FIRST BEAMS AT THE NEUTRONS FOR SCIENCE FACILITY

1. The NFS facility
2. First neutron spectra measured at NFS
3. First experiments

X. Ledoux on behalf of the NFS collaboration

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The Neutrons For Science facility

- Pulsed neutron beam (1-40 MeV)
- Continuous spectrum : d + thick converter
- QMN spectra : p + thin converter
- Irradiation capability in neutron and ion induced reactions

- High average flux in the 1-40 MeV range
- Good energy resolution

Physics case

- ❑ Fundamental physics
- ❑ Astrophysics
- ❑ New generation of reactor
- ❑ Fusion technology
- ❑ Radioisotopes production for medical applications
- ❑ Biology (cells irradiation..)
- ❑ Development and characterization of new detectors
- ❑ Study of the single-event upsets

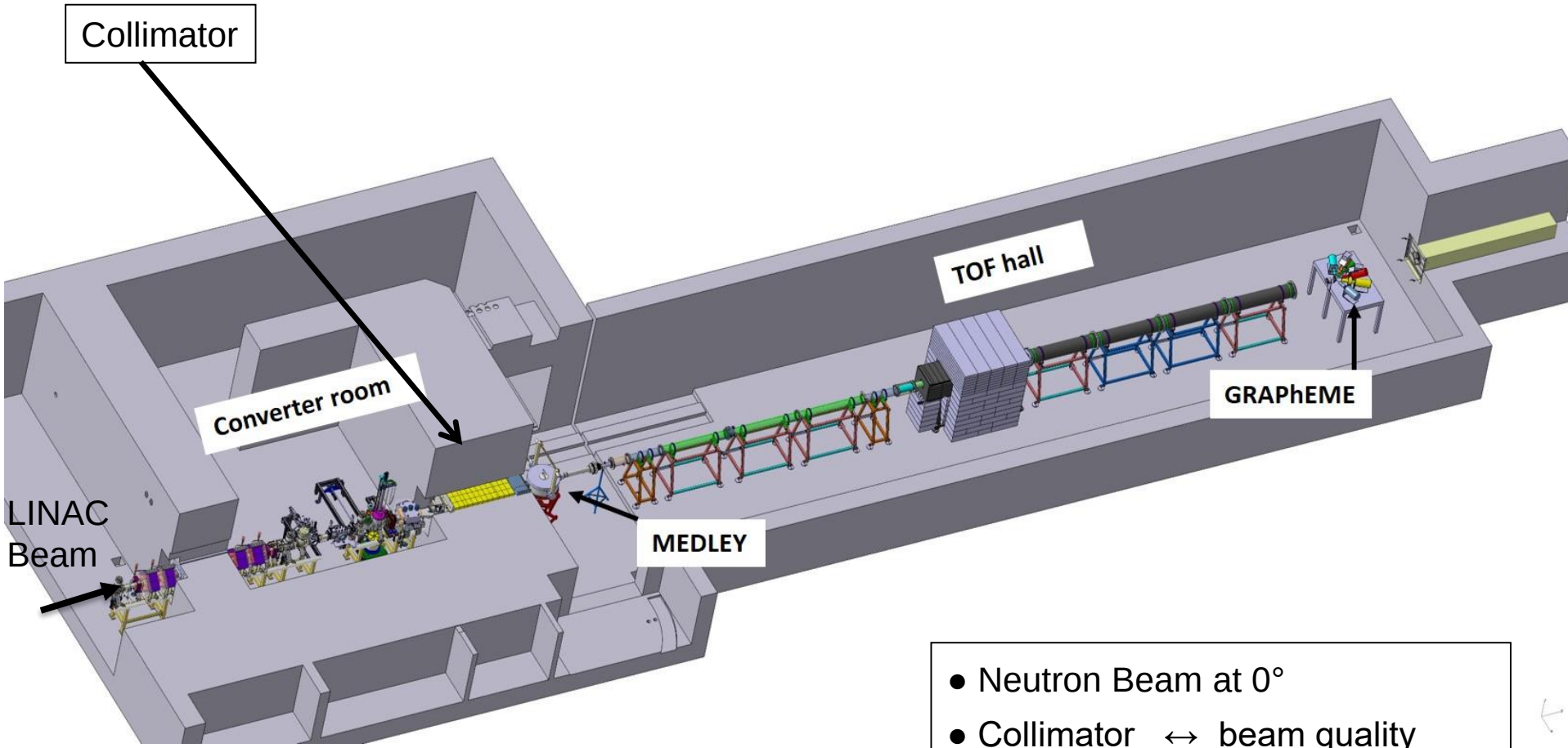
International collaboration

50 physicists

15 laboratories

8 partners

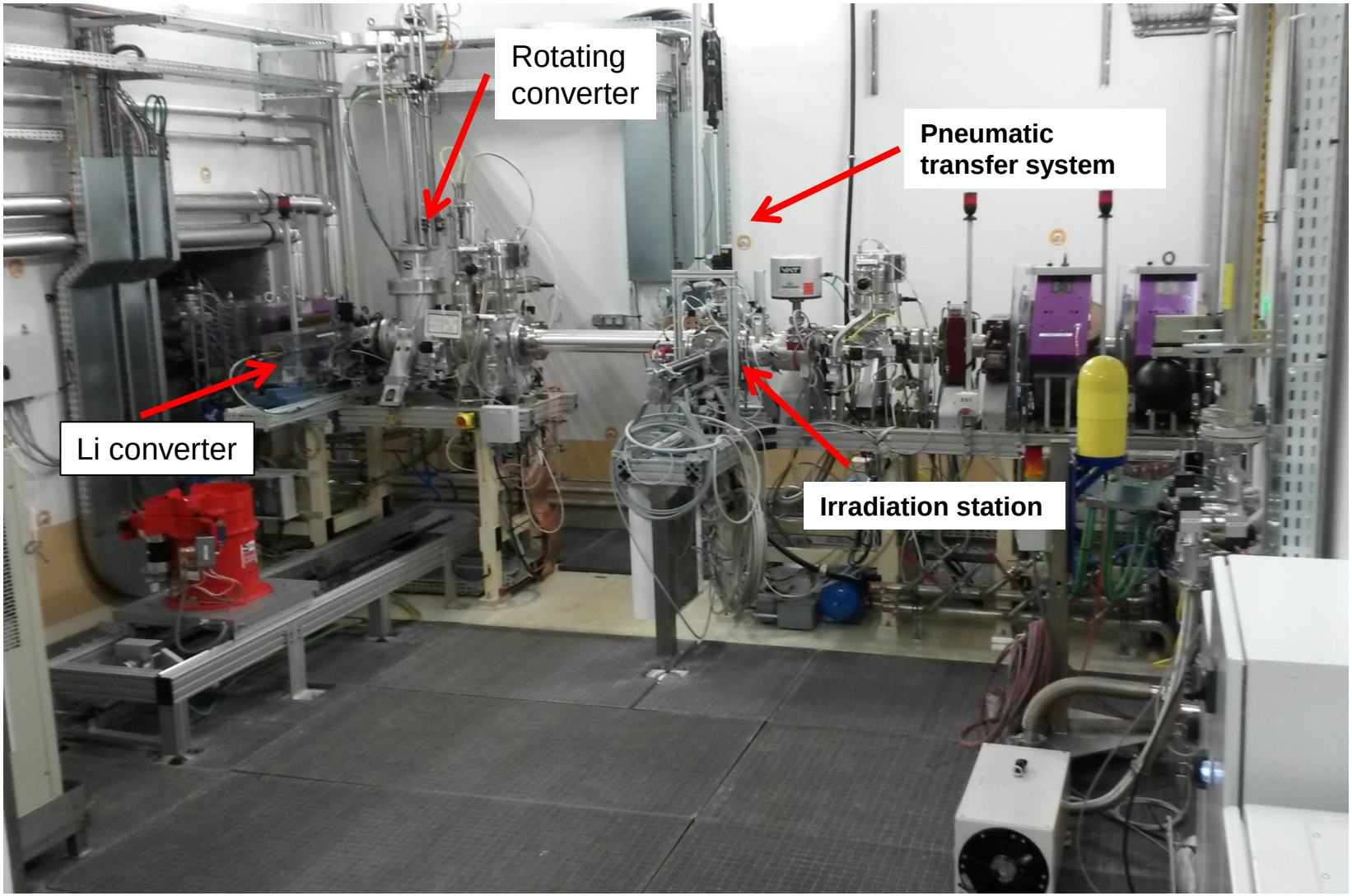
NFS layout



- Ion and neutron induced reactions
- Beam line extension
- Irradiation station (n, p, d)

- Neutron Beam at 0°
- Collimator ↔ beam quality
- Size (L x l) ≃ (28m x 6m)
  - TOF measurements
  - free flight path

