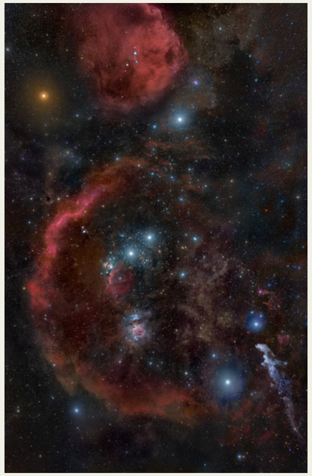
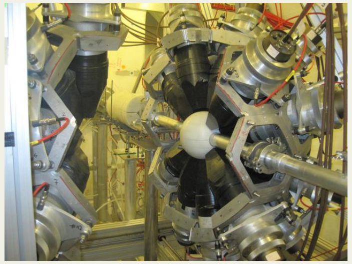
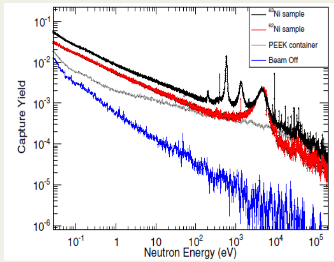
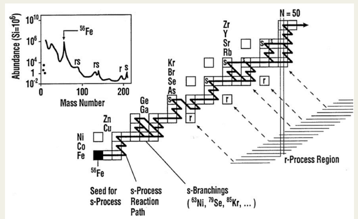
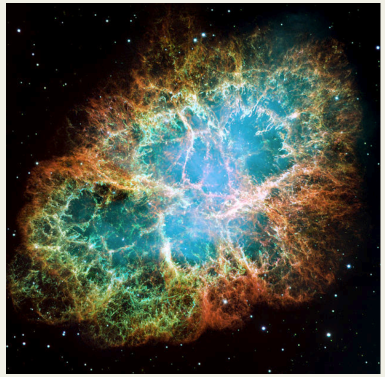
Fisica dei Neutroni a n_TOF





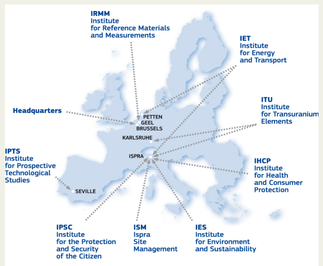


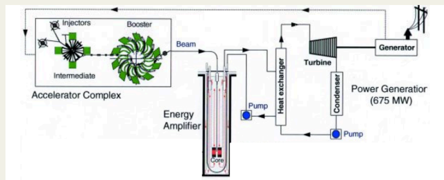




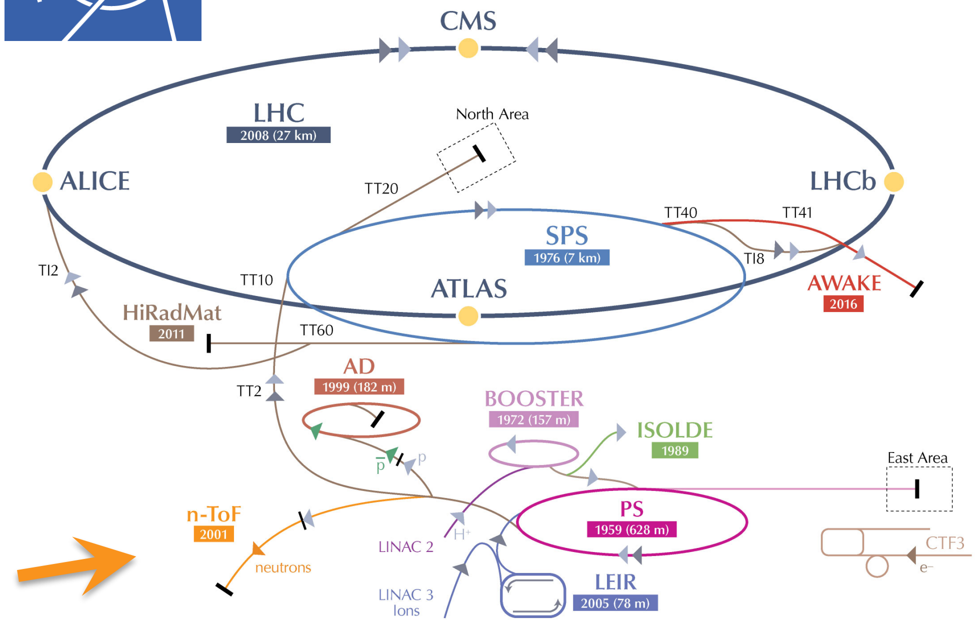
n_TOF
neutron Time Of Flight
@ CERN

GELINA
@ EC-JRC-GEEL





n_TOF Collaboration



International Collaboration

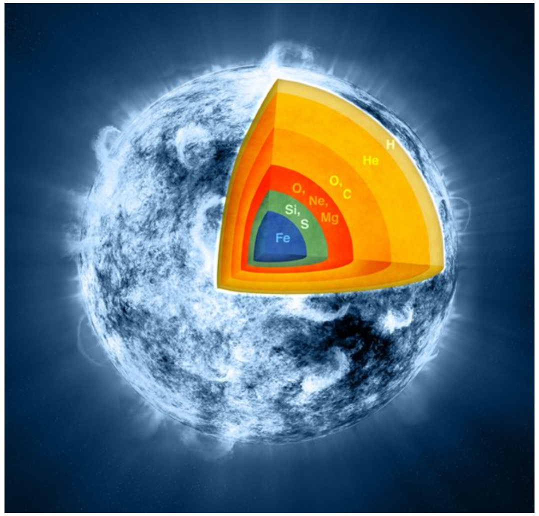
130 researchers

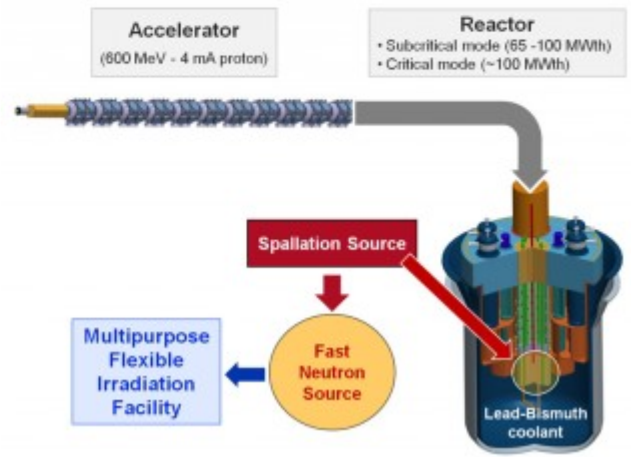
33 institutes (EU, Russia, Japan, India)

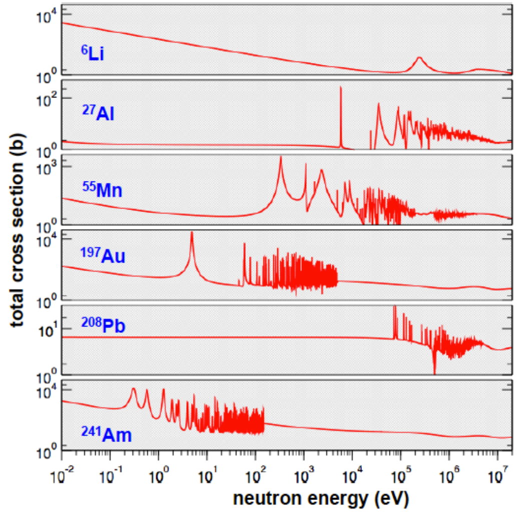
6 INFN Sections involved

Close collaboration with **ENEA**-Bologna, **INAF**-Teramo, **CNR**-Bari

Research fields







Nuclear Astrophysics

- ✓ **N**ucleosynthesis of heavy elements
- ✓ **S**tellar evolution
- ✓ **B**ig bang nucleosynthesis

Nuclear technology and medical application related to:

- ✓ **F**ission reactors (Gen-IV, ADS)
- ✓ **F**usion
- ✓ **N**eutron Imaging
- ✓ **T**ransmutation of nuclear waste
- ✓ **N**eutron capture therapy (adrotherapy)

