Effects of MgF_2 on neutrons along the keV energy range and study of the neutron capture on fluorine.

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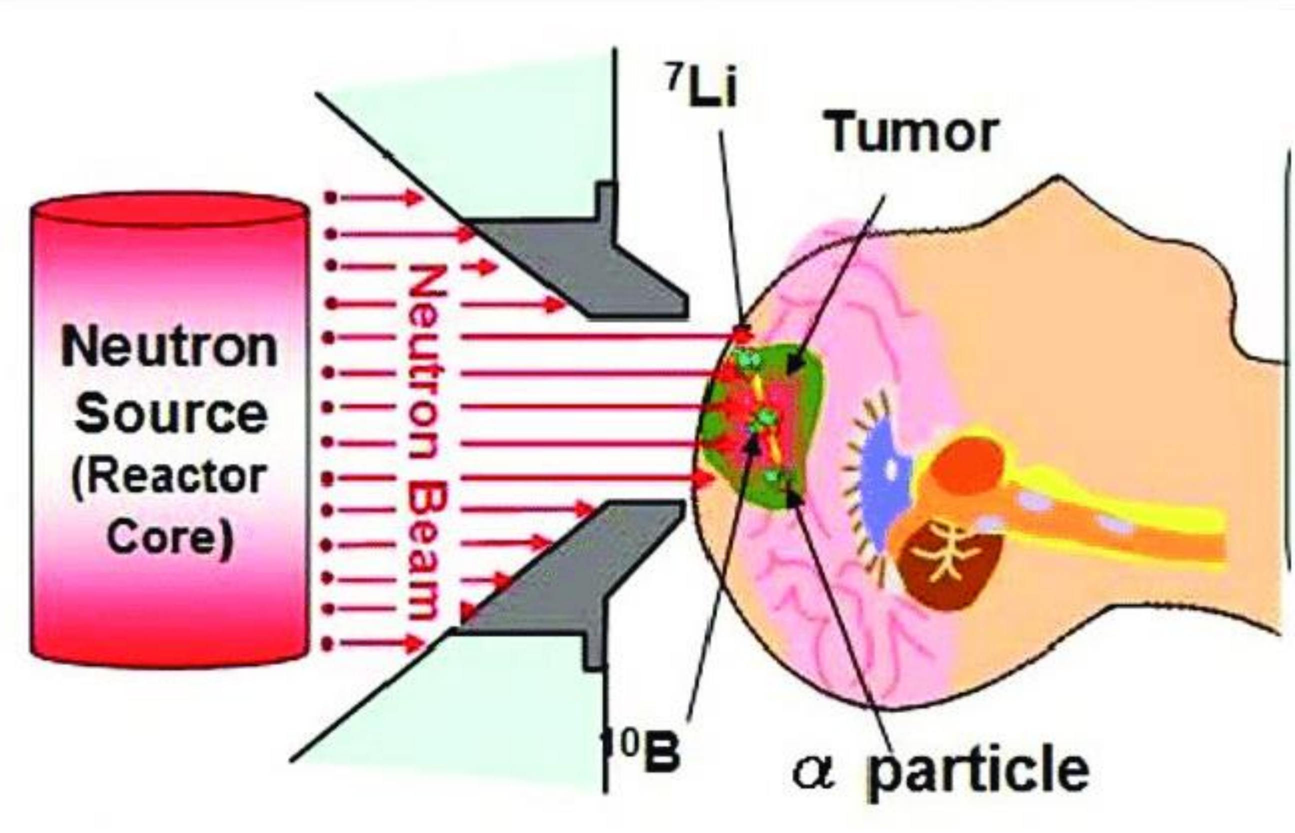
Index:

1 – Introduction:

Boron Neutron Capture Therapy (BNCT) is an experimental radiotherapy for certain tumours, selective at a celular scale. It consists on two steps:



1. Transport of a harmless and stable isotope (^{10}B) to the tumour's cell.
2. Irradiation with neutrons that will react with boron and destroy, very locally, the containing cells:

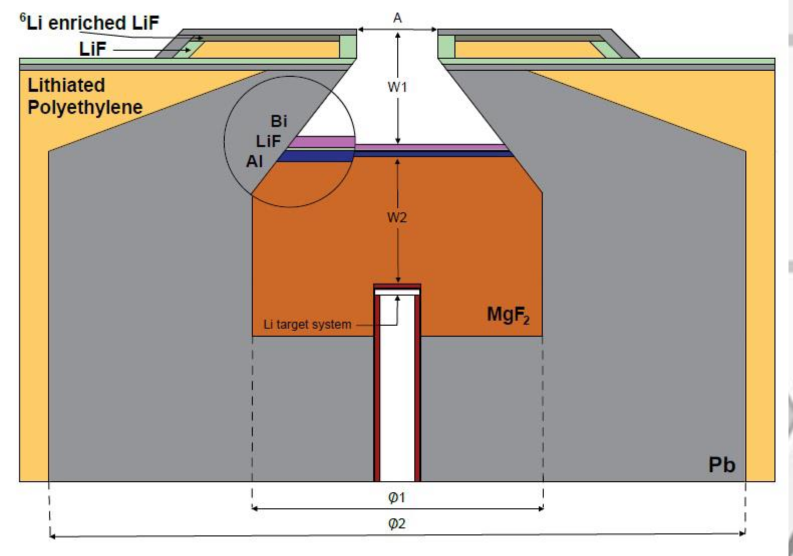
$$n + {}^{10}_{5}B \xrightarrow{Q=2,31MeV} {}^{7}_{3}Li^{*} + {}^{4}_{2}He^{2+}$$

In spite of very promising results, the clinical practice of BNCT still faces some obstacles.

2.1 – Motivation:

One of these challenges is the production of a suitable beam of neutrons to irradiate the patient. One possible approach is to moderate the neutron spectrum produced by a LiF target via the 7-Li(p,n) reaction.

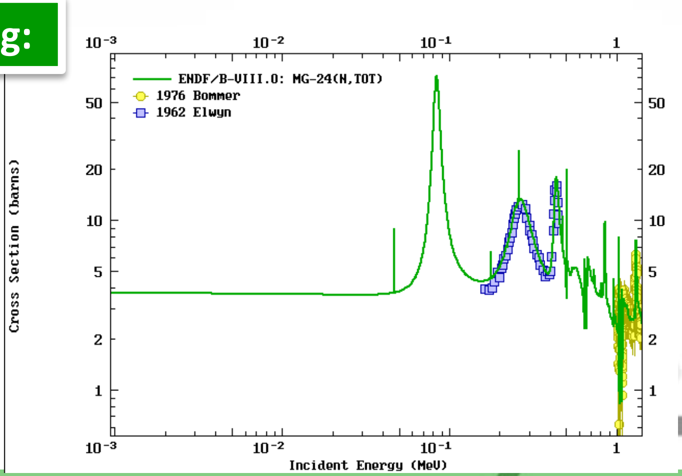
To this end, the NeMeSis project from the University of Granada has drafted a model of a Beam Shaping Assembly (BSA), a device designed to filter the aforementioned spectrum into a suitable one.



Before building it, an experimental validation at a smaller scale was to be performed. Besides, the involved cross-sections have some discrepancies and/or lack of information...

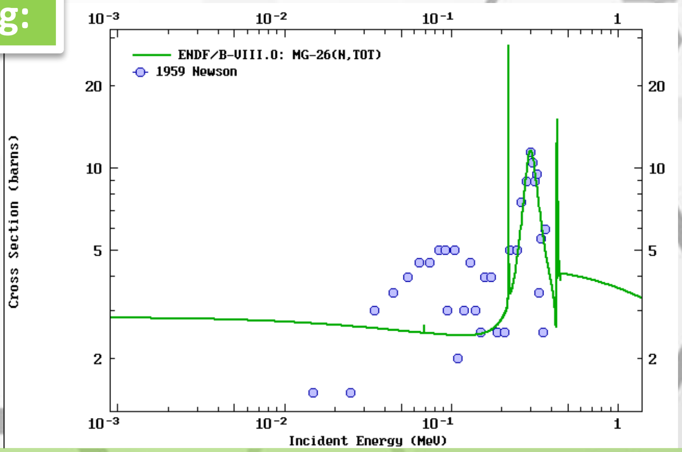
2.2 – Motivation:

^{24}Mg:



- Total cross-section in [164-455] keV. ✔
- No data around resonance at 83 keV. ✘
- Scarce data on the elastic cross-section, with measurements only made above 3 MeV. ✘

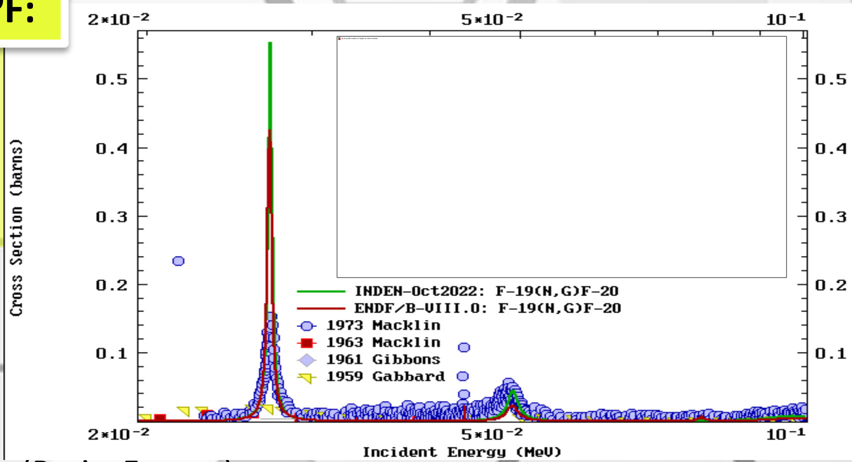
^{26}Mg:



