Developments on muonic X-ray measurement system for historical-cultural heritage samples in Japan Proton Accelerator Research Complex (J-PARC)

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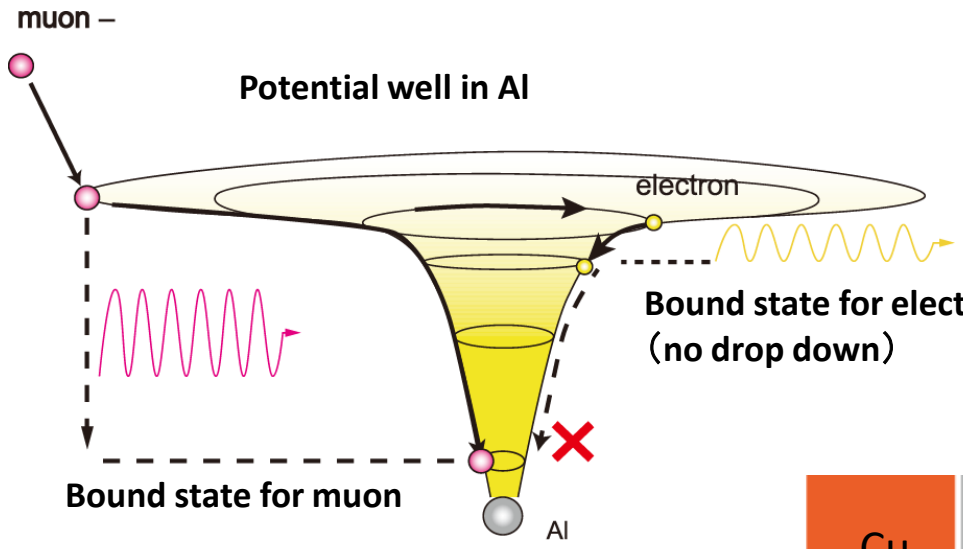
Y. Ishikake, A. Hashimoto, K. Shimomura

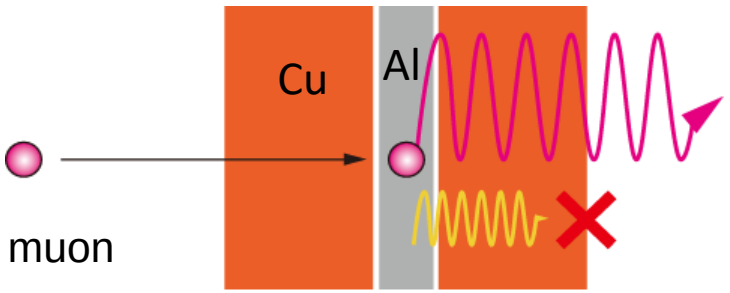
Muonic X-ray is unique and strong probe beam in non destructive elemental analysis



Muon captured in atom generates
a hard X-ray determined by quantum
transitions in atomic shell structures

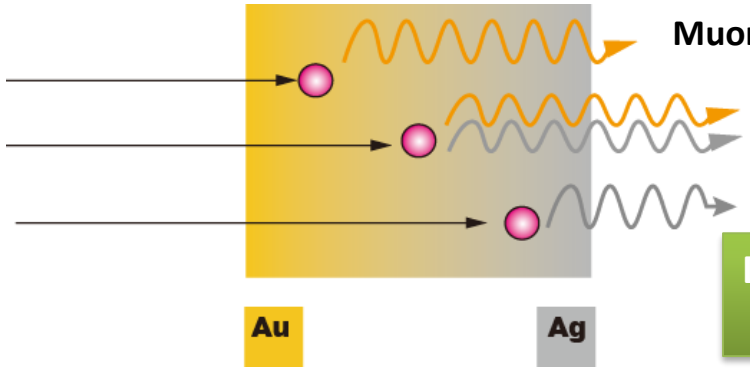
e-Kα X-ray :1.2 keV

μKα-X ray of Al
~360keV



Muonic X-ray energy
is high, and easily penetrate
a sample surrounded with
thick covering layer

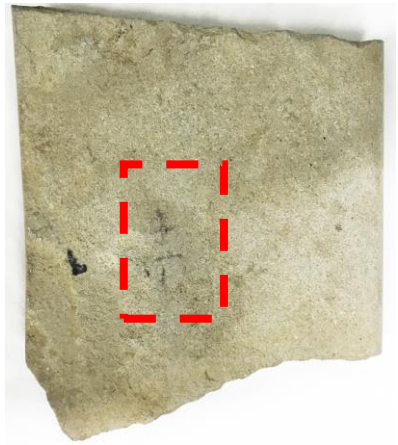
Muon as charged particle
can be selectively stopped
in target material
by changing muon energies



Depth profile of composition ratio can be revealed

Nondestructive elemental analysis for historical heritage samples

Different interests bring many samples and different survey regions (depth, area)



Is it letter used in prehistory ?

What was the material at the time it was made ?
Surface is oxidized !!

What is inside a glass bottle ?

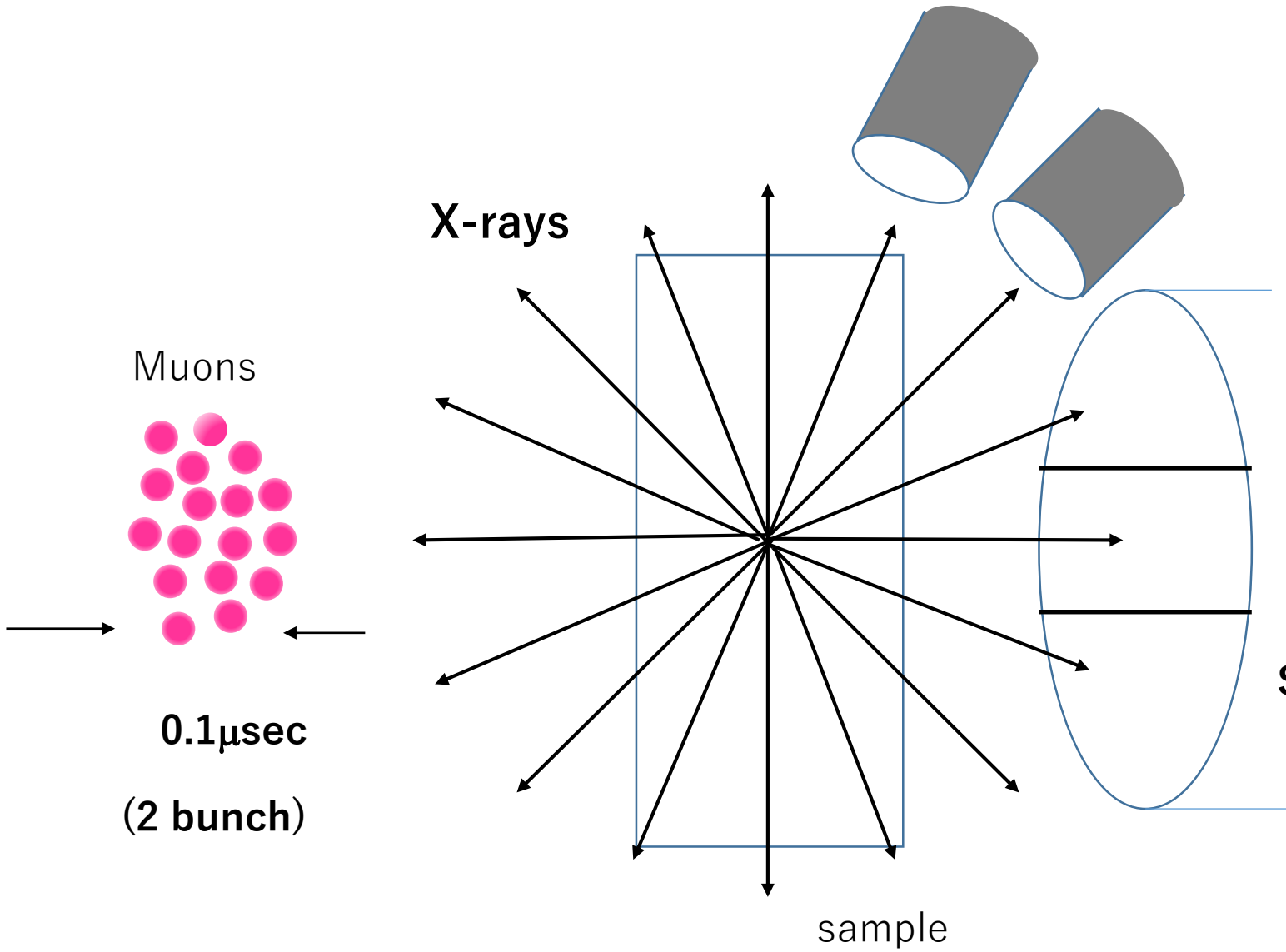
How purity is on surface ?

Muon study for archeology samples has been started in J-PARC since 2017

We have been dedicating and developing beam character, detectors, chamber, and safe sample holders for increasing detection efficiency

With one pulse,

Large solid angles with many small detectors can increase detection efficiency

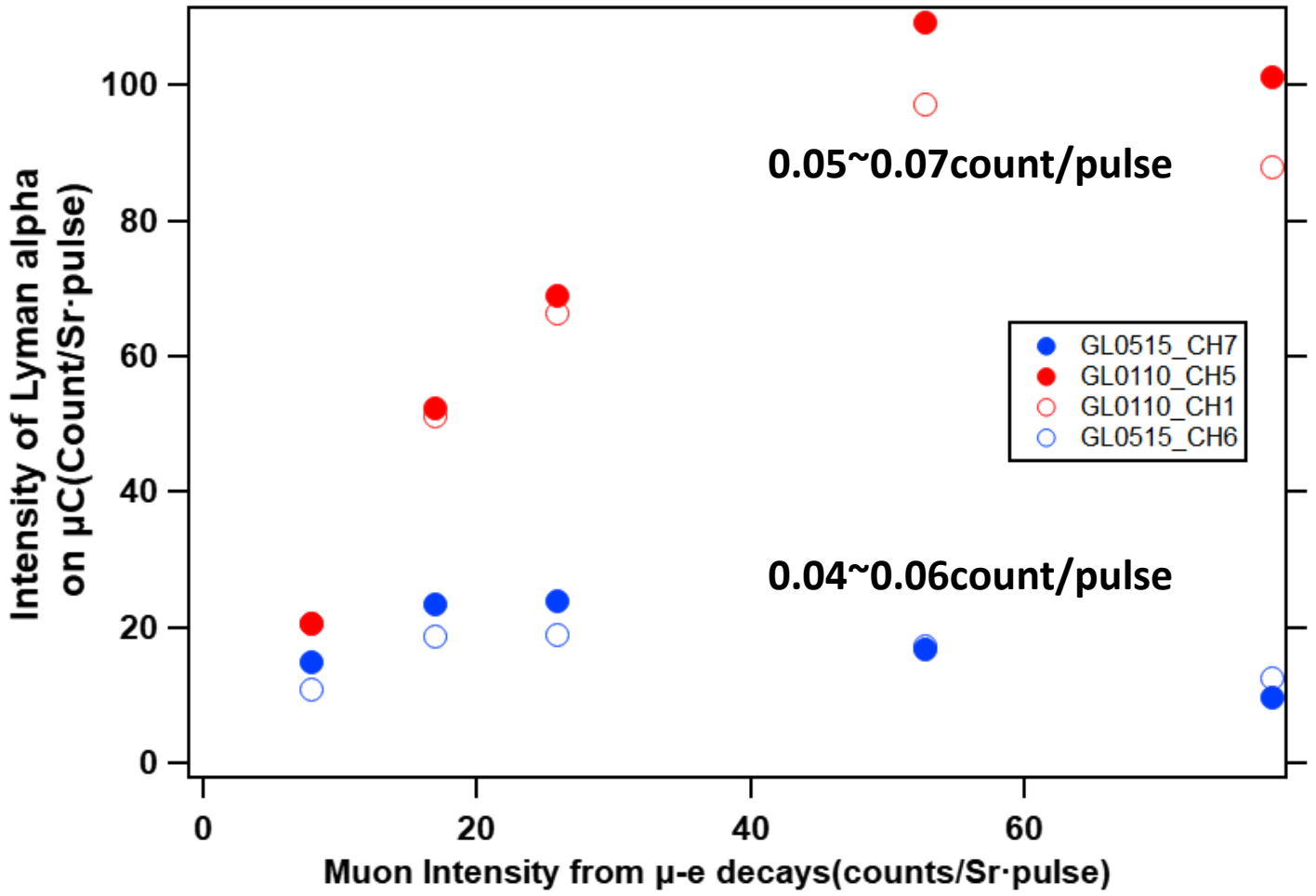


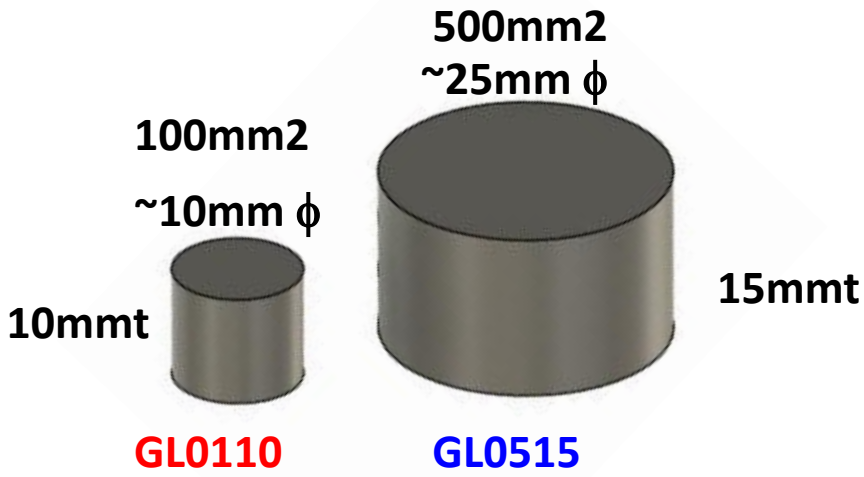
Germanium semiconductor detector takes few tenth μ sec for signal processing so that in multi-hitting X-rays energies are summed up !!

