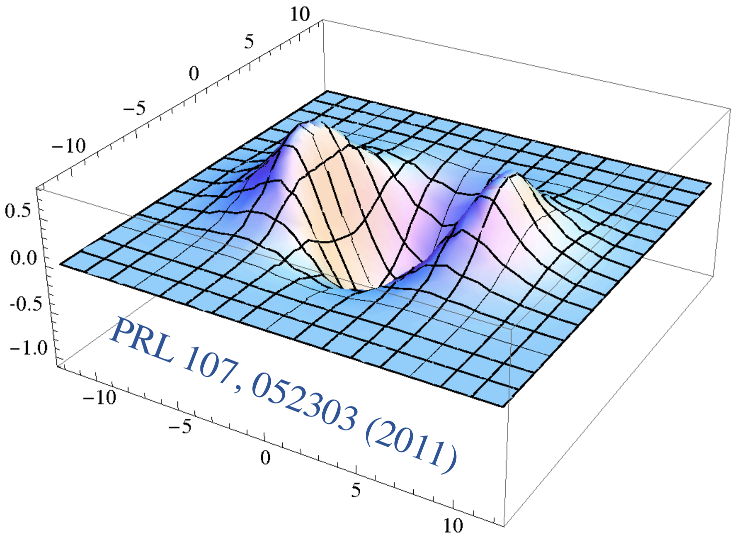
THE UNIVERSITY OF ILLINOIS AT CHICAGO

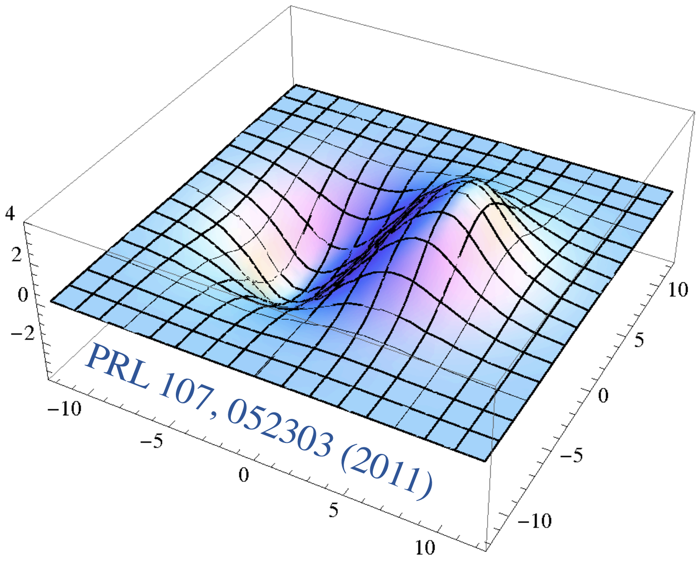
APS April Meeting

STAR

Characterization of Quadrupole charge separation at 200 GeV; Implications for the CMW



Niseem Magdy
University of Illinois at Chicago
niseem@uic.edu



In part supported by
U.S. DEPARTMENT OF ENERGY | Office of Science

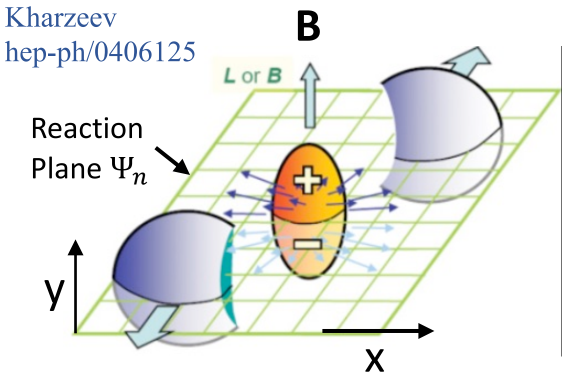
Outline

N. Magdy, et al, Phys.Lett.B 811 (2020) 135986
N. Magdy, et al, Phys.Rev.C 98 (2018) 6, 061902
N. Magdy, et al, Phys.Rev.C 97 (2018) 6, 061901

- Introduction
  - ✓ Anomalous transport
  - ✓ Prior correlators
- The $R_{\Psi m}^{(d)}$ correlator
  - ✓ $R_{\Psi m}^{(d)}$ Sensitivity to Quadrupole charge separation
- Experimental Results
  - ✓ Recent STAR measurements
- Conclusions

CME

Kharzeev
hep-ph/0406125

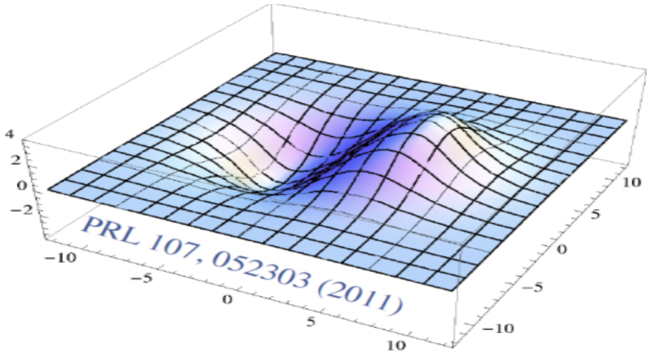


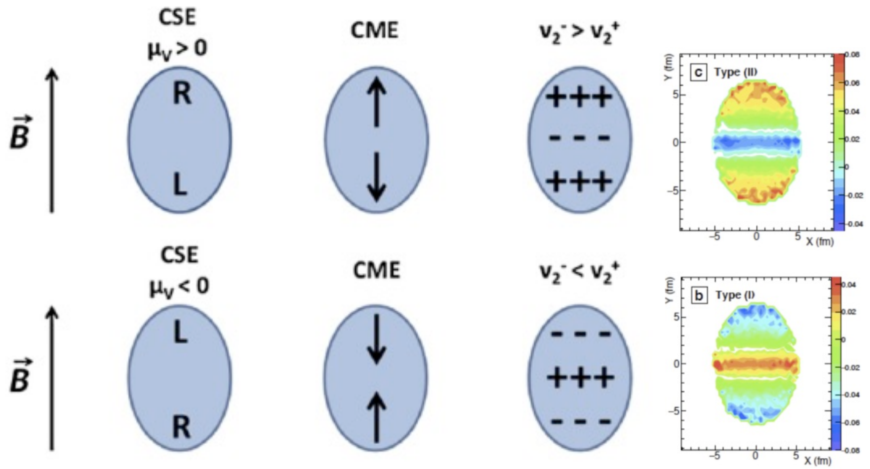
CMW

The interplay between the CSE and CME can lead to the production of a gapless collective mode or Chiral Magnetic Wave (CMW)

✓ Stems from the coupling between the density waves of the electric and chiral charges

Dmitri E. Kharzeev and Ho-Ung Yee, Phys. Rev. D83, 085007 (2011)





The CMW transports positive (negative) charges out-of-plane and negative (positive) charges in-plane to form an electric quadrupole.

