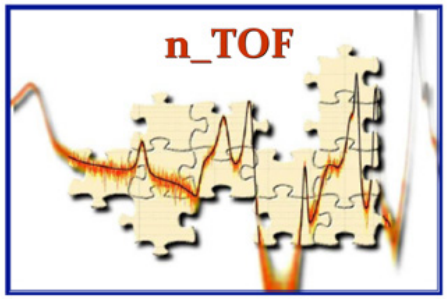
Nuclear Astrophysics @ n_TOF, CERN



Tagliente Giuseppe

Istituto Nazionale Fisica Nucleare, Sez. di Bari

INFN
ISTITUTO NAZIONALE DI FISICA NUCLEARE

ATHENA
Advanced
THeory and
Experiments for
Nuclear
Astrophysics

The n_TOF Collaboration

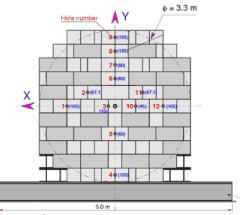
(~100 Researchers from 30 Institutes)

CERN	
Technische Universitat Wien	Austria
IRMM EC-Joint Research Center, Geel	Belgium
Charles Univ. (Prague)	Czech Republic
IN2P3-Orsay, CEA-Saclay	France
KIT – Karlsruhe, Goethe University, Frankfurt	Germany
Univ. of Athens, Ioannina, Demokritos	Greece
INFN Bari, Bologna, LNL, LNS, Trieste, ENEA – Bologna	Italy
Univ. of Tokio	Japan
Univ. of Lodz	Poland
ITN Lisbon	Portugal
IFIN – Bucarest	Rumania
CIEMAT, Univ. of Valencia, Santiago de Compostela, University of Cataluna, Sevilla	Spain
University of Basel, PSI	Switzerland
Univ. of Manchester, Univ. of York	UK

n_TOF Scientific Motivations

- Neutron cross sections relevant for Nuclear Astrophysics
- Measurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies (ADS)
- Neutrons as probes for fundamental Nuclear Physics

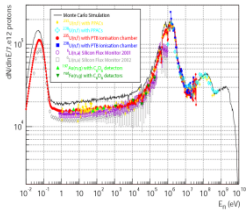
n_TOF Time line



1995-1997 **TARC** experiment

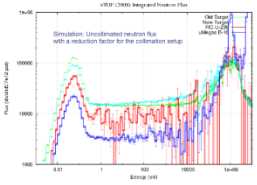
May 1998 **Feasibility** CERN/LHC/ 98-02+Add

