Electromagnetic fields in small systems from AMPT

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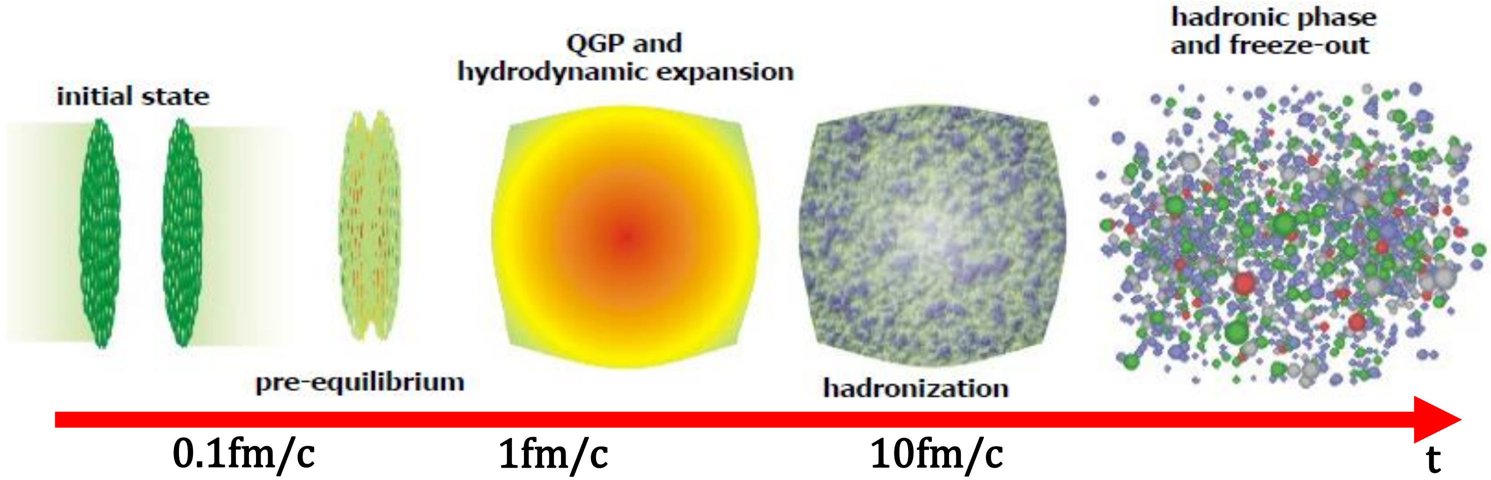
④ $< cos2(\Psi_B - \Psi_2) >$ in pAu, dAu, pPb collisions

3 Summary

Introduction: Space-Time Evolution for Heavy-Ion collisions



- The pre-equilibrium phase occurs at t<1fm/c, during which cascades occur between partons, and a large number of quarks are generated.
- The system quickly reaches the local thermal equilibrium and then enters the hydrodynamic expansion stage at 1-10fm/c.
- The temperature of the system decreases and begins to enter the hadronization. When there is no inelastic scattering between the hadrons, the chemical equilibrium is reached.
- After the chemical equilibrium, the system will continue the elastic scattering for some time, and finally when the elastic scattering between the hadrons are stopped, it is called the kinetic freeze-out stage.

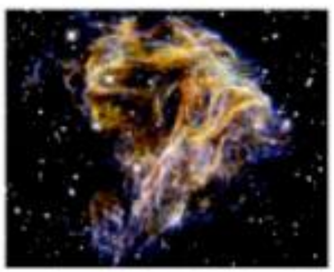
Introduction: Magnetic fields

The Earth’s magnetic field 0.6 Gauss

A common, hand-held magnet 100 Gauss

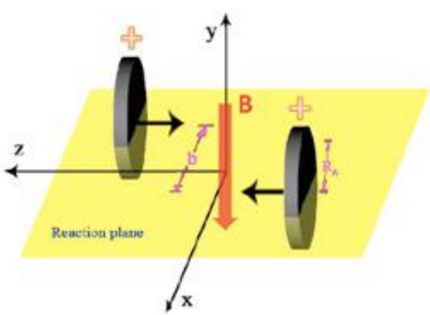
The strongest steady magnetic fields achieved so far in the laboratory 4.5×10^5 Gauss

The strongest man-made fields ever achieved, if only briefly 10^7 Gauss



Typical surface, polar magnetic fields of radio pulsars 10^{13} Gauss

Surface field of Magnetars 10^{15} Gauss



The B field at the colliding time t=0. Biot-Savart law :

$$-eB_y \sim 2 \times \gamma \frac{e^2}{4\pi} Z v_z \left(\frac{2}{b}\right)^2 \sim \boldsymbol{10^{18} Gauss}$$

Introduction: Formulas of *EM* fields

According to Li´enard-Wiechert potentials:

$$\phi = \frac{q}{4\pi\varepsilon_0[r-(\boldsymbol{V}/c)\cdot\boldsymbol{r}]}$$

$$\mathbf{A} = \frac{q\,\mathbf{v}}{4\pi\varepsilon_0 c^2[r-(\mathbf{v}/c)\cdot\boldsymbol{r}]}$$

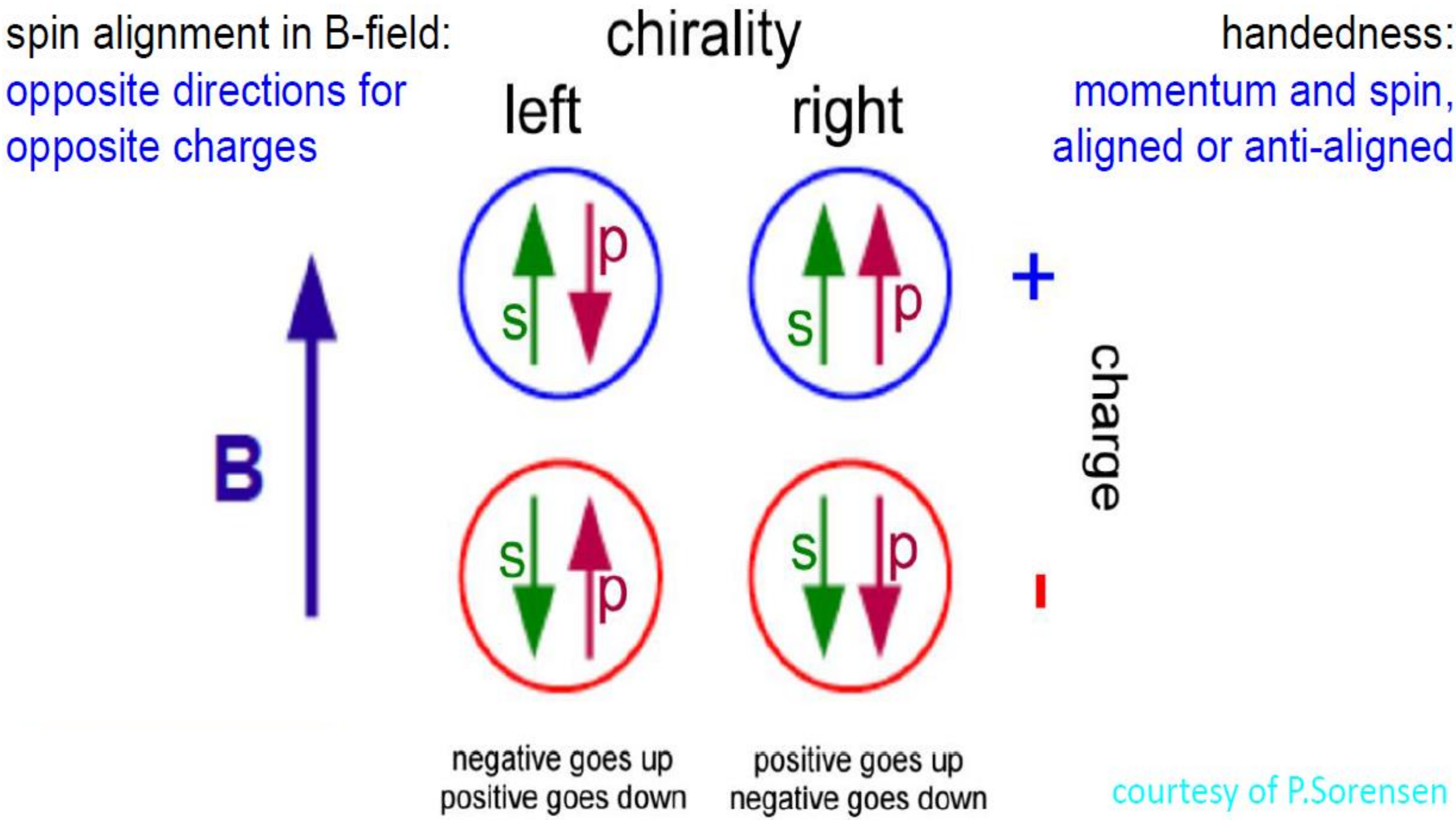
We can get the formulas of ***EM*** fields:

$$e\boldsymbol{E}(t,\boldsymbol{r}) = \frac{Ze^2}{4\pi\varepsilon_0} \sum_n^\infty \frac{\boldsymbol{R_n}-R_n\mathbf{v_n}}{(R_n-\boldsymbol{R_n}\cdot\mathbf{v_n})^3}(1-v_n{}^2)$$

