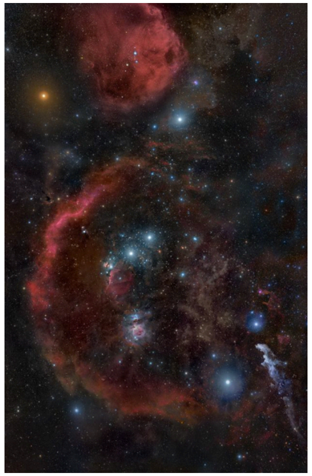
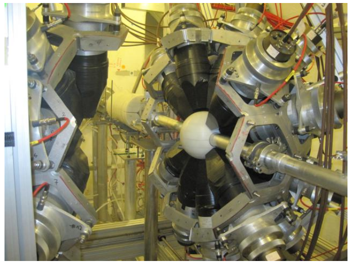
SPES exotic beams for science

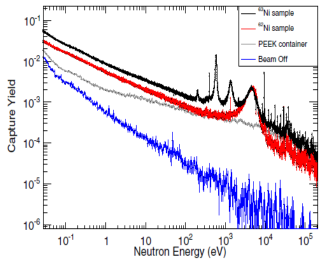
SPES one-day workshop "Nuclear Astrophysics at SPES"

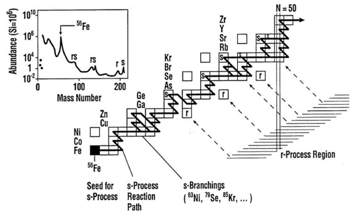
INFN Istituto Nazionale di Fisica Nucleare

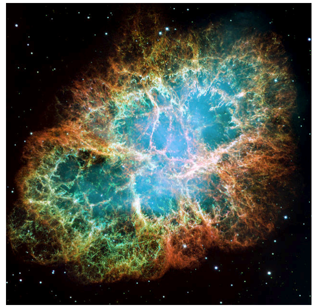
Caserta, 12-13 November 2015











Nuclear Astrophysics at CERN - n_TOF

Cristian Massimi

for the n_TOF Collaboration

n_TOF

Outline

- **The n_TOF project**

  Collaboration, objectives, basic parameters, instrumentation

- **Some examples of recent measurements and their impact on Nuclear Astrophysics**

  Branching isotopes

  Neutron source of the s process

  BBN

The n_TOF project

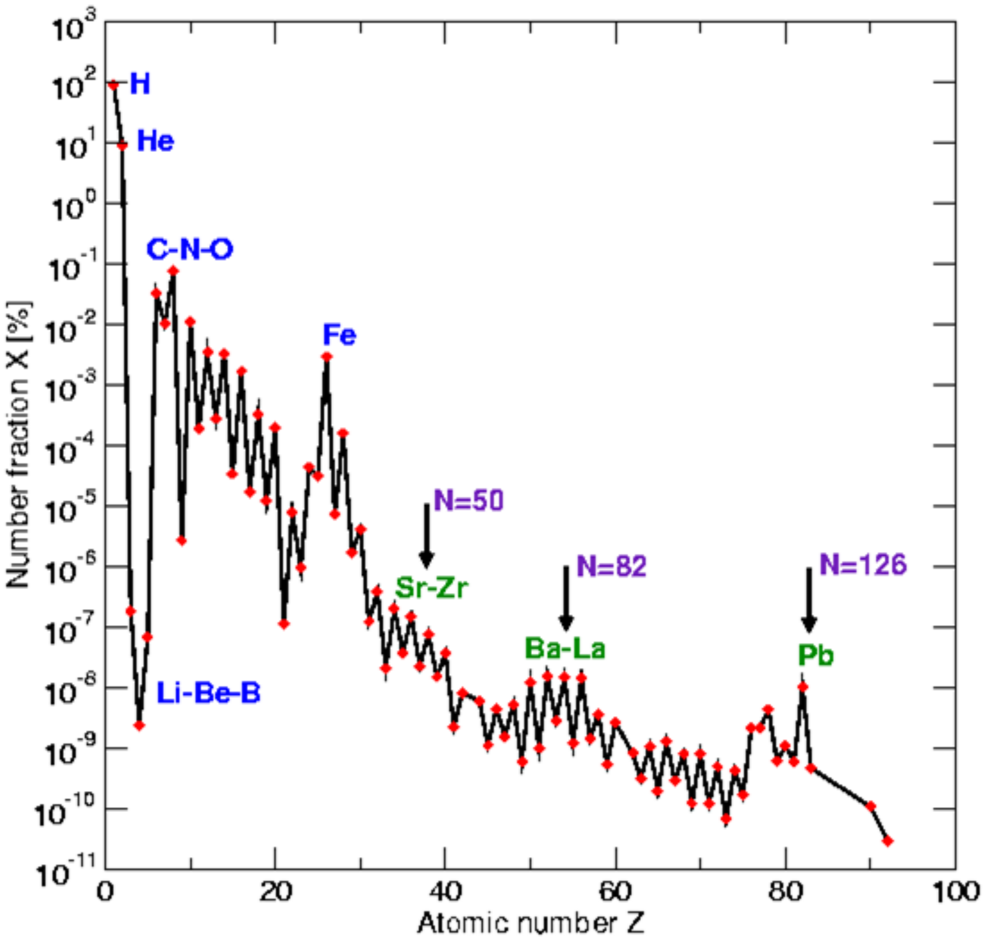
1. Atominstitut, Technische Universität Wien, Austria
2. University of Vienna, Faculty of Physics, Austria
3. European Commission JRC, Institute for Reference Materials and Measurements (IRMM)
4. Department of Physics, Faculty of Science, University of Zagreb, Croatia
5. Charles University, Prague, Czech Republic
6. Centre National de la Recherche Scientifique/IN2P3 - IPN, Orsay, France
7. Commissariat à l'Énergie Atomique (CEA) Saclay - Irfu, Gif-sur-Yvette, France
8. Johann-Wolfgang-Goethe Universität, Frankfurt, Germany
9. Karlsruhe Institute of Technology, Campus Nord, Institut für Kernphysik, Karlsruhe, Germany
10. National Technical University of Athens (NTUA), Greece
11. Aristotle University of Thessaloniki, Thessaloniki, Greece
12. Bhabha Atomic Research Centre (BARC), Mumbai, India
13. ENEA Bologna e
14. Dipartimento di Fisica, e Astronomia, Università di Bologna
15. Sezione INFN di Bologna, INFN Bari, Bologna, LNL, Trieste, LNS
16. Uniwersytet Łódzki, Lodz, Poland
17. Instituto Tecnológico e Nuclear, Instituto Superior Técnico, Universidade Técnica de Lisboa, Portugal
18. Horia Hulubei National Institute of Physics and Nuclear Engineering – Bucharest, Romania
19. Centro de Investigaciones Energeticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
20. Instituto de Fìsica Corpuscular, CSIC-Universidad de Valencia, Spain
21. Universitat Politecnica de Catalunya, Barcelona, Spain
22. Universidad de Sevilla, Spain
23. Universidade de Santiago de Compostela, Spain
24. Department of Physics and Astronomy - University of Basel, Basel, Switzerland
25. European Organization for Nuclear Research (CERN), Geneva, Switzerland
26. Paul Scherrer Institut, Villigen PSI, Switzerland
27. University of Manchester, Oxford Road, Manchester, UK
28. University of York, Heslington, York, UK

~ 130 researchers

The n_TOF project

Objective: to provide Nuclear Data for Science (and Technology)

How the elements are synthesized in the Universe?



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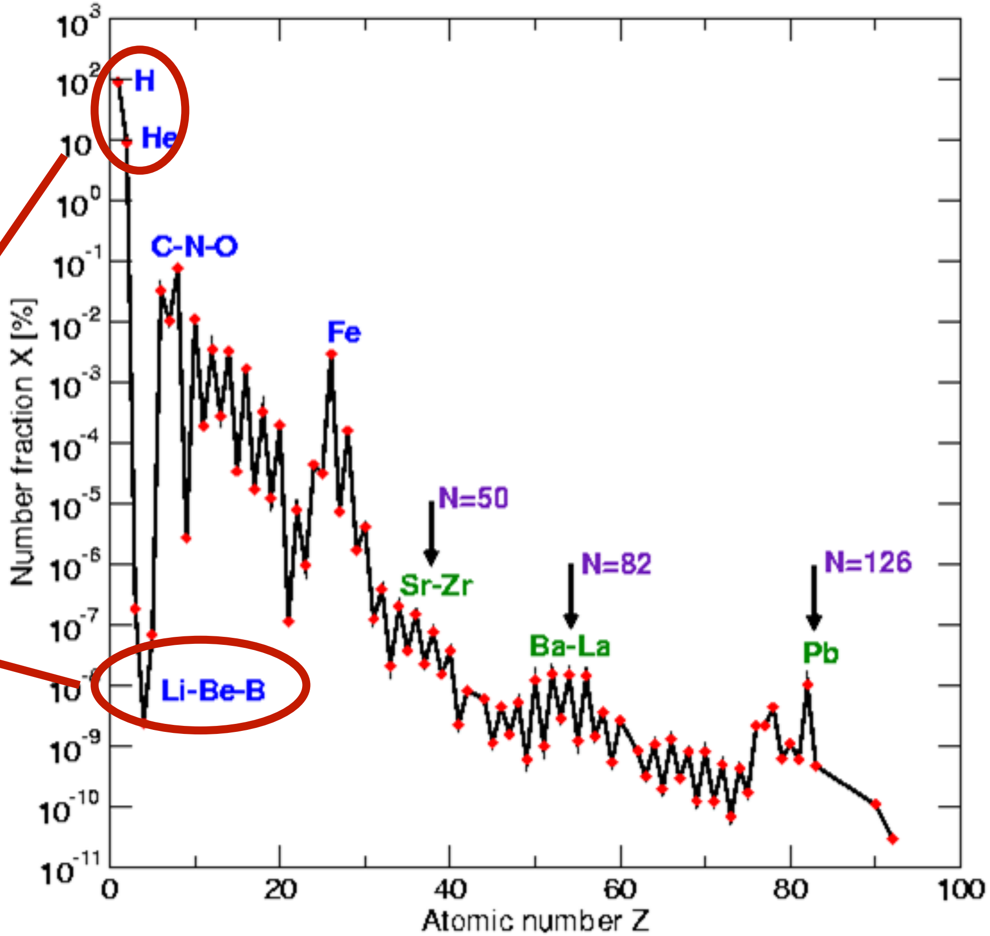

The n_TOF project

Istituto Nazionale di Fisica Nucleare

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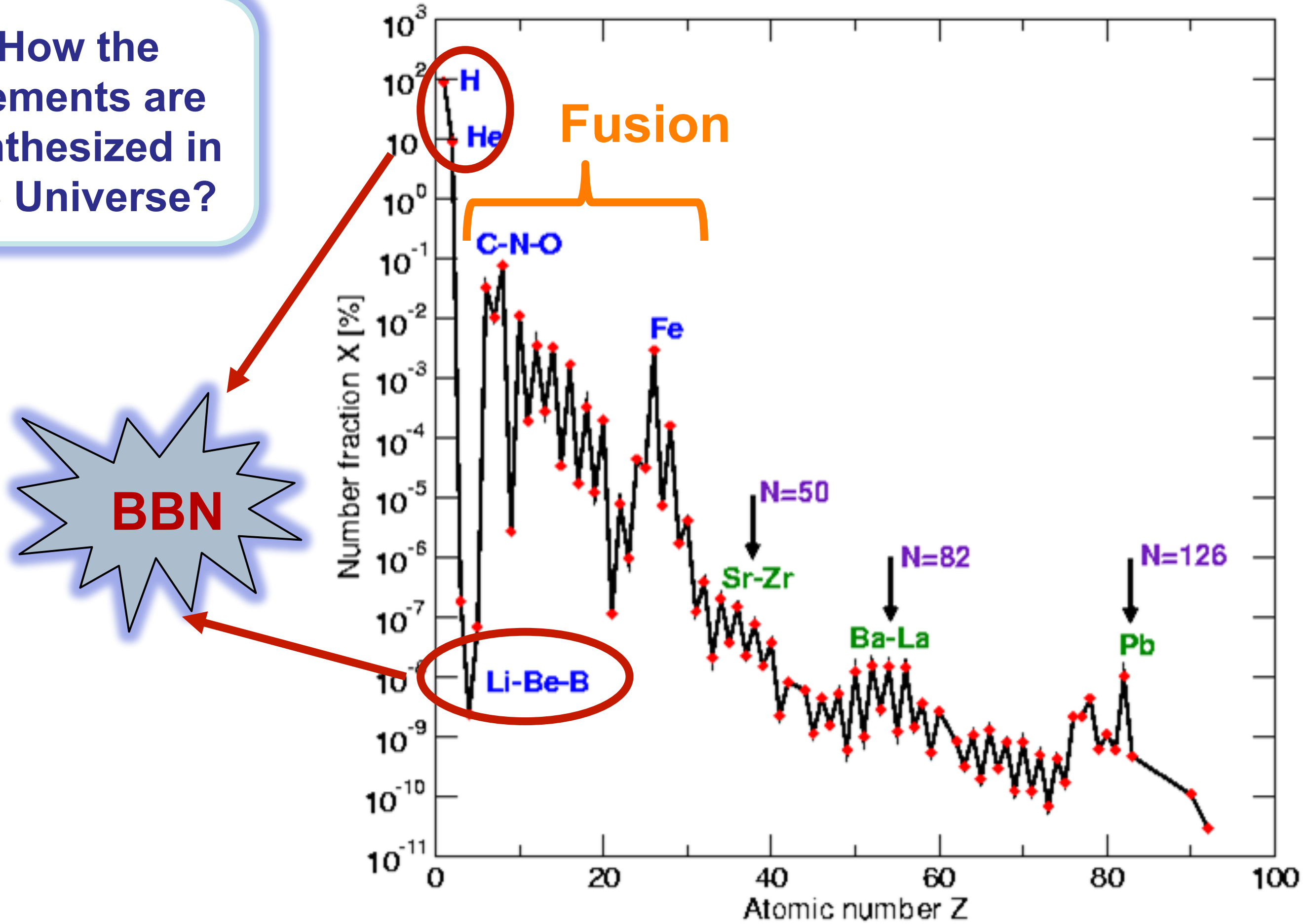

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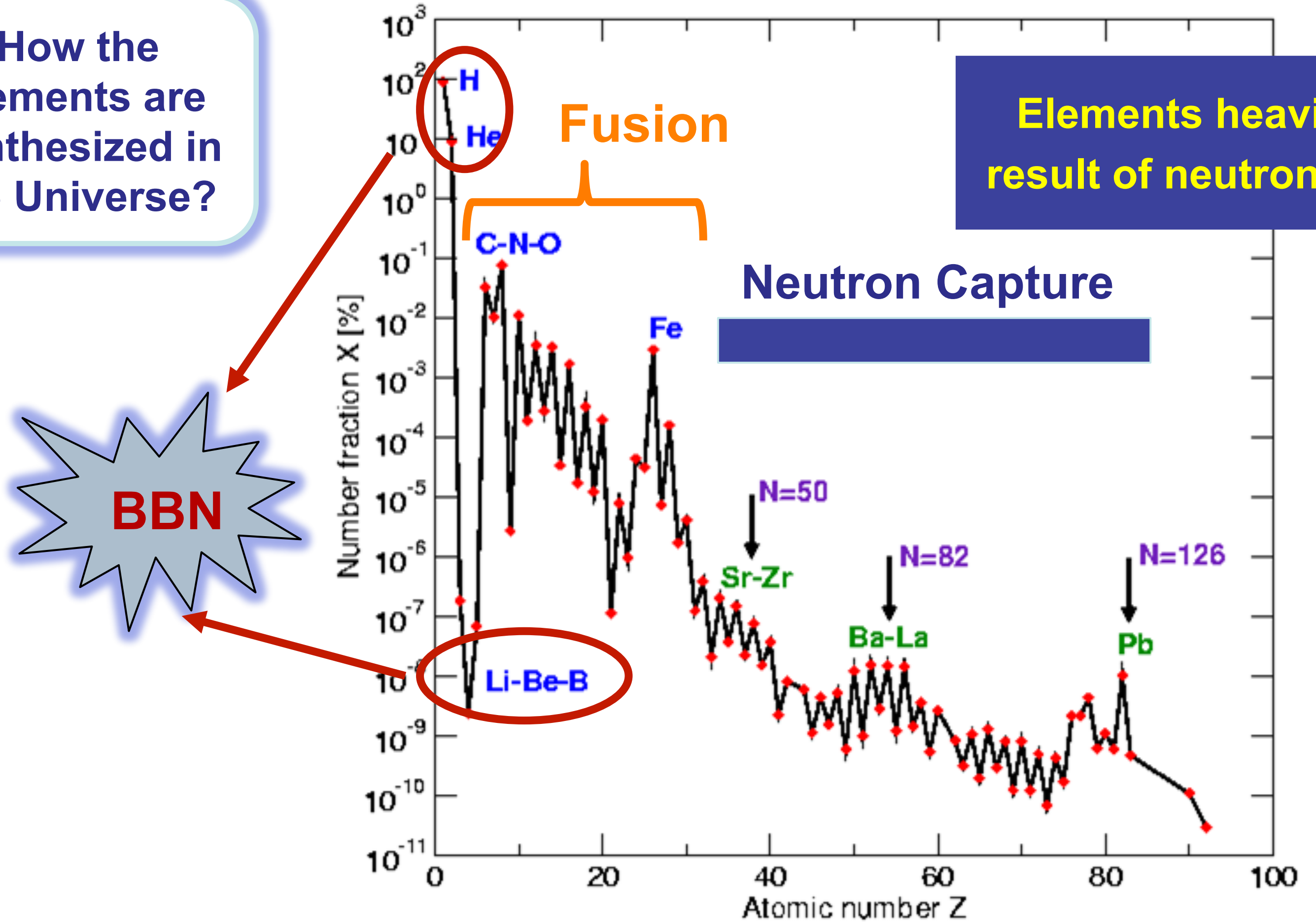
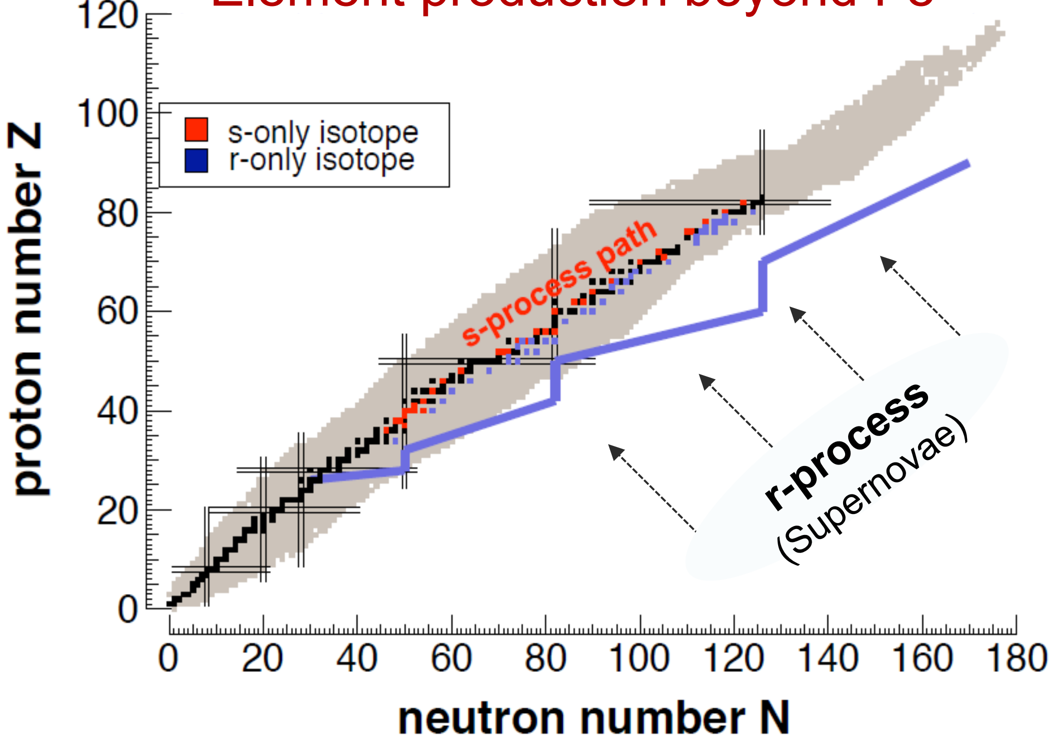


Elements heavier than Fe are the result of neutron capture processes

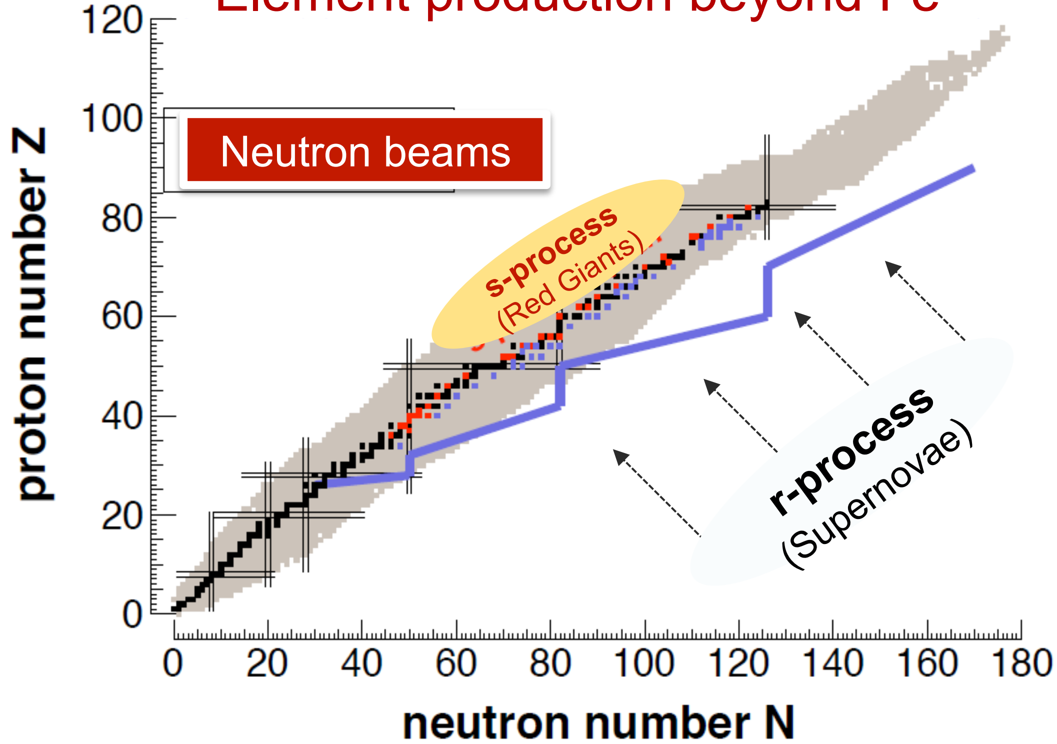
The n_TOF project

Element production beyond Fe



The n_TOF project

Element production beyond Fe

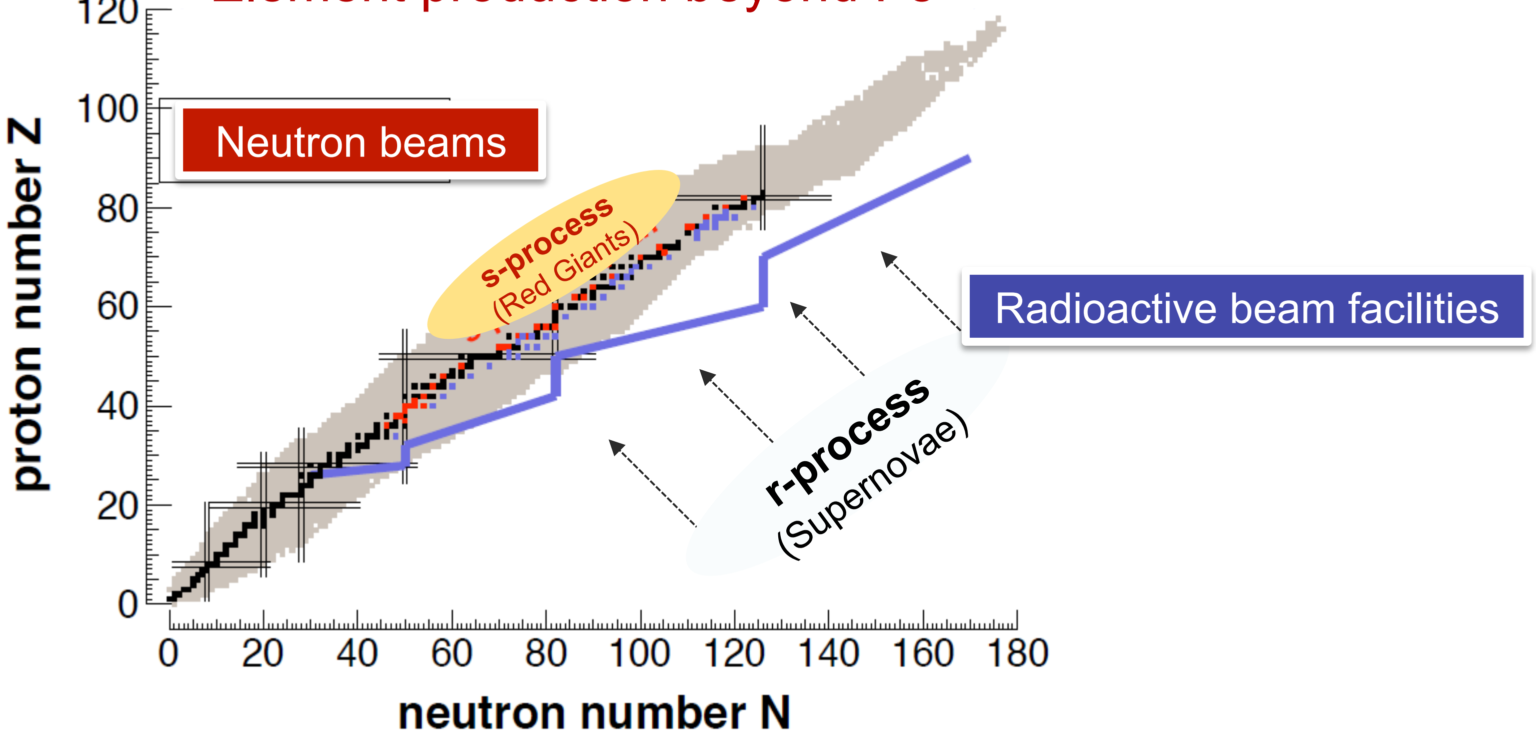


s-process (slow process):

