中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

ISINN-30

BACK-N
CSNS-WHITE NEUTRON SOURCE

Progress in neutron resonance imaging experiments using MCP at CSNS Back-n white neutron facility

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CHINESE ACADEMY OF SCIENCES

Outlook

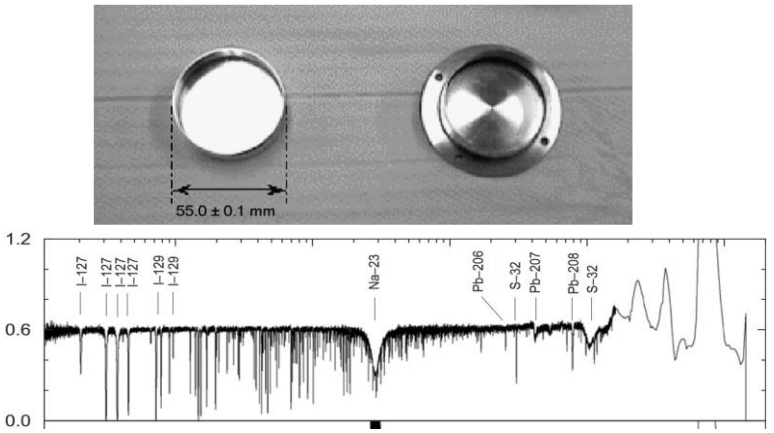
- Background
- Experiment Setup
- Data Processing and Analysis
- Result

Background

Neutron Radiography (NR), is a non-invasive method to characterize the internal structure of materials

Neutron Resonance Transmission Analysis (NRTA), is a method utilizing the different resonance peaks for the nuclide analysis.

Imaging of a old Buddha sculpture (photo left) with 150 kV X-ray (middle) and thermal neutrons (right)[1].



Pictures of the radioactive PbI_2 sample (photo upper) and its transmission spectrum(lower)[2].

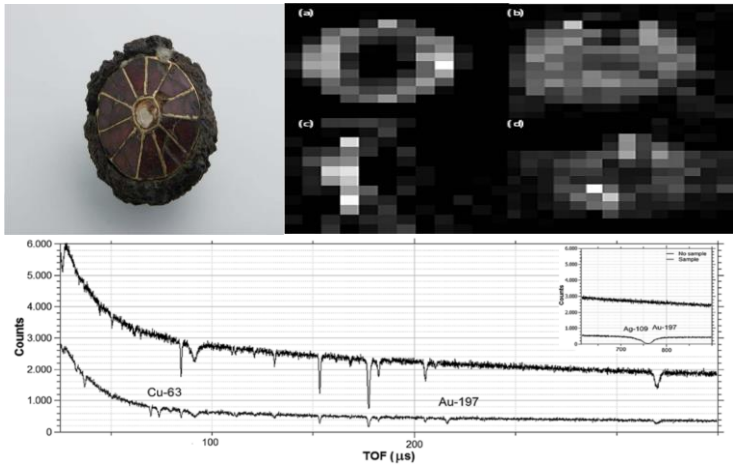
NR Nuclide Space disrubution

NRTA Nuclide content

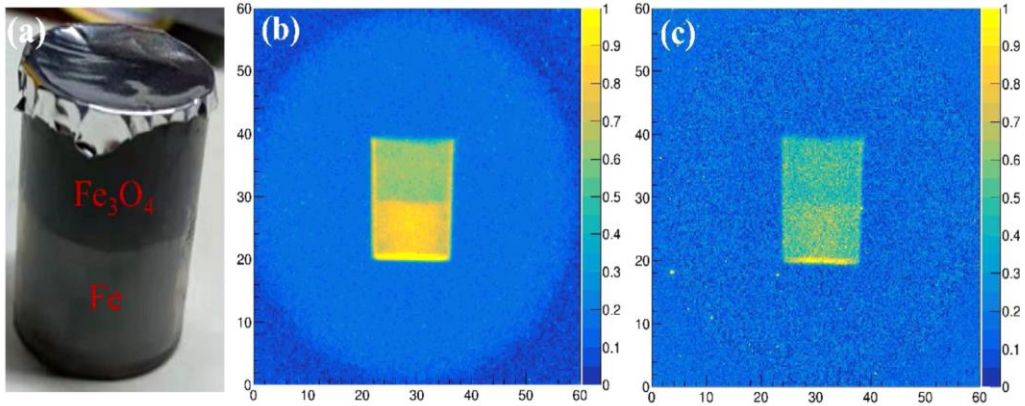
→ Neutron Resonance Transmission Imaging (NRTI)

[1] Journal of Instrumentation, 2011, 6(01): C01050.
[2]NIMA, 2007, 575(3)v: 476-488.

Background

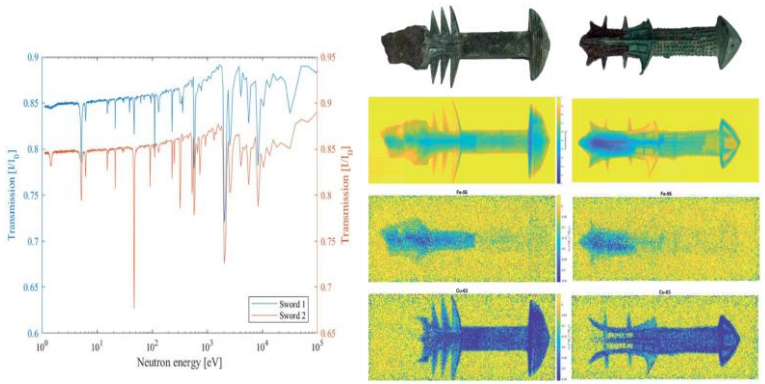


Inorganic Scintillators [1].



Gated Cameras[2].

Detector System	Spatial resolution	Characteristics
Inorganic Scintillators[1]	2 mm	It is used for 3D imaging; Spatial resolution is not good.
Gated Cameras[2]	0.1 mm	Spatial resolution is good; the nuclide content should be known before the experiment.
Gas Detectors [3]	0.8 mm	The active area is large; neutron detection efficiency is not enough.

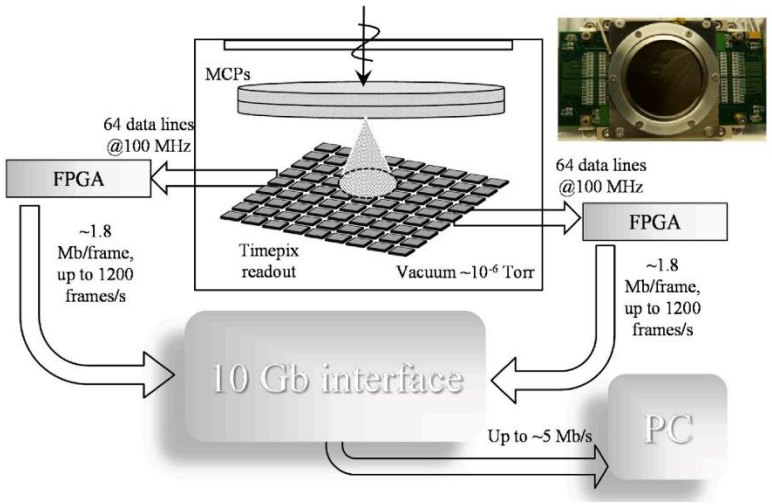


Gas Detectors (nGEM) [3].

