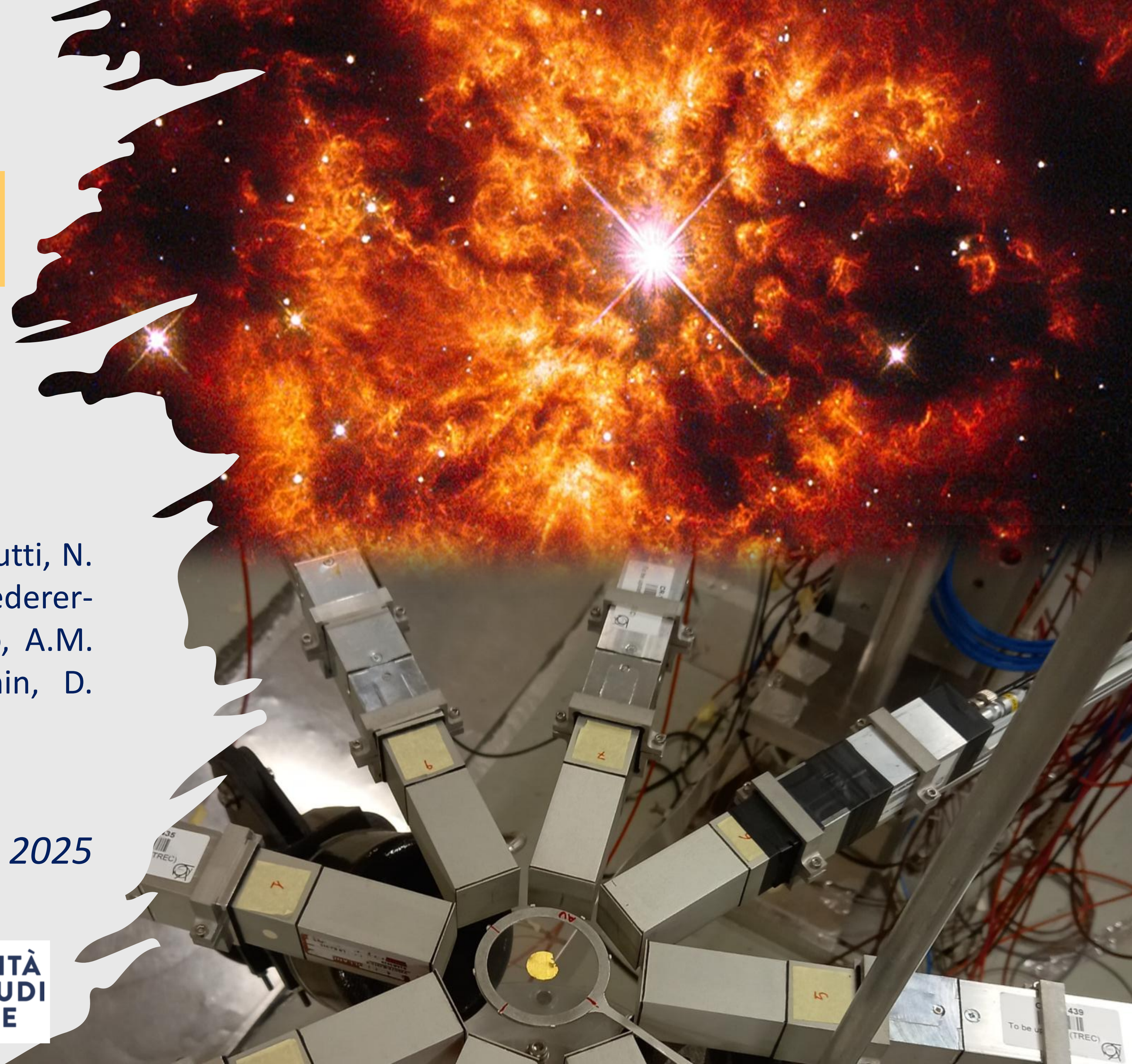
Measurement of the $^{64}Ni(n,\gamma)$ cross section at n_TOF

Michele Spelta,

G. Tagliente, P.M. Milazzo, A. Casanovas, G. Cescutti, N. Colonna, S. Cristallo, F. García-Infantes, C. Lederer-Wood, A. Manna, C. Massimi, M. Mastromarco, A.M. Mazzone, A. Mengoni, R. Mucciola, N. Sosnin, D. Vescovi and the n_TOF Collaboration

SIREN Conference, *Giulianova 8-13 June 2025*



CERN n_TOF INFN TRIESTE UNIVERSITÀ DEGLI STUDI DI TRIESTE

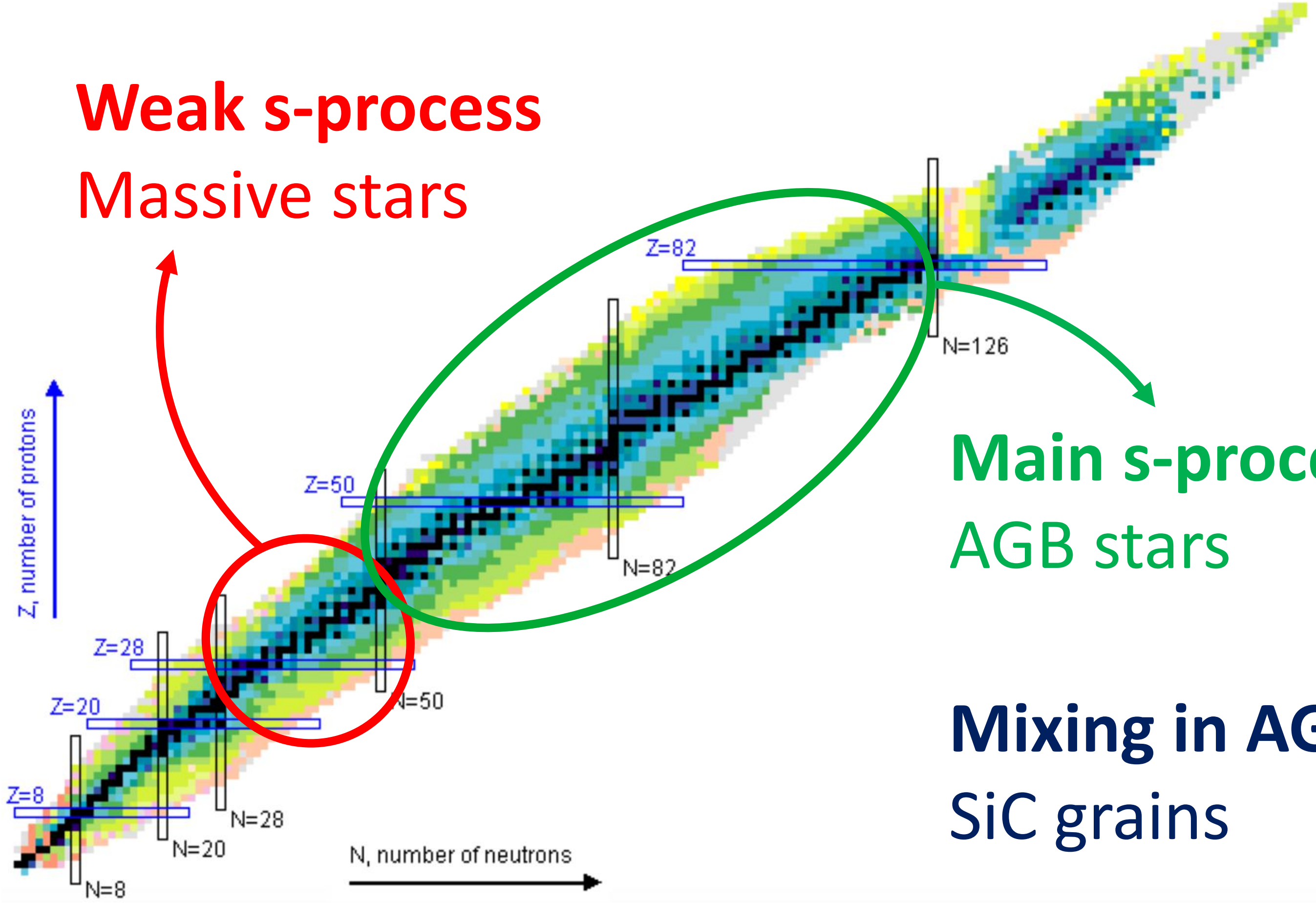
Measurement of the $^{64}Ni(n,\gamma)$ cross section at n_TOF

- What?
- Why?
- Where?
- How?
- Preliminary Results

Why: S-process

^{64}Ni(n,γ) cross section plays an important role in:

Weak s-process
Massive stars



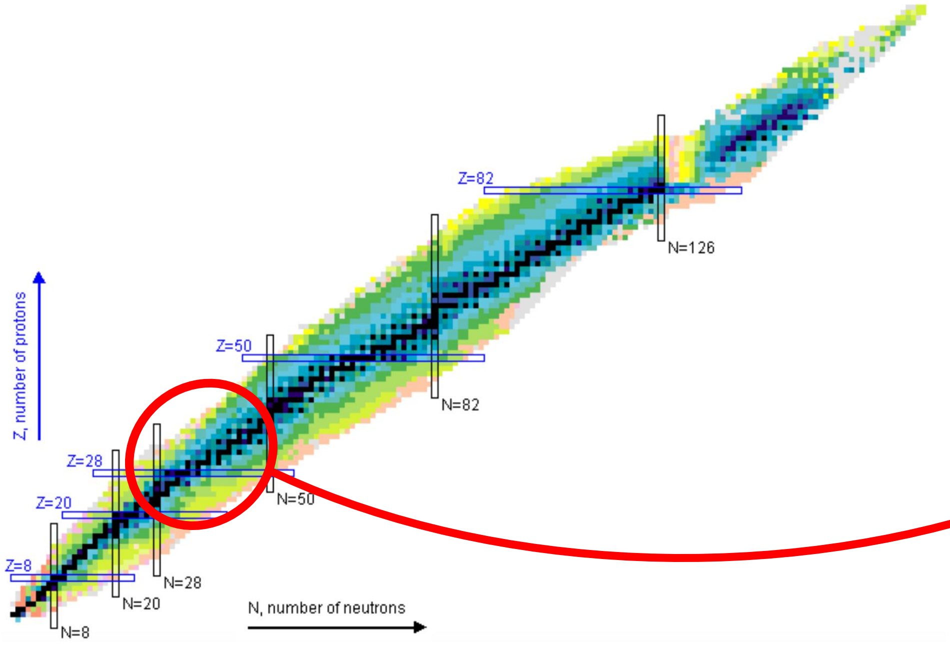
Main s-process
AGB stars

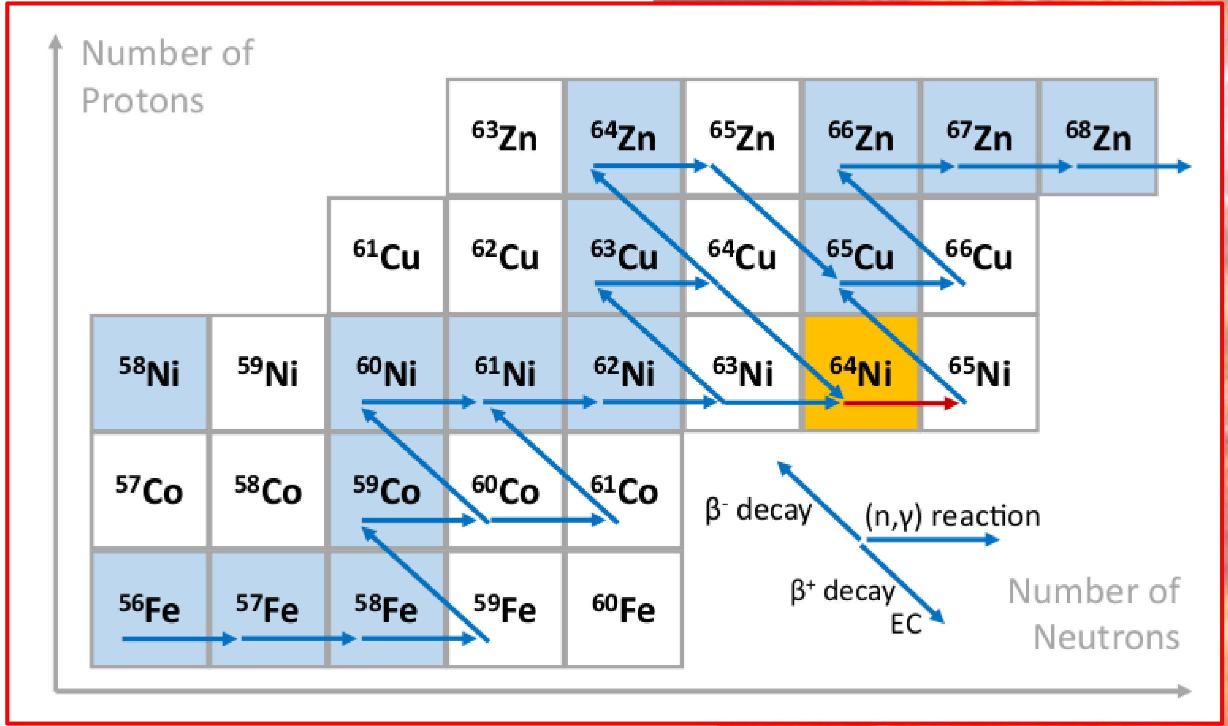
Mixing in AGB stars
SiC grains

Why: Weak s-process

Fe and Ni are among the **seeds of the s-process**:
their (n,γ) cross sections affect the abundances of all the heavier isotopes (no equilibrium)

Tain et al., CERN-INTC-2006-012 / INTC-P-208

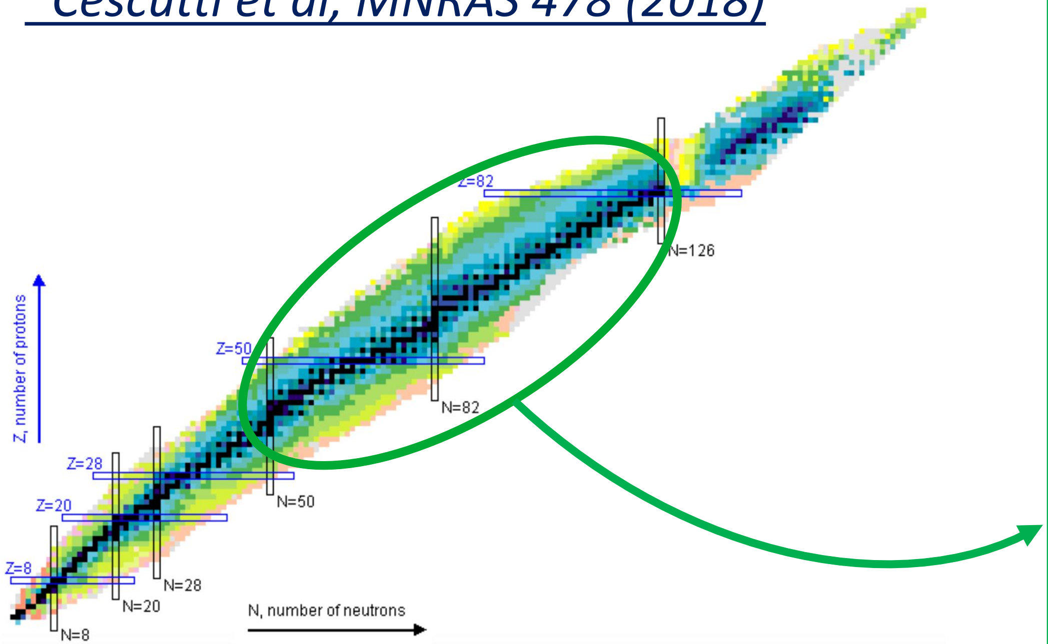




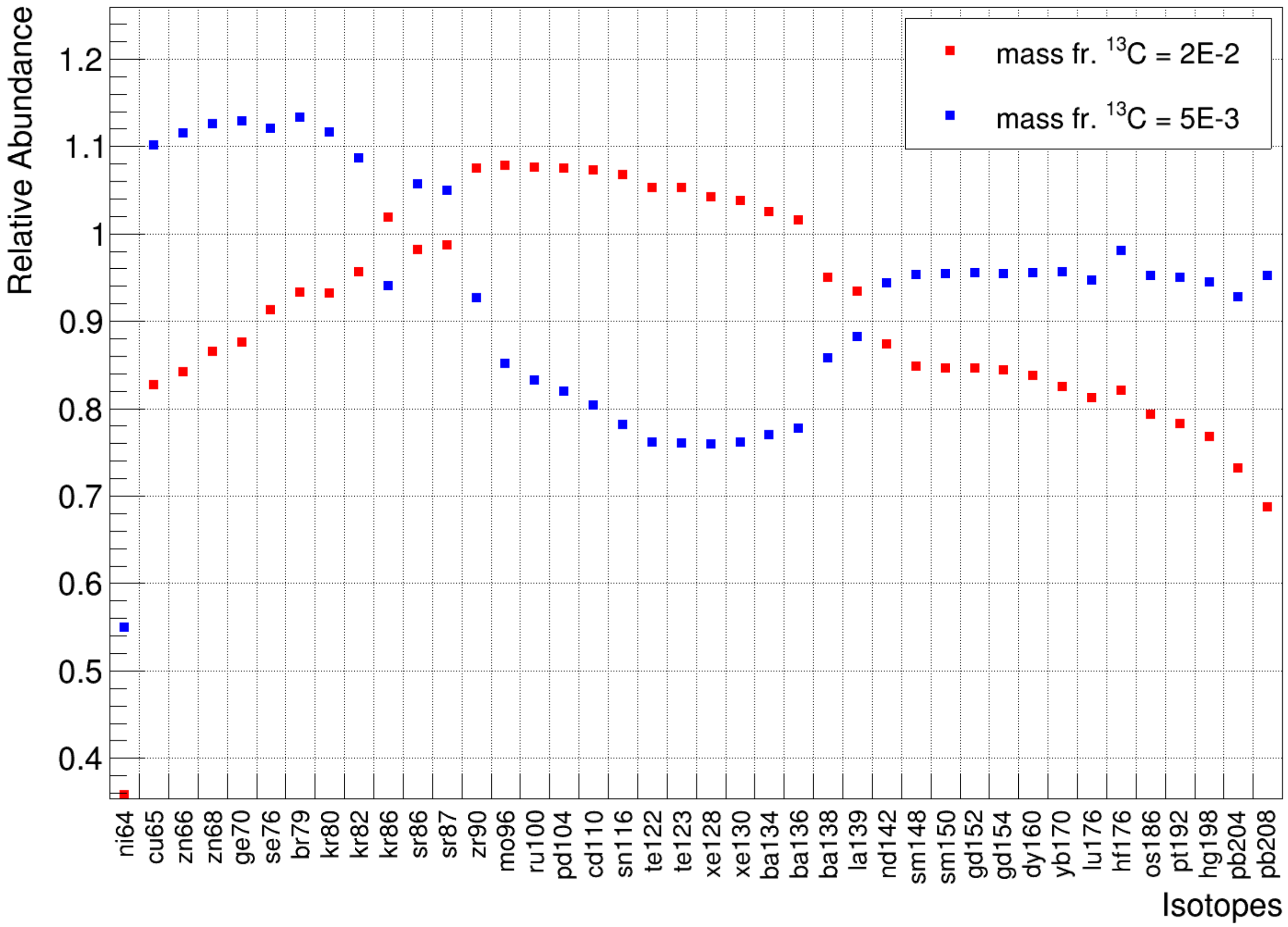
Why: Main s-process

Despite equilibrium, ^{64}Ni(n,γ) cross section has a **global impact on the main s-process abundances**

