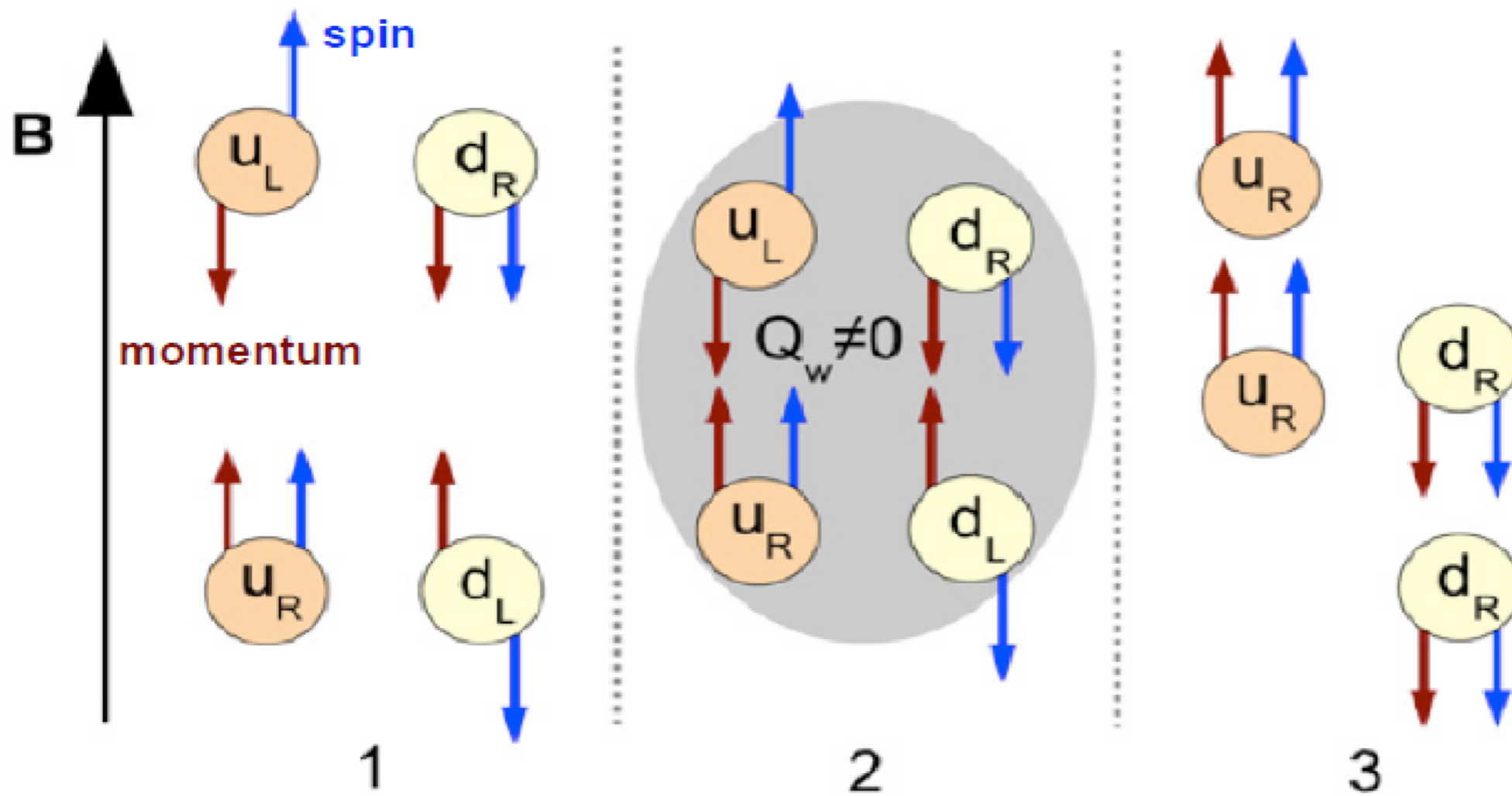


$$N_L^f - N_R^f = 2Q_W, \quad Q_W \neq 0 \rightarrow \mu_A \neq 0$$

QCD vacuum transition:

- nonzero topological charge
- chirality imbalance (local parity violation)

Chiral Magnetic Effect



D. Kharzeev, NPA 803, 227(2008)

$$j_V = \frac{N_c e}{2\pi^2} \mu_A B \rightarrow \text{electric charge separation along } B \text{ field}$$

Configuration with non-zero topological charge converts left(right)-handed fermions to right(left)-handed fermions, generating electromagnetic current along B direction and leading to electric charge separation .

Chiral Vortical Effect

Chiral Magnetic Effect vs **Chiral Vortical Effect**

Chirality Imbalance (μ_A)

Chirality Imbalance (μ_A)

Magnetic Field ($\omega \mu_e$)

Fluid Vorticity ($\omega \mu_B$)

Electric Charge (j_e)

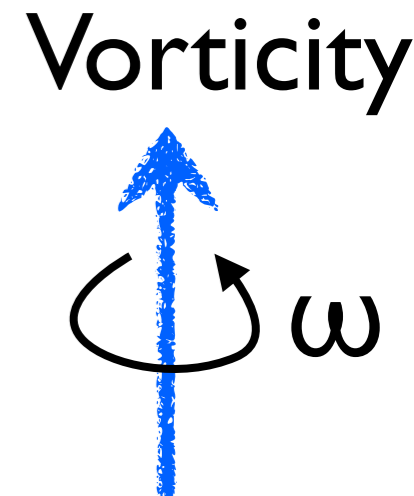
Baryon Number (j_B)

Electric charge separation

Baryon charge separation

Λ -p correlation measurement($\gamma = \langle \cos(\varphi_\Lambda + \varphi_p - 2\Phi_{RP}) \rangle$)
 can be used to search for the **Chiral Vortical Effect**

