An Experimental Handle on Magnetic Field from Spectator Protons in A+A Collisions

Subikash Choudhury

Prof. HZ Huang, Dr. W. B. He, Dr. L. Ma, Dr. W. Gang , Mr. Hu Yu

Fudan University

复旦大学

中国物理学会高能物理分会第十届全国会员代表大会暨学术年会

CHEP 2018, June 20-24

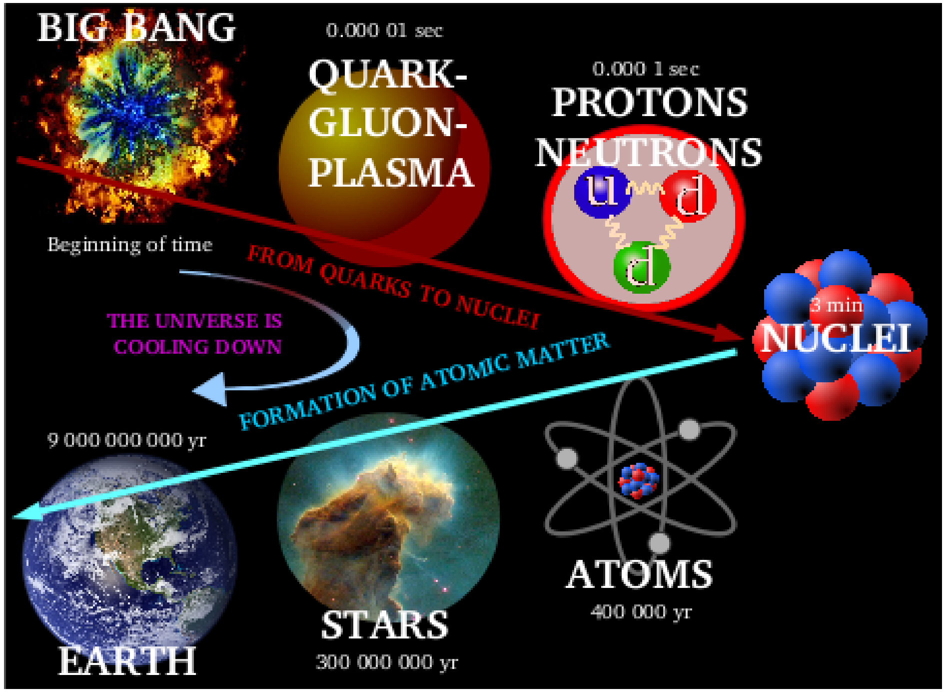
Outline

- ➢Introduction to High Energy Heavy Ion Collisions
- ➢ Chiral Anomaly in Heavy Ion Collisions
- ➢ Chiral Magnetic Effect (CME)
- ➢ Experimental determination And Challenges
- ➢ Simulation of Magnetic (B) field from the Glauber Monte Carlo
- ➢ Net-proton as an experimental control over B-field
- ➢ Summary

Relativistic Heavy Ion Collisions

Heavy ion collisions at (ultra)relativistic energies is often called as “Little Bangs”
i.e a miniaturized “Big Bang” at Laboratory.

Collisions at the scale of Millions or Trillions of eV (MeV/TeV) offers an unique avenue to access those elusive moments from few micro-seconds from the “Big Bang”
- A Time Machine



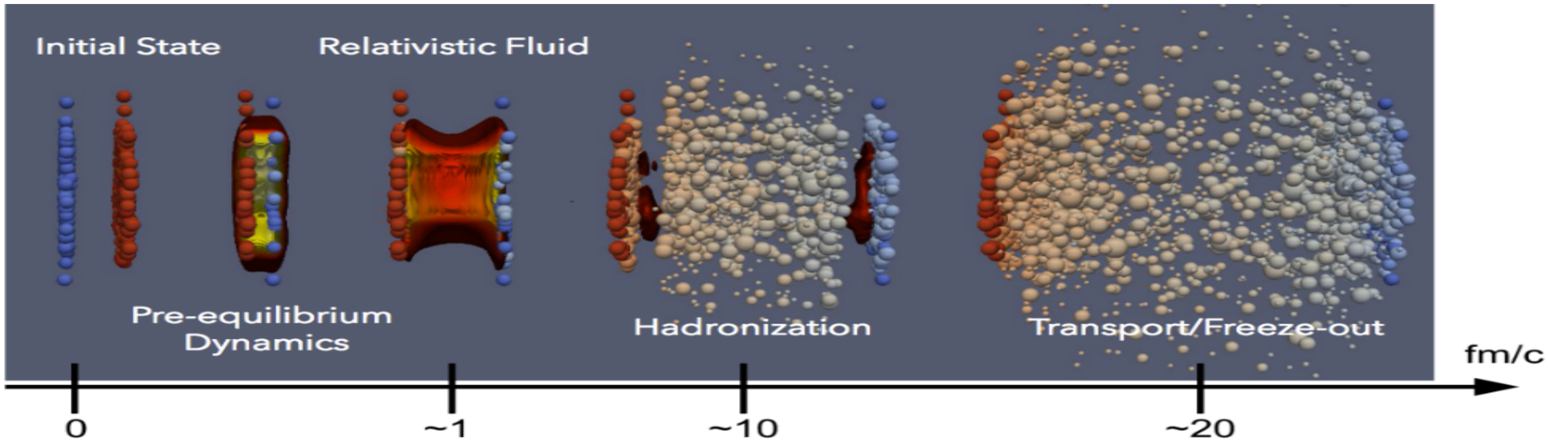
Relativistic Heavy Ion Collisions

Heavy ion collisions at (ultra)relativistic energies is often called as “Little Bangs” i.e a miniaturized “Big Bang” at Laboratory.