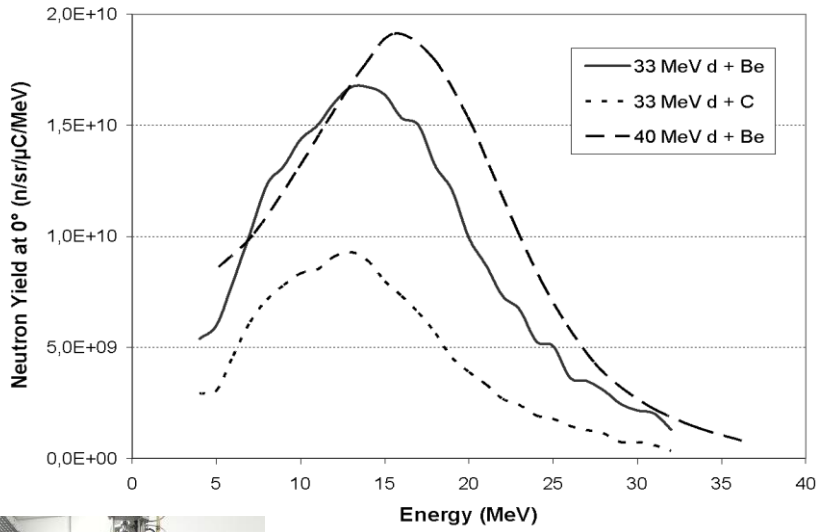
NFS: The converter room

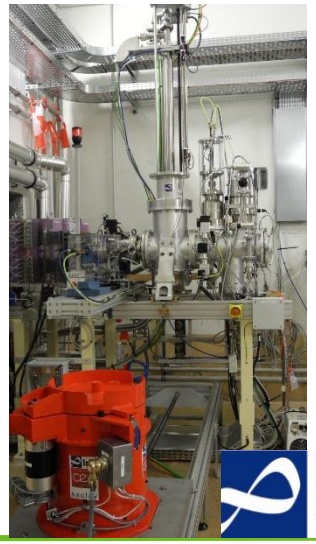


NFS: The TOF area

Neutron production reaction

Continuous spectrum
E_{max} = 40 MeV , <E> = 14 MeV





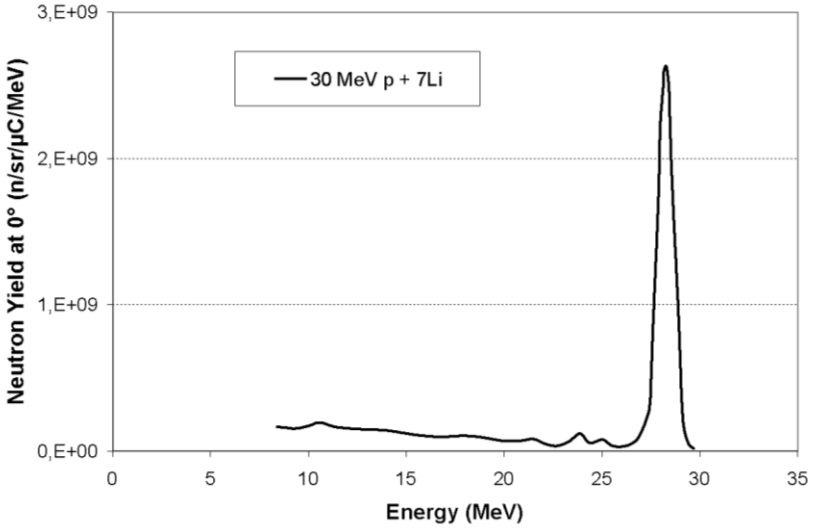
40 MeV d + Be at 50 µA

Rotating converter

thick target C or B (8mm)

P< 2 kW

Quasi-monoenergetic spectrum
E_n = up to 31 MeV



p + Li (1,5mm) or Be (0,5 mm) at 20 µA

Irfu
Institut de recherche sur les lois fondamentales de l'Univers

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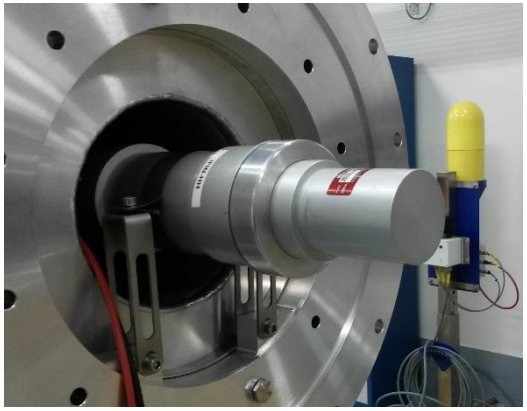
NFS commissioning

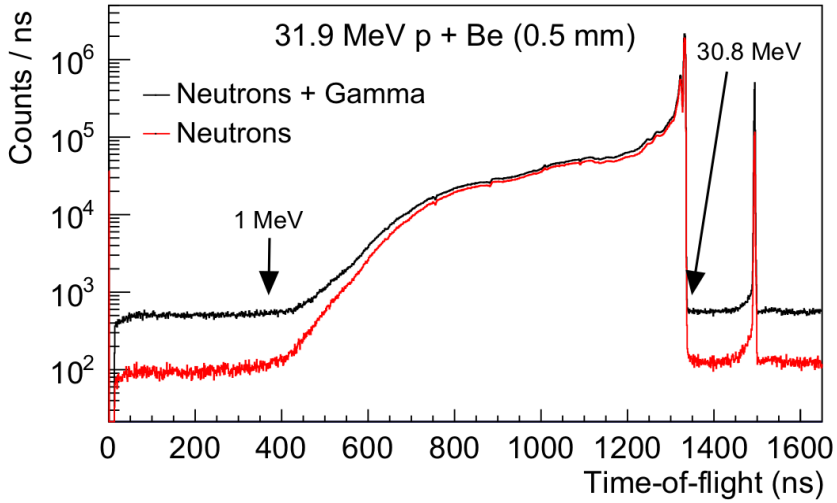
- December 2019 : First proton beam at 33 MeV in the converter cave
  - Neutron production on the Faraday Cup CF11
  - Cu(p,*) and Fe(p,*) reaction cross-section measurement by activation technique sample
- September 2020 to December 2020: proton beam
  - First quasi-mono-energetic neutron beam: 33 MeV p + Li and Be
  - Continuous neutron beam 31,9 MeV p + Be (8 mm)
  - Flux and spectrum measurement
  - Thermal tests on rotating converter
  - Transmission measurement on Carbon
  - Test of the MEDLEY detector
- July 2020: First He-4 beam
  - Thin converter
  - Cu(α,*) and Fe(α,*) reaction cross-section measurement by activation
- September 2021: First deuteron beam
  - Thin and thick converter
  - LOI-9 : test for (n,xn') reactions (IPHC)
  - Neutron background spectra measurement with Bonner spheres (IRSN)

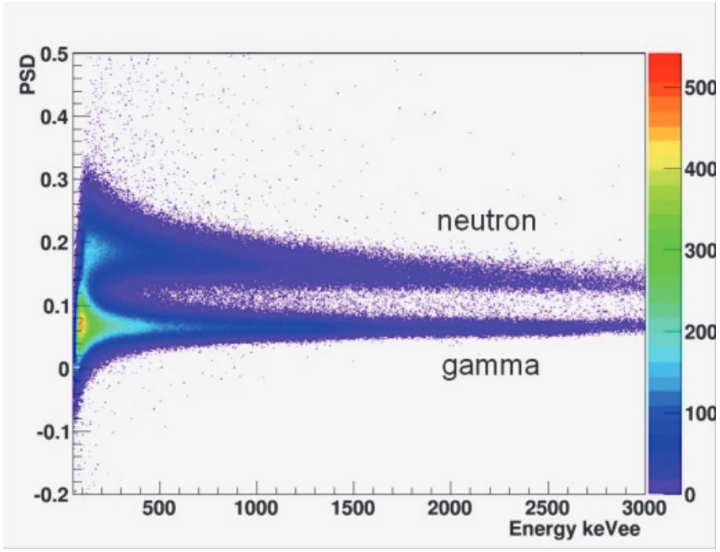
Neutron spectra measurements

Detectors based on liquid scintillator EJ309



- Neutron spectrum and flux measurement by the TOF technique
- n-γ discrimination by pulse shape analysis
- EJ309 cell (2 inches in diameter, 3 inches in length)
- Placed in the beam pipe downstream of the rotating converter (15 to 30 m)

