Testing ultra-intense magnetic field using polarization/deflection of prompt di-muons

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Contents

Magnetic field in non-central HEHIC

Spectators run as fast as light

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Lienard-Wiechert potential

$$\mathbf{B}(\mathrm{r,t}) = \frac{Ze\mu_0}{4\pi}\frac{\boldsymbol{v}\times\boldsymbol{R}}{R^3}\frac{(1-v^2/c^2)}{[1-(v/c)^2\sin\phi_{R_v}]^{3/2}}$$

Participants collide and rotate until freeze-out of QGP

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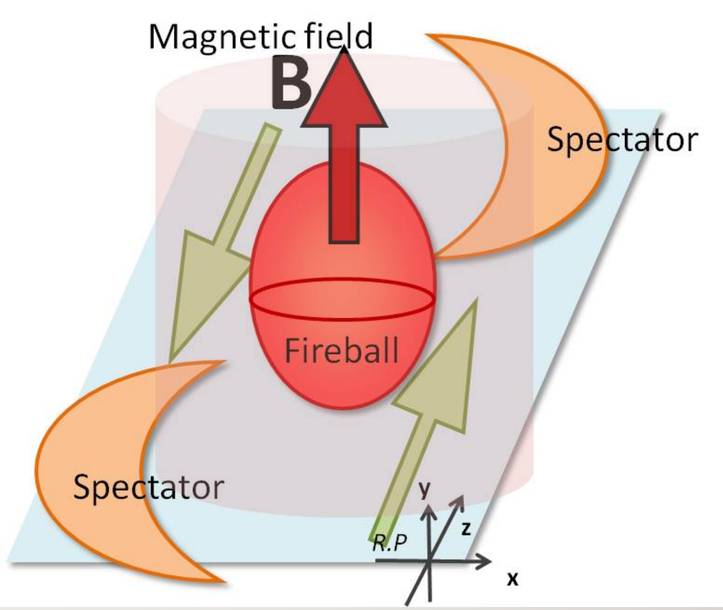
Relatively long lifetime ~ sub fm/c



Intensity[Tesla]	System
8.3	Superconducting magnet in LHC
~ 1000	Most intense magnetic field in lab
$\sim 4\times10^9$	Critical magnetic field of electron
$\sim 10^{11}$	Surface magnetic field of a magnetar
$\sim 10^{14}$	Non-central HIC in RHIC
$\sim 10^{15}$	Non-central HIC in LHC

The field is expected to reach $\sim 10^{15}$ Tesla !!

Unique phenomena in the field

The field is more intense than the critical field of electron…
→ non-linear QED

Typical effects of non-linear QED

Decay of real photon
- Photon decays into di-lepton

Birefringence
- Difference in decay probability of di-leptons with respect to the field

Other effects in extreme field

Synchrotron radiation of quarks
- Quark radiates gluon as like electronic bremsstrahlung

Chiral magnetic effect
- Current flows in the direction of the field

These phenomena are very interesting,
but the field is NOT yet experimentally detected!!