- The CME drives a dipole charge separation along the B-field
  - ✓ leads to a "dipole moment" in the azimuthal distribution of the produced charged hadrons:

$$\frac{dN}{d\Delta\phi} \propto [1 \pm 2a_1 \sin(\Delta\phi) + ...]$$

$$\tilde{a}_1 = \langle a_1^2 \rangle^{1/2} \propto \mu_5 B$$

- The detection and characterization of both the dipole and quadrupole charge separations are paramount

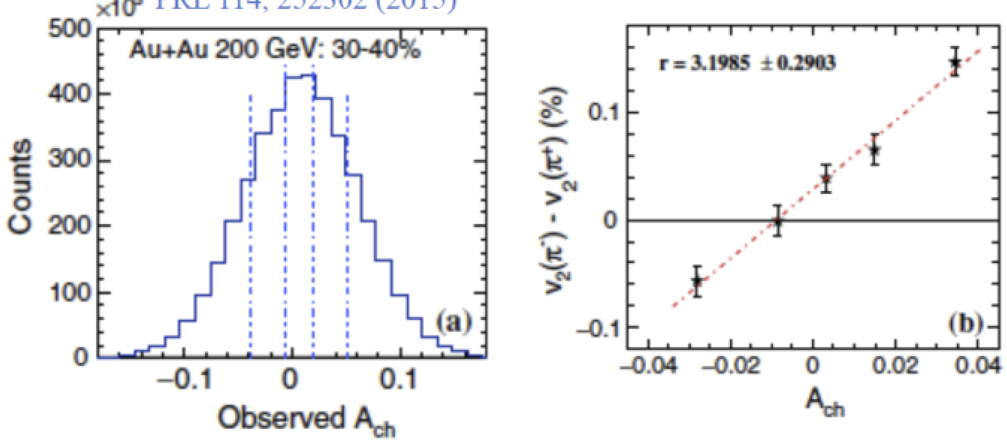
❖ Introduction:
Prior quadrupole charge separation measurements

A pervasive approach is to measure the elliptic flow difference between negatively- and positively charged particles as a function of charge asymmetry

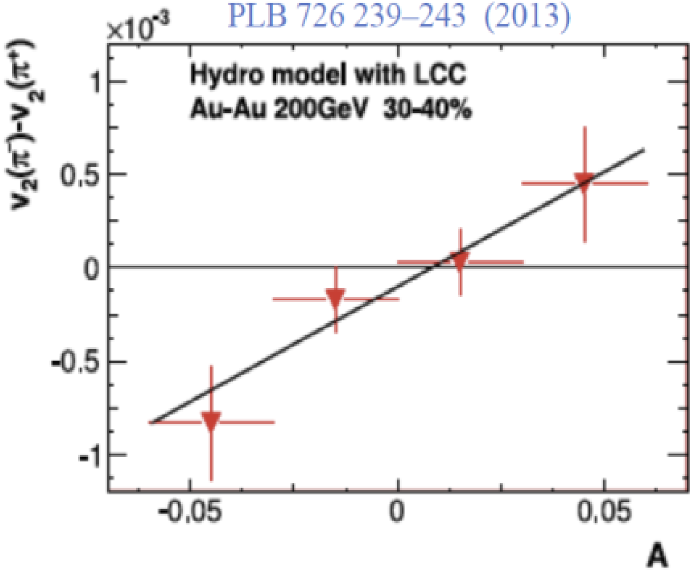
$$\Delta v_2 \equiv v_2^- - v_2^+ \simeq r A_{ch}$$

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

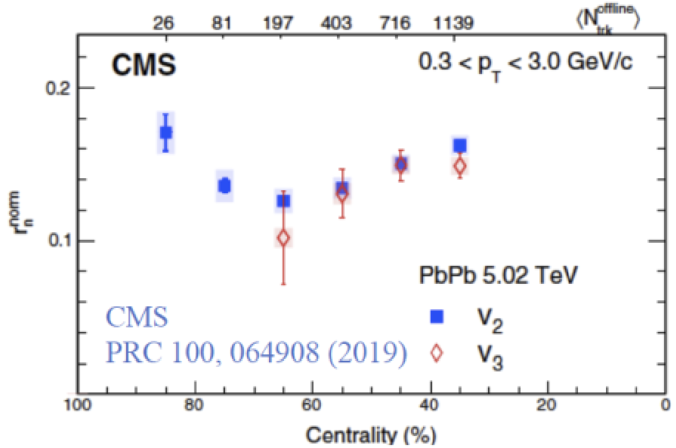
STAR
PRL 114, 252302 (2015)



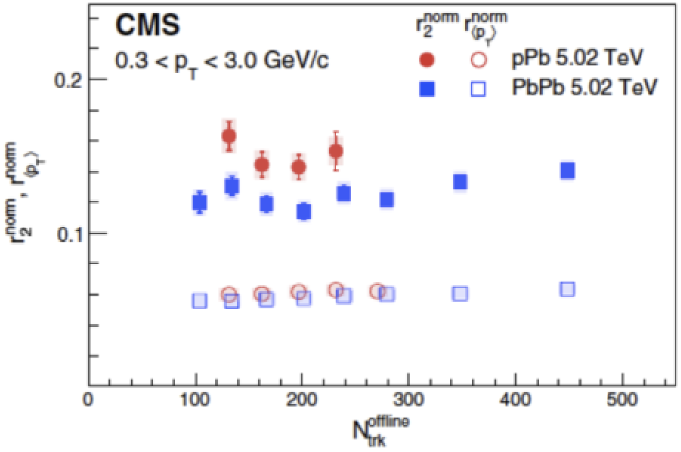
A.Bzdaka and P.Bozekb
PLB 726 239–243 (2013)



A purely background scenario can give a similar dependence



CMS
PRC 100, 064908 (2019)



➢ Similar slope parameter for:
- ✓ v_2 and v_3
- ✓ Small and large systems

Background can account for a part, if not all, of the observed charge separation signal with this correlator:

✓ Could one make a discerning measurements with a different correlator?