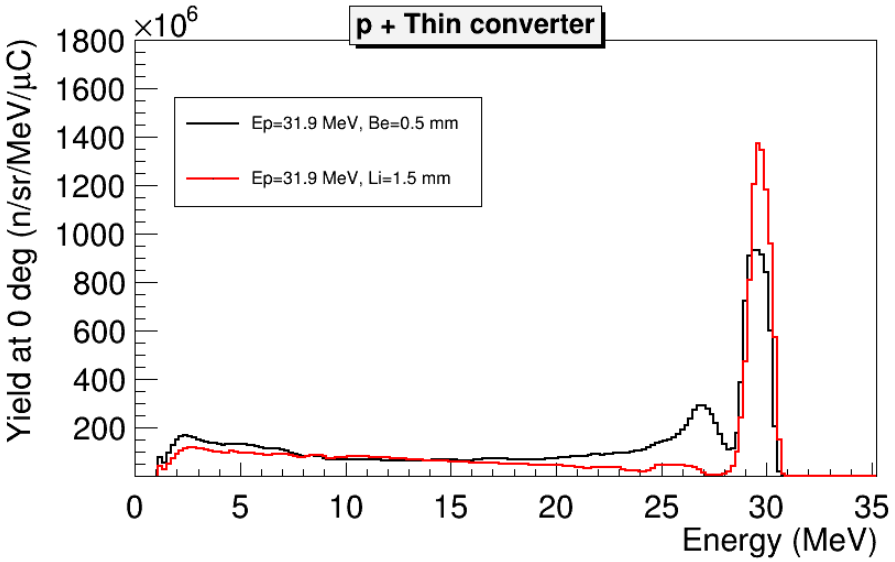




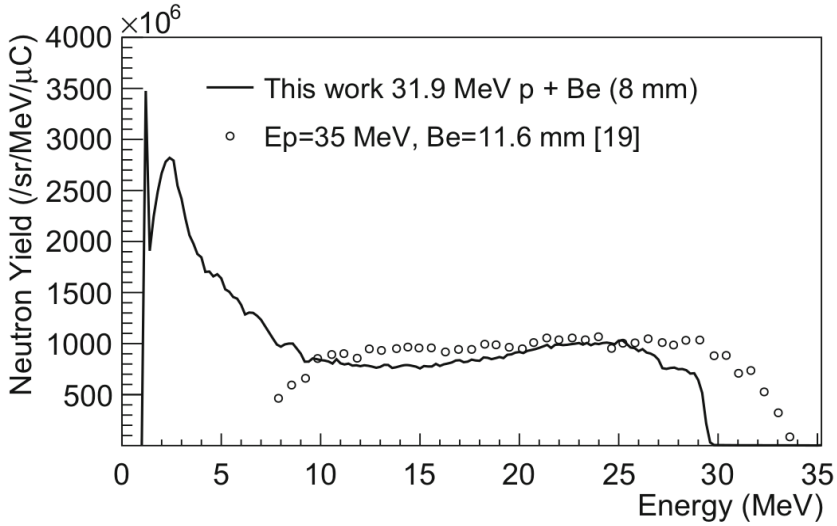
- Adaptation of the SCINFUL code:
  - Light response of EJ309 included
  - Efficiency determination

Protons @ 31.9 MeV (1)

- **Thin converter targets**
  - **Li (1.5 mm)** and **Be (0.5 mm)**
  - Quasi-mono-energetic spectra
  - Peak ratio (E>28.5 MeV) / total (E>2 MeV):
  - p + Li (1,5 mm) : 51%
  - p + Be (0,5 mm) : 32%



- **Thick converter**
  - Be (8mm)
  - Continuous spectrum
  - NFS 31,9 MeV : 1,81^{E}10 n/sr/µC



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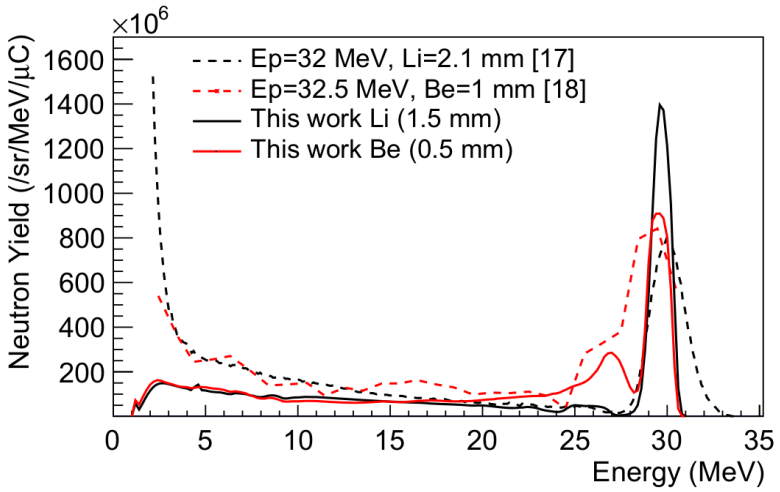
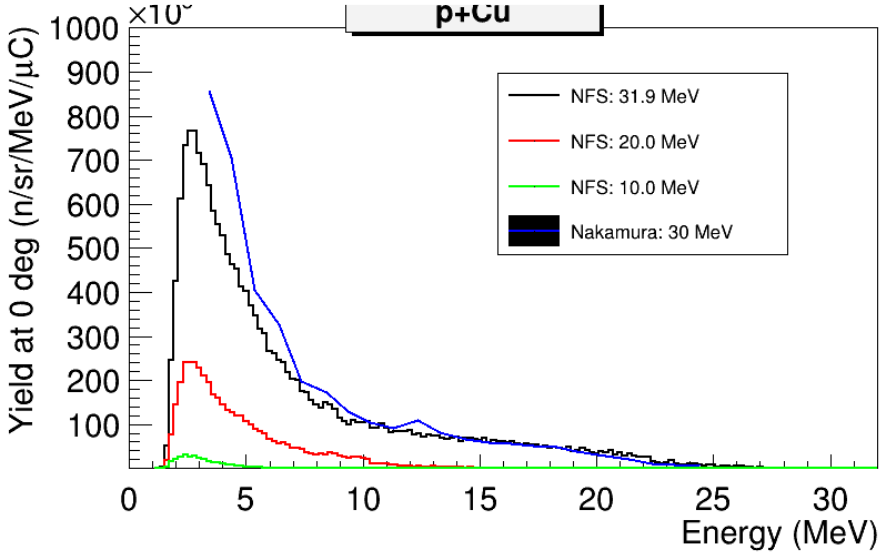
Protons @ 31.9 MeV (2)