Collisions at the scale of Millions or Trillions of eV (MeV/TeV) offers an unique avenue to access those elusive moments from few micro-seconds from the “Big Bang”
- A Time Machine

Theoretical studies based on lattice QCD predicted, under such extreme conditions a new state of matter may be produced primarily made of deconfined (nearly free) quarks and gluons, historically called the Quark Gluon Plasma

Unremitting experimental efforts have been devoted over several decades to create and characterize (also theoretical) this novel form of matter. And many are in pipe-line



Relativistic Heavy Ion Collisions

The First Sight : Winter 2000, first formal declaration of "new state of matter" at CERN SPS

The combined data coming from the seven experiments on CERN's Heavy Ion programme (at SPS) have given a clear picture of a new state of matter.........We now have evidence of a new state of matter where quarks and gluons are not confined. There is still an entirely new territory to be explored concerning the physical properties of quark-gluon matter. The challenge now passes to the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory and later to CERN's Large Hadron Collider.

- Professor Luciano Maiani, CERN Director General, [CERN Press Release on 10 Feb 2000, GENEVA]

http://press.web.cern.ch/press-releases/2000/02/new-state-matter-created-cern.

RHIC scientists accept the challenge. Five years down the line another press release came-in:

RHIC Scientists Serve Up 'Perfect' Liquid

a new state of hot, dense matter' was created 'out of the quarks and gluons .. but it is a state quite different and even more remarkable than had been predicted.

[Press release 18 April 2005]

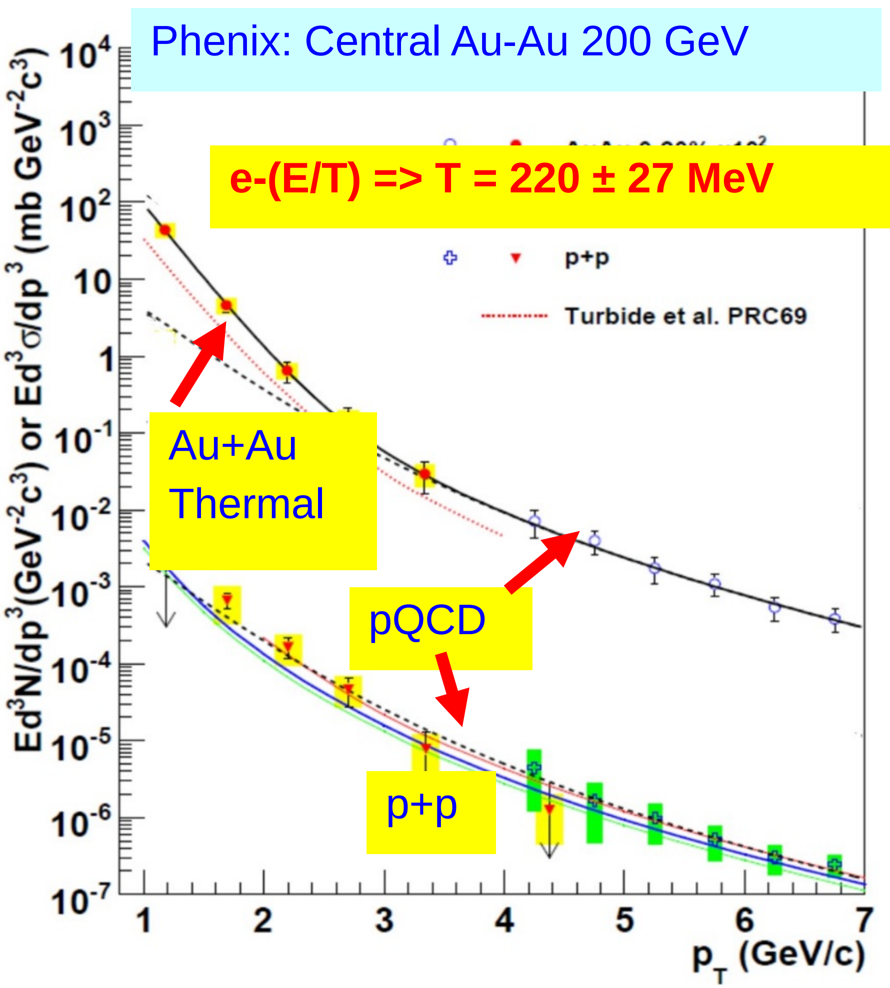
http://www.bnl.gov/newsroom/news.php?a=110303.