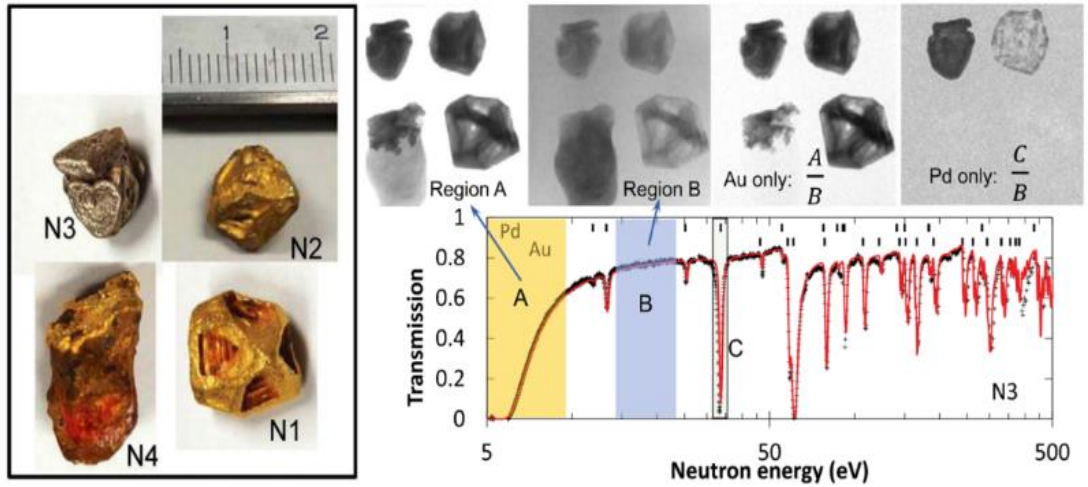
[1] Journal of Analytical Atomic Spectrometry, 2015, 30(3): 745-750.
[2] NIMA, 2023, 1048: 167892.
[3] Journal of Analytical Atomic Spectrometry, 2019, 34(12): 2420-2427.

Background

Boron-doped microchannel plates (MCPs) balance the **detection efficiency** and **spacial resolution**



Schematic diagram of an MCP/Timepix event counting detector.



NRTI was used to study the nuclide composition of natural gold Samples based on boron-doped MCP. The images of Au and Pd are clear by selecting different energy ranges .

Boroned MCP [1][2] .

[1]NIMA, 2015, 787: 20-25.
[2]Scientific Reports, 2017, 7(1): 40759.

Background

The unique capability of NRTI makes research that can only be studied non-destructively very attractive, especially for valuable samples (e.g. rare geological samples, celestial objects or cultural heritages).

Photograph of imitated lunar soil sample.

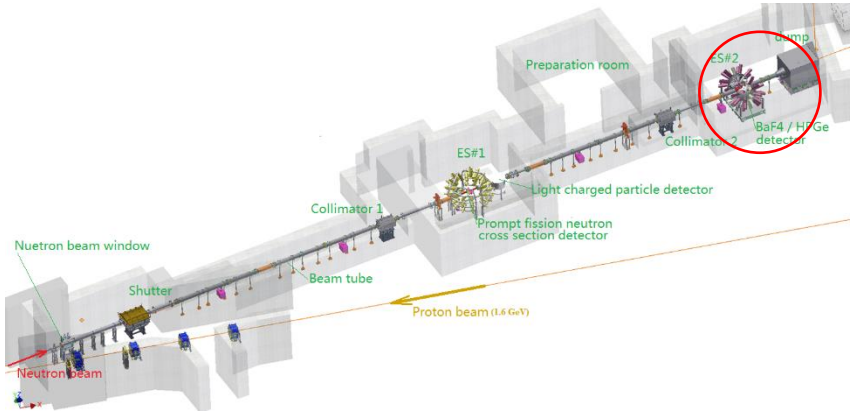
Photographs of underwater relic found in South China Sea.

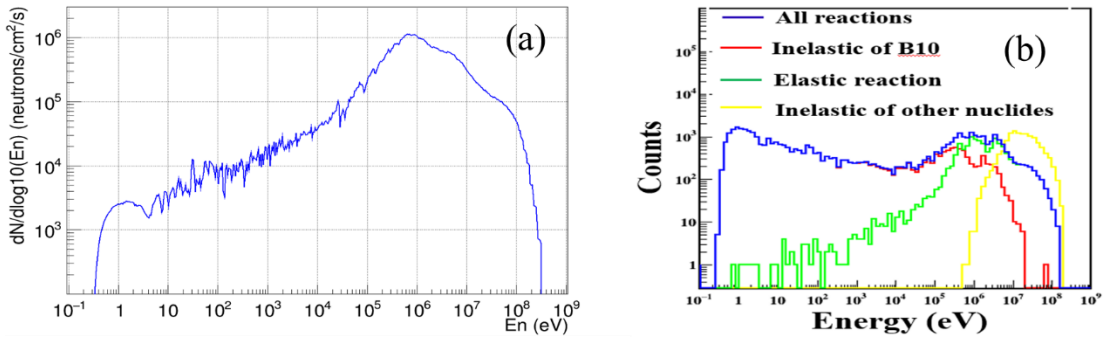
Experiment Setup

The NRTI experiment using boron-doped MCP at the back-streaming neutron line (Back-n) of the China Spallation Neutron Source (CSNS) has been conducted

CSNS Back-n

- The CSNS Back-n has a **wide energy range(**0.3 eV- 300 MeV**)**, **high neutron flux(**1×10^7@ES#2**)**, and **good energy resolution (**0.32%- 4.9%**)**
- According to simulation, the counting rate of boron-doped MCP is high and does not vary significantly with neutron energy





Neutron energy spectrum at CSNS Back-n (a) and simulated MCP count rate with neutron energy (b).