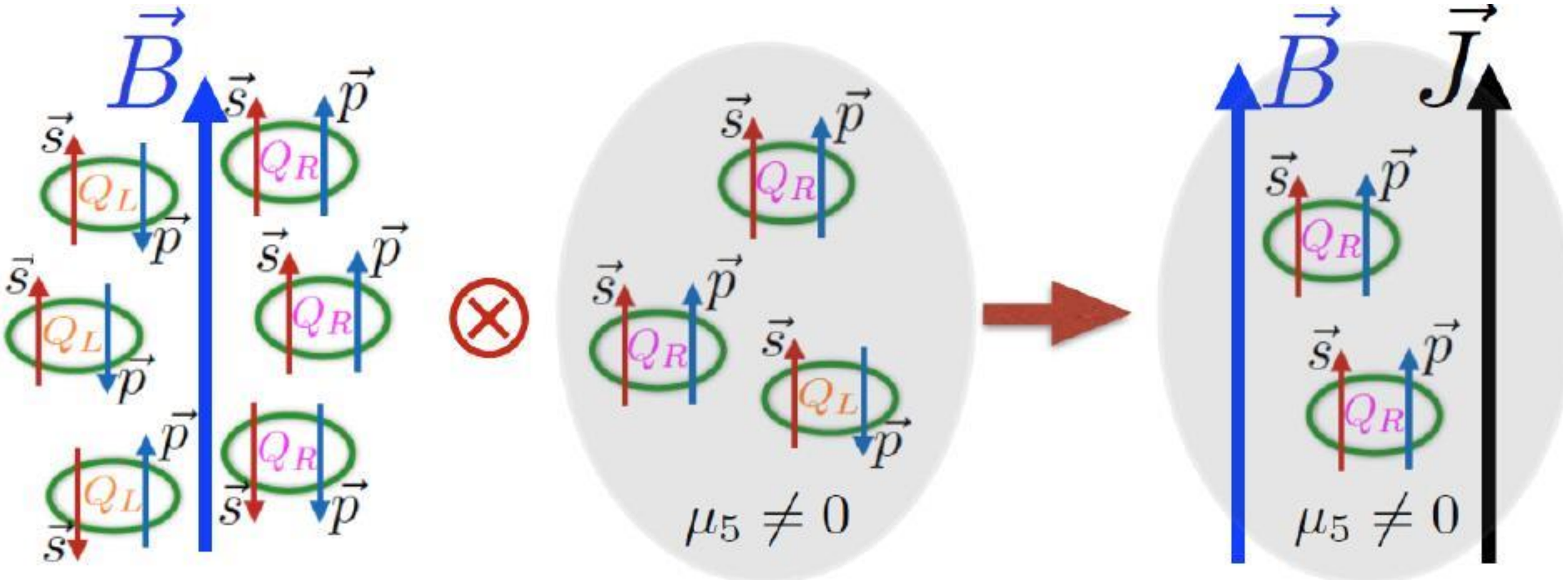
$$e\boldsymbol{B}(t,\boldsymbol{r}) = \frac{Ze^2}{4\pi\varepsilon_0 c} \sum_n^\infty \frac{\mathbf{v_n}\times\boldsymbol{R_n}}{(R_n-\boldsymbol{R_n}\cdot\mathbf{v_n})^3}(1-v_n{}^2)$$

Here t=0, $\boldsymbol{r}$ is the center of mass of participants.

Introduction: Chiral Magnetic Effect



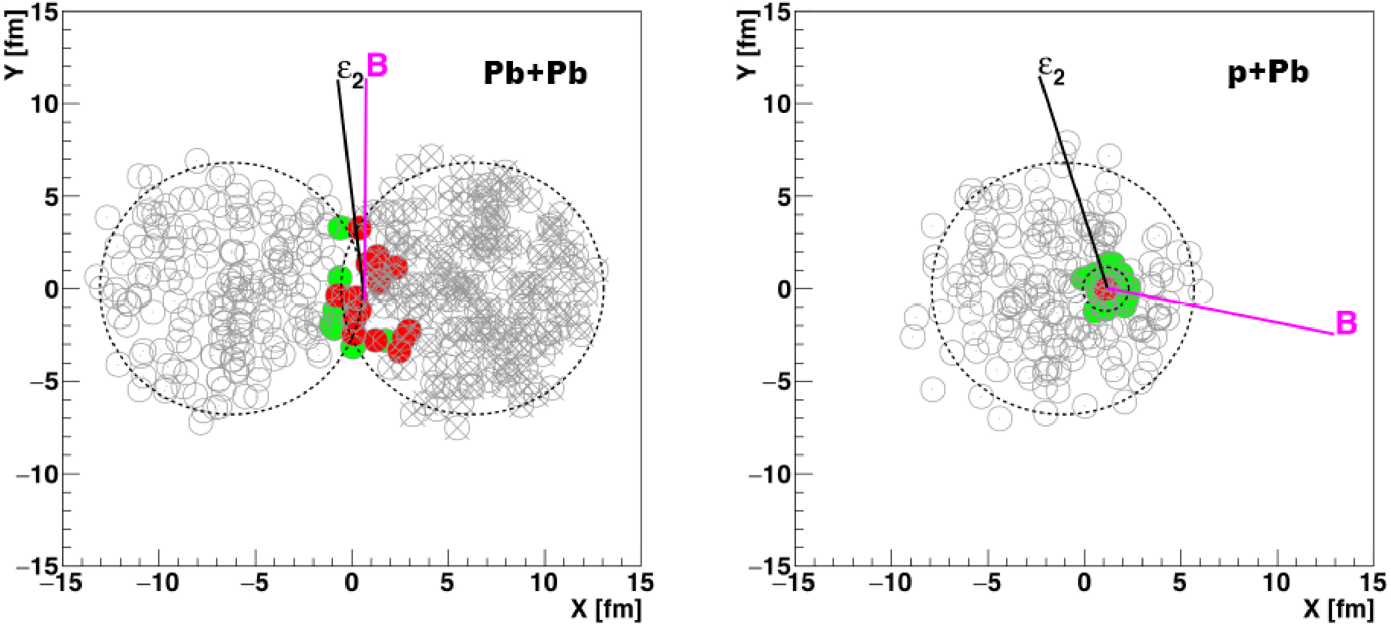
Introduction: Chiral Magnetic Effect



The chiral anomaly of QCD creates differences in the number of left and right handed quarks. An excess of right or left handed quarks lead to a current flow along the magnetic field.

$$\vec{J} = \frac{e^2}{2\pi^2}\,\mu_5\,\vec{B}$$

Introduction: to be CME or not to be CME ?

