Charge dependent particle correlations motivated by chiral magnetic/vortical effect studies

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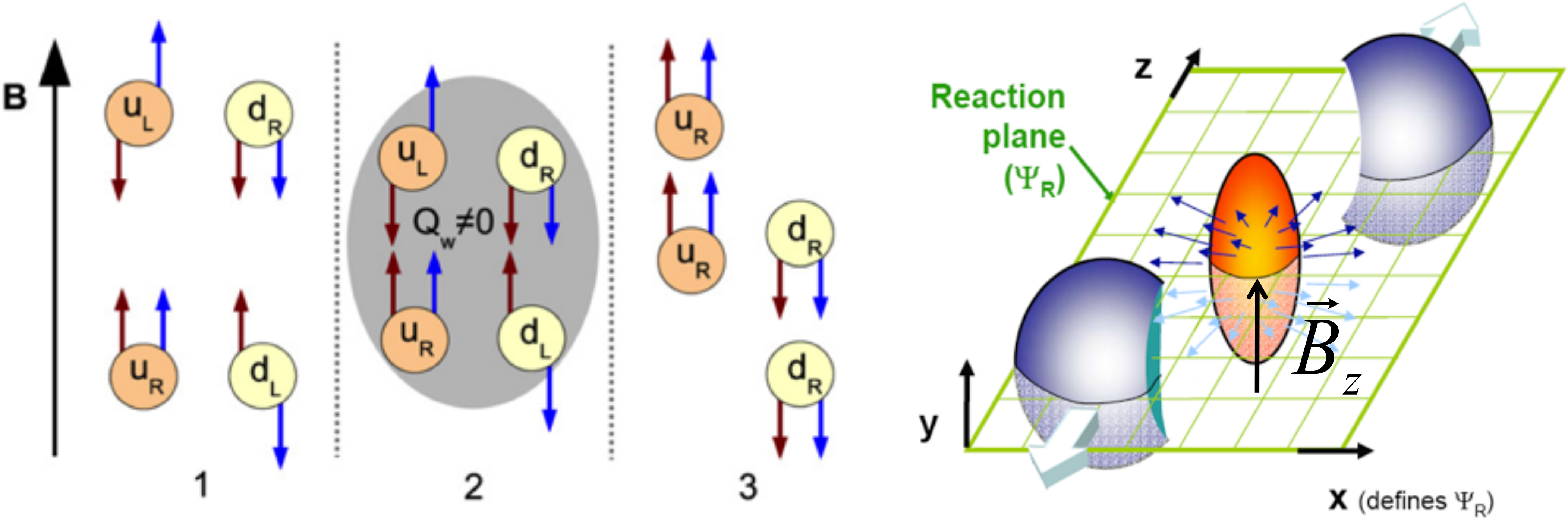
Outline

- Introduction
- RHIC-STAR experiment
- Results and discussions
- Summary

Chiral Magnetic Effect (CME)

D. Kharzeev, etc. NPA 803, 227(2008)



$j_V = \frac{N_c e}{2\pi^2}\mu_A B,$ ⇨ electric charge separation alone the B field

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

Chiral Vortical Effect (CVE)

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

Baryonic charge separation

$$\langle \cos(\phi_\Lambda + \phi_p - 2\Psi_{RP}) \rangle$$

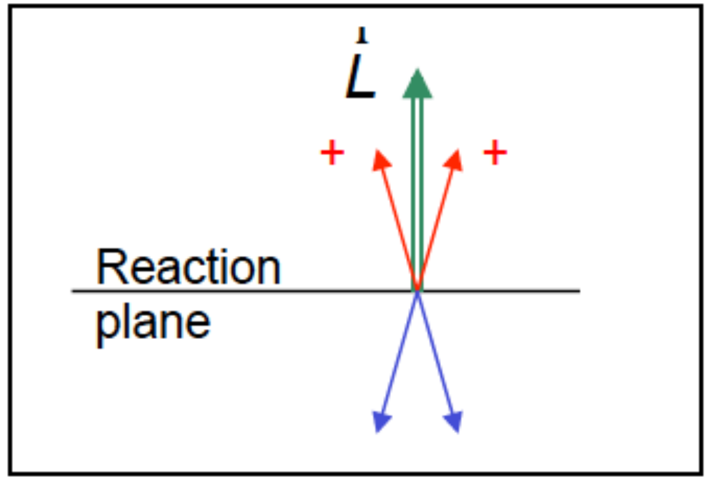
Λ–p correlation to search for the pure Chiral Vortical Effect

D. Kharzeev, A. Zhitnitsky, NPA797:67-79(2007)
D. Kharzeev, D. T. Son, PRL 106 (2011) 062301

Azimuthal Charged-Particle Correlations

Azimuthal particle distribution effectively can be described by:

$$\frac{dN_{\pm}}{d\phi} \propto \left(1 + 2v_1\cos(\Delta\phi) + 2v_2\cos(2\Delta\phi) + \ldots + 2a_{\pm}\sin(\Delta\phi)\right), \quad (1)$$



slide from S. A. Voloshin

$a > 0$ preferential emission along the angular momentum,

$a_+ = -a_-$,

The sign of Q can vary from event to event -> one has to measure correlations, $<a_\alpha a_\beta>$, P-even quantity (!) - possibility of contribution from effects not related to P-violation

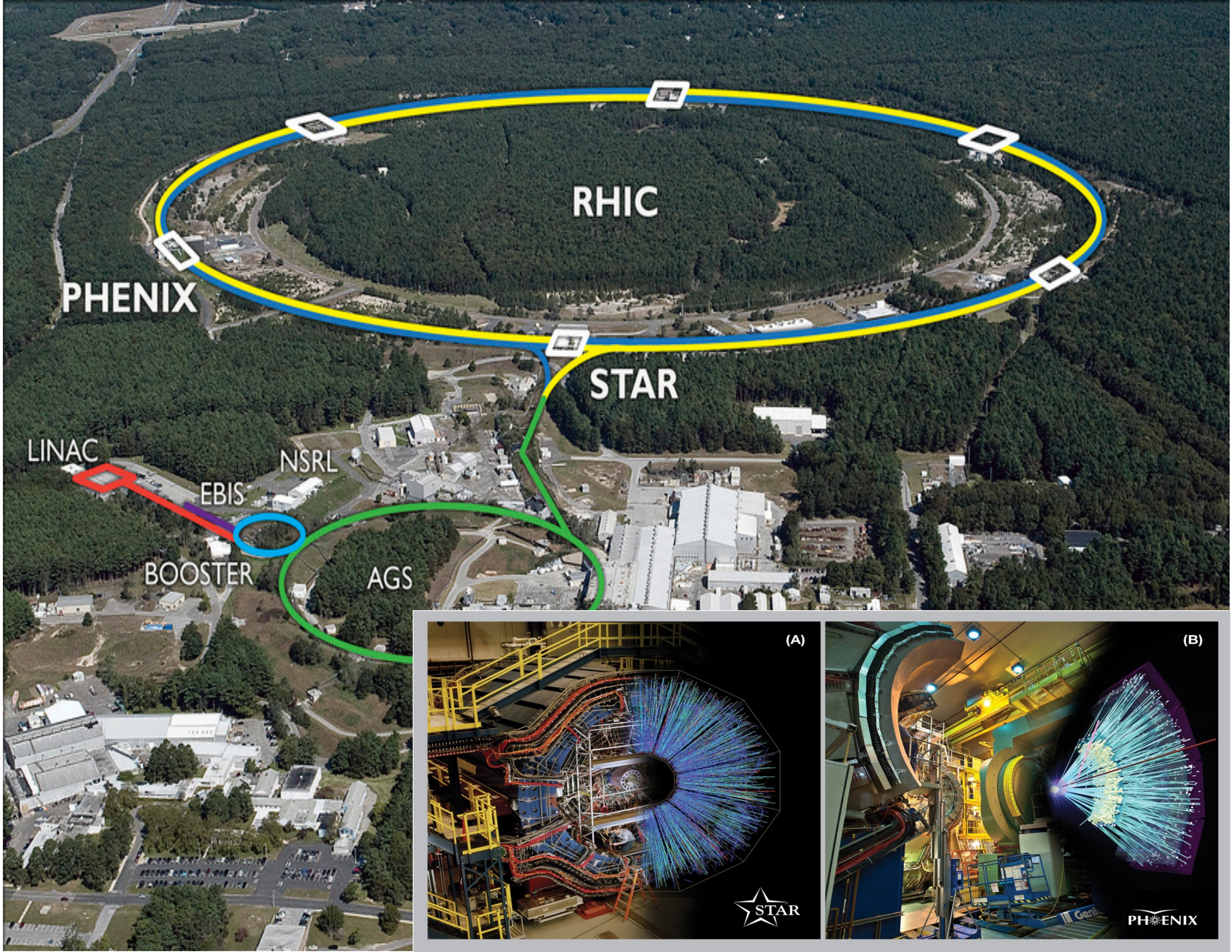
Predictions:

$a_+ = -a_-$

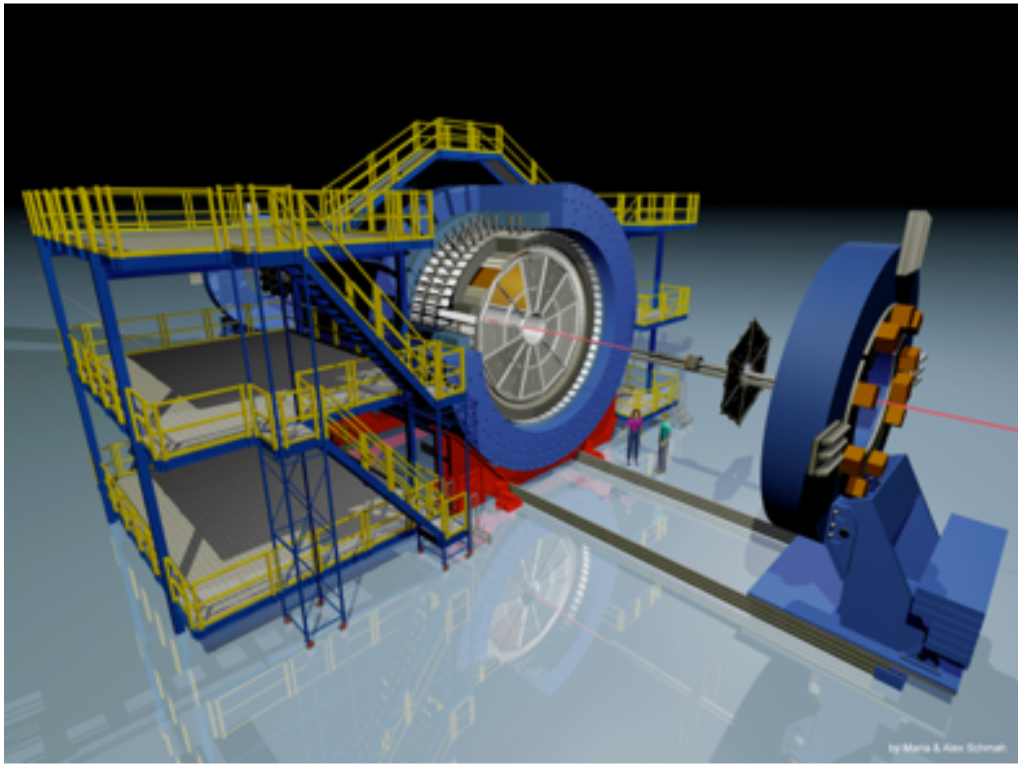
$a_+a_+ = a_-a_- = -a_+a_-$

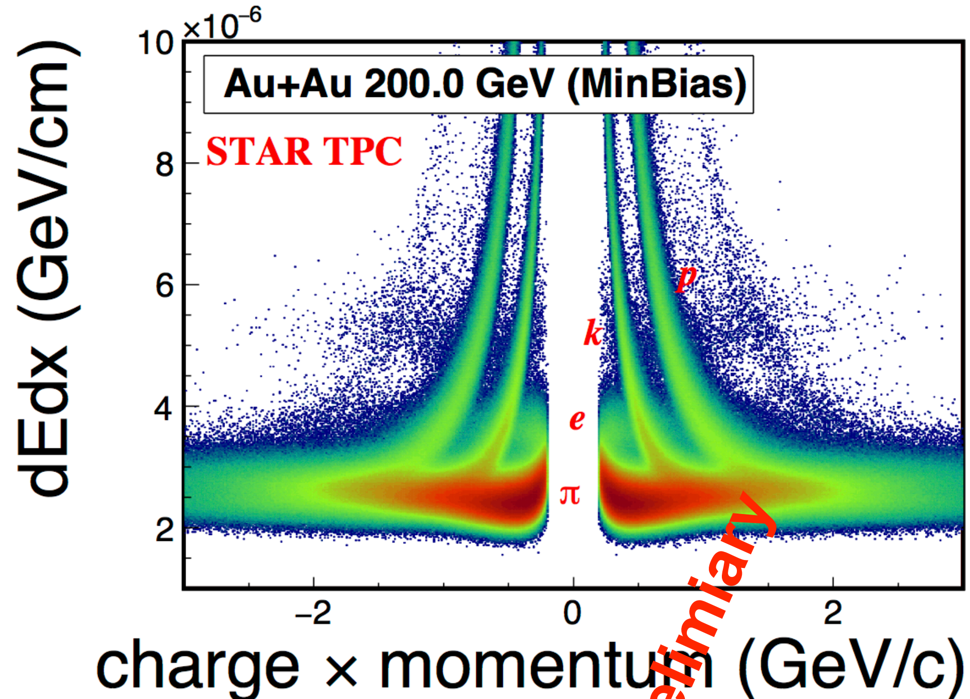
$a \sim 10^{-2}$ for midcentral coll-ns

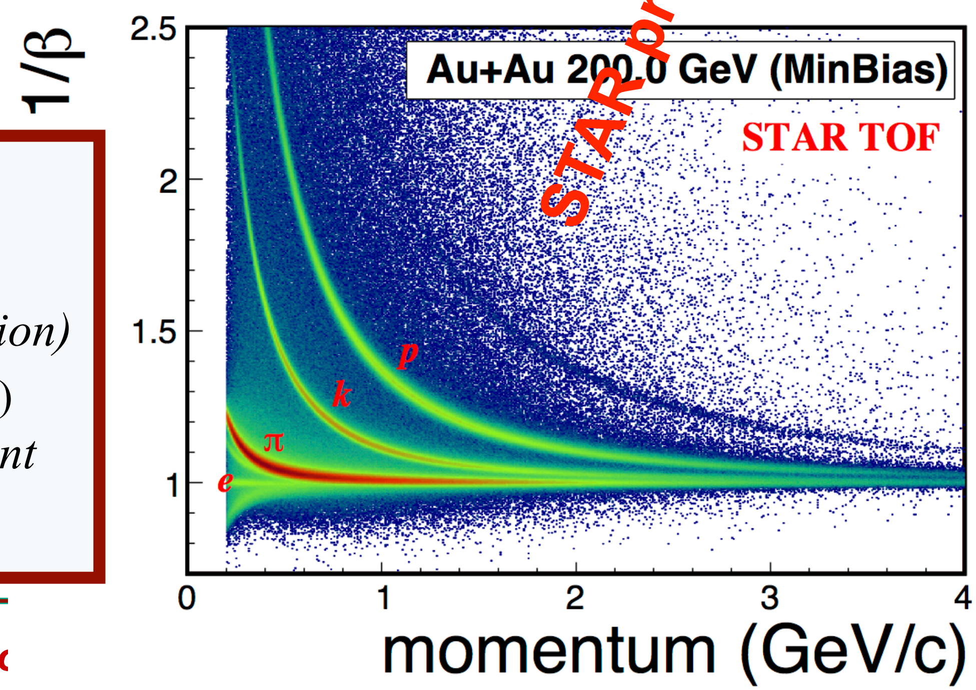
$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle =$$
$$= \langle\cos(\phi_\alpha - \Psi_{RP})\cos(\phi_\beta - \Psi_{RP})\rangle - \langle\sin(\phi_\alpha - \Psi_{RP})\sin(\phi_\beta - \Psi_{RP})\rangle$$
$$\approx (v_{1,\alpha}v_{1,\beta} - a_\alpha a_\beta)$$