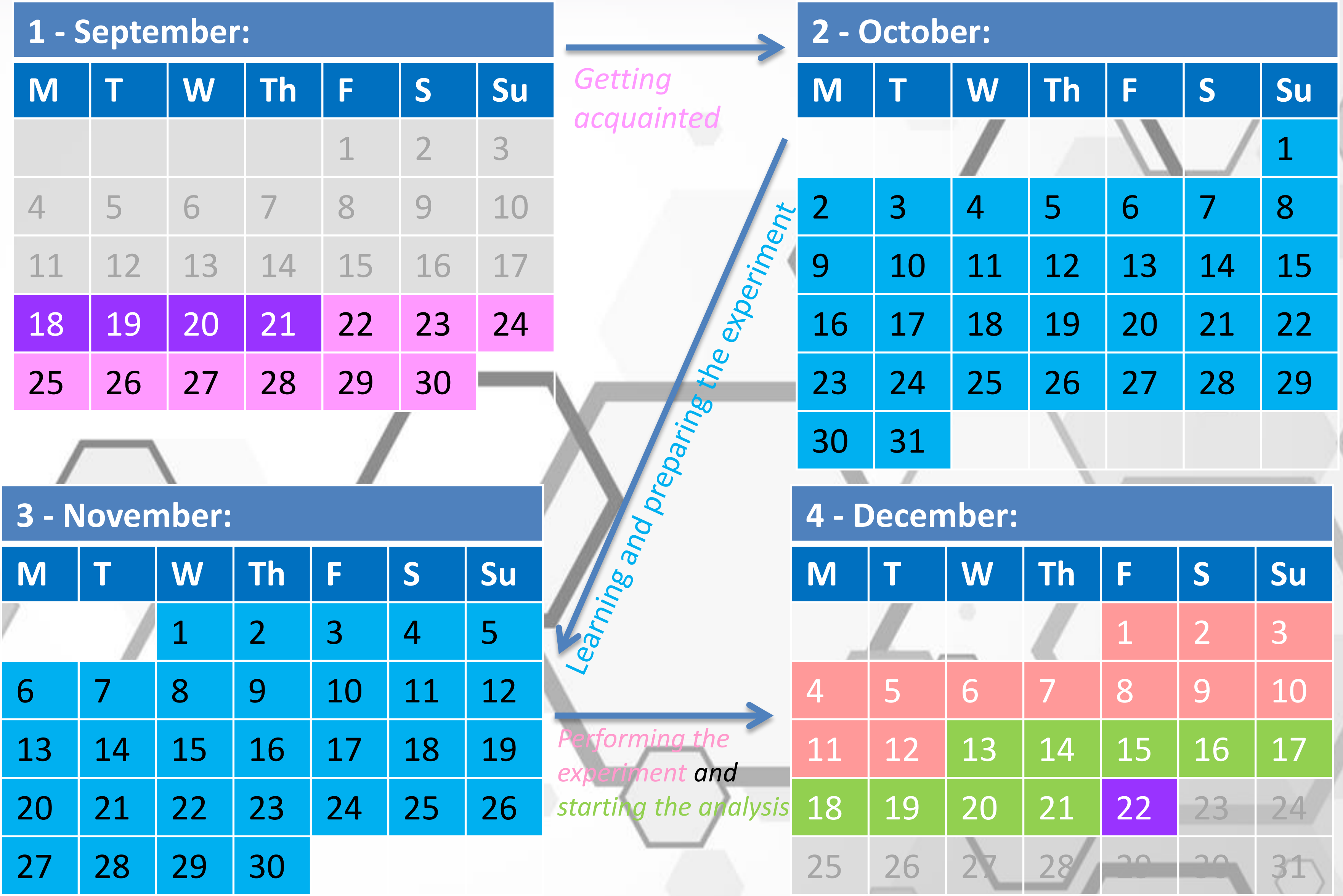
- Only one measurement, with no general agreement with ENDF evaluation. ✘
- Except around 299 keV's resonance. ✔

^{19}F:

- Total cross section well measured. ✔
- Capture cross section not so accurately known: 27 keV and 49 keV resonances disagreement. ✘



3.1 – My stay at JRC-Geel:



1 - September:

M	T	W	Th	F	S	Su
				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	

Getting acquainted

2 - October:

M	T	W	Th	F	S	Su
						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					

Learning and preparing the experiment

3 - November:

M	T	W	Th	F	S	Su
		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			

Performing the experiment and starting the analysis

4 - December:

M	T	W	Th	F	S	Su
				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

3.2 – My stay at JRC-Geel:

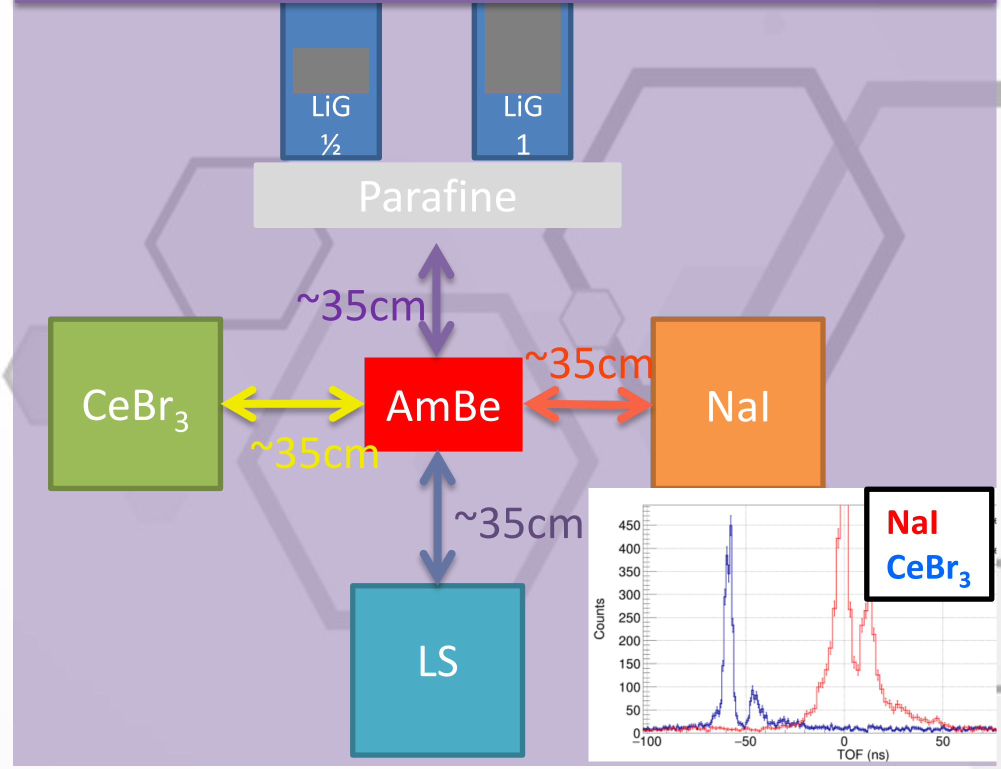
Learning about the tools to use during the experiment:

- **-Digitizer:** CAEN 5730ESB.
- **-Detectors:** CeBr$_3$, LiGlass, Long counter, Liquid Scintillator, NaI.
- **-Sources:** AmBe, 60-Co, 137-Cs.

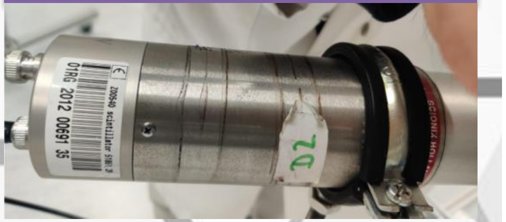
Acquisition software: ABCD.

On-line spectra calculator

Time coincidences of liquid scintillator and gamma detectors:



Setup preparations:



Setup preparations:

4 - The experiment:

-Measurement A:

*A1: Reference measurement at 1912 keV to validate the calibration of the beam.
*A2: Reference measurement at 2100 keV.
*A3: LiF characterisation at different angles.

-Measurement B:

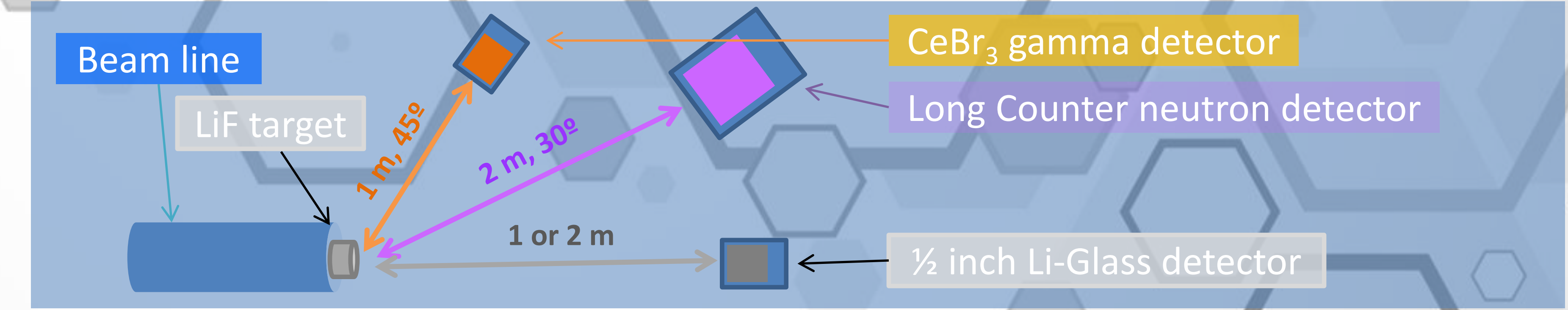
*B1: Transmission through air with dummy sample.
*B2: Transmission through thick Mg.
*B3: Transmission through thick MgF_2.
*B4: Transmission through thin MgF_2.