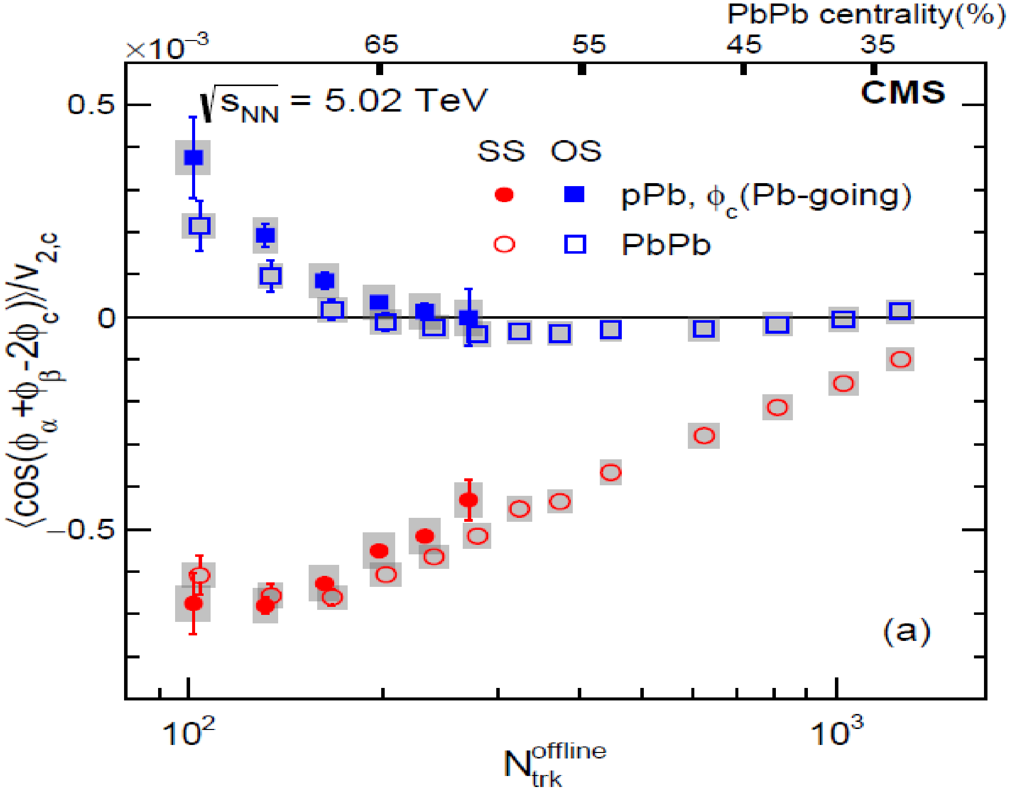


R. Belmont and J.L. Nagle,arXiv:1610.07964v1

$$Pb + Pb\text{:}\quad \boldsymbol{\varepsilon_2 \mathbin{/\!/} \Psi_B}$$

$$p + Pb\text{:}\quad \boldsymbol{\varepsilon_2\ is\ random}$$

Introduction: to be CME or not to be CME ?



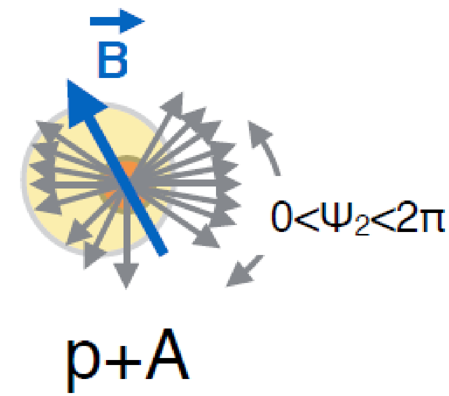
V. Khachatryan et al. (CMS), (2016), arXiv:1610.00263 [nucl-ex].

Similar magnitude and multiplicity dependence of the three-particle correlator observable in pPb collisions relative to that in PbPb collisions indicates that the dominant contribution of the correlation signal may not be related to the CME.

Introduction : Ψ_B and Ψ_2

Charge separation signal: $\Delta r \propto < B^2 \cos 2(\Psi_B - \Psi_{EP}) >$

In pA collisions, if $< \cos 2(\Psi_B - \Psi_{EP}) > \approx 0 \Longrightarrow \Delta r^{CME} \approx 0$

