P8

Measurement of 107-MeV proton-induced double-differential neutron yields for iron for research and development of accelerator-driven systems

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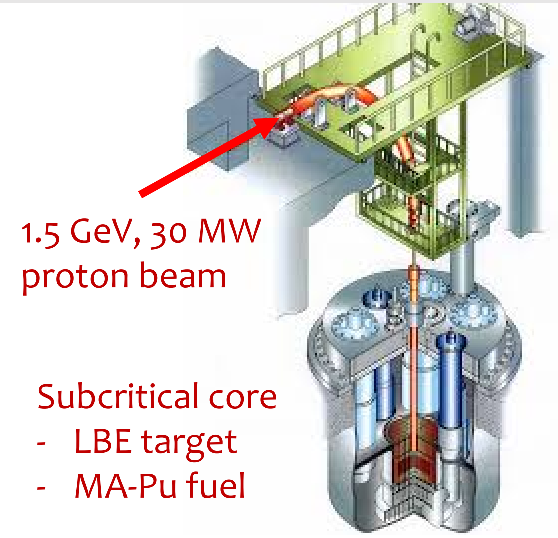
Introduction

Accelerator-Driven System (ADS)

- A system to transmute Minor Actinides (MAs) with high-energy proton beams
- Nuclear data and nuclear reaction models play an important role in estimating safety parameters for the ADS.

Energy domain: keV to GeV

Important materials: MA, Pu, Pb, Bi, Fe, …



JAEA-proposed ADS

- IAEA International benchmark test [1]

  Experimental data at energies below and around 100 MeV are scarce

- Reactor physics experiments for ADS using KUCA/FFAG at Kyoto University

  Subcriticality experiments with 100-MeV proton beam

[1] J.C. David, et al. PNST; **2**, 942–947 (2011)
[2] C. Pyeon, et al. ANE **144**, 17498 (2020)

Purpose

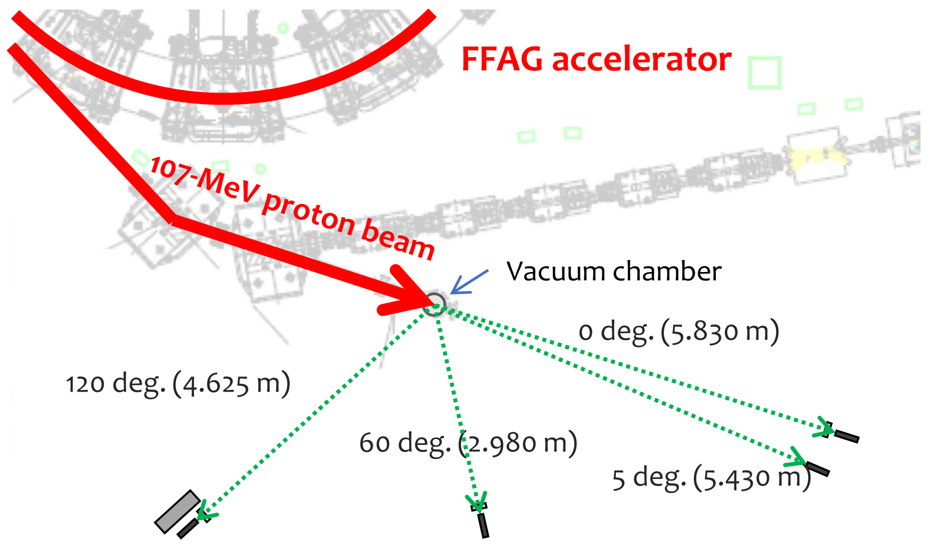
Measure nuclear data dedicated to R&D of ADS using **FFAG accelerator**

- **This work: Double-differential neutron yields (TTNY and DDX)** for **Fe**, Pb, and Bi
- Other works: Fission-fragment and fission-neutron yields for Pb and Bi