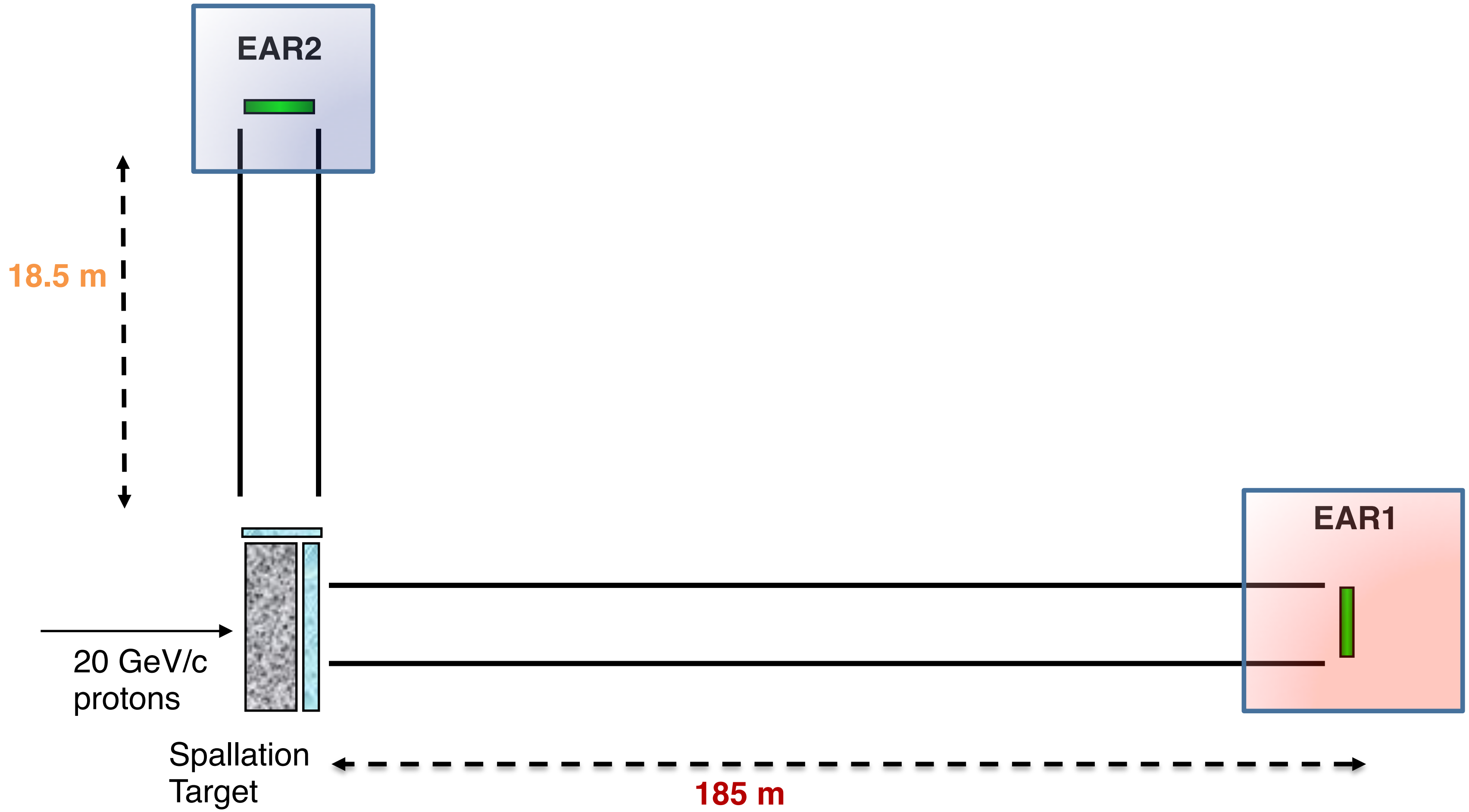
Basic Nuclear Physics

- ✓ **N**uclear structure effects on fission
- ✓ **E**xcited states (spin parity of resonances)

n_TOF facility (so far)

The features of the n_TOF facility are related to the PS proton beam:

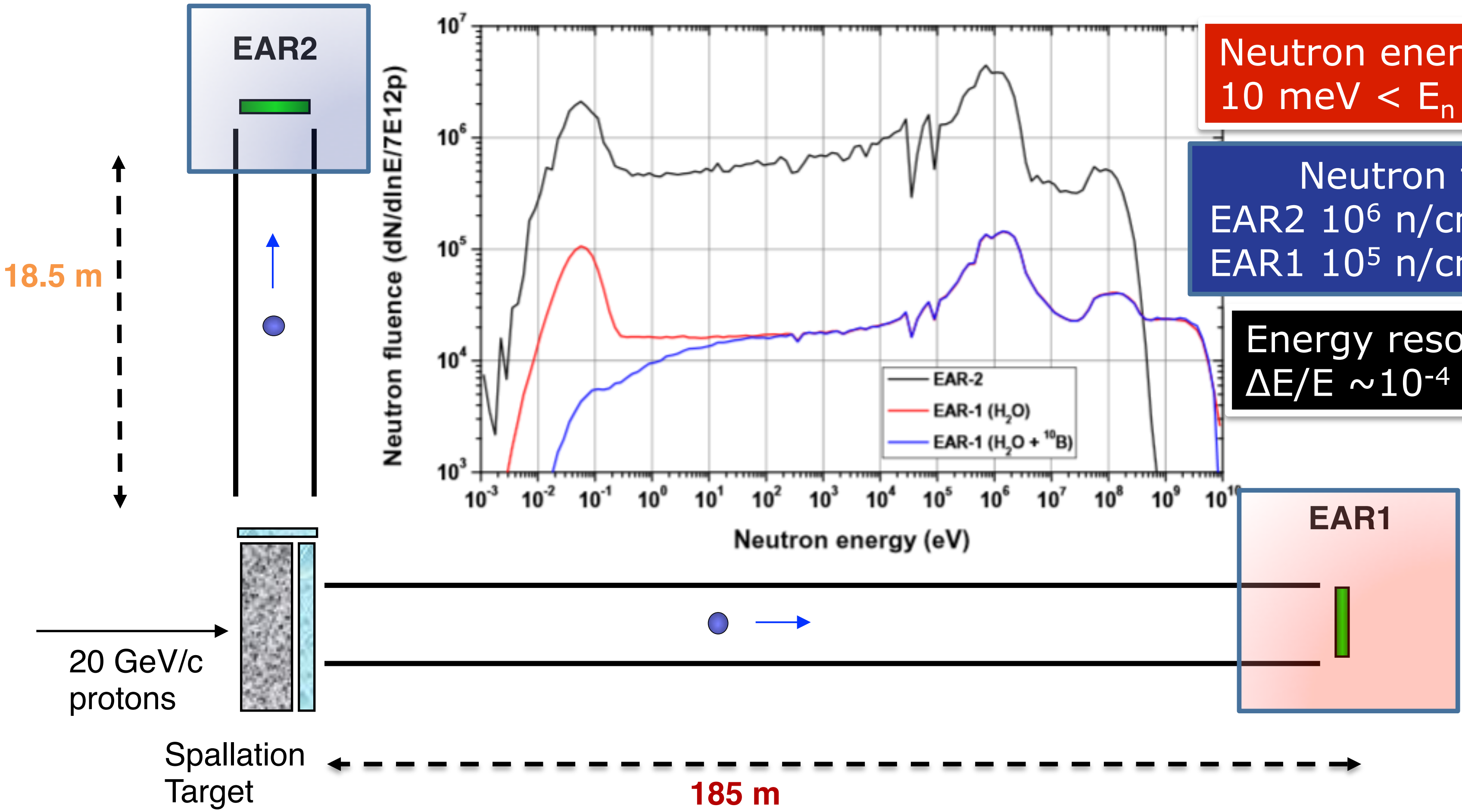
high energy, high current, low duty cycle.



n_TOF facility (so far)

The features of the n_TOF facility are related to the PS proton beam:

high energy, high current, low duty cycle.



