

Neutron inelastic cross sections on ^{14}N at GELINA

Andreea Oprea, Carlos Paradela, Arjan Plompen

European Commission, Joint Research Centre (EC-JRC), Geel, Belgium

Adina Olacel, Marian Boromiza, Alexandru Negret

Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania

Georgios Gkatis

CEA/DES/IRESNE/DER/SPRC/LEPh, Cadarache, France



Joint Research Centre

Headquarters in Brussels
and research facilities located
in 5 Member States:

- **Belgium (Geel)**
- Germany (Karlsruhe)
- Italy (Ispra)
- The Netherlands (Petten)
- Spain (Seville)



Nuclear laboratories at JRC - Geel



GELINA

neutron time-of-flight facility for high-resolution measurements



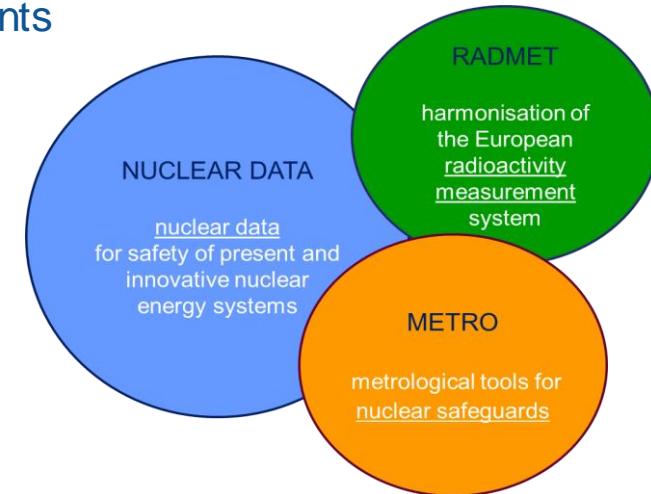
MONNET

Tandem accelerator-based fast neutron source

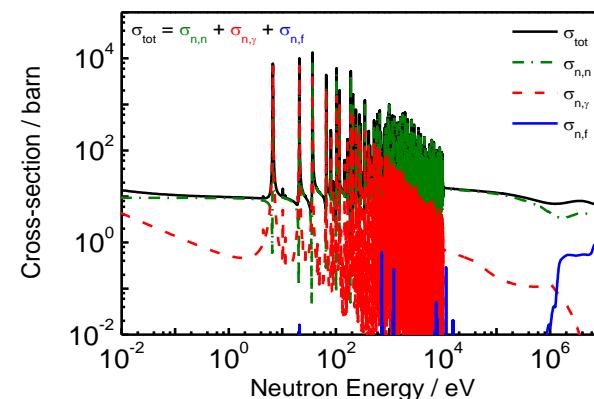
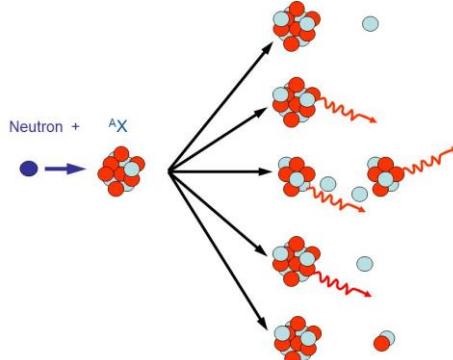


TARGET Laboratory

nuclear target preparation capabilities
(especially radioactive samples)



Neutron-induced interaction cross sections

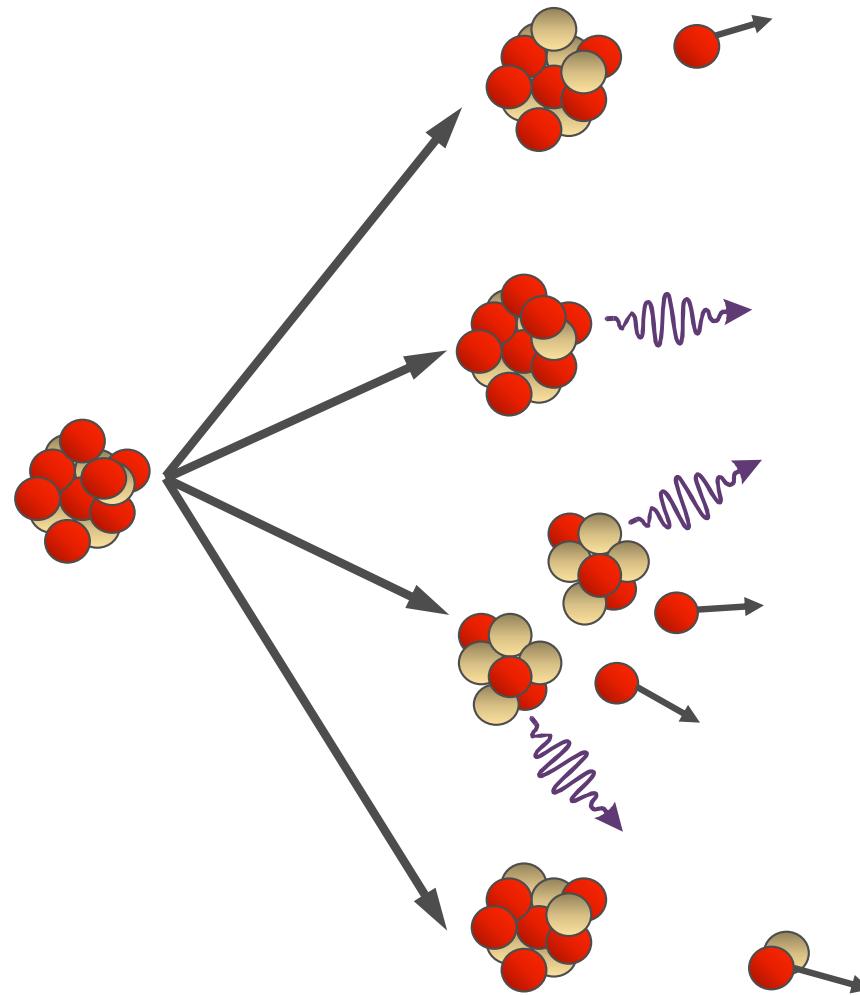


Neutron induced reactions



Neutron induced reactions

Cross section
probability that a neutron
interacts with a nucleus



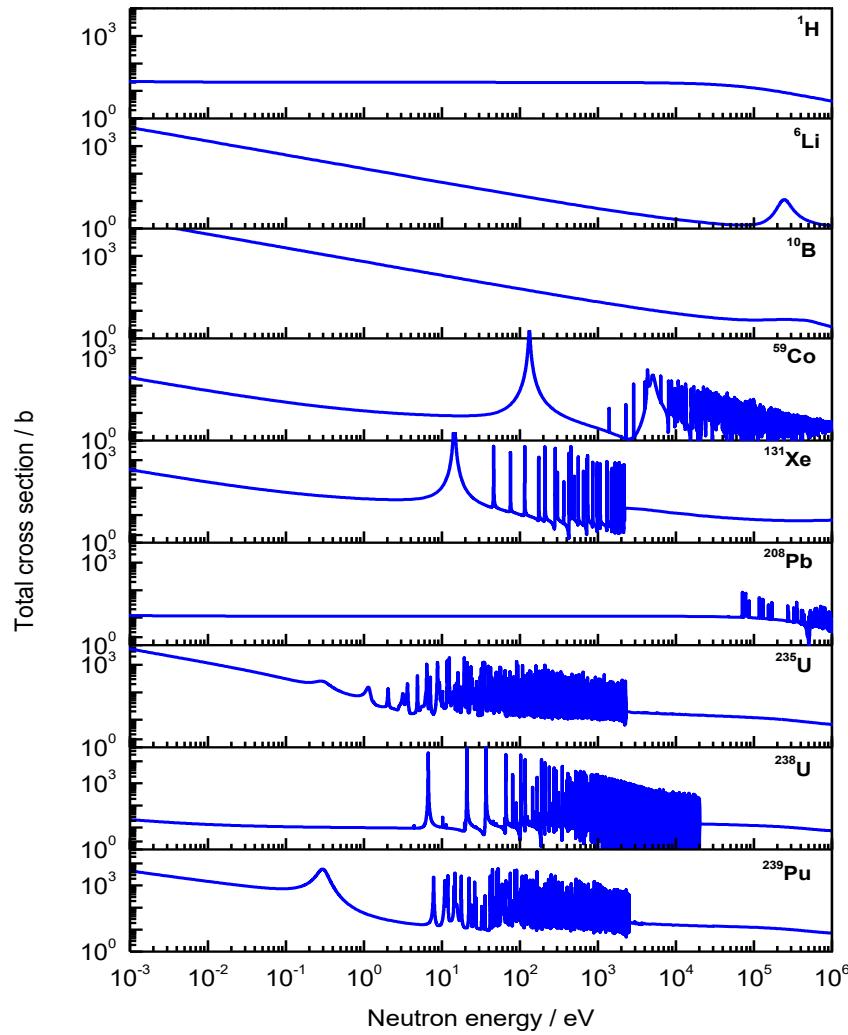
Elastic + Inelastic
 $(n,n)+(n,n')$

Capture (n,γ)

Fission (n,f)

Other reactions
 $(n,p), (n,d), (n,\alpha), \dots$

Neutron interaction probability



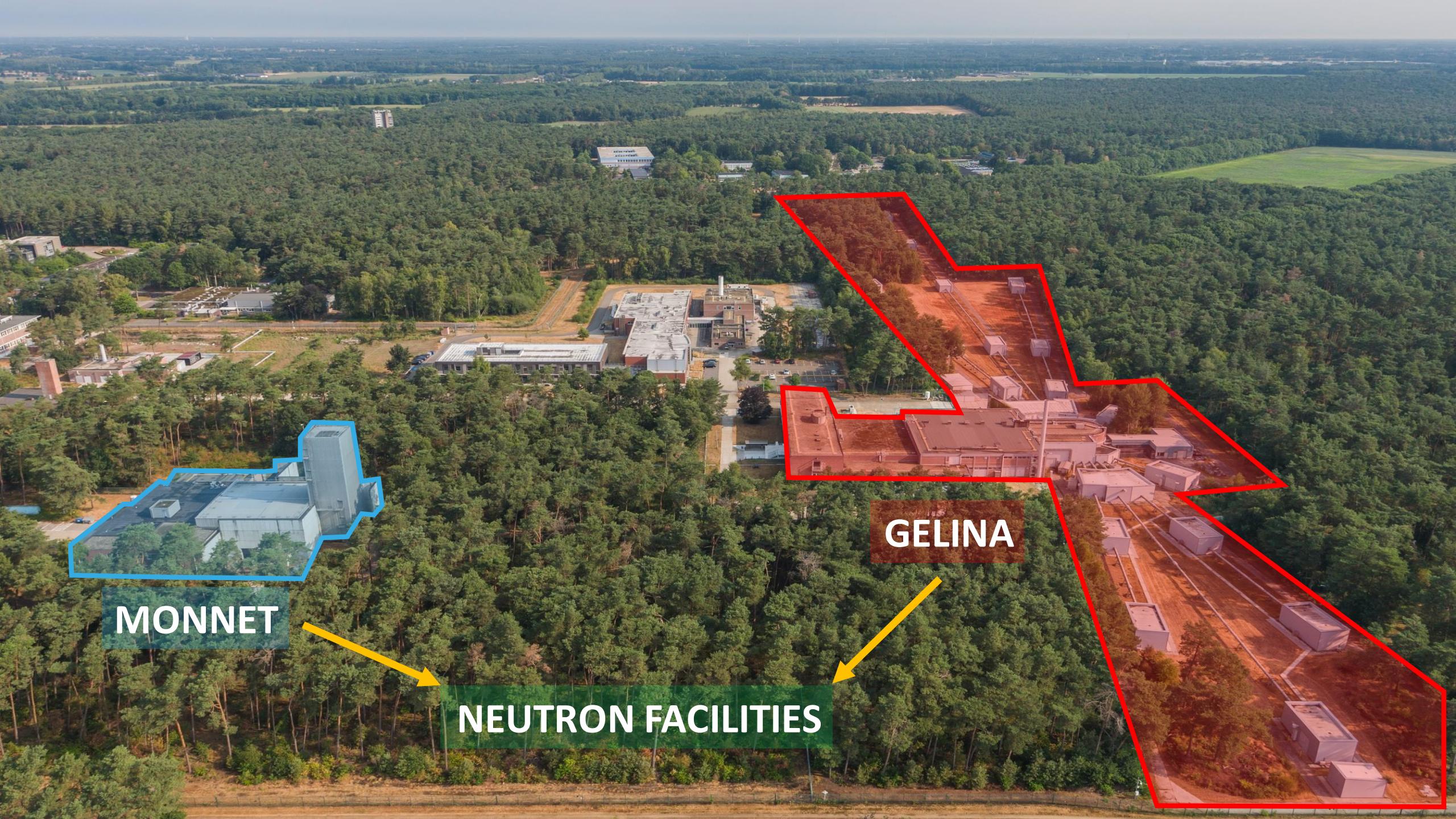
Probability depends on:

- Reaction
- Neutron energy
- Material

Probability cannot be predicted by nuclear theory

→ ***Experimental data required***

→ ***Neutron facilities***



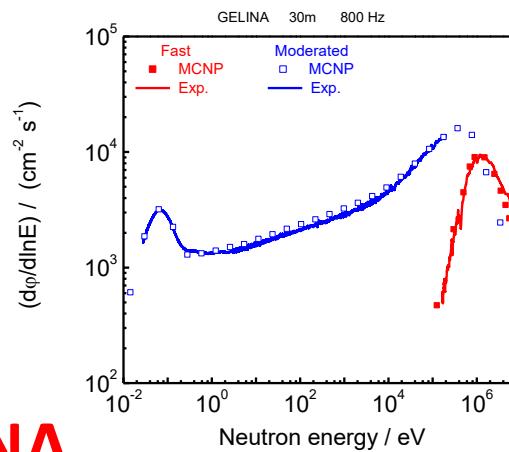
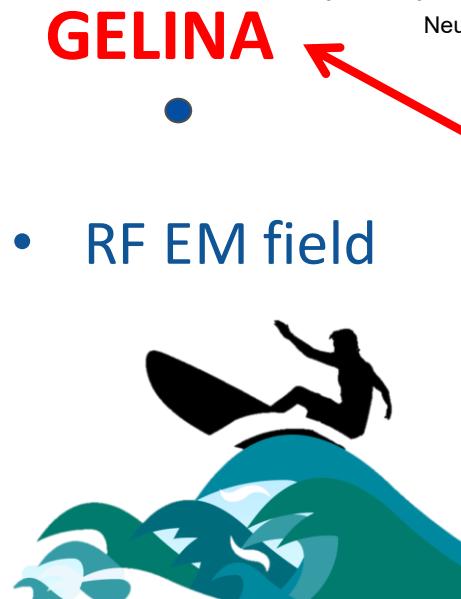
MONNET

NEUTRON FACILITIES

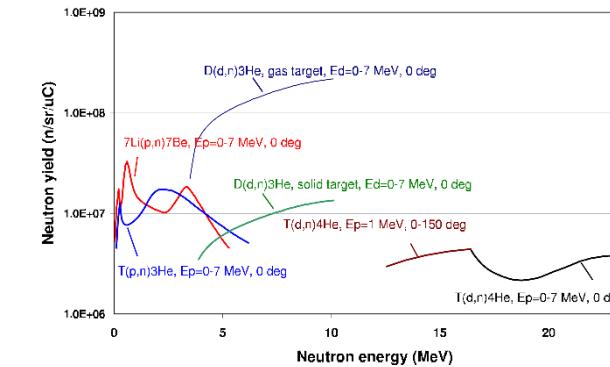
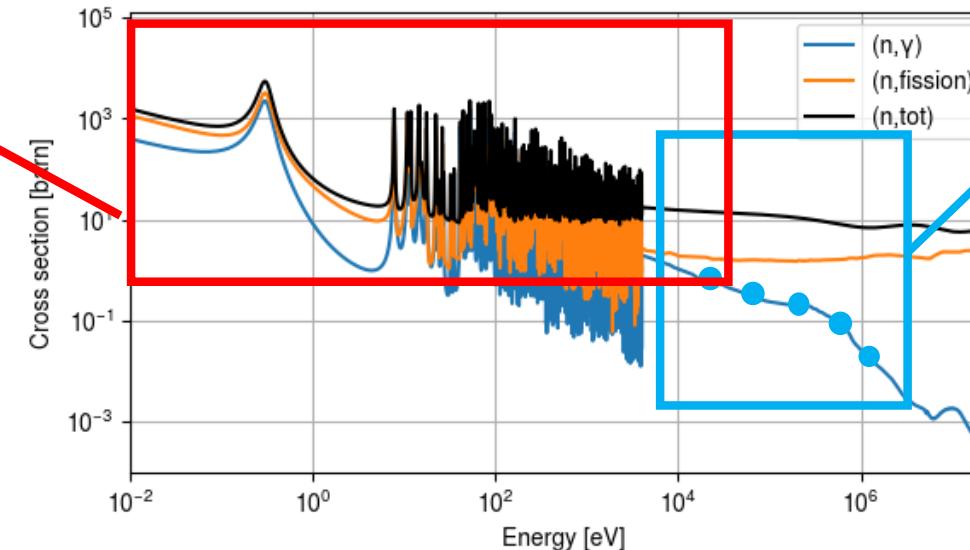
GELINA

Neutron facilities

$30\text{keV} < \text{En} < 20\text{MeV}$
 $1\text{meV} < \text{En} < 500\text{keV}$



^{239}Pu cross section



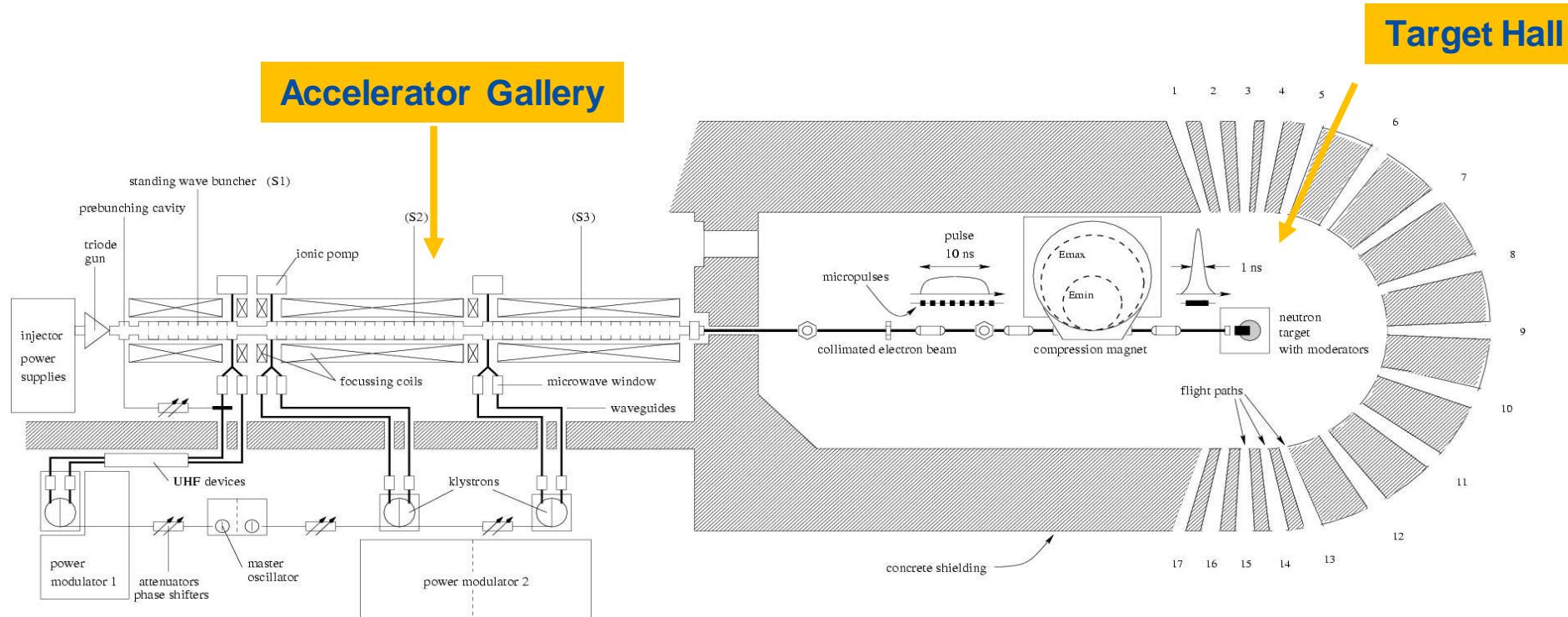
MONNET

- Static EM field

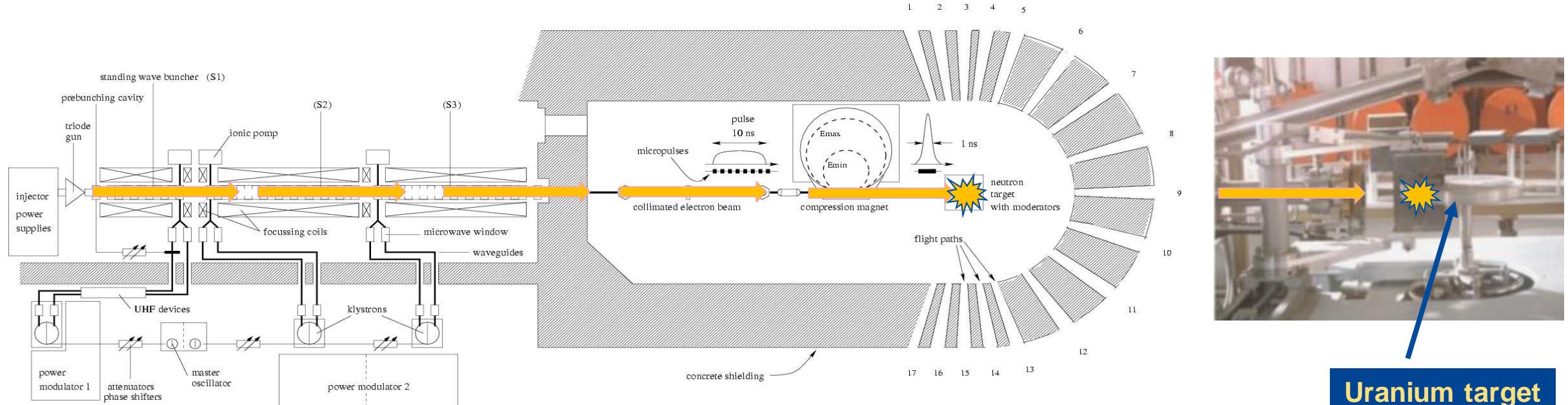


- Quasi-Monoenergetic

GELINA



GELINA neutron production

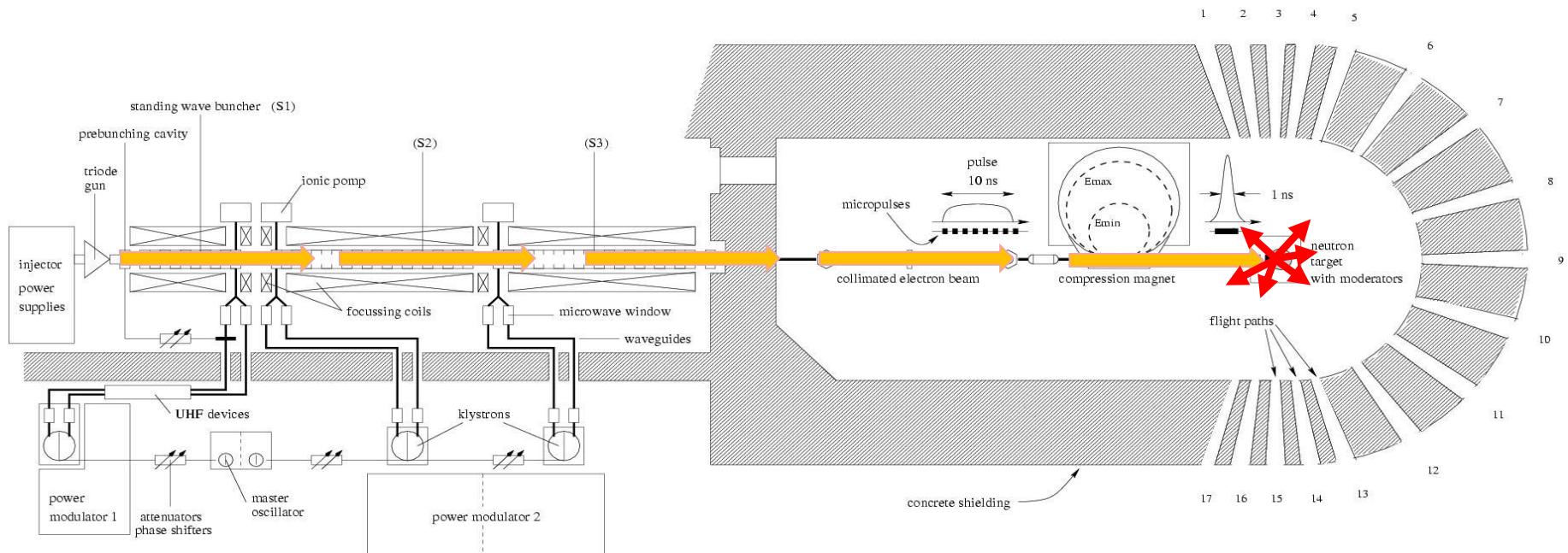


Normal Operating Parameters

Electron Energy Range : 70-140 MeV
Max Average Current : 100 μ A
Max Mean Power : 10 kW

