QCD@Work

International Workshop on QCD
Theory and Experiment

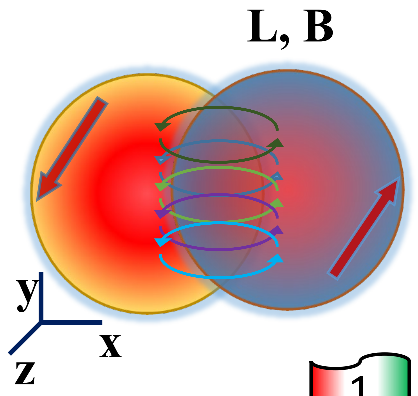
The effect of electric and chiral magnetic conductivities on azimuthally fluctuating electromagnetic fields and observables in isobar collisions.

Name: Irfan Siddique

E-mail: irfansiddique@ucas.ac.cn

Date: 20th-June-2024

中国科学院大学
University of Chinese Academy of Sciences

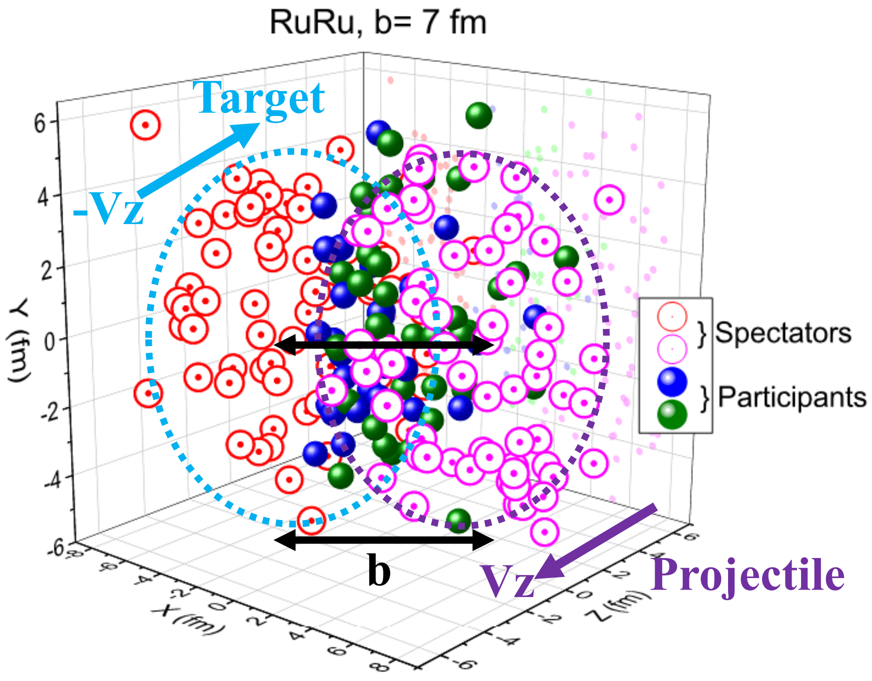


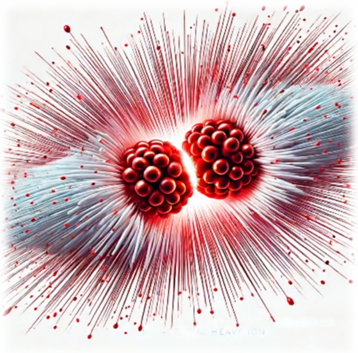
Outline

- Introduction & Motivation
- EM fields with and without medium feedback
- Numerical Results
- Summary

SIDDIQUE IRFAN. DOI: 10.1103/PhysRevC.109.034905 (2024)

Magnetic field in HICs





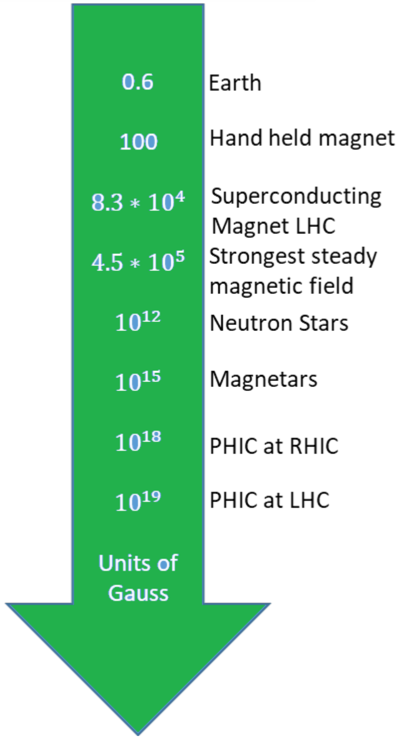
Extremely Strong magnetic fields

x-axis impact parameter
z-axis beam direction

B Fields perpendicular to reaction plane

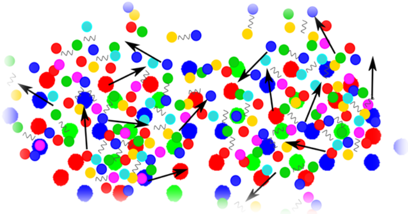
- Influencing the dynamics of QGP
- CME etc

- Time evolution and spatial distribution etc.



