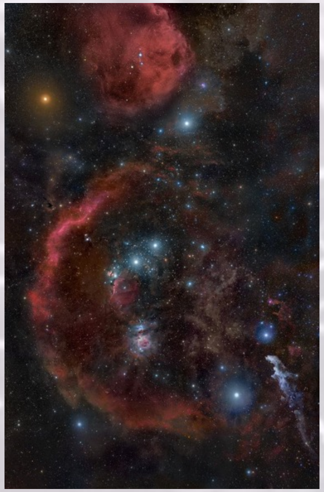
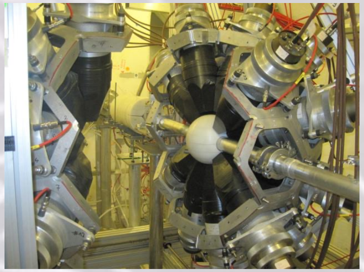
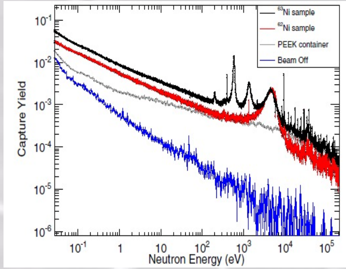
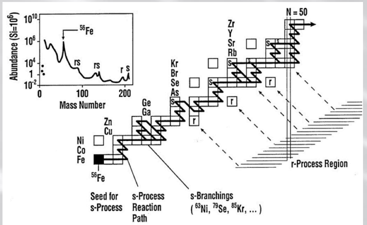
n_TOF

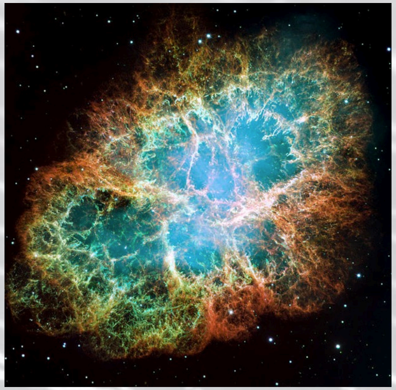
Neutron cross sections for science and technology











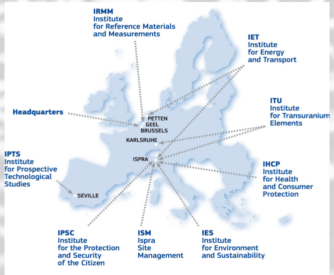
n_TOF

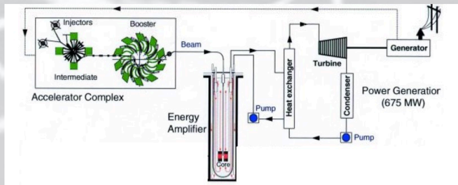
neutron Time Of Flight

@ CERN

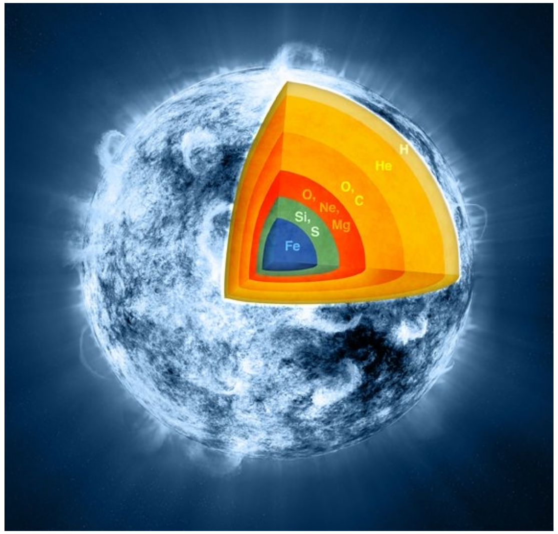
GELINA

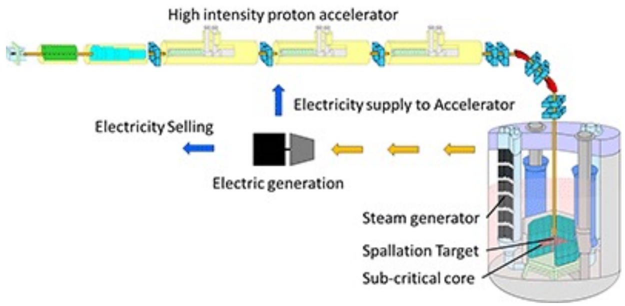
@ EC-JRC-GEEL

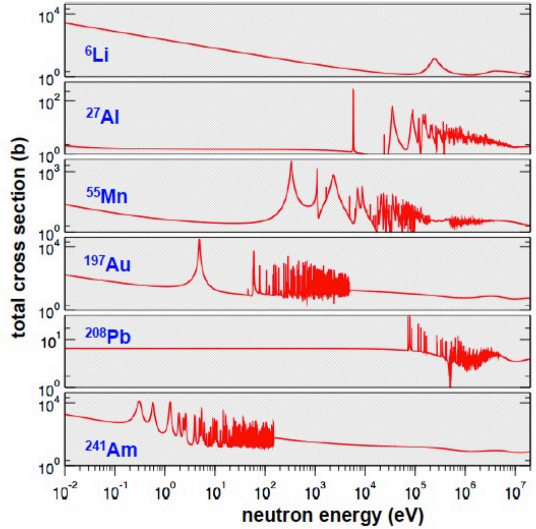




Research fields







Nuclear Astrophysics

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

Nuclear technology and medical application:

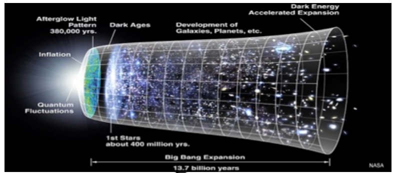
- ✓ Fission reactors (Gen-IV, ADS)
- ✓ Fusion
- ✓ Transmutation of nuclear waste
- ✓ Neutron capture therapy (adrontherapy)

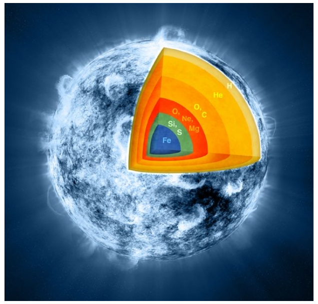
Basic Nuclear Physics

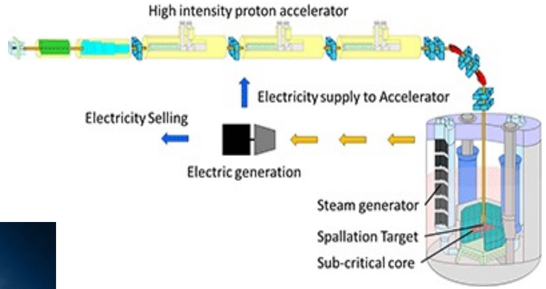
- ✓ Nuclear structure effects on fission
- ✓ Excited states (spin parity of resonances)
- ✓ Symmetries and fundamental interactions

Research fields

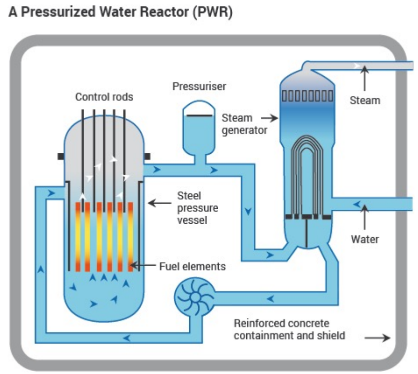
Nuclear Astrophysics Big Bang and Stellar nucleosynthesis

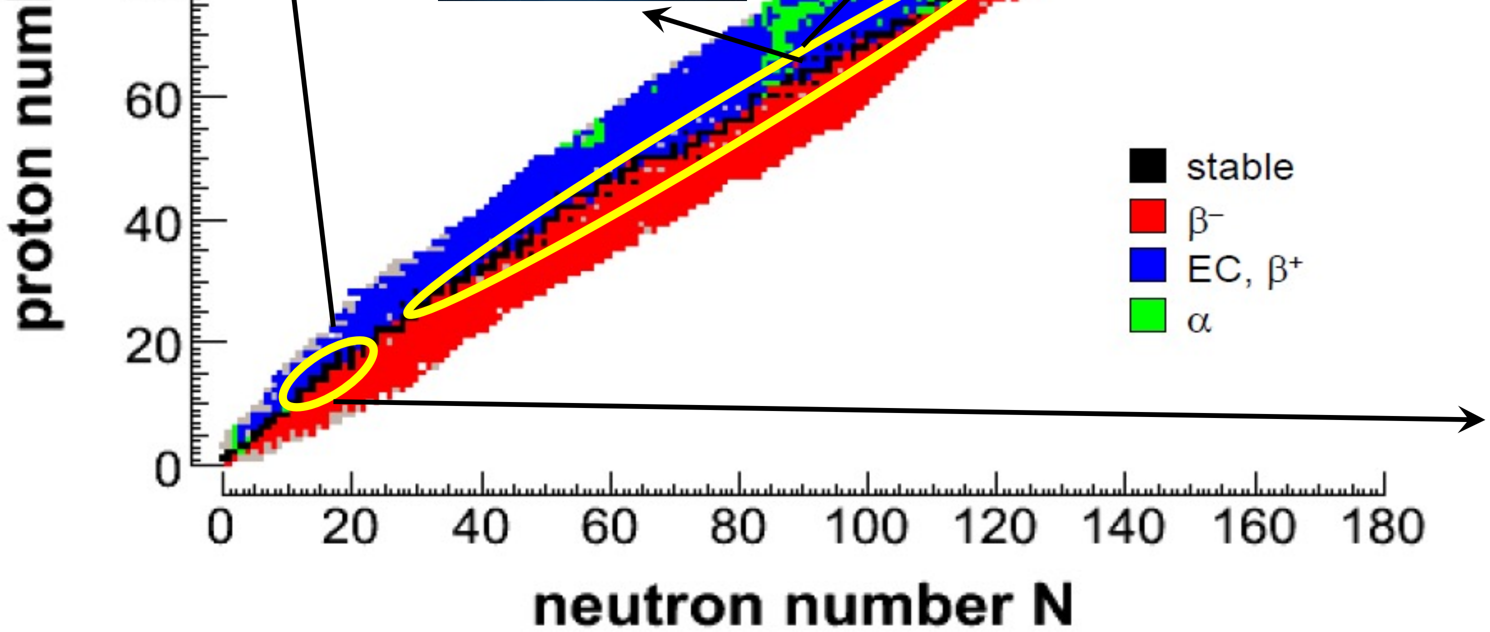




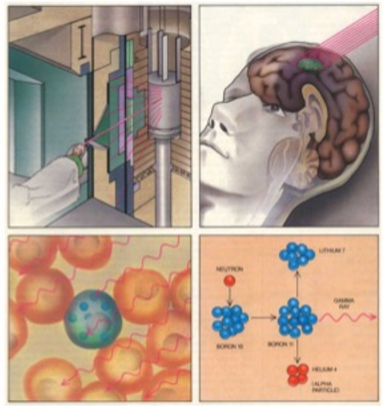


Nuclear reactors:
energy production & waste managment





Nuclear medicine
neutron capture therapy



n_TOF in numbers

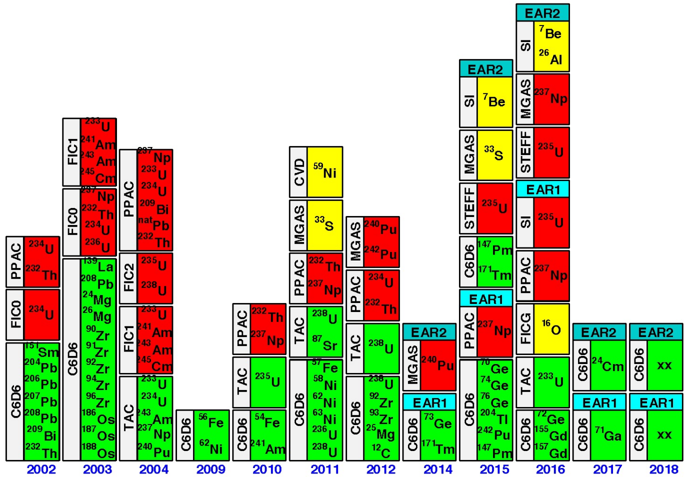
UE + UK + Japan

International collaboration
~ 130 Researchers
~ 33 Institutes

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

110 isotopes studied !!!

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



n_TOF Collaboration

11 INFN Sections

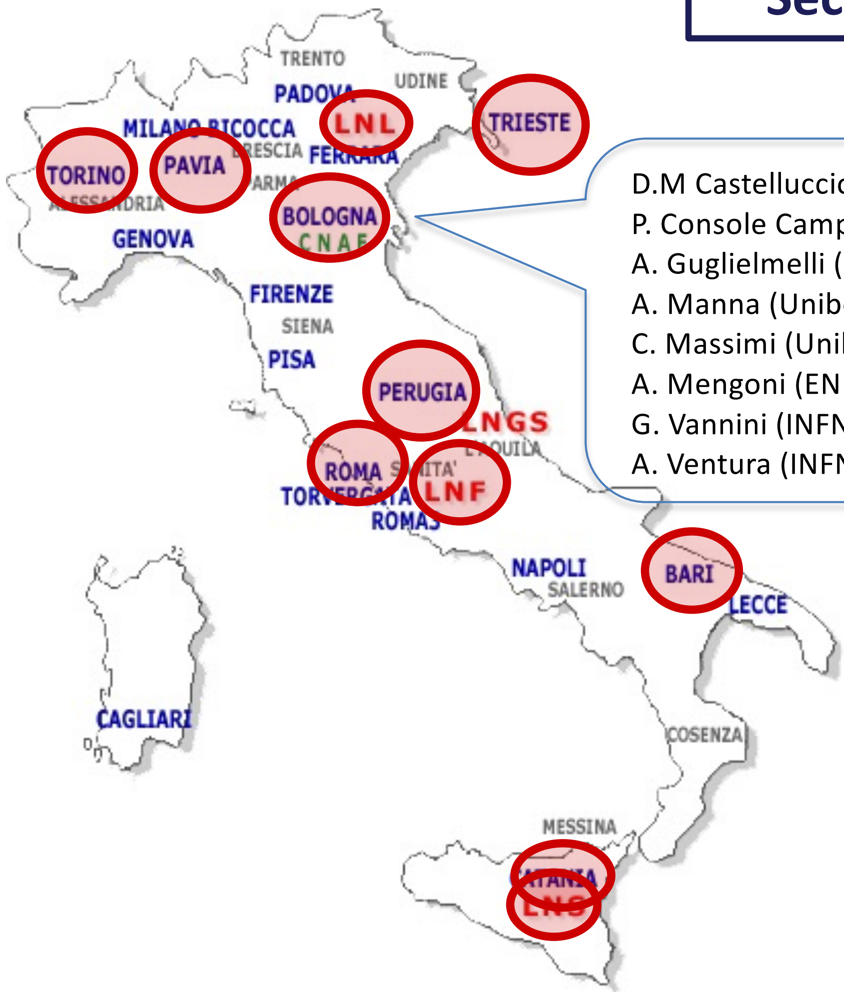
n_TOF - ITALY

33 researchers
(INFN + University)
17.0 FTE

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

47 researchers
23.6 FTE

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

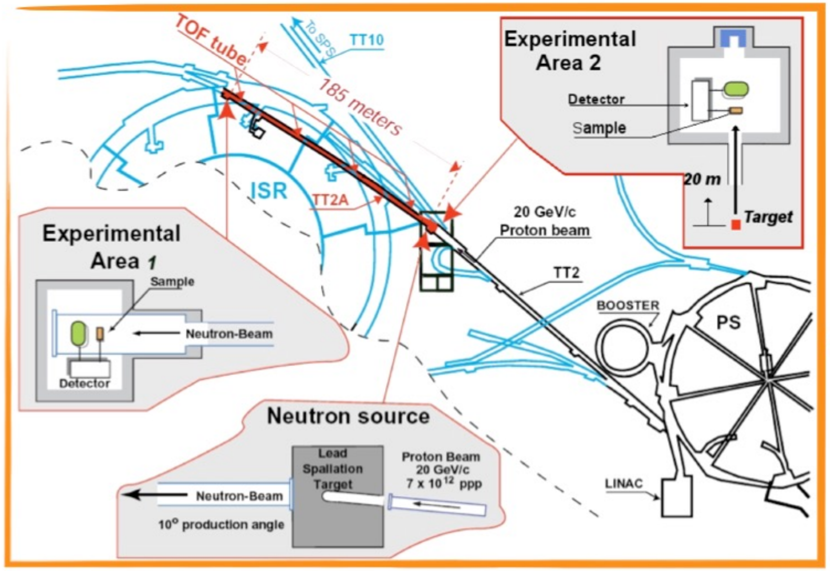


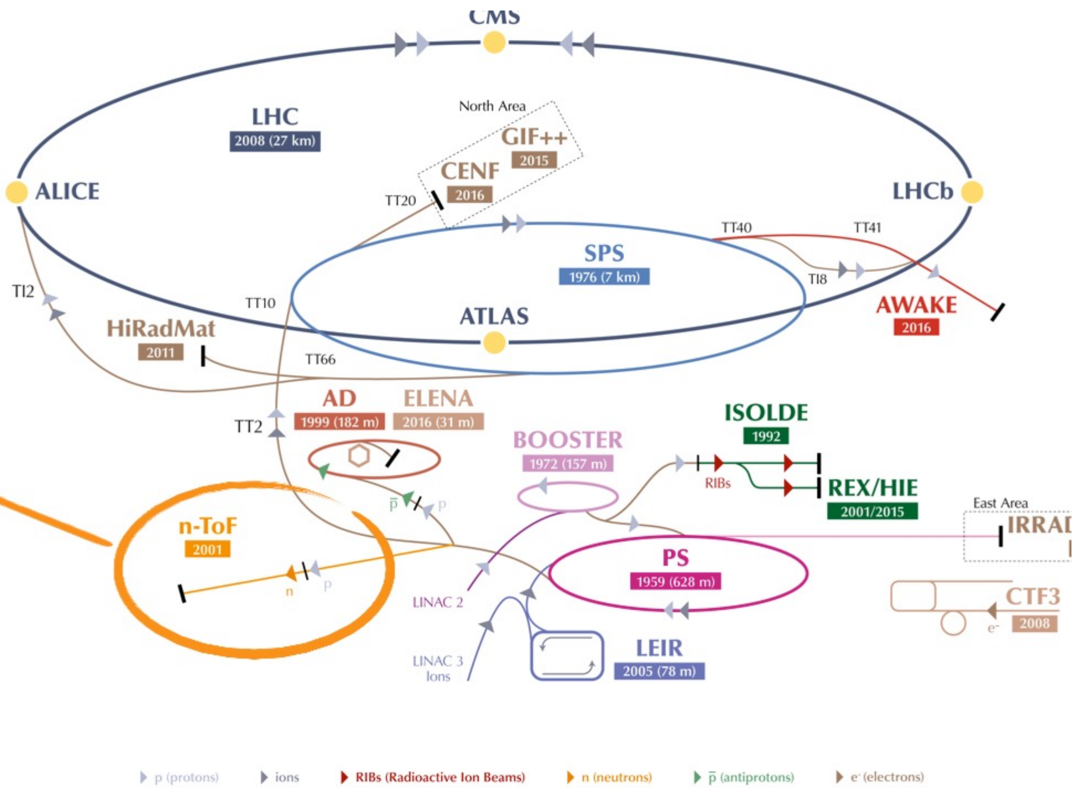
D.M Castelluccio (ENEA)
P. Console Camprini (ENEA)
A. Guglielmelli (ENEA)
A. Manna (Unibo)
C. Massimi (Unibo)
A. Mengoni (ENEA)
G. Vannini (INFN)
A. Ventura (INFN)

n_TOF facility

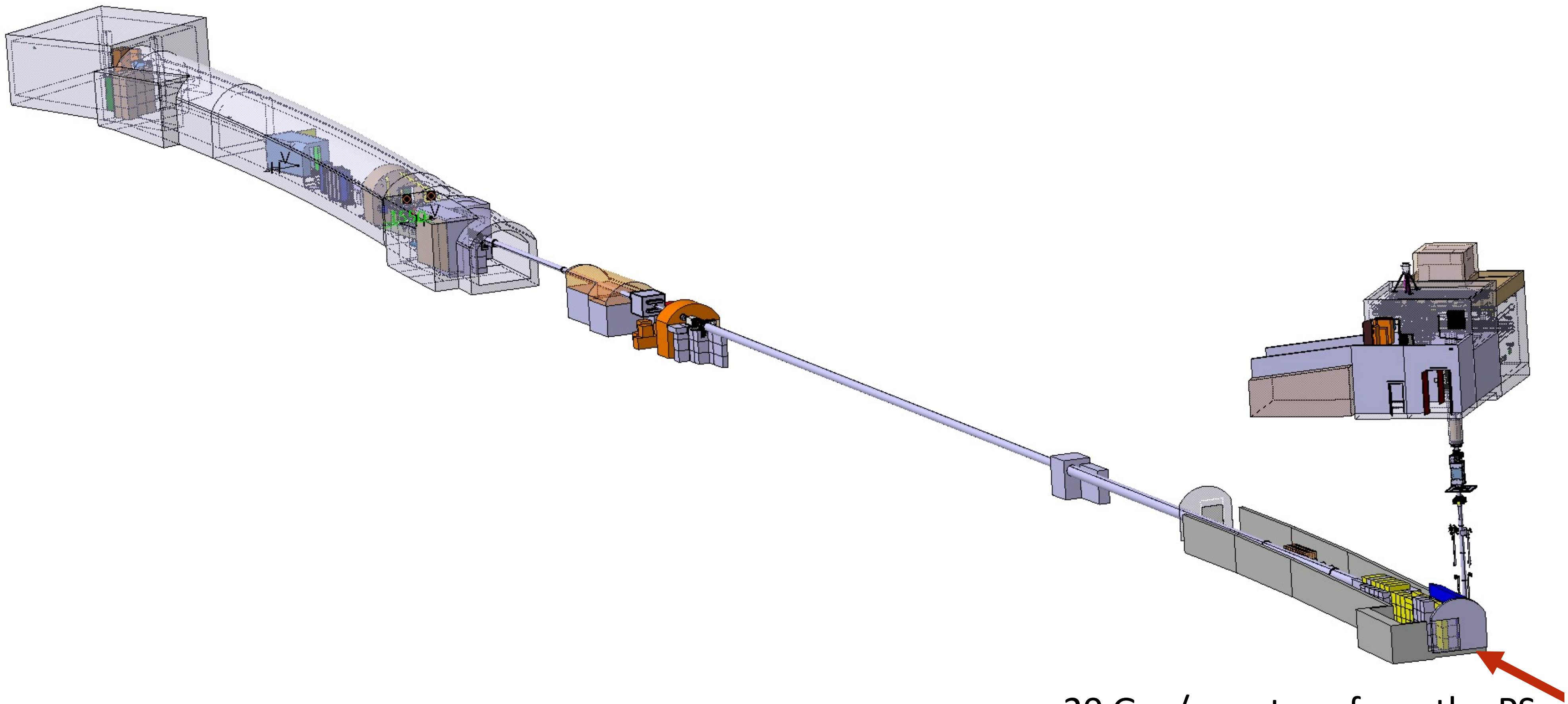
The features of the n_TOF facility are related to the PS proton beam:

high energy, high current, low duty cycle.

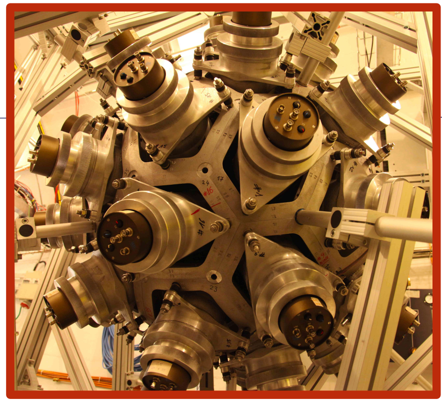


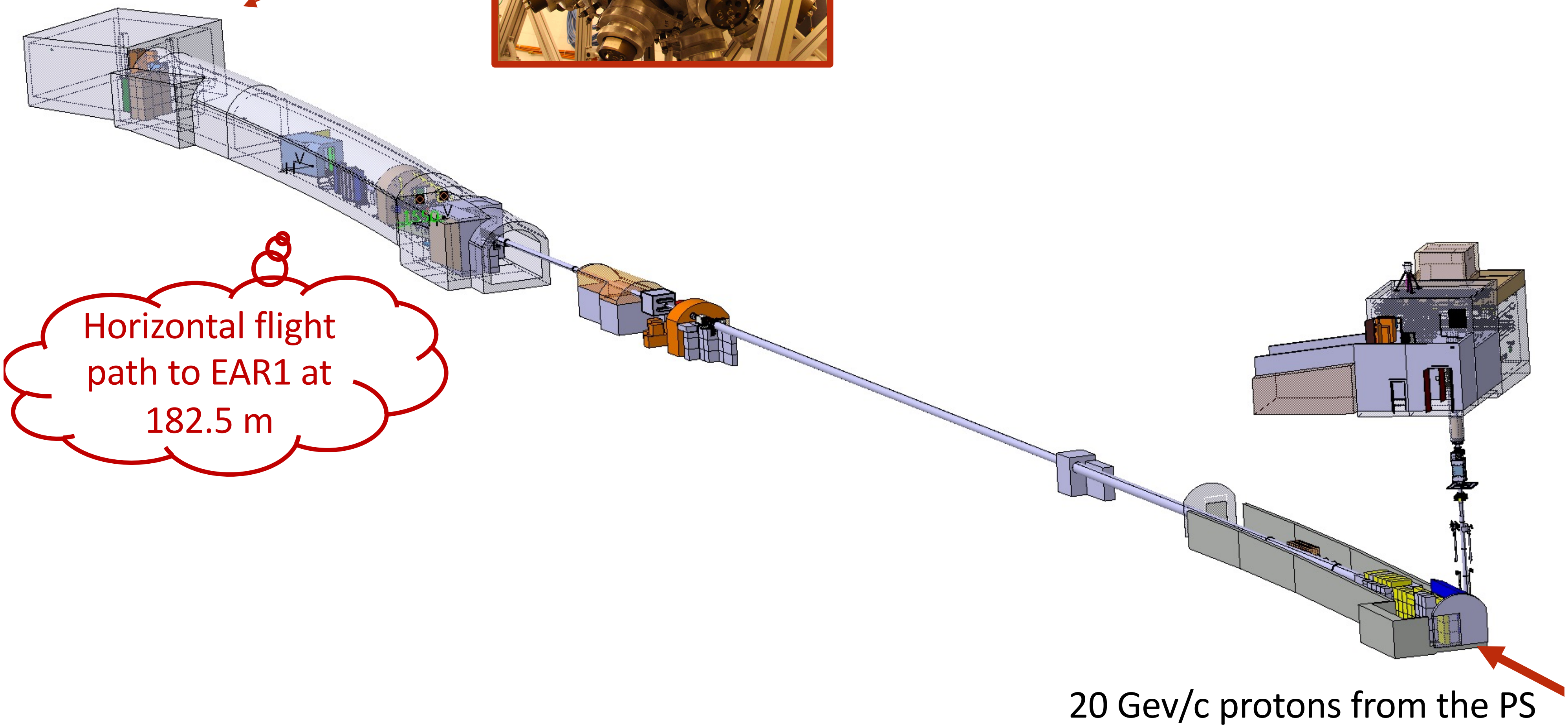


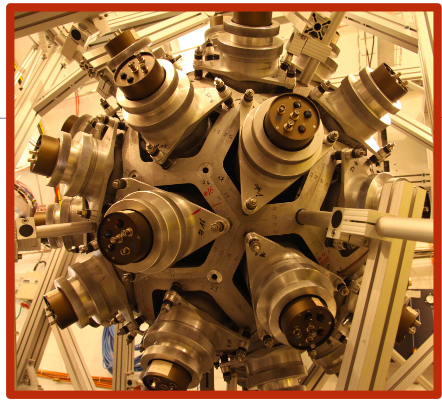
n_TOF facility

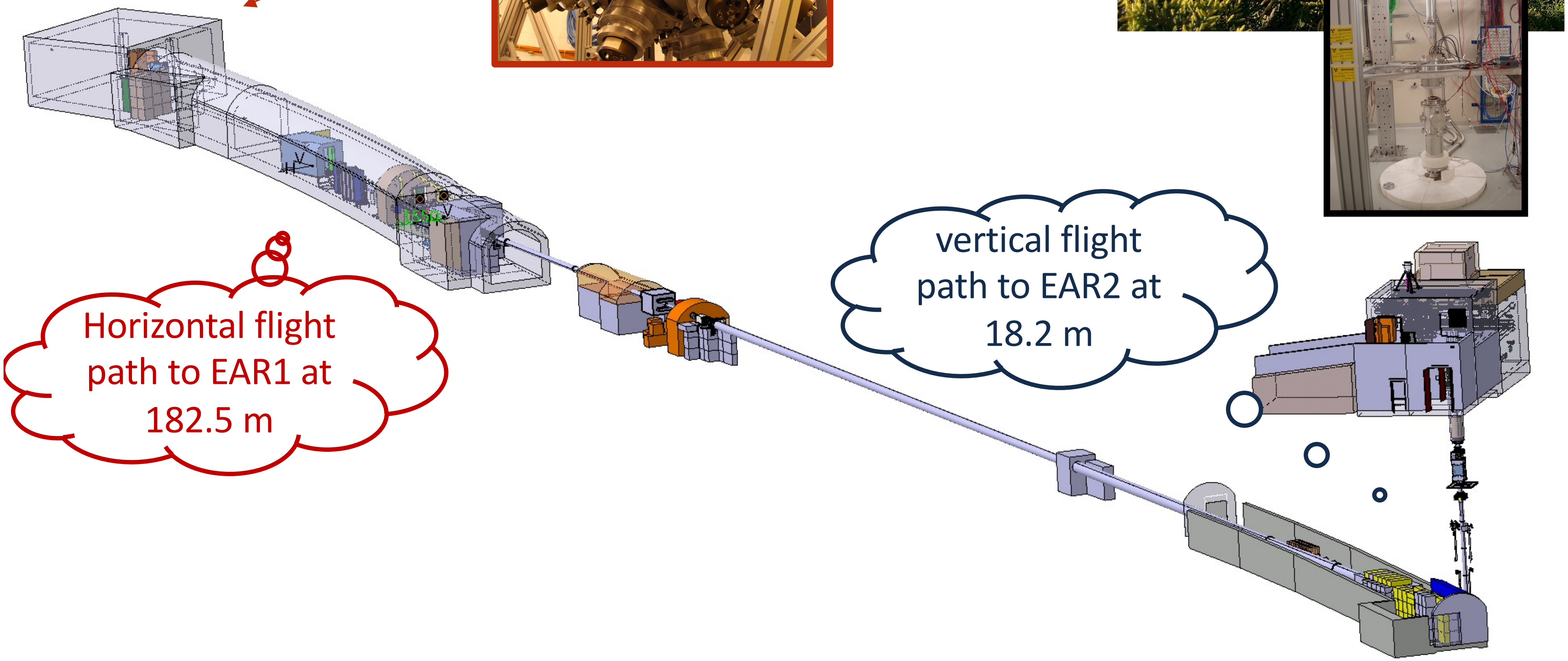


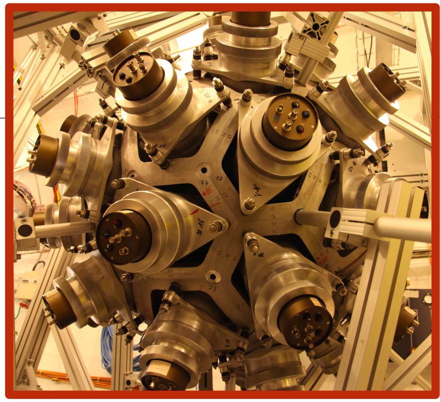
20 Gev/c protons from the PS

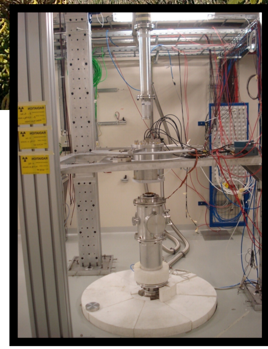


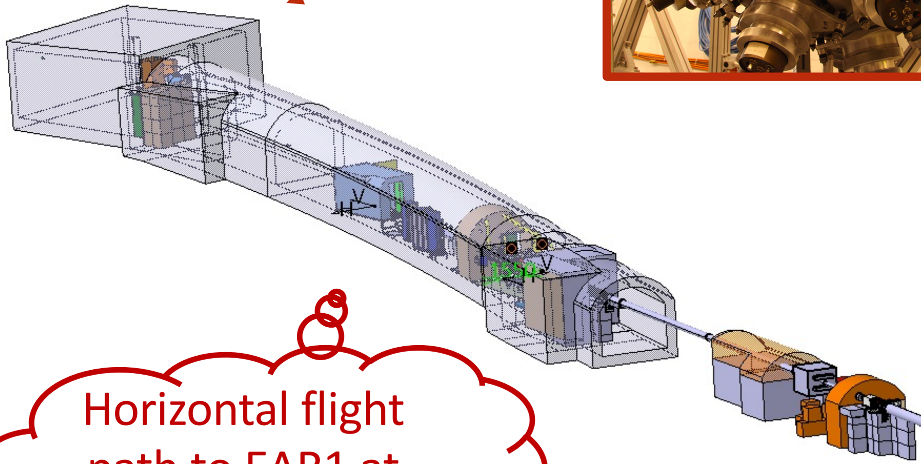

Horizontal flight path to EAR1 at 182.5 m
20 Gev/c protons from the PS

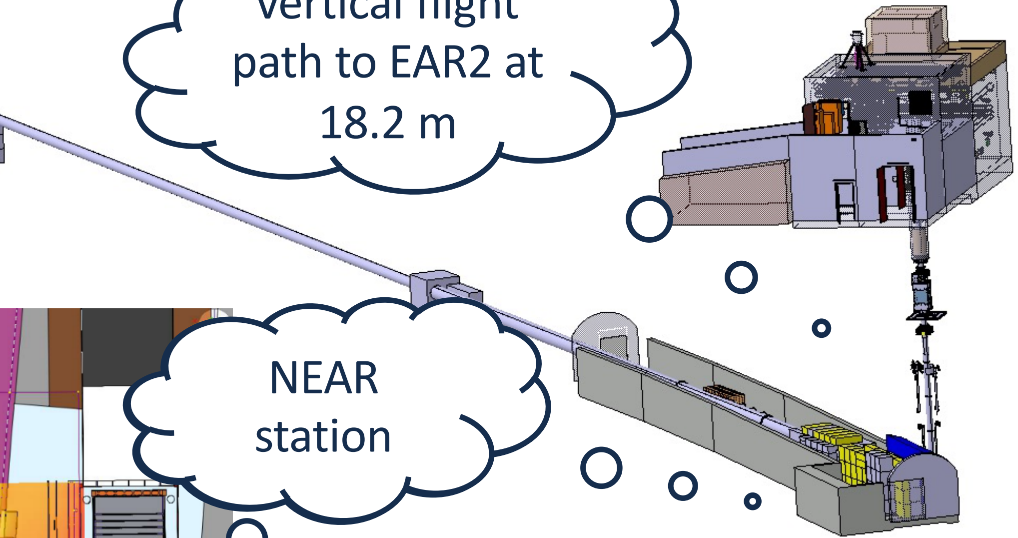



Horizontal flight path to EAR1 at 182.5 m
vertical flight path to EAR2 at 18.2 m
20 Gev/c protons from the PS







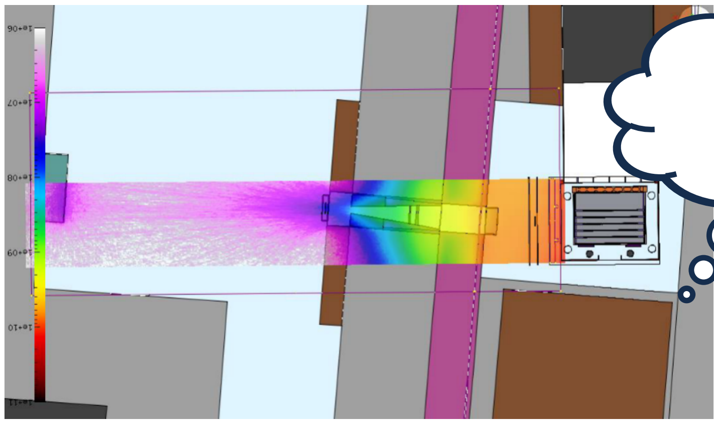


Horizontal flight path to EAR1 at 182.5 m

vertical flight path to EAR2 at 18.2 m

NEAR station

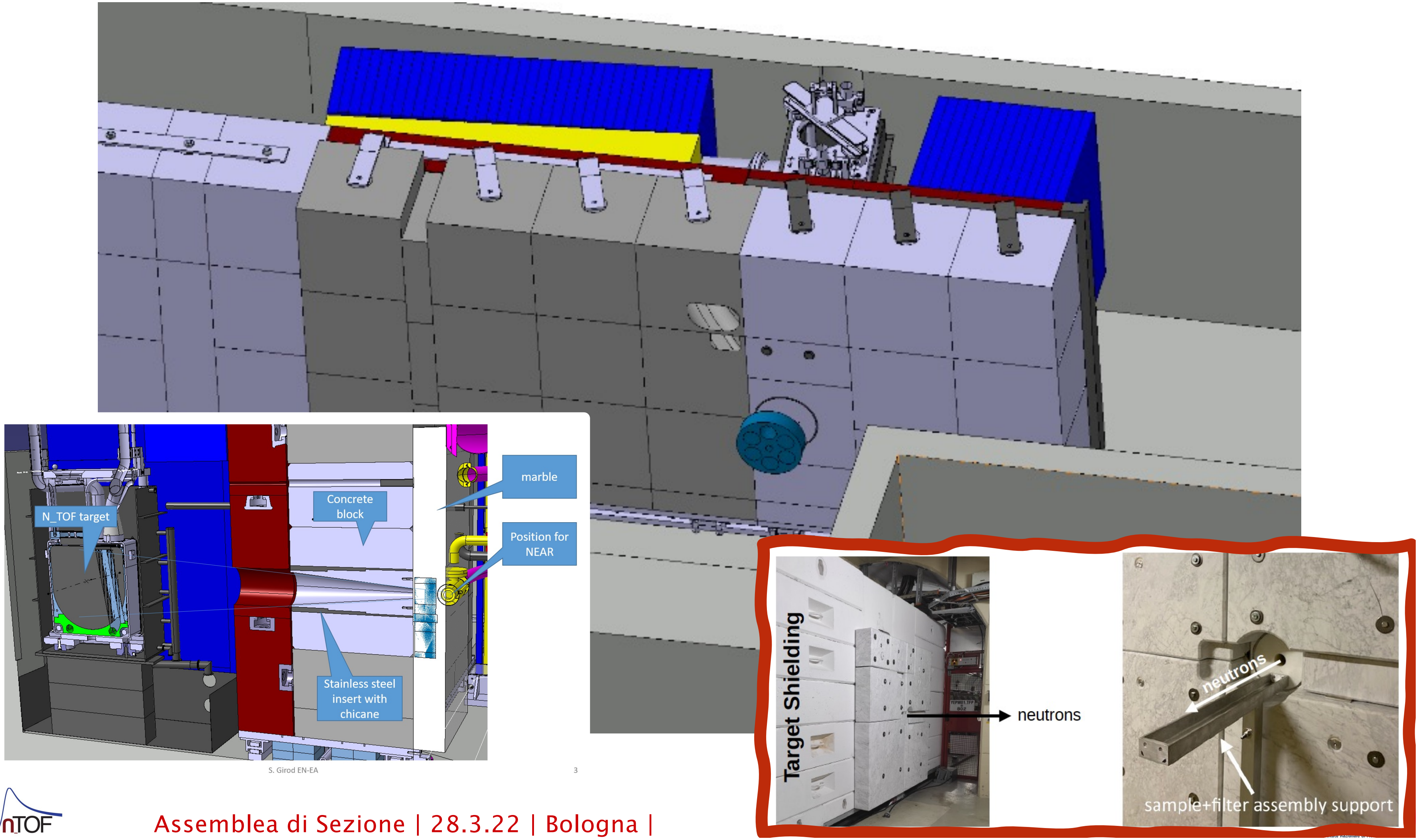
20 Gev/c protons from the PS



NEW ! ! !
commissioning
September 2021

NEAR

NEAR station: activation measurements on **rare isotopes** with **short half-life** (produced at CERN@ISOLDE or PSI). Also suitable as **irradiation station**



NEAR

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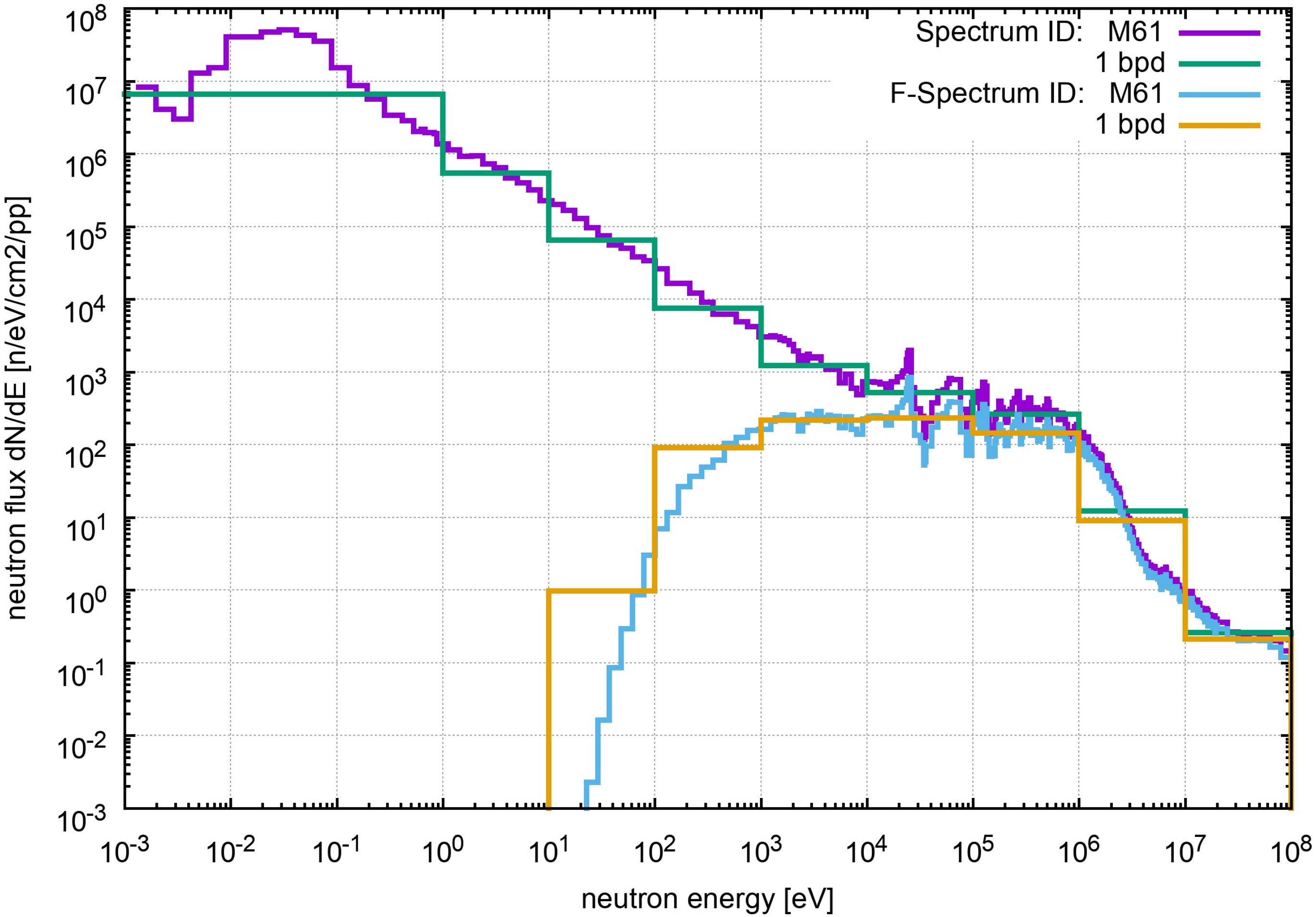
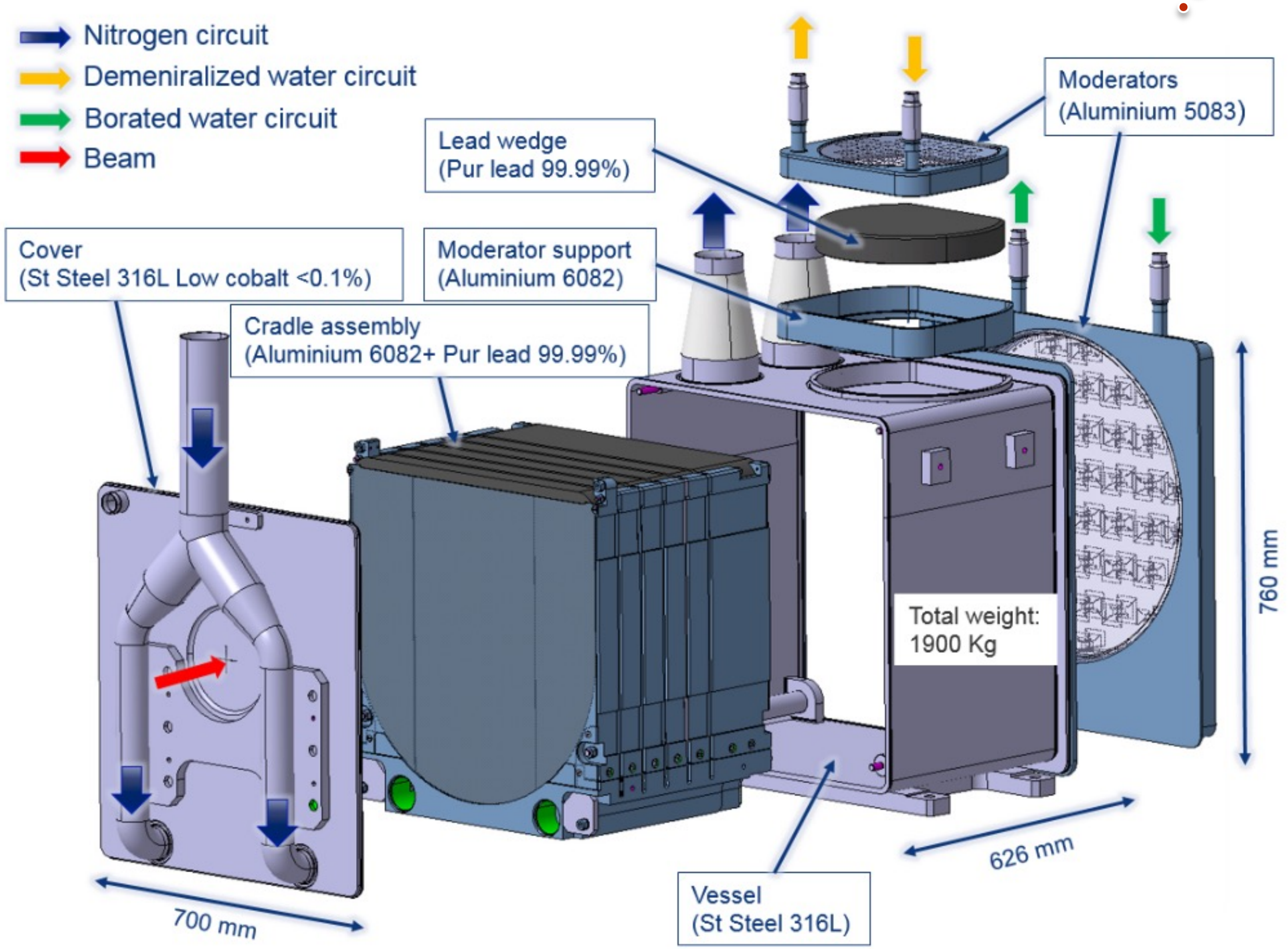


Neutron **FLUX**
@ NEAR station

Neutron energy range	n/cm²/pp
All energies	4.6×10^8
E_n<1 keV	0.2×10^8
1 keV<E_n<1 MeV	2.9×10^8
E_n>1 MeV	1.5×10^8

Spallation target #3

First beam
19.07.21



1550 Kg

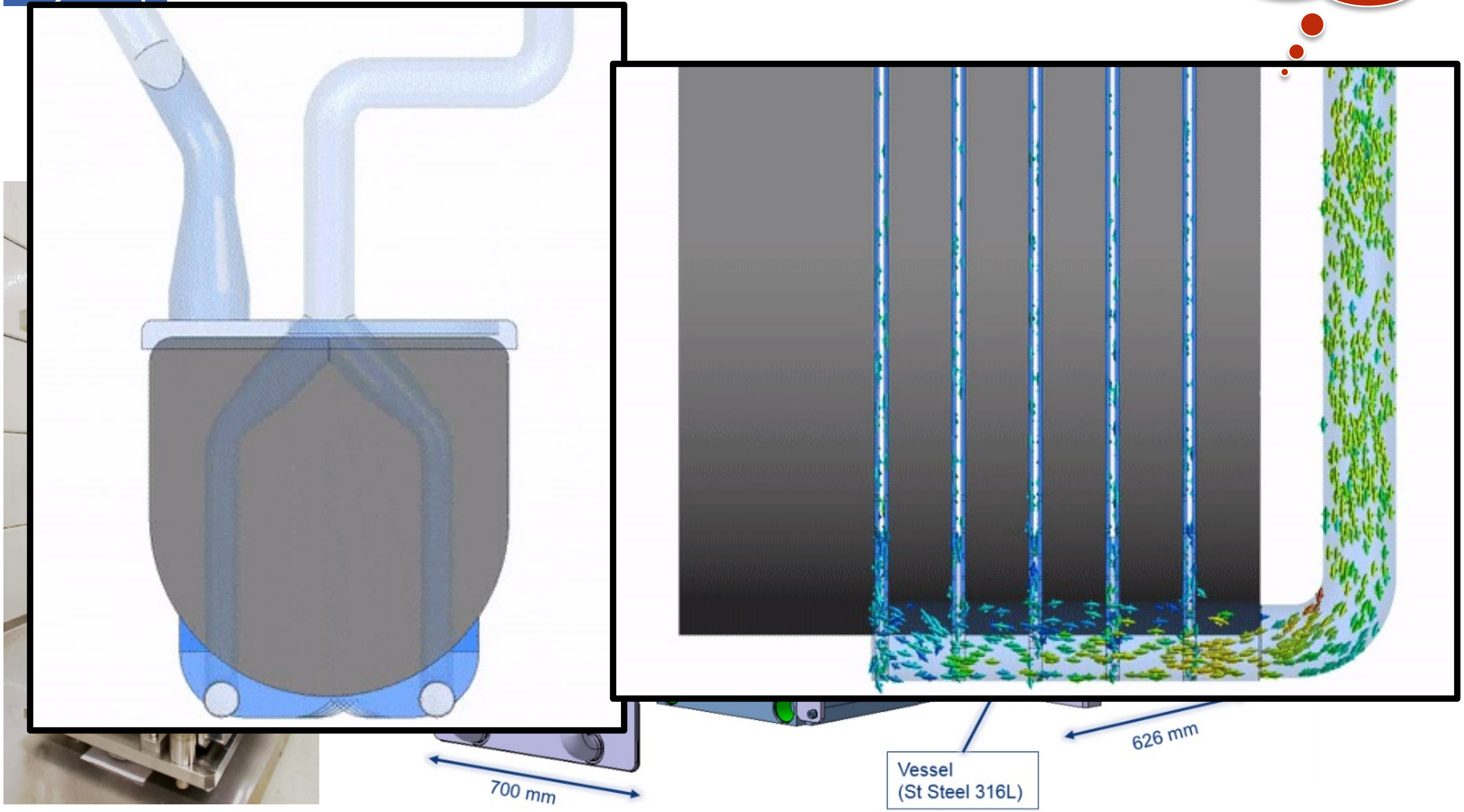
1x15cm + 5x5.0 cm Pb
64 x 62 x 46 cm

Moderator
H_2O + B

Cooling
N_2 pure (99.995%)

Spallation target #3

First beam
19.07.21



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n_TOF facility

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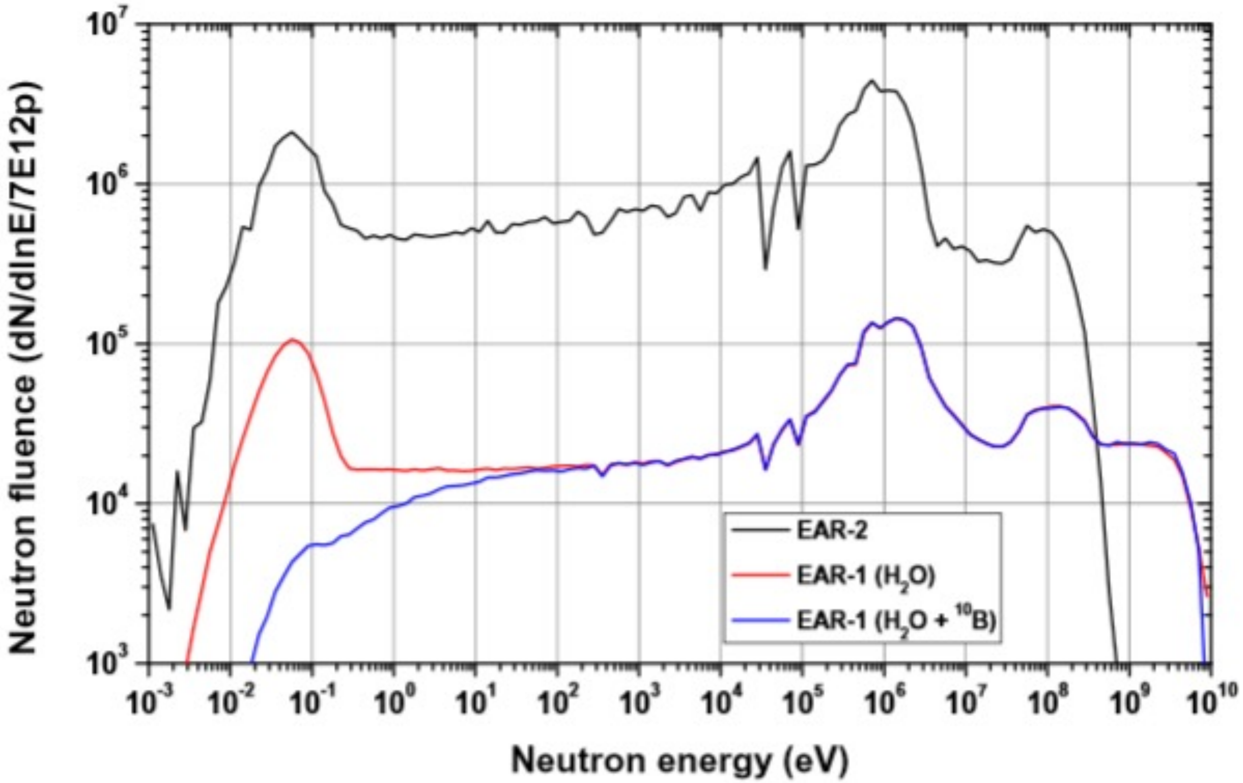


Neutron energy
10 meV < E_n < 1 GeV

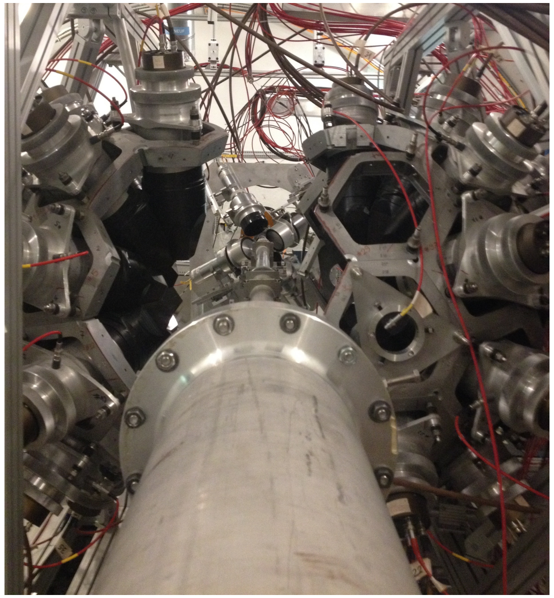
Neutron flux
EAR2 10^6 n/cm^2/pulse
EAR1 10^5 n/cm^2/pulse

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

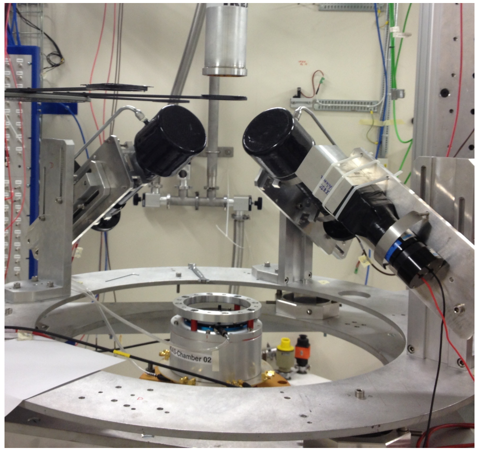
Detectors

(n,γ) reactions

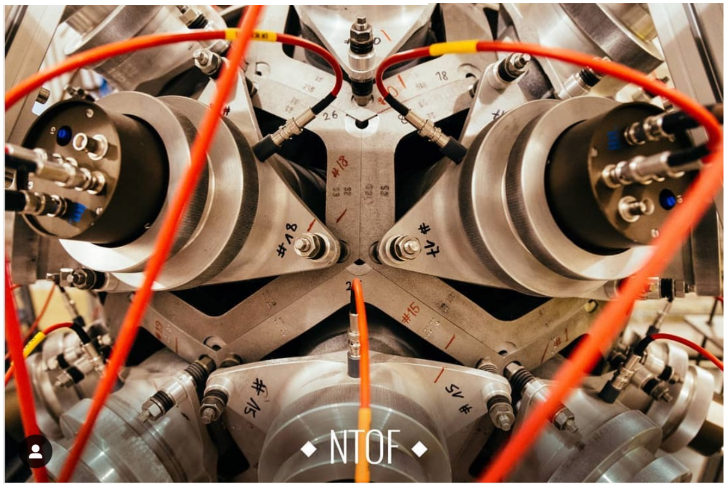
Total Absorption Calorimeter (TAC) BaF_2



C_6D_6 liquid scintillators



infn_insights •

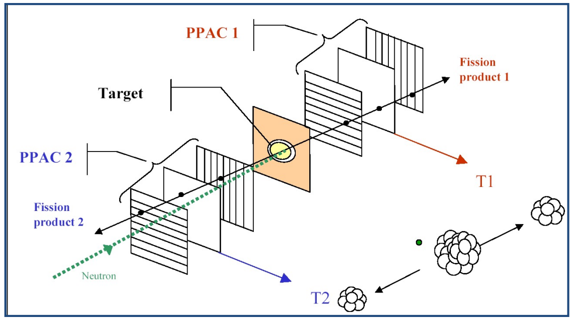


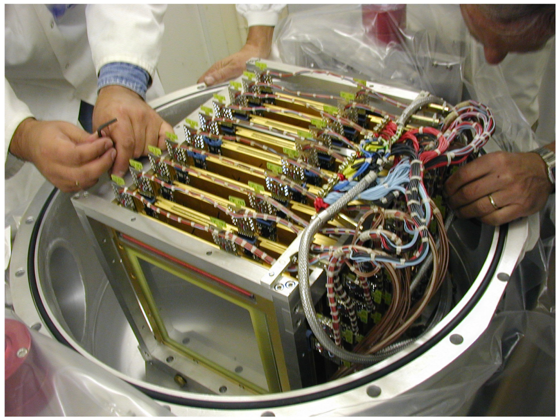
Relevant INFN contribution: test, maintenance and optimization of the capture detectors

Detectors

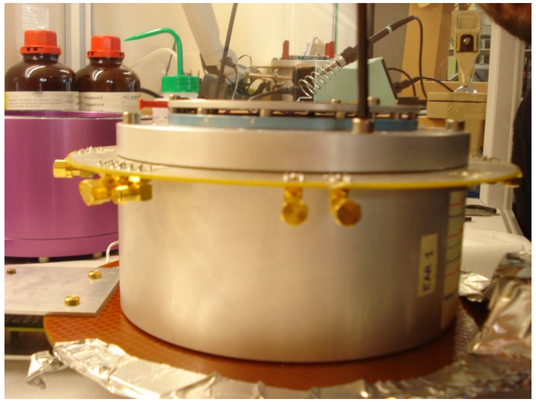
Fission reactions

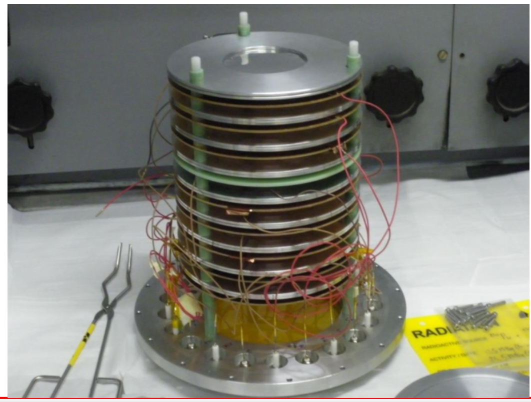
Parallel Plate Avalanche Chamber (PPAC)



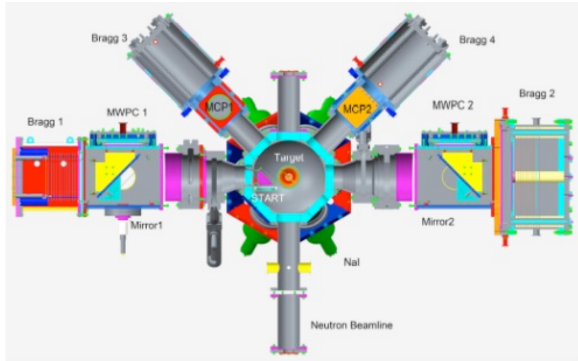


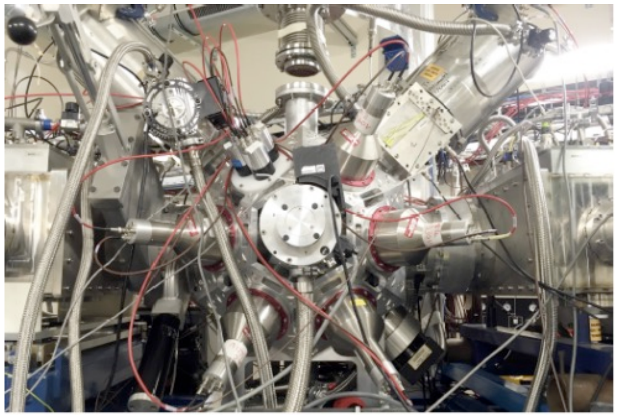
MicroMegas





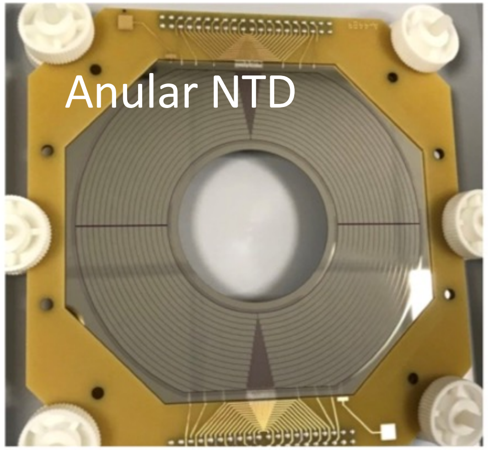
STEFF





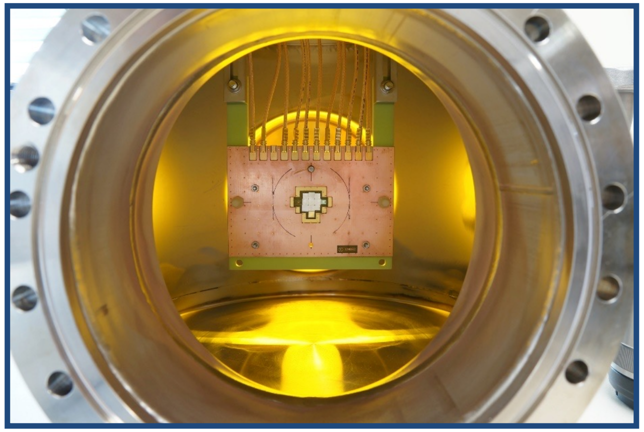
Setup based on Si detectors for high accuracy measurements (EPJ A front page) developed by LNS

Detectors

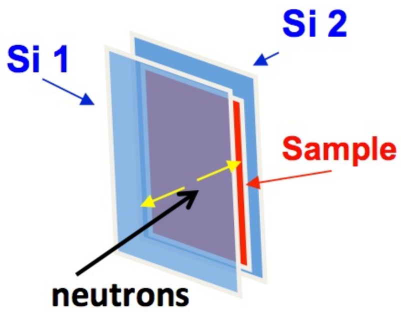


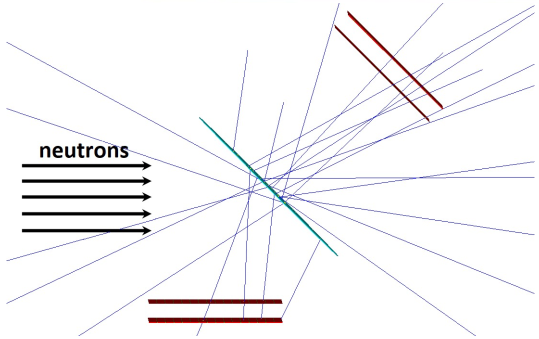
(n,cp) reactions

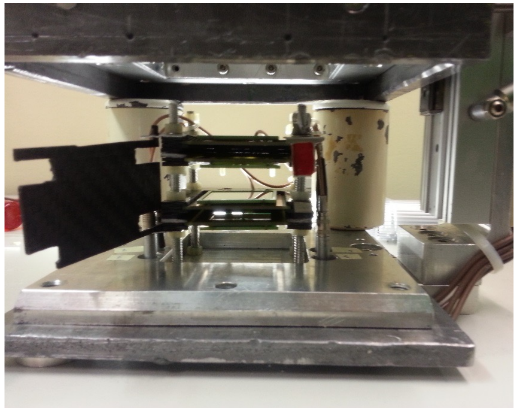
Diamond detectors

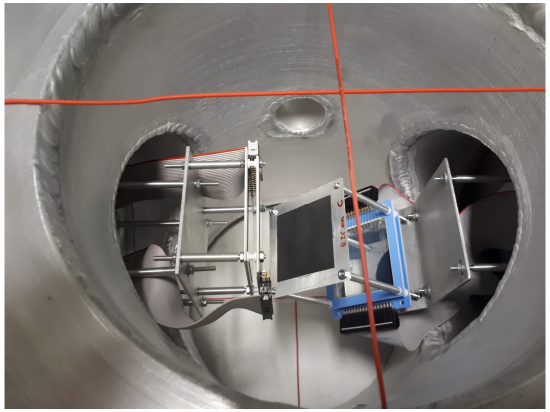


Silici



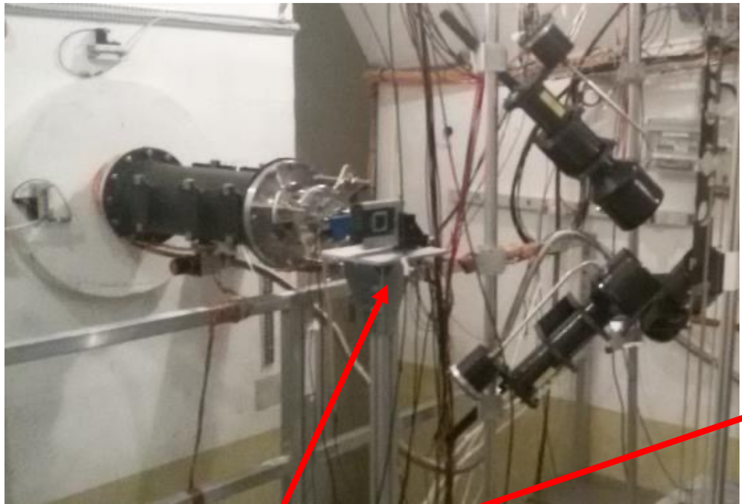


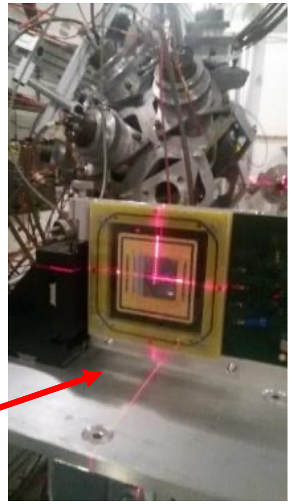


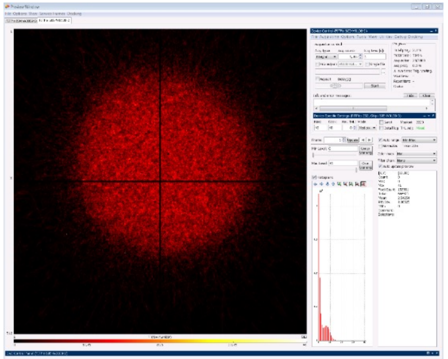


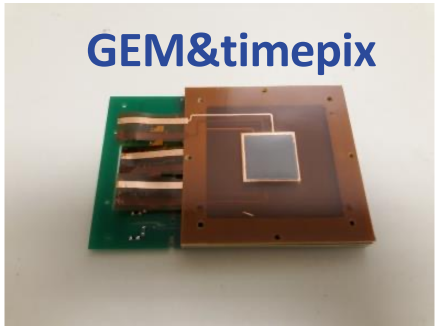
Setup for ^{7}Be(n,p), ^{7}Be(n,α) e la ^{12}C(n,p) developed by INFN

Detectors

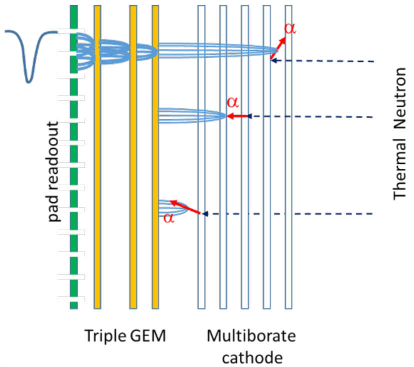


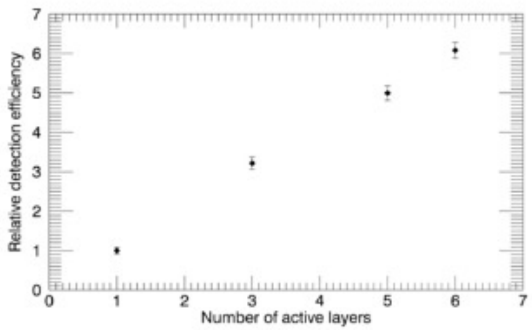


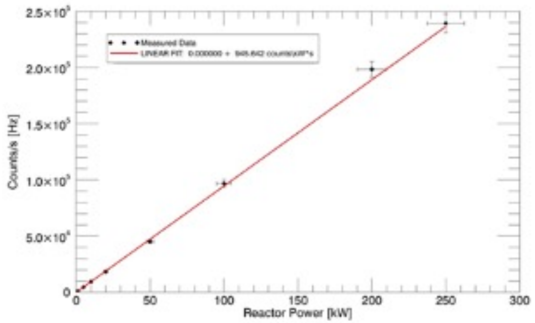




Quad-Timepixes used to find neutron beam line.
Borated GEM (High efficiency th. neutron detector) in cooperation CERN - ESS - INFN

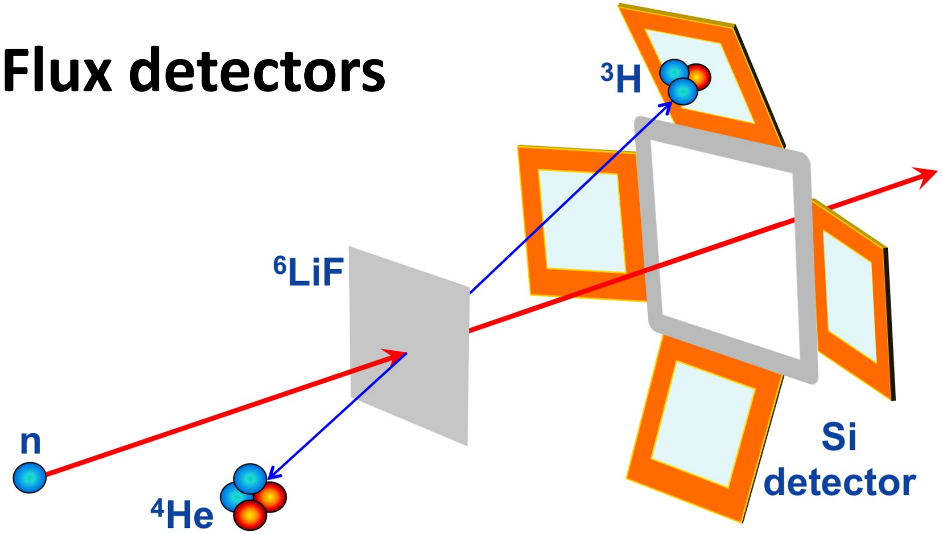




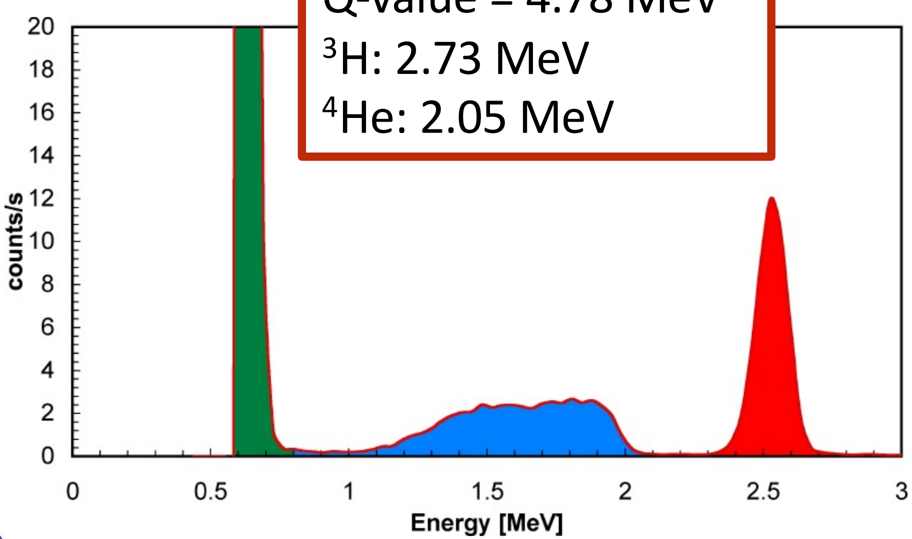


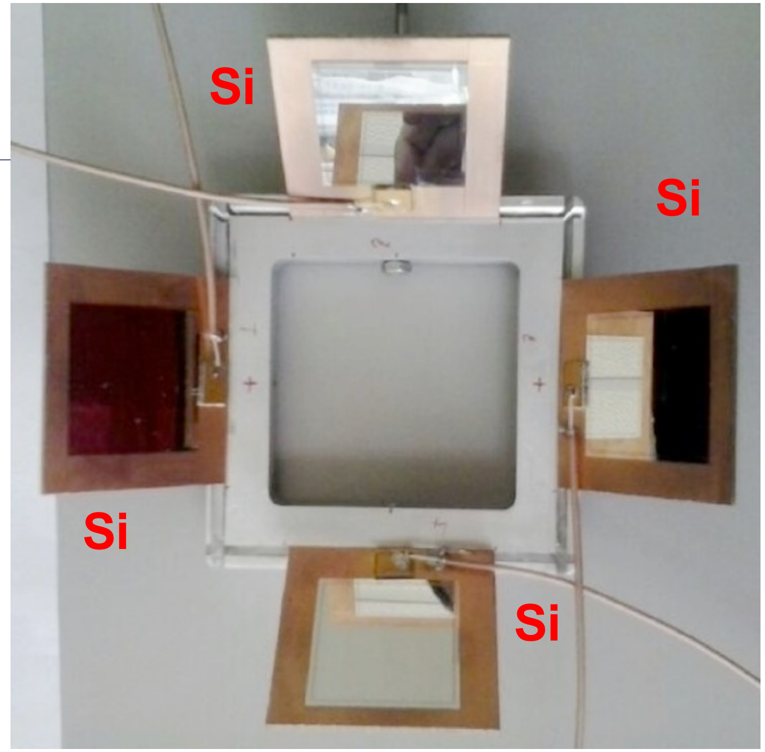
Detectors

Flux detectors

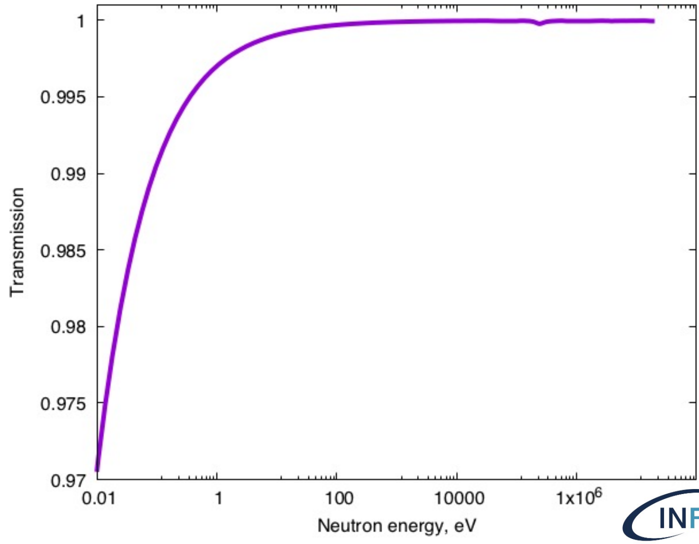


n+^{6}Li → ^{3}H + ^{4}He
Q-value = 4.78 MeV
^{3}H: 2.73 MeV
^{4}He: 2.05 MeV



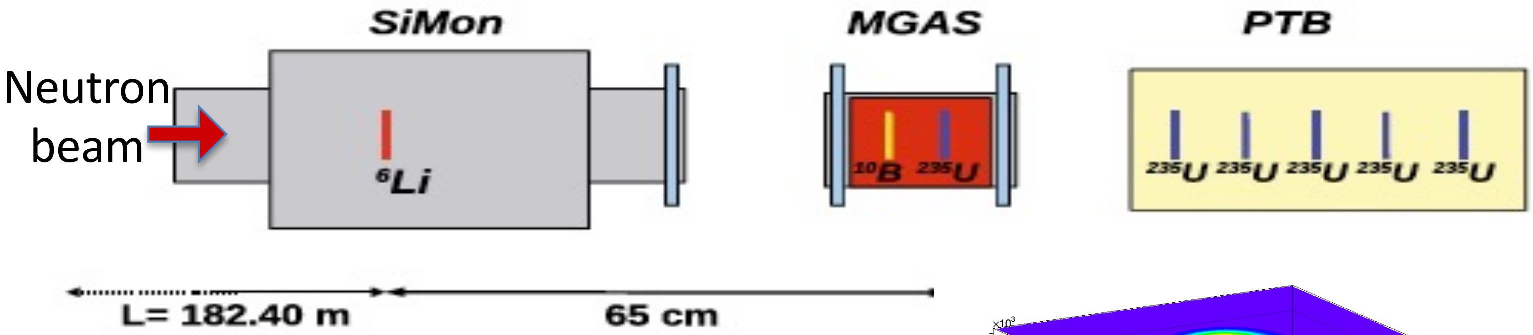


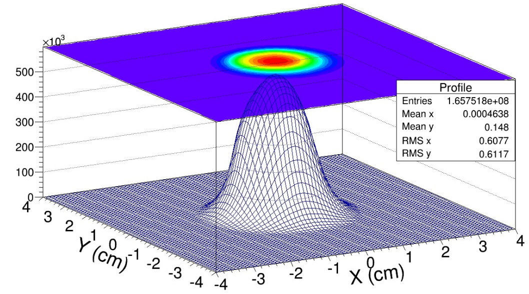
MSX09-3007 3 cm × 3 cm,
300 µm thick > particle range

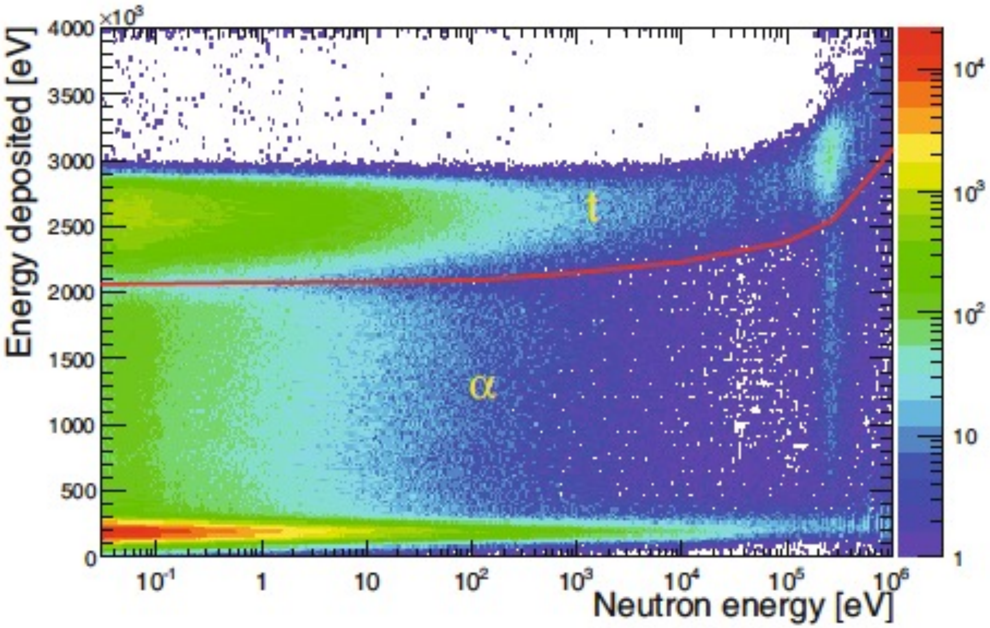


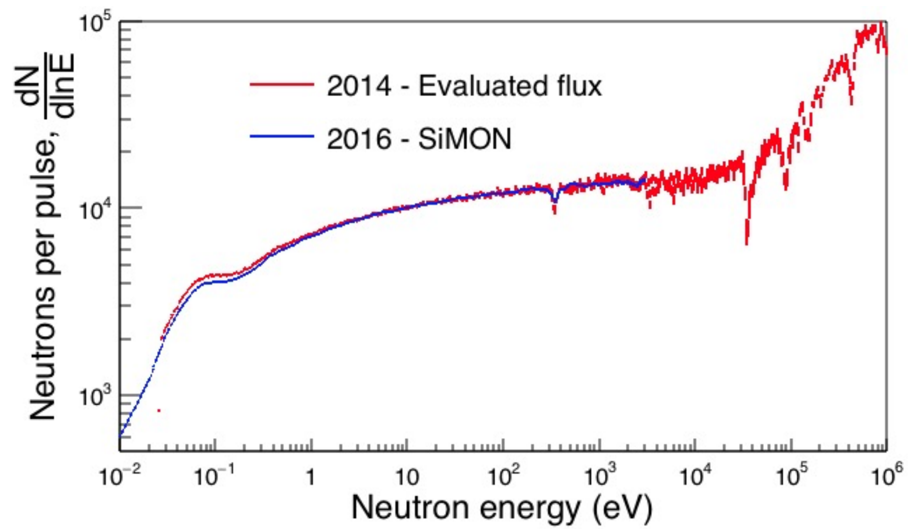
Beam characterizations

3 different detectors based on 3 neutron standards

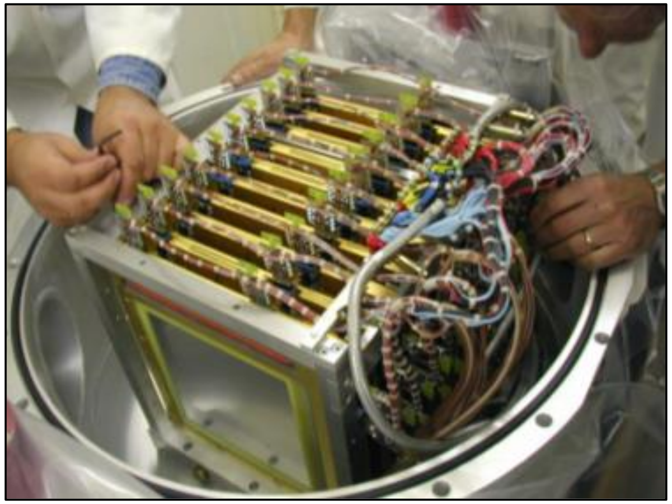




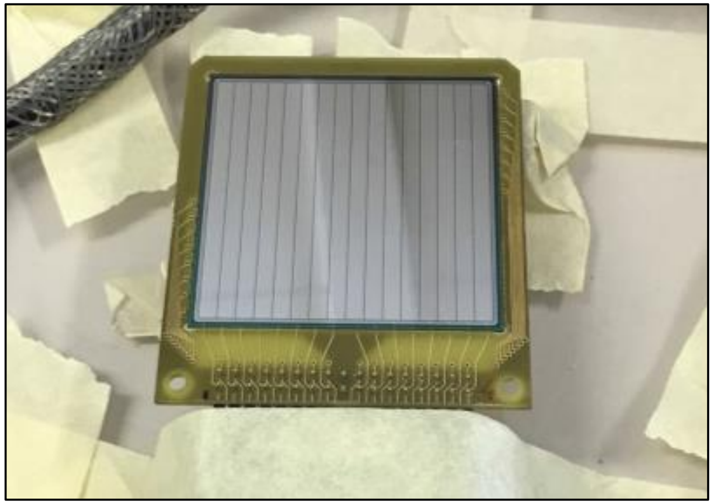




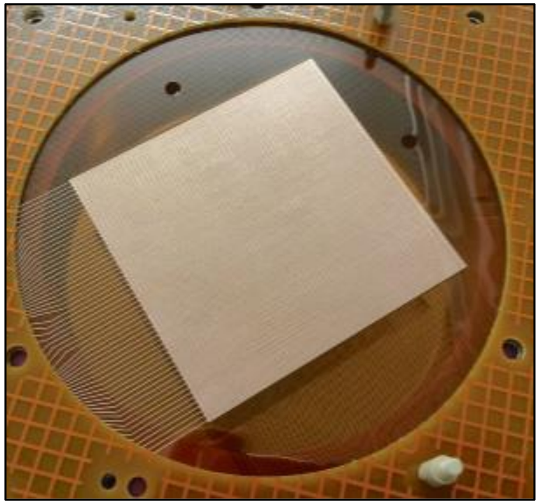
Beam characterizations



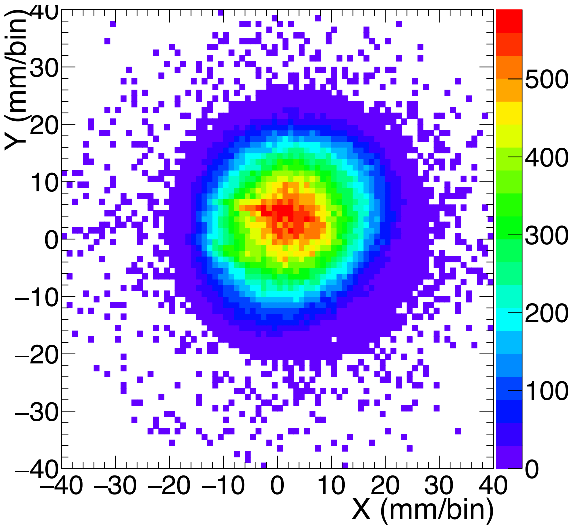
PPAC

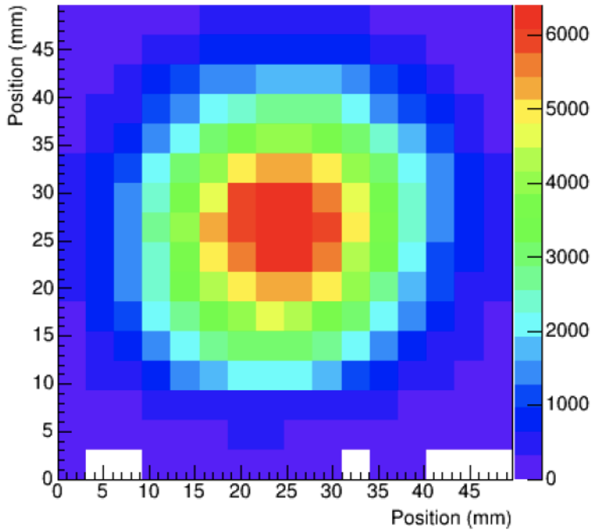


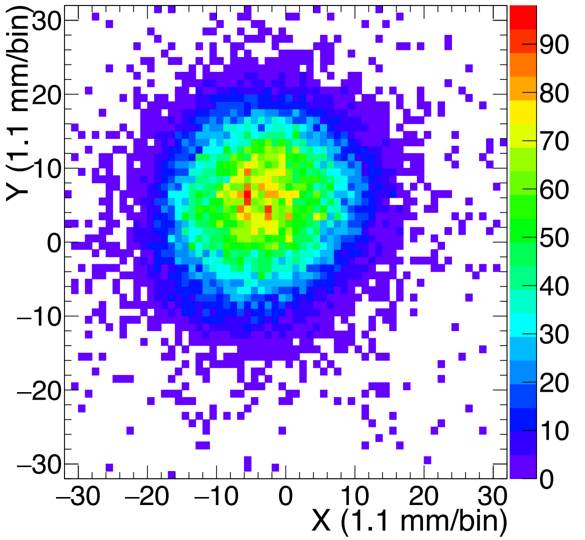
SiMon2D



XY MicroMegas

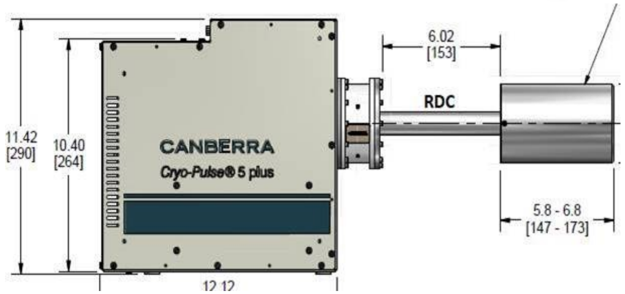


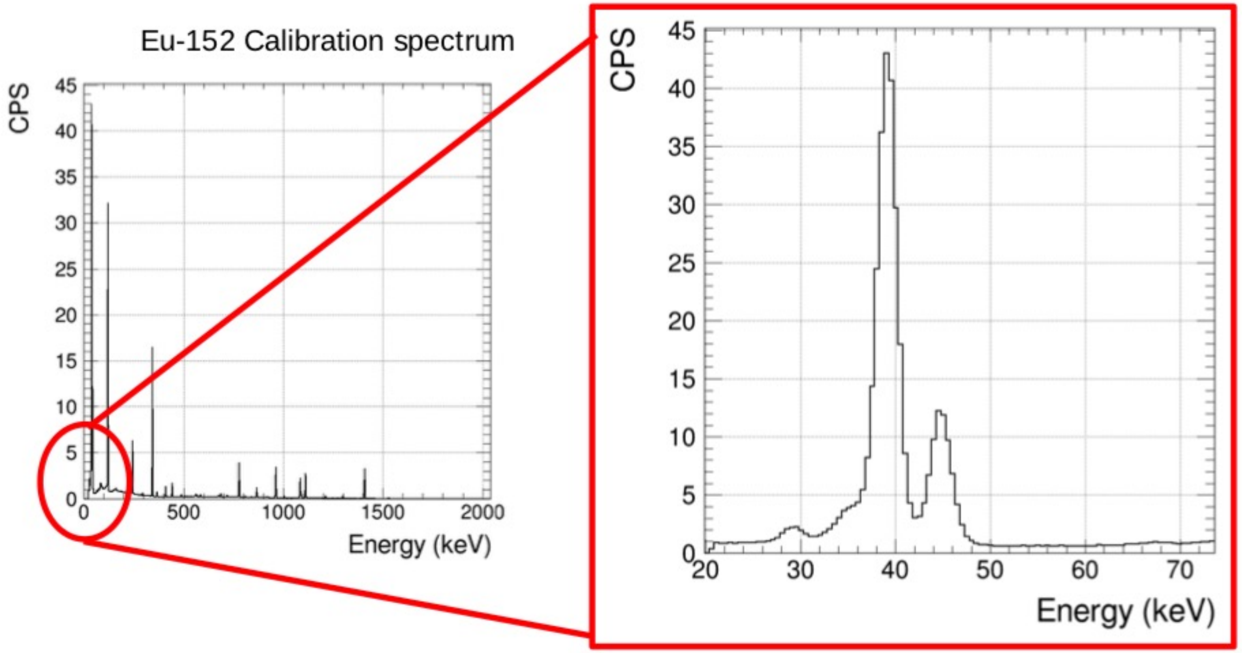




HPGe for NEAR

Measurement station equipped with HPGe

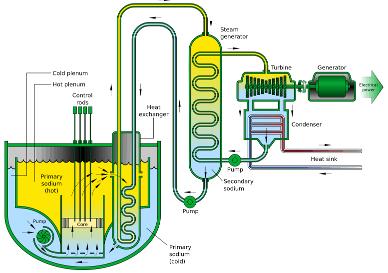




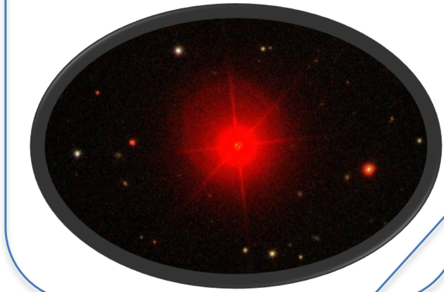
ACTIVITIES

Big Bang nucleosynthesis

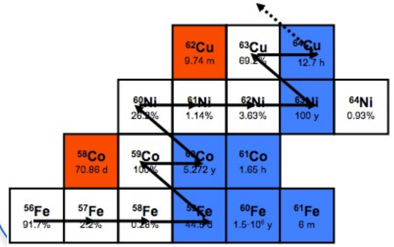
Capture cross section technologies



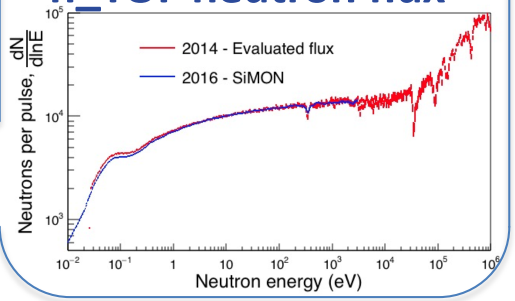
Neutron source in Red Giants stars



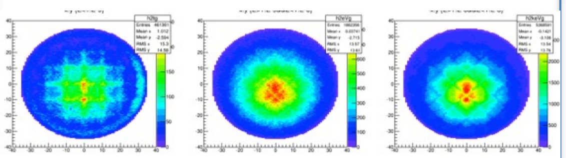
s process: Nucleosynthesis of heavy elements



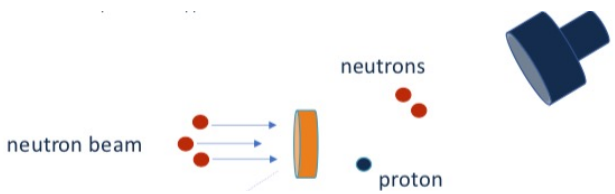
Characterization of the n_TOF neutron flux



MC Study of the n_TOF spallation source

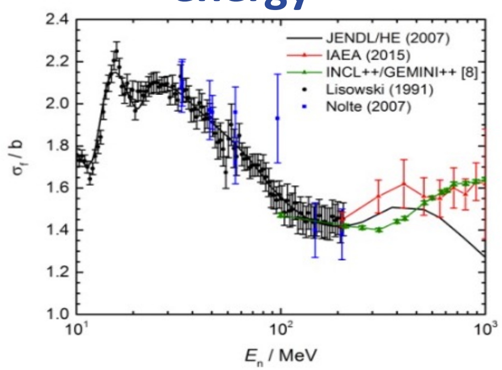


neutron – neutron scattering length

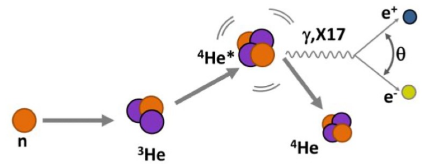


COLLABORATION with FOOT

Fission at intermediate energy



New Physics: Hunting the X17 boson



Interest

Thesis 2021:

- PhD 1

- Master 1

- Bachelor 2

Thesis

2017	3
2018	
2019	2
2020	1
2021	3

Contact for thesis:

- ENEA (→ NewCleo)

- Laboratorio per l'Energia Nucleare Applicata (LENA)

- Transmutex

n_TOF @ BO

- ✓ Richieste ai servizi limitate (… e mai programmate)
  - ✧ → **risposta sempre pronta e soddisfacente**

GRAZIE !

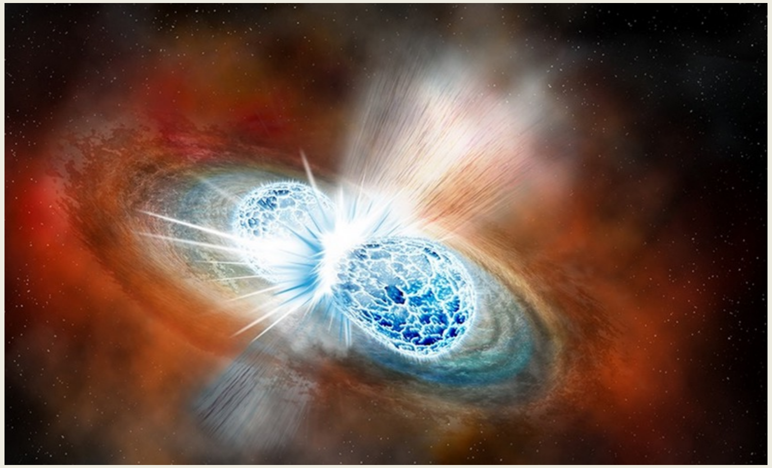
- ✓ Prezioso il supporto del **CNAF** per il calcolo

- ✓ **Per il futuro prevediamo richieste maggiori per lo sviluppo del rivelatore di neutroni in collaborazione con FOOT**

Backup slides

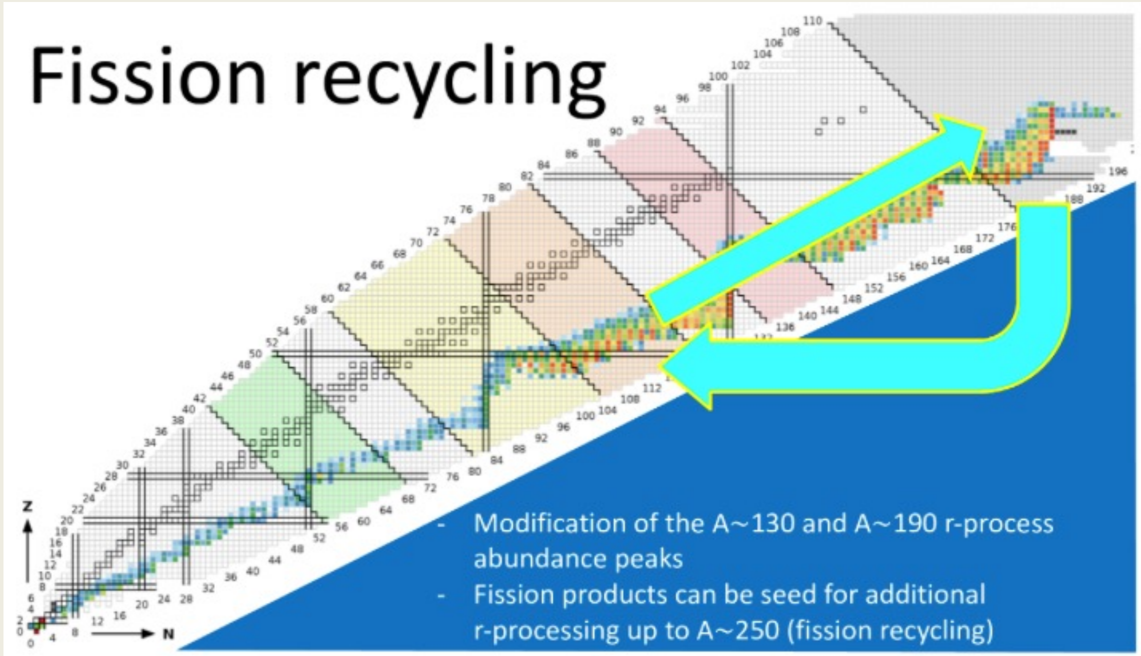
Conclusion / future

Neutron Star Merger – r process



r-process contribution to observed elemental abundances?

r process = Solar yields – s process



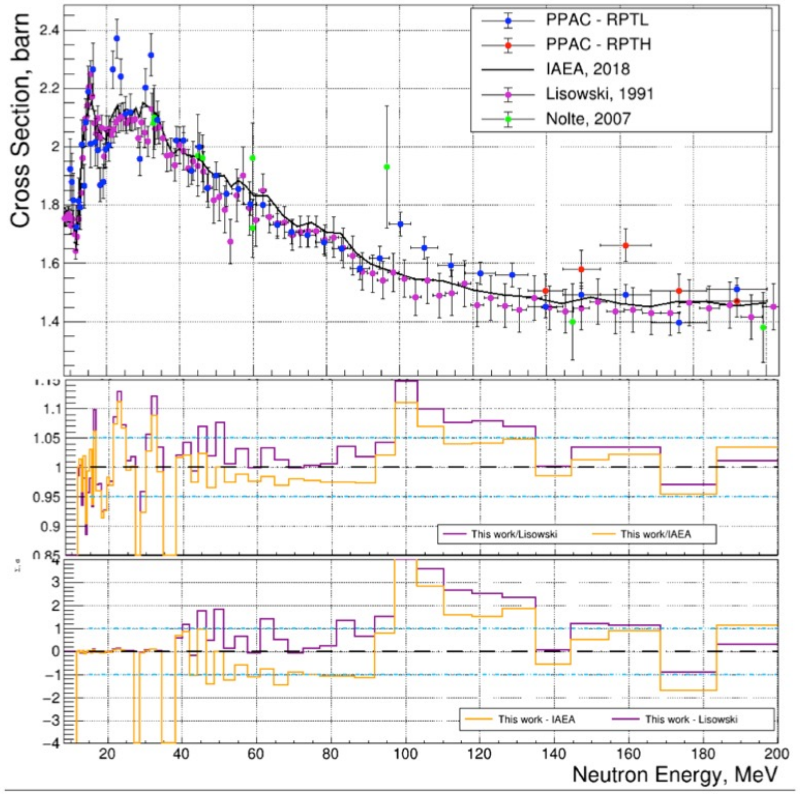
Improve the **physics** of both the **s-process** (neutron capture) and the **r-process** (fission)

Backup slides

HIGLIGHTS FISICA

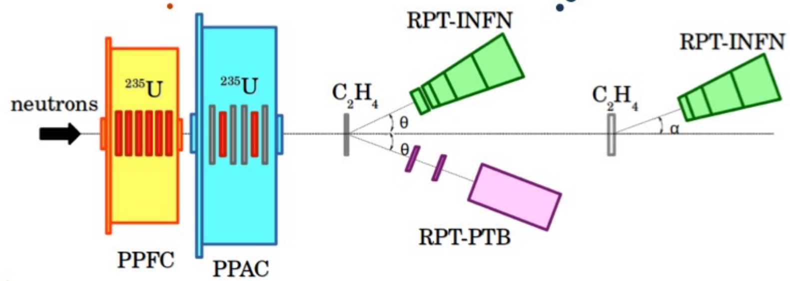
n_TOF

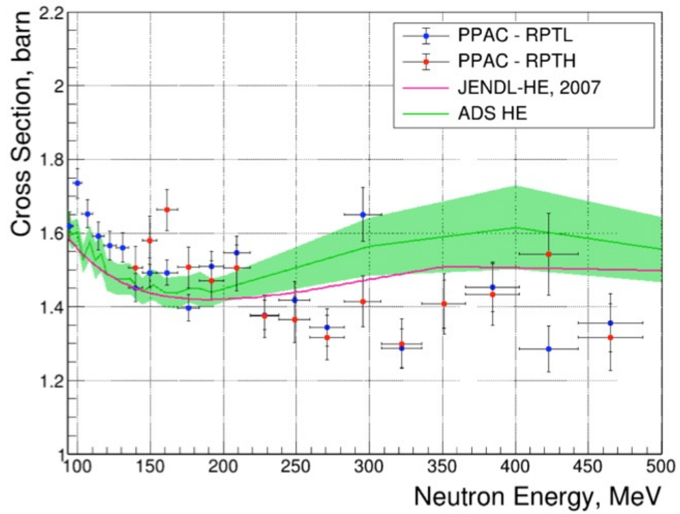
$^{235}U(n,f)$



Fission detectors

Flux detectors
n-p scattering

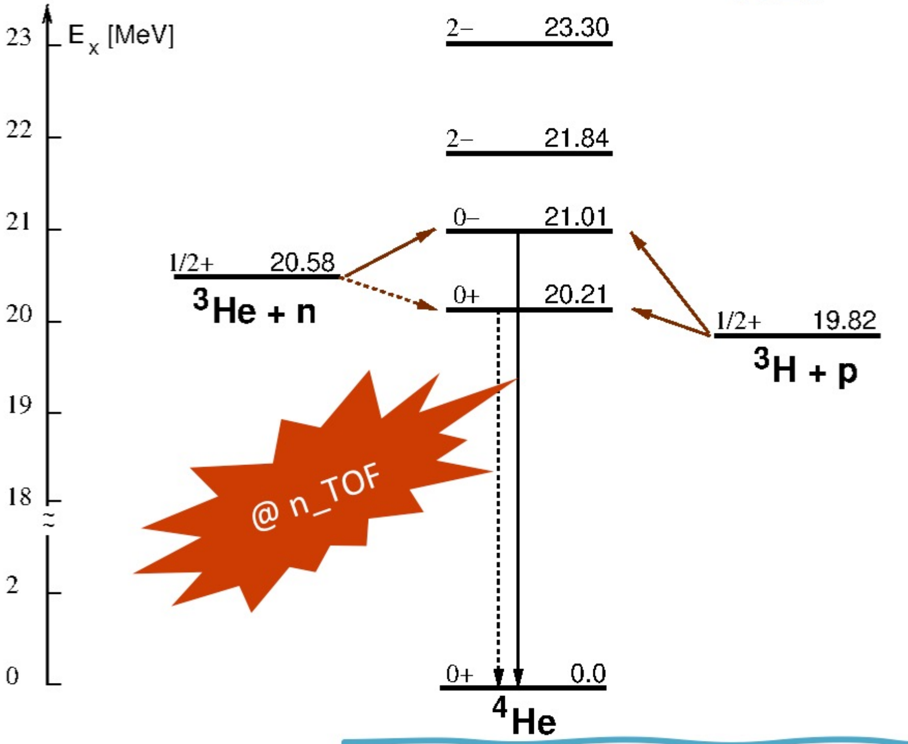


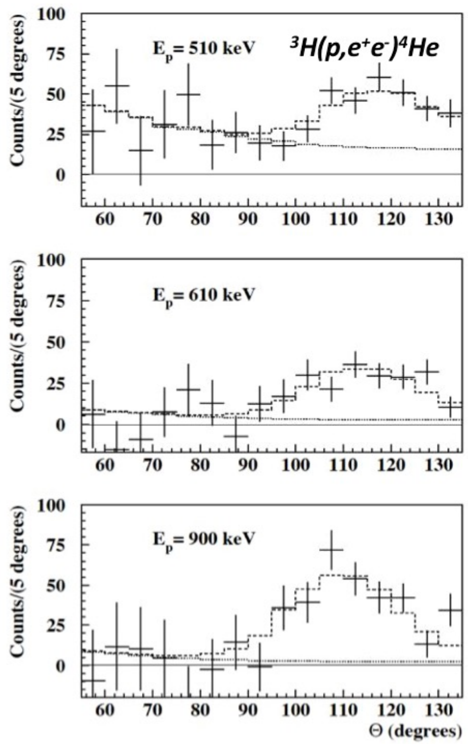


PhD Alice Manna

Backup slides

X17





Krasznahorkay, A.J.; et al.: "*Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson*". *Physical Review Letters*. **116** (42501): 042501 (2016).

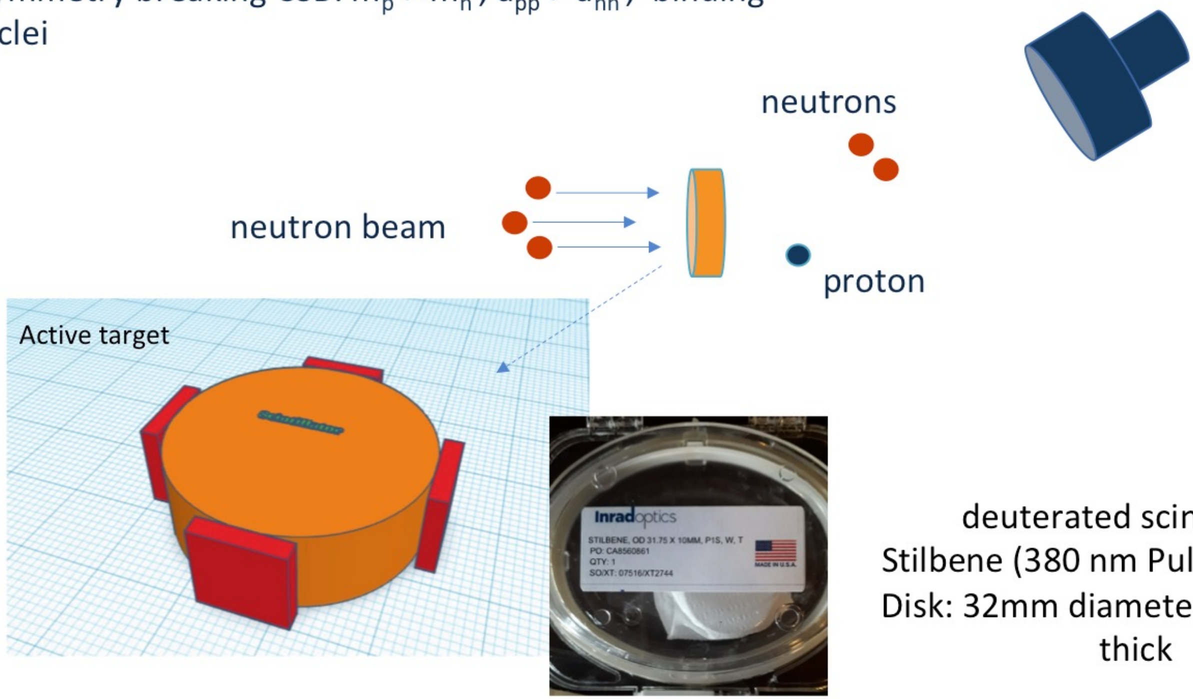
Krasznahorkay, A.J.; et al.: "New evidence supporting the existence of the hypothetic X17 particle". arXiv:1910.10459v1 [nucl-ex] (23 October 2019), arXiv:2104.10075 (20 April 2021)

$e^{+}e^{-}$ pairs created by the forbidden M0 transitions from the two 0^{-} states to the ground-state

Backup slides

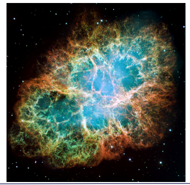
Neutron neutron scattering lenght

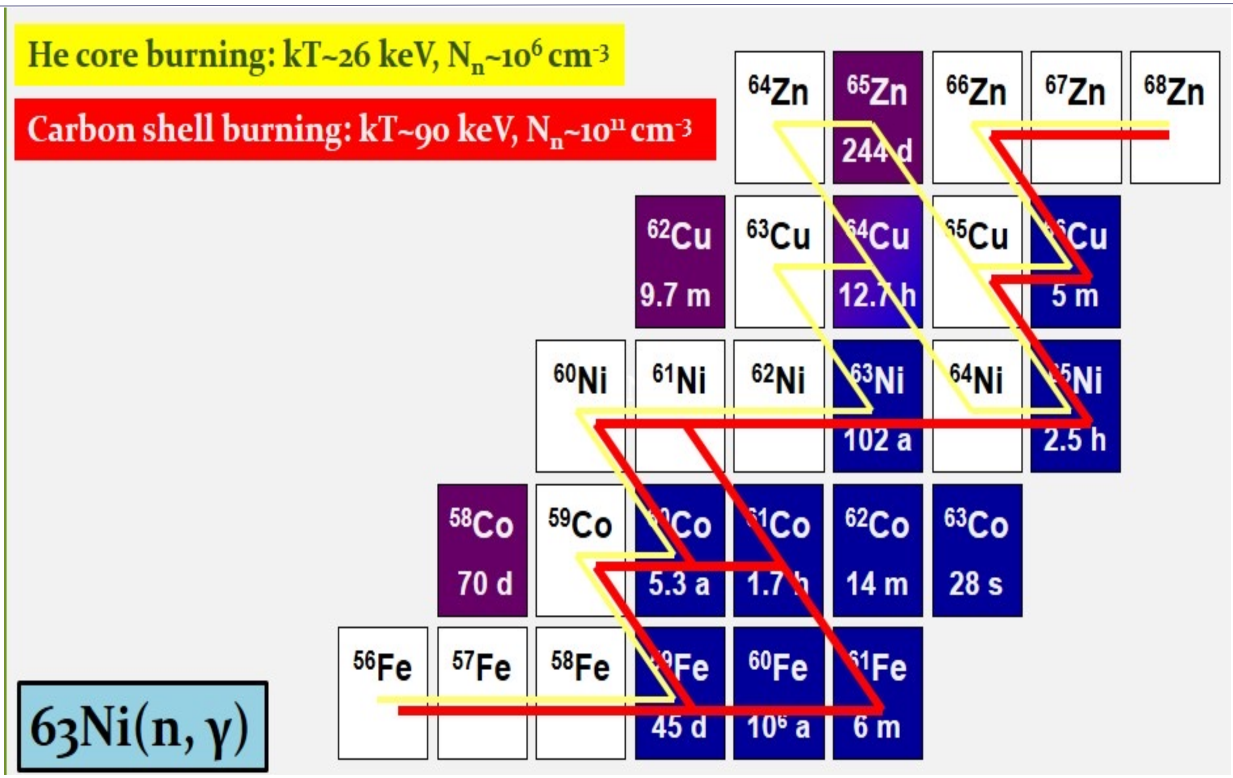
Neutrons and protons behave in the same way under nuclear interaction? Charge symmetry is a special case of the **isospin invariance**, its violation is known as charge symmetry breaking CSB: $m_p \neq m_n$; $a_{pp} \neq a_{nn}$; binding energy ≠ mirror nuclei



deuterated scintillator:
Stilbene (380 nm Pulse Shape disc.)
Disk: 32mm diameter, 5 & 10 mm thick

s-process branching





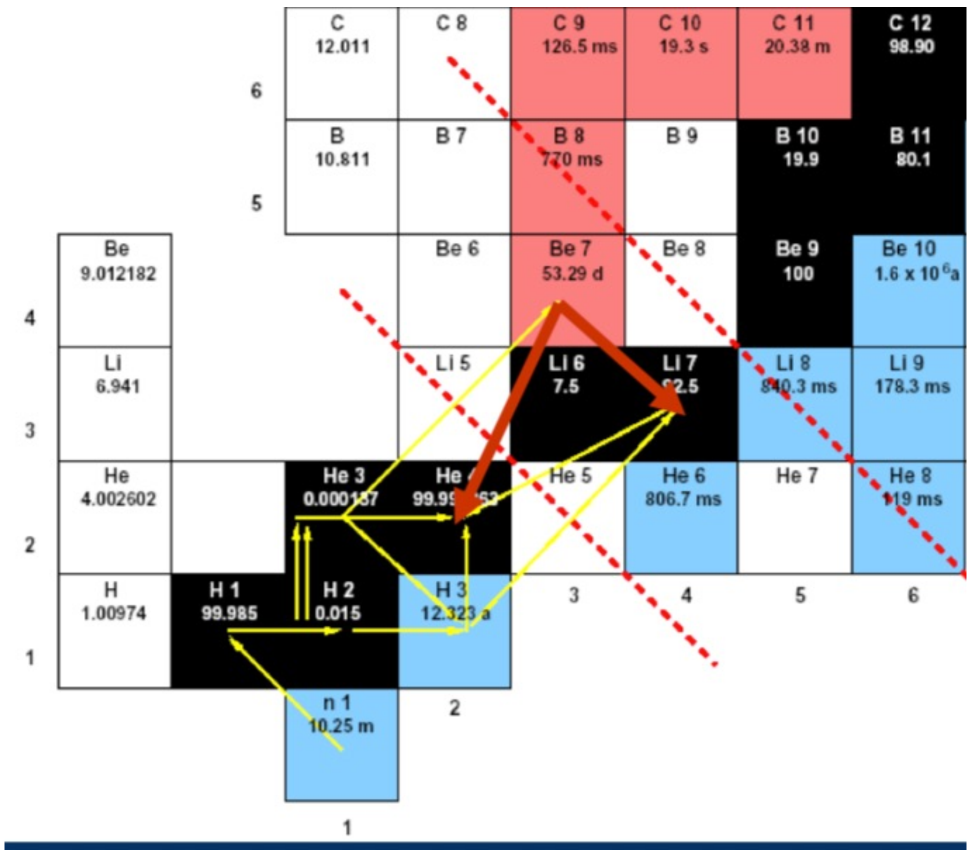
The branching depends on the **stellar condition**, on the isotope half-life and on the **neutron capture cross section**

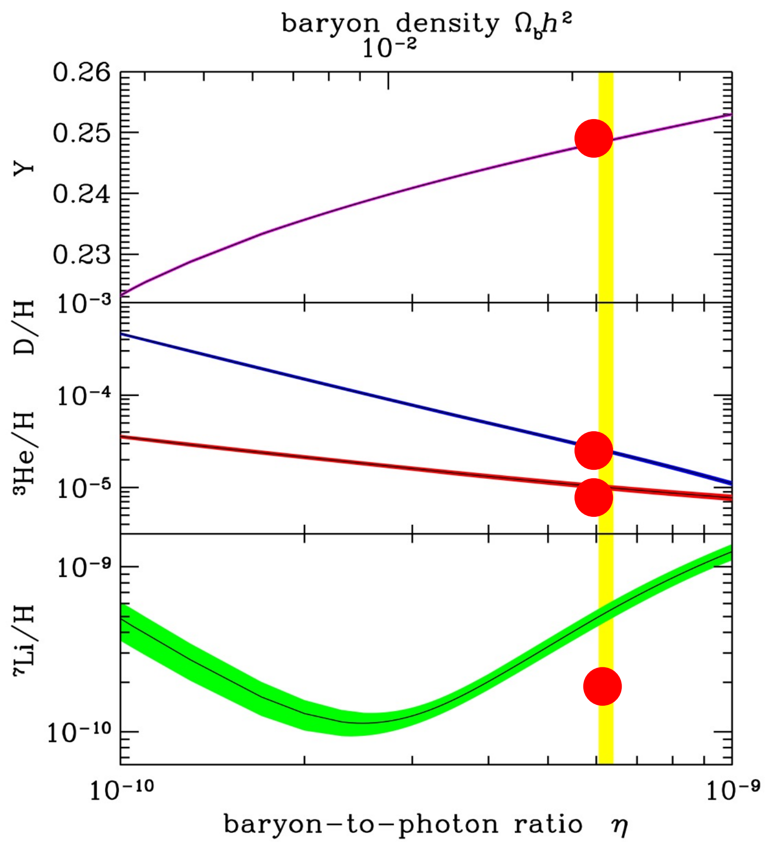
^{63}Ni ($t_{1/2}$=100 y) **first branching point** determines **abundance** of **^{63,65}Cu**

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**

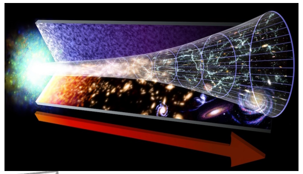
~ 95% of ^{7}**Li** is produced by the decay of ^{7}**Be** ($T_{1/2}$=53.2 d)



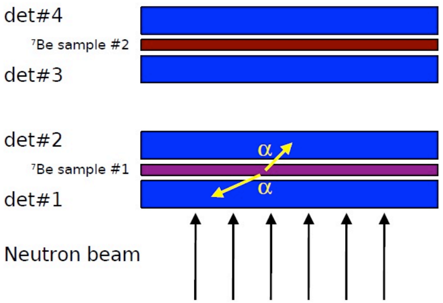


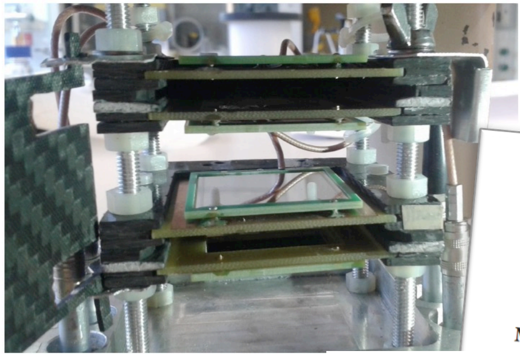
Destruction via neutron interaction?

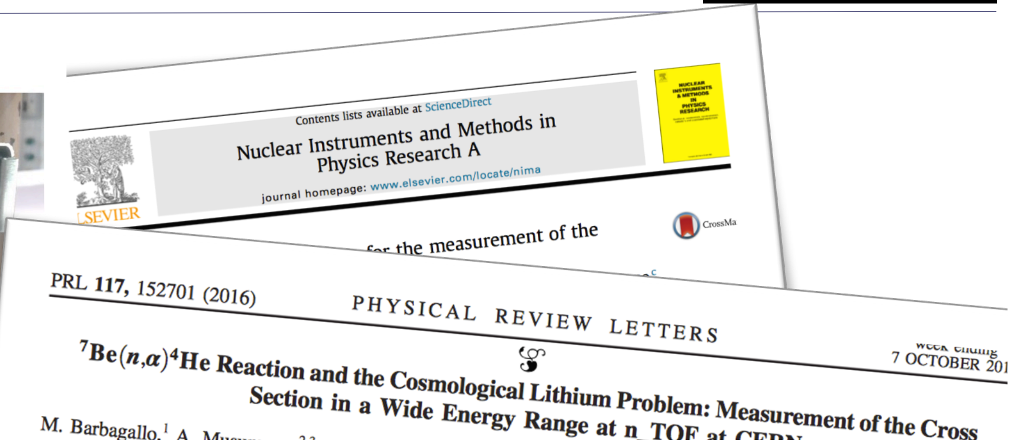
BBN: need for ^{7}Be destruction



^{7}Be(n, α)α



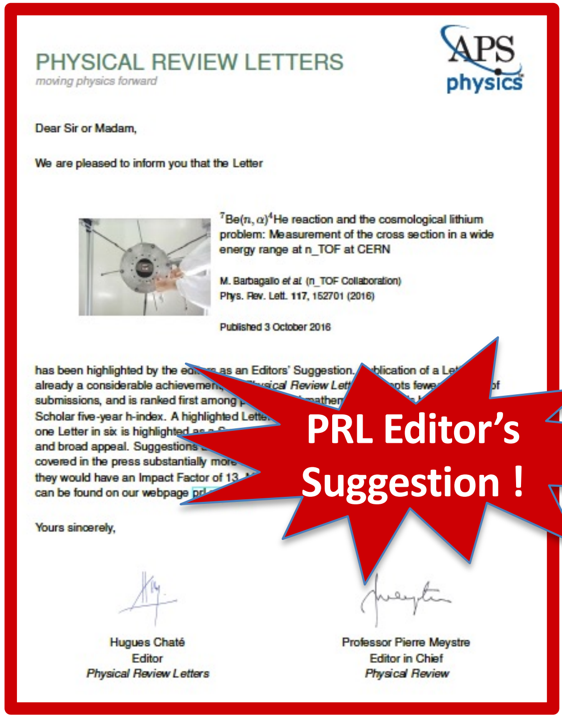



Contents lists available at ScienceDirect
Nuclear Instruments and Methods in Physics Research A
journal homepage: www.elsevier.com/locate/nima
...for the measurement of the

PRL 117, 152701 (2016) PHYSICAL REVIEW LETTERS week ending 7 OCTOBER 201

^{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,[1] A. ...


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 editors as an Editors' Suggestion. ...lication of a Le... already a considerable achievement... *Physical Review Lett*... 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 ...

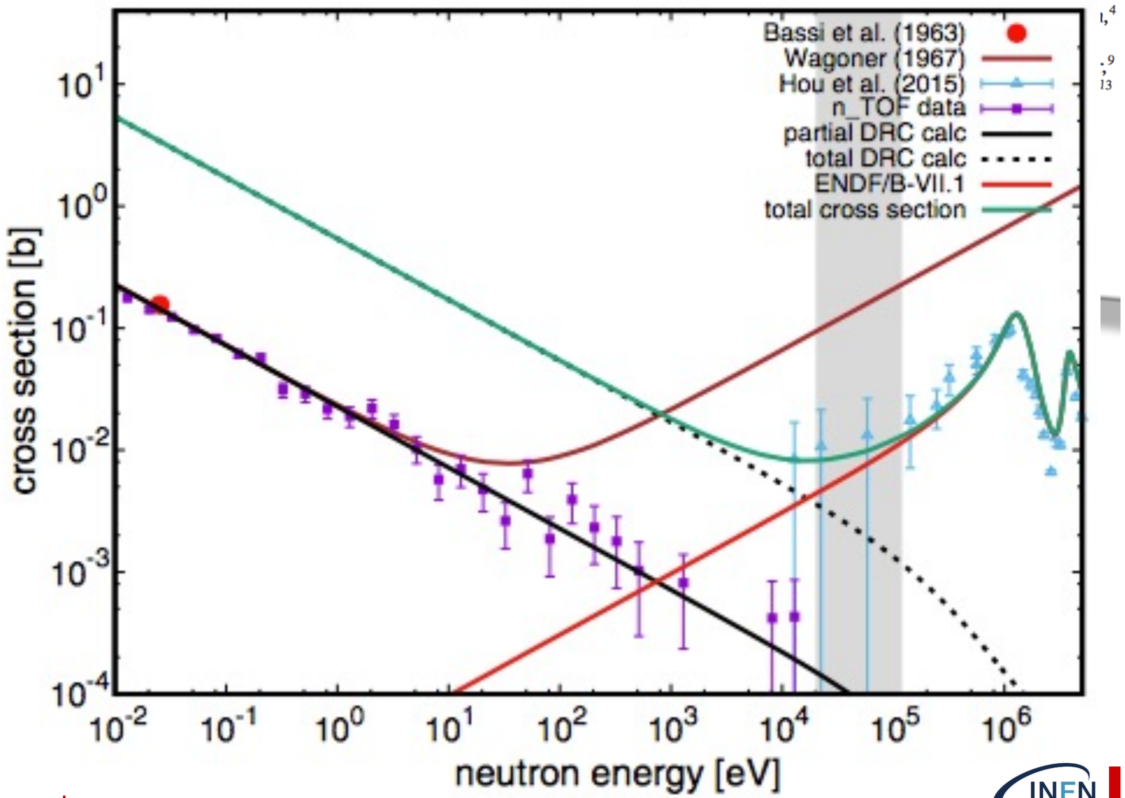
Yours sincerely,

Hugues Chaté
Editor
Physical Review Letters

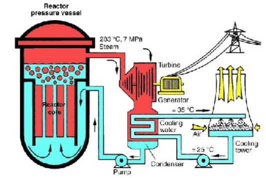
Professor Pierre Meystre
Editor in Chief
Physical Review

PRL Editor's Suggestion !

1 bachelor thesis 15/07/2016

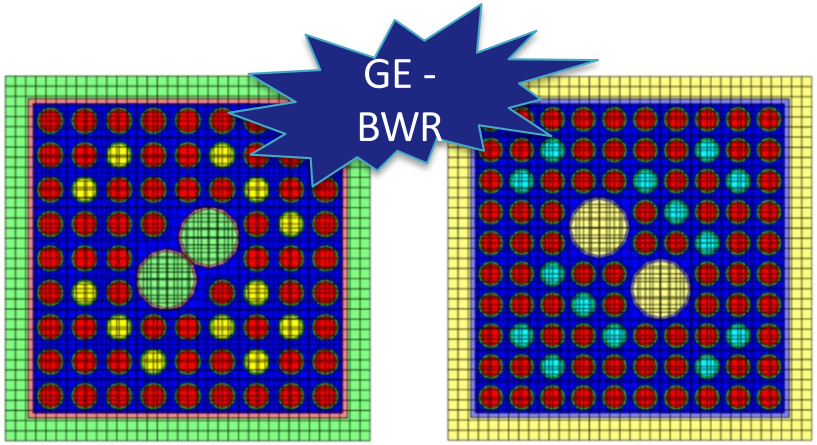


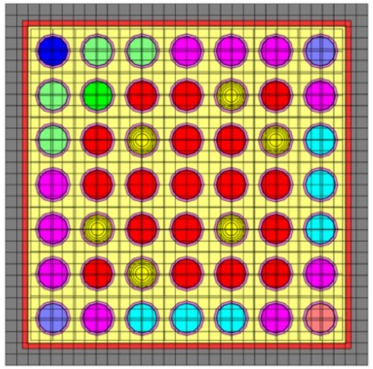
Neutron poison



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

Proposal (INFN) in close collaboration with ENEA

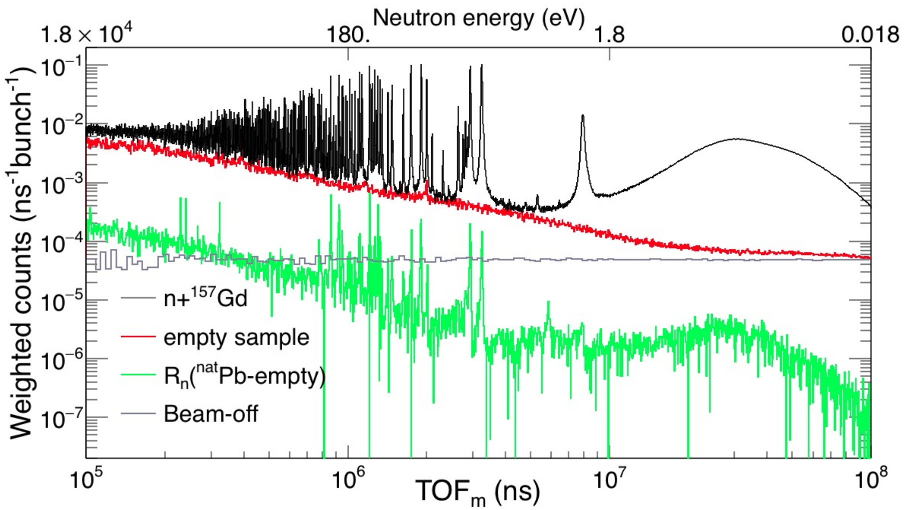




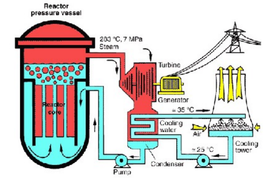
The **uncertainty** on **Gd** cross sections gives the **largest contribution** to the uncertainty on k_{eff} **after** ^{235,238}**U**.

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

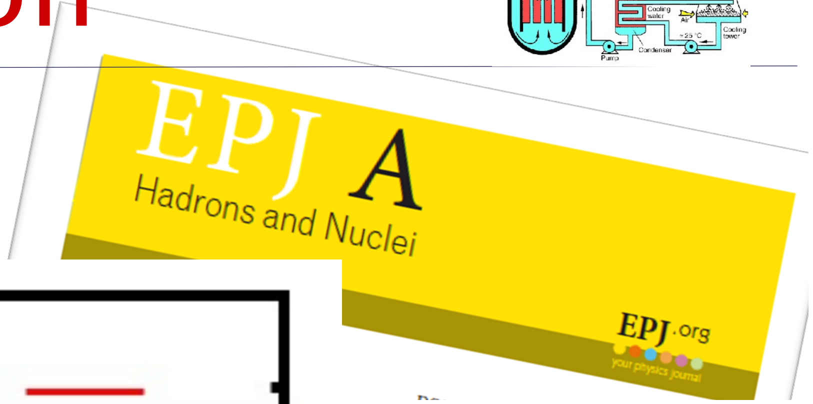
High enrichments pose severe safety problems due to the **high initial excess reactivity.** This can be **inherently compensated** by loading the fuel with **"burnable neutron poisons"**, i.e. isotopes with very high capture cross section

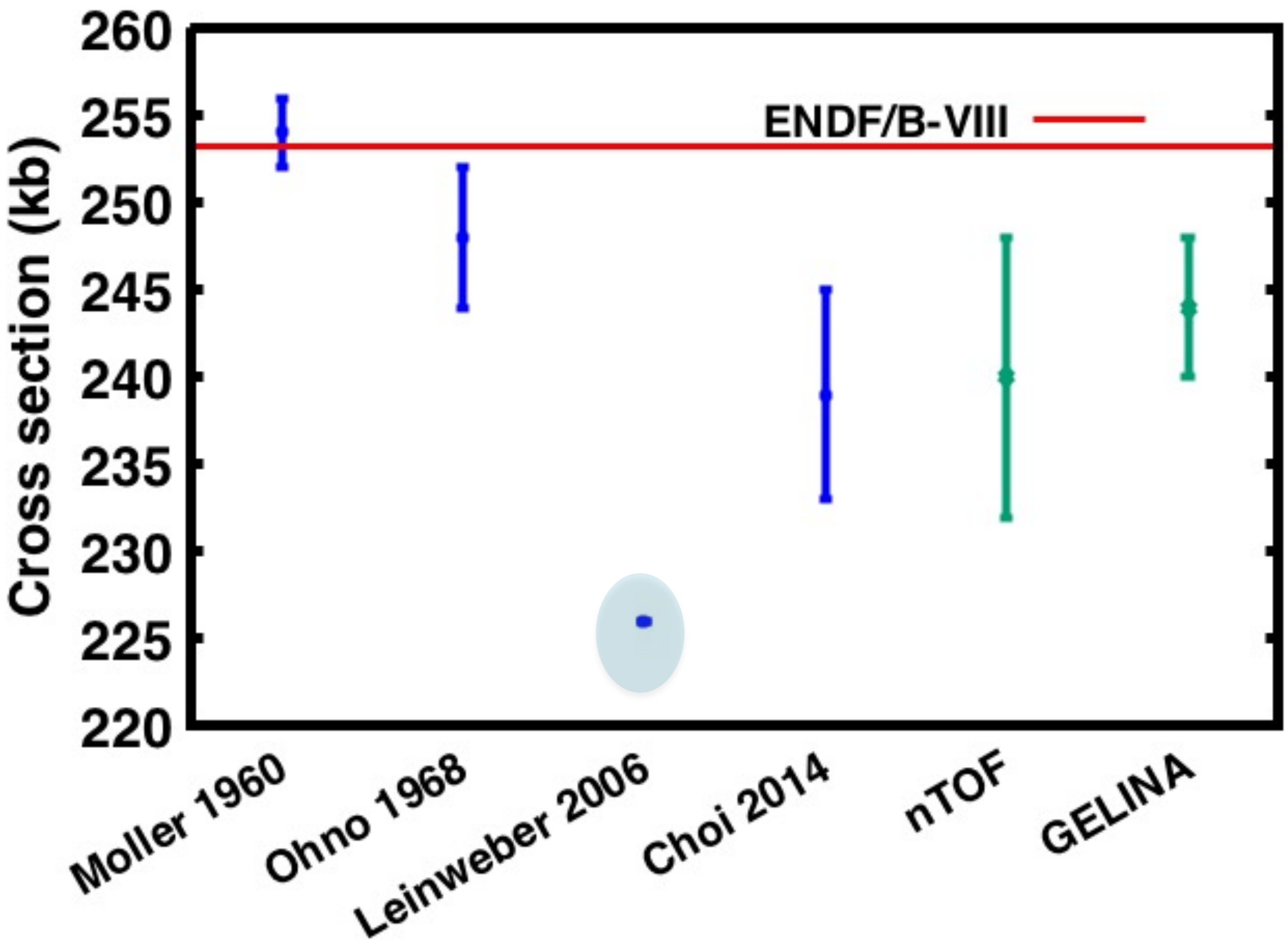


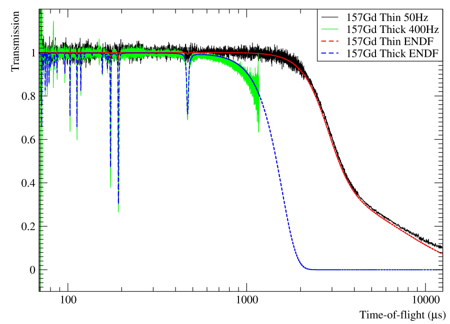
Neutron poison



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





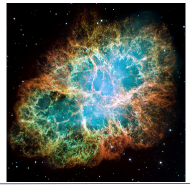


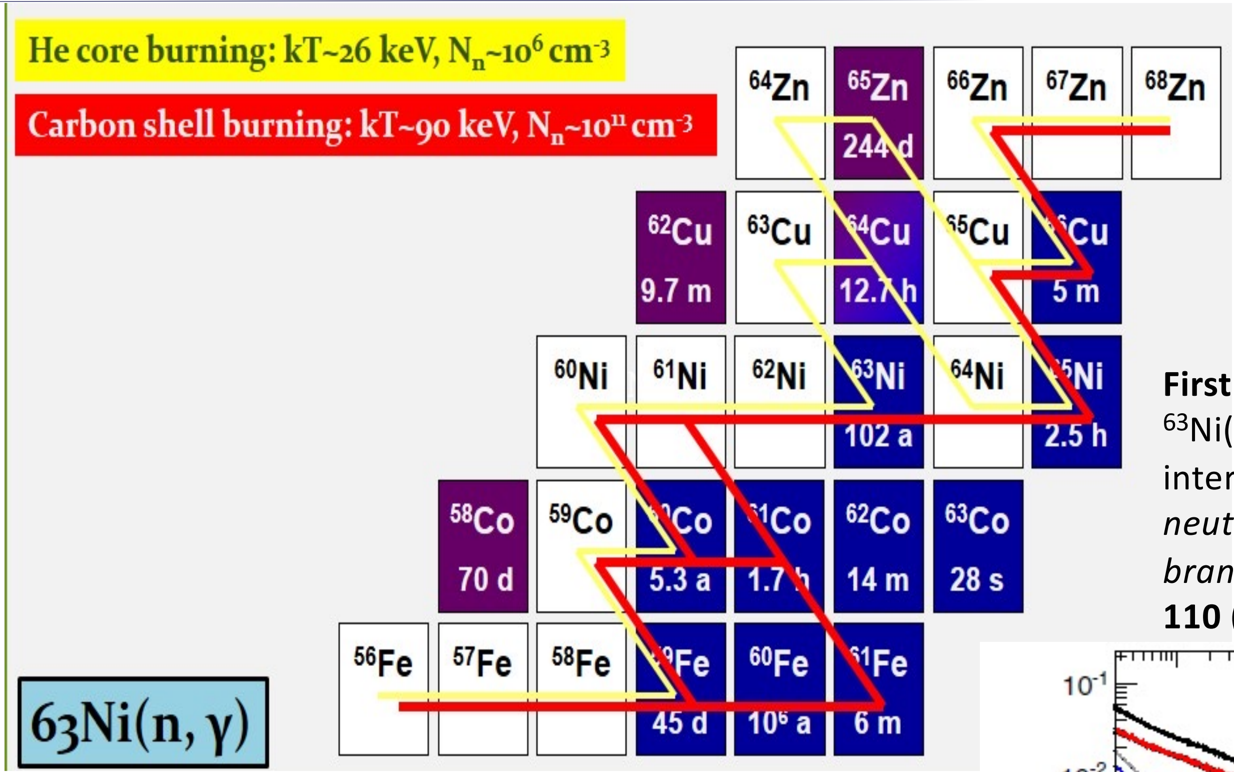
240±8 kb

244±4 kb

Ratio = 1.6%

s-process branching



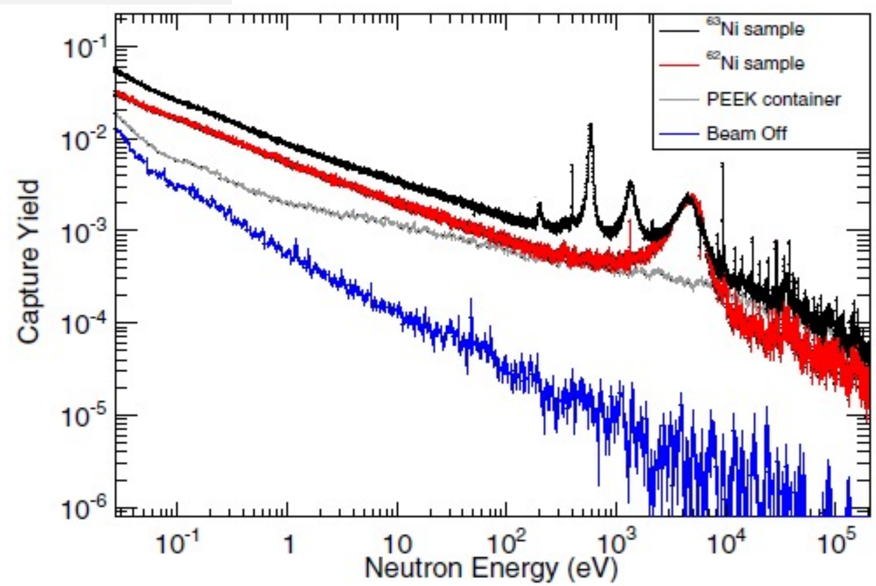


The branching depends on the **stellar condition**, on the isotope half-life and on the **neutron capture cross section**

First high-resolution measurement of the ^{63}Ni(n, γ) 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**

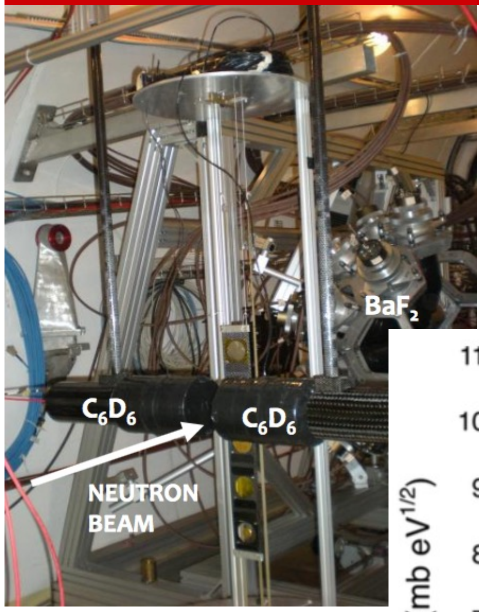
^{63}Ni ($t_{1/2}$=100 y) **first branching point** determines **abundance** of **^{63,65}Cu**

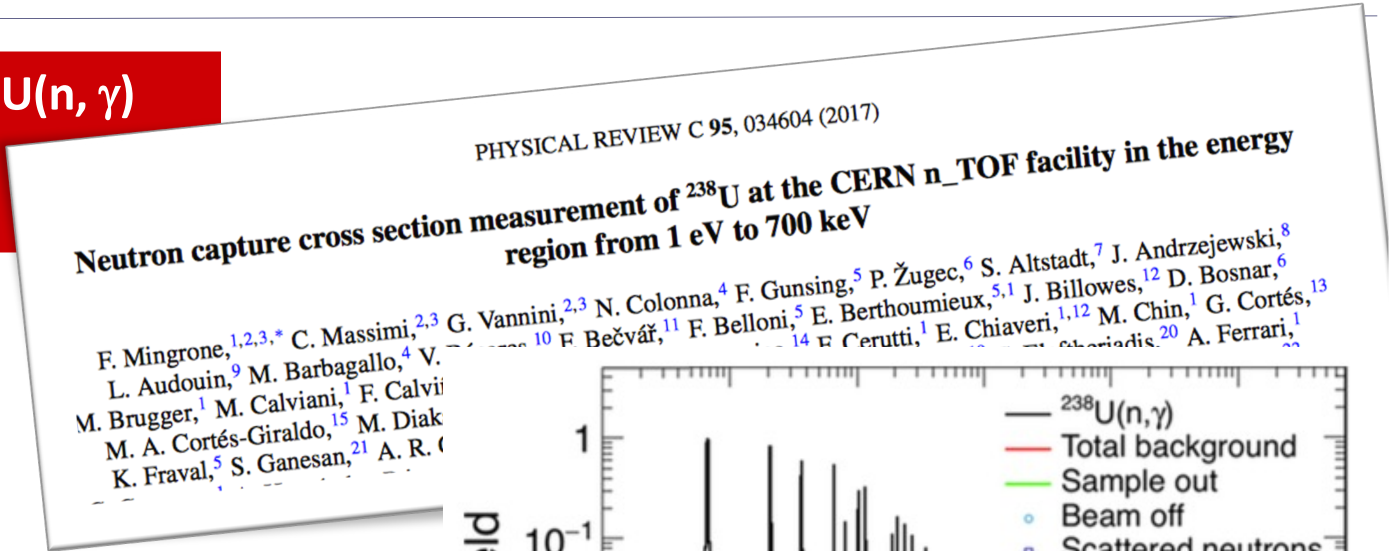
The measurement was performed in 2011 at n_TOF using an array of C_6D_6 detectors



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

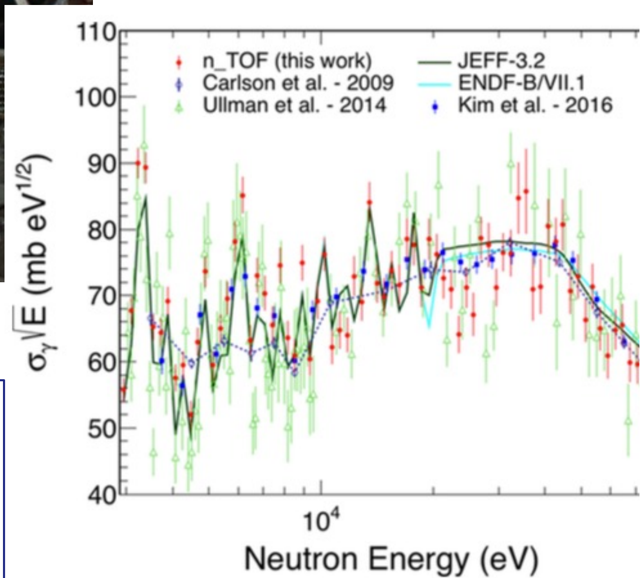
ANDES (FP7) project: $^{238}U(n, \gamma)$
- n_TOF C_6D_6 + TAC
- GELINA C_6D_6

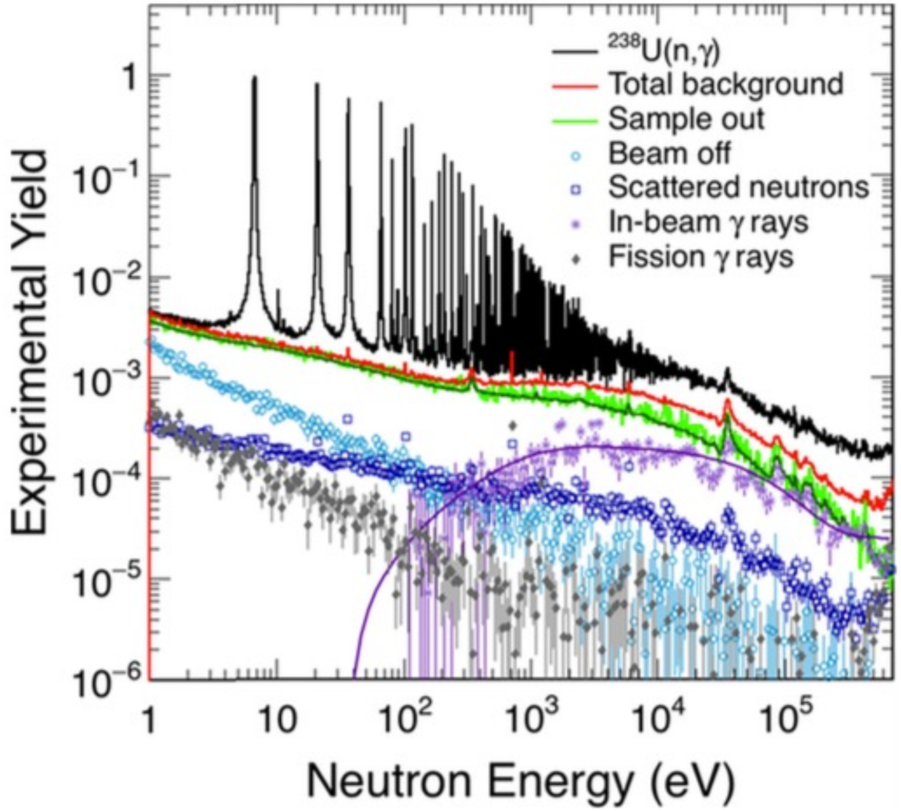



PHYSICAL REVIEW C 95, 034604 (2017)

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... 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. ...





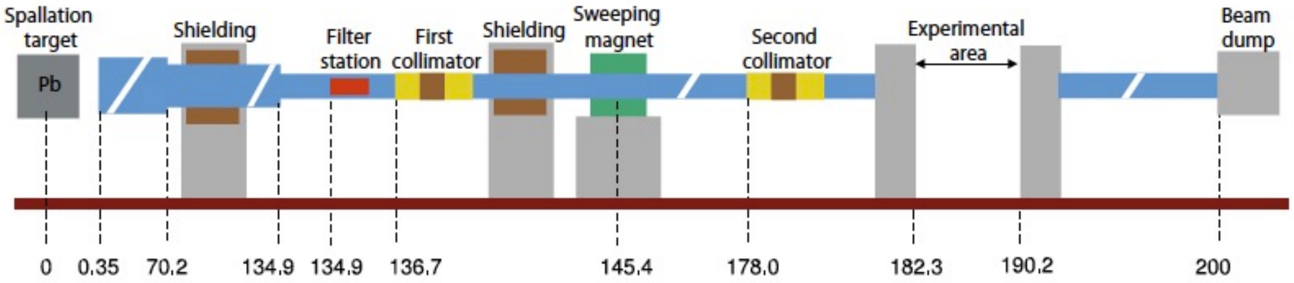
First measurement together Los Alamos, for E_n>100 keV

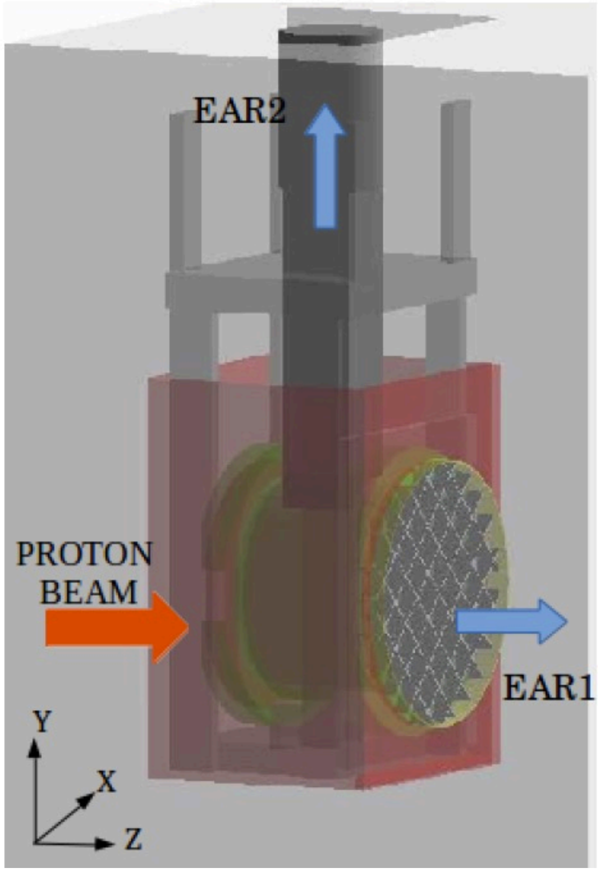
1 PhD thesis Feb. 15

MC simulation of n_TOF source

Geant4 simulation of the n_TOF neutron source and transport to EAR1

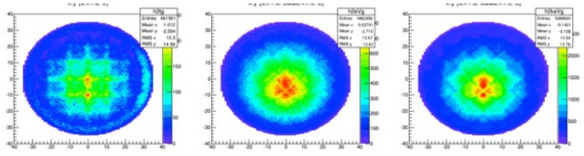
20 GeV/c protons on lead

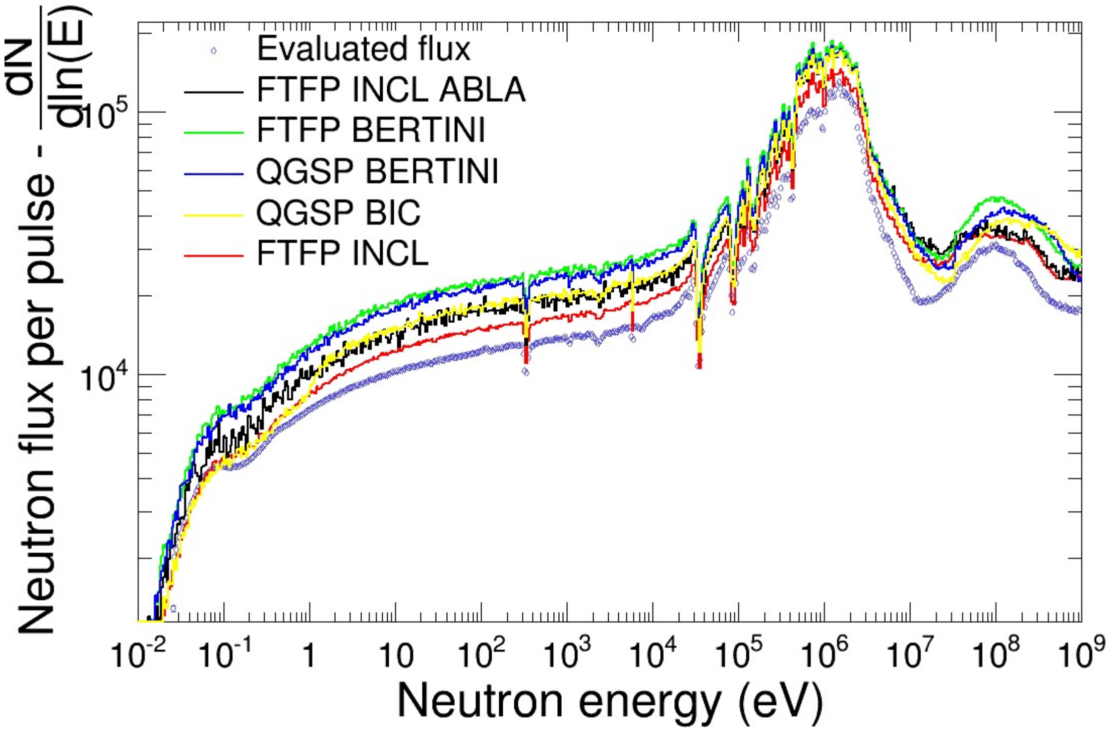




S. Lo Meo, M. A. Cortés-Giraldo, C. Massimi, *et al.*, Eur. Phys. J. A 51 (2015) 160

1 bachelor thesis 23/09/2016





^{140}Ce: Galactic chemical evolution

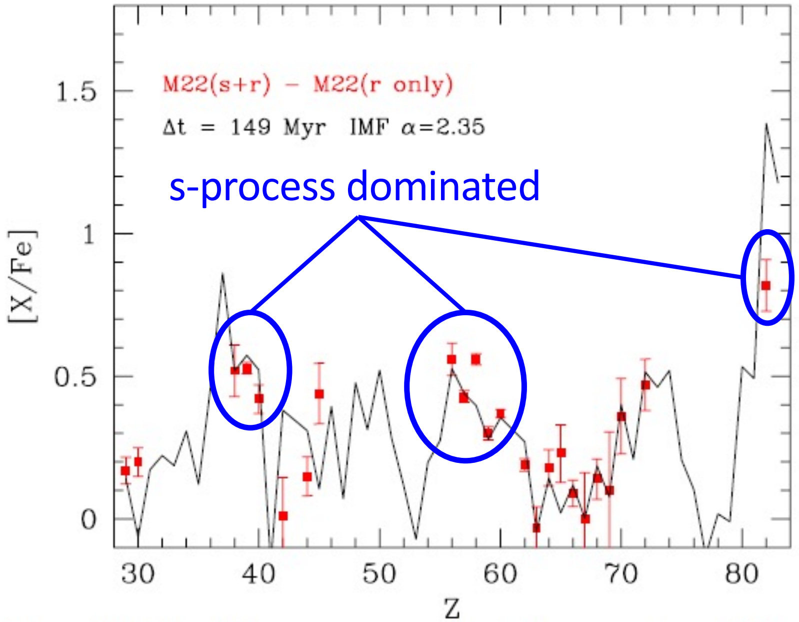


Figure 11. Best fit of the average *s*-process chemical pattern of stars in M22.

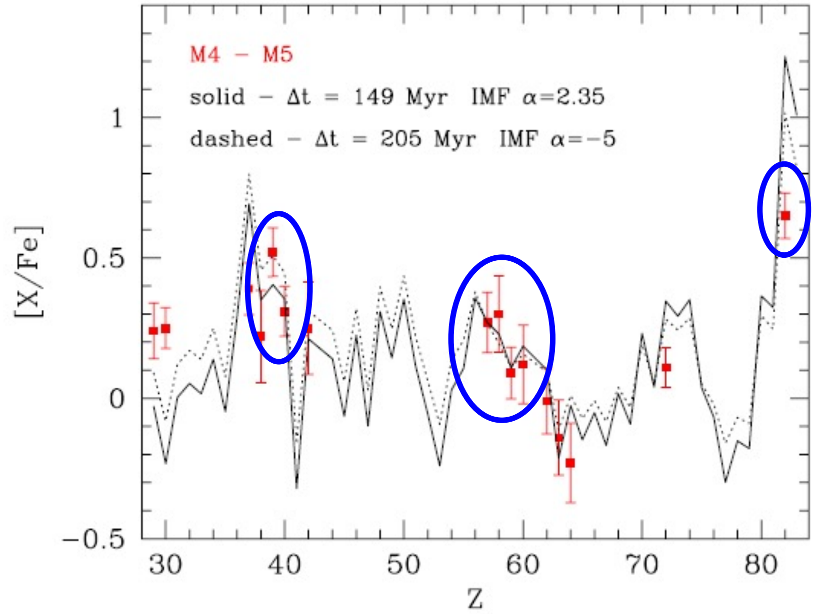


Figure 13. Best fit of the average *s*-process chemical pattern of stars in M4.

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

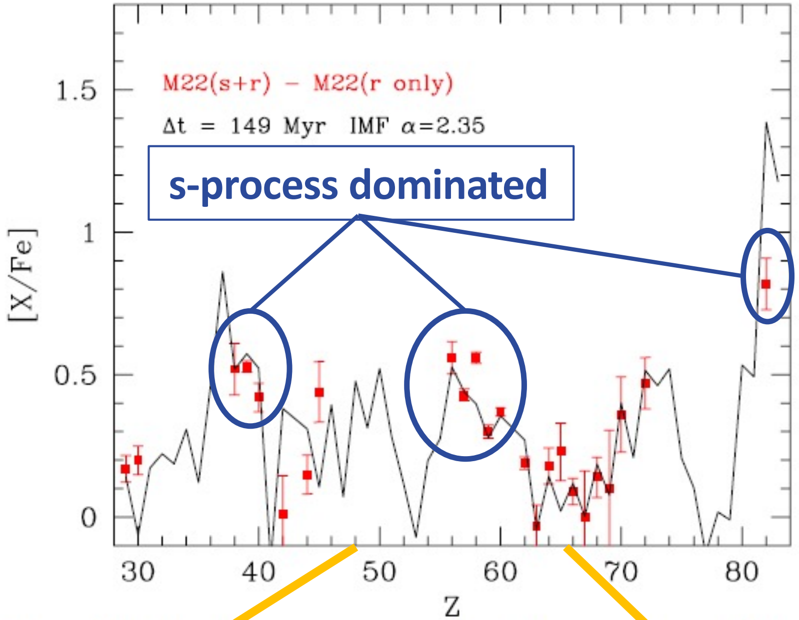
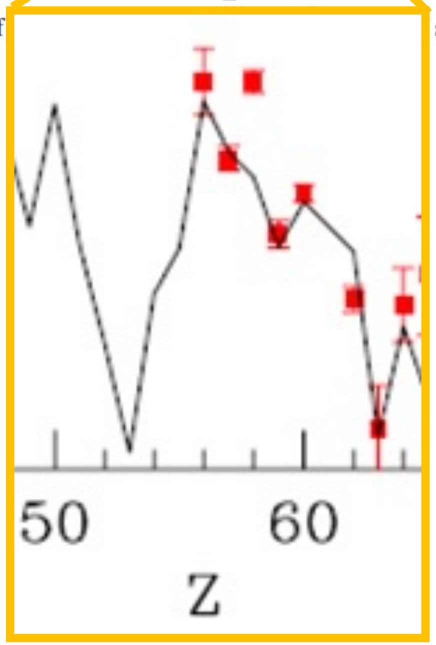


Figure 11. Best fit of … stars in M22.



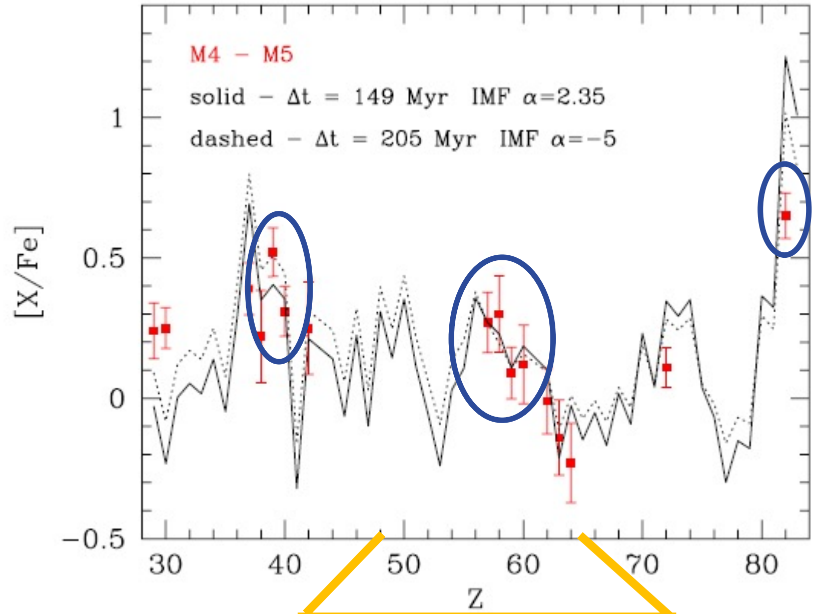
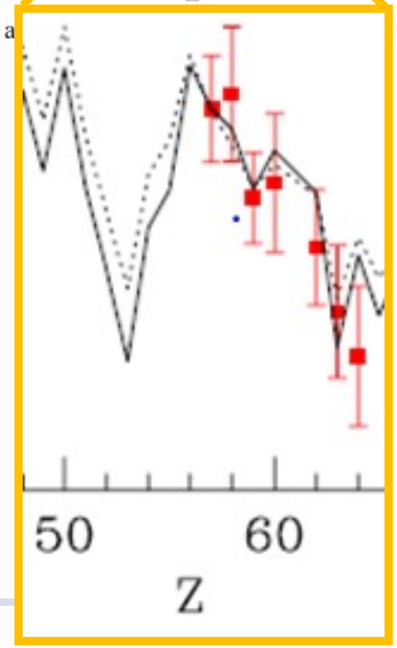


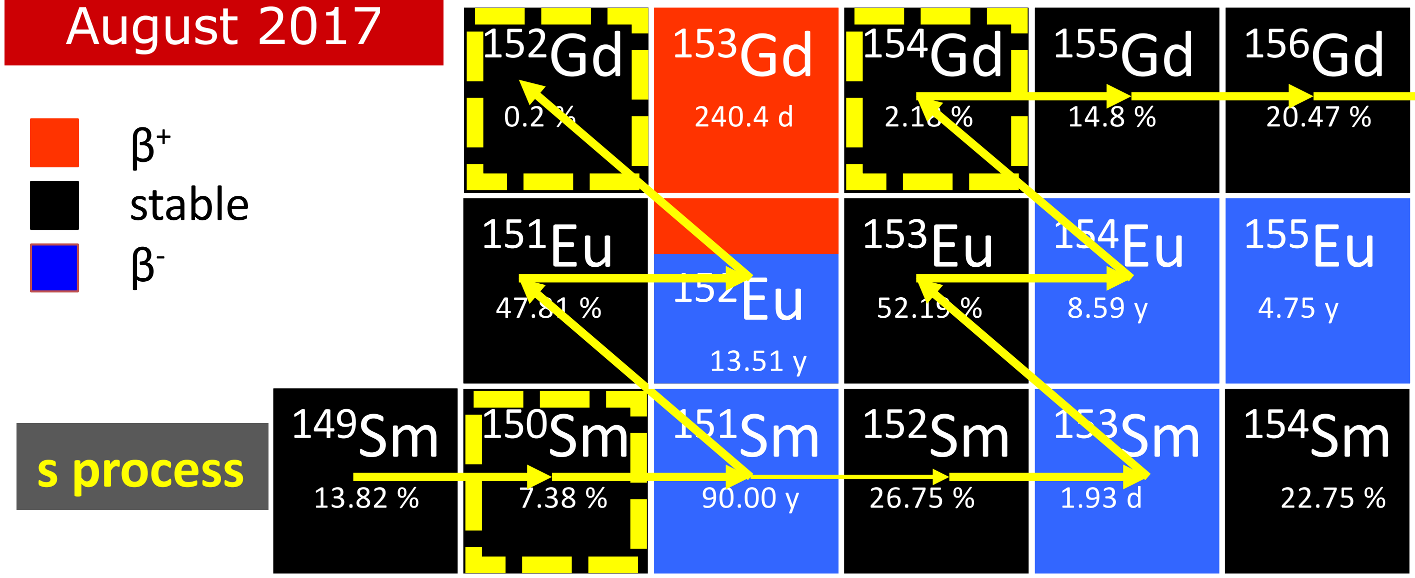
Figure 13. Best fit of the a… stars in M4.



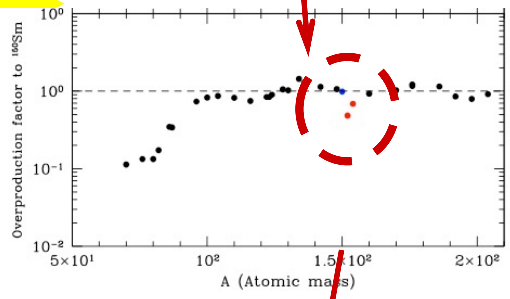
Abundances of elements in the s-process peak are well reproduced apart from Cerium

s–only isotope

^{154}Gd(n, γ)
August 2017



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

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**

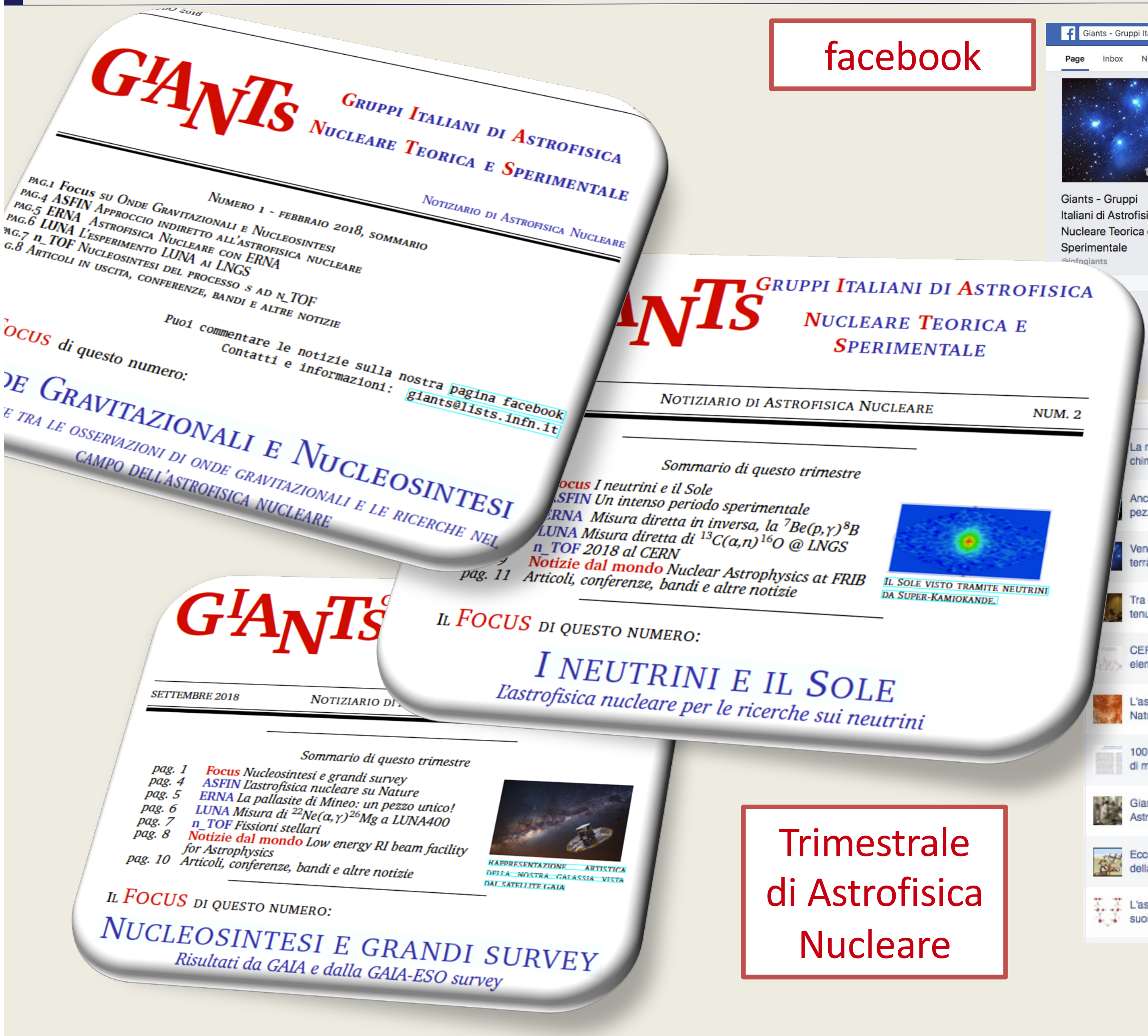
Idea of a **Newsletter** of the italian group of Nuclear Astrophysics.
Scientific board composed by 7 researchers from different experiments.

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

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

Dissemination

facebook



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

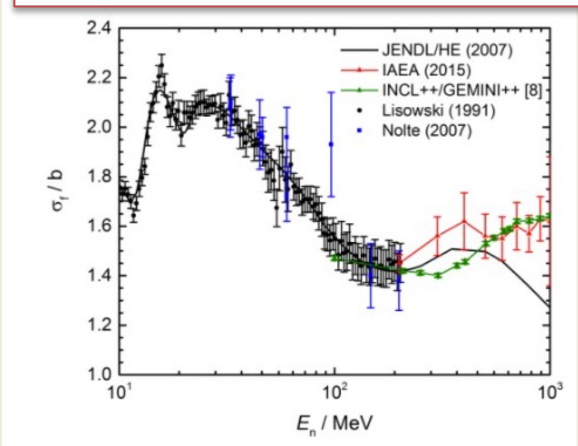
May 06, 2017

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

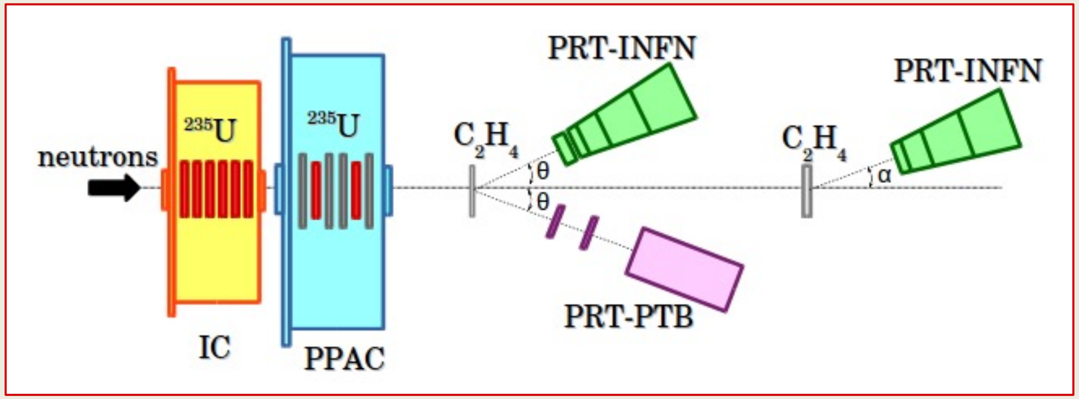


n_TOF facility is a unique tool for the cross section measurement of the **^{235}U(n, f) reaction**, **relative** to the **H(n, n)H** reaction, **up to 1 GeV.**

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

S
E
T
U
P

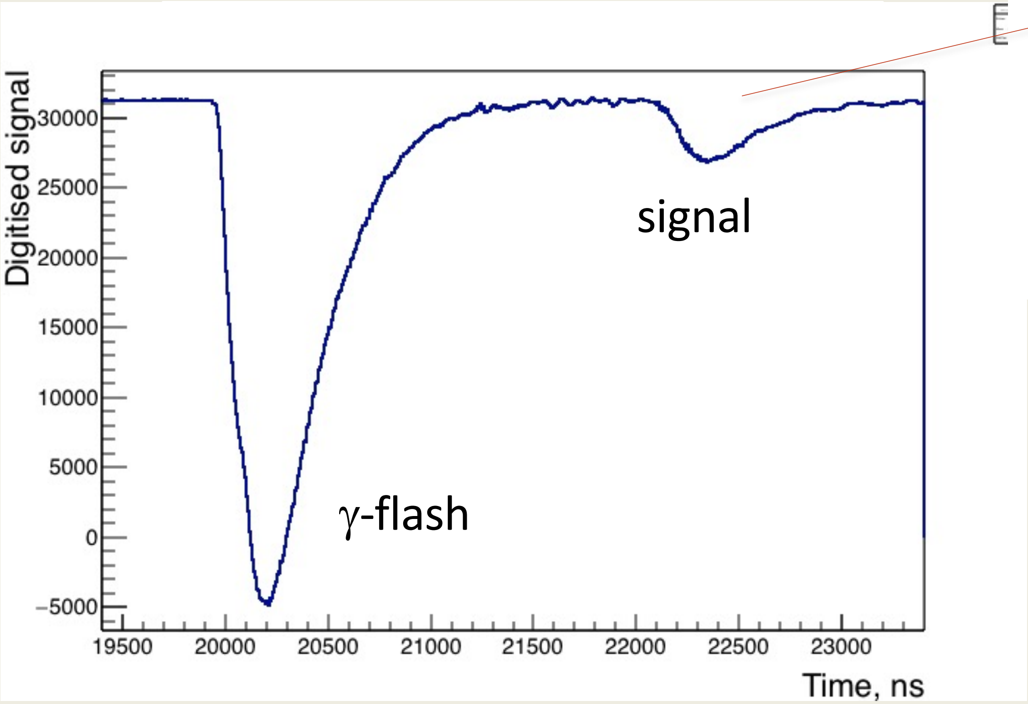


1 PhD
on this project

Silicon Monitor (SiMon)

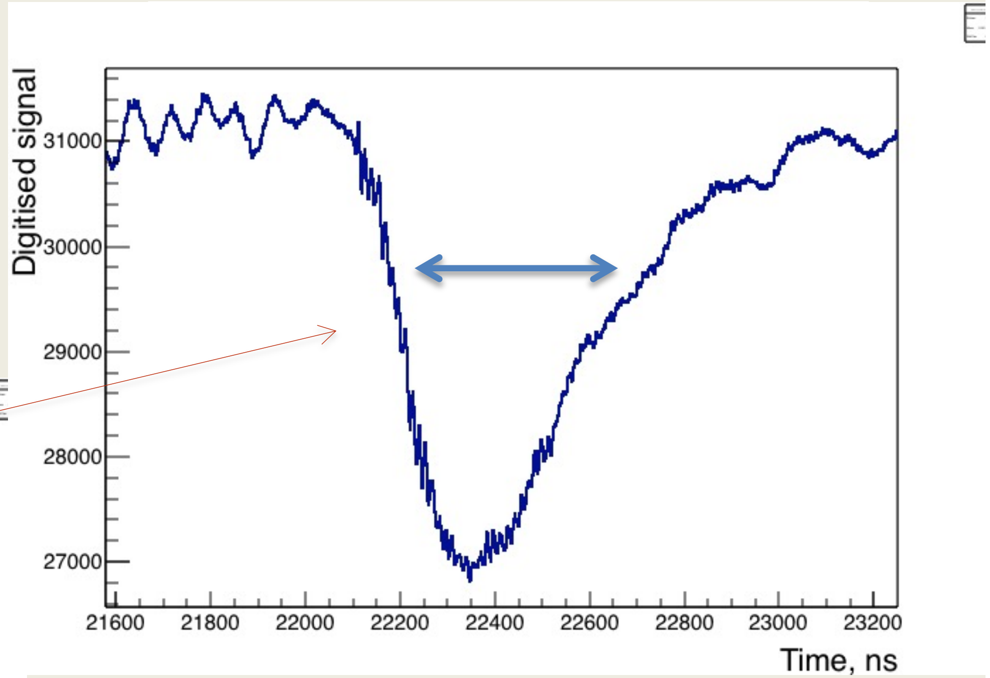
to measure flux as a function of E_n

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
UBAS – Basel, Svizzera
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}

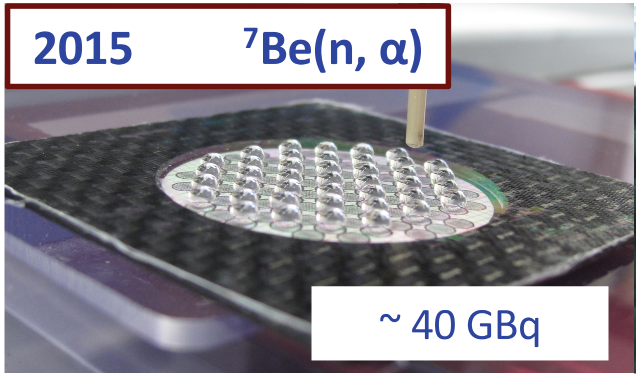
Soluzione Nucleare

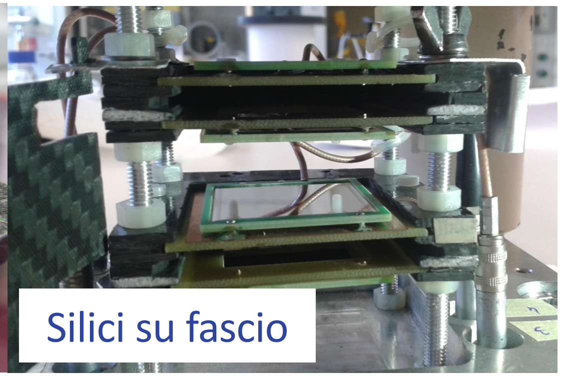
~95% del ^{7}Li deriva dalla cattura elettrocina del ^{7}Be

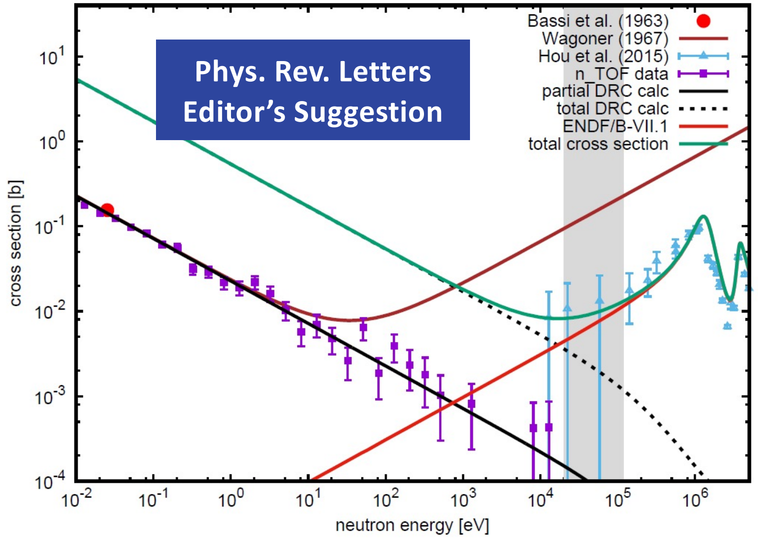
Difficoltà: (i) Attività specifica del ^{7}Be **13 GBq per μg**; (ii) vita media breve 53.3 d

n_TOF EAR 2

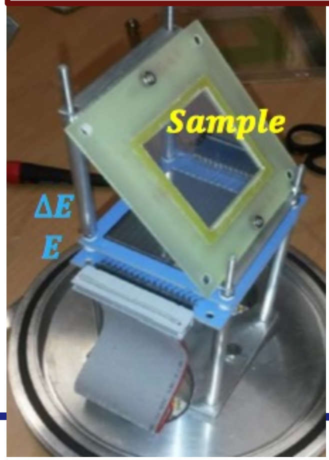
2015 ^{7}Be(n, α)







2016 ^{7}Be(n, p)



Bersaglio:

PSI (Berillio)

+

ISOLDE

(arricchimento ^{7}Be)

~ 1.1 GBq