Nuclear Physics in Greece

RECFA, Athens-Greece, 10/11/2023

Nikolas Patronis

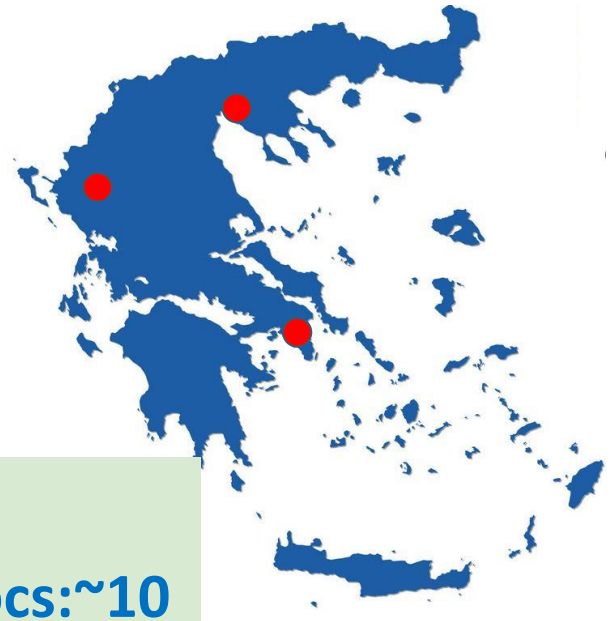
n_TOF Physics Coordinator

CERN & Univ. of Ioannina

The Hellenic Nuclear Physics community

Institutes:

- National and Kapodistrian University of Athens, Department of Physics
- National Technical University of Athens, Department of Physics
- Aristotle University of Thessaloniki
- University of Ioannina
- Hellenic centre for marine research, Anavysos
- NCSR “Demokritos”, Athens



Faculty members, Researchers: 25

Our younger colleagues:
BSc: ~40; MSc: ~15; PhD: ~25; post-docs:~10

HELLENIC REPUBLIC
National and Kapodistrian University of Athens

DEMOKRITOS

National Technical University of Athens

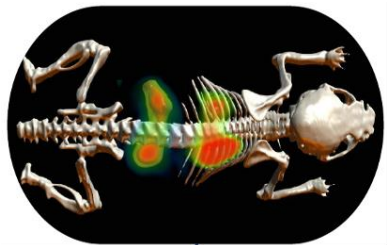
UNIVERSITY of IOANNINA

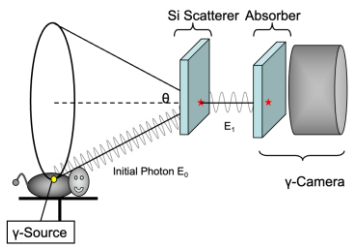
ARISTOTLE UNIVERSITY OF THESSALONIKI

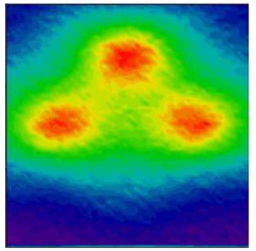
hcmr
ΕΛΚΕΘΕ

National and Kapodistrian University of Athens

- Nuclear Medical Imaging (SPECT-Lab, E. Styliaris)
  - Instrumentation for Emission Tomography (small field γ-camera, Compton Camera, Optical tomography)
  - Image Reconstruction Algorithms (iterative, stochastic)
  - Simulations on the GEANT4/GATE environment
- Nuclear Structure, Reactions and Application Group (NuSTRAP, T. Mertzimekis)
  - Nuclear Structure (shape coexistence, in exotic and stable nuclei, electromagnetic properties, symmetry, …)
  - Nuclear Reactions (Reaction studies with stable & RIB, Nuclear Astrophysics/p-process, …)
  - Instrumentation (detector developments for applied and fundamental research, sensors for marine radioactivity studies, …)



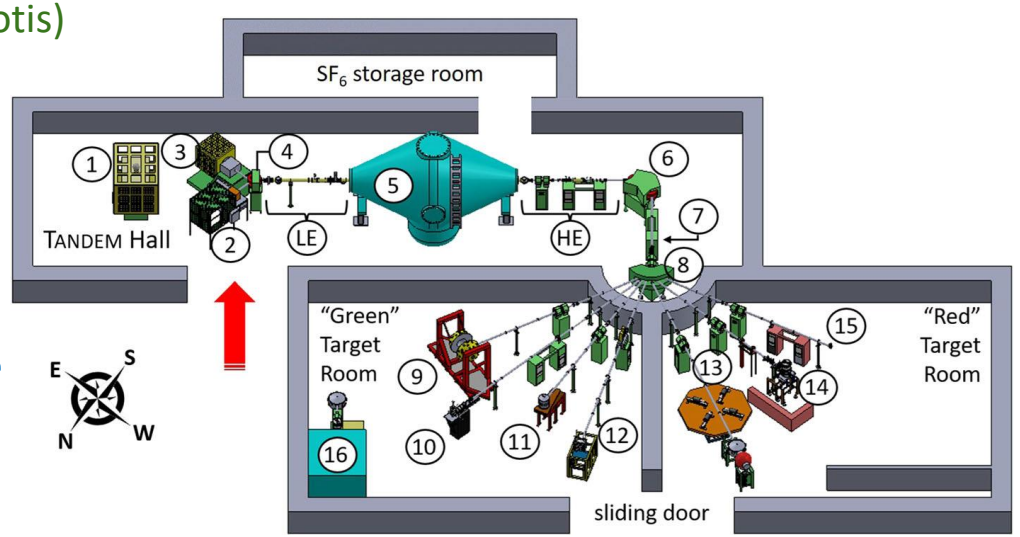




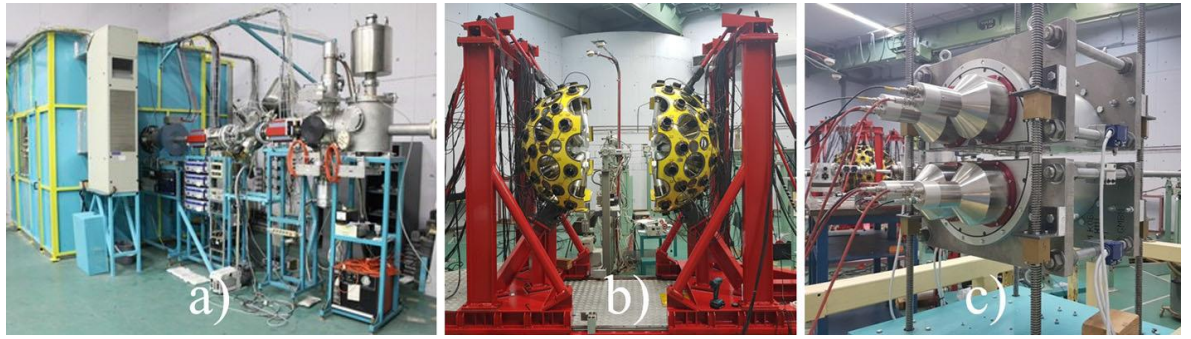
NCSR “Demokritos”

- Unique accelerator facility for fundamental and applied research
  (neutron beams keV-25 MeV, ion beams, dedicated experimental setups for particle and γ-ray spectroscopy, state of the art XRF lab)
- Nuclear Physics group (S. Harissopulos, A. Lagoyannis, A. Karydas, M. Axiotis)
  - Nuclear Astrophysics (p-process,...)
  - Nuclear Reaction studies ((n,x), (p,x), (d,x),...)
  - Nuclear Applications (IBA, NRA, RBS, XRF,...)
- Nuclear theory Group (D. Bonatsos)
  - Shape/phase transitions and nuclear shape coexistence
  - Symmetries in nuclear structure

DEMOKRITOS

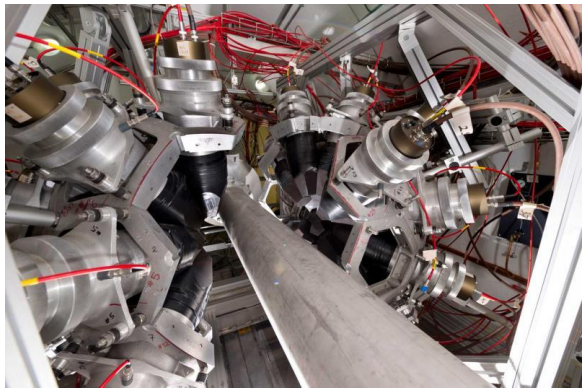


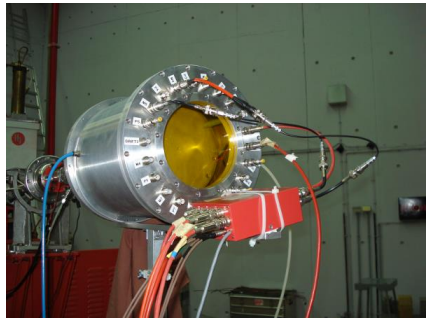

AMS (U. Oxford, under installation)



National Technical University of Athens

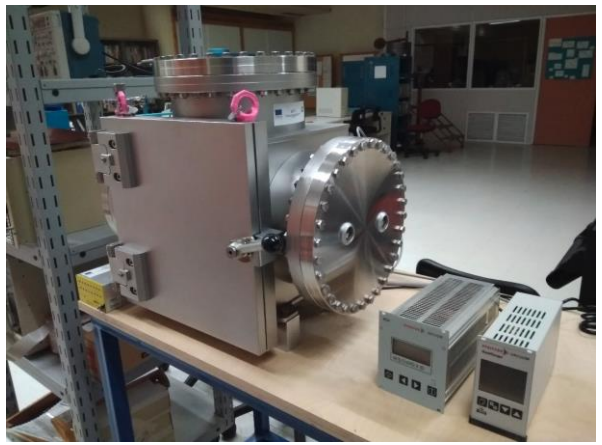
- Nuclear Physics Group (M. Kokkoris, M. Diakaki, R. Vlastou)
  - Nuclear Reactions (IBA, NRA, …)
  - Benchmarking and evaluation of nuclear reaction cross sections for IBA
  - Neutron Physics (fission reaction studies, (n,xn), …)
  - Instrumentation (detector developments for applied and fundamental research, …)
  - Radiological studies in aquatic environment