D. Kharzeev, D. T. Son, PRL 106 (2011) 062301

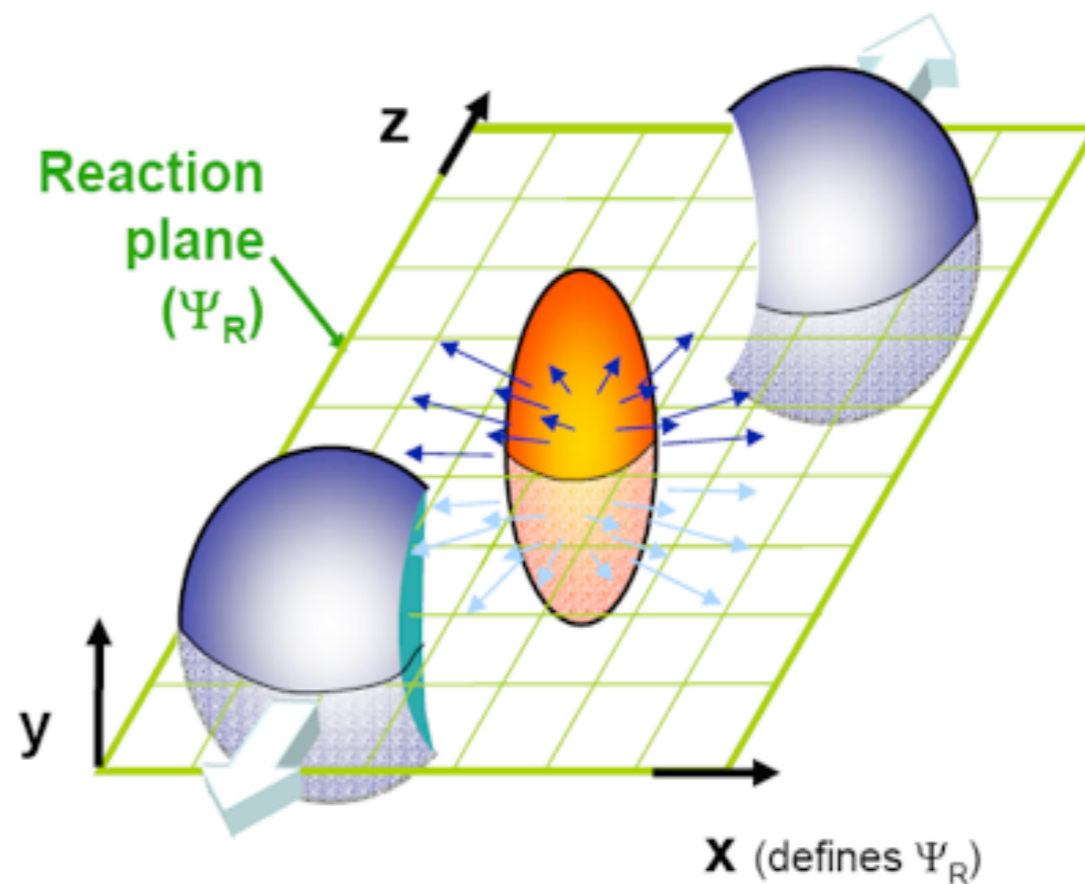


Peak magnetic field ~
 10^{15} Tesla !
 (Kharzeev et al. NPA 803
 (2008) 227)

Observable: γ correlator

$$\frac{dN_{\pm}}{d\phi} \propto 1 + 2a_{\pm} \cdot \sin(\phi^{\pm} - \Psi_{RP})$$

A direct measurement of the P -odd quantity “ a ” should yield *zero*.



$$\begin{aligned} \gamma &= \langle \cos(\phi_{\alpha} + \phi_{\beta} - 2\Psi_{RP}) \rangle \\ &= \left[\langle v_{1,\alpha} v_{1,\beta} \rangle + B_{in} \right] - \left[\langle a_{\alpha} a_{\beta} \rangle + B_{out} \right] \end{aligned}$$

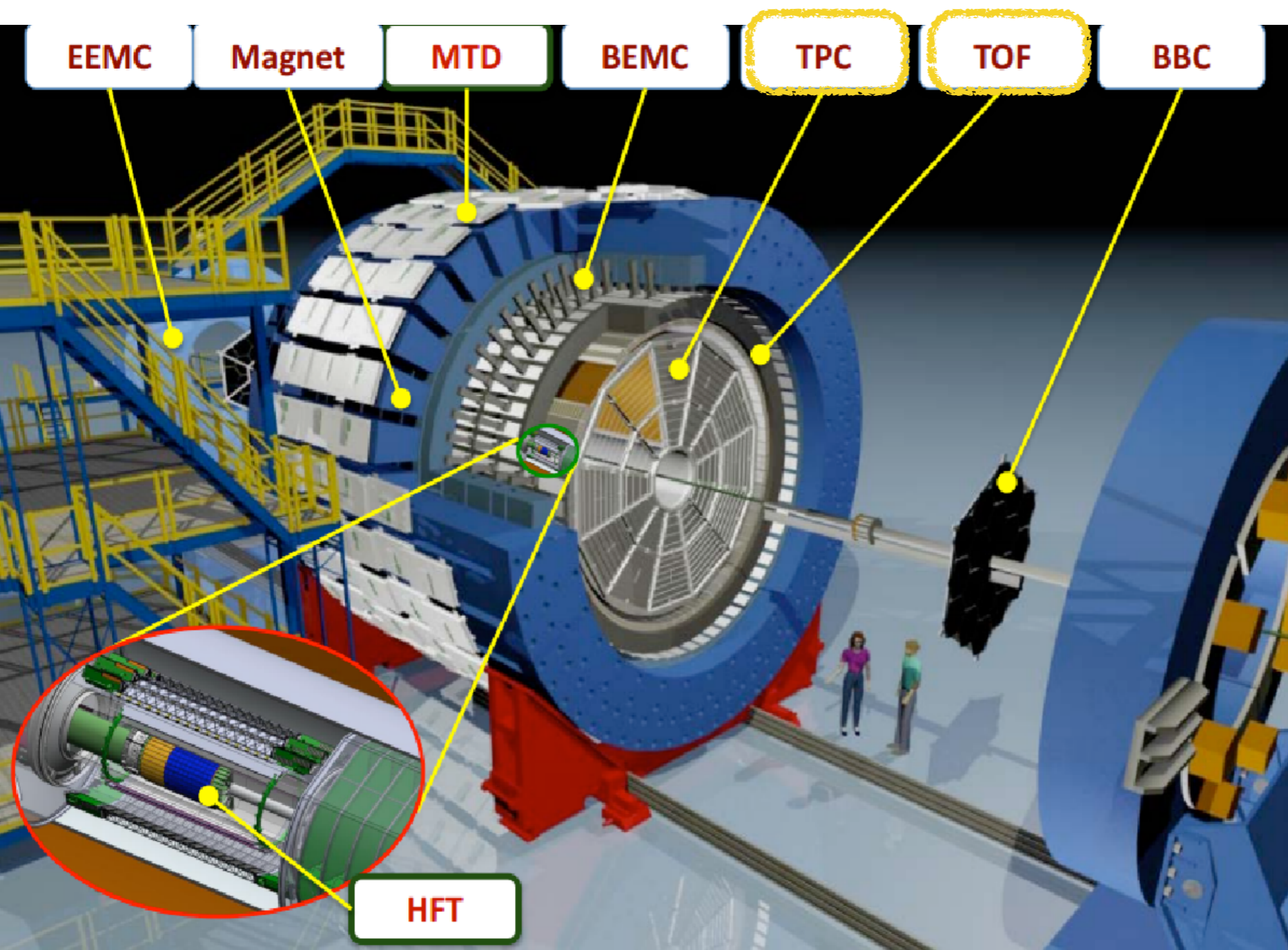
S. Voloshin, PRC 70 (2004) 057901

*background effects:
largely cancel out*

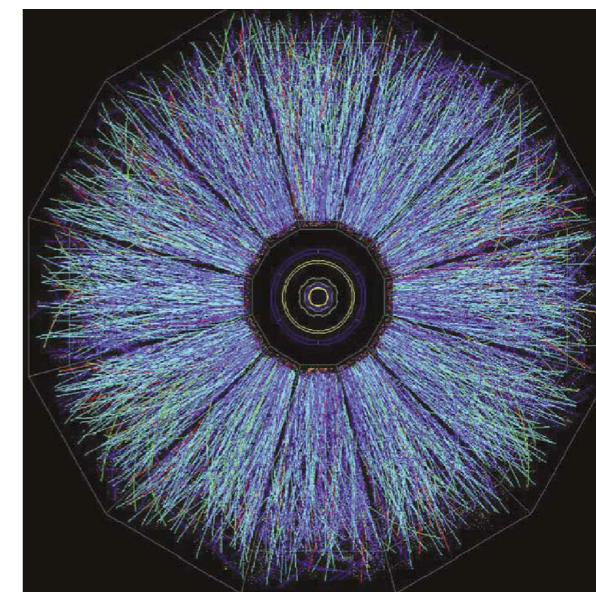
*Directed flow: expected to
be the same for SS and OS*

