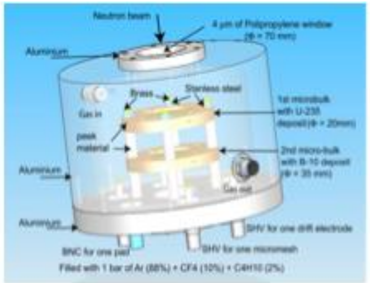
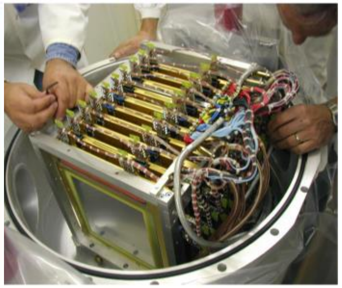
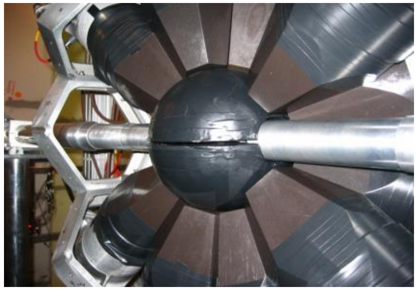
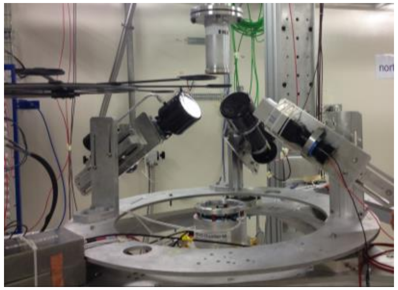
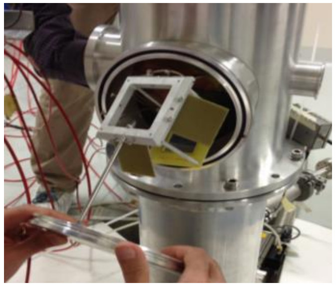
The n_TOF Collaboration

http://www.cern.ch/nTOF

Status and perspectives of the neutron time-of-flight facility n_TOF at CERN

Enrico Chiaveri

Spokesperson of n_TOF Collaboration

What is n_TOF?

- The n_TOF Collaboration was founded in 2001

  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.

- Members as of January 2019:
  - 42 Institutions (from EU, India, Japan, Russia and Australia)
  - 130 scientists
  - 2 experimental areas at CERN (EAR1, EAR2 since 2014)

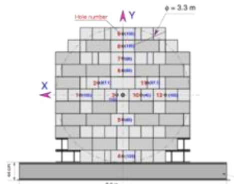
- Motivations for neutron cross section measurements @ n_TOF
  - Nuclear Astrophysics
  - Nuclear Physics
  - Nuclear Application:
    - Nuclear reactors (fission and fusion)
    - Nuclear Waste Transmutation
    - Nuclear Medicine

> “The goal of the nTOF is to provide unprecedented precision in neutron kinetic energy determination, which will in turn bring much-needed precision in neutron-induced cross-section measurements. Such measurements are vital for a range of studies in fields as diverse as nuclear technology, astrophysics and fundamental nuclear physics. The nTOF will provide neutron rates some three orders of magnitude higher than existing facilities, allowing measurements to be made more precisely and more rapidly than in the past.”
>
> CERN COURIER July 2nd 2001

The n_TOF facility: timeline

1996 — 2018

1995 – 1997



TARC Experiment

1997

Concept
by C. Rubbia
CERN/ET/Int. Note 97-19

May 1998

Feasibility
CERN/LHC/98-02+Add

Aug 1998

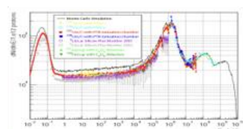
Proposal submitted

1999

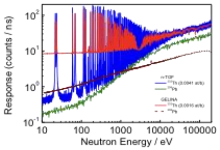
Construction started

2000

Commissioning



2001 – 2004



Phase I
Isotopes
Capture: 25
Fission: 11

2004-2007

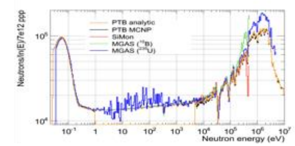
Target activation
R&D of new solutions

2008

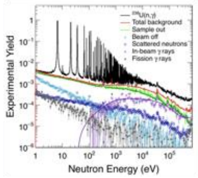
Target #2 construction

May 2009

Commissioning



2009 – 2012



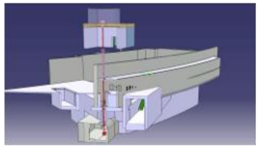
Phase II
Isotopes
Capture: 14
Fission: 3
(n,cp): 2