RHIC
PHENIX
STAR
LINAC
NSRL
EBIS
BOOSTER
AGS
(A)
(B)

STAR Detector



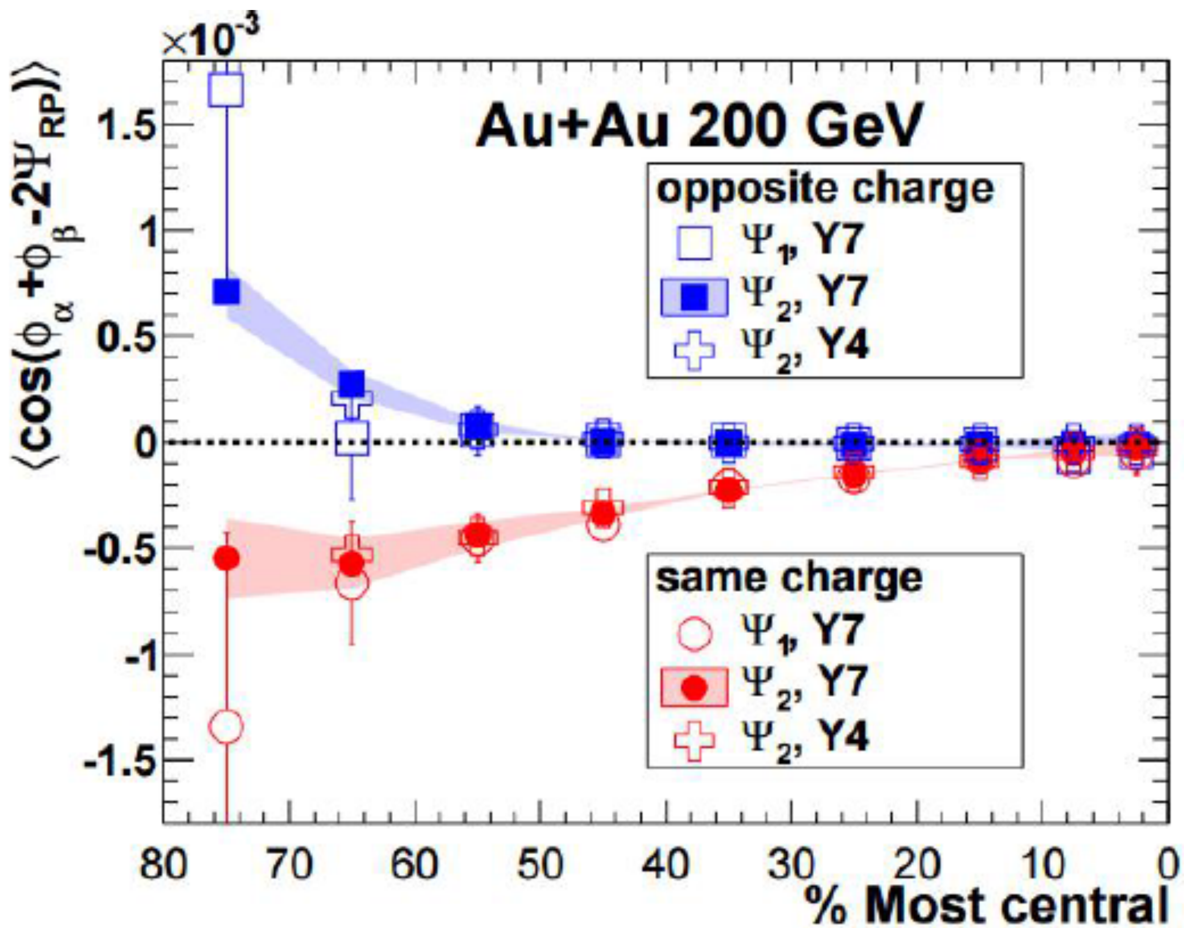




- **Time Projection Chamber** (0<ϕ<2π, |η|<1)
  Tracking – momentum
  Ionization energy loss - dE/dx (particle identification)
- **Time Of Flight detector** (0<ϕ<2π, |η|<0.9)
  Timing resolution <100ps - significant improvement of PID

Charge Separation Signal

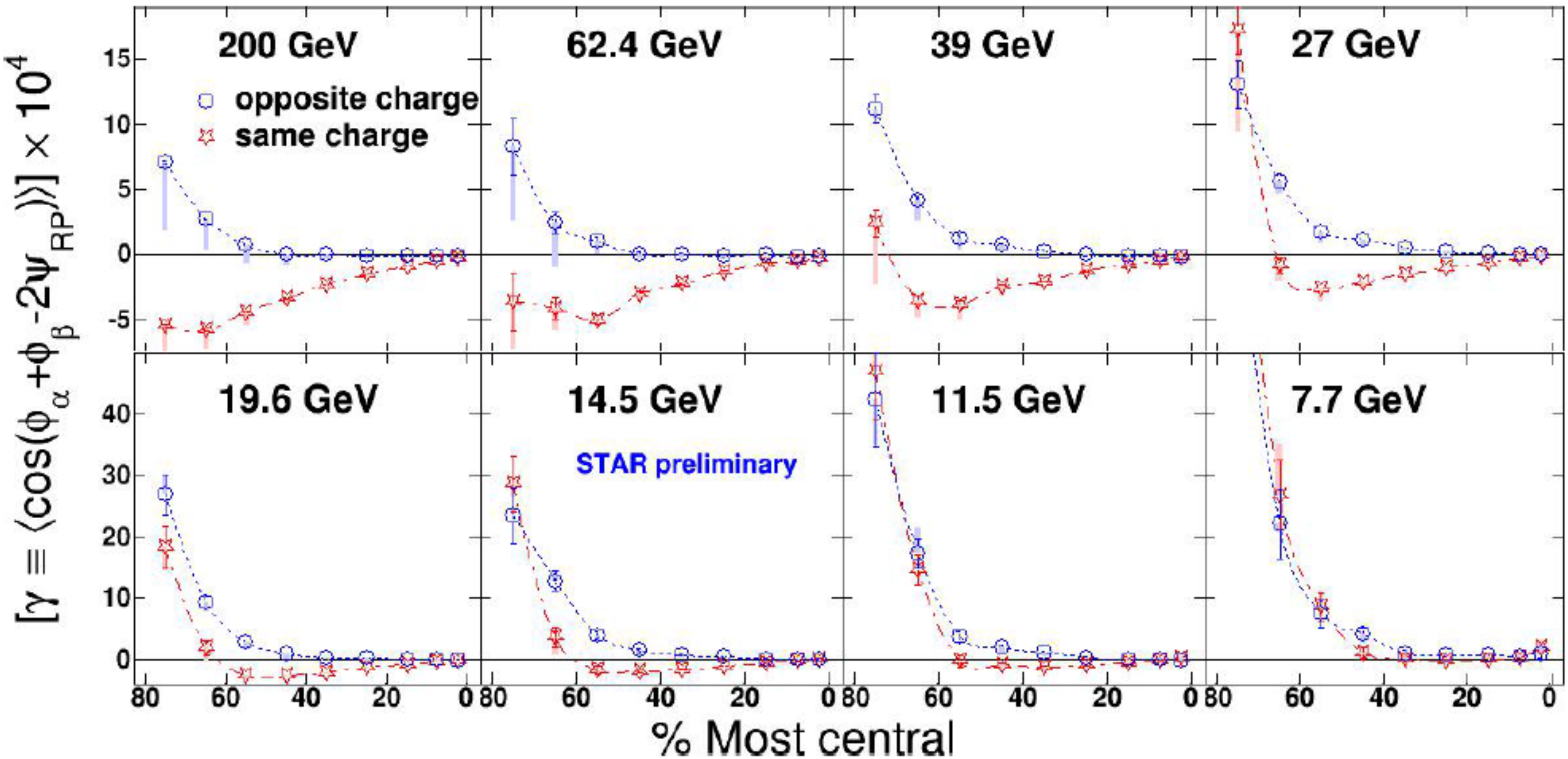
STAR collaboration, PRL 103(2009)251601; PRC 81(2010)54908; PRC 88 (2013) 64911