*P-even quantity:
still sensitive to
charge separation*

Solenoidal Tracker (STAR) @ RHIC

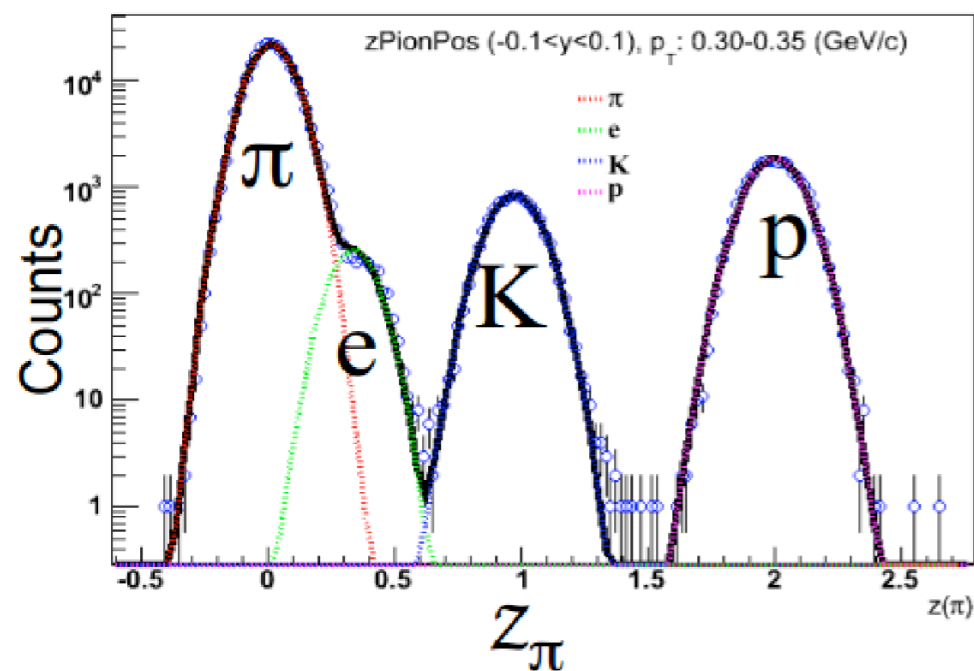
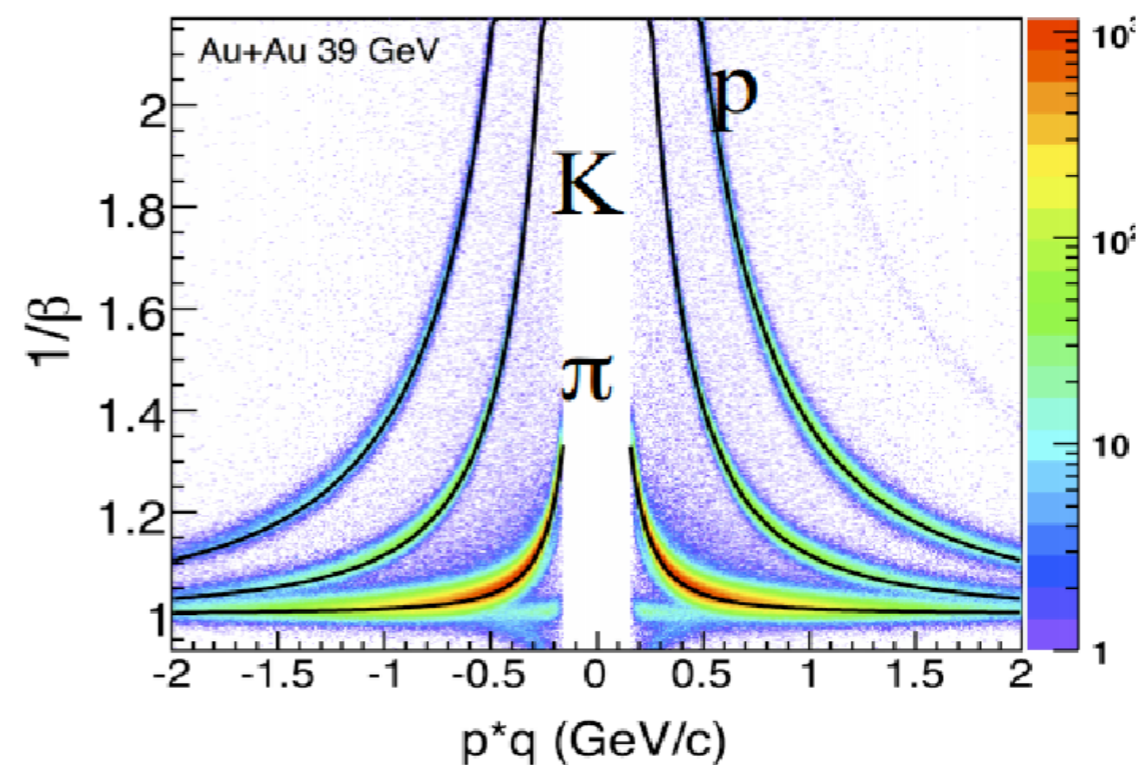
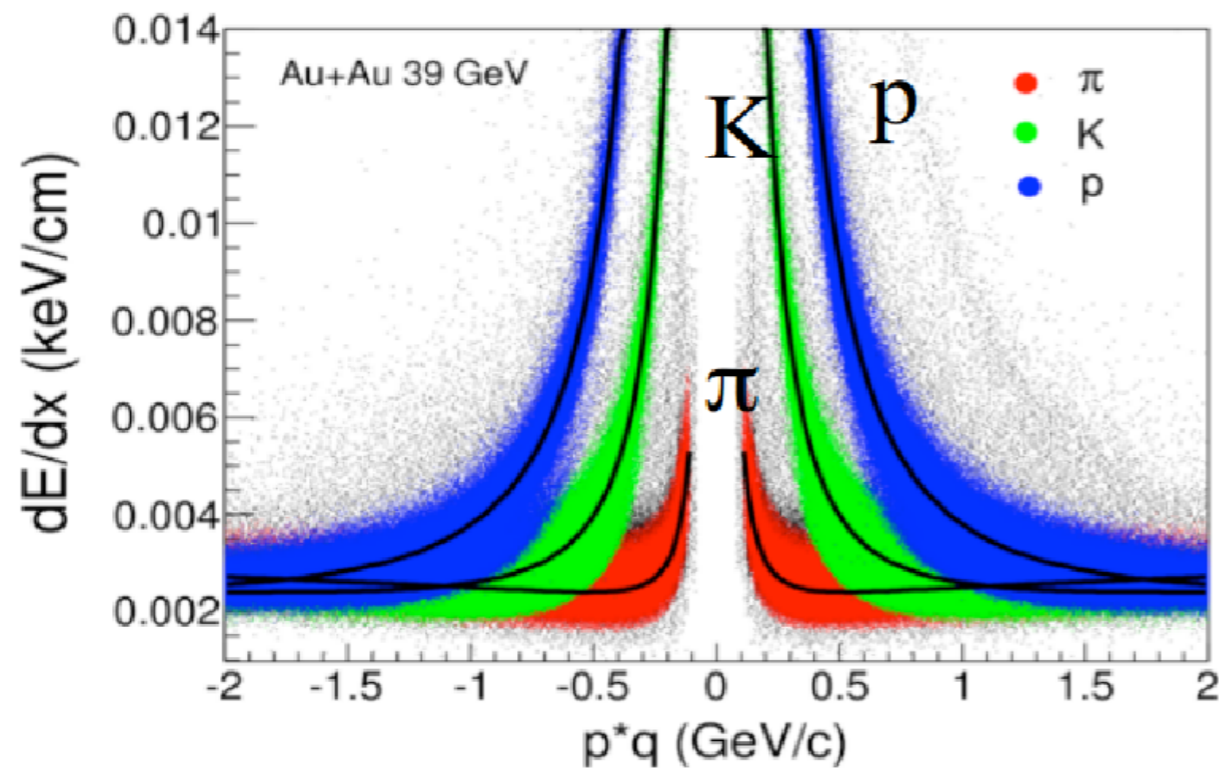


STAR is a detector tracking thousands of particles produced by ion collisions with full azimuth coverage and large acceptance.



