Beam energy dependence of charge separation using the $R_{\Psi_m}(\Delta S)$ correlator

Niseem Magdy

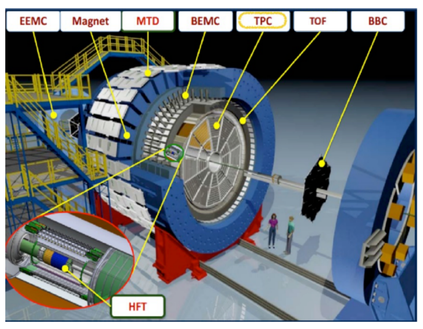
Stony Brook University

(for the STAR Collaboration)

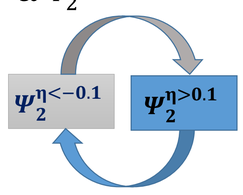
Abstract

A charge-sensitive correlator ($R_{\Psi_m}(\Delta S)$) is used to detect and characterize charge separation associated with the Chiral Magnetic Effect (CME) in heavy-ion collisions. The correlator gives a concave-shaped response relative to the second-order event plane, Ψ_2, and a null response relative to the third-order plane, Ψ_3, for CME-driven charge separation [1]. We present and discuss $R_{\Psi_m}(\Delta S)$ measurements, relative to Ψ_2 and Ψ_3, for collisions of Au+Au at $\sqrt{s_{NN}}$ = 19.6 and 200 GeV and p(d)+Au at $\sqrt{s_{NN}}$ = 200 GeV. $R_{\Psi_2}(\Delta S)$ measurements are also presented for different p_T selections.

The STAR experiment at RHIC



- The TPC detector is used in the current analysis
- Charged hadrons with 0.2 < pT < 2.0 GeV/c are used to construct $\Psi_2^{\eta>0.1}$ & $\Psi_2^{\eta<-0.1}$



- Particles with 0.35 < pT < 2.0 GeV/c and $\eta < 0$ are analyzed using $\Psi_2^{\eta>0.1}$
- Particles with 0.35 < pT < 2.0 GeV/c and $\eta > 0$ are analyzed using $\Psi_2^{\eta<-0.1}$

Only statistical uncertainty are presented

$R_{\Psi_m}(\Delta S)$ correlator

As outlined in Ref. [1], the correlators can be expressed as the ratio:

$$R_{\Psi m}(\Delta S) = \frac{C_{\Psi m}(\Delta S)}{C^{\perp}_{\Psi m}(\Delta S)}$$

$$C_{\Psi m}(\Delta S) = \frac{N(\Delta S\ \ )}{N(\Delta S_{sh})} \qquad C^{\perp}_{\Psi m}(\Delta S) = \frac{N(\Delta S^{\perp})}{N(\Delta S^{\perp}_{sh})}$$

$N(\Delta S)$

$$\langle S^{+}_{\Psi m}\rangle = \frac{\sum_1^p \sin(\frac{m}{2}\Delta\varphi)}{p}$$

$$\langle S^{-}_{\Psi m}\rangle = \frac{\sum_1^n \sin(\frac{m}{2}\Delta\varphi)}{n}$$

$$\Delta S = \langle S^{+}_{\Psi m}\rangle - \langle S^{-}_{\Psi m}\rangle$$

$N(\Delta S_{Sh})$

$$\langle S^{+}_{\Psi m}\rangle_{Sh} = \frac{\sum_1^p \sin(\frac{m}{2}\Delta\varphi)}{p^{Sh}}$$

$$\langle S^{-}_{\Psi m}\rangle_{Sh} = \frac{\sum_1^n \sin(\frac{m}{2}\Delta\varphi)}{n^{Sh}}$$

$$\Delta S_{Sh} = \langle S^{+}_{\Psi m}\rangle_{Sh} - \langle S^{-}_{\Psi m}\rangle_{Sh}$$

$\Delta\varphi = \varphi - \Psi_m$

Sensitive to charge separation (CME and Background)

$\Psi_m \rightarrow \Psi_m + \frac{\pi}{m}$

Shuffling of charges within an event breaks the charge separation sensitivity

$N(\Delta S^{\perp})$

$$\langle S^{+}_{\Psi m}\rangle^{\perp} = \frac{\sum_1^p \sin(\frac{m}{2}\Delta\varphi)}{p}$$

$$\langle S^{-}_{\Psi m}\rangle^{\perp} = \frac{\sum_1^n \sin(\frac{m}{2}\Delta\varphi)}{n}$$

$$\Delta S^{\perp} = \langle S^{+}_{\Psi m}\rangle^{\perp} - \langle S^{-}_{\Psi m}\rangle^{\perp}$$

