Beam energy and collision system dependence of charge separation using the $R_{\Psi m}(\Delta S)$ correlator

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Outline

- Introduction
  - Chiral Magnetic Effect (CME)
  - CME-charge separation vs Background-charge separation
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- $R_{\psi_m}(\Delta S)$ Correlator
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- Results
  - Event plane and small systems dependence
  - $R_{\psi 2}(\Delta S)$ vs $\langle p_T \rangle$
  - $R_{\psi m}(\Delta S)$ vs $\sqrt{s_{NN}}$
  - $R_{\psi m}(\Delta S)$ vs centrality
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  - $R_{\Psi_2}(\Delta S)$ vs $\langle p_T \rangle$
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  - $R_{\Psi_m}(\Delta S)$ vs centrality

- Conclusion
Introduction

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Chiral Magnetic Effect (CME)

- In non-central collisions a strong magnetic field is created ⊥ to $\Psi_{RP}$

D.E. Kharzeev
Prog.Part.Nucl.Phys. 75 (2014) 133-151
Introduction

Chiral Magnetic Effect (CME)

In non-central collisions a strong magnetic field is created \( \perp \) to \( \Psi_{RP} \)

Magnetic field acts on the chiral fermions with \( \mu_5 \neq 0 \) leads to an electric current along the magnetic field which leads to a charge separation

D.E. Kharzeev et al.
Prog.Part.Nucl.Phys. 88 (2016) 1-28

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Introduction

✓ Chiral Magnetic Effect (CME)

In non-central collisions a strong magnetic field is created \( \perp \) to \( \Psi_{RP} \)

- Magnetic field acts on the chiral fermions with \( \mu_5 \neq 0 \) leads to an electric current along the magnetic field which leads to a charge separation

This charge separation leads to a “dipole moment”

D.E. Kharzeev et al.
Prog.Part.Nucl.Phys. 75 (2014) 133-151

Yin Jiang et al.
arXiv:1611.04586

D.E. Kharzeev et al.
Prog.Part.Nucl.Phys. 88 (2016) 1-28
Introduction

✓ CME-charge separation vs Background-charge separation

![Graph showing correlation between \( \Psi_B \) and \( \Psi_2 \)]

\[ \text{Cu+Au, } \sqrt{s} = 200 \text{GeV} \]

\[ \langle \cos[\ln(\Psi_B \Psi_n)] \rangle \]

- \( n = 1 \)
- \( n = 2 \)
- \( n = 3 \)
- \( n = 4 \)

![Graph showing correlation between \( \Psi_B \) and \( \Psi_2 \)]

➢ \( \Psi_B \)

✓ Strong correlated with \( \Psi_2 \)
Introduction

✓ CME-charge separation vs Background-charge separation

\[ \Psi_B \]

✓ Strong correlated with \( \Psi_2 \)
✓ No correlation with \( \Psi_3 \)
Introduction

- CME-charge separation vs Background-charge separation

- $\Psi_B$
  - Strong correlated with $\Psi_2$
  - No correlation with $\Psi_3$
  - Weak correlated with $\Psi_2$ in small systems
Introduction

CME-charge separation vs Background-charge separation

- $\Psi_B$
  - Strong correlated with $\Psi_2$
  - No correlation with $\Psi_3$
  - Weak correlated with $\Psi_2$ in small systems

- Weak $B(\tau) \sqrt{S_{NN}}$ dependence
\( R_{\psi_m}(\Delta S) \) Correlator

N. Magdy et al.
arXiv: 1710.01717

\[
R_{\psi_m}(\Delta S) = \frac{C_{\psi_m}(\Delta S)}{C_{\psi_m}(\Delta S)}
\]
$R_{\psi m}(\Delta S)$ Correlator

N. Magdy et al.
arXiv: 1710.01717

$R_{\psi m}(\Delta S) = \frac{C_{\psi m}(\Delta S)}{C_{\psi m}(\Delta S)}$

$C_{\psi m}(\Delta S) = \frac{N(\Delta S)}{N(\Delta S_{sh})}$

$N(\Delta S)$

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

$\langle S_{\psi m}^+ \rangle = \frac{\Sigma_1^p \sin \left( \frac{m}{2} \Delta \varphi \right)}{p}$

