2014/08/06
The 5th Asian Triangle Heavy Ion conference @Osaka
Electromagnetic probes

Quark
Physics
Laboratory
Hiroshima University, Japan

Search for intense magnetic field via electron-positron pair asymmetry measurements in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with ALICE

ALICE

Hiroshima Univ. Remi Tanizaki
for the ALICE Collaboration

Outline

- Physics motivation
- How to detect the intense magnetic field?
  - Two approaches

1. Polarization of direct γ*

2. Deflection of e-e+ pairs

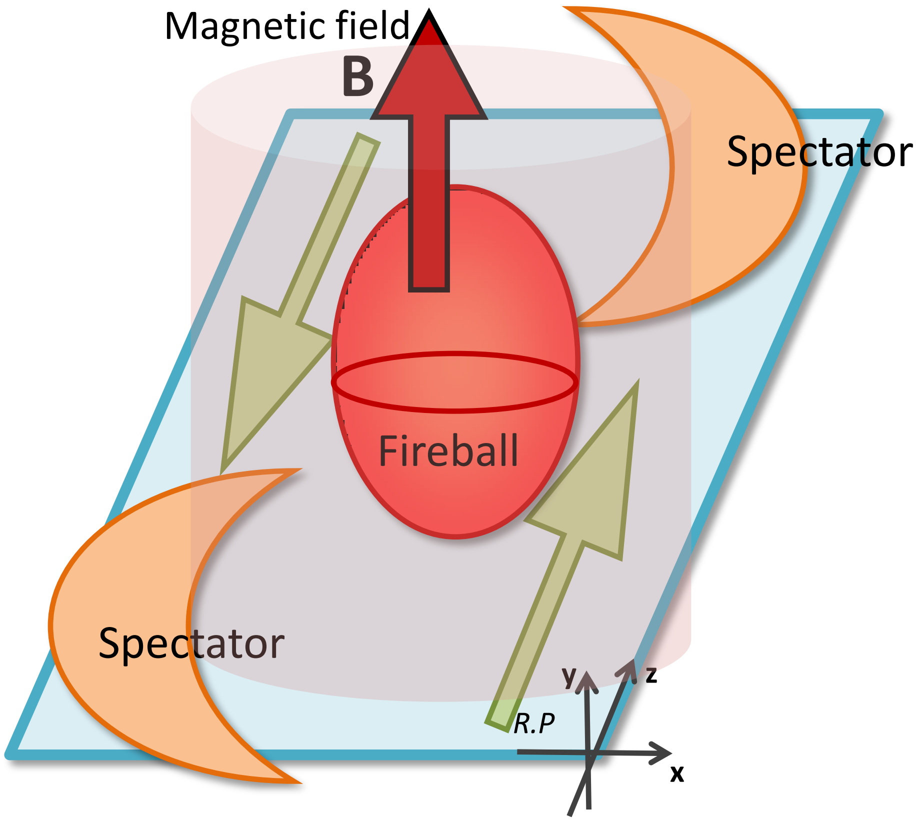
Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

methods, status, and outlook

- Summary

Intense magnetic field

Intense magnetic field should be created in non-central collisions.



→ maximum strength ~10^{15} Teslas at LHC!!!

◆ interesting expectations

- chiral magnetic effect
- synchrotron radiation
- photon decay etc...

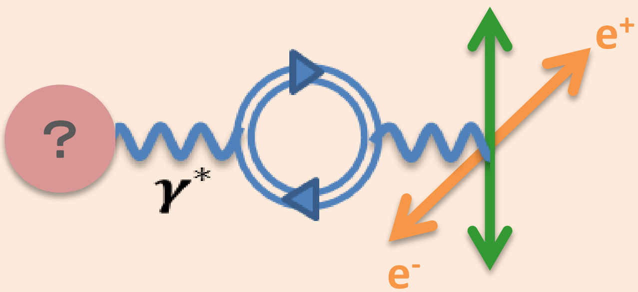
We are aiming at direct detection of the magnetic field.

How to detect the magnetic field

We have proposed **two approaches** for the detection.

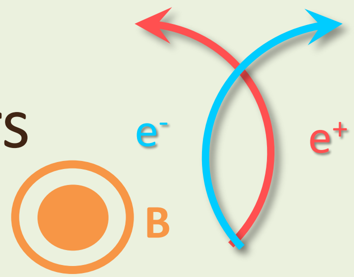
●Polarization

azimuthal anisotropy
of direct virtual photon decay



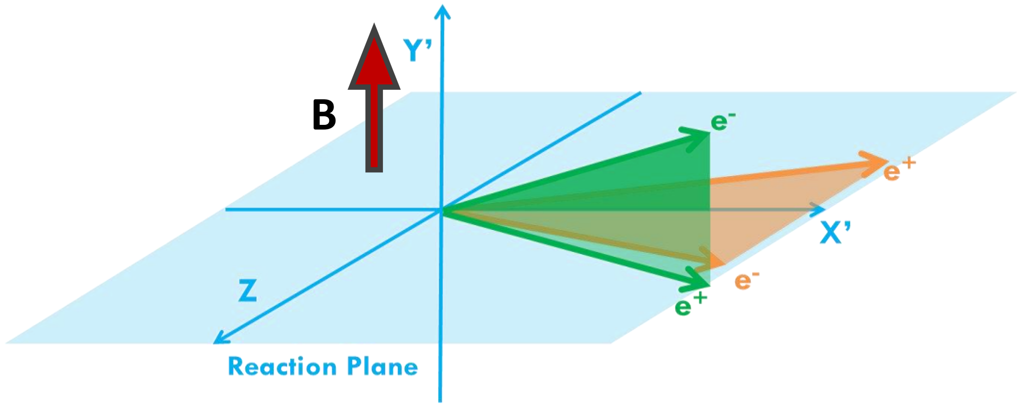
●Deflection

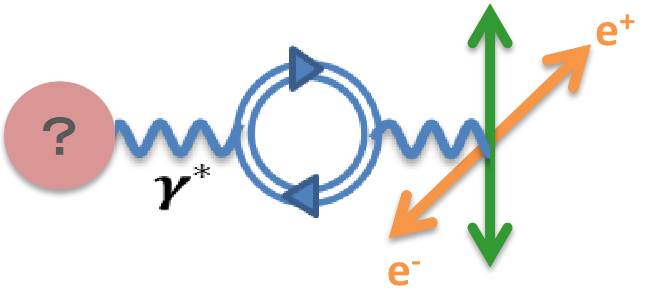
aligned deflection of electron-positron pairs
from direct virtual photon decay



