n_TOF Physics Report

71st INTC meeting, CERN, 08/11/2022

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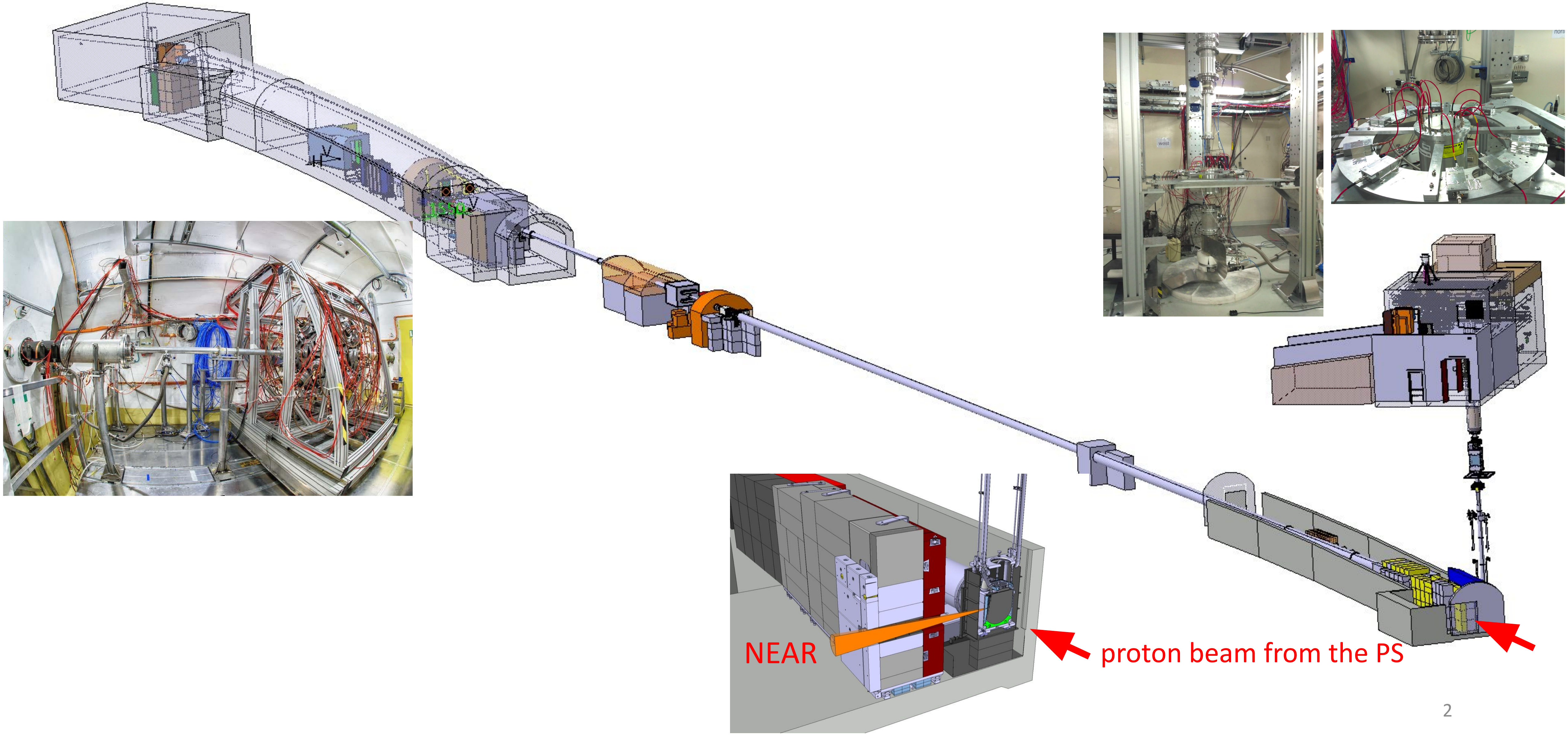
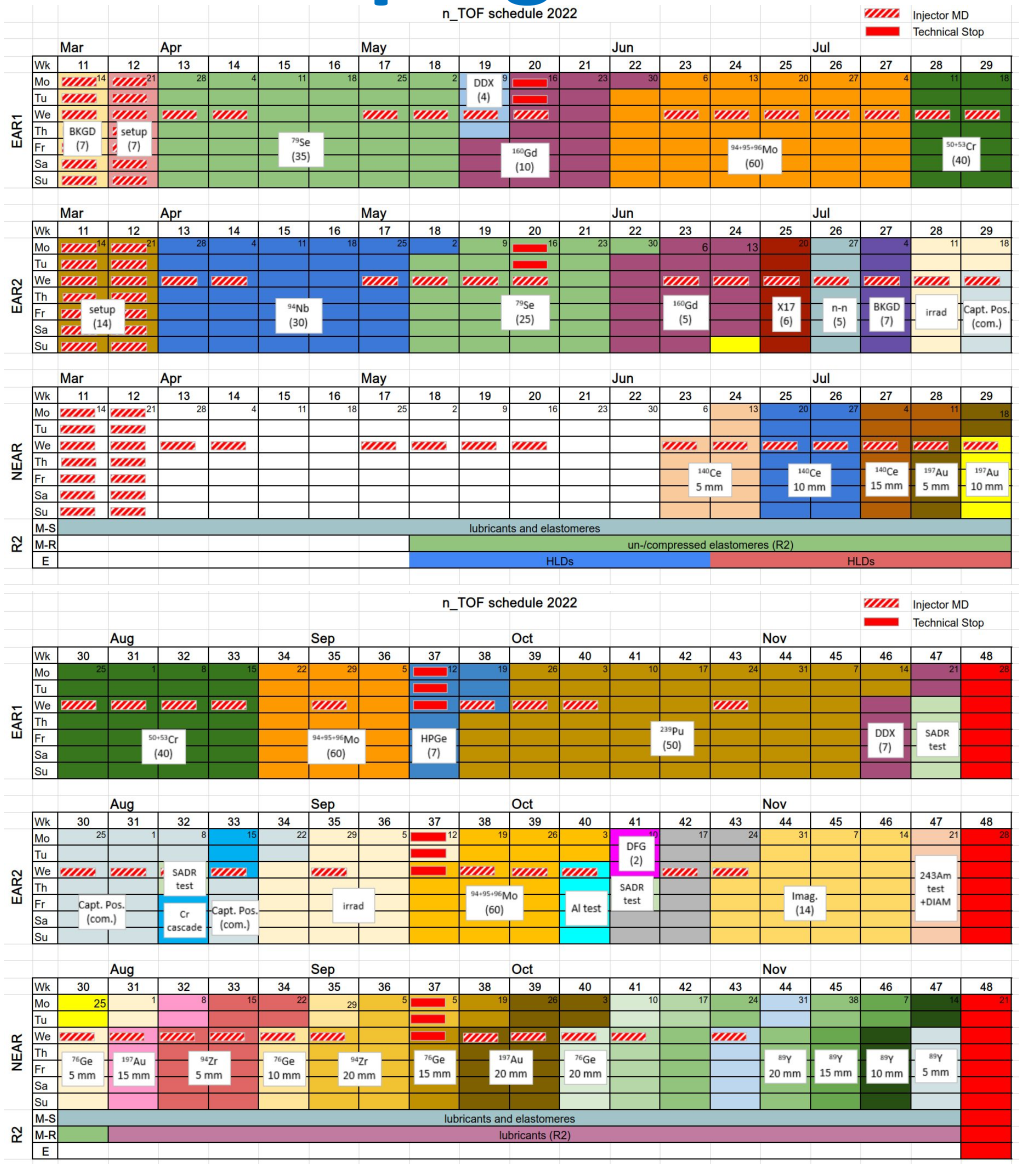
The n_TOF facility: EAR1 + EAR2 + NEAR



Highlights of the 2022 n_TOF campaign

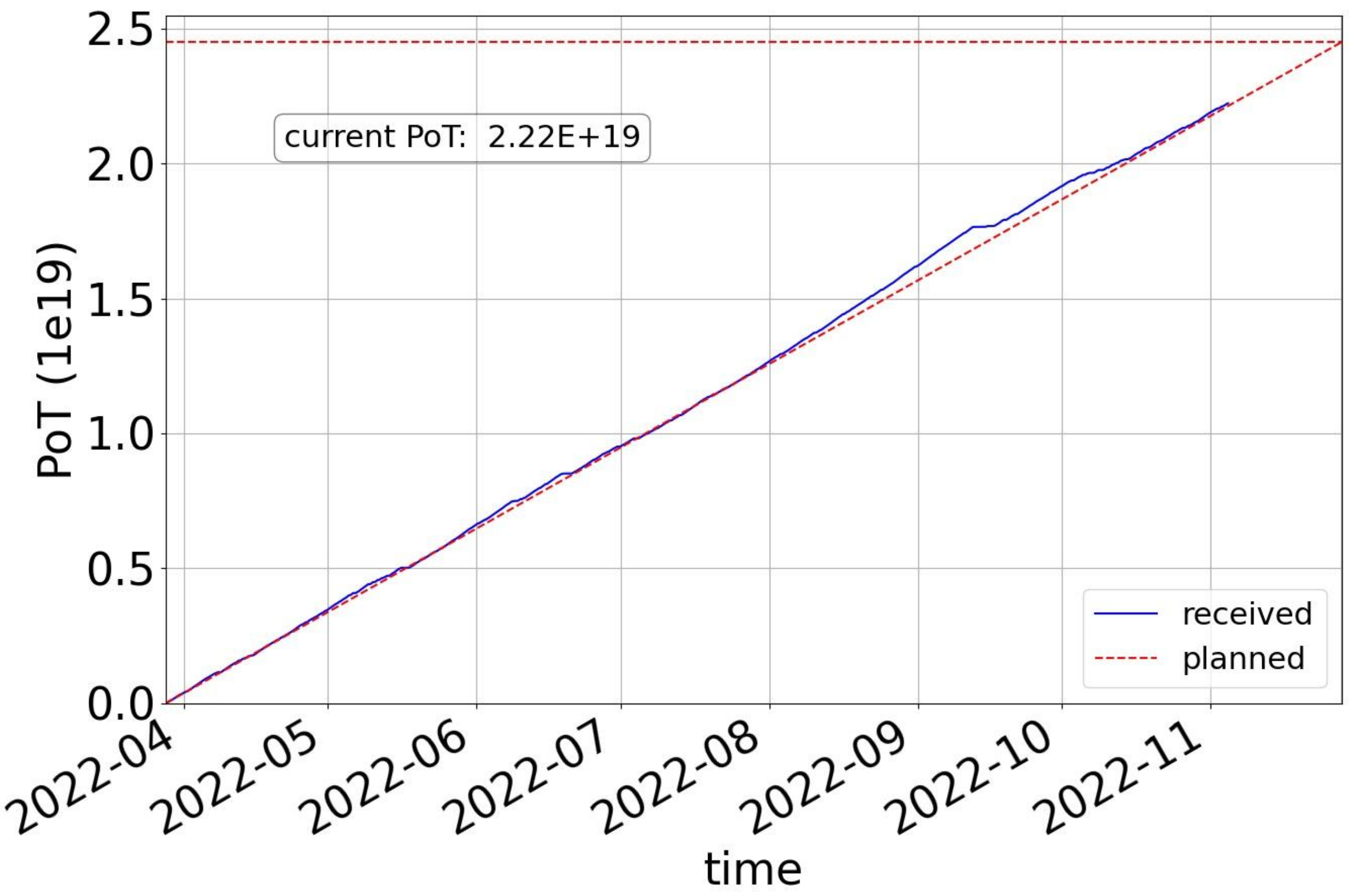
EAR1	EAR2	NEAR
• ^{79}Se(n,γ) • ^{160}Gd(n,γ) • ^{94,95,96}Mo(n,γ) • ^{50,53}Cr(n,γ) • ^{239}Pu(n,γ)(n,f)(a-ratio) • DDX det. dev. • HPGe test (postponed)	• ^{79}Se(n,γ) • ^{94}Nb(n,γ) • ^{160}Gd(n,γ) • ^{94,95,96}Mo(n,γ) • X17 detector test • nn scattering det. test • neutron imaging • diamond det. test (pending) • BKG and other commissioning actions	• ^{197}Au(n,γ) • ^{140}Ce(n,γ) • ^{76}Ge(n,γ) • ^{94}Zr(n,γ) • ^{89}Y(n,γ)

- 9 neutron capture reactions have been studied (2 of the for the first time)
- 5 neutron capture reactions have been studied at NEAR with different B4C filter configurations; Activation technique; MACS for different stellar temperatures; Some irradiations will continue on 2023
- 3 detector development projects have been accomplished
- 3 new detector setups have been successfully applied (iTED, sTED and beta-detection for NEAR)
- Diamond detector test (EAR2) is scheduled on week 47
- ^{239}Pu fission tagging measurement is ongoing (had to be extended in time) - EAR1
- neutron imaging is ongoing - EAR2



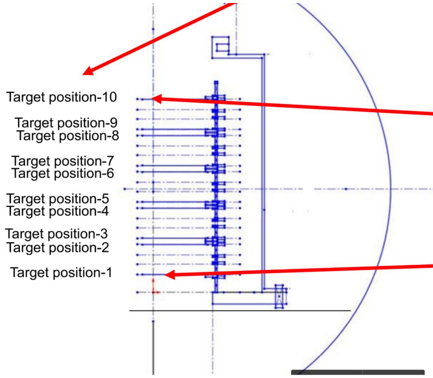
PoT status

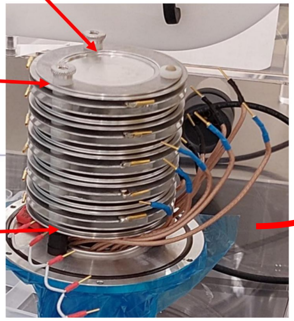
- We are receiving the expected number of protons
- The ^{239}Pu campaign had to be prolonged as to get the approved # protons.
- Many thanks to the PS teams!

