Recent results of the CERN n_TOF facility

(& future prospects)

Jorge Lerendegui-Marco
on behalf of the n_TOF Collaboration

Outline

Neutron-induced cross sections
& the CERN n_TOF facility

Recent highlights of n_TOF

Future prospects

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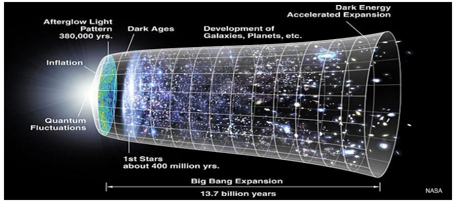
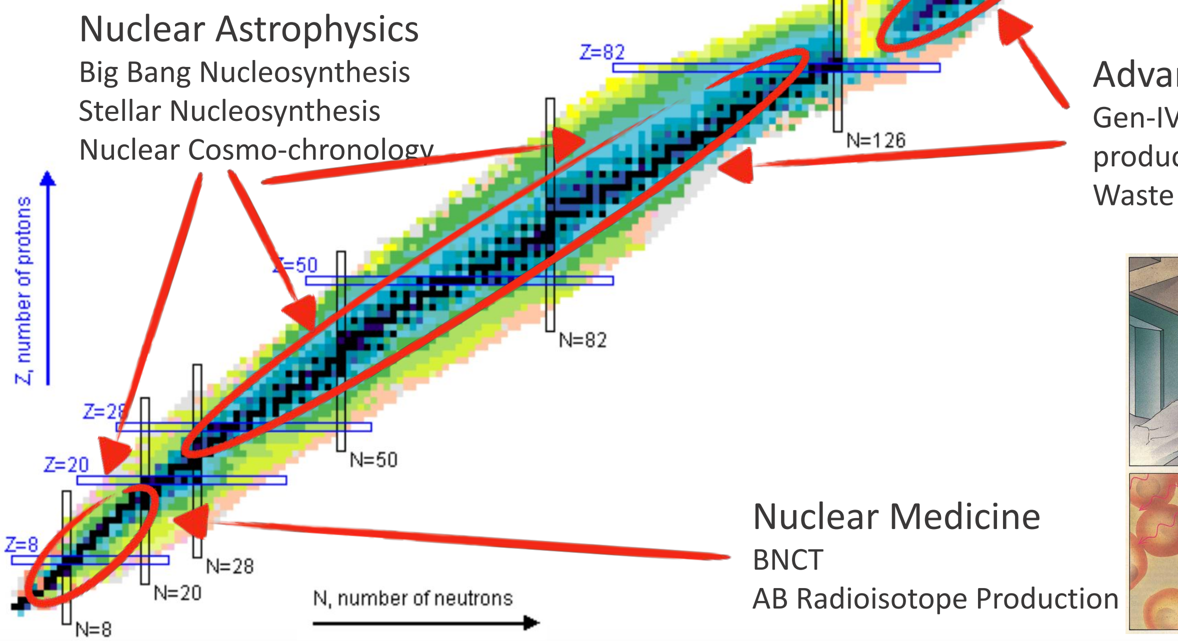
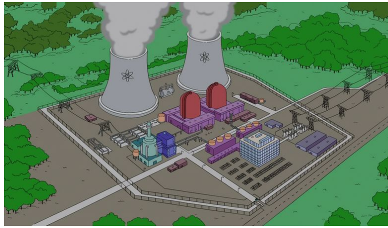
Neutron-induced cross sections: Why?



Nuclear Astrophysics

Big Bang Nucleosynthesis
Stellar Nucleosynthesis
Nuclear Cosmo-chronology



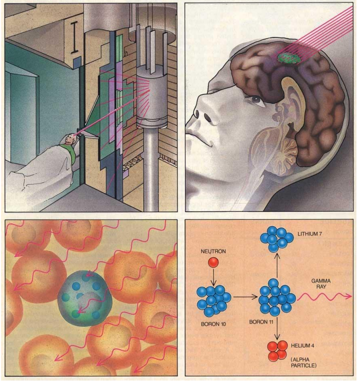


Advanced Nuclear Technologies

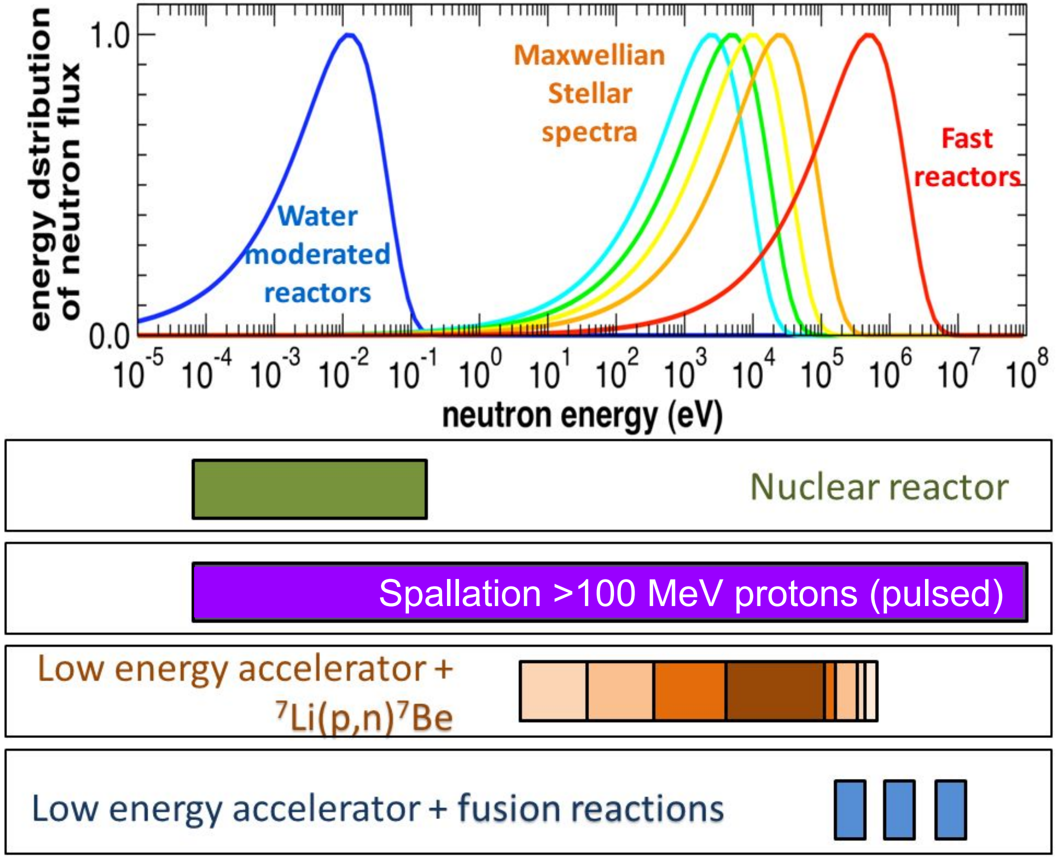
Gen-IV nuclear reactors (energy production)
Waste management

Nuclear Medicine

BNCT
AB Radioisotope Production



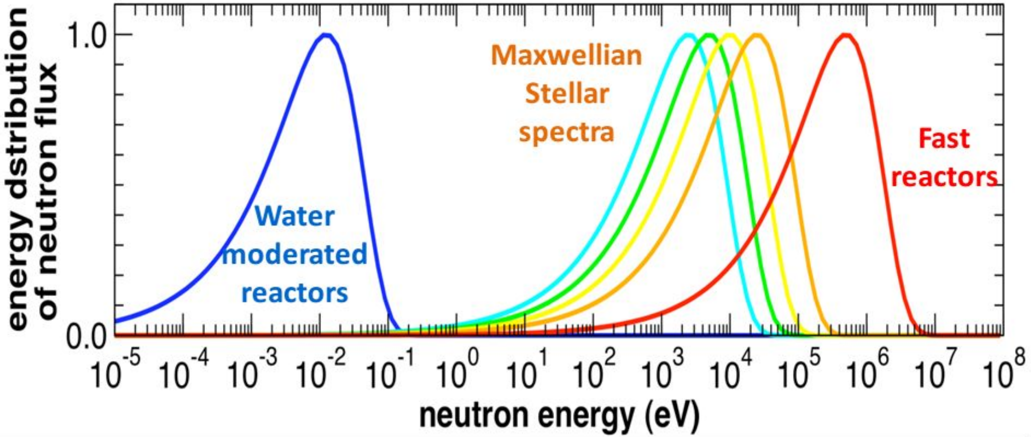
Neutron-induced cross sections: How?

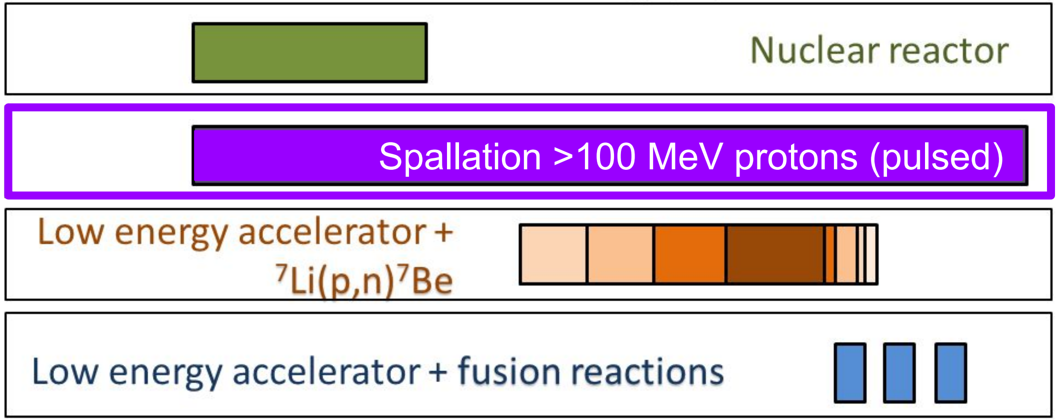


Neutron spectra

- Thermal neutrons
- White neutron beam
- Epithermal / stellar beams
- Monoenergetic Fast neutrons

Neutron-induced cross sections: How?