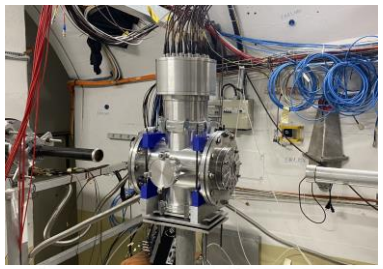
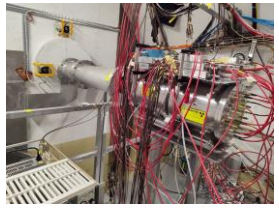
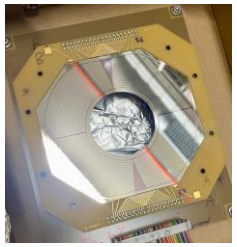


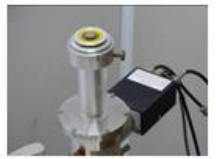
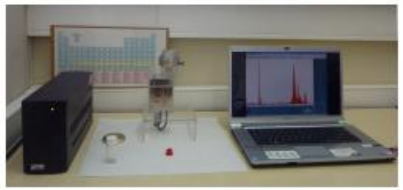
University of Ioannina

- Nuclear Physics Group (N. Patronis)
  - Neutron physics (Fission reaction studies, (n,xn), (n,cp), …)
  - Nuclear Astrophysics (s-process, p-process)
  - Nuclear Structure (transfer and Coulex reaction studies at ISOLDE)
  - Instrumentation (detector developments for fundamental research, …)
- Nuclear Applications (Ch. Papachristodoulou, K. Stamoulis)
  - Radioecology, Radioprotection
  - XRF lab (material characterization)
  - Archeometry lab



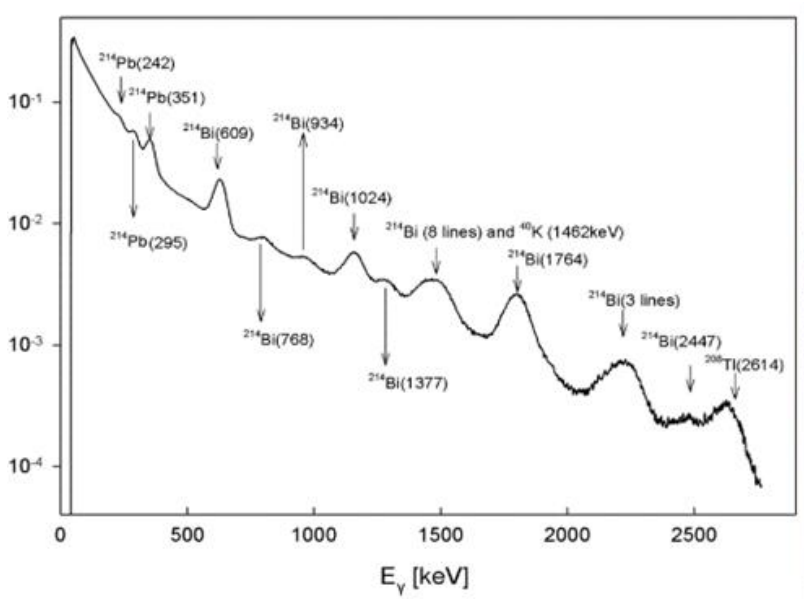



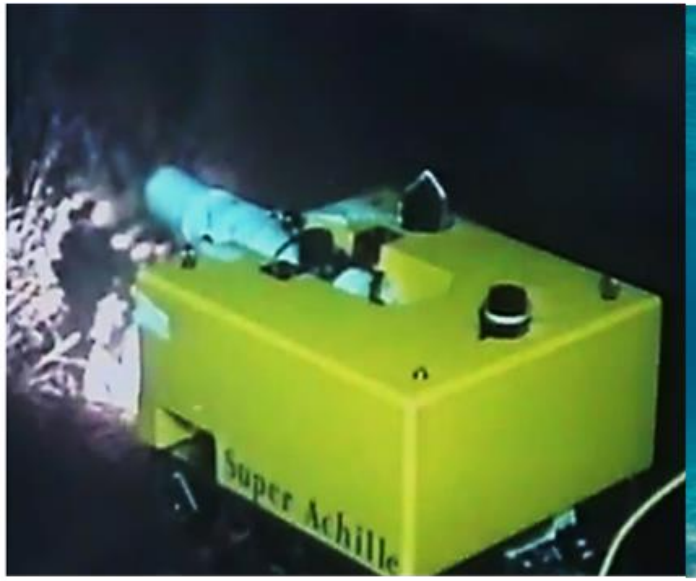

Aristotle University of Thessaloniki

- Nuclear Physics and Nuclear Applications group (A. Ioannidou, I. Savvides, S. Stoulos)
  - Environmental radioactivity and radioprotection
  - Nuclear Astrophysics
  - Nuclear fission reaction studies
  - γ-spectroscopy (characterization, detector development, in-situ spectroscopy,...)
- Nuclear theory group (Ch. Moustakidis, T. Gaitanos)
  - Nuclear matter theoretical calculations (Nuclear Physics of neutron stars,...)
  - Nuclear structure theoretical calculations

Hellenic Center for Marine Research

- Nuclear Marine applications group (Ch. Tsabaris. D. Patiris)
  - Instrumentation for radiation measurements in marine environment
  - Sea water radiation measurements and monitoring
  - Radiation measurement and monitor in mineral and thermo-mineral springs
  - Detection systems:
    - KATERINA marine sensor (stability, continuous operation, operation in deep water, …)
    - GeoMAREA marine sensor (autonomous mode of operation, self calibration, ohigh sensitivity,





Distinctions and funding of the Hellenic Nuclear Physics Community

- Distinctions
  - UoI: Prof. N. Patronis: n_TOF/CERN Physics Coordinator

- National and European funding
  - CALIBRA/3400 k€
  - EU H2020 EIC Pathfinder RAMONES / 4000 k€
  - EU Horizon Europe Widening “Nexus monARC” / 1500 k€
  - HFRI (Scholarships & research funding)/(600+200 + 60) k€
  - EU Horizon SANDA Project/ 3500 k€
  - G4G -ESA/ 500 k€

European Innovation Council

ΕΛΙΔΕΚ
Ελληνικό Ίδρυμα Έρευνας & Καινοτομίας
H.F.R.I.
Hellenic Foundation for Research & Innovation

European Commission

esa

The n_TOF facility

Is the "gluon" of the Greek Nuclear Physics Society:

- UoI and NTUA Nuclear Physics Groups are active and well involved members of the n_TOF collaboration
- AUTH members have already expressed interest to join
- Currently: >5 faculty members, 3 Post-docs, 4 PhD students, 4 MSc students, 4 BSc students
- Previous years: >7 PhD, >15 MSc thesis, …

Join forces for:

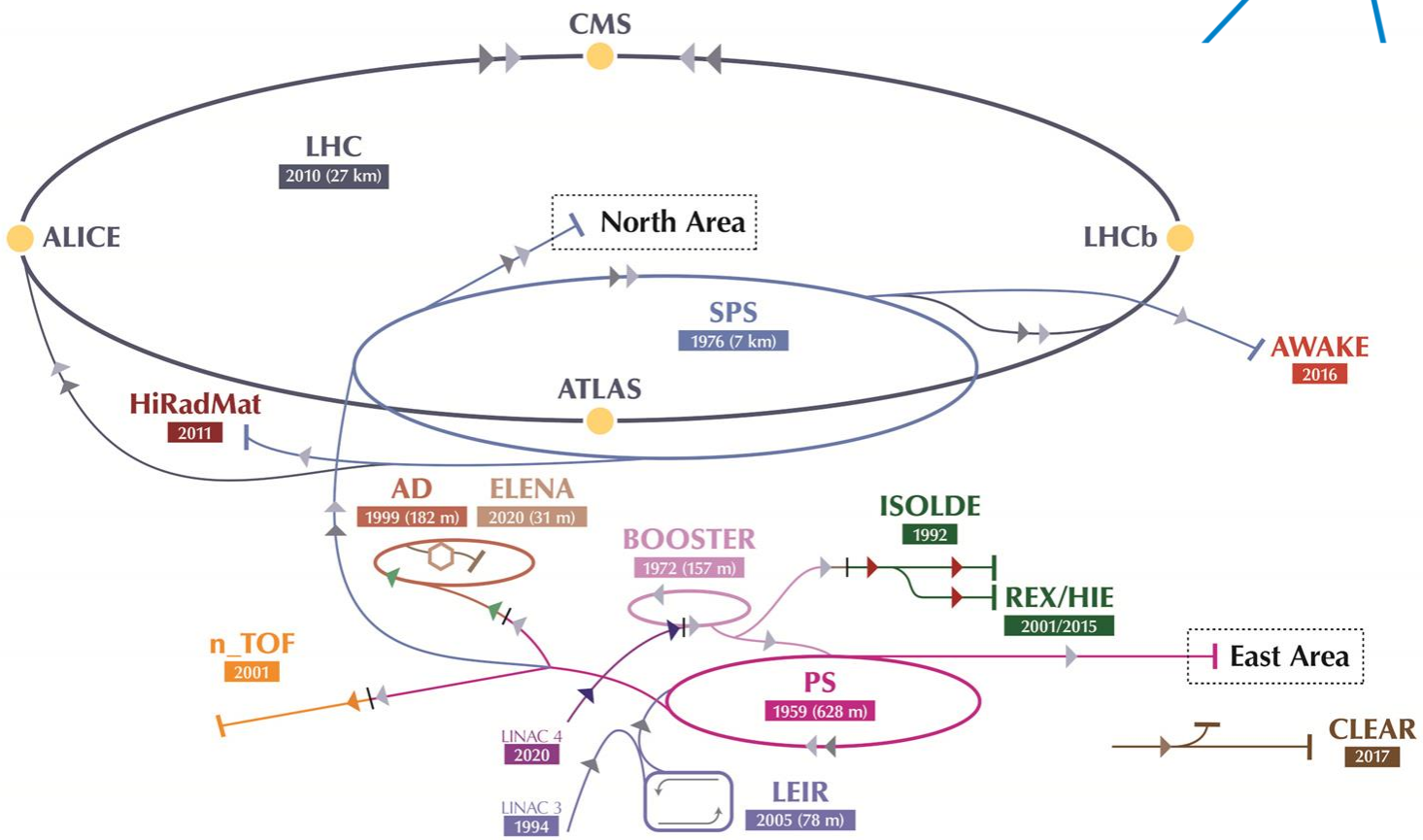
- Fission reaction studies (239Pu, 241Am, 230Th, …)
- (n,cp) reactions (medical applications, fusion technology, basic research)
- Nuclear astrophysics