NRTI based on MCP at CSNS Back-n can achieve neutron detection in the energy range of eV- tens of MeV, thereby covering the vast majority of nuclides

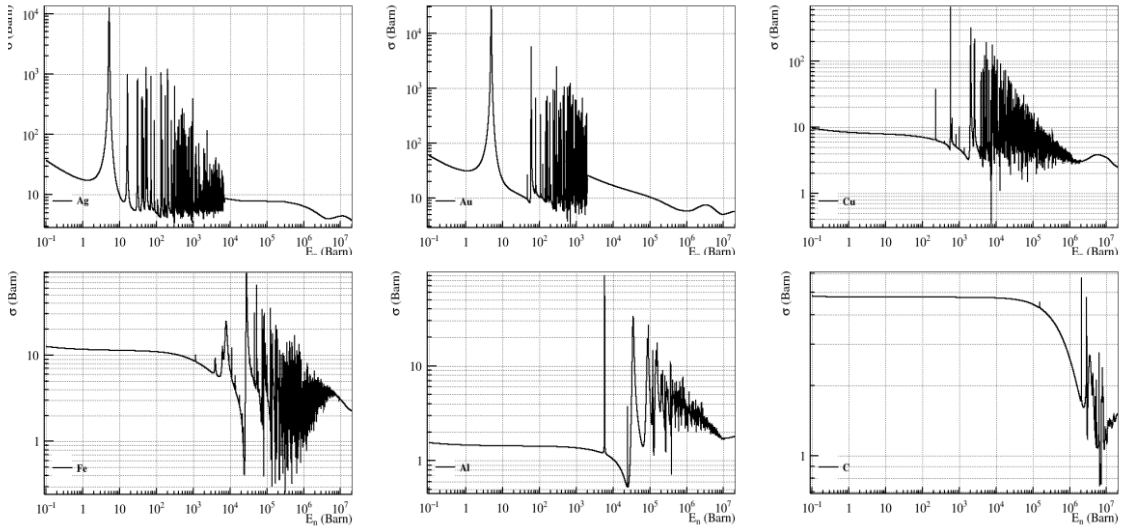
Experiment Setup

Sample

The details of the samples

Sample	Thikness(cm)	S(cm2)
C	0.1	0.5
Al	0.1	sample support
Fe	0.1	0.5
Cu	0.1	0.5
Ag	0.01	1
Au	0.01	1

Samples are cuboids / foils, except for the Al sample support

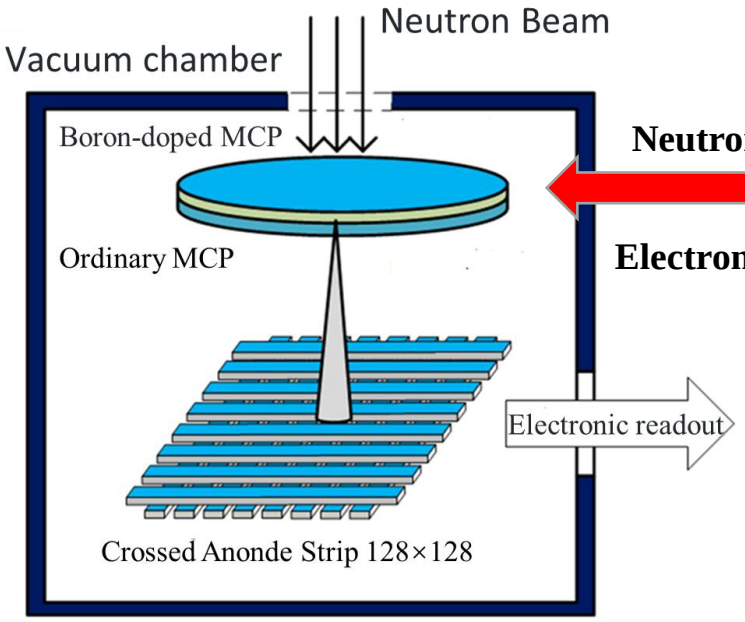


Samples used in the experiment and cross sections of (n,tot) reactions.

Au, Ag, Cu, Fe, Al, C samples was selected to cover the energy range from eV to MeV

