Neutron and photon yields for the $^{51}V(p,n)^{51}Cr$ reaction near threshold

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UNIVERSIDAD DE GRANADA

Main motivations

- Lack of data.
- Possible application to nuclear astrophysics: to be studied.
- The employment of the reaction as a useful monoenergetic neutron source at low energies.
- Use for medical applications. **We propose to study the near-threshold $^{51}V(p,n)^{51}Cr$ reaction as a neutron source for Boron Neutron Capture Therapy.**
  - **Information that is under PATENT: IPR-1070**

MY THESIS: Production and measurement of low-energy neutrons using accelerator-based neutron sources for applications in medicine.

The reaction

Natural Vanadium

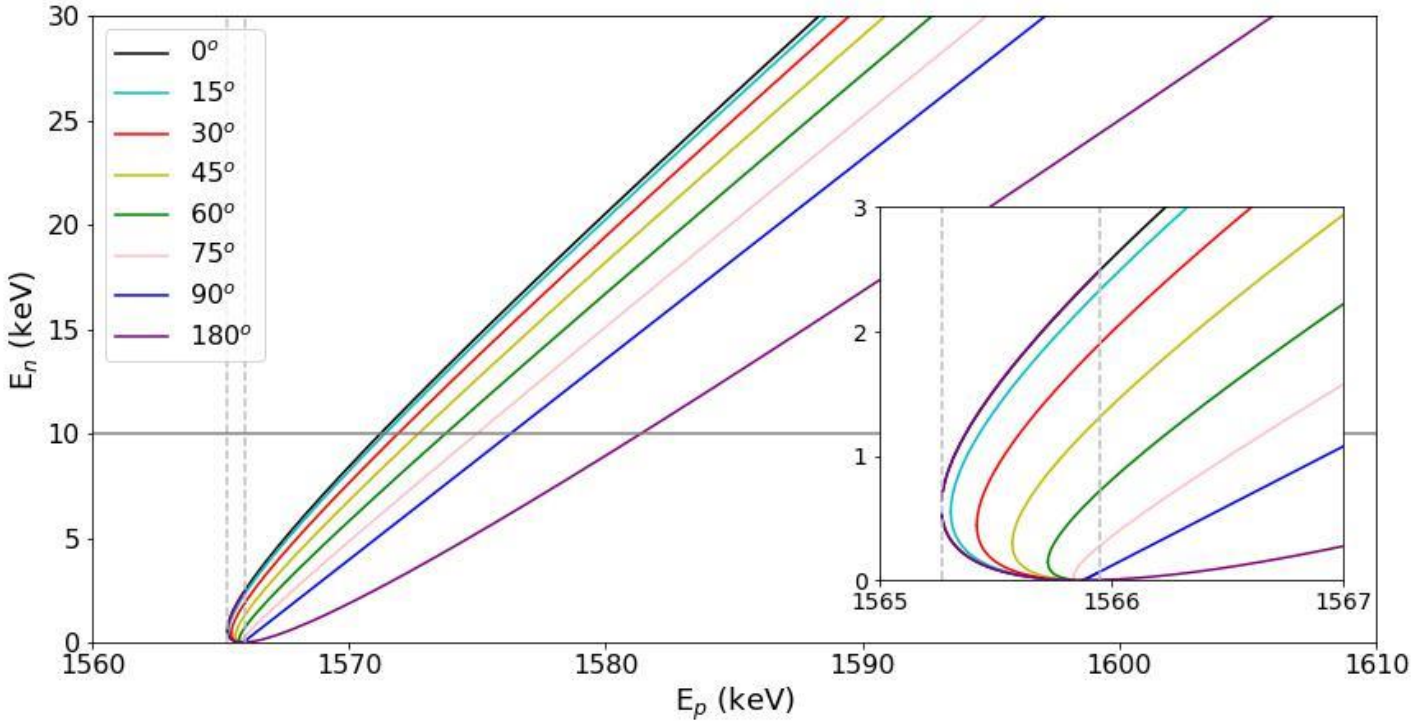
V-51 99.75%
Stable

V-50 0.25%
$t_{1/2}$= 1.5·10^{17} y

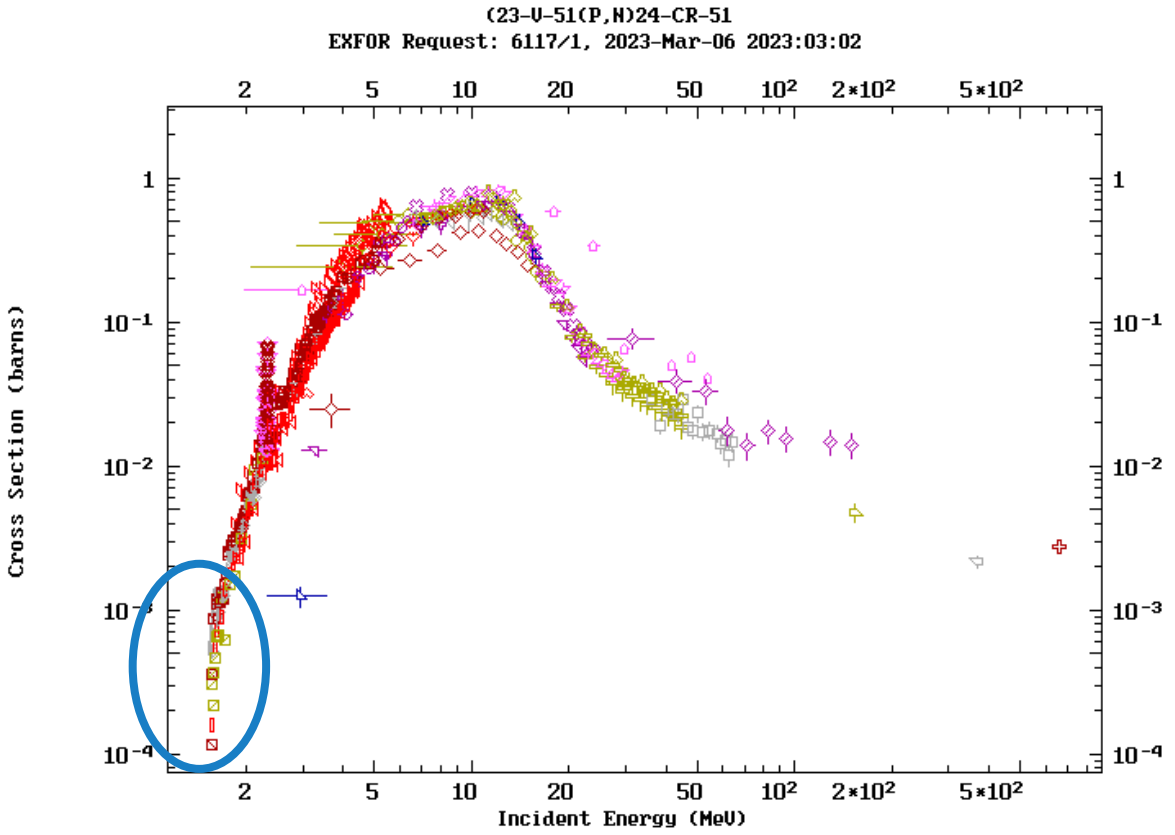
$^{51}V + p \rightarrow n + {}^{51}Cr$

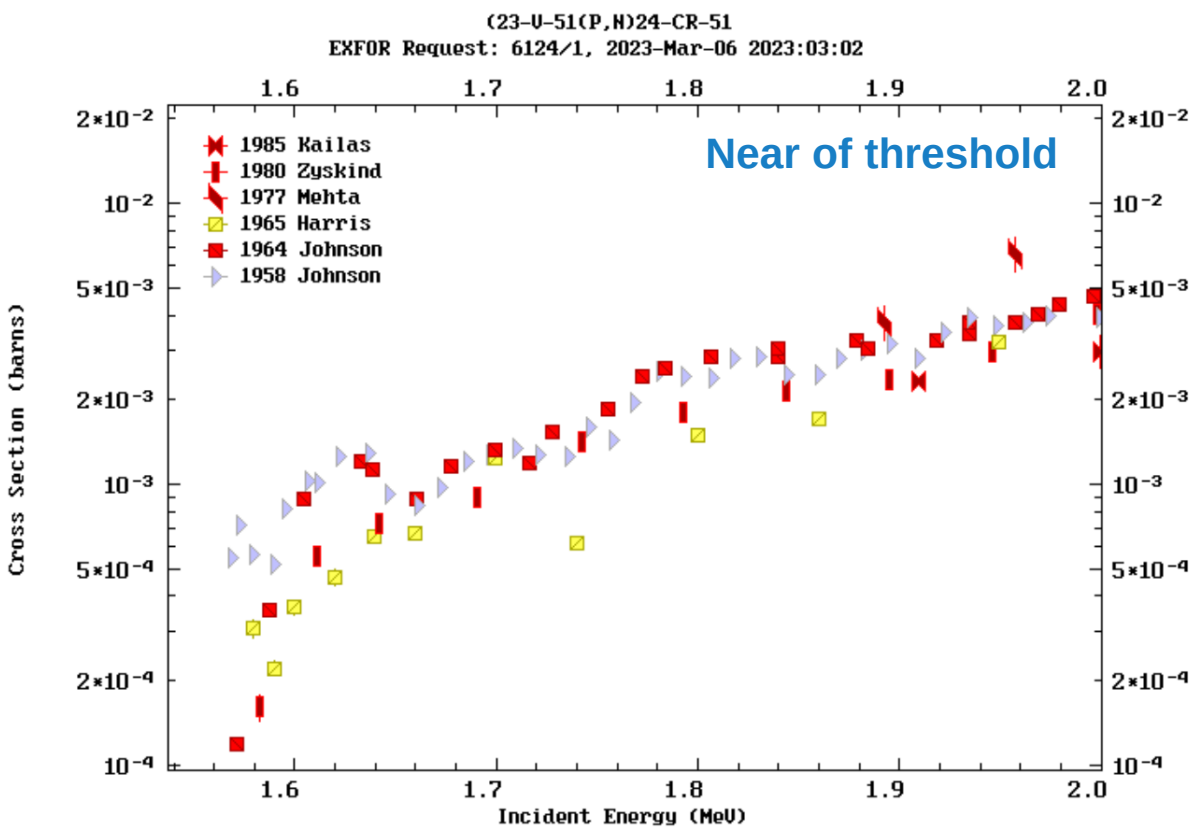
Q = -1534.92 keV

E_{th} = **1565.28 keV**



Cross section data



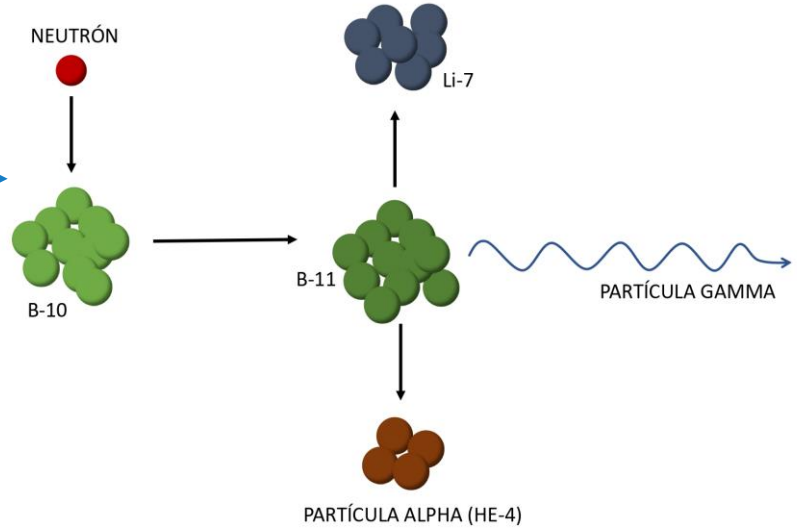


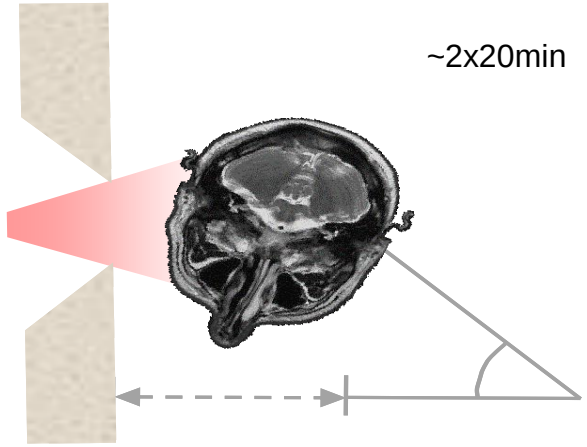
BNCT

Boron Neutron Capture Therapy (BNCT) is an experimental binary radiation therapy design for treating highly resistant tumors. **One day of treatment.**

1. A stable isotope, **^{10}B**, is **injected into the patient**, accumulating in cancer cells.

2. **Tumor region is irradiated** with epithermal neutrons, inducing (n,α) reaction in ^{10}B.

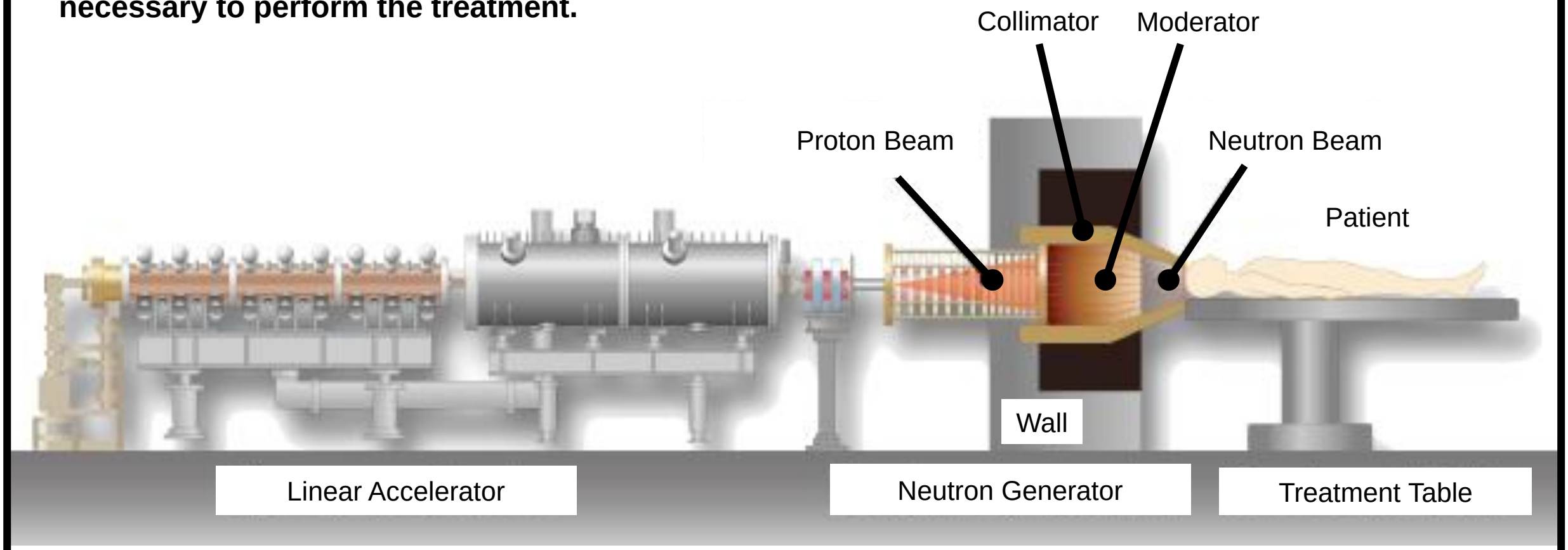




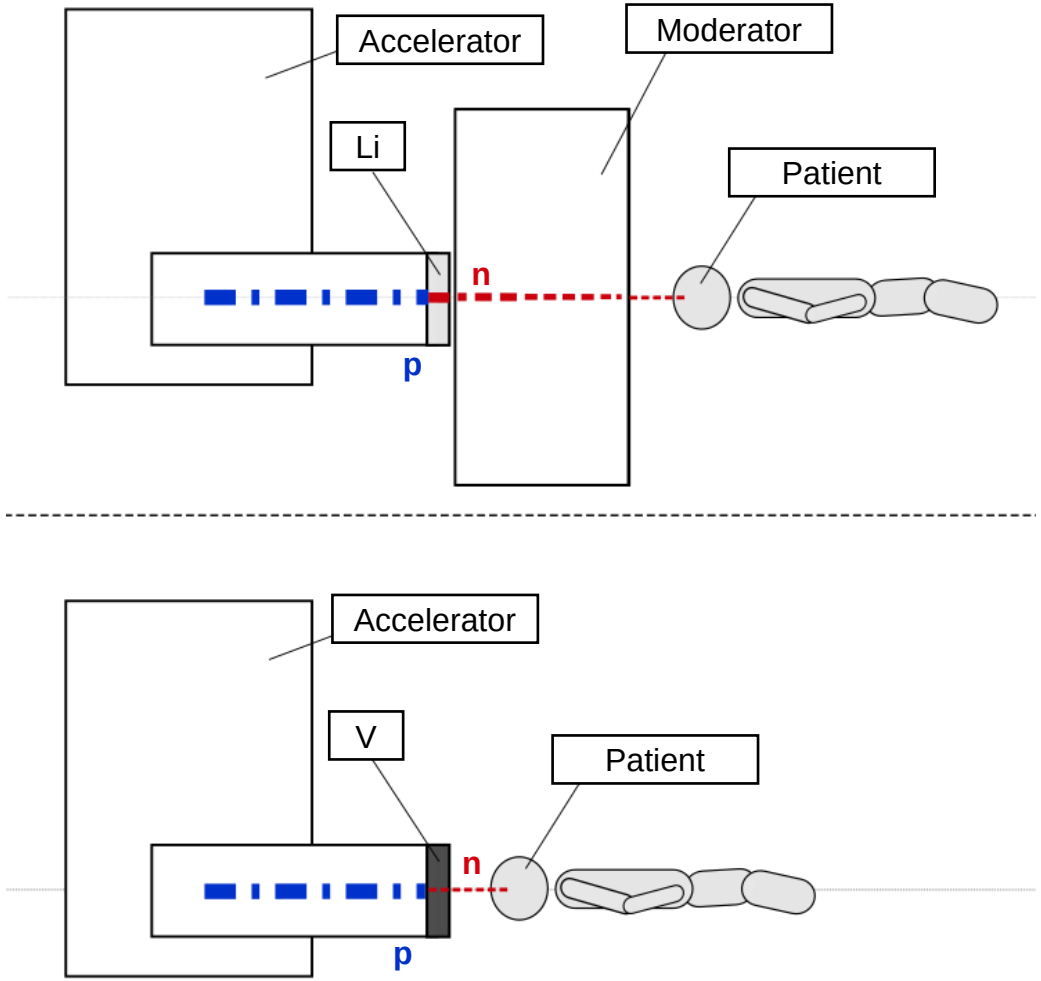
Targeted neutron irradiation is given according to the Monte Carlo dose plan.

