SCRIT ELECTRON SCATTERING FACILITY AT RIKEN

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A novel method, SCRIT (Self-Confining Radioactive isotope Ion Target), forms a target of short-lived RI (Radioactive Isotope) ions inside an electron scattering ring, which makes electron scattering experiments for short-lived nuclei possible. The SCRIT electron scattering facility is under construction at RIBF in RIKEN to realize electron scattering experiment for short-lived nuclei for the first time. The facility consists of a 150-MeV microtron, an electron storage ring equipped with a SCRIT device and an ISOL involving a low energy RI beam generator. Stable nuclei, ^{133}Cs and ^{132}Xe, were used as targets to evaluate the performance of this facility. Elastically scattered electrons from the targets were clearly observed and the luminosity was found to reach nearly 10^{27} cm^{-2}s^{-1} at the electron beam current ~200 mA, which is the required luminosity to determine the charge density distribution of the target nucleus.

1. Introduction

1.1. *Electron scattering*

With advantages as point particle and due to well-understood electromagnetic interaction, electron scattering has long been known to be the best tool to determine the charge density distribution of atomic nuclei. From the fifties of last century, the charge density distributions of most stable nuclei had been determined through elastic electron scattering, which has greatly contributed to establish the current nuclear model [1]. With the development of accelerator and experiment technologies, the research field of nuclear physics has extended to short-lived unstable nuclei. From the discovery of neutron halo nuclei, such as ^{11}Li [2,3], the internal structures of those short-lived nuclei near the drip line have been studied and some of them have already been predicted to have peculiar structures, like proton bubble[4]. Precise measurement of the charge density distributions on such nuclei is critical for understanding their structures. Due to the short life-time of short-lived nuclei far from stability line, electron scattering experiment has never been carried out to measure the charge density distribution of short-lived nucleus so far.

1.2. *SCRIT method*

The SCRIT method is based on the well-known "ion trapping" phenomenon in electron storage rings [5~7]. Residual gas is ionized and trapped by electron beam, which reduces the life-time and stability of electron beam. The SCRIT method is a positive way to use this phenomenon in electron scattering experiments for short-lived nuclei. The ions of short-lived nucleus are transported from an external ion source into an electron storage ring and trapped by electron beam itself. With a longitudinal mirror potential produced by electrodes of a SCRIT device, target ions were confined and trapped within this region, where a "support-free" target of short-lived nucleus is formed and electrons scattering off the target ions automatically occur [8]. To keep the purity of the target, the trapped ions are extracted from the target region after a certain trapping period, which depends on the life-time of target nucleus, and the next bunch of ions will be injected into trapping region.

1.3. *Feasibility studies*

A prototype of the SCRIT device was installed in KSR (Kaken Storage Ring) [9] at Kyoto University to confirm whether the injected ions were trapped by electron beam in the trapping region and the required luminosity was achieved or not. The energy of electron beam was 120 MeV and the typical beam current was around 80 mA with a life-time of 100 s. The ions of stable nucleus, ^{133}Cs, were employed as target in the feasibility studies. Approximately 10^6 Cs ions were trapped in the SCRIT device with a 260 mm long trapping region, and the luminosity was nearly 10^{26} cm^{-2}s^{-1} at the beam current of 75 mA, which is determined by observing elastically scattered electrons from the trapped ^{133}Cs ions[10,11]. According to the theoretical calculation, collision luminosity of over 10^{27} cm^{-2}s^{-1} is necessary to determine the charge density distribution with accuracy a few percent within one week measurement. Due to the maximum beam current of KSR being ~100 mA with a short life-time, a high performance electron storage ring with high beam current and long life-time is needed to achieve luminosity high enough for electron scattering experiments of short-lived nuclei

2. The SCRIT electron scattering facility

The SCRIT electron scattering facility mainly consists of three parts: an electron accelerator (RTM: Racetrack Microtron), an electron storage ring equipped with a SCRIT device (SR2: SCRIT-equipped RIKEN Storage Ring) and an ISOL involving an RI generator (SRIS: SCRIT RI beam Injector

