

# Electromagnetic field from asymmetric to symmetric heavy ion collision at 200 GeV/c

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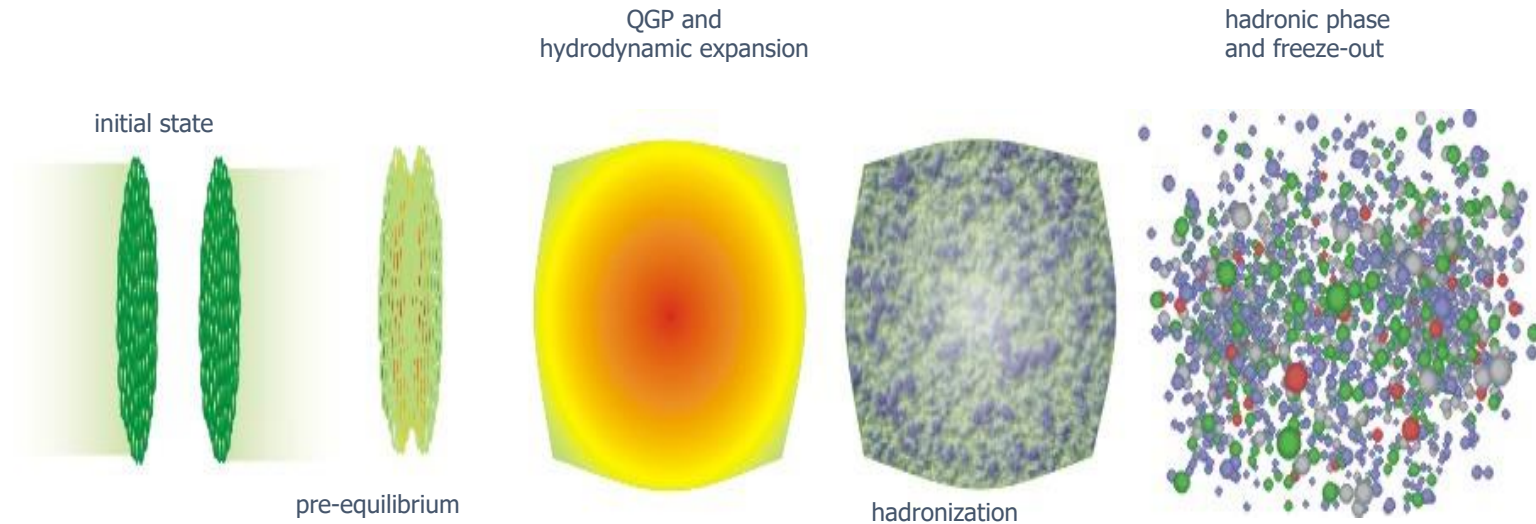
collaborator: Yu Gang Ma

Song Zhang

# Outline

- ◆ Introduction
- ◆ Methodology
- ◆ Results and Discussion
- ◆ Summary & Outlook

# Introduction



## Physics:

- 1) Parton distributions in nuclei
- 2) Initial conditions of the collision
- 3) a new state of matter – Quark-Gluon Plasma and its properties
- 4) hadronization
- 5) hadronic rescattering

# Chiral Magnetic Effect(CME)

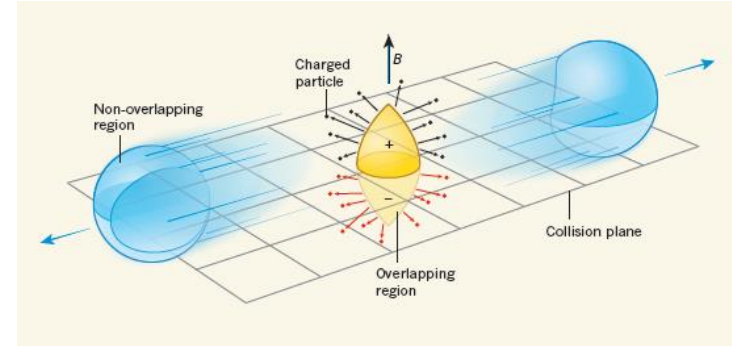
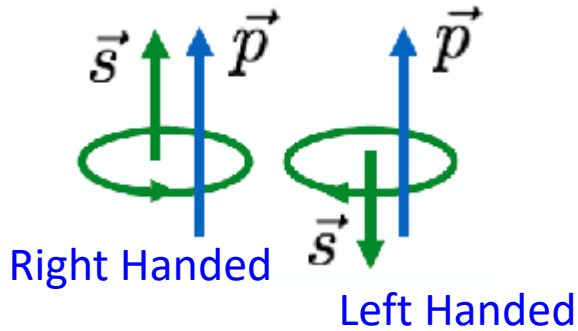
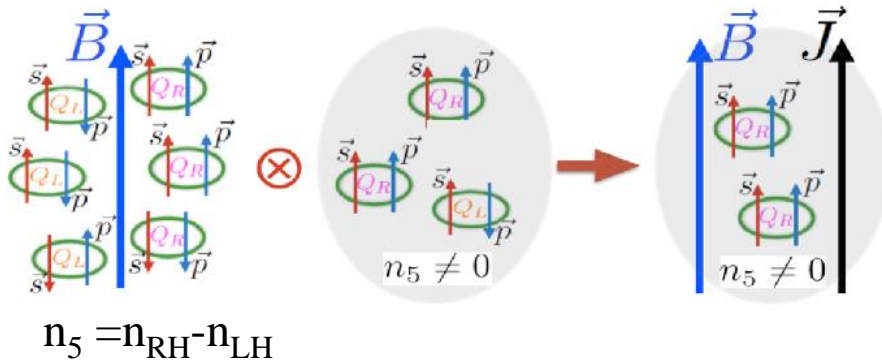


Fig.1 The chiral magnetic effect  
doi:10.1038/nature23086

Au+Au, sqrt(s)=200 GeV=> 10<sup>18</sup> Gauss  
( PRC,84,064605,2011)

