Neutron activation measurements at n_TOF

Michele Spelta,

A. Mengoni, S. Kopanos, M.E. Stamati, F. Garcia-Infantes, J. Lerendegui-Marco, A. Reina-Conde, A. Manna, N. Patronis, S. Goula, R. Mucciola, P. Perez-Maroto, M. Bacak, C. Lederer-Woods and **the n_TOF Collaboration**

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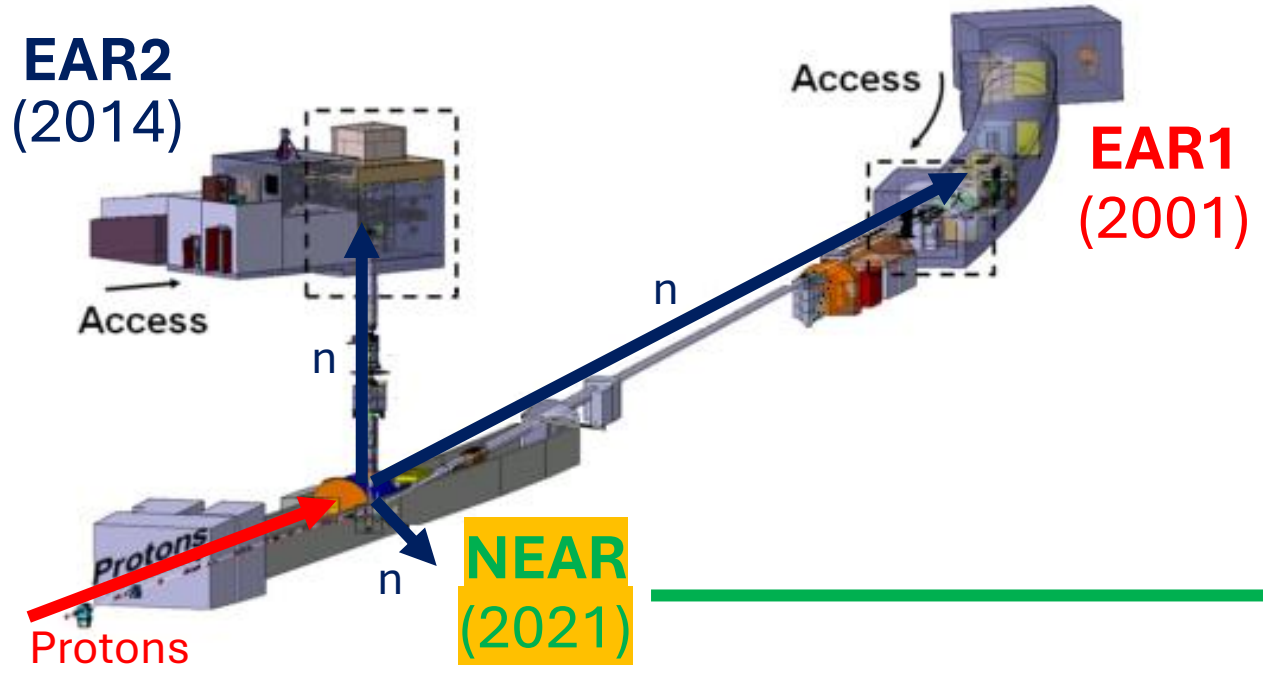
Introduction

n_TOF was born as a Time-Of-Flight facility (EAR1 & EAR2), but since 2021 a new **irradiation station** for activation measurements is available (**NEAR**)



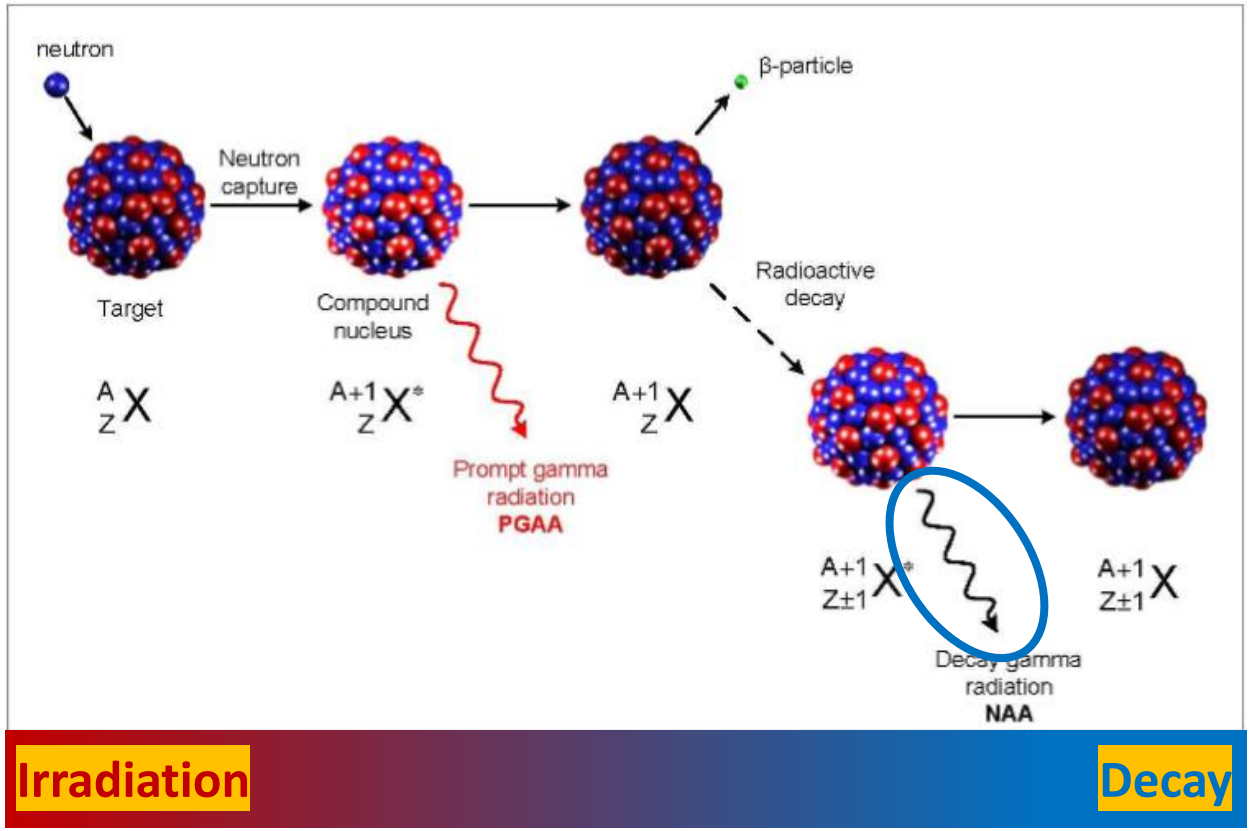
Activation measurements

- To measure neutron cross sections it's needed to "count" **Nr** of reactions in a sample

- In activation measurements, the **number of nuclei activated by the reaction of interest is counted**

- 2 Steps:
  1) **Irradiation** (produce unstable nuclei)
  2) **Measurement of the decay** products of unstable nuclei

$$\sigma \approx \frac{N_r}{n\,\varepsilon\,N_n}$$

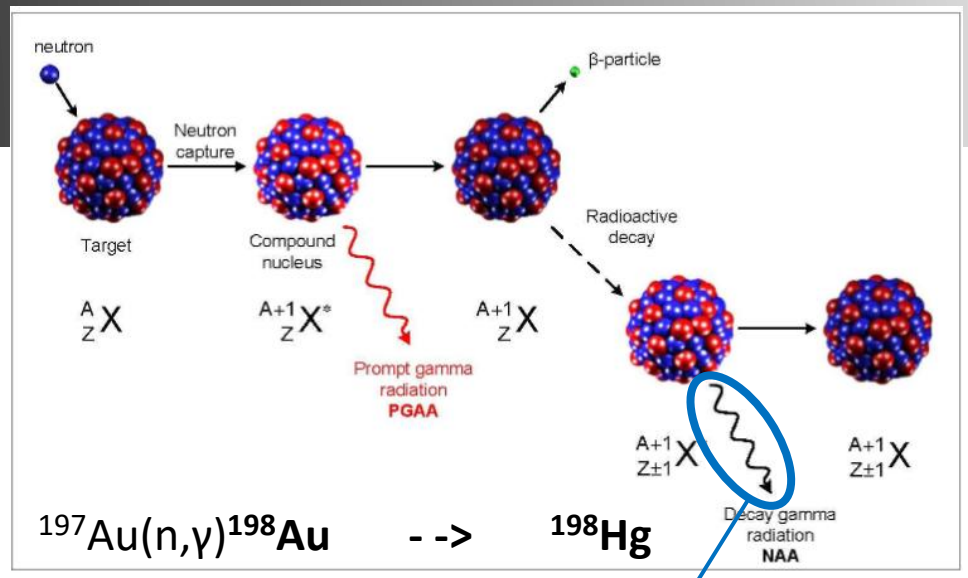


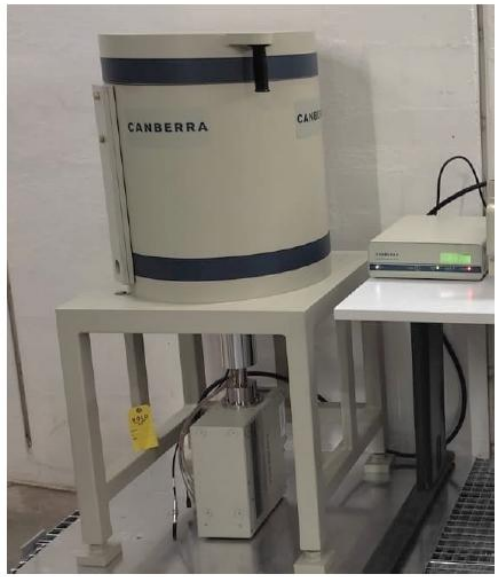
Why Activation?