Neutron energy
10 meV < E_n < 1 GeV

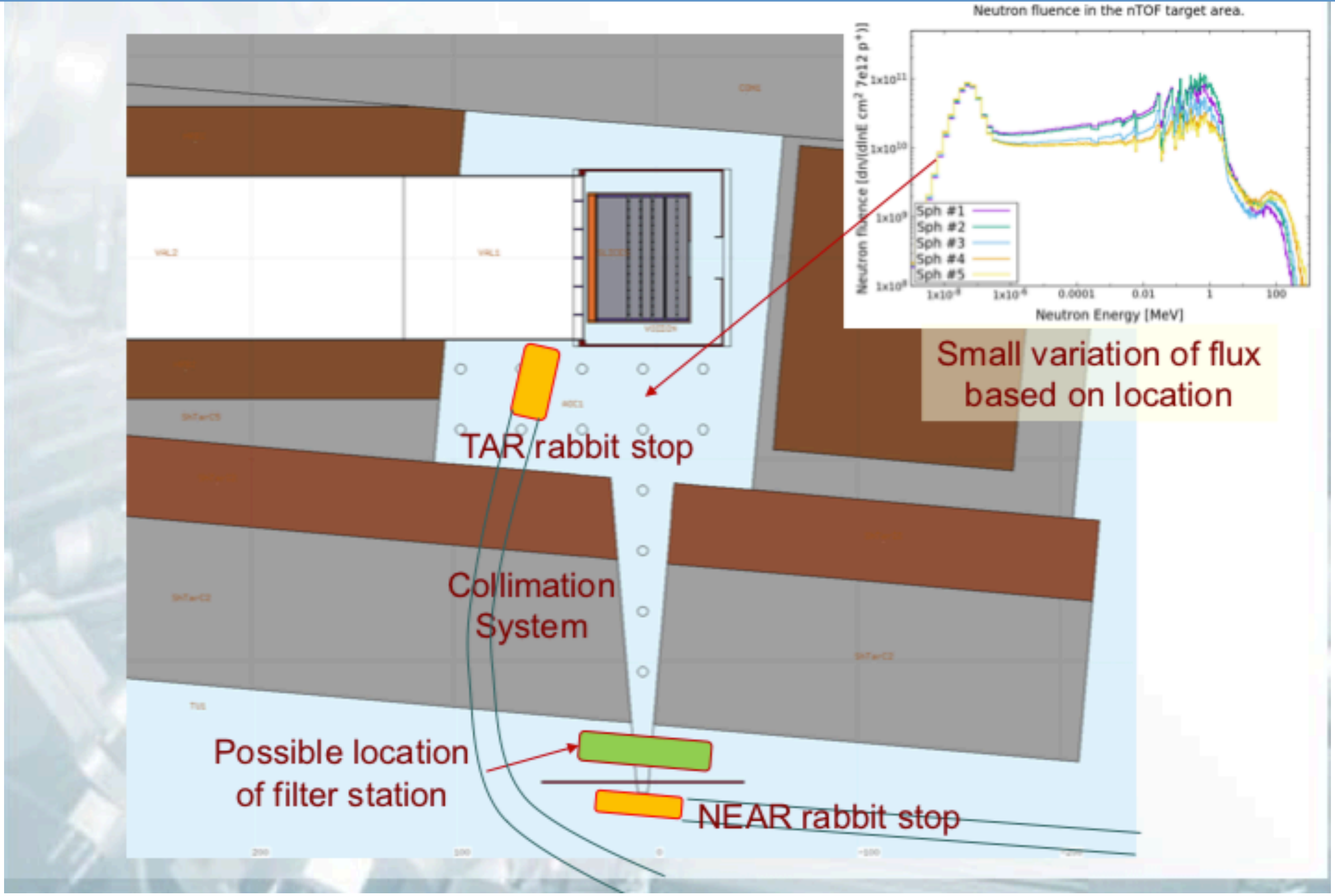
Neutron flux
EAR2 10^6 n/cm^2/pulse
EAR1 10^5 n/cm^2/pulse

Energy resolution
$\Delta E/E \sim 10^{-4}$ @ EAR1

n_TOF facility (2021)

Irradiation area few meters away from the neutron spallation target

Activation, Radiation to electronics, Imaging, Dosimetry, ….

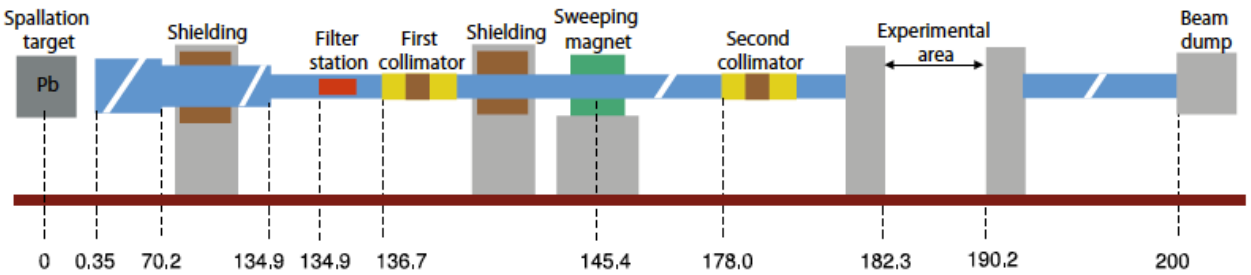


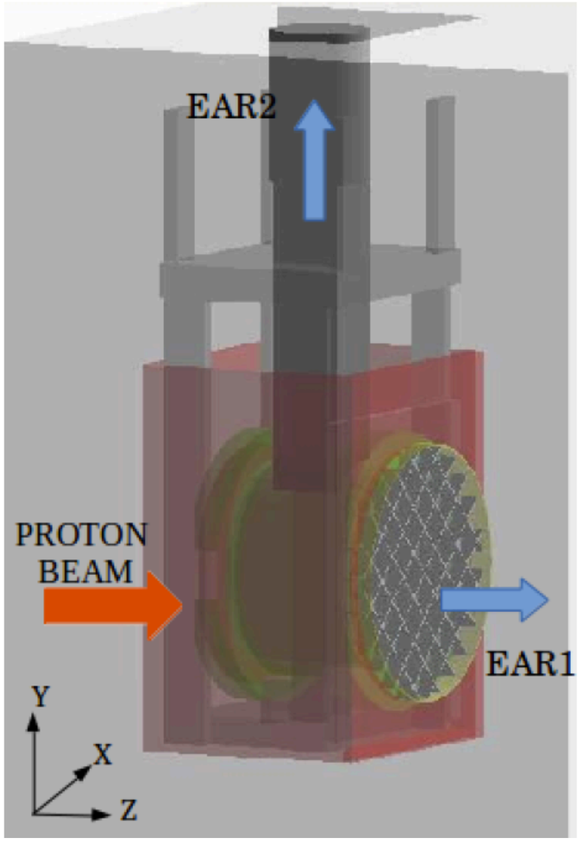
ACTIVITIES

MC simulation of n_TOF source

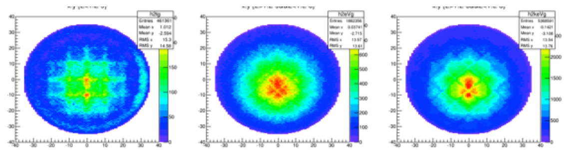
Geant4 simulation of the n_TOF neutron source and transport to EAR1

