中国物理学会高能物理分会
第十一届全国会员代表大会暨学术年会

E-M field produced in high-energy small collision systems within charge density models of nucleons

Chin. Phys. C 46, 084103 (2022)

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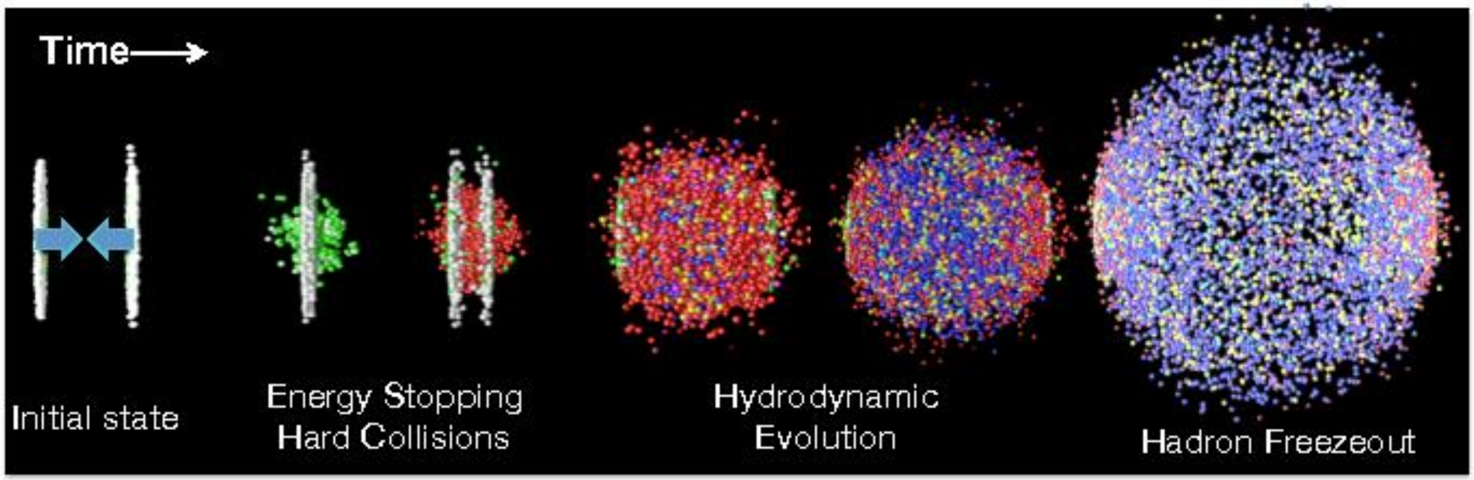
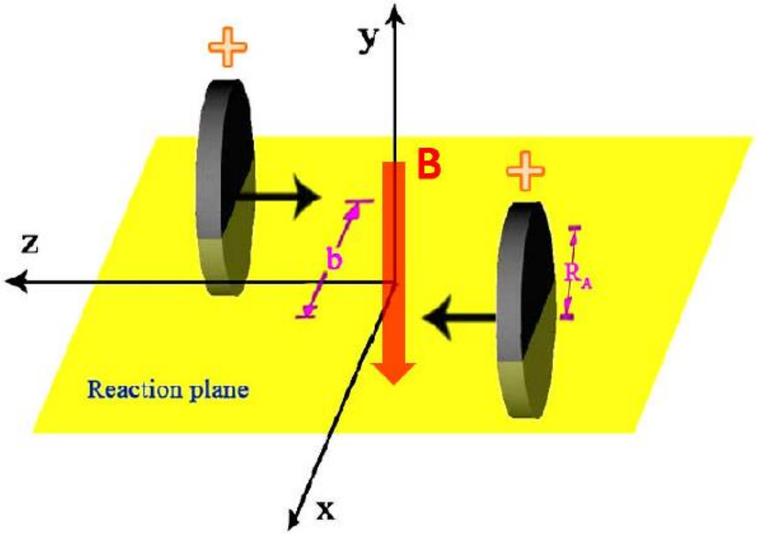
Motivation





Due to fast, oppositely directed motion of two colliding ions, off-central heavy-ion collisions can create strong transient magnetic fields.

The magnetic fields generated in Au+Au collisions at RHIC can reach ~10^{19} Gauss

Such a strong B field may influence the dynamics of QGP

Chirality imbalance + magnetic field = chiral magnetic effect (CME)

Kharzeev 2004, Kharzeev, Mclerran, Warringa, Fukushima 2007-2008

Chiral Magnetic Effect (CME) ⟹ Charge separation

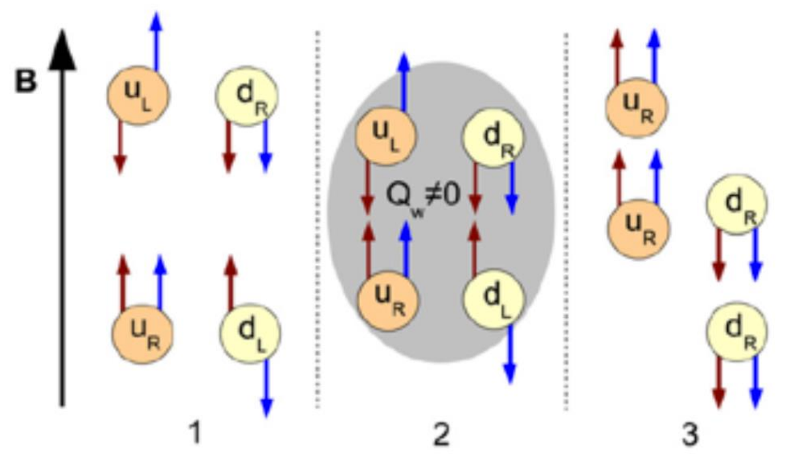
$$\vec{J} = \sigma_5 \vec{B}$$

chiral conductivity

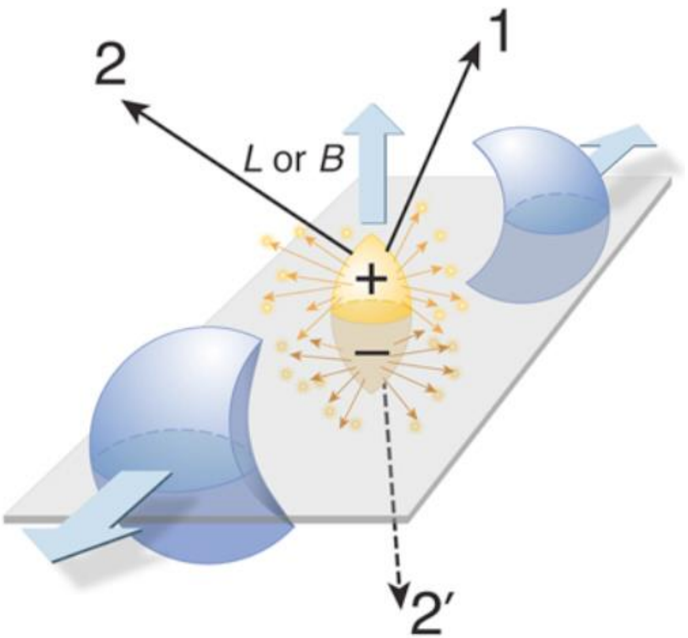
$$\sigma_5 = N_c \sum_f \frac{q_f^2 \mu_5}{2\pi^2}$$