2009

Upgrades
Borated-H_2O
Class-A
Second Line

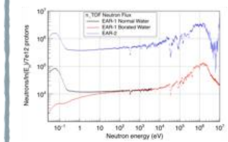
2011 – 2013

EAR2
Design and Construction



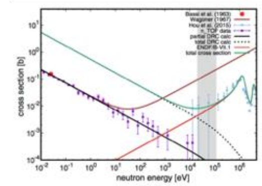
2014

Commissioning



2014 – 2018

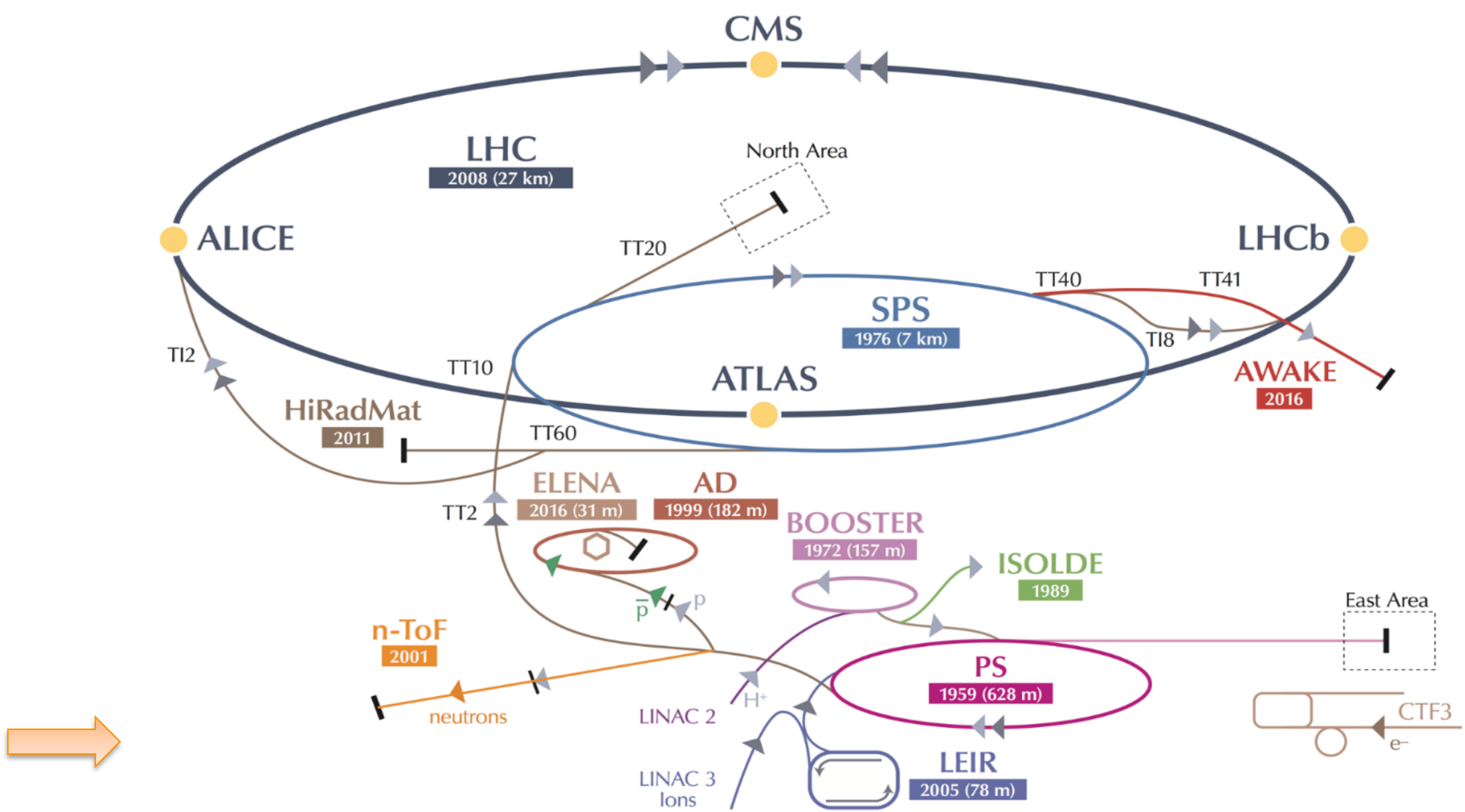
Phase III
Isotopes
Capture: 18
Fission: 5
(n,cp): 9
Neutron Imaging



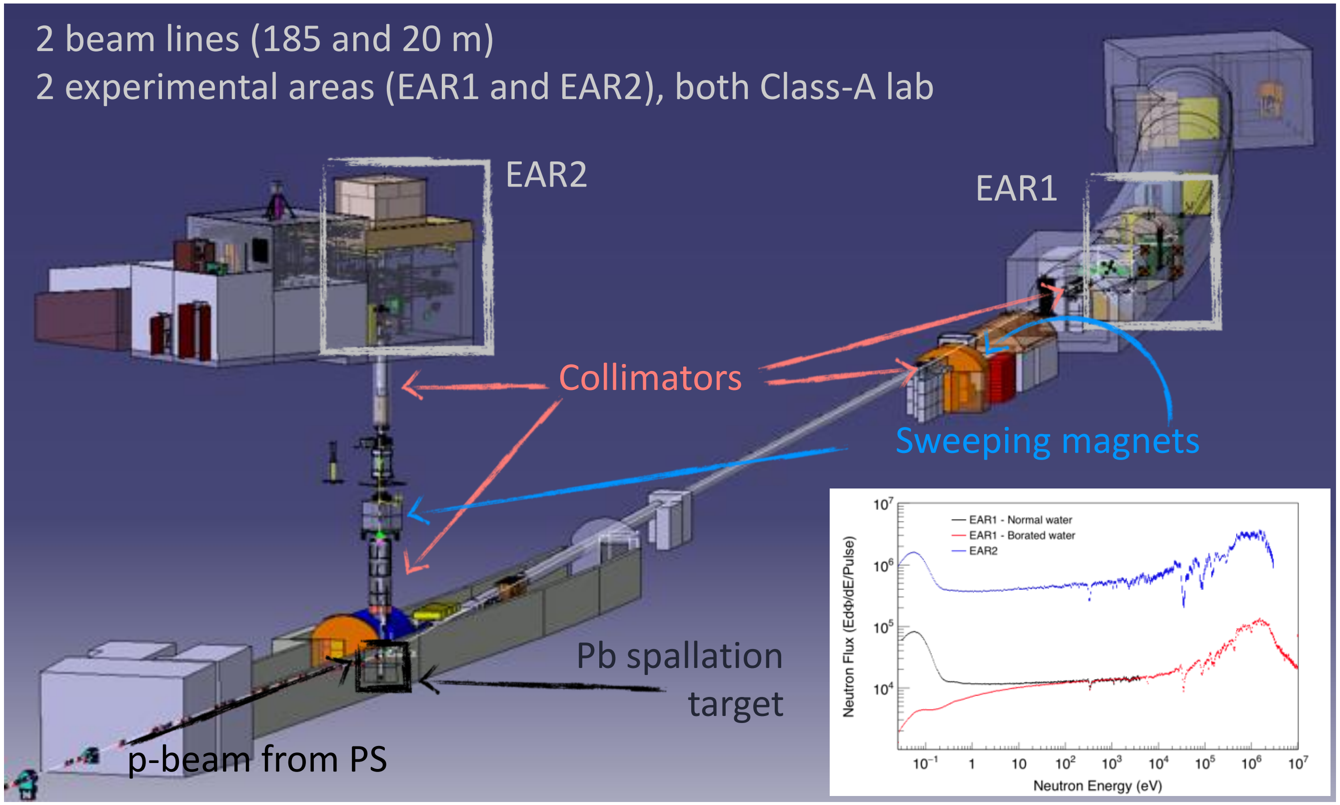
2019 – …

Future
Target #3
Irradiation station
…

The n_TOF facility: A neutron spallation source using the PS 20 GeV/c proton beam

