This project has received funding from the Euratom support safe operation of nuclear systems programme 2014-2018 under grant agreement No 847552 (SANDA)

Task 1.3: innovative devices for capture cross section measurement on actinides

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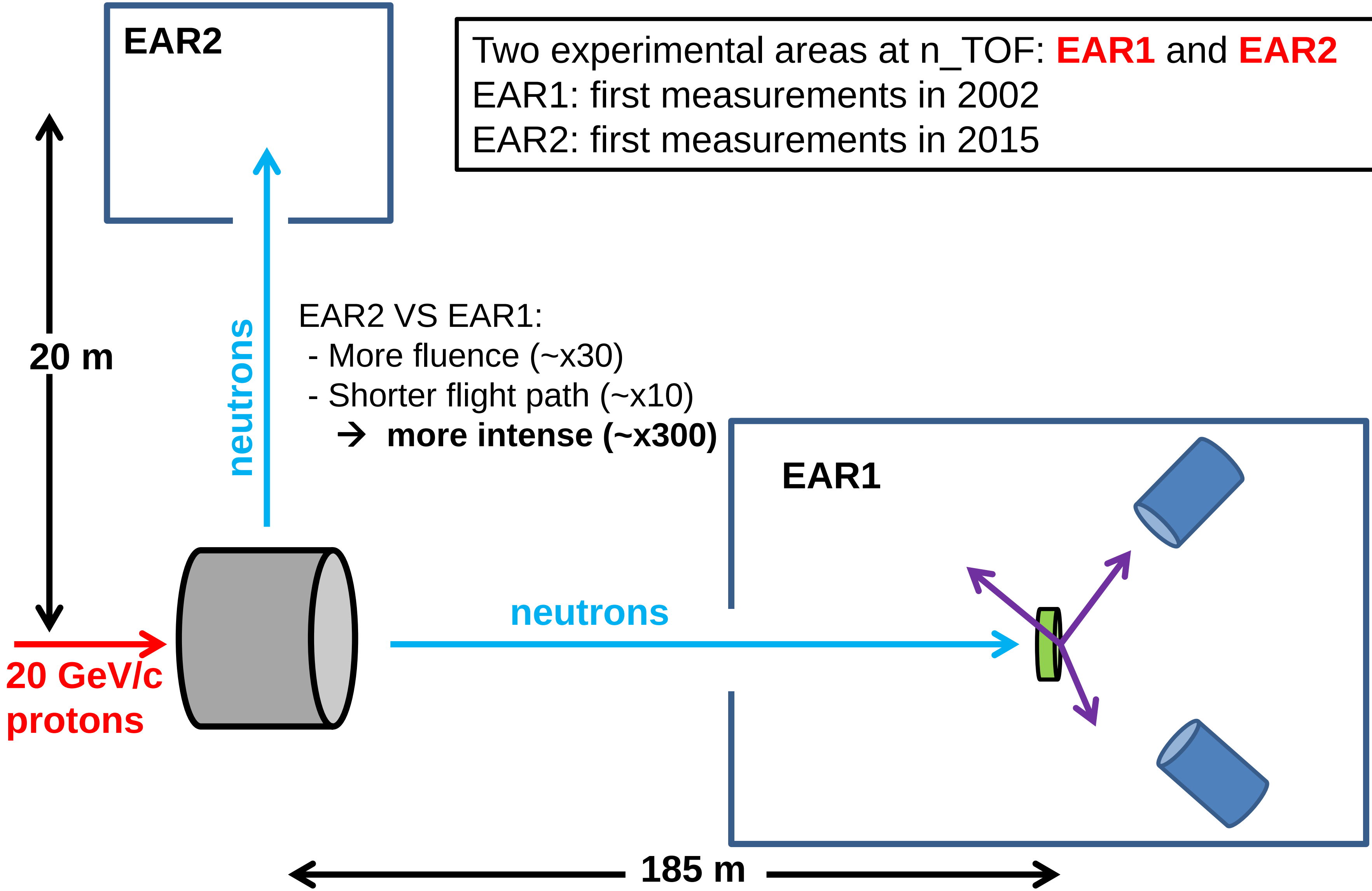
Campus d'Excel·lència Internacional

Introduction

Two experimental areas at n_TOF: **EAR1** and **EAR2**
EAR1: first measurements in 2002
EAR2: first measurements in 2015

EAR2 VS EAR1:
- More fluence (~x30)
- Shorter flight path (~x10)

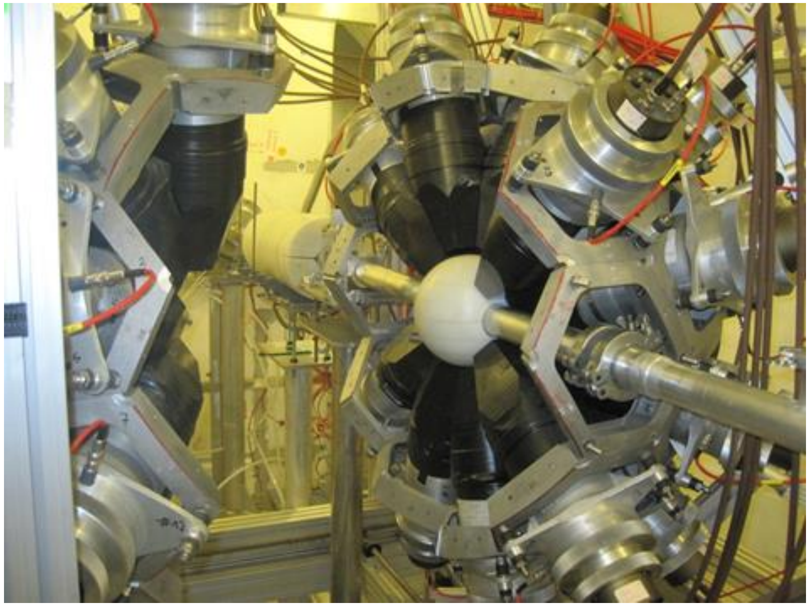
→ **more intense (~x300)**



Introduction

Situation before SANDA:

- (n,γ) cross section measurements are performed using γ-ray detectors
- Counting rates in EAR2 are ~300 times larger than counting rates in EAR1
- The γ-ray detectors used in EAR1 did not work properly in EAR2



BaF_2 detectors (TAC)

C_6D_6 detectors

Introduction

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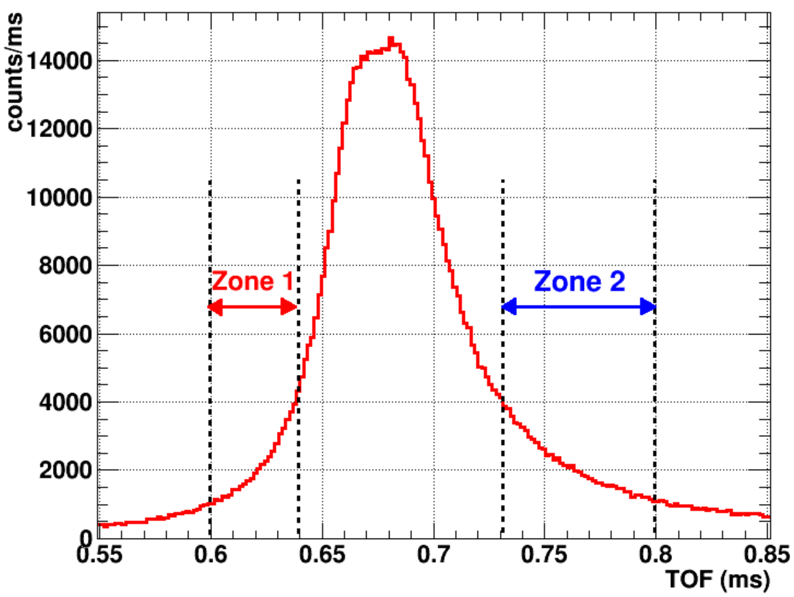
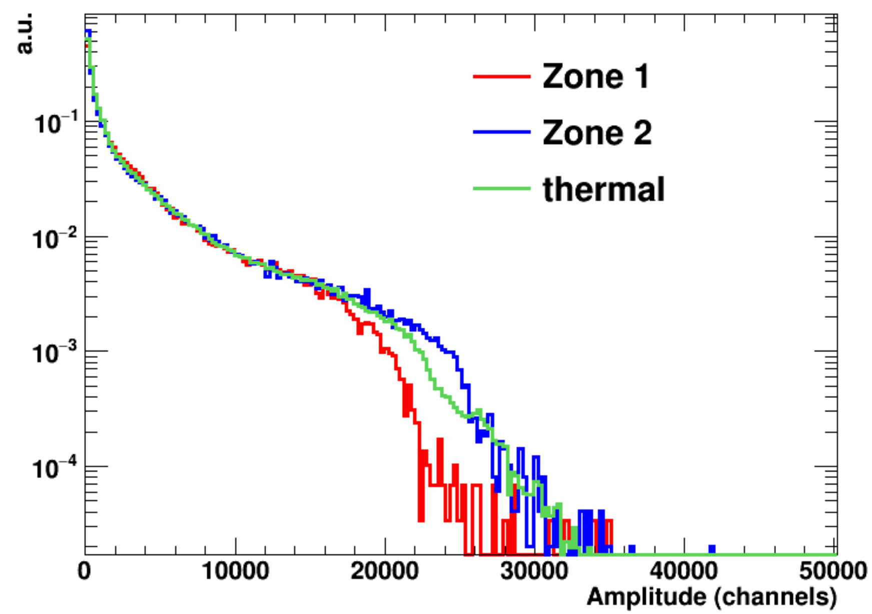
^{197}Au(n,γ)