-Measurement C:

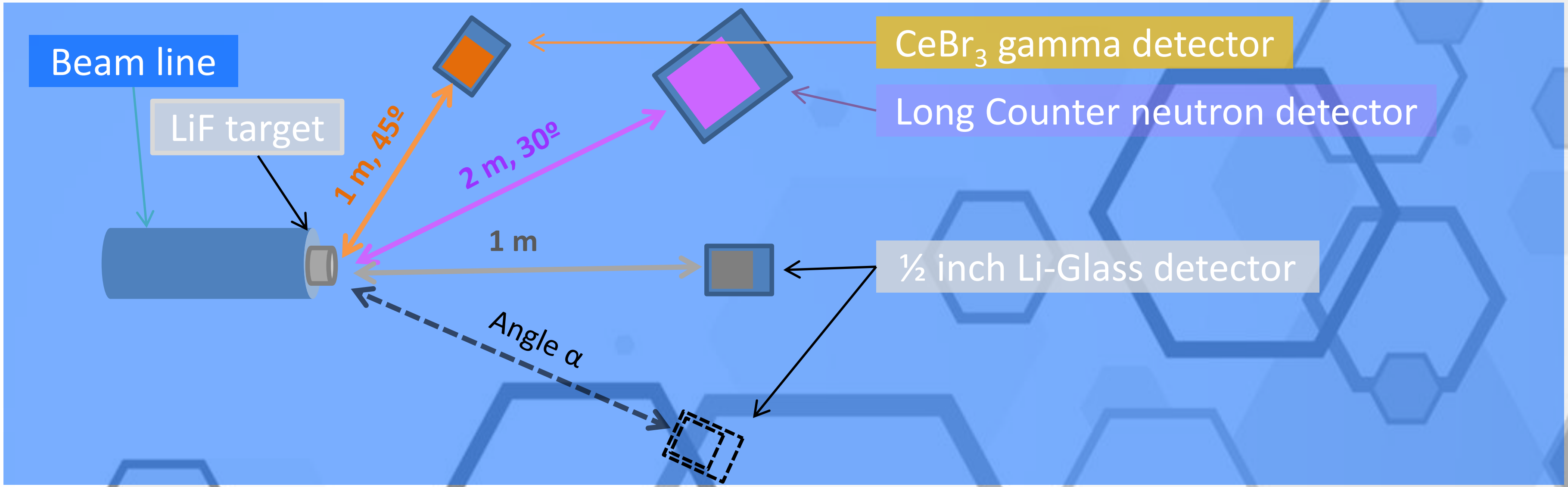
*C1: Neutrons transmitted through the core at 0º.
*C2: Neutrons transmitted and scattered through the corona at different angles.

-Measurement D: 19F(n,γ) reaction could not be studied due to timetable difficulties.

- Beam mode: Pulsed.
- Repitition rate: 1600 ns.
- Pulse width: FWHM of 2 ns.
- Proton energy: 2100 keV.
- Time of Flight technique.



4A – LiF source characterisation:

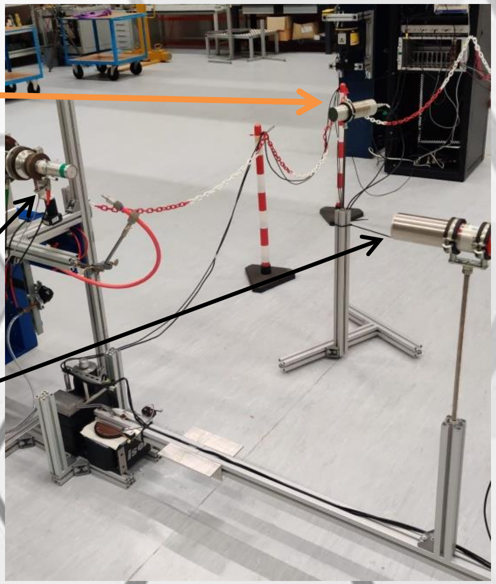


Flight path: 1 m.

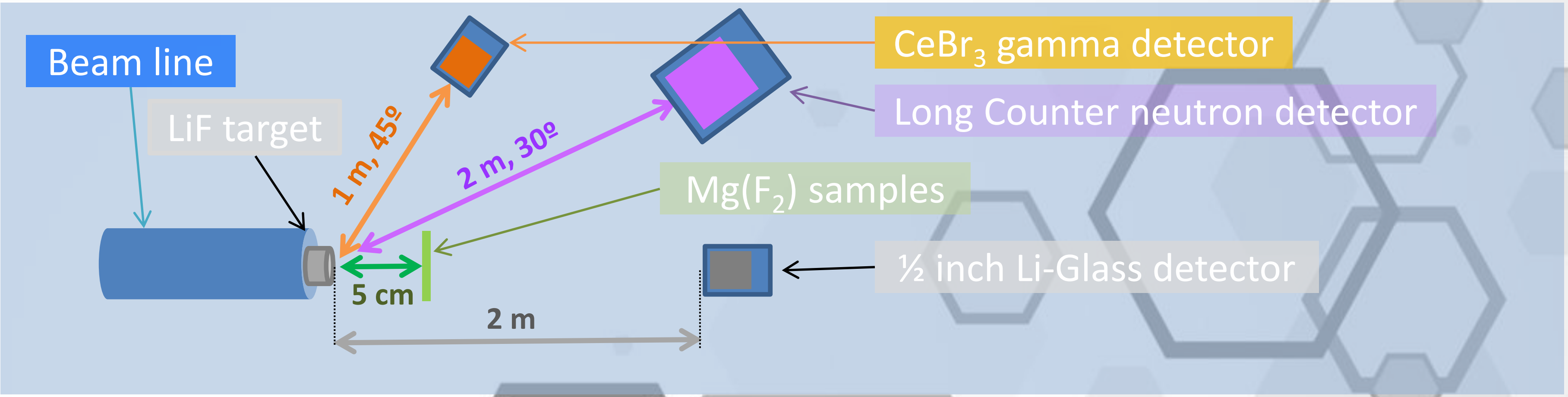
-Measurement «A1»: Measurement at 1912 keV of proton energy as reference to verify that the setup was correct with a quasi-standard neutron spectrum.

-Measurement «A2»: Measurement at 0º to validate that the results were as expected before performing the rest.

-Measurement «A3»: Measurements at angles ranging from 0º to 90º in steps of 5º to characterise the LiF spectra of emission as function of both energy and angle.



4B – Mg and MgF_2 transmission:



Flight path: 2 m.

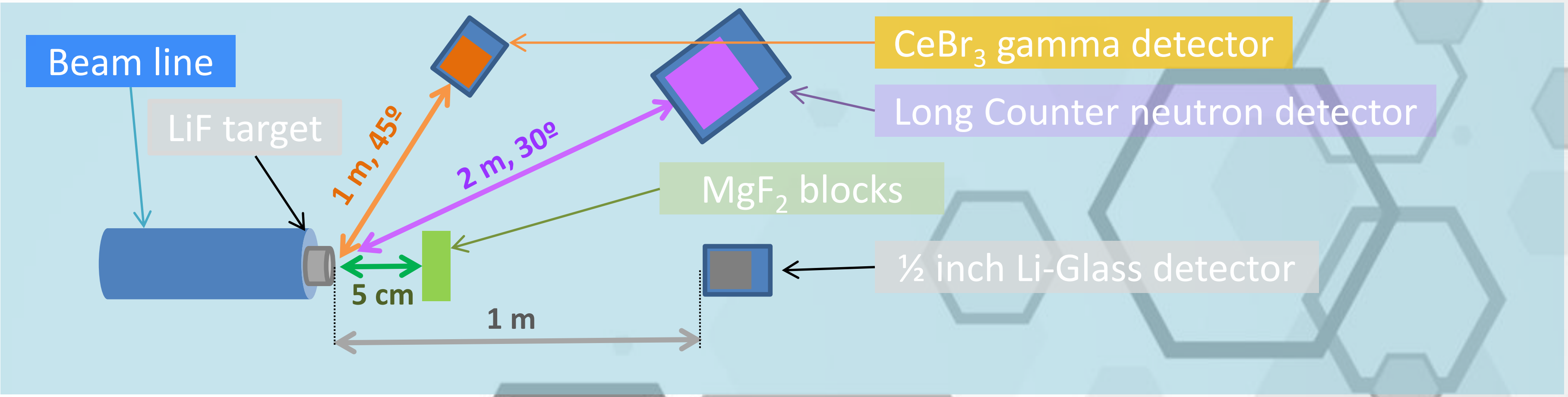
-Measurement «B1»: Measurement as reference sample-out for transmission.

-Measurement «B2»: Transmission through thick Mg.

-Measurement «B3»: Transmission through thick MgF_2.

-Measurement «B4»: Transmission through thin MgF_2 to avoid saturation around the resonance at 27 keV of 19-F.