Segmented or small detector collections can be individually measure X-ray energies as single photon

We choose LEGe detector (GL0110) with 100mm2 area and 10mm thick crystal

20MeV/c on 20mm diameter Carbon
Beam flux is controlled by using slits up and down stream



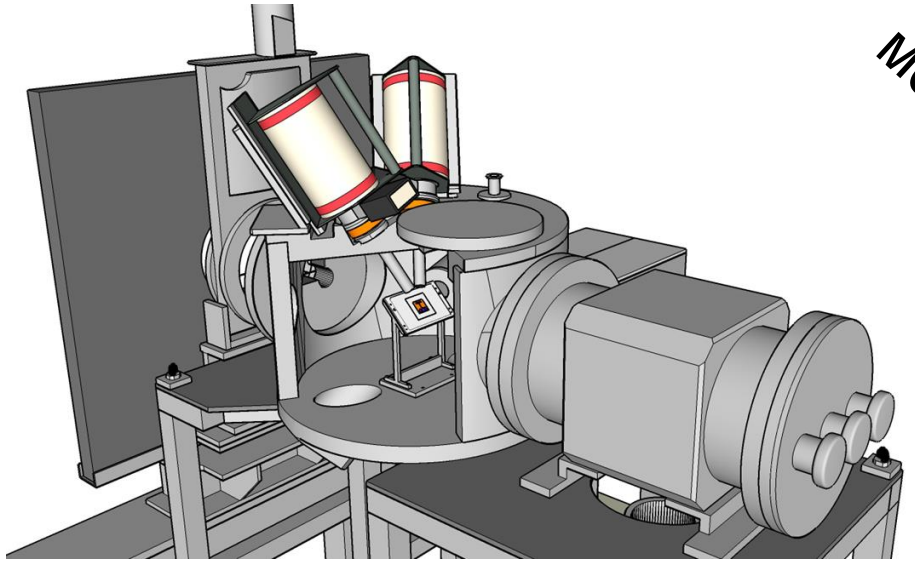


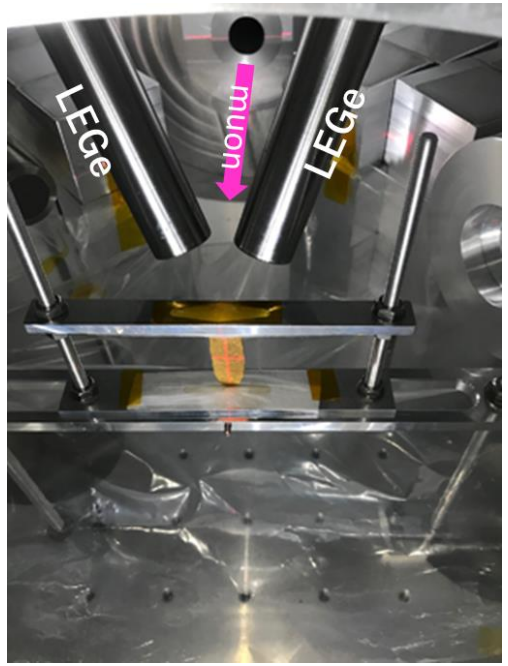
Since each Ge has different solid angle,
the observed intensities are divided
with solid angles

Vacuum Al Chamber

(2014-2020)

beam port with 380mm diameter that was designed because beam size was big





2 LEGe can be placed from up stream side of beam

Inner diameter of chamber is 600mm

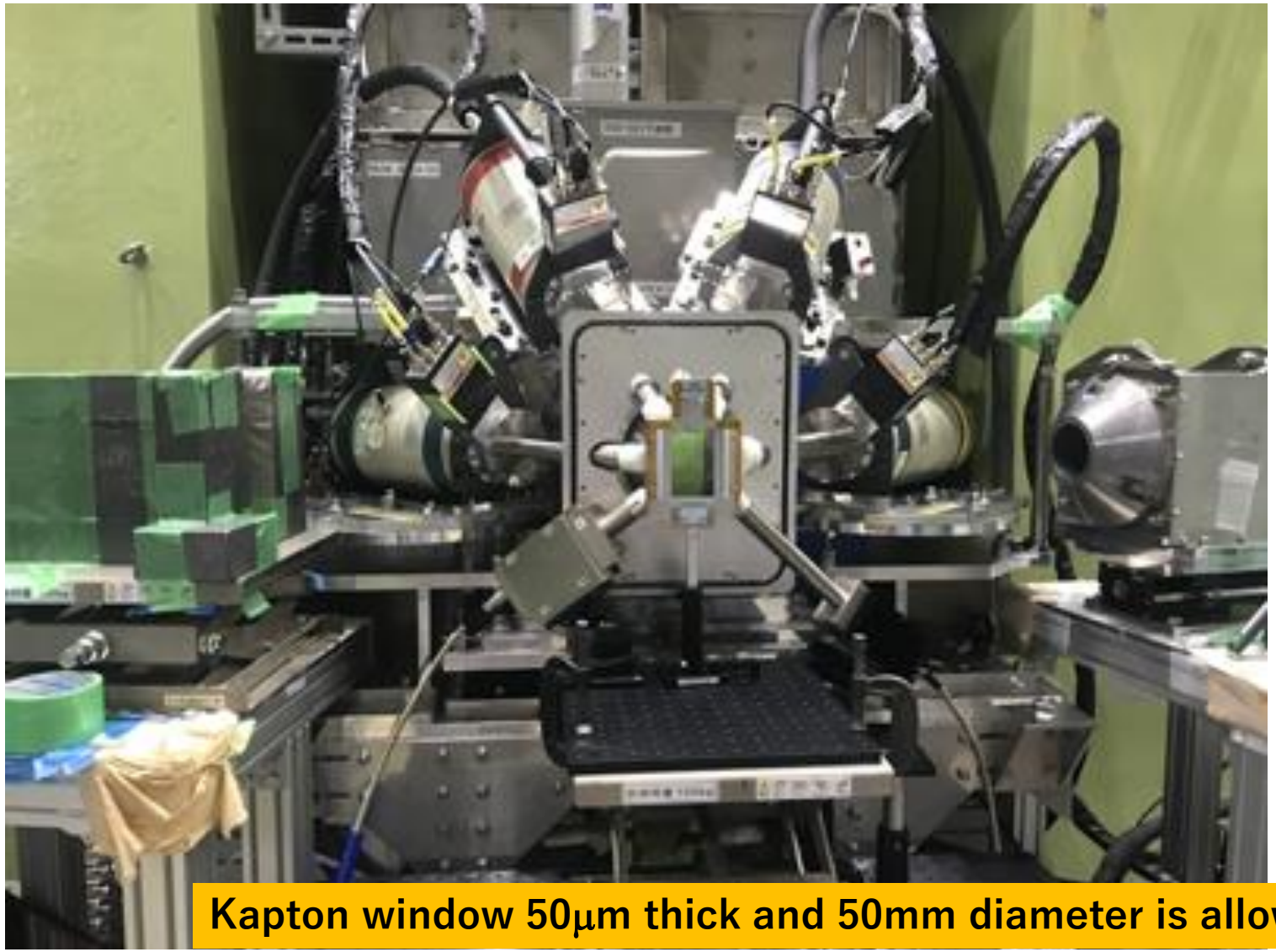
This chamber is also used for Japanese old coins

Atmosphere detection system

(2016~2021)

4 small and 2 big HPGe detectors can be placed

Small one is called to LowEnergyGe(LEGe)