$N(\Delta S^{\perp}_{sh})$

$$\langle S^{+}_{\Psi m}\rangle^{\perp}_{Sh} = \frac{\sum_1^p \sin(\frac{m}{2}\Delta\varphi)}{p^{Sh}}$$

$$\langle S^{-}_{\Psi m}\rangle^{\perp}_{Sh} = \frac{\sum_1^n \sin(\frac{m}{2}\Delta\varphi)}{n^{Sh}}$$

$$\Delta S^{\perp}_{Sh} = \langle S^{+}_{\Psi m}\rangle^{\perp}_{Sh} - \langle S^{-}_{\Psi m}\rangle^{\perp}_{Sh}$$

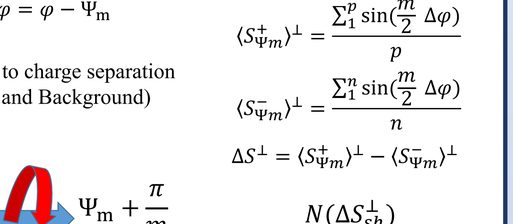
$R_{\Psi_m}(\Delta S)$ correlator width

Charge separation magnitude is reflected in the width of the $R_{\Psi m}(\Delta S)$ distribution which is influenced by number fluctuations and event plane resolution

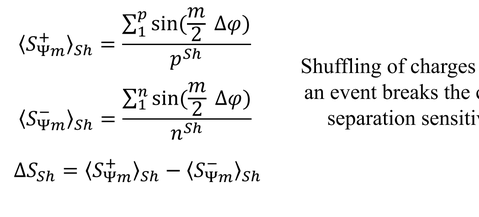
✓ Number fluctuations

The influence of the particle number fluctuations can be minimized by empirically scale the ΔS by:

$$\Delta S' = \Delta S/\sigma_{\Delta S^{sh}}$$



Accounting for number fluctuations effect on $R_{\Psi m}(\Delta S)$.



Accounting for the event plane resolution effect on $R_{\Psi m}(\Delta S)$.

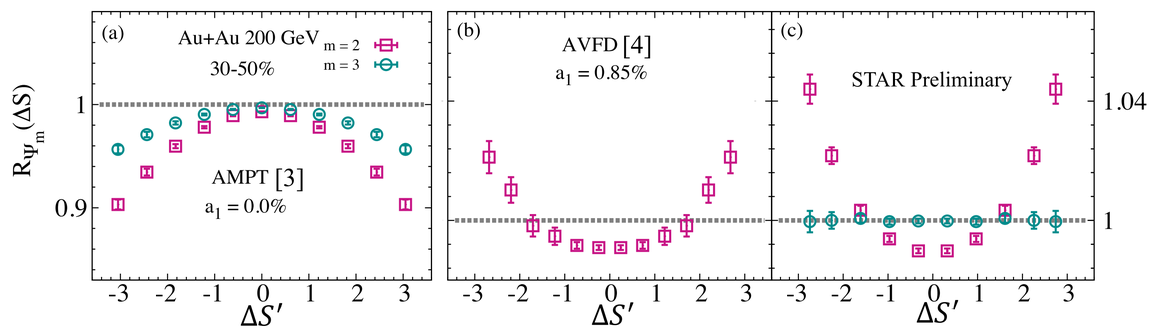
✓ Event plane resolution

The influence of the event plane resolution can be minimized by empirically scaling the $\Delta S'$ by:

$$\Delta S'' = \Delta S'/\delta_{Res}$$

$$\delta_{Res} = e^{0.5(1-Res)^2}$$

$R_{\Psi_m}(\Delta S)$ response

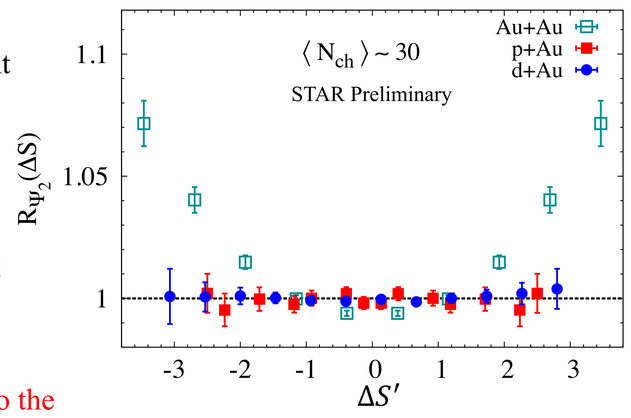


Comparison of the $R_{\Psi m}(\Delta S')$ correlators obtained from 30-50 % central Au+Au collisions from AMPT, AVFD and data.

- The distinct difference in the measured response for $R_{\Psi 2}(\Delta S')$ and $R_{\Psi 3}(\Delta S')$ panel (c) is consistent with the CME-driven charge separation.