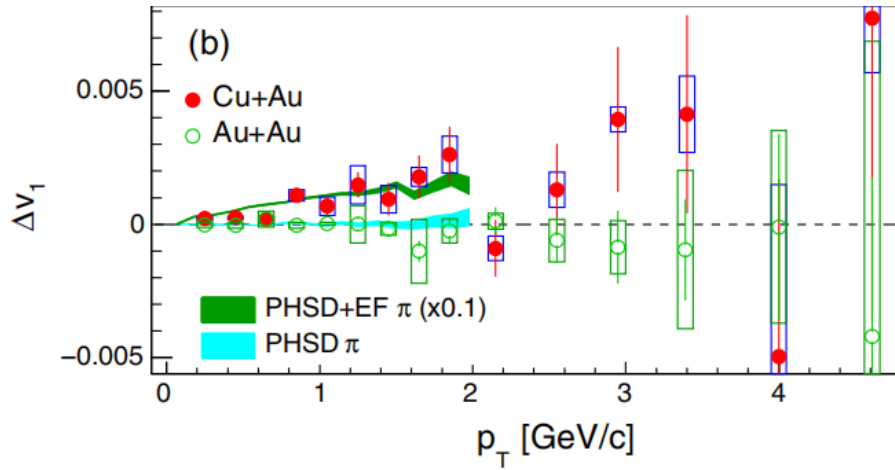


Intuitive understanding of CME(from Liao J.F.)

$$\vec{J} = \sigma_5 \mu_5 \vec{B}$$

→ reflect the local parity and charge-parity violation

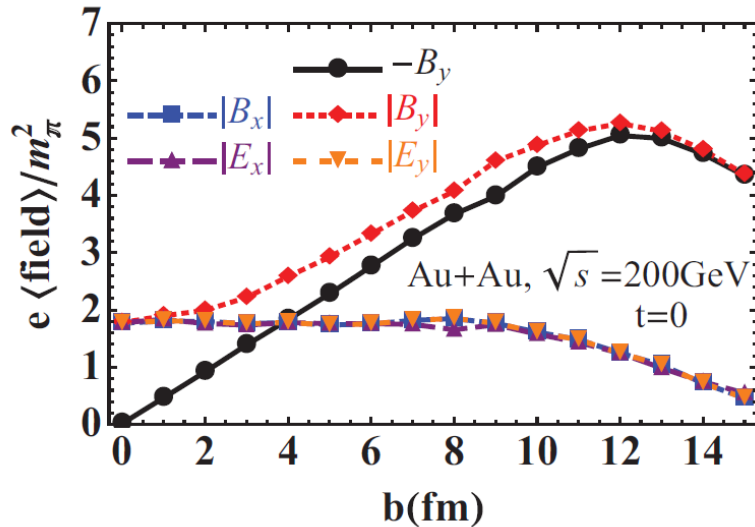
# results of STAR and theoretical calculation



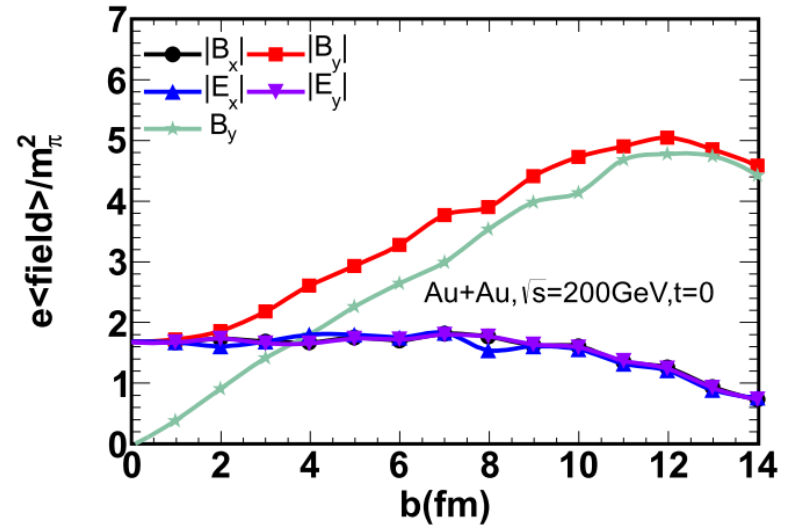
*PRL 118, 012301 (2017),  
STAR collaboration*

$$e\vec{E}(\vec{r}_i, t) = \frac{e^2}{4\pi} \sum_n Z_n \frac{1 - v_n^2}{(R_n - \vec{R}_n \cdot \vec{v}_n)^3} (\vec{R}_n - R_n \vec{v}_n)$$

$$e\vec{B}(\vec{r}_i, t) = \frac{e^2}{4\pi} \sum_n Z_n \frac{1 - v_n^2}{(R_n - \vec{R}_n \cdot \vec{v}_n)^3} \vec{v}_n \times \vec{R}_n$$



*Deng, Huang, (PRC) 85, 044907 (2012)*



*Zhao, (PRC) 97, 024910 (2018)*

# Methodology

## Li' enard-Wiechert potentials

Huang,(PRC) 85, 044907 (2012)

$$e\vec{E}(\vec{r}_i,t) = \frac{e^2}{4\pi} \sum_n Z_n \frac{1 - v_n^2}{(R_n - \vec{R}_n \cdot \vec{v}_n)^3} (\vec{R}_n - R_n \vec{v}_n)$$

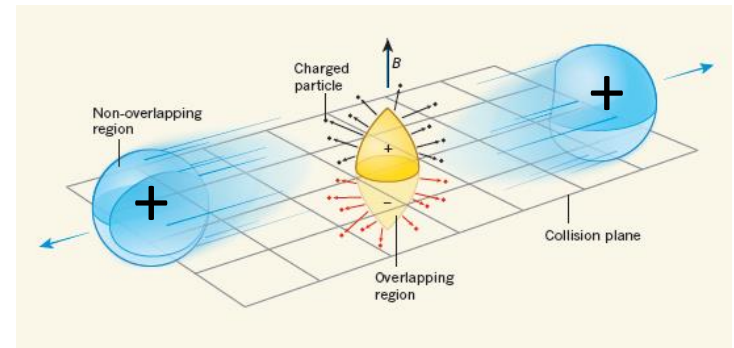
$$e\vec{B}(\vec{r}_i,t) = \frac{e^2}{4\pi} \sum_n Z_n \frac{1 - v_n^2}{(R_n - \vec{R}_n \cdot \vec{v}_n)^3} \vec{v}_n \times \vec{R}_n$$

$Z_n$  : charge number

$R_n = r - r_n$  :  $r$  is the position of field point

$r_n$  is the position of the n-th particle at the retarded time  $t_n = t - |r - r_n|$  and  $t_n < t$