- ❖ W.-T. Deng and X.-G. Huang, Phys. Rev. C 85, 044907 (2012), 1201.5108.
- ❖ J. Bloczynski, X.-G. Huang, X. Zhang, and J. Liao, Phys. Lett. B 718, 1529 (2013), 1209.6594.
- ❖ K. Hattori and X.-G. Huang, Nucl. Sci. Tech. 28, 26 (2017), 1609.00747.
- ❖ K. Tuchin, Phys. Rev. C 88, 024911 (2013), 1305.5806.

Electromagnetic Fields in HICs



QGP

- **Without medium feedback:**
  - Use of Event generator/ transport model
  - Use Lienard-Wiechert potential

$$\boldsymbol{E} = \frac{e}{4\pi}\sum_n \frac{(1-v_n^2)\boldsymbol{R}_n}{(\boldsymbol{R}_n^2 - (\boldsymbol{R}_n \times \boldsymbol{v}_n)^2)^{3/2}}$$

$$\boldsymbol{B} = \frac{e}{4\pi}\sum_n \frac{(1-v_n^2)(\boldsymbol{v}_n \times \boldsymbol{R}_n)}{(\boldsymbol{R}_n^2 - (\boldsymbol{R}_n \times \boldsymbol{v}_n)^2)^{3/2}}$$

Here $\boldsymbol{R}_n = \boldsymbol{x} - \boldsymbol{x}_n$ is the relative position vector between the field point $\boldsymbol{x}$ and the source point $\boldsymbol{x}_n$

- Over estimate or underestimate

- W.-T. Deng and X.-G. Huang, Phys. Rev. C 85, 044907 (2012), 1201.5108.
- J. Bloczynski, X.-G. Huang, X. Zhang, and J. Liao, Phys. Lett. B 718, 1529 (2013).
- K. Hattori and X.-G. Huang, Nucl. Sci. Tech. 28, 26 (2017), 1609.00747.
- K. Tuchin, Phys. Rev. C 88, 024911 (2013), 1305.5806.
- LI H, Li Sheng X, Wang Q. DOI:10.1103/physrevc.94.044903
- **Irfan Siddique** et. al Phys. Rev. C 105, 054909 (2022)
- **Irfan Siddique** et. al., Phys. Rev. C 104, 034907(2021)

$$\therefore \Gamma(a,z) = \int_z^\infty dt\, t^{a-1} exp(-t)$$

- **With medium feedback (σ & σ_χ):**

$$\boldsymbol{\nabla}\cdot\boldsymbol{B} = 0$$

$$\boldsymbol{\nabla}\cdot\boldsymbol{E} = \rho/\epsilon$$

$$\boldsymbol{\nabla}\times\boldsymbol{E} = -\partial_t\boldsymbol{B}$$

$$\boldsymbol{\nabla}\times\boldsymbol{B} = \partial_t\boldsymbol{E} + \boldsymbol{j}_{ext} + \sigma\boldsymbol{E} + \sigma_\chi\boldsymbol{B}$$

Maxwell Eqs.

Finite conductivities

$$B_\phi = \frac{Q}{4\pi}\frac{v\gamma x_T}{\Delta^{3/2}}\left(1+\frac{\sigma v\gamma}{2}\sqrt{\Delta}\right)e^A$$

$$B_r = -\sigma_\chi\frac{Q}{8\pi}\frac{v\gamma^2 x_T}{\Delta^{3/2}}\left(\gamma(vt-z)+A\sqrt{\Delta}\right)e^A$$

$$B_z = \sigma_\chi\frac{Q}{8\pi}\frac{v\gamma}{\Delta^{3/2}}e^A\left[\Delta\left(1-\frac{\sigma v\gamma}{2}\sqrt{\Delta}\right)+\gamma^2(vt-z)^2\left(1+\frac{\sigma v\gamma}{2}\sqrt{\Delta}\right)\right]$$

$$E_\phi = \sigma_\chi\frac{Q}{8\pi}\frac{v^2\gamma^2 x_T}{\Delta^{3/2}}\left(\gamma(vt-z)+A\sqrt{\Delta}\right)e^A$$

