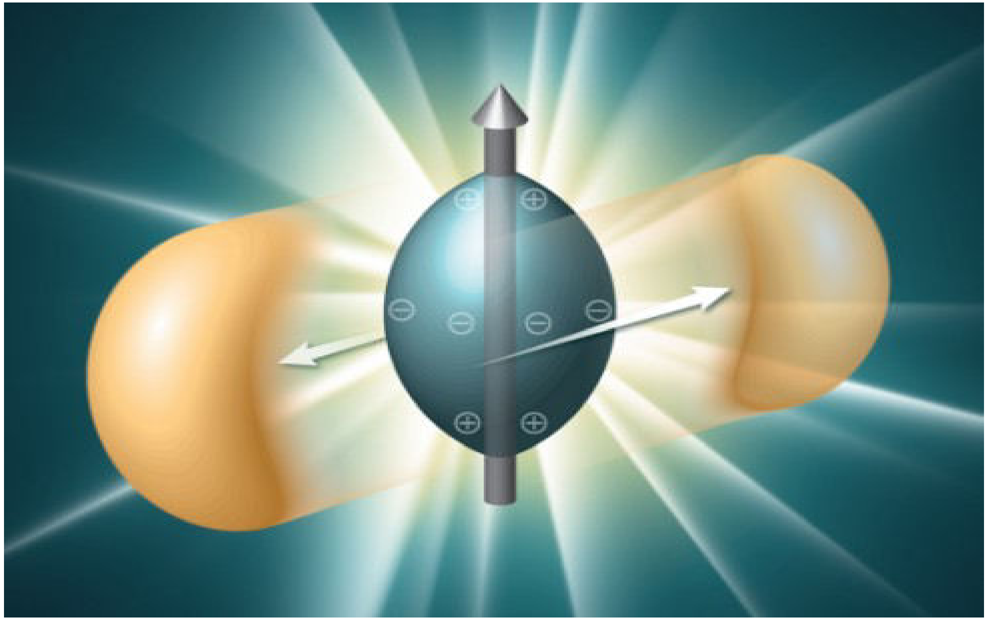
Background Study of the Chiral Magnetic Wave Using Electrons



Nihal K. Gozlukluoglu (Visiting Student UCLA)

Physics Motivation :

In search for Chiral Magnetic Wave (CMW), certain background mechanisms (Local Charge Conservation) could fake a CMW signal. We shall use electrons (positrons) to probe this background effect. <u>Because electrons(positrons) are not interacting with hot dense matter there is no CMW effect for electron!!</u>

Outline

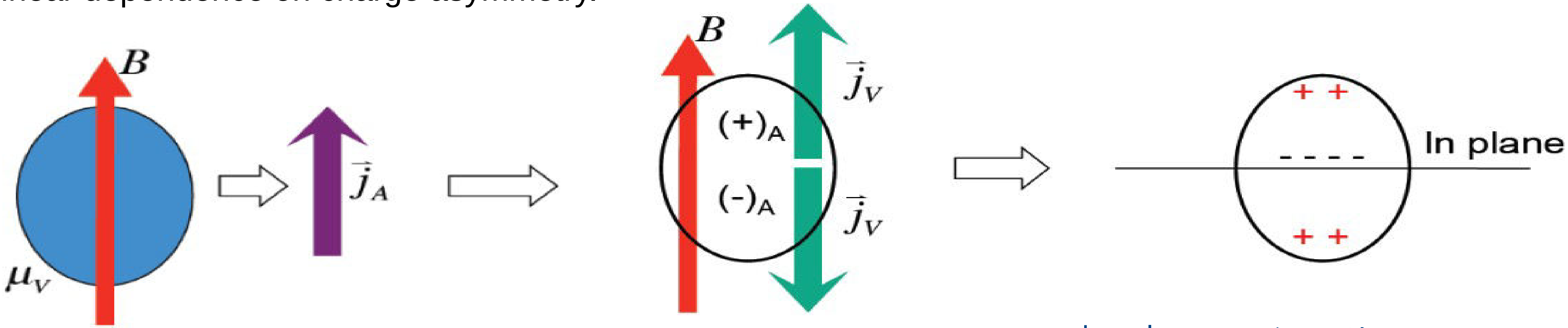
- Introduction
  - *Chiral Magnetic Wave (CMW)*
  - *Alternative Interpretation : Local Charge Conservation (LCC)*
- Methodologies

  Main Methods
  - *Inclusive Case*
  - *Exclusive Case*

  An Alternative Approach for Exclusive Case
  - *Semi Exclusive Case*
- Experimental Results
- Conclusion

Chiral Magnetic Wave

- If the CMW-induced electric quadruple exists, more negative particles will be expected in-plane direction and more positive particles will be expected to be out-of-plane direction. v_2 of charged hadrons will show a linear dependence on charge asymmetry.



Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, PRL 107, 052303 (2011)