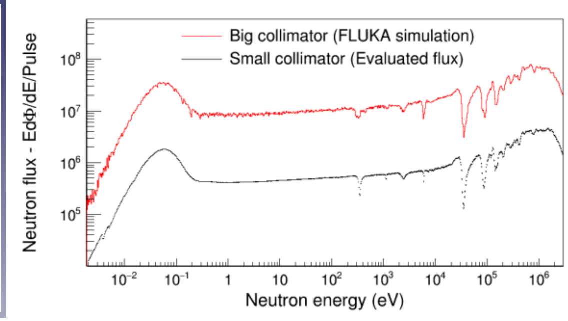


The n_TOF beam: neutron beam lines



Some figures

	EAR1	EAR2
Wide energy range	thermal to 1 GeV	thermal to 300 MeV
High instantaneous neutron flux	2 x 10^5 n/cm^2/pulse	3 x 10^6 n/cm^2/pulse
Low repetition rate	< 0.8 Hz (1 pulse/2.4 s max)	
High energy resolution	$\Delta E/E=10^{-4}$ (@10 keV)	$\Delta E/E=10^{-3}$ (@10 keV)



- Main feature of n_TOF is the synthesis of extremely high instantaneous neutron flux and excellent energy resolution
- Unique facility for measurements of radioactive isotopes (maximize S/N)
  - Branch point isotopes (astrophysics)
  - Actinides (nuclear technology)

n_TOF Experimental AReas: complementarities

EAR1

- Broad energy range up to GeV
- Excellent energy resolution: very long baseline
- High instantaneous flux
- Low background
- Precision measurements (actinides)
- Ideal for capture cross section measurements

EAR2

- Neutron fluence is on average increased by a factor of 40 wrt EAR1
- Good energy resolution
- Very small mass samples (<1 mg) could be measured
- Radioactive samples measurements
- Very small cross-section
- Much shorter time scale measurement
- Running in parallel with Experimental Area 1