TTNY experiment

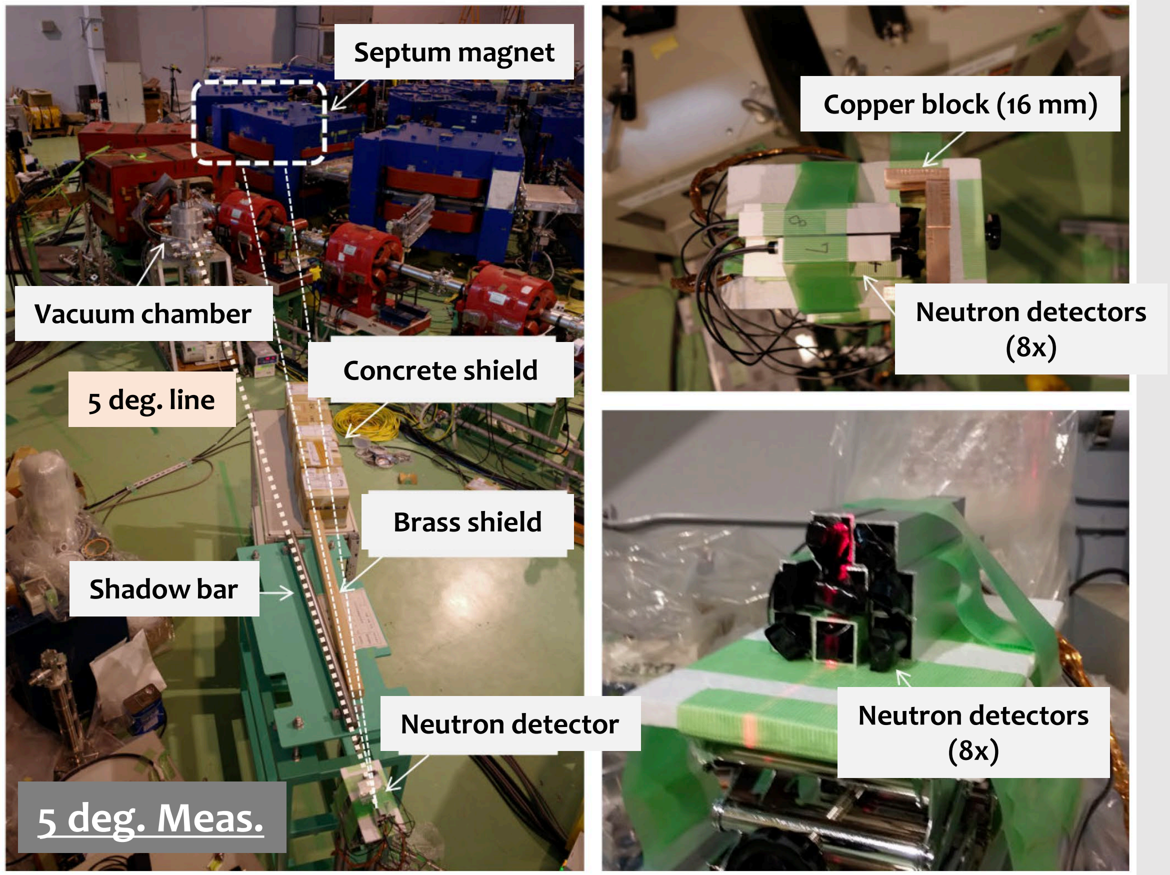
A **thick** iron disk installed in vacuum chamber was irradiated with 107-MeV protons, and then TTNY was measured.

- **Shielding blocks** for reducing background neutrons coming from **FFAG septum magnet**
- **Stacked neutron detectors** for good statistics



Condition for TTNY measurement at 5 deg.

Target	^{nat}Fe (46 mm in diameter, 30 mm thick)
Beam	Proton (energy: 107 MeV, current: 50 pA)
Meas. time	Foreground measurement: 64.9 min Background measurement: 55.6 min (w/ shadow bar)

