The n_TOF Collaboration, www.cern.ch/nTOF

ERINDA workshop

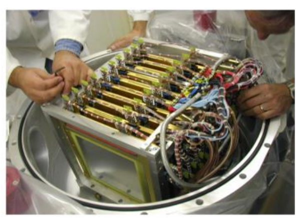
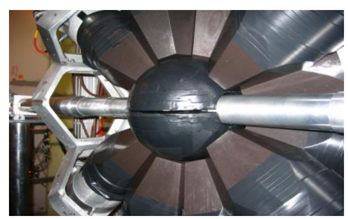
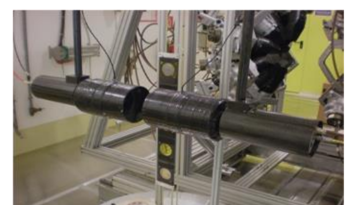
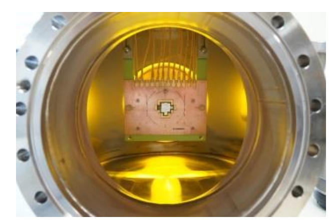
organized by the CERN EN-STI group on behalf of the n_TOF Collaboration

CERN, Geneva, CH - 1-3 October 2013

Physics at the new CERN neutron beam line

Carlos GUERRERO on behalf of *The n_TOF Collaboration*

CERN, Geneva (Switzerland)

With figures from: E. Chiaveri, V. Vlachoudis, S. Girod, S. Barros, C. Lederer, C. Weiss, G. Smith, S. Pomp, …

The n_TOF Collaboration

The n_TOF Collaboration
30 Research Institutions from Europe, Asia and USA.
16 PhD students

NUCLEAR ASTROPHYSICS: stellar nucleosynthesis

Neutron capture and (n,α) cross section of stable & unstable isotopes playing a role in the *s*- and *r*-processes (0.1-500 keV).

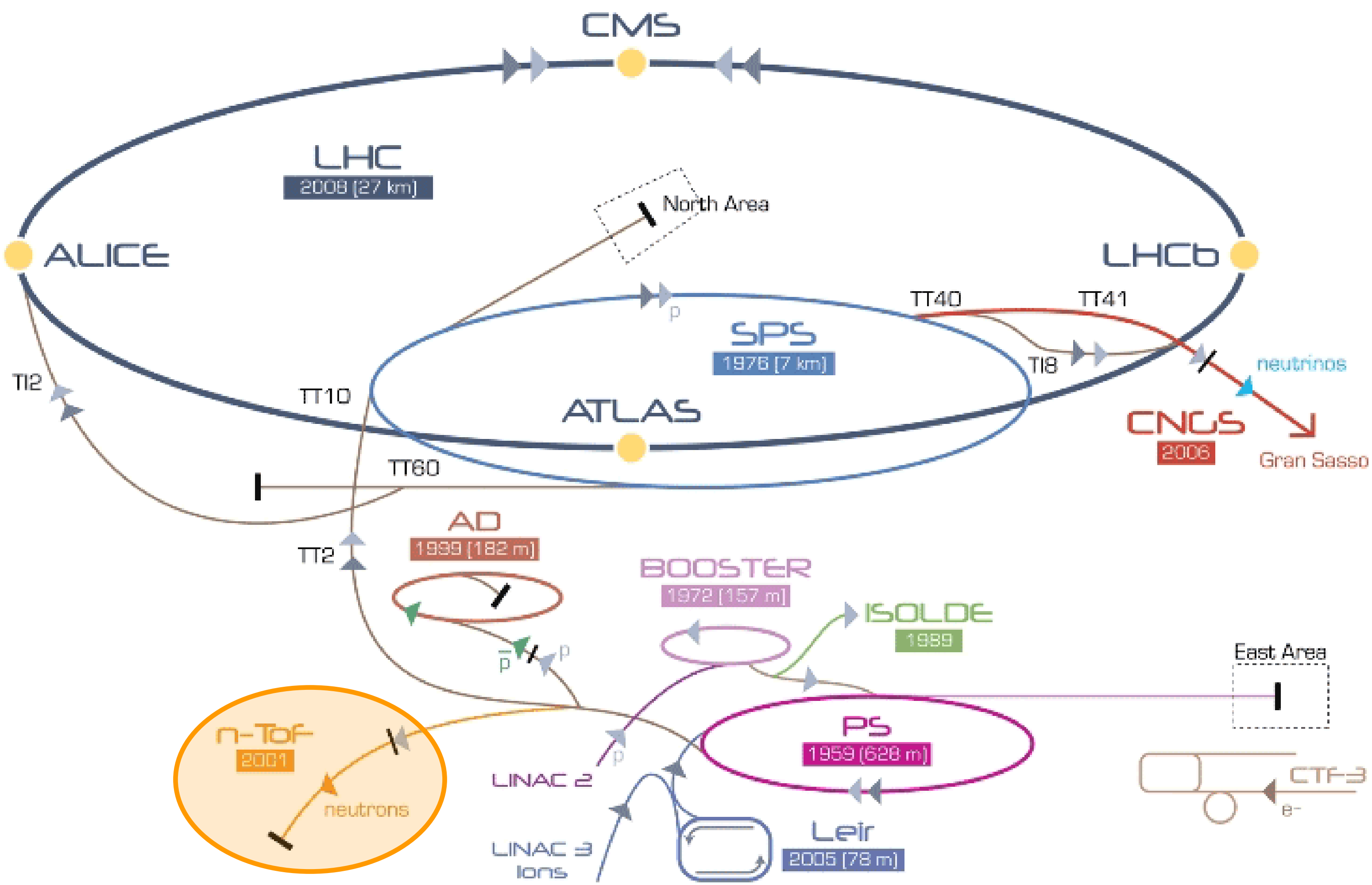
NUCLEAR TECHNOLOGIES: ADS, Gen-IV and Th/U fuel cycle

Neutron capture and fission cross sections of Actinides in the thermal (meV), epithermal (eV-keV) and fast (MeV) energy regions.