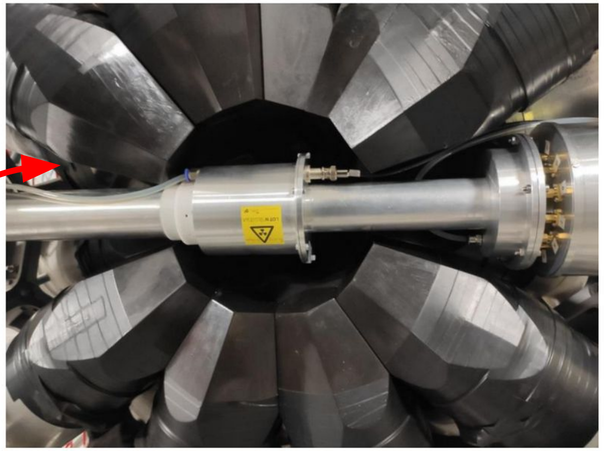


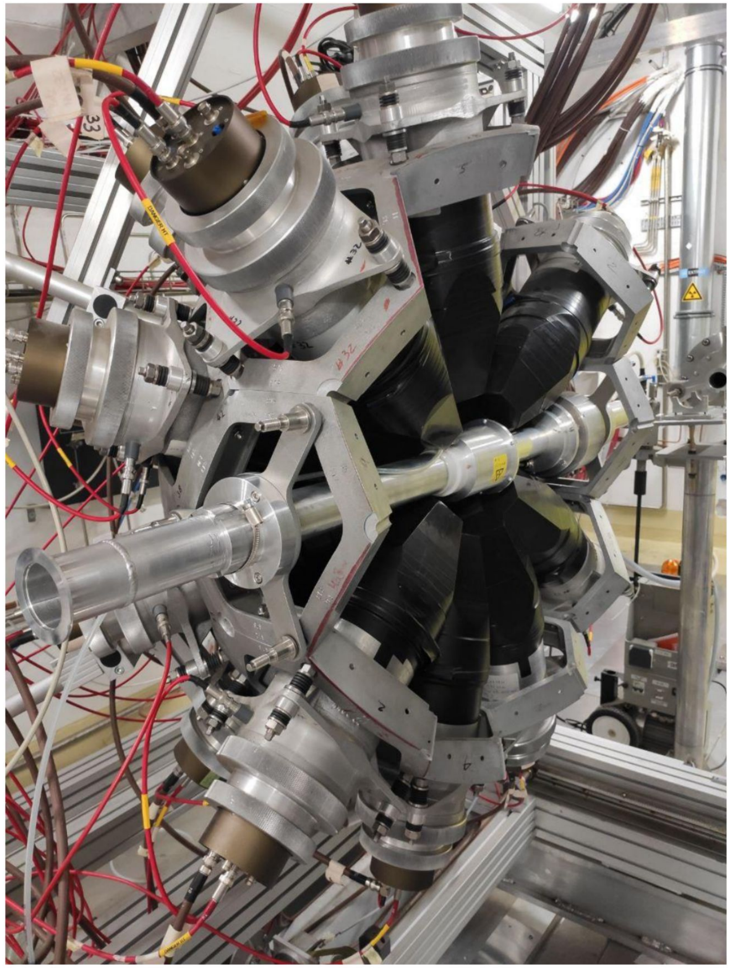
^{239}Pu(n,γ) with fission tagging

- ^{239}Pu plays a central role in the operation of fast reactors and ADS systems
- More accurate ^{239}Pu capture and fission cross section data are needed
- The goal is to measure simultaneously the neutron-induced capture and fission rates with fission tagging
- fission events recorded with ~92% efficiency in the fission chamber
- Recording singles, coincidence and anticoincidence events between TAC and fission chamber we can determine the α-ratio = (n,γ) and (n,f) cross section ratio
- challenging measurement: ~2MBq/mg, data flow: 1TB/h
- Two targets 330 MBq and 33 MBq





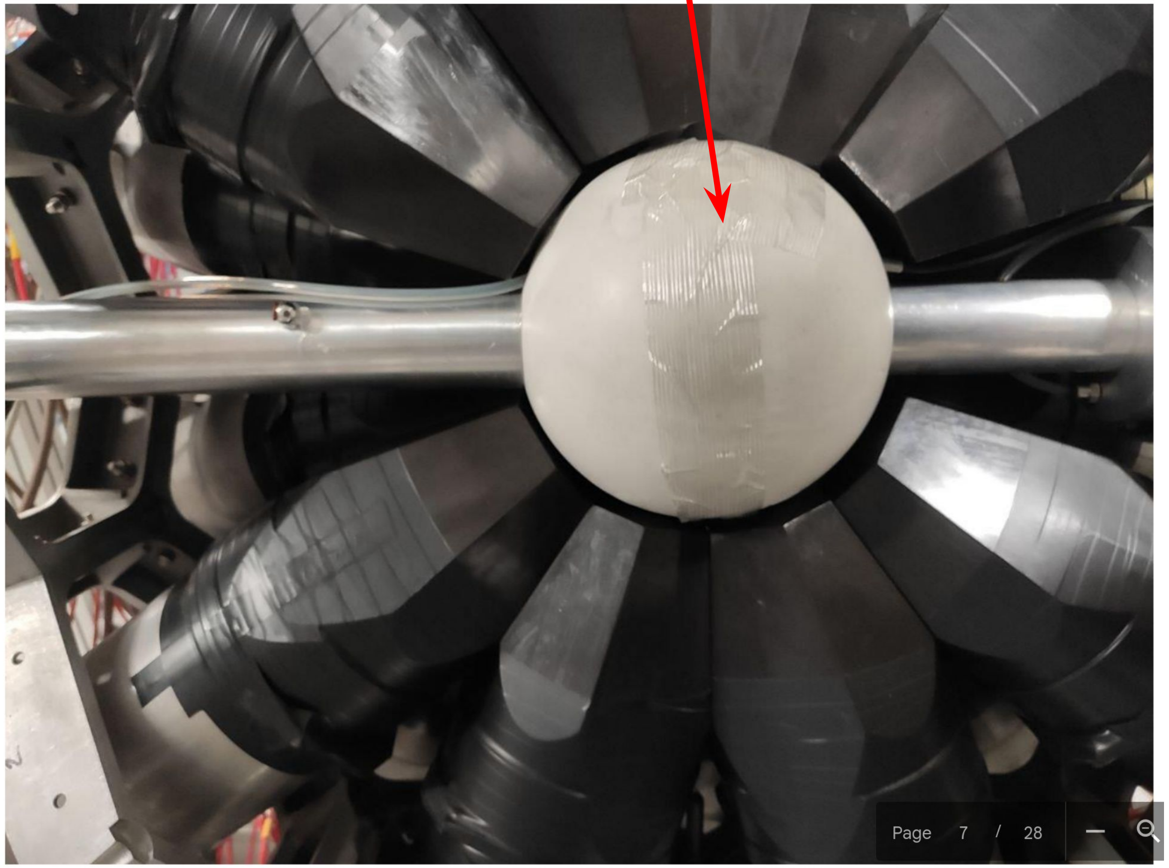


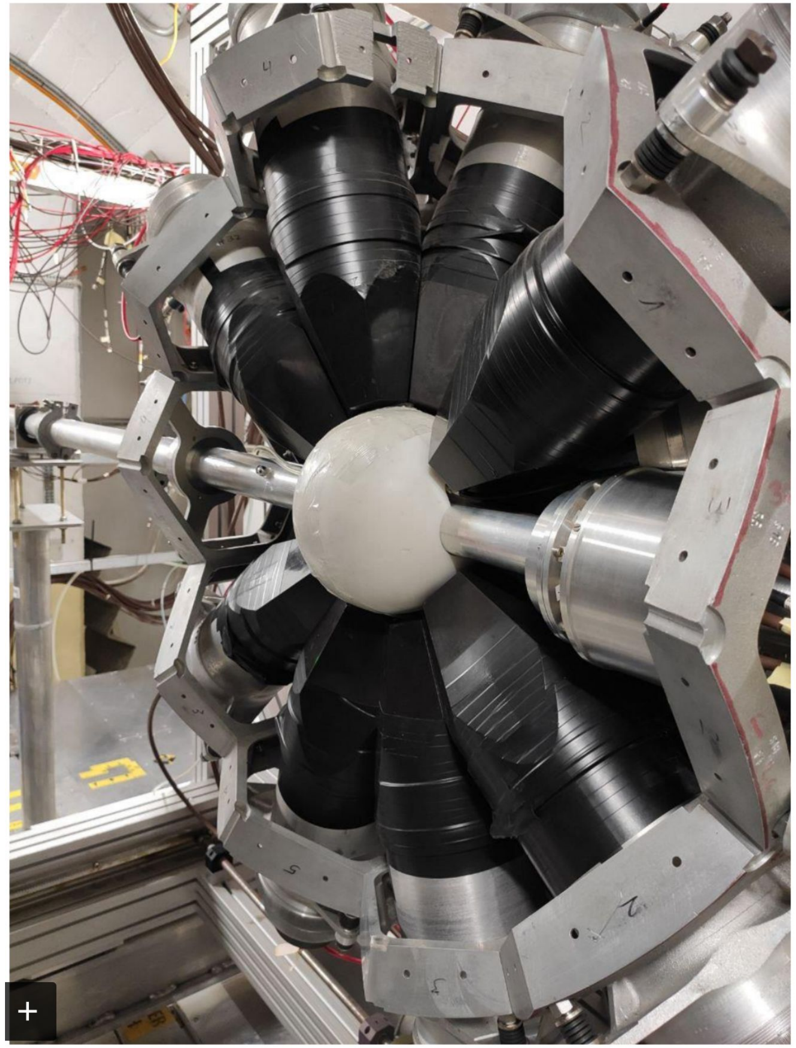


Many thanks to CIEMAT group: Adrian Sanchez Caballero, Victor Alcayne, Daniel Cano Ott,...

