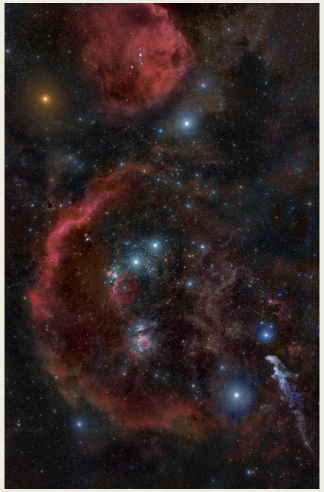
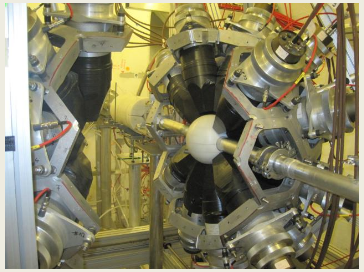
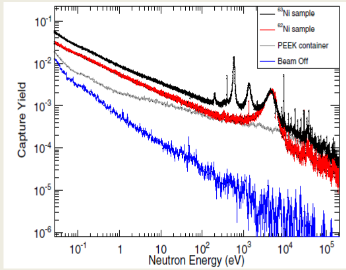
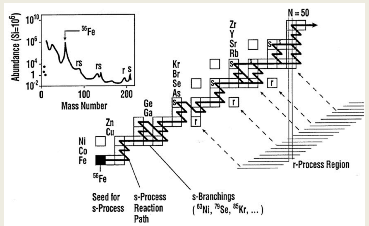
n_TOF

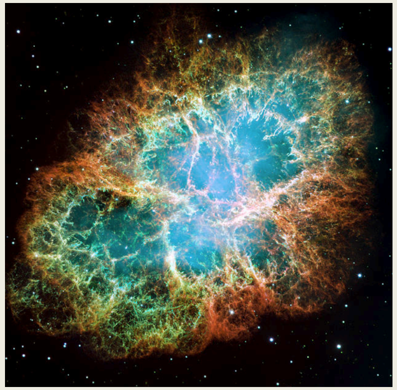
Neutron cross sections for science and technology











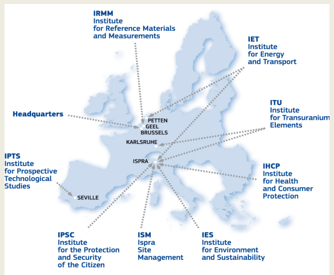
n_TOF

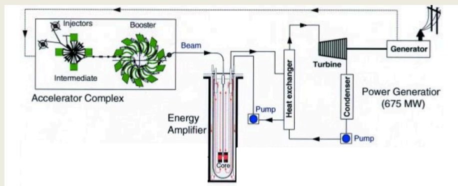
neutron Time Of Flight

@ CERN

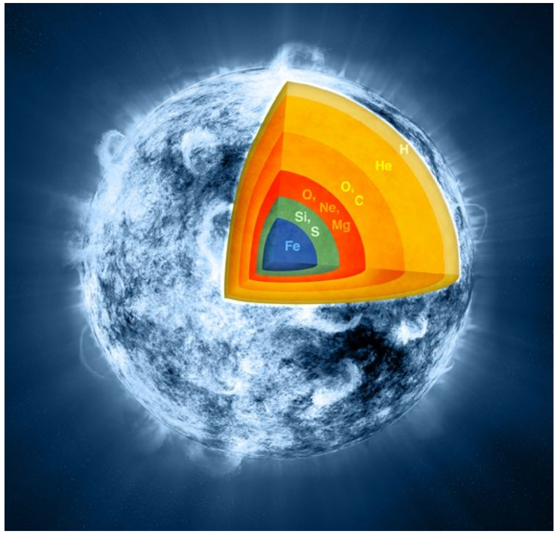
GELINA

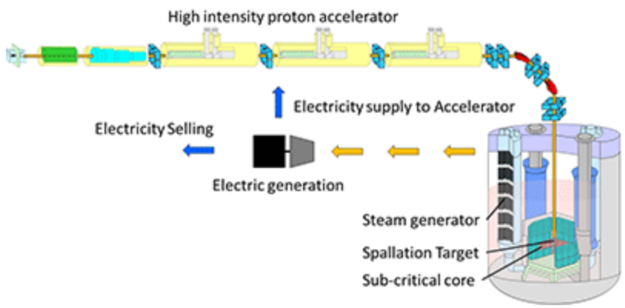
@ EC-JRC-GEEL

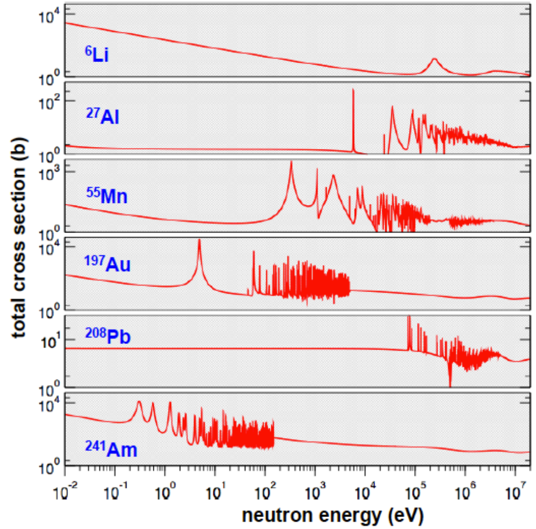




Research fields







Nuclear Astrophysics

- ✓ Nucleosynthesis of heavy elements
- ✓ Stellar evolution
- ✓ Big bang nucleosynthesis

Nuclear technology and medical application:

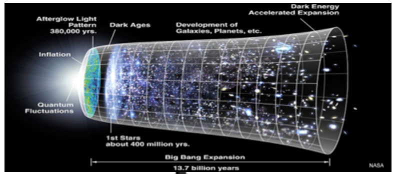
- ✓ Fission reactors (Gen-IV, ADS)
- ✓ Fusion
- ✓ Transmutation of nuclear waste
- ✓ Neutron capture therapy (adrotherapy)

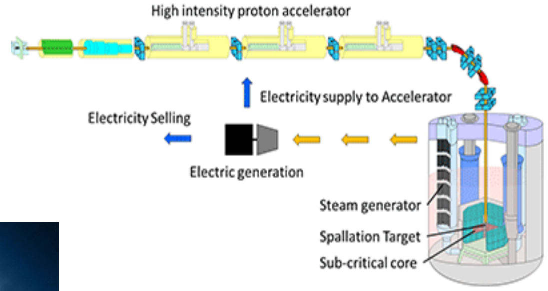
Basic Nuclear Physics

- ✓ Nuclear structure effects on fission
- ✓ Excited states (spin parity of resonances)

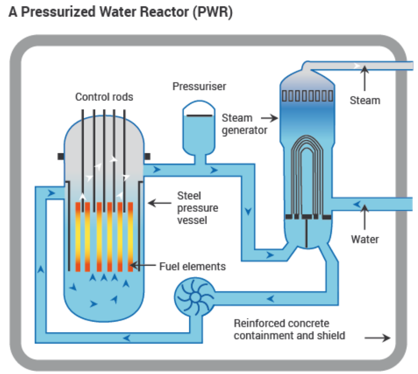
Research fields

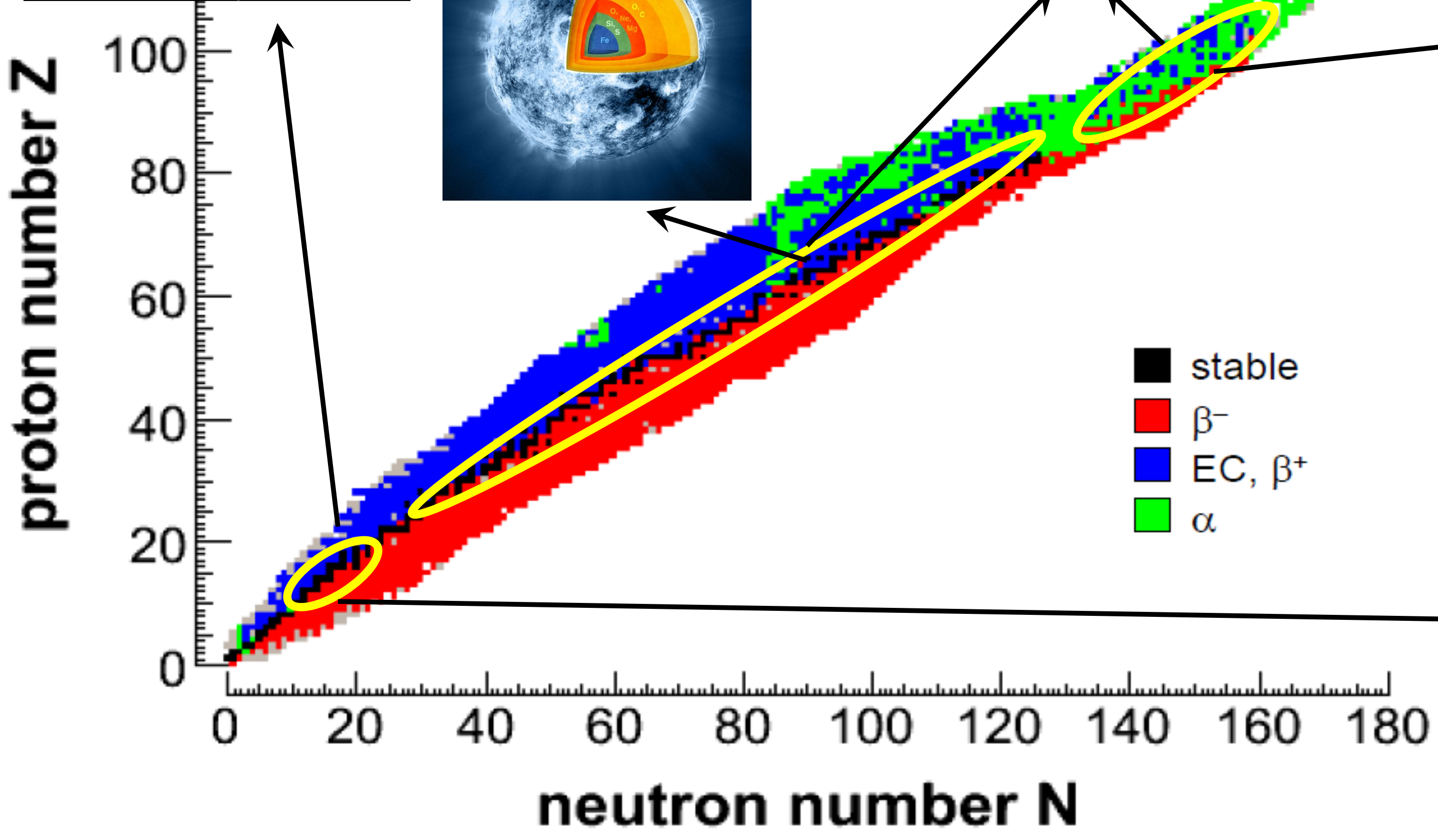
Nuclear Astrophysics Big Bang and Stellar nucleosynthesis



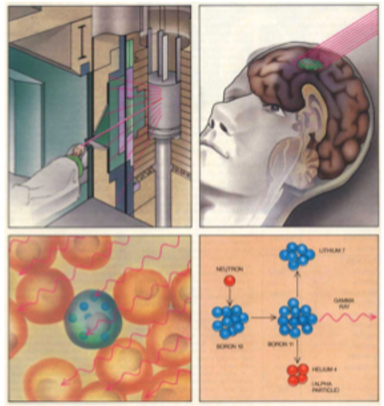


Nuclear reactors:
energy production & waste managment

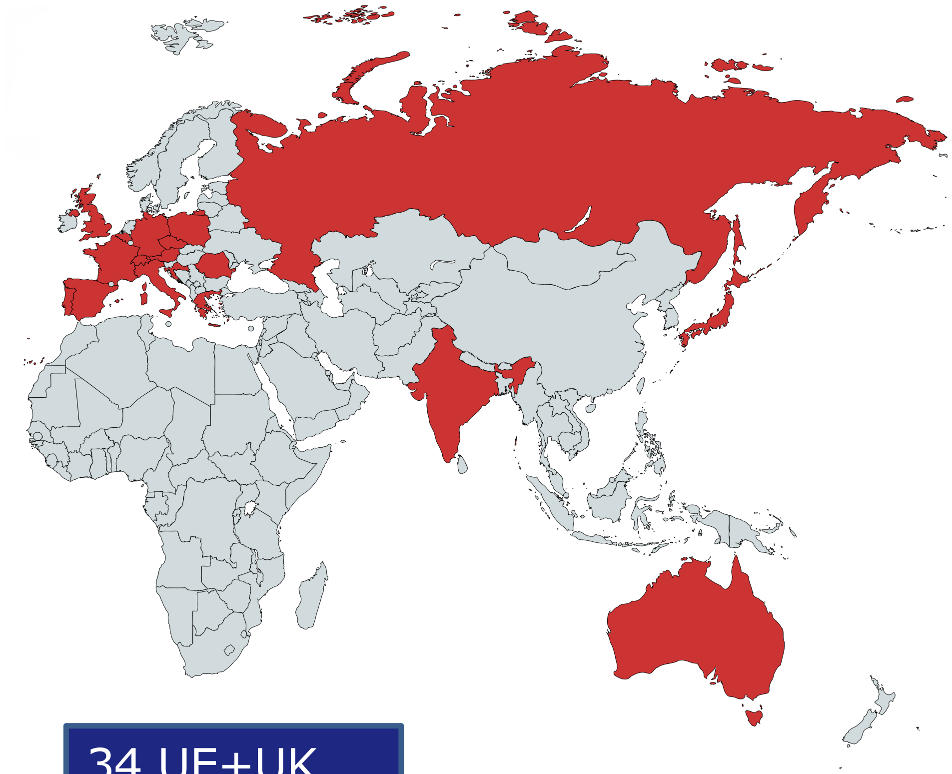




Nuclear medicine
neutron capture therapy



n_TOF in numbers



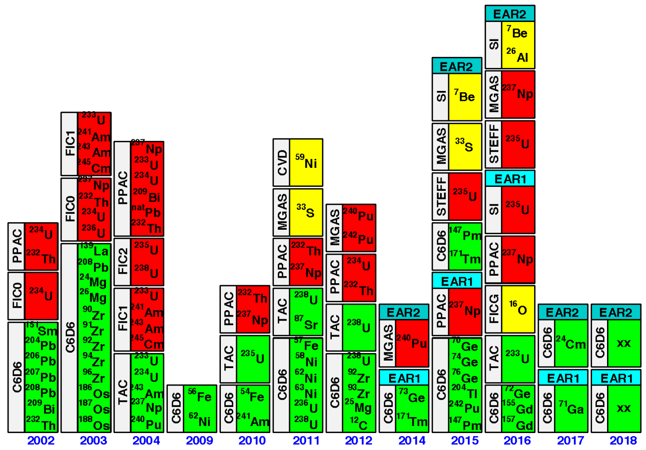
International collaboration
130 Researchers
38 Institutes

Spokesperson:
A. Mengoni (ENEA, **INFN-Bo**)

Since 2001: 104 isotopes measured
(capture, fission, cp)

34 UE+UK
2 Japan
1 India
1 Australia

Data available on EXFOR.
https://twiki.cern.ch/twiki/bin/view/NTOFPublic/DataDissemination



n_TOF Collaboration

9 INFN Sections

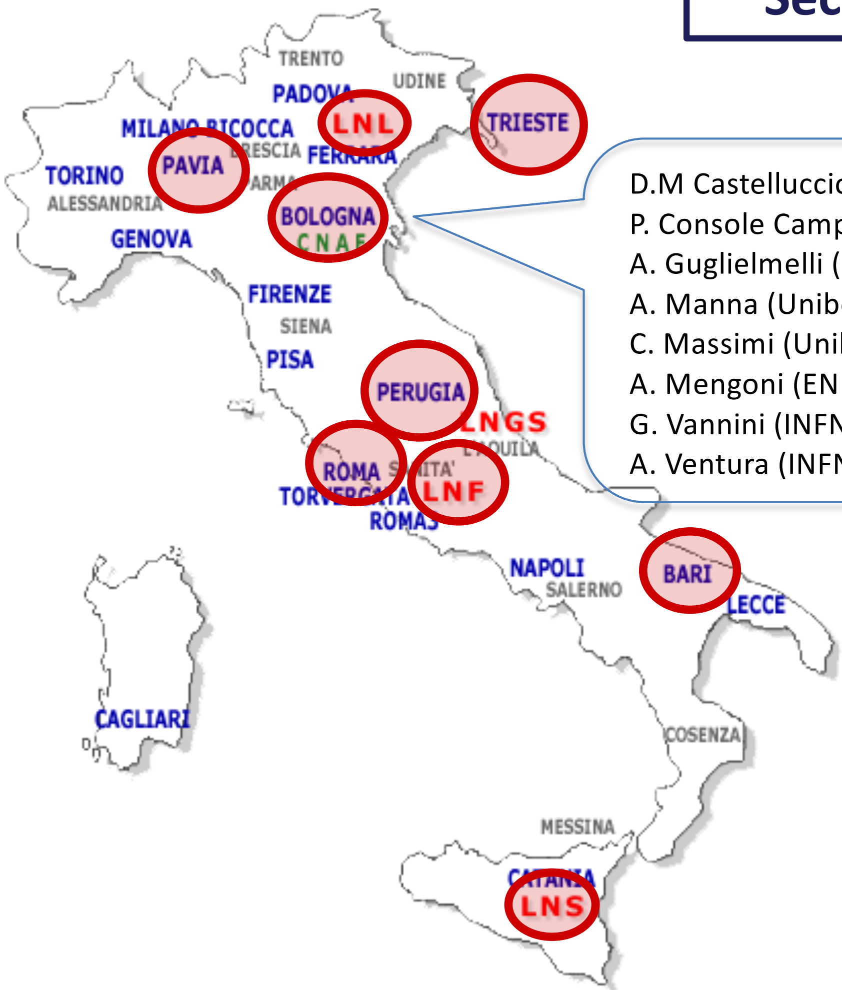
n_TOF - ITALY

21 researchers
(INFN+University)
12.1 FTE

Close collaboration with
ENEA (Bologna, Frascati)
INAF (Teramo), **CNR** (Bari)

29 researchers
15.5 FTE

Responsabile Nazionale:
C. Massimi (Unibo, **INFN-Bo**)

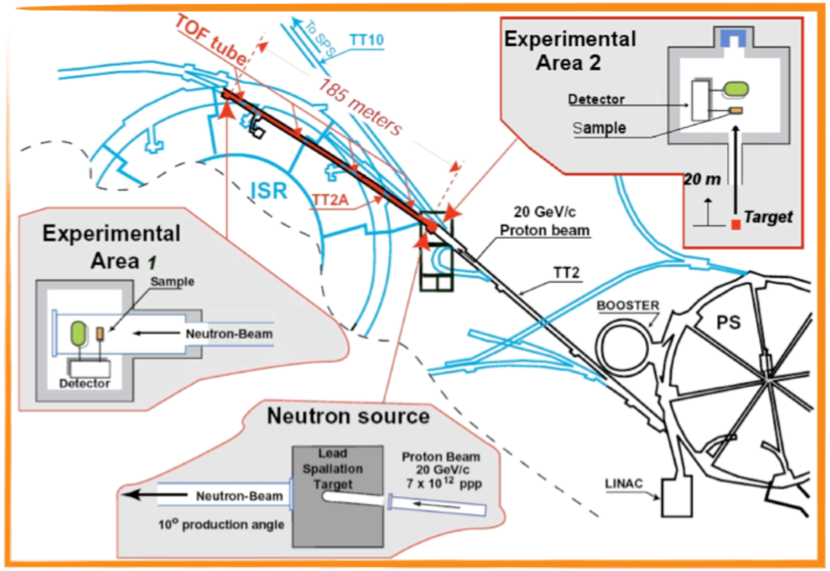


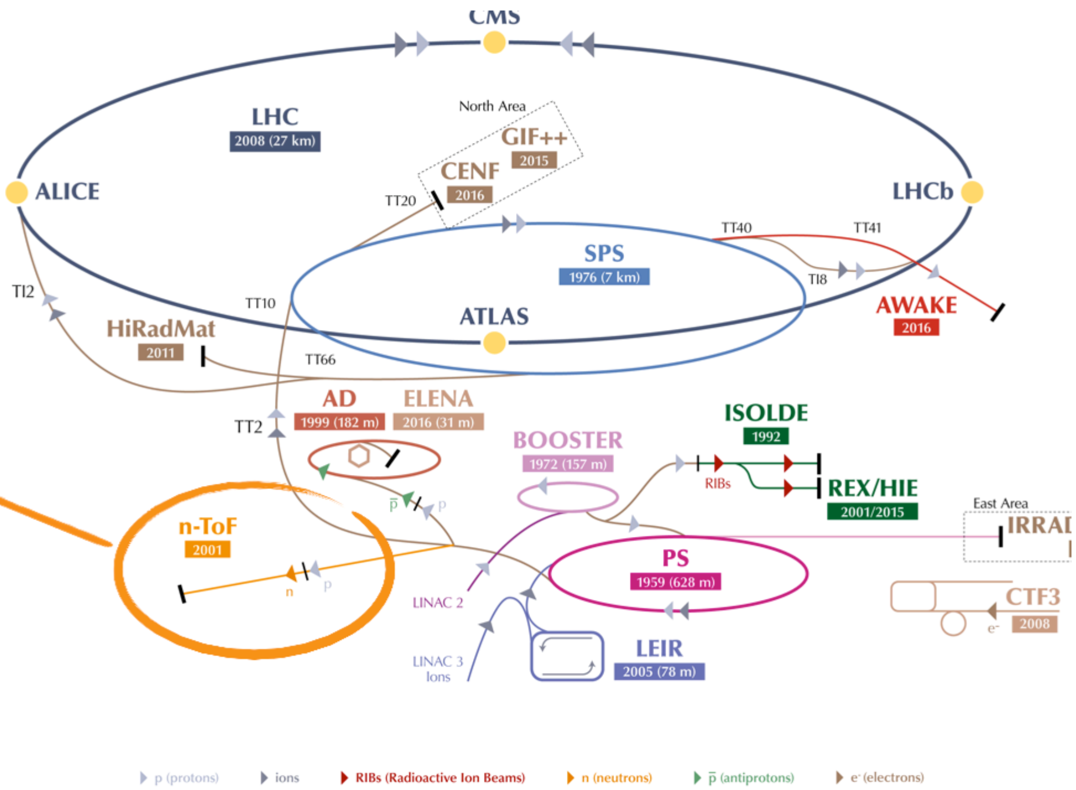
D.M Castelluccio (ENEA)
P. Console Camprini (ENEA)
A. Guglielmelli (ENEA)
A. Manna (Unibo)
C. Massimi (Unibo)
A. Mengoni (ENEA)
G. Vannini (INFN)
A. Ventura (INFN)

n_TOF facility

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

high energy, high current, low duty cycle.





