### Intense Magnetic Field Production in Non-Central Relativistic Nucleus-Nucleus Collisions

Kenta Shigaki, Ken-Ichi Ishikawa, and Asako Tsuji (Hiroshima University)

#### Physics Interests
A very intense magnetic field is expected in non-central nucleus-nucleus collisions, and to reach ~10¹⁴ T at the LHC energies. Not only being the strongest magnetic field in the Universe (cf. ~ 20¹¹ T at the surface of magnetars), various consequences of physics interests in discussion, including chiral magnetic effects (K.Fukushima, D.Kharzeev, H.J.Warringa, PhysD 78 (2008) 074033), synchrotron radiation, and non-linear behaviors of QED e.g. photon splitting and real photon decaying into di-leptons.

#### Unsung Experimental Topic
It should be noted that the field itself in nucleus-nucleus collisions is yet to be directly detected, along with the physics interests on the various consequent phenomena. Even though the field is generated by well-understood electromagnetism and the component by the passing spectator nucleons is straightforward to calculate, the space-time evolution of the field is governed by that of the whole collision system. With a goal to directly detect and determine the field, we evaluate its expected intensity and lifetime based on cascade and static models, and its possible effects on real/virtual photon anisotropy and polarization based on QED calculations of polarization tensors. New approaches are then proposed and examined if feasible to detect the field via direct virtual photon (di-lepton) measurements at LHC-ALICE and RHIC-PHENIX experiments.

### Field Intensity Estimations by Cascade Models

One of the standard approaches to estimate the magnetic field intensity in nucleus-nucleus collisions is to utilize cascade models, e.g. HIBÜN, 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 also grows with the beam energy in proportion to the inverse of the time, 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 much lower peak intensities, but with longer lifetimes. A hydro-dynamical model of the 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.

### Data-Driven Estimation of Field Intensity in Fireball

The fireball after a collision has an angular momentum in non-central cases as the finite stopping of the incoming nuclei leaves a fraction of the initial angular momentum of the system there. The field intensity due to the angular momentum of the positively charged fireball is evaluated by a Glauber calculation and the baryon stopping power based on real data and simulations. The results are shown in the plot on the right. It is found that the effect is most prominent in semi-central collisions, like the elliptic flow is.

### Effects of the Intense Magnetic Field

The effects of the intense magnetic field are quantitatively evaluated via QED calculations of vacuum polarization tensors of photons. As one of the first results, the expected anisotropy of virtual photons due to the field is shown in the plot below. At this moment, the calculable ranges are limited in low mass and/or low transverse momentum regions, without the di-muon channels to open. Polarization of virtual photons is also under calculation within the same framework. It can be naively expected that the polarization is in the similar order to the anisotropy of hadronic studies, as their fields are still in progress.

### Field-Dependent Factor of Virtual Photon Yield

New approaches to detect the magnetic field via virtual photon (low mass di-lepton) measurements are proposed and their experimental feasibilities are under examination. The (1) anisotropy of direct virtual photons. The existence of an intense magnetic field allows virtual photons to decay into di-leptons only at the Landau levels, and hence affect the production rate of di-leptons. QED calculations of vacuum polarization tensors of photons indicate the effect is in the order of c/10⁻³ due to the field intensity expected at LHC and RHIC, which is within an experimental reach though challenged by other sources of anisotropy also known as the elliptic flow. (2) polarization of direct real/virtual photons. Photons get polarized in magnetic field. That of virtual photons is an especially promising probe, while none of current heavy ion experiments at LHC or RHIC is capable of measuring that of real photons. The polarization should be in the similar order of magnitude to the anisotropy. In case virtual photons are polarized in the order of c/10⁻³, both the LHC-ALICE and RHIC-PHENIX experiments should be marginally able to detect it assuming the statistics and signal-to-background ratios in the past data.

### Theoretical Prospects

Calculations of virtual photon rates in higher mass and transverse momentum regions are required to match the experimentally accessible kinematic regions. An exact calculation is made in the case of photons parallel to the field even above the di-muon channel threshold. That for photons perpendicular to the field is in progress, while the lowest Landau level approximation is used for di-electron channels, to complete quantitative predictions of anisotropy and polarization of virtual photons due to the magnetic field.