$\langle S_{\psi m}^- \rangle = \frac{\Sigma_1^n \sin \left( \frac{m}{2} \Delta \varphi \right)}{n}$

$\Delta S = \langle S_{\psi m}^+ \rangle - \langle S_{\psi m}^- \rangle$

Sensitive to charge separation
(CME and Background)
\[ R_{\Psi m}(\Delta S) \] Correlator

N. Magdy et al.
arXiv: 1710.01717

\[ R_{\Psi m}(\Delta S) = \frac{C_{\Psi m}(\Delta S)}{C_{\Psi m}^{\perp}(\Delta S)} \]

\[ C_{\Psi m}(\Delta S) = \frac{N(\Delta S)}{N(\Delta S_{sh})} \]

\[ \Delta \varphi = \varphi - \Psi_m \]

\[ \langle S_{\Psi m}^+ \rangle = \frac{\sum_1^p \sin \left( \frac{m}{2} \Delta \varphi \right)}{p} \]

\[ \langle S_{\Psi m}^- \rangle = \frac{\sum_1^n \sin \left( \frac{m}{2} \Delta \varphi \right)}{n} \]

\[ \Delta S = \langle S_{\Psi m}^+ \rangle - \langle S_{\Psi m}^- \rangle \]

\[ N(\Delta S_{sh}) \]

\[ \langle S_{\Psi m}^+ \rangle^{sh} = \frac{\sum_1^p \sin \left( \frac{m}{2} \Delta \varphi \right)}{p^{sh}} \]

\[ \langle S_{\Psi m}^- \rangle^{sh} = \frac{\sum_1^n \sin \left( \frac{m}{2} \Delta \varphi \right)}{n^{sh}} \]

\[ \Delta S_{sh} = \langle S_{\Psi m}^+ \rangle^{sh} - \langle S_{\Psi m}^- \rangle^{sh} \]

Sensitive to charge separation (CME and Background)

Shuffling of charges within an event breaks the charge separation sensitivity
**$R_{\Psi m}(\Delta S)$ Correlator**

N. Magdy et al.
arXiv: 1710.01717

$$R_{\Psi m}(\Delta S) = \frac{C_{\Psi m}(\Delta S)}{C_{\Psi m}^\bot(\Delta S)}$$

$C_{\Psi m}(\Delta S) = \frac{N(\Delta S)}{N(\Delta S_{sh})}$

$N(\Delta S) \quad \Delta \varphi = \varphi - \Psi_m$

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

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

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

$N(\Delta S_{sh})$

$$\langle S_{\Psi m}^+ \rangle^{sh} = \frac{\sum_1^p \sin\left(\frac{m}{2} \Delta \varphi \right)}{p^{sh}}$$

$$\langle S_{\Psi m}^- \rangle^{sh} = \frac{\sum_1^n \sin\left(\frac{m}{2} \Delta \varphi \right)}{n^{sh}}$$

$\Delta S_{sh} = \langle S_{\Psi m}^+ \rangle^{sh} - \langle S_{\Psi m}^- \rangle^{sh}$

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
- $R_{\psi m}(\Delta S)$ Correlator
  
  N. Magdy et al.  
arXiv: 1710.01717

- $N(\Delta S)$ distributions:
  - Gaussian like distribution

- $N(\Delta S)$ distributions:
  - Carry charge separation information

\[ Fit(x) = a e^{-0.5 \left( \frac{x}{\sigma} \right)^2} \]
\( R_{\Psi m} (\Delta S) \) Correlator

N. Magdy et al.
arXiv: 1710.01717

- \( N(\Delta S) \) distributions:
  - Gaussian like distribution

- \( N(\Delta S) \) distributions:
  - Carry charge separation information

- \( N(\Delta S_{sh}) \) distributions:
  - Carry no separation information

\( \text{Fit}\ (x) = a \ e^{-0.5 \left( \frac{x}{\sigma} \right)^2} \)

