湖州师范学院 Huzhou University

IMPORTANCE OF NON-FLOW BACKGROUND ON THE CHIRAL MAGNETIC WAVE SEARCH

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OUTLINE

- Introduction
- **Background Sources:**
  1. Trivial linear-A_{ch} term
  2. The multiple pion source effect
  3. Non-flow effect
  4. Local charge conservation, decay kinematics

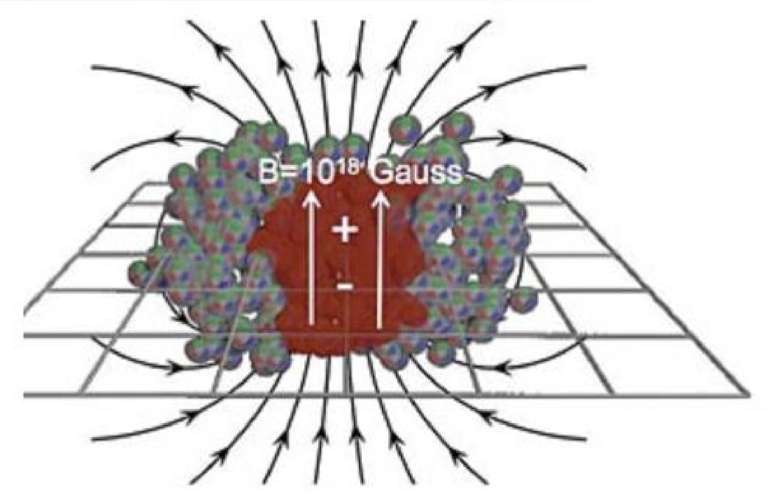
- Local charge conservation [A. Bzdak, PLB (2013)]
- Isospin chemical potential [Y. Hatta et al, NPA (2016)]

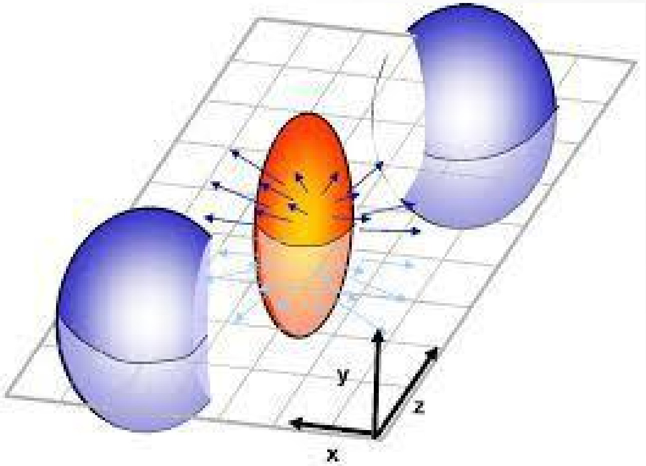
- Summary

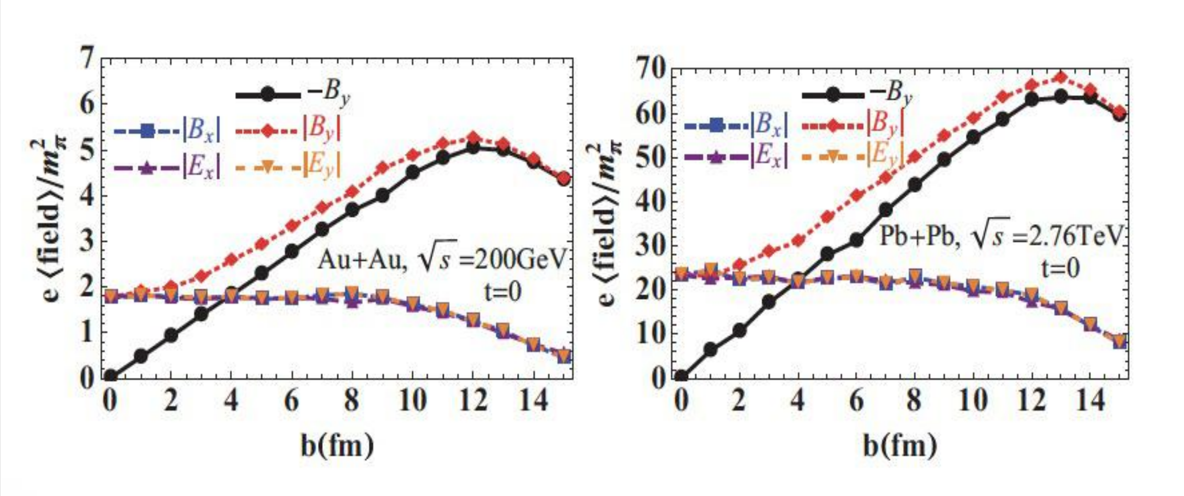
HJX, J. Zhao, Y. Feng, F. Wang, *"Complications in the interpretation of the charge asymmetry dependent π flow for the chiral magnetic wave"*, Phy.Rev. C101 (2020), 014913 , arXiv:1910.02896

INTRODUCTION

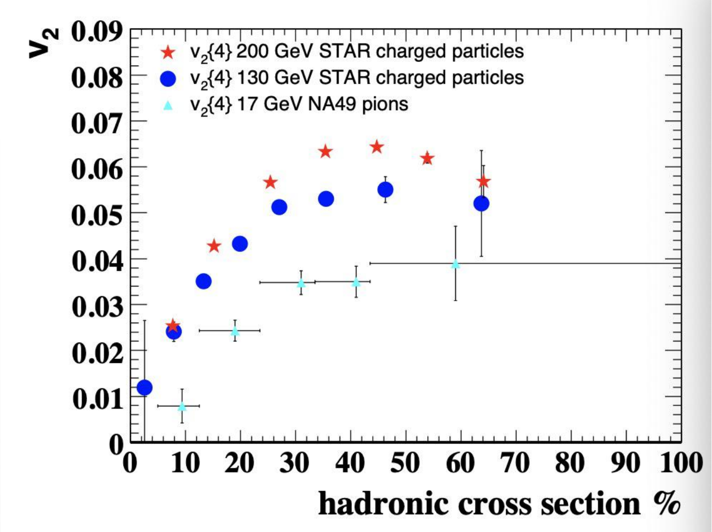
HEAVY ION COLLISIONS







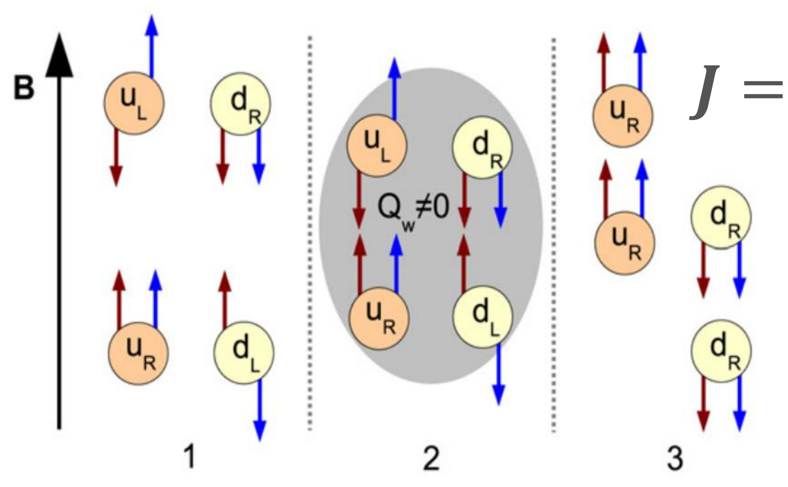
Deng, PRC85, 044907 (2012)



STAR, NPA757, 102 (2005)

CHIRAL MAGNETIC EFFECT

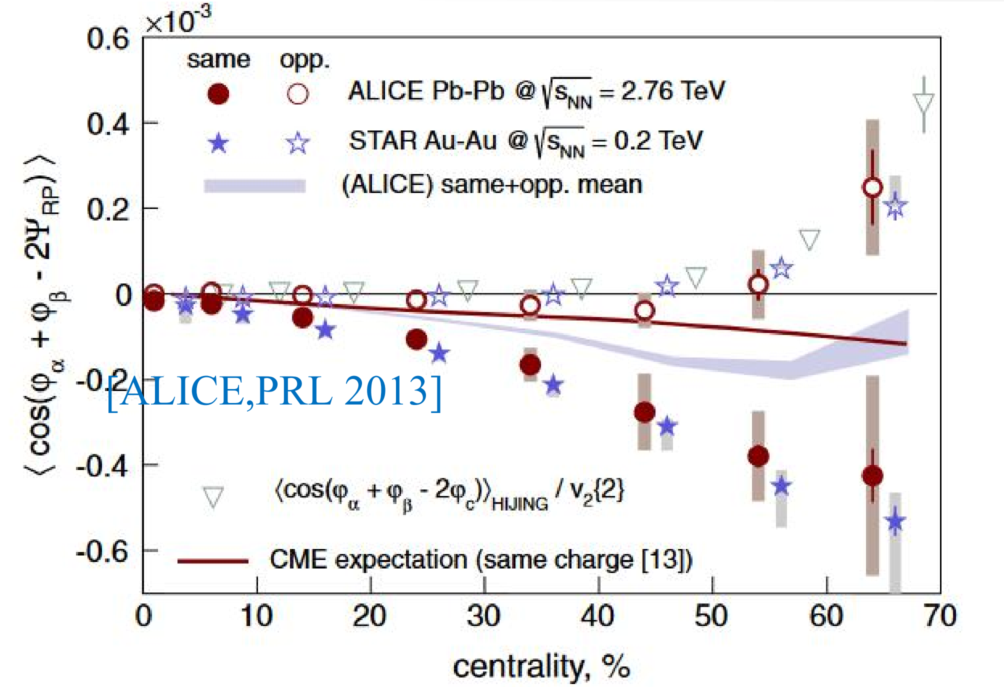
D.E. Kharzeev et al. / Nuclear Physics A 803 (2008) 227–253



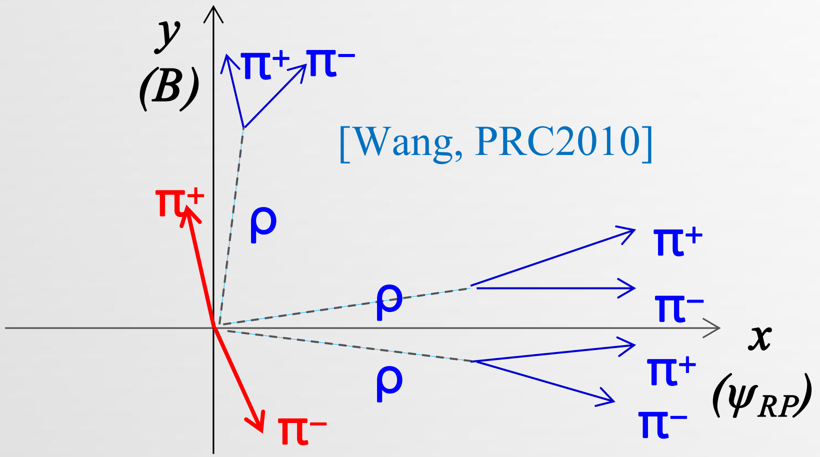
$$J = \left(\frac{(Qe)^2}{2\pi^2}\mu_5\right)\boldsymbol{B}$$