$$E_r = \frac{Q}{4\pi}\left[\frac{v x_T}{\Delta^{3/2}}\left(1+\frac{\sigma v\gamma}{2}\sqrt{\Delta}\right)-\frac{\sigma}{v x_T}\left(1+\frac{v\gamma(t-z/v)}{\sqrt{\Delta}}\right)e^{-\sigma(t-z/v)}\right]e^A$$

$$E_z = \frac{Q}{4\pi}\left\{-\frac{1}{\Delta^{3/2}}\left[v\gamma\left(t-\frac{z}{v}\right)+A\sqrt{\Delta}+\frac{\sigma\gamma}{v}\right]e^A+\frac{\sigma^2}{v^2}e^{-\sigma\left(t-\frac{z}{v}\right)}\Gamma(0,-A)\right\}$$

Isobar collisions ($Ru^{96}_{44} + Ru^{96}_{44}$ & $Zr^{96}_{40} + Zr^{96}_{40}$)

The difference in number of protons can generate different magnitudes of electromagnetic fields and related induced effects, but the same mass number in two isobar systems can generate the same background effect .

Woods-Saxon distribution for Ru and Zr

$$\rho = \frac{\rho_0}{1 + exp\left[\frac{r - R(1 + \beta_2 Y_{20} + \beta_4 Y_{40})}{a}\right]}$$

β_i deformation parameter

$Y_i(\theta)$ spherical harmonic functions

f surface thickness parameter

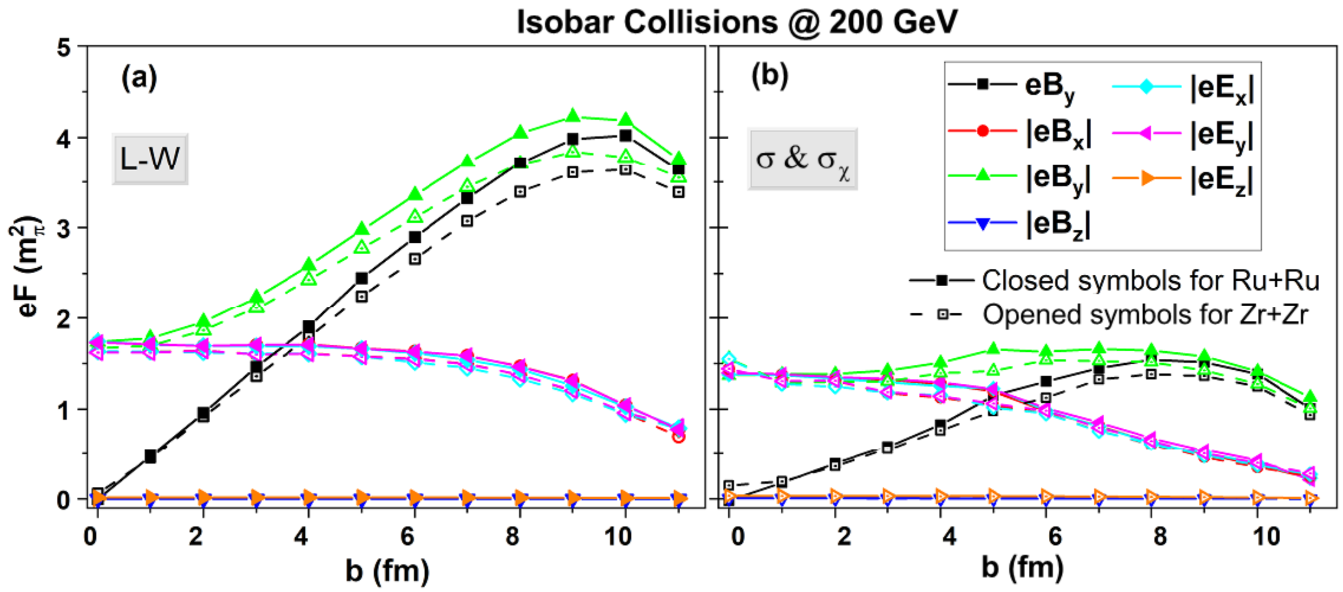
Deformed Nuclei Case			
	R_0	a	β_2
Ru	5.085	0.46	0.158
Zr	5.020	0.46	0.08
Halotype Nuclei Case			
Ru, n	5.085	0.523	0
Ru, p	5.085	0.523	0
Zr, n	5.021	0.592	0
Zr, p	5.021	0.523	0

