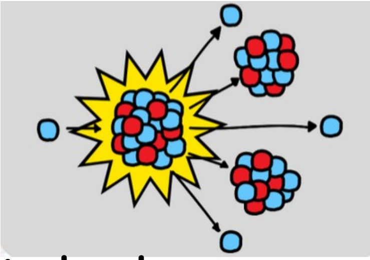
The neutron Time-of-Flight facility, n_TOF at CERN: Status and perspectives

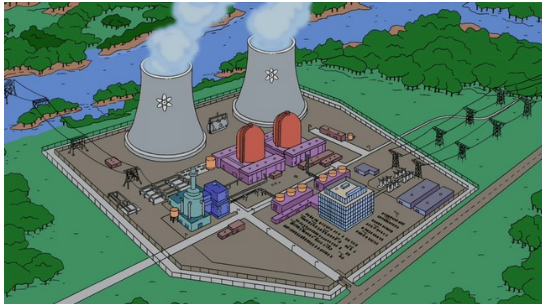
A. Manna on behalf of the n_TOF Collaboration

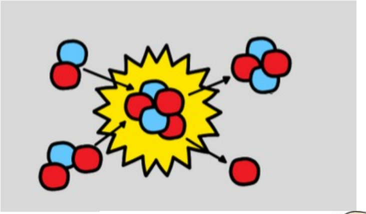
European Nuclear Physics Conference, 21–26 Sept 2025 Moho

n_TOF, Why??

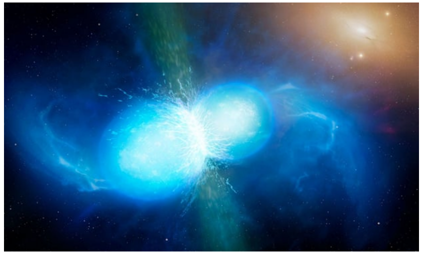


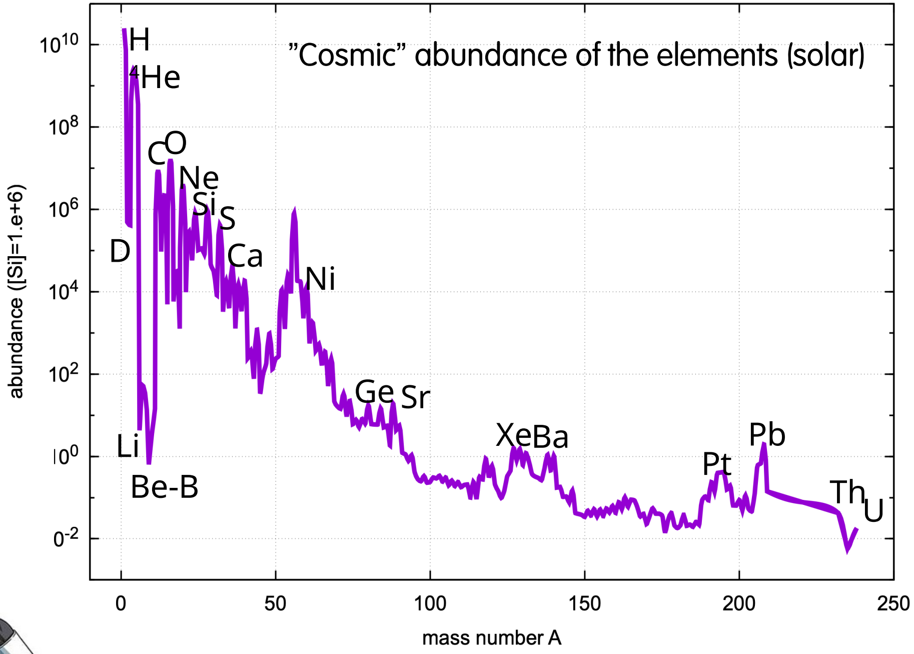
Nuclear technology





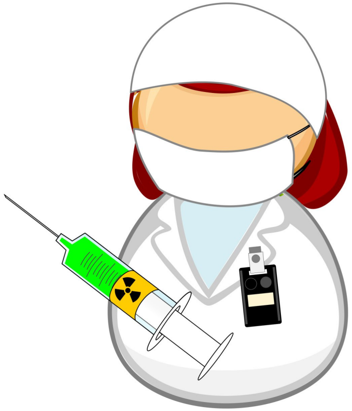
Nuclear Astrophysics



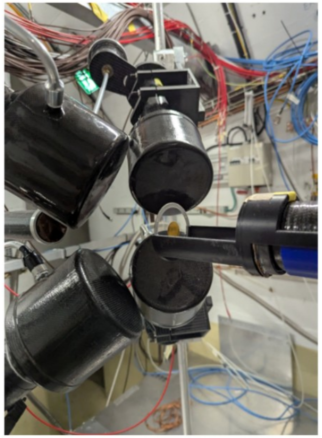


Basic Nuclear Physics

Nuclear medicine

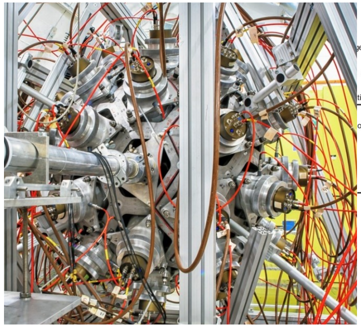


(n,γ)

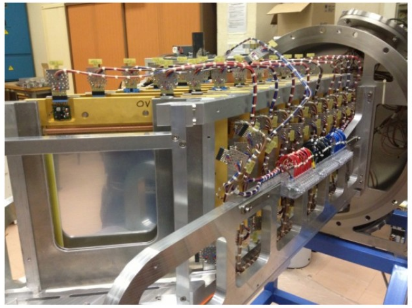


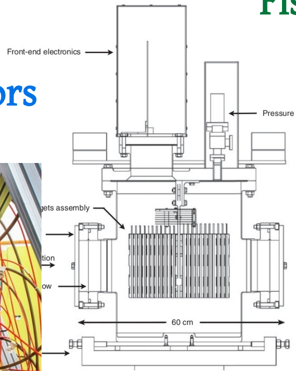
C6D6 liquid scintillators

BaF - TAC



(n,f)



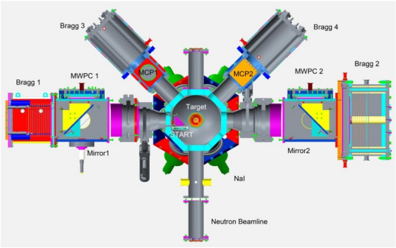


Fission chambers

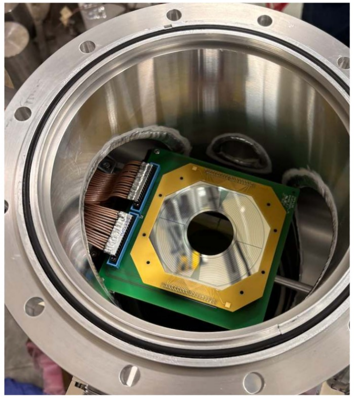
PPAC

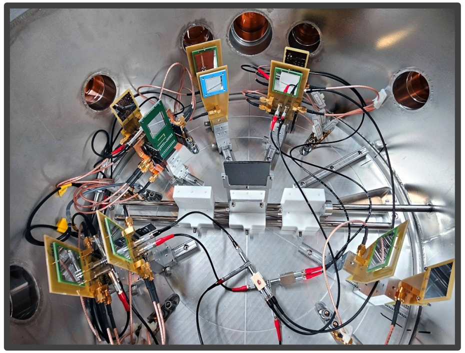
uMEGAS

STEFF



(n,cp)



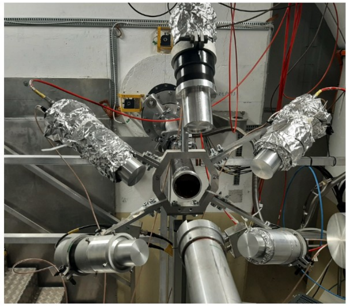


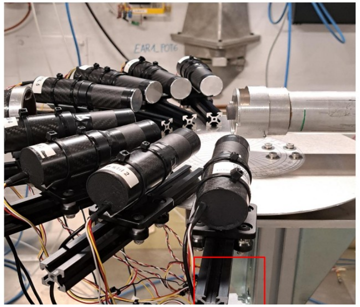
Silicon detectors

(n,n')

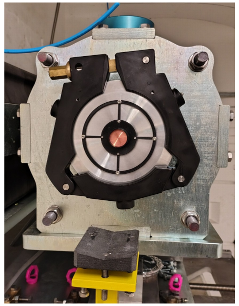
LaBr

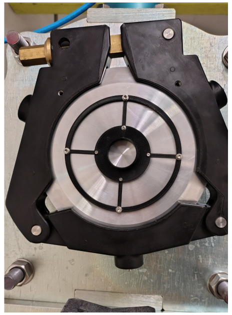
Stilbene detectors

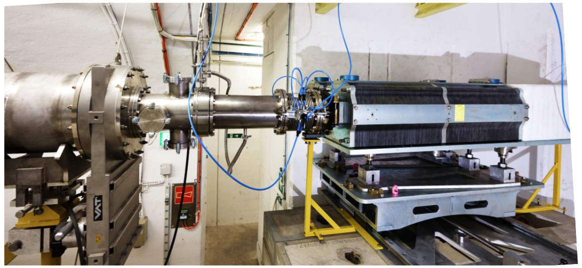




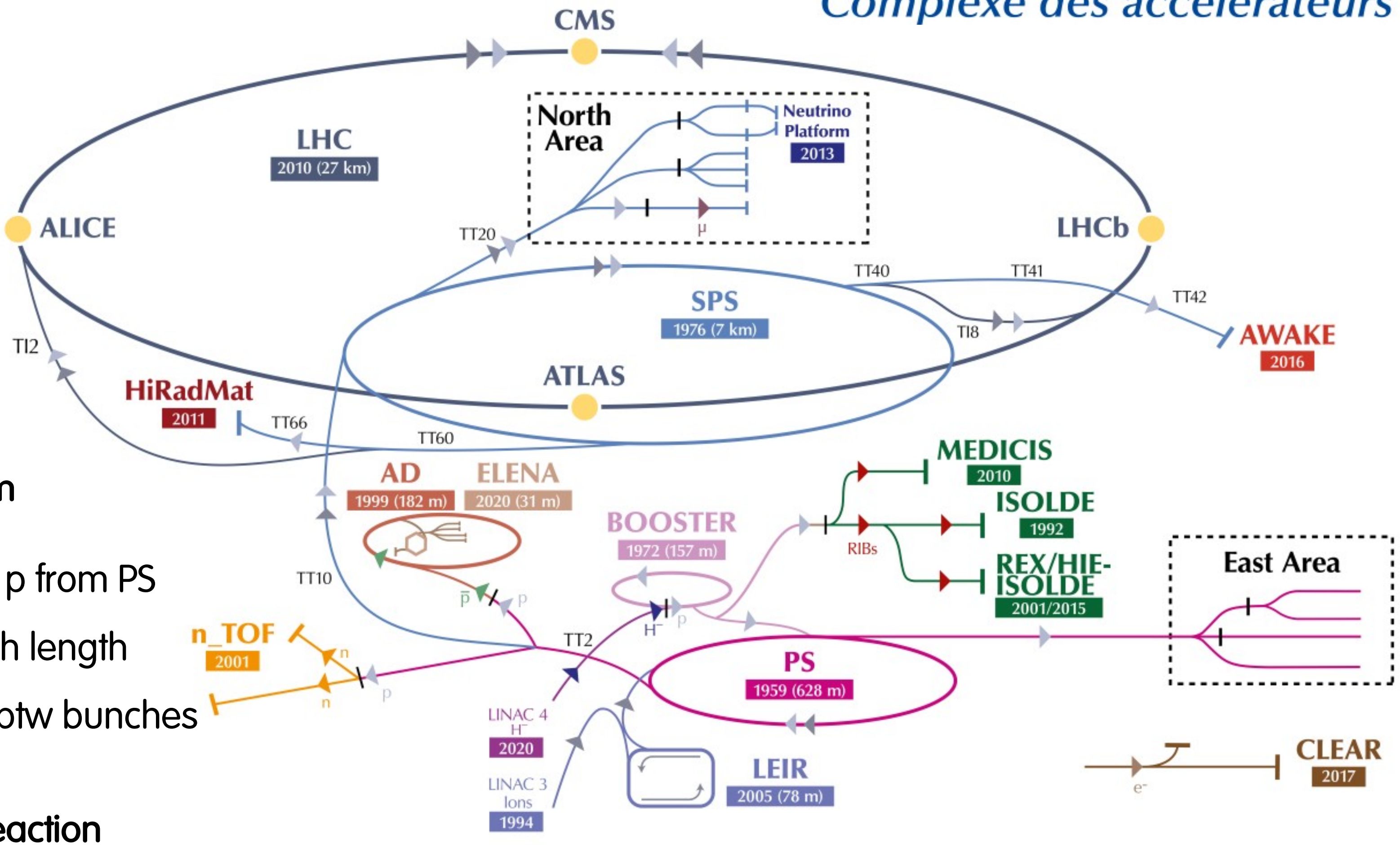
(n,tot)