The n_TOF facility

Motivation:

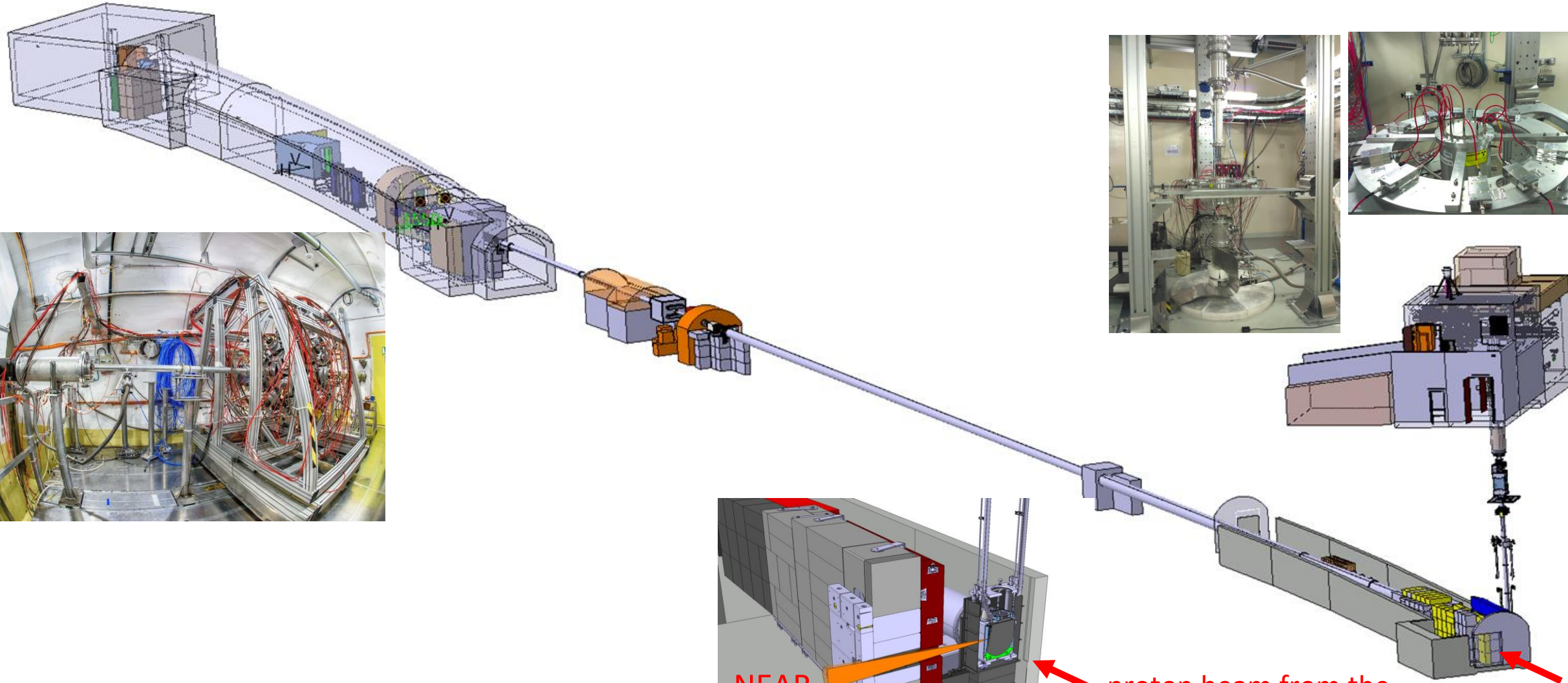
High precision neutron induced cross section measurements for:

- Nuclear astrophysics
- ADS systems and G4 Fast neutron reactors
- Medical physics
- Basic research
- Fusion technology



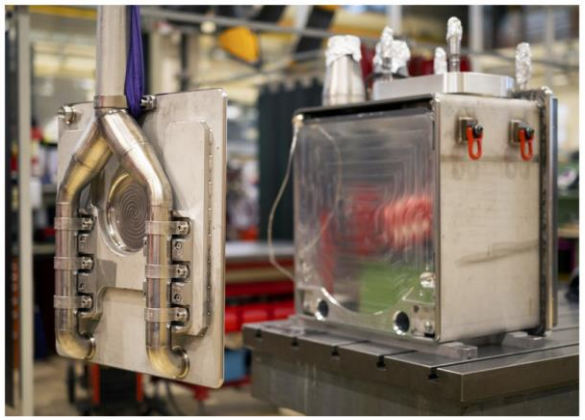
140 researchers
40 research institutions/teams
20 PhD students/year