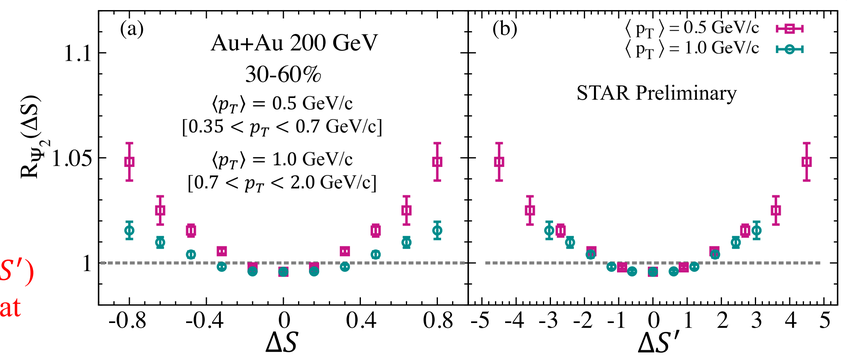
$R_{\Psi_m}(\Delta S)$ response for small and large systems

- The noticeably flat distributions for p(d)+Au collisions are consistent with the reduced magnetic field strength and the approximately random $\vec{B}$-field orientations (relative to Ψ_2) expected in these collisions. The distribution for peripheral Au+Au collisions is decidedly concave-shaped.
- These observations contrast with the large background-driven signal observed for p+Pb and peripheral Pb+Pb collisions at the LHC [2], with the γ correlator.
- These results suggest that the $R_{\Psi 2}(\Delta S')$ correlator is less sensitive to the backgrounds than the γ correlator.



$R_{\Psi_2}(\Delta S)$ response to $\langle p_T \rangle$ selections

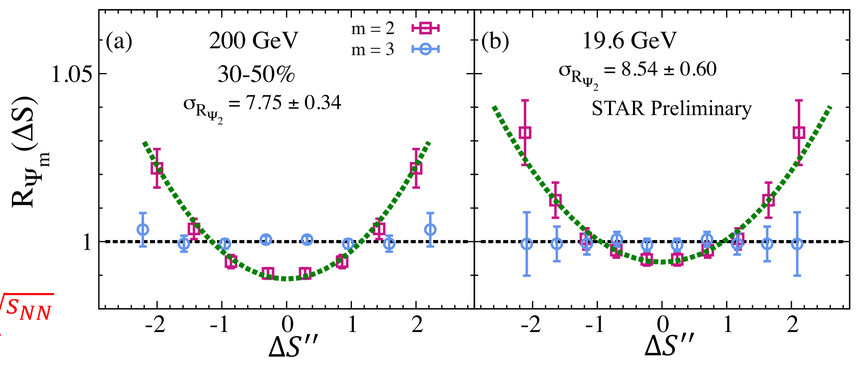
- The influence of background-driven charge separation on $R_{\Psi 2}(\Delta S)$ can be increased (decreased) by selecting particles with larger (smaller) $\langle p_T \rangle$
- The visibly good agreement between the scaled ($\Delta S'$) correlators for the two $\langle p_T \rangle$ selections, confirms that they are not strongly influenced by background-driven charge separation.



$R_{\Psi 2}(\Delta S)$ correlators obtained for 30-60% central Au+Au collisions, two different $\langle p_T \rangle$ selections for which v_2 changes roughly by a factor of 2.

Beam energy dependence

- The $R_{\Psi 3}(\Delta S'')$ distributions are all flat, while those for $R_{\Psi 2}(\Delta S'')$ are concave-shaped, suggesting the presence of a CME-driven charge separation contribution in mid-central Au+Au collisions spanning the range $\sqrt{s_{NN}}$ = 19.6 - 200 GeV.
- The extracted $\sigma_{R_{\Psi 2}(\Delta S'')} \propto 1/a_1$, ($a_1$ is Fourier dipole coefficient) suggest weak (if any) $\sqrt{s_{NN}}$ dependence for the CME-driven charge separation for the centrality selection and beam energy range.
- Such a dependence could result if:
  - ✓ The lifetime of the $\vec{B}$-field varies with $1/\sqrt{s_{NN}}$
  - ✓ The magnitude of the $\vec{B}$ grows with $\sqrt{s_{NN}}$



Conclusion

Charge separation correlator, $R_{\Psi m}$(for m = 2,3), is investigated in p(d)+Au ($\sqrt{s_{NN}}$ =200 GeV), and Au+Au collisions ($\sqrt{s_{NN}}$ = 19.5 - 200 GeV) using the STAR detector.

- $R_{\Psi m}$ measurements show:
  - ✓ Expected difference in the response for Ψ_2 and Ψ_3
  - ✓ Expected difference in the response for small (p(d)+Au) and large systems (Au+Au)
  - ✓ $\sqrt{s_{NN}}$ independence
  - ✓ $\langle p_T \rangle$ independence
- The presented $R_{\Psi m}$ results are consistent with the expectation for CME-driven charge separation.

Reference

[1] N. Magdy, et al., arXiv:1710.01717

[2] CMS Collaboration Phys. Rev. Lett. 118, 122301 (2017)

[3] Zi-Wei Lin, et al., Phys. Rev. C72, 064901 (2005)

[4] Yin Jiang, et al., arXiv:1611.04586

U.S. DEPARTMENT OF ENERGY | Office of Science

The STAR Collaboration

drupal.star.bnl.gov/STAR/presentations

BROOKHAVEN NATIONAL LABORATORY