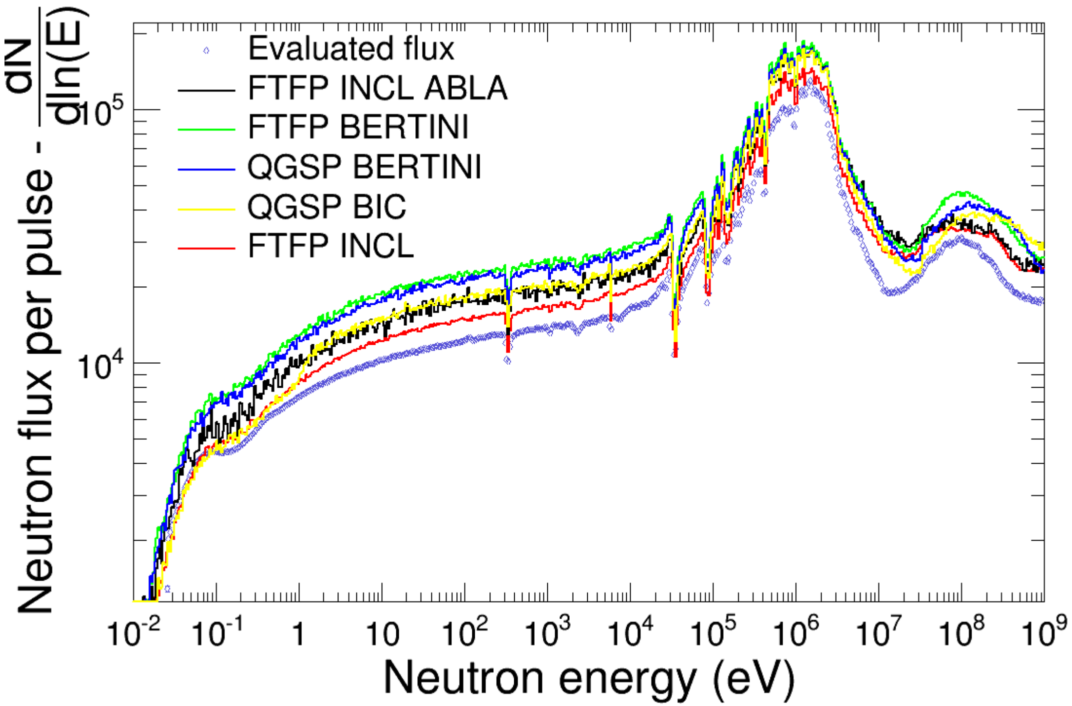
20 GeV/c protons on lead





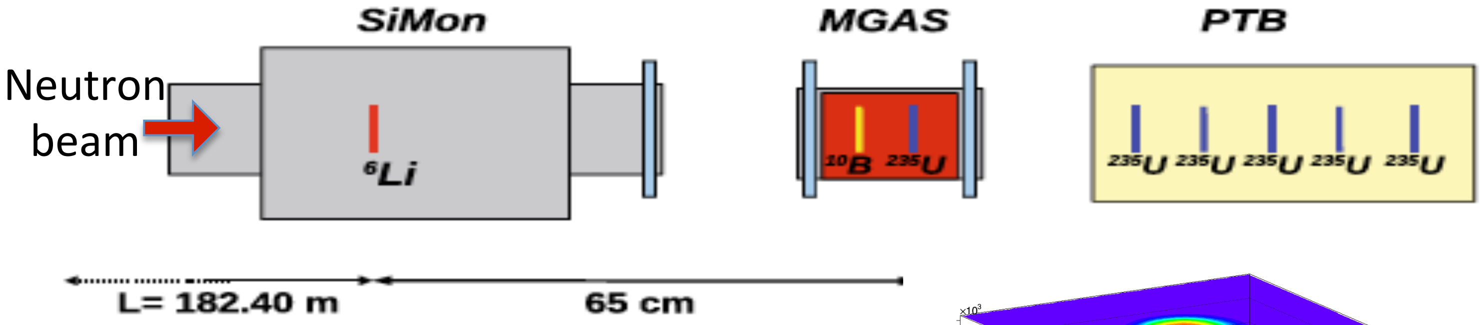
S. Lo Meo, M. A. Cortés-Giraldo, C. Massimi, *et al.*, Eur. Phys. J. A 51 (2015) 160



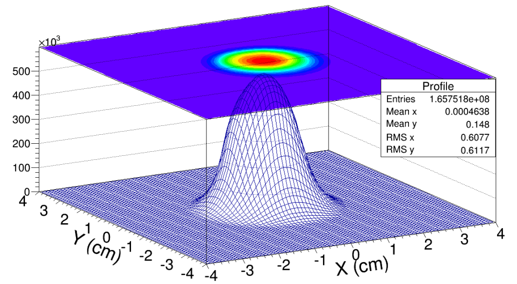


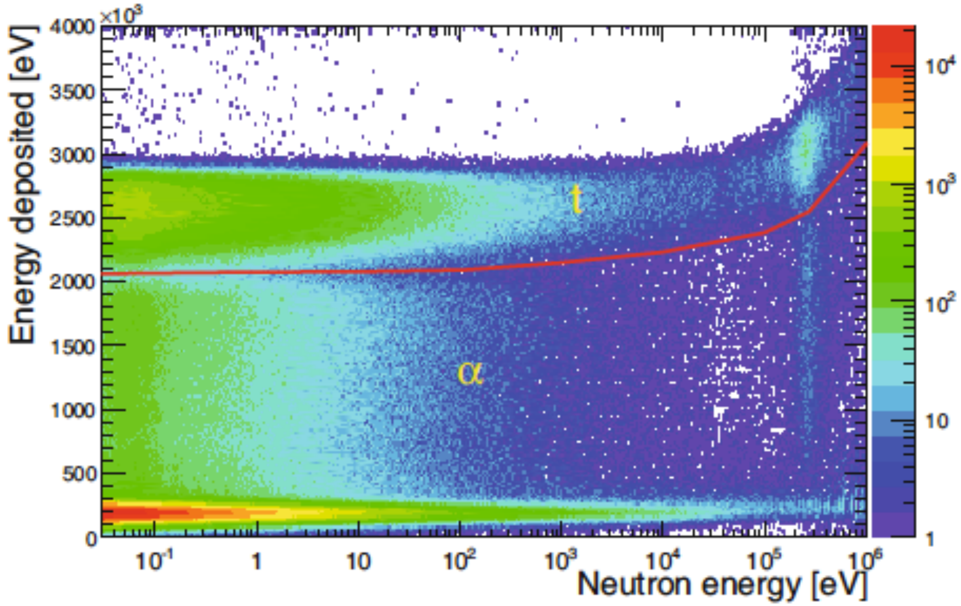
Beam characterization

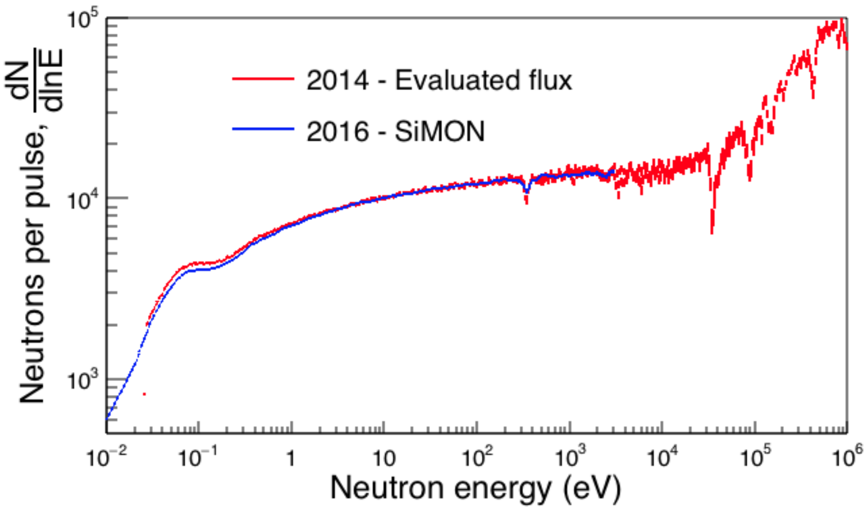
3 different detectors based on 3 neutron standards



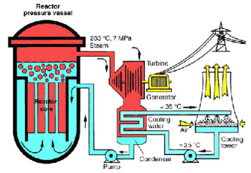
M. Barbagallo,, *et al.*, Eur. Phys. J. A 49 (2013) 156