Pulsed white neutron beams
+
time-of-flight
=
Most comprehensive energy range

Neutron spectra

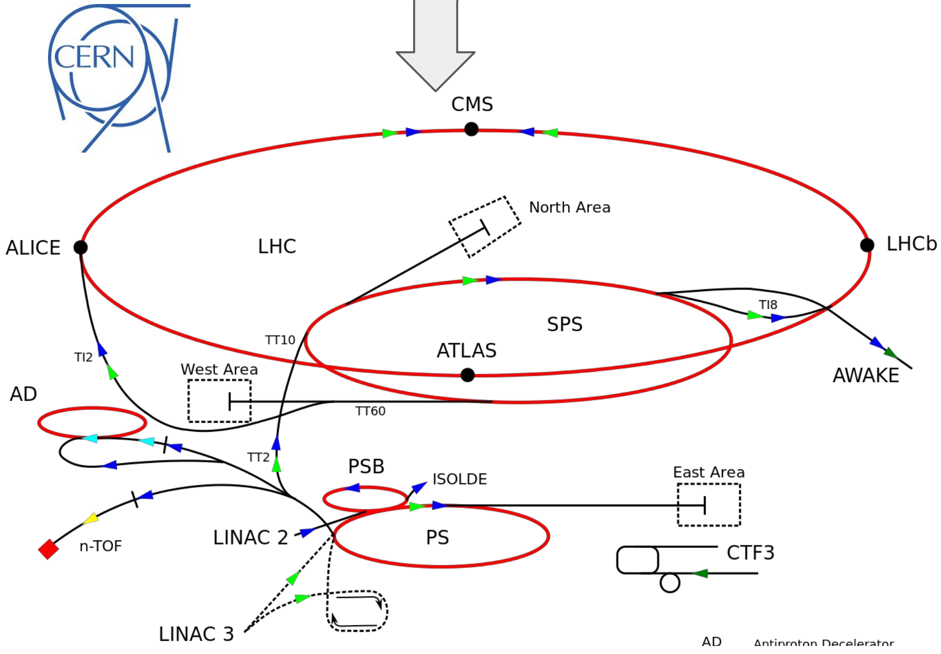
Thermal neutrons

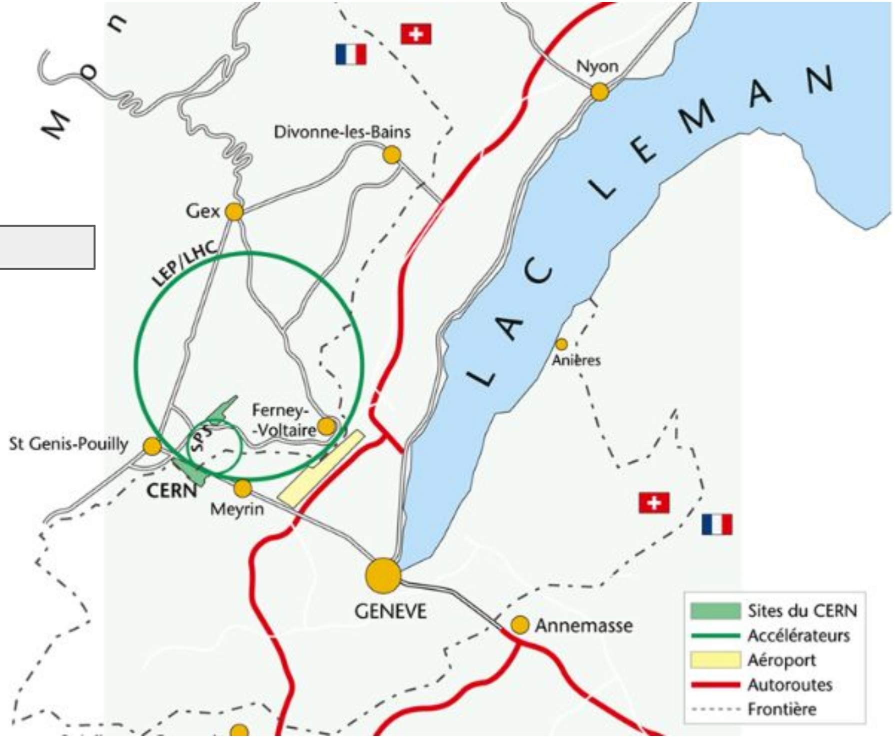
White neutron beam

Epithermal / stellar beams

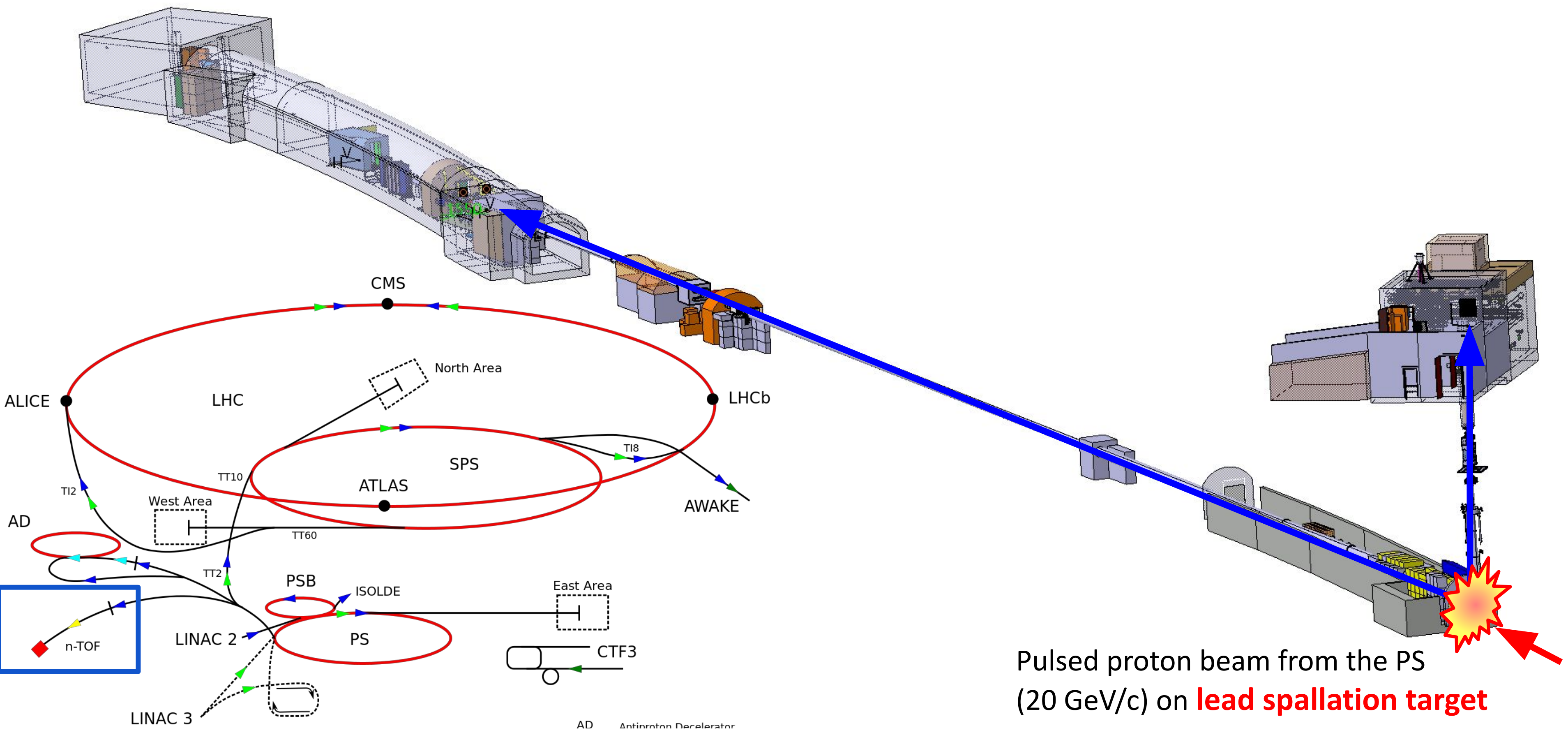
Monoenergetic Fast neutrons

The CERN n_TOF Facility



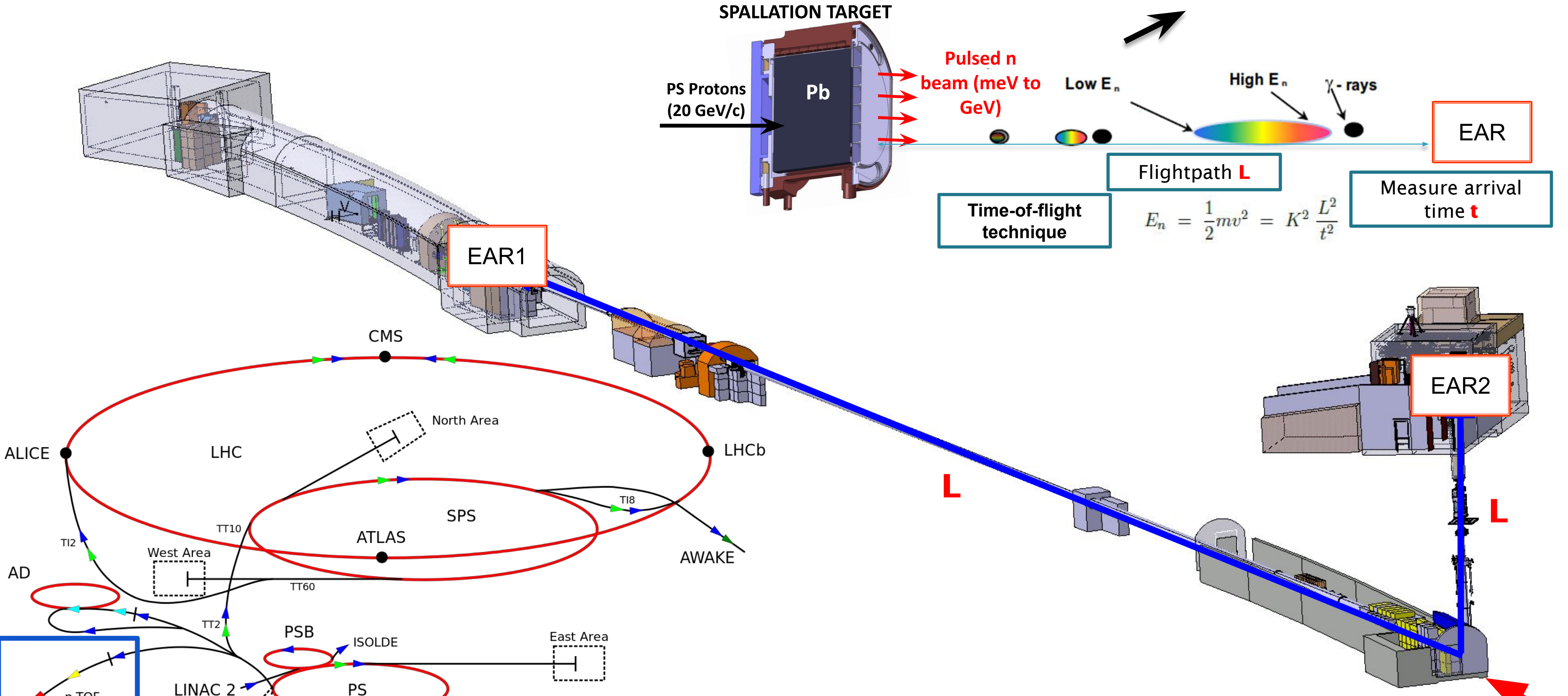


The CERN n_TOF Facility



Pulsed proton beam from the PS (20 GeV/c) on **lead spallation target**

The CERN n_TOF Facility



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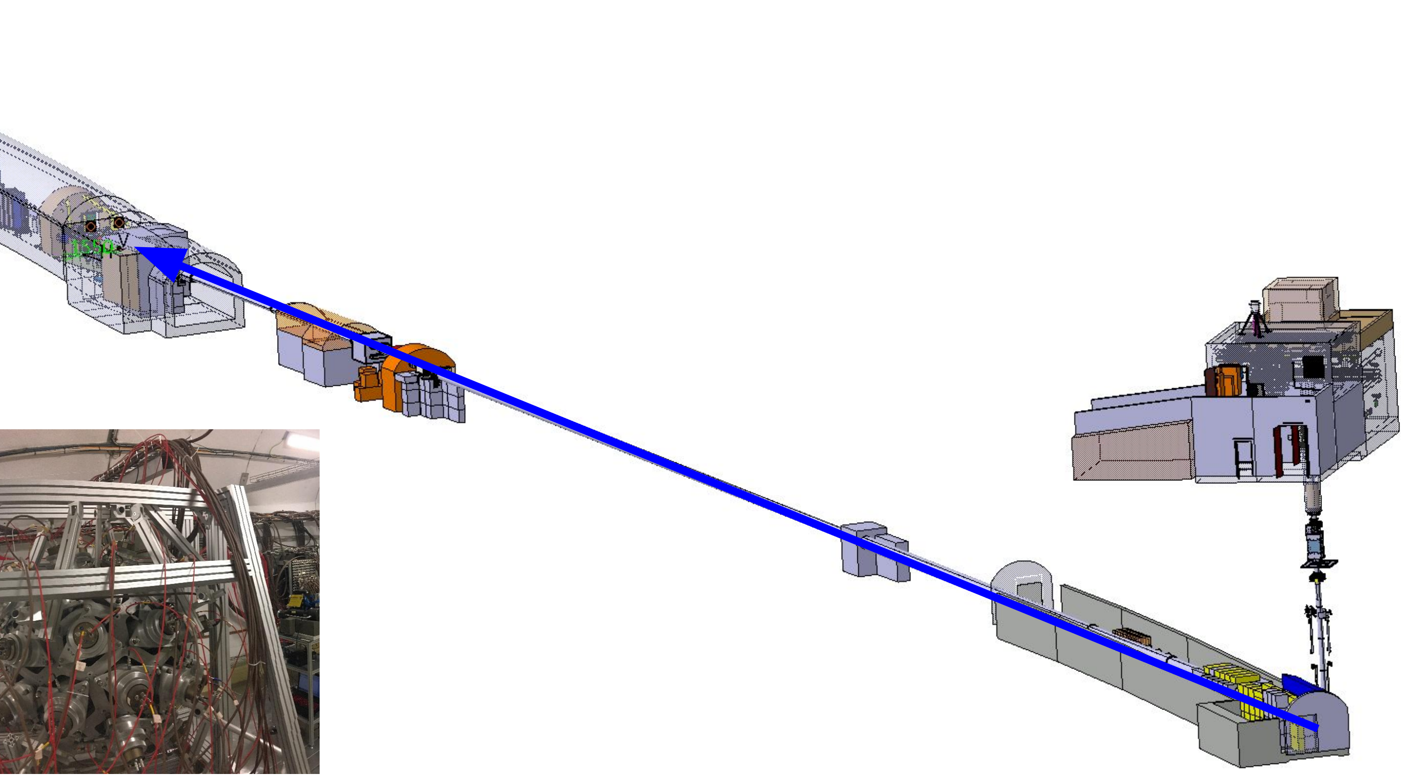
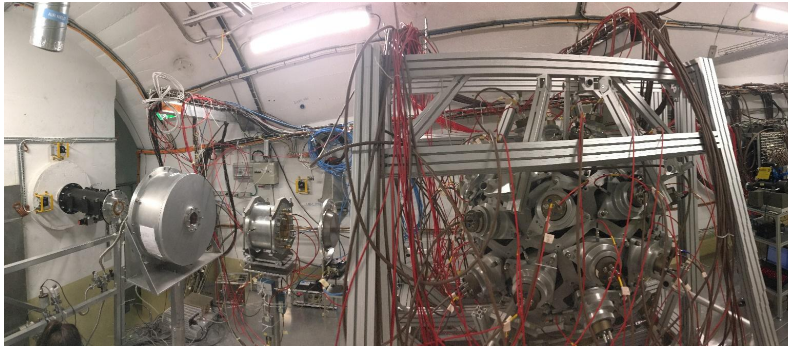


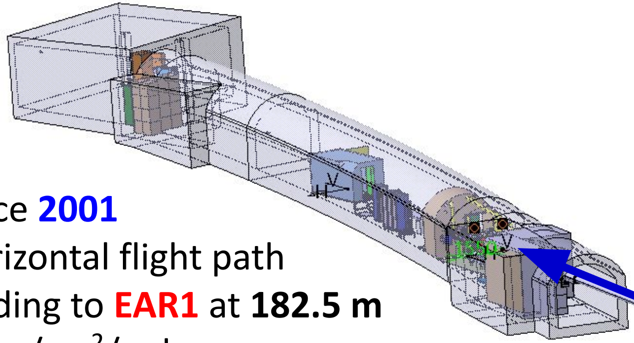
Since **2001**
Horizontal flight path
leading to **EAR1** at **182.5 m**
10^5 n/cm^2/pulse
$\Delta E/E \sim 10^{-4}$

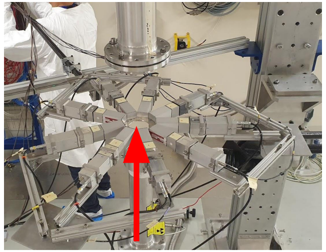


n_TOF uniqueness:
Very high E_n resolution

The CERN n_TOF Facility

n_TOF uniqueness:
Highest instantaneous flux





Since **2001**
Horizontal flight path
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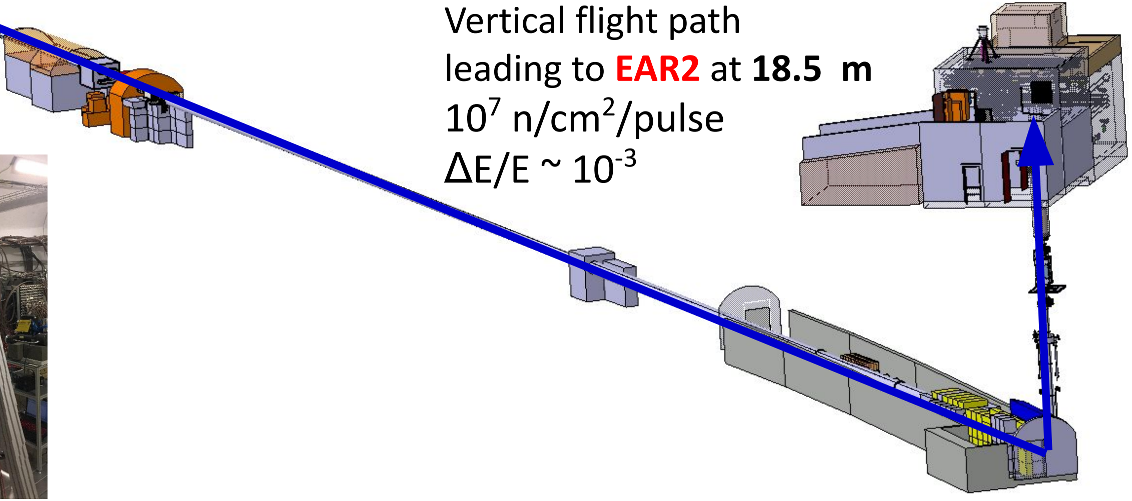
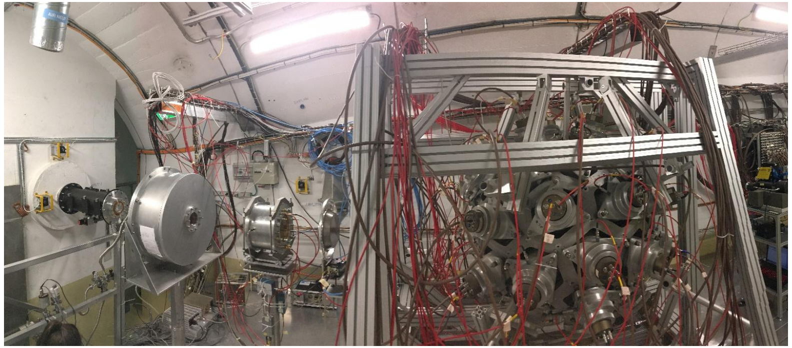
10^5 n/cm^2/pulse
$\Delta E/E \sim 10^{-4}$

Since **2014**
Vertical flight path
leading to **EAR2** at **18.5 m**
10^7 n/cm^2/pulse
$\Delta E/E \sim 10^{-3}$





n_TOF uniqueness:
Very high E_n resolution

The CERN n_TOF Facility

n_TOF uniqueness:
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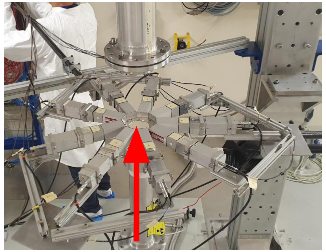

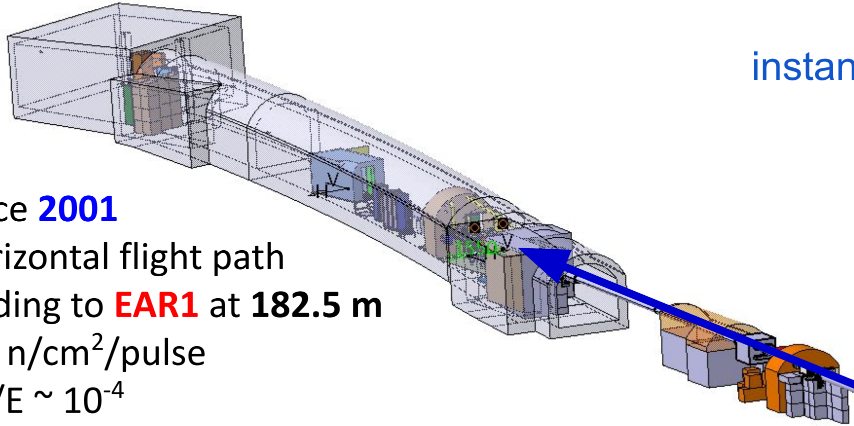

Since **2001**
Horizontal flight path
leading to **EAR1** at **182.5 m**
10^5 n/cm^2/pulse
$\Delta E/E \sim 10^{-4}$

Since **2014**
Vertical flight path
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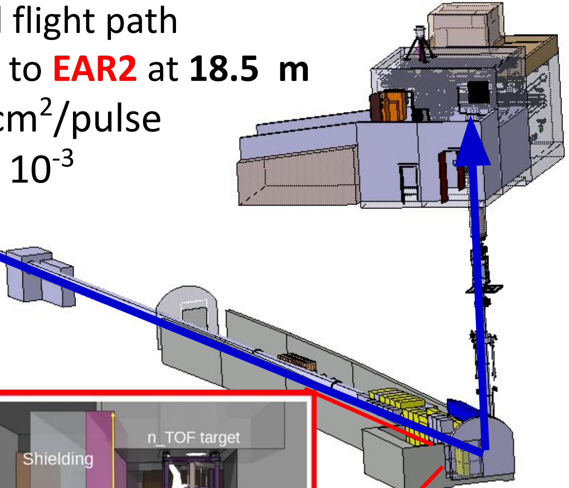
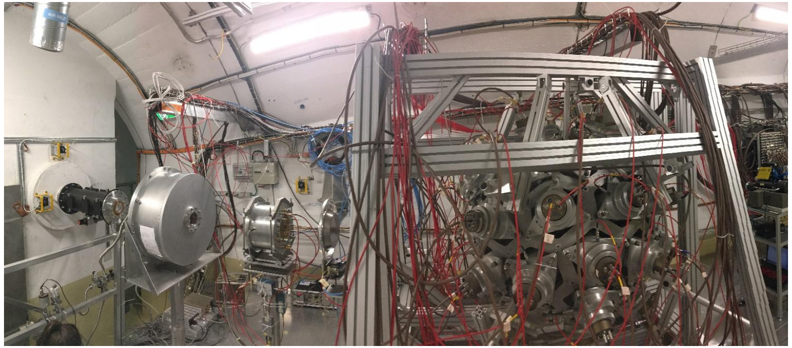
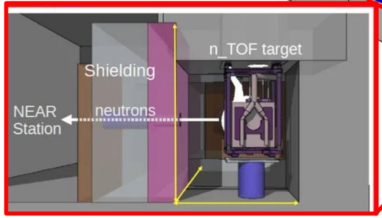




Since **2022**
Activation facility **NEAR**
at **3 m**
10^9 n/cm^2/pulse



n_TOF uniqueness:
Energy tuning & complementary TOF-Activation

n_TOF uniqueness:
Very high E_n resolution

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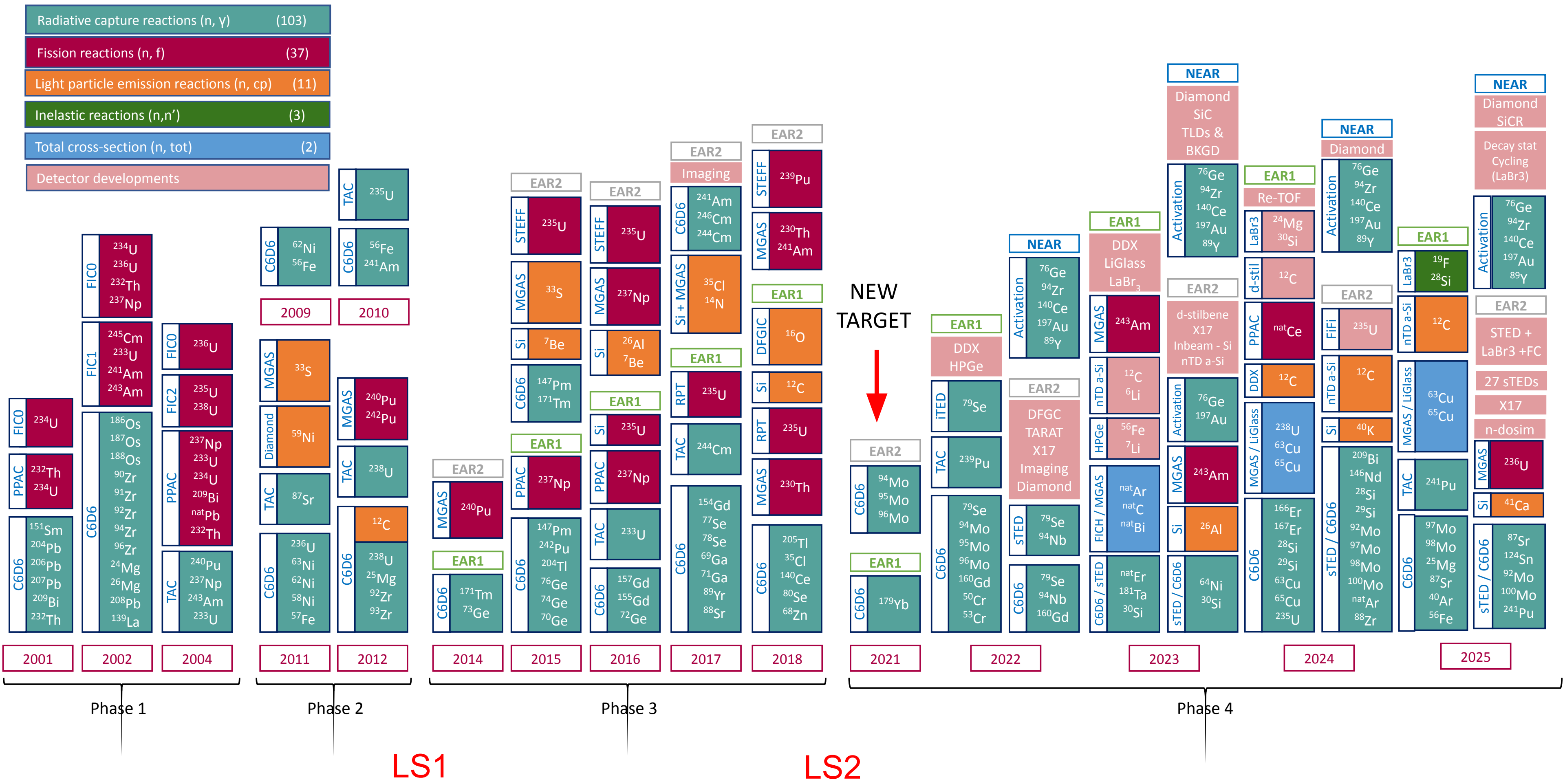
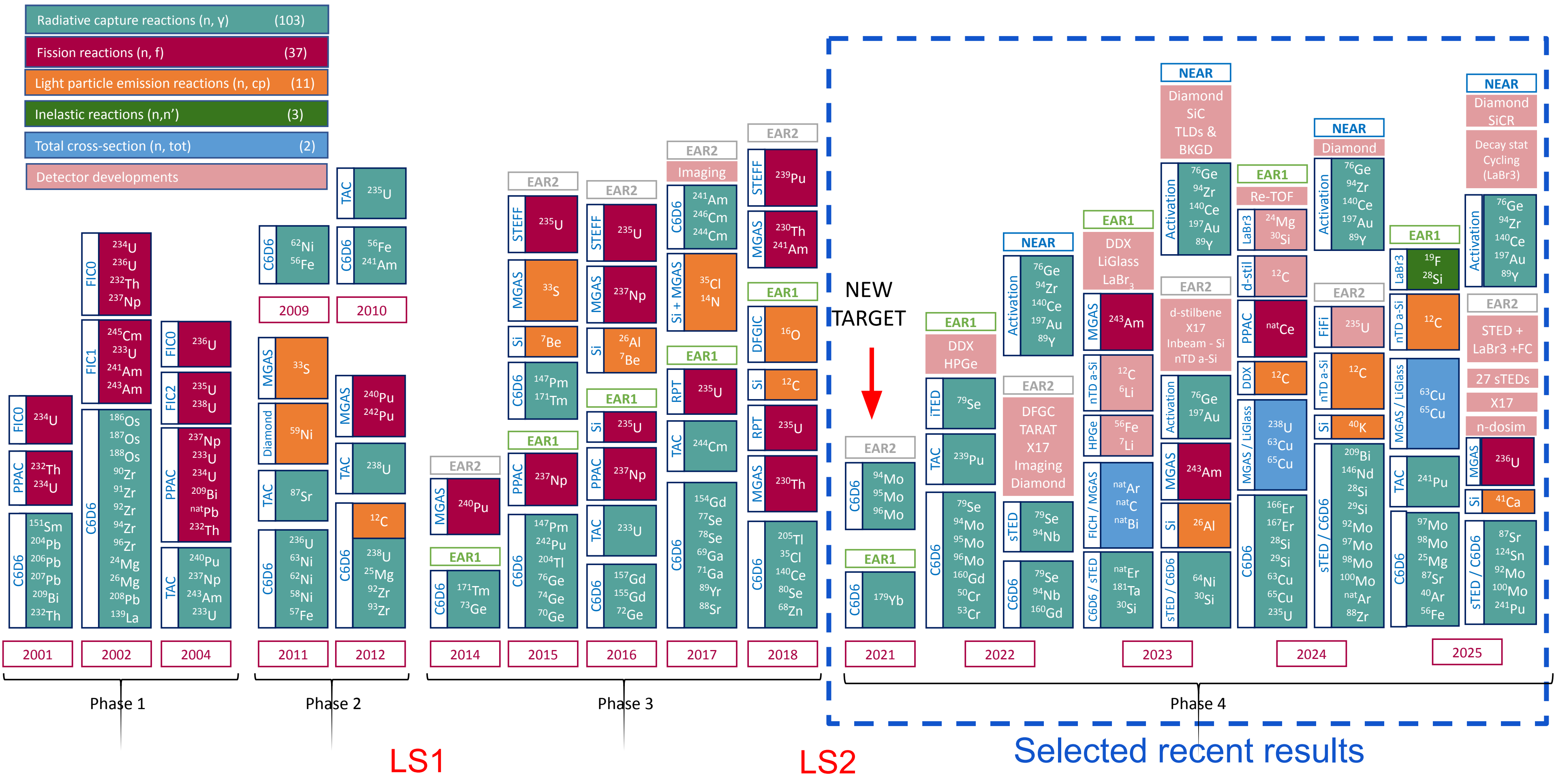
n_TOF physics programme