\( N(\Delta S) \)

\( N(\Delta S_{sh}) \)

\( N(\Delta S_{\perp}) \)

\( N(\Delta S_{\perp,sh}) \)
**$R_{\Psi_m}(\Delta S)$ Correlator**

N. Magdy et al.
arXiv: 1710.01717

- $N(\Delta S)$ distributions:
  - Gaussian like distribution

- $N(\Delta S)$ distributions:
  - Carry charge separation information

- $N(\Delta S_{sh})$ distributions:
  - Carry no separation information

---

**Fit**

$\text{Fit}(x) = a \ e^{-0.5 \left( \frac{x}{\sigma} \right)^2}$

---

**Graphs**

1. $N(\Delta S)$ distributions for Au+Au 200 GeV 40-50%
2. $N(\Delta S_{sh})$ distributions for Au+Au 200 GeV 40-50%
3. $N(\Delta S_{\perp})$ distributions for Au+Au 200 GeV 40-50%
4. $N(\Delta S_{\perp})$ distributions for Au+Au 200 GeV 40-50%
\[ R_{\Psi_m}(\Delta S) \text{ Correlator} \]

Background

N. Magdy et al.
arXiv: 1710.01717

\[ \Psi \] in background models:

\[ \checkmark \] Similar response for \( \Psi_2 \) and \( \Psi_3 \)
R_{\Psi_m}(\Delta S) Correlator Background

N. Magdy et al.
arXiv: 1710.01717

R_{\Psi_m} in background models:

- Similar response for \Psi_2 and \Psi_3
- The R_{\Psi_m} width change with \langle p_T \rangle
\textbf{R}_{\Psi m}(\Delta S) \text{ Correlator Background}

N. Magdy et al.
arXiv: 1710.01717

\begin{itemize}
  \item $R_{\Psi m}$ in background models:
  \begin{itemize}
    \item Similar response for $\Psi_2$ and $\Psi_3$
    \item The $R_{\Psi m}$ width change with $\langle p_T \rangle$
    \item Similar response for small and large systems
  \end{itemize}
\end{itemize}

Y. Feng et al.
arXiv: 1803.02860

\begin{figure}
  \centering
  \includegraphics[width=\textwidth]{figures}
  \caption{Graph showing $R_{\Psi m}(\Delta S)$ for different $m$ values.}
\end{figure}

\begin{figure}
  \centering
  \includegraphics[width=\textwidth]{figures}
  \caption{Comparison of $R_{\Psi m}(\Delta S)$ for AMPT and different system sizes.}
\end{figure}

\begin{figure}
  \centering
  \includegraphics[width=\textwidth]{figures}
  \caption{Comparison of $R_{\Psi m}(\Delta S)$ for different $\langle p_T \rangle$ values.}
\end{figure}

Piotr Bozek
arXiv: 1711.02563
R_{\psi m}(\Delta S) Correlator

- Charge separation magnitude is reflected in the width of the $R_{\psi m}(\Delta S)$ distribution
- $R_{\Psi_m}(\Delta S)$ Correlator

- Charge separation magnitude is reflected in the width of the $R_{\Psi_m}(\Delta S)$ distribution

- $R_{\Psi_m}(\Delta S)$ width affected by:
  - Number fluctuations

![Graph showing the $R_{\Psi_2}(\Delta S)$ distribution for Au+Au 200 GeV events at different centrality classes. The graph includes data points for 100%, 90%, 70%, and 50% centrality, with error bars indicating the statistical uncertainty. The plot is labeled with "STAR Preliminary." ]
\[ R_{\psi m}(\Delta S) \] Correlator

- Charge separation magnitude is reflected in the width of the \( R_{\psi m}(\Delta S) \) distribution

- \( R_{\psi m}(\Delta S) \) width affected by:
  - Number fluctuations

\[ \Delta S' = \Delta S / \sigma_{\Delta S^{sh}} \]
**$R_{\Psi_m}(\Delta S)$ Correlator**