4C - Beam Shaping Assembly moderation test:



Beam line

LiF target

1 m, 45º

2 m, 30º

5 cm

1 m

$CeBr_3$ gamma detector

Long Counter neutron detector

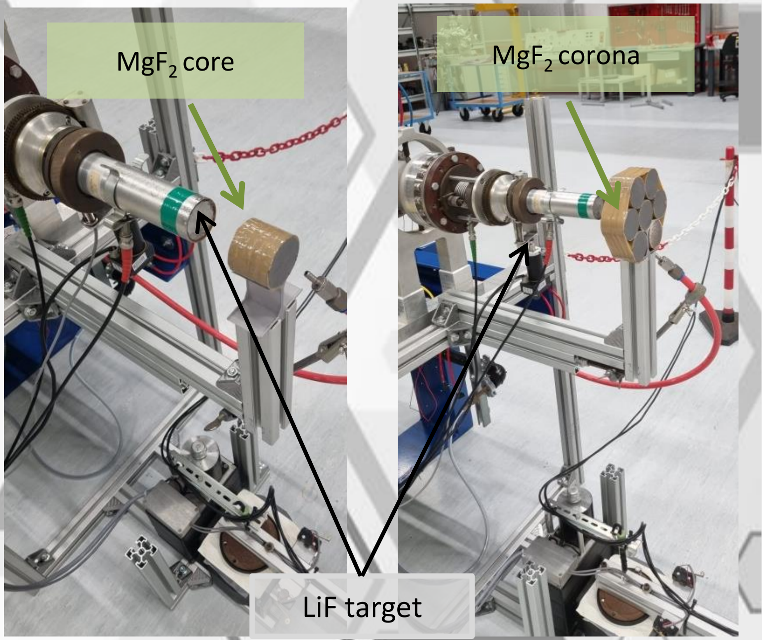
MgF_2 blocks

½ inch Li-Glass detector

Flight path: 1 m.

-Measurement «C1»: Measurement of the core at 0º.

-Measurement «C2»: Measurement of the corona at angles ranging from 0º to 90º in steps of 5º, in the exact same way as in the «A3» part. This will allow to quantitatively evaluate the moderation and the scattering produced by the MgF_2 moderator which is to be present in the future BSA.



MgF_2 core

MgF_2 corona

LiF target

5 – Analysis and preliminary results:

1 – Preliminary filtering and processing of the raw data in order to obtain the detected events.
2 – Filtering of the events to discard electronic noise and correct dead-time, background, efficiency, resolution function and multiple scattering effects.

3 – Comparison of the experimentally measured LiF yield with the simulated yield from Lee & Zhou (C.L. Lee and X.-L. Zhou, NIMB, 1999).

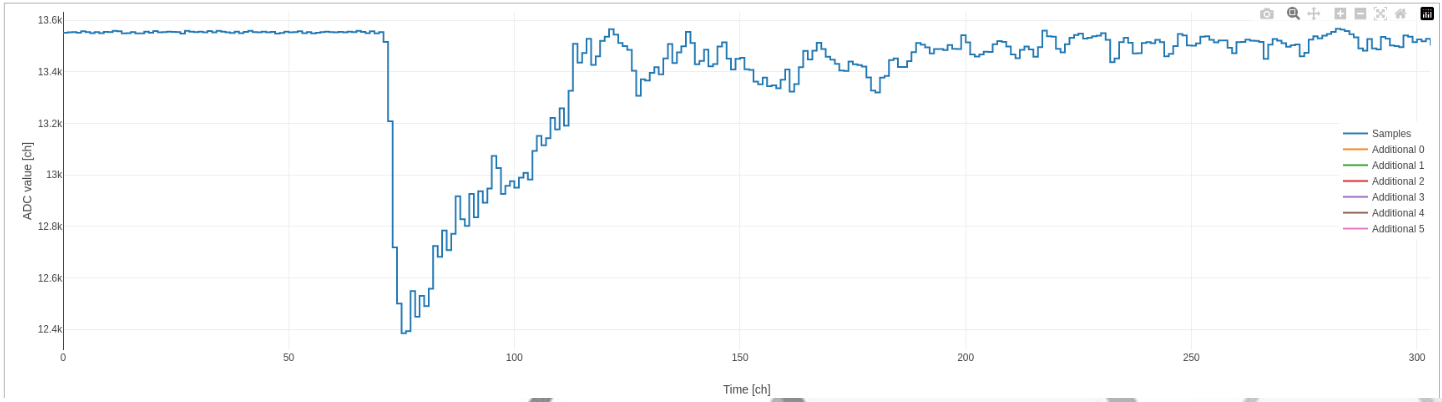
4 – Calculating the cross-sections of the Mg and F isotopes using the transmission measurements.
5 – Fitting the experimentally obtained cross-sections with SAMMY.

6 – Evaluating and validating the results experimentally measured from the BSA moderation with simulations.

5O.1 – Filtering of the events:

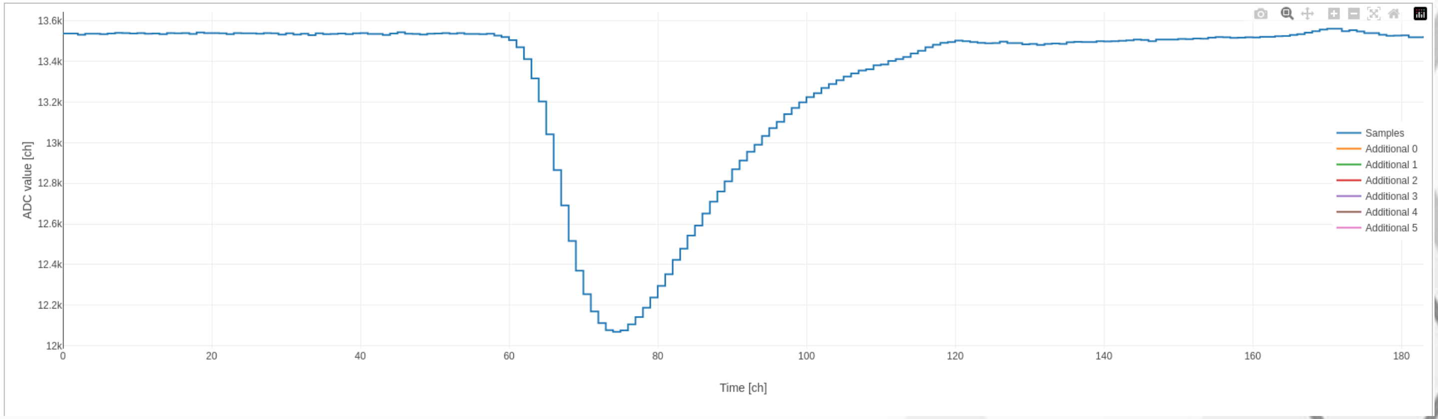
Lithium-glass neutron detector signals:

Timestamp: 26064341706205130



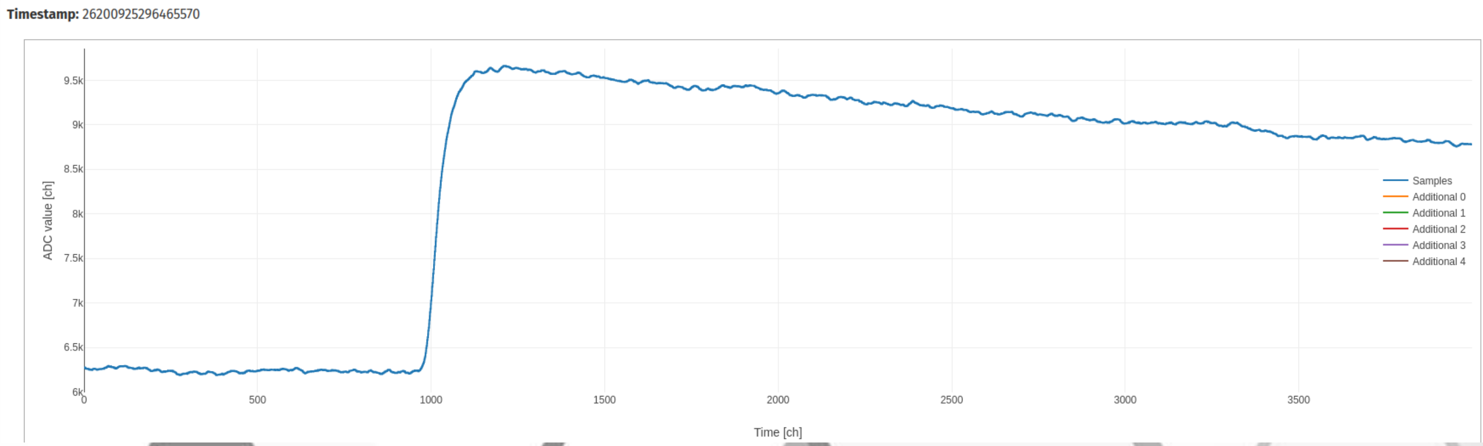
CeBr$_3$ gamma detector signals for normalization:

Timestamp: 26103698331349896



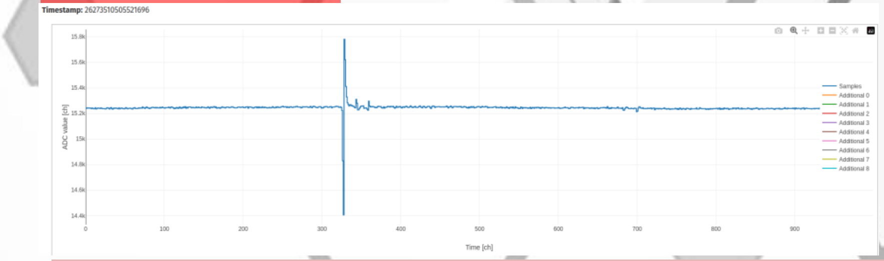
5O.2 – Filtering of the events:

Long Counter / «De Pangher» neutron detector signals for normalization:

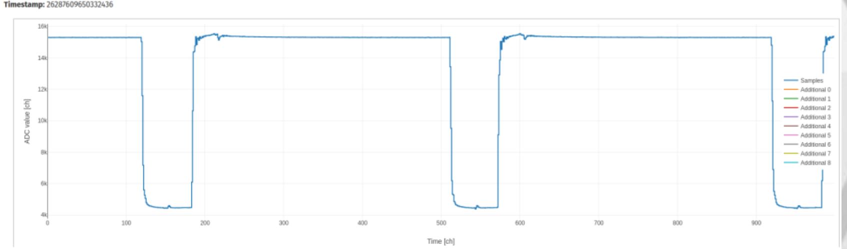


Reference signals for the calculation of Time of Flight.