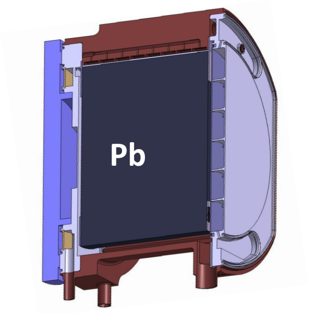
n_TOF physics programme



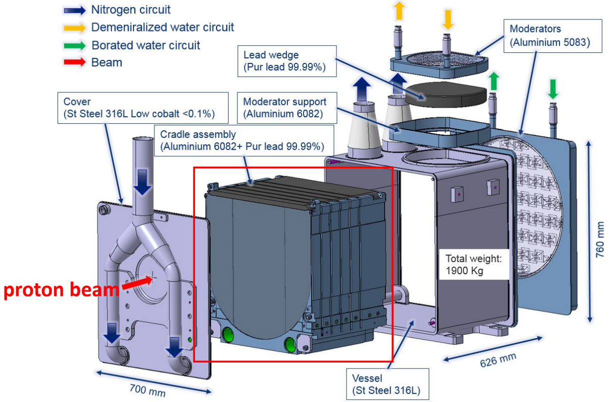
Facility upgrade

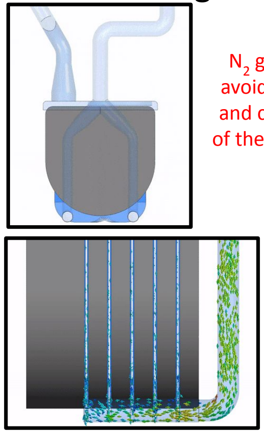
Motivation: Improving target safety & performance + improving physics performance (flux & resolution)

TARGET #2: Water cooled & moderated Pb block

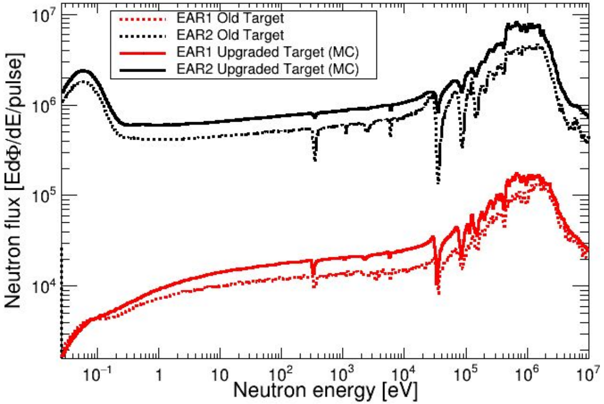


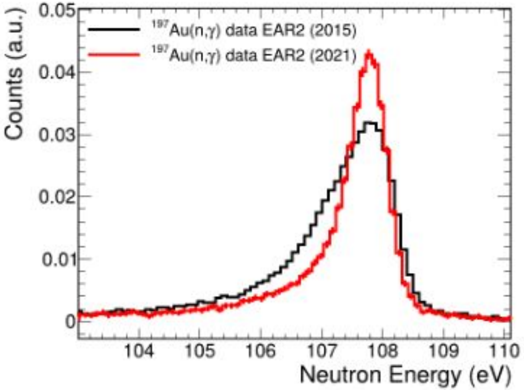
TARGET #3: N-cooled and water moderate Pb target





N$_2$ gas cooling to avoid Pb corrosion and contamination of the cooling circuit





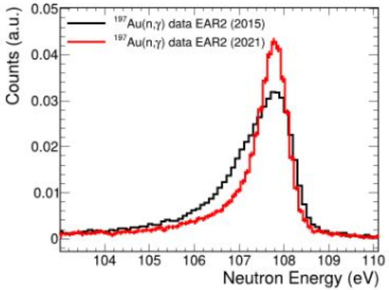
Upgrade:
- +30-50% higher flux
- Clear improvement in the neutron energy resolution of n_TOF-EAR2

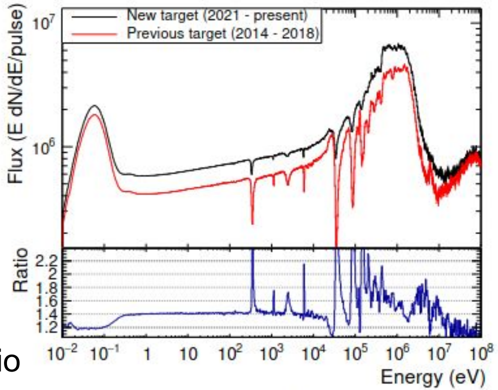
R Esposito et al. *Phys. Rev. Accel. Beams* **24**, 093001 (2021)

J. Lerendegui-Marco et al., EPJ WOC **284**, 01028 (2023)

(n,g) on radioactive isotopes for astrophysics

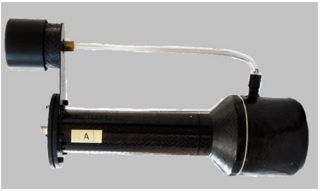
Motivation: Measuring (n,g) on radioactive isotopes for the s-process
Challenges: Signal-to-background: low mass + sample activity background

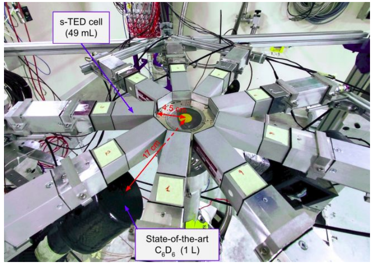




EAR2 & target #3:
Improved signal-to-background ratio for radioactive samples

J.A. Pavón-Rodríguez et al., EPJ-A (accepted) (2025)





1L → 50 mL

V. Alcayne , Rad. Chem. Phys. **217**, 111525 (2025)

New segmented C6D6:
segmentation & optimum signal-to-background

Recent upgrades:
1) **Upgraded facility:** higher flux & better resolution in EAR2
2) **Optimized detectors**: deal w/ high C. rates & higher SBR

(n,g) on radioactive isotopes for astrophysics

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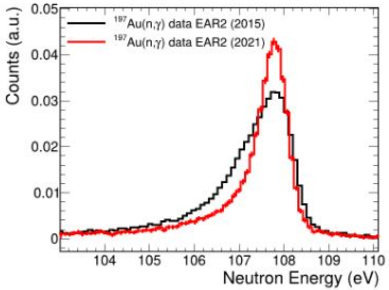
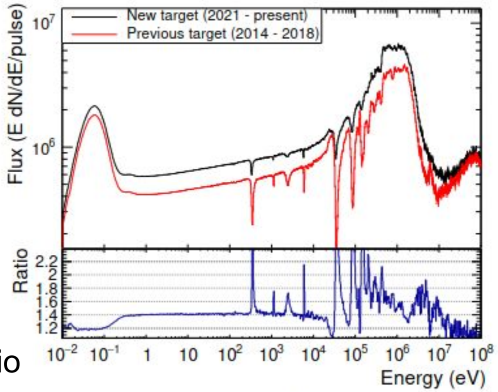
Challenges: Signal-to-background: low mass + sample activity background

+ astro-highlights by P.M. Milazzo





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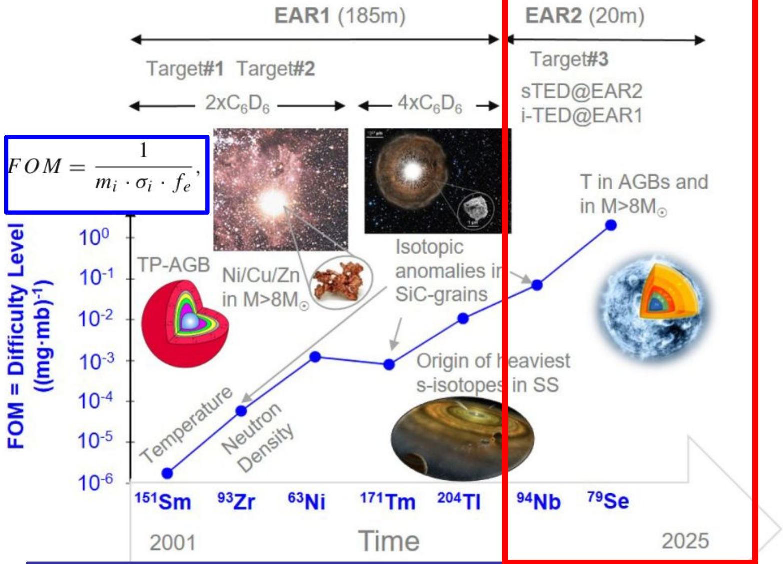
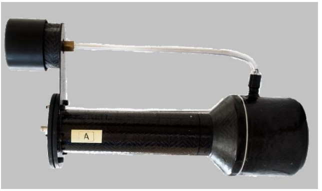
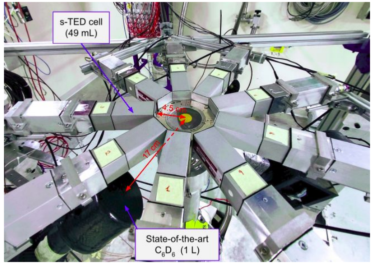


C. Domingo-Pardo et al., Eur. Phys. J. A 61, 105 (2025).





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New segmented C6D6: segmentation & optimum signal-to-background

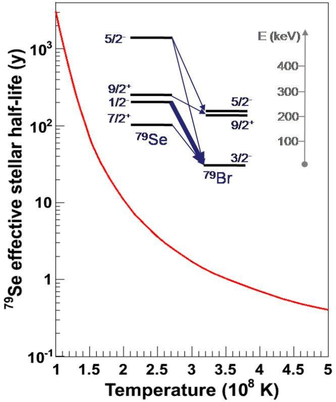
V. Alcayne , Rad. Chem. Phys. **217**, 111525 (2025)

Recent upgrades:
1) **Upgraded facility:** higher flux & better resolution in EAR2
2) **Optimized detectors**: deal w/ high C. rates & higher SBR

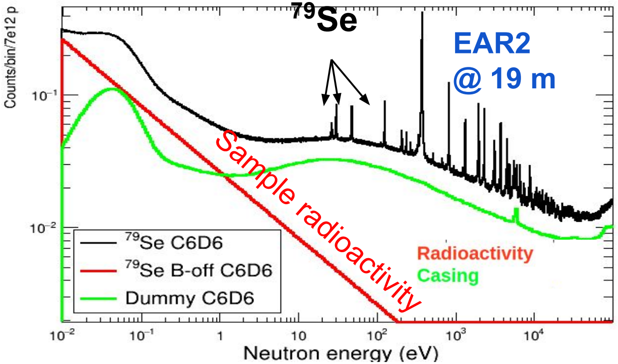
→ Unsurpassed sensitivity: First ever (n,g) on **^{79}Se, ^{94}Nb**

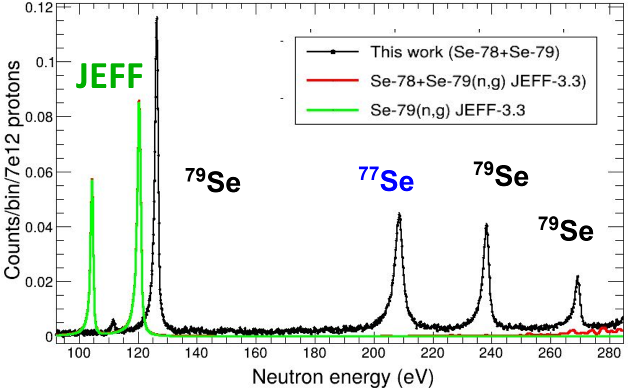
(n,g) on radioactive isotopes for astrophysics

^{79}Se(n,g): Thermal condition of weak s-process



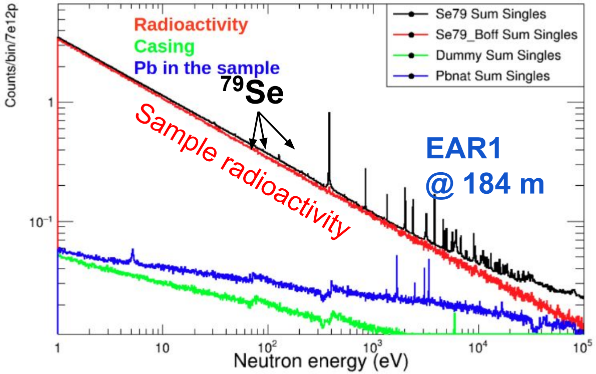
n_TOF EAR2: High n-flux overcomes activity background





PRELIMINARY

Sample: Produced at ILL via 78Se(n,g)



m = **2.7 mg**
(+3g of PbSe
+ **^{60}Co activity (~10 MBq)**)

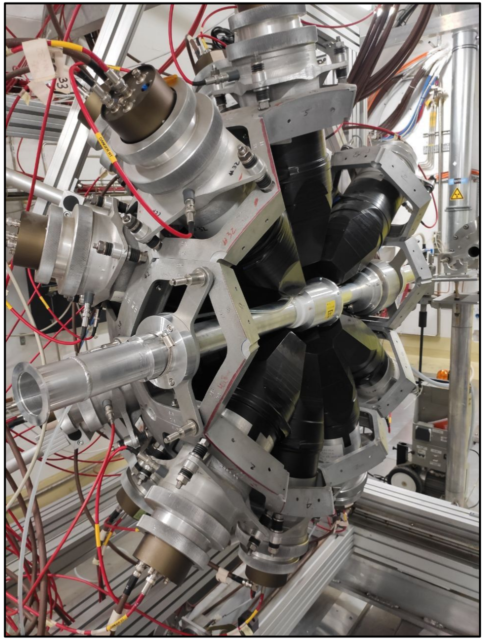
Recent highlights: **^{79}Se(n,g)**

- First ever measurement
- Analyze ~15 resonances
- **First experimental constrain to the stellar MACS**

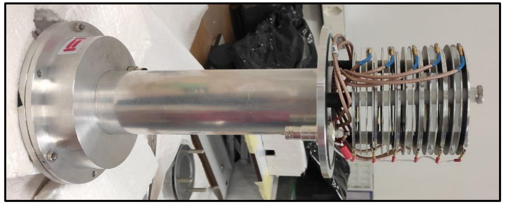
Lerendegui-Marco, J. et al., EPJ Web Conf. 279, 13001 (2023).
Lerendegui-Marco, J. et al., EPJ Web Conf. (ND2025) (2026)

(n,g)/(n,f) of fissile isotopes for nuclear technology

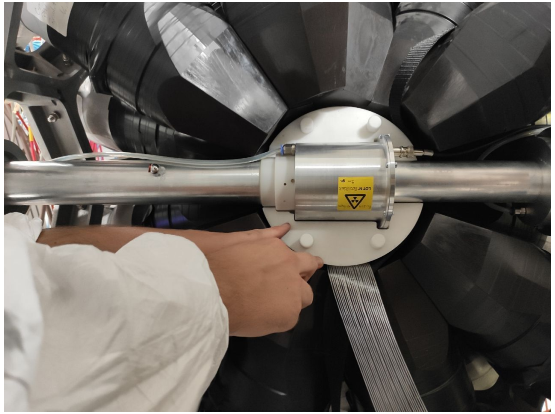
Motivation: Measure with high accuracy (n,g) and (n,f) on fissile isotopes (233U, 235U, **239Pu,** 241Pu)
Challenge: Discrimination between (n,g) from (n,f) events not possible with g-ray detectors



Fission chamber (FC): 90% eff
Detect Fission Fragments



Total Absorption Calorimeter (TAC):
40 BaF2 crystals: Very high eff.
Detect (n,g/f) g-rays



C. Guerrero et al., *EPJ-A **48**, 29, (2012)*

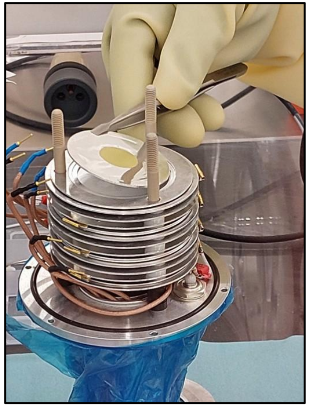
J. Balibrea et al., Phys. Rev. C **102**, 044615 (2020)

Solution: Fission tagging = fission chamber (FC) in time coincidence with the total absorption calorimeter (TAC)

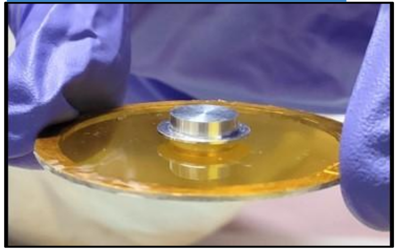
(n,g)/(n,f) of fissile isotopes for nuclear technology

1. FC config.

- 10 thin Pu samples (< 1 mg).
- Use FC + TAC simultaneously.
- Measure fission and capture (up to 1 keV).

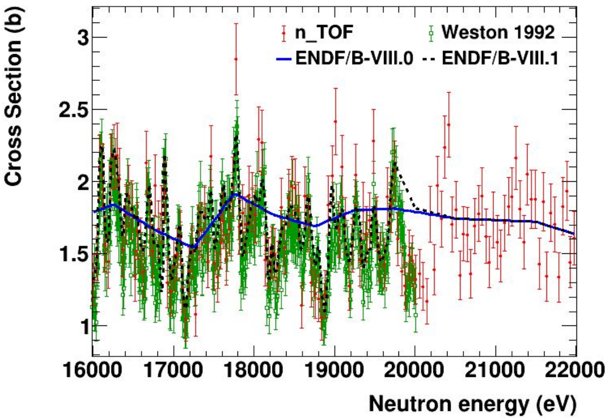


2. TS config.

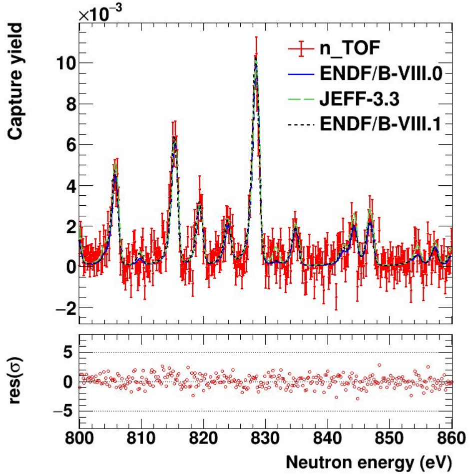


- 1 thick sample (~100 mg).
- Use only TAC.
- Measure capture above 1 keV.