- **Capture times** long relative to decay time
- Involves mostly **stable isotopes**
- $\mathbf{N_n}$ = 10^8 n/cm^3 , $\mathbf{E_n}$ = 0.3 – 300 keV

The n_TOF project

Element production beyond Fe



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- **Capture times** long relative to decay time
- Involves mostly **stable isotopes**
- $\mathbf{N_n}$ = 10^8 n/cm^3 , $\mathbf{E_n}$ = 0.3 – 300 keV

r-process (rapid process):

- **Capture times** short relative to decay times
- Produces **unstable isotopes** (neutron-rich)
- $\mathbf{N_n}$ = $10^{20\text{-}30}$ n/cm^3

The n_TOF project

s-process nucleosynthesis proceeds through **neutron captures** and successive **β-decay.**

The abundance of elements in the Universe depends on:

- **thermodinamic conditions** (temperture and neutron density);
- **neutron capture cross-sections.**

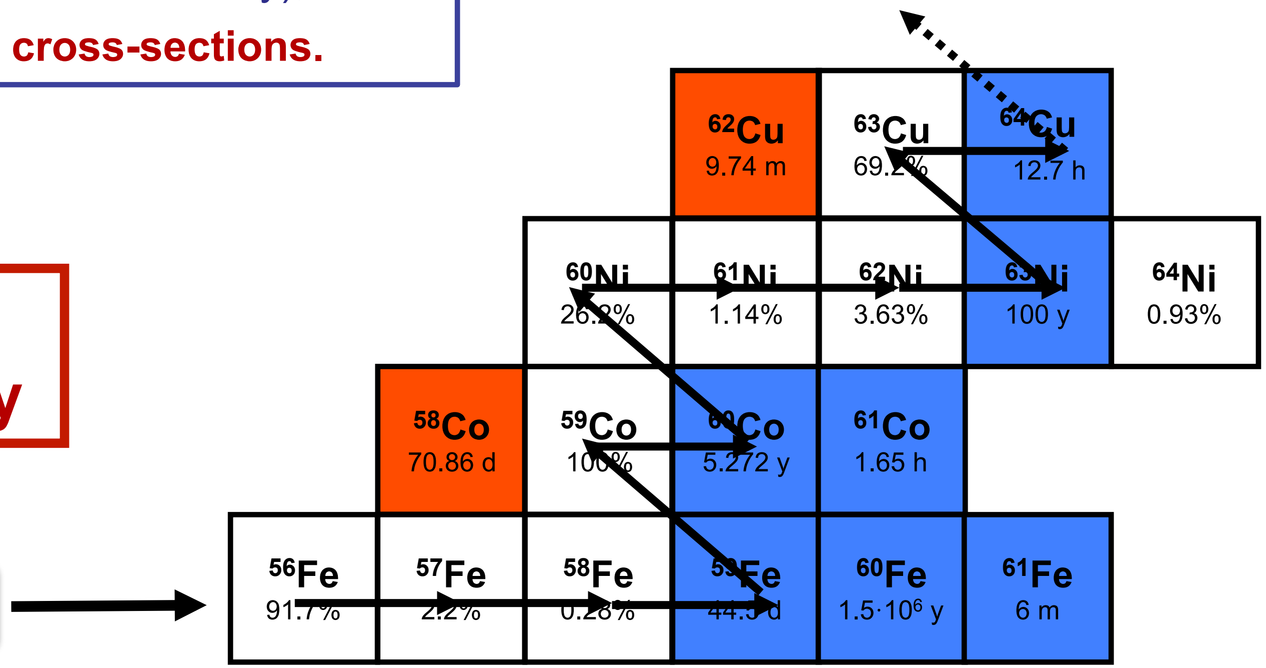
Need of **new** and **accurate** neutron capture cross-sections:

- **refine models** of stellar nucleosynthesis in the Universe;
- obtain information on the **stellar environment and evolution**

σ(n, γ) is a key quantity

s process

Along the β-stability valley



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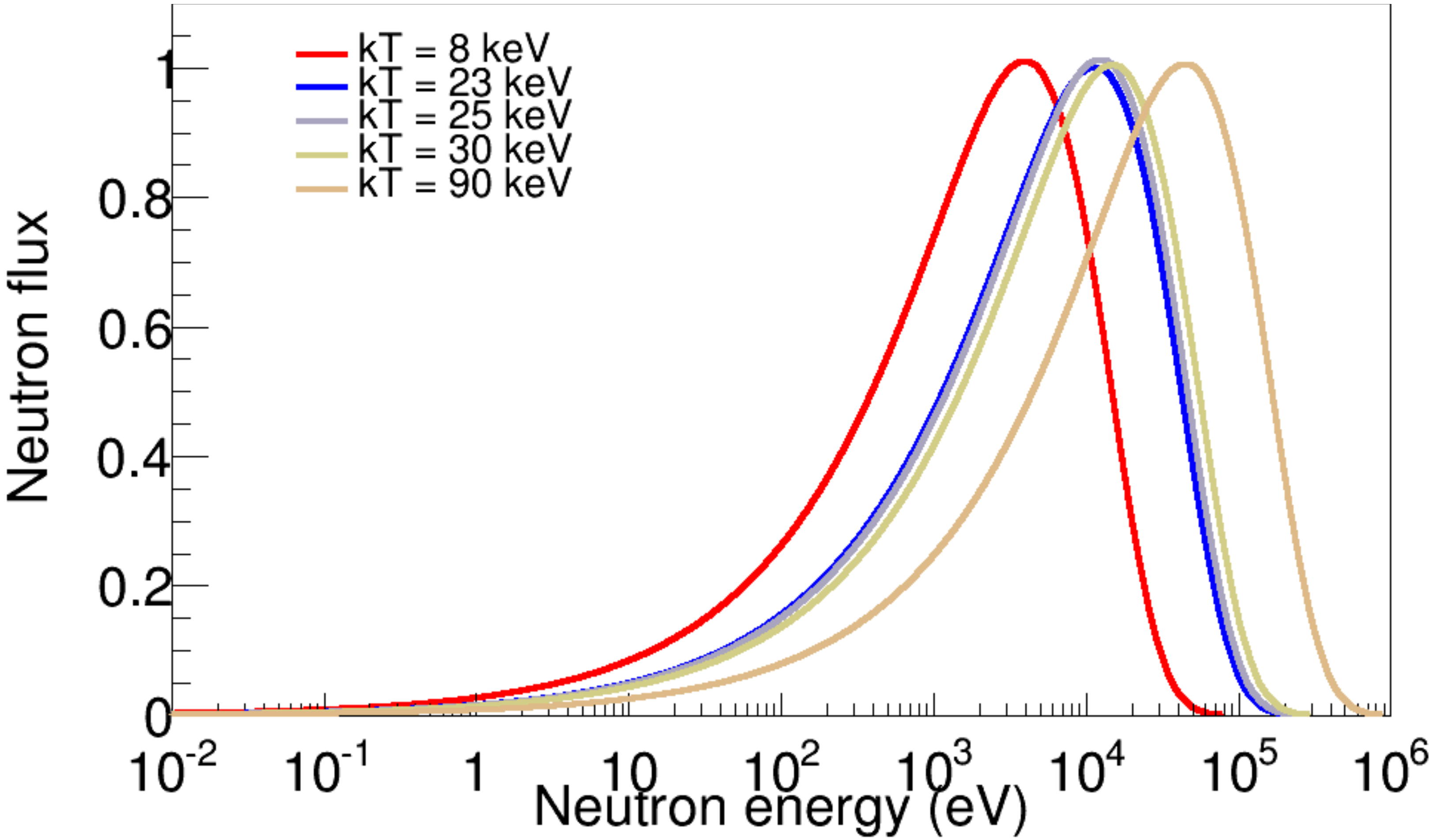
Stellar spectra: AGB (8, 23 keV) and Massive stars (25, 90 keV)



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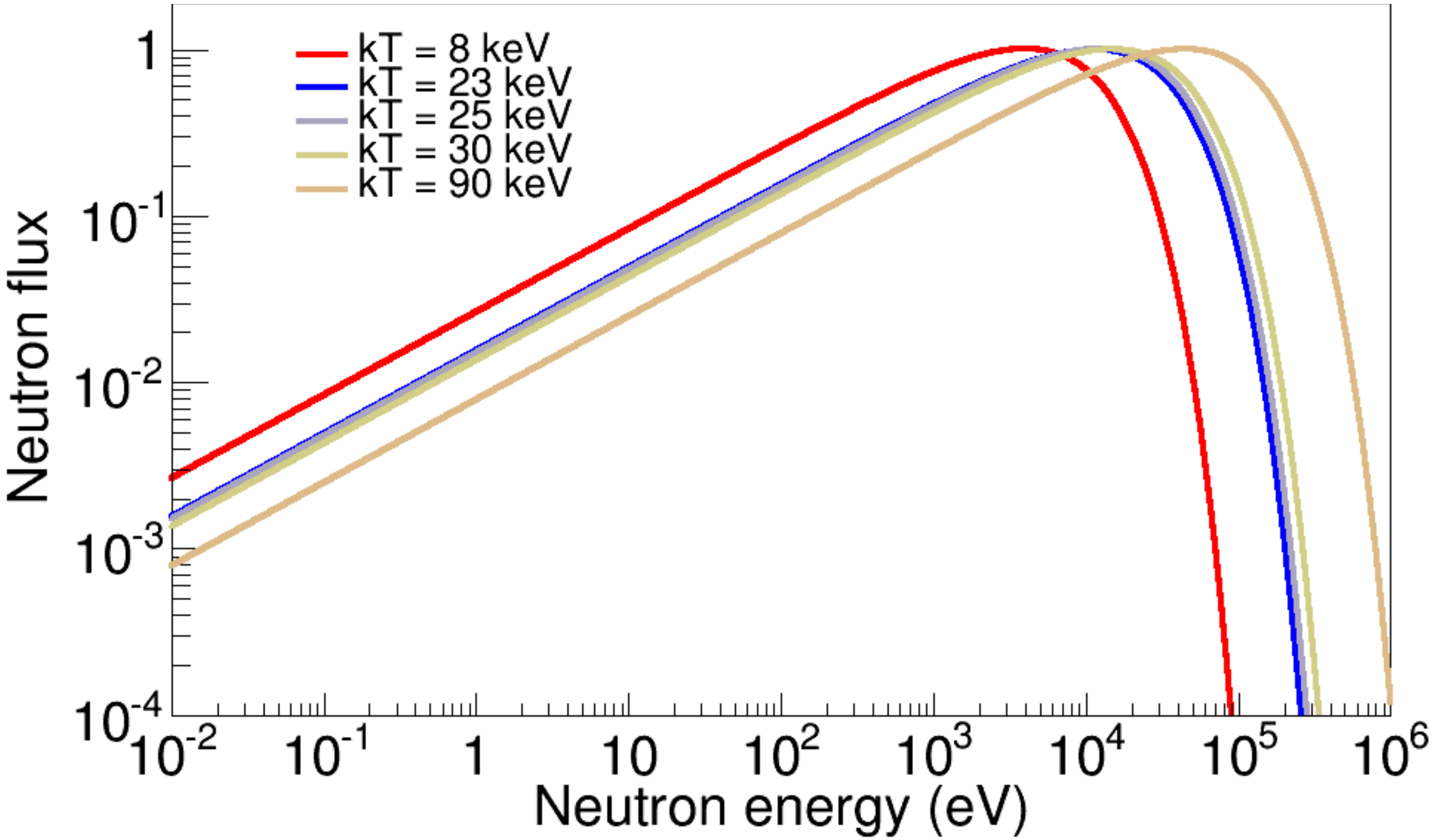

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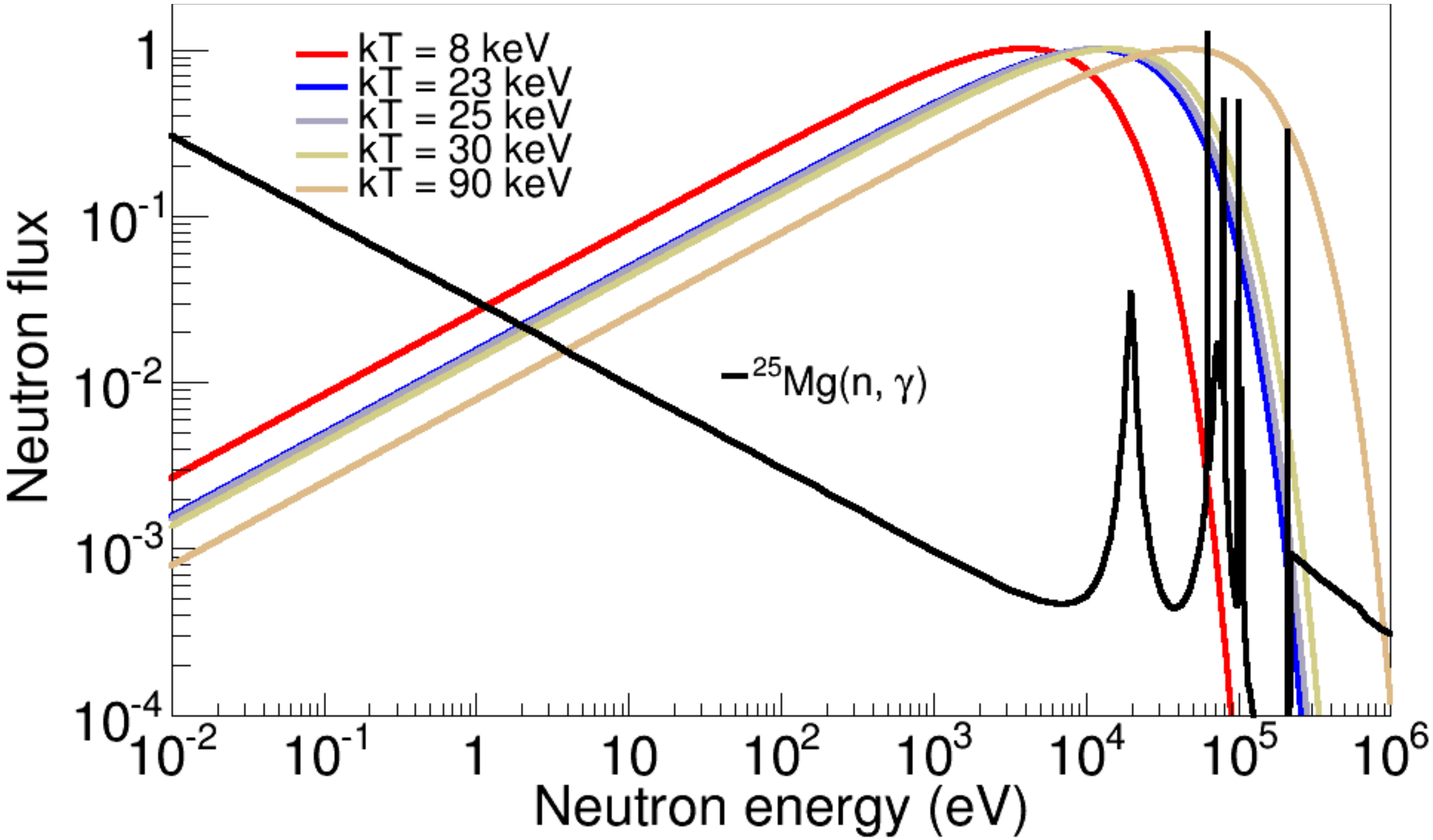
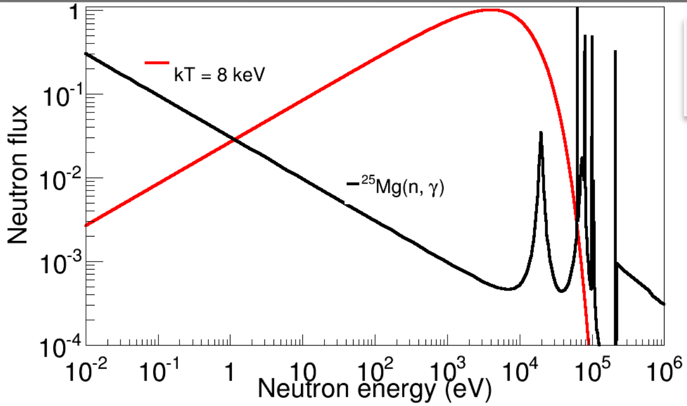


The n_TOF project



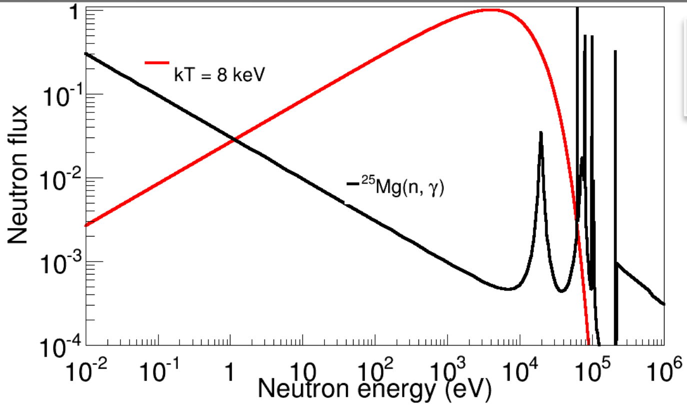
For Astrophysical applications it is important to determine **Maxwellian Averaged Cross-Sections (MACS)**, for various temperatures (kT depends on stellar site).

Reaction rate (cm^{-3}s^{-1}): $r = N_A N_n v \sigma(v)$

$$r = N_A N_n \langle \sigma \cdot v \rangle$$

$$MACS \equiv \frac{\langle \sigma \cdot v \rangle}{v_T} = \frac{2}{\sqrt{\pi}(kT)^2} \int_0^\infty \sigma(E) E e^{-E/(kT)} dE$$

The n_TOF project



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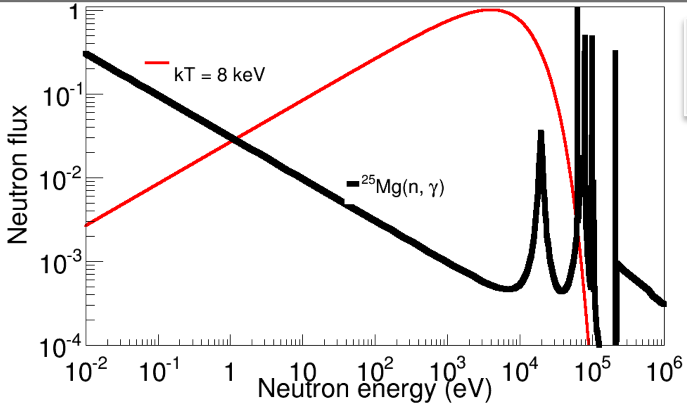
Two methods are used to determine MACS:

The n_TOF project



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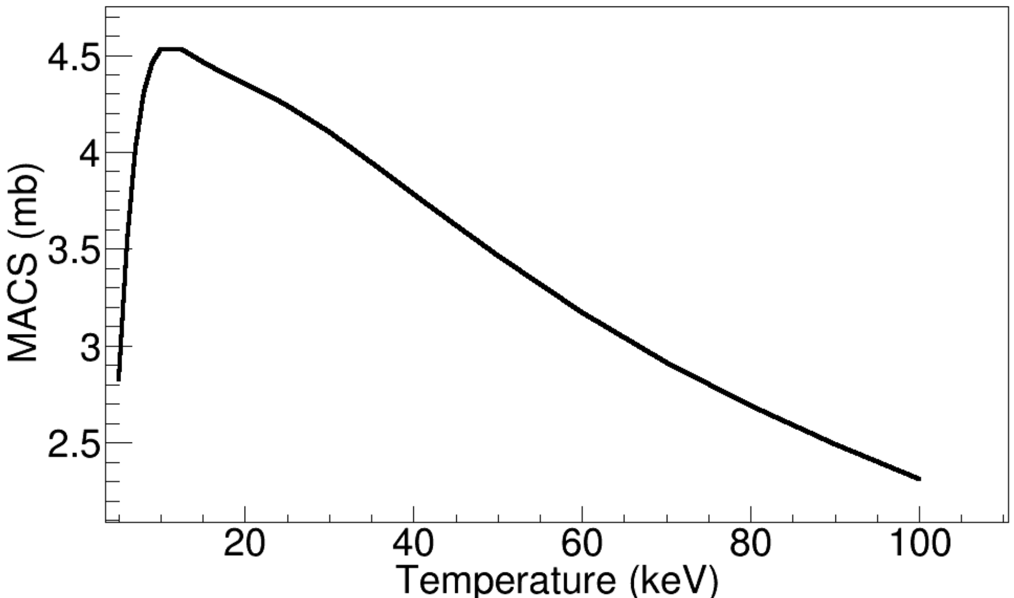
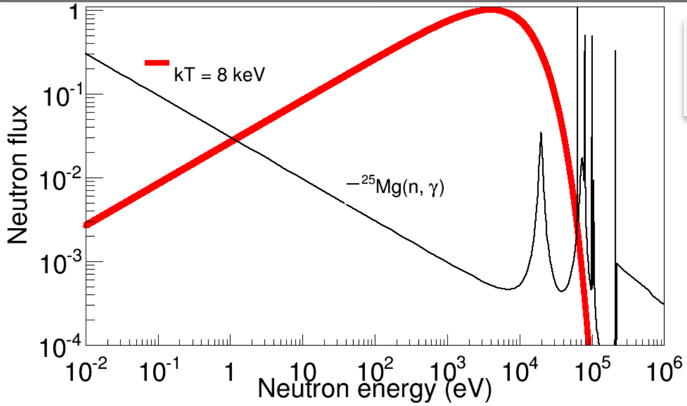
1. measurement of **energy dependent** neutron capture cross-sections;



The n_TOF project



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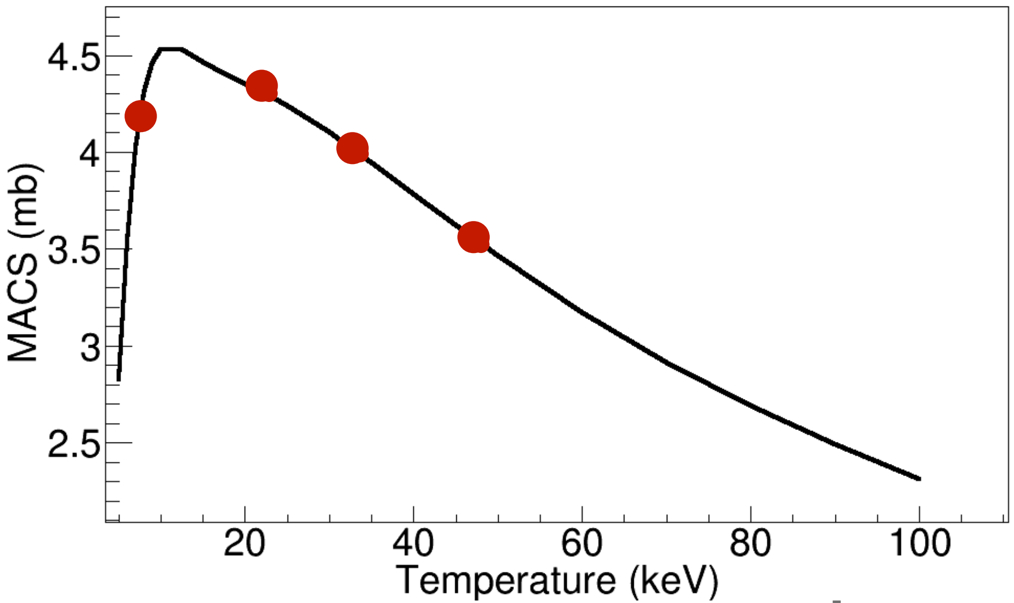
Two methods are used to determine MACS:

1. measurement of **energy dependent** neutron capture cross-sections;
2. **integral measurement** (energy integrated) using neutron beams with suitable energy spectrum.



