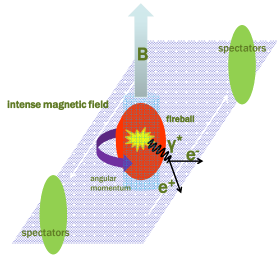
Search for Intense Magnetic Field via Di-Electron Asymmetry in Pb-Pb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with ALICE at LHC

Kenta Shigaki (Hiroshima University) for the ALICE Collaboration

Physics Interests

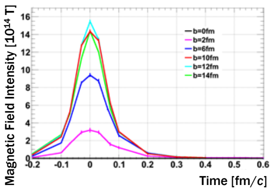
A very intense magnetic field is expected in non-central nucleus-nucleus collisions, and to reach ~ 10^{14} T at the LHC energies. Not only being the most intense magnetic field in the Universe (*cf.* ~ 10^{11} T on the surface of magnetars), it is of a fundamental physics interest as exceeding the critical magnetic field for electrons at 4×10^{9} T where non-linear behaviors of QED, *e.g.* photon splitting and real photon decaying into di-leptons, are expected, along with other consequences including chiral magnetic effects (K.Fukushima, D.E.Kharzeev, H.J.Warringa, PRD78 (2008) 074033), synchrotron radiation of quarks, and lower QCD critical temperature.



Field Intensity Estimation

One of the standard approaches to estimate the magnetic field intensity in nucleus-nucleus collisions is to utilize cascade models, *e.g.* HIJING, JAM, *etc.*. A result showing the time evolution of the field is presented below. The cascade models predict the main component of the field is generated by the spectator nucleons, leading to the peripheral collisions to reach the maximum field intensity. The spectator component grows with the beam energy in proportion to the $\beta\gamma$, while its lifetime gets inverse-proportionally shorter. Another component by the participant nucleons, or by the rotating fireballs after the collisions, is found to have lower peak intensities, but with longer lifetimes. A hydro-dynamical model with local velocity distributions as an initial condition is desired for a better prediction of the potentially long-lived participant contribution, as the evolution of the component by the "perfect fluid" fireball may not be very properly handled in the present cascade models.

Field Intensity Estimation with a Cascade Model JAM



← An estimate of the magnetic field intensity and time evolution in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with a hadron cascade model JAM (Y.Nara, N.Otuka, A.Ohnishi, K.Niita, S.Chiba, PRC61 (2000) 024901).

Experimental Approaches and Feasibilities

New approaches to detect the magnetic field via di-electron asymmetry measurements are proposed and their experimental feasibilities are examined.

(1) anisotropic decay of virtual photons into di-electrons. Photons get polarized in a magnetic field. That of virtual photons is an especially promising probe, detectable via their anisotropic decay into di-electrons, while none of current heavy ion experiments at LHC or RHIC is capable of measuring that of real photons. QED calculations of vacuum polarization tensors of photons indicate the effect can reach the order of $o(10^{-1})$ with the field intensity expected at LHC, which is within an experimental reach (K.-I.Ishikawa, D.Kimura, K.Shigaki, A.Tsuji, Int. J. Mod. Phys. A28 (2013) 1350100).

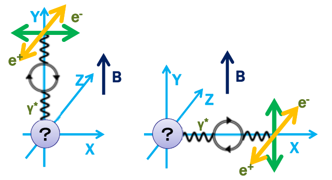
(2) aligned deflection of low-mass electron-positron pairs. The intense magnetic field serves just like a tiny magnetic spectrometer deflecting charged particles in accordance to their charge signs. Though the path length is short in the order of 1 fm, the very high intensity makes the bending angle for particles at ~ 1 GeV/c to be ~ 1 degree, which is again within an experimental reach with ALICE. The aligned defection can be detectable by looking at correlated unlike charge sign pairs, *e.g.* e^+e^- from low-mass virtual photon decay.

Data Set and Statistics

38 million Pb-Pb collision events at $\sqrt{s_{NN}}$ = 2.76 TeV, including central, semi-central, and minimum-bias triggered, have been analyzed, with an ALICE standard event selection, track selection, and electron identification.

Anisotropic Decay of Virtual Photons into Di-Electrons

Polarization of direct virtual photons is searched for, via their anisotropic decay into e^+e^-. The anisotropy is measured with respect to the reaction plane, determined with the ALICE V0 detectors, as a function of invariant mass of e^+e^- pair, and with centrality slices. The magnetic field is supposed to be perpendicular to the reaction plane. The detector effect is corrected by comparing the asymmetry in e^+e^- pairs (nearly) transverse to the field with that in pairs (nearly) parallel to the field. The latter is expected to show only the detector effect, since no linear polarization can exist due to a magnetic field parallel to a (virtual) photon.

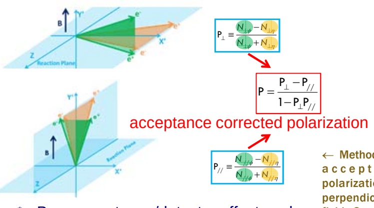


← Schematics of virtual photon polarization in a magnetic field and their anisotropic decay into e^+e^- pairs. Photons (nearly) perpendicular to the field (right) are polarized and decay in an anisotropic manner.

All e^+e^- pairs are first categorized according to the azimuthal angle measured from the reaction plane, either as (nearly) perpendicular to the field, where physics polarization can be expected, or as (nearly) parallel to the field, where no physics polarization is expected. The two sets of e^+e^- pairs are then further categorized in terms of the decay plane into e^+ and e^-, either as (nearly) azimuthal (in ϕ direction) or as (nearly) longitudinal (in η direction). The acceptance corrected polarization is calculated from the ratios of the numbers of e^+e^- pairs in the four categories.