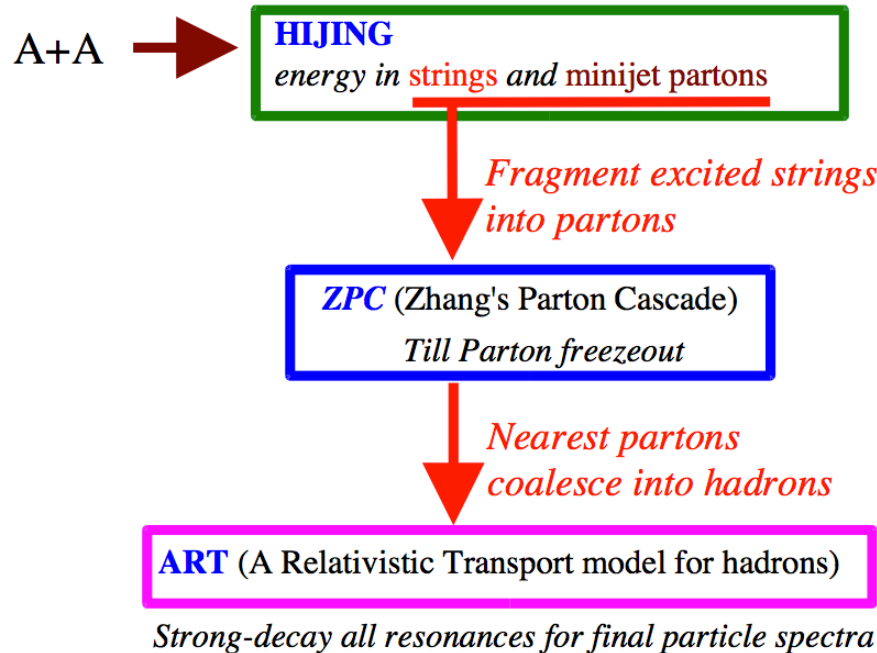
$$v_x = v_y = 0, v_z^2 = 1 - (2m_N / \sqrt{s})^2 \quad (\text{the Lorentz contraction is considered})$$



# AMPT model

Lin, (PRC) 72, 064901 (2005)

## Structure of AMPT model with String Melting

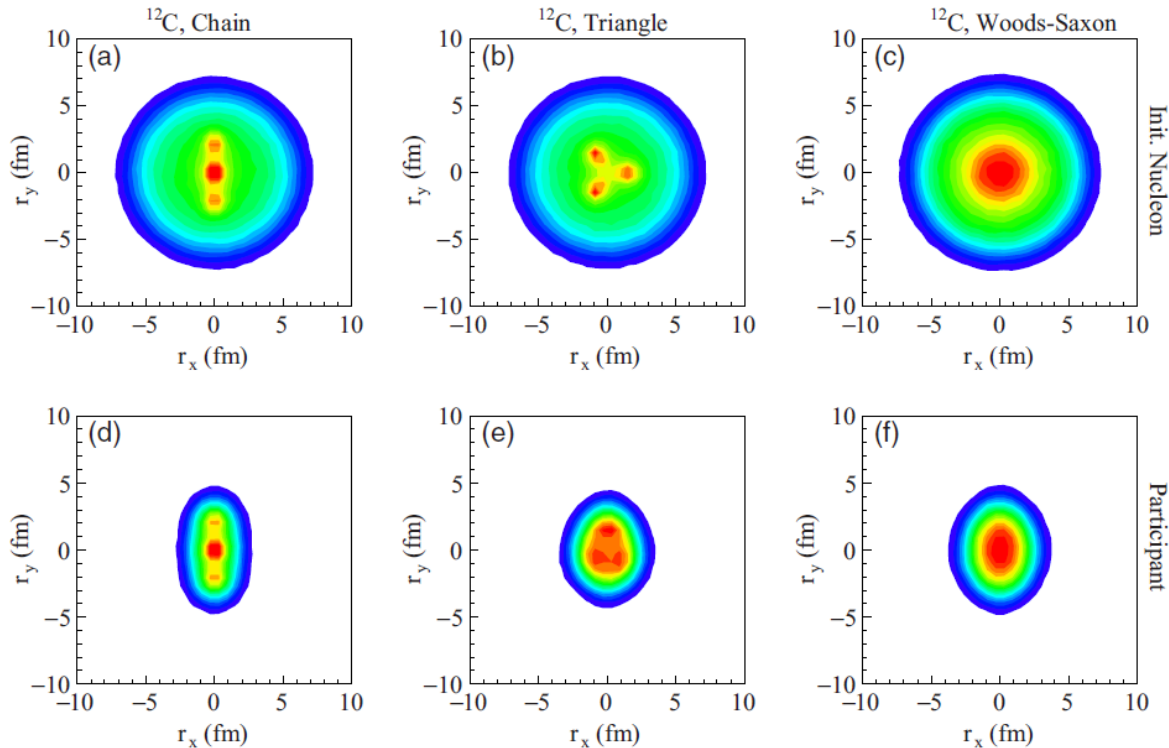


- HIJING model:
- position sampled according to the Woods- Saxon distribution.
- The initial coordinate and momentum distribution of minijet partons and soft string excitations