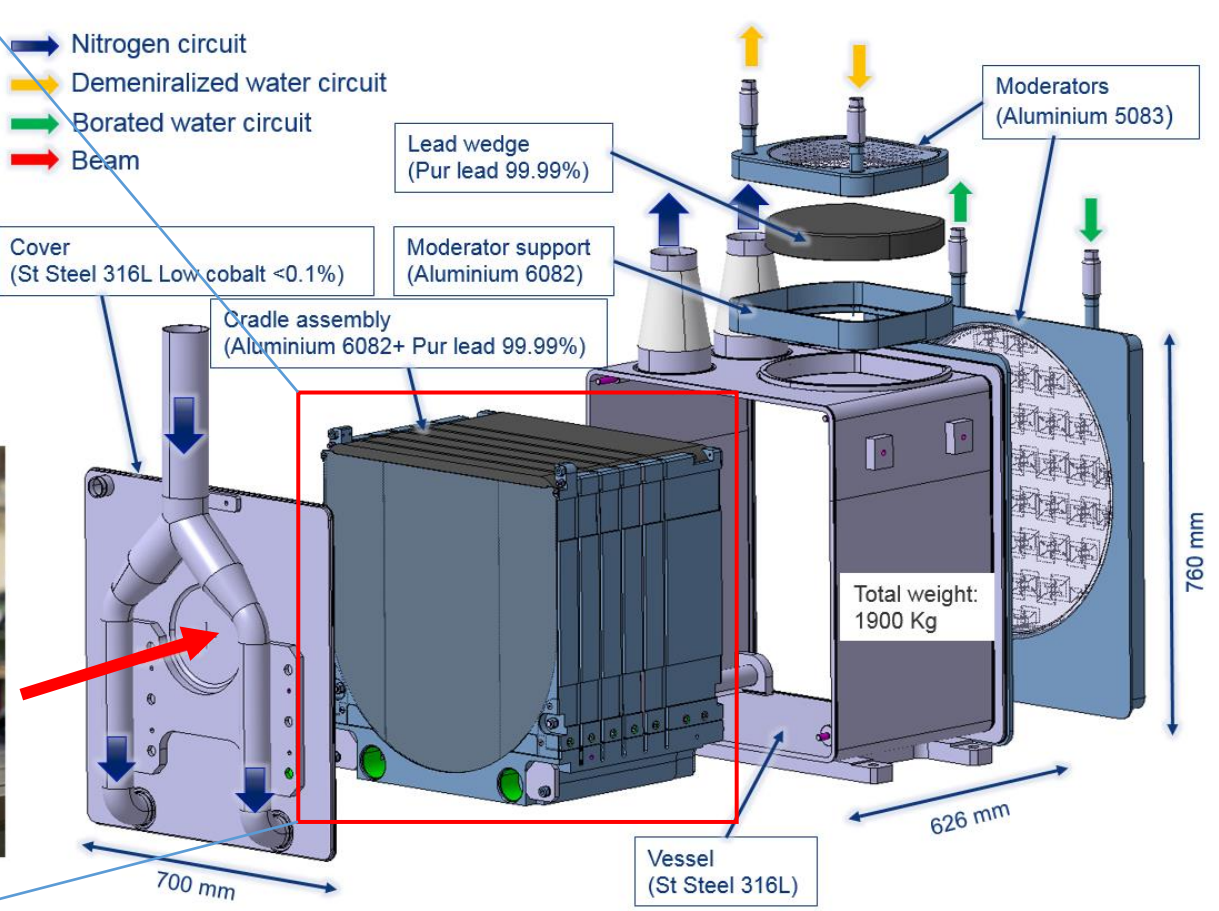
The n_TOF facility: EAR1 + EAR2 + NEAR

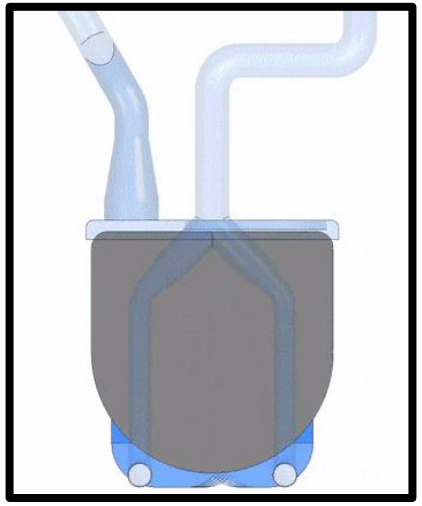


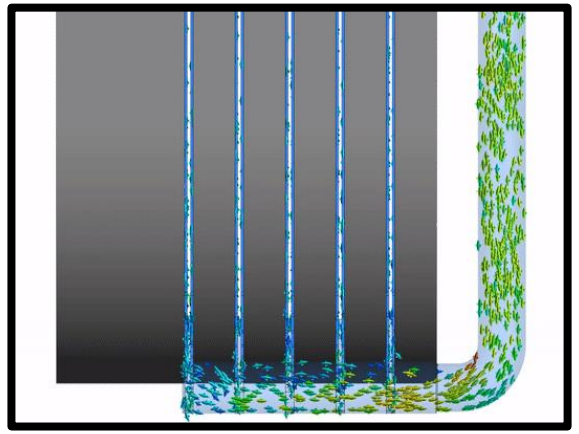
The n_TOF facility

3rd generation target









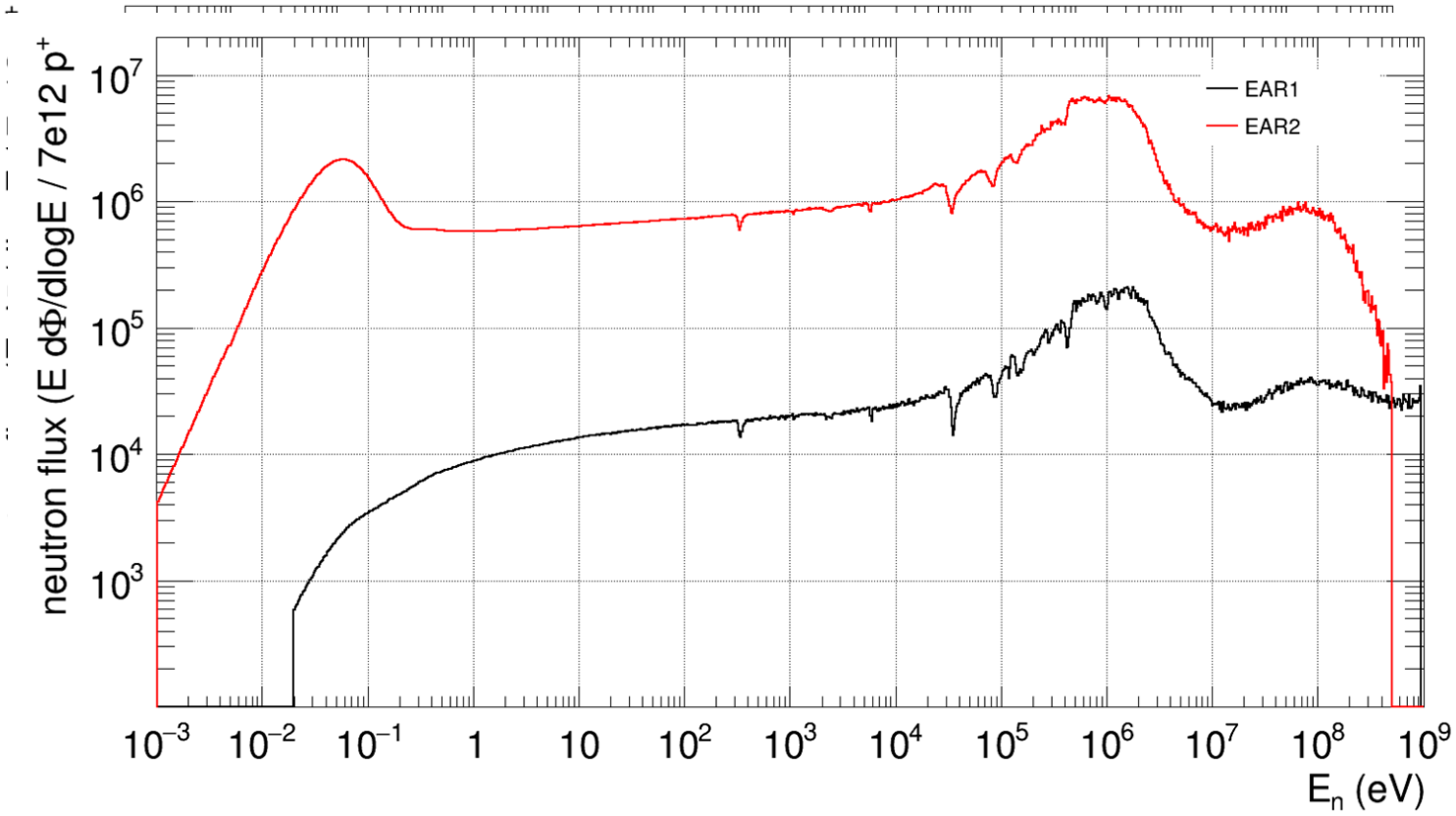
N_2 gas cooling to avoid Pb corrosion and contamination of the cooling circuit

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

The n_TOF facility

proton beam momentum	20 GeV/c
intensity (dedicated mode)	8.5 x 10^{12} protons/pulse
repetition frequency	1 pulse/1.2s
pulse width	7 ns (rms)
n/p	300
lead target dimensions	70x76x63 cm^3
cooling & moderation material	N_2 & H_2O (borated)
moderator thickness in the exit face	5 cm
neutron beam dimension in EAR-1 (capture mode)	2 cm (FWHM)

The n_TOF facility



- EAR1: 8.6E5 n/pulse
- EAR2: 3.4E7 n/pulse
- NEAR: 9E8 n/cm^2/pulse
- Pulse = 850E10 protons
- Max average proton intensity = 220E10 protons/s

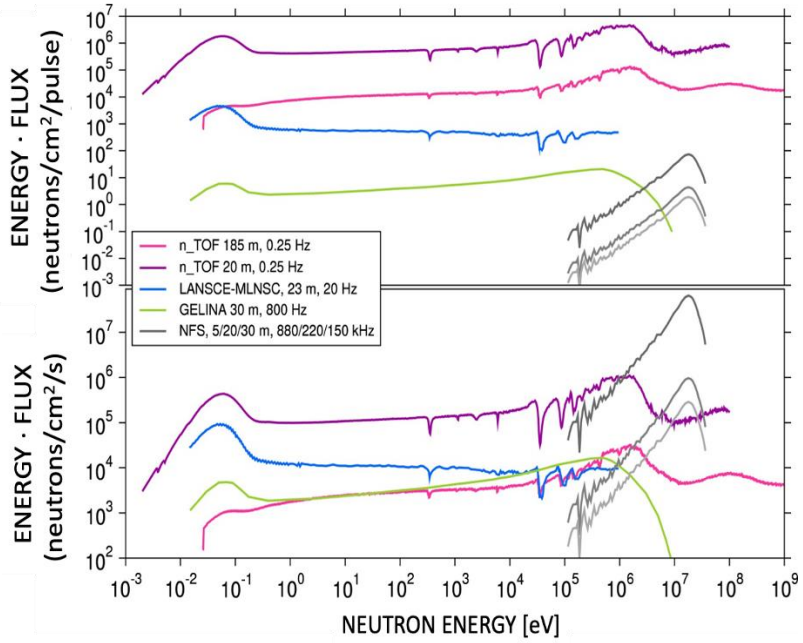
Neutron physics data for 11 orders of magnitude of neutron energies

The n_TOF facility: Is a unique neutron facility

- neutron source instantaneous intensity and energy distribution
- repetition rate of the driver
- time (or neutron energy) resolution
- background conditions
- n_TOF is @ CERN: ISOLDE a few tenths meter away, …