with aixal or chiral chemical potential

$$\mu_5 = \frac{\mu_R - \mu_L}{2}$$



Experiment searches of CME



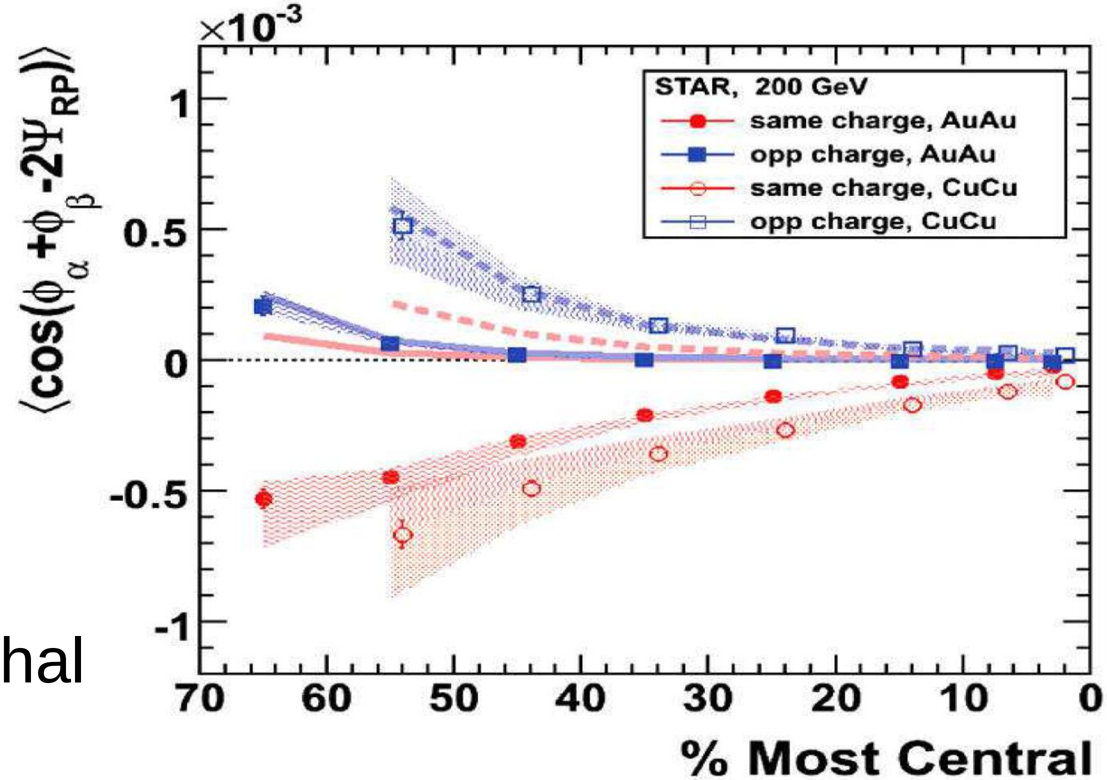
Two particle charge azimuthal correlation function:

$$\gamma_{q_1,q_2} = \langle \cos\ \phi_1 + \phi_2 - 2\psi_{RP}\ \rangle$$

$$\gamma_{ss} = (\gamma_{++} + \gamma_{--})/2$$

$$\gamma_{os} = \gamma_{+-}$$

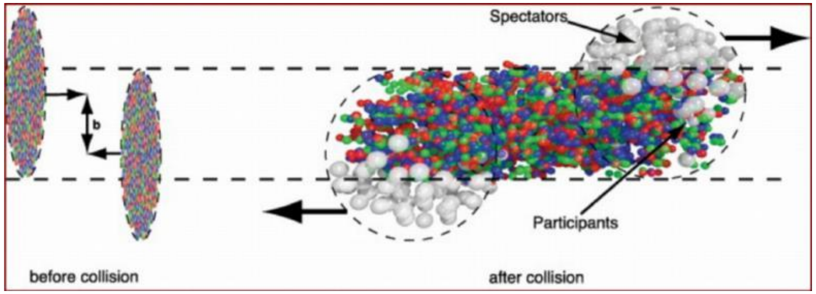
charge correlation in Au+Au, Cu+Cu, and Pb+Pb are consistent with CME:

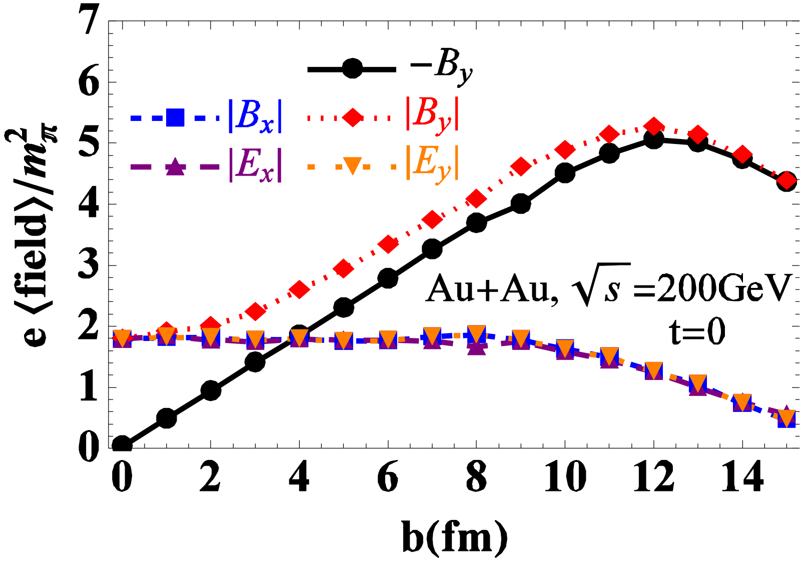


STAR, Phys. Rev. Lett. 103, 251601

A+A Collision

WTD and X.-G. Huang, Phys. Rev. C 85, 044907(2012)

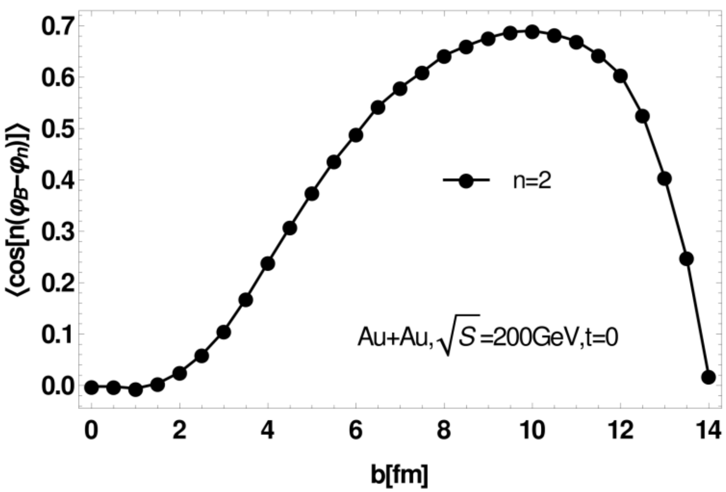


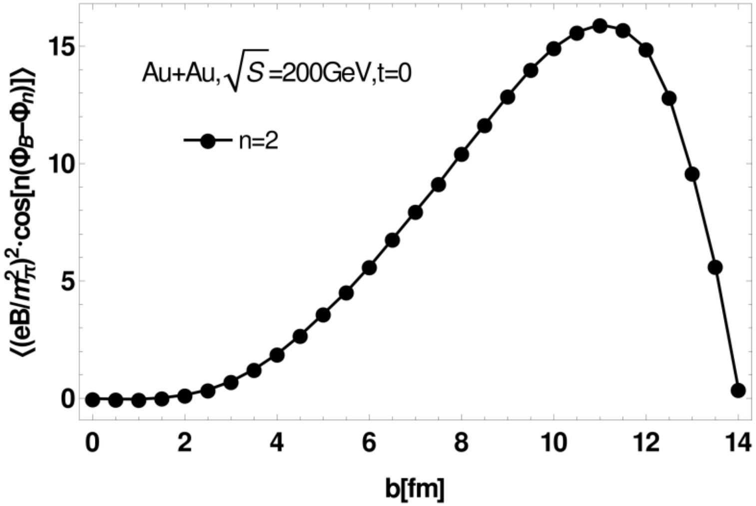


Angular correlation between B and event plane in A+A collisions

$$\mathrm{Cos}[2(\varphi_B - \varphi_2)]$$

$$B^2\mathrm{Cos}[2(\varphi_B - \varphi_2)]$$

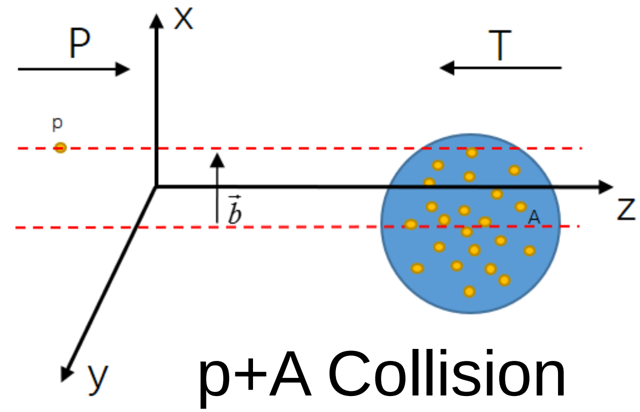




In Small system collisions (p+A)