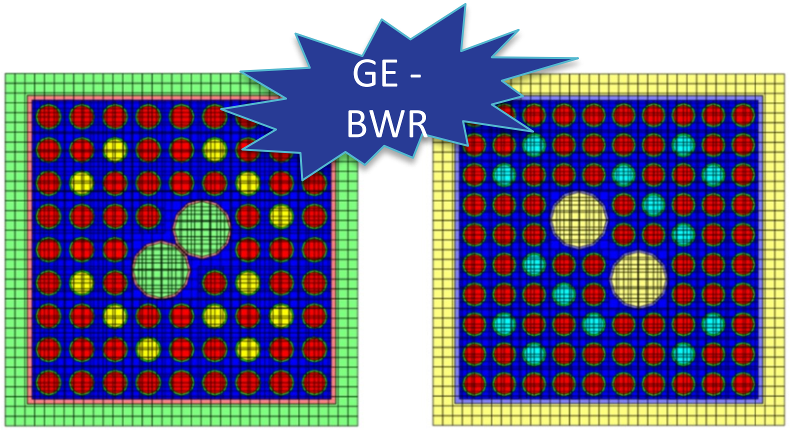


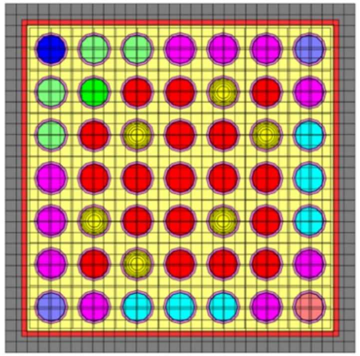
Neutron poison



$^{155,157}Gd(n, \gamma)$
"burnable neutron poison"

Proposal (INFN) in close collaboration with ENEA



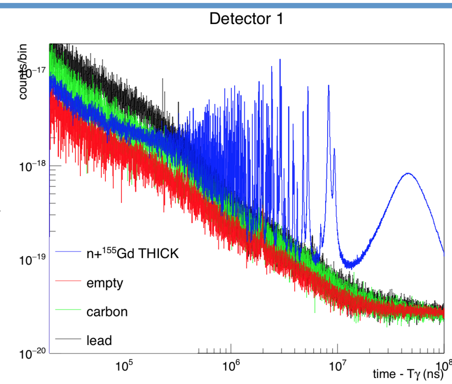


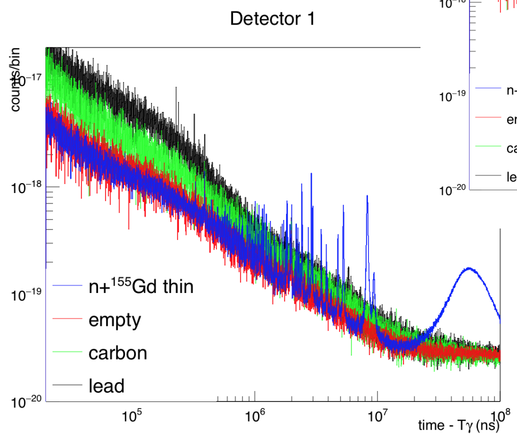
The **uncertainty** on **Gd** cross sections gives the **largest contribution** to the uncertainty on k_{eff} **after $^{235,238}U$.**

To increase the **efficiency** of **reactor fuel,** it is necessary to **increase** the initial **enrichment of ^{235}U** in the fuel.

High enrichments pose severe safety problems due to the **high initial excess reactivity.** This can be **inherently compensated** by loading the fuel with **"burnable neutron poisons"**, i.e. isotopes with very high capture cross section

TOF spectra



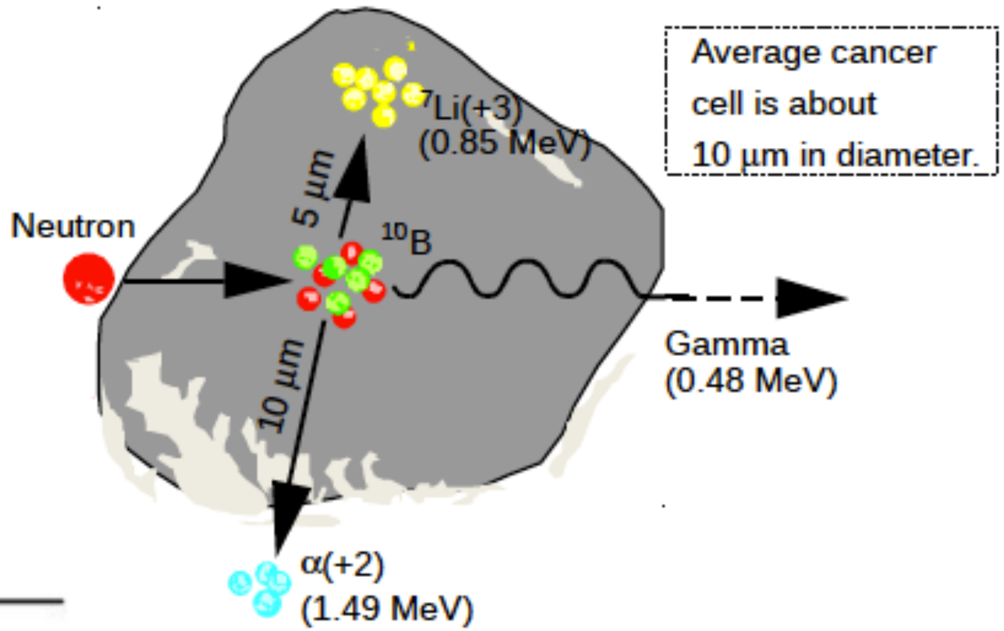


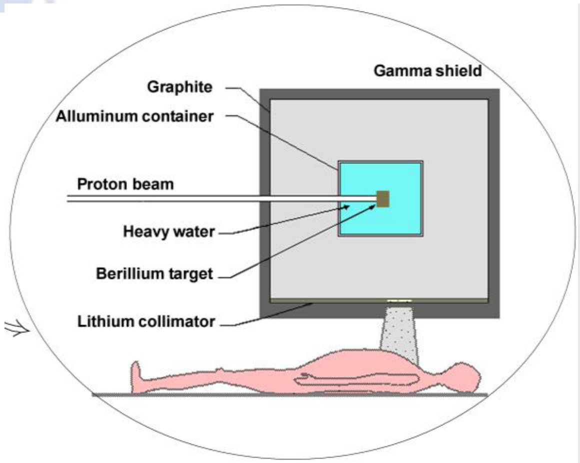
4 C_6D_6
EAR1

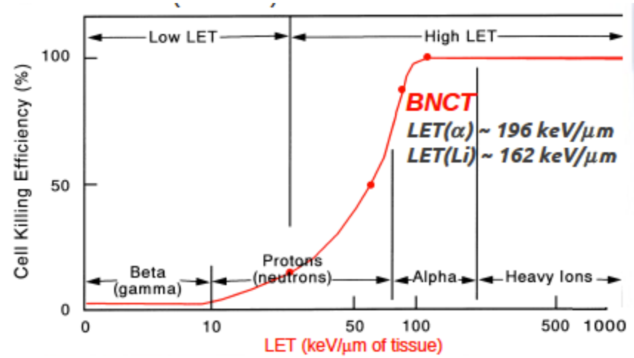
Neutron poison

$^{155,157}Gd(n, \gamma)$
BNCT

element	weight fraction	capture reaction	σ (barns) at 25 meV
H	~ 10%	$^{1}H(n,\gamma)^{2}H$	0.322
N	~ 3%	$^{14}N(n,p)^{14}C$	1.8
B	~ 20-35 ppm	$^{10}B(n,\alpha)^{7}Li$	3837