^{197}Au(n,γ)



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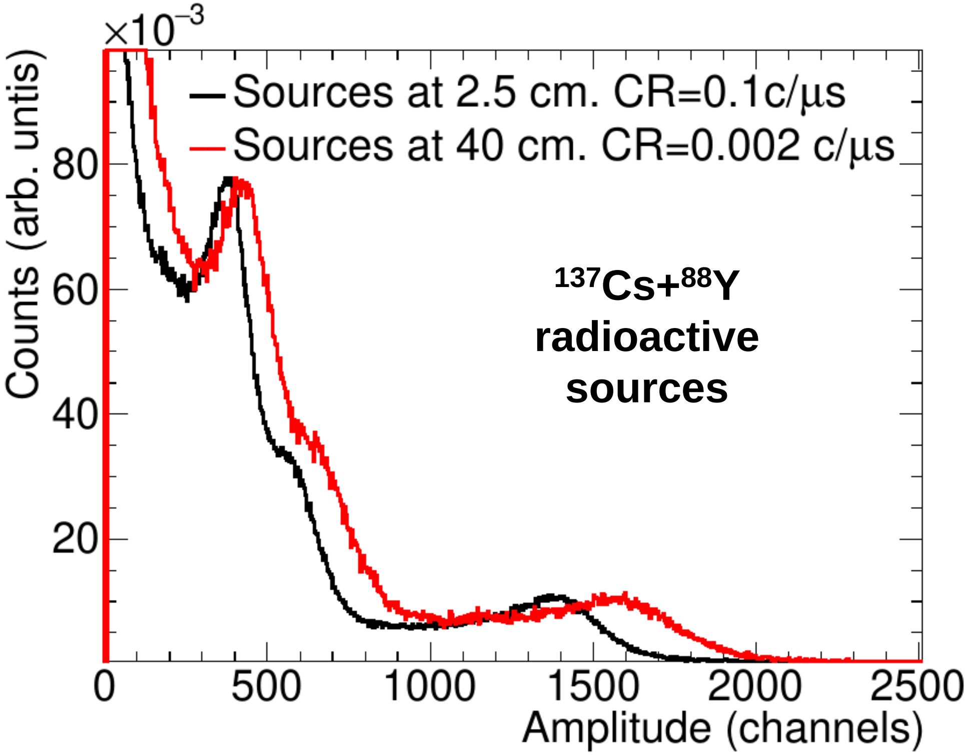


Introduction

<u>Goal of SANDA Task 1.3</u>: Develop γ-ray detectors capable of operating in the n_TOF EAR2 for measuring (n,γ) cross section of actinides.

Limitations of EAR1 γ-ray detectors operating in EAR2:

- Pile-up
- Gain variations with high counting rates

Two **new detectors** were studied:

- **sTED:** segmented Total Energy Detector
- **i-TED**: Gamma ray detector with imaging capabilities

sTED

The sTED

Idea → reduce the size of the detector to reduce the counting rates + use many detectors to have a reasonable detection efficiency.

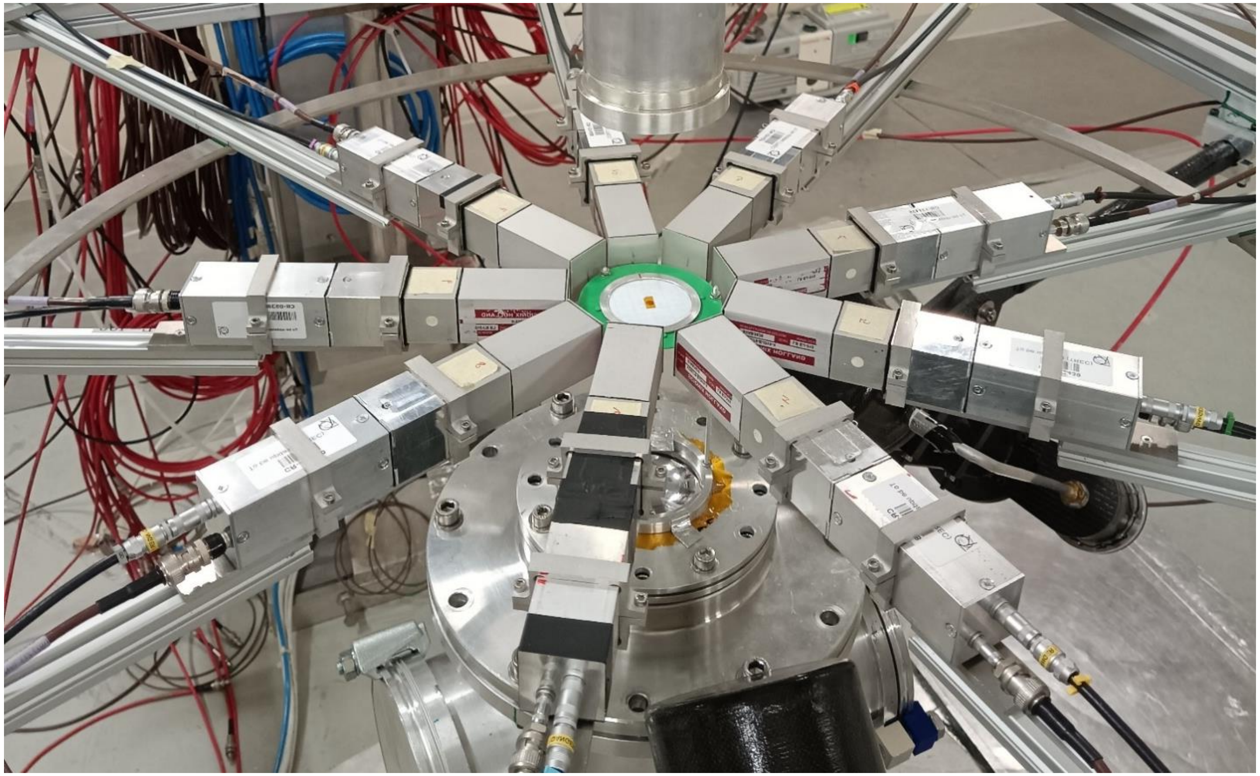
BICRON → 0.621 L of C_6D_6

Carbon fiber detectors → 1 L of C_6D_6

sTED modules → 0.049 L of C_6D_6
13 times smaller than BICRON
20 times smaller than Carbon fiber

The sTED

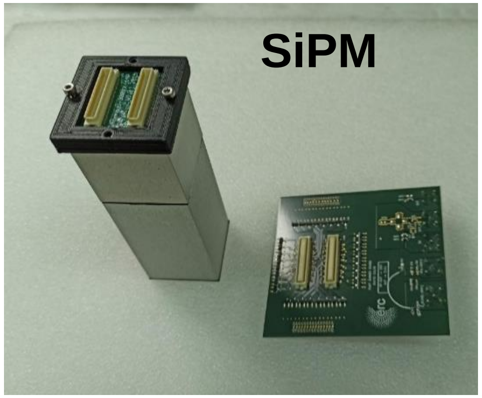
Idea → reduce the size of the detector to reduce the counting rates + use many detectors to have a reasonable detection efficiency.