The CERN accelerator complex
Complexe des accélérateurs du CERN



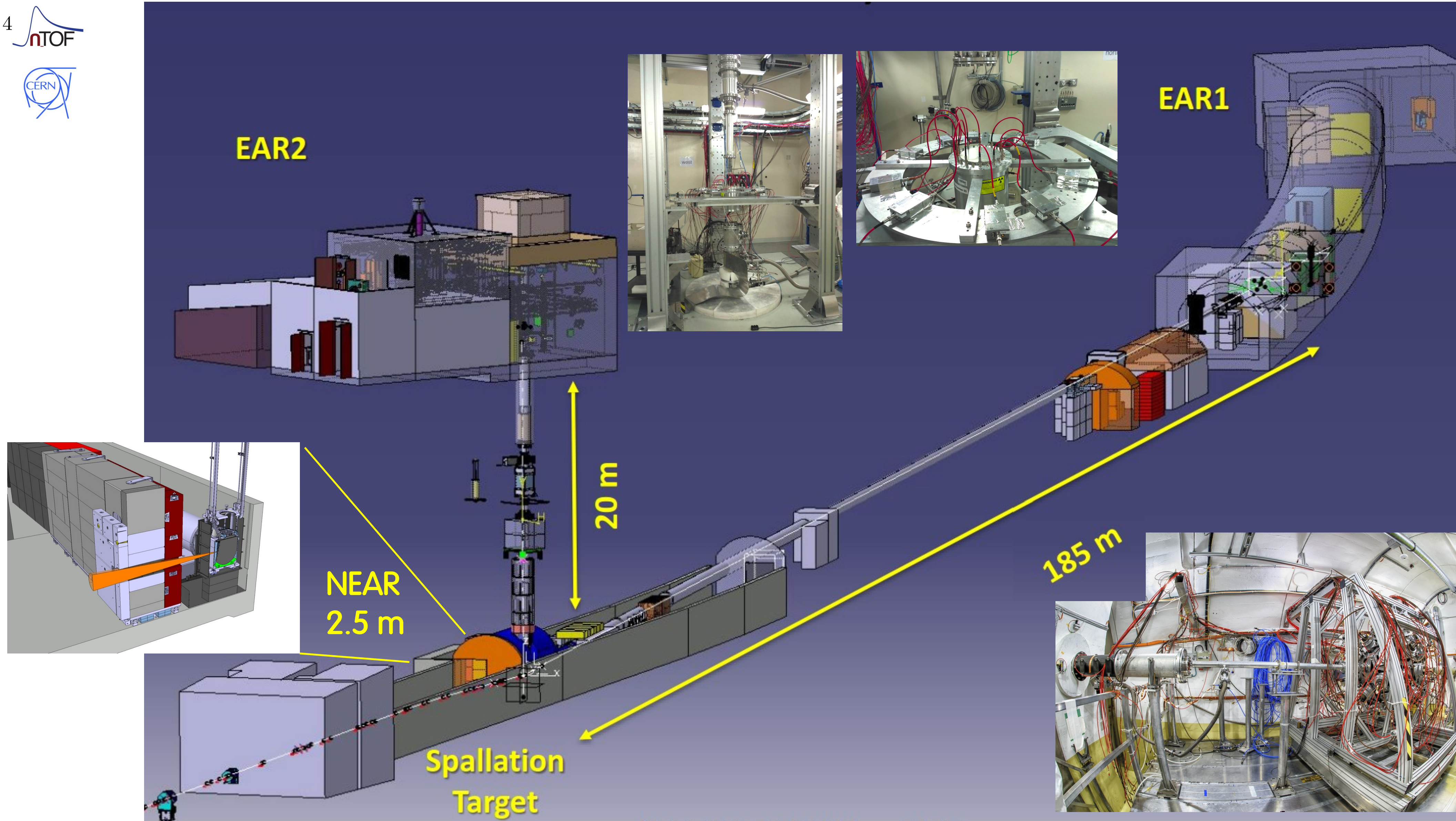
Proton beam

- 20 GeV/c p from PS
- 7 ns bunch length
- Min. 1.2s btw bunches

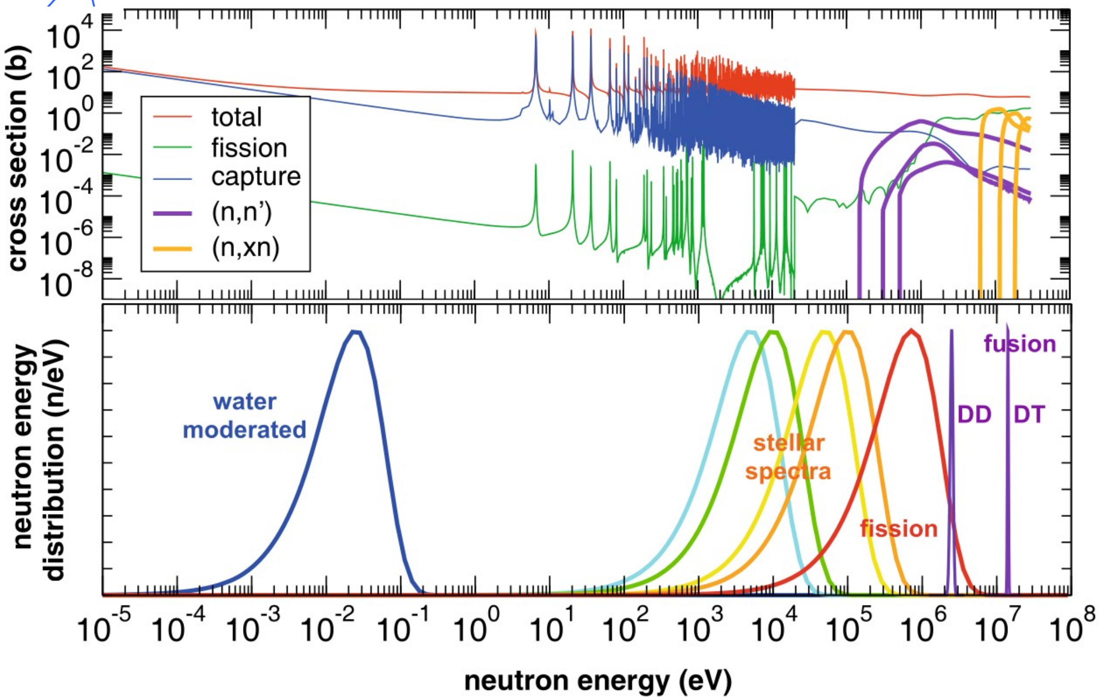
Spallation reaction

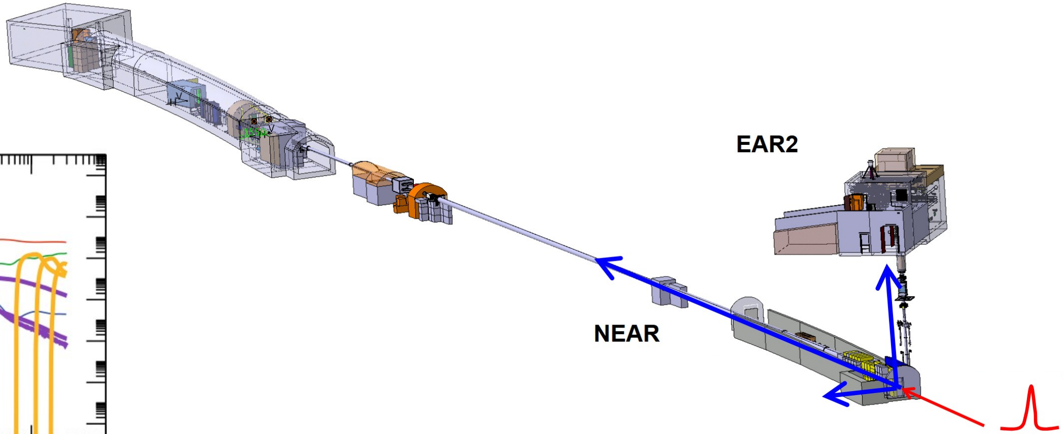
300 neutrons per incident proton

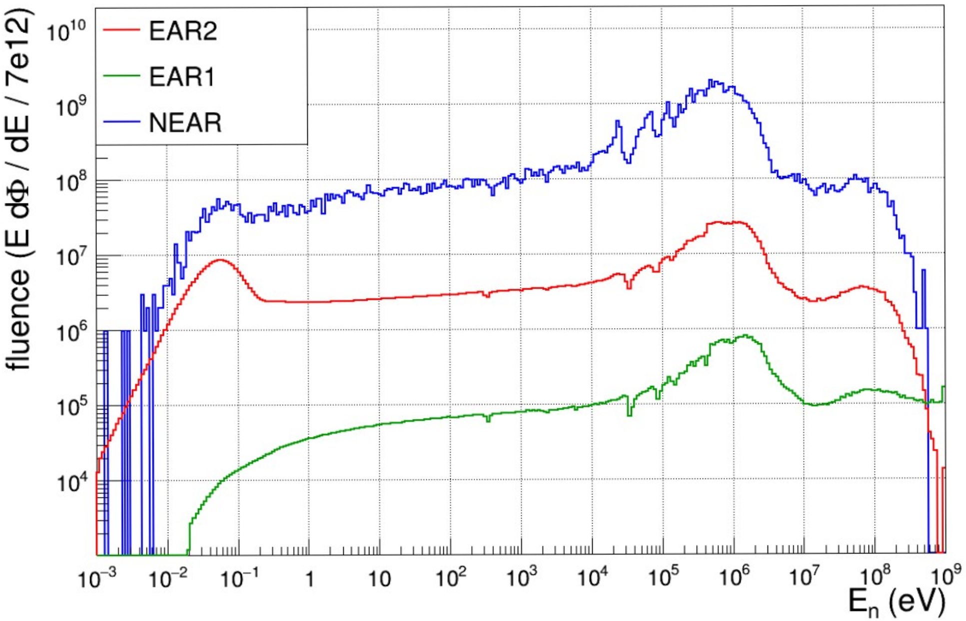
C. Rubbia et al., A high resolution spallation driven facility at the CERN-PS to measure neutron cross sections in the interval from 1 eV to 250 MeV CERN/LHC/98-02(EET) 1998


