7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

# Observing the birth of relativistic Coulomb fields

M. Ota[1], K. Kan[2], T. Matsui[3], and M. Nakajima[4]
[1] National Institute for Fusion Science (NIFS),
[2] National Institutes for Quantum Science and Technology (QST),
[3] Department of Electrical and Electronic Engineering, Mie University,
[4] Institute of Laser Engineering (ILE), Osaka University
e-mail (speaker): ota.masato@nifs.ac.jp

Relativity changed the concept of time and space. The theory showed that scales of time and space are not absolute but relative: time and space can expand and contract. Special relativity describes the difference between physics in a static system and in an inertial system, especially when the relative speed between the systems is as high as the speed of light. A. Einstein presented a paper about special relativity in 1905 titled "On the electrodynamics of moving bodies"[1]. Relativistic phenomena predicted in the paper such as time dilation and rest mass energy were demonstrated and applied to GPS and nuclear power plants, respectively. However, the contraction of the Coulomb field, which is the phenomenon referred to by the title of the paper, has not yet been demonstrated. This is because ultrafast electric-field measurement with a temporal resolution of sub-picosecond was necessary. We have conducted electro-optic sampling[2] on the Coulomb field around a high-energy electron beam with the high temporal resolution; we have succeeded in visualizing the electric-filed contraction and observing the process of the relativistic Coulomb-field generation[3].

Figure 1 shows the simplified schematic of the experimental setup, which is conducted by using a photocathode linac at SANKEN, Osaka University. Ti:sapphire laser with a pulse width of ≤130 fs (FWHM) and a central wave length of 800 nm is divided into two: one is for the generation of the electron beam and the other is for the probe laser. The electron beam generated by the linac propagates in the air after passing through the acceleration tube. The Coulomb field around the beam contracts in the propagation direction due to the relativistic effect. Therefore, the Coulomb field can be regarded as a half-cycle terahertz pulse. When the electron beam passed by the ZnTe crystal, which has the Pockels effect, birefringence was induced inside the crystal depending on the strength and the temporal evolution of the Coulomb field. Measuring the modulation of the polarization of the probe laser enables us to evaluate the information of the Coulomb field.

In the experiment, we put an aluminum foil in front of the ZnTe crystal with a distance D and made the Coulomb field around the electron beam canceled. In this situation, after the passage of the foil, the Coulomb field propagates in the air with a spherical shape whose radius corresponds to the propagation distance of the beam (D), as predicted by the Liénard-Wiechert potentials (LWP). Figures 2 (a-c) show the experimental results. Here, the spherical Coulomb field asymptotically coincides with the relativistically contracted planar electric field with the increase of the propagation distance. The experimental results are quantitatively verified by the numerical simulation, as shown in Figs. 2 (e-f). This result corresponds to verifying the theory that the Lorentz transformation of the electromagnetic potentials corresponds to the solution of the LWP in the far field from a boundary. Therefore, we have succeeded in demonstrating the relativistic Coulomb fields. In addition, our result is one of the most direct and intuitive experimental results of relativity.

References
[1] A. Einstein: Ann. Phys. **17**, 891 (1905).
[2] Wu, Q. & Zhang, X. C. Appl. Phys. Lett. **67**, 3523–3525 (1995).
[3] M. Ota *et al*., Nat. Phys. **18**, 1436, (2022).

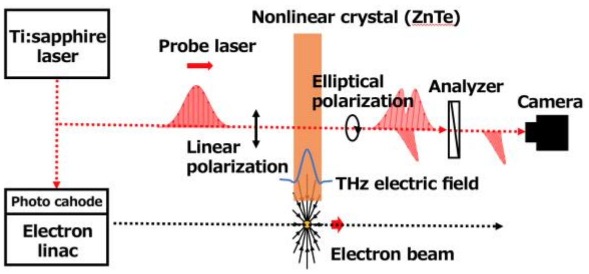


Fig.1 Schematic of the experimental setup.

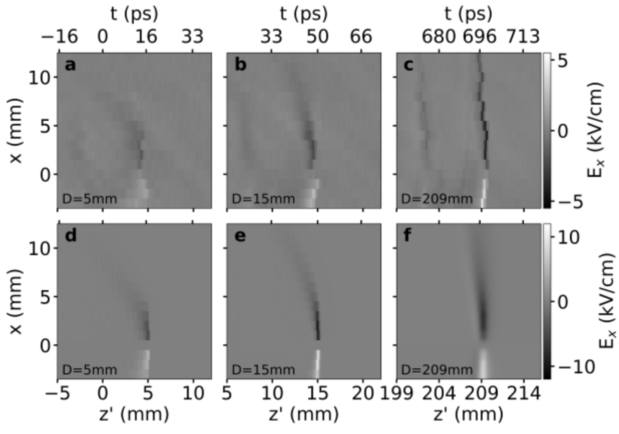


Fig.2 (a-c) Experimental results. (e-f) Particle-in-cell simulation results. The D on the lower left in each figure denotes the distance between the Al foil and the ZnTe crystal.