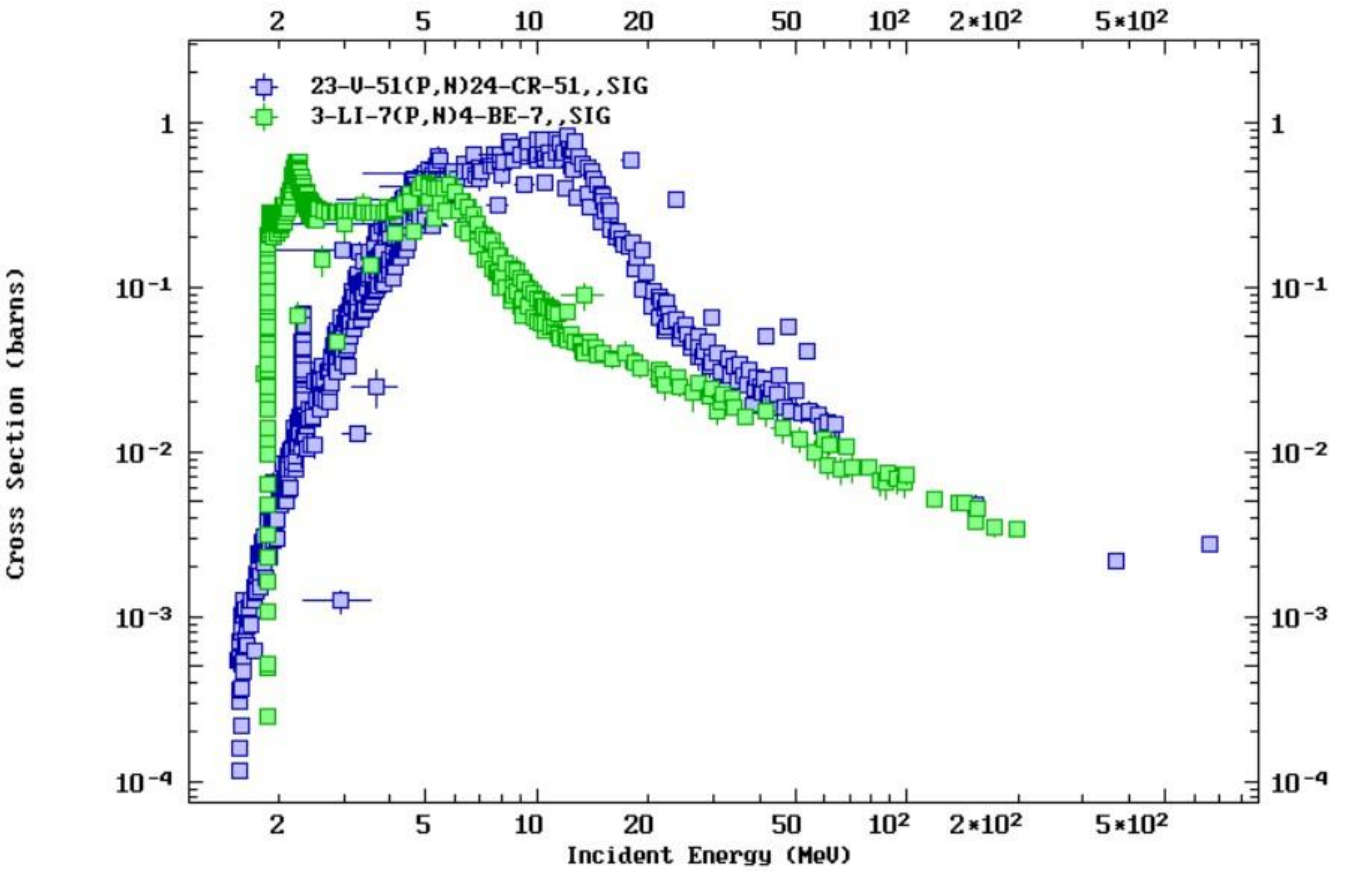
BNCT

An epithermal neutron source is necessary to perform the treatment.

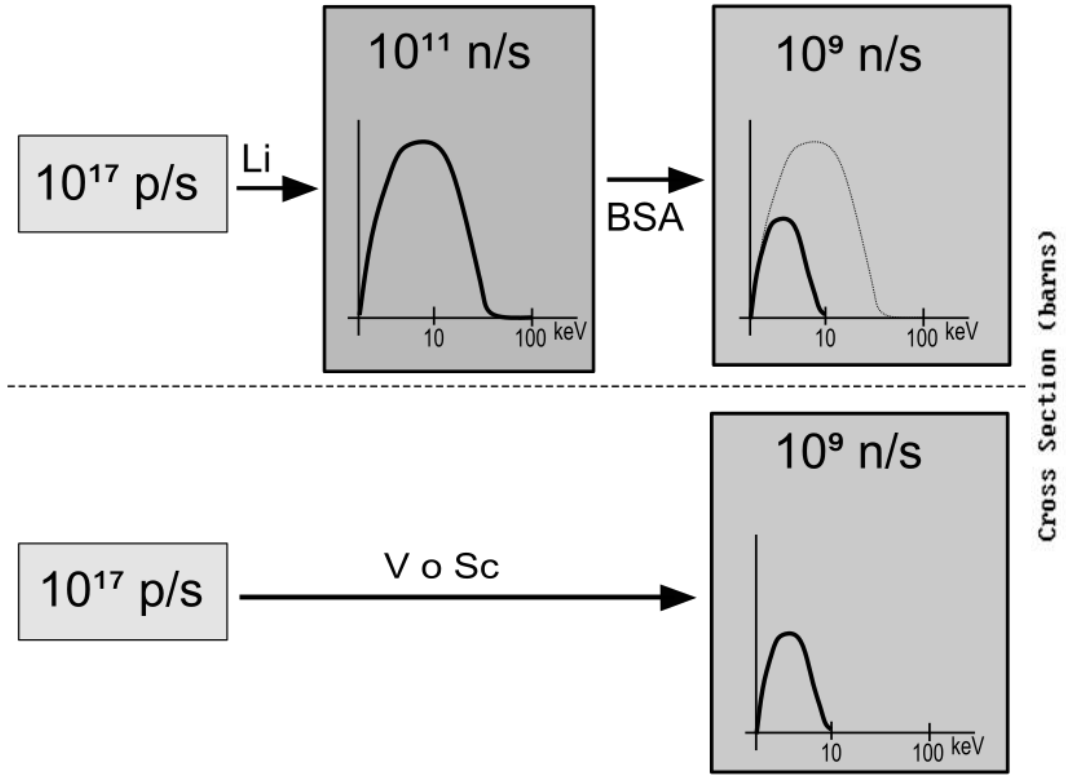


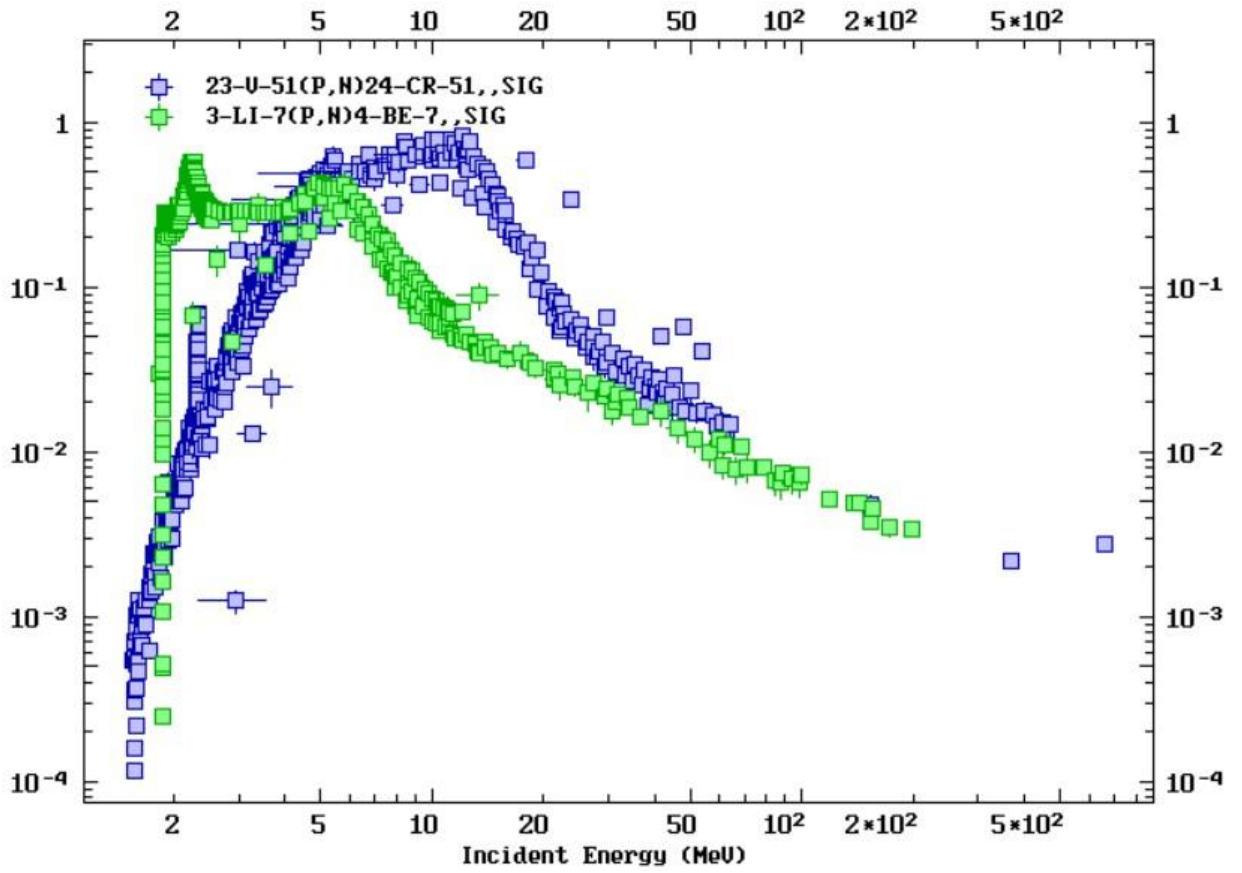
BNCT


Accelerator
Moderator
Li
Patient
n
p
Accelerator
V
Patient
n
p


23-V-51(P,N)24-CR-51,,SIG
3-LI-7(P,N)4-BE-7,,SIG
Cross Section (barns)
Incident Energy (MeV)
2
5
10
20
50
10²
2*10²
5*10²
1
10⁻¹
10⁻²
10⁻³
10⁻⁴

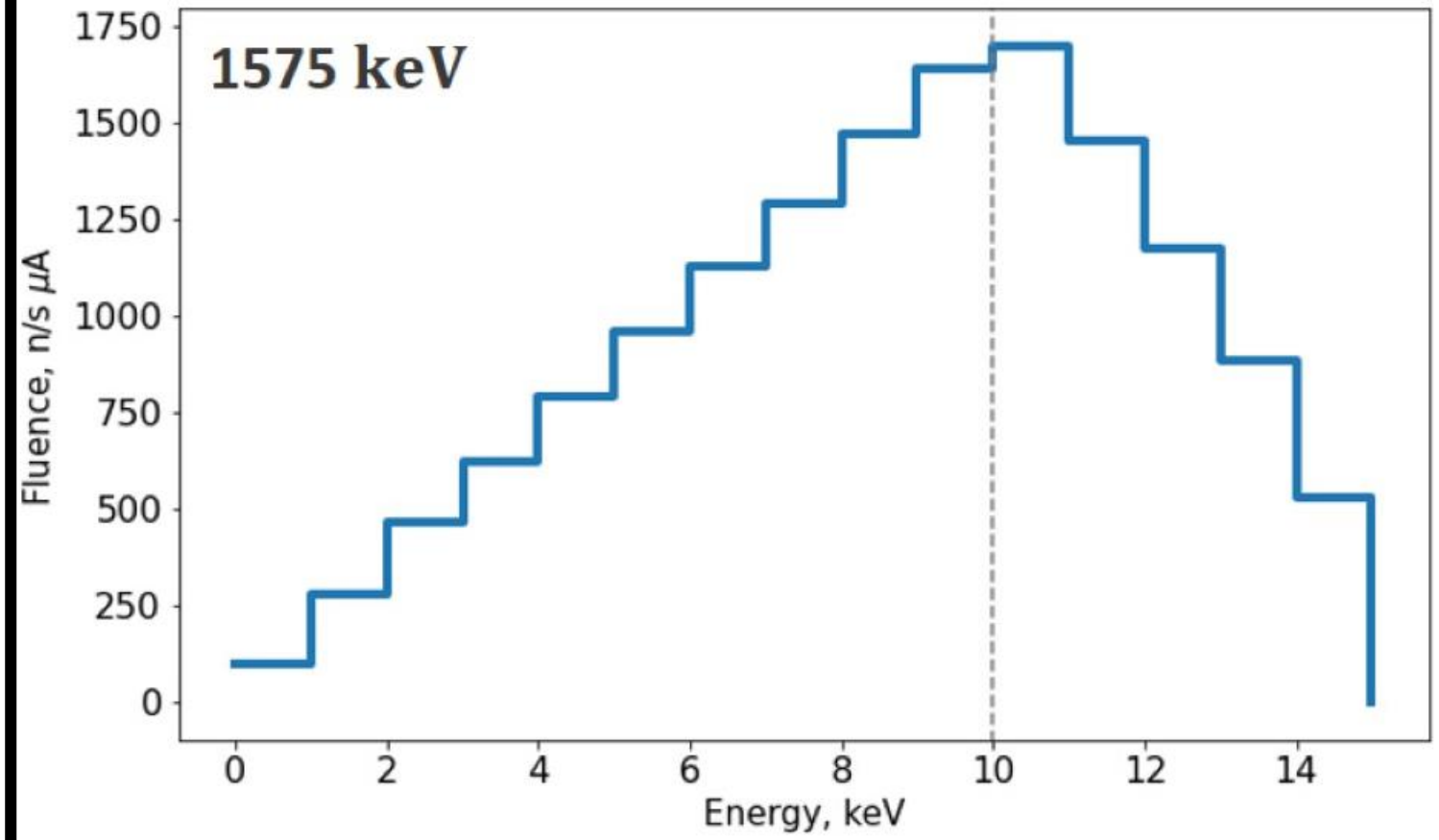
BNCT

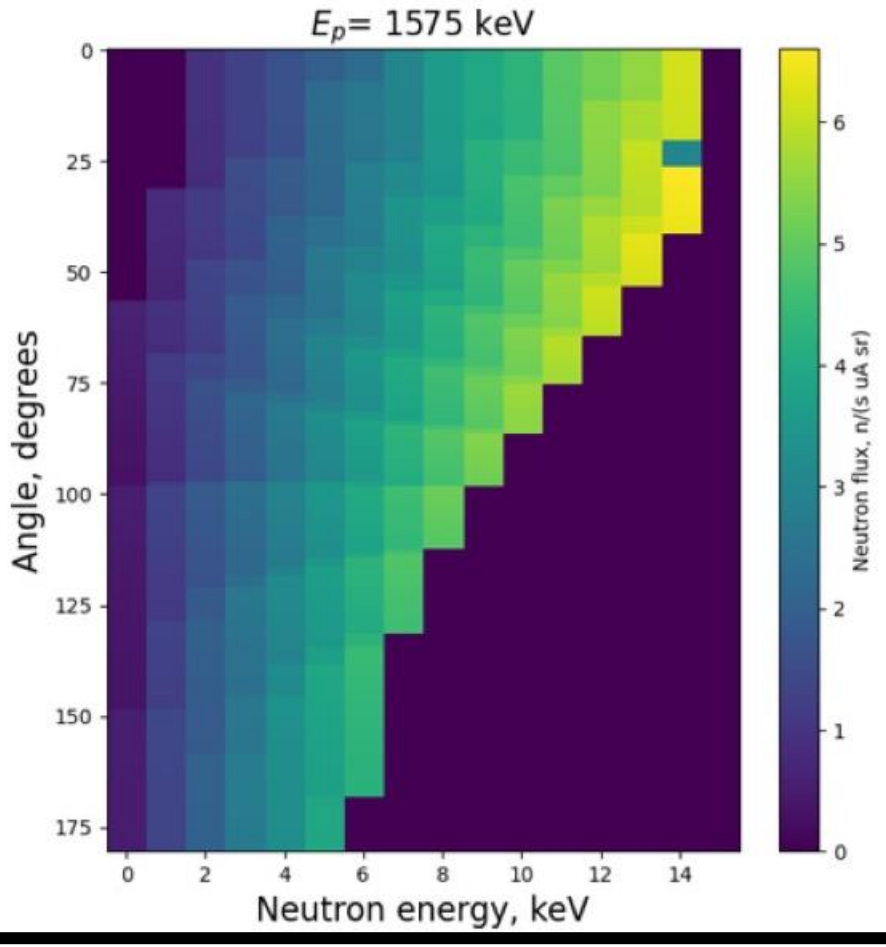

10¹⁷ p/s
Li
10¹¹ n/s
10 100 keV
BSA
10⁹ n/s
10 100 keV
10¹⁷ p/s
V o Sc
10⁹ n/s
10 100 keV


23-V-51(P,N)24-CR-51,,SIG
3-LI-7(P,N)4-BE-7,,SIG
Cross Section (barns)
Incident Energy (MeV)
2 5 10 20 50 10² 2*10² 5*10²
1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴

BNCT

Integrated flux based on kinematics and theoretical data.





Goals of the proposal

- **To measure and determine via time-of-flight technique the most adequate proton energy beam for the ^{51}V(p,n)^{51}Cr reaction. It should be at AROUND 1575 keV.**
- To measure the **neutron yield** ^{51}V(p,n)^{51}Cr reaction near threshold by measuring the Chromium-51 decay itself and by the forward neutron yield detectors directly.
- To measure the forward **photon yield** at the selected proton energy.
- As calibration: To measure the well-known **^{7}Li(p,n)^{7}Be** reaction at 1912 keV:
  - To check the setup.
  - To check the analysis.
  - To use it as additional **reference** for the neutron yield of the ^{51}V(p,n)^{51}Cr reaction.

