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First result from SCRIT electron scattering facility:Charge density distribution of ^{132}Xe

K. Tsukada[*,†] **K. Kasama, K. Namba, T. Suda, T. Tamae**
Research Center for Electron-Photon Science, Tohoku University, 1-2-1 Mikamine, Sendai, 981-0928, Japan

M. Hara, S. Ichikawa, T. Ohnishi, M. Wakasugi, M. Watanabe
RIKEN Nishina Center, Wako, Saitama, 351-0198, Japan

K. Adachi, A. Enokizono, T. Fujita, M. Hori, K. Kurita, S. Sasamura, M. Togasaki, N. Uchida, K. Yamada
Department of Physics, Rikkyo University, Toshima-ku, Tokyo, 171-8501, Japan

S. Wang
School of space science and physics, Shangdong University

We have constructed the SCRIT electron scattering facility at RIKEN in order to realize electron scattering off unstable nuclei. Because electron scattering is the most powerful and reliable tool to study the internal structure of the atomic nuclei as demonstrated for many stable nuclei in the latter half of the 20th century, actualization of electron scattering for the unstable nuclei has been long awaited. Recently, we have performed a series of elastic electron scattering experiments with ^{132}Xe target. The high luminosity of around 10^{27} cm^{-2}s^{-1} which is a minimum-requirement for electron scattering is achieved with using only 10^8 target ions. By comparing with a DWBA calculation assuming the two-parameter Fermi distribution as the nuclear charge density distribution, it is found that a root-mean-square of radius is consistent with that from the measurement of X-ray of muonic atom and an information of surface shape of ^{132}Xe nucleus is extracted for the first time.

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*Speaker.
†tsukada@lns.tohoku.ac.jp

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1. Introduction

Electron scattering gives the most powerful and reliable information of the internal structure of the atomic nuclei. Many stable nuclei have been investigated by electron scattering experiments in the latter half of the 20th century. after the monumental measurement by R. Hofstadter and his colleagues[1]. Electron scattering has some unique and invaluable features; the electron is a structureless particle and interacts with the nucleus through the electromagnetic interaction which is the best known interaction, and the electromagnetic interaction is moderately weak to probe whole volume of the target nucleus without serious distortion. Therefore the experimental data can be directly compared with theoretical calculations with the least model dependence. This method, however, has been applied mostly only stable nuclei due to the difficulty in preparing the target material for short-lived unstable nuclei. Since it has been revealed that some of nuclei far from the stability valley exhibit exotic features such as neutron halo, neutron skin, level inversion, proton bubble structure, evolution of magic numbers, and so on[2, 3, 4], actualization of electron scattering for the unstable nuclei has been desired.

Two methods are proposed to carry out electron scattering off unstable nuclei, namely electron-RI (Radioisotope) collision, and electron scattering with a fixed target as was the case in the past experiments for stable nuclei. The first method is planned at FAIR in Darmstadt, the ELISe project[5], in which the electron-RI collider consisting of the RI storage ring and the electron ring will allow us to perform electron scattering targeting a variety of unstable nuclei. In this paper, the second method with a completely new and novel target-forming technique, SCRIT (Self-Confining Radioactive Isotope Target)[6], is discussed. The feasibility of SCRIT was already demonstrated with a prototype device[7, 8], and following the success of the feasibility study, we completed the SCRIT electron scattering facility dedicated for exotic nuclei in the RI Beam Factory at RIKEN[9].

We report the first result of elastic electron scattering off ^{132}Xe nucleus at the SCRIT facility. Although the ^{132}Xe is a stable nucleus, only the root-mean-square of radius has been reported with some assumptions ($\langle r^2 \rangle^{1/2}$=4.787 fm for ^{132}Xe) by measurements of X-ray transition (2P-2S) of muonic atom[10]. The present result is, therefore, the first determination of the surface shape of ^{132}Xe nucleus.

2. Experimental apparatus

The overview of the facility is shown in Fig. 1. The facility consists of RTM (a 150-MeV racetrack microtron), SR2 (an electron storage ring) equipped with SCRIT, ERIS (an electron-beam driven RI separator for SCRIT)[11], WiSES (a window-frame spectrometer for electron scattering), and LMon (a luminosity monitor).

The 150 MeV-electrons from RTM are stored and accelarated in SR2. During the electrons circulating, target ions are mass-separated and delivered into SCRIT by ERIS, and then scattered electrons are measured by WiSES.