- Fission data:



- Capture data:



Recent highlight: 239Pu(n,g) / (n,f)

- Extend high-resolution data of (n,f) beyond 20 keV
- (n,g) data up to few keV, due to the combination of FC and TC configs

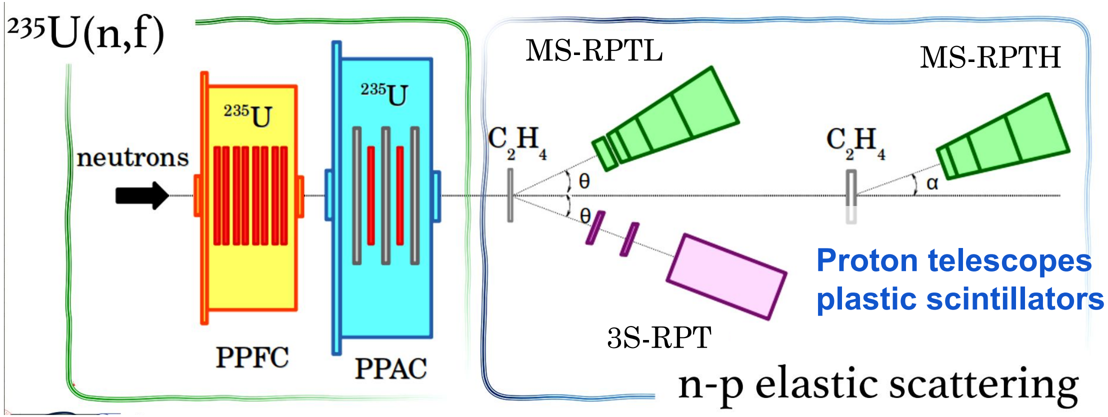
Just performed in 2025: 241Pu(n,g)/(n,f)

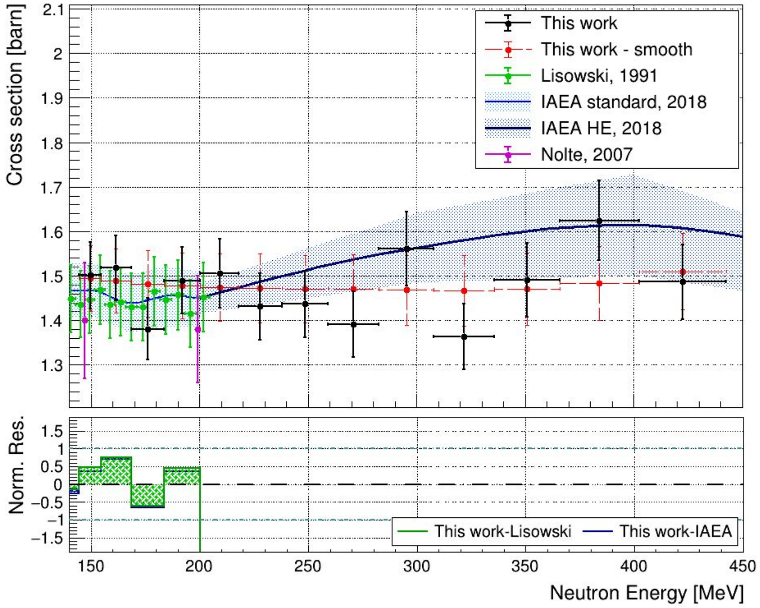
A. Sánchez et al, EPJ WOC, **294**, 01003 (2024)

E. Duppont, CERN-INTC-2023-066 (2023)

Extending energy (n,f) standard for nuclear technology

Motivation: Extending the range of fission cross sections to higher neutron energies





Parallel plate fission (ionization) chamber

4 x d-sided ^{235}U (99.93% ^{235}U) ~ 300ug/cm^2

Parallel Plate Avalanche Counter

2 x ^{235}U (92.7% ^{235}U) = 28 mg ~ 270ug/cm^2

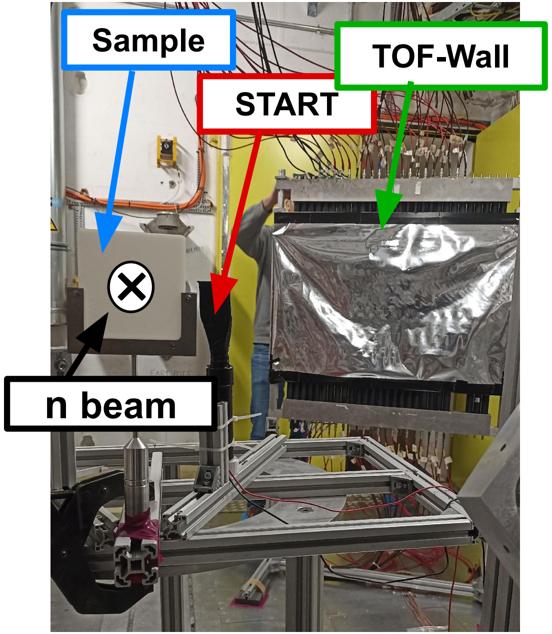
Solution: Use the neutron-proton elastic scattering cross section as a reference

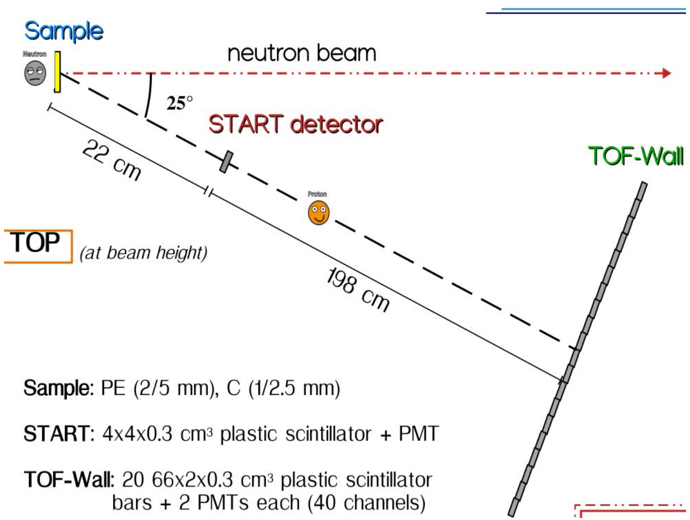
Recent highlight: First ever 235U(n,f) cross section from 200 to 440 MeV

A. Manna, E. Pirovano, PLB *860 139213 (2025)*

Extending energy (n,f) standard for nuclear technology

Challenge: Main limitation to extend to higher energies (n,p'), which becomes relevant at En>450MeV





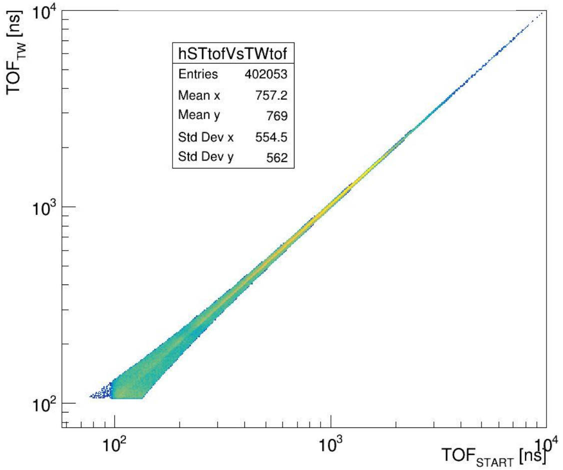
Sample: PE (2/5 mm), C (1/2.5 mm)

START: 4x4x0.3 cm³ plastic scintillator + PMT

TOF-Wall: 20 66x2x0.3 cm³ plastic scintillator bars + 2 PMTs each (40 channels)

Kinematic elastic channel:

$$E_p = E_n \cos^2\vartheta.$$

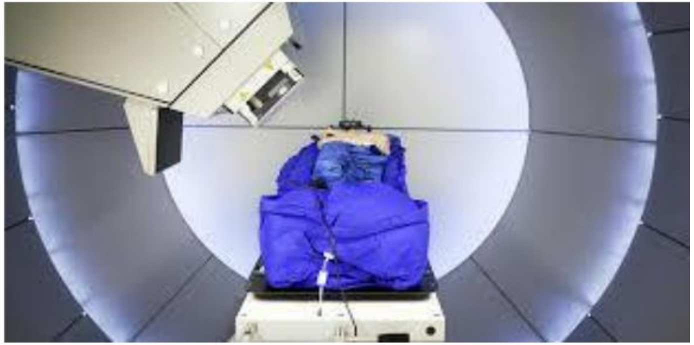


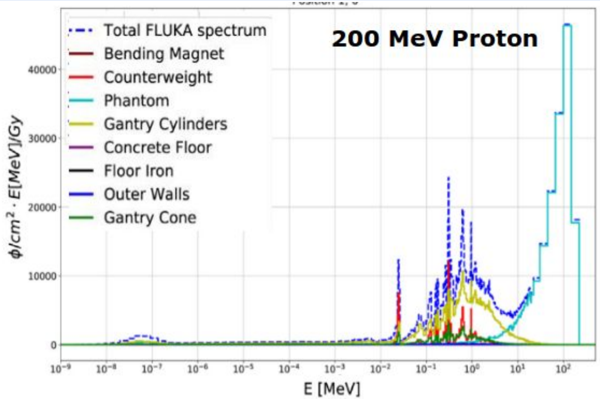
Latest upgrade: RE-TOF detector discriminating between outgoing protons from elastic & inelastic channel

A. Manna, EPJ WOC ND2025 *(2026)*

Double differential (n,cp) cross section for n-dosimetry

Motivation: (n,cp) DDX at neutron energies up to 200 MeV for secondary neutron dosimetry

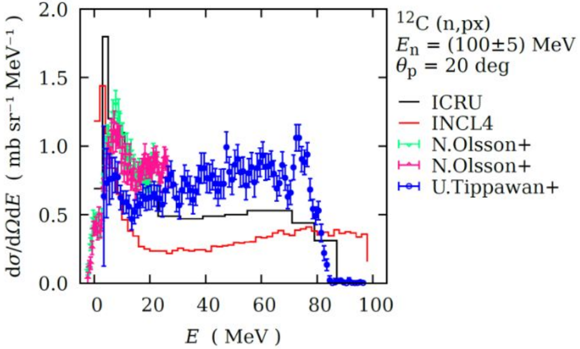




https://doi.org/10.1016/j.zemedi.2021.01.001

Present Status:

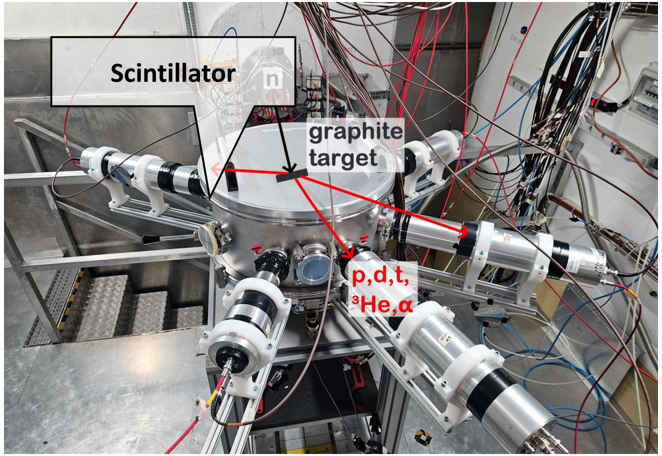
- Few datasets,
- E_n<100 MeV
- big discrepancies vs evaluations (INC models)

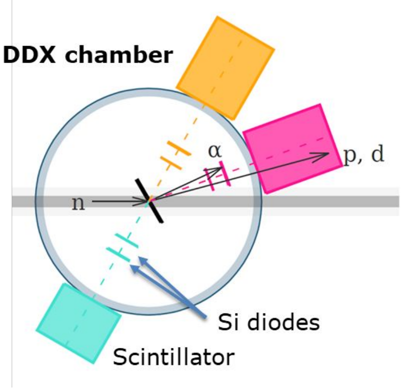


Solution: (n,cp) in continuous energy range above 100 MeV at n_TOF (EAR1)

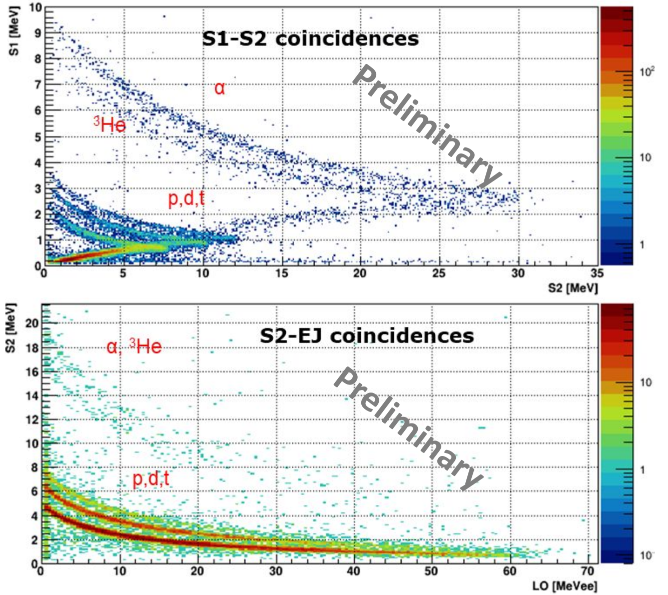
Double differential (n,cp) cross section for n-dosimetry

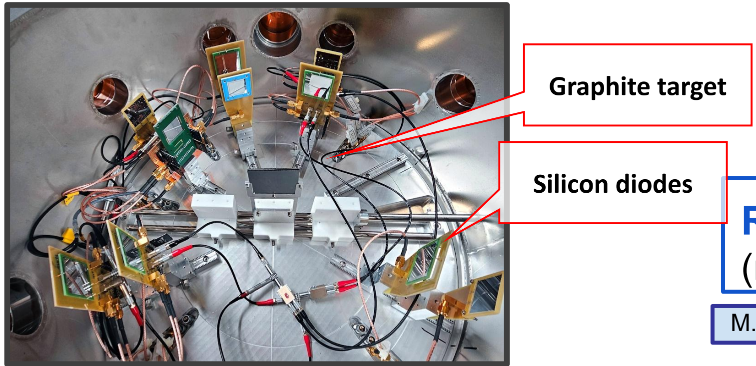
Motivation: (n,cp) DDX at neutron energies up to 200 MeV for secondary neutron dosimetry
Challenges via TOF: Operation & accurate particle discrimination at short time of flights (g-flash)





Particle ID: Δ*E*-*E* telescope + plastic scint: TOF technique





Recent highlight: proof-of-concept of double differential (n,p/d/t/³He/a) cross sections up to neutron energies of 250 MeV

M. Dietz, EPJ WOC **288**, 01003 (2023)
A. Di Chicco, EPJ WOC (ND2025) (2026)

Outline

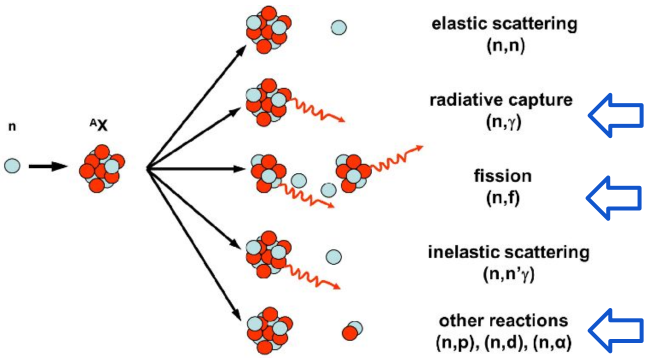
Neutron-induced cross sections
& the CERN n_TOF facility

Recent highlights of n_TOF

Future prospects

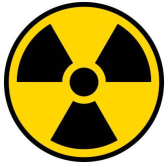
The future

Beyond fission, capture & cp reactions



FUTURE of n_TOF

Small masses, radioactive isotopes



More sensitive & accurate measurements

The future

FUTURE of n_TOF

Beyond fission, capture & cp reactions

Inelastic reactions

Also new: (n,tot) XS via transmission. See talk by P.M. Milazzo

Small masses, radioactive isotopes

New synergies: NEAR- ISOLDE & the future n_ACT

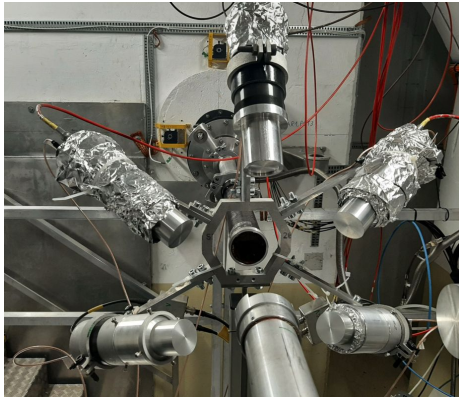
More sensitive & accurate measurements

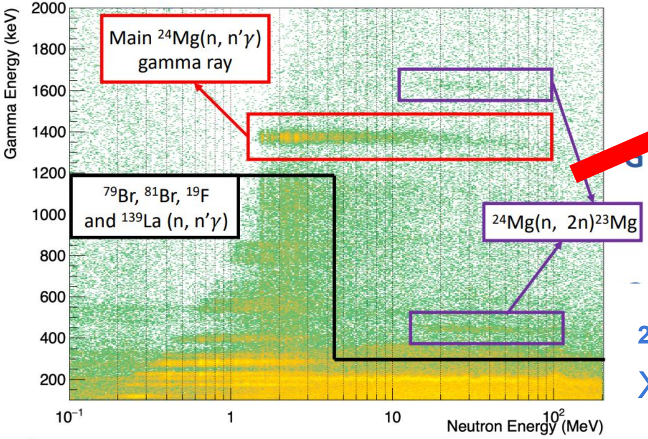
New generation of detectors

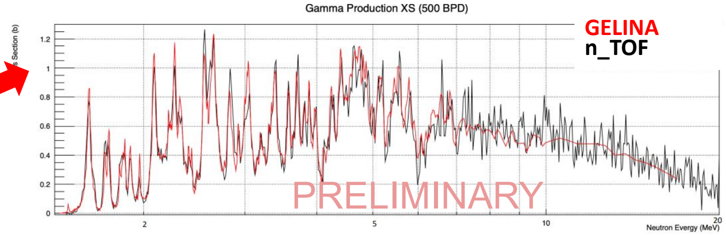
New reaction channels: (n,n’)

Motivation: Inelastic (n,n´ɣ) cross sections of light elements are relevant for the design of Gen IV reactors, fusion reactors, medicine (BNCT) or space exploration.
Challenges: High neutron flux at 10-50 MeV & high-resol detectors that can operate short after g-flash

2024: 5 x mixed LaBr3 @ 125°







^{24}Mg(n,n’g): 1346 keV gamma production XS matches GELINA data

Solution:

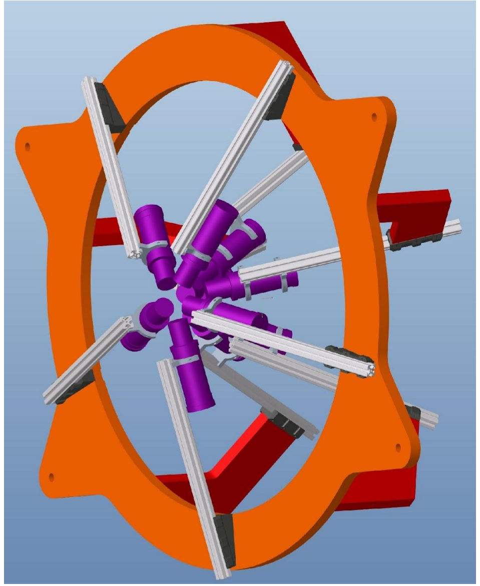
- n_TOF-EAR1: high flux in the tens of MeV + good separation between g-flash and fast neutrons
- LaBr3(Ce): good compromise between energy resolution, fast response & high c.rate capability
- Validation of (n,n’) at n_TOF: 24Mg(n,n’)

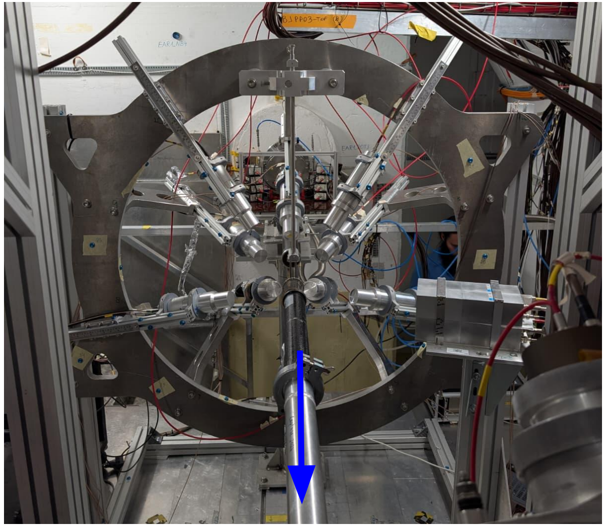
C. Petrone, CERN-INTC-2023-062 (2023)
M. Birch et al., *EPJ-WOC ND2025 (2026)*

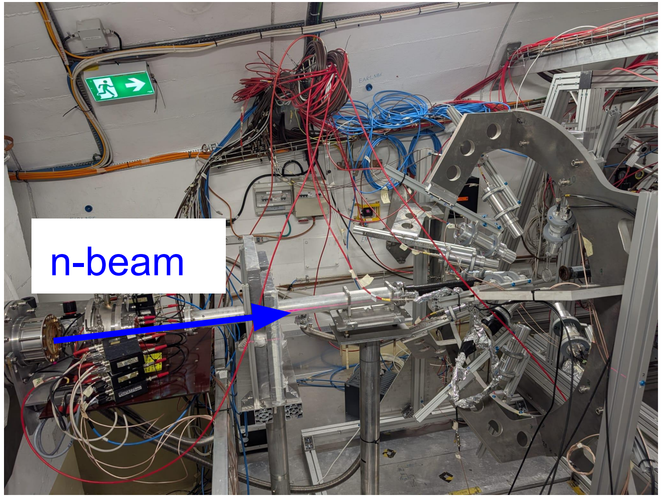
New reaction channels: (n,n’)

2025: 8+2 identical LaBr3
@ 150 and 110°

Backwards: suppress scattered g-flash
Angles: direct angle-integrated XS







Just done in 2025: 19F, 28Si(n,n')