Max Frequency : 800 Hz
Pulse Width : 1-2 ns
Max Neutron Flux: $2 \times 10^{13} \text{ 1/cm}^2\text{s}$

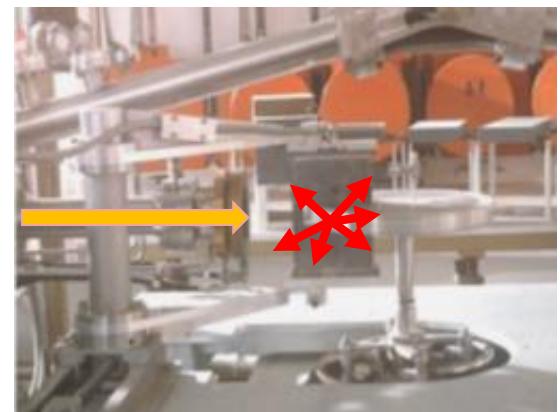
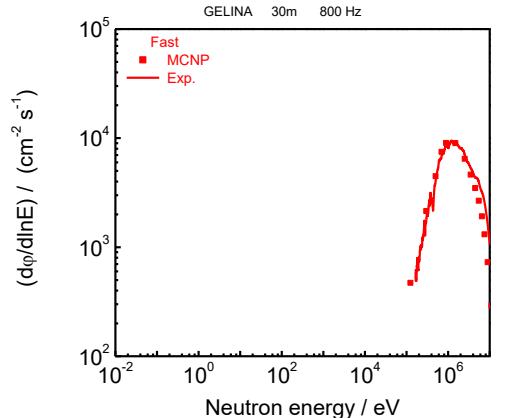
GELINA neutron production



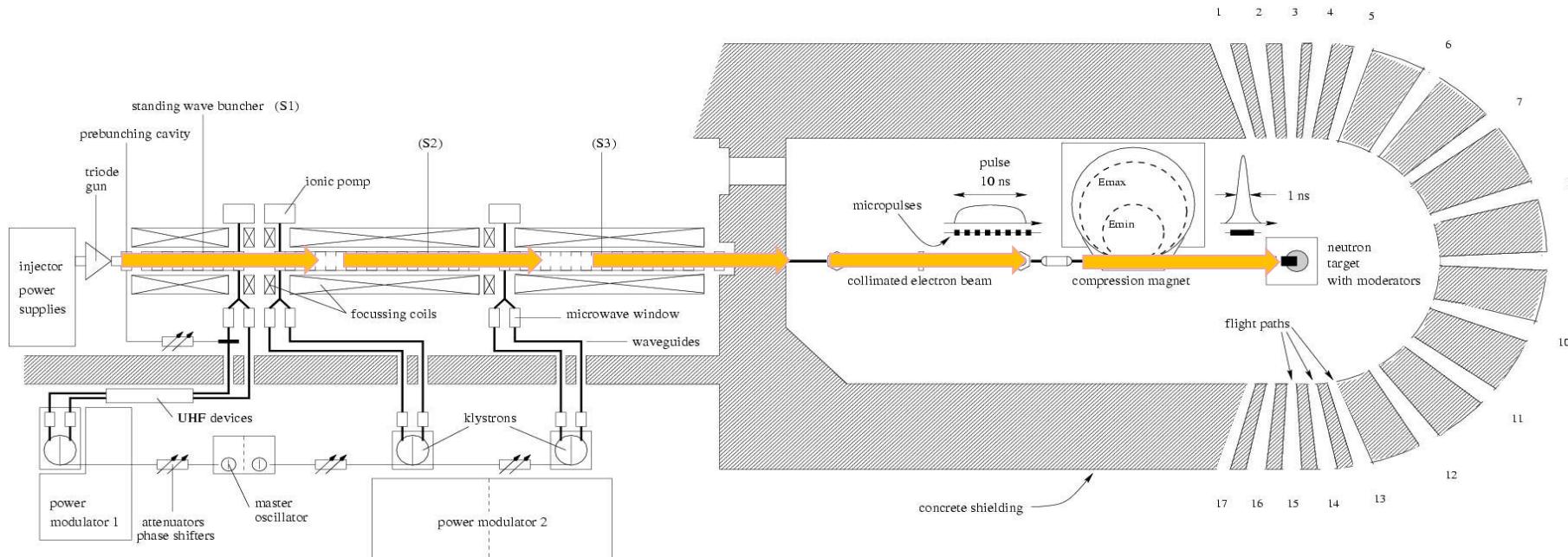
Normal Operating Parameters

Electron Energy Range : 70-140 MeV
 Max Average Current : 100 μ A
 Max Mean Power : 10 kW

Max Frequency : 800 Hz
 Pulse Width : 1-2 ns
 Max Neutron Flux: $2 \times 10^{13} \text{ 1/cm}^2\text{s}$



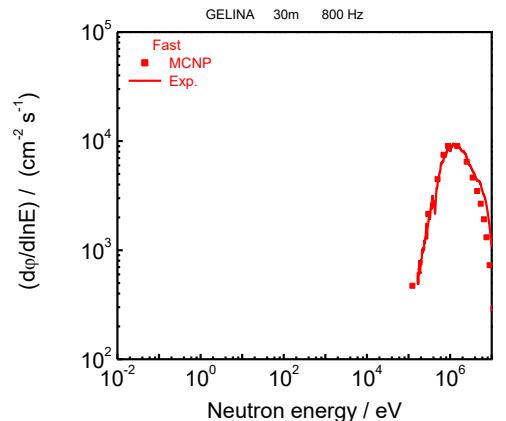
GELINA neutron production



Normal Operating Parameters

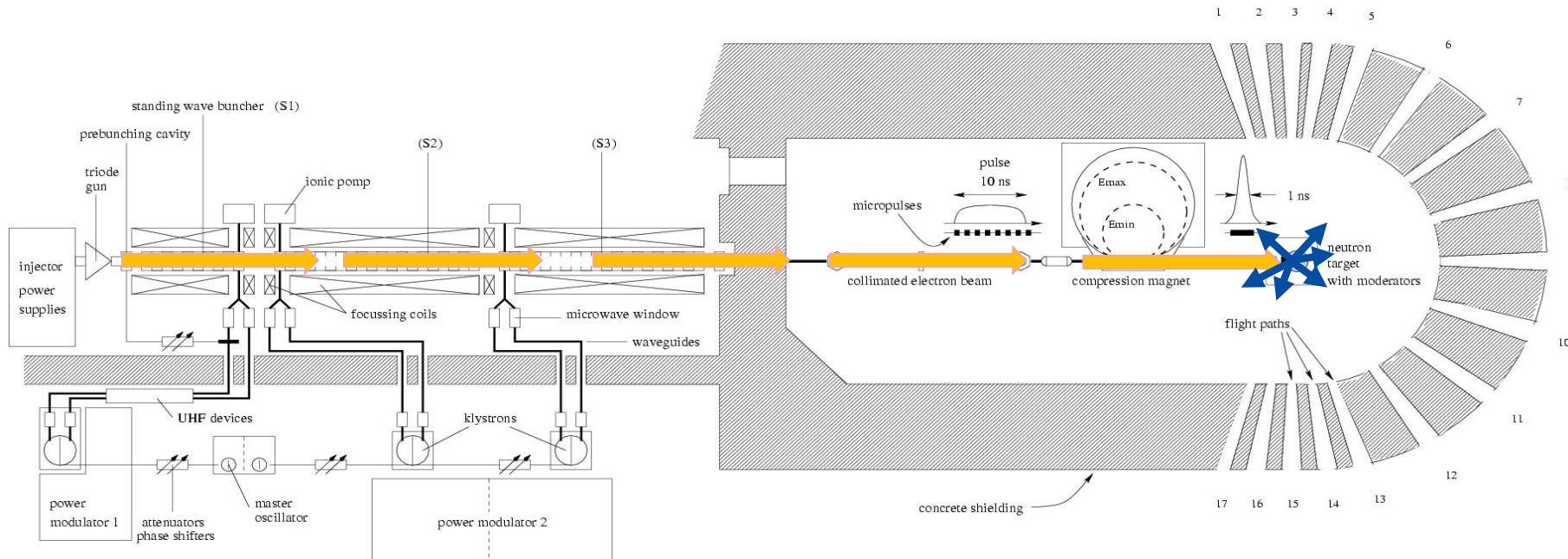
Electron Energy Range : 70-140 MeV
 Max Average Current : 100 μ A
 Max Mean Power : 10 kW

Max Frequency : 800 Hz
 Pulse Width : 1-2 ns
 Max Neutron Flux: $2 \times 10^{13} \text{ 1/cm}^2\text{s}$



Moderators

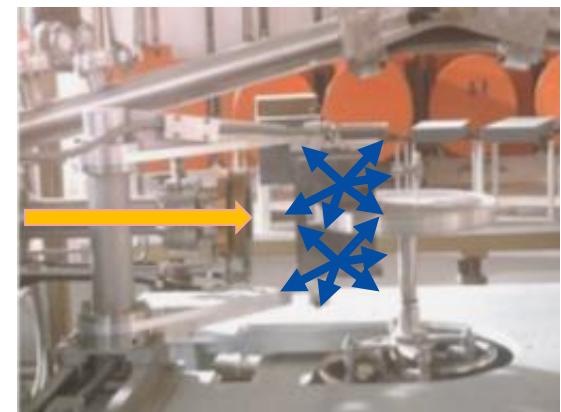
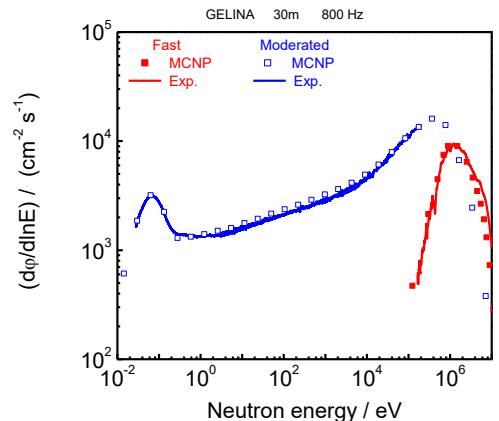
GELINA neutron production



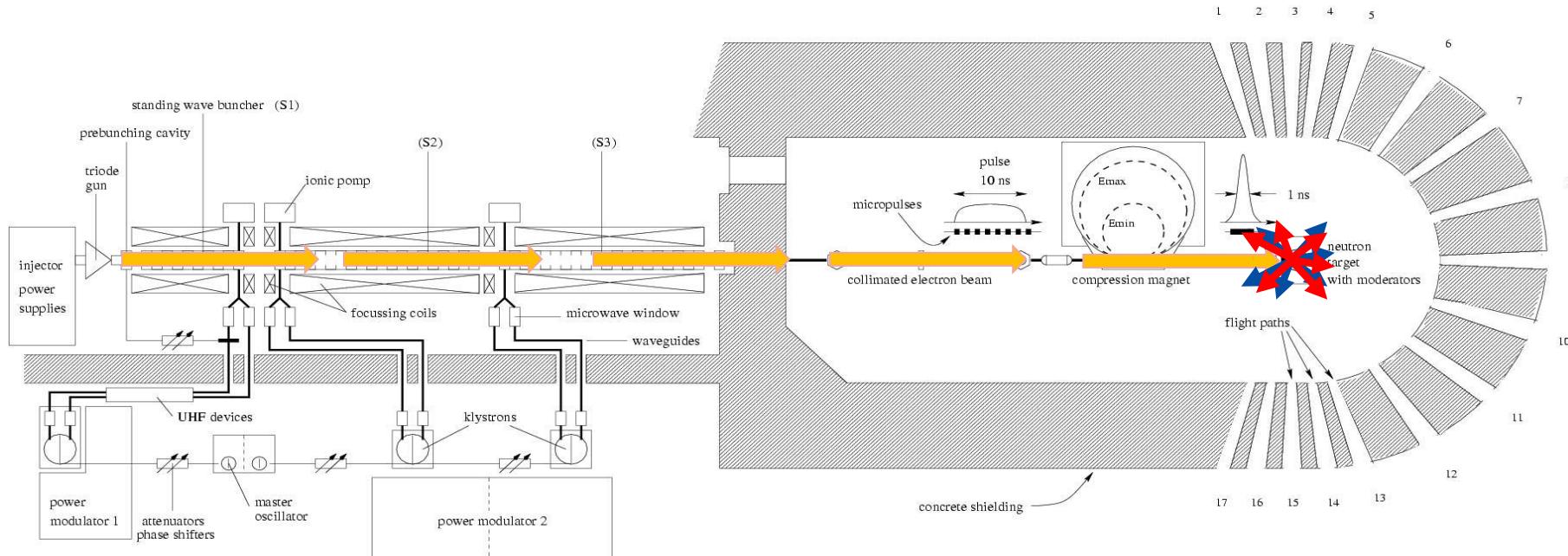
Normal Operating Parameters

Electron Energy Range : 70-140 MeV
 Max Average Current : 100 μ A
 Max Mean Power : 10 kW