PKUP signals:



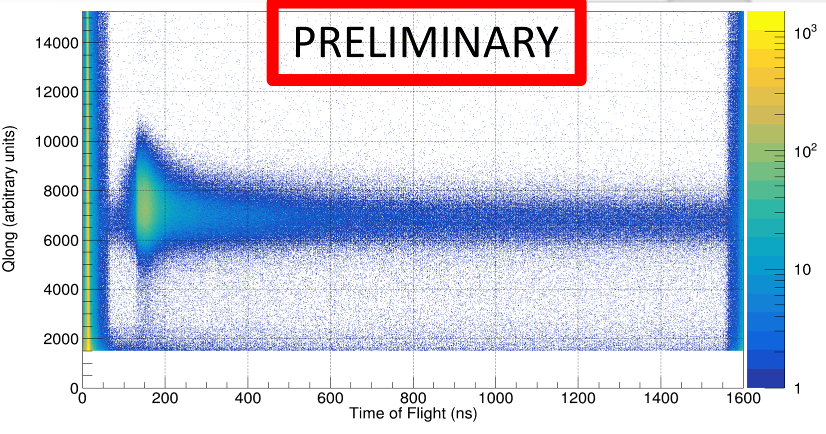
Beam chopper signals:

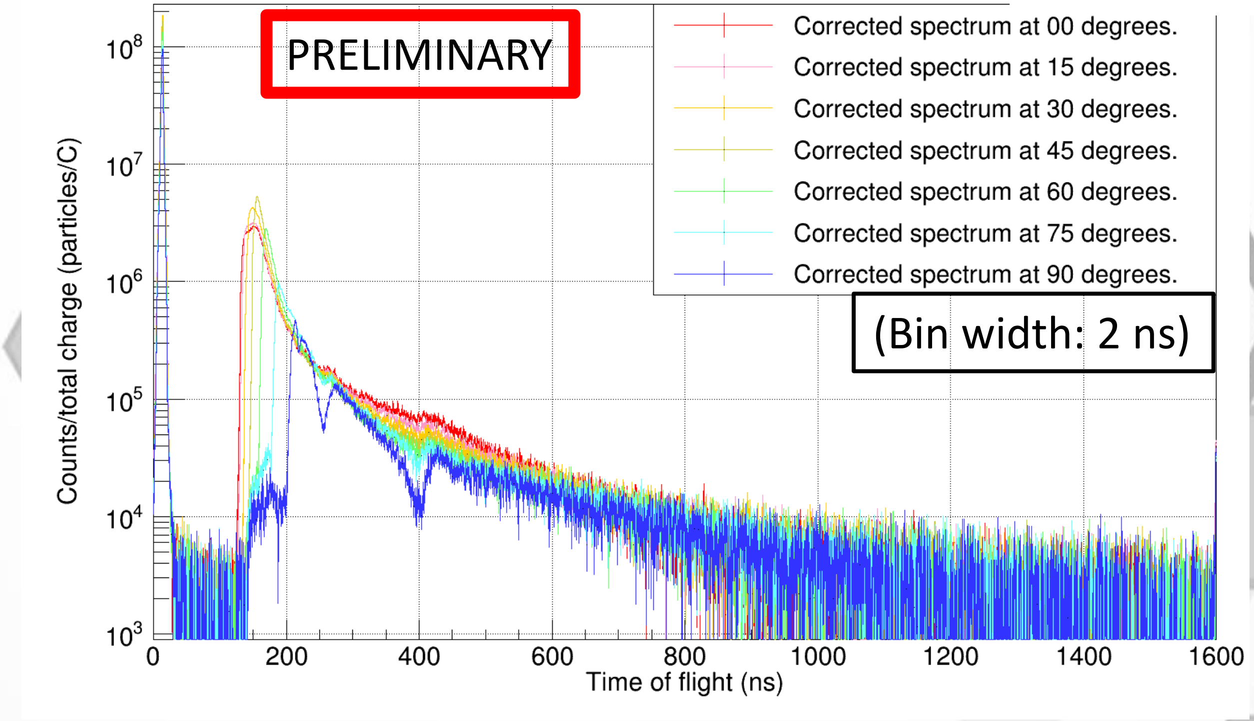


PKUP signals are faster (digitizer may have more problems detecting them) but Beam chopper signals require extra filtering due to the repetition rate that was used.

5A.1 – Neutron spectra and corrections:

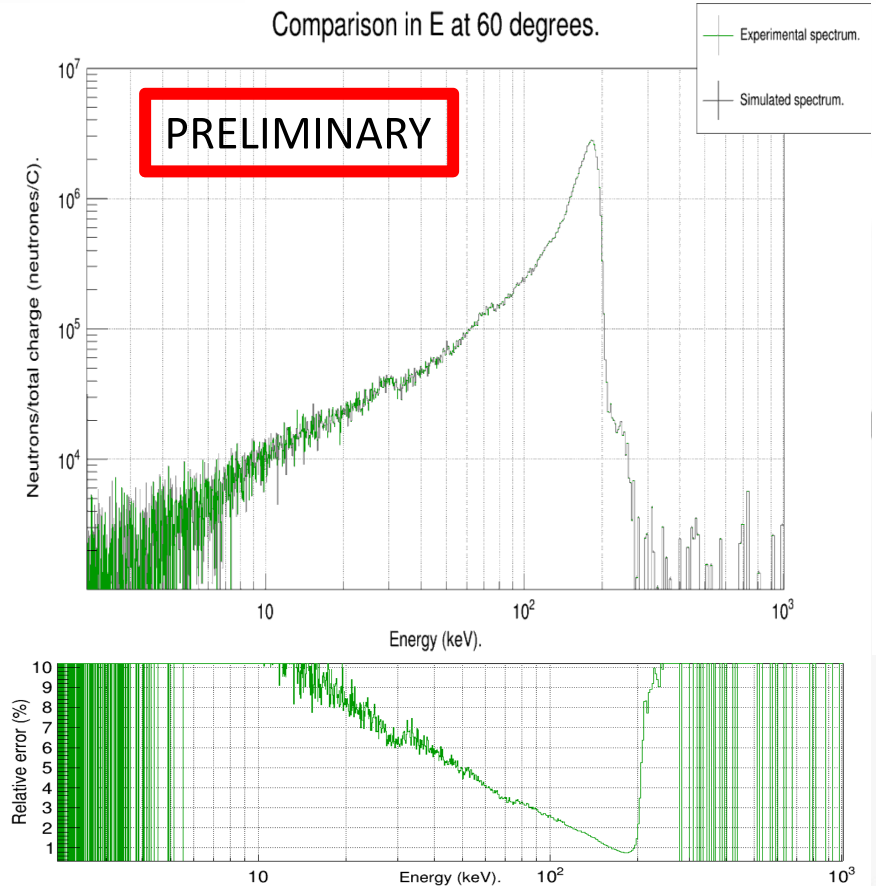
Correction:
1 → Electronic noise elimination: cut-offs at low and high qlong values.

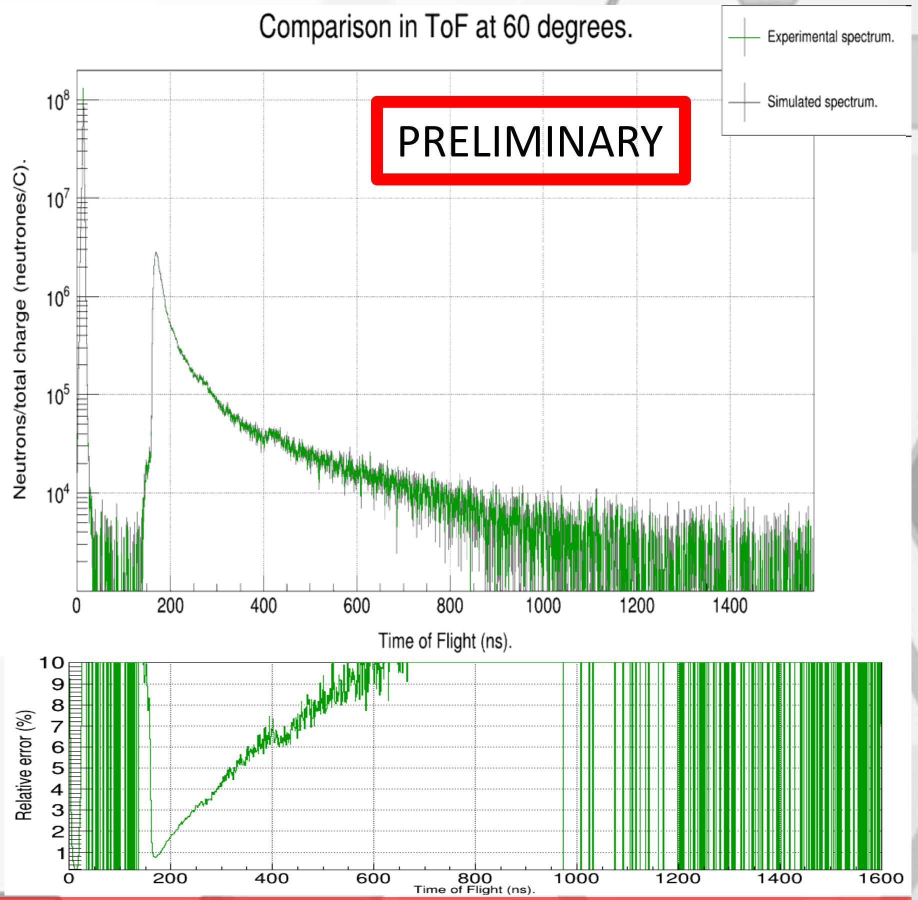




Corrections:
2 → Dead-time corrections.
3 → Background (past pulses stacking correction).