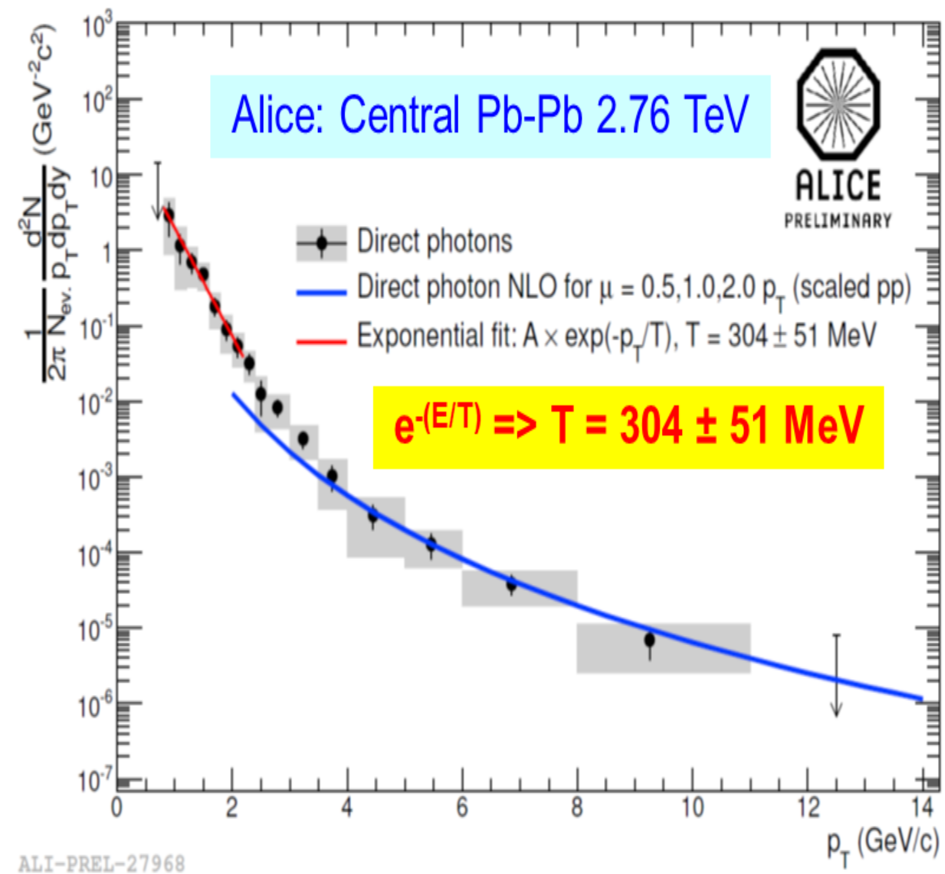
DOE calls out: ".. investment paying off"

So, we have the confirmation that hot and dense QGP is produced. In contrary to the expectation, its a perfect liquid and not gas.

Relativistic Heavy Ion Collisions

How "hot" is QGP ?





300 MeV ~ 10^{10} K

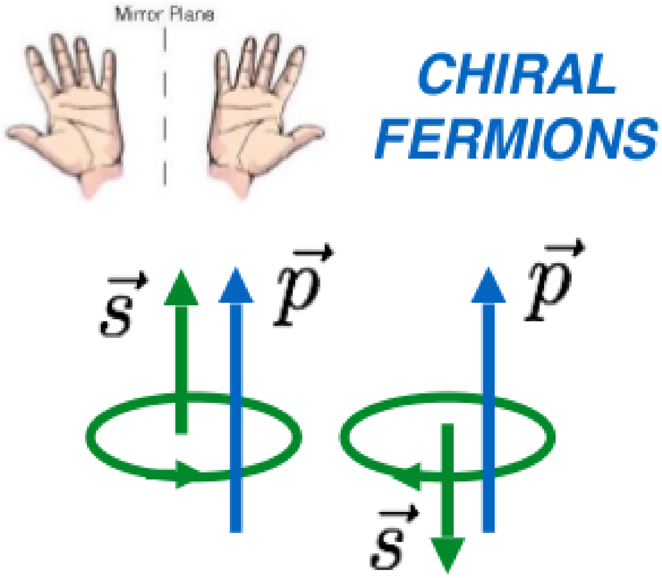
10^4 times temperature of the core of the Sun (15 million Kelvin)

Besides being super-hot, these collisions produce the strongest magnetic field ~ 10^{18} times the Earth' Magnetic field.

Chiral Anomaly in HIC

Heavy ion collisions produce a de-confined state of quarks and gluons: the Quark Gluon Plasma