EAR2
EAR1
20 m
185 m
NEAR
2.5 m
Spallation
Target

n_TOF facility







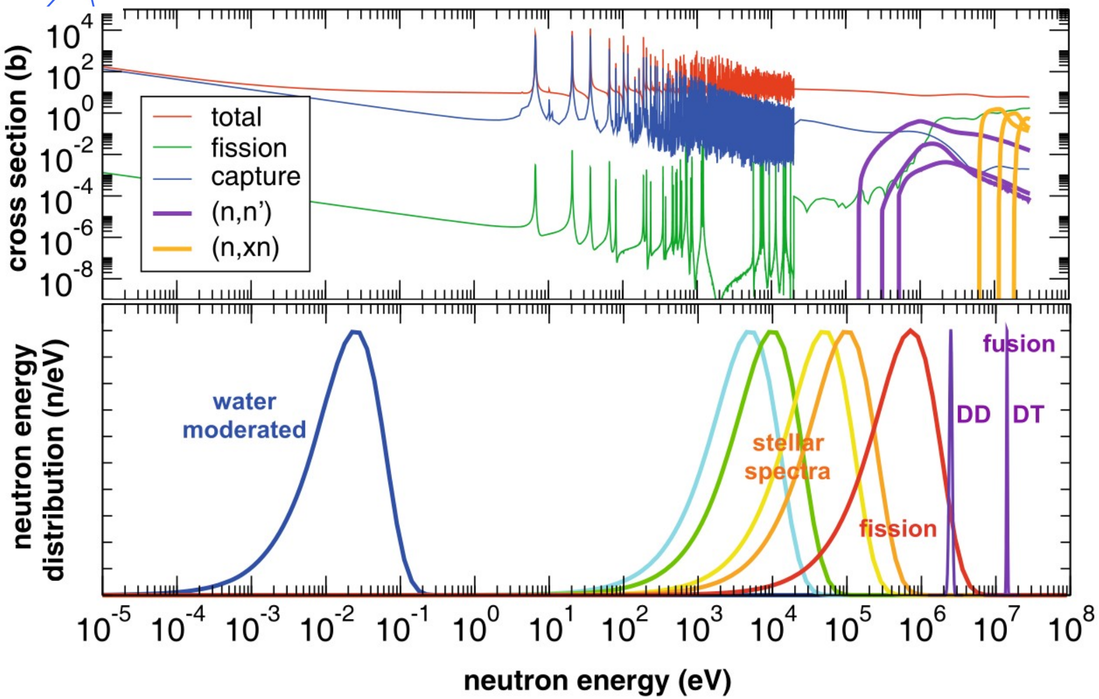
@ target : $2 \cdot 10^{15}$ n/pulse

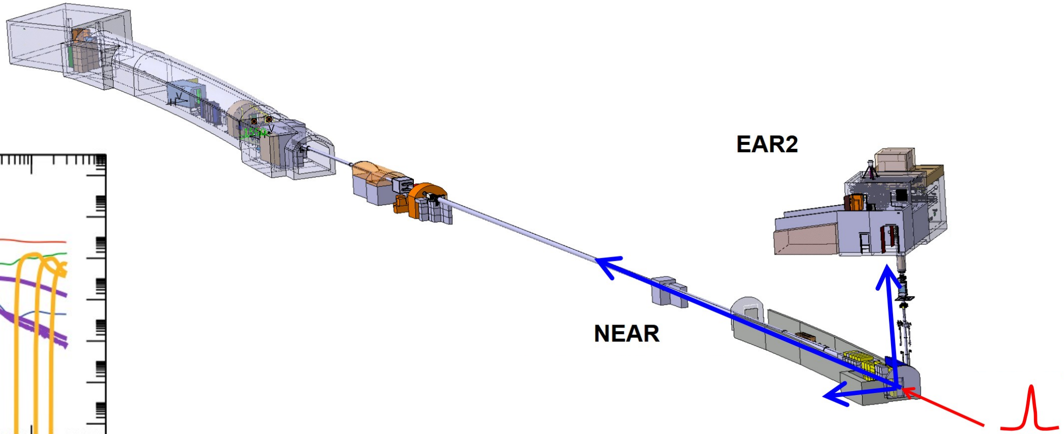
@ EAR 1: $8 \cdot 10^{5}$ n/pulse

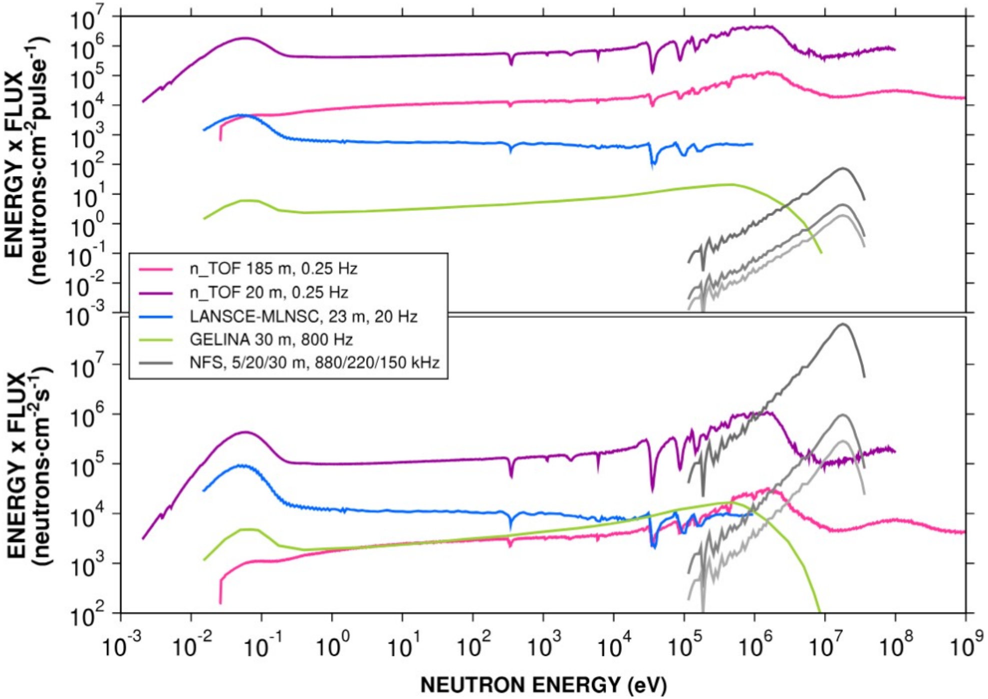
@ EAR 2: $3 \cdot 10^{7}$ n/pulse

@ NEAR: $8 \cdot 10^{8}$ n/pulse

n_TOF facility

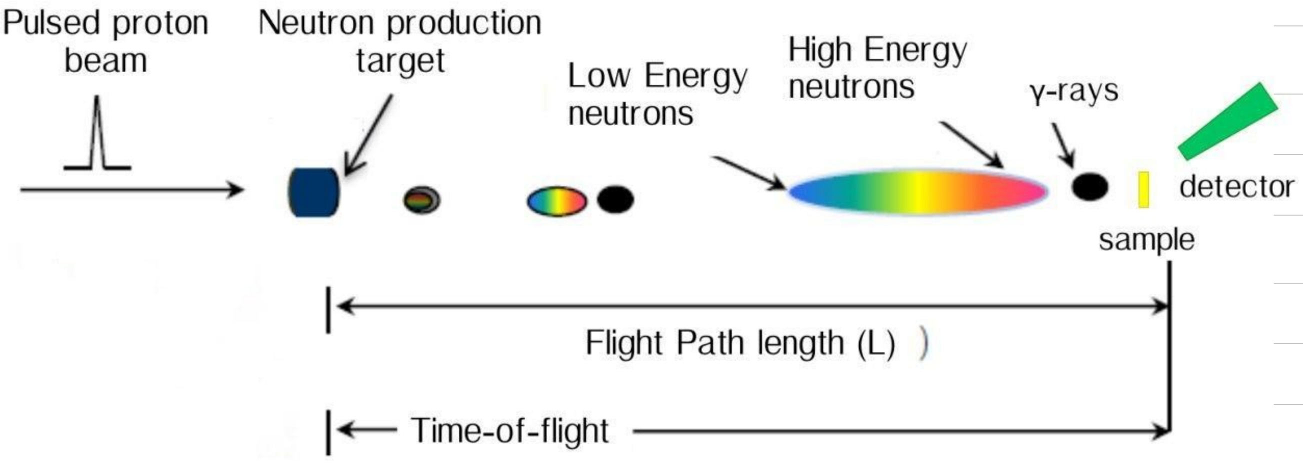






@ target : $2{\cdot}10^{15}$ n/pulse
@ EAR 1: $8{\cdot}10^{5}$ n/pulse
@ EAR 2: $3{\cdot}10^{7}$ n/pulse
@ NEAR: $8{\cdot}10^{8}$ n/pulse

n_TOF facility



$$E_n = E_{tot} - mc^2 = mc^2(\gamma - 1) \qquad \gamma = \frac{1}{\sqrt{1-(v/c)^2}},$$

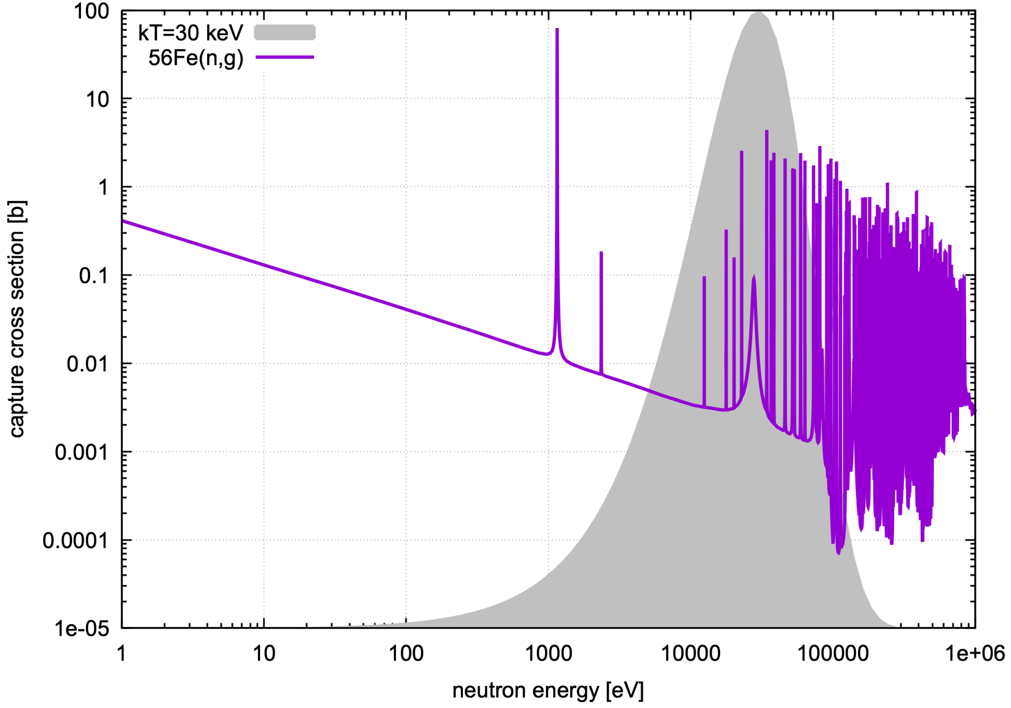
$$\frac{\Delta E}{E} = (\gamma+1)\gamma\frac{\Delta v}{v}. \qquad \frac{\Delta v}{v} = \sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}.$$