[Voloshin, RPC2004]

$$\begin{aligned}\gamma \equiv \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{\rm RP})\rangle &= \langle \cos\Delta\phi_\alpha \cos\Delta\phi_\beta\rangle - \langle \sin\Delta\phi_\alpha \sin\Delta\phi_\beta\rangle \\ &= [\langle v_{1,\alpha} v_{1,\beta}\rangle + B_{\rm IN}] - [\langle a_\alpha a_\beta\rangle + B_{\rm OUT}] \\ &\approx -\langle a_\alpha a_\beta\rangle + [B_{\rm IN} - B_{\rm OUT}],\end{aligned}$$



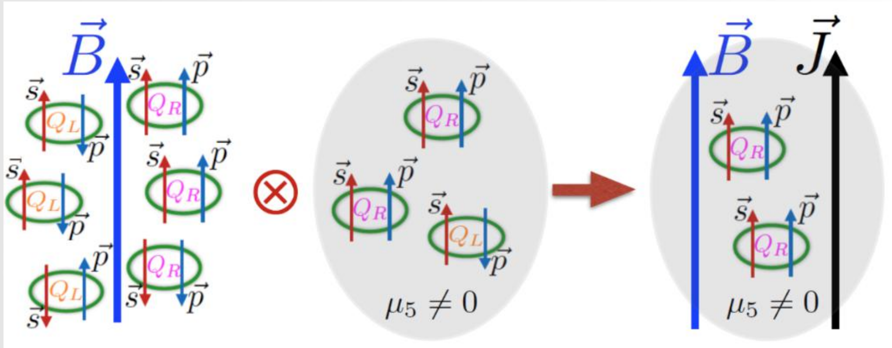
[ALICE,PRL 2013]



[Wang, PRC2010]

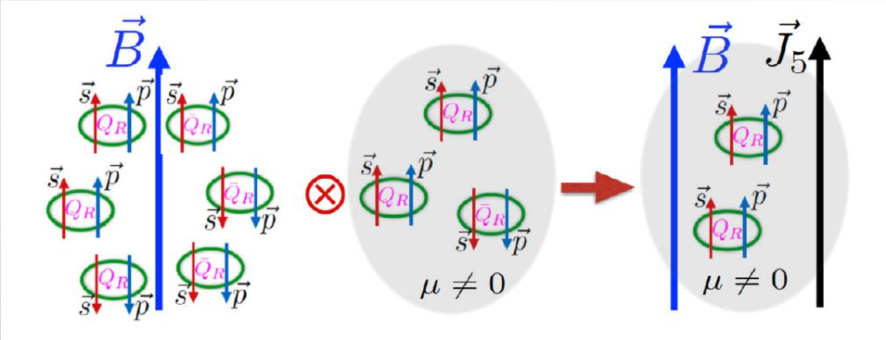
Elliptic flow: **BACKGROUND**

CHIRAL MAGNETIC WAVE

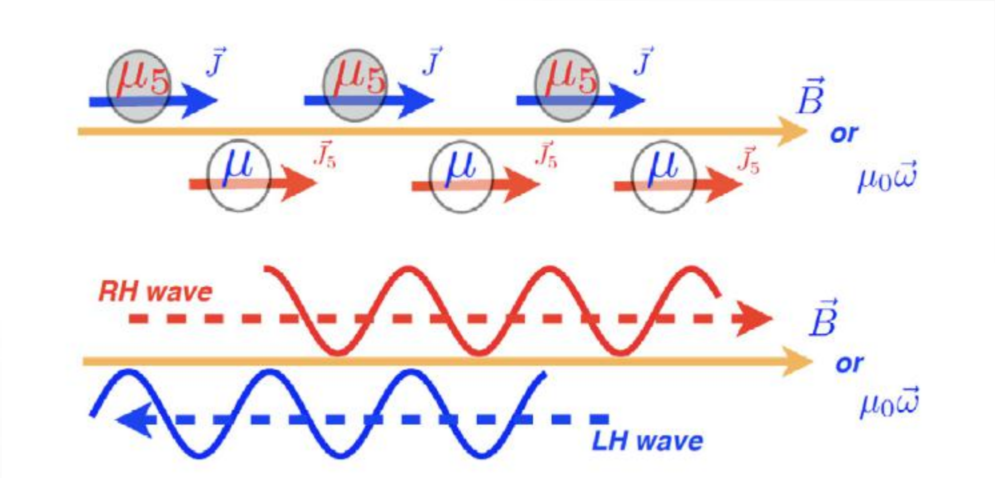


Chiral Magnetic Effect: $\boldsymbol{J} = \left(\frac{(Qe)^2}{2\pi^2}\mu_5\right)\boldsymbol{B}$

Chiral Separation Effect: $\boldsymbol{J}_5 = \left(\frac{(Qe)^2}{2\pi^2}\mu\right)\boldsymbol{B}$



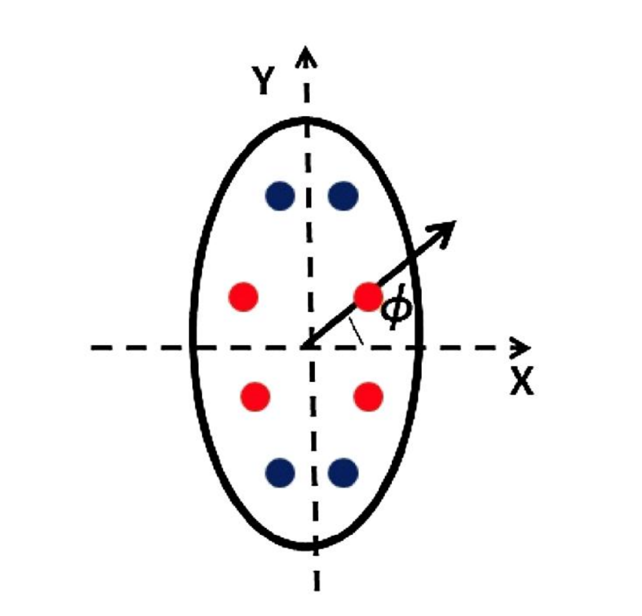
D. Kharzeev, PLB 633, 260 (2006)
D. Kharzeev, PRD 83, 085007 (2006)
D. Kharzeev, PPNP 88, 1 (2016)
…



The **Chiral Magnetic Wave (CMW)** is a gapless collective excitation of the QGP stemming from the interplay of the CME and CSE

THE CMW OBSERVABLE

Y. Burnier, PRL 107, 052303 (2011)



Charge quadrupole moment

The A_{ch}-dependent elliptic flow

$$v_2^{\pm} = v_2 \mp \frac{rA_{ch}}{2}$$

where

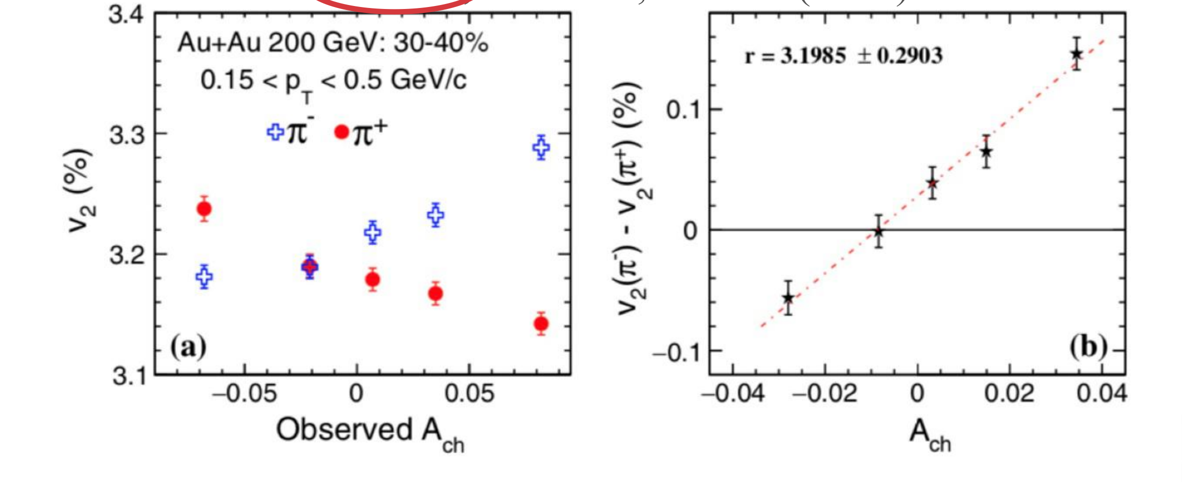
$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$

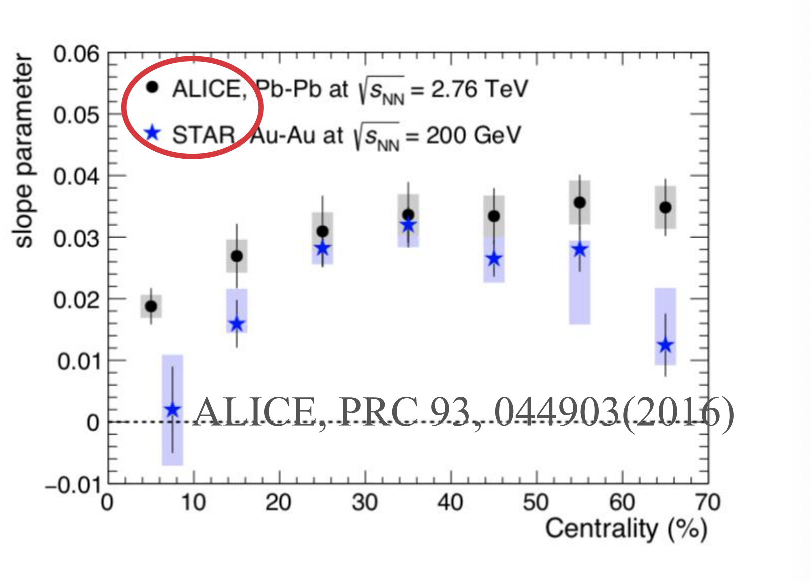
The CMW observable:
slope of $\Delta v_2(A_{ch}) \equiv v_2^-(A_{ch}) - v_2^+(A_{ch})$

Elliptic flow: **SIGNAL**

EXPERIMENTAL MEASUREMENTS

STAR, PRL 114, 252302 (2015)