- Charge separation magnitude is reflected in the width of the $R_{\Psi_m}(\Delta S)$ distribution

- $R_{\Psi_m}(\Delta S)$ width affected by:
  - Number fluctuations
    \[ \Delta S' = \Delta S / \sigma_{\Delta S}^{sh} \]
  - EP-resolution

---

![Graph](image-url)

- **Fit** ($x$) = $a e^{0.5 \left(\frac{x}{\sigma}\right)^2}$

- **Toy-Model**
  - $a_1 = 1\%$
  - $\text{Res}(\psi_2) = 1.000$
  - $\text{Res}(\psi_2) = 0.726$
  - $\text{Res}(\psi_2) = 0.499$
  - $\text{Res}(\psi_2) = 0.331$
\( R_{\Psi m}(\Delta S) \) Correlator

- Charge separation magnitude is reflected in the width of the \( R_{\Psi m}(\Delta S) \) distribution

- \( R_{\Psi m}(\Delta S) \) width affected by:
  - Number fluctuations
    \[ \Delta S' = \Delta S / \sigma_{\Delta S}^{sh} \]
  - EP-resolution
    \[ \Delta S'' = \Delta S' / \delta_{Res} \]
    \[ \delta_{Res} = e^{0.5(1-Res)^2} \]
Data Analyses

STAR Experiment at RHIC

- The TPC detector is used in the current analysis
Data Analyses

STAR Experiment at RHIC

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- Charged hadrons with $0.2 < p_T < 2.0$ GeV/c are used to construct $\psi_2^{\eta>0.1}$ & $\psi_2^{\eta<-0.1}$
Data Analyses

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

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- The TPC detector is used in the current analysis
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- Particles with $0.35 < p_T < 2.0$ GeV/c and $\eta > 0$ are analyzed using $\Psi_2^{\eta<-0.1}$
Results

- Event plane and small systems dependence
Results

- Event plane and small systems dependence

Measurements for $R_{\Psi_m}$ show:

- Different response for $R_{\Psi_2}$ and $R_{\Psi_3}$
Results

- Event plane and small systems dependence

Measurements for $R_{\psi_m}$ show:

- Different response for $R_{\psi_2}$ and $R_{\psi_3}$

- Different response for small (p(d)+Au) and large (Au+Au) systems
Results

Event plane and small systems dependence

- Measurements for $R_{\Psi m}$ show:
  - Different response for $R_{\Psi 2}$ and $R_{\Psi 3}$
  - Different response for small $(p(d)+Au)$ and large $(Au+Au)$ systems

- $R_{\Psi m}$ results are consistent with the expectation for CME-driven charge separation.
Results

✓ Event plane and small systems dependence

Measurements for $R_{\Psi m}$ show:

✓ Different response for $R_{\Psi 2}$ and $R_{\Psi 3}$

✓ Different response for small $(p(d)+Au)$ and large $(Au+Au)$ systems

$R_{\Psi m}$ results are consistent with the expectation for CME-driven charge separation.

✓ Note that these observations contrast with those from the $\gamma$ correlator.

[CMS Collaboration arXiv:1610.00263]
Results

- $R_{\psi_2}(\Delta S) \text{ vs } \langle p_T \rangle$

- Measurements show:
  - $v_2$ (background) increases with $\langle p_T \rangle$
Results

✓ $R_{\Psi_2}(\Delta S)$ vs $\langle p_T \rangle$

Measurements show:

✓ $v_2$ (background) increases with $\langle p_T \rangle$

✓ But $R_{\Psi_2}$ width increases with $\langle p_T \rangle$

- Number fluctuations?

\[ \langle p_T \rangle = 0.5 \text{ GeV/c} \]
\[ [0.35 < p_T < 0.7 \text{ GeV/c}] \]

\[ \langle p_T \rangle = 1.0 \text{ GeV/c} \]
\[ [0.7 < p_T < 2.0 \text{ GeV/c}] \]
Results
✓ $R_{\Psi_2}(\Delta S) \text{ vs } \langle p_T \rangle$

Measurements show:
✓ $v_2$ (background) increases with $\langle p_T \rangle$
✓ But $R_{\Psi_2}$ width increases with $\langle p_T \rangle$
  - Number fluctuations?