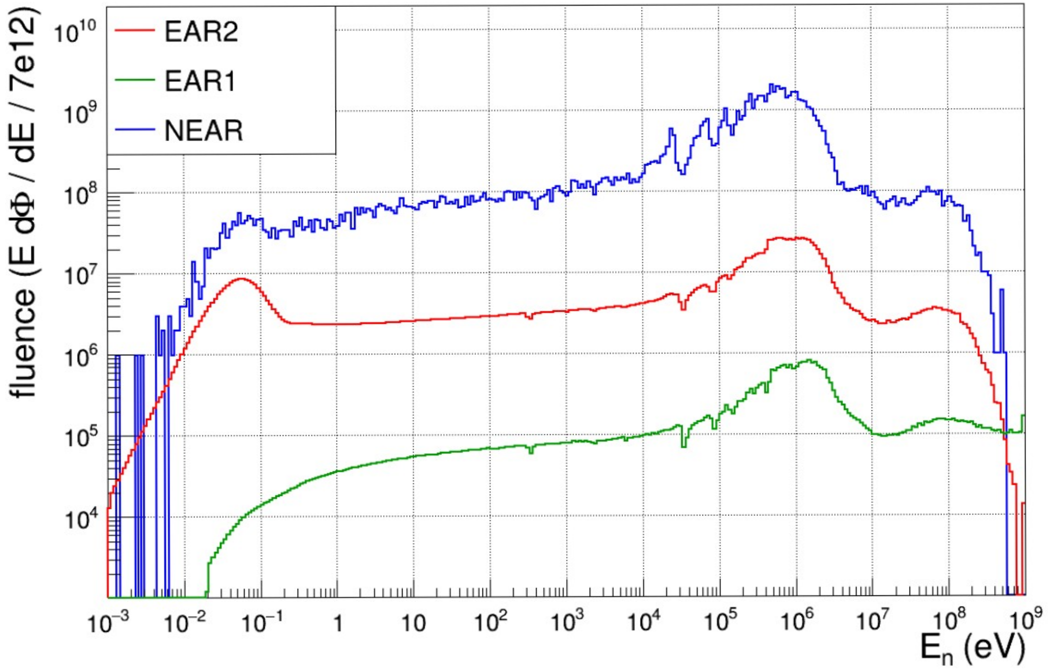
Energy (eV)	TOF(μs)		
	EAR1	EAR2	NEAR
10^{-2}	$1.3 \cdot 10^5$	$1.5 \cdot 10^4$	$2.2 \cdot 10^3$
10^{-1}	$4.2 \cdot 10^4$	$4.6 \cdot 10^3$	690
1	$1.3 \cdot 10^4$	$1.5 \cdot 10^3$	220
10	$4.2 \cdot 10^3$	460	69
10^2	$1.3 \cdot 10^3$	145	22
10^3	420	45.9	6.9
10^4	133	14.5	2.2
10^5	41.5	4.5	0.68
10^6	12.7	1.39	0.21
10^7	3.63	0.39	0.06
10^8	0.82	0.09	0.01
10^9	0.09	nan not a neutron	nan

NEAR Station

Maxwellian-Averaged capture Cross Section (MACS)

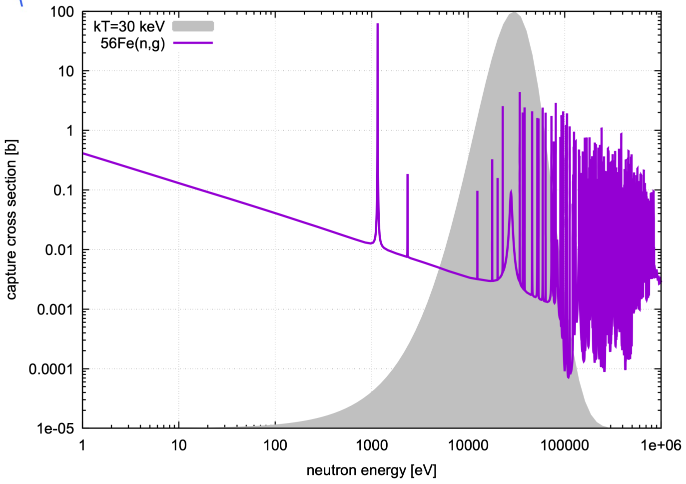
$$\frac{<\sigma(v)\, v>}{v_T} = \frac{2}{\sqrt{\pi}} \frac{1}{(kT)^2} \int \sigma(E)\, E\, e^{-\frac{E}{kT}}\, dE$$

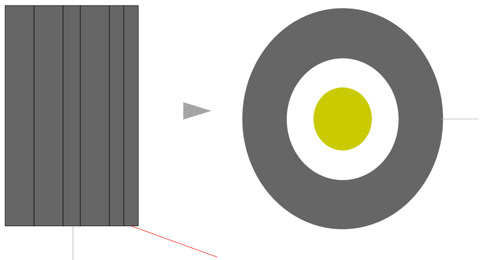




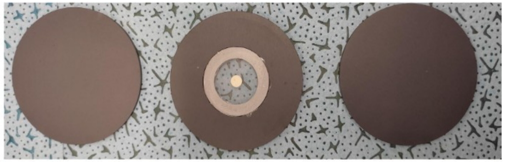
NEAR Station

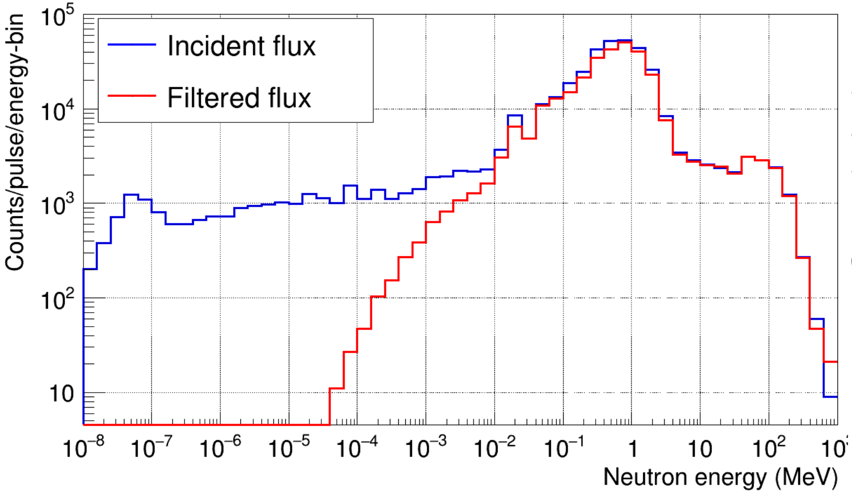
With suitable filters (i.e. B4C) the neutron flux can be shaped to obtain Spectral Averaged Cross Section (SACS) close to the **Maxwellian-Averaged capture Cross Section (MACS)**