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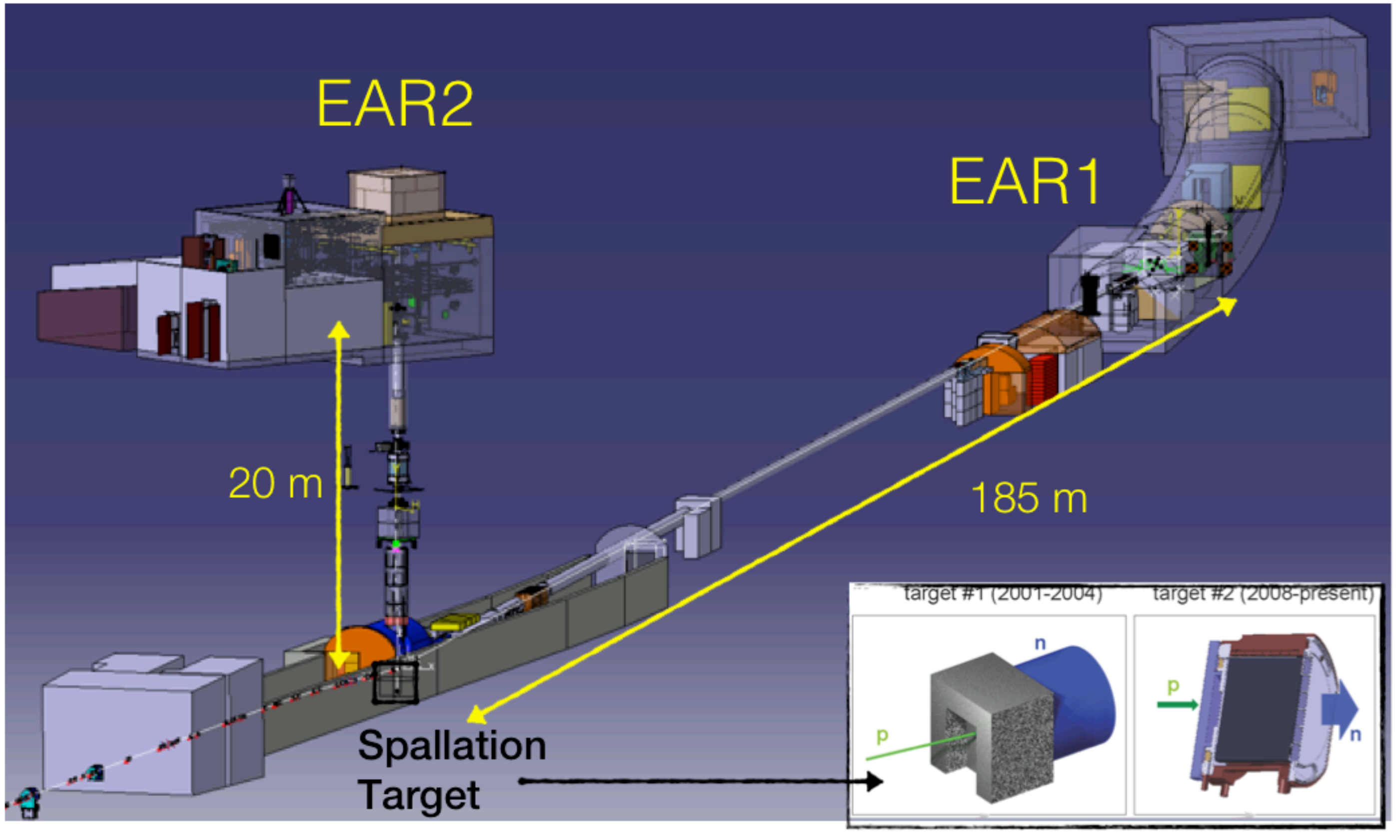


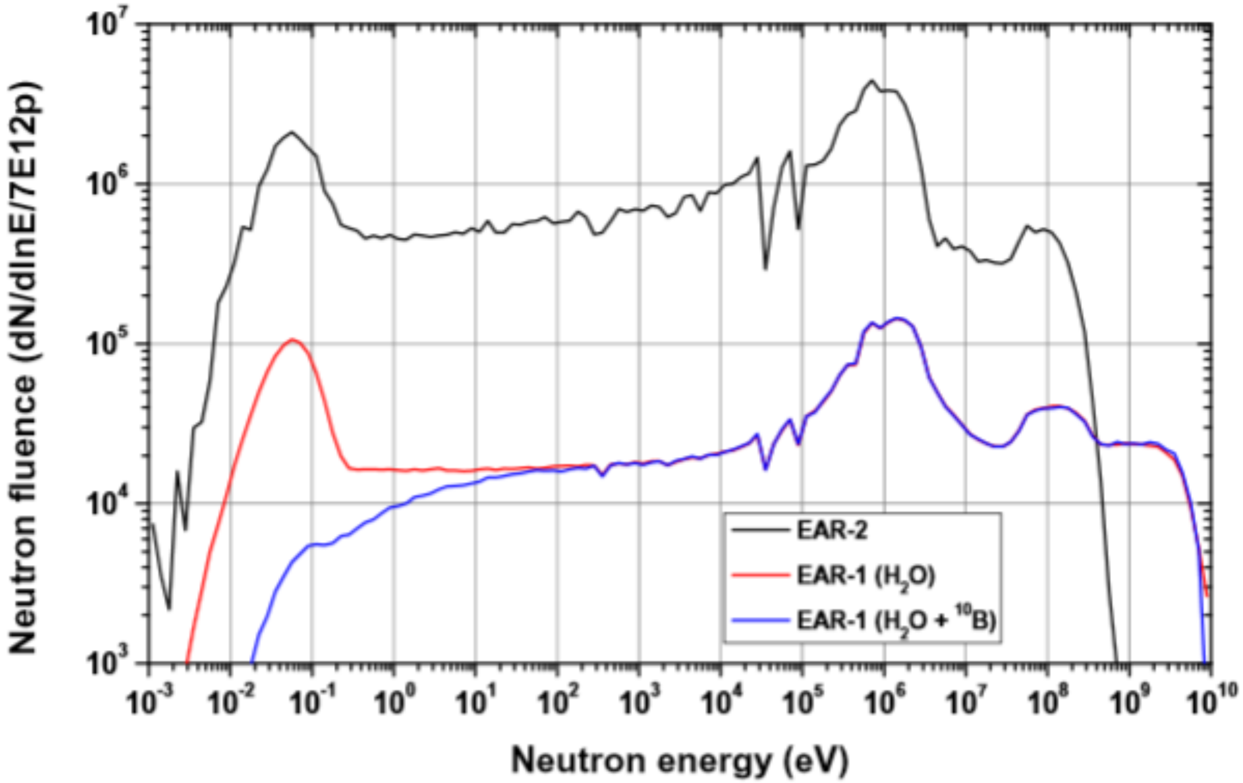
In figures…

Horizontal Beam Line (EAR1) Distance to target center [m]	Beam Line Element	Vertical Beam Line (EAR12 Distance to target center [m]
136.7 – 138.7 (⌀110 mm)	1st collimator	7.4 – 8.4 (⌀100 mm)
134.9	Filter Box	11.4
145.4	Magnet center	10.4
178.0 - 180.5 (⌀18 or 80 mm)	2nd collimator	15.04 – 18.04 (⌀21.8 mm)
182.3 – 190.2	Experimental area	18.16 – 23.66
200	Beam Dump	24.73

n_TOF facility

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

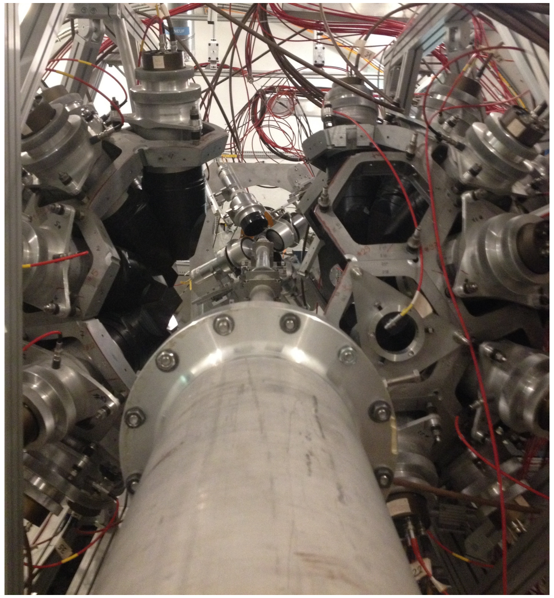
Neutron flux
EAR2 10^6 n/cm^2/pulse
EAR1 10^5 n/cm^2/pulse

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

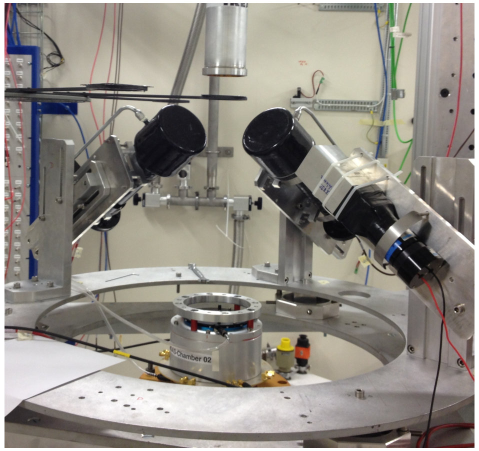
Detectors

(n,γ) reactions

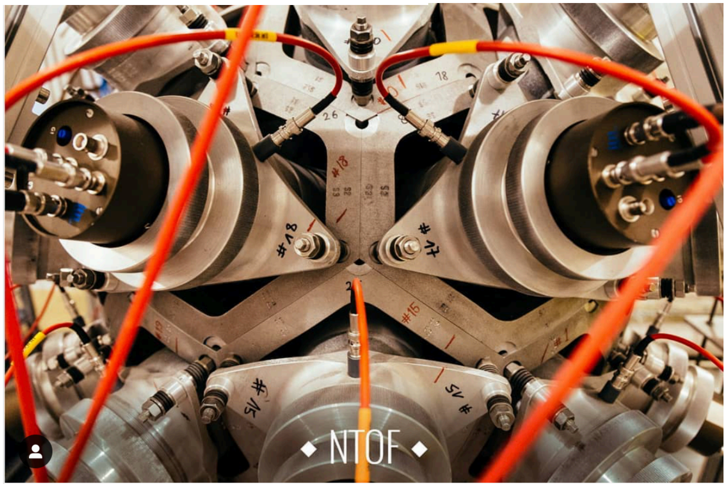
Total Absorption Calorimeter (TAC) BaF_2



C_6D_6 liquid scintillators



infn_insights •

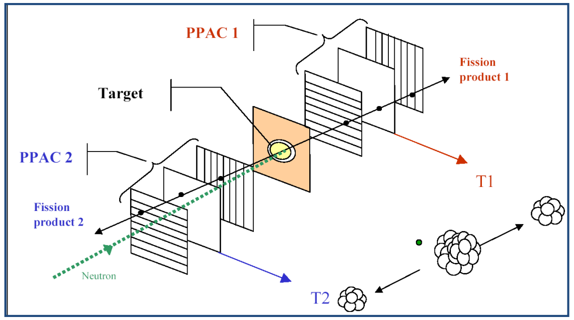


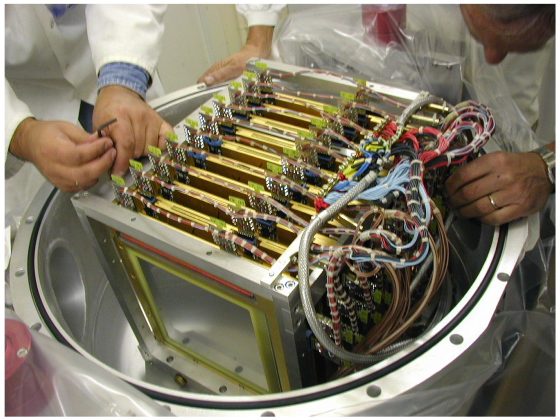
Relevant INFN contribution: test, maintenance and optimization of the capture detectors

Detectors

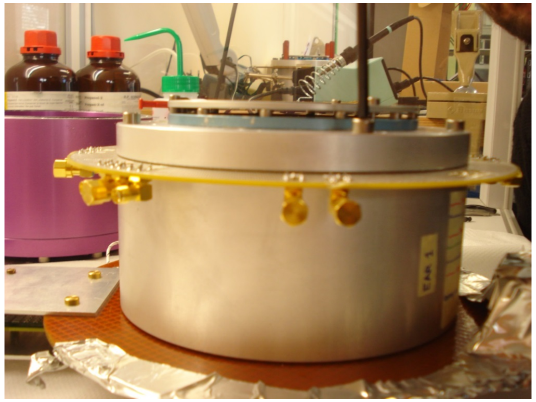
Fission reactions

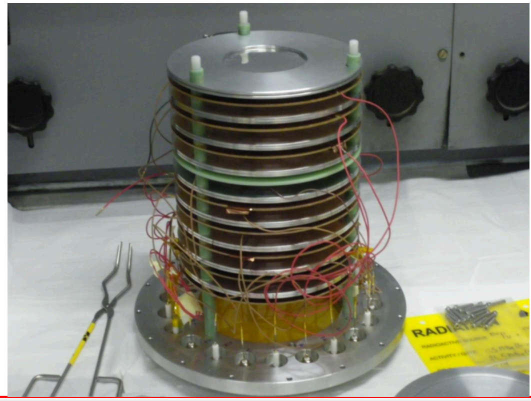
Parallel Plate Avalanche Chamber (PPAC)



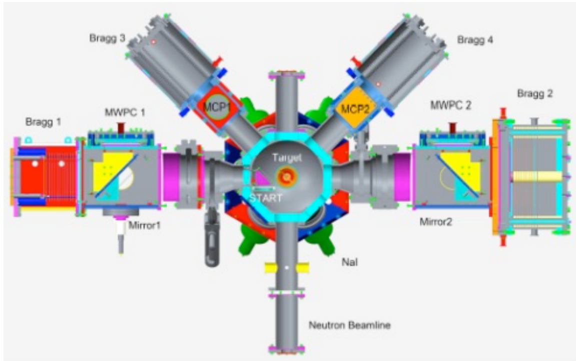


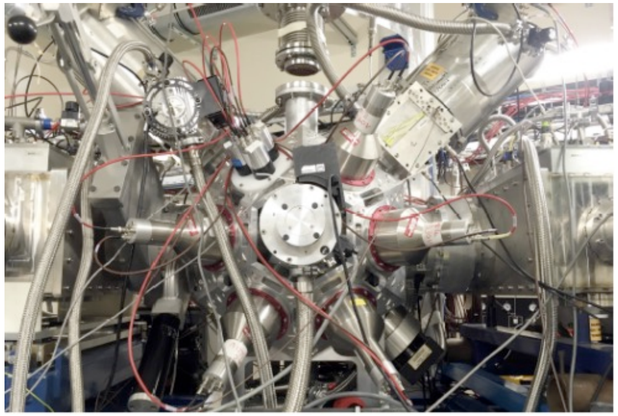
MicroMegas





STEFF



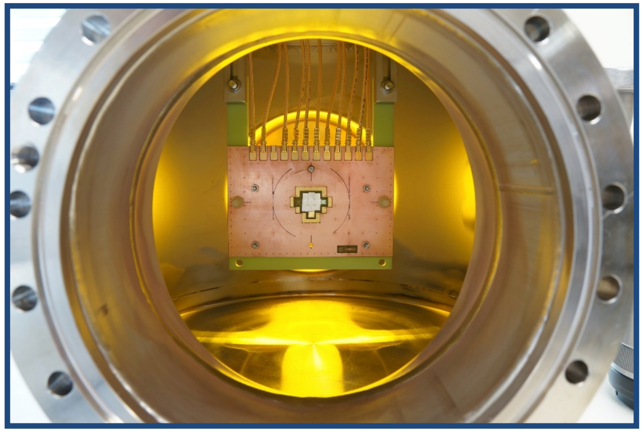


Setup based on Si detectors for high accuracy measurements (EPJ A front page) developed by LNS

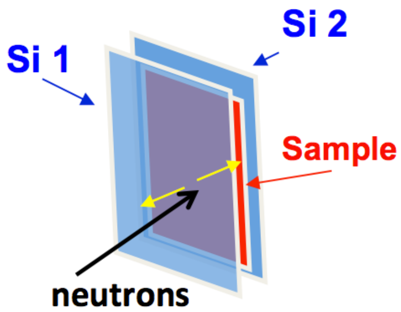
Detectors

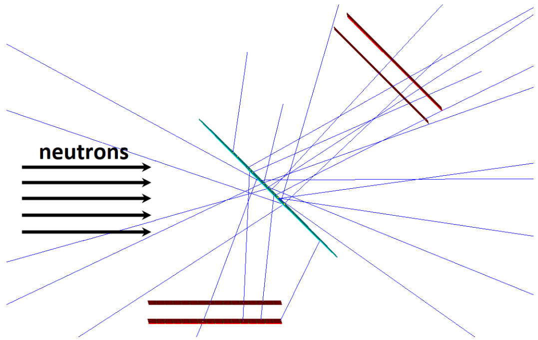
(n,cp) reactions

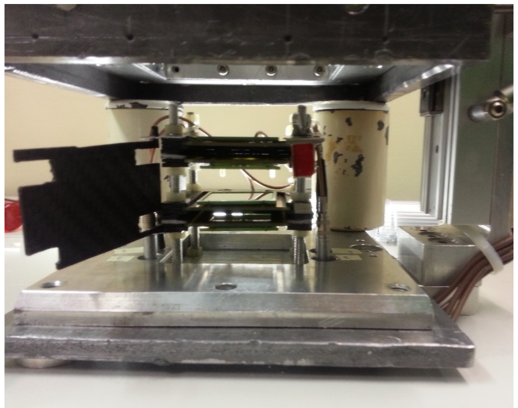
Diamond detectors

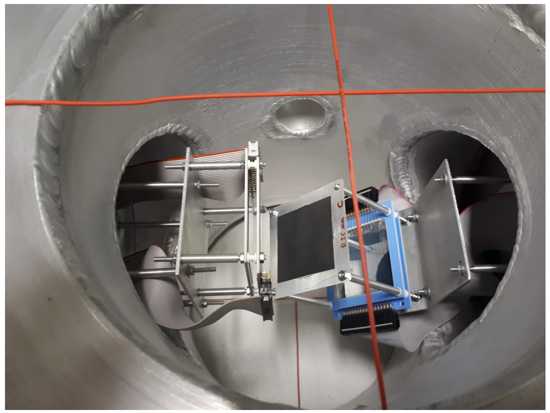


Silici









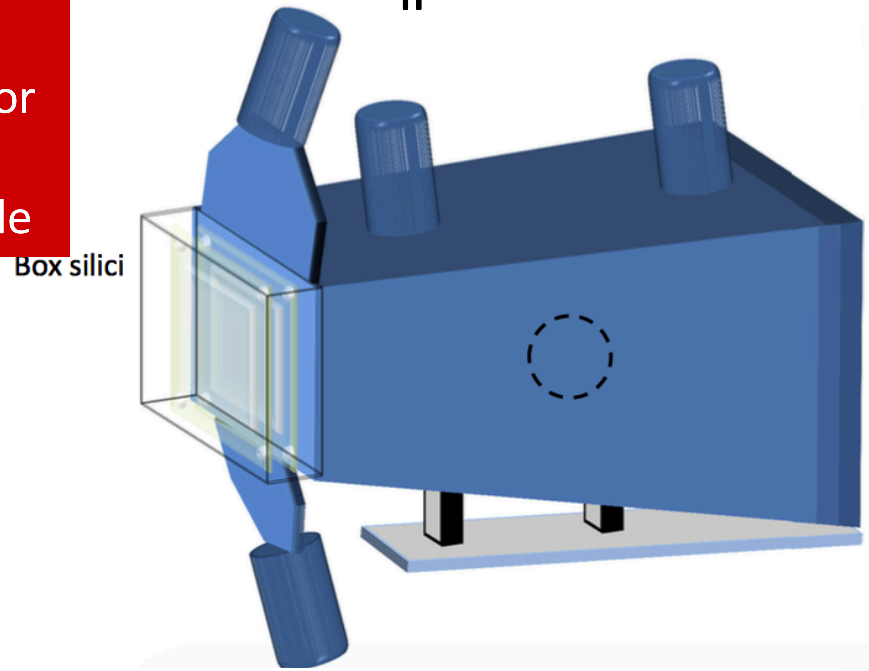
Setup for $^{7}Be(n,p)$, $^{7}Be(n,\alpha)$ e la $^{12}C(n,p)$ developed by INFN