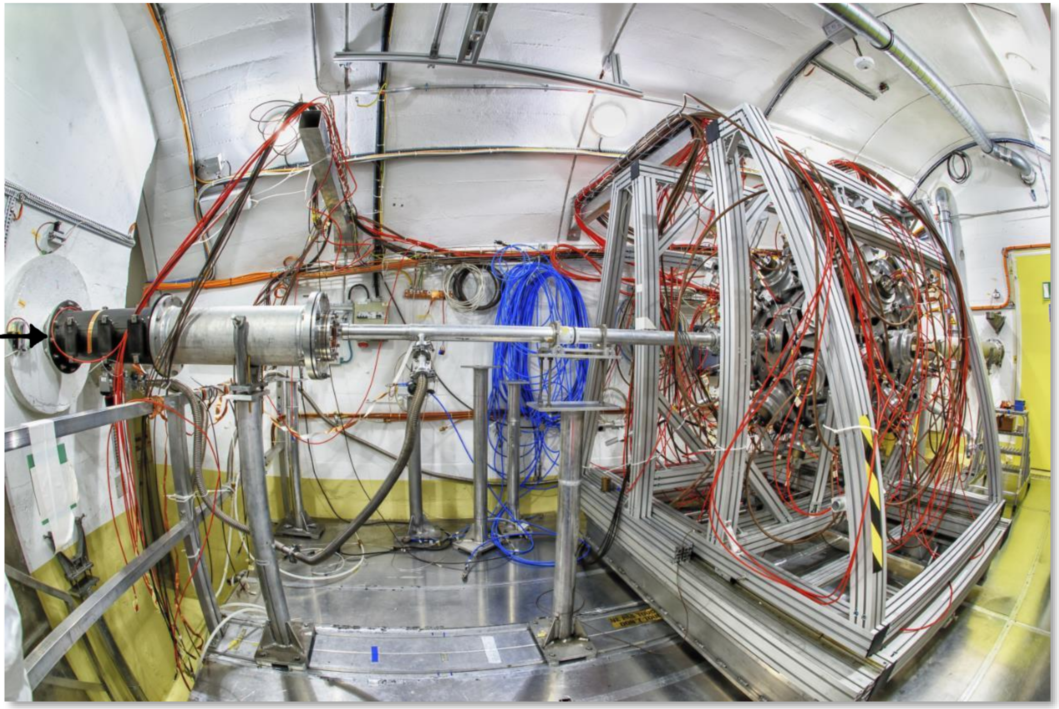
n_TOF Experimental AReas: EAR1

Entrance of n_TOF beam line

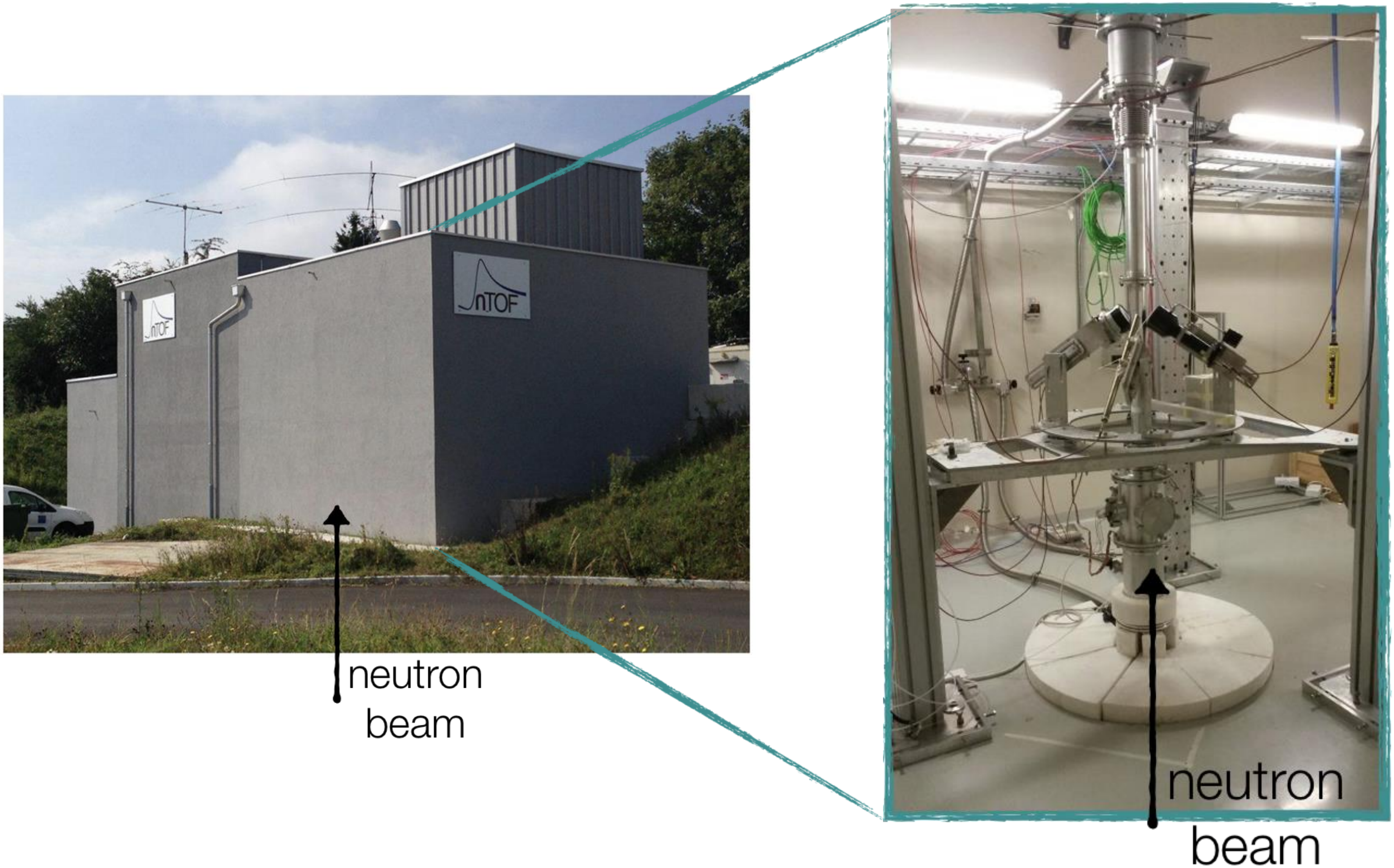
Escape line

neutron beam

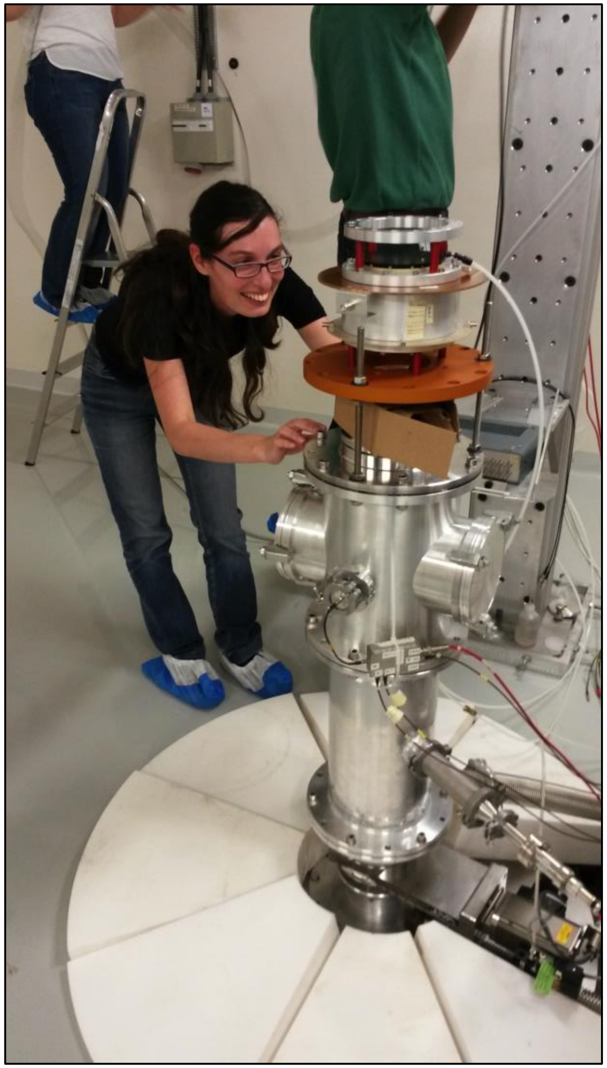
EAR-1 bunker

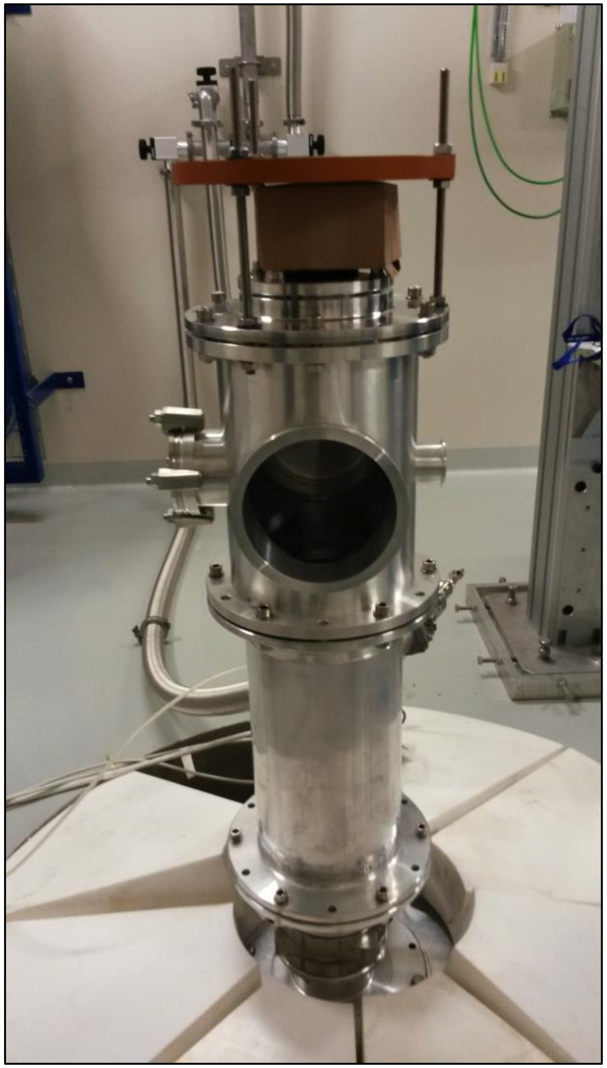