$$A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

Charge Asymmetry

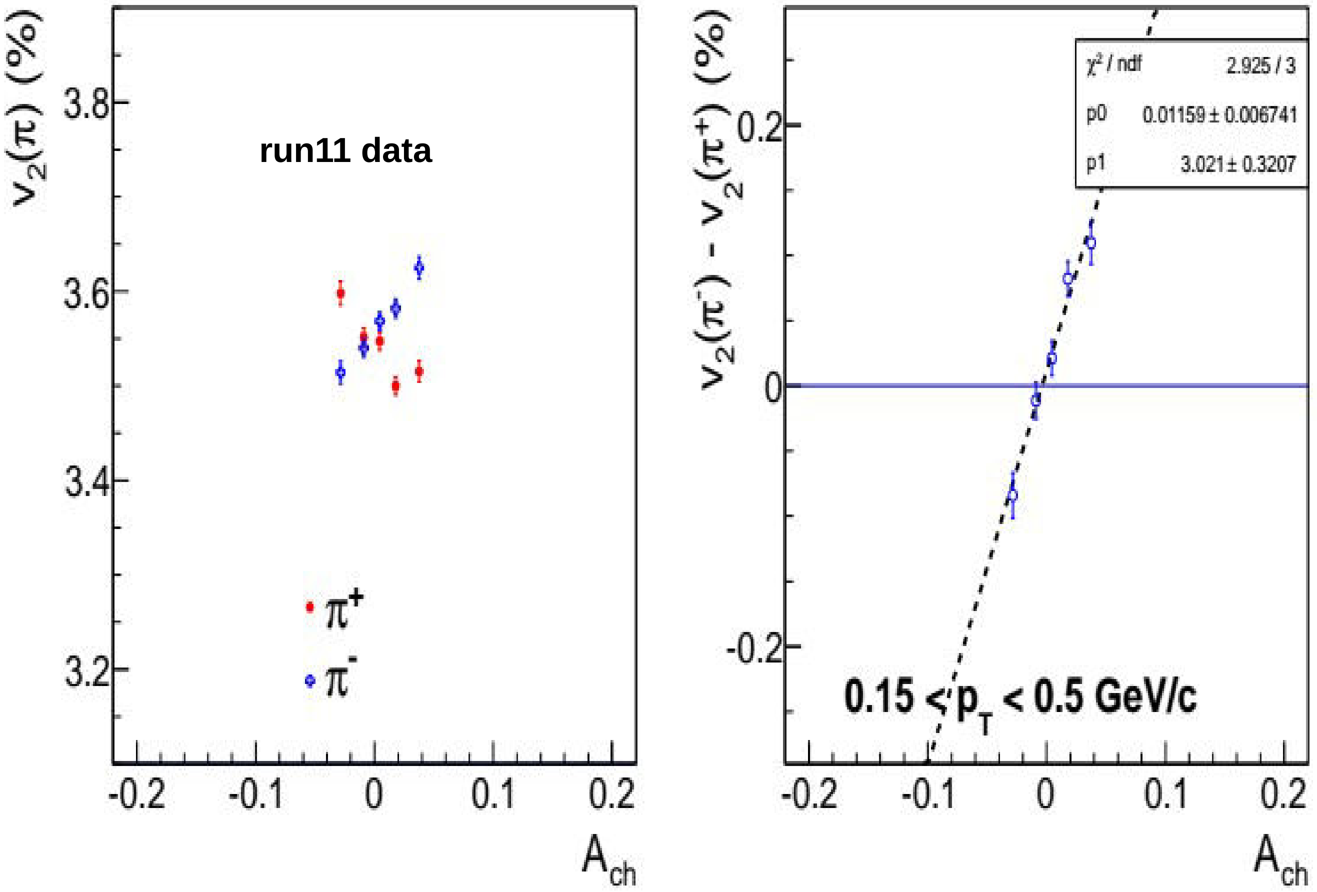
quadrupole moment

Slope parameter

$$v_2^{\pm} = v_2^{base} \mp \left(\frac{q_e}{\bar{\rho}_e}\right) A_{ch} = v_2^{base} \mp \frac{rA_{ch}}{2}$$

net charge density

CMW Signal and Pion Elliptic Flow

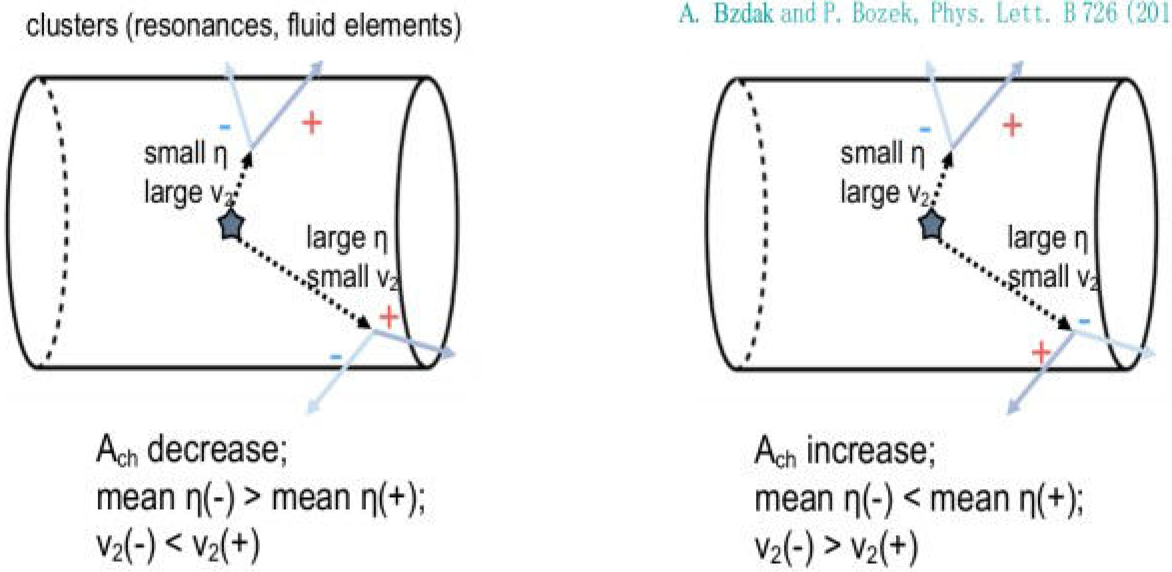


- A_{ch} is divided into 5 bins.
- Centrality 30% – 40% , Au+Au collision, 200 GeV.
- The sub-event build by $K^{\pm}$, p and $\pi^{\pm}$.
- The eta gap between POI and Evet Plane (EP) is $|\eta| < 0.3$.
- The slope, *r*, is used to quantified the effect.
- Although data looks align with the CMW expectation we can not exclude possibility of background contribution.

Alternative Interpretation : Local Charge Conservation (LCC)

- In the STAR experiment, the elliptic flow is measured in $|\eta| < 1$ that is broader than the typical width of the balance function.

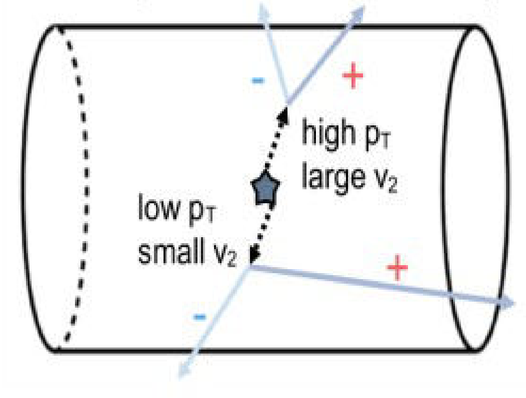
A. Bzdak and P. Bozek, Phys. Lett. B 726 (2013) 239



- Clusters (fluid elements or a resonance) located close to acceptance boundary produce one pion outside boundary. v_2 decreases with $|\eta|$.