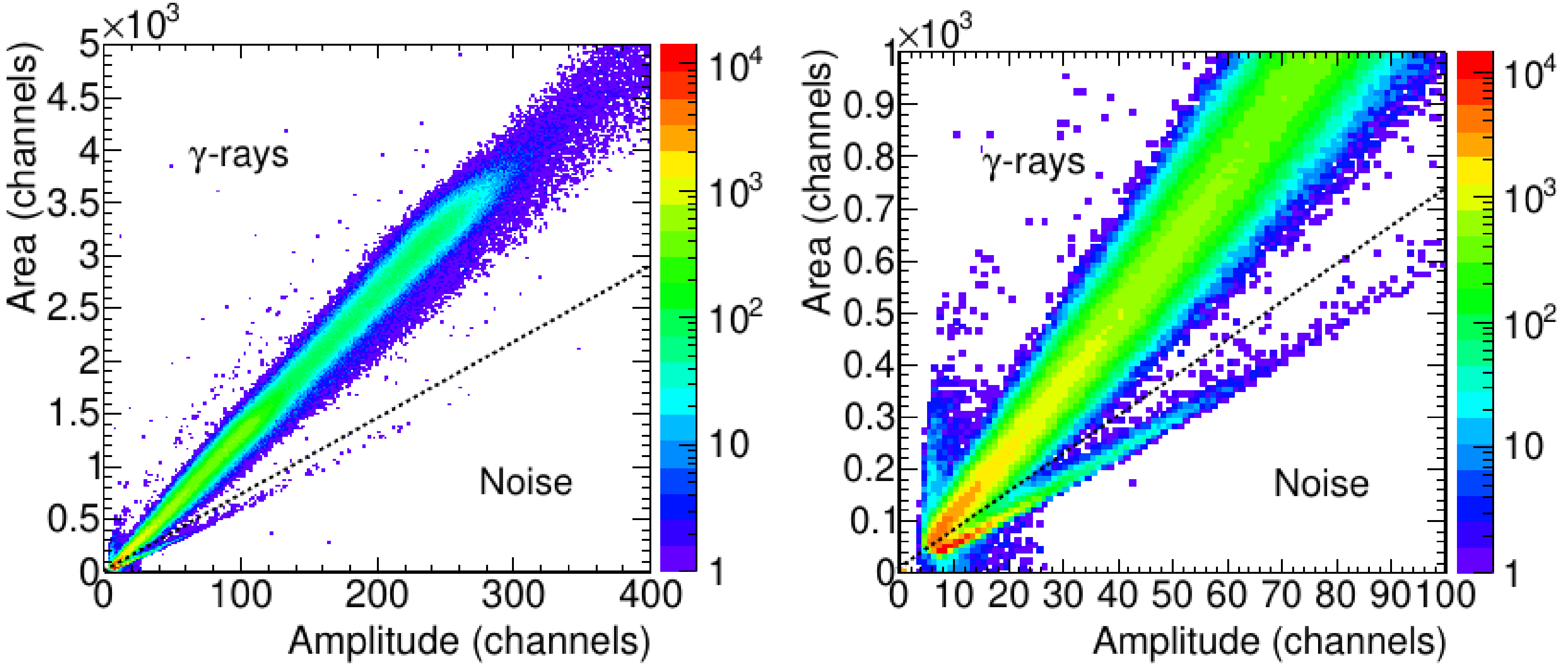
Picture from J. Lerendegui IFIC (Valencia)

Test of different PMTs

- Gain variations → PMT
- We have characterized the performance of:
  - PMT model R5611A (Scionix)
  - PMT model R2076 (Scionix)
  - PMT model R11265U (Hamamatsu)
  - SiPM ArrayJ-30035-64P-PCB with readout board developed by IFIC

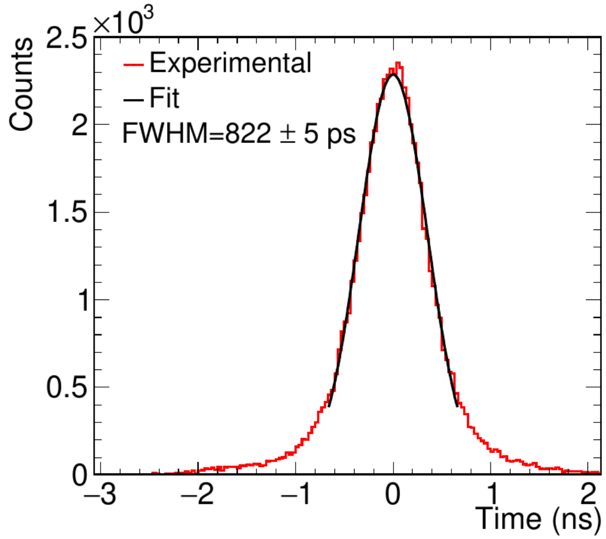


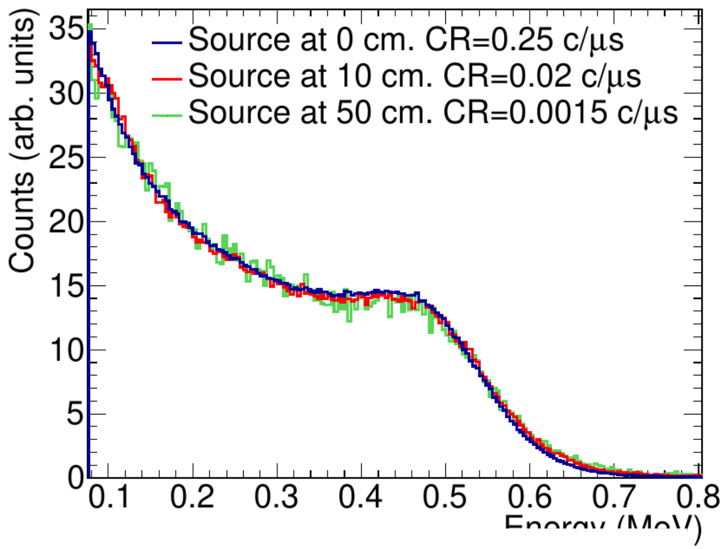
Test of different PMTs

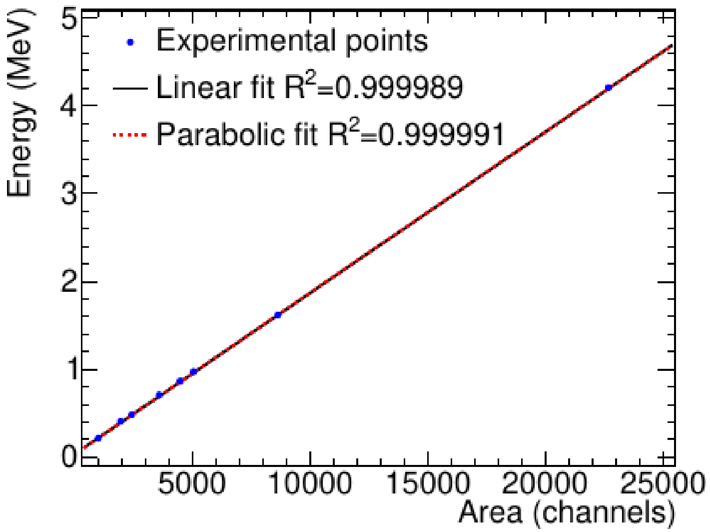


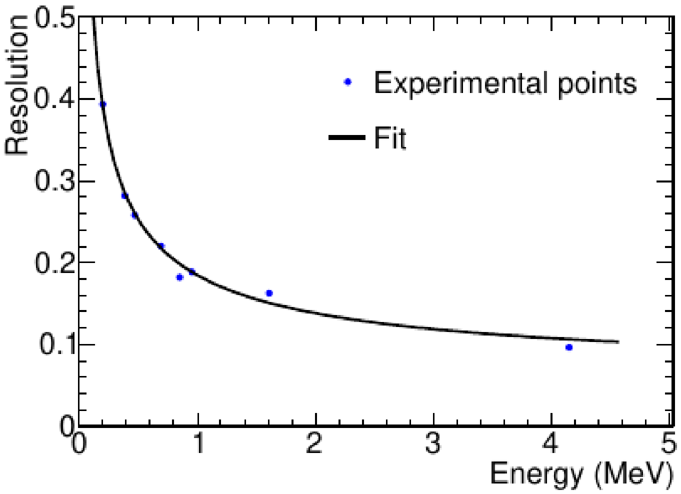
2D plot showing the amplitude versus the area of the sTED signals with a R5611A photomultiplier when measuring an ^{88}Y calibration source