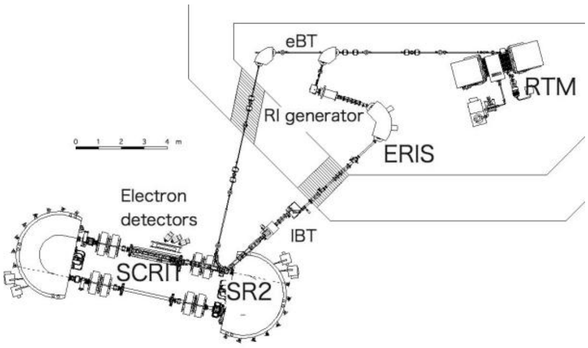

Fig. 1 Layout of the current SCRIT electron scattering facility.

System) [12], as shown in Fig.1. Electrons are accelerated up to 150 MeV by RTM, transported through an electron beam transport line (eBT) and accumulated in SR2. The RTM plays another role as a driver for RI production. RI ions are generated via photo-fission reaction of uranium. Electron beam with the energy of 150 MeV from RTM irradiates the multiply-stacked $^{238}UC_x$ target disks, where the contained ^{238}U is amounts to be 50 g.

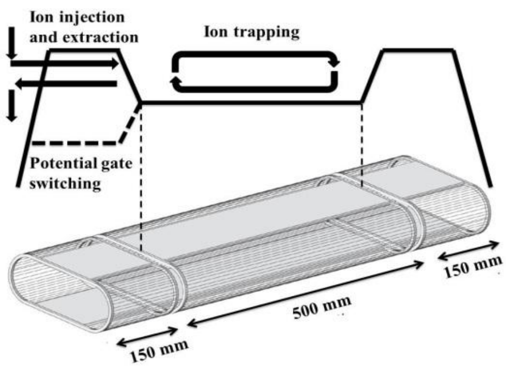

Fig. 2 The structure of SCRIT electrodes and its potential structure for ion injection, ion trapping and ion extraction.

Gamma rays in the electromagnetic-shower process excite the giant dipole resonance at around 15 MeV where fission reaction is strongly induced. The total fission rate of 2×10^{11} fissions/s is expected from the gamma-ray production rate obtained from the simulation and the measured cross section of the photofission [13] of uranium at the electron beam power of 1 kW. Production rate of ^{132}Sn, which is double magic nucleus as the first target for electron scattering at this facility, is estimated to be 2×10^{9} particles/s using independent chain yield [14].

RI ions beam from the ISOL are transported to a cooler buncher, which stacks continuously injected RI ions for appropriate time. Pulsed RI ion beams extracted from the cooler buncher will be transported to the SCRIT device through 7.0 m long ion beam transport line (IBT). Before guiding into SCRIT device, ion beams going downward in vertical direction are bent 90 degree into the direction of the electron beam axis by a deflector system.

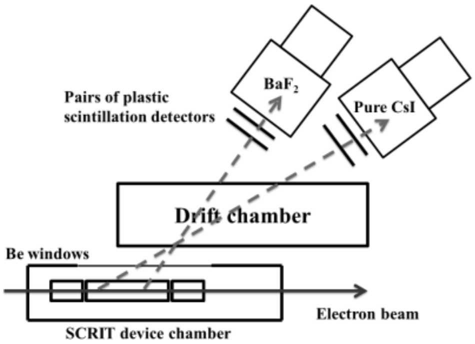

Fig. 3 The schematic diagram of scattered electrons detection system

The positions of both electron beam and ion beam are monitored by two scraper type of beam position monitors to maximize the overlap between electron beam and ion beam for obtaining high collision luminosity. The electron beam orbit in the SR2 is defined by two 180-degree bending magnets with the radius of 0.87 m and four sets of quadrupole doublet. The circumference of SR2 is 21.946 m and 14 bunches are circulated in the ring with an RF frequency of 191.244 MHz. The energy of electron beam can be set from 150 MeV to 700 MeV. A SCRIT device is inserted in one of the straight section of SR2. The SCRIT device is an assembly of three racetrack-shape of cylindrical electrodes, whose sidewall is formed by thin wire stripe to make material thickness negligible for scattered electrons coming out and produces electrostatic mirror potential for longitudinal ion trapping as schematically shown in Fig.2. The potential at the long middle electrode, 500 mm in length, is tuned to reduce the kinetic energy of the trapped ions to less than a few eV, and the short electrodes, 150 mm in length for each, at both ends form the trapping potential. Ion beam injection and extraction of trapped ions are controlled by fast switching of one of mirror potential.