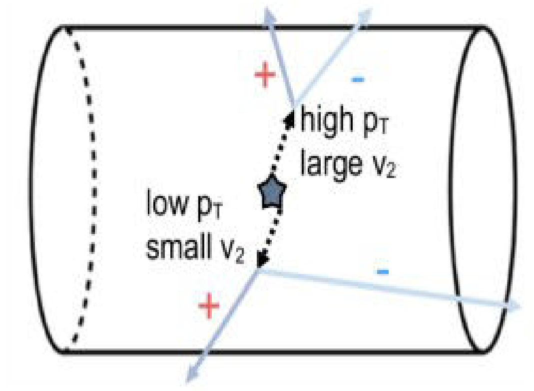
Alternative Interpretation : Local Charge Conservation (LCC)

- The elliptic flow of clusters with a small transverse momentum (velocity) is less than that of clusters with a high transverse momentum.



A_{ch} decrease;
mean $p_T(-)$ < mean $p_T(+)$;
$v_2(-) < v_2(+)$

A. Bzdak and P. Bozek, Phys. Lett. B 726 (2013) 239

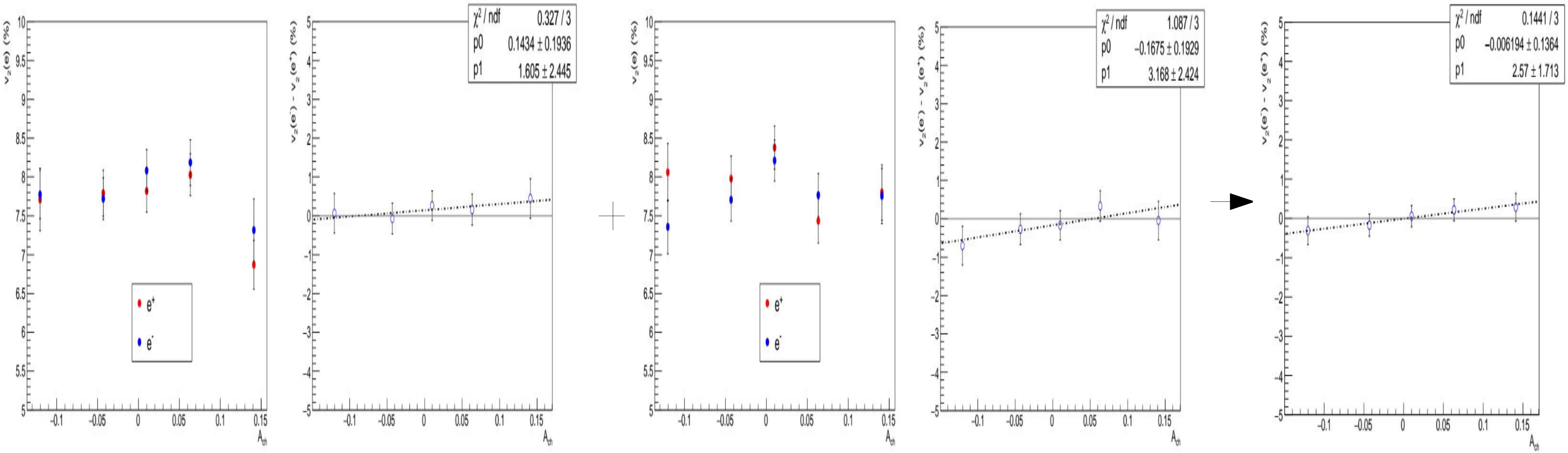


A_{ch} increase;
mean $p_T(-)$ > mean $p_T(+)$;
$v_2(-) > v_2(+)$

- Clusters with low p_T have particles more separated in η than high-p_T clusters. v_2 increases with p_T .

METHODOLOGIES

- Minimum-bias triggered events taken by the STAR detector from 2011, Au+Au , at √s = 200 GeV.
- A_{ch} is divided into 5 bins.
- $0.15 < p_T < 0.5$ GeV/c
- If POI and event plane have the same electrical charge sign we say same sign (SS). In other way it's Opposite Sign. We combine SS and OS. In the following example Centrality bin is 50% - 60%.



Same Sign Opposite Sign

METHODOLOGIES
Inclusive And Exclusive Cases

- Dileptons has been suggested as ”penetrating probes” for the hot and dense medium created in heavy-ion collisions, because they are produced during the whole evolution <u>and not subject to the violent strong interactions in the medium so there is no CMW effect for electron!!</u> Choosing our POI as electron (e^-) can provide us a good probe to the pure background.

Main Methods

Inclusive Case

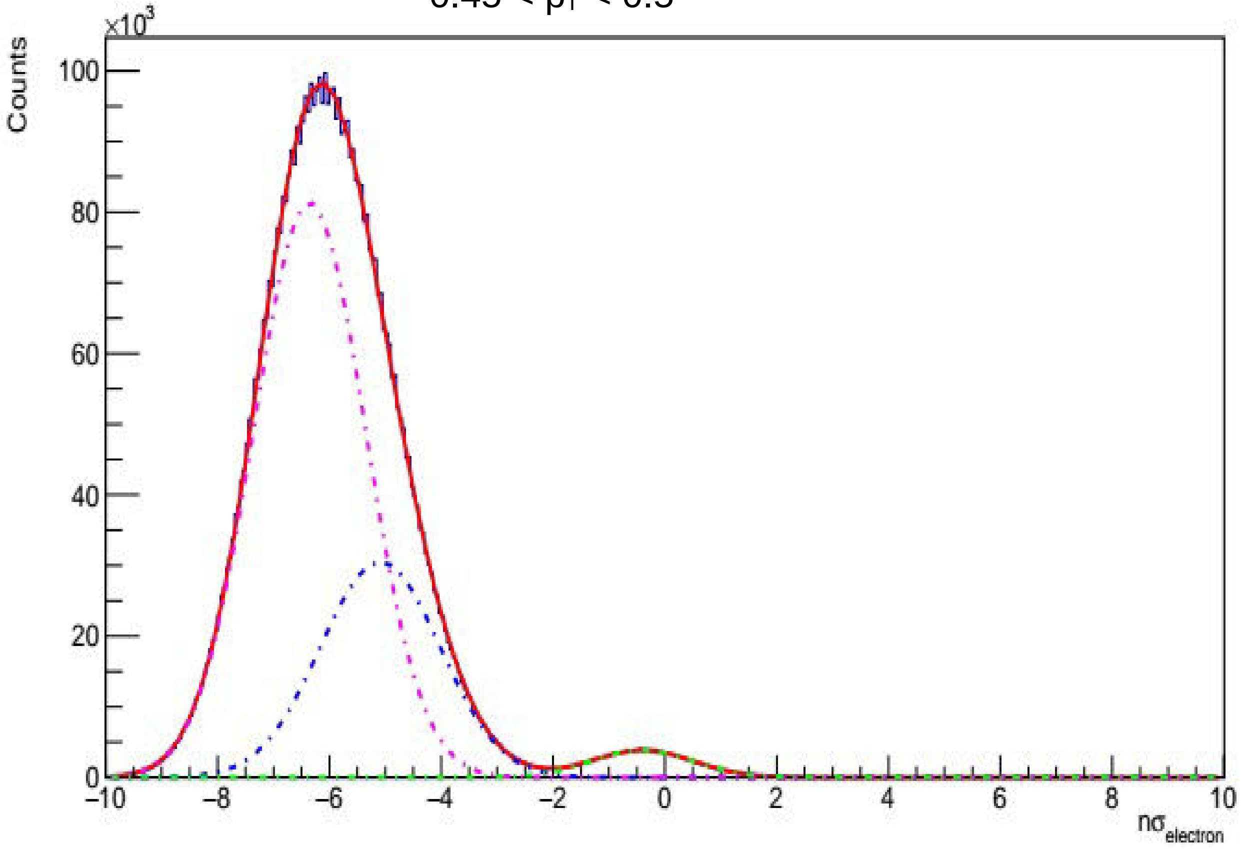
- The Inclusive case is that electrons/positrons are included to count charge asymmetry.
- There is a big chance to see LCC effects in this case.