Characterization of the sTED modules

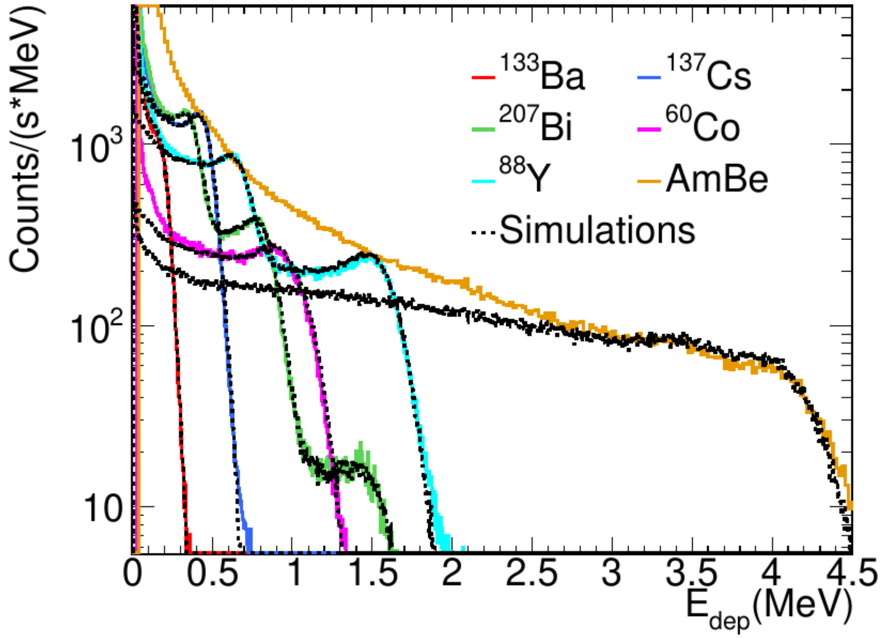


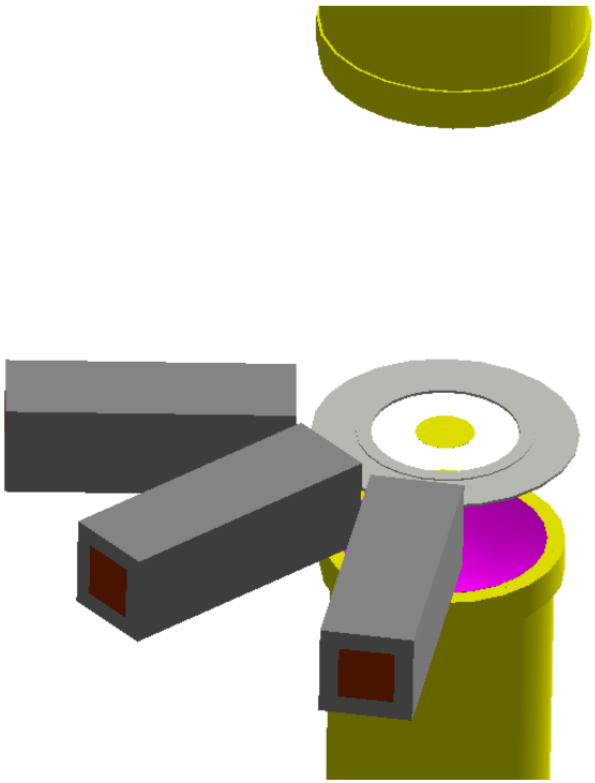






Characterization of the sTED modules

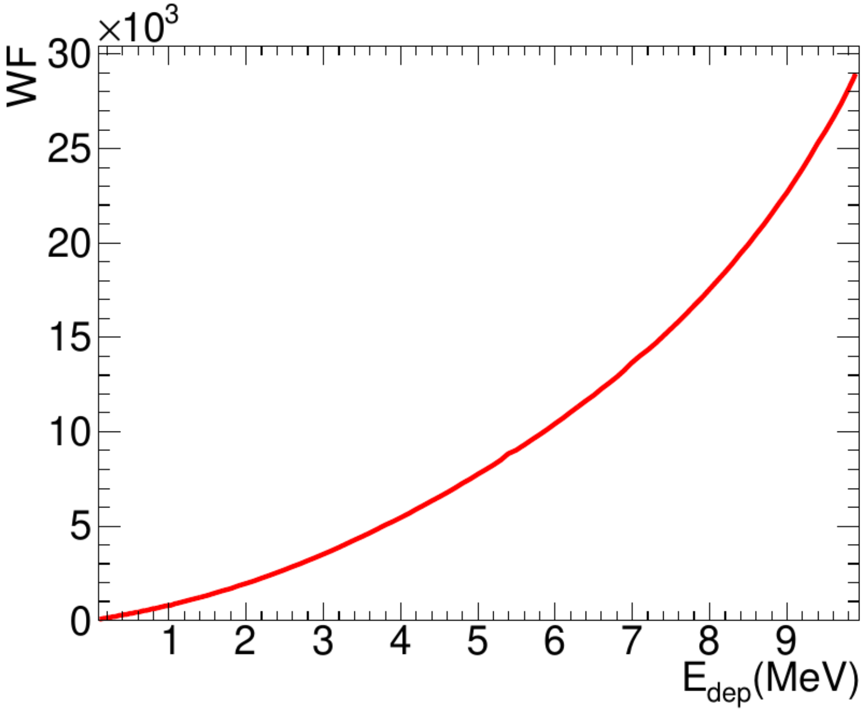


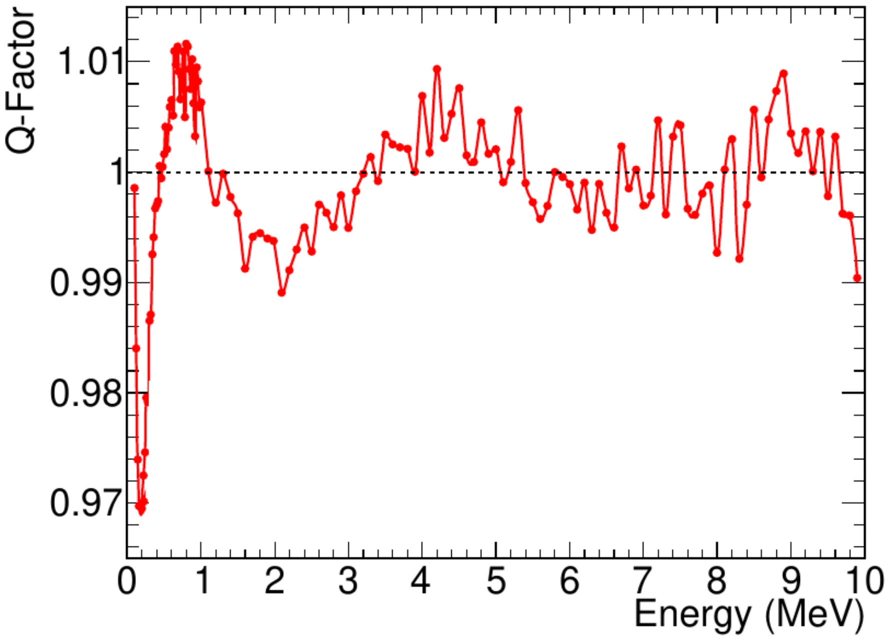


Estimation of the neutron sensitivities $((\varepsilon_n/\varepsilon_\gamma)\cdot(\Gamma_n/\Gamma_\gamma))$ of one sTED module for different nuclei and resonances. For details see the text.