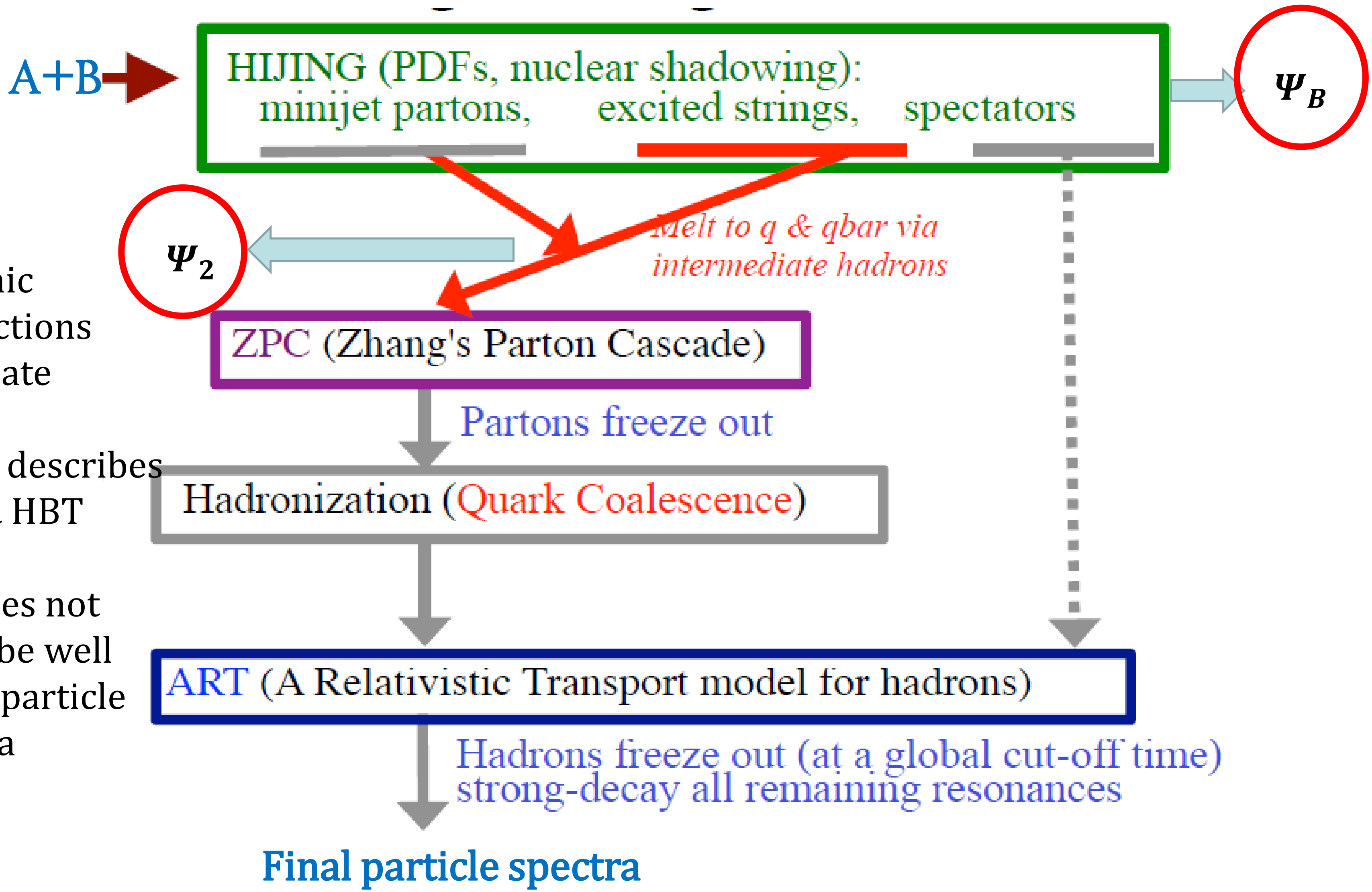


Our work： ①magnetic field

② $< \cos 2(\Psi_B - \Psi_2) >$

$\Psi_2 = \Psi_{EP}$

Introduction : string-melting AMPT model



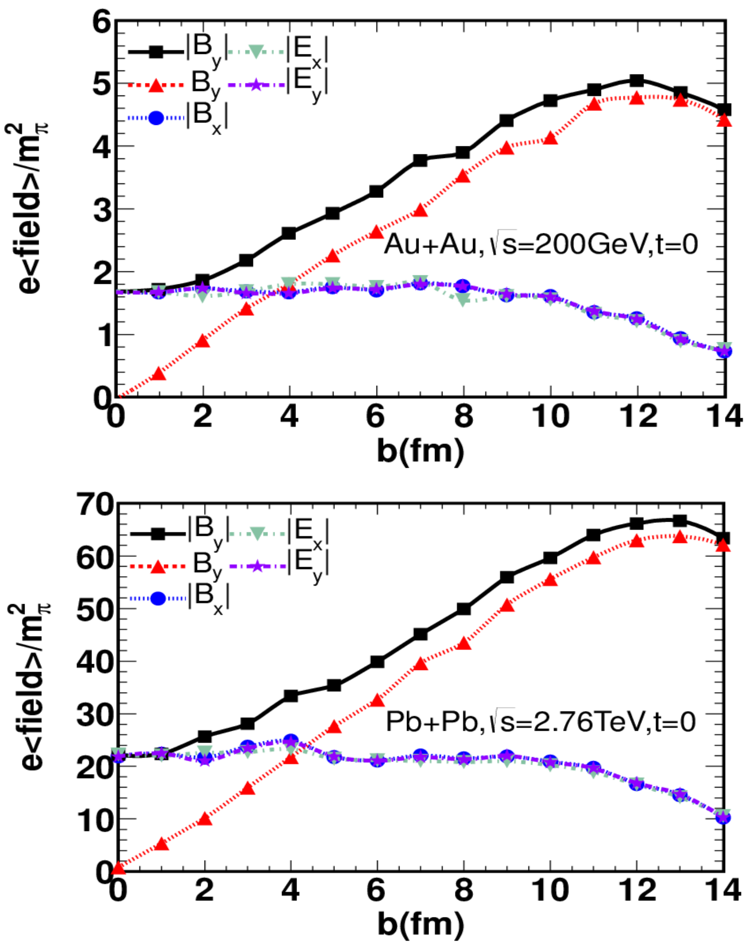
Partonic interactions dominate

Better describes flow & HBT

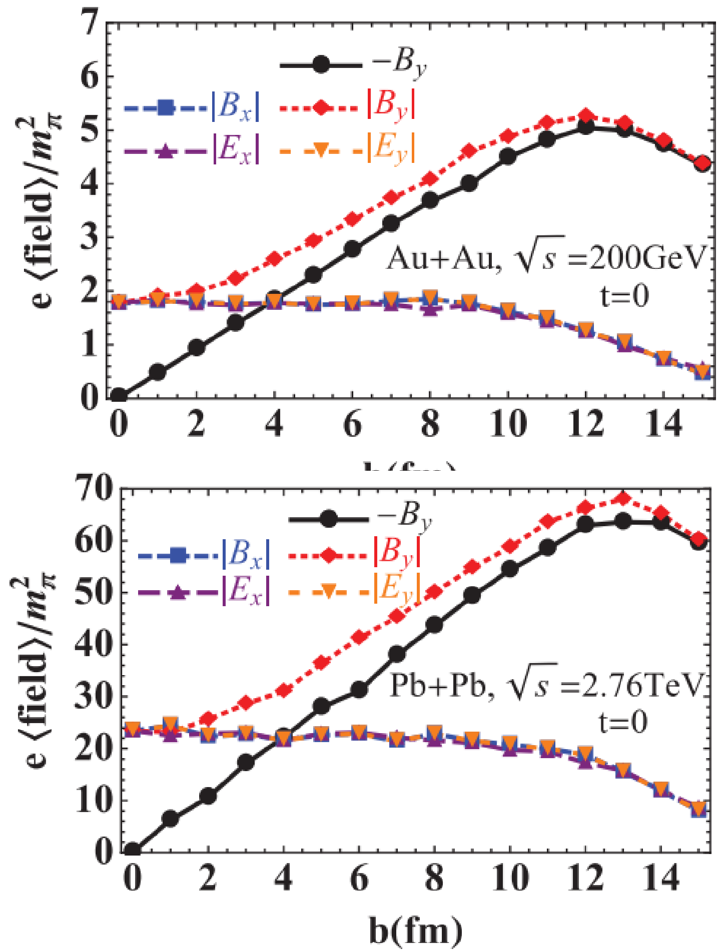
but does not describe well single particle spectra

2 Numerical results and discussions

EM fields in $AuAu$, $PbPb$ collisions



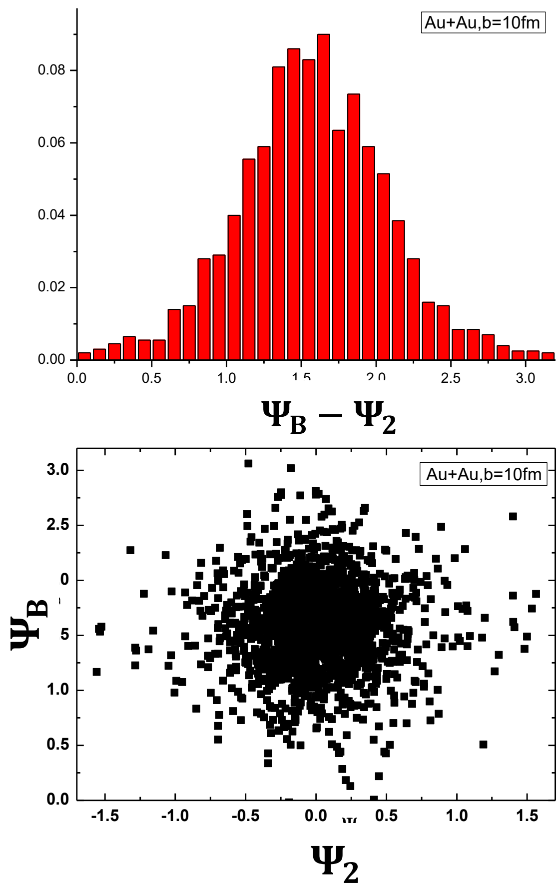
our results



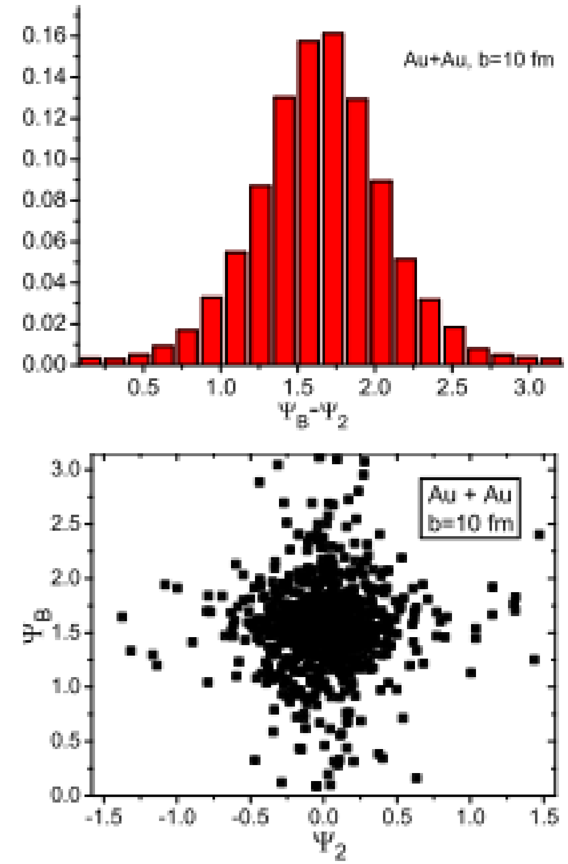
W. T. Deng and X. G. Huang, Phys. Rev. C 85, 044907 (2012)

The results are almost the same.

Ψ_B and Ψ_2 in $\sqrt{S} = 200GeV\ AuAu$ collisions



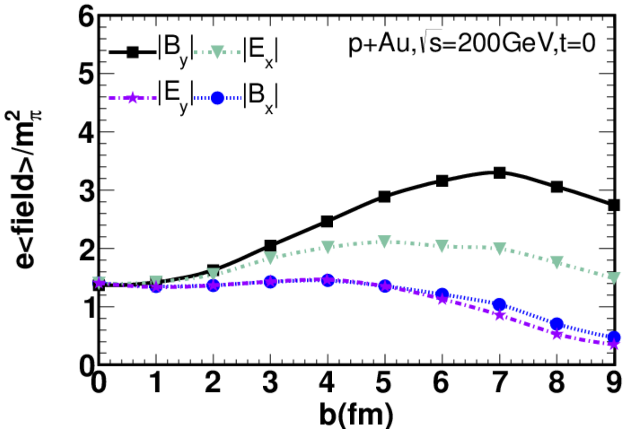
our results

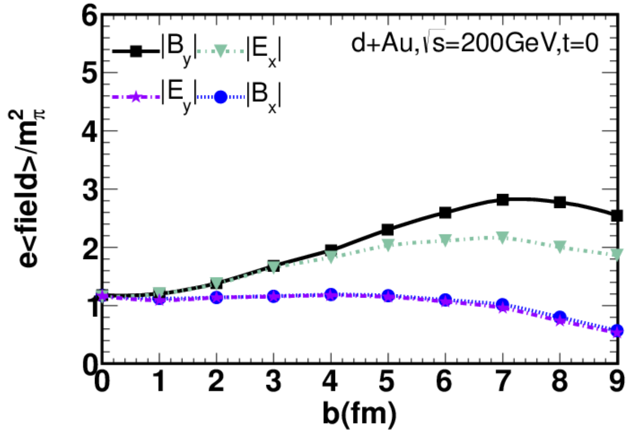


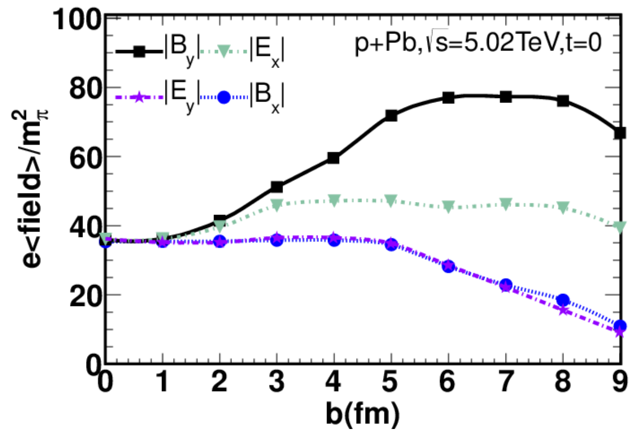
John Bloczynski, X.G Huang et al, arXiv:1209.6594v2

The results are almost the same.