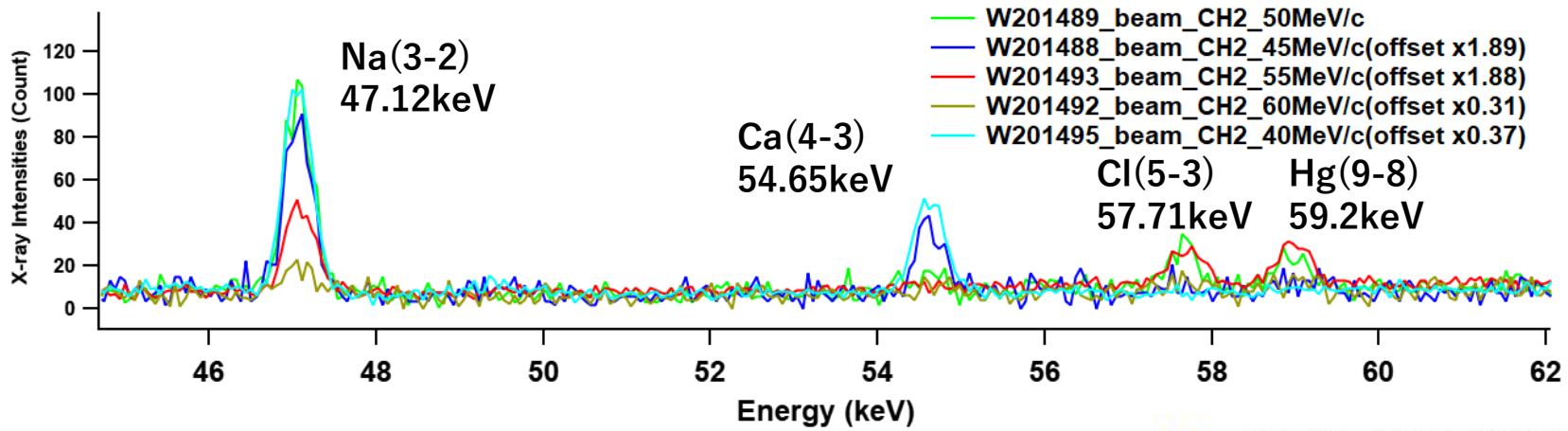


Kapton window 50μm thick and 50mm diameter is allowed to use muons from 13 MeV/c

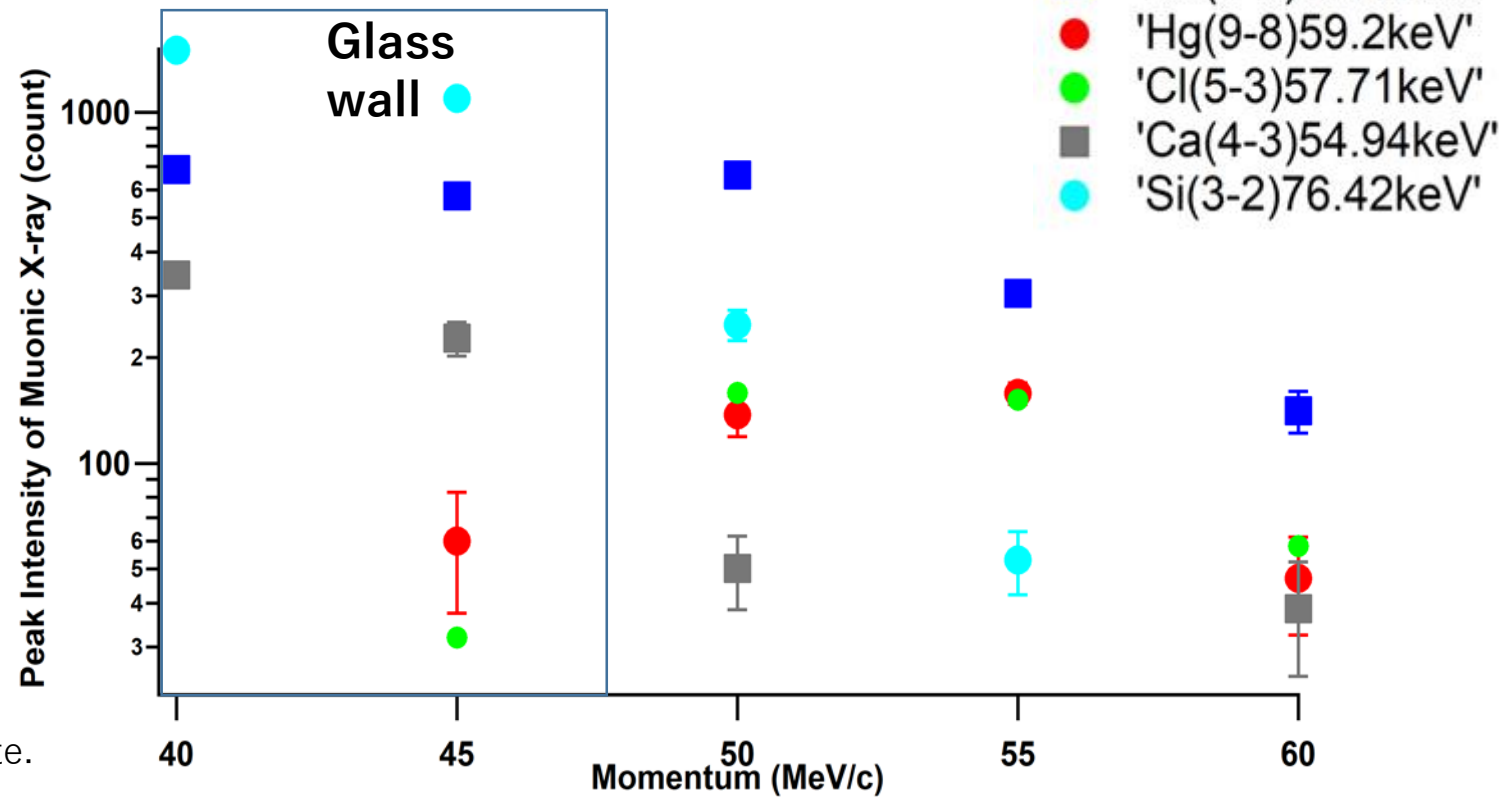
Ingredients of a drag used in 19th in a bottle that can not opened, are revealed with muons

muons

Medical scientists
who became
the founder of
the Osaka University School of Medicine used this botte.



Mercury Chroride with NaCl can be indicated !



Original Paper | Published: 13 March 2021

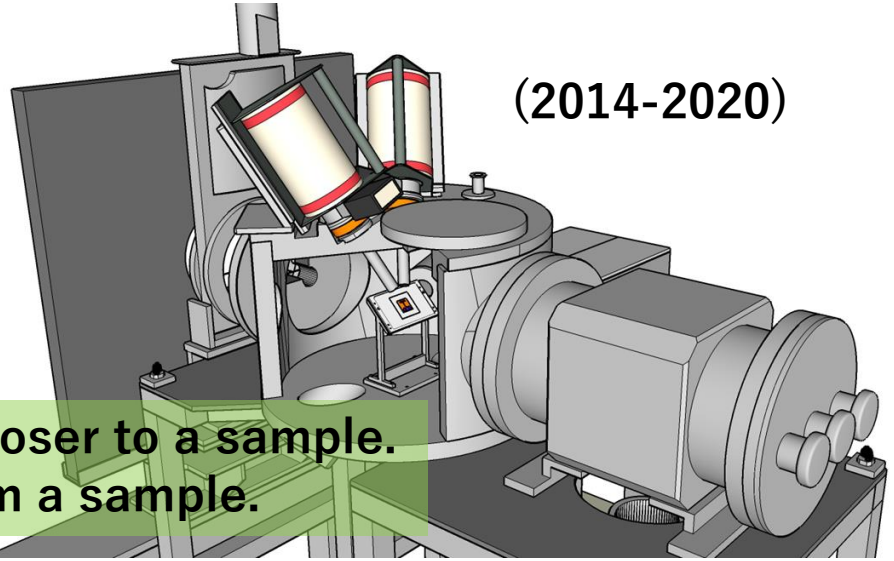
A novel challenge of nondestructive analysis on OGATA Koan's sealed medicine by muonic X-ray analysis

Kayoko Shimada-Takaura, Kazuhiko Ninomiya, Akira Sato, Naomi Ueda, Motonobu Tampo, Soshi Takeshita, Izumi Umegaki, Yasuhiro Miyake & Kyoko Takahashi

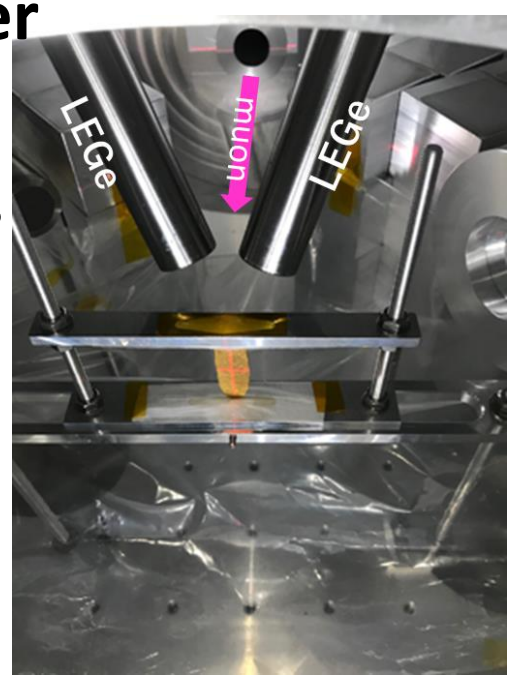
Journal of Natural Medicines **75**, 532–539 (2021) | Cite this article

X-ray detection chamber rebuilding into Half Spherical Chamber

For obtaining higher detection efficiency,
We have developed new detection chamber



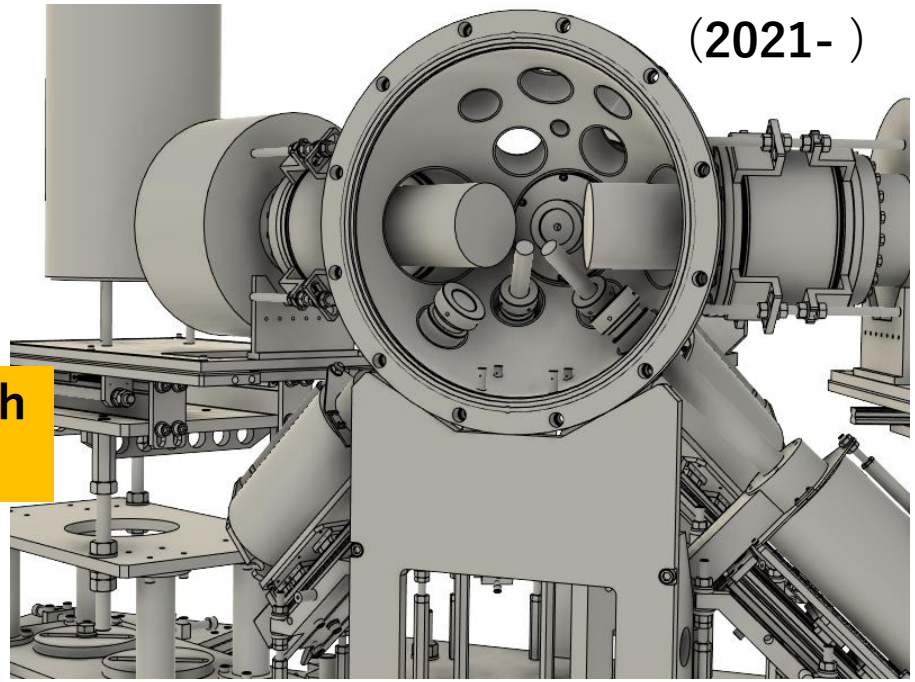
(2014-2020)



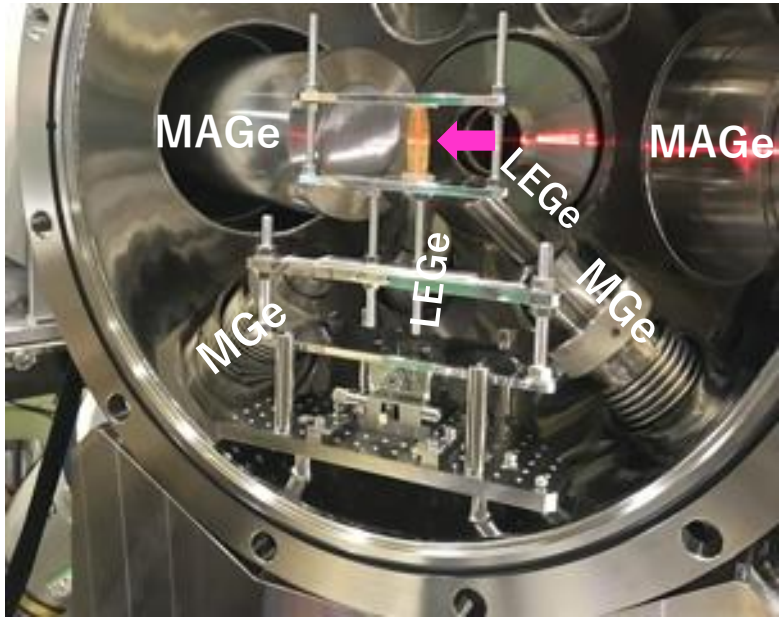
Only 2 Ge detectors can get closer to a sample.
Other detectors is put far from a sample.

Vacuum or He-gas environment
is compatible

9 Ge detectors can get closer

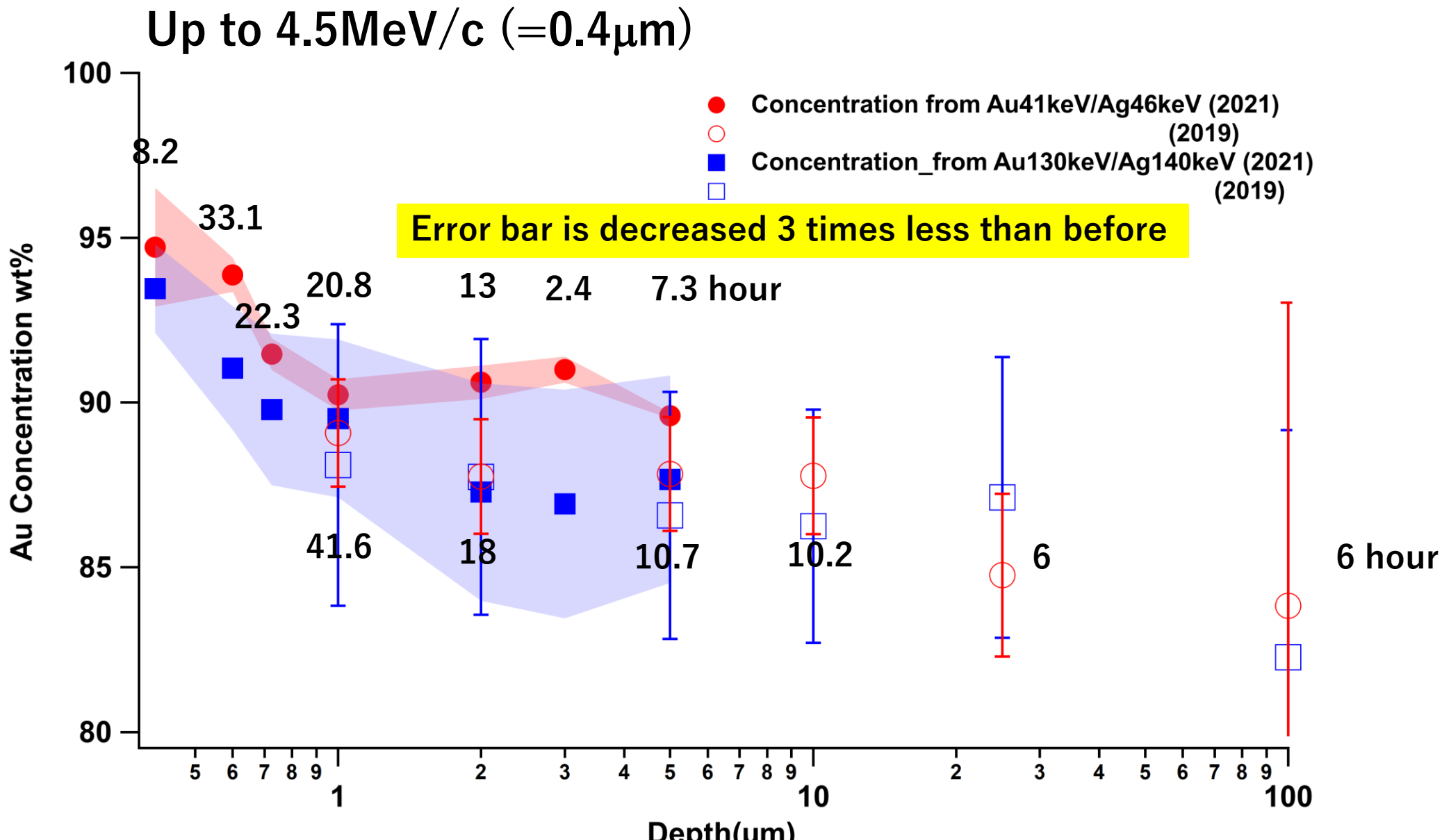


(2021-)