Max Frequency : 800 Hz
 Pulse Width : 1-2 ns
 Max Neutron Flux: $2 \times 10^{13} \text{ 1/cm}^2\text{s}$



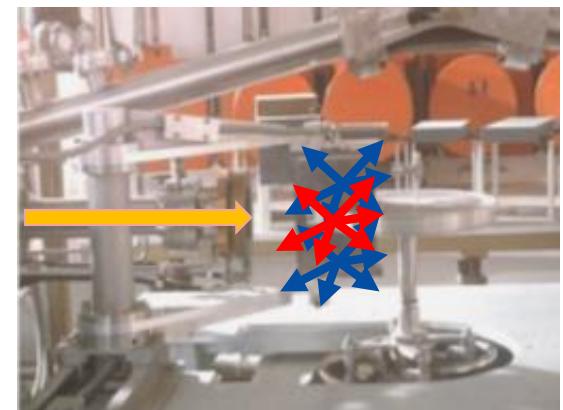
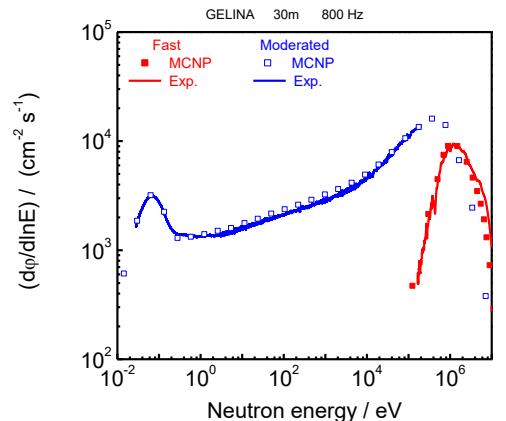
GELINA neutron production



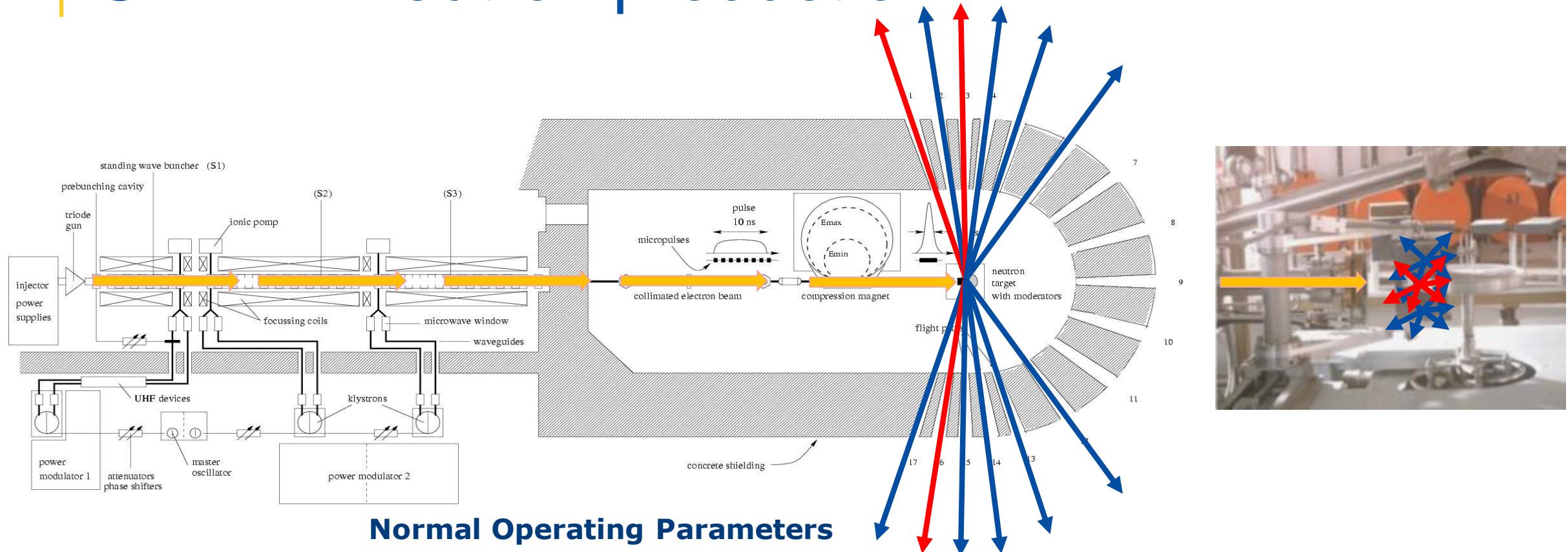
Normal Operating Parameters

Electron Energy Range : 70-140 MeV
 Max Average Current : 100 μ A
 Max Mean Power : 10 kW

Max Frequency : 800 Hz
 Pulse Width : 1-2 ns
 Max Neutron Flux: $2 \times 10^{13} \text{ 1/cm}^2\text{s}$



GELINA neutron production



Normal Operating Parameters

Electron Energy Range : 70-140 MeV
Max Average Current : 100 μ A
Max Mean Power : 10 kW

Max Frequency : 800 Hz
Pulse Width : 1-2 ns
Max Neutron Flux: $2 \times 10^{13} 1/\text{cm}^2*\text{s}$

GELINA

CONTROL ROOM

**ELECTRON
ACCELERATOR**

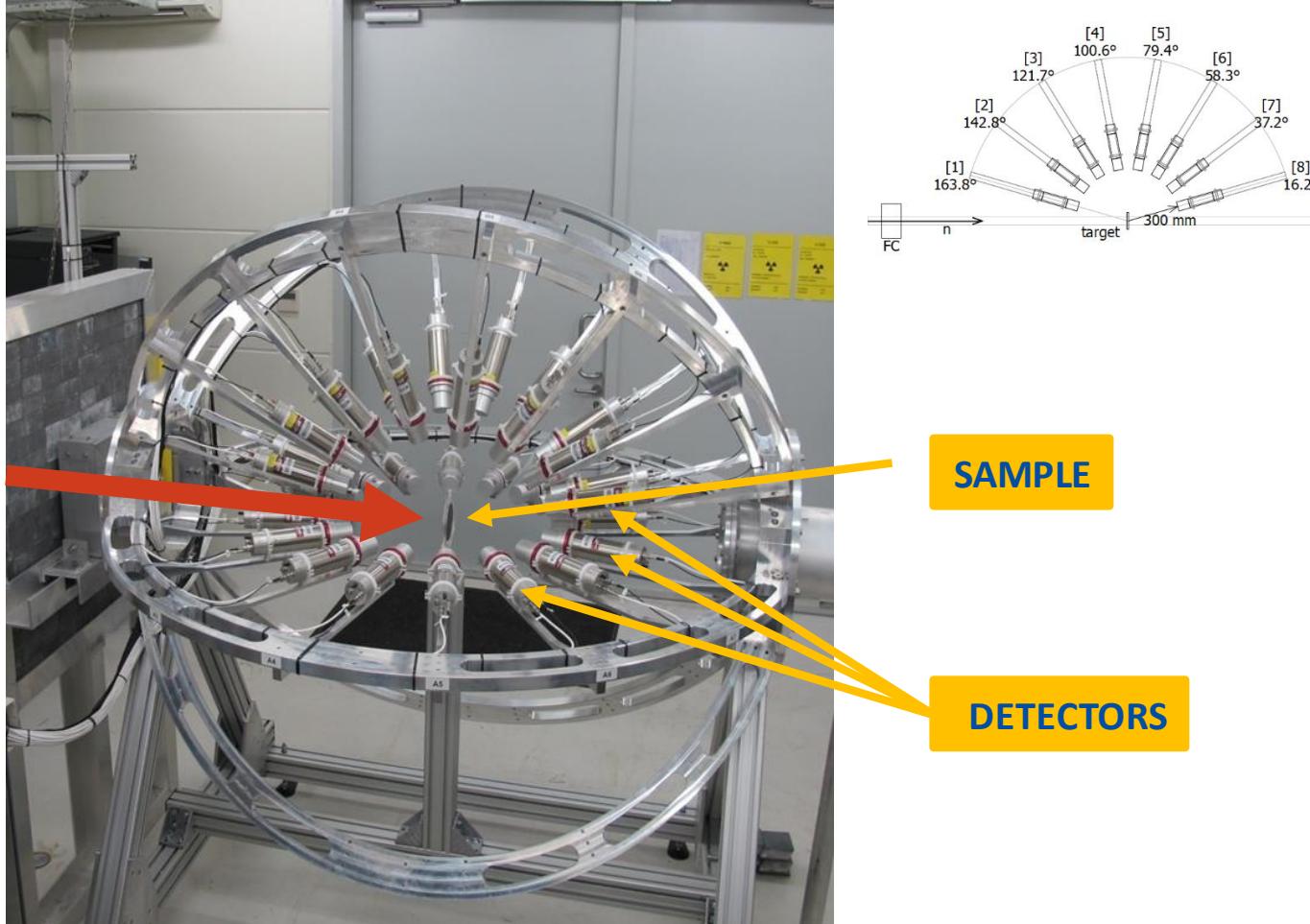
MEASUREMENT STATIONS

NEUTRON TARGET

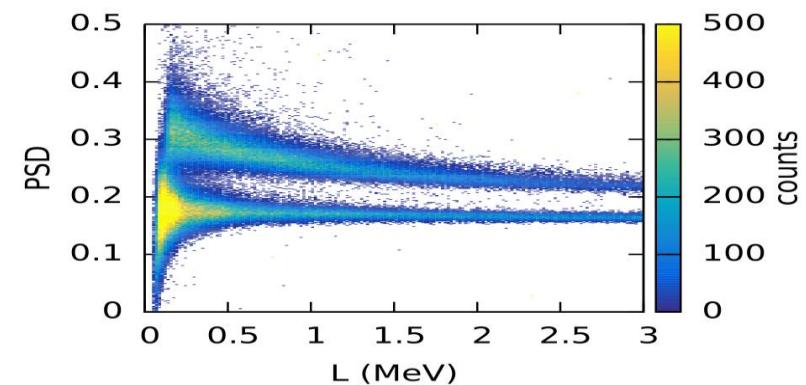
MEASUREMENT STATIONS

ELISA (Elastic and Inelastic Scattering Array)

Collaboration: PTB (GE), CEA Cadarache(FR); PhD student: G. Gkatis

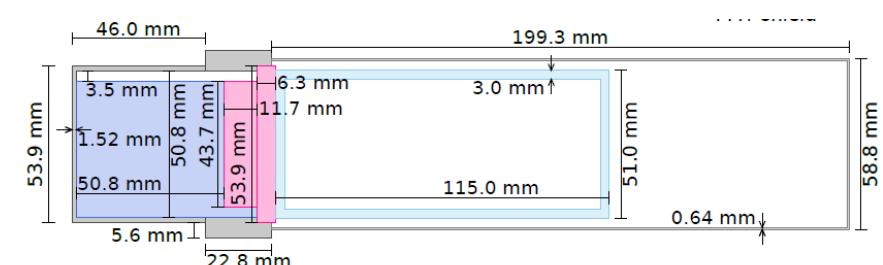
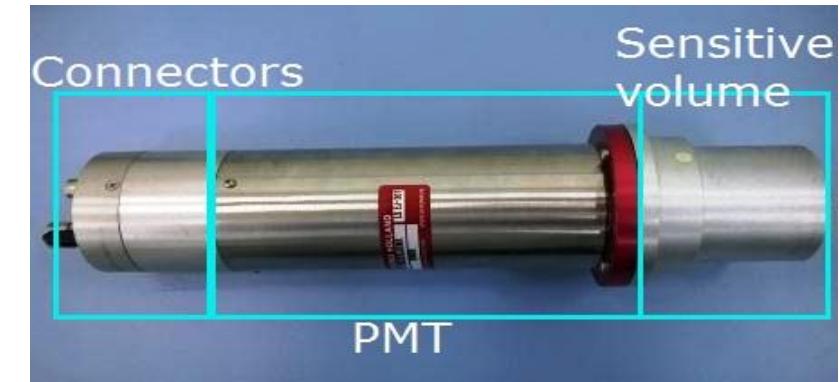