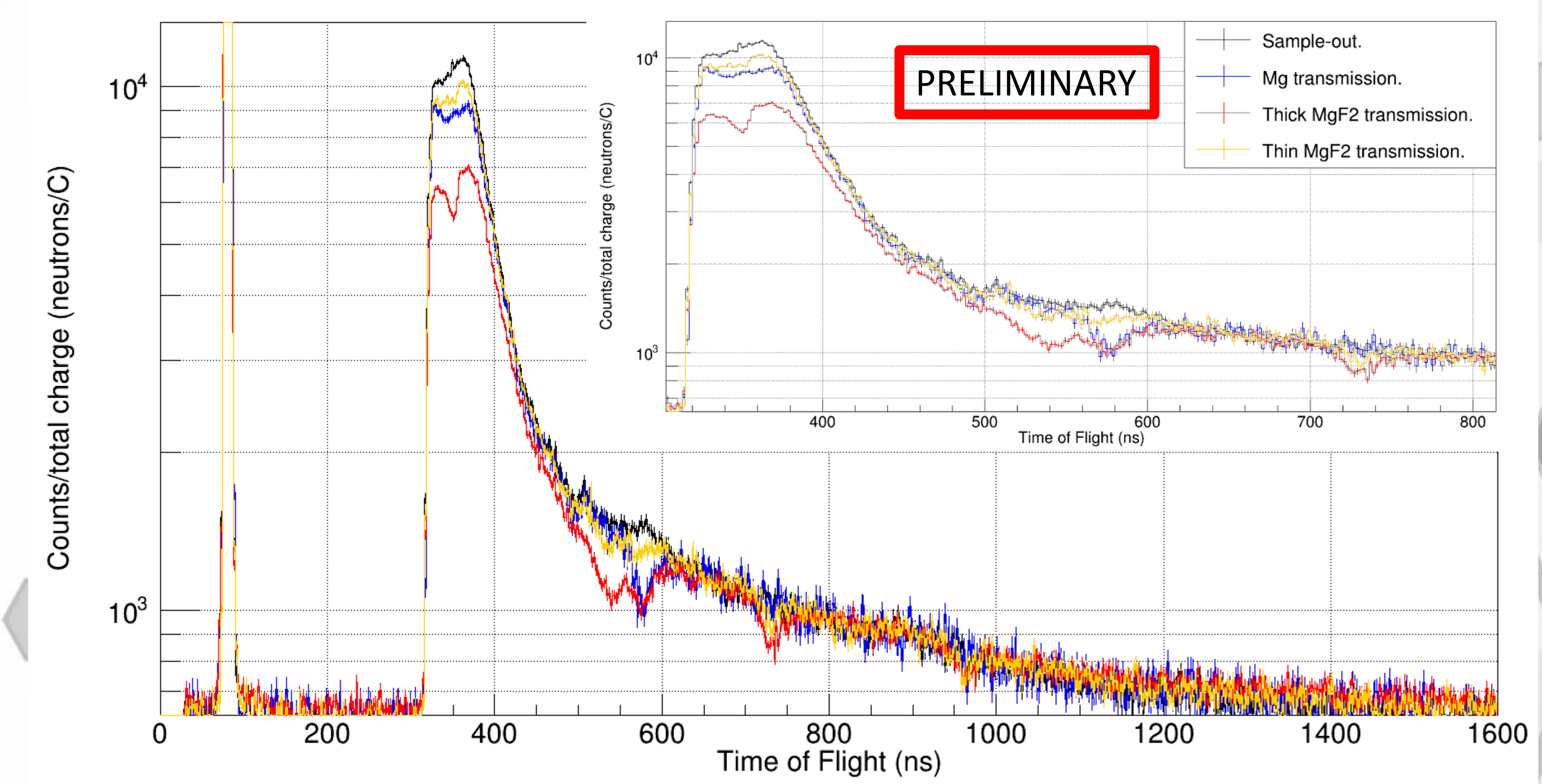
5A.2 – Comparison between experimental results and simulated spectra:





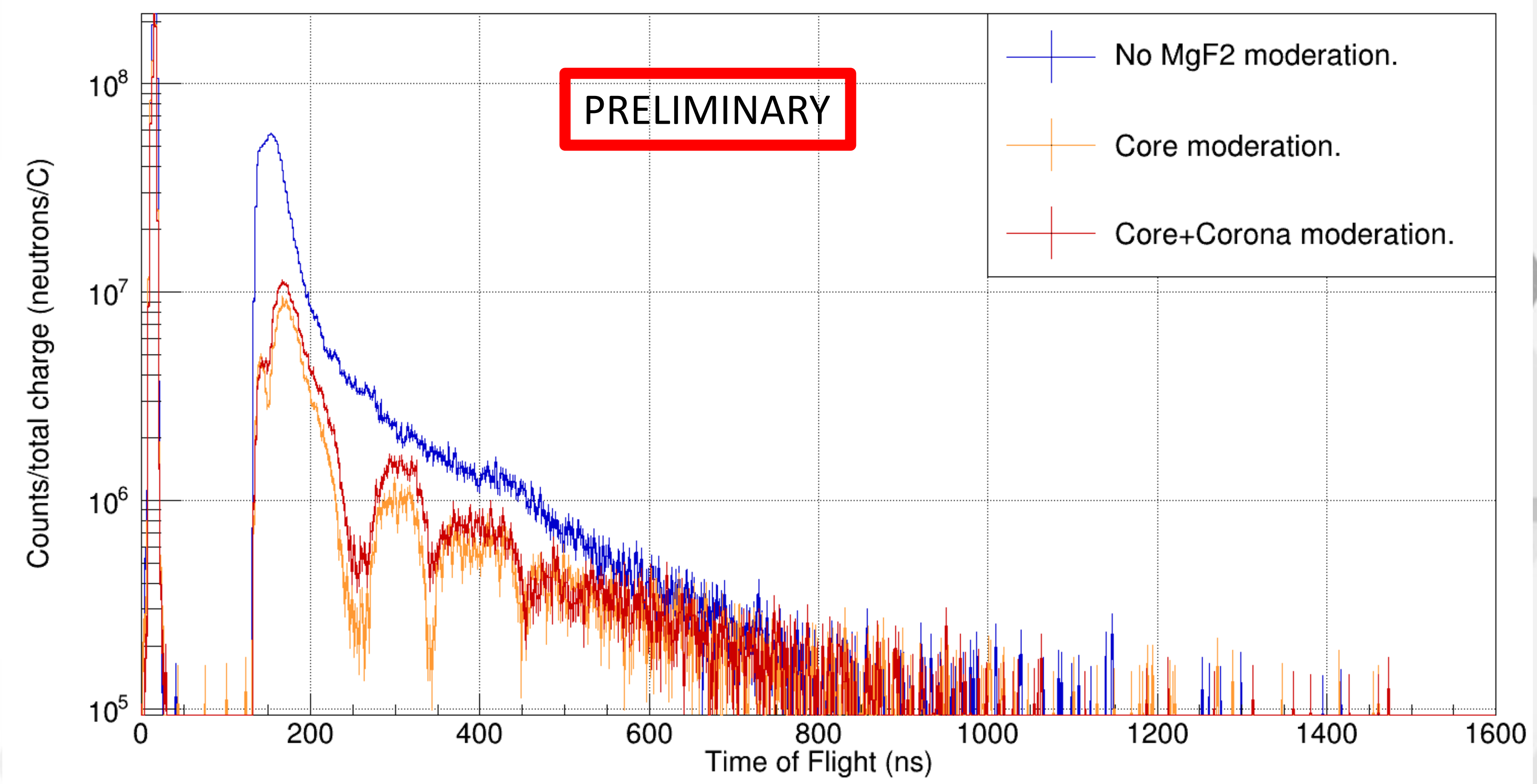
Some initial agreements: normalizations using the total charge, the energy range of interest, as well as the highest energy of neutrons around 350 keV, corresponding to the proton energy of 2.1 MeV, as expected.

5B – Transmission through samples:



The LiF should match the simulated spectra before the cross-sections are calculated!

5C – BSA comparison:



The LiF must match perfectly the simulated spectra and the measured cross-sections must be included before simulating the BSA moderation!

6 – Conclusions:

✓ Experiment was a great success, with almost everything planned to be measured favorably achieved.