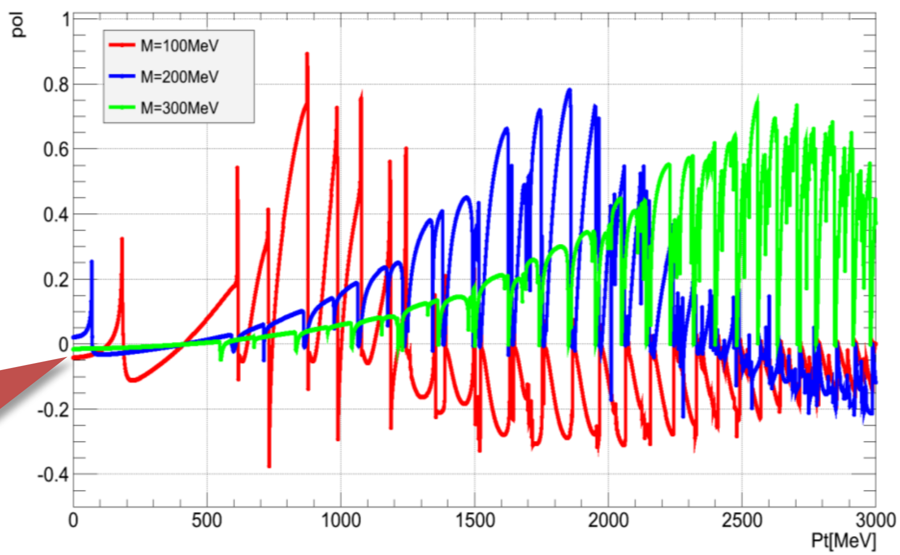
Polarization : azimuthal anisotropy of γ∗ decay

Virtual photons perpendicular to the field strongly interact with the field and dielectron production rate becomes anisotropic.





Di-electron polarization

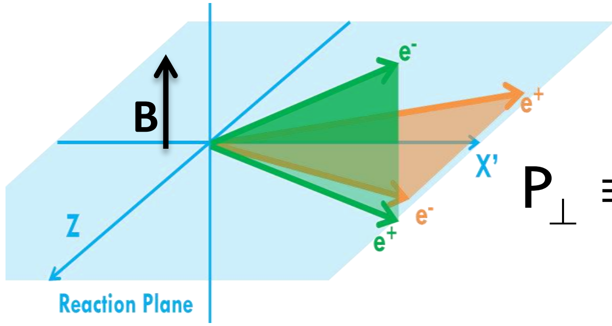


Effects of the strong magnetic field are evaluated via QED one loop calculations of vacuum polarization tensor.

Virtual photons are polarized in the order of 10^{-1} !!

Data-driven acceptance correction

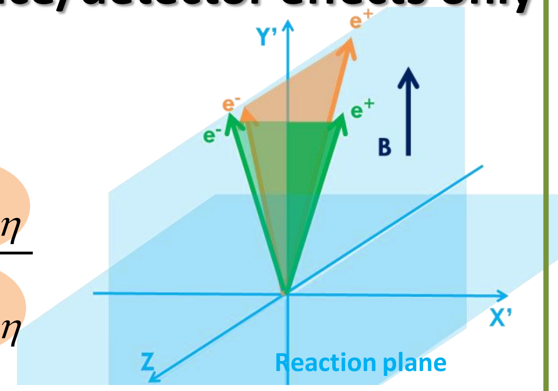
γ*⊥ B **physics + acceptance/detector effects**



$$P_{\perp} \equiv \frac{N_{\perp\phi} - N_{\perp\eta}}{N_{\perp\phi} + N_{\perp\eta}}$$

γ*// B **acceptance/detector effects only**

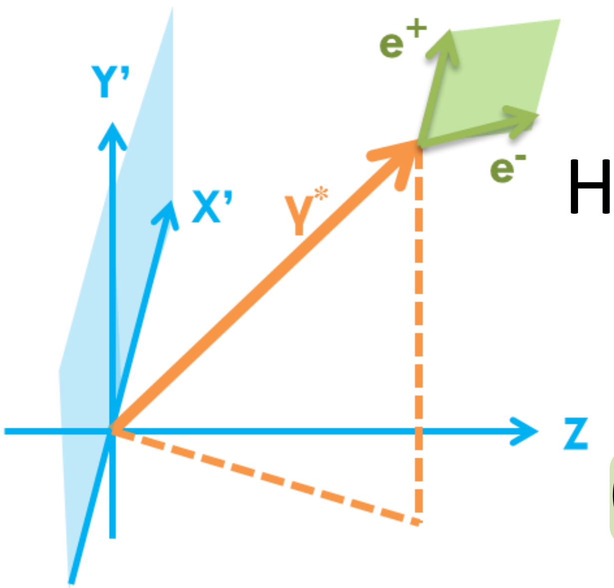
$$P_{//} \equiv \frac{N_{//\phi} - N_{//\eta}}{N_{//\phi} + N_{//\eta}}$$



Acceptance corrected polarization

$$P = \frac{P_{\perp} - P_{//}}{1 - P_{\perp}P_{//}}$$

Kinematic variable #4



How to separate decay orientations

We selected kinematic variable that can separate physics scenarios.

