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n_TOF

Measurement of the ^{154}Gd neutron capture cross-section at n_TOF, and its astrophysical implications

Annamaria Mazzone
INFN Bari / CNR-IC
on behalf of the n_TOF Collaboration

EuNPC
2018 European Nuclear Physic Conference
September 6, Bologna

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The Proposal

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the neutron capture cross section of gadolinium even isotopes relevant to Nuclear Astrophysics

December 5, 2015

C. Massimi[1,2], F. Mingrone[1], S. Cristallo[3], E. Berthoumieux[4], D.M. Castelluccio[1,5], N. Colonna[6], M. Diakaki[4], R. Dressler[7], E. Dupont[4], F. Gunsing[4,8], S. Lo Meo[1,5], P.M. Milazzo[9], A. Musumarra[10], D. Schumann[7], G. Tagliente[6], G. Vannini[1,2], V. Variale[6]

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Outlines

Scientific Motivations

Measurement & Analysis

Astrophysical Implications

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Outlines

- Scientific Motivations
- Measurement & Analysis
- Astrophysical Implications

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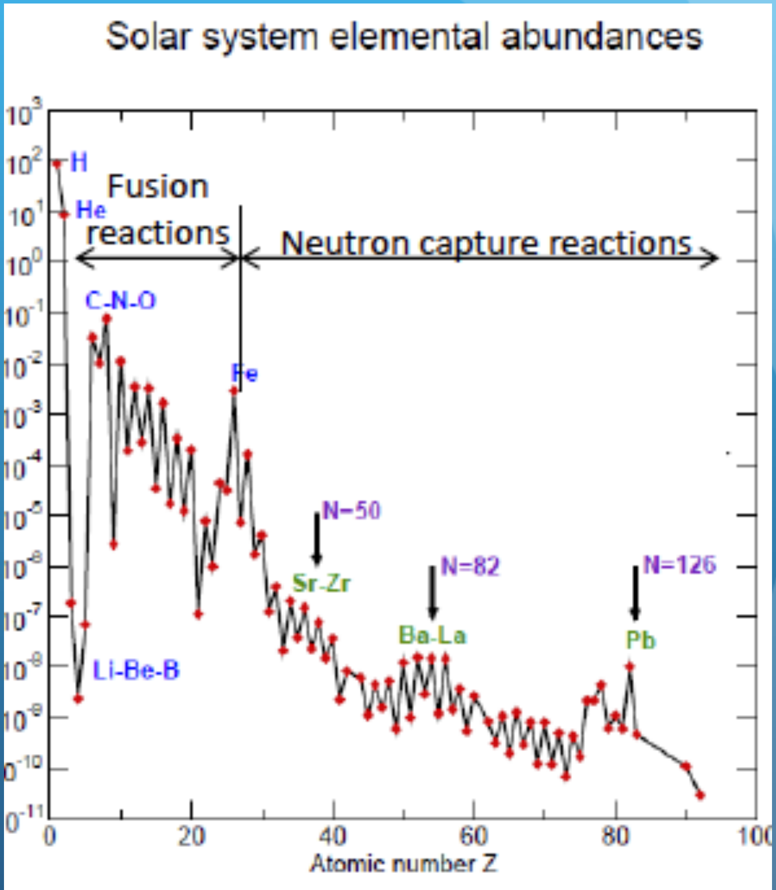
Solar Nucleosynthesis

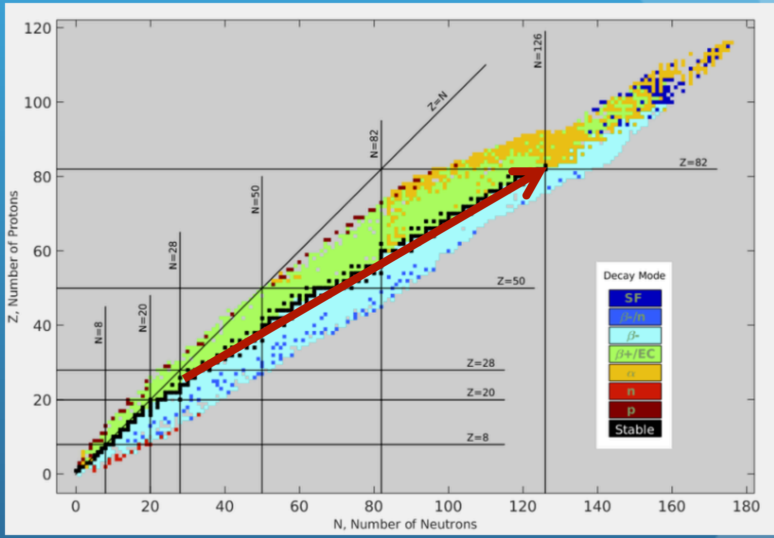
Chemical elements beyond Iron are synthesized via neutron capture reactions in stars

- ≈½ by the s-process
- ≈½ by the r-process

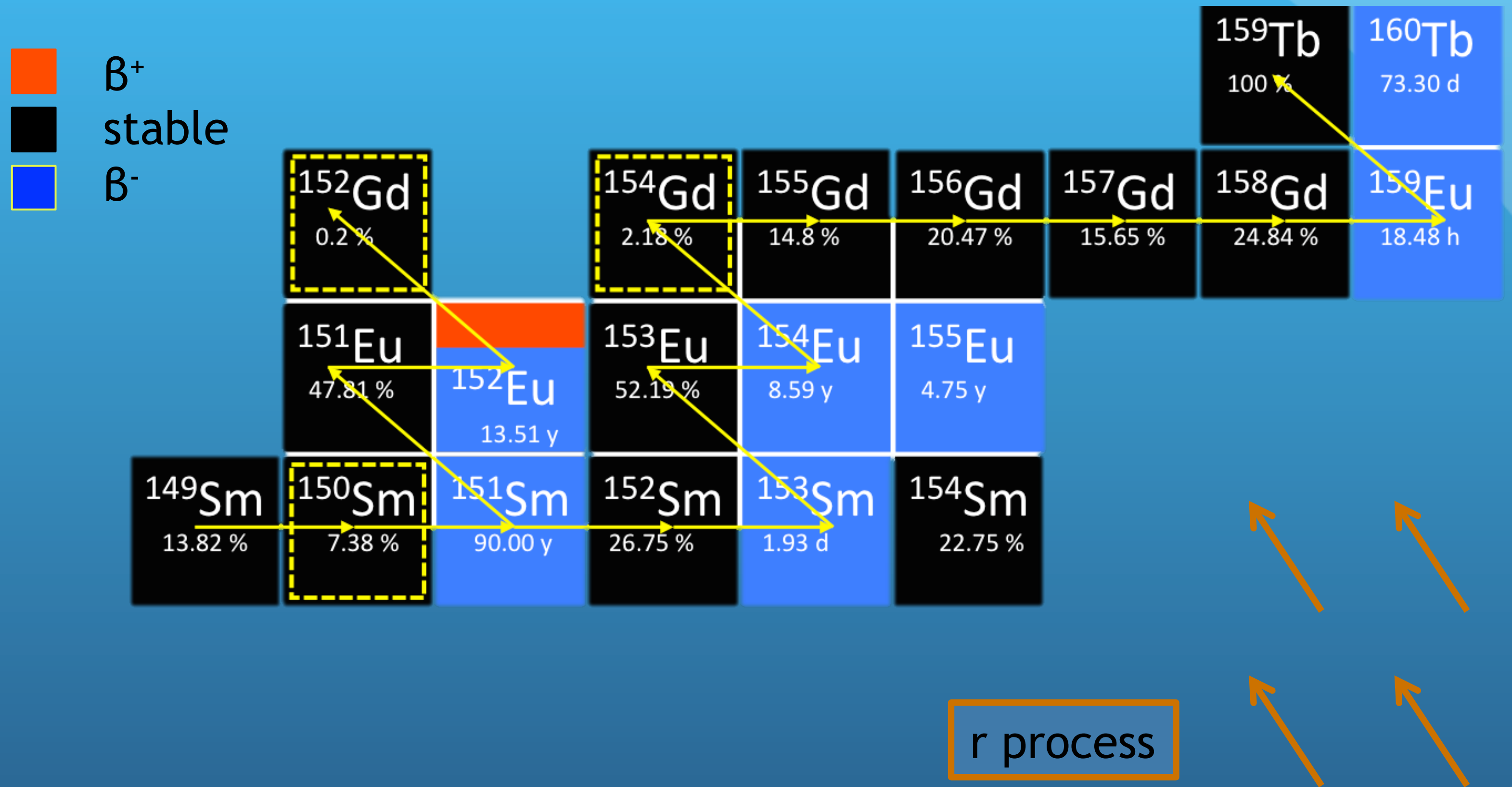


s-Process

- The time scale for n capture reactions being much slower than for beta-decays implies that the reaction path follows the stability valley
- **Low-mass Asymptotic Giant Branch (AGB)** stars are the sites for the main component of the s-process, for elements between strontium and lead.



