# Electromagnetic field fluctuation and its correlation with the participant plane in Au+Au and isobaric collisions at $\sqrt{s_{NN}}$ = 200 GeV


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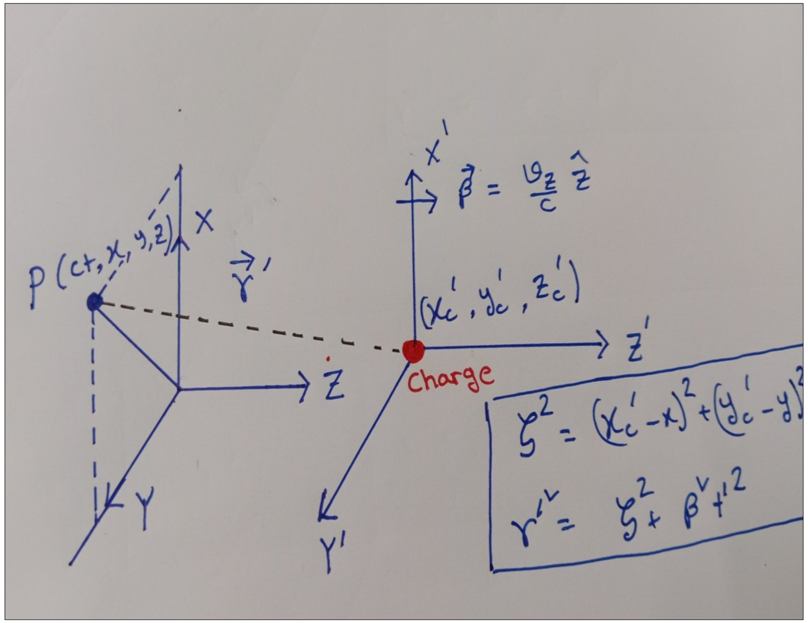
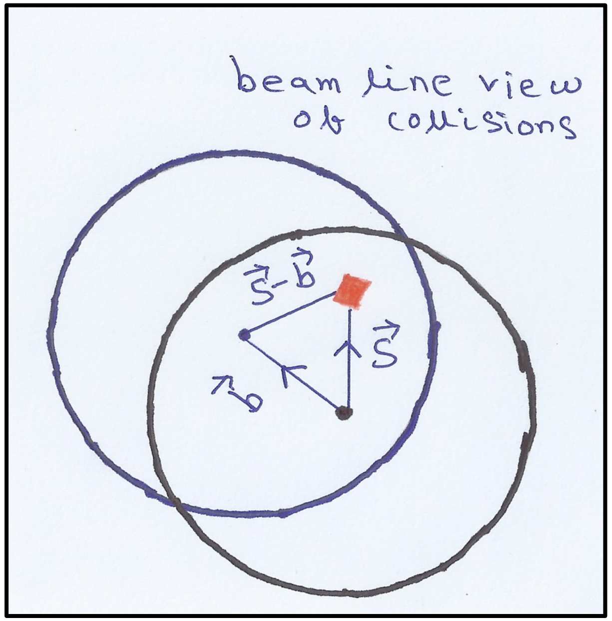
# Outline

- Production of Electric (**E**) and Magnetic (**B**) Fields in Heavy-Ion collisions
- **E.B** correlation with participant plane
- Summary

# Production of Electric (E) and Magnetic (B) Fields in Heavy-Ion collisions




$$\begin{pmatrix} ct' \\ x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \gamma & 0 & 0 & -\gamma\beta \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\gamma\beta & 0 & 0 & \gamma \end{pmatrix} \begin{pmatrix} ct \\ x \\ y \\ z \end{pmatrix}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

**Λ :Transformation matrix**

$$\beta = \frac{v_z}{c} = \sqrt{1 - \left(\frac{2m_p}{\sqrt{s_{NN}}}\right)^2}$$

- **E** and **B** are the elements of a second rank tensor $F^{\alpha\beta}$ = $\begin{pmatrix} 0 & -E_x & -E_y & -E_z \\ E_x & 0 & -B_z & B_y \\ E_y & B_z & 0 & -B_x \\ E_z & -B_y & B_x & 0 \end{pmatrix}$

$$F^{\alpha\beta} = \frac{\partial x^\alpha}{\partial x'^\gamma}\frac{\partial x^\beta}{\partial x'^\delta}F'^{\gamma\delta} \longrightarrow F = \Lambda F' \tilde{\Lambda}$$

$$E_x = \gamma E'_x + \gamma\beta B'_y, \quad (1)$$

$$E_y = \gamma E'_y - \gamma\beta B'_x, \quad (2)$$

$$E_z = E'_z, \quad (3)$$

- We use cutoff value of $\zeta = 0.3$ fm.