3. Performance of the SCRIT device

To determine the achievable luminosity at this facility, elastically scattered electrons from the trapped ions are measured using a detection system, which consists of a drift chamber, two pairs of plastic scintillation detectors and two calorimeters, as shown in Fig.3. The trajectories of the scattered electrons are determined by the drift chamber, which consists of two layers with 128 hexagonal shape drift cells. The filling gas was a mixture of helium (50%) and ethane (50%). A pair of 10 mm thickness plastic scintillation detectors, 120×120 mm^2 in area, is placed in front of each calorimeter to define the solid angle. Two calorimeters, pure CsI crystals and BaF_2 crystals, measure the energy of the scattered electrons. Each calorimeter consists of seven 200mm-length-optically isolated crystals with hexagonal shape cross section. The distances from the SCRIT center to the front surfaces of the calorimeters are 1540 (CsI) and 1157 (BaF_2) mm, respectively. Gain changes of the calorimeters were continuously monitored by a gain monitoring system using an LED. The detection system covers the scattering angle from 25-degree to 50-degree. Scattered electron from trapped target ions went out of the SCRIT device through a 2 mm thickness Be window.

3.1. *Testing experiment of ^{133}Cs and ^{132}Xe*

To evaluate the performances of this new facility, a series of experiments using stable ^{133}Cs and ^{132}Xe ions have been performed since June, 2011.

The energy of electron beam was fixed to be 150 MeV. The measurements started at beam current around 220 mA and continued to 180 mA to keep a high luminosity. To confirm the electrons coming from trapped ion target, the measurement was separated into with target (ion on) and without target (ion off) measurement. Each measurement maintained 45 ms to simulate an experiment using the short-lived nucleus by controlling the grid of the ion source, and two measurements were continuously repeated during the experiment.

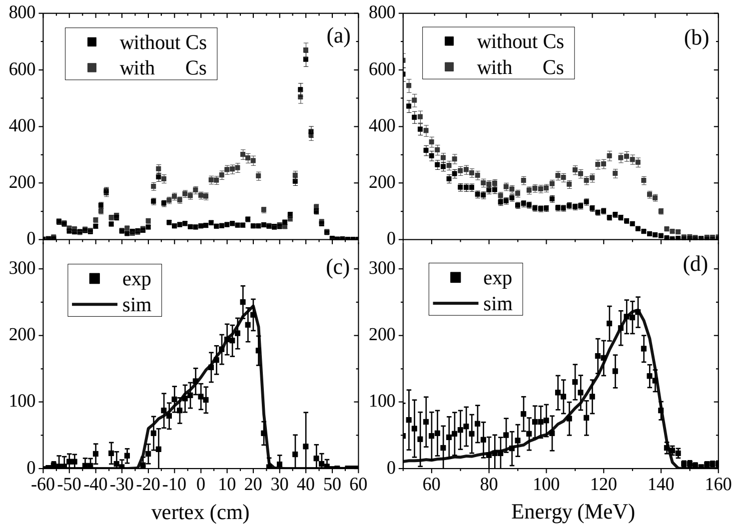

Fig.4 Vertex distribution ((a) and (c)) and energy spectra ((b) and (d)) of scattered electrons. Red(black) points in (a) and (b) show yield of scattered electrons with(without) Cs ion target. Black points are experimental data after subtracting background and the blue line is simulated result in (c) and (d).

