Research Facility Development Division
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SCRIT Team

1. Abstract

The SCRIT Electron Scattering Facility has been constructed at RIKEN RIBF. This aims at investigation of internal nuclear structure for short-lived unstable nuclei by means of electron scattering. SCRIT (Self-Confining RI Ion Target) is a novel method to form internal targets in an electron storage ring. This is a unique method for making electron scattering experiments for unstable nuclei possible. Construction of the facility has been started in 2009. This facility consists of an electron accelerator (RTM), a SCRITequipped electron storage ring (SR2), an electron-beam-driven RI separator (ERIS), and a window-frame spectrometer for electron scattering (WiSES) which consists of a large window-frame dipole magnet, drift chambers and trigger scintillators. Installation of all components in the facility was completed in 2015. After the comprehensive test and tuning, the luminosity was reached to $3 \times 10^{27}/(\mathrm{cm}^2\mathrm{s})$ with the number of injected ions of 3×10^8. In 2016, we successfully completed a measurement of diffraction of scattered electrons from ^{132}Xe nuclei and determined the charge density distribution for the first time. In 2021, we have been trying to obtain the world first electron scattering data of unstable nuclei.

2. Major Research Subjects

Development of SCRIT electron scattering technique and measurement of the nuclear charge density distributions of unstable nuclei.

3. Summary of Research Activity

SCRIT is a novel technique to form internal target in an electron storage ring. Positive ions are three dimensionally confined in the electron beam axis by transverse focusing force given by the circulating electron beam and applied electrostatic longitudinal mirror potential. The created ion cloud composed of RI ions injected from outside works as a target for electron scattering. Construction of the SCRIT electron scattering facility has been started in 2009. The electron accelerators RTM and the storage ring SR2 were successfully commissioned in 2010. Typical accumulation current in SR2 is 250–300 mA at the energy range of 120–300 MeV that is required energy range in electron scattering experiment. The SCRIT device was inserted in the straight section of SR2 and connected to an ISOL named ERIS (Electron-beam-driven RI separator for SCRIT) by 20-m long low energy ion transport line. A buncher system based on RFQ linear trap named FRAC (Fringing-RF-field-Activated dc-to-pulse converter) was inserted in the transport line to convert the continuous beam from ERIS to pulsed beam, which is acceptable for SCRIT. The detector system WiSES consisting of a high-resolution magnetic spectrometer, drift chambers and trigger scintillators, was constructed, and it has a solid angle of 100 msr, energy resolution of 10^{-3}, and the scattering angle coverage of 25–55 degrees. A wide range of momentum transfer, 80–300 MeV/c, is covered by changing the electron beam energy from 150 to 300 MeV.

We successfully measured a diffraction pattern in the angular distribution of scattered electron from ^{132}Xe isotope at the electron beam energy of 150 MeV, 200 MeV, and 300 MeV, and derived the nuclear charge distribution by assuming two-parameters Fermi model for the first time. At this time, luminosity was reached to $3 \times 10^{27}/(\mathrm{cm}^2\mathrm{s})$ at maximum and the averaged value was $1.2 \times 10^{27}/(\mathrm{cm}^2\mathrm{s})$ with the number of injected target ions of 3×10^8.

We are now under preparation for going to the experiments for unstable nuclei. There are some key issues for that. They are increasing the intensity of the RI beams from ERIS, efficient DC-to-pulse conversion at FRAC, improving the transmission efficiency from FRAC to SCRIT, and effective suppression of the background in measurement of scattered electrons. RI beam intensity will be improved by upgrading the electron beam power from 10 W to 60 W, increasing the contained amount of U in the target ion source, and some modifications in mechanical structure in the ion source. For upgrading the electron beam power, the RF system of RTM has been maintained intensively, and we will continue the development of RTM. For efficient DC-to-pulse conversion, we established the two-step bunching method, which is time compression at FRAC in combination with pre-bunching at the ion source using grid action. Furthermore, we will improve the conversion efficiency and the transmission efficiency from FRAC to the SCRIT device by cooling the trapped ions using minuscule amounts of a buffer gas. These improvements on FRAC were already confirmed in off-line test. Since one of significant contribution to the background for scattered electron is scattering from massive structural objects around the trapping region originated from halo components of the electron beam, we remodeled the SCRIT electrodes. The vacuum pump system at the SCRIT device has been upgraded to reduce the contribution of residual gases. Luminosity for radioactive Xe isotopes is expected to be more than $10^{26}/(\mathrm{cm}^2\mathrm{s})$ after these improvements. Then, we will be able to start experiments for unstable nuclei. When further upgrading in the RTM power planed to be 3 kW will be achieved, we can extend the measurements to more exotic nuclei.

In 2018, we developed several instruments. One is the introduction of the surface-ionization type ion source at ERIS in order to increase kinds of radioactive beam and to produce high intensity beam. Another development is the upgrading of the drift chamber located in front of the magnetic spectrometer of WiSES to improve the momentum resolution and angular acceptance. These developments help us to realize experiments for unstable nuclei.