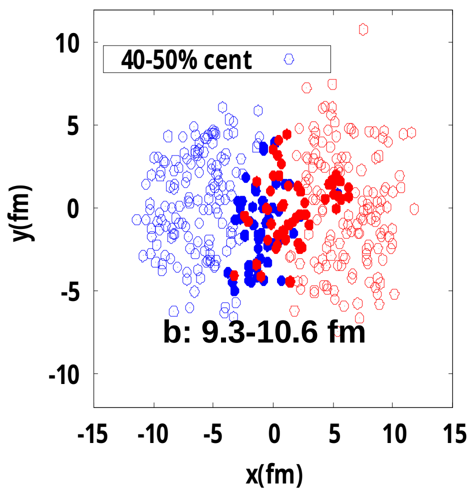
# Production of Electric (E) and Magnetic (B) Fields in Heavy-Ion collisions

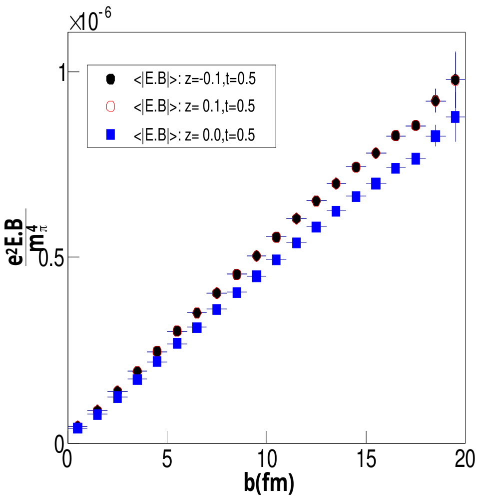
$$
\begin{aligned}
E_x &= \frac{\gamma q x}{\left(\zeta^2 + \beta^2\gamma^2 (t-\beta z)^2\right)^{3/2}}, & (1)\\
E_y &= \frac{\gamma q y}{\left(\zeta^2 + \beta^2\gamma^2 (t-\beta z)^2\right)^{3/2}}, & (2)\\
E_z &= \frac{q\beta\gamma (t-\beta z)}{\left(\zeta^2 + \beta^2\gamma^2 (t-\beta z)^2\right)^{3/2}}, & (3)\\
B_x &= \frac{-\gamma\beta q y}{\left(\zeta^2 + \beta^2\gamma^2 (t-\beta z)^2\right)^{3/2}}, & (4)\\
B_y &= \frac{\gamma\beta q x}{\left(\zeta^2 + \beta^2\gamma^2 (t-\beta z)^2\right)^{3/2}}, & (5)\\
B_z &= 0. & (6)
\end{aligned}
$$

- Monte Carlo Glauber model was used to get the nucleons positions.

$$
\rho(r,\theta) = \frac{\rho_0}{1 + exp\left[\frac{r - R\left(1+\beta_2 Y_2^0(\theta)\right)}{a}\right]}
$$

| Nuclei | R | $\beta_2$ | a |
|---|---|---|---|
| Au | 6.38 | 0 | 0.535 |
| Ru | 5.085 | 0.158 | 0.46 |
| Zr | 5.02 | 0.08 | 0.46 |

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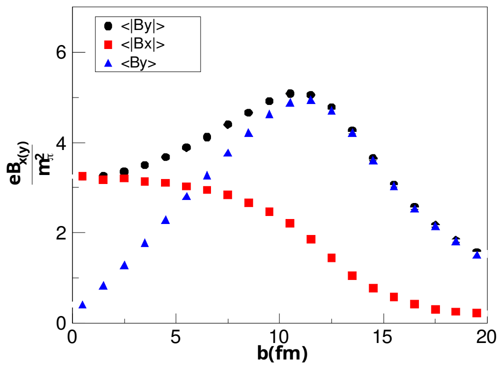
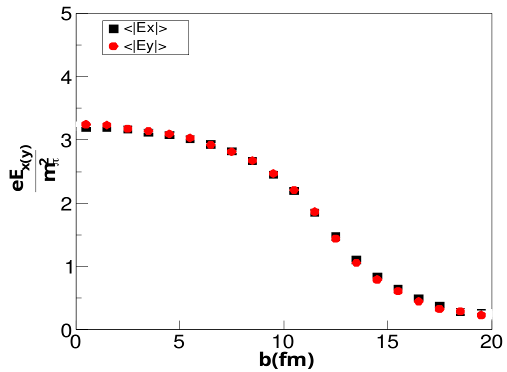
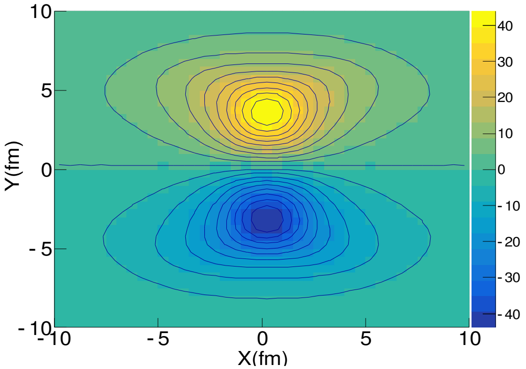
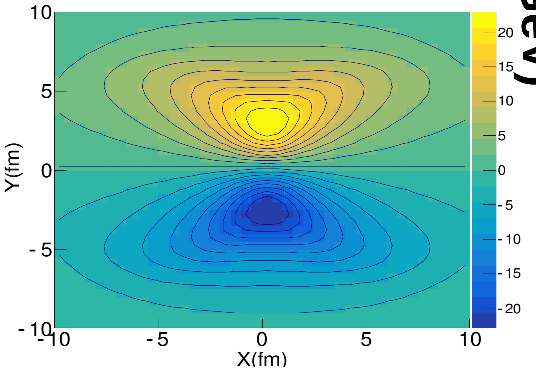
Au+Au (200 GeV)