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p + Li E> 28,5 MeV

NFS 31,9 MeV : 1,77^{E}9 n/sr/µC

Uno 32 MeV : 1,88^{E}9 n/sr/µC

Batty 30 MeV : 1,17^{E}9 n/sr/µC

p + Cu Yield at 0° (E>4 MeV):

Nakamura 30 MeV : 2,68^{e}9 n/sr/µC

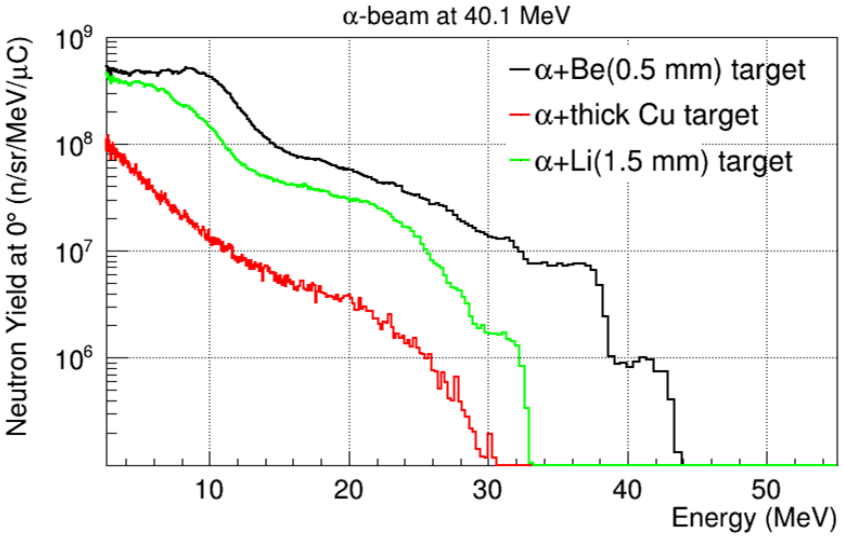
NFS 31,9 MeV : 2,27^{e}9 n/sr/µC

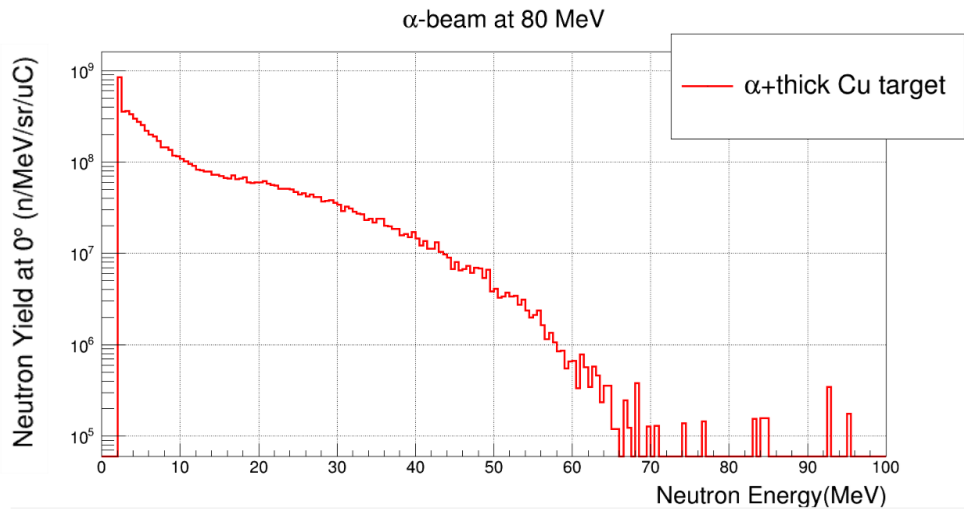