G. Lorusso et al., *CERN-INTC-2024-074 (2024)*

C. Petrone, M. Bacak et al., CERN-INTC-2024-05 (2024)

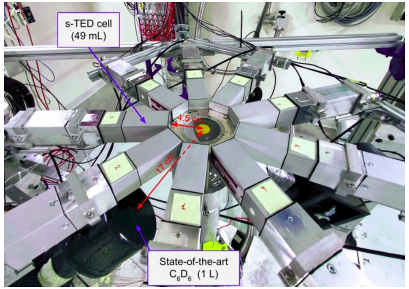
Future:

- Upgraded setup: 10 (2025), 24 (2026) detectors
- 2 first physics cases in 2025 & many reactions to be measured

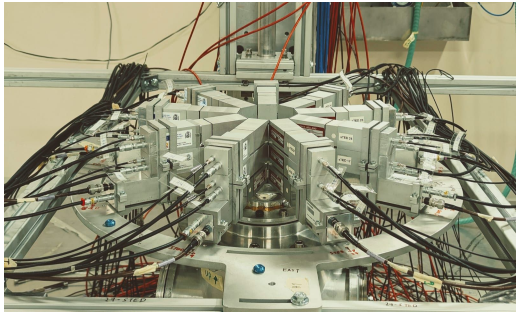
New generation of solid TED detectors

Motivation: Enhance sensitivity for challenging (n,g) in EAR2 : small samples of unstable isot, small XS
Challenge: Detectors based on liquid C_6D_6: thick encapsulations (neutron-sensitivity), chemical hazards

State-of-the-art: 9 sTED ring



Upgraded (End 2025): 27 sTEDs (eff↑)

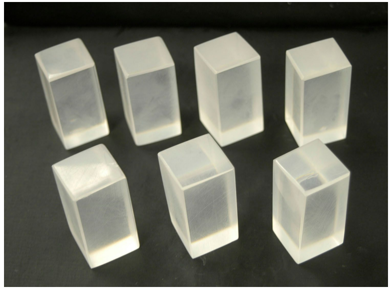


V. Alcayne , Rad. Chem. Phys. **217**, 111525 (2025)

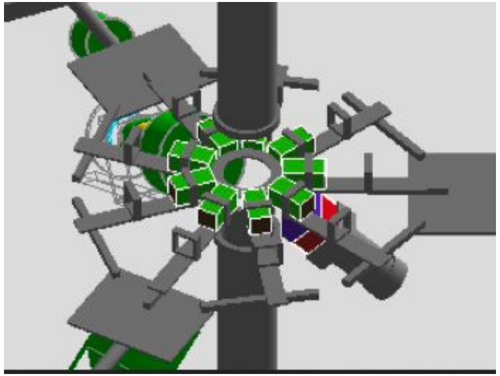
J. Balibrea-Correa et al., *NIM-A* **1072**, 170110 (2025)

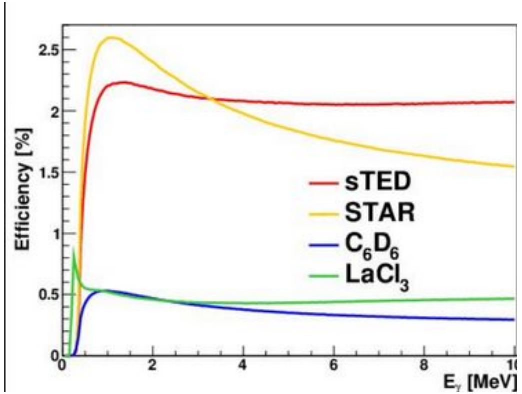
Assembly at IFIC (End 2025)

New generation: deuterated plastic scintillators



Commissioning at n_TOF-EAR2 (2026)



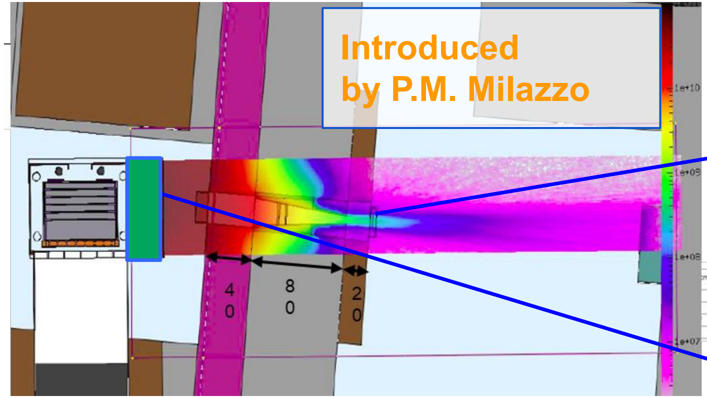


Future solution:
- Solid d-stilbene ($C_{10}D_{12}$)
- Higher density (1.24 g/cm^3)
- Negligible chemical hazard
- Thinner encapsulations
- Extra: better n/gamma discrimination → n,xn

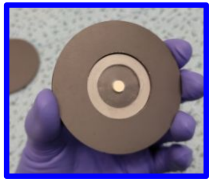
New facilities: n_TOF NEAR

Motivation: Access smaller masses, unstable isotopes, mainly for stellar (n,g)
Challenge: TOF technique with state-of-the-art sensitivity requires ~10^{18} atoms

Solution: n_TOF-NEAR
- Higher flux (@ 3m)
- Activation technique

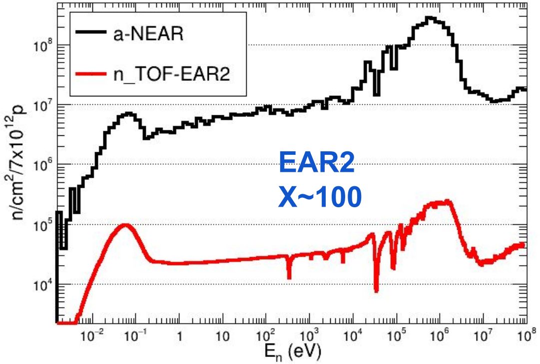


9×10^8 n/cm2/pulse → **Mass limit ~ 10^{15} atoms**

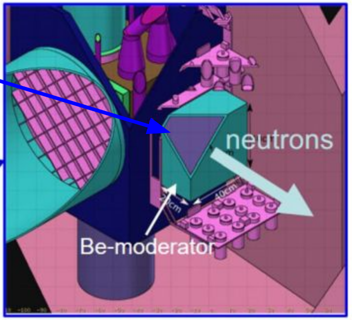


$^{10}B_4C$ Filters

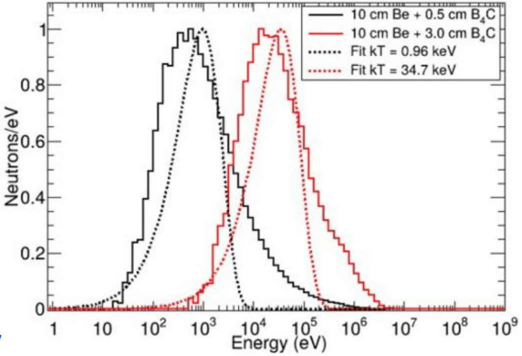
Stellar capture rates at different temperatures
kT :0.1~500 keV



White neutron beam
moderator + filters
=
"quasi-maxwellian"



Be / Al203 moderator



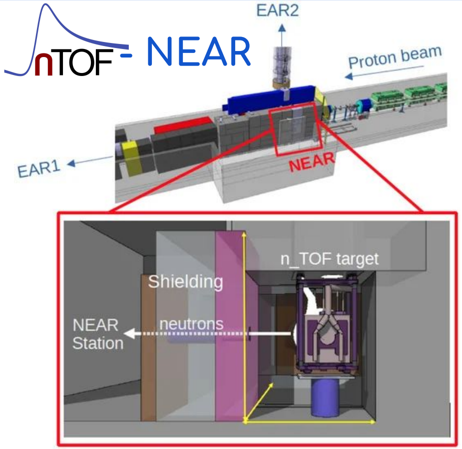
N. Patronis et al., *Eur. Phys. J. A* **61**, 215 (2025).

Future of NEAR: Synergies with ISOLDE

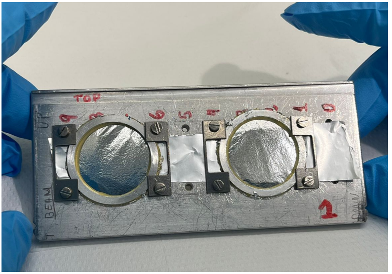
Future: Exploit the unique location of n_TOF-NEAR & ISOLDE for a synergic collaboration

Challenge: (n,g) on unstable isotopes s- and i- processes of stellar nucleosynthesis → **difficult to produce targets**

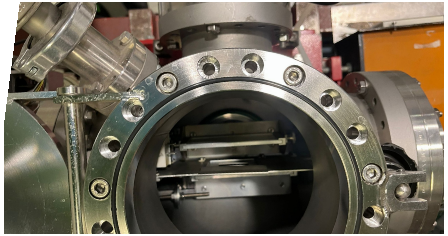
Solution: Produce samples of relevant unstable nuclei at **ISOLDE** & measure MACS at **NEAR**



First case: ^{135}Cs sample produced at ISOLDE for (n,g) at NEAR (2026)

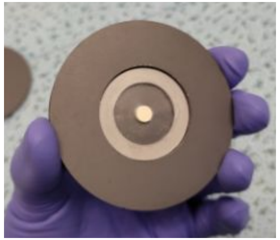


Sample holder & backings



Implantation in the SSP chamber ISOLDE (**2x10^{15} at**)

Sample into filters of NEAR



Experiment at n_TOF-NEAR (2026)

J. Lerendegui-Marco et al., [CERN-INTC-2022-040 (2022)]

Long-term future: n_Act @ BDF

Future: **n_ACT at BDF**: a high flux neutron activation station at the CERN SPS Beam Dump Facility (BDF)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

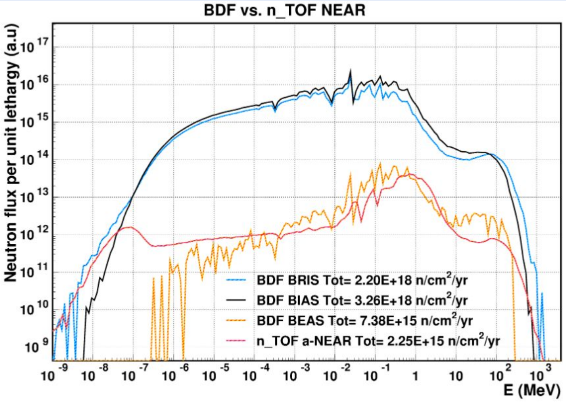
Proposal to the SPS and PS Experiments Committee

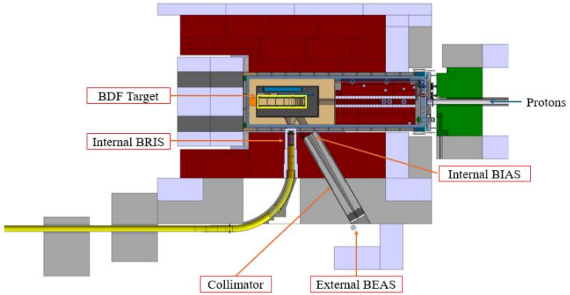
n_ACT@BDF: A Neutron Activation Station at the SPS Beam Dump Facility (BDF)

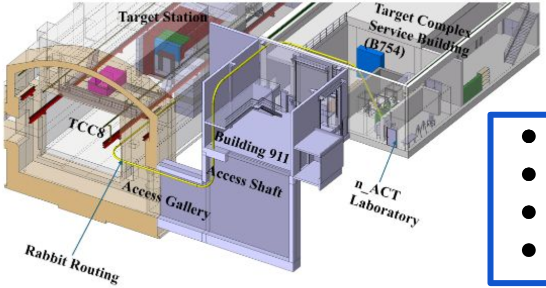
, CERN-SPSC-2024-027 ; SPSC-EOI-023 (2025)

November 11, 2025

n_ACT







- (n,g) on s- & i-process unstable nuclei
- Act + AMS cosmochemistry: 60Fe, 181Hf
- Rare stable isotopes (e.g. Ca-44,46,48)
- (n,cp) for nuclear technologies: scarce data

n_ACT: A unique activation station towards more challenging measurements

- **World-leading neutron flux**: neutron flux x1000 vs. n_TOF a-NEAR.
- **Three complementary activation stations** (BIAS, BEAS, BRIS) integrated into the BDF target complex.
- **Flexible neutron spectral shaping**: Use of compact B_4C filters + Be moderator to generate quasi-Maxwellians.
- **Unique synergies**: Complementarity with n_TOF (TOF + activation) & proximity to ISOLDE.

To recap: n_TOF in few words

n_TOF: measuring high-resolution neutron-induced cross sections at CERN for 25 years

The n_TOF collaboration:

~140 researchers, 30+ institutions, mostly Europe (also Japan, India and the USA)
~10 PhD students/year

Exciting recent results:

- Key (n,g) on radioactive isotopes for astrophysics,
- (n,g) on fissile isotopes for nucl. technologies,
- Extending the energy limits of fission standards,
- First (n,cp) DDX for n-dosimetry, …

Many ongoing and future developments…

- First measurements of (n,n´),
- New generations of detectors,
- NEAR: a high-flux facility for activations & synergies with ISOLDE,
- The future n_Act facility

… towards a bright future for neutron induced cross sections at CERN

Thank you!

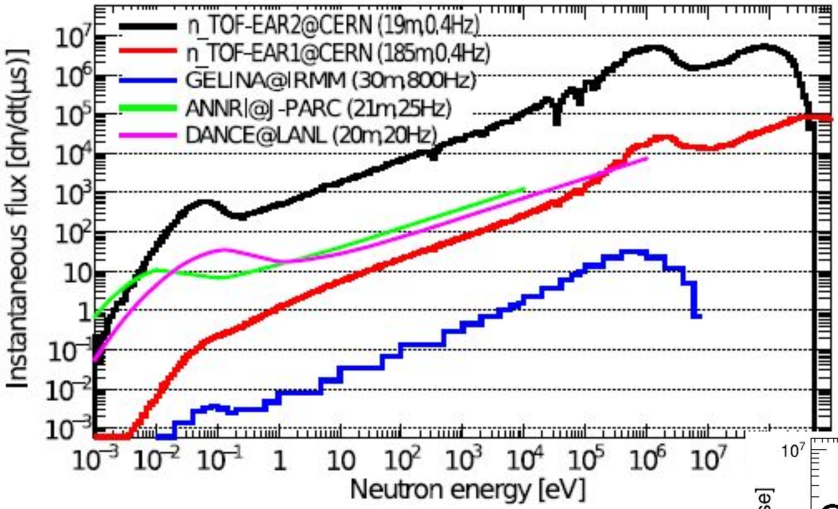
Jorge Lerendegui-Marco
Instituto de Física Corpuscular, Valencia (Spain)
CERN n_TOF Collaboration
jorge.lerendegui.marco@cern.ch

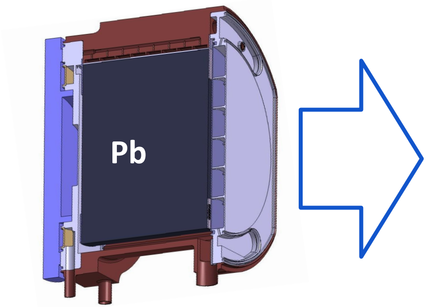
Recent results of the CERN n_TOF facility

(& future prospects)

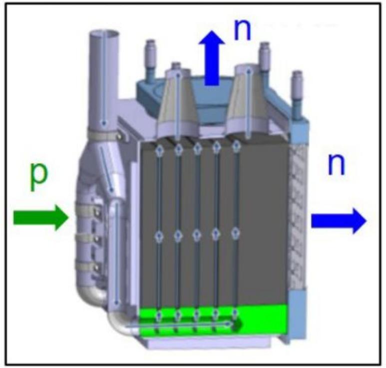
BACK-UP (more about recent highlights & future)

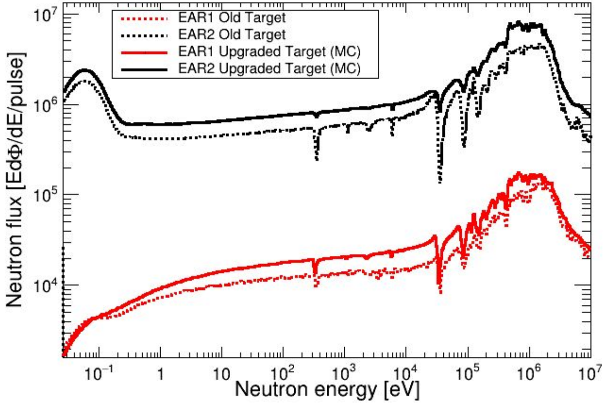
EAR2 → instantaneous flux

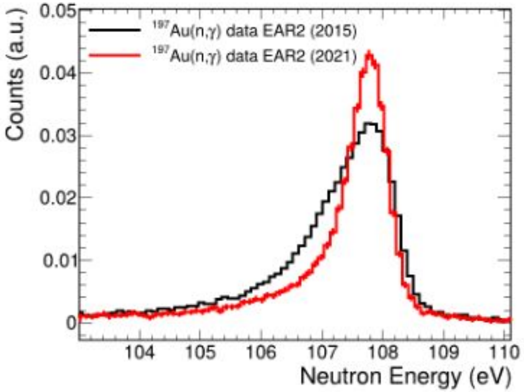




Target#3 (2021-present)







J. Lerendegui-Marco et al., Eur. Phys. J. *A* **52**, 100 (2016).

J.A. Pavón-Rodríguez et al., Eur. Phys. J. *A* (arxiv) (2025)

+ Recent highlights: Al-26(n,cp)

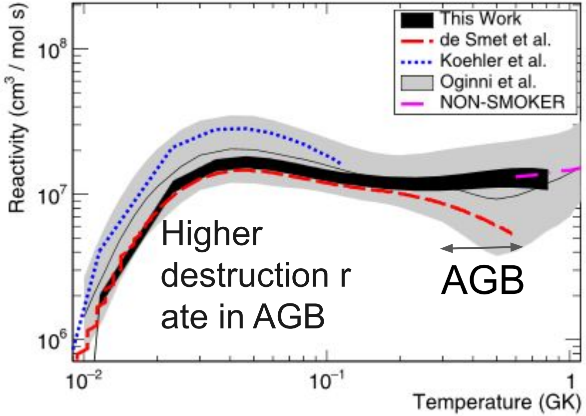
PHYSICAL REVIEW C **104**, L032803 (2021)

Letter

Destruction of the cosmic γ-ray emitter ^{26}Al in massive stars: Study of the key ^{26}Al(n, α) reaction

C. Lederer-Woods,[1,*] P. J. Woods,[1] T. Davinson,[1] A. Estrade,[1,†] J. Heyse,[2] D. Kahl,[1,‡] S. J. Lonsdale,[1] C. Paradela,[2]

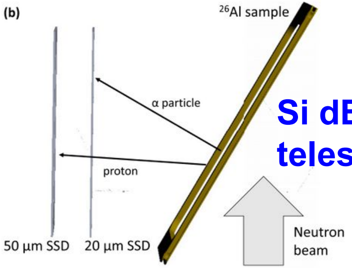
Neutron-induced destruction of the cosmic-ray emitter Al-26 (T1/2 = 0.7 Myr)



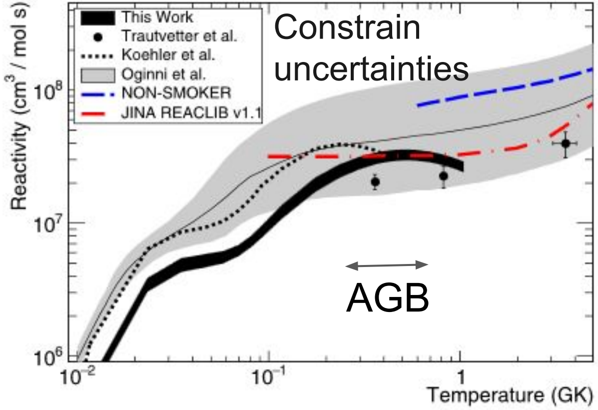
PHYSICAL REVIEW C **104**, L022803 (2021)

Letter

Destruction of the cosmic γ-ray emitter ^{26}Al in massive stars: Study of the key ^{26}Al(n, p) reaction



Si dE/E telescope



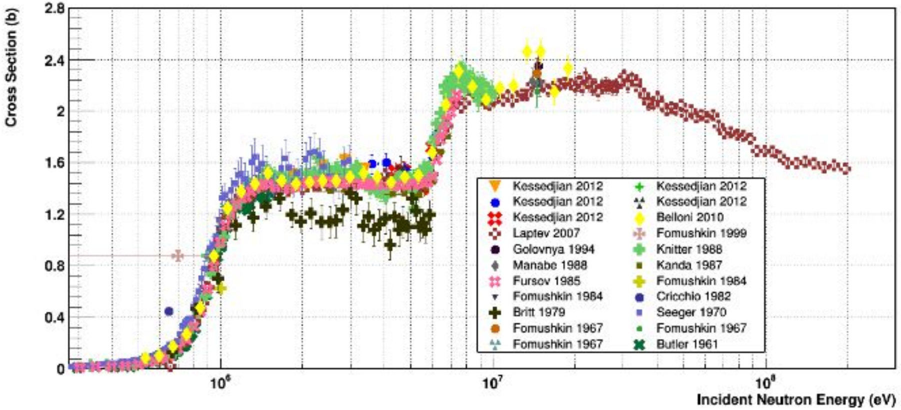
- Significant discrepancies in the Al-26 destruction rates.
- Impact in the Al-26 production in supernovae and AGB origin of our early solar system

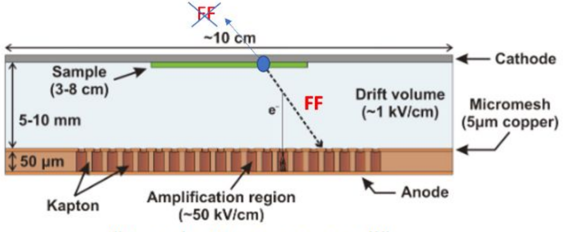
Neutron sources: neutron cross sections of light elements acting as neutron poison, or linked to stellar neutron sources.