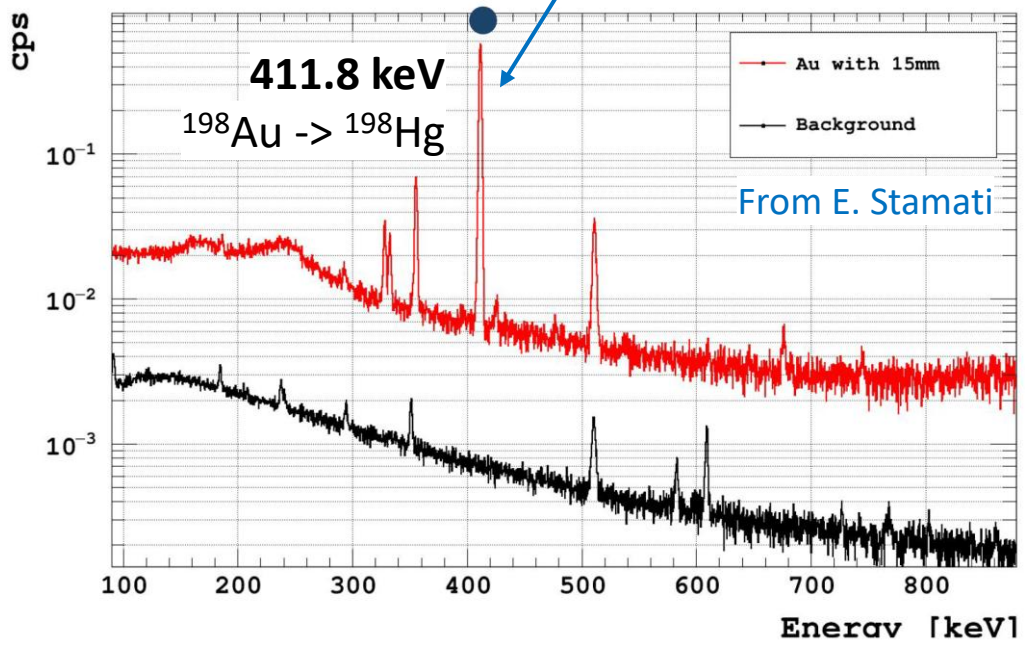
Possibility to select **specific γ-rays** in high resolution detectors (HPGe) after irradiation in **huge neutron fluxes**

- **High selectivity**
  (no need of monoisotopic samples)
- **High sensitivity**
  (ng-mass-samples)

Advantageous for small cross sections, small-mass and/or radioactive samples







Why Activation?

(n, γ) cross sections on **radioactive isotopes** are important in astrophysics:

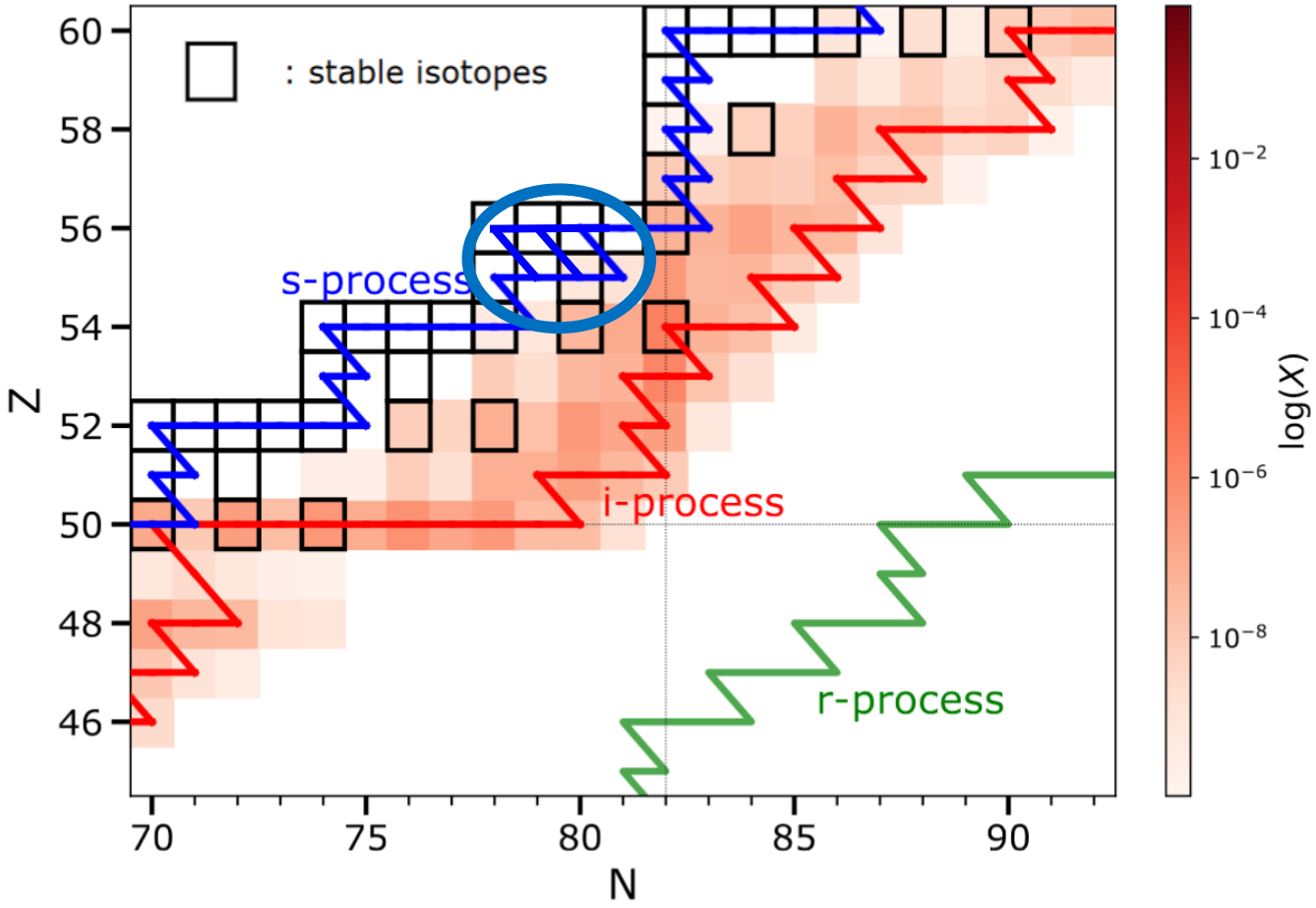
- **Branching points of s-process**
  (Accurate n,γ XS to constrain stellar parameters)

  E.g. ***^{134,135}Cs*** *(2y, 1.3My),* ^{147}*Pm (2.6y),* ^{171}*Tm (702d),* ^{94}*Nb (20ky),…*

- **i-process**
  (Accurate n,γ XS to simulate i-process nucleosynthesis)

  E.g. ^{66}*Ni (55h),* ^{72}*Zn (47h),* ^{125}*Sb (2.8y),* ^{137}*Cs (30y),* ^{144}*Ce (285d),* ^{141}*La (3.9h) …*

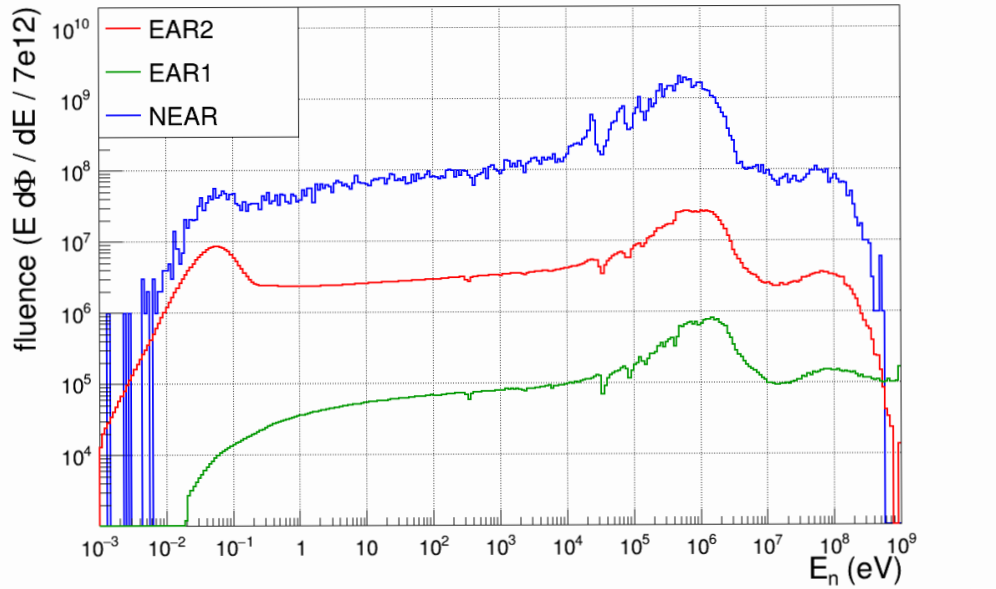
From *A. Choplin, EPJ Web of Conferences 279, 07001 (2023)*