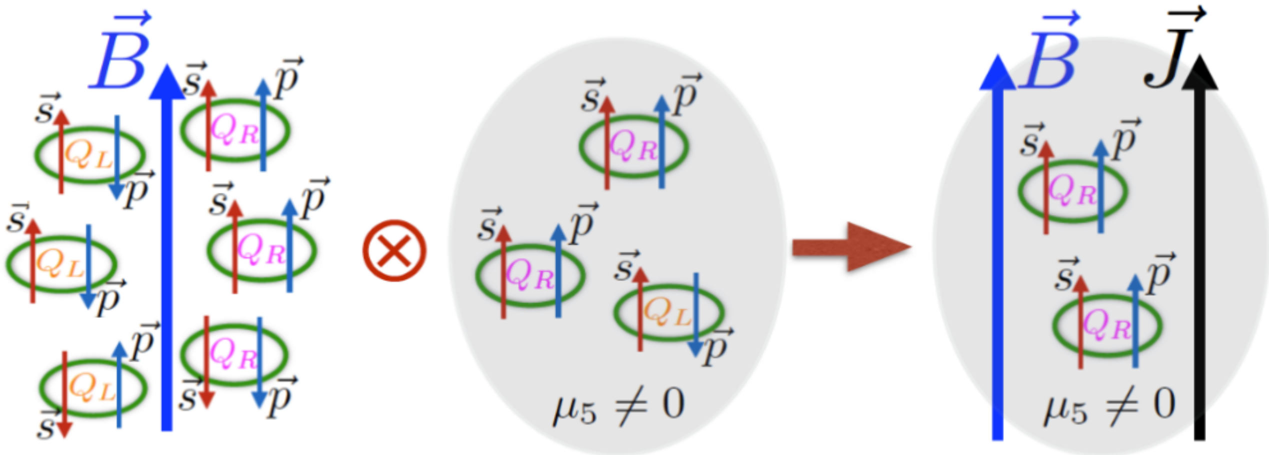
Strong interactions governed by QCD in general conserve parity, i.e, equal number of left (LH) and right (RH) handed quarks



But some local domains may be produced with net-chirality, i.e, imbalance in the number of LH and RH quarks

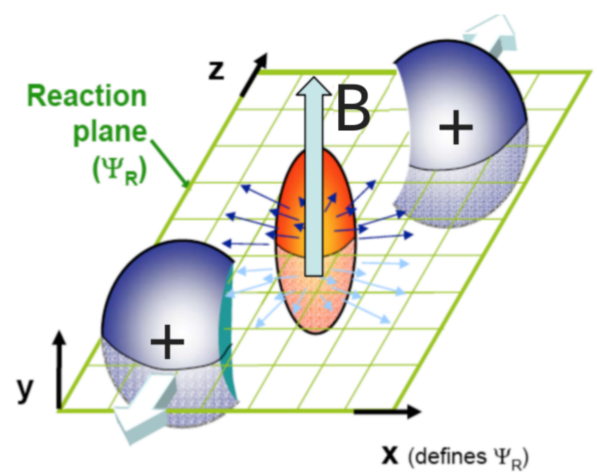
The Chiral Magnetic Effect

This chiral imbalance in presence of strong B-field manifest itself in a macroscopic charge separation known as the Chiral Magnetic Effect (CME)



The charge separation is along the direction of B-field resulting in a transport current.

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

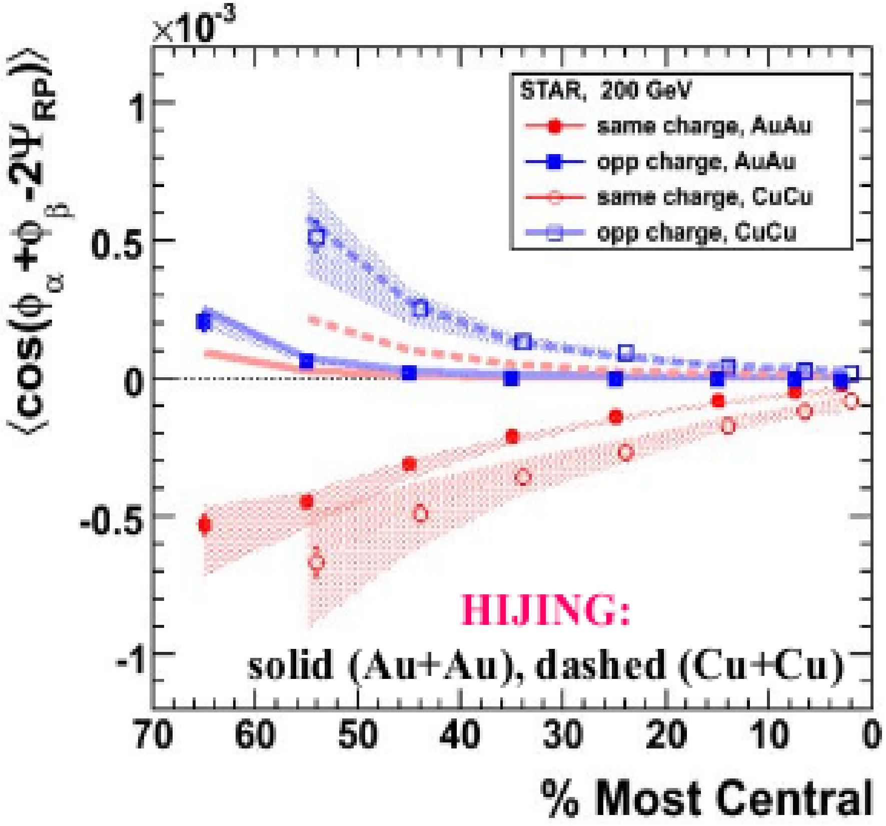


Experimental Observable

➢ The CME induced charge separation is along the B-field or perpendicular to reaction plane.

➢ The charge-dependent 3-particle correlator (γ)[1] is one of the experimental measure of CME-driven charge separation.

➢ Although the measurements are qualitatively consistent with the CME expectations but it still remains inconclusive mainly because of several known sources of background that may account for the observed signal partially or fully.