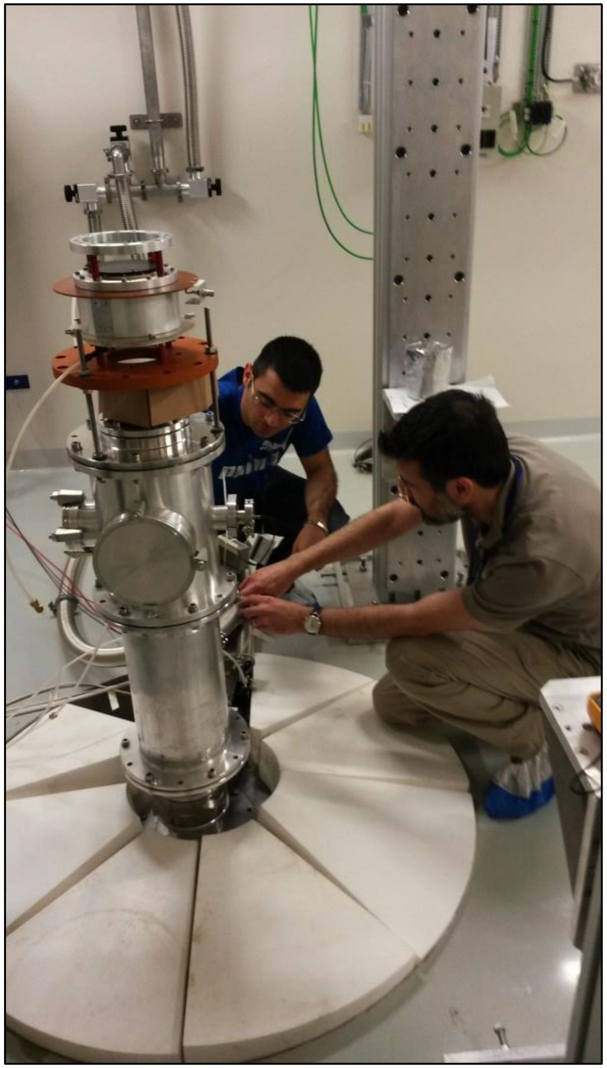
n_TOF Experimental AReas: EAR2



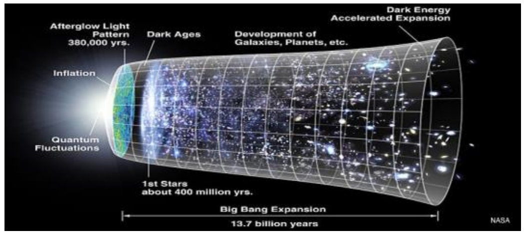
n_TOF Experimental AReas: EAR2

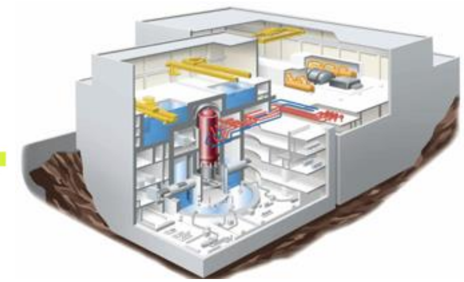






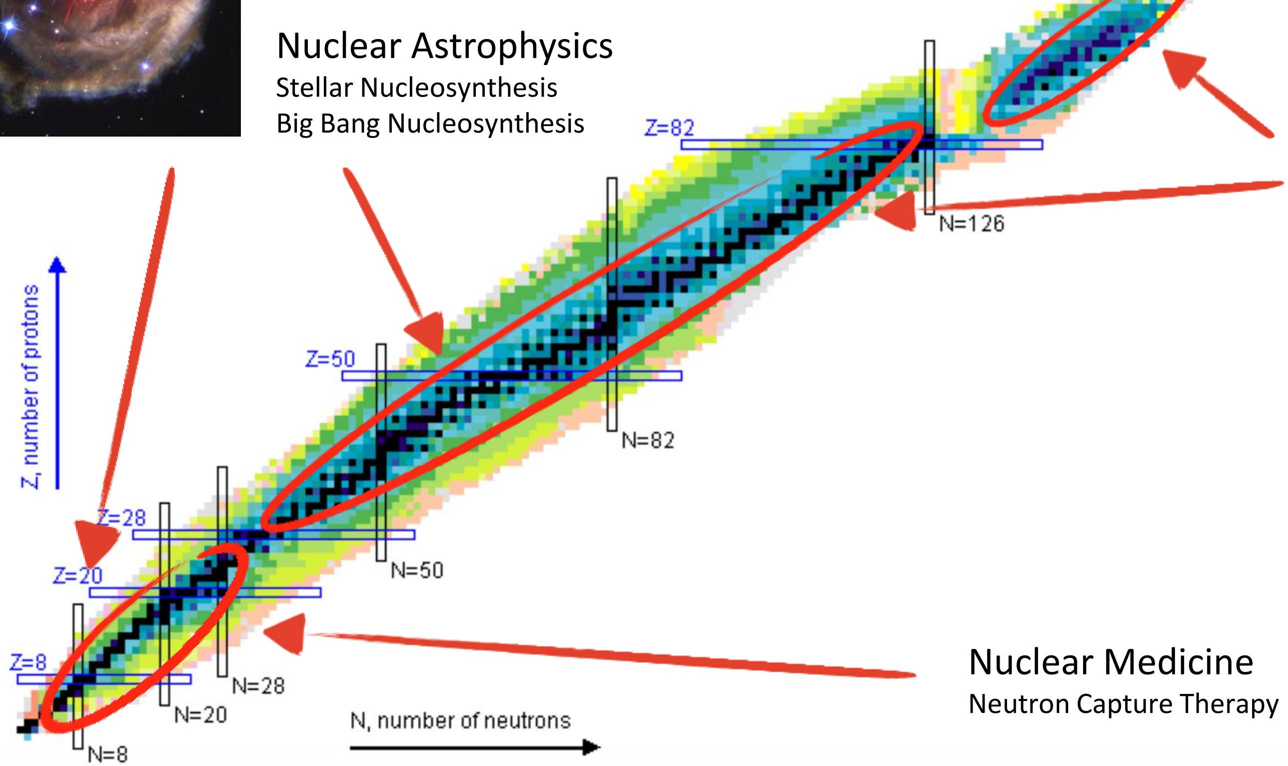
The n_TOF physics program: neutron-induced reaction measurements