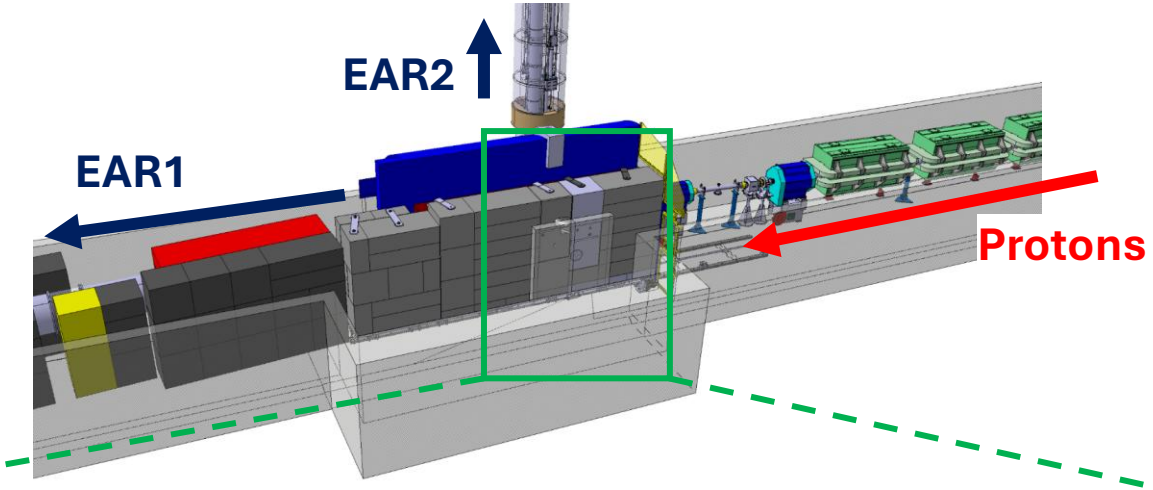


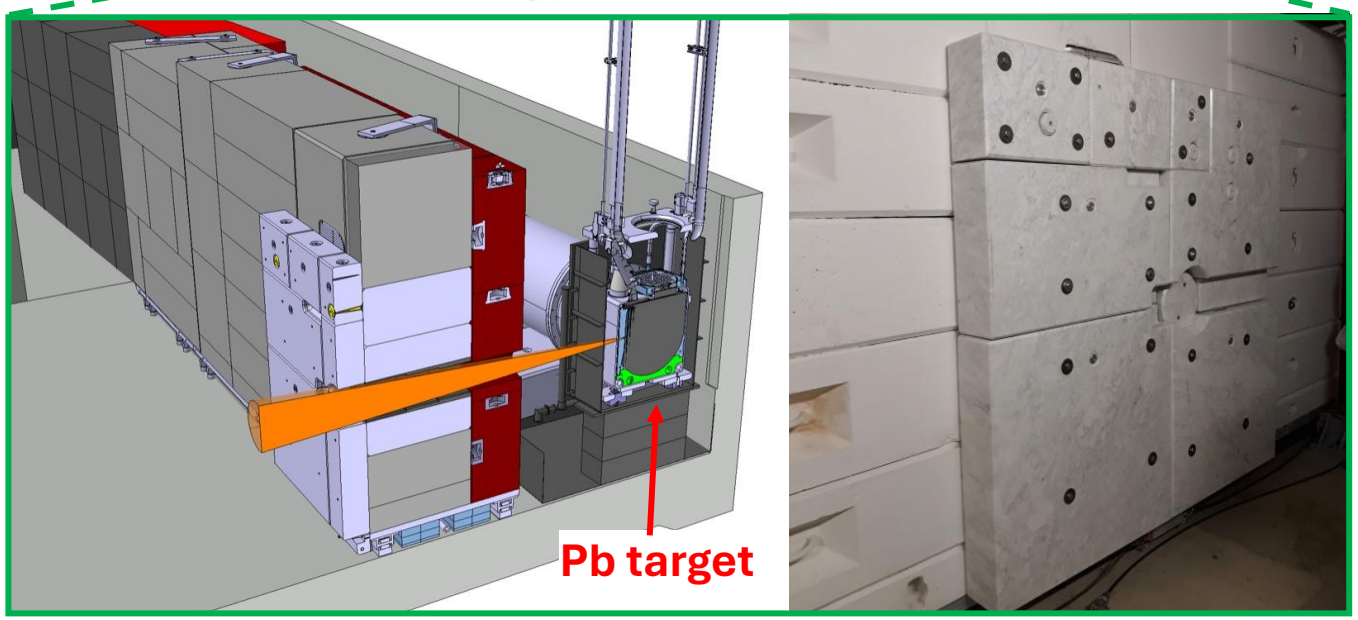
n_TOF NEAR

NEAR irradiation station is located at ≈ **3 m** from spallation target and receives a neutron flux of ≈ **10^9 neutrons/pulse**.
(Not only for astrophysics!)