The n_TOF project

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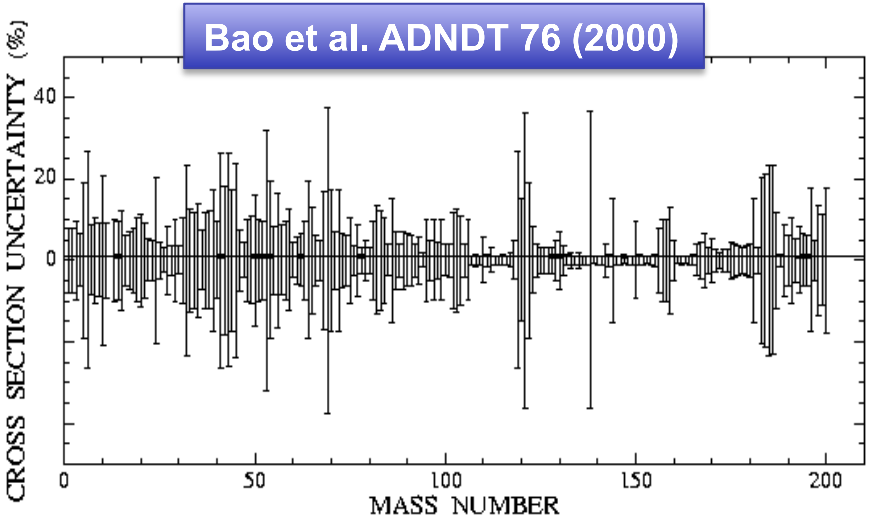
Huge amount of data collected on many isotopes, mostly **stable**. Main features of s-process now **well understood**.

However, cross-section **uncertainties** in some cases remain **high**, in particular if compared with progresses in:

- observations of abundances;
- models of stellar evolution.

Bao et al. ADNDT 76 (2000)

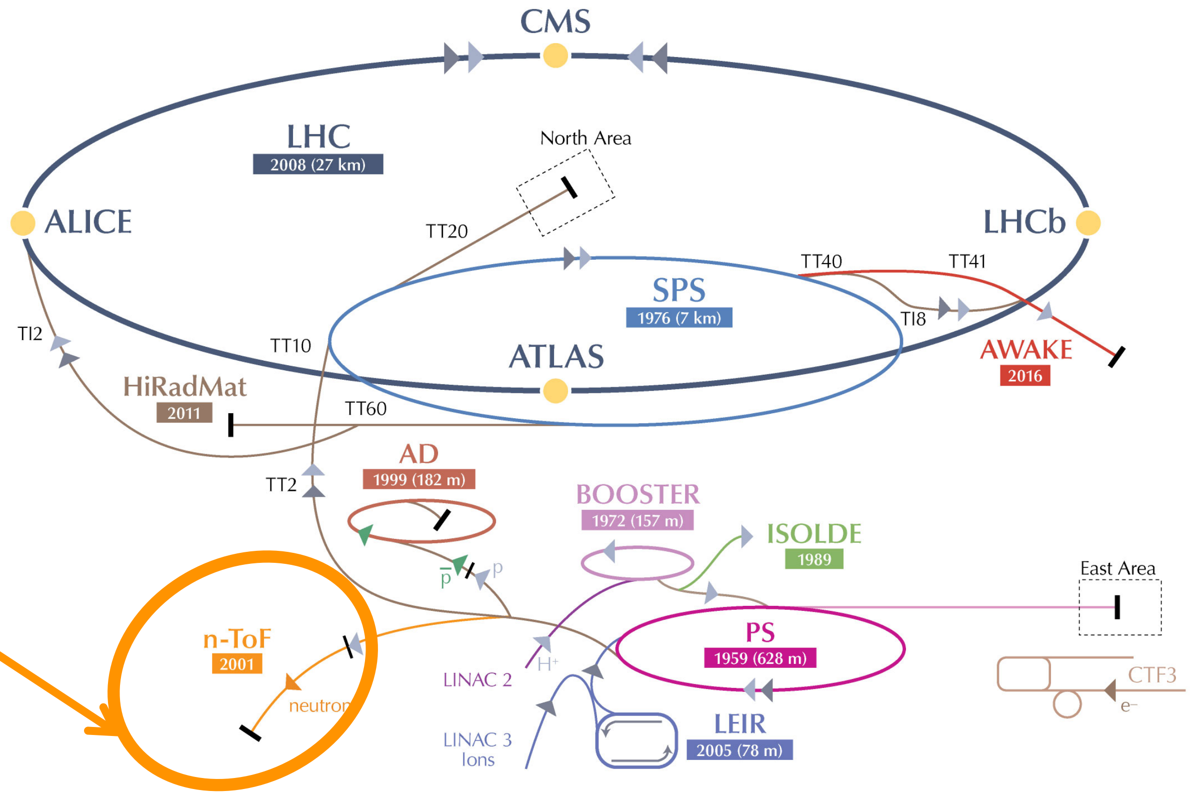


For three classes of nuclei data are lacking or need substantial improvements:

1. Nuclei with **low cross-section**, in particular neutron magic nuclei (s-process bottleneck):
   - **N=50** ^{86}**Kr**, ^{87}**Rb**, ^{88}**Sr**, ^{90}**Zr**
   - **N=82** ^{138}**Ba**, ^{139}**La**, ^{140}**Ce**
2. Isotopes unavailable in large amount, such as rare or expensive isotopes:
   - ^{25,26}**Mg**, ^{186,187}**Os**, ^{180}**W, etc…**
3. Radioactive **branching** isotopes (“stellar thermometers”):
   - ^{79}**Se**, ^{85}**Kr**, ^{151}**Sm**, ^{163}**Ho**, ^{204}**Tl**, ^{205}**Pb**

n_TOF

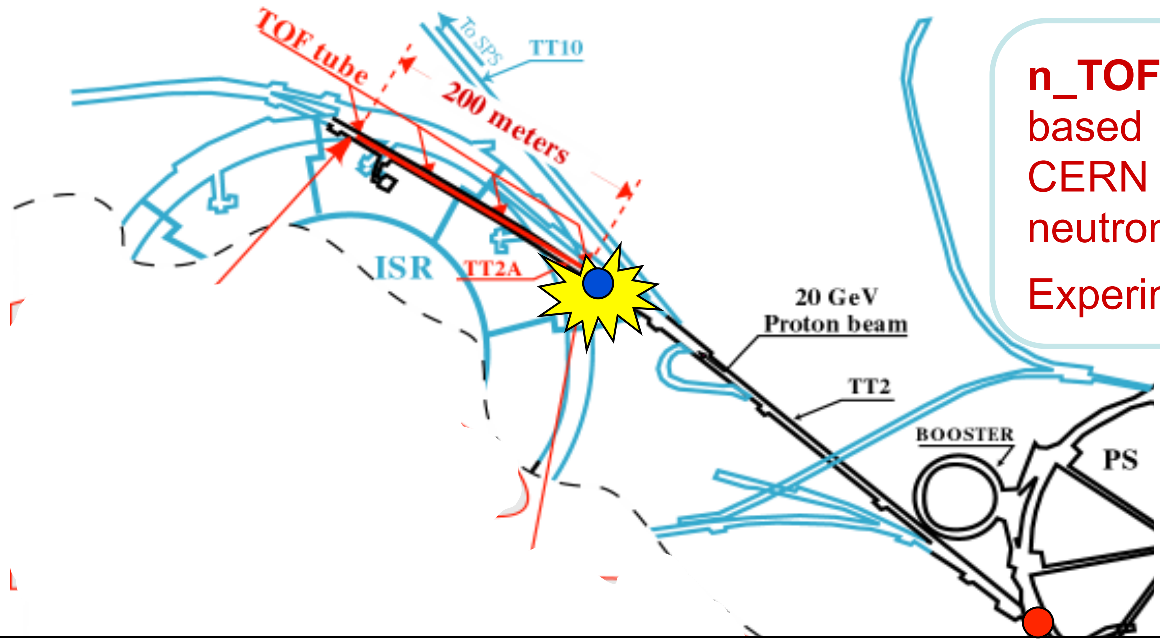
The n_TOF project



Neutron Time-Of- Flight facility: **n_TOF**

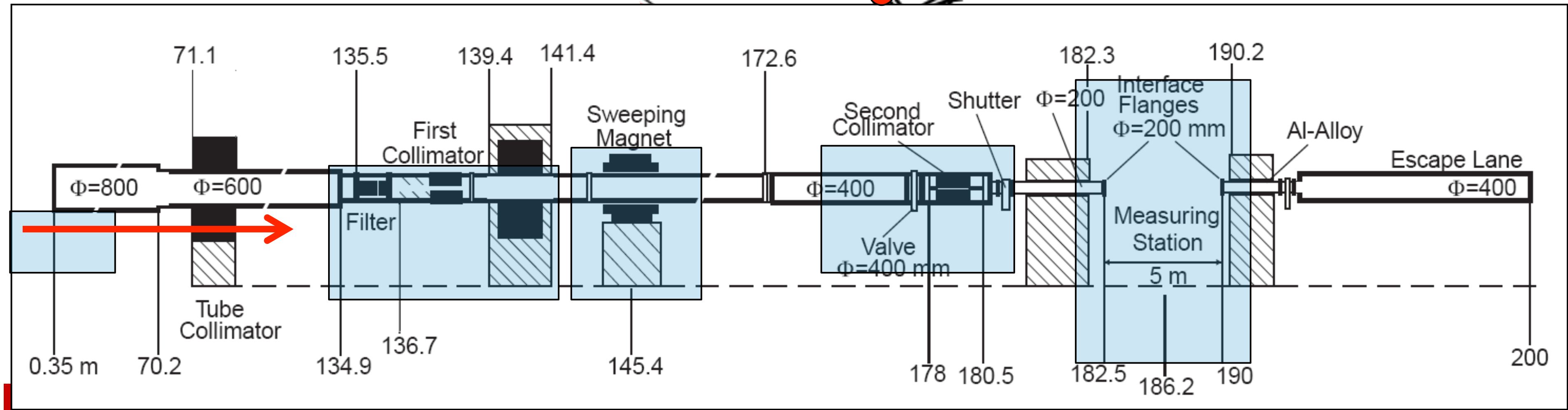
The n_TOF project

Istituto Nazionale di Fisica Nucleare



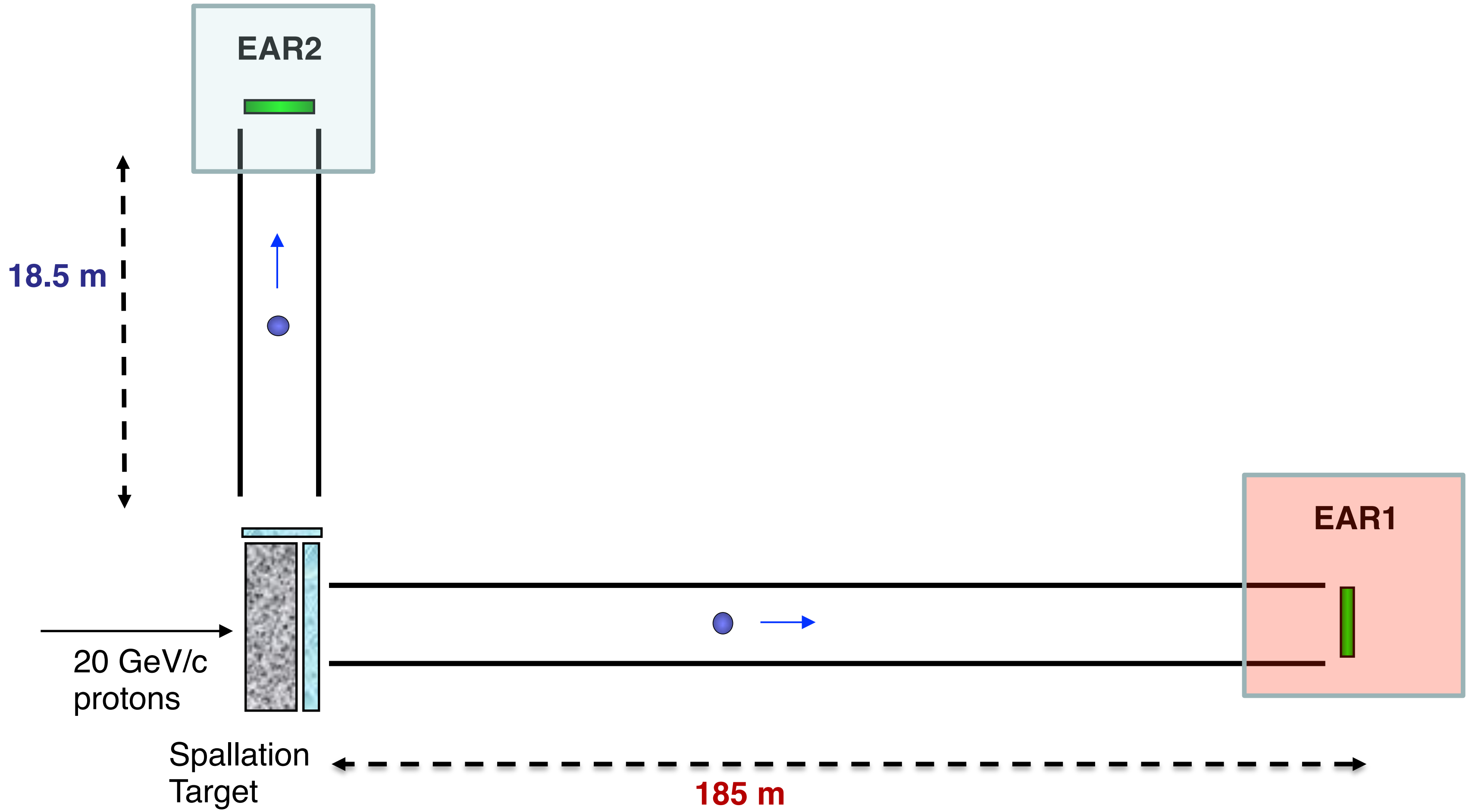
n_TOF is a **spallation** neutron source based on **20 GeV/c protons** from the CERN PS hitting a **Pb block** (~300 neutrons per proton and ~ $7x10^{12}$ ppp).

Experimental area at **185 m** and **18.5 m**.



The n_TOF project

The advange of n_TOF are a direct consequence of the characteristics of the **PS proton beam**: **high energy, high peak current, low duty cycle.**



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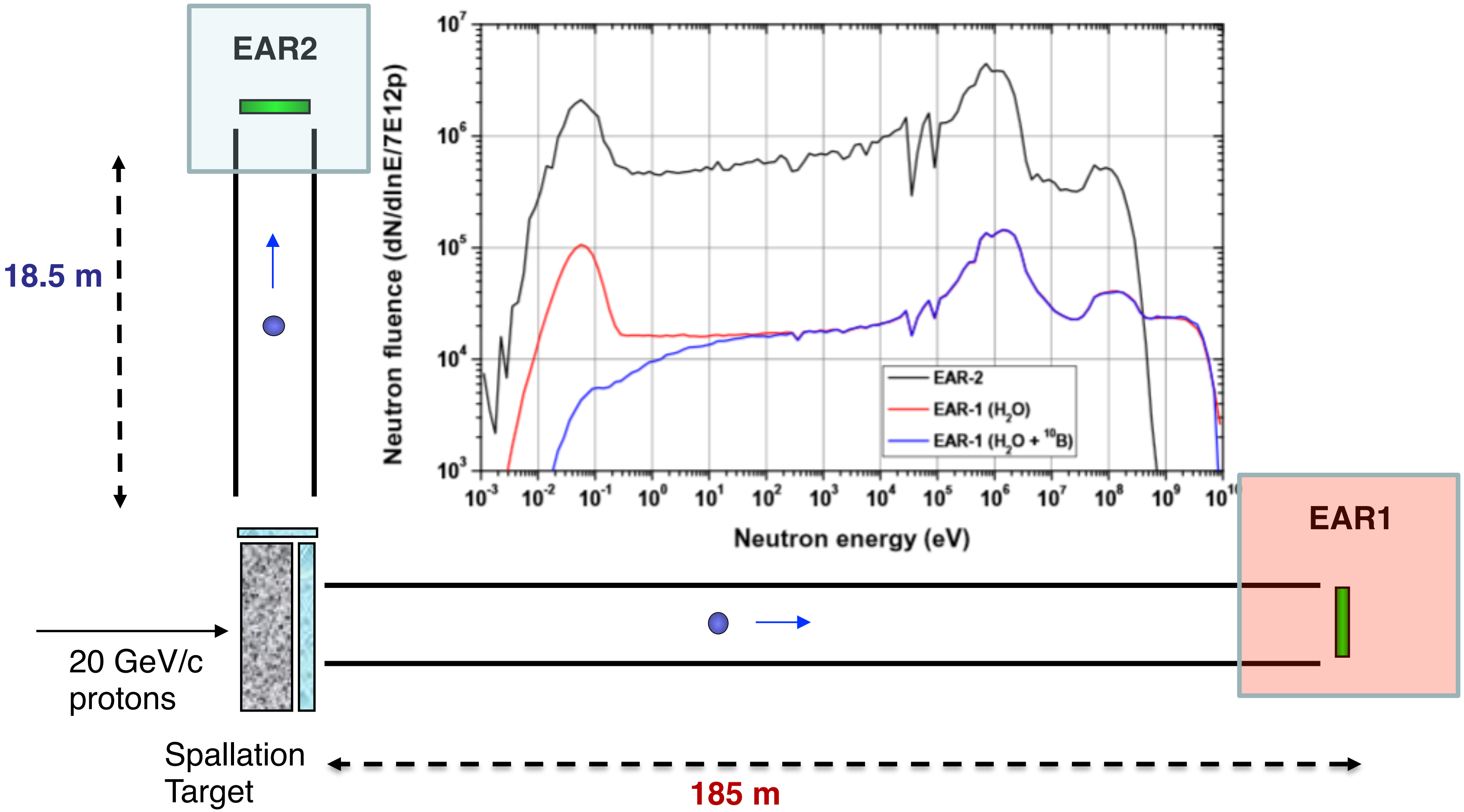

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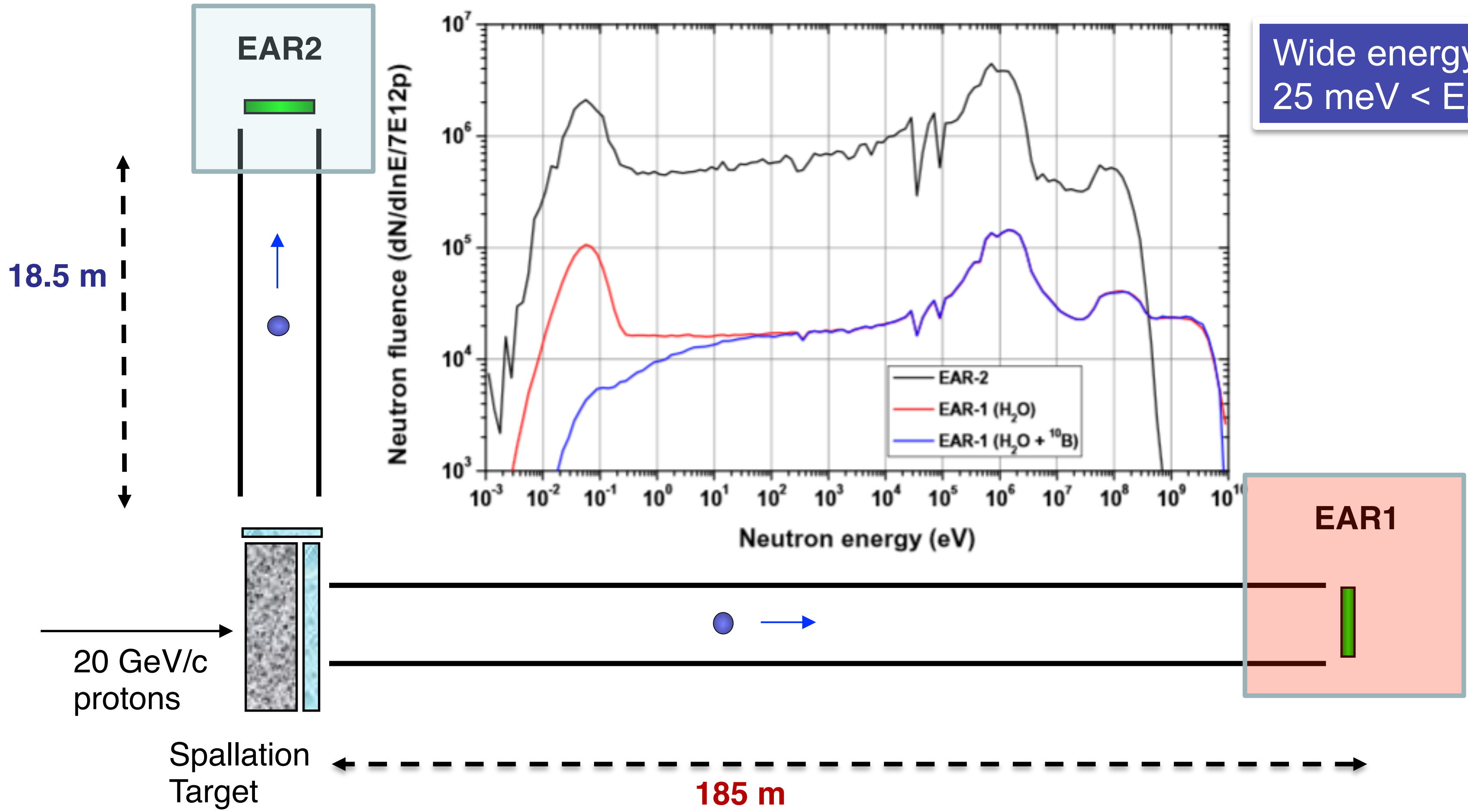
Wide energy range:
25 meV < E_n < 1 GeV



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INFN Istituto Nazionale di Fisica Nucleare

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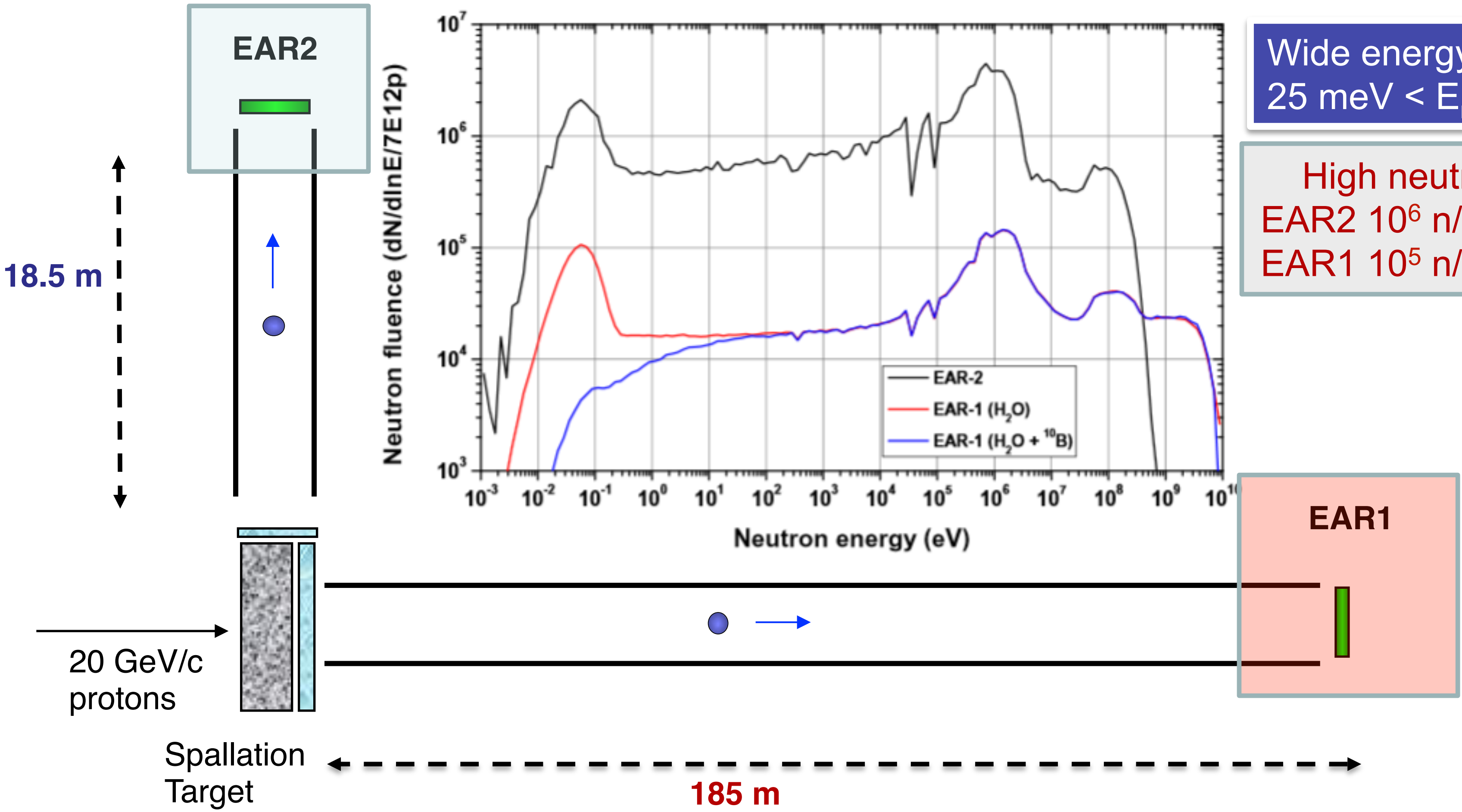

Wide energy range:
25 meV < E_n < 1 GeV

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

The n_TOF project

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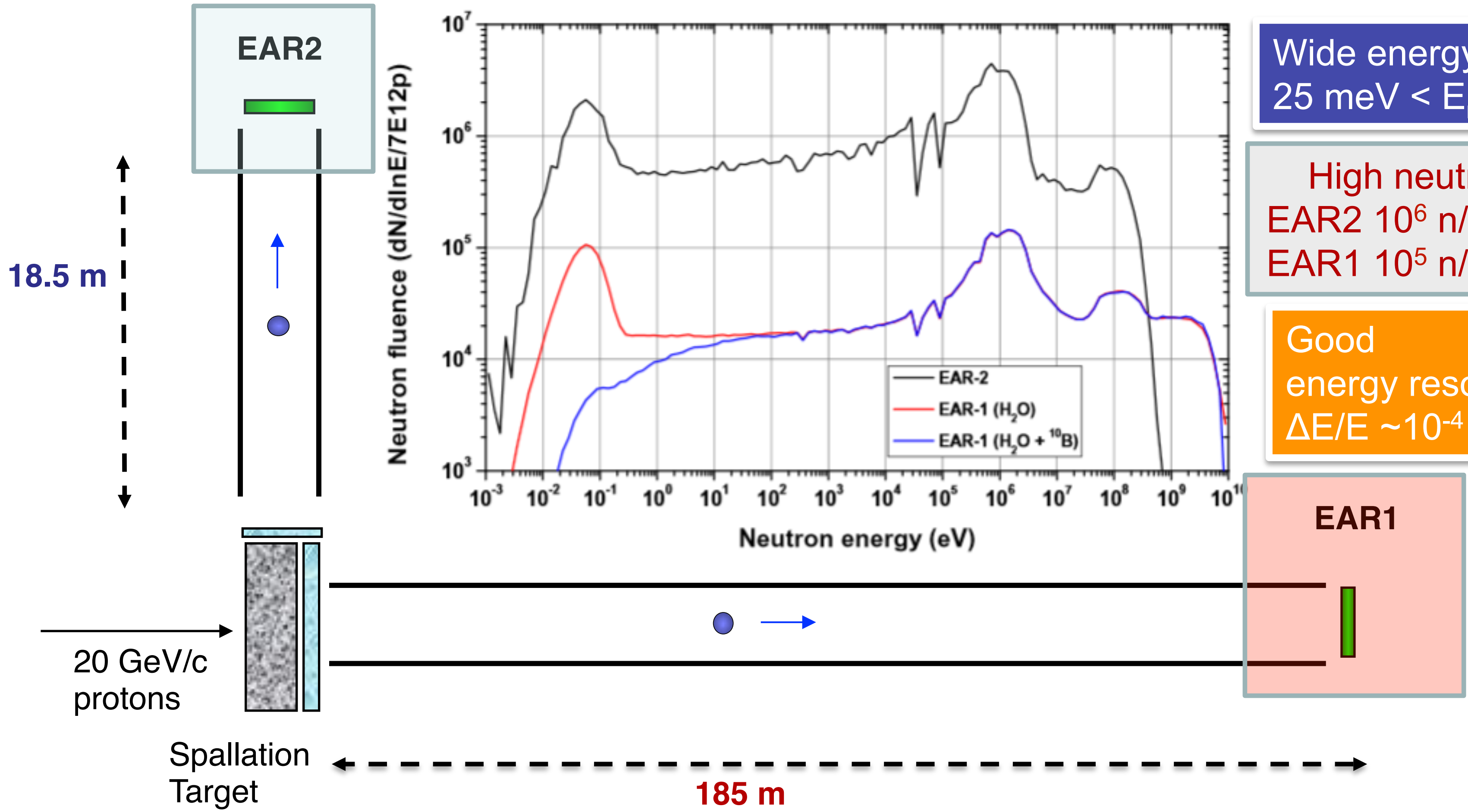


Wide energy range: 25 meV < E_n < 1 GeV

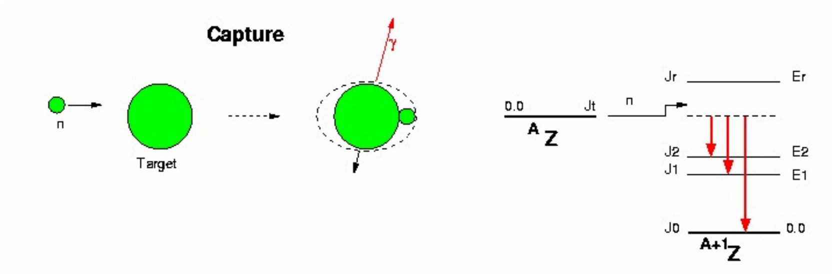
High neutron flux
EAR2 10^6 n/cm^2/pulse
EAR1 10^5 n/cm^2/pulse

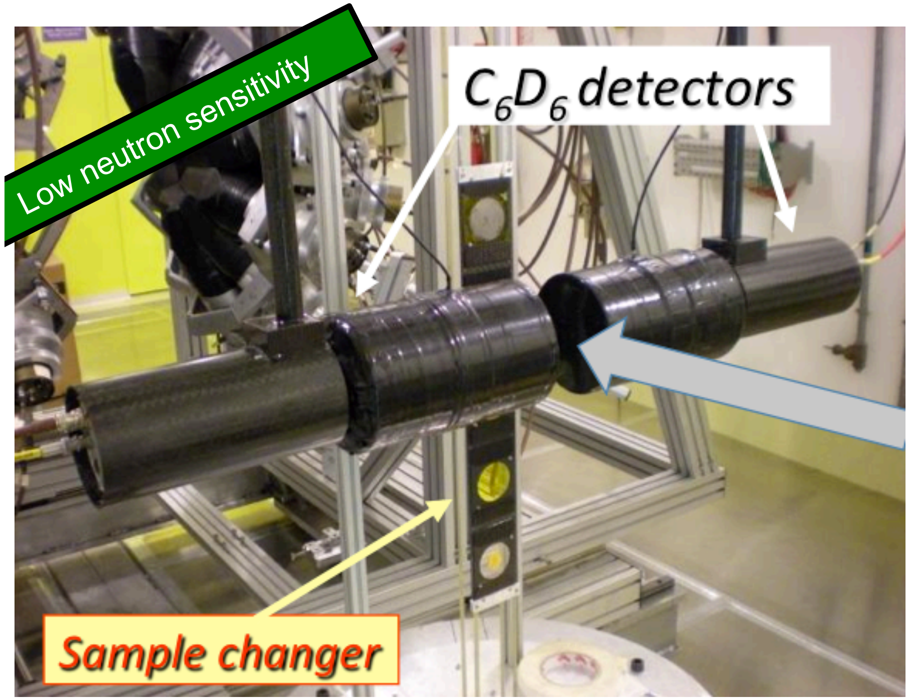
Good energy resolution
$\Delta E/E \sim 10^{-4}$ @ EAR1

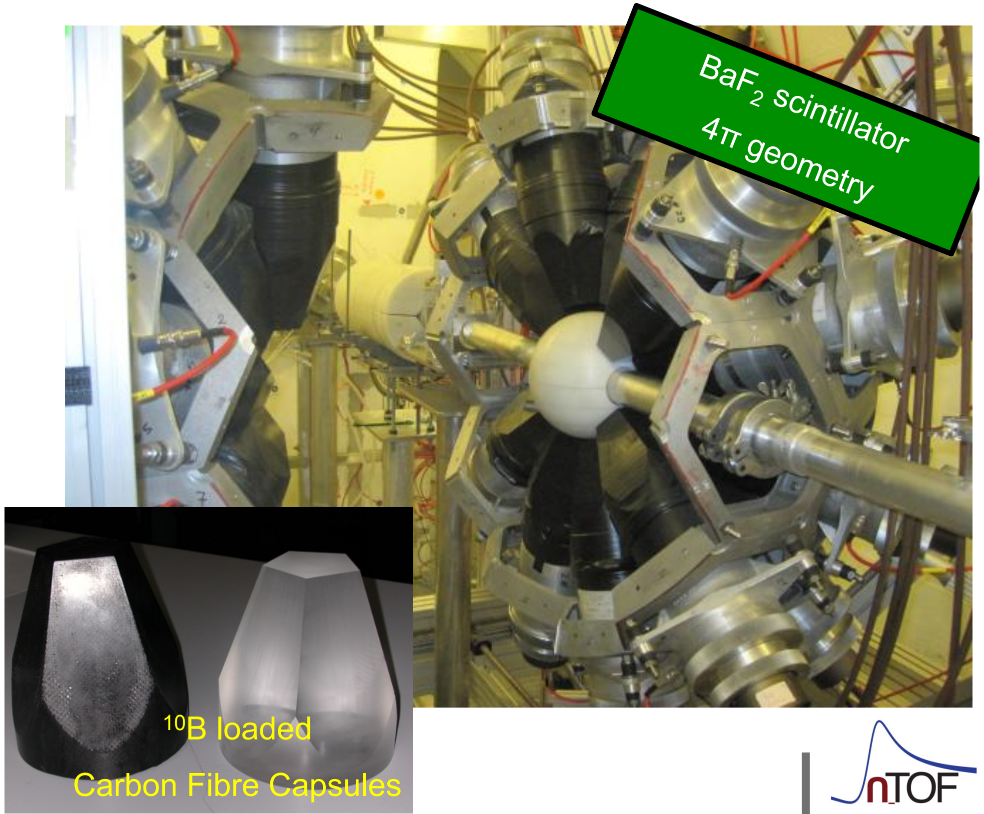
The n_TOF project

Detectors for (n, γ) reaction

Capture reactions are measured by detecting γ-rays emitted in the de-excitation process. **Two different systems**, to minimize different types of background







LNL @ n_TOF

Detector for (n, γ) reaction

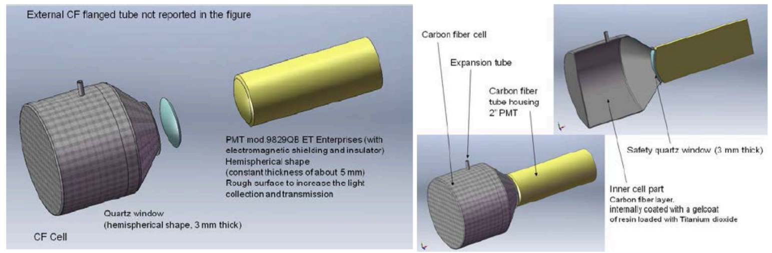
n_TOF Internal Report (June 2013)

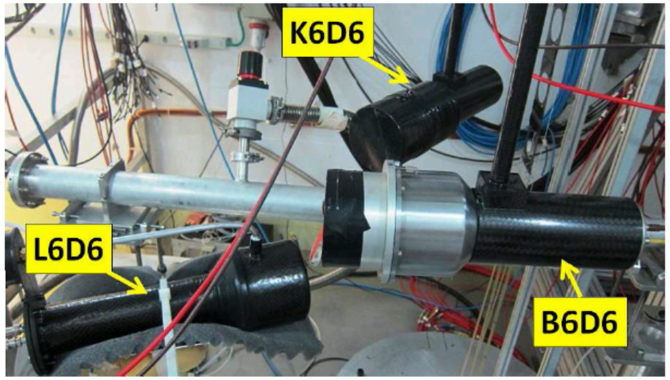
New C_6D_6 detectors: reduced neutron sensitivity and improved safety

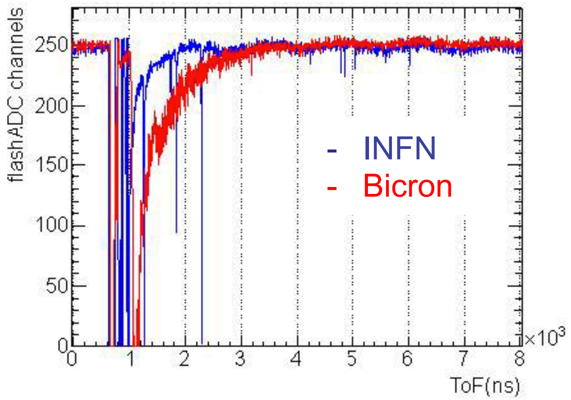
P.F. Mastinu[1], R. Baccomi[2], E. Berthoumieux[3], D. Cano-Ott[4], F. Gramegna[1], C. Guerrero[5], C. Massimi[6], P.M. Milazzo[2], F.Mingrone[6], J. Praena[7], G. Prete[1], A.R. García[4]

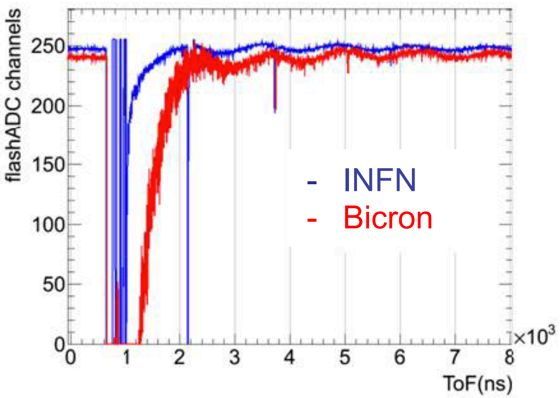
[1] Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali di Legnaro, Italy
[2] Istituto Nazionale di Fisica Nucleare (INFN), Trieste, Italy
[3] CEA, Irfu, Gif-sur-Yvette, France
[4] Centro de Investigaciones Energeticas Medioambientales y Technologicas, Madrid, Spain
[5] CERN, European Organization for Nuclear Resarch, Geneva, Switzerland
[6] Dipartimento di Fisica e Astronomia, Università di Bologna and Sezione INFN di Bologna, Italy
[7] Universidad de Sevilla, Spain

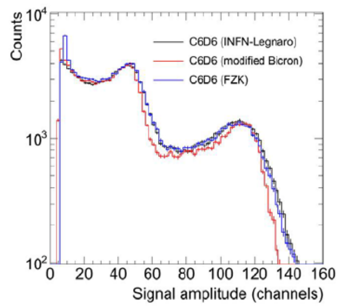
(The n_TOF Collaboration, http://cern.ch/nTOF)







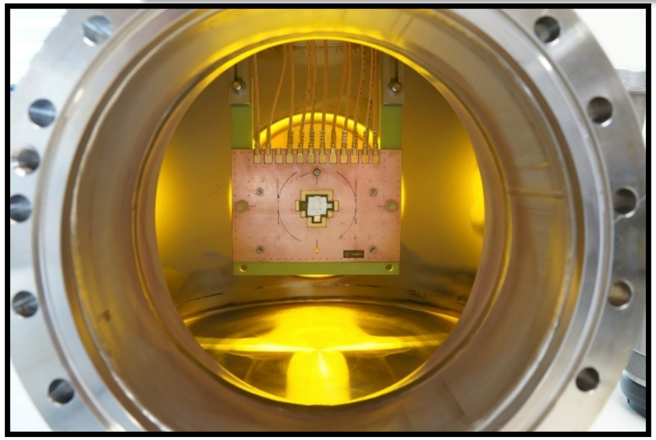




The n_TOF project

Detectors: (n, p) and (n, α) reactions

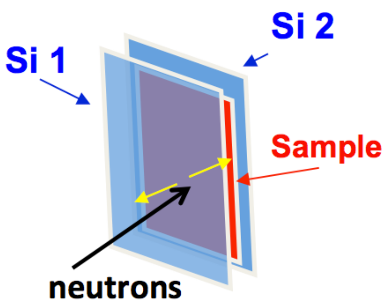
Gas and solid state detectors are used for detecting charged particles, depending on the energy region of interest and the Q-value of the reaction



Silicon detectors
Silicon sandwich
Diamond detector
ΔE-E Telescopes

Micromegas chamber

- low-noice, high-gain, radiation-hard detector



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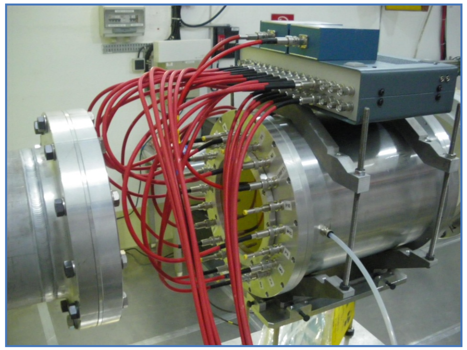
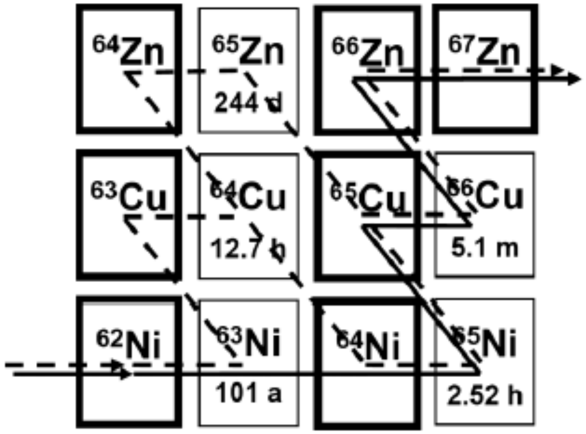


The case of ^{63}Ni

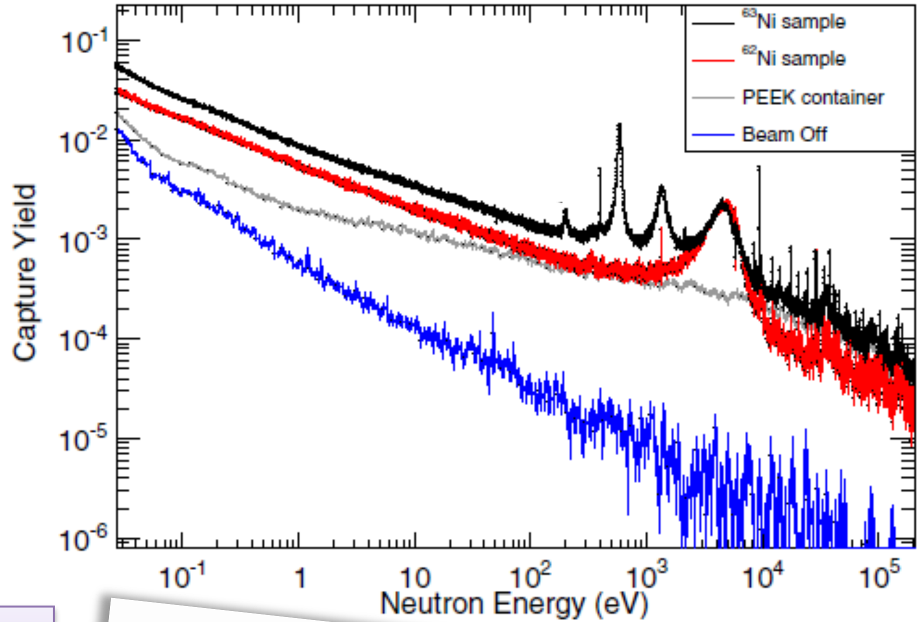


^{63}Ni ($t_{1/2}$=100 y) represents the **first branching point** in the s-process, and determines the **abundance** of **^{63,65}Cu**

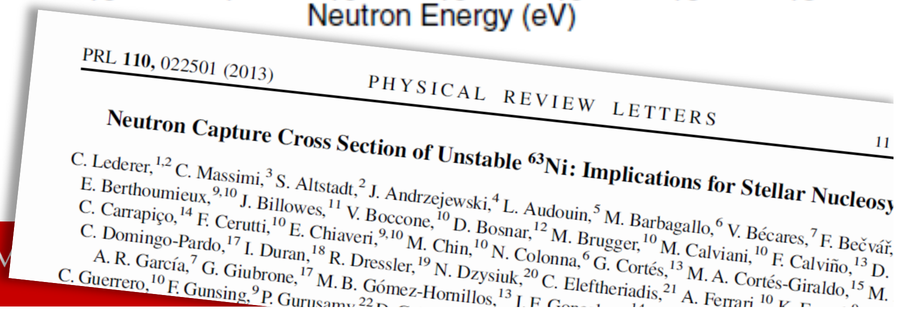
^{62}Ni sample (1g) irradiated **in thermal reactor** (1984 and 1992), leading to enrichment in **^{63}Ni** of **~13 %** (131 mg)

In 2011 ~ **15.4 mg ^{63}Cu** in the sample (from ^{63}Ni decay).

After **chemical** separation at PSI, **^{63}Cu** contamination <**0.01 mg**



First high-resolution measurement of ^{63}Ni(n, γ) in the astrophysical energy range.


PRL **110,** 022501 (2013) PHYSICAL REVIEW LETTERS

Neutron Capture Cross Section of Unstable ^{63}Ni: Implications for Stellar Nucleosy

C. Lederer,[1,2] C. Massimi,[3] S. Altstadt,[2] J. Andrzejewski,[4] L. Audouin,[5] M. Barbagallo,[6] V. Bécares,[7] F. Bečvář, E. Berthoumieux,[9,10] J. Billowes,[11] V. Boccone,[10] D. Bosnar,[12] M. Brugger,[10] M. Calviani,[10] F. Calviño,[13] D. C. Carrapiço,[14] F. Cerutti,[10] E. Chiaveri,[9,10] M. Chin,[10] N. Colonna,[6] G. Cortés,[13] M. A. Cortés-Giraldo,[15] M. C. Domingo-Pardo,[17] I. Duran,[18] R. Dressler,[19] N. Dzysiuk,[20] C. Eleftheriadis,[21] A. Ferrari,[10] A. R. García,[7] G. Giubrone,[17] M. B. Gómez-Hornillos,[13] C. Guerrero,[10] F. Gunsing,[9] P. Gurusamy,

The case of ^{25}Mg

Constraints for the $^{22}Ne(\alpha, n)^{25}Mg$ reaction

Element	**Spin/ parity**
^{22}Ne	0^+
^{4}He	0^+

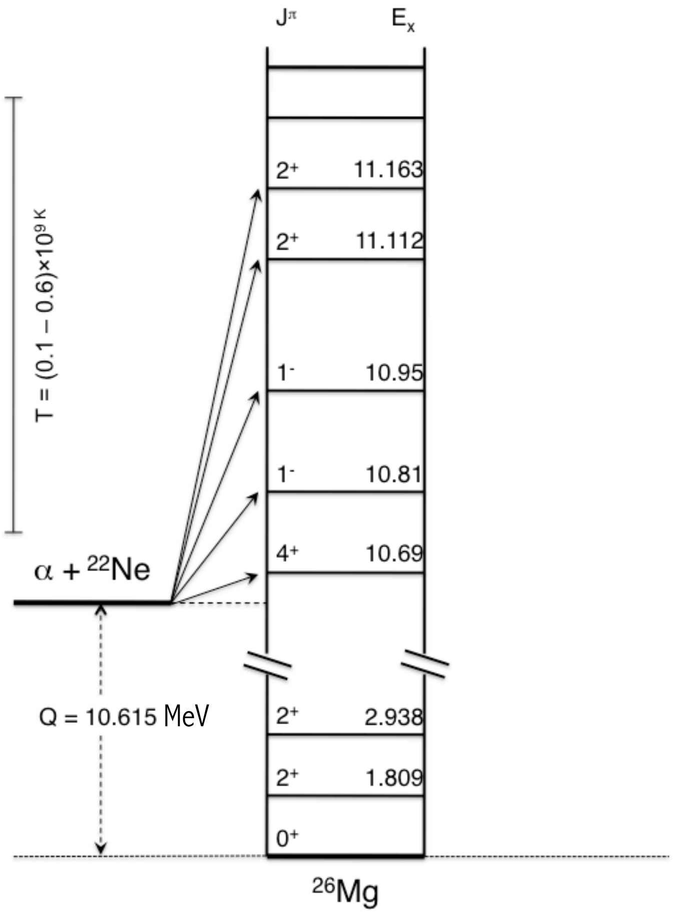
Only **natural-parity states in ^{26}Mg** can participate in the $^{22}Ne(\alpha, n)^{25}Mg$ reaction

$$\vec{J} = \underbrace{\vec{I} + \vec{i}}_{} + \vec{\ell}$$

$$\vec{J} = 0 + \vec{\ell}$$

$$\pi = (-1)^{\ell}$$

$J^{\pi} = 0^+, 1^-, 2^+, 3^-, 4^+ \ldots$



The case of ^{25}Mg

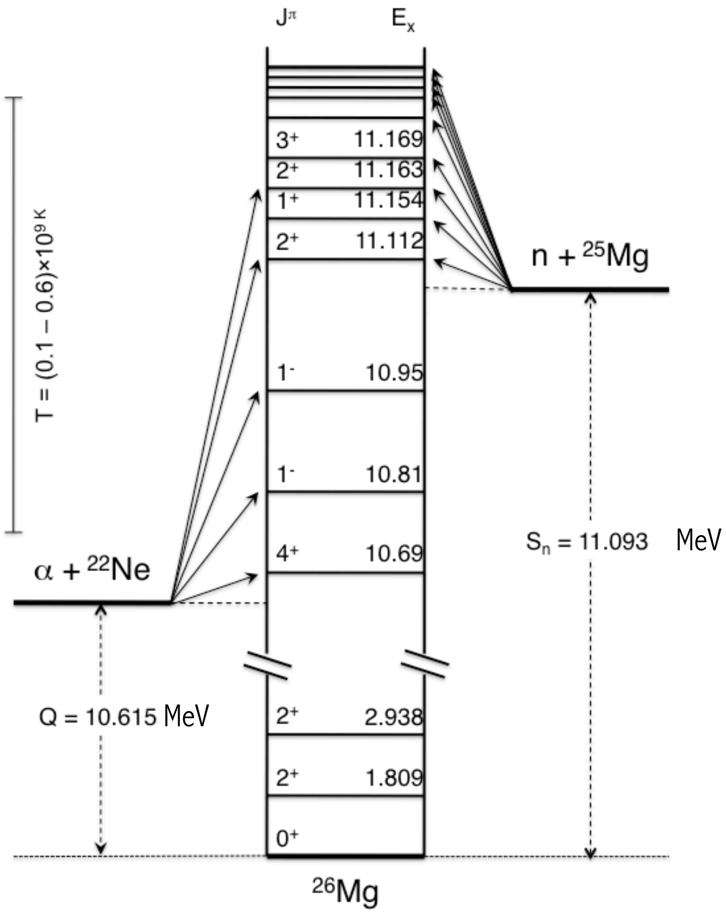
Constraints for the ^{22}Ne(α, n)^{25}Mg reaction

Element	Spin/ parity
^{25}Mg	$5/2^+$
neutron	$1/2^+$

$$\vec{J} = \underbrace{\vec{I} + \vec{i}}_{} + \vec{\ell}$$

$$\vec{J} = 2 + \vec{\ell} \qquad \vec{J} = 3 + \vec{\ell}$$

s-wave → J^π= **2⁺**, 3⁺
p-wave → J^π= **1⁻**, 2⁻, **3⁻**, 4⁻
d-wave → J^π= **0⁺**, 1⁺, **2⁺**, 3⁺, **4⁺**, 5⁺
States in ^{26}Mg populated by ^{25}Mg+n reaction



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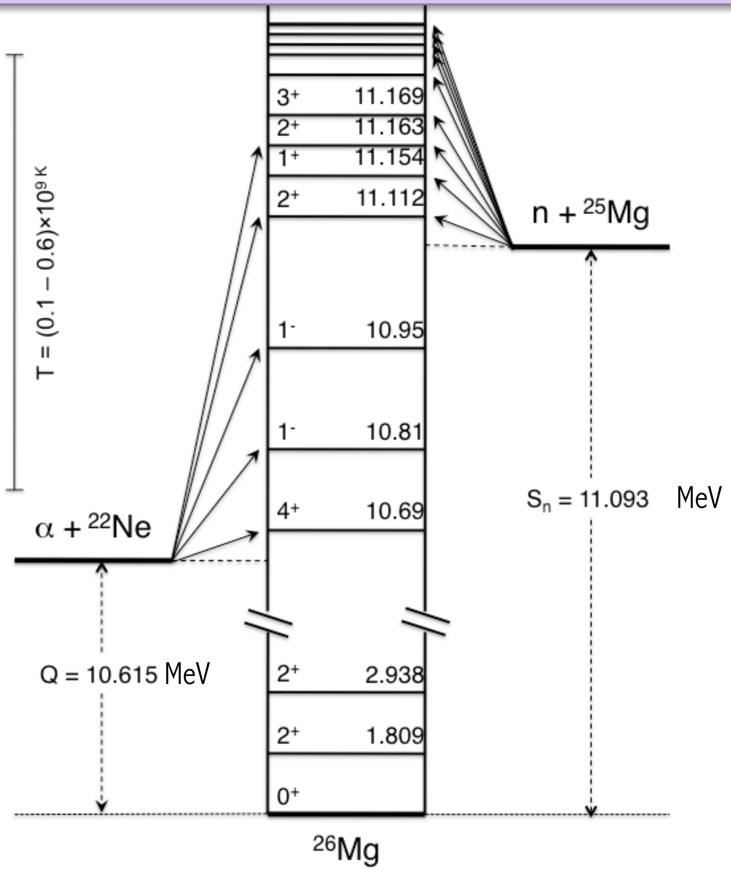
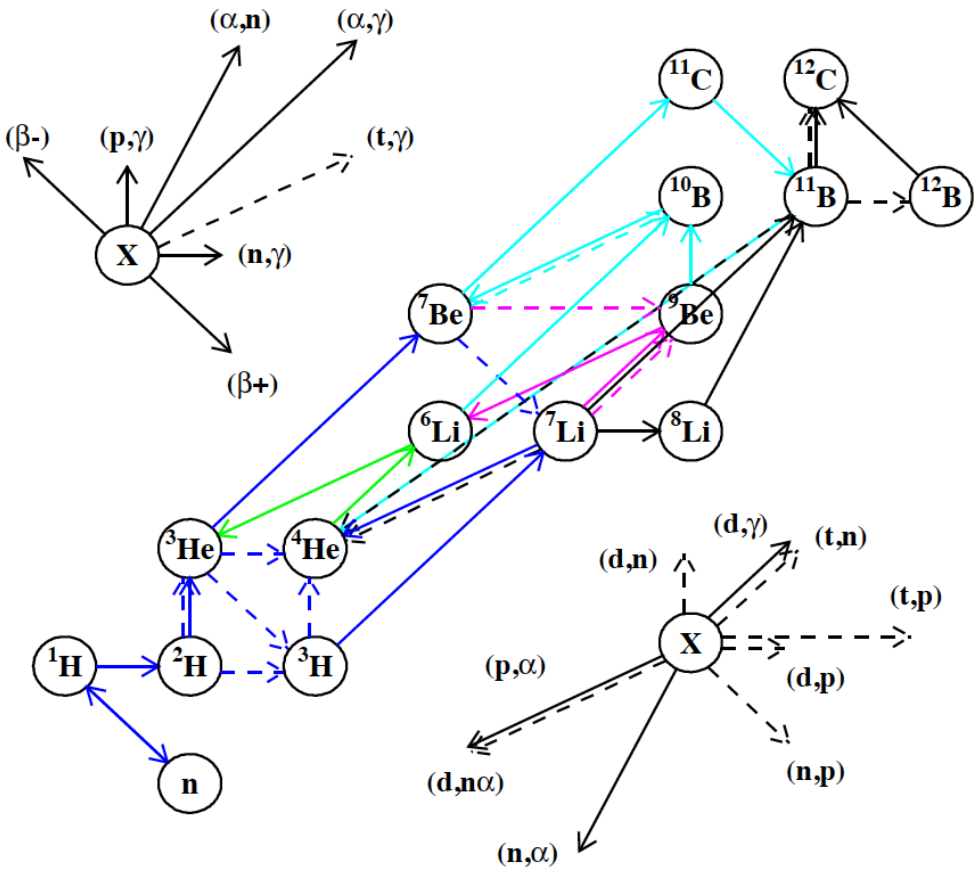
States in ^{26}Mg populated by ^{25}Mg+n reaction

Experimental **evidence** of **natural spin parity** states in the energy region of interest



The case of ^{7}Li

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**



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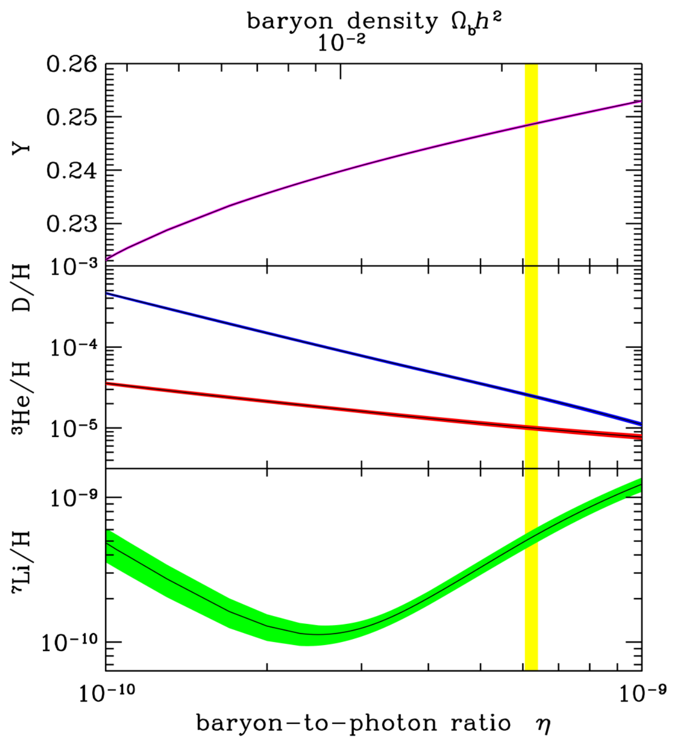

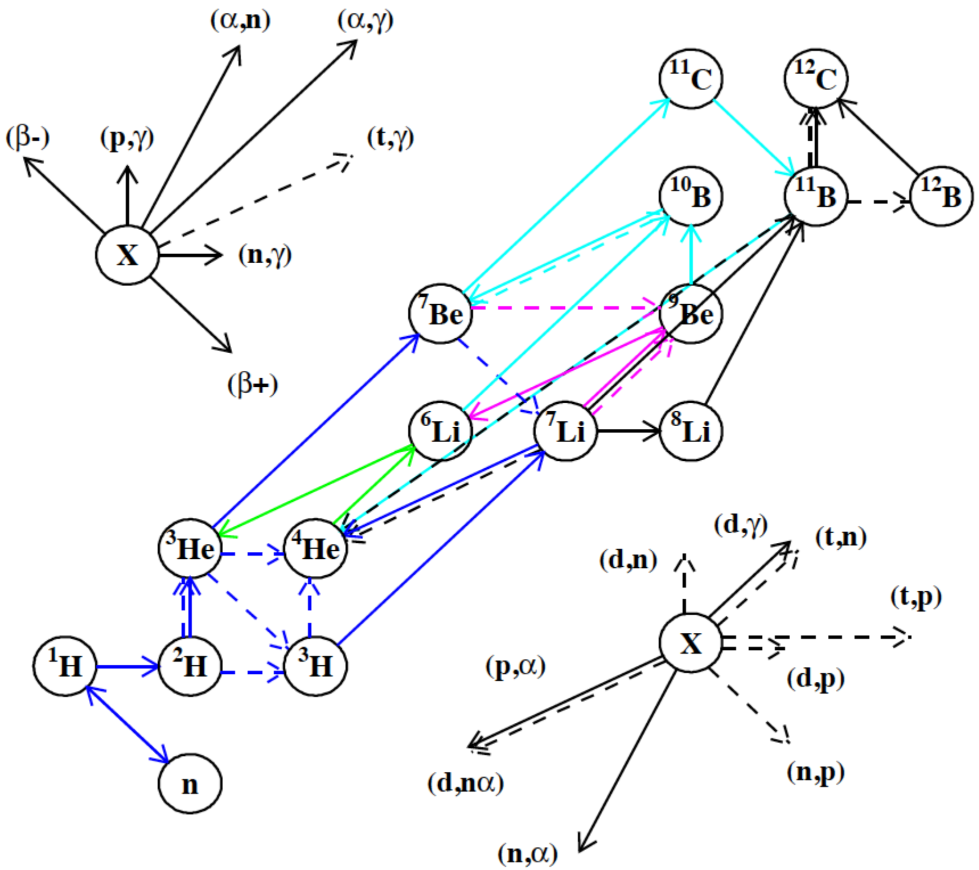

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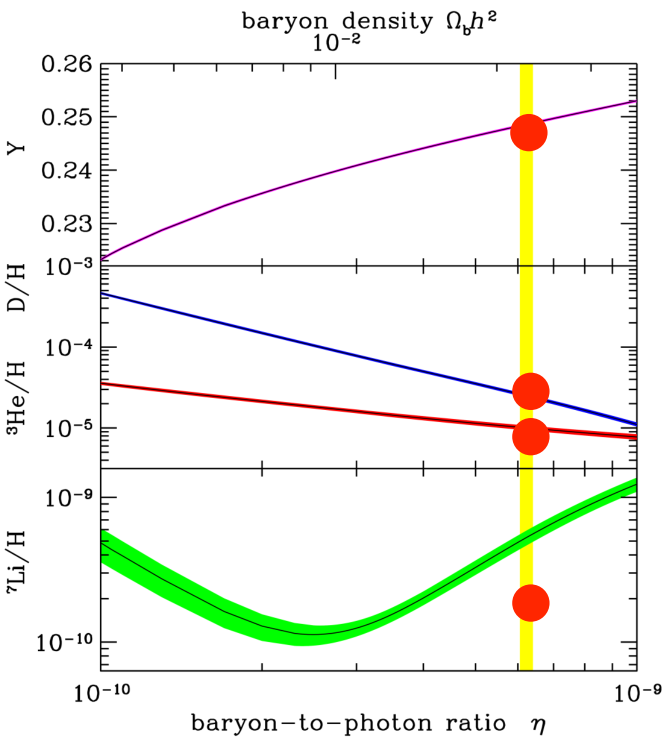

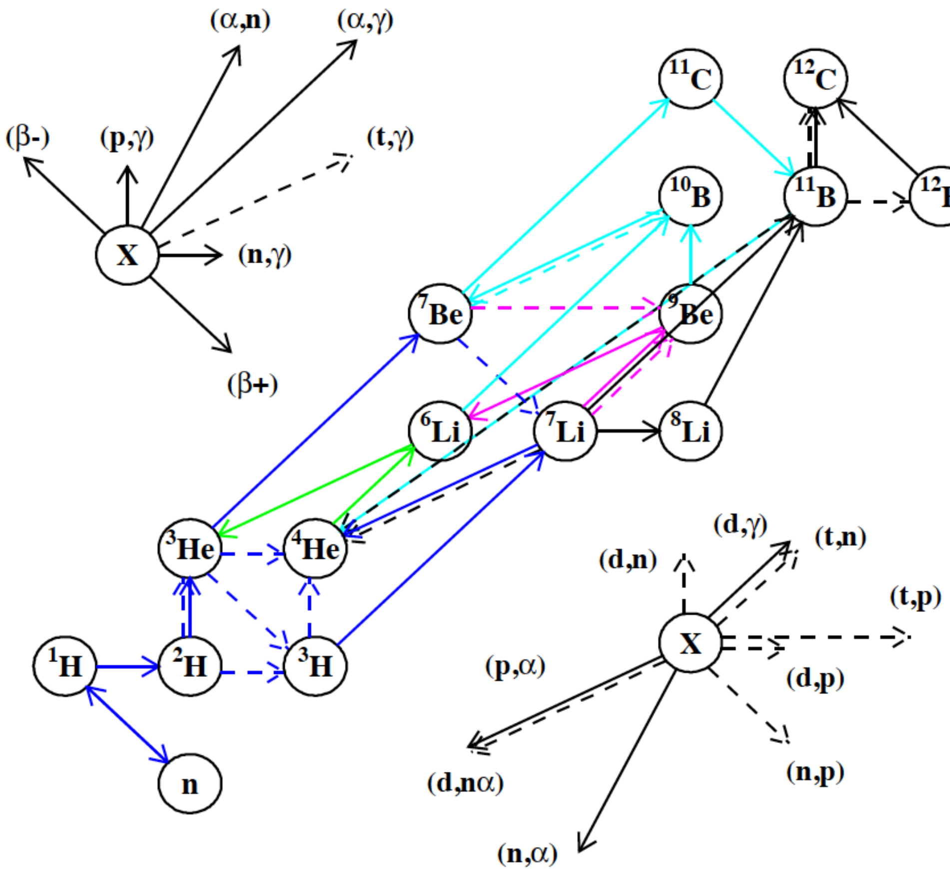

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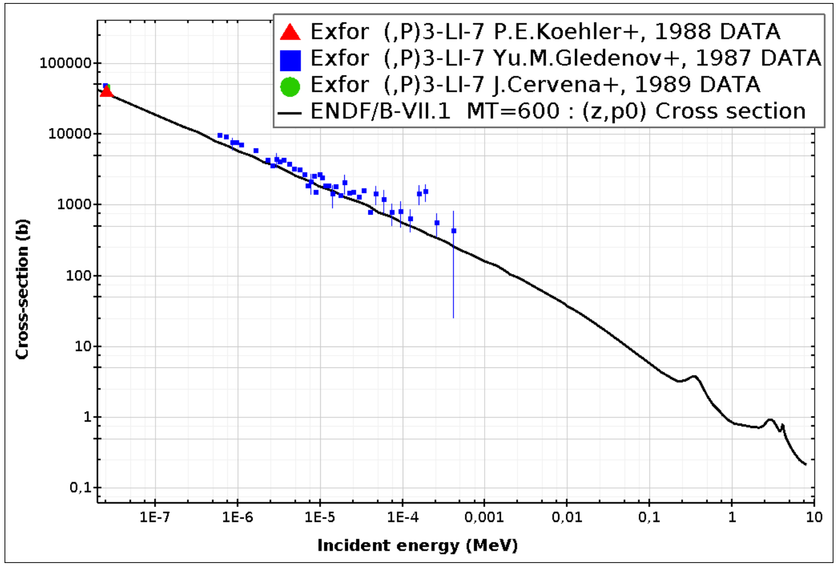

^{7}**Be(n, p)**

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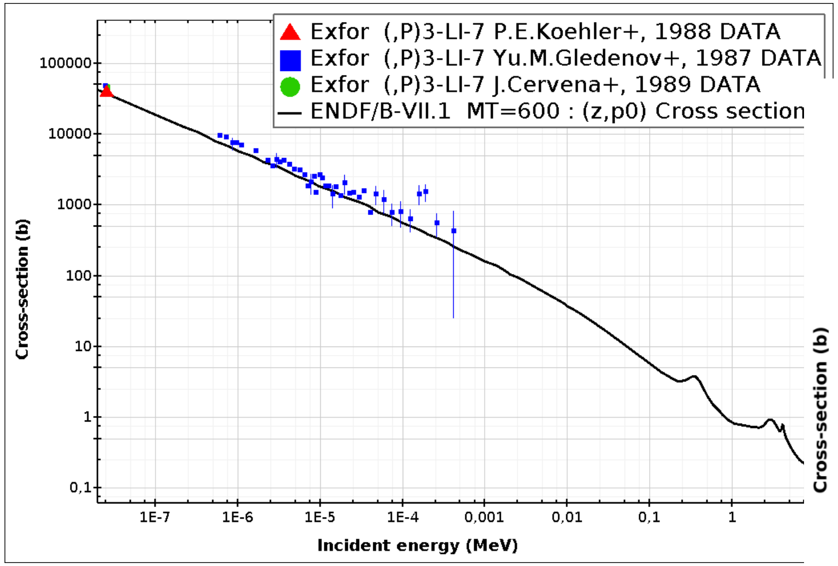
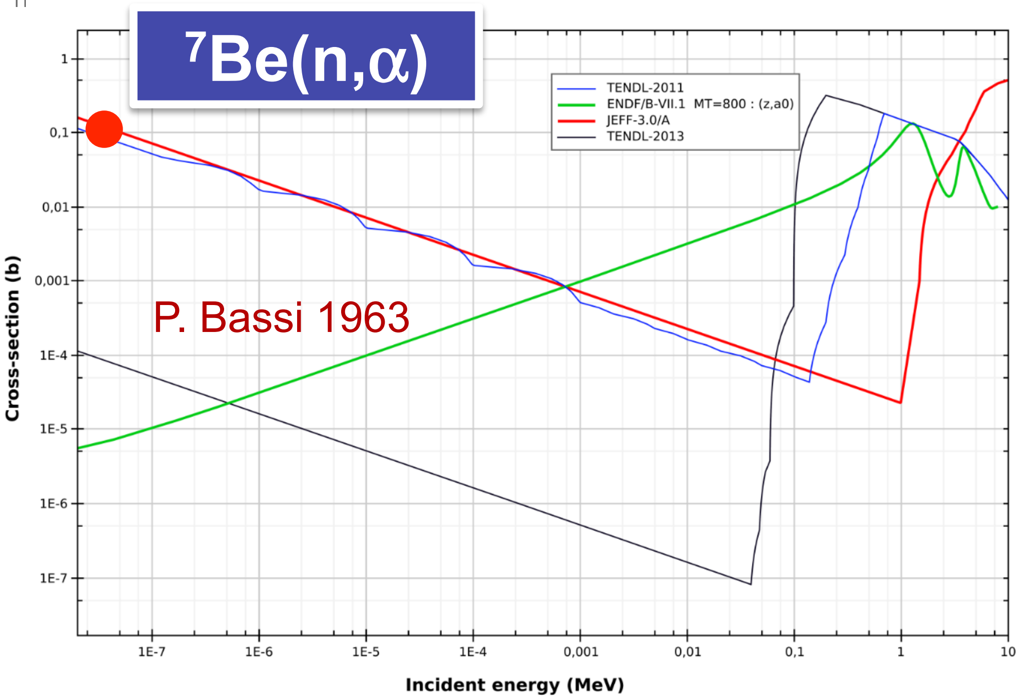


^{7}Be(n, p)

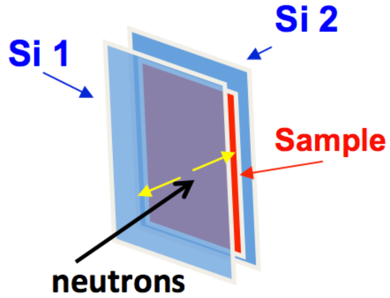


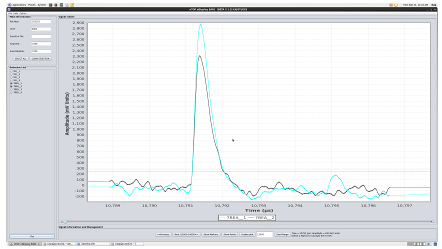
LNS @ n_TOF

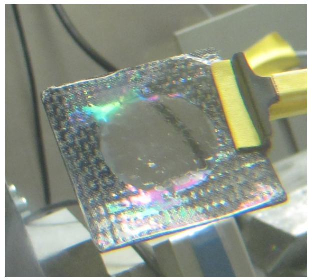
The (n, α) reaction produces **two α-particles** emitted back-to-back with **several MeV energy** (Q-value=19 MeV)

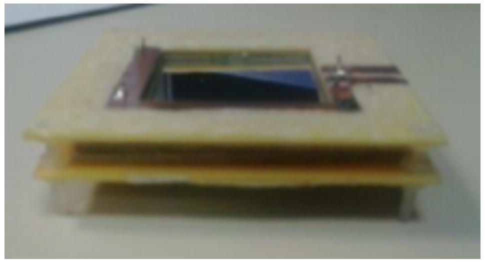
2 Sandwiches of **silicon detector** (140 mm,3x3cm^2) with ^{7}Be sample in between **directly inserted in the neutron beam**

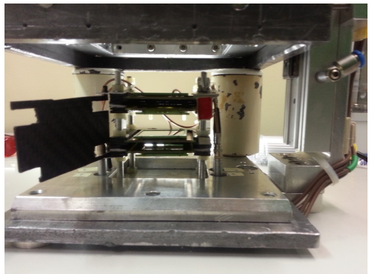
Coincidence technique: strong background rejection

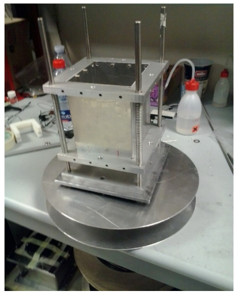


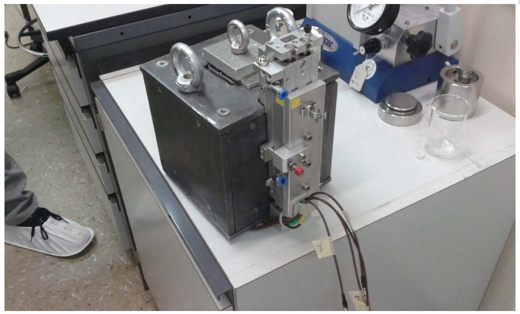


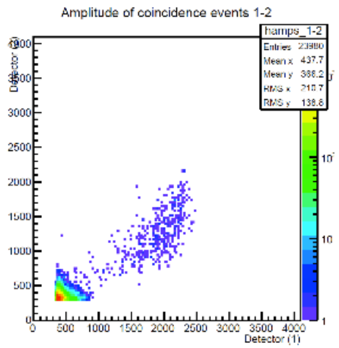












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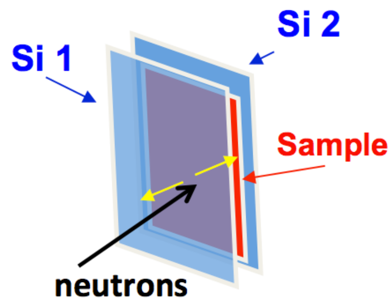
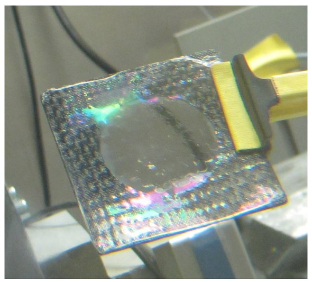
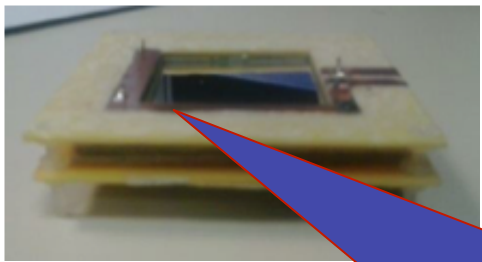
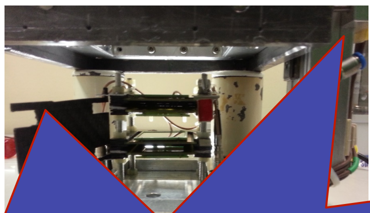
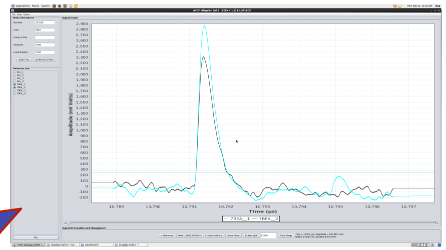
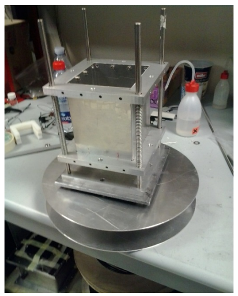
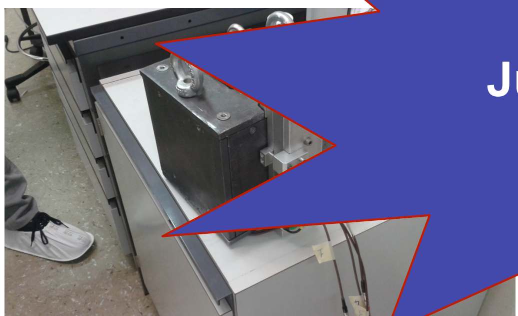
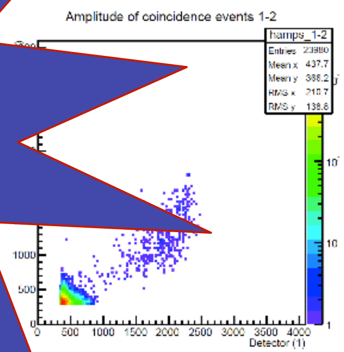
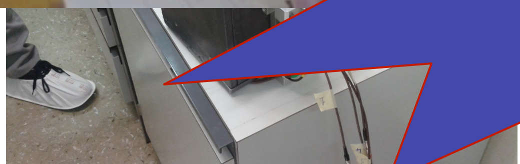
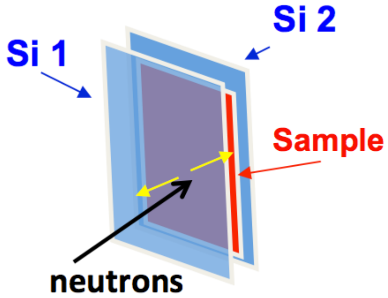


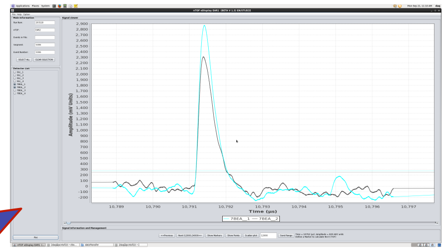








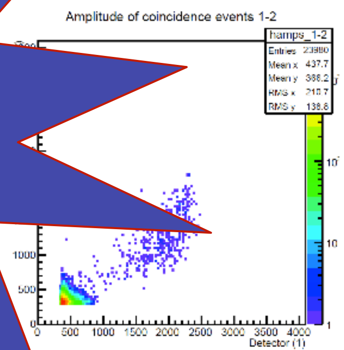
Just measured !

LNS @ n_TOF









… soon the first
^{7}Be(n, α) cross section

Conclusions

… a lot has been done, since 2001

Cross sections relevant for Nuclear Astrophysics

- branching point isotopes
  - ^{151}Sm, ^{63}Ni, ^{147}Pm, ^{171}Tm, ^{203}Tl
- abundancies in presolar grains
  - $^{91,92,93,94,96}Zr$
- magic nuclei and end-point
  - ^{139}La, ^{90}Zr, $^{204,206,207,208}Pb$, ^{209}Bi
- seeds isotopes
  - $^{54,56,57}Fe$, $^{58,60,62}Ni$
- isotopes of special interest
  - $^{186,187,188}Os$ (cosmocronometer), $^{24,25,26}Mg$ (neutron poison)

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Always looking for good ideas

ALMA MATER STUDIORUM
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Cristian Massimi

Dipartimento di Fisica e Astronomia

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INFN – Bo @ n_TOF

INFN Istituto Nazionale di Fisica Nucleare

Reference Cross Section for Astrophysics

- Mass … 0446…
- Leder … 83 (2… …v. C
- Mass … …LINA, The E…

Karlsruhe Astrophysical Database of Nucleosynthesis in Stars

s-process [Standards] [Logbook] [FAQ] [Links] [Disclaimer] [Contact] p-process

▼ Available isotopes for Gold (Z=79)

^{197}Au ^{198}Au

Go to isotope [ ] Go!

▼ Recommended MACS30 (Maxwellian Averaged Cross Section @ 30keV)

$$^{197}Au\ (n,\gamma)^{198}Au$$

Total MACS at 30keV: 612.8 ± 7.0 mb

Cross sections do not include stellar enhancement factors!

▼ History

Version	Total MACS [mb]	Partial to gs [mb]	Partial to isomer [mb]
1.0	612.8 ± 7.0	-	-
0.0	582 ± 9	-	-

(Version 0.0 corresponds to Bao et al.)

▼ Comment

Au-197 is used as standard for most astrophysical cross section measurements. Unfortunately, it is at the moment only a standard in the thermal region and between E(n)= 200 keV and 2.8 MeV (au197). Recent measurements at nTOF (CL11, CM10) and GELINA (MBD14) show a discrepancy of about 5% to the previously used standard value at kT= 30 keV from RaK88 and Mac82e.
The new recommended standard cross section for the astrophysical energy region was derived between kT= 5 and 50 keV by the weighted average of the GELINA measurement of MBD14 and the nTOF measurement of CL11,CM10. The uncertainty in this energy range was taken from MBD14. For the energies between kT= 60-100 keV we used the average of the recent libraries (jeff32, jendl40, endfb71) and the uncertainty from the standard deviation given in jeff32 and endfb71.
The previous standard value used for activations with the Li-7(p,n)Be-7 reaction at E(p)= 1912 keV was 586 (9) mb, the so-called "Ratynski value" (RaK88). At this energy the neutrons are collimated in a forward cone of 120 degree opening angle and resemble a quasi-stellar neutron spectrum of kT= 25 keV. With the new results this value would change to 632 (9) mb.

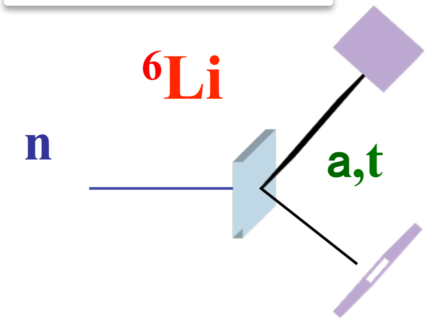
nTOF

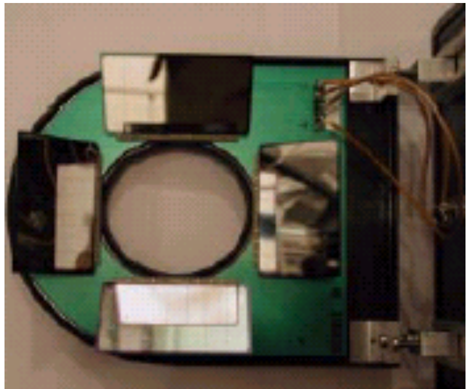
INFN @ n_TOF

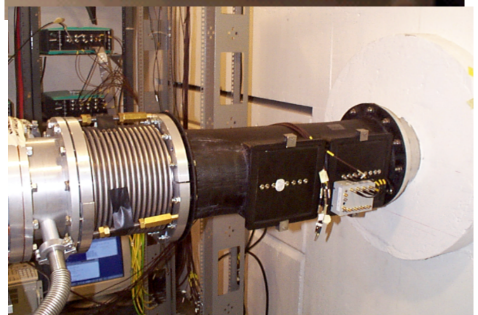
SiMon – EAR1

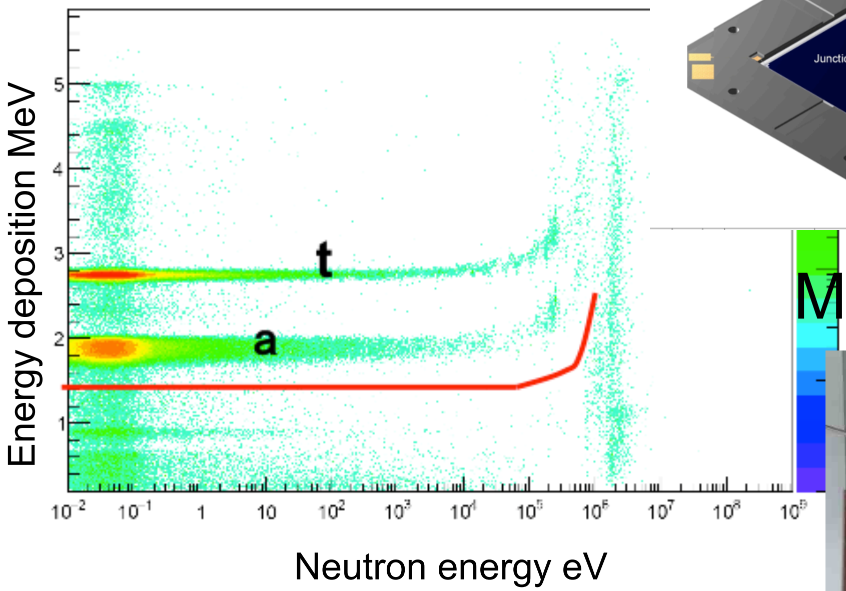
Detector for the neutron flux

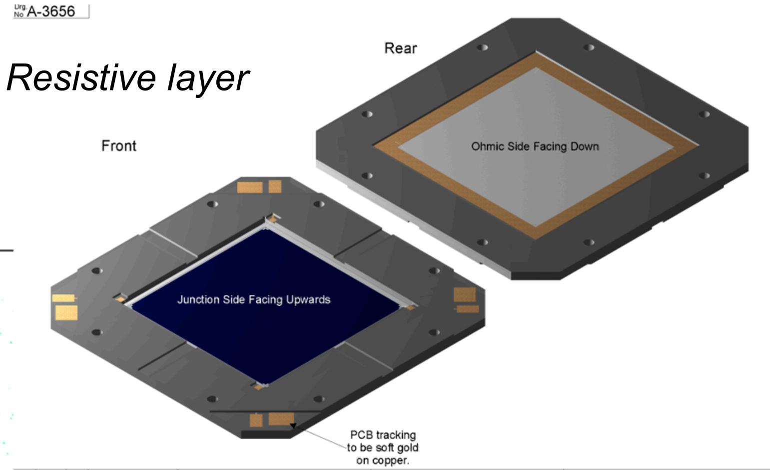
SiMon – EAR2











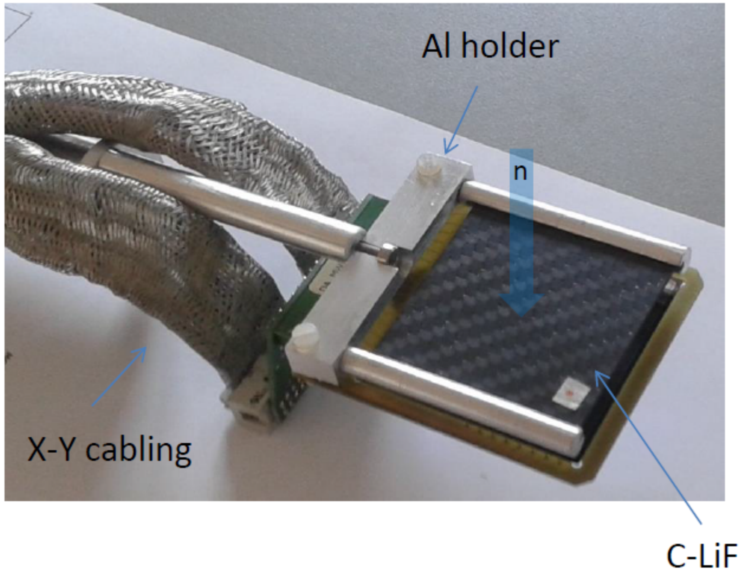
Monitor + profile

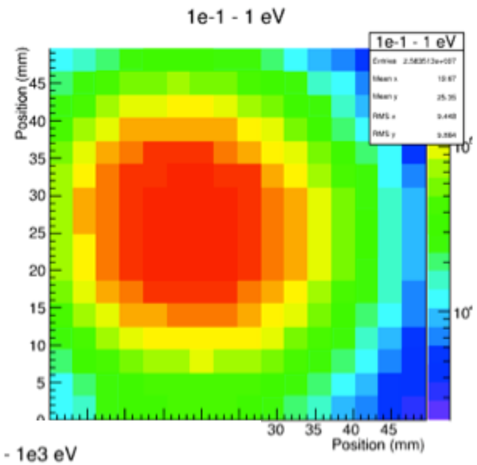
INFN @ n_TOF

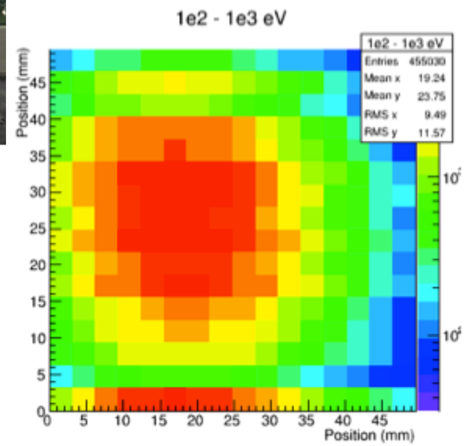
Detector for the neutron flux

The **spatial distribution** of neutrons as a function of energy has been measured by means of a **double side silicon strip detector** (DSSSD).

- 16 x 16 Si sensor strips
- 3 mm wide strips, 500 mm thick
- 50 x 50 mm² X-Y grid
- LiF converter

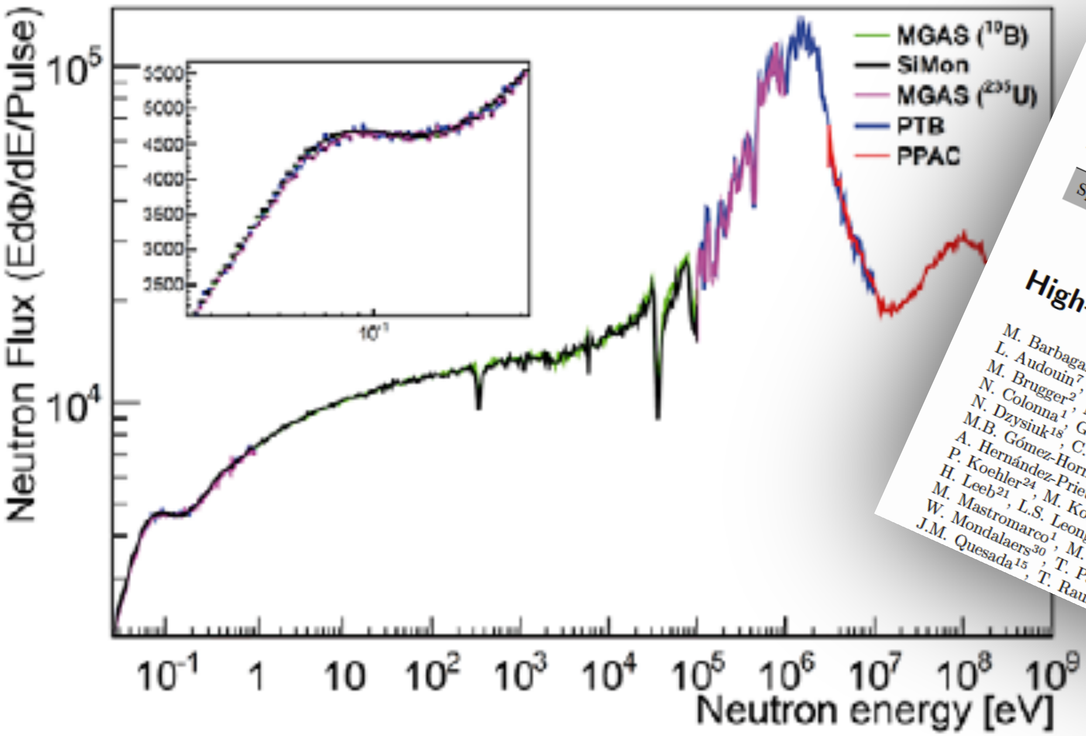




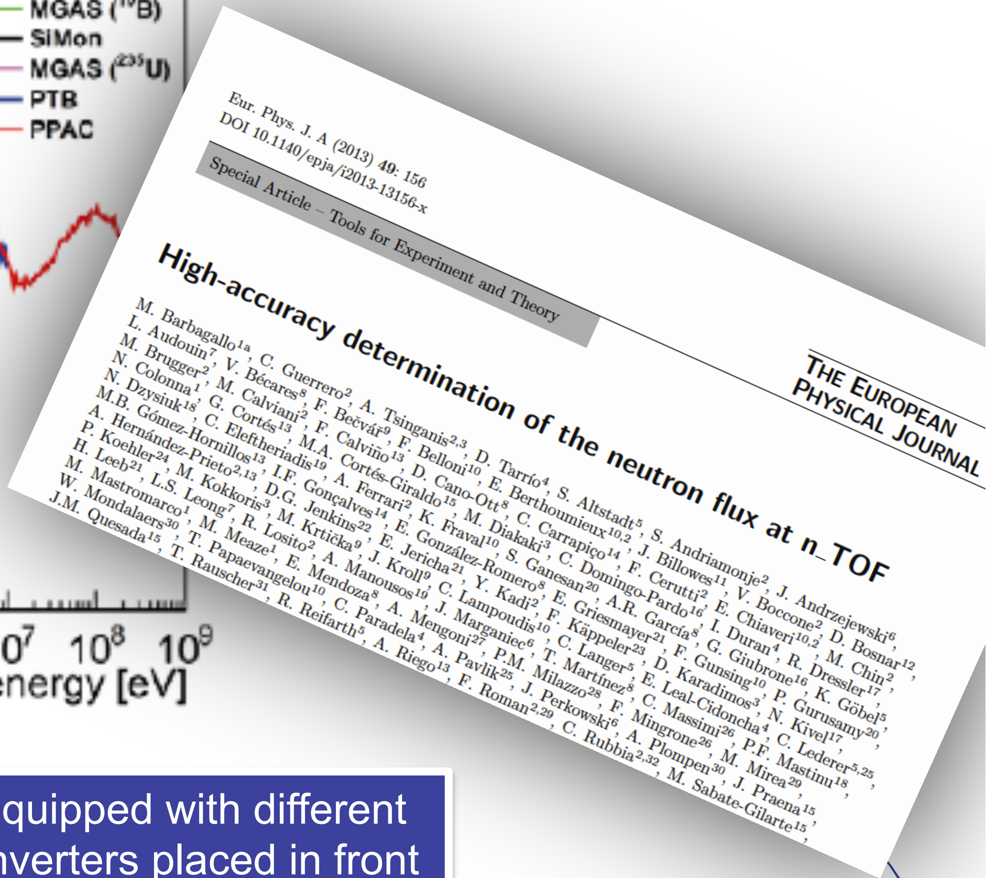


INFN @ n_TOF

Study of the neutron flux



Reaction	Energy range of standard
H(n,n)	da 1 keV a 20 MeV
^{3}He(n,t)	da 0.0253 eV a 50 keV
^{6}Li(n,α)	da 0.0253 eV a 1 MeV
^{10}B(n,α)	da 0.0253 eV a 1 MeV
^{197}Au(n,γ)	0.0253 eV e da 0.2 MeV a 2.5 MeV
^{235}U(n,f)	0.0253 eV e da 0.15 MeV a 200 MeV
^{238}U(n,f)	da 2 MeV a 200 MeV


Eur. Phys. J. A (2013) 49: 156
DOI 10.1140/epja/i2013-13156-x
Special Article – Tools for Experiment and Theory
THE EUROPEAN PHYSICAL JOURNAL

High-accuracy determination of the neutron flux at n_TOF

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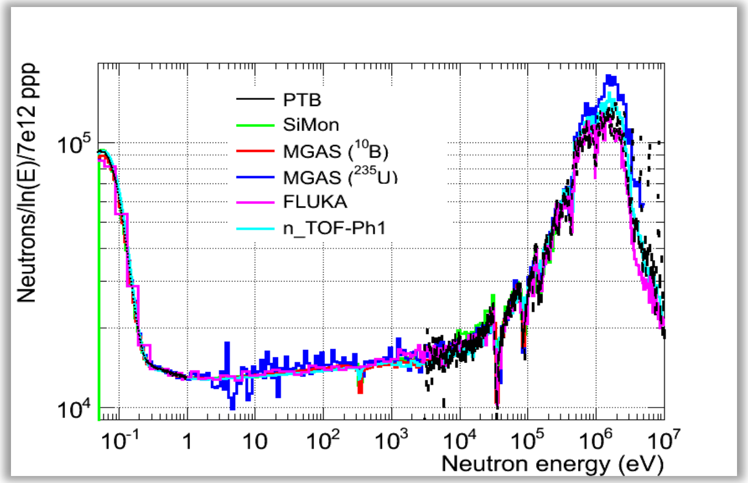
Detectors equipped with different neutron converters placed in front of the sensible layer or volume

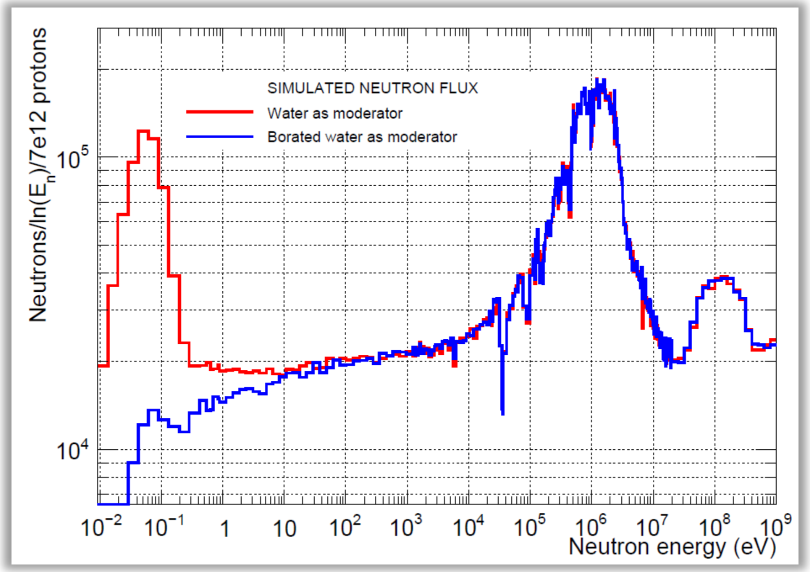
Flux

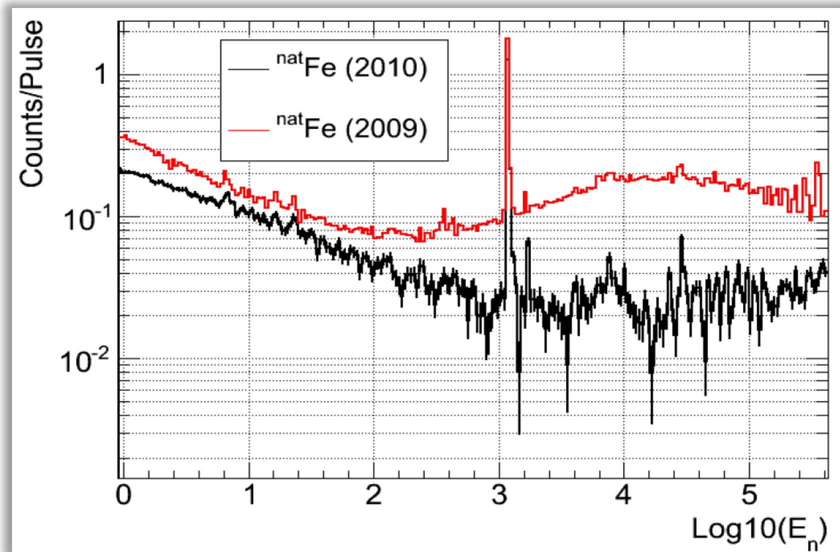
The flux was measured for each target, with **four** different systems based on **^{6}Li, ^{10}B and ^{235}U.**

Measurements were repeated for the **^{10}B-water moderator** (the thermal peak in the flux is suppressed).

The use of borated water suppresses the 2.2 MeV g-rays from ^{1}H(n,g)^{2}H. Background reduced by a factor of 10 in some energy regions!







INFN – Bo @ n_TOF

INFN Istituto Nazionale di Fisica Nucleare

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Neutron capture cross section of ^{25}Mg and its astrophysical implications

January 4, 2012

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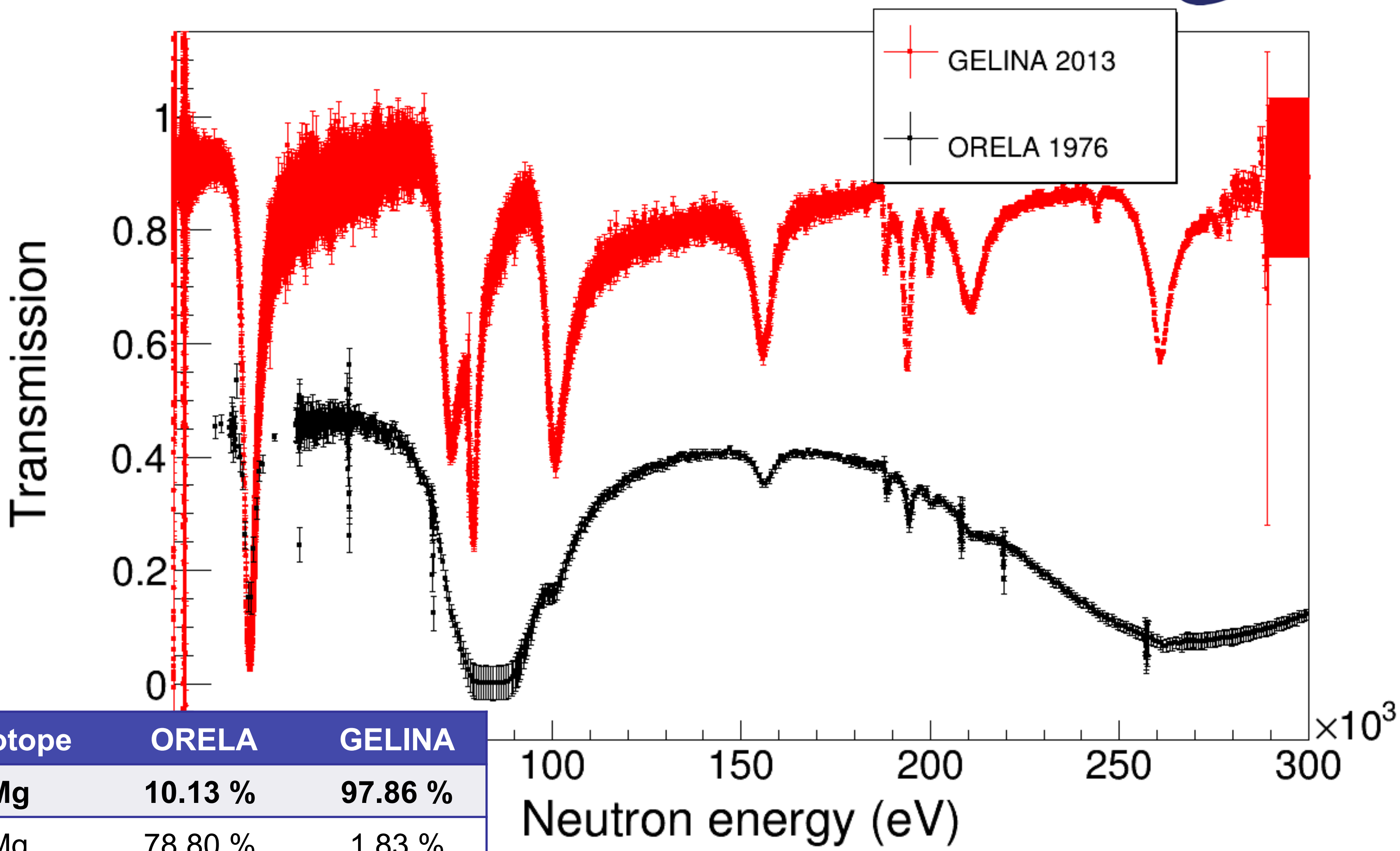
1. **CONSTRAINTS for ^{22}Ne(α, n) ^{25}Mg:** it is one of the most important **neutron source in Red Giant stars.** Its **reaction rate** is very **uncertain** because of the **poorly known property of the states in ^{26}Mg**. From neutron measurements the **J$^{\pi}$** of ^{26}Mg states can be deduced.

2. **NEUTRON POISON: ^{25,26}Mg** are the most important **neutron poisons** due to neutron capture on Mg stable isotopes in competition with neutron capture on ^{56}Fe (the basic s-process seed for the production of heavy isotopes).

INFN – Bo @ n_TOF



Isotope	ORELA	GELINA
^{25}Mg	**10.13 %**	**97.86 %**
^{24}Mg	78.80 %	1.83 %
^{26}Mg	11.17 %	0.31 %

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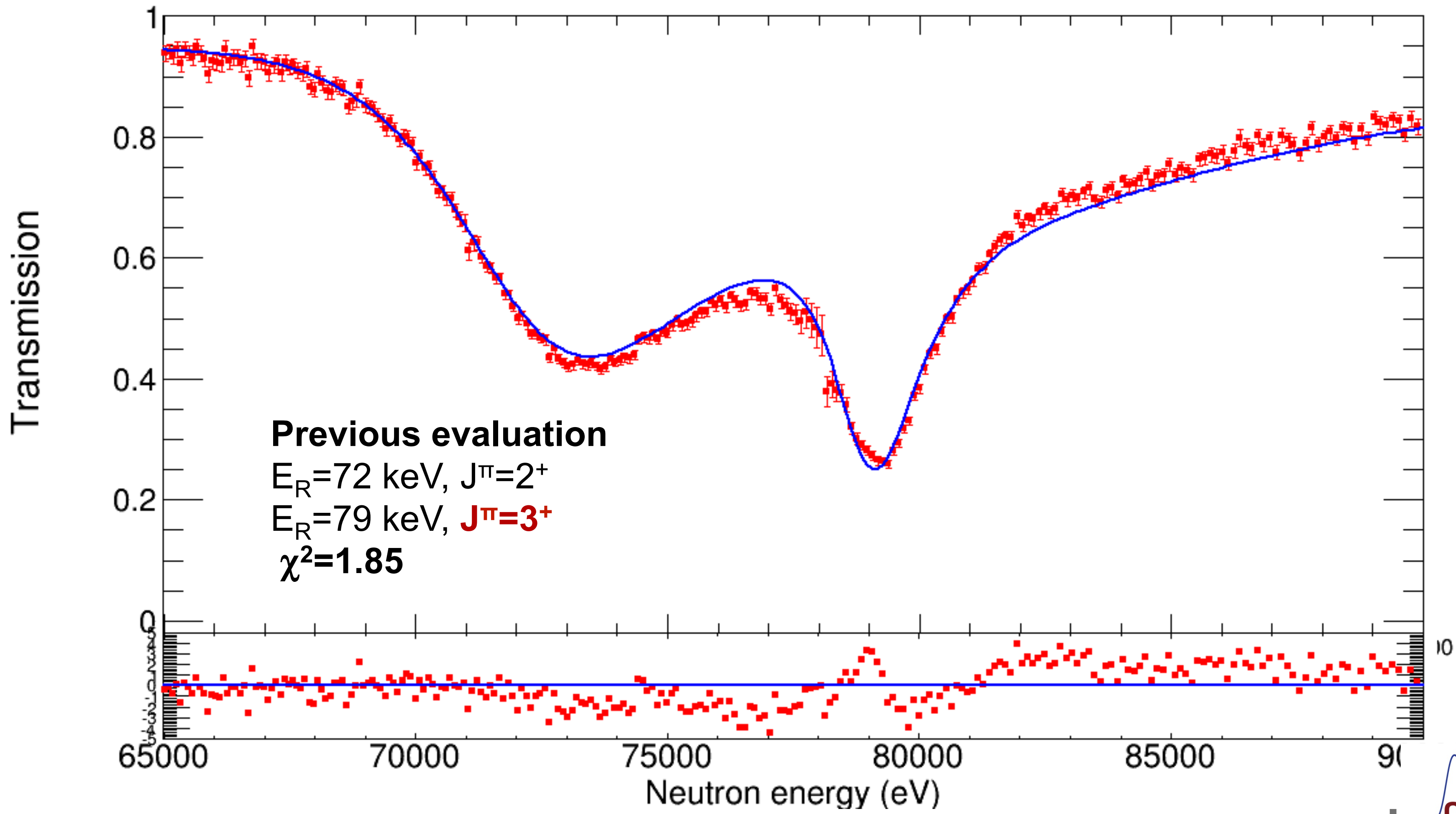
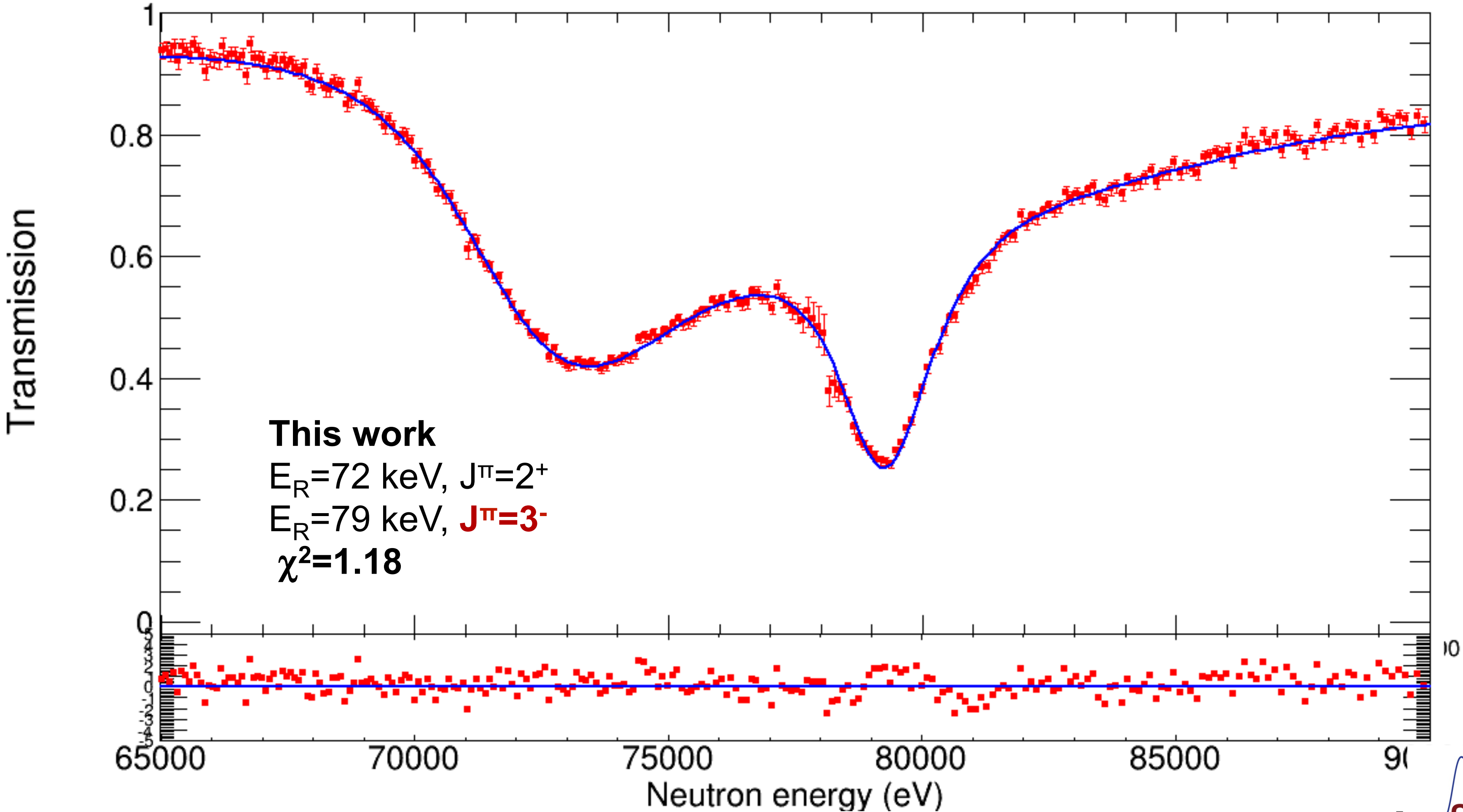


Transmission
Neutron energy (eV)
Previous evaluation
E_R=72 keV, J^π=2^+
E_R=79 keV, J^π=3^+
χ^2=1.85

INFN – Bo @ n_TOF

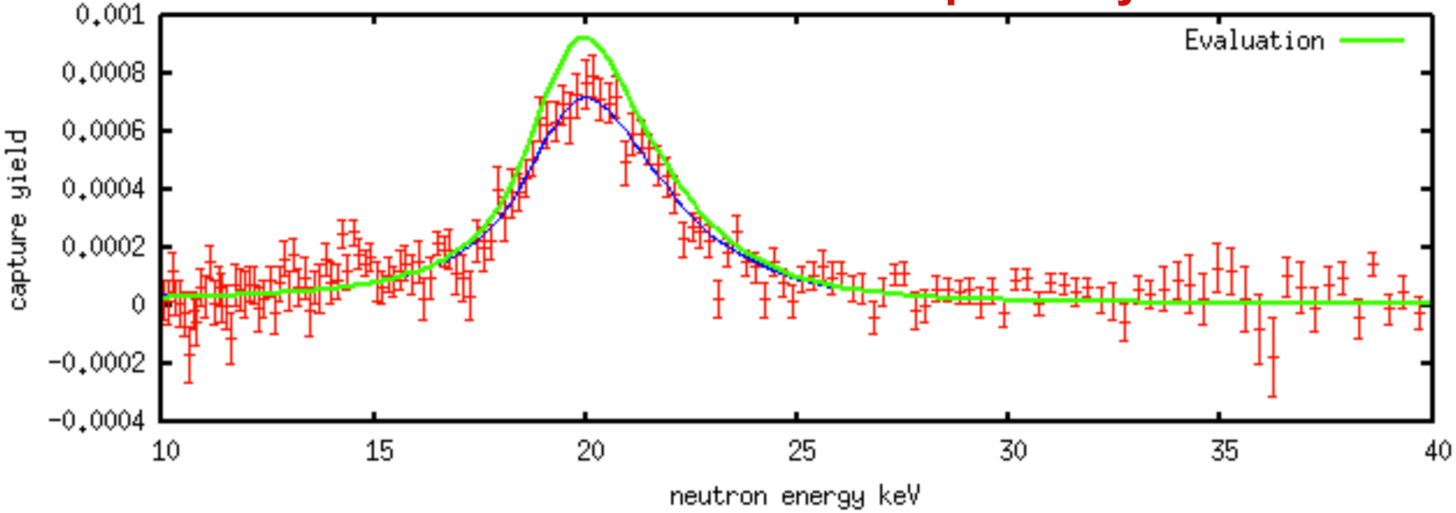
Experimental evidence of natural spin parity



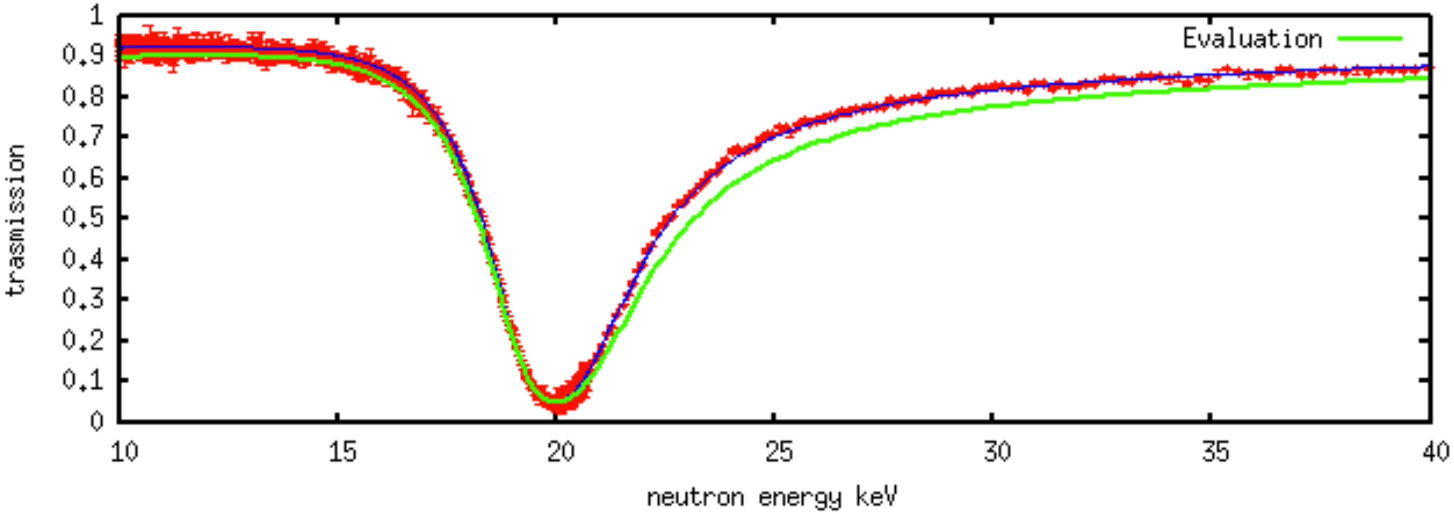
Data Analysis

Istituto Nazionale di Fisica Nucleare

Simultaneous Resonance Shape Analysis



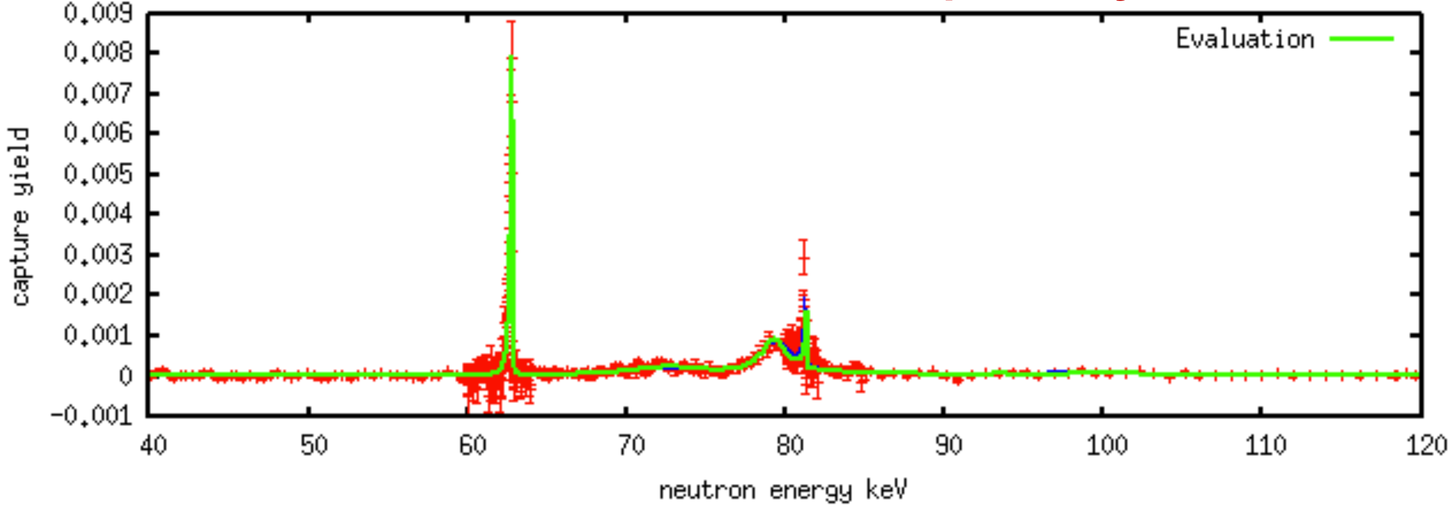
^{25}Mg(n, γ) @ n_TOF



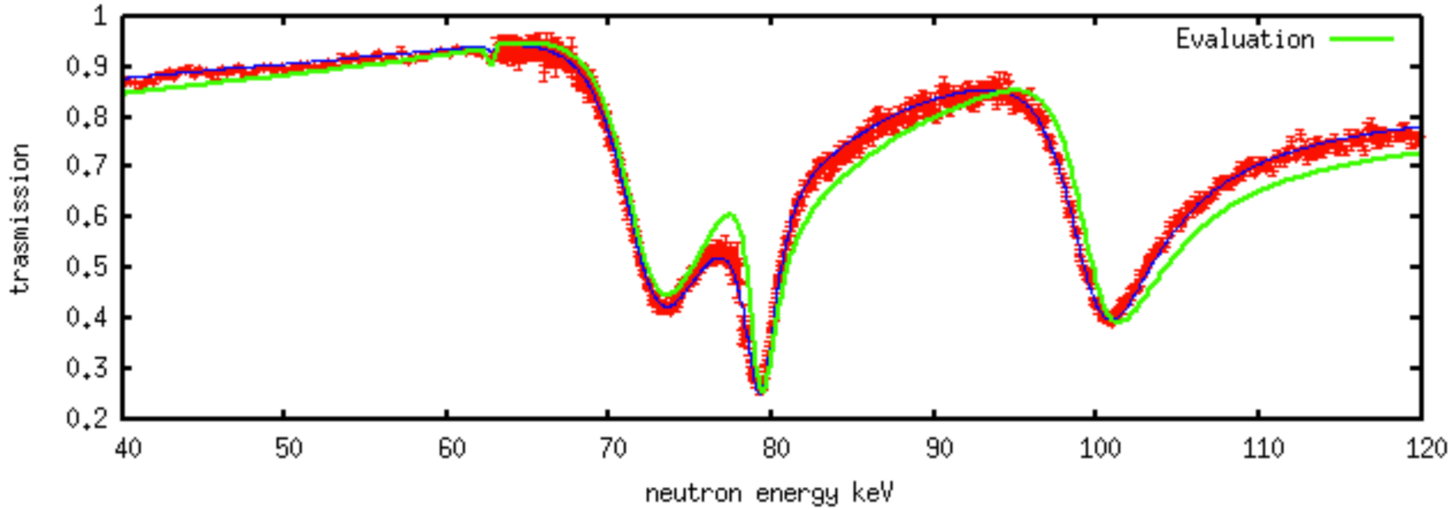
^{25}Mg(n, tot) @ GELINA

Data Analysis

Simultaneous Resonance Shape Analysis



^{25}Mg(n, γ) @ n_TOF



^{25}Mg(n, tot) @ GELINA

Data Analysis

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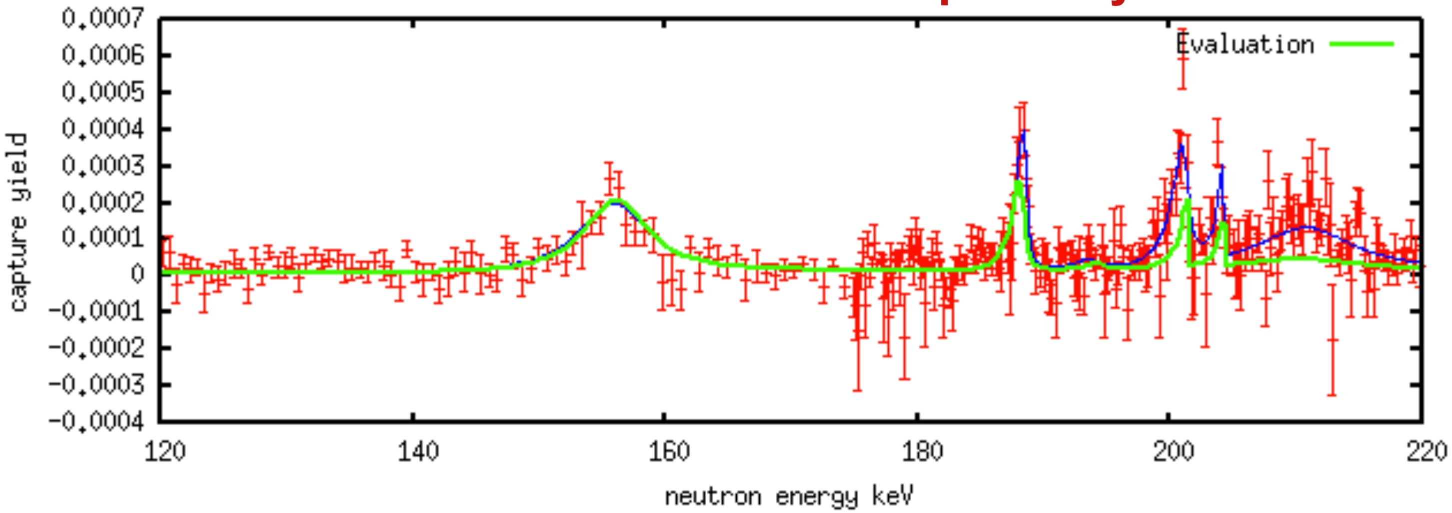
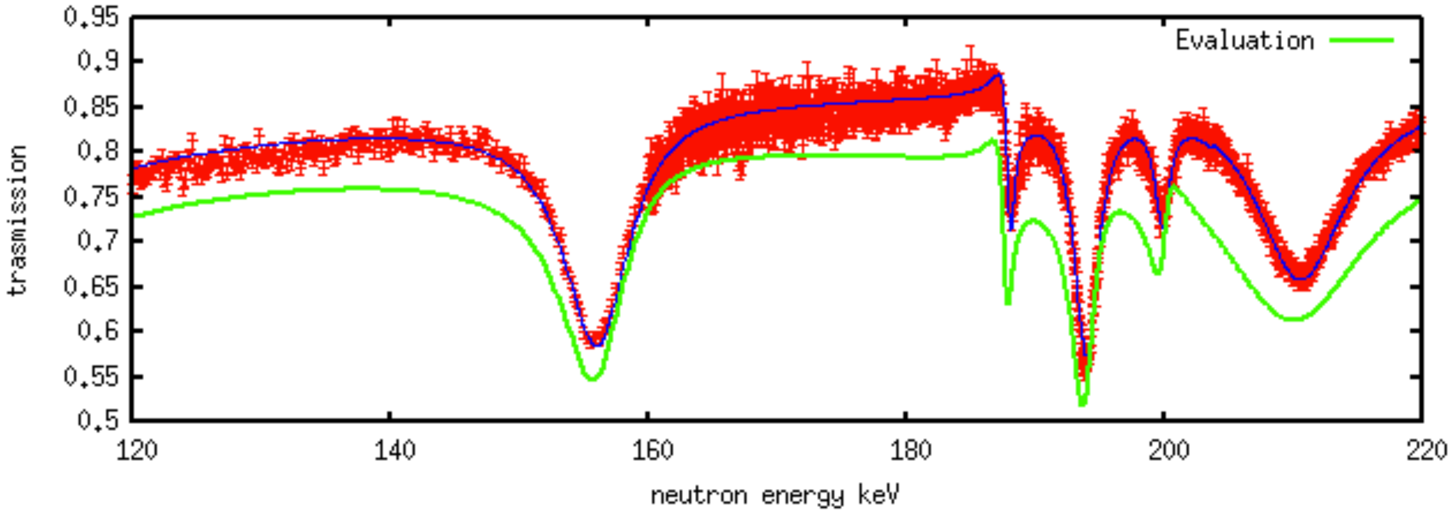
Simultaneous Resonance Shape Analysis



^{25}Mg(n, γ) @ n_TOF



^{25}Mg(n, tot) @ GELINA

Data Analysis

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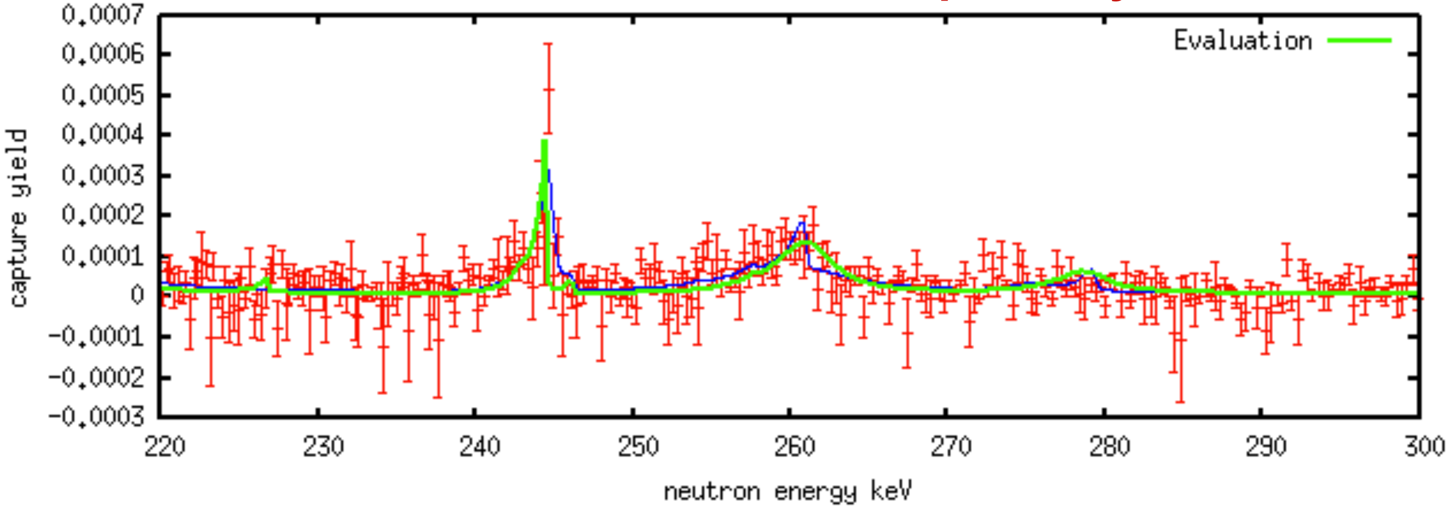
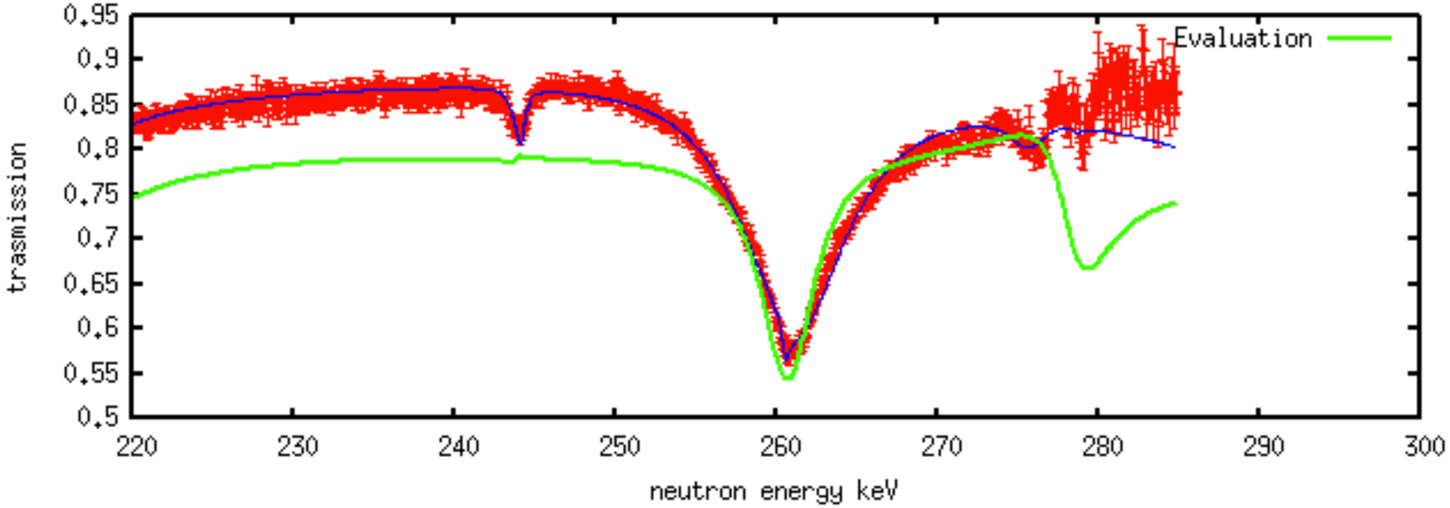
Simultaneous Resonance Shape Analysis



$^{25}Mg(n, \gamma)$ @ n_TOF

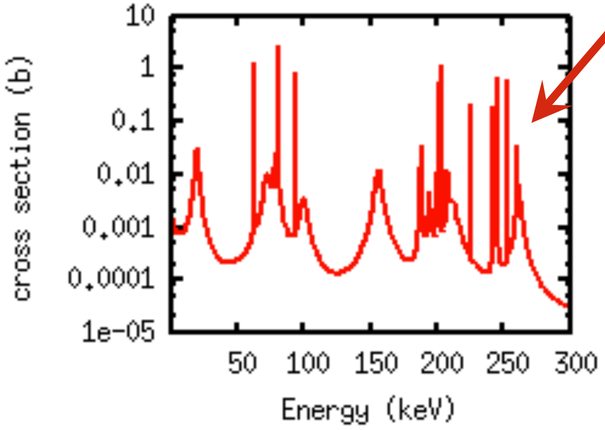


$^{25}Mg(n, tot)$ @ GELINA

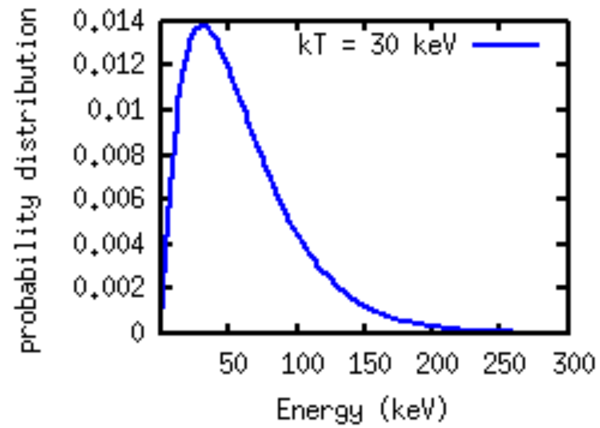
Results

$^{25}Mg(n, \gamma)^{26}Mg$ resonances → **R-matrix** parameterization of the **cross section**

E_n (keV)	ℓ	J^π	Γ_γ (eV)	Γ_n (eV)
−154.25	0	2^+	6.5	30000
19.86 ± 0.05	0	2^+	1.7 ± 0.2	2310 ± 30
62.727 ± 0.003	1^a	$1^{+\ a}$	4.1 ± 0.7	28 ± 5
72.66 ± 0.03	0	2^+	2.5 ± 0.4	5080 ± 80
79.29 ± 0.03	0	3^+	3.3 ± 0.4	1560 ± 80
81.117 ± 0.001	0^b	$(2)^+$	3 ± 2	0.8 ± 0.7
93.60 ± 0.02	(1)	(1^-)	2.3 ± 2	0.6 ± 0.2
100.03 ± 0.02	0	3^+	1.0 ± 0.1	5240 ± 40
$[101.997 \pm 0.009]$	[1]	$[2^-]$	$[0.2 \pm 0.1]$	$[4 \pm 3]$
$[107.60 \pm 0.02]$	$[0]^b$	$[3^+]$	$[0.3 \pm 0.1]$	$[2 \pm 1]$
156.34 ± 0.02	(1)	(2^-)	6.1 ± 0.4	5520 ± 20
188.347 ± 0.009	0	$(2)^+$	1.7 ± 0.2	590 ± 20
194.482 ± 0.009	(1)	$4^{(-)}$	0.2 ± 0.1	1730 ± 20
200.20 ± 0.03	1^b	1^-	0.3 ± 0.3	1410 ± 60
200.944 ± 0.006	(2)	(2^+)	3.0 ± 0.3	0.7 ± 0.7
203.878 ± 0.001	(1)	(2^-)	0.8 ± 0.3	2 ± 1
208.27 ± 0.01	(1)	(1^-)	1.2 ± 0.5	230 ± 20
211.14 ± 0.05	(1)	(2^-)	3.1 ± 0.7	12400 ± 100
226.255 ± 0.001	(1)	(1^-)	4 ± 3	0.4 ± 0.2
242.47 ± 0.02	(1)	(1^-)	6 ± 4	0.3 ± 0.2
244.60 ± 0.03	1	$1^{-\ c}$	3.5 ± 0.6	50 ± 20
245.552 ± 0.002	(1)	(1^-)	2.3 ± 2	0.5 ± 0.2
253.63 ± 0.01	(1)	(1^-)	3.1 ± 2.7	0.1 ± 0.1
261.84 ± 0.03	(1)	$4^{(-)}$	2.6 ± 0.4	3490 ± 60
279.6 ± 0.2	(0)	(2^+)	1.9 ± 0.7	3290 ± 50
311.57 ± 0.01	(2)	(5^+)	(0.84 ± 0.09)	(240 ± 10)



Convoluted with **neutron** stellar **flux**



MACS and reaction rate

$^{25}Mg(n, \gamma)$ @ n_TOF

Results

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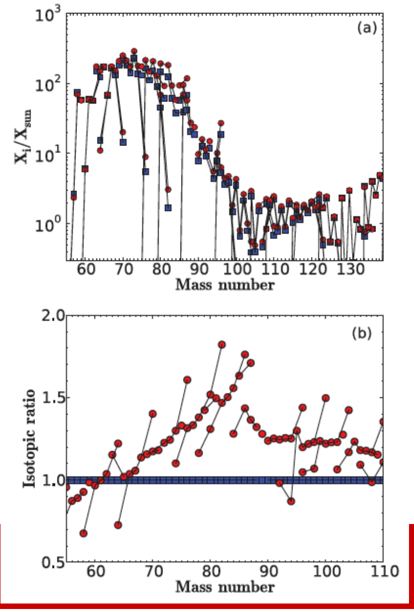
Stellar site	Temperature keV	MACS (Massimi 2003)	MACS (KADoNiS)	MACS Massimi 2012
He - AGB	8	**4.9±0.6 mb**	4.9 mb	**4.3 mb**
He - AGB	23	**3.2±0.2 mb**	6.1 mb	**4.3 mb**
30	30	**4.1±0.6 mb**	6.4±0.4 mb	**4.1 mb**
He – Massive	25	**3.4±0.2 mb**	6.2 mb	**4.2 mb**
C - Massive	90	**2.6±0.3 mb**	4.0 mb	**2.5 mb**



Old Sample, oxide powder

Capture

New Sample, metal disc

Capture + transmission