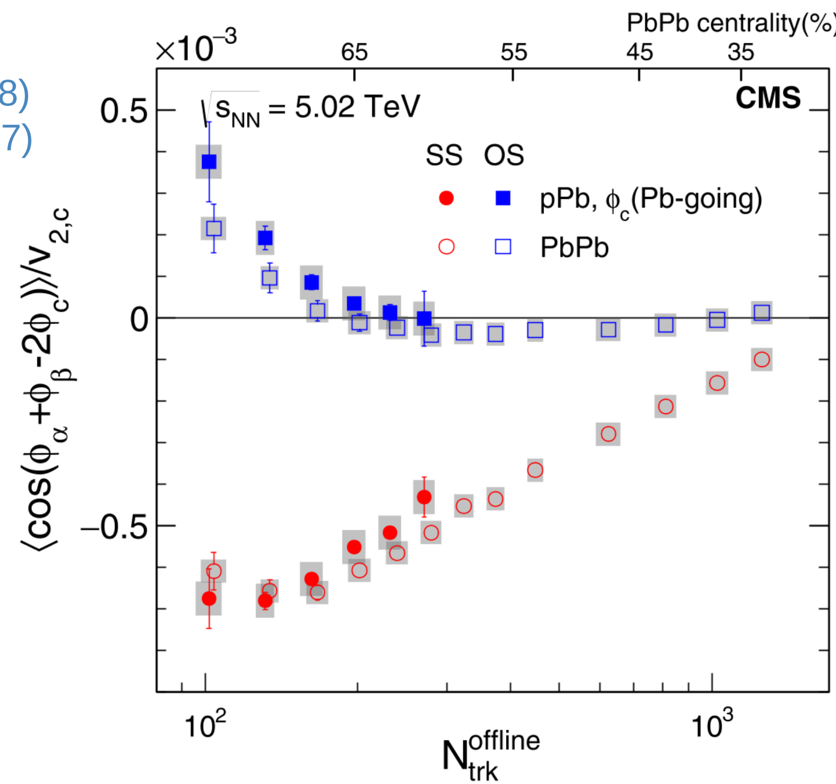
People do NOT expect CME in p+A, since the assumption of anglular de-correlation between B and event plane is accepted commonly.

X.-L. Zhao, Y.-G. Ma, and G.-L. Ma, Phys. Rev. C 97,(2018)
R. Belmont and J. L. Nagle, Phys. Rev. C 96, 024901(2017)



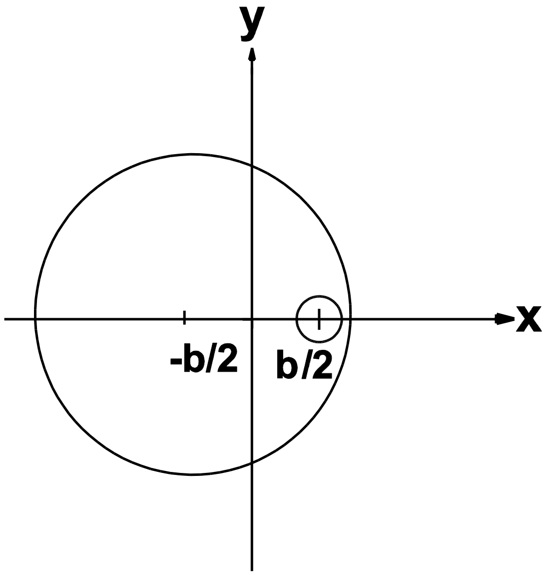
But exp. results show a similar charge azimuthal correlation in p+A with A+A.

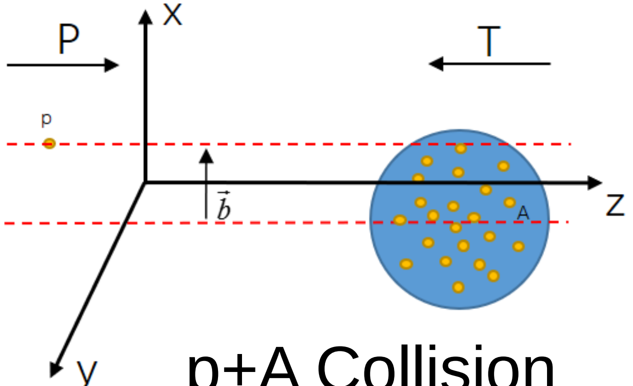
- Only background effect contributes to charge separation effect?
- Indeed anglular de-correlation between φ_B and φ_2 in p+A?



PRL 118, 122301 (2017)

Framework





p+A Collision

Lienard-Wiechert potential

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

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

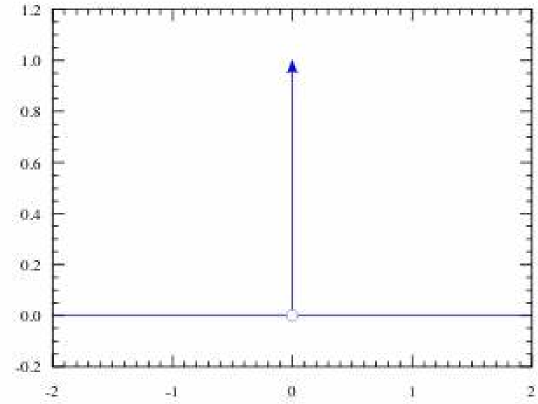
with retarded condition $t_n = t - |\mathbf{r} - \mathbf{r}_n|$

Relative position $\mathbf{R}_n = \mathbf{r} - \mathbf{r}_n$

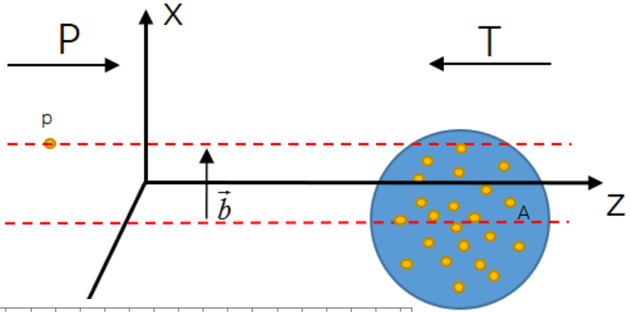
Charge profile of nucleon

In previous calculation, we treat proton as a Point-Like particle with charge.

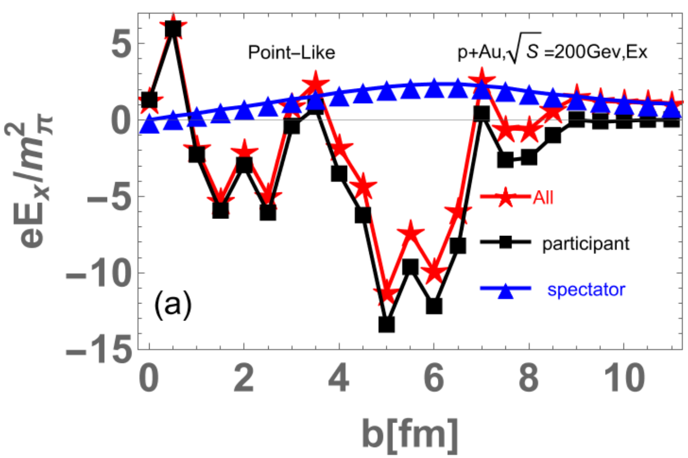
$$\rho(r) = \delta(r - r_0)$$

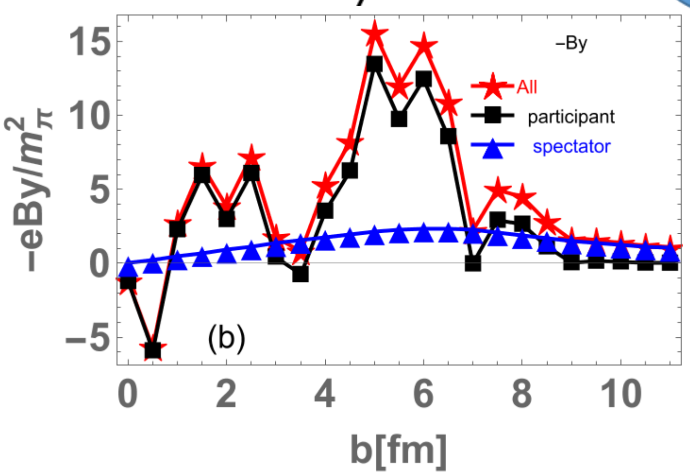


It is a good approximation in A+A collision.