Difference : C12 has  $\alpha$ -clustering configuration

# Cluster

*S Zhang, (prc) ,95, 064904 (2017)*



**upper panels:** Cluster initial intrinsic nucleon distribution of the  $^{12}\text{C} + ^{197}\text{Au}$  system

**lower panels:** Participant distributions of the  $^{12}\text{C} + ^{197}\text{Au}$  system

**but the  $\alpha$ -clustering effect on electromagnetic field strength in heavy-ion collisions hasn't been discussed**



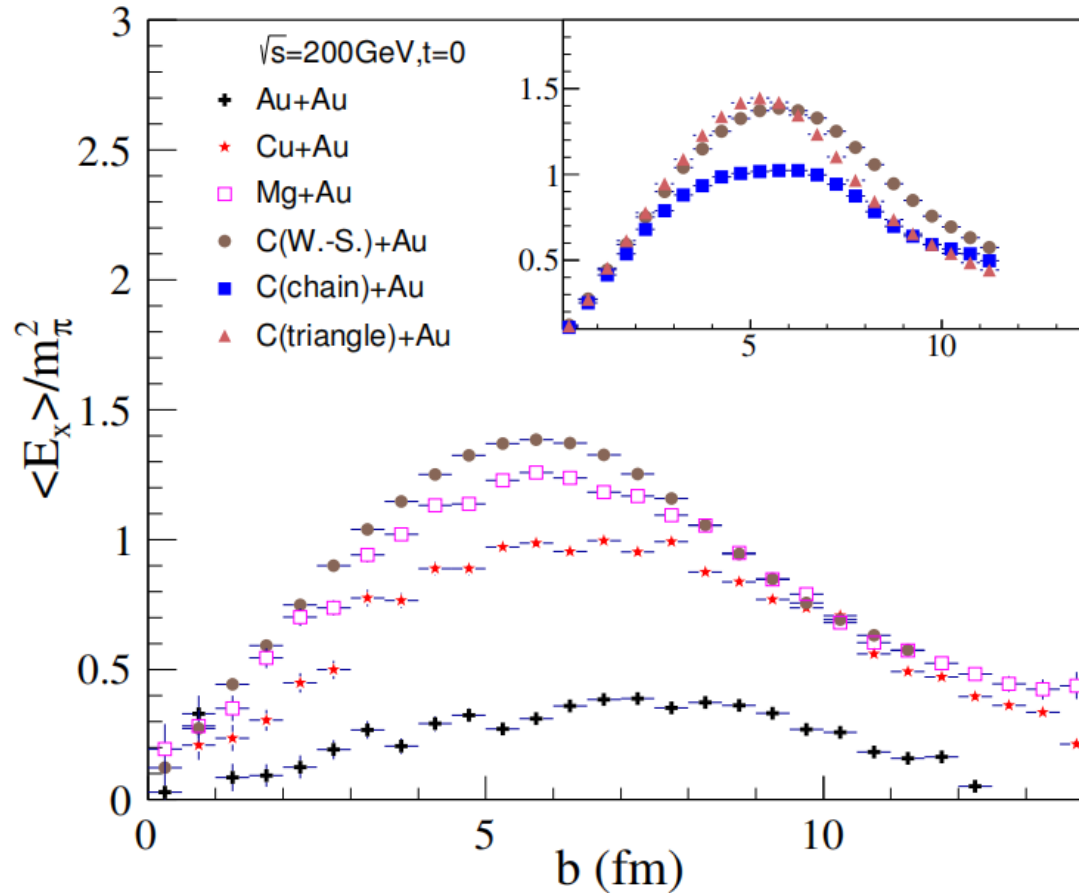
# Participant plane

$$\Psi_n\{PP\} = \frac{\tan^{-1} \left( \frac{\langle r_{part}^2 \sin(n\phi_{part}) \rangle}{\langle r_{part}^2 \cos(n\phi_{part}) \rangle} \right) + \pi}{n}$$

- Event plane constructed by the beam direction  $z$  and the impact parameter.
- In the AMPT model, event plane angle is random, so we rotated the coordinate plane of every event to the same event plane
- $\Psi_n\{PP\}$ :  $n$ -th order participant plane angle
- $r_{part}$  : coordinate position
- $\phi_{part}$  : azimuthal angle of participants
- average  $\langle \dots \rangle$  : density weighting

# results

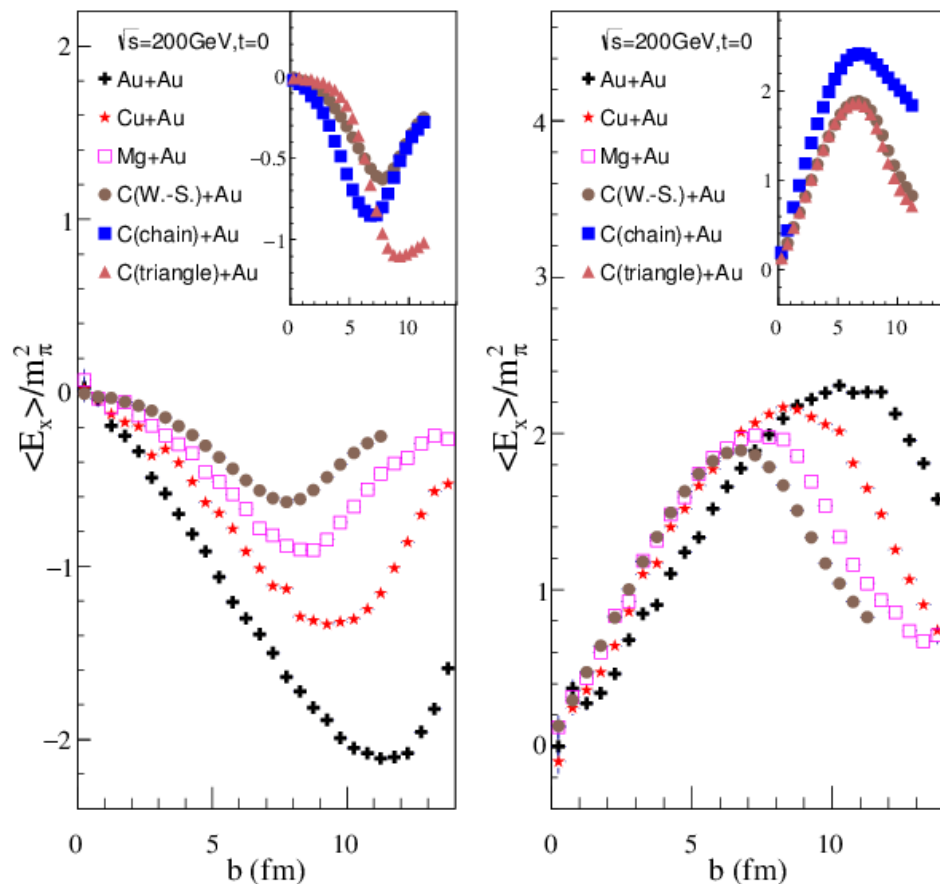
## impact parameter dependence of $\langle E_x \rangle$



▲ increase with the increasing of asymmetry between the projectile and target nuclei

▲ impact parameter dependences for these three configurations of C-12 are similar