- Correlator indicates charge separation signal
- Confirmed with 1st-order EP (from spectator neutron v_1)

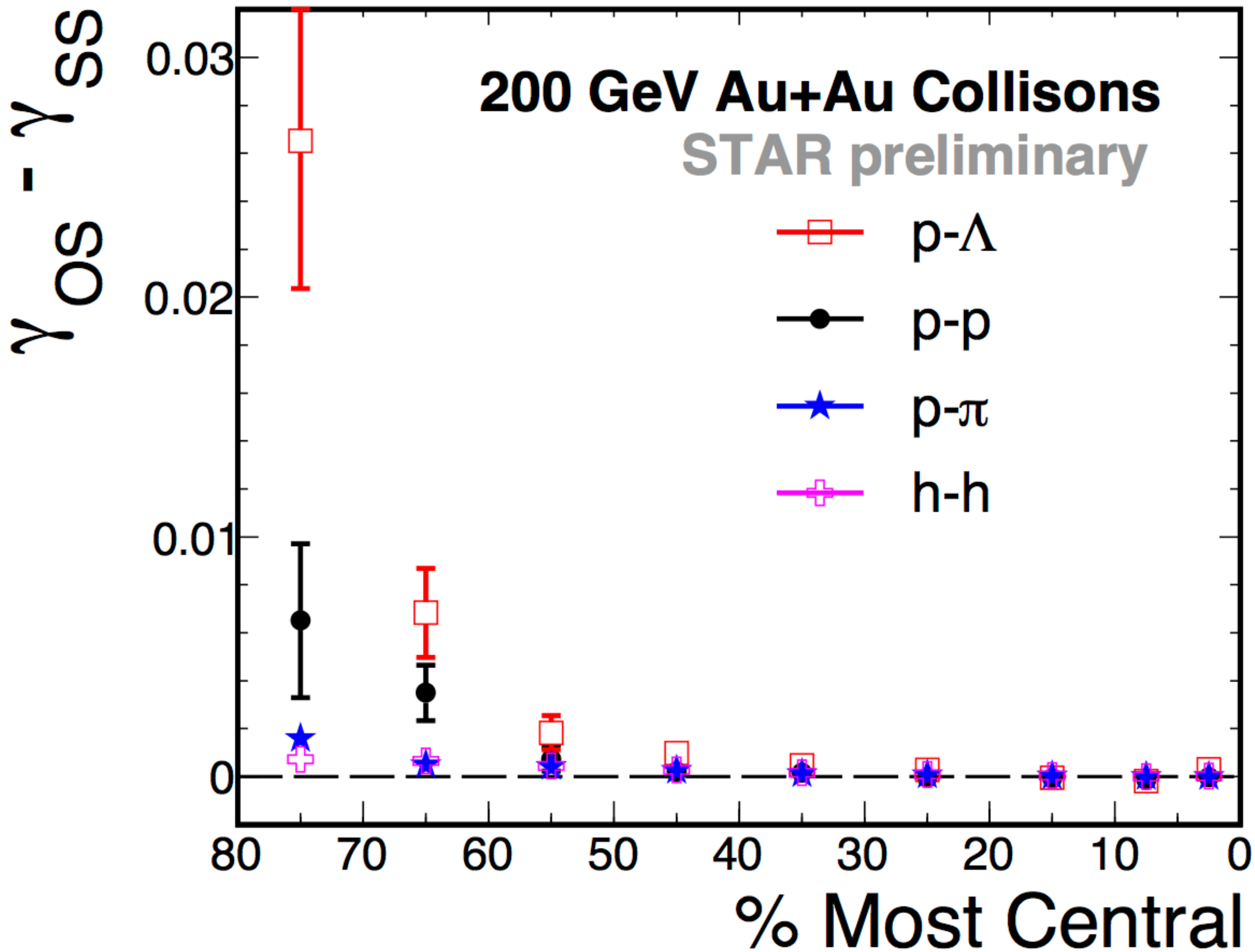
Beam Energy Scan

PRL 113 (2014) 052302



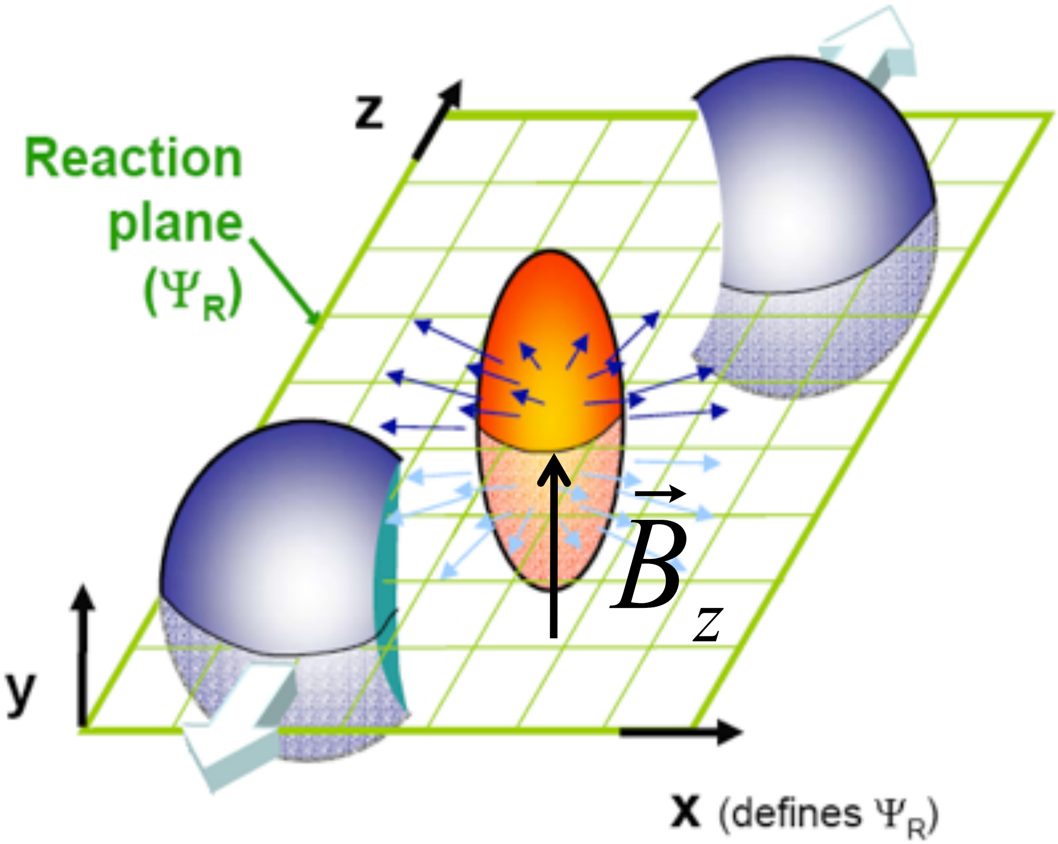
Charge separation starts diminishing at low beam energies