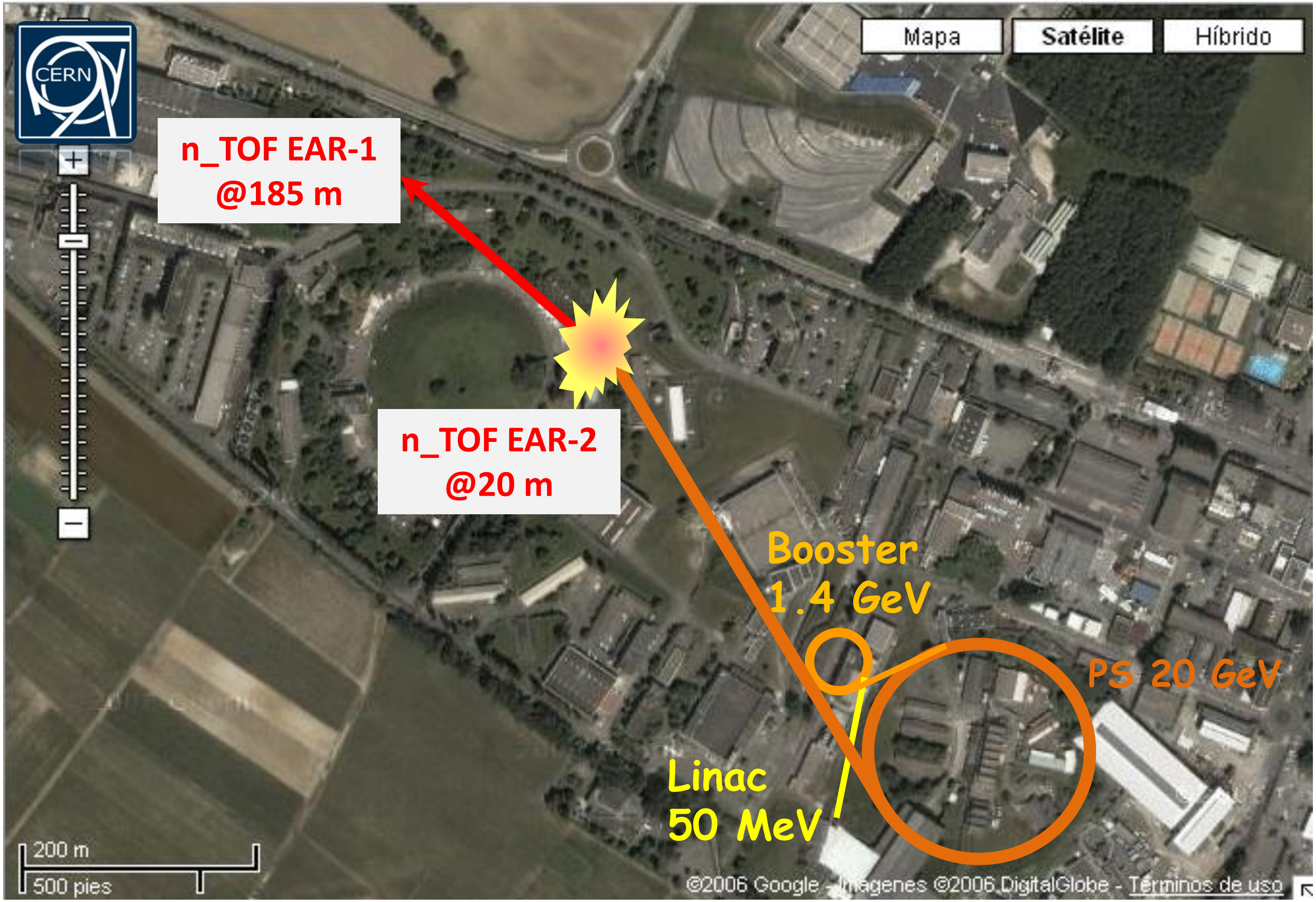
BASIC NUCLEAR PHYSICS: fission process, levels densities, γ-ray strength functions

Time-of-Flight measurements with dedicated detectors providing valuable information on basic nuclear physics quantities.

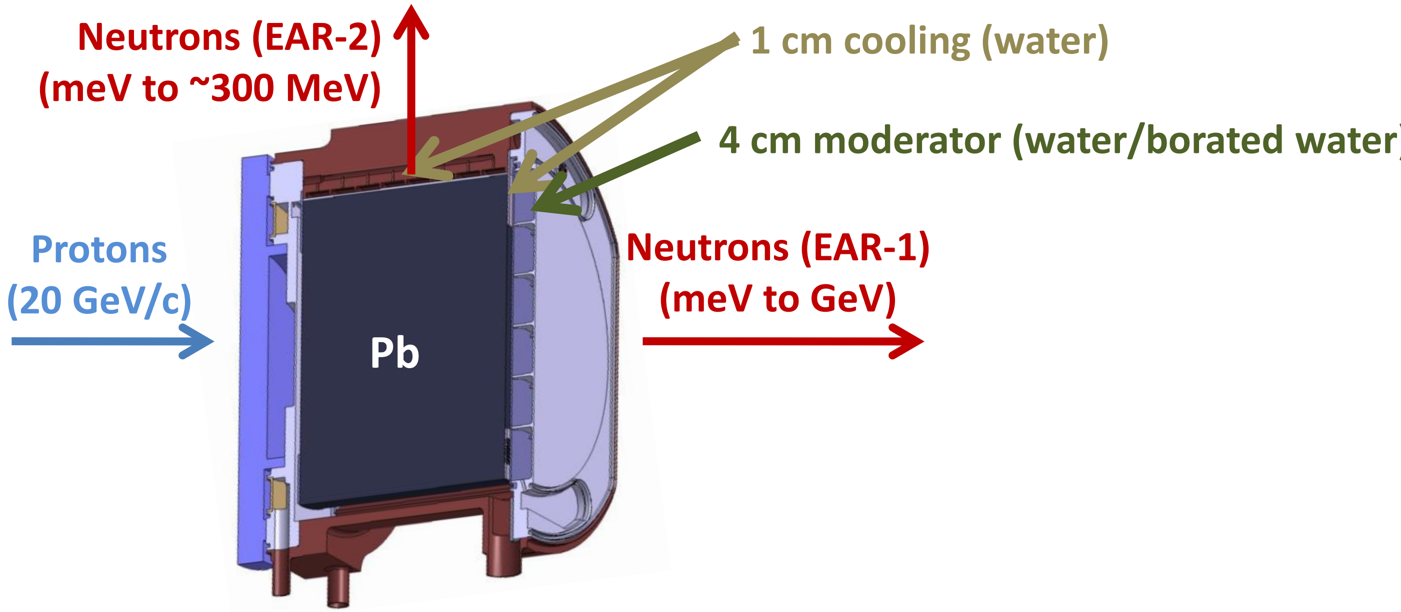
n_TOF: A spallation neutron source using the PS 20 GeV/c p beam



The n_TOF Facility at CERN



The n_TOF lead spallation target (from 2008 onwards)



Approx. 400 FAST (MeV-GeV) neutrons/proton (20 GeV/c) are generated @target

- **EAR-1:** Moderation in 5 cm of water+^{10}B-water and **185 m horizontal** flight path (meV to GeV)
- **EAR-2:** Moderation in ~1 cm of water meV to GeV and **20 m vertical** flight path (meV to ~300 MeV)