❖ The extended $R^{(\mathrm{d})}_{\Psi 2}$ correlator

d = 2 for quadrupole charge separation

N. Magdy, et al. Phys.Lett.B 811 (2020) 135986
N. Magdy, et al. Phys.Rev.C 98 (2018) 061902
N. Magdy, et al. Phys.Rev.C 97 (2018) 061901
D. Shen, et al. Phys.Rev.C 100 (2019) 064907

$$R^{(d)}_{\Psi 2}(\Delta S) = \frac{C_{\Psi 2}(\Delta S_d)}{C^{\perp}_{\Psi 2}(\Delta S_d)}$$

$$C_{\Psi 2}(\Delta S) = \frac{N(\Delta S_d)}{N(\Delta S_d)_{Sh}}$$

$$\Delta\varphi = \varphi - \Psi_2$$

$$C^{\perp}_{\Psi 2}(\Delta S) = \frac{N(\Delta S_d)^{\perp}}{N(\Delta S_d)_{Sh}{}^{\perp}}$$

Sensitive to charge separation (Signal and Background):

$$N(\Delta S_d) = \mathrm{N}(\langle S^{+}_{\Psi 2}\rangle_d - \langle S^{-}_{\Psi 2}\rangle_{\mathrm{d}})$$

$$N(\Delta S_d)^{\perp} = \mathrm{N}(\langle S^{+}_{\Psi 2}\rangle^{\perp}_{d} - \langle S^{-}_{\Psi 2}\rangle^{\perp}_{d})$$

w_i: charge-dependent detector acceptance

$$\langle S^{+}_{\Psi 2}\rangle_d = \frac{\sum_1^p w_p \sin[d(\Delta\varphi)]}{w_p}$$

$$\langle S^{+}_{\Psi 2}\rangle^{\perp}_{d} = \frac{\sum_1^p w_p \cos[d(\Delta\varphi)]}{w_p}$$

p/n: number of positive/negative hadrons per event

$$\langle S^{-}_{\Psi 2}\rangle_d = \frac{\sum_1^n w_n \sin[d(\Delta\varphi)]}{w_n}$$

$$\langle S^{-}_{\Psi 2}\rangle^{\perp}_{d} = \frac{\sum_1^n w_n \cos[d(\Delta\varphi)]}{w_n}$$

Shuffling of charges within an event breaks the charge separation sensitivity:

$$N(\Delta S_d)_{Sh} = \mathrm{N}(\langle S^{+}_{\Psi 2}\rangle_d - \langle S^{-}_{\Psi 2}\rangle_{\mathrm{d}})_{\mathrm{Sh}}$$

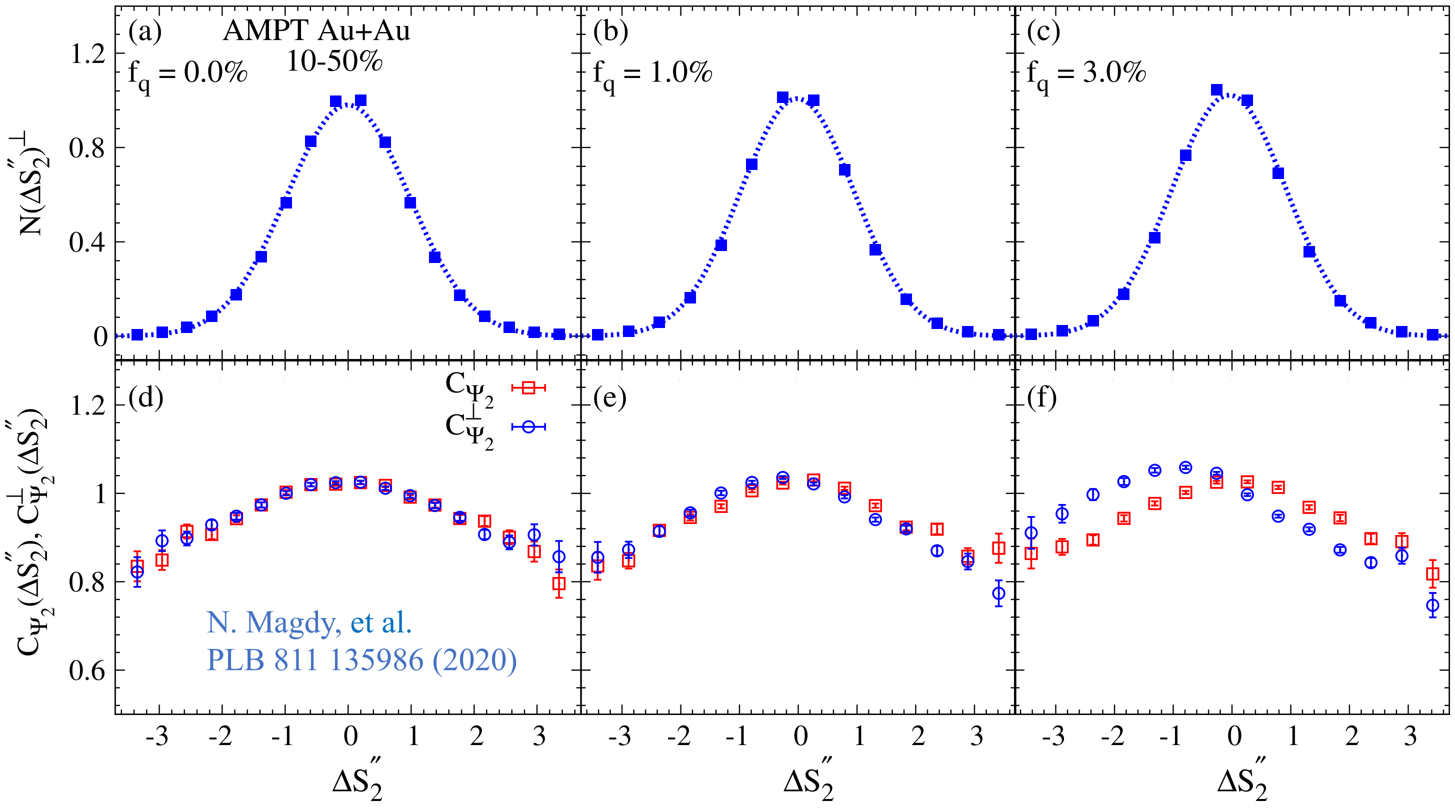
$$N(\Delta S_d)^{\perp} = N\left(\langle S^{+}_{\Psi 2}\rangle^{\perp}_{d} - \langle S^{-}_{\Psi 2}\rangle^{\perp}_{d}\right)_{Sh}$$

❖ The $R^{(2)}_{\Psi_m}(\Delta S_2)$ [quadrupole correlator]

N. Magdy, et al. Phys.Lett.B 811 (2020) 135986
D. Shen, et al. Phys.Rev.C 100 (2019) 064907

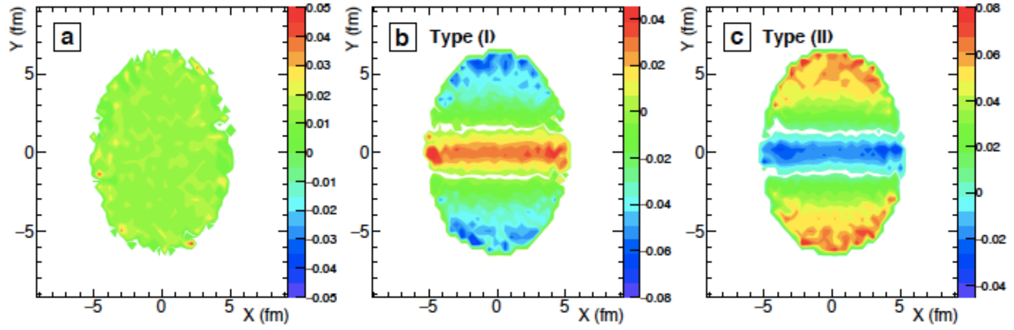
➢ The AMPT used to simulate the charge quadrupole moment resulting from the CMW effect.