2000 **Commissioning**



2008 **New Target** construction

May 2009 **Commissioning**



2009-2012 **Phase II** Isotopes Capture: 14 Fission: 6 (n,α): 2

July 2014 **Commissioning EAR2**

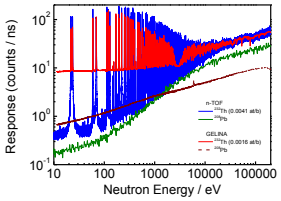
1996 **2009** **2014**

1997 **Concept** by C.Rubbia CERN/ET/Int. Note 97-19

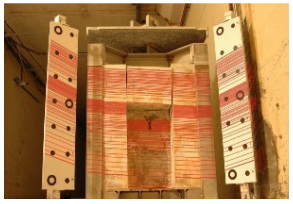
Aug 1998 **Proposal** submitted

1999 **Construction** started

2001-2004 **Phase I** Isotopes Capture: 25 Fission: 11

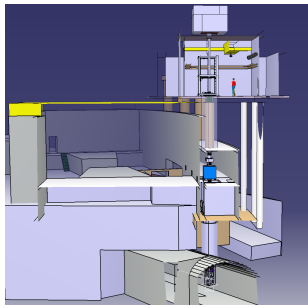


2004-2007 **Problem** Investigation



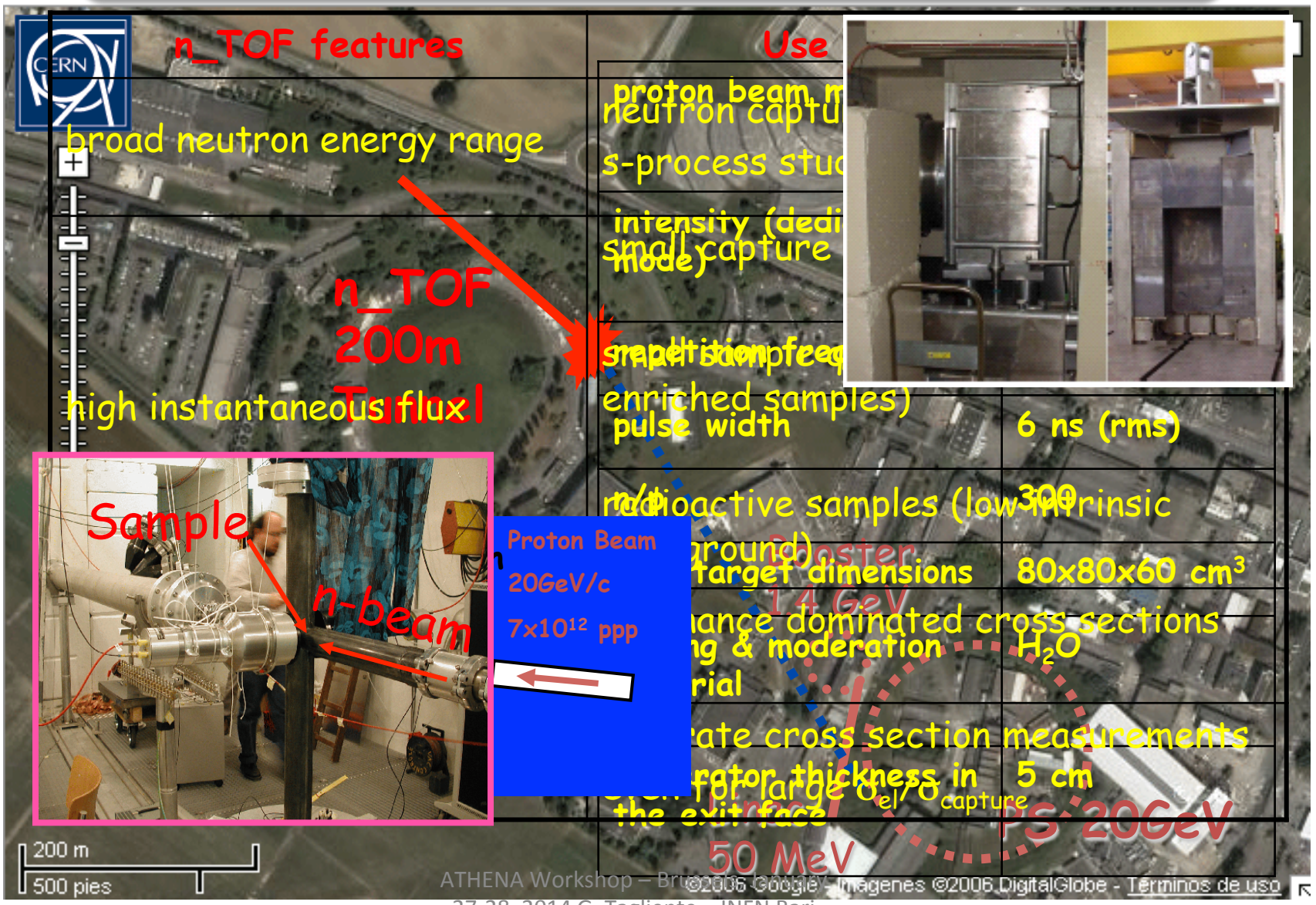
2009 **Phase II**

2010 **Upgrades:** Borated-H_2O Class-A

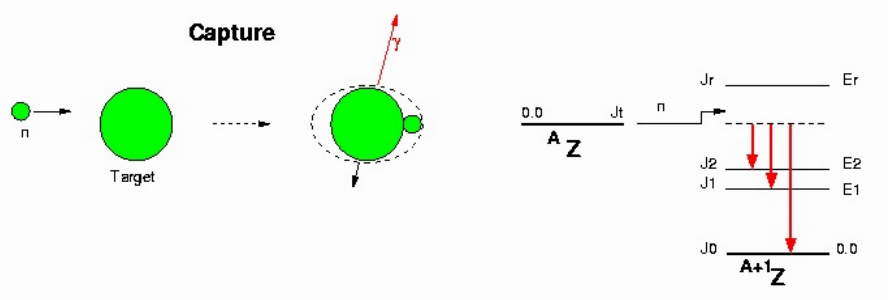


2013-2014 **Construction** second beam line EAR2

n_TOF Facility

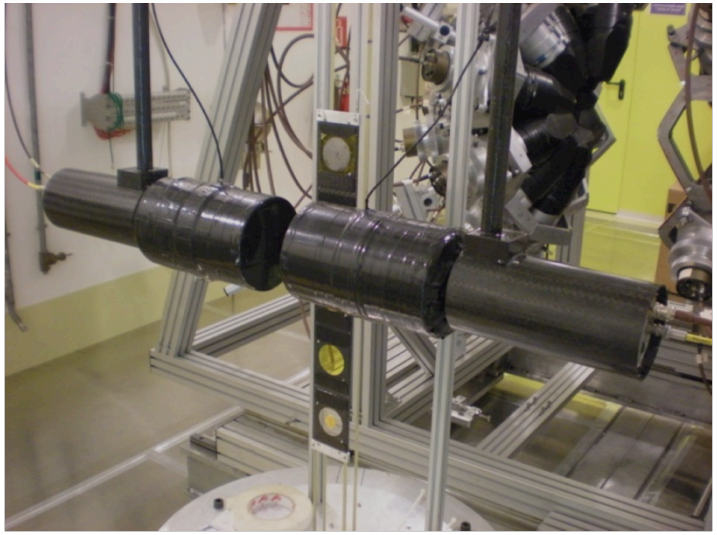


Detectors for capture reactions



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

At n_TOF, two detection systems are used, for different purposes.

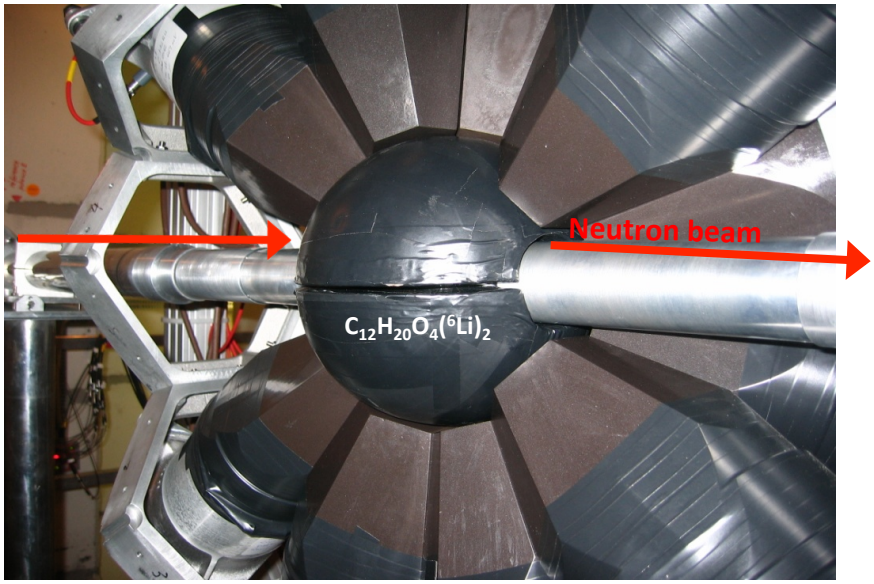


C_6D_6 (deuterated liquid scintillators)

- low neutron sensitivity device
- used for low cross-section samples

Total Absorption Calorimeter (TAC)

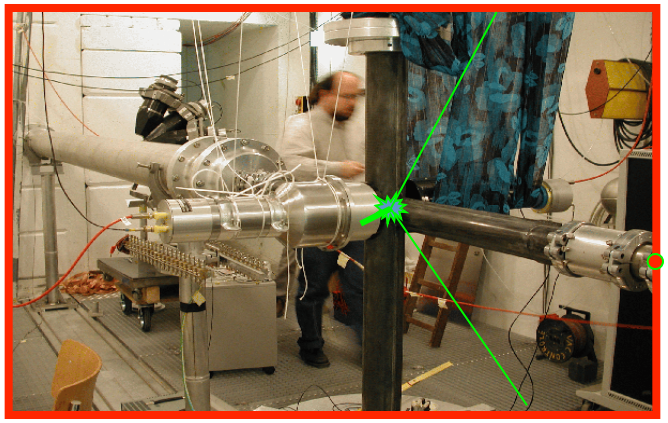
- High-efficiency **4π** detector (40 BaF_2 scintillators with neutron shielding)
- mostly used for fissile isotopes (actinides)

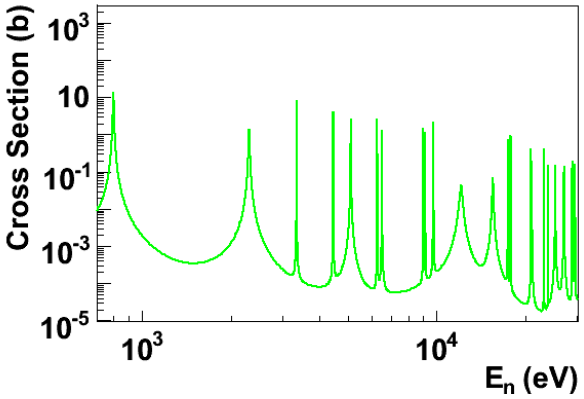


(n,γ) Total energy detection @ n_TOF

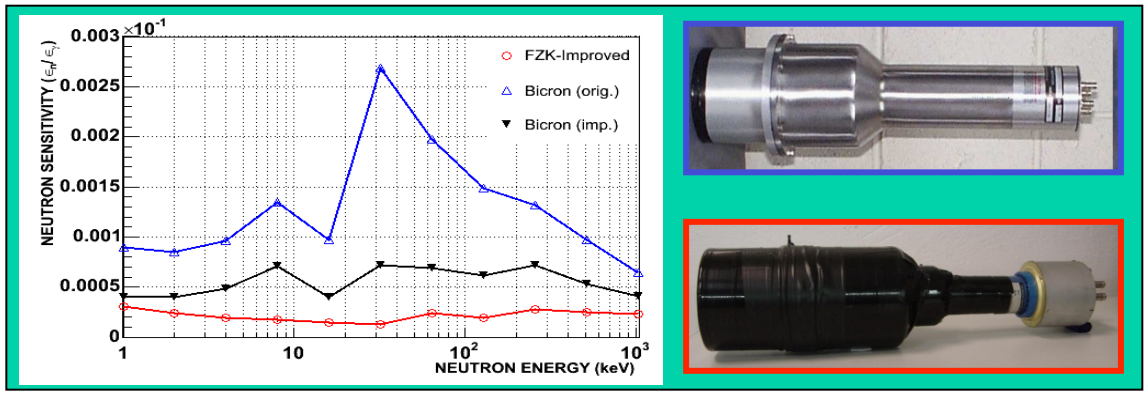
Improvements in the Experimental Setup & Data Analysis

