Search for strong magnetic field via electron-pair asymmetry measurement in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV at RHIC-PHENIX

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Tomoya Hoshino (Hiroshima University / RIKEN)
for the PHENIX collaboration

PHENIX

Quark Physics Laboratory, Hiroshima University, Japan

RIKEN's Programs for Junior Scientists

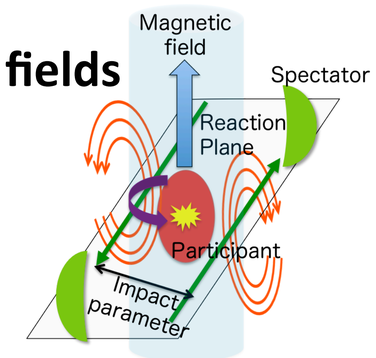
Motivation

➢ Strong magnetic field in heavy ion collisions

- Expected to be created in non-central collisions
- The magnitude of the field reaches about **10^{14} Teslas @ RHIC**
- Time evolution of the field and centrality dependence are estimated by theories [1]
- Yet to be detected by experimentally

➢ Interesting phenomena in strong fields

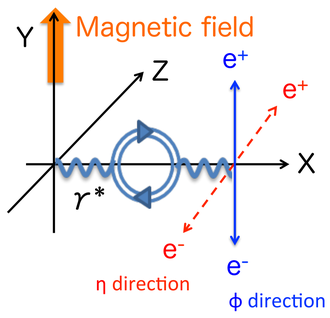
- Chiral magnetic effect
- Non-liner QED effects
  e.g. real photon decay, vacuum birefringence
- Synchrotron radiation



Electron-pair asymmetry

➢ Virtual photon decay in the strong field

- Its probability depends on the field direction
  - Calculated with the vacuum polarization tensor in a strong magnetic field [2]
  - The decay probability parallel to the field is higher than perpendicular to the field



➢ How to measure this asymmetry

- A new observable
  - Using ratios of number of electron pairs

$$P_{in} = \frac{N_{\phi,in} - N_{\eta,in}}{N_{\phi,in} + N_{\eta,in}} \qquad P_{out} = \frac{N_{\phi,out} - N_{\eta,out}}{N_{\phi,out} + N_{\eta,out}}$$

- In-plane (Perpendicular to the magnetic field)
  - Signal expected region
    - Signal + acceptance difference

$$P_{in} = \frac{A(1+P) - B(1-P)}{A(1+P) + B(1-P)}$$

- Out-of-plane (Parallel to the magnetic field)
  - To use acceptance cancellation
    - Acceptance difference

$$P_{out} = \frac{A - B}{A + B}$$

Acceptance-corrected polarization

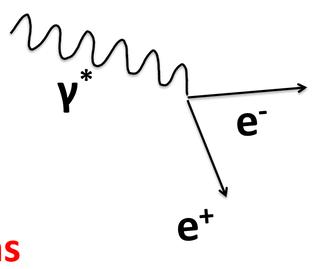
$$P = \frac{P_{out} - P_{in}}{1 - P_{in} P_{out}}$$

A: ϕ acceptance
B: η acceptance
P: Polarization
N: Number of electron pairs
N_φ: Perpendicular to the field
N_η: Parallel to the field