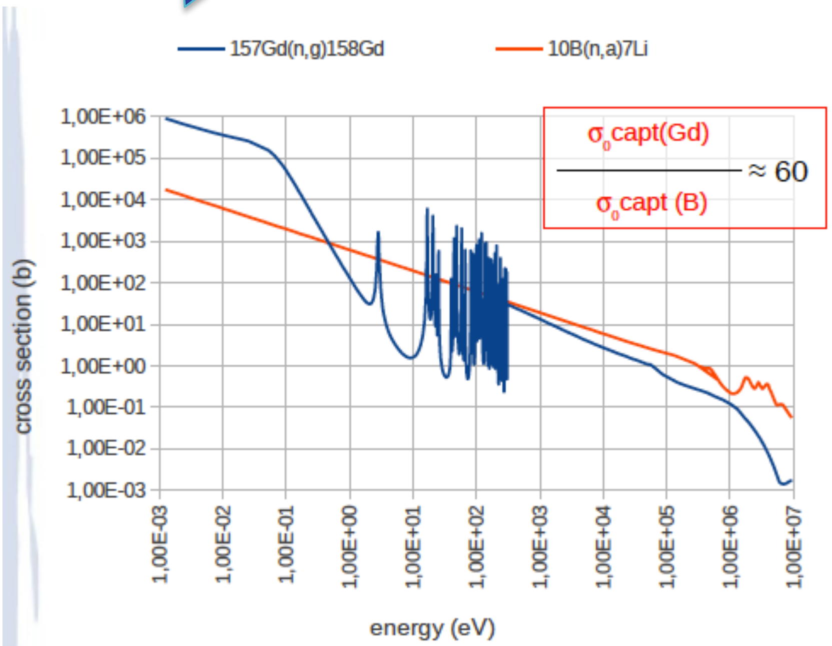


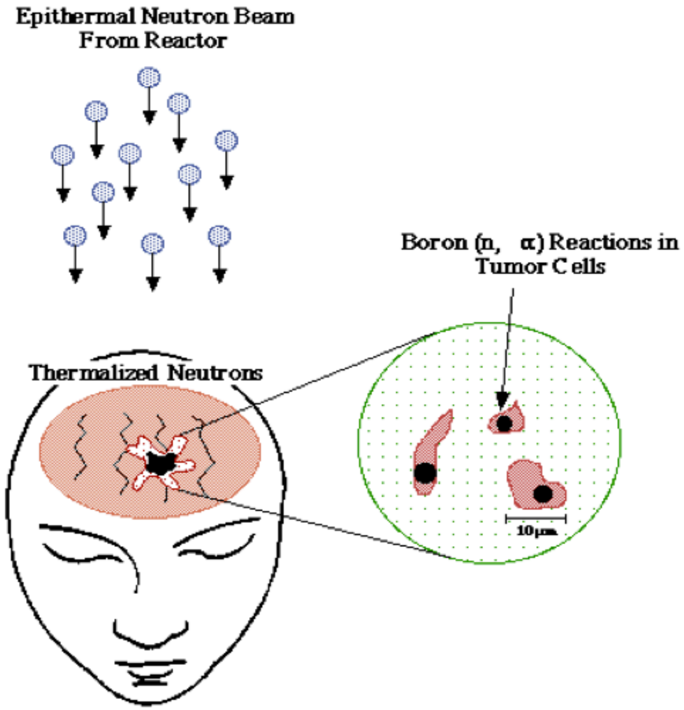


Neutron poison

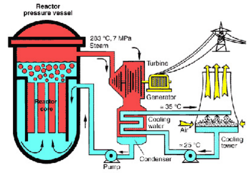
$^{155,157}Gd(n, \gamma)$
BNCT

Beyond Boron:
^{157}Gd, ^{33}S, …





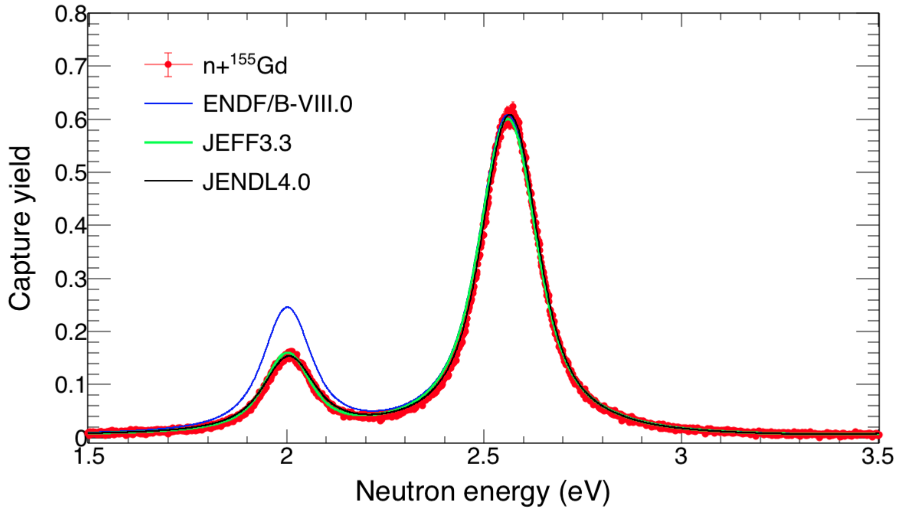
Neutron poison

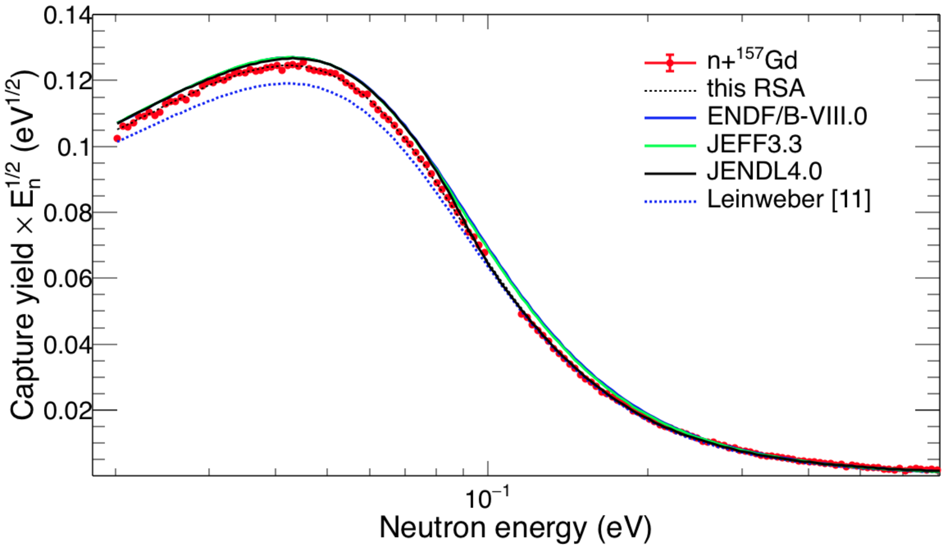


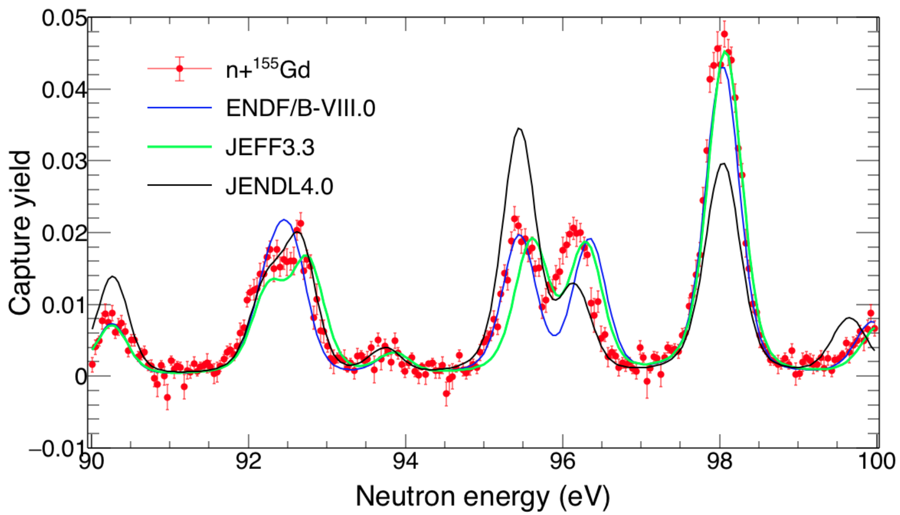
^{155,157}Gd(n, γ)
"burnable neutron poison"

TABLE I. ^{155}Gd and ^{157}Gd thermal cross sections (in kb) as reported in literature, compilation [8] and evaluations.