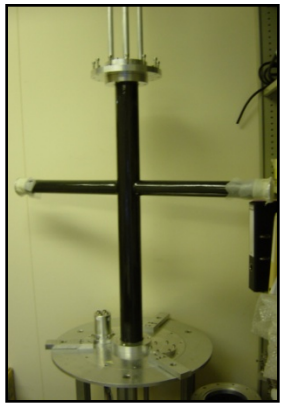
- Lowest neutron sensitivity ➡ No neutron background corrections !





(n,γ)



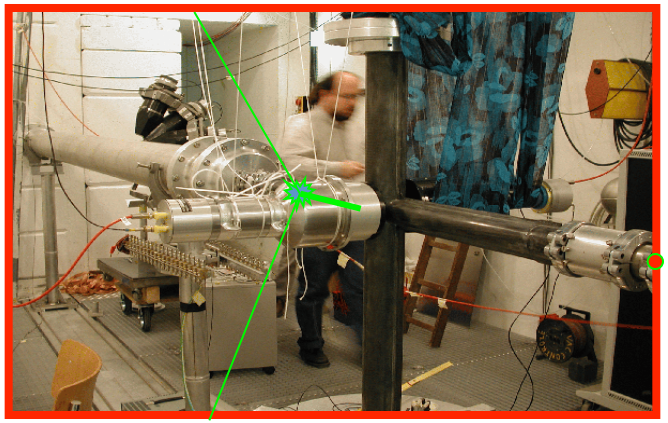


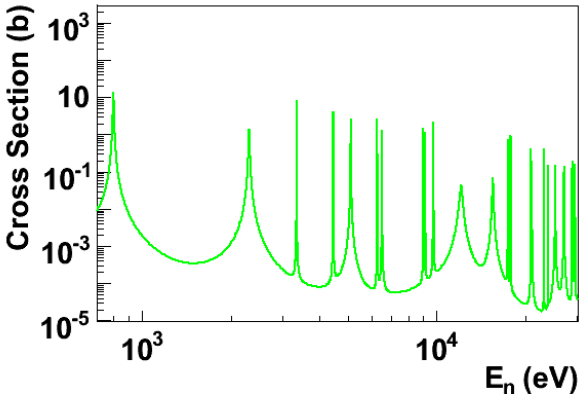
R. Plag et al., Nucl. Instr. & Methods A, 496 (2003) 425

(n,γ) Total energy detection @ n_TOF

Improvements in the Experimental Setup & Data Analysis

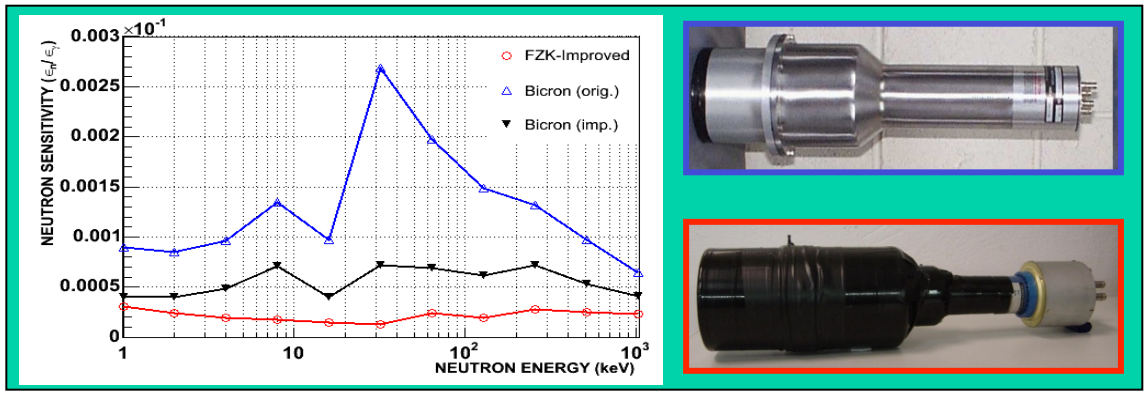
- Lowest neutron sensitivity ➡ No neutron background corrections !

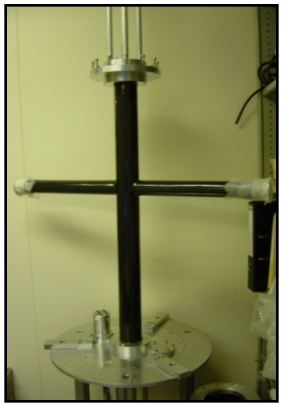




(n,n)

(n,γ)





- n_TOF: first facility with a neutron sensitivity optimized below measurable levels.
- All the (n,γ) measurements with C_6D_6 (since start in 2002) were made with this improved setup.

R. Plag et al., Nucl. Instr. & Methods A, 496 (2003) 425

The experimental activity at n_TOF: Ph I

- Cross sections relevant in Nuclear Astrophysics
  - s-process: branchings
  - abundancies in presolar grains
  - Magic nuclei
  - Isotopes of particular interess