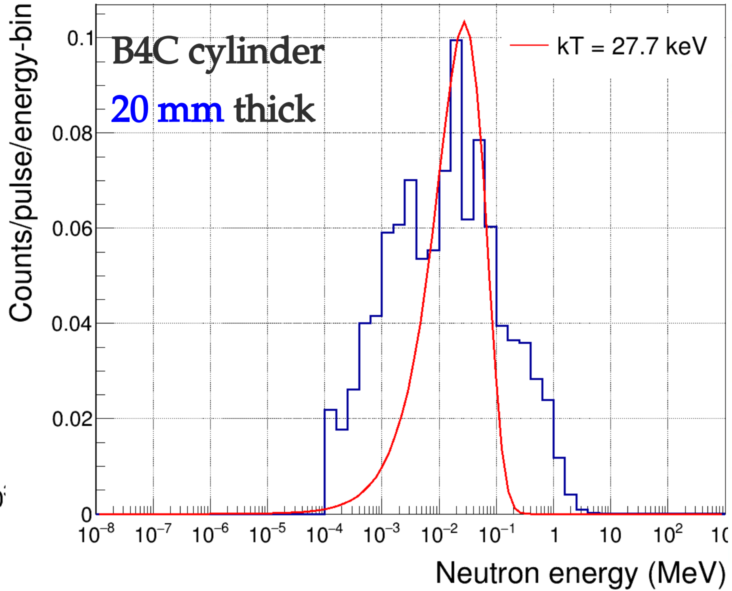


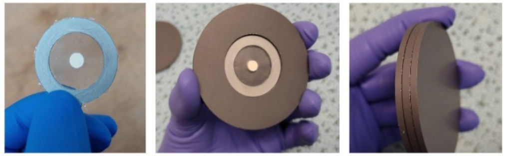


Each B4C thickness corresponds to a **kT temperature**

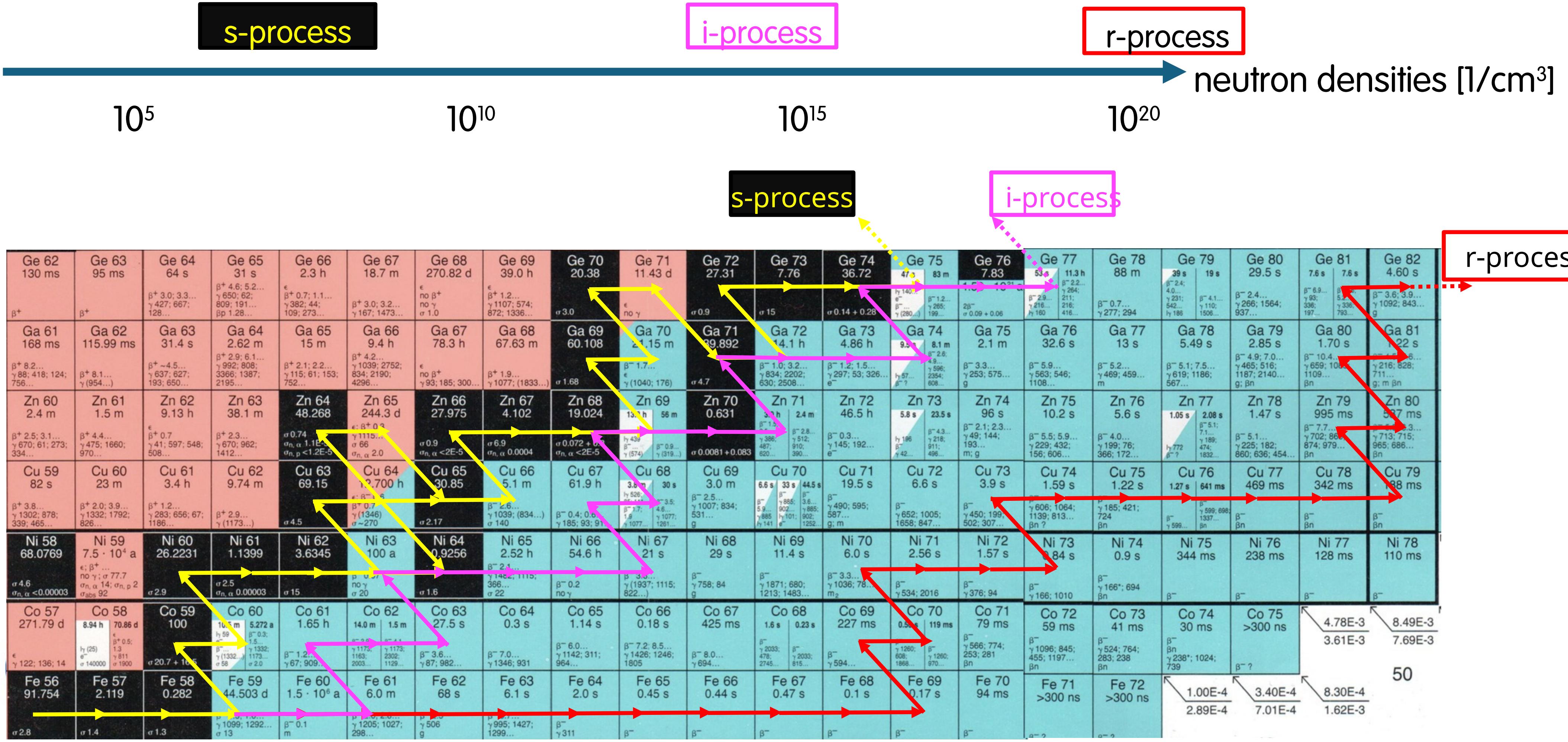




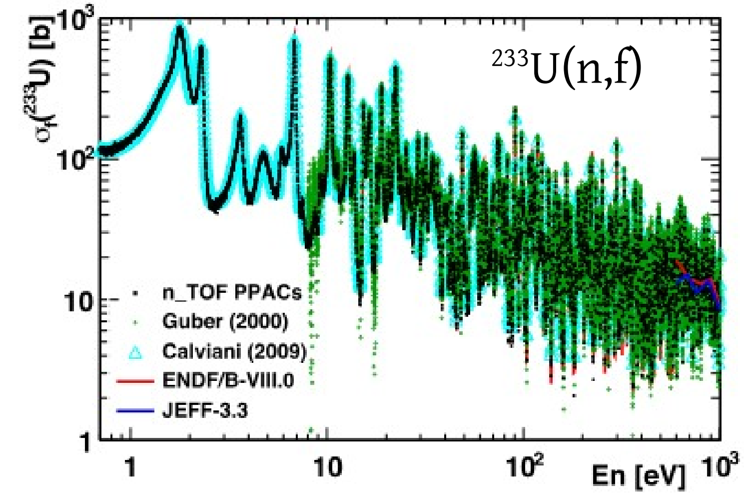


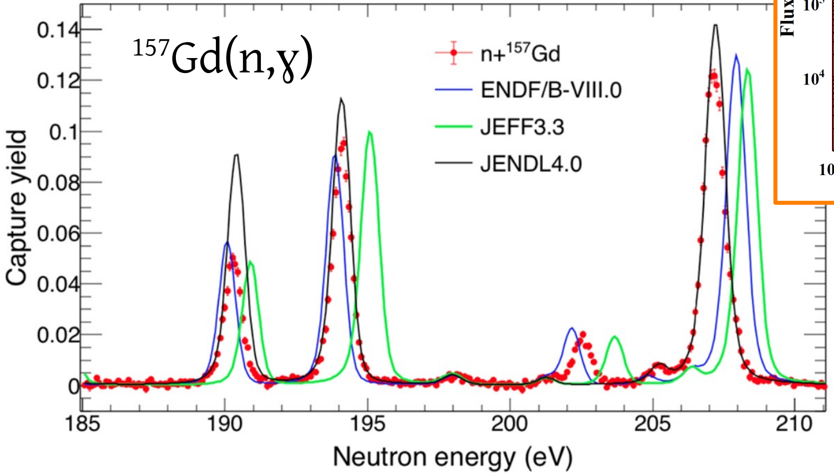


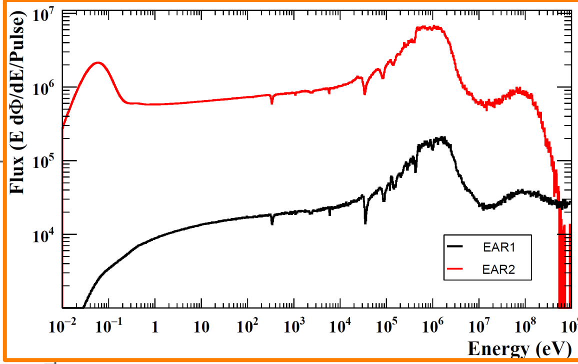
NEAR Station



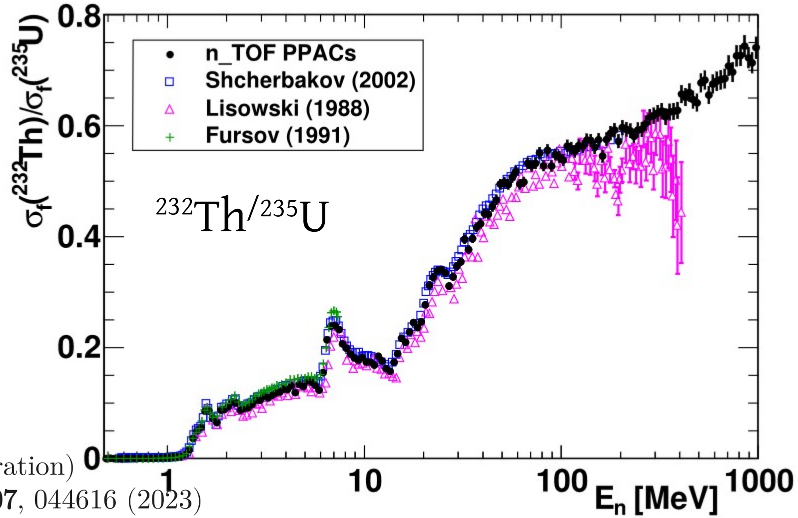
Time Of Flight Area - EAR1

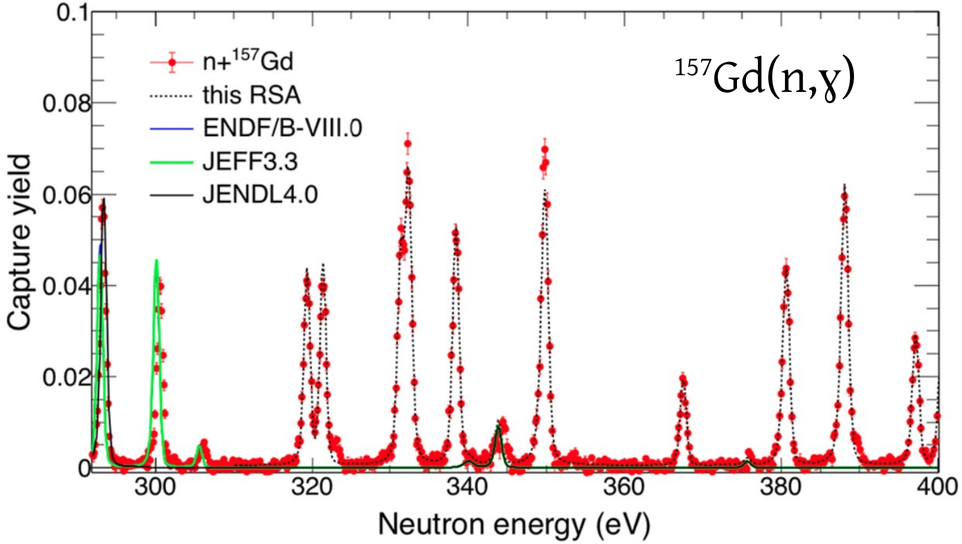






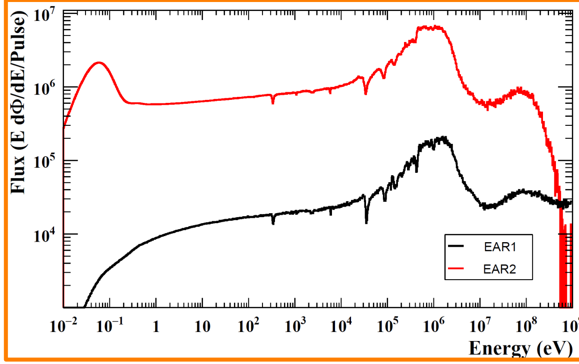
M. Mastromarco *et al.*
(The n_TOF Collaboration)
Eur. Phys. J. A **55**, 9 (2019)
DOI: 10.1140/epja/i2019-12692-7



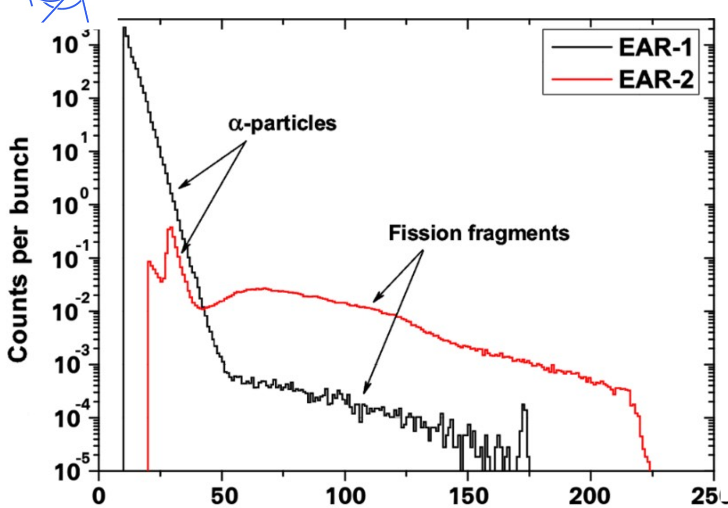


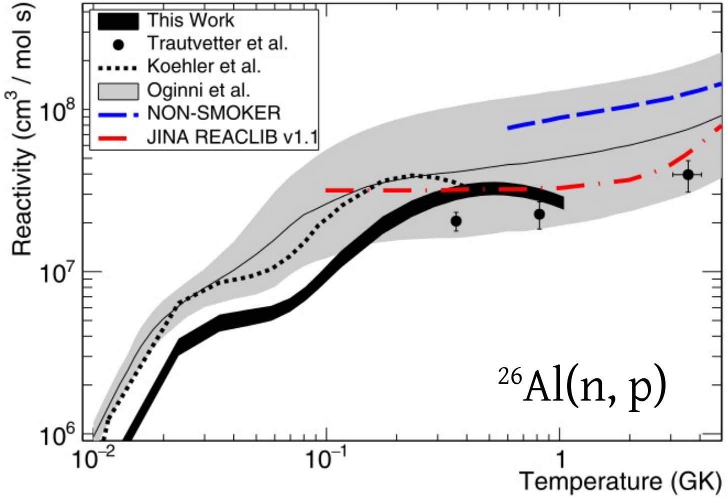
D. Tarrío *et al.*
(The n_TOF Collaboration)
Physical Review C **107**, 044616 (2023)
DOI: 10.1103/PhysRevC.107.044616

Time Of Flight Area - EAR2

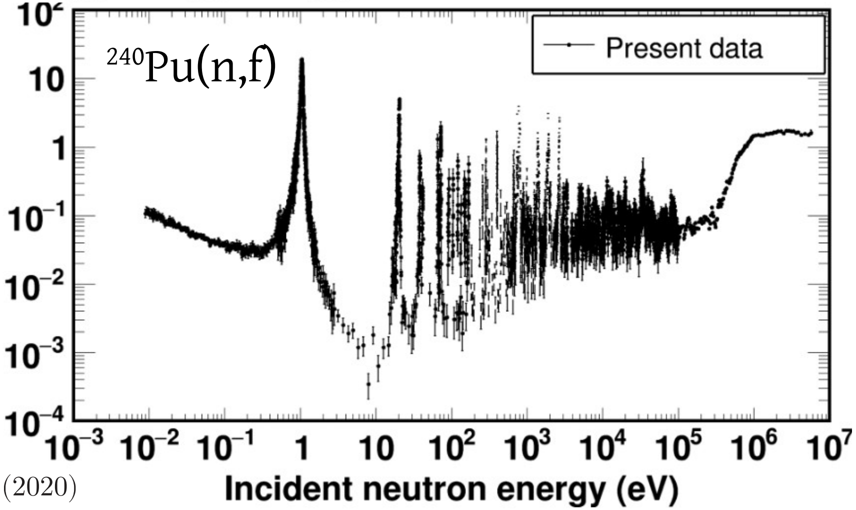


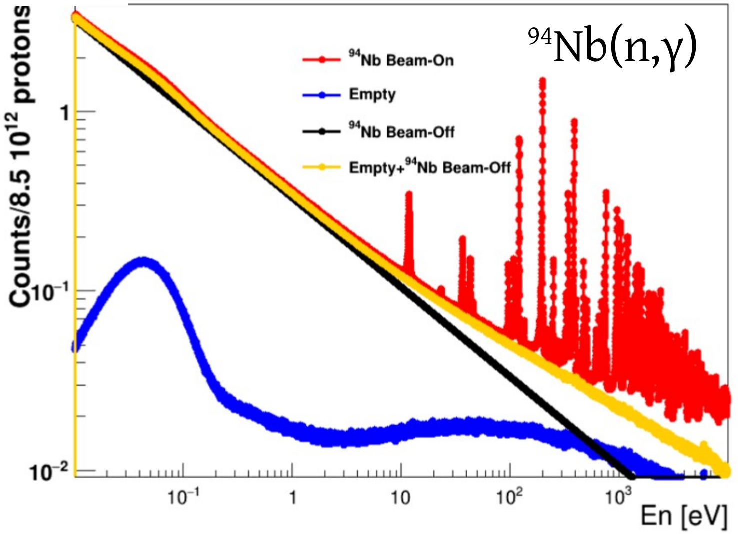
C. Lederer-Woods *et al.*(The n_TOF Collaboration)
Physical Review C **104**, L022803 (2021)
DOI: 10.1103/PhysRevC.104.L022803