ToF (GeV) ~ 630 ns

ToF (MeV) ~ 13 μs // 1.3 μs

ToF (keV) ~ 420 μs // 42 μs

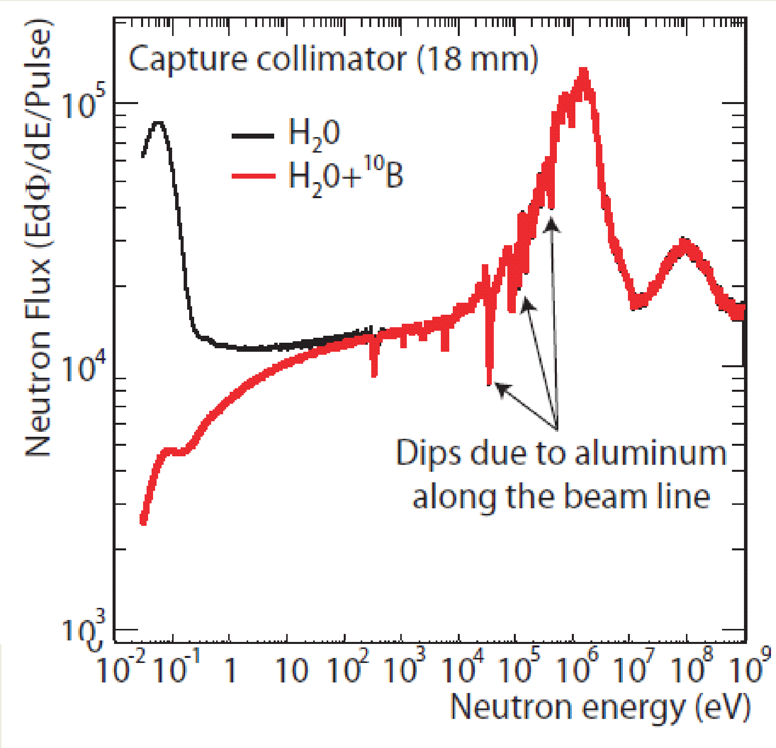
ToF (eV) ~ 13 ms // 1.3 ms

ToF (10 meV) ~ 133 ms // 13 ms

The existing n_TOF EAR1 @185 m

Main characteristics of the existing n_TOF EAR-1

NEUTRON FLUX

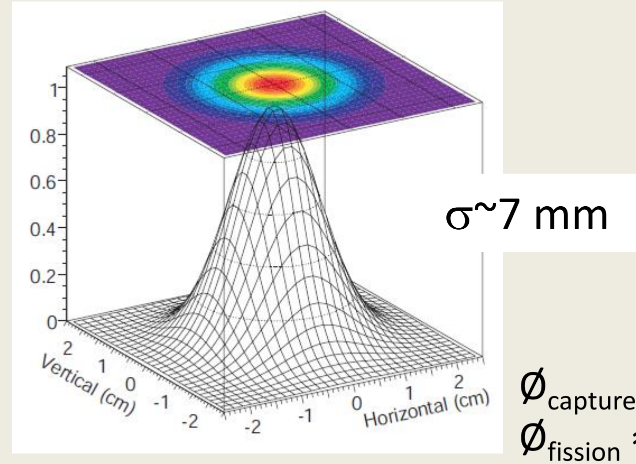


$0{,}6\cdot10^6$ neutrons/pulse (capture mode)

$12\cdot10^6$ neutrons/pulse (fission mode)

See C. Guerrero et al. *Eur Phys. J. A 49:27 (2013)*

BEAM PROFILE

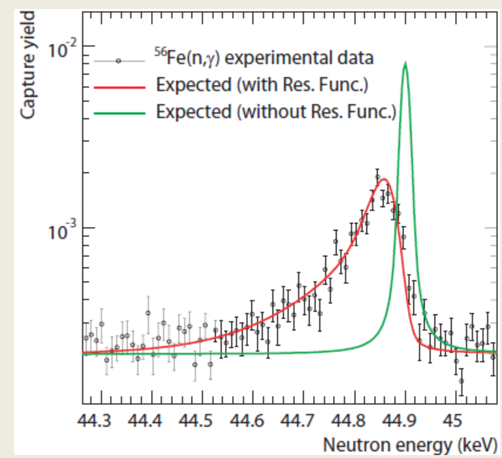


$Ø_{capture} \approx 2$ cm

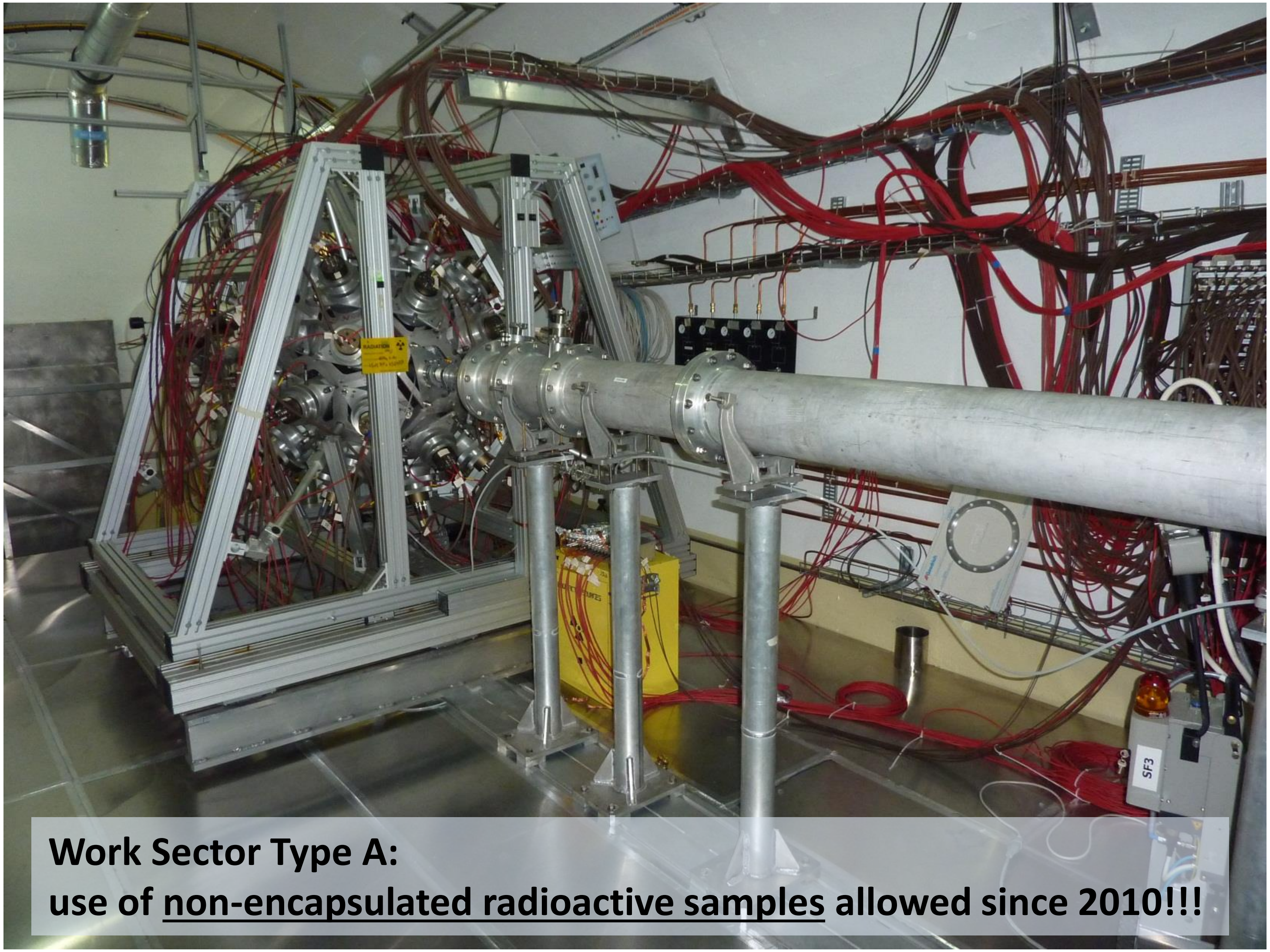
$Ø_{fission} \approx 8$ cm

ENERGY RESOLUTION

E_n (eV)	$\Delta E_n/E_n$
1	$4.3\cdot10^{-4}$
10	$4.3\cdot10^{-4}$
10^2	$4.3\cdot10^{-4}$
10^3	$7.5\cdot10^{-4}$
10^4	$1.7\cdot10^{-3}$
10^5	$5.4\cdot10^{-3}$
10^6	$2.8\cdot10^{-3}$



Main characteristics of the existing n_TOF EAR-1



Work Sector Type A:
use of <u>non-encapsulated radioactive samples</u> allowed since 2010!!!

n_TOF EAR1 Phase2 (2009-2012)