^{239}Pu(n,γ) with fission tagging

PE-Li neutron absorber





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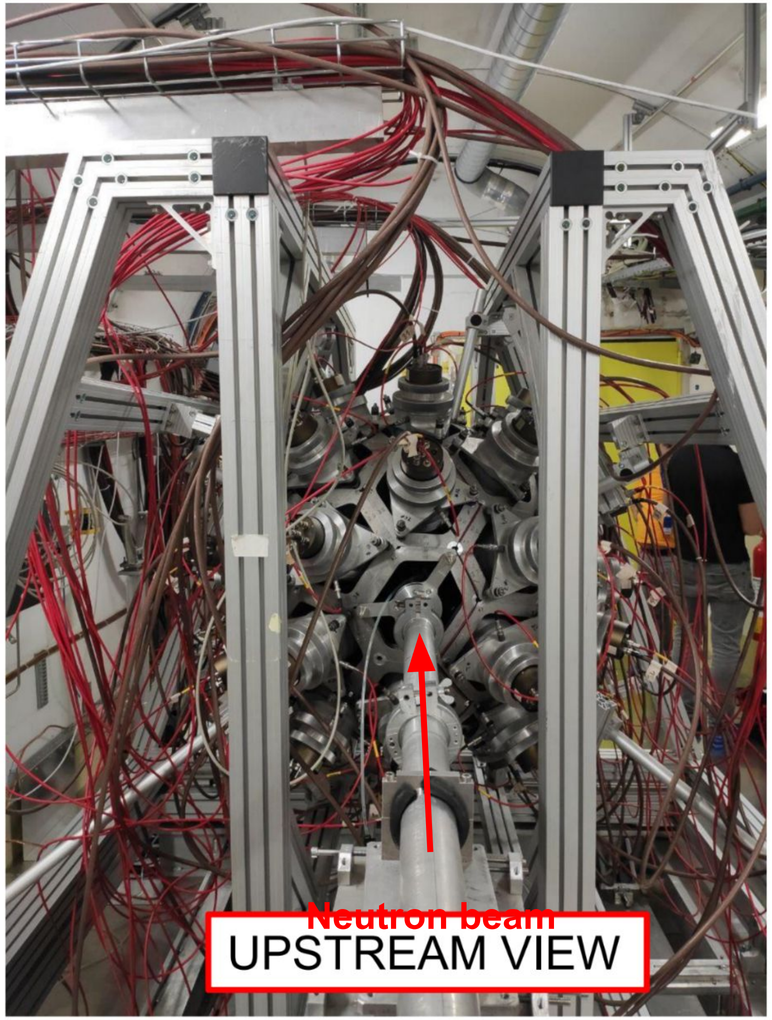
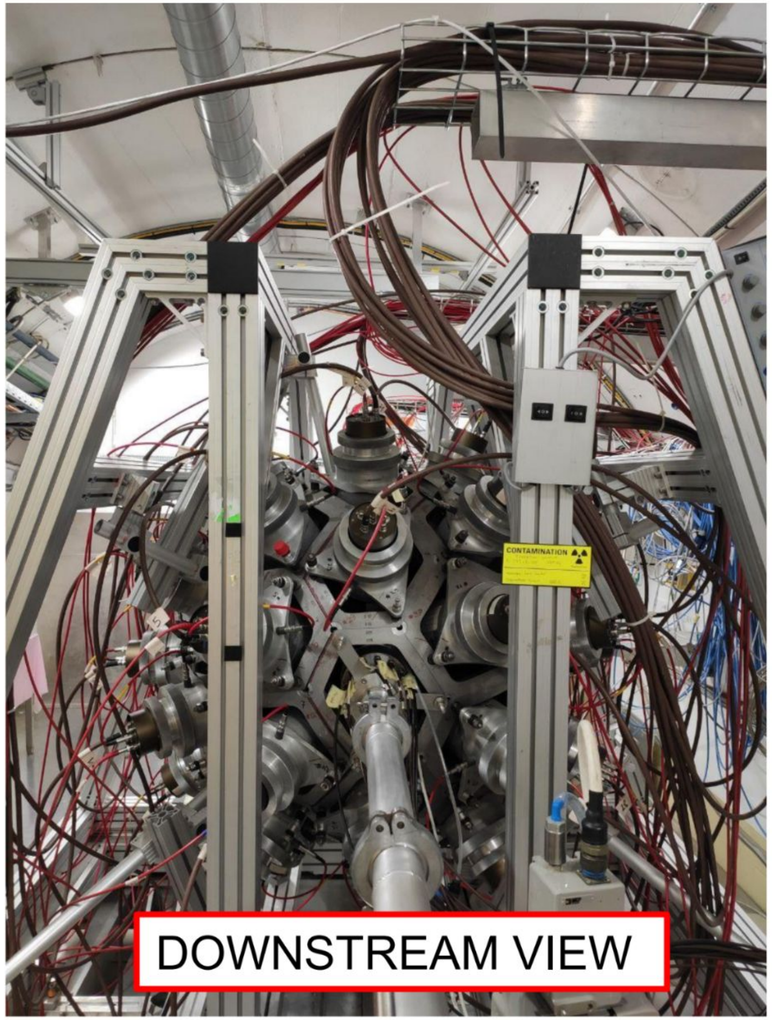
^{239}Pu(n,γ) with fission tagging

Final setup: TAC closed





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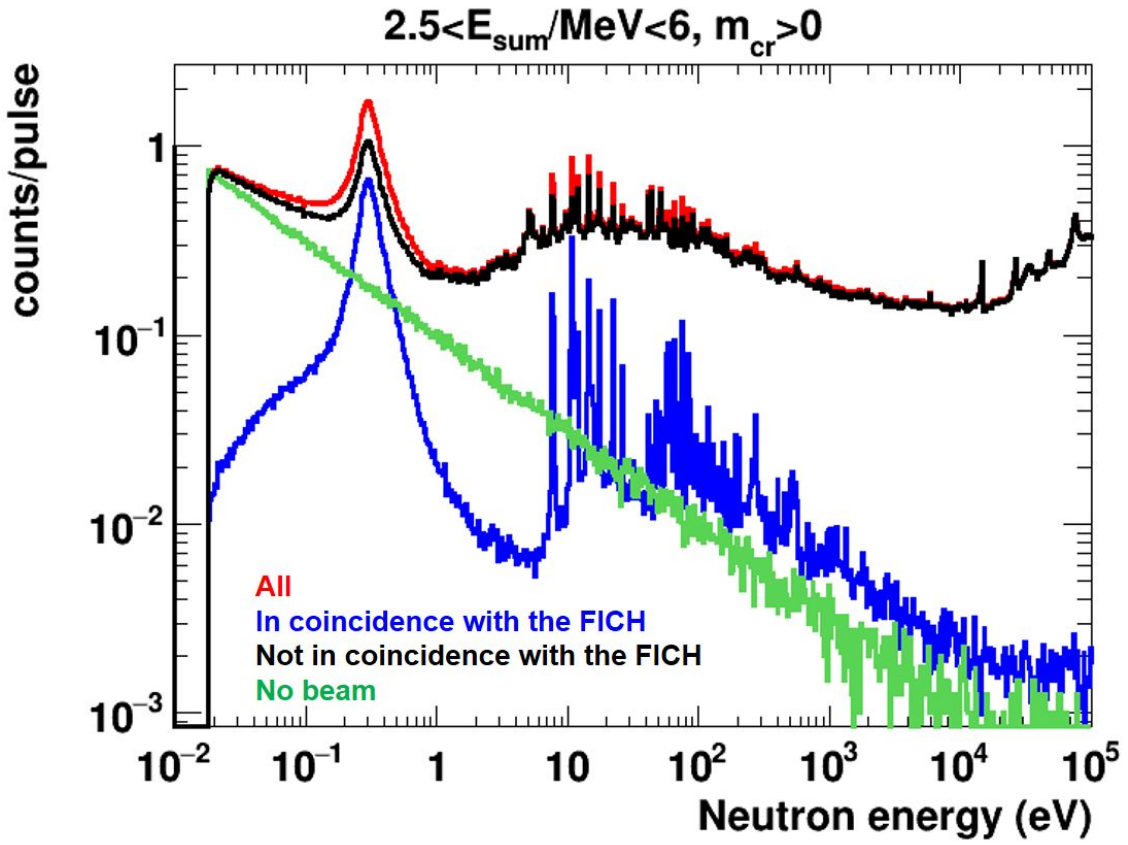
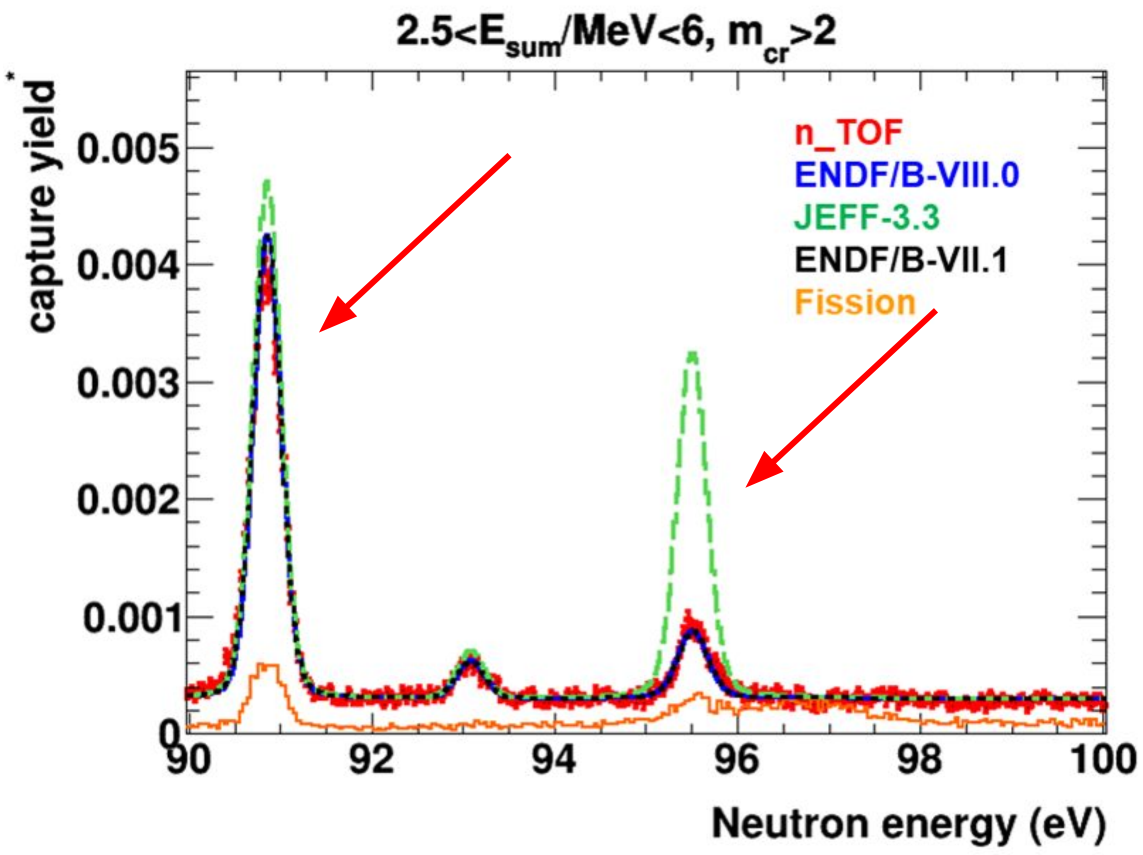
$^{239}Pu(n,\gamma)$ with fission tagging





Deviations between JEFF-3.3 and ENDF/B-VIII can be nicely resolved through n_TOF data

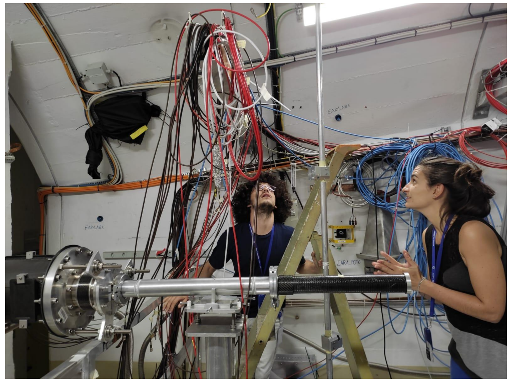
Many thanks to CIEMAT group: Adrian Sanchez Caballero, Victor Alcayne, Daniel Cano Ott,...

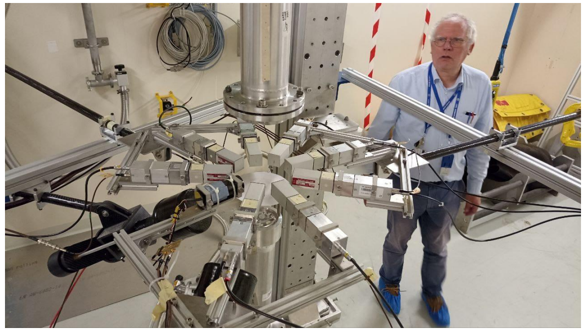
Conclusions

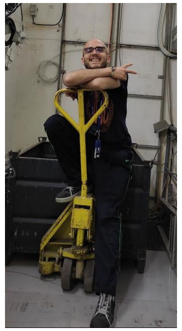
- So far we had a smooth 2022 n_TOF campaign
- 9 neutron capture reactions were studied (astrophysics & energy applications); two of them for the first time
- Measurements with low mass samples (mg) can be performed thanks to the development of new detection setups and thanks to neutron beam improvements is EAR2
- Several detector tests were successfully performed. From first results we are confident that n_TOF is ready to launch new type of measurements in the near future
- The n_TOF target works nicely and smoothly. We can even go from 165E10pps to 220E10 pps (many thanks to SY-STI group!)
- The delivered protons are following our expectations (many thanks to PS teams!)
- A lot of data have to be analysed. Thankfully our enthusiastic young colleagues are there (Jose, Francisko, Elisso, Riccardo, Stella, Pablo, Adrian,...)

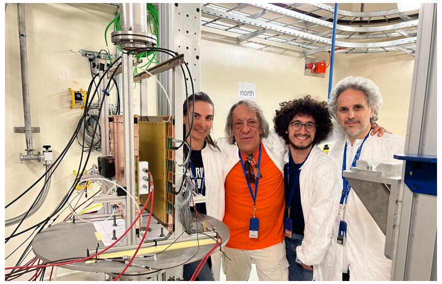
Many thanks to the n_TOF local team!

Alberto Mengoni, Michael Bacak, Alice Manna, Simone Amaducci, Adria Casanovas, Victor Alcayne, Francisco Garcia, Jose Antonio Pavon Rodriguez, Elisso Stamati, Stella Goula, Roberto Zarrella, Jorge Lerendegui, …









Thank you so much for attention!