STAR Particle Identification

TPC $\sqrt{s_{NN}} = 39 \text{ GeV Au + Au Collisions}$ **TPC+ToF**

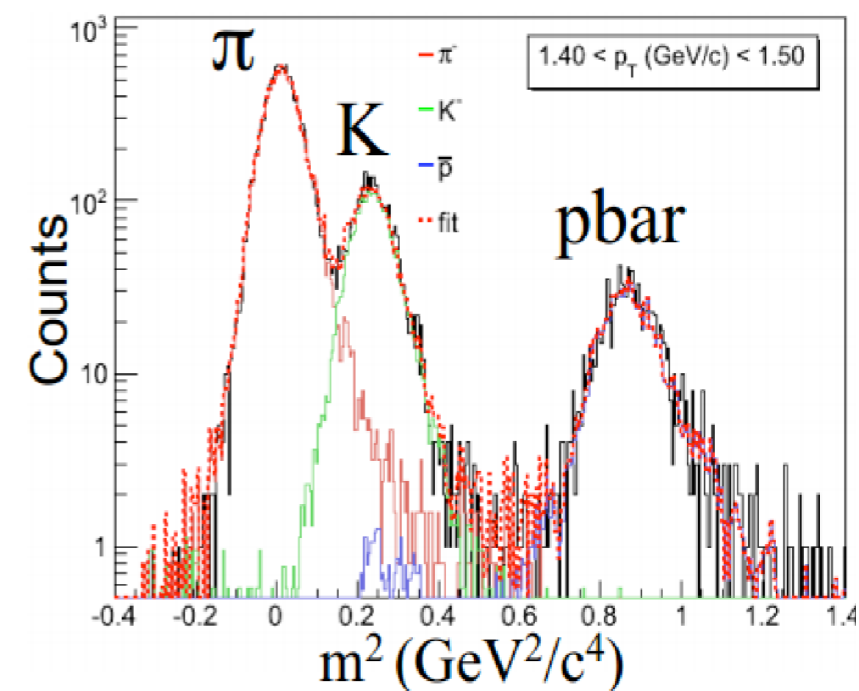


$$z = \log \left(\frac{(dE/dx)_{\text{meas.}}}{(dE/dx)_{\text{theory}}} \right)$$

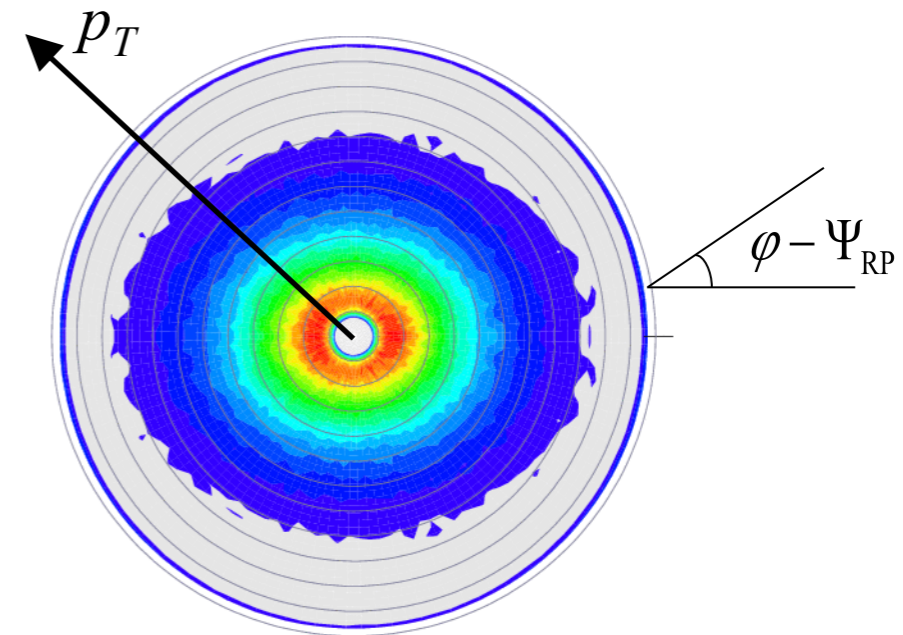
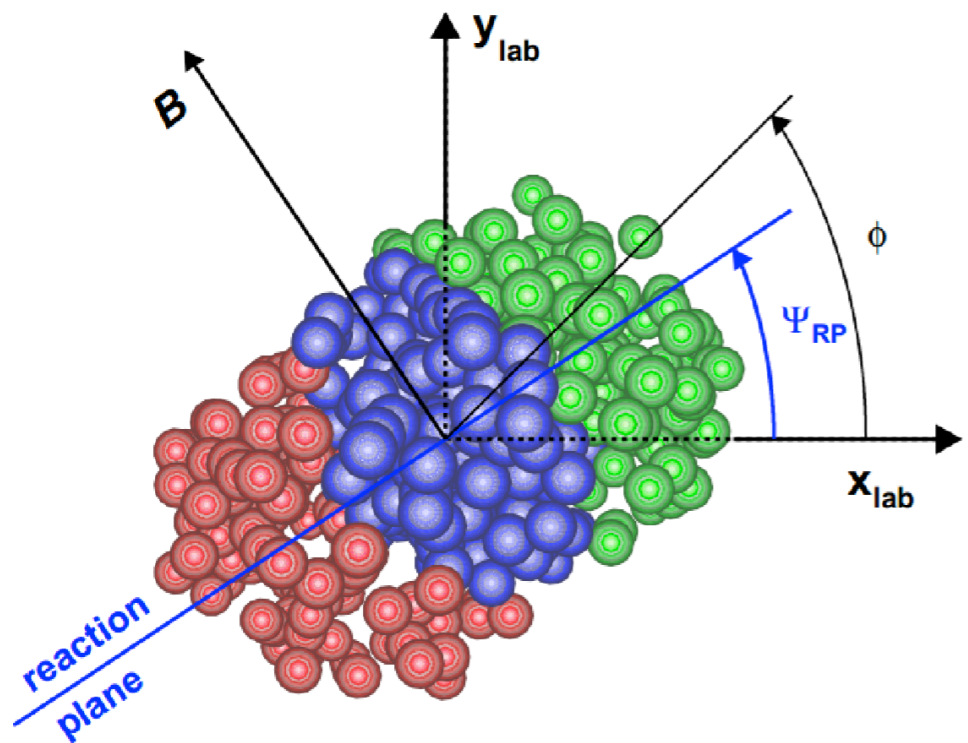
H. Bichsel, NIM A. 562 (2006) 154