10 DAYS OF BEAM LINE → Two weeks: 9th – 20th October

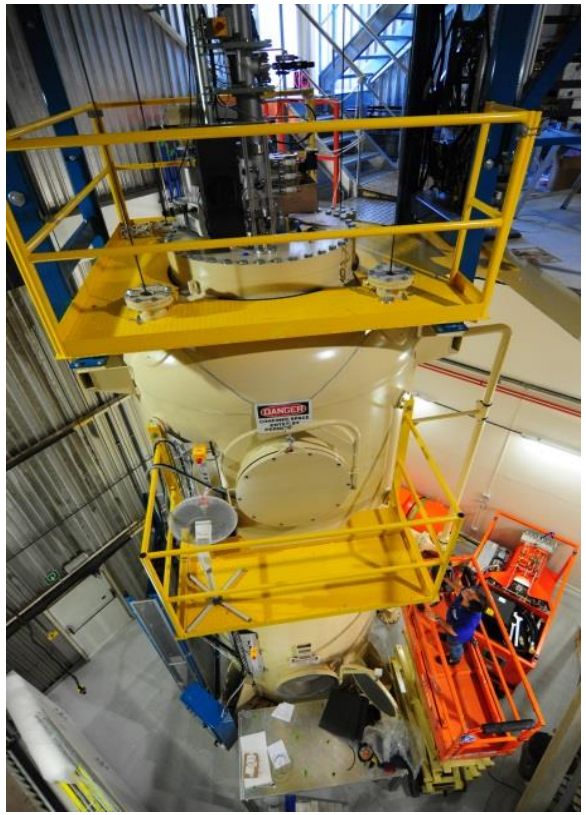
Three months in MONNET

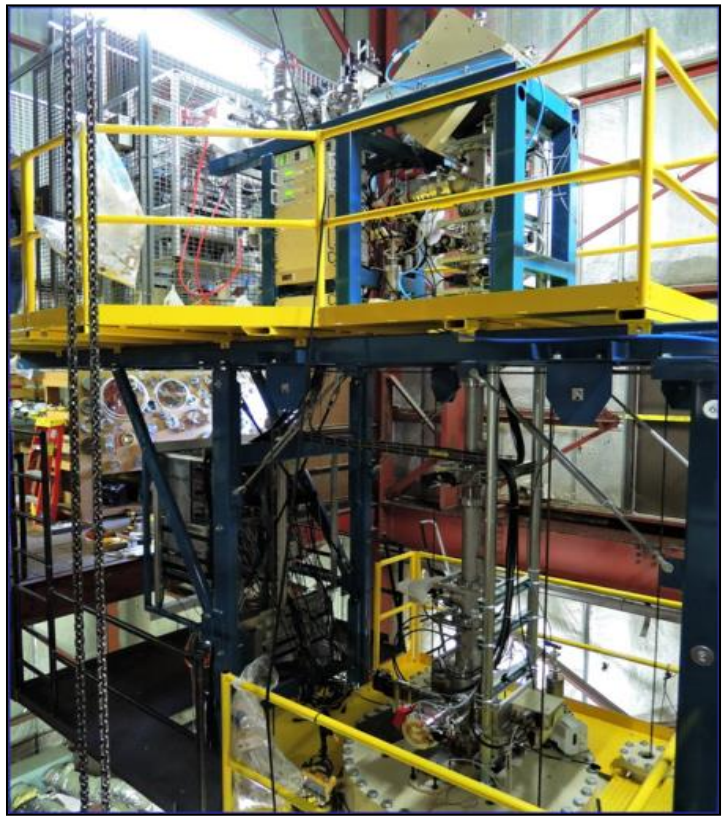
Neutron and photon yields for the $^{51}V(p,n)^{51}Cr$ reaction near threshold

MONNET

The tandem accelerator based fast neutron source (MONNET) is a 3.5 MV electrostatic accelerator for the production of continuous and pulsed proton-, deuteron- and helium ion beams

- Protons, deuterons and alpha particles
- DC (Ip,d < 50 μA)
- Pulsed beam available (1 – 2 ns)
- Energy range: 200 keV – 7 MeV





Three months in MONNET

Neutron and photon yields for the $^{51}V(p,n)^{51}Cr$ reaction near threshold

European Commission JOINT RESEARCH CENTRE ARIEL

2023 SEPTEMBER

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

2023 OCTOBER

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

2023 NOVEMBER

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

Learning about detectors and ABCD

Experiment

Data preliminar analysis

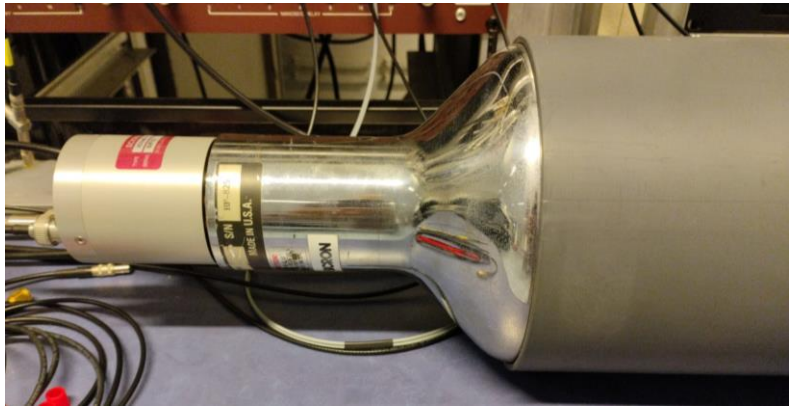
Learning about detectors and ABCD

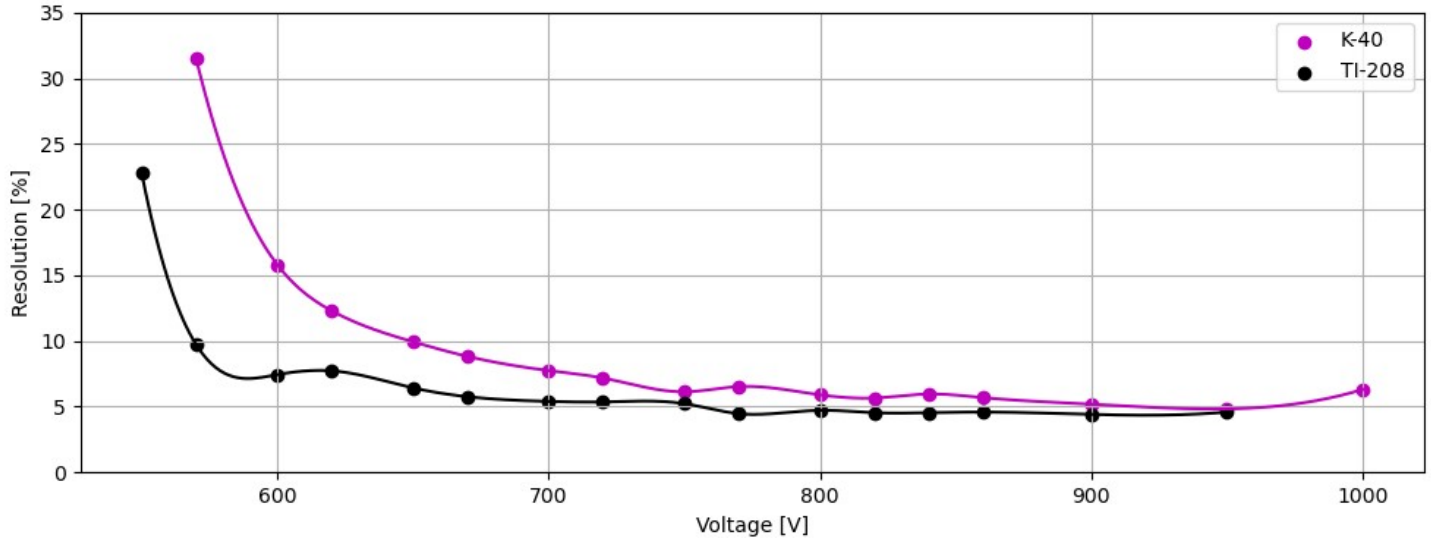
ABCD
Data Adquisition System

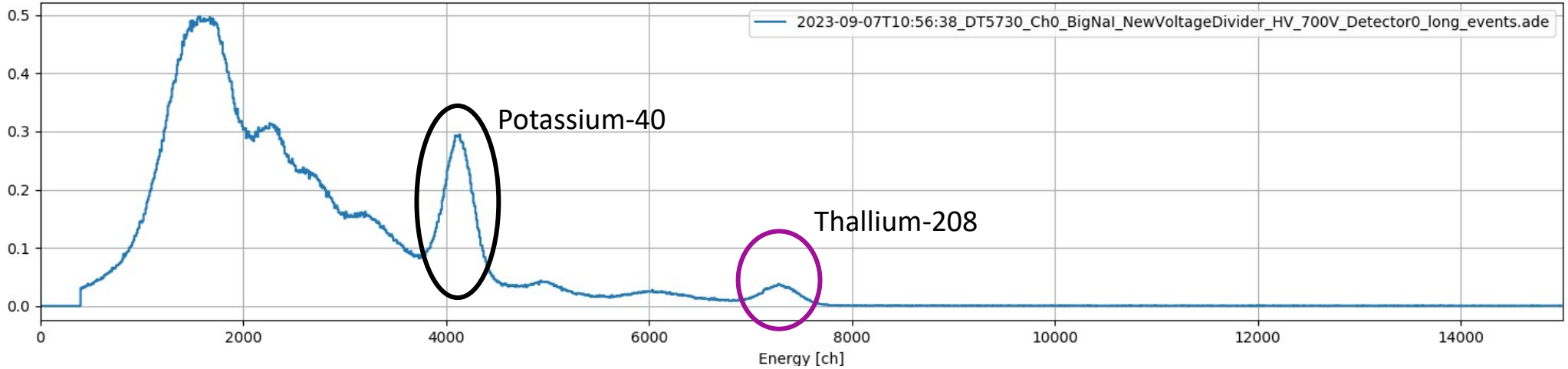
Events: Timestamps,
Q-long, Q-short, PSD…