Next: extend>1 GK (Massive stars)

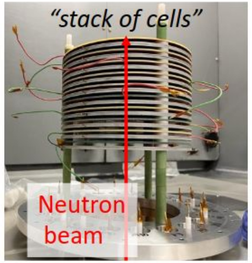
Recent highlights: Am-243(n,f)

Motivation: lack of data above 20 MeV + discrepancies below





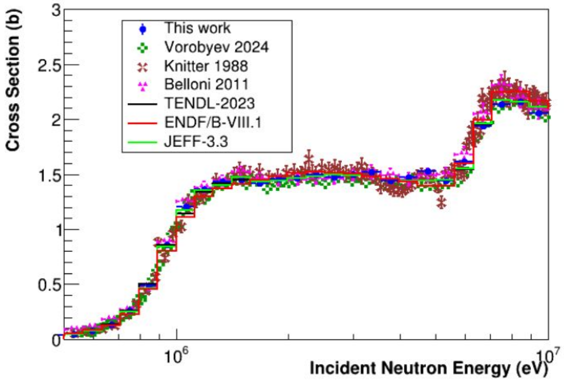
“Sample-Micromegas cell”

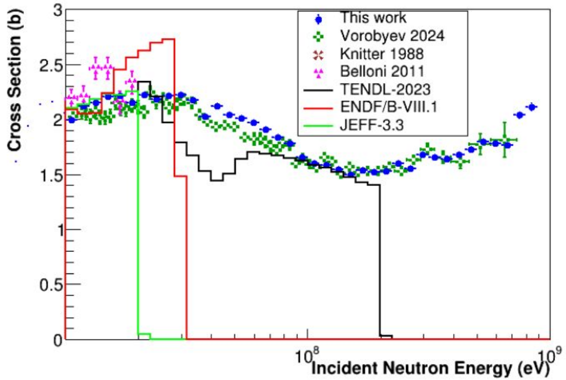


3) SAMPLES: Very specific sample characteristics :

11 ^{243}Am samples in the form of thin disks (6cm diameter):

- **“Hybrid” configuration : thin – 0.09 mgr and thick ~4 mgr,**



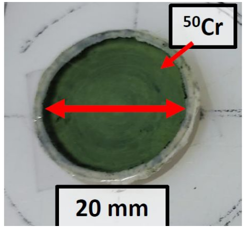


M. Diakaki,
ARIEL Final Workshop
(2024)

N. Nikolaos Kyritsis ARIEL Final Workshop (2024)

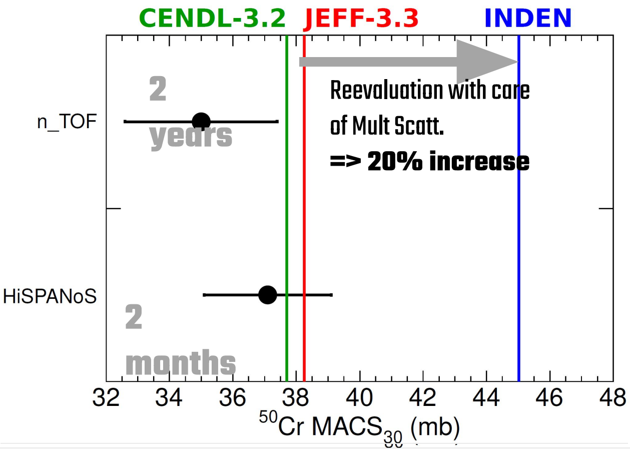
- Results **agreeing with JEFF** up to 20 MeV
- **Good agreement** with other experimental data **above 20 MeV**

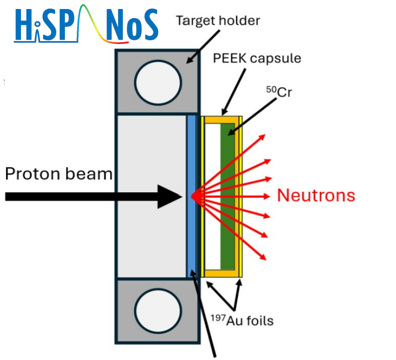
+ Recent highlights: Combining differential & integral

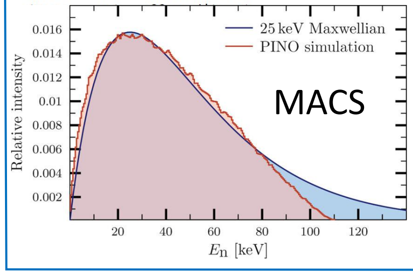


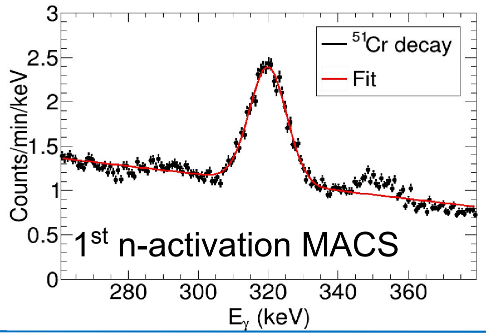
All enriched $^{50}CrO_2$ in EU and USA [to our knowledge]

- 95% enriched
- 723 mg

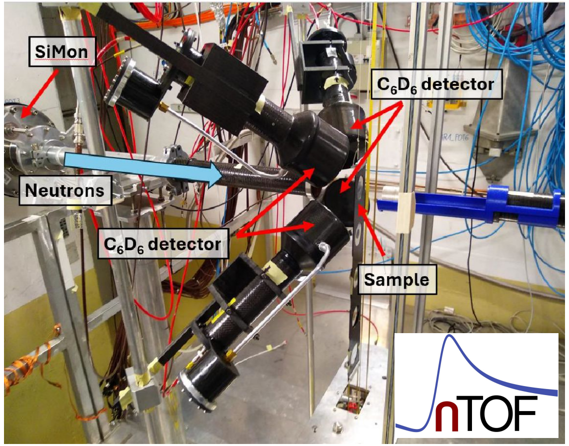




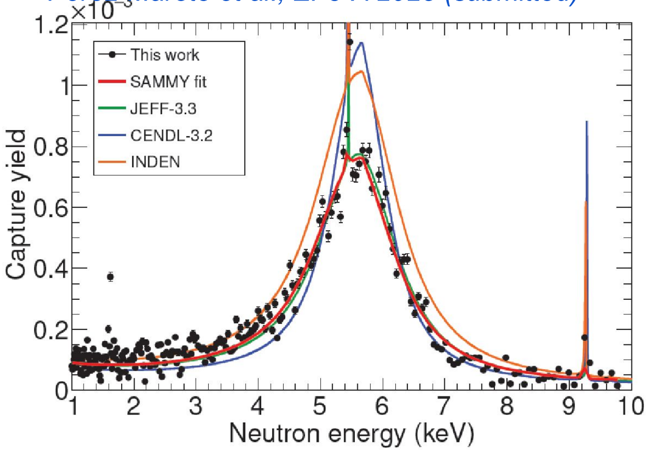




Perez-Maroto et al., PLB 2025

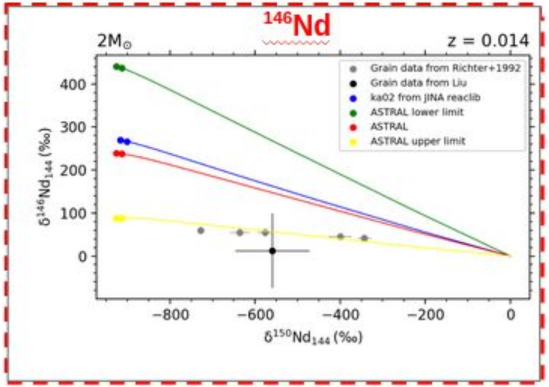


Perez-Maroto et al., EPJ-A 2025 (submitted)

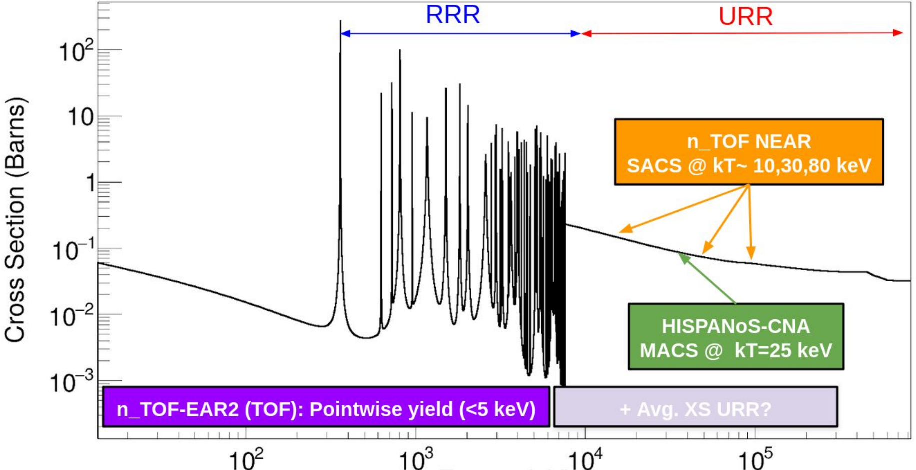


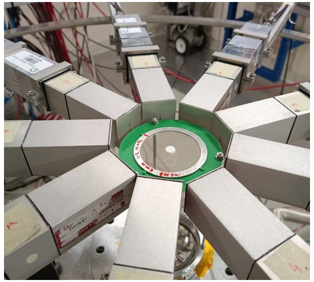
+ Recent highlights: (n,g) Combining TOF & NEAR

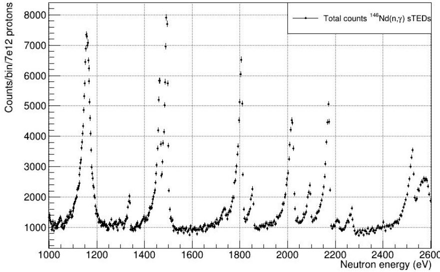
146(n,g) using complementary facilities to solve astrophysical discrepancies



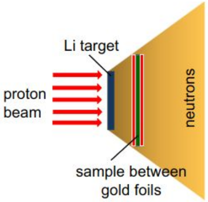
Pressed powder,
8 mm diam, 212.4 mg oxide,
97.4% enrichment 146Nd

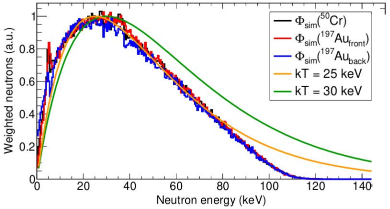


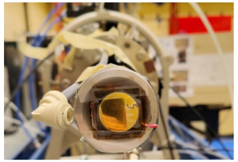




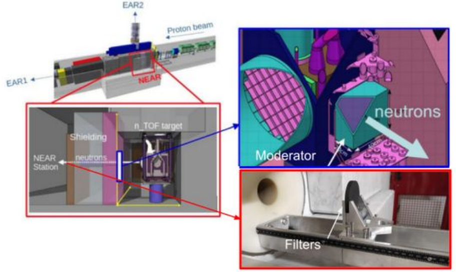
RRR < 5 keV: TOF @ n_TOF EAR2

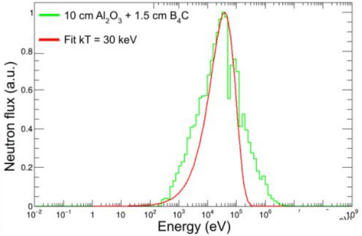






MACS @ 25 keV: Activation at HisPANoS-CNA





MACS @different kT: Activation at n_TOF-NEAR

+ Recent highlights: unstable s-process branching points

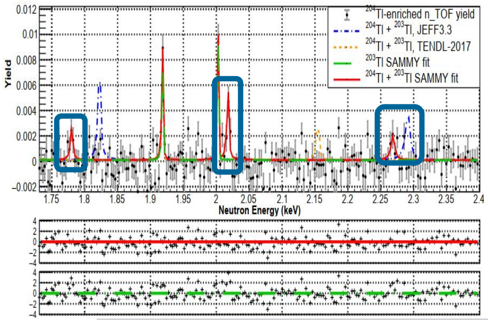
Tl-204(n,ɣ)

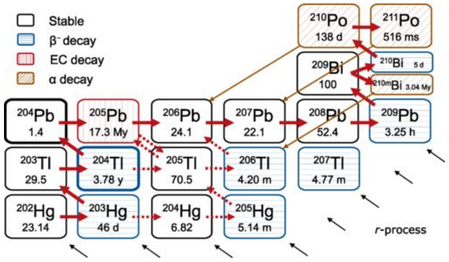
First measurement ever
TOF-unique case

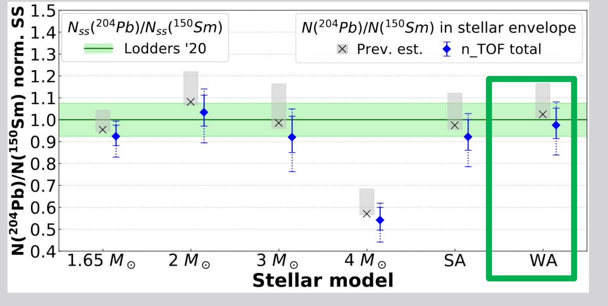
m = 9 mg
(+200 mg ^{203}Tl)
σ = 260(90) mb

PAUL SCHERRER INSTITUT

NEUTRONS FOR SOCIETY

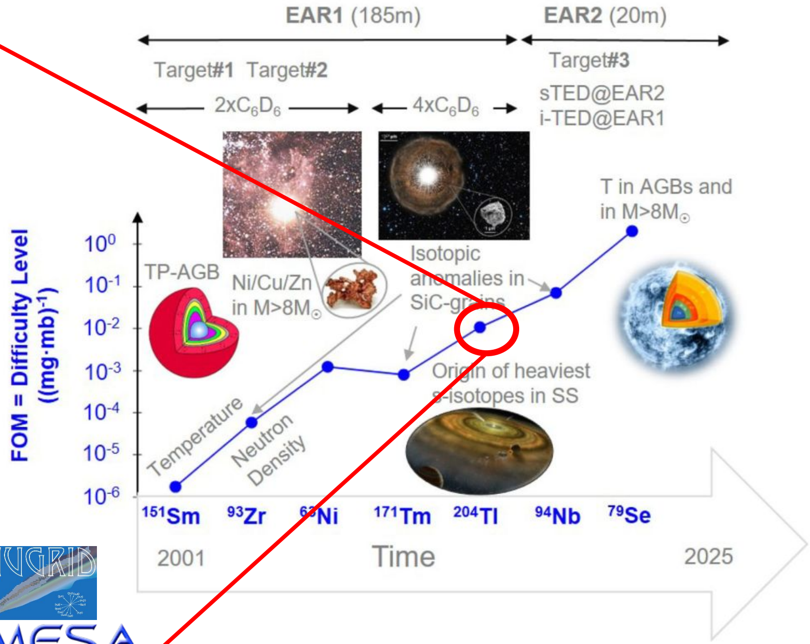






NUGRID

MESA



See talk
by P.M. Milazzo

Uncertainty in the abundance of the heaviest s-only 204Pb has been reduced from ~30% down to +8%/−6%

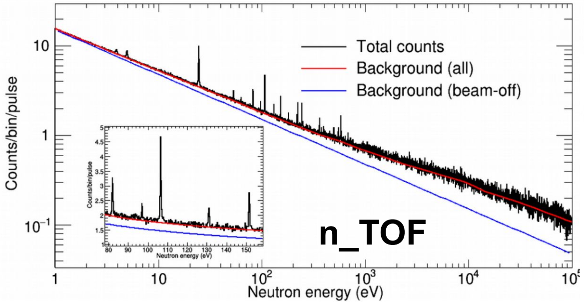
A. Casanovas, *Phys. Rev. Letters* ***133***, *052702 (2024).*

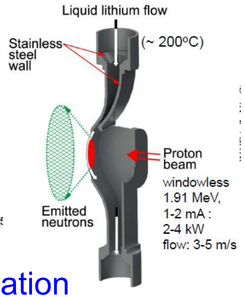
+ Recent highlights: unstable s-process branching points

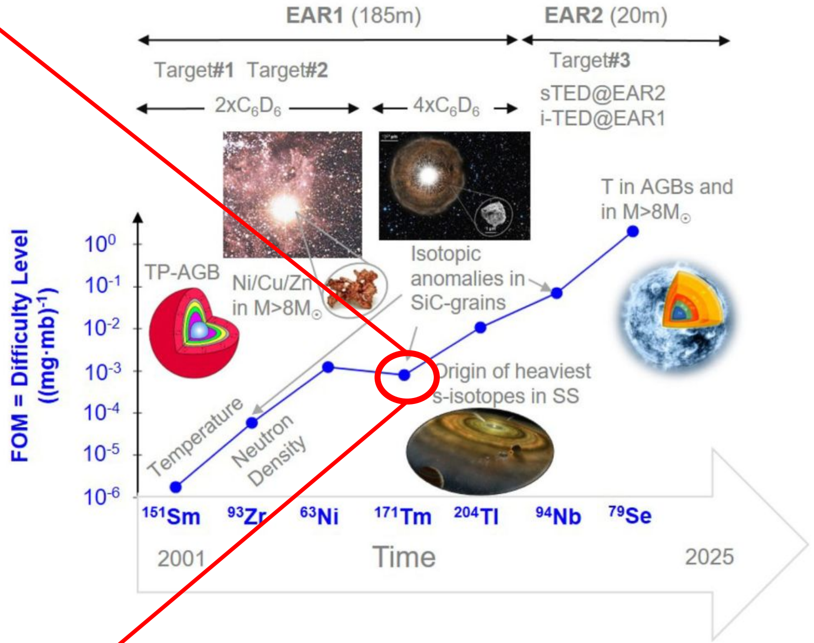
Tm-171(n,γ)

First measurement ever!
TOF @ n_TOF + activation @ LiLIT

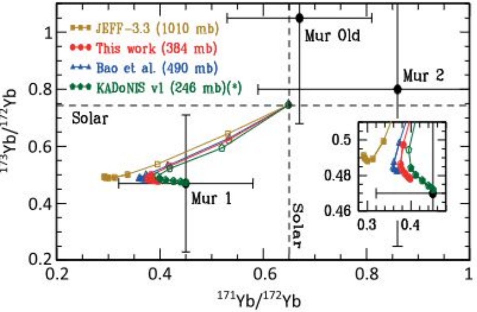
m = 3.1 mg
97.9% pure
σ = 384(40) mb

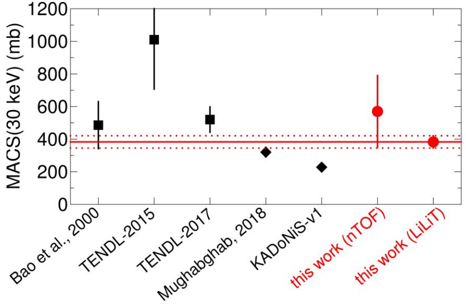






Consistent TOF & activation





Yb-ratios SiC grains: Improved agreement vs JEFF-3.3

See talk by P.M. Milazzo

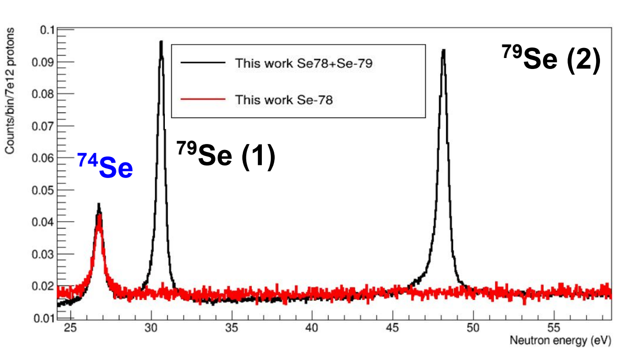
C. Guerrero et al., *Phys. Rev. Letters* **125**, 142701 (2020)