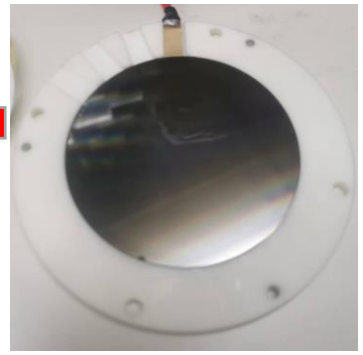
Experiment Setup

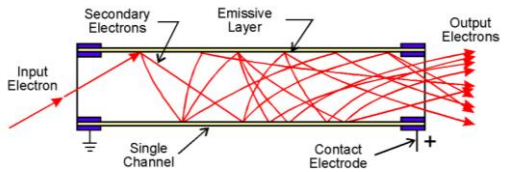
MCPs

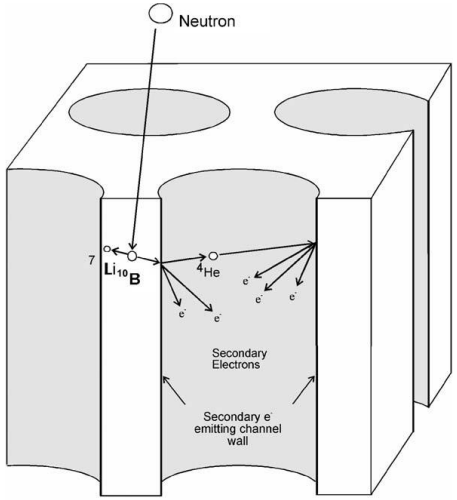


Neutron absorption

Electron multiplication





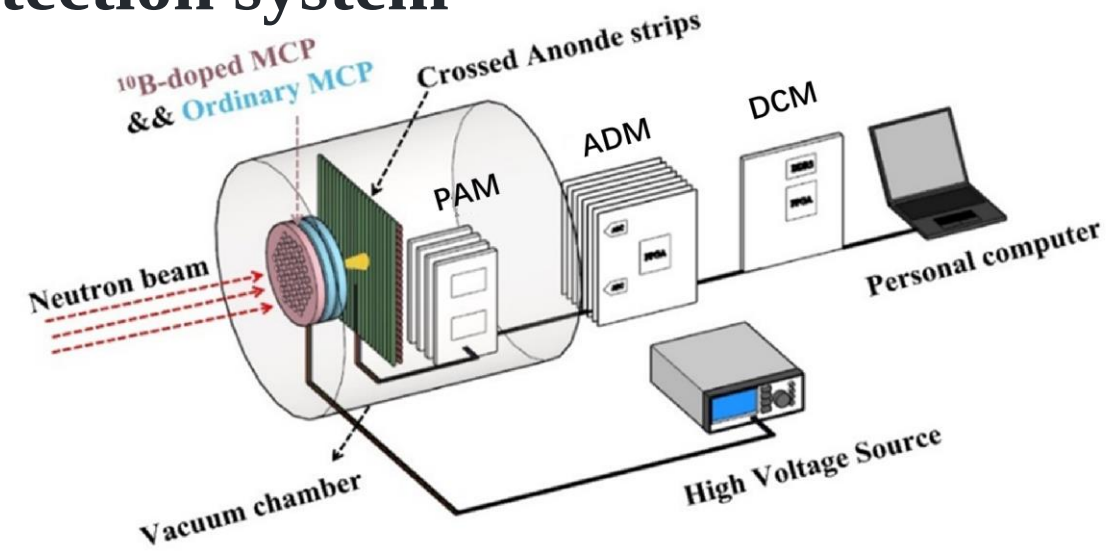


Two kind of MCPs

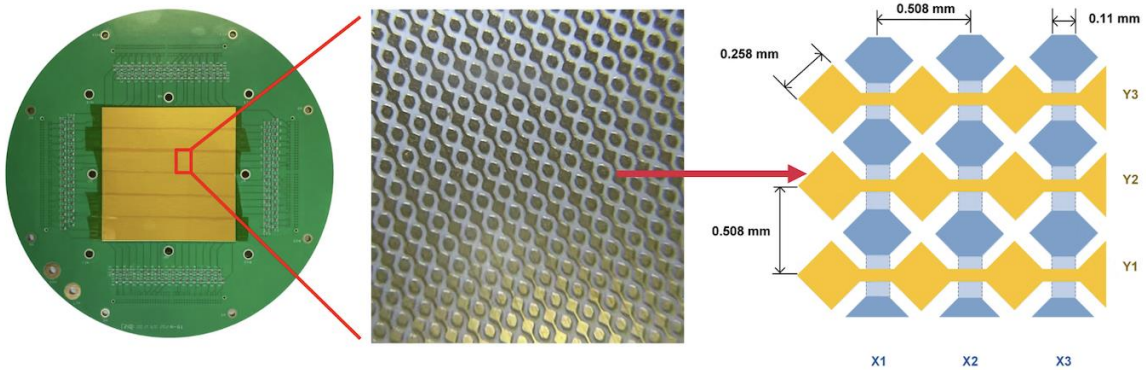
Parameters	B-MCP	Ordinary MCP
Diameter (mm)	56	56
Thickness (μm)	480	480
Pore inner diameter (μm)	8.8	8.8
Pore area ratio (%)	~65	~65
Gain	~115@800V	~10720@1000V
^{10}B (mol%)	15	-

Experiment Setup

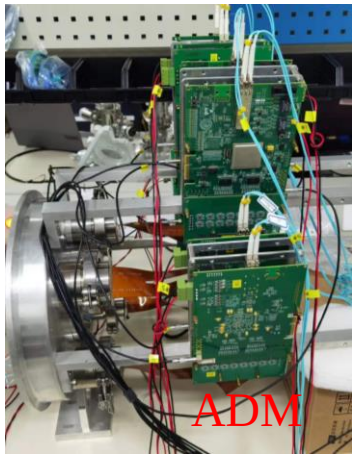
Detection system



Schematic diagram MCP detection system.

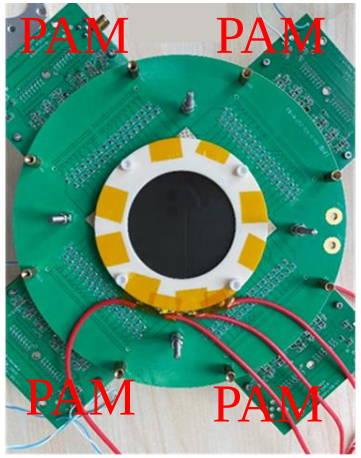


Crossed Anonde Strip 128x128

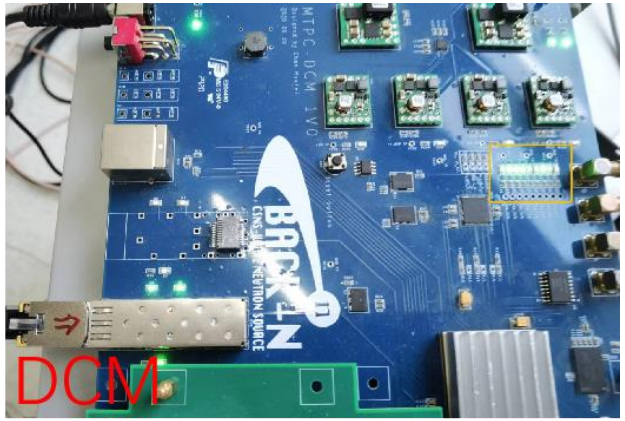


Sample rate : **80 MSPS**
Sampling resolution:**12 bit**

Analog-to-Digital Module



Pre-Amplifier Module



Data Concentrator Module

Experiment Setup

Experiment Condition

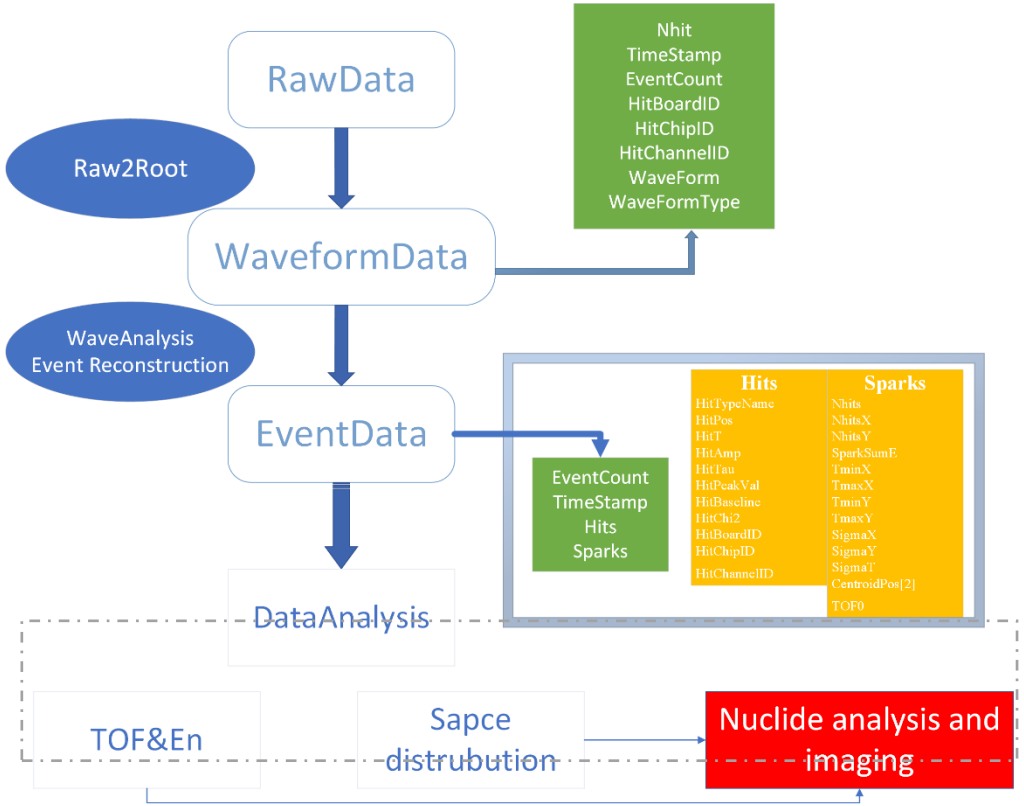
Photograph of the MCP Detector.