40-50% Centrality : E.B Plot




70-80% Centrality

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# E.B correlation with participant plane ( Au+Au)

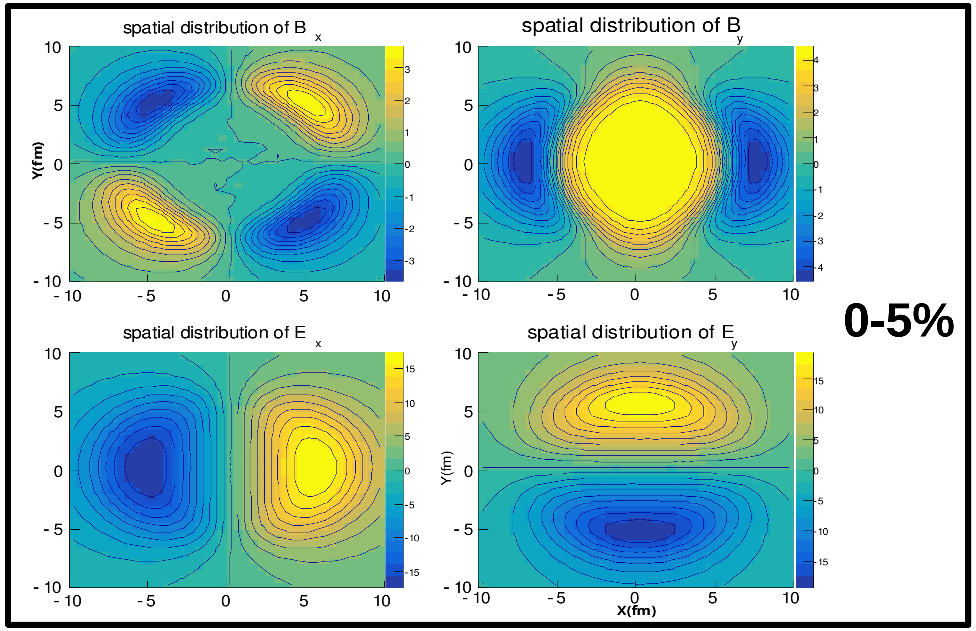
- **E.B** are responsible for the transition of chiral fermions from the left handed chirality branch to the right handed chirality branch at a rate $\sim e^2/(2\pi^2)\mathbf{E}\cdot\mathbf{B}$ .
- The **E.B** symmetry plane is defined as $\psi_{\mathcal{E}}$.

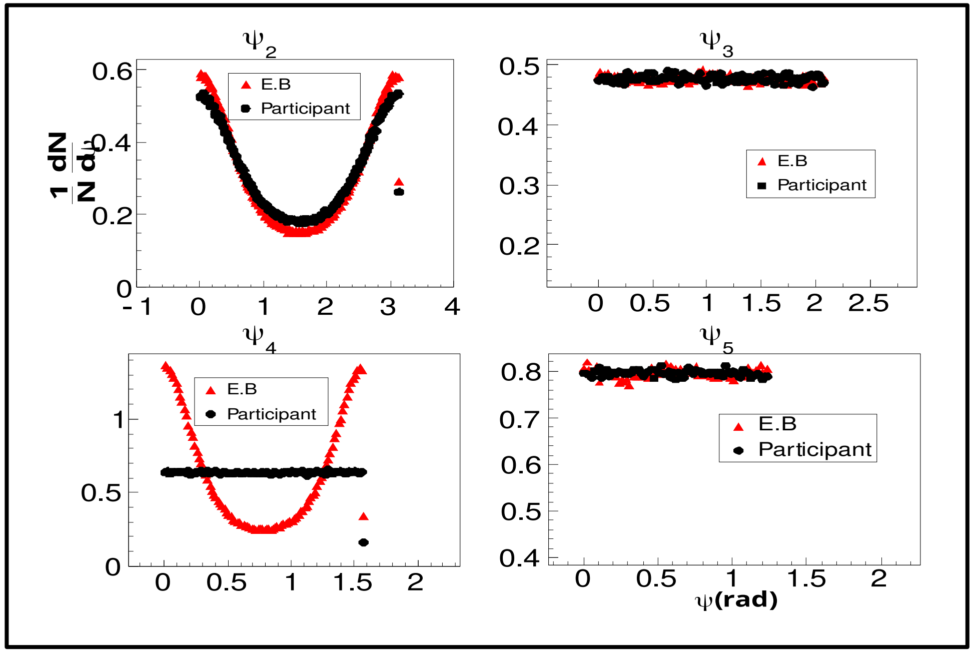
( PRL 103,191601; PRD 78, 074033)

$$\epsilon_n e^{in\psi_{\mathcal{E}}} = -\frac{\int dxdy r^n e^{in\varphi}\mathcal{E}(x,y)}{\int dxdy r^n \mathcal{E}(x,y)}$$

$$\psi_{\mathcal{E}} = \frac{1}{n} arctan \frac{\int dxdy r^n \sin(n\varphi)\mathcal{E}(x,y)}{\int dxdy r^n \cos(n\varphi)\mathcal{E}(x,y)} + \frac{\pi}{n}$$

$$\mathcal{E}(x,y) = \mathbf{E}\cdot\mathbf{B}$$
$$r^2 = (x- < x >)^2 + (y- < y >)^2$$