Isotope	E_n (eV)	$\frac{\Gamma_n}{\Gamma_\gamma}$	$\frac{\varepsilon_n}{\varepsilon_\gamma}$	$(\varepsilon_n/\varepsilon_\gamma)\cdot(\Gamma_n/\Gamma_\gamma)$
^{197}Au	4.91	$1.2\cdot10^{-1}$	$1.6\cdot10^{-3}$	$2.0\cdot10^{-4}$
^{240}Pu	5.01	$8.4\cdot10^{-2}$	$1.6\cdot10^{-3}$	$1.4\cdot10^{-4}$
^{244}Cm	7.66	4.9	$1.6\cdot10^{-3}$	$8.0\cdot10^{-3}$
^{244}Cm	86.1	$6.6\cdot10^{-1}$	$5.5\cdot10^{-4}$	$3.6\cdot10^{-4}$
^{207}Bi	12 100	$2.2\cdot10^{3}$	$1.1\cdot10^{-4}$	$2.4\cdot10^{-1}$
^{207}Pb	41 100	$3.7\cdot10^{2}$	$2.3\cdot10^{-4}$	$8.4\cdot10^{-2}$

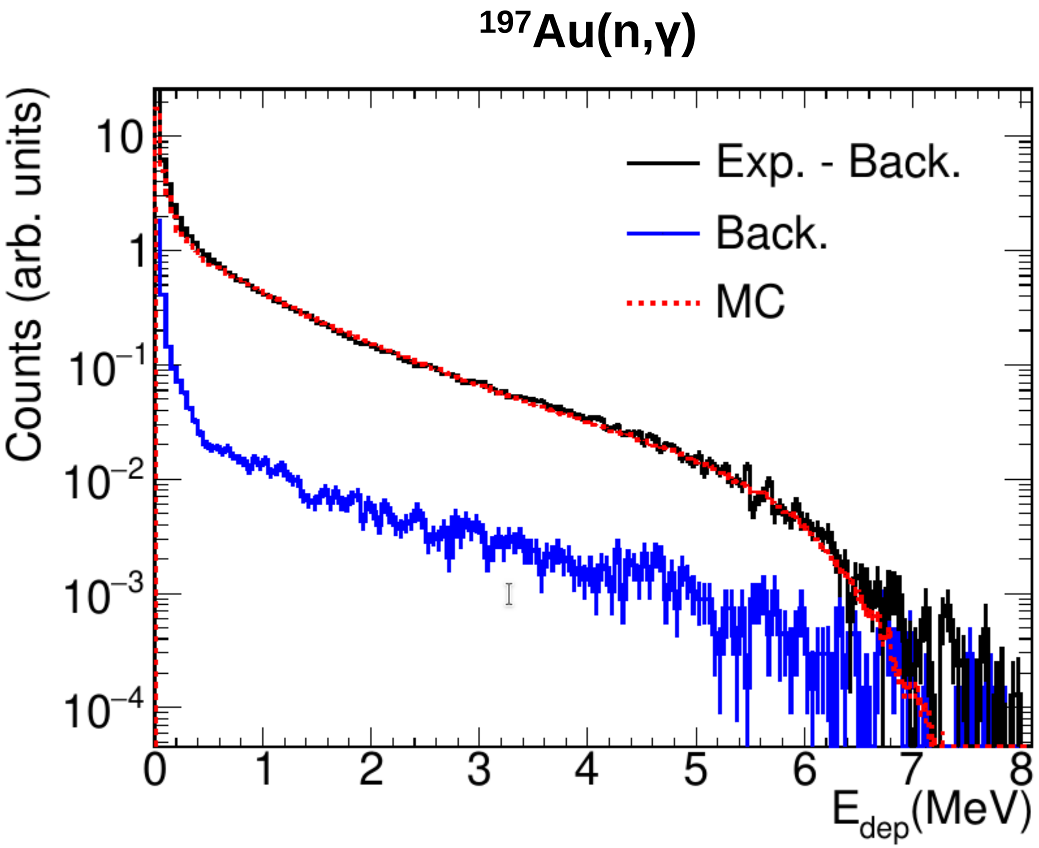
Characterization of the sTED modules





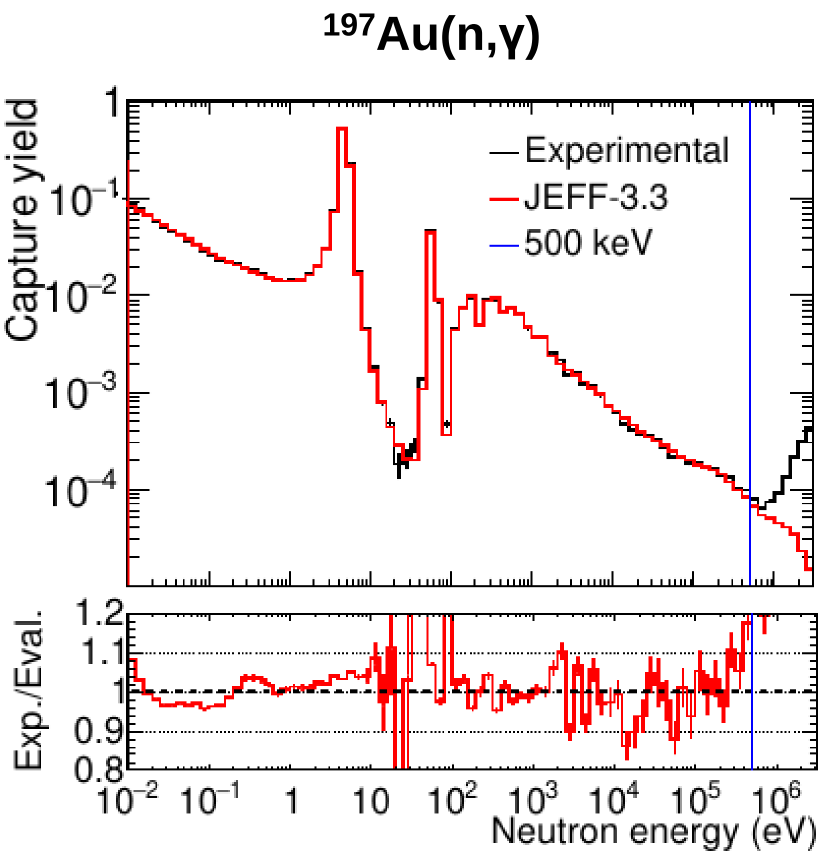
The applicability of the PHWT has been validated by Monte Carlo simulations, by verifying that a smooth WF is capable of producing a weighted efficiency proportional to the γ-ray energy

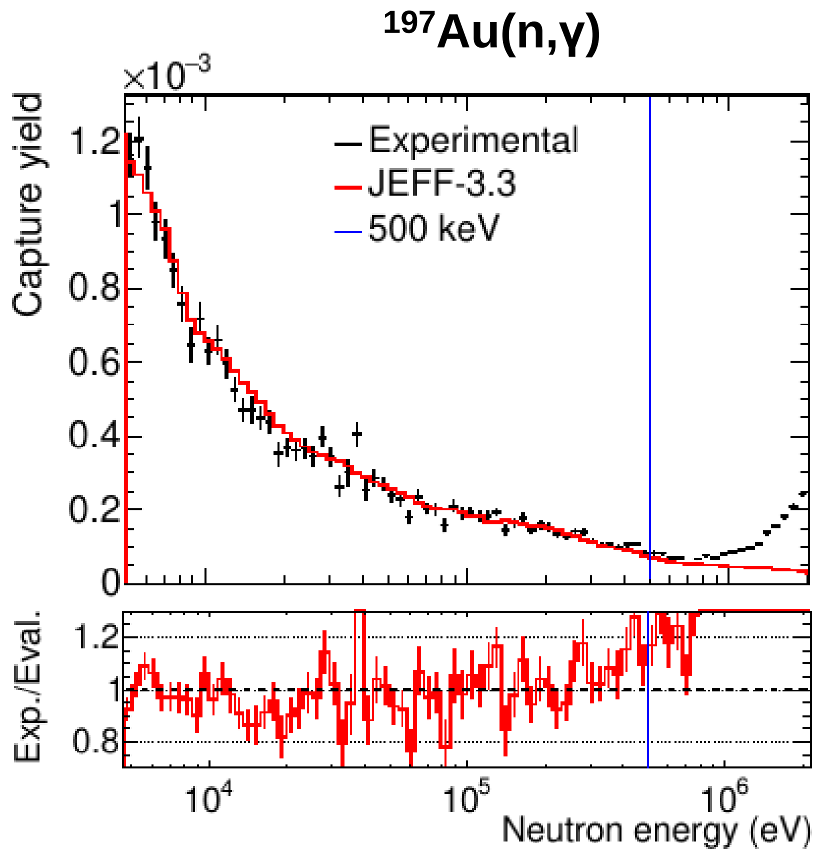
Measurements at n_TOF EAR2



Experimental deposited energy spectra in one sTED module (Exp.-Back.) with background subtracted (Back.) and simulated with NuDEX+Geant4 (MC) for ^{197}Au(n,γ) cascades.