Learning about detectors and ABCD

Big NaI Detector

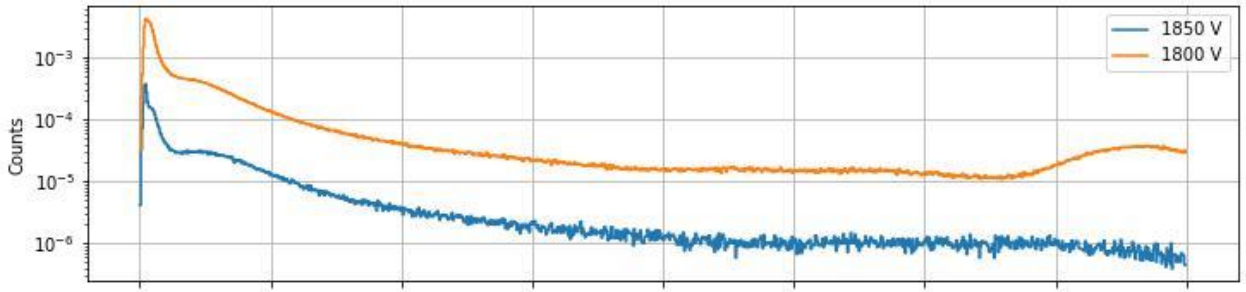




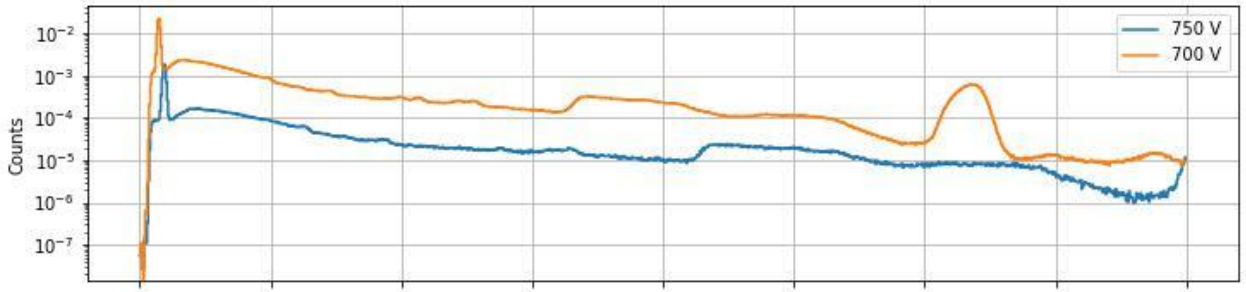


Learning about detectors and ABCD

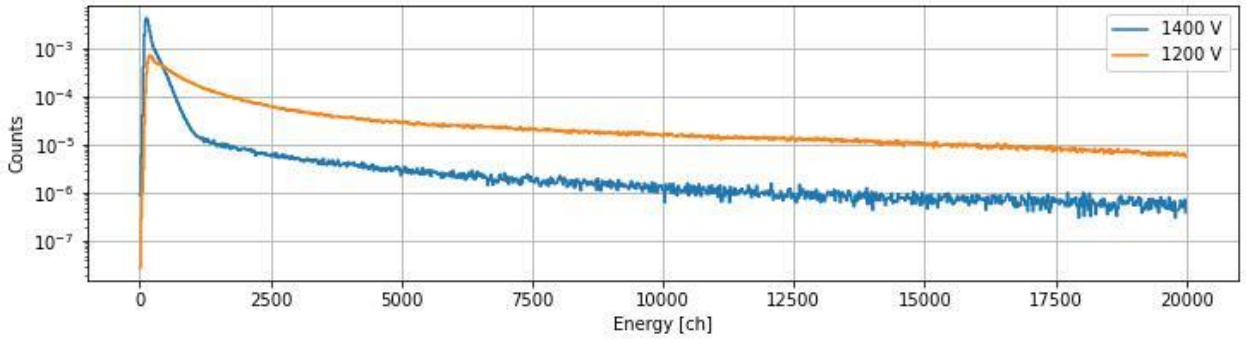
LiGlass detector



LaBr Detector

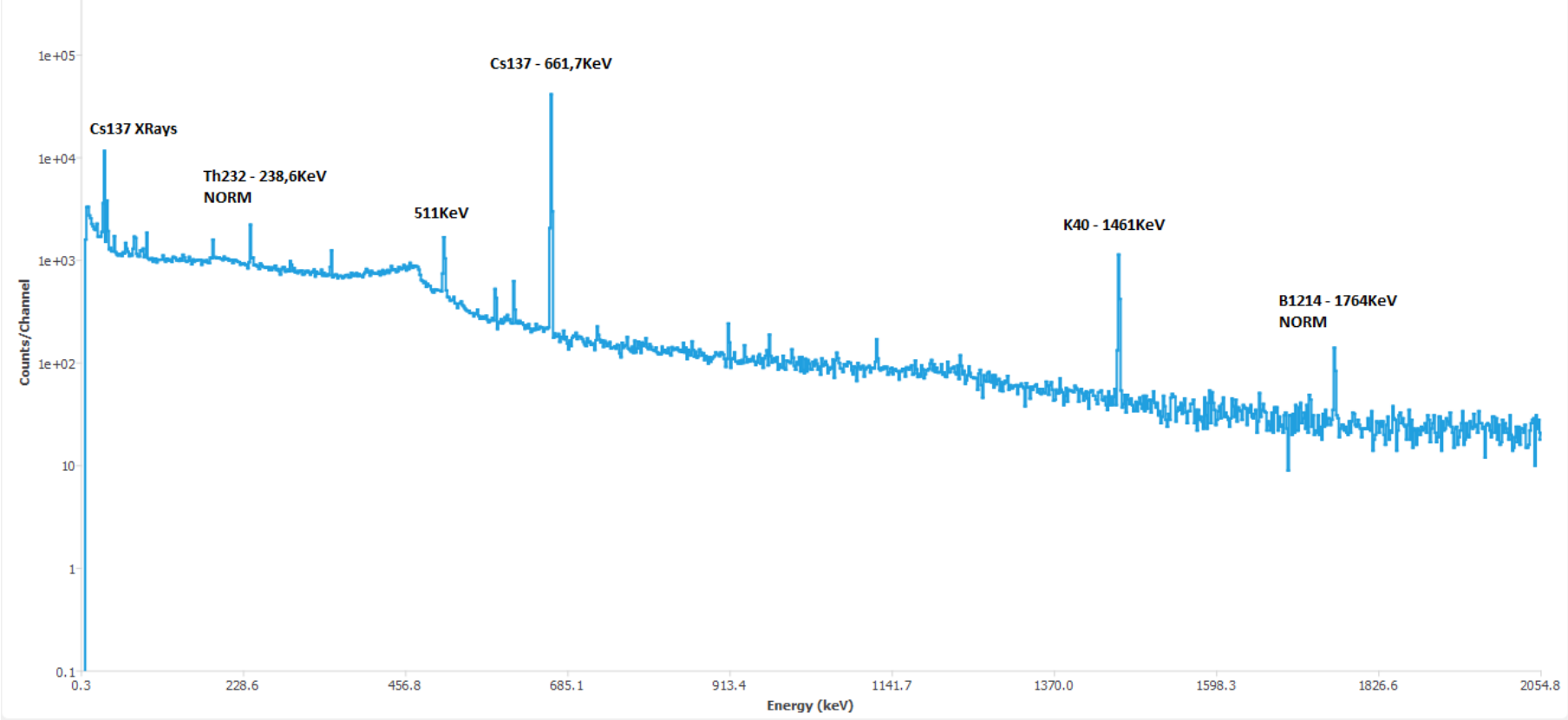


Liquid Scintillator

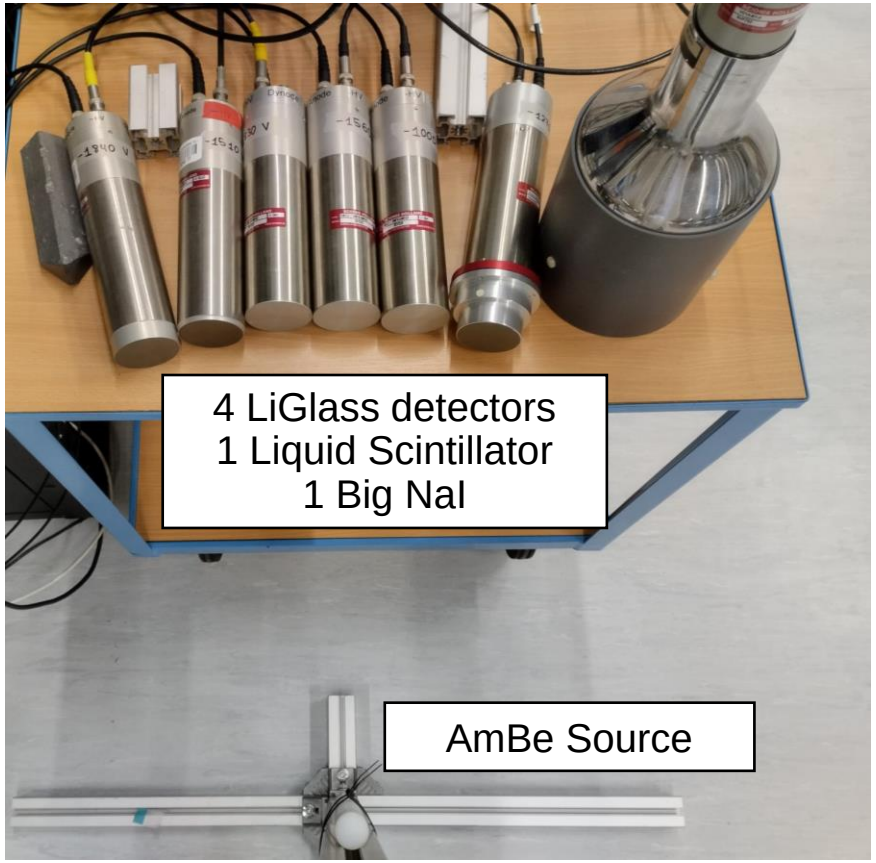


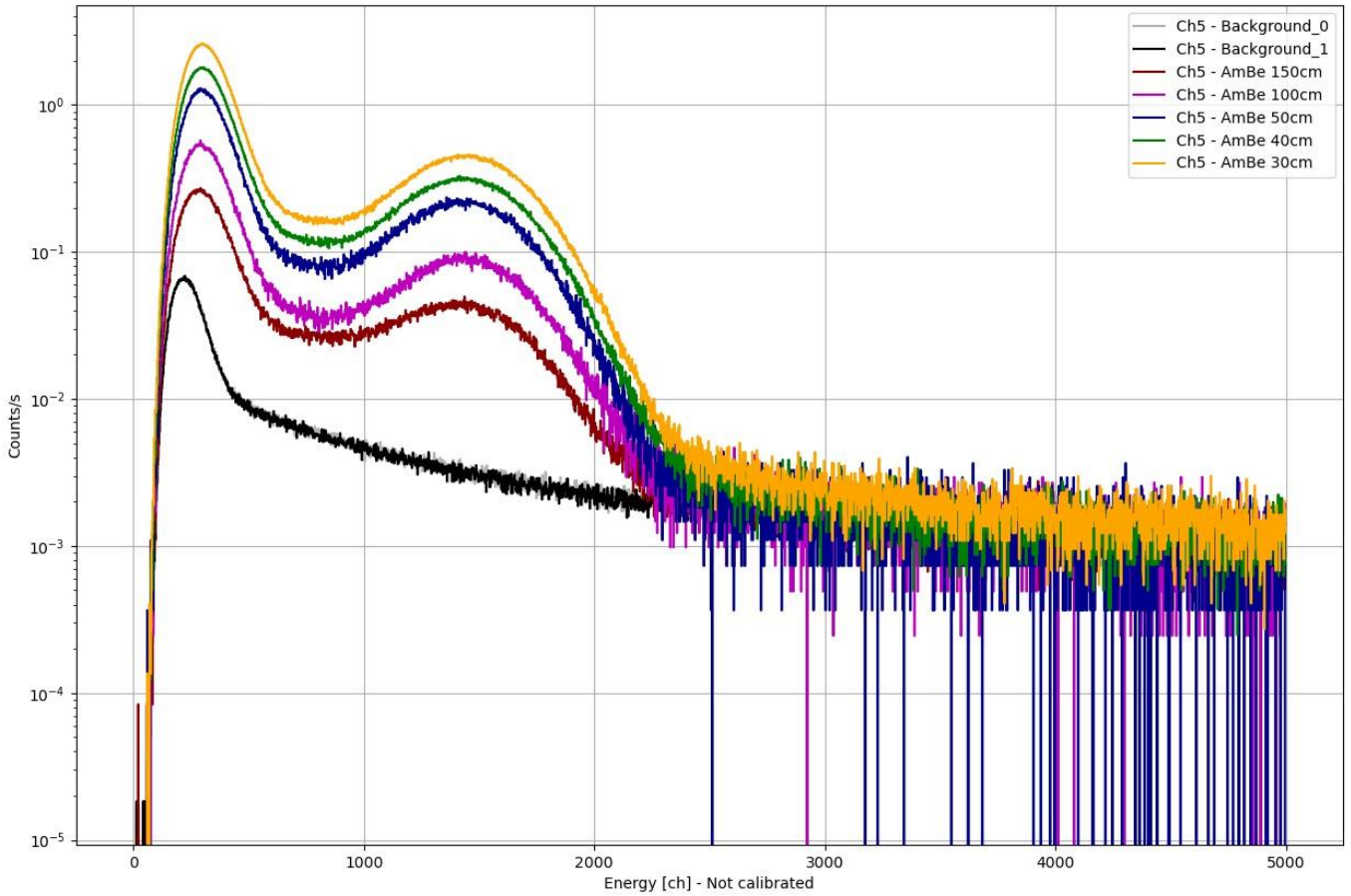
Learning about detectors and ABCD

HPGe Detectors

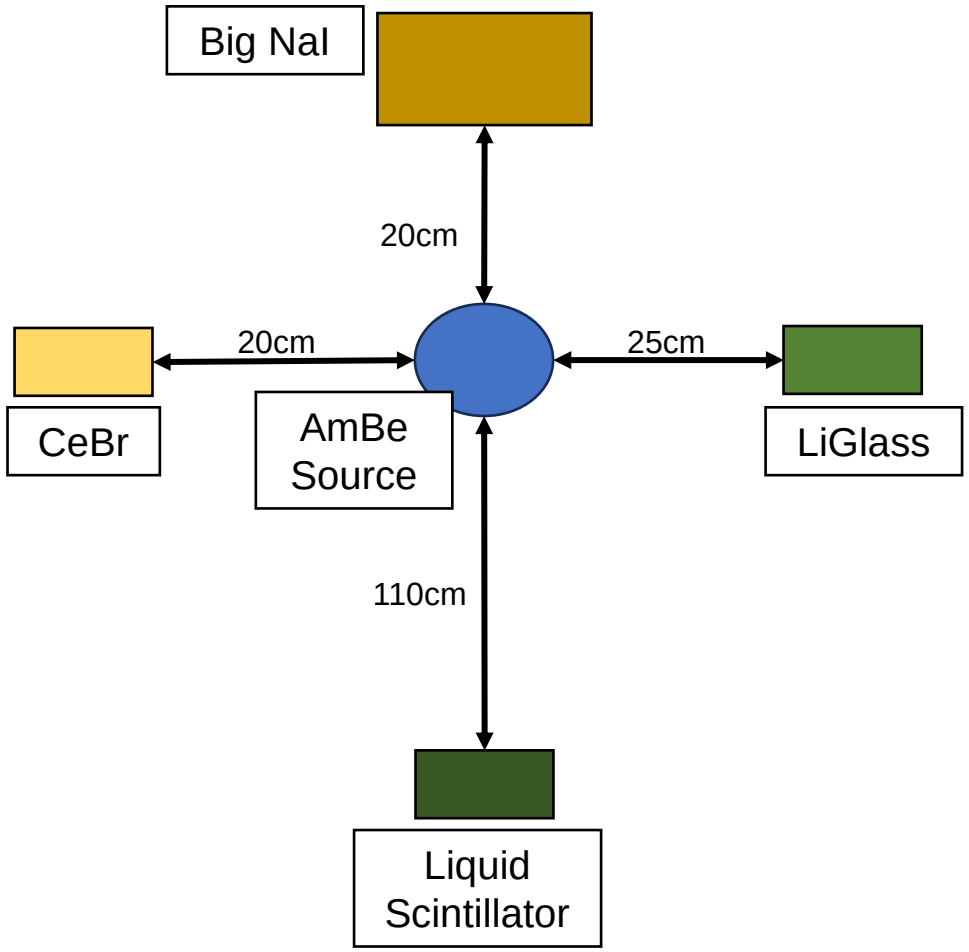


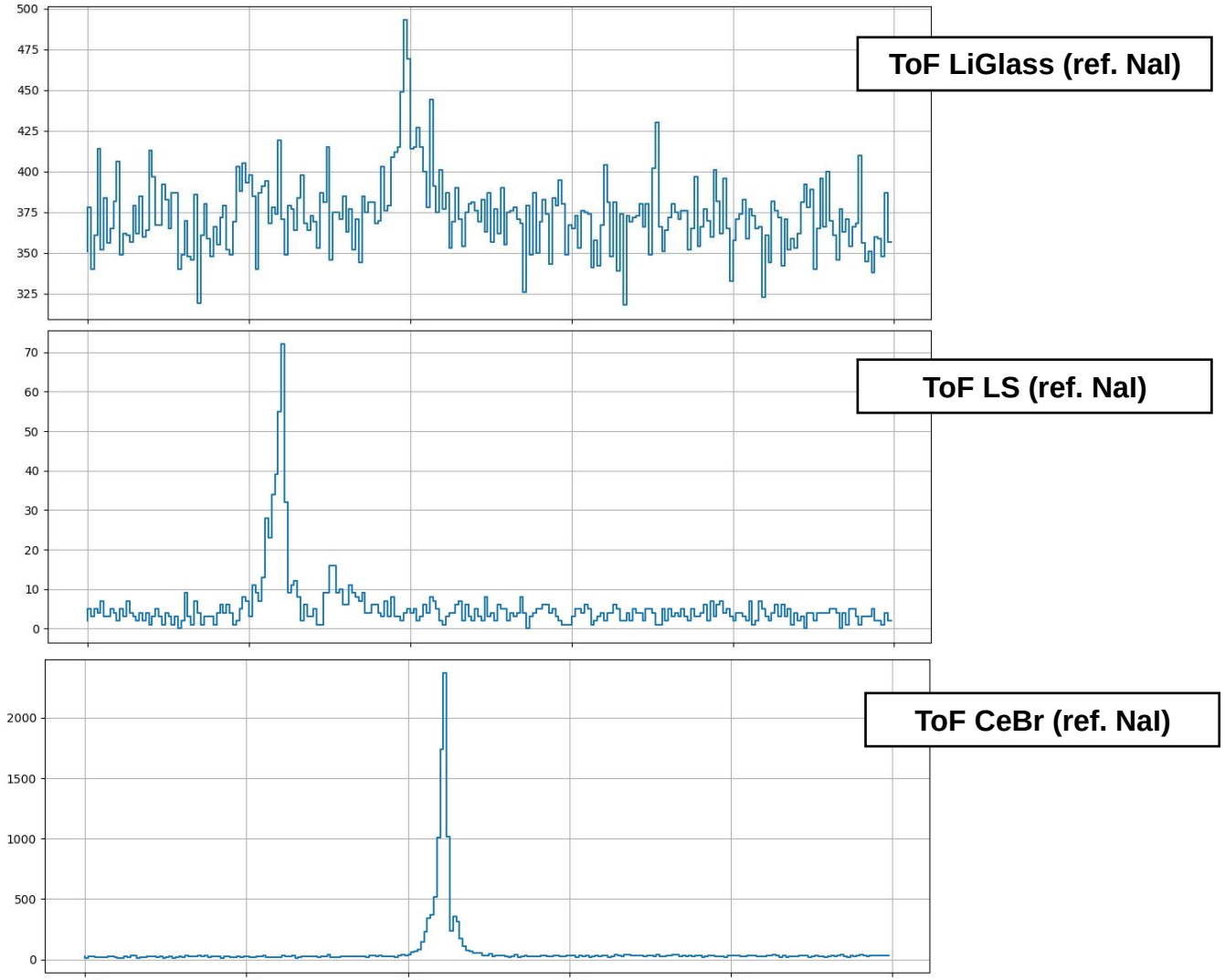
Learning about detectors and ABCD





Learning about detectors and ABCD

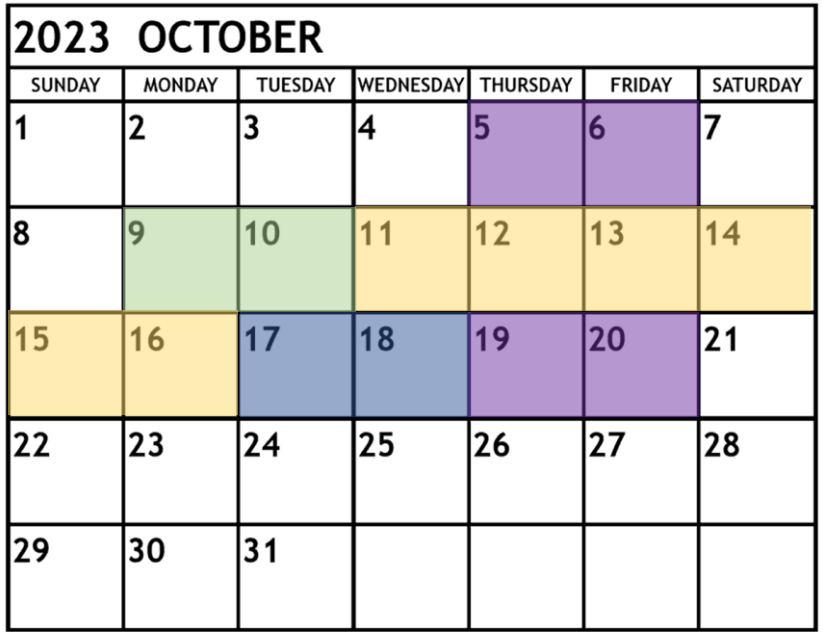




PATENT: IPR-1070

Experiment

1. **Activation experiment V-51**
2. **ToF LiF**
3. **ToF Vanadium**
4. **ToF LiF + Vanadium transmission**



2023 OCTOBER

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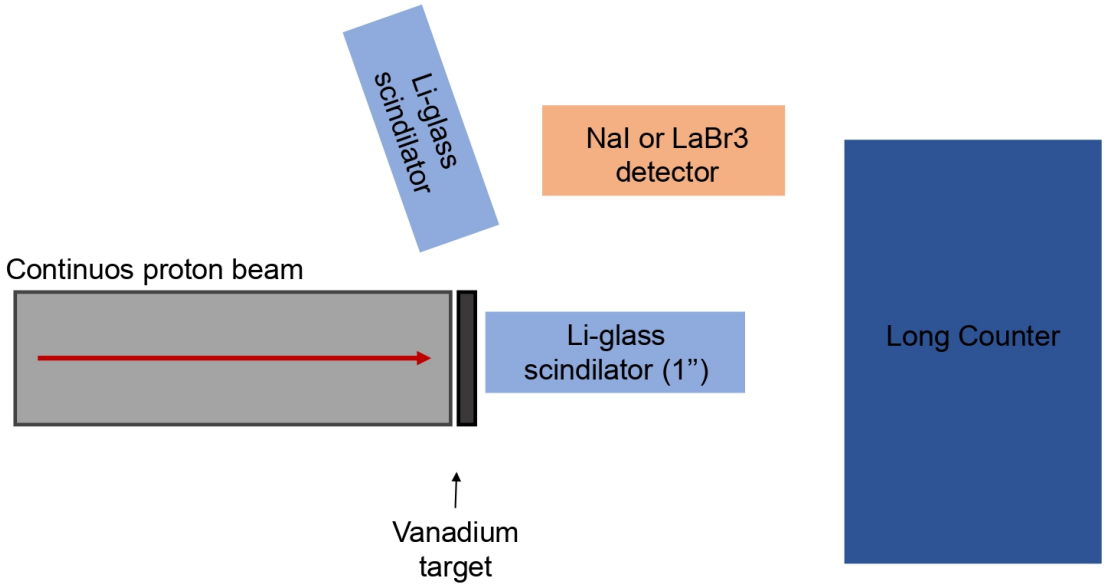
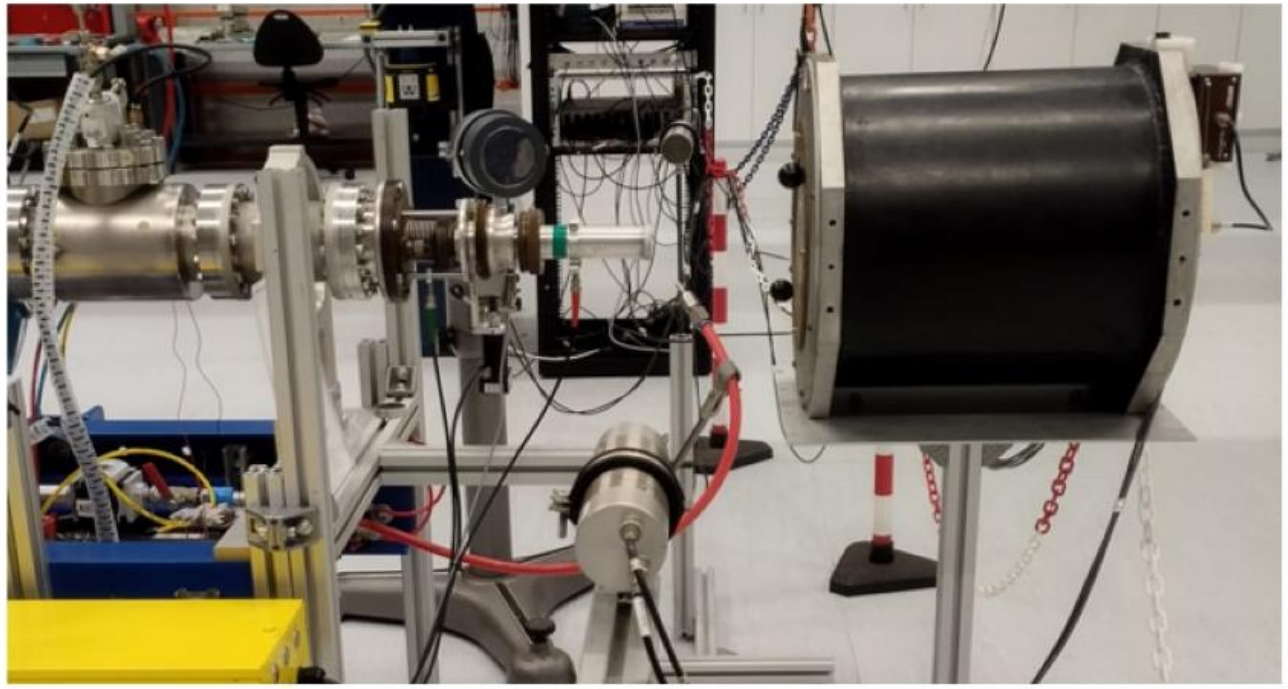
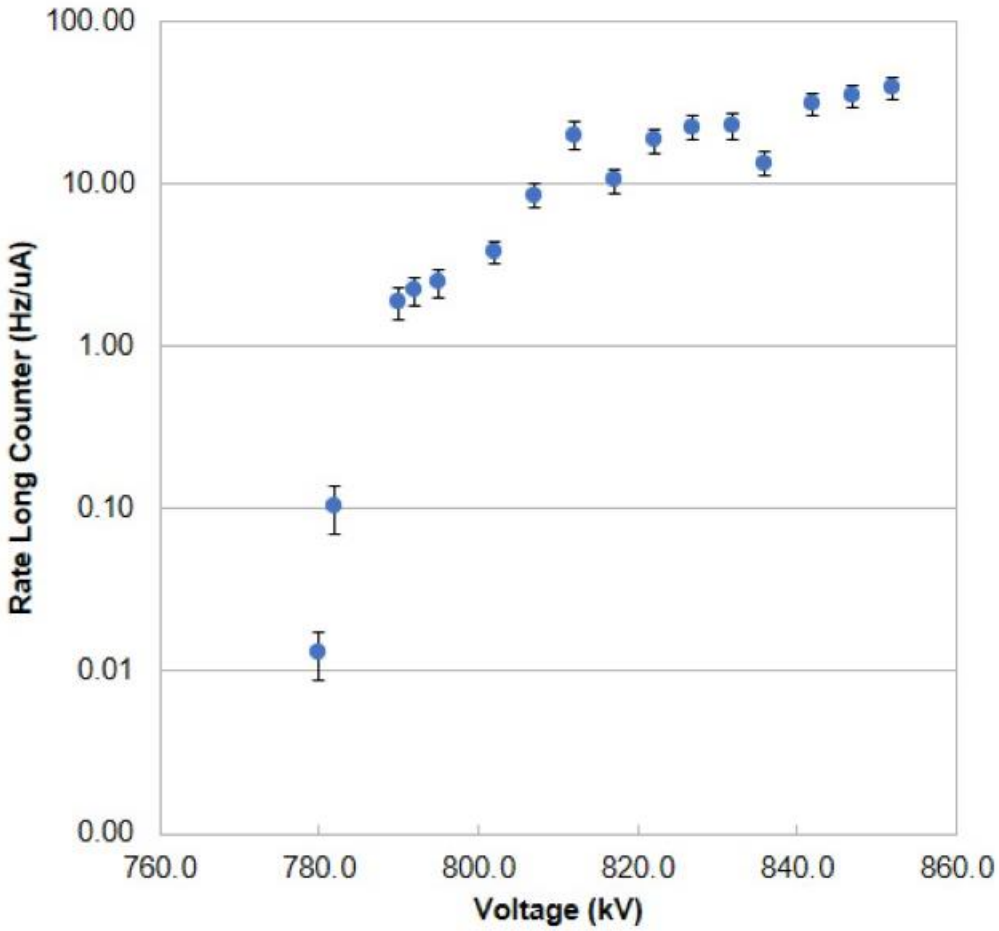
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