Nuclear technologies

Nuclear Astrophysics

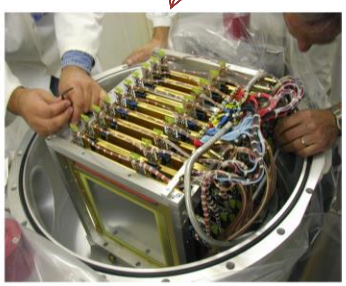
Medical applications

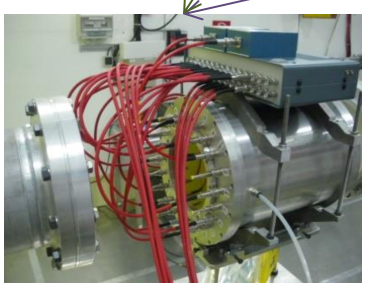
Ang. Distrib. FF
^{232}Th, ^{237}Np, ^{234,235,238}U

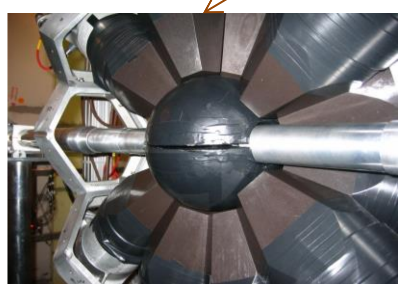
Fission
^{240,242}Pu, ^{235}U

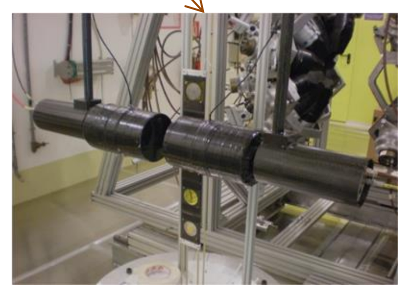
Neutron capture
^{54,56,57}Fe, $^{58,60,62,\mathbf{63}}$**Ni**, ^{25}Mg, ^{93}Zr, $^{\mathbf{235},236,238}$**U**, **^{241}Am**

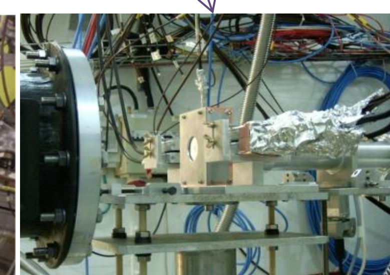
(n,α)
^{10}B, ^{33}S, **^{59}Ni**





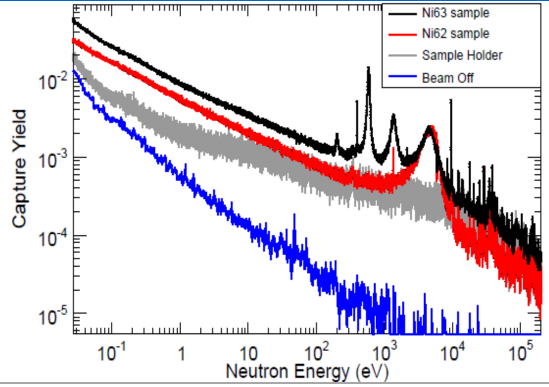




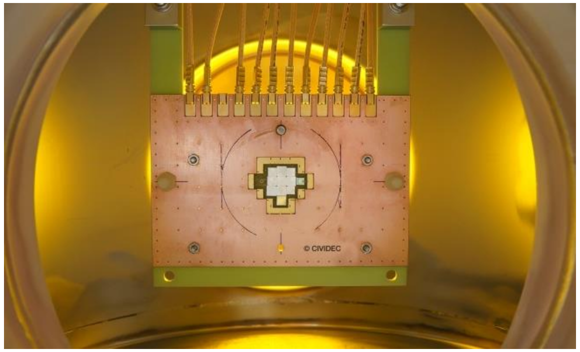


Recent results

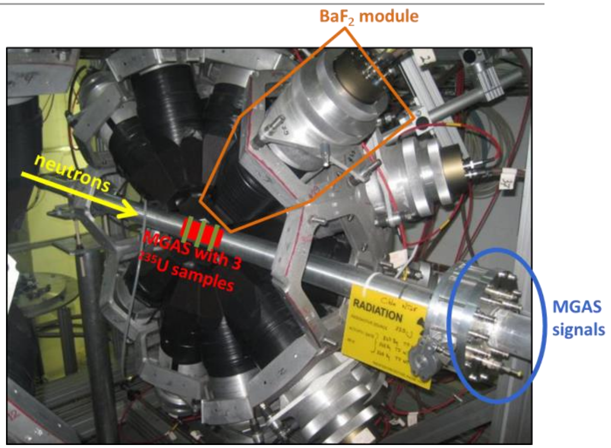
C. Lederer et al., "**Neutron capture cross section of unstable ^{63}Ni: implications for stellar nucleosynthesis**", Phys. Rev. Lett. 110 (2013) 022501



C. Weiss et al., "**A new CVD diamond mosaic-detector for (n,α) cross-section measurements at the n_TOF experiment at CERN**", Nucl. Instrum. and Meth. A (In Press)



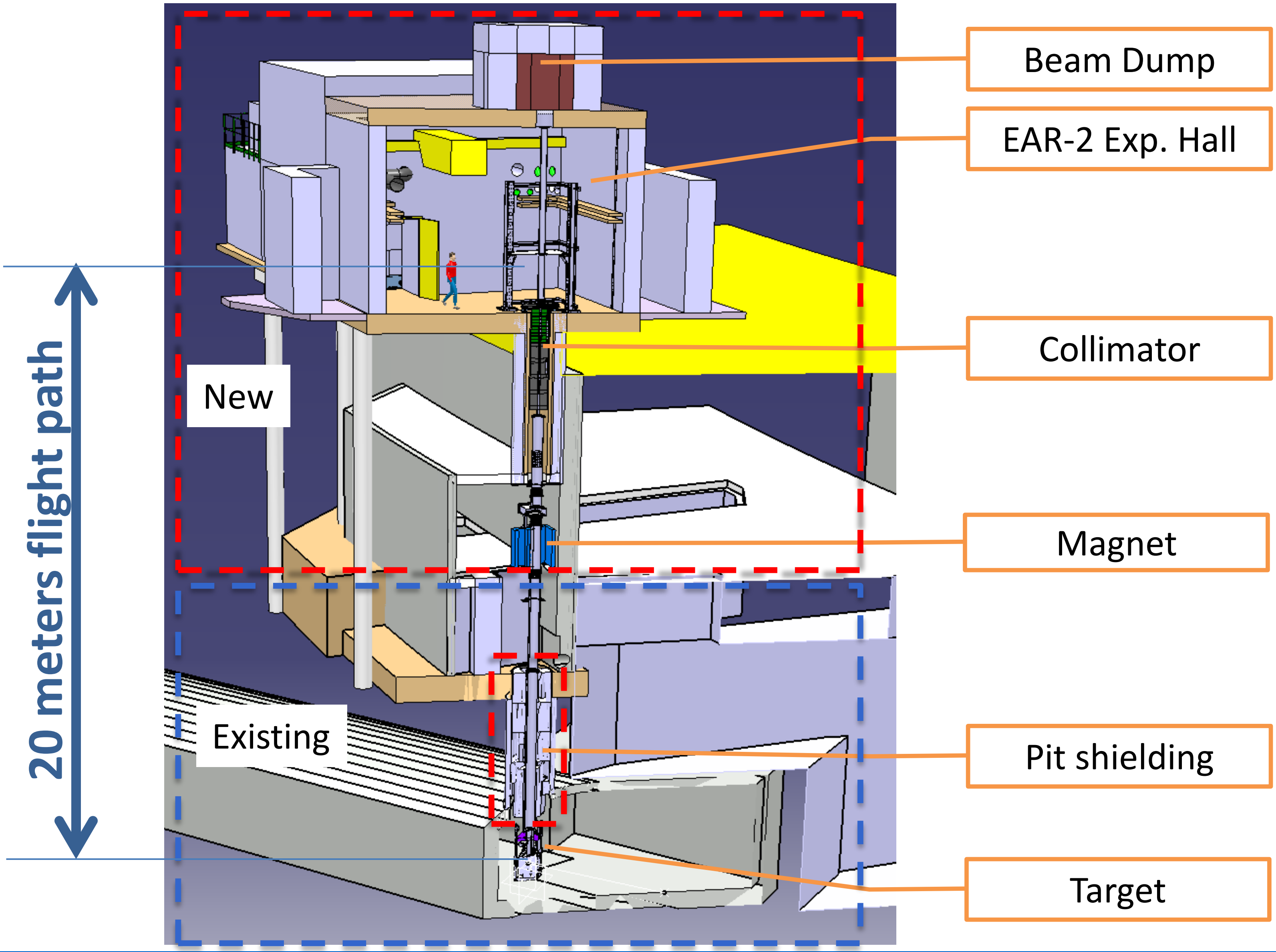
C. Guerrero et al., "**Simultaneous measurement of neutron-induced capture and fission reactions at CERN**", Eur. Phys. J. A (2012) 48:29