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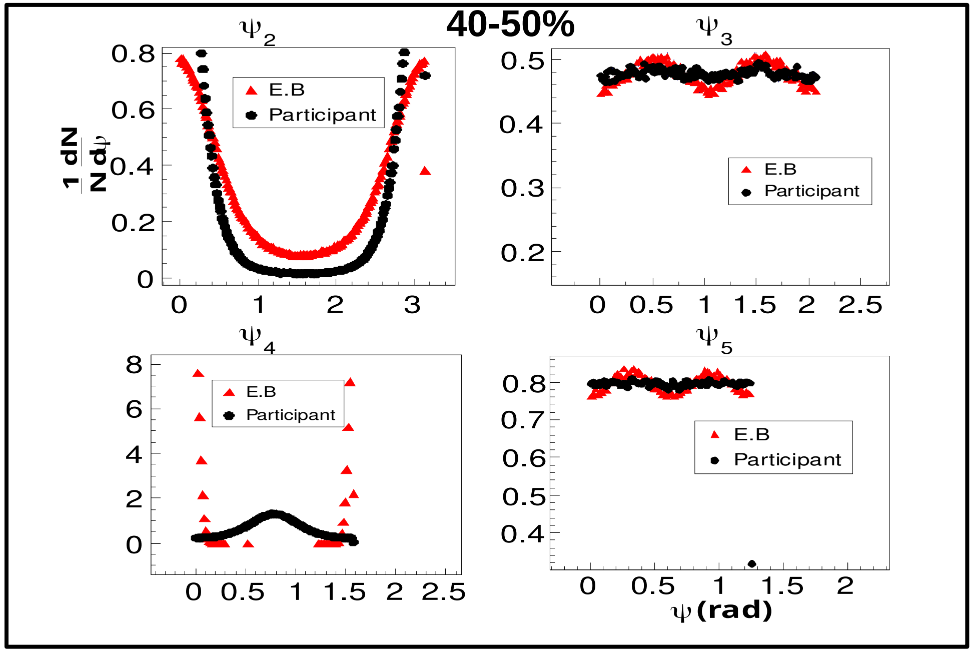
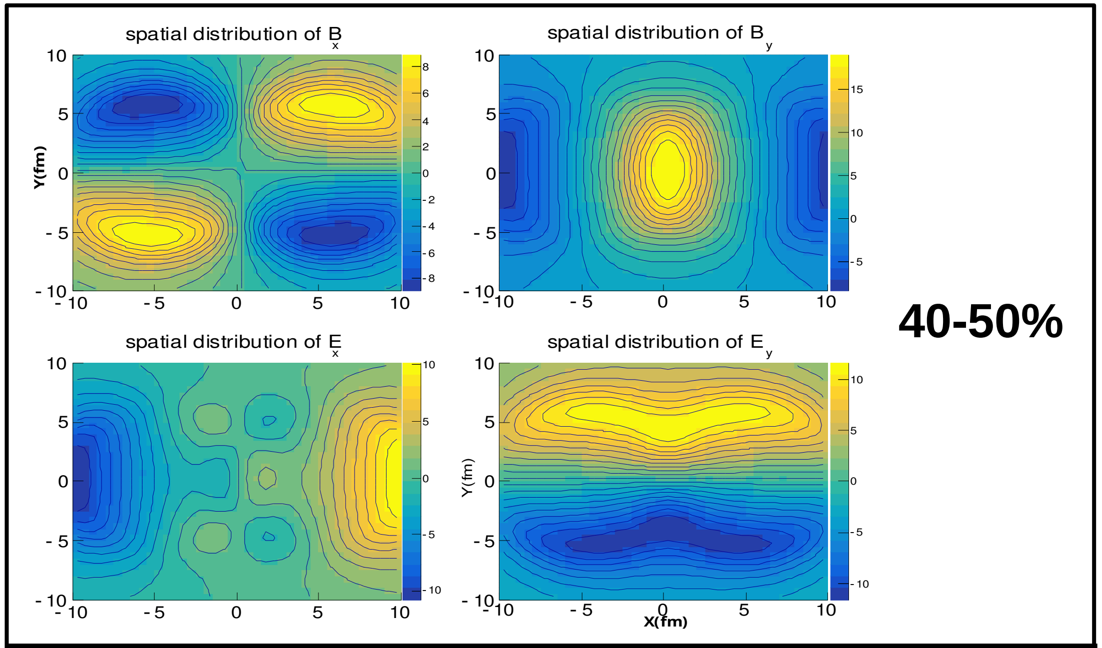
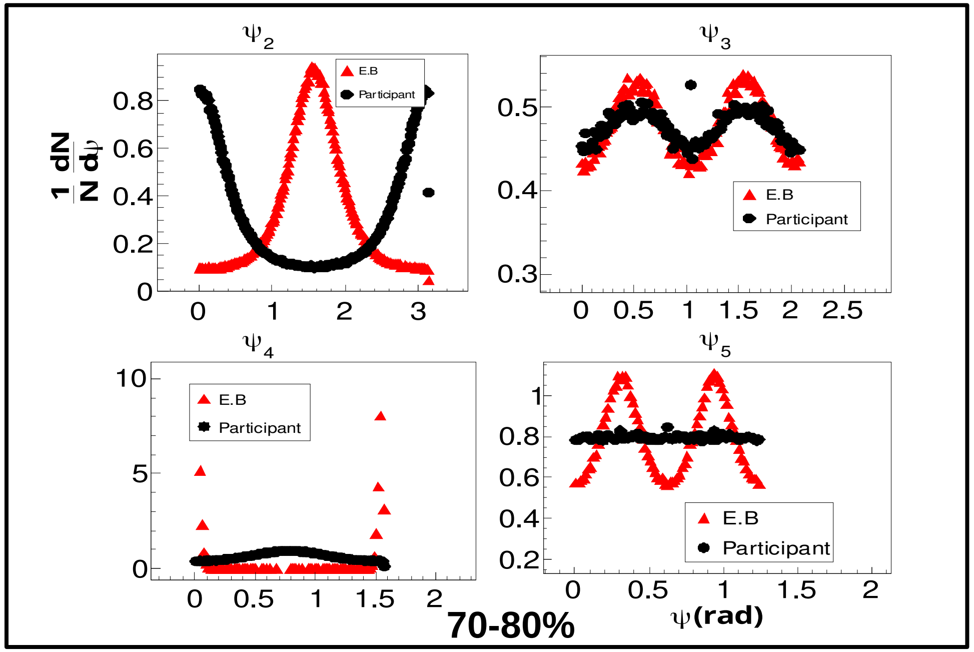
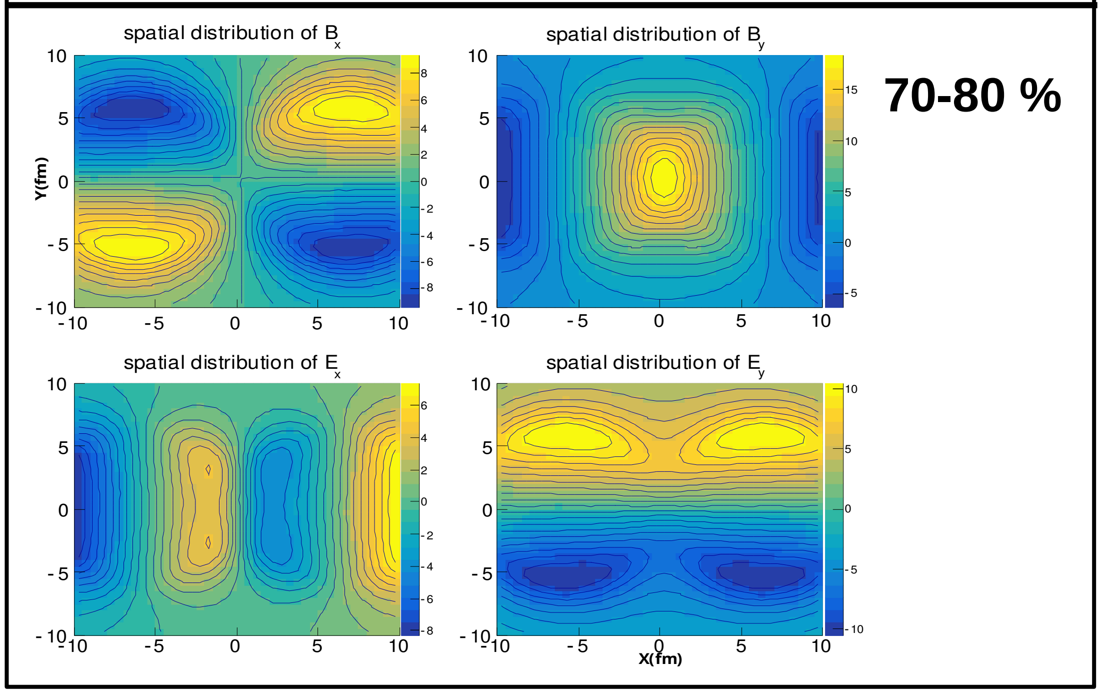
- The broken rotational symmetry of the collision zone is reflected in $\psi_p^2$ for 0-5% centrality.

# E.B correlation with participant plane (Au+Au)



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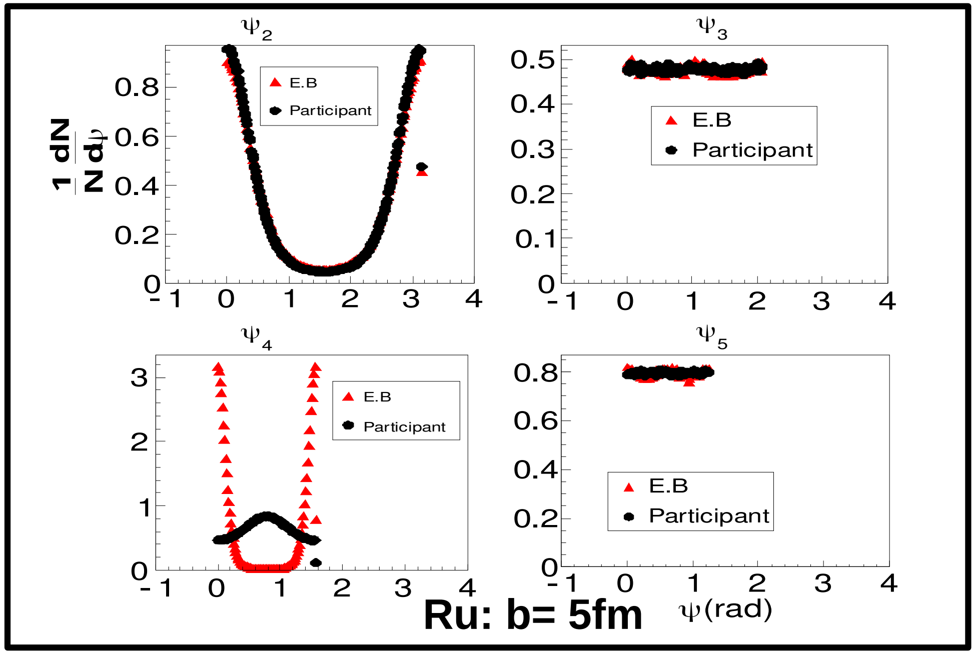
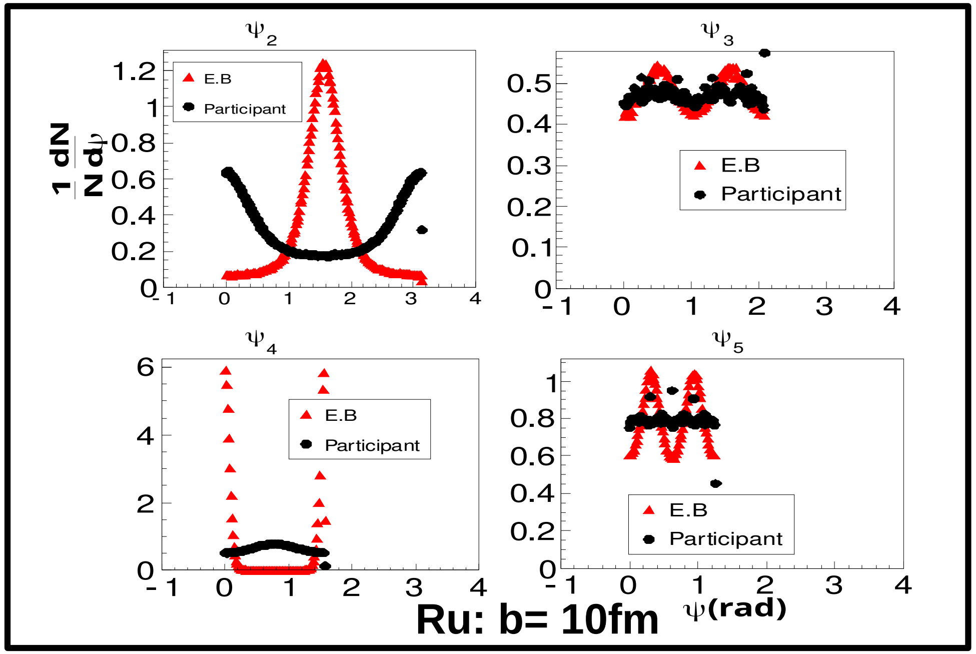
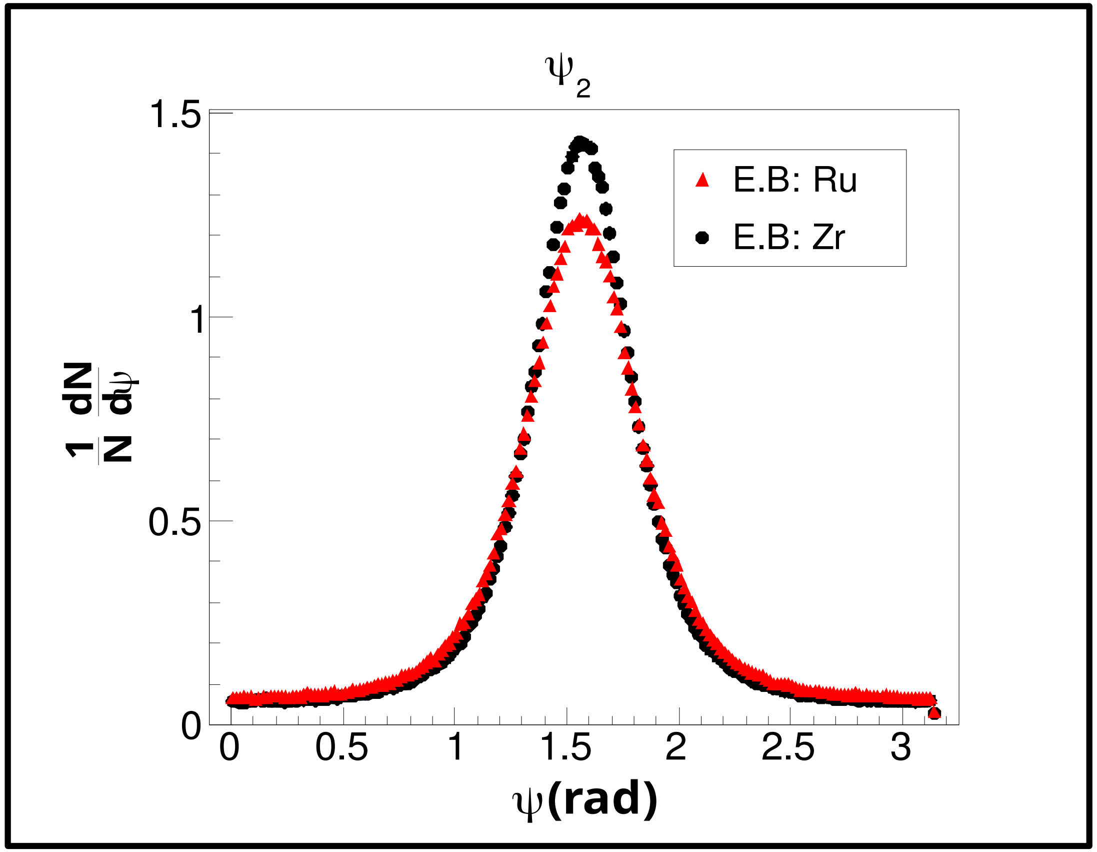
# E.B correlation with participant plane (Au+Au)