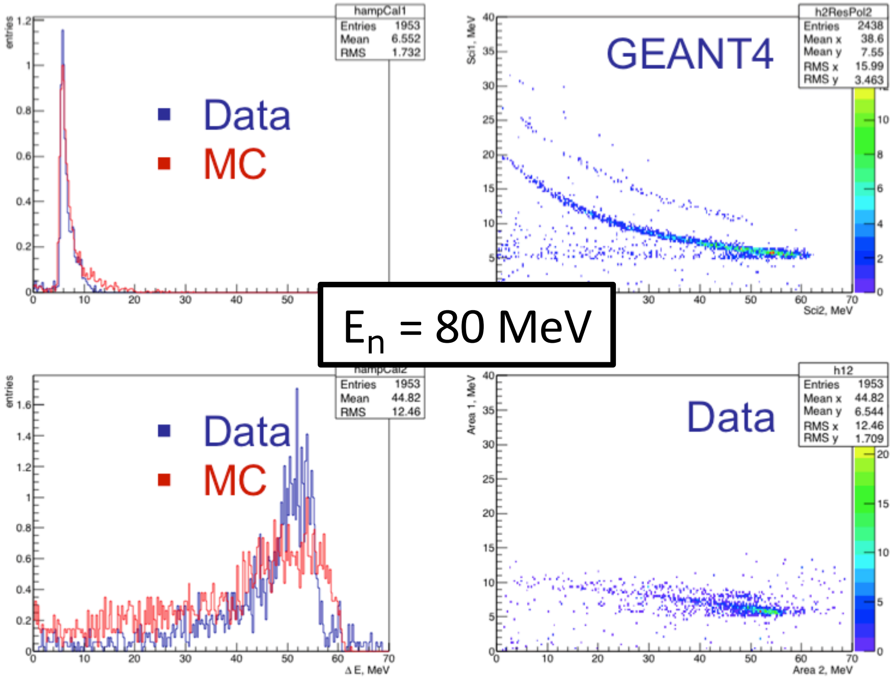
Detectors

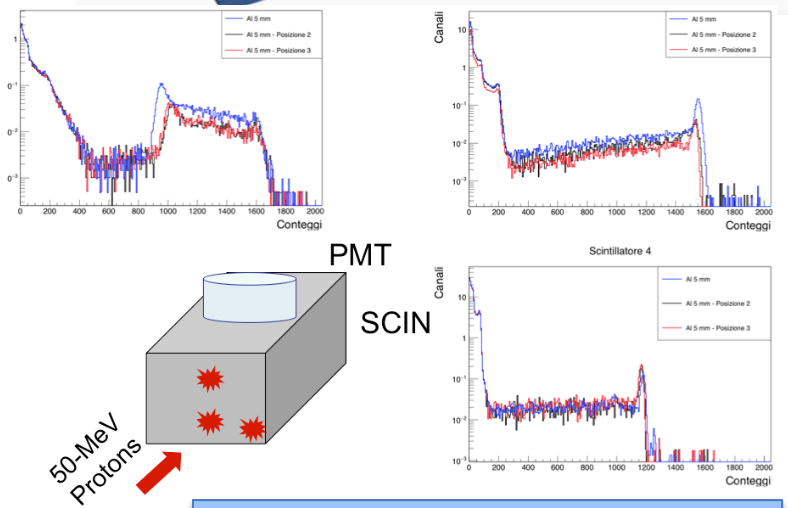
Flux detectors
E_n>10 MeV

Research and development of a counter telescope (made of plastic scintillators and silicon detectors) for recoil protons, originating from the n-p elastic scattering of neutrons on a polyethylene C_2H_4 sample

- MC Geant4
- Test with protons @ LNS (2017)
- Test on beam @ n_TOF (2017)



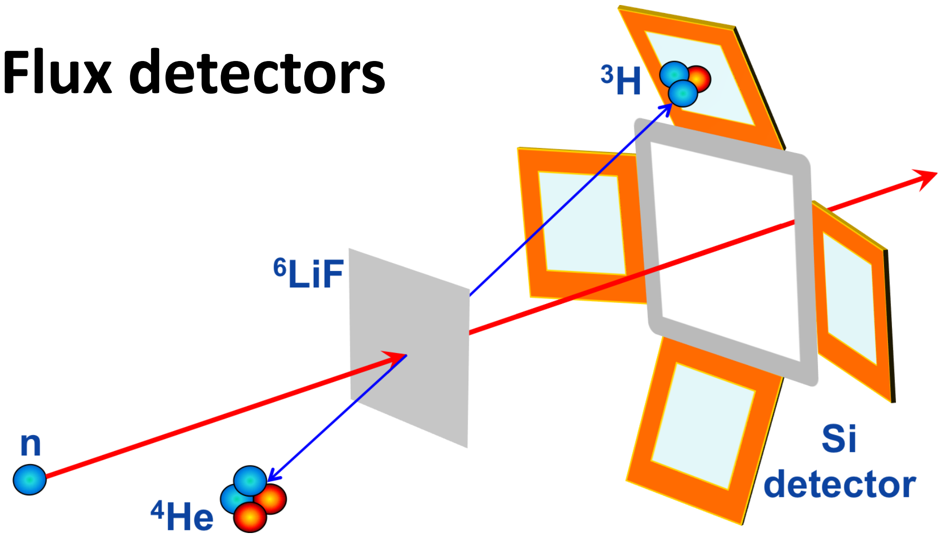


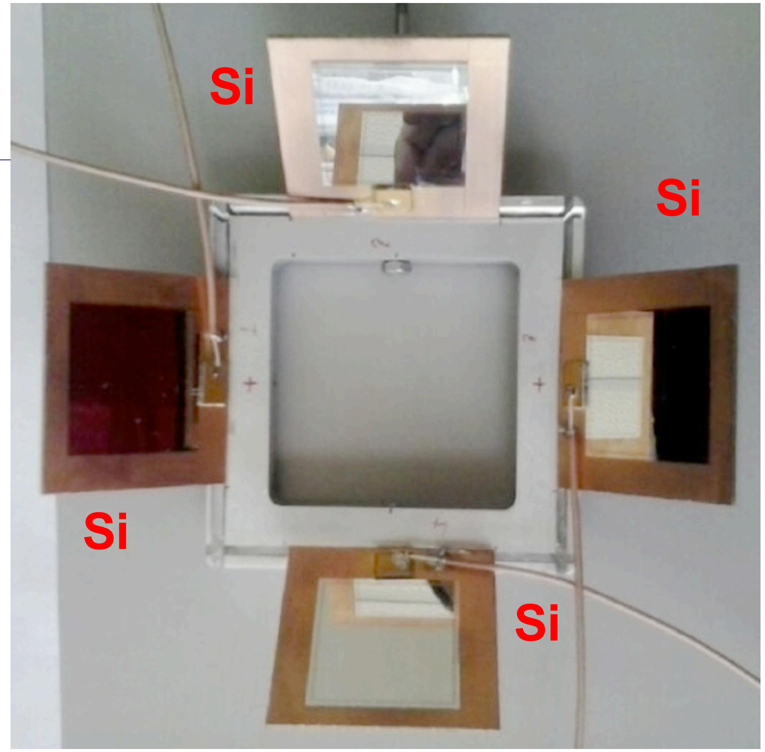


PhD A. Manna (UniBo)