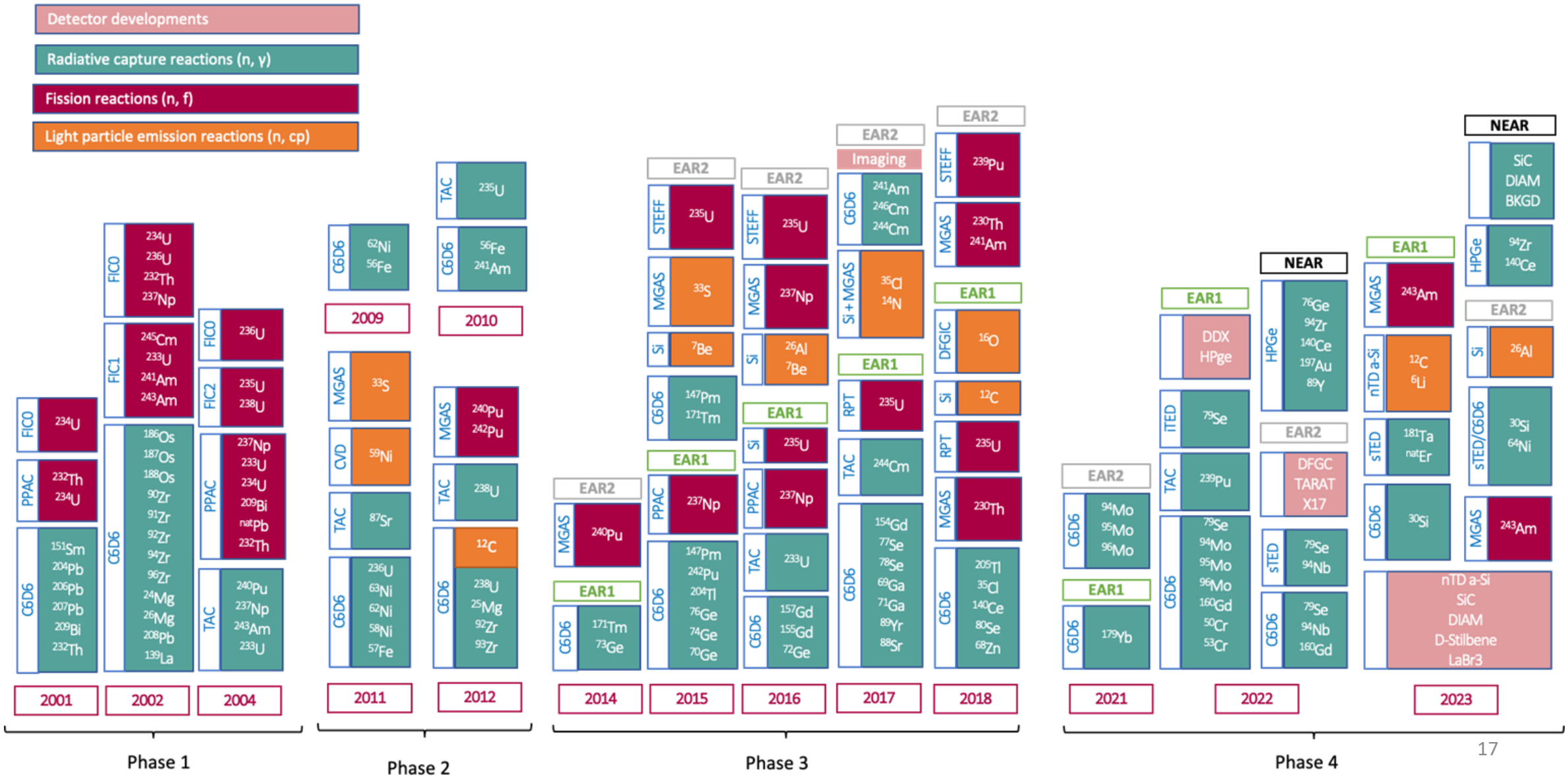
Reaction	Energy	Research area	Reference
^{171}Tm(n,γ)	< 1 MeV	stellar nucleosynthesis	PRL **125**, 142701 (2020)
^{7}Be(n,p)	< 1 MeV	big bang nucleosynthesis	PRL **121**, 042701 (2018)
^{7}Be(n,α)			PRL **117**, 152701 (2016)
^{63}Ni(n,γ)	< 1 MeV	stellar nucleosynthesis	PRL **110**, 022501 (2013)
^{151}Sm(n,γ)	< 1 MeV	stellar nucleosynthesis	PRL **93**, 161103 (2004)
^{232}Th(n,f), ^{233}U(n,f)	< 1 GeV	advanced fuel cycles	PRC **107**, 044616 (2023)
^{235}U(n,f)	< 1 MeV	cross section standard	EPJA **55**, 120 (2019)
^{238}U(n,f)/^{235}U(n,f)	1 MeV - 1 GeV	cross section standard	PRC **91**, 024602 (2015)
^{232}Th(n,γ)	< 1 MeV	advanced fuel cycles	PRC **86**, 019902 (2012)
^{245}Cm(n,f)	< 1 MeV	transmutation of MA	PRC **85**, 034616 (2012)

Neutron Physics with particle accelerators
N. Colonna, F. Gunsing, and F. Käppeler
Progress in Particle and Nuclear Physics, **101**, 177 (2018)
https://doi.org/10.1016/j.ppnp.2018.02.002



Neutron physics data for 11 orders of magnitude of neutron energies

The n_TOF history in a nutshell



The n_TOF (bright!) future

Short term

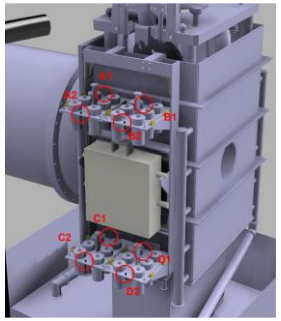
- Ready to launch new type of physics measurements ((n,n'), (n,xn), (n,cp), (n,tot), ...)
- Ready to go ahead with other applications (imaging, R2E, …)

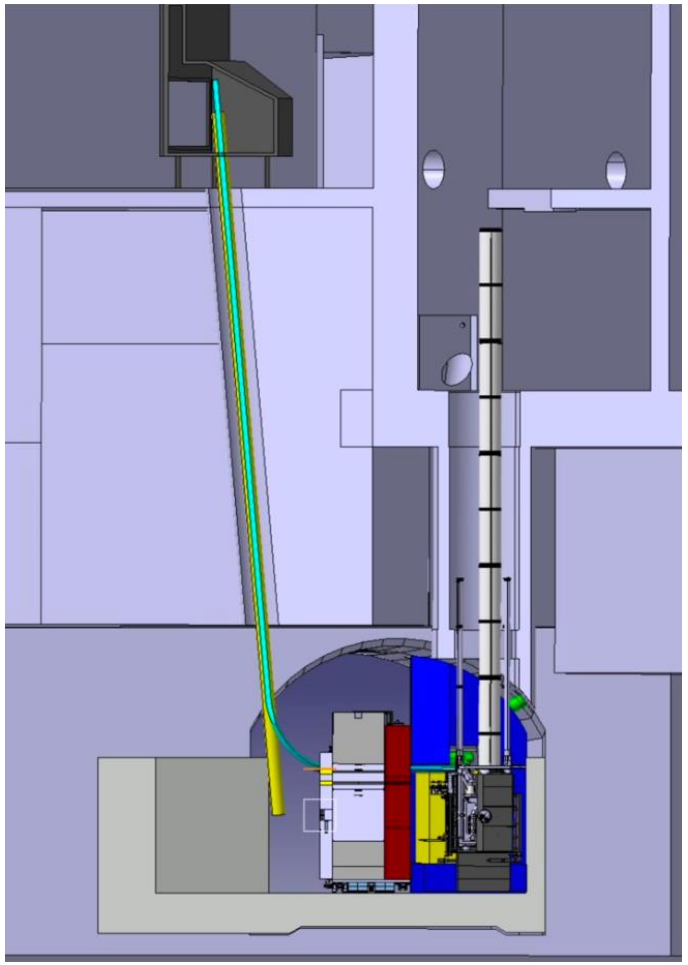
Mid term

- Rabbit and gamma spectroscopy station (funding for Clover HPGe ensured)
- Moderator for NEAR beam

Long term

- Discussions for next (high power?) #4 n_TOF target (LS4)
- REAR station? (post LS4)
- …





Conclusions

- The Hellenic Nuclear Physics community is a continuously growing and dynamic community from the point of view of attracting young researchers and postgraduate students.
- Concerning Faculty/Researchers: A strong reduction in the number of permanent positions has occurred in the past ten years (hirings << retirements).
- The funding of Nuclear Physics Research is also significantly reduced.
- Research items within the Hellenic Nuclear Physics community:
  - Fundamental research in nuclear structure and nuclear reaction mechanisms
  - Applied nuclear physics research
  - Nuclear theory
- NCSR “Demokritos” is the hub for the Greek Nuclear Physics Community offering training and hands-on involvement (especially in neutron beams) for younger colleagues and students. Dedicated and movable setups are there along with a variety of ion beams and different energies of neutron beams
- The n_TOF/CERN collaboration unites us in shared projects and research initiatives. The ongoing synergies between Greek institutes and international partners contribute to the continual growth, strengthening, and enrichment of the nuclear physics program within the n_TOF framework.

Thank you so much for your attention!

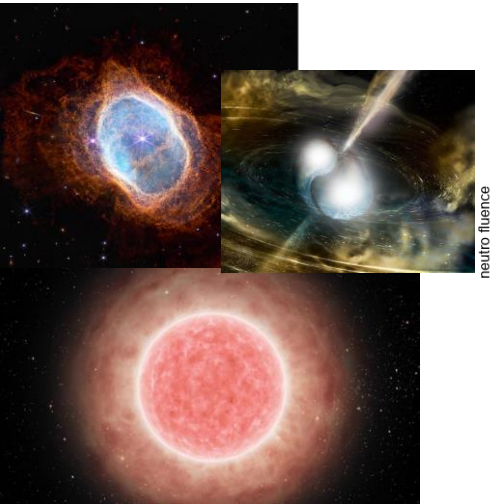
Extra Slides

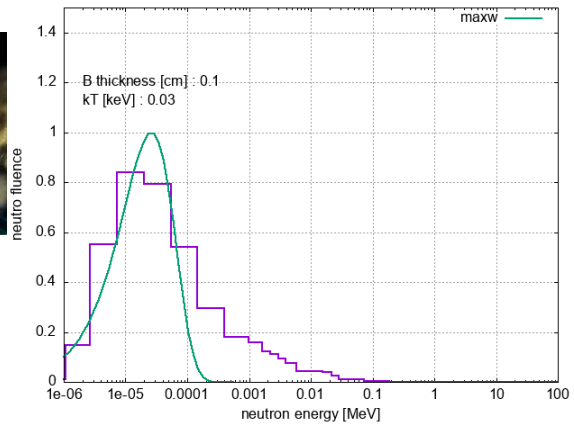
The NEAR station

The NEAR Station is the n_TOF facility's new high-flux irradiation station.