A. Mengoni, CERN-INTC-2020-073 / INTC-I-222 (2020)

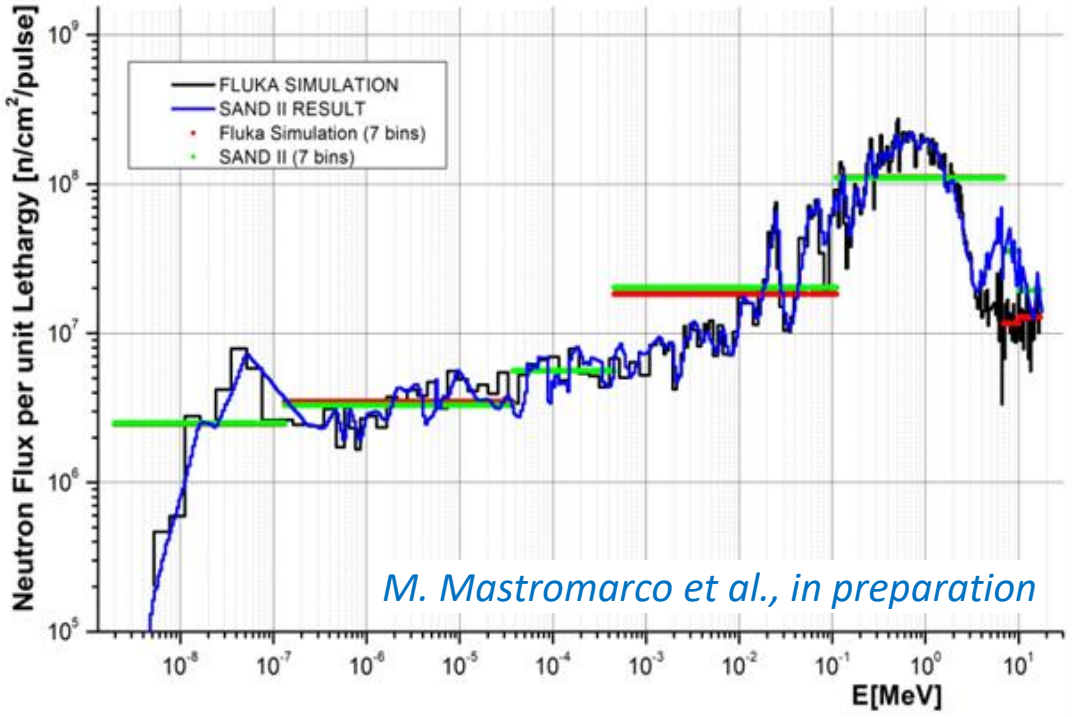


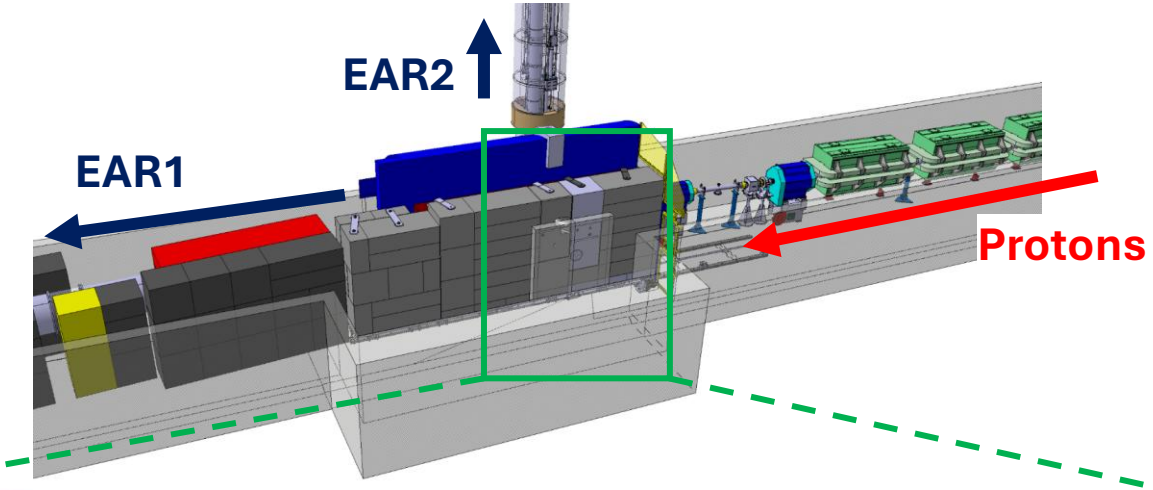


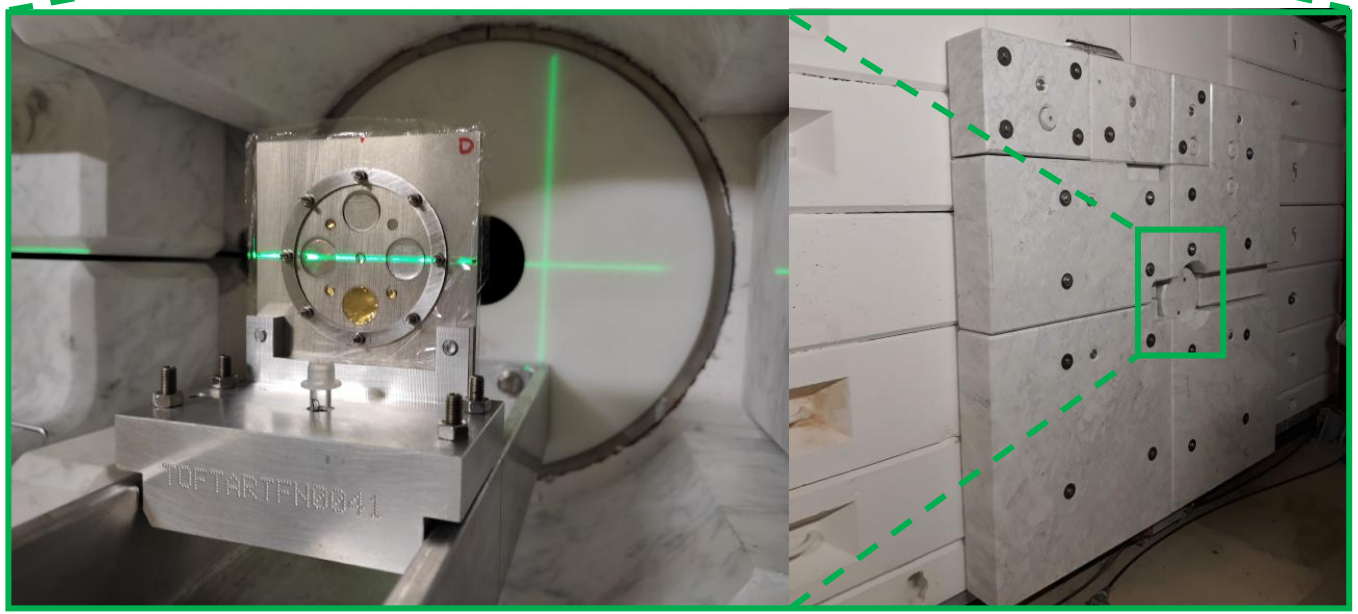


n_TOF NEAR

NEAR neutron flux has been simulated (FLUKA) and validated with **Multifoil Activation Measurements**



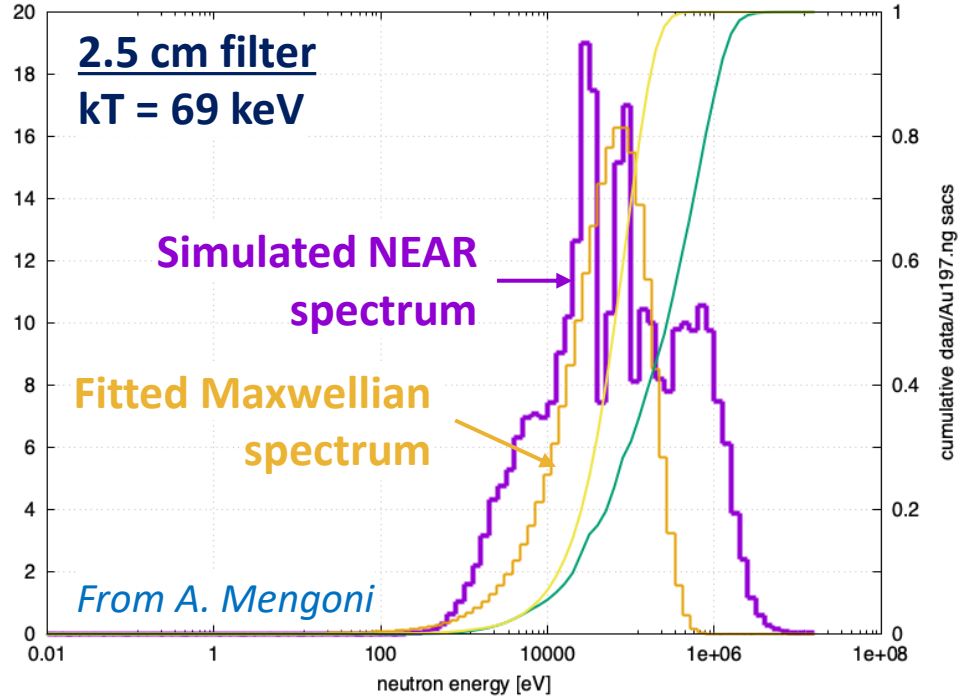




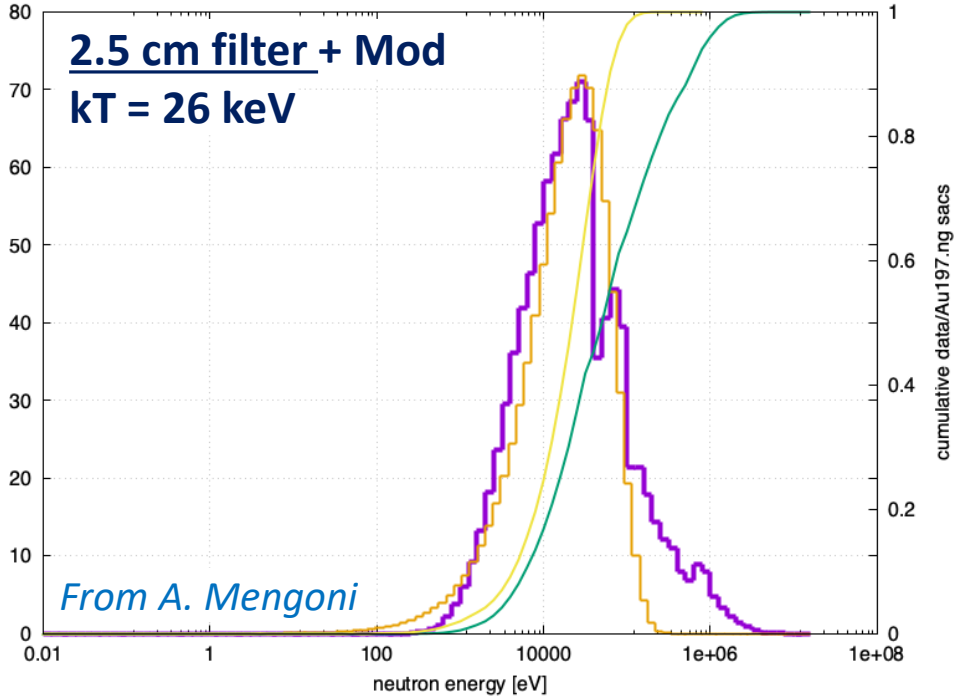
Quasi-Maxwellian Spectrum

Neutron spectrum needs to be shaped to a **quasi-Maxwellian spectrum** to get MACS:

- **B_4C filters** (95% ^{10}B)
  - Filter low-energy neutrons
  - Thickness defines stellar temperature



- **Al_2O_3 moderator** *(Winter 2025)*
  - Shift neutron flux in the energy range of astrophysical interest



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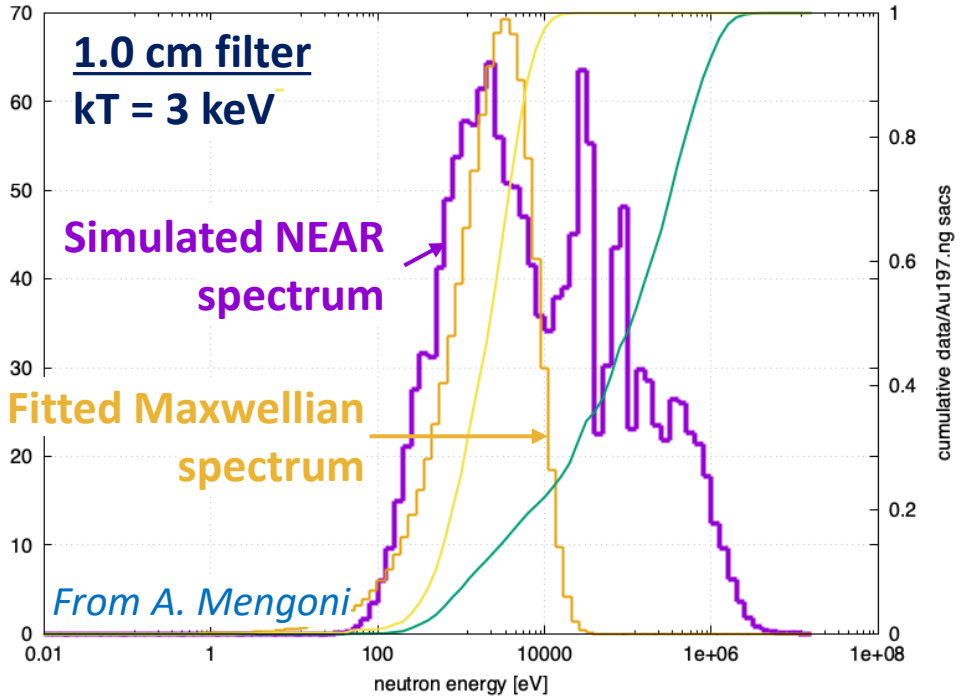