^{151}Sm

$^{204,206,207,208}Pb$,^{209}Bi

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

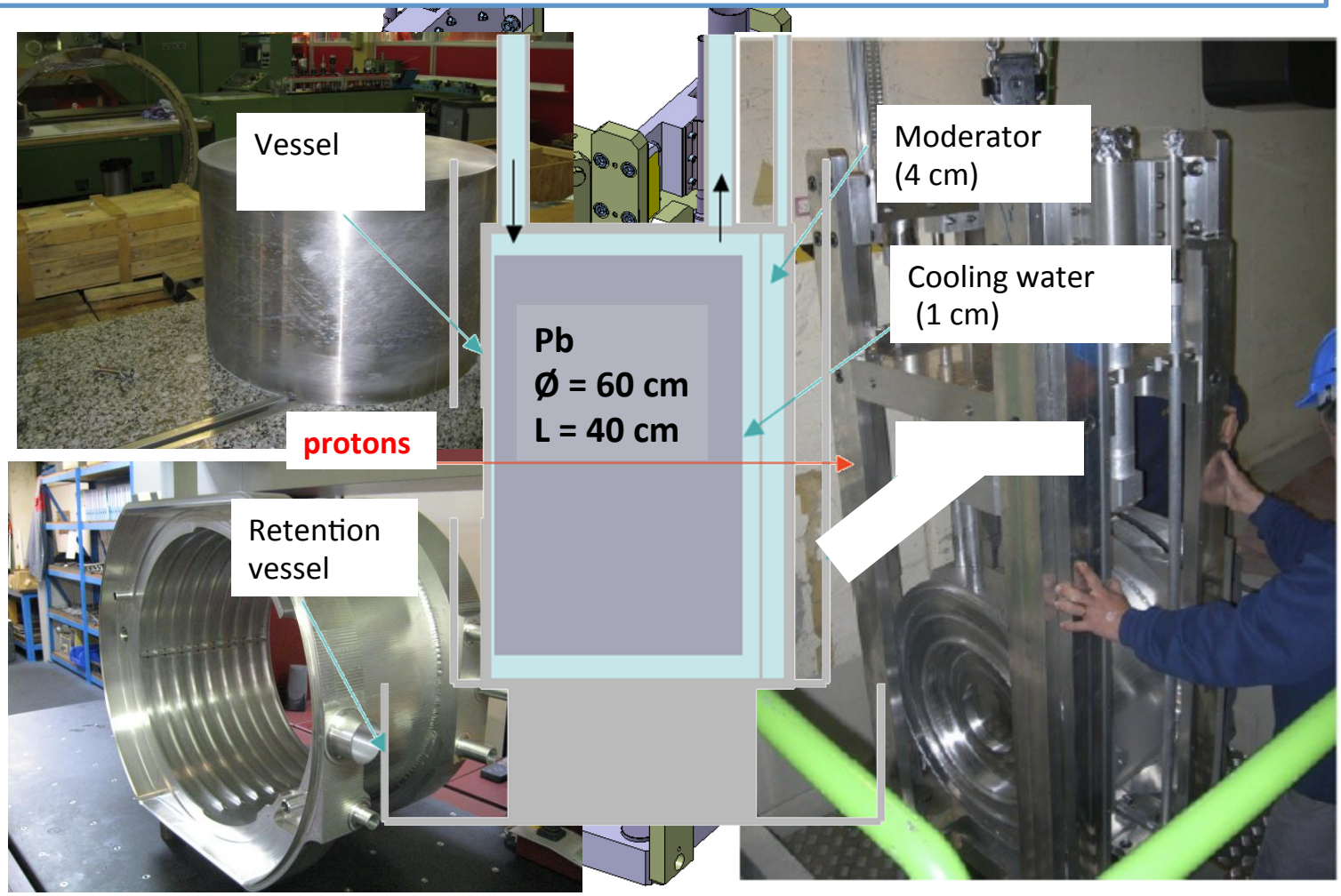
$^{186,187,188}Os$

- In the period 2002-2004 measured long-needed **capture and fission** cross-sections for **36 isotopes**, 18 of which radioactive.
- The unprecedented combination of **excellent resolution**, **unique brightness** and **low background** has allowed to collect **high-accuracy data**, in some cases for the **first time ever**.

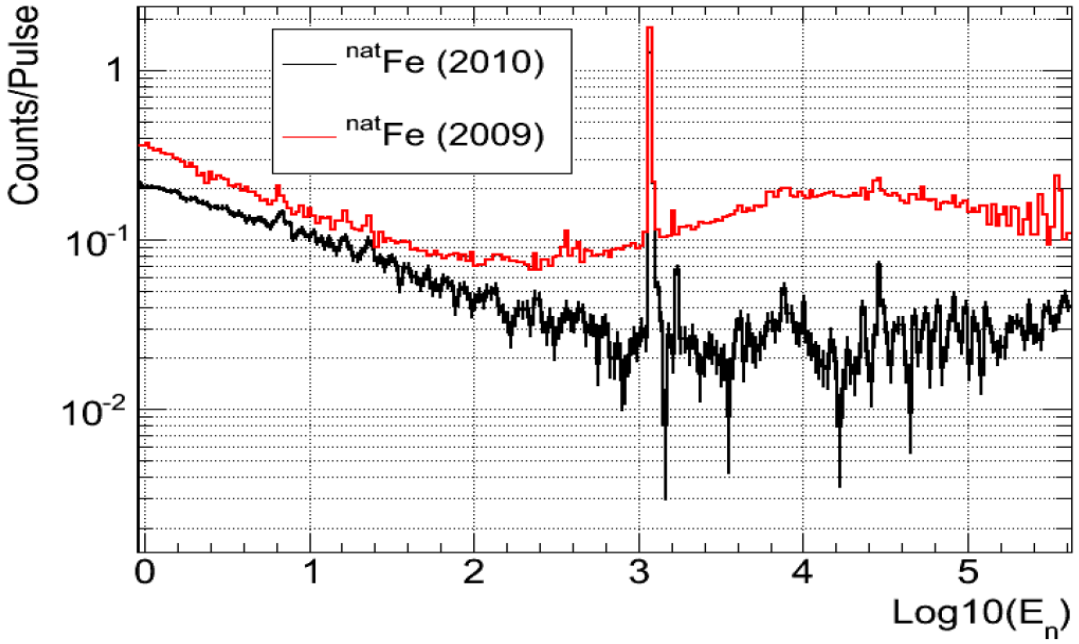
n_TOF Phase II

The new spallation Target

The cooling and the moderator systems in the target are separated, so to optimize neutron spectrum or minimize background



