Collision-system dependence of charge separation relative to the second- and third-order event planes; Implications for the Chiral Magnetic Effect in STAR

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Abstract
A charge-sensitive correlator ($R_{\Psi_2}(\Delta S)$) 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, $\Psi_2$, and a null response relative to the third-order plane, $\Psi_3$, for CME-driven charge separation [1]. We present and discuss $R_{\Psi_2}(\Delta S)$ measurements relative to $\Psi_2$ and $\Psi_3$ for collisions of U+U at $\sqrt{s_{NN}} = 193$ GeV, Au+Au, Cu+Au and p(d)+Au at $\sqrt{s_{NN}} = 200$ GeV. The $R_{\Psi_2}(\Delta S)$ measurements are also presented for different event-shape selections.

The STAR experiment at RHIC

- The TPC detector is used in the current analysis.
- Charged hadrons with $0.2 < p_T < 2.0$ GeV/c are used to construct $W_{pT0}$ and $W_{pT1.1}$.
- Particles with $0.35 < p_T < 2.0$ GeV/c and $\eta < 0$ are analyzed using $W_{pT0}$.
- Particles with $0.35 < p_T < 2.0$ GeV/c and $\eta > 0$ are analyzed using $W_{pT1.1}$.

$R_{\Psi_2}(\Delta S)$ correlator

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

$$R_{\Psi_2}(\Delta S) = \frac{\langle N(\Delta S) \rangle_{\Psi_2}}{\langle N(\Delta S) \rangle_{\Psi_3}}$$

Sensitive to charge separation (CME and background):

$$N(\Delta S) = N_0(\Delta S) + \Delta N(\Delta S)$$

$$N_0(\Delta S) = N_0^+(\Delta S) - N_0^-(\Delta S)$$

$$\Delta N(\Delta S) = \Delta N^+(\Delta S) - \Delta N^-(\Delta S)$$

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

$$N_0(\Delta S) = N_0^+(\Delta S) = N_0^-(\Delta S)$$

$$\Delta N(\Delta S) = \Delta N^+(\Delta S) = \Delta N^-(\Delta S)$$

Corrections for number fluctuations and the event plane resolution effects on the $R_{\Psi_2}(\Delta S)$

Charge separation magnitude is reflected in the width of the $R_{\Psi_2}(\Delta S)$ distribution which is influenced by number fluctuations and event plane resolution. A scaling procedure was developed to mitigate both of these effects. This procedure was validated with the Au+Au data by selectively modifying the number fluctuations and the event plane resolution. Such modifications were accomplished by selecting a fraction of the particles in the sub-events used to (i) evaluate the event plane, (ii) measure charge separation relative to the event plane and (iii) both. Here we show a similar example using the AMPT model for case (iii).

- Number fluctuations
- Event plane resolution

The influence of the particle number fluctuations can be minimized by empirically scaling the $\Delta S$ by $\delta_{pT0}$ to be $\Delta S^\prime$.

$R_{\Psi_2}(\Delta S)$ response

- The $R_{\Psi_2}(\Delta S)$ and $R_{\Psi_3}(\Delta S)$ give similar response to the background irrespective of the correlator shape.

$R_{\Psi_2}(\Delta S)$ response for small and large systems

- The noticeably flat/convex distributions for p(d)+Au collisions are consistent with the reduced magnetic field strength and the approximately random $\phi$-field orientations relative to $\Psi_2$ 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 $\phi$ correlator.

- These results suggest that the $R_{\Psi_2}(\Delta S^\prime)$ correlator is less sensitive to the backgrounds than the $\phi$ correlator.

$R_{\Psi_2}(\Delta S)$ response to event-shape selections

- Events are further subdivided into groups with different $q_2$ magnitudes.

The $q_2$ distribution for 40-50% Au+Au collisions at 200 GeV for the sub-event sample with $|\Psi_2| < 0.3$.

$R_{\Psi_2}(\Delta S)$ correlators obtained for 20-50% central Au+Au collisions, for different $q_2$ selections.

The $q_2$ distributions are sensitive to the background-driven charge separation.

Collision-system dependence of the $R_{\Psi_2}(\Delta S)$

The $R_{\Psi_2}(\Delta S)$ and $R_{\Psi_3}(\Delta S)$ for 0-20% centrality selection in different collision systems.

- The $R_{\Psi_2}(\Delta S)$ correlators for different collision systems is distinctly different from those for $R_{\Psi_2}(\Delta S)$ correlators.
- The $R_{\Psi_2}(\Delta S)$ decidedly concave-shaped, as would be expected for CME-driven charge separation with limited influence from background-driven charge separation.

Conclusions

Charge separation correlator, $R_{\Psi_m}$ (for $m = 2,3$), is investigated in U+U collisions at $\sqrt{s_{NN}} = 193$ GeV, Au+Au, Cu+Au and p(d)+Au collisions at $\sqrt{s_{NN}} = 200$ GeV using the STAR detector.

- $R_{\Psi_2}$ measurements show:
  - Expected difference in the response for $\Psi_2$ and $\Psi_3$.
  - Expected difference in the response for small (p(d)+Au) and large systems (Au+Au).
  - $R_{\Psi_2}$ width is $q_2$ independent (weak $\Psi_2$-driven background sensitivity).

The presented $R_{\Psi_2}$ results are consistent with the expectations for CME-driven charge separation.

Reference