^{239}Pu(n,γ) with fission tagging

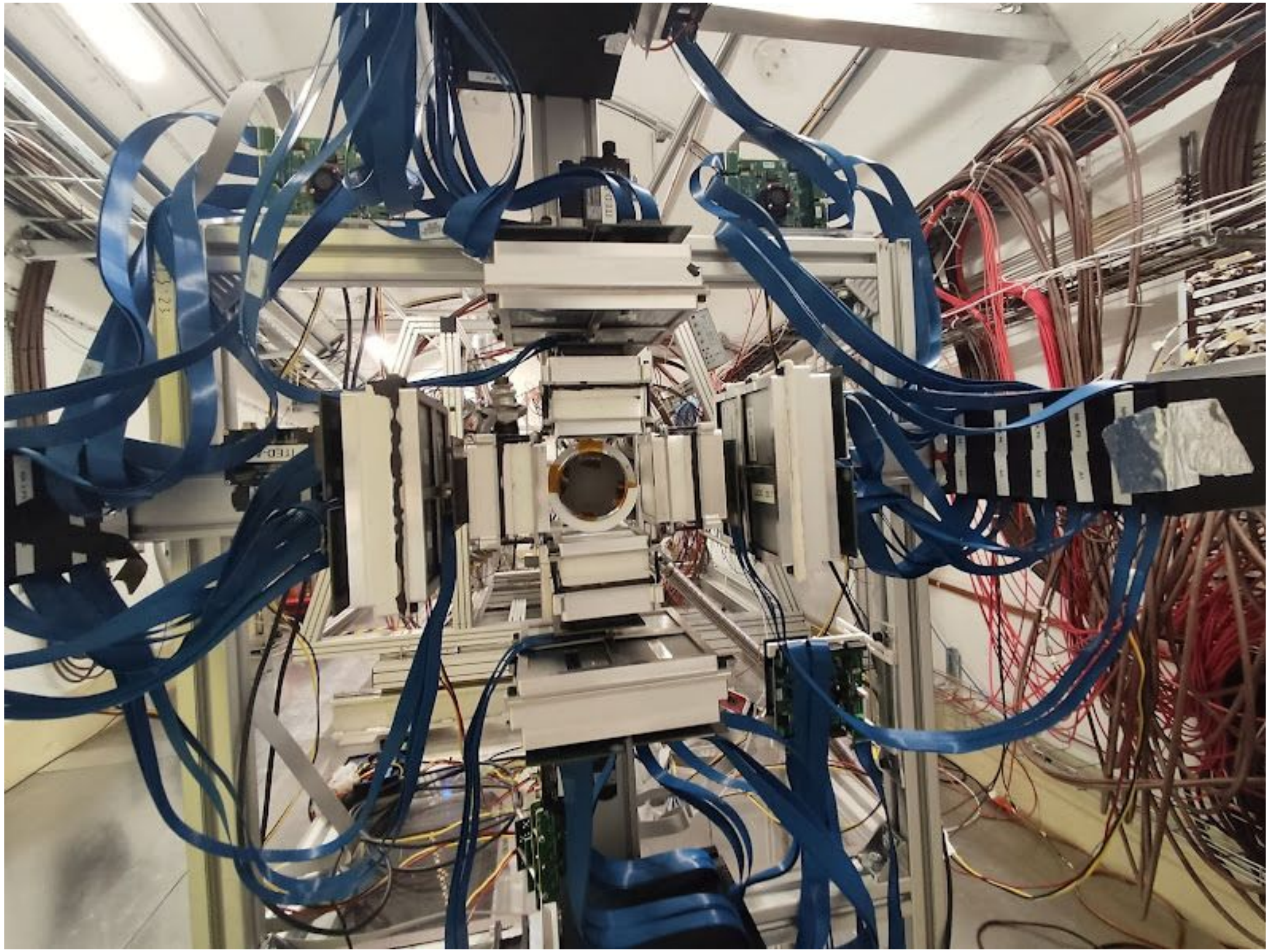
Motivation

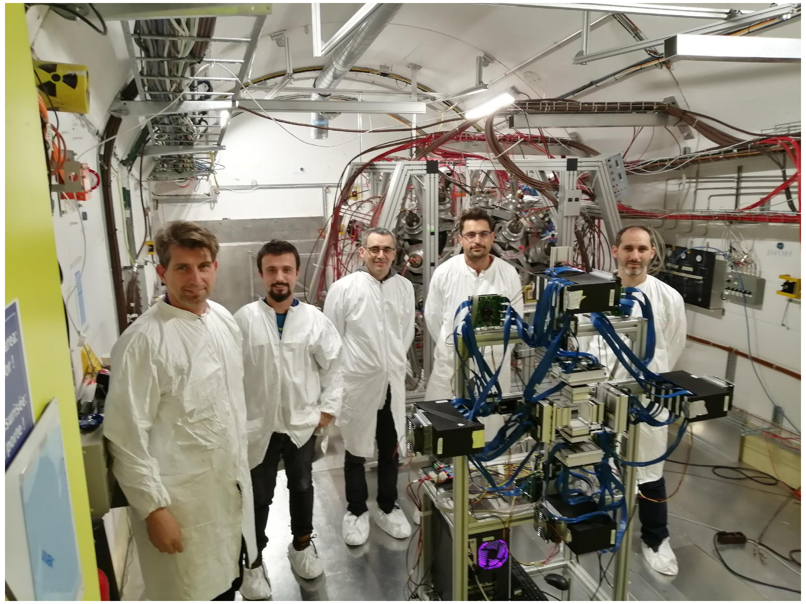
- 239Pu plays a central role in the operation of fast reactors
- More accurate 239Pu capture and fission cross section data are needed
- The **goal is to measure simultaneously the neutron-induced capture and fission rates**

Details of the experiment

- **Objective**: measuring the ^{239}Pu (n,γ) and (n,f) cross section (α-ratio).
- **NEW fission chamber** (University of Lodz) with **~10 x 1mg ^{239}Pu targets** (JRC-Geel).
- **NEW thick ^{239}Pu (100 mg) encapsulated sample** (JRC-Geel)
- **NEW neutron absorber** (designed by CIEMAT and fabricated by CERN)
- **NEW pipes and structure material** for the fission chamber inside the TAC (made by O. Aberle and O. Fjeld)
- **NEW pulse shape analysis routine** for both Fission Chamber and Total Absorption Calorimeter
- Total protons: 5×10^8
  - 3×10^8 Fission Chamber configuration
  - 2×10^8 thick sample configuration

$^{79}Se(n,\gamma)$ @ EAR1 & EAR2



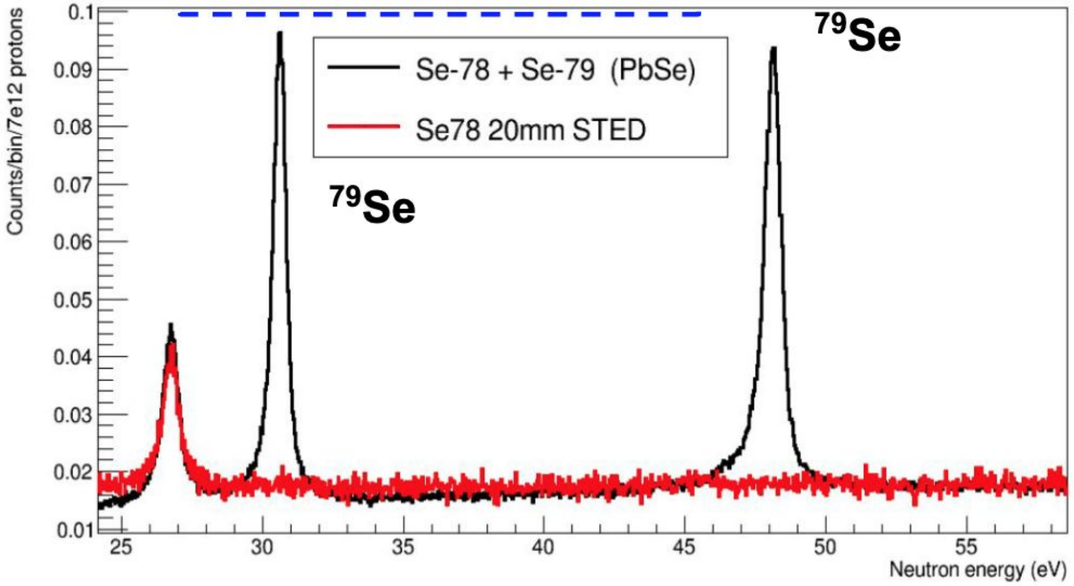


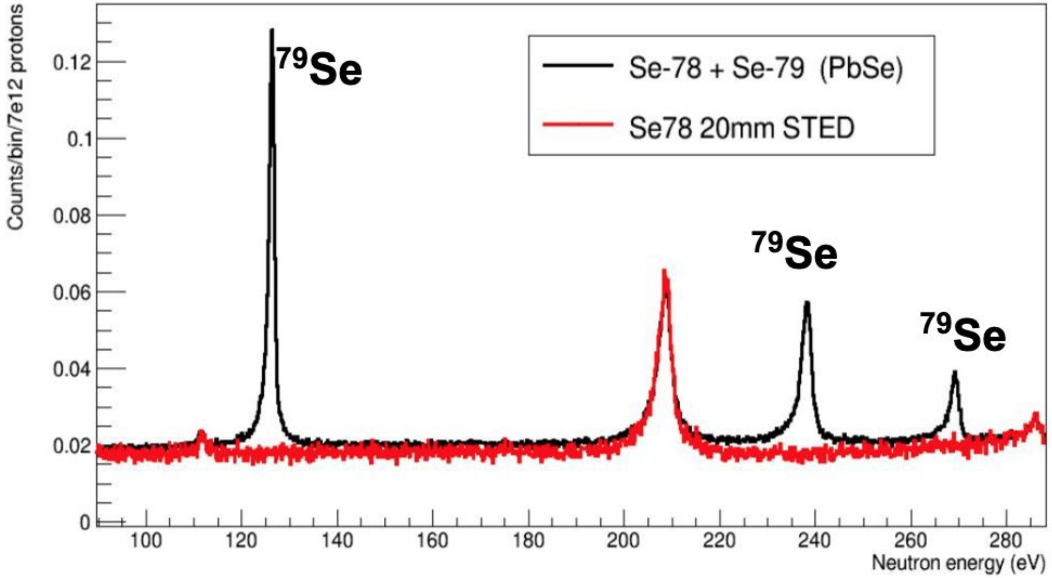
$^{79}Se(n,\gamma)$ @ EAR1 & EAR2

Resonances of Se-79 First ever measured!

Only dedicated :
~1.25e18p

- **Se-78 disc** vs **Se-79 (PbSe) sample**
- Sum of the STEDs is plotted

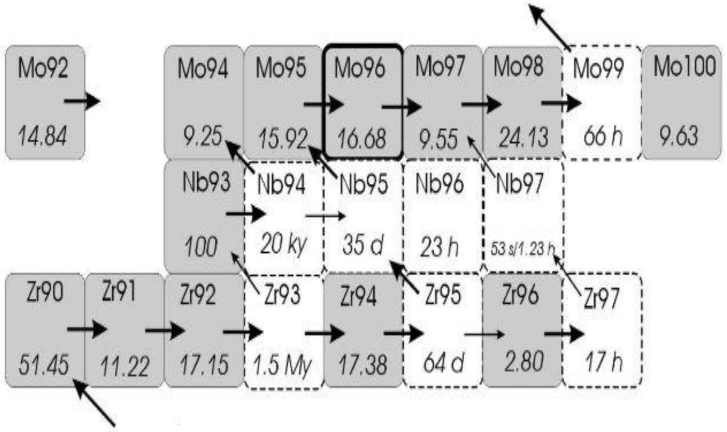




5 resonances below the first large resonance of Se-78 at 400 eV

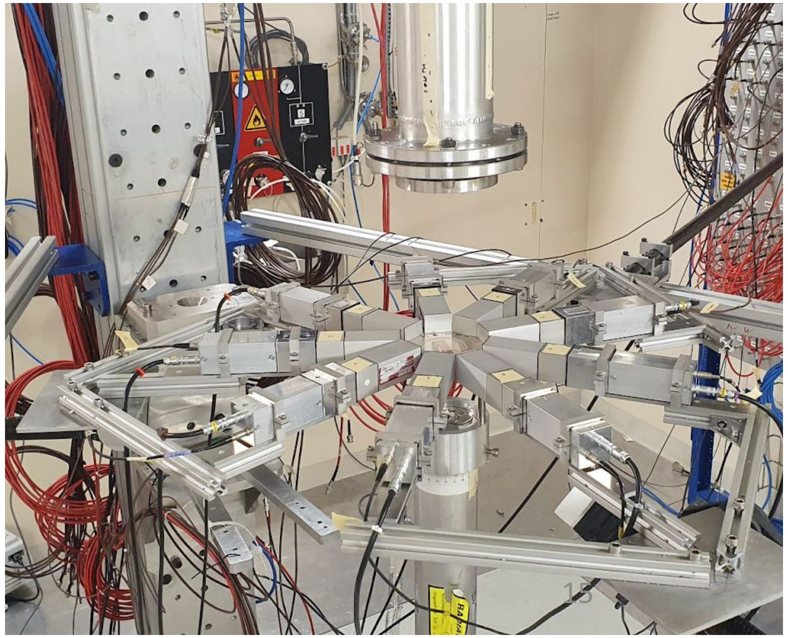
Thanks to Jorge Lerendegui, Cesar Domingo et al. (IFIC)