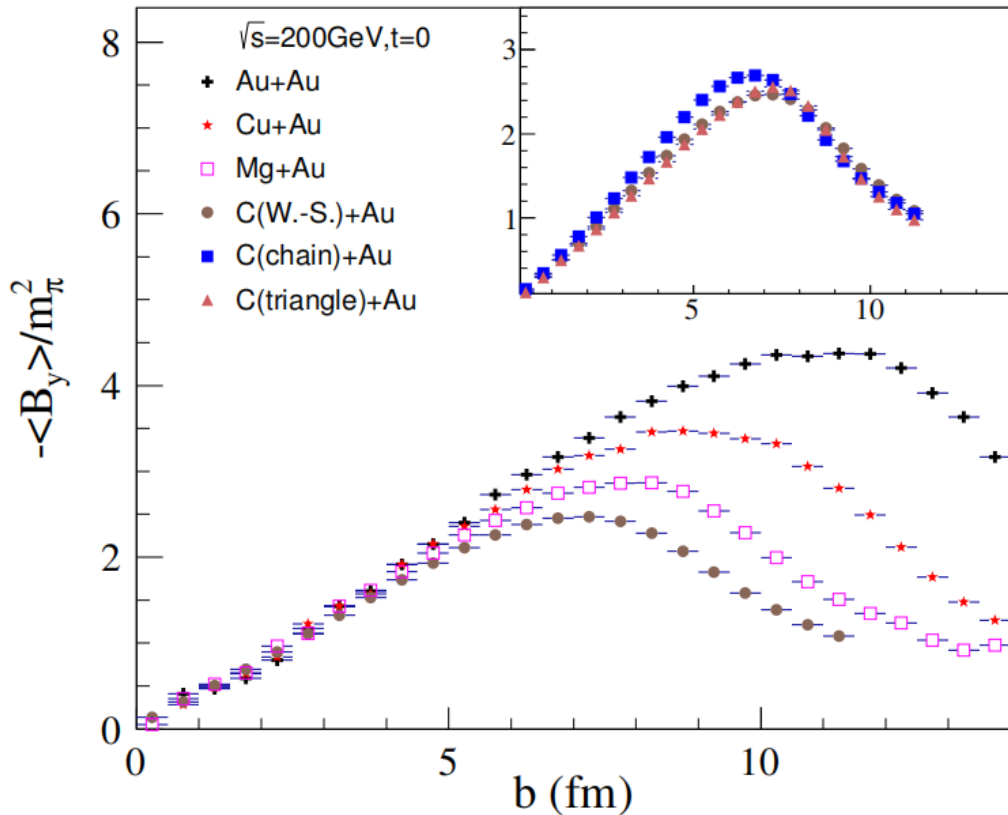
# Ex of projectile and target nucleons



- ▲ asymmetric collision system
- dependence of the electromagnetic fields can be further investigated by the fields generated from the projectile and target nucleons
- ▲ moving direction is opposite
- ▲ asymmetric projectile and target nucleus collisions will produce stronger electric field than symmetrical collision system.

projectile (left side): negative value and monotonic charge number dependence  
 target (right side): positive value and weak dependence on proton number of projectile

# impact parameter dependence of $-\langle B_y \rangle$

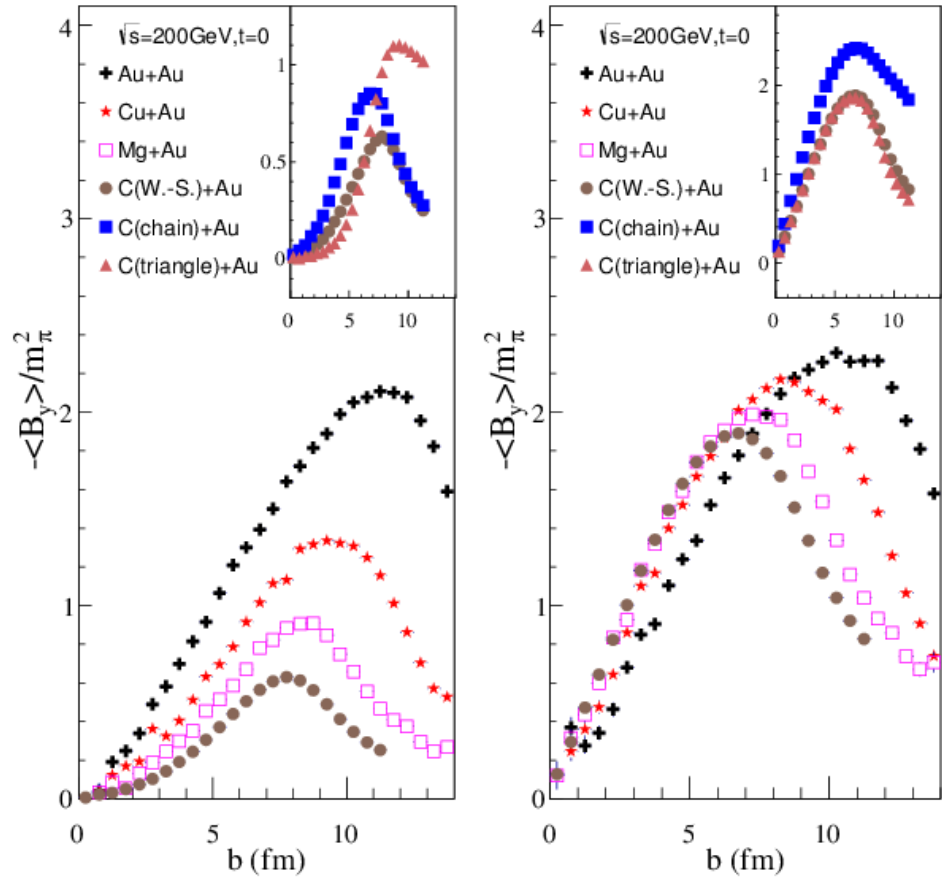


→ similar impact parameter dependence but different system dependence with electric fields

→ decrease with the increasing of asymmetry between the projectile and target nuclei.