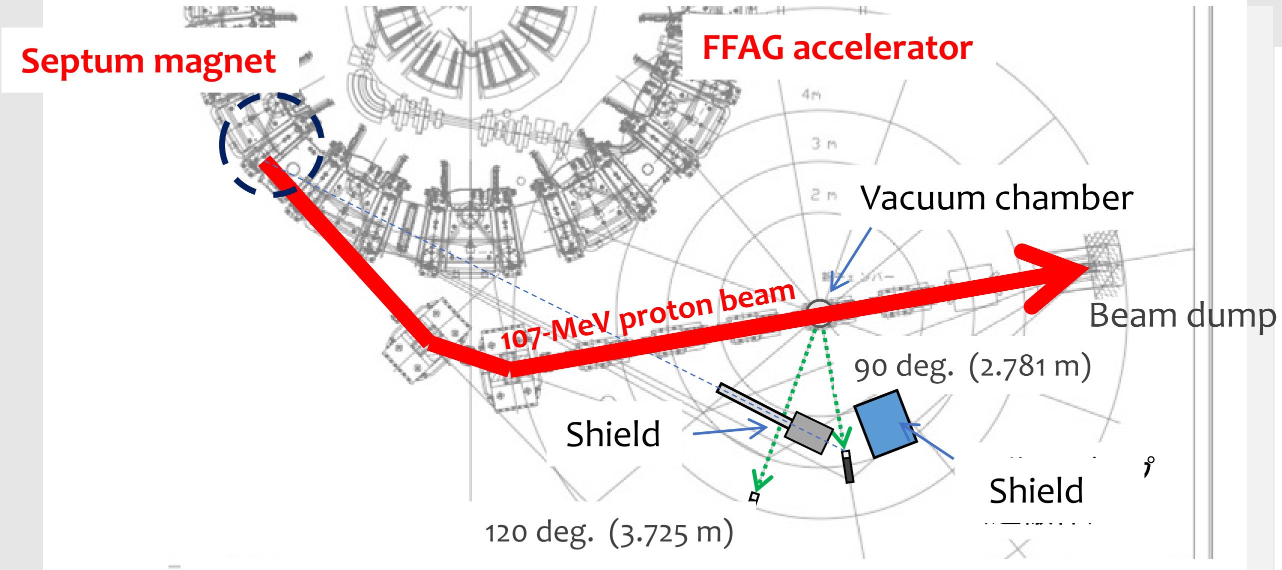


Picture of TTNY measurement at 5 deg.

DDX experiment

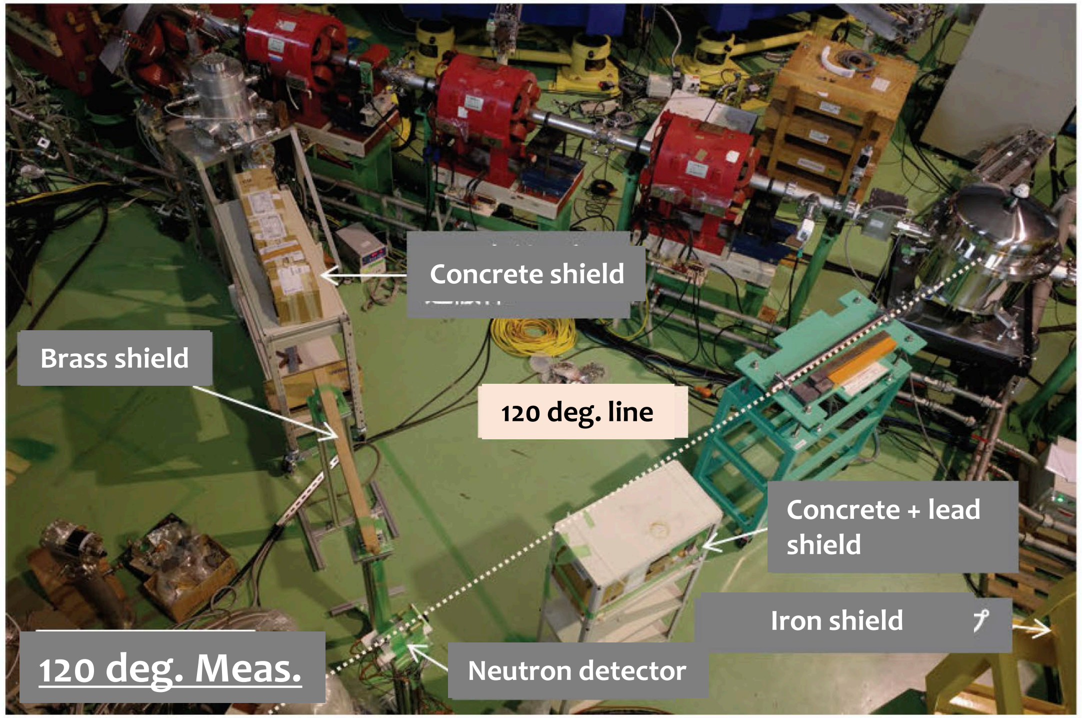
A **thin** iron disk installed in vacuum chamber was irradiated with 107-MeV protons, and then DDX was measured.