The new spallation Target



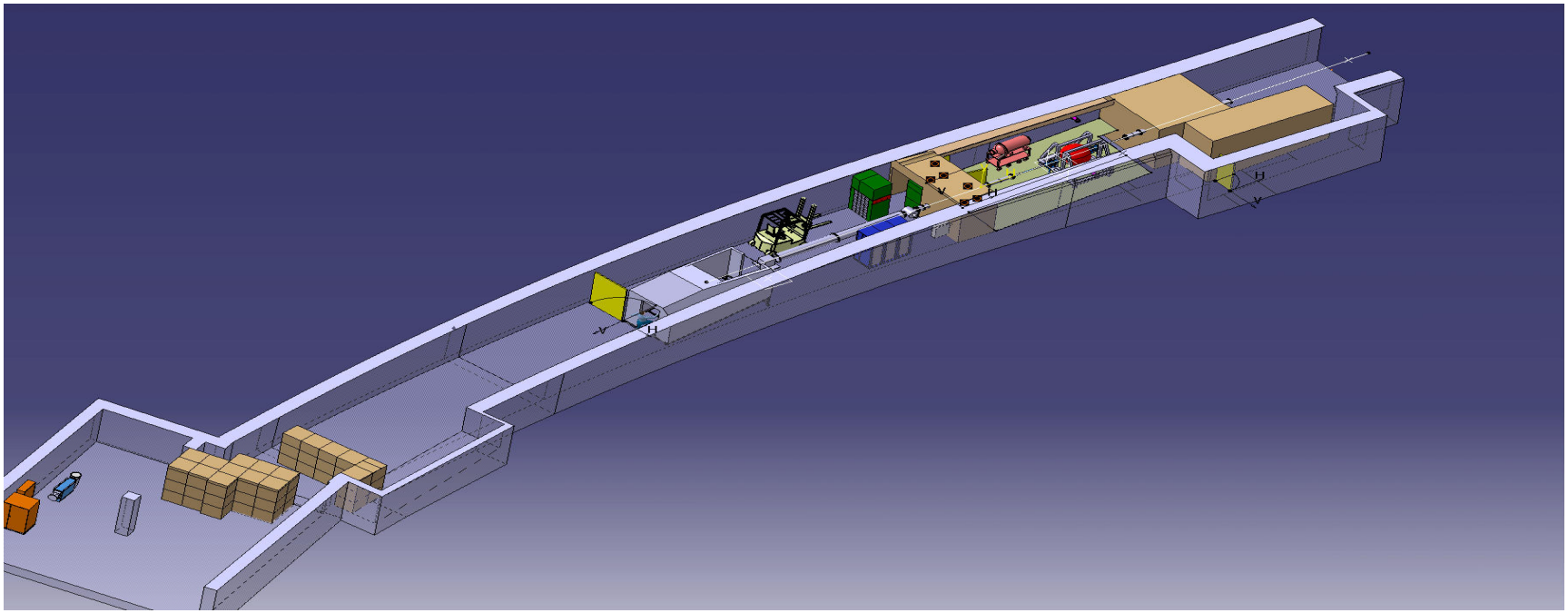
Moderator

2009 H_2O

2010 H_20 + H_3BO_3 (borated water)

The borated water as moderator reduces the background of a factor 10!!
In the energy region 1-100 keV !

Work Sector of Type A



Since 2010 the n_TOF experimental area was transformed in work sector type A.
It allows to measure sample with very high activity.

The experimental activity @ n_TOF: Ph II

- Cross sections relevant in Nuclear Astrophysics
  - s-process: seeds isotopes

^{54,56,57}Fe

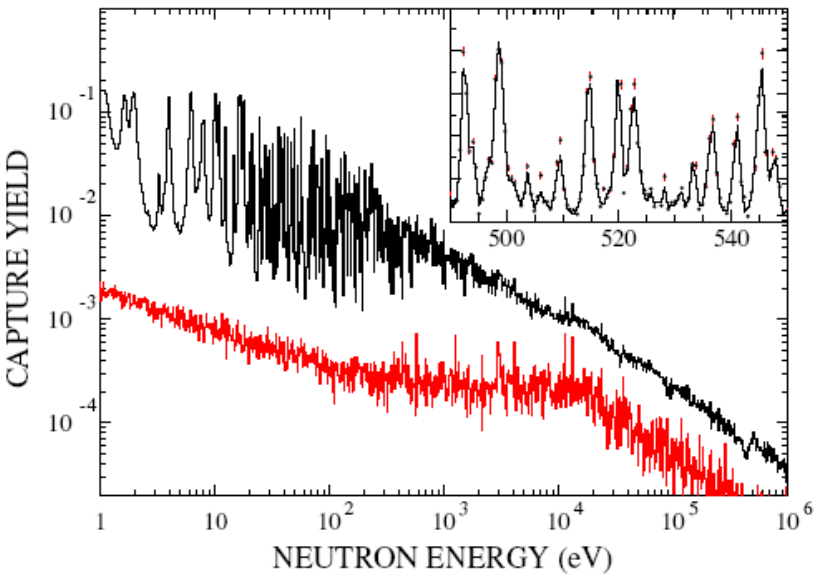
^{58,60,62}Ni, ^{63}Ni

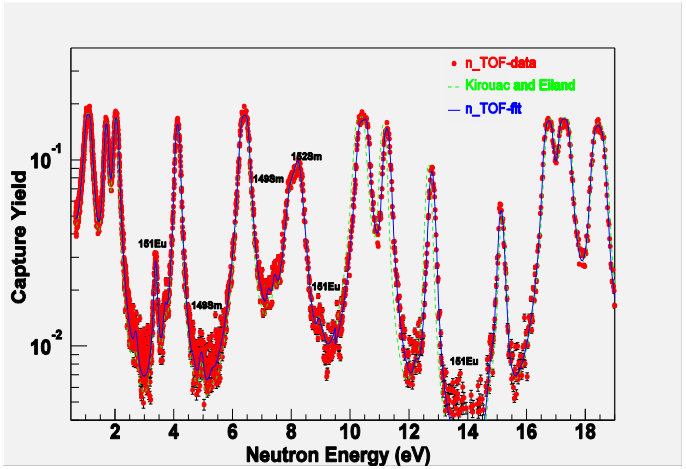
^{25}Mg

^{93}Zr

In the period 2009-2012 measured long-needed **capture and fission** cross-sections for **22 isotopes**, 14 of which radioactive.

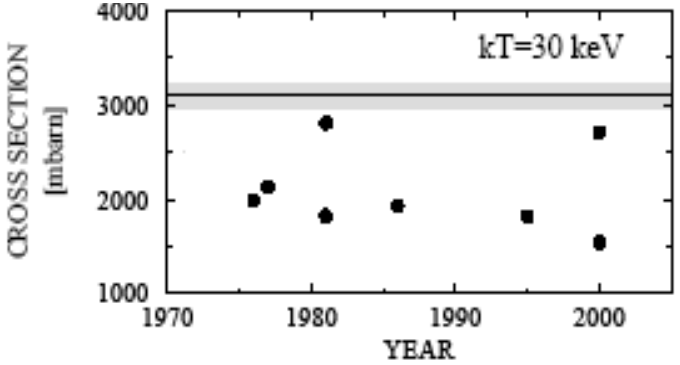
The experimental results: ^{151}Sm





Measured for the first time at a time-of-flight facility
Resonance analysis with SAMMY code.

Maxwellian averaged cross-section experimentally determined for the first time



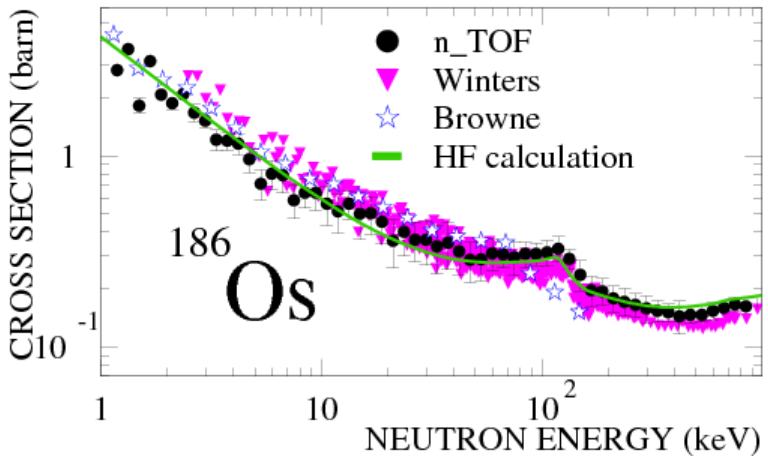
s-process in AGB stars produces 77% of ^{152}Gd,

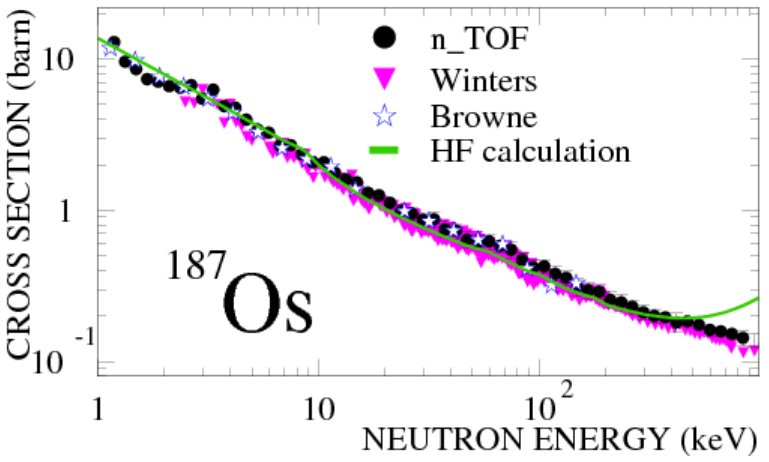
23% from p process

Maxwellian averaged (n,γ) cross section of the ^{151}Sm and previous calculation (symbol)

NO PREVIOUS MEASUREMENTS!