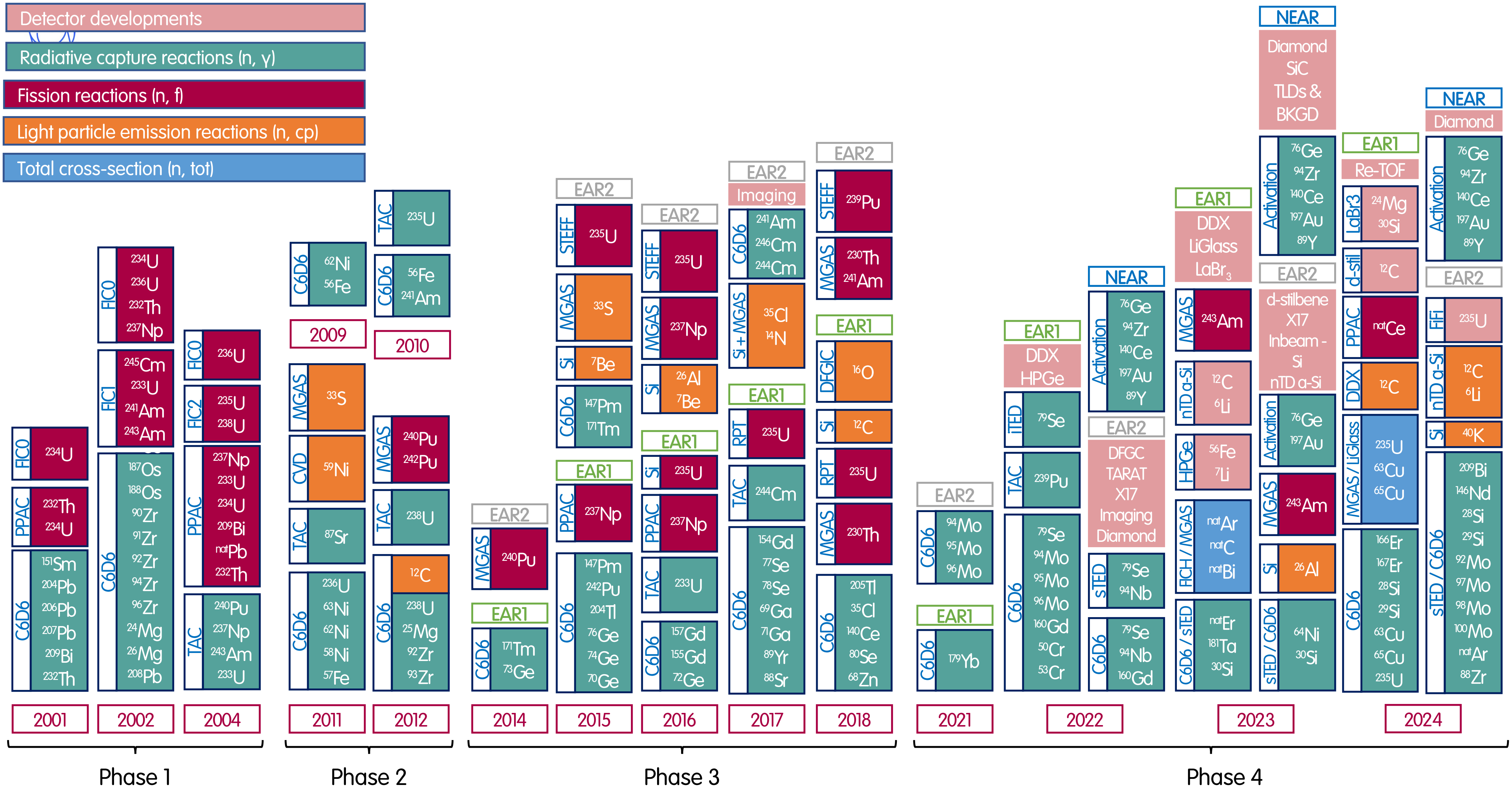


J. Balibrea-Correa*et al.* The n_TOF Collaboration)
EPJ Web Conf. 279 (2023)
DOI: 10.1051/epjconf/202327906004



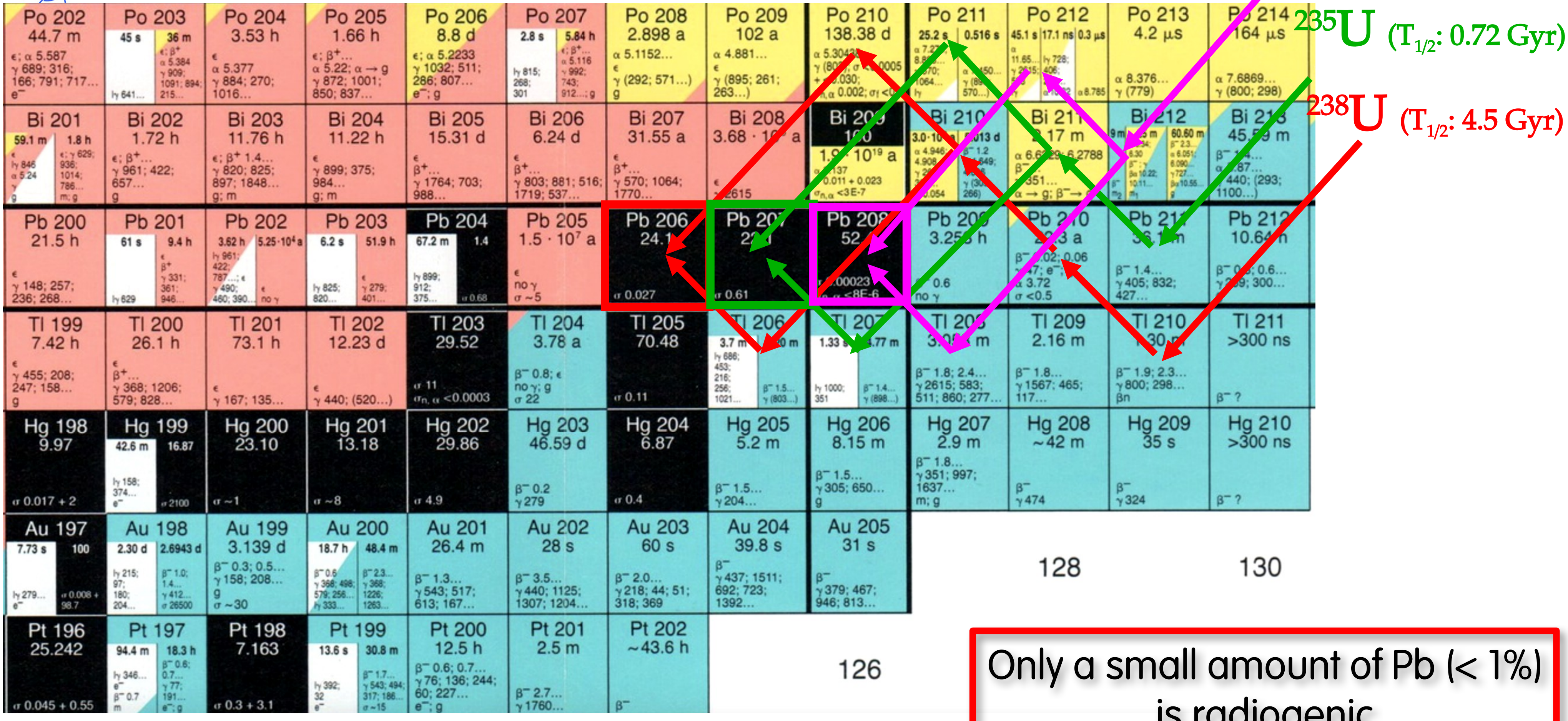


A. Stamatopoulos *et al.*
(The n_TOF Collaboration)
Physical Review C **102**, 014616 (2020)
DOI: 10.1103/PhysRevC.102.014616


Detector developments
Radiative capture reactions (n, γ)
Fission reactions (n, f)
Light particle emission reactions (n, cp)
Total cross-section (n, tot)
2001
FIC0 234U
PPAC 232Th 234U
C6D6 151Sm 204Pb 206Pb 207Pb 209Bi 232Th
2002
FIC0 234U 236U 232Th 237Np
FIC1 245Cm 233U 241Am 243Am
C6D6 187Os 188Os 90Zr 91Zr 92Zr 94Zr 96Zr 24Mg 26Mg 208Pb
2004
FIC0 236U
FIC2 235U 238U
PPAC 237Np 233U 234U 209Bi natPb 232Th
TAC 240Pu 237Np 243Am 233U
2009
C6D6 62Ni 56Fe
2010
TAC 235U
C6D6 56Fe 241Am
2011
MGAS 33S
CVD 59Ni
TAC 87Sr
C6D6 236U 63Ni 62Ni 58Ni 57Fe
2012
MGAS 240Pu 242Pu
TAC 238U
C6D6 12C 238U 25Mg 92Zr 93Zr
2014
EAR2
MGAS 240Pu
EAR1
C6D6 171Tm 73Ge
2015
EAR2
STEFF 235U
MGAS 33S
Si 7Be
C6D6 147Pm 171Tm
EAR1
PPAC 237Np
C6D6 147Pm 242Pu 204Tl 76Ge 74Ge 70Ge
2016
EAR2
STEFF 235U
MGAS 237Np
Si 26Al 7Be
EAR1
Si 235U
PPAC 237Np
TAC 233U
C6D6 157Gd 155Gd 72Ge
2017
EAR2
Imaging
C6D6 241Am 246Cm 244Cm
Si + MGAS 35Cl 14N
EAR1
RPT 235U
TAC 244Cm
C6D6 154Gd 77Se 78Se 69Ga 71Ga 89Yr 88Sr
2018
EAR2
STEFF 239Pu
MGAS 230Th 241Am
EAR1
DFGIC 16O
Si 12C
RPT 235U
MGAS 230Th
C6D6 205Tl 35Cl 140Ce 80Se 68Zn
2021
EAR2
C6D6 94Mo 95Mo 96Mo
EAR1
C6D6 179Yb
2022
EAR1
DDX HPGe
iTED 79Se
TAC 239Pu
C6D6 79Se 94Mo 95Mo 96Mo 160Gd 50Cr 53Cr
NEAR
Activation 76Ge 94Zr 140Ce 197Au 89Y
EAR2
DFGC TARAT X17 Imaging Diamond
sTED 79Se 94Nb
C6D6 79Se 94Nb 160Gd
2023
EAR1
DDX LiGlass LaBr3
MGAS 243Am
nTD a-Si 12C 6Li
HPGe 56Fe 7Li
FICH / MGAS natAr natC natBi
C6D6 / sTED natEr 181Ta 30Si
NEAR
Diamond SiC TLDs & BKGD
Activation 76Ge 94Zr 140Ce 197Au 89Y
EAR2
d-stilbene X17 Inbeam - Si nTD a-Si
Activation 76Ge 197Au
MGAS 243Am
Si 26Al
sTED / C6D6 64Ni 30Si
2024
EAR1
Re-TOF
LaBr3 24Mg 30Si
d-stil 12C
PPAC natCe
DDX 12C
MGAS / LiGlass 235U 63Cu 65Cu
C6D6 166Er 167Er 28Si 29Si 63Cu 65Cu 235U
NEAR
Diamond
Activation 76Ge 94Zr 140Ce 197Au 89Y
EAR2
FiFi 235U
nTD a-Si 12C 6Li
Si 40K
sTED / C6D6 209Bi 146Nd 28Si 29Si 92Mo 97Mo 98Mo 100Mo natAr 88Zr
Phase 1
Phase 2
Phase 3
Phase 4

What is the origin of Lead?