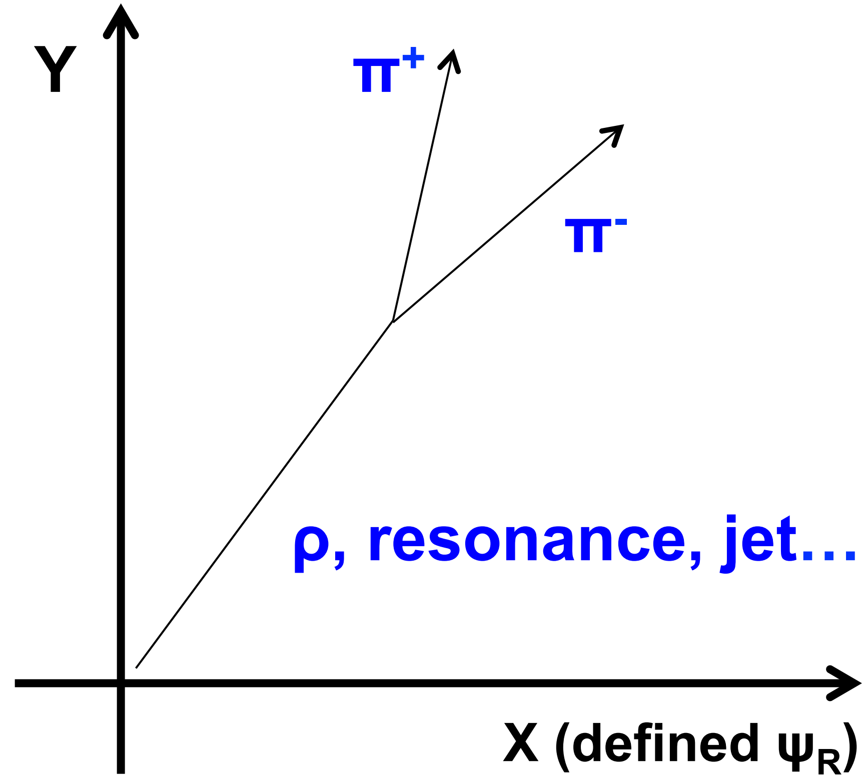
PID Correlation



- charge separation signal shows: p-Λ > p-p > p-π

Flow Related Background



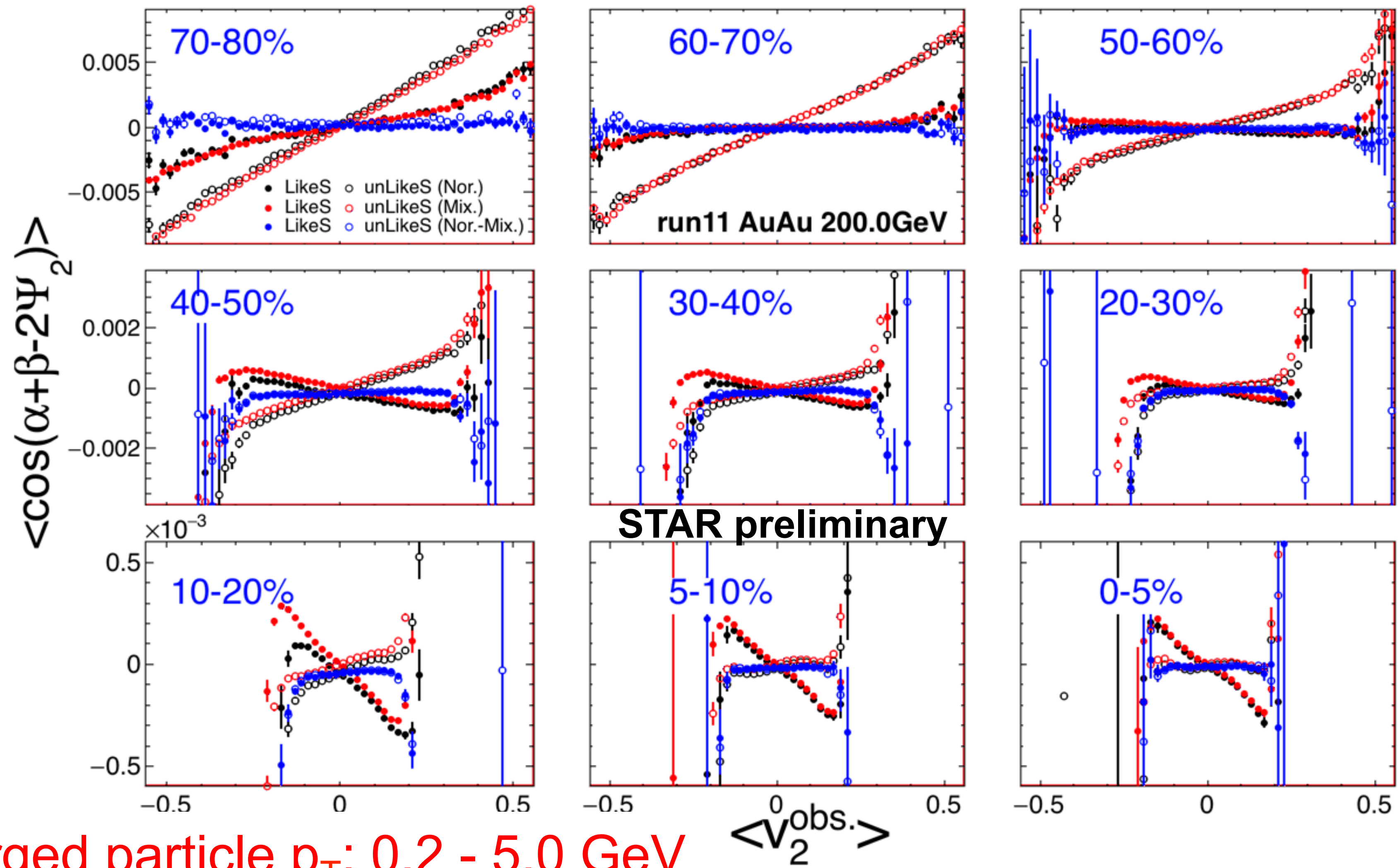


$$\langle cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle \sim \langle cos(\Delta\phi)\rangle * \langle cos2(\phi_\gamma - \Psi_{RP})\rangle$$