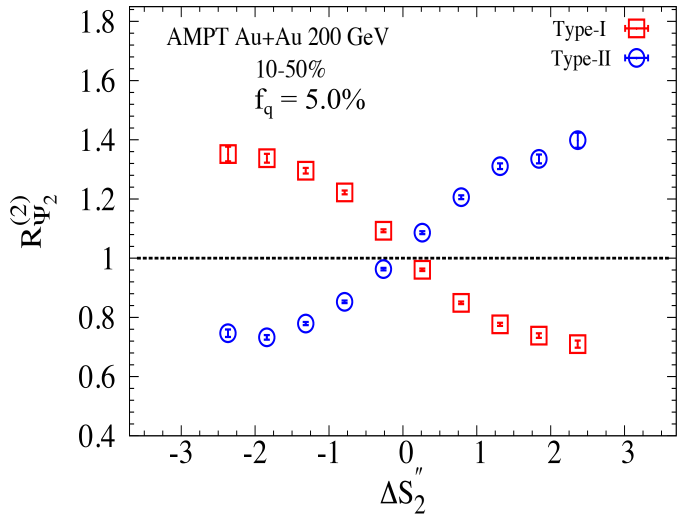
Type-II dominates



The fraction f_q, characterize the strength of the quadrupole charge separation signal.

D. Shen, et al.
PRC 100, 064907 (2019)



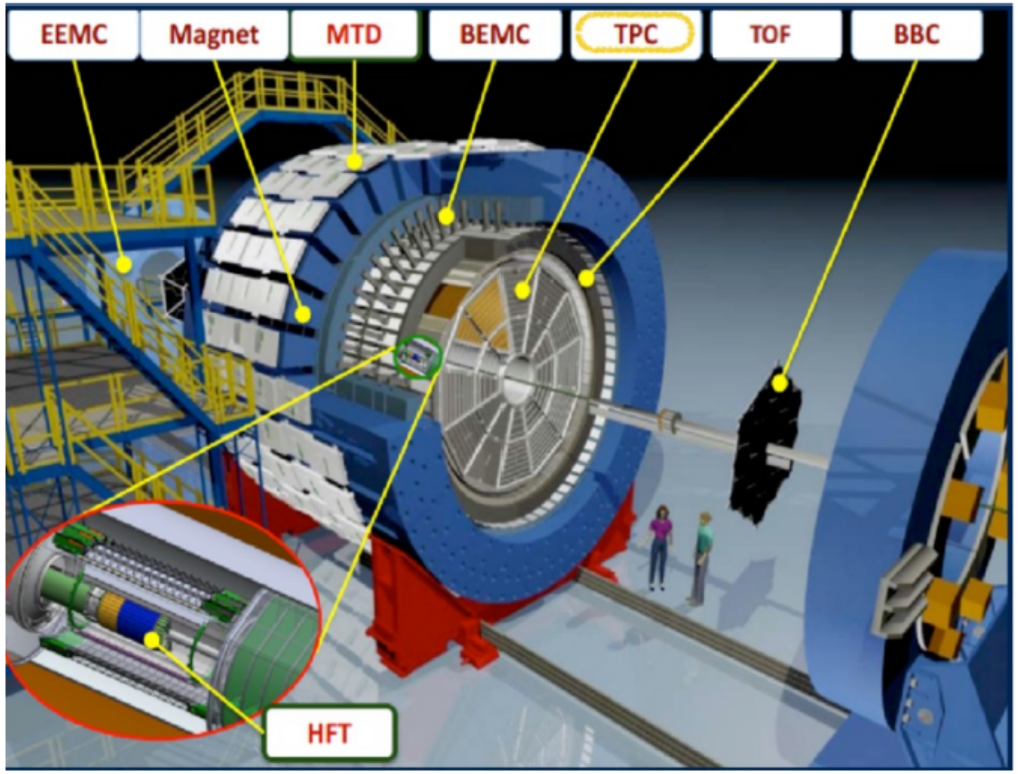


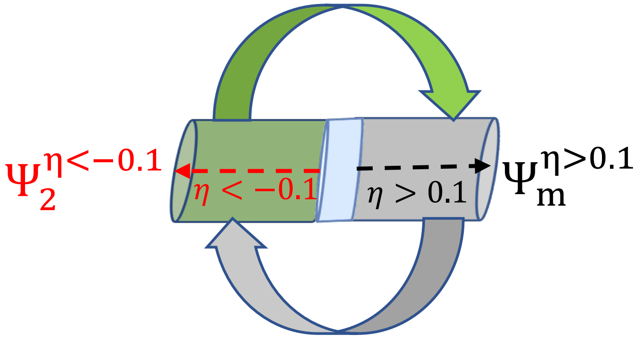
➢ The charge quadrupole shifts the distribution mean value
✓ A stronger shift for large input signal

❖ $R_{\Psi m}^{(2)}$ in Data

N. Magdy, et al.
PLB 811 135986 (2020)

- TPC detector used in the current analysis
- Au+Au at 200 GeV data from year 2011 is used
- Charged hadrons with $0.2 < p_T < 2.0$ GeV/c used to construct $\Psi_m^{\eta>0.1}$ & $\Psi_m^{\eta<-0.1}$
- Particles with $0.35 < p_T < 2.0$ GeV/c and $-1 > \eta < -0.1$ analyzed using $\Psi_m^{\eta>0.1}$
- Particles with $0.35 < p_T < 2.0$ GeV/c and $1 > \eta > 0.1$ analyzed using $\Psi_m^{\eta<-0.1}$





