Neutron detection at n_TOF

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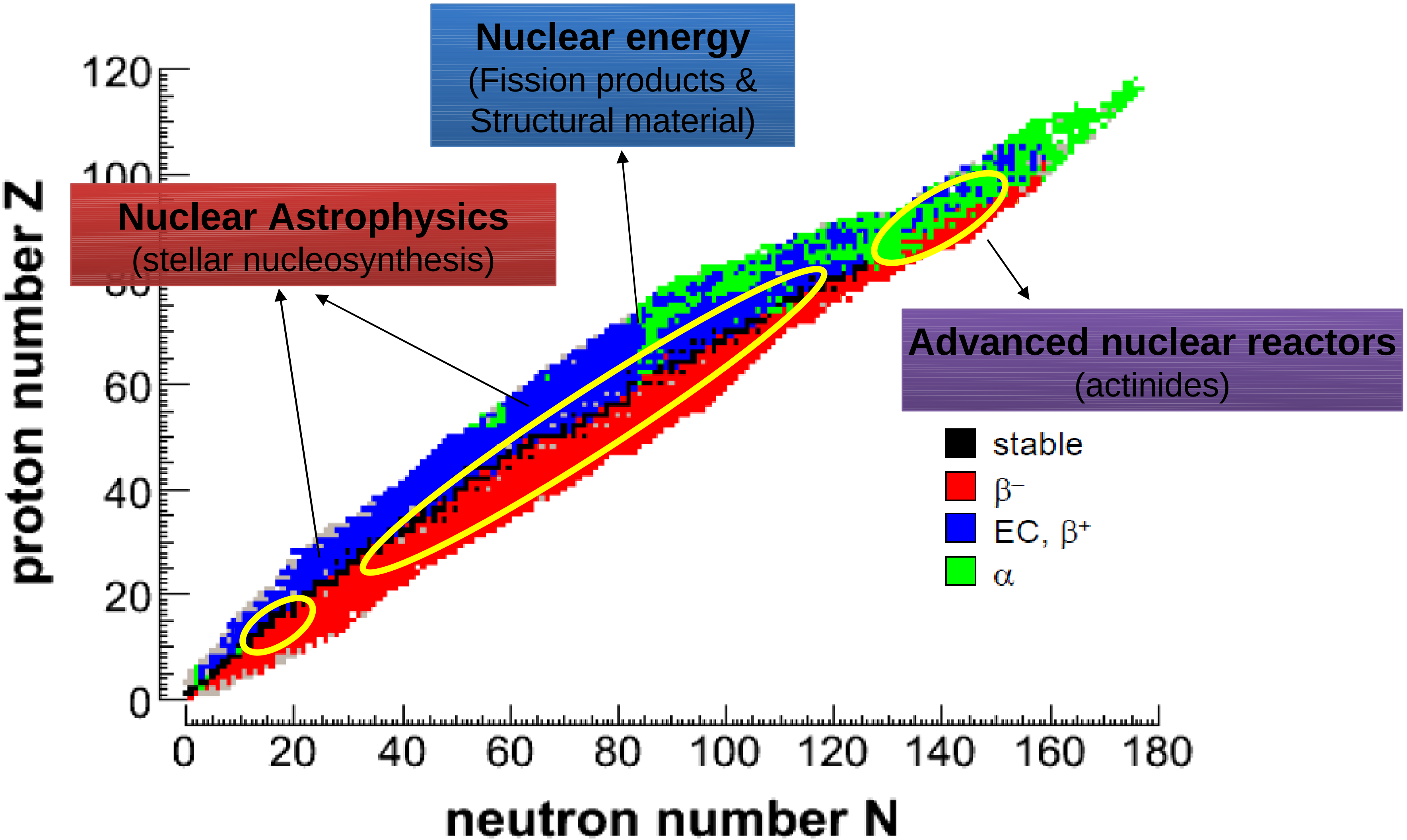
n_TOF measurements at glance

Neutron induced fission and capture reactions

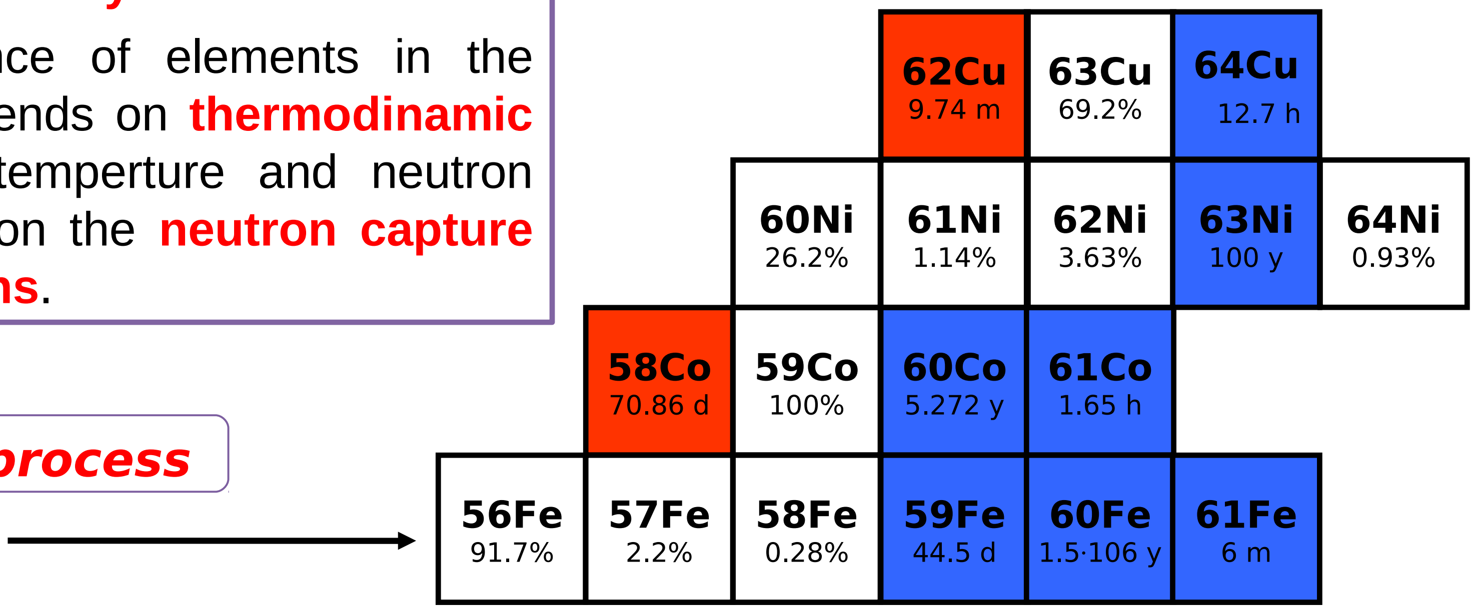


The s-process nucleosynthesis

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) and on the **neutron capture cross-sections**.

s-process



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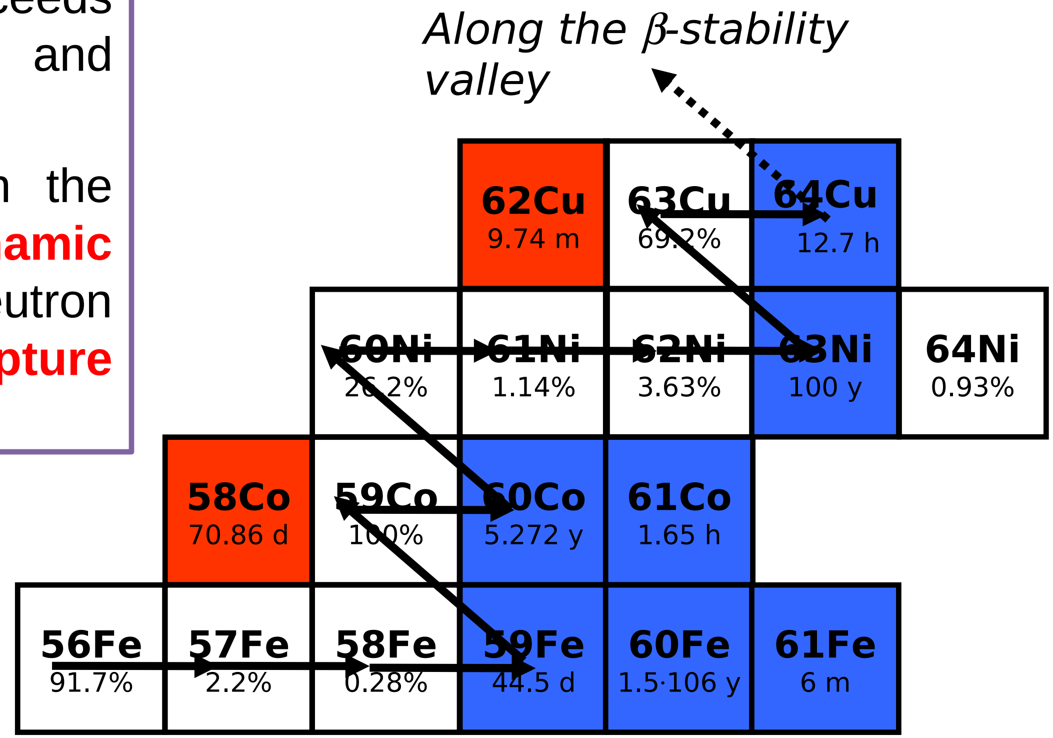

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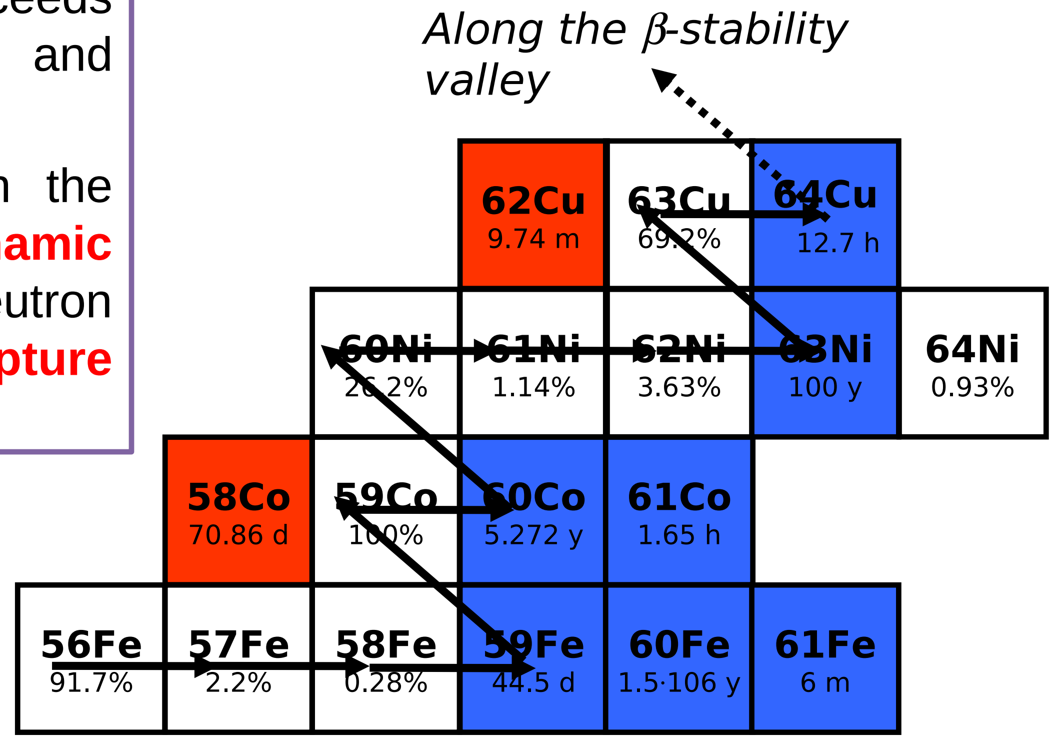


σ(n,γ) is a key quantity

Need of new and accurate neutron cross-sections:
- **refine models** of stellar nucleosynthesis in the Universe
- obtain information on the **stellar environment and evolution**