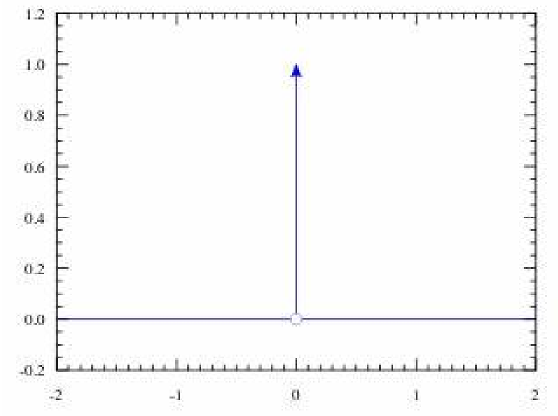


But in Small system, the fields at c.m. of the small overlap region:



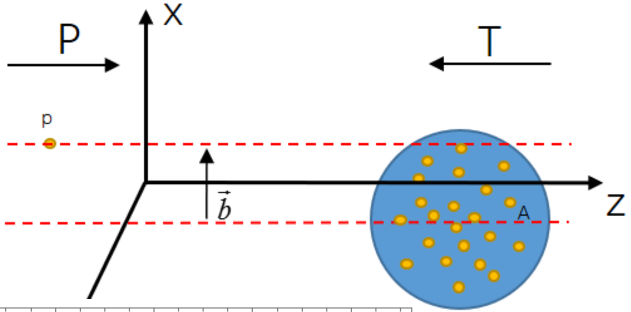


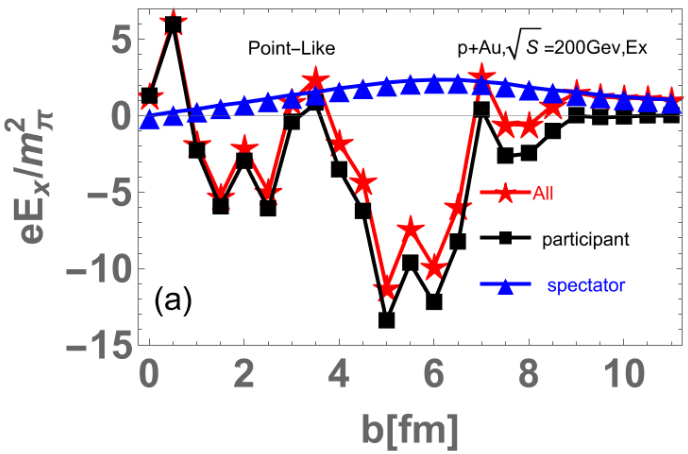
Point-Like model

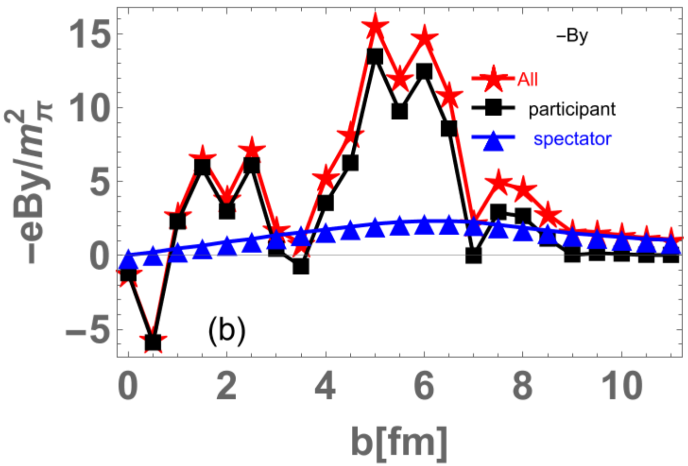


In Small system, it brings:

- a huge fluctuation on field strength event-by-event
- Any possible angular correlation of φ_B and φ_2 would be hided behind this huge fluctuations.



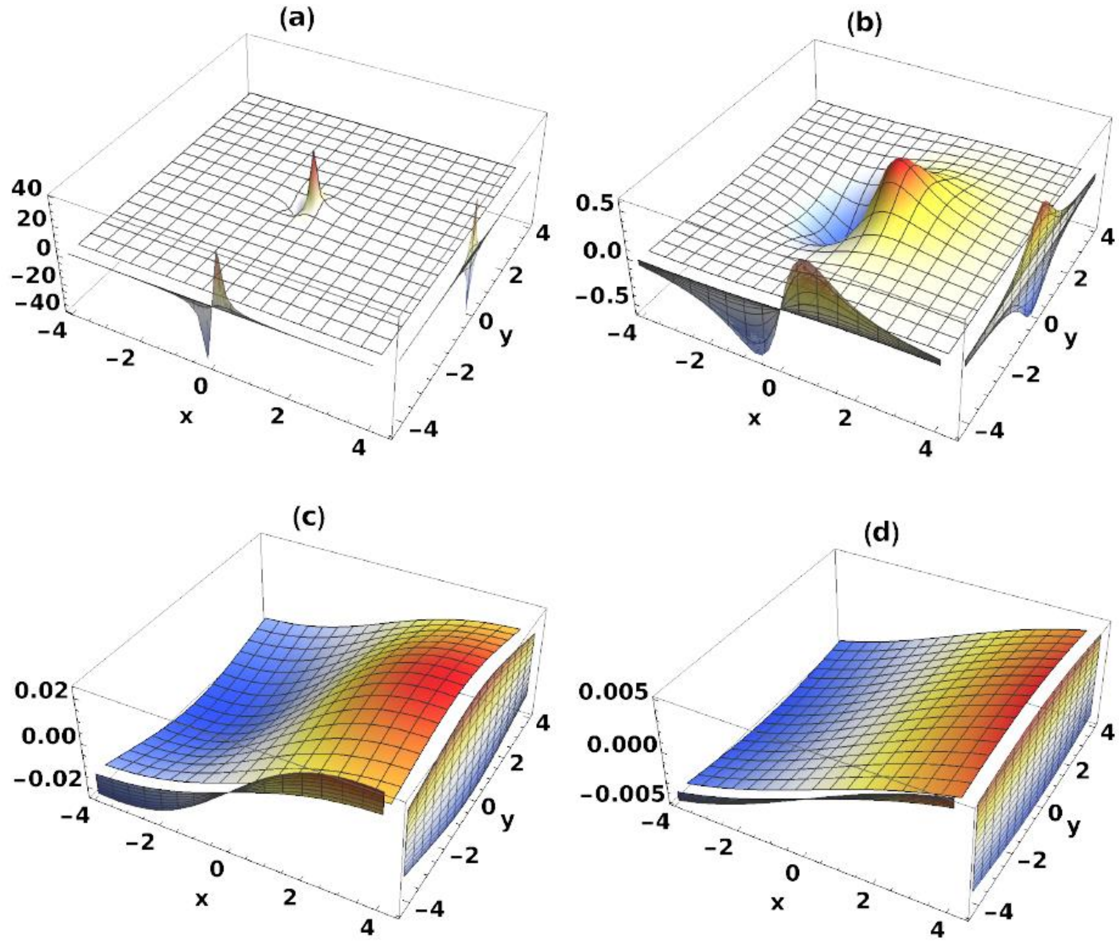




Point-Like model

We check the space distribution of magnetic field B_y produced by a single proton on x−y plane