EM fields in pAu, dAu, pPb collisions





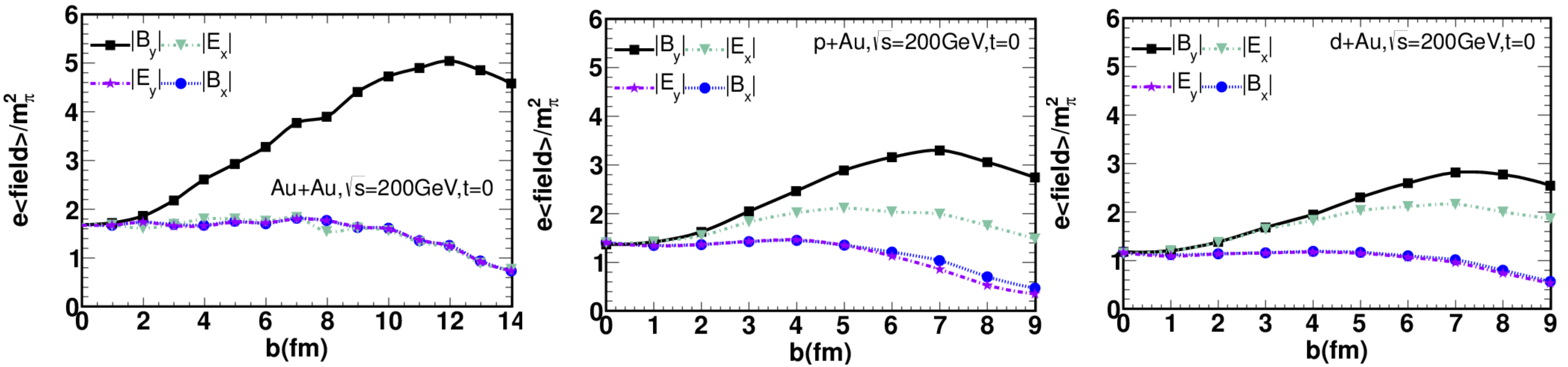


$$\frac{|B_{pPb}|}{|B_{pAu}|} \approx \frac{|B_{pPb}|}{|B_{dAu}|} \approx 25$$

$$\frac{5020GeV}{200GeV} \approx 25$$

$$B \propto \sqrt{s}$$

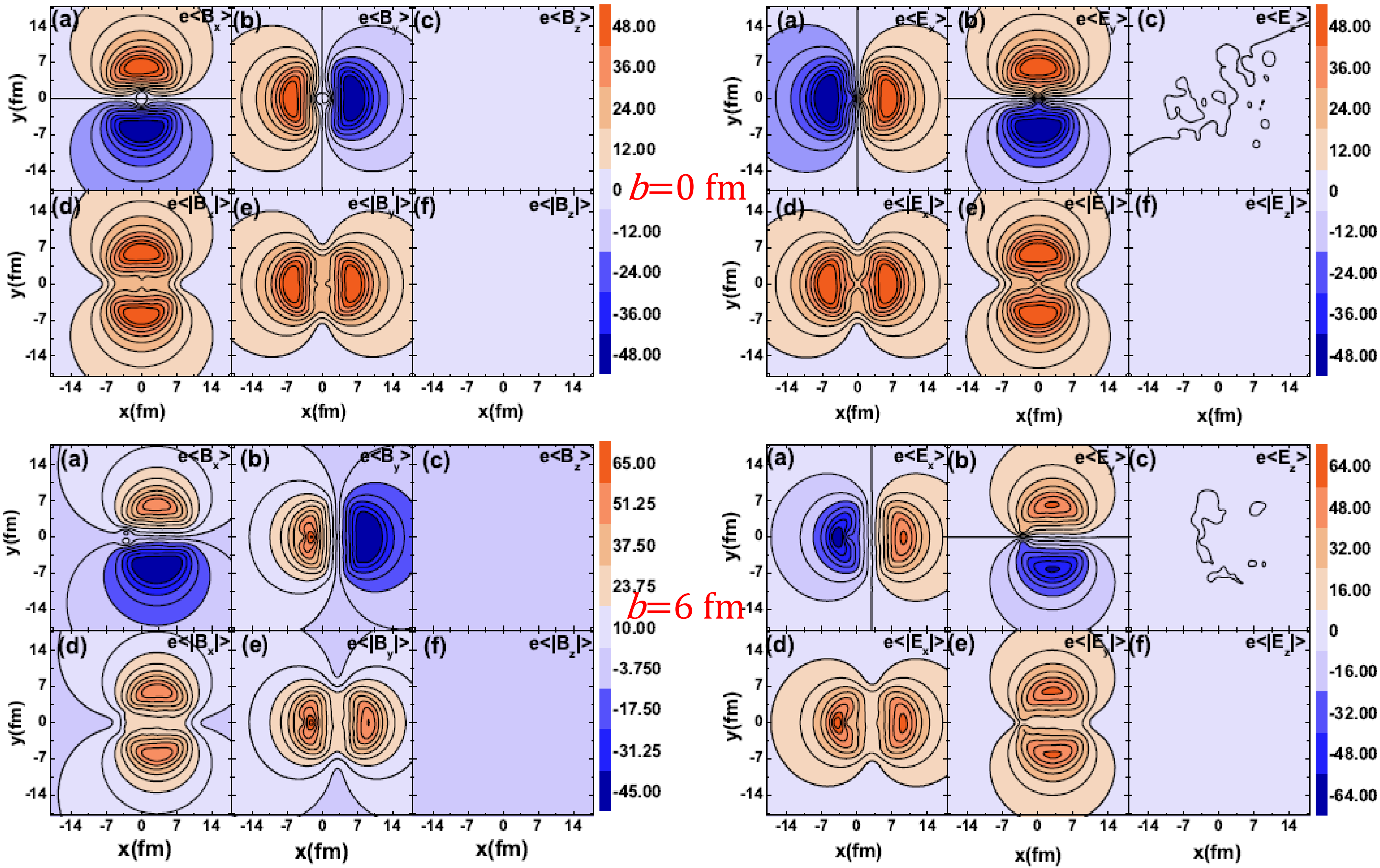
EM fields in $AuAu$, pAu, dAu collisions