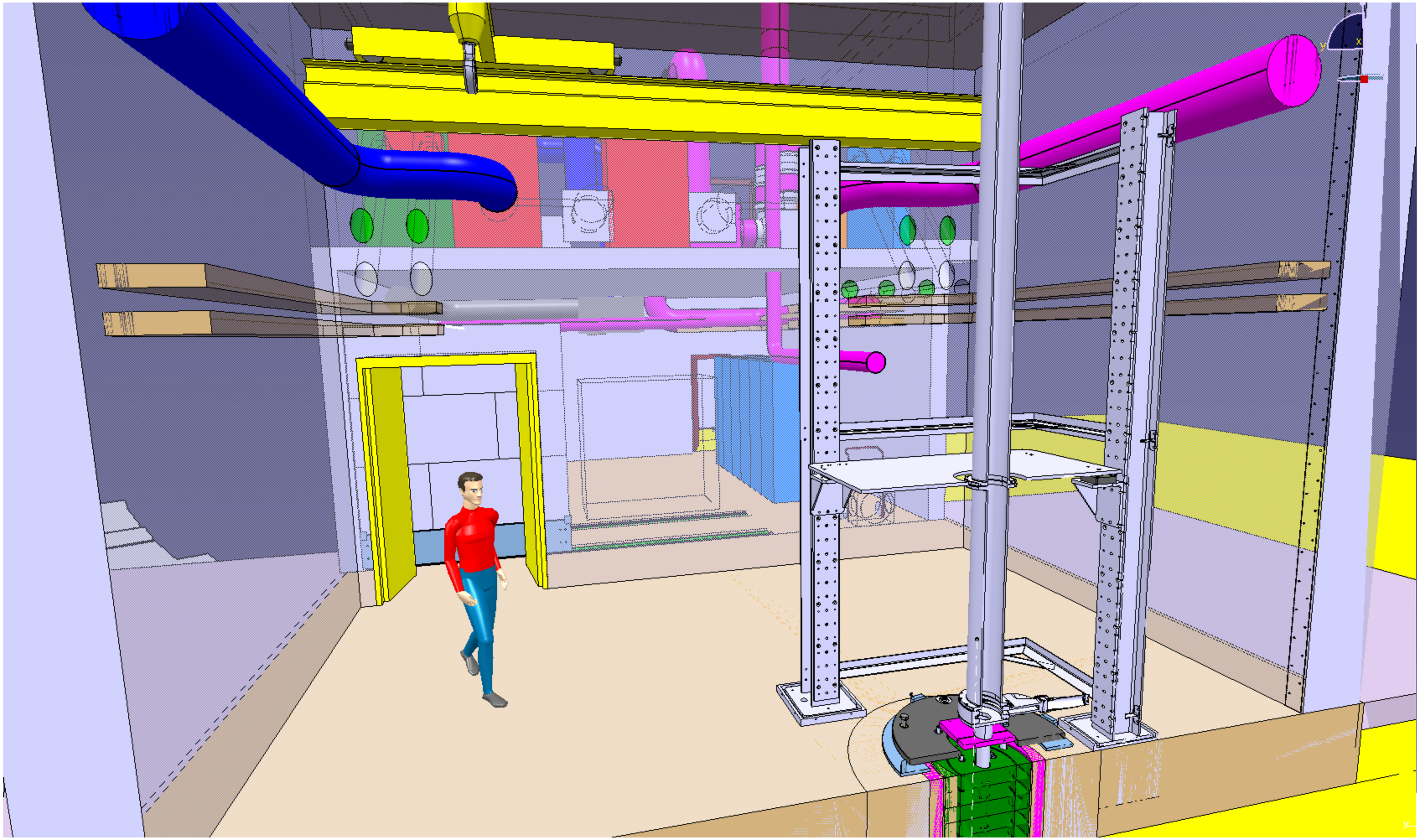
See more on E. Mendoza and A. Tsinganis talks!

The future n_TOF EAR2 @20 m

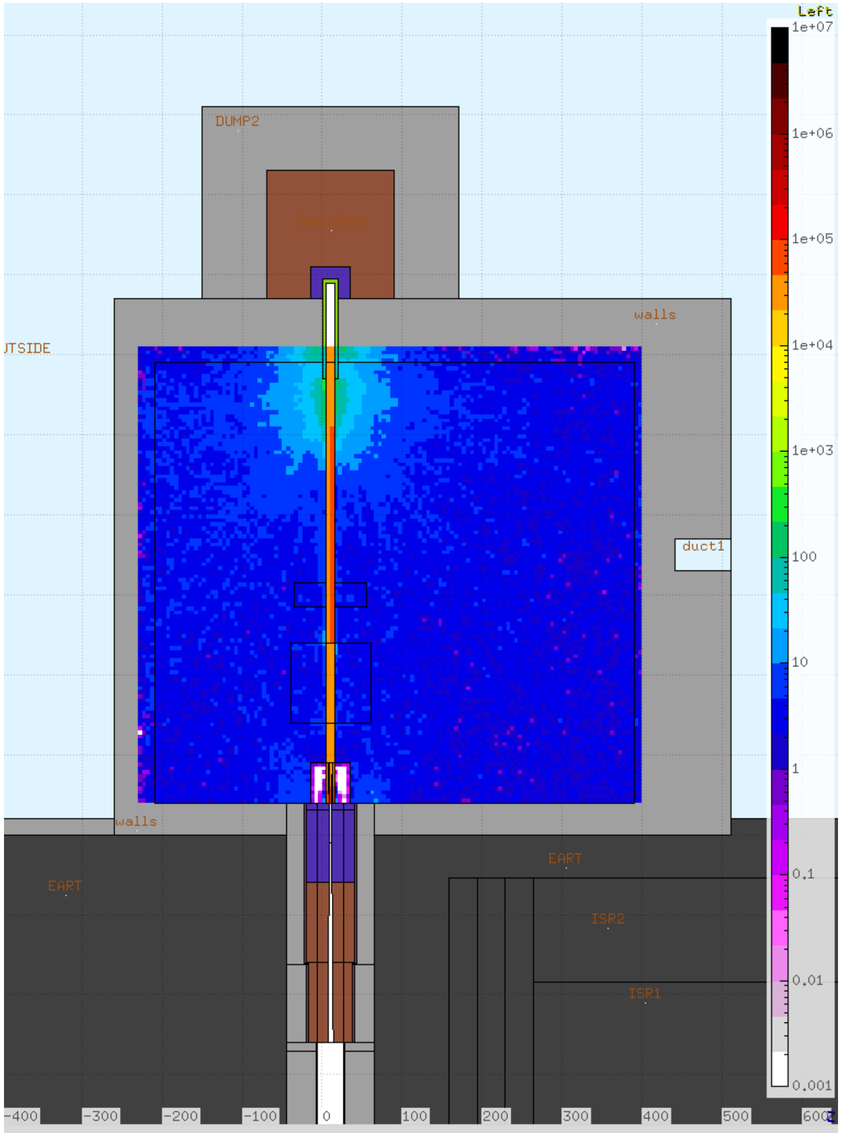
The future: n_TOF vertical flight path at 20 m