$$m^2 = p^2 \left(\frac{c^2 t^2}{L^2} - 1 \right)$$

c =velocity of light,
 L =path length



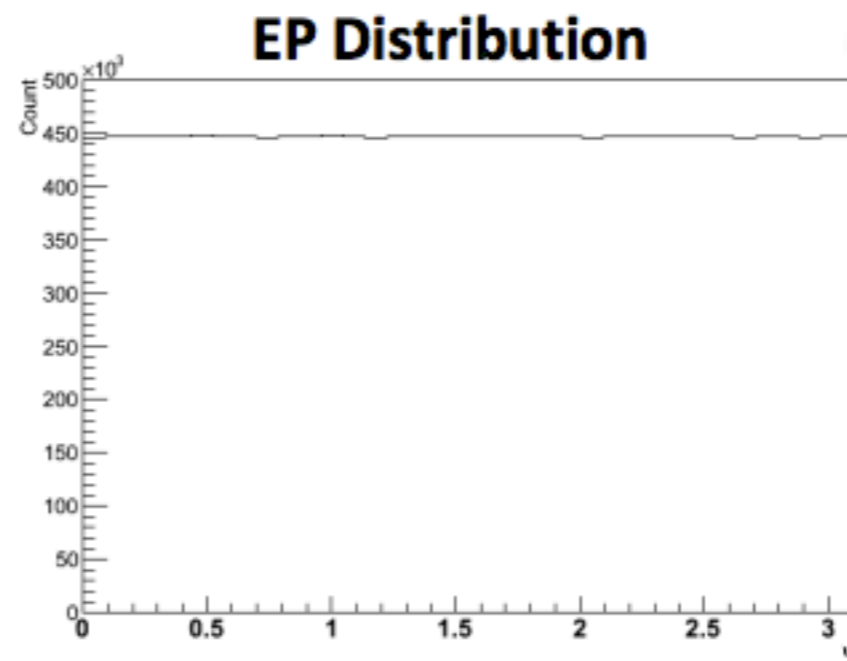
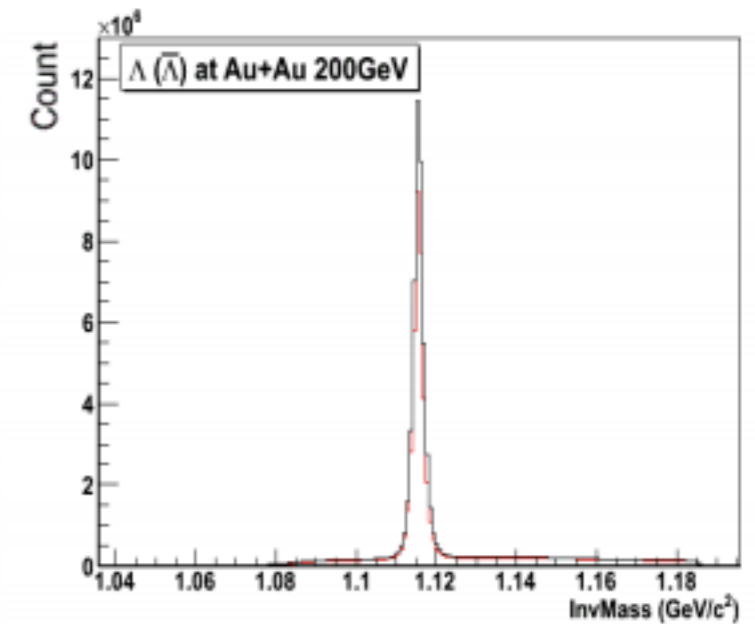
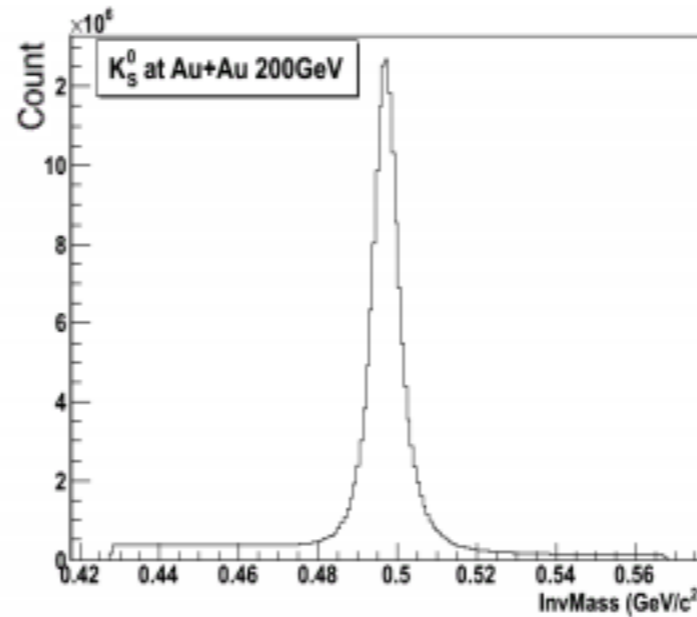
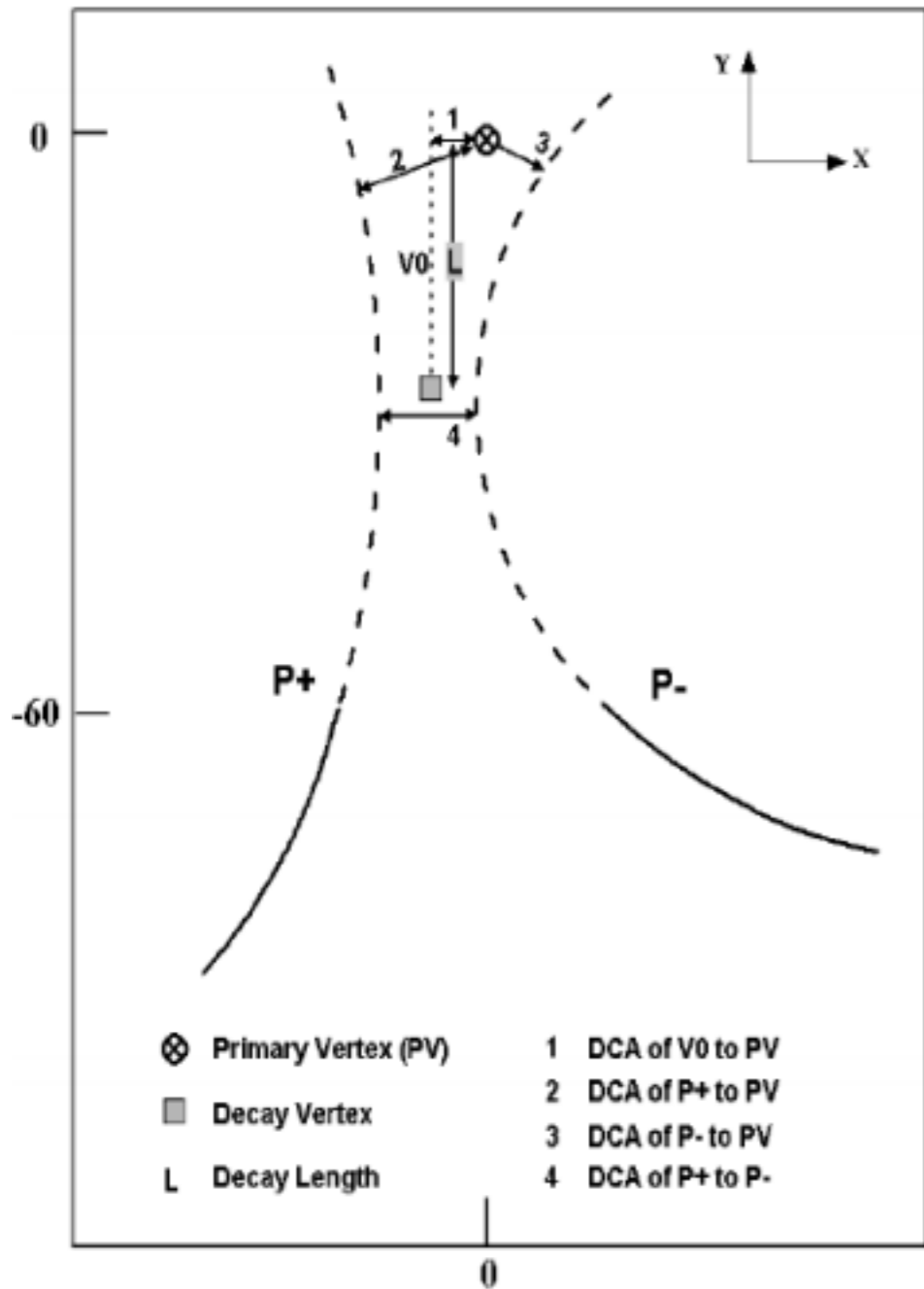
Define Event Plane



$$Q_n \cos(n\Psi_n) = Q_x = \sum_i w_i \cos(n\phi_i)$$
$$Q_n \sin(n\Psi_n) = Q_y = \sum_i w_i \sin(n\phi_i)$$
$$\Psi_n = \left(\tan^{-1} \frac{Q_y}{Q_x} \right) / n$$

The estimated reaction plane is called the event plane.