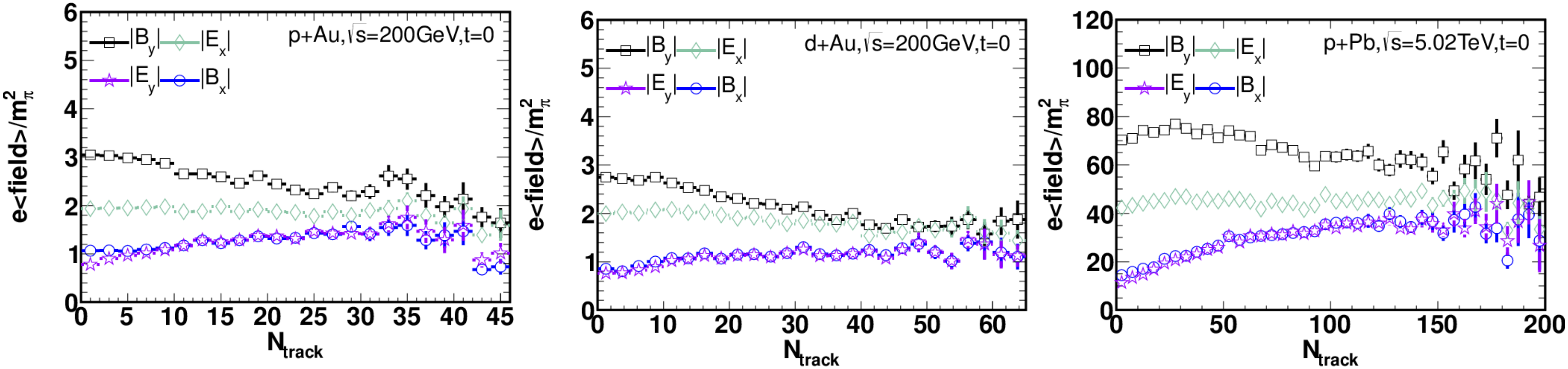
$$\frac{|B_{AuAu}|}{|B_{pAu}|} \approx \frac{|B_{AuAu}|}{|B_{dAu}|} \approx 2$$

$$B \propto Z$$

Spatial distribution of EM fields in $\sqrt{S} = 5.02TeV$ pPb collisions



EM fields in pAu, dAu, pPb collisions



$$\Delta r \propto \underline{<} \; \underline{B^2 \cos 2(\Psi_B - \Psi_2)} >$$

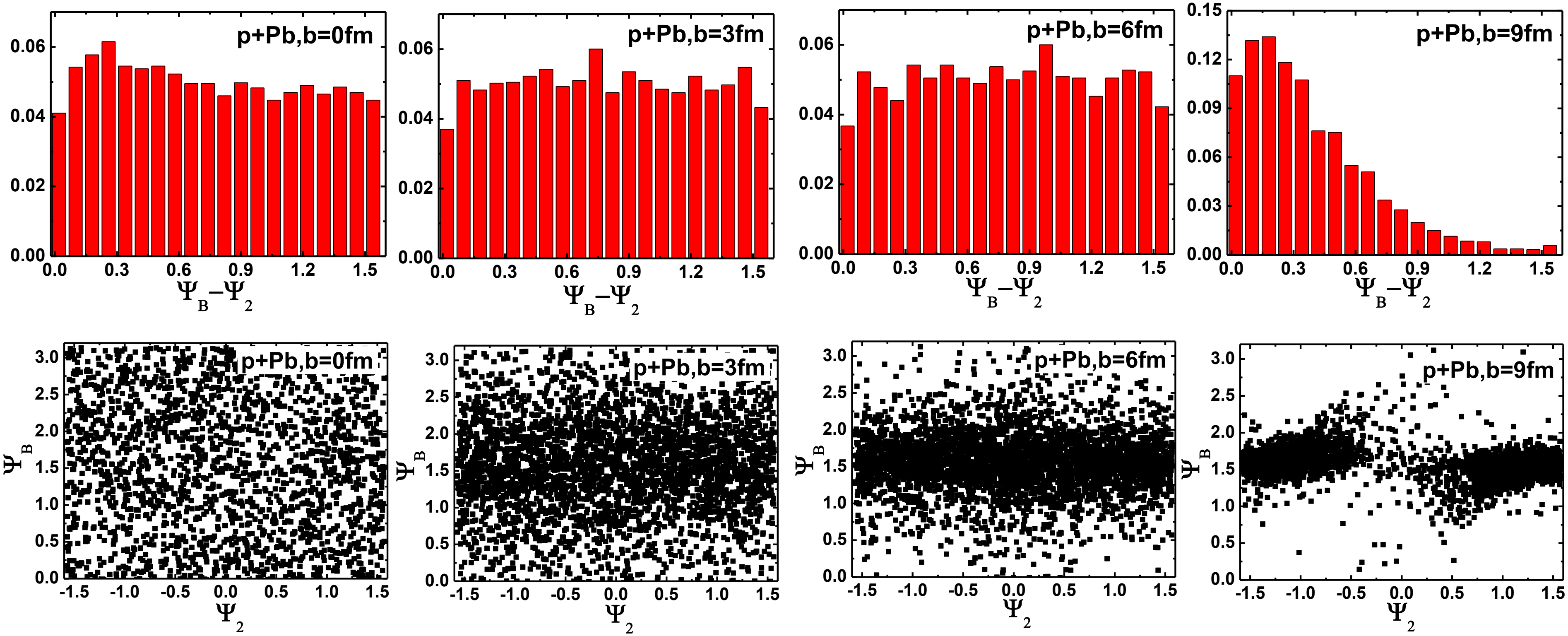
√ ???

N_{track} is the number of charged particles after collisions.

The definitions of N_{track} are the same to the experiments.

RHIC energy: $|\eta| < 2.4$ & $P_T > 0.4\ GeV$ LHC energy : $|\eta| < 1$ & $P_T > 0.15\ GeV$

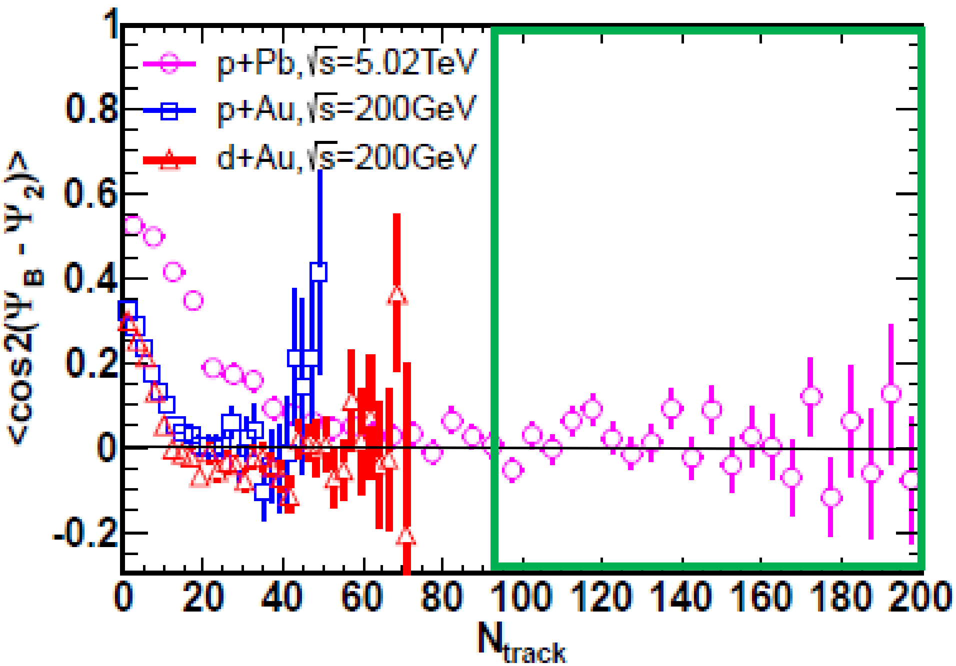
Ψ_B and Ψ_2 in pPb collisions at $\sqrt{S} = 5.02TeV$

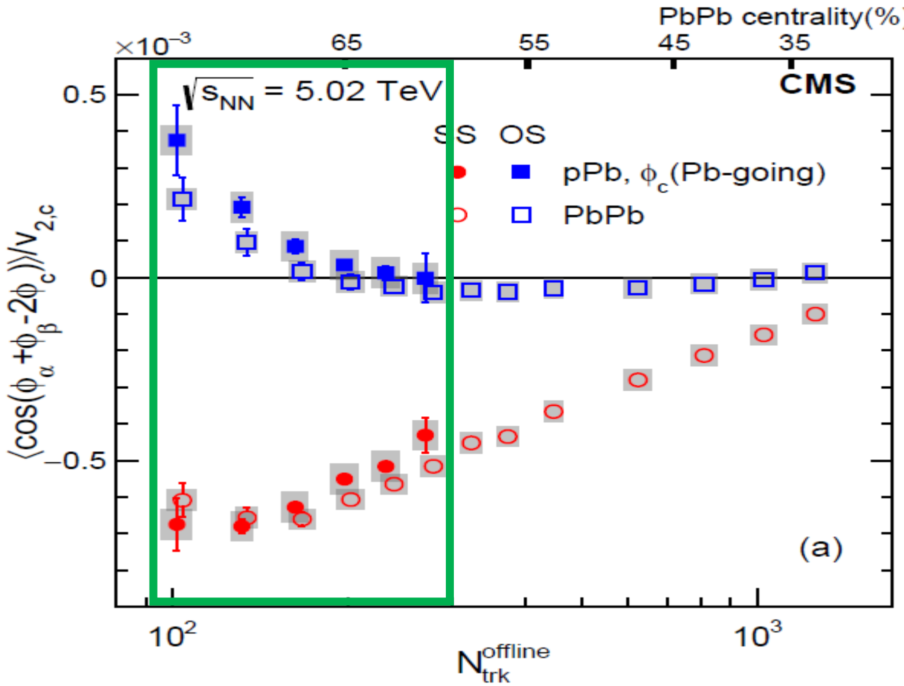


Going from $b = 3$ to 6 fm, $\Psi_B \rightarrow \frac{\pi}{2}$, but Ψ_2 is always random.