**Cescutti et al, MNRAS 478 (2018)*

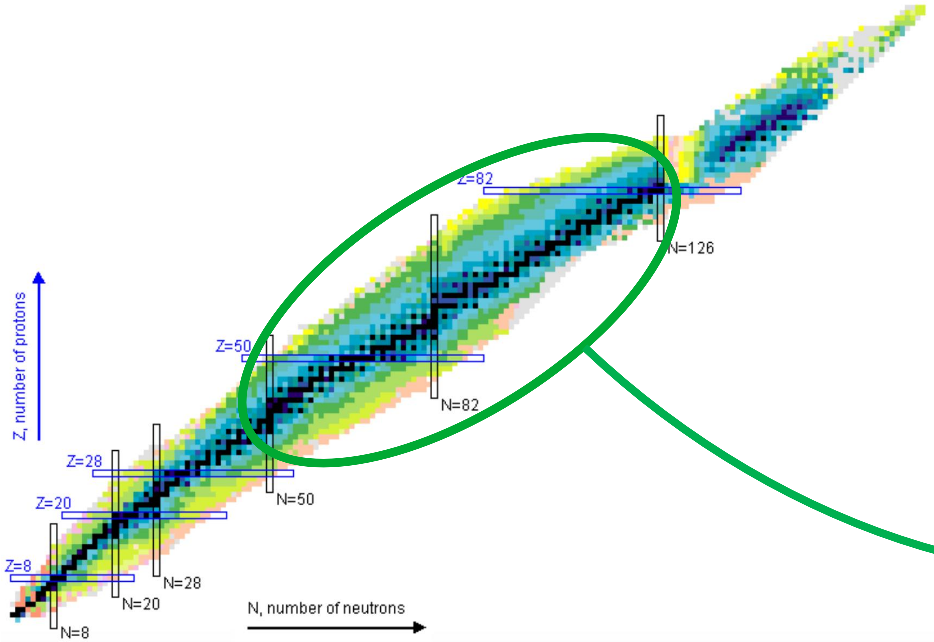


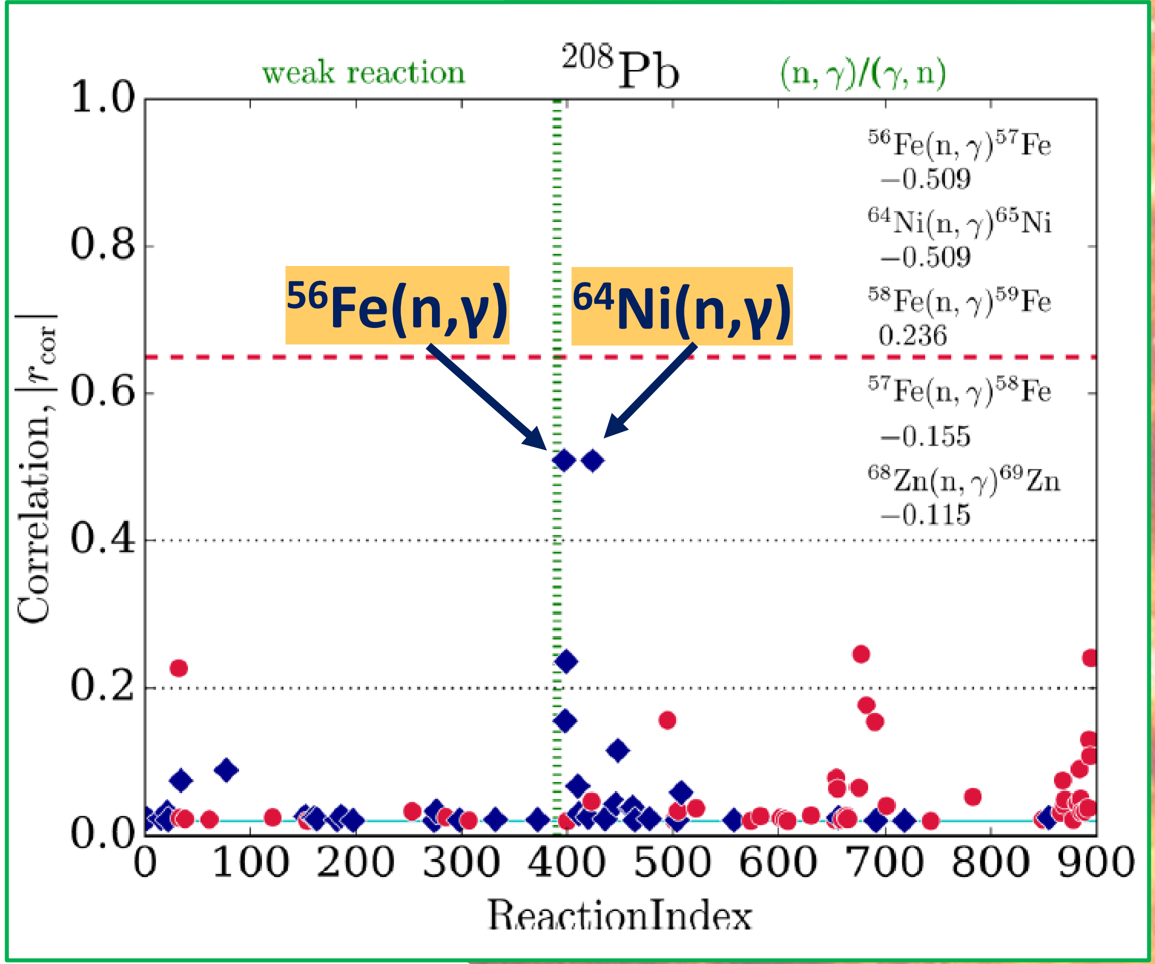
My work using the ***PizBuin*** Code*: ^{64}Ni(n,γ) σ **x2**



Why: Main s-process

A large-scale MC sensitivity study using PizBuin* confirms **^{64}Ni(n,γ) among the 3 key reactions whose σ globally affects s-process abundances**



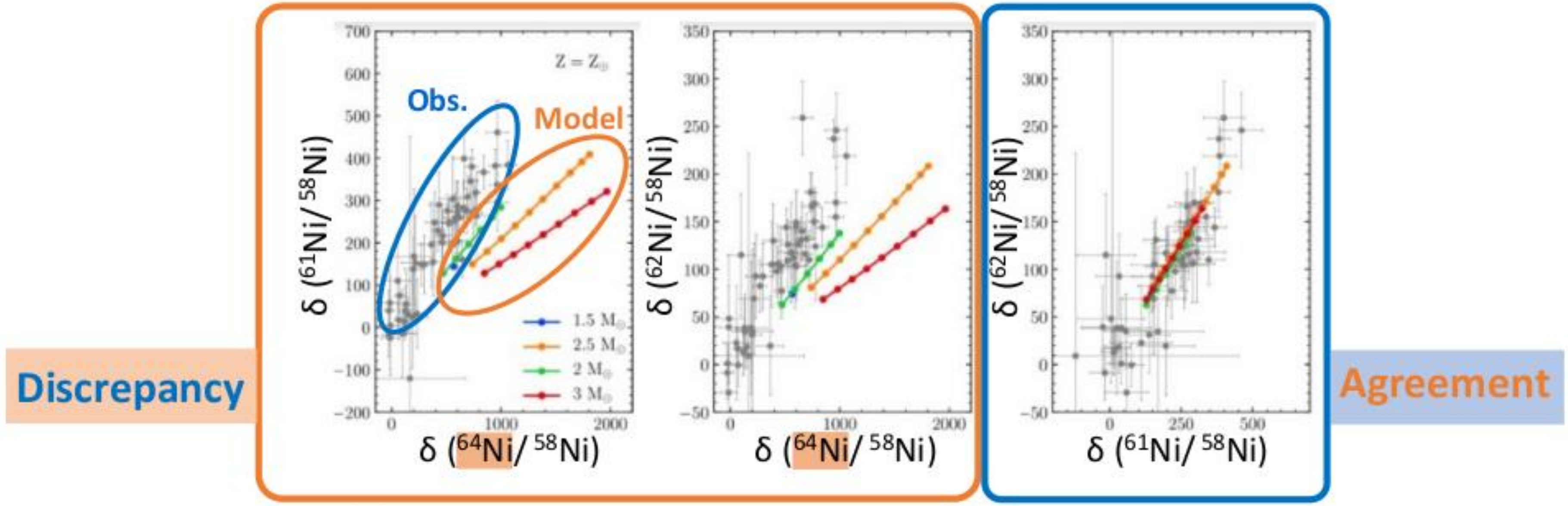


*From: *Cescutti et al, MNRAS 478 (2018)*

Why: Mixing in AGB

^{64}Ni(n,γ) cross section has an important effect on the predictions of a **model for mixing in AGB stars**, based on magnetic buoyancy

D. Vescovi et al., ApJ Lett. 897 (2020)



Possible inaccurate ^{64}Ni(n,γ) cross section?

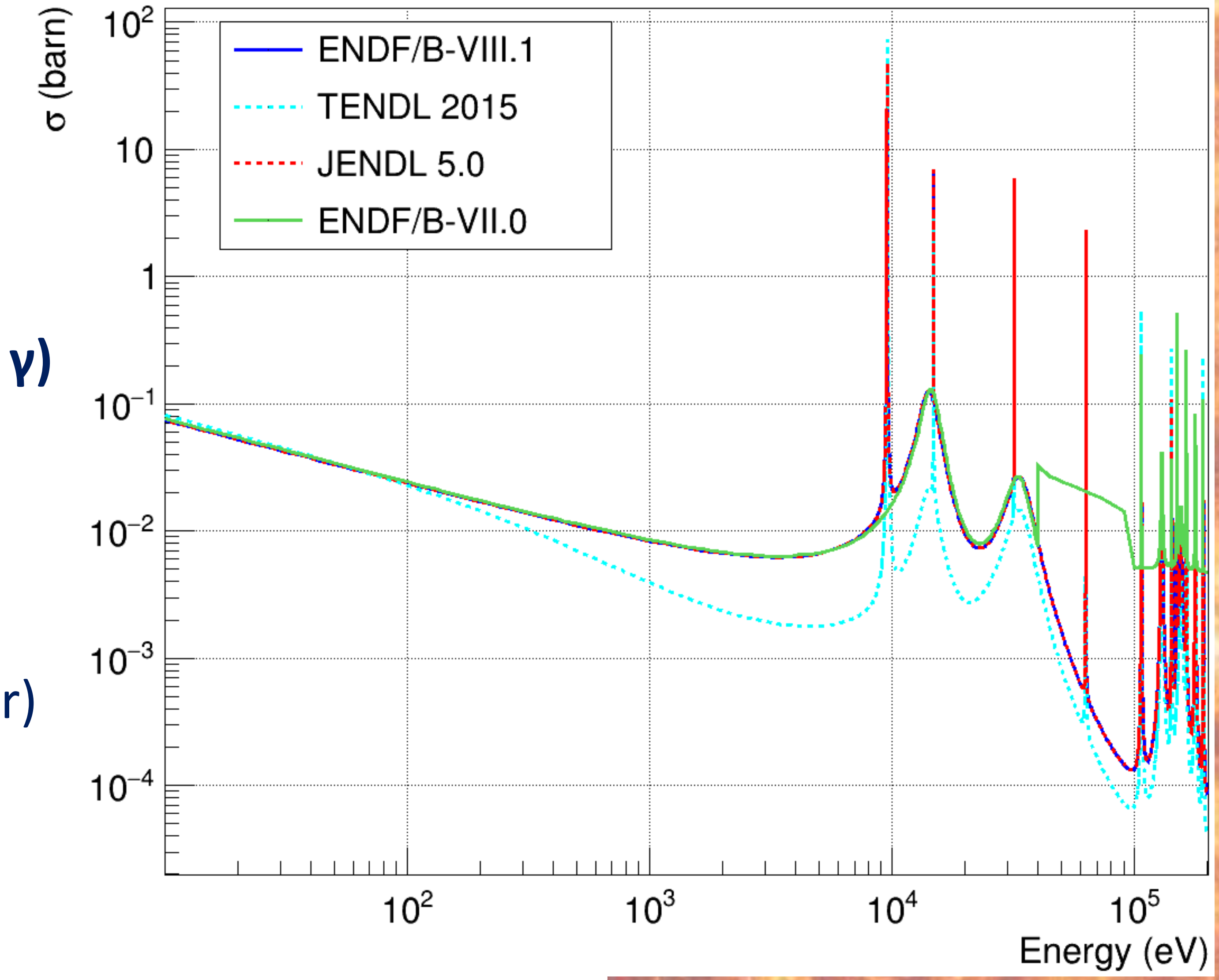
Why: Data in literature

^{64}Ni(n,γ) time-of-flight data are scarce…

- Farrell (1966), J.AP 37, 367 (n,tot)
- **Beer (1975)**, J. NP/A 240, 29 (n,tot), **(n, γ)**
- **Wisshak (1984)**, J.NSE 87, 48 **(n, γ)**

…and discrepant:

- P-wave resonances (only in (n, γ) Beer)
- 9.52 keV resonance
- S-wave radiative kernels (factor 2)