Woods-Saxon parameters for Ru and Zr

MCGlauber model

- B. Pritychenko, M. Birch, B. Singh, and M. Horoi, arXiv:1312.5975.
- Q. Y. Shou *et al.*, arXiv:1409.8375.
- H.-j. Xu, H. Li, X. Wang, C. Shen, and F. Wang, arXiv:2103.05595.
- X.-L. Zhao and G.-L. Ma, arXiv:2203.15214

Impact parameter dependence



Compared at $t = t_Q$ (peak value time)

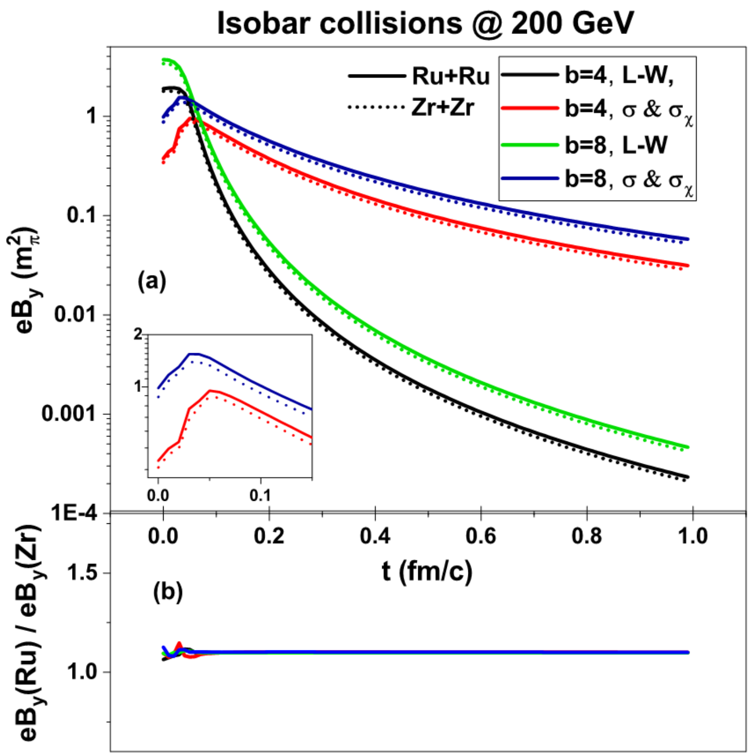
$\sigma = 5.8$ MeV
$\sigma_\chi = 1.5$ MeV