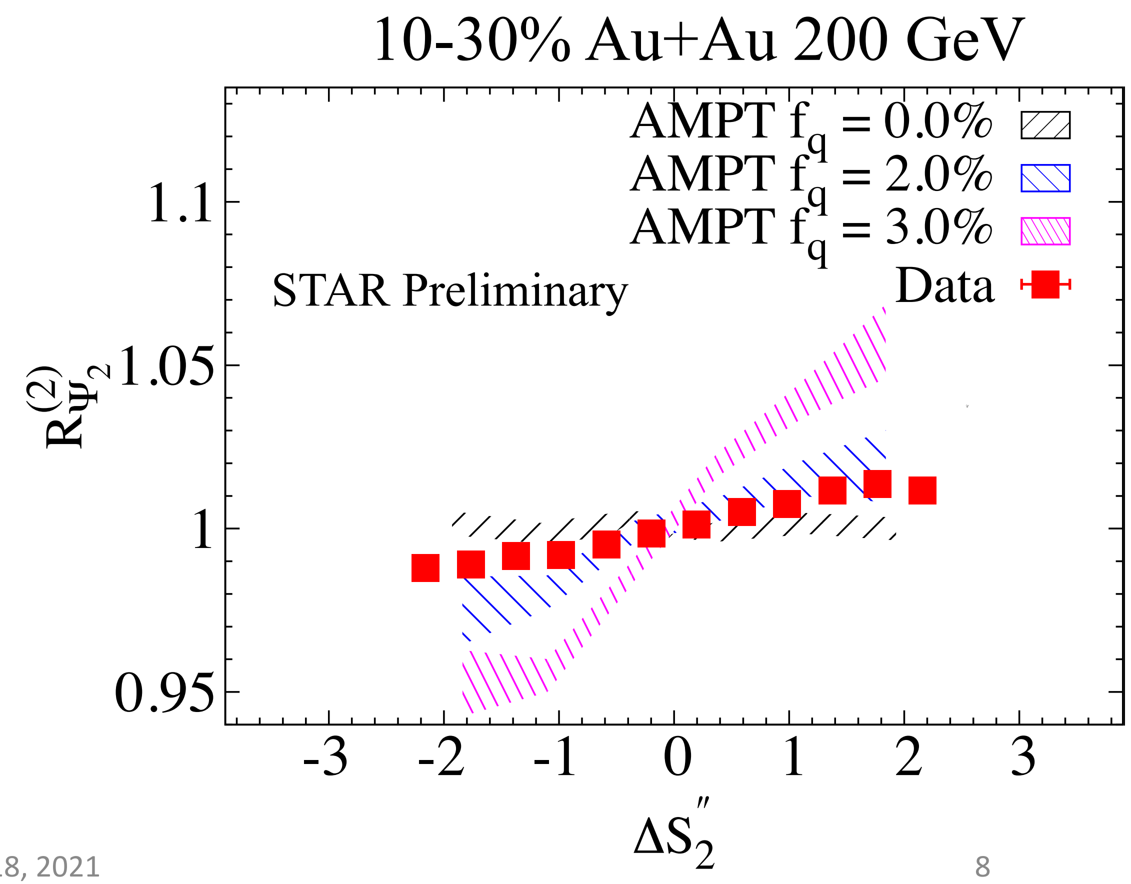
❖ The $R_{\Psi_m}^{(2)}(\Delta S_2)$ [quadrupole correlator]

➢ The correlator response to quadrupole charge separation:

The $R_{\Psi_2}^{(2)}$ distributions for charged particles for 10-30% central events in Au+Au collisions. Data are compared to AMPT with different quadrupole charge separation

➢ The charge quadrupole strength is reflected in the slope of $R_{\Psi_2}^{(2)}$ vs. $\Delta S_2''$:

- ✓ Linear dependence of $R_{\Psi_2}^{(2)}$ on $\Delta S_2''$ similar to AMPT with quadrupole charge separation signal



❖ The $R^{(2)}_{\Psi_m}(\Delta S_2)$ [quadrupole correlator]

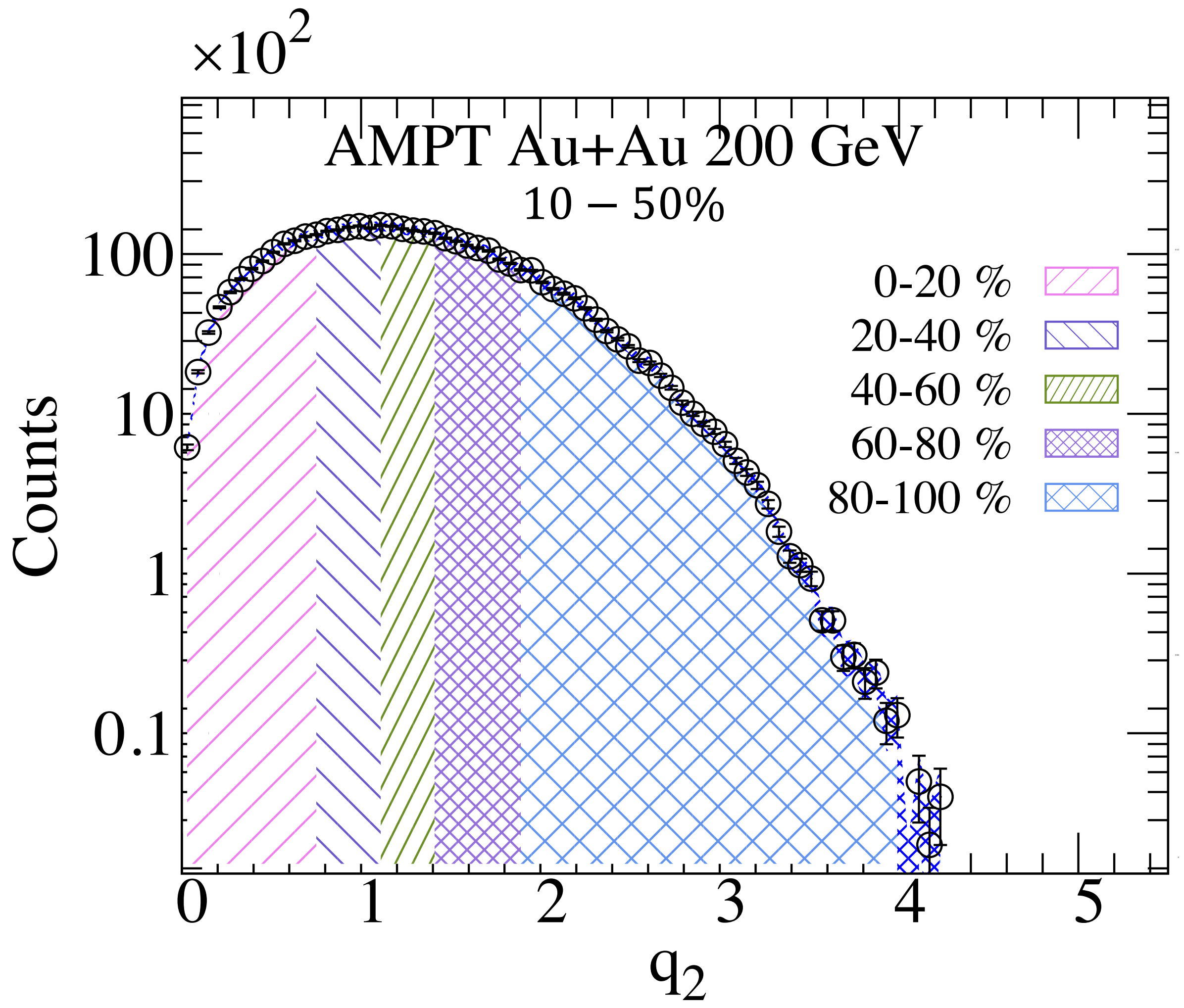
- ➢ The correlator response in quadrupole charge separation:
  - ✓ The v_2-driven background