[1] S. Voloshin, Phys. Rev. C, 057901 (2004)

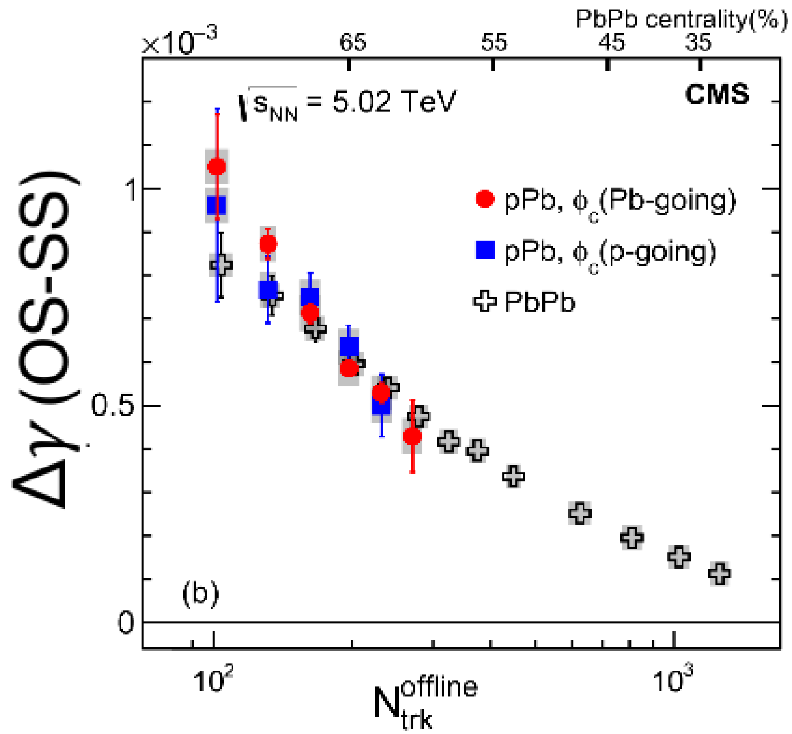
Challenges

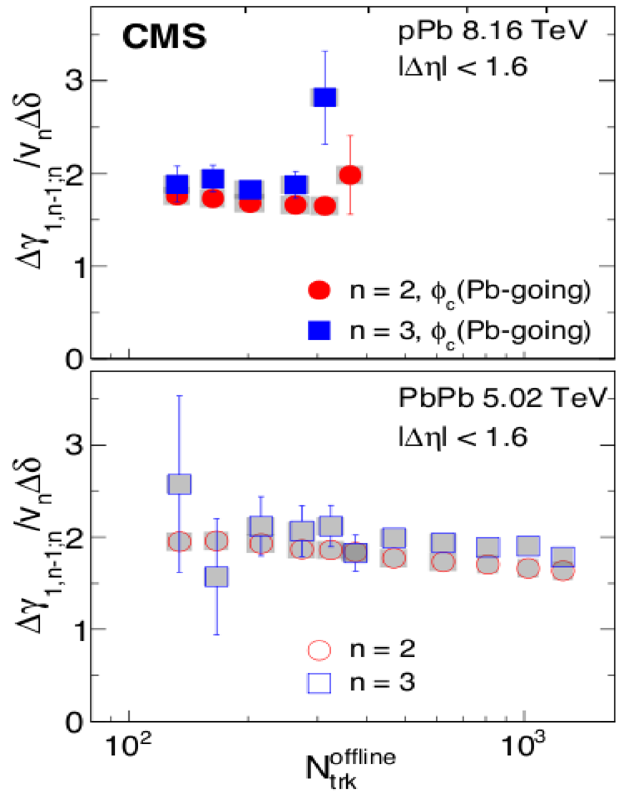
Difficult measurement:

- On average the charge separation is zero
- Weak signal strength, if any
- Known and unknown background contributions.
- No direct experimental measure or control over B-field

Charge separation signal: $\Delta\gamma \sim \left\langle B^2 \cos 2\left(\Psi_B - \Psi_{EP}\right)\right\rangle$

- Recent CMS measurements find identical response in pA and PbPb collisions
- Consistent with the background





Challenges

Difficult measurement:

- On average the charge separation is zero
- Weak signal strength, if any
- Known and unknown background contributions.
- No direct experimental measure or control over B-field

Charge separation signal: $\Delta\gamma \sim \left\langle B^2 \cos 2\left(\Psi_B - \Psi_{EP}\right)\right\rangle$

- Recent CMS measurements find identical response in pA and PbPb collisions
- Consistent with the background

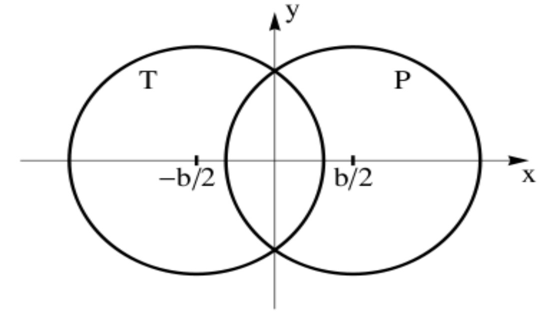
RHIC is poised to make a breakthrough with isobaric collisions, where the background Contribution is identical but B-field changes by 10-15%

$^{96}Ru+^{96}Ru$ and $^{96}Zr+^{96}Zr$ at $\sqrt{s_{NN}} = 200$ GeV

Complementary measurements may be pursued at lower energy regime, for example AuAu 27 GeV collisions or lower.