Why: Data in literature

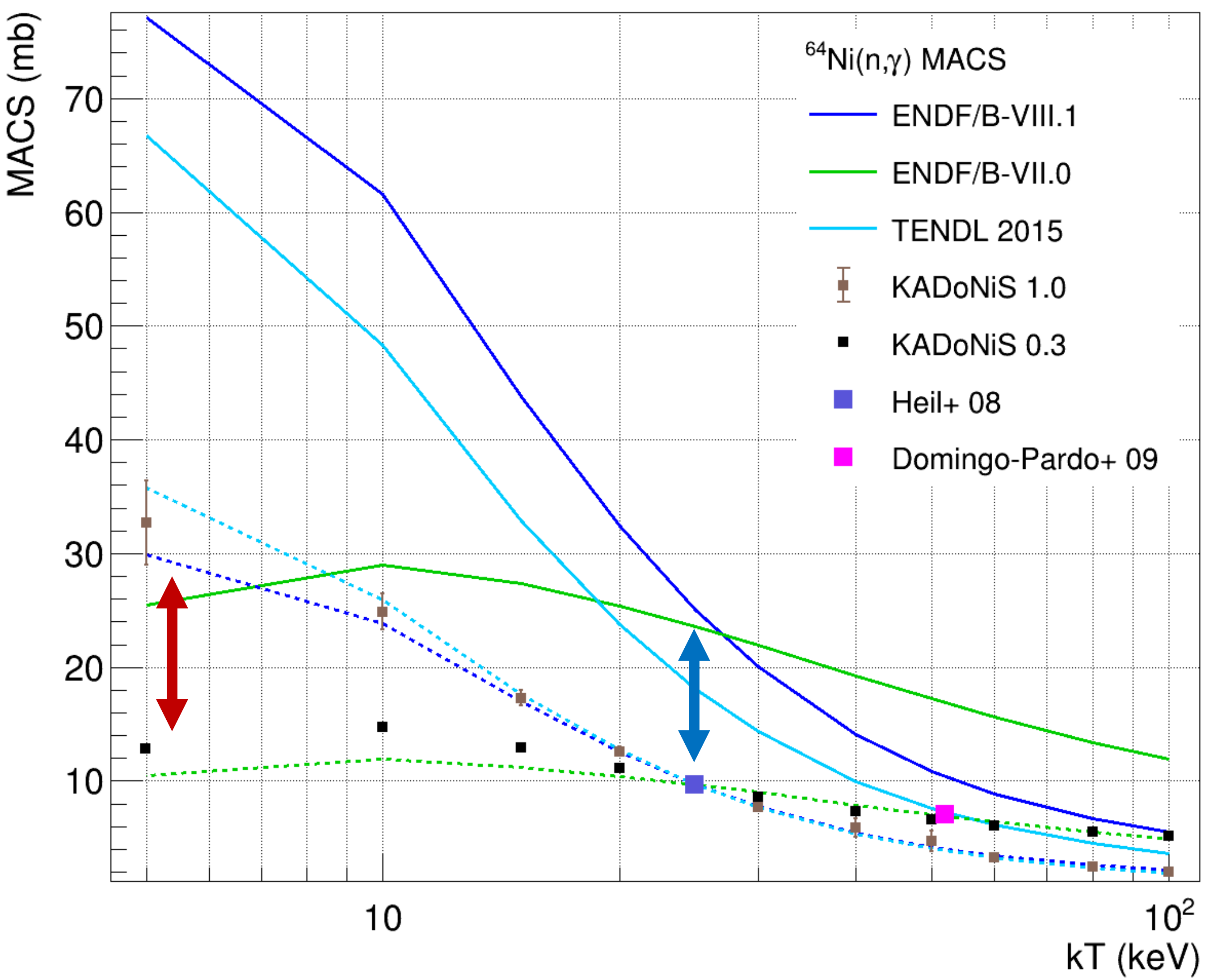
^{64}Ni(n,γ) MACSs are also discrepant:

- Discrepancy **TOF vs Activation*** measurements

  *Heil (2008), J. PR/C 77, 015808

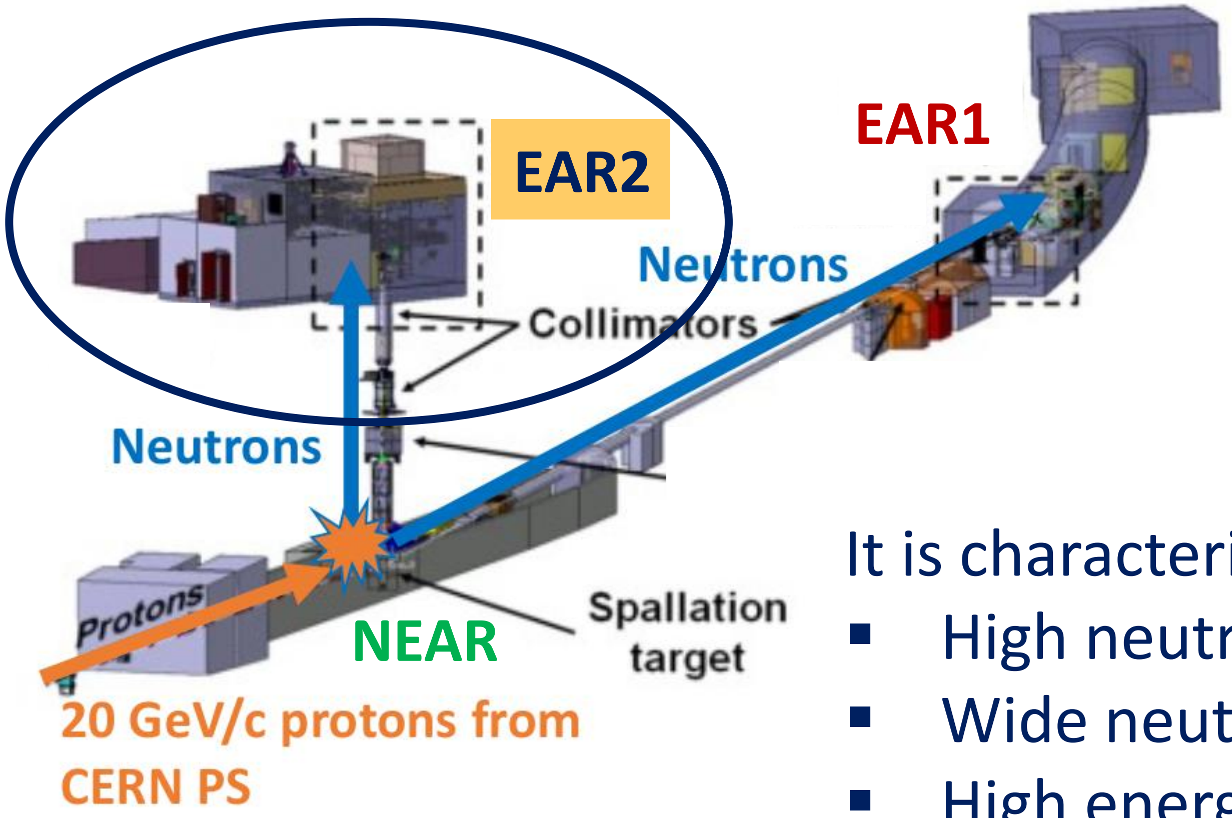
  *Domingo-Pardo (2009), C 13NG, P230

- Discrepancy in the **energy extrapolation** of the MACS



Where: n_TOF facility

The **n_TOF facility** is a **pulsed white neutron source at CERN**



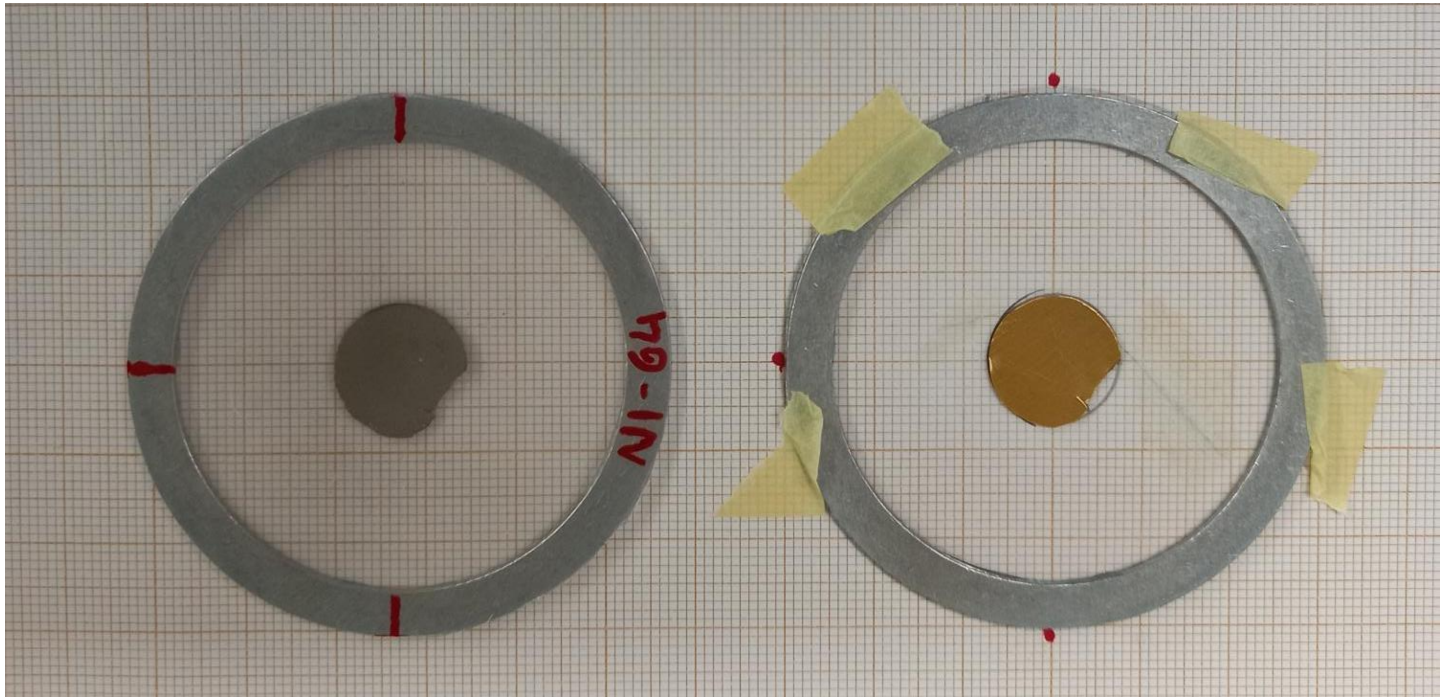
It is characterized by:

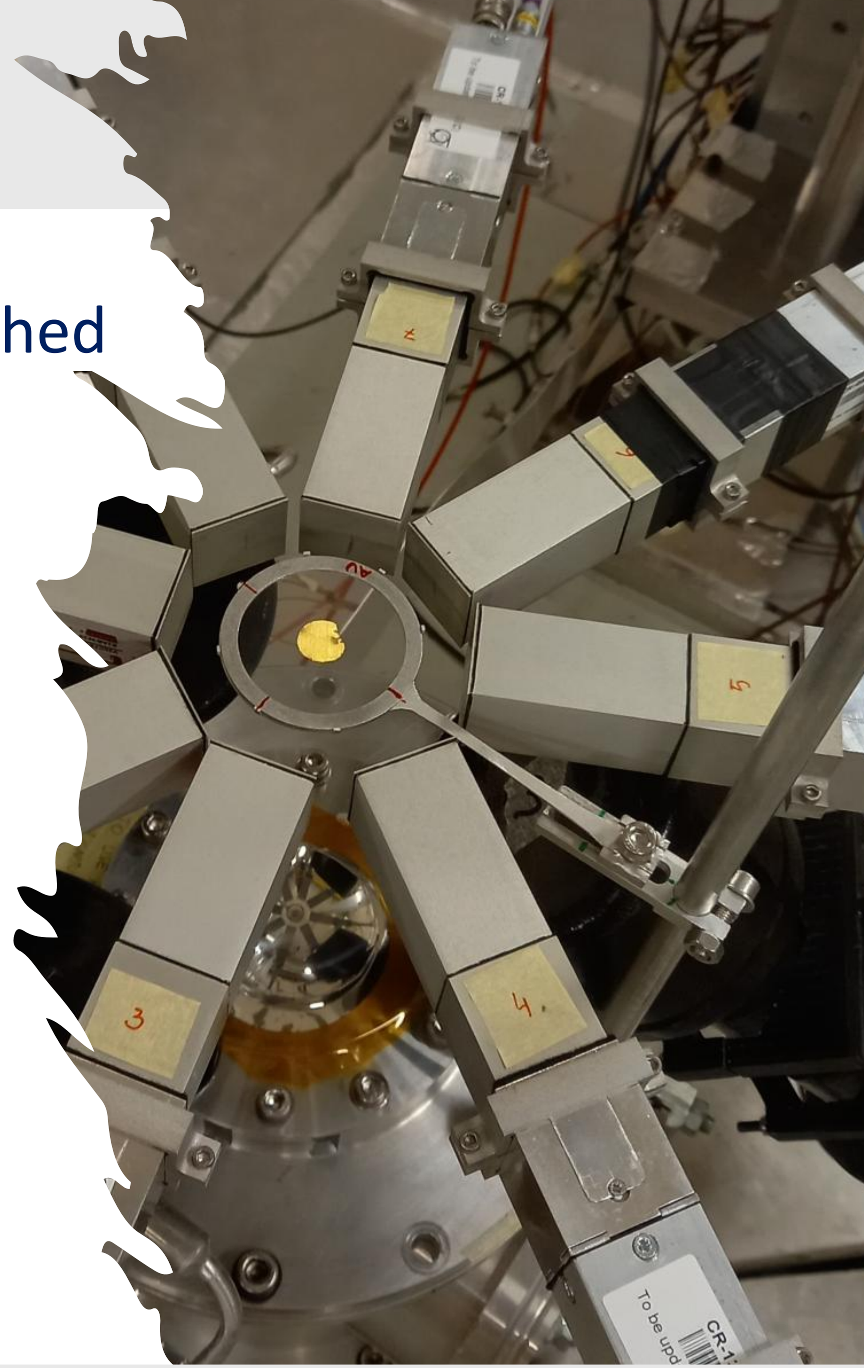
- High neutron flux
- Wide neutron energy range
- High energy resolution

How: The sample

^{64}Ni enriched sample: 15 mm, 427 mg, **99.5 % ^{64}Ni** enriched
Metal grains, cryo-milled and pressed

Work by R.Reifarth, T. Heftrich, D. Plonka et al. at Unversity of Frankfurt



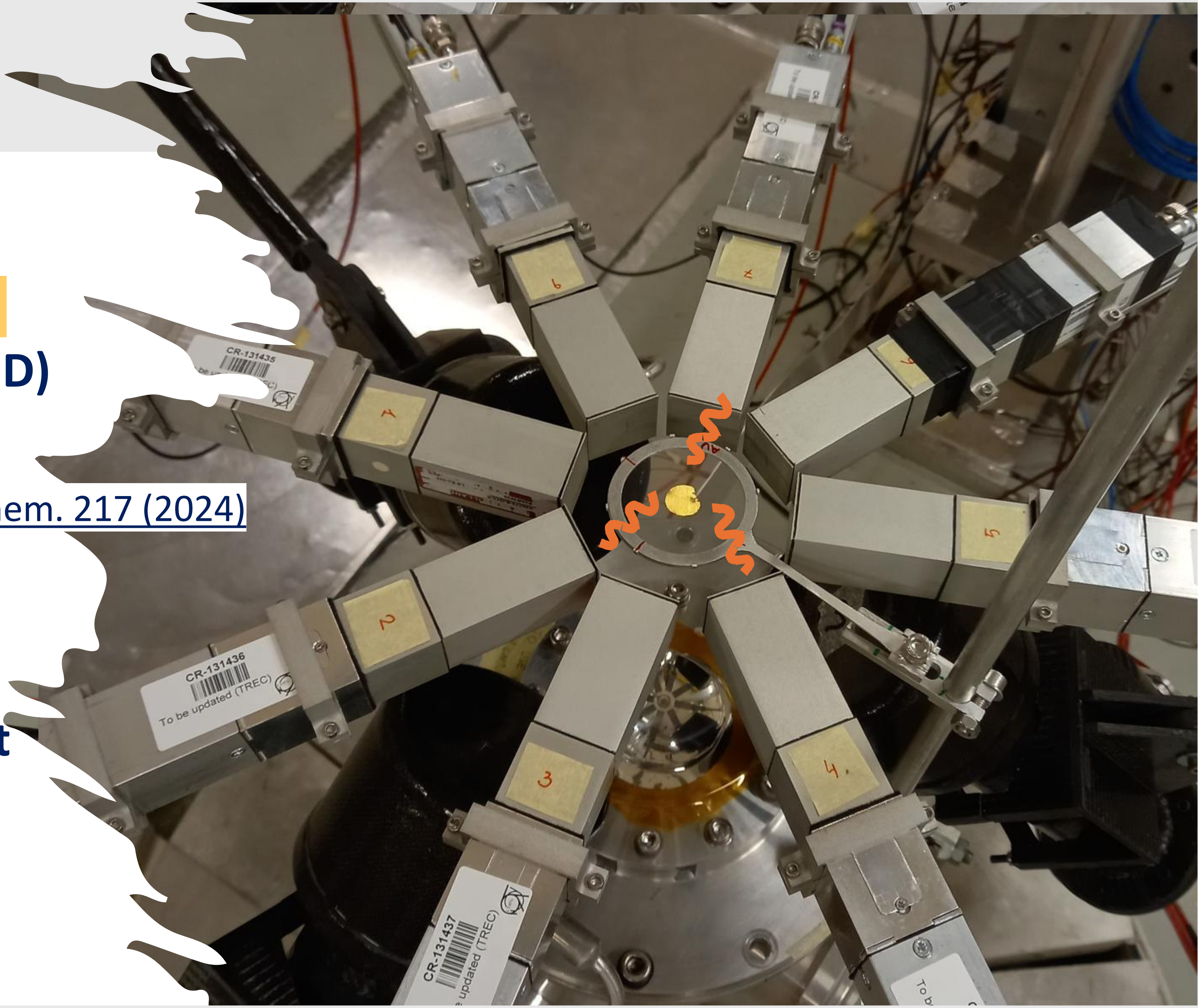


How: Setup

- **γ-rays** from capture are detected with **8 segmented C_6D_6 liquid scintillators (sTED) optimized for EAR2**

  Alcayne et al., Rad. Phys. and Chem. 217 (2024)

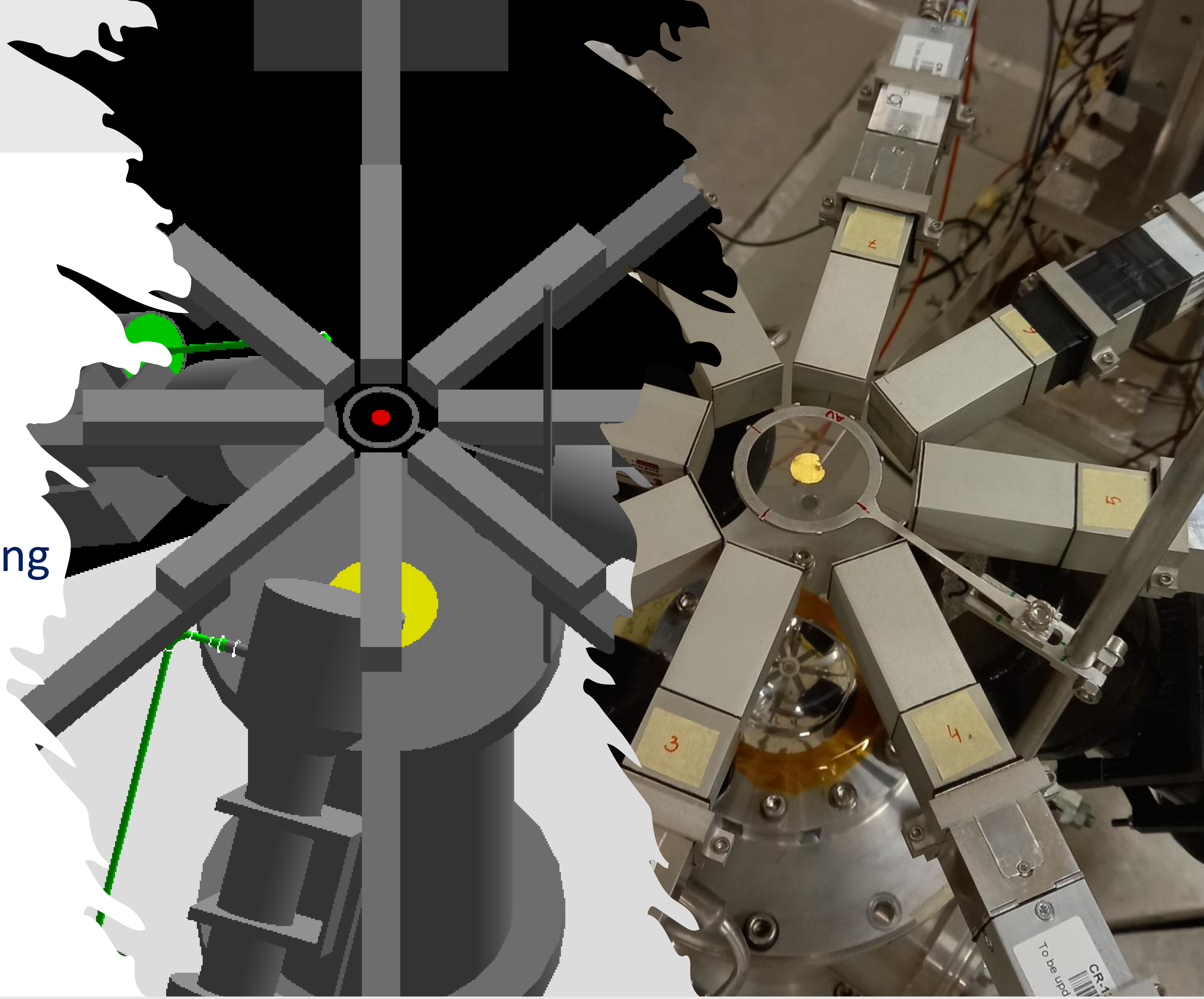
- **Total Energy Detection** technique with **Pulse Height Weighting Technique**



How: Analysis

Detector Efficiency:

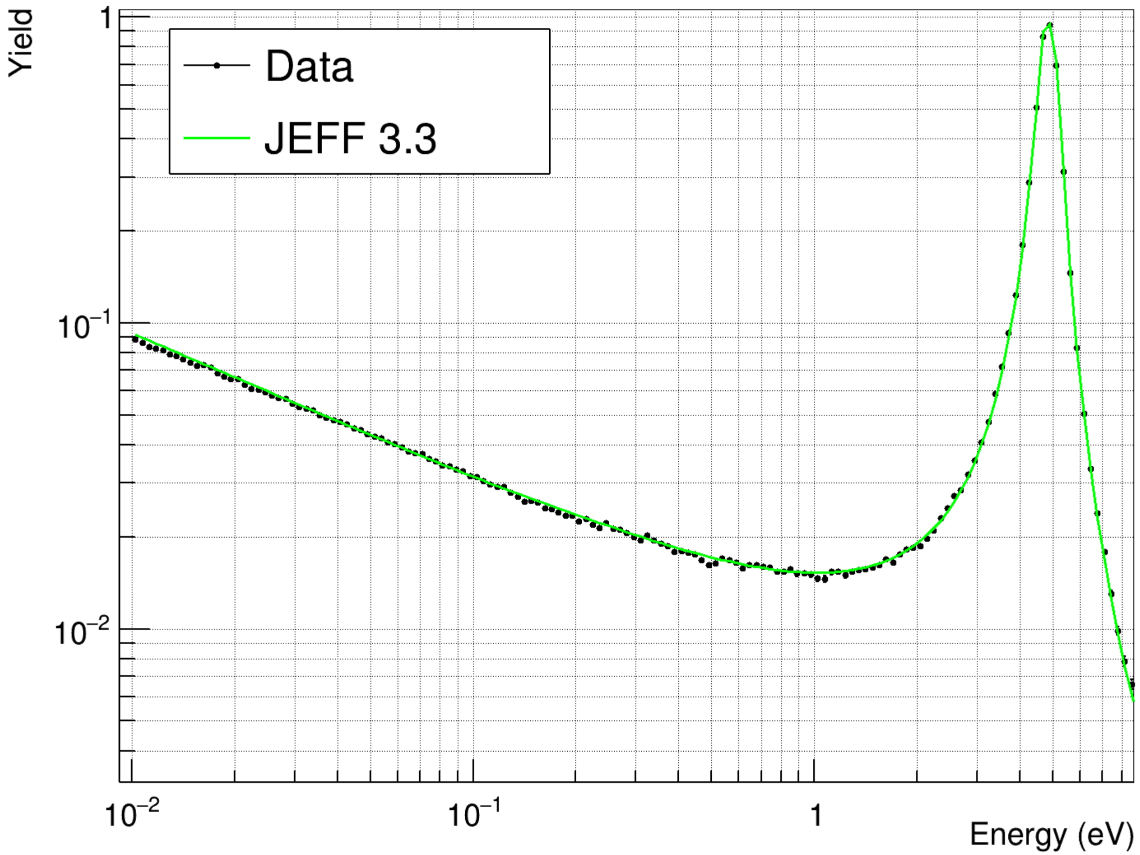
- **TED** requires ε ∝ E_γ
- **PHWT** establishes this condition properly weighting the counts, based on E_{dep}
- Weighting functions from <u>**MC simulations**</u>

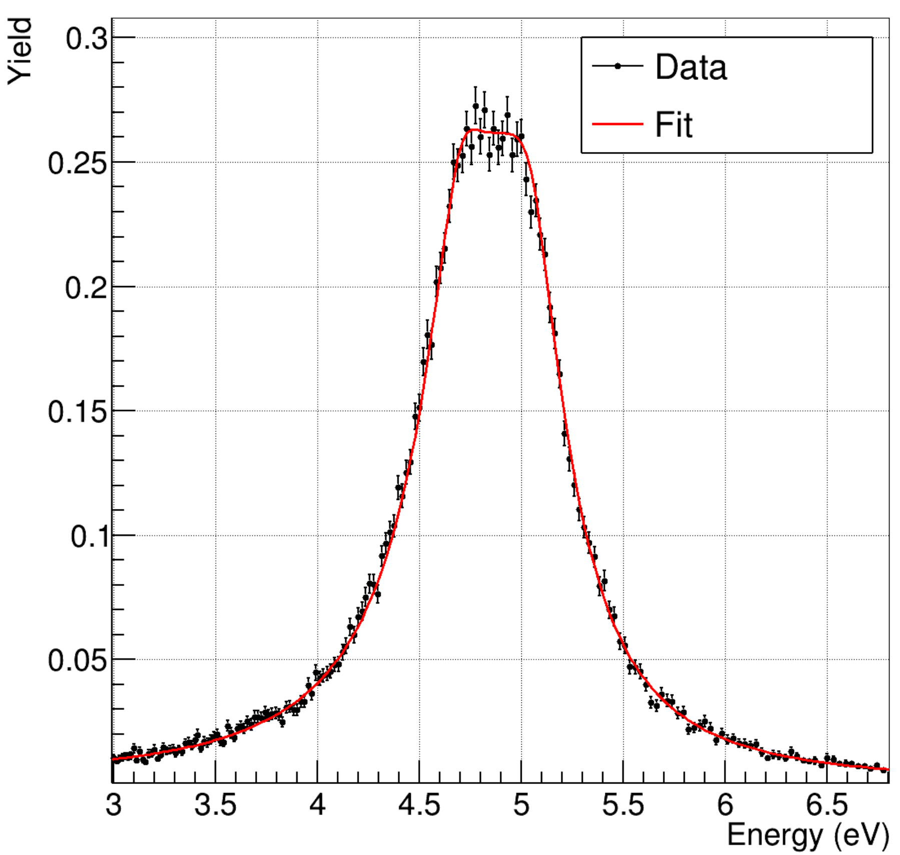


How: Analysis

Normalization:

- **<u>Gold sample</u> of same dimension** is used to normalize (B.I.F., efficiency,…)



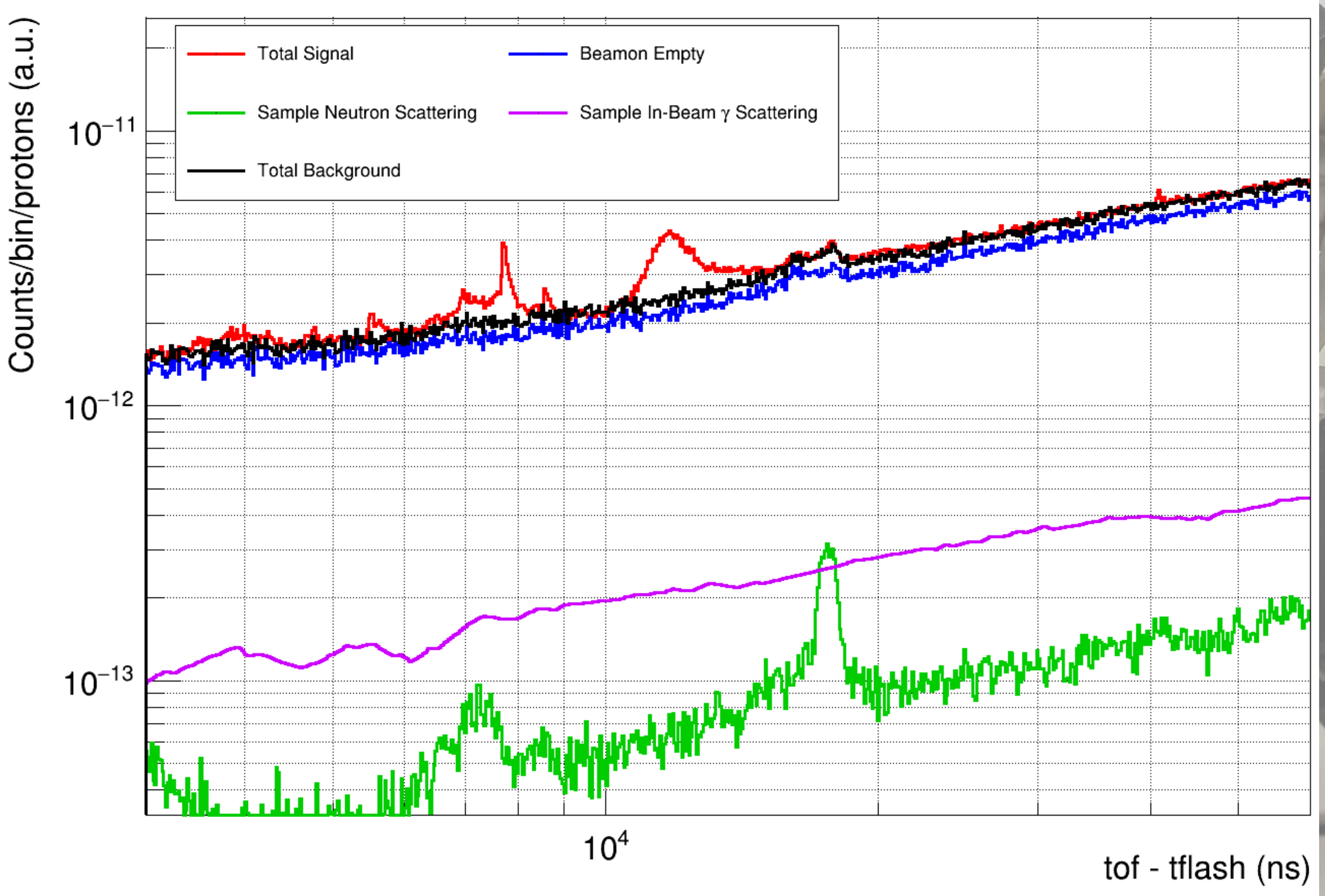


How: Analysis

Background: Gamma rays produced by scattered neutrons

Estimated with ancillary measurements:

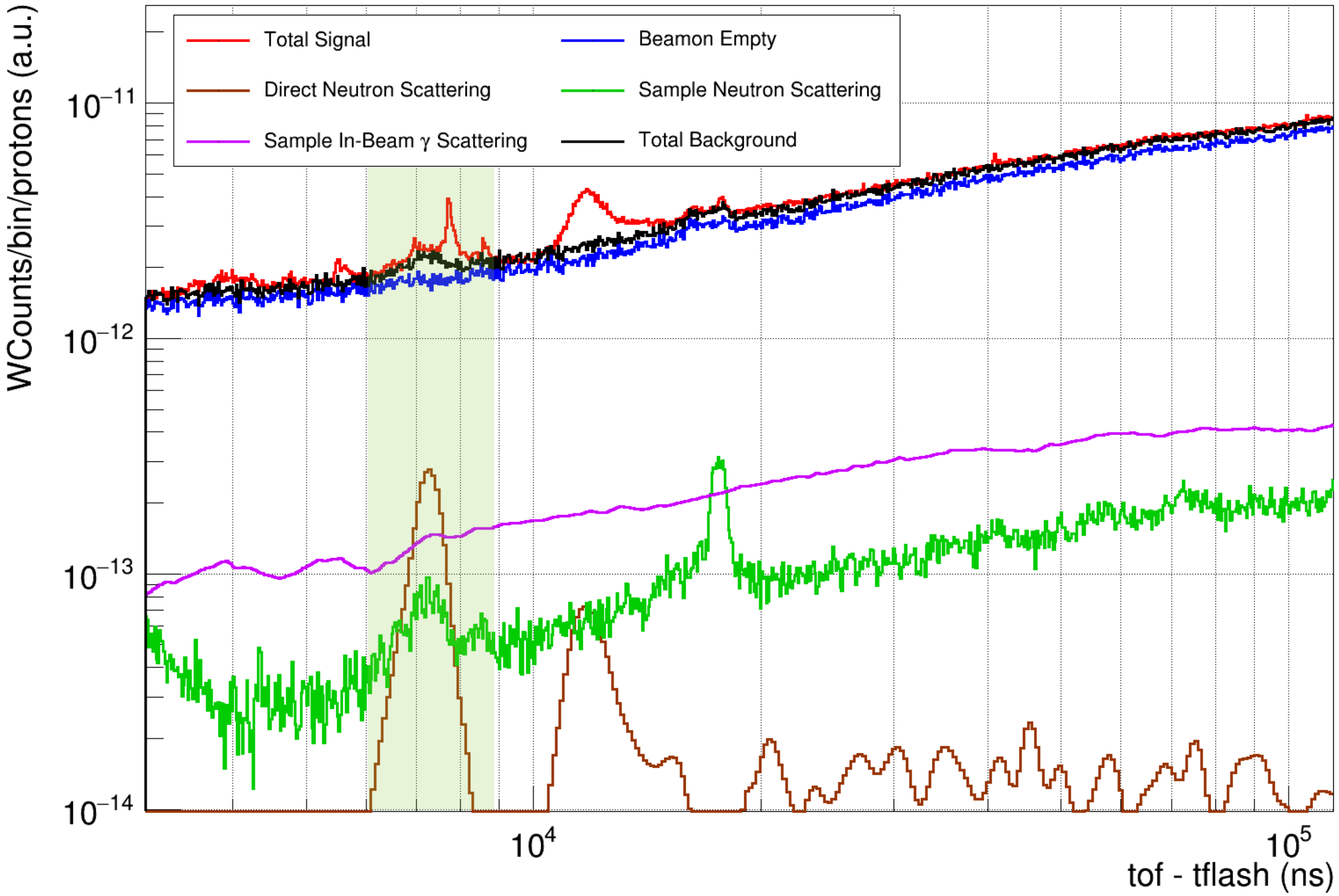
- **Empty** = sample-independent
- **Lead** = sample-dependent in-beam gamma scattering
- **Carbon** = sample-dependent neutron scattering

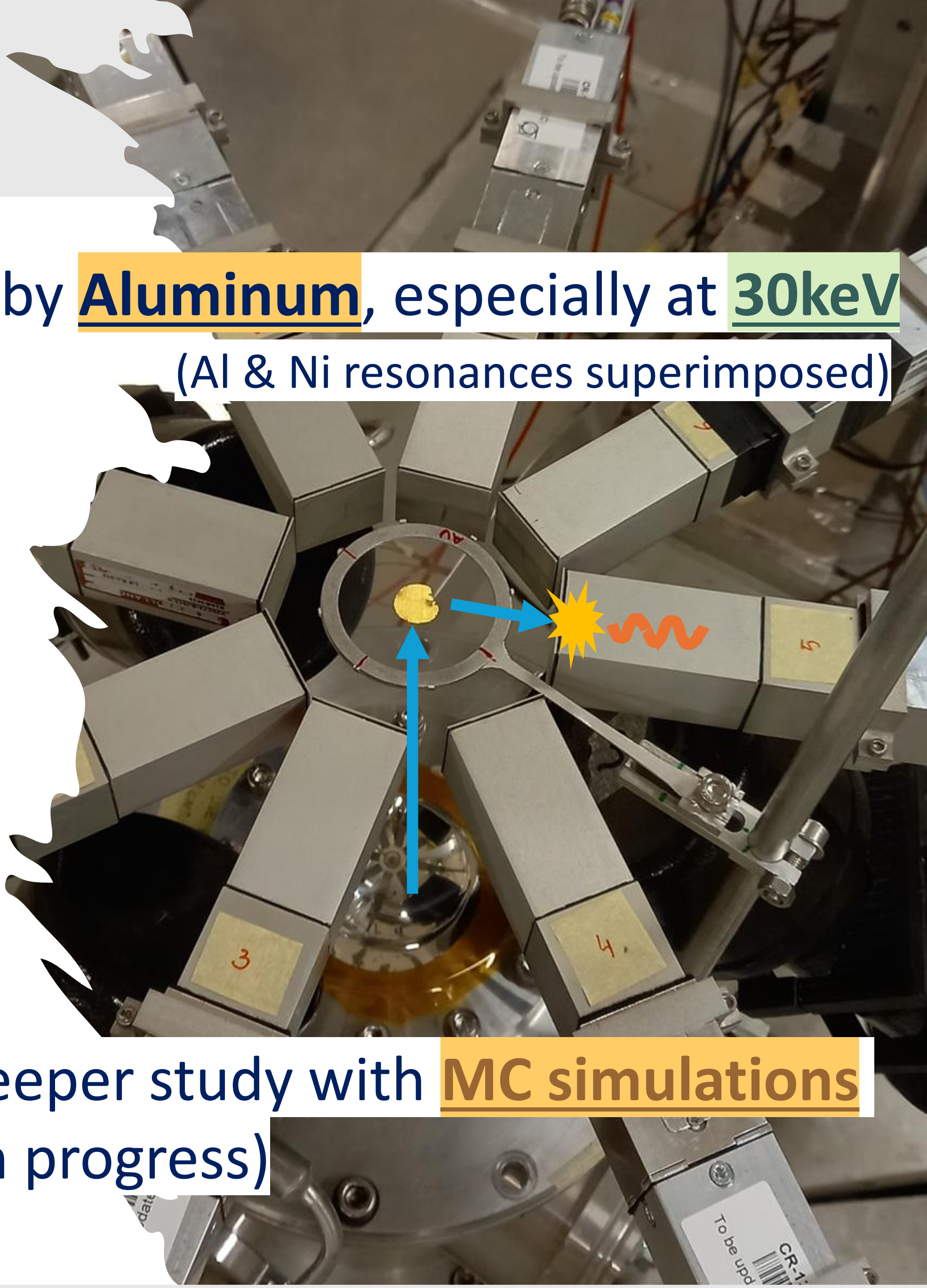


How: Analysis

Background: Neutron scattered by ^{64}Ni are captured by **Aluminum**, especially at **30keV**

(Al & Ni resonances superimposed)





Deeper study with MC simulations (in progress)

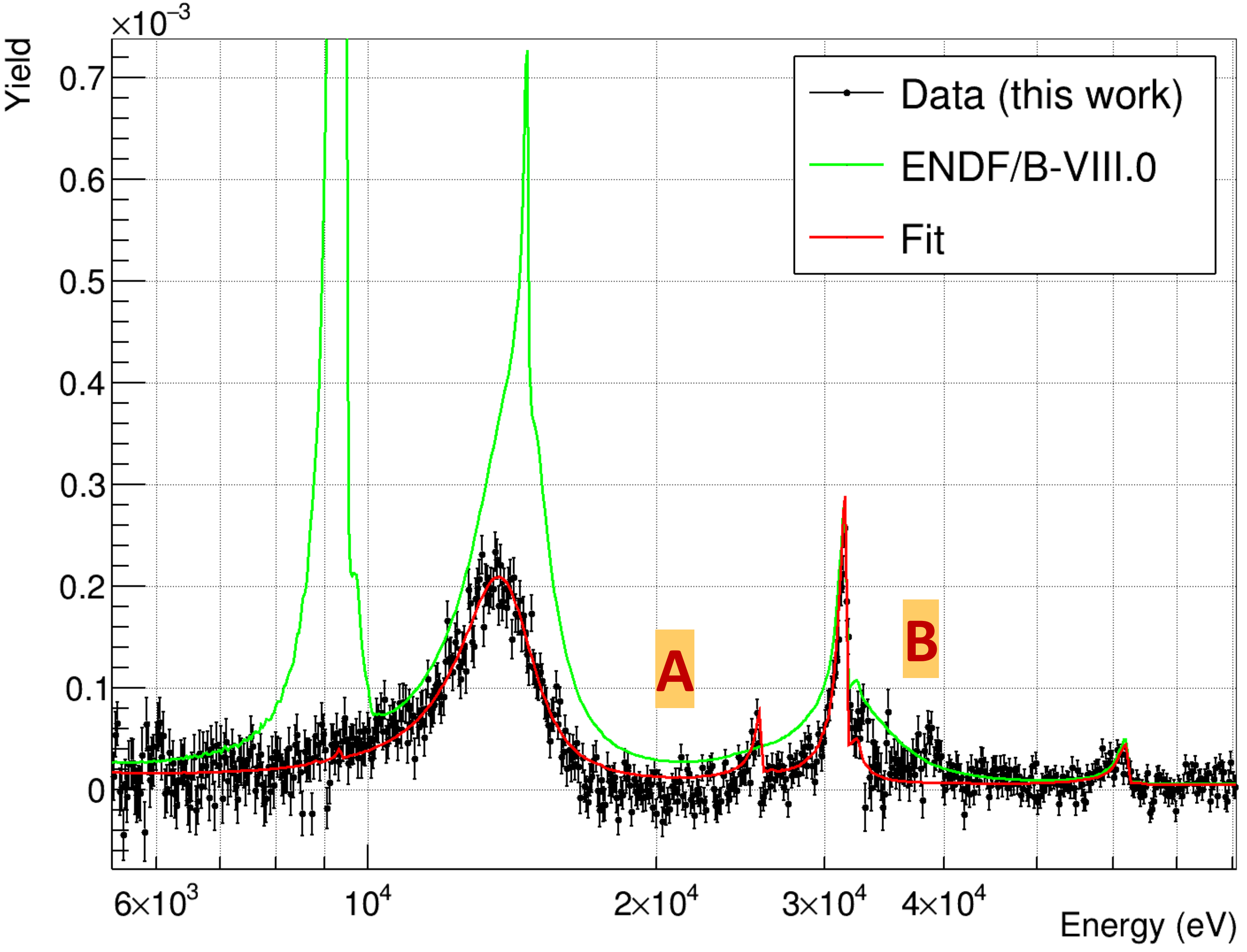
Preliminary Results

Resonances fitted with **SAMMY** (R-Matrix code)