$$Q_{2,x} = \sum_{i=1}^{M} \cos(2\,\varphi_i)$$

$$Q_{2,y} = \sum_{i=1}^{M} sin(2\,\varphi_i)$$

$$|Q_2| = \sqrt{Q_{2,x}^2 + Q_{2,y}^2}$$

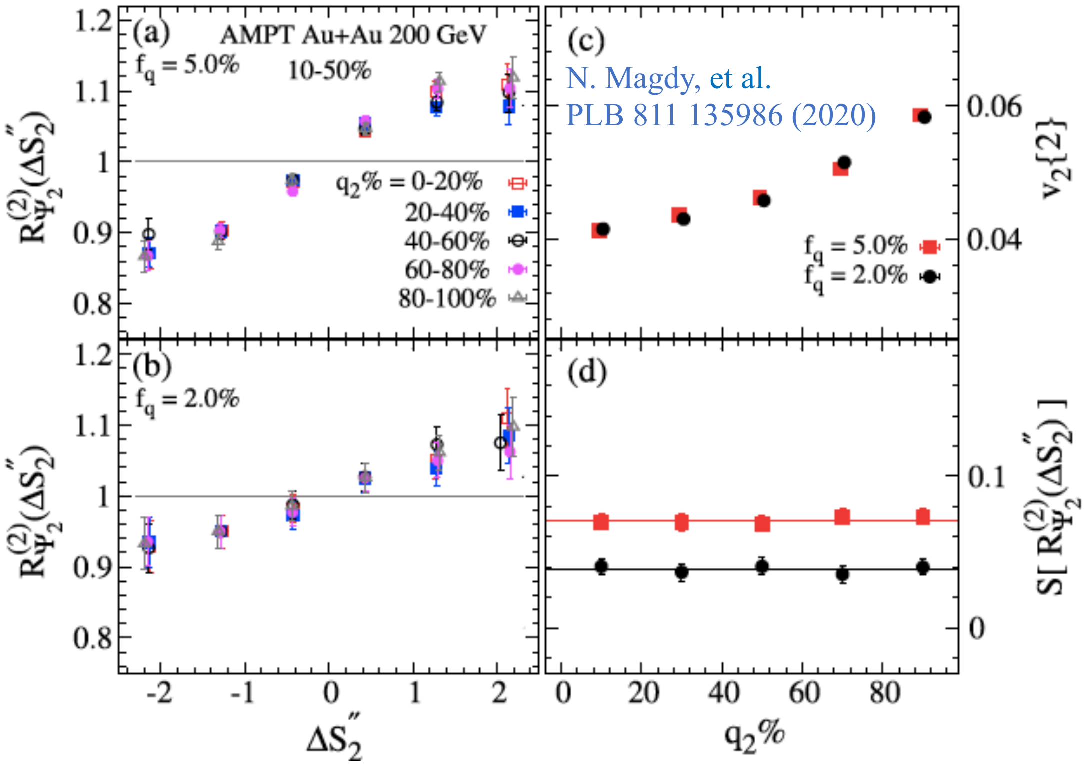
$$q_2 = \frac{|Q_2|}{\sqrt{M}}$$

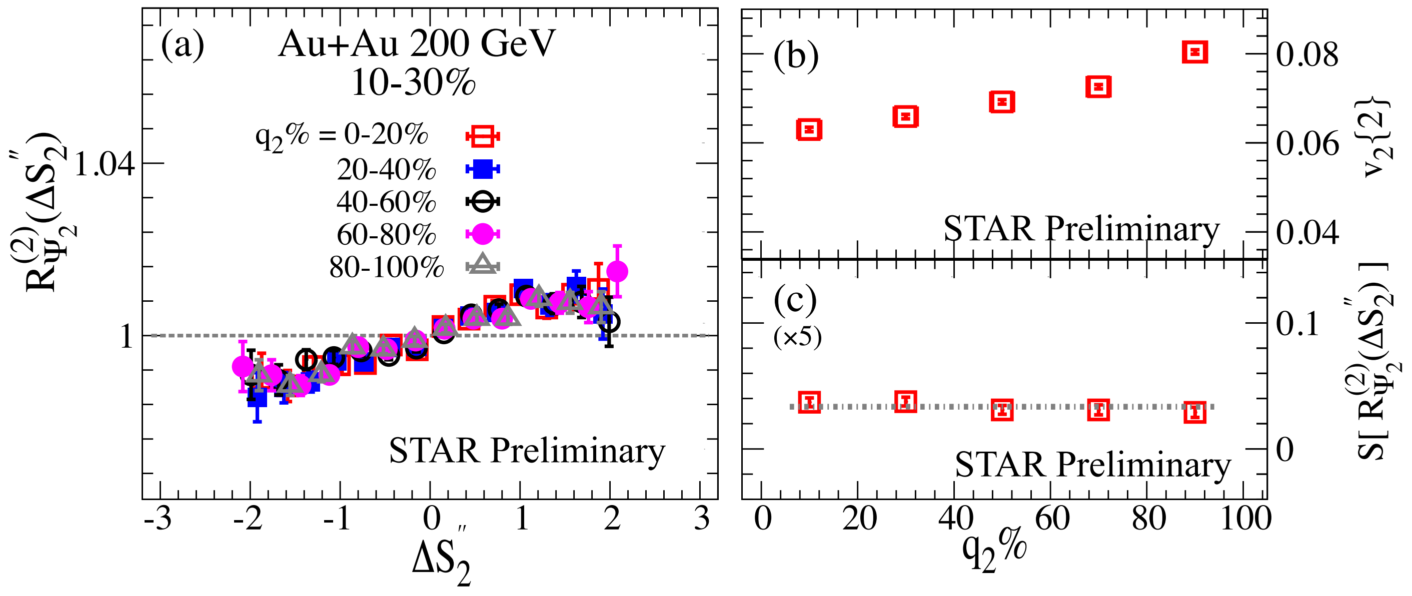


❖ The $R^{(2)}_{\Psi_m}(\Delta S_2)$ [quadrupole correlator]

➢ The correlator response in quadrupole charge separation:

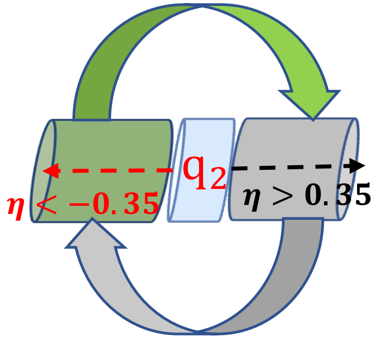
✓ The v_2-driven background





➢ Variation of q_2 leading to ~30% variation of v_2 in 10-30% centrality does not lead to any significant variation of $R^{(2)}_{\Psi 2}$