- **Shielding blocks** for reducing background neutrons coming from **FFAG septum magnet** and **beam dump**
- **Stacked neutron detectors** for good statistics



Condition for DDX measurement at 120 deg.

Target	^{nat}Fe (46 mm in diameter, 2 mm thick)
Beam	Proton (energy: 107 MeV, current: 100 pA)
Meas. time	Foreground measurement: 100.0 min Background measurement: 90.9 min (w/ shadow bar)

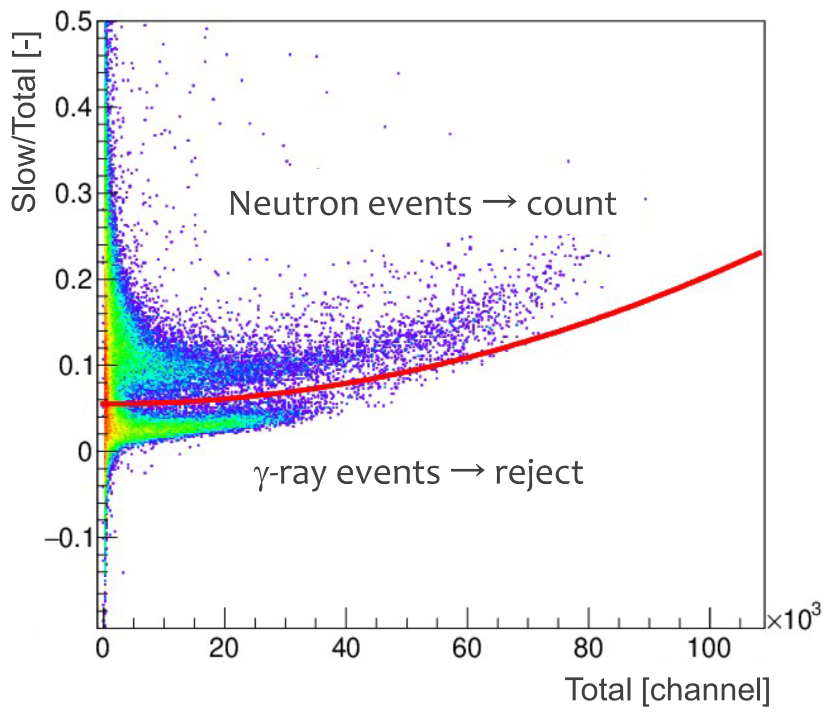


Picture of DDX measurement at 120 deg.

Data analysis

- **Procedure**

1. **Pulse shape discrimination**
   Count neutron events via pulse shape discrimination
2. **TOF spectrum**
   Obtain TOF spectrum from neutron and kicker-magnet signals
3. **Energy spectrum**
   Obtain energy spectrum from the TOF spectrum with relativistic kinematics
4. **DDX and TTNY**
   Obtain DDX and TTNY considering detection efficiency, solid angle, etc.



Pulse shape discrimination (PSD) plot

- **Formula**

DDX: $$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E\mathrm{d}\Omega} = \frac{N_n(E_n,\theta)}{\Delta E_n \Delta\Omega} \frac{1}{N_p N_t \varepsilon(E_n)\eta(E_n)}$$