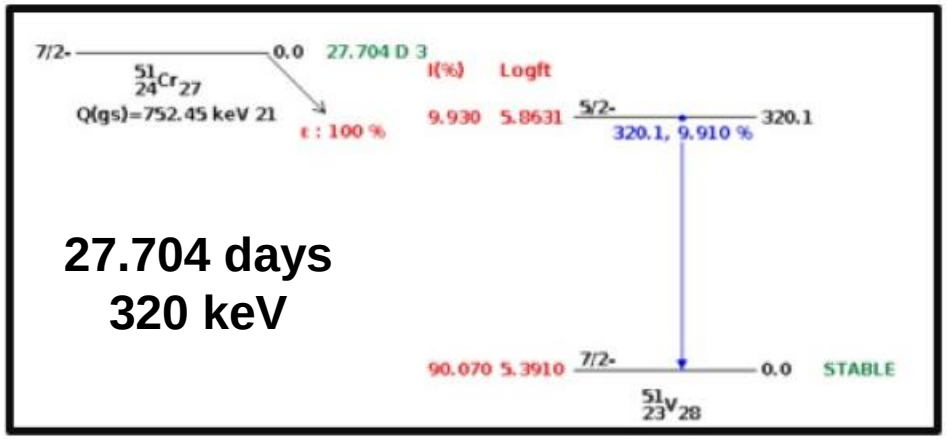
Activation experiment V-51

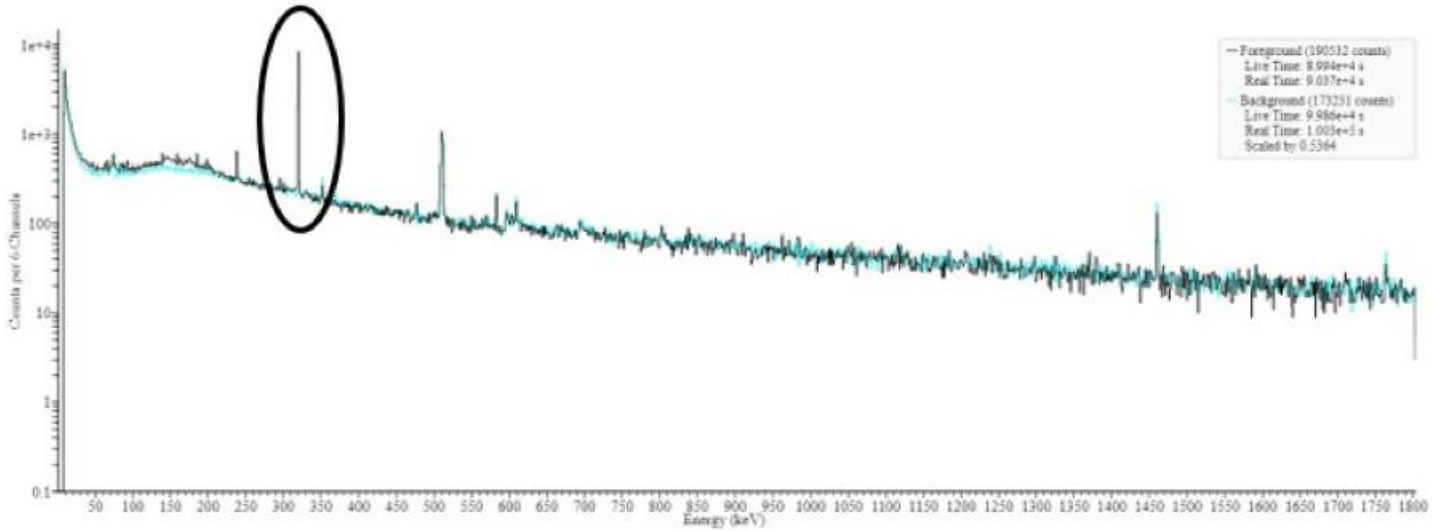




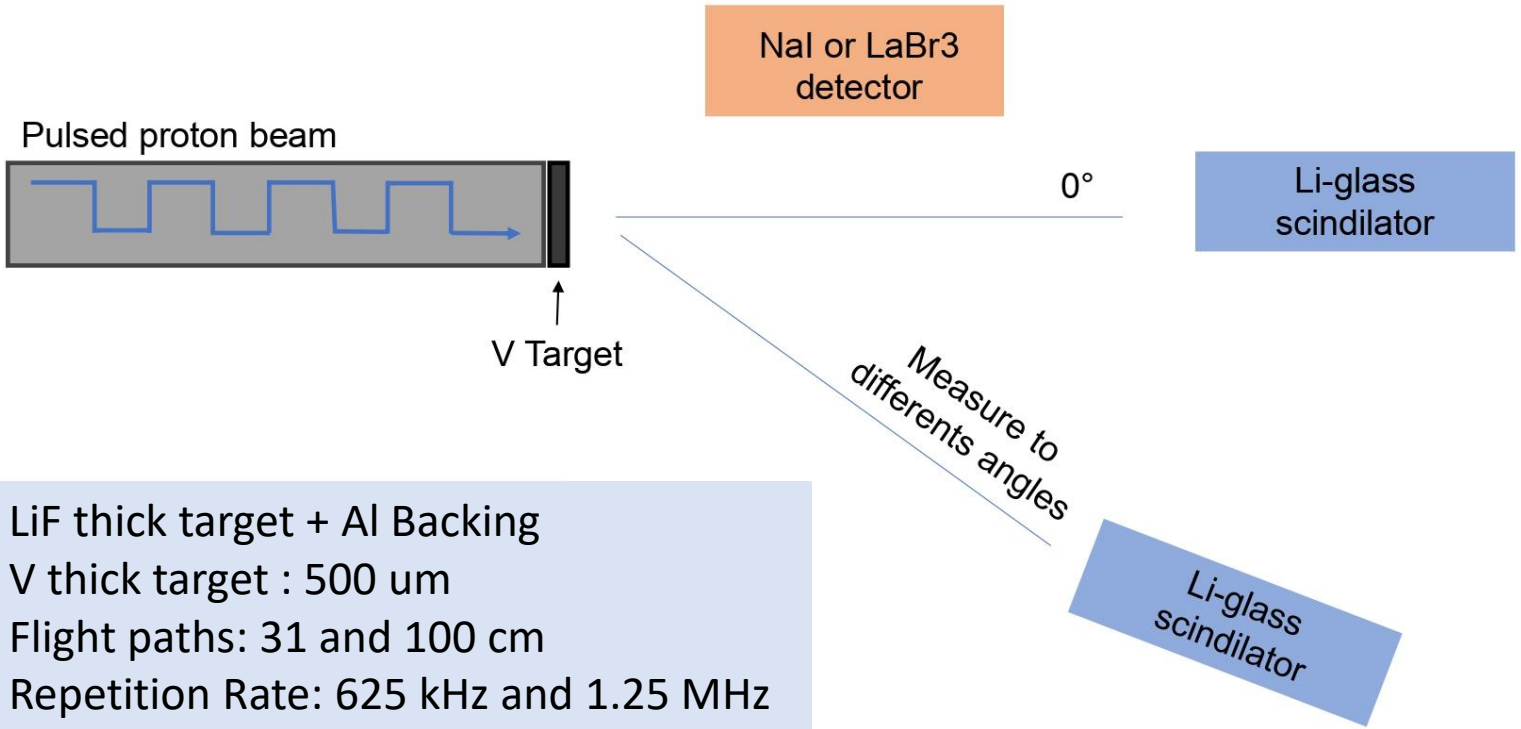
Activation experiment V-51





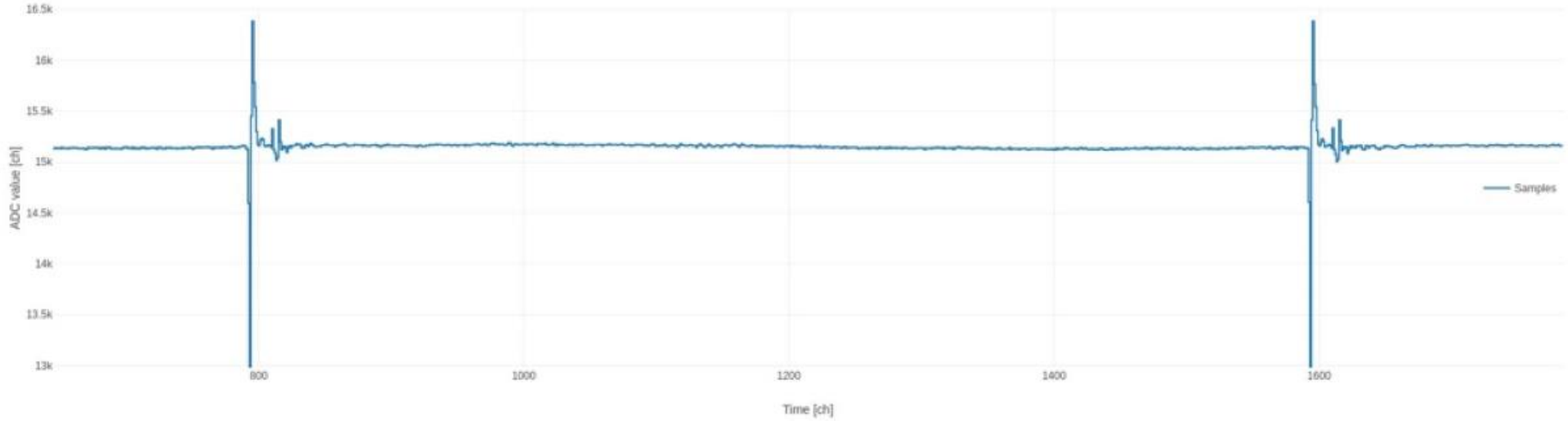


ToF experiments

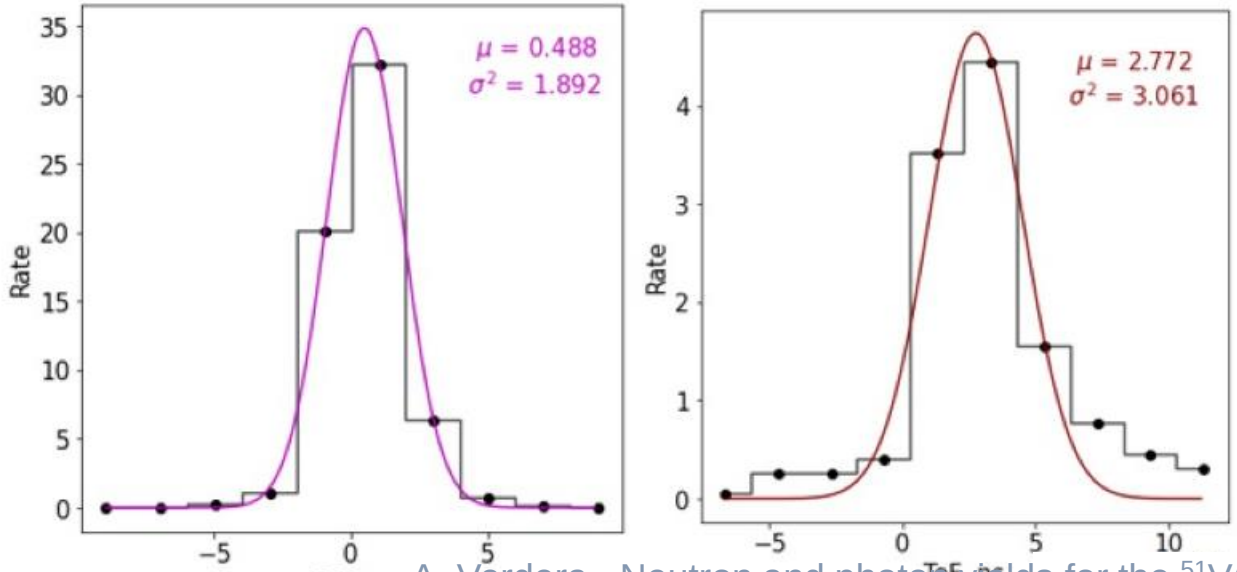


- LiF thick target + Al Backing
- V thick target : 500 um
- Flight paths: 31 and 100 cm
- Repetition Rate: 625 kHz and 1.25 MHz
- Pulse width 1-2 ns