Angle between

$(p_{e^+} \times p_{e^-})$ and $(e_{X'} \times e_{Y'})$

$$\begin{cases} 0 \sim \frac{\pi}{4} : N_{*\phi} \\ \frac{\pi}{4} \sim \frac{\pi}{2} : N_{*\eta} \end{cases}$$

Preliminary result on polarization

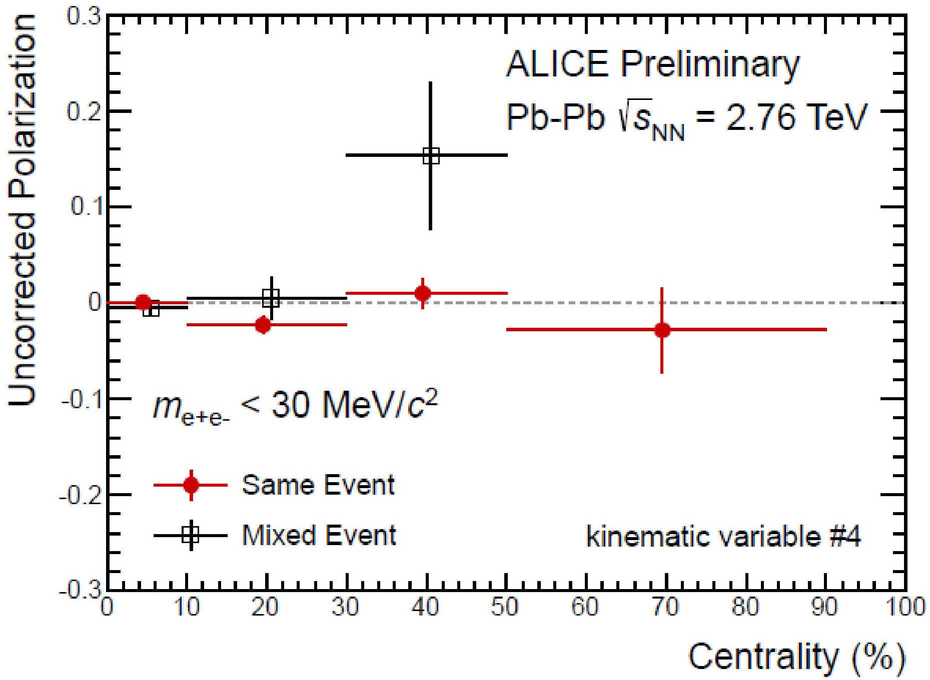
Data set : Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV (Statistics : 38 M events)

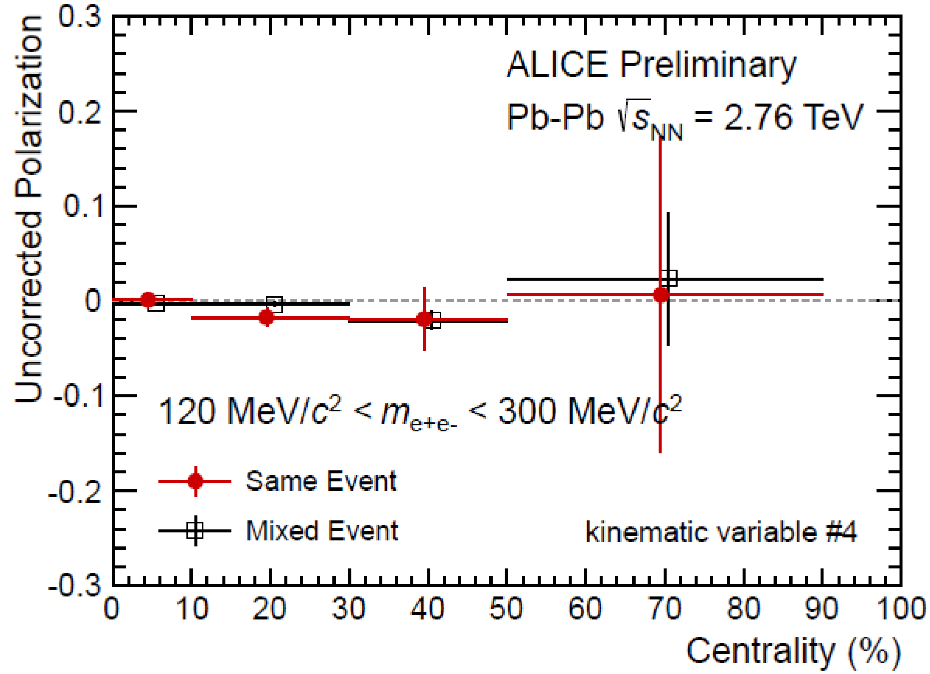
Centrality dependence of polarization

without background subtraction or reaction plane resolution correction

- $m_{e^+e^-} < 100$ MeV/c^2 :
  π^0 Dalitz decay is dominant

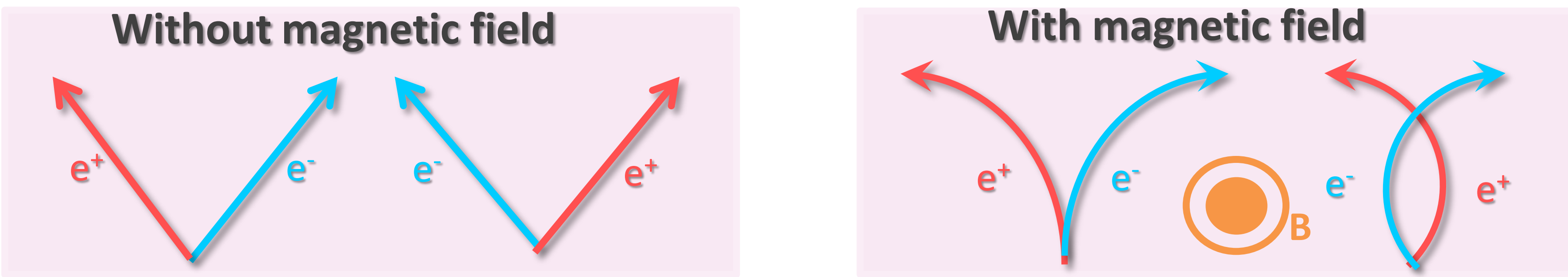
- $m_{e^+e^-} > 100$ MeV/c^2 :
  The signal is expected
  Combinatorics are dominant





Aligned deflection of e^+e^- from γ*

Direction from electron to positron is aligned to the direction of the magnetic field.



Proposed observable : $$\cos\alpha \equiv \frac{\vec{p}_{e^-} \times \vec{p}_{e^+}}{|\vec{p}_{e^-} \times \vec{p}_{e^+}|} \cdot \frac{\vec{B}}{|\vec{B}|}$$

low mass dielectrons from direct virtual photons

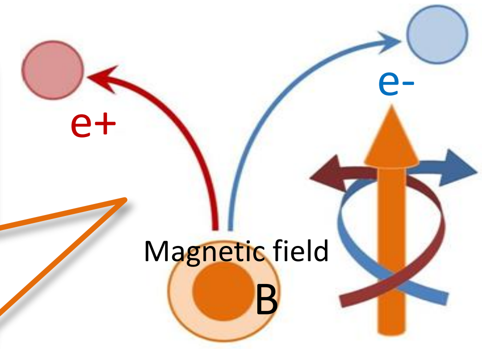
1: well correlated!! 2: early production!!