Probes for the field detection

➢ Requirements for probes

- Originating from initial stage
- Electro-magnetic probes



➢ Probes from pQCD process

e.g. Direct photons, **virtual photons**

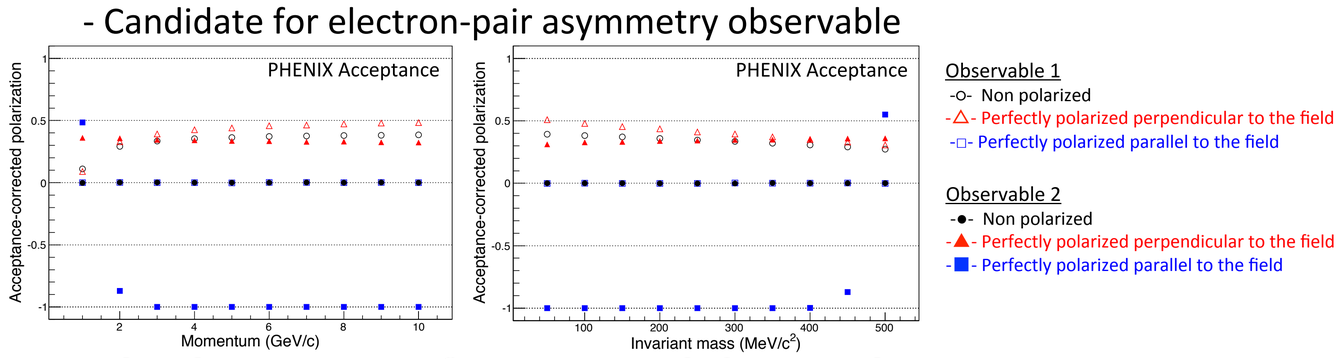
➢ Control processes from later stage

e.g. Decay photons, **Dalitz decay electrons**

Monte Carlo study

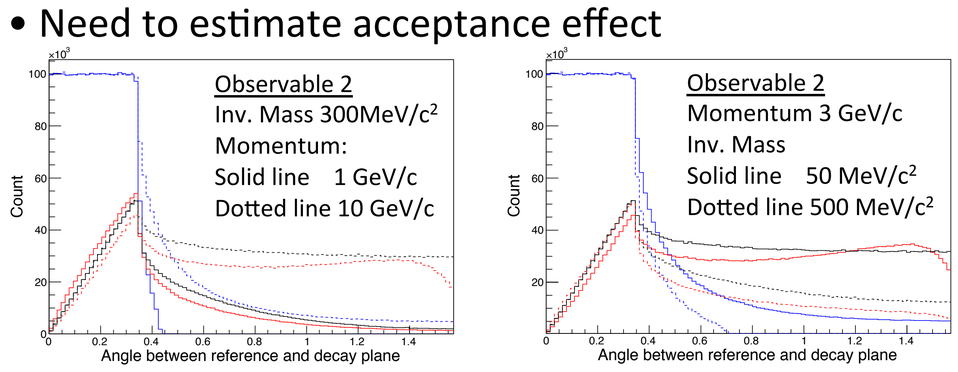
➢ Momentum and invariant mass dependence

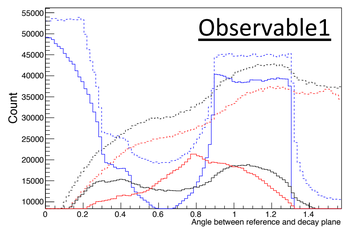
- Comparison with two type observables
- Observable 2 can separate the direction of polarization
  - Candidate for electron-pair asymmetry observable



➢ Angles between reference and decay plane

- Need to estimate acceptance effect





Inv. Mass 300MeV/c²
Momentum:
Solid line 1 GeV/c
Dotted line 10 GeV/c

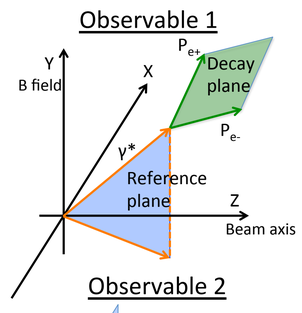
Analysis overview

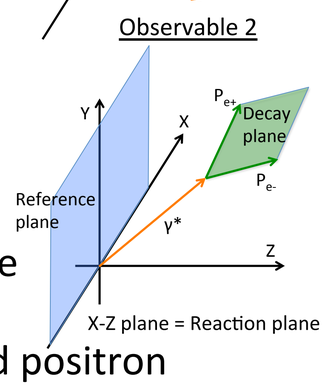
➢ Monte Carlo simulation

- Simulation for two-body decay with the asymmetry
  - Determine which observable is good
  - Estimate invariant mass and momentum dependence on polarization