→ the dominant effect of magnetic field is symmetrical collision system

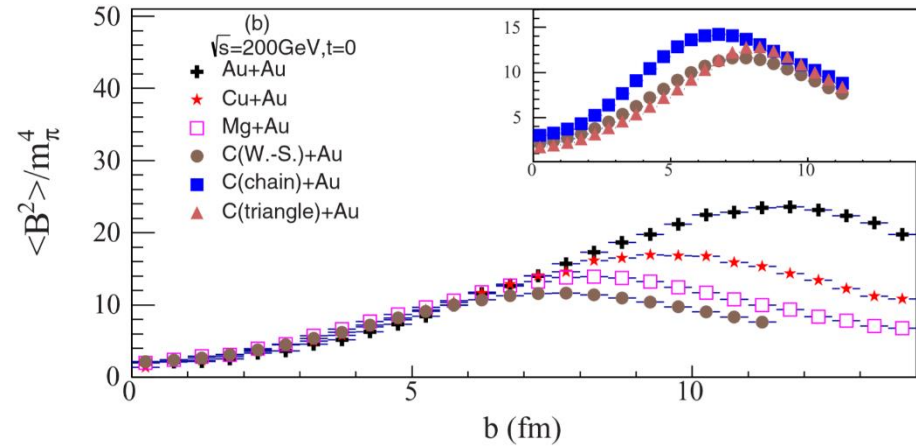
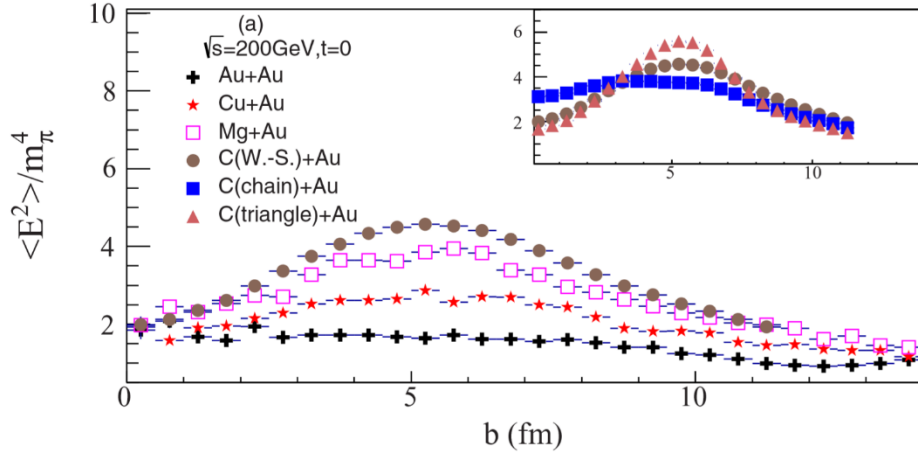
# $-\langle B_y \rangle$ of projectile and target nucleons



▲ projectile and target nucleus have the same sign

▲ the overlapping contribution from the projectile and the target nucleus

# impact parameter dependence of $\langle E^2 \rangle$ and $\langle B^2 \rangle$



→ consider the fluctuation effect

insets → present the initial geometrical dependence of electromagnetic field.

$E^2$ : triangle > w-s > chain

$B^2$ : chain

→ initial geometrical effect is expected through the system scan experiment of electromagnetic effect measurements

# Summary & Outlook

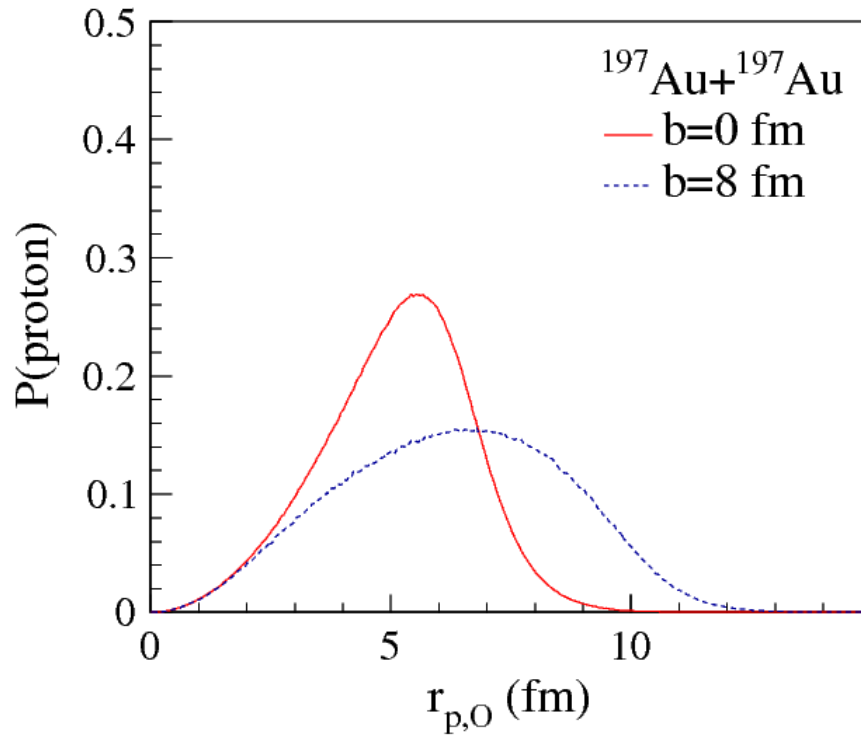
- Asymmetric projectile and target nuclear collisions will produce stronger electric field than symmetrical collision system, but the magnetic field will be in the reverse trend. The dominant effect from electric field or magnetic field is proposed in asymmetrical or symmetrical collision system, respectively. This study sheds light on experiments to investigate different effects from electric or magnetic field in heavy ion collisions
- The initial geometrical effect from exotic nuclear was also investigated and the electromagnetic field presents initial geometrical dependence with different configurations of carbon nucleus. Therefore, a probe to distinguish the exotic nuclear structure is proposed by measuring electromagnetic effect through system scan in relativistic heavy-ion collisions.

Thanks for your attention !



**Back up**

# Proton distribution probability



▲ avoid the divergence

→ the origin of coordinate system  
( $\vec{r} = 0$ )