- Flow -> might be dominant source of background for CME signals
- Flowing clusters produce CME like signal

now study event-by-event flow vs Azimuthal Charged-Particle Correlations

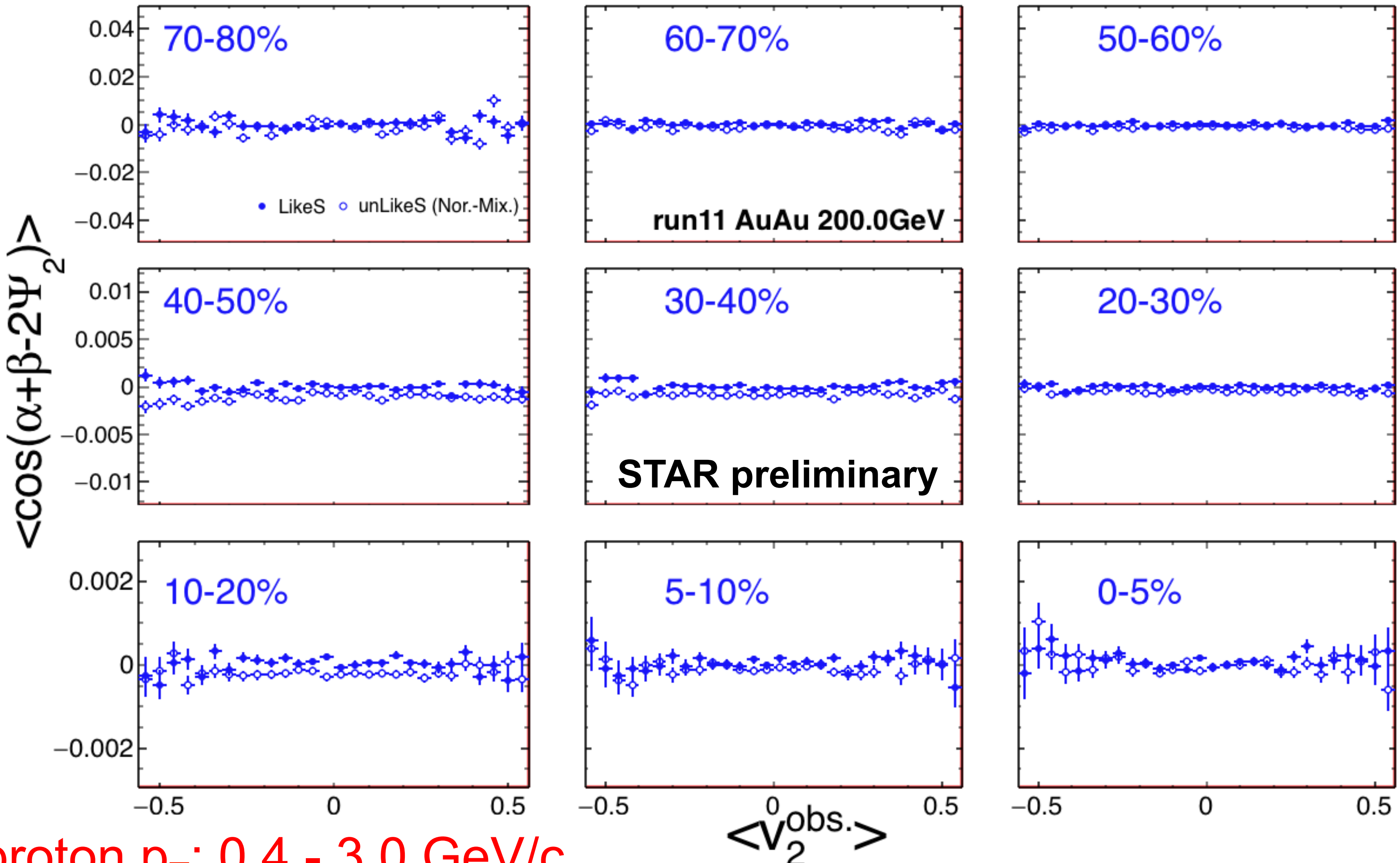
Three Particle Correlator vs v_2



Charged particle p_T: 0.2 - 5.0 GeV

- Mix-event are used to estimate the background correlation between correlator and v_2 (mix-event with event plane from another event)