Simulation of aligned deflection

- electrons (momentum: order 1 GeV/c)
- magnetic field (order 10^{14} T)

when the electrons move through 1 fm in the field,

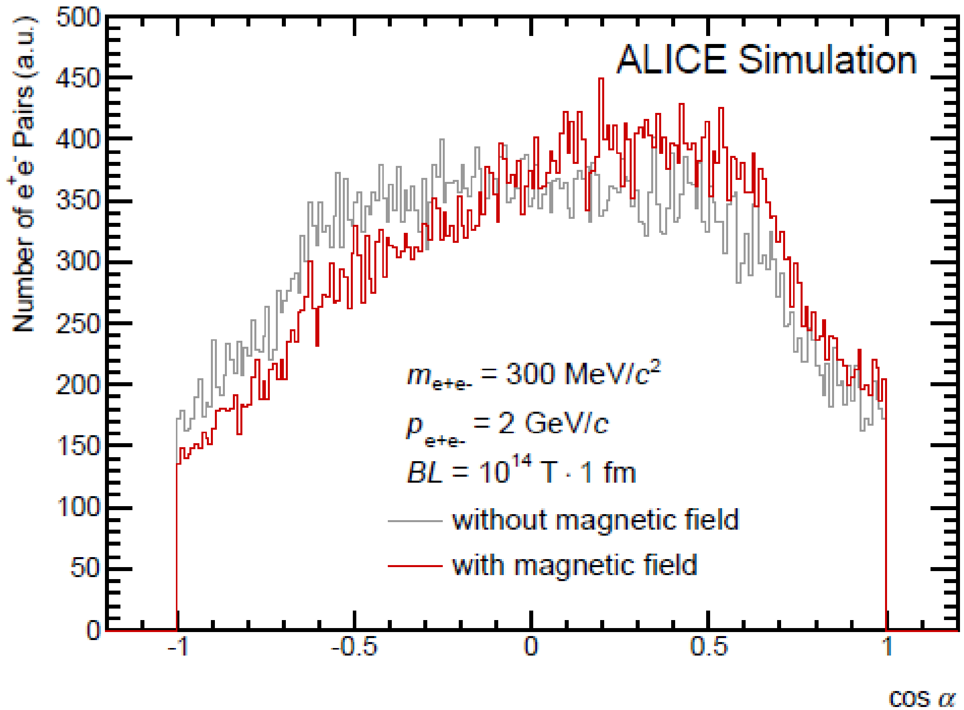
→ deflection ~ 1 degree



Estimate of aligned deflection with Monte Carlo simulation

- virtual photon mass = 300 MeV/c^2
- virtual photon momentum = 2 GeV/c
- bending power = 10^{14} T × 1 fm

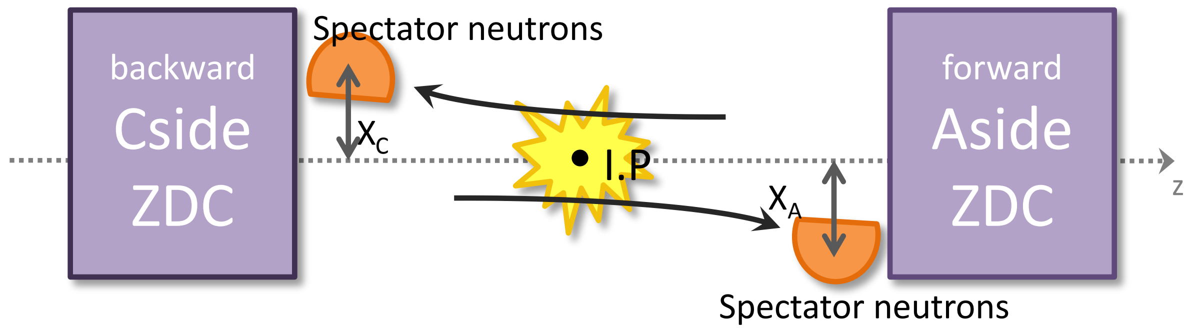
Average shift ~ 0.06



Magnetic field vector determination

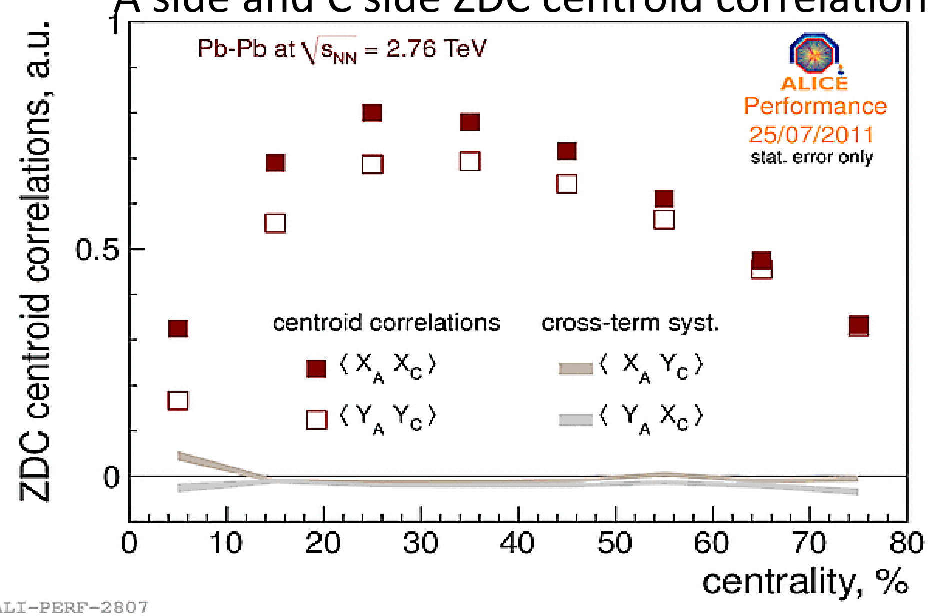
Need to determine the direction of intense magnetic field.

It depends on the orientation of the reaction plane.