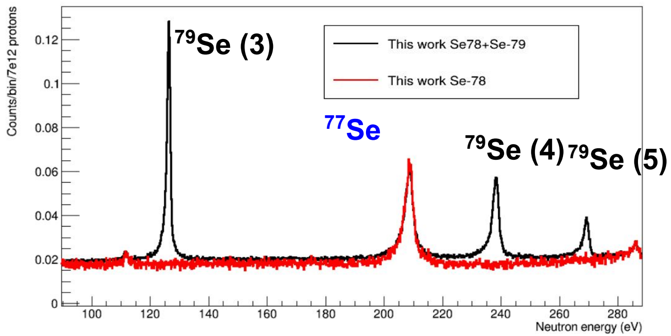
+ Recent highlights: unstable s-process branching points

Se-79(n,ɣ)

IDENTIFICATION
79Se resonances:

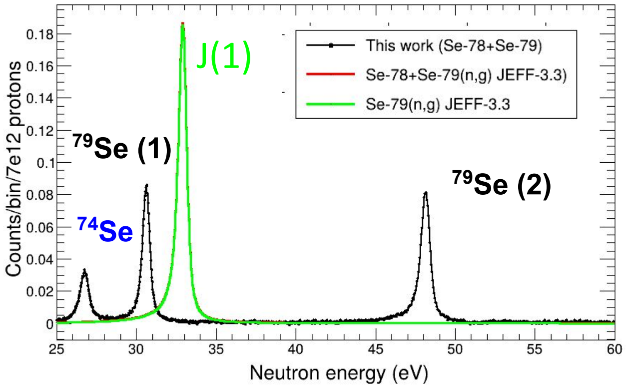
- **Se-78 disc** vs **Se-79 +Se-78 sample**
- Sum of the STEDs is plotted

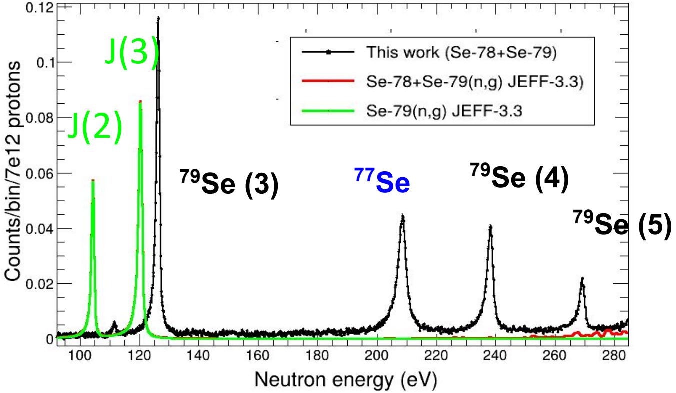




Comparison to predictions of evaluations:

- This work (Se-79+Se-78)
- Se-78 + Se79 (JEFF-3.3)
- Se-79 (JEFF-3.3)





JEFF-3.3 = Just one possible XS (TALYS) → Models cannot predict the energy of resonances!

+ Recent highlights: unstable s-process branching points

Challenges unstable s-process branching points:

1. TOF requires mass >= 5x10^{17}-10^{18} atoms (EAR2)
2. Mass/Activity: **radiation hazard & activity background**

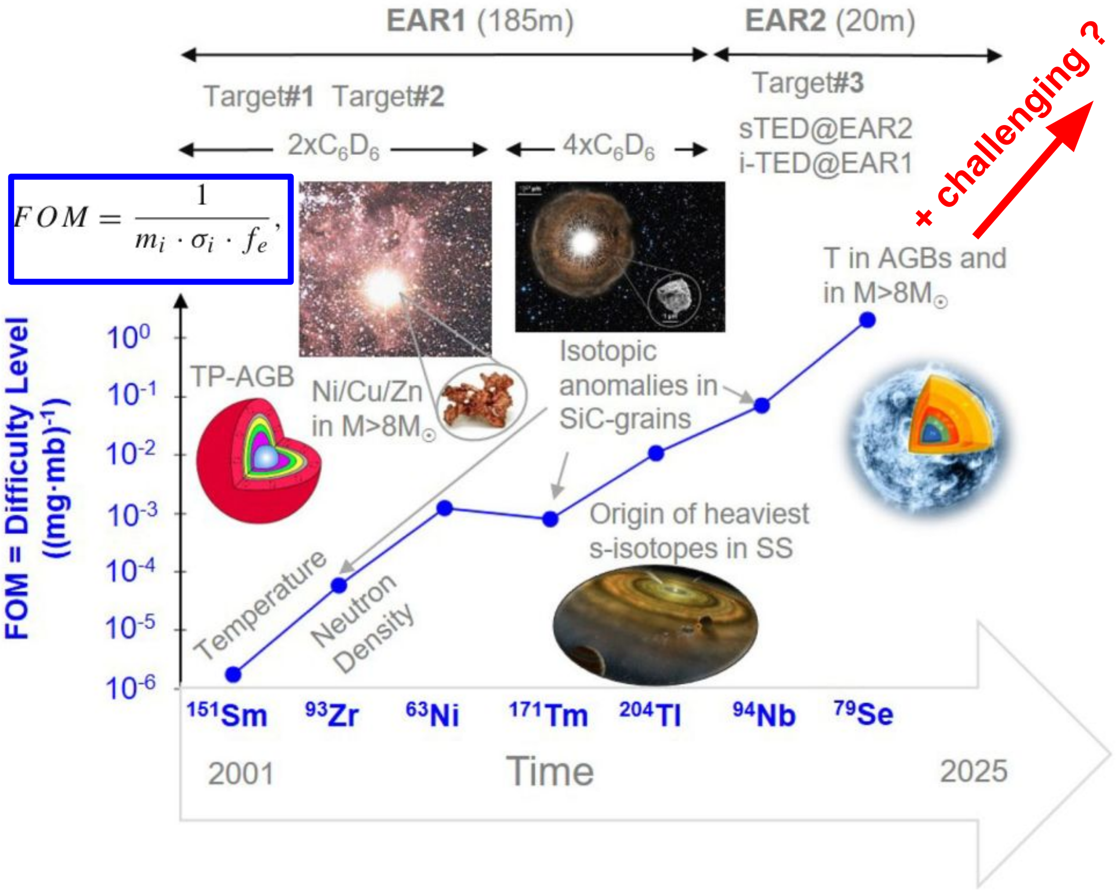
→Many (n,g) reactions still not accessible via TOF

SOLUTION:

Activation in high flux facilities

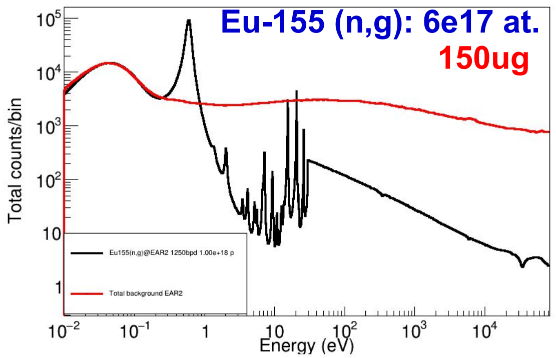
(HIGHER SENSITIVITY → LOWER MASS REQUIRED)

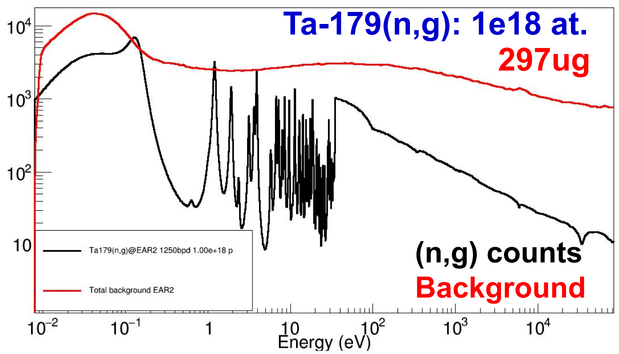
$$FOM = \frac{1}{m_i \cdot \sigma_i \cdot f_e},$$

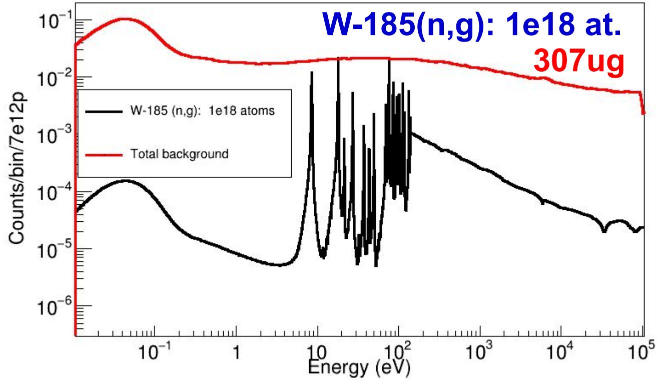


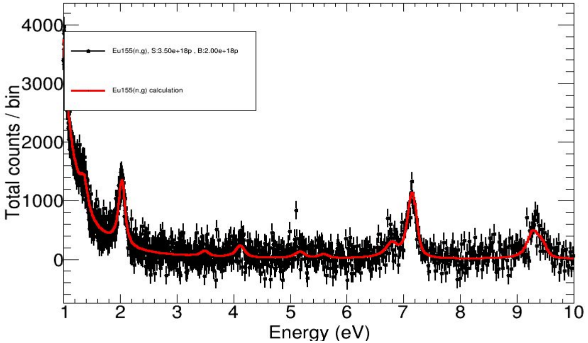
+ Recent highlights: unstable s-process branching points

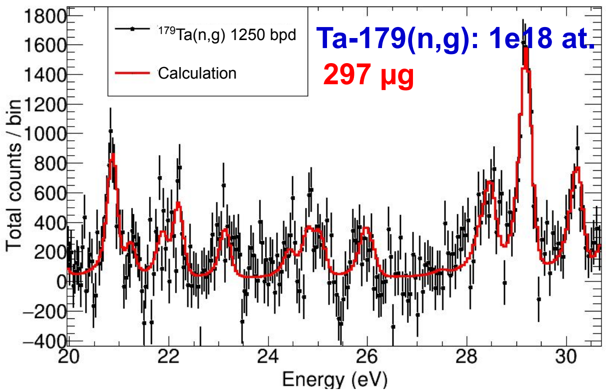
Estimated results in the upgraded **n_TOF-EAR2** with the **best sensitivity achieved so far with the STEDs**

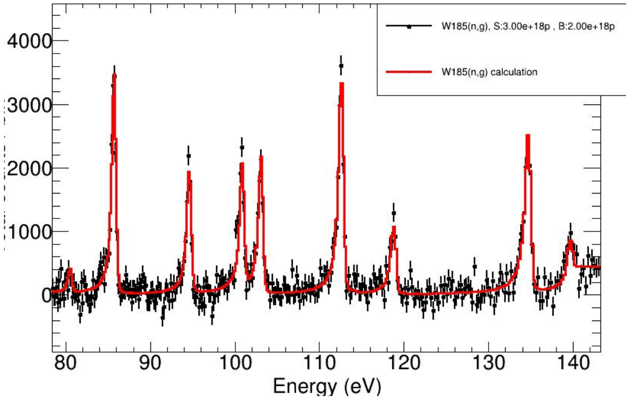












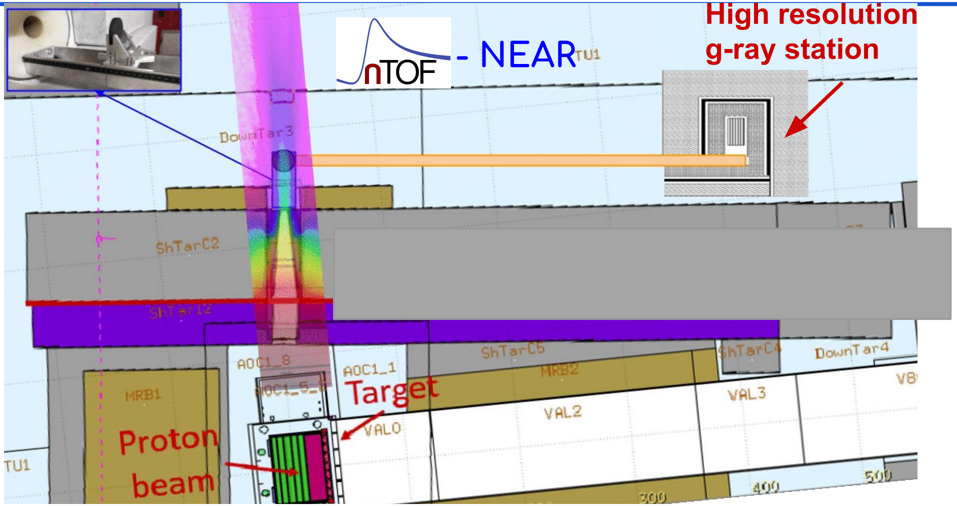
Limit: ~1e18 atoms (too high) currently required →We need **complementary techniques** → **ACTIVATION**!

Future of NEAR: Cyclic activation?

Future: Access short lived reaction products profiting from the low rep. rate of n_TOF beam

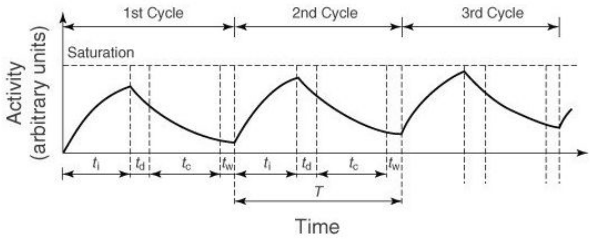
CYCLING @ NEAR: CYCLIc activation for (N,G) measurements

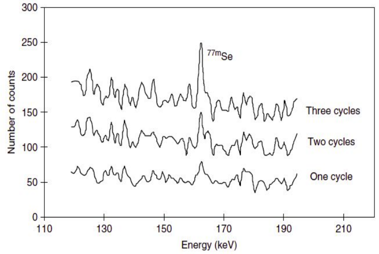
- Allows: activation with short lived (s, min) (n,g) products
- Especially interesting for unstable isotopes.
- Well suited to the rep. Rate (>0.8Hz) of n_TOF



Interesting cases for astrophysics:

- s-process/AGB: ^{107,109}Ag(n,γ), ^{26}Mg(n, γ), ^{50}Ti(n,γ), ^{19}F(n, γ), ^{60}Fe(n, γ)
- i-process: ^{137}Cs(n,γ), ^{144}Ce(n,γ), ^{132}Te(n,γ),...





C. Domingo-Pardo, et al., *Eur. Phys. J. A* **59**, 8 (2023)

J. Lerendegui, M. Bacak *CERN-INTC-2022-018 ; INTC-I-241*.

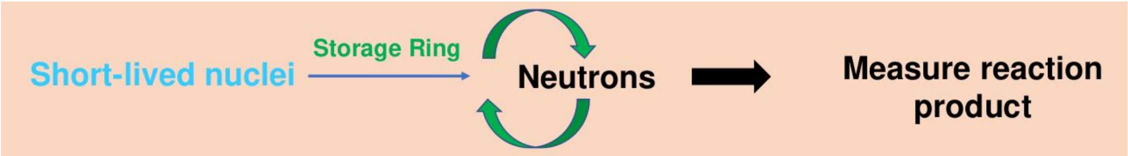
H. Beer, et al., Nucl. Inst. Meths. 337, 2–3 (1994)

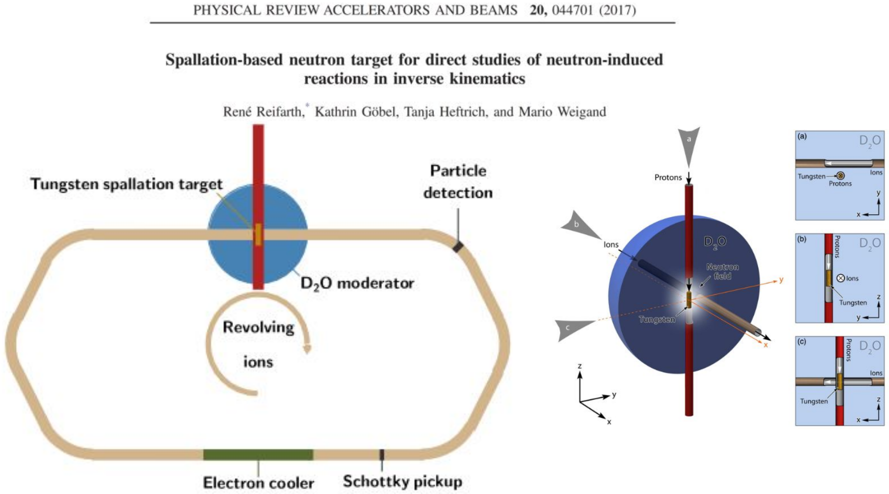
Future: (n,g) with RIB rings + neutron targets?

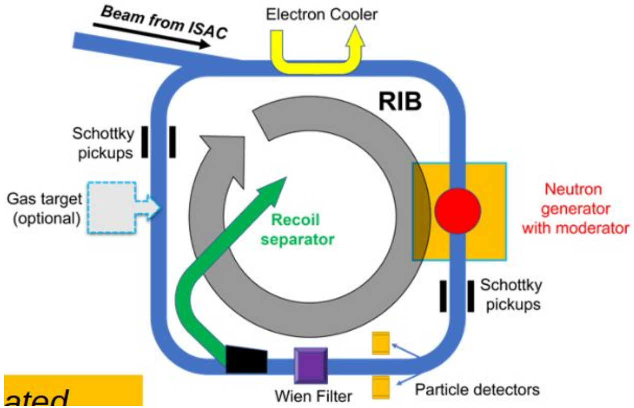
DIRECT (N,G) IN INVERSE KINEMATICS

Aim: short-lived (s- and i-process)

- s-process: ^{134}Cs ($t_{1/2}$ = 2.06 y), ^{147}Nd ($t_{1/2}$ = 11 d), ^{148}Pm ($t_{1/2}$ = 5.37 d), ^{153}Gd ($t_{1/2}$ = 240.4 d), ^{160}Tb ($t_{1/2}$ = 72.3 d), ^{170}Tm ($t_{1/2}$ = 128.6 d), and ^{204}Tl ($t_{1/2}$ = 3.78 y).
- i-process: ^{66}Ni ($t_{1/2}$ = 54.6 h), ^{75}Ga ($t_{1/2}$ = 126 s), ^{135}I ($t_{1/2}$ =6.58 h), ^{141}Ba ($t_{1/2}$ = 18.27 m), and ^{141}La ($t_{1/2}$ = 3.92 h).







Neutron target facility @ LANL

800 MeV p, 100 mA + spallation target + moderation
n density= 8*10^9 n/cm2

TRISR @ ARIEL-TRIUMF

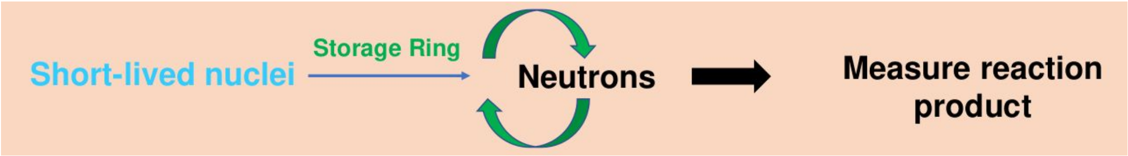
Compact high-flux neutron generator:
10^8 n/cm2/s

I. Dillmann et al., *Eur. Phys. J. A* **59**, 105 (2023).

Future: (n,g) with RIB rings + neutron targets?

DIRECT (N,G) IN INVERSE KINEMATICS

Aim: short-lived (s- and i-process)

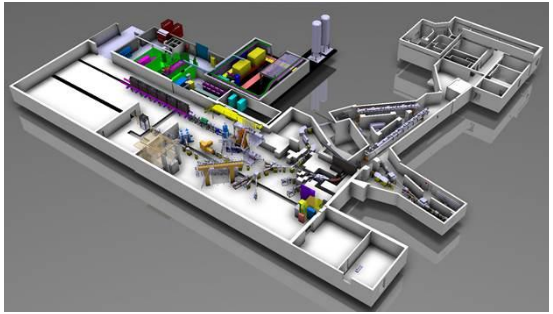


– s-process: ^{134}Cs ($t_{1/2}$ = 2.06 y), ^{147}Nd ($t_{1/2}$ = 11 d), ^{148}Pm ($t_{1/2}$ = 5.37 d), ^{153}Gd ($t_{1/2}$ = 240.4 d), ^{160}Tb ($t_{1/2}$ = 72.3 d), ^{170}Tm ($t_{1/2}$ = 128.6 d), and ^{204}Tl ($t_{1/2}$ = 3.78 y).