Nuclear technologies

Nuclear technologies

244, 245Cm
1.5 Kg/yr

241Am:11.6 Kg/yr
243Am: 4.8 Kg/yr

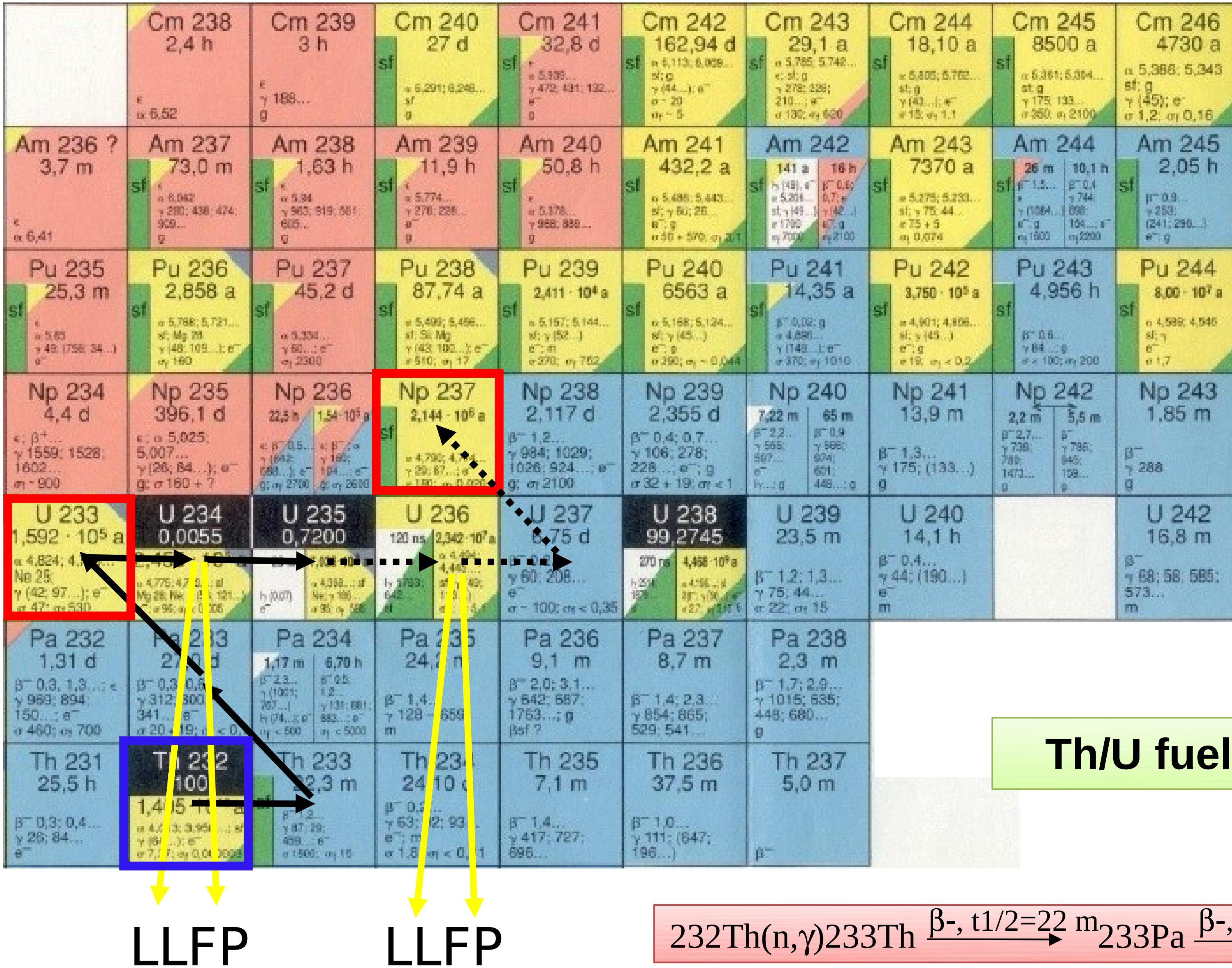
239Pu: 125 Kg/yr

237Np: 16 Kg/yr

LLFP
76.2 Kg/yr

Quantities refer to yearly production in 1 GWe LW reactor

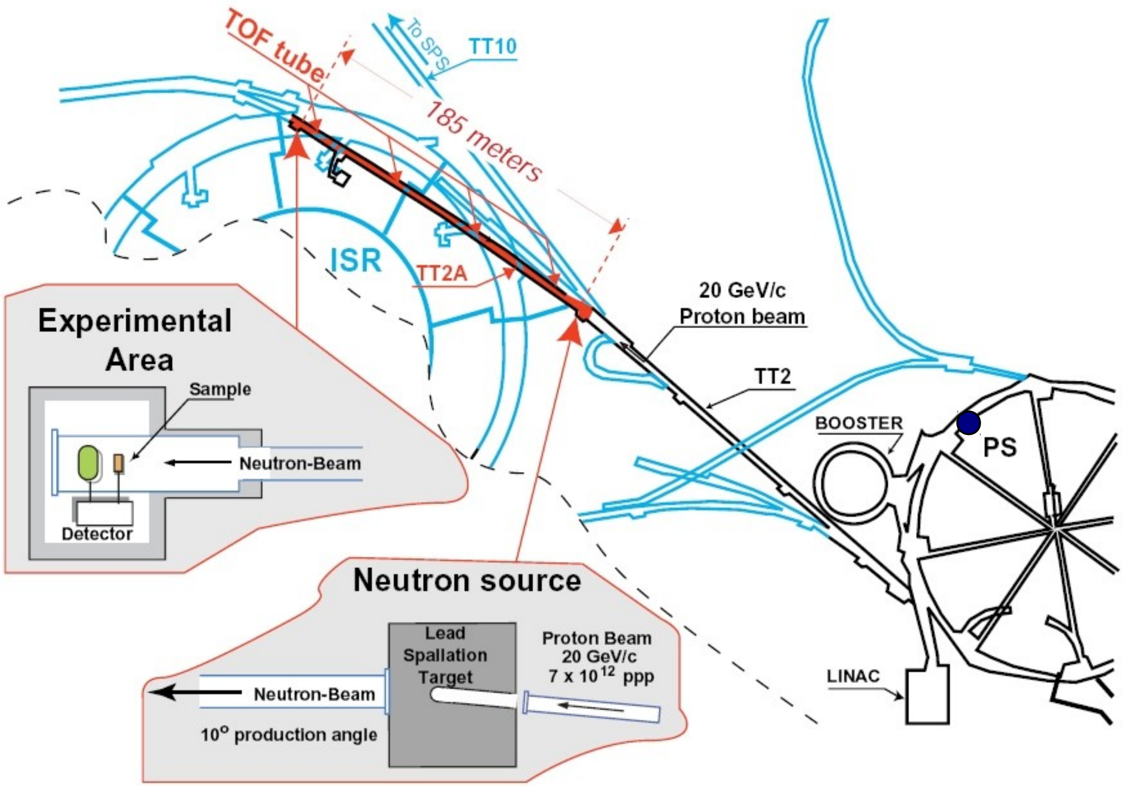
Nuclear technologies



Th/U fuel cycle

$$^{232}Th(n,\gamma)^{233}Th \xrightarrow{\beta^-,\ t_{1/2}=22\ m} {}^{233}Pa \xrightarrow{\beta^-,\ t_{1/2}=27\ d} {}^{233}U$$

The n_TOF facility at CERN



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Experimental area at **200 m.**

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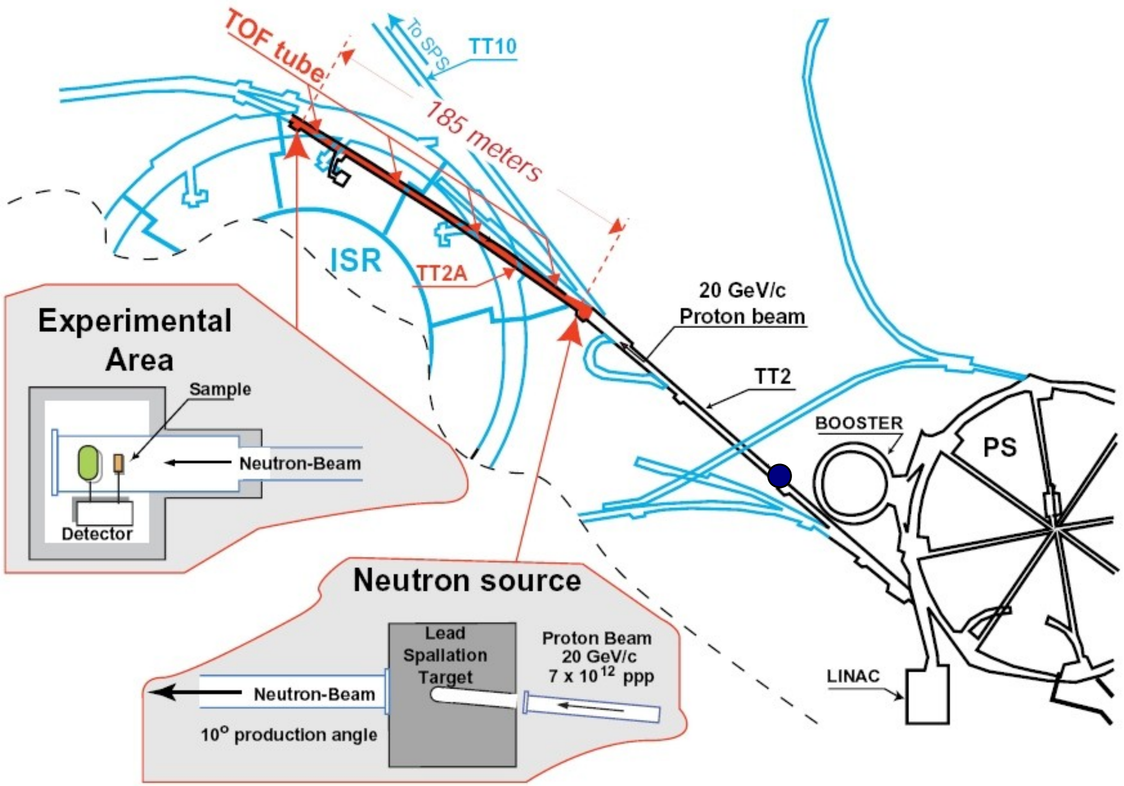

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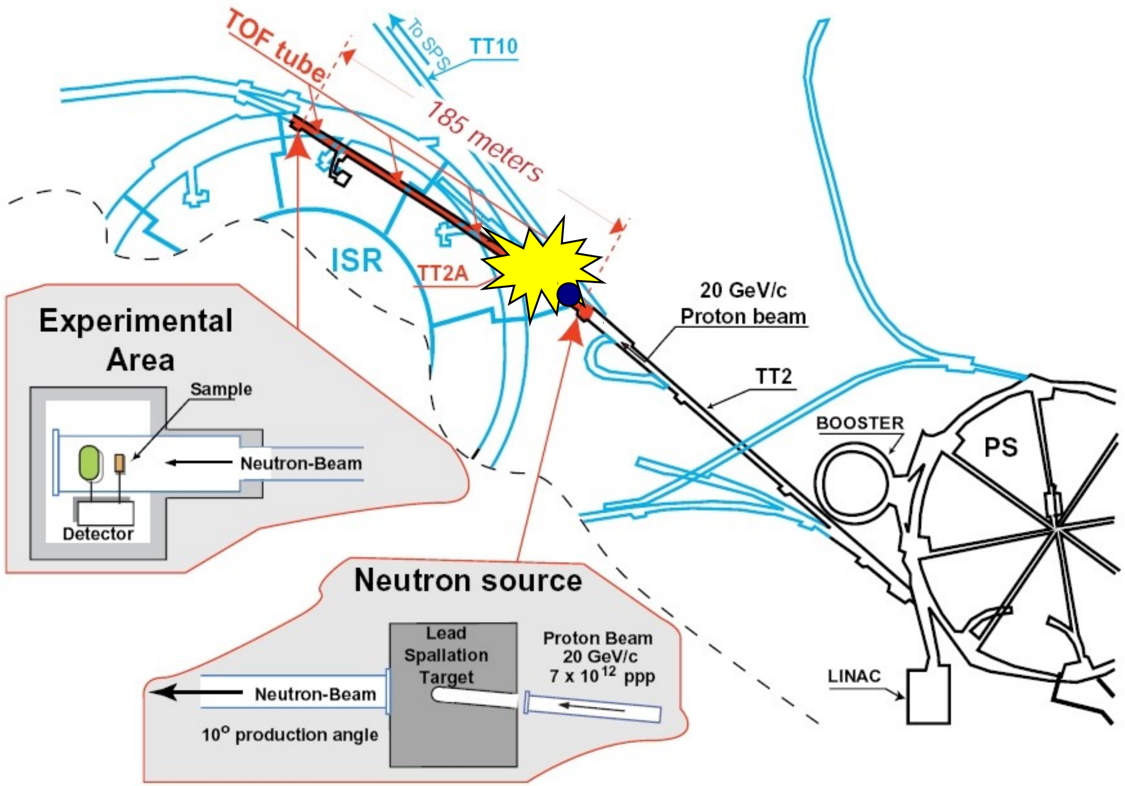