Two regions of activities

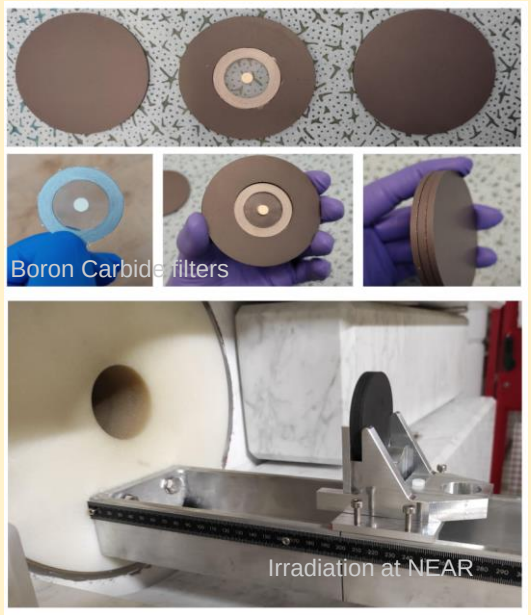
1) The irradiation area i-NEAR. Located next to the lead spallation target: high neutron dose material studies
2) **The activation area a-NEAR**. Located just outside the target bunker shielding, at only 3m distance from the target: **nuclear astrophysics studies**



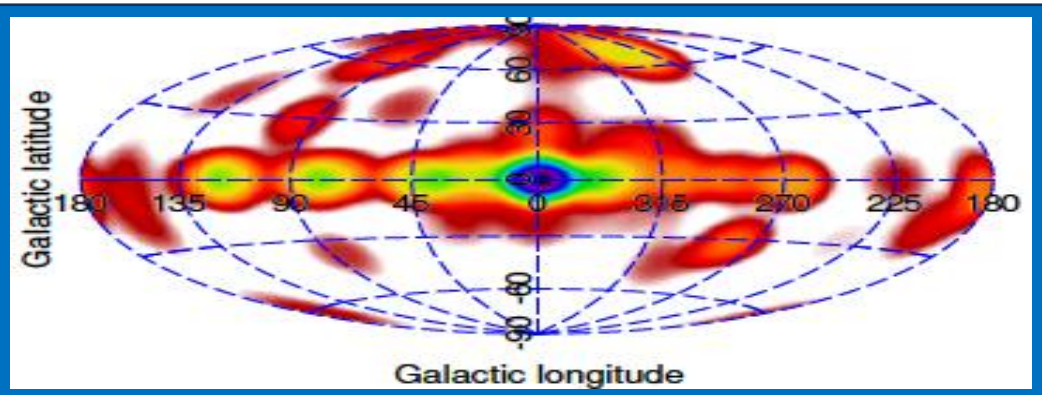


We can make **integrated reaction rate measurements by shaping** the neutron spectrum to look as close as possible to the stellar one

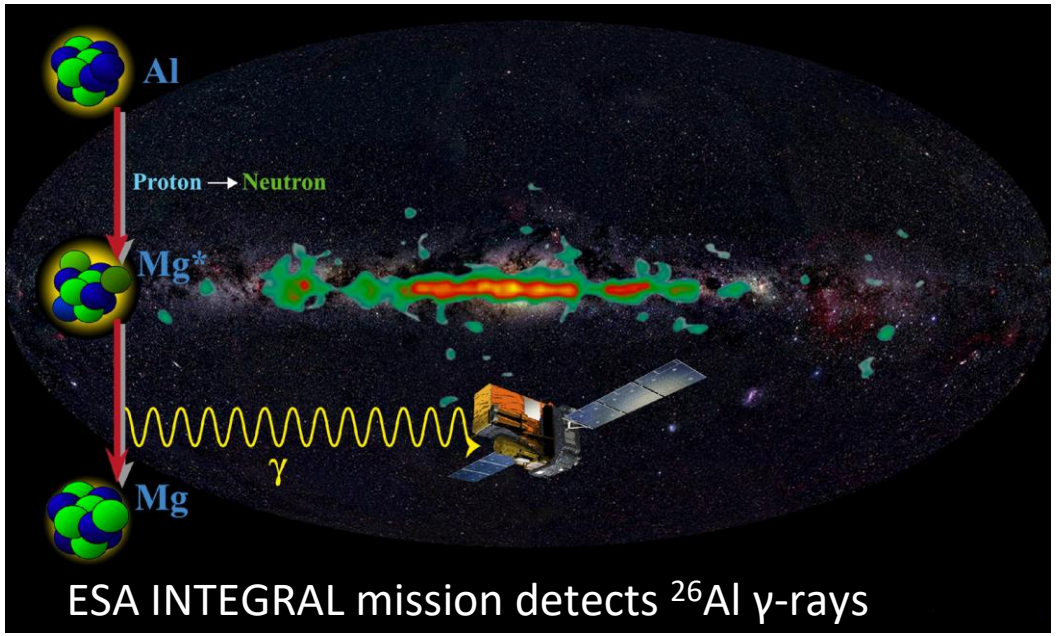
- **The proof-of-principle** study **of shaping the n_TOF-NEAR neutron spectrum** towards the extraction **of stellar reaction rates** was **explored for the first time**
- **Boron carbide filters** were used **for the shaping the n_TOF - NEAR neutron spectrum**
- **Really promising results (!) showing that we can indeed obtain the stellar reaction rates even for the most challenging and unexplored physics cases**



Understanding the ^{26}Al "Galactic snapshot" at n_TOF



The distribution of the ^{26}Al "light "(=1.8 MeV γ-ray) across the Milky Way. This is a "snapshot" of the ongoing chemical elements production



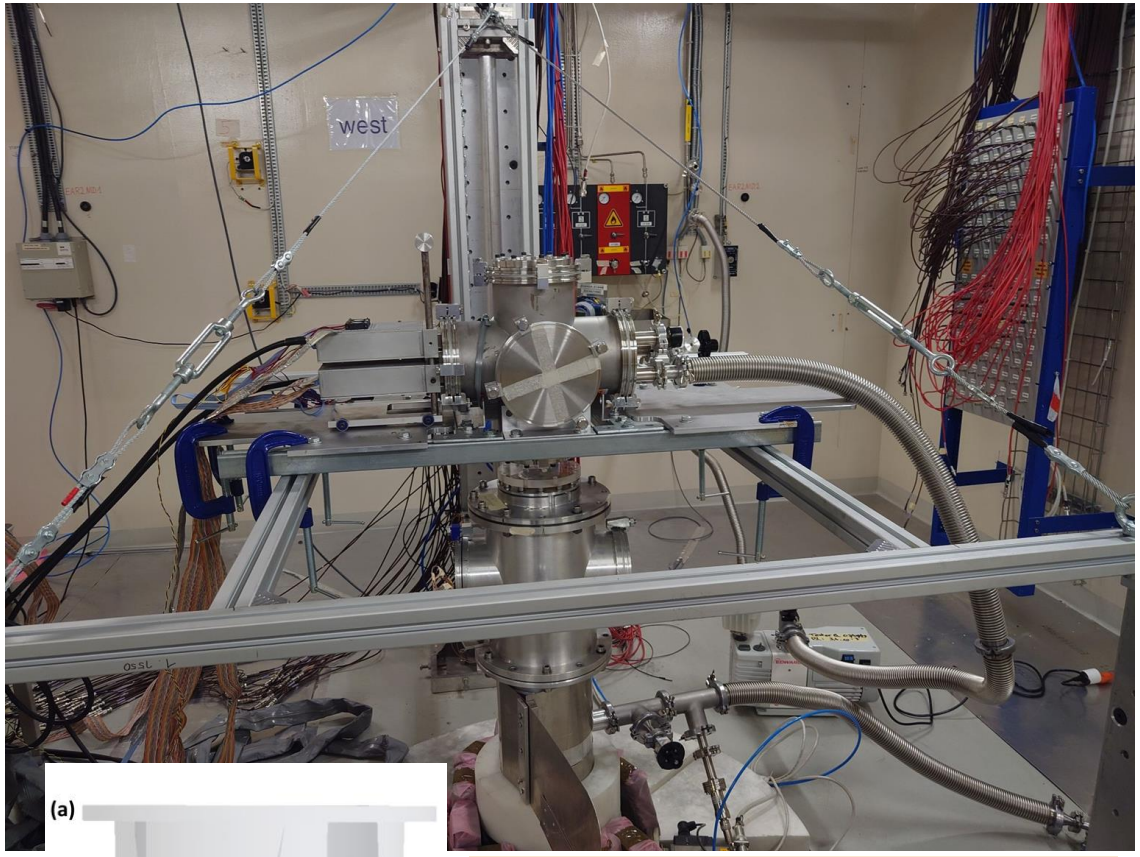
ESA INTEGRAL mission detects ^{26}Al γ-rays

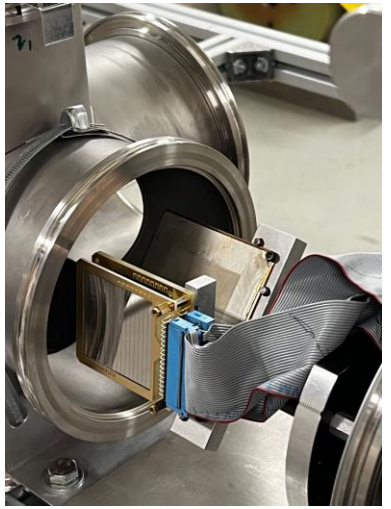
- **^{26}Al is a radioactive nucleus produced in massive stars**
- The ^{26}Al half-life time (=720 10^3 y) is still very small with respect to the age of Universe.
- Each **^{26}Al nucleus** decay produce one **highly energetic γ-ray at 1.8 MeV**. The **interstellar medium is transparent to this "light"**
- By recording these γ-rays **we have a "snapshot" of on-going nucleosynthesis in our Galaxy**. Accordingly, we can trace the dynamics of the Milky Way (rotational speed, expansion, chemical element production, etc)
- By studying the 26Al(n, p/a) reactions up to 500 keV we can determine the 26Al destruction rates in massive stars which are the major source of 26Al in our galaxy