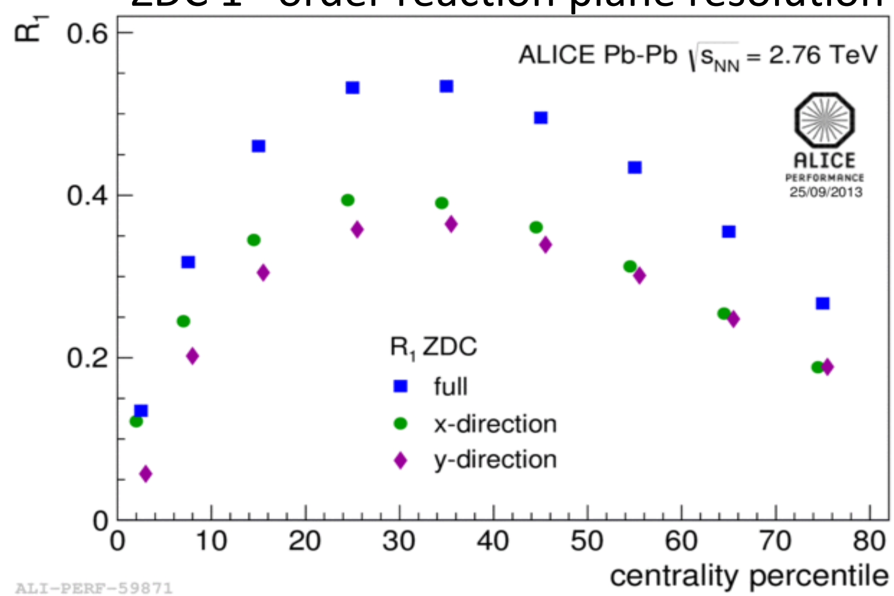


by **neutron Zero Degree Calorimeters (on both sides)**

A side and C side ZDC centroid correlation



ZDC 1st order reaction plane resolution



Status of deflection analysis

- Data set
  - Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
  - Trigger:
    Minimum Bias+Central+SemiCentral
  - Statistics : 38 M events
- electron ID
  - ITS+TPC+TOF

Current status

Real data analysis is in progress
for different invariant mass, p_T, and centrality ranges.

- Deflection calculation is finished for all statistics.
- Next → Background subtraction

Summary

Search for intense magnetic field via two approaches.

- **Polarization** : azimuthal anisotropy of γ* decay
  - Preliminary polarization has been obtained with full statistics.

- **Deflection** : aligned deflection of e^+e^- pairs from γ* decay.
  - Orientation of magnetic field is reconstructed with ZDC.
  - Real data analysis is in progress.

<u>Future prospects</u>

- Background subtraction

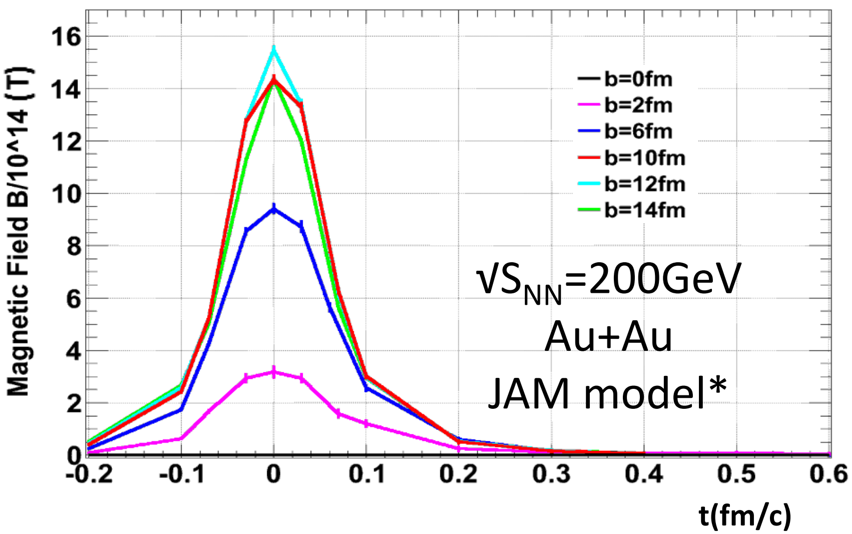
  BG is being estimated by mixed event and like sign pairs.
- Reaction plane resolution correction

BACK UP

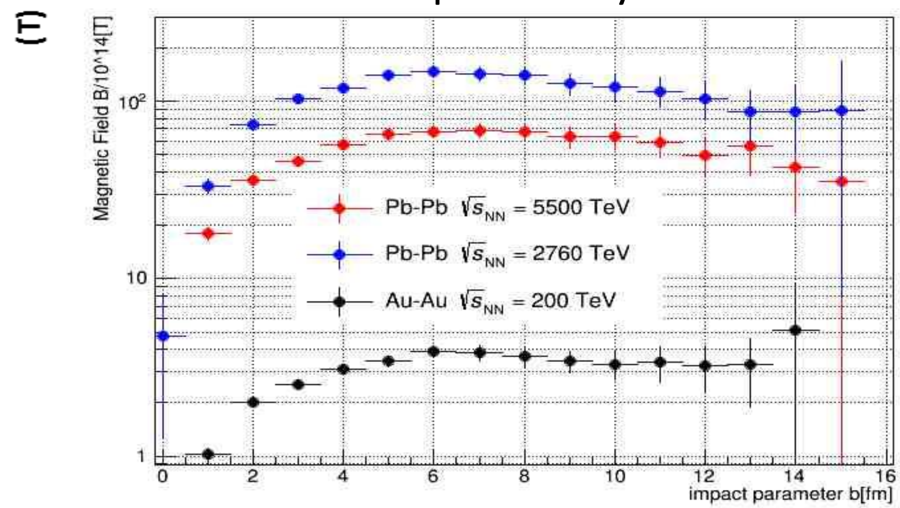
The field estimation

Impact parameter, energy, and time dependence

Spectators and participants



Participants only



- The field intensity reaches maximum in peripheral collisions (B_{max}~10^{15}Tesla) and grows with the beam energy.
- The field rapidly damps, but is still above B_c for a few fm/c.