➢ Procedures for the simulation

- The magnetic field direction 'κ' and reaction plane 'ψ'
  - Randomly direction of the magnetic field in X-Y plane
  - Reaction plane ψ can be calculated by 'κ - π/2'
- Electron-pair from virtual photon
  - Create 3 types of polarization
    1.) Non polarized
    2.) Perfectly polarized perpendicular to the field
    3.) Perfectly polarized parallel to the field





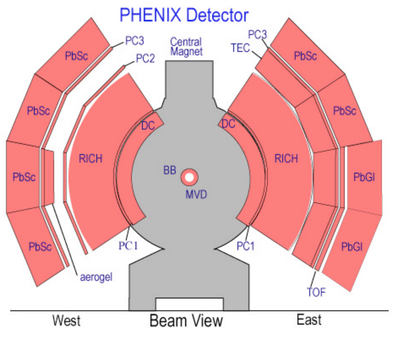
➢ How to calculate electron-pair asymmetry

1. Divide into in-plane and out-of-plane w.r.t reaction plane
   - Use the phi angle of electron pair and reaction plane ψ
2. Calculate decay plane with cross product of electron and positron
3. Classify the direction of decay plane into 'ϕ' and 'η' direction
   - Use the angle between decay plane and reference planes
   - Reference planes
     - Observable 1: $(\vec{p}_{e+} + \vec{p}_{e-}) \times (\vec{p}_{e+} + \vec{p}_{e-})_{XZ}$
       Cross product of electron-pair momentum and its projection to reaction plane (X-Z plane)
       This observable depends on both virtual photon momentum and reaction plane ψ
     - Observable 2: $(\vec{e}_X \times \vec{e}_Y)$
       Cross product of X and Y axis unit-vector
       This observable is independent of reaction plane and the vector is always towards beam axis

PHENIX detector

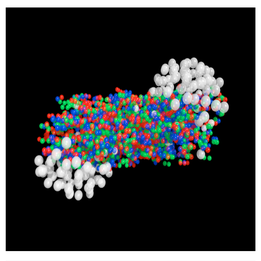
Has an excellent eID capability
Acceptance Δϕ = π, |η| < 0.35

- ➢ Electron identification
  - Ring-imaging Cherenkov detector
  - Electro-Magnetic Calorimeter
- ➢ Momentum measurement
  - Drift Chamber
- ➢ Centrality and Reaction Plane
  - Beam-Beam Counter

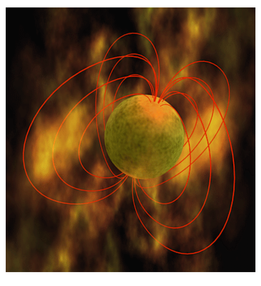


Strong magnetic field

10^{14} Tesla
Heavy ion collisions @ RHIC

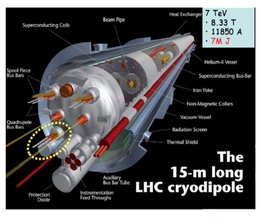


10^{11} Tesla
Magnetar Surface



4×10^{9} Tesla
Critical magnetic field
$\sqrt{eB}=m_e$ = 0.5 MeV

8.3 Tesla
Superconducting magnet @ LHC



Summary & Outlook

- ➢ Strong magnetic field is expected to be created in heavy ion collisions
- ➢ Time evolution and centrality dependence of the field are discussed by theories but is yet to be detected experimentally
- ➢ We propose a new observable to detect the field
- ➢ We estimate invariant mass and momentum of virtual photon dependence on measured polarization
- ➢ We need to estimate acceptance effect. It helps to understand the properties of observable
- ➢ Background contributions are under study

References

[1] W.-T. Deng et al., Phys. Rev. Lett. 103, 251601 (2009)
[2] K. Ishikawa et. al, Int. J. Mod. Phys. A28 (2013) 1350100