In 2019, we installed a newly designed SCRIT electrodes. The main purpose of the replacement was to lower the background during the measurement due to the electron scattering from the SCRIT electrodes itself but not from the ion targets for the experiment. For that purpose, we employed thin metal wires to construct the electrodes rather than metal plates nor blocks. In addition, we modified the inside structure of the SCRIT chamber to symmetrize the electric ground potential affecting the potential curve inside the electrodes.

In 2020, we tested accelerators RTM and SR2 if they bear for long term experiment for 24 hours. Currently, we are adjusting the SR2 accelerator and ion source ERIS to be ready for the real electron scattering measurement of unstable nuclei.

In 2021, ERIS became ready to provide enough ions for the experiment of unstable nuclei. We have been trying to measure electron scattering of unstable nuclei. Hopefully, we can publish those data very soon.

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List of Publications & Presentations

Publications

[Original Papers]

須田利美, 本多佑記, 瀧大祐, 郷家大雅, C. Legris, 石崎一志, 三浦禎雄, 武藤俊哉, 玉江忠明, 前田幸重, Z. Hang, 塚田暁, 「Proton radius」, 原子核研究 **66**, 2–11 (2021).

須田利美, 本多佑記, 前田幸重, 塚田暁, 「陽子半径」, 高エネルギーニュース **40**, 107–116 (2022).

[Proceeding]

T. Ohnishi, K. Adachi, A. Enokizono, T. Fujita, M. Hara, M. Hori, T. Hori, S. Ichikawa, K. Kurita, T. Suda, T. Tamae, K. Tsukada, M. Togasaki, N. Uchida, M. Wakasugi, M. Watanabe, and K. Yamada, "The SCRIT electron scattering facility at RIKEN RI Beam Factory," JPS Conf. Proc. **35**, 011027 (2021).

Presentations

[International Conferences/Workshops]

T. Suda (oral), "Study of radii of proton and exotic nuclei by electron scattering," 2021 Symposium on Nuclear Data, Online, November 18–19, 2021.

C. Legris (oral), "Commissioning results for the ULQ2 experiment towards the proton charge radius determination," The Nineth International School for Strangeness Nuclear Physics, RCNP, Osaka University, Online, December 13–16, 2021.

T. Goke (oral), "New type scattering chamber optimized for proton radius measurement by low-energy electron scattering," The Nineth International School for Strangeness Nuclear Physics, RCNP, Osaka University, Online, December 13–16, 2021.

[Domestic Conferences/Workshops]

大西哲哉 (招待講演), 「The SCRIT e-RI scattering facility at RIKEN」, RCNP での次期計画検討会, 大阪府茨木市 (大阪大学核物理研究センター), 2021 年 9 月 27–29 日.

H. Wauke (oral), "Study of internal structure of unstable nuclei by electron scattering," The RIBF Users Meeting 2021, RIKEN, Japan, Online, September 7–9, 2021.

T. Goke (poster), "Development of new vacuum scattering target chamber optimized for proton radius measurement by low-energy electron scattering," ELPH Symposium 2022, Sendai, March 11, 2022.

T. Goke (oral), "Future plans for proton radius measurement by low-energy electron scattering," JPS 2021 Autumn Meeting, Kobe, Online, September 14–17, 2021.

C. Legris (oral), "First test results for the ULQ2 experiment towards the proton charge radius determination," JPS 2021 Autumn Meeting, Kobe, Online, September 14–17, 2021.

H. Wauke (oral), "Isotope and isotone dependence of nuclear charge density distribution at SCRIT electron scattering facility," 2022 Annual (77th) Meeting of The Physical Society of Japan, Okayama, Online, March 15–19, 2022.

T. Goke (oral), "Development of new vacuum scattering target chamber for proton radius measurement by low-energy electron scattering," 2022 Annual (77th) Meeting of The Physical Society of Japan, Okayama, Online, March 15–19, 2022.

Y. Ishikura (oral), "Commissioning of the twin spectrometers for proton radius measurement by low-energy electron scattering," 2022 Annual (77th) Meeting of The Physical Society of Japan, Okayama, Online, March 15–19, 2022.

[Seminar]

須田利美（招待講演),「陽子のサイズがおかしい？」, 千葉大学先進科学プログラム・オムニバスセミナー, 千葉県千葉市（千葉大学), 2021 年 10 月 15 日.

Outreach Activities

須田利美 (インタービュー記事), 「陽子の半径の正確な値を突き止めよ—半世紀前の古い加速器だからこそできること」, 国立大学附置研・センター会議, http://shochou-kaigi.org/interview/interview_93/ .

須田利美（特別講義),「陽子などの物の大きさはどう測る？」, 埼玉県立熊谷高等学校, 埼玉県熊谷市 (埼玉県立熊谷高等学校), 2022 年 1 月 14 日.

須田利美 (集中講義), 「電子散乱による原子核研究」, 北海道札幌市 (北海道大学物理学科), 2021 年 12 月 13–15 日.