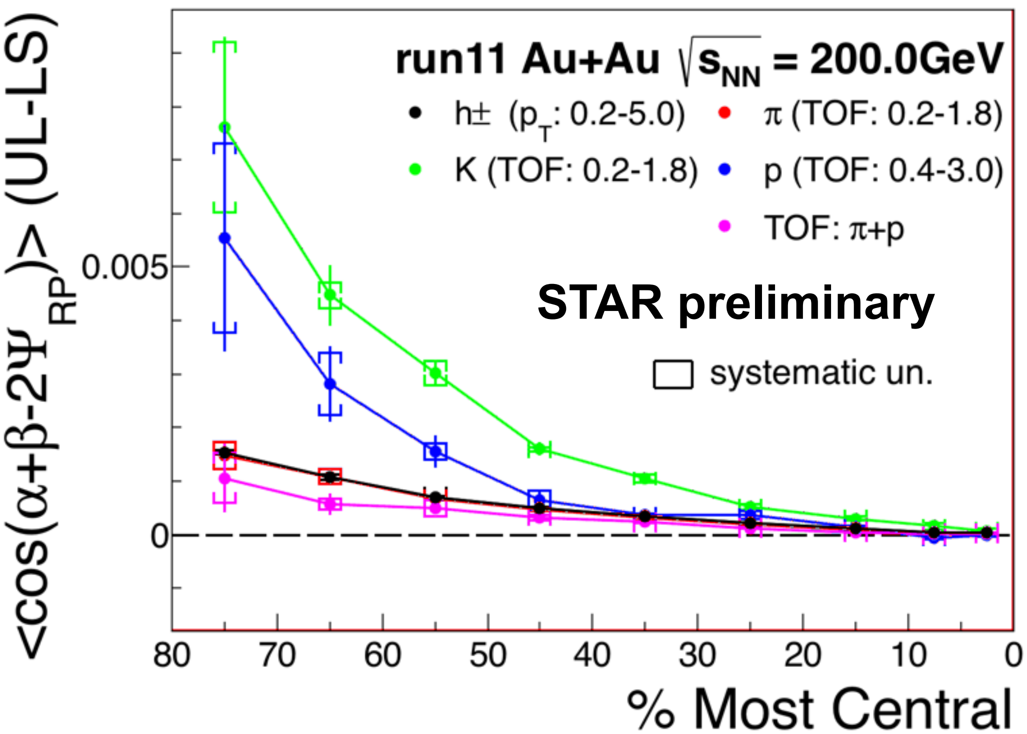
Three Particle Correlator vs v_2

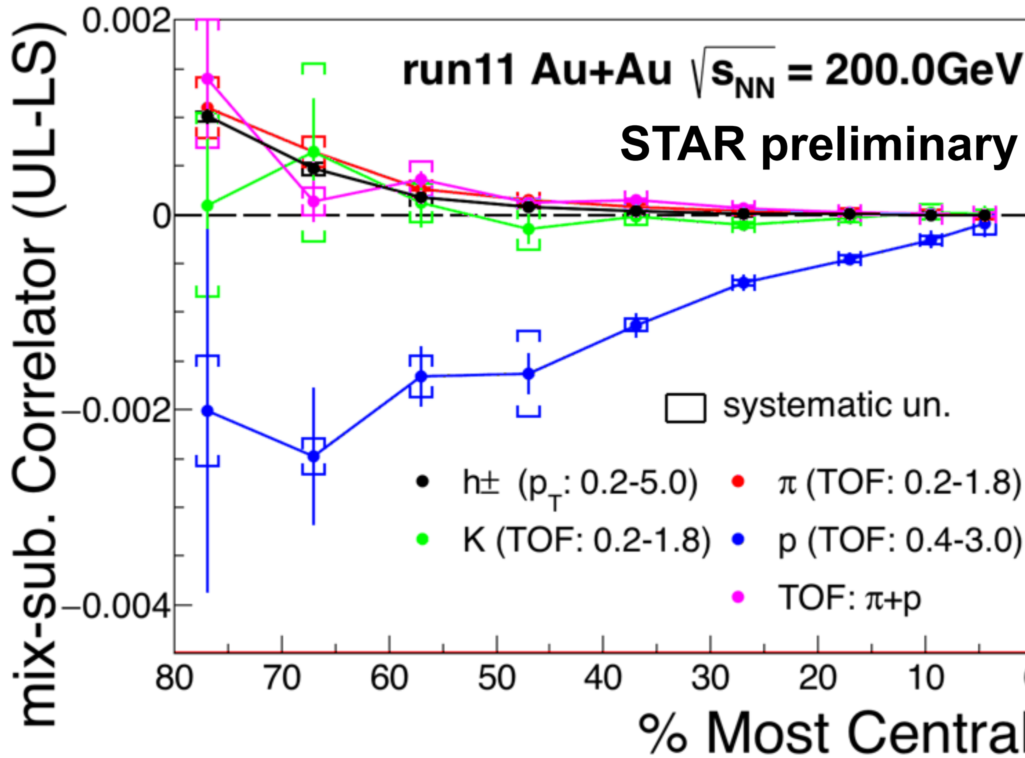


proton p_T: 0.4 - 3.0 GeV/c

- Mix-event subtracted results for proton

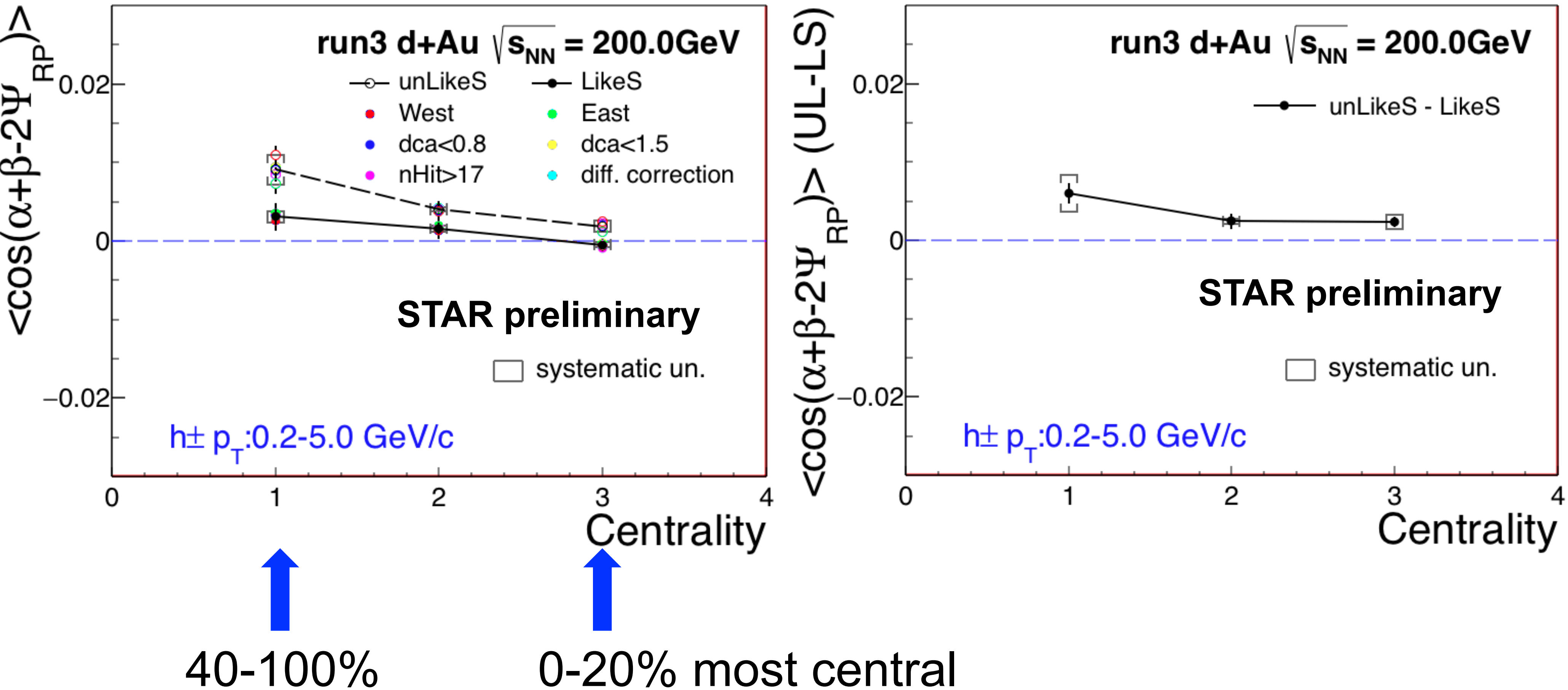
Results With Flow Bkg. Suppressed





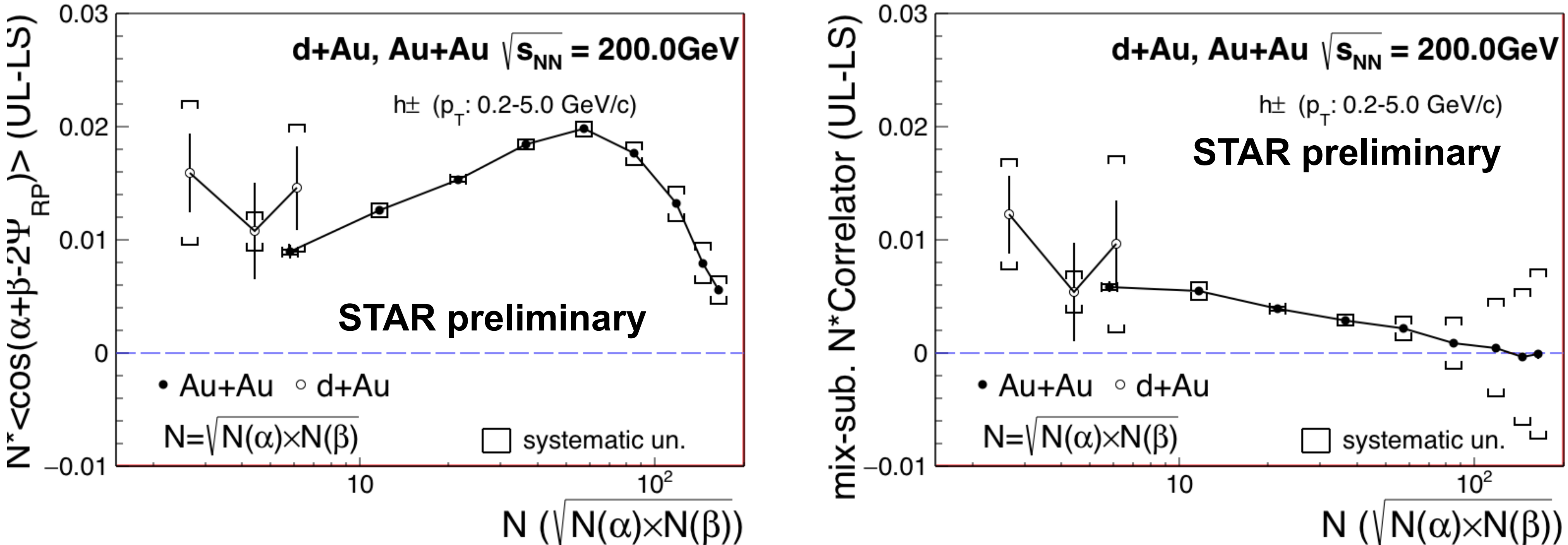
- With flow background suppression, proton results become negative