* JAM (Y.Nara, N.Otuka, A.Ohnishi, K.Niita, S.Chiba, PRC61 (2000) 024901)

Invariant Mass of Di-electron

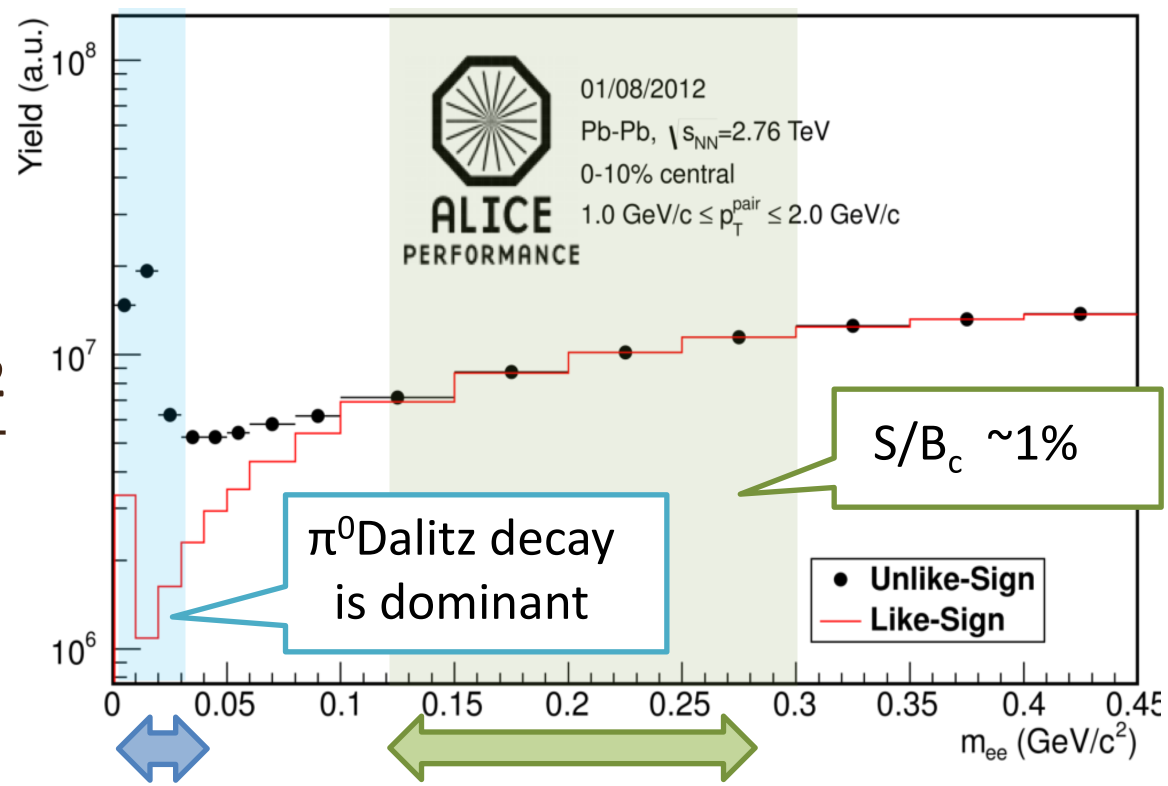
◆ ***m*$_{e^+e^-}$ < 100 MeV/*c*^{2}**

π^0 Dalitz decay is dominant.

◆ ***m*$_{e^+e^-}$ > 100 MeV/*c*^{2}**

Combinatorics are dominant.

Invariant mass distribution of dielectron



ALICE Detector

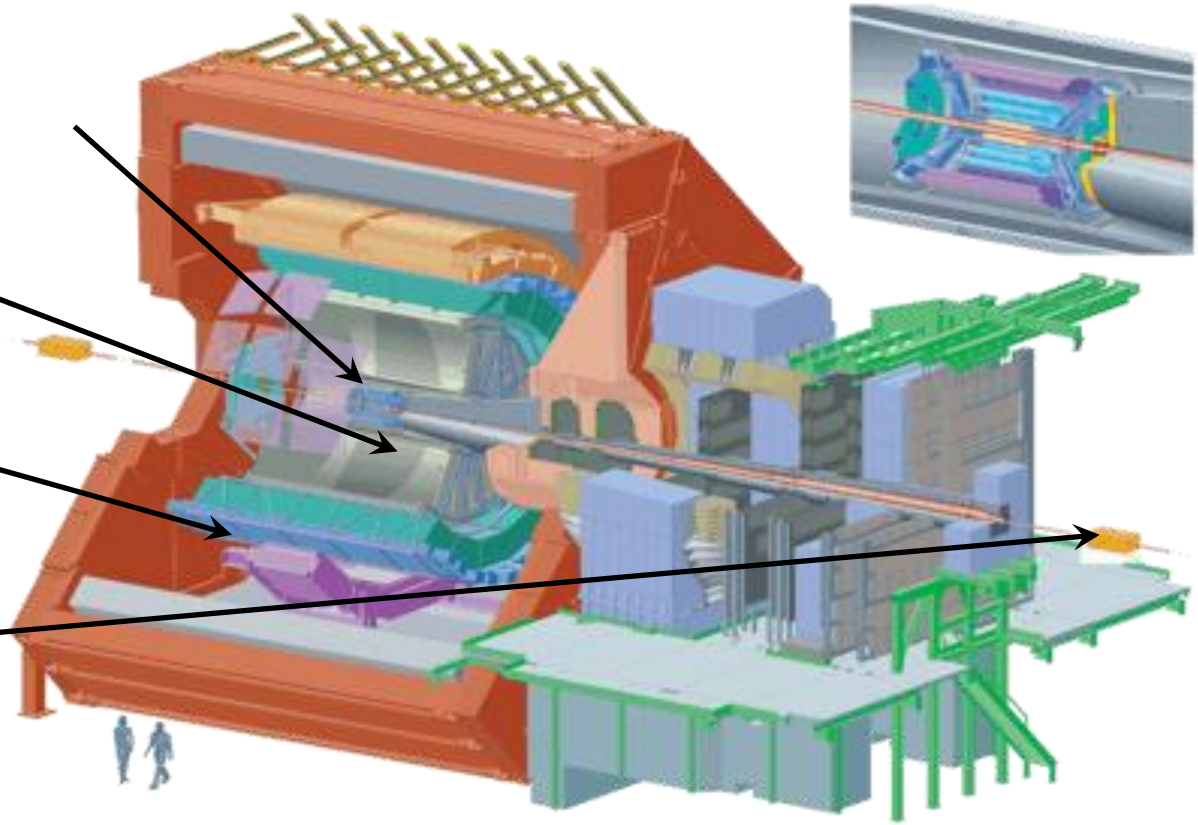
Inner Tracking System(ITS)
Tracking・Vertex・PID

Time Projection Chamber(TPC)
Tracking・PID

Time of Flight(TOF)
・PID

Zero Degree Calorimeter(ZDC)
・Reaction plane

VZERO
Centrality・Reaction plane



＜Data set＞ Pb+Pb 11h AOD data (Train : All statistics)

Trigger : MB+Central+SemiCentral

Feasibility of field detection @ ALICE

Example: 2011 Pb-Pb $\sqrt{s_{NN}}$ =2 .76 TeV 0-10% central

(Real analysis will utilize non-central collisions.)