Measurements at n_TOF EAR2





sTED experimental capture yield obtained with a ^{197}Au sample (Experimental) compared with the yield obtained for the JEFF-3.3 nuclear data library (Evaluation).

Conclusions

After initial design work, we have characterized the sTED detectors and validated them by measuring ^{197}Au(n,γ) in the EAR2 → results are in well agreement with the evaluations from thermal up to at least 500 keV.

At the moment, all the tests we have carried out with the sTEDs have given positive results.

The sTED are now the standard capture setup for n_TOF EAR2. They (9 sTEDs) have been used to measure:

2021: ^{94,95,96}Mo(n,γ)

2022: ^{79}Se(n,γ)

2023: ^{28,29,30}Si(n,γ), ^{64}Ni(n,γ), ^{160}Gd(n,γ)

2024: ^{209}Bi(n,γ), ^{146}Nd(n,γ), ^{97,98}Mo(n,γ)

Papers:

- V. Alcayne et al., *A Segmented Total Energy Detector (sTED) optimized for (n, γ) cross-section measurements at n_TOF EAR2*, Radiat. Phys. Chem. 217, 111525 (2024).
- E. Mendoza et al., *Neutron capture measurements with high efficiency detectors and the Pulse Height Weighting Technique*, Nucl. Instr. Meth. 1047, 167894 (2023).

Deliverable: D1.7 Report on the development and performances of the new detectors for capture cross section measurements at n-TOF. CIEMAT. M48 (Sept. 2023).

iTED

SANDA

Supplying Accurate Nuclear Data for energy and non-energy Applications

HORIZON2020

(A Nuclear Data Euratom Project in H2020)

We acknowledge the group at IFIC(CSIC-UV), J. Balibrea-Correa, C. Domingo-Pardo, I. Ladarescu, and J. Lerendegui-Marco, for their contribution to this project through temporary material transfer and experiment participation

i-TED for measurement on actinides @EAR2 n_TOF

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iTED for n_TOF

GOAL

Feasibility study of performing measurements in realistic conditions at n_TOF EAR2.

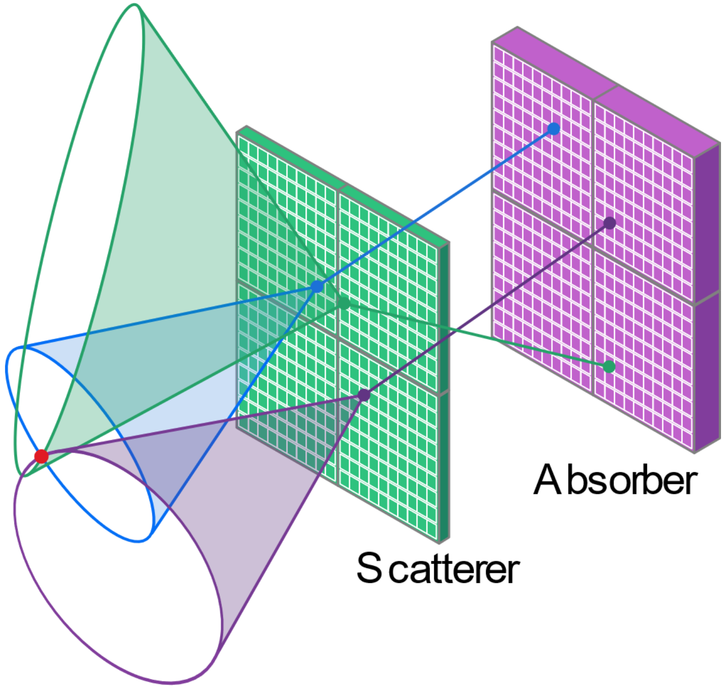
Study the behavior of the system in the laboratory, in order to characterize its dead-time and count-rate capabilities

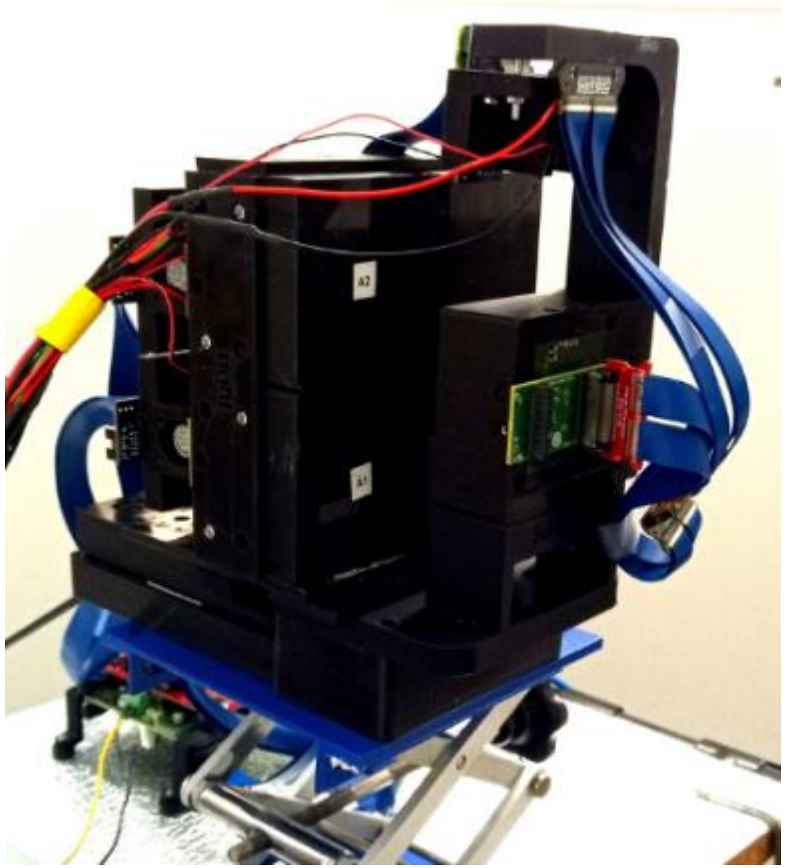
COMMITMENTS

D1.7 Report on the development and performances of the new detectors for capture cross section measurements at n-TOF. **CIEMAT. M48**