In very peripheral collisions(last figure), Ψ_2 is special because the number of partons is less and they can't define Ψ_2 very well.

$< \cos 2(\Psi_B - \Psi_2) >$ in pAu, dAu, pPb collisions





For high−multiplicity events, $< \cos 2(\Psi_B - \Psi_2) > \approx 0 \Longrightarrow \Delta\gamma^{CME} \approx 0.$

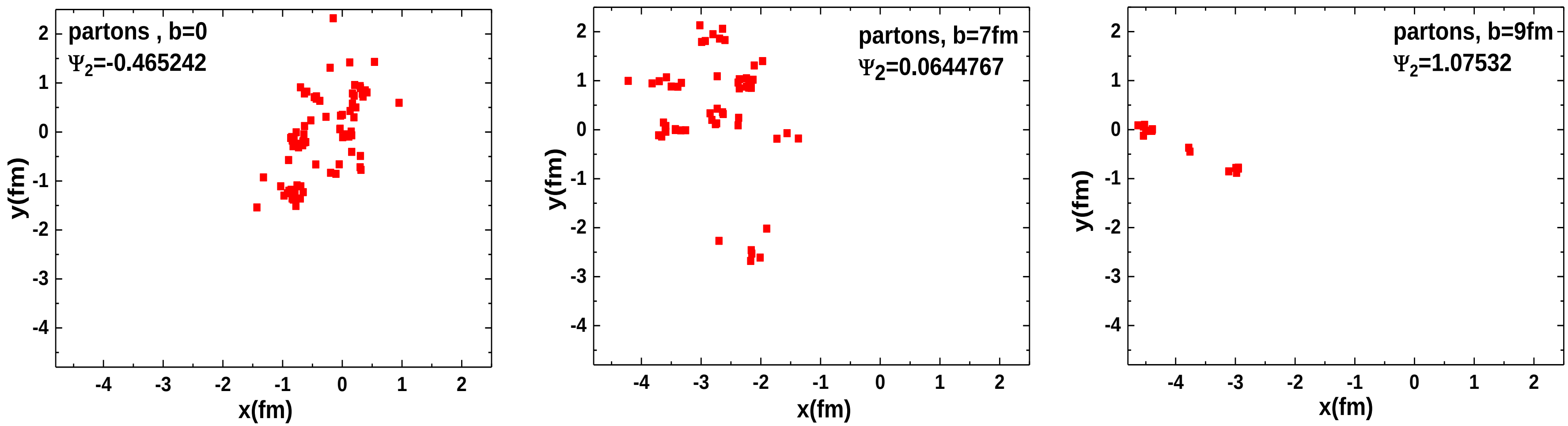
Summary

Using AMPT, we studied :

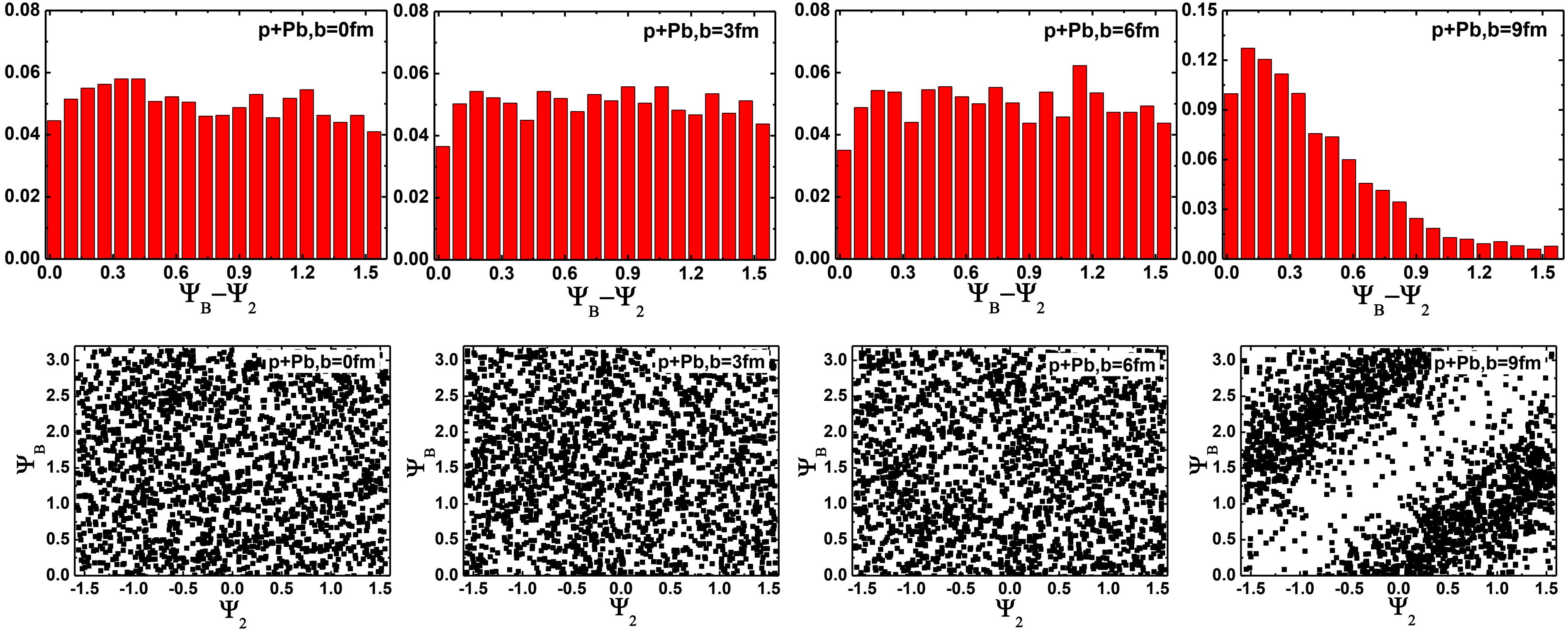
- the relationships between $\boldsymbol{EM}$ fields and b, N_{track}.
- the spatial distributions of the $\boldsymbol{EM}$ fields.
- in pAu, dAu, pPb collisions, $< cos2(\Psi_B - \Psi_2) > \approx 0$ for high-multiplicity events. This indicates that the traditional experimental CME observable three-particle correlation is not sensitive to CME any more for small systems.

Thank you for your attention!

The distributions of partons and Ψ_2 in differet centrality

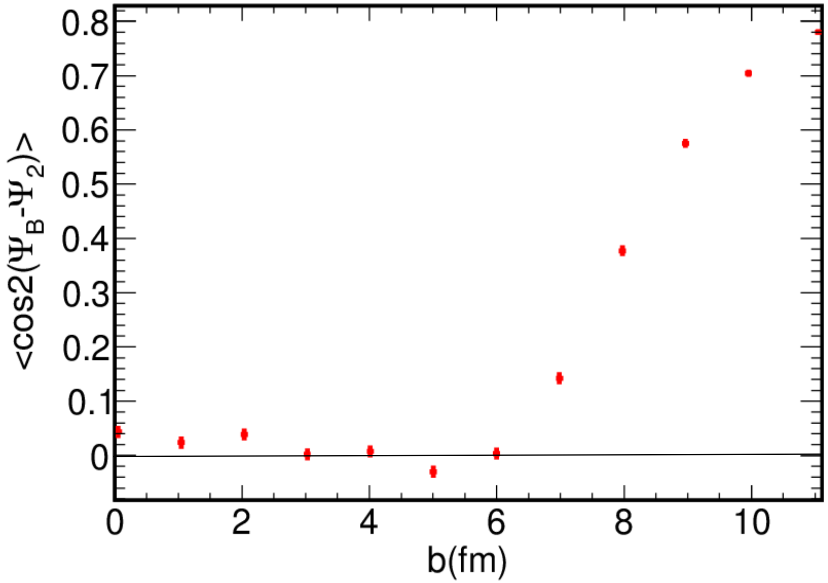


Ψ_B and Ψ_2 in $\sqrt{S} = 5.02TeV\ pPb$ collisions, random orientation of reaction plane in AMPT



Ψ_B & Ψ_2 are all random.