- 32 liquid organic scintillators
- n/g discrimination via pulse shape analysis
- Time resolution ~1 ns
- Neutron flux monitoring with a ^{235}U fission chamber
- ^{54}Fe , ^{56}Fe , ^{23}Na , $^{\text{nat}}\text{C}$



Neutron detectors

- 32 liquid organic scintillators:
 - 16 EJ301 – xylene (C_8H_{10}) - (n-p)
 - 16 EJ315 – deuterated benzene (C_6D_6) - (n-d)
- Scintillation fluorescent light when ionizing radiation interacts with the liquid
- Two types of detection:
 - Photons: via Compton scattering
 - Neutrons: via elastic scattering on the hydrogen nuclei

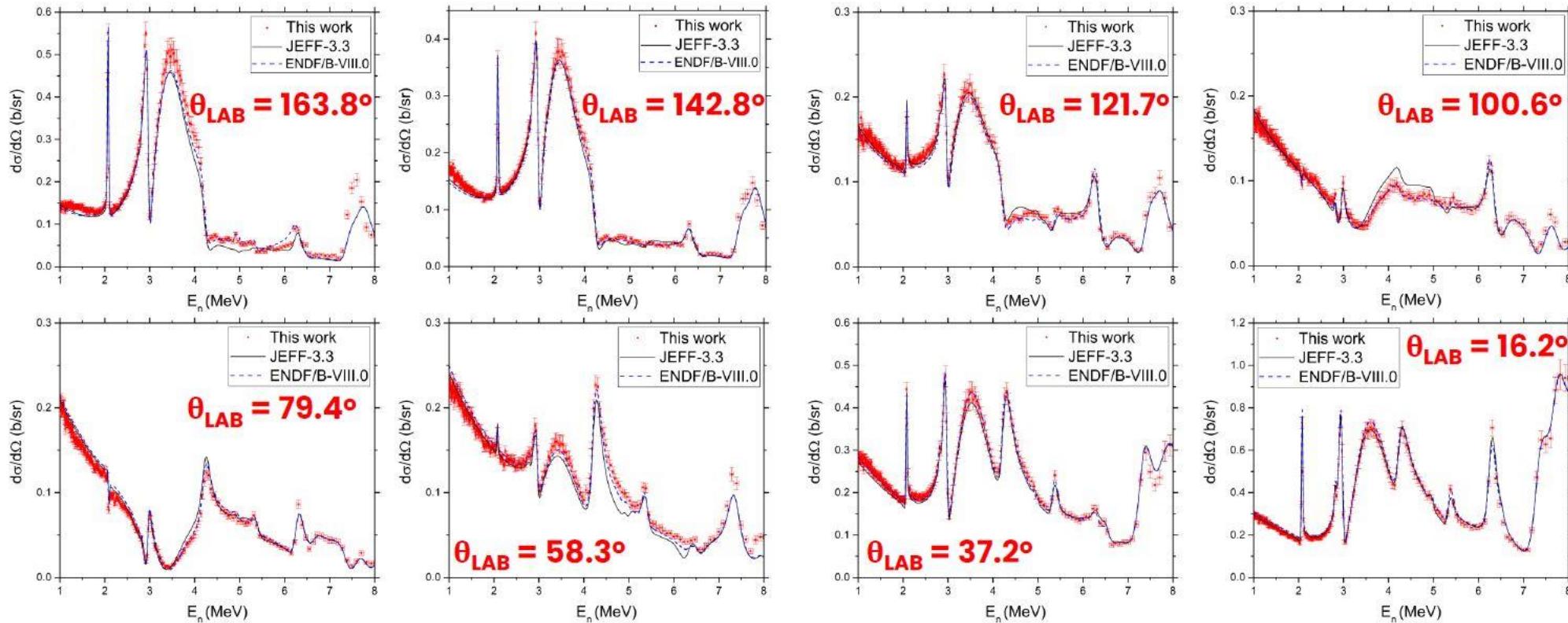


Digitizer-based acquisition system + NIM electronics for the FC

- The goal is to produce **high-resolution cross section data** of neutron scattering in the fast neutron energy range

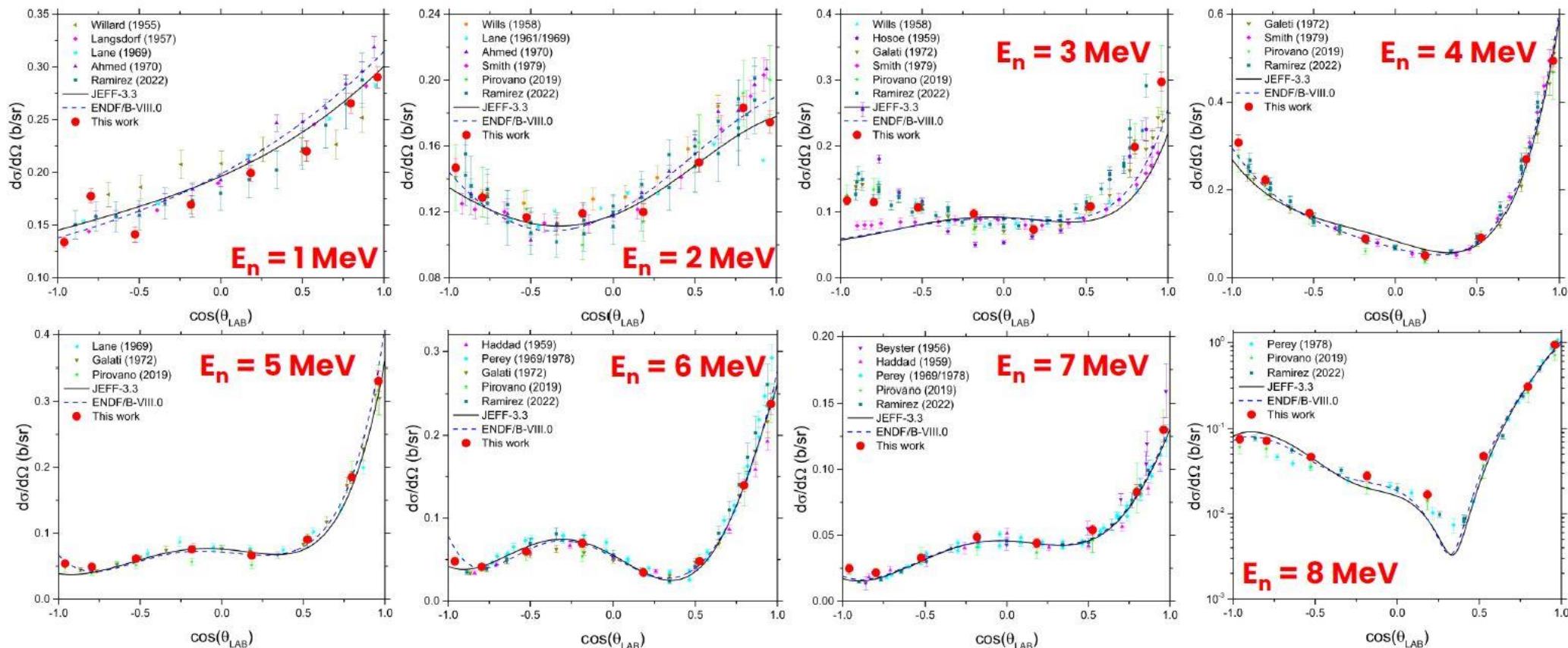
Differential cross section $^{nat}C(n,n)$ - JEFF 3.3

Preliminary Results- Courtesy Georgios Gkatis



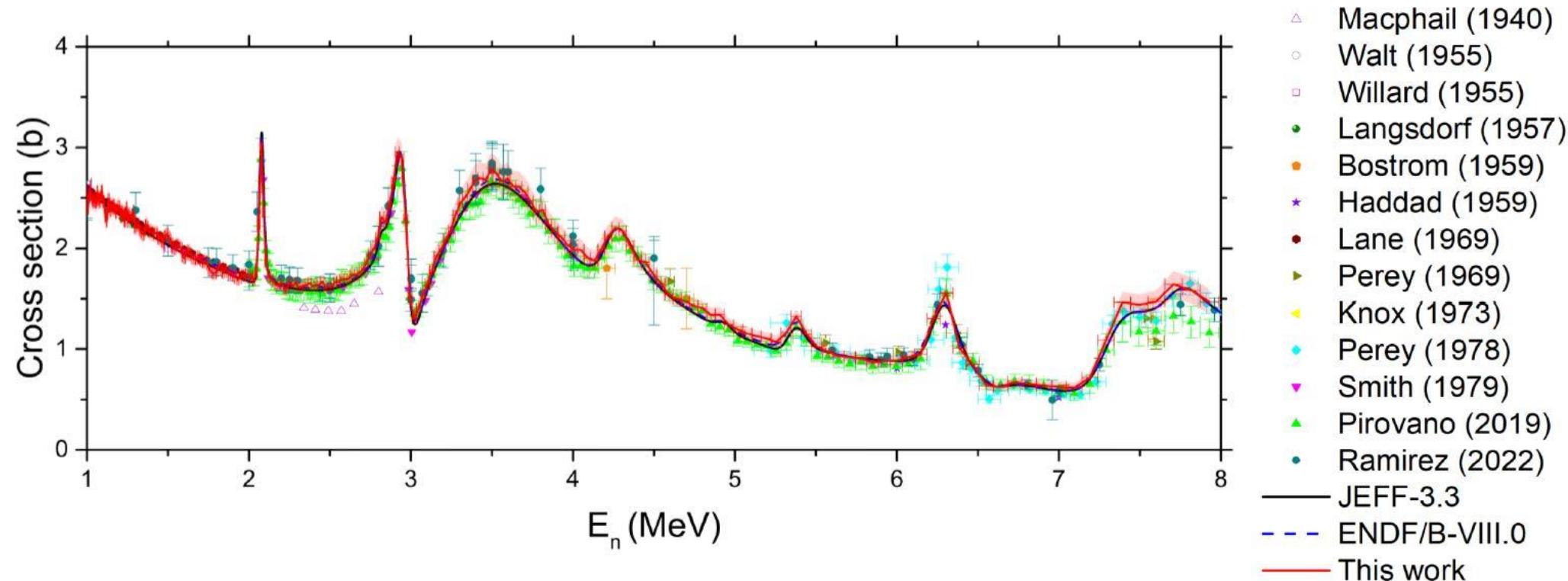
Angular distribution ${}^{nat}C(n,n)$ - EXFOR

Preliminary Results- Courtesy Georgios Gkatis



Angle-Integrated

Preliminary Results- Courtesy Georgios Gkatis



- Total uncertainties of the cross sections vary from 3% to 10%.
- Good agreement with the experimental data available in the literature.