The i-TED concept

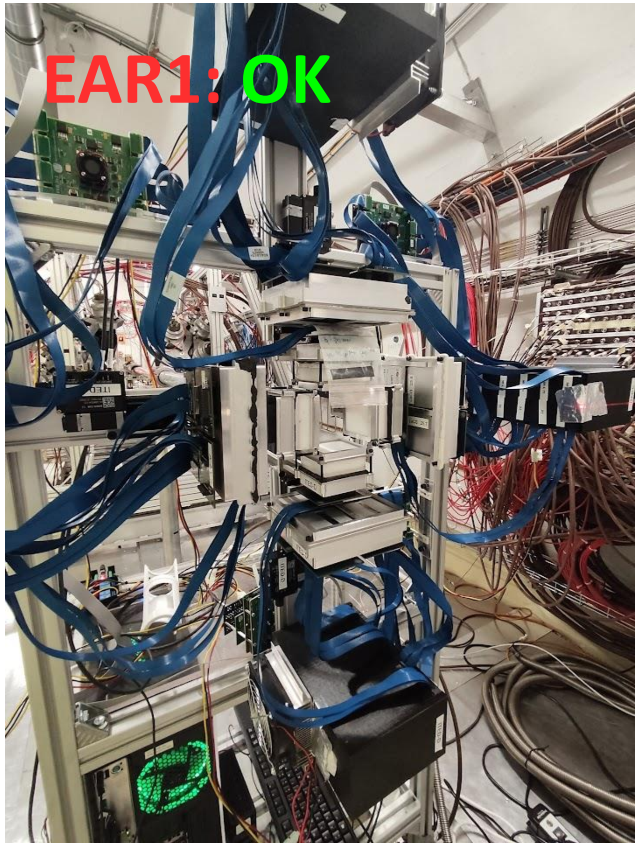
Compton camera principle

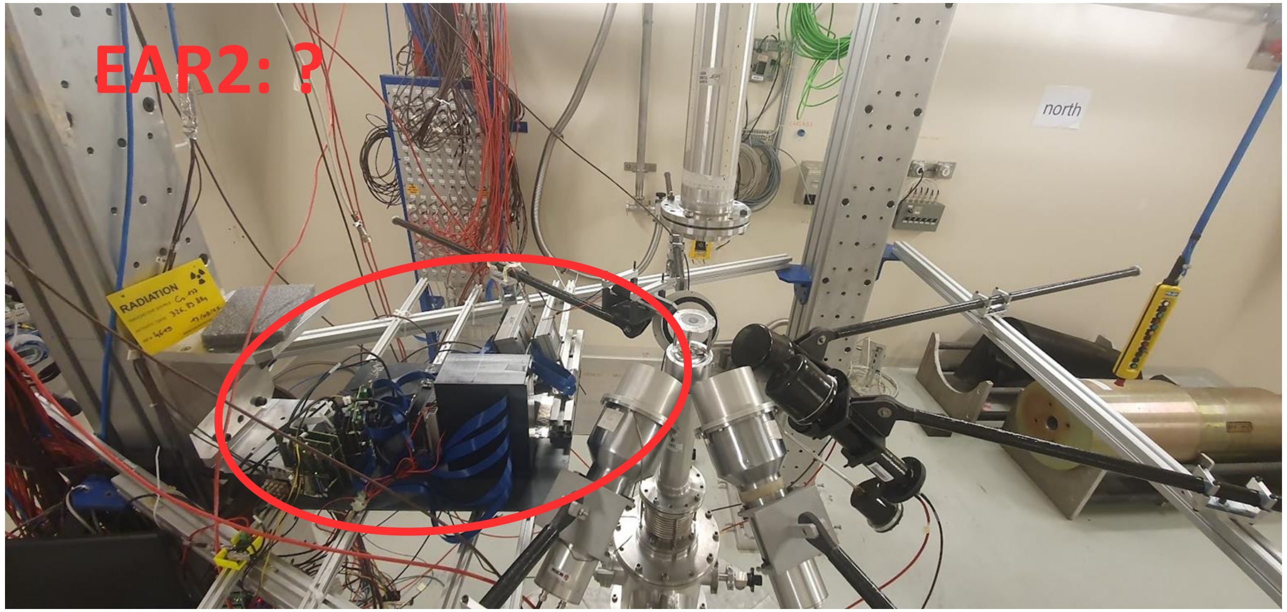




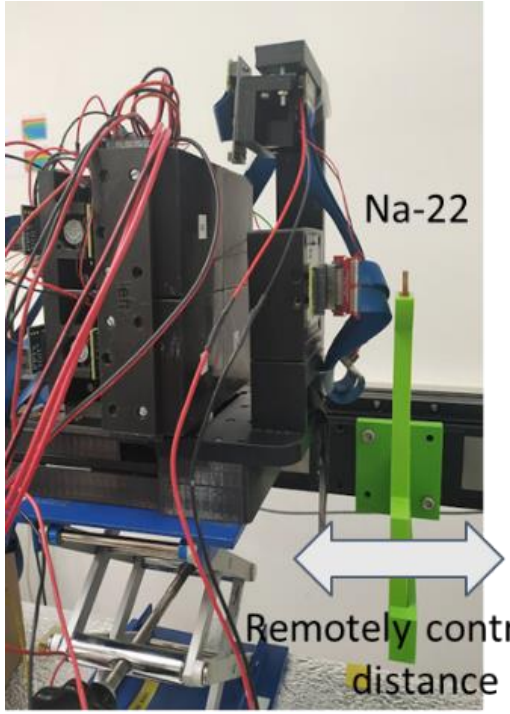
i-TED Tests at EAR2

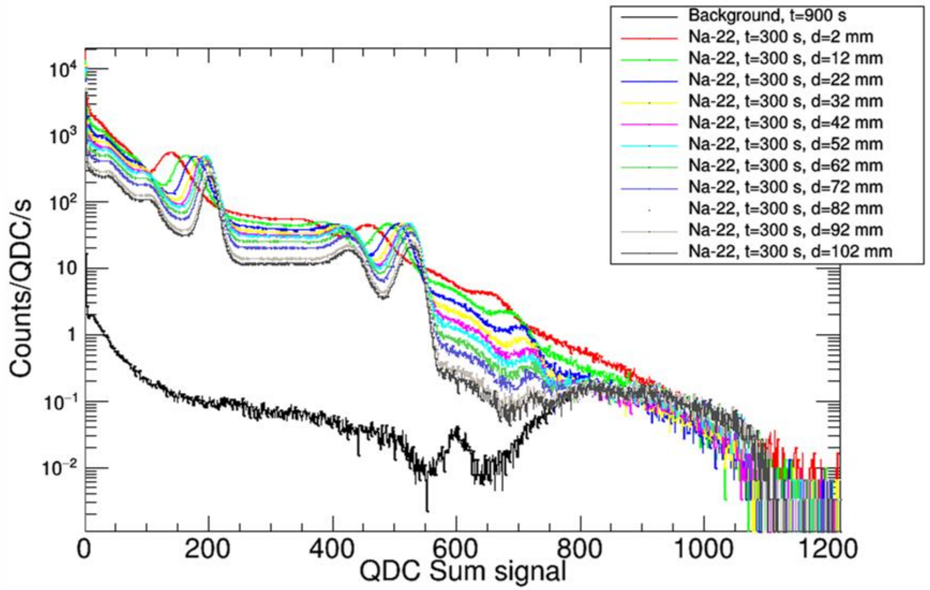
- Full i-TED array in EAR1 for ^{79}Se(n,g) cross-section measurement: performance OK
- Question: capable of working @ EAR2 in Actinide-like high count-rate conditions?