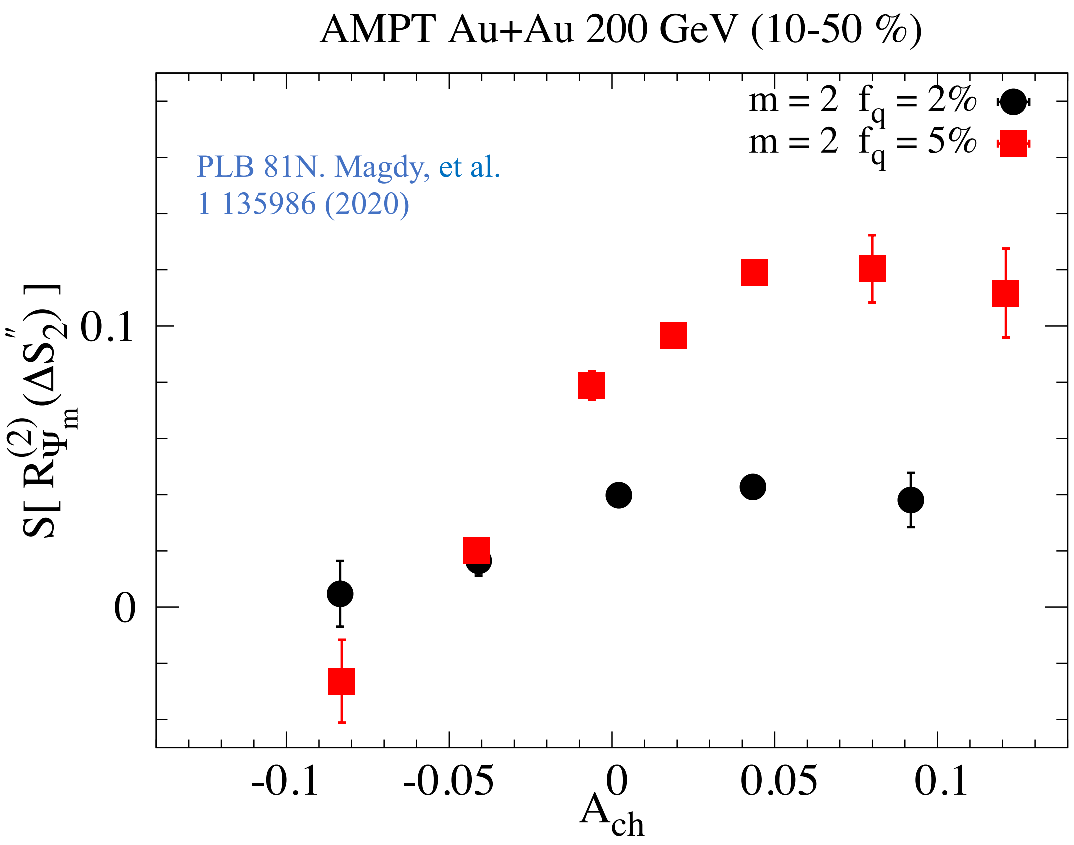
➢ $R^{(2)}_{\Psi 2}$ is not strongly influenced by v_2 background-driven charge separation

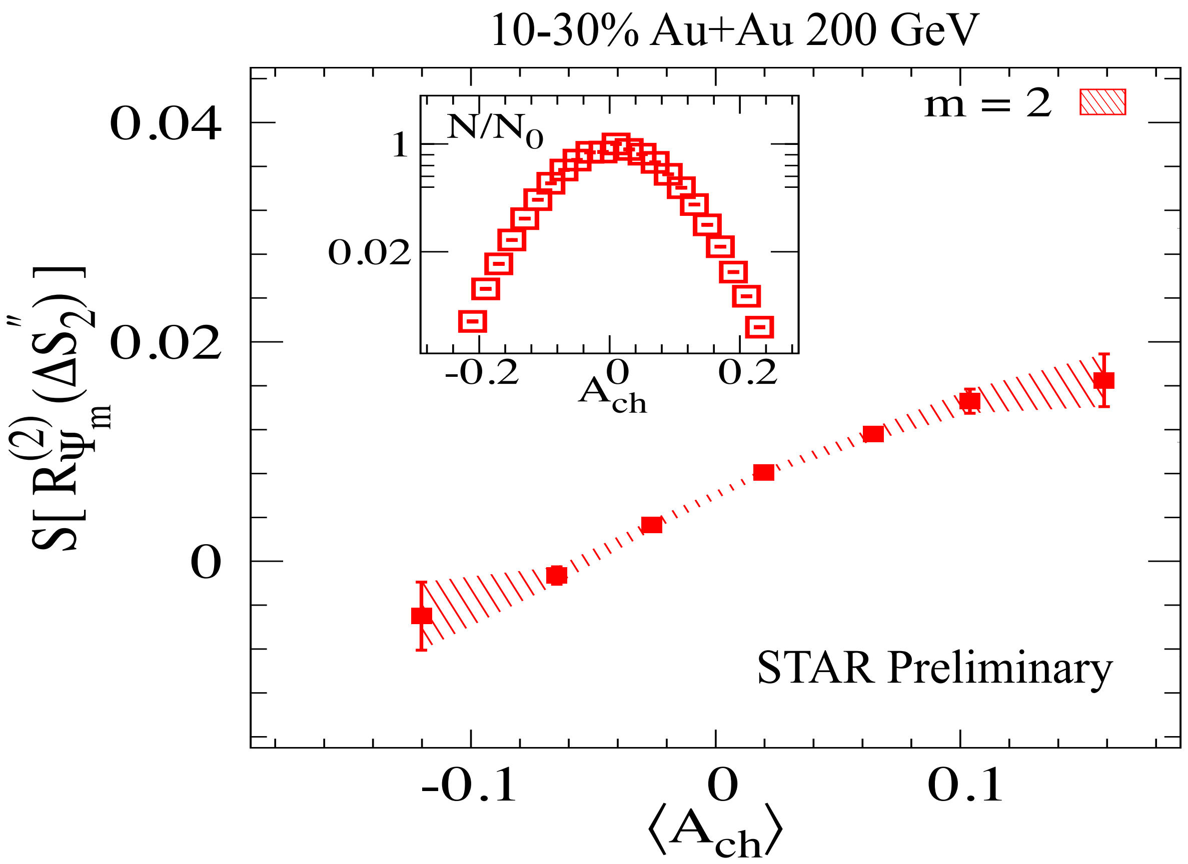


❖ The $R^{(2)}_{\Psi_m}(\Delta S_2)$ [quadrupole correlator]

➢ The correlator response in quadrupole charge separation:

The charge asymmetry dependence of the slope $S(R^{(2)}_{\Psi_2})$ from data and the AMPT model





➢ The $R^{(2)}_{\Psi_2}$ slope is sensitive to the charge asymmetry variations.