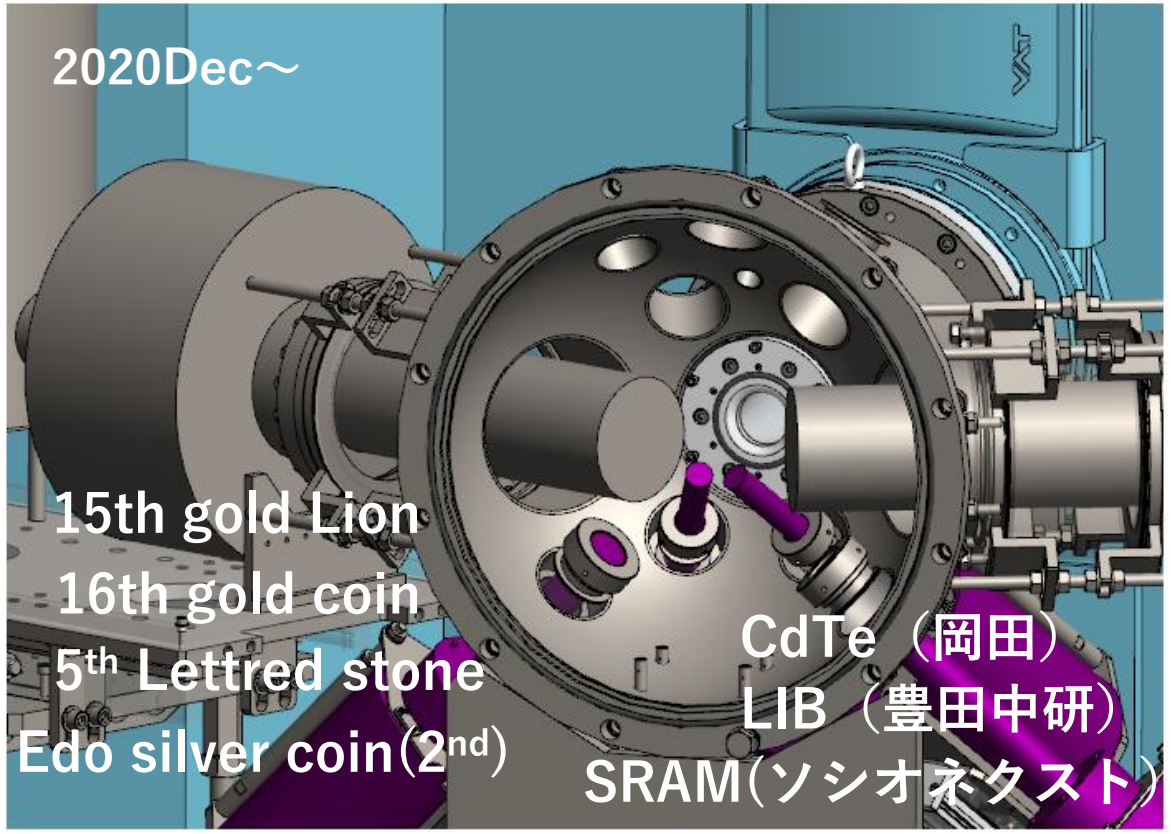
The sample can be covered with
larger solid angle of detectors

Hemisphere Chamber system revealed that gold concentration in Kisei coin was enriched in depth at less than 1μm



Half Spherical Chamber Developments; Increasing Ge detectors from 4 into 7.

and, also beam duct has been changed it with large diameter (See detail in poster session!)

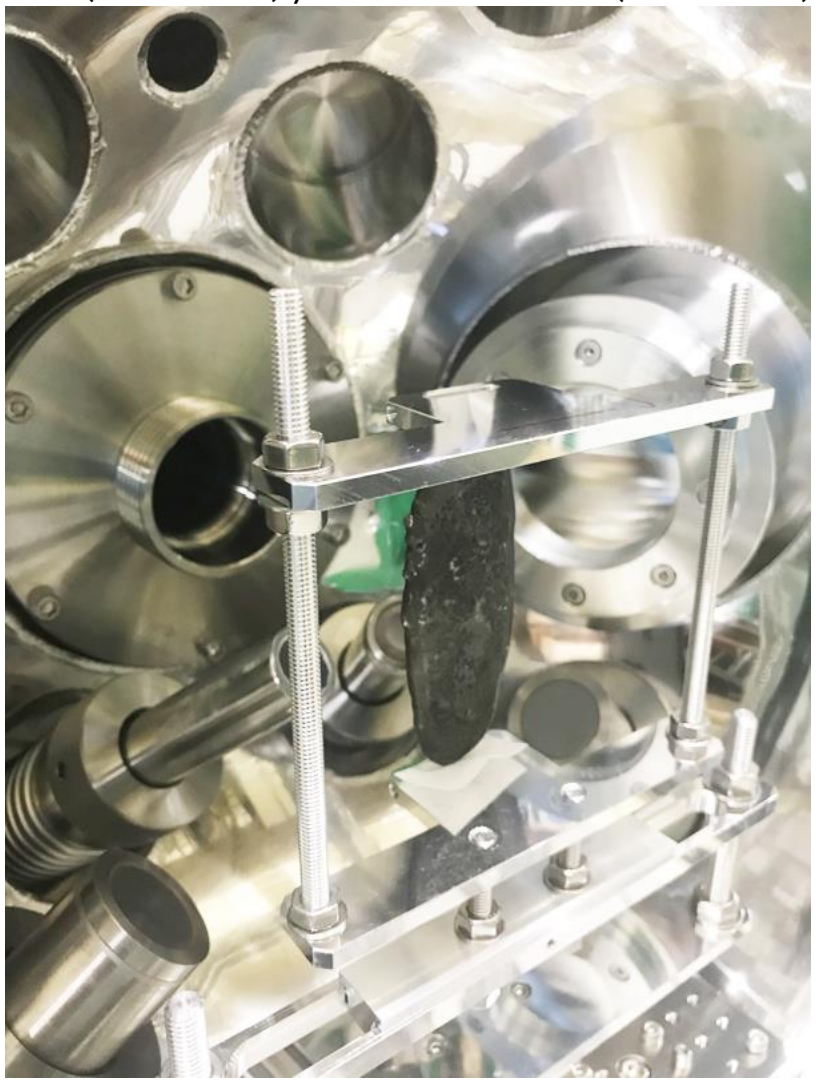


2 LEGe(GL0110), and 2 MGe(GL0515)

5 LEGe(GL0110) 2 MGe

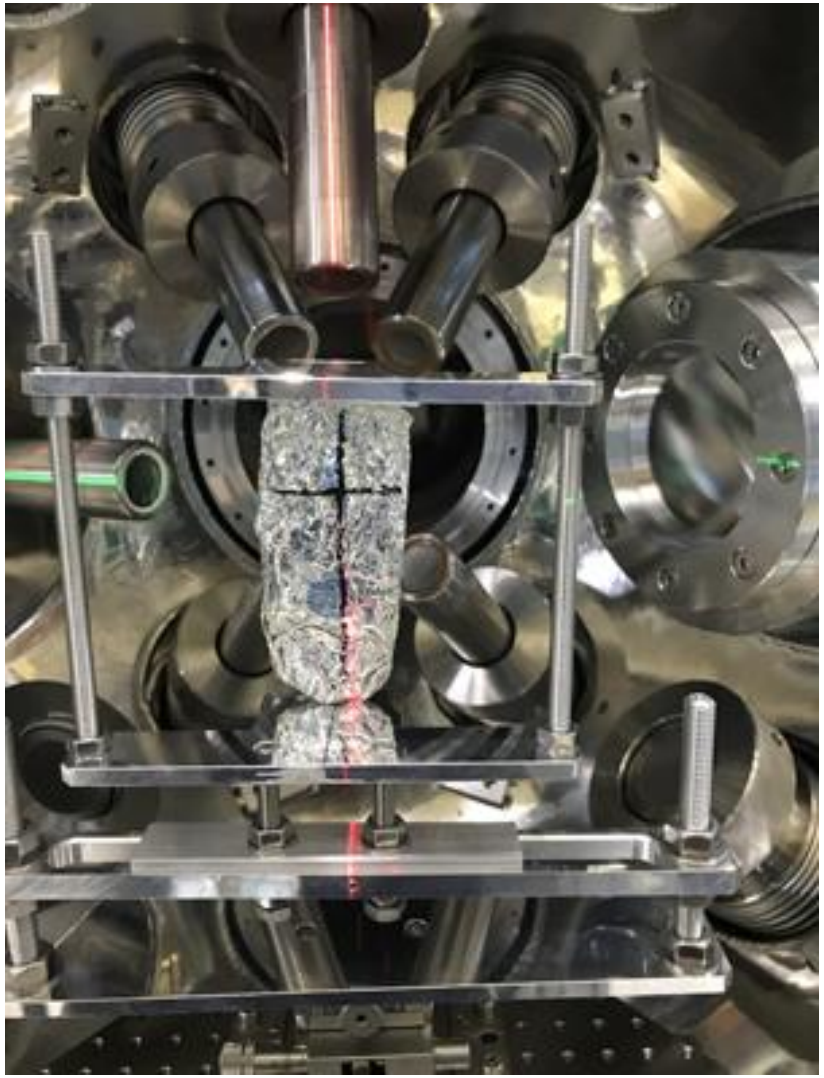
Same sample (Japanese Silver Coin) experiment
were able to provide detection efficiency difference between before and after upgrading

2021Feb（620kW）
2 LEGe(GL0110)，　and 2 MGe(GL0515)