Motivations



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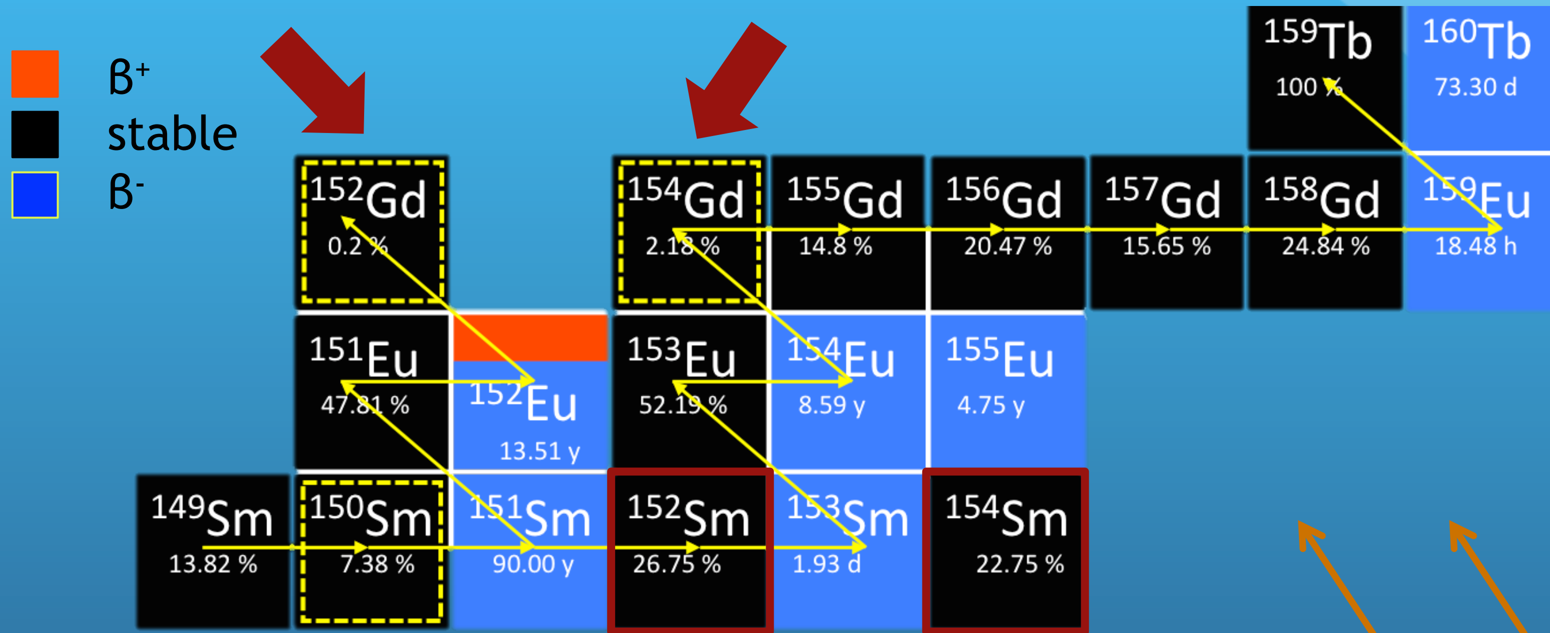
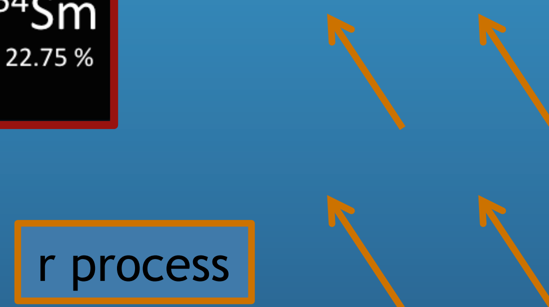
Motivations





^{152}Gd and ^{154}Gd are s-only isotopes

They can be produced only via s-process because they are shielded against the β-decay chains from the r-process region by the isobars samarium

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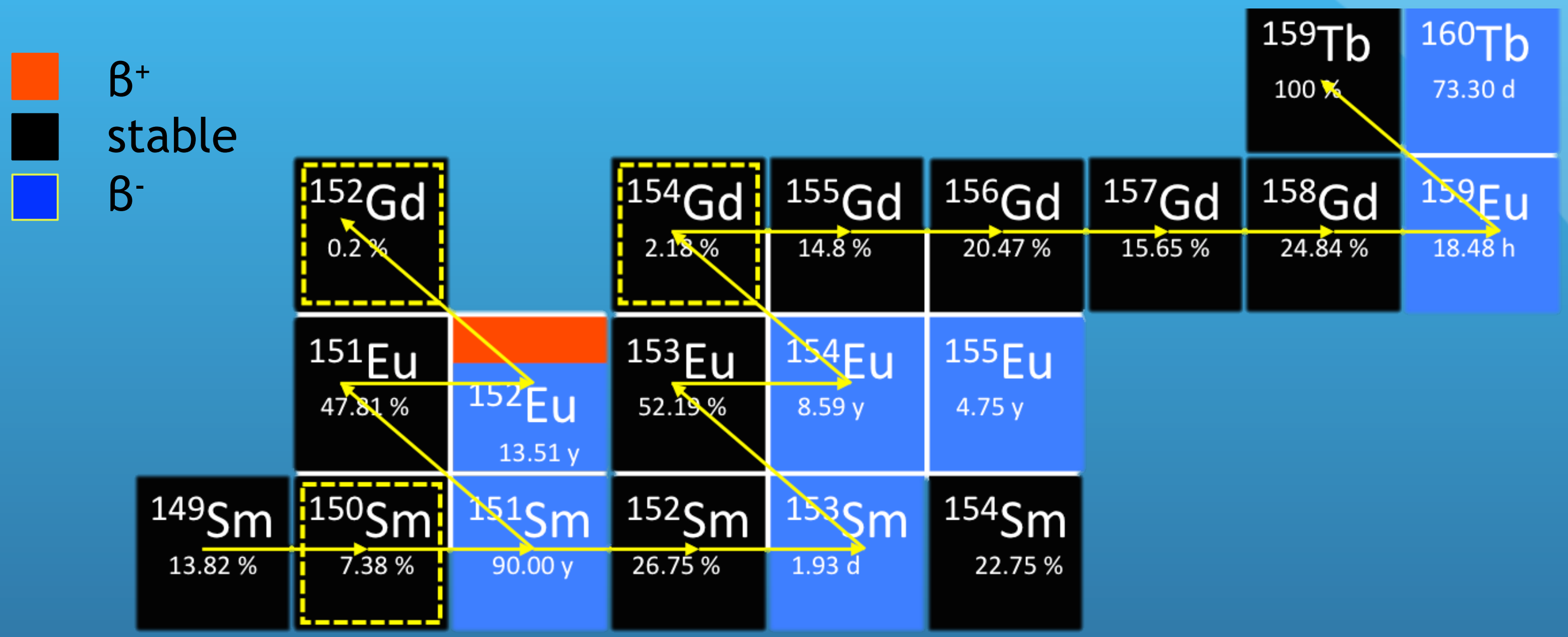
n_TOF

Motivations



^{152}Gd and ^{154}Gd are s-only isotopes

They can be produced only via s-process because they are shielded against the β-decay chains from the r-process region by the isobars samarium