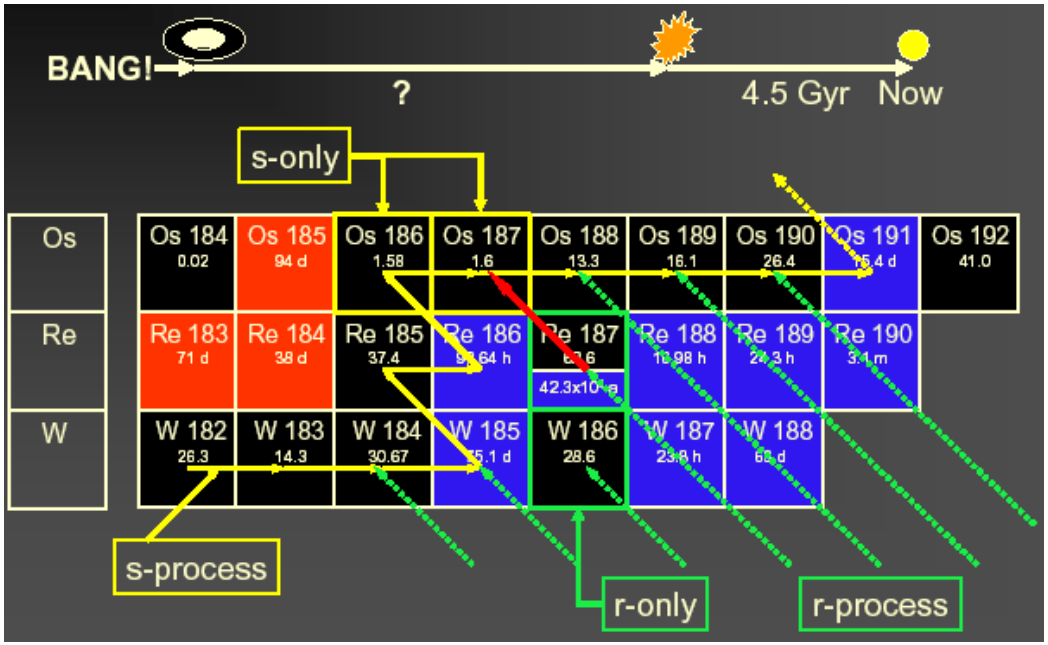
The experimental results: ^{186,187}Os





$$^{187}\mathrm{Os}_c = {}^{187}\mathrm{Os} - \frac{\sigma(186)}{\sigma(187)}\,{}^{186}\mathrm{Os}$$

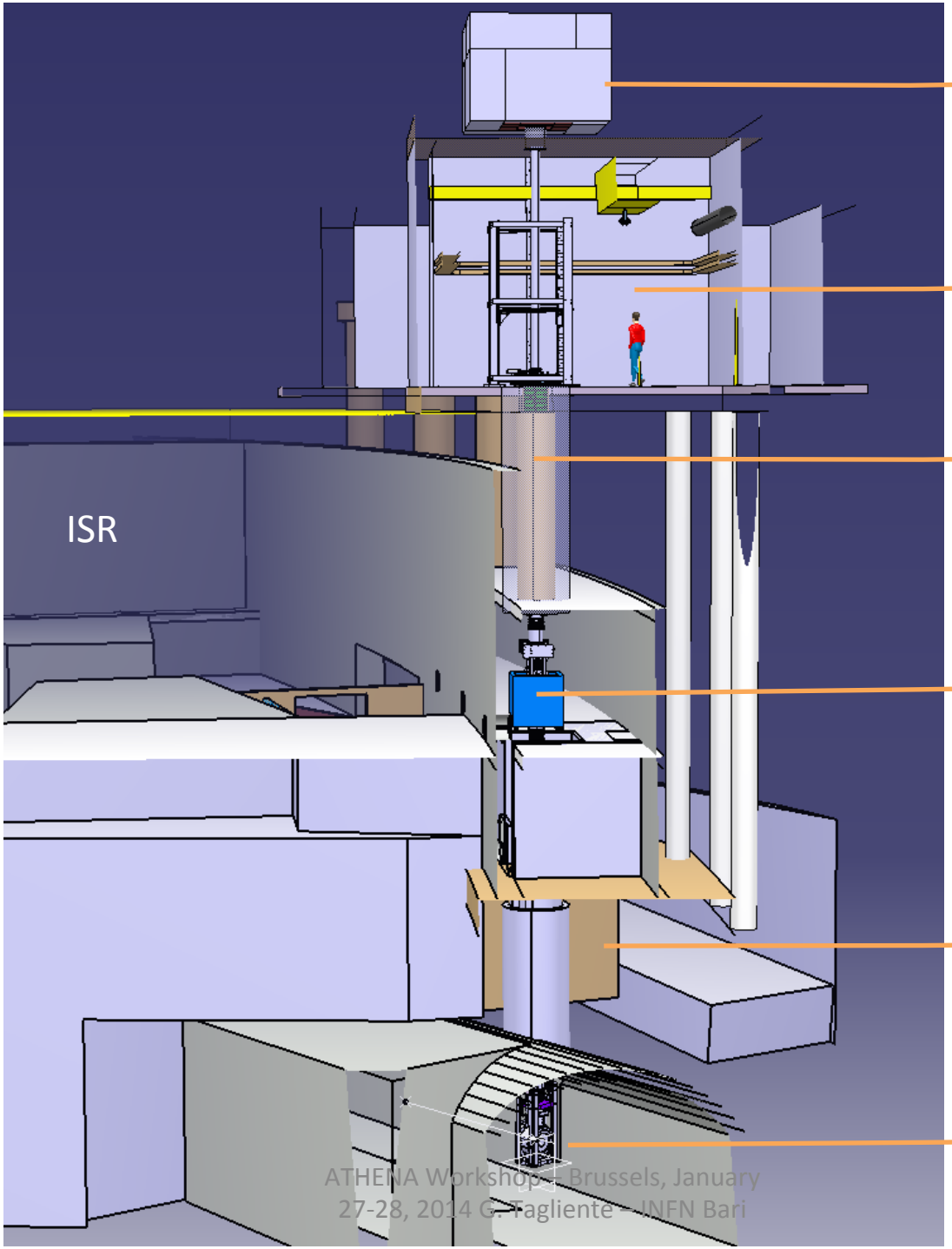
$$\frac{\sigma(186)}{\sigma(187)} = 0.42 \pm 0.02$$