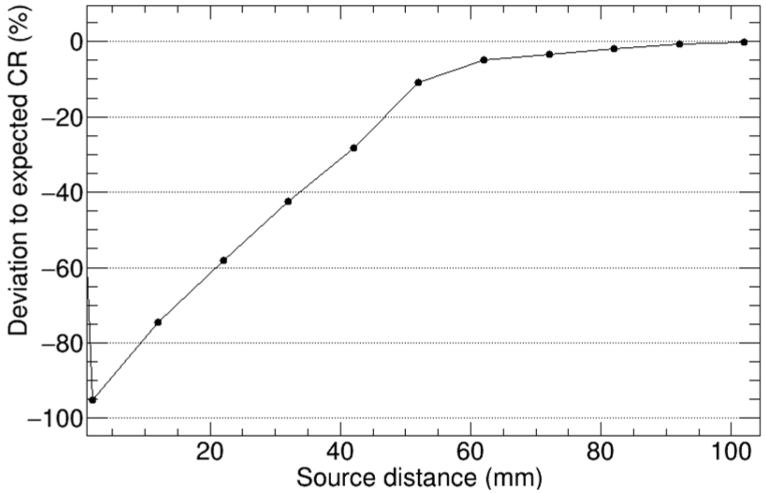




Tests at laboratory with a high-activity 22Na g-ray source

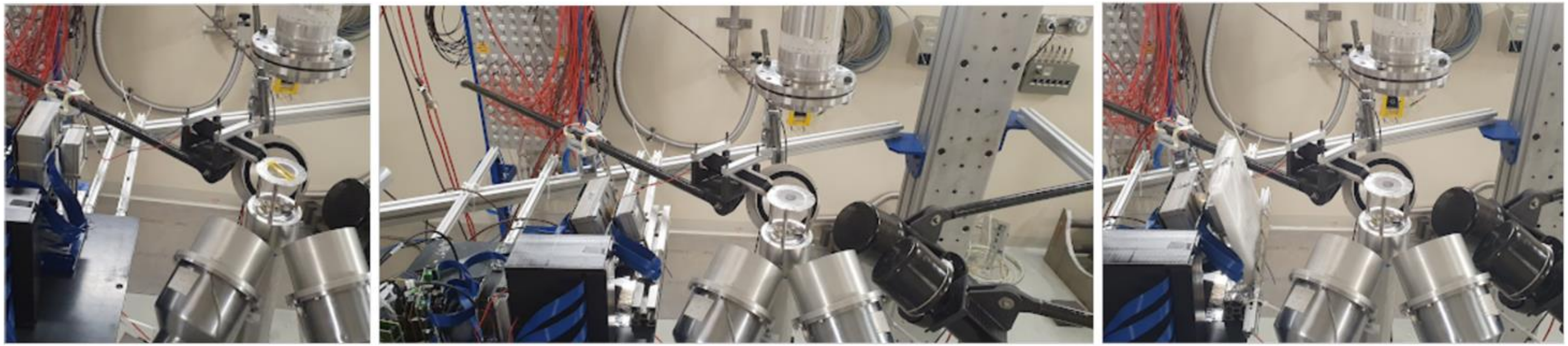






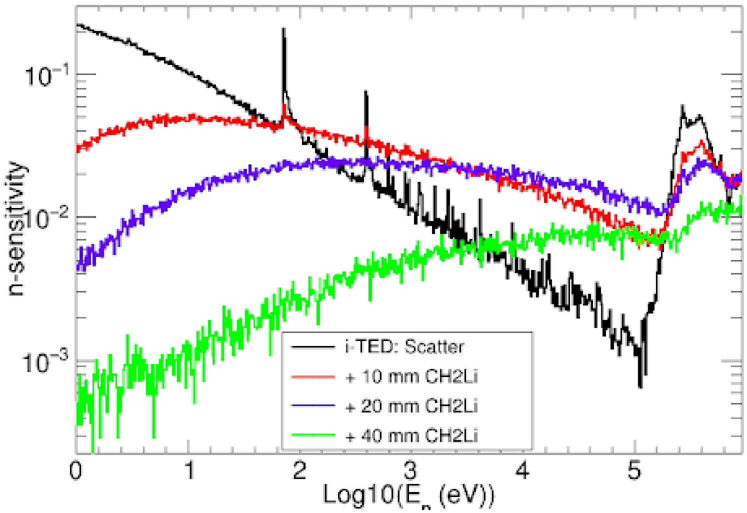
- Using a 2MBq ^{22}Na source, the performance of the i-TED system was explored for a large range of count-rate conditions
- Beyond 500kHz one observes significant gain and dead-time effects

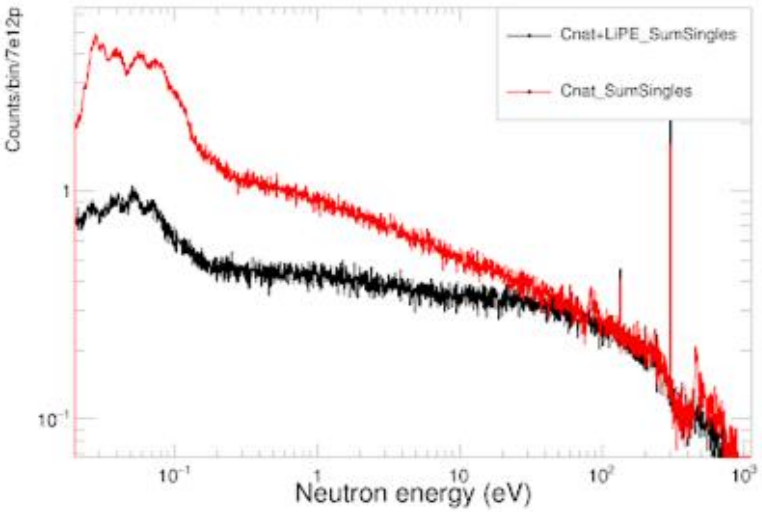
i-TED Tests at EAR2 under high count-rate



- Several tests with beam at EAR2 in order to test the performance of the i-TED system under different count-rate conditions
- Different set-ups tested: including 90º configuration, 135º configuration and ^{6}Li-High density Polyethylene shielding

i-TED Tests at EAR2 under high count-rate conditions

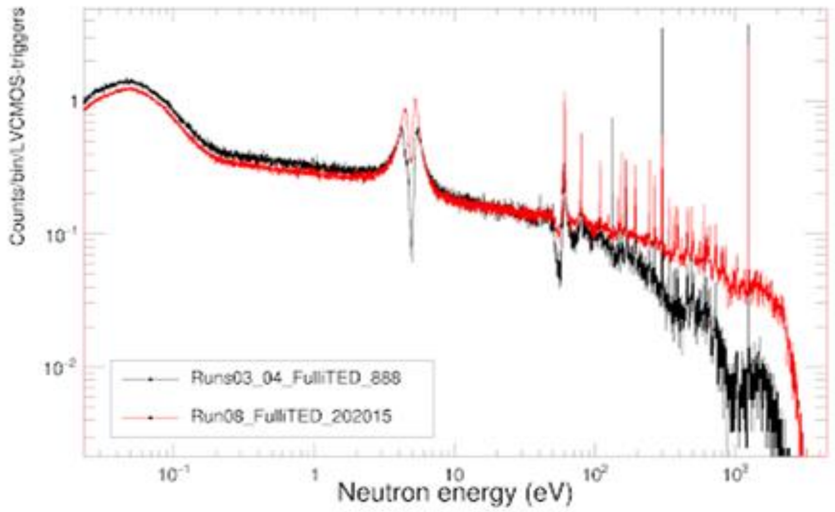


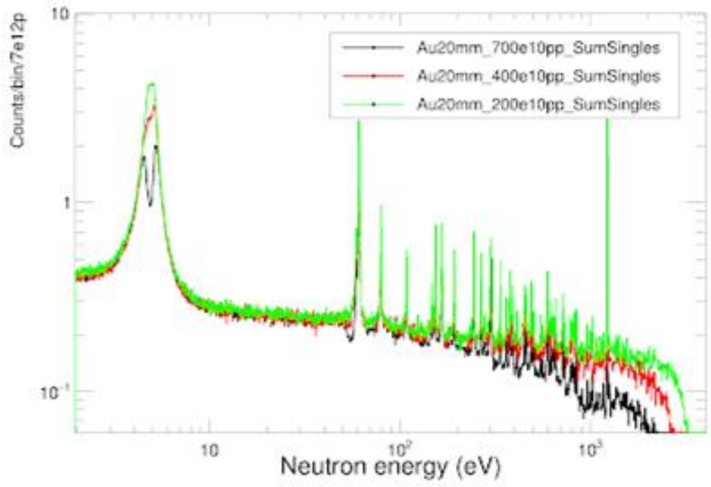


^{6}Li-HDPE Effect:

- Different absorber-thickness tested, large intrinsic neutron-sensitivity background suppression capability with 20-40 mm thick ^{6}Li HDPE
- Effect confirmed utilizing a natC sample in beam at EAR2 with one i-TED module

i-TED Tests at EAR2 under high count-rate conditions





High count rate conditions (thick Gold sample):

- Strong dead-time effects noticeable at high instantaneous count rates
- A reduction of a factor x3 is required in beam intensity at EAR2 to operate comfortably
- Equivalently, an enhancement in CR capability by a factor of x3 would be convenient for the full exploitation of EAR2 capabilities with i-TED (e.g. actinides measurements)

Outlook and conclusions

- The i-TED concept has been successfully demonstrated at EAR1 for background suppression by means of gamma-ray imaging (79Se(n,g) exp.)
- At EAR2 the performance of the system is rather limited owing to limitations in count-rate capabilities, which start to appear beyond 500kHz per detector
- At EAR2, optimizations in set-up angle (in-beam gamma-rays) and intrinsic neutron sensitivity (6Li HDPE) have provided some improvements, albeit not high enough for a reliable performance of i-TED at EAR2
- Enhancement in CR capability by a factor of x3 would be required for applying the i-TED system to the actinides in EAR2
- New generation read-out electronics (not yet commercially available) may provide in the future the required speed upgrade for the present application.

D1.7 Report on the development and performances of the new detectors for capture cross section measurements at n-TOF. **CIEMAT. M48** ✓