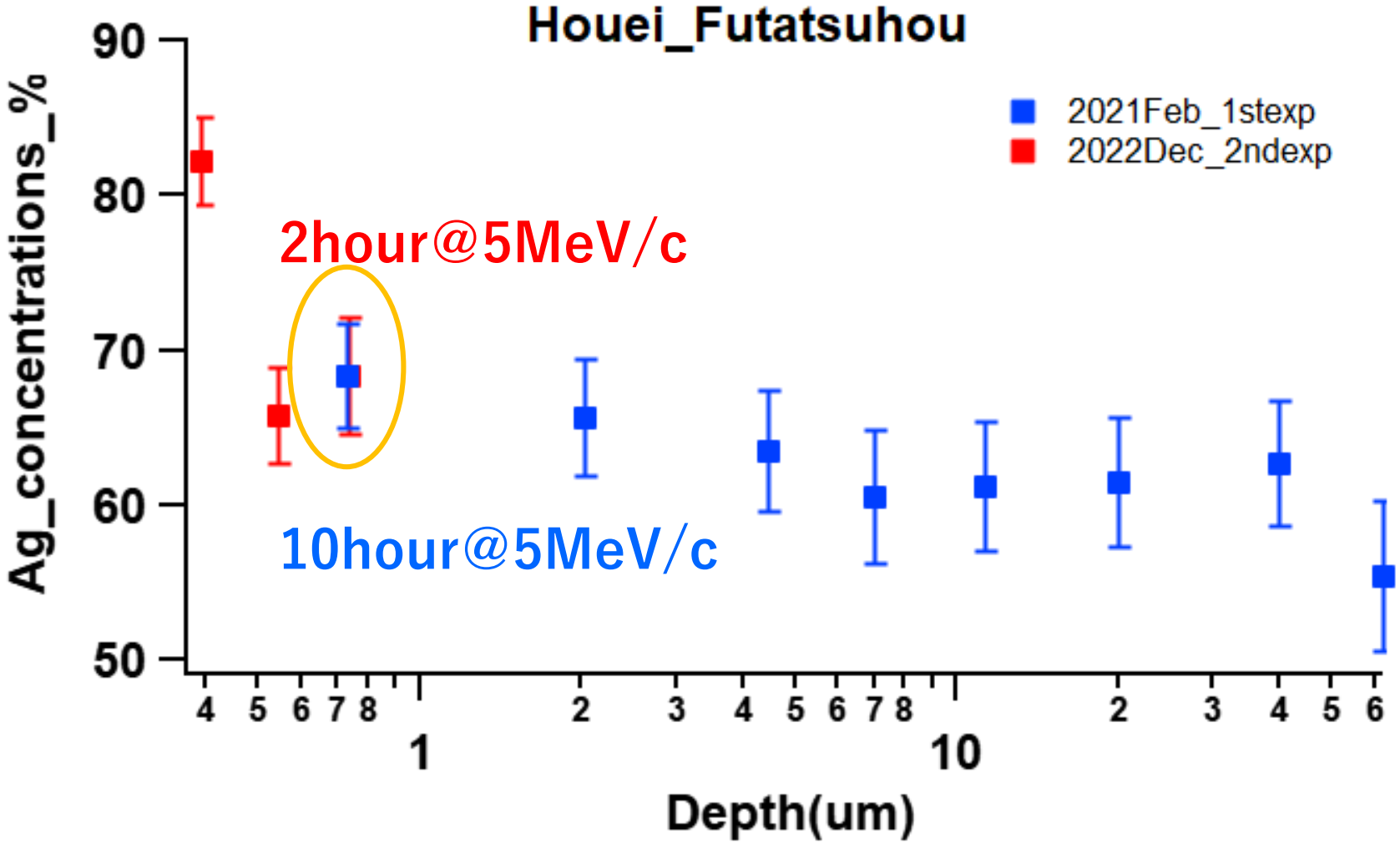
2022Dec（730kW）
5 LEGe(GL0110) 2 MGe

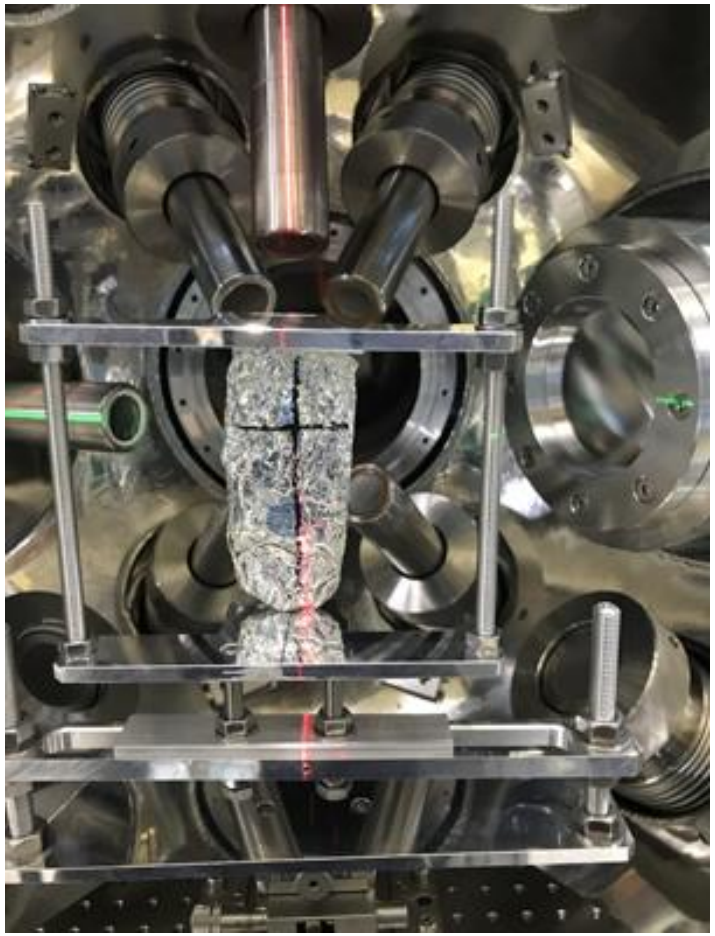
～1.2times



5times increase of detection efficiency compared to before up grade.

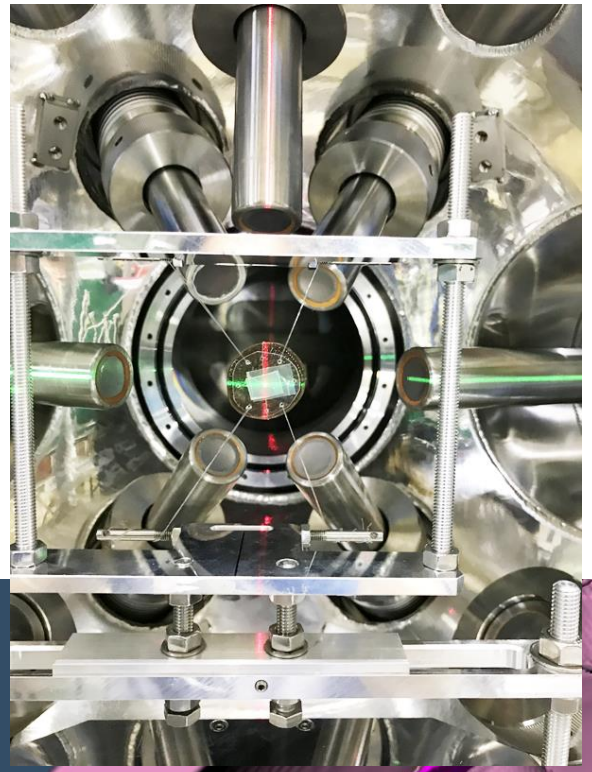
Measured peaks: Ag140keV/Cu115keV

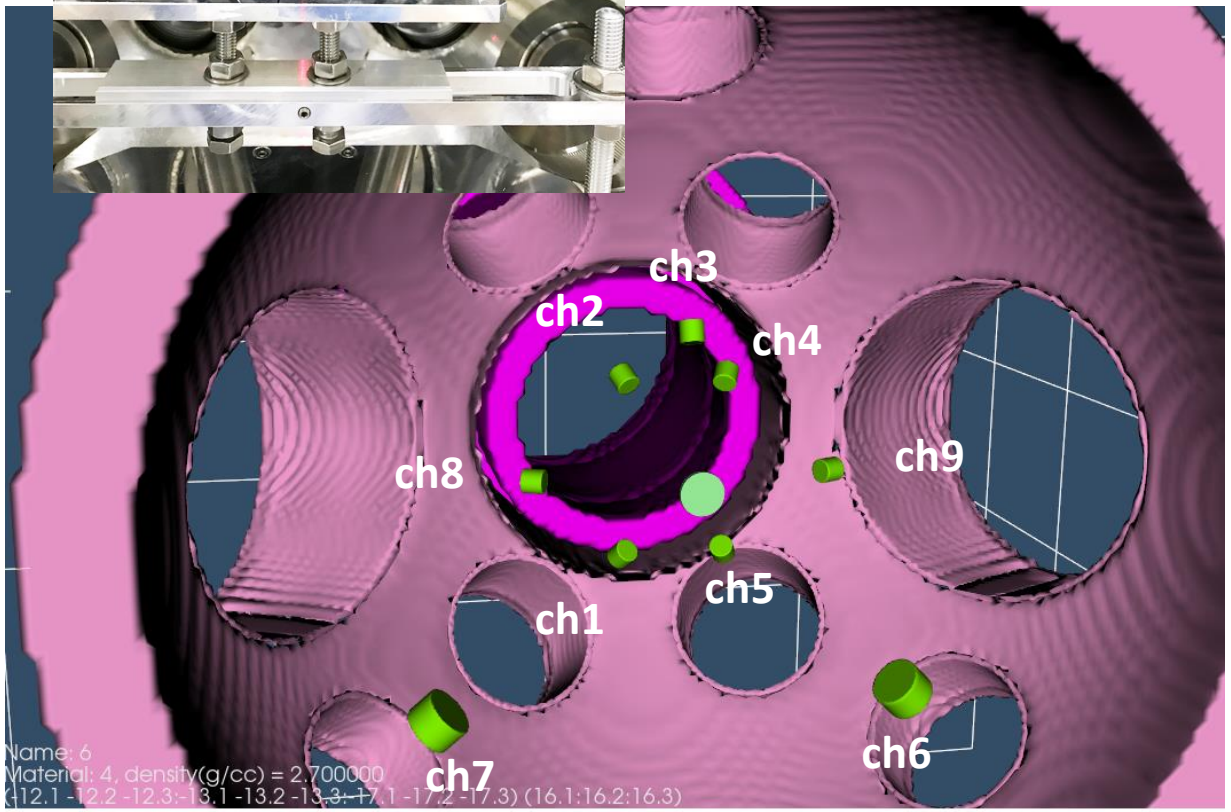


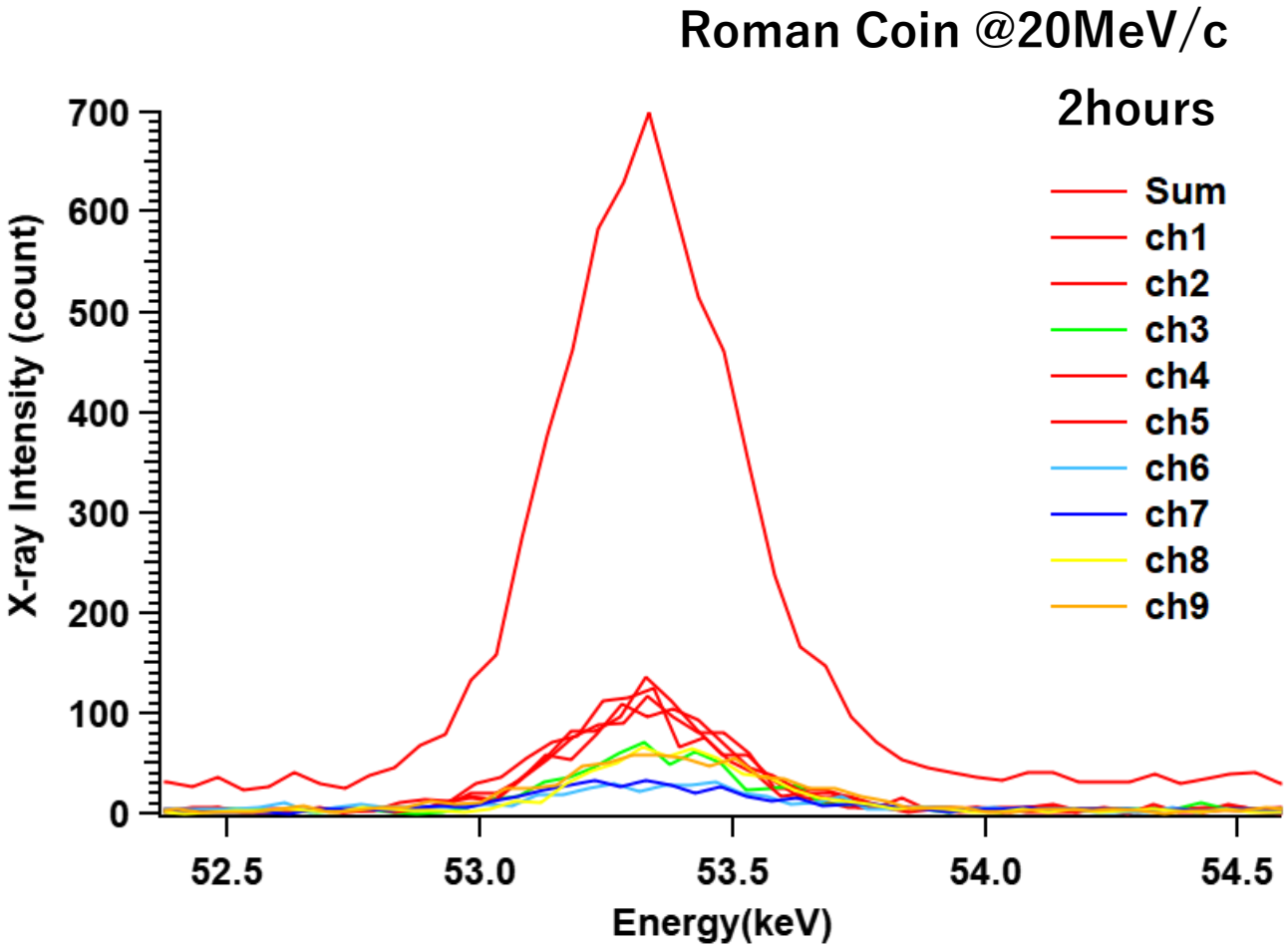


Present Status in Half Spherical Chamber system

We have increased totally 9 Ge detectors, 7 LEGe and 2 MGe.