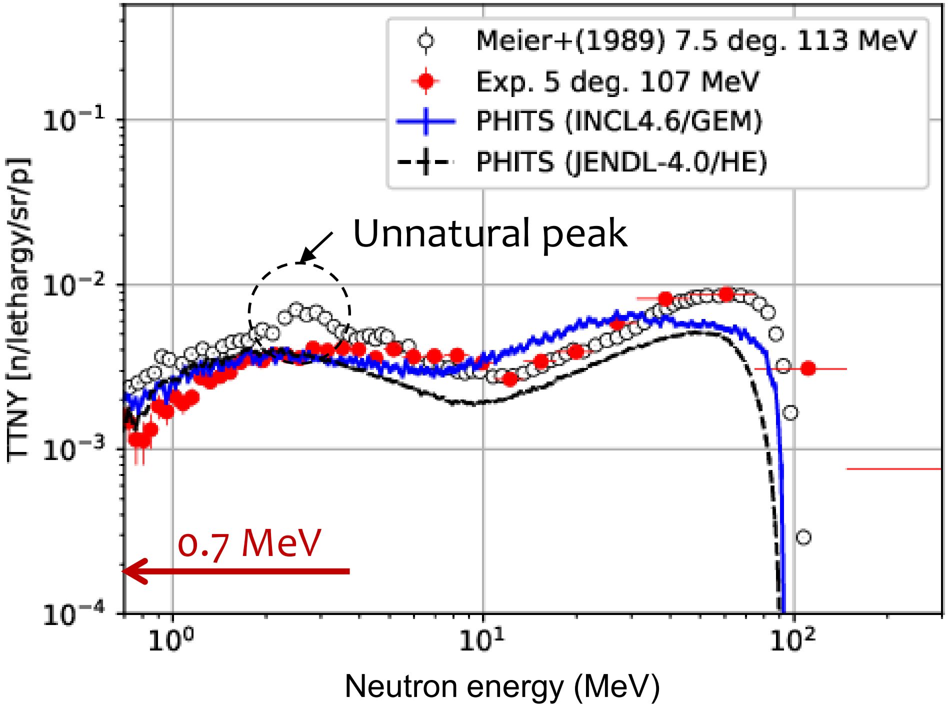
TTNY: $$\frac{\mathrm{d}^2 Y}{\mathrm{d}E\mathrm{d}\Omega} = \frac{N_n(E_n,\theta)}{\Delta E_n \Delta\Omega} \frac{1}{N_p \varepsilon(E_n)\eta(E_n)}$$

- E_n : Neutron energy
- θ : Emission angle
- Ω : Solid angle
- N_n : Number of detected neutrons
- N_p : Number of incident protons
- N_t : Target area density
- ε : Neutron detection efficiency*
- η : Neutron attenuation*

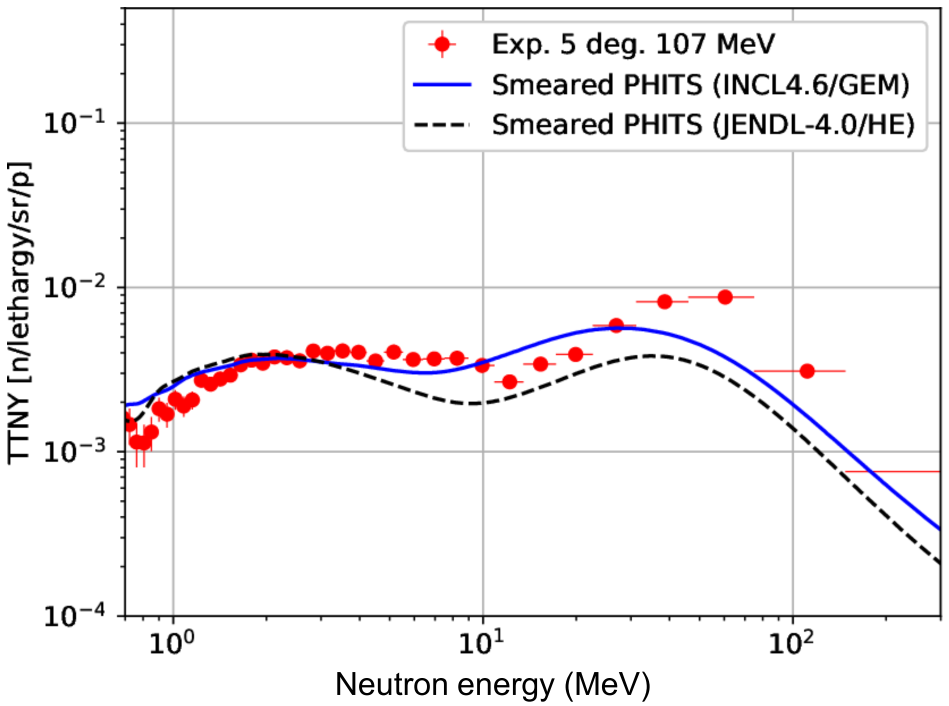
*ε and η were obtained by **SCINFUL-R** and **PHITS**, respectively

Results (TTNY, 5 deg.)

The obtained TTNY was compared with a calculation results by the nuclear reaction model **INCL4.6/GEM** and those by the evaluated nuclear data library **JENDL-4.0/HE**, together with experimental data by **Meier et al.** (E_p = 113 MeV, angle = 7.5 deg.).