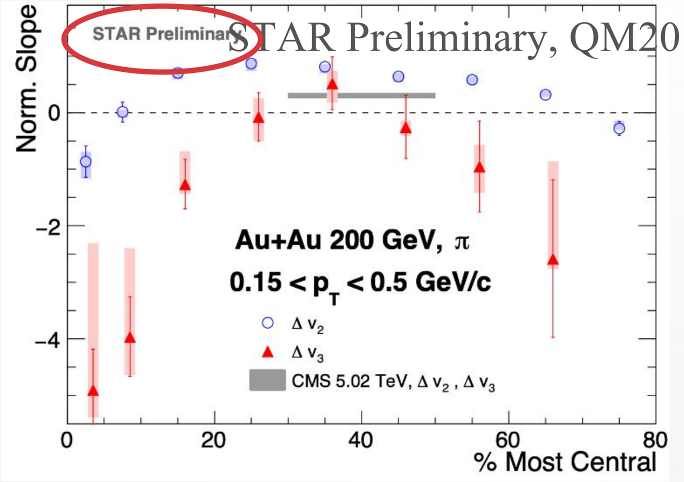




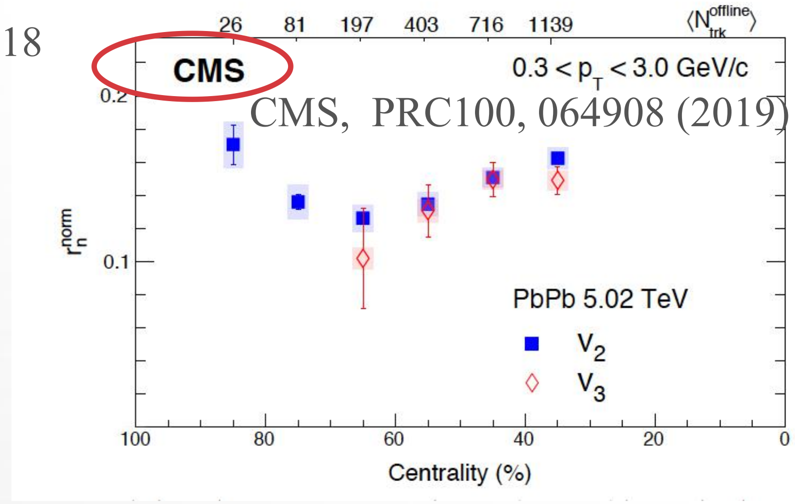
ALICE, PRC 93, 044903(2016)

Norm slope is extracted from

$$Norm.\Delta v_n = 2\frac{v_n^- - v_n^+}{v_n^+ + v_n^-}$$



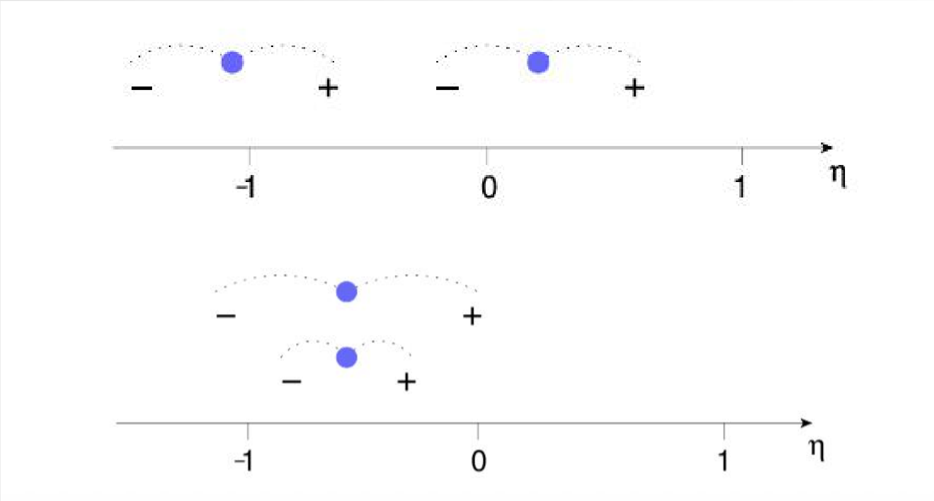
STAR Preliminary, QM2018

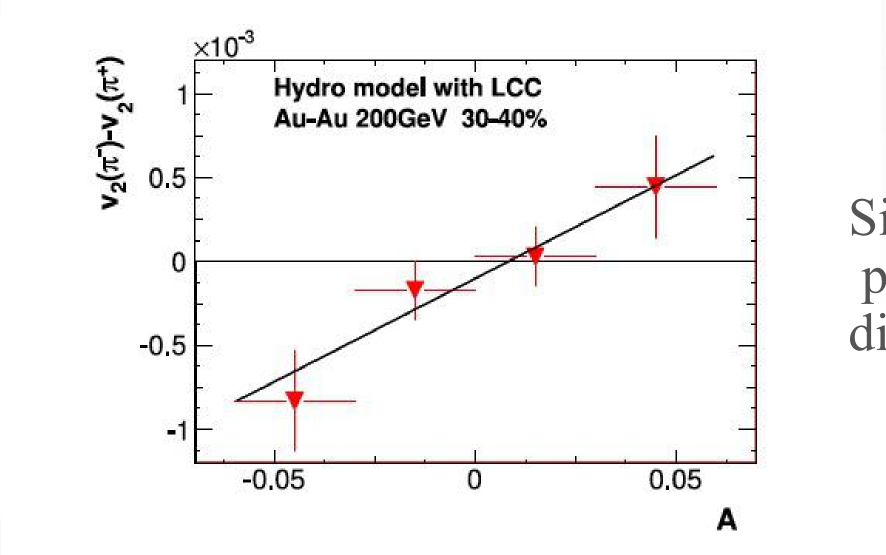


CMS, PRC100, 064908 (2019)

THE BACKGROUNDS

Local Charge Conservation [A. Bzdak, PLB (2013)]



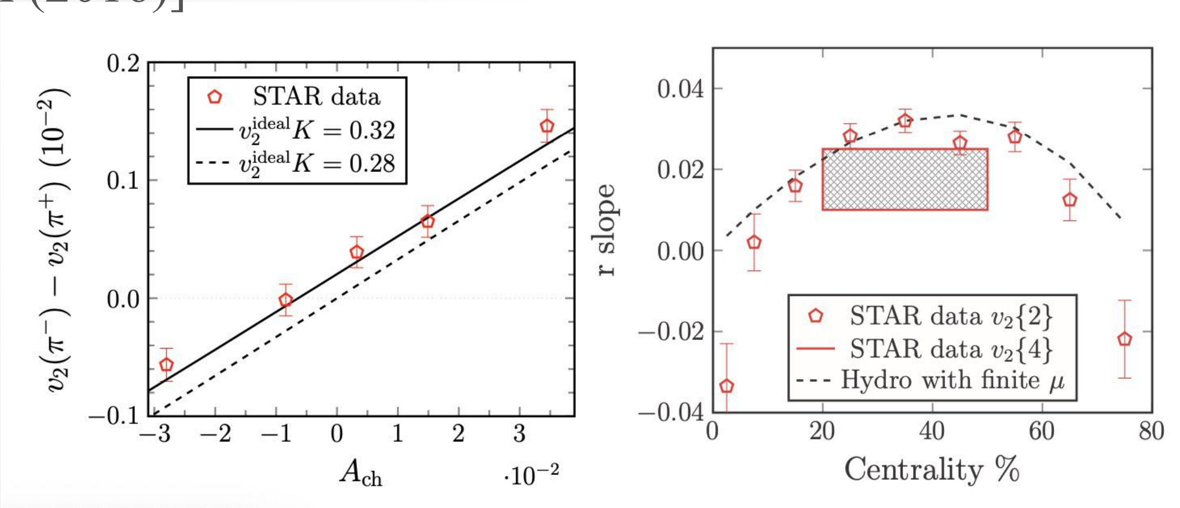


Similar slope for
pion triangle flow
differenes

Isospin chemicial poential [Y. Hatta, NPA (2016)]

$$r \approx \frac{\Delta v_2^{\pi}}{A_{ch}} \propto \frac{\mu_I/T}{A_{ch}} \frac{\eta}{s} \frac{\epsilon}{S^2} \frac{dN}{dy} ,$$

Negative slope for
kaon elliptic flow
differenes



NON-FLOW BACKGROUND

Two particles correlations [N. Borghini, PRC2000]:

- Transverse momentum coservation
- Resonance decays
- HBT, Coulomb and strong interaction
- .....

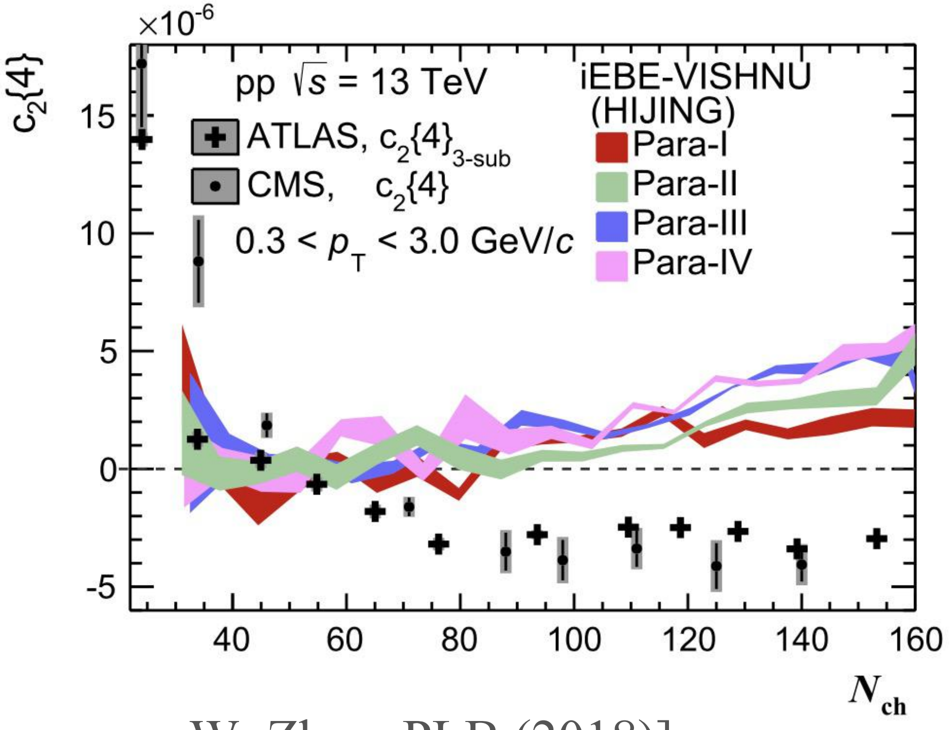
N-particles correlations:

- Jet emission
- ......

Flow in small sysmtem

Flow in most central heavy ion collisions

......



W. Zhao, PLB (2018)]

For the CMW measurment:
[STAR, PRL(2015)] The non-flow correlations are largely canceled in the v_2 difference between π^- and π^+.
???