Scaling out the number fluctuations:
Results

✓ $R_{\Psi_2}(\Delta S)$ vs $\langle p_T \rangle$

Measurements show:

✓ $v_2$ (background) increases with $\langle p_T \rangle$

✓ But $R_{\Psi_2}$ width increases with $\langle p_T \rangle$

- Number fluctuations?

Scaling out the number fluctuations:

✓ $R_{\Psi_2}$ is $\langle p_T \rangle$ independent
Results

✓ \( R_{\psi_m}(\Delta S) \) vs \( \sqrt{s_{NN}} \)
Results

✓ $R_{\Psi_m}(\Delta S) \text{ vs } \sqrt{S_{NN}}$

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$

$\tau \propto \frac{1}{\sqrt{S_{NN}}}$

$B \propto \sqrt{S_{NN}}$

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$
Results

✓ $R_{\Psi_m}(\Delta S)$ vs $\sqrt{S_{NN}}$

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$
✓ $R_{\Psi_2}$ width is $\sqrt{S_{NN}}$ independent
Results

- $R_{\Psi_m}(\Delta S)$ vs $\sqrt{S_{NN}}$

Measurements show:
- Different response for $\Psi_2$ and $\Psi_3$
- $R_{\Psi_2}$ width is $\sqrt{S_{NN}}$ independent

- $R_{\Psi_m}$ results are consistent with the expectation for CME-driven charge separation.
Results
✓ $R_{\psi_m}(\Delta S)$ vs centrality (Au+Au)
Results

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (Au+Au)

$Fit(x) = a e^{0.5 \left( \frac{x}{\sigma} \right)^2}$

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$
Results

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (Au+Au)

Fit $(x) = a e^{0.5 \left( \frac{x}{\sigma} \right)^2}$

STAR Preliminary

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$

✓ $R_{\Psi_2}$ width is centrality dependent

All widths are normalized to the width of 0-20% (smallest $a_1$)
Results

✓ $R_{\psi_m}(\Delta S)$ vs centrality (Au+Au)

$Fit(x) = a e^{0.5 \left(\frac{x}{\bar{x}}\right)^2}$

![Graph showing $R_{\psi_m}(\Delta S)$ vs centrality for different Au+Au collisions](image)

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$
✓ $R_{\psi_2}$ width is centrality dependent

All widths are normalized to the width of 0-20% (smallest $a_1$)

✓ $R_{\psi_m}$ results are consistent with the expectation for CME-driven charge separation.
Results

✓ $R_{\psi_m}(\Delta S)$ vs centrality (U+U)
**Results**

- ✔ $R_{\Psi_m}(\Delta S)$ vs centrality (U+U)

$$Fit(x) = a \, e^{0.5 \left( \frac{x}{\sigma} \right)^2}$$

![Graph showing $R_{\Psi_m}(\Delta S)$ vs centrality (U+U) for different centrality ranges: 20-30%, 40-50%, and 60-70%.

- Measurements show:
  - ✔ Different response for $\Psi_2$ and $\Psi_3$
**Results**

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (U+U)

$Fit(x) = a e^{0.5 \left(\frac{x}{\sigma}\right)^2}$

![Graph showing $R_{\Psi_m}(\Delta S)$ vs centrality for different U+U 193 GeV and Cu+Au 200 GeV centrality ranges.](image)

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$

✓ $R_{\Psi_2}$ width is centrality dependent
Results

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (U+U)

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$
✓ $R_{\Psi_2}$ width is centrality dependent

✓ $R_{\Psi_m}$ results are consistent with the expectation for CME-driven charge separation.
Results