Proof of galactic chemical evolution (GCE) models

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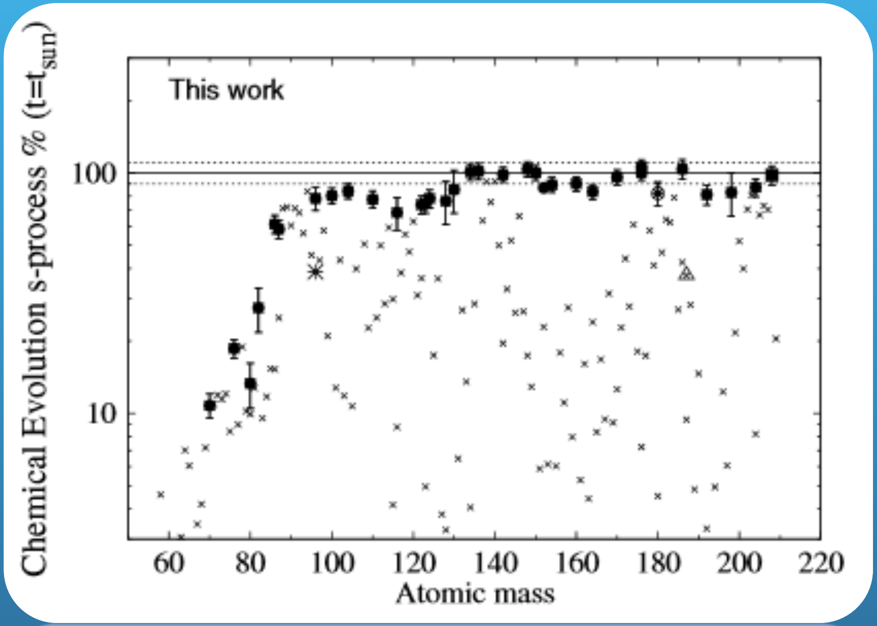
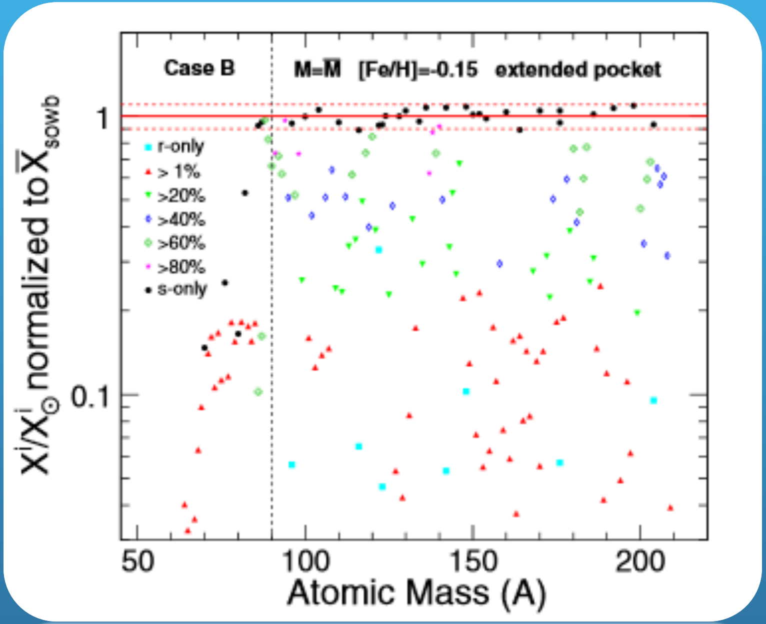
3 Recent Independent Studies…



S. Bisterzo, *et al.*, The Astrophysical Journal 787 (2014) 10

3 Recent Independent Studies…



C. Trippella, *et al.*, The Astrophysical Journal 787 (2014) 41

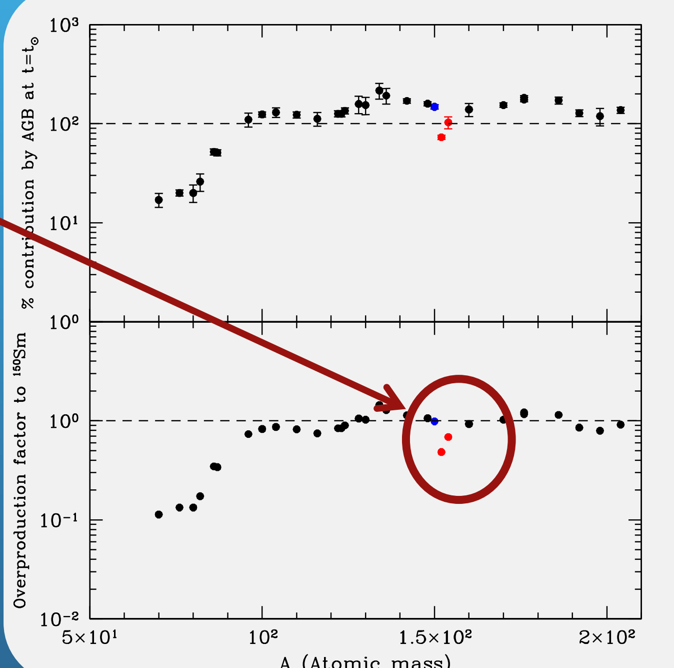
3 Recent Independent Studies…

Constraints for the ^{13}C pocket, i.e. the main neutron source of the s process

Disagreement of more than 20% between observation and model calculation of s-process abundances

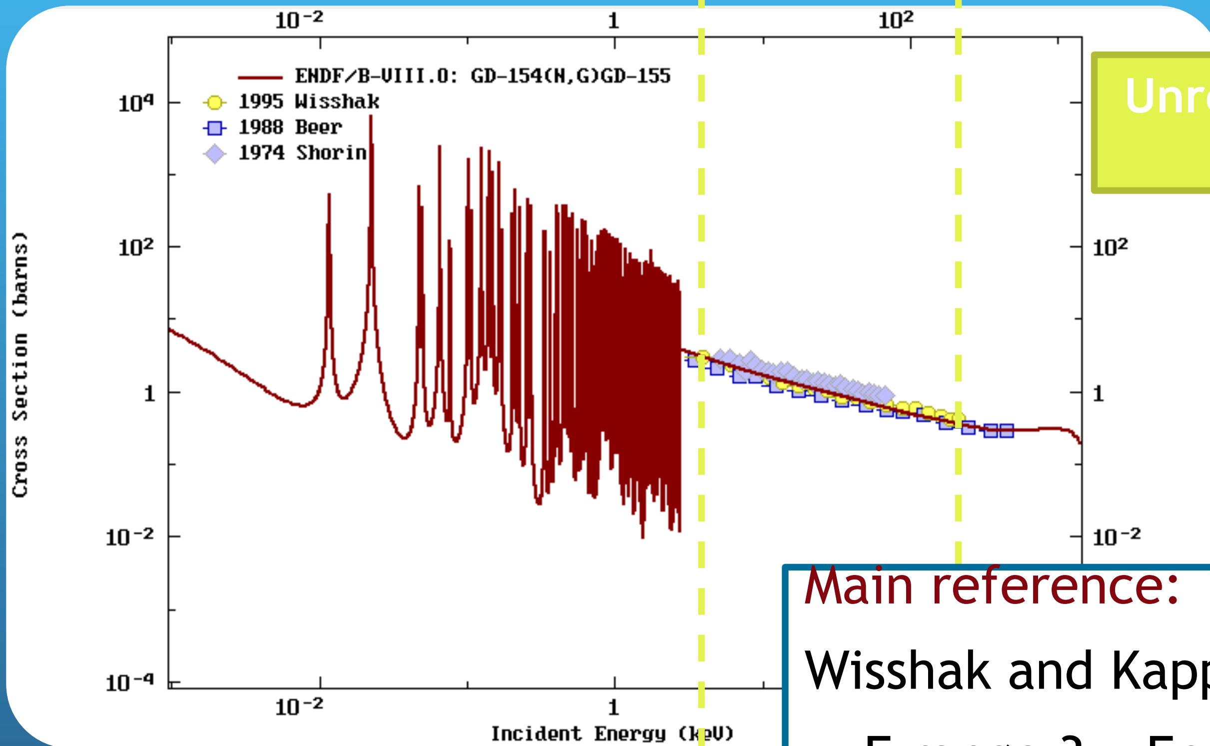
So far, no conclusive identification of the causes of the disagreement:

more accurate nuclear data needed !!!