^{94}Nb(n,γ) XS @ EAR2

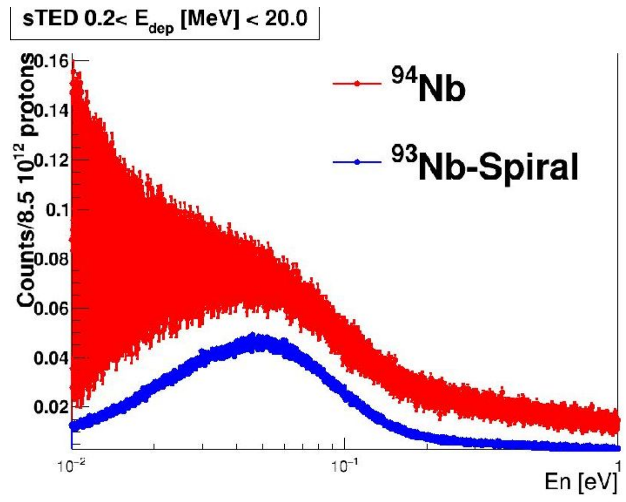


- Physics motivation:
  - The predicted s-process abundance of Mo-94 is five times less than the observed (SiC grains from Murchison met.)
  - No exp. data in the resolved and un-resolved resonance energy region
  - Nuclear waste disposal and transmutation
- Sample: ^{93}Nb irr. @ ILL, PSI preparation & characterization
- sTED – n_TOF detector development

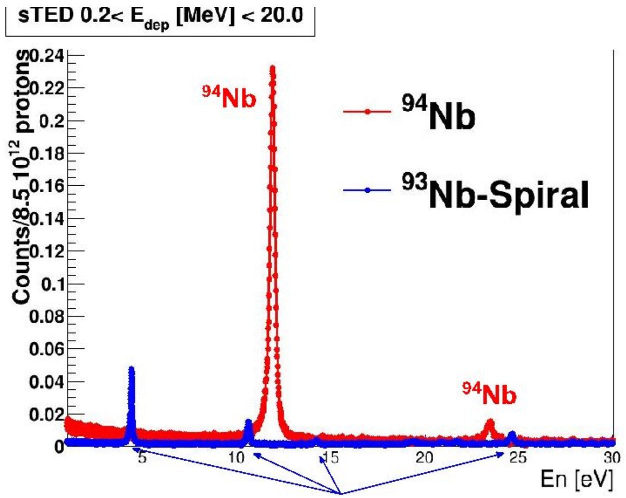
  ***s**egmented TED detector – for high rates (EAR2)*
  - C_6D_6 liquid scintillators (future: investigating inorganic scint.)
  - 1/20 smaller volume (to resolve rate & γ-flash issues @ EAR2)
  - SiPMs – smaller volume/mass for interaction with γ-flash



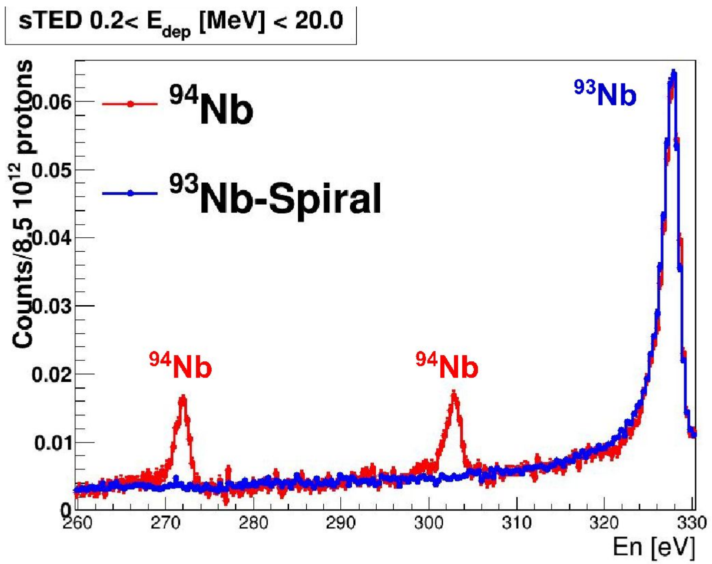
^{94}Nb(n,γ): Some of the identified resonances

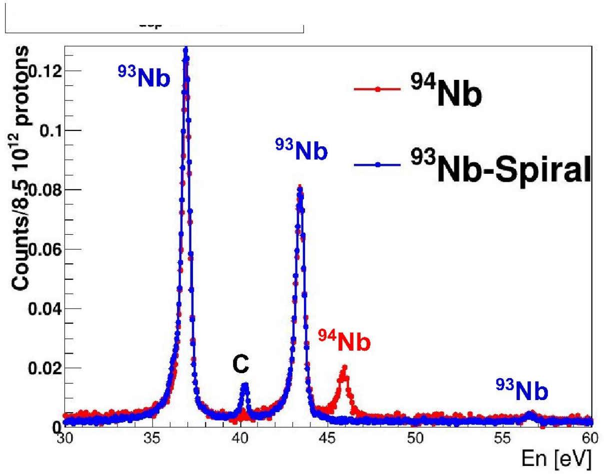


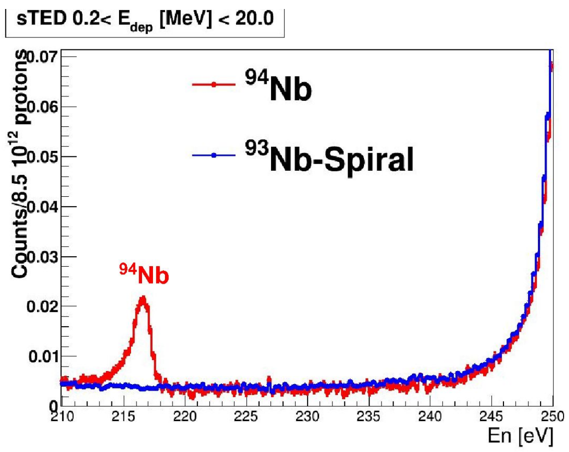
Large Nb-94 thermal cross-section (as expected)

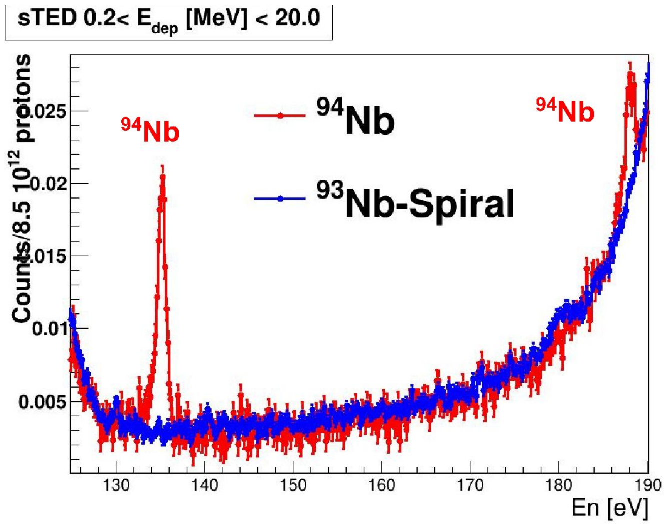


Multiple resonances contaminants in Nb93-spiral (as expected)



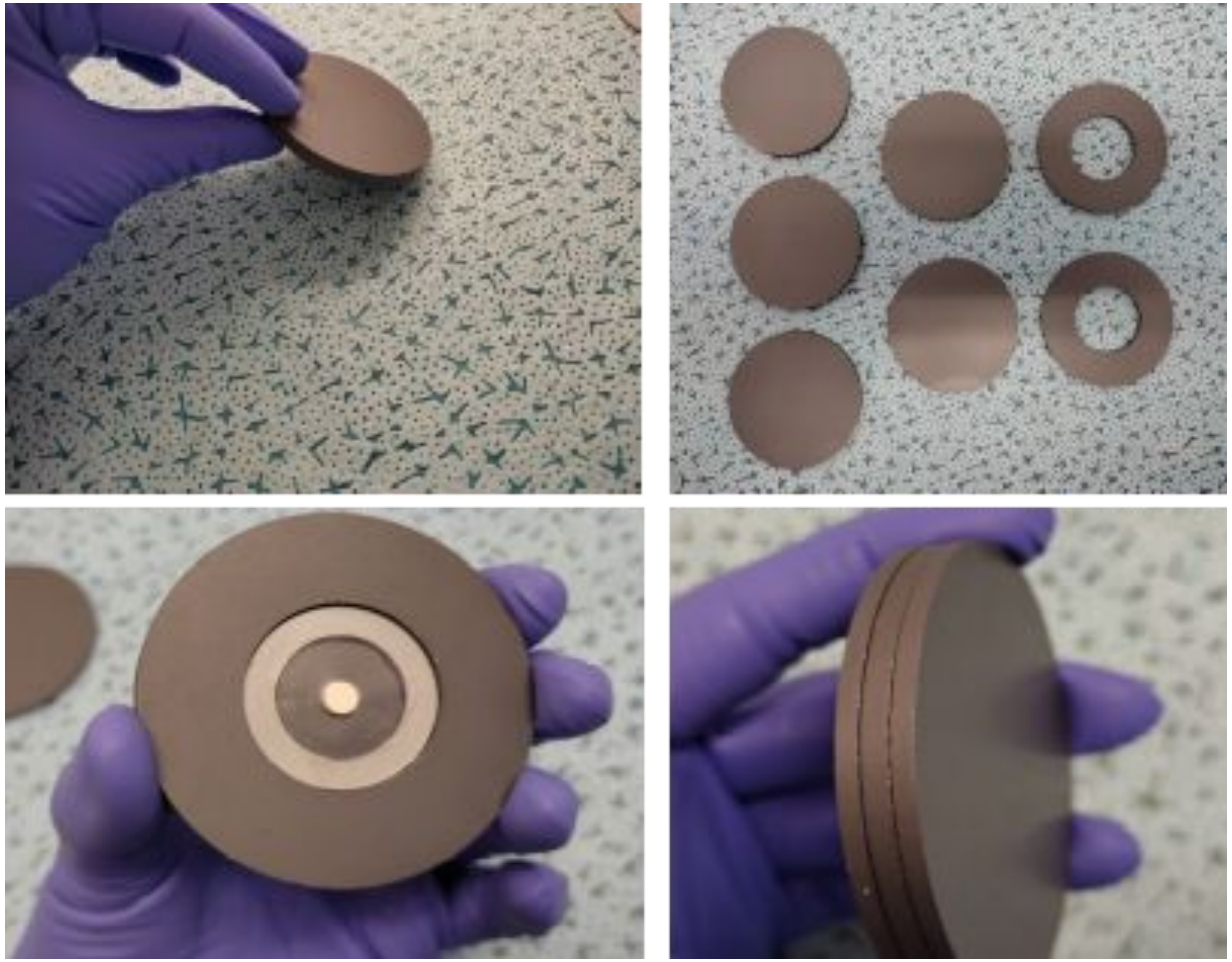






Thanks to Javier Balibrea Correa et al. (IFIC)

Experimental method and setup



Reactions

- ^{197}Au(n,γ)
- ^{140}Ce(n,γ)
- ^{76}Ge(n,γ)
- ^{94}Zr(n,γ)
- ^{89}Y(n,γ)

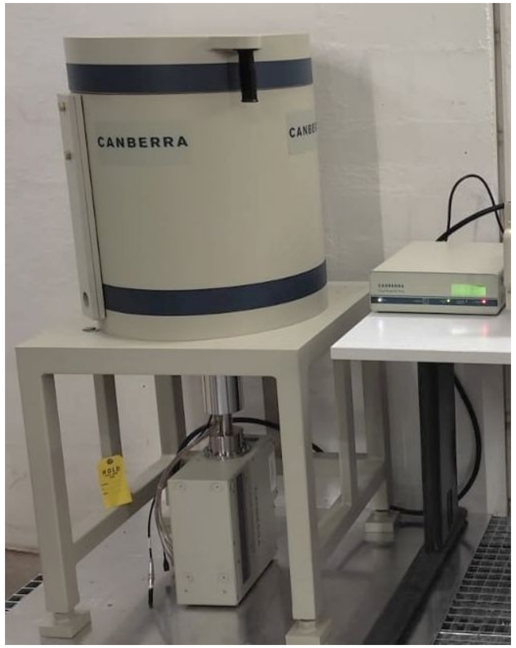
B4C filters

- 2.5, 5.0, 7.5, 10 mm thickness on both sides
- 60 mm in diameter
- 30 mm inner hole