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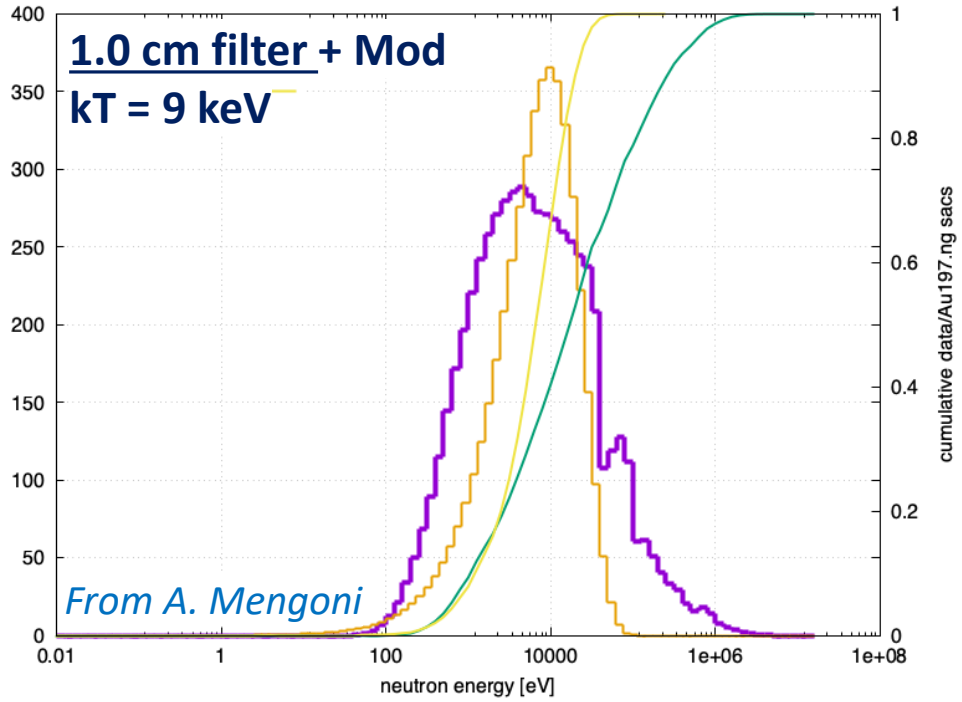


Current Activity at NEAR

Benchmarking the feasibility of measuring MACS at NEAR.

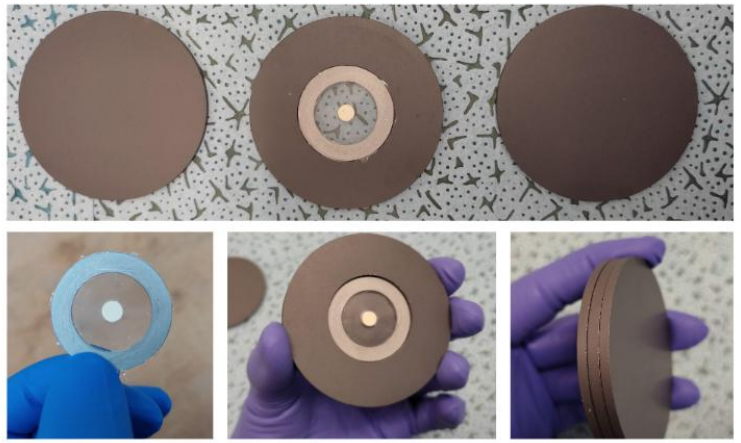
- **Problem:** **quasi-**Maxwellian spectrum, we can only measure a SACS *(Spectral Average CS)*

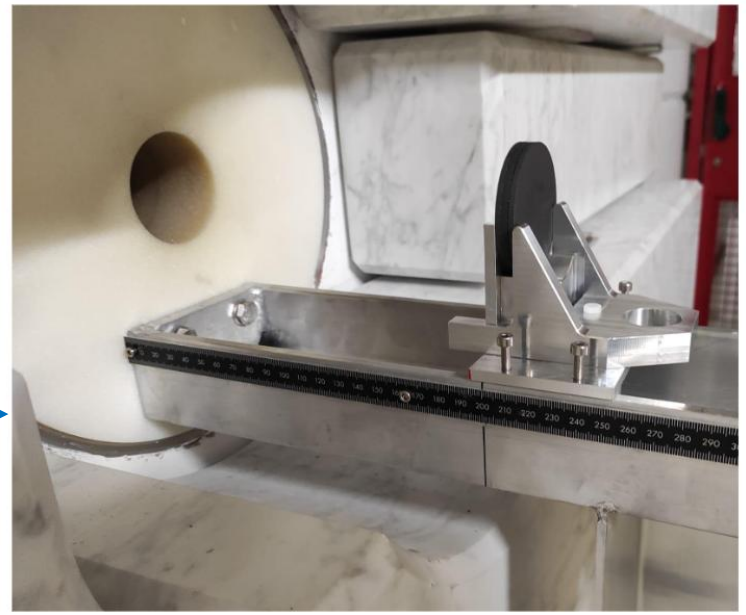
- **Solution:** Need to estimate a "universal" correction **factor to convert SACS to MACS** for each filter thickness

Measuring SACS and compare to calculated MACS:

$^{197}Au(n,\gamma)$	$^{76}Ge(n,\gamma)$	$^{140}Ce(n,\gamma)$	$^{94}Zr(n,\gamma)$	$^{109}Ag(n,\gamma)$

Reference





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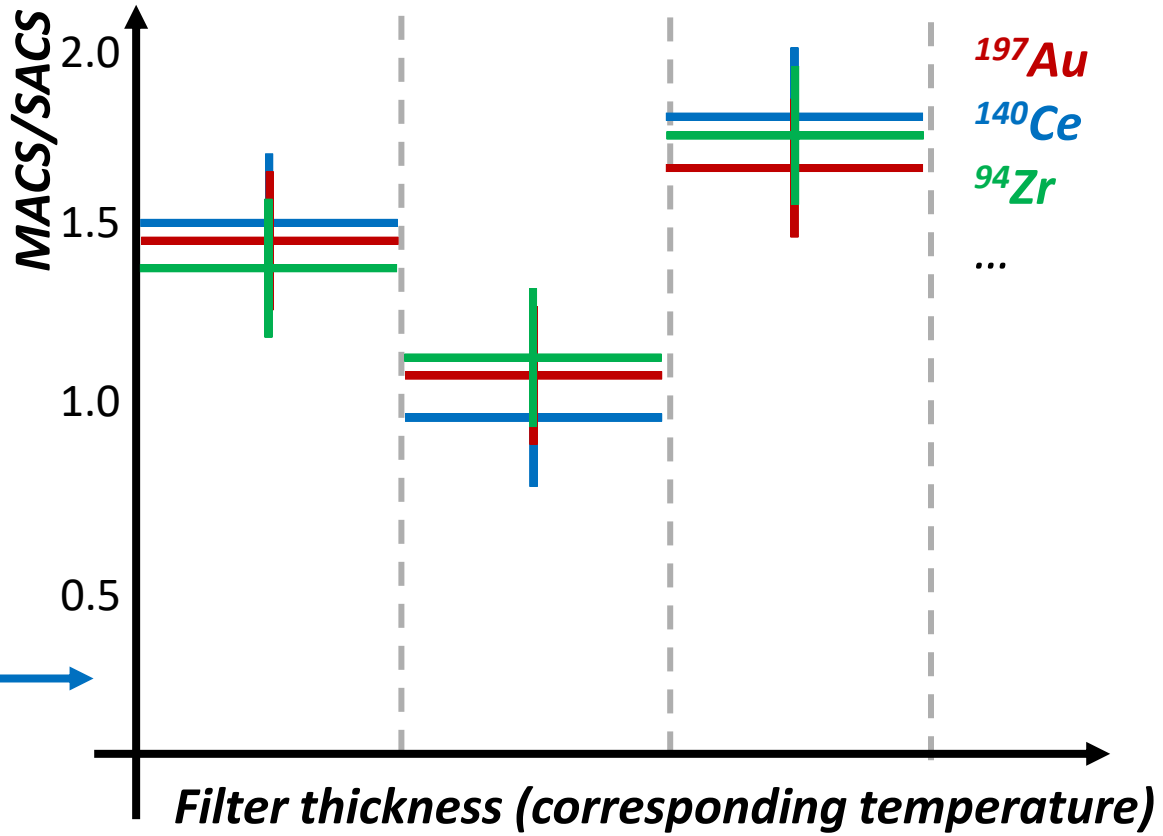