$0.1\mathrm{GeV}/c^2 \le M_{ee} \le 0.3\mathrm{GeV}/c^2$, $1.0\mathrm{GeV}/c \le p_t^{pair} \le 2.0\mathrm{GeV}/c$

$$\text{statistical significance} = \frac{\text{signal}}{\sqrt{\text{signal} + \text{background}}}$$

$$\approx \frac{N^{all}_{e^+e^-} \times S/B_{cb} \times (1 - f_{hadronic}) \times R_{E.P.} \times A}{\sqrt{N^{all}_{e^+e^-}}}, \frac{N^{all}_{e^+e^-}/2 \times S/B_{cb} \times (1 - f_{hadronic}) \times R_{E.P.} \times P}{\sqrt{N^{all}_{e^+e^-}/2}}$$

- ✓ # of all e^+e^- pair ~4×10^7
- ✓ S/B_{cb} ratio ~1%
- ✓ Direct components ~20%
- ✓ E.P. resolution ~ 50%
- ✓ Anisotropy ~20%
- ✓ Polarization ~40%

Expected statistical significances

Anisotropy ~1σ

Polarization ~2σ

having possibility that we detect the field !!!

Detail of calculation for polarization

$$P_{//} = 0$$

If acceptance is 100%

$$P_{\perp} = \frac{(1+P)-(1-P)}{(1+P)+(1-P)} = P$$

$$P_{//} = \frac{(A-B)}{(A+B)}$$

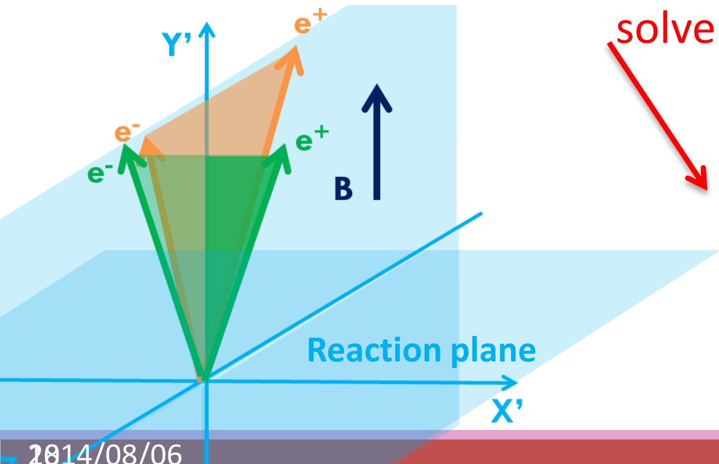
A : η acceptance
B : ϕ acceptance

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

$$P_{//} \equiv \frac{(C-1)}{(C+1)}$$

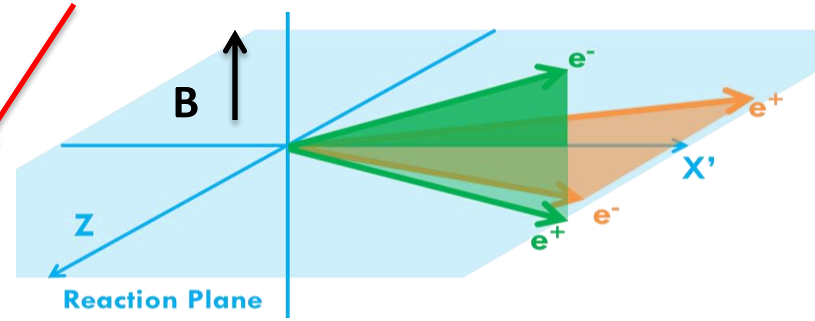
A/B = C

$$P_{\perp} = \frac{(C-1)+(C+1)P}{(C+1)+(C-1)P}$$



solve simultaneous equations

$$P = \frac{P_{\perp} - P_{//}}{1 - P_{\perp}P_{//}}$$



Data set and PID (Polarization)

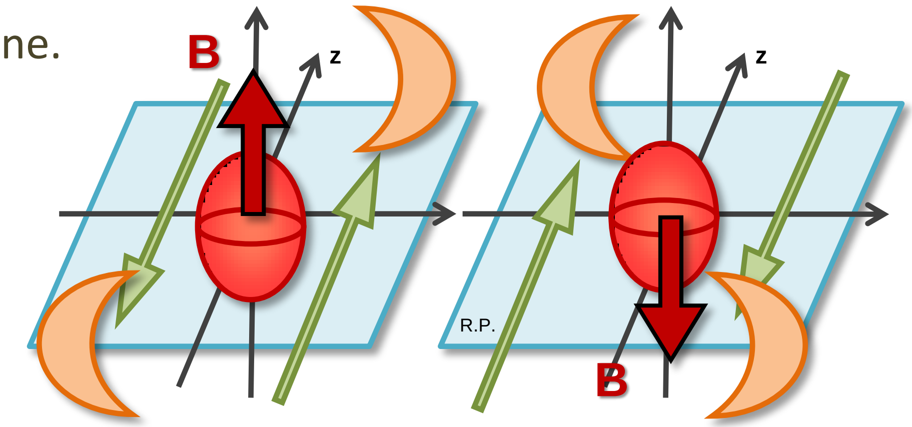
- Data set
  - Trigger : MB+Central+SemiCentral
- PID
  - TPC+TOF Cuts
- Axis of the magnetic field
  - The field appears perpendicularly to the reaction plane
  - Reconstructed by VZERO reaction plane
- without background subtractions or EP resolution corrections

Orientation of the magnetic field

Need to determine the direction of intense magnetic field.