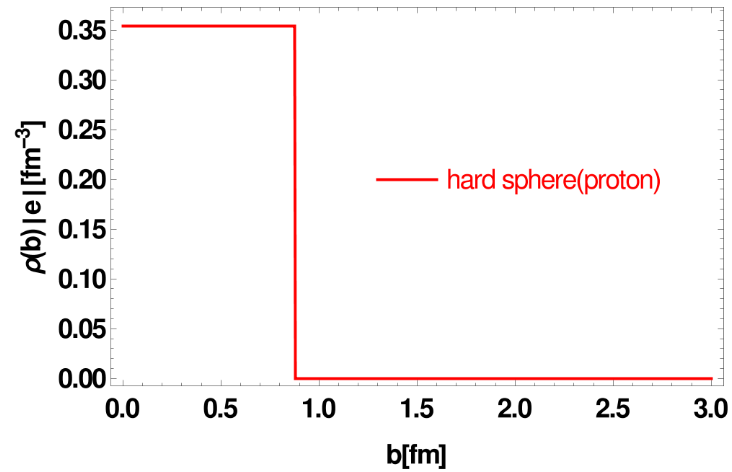
$z = 0$ $\qquad$ $z = 1/\gamma$ fm



$z = 5/\gamma$ fm $\qquad$ $z = 10/\gamma$ fm

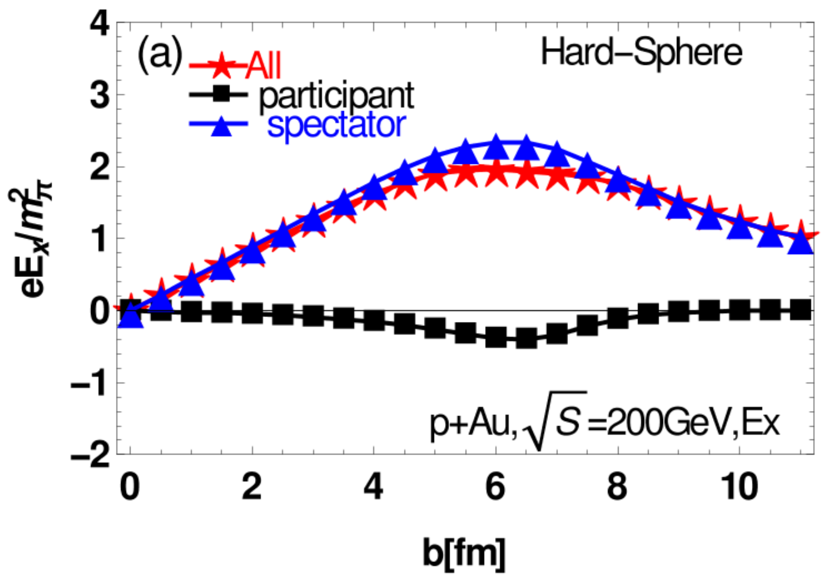
Hard-Sphere model

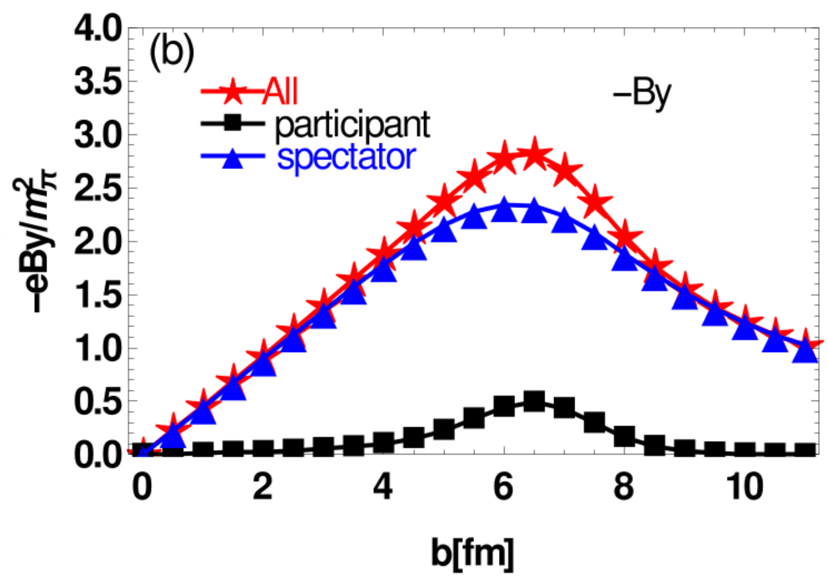
$$\rho(r) = \begin{cases} \rho_0 & r \le R_p \\ 0 & r > R_p \end{cases}$$



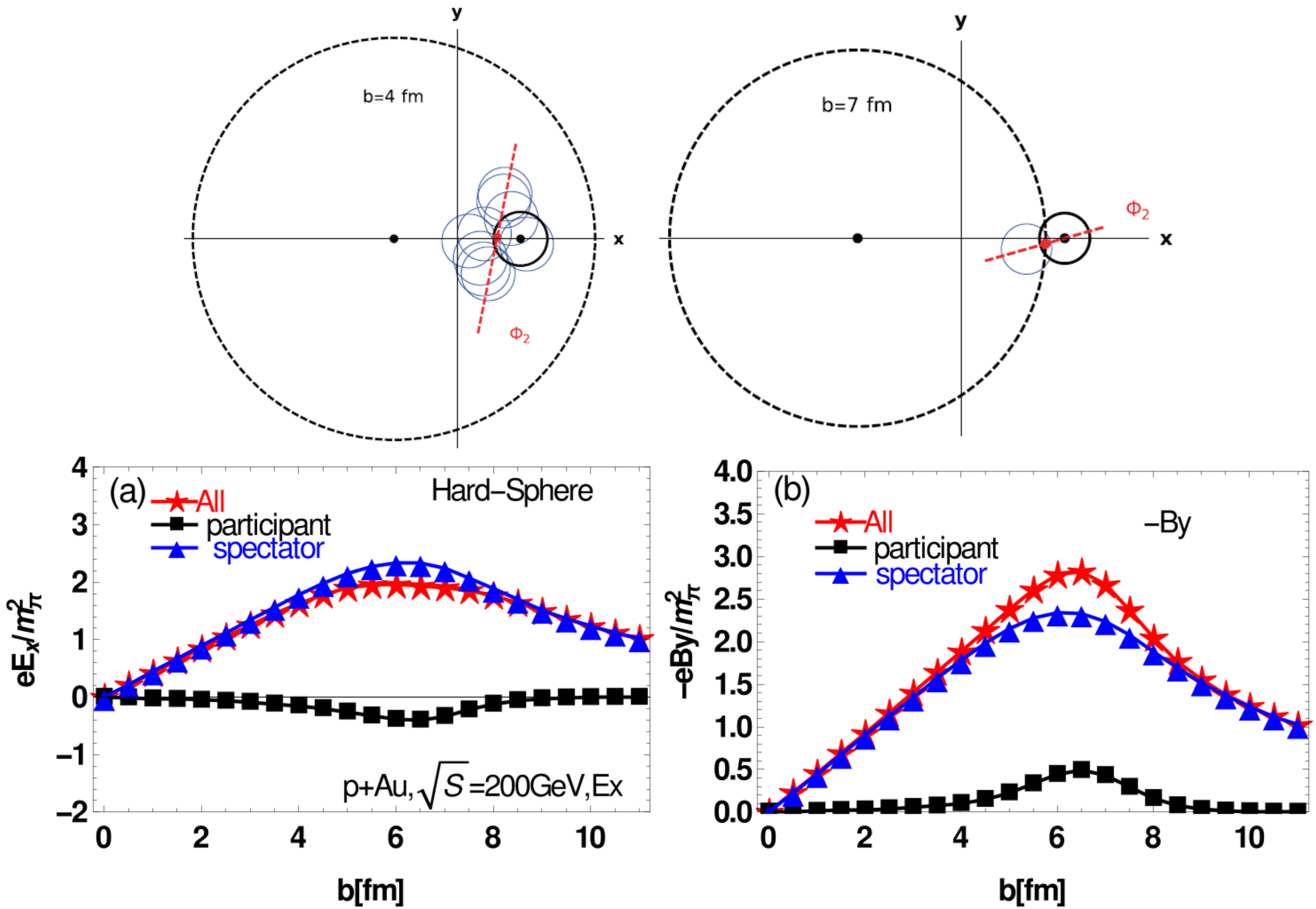
With R_p= 0.88 fm

The huge fluctuation is eliminated





Hard-Sphere model



Realistic Charge-Profile model

$$\rho(\mathrm{b}) = \int_0^\infty \mathrm{dQ}\frac{Q}{2\pi}\mathrm{J}_0(\mathrm{Qb})\frac{\mathrm{G_E(Q^2)} + \tau\mathrm{G_M(Q^2)}}{1+\tau}$$

J_0 a cylindrical Bessel function. $\tau = Q^2 / 4M^2$

Ann. Rev. Nucl. Part. Sci., 2010, 60(60):1–25

electric form factor G_E

$$G_{Ep}(Q^2) = \frac{1 + a^E_{p,1}\tau}{1 + b^E_{p,1}\tau + b^E_{p,2}\tau^2 + b^E_{p,3}\tau^3}$$

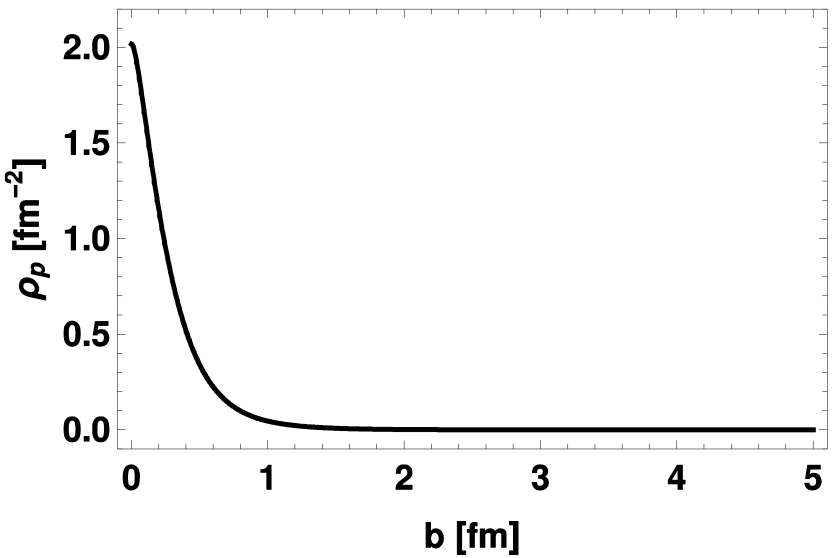
magnetic form factor G_M

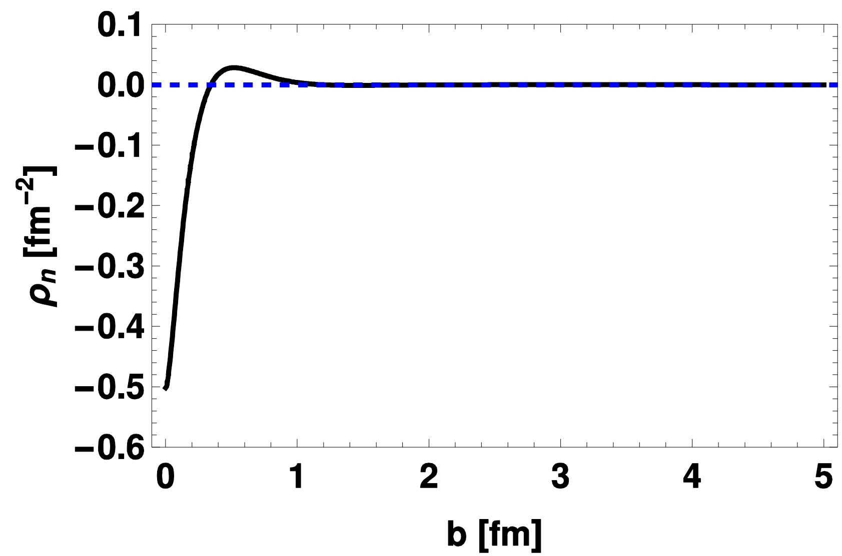
$$\frac{G_{Mp}(Q^2)}{\mu_p} = \frac{1 + a^M_{p,1}\tau}{1 + b^M_{p,1}\tau + b^M_{p,2}\tau^2 + b^M_{p,3}\tau^3}$$