NFS 20,0 MeV : 4,12^{e}8 n/sr/µC

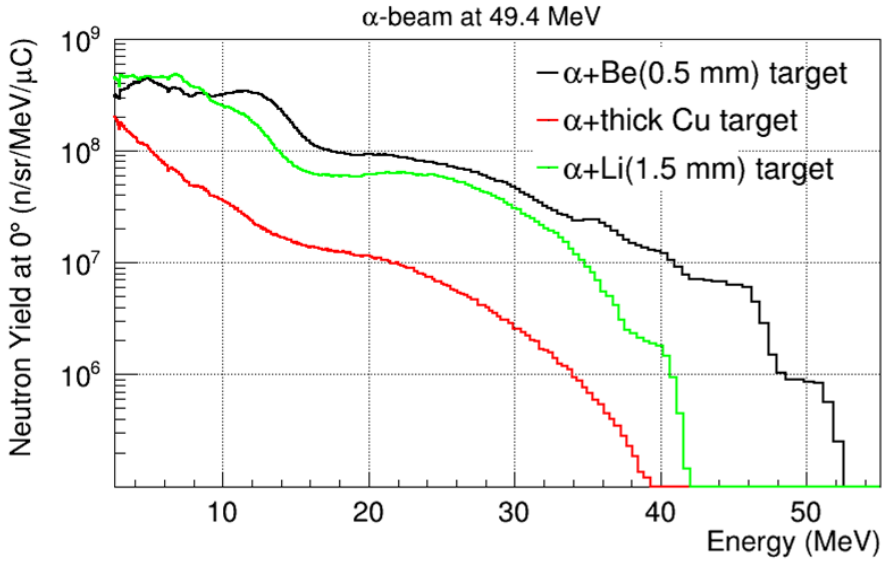
NFS 10,0 MeV : 1,12^{e}7 n/sr/µC

Good agreement between published data and NFS measurements

Helium-4 @ between 40 and 80 MeV

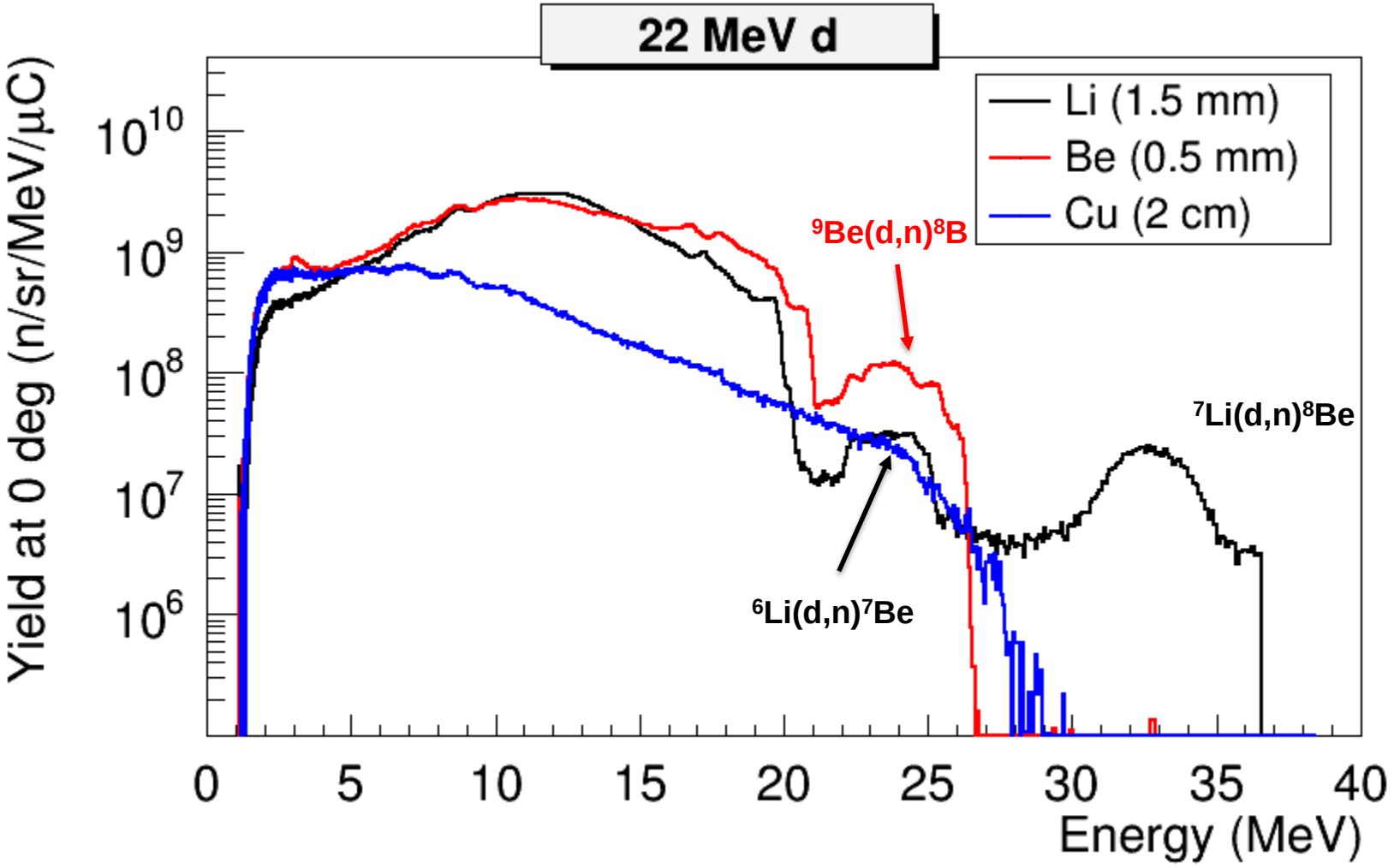






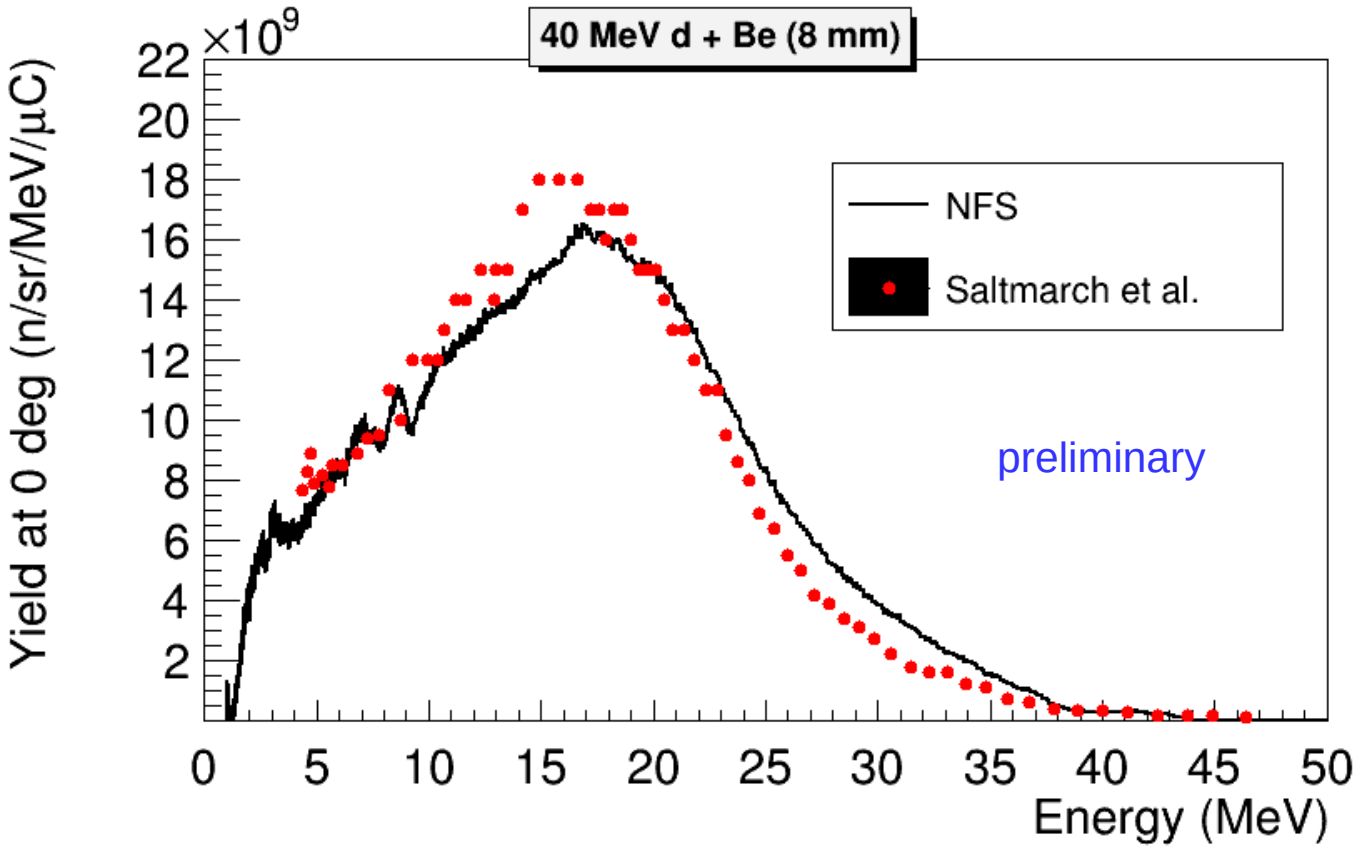
Eα limited to 50 MeV with thin converters