Exclusive Case

- The Exclusive case is that electrons/positrons are excluded when counting charge asymmetry.
- Thus LCC effects are greatly suppressed.

Electron Purity

$0.45 < p_T < 0.5$

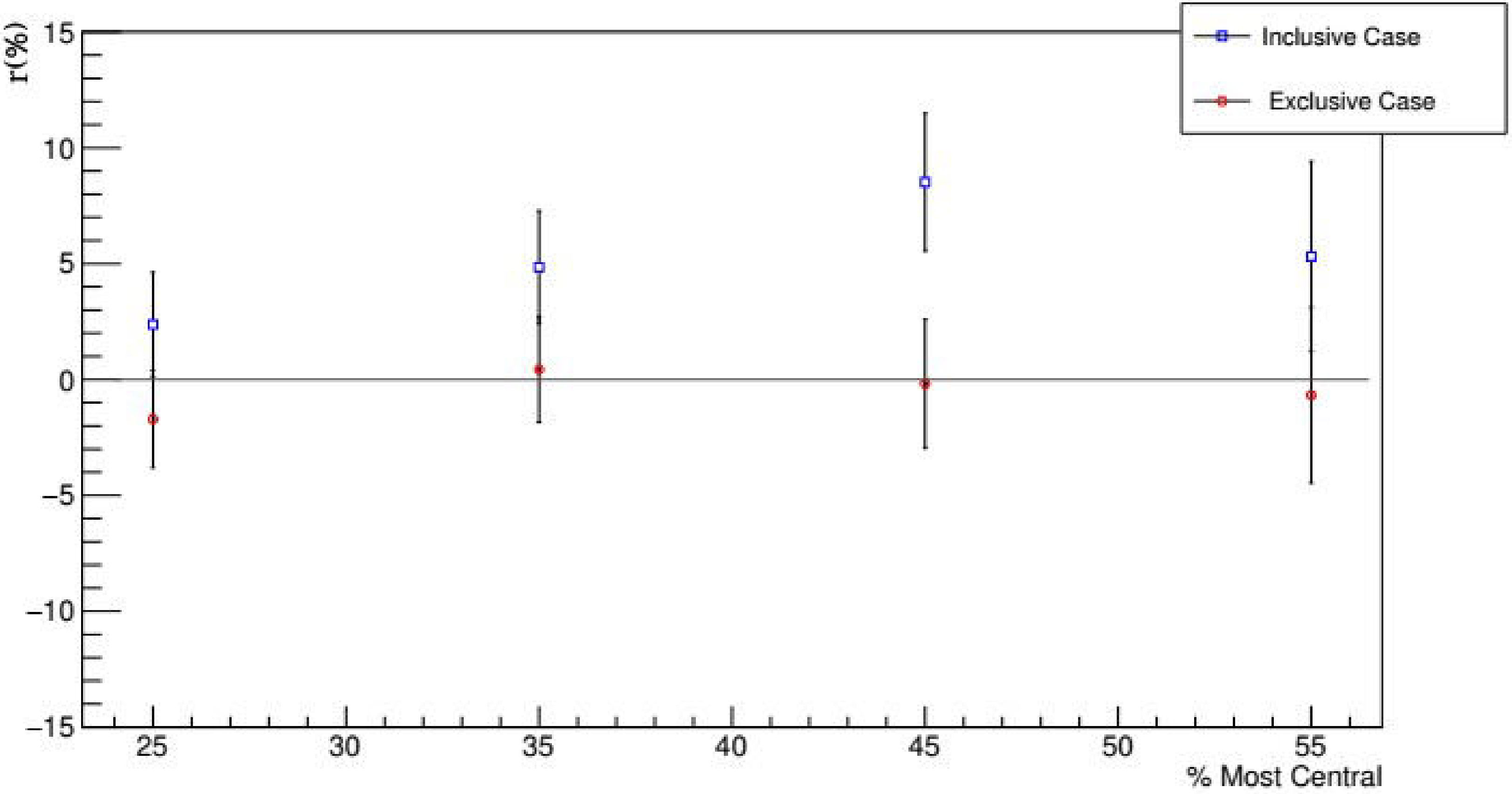


Total counts = 8530.63

Total electrons = 8372.11

Electron purity = 0.981418

Experimental Results
Exclusive Case and Inclusive Cases



Discussion

- Our study indicates that other physics mechanisms can give rise to slope parameter of Δv_2 (A_{ch}) in Inclusive case. Like LCC which is a non-CMW mechanisms.

- For Exclusive case, the Δv_2 (A_{ch}) has a slope consistent to zero. It shows us that in Exclusive case the LCC effects can actually be suppressed.