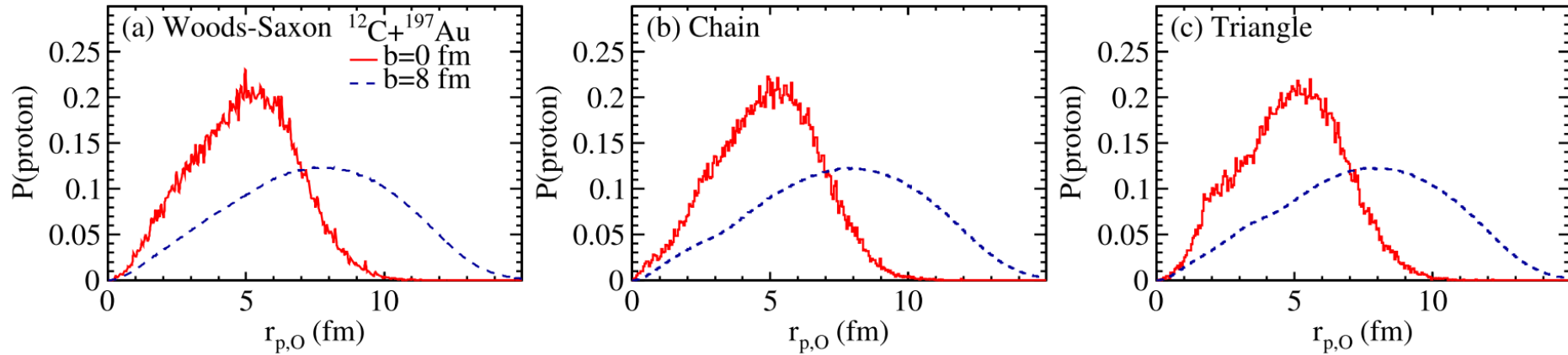
→ initial time  $t=0$  : two colliding  
nuclei completely overlap

→  $r_{p,O}$  : the distance of the  
field point and proton

▲ increases and then decreases

▲ probability of the peak: peripheral collisions > central collisions

# Proton distribution probability



→  $P(\text{proton})$  is negligible near  $r_{p,O}=0$  ( $\vec{r} = 0$ )

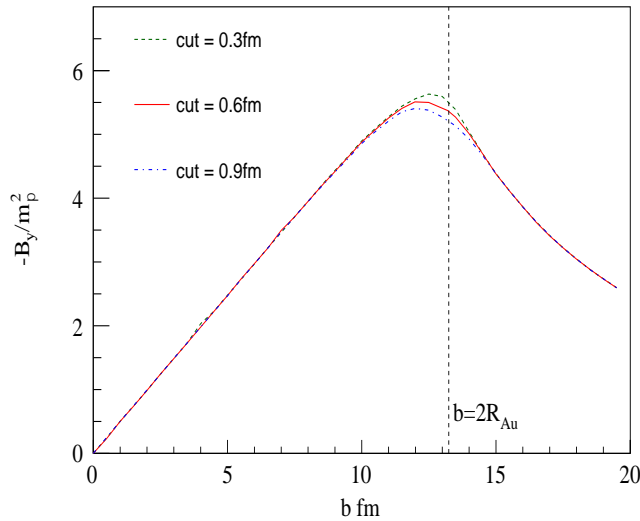
▲ electromagnetic field computed must diverge when a proton appears too close to the observation point



choose a cutoff length

# choice of cut condition

schematic diagram for Au+Au collisions at different impact parameter range



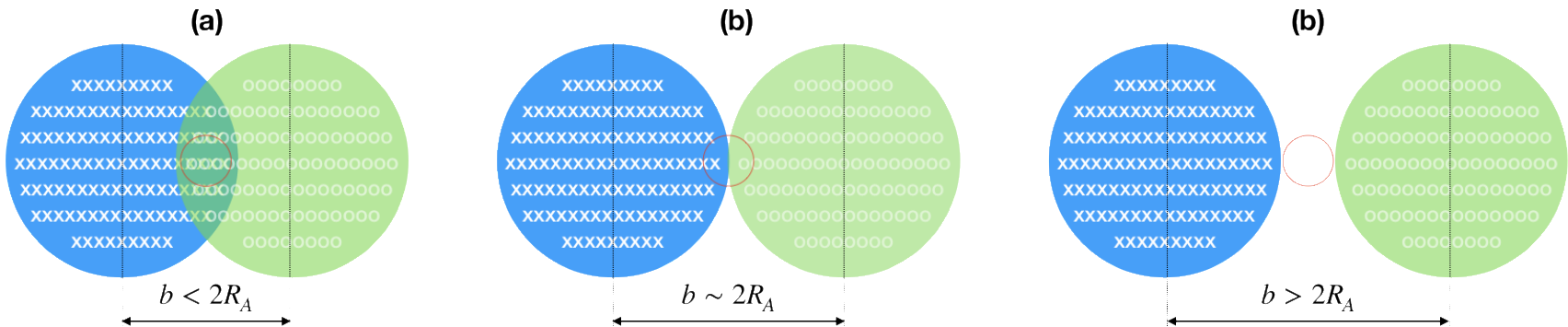
- (a) cancel out
- (b) the magnetic-field  $\langle B_y \rangle$  will be reduced with increasing of the cutoff
- (c) no overlap region