Detectors

Flux detectors



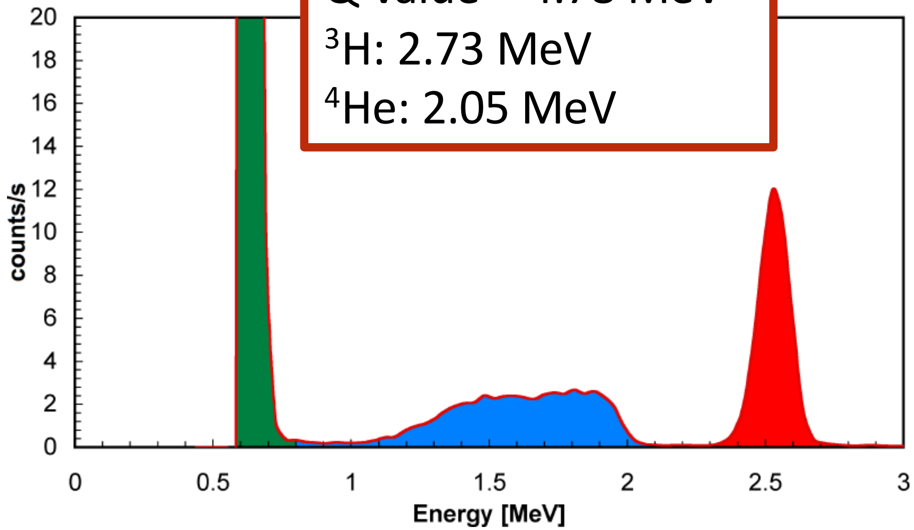


$n + {}^{6}Li \rightarrow {}^{3}H + {}^{4}He$

Q-value = 4.78 MeV

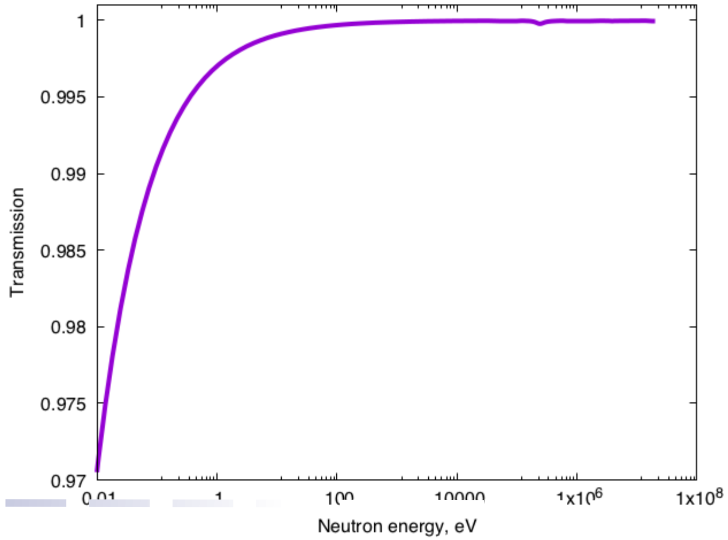
^{3}H: 2.73 MeV

^{4}He: 2.05 MeV



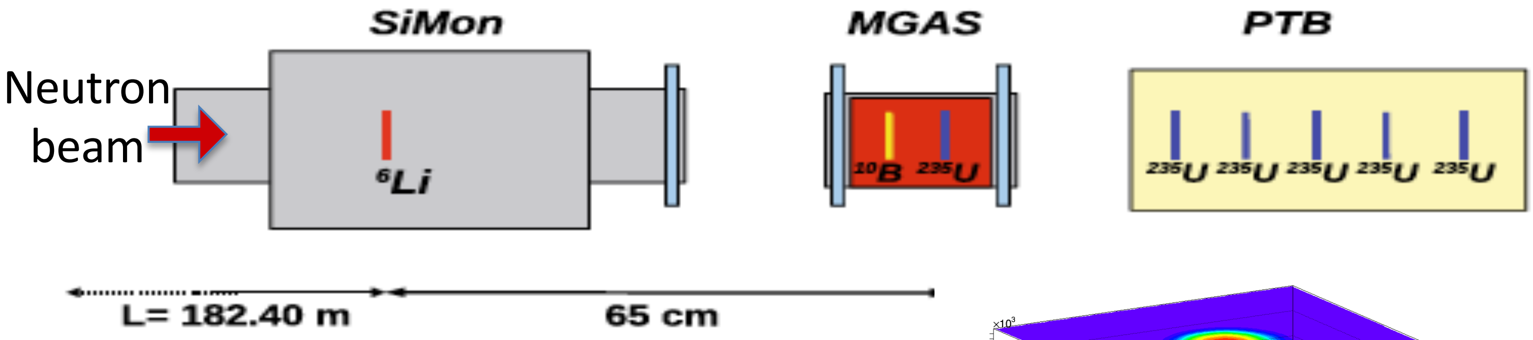
MSX09-3007 3 cm × 3 cm,

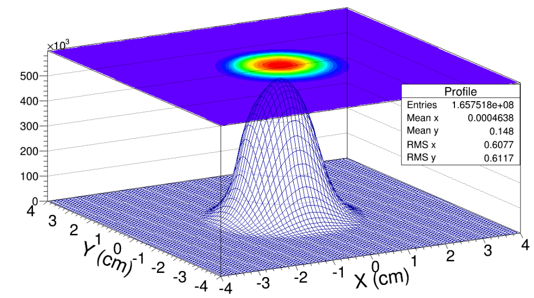
300 μm thick > particle range

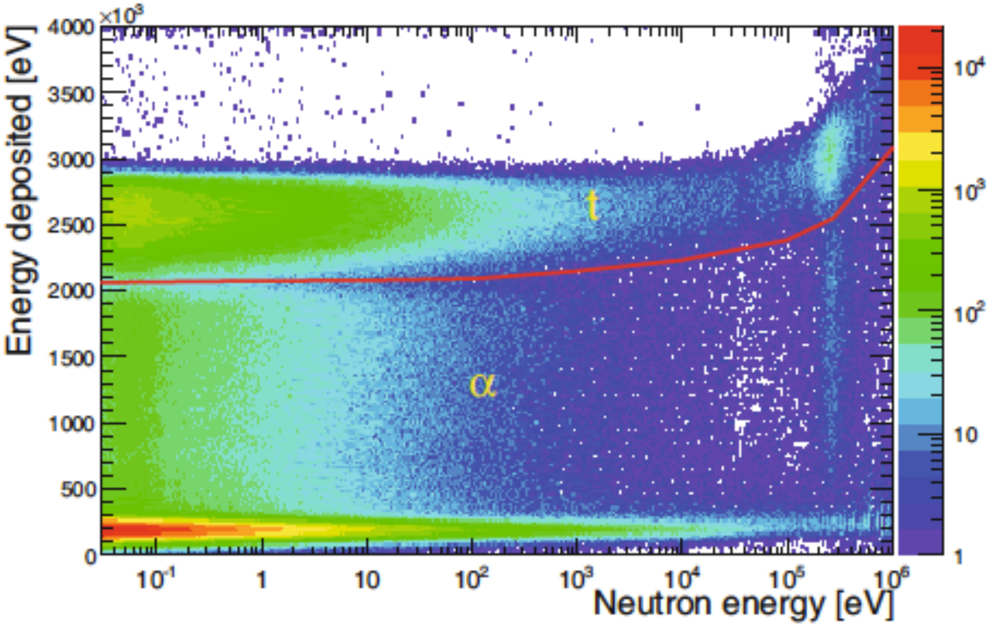


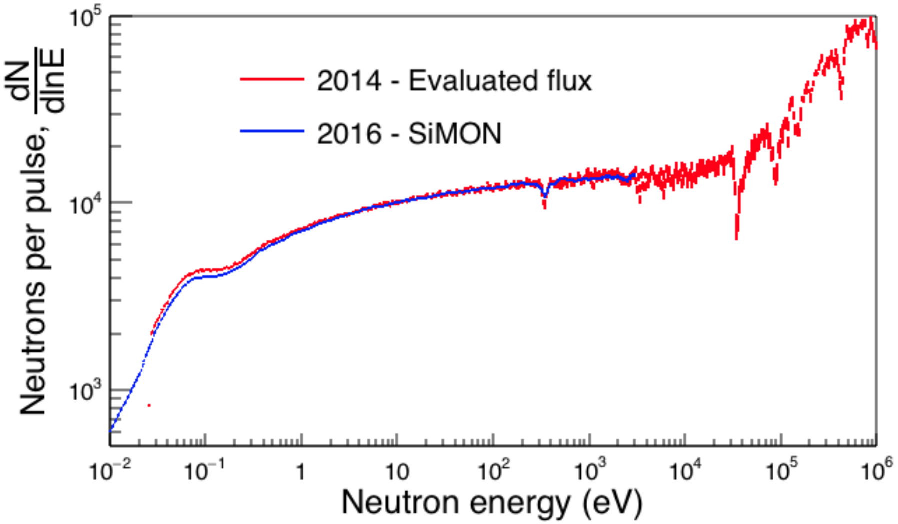
Beam characterizations

3 different detectors based on 3 neutron standards

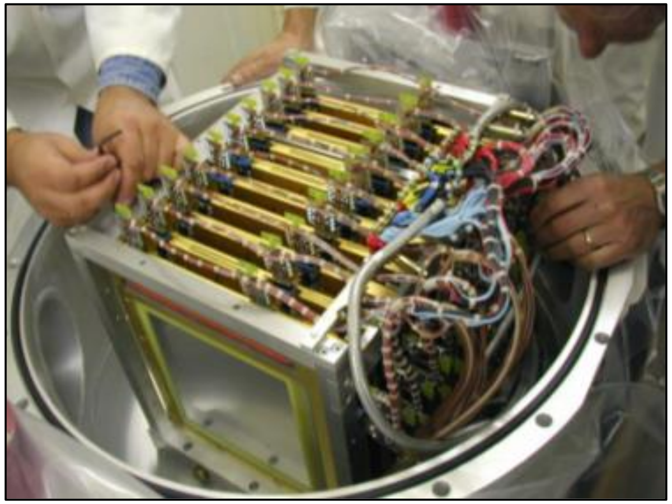




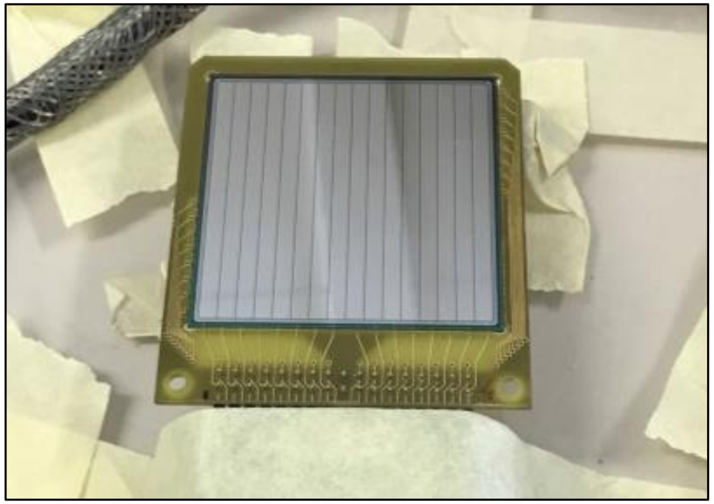




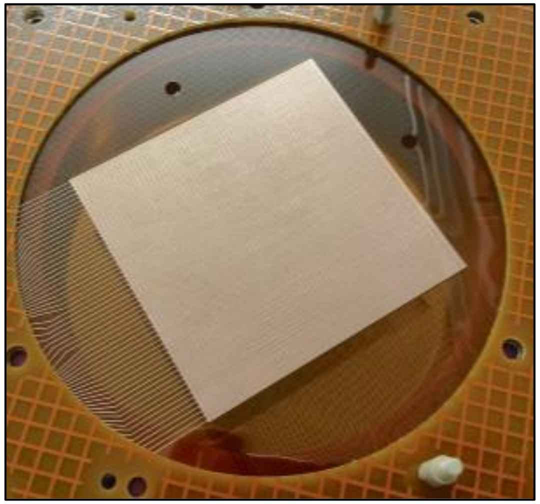
Beam characterizations



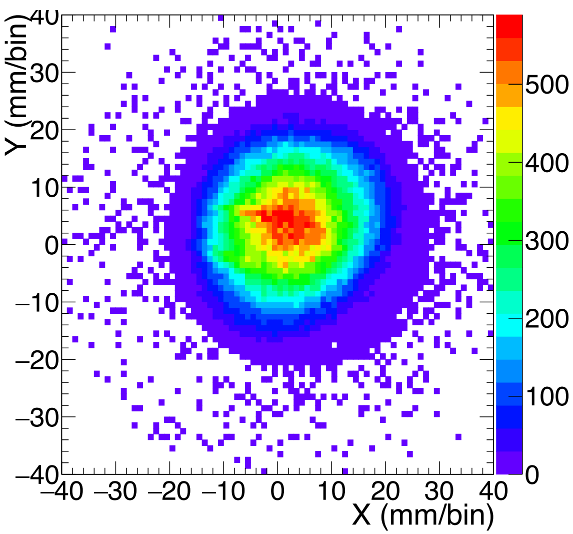
PPAC

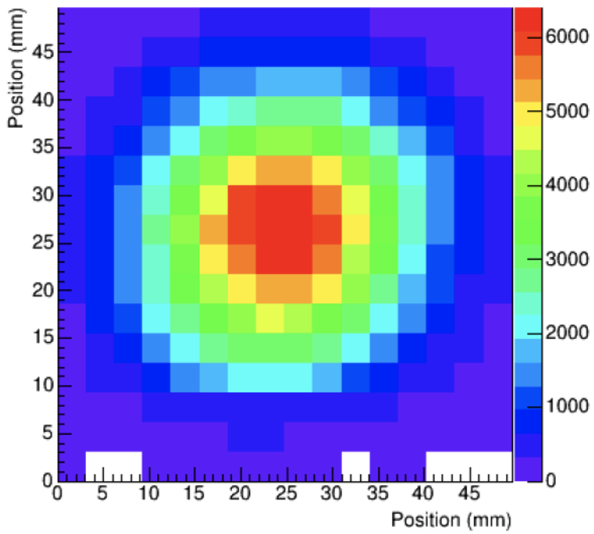


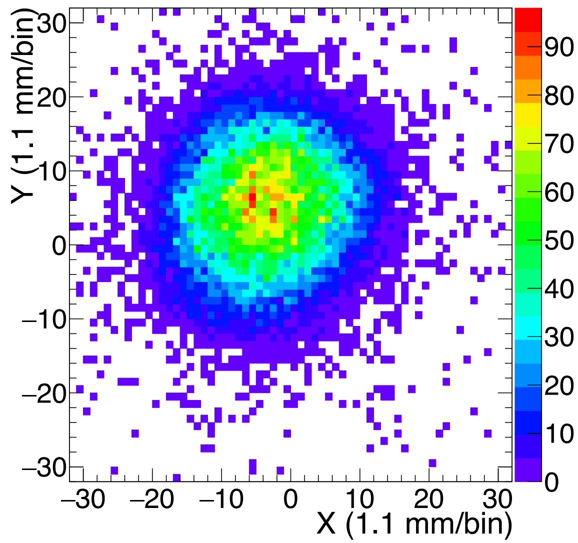
SiMon2D



XY MicroMegas



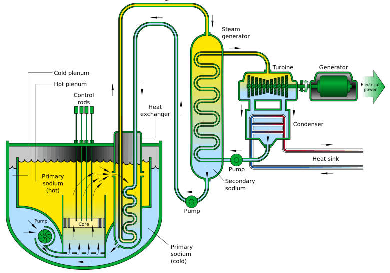




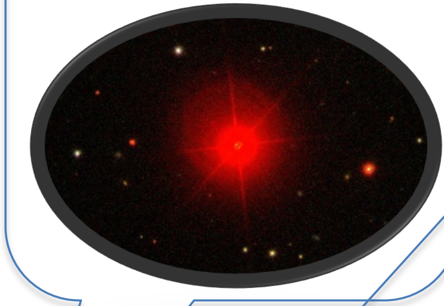
ACTIVITIES

Big Bang nucleosynthesis

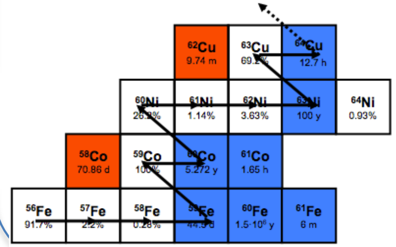
Capture cross section technologies



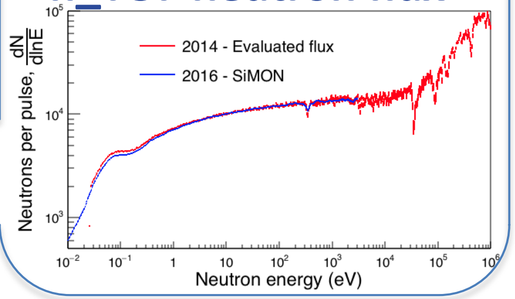
Neutron source in Red Giants stars



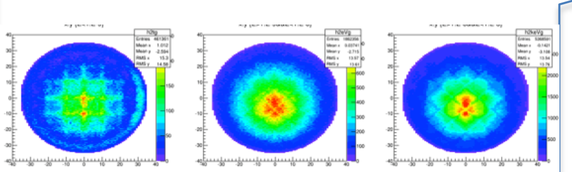
s process: Nucleosynthesis of heavy elements



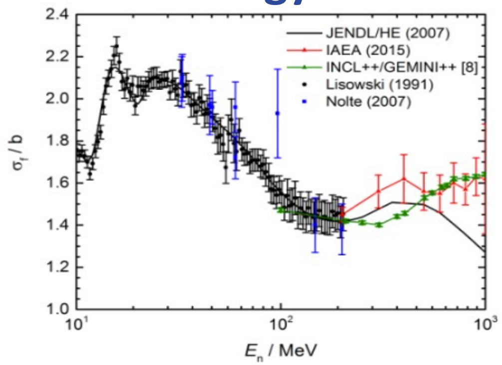
Characterization of the n_TOF neutron flux



MC Study of the n_TOF spallation source

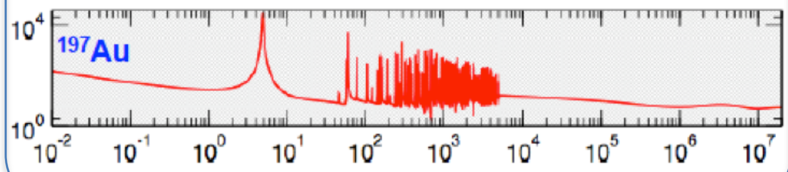


Fission at intermediate energy



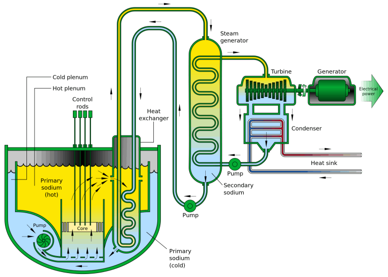
A newsletter for nuclear astrophysics

^{197}Au(n,γ) as reference cross section



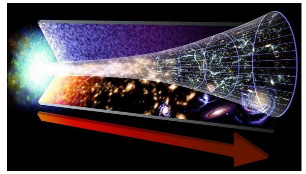
Big Bang nucleosynthesis

Capture cross section technologies



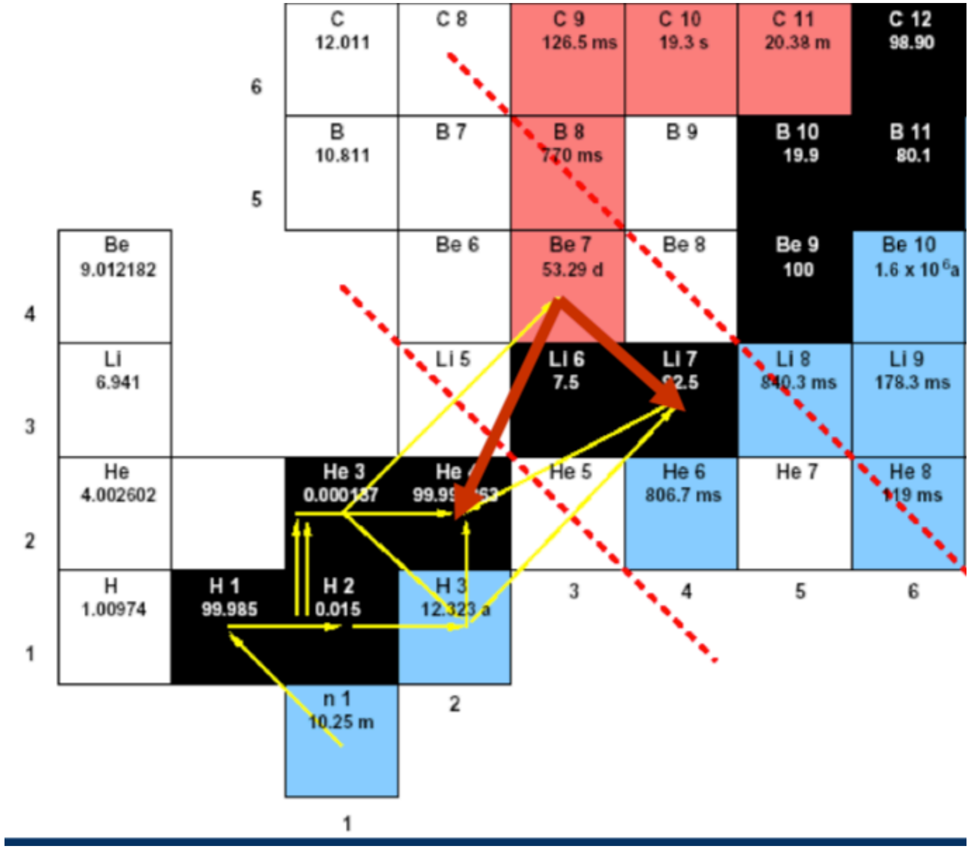
ACTIVITIES

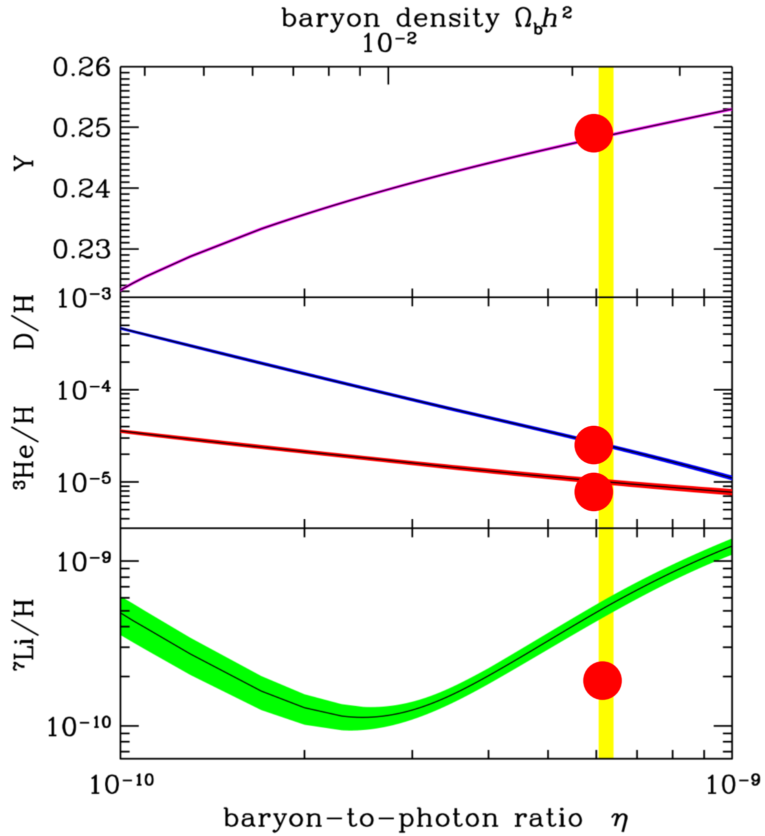
BBN: need for ^{7}Be destruction



BBN successfully predicts the abundances of primordial elements such as ^{4}He, D and ^{3}He. Large **discrepancy** for ^{7}**Li**, which is produced from electron capture decay of ^{7}**Be**

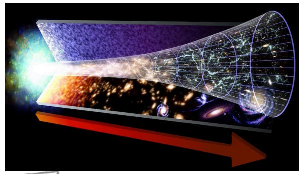
~ 95% of ^{7}**Li** is produced by the decay of ^{7}**Be** ($T_{1/2}$=53.2 d)



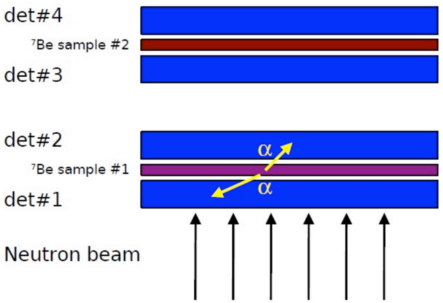


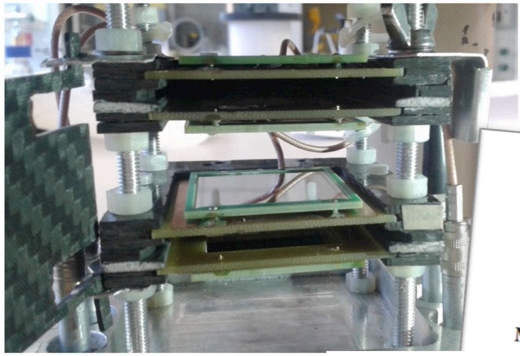
Destruction via neutron interaction?

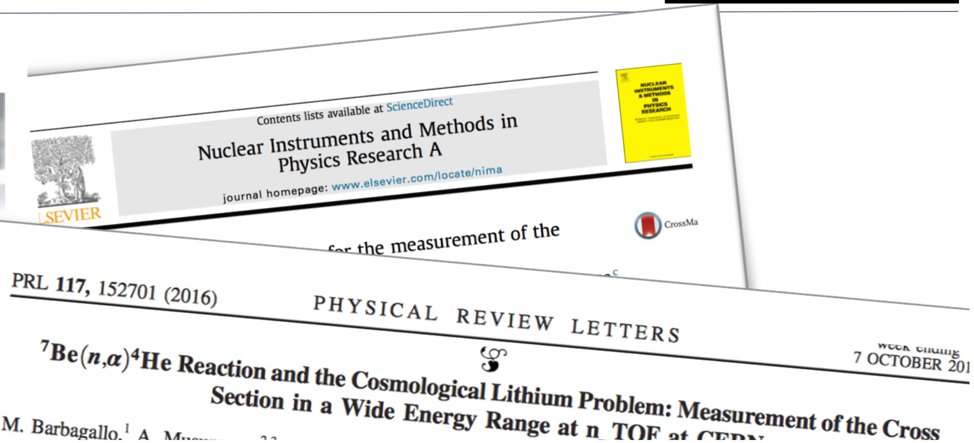
BBN: need for ^{7}Be destruction

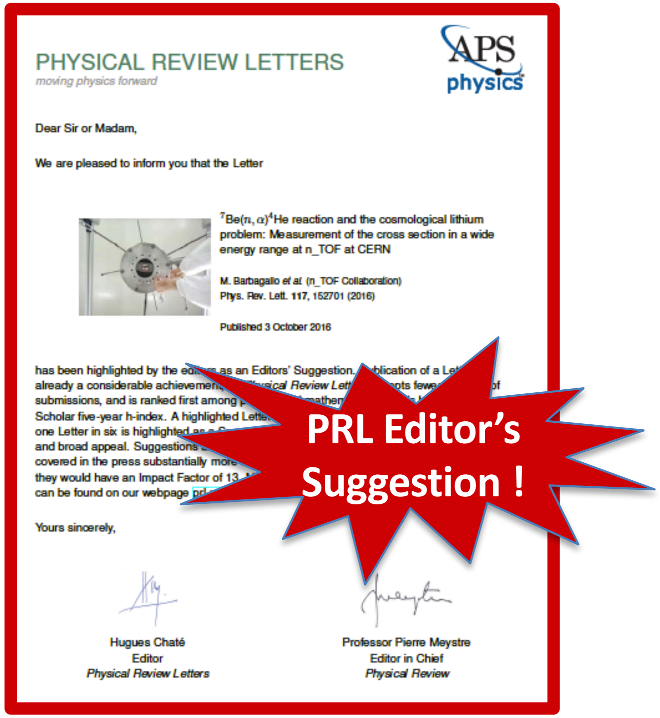


$^{7}Be(n, \alpha)\alpha$








PHYSICAL REVIEW LETTERS
moving physics forward
APS physics

Dear Sir or Madam,

We are pleased to inform you that the Letter

$^{7}Be(n,\alpha)^{4}He$ reaction and the cosmological lithium problem: Measurement of the cross section in a wide energy range at n_TOF at CERN

M. Barbagallo *et al.* (n_TOF Collaboration)
Phys. Rev. Lett. **117**, 152701 (2016)

Published 3 October 2016

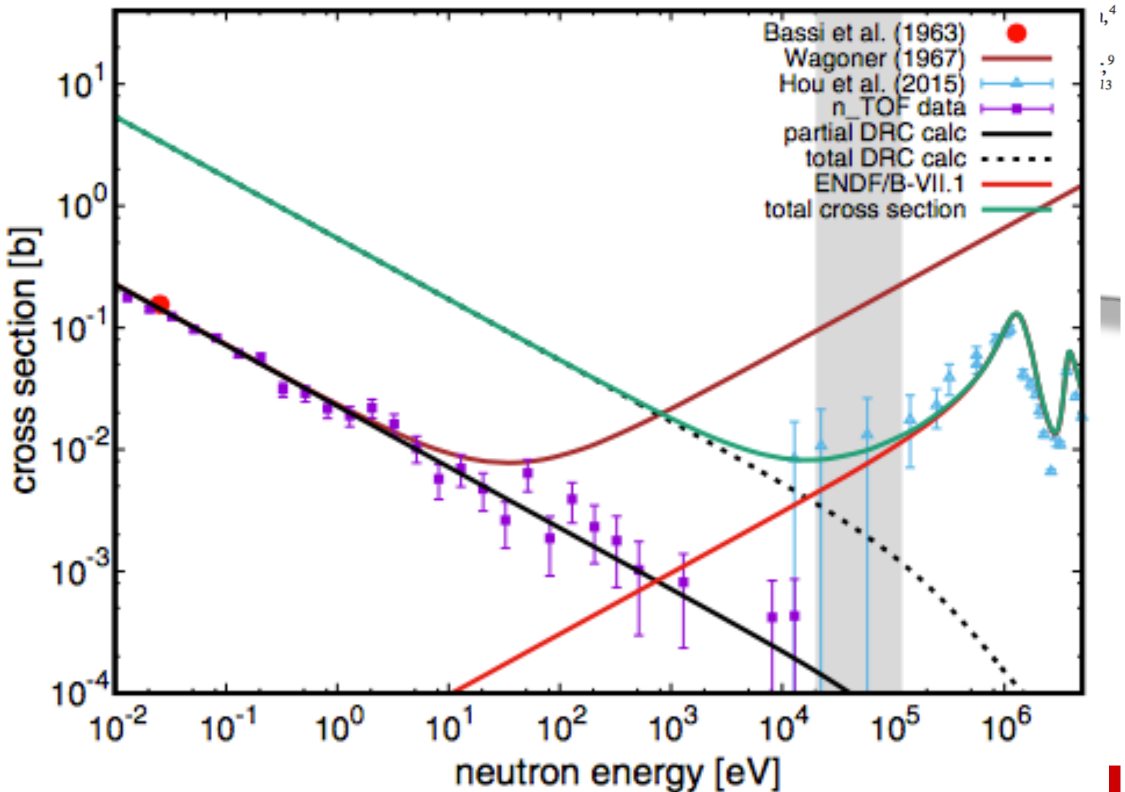
has been highlighted by the ed... as an Editors' Suggestion. ...blication of a Le... already a considerable achievemen... *Physical Review Lett*... ...pts fewe... ...of submissions, and is ranked first among ... Scholar five-year h-index. A highlighted Lette... one Letter in six is highlighted as a S... and broad appeal. Suggestions... covered in the press substantially more... they would have an Impact Factor of 13... can be found on our webpage...