Reference	Year	Thermal cross section n + ^{155}Gd	n + ^{157}Gd
Møller [9]	1960	58.9(5)^a	254(2)^a
Ohno [10]	1968	61.9(6)^a	248(4)^a
Leinweber [11]	2006	60.2^b	226^b
Mughabghab	2009	60.9(0.5)	254.0(0.8)
JENDL-4.0	2016	60.735	253.25
JEFF-3.3	2017	60.89	254.5
ENDF/B-VIII.0	2018	60.89	253.32





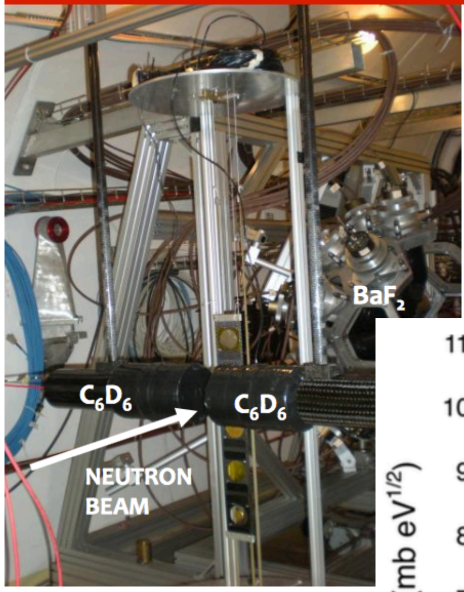


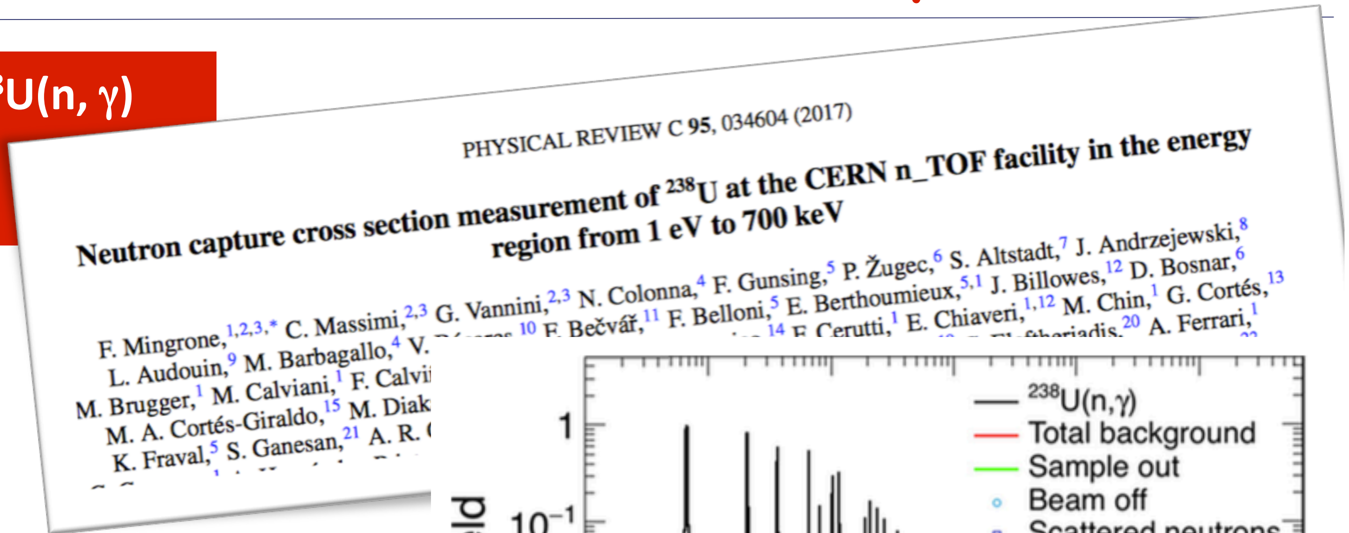
backup

Measurement of $^{238}U(n, \gamma)$

ANDES (FP7) project: $^{238}U(n, \gamma)$

- **n_TOF C_6D_6 + TAC**
- **GELINA C_6D_6**

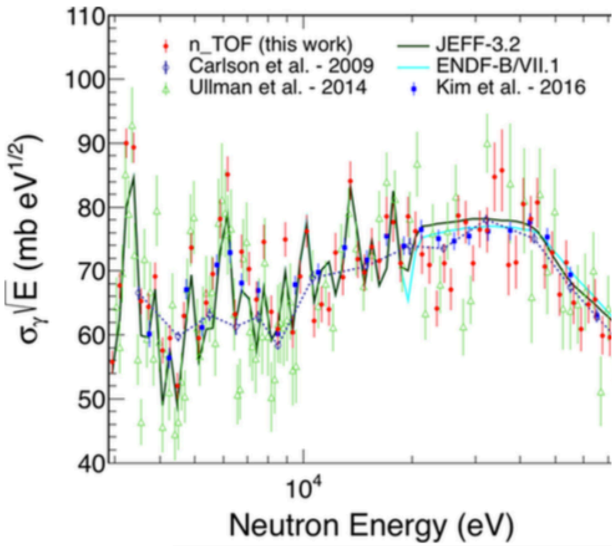


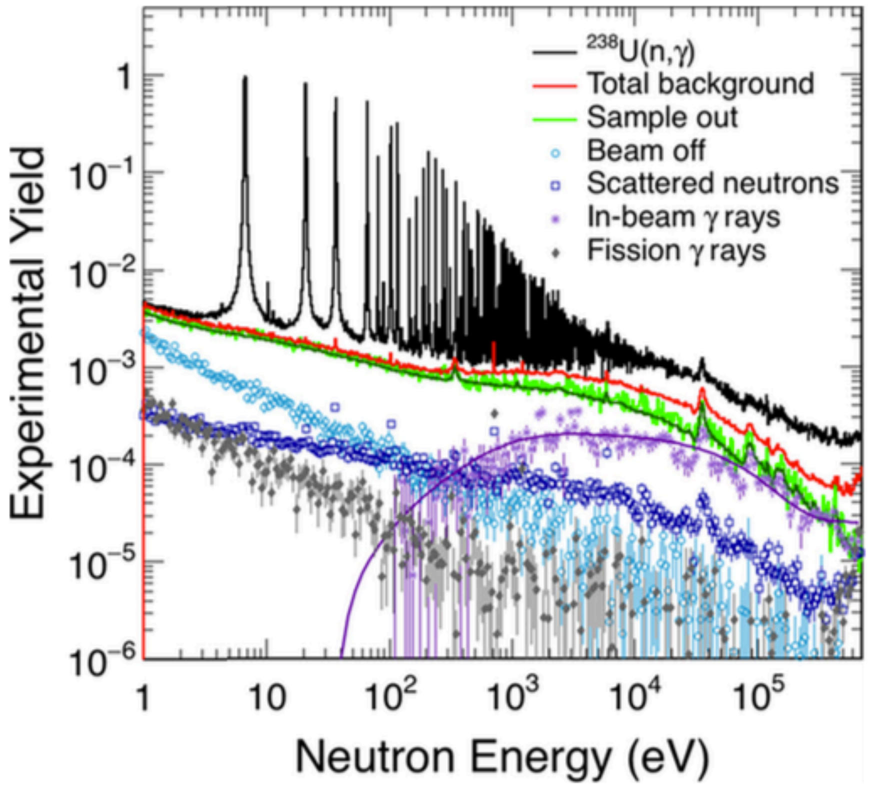


PHYSICAL REVIEW C 95, 034604 (2017)

Neutron capture cross section measurement of ^{238}U at the CERN n_TOF facility in the energy region from 1 eV to 700 keV

F. Mingrone,[1,2,3,*] C. Massimi,[2,3] G. Vannini,[2,3] N. Colonna,[4] F. Gunsing,[5] P. Žugec,[6] S. Altstadt,[7] J. Andrzejewski,[8] L. Audouin,[9] M. Barbagallo,[4] V. … M. Brugger,[1] M. Calviani,[1] F. Calvi… E. Berthoumieux,[5,1] J. Billowes,[12] D. Bosnar,[6] M. A. Cortés-Giraldo,[15] M. Diak… F. Bečvář,[11] F. Belloni,[5] … F. Cerutti,[1] E. Chiaveri,[1,12] M. Chin,[1] G. Cortés,[13] K. Fraval,[5] S. Ganesan,[21] A. R. … A. Ferrari,[1]





First measurement together Los Alamos, for E_n>100 keV

n_TOF 1/3 – **past**

Phase 1: 2001 – 2004 (EAR1)

Nuclear Astrophysics
Nuclear technology

Capture (n, γ)