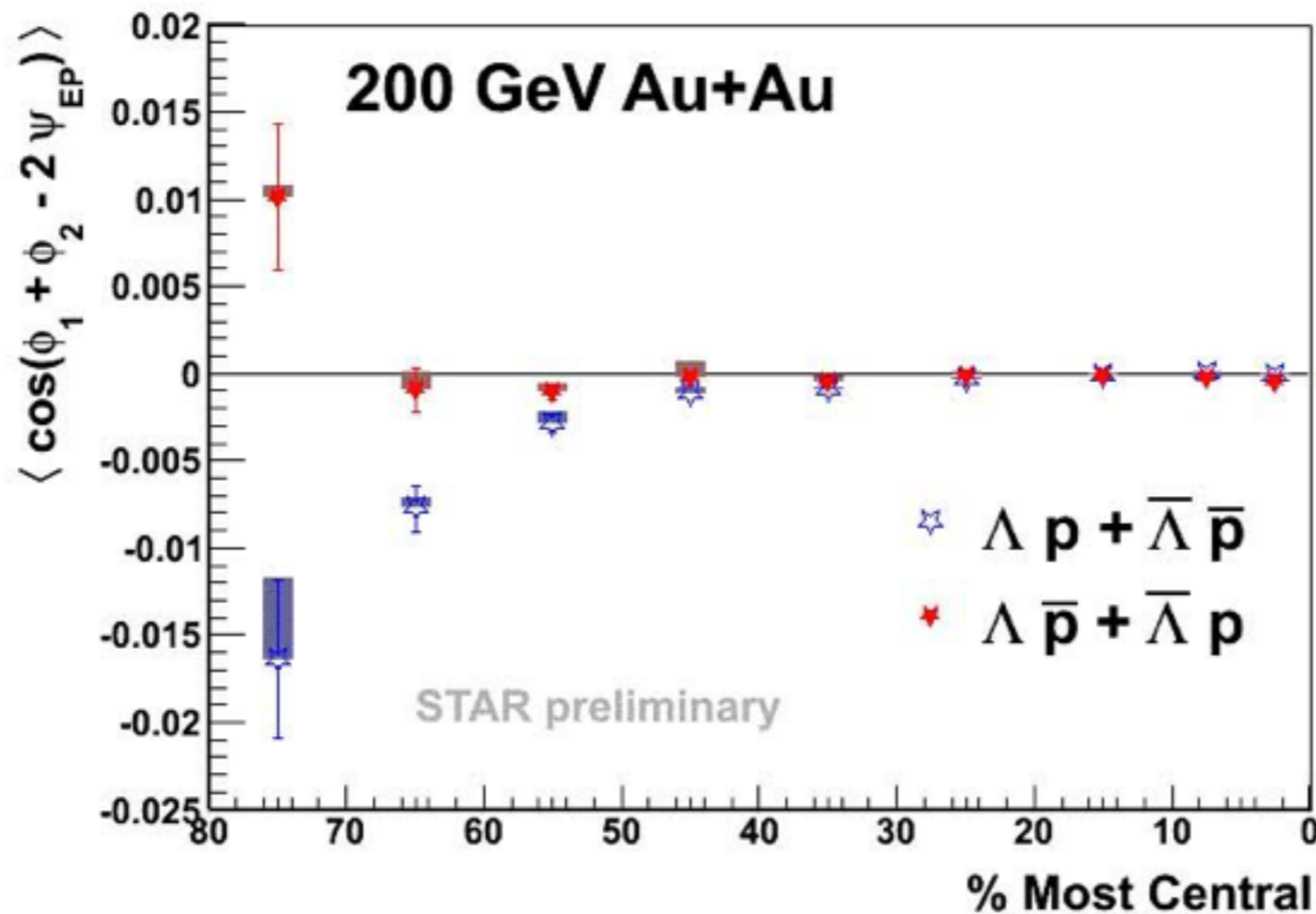
Lambda(Ks0) and Event Plane Reconstruction



Shifting method used to flatten the EP distribution.

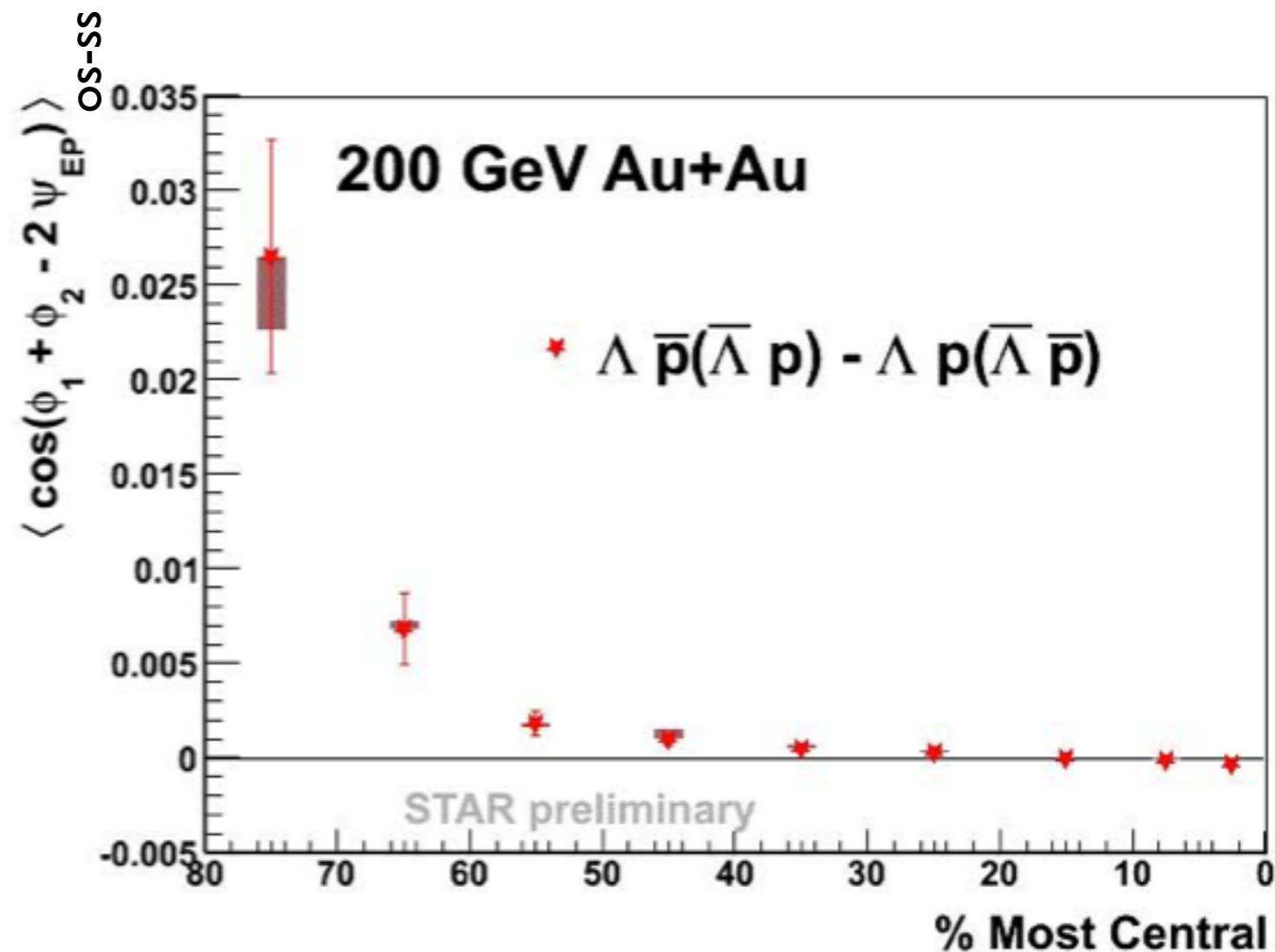
E877, Phys. Rev. C 56 (1997) 3254

Lambda-Proton Correlation(I)