S. Cristallo, *et al.*, The Astrophysical Journal 801 (2015) 53

Gd Data In Literature



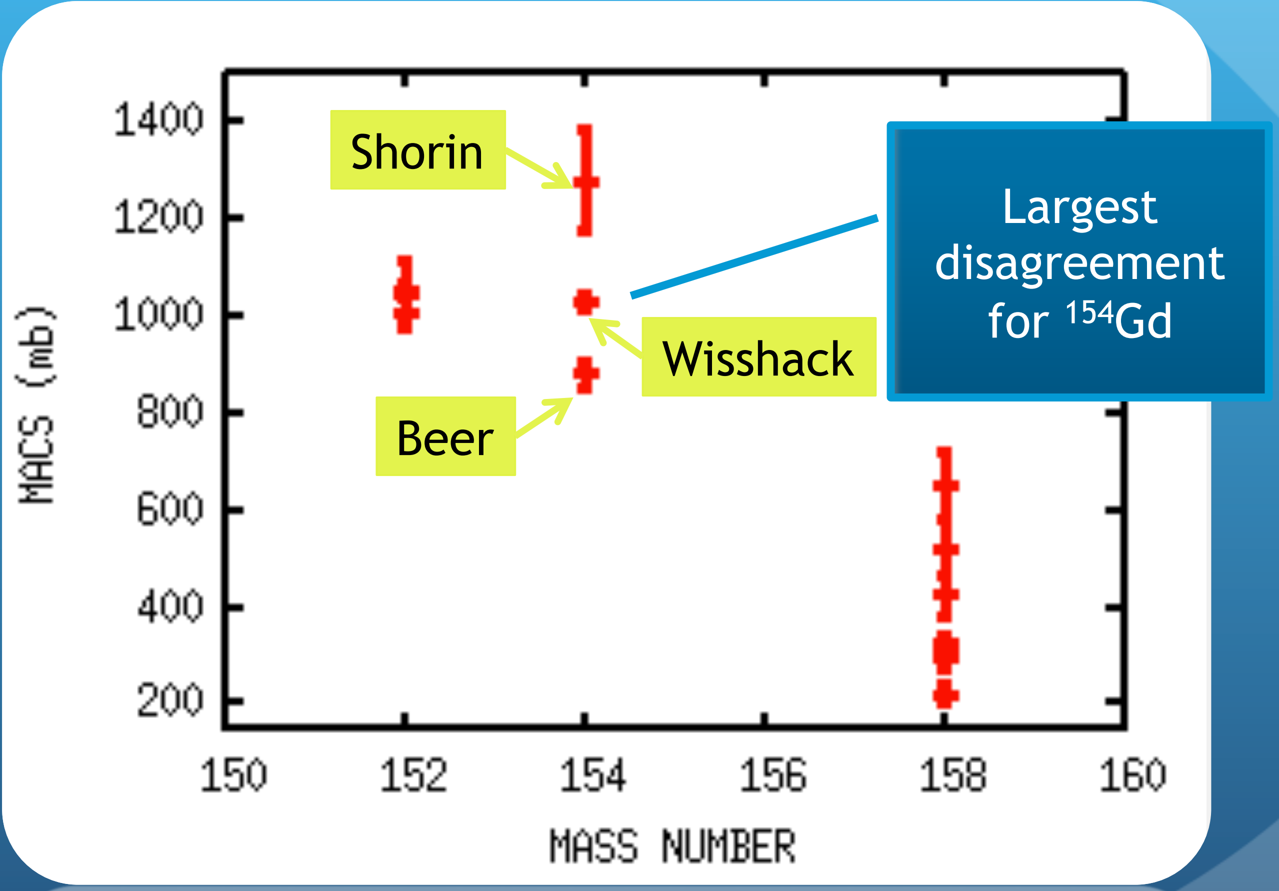
Unresolved Resonance Region

Main reference:

Wisshak and Kappeler

- E range 3 < En < 200 keV
- 4π BaF2 detector
- The error is of about 1%

MACS


MACS (mb)
1400
1200
1000
800
600
400
200
150
152
154
156
158
160
MASS NUMBER
Shorin
Wisshack
Beer
Largest disagreement for 154Gd

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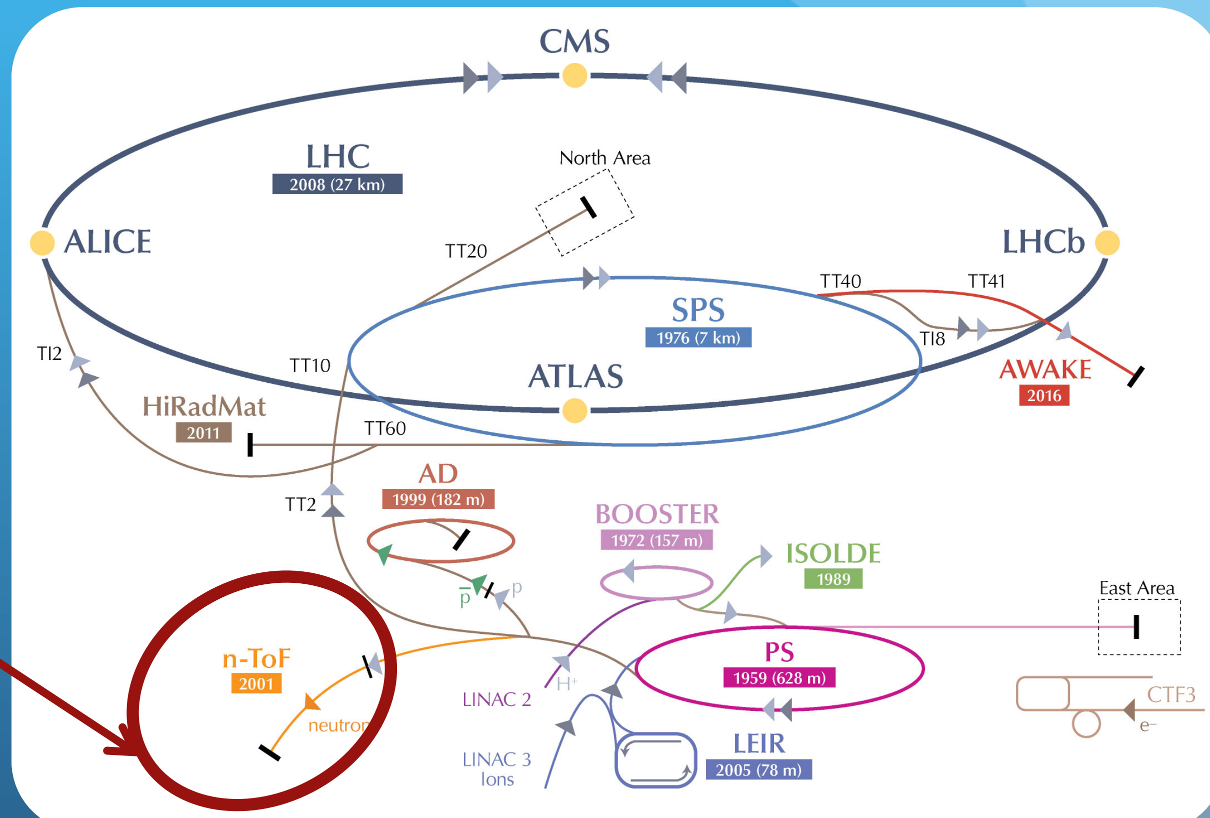
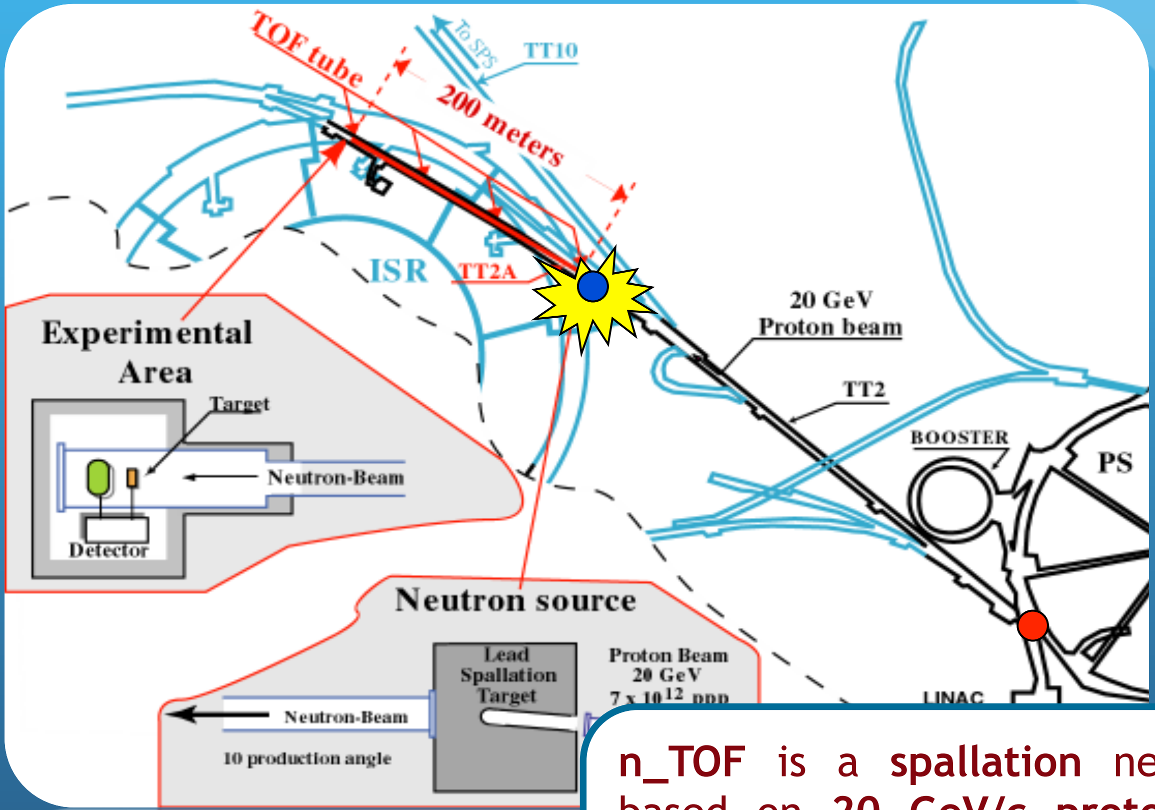
The n_TOF project



Neutron Time-Of- Flight facility: **n_TOF**

The CERN n_TOF facility features a pulsed white neutron beam (meV to GeV) where capture cross sections are measured as function of the neutron energy using the time-of-flight technique.