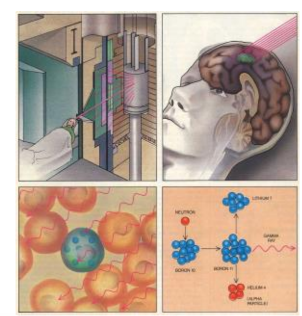


Nuclear Astrophysics
Stellar Nucleosynthesis
Big Bang Nucleosynthesis

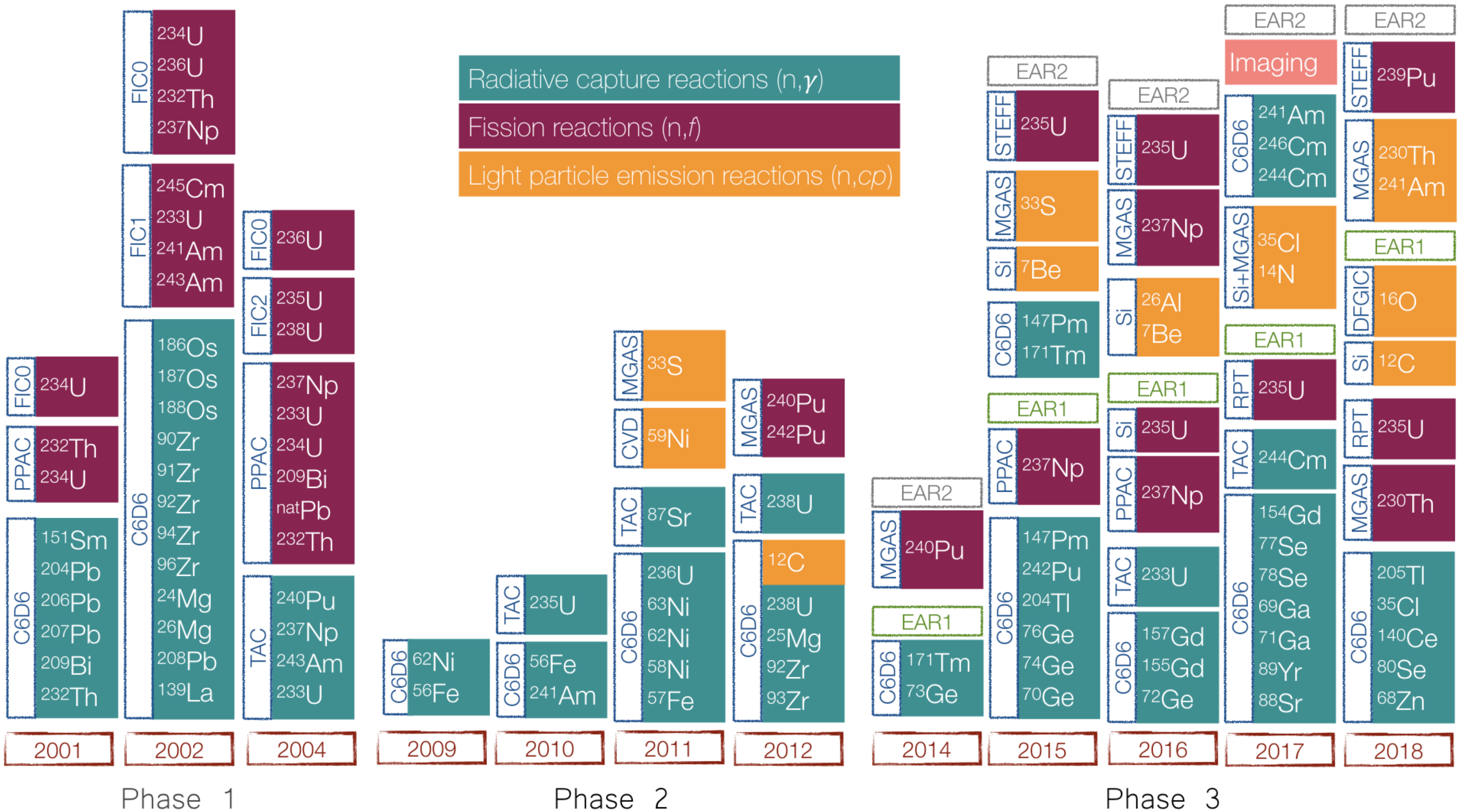
Nuclear Technologies
Nuclear reactors (energy production)
Waste management



Nuclear Medicine
Neutron Capture Therapy



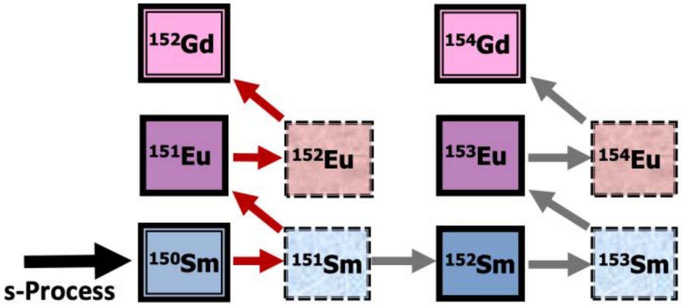
The n_TOF physics program: neutron-induced reaction measurements



The future program at n_TOF: Nuclear Astrophysics

Study of s-process nucleosynthesis of heavy elements

- The synthesis of heavy elements in the Universe is based on a balance between neutron capture reactions and subsequent beta-decays (slow and rapid processes)
- The abundance of elements in the Universe depends on the **thermodynamic conditions** of the stellar medium (temperature and neutron density) and on the **neutron capture cross-section**



Branching point (BP) isotopes (radioactive):