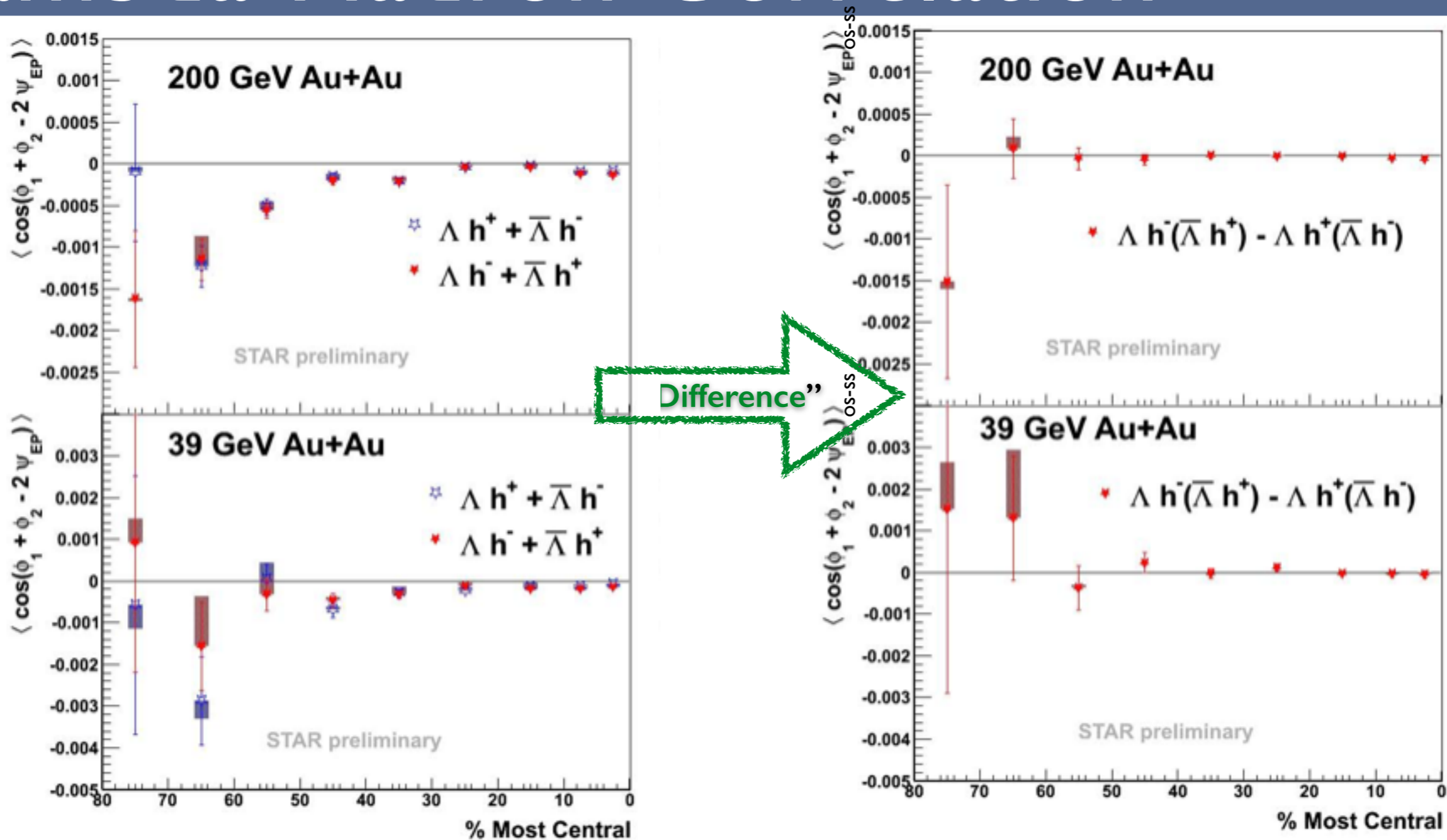
- ▶ $\Lambda - p$ ($\Lambda - \bar{p}$) and $\bar{\Lambda} - \bar{p}$ ($\bar{\Lambda} - p$) (same baryon number / oppo baryon number) show similar behaviors and their combination results are compared;
- ▶ “same B” is systematically lower than “oppo B” in the mid-central and peripheral collisions.

Lambda-Proton Correlation(2)



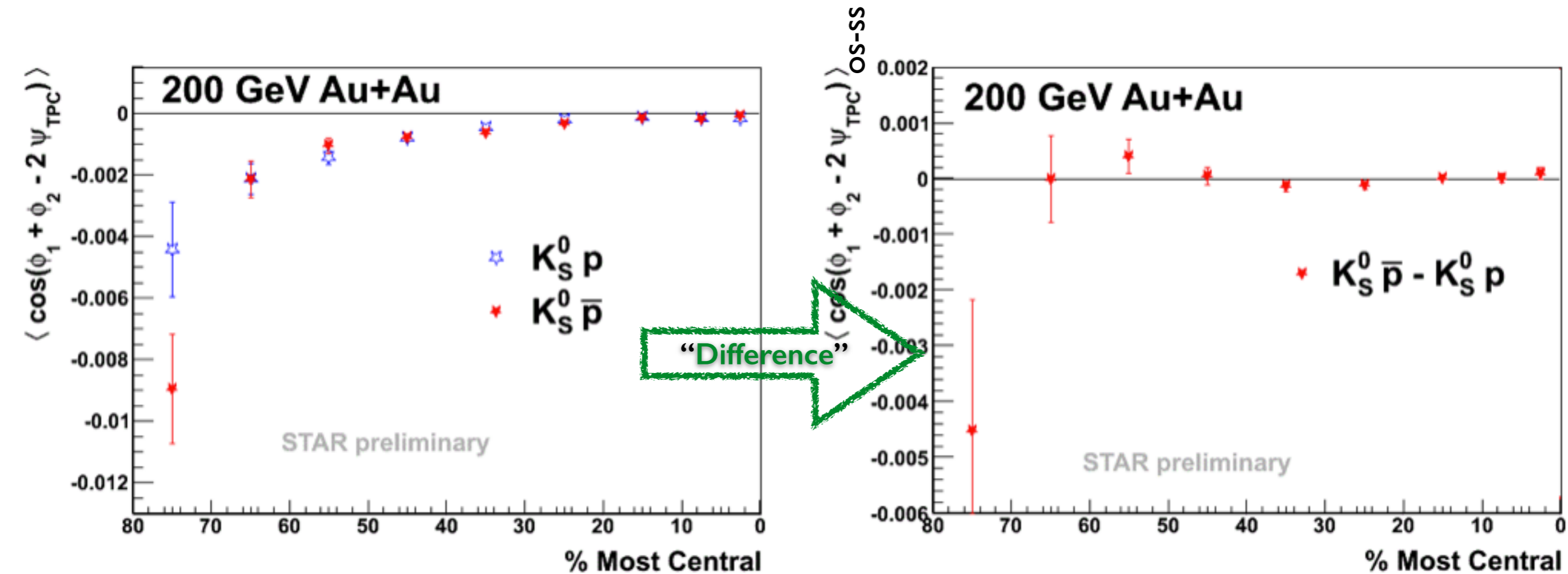
► **oppo B** - **same B** shows significant separation signal in peripheral bins, which is consistent with CVE prediction.