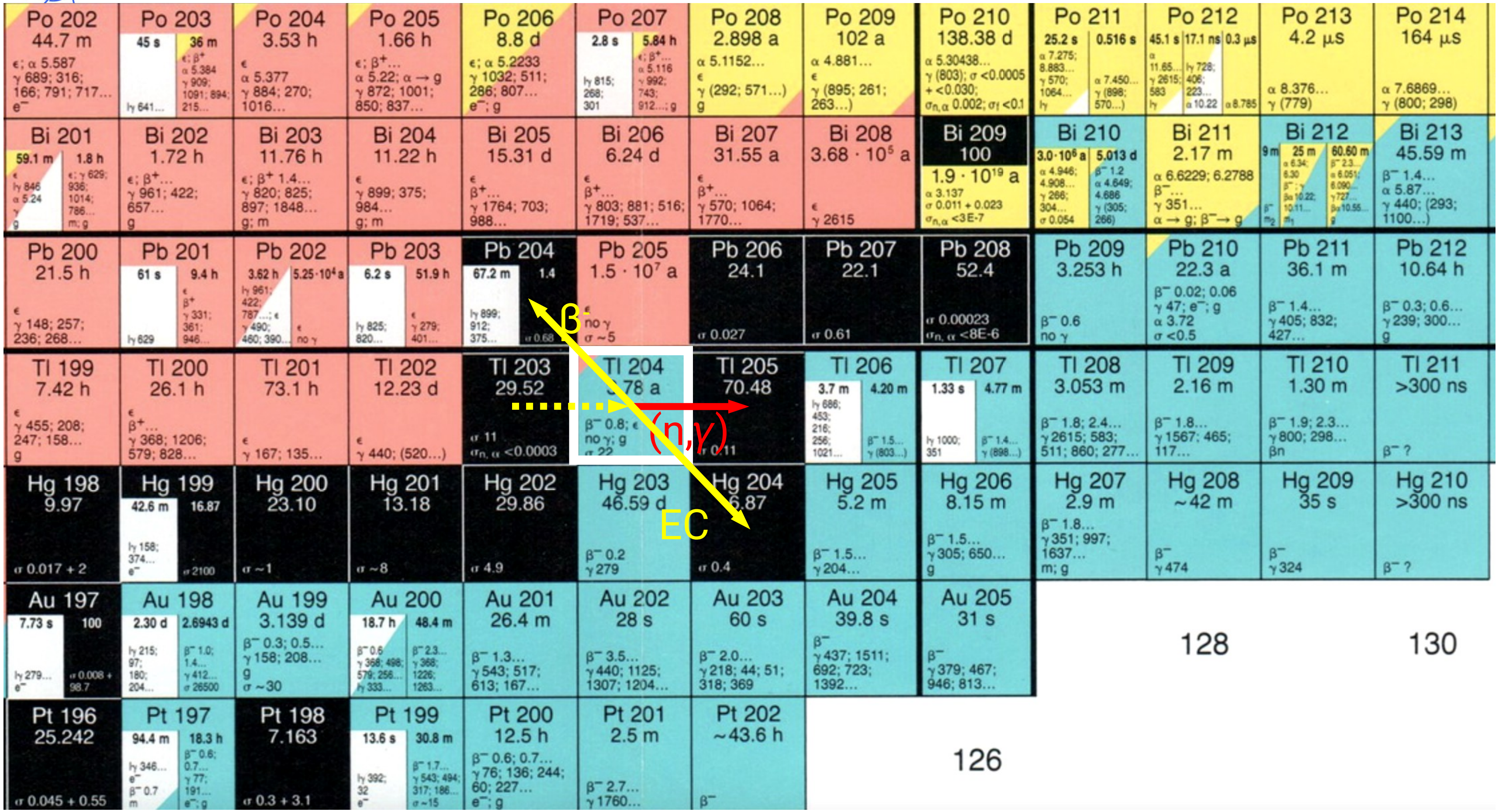
^{232}Th ($T_{1/2}$: 14.1 Gyr)



Only a small amount of Pb (< 1%) is radiogenic

What is the origin of Lead?

^{204}Tl(n,γ) experiment

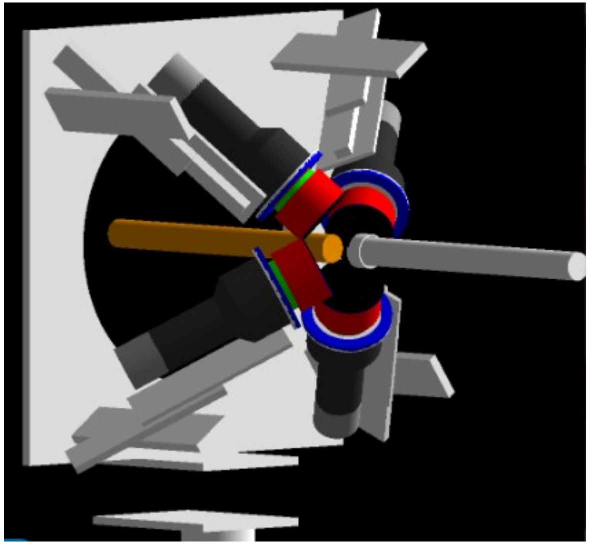


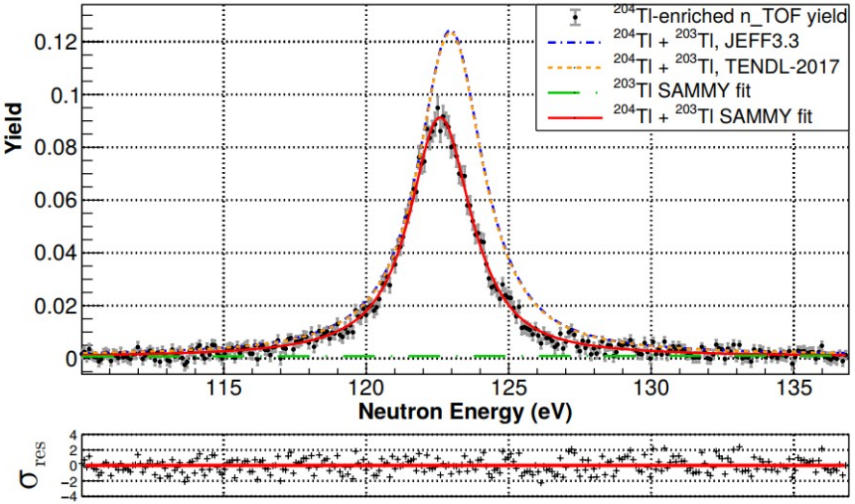
^{204}Tl(n,γ) experiment

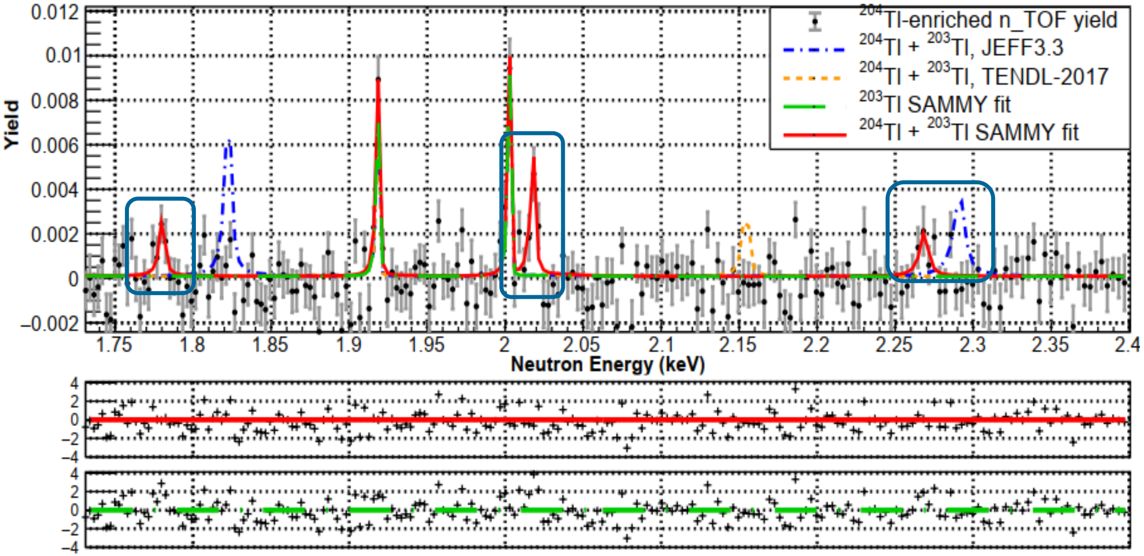
Pellet containing 225 mg of ^{203}Tl, 99.5% isotopic purity, produced at **PSI**

Irradiated at **ILL reactor** with thermal neutrons for 56 days:
9 mg of ^{204}Tl (τ =3.78 yr) produced

180 GBq of β activity
620 mSv/h contact
18 mSv/h a 10 cm







A Casanovas-Hoste *et al.* (The n_TOF Collaboration)
Physical Review Letters **133**, 052702 (2024)
DOI: 10.1103/PhysRevLett.133.052702

^{204}Tl(n,γ) experiment

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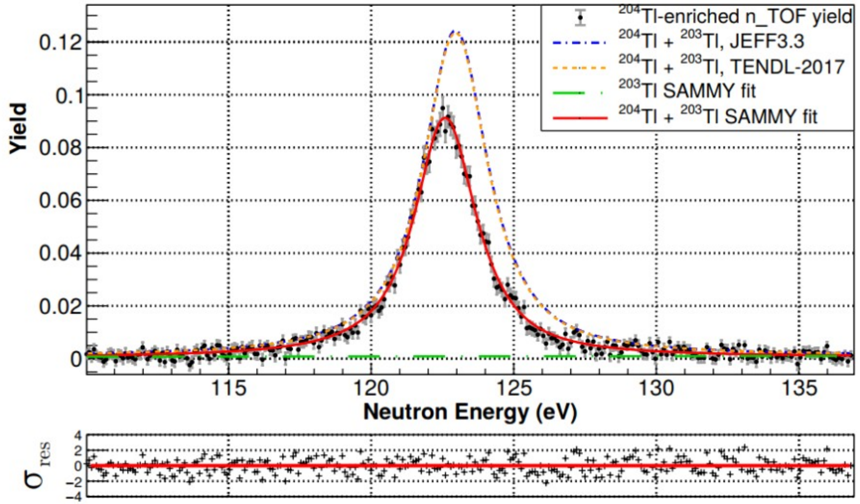
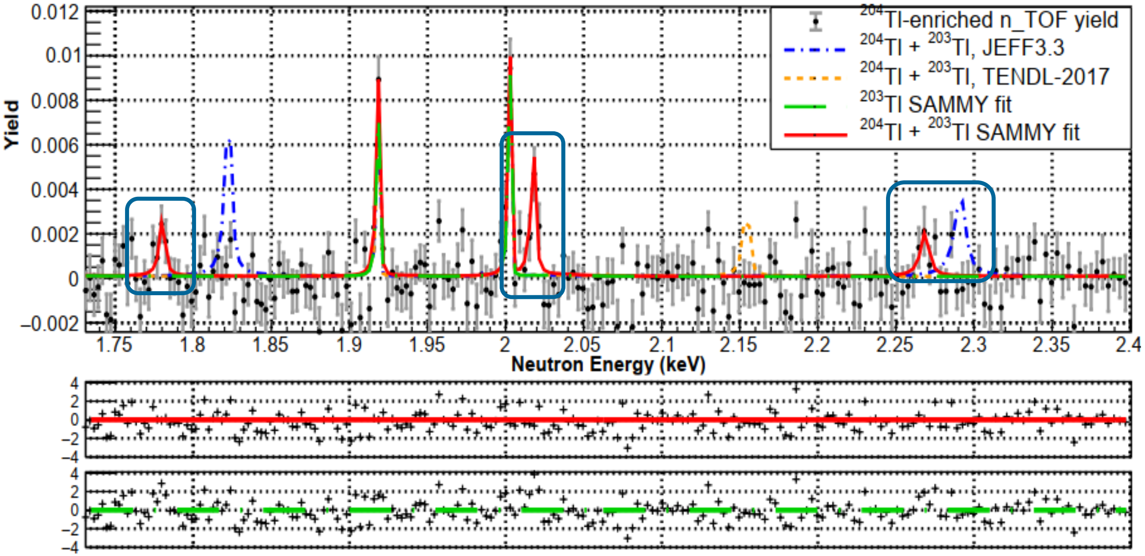
620 mSv/h contact
18 mSv/h a 10 cm



