Silicon pad detector with large effective area for SHE experiments

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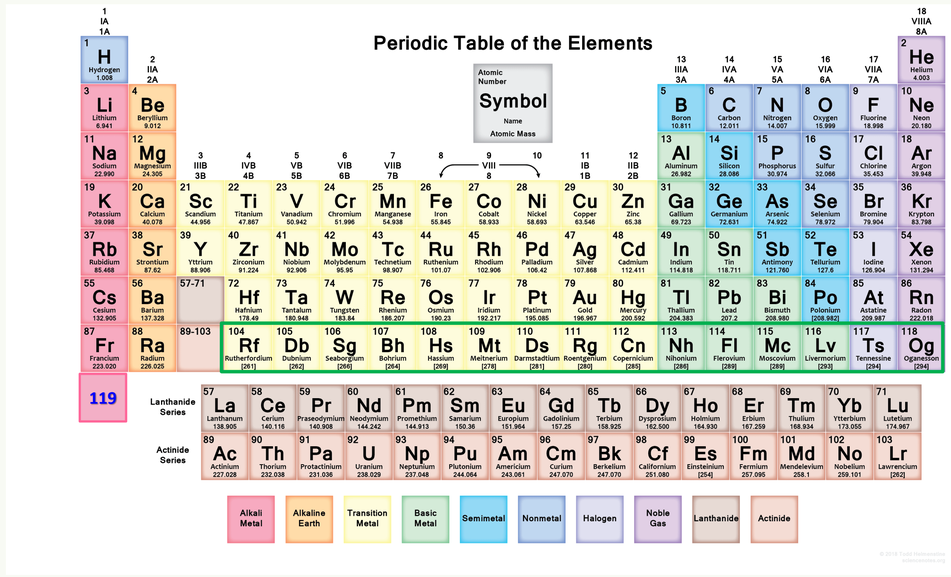
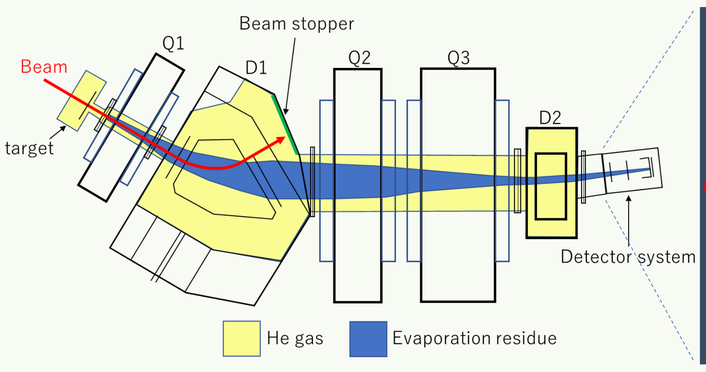
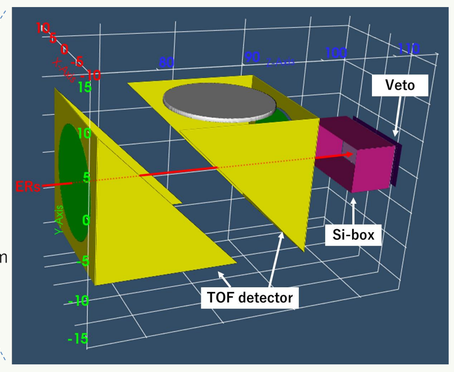
Introduction



Elements with atomic number $Z \geq 104$ are called superheavy elements (**SHEs**). SHEs are synthesized through a nuclear reaction between beam nuclei and target nuclei.

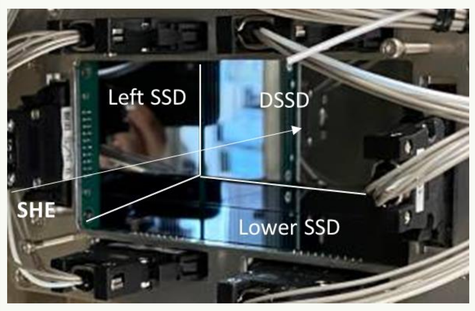


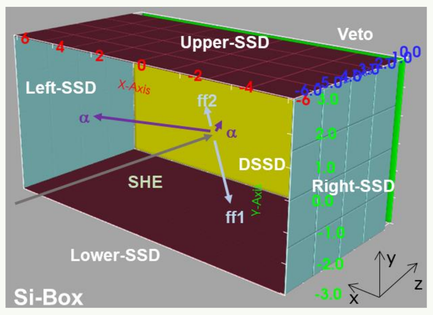
GARIS-II and GARIS-III

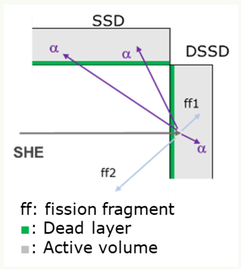


GARIS detection system

At RIKEN, a search for **new element with Z = 119** through the reaction between a ^{51}V beam and a ^{248}Cm target using gas-filled recoil separators (**GARIS-II** and **GARIS-III**) has been started. The produced SHEs are separated from the incident beam and background particles by the GARIS and transported to a **Si box** equipped at the focal plane of the GARIS system.