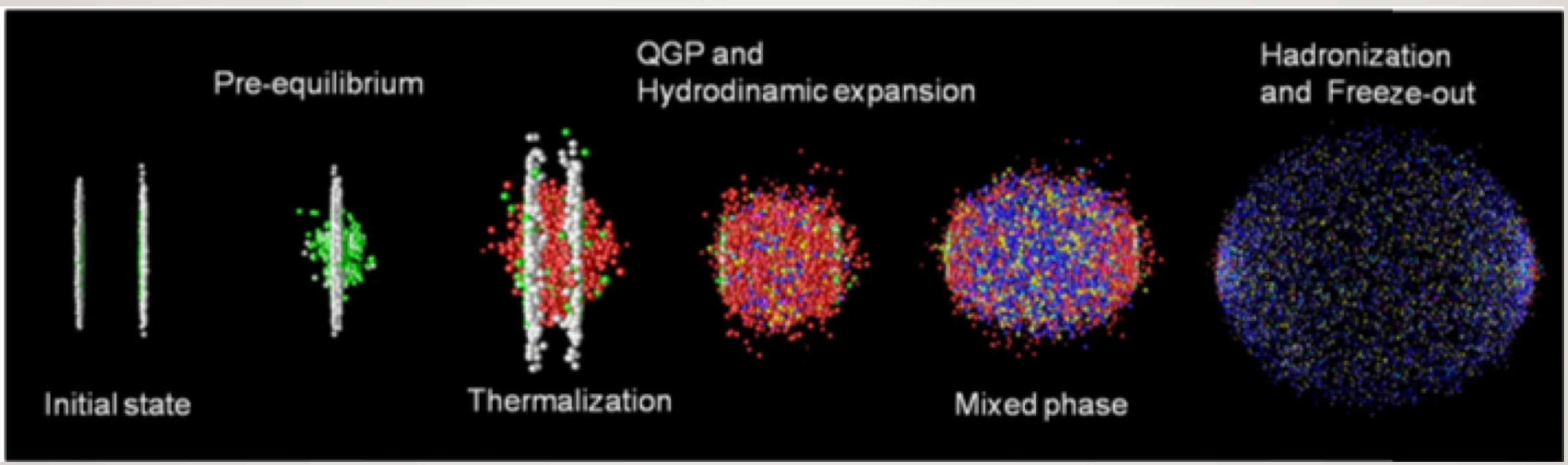
Selection of the appropriate probe

Magnetic field declines rapidly → Existing at initial stage
Come out through in QGP → Not disturbed by strong force

→ Direct photon polarization

- Polarization of photon is difficult to detect…

→ Di-lepton polarization from direct virtual photon



prompt photon thermal photon decay photon

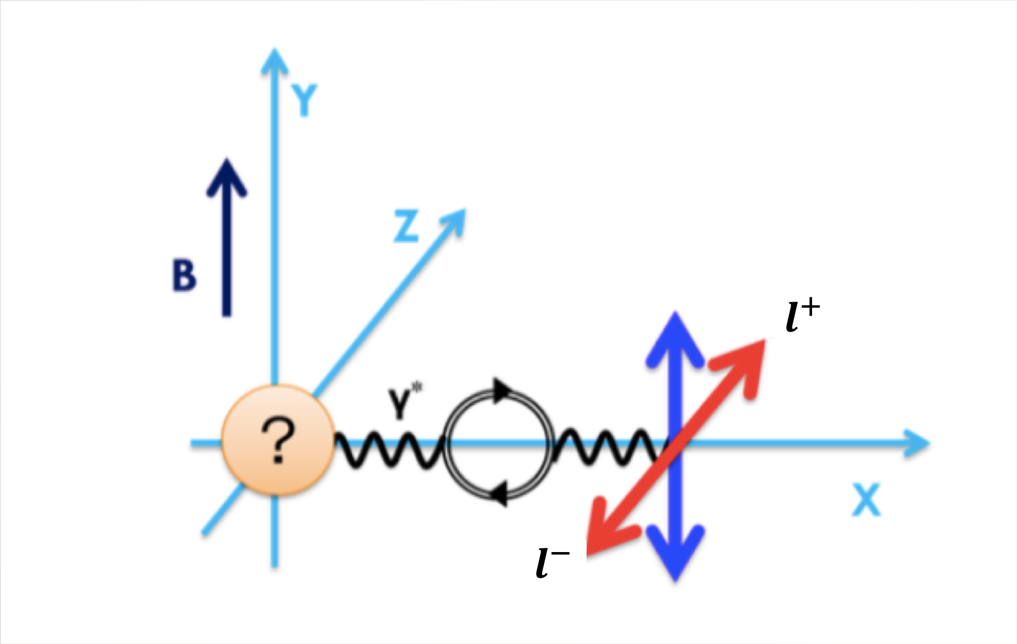
direct photon

How do we detect the field ??

We propose two observables on di-lepton analysis

1. Polarization - Difference of decay probability to the field

Due to birefringence of photon,
the number of RED di-leptons and BLUE di-leptons are different.