II. BACKGROUND SOURCES

1) ANALYSIS FLAW: TRIVIAL LINEAR A_{ch} TERM

Q-cumulant flow method [Bilandzic, PRC(2011)]

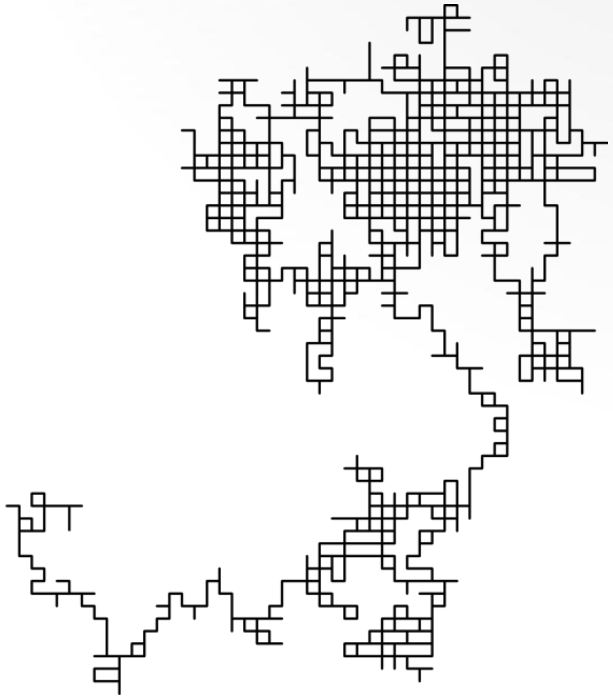
$$Q_n = \sum_{i=1}^{M} e^{in\varphi_i},$$

$$\langle 2\rangle_{n,-n} = \frac{|Q_n|^2 - M}{M(M-1)},$$

$$\langle 4\rangle_{n,n,-n,-n} = \frac{|Q_n|^4 + |Q_{2n}|^2 - 2\cdot \mathrm{Re}[Q_{2n}Q_n^* Q_n^*]}{M(M-1)(M-2)(M-3)} - 2\frac{2(M-2)\cdot |Q_n|^2 - M(M-3)}{M(M-1)(M-2)(M-3)},$$

$$c_n\{2\} = \langle\langle 2\rangle\rangle_{n,-n},$$
$$c_n\{4\} = \langle\langle 4\rangle\rangle_{n,n,-n,-n} - 2\cdot \langle\langle 2\rangle\rangle_{n,-n}^2.$$

$$v_n\{2\} = \sqrt{c_n\{2\}}, \quad v_n\{4\} = \sqrt[4]{-c_n\{4\}}.$$



Random walk, form wiki

1) ANALYSIS FLAW: TRIVIAL LINEAR A_{ch} TERM

The two-particle Q-cumulant flow for particle of interset (POI) $v_n\{2\} = d_n\{2\}/\sqrt{c_n\{2\}}$

For all charges as reference particles (REF), $d_n\{2\}$ can be written as

$Q_n = Q_{n+} + Q_{n-}$

$$M = \frac{2N_+}{1 + A_{ch}} = \frac{2N_-}{1 - A_{ch}}$$

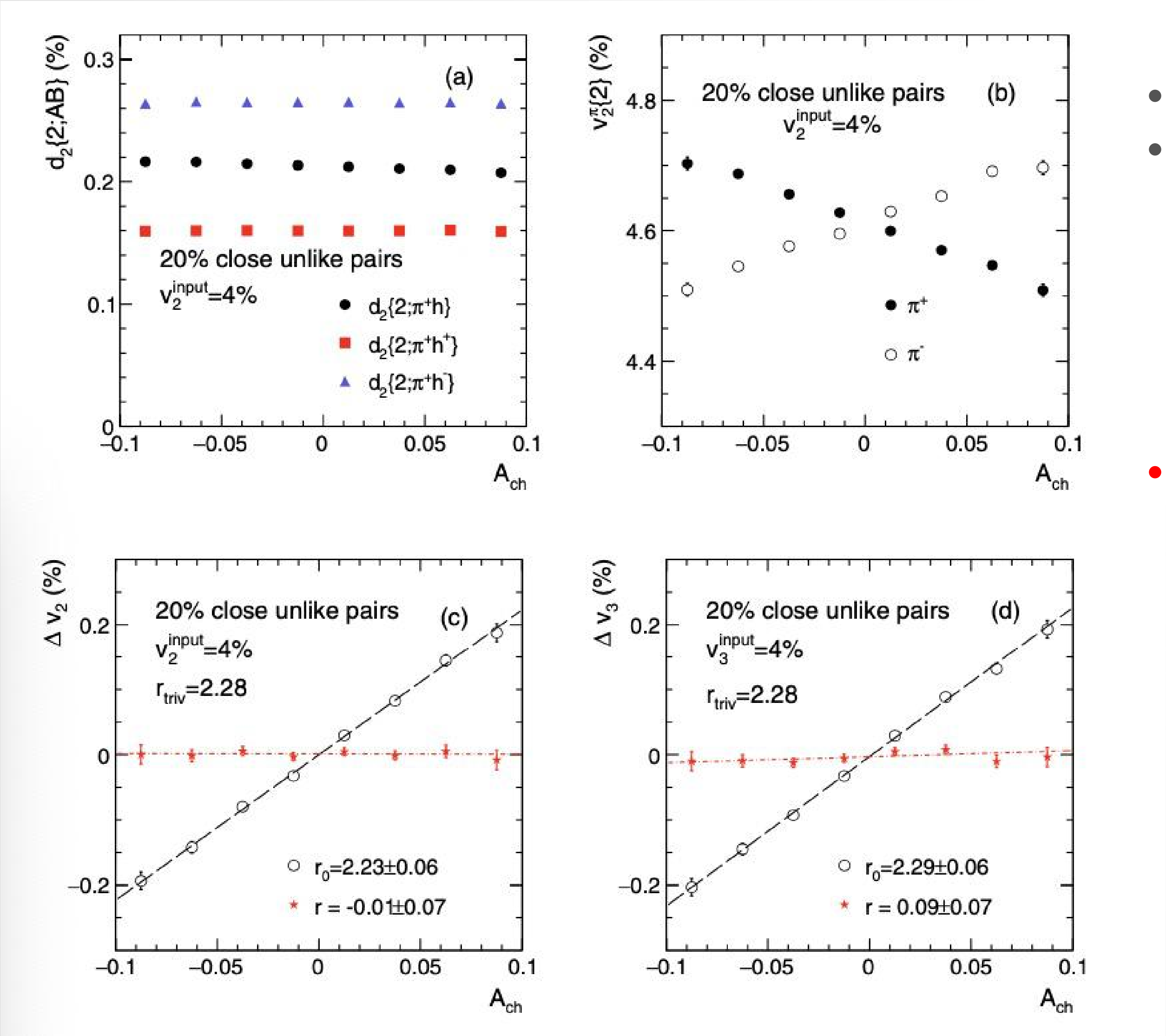
$$d_n\{2;\pi^\pm h\} = \left\langle \frac{\sum q_n^{\pi^\pm} Q_n}{\sum mM} \right\rangle = \frac{1 + A_{ch}}{2} \left\langle \frac{q_n^{\pi^\pm} Q_{n+}}{mN_+} \right\rangle + \frac{1 - A_{ch}}{2} \left\langle \frac{q_n^{\pi^\pm} Q_{n-}}{mN_-} \right\rangle$$

$$= \frac{d_n\{2;\pi^\pm h^+\} + d_n\{2;\pi^\pm h^-\}}{2} + \frac{d_n\{2;\pi^\pm h^+\} - d_n\{2;\pi^\pm h^-\}}{2} A_{ch}.$$

The trivial term arises when:

- All charges are included in REF
- Non-flow differs between like- and unlike-sign pairs. (if only flow, then it vanishes)

1) ANALYSIS FLAW: TRIVIAL LINEAR A_{ch} TERM



- Non-flow correlations: close unlike-sgin pairs
- A toy Monte Carlo study:
  - pion only
  - pT and eta spectra, 30-40% AuAu@$\sqrt{s_{NN}}$ = 200 GeV.
  - Poisson multiplcity fluctuation.

- Single-sign charges as reference to remove the trivial term

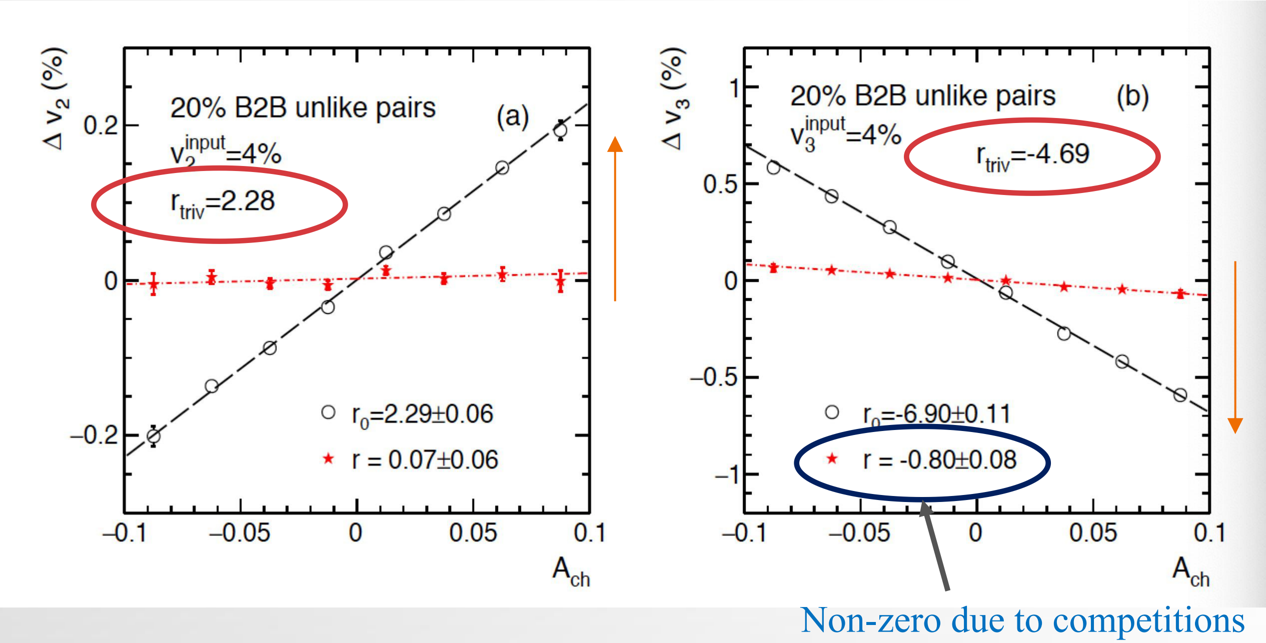
$$\bar{v}_n^{\pi} \equiv \frac{v_n^{\pi}\{2;h^+\} + v_n^{\pi}\{2;h^-\}}{2}.$$