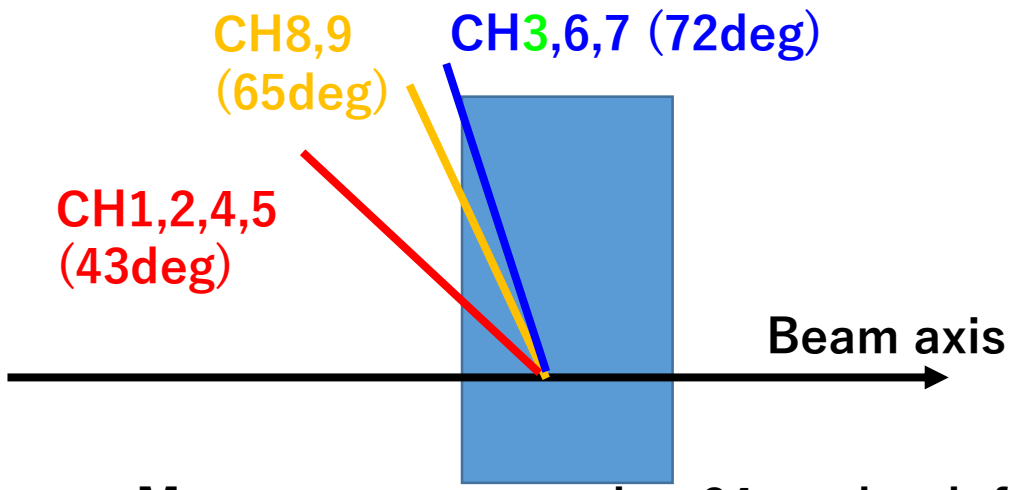




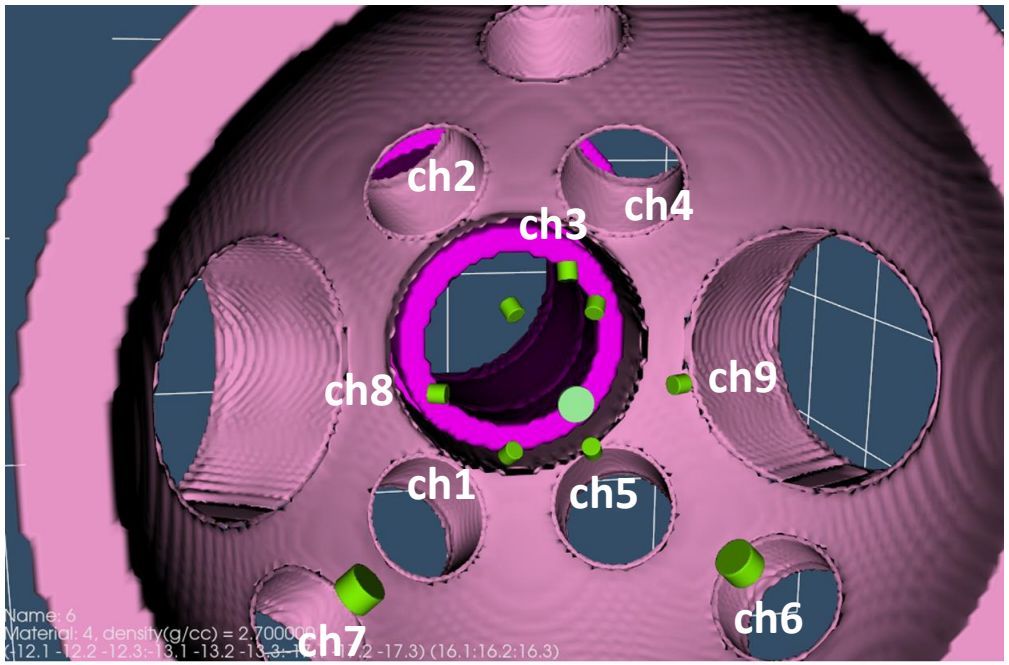


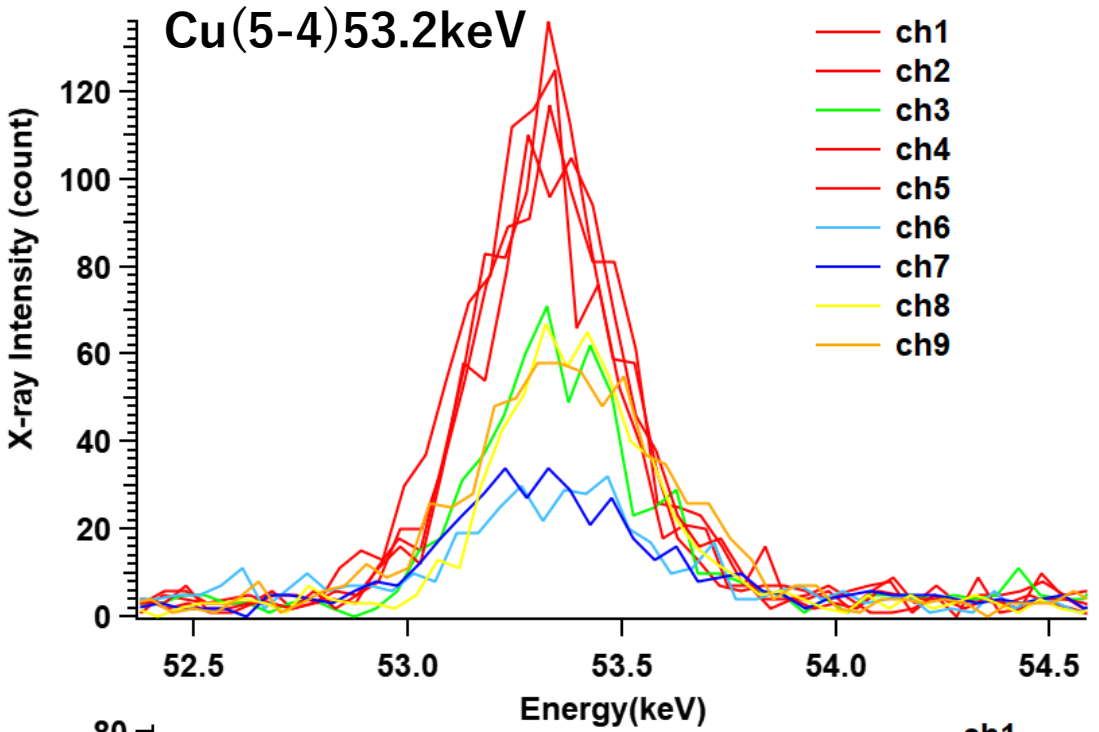
Detector increases provide increases of detection efficiency but do not provide 9times increase.

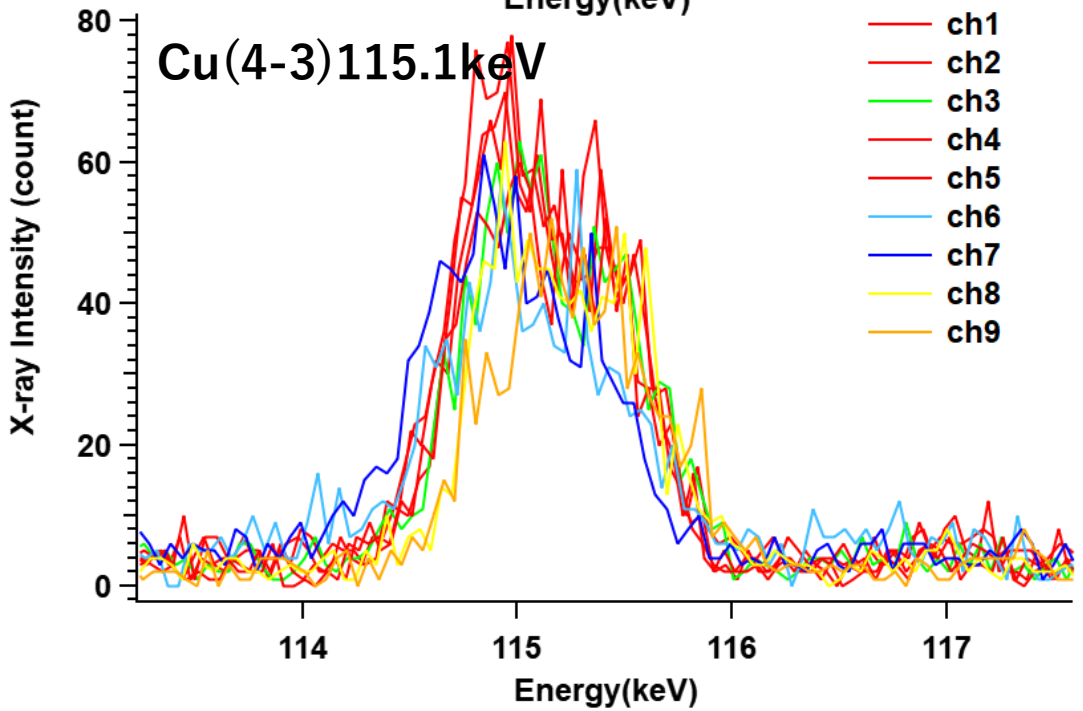
As muon impinging depth increases, observed intensity of low-energy X-rays varied with the angle of detectors.



Muons were stopped at 64um depth from surface

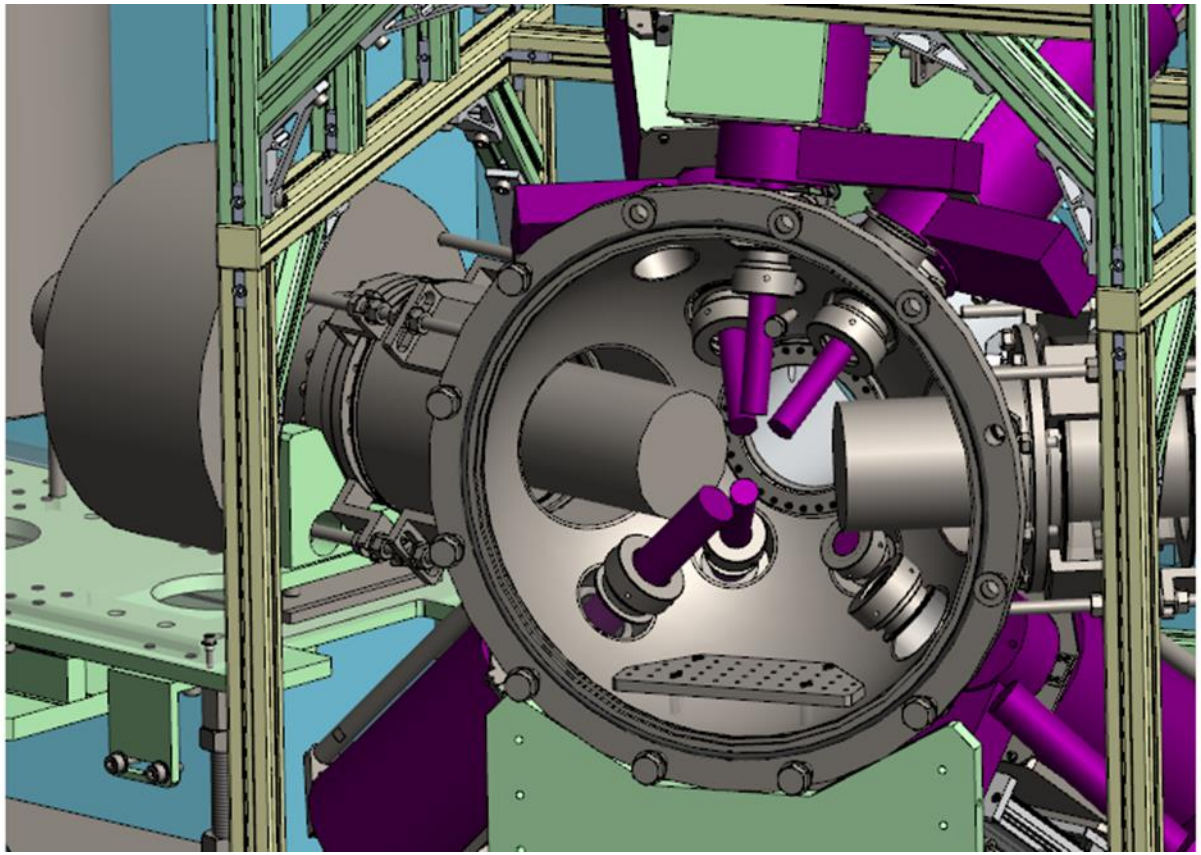


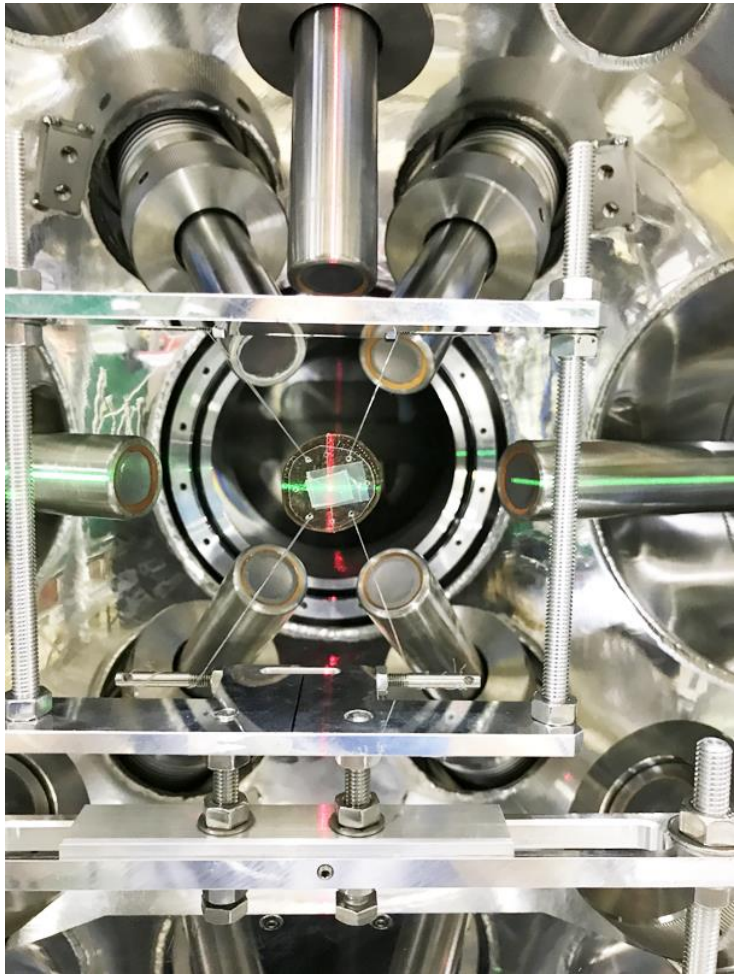




Aiming to further increase detection efficiency….