Deuteron beam @ 22 MeV



Deuteron beam @ 40 MeV

Measured with EJ309 and Flight path of 30,86 m



Flux at 5 meters : 8.10^7 n/s/cm^2

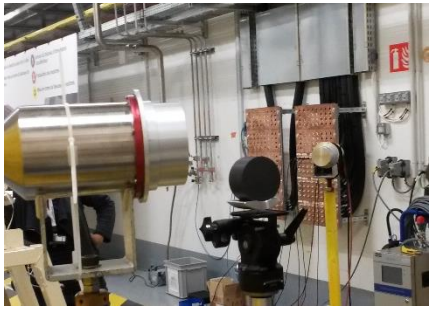
at 15 MeV : 5.10^6 n/s/cm^2/MeV

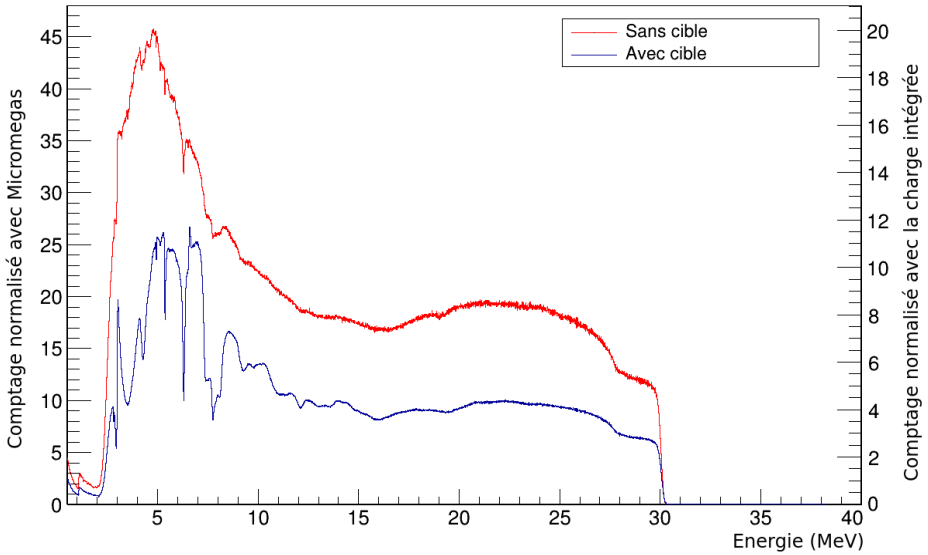
at 30 MeV : 6.10^5 n/s/cm^2/MeV

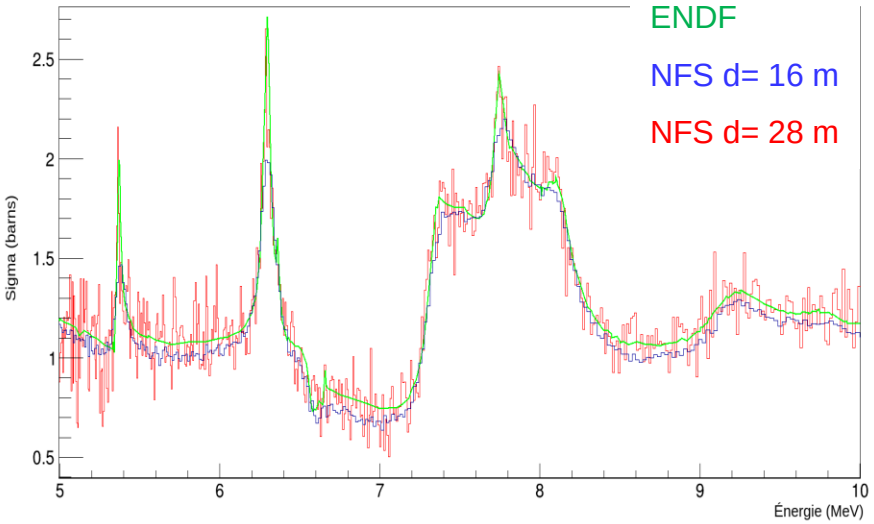
Transmission measurement

- Transmission measurement with Carbon samples (2, 4 and 6 cm thick)
- Total cross-section reaction measurement
- NFS Energy resolution estimation

$$\sigma_T = -\frac{1}{nl}\ln\frac{R_i - B_i}{R_o - B_o}.$$







$$\frac{\Delta E}{E} = \gamma(\gamma+1)\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

$\sigma_t \approx 1$ ns

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PAC 2020

- 9 experiences submitted to the PAC → 7 accepted

NUM	Title	Spokesperson	UT Allocated
E799	Excitation functions of short-lived isotopes in proton induced reactions on ^{nat}Fe	E. Simeckova, NPI, Rez	5
E800	LIONS - Light-Ion Production Studies with Medley at the NFS facility	A.V. Prokofiev, Uppsala University	17
E802	GARIC - Gas production In Chromium by neutrons	A.V. Prokofiev, Uppsala University	21
E804	Measurement of fission cross sections standards relative to elastic n-p scattering at neutron energies 1- 40 MeV	D. Tarrio, Uppsala University	31