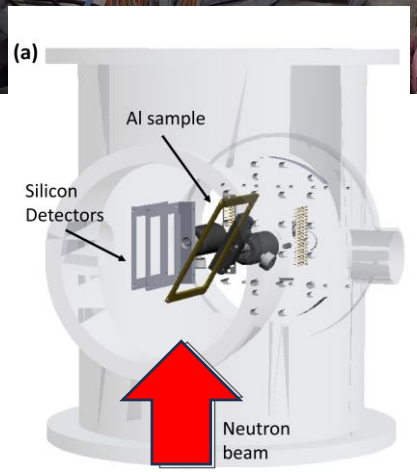
Aim of the measurement is to extend cross section data up to 500 keV

Many thanks to Claudia LEDERER-WOODS and U. of Edinburgh

Understanding the ^{26}Al "Galactic snapshot" at n_TOF







Setup/Conditions

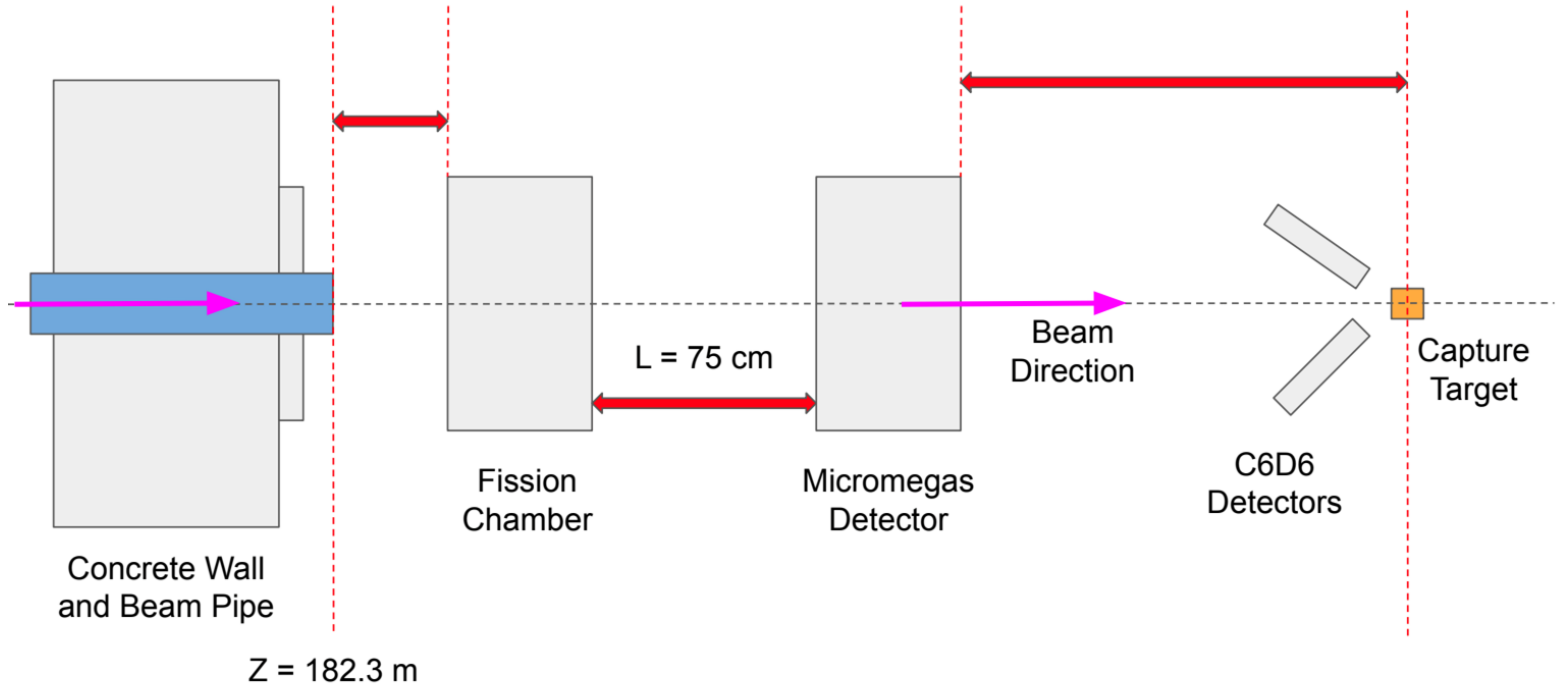
- Sample*: 6 × 5 cm^2; 2.58(12) × **10^{17} atoms of ^{26}Al** on a 7.5-μm Ni foil
- 20 um SSD + 150 um DSSSD @ 90 deg

*damaged in later a test
https://edh.cern.ch/Document/General/IncidentDeclaration/9967462

Many thanks to Claudia LEDERER-WOODS and U. of Edinburgh

First n_TOF transmission measurement: MArEx

- Transmission test measurements (Al/Bi) using beam filters
- Transmission test measurements (Al, C) before second collimator
- First n_TOF gas target (Ar) transmission measurement **successfully realized!**



METHOD

- **Transmission measurement using beam filters (Al, Bi)**
- **Transmission measurements with standard samples (Al, C) placed before 2nd collimator**
- **Transmission measurement with Ar gas target realized before the second collimator**

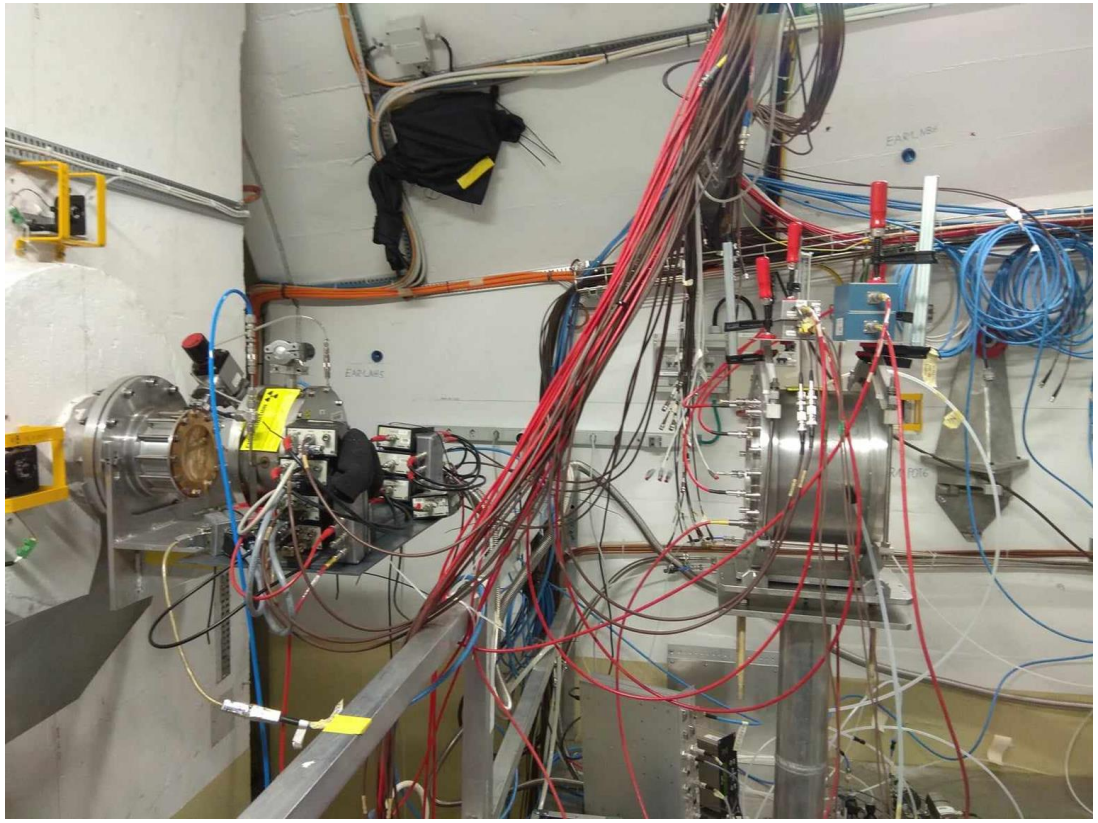
SETUP

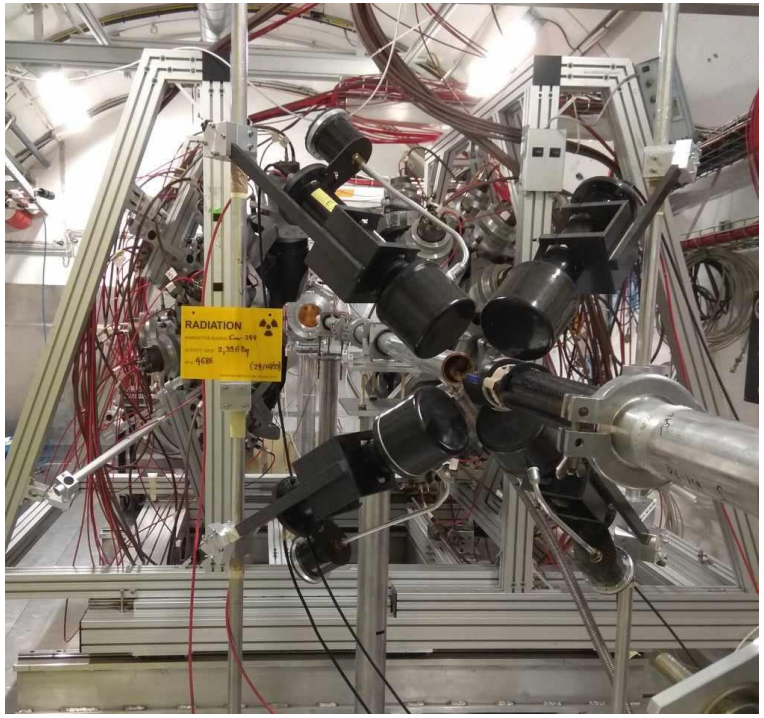
- **PTB LMFC (U5) (Fission Chamber)**
  - **6 samples: 1.9 mg/cm2, 42 mm**
  - **2 blanks (front, back)**
  - **gas Ar/CF4 90/10**
- **MGAS (10B)**
  - **18.82 ug/cm2**
  - **8 ugr/cm2**
- **C6D6 (Au,Ta)**
  - **4 x C6D6 @ 9 cm**
  - **Au/Ta sample ~45 mm diameter**

Many thanks to MArEx team!