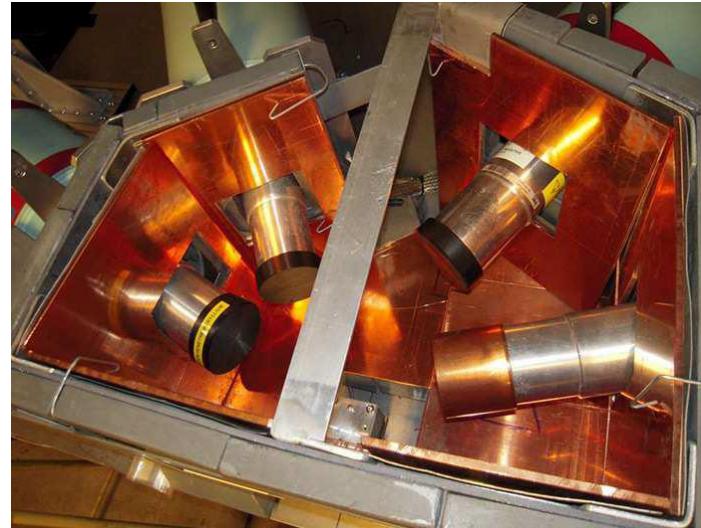
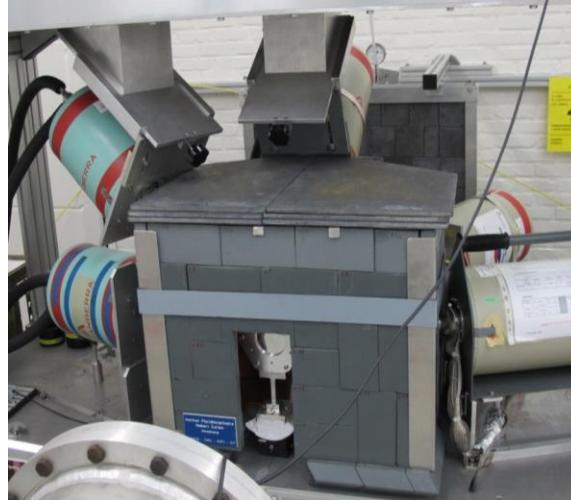
GRAPhEME (Germanium array for actinides precise measurements)

Collaboration CNRS (FR)

(n,n'γ): γ-ray production cross sections at L = 30 m

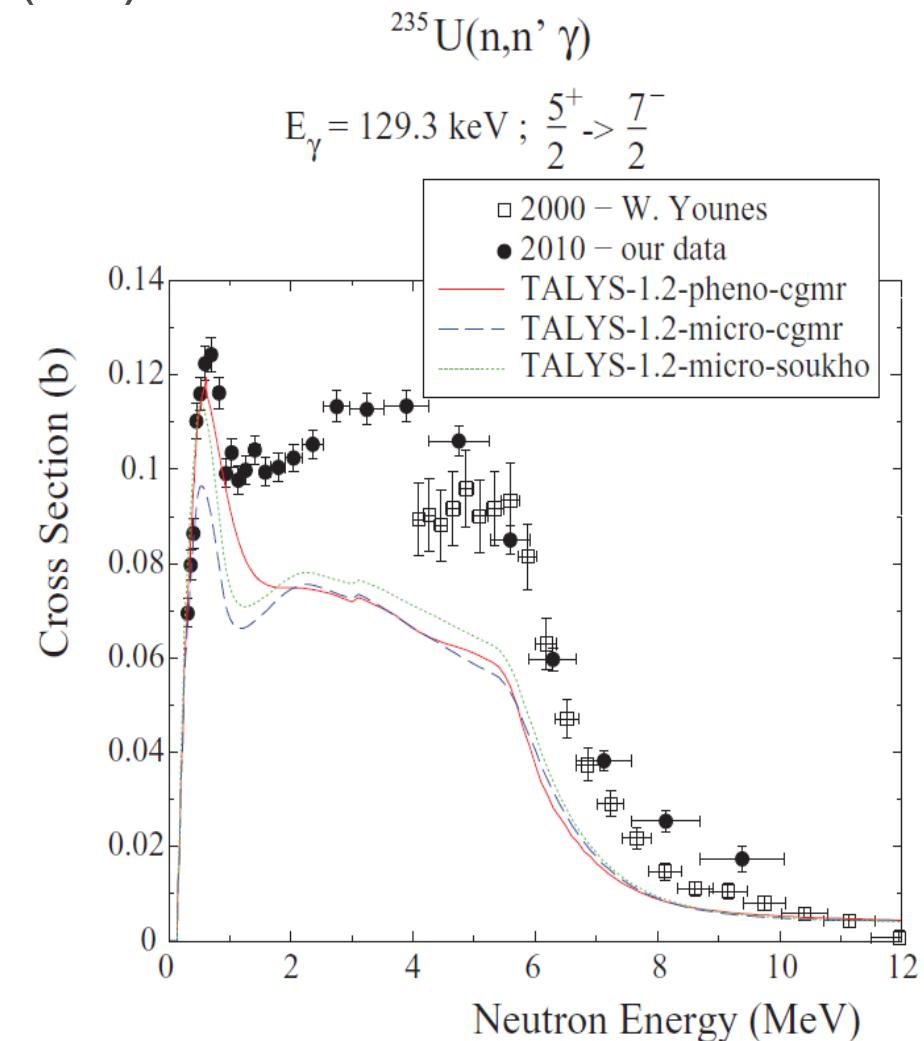
- 5 planar HPGe detectors (1 segmented, 36 pixels)
- Fluence rate measurements (IC): $^{235}\text{U}(n,f)$

^{238}U , ^{235}U , ^{232}Th , $^{\text{nat}}\text{W}$



Kerveno et al., EPJA 51 (2015) 167

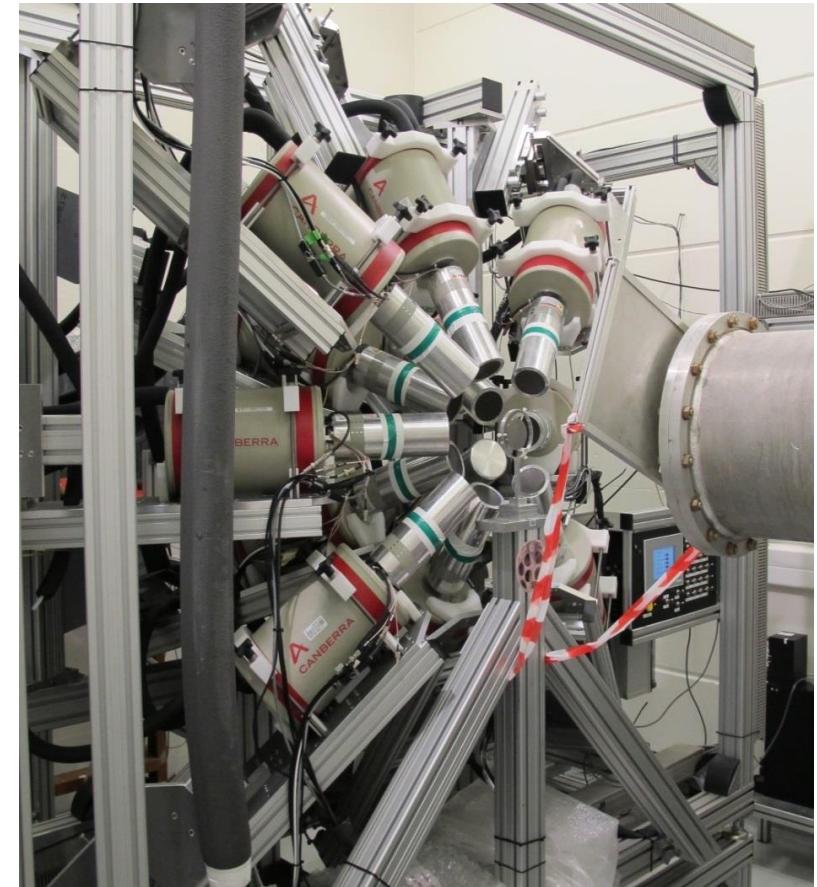
M. Kerveno on October 12



GAINS (Gamma Array for Inelastic Neutron Scattering)

Collaboration IFIN-HH (RO)

- 100m distance from neutron source (FP3_100m)
- 3 sets of **HPGe** detectors (110° , 125° , 150°), $d=17\text{cm}$
- Relative efficiency: 100%
- FWHM typically $\sim 2.5 \text{ keV}$ for the 1408keV of ^{152}Eu
- Digital acquisition (ACQIRIS digitizers)
- ✓ 12 bit amplitude resolution (4096 channels)
- ✓ 420MS/s (2.38 ns)
- Neutron flux monitoring with a ^{235}U fission chamber
- ***time of flight +g spectroscopy technique***
- ✓ n *time of flight* $\rightarrow E_n$
- ✓ Pulse amplitude $\rightarrow E_g$
- ^7Li , ^{12}C , ^{16}O , ^{23}Na , ^{24}Mg , ^{28}Si , $^{\text{nat}}\text{Ti}$, $^{\text{nat}}\text{Mo}$, ^{52}Cr , ^{54}Fe , ^{56}Fe , ^{57}Fe ,
 ^{58}Ni , ^{60}Ni , ^{76}Ge , $^{\text{nat}}\text{Zr}$, $^{206,207,208}\text{Pb}$, ^{209}Bi , ^{54}Fe , **$^{14}\text{N (Preliminary)}$**

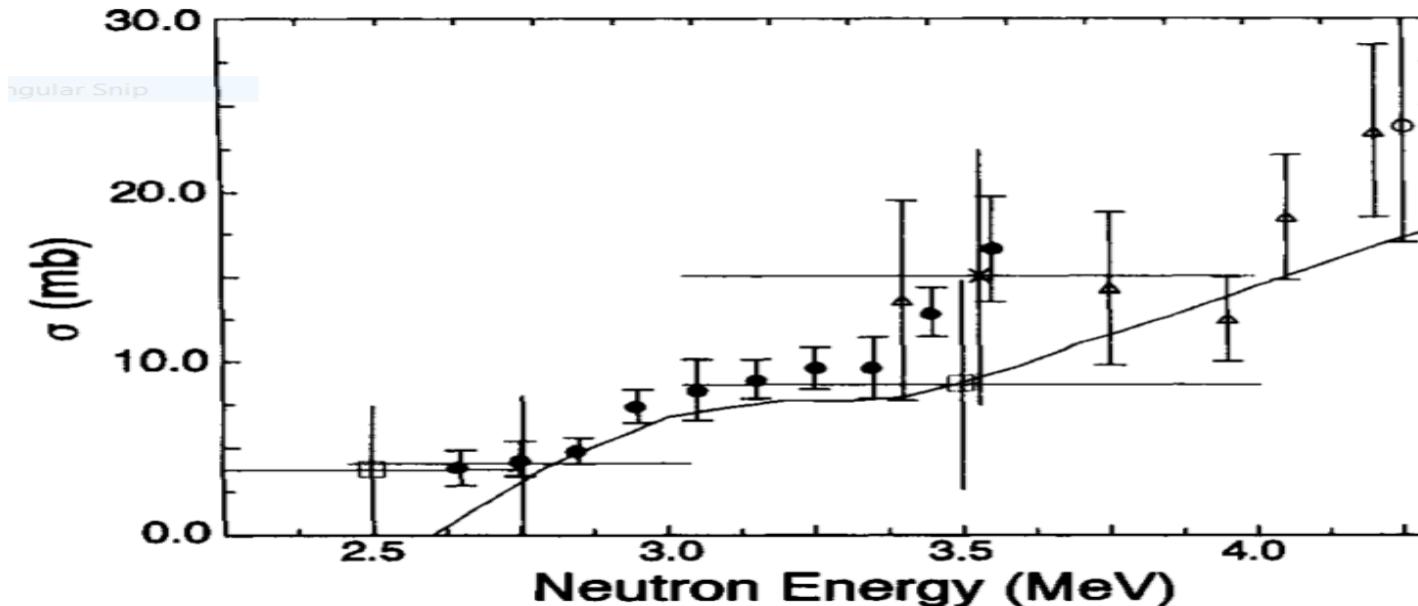


Results)

Why ^{14}N ?

- Nitrides (UN , UN_2)- proposed as fuels for liquid-metal-fast-breeder reactors
- N-based minor actinides compounds (NpN , AmN)- studied as feasible candidates for ADS facilities as part of the minor actinides re-cycling process.
- Presence of ^{14}N affects the fuel density and increases the parasitic absorption and moderation of neutrons => negative impact on the neutron economy
- ^{14}N (99.63%) ^{15}N (0.36%) is used in nitrides
- $^{14}\text{N}(\text{n},\text{p})$ produces the highly toxic ^{14}C
- Enriched ^{15}N produces ^{14}N via (n,d) reaction => very small effective cross section
- We can't get rid of ^{14}N inside the fuel -> we need to know the neutron-induced inelastic channel
- Part of the European SANDA project

^{14}N : Status of the data prior to our experiment



- Several angle-integrated γ -production cross section points only for the first transition in ^{14}N and only below 4.2 MeV
- No angle-integrated data for the other ^{14}N transitions

What do we expect?



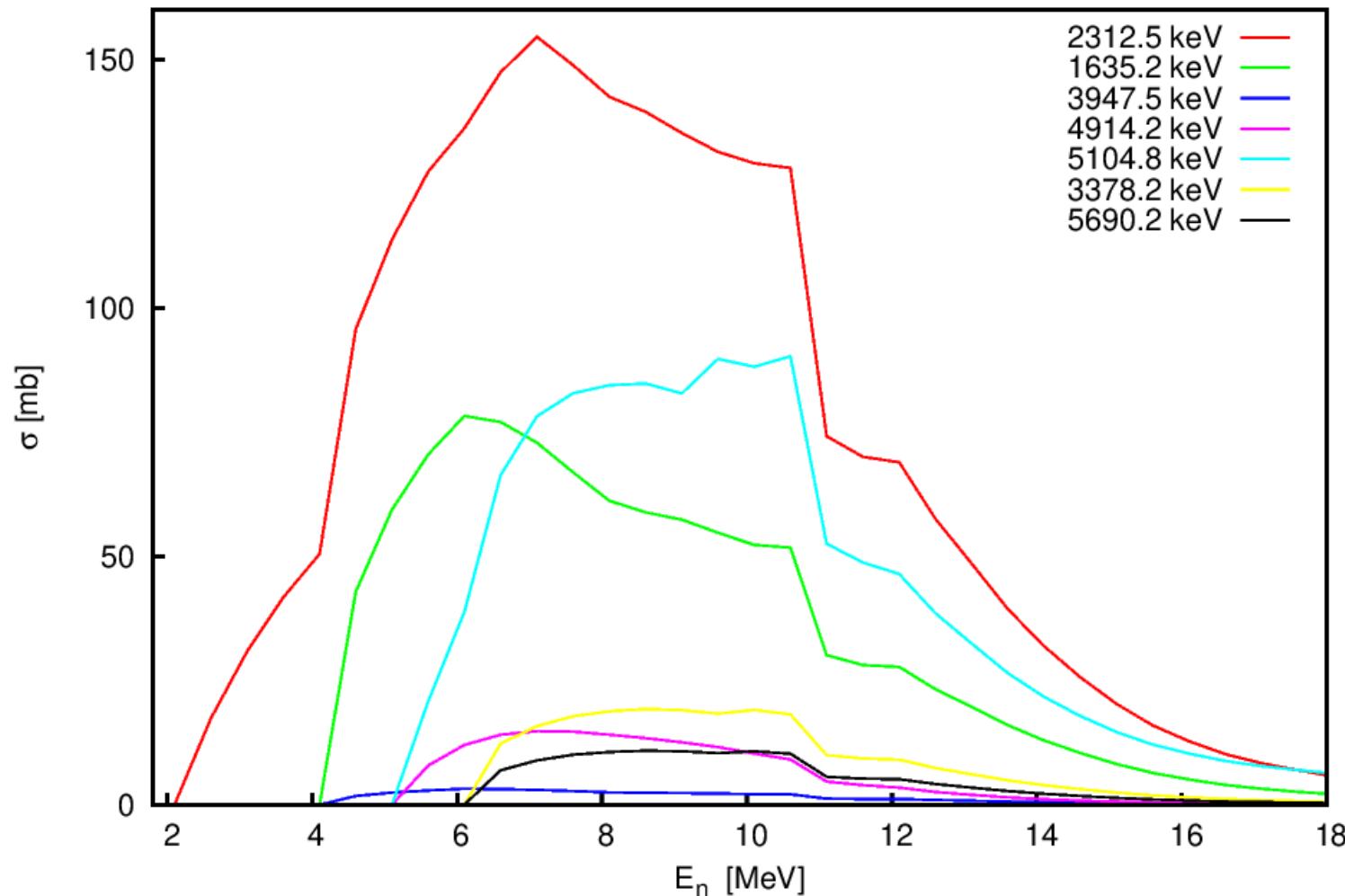
Plate: 100mm x 100mm
Thickness 3.85-4.42mm
m: 103.841g



- Accurate neutron-induced data in the entire energy range of the inelastic channel
- Incident energy resolution of 3keV at 1Mev and 80keV at 10 MeV
- Low uncertainty (<5% for the strongest transitions) for the γ -production cross sections

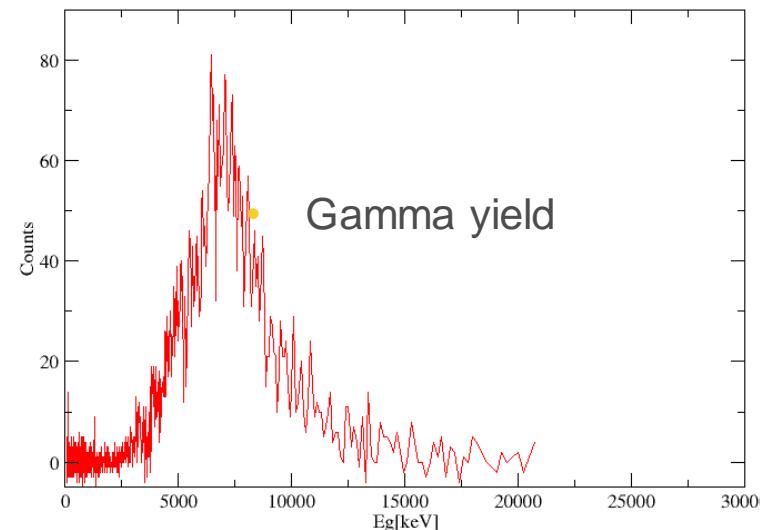
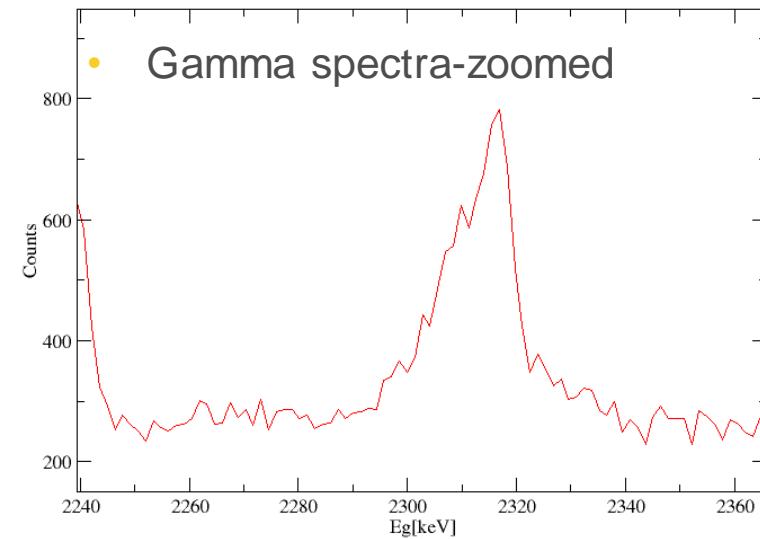
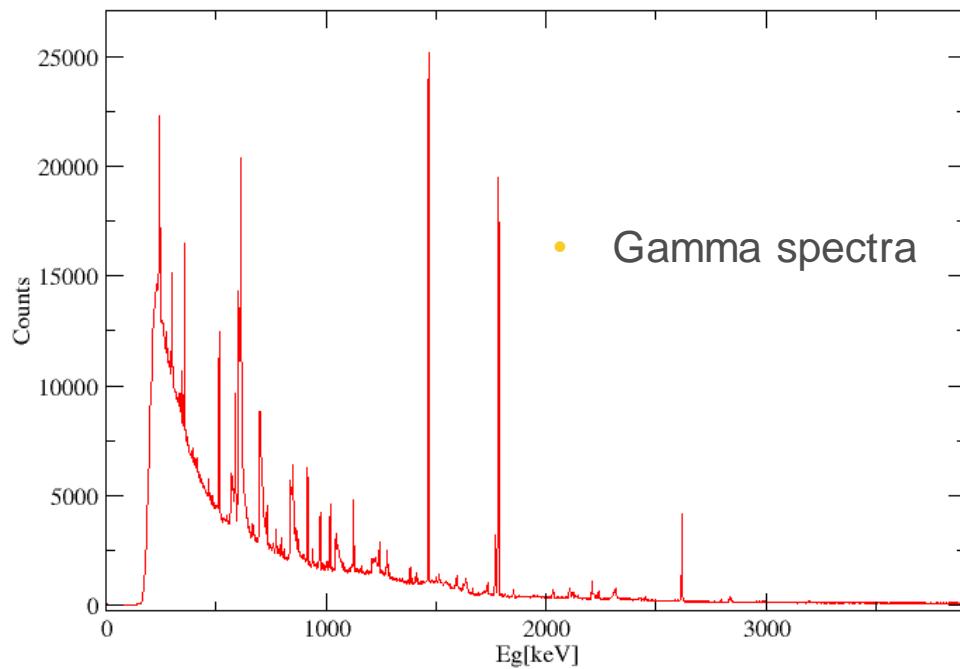
These will be further used to calculate the level and the total inelastic cross sections by making use of the known level scheme of this nucleus.

The neutron-induced inelastic cross section for the most intense transitions in ^{14}N , according to TALYS 1.9.

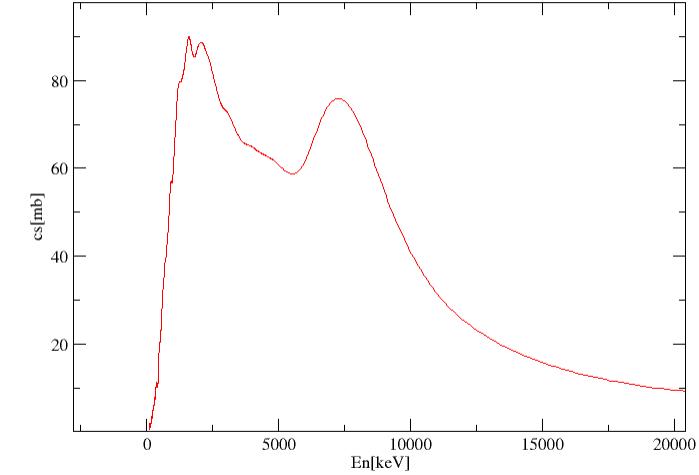
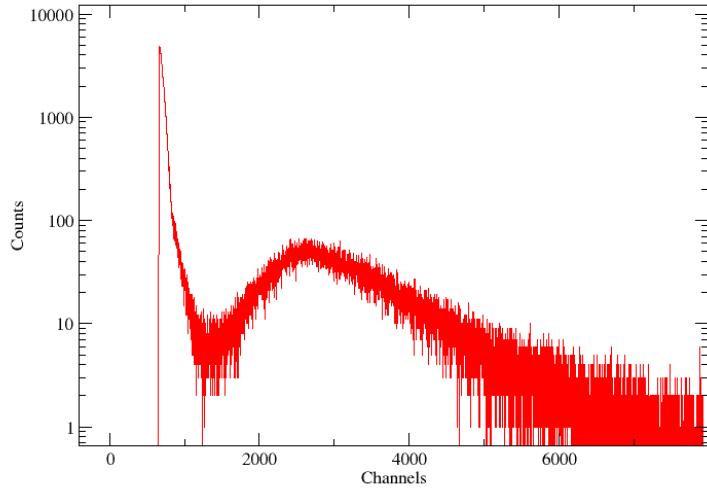


Data analysis

γ spectroscopy measurements
2312 keV



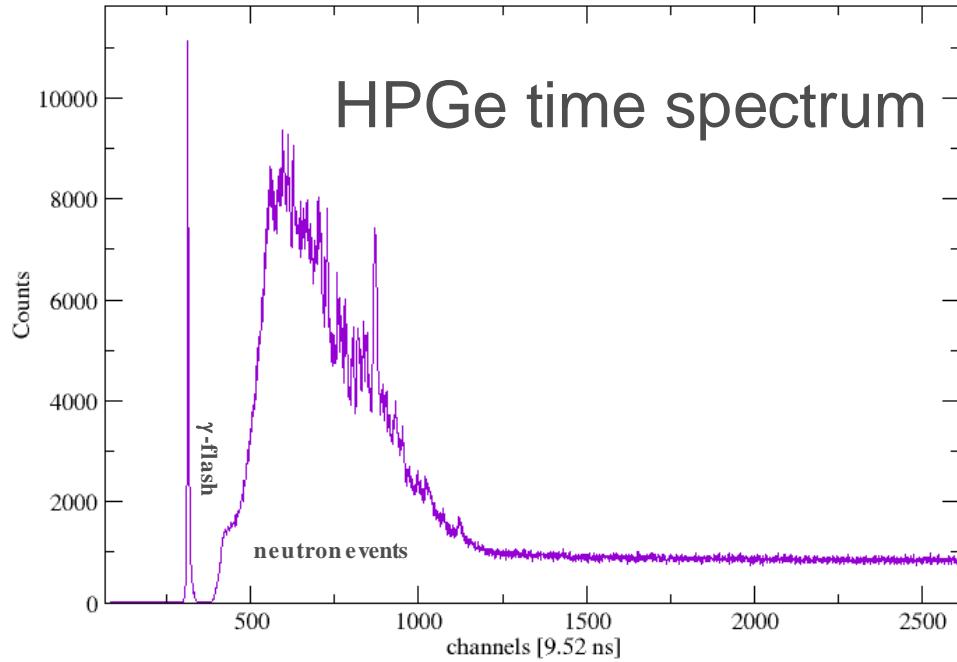
Fission chamber



- The amplitude spectrum of events corresponding to the FC
- Yield FC

Calibration in time of flight

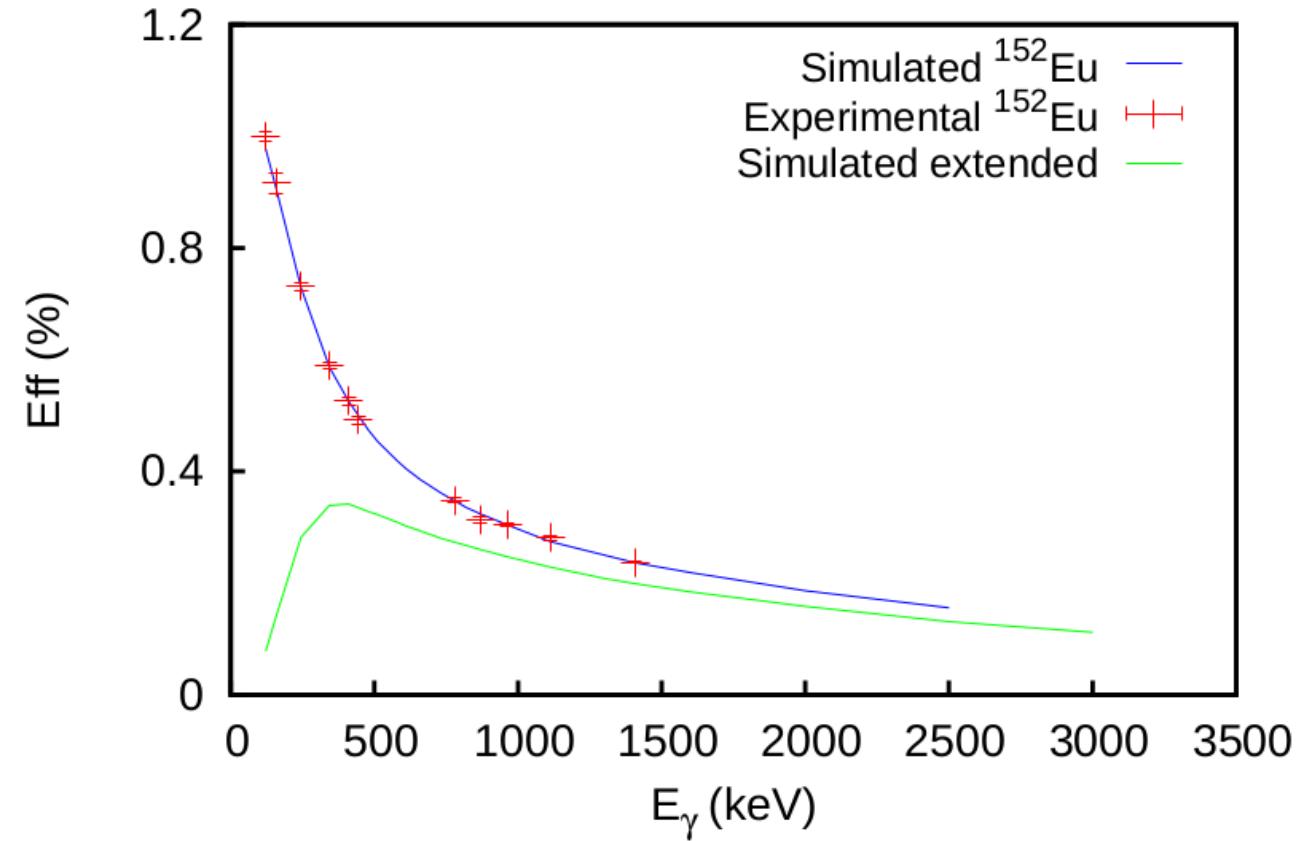
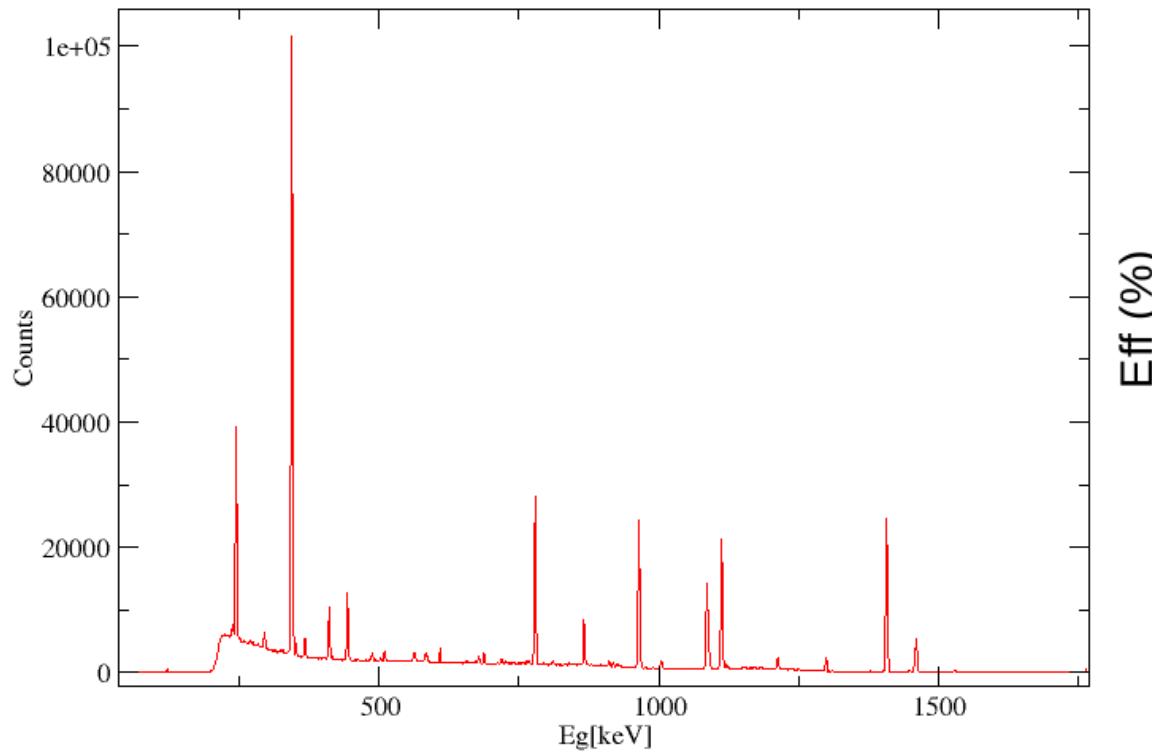
$$t_{\gamma\text{-}flash} = \frac{d_{\text{flight path}}}{c} = \frac{10000 \text{ cm}}{29.979 \text{ cm/ns}} = 333.56 \text{ ns}$$

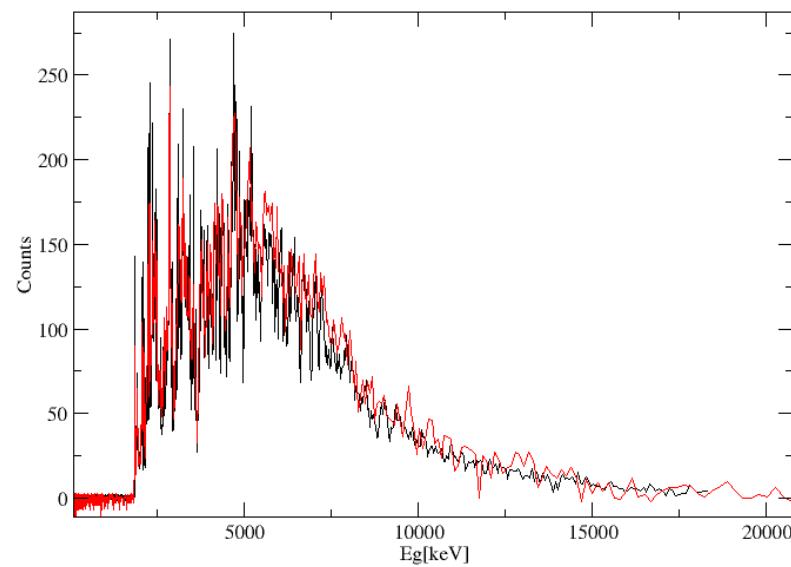
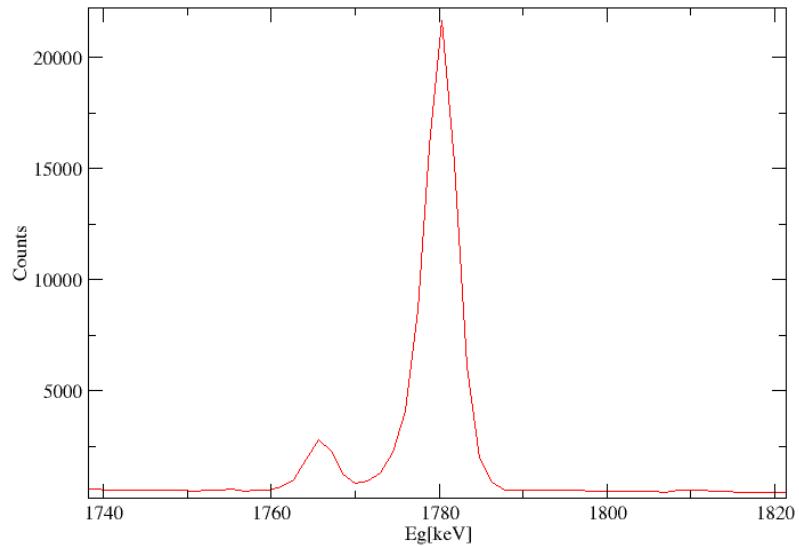


$$E_n = m_0 c^2 \left[\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right]$$

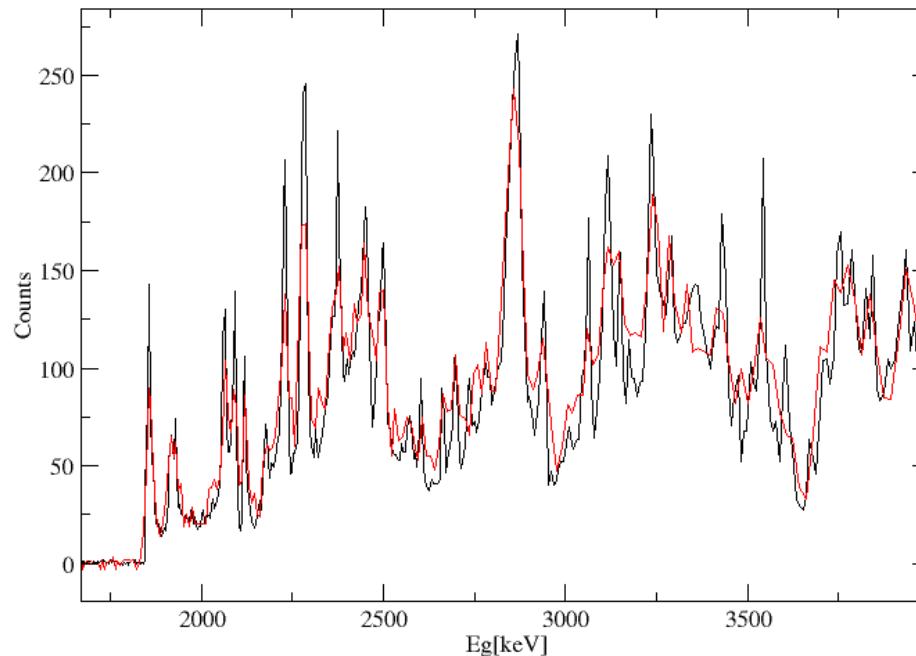
Calculate the neutron energy by using the
 γ -flash as a time reference!!!

The efficiency curve of a HPGe detector





- 1778.9 keV ^{28}Si
- Black: A. Negret (2013)
- Red: A. Oprea (2023)



Conclusions & future work

- We measured the first 2 transitions in ^{14}N (2312.5 keV, 1635.2 keV)
- Cross check: ^{28}Si : 1778.9 keV, 2838 keV and 3200keV

FUTURE DATA ANALYSIS STEPS:

:

- Differential gamma production cross sections at 110 and 150 degrees
- Angle-integrate these cross section
- Further corrections: multiple scattering corrections (MSC)
- Submit the final data to EXFOR
- Write and publish a paper

Thank you for your attention!