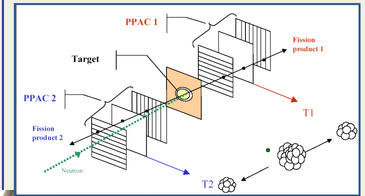
^{151}Sm
^{204,206,207,208}Pb
^{209}Bi
^{232}Th
^{24,25,26}Mg
^{90,91,92,94,96}Zr
^{93}Zr
^{139}La
^{186,187,188}Os
^{197}Au
^{233,234}U
^{237}Np, ^{240}Pu
^{243}Am

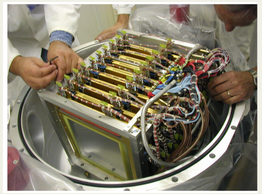
26 isotopes (8 radioactive)

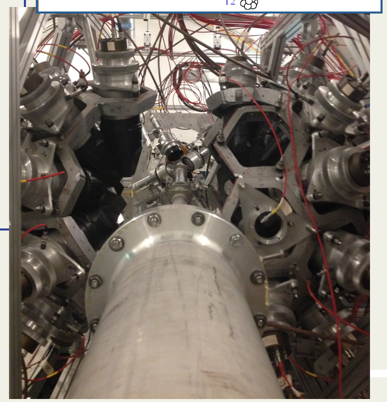
Fission (n, f)

^{233,234,235,236,238}U
^{232}Th
^{209}Bi
^{237}Np
^{241,243}Am, ^{245}Cm
^{nat}Pb

12 isotopes (10 radioactive)

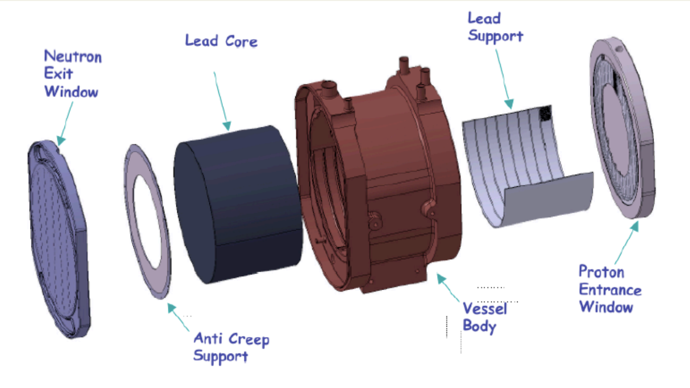






n_TOF 2/3 – present

Phase 2: 2009– 2012 (EAR1)
Phase 3: 2014-2018 (EAR1+EAR2)



Capture (n, γ)

^{58,62}Ni
^{63}Ni
^{54,56,57}Fe
^{241}Am
^{235,236,238}U
^{25}Mg
^{93}Zr
^{87}Sr

^{147}Pm, ^{171}Tm
^{203,204}Tl
^{70,72,74,76}Ge
^{155,157}Gd
^{69,71}Ga
$^{239, 242}$Pu, ^{233}U
^{244,246}Cm

30 isotopes (14 radioactive)

Reaction (n, α) e (n, p)

^{10}B
^{59}Ni , ^{33}S

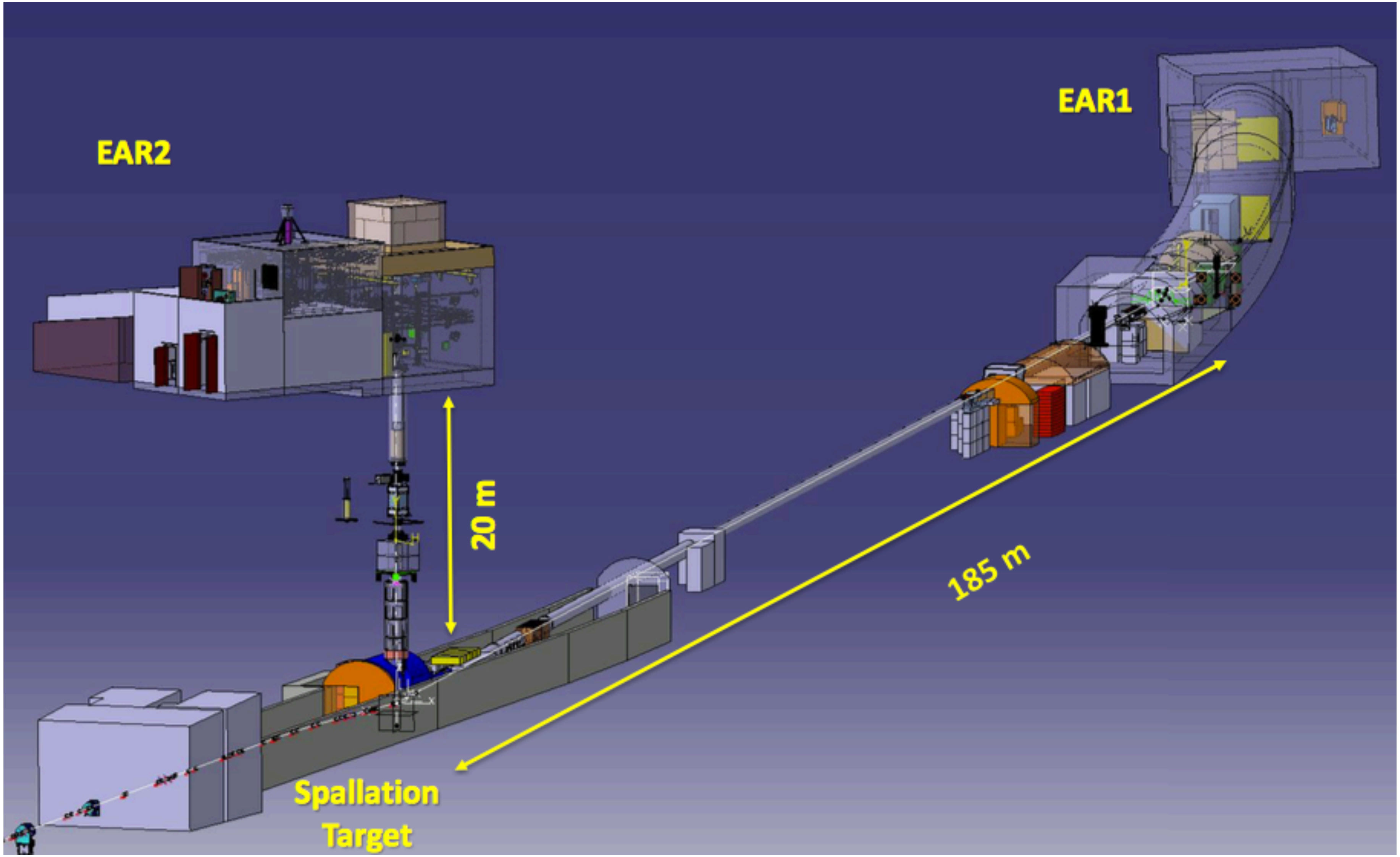
^{7}Be, ^{26}Al
^{35}Cl, ^{16}O, ^{14}N, ^{33}S
^{12}C, ^{19}F

Fission (n, f)

^{237}Np, ^{232}Th

STEFF, ^{231}Pa, ^{238}Pu

n_TOF



n_TOF collaboration

BARC – Mumbai, India
CEA – Saclay, Francia
CERN – Geneva, Svizzera
CIEMAT – Madrid, Spagna
ENEA – Bologna, Italia
IFIC – Valencia, Spagna
IFIN – Bucharest, Romania
INFN, Italia
IPNO – Orsay, Francia
IST – Lisbon, Portogallo
JAEA – Tokyo, Giappone
JINR – Dubna, Russia
JRC – Geel, Belgio
KIT - Karlsruhe , Germania
NTUA – Athens, Grecia
PSI – Villingen, Svizzera
PTB - Braunschweig, Germania
TIOT – Tokyo, Giappone
UBAS – Basel, Svizzera
UCAN – Canberra, Australia
UEDB – Edinburgh, Regno Unito
UGF – Frankfurt, Germania
UGRAN – Granada, Spagna
UIG – Ioannina, Grecia
ULP – Lodz, Polonia
UMAN – Manchester, Regno Unito
UPC – Barcelona, SPagna
UPRG - Prague , Repubblica ceca
USC – Santiago, Spagna
USE – Sevilla, Spagna
UVIE – Vienna, Austria
UYRK – York, Regno Unito
UZAG – Zagreb, Croazia