Realistic Charge-Profile model

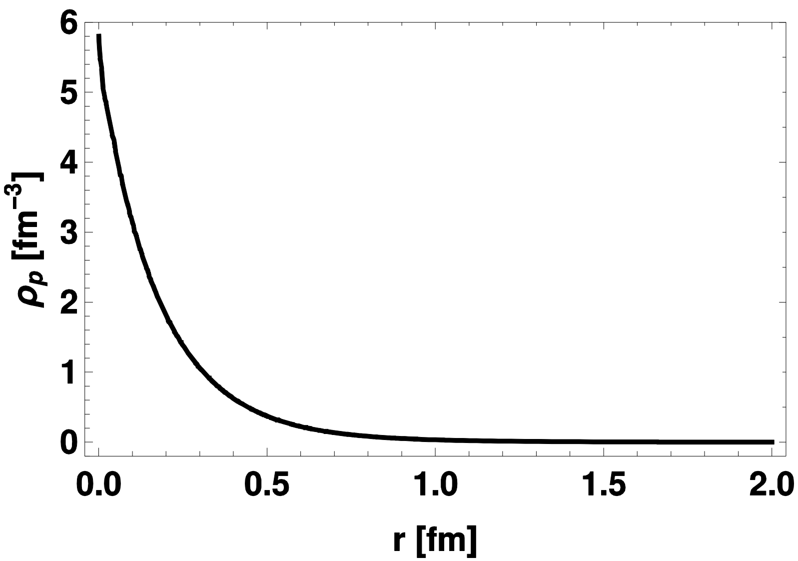
Proton | Neutron

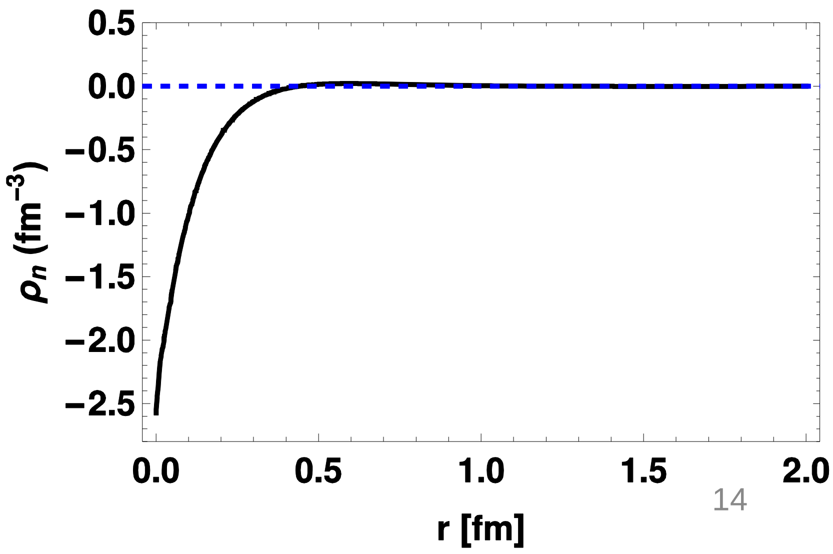
2-D Profile





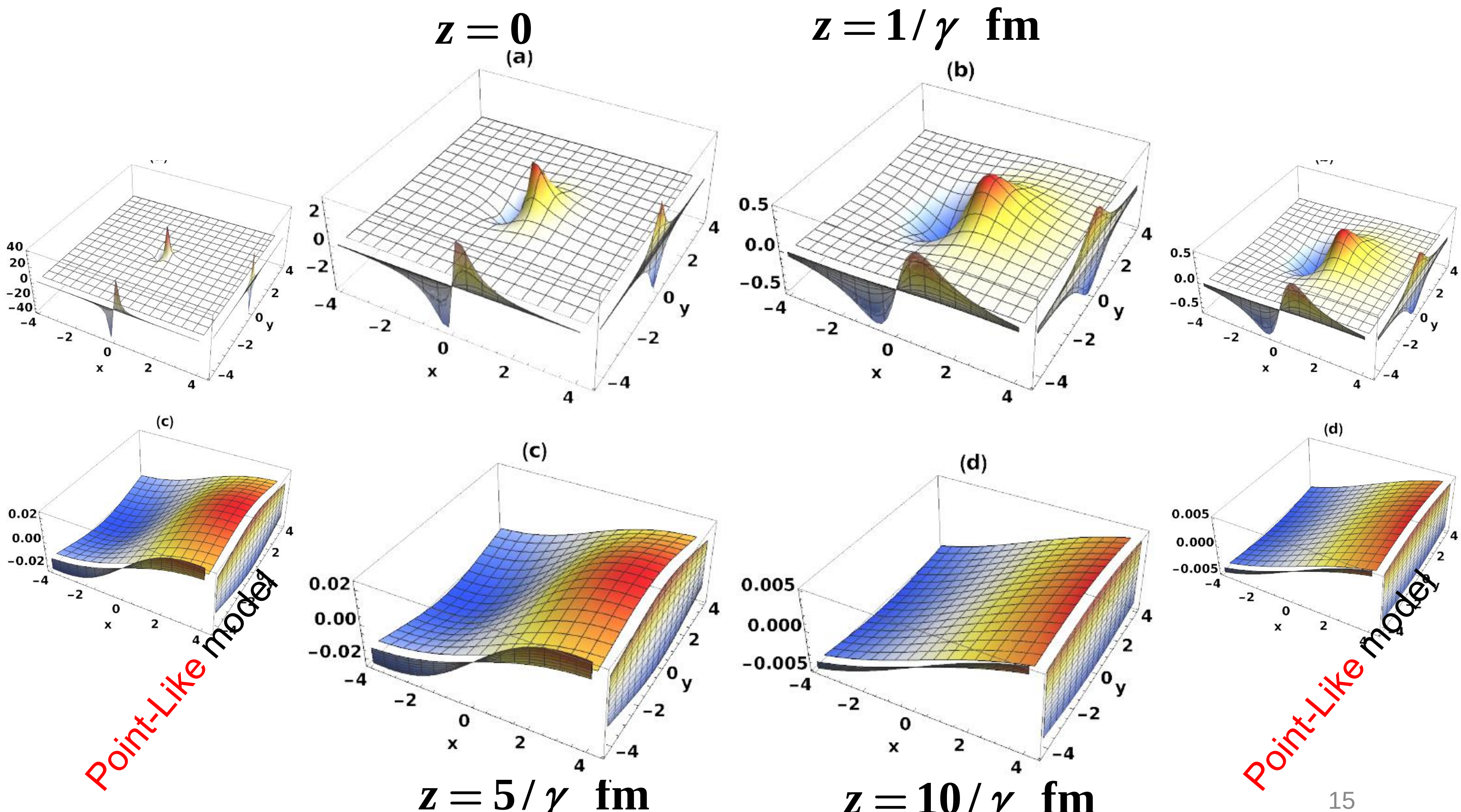
3-D Profile





Realistic Charge-Profile model