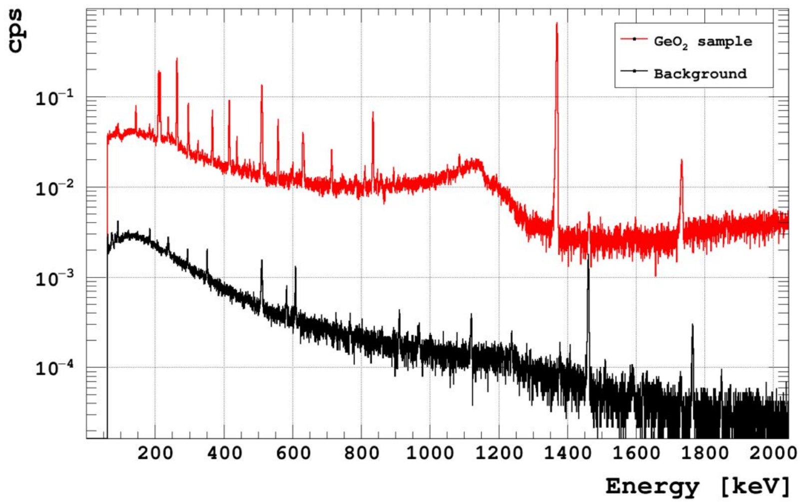
Experimental method and setup

Irradiations @ 20 cm with respect the collimator exit

γ-ray measurement using 60% rel. eff HPGe, shielded by 20 cm lead barrel, el. cooled



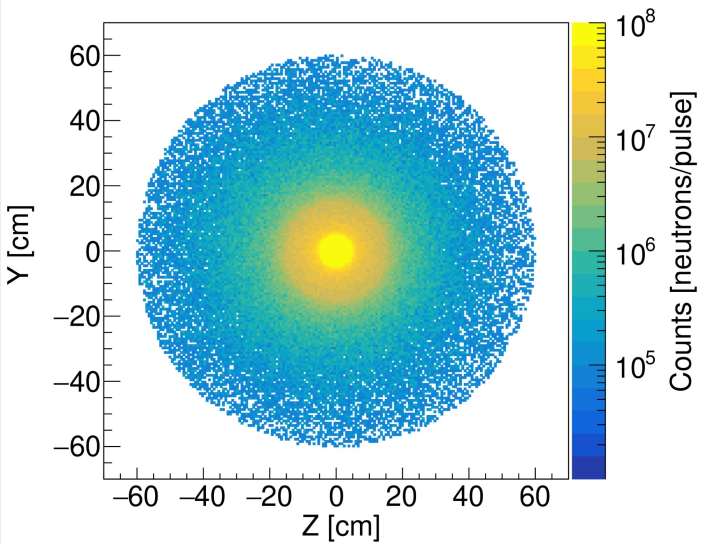
Analysis & SACS estimation

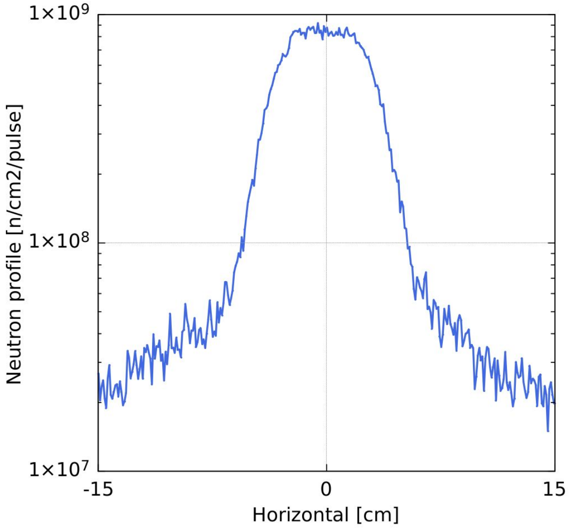


Experimental method and setup: irradiations

Irradiations @ 20 cm with respect the collimator exit

Beam spatial profile at the irradiation position

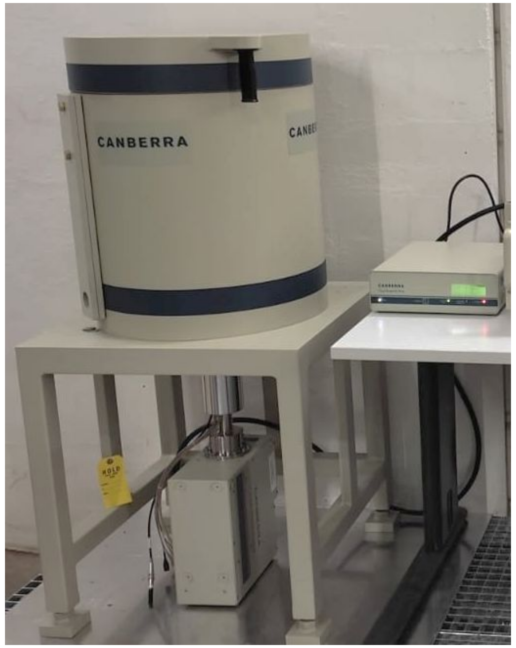


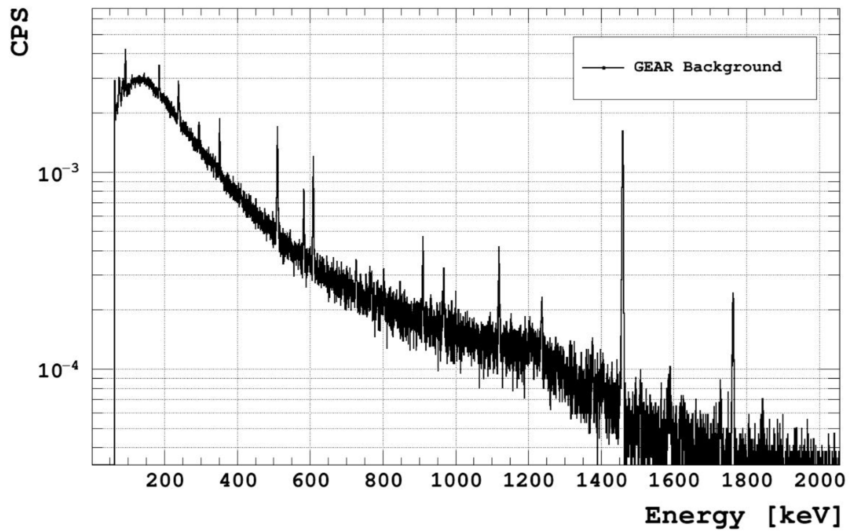


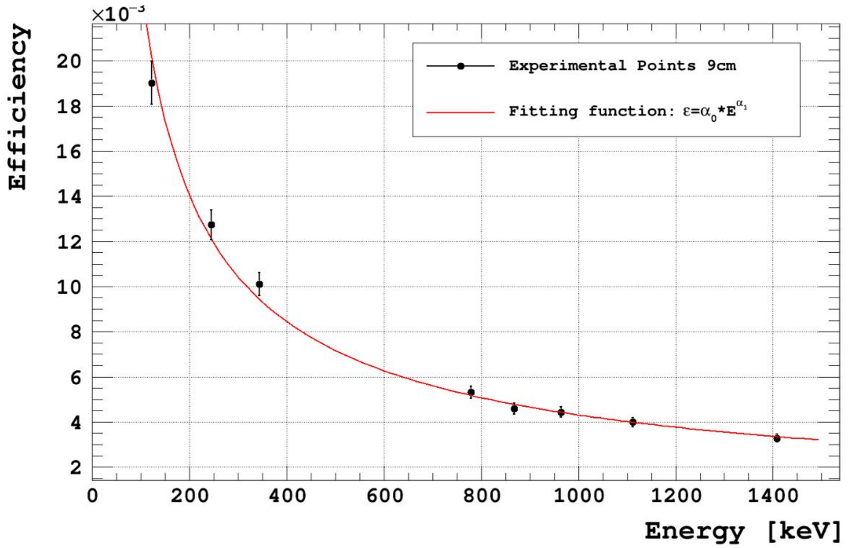
Experimental method and setup: γ spectroscopy

GEAR station

γ-ray measurement using 60% rel. eff HPGe, shielded by 20 cm lead barrel, el. cooled