- Neutron flux: **1.025×10^6 n/cm^2/s**
- Neutron beam spot: **φ 30 mm**
- Experiment position: **ES#2 L=~77m**
- Experiment duration： **2024 2.3-2.5 && 2024 3.4-3.7 (7 days)**
- Bias voltage: **B-MCP 800 V / ordinary MCP 800 - 900 V**

Data Processing and Analysis

Program Framework

The framework of data processing and analysis program was based on **BLUET-v4[1](** A framework is developed for the data processing and analysis of advanced detectors)



[1] *https://code.ihep.ac.cn/csns-backn-tpc/bluet-v4*

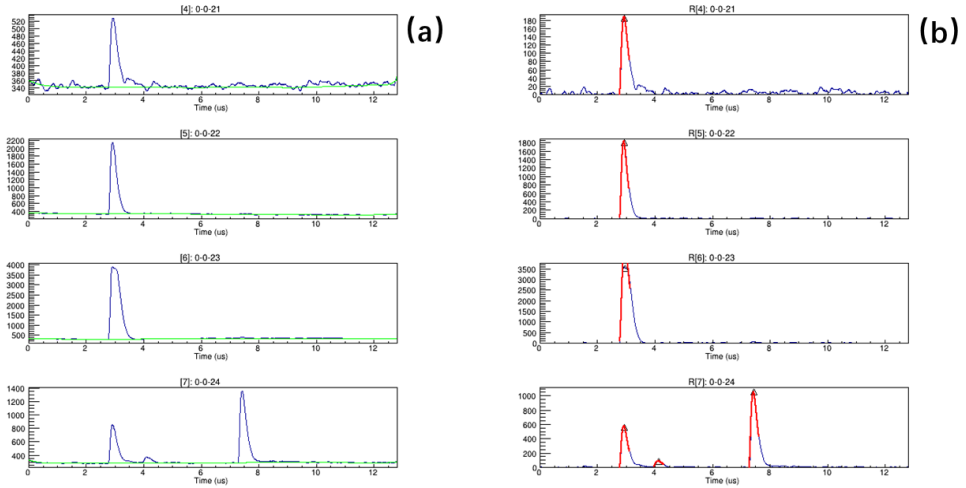
Data Processing and Analysis

Waveform analysis and event reconstruction

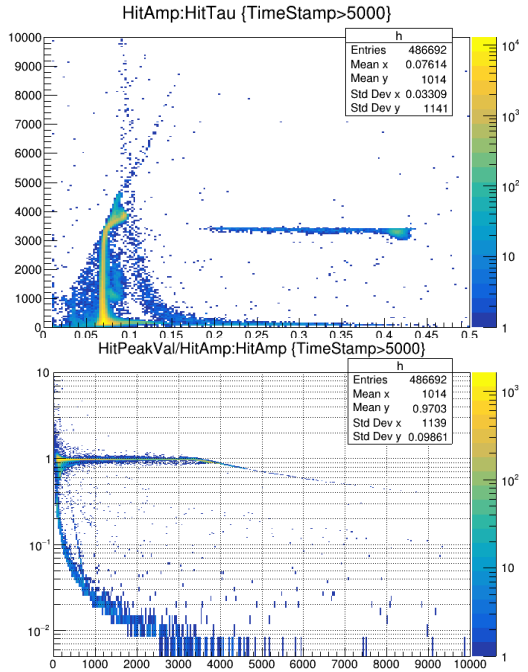
Baseline subtraction → **Fit** → **Signal Selection** → **Event Reconstruction**

Timing & amplitude

$$f(t) = B + A\left(\frac{t - t_0}{\tau}\right)^2 e^{-(t-t_0)/\tau}$$

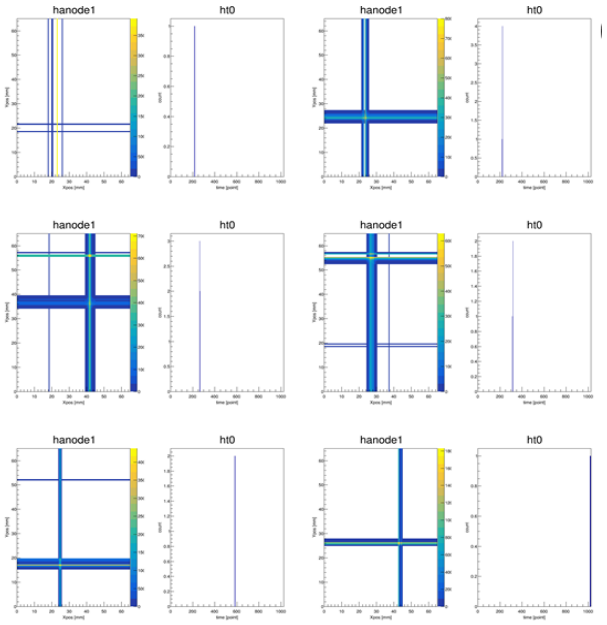


Original waveform(a) and waveform after baseline subtraction with the red line indicating the fitting result (b).



Signal selection using fitting parameters.

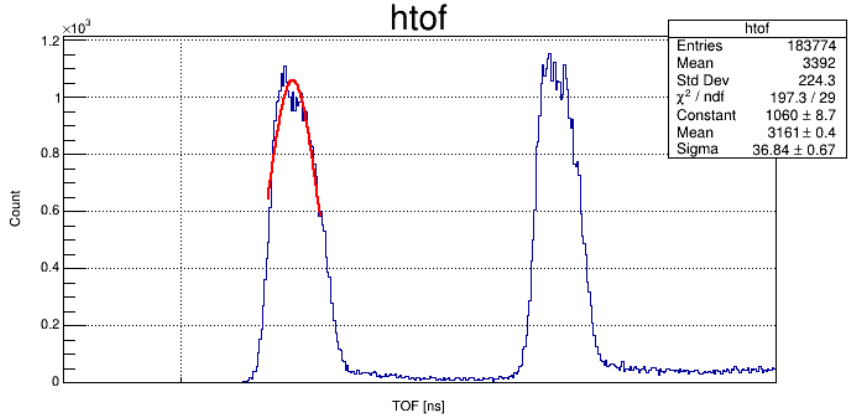
A 10 ns time interval



Event hit after event reconstruction.