Figure 4(a) and 4(b) show the vertex distributions of scattered electrons, whose energy loss in calorimeter is over 100 MeV and the energy spectra of scattered electrons from trapping region in ion on and off measurement. A yield enhancement of scattered electrons from the target is clearly seen in both figures. The sharp peaks around -35 cm, -15 cm and 40 cm in Fig. 4(a) are attributed to beam halo hitting the terminal electrodes. Figure 4(c) and 4(d) show the vertex distribution and energy spectra after subtracting the contribution of ion off measurement. In Fig. 4(c), the events only came from the region -25 cm to 25 cm, which is consistent with the design value for the trapping region of the SCRIT device and the blue line shows the result of a GEANT4 simulation assuming that the trapped Cs ions are uniformly distributed along the trapping region. The line in Fig. 4(d) is also the simulation result for the detector response for 150 MeV electrons. Those events of scattered electrons should be mainly from elastic scattering. Considering the solid angle and elastic cross section, the achieved luminosity was concluded to be nearly 10^{27} $cm^{-2}s^{-1}$ at beam current ~200 mA.

To check the performance of the new ion transport line, like mass resolution and transport efficiency, natural Xe gas including nine stable Xe isotopes was used as a target instead of Cs since April, 2012. Elastically scattered events from trapped ^{132}Xe ions were clearly seen and the luminosity was estimated to be around 4×10^{26} $cm^{-2}s^{-1}$ at electron beam current ~200 mA. The number of injected ions from the ion source in the Xe experiment was set to be similar to that of short-lived nucleus experiment, which was nearly one fourth of that in the Cs experiment, but the achieved luminosity was almost half of that in the Cs experiment, which indicated that transport efficiency for target ions and the beam size of ions in the trapping region in the Xe experiment were much improved. High enough luminosity for electron short-lived nucleus scattering experiment is expected with small number of injected target ions.

3.2. *Electron spectrometer*

To preciously identify the elastically scattering electrons, an electron spectrometer with momentum resolution, $\Delta p/p$, ~ 1×10^{-3} is under construction.

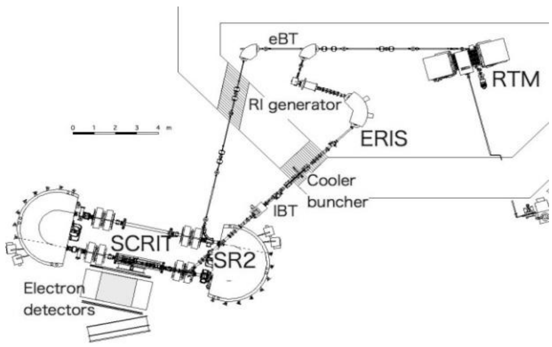

Fig. 5 Layout of the SCRIT electron scattering facility with an electron spectrometer.

Due to the long target region, 500 mm, a non-focusing type spectrometer is employed. The gap of the spectrometer is 170 cm (width) × 29 cm (height) × 140 cm (length) and covers the scattering angle from 30-degree to 60-degree with a solid angle of ~100 msr. The magnetic field is 0.8 T for 300 MeV electrons. The momentum transfer region for elastic scattering will be from

80 MeV/c at E_e=150 MeV to 300 MeV/c at E_e=300 MeV.

Two drift chambers are placed at both the entrance and exit of the magnet to determine the trajectory of the scattered electrons, as show in Fig.5.

4. Conclusion

The SCRIT electron scattering facility is under construction at RIBF. The construction of the electron accelerator, electron storage ring with a SCRIT device and RI beam transport line were completed and successfully operated with stable ions. The collision luminosity between electron beam and target ions was achieved around 10^{27} $cm^{-2}s^{-1}$ and 4×10^{26} $cm^{-2}s^{-1}$ at electron beam current ~200 mA in ^{133}Cs and ^{132}Xe experiment, respectively.

The RI ion generator and an ISOL have been already installed and now are in operation. An electron spectrometer with high momentum resolution is under construction and will be installed in the beginning of 2014. The Day One experiment will be elastic electron scattering for short-lived Sn isotopes including a doubly magic nuclei ^{132}Sn in the year 2014.

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