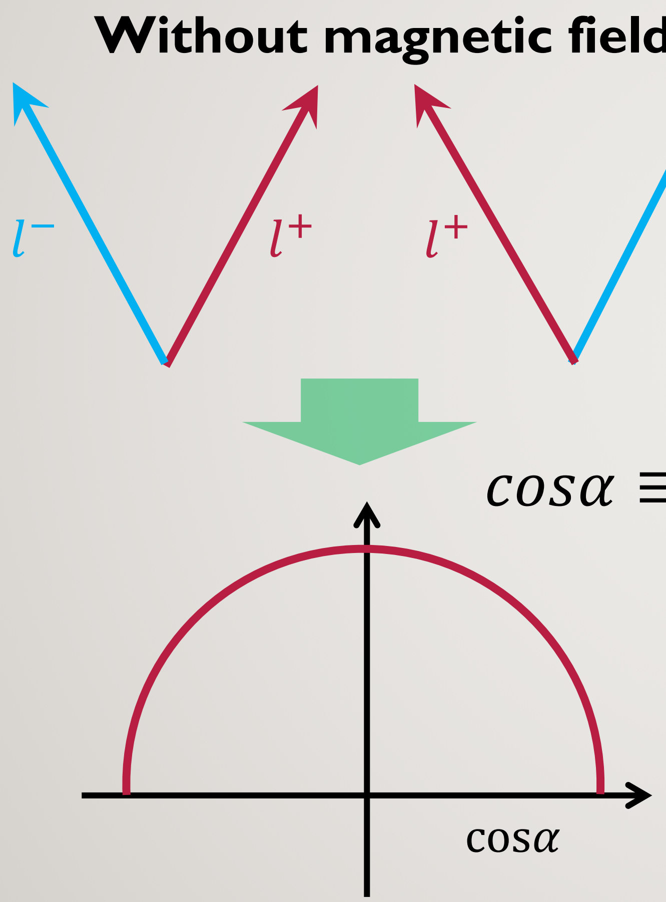
$$N_{\perp} \equiv N_{RED}, N_{\parallel} \equiv N_{BLUE}$$

"Polarization" is defined

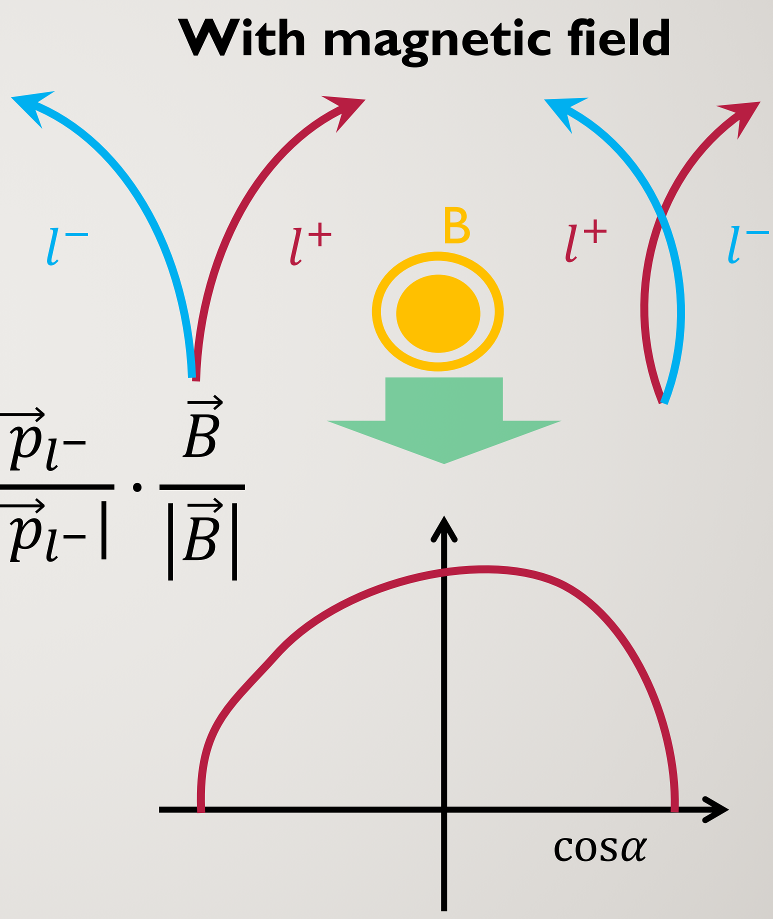
$$P \equiv \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$

How do we detect the field ??

2. Deflection - Skewness of $cos\alpha$



$$cos\alpha \equiv \frac{\vec{p}_{l^+} \times \vec{p}_{l^-}}{|\vec{p}_{l^+} \times \vec{p}_{l^-}|} \cdot \frac{\vec{B}}{|\vec{B}|}$$



Goal for this evaluation

The final goal is to detect the field experimentally with LHC ALICE experiment Pb-Pb $\sqrt{s_{NN}} = 5.5\ \mathrm{TeV}$ Run 3 2021

- Need to evaluation the possibility of detection
- Probe is di-muon from direct virtual photon (call it "direct di-muon",dd)

To evaluate how significantly magnetic field can be confirmed

- Observables are "Polarization" and "Deflection"

From Run3, new detector "Muon Forward Tracker" is installed

- Evaluate how much BG muons can be reduced

In this presentation, only "Polarization" result is reported.