– i-process: ^{66}Ni ($t_{1/2}$ = 54.6 h), ^{75}Ga ($t_{1/2}$ = 126 s), ^{135}I ($t_{1/2}$ =6.58 h), ^{141}Ba ($t_{1/2}$ = 18.27 m), and ^{141}La ($t_{1/2}$ = 3.92 h).

- Posible at CERN n_TOF beam & ISOLDE?

CERN ISOLDE + nTOF + RING?



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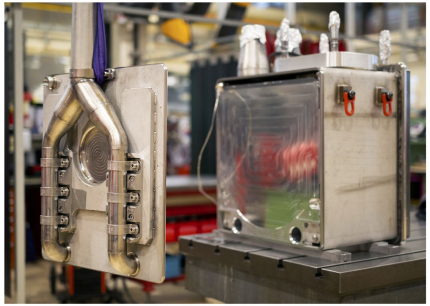

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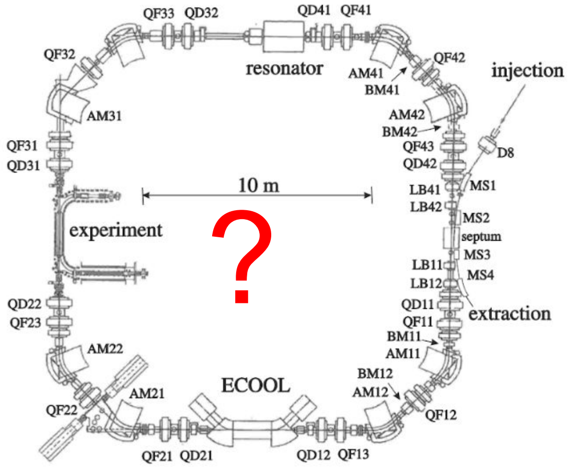
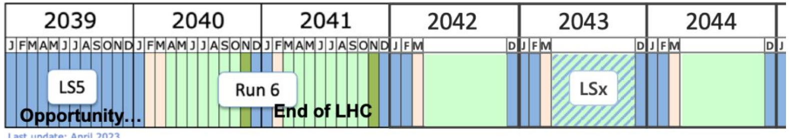


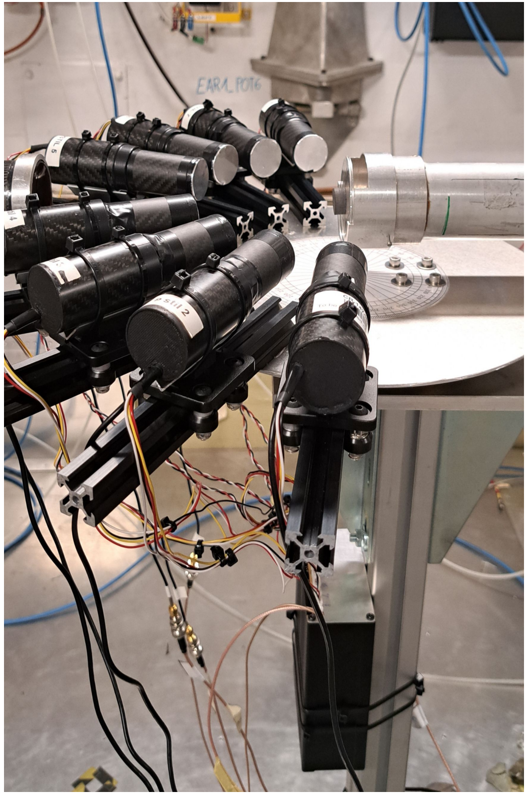


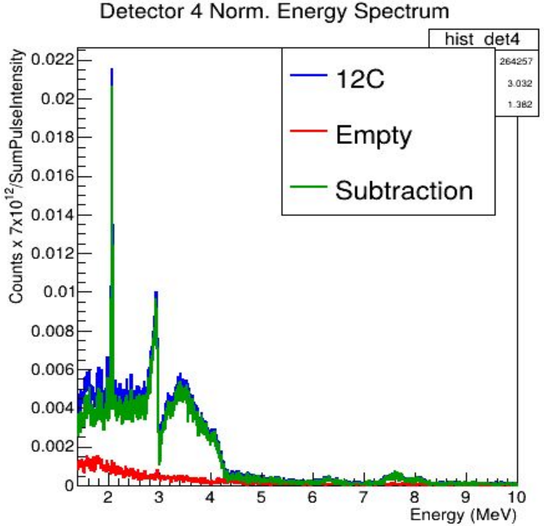
Project: Storage ring at HIE-ISOLDE

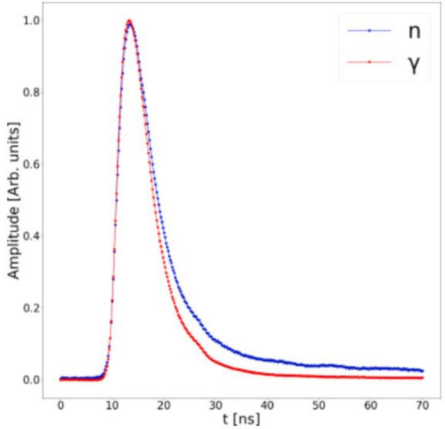
M. Grieser et al., Eur. Phys. J Spec. Top. 207, 1 (2012)

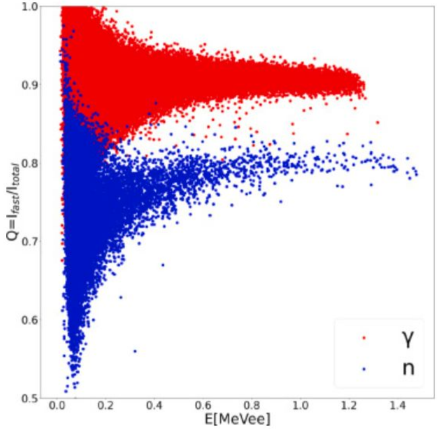
New reaction channels: (n,xn) & (n,xng)

Deuterated stilbene scintillators





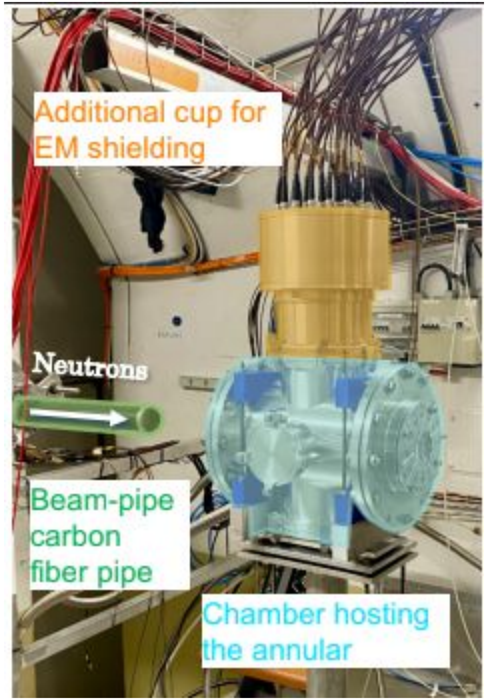


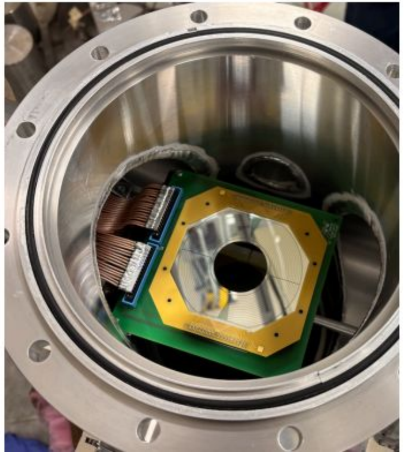


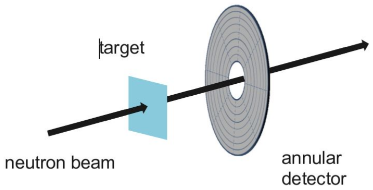
Stilbene multi-detector array for elastic and inelastic neutron cross-section channels

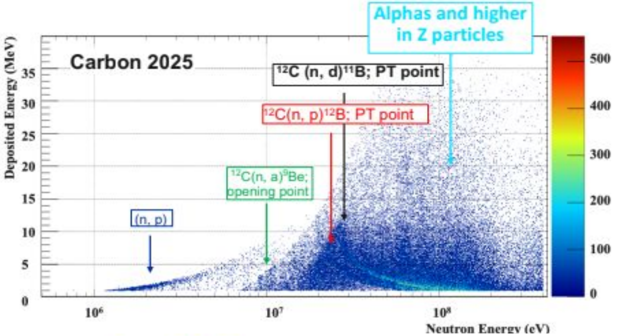
J. Balibrea-Correa et al., *NIM-A* **1072,** 170110 (2025)

New detectors: n-TD, Alternative to telescopes for (n,cp)





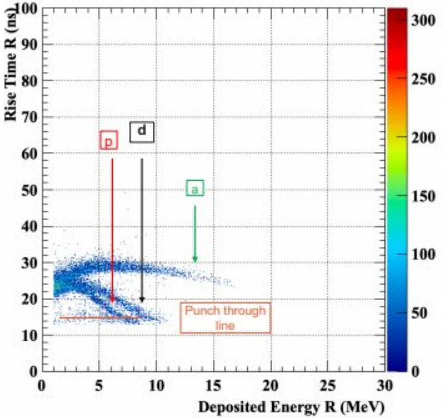




^{12}C(n,cp): Single-parameter PID

Carbon Data (E_n < 30 MeV)

- **Three distinct structures** observed from **protons**, **deuterons**, and **alpha** particles, along with the PT line.
- **Charge discrimination** between Z = 1 (hydrogen isotopes) and Z = 2 (helium isotopes) at 2.5 MeV is achieved
- **Clear p/d separation** observed at 4 - 4.1 MeV.



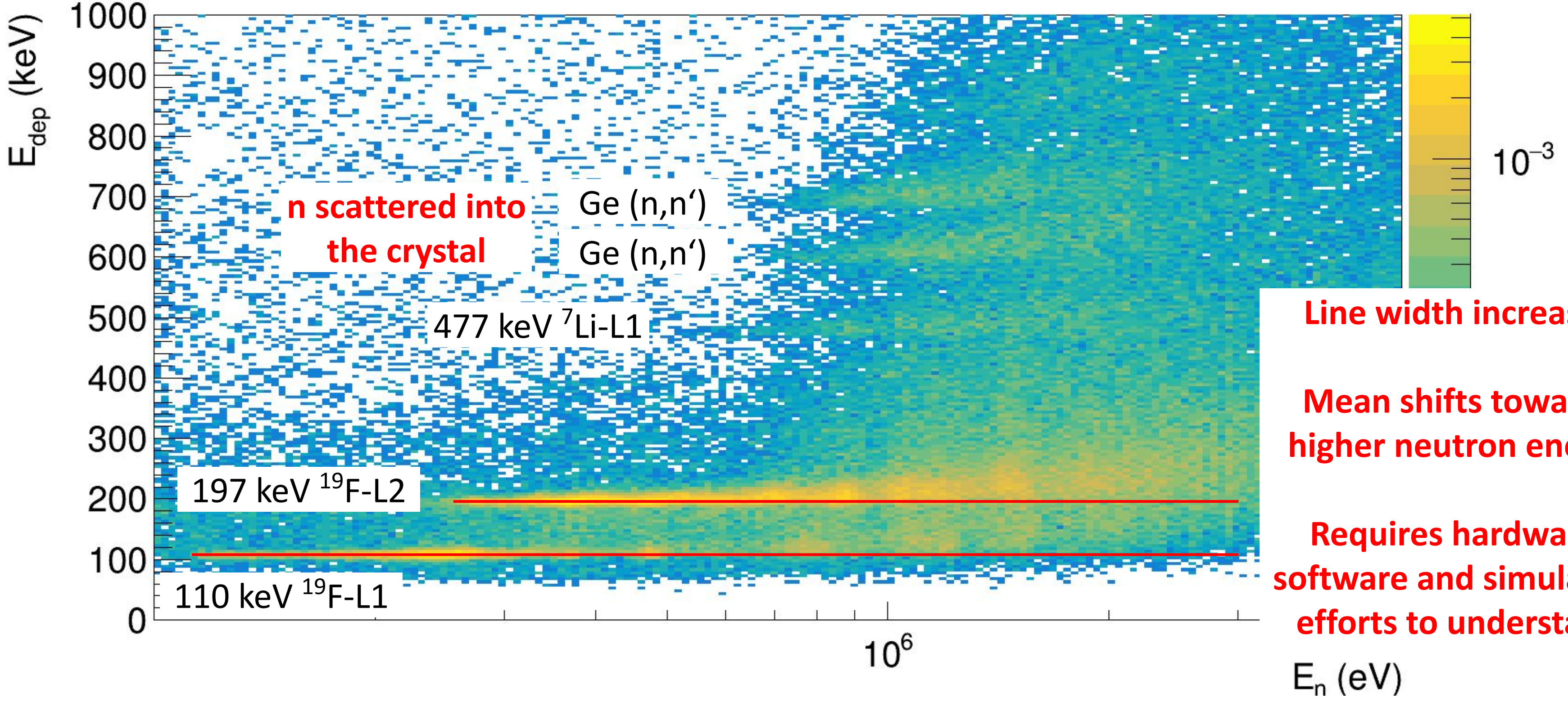
Recent highlight: New annular n-TD single-stage detector with particle discrimination

S. Goula et al., *HNPS* (2022)

S. Goula et al., *EPJ WOC (ND2025)* (2026)

New reaction channels: (n,n’)

Results from HPGe + LiF



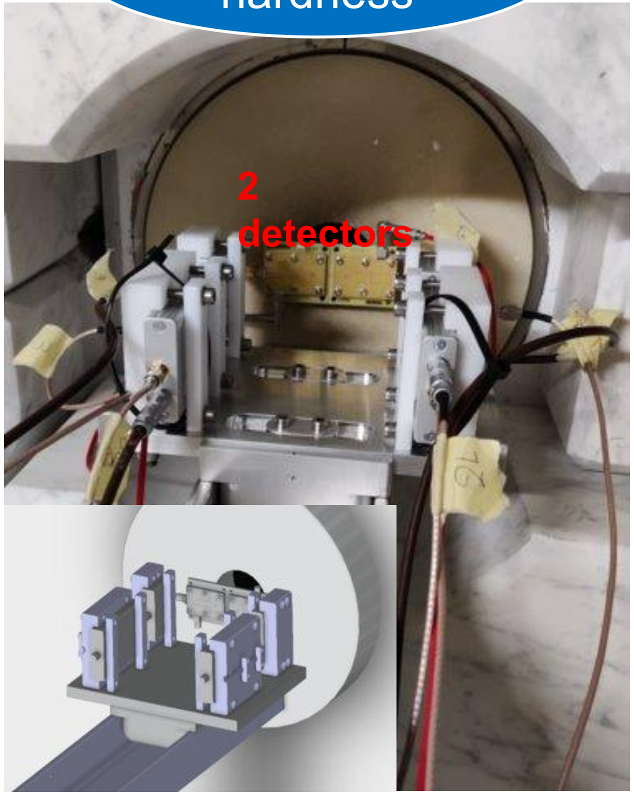
Line width increases

Mean shifts towards higher neutron energy

Requires hardware, software and simulation efforts to understand

New detectors: diamond for high neutron fluxes

Radiation hardness



M. Bacak, K. Kaperoni (private communic.)

Diamonds @ NEAR

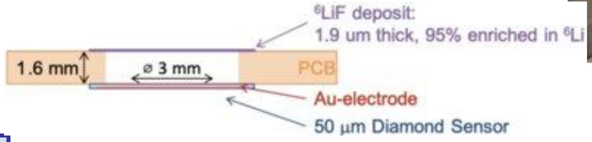
Pulsed mixed field environment

@ 2.3 m from target

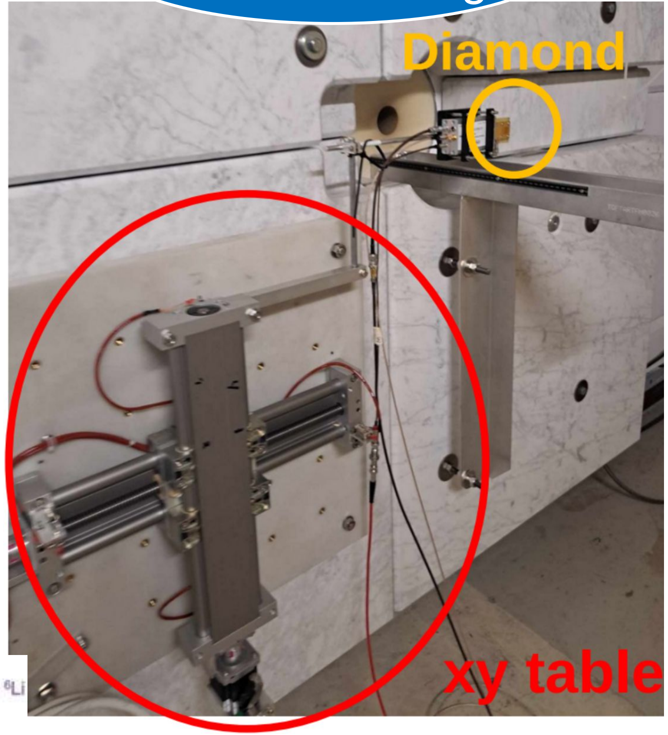
1.51e9 n/cm^2/7e12

En>1 MeV: 100-1000 cts/ns/cm^2

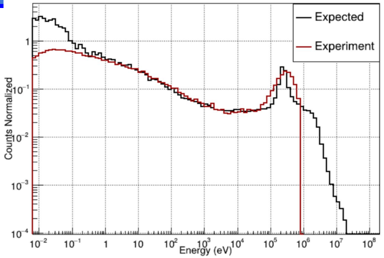
= current measurement



NEAR station commissioning



New detectors: diamond for high neutron fluxes

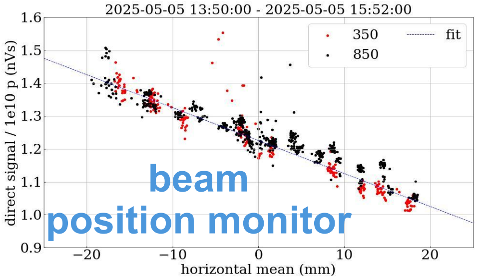


low energy TOF flux

Radiation hardness

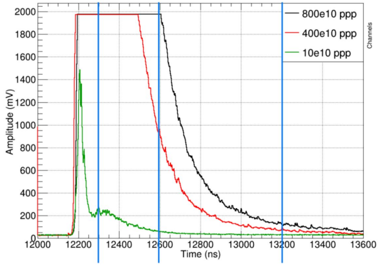
NEAR station commissioning

Diamonds @ NEAR



beam position monitor

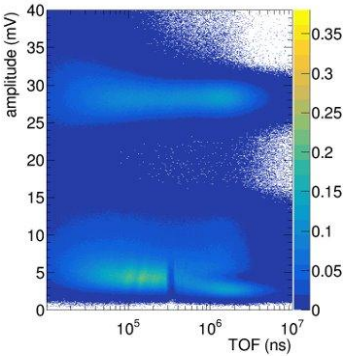
integral fast flux

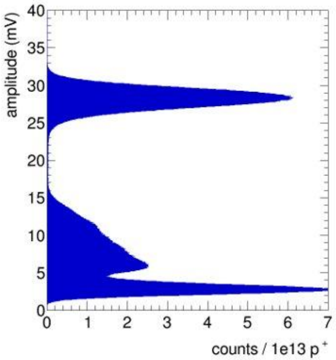


TOF = 134 ns
En = 2.6 MeV

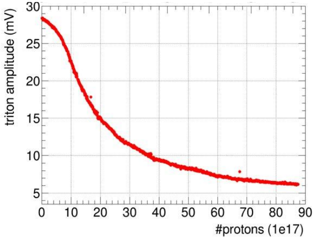
TOF = 434 ns
En = 0.2 MeV

TOF = 1034 ns
En = 0.04 MeV

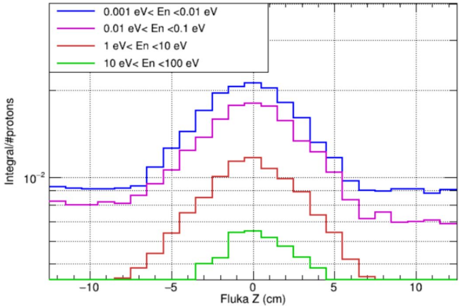




degradation vs dose



beam profile



M. Bacak, K. Kaperoni (private communic.)