2.1 Target preparation:ERIS and SCRIT

^{132}Xe target ions was extracted from the natural xenon gas which was introduced at an entrance branch of the ERIS system. After the mass separation, pure ^{132}Xe ions were bunched and delivered

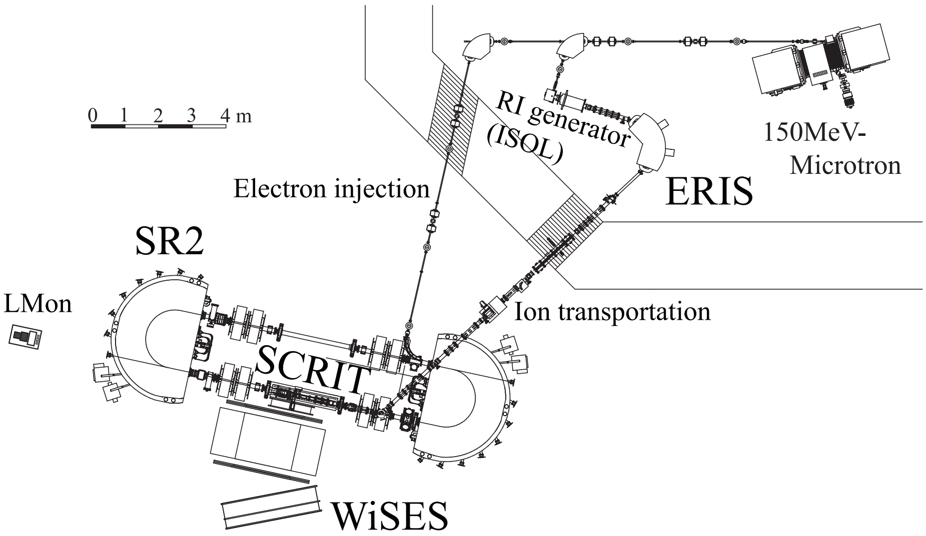

Figure 1: Overview of the SCRIT electron scattering facility.

into the SCRIT.

The target ions were stored in the SCRIT for a few hundred ms and ejected to refresh the target quality because the amount of the residual gas ions also increased due to the ionization and trap by the electron beam. The SCRIT operation with and without target ions were alternated for the comparative measurement and the background subtraction. At the present experiments, the trapping times were set to be 240 ms which was decided to maximize the ratio between the number of target ions and residual gases. The interval among the trapping times was fixed to be 10 ms.

Details of SR2, ERIS and SCRIT are described in [12].

2.2 Electron spectrometer (WiSES) and Luminosity monitor (LMon)

WiSES consists of a dipole magnet, drift chambers at the entrance and the exit of the magnet, two scintillation counters used for trigger generation, and a helium bag made of a 30 μm thick vinyl installed between two drift chambers to reduce the multiple-scattering effect. The magnitude of the magnetic field was always monitored by an NMR positioned at the flat field region. and was adjusted to be 0.41, 0.54, and 0.80 T for the electron beam energy(Ee) of 151, 201, 301 MeV, respectively. The solid angle of the spectrometer is about 80 msr covering the scattering angle from 30 to 60°. The designed momentum resolution ($\delta p/p$) is $2{\sim}4\times10^{-3}$ depending on the scattered electron momentum.

LMon which is located 7 m downstream from the SCRIT consists of pure CsI crystal array and a set of fiber-scintillation counters. By measuring the energy and the spatial distribution of the bremsstrahlung photon, the abusolute luminosity can be estimated.

Details of WiSES and LMon are explained in [13, 14].

2.3 Acceptance commissioning

For spectrometer acceptance studies, two types of target have been used. The first was a tungsten wire of 50 μmϕ which was tensioned horizontally and was remotely controlled to move vertically towards the electron beam. Since the wire target was considered as a point source of scattered electrons, an acceptance of WiSES could be examined using known angular distributions of elastic scattering at the low-momentum transfer region. The second was ^{208}Pb ions which was evaporated from a natural lead heated up to about 300°C and delivered into SCRIT by ERIS. Figure 2 shows obtained differential cross sections multiplied by luminosity to the effective momentum transfer (q_{eff}) for elastic scattering off ^{208}Pb with the electron beam energies of E_e=151, 201, and 301 MeV. The q_{eff} is defined as,

$$q_{eff} = q[1 + \frac{4}{3}(Z\alpha/E_i R)] \tag{2.1}$$

$$R = 1.2 \times A^{1/3} \text{ [fm]}, \tag{2.2}$$

by taking into account the coulomb attraction between the electron and the nucleus, where q is the momentum transfer calculated by the measured angle as $q = 2E_i \sin(\theta/2)$, E_i the initial electron energy, θ the polar angle of scattered electron, Z and A the atomic and mass number of the nucleus, α the fine structure constant, respectively.