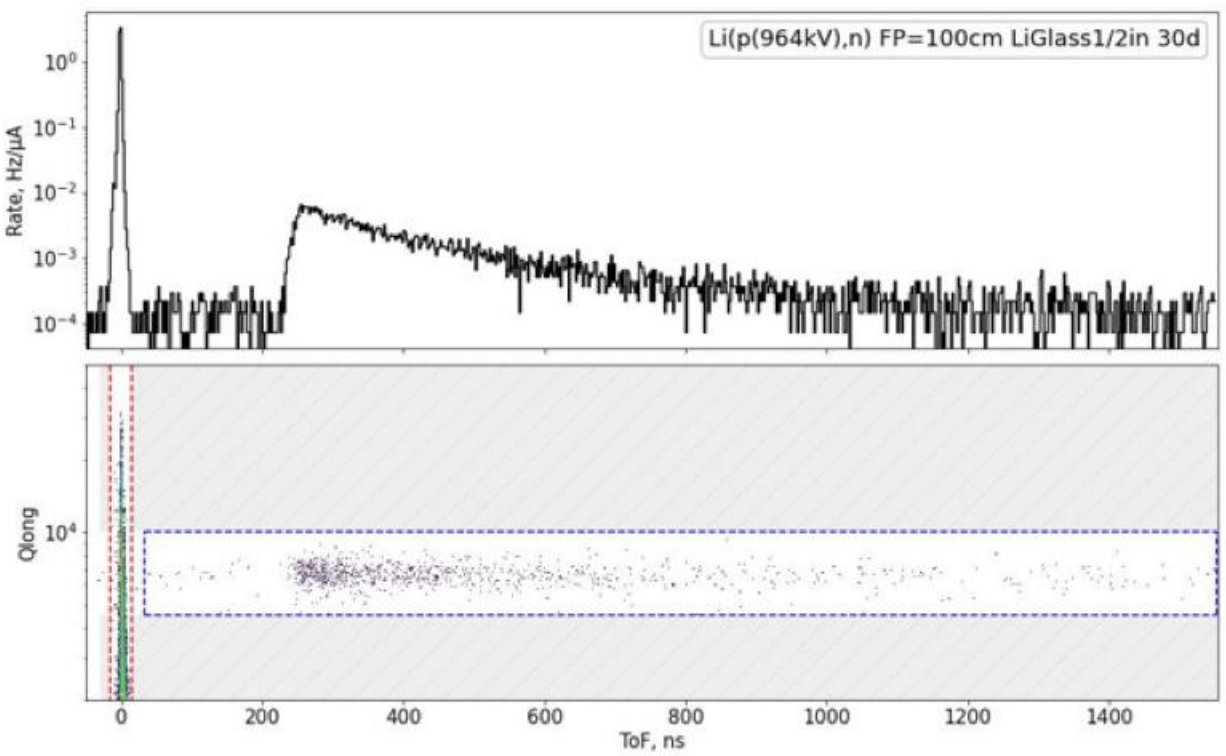
Accelerator in pulsed mode

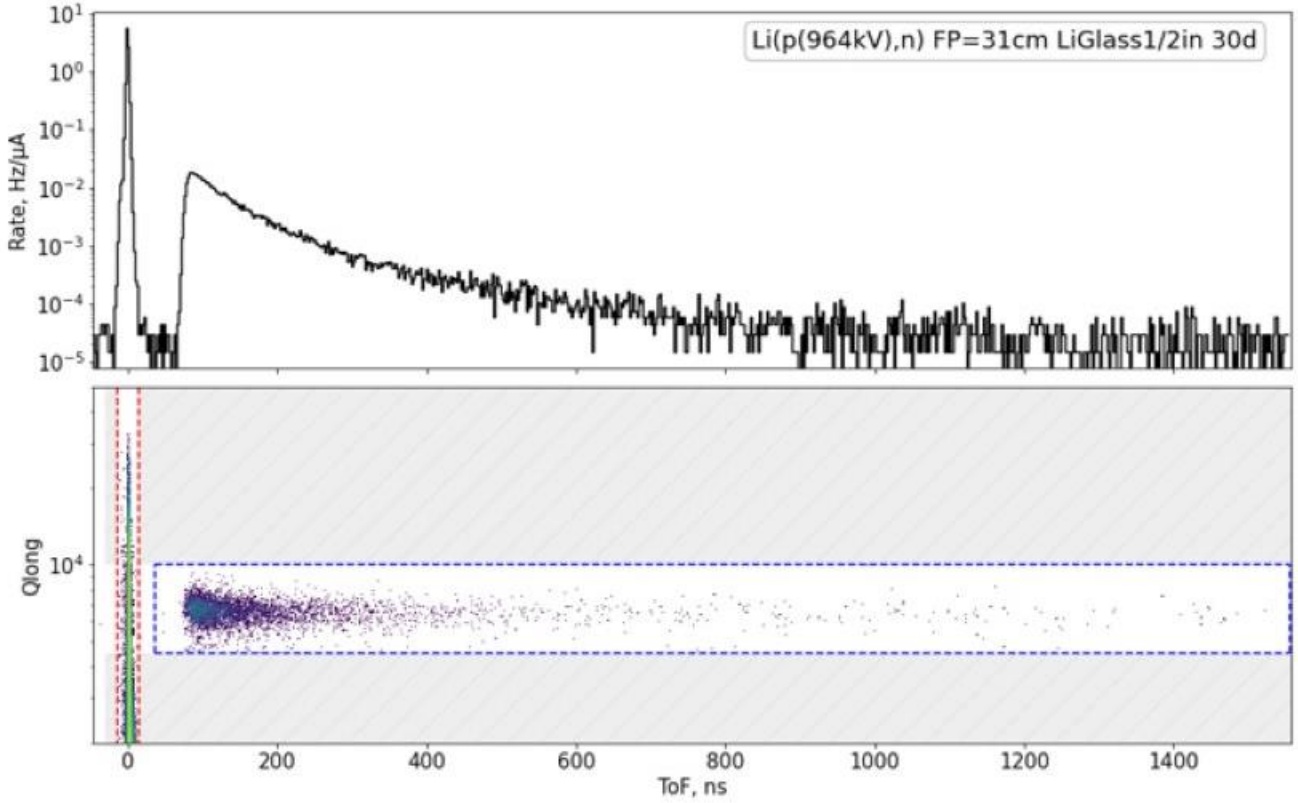


Gamma flash fits

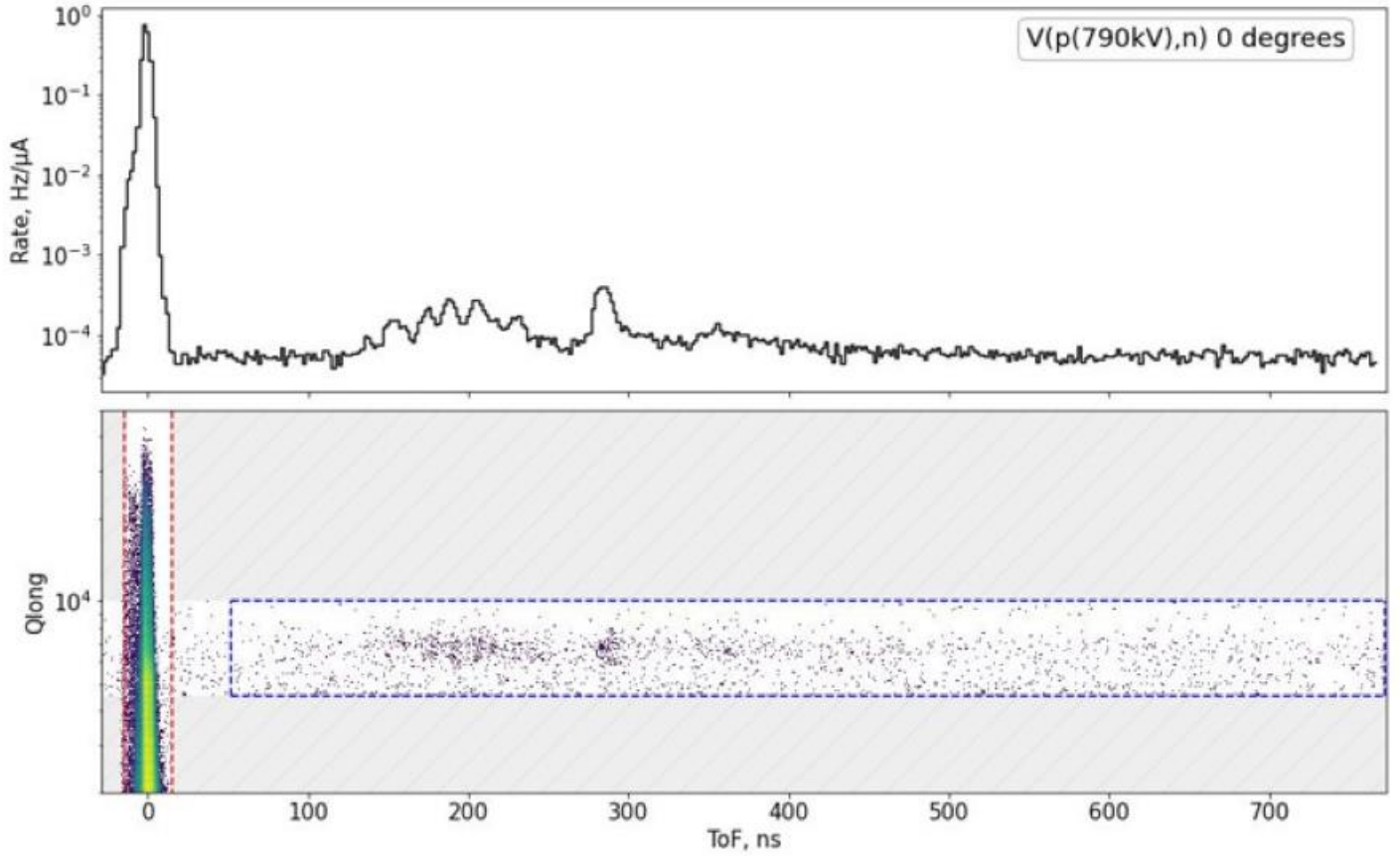


ToF LiF 964kV

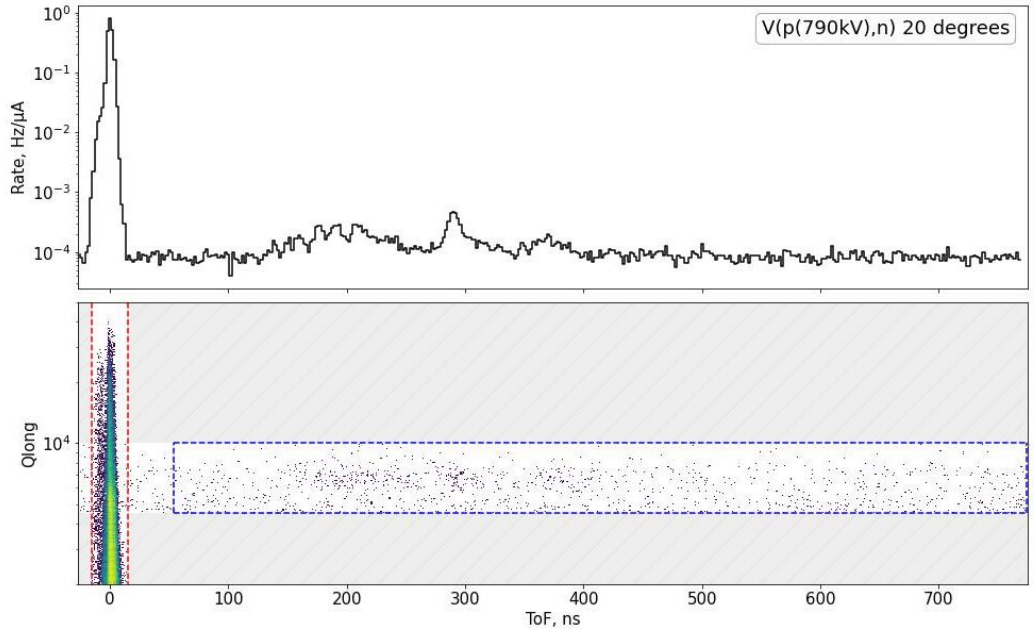


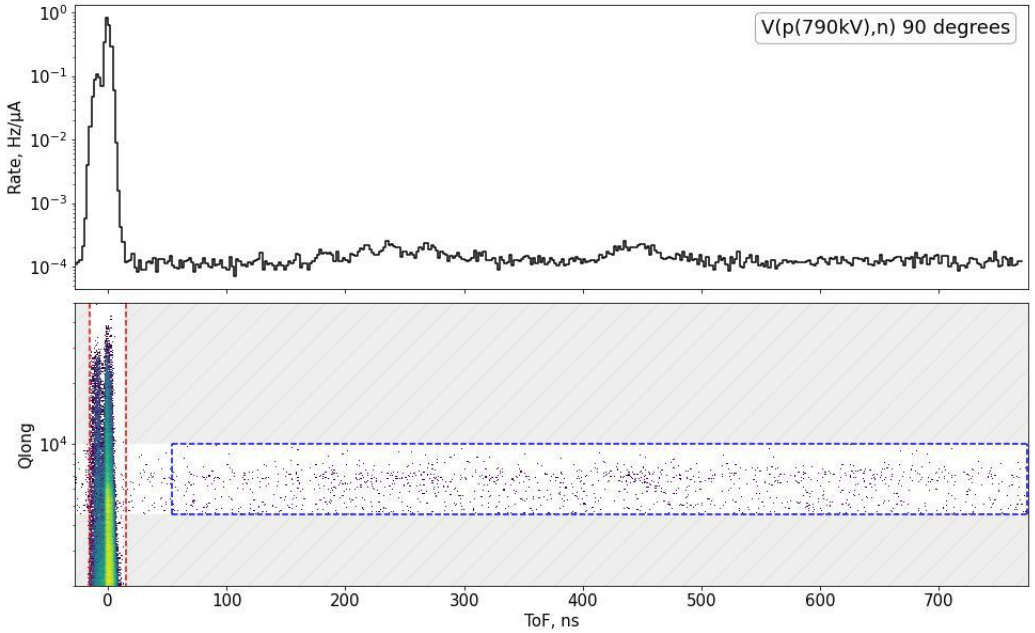


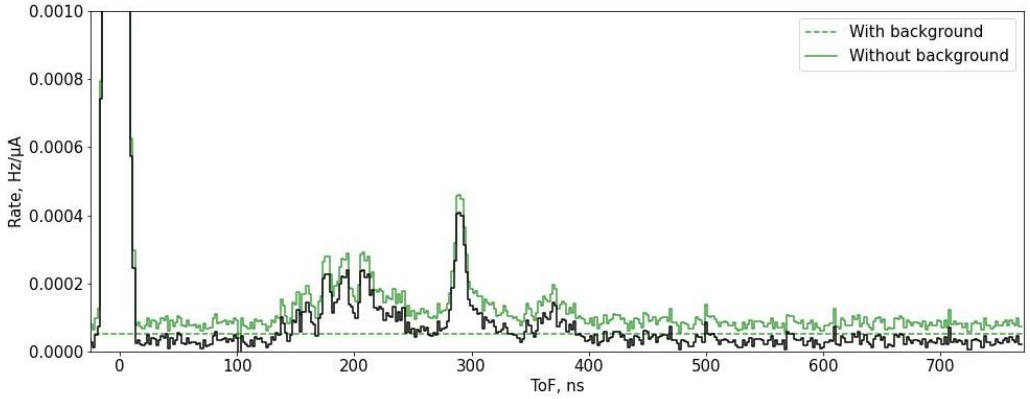
ToF Vanadium 790kV

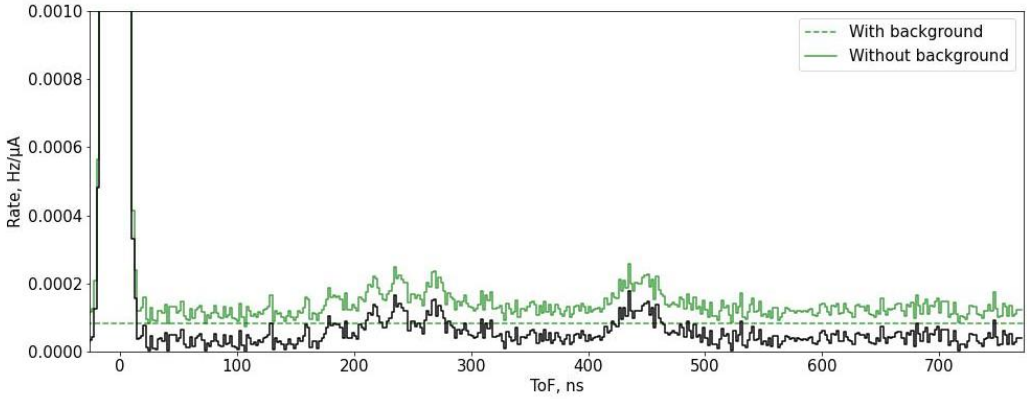


ToF Vanadium 790kV

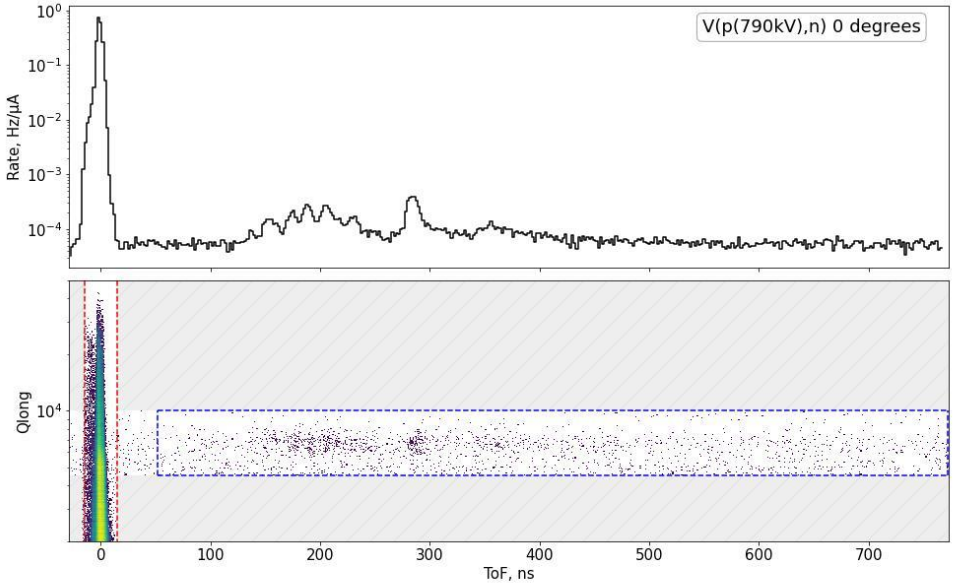


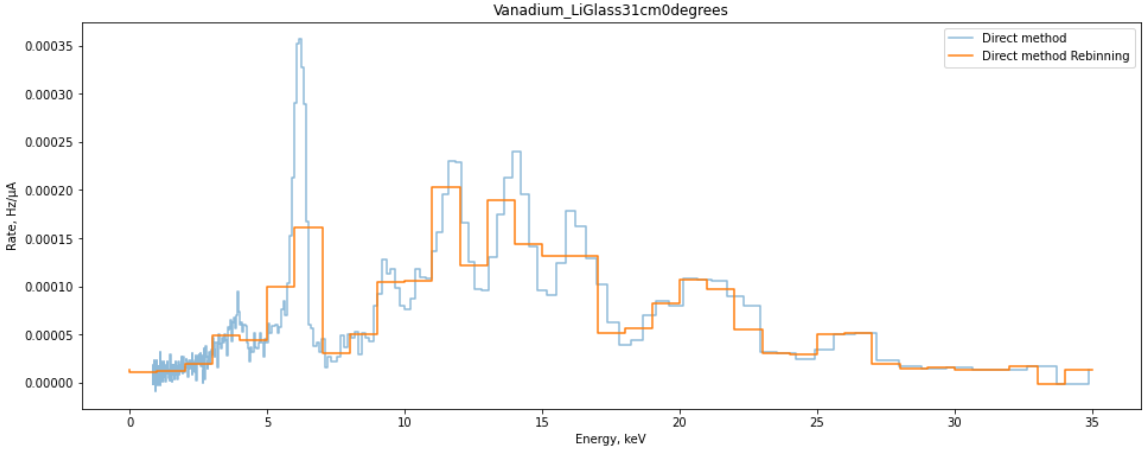


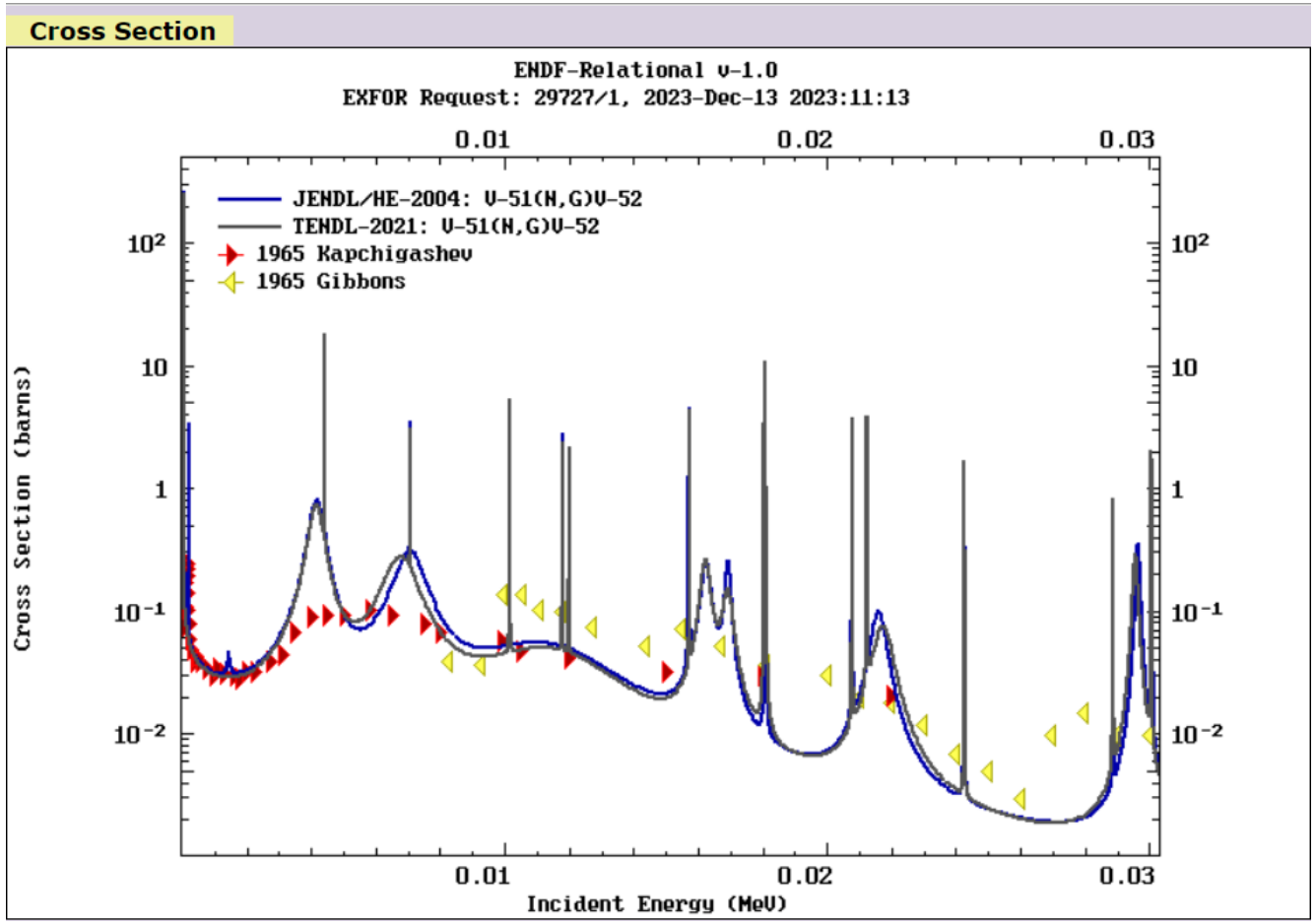




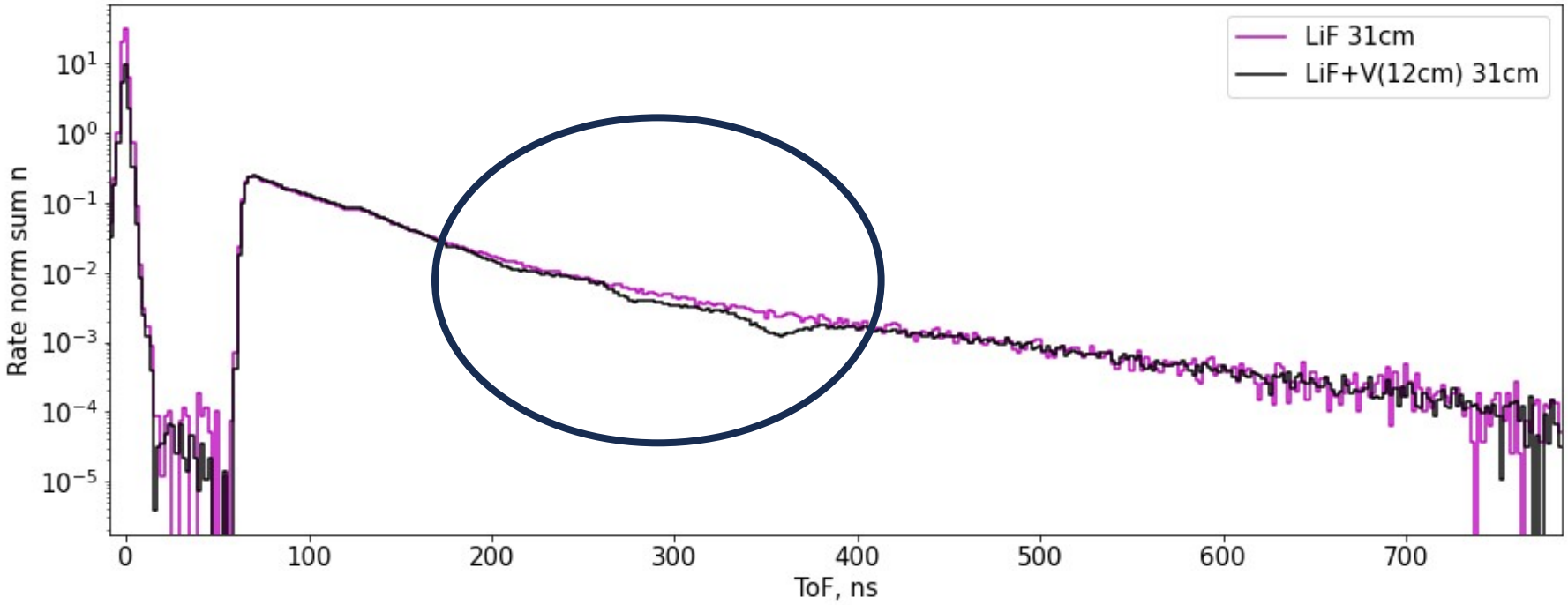
Vanadium-51

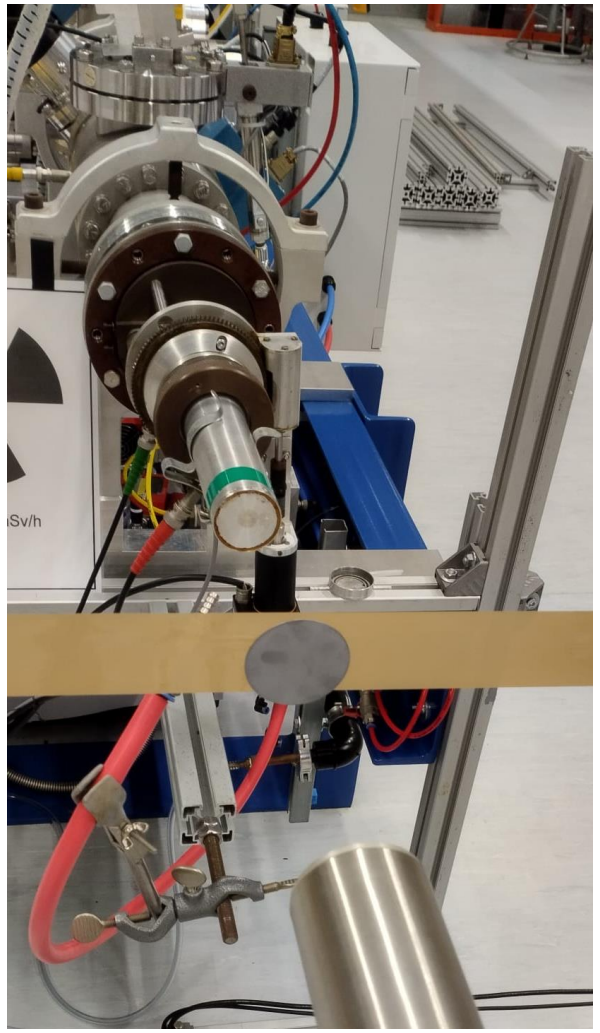

V(p(790kV),n) 0 degrees
Rate, Hz/μA
Qlong
ToF, ns


Vanadium_LiGlass31cm0degrees
Direct method
Direct method Rebinning
Rate, Hz/μA
Energy, keV


Cross Section
ENDF-Relational v-1.0
EXFOR Request: 29727/1, 2023-Dec-13 2023:11:13
JENDL/HE-2004: V-51(N,G)V-52
TENDL-2021: V-51(N,G)V-52
1965 Kapchigashev
1965 Gibbons
Cross Section (barns)
Incident Energy (MeV)

ToF LiF + Vanadium transmission





Conclusions

The characterization of the neutron and photon yields of the reaction $^{51}V(p,n)^{51}Cr$ at energies close to the threshold have been performed in the JRC-MONNET facility the last year.

For me the main objective of this characterization is the use for BNCT.
Information that is under PATENT: IPR-1070.

The experiment was successfully completed, fulfilling all the objectives and making one more transmission measurement.

We are now in the post-analysis phase.