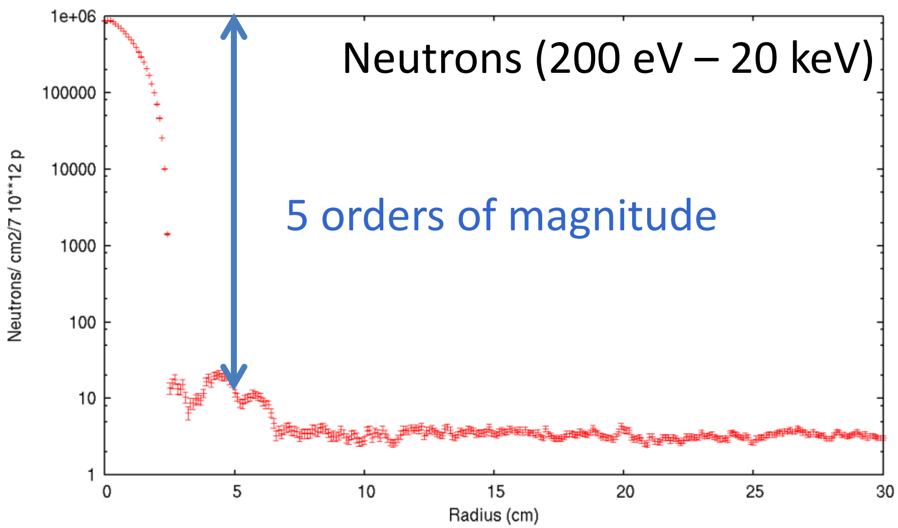


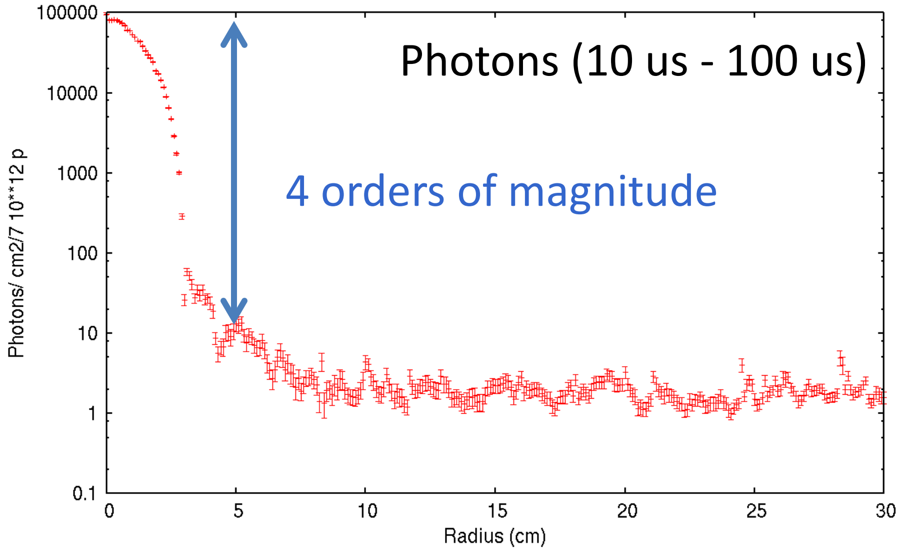
The future: n_TOF vertical flight path at 20 m