$$e\mathbf{F}_{Au} > e\mathbf{F}_{Ru} > e\mathbf{F}_{Zr}$$

$$|eB_x| \approx |eE_x| \approx |eE_y|$$

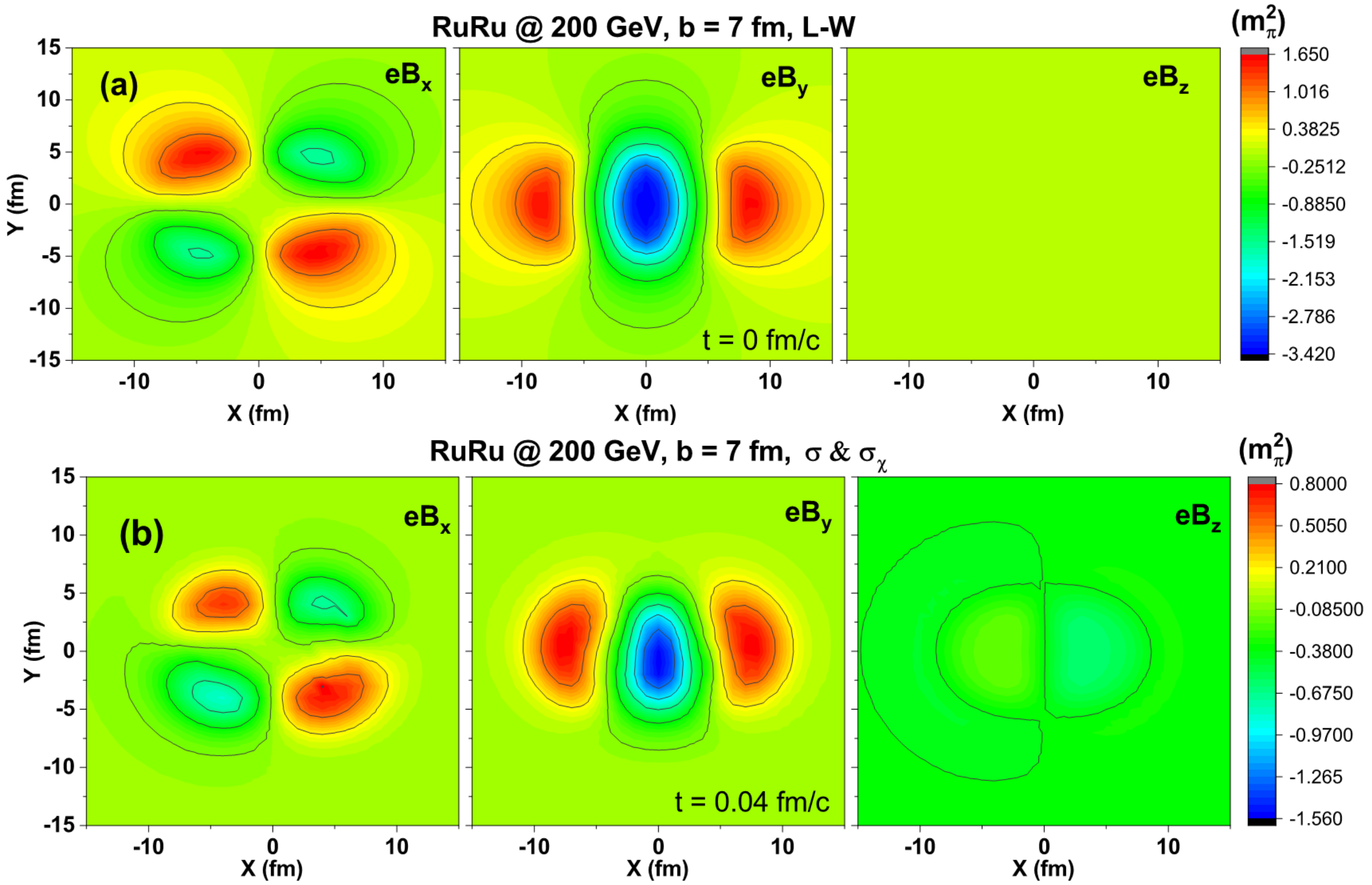
$$eF_z \ll eF_{x,y} \sim 0$$

Time-Evolution



- Damps slower
- Ratio ~ 10%

Spatial Distribution



- Inhomogeneous
- L-W symmetrical
- With σ & σ_χ partially symmetric

- Asymmetry due to non vanishing radial component in the presence of σ_χ.

Effects on correlation

According to the expectations from CME, the difference between the correlation of opposite charge pairs and same charge pairs is expected to be directly proportional to the strength of the squared magnetic field and $\cos 2(\Psi_B - \Psi_2)$,

$$\Delta\gamma = \gamma_{opposite} - \gamma_{same} \propto (\mathrm{eB})^2 \cos 2(\Psi_B - \Psi_2)$$

Quantitative contribution to B-induced effect

Where Ψ_B represents the azimuthal angle of the magnetic field and Ψ_2 represents the second harmonic participant plane

$$\Psi_n = \frac{\mathrm{atan2}\left(\langle r_p^2 \sin(n\phi_p)\rangle, \langle r_p^2 \cos(n\phi_p)\rangle + \pi\right)}{n}$$

$$X_c = 2\frac{c^{Ru} - c^{Zr}}{c^{Ru} + c^{Zr}}$$, Relative Ratios

For similarity or dissimilarity

- J. Bloczynski, X.-G. Huang, X. Zhang, and J. Liao, Phys. Lett. B **718**, 1529 (2013), arXiv:1209.6594.
- J. Bloczynski, X.-G. Huang, X. Zhang, and J. Liao, Nucl. Phys. A **939**, 85 (2015), arXiv:1311.5451.
- S. Chatterjee and P. Tribedy, Phys. Rev. C **92**, 011902 (2015), arXiv:1412.5103.
- X.-L. Zhao, G.-L. Ma, and Y.-G. Ma, Phys. Rev. C **99**, 034903 (2019), arXiv:1901.04151.