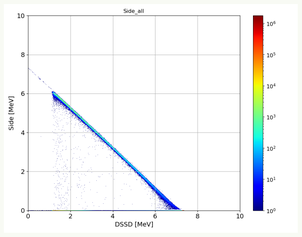


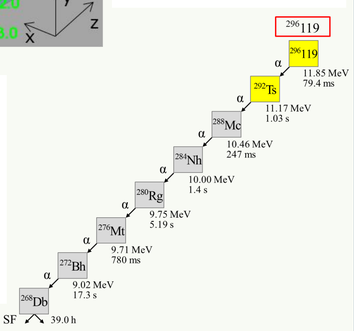




Si-box consists of **five SSDs**.

- **One** is **DSSD** which faces the direction of incoming SHEs.
- Other **four SSDs** surround the DSSD to detect an α particle or a fission fragment that escapes from the DSSD.

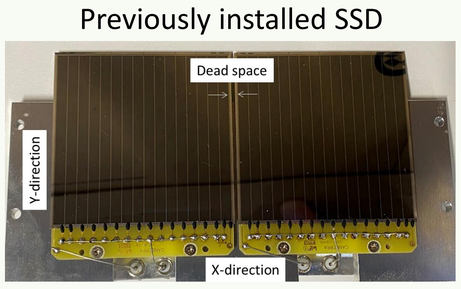




The identification of SHEs is performed by the correlation analysis of mother and daughter nuclei using the implantation energy and position, the decay energy and position, and the time difference between the implantation and decay events.

Newly developed SPD

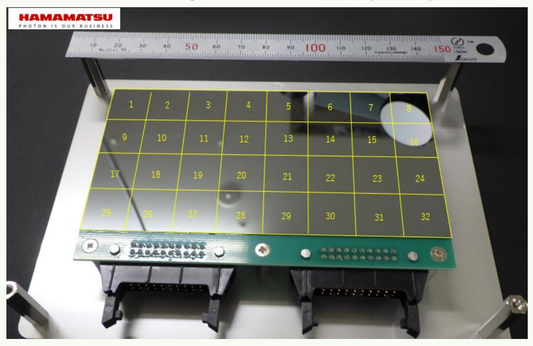
Previously installed SSD



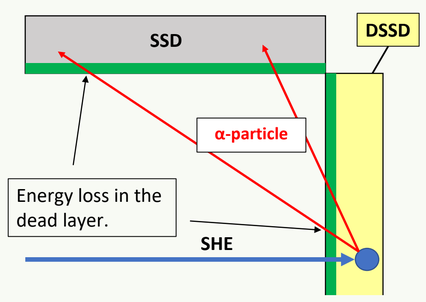
2 × SSD : CANBERRA PF-16CT-58*58-300-EB

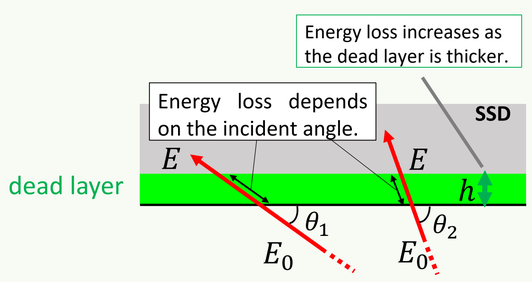
Mounted above and below the DSSD. Two SSDs arranged horizontally, each with a sensitive area of 58 × 58 mm². The SSD is not position-sensitive, and the gap between the two SSDs acts as a dead space for charged particles.

New Si pad detector (SPD)



Newly developed PSD for upper and lower SSD: The active area and thickness are **123 × 60 mm²** (**no dead space**) and 320 μm, respectively. The active area is segmented into **32 channels** (8 × 4) each with an electrode pad of 15 × 15 mm² (**position-sensitive**). The left and right SSDs were presented in a previous work (Kuramoto et al., JJAP 2023).