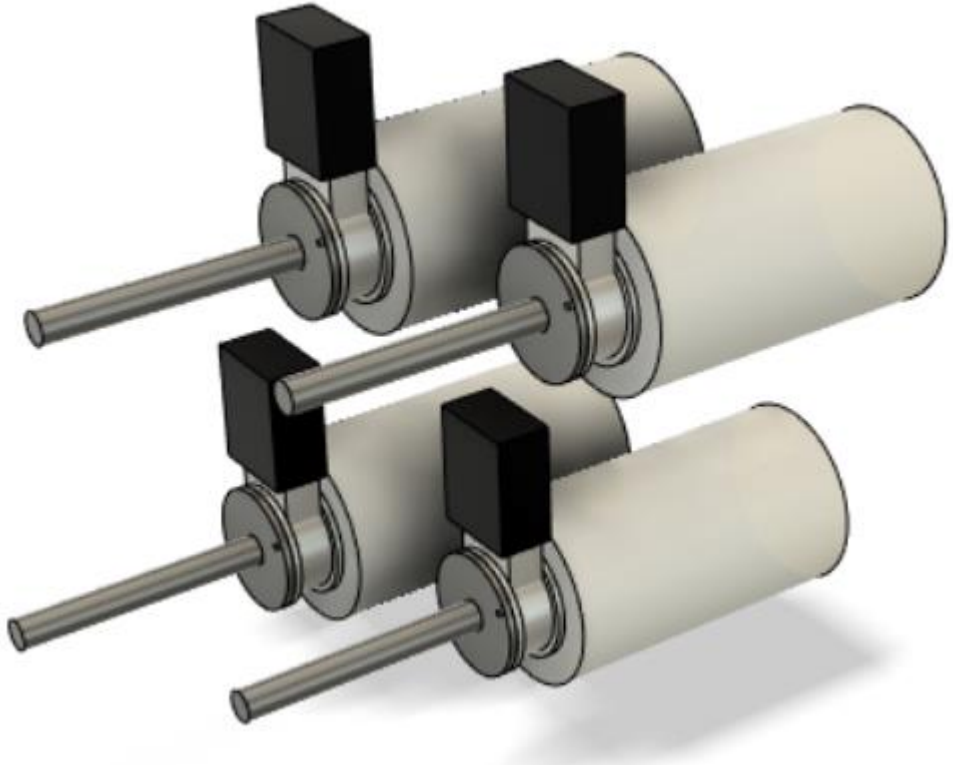
We would like to place many detectors at an angle as close to the beam axis as possible, but geometry no longer allows this.

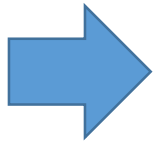


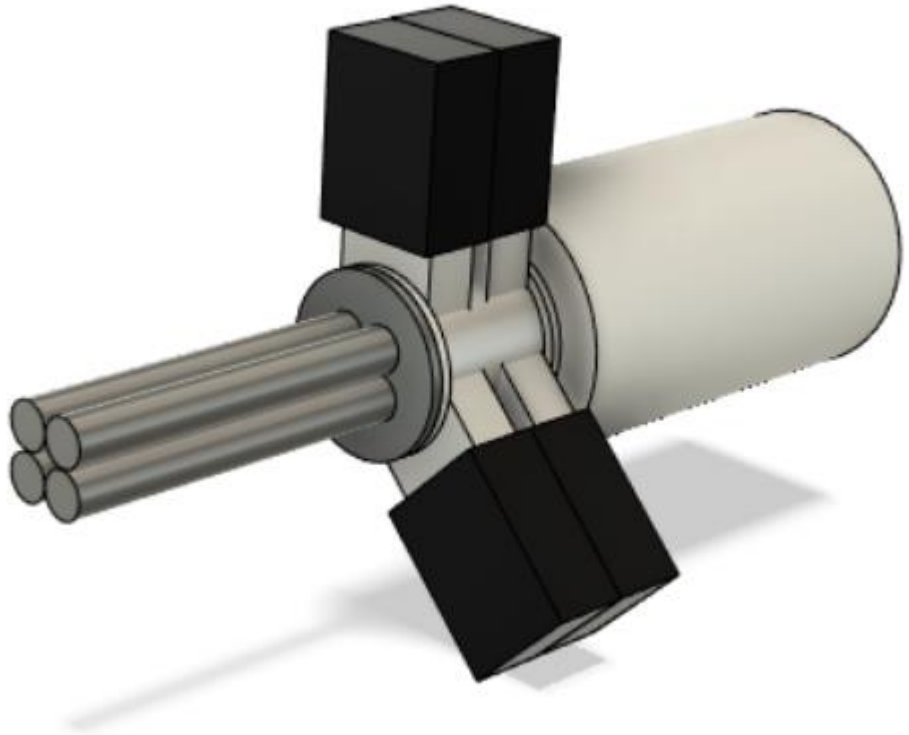


Modification of GL0110 to a 4-element detector

Removing each end-cap part, and converting 4-element detector





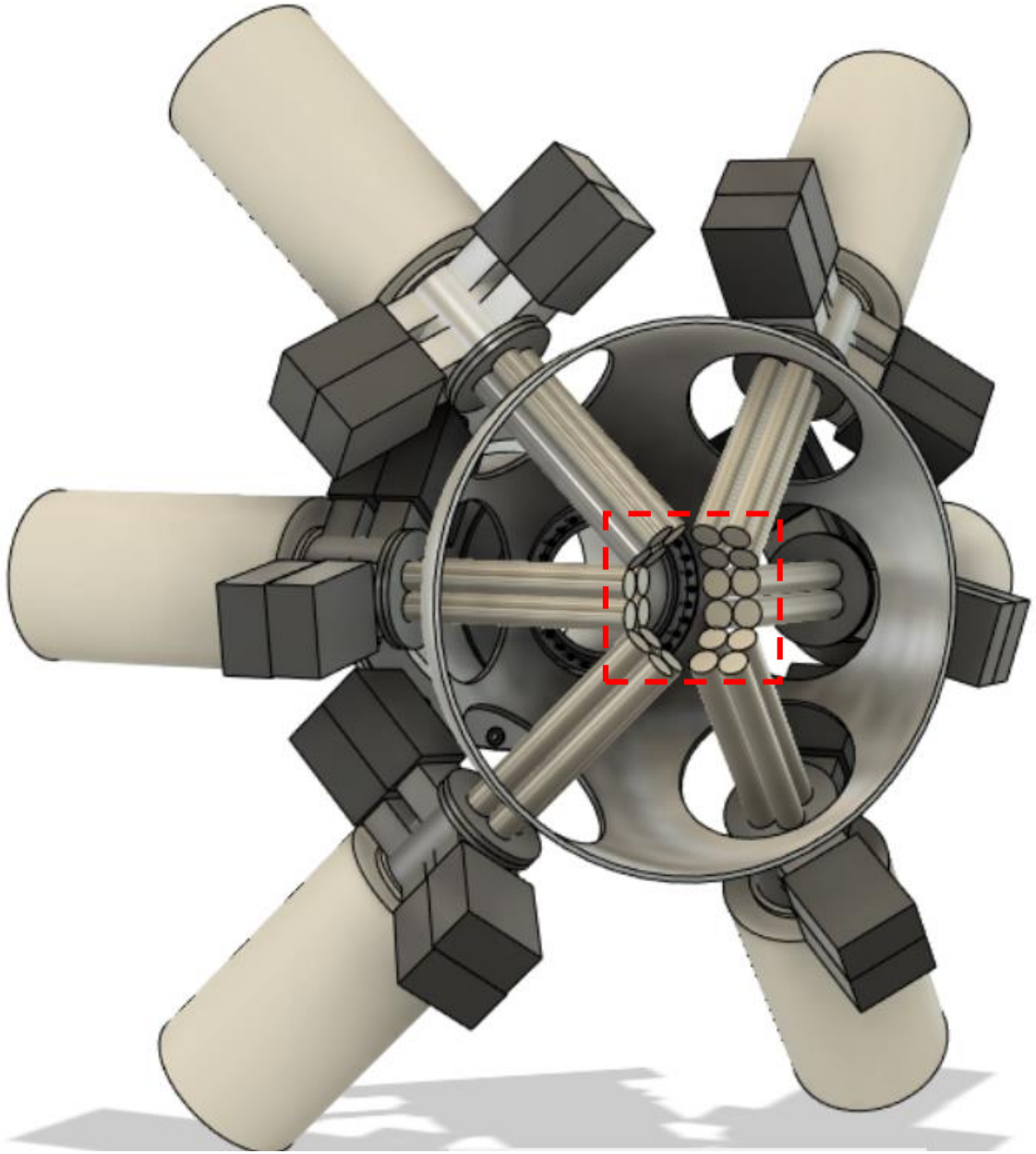


4million yen per detector
(~2.35x10^4 CHF)

Since each crystal is covered with metal end cap, electrical noises are prevented such as cross-talk

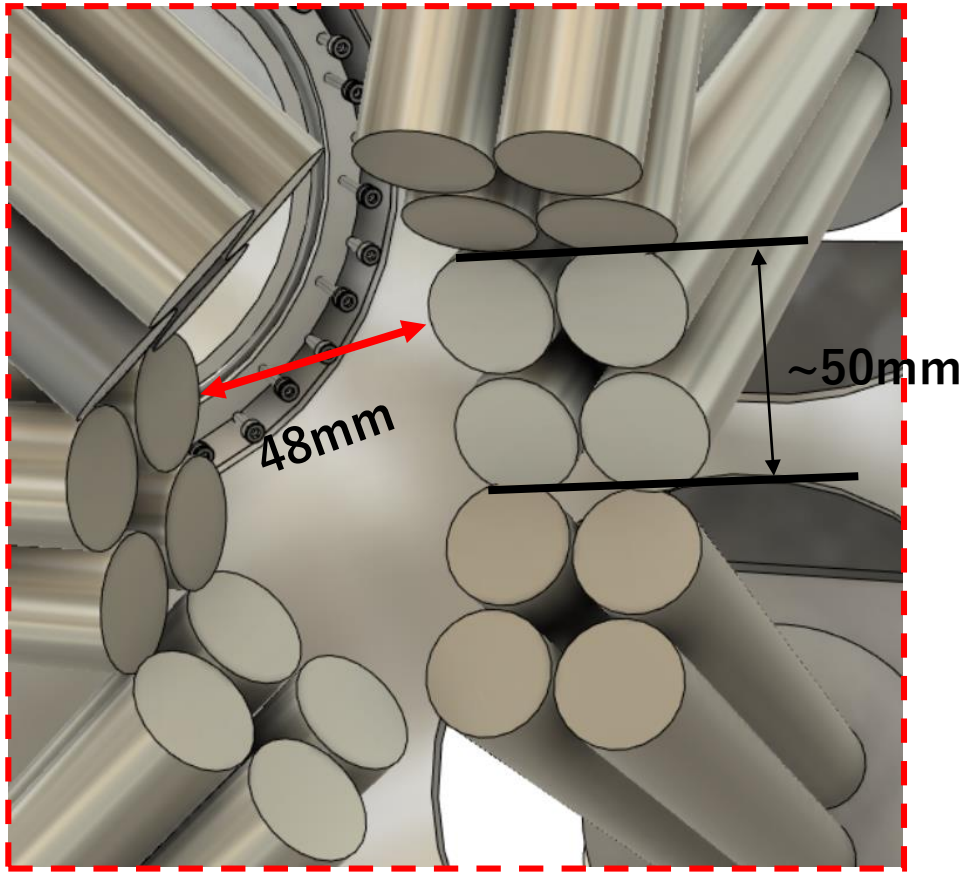
If we rely on all to Canberra, it takes almost 10 times money. The modifications should be as simple as possible, so that they can be done by other production company.

「24eyes」: new detection system for future development



Every detectors are placed at an angle of less than 50 deg.