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- Distribution of the second order plane for Ru+Ru Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV for b = 10 fm.

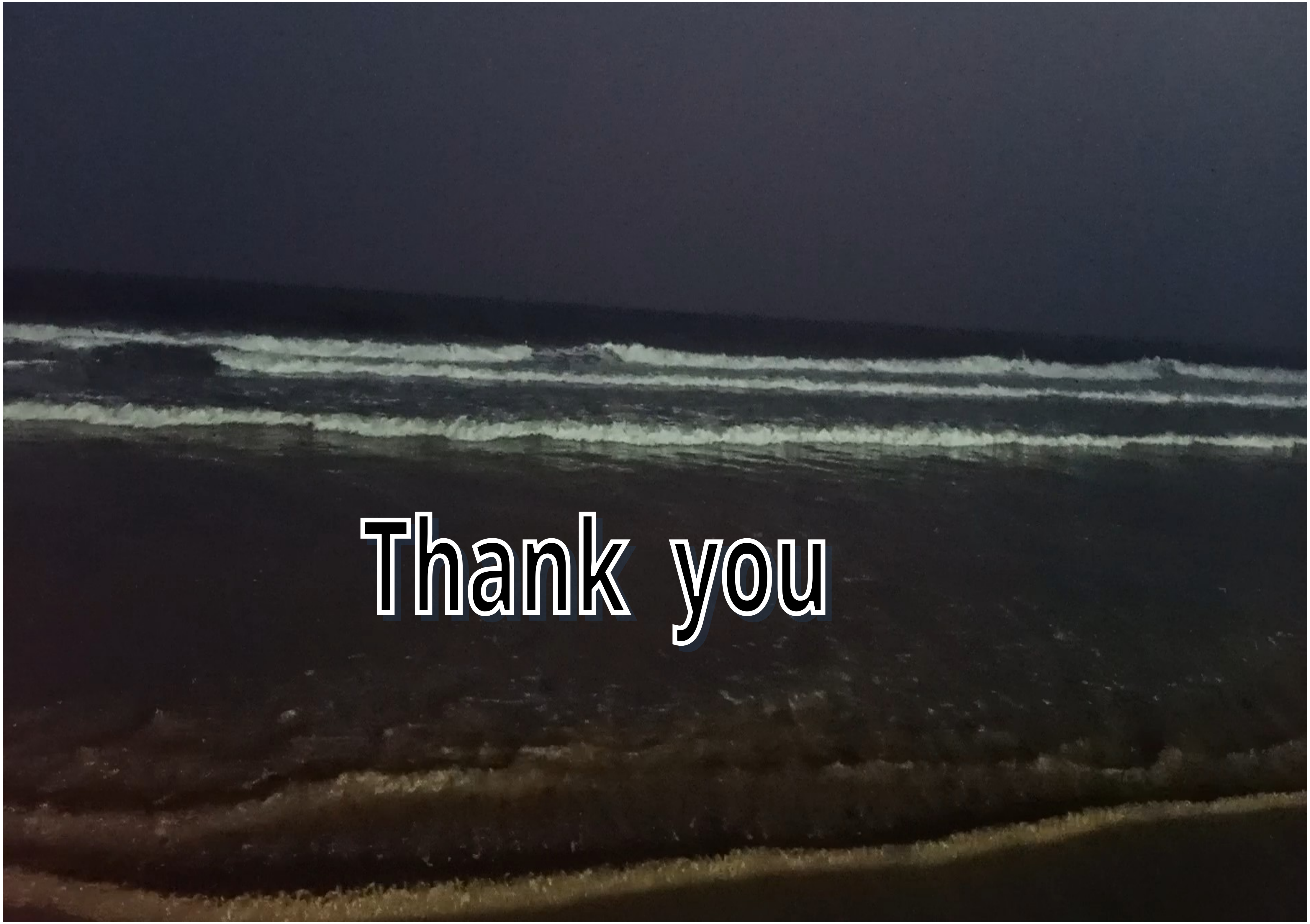
# Summary

- We study the event-by-event fluctuations of the electric and the magnetic fields and their possible correlation with the geometry of the high-energy heavy-ion collisions.