__To be fixed:__

A. **Background** not well fitted in the valley

B. **Region of 30 keV** is «polluted» by Aluminum



Preliminary Results

A. **No** resonance at **9.52 keV**

B. **No** resonance at **14.8 keV**

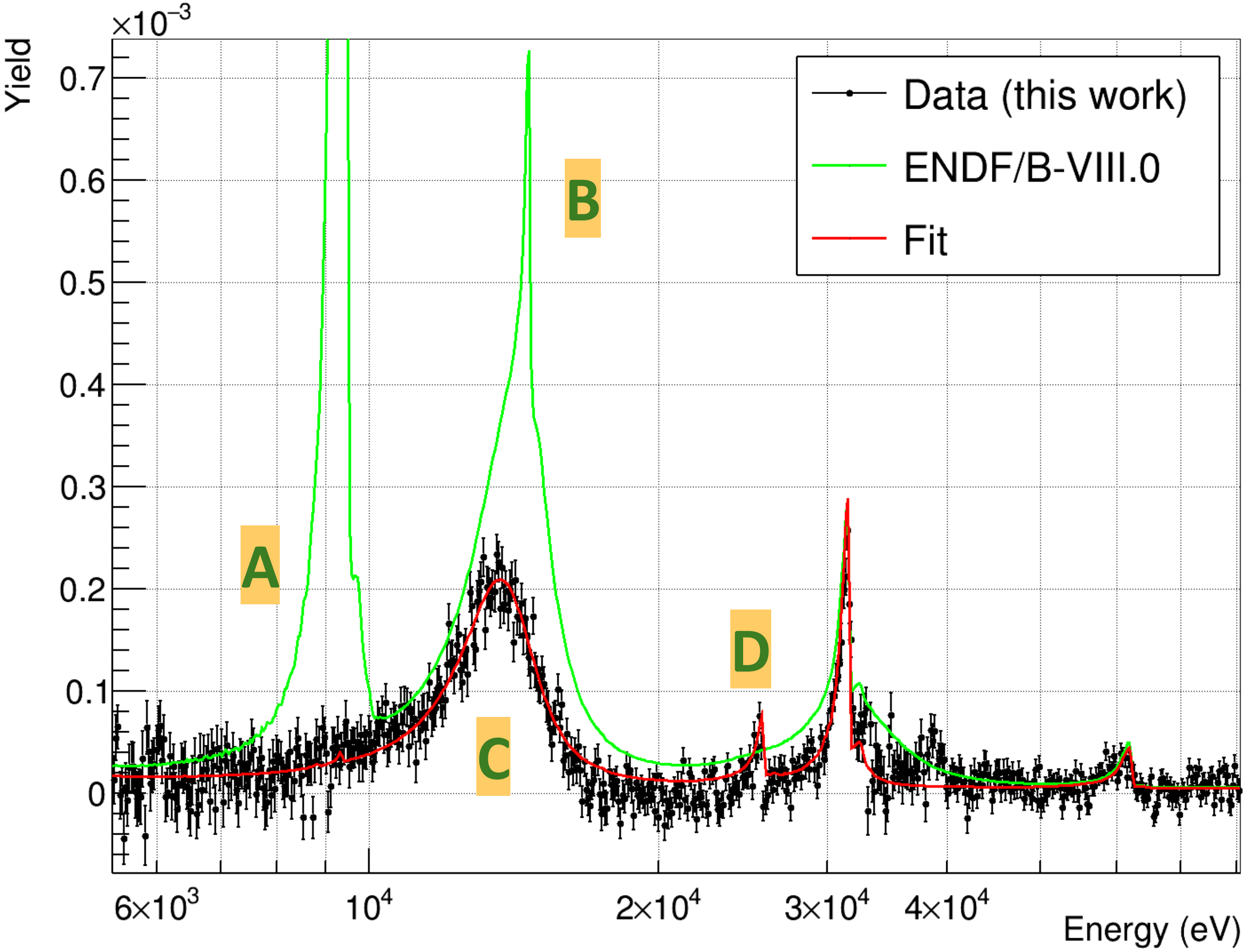
Only in Beer+ (1975)

C. **Reduced** capture kernel for resonance at **13.7 keV**

≈ Wisshak+ (1984)

D. **New** resonance at **26 keV ?**

Wisshak+ (1984) ??

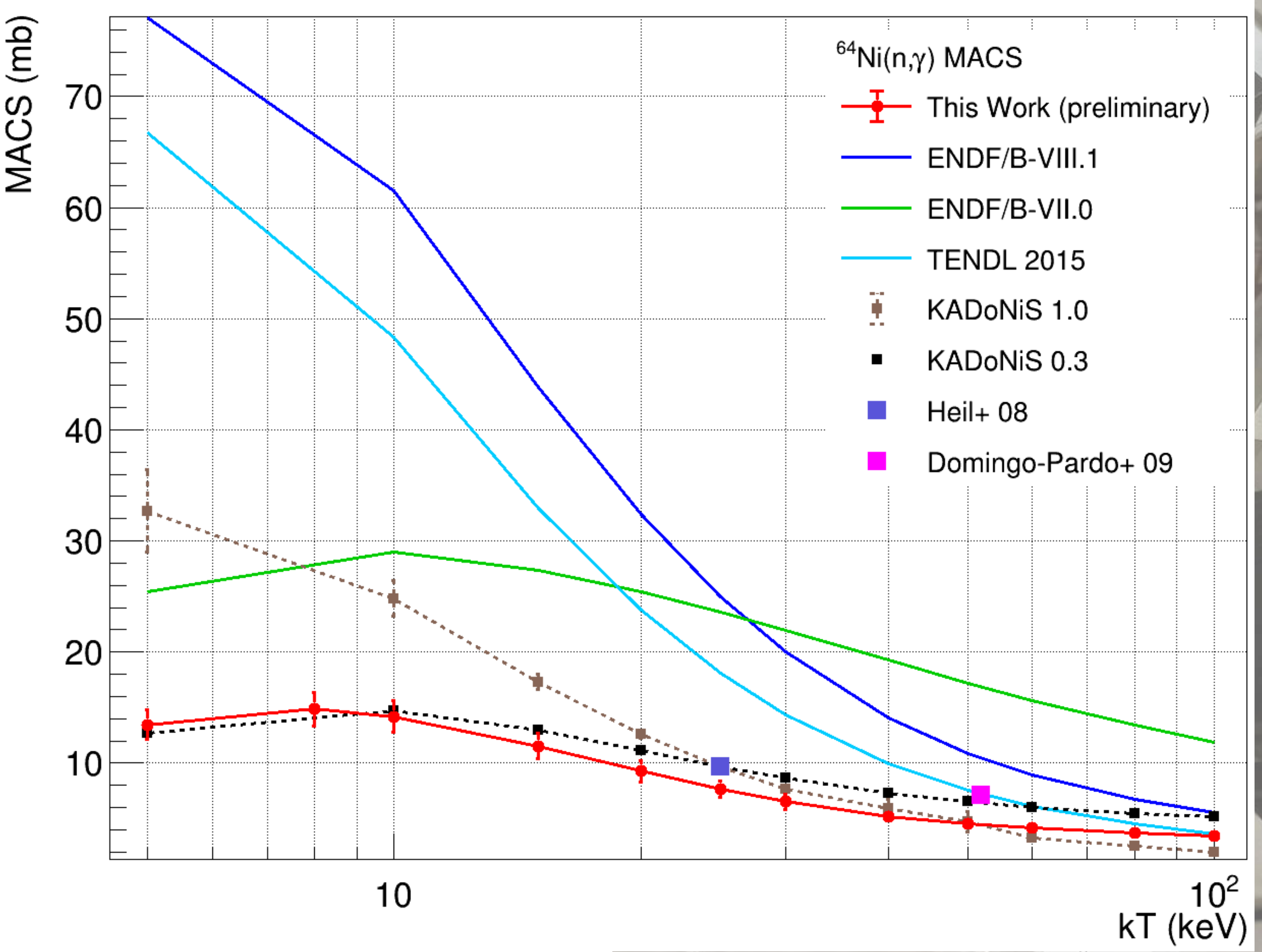


Preliminary Results

Preliminary MACS

- Not yet fully reliable @ **30 keV**
- **Direct capture** to be adjusted

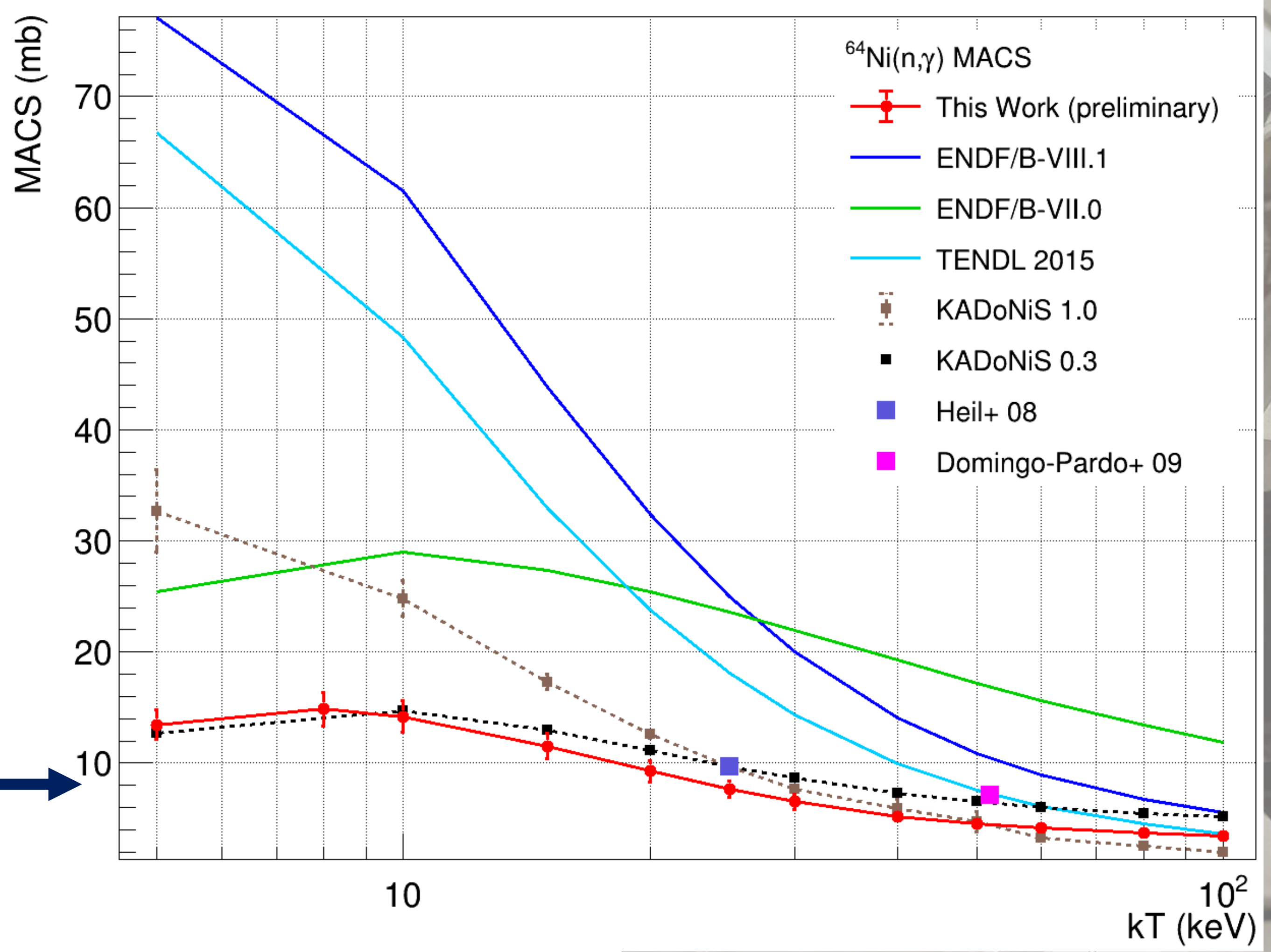
- Closer to **activation measurements**
- Similar to extrapolation of **KADoNiS0.3**



Conclusion

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under grant agreement No 101057511

- **What?** Measurement of the ^{64}Ni(n,γ) cross section
- **Why?** Global impact on s-process abundances and crucial in testing a mixing model of AGB stars
- **Where?** n_TOF facility at CERN
- **How?** Optimized Segmented C_6D_6 scintillators
- **Preliminary Results**



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