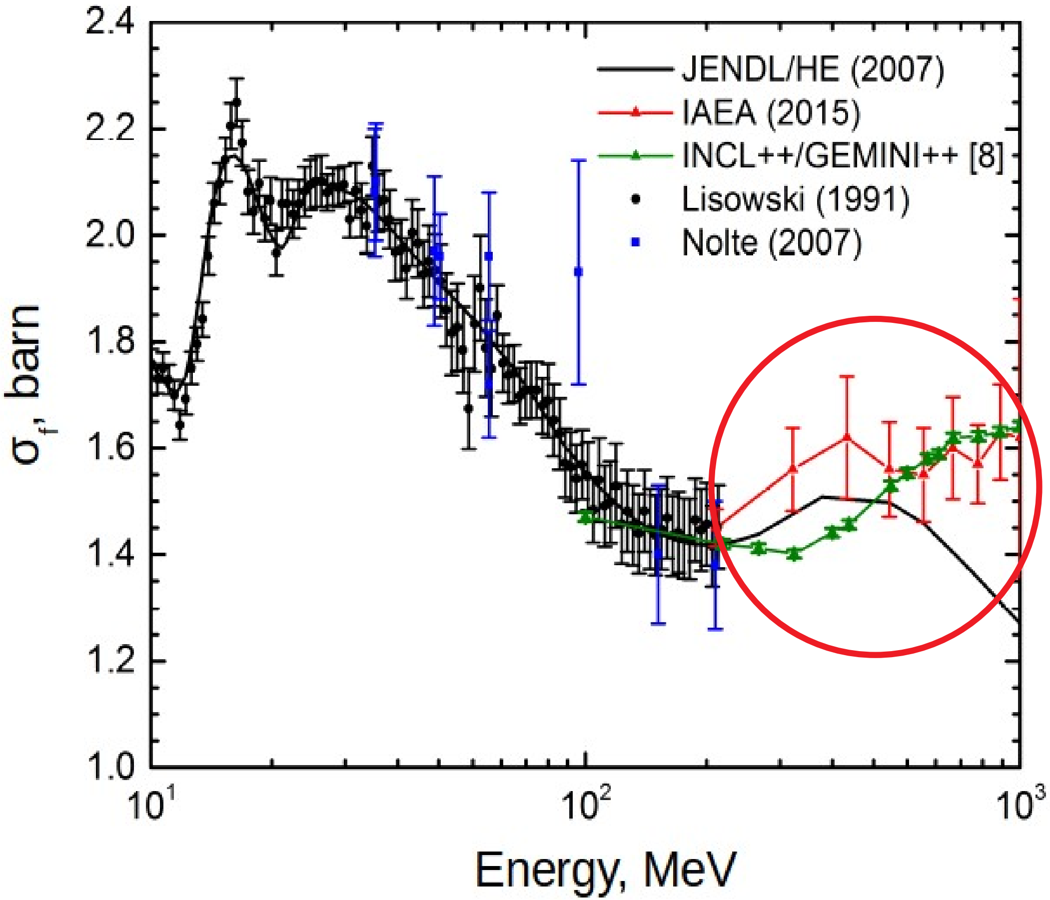
By using the **new ^{204}Tl MACS**, the **uncertainty from the ^{204}Tl(n,γ) cross section** on the *s*-process abundance of ^{204}Pb has been **reduced from ~30% down to +8%/-6%**, and the *s*-process calculations are in agreement with the latest solar system abundance of ^{204}Pb reported by K. Lodders in 2021.



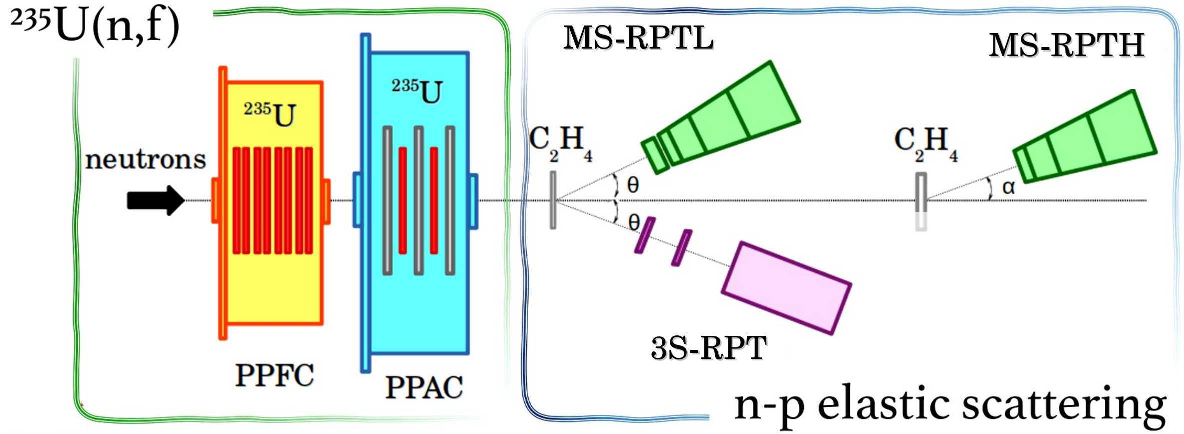
A Casanovas-Hoste *et al.* (The n_TOF Collaboration)
Physical Review Letters **133**, 052702 (2024)
DOI: 10.1103/PhysRevLett.133.052702

^{235}U(n,f) experiment

^{235}U(n,f) is one of the most significant cross-section standards at 0.025 eV and [0.15-200] MeV **BUT** there are **no experimental data above 200 MeV**



^{235}U(n,f) experiment



Parallel plate fission (ionization) chamber

4 double sided ^{235}U (99.93% ^{235}U) = 32,660

Parallel Plate Avalanche Counter

2 ^{235}U (92.7% ^{235}U) = 28 mg

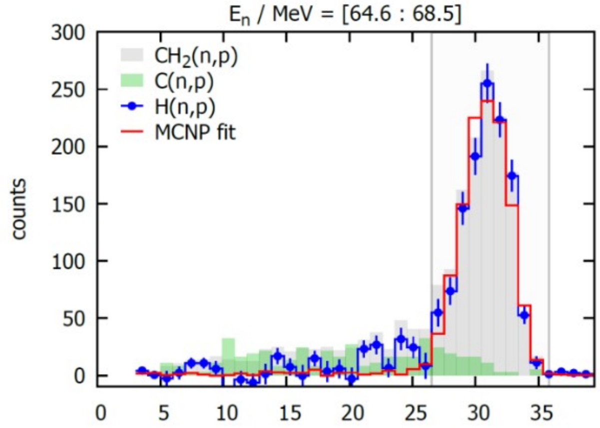
well characterized detector in the neutron energy: 0,025 eV - 200 MeV

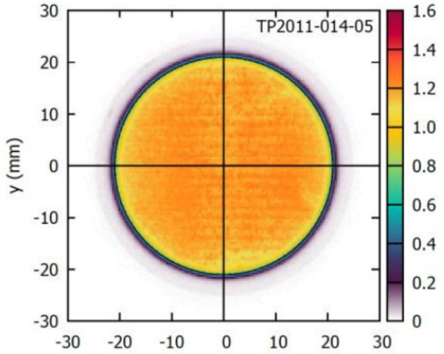
coincidence analysis - detection of the 2 FFs neutron energy: 0,025 eV - 1 GeV

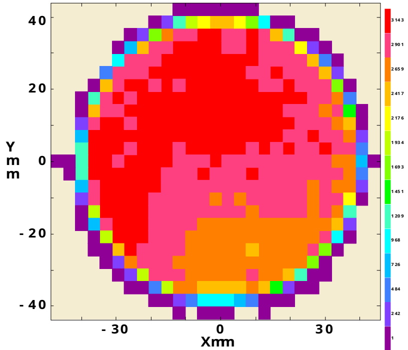
Recoil Proton Telescopes @ 25°and @ 20°

^{1}H(n,n)p events identification:

- selection of multiple coincidences
- analysis of the ΔE-E matrix

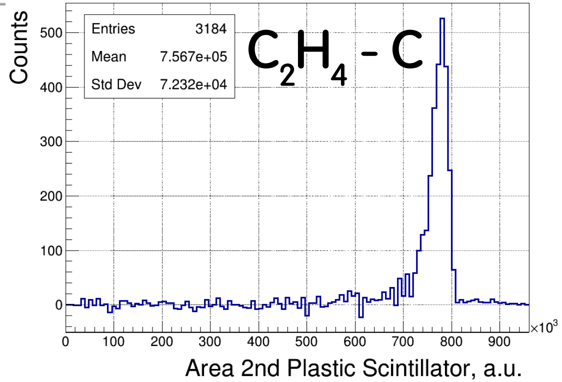






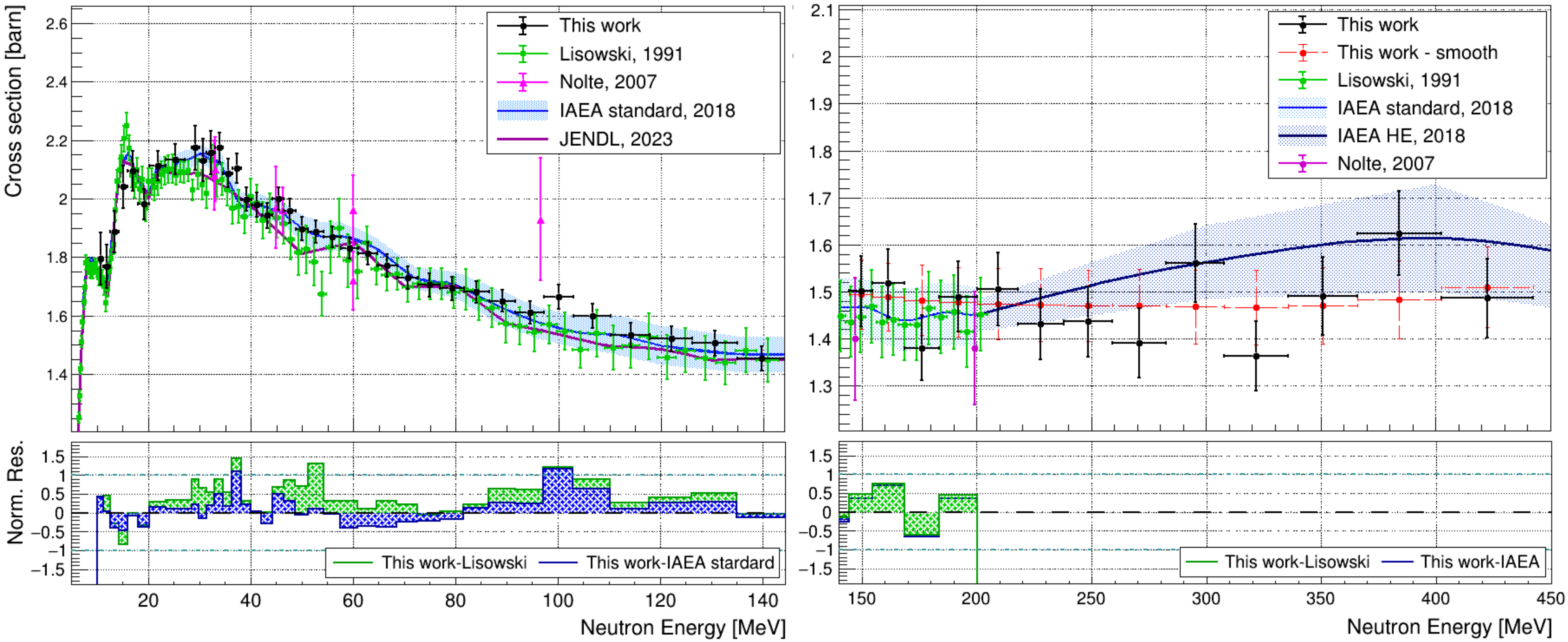
Elisa Pirovano et al,
JINST **18** P11011(2023)
DOI: 10.1088/1748-0221/18/11/P11011

Alice Manna et al,
JINST **18** P04024 (2023)
DOI: 10.1088/1748-0221/18/04/P04024



^{235}U(n,f) experiment

A Manna, E. Pirovano *et al.* (The n_TOF Collaboration)
Physics Letters B , 860 139213 (2025)
DOI: 10.1016/j.physletb.2024.139213



^{235}U **fission cross-section** relative to neutron-proton elastic scattering. This was the **first time** this measurement was conducted in the **10 to 440 MeV energy range**, which extended the upper limit of previous research by more than 200 MeV.

R. Mucciola, *Neutron capture and total cross-section measurements on Mo isotopes at n_TOF and GELINA*

R. Zarrella, A. Manna, *Re-TOF: A novel detector for the measurement of the fission cross section induced by high energy neutrons*

M. Spelta, *Measurements of neutron capture cross sections for nucleosynthesis at n_TOF: the cases of 64Ni(n, γ) and 30Si(n, γ)*

N. Pieretti, *Measurement of Cu neutron capture cross sections at the n_TOF facility*

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140 researchers, mostly from Europe (+ Japan and the USA)

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Thank you for your attention

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