$$\rho(r) = N_Z / \{1 + \exp[(r - R_A)/a]\}$$

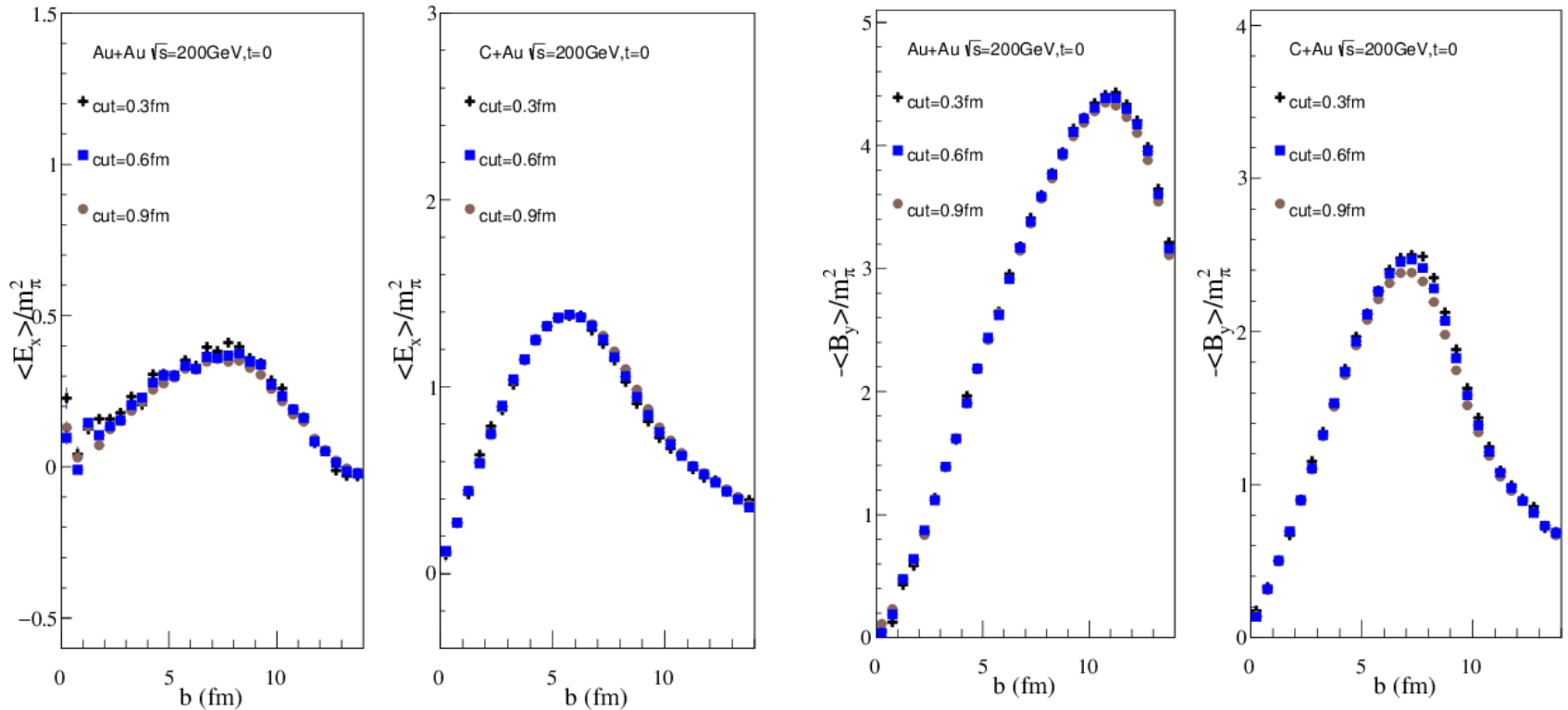
$$Z_{\text{eff}}^{\pm}(t, \mathbf{x}) = 4\pi \int_0^{r^{\pm}} dr' r'^2 \rho(r'),$$

$$e\mathbf{B}^{\pm} = \frac{\alpha_{\text{EM}} Z_{\text{eff}}^{\pm}}{(r^{\pm})^3} \sinh(\pm Y_{\text{beam}}) (\hat{\mathbf{x}}^{\pm} \times \mathbf{e}_z),$$

▲  $b \sim 2R_{\text{Au}}$  : a little effect to magnetic-field



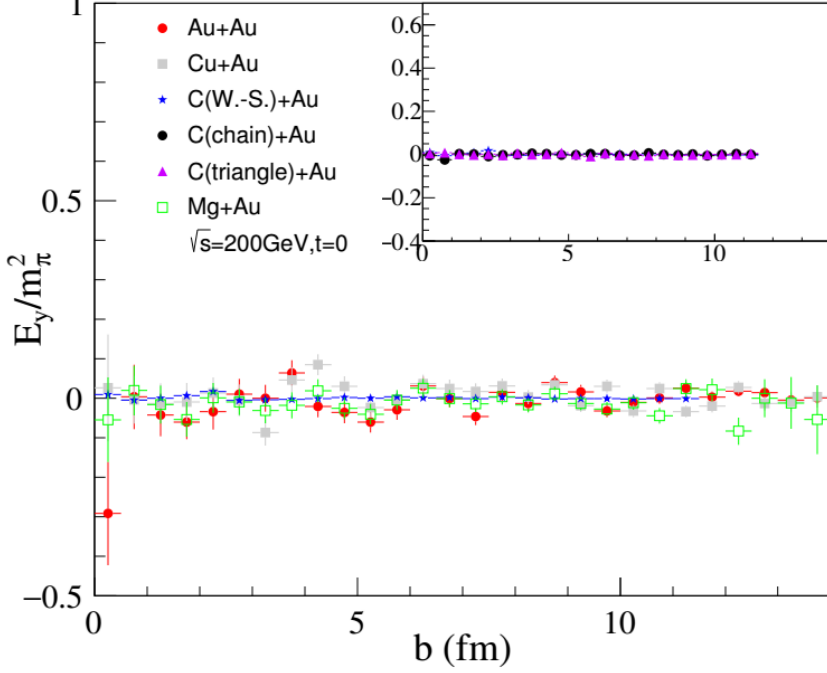
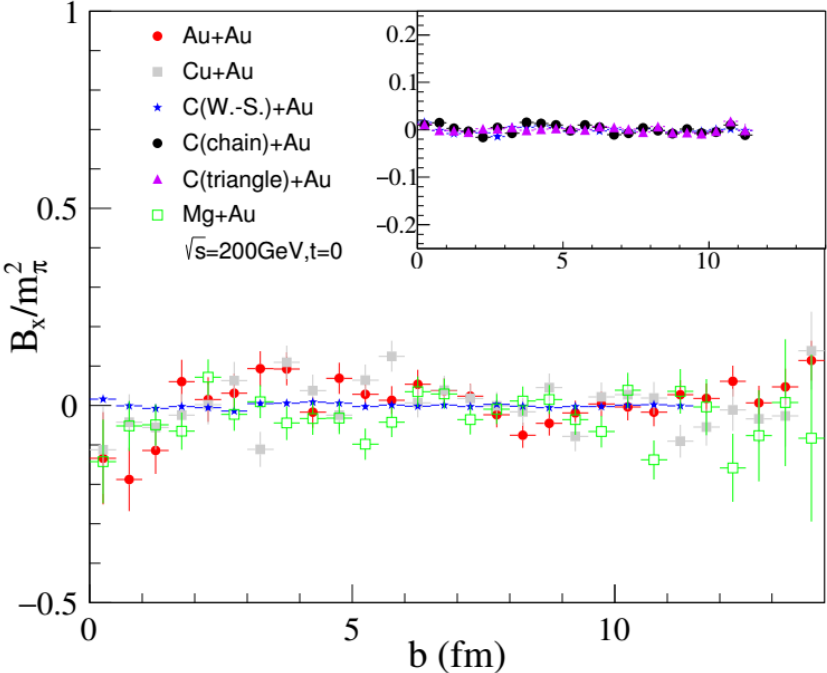
# choice of cut condition



→ vary the cutoff and check how the fields change

→ the cutoff affect little to the fields.

# impact parameter dependence of $\langle B_x \rangle$ and $\langle E_y \rangle$



▲ present 0 value

rotated event by event → result in the mirror symmetry of the collision geometry