The n_TOF project

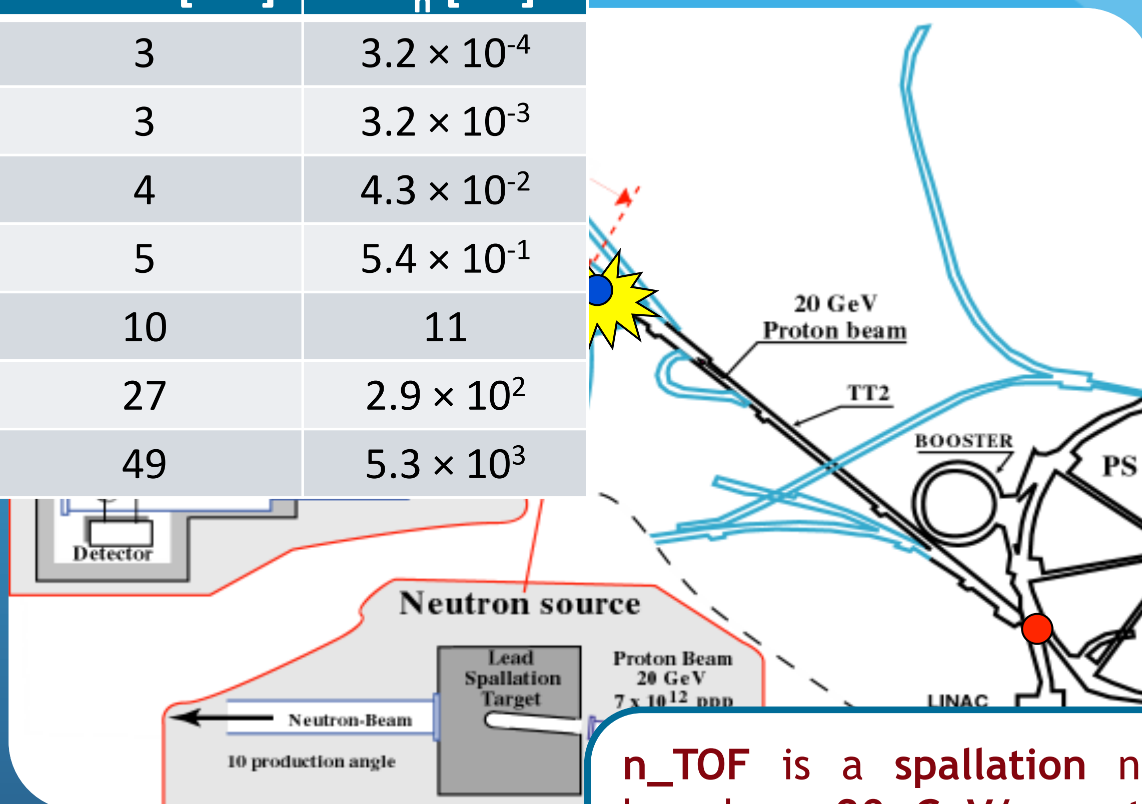


n_TOF is a **spallation** neutron source based on **20 GeV/c protons** from the CERN PS hitting a **Pb block** (~300 neutrons per proton and ~ $7x10^{12}$ ppp).

Experimental area at **185 m** and **18.5 m.**

The n_TOF project

E_n [eV]	FWHM [cm]	ΔE_n [eV]
1	3	3.2×10^{-4}
10	3	3.2×10^{-3}
10^2	4	4.3×10^{-2}
10^3	5	5.4×10^{-1}
10^4	10	11
10^5	27	2.9×10^2
10^6	49	5.3×10^3



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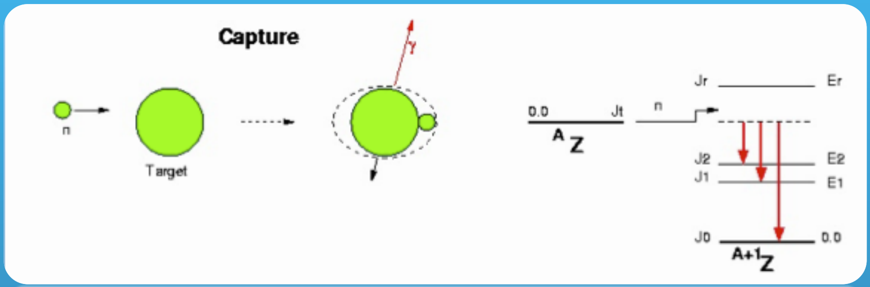
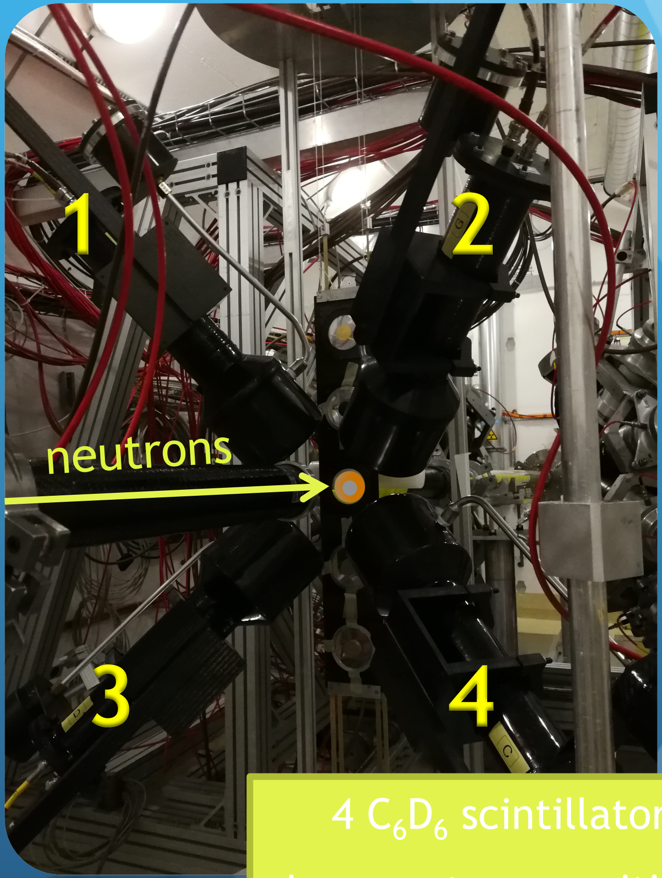
Experimental Set-Up



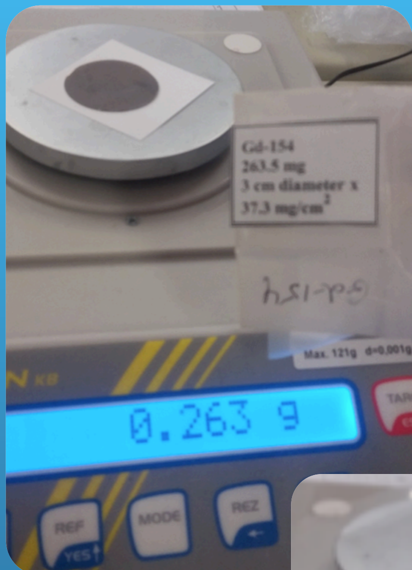
Capture reactions are measured by detecting γ-rays emitted in the de-excitation process



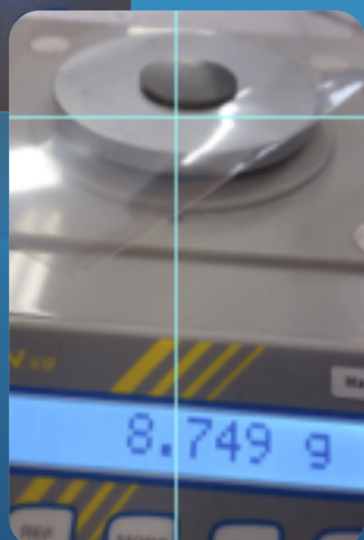
4 C_6D_6 scintillators

Low neutron sensitivity

Gd Samples



ORNL
0.263 g
Gd metal
^{154}Gd ~ 66,78 %



GOODFELLOW
8.749 g
Natural Gd
99%

Radius = 1.5 cm

n-capture Gd Campaign

Isotope	Protons	note
^{197}Au	4×10^{16}	Cyclic – after calibration
^{154}Gd	1.88×10^{18}	
^{nat}Gd	2.3×10^{17}	
Carbon	4×10^{16}	From ^{88}Sr and ^{89}Y campaign
Lead	1.2×10^{17}	
Empty	3.5×10^{17}	
Others	2.0×10^{17}	Filters bkg

2.6×10^{18}

Full calibration (^{137}Cs, ^{88}Y, Am-Be and Cm-C composite γ-ray source) every week !!!