$< \cos 2(\Psi_B - \Psi_2) >$ in $\sqrt{S} = 5.02 TeV\ pPb$ collisions random orientation of reaction plane in AMPT



The results of $< \cos 2(\Psi_B - \Psi_2) >$ are similar to previous calculations.

This is because the rotation of the coordinate system does not affect the results of $\Psi_B - \Psi_2$.

The definitions of $\boldsymbol{\Psi_B}$ and $\boldsymbol{\Psi_2}$

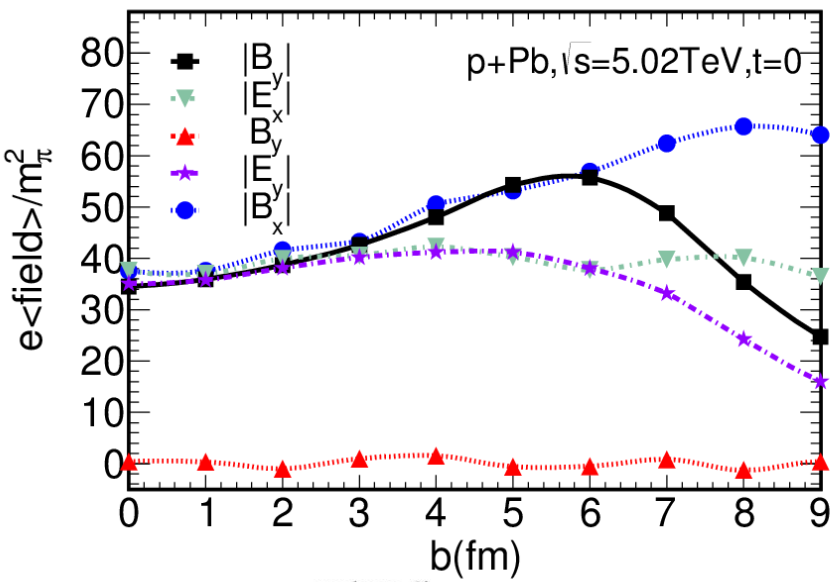
$$\Psi_2 = \frac{\mathrm{atan2}(< r^2 \sin(2\phi) >, < r^2 \cos(2\phi) >)+\pi}{2}$$

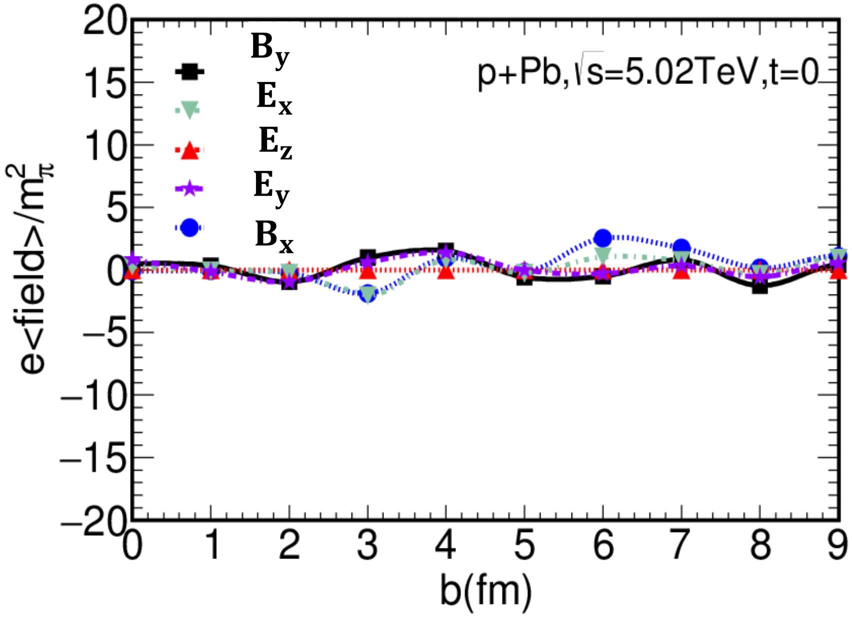
$$\Psi_\mathrm{B} = \mathrm{atan2}(\mathrm{B}_y, \mathrm{B}_\mathrm{x})$$

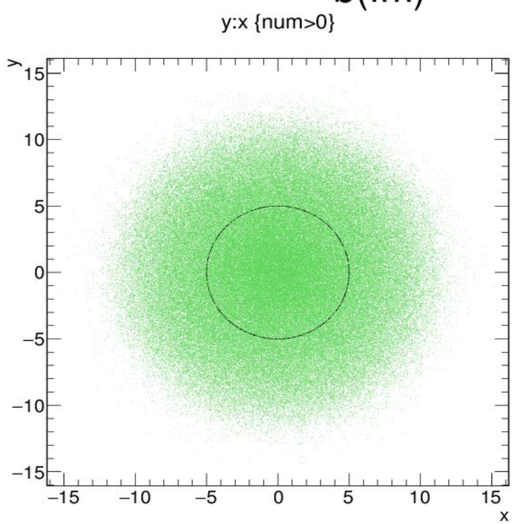
$$\Psi_B \in (-\pi, \pi), \Psi_2 \in ({\color{red}-\pi, \pi})$$

or $\Psi_B \in (-\pi, \pi), \Psi_2 \in \left({\color{red}-\frac{\pi}{2}, \frac{\pi}{2}}\right)$

EM fields in $\sqrt{S} = 5.02TeV\ pPb$ collisions random orientation of reaction plane in AMPT



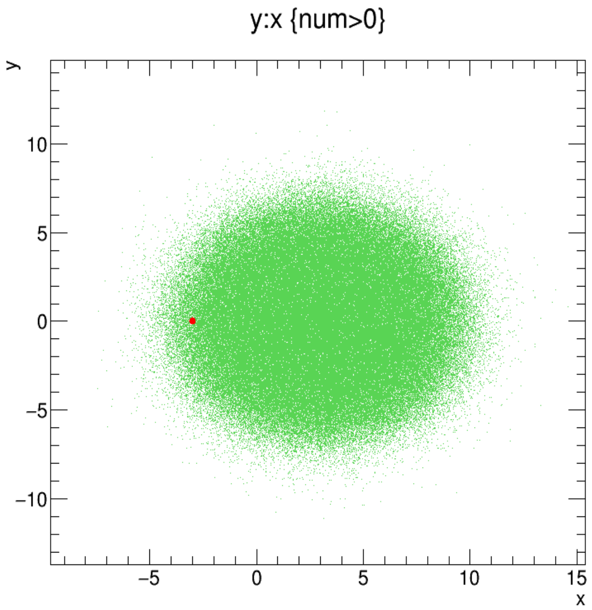




green dots are the nucleons of Pb

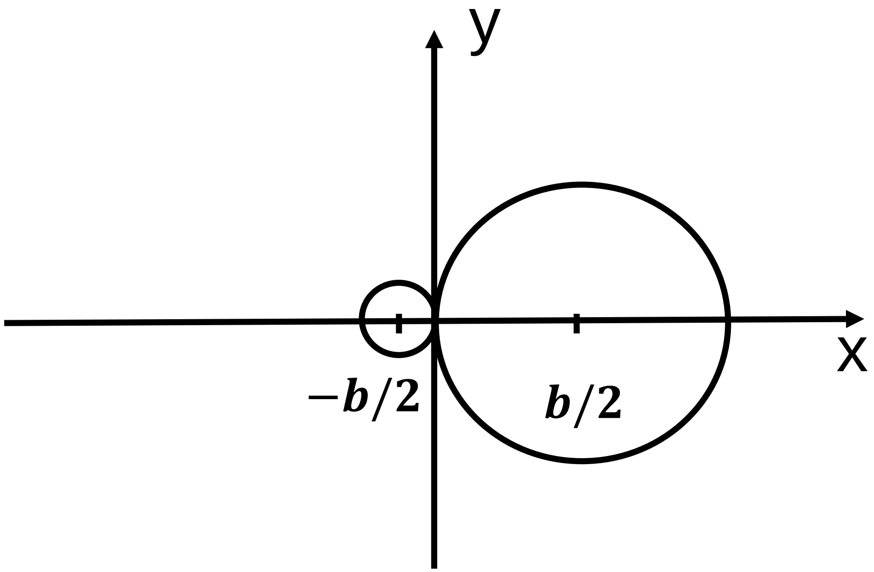
black dots are the nucleons of p

Geometry of particular events in small systems



green dots are the nucleons of Pb

red dots are the nucleons of p



Geometry in AA collisions

The geometric image: