Development of ultrafast electric field measurement around electric beam and charged particles ~First experimental demonstration of relativistic Coulomb electric field contraction~

Institute of Laser Engineering

Associate Professor Makoto Nakajima

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Abstract

We developed the evaluation method of ultrafast spatio-temporal distribution of electric field around electron beam and charged particles using the electro-optic sampling technique. We succeeded in observing ultrafast dynamics of the electric field by single shot detection method. We demonstrated the first observation of the contraction of the Coulomb electric field by the electron beams moving at close to the speed of light. The contraction of the Coulomb electric field observed this time is a fundamental phenomenon predicted by the theory of special relativity, and we succeeded in observing the electric field contraction process experimentally for the first time (see Figures 1 and 2, Papers 1,2). This developed method is very powerful in evaluating the spatio-temporal profile of the electron beam itself and the electric field around it.

Background & Results

Technologies for generating electron beams, charged particles, etc. are rapidly improving, and pulsed light sources in the picosecond and femtosecond range are also being developed. The evaluation methods of the profile of electron beam and the spatio-temporal distribution of the electric field are demanded. This time we developed the single shot evaluation method with the step-like mirror of echelon. Figure 1 show the image of the formation process of the relativistic electric field contraction that accompanies the propagation of a near-light-speed electron beam. Figure 2 shows the observed spatio-temporal distribution of the Coulomb electric field which shows relativistic contraction clearly. This electric field contraction is the fundamental phenomenon predicted by the special relativity by Einstein over 100 years ago. We demonstrated it experimentally for the first time. The distribution of contracted electric field is perpendicular to the propagation direction of the electron bunch. This evaluation method is very powerful and provide the information on spatio-temporal distribution of the electric field in ultrafast time scale by the single show detection. From the distribution, we can obtain also the information on the electron beam profile in spatio-temporal dimension [See the paper 1,2 as shown below].

Significance of the research and Future perspective

Electron beams and charged particles are expected to be used in applications, not only in medicine but also in applications that utilize electron beam exposure technology for nanotechnology and semiconductor industry, and sterilizing effects for food industry. Our method can evaluate the spatio-temporal distribution of the electric field in ultrafast time scale with the single shot detection. This research result demonstrates the fundamental phenomenon of special relativity in electromagnetism proposed by Einstein. But it can also be used to evaluate the pulse characteristics of electron beams and charged particles, and is very useful for developing applications based on the electron beams as an essential tool for the evaluation.

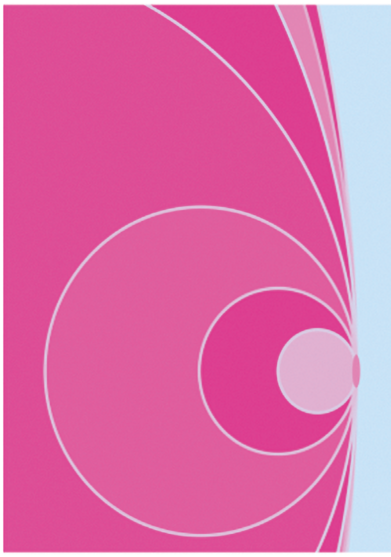

Figure 1 Image of the formation process of the relativistic electric field contraction that accompanies the propagation of a near-light-speed electron beam (shown as an ellipse in the figure)

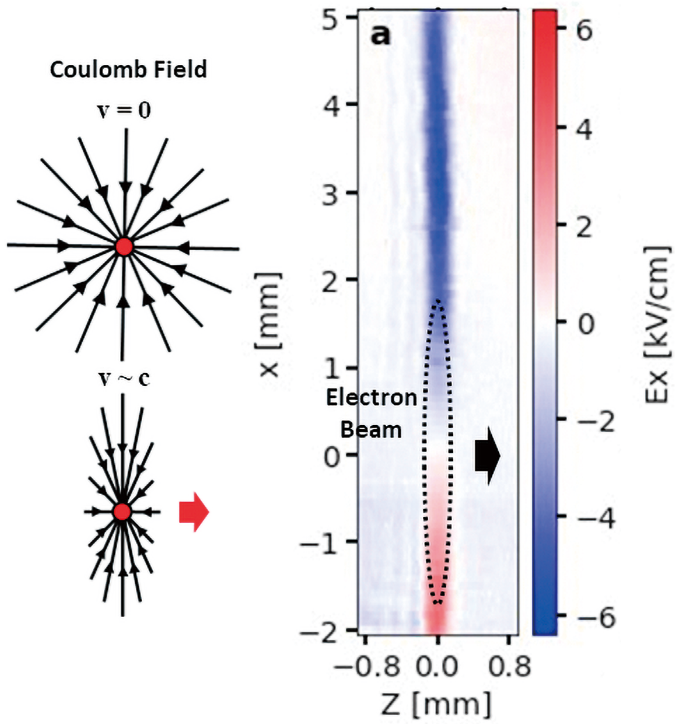

Figure 2 Observed spatio-temporal image of the relativistic contraction of Coulomb electric field around an electron beam moving at close to the speed of light

Patent	Japanese Patent Application No.2021-106147
Treatise	Ota, Masato; Nakajima, Makoto et al. Ultrafast visualization of an electric field under the Lorentz transformation. Nature Physics. 2022, 18, 1436-1440. doi: 10.1038/s41567-022-01767-w Ota, Masato; Nakajima, Makoto et al. Longitudinal and transverse spatial beam profile measurement of relativistic electron bunch by electro-optic sampling. Applied Physics Express. 2021, 14, 026503. doi: 10.35848/1882-0786/abd867 Arikawa, Yasunobu; Nakajima, Makoto et al. The conceptual design of 1-ps time resolution neutron detector for fusion reaction history measurement at OMEGA and the National Ignition Facility. Review of Scientific Instruments. 2020, 91, 063304. doi: 10.1063/1.5143657
URL	https://resou.osaka-u.ac.jp/en/research/2022/20221021_1
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