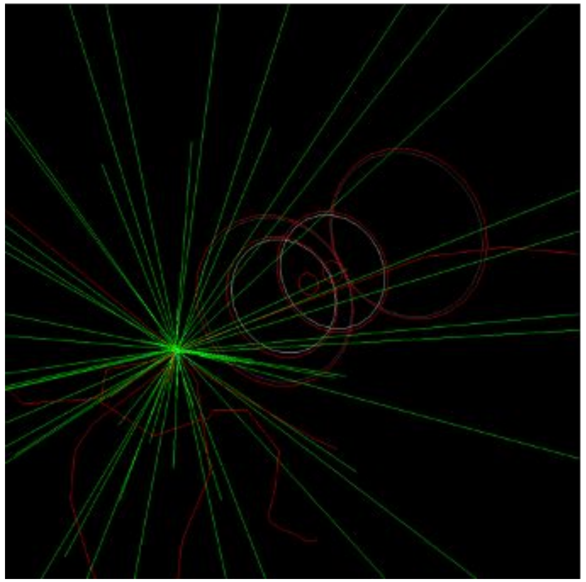


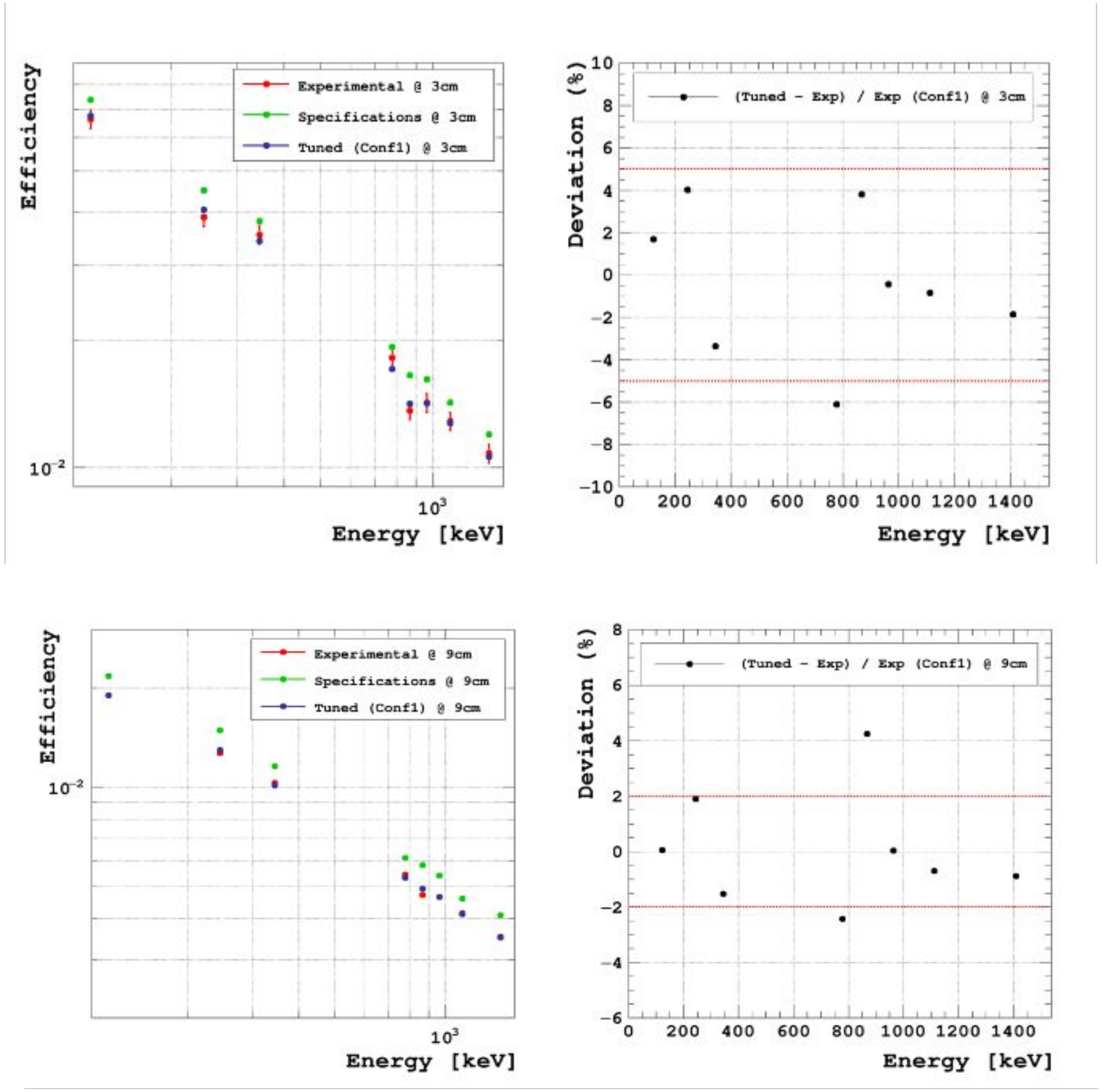




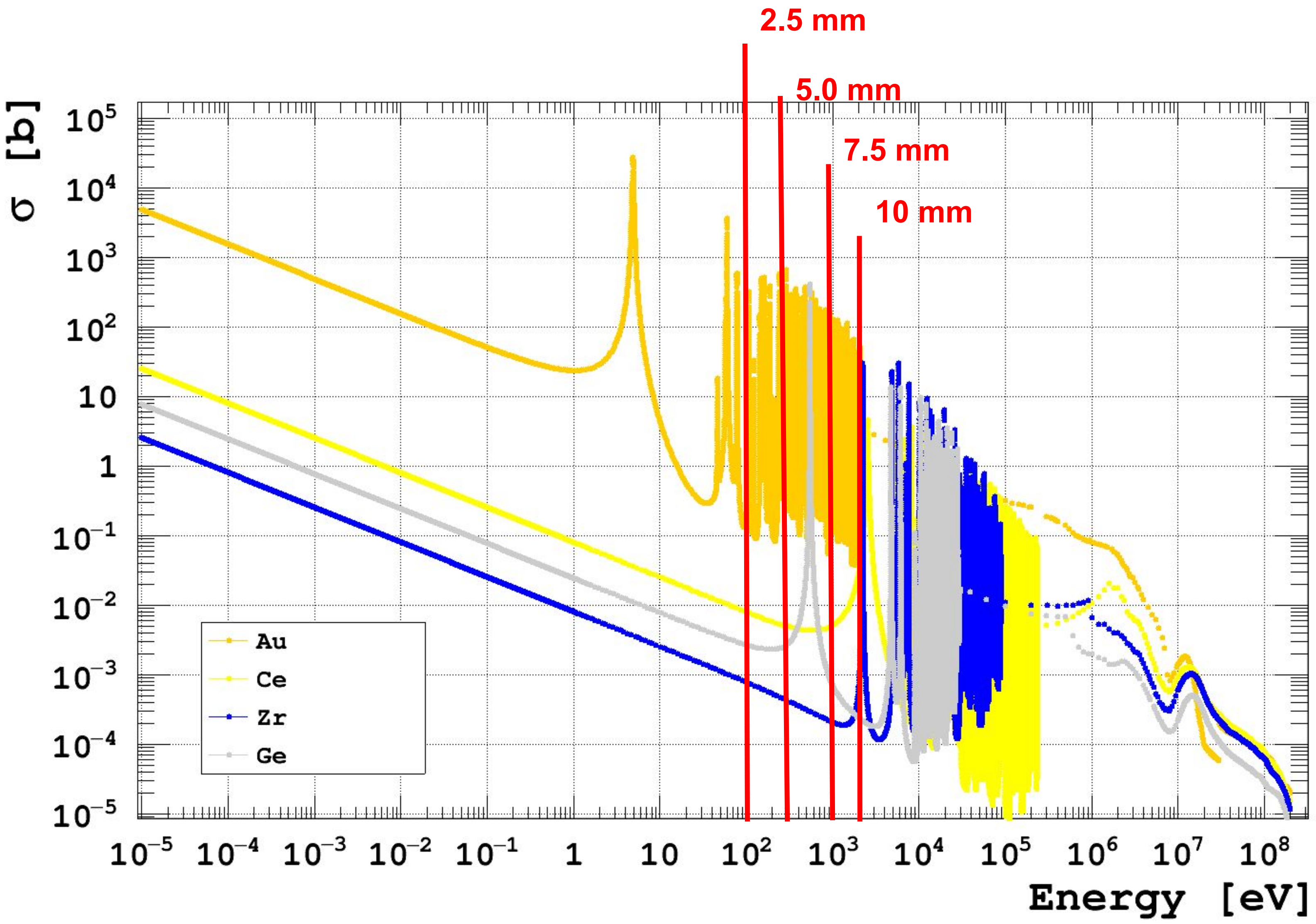
Experimental method and setup: γ spectroscopy

GEANT4 characterization





Experimental method and setup



Reactions

- $^{197}Au(n,\gamma)$
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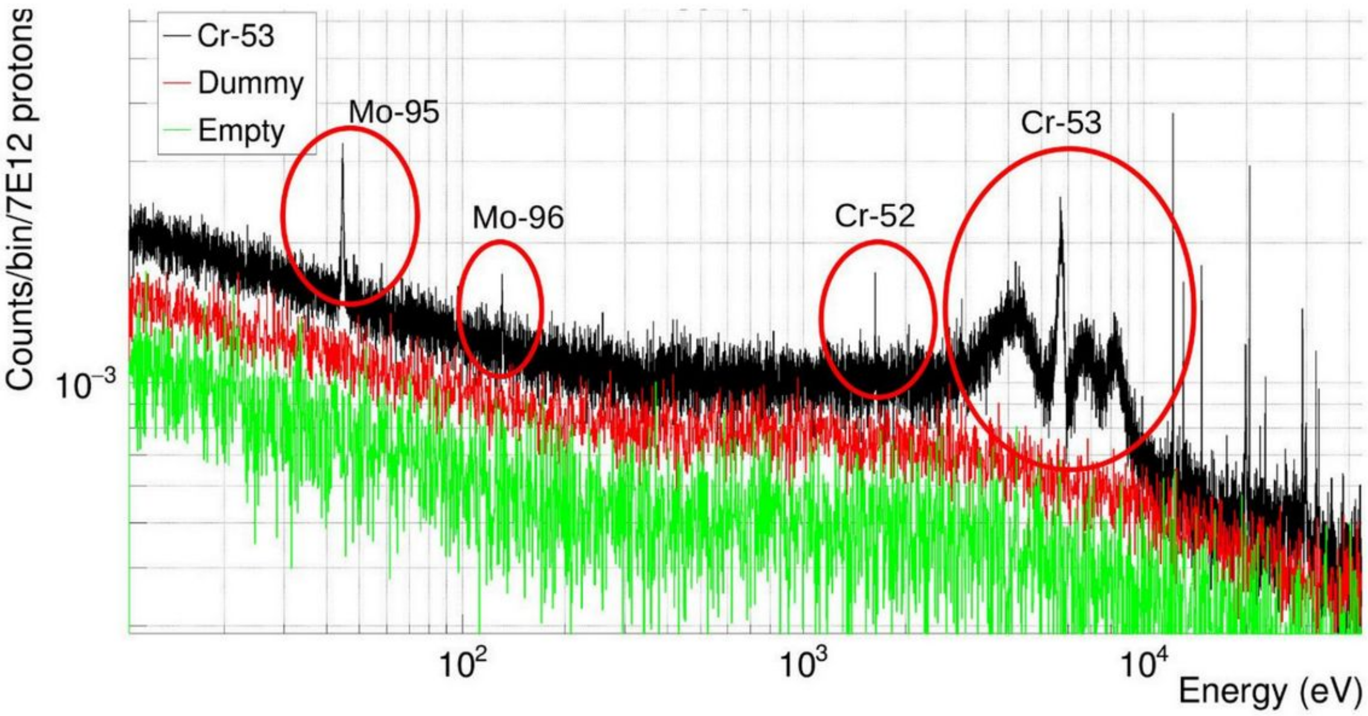
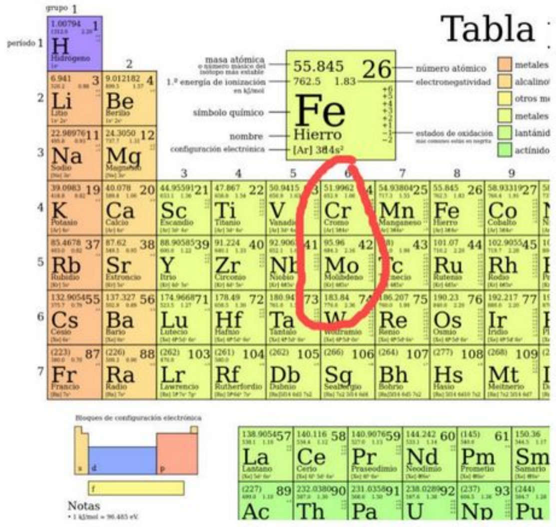
B4C filters

- 2.5, 5.0, 7.5, 10 mm thickness on both sides

$^{50,53}Cr(n,\gamma)$

Mo-nat contamination





First estimations: ~1300ppm

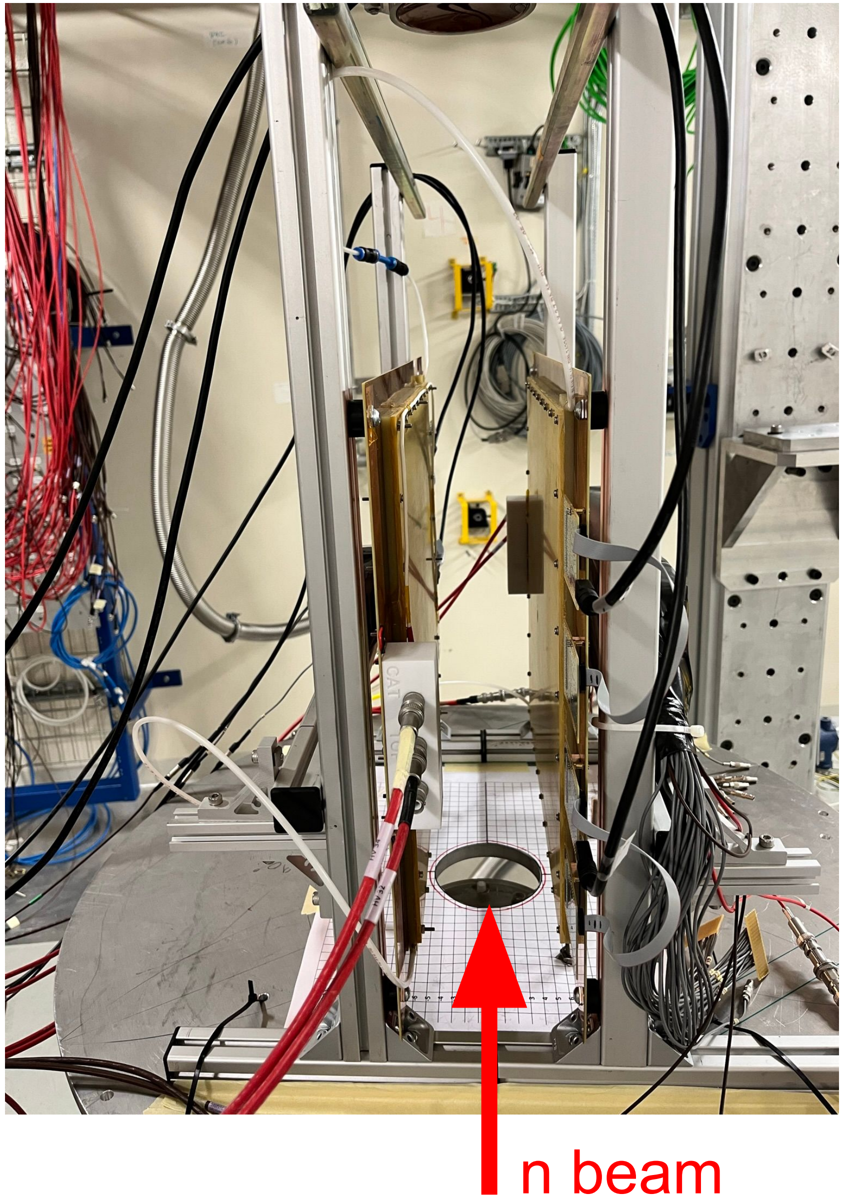
X17 test @ EAR2

X17 detection setup:

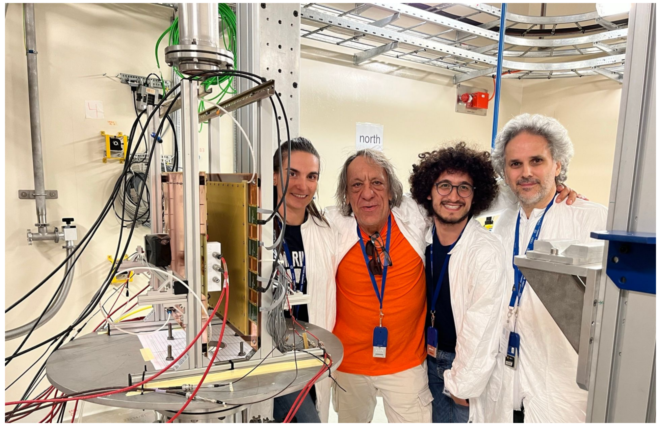
- TPC
- LYSO
- Plastic

Objectives:

- gamma flash response
- Mechanical structure test, alignment and compatibility
- Maximum energy we can go



n beam



Thanks to Carlo Gustavino, Evaristo Cisbani, Alice Manna, Roberto Zarella et al. (INFN)