slope parameters:

r_{triv}: trivial contribution
r_0: trival-included
r: trivial-removed

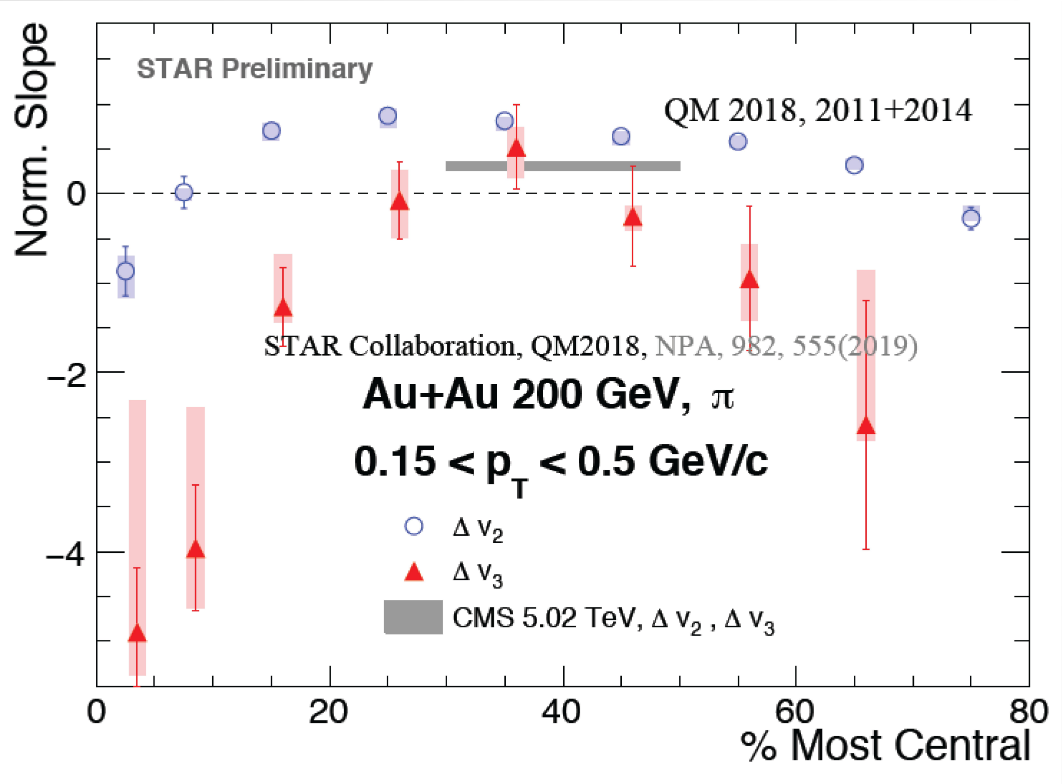
1) TRIVIAL LINEAR A_{ch} TERM: TOY MODEL STUDY

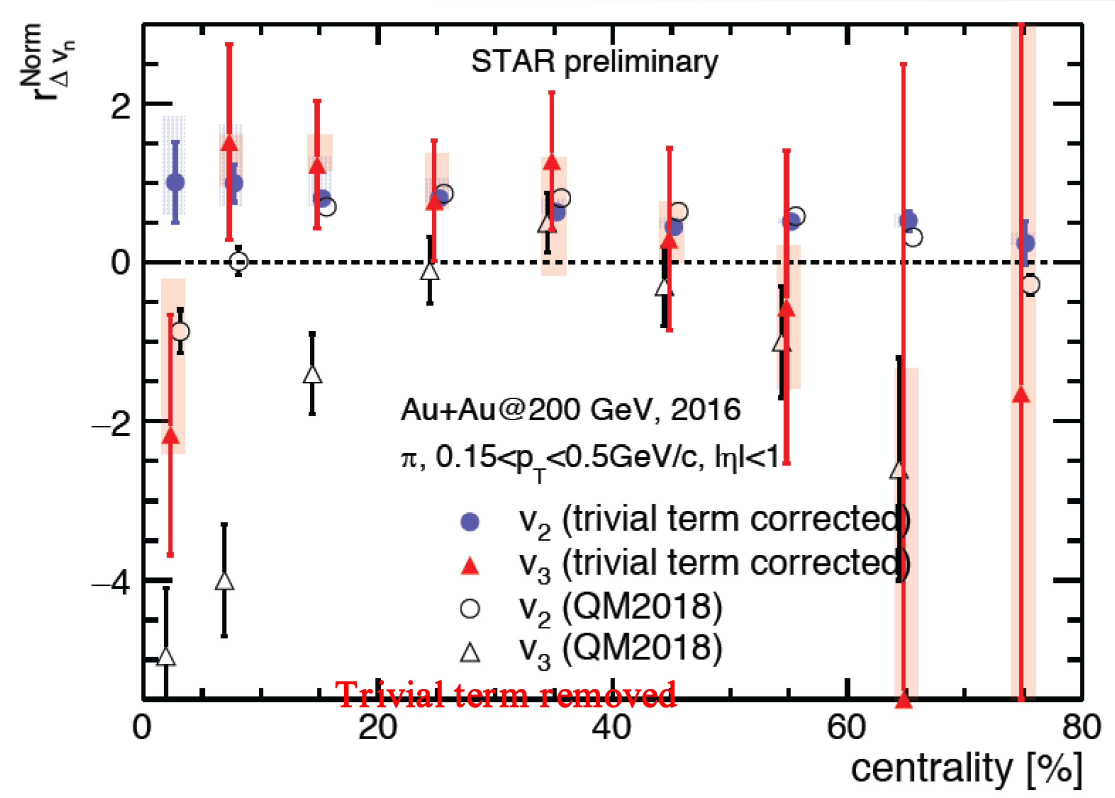
- Back-to-back unlike-sign non-flow correlations
- v_n= 4% is used for both π^+ and π^-, no input Ach dependence.
- r_0 (trivial term included), r (trivial term removed)



- The trivial slope is positive for $\Delta v_2(A_{ch})$ and negative for $\Delta v_3(A_{ch})$.
- Single-sign charges as reference to remove the trivial term

1) TRIVIAL LINEAR A_{ch} TERM: STAR MEASUREMENT



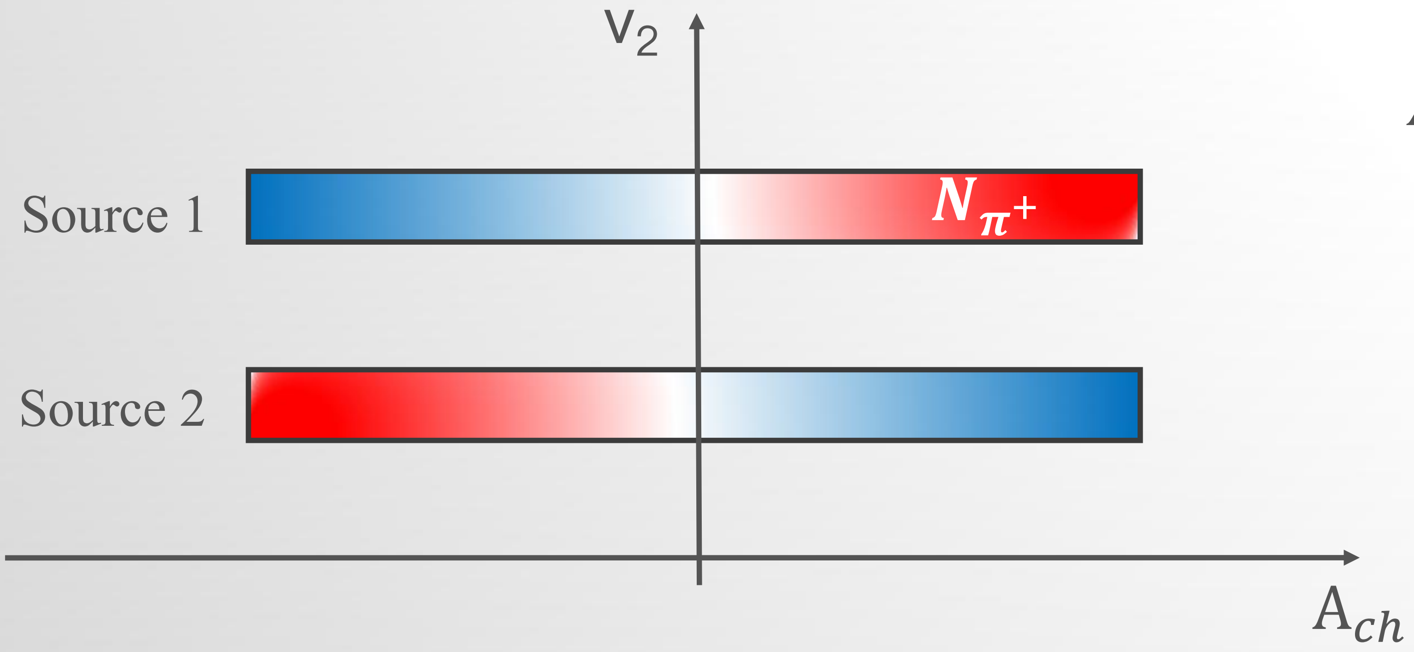


H. Xu (STAR), QM2019 poster

2) THE MULTIPLE PION SOURCE EFFECT

From the two-component model ($\epsilon = N_D/N_P$), assume the charge asymmetry distributions of each sources A_P and A_D are both normal distributions with width σ_P and σ_P,

$$\Delta v_n = \frac{2\epsilon(\epsilon\sigma_D^2 - \sigma_P^2)(v_{n,P} - v_{n,D})}{(1+\epsilon)(\epsilon^2\sigma_D^2 + \sigma_P^2)} A_{ch} \equiv r^{2C} A_{ch}$$



A_D and A_P differences

➔ different A_{ch}, different component ratio

➔ competition between different pion flow

➔ A_{ch} dependence pion flow

➔ slope parameter

3) NON-FLOW DILUTION EFFECT

For like-sign non-flow correlations:

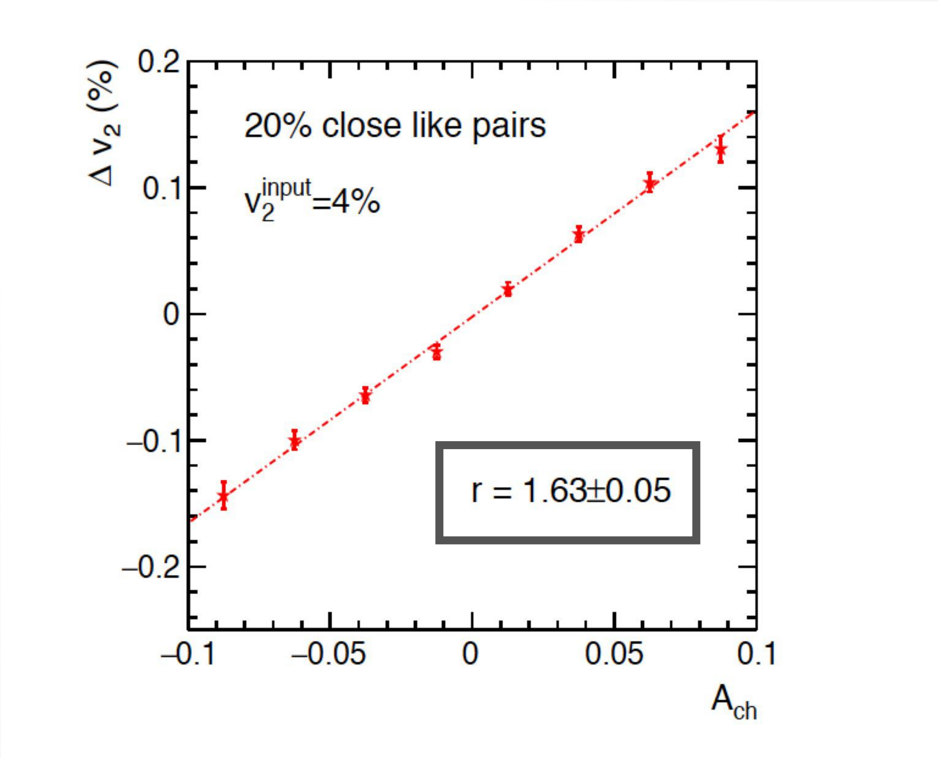
$A_{ch} > 0$

➔ large π^+ multiplicity

➔ more non-flow dilution

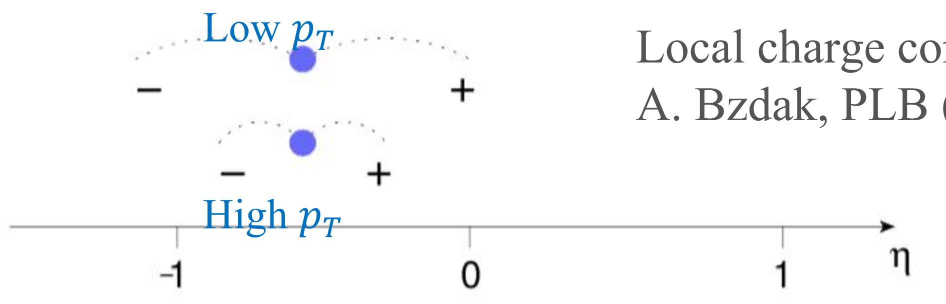
➔ smaller π^+ v_2

➔ positive slope



- ❑ Close-pair like-sign non-flow correlations
- ❑ Trivial term have been removed

4) LOCAL CHARGE CONSERVATION (LCC) EFFECT

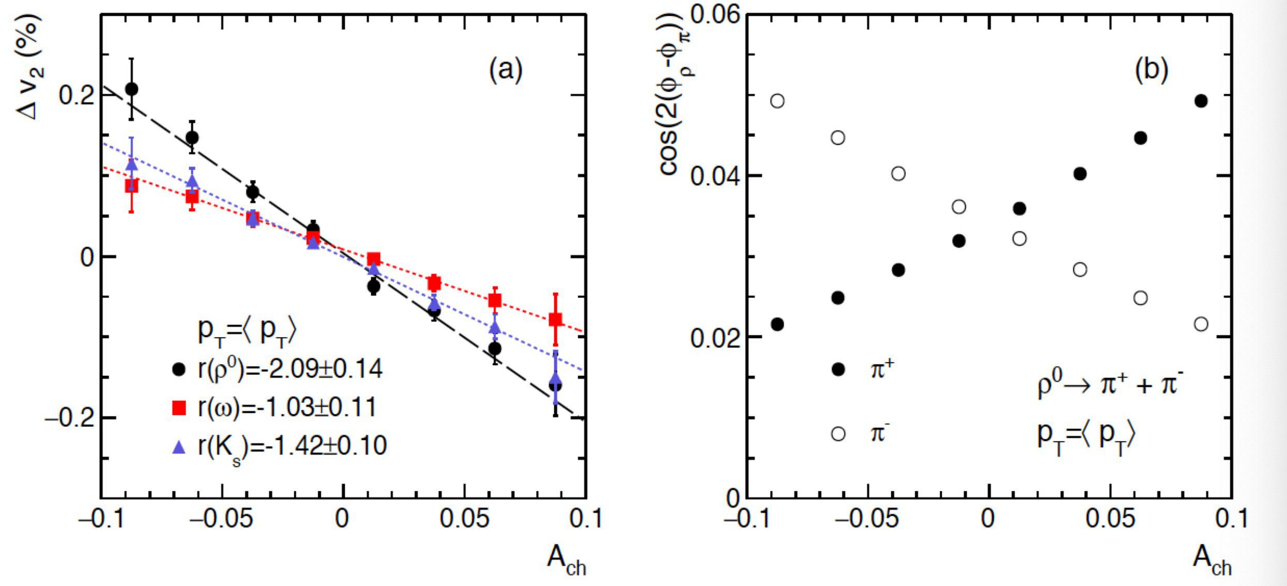


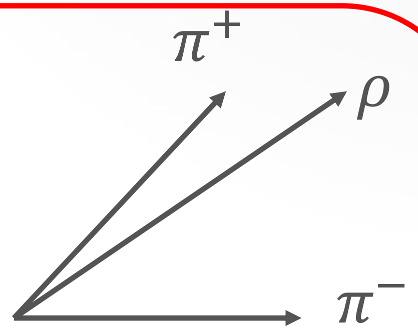
Local charge conservation
A. Bzdak, PLB (2013)

Fix resonance p_T (use mean value from data).

No effect from LCC.

DETOUR – EFFECT OF DECAY KINEMATICS





At $A_{ch} > 0$:

➔ π^+ in acceptance

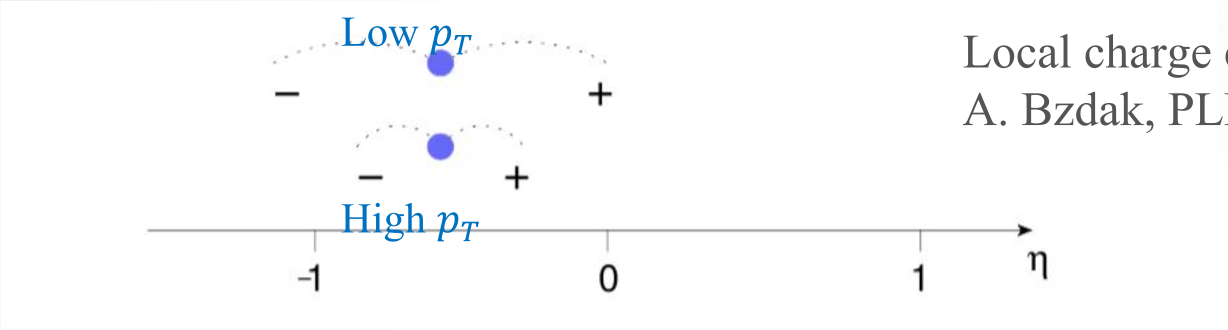
➔ π^+ on average closer to ρ

➔ less azimuth dilution

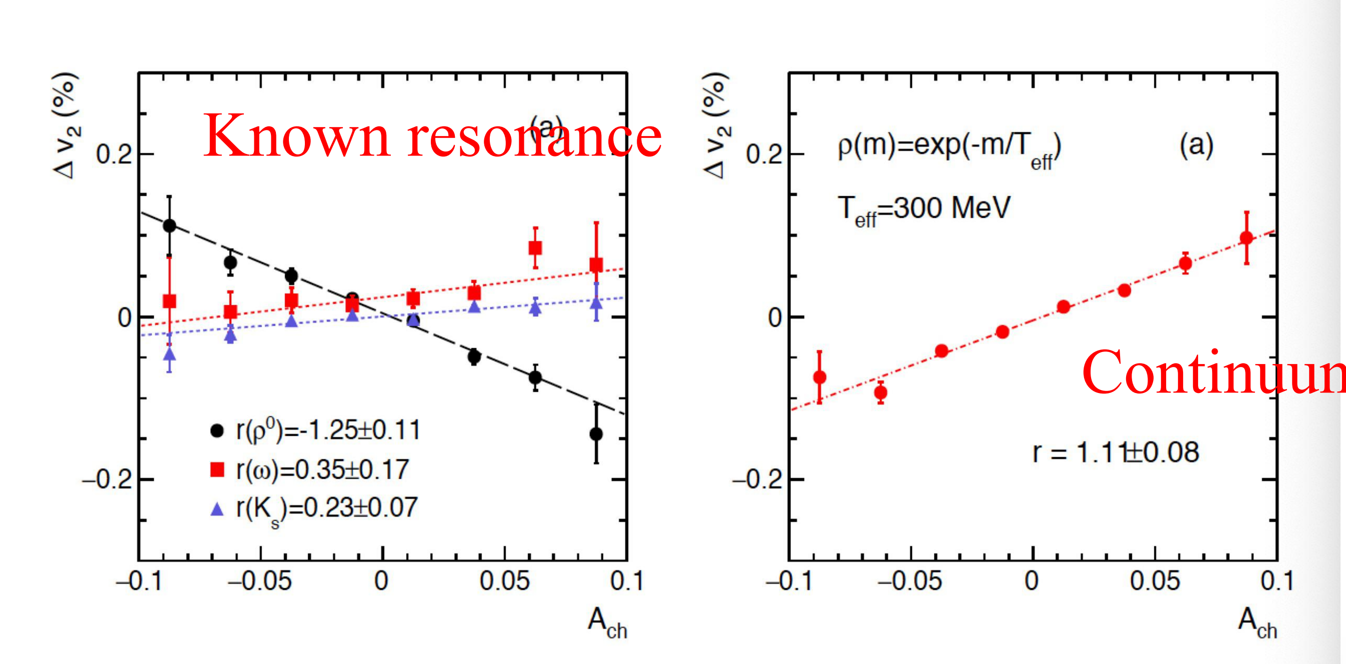
➔ larger π^+ v_2, negative slope

Without LCC effect, the slope parameter from decays is negative.