✓ $R_{\psi_m}(\Delta S)$ vs centrality (Cu+Au)
Results

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (Cu+Au)

$Fit(x) = a e^{0.5 \left( \frac{x}{\sigma} \right)^2}$

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$
Results

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (Cu+Au)

Fit($x$) = $a e^{0.5 \left( \frac{x}{\sigma} \right)^2}$

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$

✓ $R_{\Psi_2}$ width is centrality dependent
Results

✓ $R_{\Psi_m}(\Delta S)$ vs centrality (Cu+Au)

Measurements show:

✓ Different response for $\Psi_2$ and $\Psi_3$

✓ $R_{\Psi_2}$ width is centrality dependent

✓ $R_{\Psi_m}$ results are consistent with the expectation for CME-driven charge separation.
Conclusion

Charge separation correlators $R_{\psi m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.
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Charge separation correlators $R_{\Psi_m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

- $R_{\Psi_m}$ measurements show:
  - Expected difference in the response for $\Psi_2$ and $\Psi_3$
Conclusion

Charge separation correlators $R_{\Psi_m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

- $R_{\Psi_m}$ 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
Conclusion

Charge separation correlators $R_{\Psi m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

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  Consistent with random $\vec{B}$-field orientations
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Charge separation correlators $R_{\psi_m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

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  - Expected difference in the response for $\Psi_2$ and $\Psi_3$
  - Expected difference in the response for small (p(d)+Au) and large systems
    - Consistent with random $\vec{B}$-field orientations

- $R_{\psi_2}$ width:
  - $R_{\psi_2}(\Delta S')$ width is $\langle p_T \rangle$ independent
    - (Inconsistent with flow-driven background)
Conclusion

Charge separation correlators $R_{\Psi m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

- $R_{\Psi m}$ 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
    - Consistent with random $\vec{B}$-field orientations

- $R_{\Psi 2}$ width:
  - $R_{\Psi 2}(\Delta S')$ width is $\langle p_T \rangle$ independent
    - (Inconsistent with flow-driven background)
  - $R_{\Psi 2}(\Delta S'')$ width is $\sqrt{s_{NN}}$ independent
    - (Consistent with $\vec{B}(\tau) \sqrt{s_{NN}}$ dependence)
Conclusion

Charge separation correlators $R_{\Psi_m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

- $R_{\Psi_m}$ 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
    Consistent with random $\vec{B}$-field orientations

- $R_{\Psi_2}$ width:
  - $R_{\Psi_2}(\Delta S')$ width is $\langle p_T \rangle$ independent
    (Inconsistent with flow-driven background)
  - $R_{\Psi_2}(\Delta S'')$ width is $\sqrt{S_{NN}}$ independent
    (Consistent with $\vec{B}(\tau) \sqrt{S_{NN}}$ dependence)
  - $R_{\Psi_2}(\Delta S''')$ width is decreasing with centrality
    (Consistent with the the $\vec{B}$-field increase with centrality)
Conclusion

Charge separation correlators $R_{\Psi_m}$, are investigated in p(d)+Au, Cu+Au (200 GeV), U+U (193 GeV) and Au+Au collisions (19.6 - 200 GeV) in the STAR experiment.

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  - Expected difference in the response for small (p(d)+Au) and large systems
    Consistent with random $\vec{B}$-field orientations

- $R_{\Psi_2}$ width:
  - $R_{\Psi_2}(\Delta S')$ width is $\langle p_T \rangle$ independent
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  - $R_{\Psi_2}(\Delta S'')$ width is $\sqrt{S_{NN}}$ independent
    (Consistent with $\vec{B}(\tau) \sqrt{S_{NN}}$ dependence)
  - $R_{\Psi_2}(\Delta S'')$ width is decreasing with centrality
    (Consistent with the the $\vec{B}$-field increase with centrality)

- These $R_{\Psi_m}$ results are consistent with the expectation for CME-driven charge separation.
AVFD implies that the use of the $R_{\Psi_m}$ correlators in the isobar data will provide useful information to characterize both signal and background.
THANK YOU