First n_TOF transmission measurement:

- Transmission test measurements (Al/Bi) using beam filters
- Transmission test measurements (Al, C) before second collimator
- First n_TOF gas target (Ar) transmission measurement **successfully realized!**

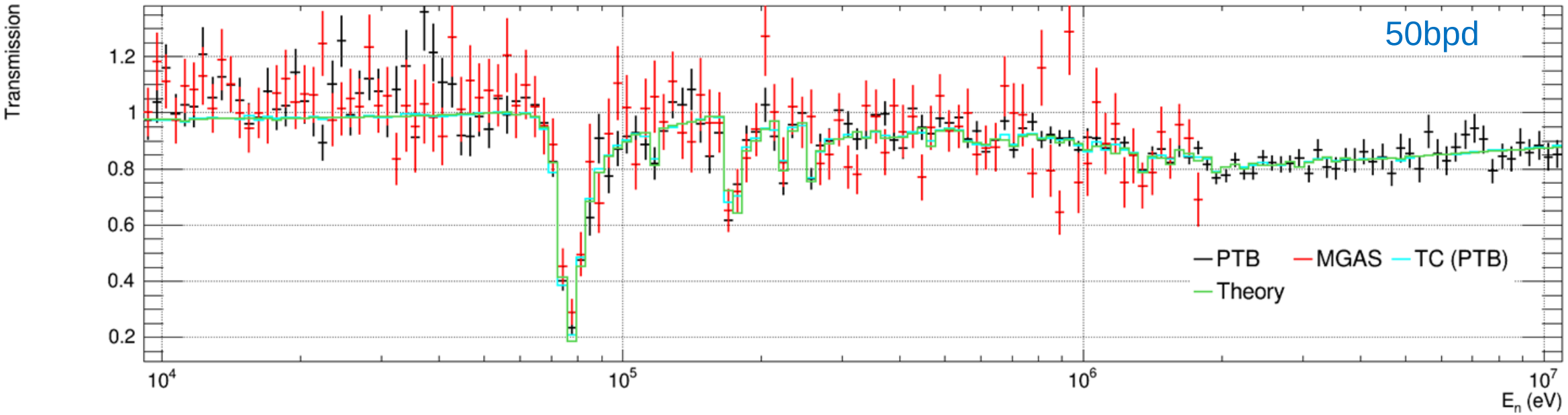




Many thanks to MArEx team!

First n_TOF transmission measurement: MArEx

- Ar gas target transmission measurement (before 2nd collimator)

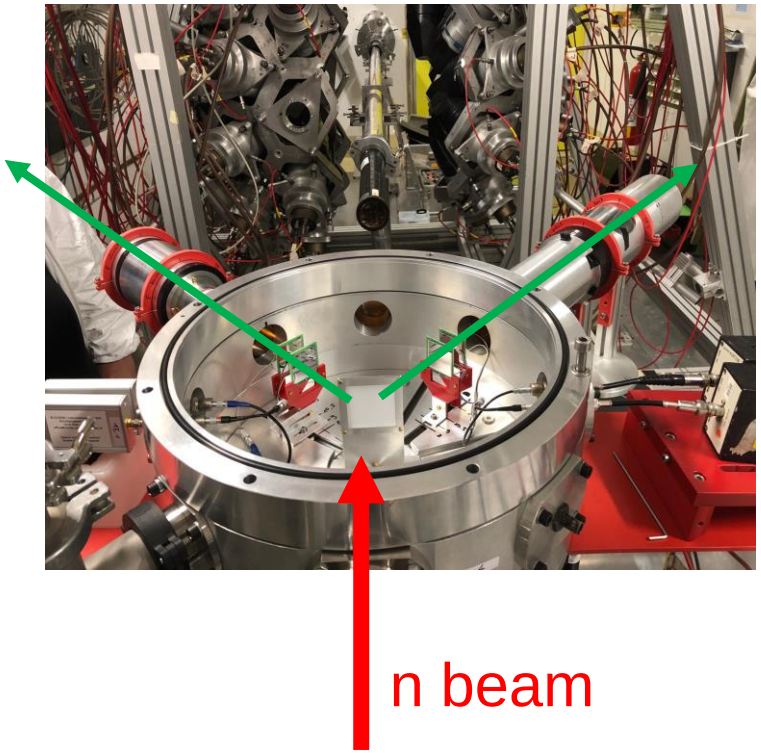


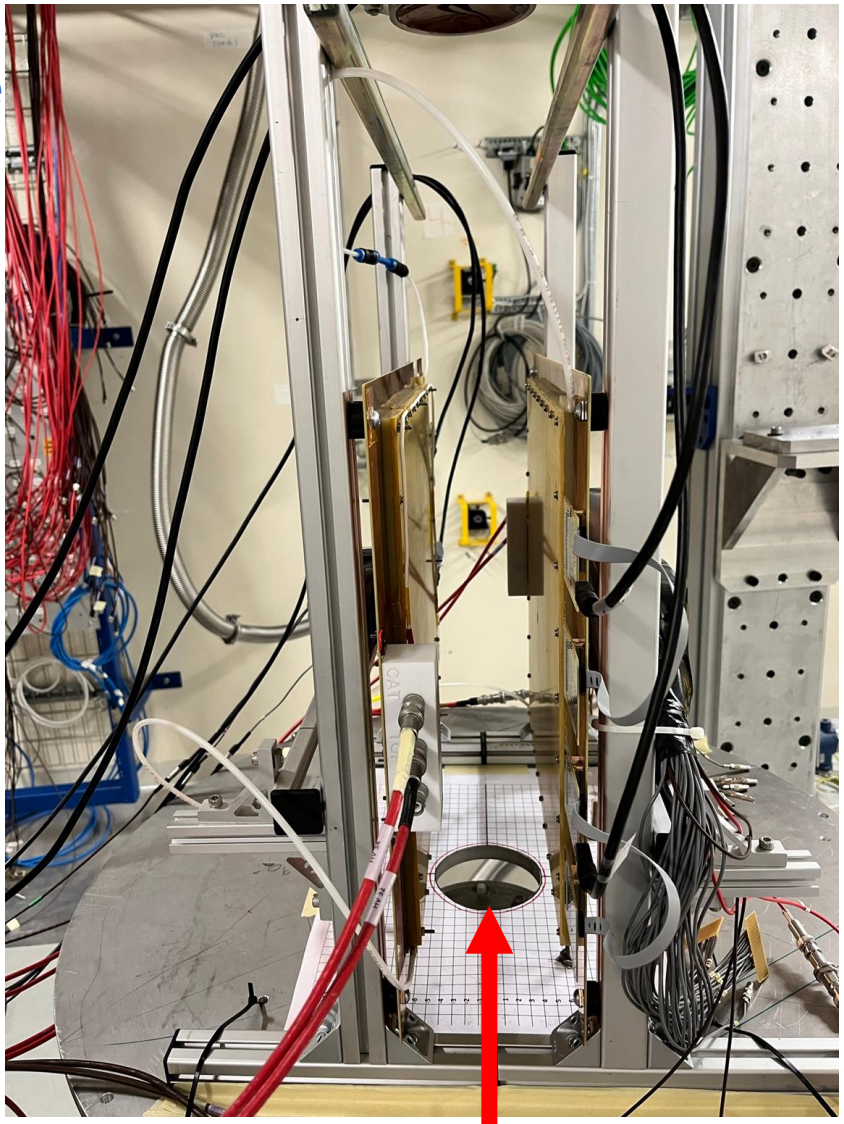
Many thanks to MArEx team!

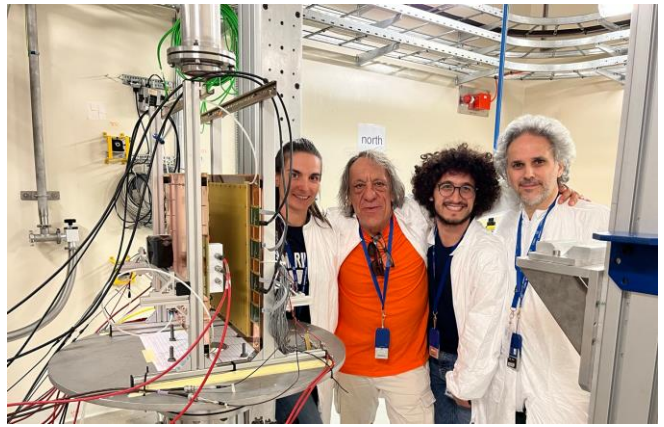
Detector

DDX:

Double-Differential Charged-Particle detection setup for XS measurements from 20 to 200 MeV







X17 detection setup:

- TPC
- LYSO
- Plastic

Resolution function – setup