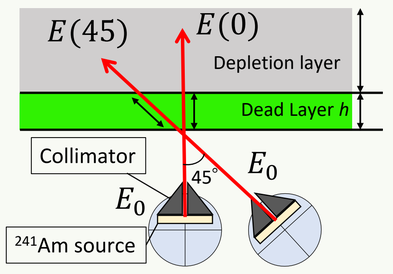




The energy of the escaped particle is deduced by **summing** the deposited energies in the active layers for both the DSSD and SSD.

A **thin dead layer** is required for **precise energy measurement** of charged particles emitted from a DSSD through the decay chain of an SHE.

Evaluation method

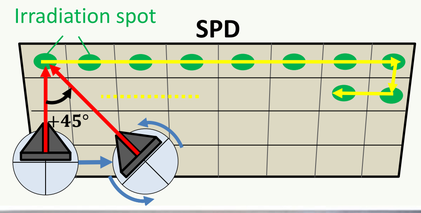


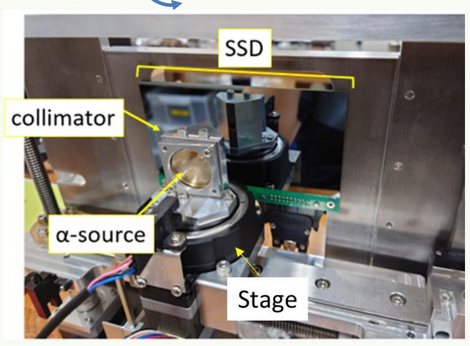
When the initial energy of α particle is E_0 , the observed energy E(θ) in the SSD is described by

$$E(\theta) = E_0 - \frac{dE}{dx}\frac{h}{\cos\theta}$$

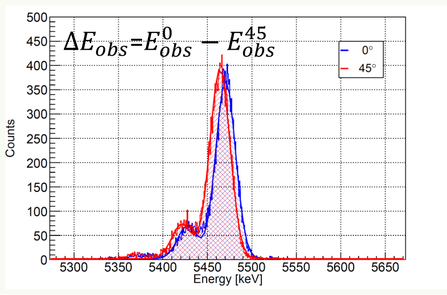
The dead layer thickness h is evaluated by comparing the peak energies at incident angles θ = 0° and 45° for α particles.

1) ^{241}Am α particles were irradiated by automatically moving and rotating (θ= 0° and 45°) the α source for each segmented portion of the SPD.

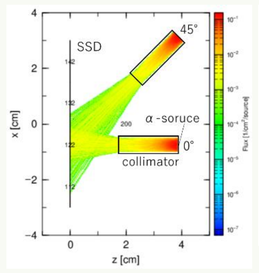


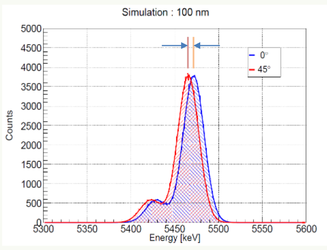


2) The peak energy difference ΔE_{obs} is obtained from the experimental results.



3) Monte Carlo simulation using PHITS code was performed by changing the thickness of h for both incident angles. Then, the peak energy difference ΔE_{sim} is obtained.





$$\Delta E_{sim}(h) = E^0_{sim}(h) - E^{45}_{sim}$$

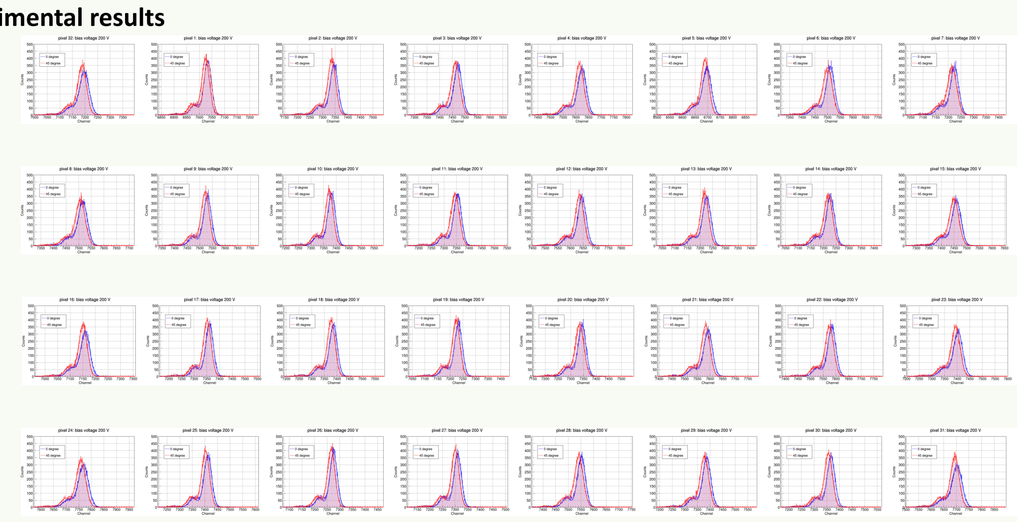
4) The obtained peak channels ($\Delta E_{obs}(h)$ and $\Delta E_{sim}(h)$) are compared.