B-field simulation from Glauber MC

Fast moving nuclei, mainly spectators in off-central collisions generate transient but strong B-field.



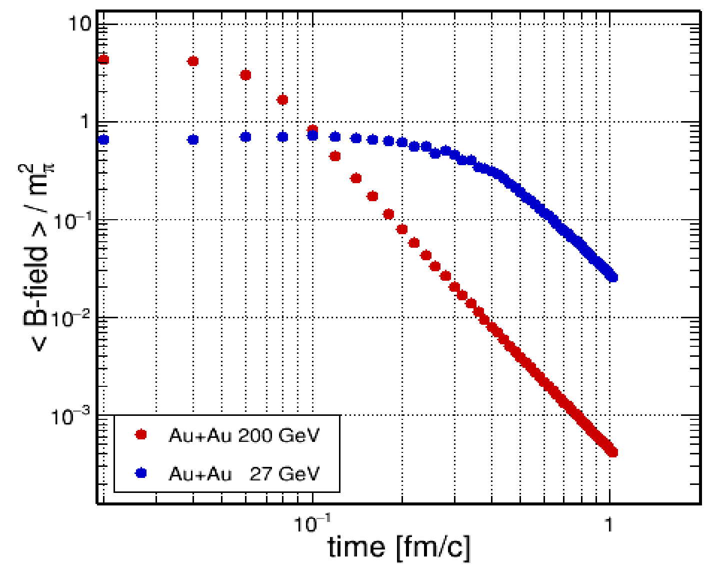
In Au-Au collisions at top-RHIC energy it can be as high as eB$\sim m_{\pi}^{2} \sim 10^{18}$ Gauss.

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

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

Using the Liénard-Wiechart potentials, magnetic fields due to spectator protons are calculated event-by-event.

The time evolution of magnetic field at x =0, y=0 in mid-central (b = 8 fm) Au+Au collisions at 200 GeV and 27 GeV centre-of-mass energy



B-field at 200 GeV drops very sharply than 27 GeV

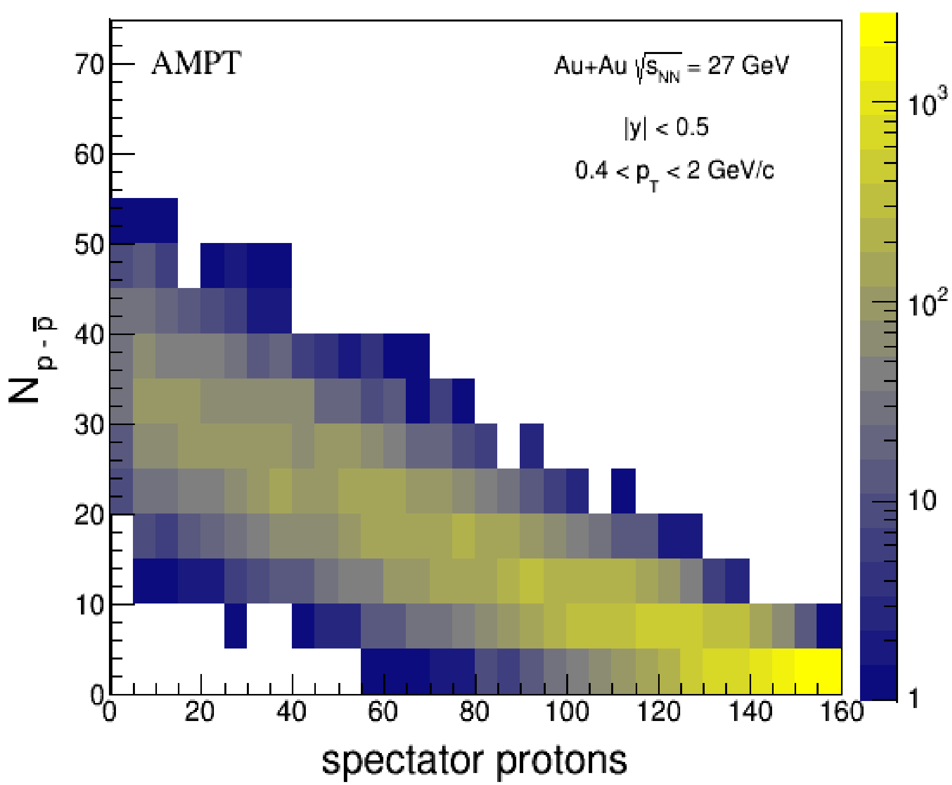
Compromise in strength but longer life time may enhance the CME-signal

Net-proton : An experimental Handle on B-fields from Spectators

At low and intermediate energies at RHIC, because of baryon stopping, net baryon hence the net proton fluctuates around a large non-zero value.

Can we use net-protons as an experimental handle over B-field ?