14th August 2017
10th September 2017

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Data Analysis

NEUTRON CAPTURE YIELD: probability for a neutron to be captured in the sample

COUNTS NUMBER

BACKGROUNDS NUMBER

$$Y(E_n) = f_N(E_n)\frac{C(E_n) - B(E_n)}{\Phi(E_n)\epsilon_c}$$

NORMALIZATION FACTOR

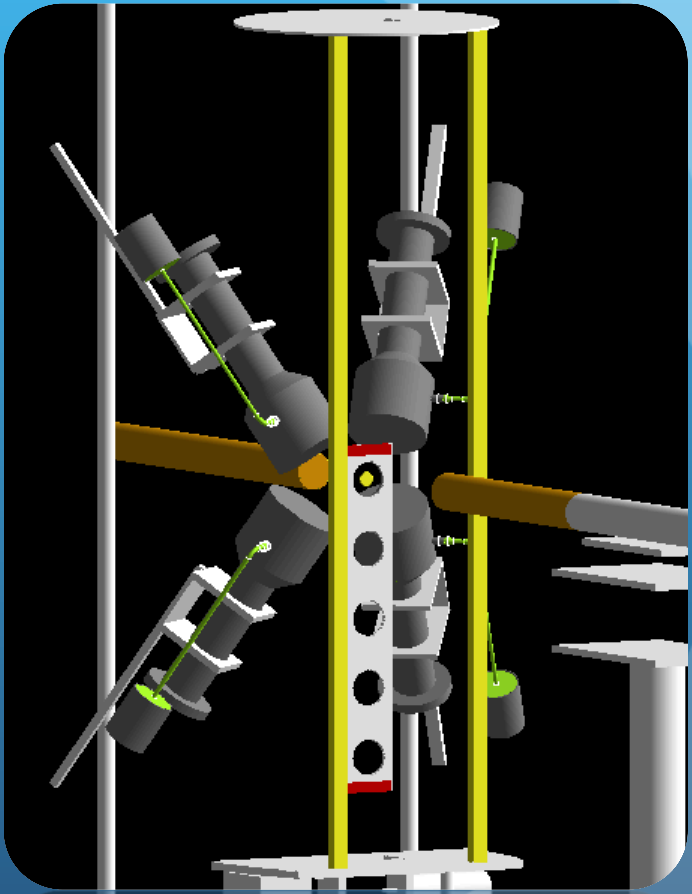
NEUTRON FLUX SPECTRUM

DETECTION EFFICIENCY

Detection Efficiency

ε_C was calculated using the Pulse Height Weighting Technique (PWHT)

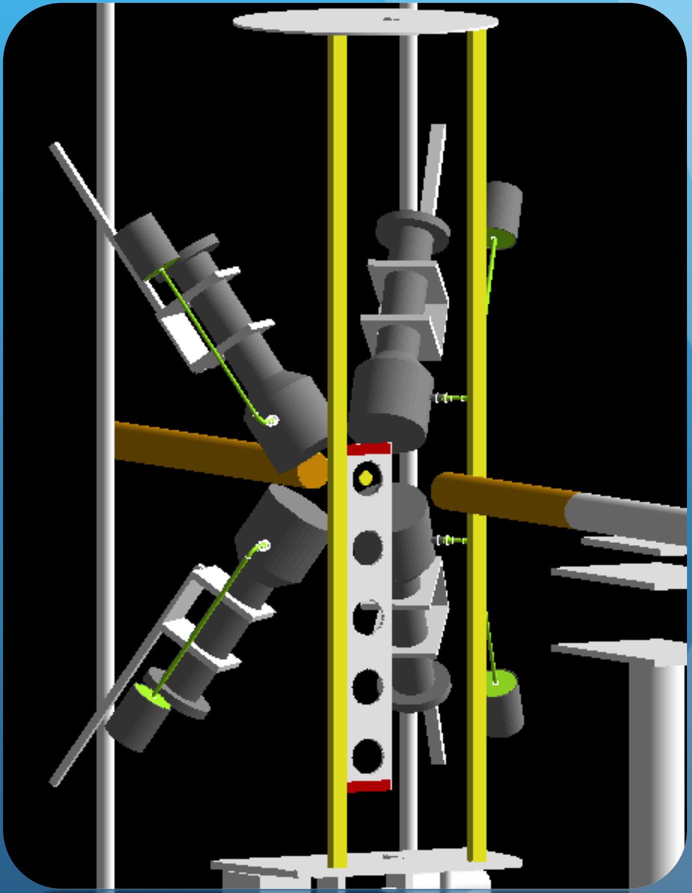
It is valid for small efficiency gamma-ray detector.
Only one gamma-ray out of the capture cascade is registered at a time, whose detection efficiency is proportional to the γ energy.



Detection Efficiency

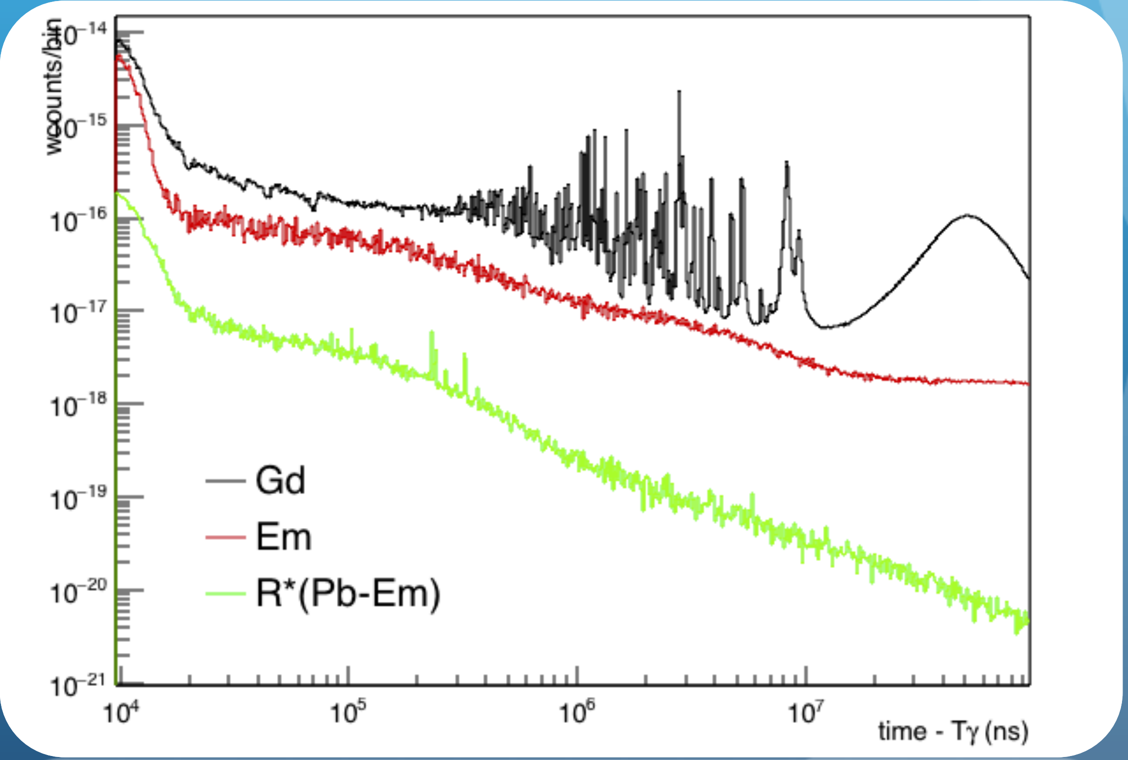
ε_C was calculated using the Pulse Height Weighting Technique (PWHT)

The proportionality between E_γ and the efficiency that can be achieved by applying pulse height dependent weights. The weighting factors were determined by simulating the detector response in GEANT4.