Measured distributions are well reproduced with a theoretical calculation using the charge density distribution precisely determined by electron scattering[15]. It should be noted that an influence of inelastic scattering is negligibly small[17, 18].

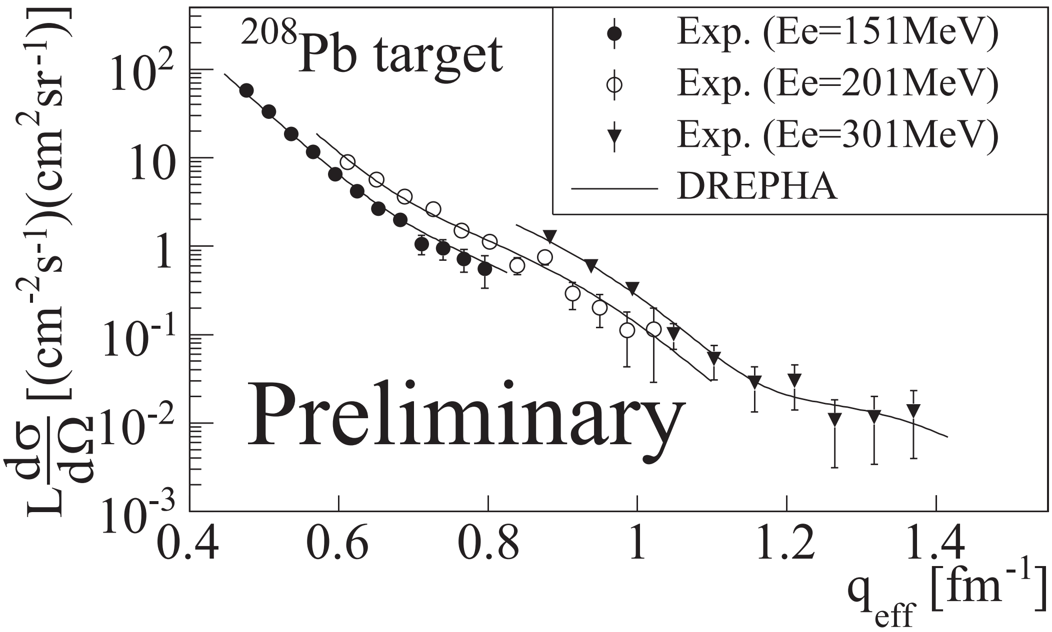

Figure 2: Differential cross sections multiplied luminosity to the effective momentum transfer for E_e=151, 201 and 301 MeV. Lines are DWBA calculations assuming the Sum-Of-Gaussian as the nuclear charge density distribution[15].

3. Experiment with ^{132}Xe target

The measurements of elastic scattering for ^{132}Xe target were carried out at electron beam energies of 151, 201, and 301 MeV. Since the position and opening angle of our spectrometer were fixed, the electron beam energies were set to cover the momentum transfer region from 0.4 to 1.4 fm^{-1}. The electron beam current was typically 250 mA decreasing to 150 mA at the end of a 40-minutes data-taking run. The beam size was about 2 $mm^H \times 0.4$ mm^V in sigma at the center of SCRIT. The number of ^{132}Xe ions introduced in SCRIT was estimated to be 2.3×10^8 [particles/pulse][12]. Totally, measurement times were 7.8×10^3, 1.3×10^5, and 1.9×10^5 sec for the electron beam energies of 151, 201, and 301 MeV, respectively. Figure 3 shows differential cross sections multiplied by luminosity. The systematic error is estimated to be about 5% due to the ambiguity of the spectrometer acceptance.