d+Au Collisions



- Sizeable charge separation effect in small system d+Au collisions

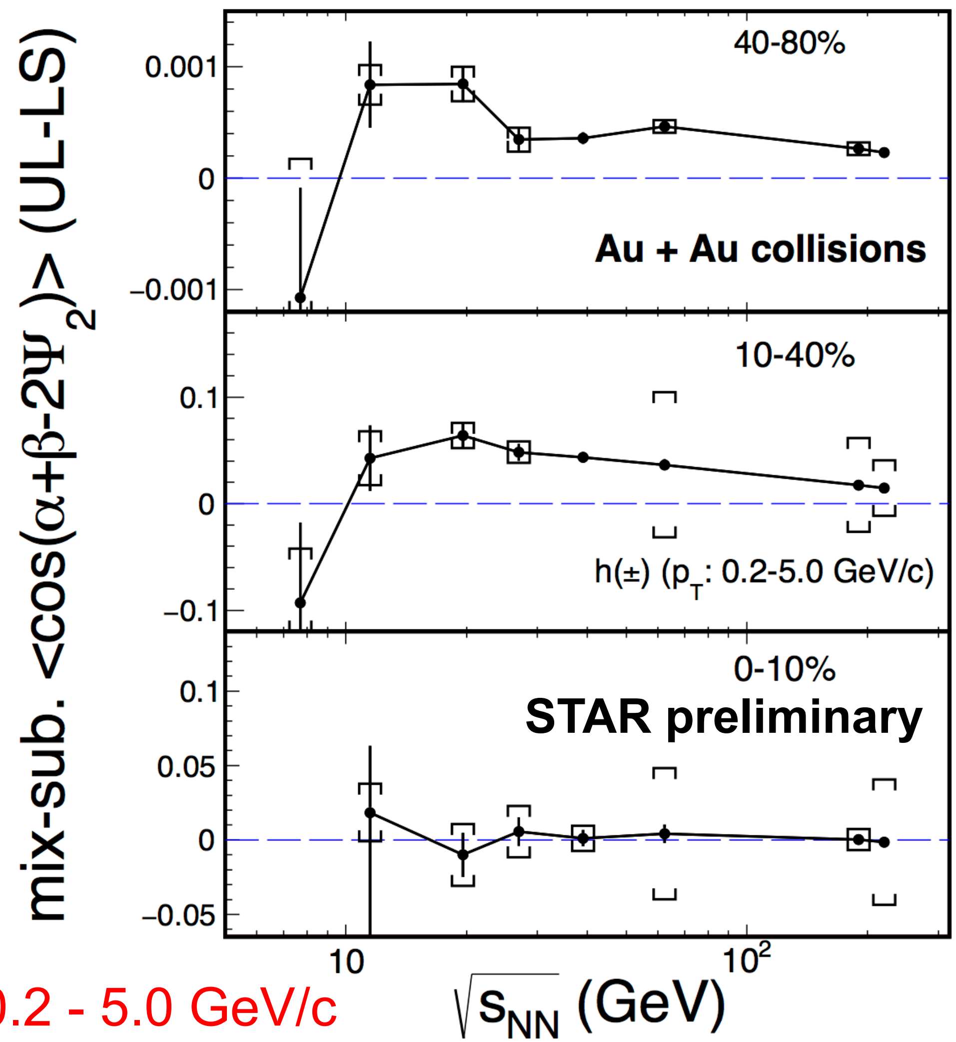
System Size Dependent



$$\frac{N(signal)}{N(\alpha)^*N(\beta)} \sim \frac{1}{N}$$ ⇒ Multiplicity effect

- At same multiplicity d+Au and Au+Au show similar charge separation
- More data needed for d+Au collisions

Beam Energy Dependent



Charged particle p_T: 0.2 - 5.0 GeV/c

- In central collisions, charge separation signal is consistent with 0
- In non-central collisions, below 19.6 GeV signal became negative
- Consistent with published results (PRL 113 (2014) 052302)

Summary

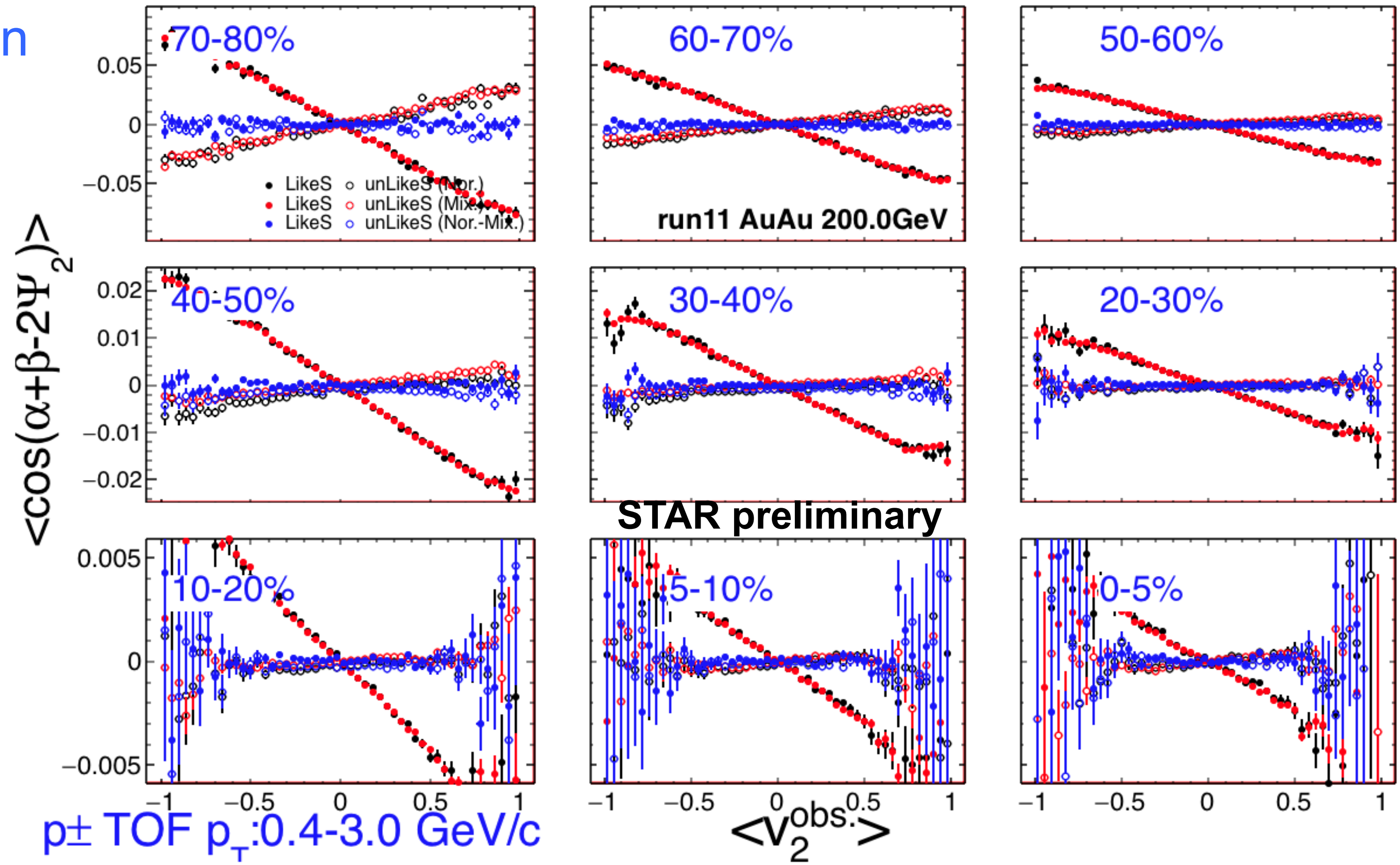
The energy and system size dependent flow-background subtracted three-particle correlator analysis has been presented. We conclude:

- With flow background suppression, proton results become negative
- Flow suppressed three-particle correlator shows finite charge separation at mid- and low centrality bins
- Within uncertainty, d+Au results are consistent with those from low multiplicity 200 GeV Au+Au collisions. More data needed for d+Au collisions

backup

Three Particle Correlator vs v_2

proton



p± TOF p_T:0.4-3.0 GeV/c

- Mix-event are used to estimate the background correlation between correlator and v_2 (mix-event with eventplane from another event)