4) LCC: INDIVIDUAL SOURCE

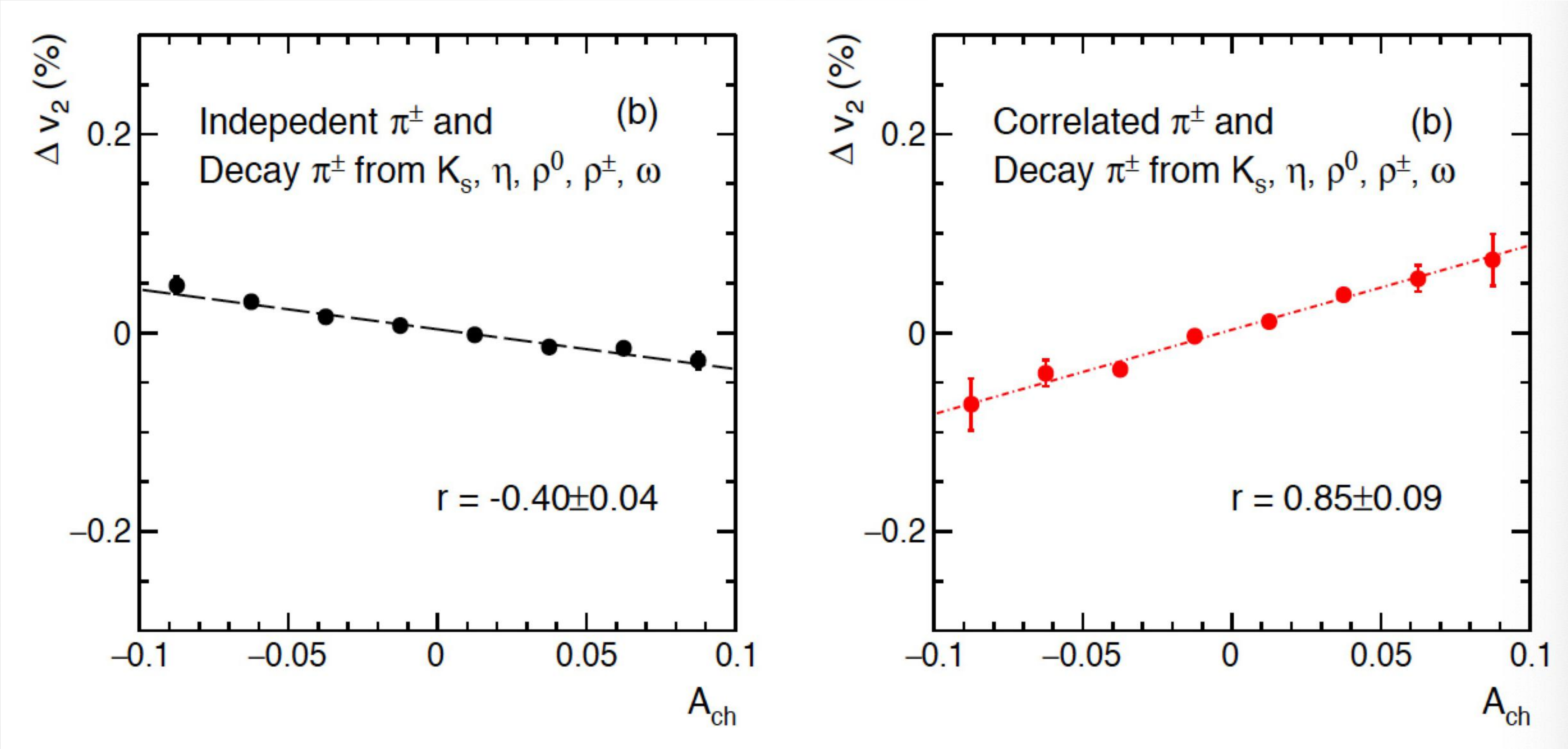


Local charge conservation
A. Bzdak, PLB (2013)



Mass effect, 2-body or 3-body decays

4) LCC: MULTIPLE SOURCE



Primordial π^+ and π^-:

- ❑ Independent production
- ❑ LCC correlations

SUMMARY

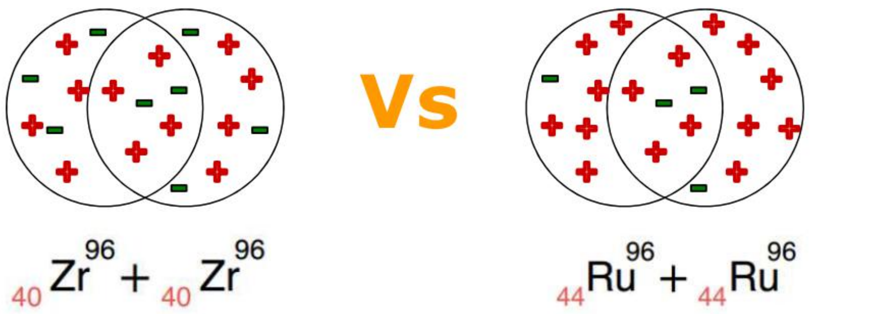
Non-CMW mechanisms can generate A_{ch}-dependent π flows

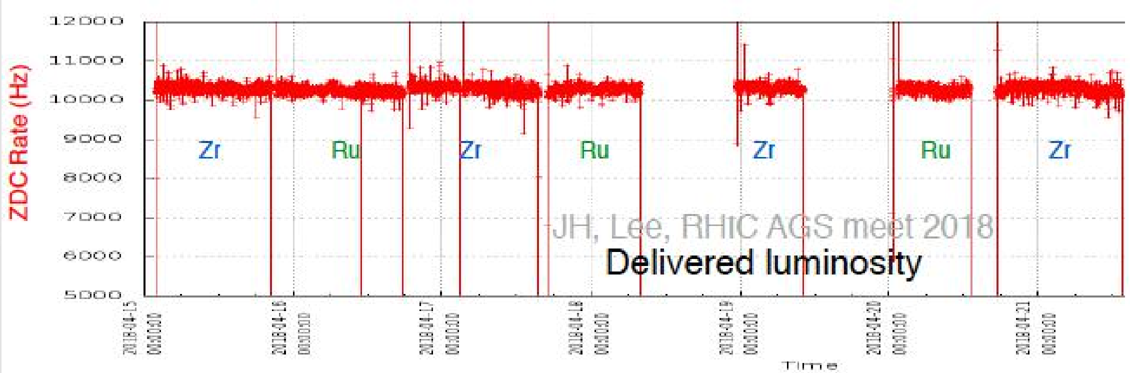
1. Trivial linear-A_{ch} term
2. The multiple pion source effect HJX, PRC(2020)
3. Non-flow effect
4. Resonance decays, decay kinematics, Local Charge Conservation

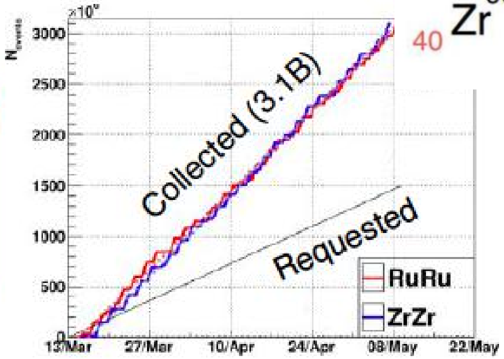
- The A_{ch}-dependent pion flow v_2 difference CMW observable is awfully complicated !!
- In order to say anything about the CMW, a precise modeling of all heavy–ion collision backgrounds is a must-prerequisite.