$$\delta E\ (h) = \Delta E_{obs}(h) - \Delta E_{sim}(h)$$

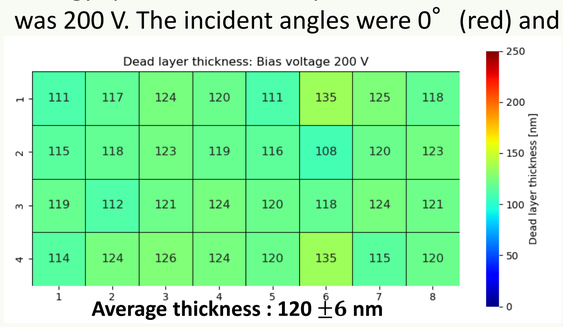
The thickness of h for δE= 0 is defined as the dead layer thickness in the SPD.

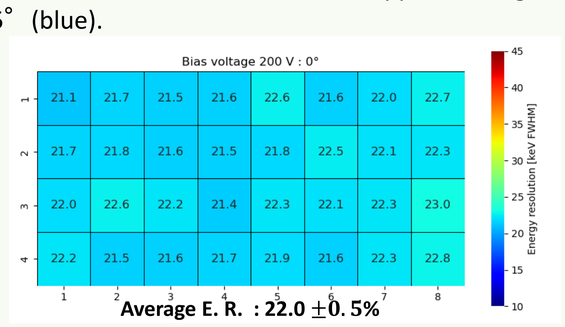
Results and simulation study

Experimental results



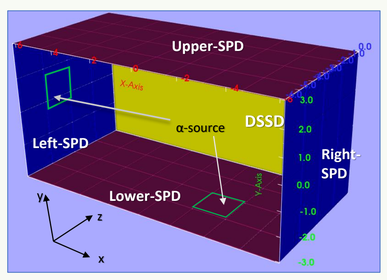
Energy spectra of ^{241}Am α particles obtained from pixels 1 to 32 of the SPD when the applied voltage was 200 V. The incident angles were 0° (red) and 45° (blue).





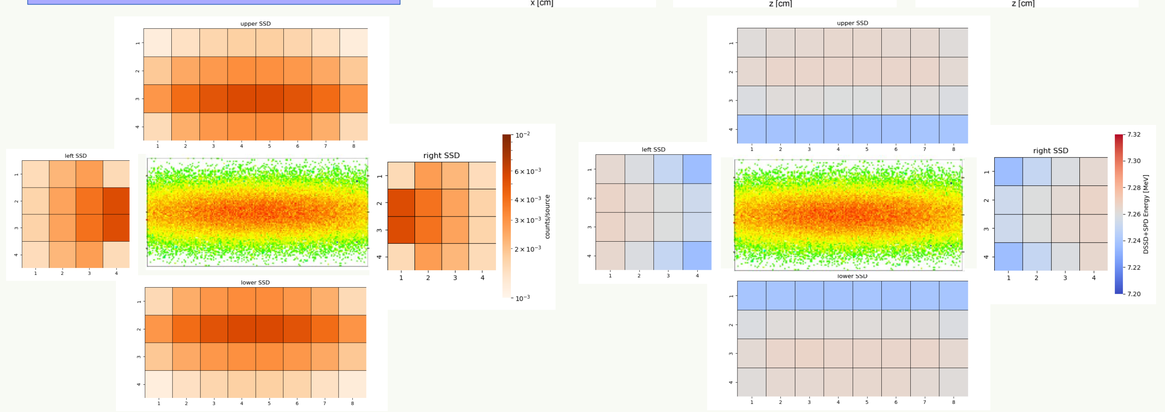
Maps of dead layer thickness (left) and energy resolution (FWHM, right)

Simulation study



α-source

Energy: 7.320 MeV (^{207m}Ra), events number : 10^7 , **dead layer 120 μm**
Position: x, y: Gaussian distribution (x, y center, σ_x: 51.0 mm, σ_y : 8.5 mm, z: a depth of 10 μm within the DSSD), Direction: 4π



Count maps obtained by SPD. The **detection efficiency** of **91%** obtained with the Si-Box.

Energy maps obtained using DSSD+SPD for a 7.320 MeV α-ray. The maximum and minimum energies are 7.267 and 7.236 MeV, respectively.