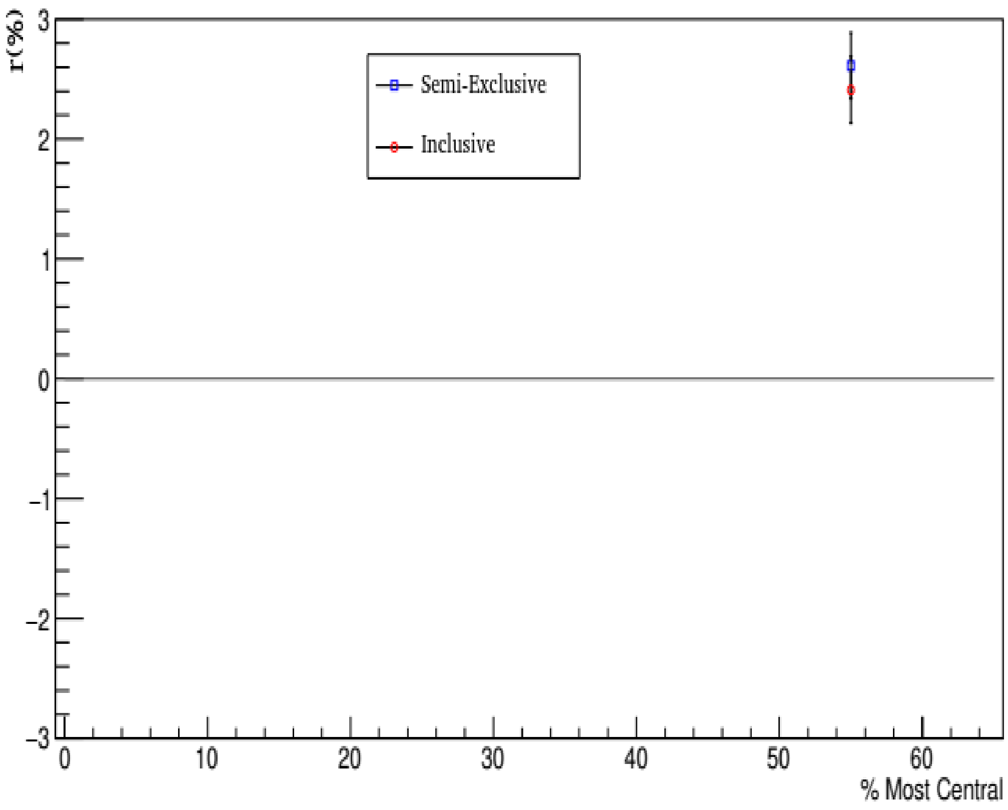
An Alternative Approach for Exclusive Case (Semi Exclusive Case)

- It may not be feasible to exclude pions from A_{ch} like we did previously in Exclusive case.

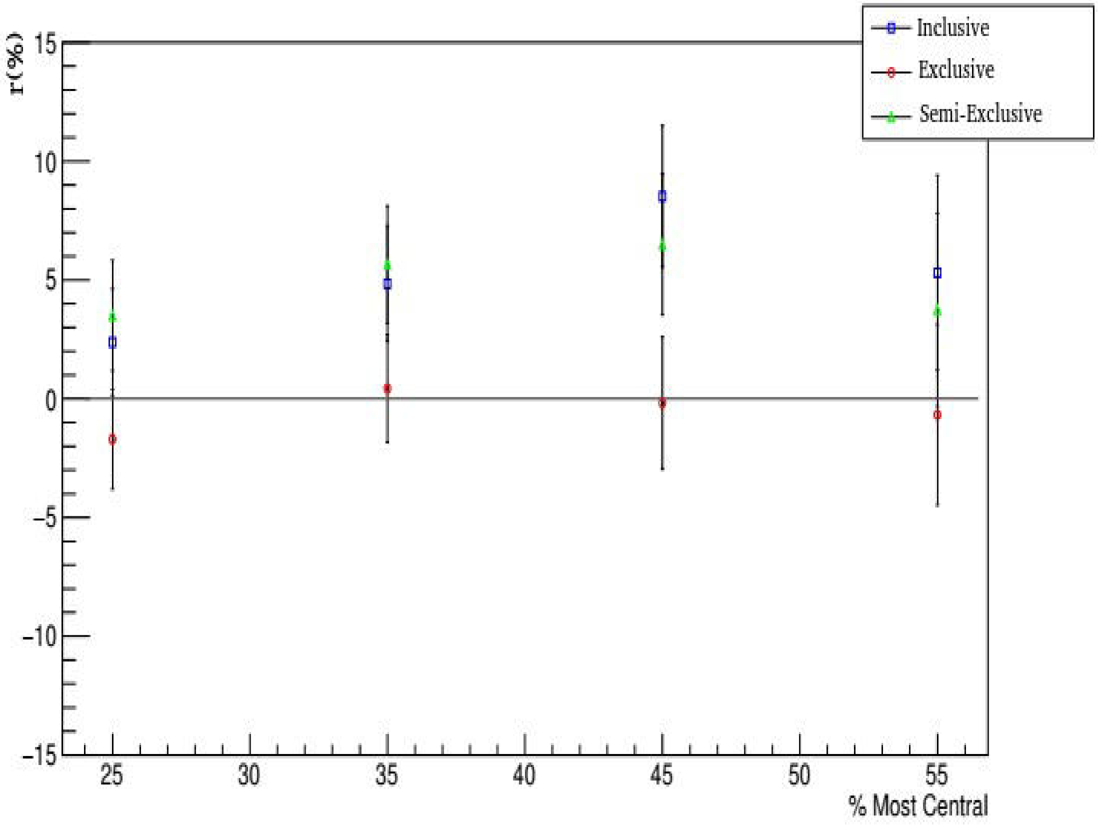
- A_{ch} redefined by excluding the POI when filling its v_2 vs A_{ch}. In this way it is different than rejecting all POI *for* A_{ch}.So we can call this method Semi Exclusive Case. Both ($\pi^{\pm}$) and ($e^{\pm}$) used as our POI.

Experimental Results

Pion



Electron



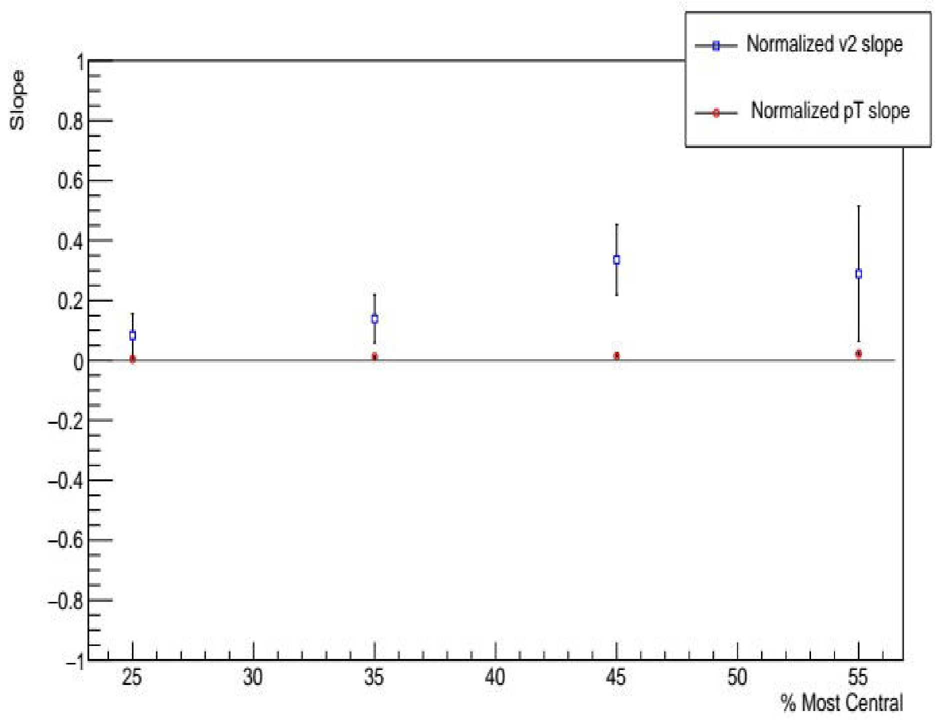
Experimental Results

Normalized p_T and v_2 Plots for Electron

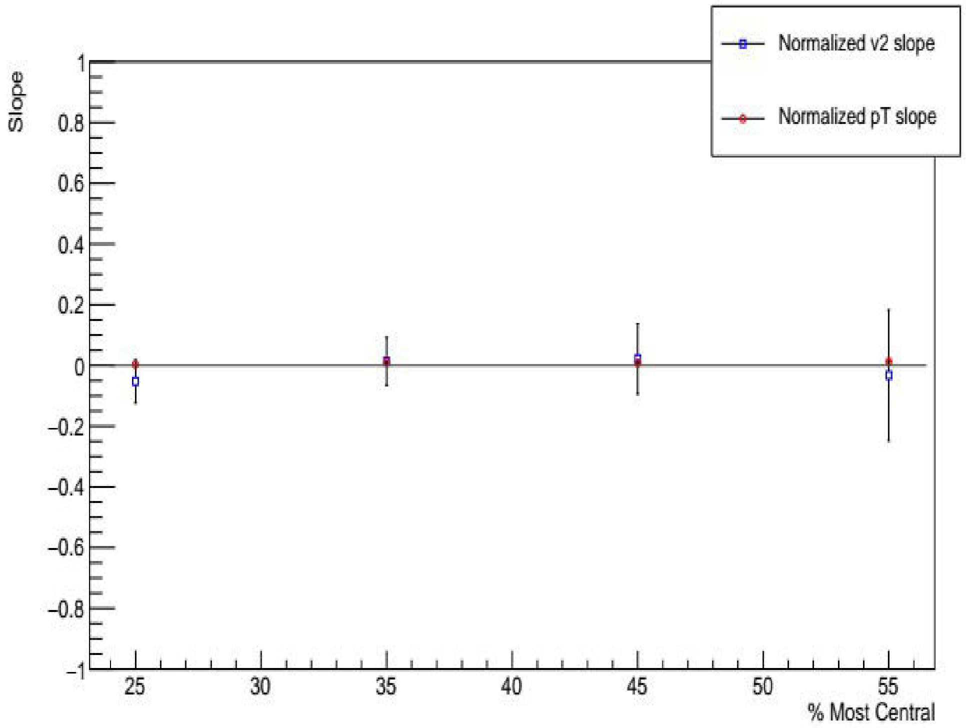
Normalization for Mean p_T : Normalized p_T = $2 * [p_T(-) - p_T(+)] / [p_T(-) + p_T(+)]$

Normalization for v_2 : Normalized v_2 = $2 * [v_2(-) - v_2(+)] / [v_2(-) + v_2(+)]$

INCLUSIVE CASE



EXCLUSIVE CASE



Conclusion

- Inclusive case for electron gives rise to slope parameter which indicates LCC effects which is a non CMW mechanism could fake the signal. And LCC effects could be an effective source for background.

- For electron we suppress the LCC effects by applying Exclusive case method.

- Both for Electron and Pion, Semi Exclusive case didn’t create any difference from Inclusive Case.

- In low p_T region ($0.15 < p_T < 0.5$ GeV), the normalized p_T slope cannot explain the normalized v_2 slope.

Thank you for your attention …

BACKUP SLIDES

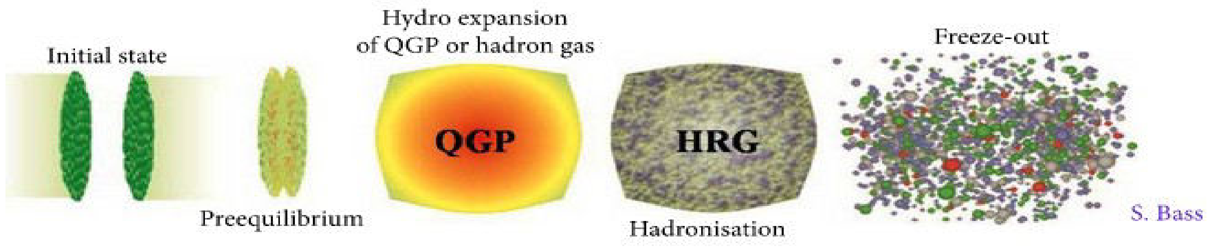
BACKUP SLIDES (Cuts for Electrons)

- The cuts for electrons :

- DCAGlobal < 1.0 cm
- NdEdx > 10
- 0.15 < Pt < 0.5 GeV/c

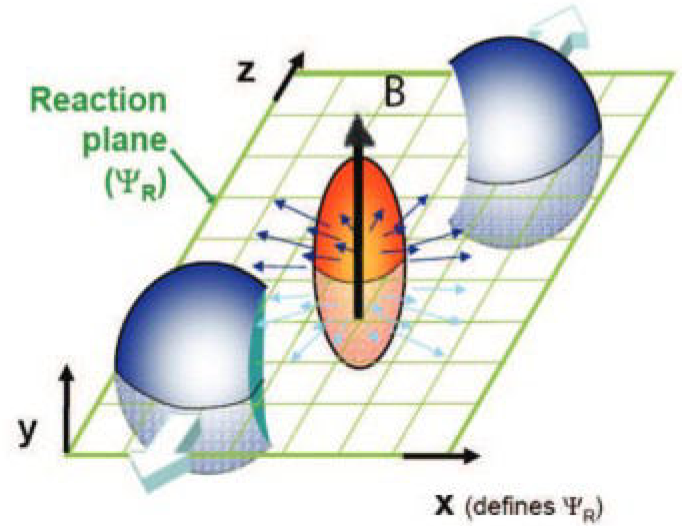
- |TofYLocal| < 1.8 cm
- |nSigma_e| < 3
- |eta| < 1
- |beta -1| < 0.03
- TOFflag >= 1

BACKUP SLIDES (CMW)



- When positively charged nuclei move they generate electric currents which in turn induce the magnetic fields.

- Reaction plane defined by the impact parameter and the collision axis.

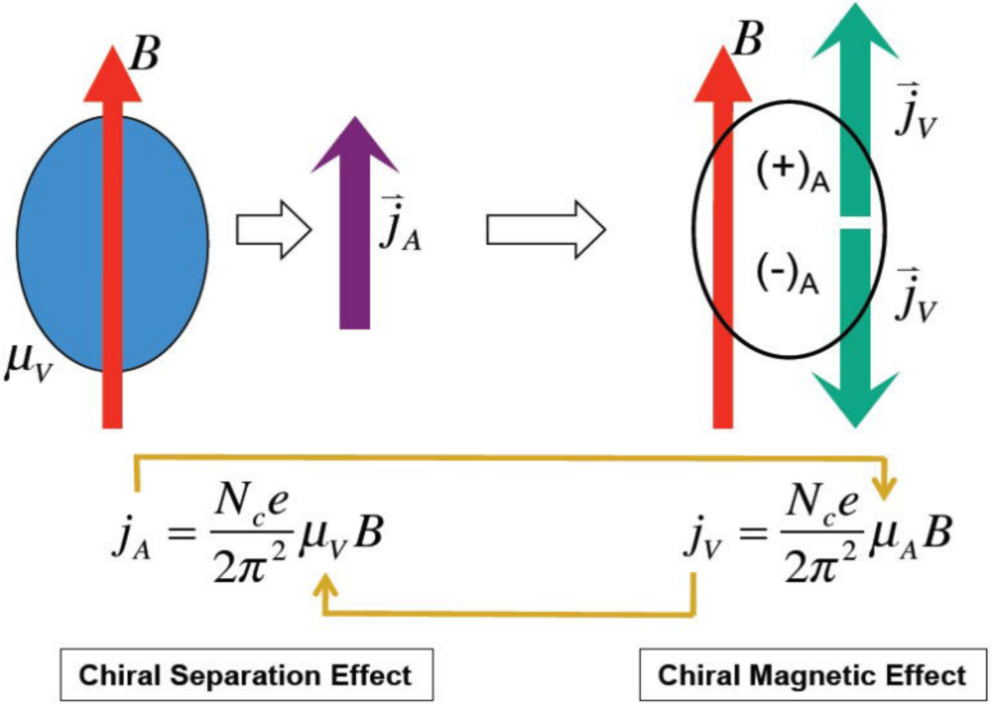


- Strong magnetic field ~10^{15} Tesla!
 (Kharzeev et al. NPA 803 (2008) 227).

- Non-central nuclear collisions would lead to the asymmetry in the emission of positively and negatively charged particles perpendicular to reaction plane .

- Such a charge separation is a consequence of the in the number of quarks with positive and negative helicities position in the strong magnetic field.

- CME : The Chiral Magnetic Effect is the generation of vector current by external magnetic field in chirality-imbalanced (P-odd) medium.
- CSE : Chiral Separation Effect represents the generation of the axial current along with the external magnetic field in the presence of finite vector charge density.
- The Chiral Magnetic Wave (CMW) is a gapless collective excitation of quark-gluon plasma (QGP) in the presence of an external magnetic field merges from the interplay of Chiral Magnetic and Chiral Separation effects. (Y.Burnier, D.E Kharzeev, J.Liao and H-U Yee, PRL 107, 052303 (2011)).



CSE + CME → Chiral Magnetic Wave:
collective excitation
signature of chiral symmetry restoration

BACKUP SLIDES (CMW)

- The CME in QCD coupled to electromagnetism assumes a chirality asymmetry between left- and right-handed quarks, parametrized by an axial chemical potential μ_A. At finite μ_A, an external magnetic field induces the vecto $j_i = \bar{\psi}\gamma_i\psi$:

$$\boldsymbol{j}_V = \frac{N_c\, e}{2\pi^2}\mu_A \boldsymbol{B};$$

axial chemical potential

- The Chiral Separation Effect (CSE) refers to the separation of chiral charge along the axis of external magnetic field at finite density of vector charge (e.g. at finite baryon number density). The resulting axial current is given by

$$\boldsymbol{j}_A = \frac{N_c\, e}{2\pi^2}\mu_V \boldsymbol{B},$$

vector chemical potential

- We consider CMW at finite baryon density and find that itinduces the electric quadrupole moment of the quark-gluon plasma produced in heavy ion collisions: the ”poles” of the produced fireball (pointing outside of the reaction plane) acquire additional positive electric charge, and the ”equator” acquires additional negative charge. We point out that this electric quadrupole deformation lifts the degeneracy between the elliptic flows of positive and negative pions leading to $v_2(\pi+) < v_2(\pi-)$, and estimate the magnitude of the effect.

BACKUP SLIDES CMW

- The net electric charge density is a sum of the initial charge density and the modulation caused by the propagating CMW. Keeping the leading term in the multipole expansion, we thus write

$$\rho_e \equiv \bar{\rho}_e - 2q_e \cos(2\phi) = \bar{\rho}_e \left[1 - \left(\frac{q_e}{\bar{\rho}_e}\right) 2\cos(2\phi)\right]$$

quadrupole term   net charge density

- The charge dependence of the elliptic flow of hadrons. Indeed the φ-dependence in equation below leads to a charge dependent elliptic flow term:

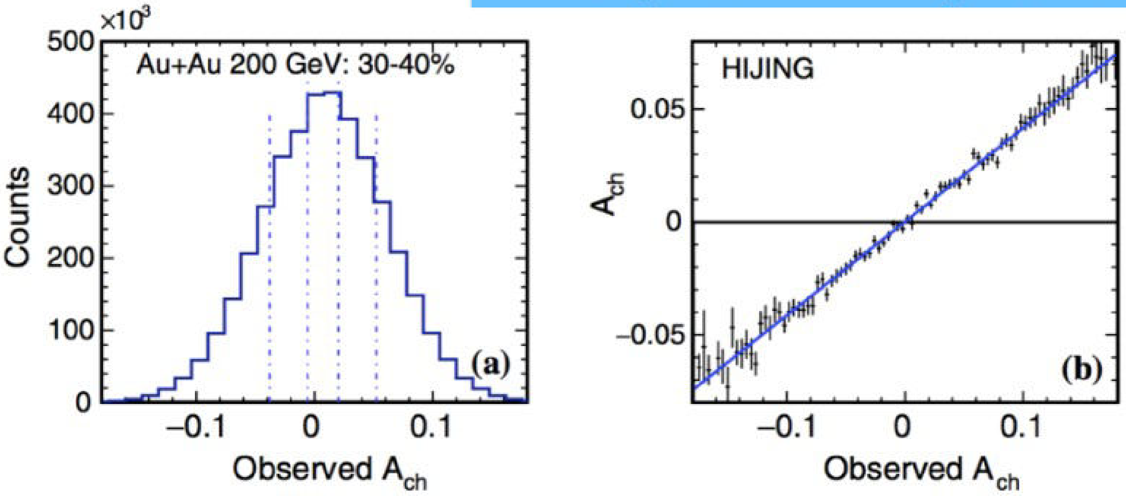
$$\frac{dN_\pm}{d\phi} = N_\pm \left[1 + 2v_2 \cos(2\phi)\right] \approx \bar{N}_\pm \left[1 + 2v_2 \cos(2\phi) \mp \left(\frac{q_e}{\bar{\mu}_e}\right) \left(\frac{\bar{N}_+ - \bar{N}_-}{\bar{N}_+ + \bar{N}_-}\right) 2\cos(2\phi)\right];$$

➡ In deriving this relation we assumed $v_2 << 1$ and $(\bar{N}_+ - \bar{N}_-) << \bar{N}_\pm$. The elliptic flow thus becomes charge dependent:

$$v_2^\pm = v_2 \mp \left(\frac{q_e}{\bar{\rho}_e}\right) A_\pm;$$

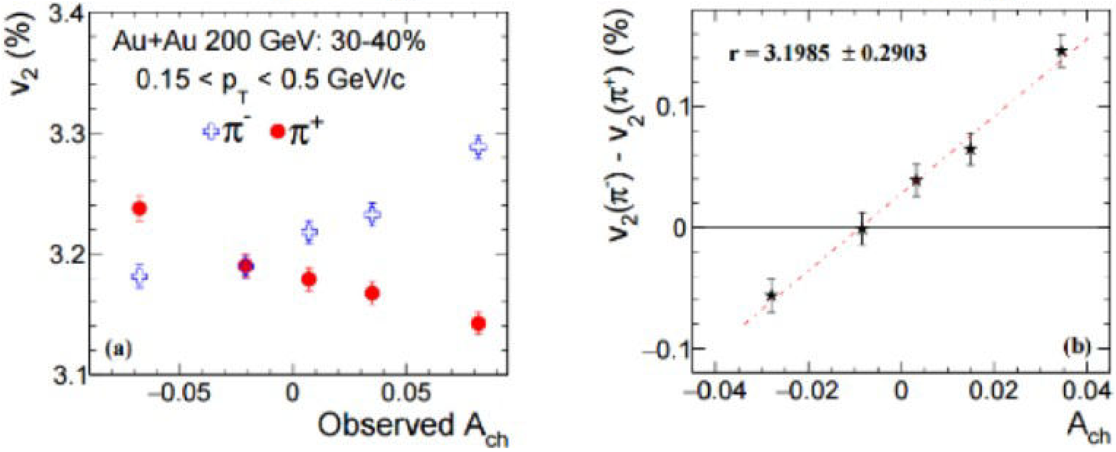
First preliminary data at STAR

STAR, PRL 114 (2015) 252302



$$A_{\rm ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

- A_{ch} is divided into 5 bins.
- The true A_{ch} and the observed A_{ch} are linearly correlated.
- Data are qualitatively consistent with the expectations from the CMW picture.
- The slope, r, is used to quantified the effect.



$$v_2^{\pm} = v_2^{\rm base} \mp \left(\frac{q_e}{\bar{\rho}_e}\right) A_{\rm ch}$$

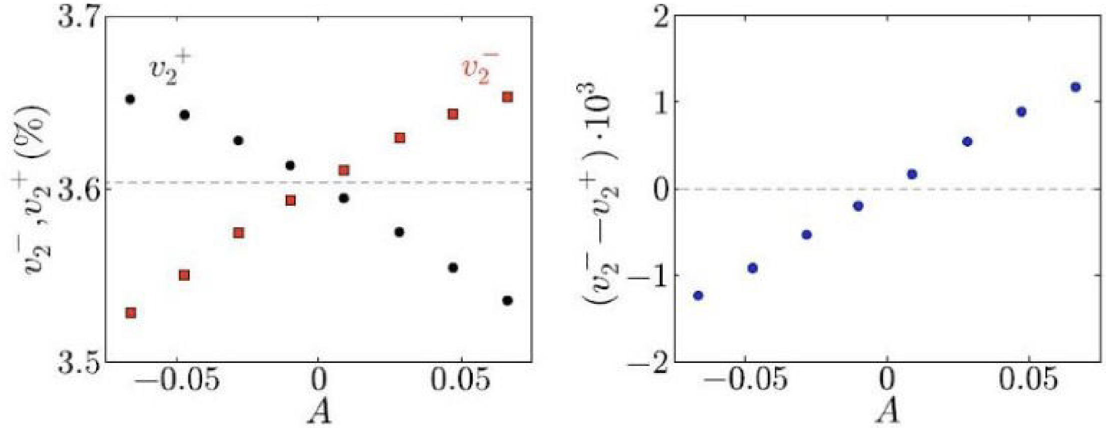
Alternative interpretation: Local Charge Conservation

A. Bzdak and P. Bozek, Phys. Lett. B 726 (2013) 239

$$\left\langle v_2^+ \right\rangle_A \approx \left\langle v_2^+ \right\rangle_{A=0} - \alpha A \left[\left\langle v_2^+ \right\rangle_{A=0} - \left\langle v_2^+ \right\rangle_{\text{asym}} \right]$$

$$\left\langle v_2^- \right\rangle_A \approx \left\langle v_2^- \right\rangle_{A=0} + \alpha A \left[\left\langle v_2^- \right\rangle_{A=0} - \left\langle v_2^- \right\rangle_{\text{asym}} \right]$$

As long as $\left[\left\langle v_2^+ \right\rangle_{A=0} - \left\langle v_2^+ \right\rangle_{\text{asym}} \right]$ correlates with η and p_T, we will see this linear relationship between v_2 and A_{ch}.



Local charge conservation (LCC) at freeze-out, when folded with the characteristic shape of $v_2(\eta)$ and $v_2(p_T)$ at RHIC energies, can be manifested in both v_2 and v_3:

$$\Delta v_3/\Delta v_2 \sim v_3/v_2$$