The endcap can be close up to 60mm



Summary

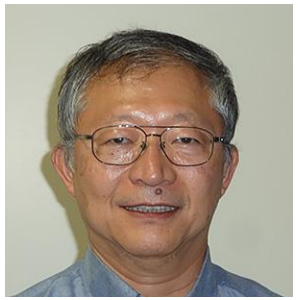
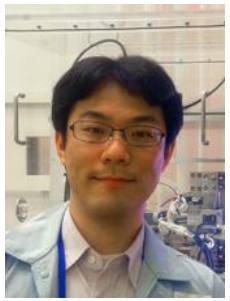
We have been developing detection systems of muonic X-ray suitable for strong pulsed muon source.

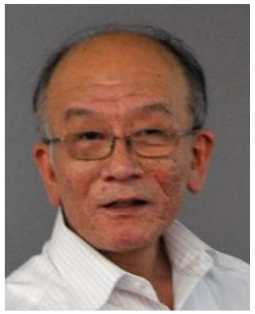
In present, We have placed 9 Ge detectors and achieved 5 times increase of detection efficiency compared between before and after upgrade.

Aiming further increase of detection efficiency,
We are planning to develop 4-elemental Ge detector by modifying 4 Ge detectors

Collaborators

KEK MUSE



M.Tampo, Y. Miyake, S. Takeshita, I.Umegaki, and K. Shimomura

National Museum of Japanese history

National Museum of Nature and Science

T. Saito

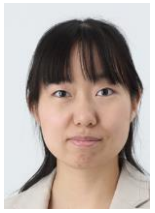
T. Kutsuna

Yamanashi Prefectural Museum

M. Saigan

Osaka Univ





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K. Takaura, A Sato

International Christian Univ

M. K. Kubo

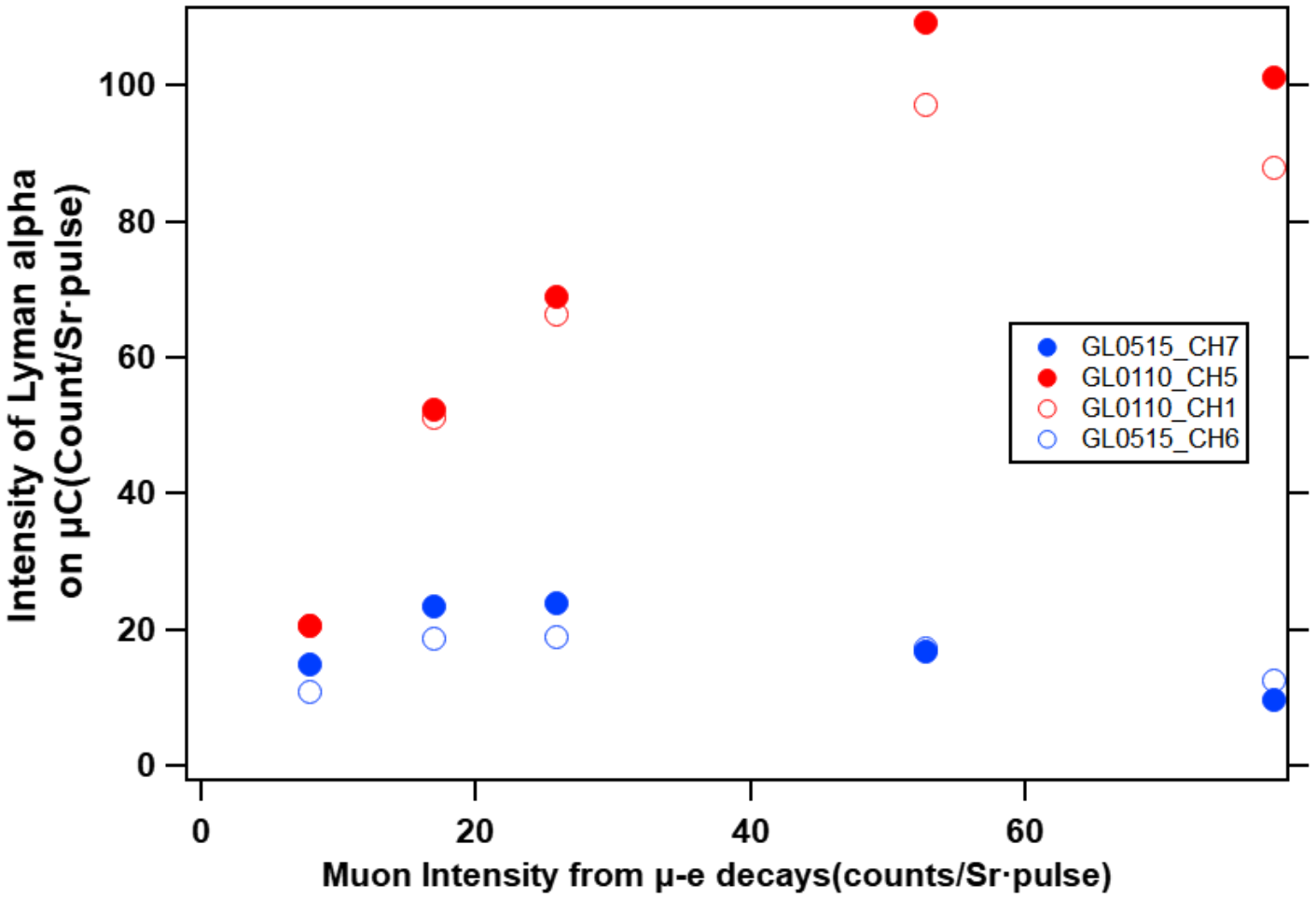
Okayama Univ

A. Seike

N. Matsumoto

My suggestions for PSI and J-PARC collaborations in Muonic X-ray measurements.

In pulsed muon source, it is now big issue for measuring muon numbers precisely

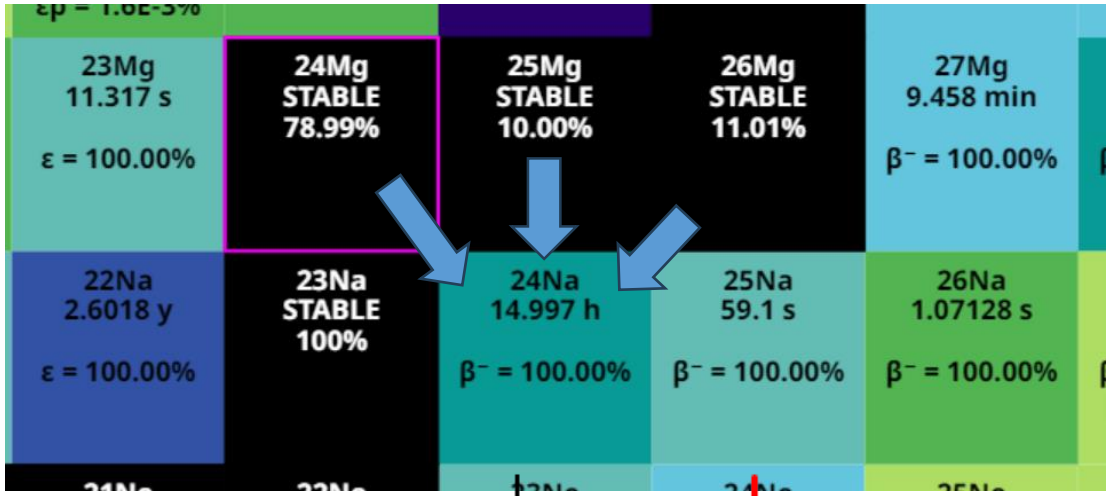


There are two ways to measure muon numbers

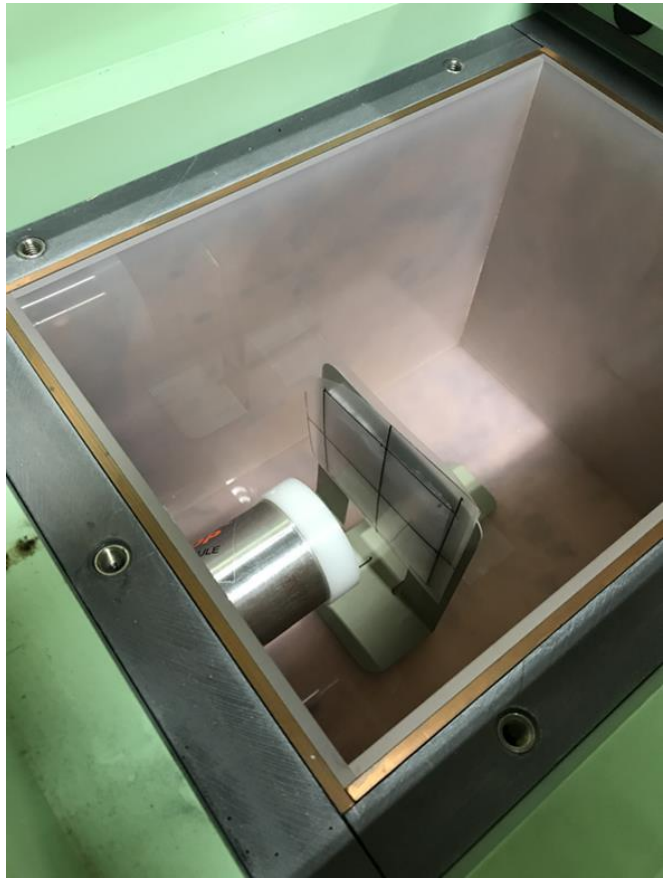
1. Measuring decay electrons
2. Measuring Muonic X-rays of Lyman alpha

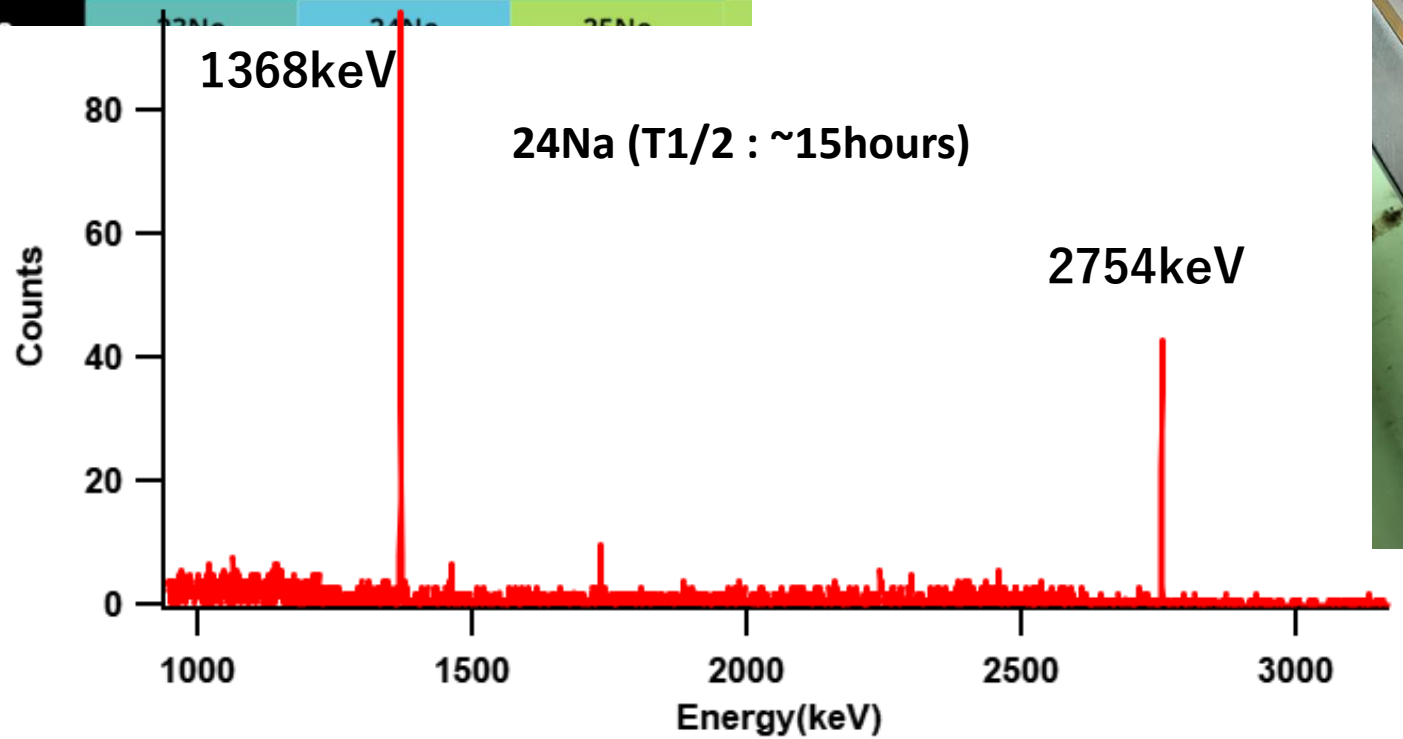
knowing absolute efficiency observed Muonic X-rays per muon is very important Issue.

If we know production efficiency from muon absorbed Mg to 24Na, from Mg activation measurements , we can know muon number.



In PSI, precise muon number measuring can be done with activation measurements. (I believe !)





I want to ask you is there such shielding staffs in PSI muon?