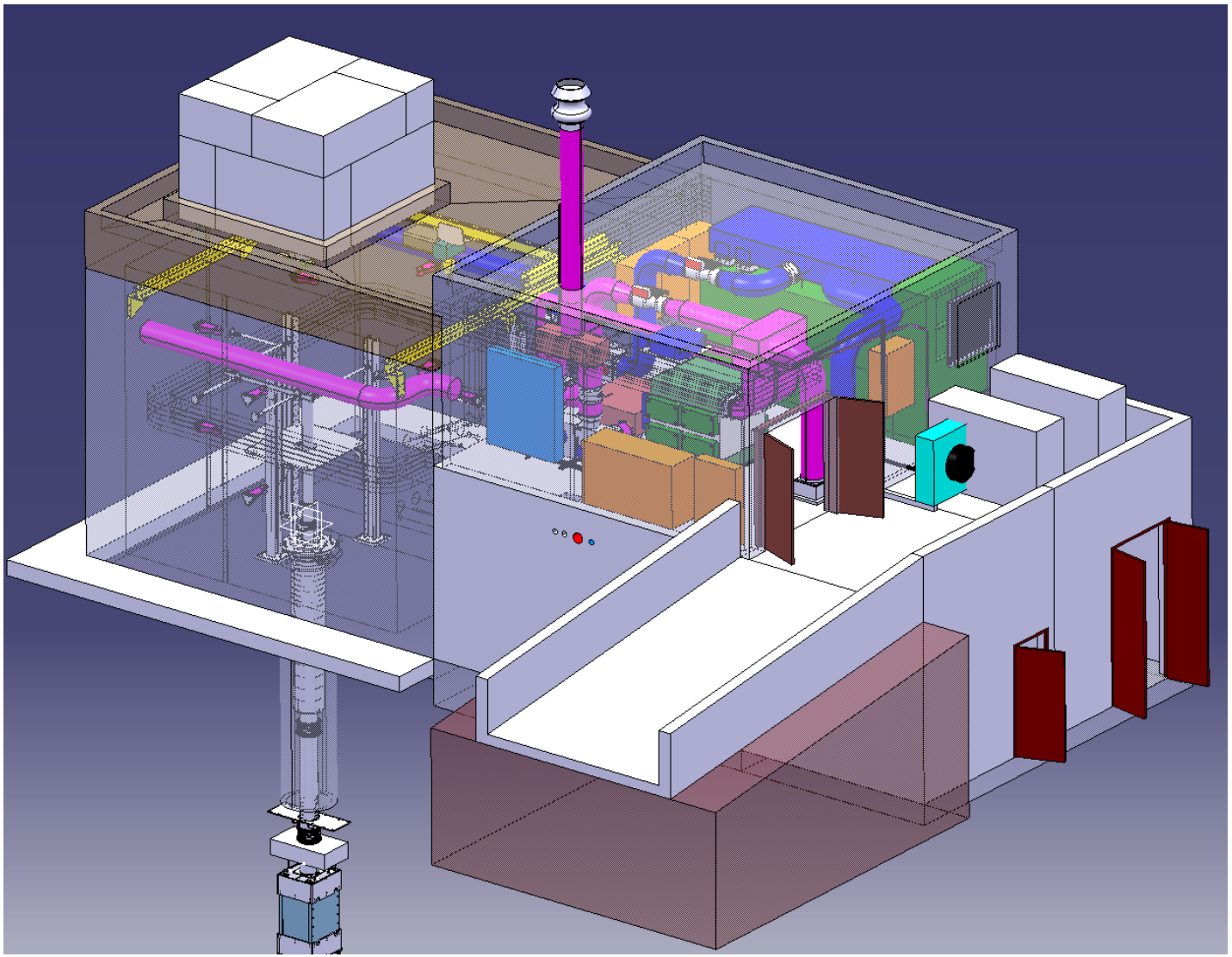
Publications

Isotope	Reference
^{24,25,26}Mg	PRC 85 (2012) 044615
^{58}Ni	PRC 89 (2014) 014605
^{62}Ni	*Submitted to PRC*
^{63}Ni	*PRL 110 (2013) 022501*
^{90}Zr	PRC 77 (2008) 035802
^{91}Zr	PRC 78 (2008) 045804
^{92}Zr	PRC 81 (2010) 055801 APJ 780 (2014) 95
^{93}Zr	*PRC 87 (2013) 014622*
^{94}Zr	PRC 84 (2011) 015801
^{96}Zr	PRC 84 (2011) 055802
^{139}La	PRC 75 (2007) 035807
^{151}Sm	PRL 93 (2004) 161103 – PRC 73 (2006) 034604
^{186,187,188}Os	PRC 82 (2010) 015802 – PRC 82 (2010) 015804
^{204}Pb	PRC 75 (2007) 015806
^{206}Pb	PRC 76 (2007) 045805
^{207}Pb	PRC 74 (2006) 055802
^{209}Bi	PRC 74 (2006) 025807