☹ Only missing part was the study of the 19F capture reaction studying the gammas emission, due to timetable issues, but current plans ongoing to measure it in future experiments.

! Presented results are very preliminar.

→ Work in progress, much to be done yet.

? Any questions, suggestions or comments are more than welcome.

Thanks so much for listening!

7 – Acknowledgments:

Accelerator and Research reactor Infrastructures for Education and Learning

ARIEL

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(MONNET Team)

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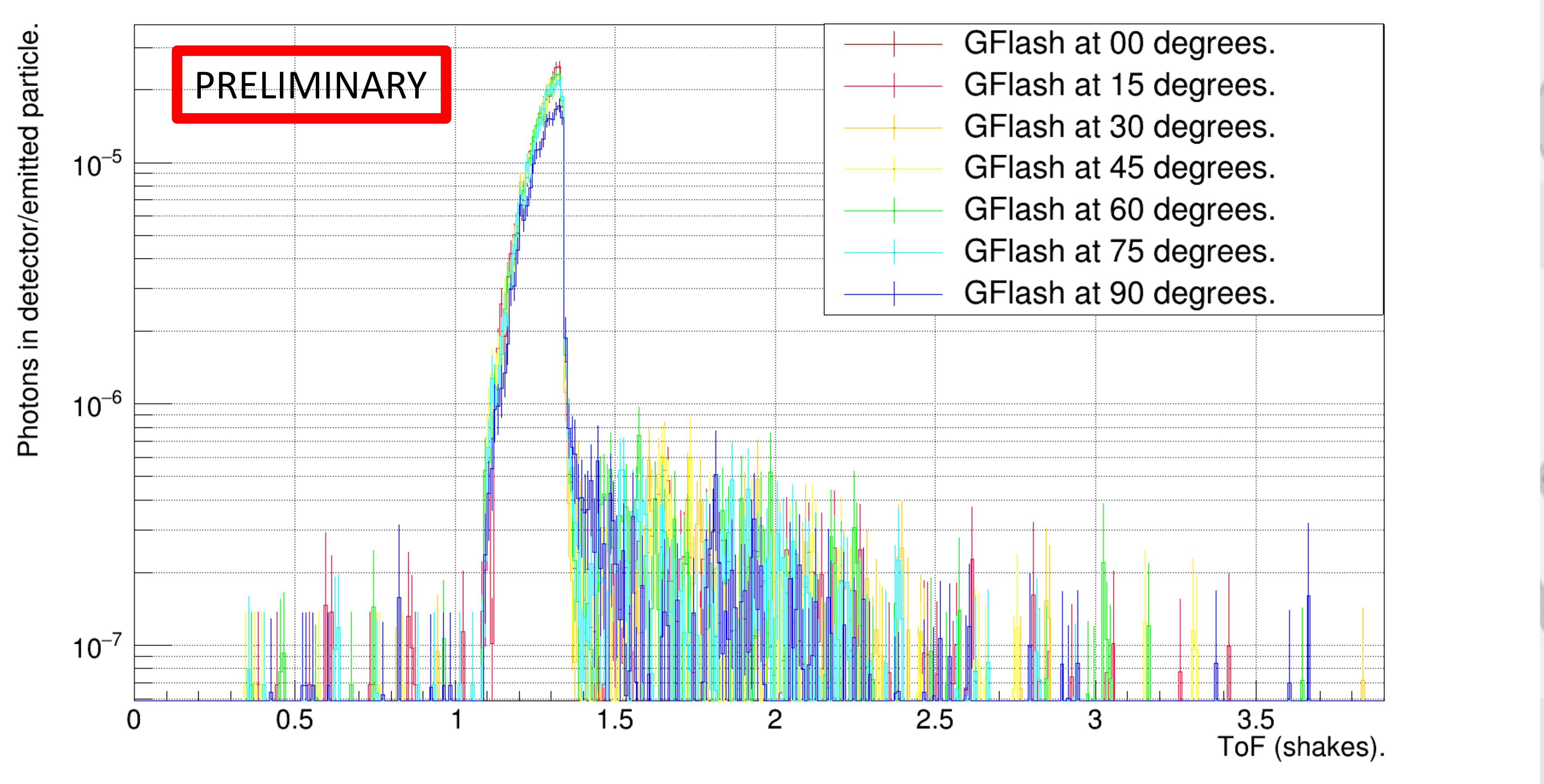
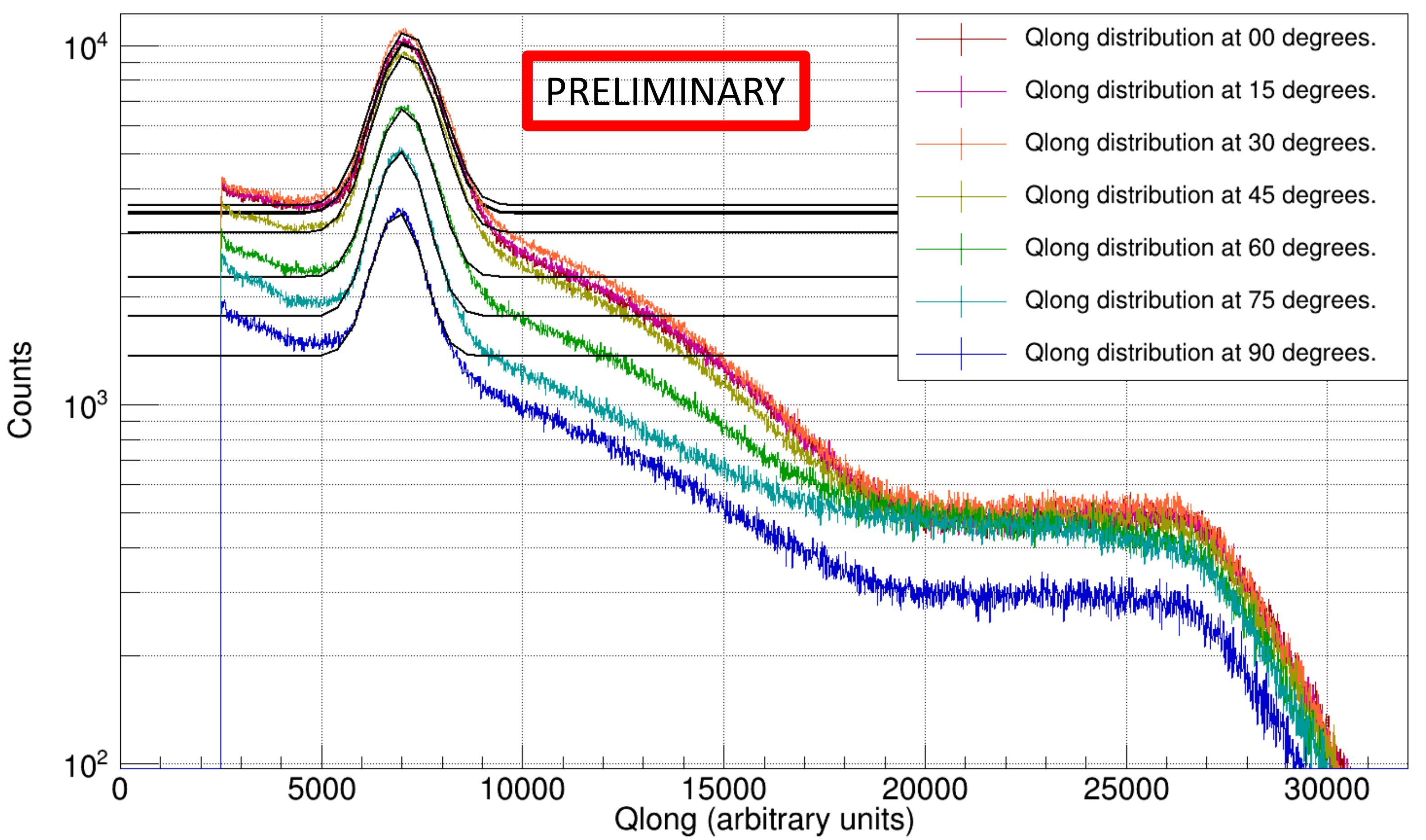
contra el cáncer

Appendix (I): γ-flash correction.



The time of flight is not directly obtained by time subtraction of a signal and the beginning of the pulse that produced it. Since there is an offset in timestamps due to the digitizers processing and length differences in the cables, it must be «manually» set. As reference, we take the position obtained via MCNP simulations.

Appendix (II): Electronic noise correction.