Background Subtraction

- Beam related background ➔ Empty Frame
- Scattered neutrons in the sample ➔ Pb Sample



Neutron Capture Cross Section

preliminary

Resonance Shape Analysis

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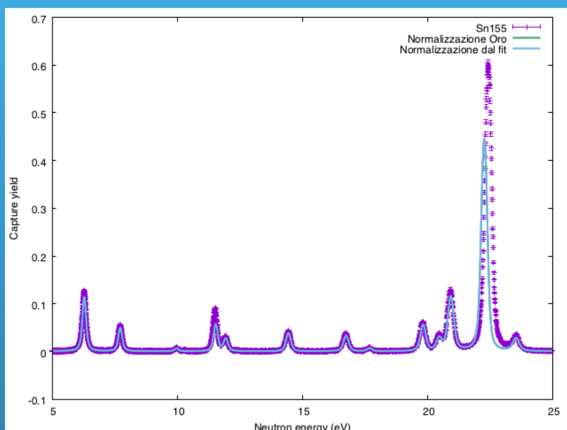
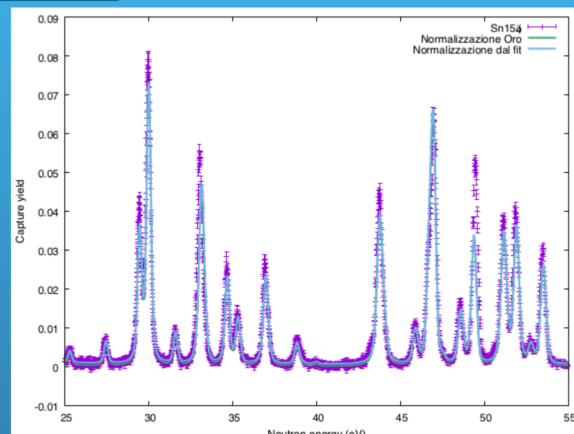
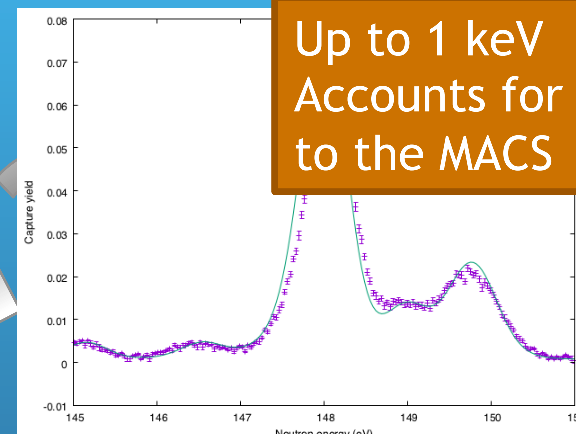
RESOLVED RESONANCE REGION





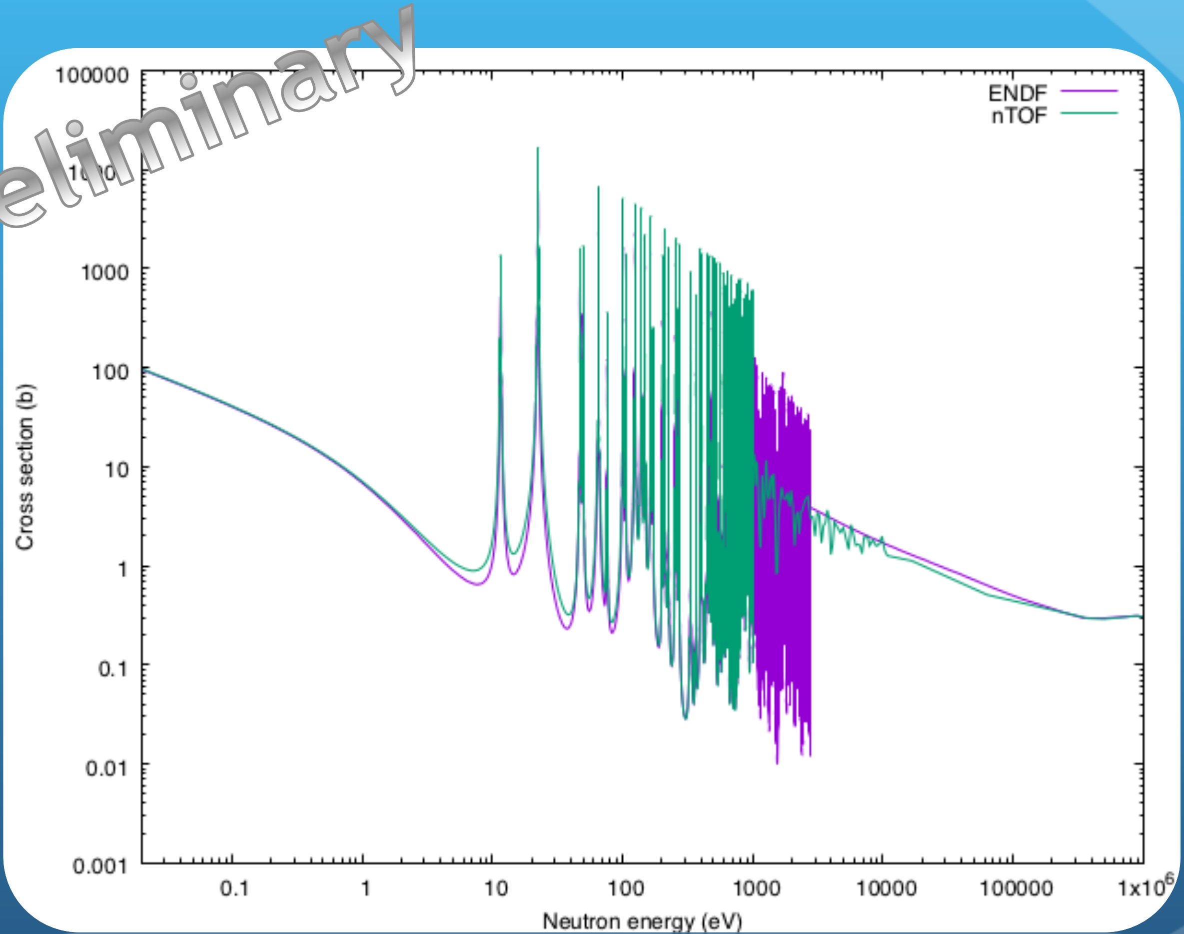


Up to 1 keV Accounts for 15% to the MACS

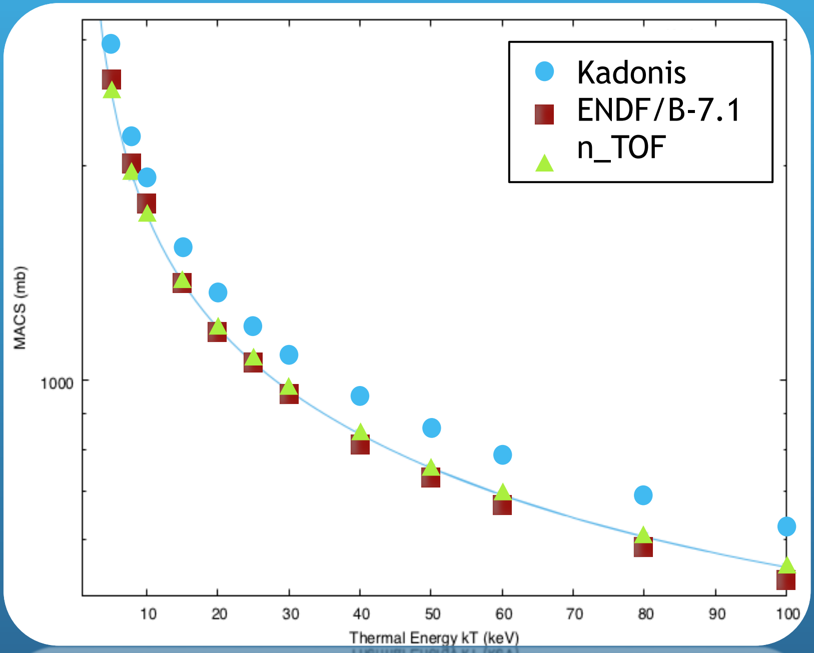
UNRESOLVED RESONANCE REGION

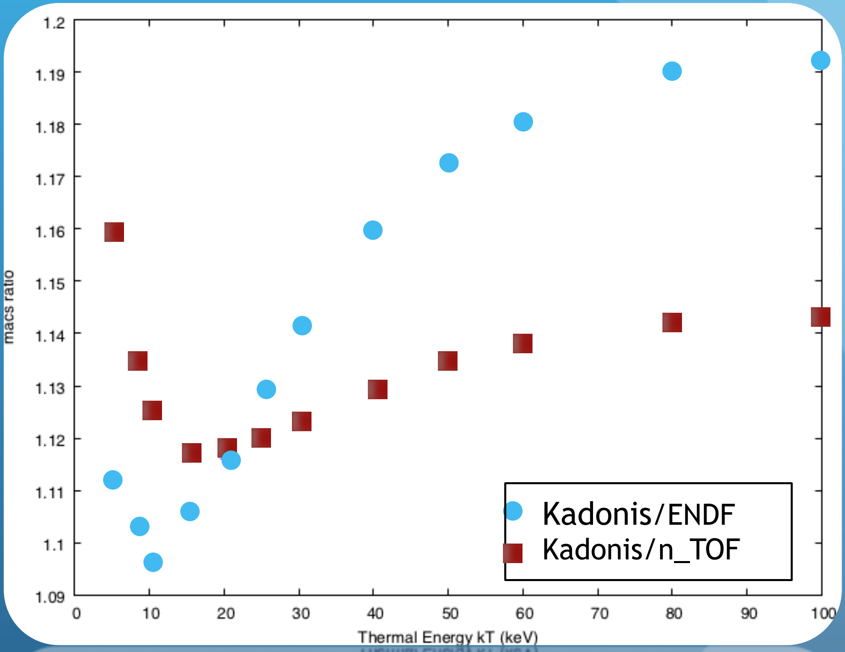
→ Accounts for the 80% to the MACS

Neutron Capture Cross Section



Maxwellian Averaged Cross Section (MACS)