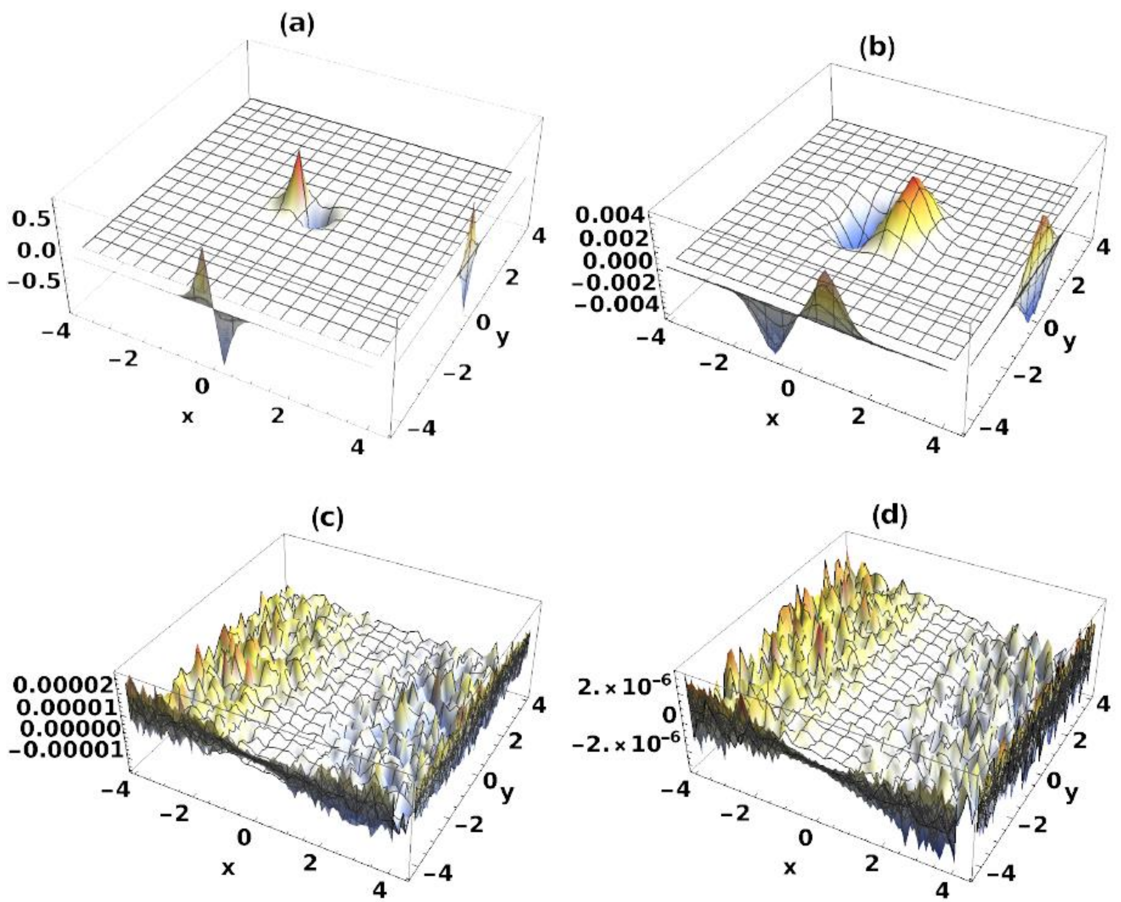
the space distribution of B_y produced by a single Proton



Realistic Charge-Profile model

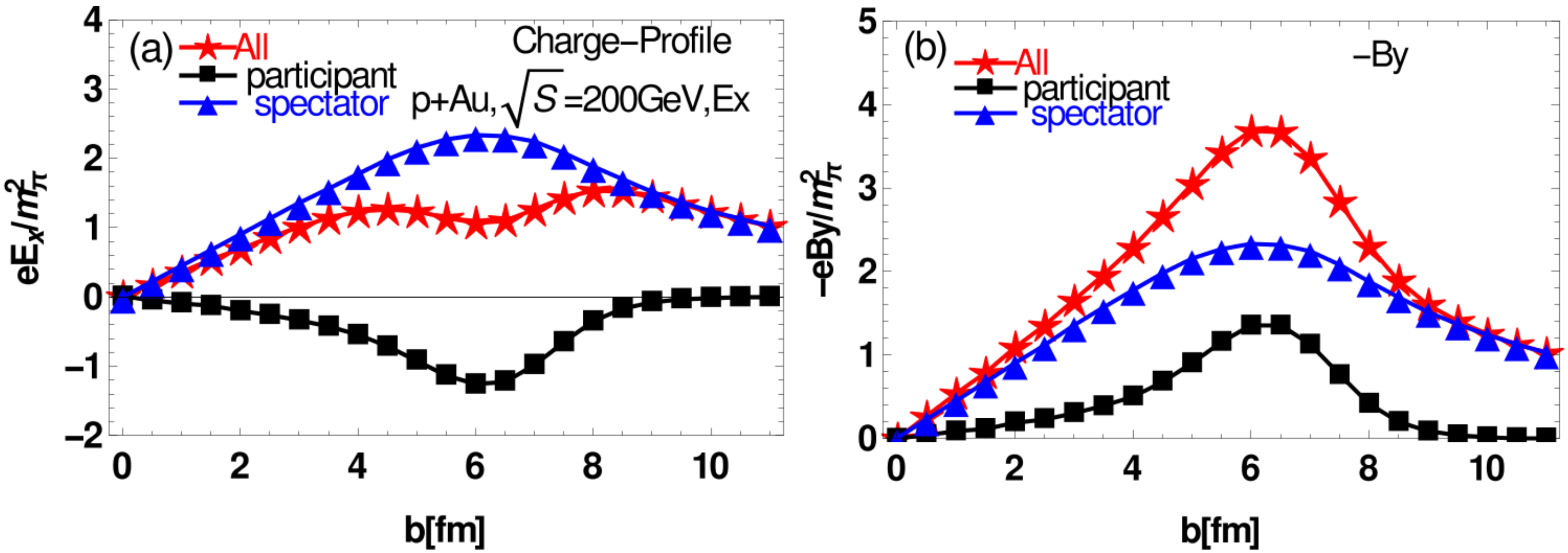
the space distribution of B_y produced by a single Neutron