Lambda-Hadron Correlation



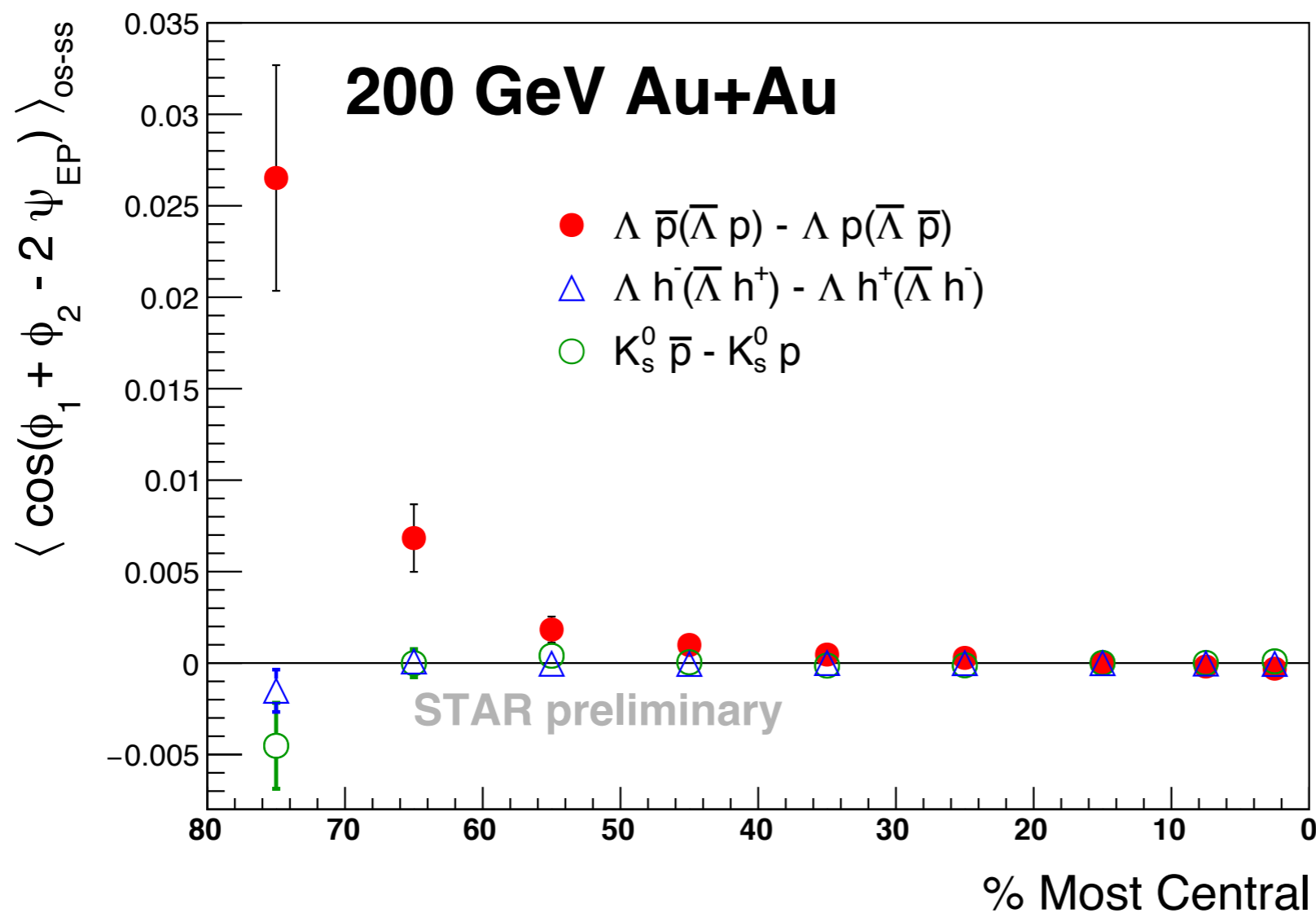
- ▶ Replace proton with charged hadron.
- ▶ As expected, difference between “same baryon number” and “opposite baryon number” is consistent with ZERO.

Ks0-Proton Correlation



- Replace Lambda with Ks0(no baryon charge). As CVE predicted, no significant separation signal observed.

Correlation Comparison

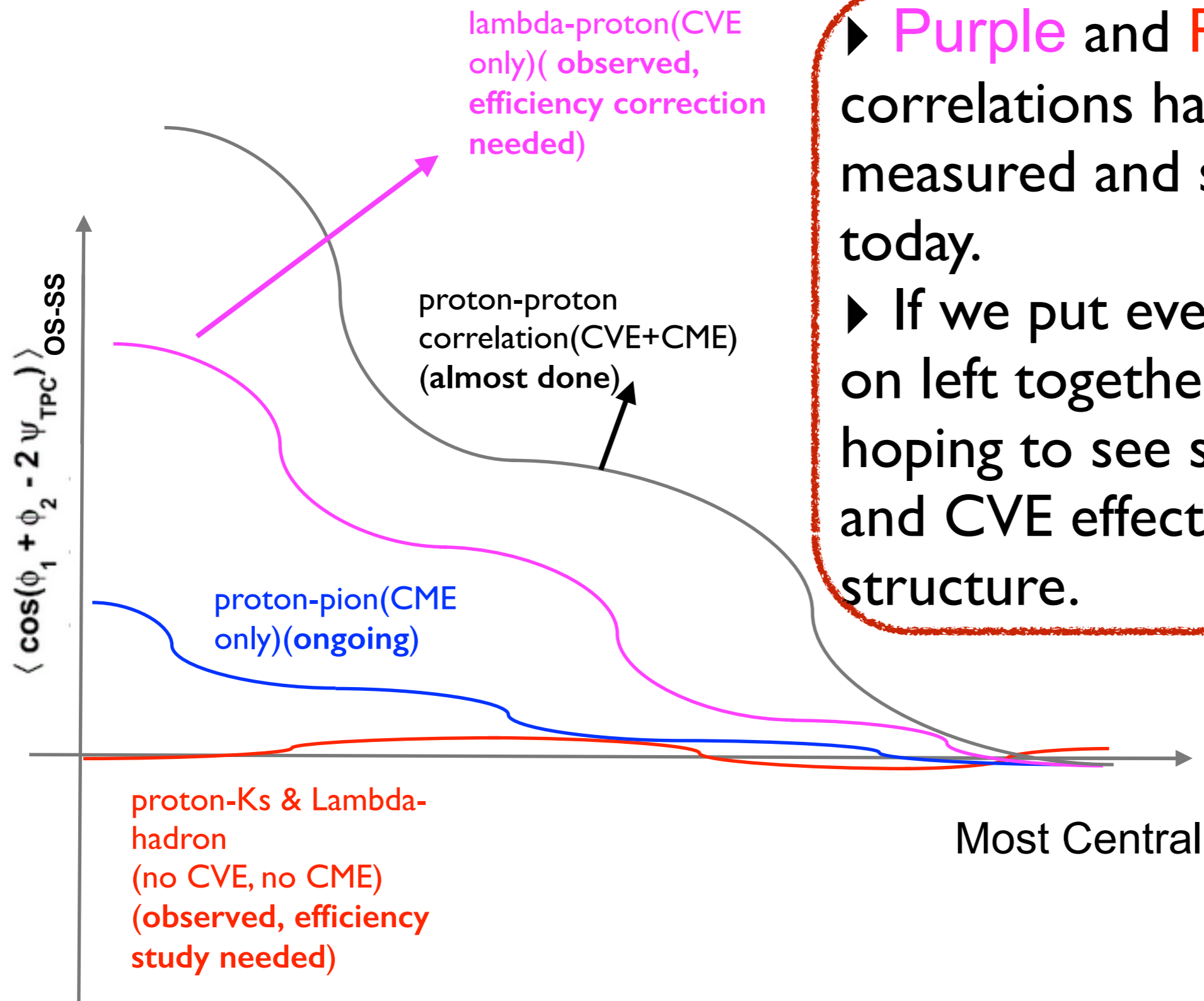


Put our results together, we can see separation effect is
baryon number dependent.

Summary

- ▶ Results on the centrality dependence of the Λ -p correlation from 39 GeV and 200 GeV AuAu collisions are shown. We observed the baryon-number separation across the event plane, especially in peripheral collisions.
- ▶ K_s^0 -p and Λ -h (proton excluded) correlation functions show no separations.
- ▶ Those observations are consistent with expectation from CVE calculation.

Outlook: CME and CVE Manifestation in Correlation Hierarchy



- ▶ **Purple** and **Red** correlations have been measured and showed today.
- ▶ If we put everything listed on left together, we are hoping to see such a CME and CVE effects hierarchical structure.