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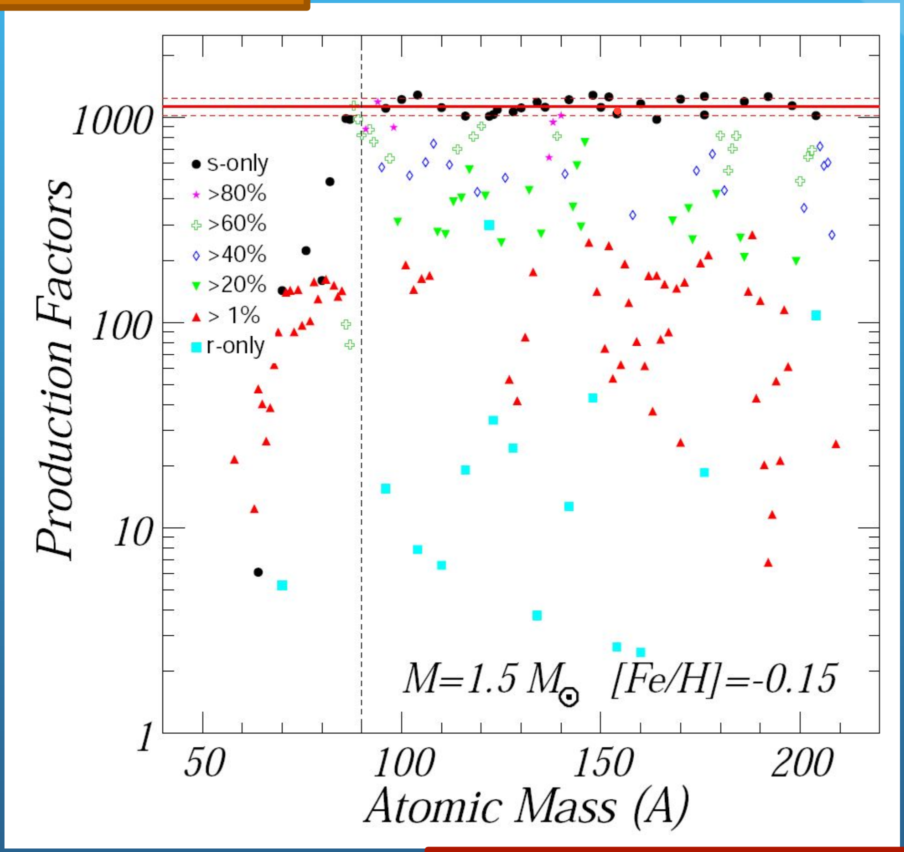
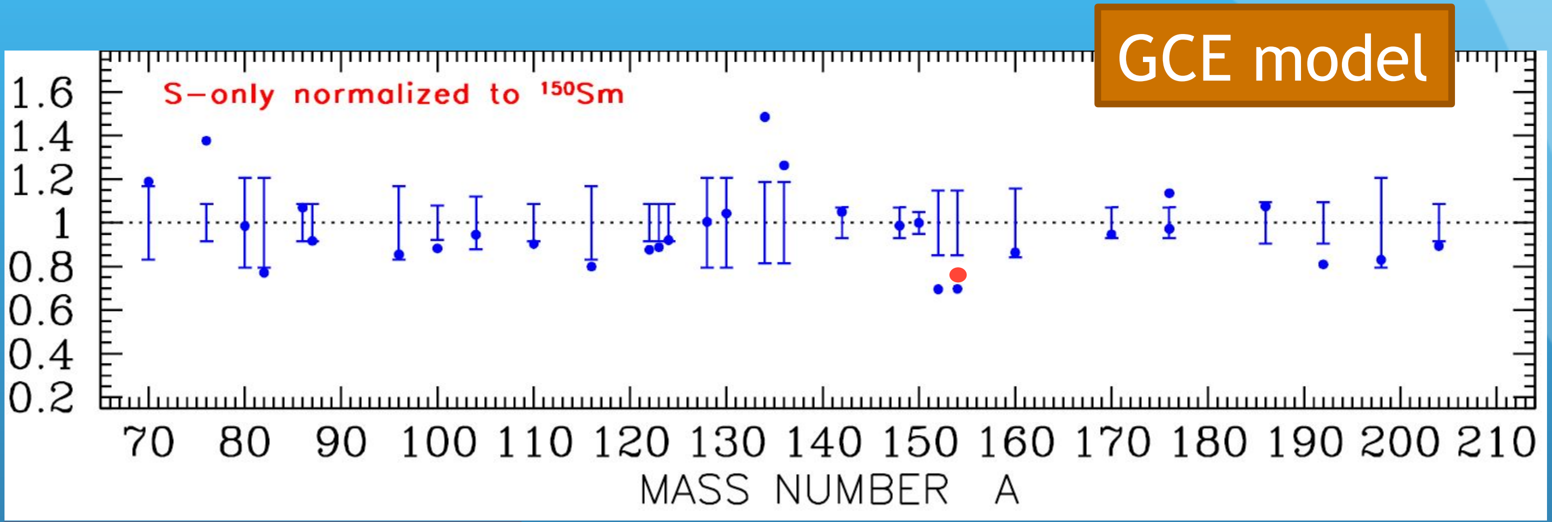
Single stellar model



Trippella, The Astr. Jour. 2016

Preliminary Results

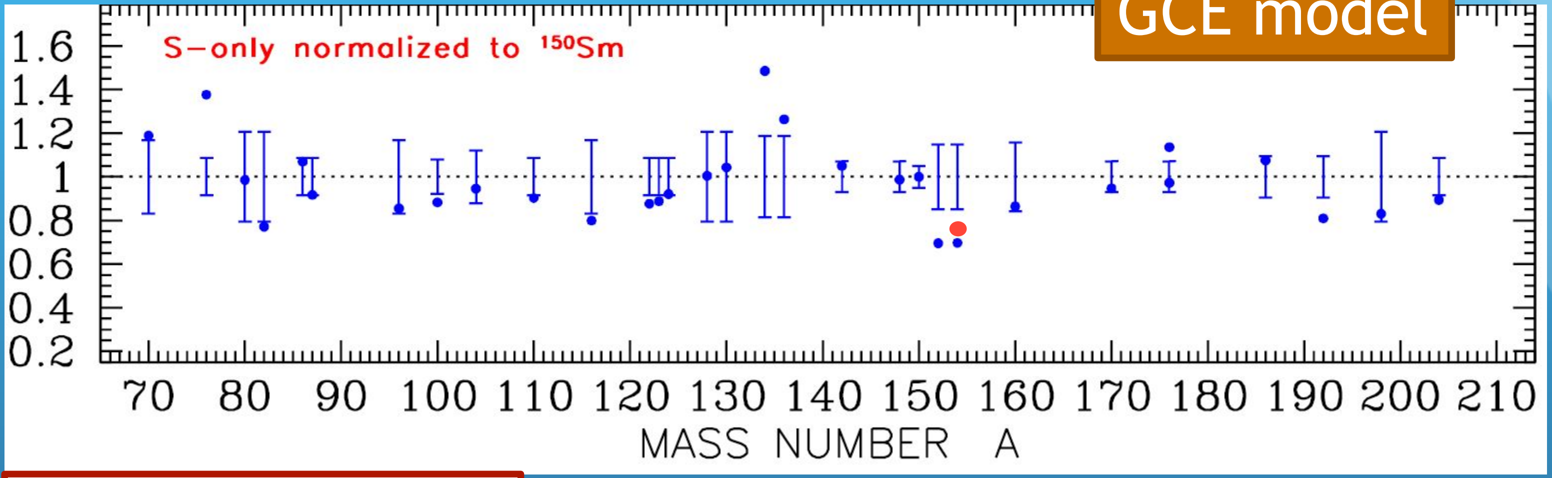


Prantzos, MNRAS 2018

- M=1.5 Msun Production(154Gd)=+9%
- M=2.0 Msun Production(154Gd)=+5%
- M=3.0 Msun Production(154Gd)=+4%

Preliminary Results

GCE model



Prantzos, MNRAS 2018

Increse of 5% does not justify the 40% discrepancy in the model

Gd cross section is not the solution

Outlook

- recalculate the model with a lower metallicity
- study the production cross section of ^{153}Eu(n,γ)154Eu that β- decays in ^{154}Gd
- change the main neutron source mechanism into the FRUITY models

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Conclusion

- The preliminary value for neutron cross section of Gd154 was calculated in the energy range 1meV-100keV
- The evaluated MACS is ≈15% lower than that obtained in KADONIS 1.0 and 8% lower than Bao&Kaeppeler.

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THANK YOU FOR YOUR ATTENTION

Neutron flux