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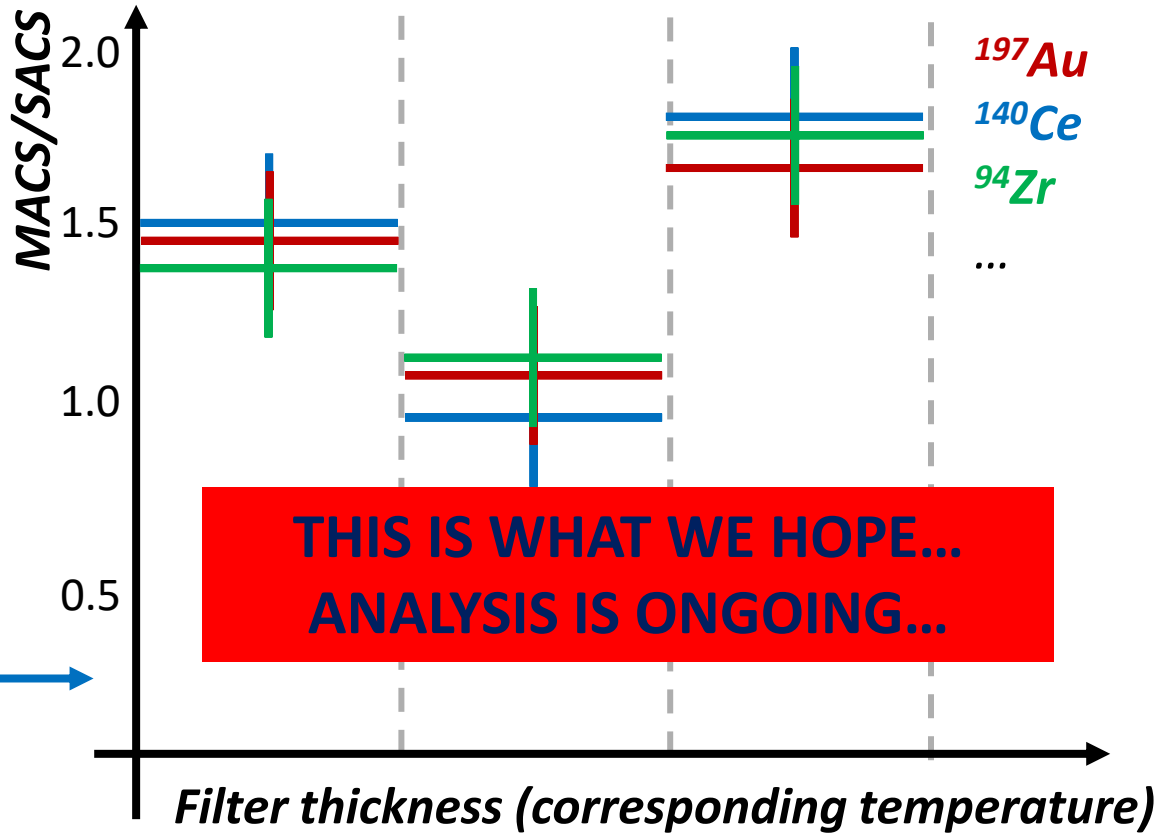


Future plans

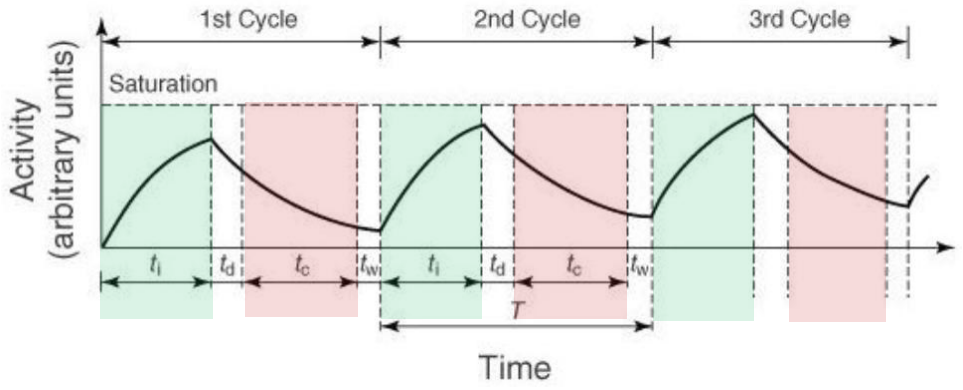
CYCLING at NEAR
for short-lived activated nuclei

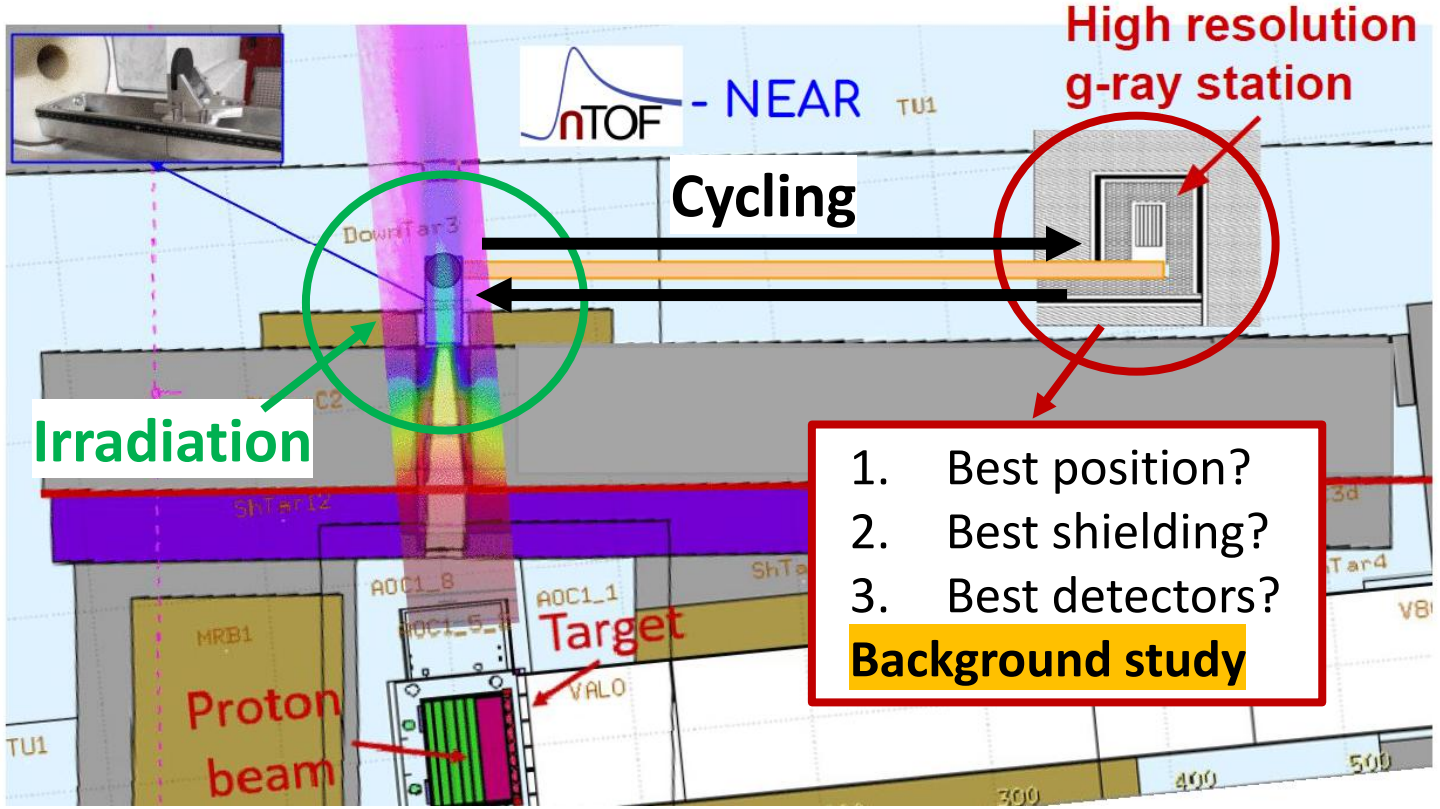
Synergy with ISOLDE
for radioactive target production

n_ACT @ BDF/SHiP
for very small-mass and low-XS samples

CYCLING at NEAR

- Measurement of short-lived products is now prevented by **6 h cool-down** for NEAR access
- **Cyclic irradiation and activation measurements in a decay station inside NEAR** (**CYCLI**c activation for **N,G** measurements) would allow to measure s-**min** half-lives