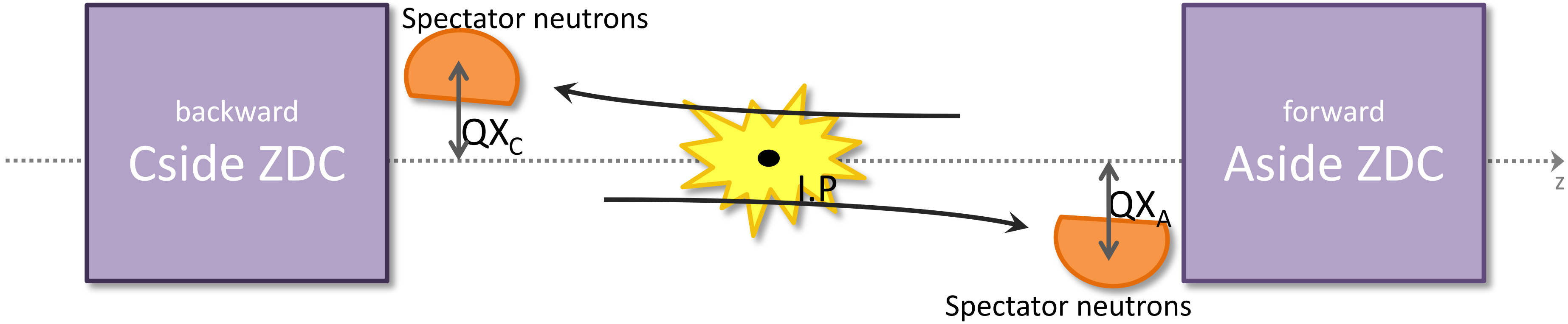
The field appears perpendicularly to the reaction plane.

Its direction depends on the orientation of reaction plane.



Reconstruct the orientation of the reaction plane

by neutron Zero Degree Calorimeters (A and C)



Good kinematic variable selected

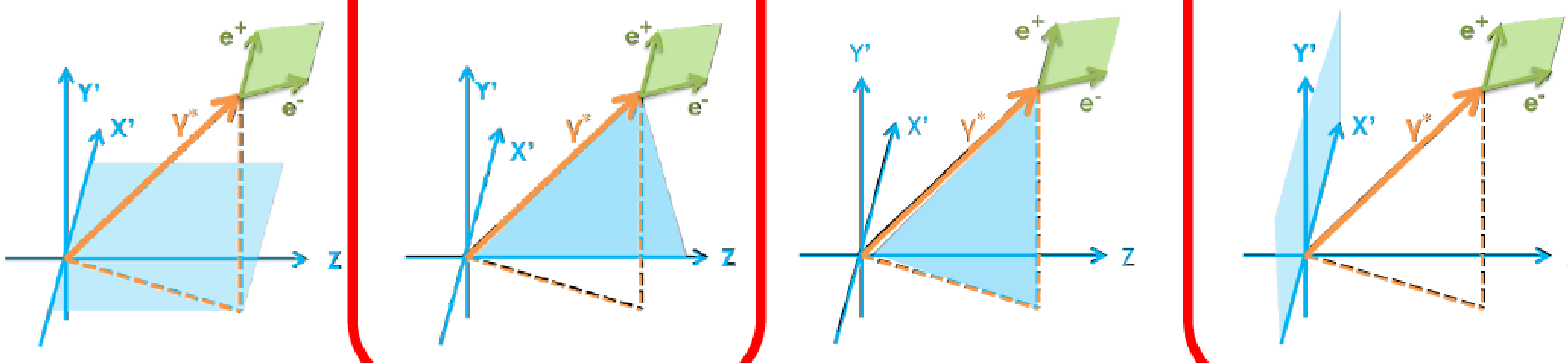
definitions of decay plane w.r.t. field direction angle between $(p_{e^+} \times p_{e^-})$ and:

1 : $(e_{X'} \times e_Z)$

2: $(P_{e^+} + P_{e^-}) \times e_Z$

3: $(P_{e^+} + P_{e^-}) \times (P_{e^+} + P_{e^-})_{X'Z}$

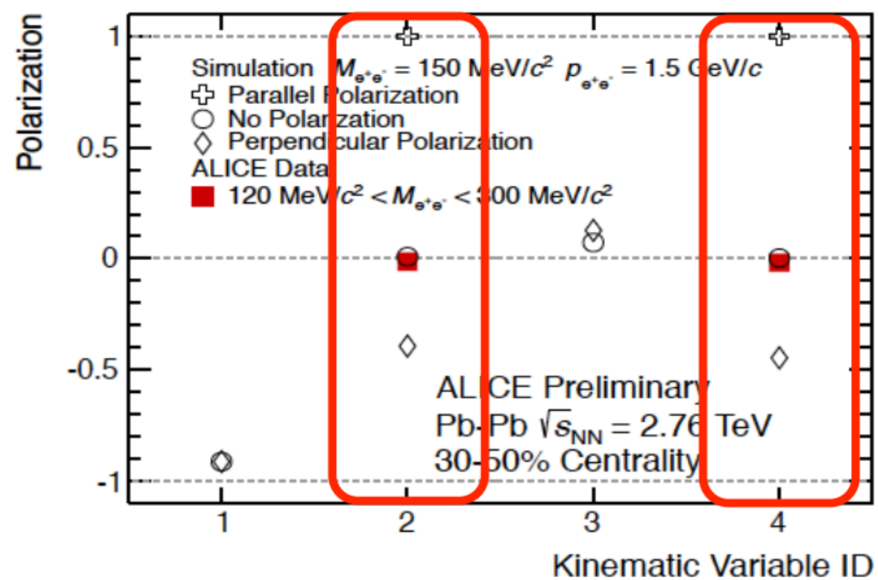
4 : $(e_{X'} \times e_{Y'})$



selection criteria:
separation of physics scenarios

→ "**2**" and "**4**" above

- Good kinematic variables identified
- No "polarization" observed



Polarization results

Centrality dependence of polarization

◆ M_{ee}<100MeV:
π^0 Dalitz decay is dominant

◆ M_{ee}>100MeV :
Combinatorics are dominant

Same Event   Mixed Event

Event statistics : 38M Event