Detailed FLUKA simulation for the design of collimators and dump



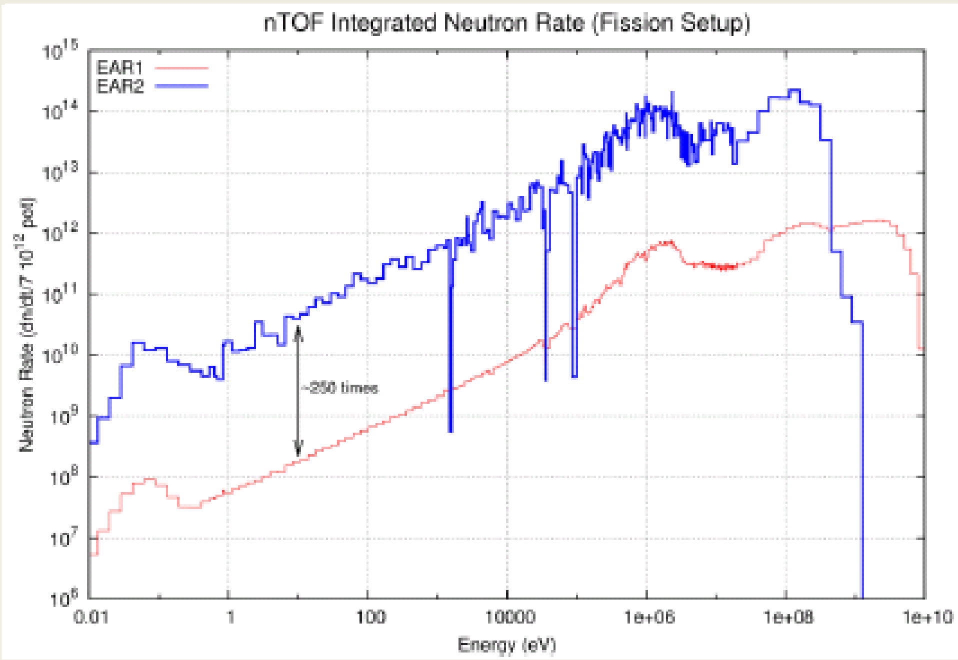




Construction of n_TOF EAR-2

Main characteristics of the future n_TOF EAR-2

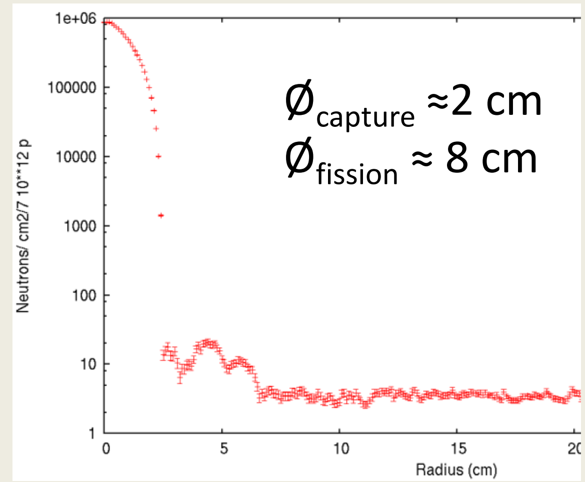
NEUTRON FLUX

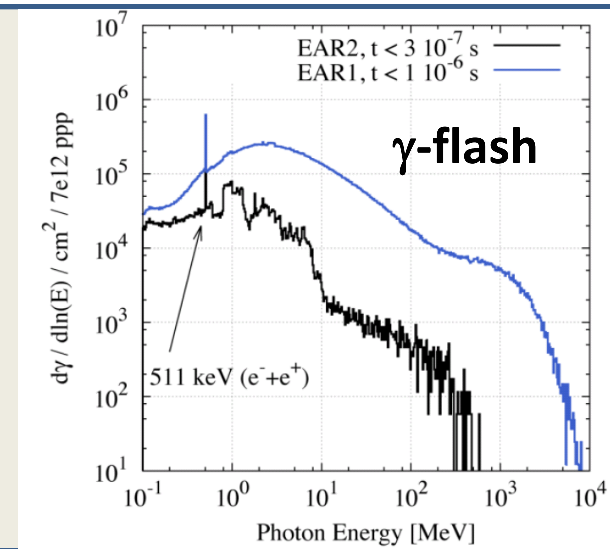


$\phi_{EAR\text{-}2} \sim 25 \times \phi_{EAR\text{-}1}$

E. Chiaveri et al., “Proposal for n_TOF Experimental Area 2”, CERN-INTC-2012-029

BEAM PROFILE





Proposals for experiments at n_TOF EAR-2

Advantages of EAR-2 compared to EAR-1:

- on very small samples: reduce activity or use samples with limited availability
- on isotopes with very small cross sections: where signal/background ratio is crucial
- in much shorter time: some meas. can be eventually repeated to reduce systematic errors
- on neutron-induced cross sections at high energies (E_n>1-100 MeV), which are not possible in the existing EAR-1, will benefit if the γ-flash is reduced.
- possibility to bring a 'basket' with electronics component down to only 1.5 m from the target (10^{10} neutrons/pulse): irradiation facility (e.g. SEE)

Proposals (some) for experiments at n_TOF EAR-2

Commissioning
- First beam scheduled for July 2014
- The commissioning, led by F. Gunsing, will take 3 to 6 months
- First beams for physics by the end of 2014: detailed proposal for CERN INTC February 2014

Nuclear Technology
- The role of ^{238}Pu and ^{244}Cm in the management of nuclear waste: (n, γ) cross sections
- Measurement of the capture (and fission) cross sections of the fissile ^{239,241}Pu and ^{245}Cm
- Measurements of (n,xn) reaction cross sections with HPGe detectors (^{197}Au, ^{181}Ta, etc.)
- Measurements of (n,n) and (n,xn) reactions cross sections with CsI+Si telescopes
- Fission process and the emission of prompt γ's on ^{235}U and ^{239,241}Pu isotopes with STEFF
- Fission cross section of the ^{230}Th, ^{231}Pa and ^{232}U reaction
- …..

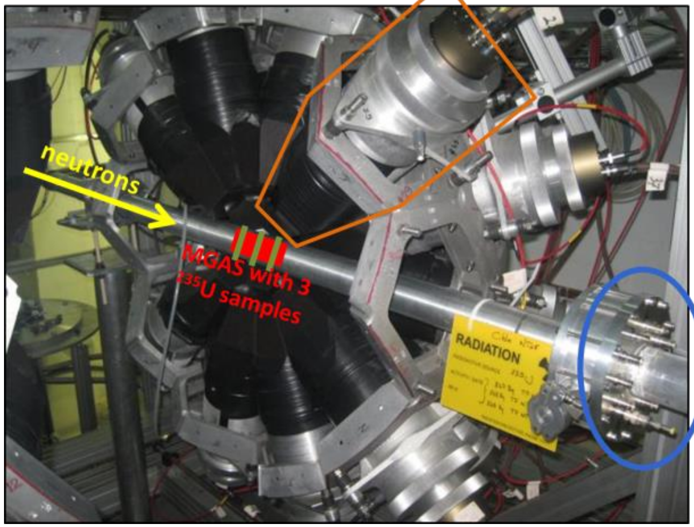
Astrophysics
- Measurement of the ^{25}Mg(n, α)^{22}Ne cross section
- Neutron capture measurement of the *s*-process branching points ^{79}Se and ^{147}Pm
- Destruction of the cosmic γ-ray emitter ^{26}Al by neutron induced reactions
- Measurement of ^{7}Be(n,p)^{7}Li and ^{7}Be(n,α)^{4}He cross sections, for the cosmological Li problem.
- …..

Others include basic nuclear physics, medical physics, detectors tests, etc.

Capture cross sections of fissile isotopes

TAC + MGAS technique successful @ EAR1, **BUT**:

- For ^{233}U and ^{235}U masses of ~30-100 mg used
- Requires a stack of many samples/ detectors
- Background from fission detectors
- Difficulty to find large number of samples
- The thin/Thick approach also difficult (samples)
- Need TAC for background identification (no C6D6)
- γ-flash limits the neutron energy (E_n<10 keV)



All these are overcome at EAR-2

- A two sample back-to-back approach will be employed
- Detector choice for capture could be array of C_6D_6 (x4) or new calorimeter (see CHANDA!)
- The reduced γ-flash should allow for a higher energy limit
- First campaigns for ^{233}**U** and ^{235}**U**, then ^{239,241}**Pu** and ^{245}**Cm**

(n,n) and (n,xn) cross sections at high energy

Physics: optical model, …

Applications: ADS, SEE, Medical, Dosimetry, …

Exp. data: some (n,n) above 30 MeV [e.g. Öhrn et al., PRC**77** (2008) 024605]

almost nothing on (n,nx)! [e.g. Sagrado Garcia et al., PRC**84** (2011) 044619]

Option A

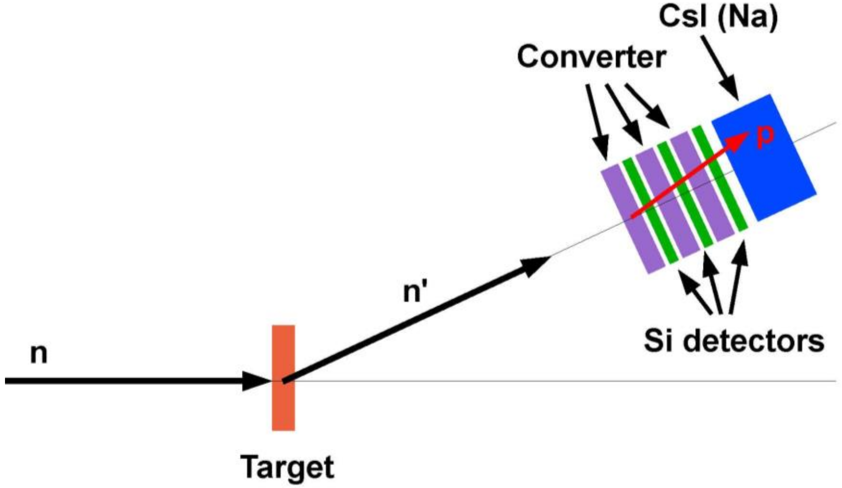
Principle:
Measure (n,xn) through identification of the reaction product's γ-ray emission.

Detectors:
HPGe (γ-flash could be an issue).

Groups involved:
NTUA (Greece), CEA (France), IFIN-HH (Romania) et al.

Option B

Principle: Measure the ejected neutron via the associate proton recoil in a convertor.