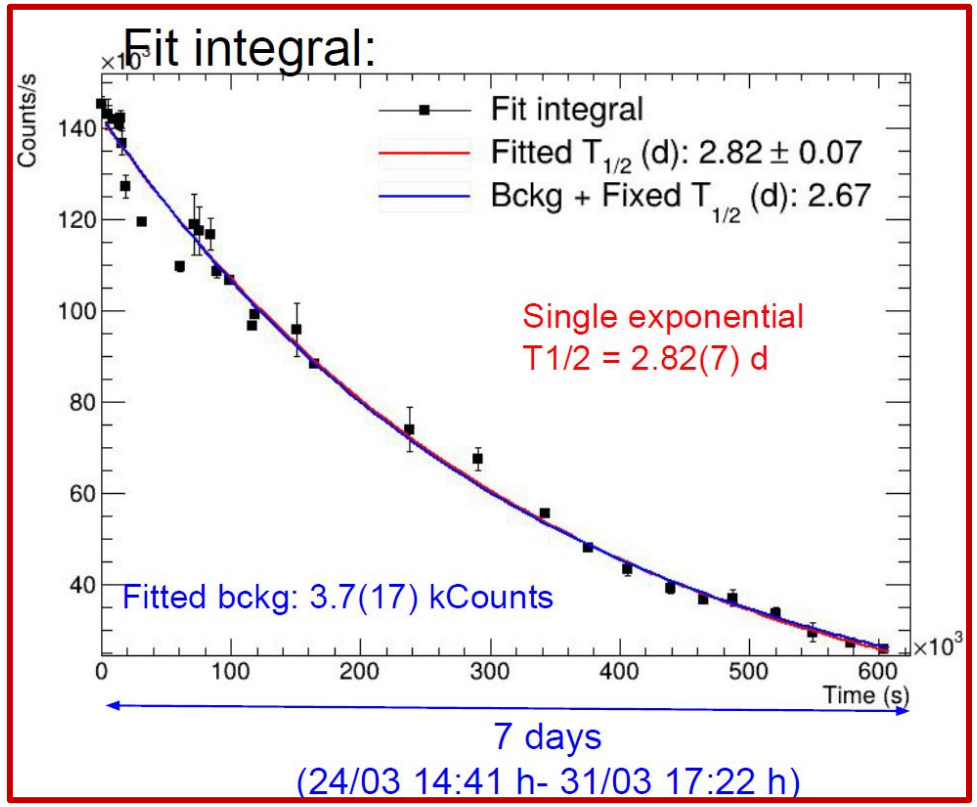


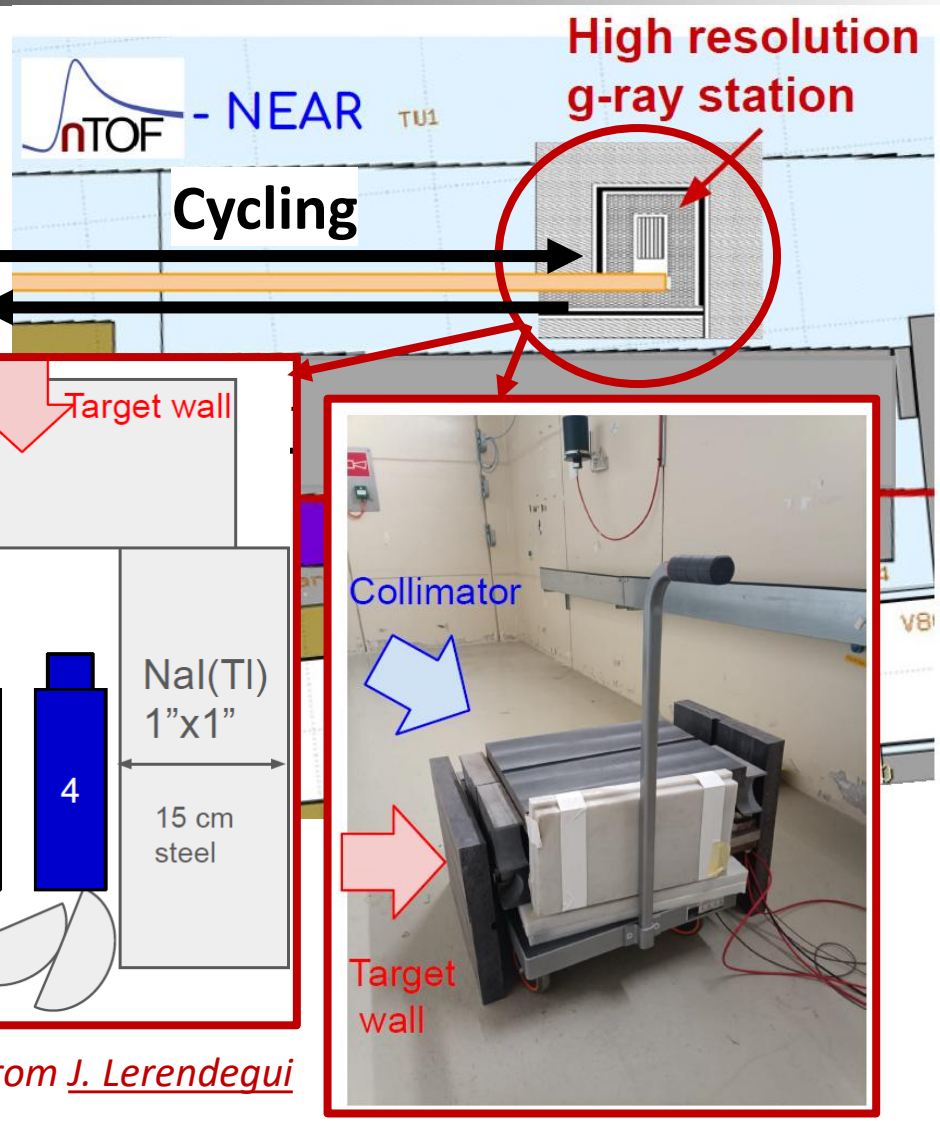


J. Lerendegui et al, CERN-INTC-2022-018 / INTC-I-241 (2022)

CYCLING at NEAR

- First **test with Au activation** is successful,
- but activity is too large wrt sample of interest
- Improvement of **background** and **gain shift** needed