Conclusion

A novel correlator $R_{\psi_2}^{(2)}(\Delta S_2)$, has been used to study the quadrupole charge separation in Au+Au at 200 GeV from data and AMPT model:

- Au+Au at 200 GeV AMPT simulations:
  - The $R_{\Psi_2}^{(2)}$ shows a sensitivity to small input quadrupole charge separation signals

- Au+Au at 200 GeV measurements:
  - The measurements show patterns and trends compatible with those expected for small quadrupole charge separation signal in the Au+Au data.

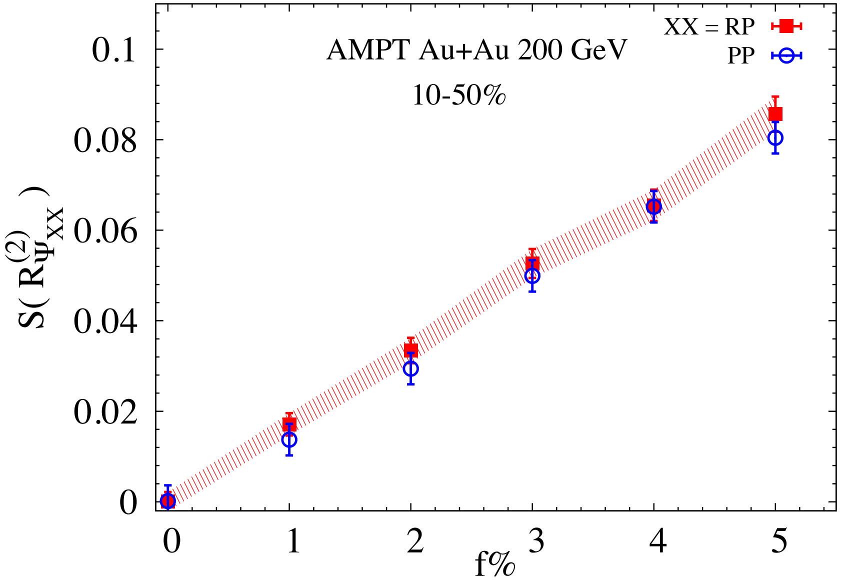
We observed a qualitative similarity between data and AMPT with quadrupole charge separation signal. Therefore, providing a comprehensive set of measurements as well as simulations will lead more to a better understanding of the new observable.

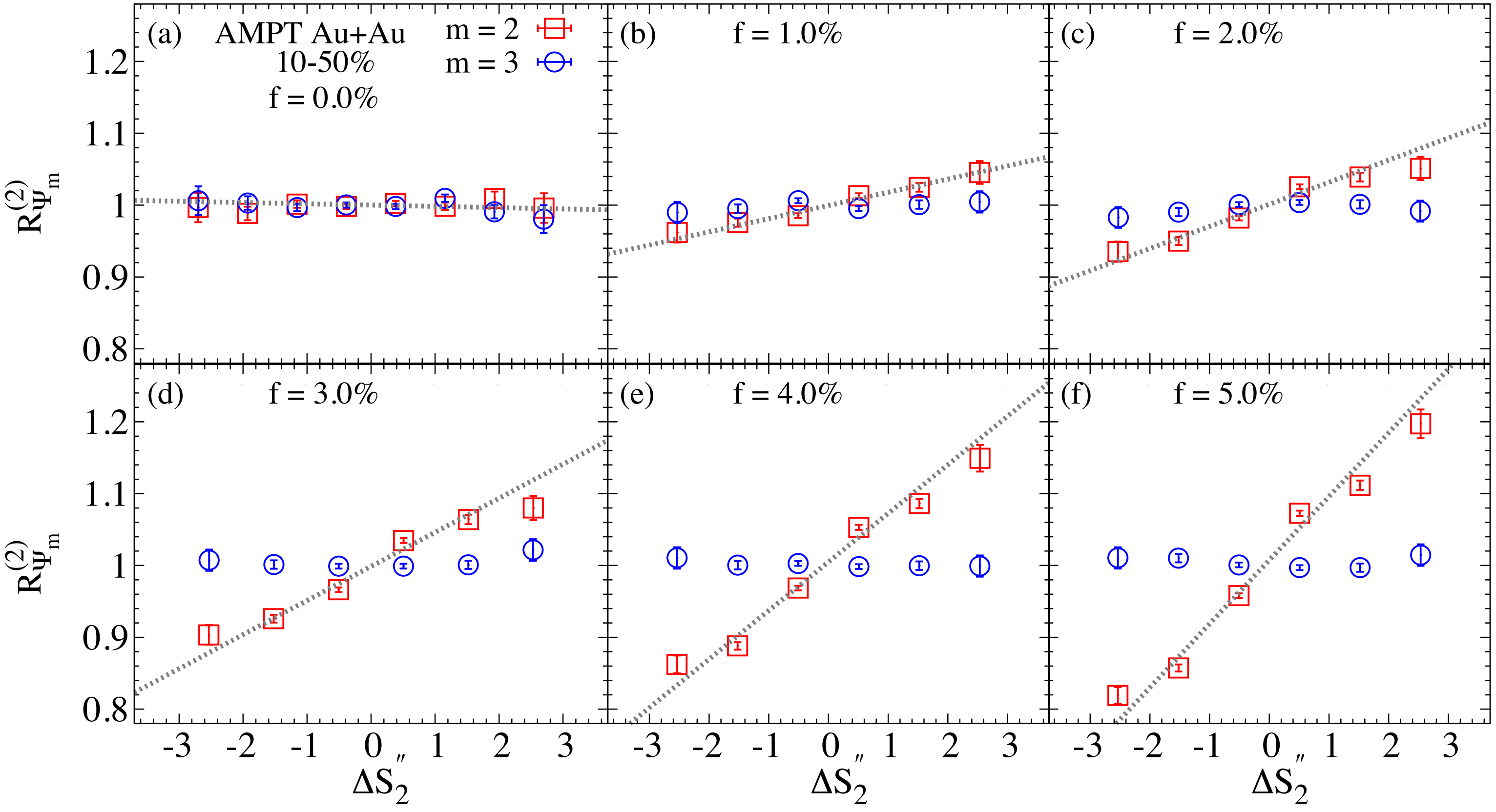
Thank You

❖ The $R^{(2)}_{\Psi_m}(\Delta S_2)$ [quadrupole correlator]

➢ The correlator response in CMW scenarios:

The $R^{(2)}_{\Psi m}(m = 2,3)$ correlators from the AMPT model for several input charge quadrupole signal.





- ➢ The $R^{(2)}_{\Psi XX}$ slope is sensitive to all input signals
  - ✓ $R_{\Psi xx}$ is essentially event plane independent
  - ✓ The slopes are linearly related to the input signal

- ➢ The charge quadrupole strength captured in the $R^{(2)}_{\Psi 2}$ slope
  - ✓ $R^{(2)}_{\Psi 3}$ show no sensitivity to the input signal