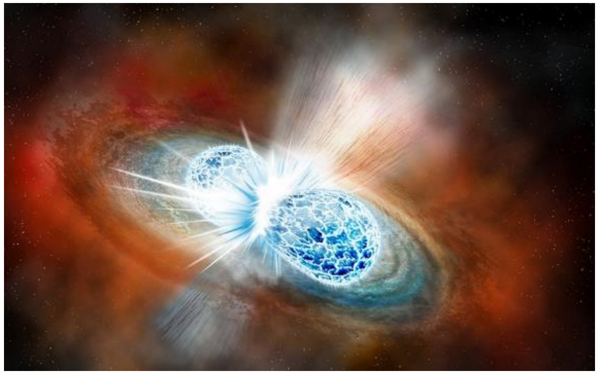
- Unique features due to the comparable time scale of the isotopes' half-lives and neutron capture time.
- Neutron capture cross-section measurement of radioactive isotopes ⇒ need of a very high instantaneous neutron flux to maximize the signal-to-background ratio

n_TOF is the ideal facility

BP (n,γ) cross-section measured at n_TOF	New short-lived BP to be studied at n_TOF
^{63}Ni ($t_{1/2}$=100 yr) ^{151}Sm ($t_{1/2}$=90 yr) ^{93}Zr ($t_{1/2}$=1.5E6 yr)	^{134}Cs ($t_{1/2}$=2.1 yr) ^{85}Kr ($t_{1/2}$=10.7 yr) ^{185}W ($t_{1/2}$=75.4 d)

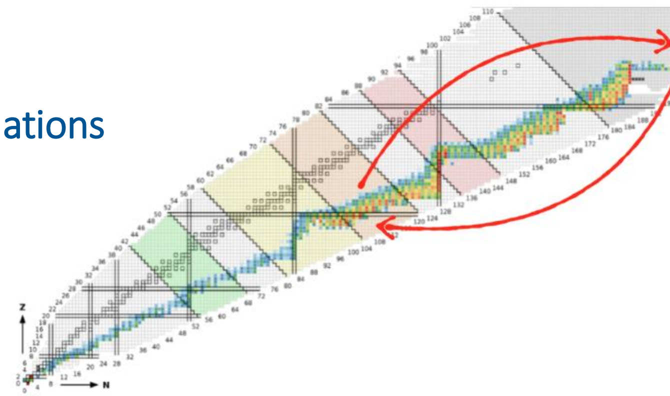
Samples: collaboration between CERN, ILL and PSI
Detectors: new developments for γ-background discrimination and high-precision γ-spectroscopy
Proof of concept: ^{171}Tm ($t_{1/2}$=1.92 yr)

The future program at n_TOF: Nuclear Astrophysics



Study of r-process nucleosynthesis in explosive scenarios of Supernovae and Neutron Star Mergers

- Fission processes play an important role in shaping the abundance distribution of r-nuclei:
  - recycle matter during neutron irradiation
  - contribute to the heating of the ejected material



Need new data for refining fission models used in r-process calculations

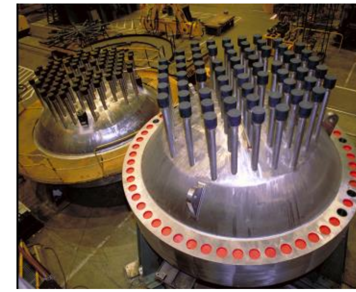
- Data on a full isotopic chain (not available at present) provide strong constraints for the optimization of fission models
- Fission cross-section measurement of short-lived actinides
  $\Rightarrow$ need the high luminosity of the n_TOF second experimental area

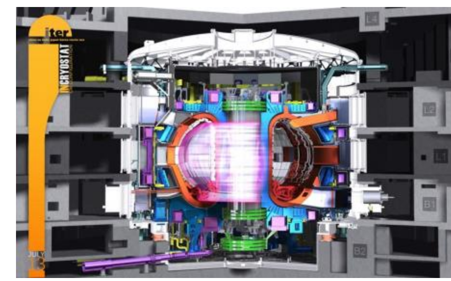
			Cf249 351 y 9/2- α,sf	Cf250 13.08 y 0+ α,sf	Cf251 898 y 1/2+ α	Cf252 2.645 y 0+ α,sf
	Cm243 29.1 y 5/2+ EC,α,sf,...	Cm244 18.10 y 0+ * α,sf	Cm245 8500 y 7/2+ α,sf ✓	Cm246 4730 y 0+ α,sf	Cm247 1.56E+7 y 9/2- α	Cm248 3.40E+5 y 0+ α,sf
Pu238 87.7 y 0+ α,sf	Pu239 24110 y 1/2+ α,sf ✓	Pu240 6563 y 0+ α,sf ✓	Pu241 14.35 y 5/2+ β-,α,sf,...	Pu242 3.733E+5 y 0+ α,sf ✓		Pu244 8.08E+7 y 0+ α,β-β-,sf,...

Samples: collaboration between CERN(n_TOF, ISOLDE), ILL and PSI
Detectors: present detectors (PPAC, MicroMegas, Silicons) optimized for low-mass samples
Proof of concept: ^{7}Be ($t_{1/2}$=52 d)

The future program at n_TOF: Nuclear Applications

Energy and Environmental Science





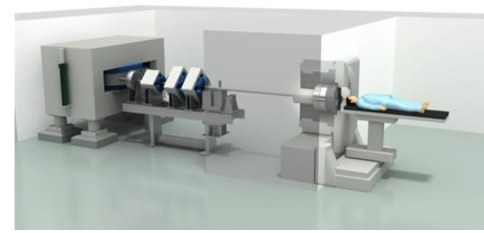
Fission reactors:

- Nuclear data needed in order to improve safety of current reactors and design of innovative ones (Gen. IV), and for safe disposal of nuclear waste
- Need to measure neutron-induced reaction on actinides and fission fragments (same as Nuclear Astrophysics with different targets)

Fusion reactors:

- Estimate lifetime of structural material. Embrittlement due to gas (hydrogen and helium) production.
- Need to study (n,p) and (n,α) reactions on various stable isotopes.

Nuclear Medicine



Neutron data needed for:

- studying innovative therapeutic modalities (for example, Sulphur-enhanced BNCT).
- Production root of new radioisotopes for theranostic (for example, ^{177}Lu).