The complete experiment, with the time-of-flight and activation measurements, is intended to be part of my training as PhD student and early researcher. Since, the study of this reaction is the major part of my PhD Tesis. ARIEL has granted funding for the experiment and also for a 12-week stay in the JRC-Geel.

Neutron and photon yields for the $^{51}V(p,n)^{51}Cr$ reaction near threshold

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Thanks for your attention!

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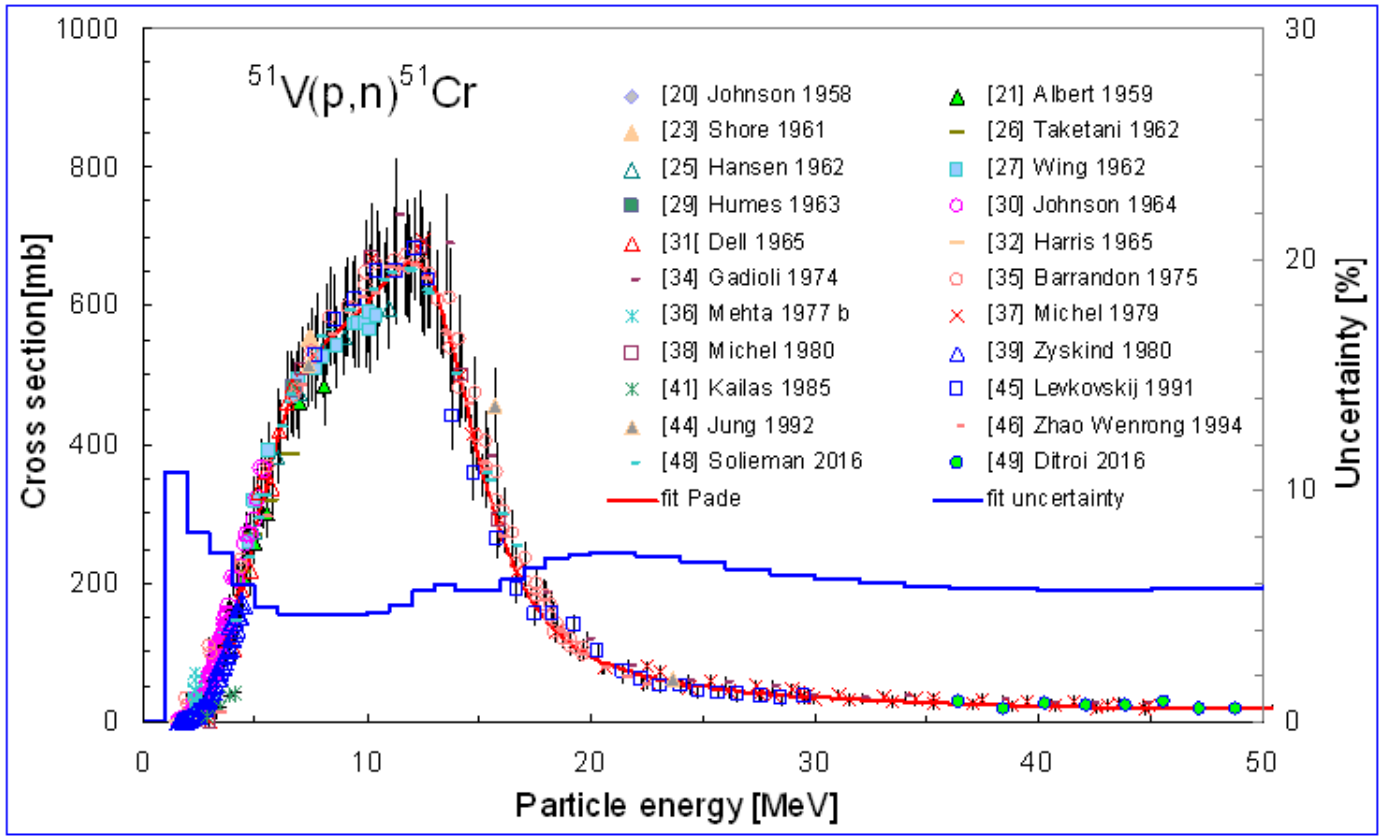
European Commission JOINT RESEARCH CENTRE

ARIEL

This project has received funding from the Euratom research and training program 2014-2018 under grant agreement No. 847594

New cross section data



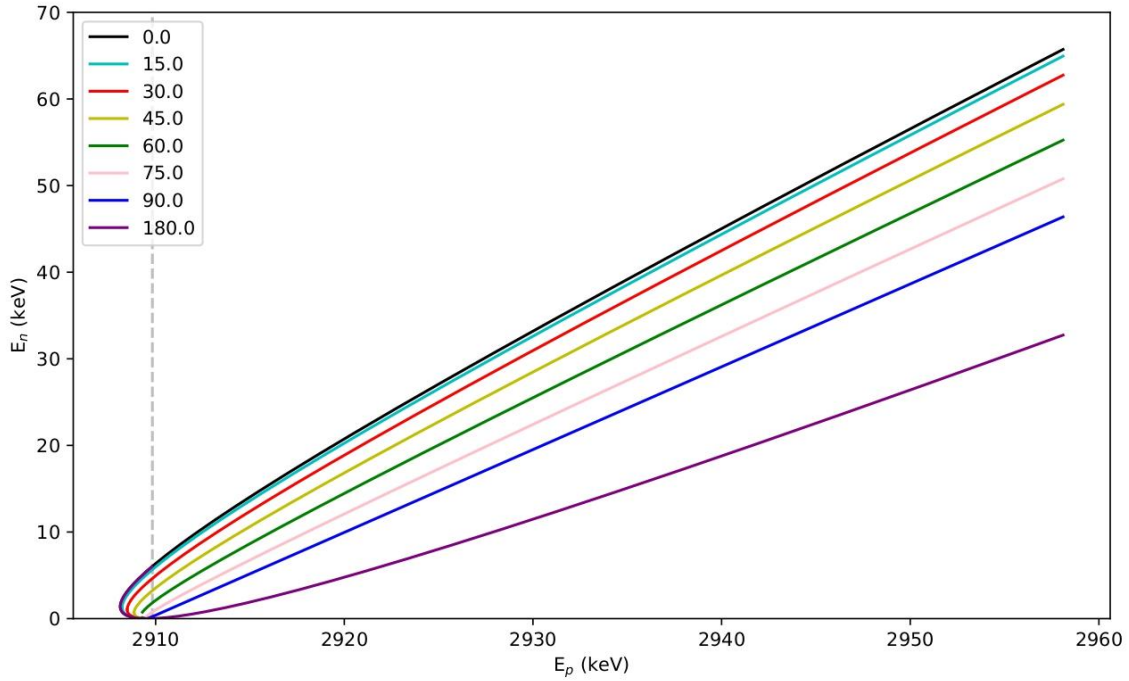
https://www-nds.iaea.org/medical/v1p51cr0.html

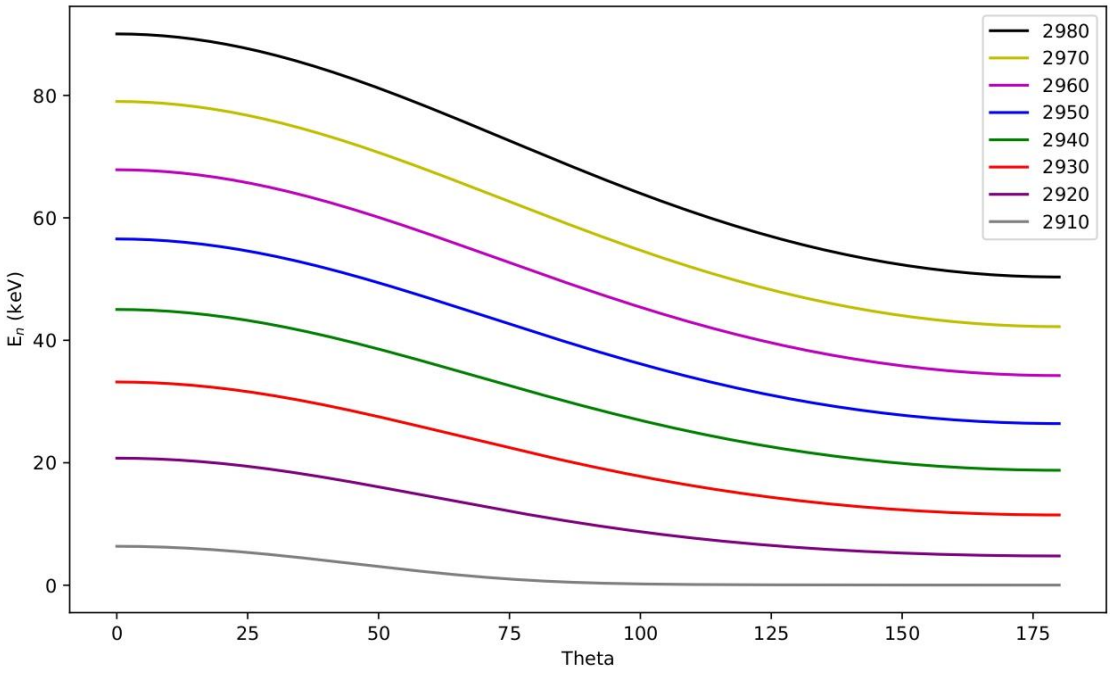
Tabulated cross section has an energy range of 1.6 to 50 MeV

A similar reaction: $^{45}Sc(p,n)^{45}Ti$

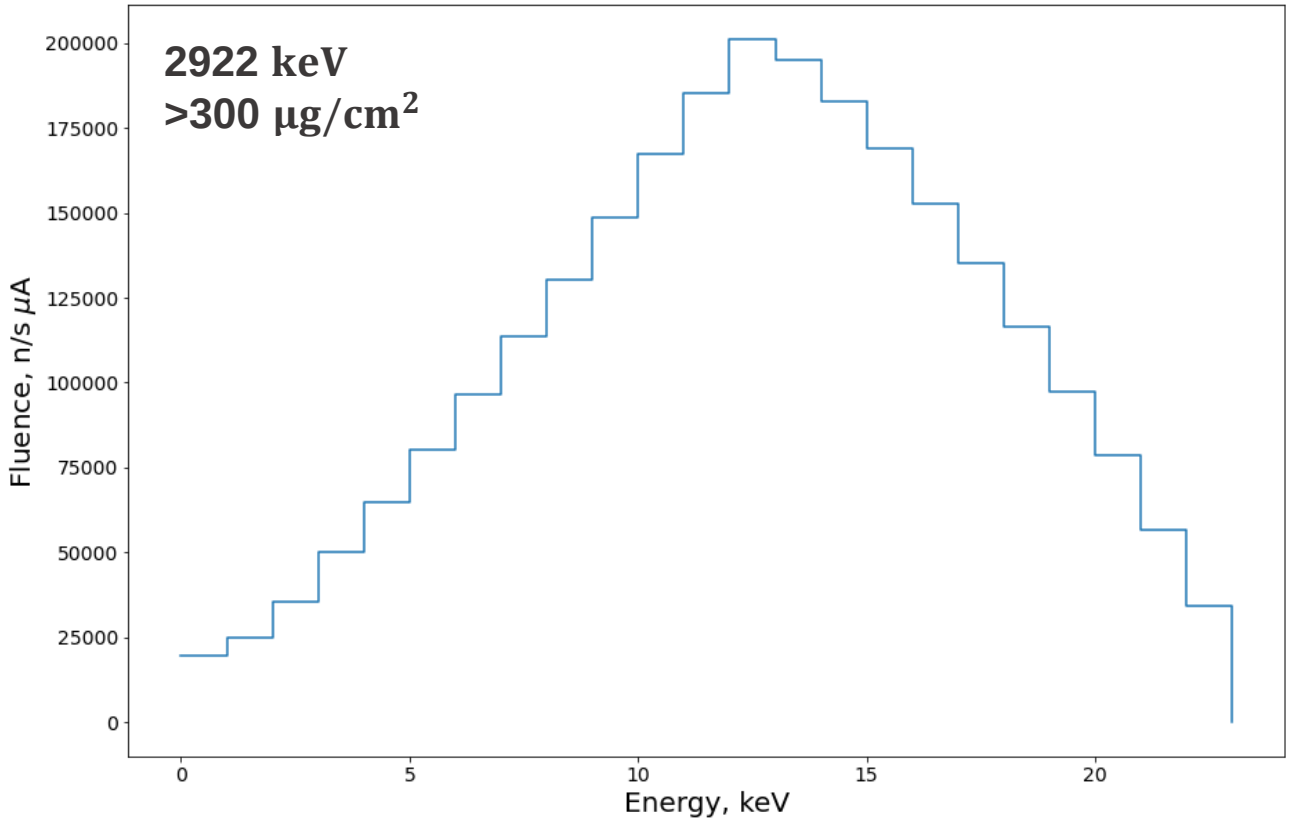
$$Sc - 45 + p \rightarrow Ti - 45 + n$$

$$Q = -2844.4\ keV \quad E_{th} = 2908.2\ keV$$





A similar reaction: $^{45}Sc(p,n)^{45}Ti$



	CRITERIA	2922 keV (>300 $\mu g/cm^2$)
ϕ_T	$> 10^9\ n_{epi}/cm^2 s$	2516064 $n/(s\mu A)$
ϕ_{epi}/ϕ_T (%)	-	98.63
ϕ_{epi}/ϕ_{fast}	> 20	26.77
$\phi_{epi}/\phi_{thermal}$	> 100	122.62
J_n/ϕ_{epi}	> 0.7	1.04
$\dot{D}_{fast}/\phi_{epi}$	$< 2 \cdot 10^{-13}$	$5.28 \cdot 10^{-30}$
$\dot{D}_{\gamma}/\phi_{epi}$	$< 2 \cdot 10^{-13}$	$1.01 \cdot 10^{-17}$