Using model simulation (AMPT), we find an interesting anti-correlation between net-protons and spectator protons



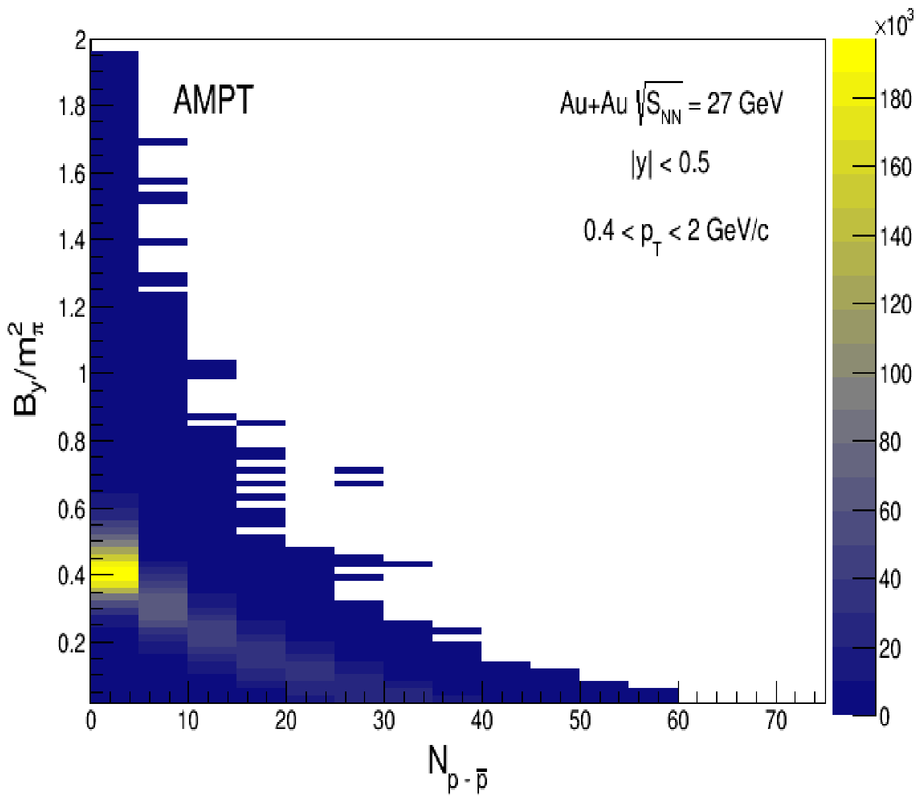
Net-proton : An experimental Handle on B-fields

At low and intermediate energies at RHIC, because of baryon stopping, net baryon hence the net proton fluctuates around a large non-zero value.

Can we use net-protons as an experimental handle over B-field ?

Using model simulation (AMPT), we find an interesting anti-correlation between net-protons and spectator protons

Less net-protons means higher Spectator proton, implies larger B-field



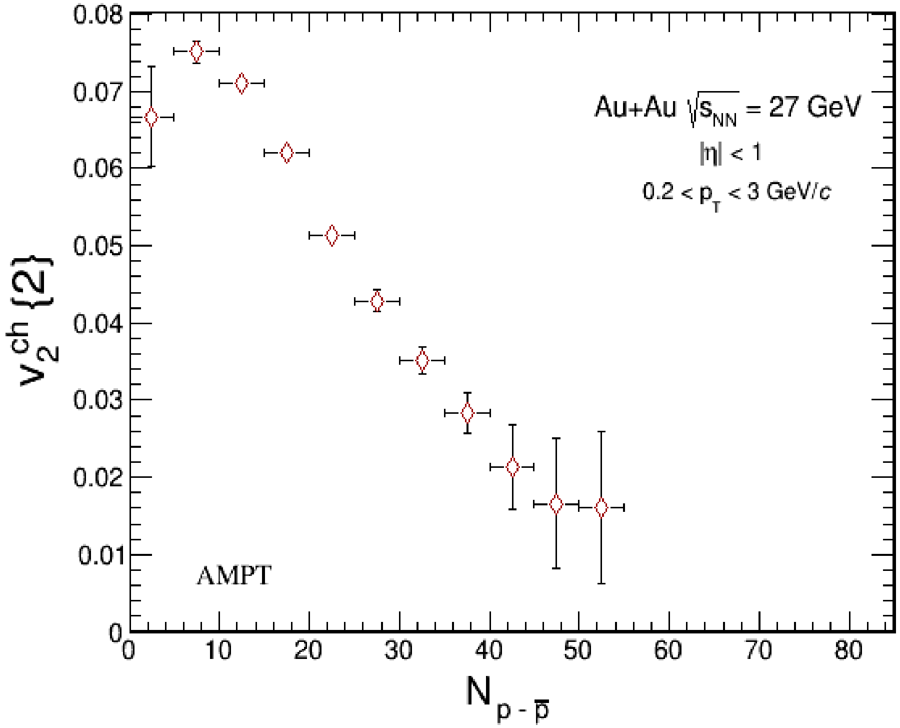
This anti-correlation can be exploited to classify events into varying strength of magnetic fields

Background dist (v_2) with net-proton

Since v_2 or elliptic flowis the major source of background to the CME study, one needs to look how it varies with net-proton as well