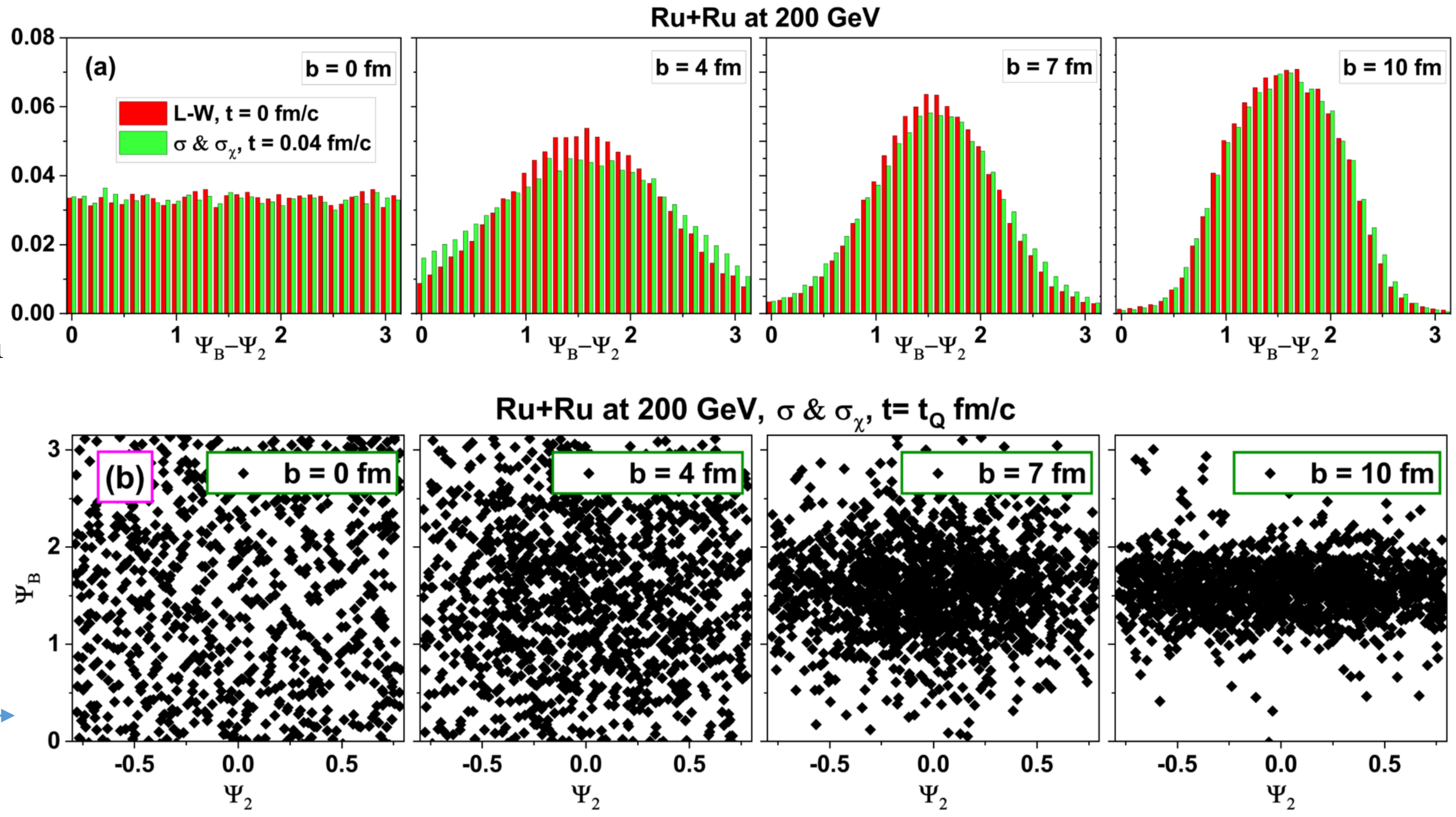
Correlations between magnetic field and participant plane