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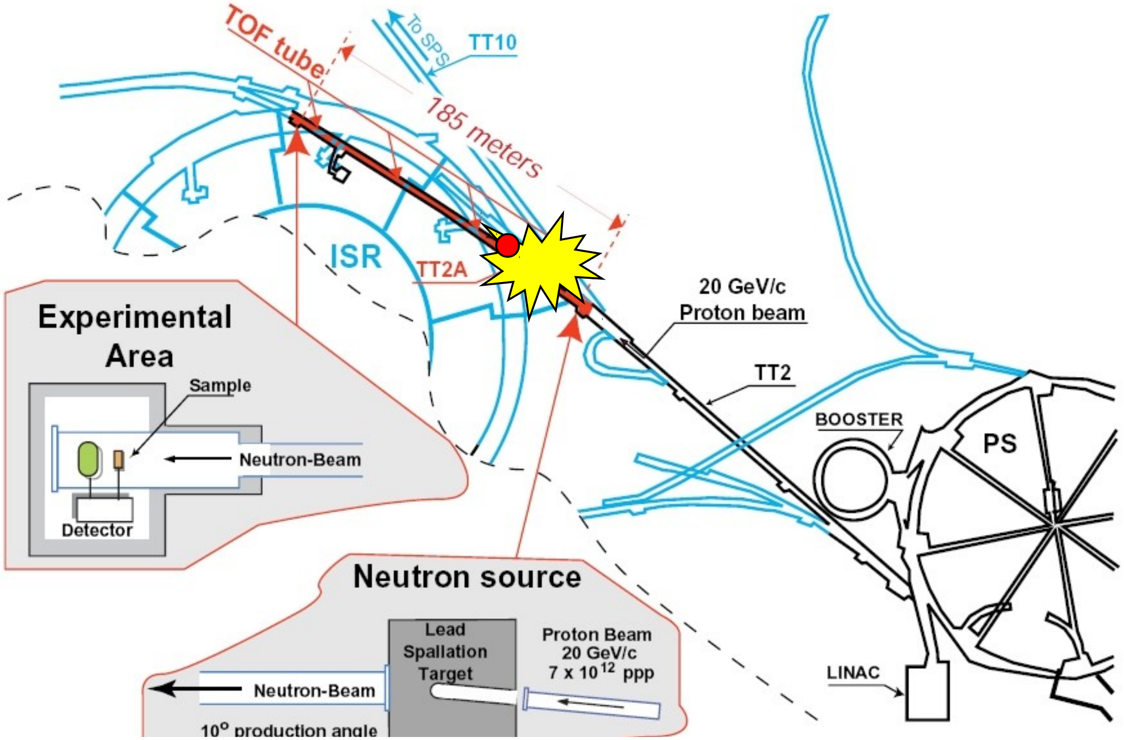

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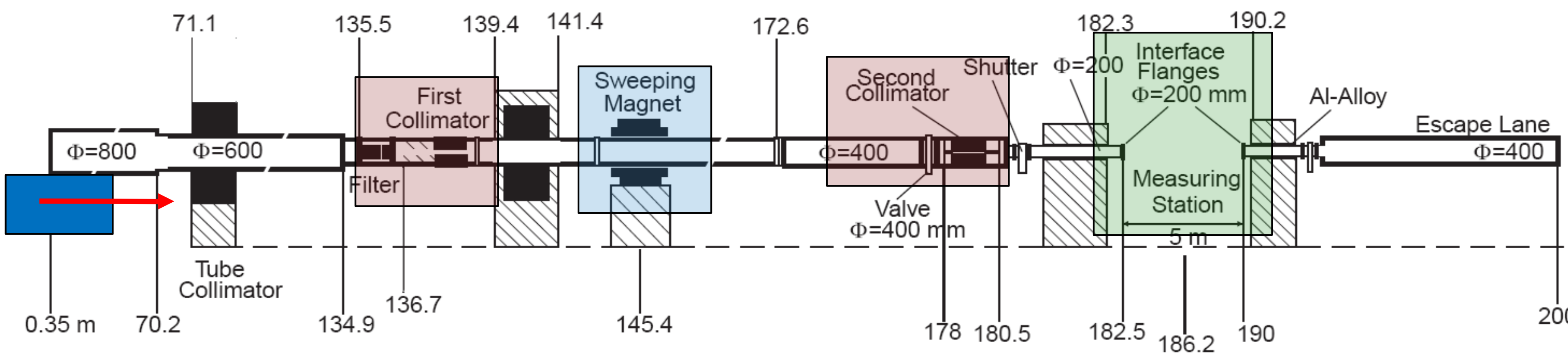
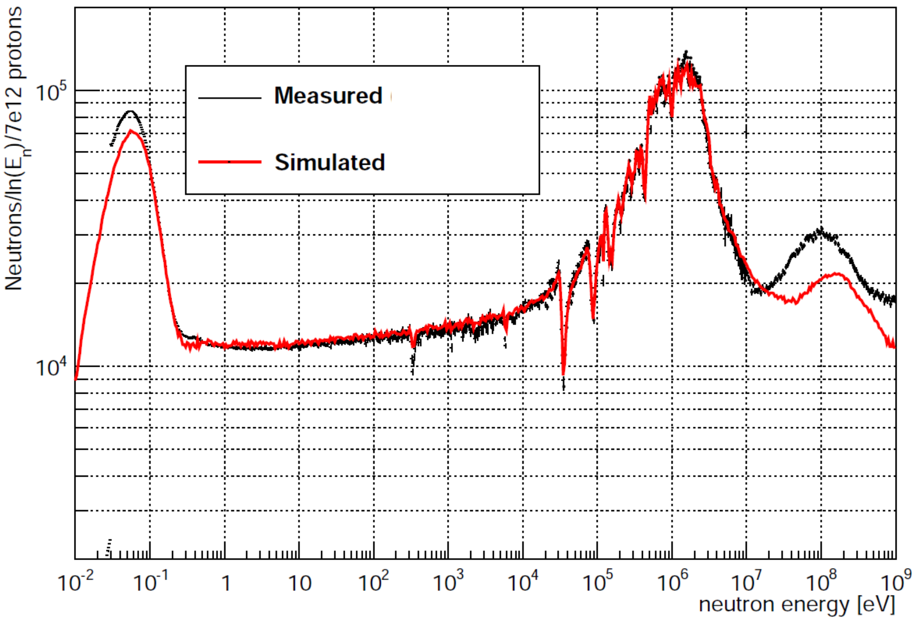


n_TOF features



Main feature:

- **extremely high instantaneous neutron flux** (*10^5 n/cm^2/pulse).*
- very convenient for measurements of **radioactive isotopes,**
- **low cross sections,**
- **Isotope available in small quantity**

Other features of the neutron beam:

- high **resolution in energy** (*ΔE/E = 10^{-4}*) study **resonances**
- Wide **energy range** (25 meV<En<1 GeV) measure **fission** up to 1 GeV
- low **repetition** rate (*< 0.8 Hz)* no **wrap-around**

n_TOF measurements

Phase 1* *(2001-2004)

Capture

^{151}Sm

^{232}Th

$^{204,206,207,208}Pb$, ^{209}Bi

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

Phase 2* *(2009-2012)

Capture

^{25}Mg

^{88}Sr

$^{58,60,62}Ni$, ^{63}Ni

$^{54,56,57}Fe$

$^{236,238}U$

^{241}Am

Fission

$^{240,242}Pu$

$^{235}U(n,\gamma/f)$

^{232}Th, ^{234}U

^{237}Np (FF ang.distr.)

(n,α)

^{33}S, ^{59}Ni

n_TOF neutron flux

The accurate determination of **neutron cross sections** requires a high accuracy knowledge of the **neutron flux** (typically within 1-3 %)

$$\sigma_X(E_n) \propto \frac{C_X(E_n) - B(E_n)}{\Phi(E_n)}$$

Neutron measurements are a priority in every **time-of-flight facility**.

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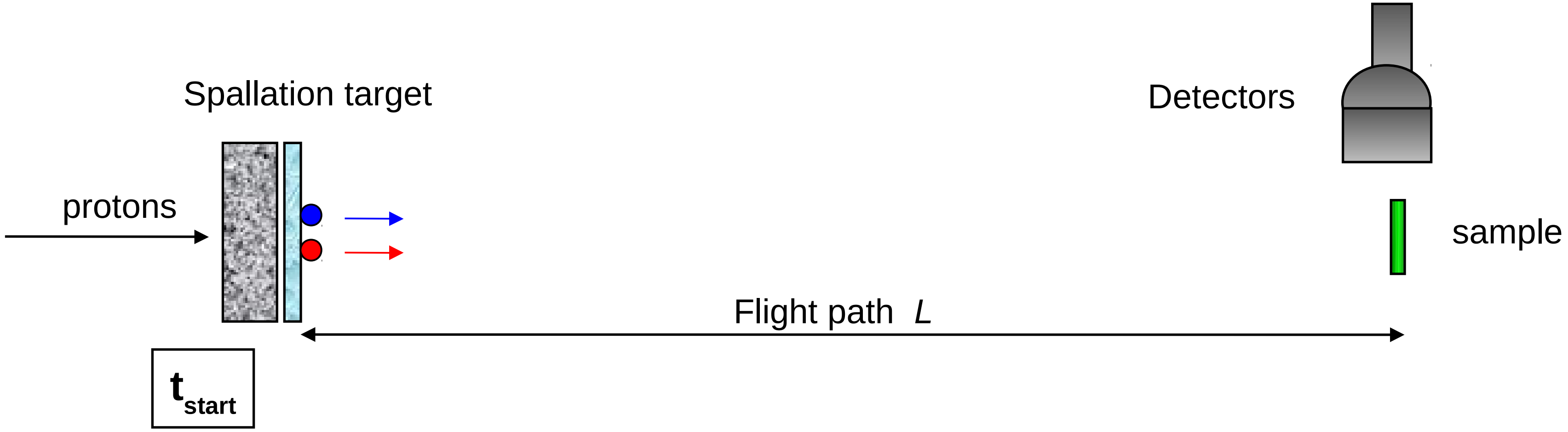

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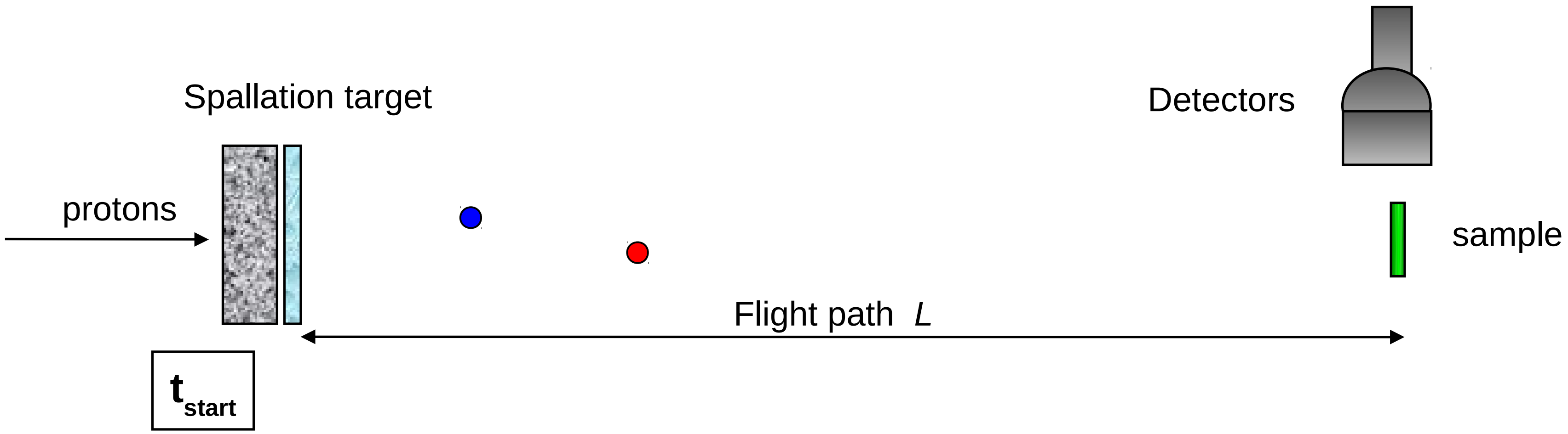

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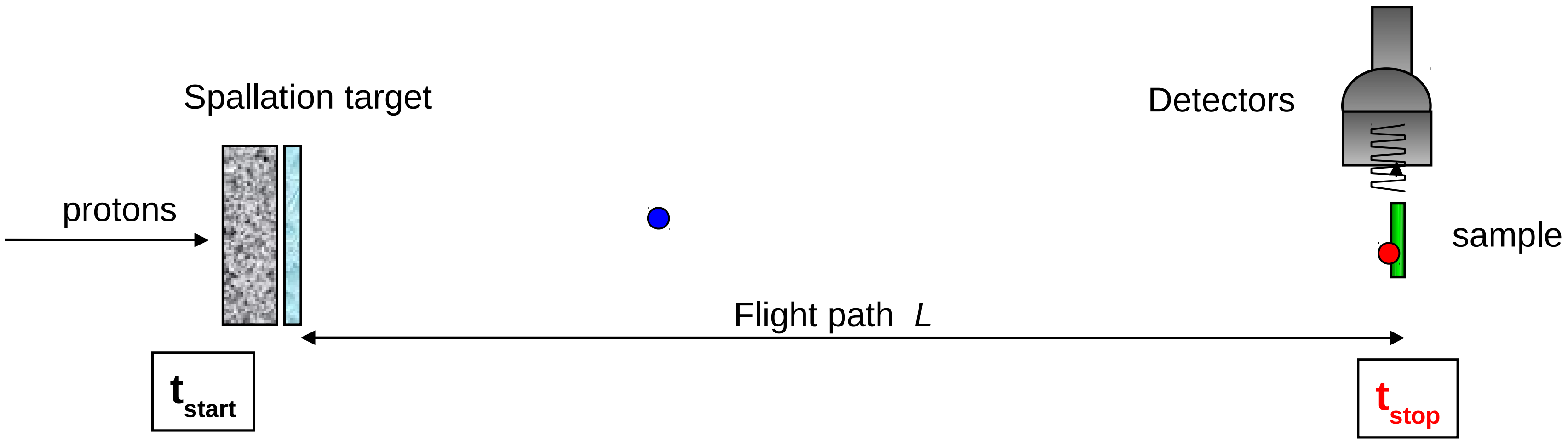

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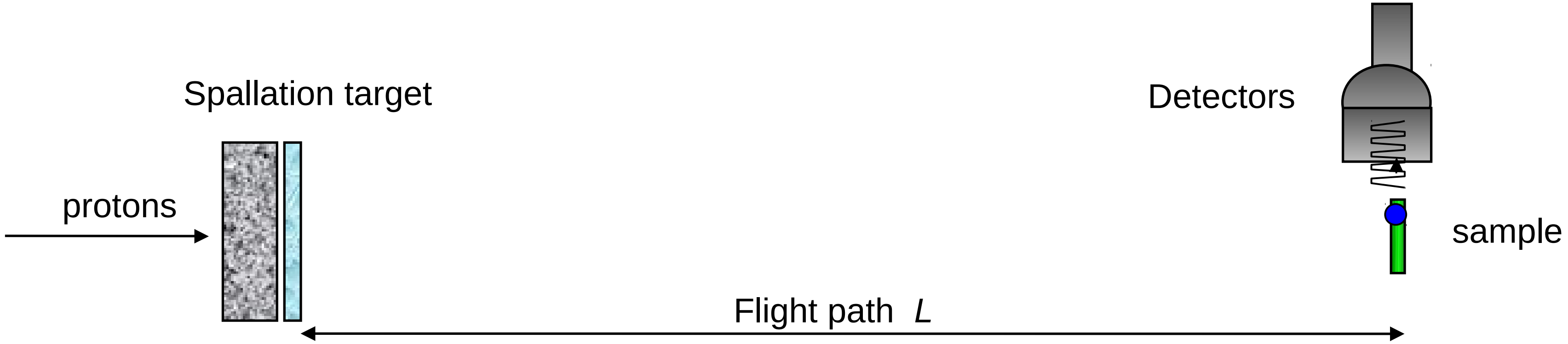


t_{start}

$TOF = t_{stop} - t_{start}$

t_{stop}

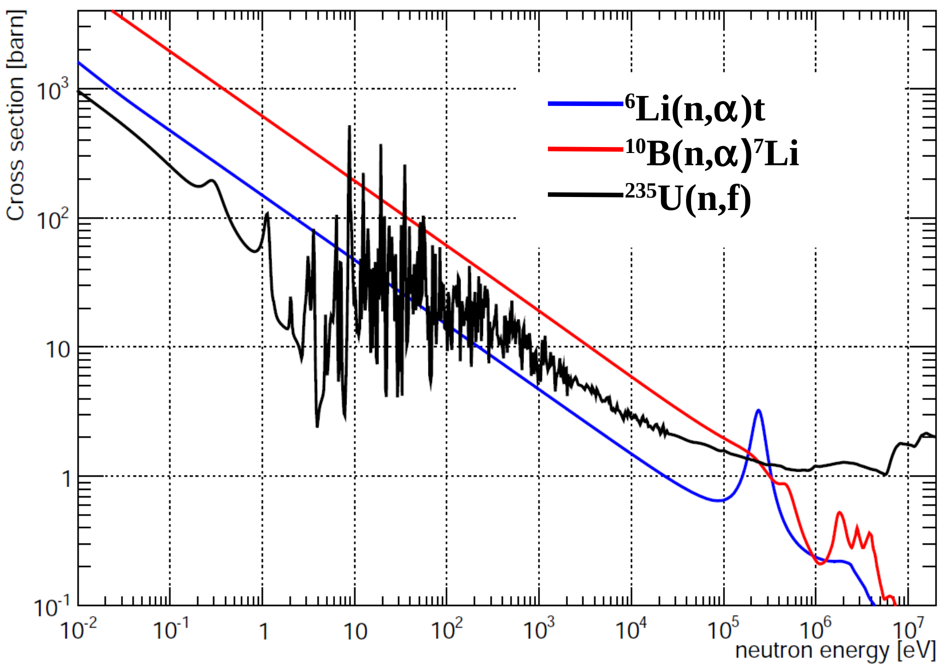
t_{stop}

$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1-\beta^2}} - 1 \right) \qquad with \qquad \beta = \frac{v_n}{c} = \frac{L}{cTOF}$$

neutron detection at n_TOF

At n_TOF, **4 different neutron detection systems** based on **3 different reactions** are used to measure neutrons and to monitor the neutron flux.

Such an approach allows to achieve **high accuracy** (quantified later) in flux determination



Reaction	Standard energy range
$H(n,n)$	1 keV to 20 MeV
$^3\mathrm{He}(n,t)$	0.0253 eV to 50 keV
$^6\mathrm{Li}(n,\alpha)$	0.0253 eV to 1 MeV
$^{10}\mathrm{B}(n,\alpha)$	0.0253 eV to 1 MeV
$^{197}\mathrm{Au}(n,\gamma)$	0.0253 eV **and** 0.2 MeV to 2.5 MeV
$^{235}\mathrm{U}(n,f)$	0.0253 eV **and** 0.15 MeV to 200 MeV
$^{238}\mathrm{U}(n,f)$	2 MeV to 200 MeV

$$\Phi(E_n) = \frac{C_X(E_n) - B(E_n)}{n \cdot \varepsilon(E_n) \cdot \underline{\sigma_X(E_n)}}$$

neutron detectors at n_TOF

Neutron detectors are used at n_TOF both to **measure** and **monitor** neutron flux.

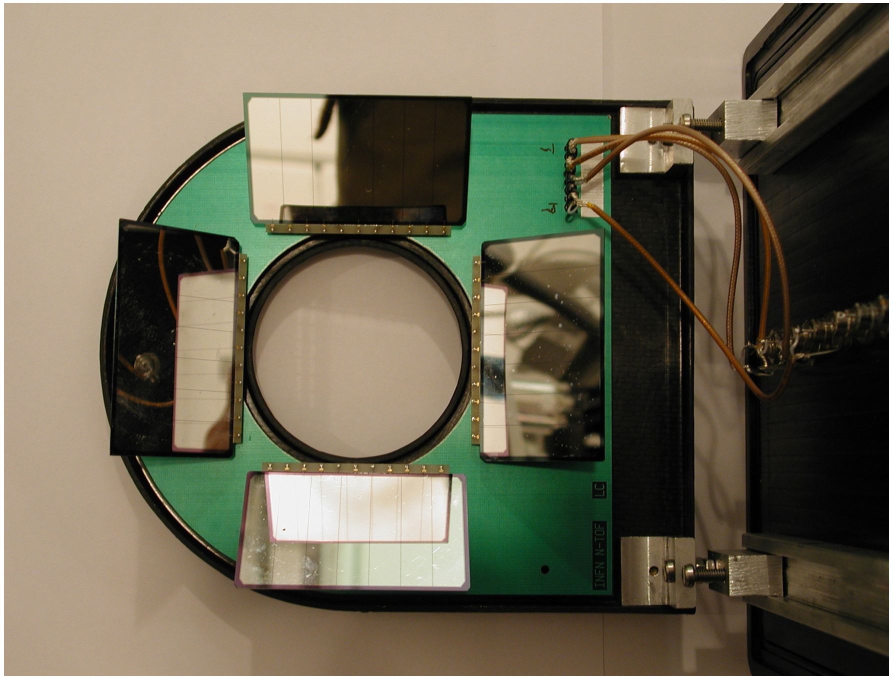
- **1 Silicon based detection system**
- **2 Micromegas detectors**
- **1 Calibrated fission chamber**
- **1 Parallel Plate Avalanche Counter**

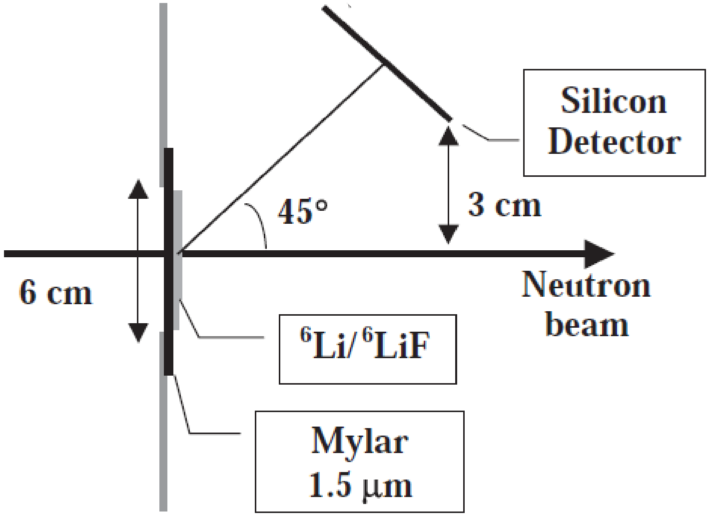
General features:

- Low efficiency (few % or less)
- Small in-beam masses (transparency)
- Fast response (~ ns)
- Radiation hardness

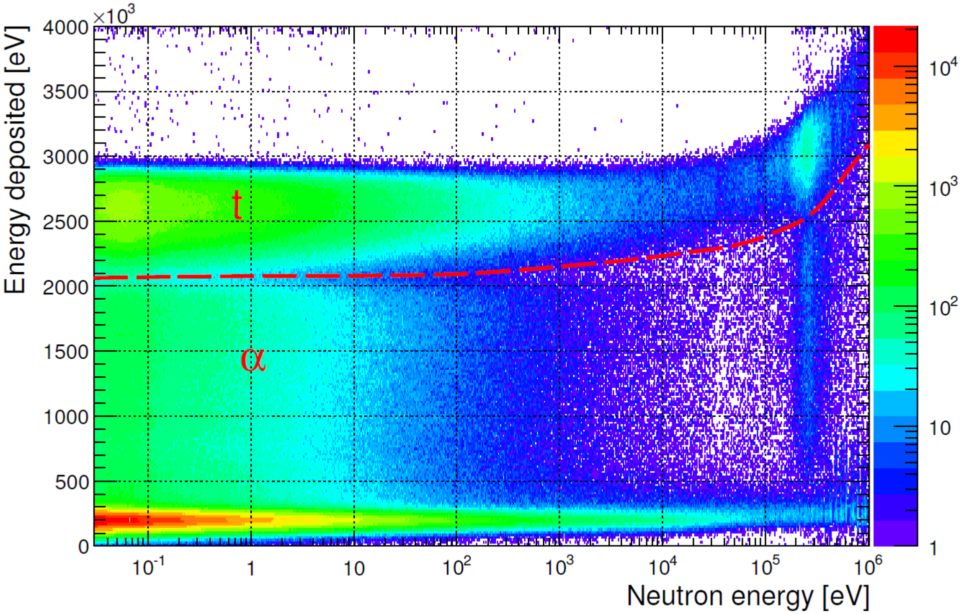
Silicon Monitor (SiMon)

Array of four 6x4 cm^2 silicon detectors + a 300 μm ^{6}Li thin converter foil





n + ^{6}Li ⟶ α + t + 4.78 MeV



Detection efficiency ~ 0.4% at thermal energy

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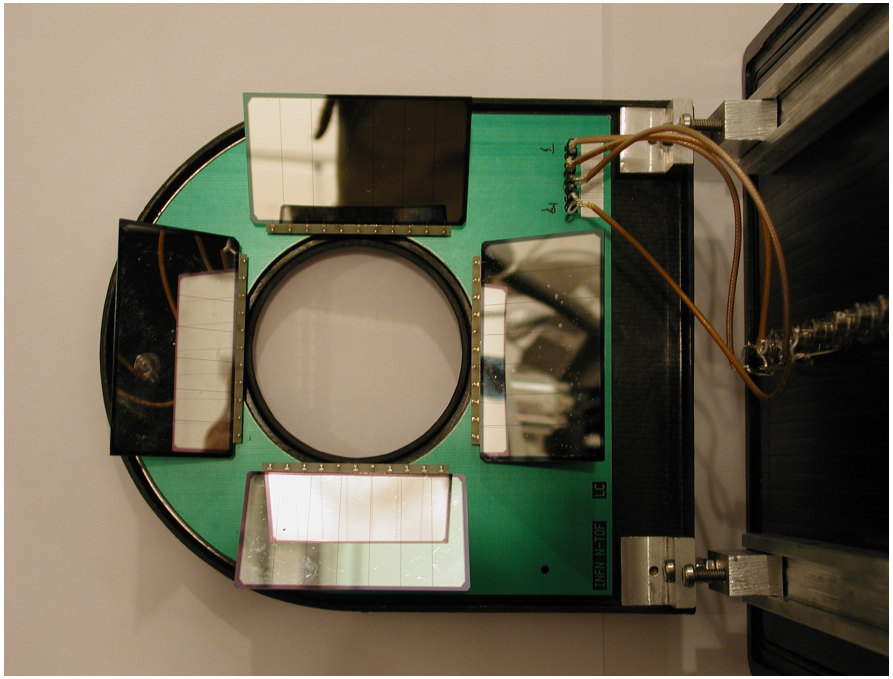

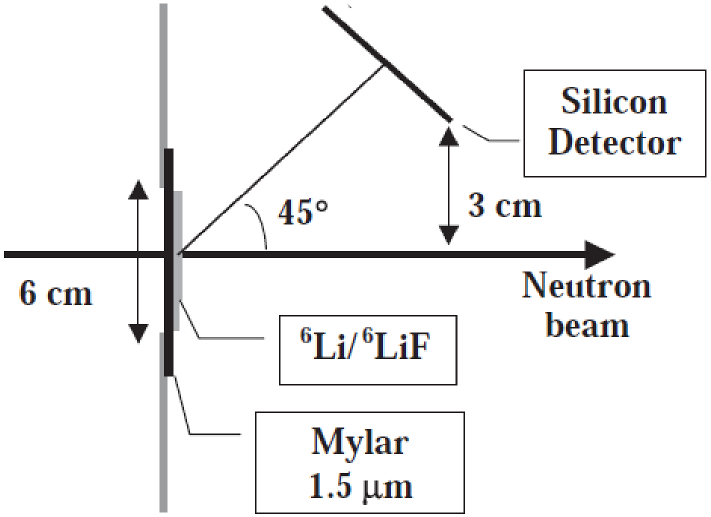

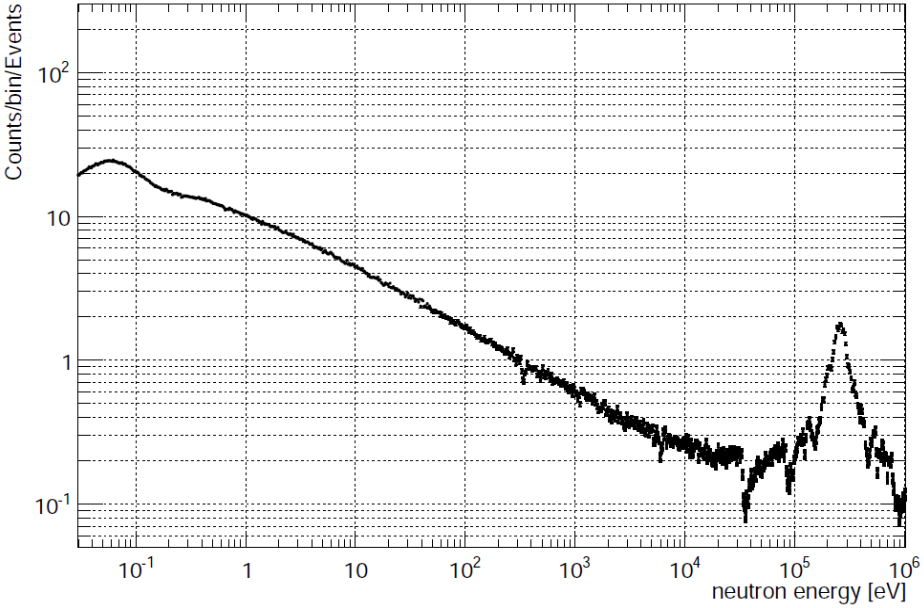

$$n + {}^6Li \longrightarrow \alpha + t + 4.78\ MeV$$

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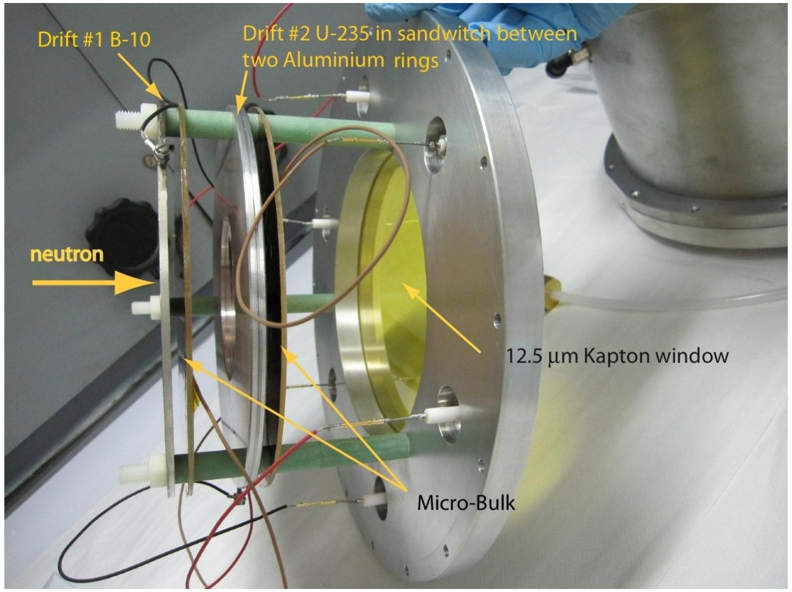
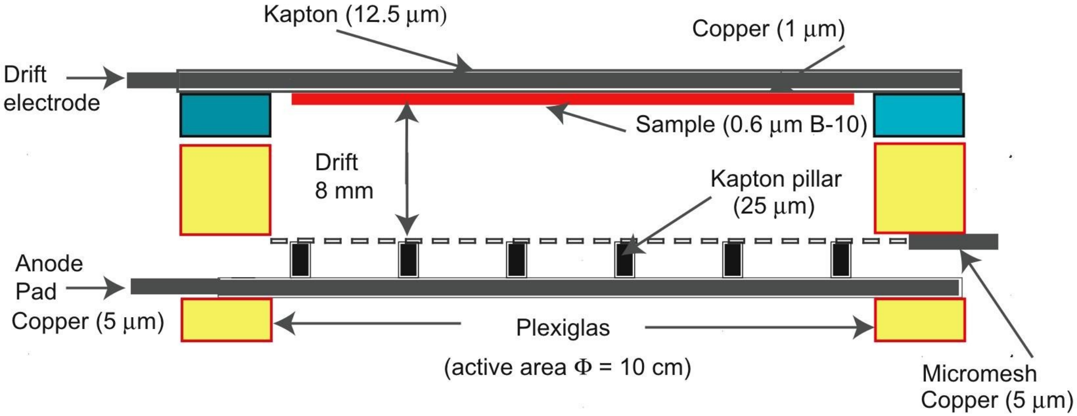
MicroMegas detectors

2 MicroMegas detectors equipped with **^{10}B** (0.6 µm) and **^{235}U** (1 mg) deposits





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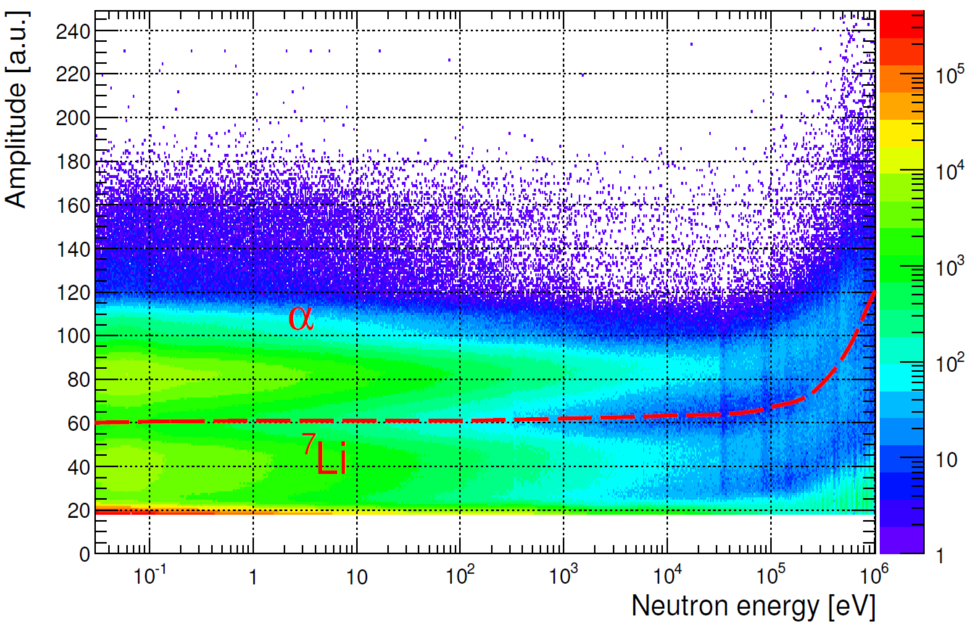
$$^{235}\mathrm{U} + n \rightarrow FFs \qquad Q-value \sim 200\,MeV$$



Detection efficiency < 1% at thermal energy

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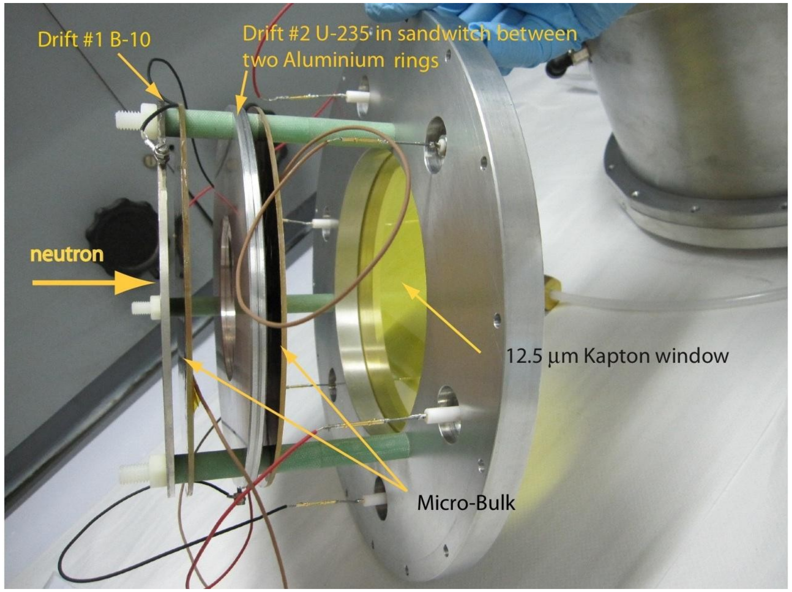

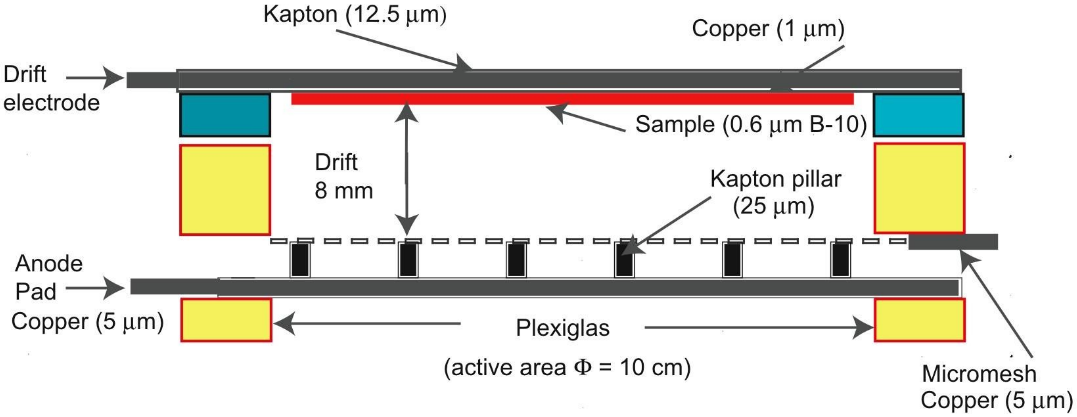

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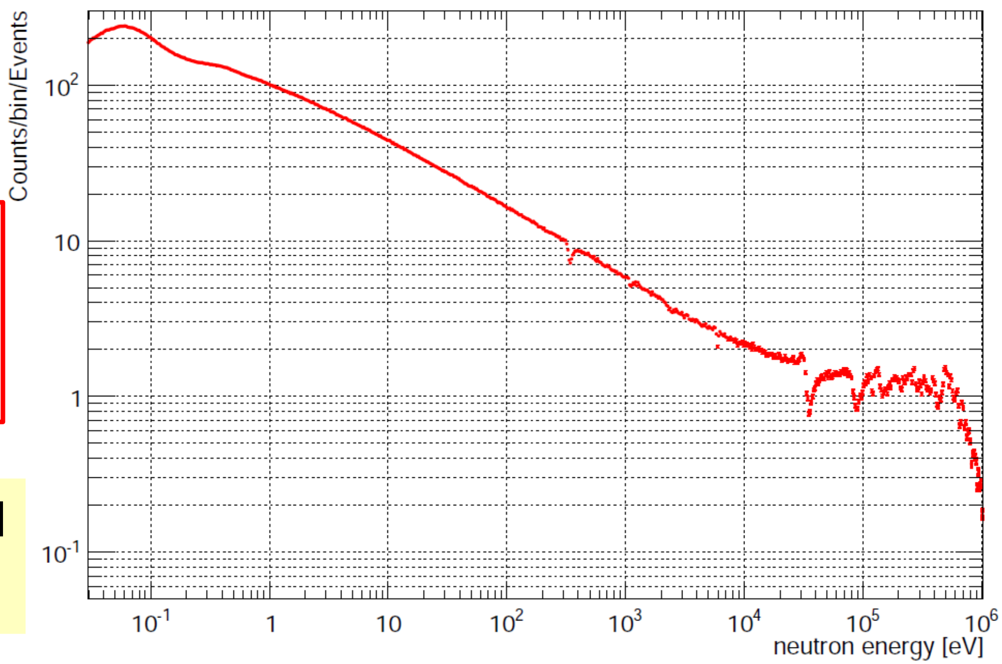

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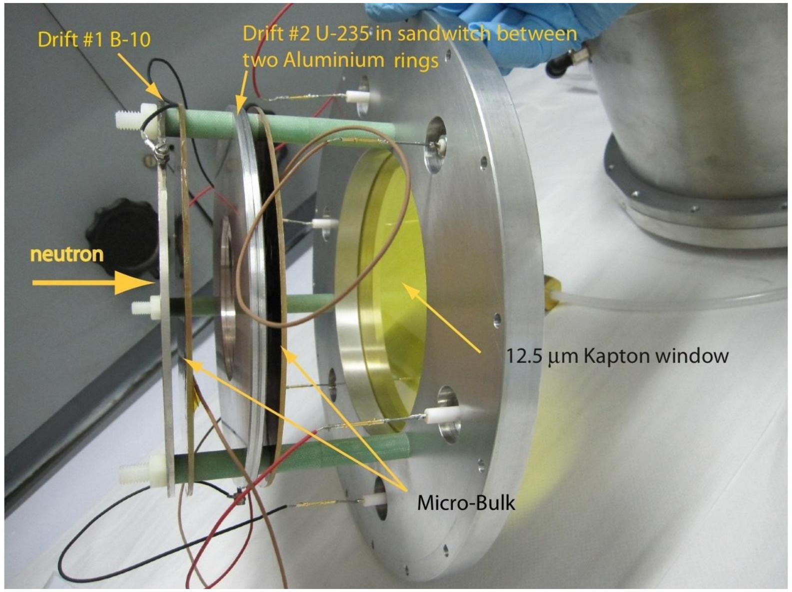

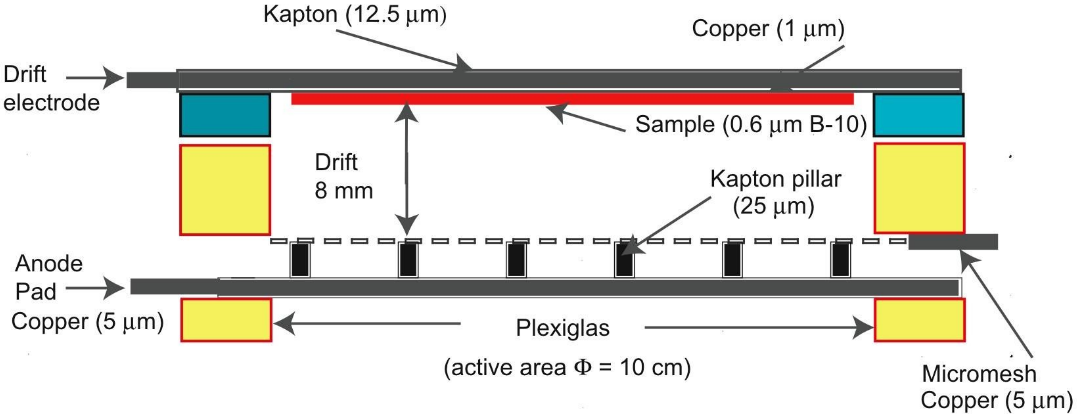

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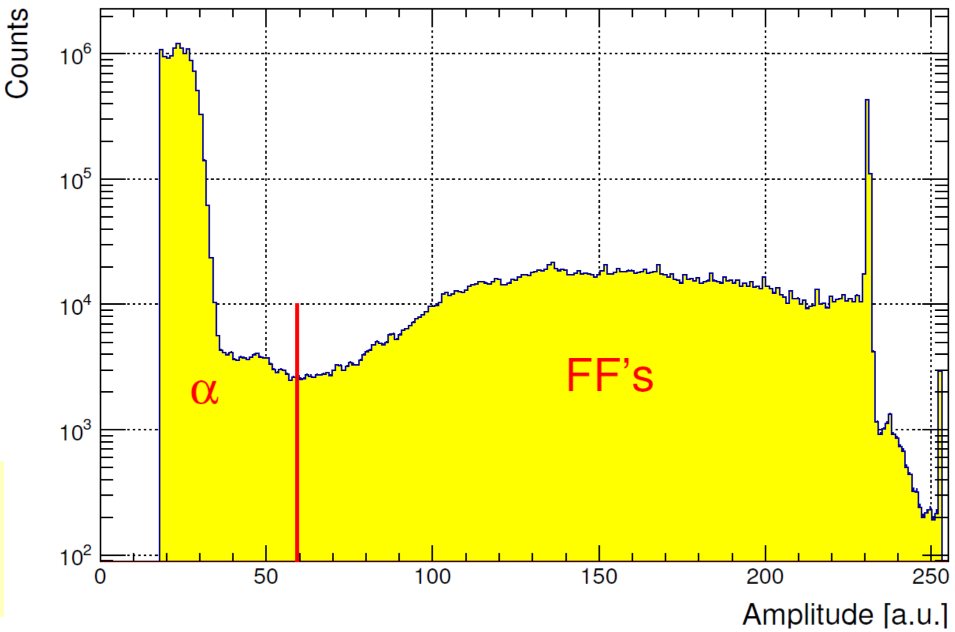

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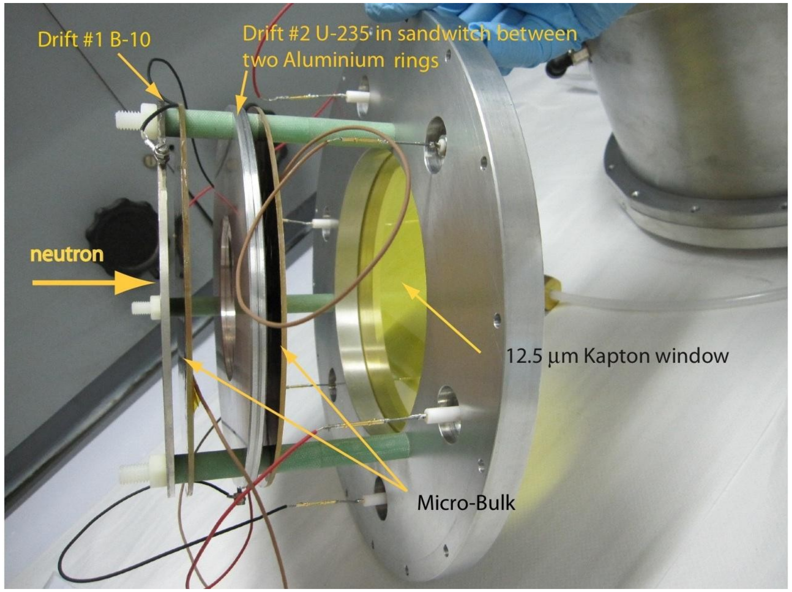

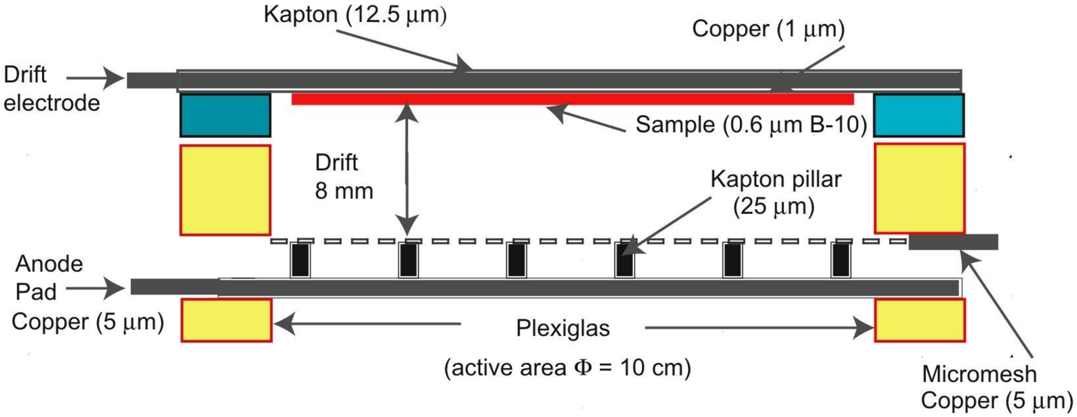

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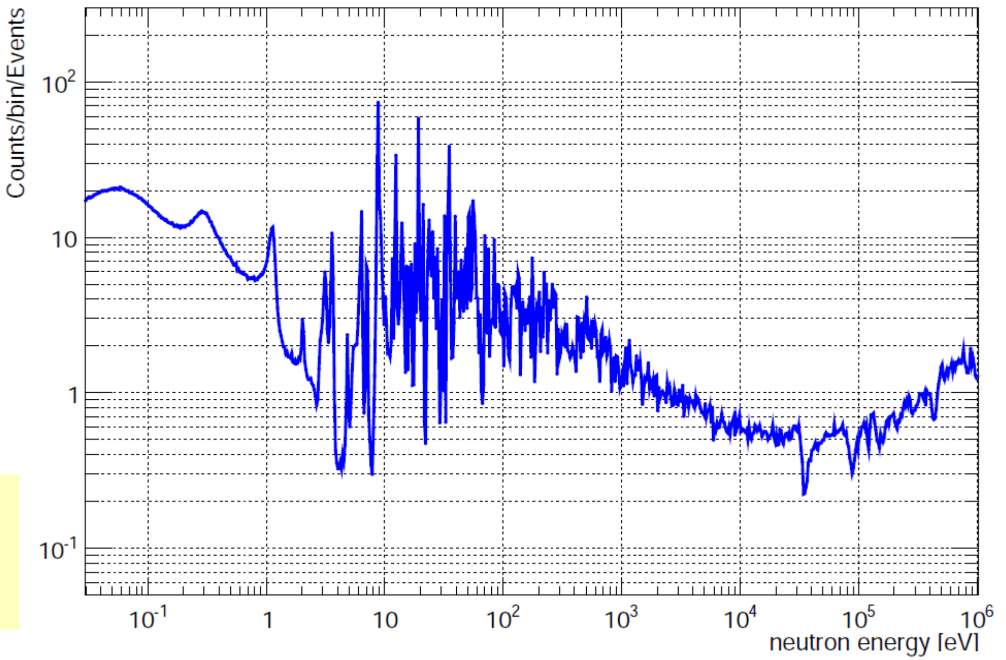
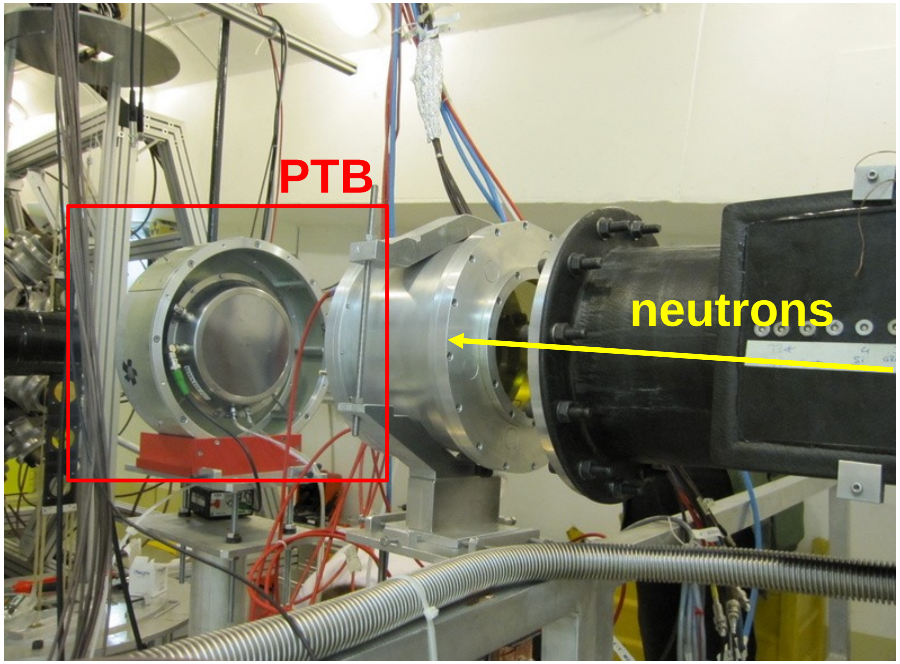
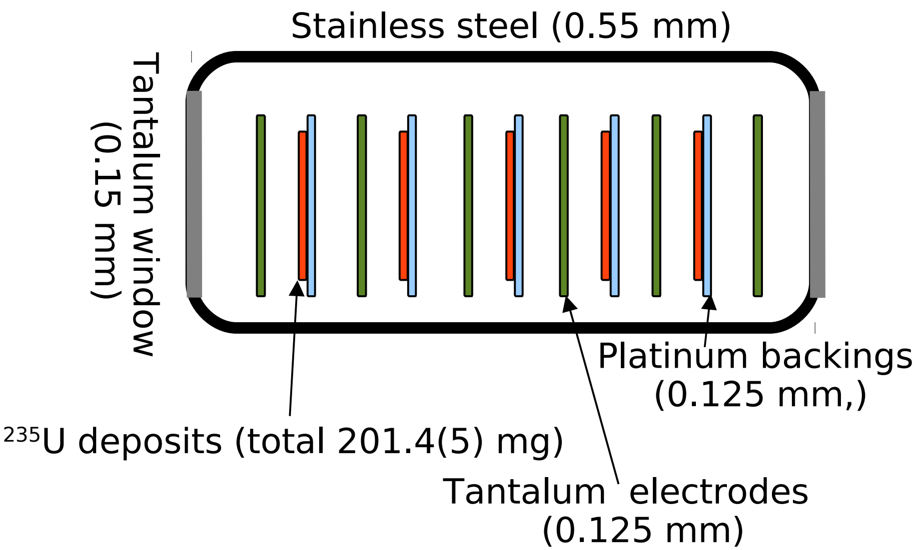


Detection efficiency < 1% at thermal energy

The PTB calibrated fission chamber

PTB detector is a **fission chamber** loaded with 201.4(5) mg of ^{235}U in five deposits.



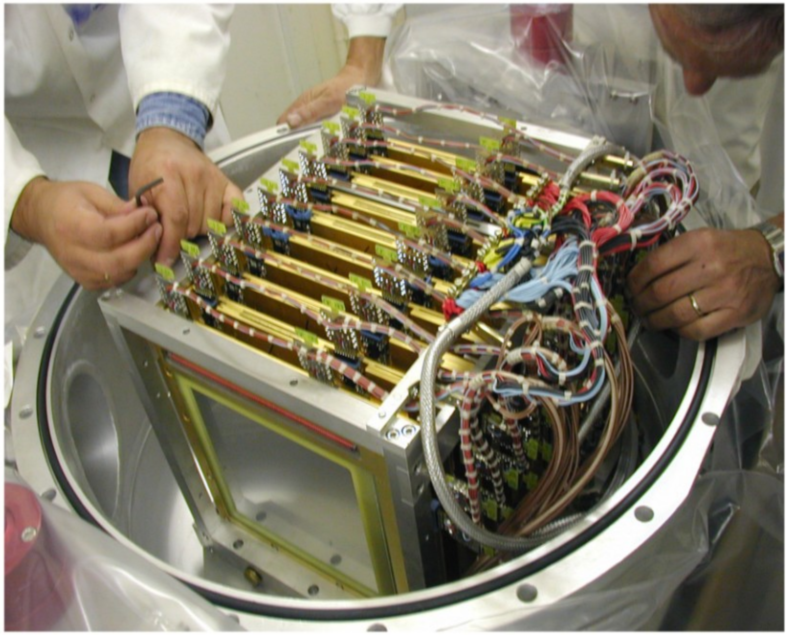


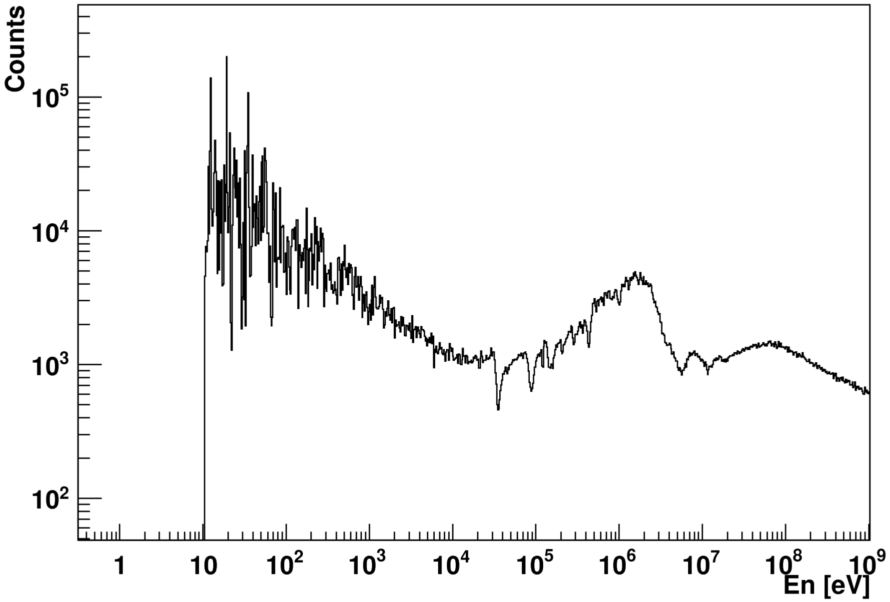
The PTB chamber is calibrated, meaning that the mass of ^{235}U and the detection efficiency are well known from previous “international intercomparisons”.

Reference detector in measuring neutron flux, not only at n_TOF.

Parallel Plate Avalanche Counter (PPAC)

At n_TOF PPAC detector is a stack of 10 parallel plate avalanche counters. Some of them are loaded with ^{235}U or ^{238}U in order to measure neutron flux.



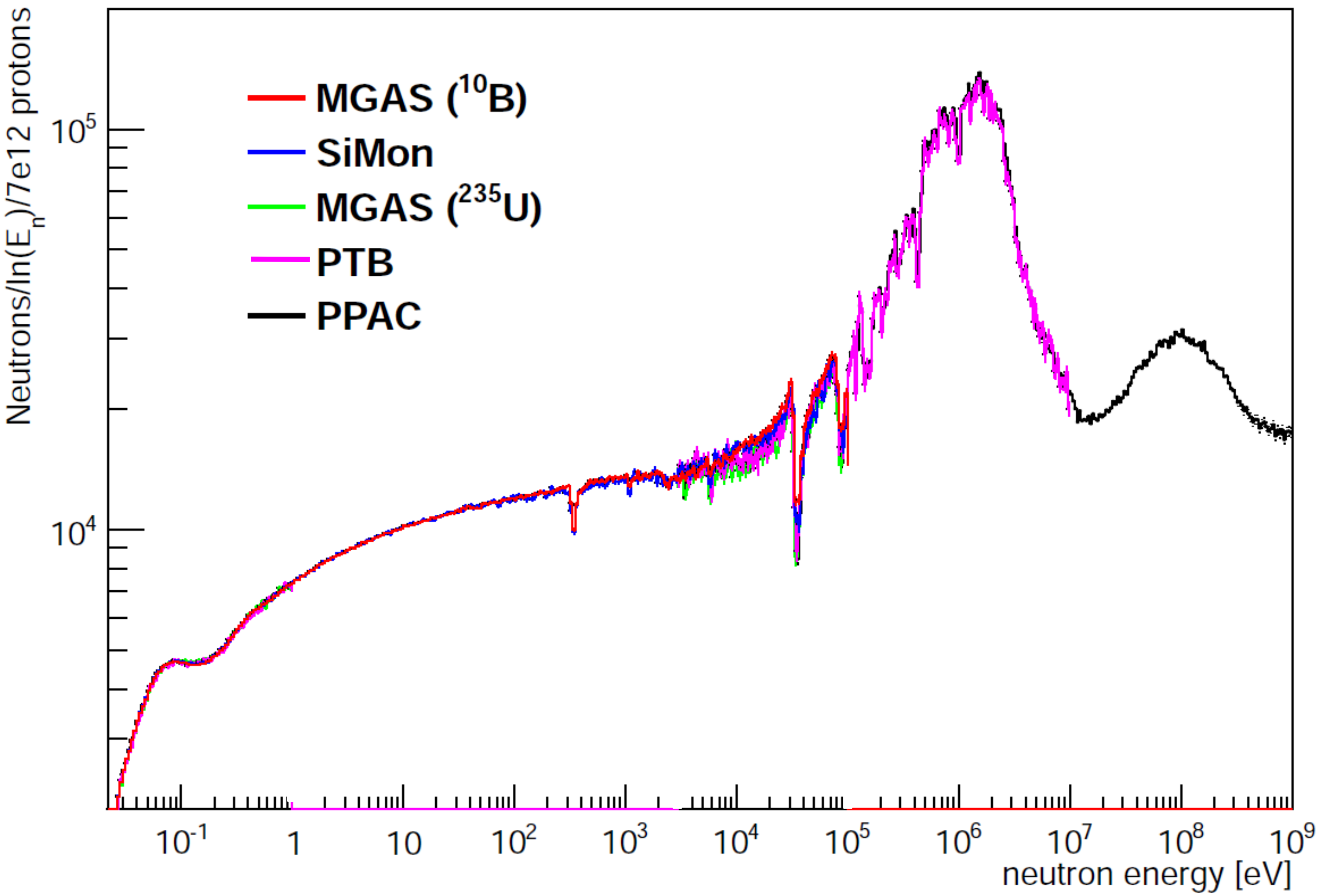


Fission fragments detected **in coincidence**, rejection of α background.

Fast response

Very low sensitivity to γ

Results from neutron measurements

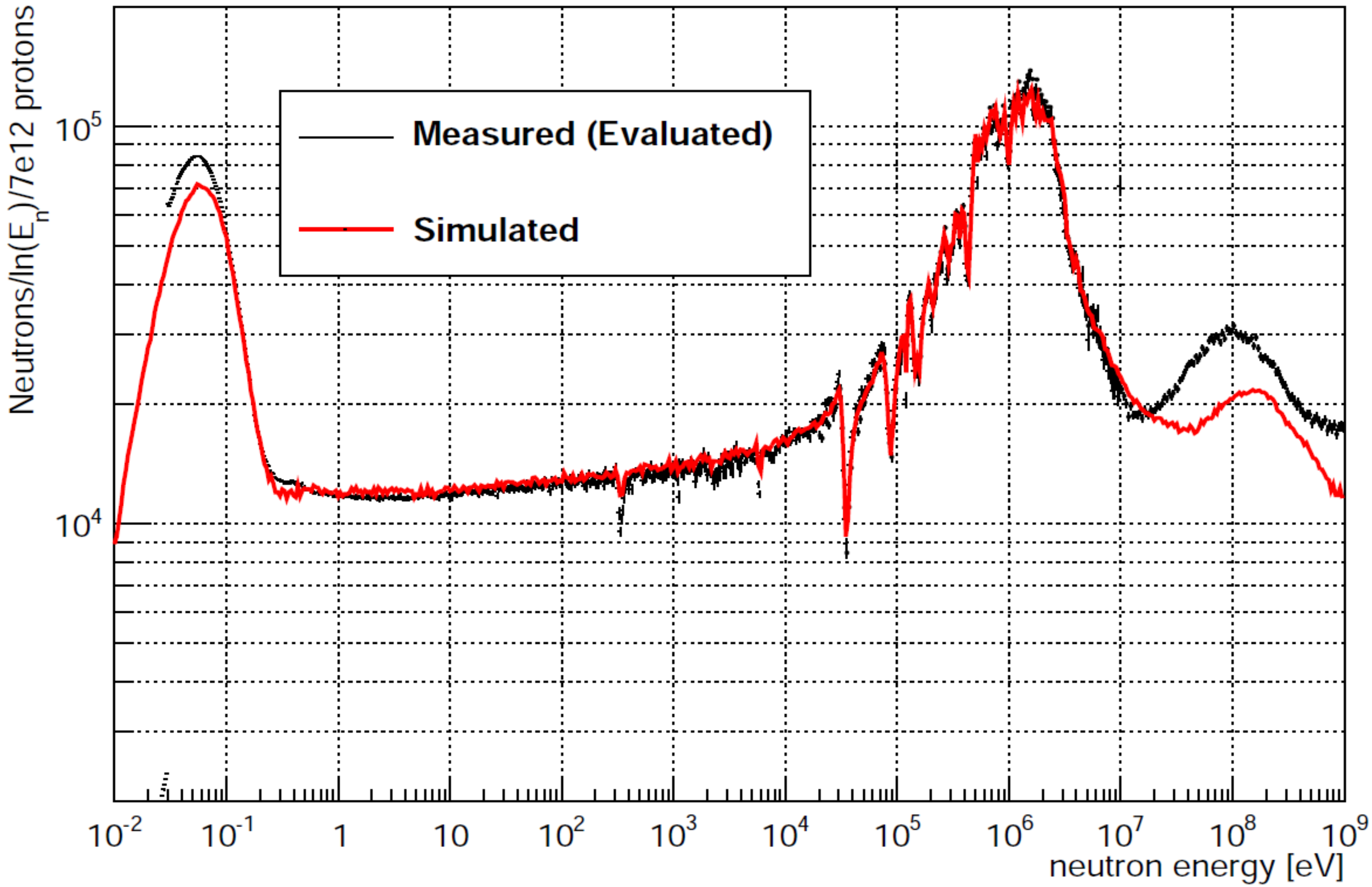


Measurements from 0.025 eV up to 1 GeV

Up to few keV results from different detectors agree within 2% (or less)

From few keV to higher energies agreement within 4-5%

Results from neutron measurements



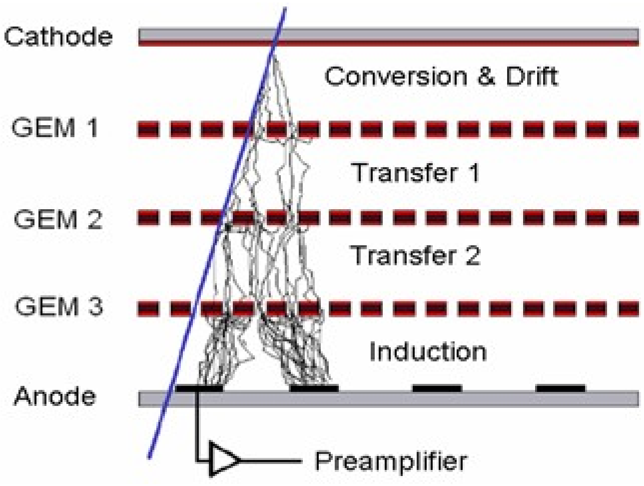
After carefull comparisons an **evaluated neutron flux** has been then determined combining results from all the detectors where they are considered reliable.

Other neutron detectors

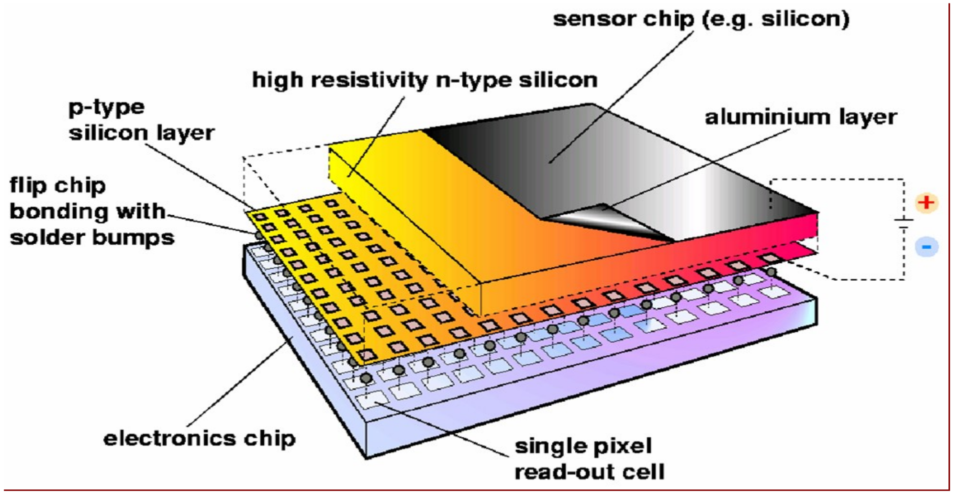
At n_TOF some measurements are also dedicated to test innovative neutron detectors, **both** in the context of the collaboration **and** from proposals of external research groups.

Recently (among others):

Triple GEM detector



MEDIPIX detector



Fast neutron (elastic scattering in Polyethilene)
Slow neutron (^{10}B converter)

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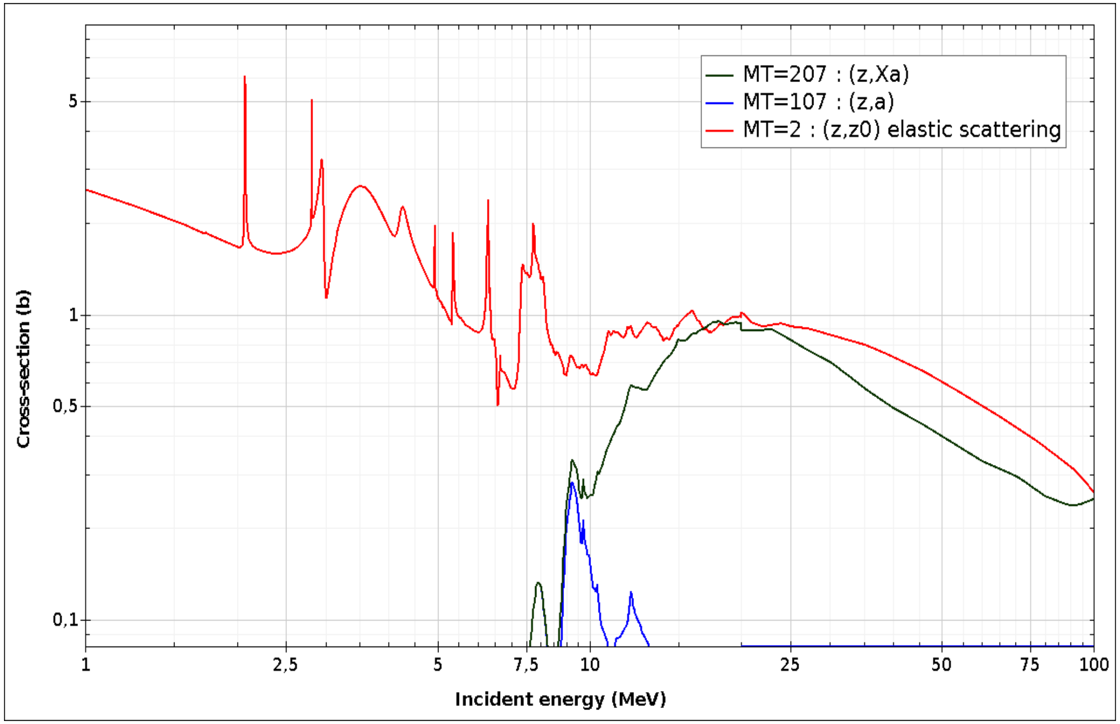
Single-Crystal Diamond Detector (SDD)



Fast neutron detection is achieved by detecting charge particles produced via the reactions:

- $^{12}C(n,\alpha)^{9}Be$
(Q_{value}=5.7 MeV, E_{thr}=6.17 MeV)

- $^{12}C(n,n')3\alpha$
(Q_{value}= 7.23 MeV, E_{thr}=7 MeV)

Conclusions

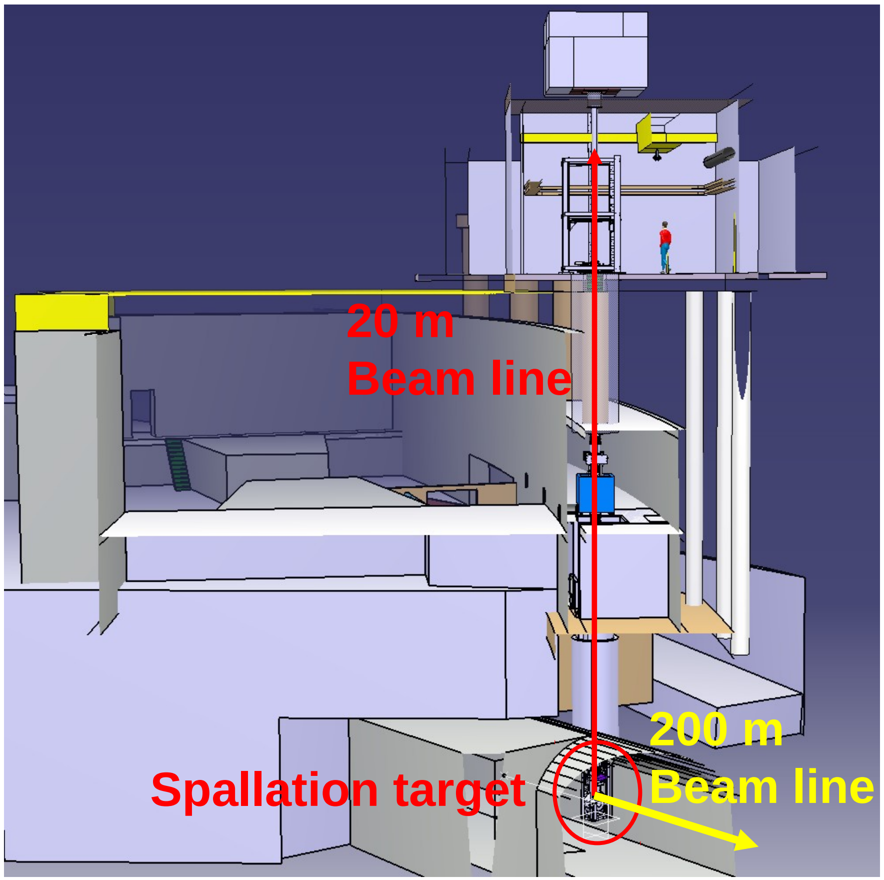
- The **n_TOF facility** is active since 2001, with the aim of addressing the request of accurated nuclear data for **nuclear astrophysics** and **nuclear technologies**.
- The **high quality** of its **neutron beam** makes **n_TOF** a unique facility in the world for cross section measurements of neutron induced reactions.
- **Several neutron detection systems** based on **standard reactions** are used to measure neutrons flux with high accuracy. Results show a very nice agreement.
- **R&D activity** is welcome...

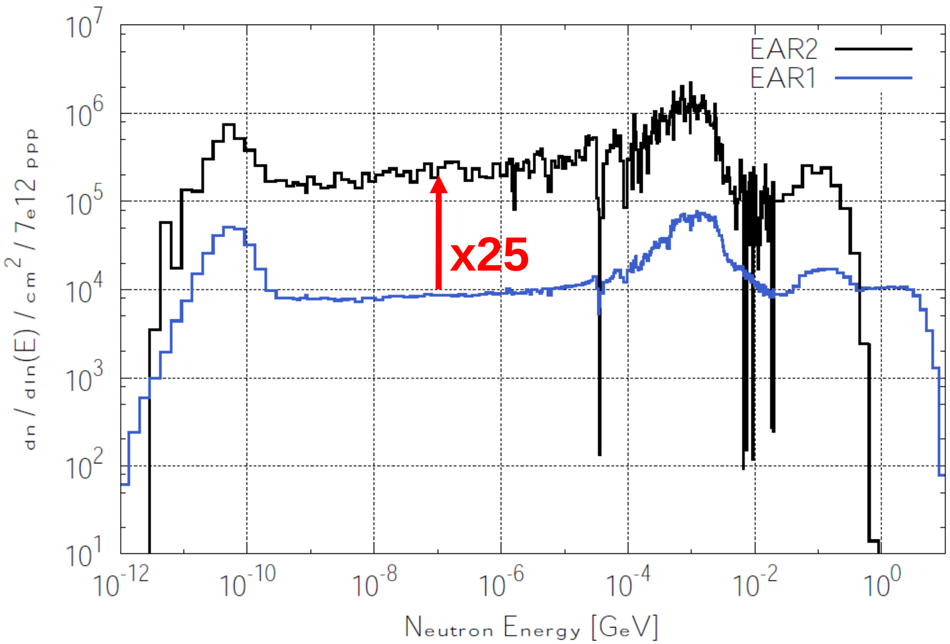
Conclusions

- The **n_TOF facility** is active since 2001, with the aim of addressing the request of accurated nuclear data for **nuclear astrophysics** and **nuclear technologies**.
- The **high quality** of its **neutron beam** makes **n_TOF** a unique facility in the world for cross section measurements of neutron induced reactions.
- **Several neutron detection systems** based on **standard reactions** are used to measure neutrons flux with high accuracy. Results show a very nice agreement.
- **R&D activity** is welcome....also for measurements in the second experimental area presently under construction.

~~Conclusions~~ EAR2

Experimental Area 2 will be placed at 20 m from the spallation target.





Higher fluence, by a factor of 25, relative to EAR1.

The **shorter flight path** implies a factor of 10 smaller time-of-flight.

Global gain by a factor of **250 in the signal/background ratio** for radioactive isotopes!

Conclusions

- The **n_TOF facility** is active since 2001, with the aim of addressing the request of accurated nuclear data for **nuclear astrophysics** and **nuclear technologies**.

- The **high quality** of its **neutron beam** makes **n_TOF** a unique facility in the world for cross section measurements of neutron induced reactions.

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- **R&D activity** is welcome....also for measurements in the second experimental area presently under construction.

Thanks for your kind attention

Back-up slides

Back-up slide