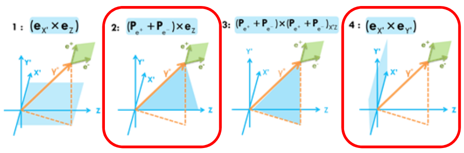
As the kinematic parameter to separate azimuthal and longitudinal decay is not necessarily unique, we have tried and investigated 4 candidate parameters. A simple Monte Carlo simulation has been performed to confirm the method of acceptance correction and to evaluate the 4 candidate kinematic parameters. The candidate kinematic parameters "2" and "4" are found to have better discrimination for 3 extreme physics scenarios: no polarization, full polarization parallel to the magnetic field, and full polarization perpendicular to the field.

$\gamma^* \perp B \rightarrow$ physics + acceptance/detector effects

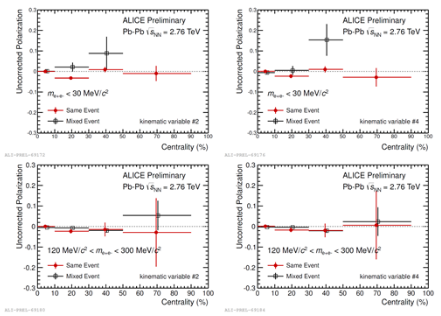


$\gamma^* // B \rightarrow$ acceptance/detector effects only

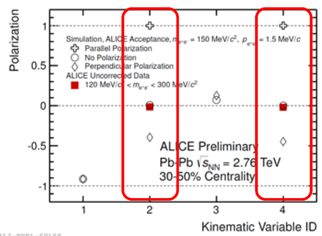
← Methodology to measure the acceptance corrected polarization of virtual photons perpendicular to the magnetic field. See text for details.



↑ Four kinematic parameters have been evaluated with a Monte Carlo simulation in terms of effective separation of different physics scenarios, *e.g.* no polarization and full polarization. Two of the parameters ("2" and "4") are found to have good separation powers.



← Preliminary results of polarization measurement in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV at ALICE, for different invariant mass regions and as a function of collision centrality. No background subtraction, no resolution correction. No polarization is observed beyond the uncertainties.



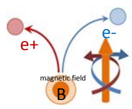
↑ Compilation of simulation results with 4 kinematic variables and 3 physics scenarios and real data analysis. Parameters "2" and "4" exibit good separation powers for different scenarios. Preliminary results in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV are overlaid. It should be noted that the real data results are before background subtraction and resolution correction.

The polarization is expected to be more prominent in mass regions above the π^0 mass where the fraction of direct virtual photons is higher, and in semi-central collisions where the most intense magnetic field is created. A very low mass region, *e.g.* < 30 MeV/c^2, should serve as a reference, as it is dominated by Dalitz decay e^+e^- pairs (created in a late stage) and no polarization is expected. The values obtained using the kinematic variables "2" and "4", are consistent with 0 and also with simulation results with no polarization, *i.e.* no polarization is observed beyond the uncertainty. The analysis needs to be refined, however, at least including: (1) background contributions not from direct virtual photons, *e.g.* combinatorial and Dalitz decays, should be subtracted, (2) better electron identification should be applied, and (3) reaction plane resolution should be corrected.

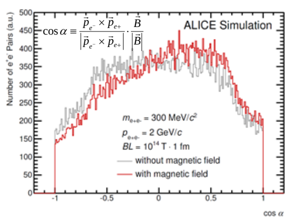
Aligned Deflection of Low-Mass Electron-Positron Pairs

Aligned deflection of e^+e^- pairs is searched for, with respect to the magnetic field, as a function of invariant mass of e^+e^- pair, and with centrality slices. The orientation of magnetic field is supposed according to displacement of the two colliding nuclei, determined with the ALICE neutron ZDC detectors. The average of opening vectors from e^- to e^+ should be shifted as they bend in opposite directions in the magnetic field, while the pairs have finite initial opening angles due to finite masses.

The aligned deflection is expected to be more prominent in mass regions above the π^0 mass where the fraction of direct virtual photons is higher, and in semi-central collisions where the most intense magnetic field is created. A very low mass region, *e.g.* < 30 MeV/c^2, should serve as a reference, as it is dominated by Dalitz decay e^+e^- pairs (created in a late stage) and no deflection is expected.



→ A proof of principle MC simulation, for virtual photons with mass at 300 MeV/c^2 and momentum at 2 GeV/c, assuming all e^+ and e^- are deflected by a constant magnetic field at 10^{14} T with a fixed path length at 1 fm.,



Summary and Prospects

Polarization of direct virtual photons is an especially promising probe of the intense magnetic field in nucleus-nucleus collisions, together with an even more direct signal of aligned defection of electron-positron pairs. ALICE at LHC has a capability to measure electron pairs with respect to the reaction plane/vector. The experimental data analysis has started and is in a preliminary stage. Subtraction of combinatorial background and virtual photons from other sources, *e.g.* Dalitz decays of π^0, η, *etc.* will be a key issue.

Presented by K.Shigaki (Hiroshima University) for the ALICE Collaboration at the 24th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions (Quark Matter 2014) in Darmstadt, Germany, on May 19 – 24, 2014