X17 test1 @ EAR1

DDX:

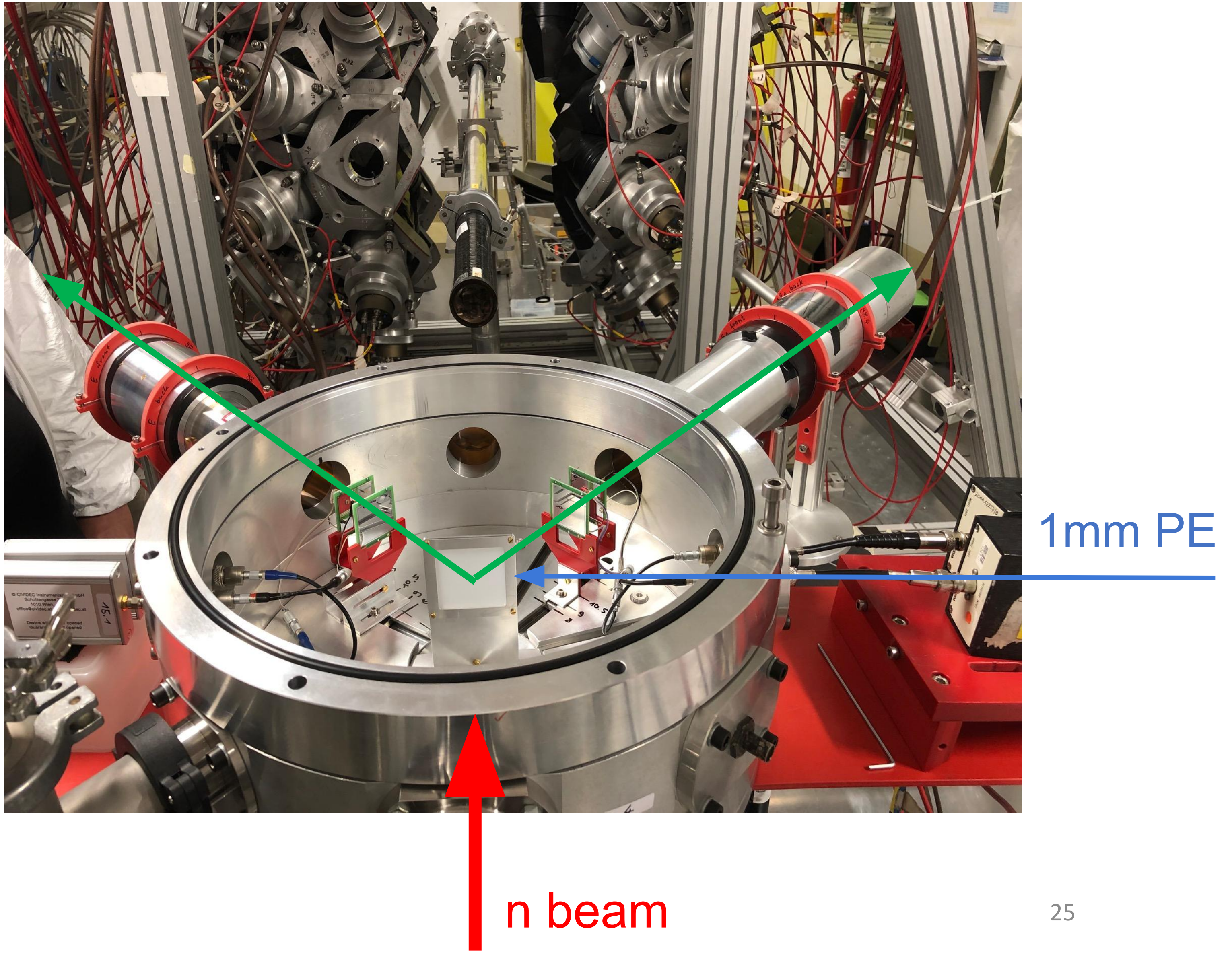
Double-Differential Charged-Particle detection setup for XS measurements from 20 to 200 MeV

Objectives:

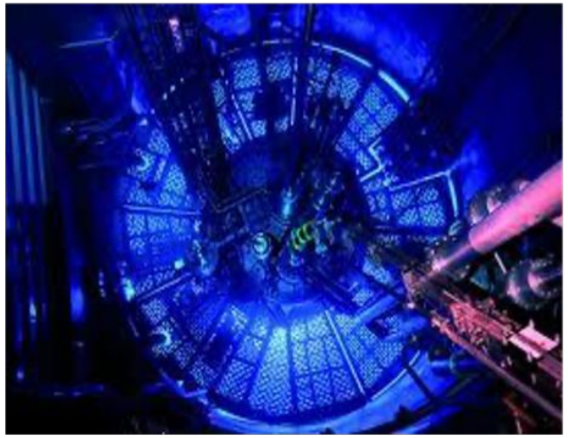
- gamma flash response
- Necessity for a switcher circuit
- Mechanical structure test, alignment and compatibility
- Maximum energy we can go
- Particle identification and energy resolution

Setup:

- Telescope 1: DE2-507 μm Si
  E3 -100 mm plastic scint.
- Telescope 2: DE1 51 μm Si
  DE2 1043 μm Si
  E3 $CeBr_3$ scint.
- Test using $^{12}C(n,cp)$; cp = p,d,a,…



3.7 mSv/h in contact
120 uSv/h at 10 cm



~3mg of Se-79 produce via $^{78}Se(n,\gamma)$

Isotope	Mass (g)
Se-78	1.064
Se-79	0.003
Pb-208	2.838
Al-27	1.0244

Figure **1** 79Se sample in alloy of PbSe (sideview)

Figure **2** 79Se sample in alloy of PbSe (top view)

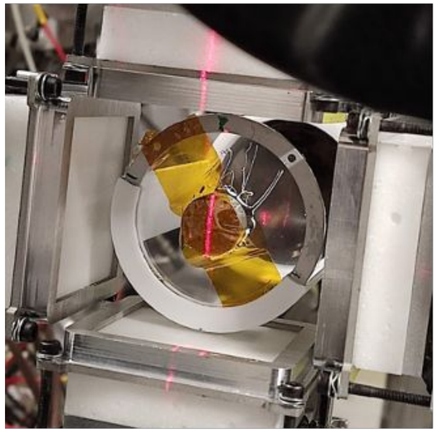
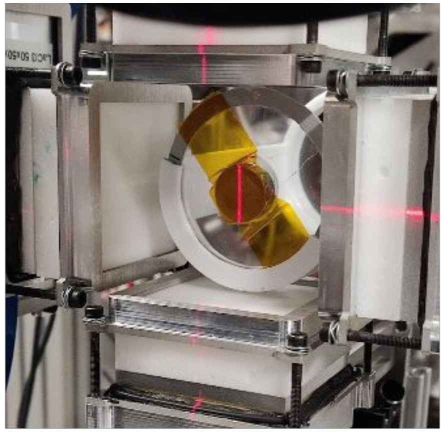
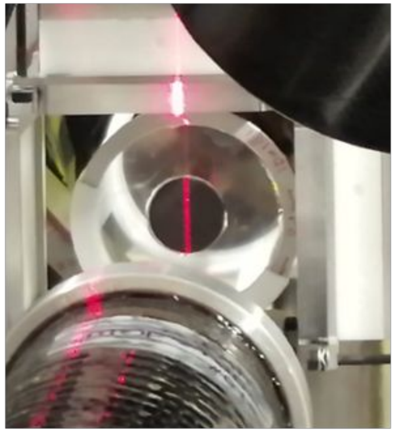
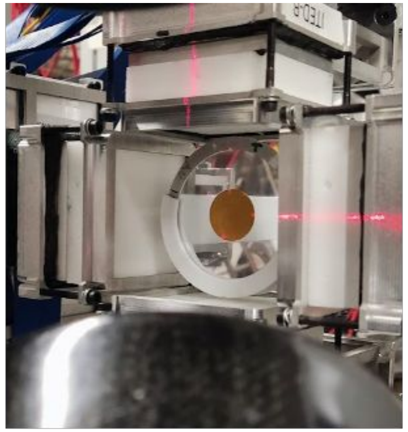
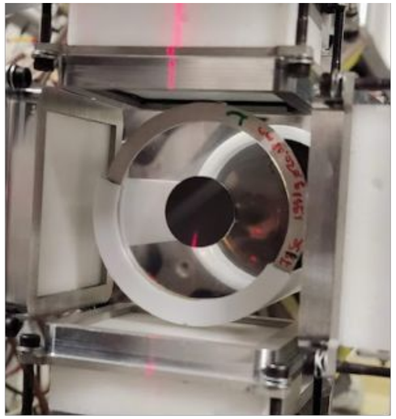
Co-60 contamination on the Al casing
RP-veto mandatory

Origin: most likely external contamination in ILL Hot cell

Se-79 sample

Isotope	Activity (Mbq)
Se-79	4.33E-01
Se-75	5.66E+00
Ag-110m	2.04E-01
Zn-65	2.33E-01
Co-60	1.40E+00

gamma emmiters

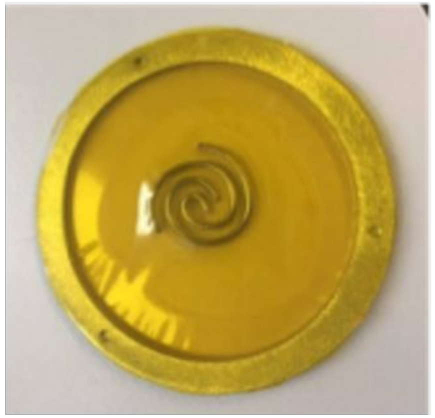
     

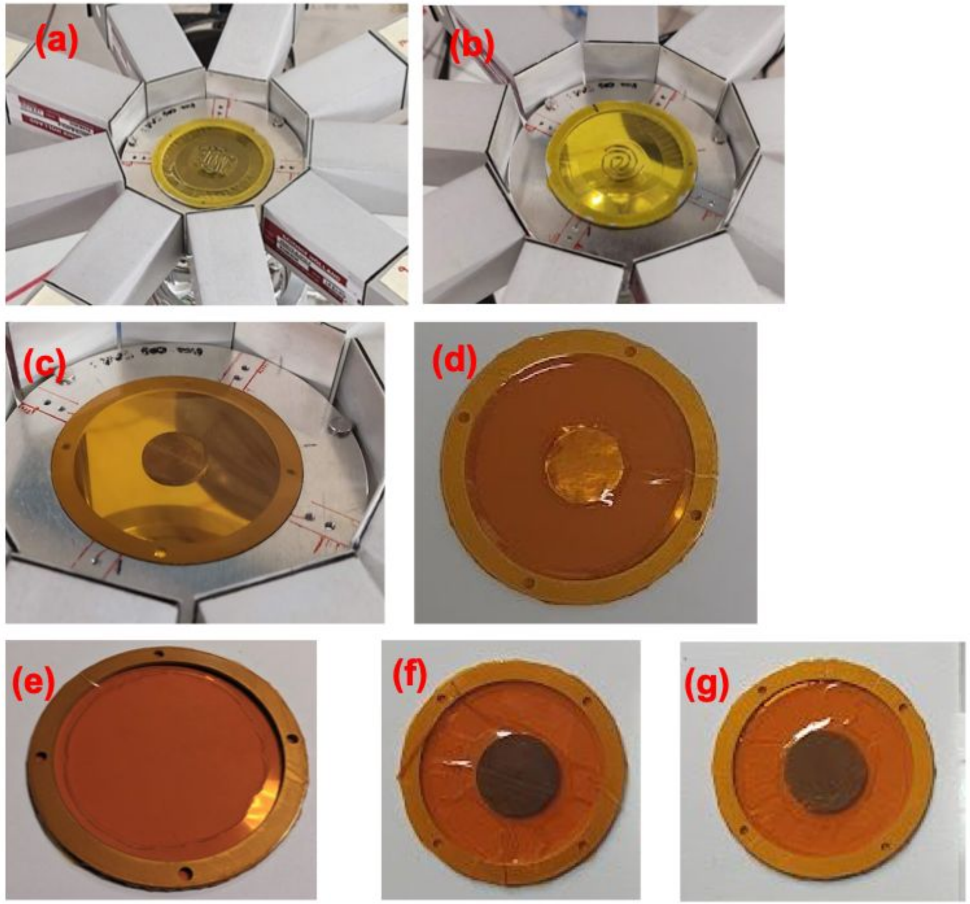
Same samples with i-TED + C_6D_6 at EAR1 and s-TED + C_6D_6 & EAR2
to have systematic uncertainties under control

304 mg hyper-pure ^{93}Nb+^{94}Nb material (47+45 mm wires)

$^{94}Nb/^{93}Nb$ ~ 1% (1.5×10^{19} ^{94}Nb atoms)

10.1 MBq (only ^{94}Nb) [e- (200 keV) + γ(702+871 keV)]





The NEAR station