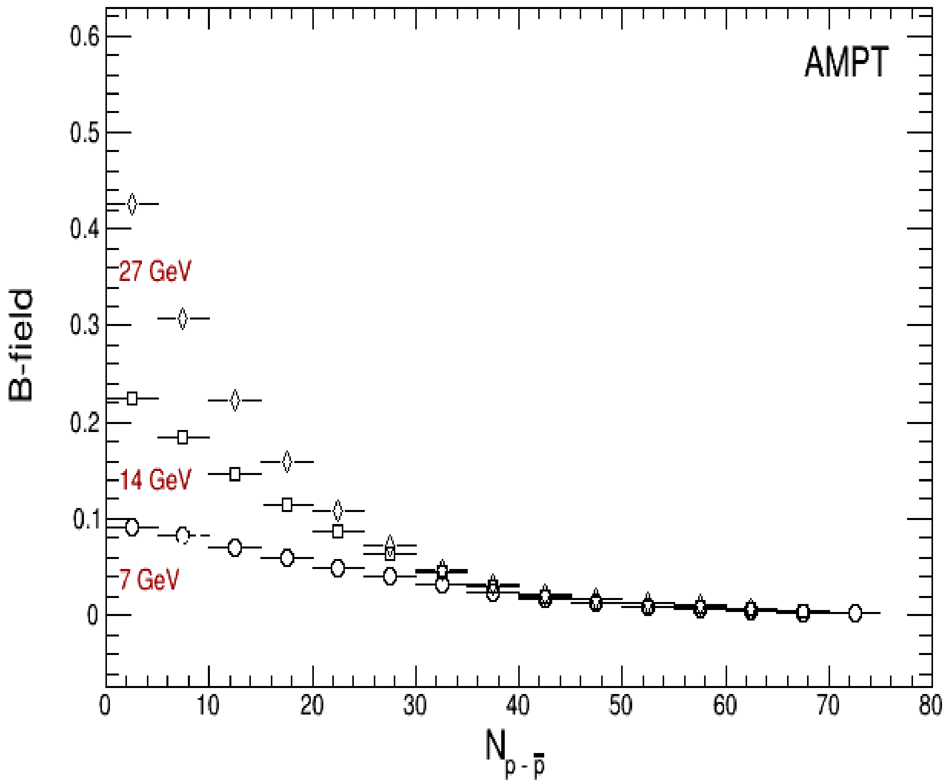
v_2 has a similar (decreasing) trend With net-proton number

We may additionally use the concept of Event Shape Engineering (ESE) [2] to minimize the v_2 background

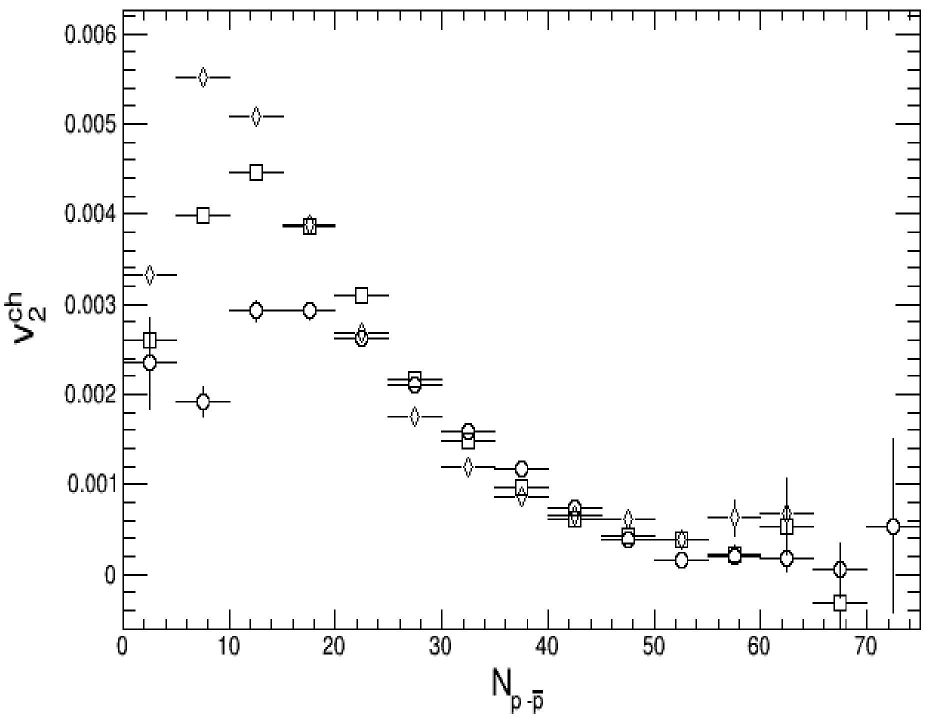


[2]F. Wen et al., Chinese Phys C 42(1) (2018) 014001 [arXiv:1608.03205]

Beam Energy Dependence



v_2 at lower net-proton shows
A decreasing trend. Could be
useful



- B-field increases with beam energy
- Net-proton < 30, B-field increases at all energies

Summary

Hint of charge dependent separation, qualitatively consistent with CME has been Observed.

Background contributions remain ambiguous. CMS on the other hand says such separation is background driven.

Iso-bar collisions and BES phase II at RHIC may provide decisive evidence of CME
- Isobar has different B-field but same background
- Lower energy has longer B-field life and less flow/ nonflow background.

We propose a new technique of Studying CME in A+A collisions using net-protons
- Use of net-proton may allow e-by-e determination of B-field
- Further studies are underway to test its sensitivity.

THANK YOU / 谢谢