BACKUP

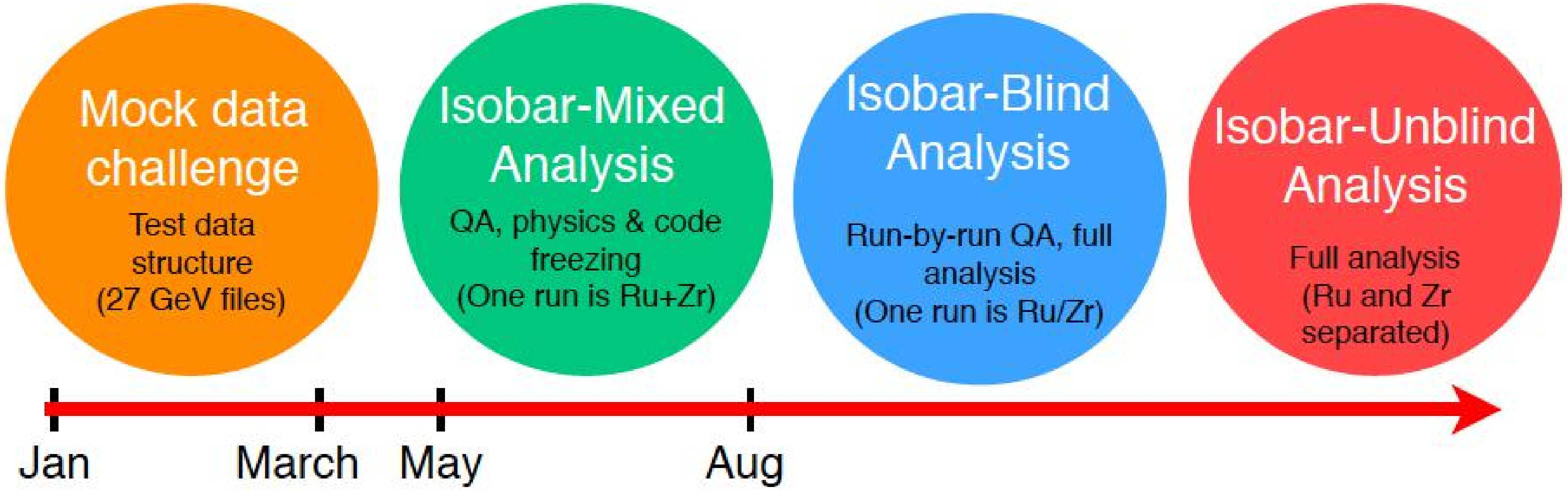
STAR ISBAR COLLISIONS





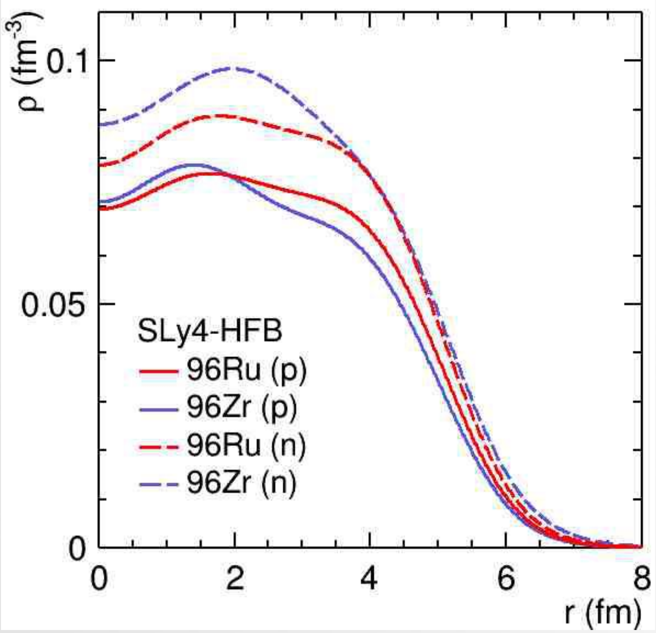


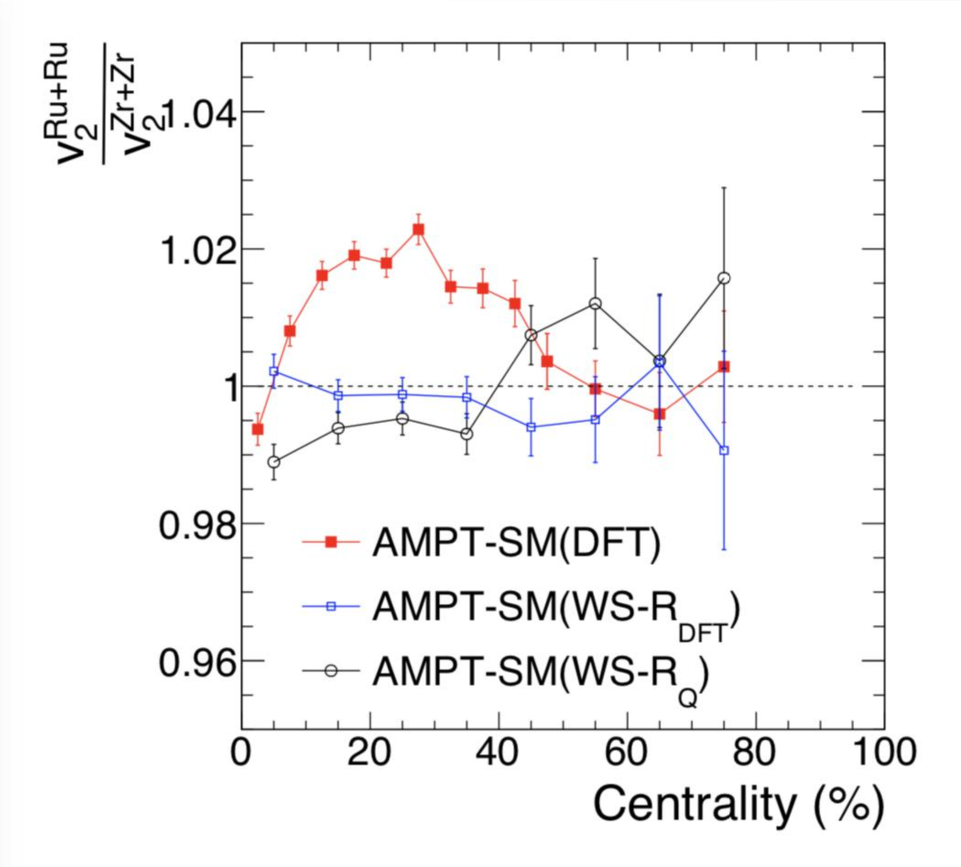
3.1B events for both Ru+Ru, Zr+Zr collected over 8 weeks
Plans for blind analyses of the data was laid down from the beginning



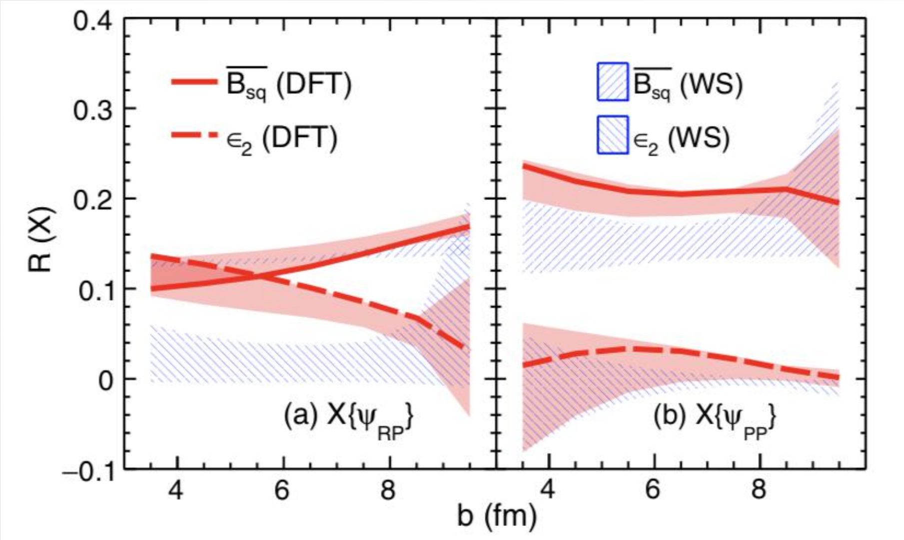
Z. Xu, QM2019

ISBAR COLLISIONS AND CME



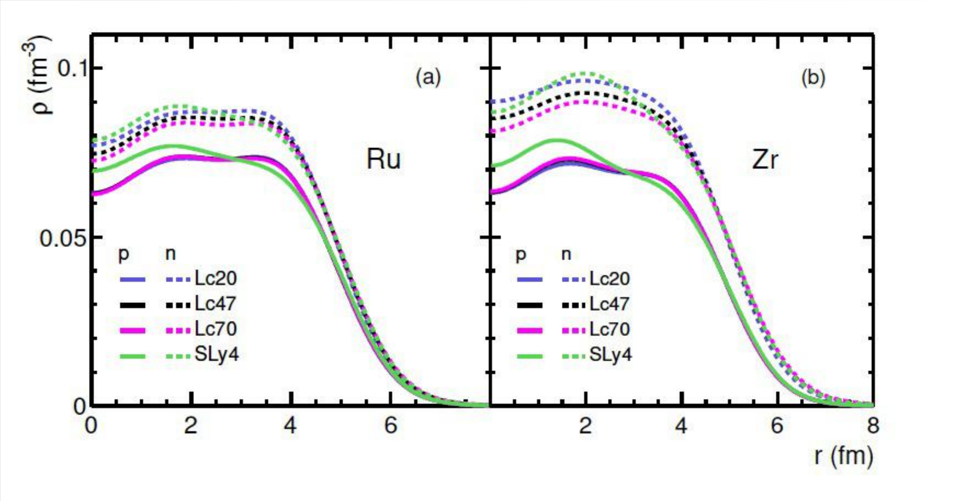


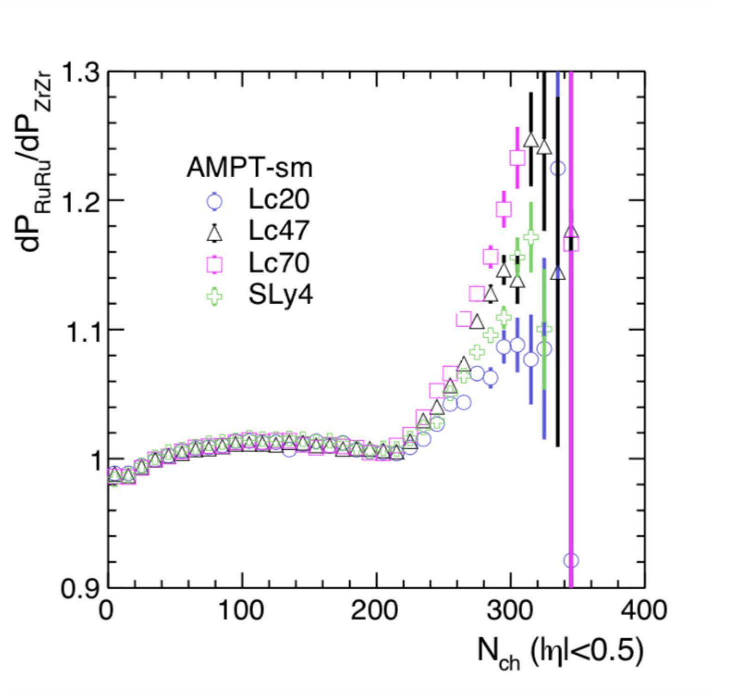
HJX, PRL(2018)
Li, PRC(2018)

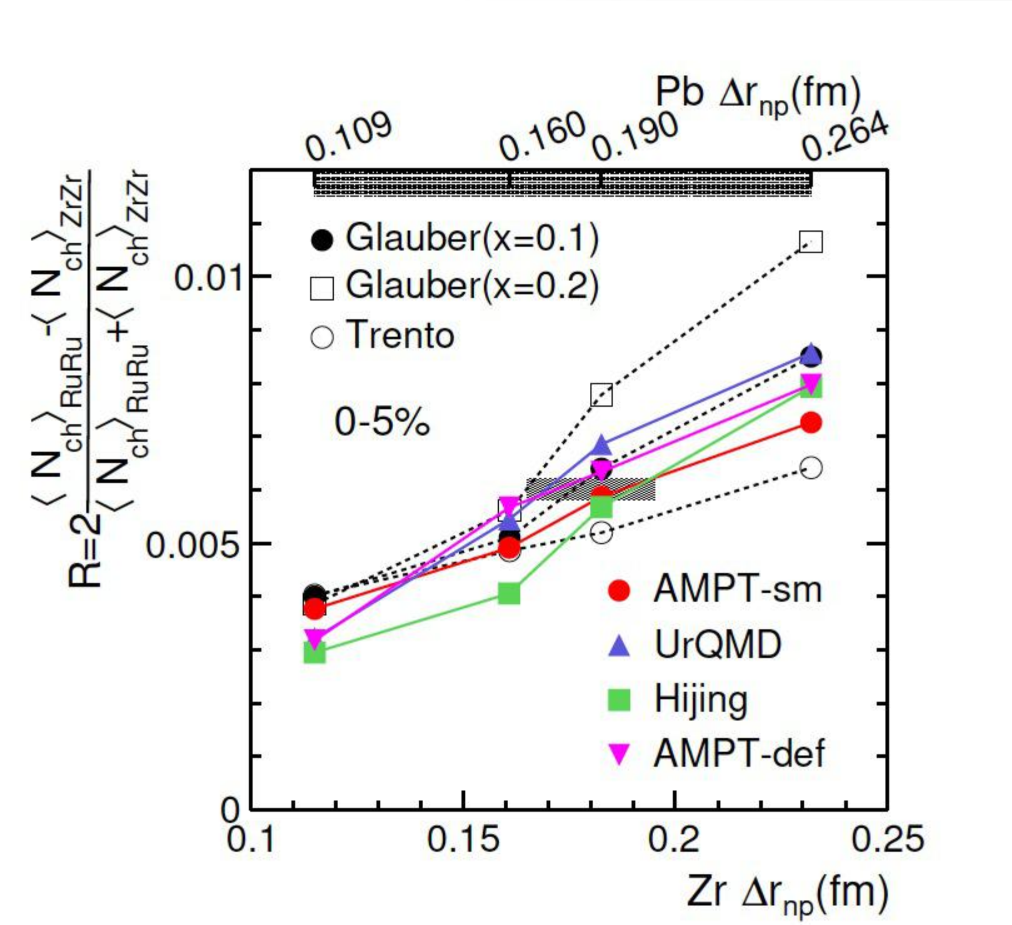


The isobar (nucleon/charge) density distributions play important role on the CME search!

ISBAR COLLISIONS AND NEUTRON SKIN







H. Li, arXiv: 1910.06170

The Nch distributions in isobaric collisions may be used to determine the neutron skin.