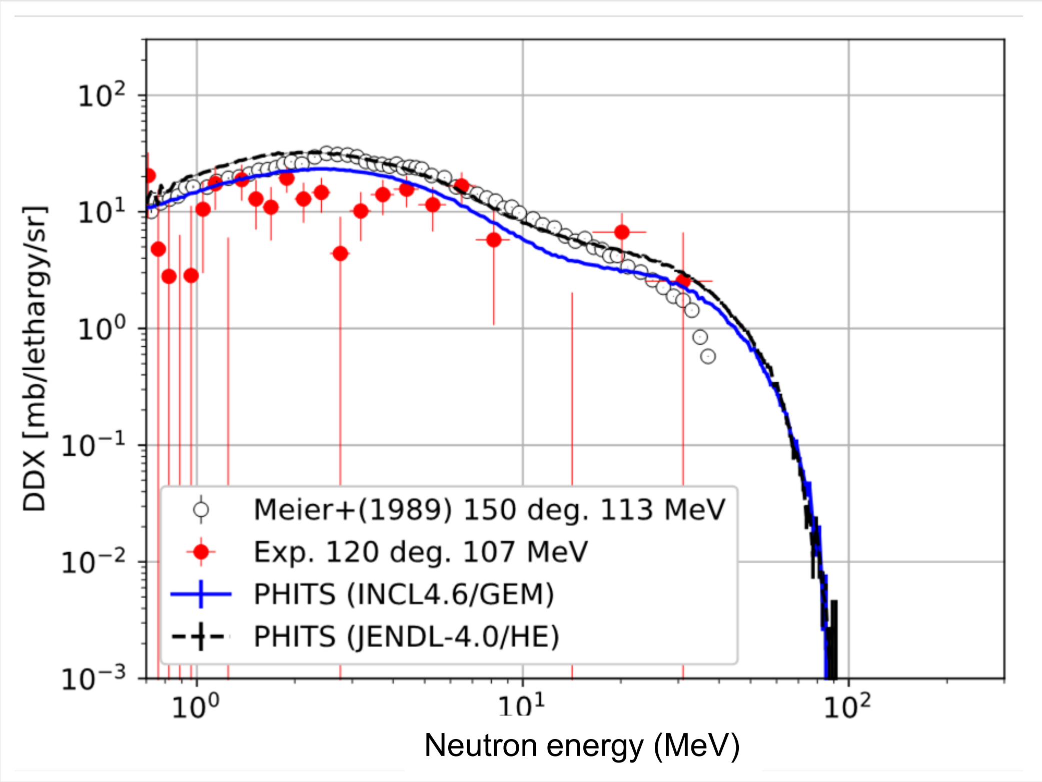
Comparison between experiments and calculations



TTNY smeared with time resolution

Results (DDX, 120 deg.)

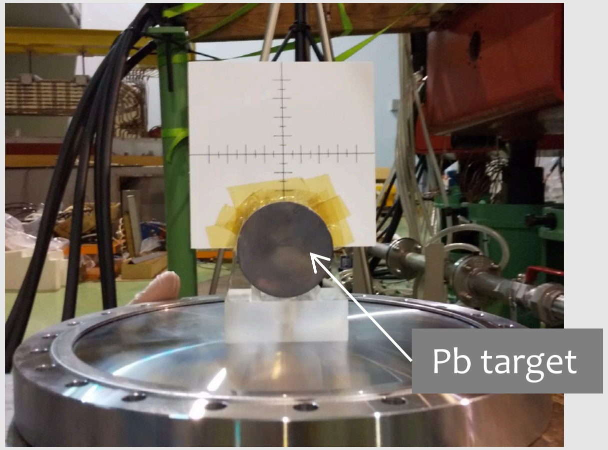
The obtained DDX was compared with a calculation results by the nuclear reaction model **INCL4.6/GEM** and experimental data by **Meier et al.** (E_p = 113 MeV, angle = 150 deg.).



← Unfortunately, sufficient statistics could not be obtained due to background neutrons.

Necessary measures:

- Enhancing shielding to reduce background neutrons
- Increasing measurement duration and shortening flight path (tradeoff with energy resolution) to obtain good statistics



Pb target before installing in vacuum chamber (next experiment)

Bi target (after the next experiment)

- Additional experiment for Fe was conducted on **Oct. 11–16.** Its data analysis is on going.
- Experiment for Pb will be conducted on **Nov. 22–26**.