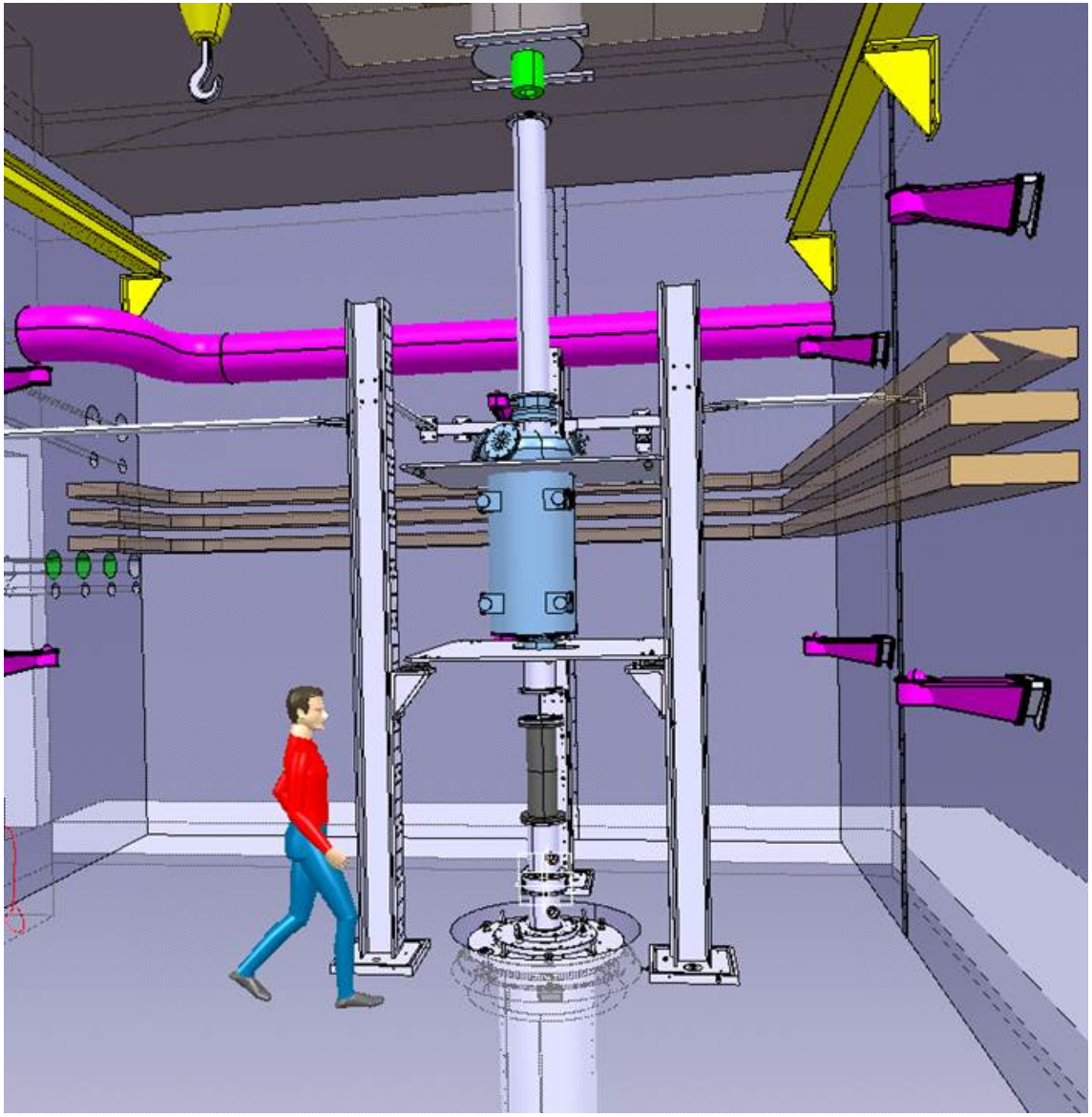
The second Experimental ARea @ n_TOF


Neutron beam dump
EAR2 bunker 20 m from Target
Collimator
ISR
Permanent magnet
Existing shaft
Spallation Target

EAR 2 general view



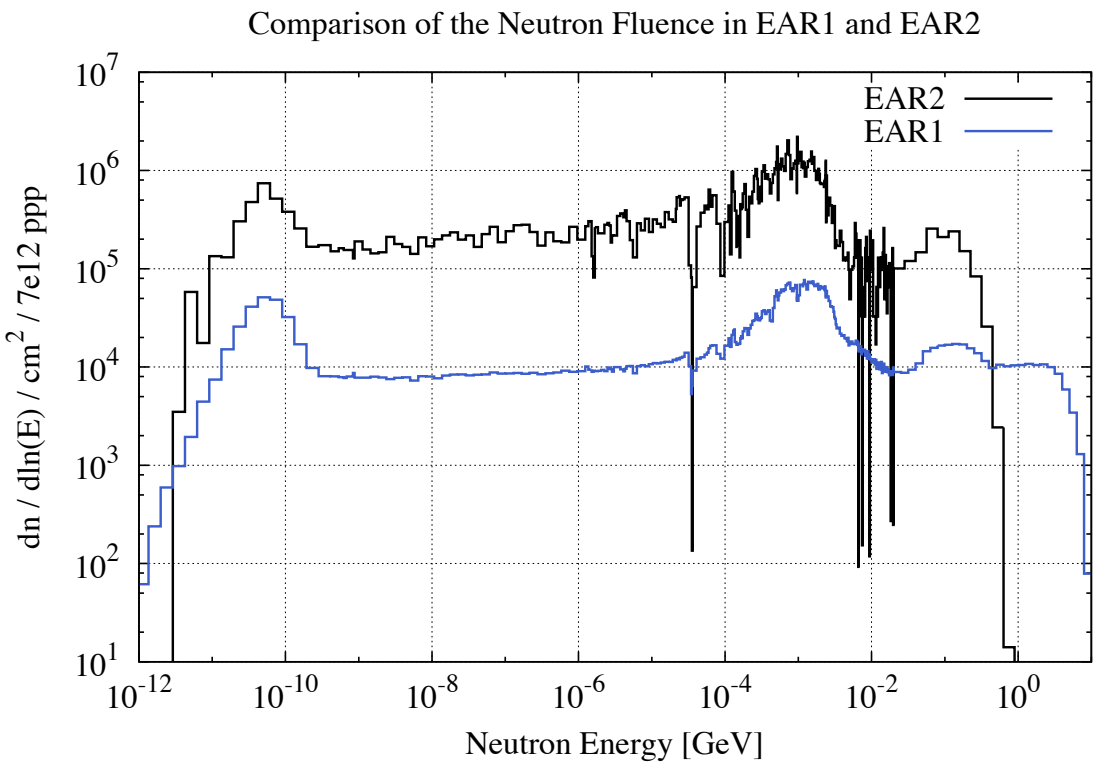
Sketch of possible installation of Detectors



Sketch of possible installation of Detectors

Status of EAR 2

Main features of EAR 2



Higher fluence, by a factor of 25, relative to EAR1.

The **shorter flight path** implies a factor of 10 smaller time-of-flight.

Global gain by a factor of **250 in the signal/background ratio** for radioactive isotopes!

The huge gain in signal-to-background ratio in EAR2 allows to measure radioactive isotopes with **half lives as low as a few years.**

The experimental program EAR 2

The EAR2 will allow to:

- measure samples of **very small mass (<1 mg)**
- measure **short-lived radioisotopes** (down to a few years)
- collect data on a much **shorter time scale**
- **measure (n,charged particle)** reactions with **thin samples**

Letter of intent for measurements in EAR2:

- **(n,p)** and **(n,α)** cross sections on **^{7}Be, ^{25}Mg, ^{26}Al**
- **Fission** cross sections of the **short lived actinides ^{232}U, ^{238,241}Pu and ^{244}Cm**
- **Capture** cross section of **^{79}Se, ^{245}Cm**
- Cross section and angular distribution of fragments from **^{232}U(n,f)**

Status of the EAR2:

- **Approved by CERN,** final design phase
- **Start construction** in May 2013
- **Beam ready** in mid-2014
- **Physics start** in 2015

AstroPhysics program EAR I & EAR II

Isot.	R	Comments
^{70,72,73}Ge	(n,γ)	s-process flow
^{171}Tm,^{204}Tl	(n,γ)	Branching points

Isot.	R	Comments
^{147}Pm	(n,γ)	Branching point
^{26}Al	(n,p/α)	^{26}Al galactic abundance
^{53}Mn	(n,γ)	Explosive stage of stellar evolution
B,C,^{14}N,O,^{19}F	(n,α)	n capture in light nuclei
^{79}Se	(n,γ)	Branching point

Conclusions

- There is need of **accurate new data** on neutron cross-section both for **astrophysics and advanced nuclear technology.**
- Since 2001, **n_TOF@CERN** has provided an important contribution to the field, with an intense activity on **capture and fission measurements**.
- Several results of interest for **stellar nucleosynthesis** (Sm, Os, Zr, Ni, Fe, etc…).
- Important data on actinides, of interest for **nuclear waste transmutation.**
- To date, high resolution measurements performed in **EAR1** in optimal conditions (borated water moderator, Class-A experimental area, etc…).
- A second **experimental area at 20 m** for high flux measurements is in construction.
- The EAR2 (starting in 2015) will open **new perspectives** for frontier measurements on short-lived radionuclides.