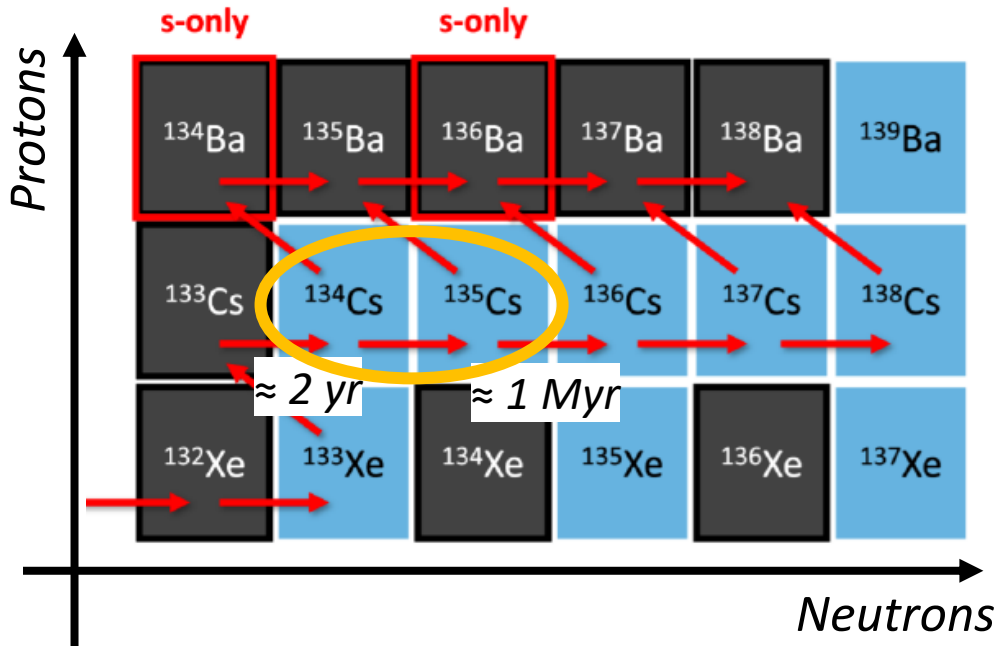




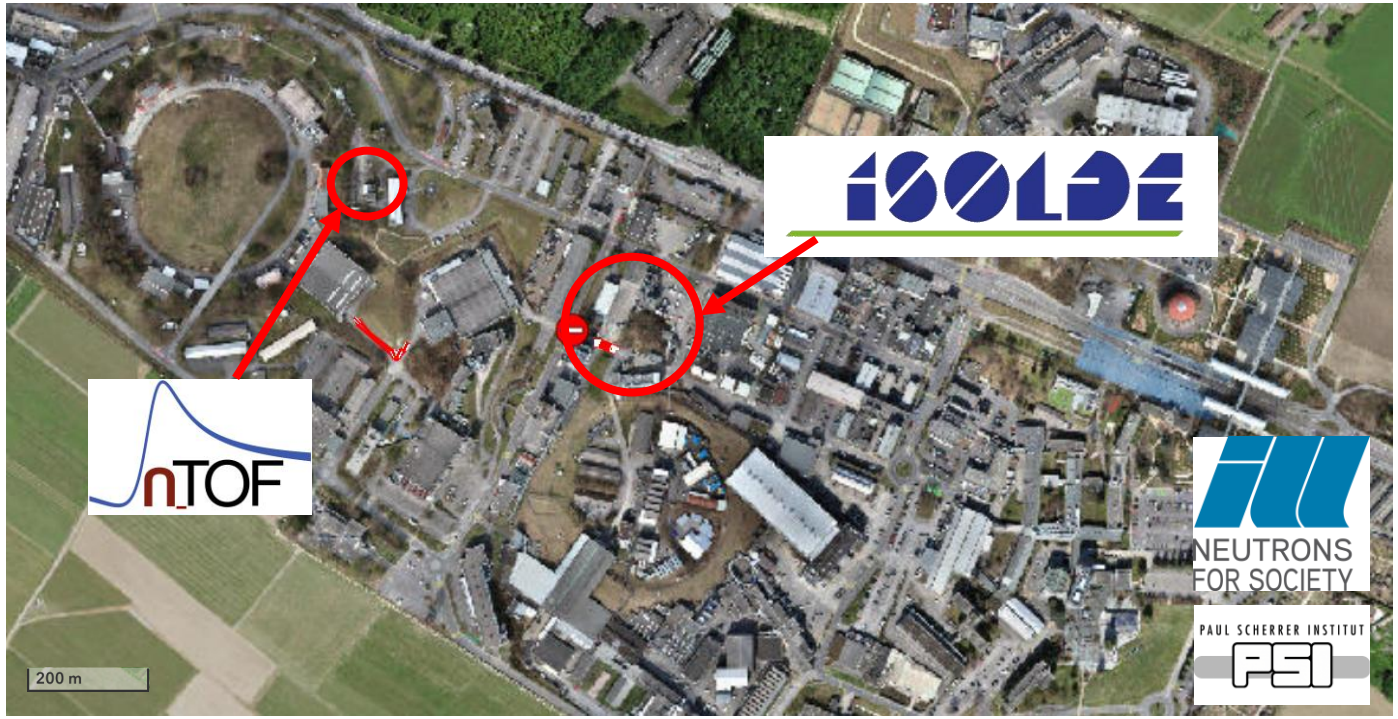
Pictures and plot from J. Lerendegui

Synergy with ISOLDE

- Irradiation of radioactive isotopes ideally requires **$\Delta t_{production\text{-}irradiation}$ < lifetime**
- **Walking distance between NEAR and ISOLDE** may be advantageous to produce and irradiate radioactive samples with lifetimes down to ≈ hours/day.
- First collaboration: **Cs-135 production**

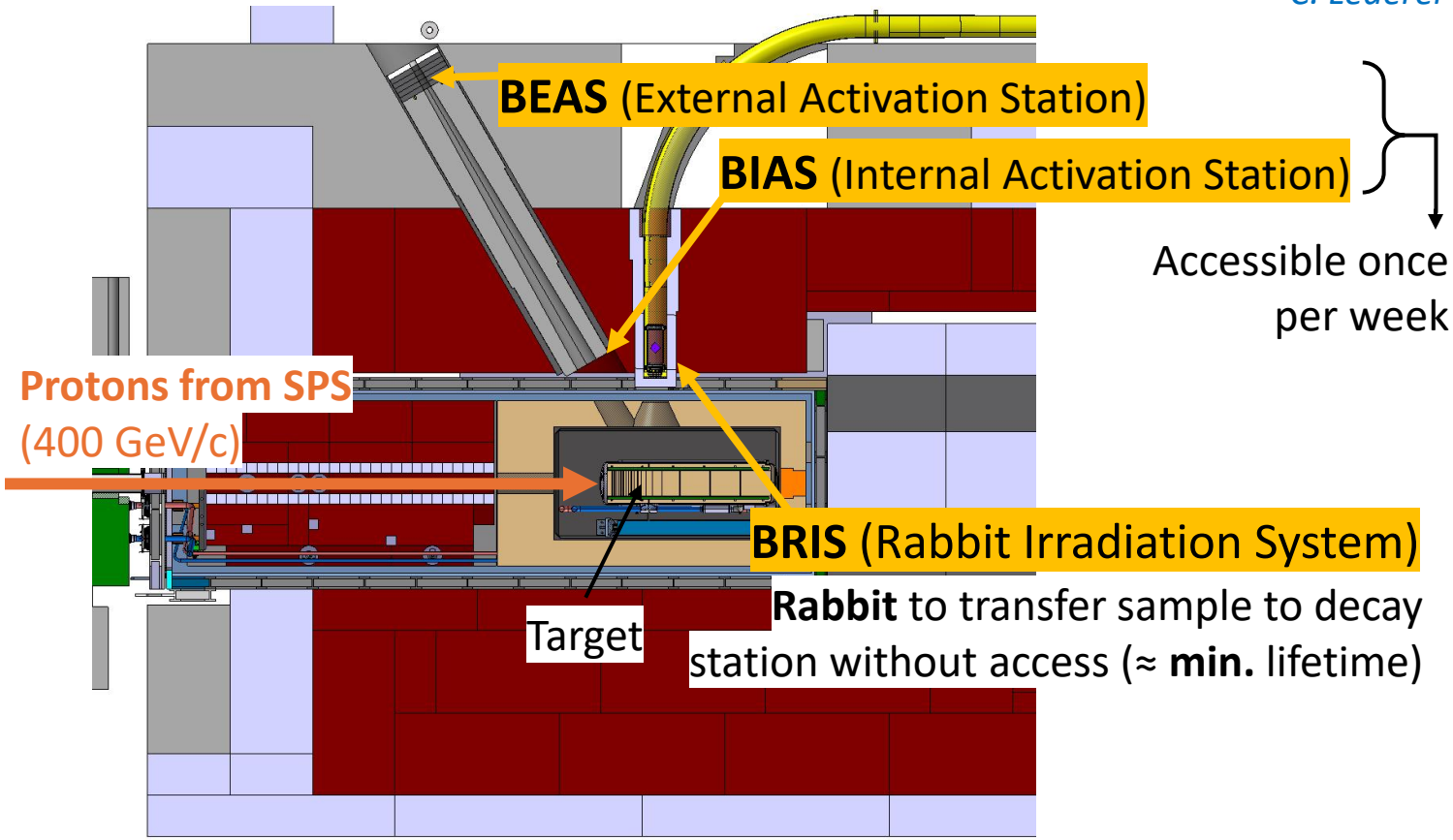


J. Lerendegui et al, CERN-INTC-2022-040 / INTC-P-641 (2022)

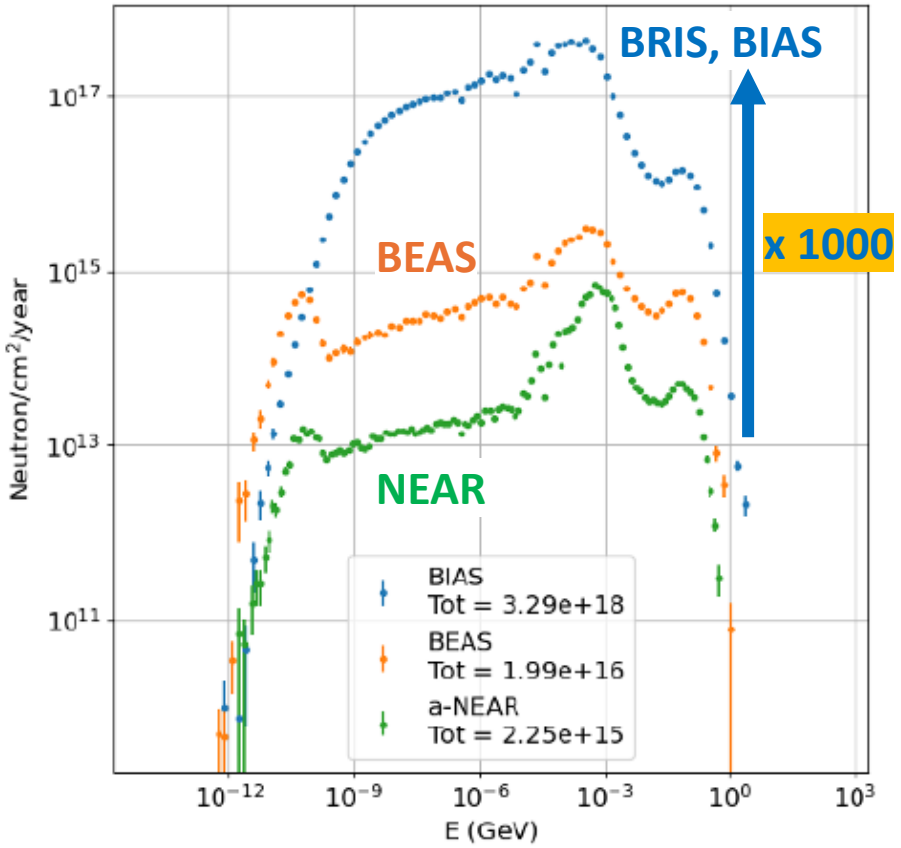


n_ACT @ BDF/SHiP

Ambitious project for **new parasitic activation stations at the future BDF** (Beam Dump Facility) for the SHiP experiment.



C. Lederer-Woods et al, CERN-SPSC-2024-027 / SPSC-EOI-023 (2024)



n_ACT @ BDF/SHiP

2031 / 2035

Combination of:

- High **neutron flux** (x1000 wrt NEAR)
- Vicinity to **ISOLDE**
- **Rabbit system** for moving “instantaneously” irradiated samples
- **Expertise from NEAR** in shaping neutron flux with filters + moderator

Unique combination to measure stellar MACS at different temperatures for radioactive and/or small-mass and/or small-cross section samples, not accessible elsewhere

e.g. (n,γ) on ^{94}Nb, ^{147}Pm, ^{163}Ho, ^{171}Tm,...

Summary

- **NEAR**: irradiation station for activation measurements at n_TOF
- Advantageous for **small-mass and/or radioactive samples** (e.g. s-process branchings, i-process nuclei)
- Now **testing feasibility of MACS measurements at different temperatures**, with quasi-Maxwellian spectra shaped with filter (+ moderator)
- **Cyclic activation** and synergy with **ISOLDE** are planned
- Long term project (2031/35) for **new parasitic irradiation stations at BDF/SHiP** to reach more extreme physics cases