Yours sincerely,

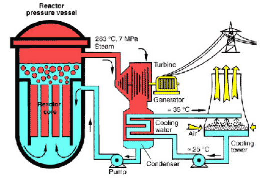
Hugues Chaté
Editor
Physical Review Letters

Professor Pierre Meystre
Editor in Chief
Physical Review

1 bachelor thesis 15/07/2016

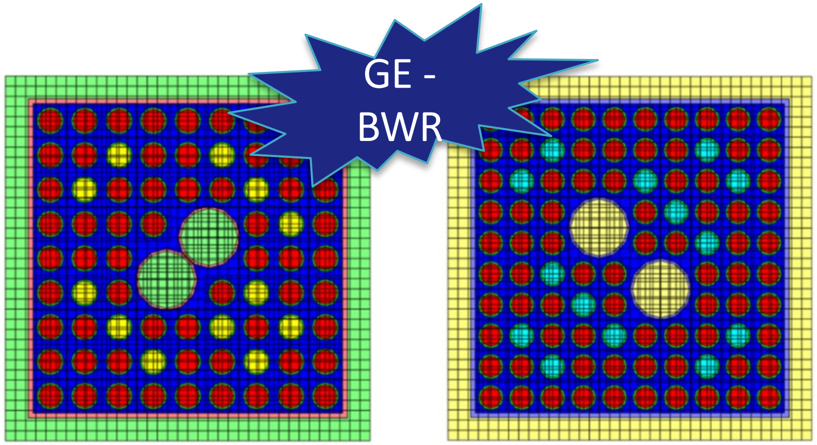


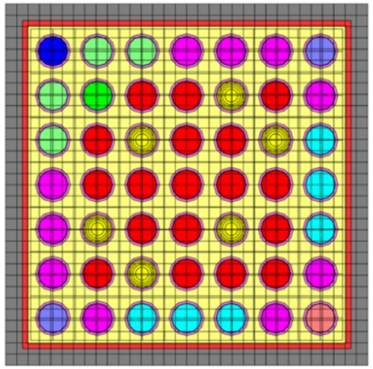
Neutron poison



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

Proposal (INFN) in close collaboration with ENEA

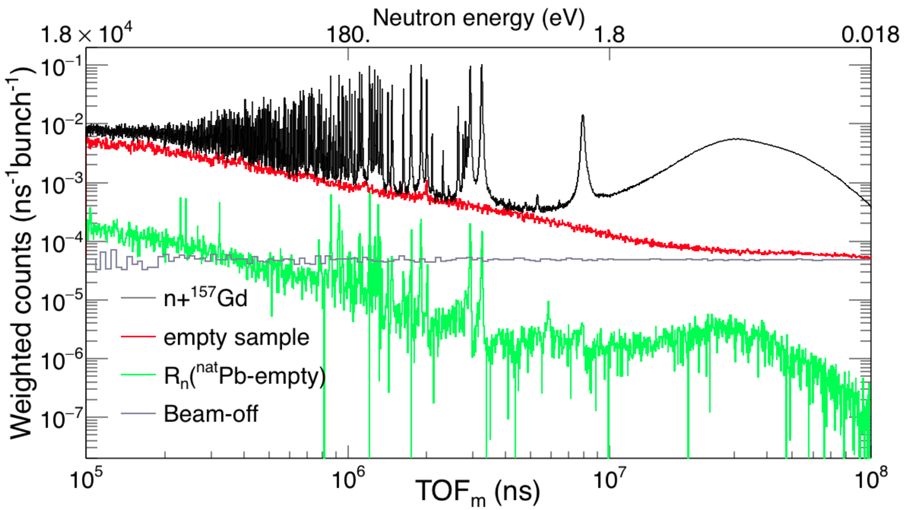




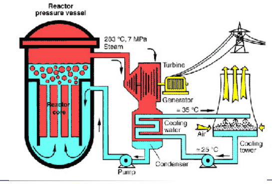
The **uncertainty** on **Gd** cross sections gives the **largest contribution** to the uncertainty on k_{eff} **after** **^{235,238}U**.

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

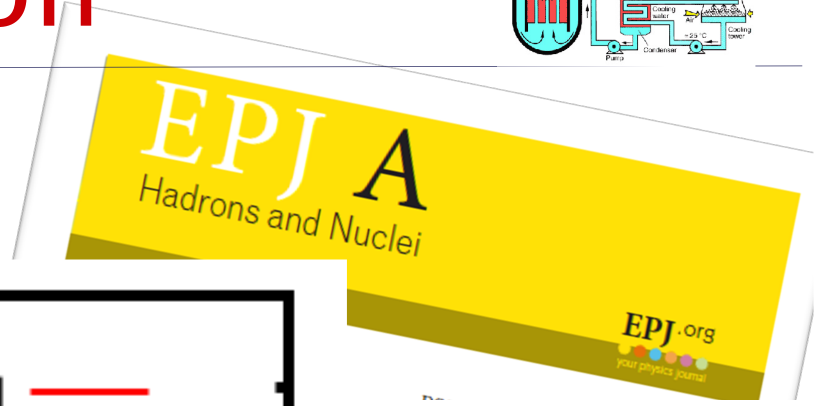
High enrichments pose severe safety problems due to the **high initial excess reactivity.** This can be **inherently compensated** by loading the fuel with **"burnable neutron poisons"**, i.e. isotopes with very high capture cross section

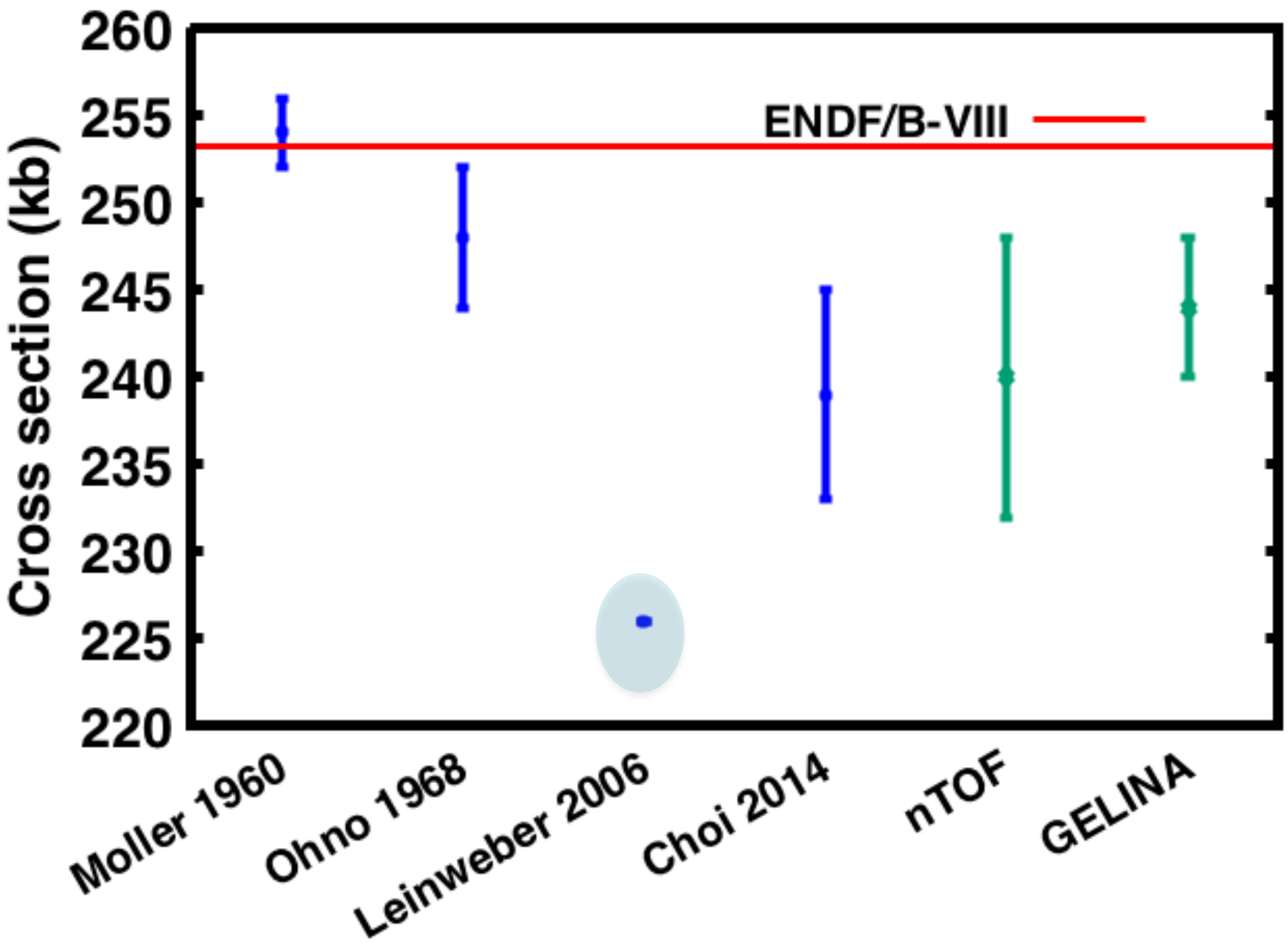


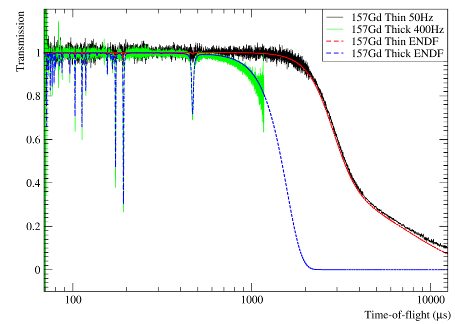
Neutron poison



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







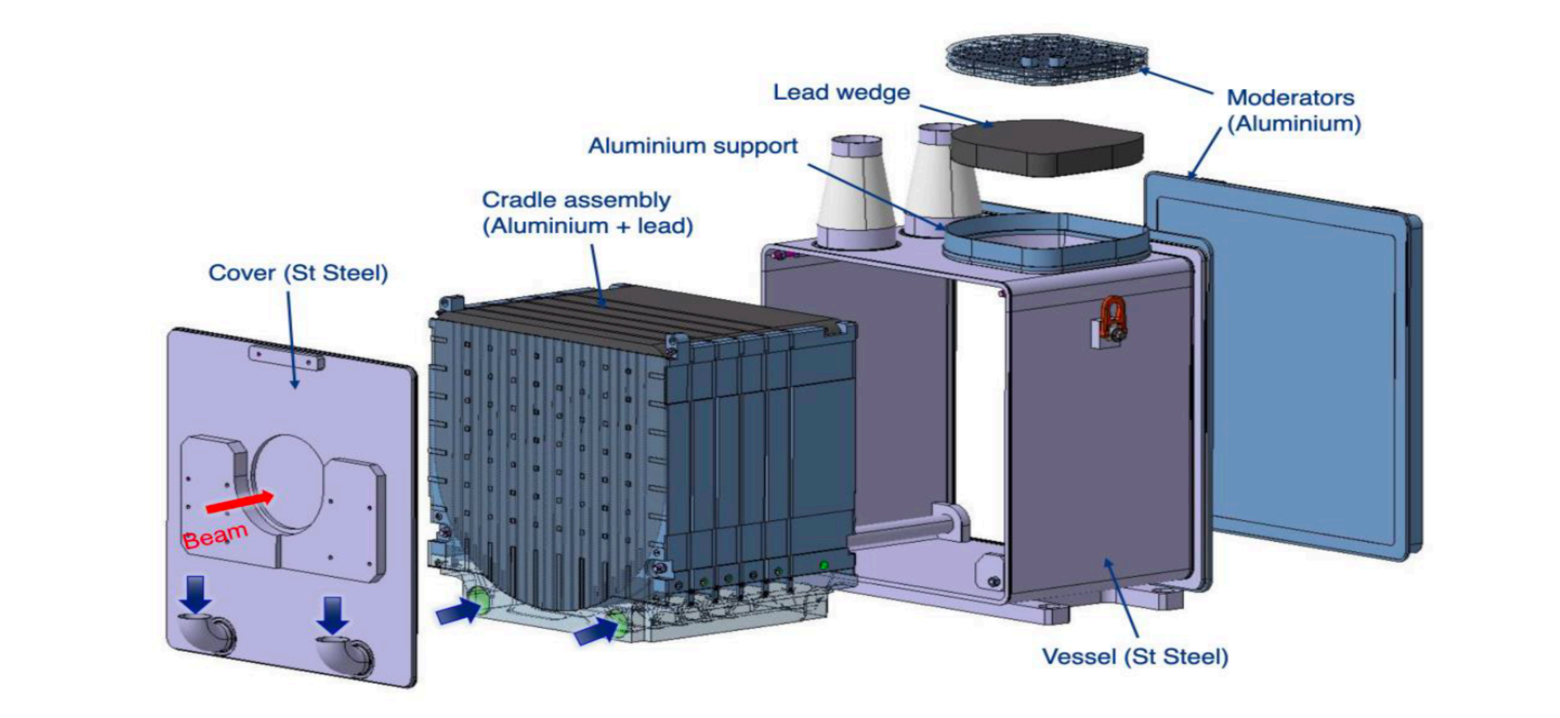
240±8 kb

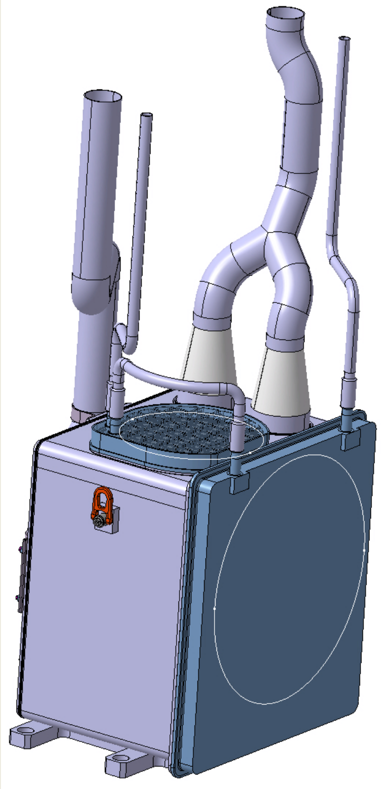
244±4 kb

Ratio = 1.6%

Conclusion / future

The new spallation target (target #3) is being installed (2020)
It was studied to operate until 2030 (LS3-LS4) budget CERN 1.4 MCHF

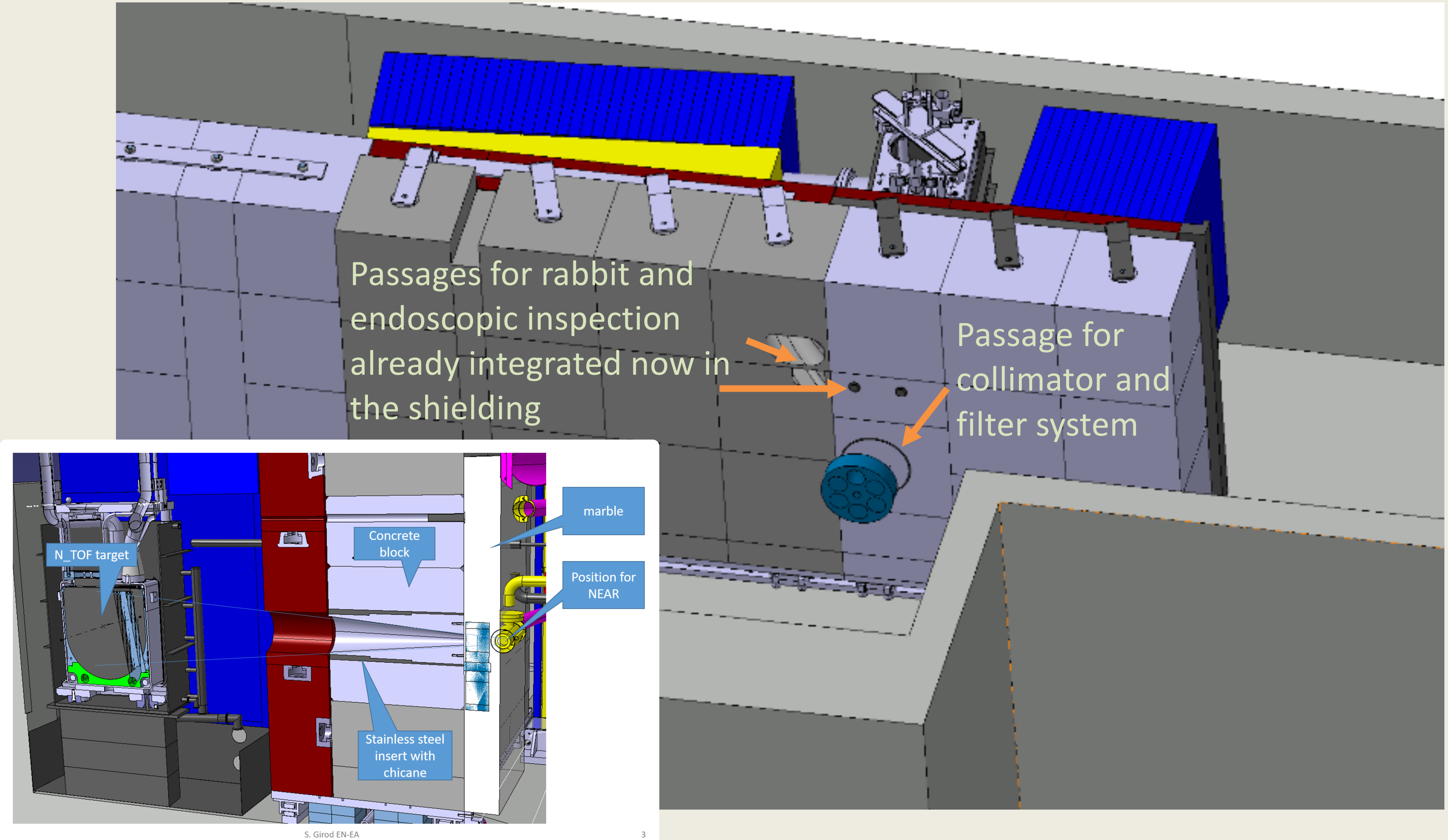




Weight 1550 Kg	15 cm Pb slices 64 x 62 x 46 cm	Borated water moderator	N_2 cooling

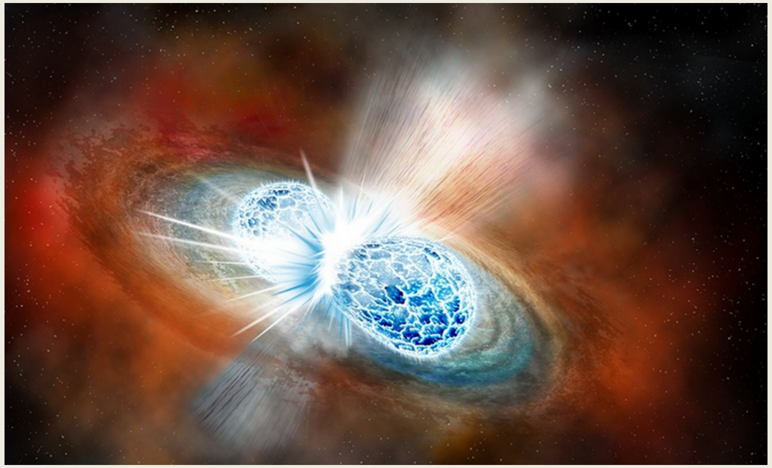
Conclusion / future

Construction of the NEAR station (EAR-3) for activation measurements on rare isotopes and short-lived radioisotopes (produced at ISOLDE@CERN or PSI)



Conclusion / future

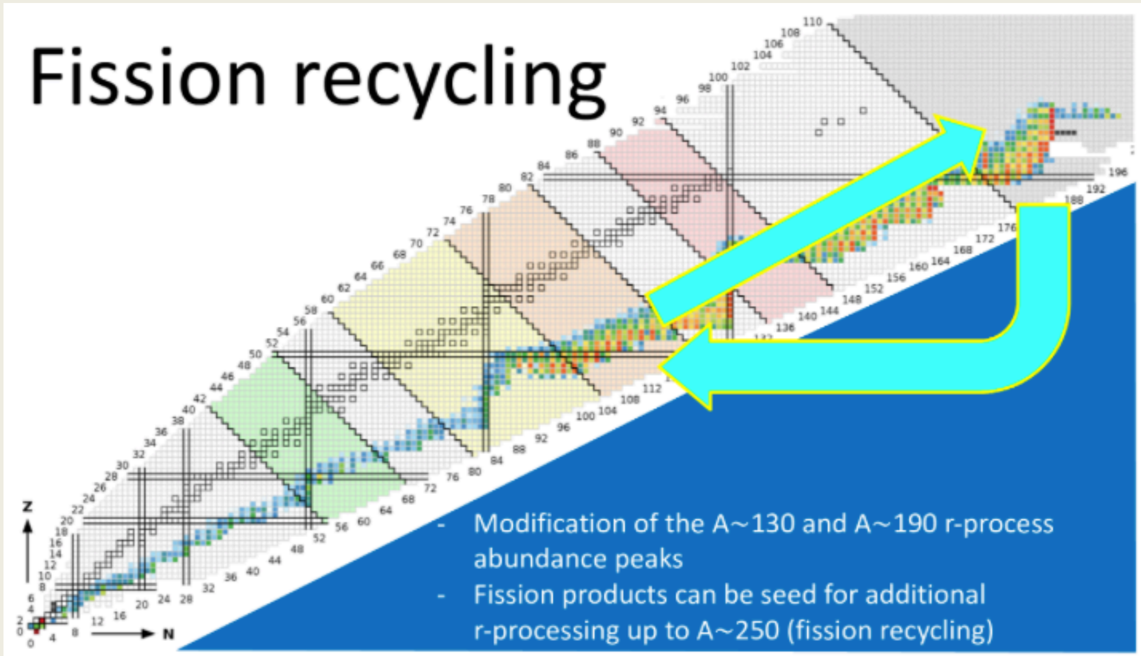
Neutron Star Merger – r process



r-process contribution to observed elemental abundances?

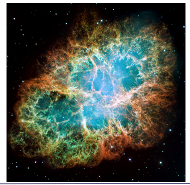
r process = Solar yields – s process

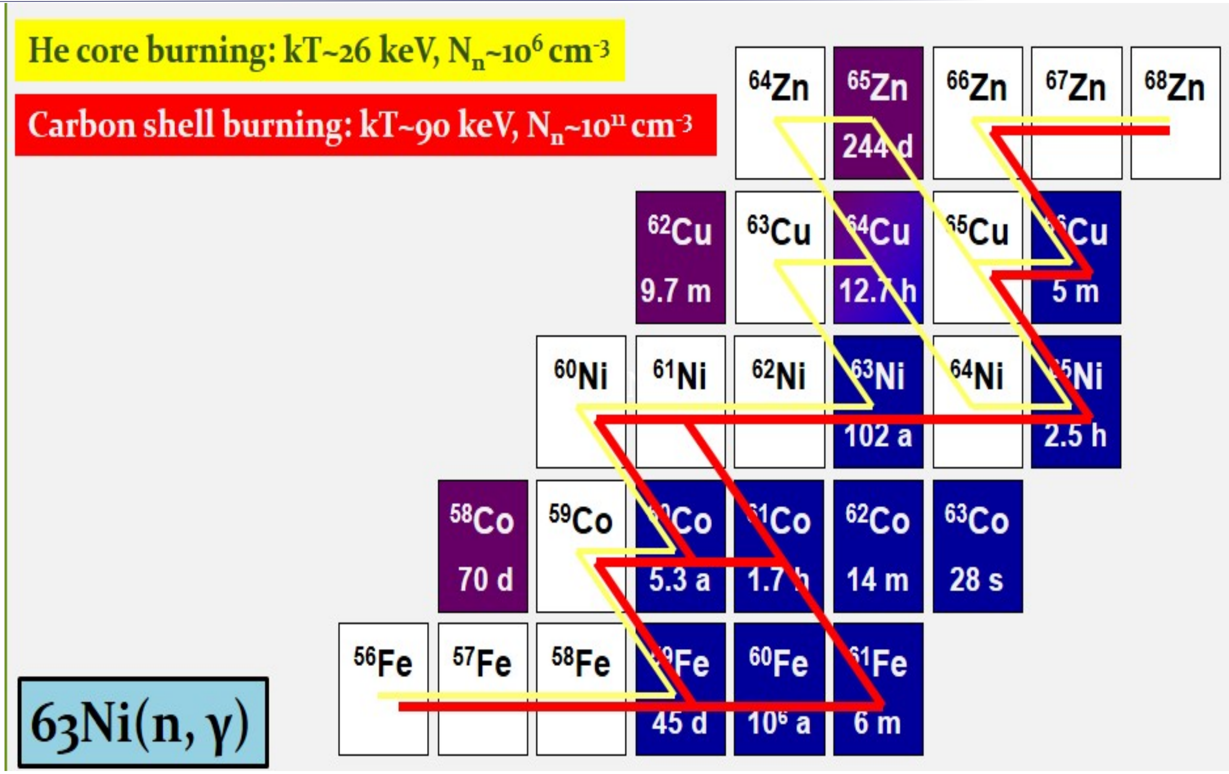
Improve the **physics** of both the **s-process** (neutron capture) and the **r-process** (fission)



Backup slides

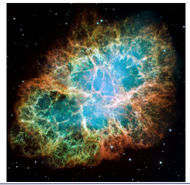
s-process branching



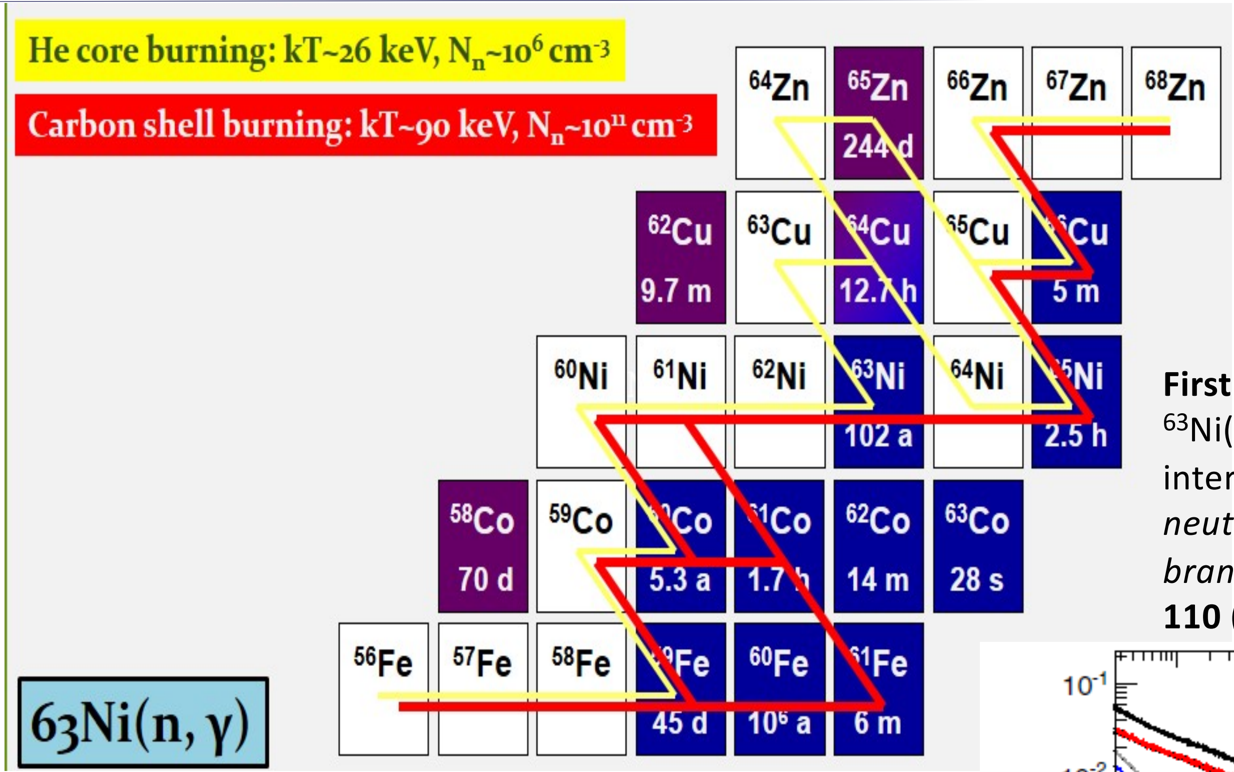


The branching depends on the **stellar condition**, on the isotope half-life and on the **neutron capture cross section**

^{63}Ni ($t_{1/2}$=100 y) **first branching point** determines **abundance** of **^{63,65}Cu**



s-process branching

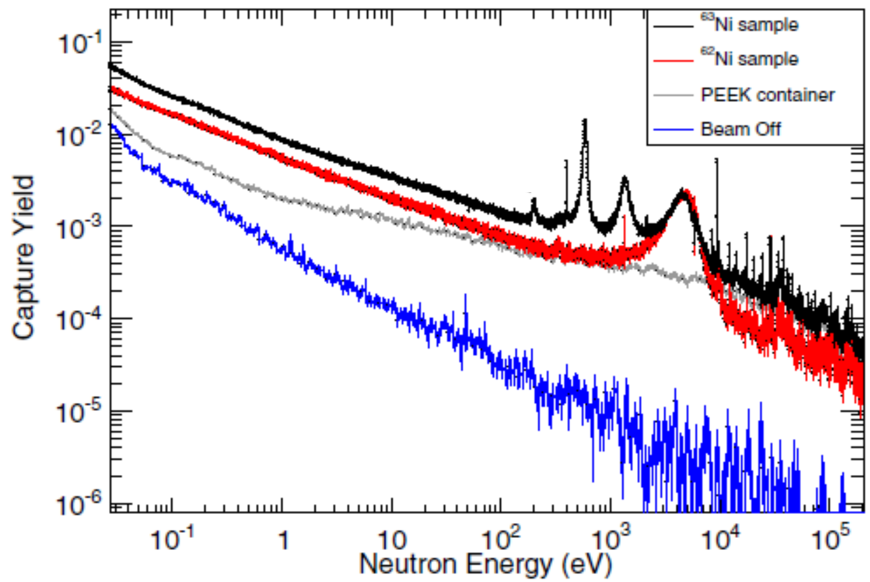


The branching depends on the **stellar condition**, on the isotope half-life and on the **neutron capture cross section**

^{63}Ni ($t_{1/2}$=100 y) **first branching point** determines **abundance** of $^{63,65}Cu$

First high-resolution measurement of the $^{63}Ni(n, \gamma)$ reaction in the energy range of interest to s-process nucleosynthesis: «*The neutron capture cross-section of the s process branch point isotope ^{63}Ni*» **Phys. Rev. Letters 110 (2013) 022501**

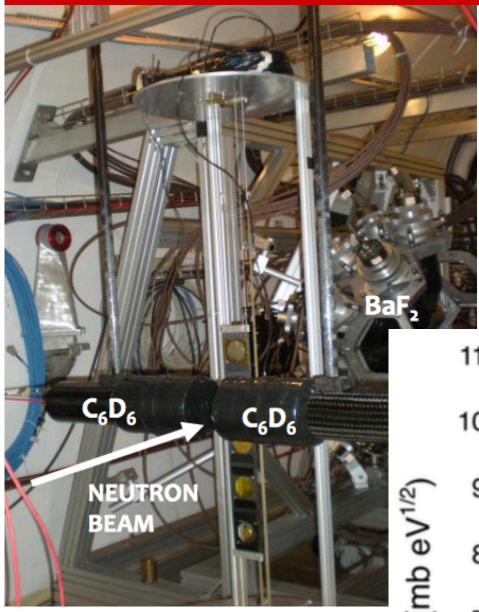
The measurement was performed in 2011 at n_TOF using an array of C_6D_6 detectors

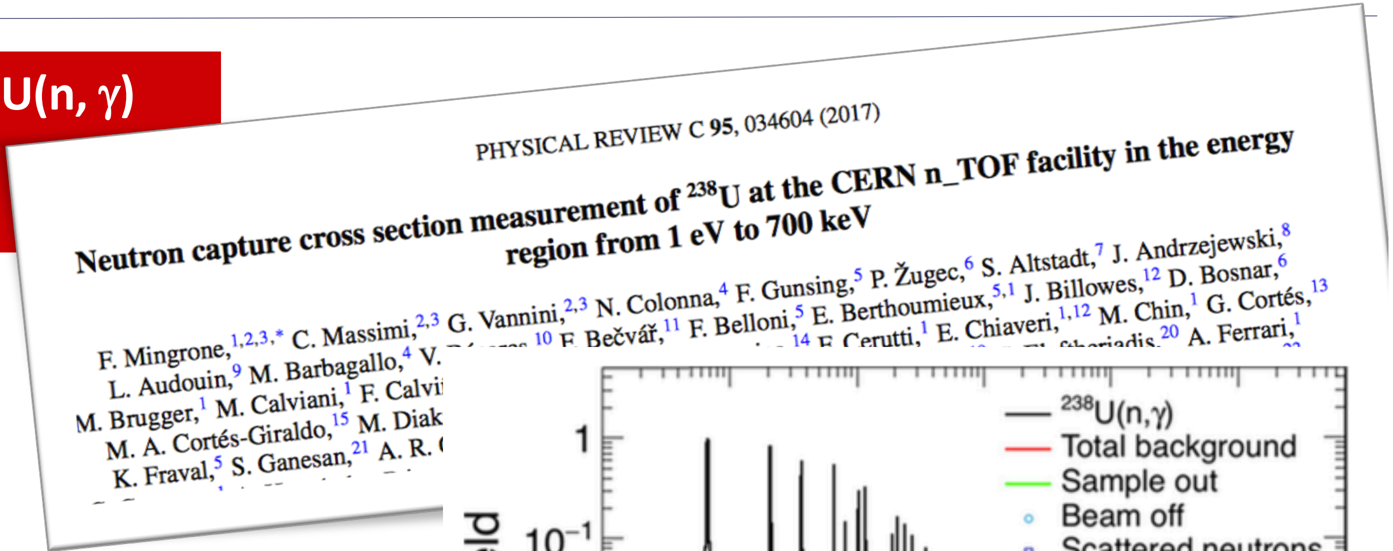


Measurement of $^{238}U(n, \gamma)$

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

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

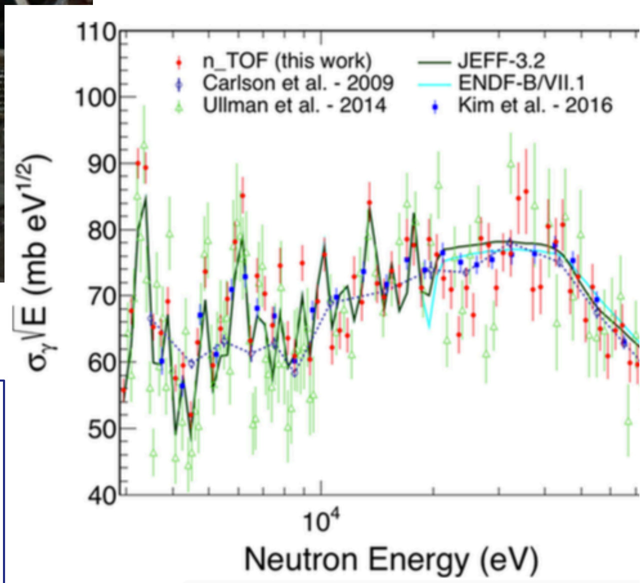


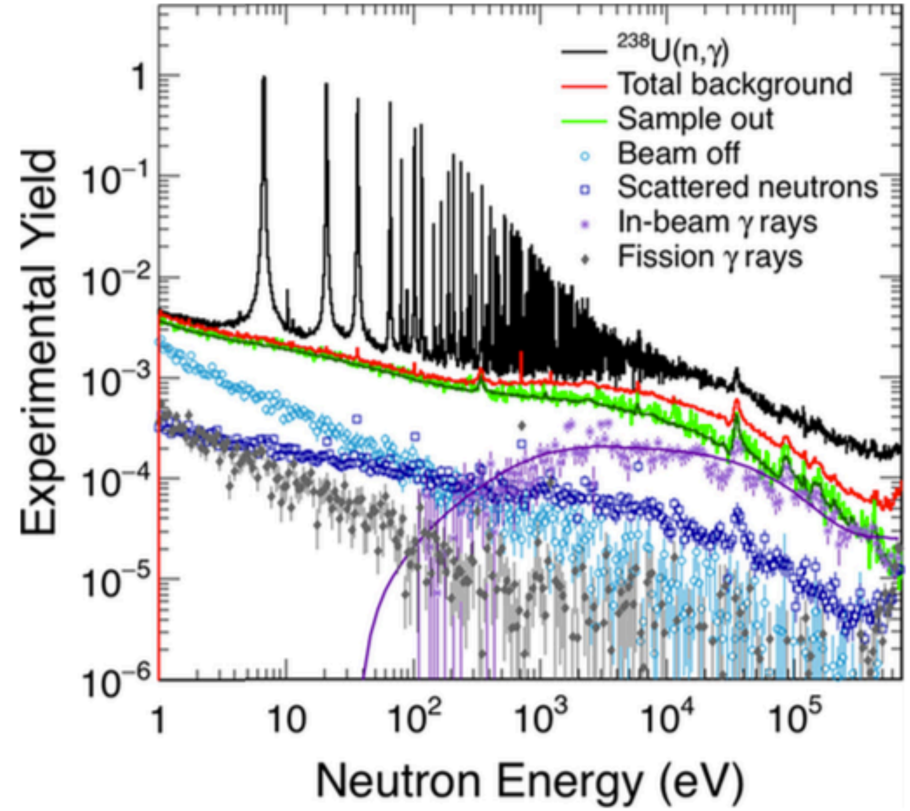


PHYSICAL REVIEW C 95, 034604 (2017)

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. ... F. Bečvář,[11] F. Belloni,[5] E. Berthoumieux,[5,1] J. Billowes,[12] D. Bosnar,[6]
M. Brugger,[1] M. Calviani,[1] F. Calvi... F. Cerutti,[1] E. Chiaveri,[1,12] M. Chin,[1] G. Cortés,[13]
M. A. Cortés-Giraldo,[15] M. Diak... A. Ferrari,[1]
K. Fraval,[5] S. Ganesan,[21] A. R. ...





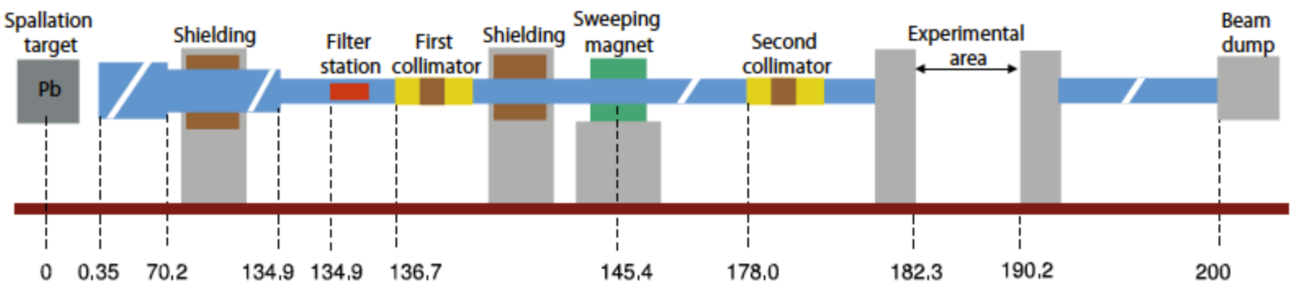
First measurement together Los Alamos, for E_n>100 keV

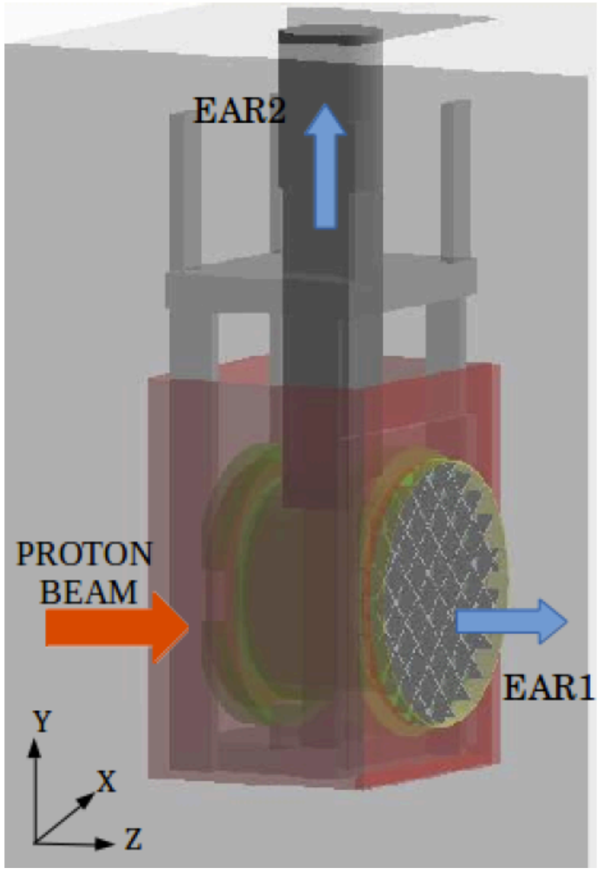
1 PhD thesis Feb. 15

MC simulation of n_TOF source

Geant4 simulation of the n_TOF neutron source and transport to EAR1

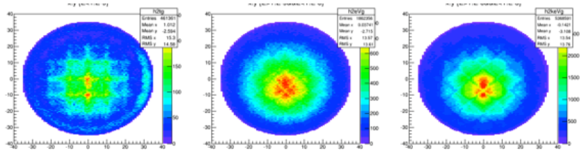
20 GeV/c protons on lead

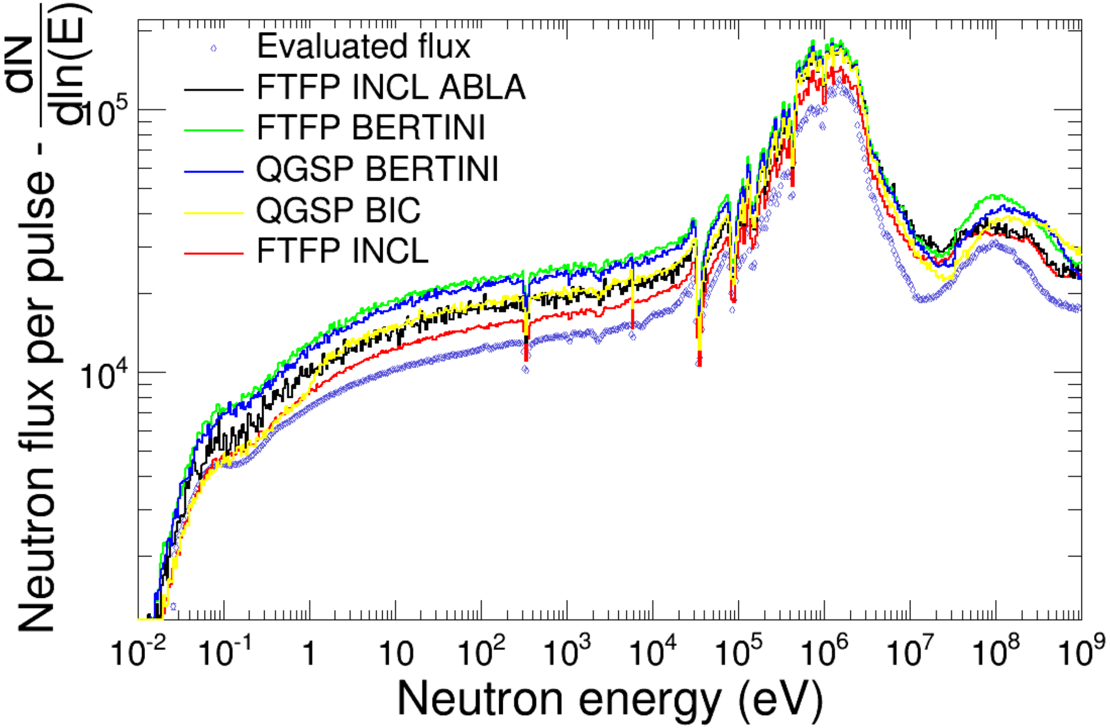




S. Lo Meo, M. A. Cortés-Giraldo, C. Massimi, *et al.*, Eur. Phys. J. A 51 (2015) 160

1 bachelor thesis 23/09/2016





^{140}Ce: Galactic chemical evolution

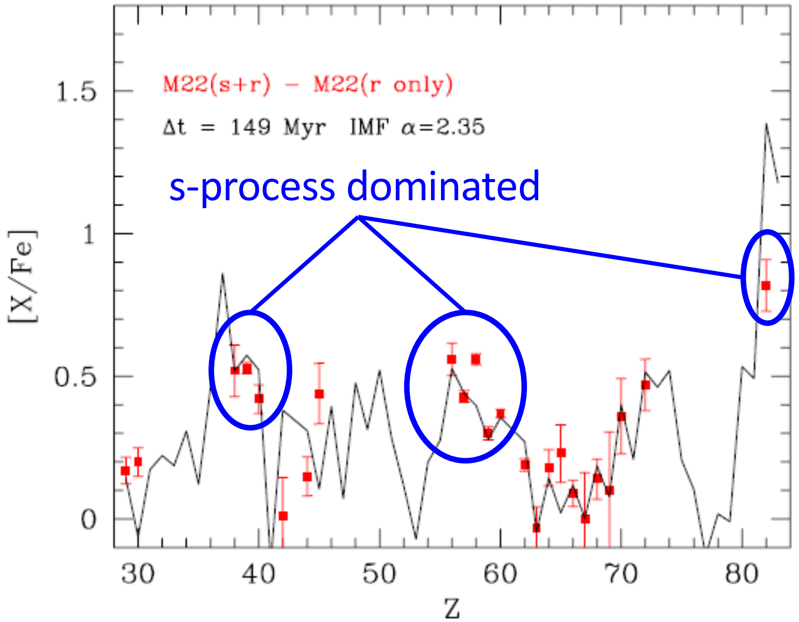


Figure 11. Best fit of the average *s*-process chemical pattern of stars in M22.

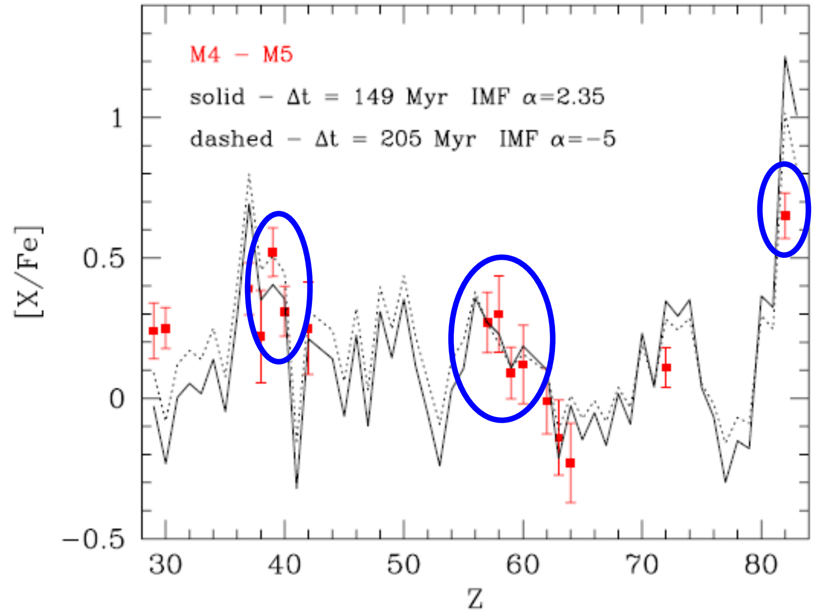


Figure 13. Best fit of the average *s*-process chemical pattern of stars in M4.

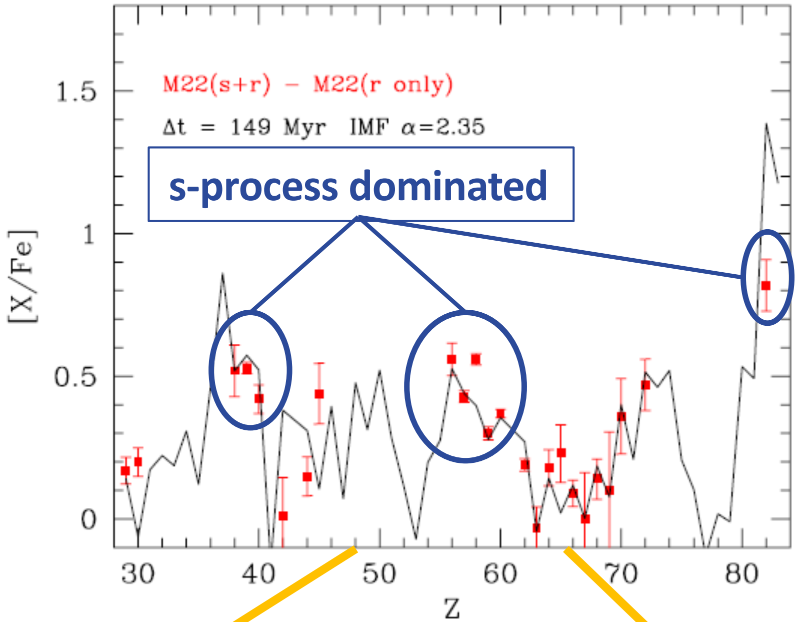
The pollution of AGB stars with a mass ranging between 3 to 6 MSUN may account for most of the features of the s-process enrichment of M4 and M22.

M22

M4

M5

^{140}Ce: Galactic chemical evolution



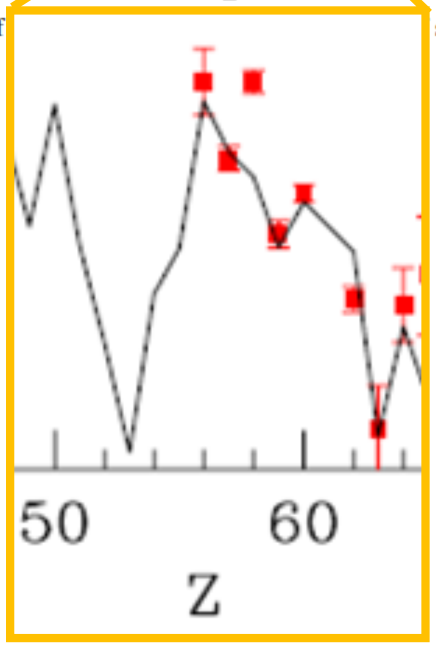
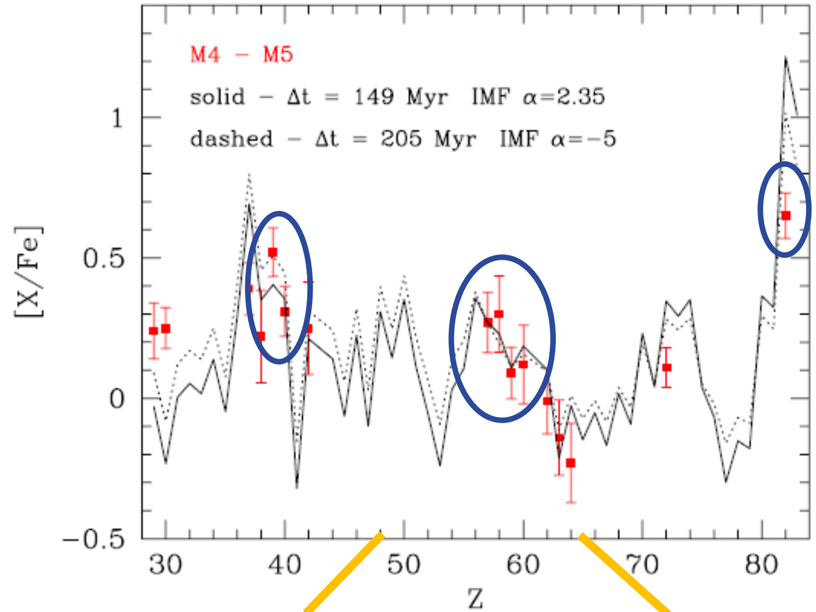


Figure 11. Best fit of ... stars in M22.



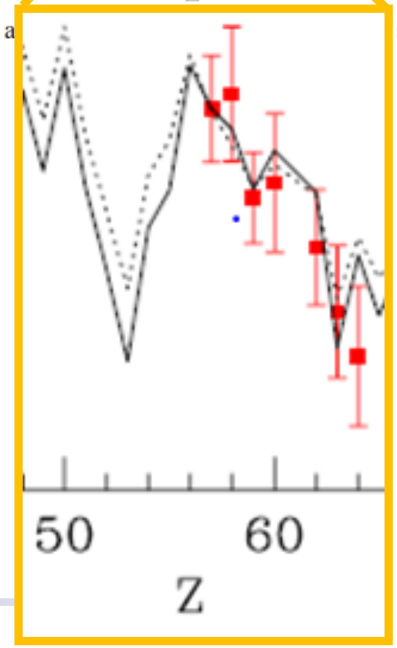


Figure 13. Best fit of the a... stars in M4.

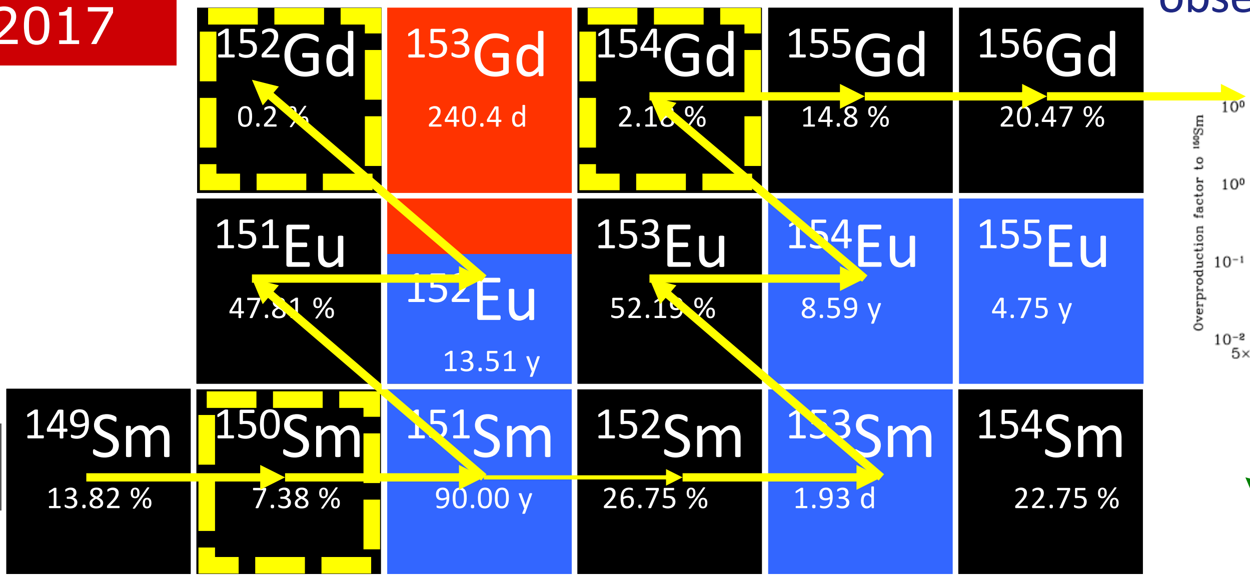
Abundances of elements in the s-process peak are well reproduced apart from Cerium

s–only isotope

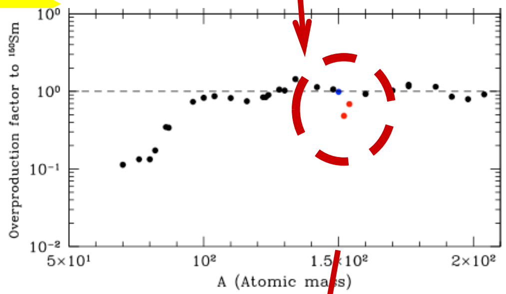
^{154}Gd(n, γ)
August 2017

- β+ (red)
- stable (black)
- β- (blue)

s process



Disagreement between observations and models



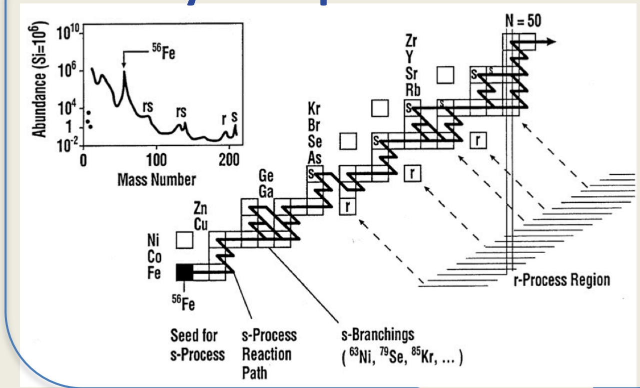
r process

Discrepancies in nuclear data need to be resolved

^{152}Gd e **^{154}Gd** are **s-only** isotopes: they can be produced only via s process because they are shielded against the β-decay chains from the r-process region by the isobars samarium.

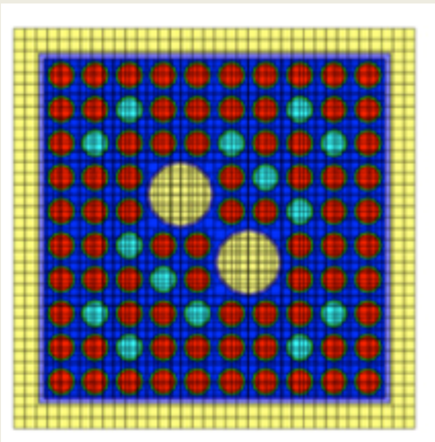
Proposal (INFN) in close collaboration with INAF

s-only isotope ^{154}Gd



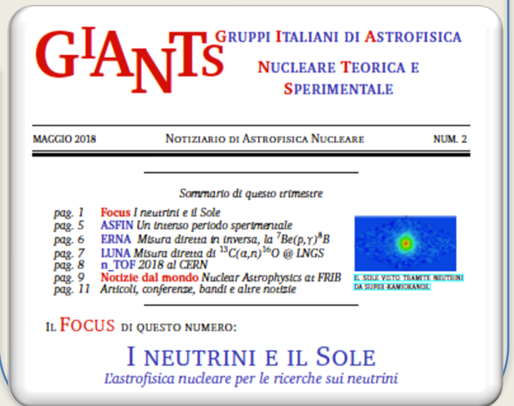
^{140}Ce: test for the galactic chemical evolution

$^{155,157}Gd(n,\gamma)$: BWR reactors and other applications



ONGOING ACTIVITIES

A newsletter for nuclear astrophysics


GIANTS — Gruppi Italiani di Astrofisica Nucleare Teorica e Sperimentale

MAGGIO 2018 — Notiziario di Astrofisica Nucleare — NUM. 2

Sommario di questo trimestre

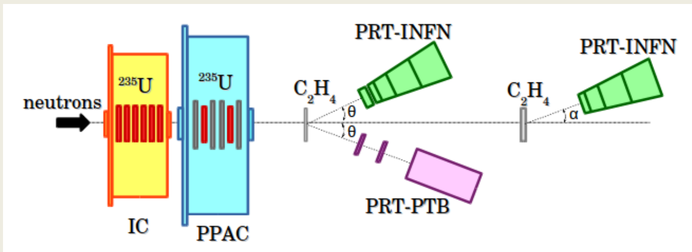
- pag. 1 Focus I neutrini e il Sole
- pag. 5 ASFIN Un intenso periodo sperimentale
- pag. 6 ERNA Misura diretta in inversa, la $^7Be(p,\gamma)^8B$
- pag. 7 LUNA Misura diretta di $^{13}C(\alpha,n)^{16}O$ @ LNGS
- pag. 8 n_TOF 2018 al CERN
- pag. 9 Notizie dal mondo Nuclear Astrophysics at FRIB
- pag. 11 Articoli, conferenze, bandi e altre notizie

Il Focus di questo numero:

I NEUTRINI E IL SOLE

L'astrofisica nucleare per le ricerche sui neutrini

$^{235}U(n,f)$ at E_n>200 MeV



ONGOING ACTIVITIES

A newsletter for nuclear astrophysics


GIANTS GRUPPI ITALIANI DI ASTROFISICA NUCLEARE TEORICA E SPERIMENTALE

MAGGIO 2018 NOTIZIARIO DI ASTROFISICA NUCLEARE NUM. 2

Sommario di questo trimestre

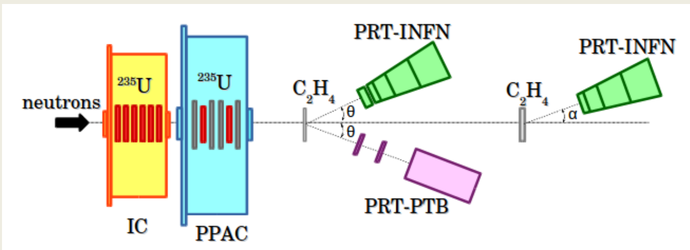
IL SOLE VISTO TRAMITE NEUTRINI DA SUPER-KAMIOKANDE

IL FOCUS DI QUESTO NUMERO:

I NEUTRINI E IL SOLE

L'astrofisica nucleare per le ricerche sui neutrini

$^{235}U(n,f)$ at E_n>200 MeV



Dissemination

26 presentations
by **PhD students**
and **postdocs**

http://agenda.infn.it/event/GIANTS-IX

9th edition, Bologna
5-6 October 2017

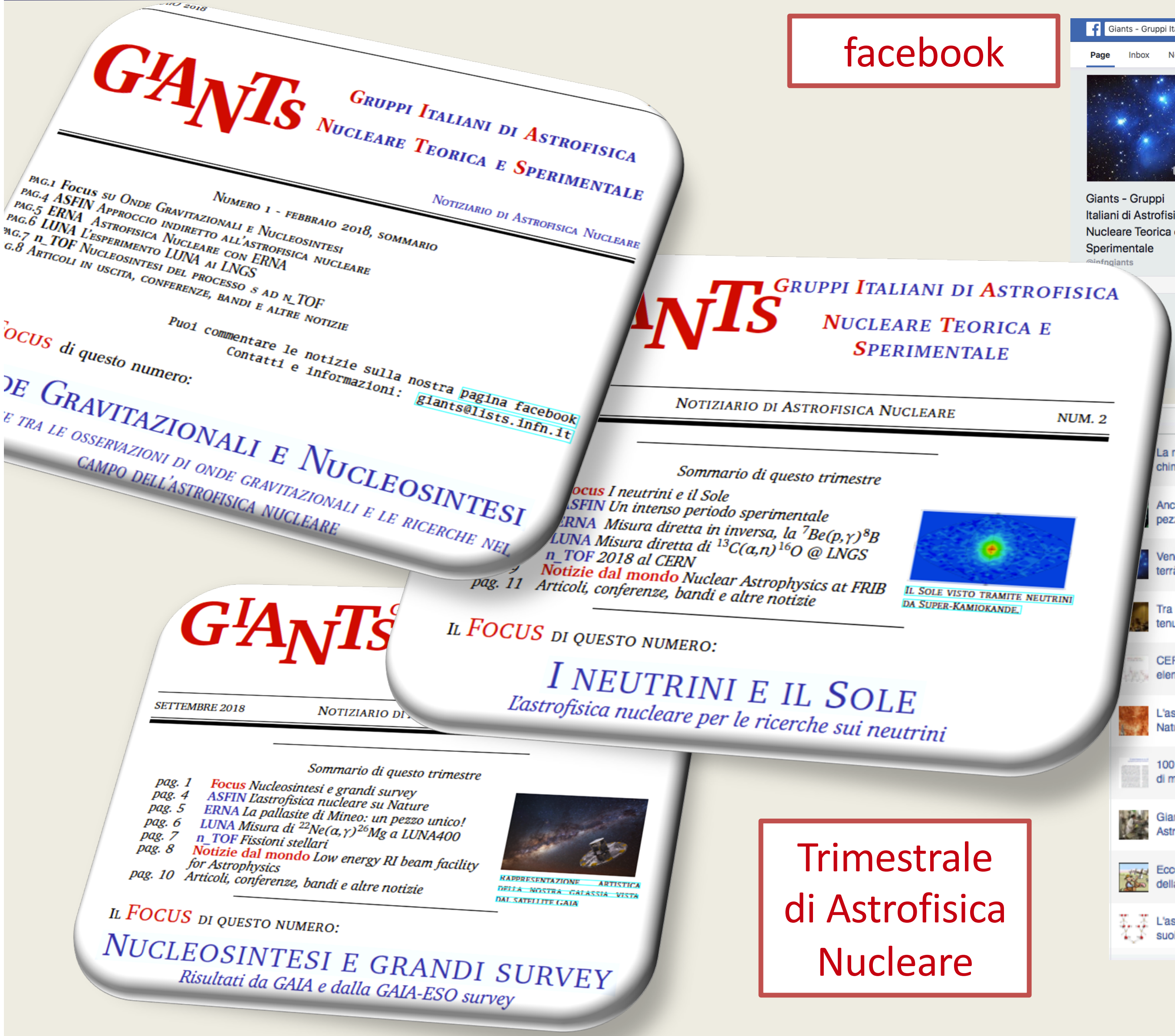
Organizing committee composed by young researchers from **n_TOF, ASFIN, ERNA** and **LUNA**

Idea of a **Newsletter** of the italian group of Nuclear Astrophysics.
Scientific board composed by 7 researchers from different experiments.

- 1st number February 2018
- We are on facebook:

https://www.facebook.com/infngiants/

Dissemination



facebook

	Type	Targeting	Reach	Engagement
La maggior parte degli elementi chimici di cui è composto			320	31 16
Anche la Pallasite di Mineo (il pezzo unico protagonista di un			182	9 7
Venerdì 28 settembre 2018 si terrà in 116 città italiane la			109	2 0
Tra il 24 e il 29 Giugno si è tenuta presso i Laboratori			721	109 34
CERIO UNA VOLTA.... Tutti gli elementi che conosciamo in			809	109 39
L'astrofisica nucleare su Nature!			51	4 7
100 miliardi di miliardi di miliardi di miliardi di neutrini al secondo!			854	86 25
Giants - Gruppi Italiani di Astrofisica Nucleare Teorica e			54	20 9
Ecco a voi il secondo numero della newsletter dei GIANTS In			228	29 19
L'astrofisica nucleare ha, tra i suoi obiettivi, la misura della			2.4K	233 97

Trimestrale di Astrofisica Nucleare

Proton recoil telescope

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the $^{235}U(n,f)$ cross section relative to n-p scattering up to 1 GeV

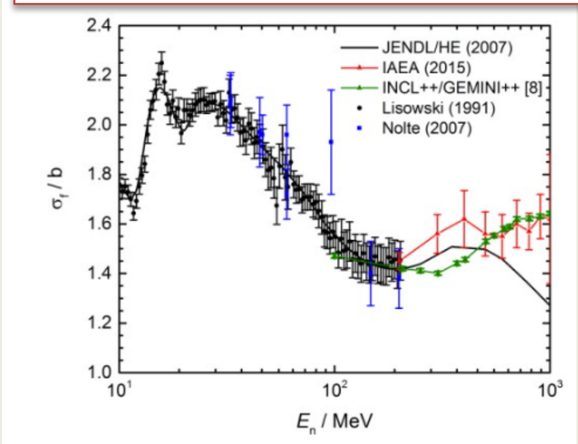
May 06, 2017

L. Audouin[1], M. Barbagallo[2], N. Colonna[2], L. Cosentino[2], M. Diakaki[3,4], I. Duran[5], P. Finelli[6,2], P. Finocchiaro[2], J. Heyse[7], S. Lo Meo[8,2], C. Massimi[2,6], P.F. Mastinu[2], P.M. Milazzo[2], F. Mingrone[3], A. Musumarra[2,9], R. Nolte[10], C. Paradela[7], D. Radeck[10], P. Schillebeeckx[7], L. Tassan-Got[1], G. Vannini[2,6], A. Ventura[2]

[1] CNRS-IN2P3, Univ. Paris-Sud, Univ. Paris-Saclay, Orsay, France
[2] INFN - sezioni di Bari, Bologna, LNL, LNS and Trieste, Italy
[3] CERN, Switzerland
[4] National Technical University of Athens, Greece
[5] Universidad de Santiago de Compostela, Spain
[6] Dipartimento di Fisica e Astronomia, University of Bologna, Italy
[7] European Commission, Joint Research Centre - Geel, Belgium
[8] ENEA - Bologna, Italy
[9] Dipartimento di Fisica e Astronomia, University of Catania, Italy
[10] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Spokespersons: C. Massimi (massimi@bo.infn.it), R. Nolte (ralf.nolte@ptb.de) and L. Cosentino (cosentino@lns.infn.it)
Technical coordinator: O. Aberle (oliver.aberle@cern.ch)

Measurement ongoing at CERN: $^{235}U(n, f)$
First measurement for **E_n>200** MeV (extension of the standard)
First experimental determination of the neutron flux E_n>200 MeV

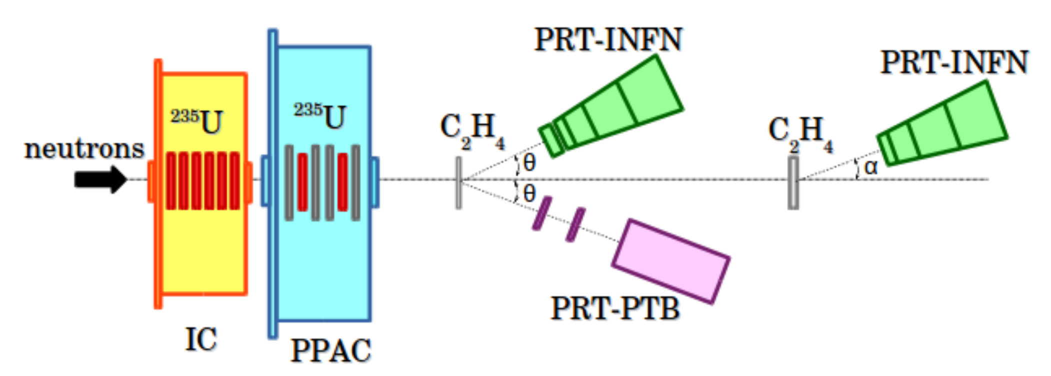


n_TOF facility is a unique tool for the cross section measurement of the **$^{235}U(n, f)$ reaction**, **relative** to the **H(n, n)H** reaction, **up to 1 GeV.**

For this measurement a **Proton Recoil Telescope** has been developed and realized with fast scintillators and solid state detectors. It has been successfully tested in 2016 and 2017 at the n_TOF facility.

Proposal approved by the INTC committee, meeting 28.06.2017

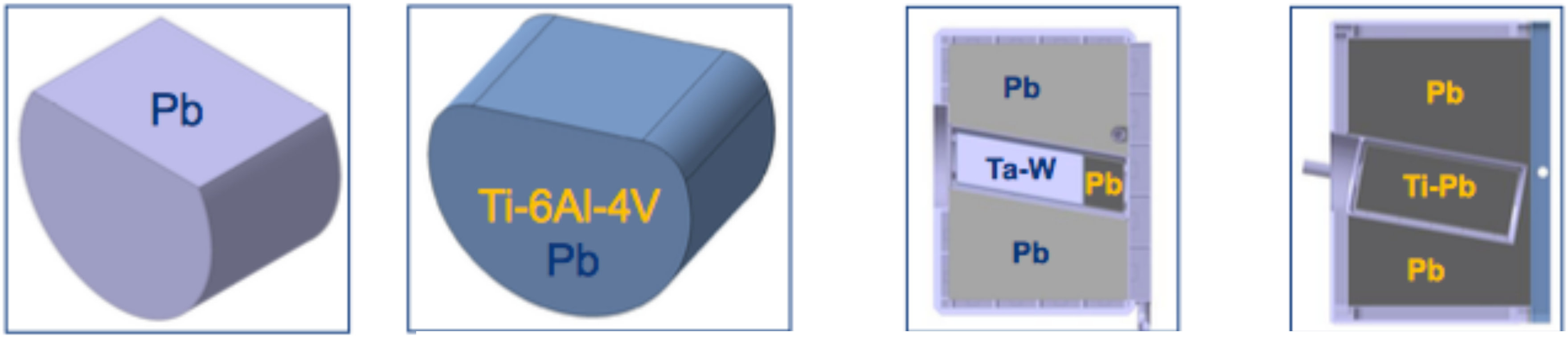
SETUP



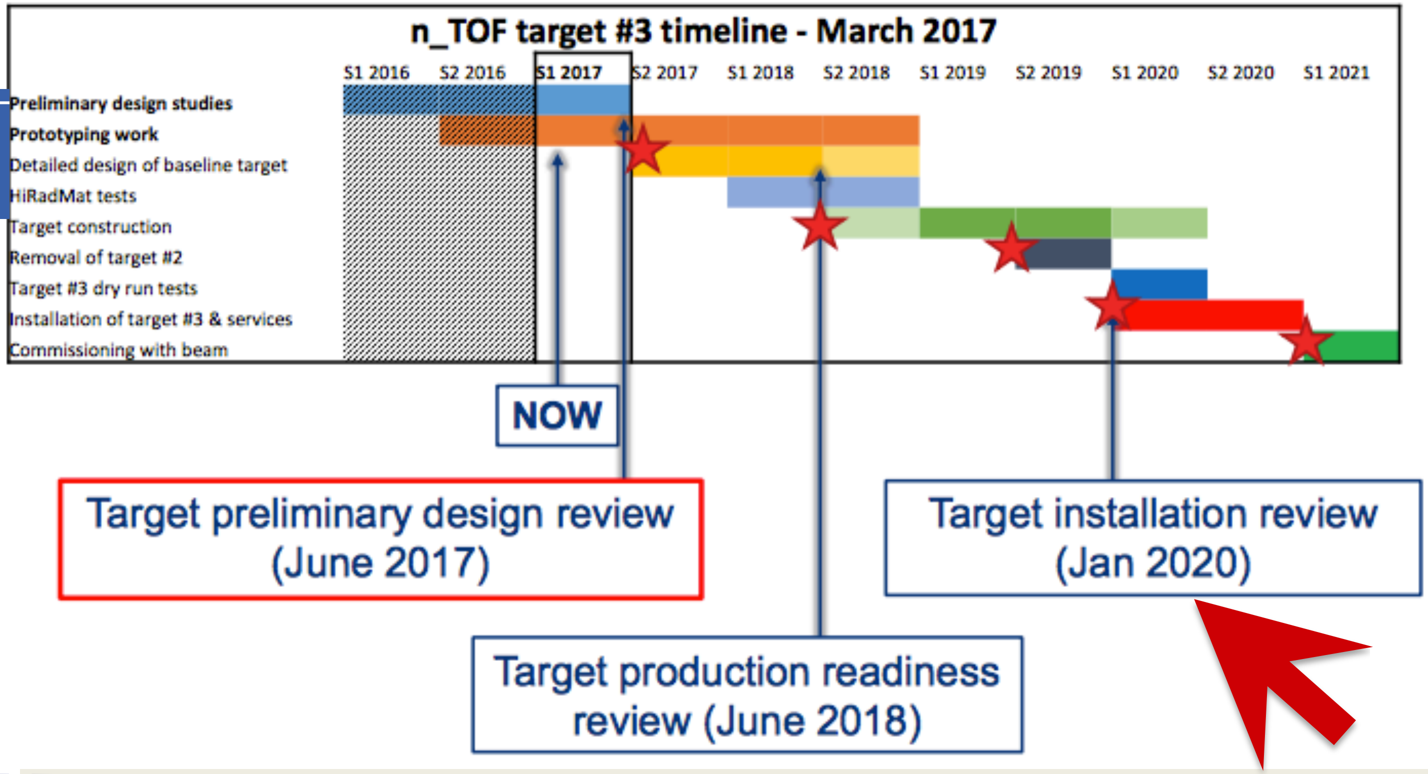
1 PhD
on this project

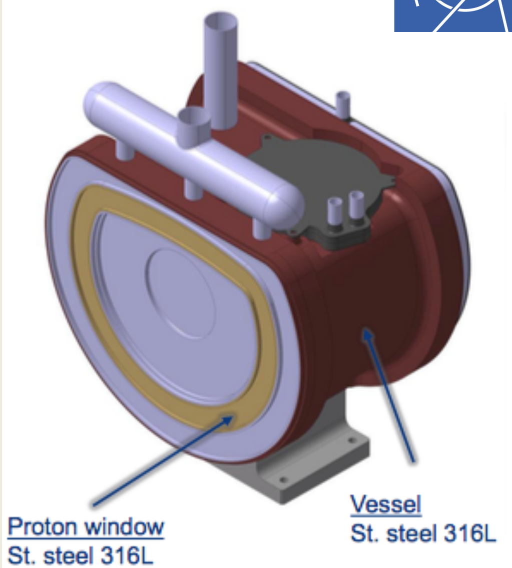
Conclusion

Approved**, operational 2020-2030 (LS3-LS4)**



n_TOF Target #3 Project Working Group

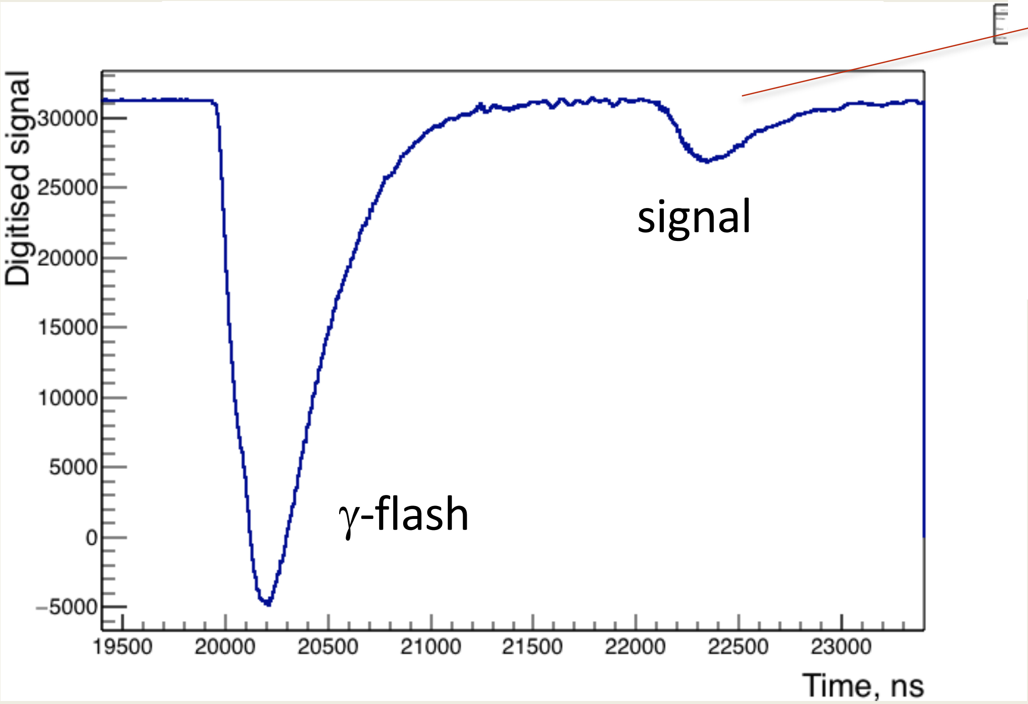




Silicon Monitor (SiMon)

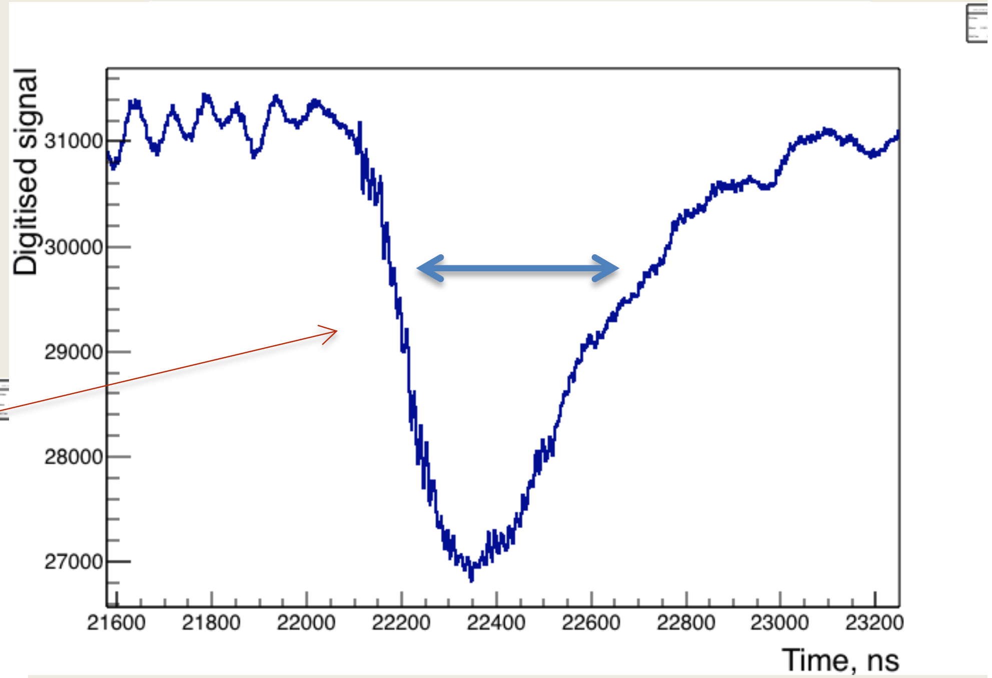
to measure flux as a function of E_n

SiMon is **not** a **fast** detector
risetime ~ 25 ns
Signal width ~ 500 ns



Performances under neutron beam

After shaping the signal (amplifier)



Each silicon detector connected to a fADC:

- Sampling rate 100-1000 MS
- Resolution 14 bit

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

Misura del rate di distruzione del ^{7}Be

Problema cosmologico del litio

Osservazioni: (Li/H)=(1.7±0.5)×10^{-10}

Teoria (BBN): (Li/H)=(5.1±0.7)×10^{-10}

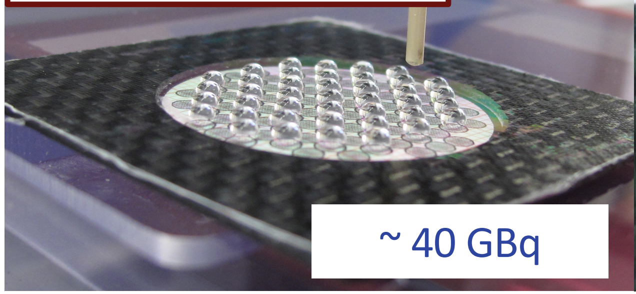
Soluzione Nucleare

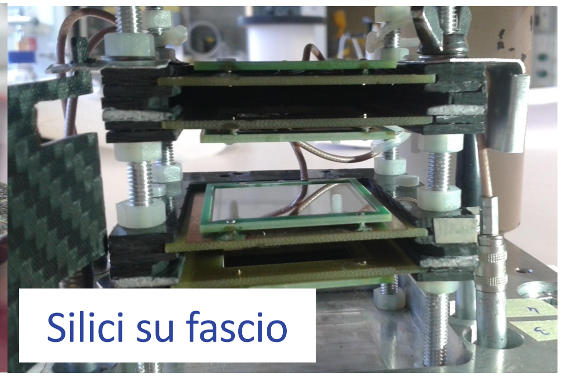
~95% del ^{7}Li deriva dalla cattura elettrocina del ^{7}Be

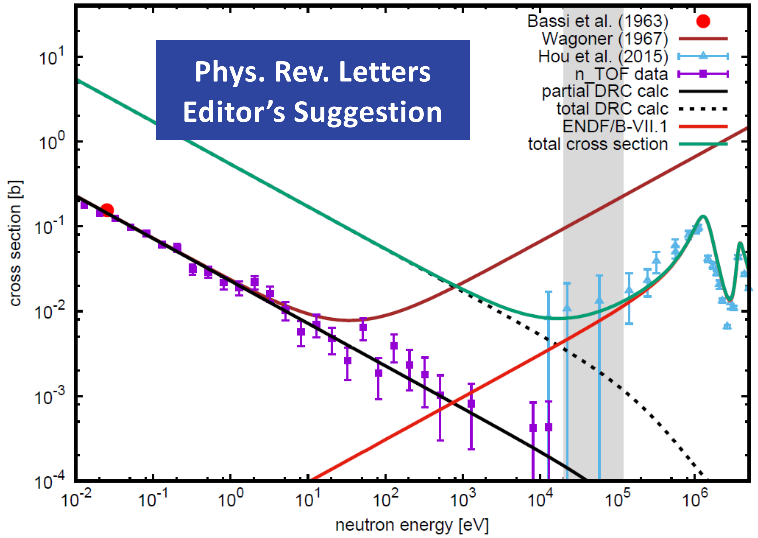
Difficoltà: (i) Attività specifica del ^{7}Be **13 GBq per μg**;
(ii) vita media breve 53.3 d

n_TOF EAR 2

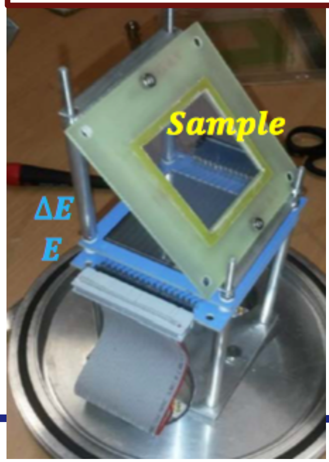
2015 ^{7}Be(n, α)







2016 ^{7}Be(n, p)



Bersaglio:
PSI (Berillio)
+
ISOLDE
(arricchimento ^{7}Be)
~ 1.1 GBq