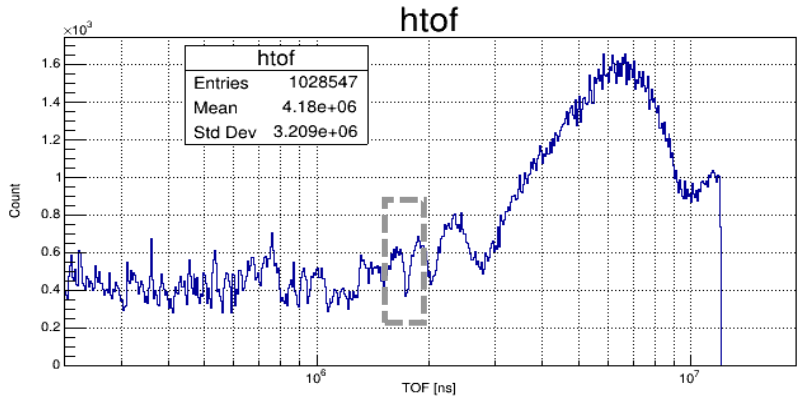
Data Processing and Analysis

TOF Method



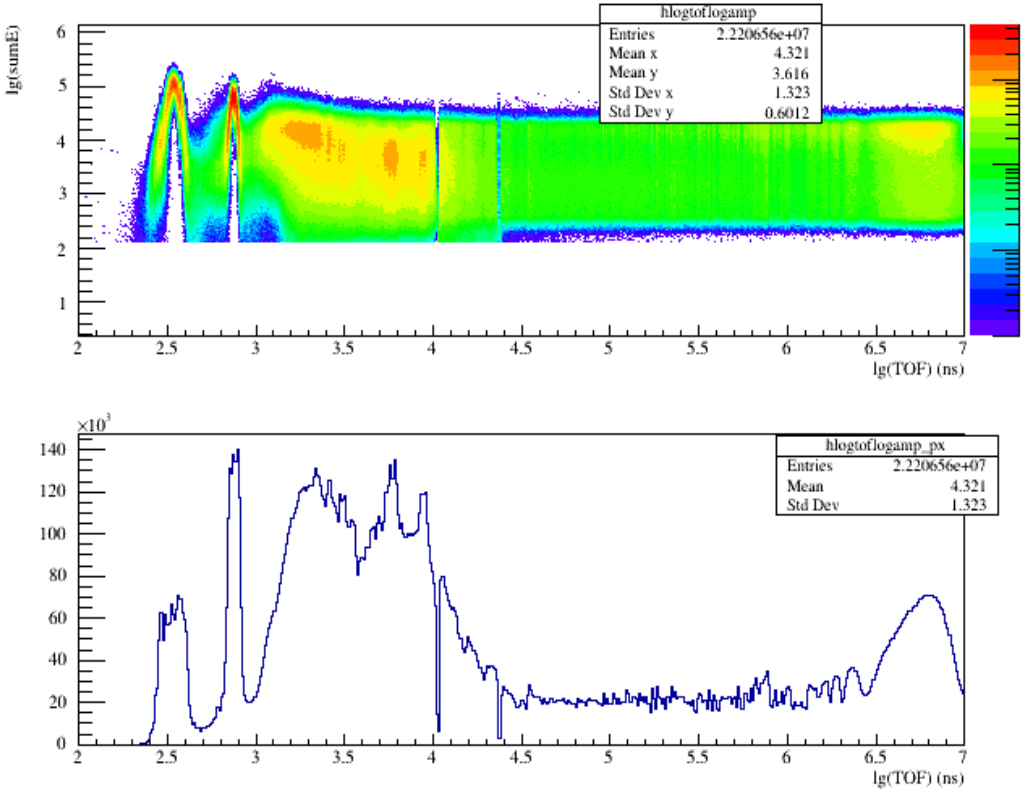
Tg was calibrated using γ-flash.

$$TOF = T - T_g + L/c$$



L was calibrated using the resonance peak of ^{181}Ta (n, tot) reaction.

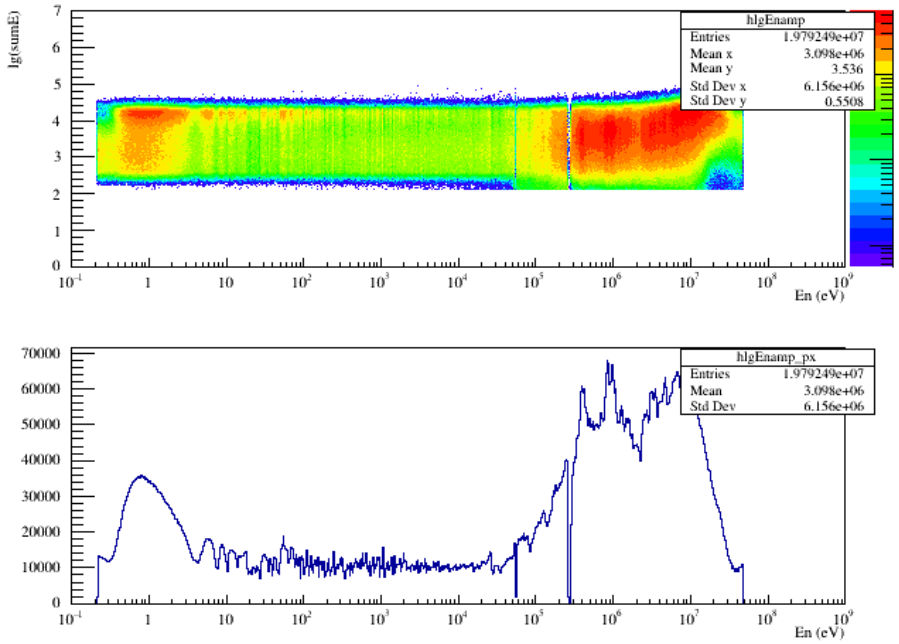
Tg=3161 ns
L=76.81 m



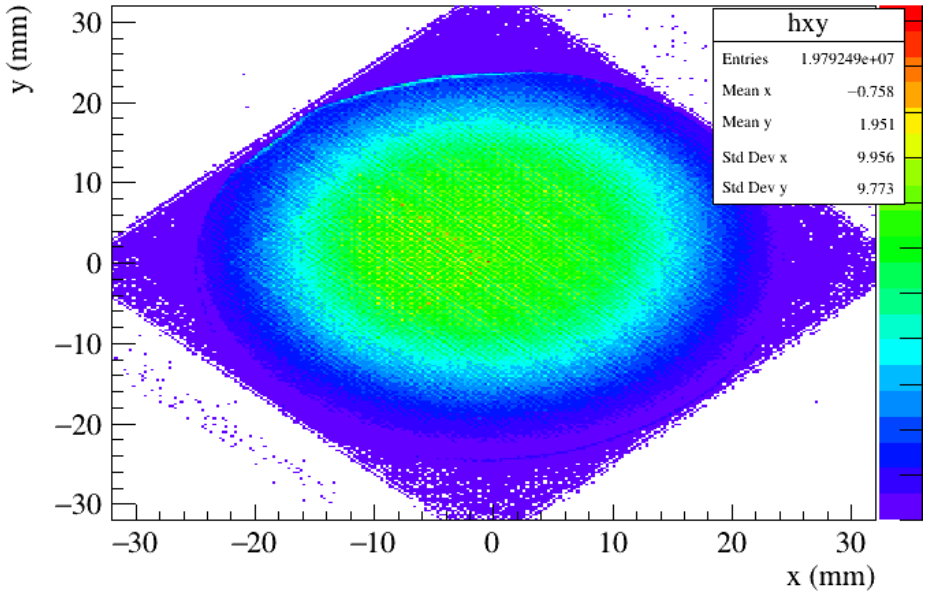
2D distribution of TOF vs. amplitude (a) and TOF spectrum (b).

Data Processing and Analysis

Open Beam Data



Reaction rate as a function of neutron energy.