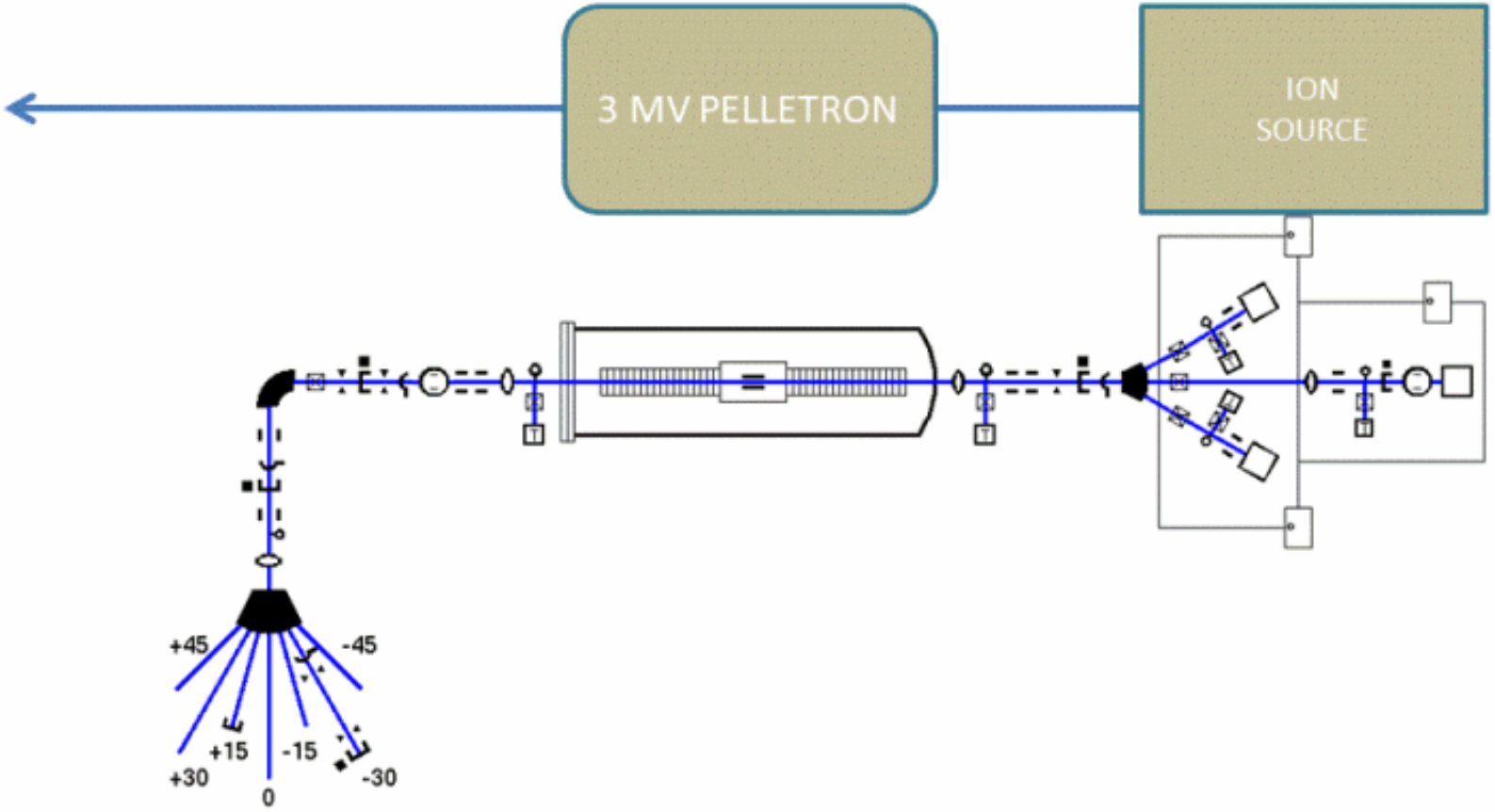
Our team's previous experience

CNA: Centro Nacional de Aceleradores, Sevilla

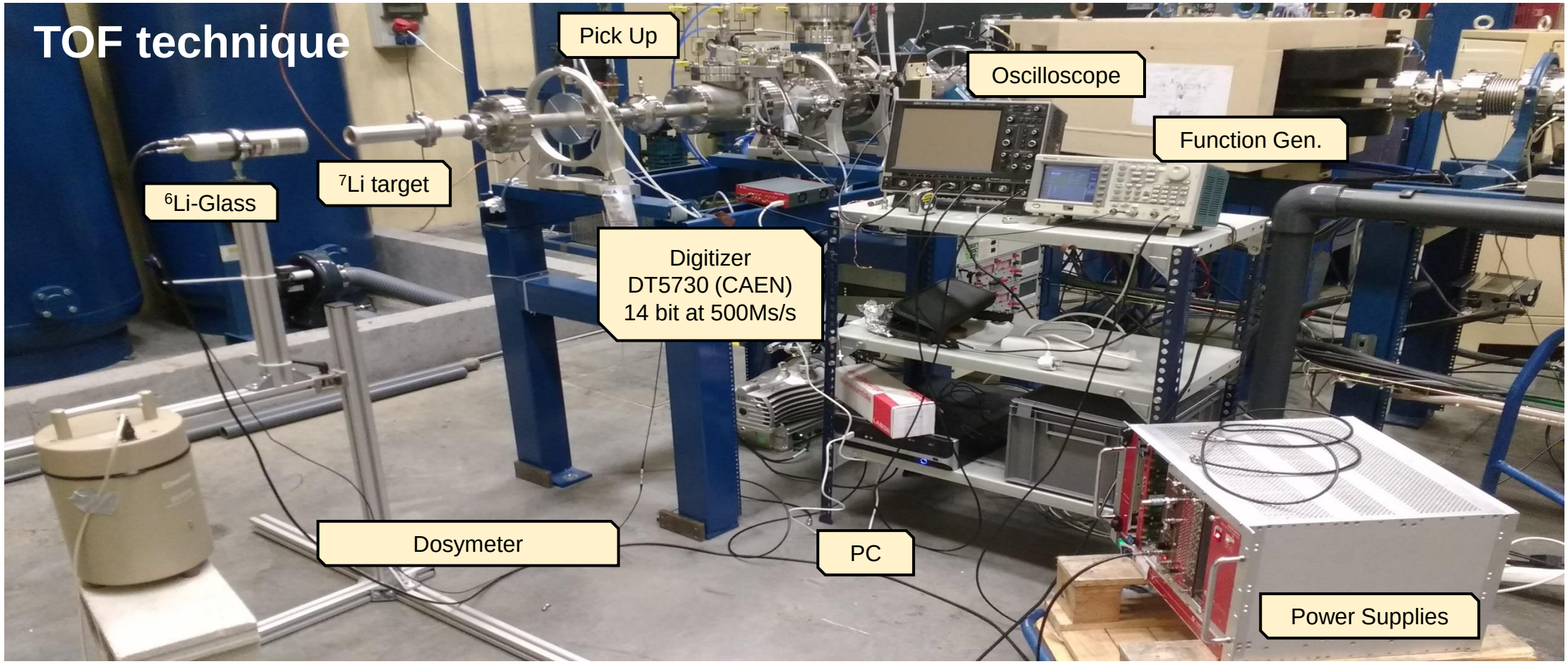
Miguel Macías Thesis

HiSPANoS (HiSPAlis Neutron Source) at CNA: installation and commissioning of the first neutron time of fight beamline in Spain

Supervisors: J. Praena And B. Fernández



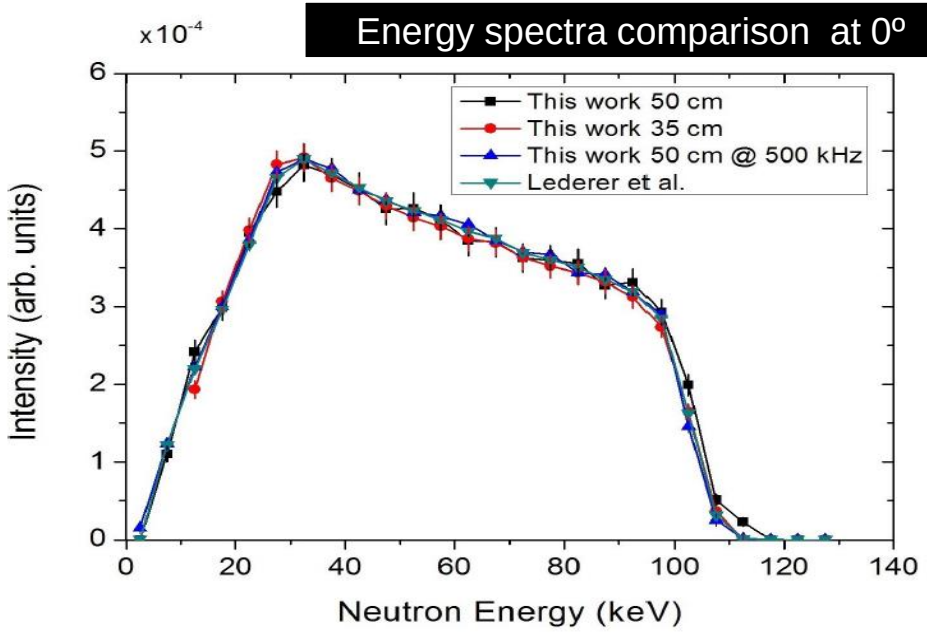
Our team's previous experience

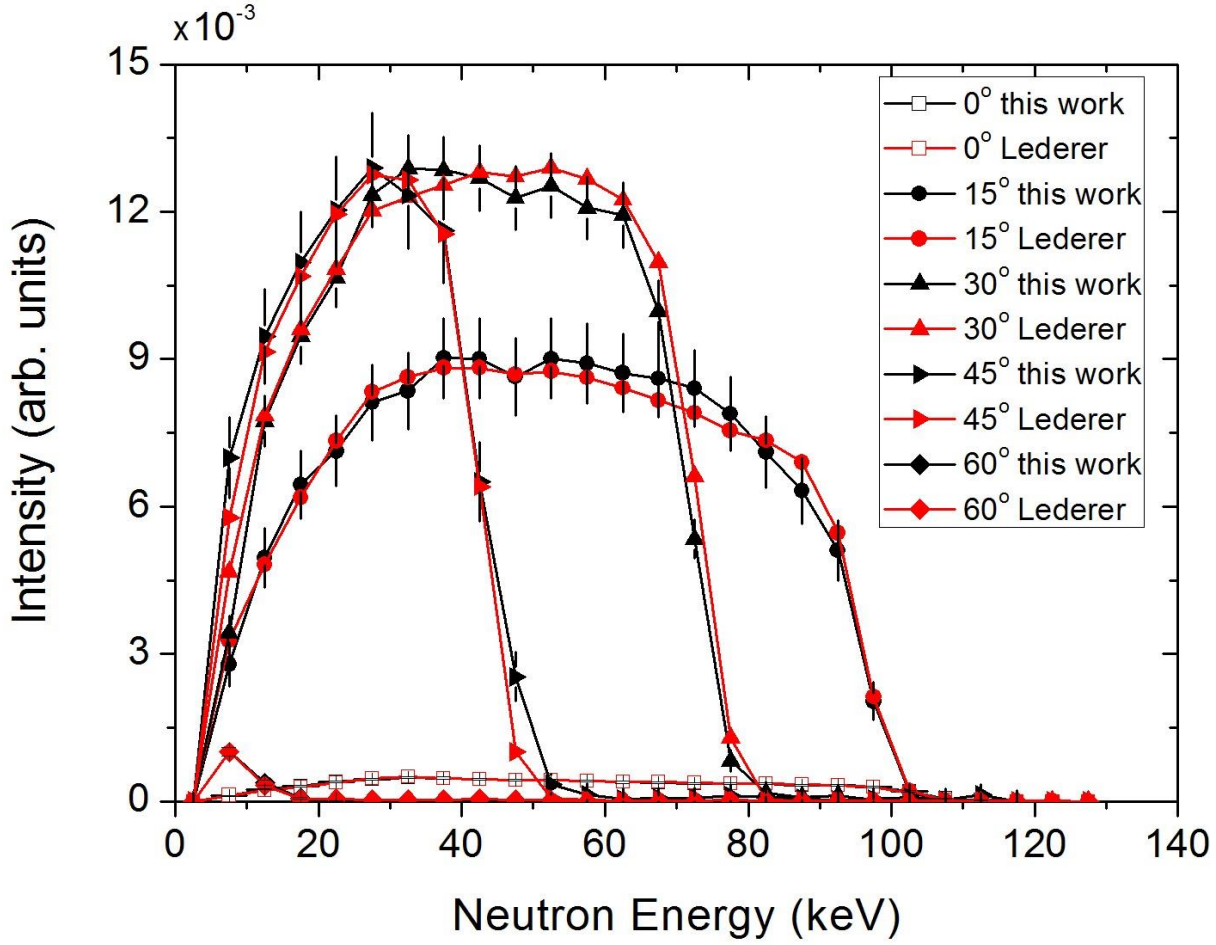


Our team's previous experience

TOF technique
$^{7}Li(p,n)^{7}Be$ reaction

Energy spectra comparison at 0º





More about BNCT

A **neutron beam** is necessary to perform the treatment:

- **Nuclear reactors**: has been the only way for a long time, limiting the therapy potential:
  1. Logistic problems.
  2. Not optimized neutron beam.

- **Accelerator-Based** neutron sources for NCT:
  1. Open the possibility to implement this therapy in hospitals.
  2. Development in Russia, Italy, UK, Israel, Japan, Argentina, China or Finland.
  3. From reactor beams to more versatile and safety AB-BNCT beams.

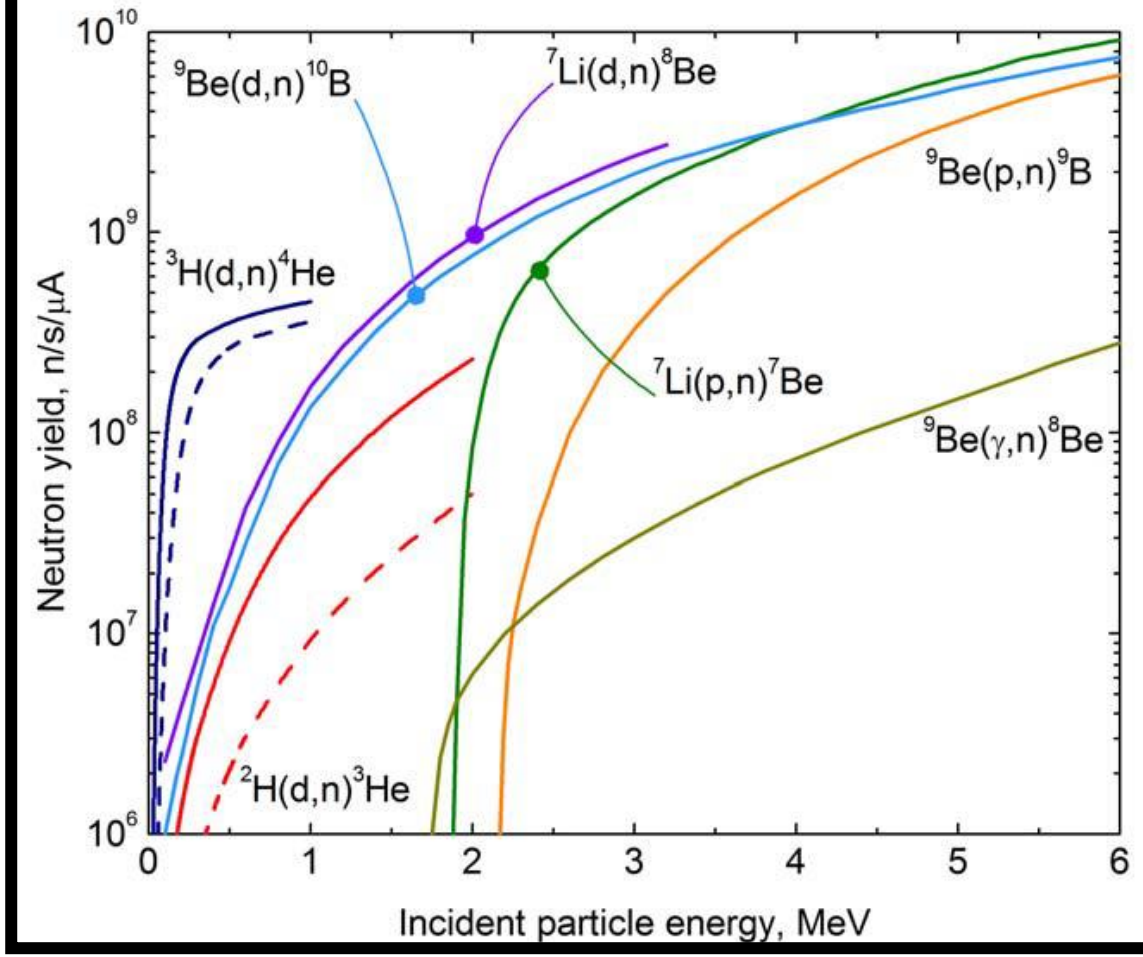
NeuCure and NeuBoron already working

NeuCure (Japan)

NeuBoron (China)

Neutron Therapeutics (Finland)

More about BNCT



Current production reactions for BNCT

Reaction	Q Value [MeV]	Threshold Energy [MeV]	Minimum Product Energies [MeV]
^{2}H(d,n)^{3}He	+3.269	NA	^{3}He: 0.82 n: 2.45 *
^{3}H(d,n)^{4}He	+17.589	NA	^{4}He: 3.54 n: 14.05
^{7}Li(p,n)^{7}Be†	-1.644	1.880	^{7}Be: 0.21 n: 0.03
^{7}Li(d,n)^{8}Be	+15.031	NA	^{8}Be: 1.68 n: 13.35
^{9}Be(p,n)^{9}B	-1.850	2.057	^{9}B: 0.18 n: 0.023
^{9}Be(d,n)^{10}B	+4.361	NA	^{10}B: 0.40 n: 3.96

More about BNCT

Institute	Accelerator	Beam energy	Intensity	Reaction	Max. n energy
Kyoto Univ, Japan (in clinical trials)	Cyclotron	30 MeV	1 mA	^{9}Be(p,n)	28 MeV
Helsinki Univ. Cent. Hospital, Finland	Electrostatic (Hyperion)	2.6 MeV	30 mA	^{7}Li(p,n)	0.89 MeV
Budker Institute, Novosibirsk, Russia	Vacuum insulated Tandem	2.5 MeV	2 mA	^{7,}Li(p,n)	0.79 MeV
IPPE Obninsk, Russia	Cascade generator KG-2.5	2.3 MeV	3 mA	^{7}Li(p,n)	0.57 MeV
Birmingham Univ., UK	Electrostatic (Dynamitron)	2.8 MeV	1 mA	^{7}Li(p,n)	1.1 MeV
Tsukuba Univ., Japan	RFQ-DTL [a]	8 MeV	10 mA	^{9}Be(p,n)	6.1 MeV
CNEA Bs. As., Argentina	Tandem Electrost. Quadrupole	1.4 MeV 2.5 MeV	30 mA 30 mA	^{9}Be(d,n) ^{7}Li(p,n)	5.7 MeV 0.79 MeV
INFN, Italia	RFQ [a]	5 MeV	50 mA	^{9}Be(p,n)	3.1 MeV
SOREQ, Israel	RFQ-DTL [a]	4 MeV	2 mA	^{7}Li(p,n)	2.3 MeV
LBNL, USA	Electrostatic	2.5 MeV	50 mA	^{7}Li(p,n)	0.79 MeV
National Cancer Center, Japan	RFQ [a]	2.5 MeV	20 mA	^{7}Li(p,n)	0.79 MeV
Xiamen Humanity Hospital, China	Electrostatic (VITA)	2.5 MeV	10 mA	^{7}Li(p,n)	0.79 MeV
Nagoya Univ., Japan	Electrostatic (Dynamitron)	2.8 MeV	15 mA	^{7}Li(p,n)	1.1 MeV
Gachon Univ. Gil Med. Center, S.Korea	RFQ-DTL [a]	10 MeV	8 mA	^{9}Be(p,n)	8.1 MeV
Southern Tohoku Hosp, Fukushima, JP	Cyclotron	30 MeV	1 mA	^{9}Be(p,n)	28 MeV
Granada Univ., Spain	Electrostatic (Hyperion)	2.1 MeV	30 mA	^{7}Li(p,n)	0.35 MeV

Current projects