Samples: collaboration between CERN(n_TOF, ISOLDE), ILL and PSI
Detectors: present detectors (PPAC, Micro Megas, Silicons) optimized for low-mass samples, new developments for (n,α) measurements (gaseous targets, silicon telescopes, …)

Conclusions and perspectives

- The n_TOF facility exploits as a powerful neutron source a pulsed proton beam (20 GeV/c) from the CERN Proton Synchrotron coupled to a lead spallation target
- Unique characteristics: very high resolution neutron spectrometer exploiting a white energy spectrum and a very high instantaneous flux

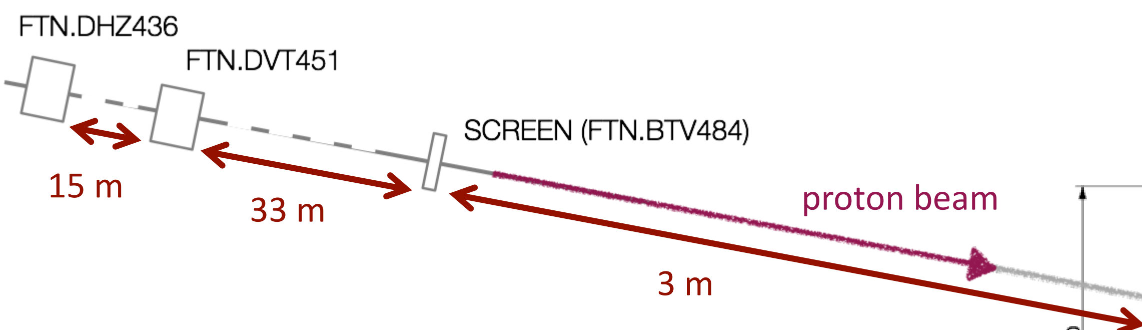
- The Class-A experimental areas combined with flexible detection systems allows to perform a variety of neutron-induced cross section measurements

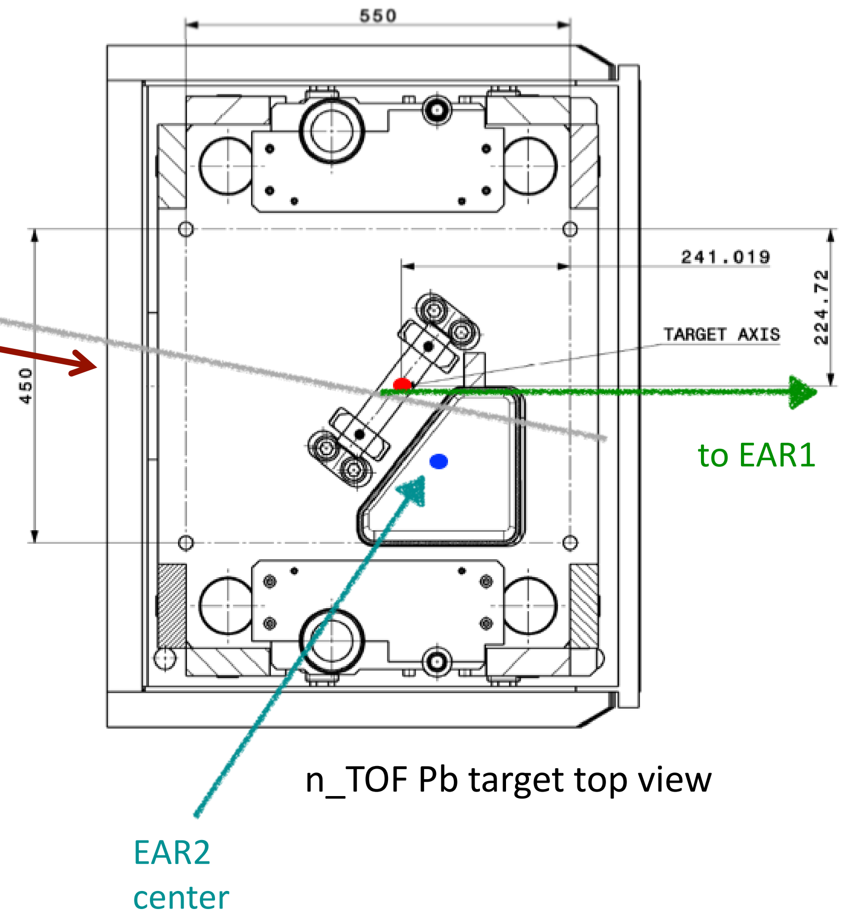
- n_TOF after LS2
  - Proton beam - target assembly: higher proton intensity (up to 10^{13} ppp), double bunch from PS
  - Neutron beam-line: neutron imaging, irradiation station with Target #3
  - Detection techniques: gaseous targets, γ spectrometry with Ge detectors, position sensitive scintillators for (n,γ) measurements (i-TED)

Thank you for your attention

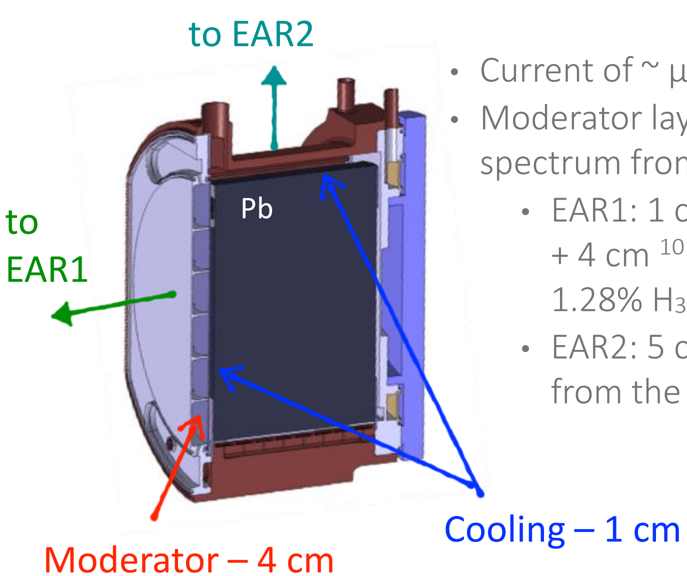
A bright future for neutron physics at CERN!

The n_TOF beam: spallation target





n_TOF Pb target top view



- Current of ~ μA
- Moderator layer of 5 cm (energy spectrum from meV to GeV):
  - EAR1: 1 cm of normal water + 4 cm ^{10}B-water (H_2O + 1.28% H_3BO_3)
  - EAR2: 5 cm of normal water from the cooling circuit