Evaluation method

1. Generate 10^7 pp events by PYTHIA
   - $\sqrt{s} = 5.5$ TeV
   - pseudo rapidity range -4.0 < eta < -2.5
2. Scaling it up to Pb-Pb event

PYTHIA

* Event generator
* Can generate with any CMS energy pp events

Scaling method

Origin of muon and scaling factor

N_{coll} (Number of binary collisions): Direct Photon, Heavy Flavor(c,b)

N_{part} (Number of participants): Vector Meson($\rho, \omega, \varphi, \eta$ etc…), $\pi^{\pm}, K^{\pm}$

3. Reconstruct invariant mass and pT with di-muons
4. Calculate "Polarization" and its significance
   - Assuming all direct di-muons decay parallel to the field
   - Centrality 30 - 50 %
   - In Run 3, ALICE expects to take ~10^{10} Pb-Pb events

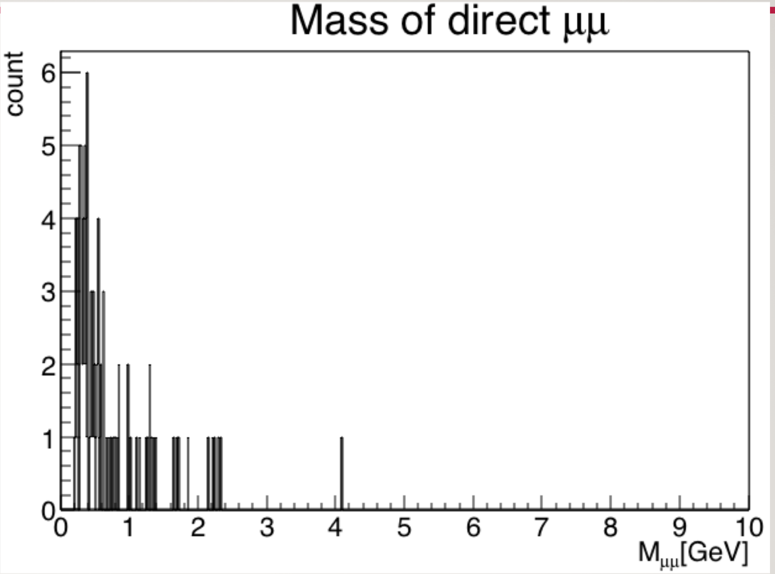
Result – Mass & pT distribution

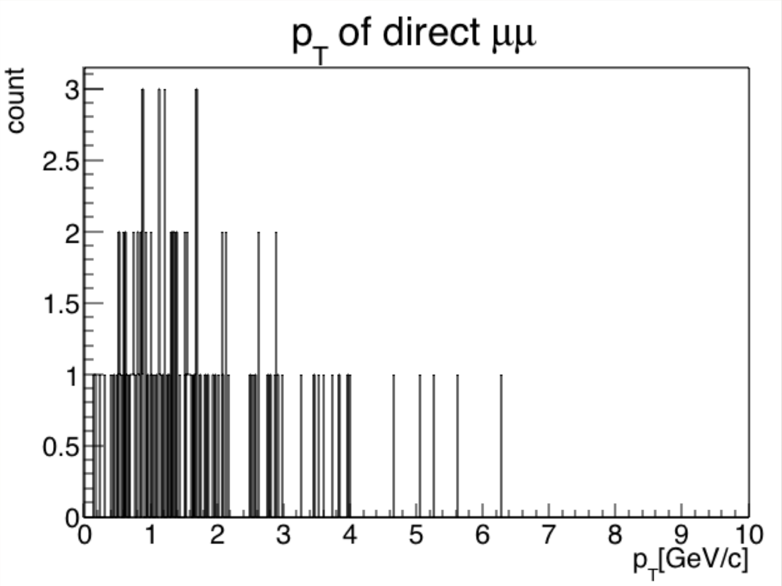
Mass and pT of direct di-muons

0.21 < M(dd) < 2.4 GeV

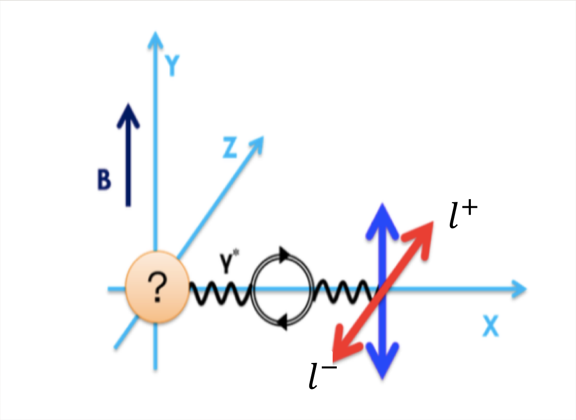
0.2 < pT(dd) < 7 GeV/c

- Existing direct di-muons
- Mass mainly < 1.0 GeV
- pT wide distribution





Result - Polarization & significance



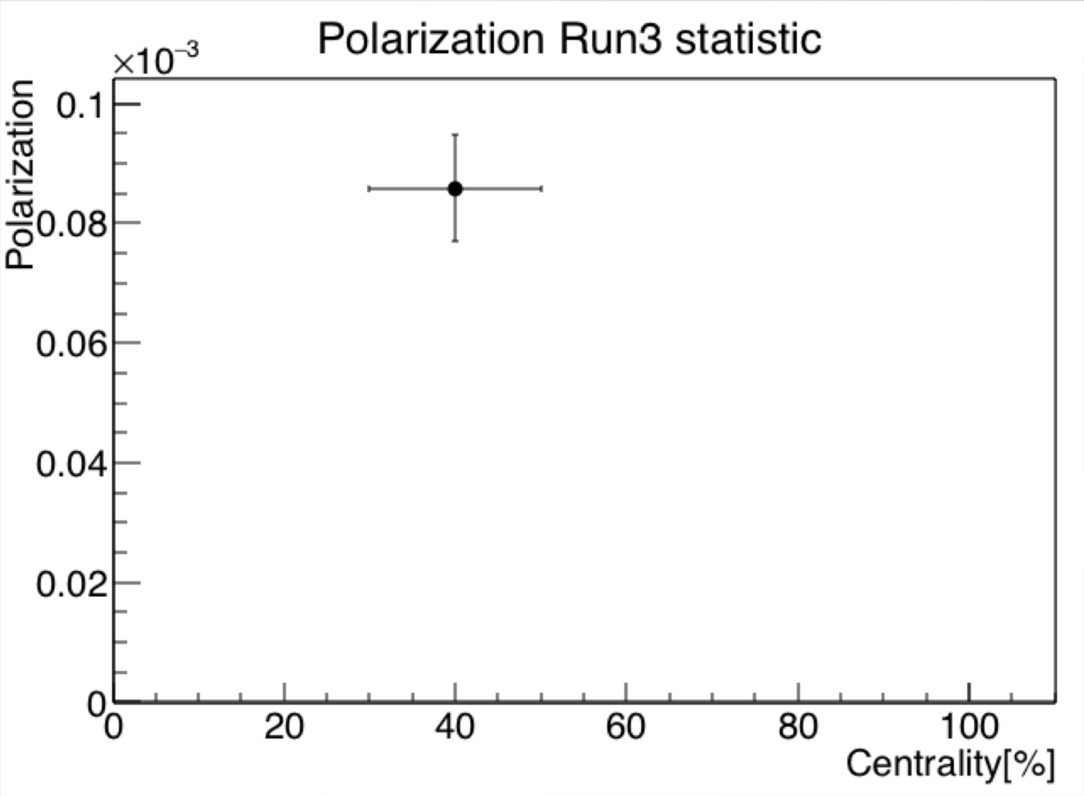
$S = N_{dd}, B = N_{all\ \mu\mu}$

$N_{\perp} \equiv N_{RED}, N_{\parallel} \equiv N_{BLUE}$

$$P = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}} = \frac{S}{S + B}$$

Significance scaled in Run3

$$\mathrm{Sig} = \frac{P}{\sigma_P} \times \sqrt{\frac{\text{Run 3 PbPb N event}}{\text{pythia PbPb n event}}} \sim 9.5$$



P can be confirmed significantly

Future plan

Many factors still need to be considered

- Reaction Plane Resolution
- Detector efficiency
- method for count $N_{\perp}, N_{\parallel}$

Muon from pi,K is dominant back ground

- Evaluate how much BG is reduced with MFT

Another observable, "Deflection"

- Calculate it in same situation with Polarization

Summary

In non-central HEHIC , ultra-intense magnetic field is generated

- $B_{max} \sim 10^{15}$ Tesla

Unique phenomena is expected in such an extreme field

- non-linear QED, Synchrotron radiation, Chiral magnetic effect…

To detect it, two observables are proposed

- Polarization, Deflection

As a result, P can be confirmed significantly

- Statistics is ALICE Pb-Pb Run3 2021
- Assuming 100% parallel decay to the field

This is one of the ideal result, more detailed evaluation will be done