Histogram $\Psi_B - \Psi_2$

b = 0 fm ✗ no correlation

b > 0 fm ✓ correlation

2D distribution plot for Ψ_B and Ψ_2

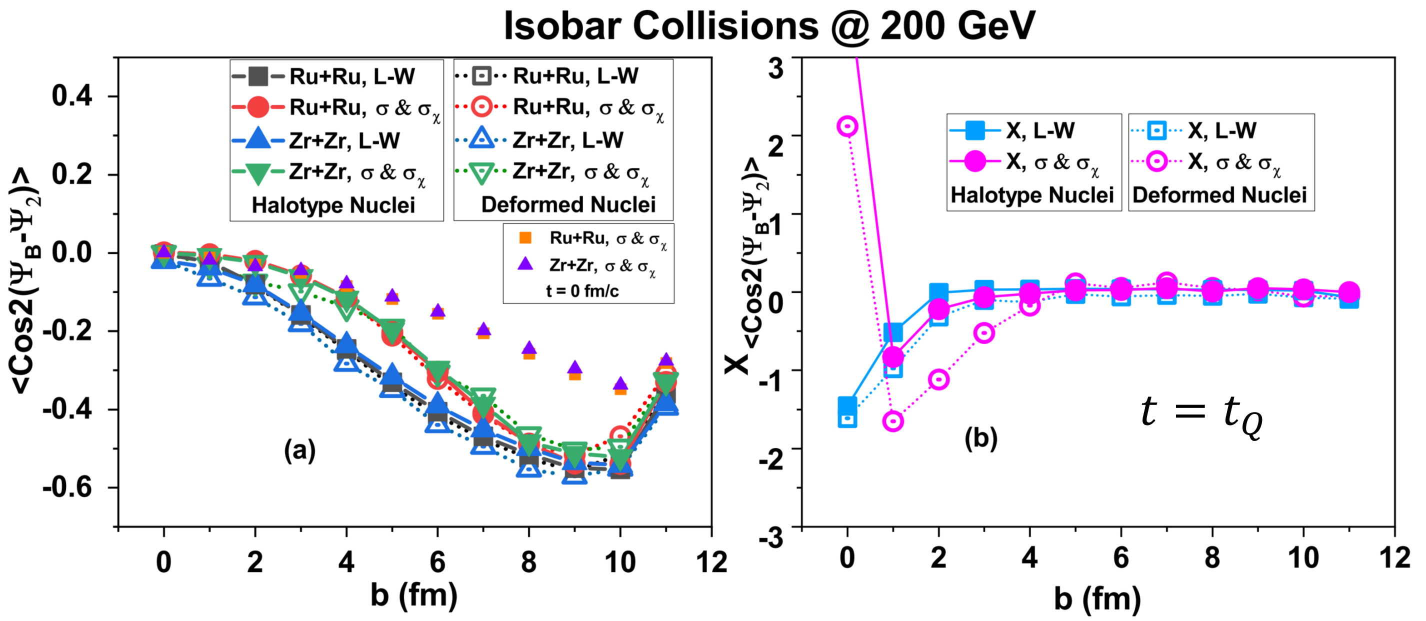


- Fluctuates strongly in azimuthal direction
- b > 0 fm the concentration of distributions at $(\Psi_B, \Psi_2) = (\pi/2, 0)$ indicating correlation

Correlations

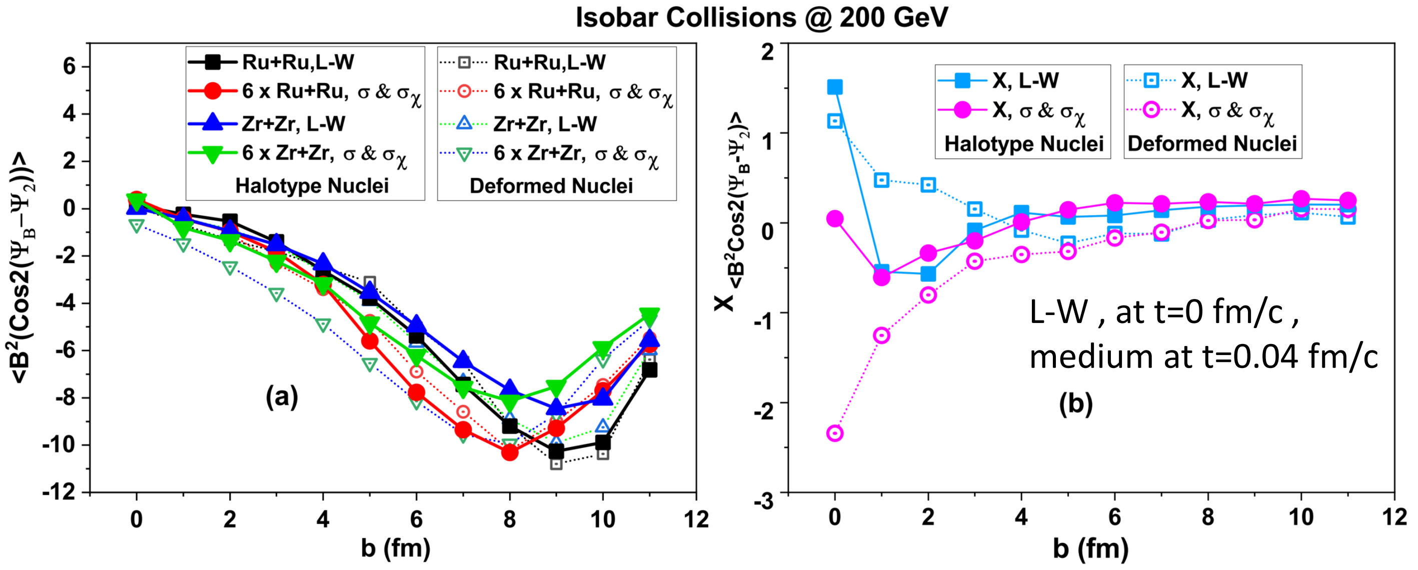
1. $\cos 2(\Psi_B - \Psi_2)$

Correlation for azimuthal Fluctuations of magnetic field



2. $(\mathrm{eB})^2\cos 2(\Psi_B - \Psi_2)$

Inherits influence from both strength of magnetic field and $\cos 2(\Psi_B - \Psi_2)$



3. $\left\langle (\mathbf{eB})^2 \cos 2(\Psi_B - \Psi_2) \right\rangle_t$

$$\langle \mathbf{G} \rangle_t(x) \equiv \frac{\int \mathbf{G}(t,x)\, dt}{\int dt} \qquad \therefore\ \mathbf{G} \equiv (\mathbf{eF})^2 \cos 2(\Psi_F - \Psi_2)$$

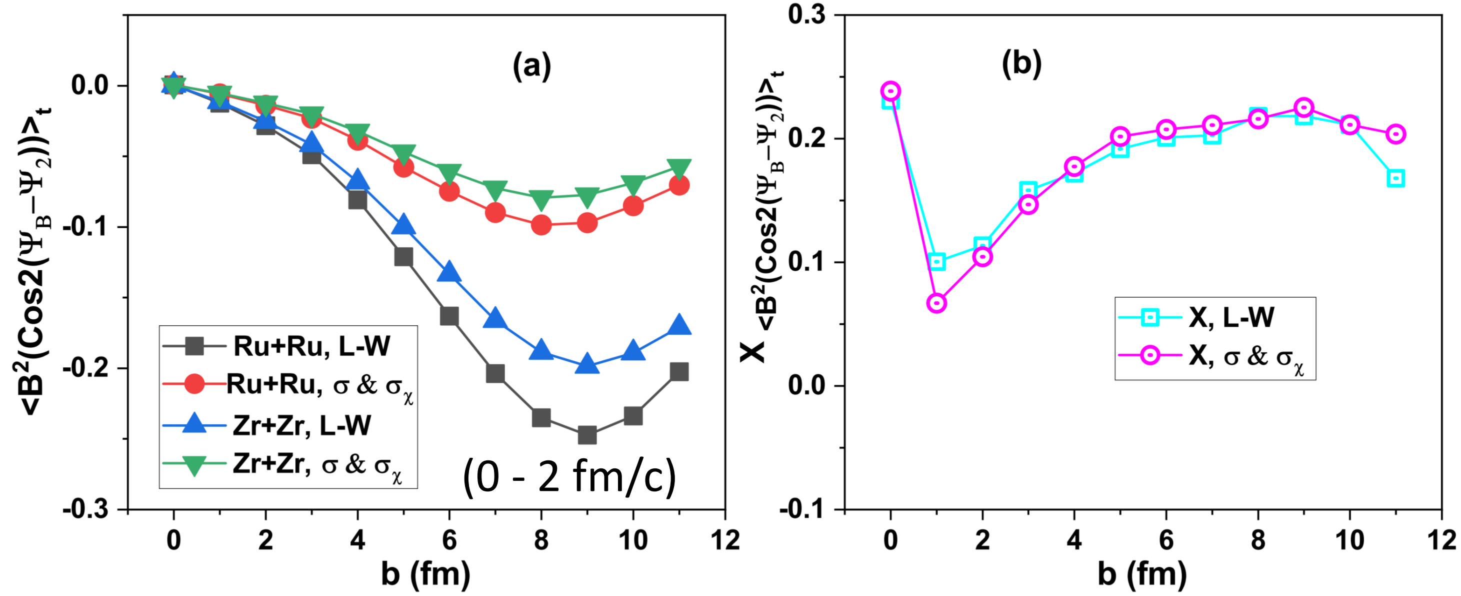
F is **B** or **E**

Time-averaged correlation

EM fields behavior varies with respect to both time and space, so their impact on physical observables should be at average level in lifespan of quark and nuclear matter. To quantify the average effects of correlators on physical observables time-averaged correlation can be defined

$$\langle \mathbf{G} \rangle_t(x) \equiv \frac{\sum_i \ \mathbf{G}(t_i, x)\, \Delta t_i}{\sum_i \ \Delta t_i}$$

Isobar Collisions @ 200 GeV



Summary

Effects of the electric (σ) and chiral magnetic (σ) conductivities on the space and time evolution of the electromagnetic fields.

Partially asymmetric spatial distribution as compared to zero-conductivity system.

Decay in the presence of conductivities is much slower as compared to zero conductivity system.

Studied effect on magnetic field related correlations which reflect the importance of taking into account medium feedback.