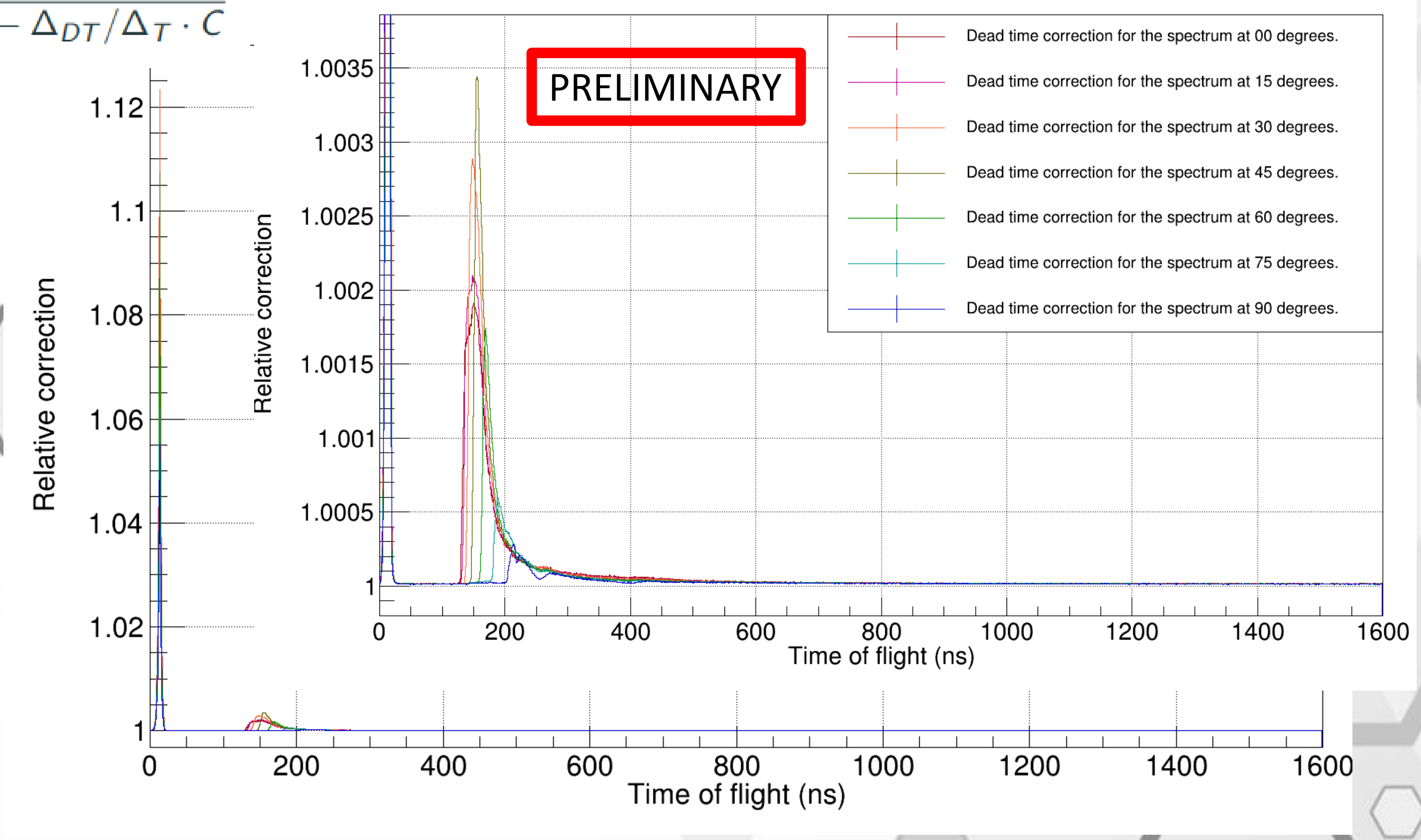
There are a lot of false signals at low energies (Qlong), while neutrons are scattered around a Qlong of about 6000, so we fit the shape produced by them over the decaying profile and evaluate how many of them were removed in the cut (luckily, less than 0.01%).

Appendix (III): Dead time corrections.

$$C_{DT}(C) = C \cdot f_R$$

$$f_R = \frac{1}{1 - \Delta_{DT}/\Delta_T \cdot C}$$

The correction of dead time is very small, since there were, in average, only 0.00001204073 counts/pulse.



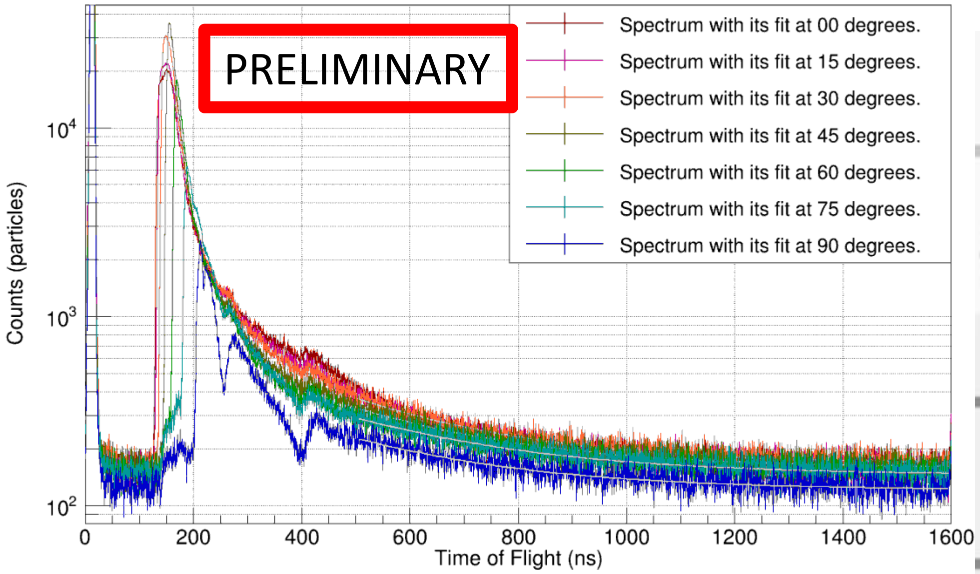
Appendix (IV): Background correction.

For a general decaying tail described by a function, C1(tof), the stacked background from past pulses when we are measuring a pulse N, would be:

$$C(tof) = \sum_{k=0}^{N-1} C_1(tof + 1600 \cdot k)$$

Let's try assuming an exponential shape («by the looks of it» and because it is easy to operate when N tends to infinity) and see if the experimental shape fits it:

$$C_1(tof) = a \cdot e^{-b \cdot tof} + c \implies C_N(tof) = \frac{ae^{-b \cdot tof}}{1 - e^{-1600 \cdot b}} + C$$

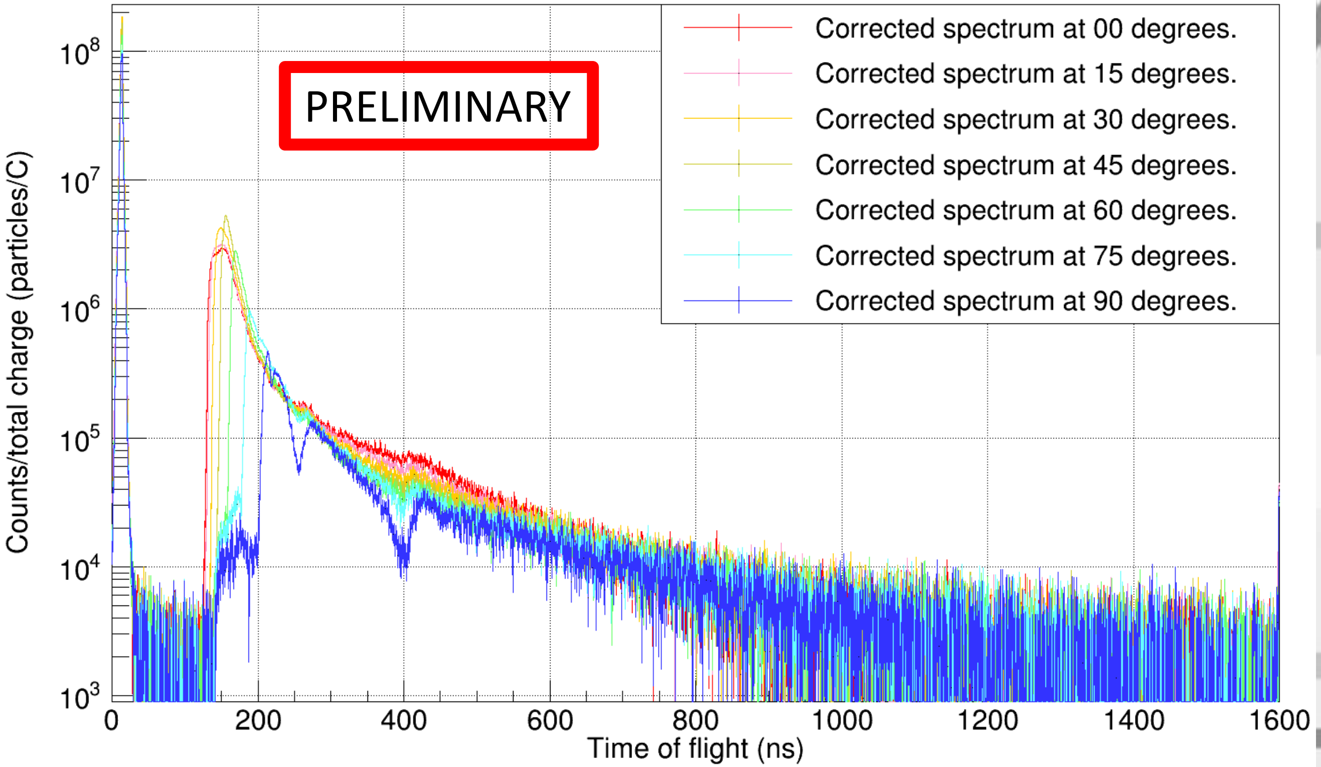


Appendix (IV): Background correction.

Seems to work well, so the correction that we must subtract would be:

$$S(tof) = \sum_{k=1}^{N-1} C_1(tof + 1600 \cdot k)$$

$$C_1(tof) = a \cdot e^{-b \cdot tof} + c \implies S(tof) = \frac{a e^{-b \cdot tof}}{e^{1600 \cdot b} - 1} + C$$



Appendix (V): Digitizer characteristics.

Digitizer model: **CAEN 5730ESB.**

Input signals are read by a Flash ADC, 14-bit resolution and 500 MS/s sampling rate.