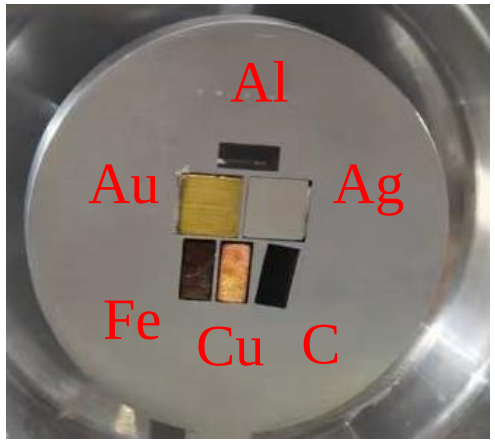


The spatial profile of the neutron beam. (0.25 mm/bin)

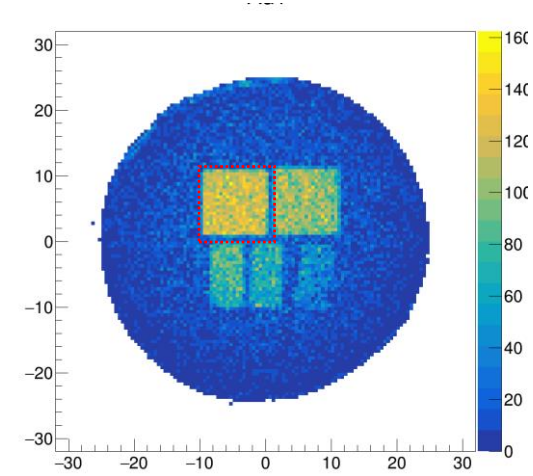
The **resonant structure** due to spallation target can be observed clearly

The **spacial resolution** is good by using the charge center-of-mass method

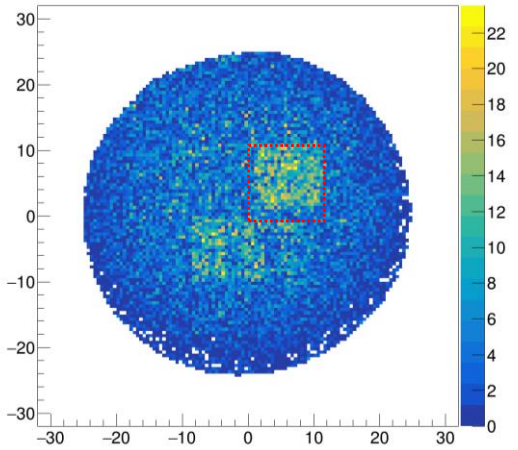
Result



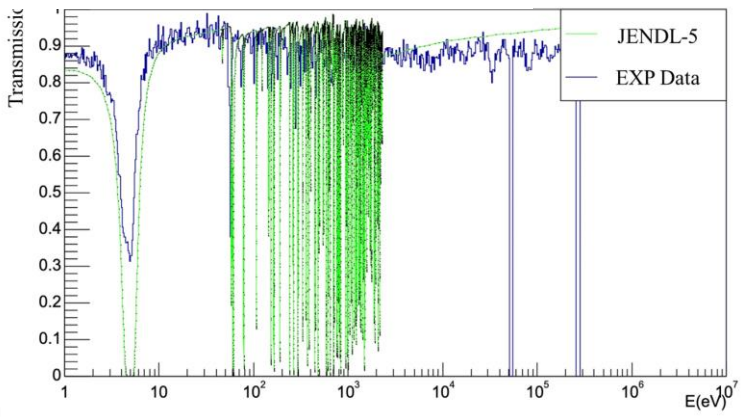
$$T_{\exp}(E) = \frac{C_{\text{in}}(E)}{C_{\text{out}}(E)}$$

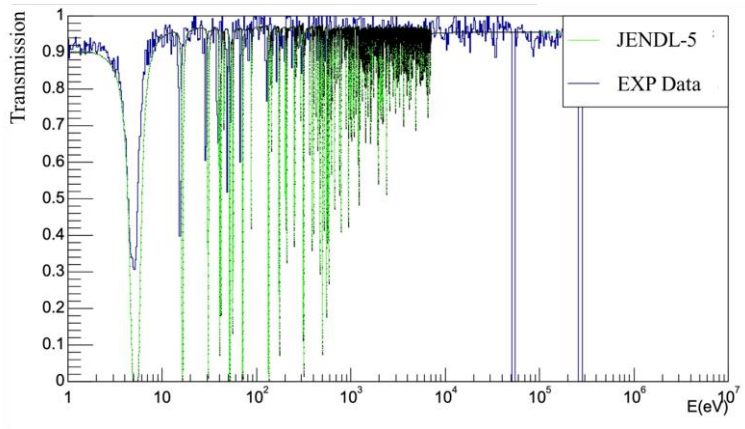


Au
3.8-5.5eV



Ag
15.14-15.85eV

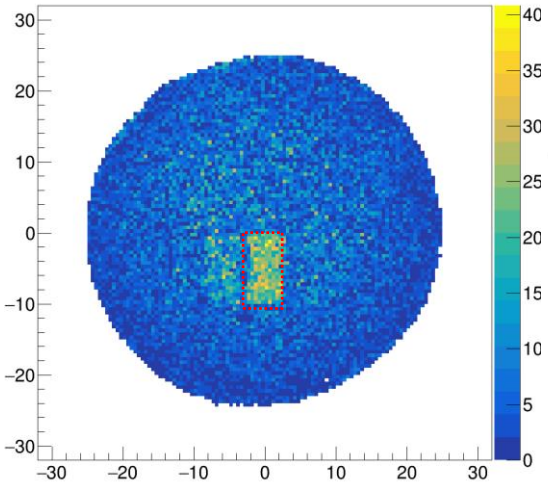




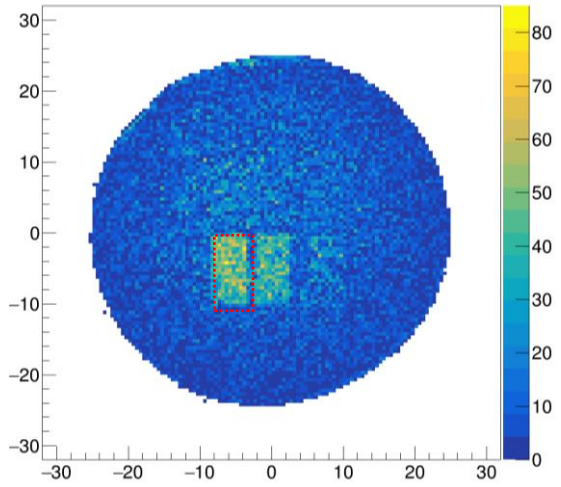
Neutron transmission images in resonance peaks range and neutron transmission spectra measured for different samples.

- The images were obtained by normalization of the "sample in" data by the "open beam" data measured separately.
- The experimental transmission was obtained in the sample area.