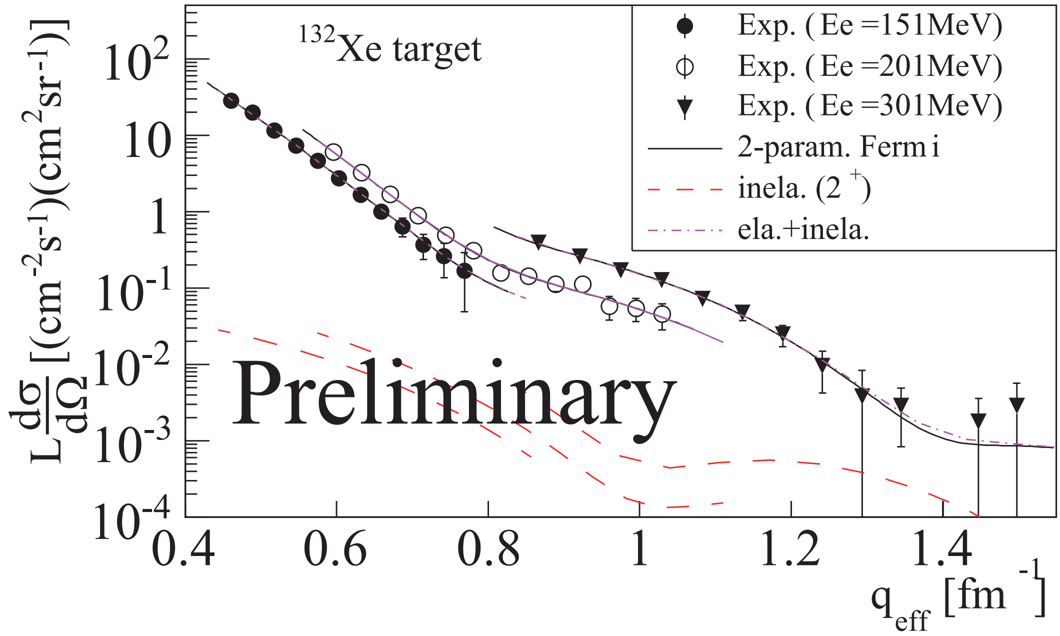

Figure 3: Differential cross sections multiplied by the luminosity to the effective momentum transfer for E_e=151, 201 and 301 MeV. The lines represent a DWBA calculation for elastic scattering assuming a two-parameter Fermi distribution as the nuclear charge density distributions (black solid), a phase shift calculation for inelastic scattering (red dashed, 2^+, Ex=0.67 MeV), and sum of them (purple dot-dashed). The parameters for two-parameter Fermi distribution are the best values to reproduce our work.

The solid line shown in Fig.3 are elastic cross sections calculated by a DWBA code, DREPHA[16], assuming a two-parameter Fermi distribution as the nuclear charge density distribution as,

$$\rho(r) = \frac{\rho_0}{1+\exp\left(\frac{4.4(r-C)}{t}\right)},$$

where ρ_0 is the density at the center of the nucleus, C and t the surface distribution parameters, respectively. The luminosity value for each energy is considered as the fitting parameter in the present analysis because the study of the LMon to determine the absolute value of luminosity is underway. The luminosity evaluated by fitting are 0.87×10^{27}, 1.06×10^{27}, and 1.55×10^{27} $cm^{-2}s^{-1}$ for E_e=151, 201, and 301 MeV, respectively. Contamination of inelastic scattering processes corresponding to some excited state (2^+, Ex=0.67 MeV, 1.3 MeV and so on) should exist because the momentum resolution of our spectrometer does not allow us to separate these states from the ground state. Based on theoretical calculations[19, 20], dashed-line in the figure, the amount of the contribution of the first excited state is evaluated to be less than 1 % of that of the ground state below 1.2 fm^{-1}, and to reach up to 10 % at 1.4 fm^{-1}. Those influence is, therefore, much smaller than the statistical errors.

By changing parameters, C and t, of the two-parameters Fermi distribution, the most probable values are firstly extracted to be C=5.4±0.1 fm (preliminary) and t=2.7±0.4 fm (preliminary), and resulting $\langle r^2 \rangle^{1/2}$=4.8±0.1 fm (preliminary). Note that the root-mean-squared of radius from the X-ray measurement of muonic atom ($\langle r^2 \rangle^{1/2}$=4.787 fm) is very consistent with our result.

4. Summary

The SCRIT electron facility has been constructed to realize electron scattering off unstable nuclei for the first time. The primary goal of this facility is to determine their charge density distributions by elastic electron scattering. The angular distributions for Ee=150, 200, and 300 MeV are well reproduced with calculations assuming a two-parameters Fermi as a nuclear charge density distribution. By changing parameters, C and t, of the two-parameters Fermi, the charge radius and diffuseness can be extracted independently.

Following this successful experiments, electron scattering experiment with series of the Xe isotopes and ^{132}Sn trapped by the SCRIT system will be performed in the near future.

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