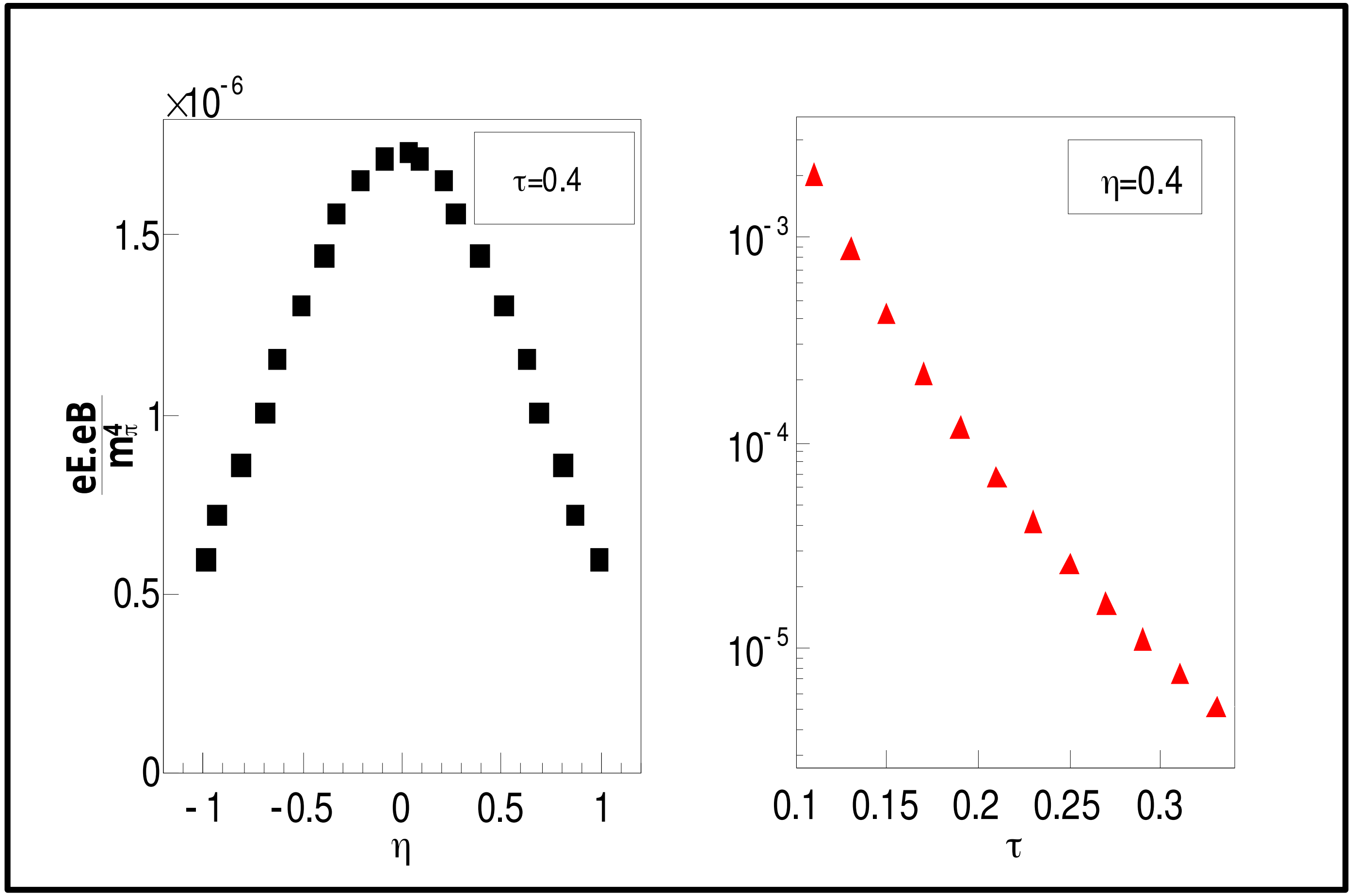
- We investigated the centrality (impact parameter) dependence of the symmetry plane angle $\psi_{\mathcal{E}}$ and its possible correlation with the participant plane.

- We show that $\psi_{\mathcal{E}}$ is strongly correlated with $\psi_p$ for third and fifth order harmonics for Au+Au, Ru+Ru, and Zr+Zr collisions.

- The second-order planes $\psi_{\mathcal{E}}$ and $\psi_p$ mostly coincide with each other except for the peripheral collisions, where a rotation by π/2 is observed for $\psi_{\mathcal{E}}$ irrespective of the collision system size.


Thank you

# Backup



×10⁻⁶
τ=0.4
1.5
1
0.5
0
eE.eB / m_π^4
- 1
-0.5
0
0.5
1
η
η=0.4
10⁻³
10⁻⁴
10⁻⁵
0.1
0.15
0.2
0.25
0.3
τ