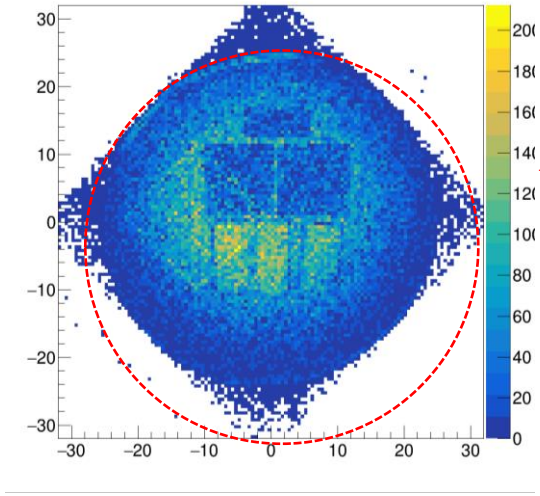
Result



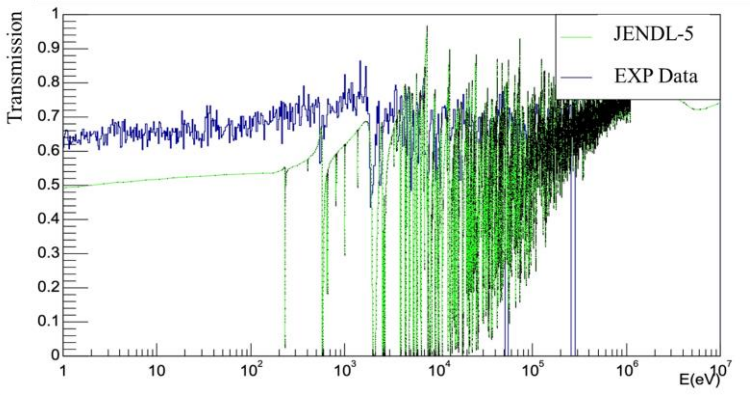
Cu
1862-2089 eV

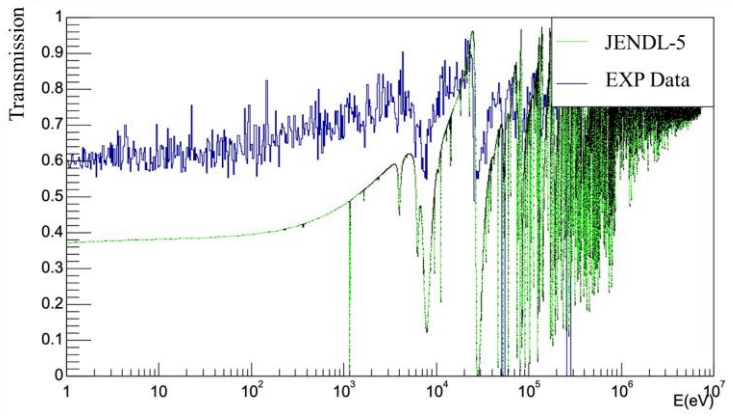


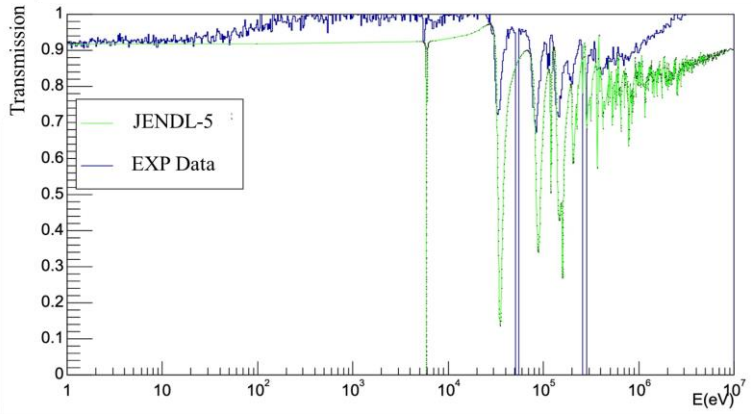
Fe
5888-8128 eV



Al
363-478 keV





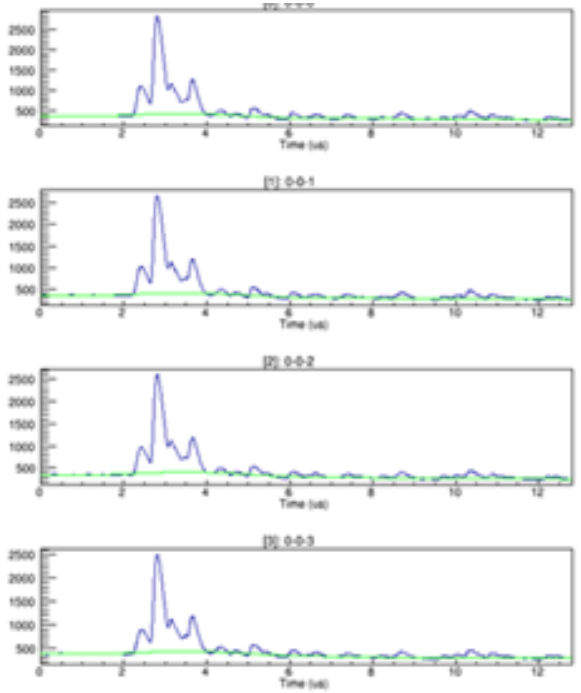


Neutron transmission images in different energy range and neutron transmission spectra measured for different samples.

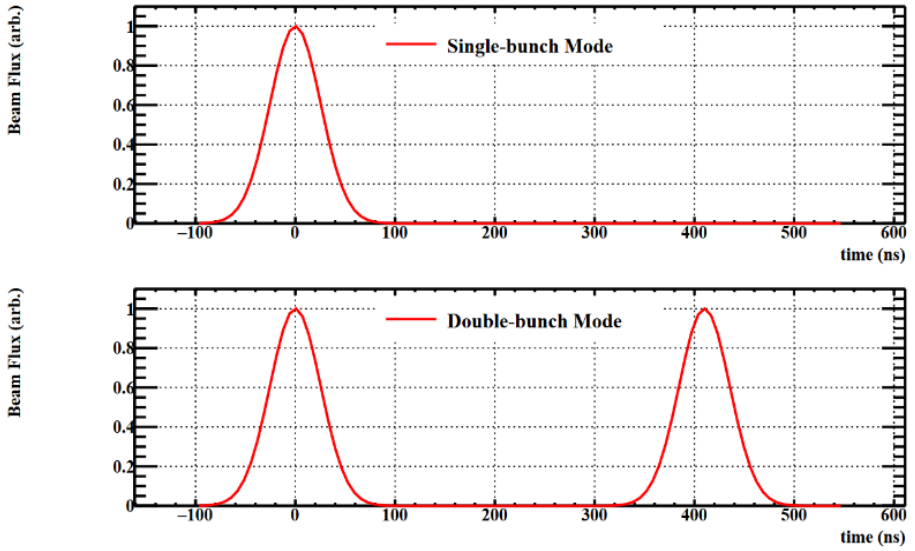
Summary

- The online NRTI experiment using boron-doped MCP at CSNS Back-n was conducted
- The main functions of the data processing and analysis program have been implemented
- NRTI of simple samples (Au, Ag, Cu, Fe, Al) has been achieved

Thank you



Pile-up signal



Comparation of single bunch and double bunch mode