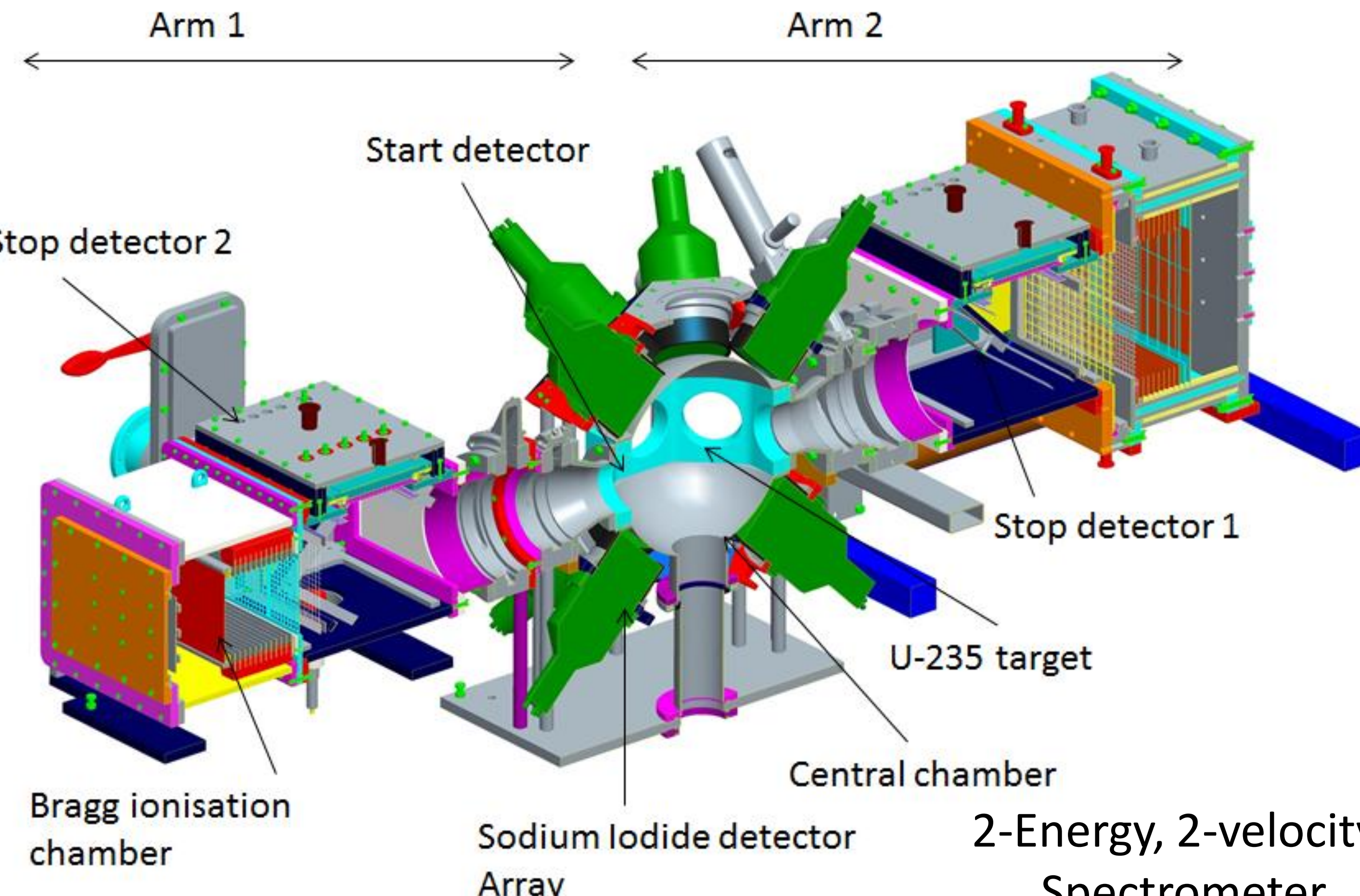


Groups involved: UU (Sweden), CEA (France) et al.

(n,f) and prompt γ-ray emission of ^{235}U and ^{239,241}Pu with STEFF

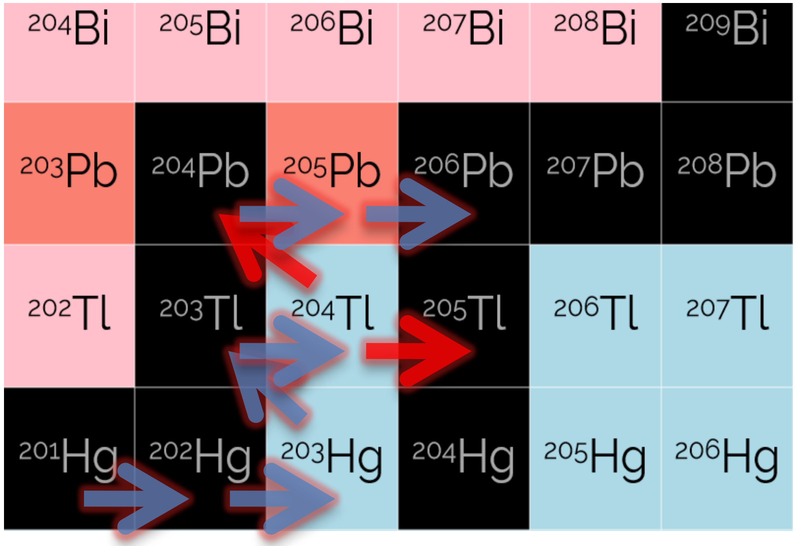
STEFF: Spectrometer for Exotic Fission Fragments [*University of Manchester* (UK)]

- Fragment Mass identification through ToF (velocity) plus Bragg IC (energy)
- γ-rays energies and multiplicities through NaI detector array (x16) **[NEA HPRL]**



2-Energy, 2-velocity Spectrometer.

Tackling the *s*-process branching points ^{79}Se, ^{147}Pm, ^{171}Tm and ^{204}Tl



e.g. *s*-process branching at ^{204}Tl

^{205}Pb ($t_{1/2}$ = 1.5x10^{7} a) is s-only, thus the SS abundances of ^{205}Pb/^{205}Tl provides chronometric info on the time span between the last nucleosynthetic events and the formation of solar system solid bodies. (At present, upper limit for the ^{205}Pb/^{204}Pb abundance ratio of 9x10^{-5} in meteorites)

Production via (n,γ) or (n,γ)β^{-} in the ILL research reactor

$\Phi_{n,th}$ = 1.5x10^{15} n/cm^{2}/s (→ 60 days)

^{147}Pm: ^{146}Nd(n,γ)^{147}Nd (β^{-}, 10d)^{147}Pm → 0.29 mg (2.6 y)

^{171}Tm: ^{170}Er(n,γ)^{171}Er (β^{-}, 7.5h)^{171}Tm → 3.69 mg (1.9 y)

^{204}Tl: ^{203}Tl(n,γ)^{204}Tl → 11.0 mg (3.8 y)

GOAL is to measure MACS with C_6D_6 at EAR-2

NEUTRONS FOR SCIENCE

ILL: a source for radioactive samples

Conclusions and perspectives

The new n_TOF EAR-2 20 m neutron beam line will be operative at CERN from July 2014

25 times higher flux (n/pulse) than n_TOF EAR1 (185 m)
250 times higher flux neutron rate (n/s) than n_TOF EAR1
Reduced energy resolution(no RR above ~10 keV)
Runs in parallel to EAR1

First physics experiments by end 2014:

- Capture on fissile isotopes
- Capture on small mass *s*-process branching points
- Fission spectroscopy and prompt γ-rays with STEFF
- Elastic/inelastic reactions (HPGe or CsI+Si telescopes)
- Fission on high activity samples (e.g. ^{240}Pu)
- Irradiation of electronic components (@1.5 m)
- …