$z = 0$ $\qquad$ $z = 1/\gamma$ fm

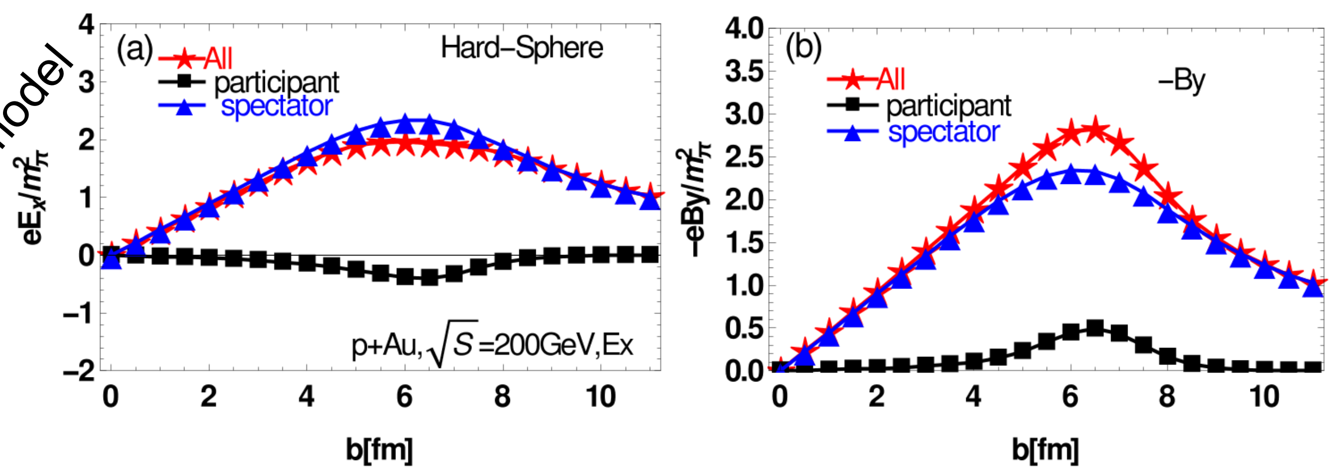


$z = 5/\gamma$ fm $\qquad$ $z = 10/\gamma$ fm

Realistic Charge-Profile model　　Field Strength

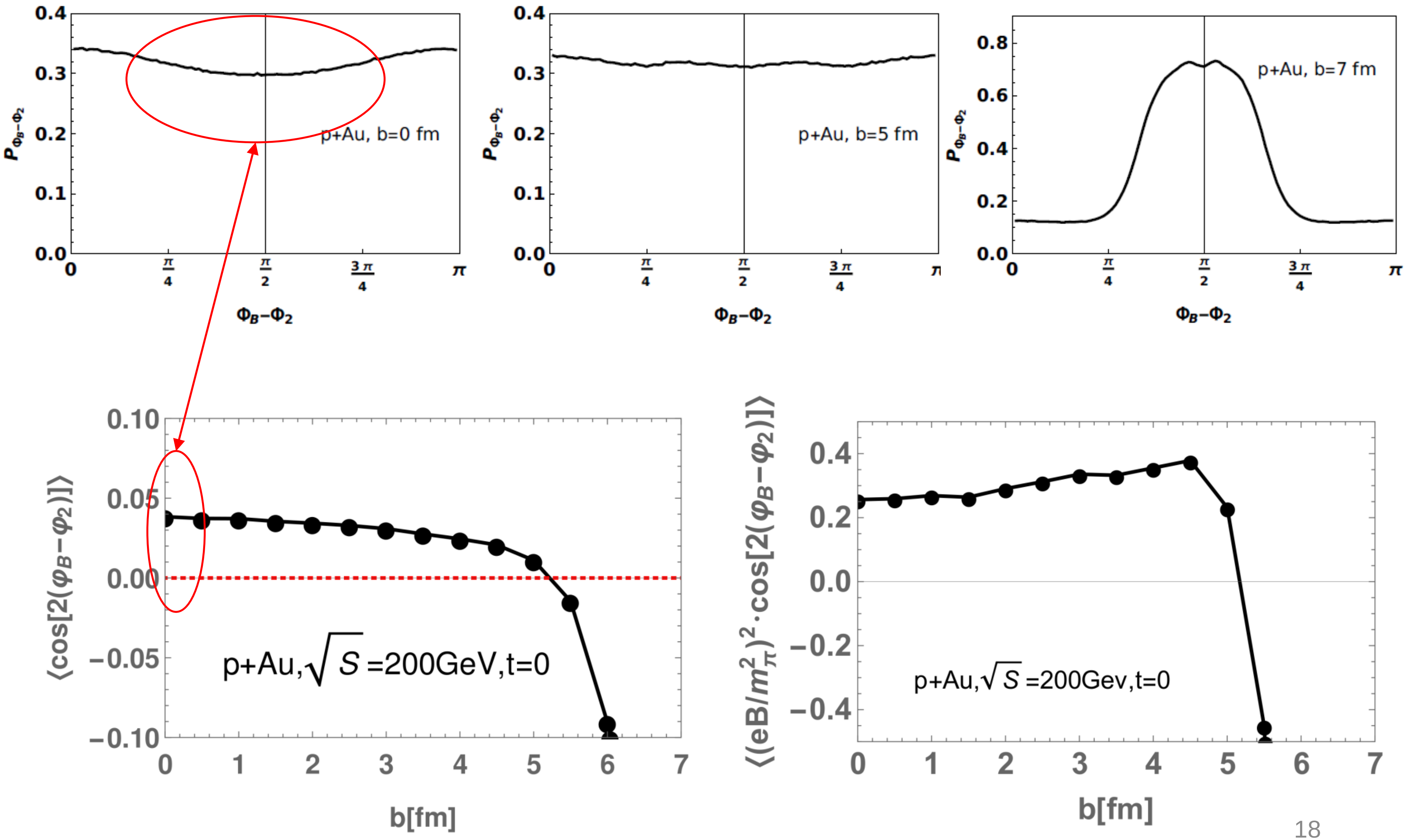


Hard-Sphere model



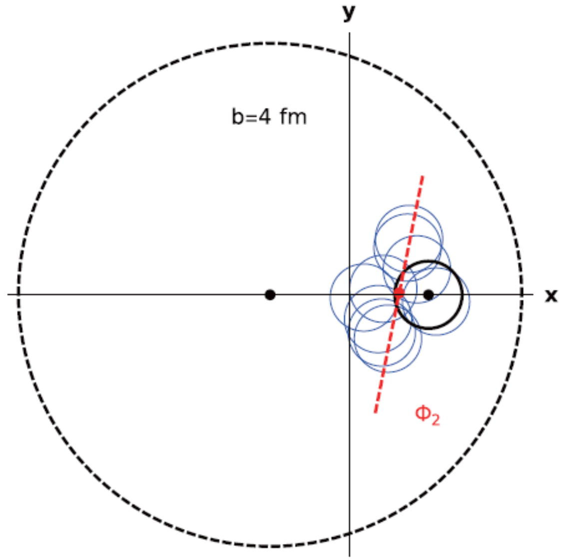
- Spectators still contributes mostly to strength of B_y.
- Participants’ contribution is significant.

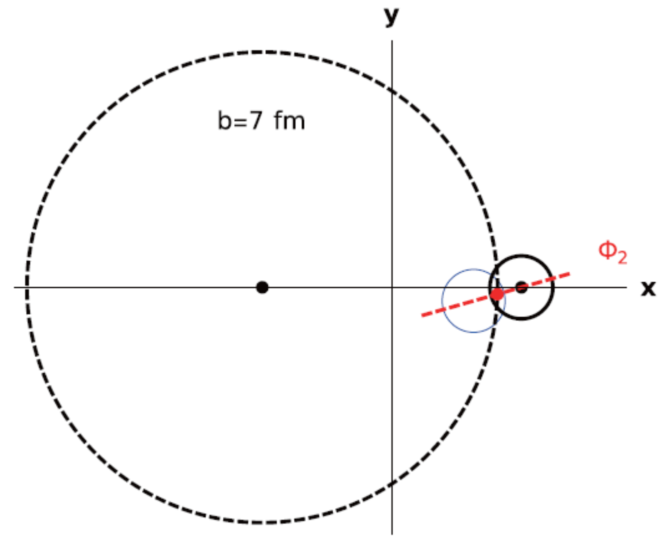
Realistic Charge-Profile model Angular Correlation

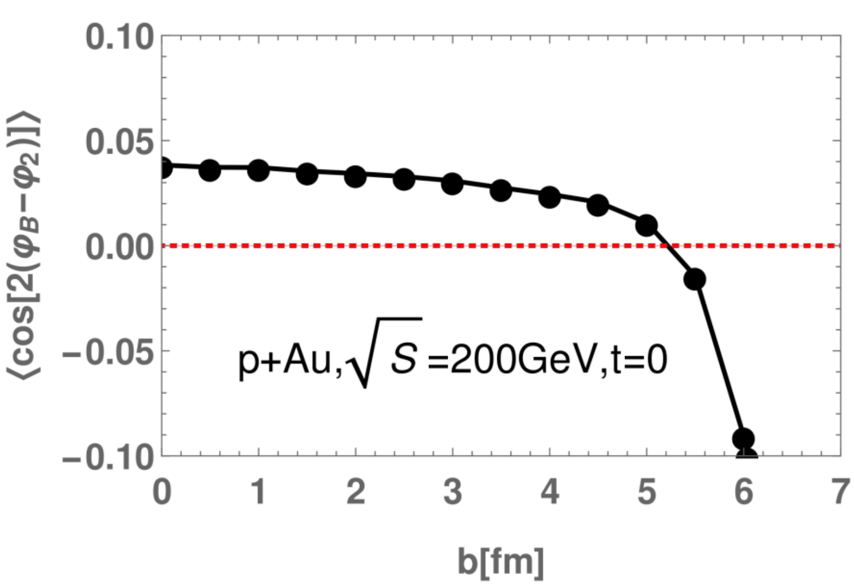


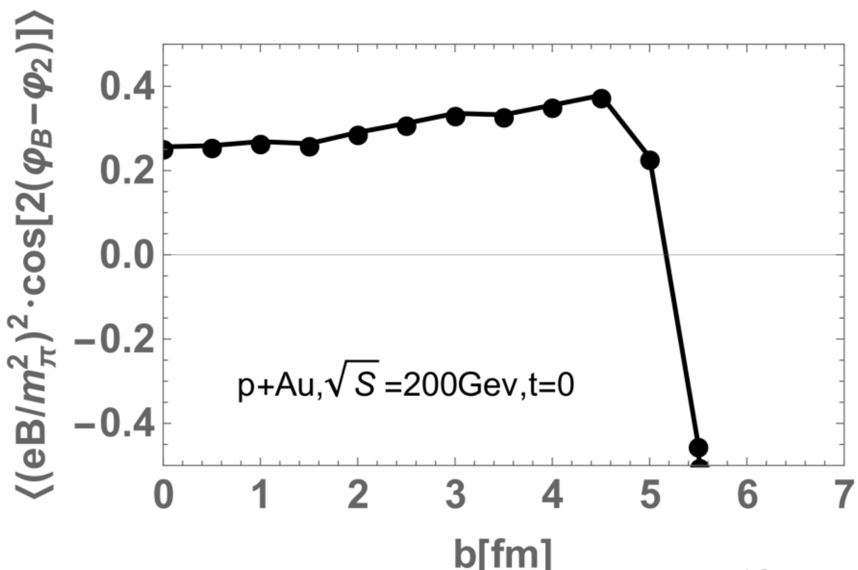
Realistic Charge-Profile model

Angular Correlation









Summary

- With realistic charge profile of nucleon, the properties of fields produced in small system are studied

- A non-ignorable angular correlations of φ_B and φ_2 are found in high-energy small collision systems.

- More study is needed on CME in small system