E807	Study of the (n,xn) and (n,f) reaction for U238	G. Bélier, CEA-DAM	12
E811	Study of the (n,alpha) reactions of interest for nuclear reactors - the SCALP Project	F. R. Lecolley, lpc Caen	12
E814	235U Fission fragment study with FALSTAFF at NFS	D. Doré, CEA/IRFU/DPhN	11

- 3 Letters of Intents

NUM	Title	Spokesperson
Loi 5	(n,n'g) reactions at NFS: a new probe to study the pygmy dipole resonance	M. Vandebrouck, CEA/IRFU/DPhN
Loi 7	New Judicious Experiments for Dark sectors Investigations at SPIRAL2	B. Bastin, GANIL
Loi 9	(n,xn g) reaction cross sections measurements for nuclear energy applications	M. Kerveno, CNRS/ PHC

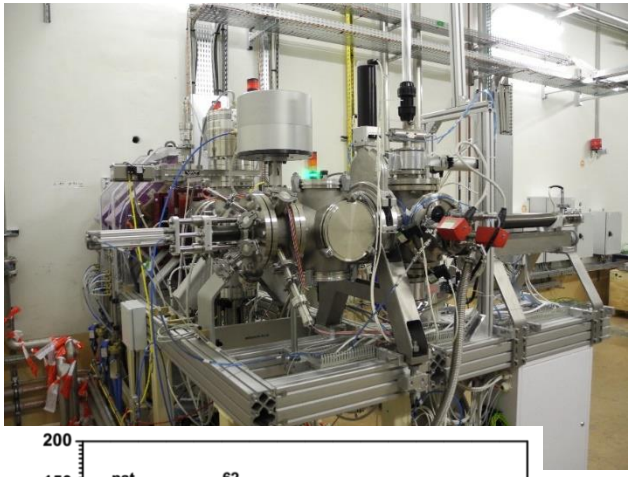
E799: Excitation functions of short-lived isotopes in proton-induced reactions on ^{nat}Fe

Spokesperson : E. Simeckova, NPI, Rez

Measurement of reaction cross-sections by activation technique :

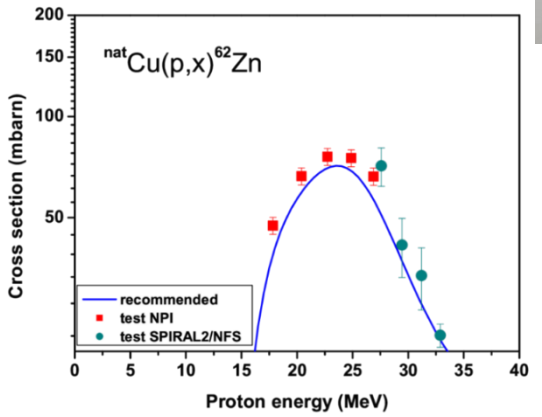
- data for IFMIF facility design
- improvement of reaction model

Goal: measure the ^{58m}Co and ^{58g}Co alimentation

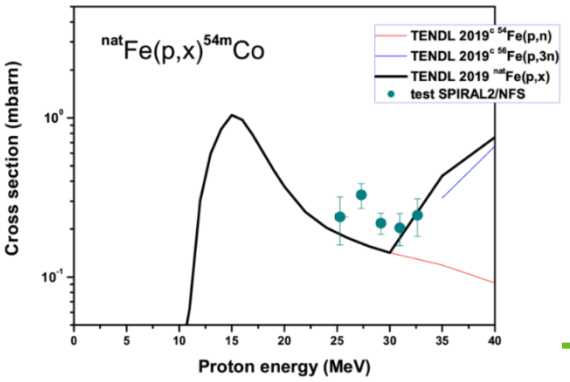


Commissioning : Irradiation station tested in December 2019

- 33 MeV proton beam
- 80 nA beam intensity
- Fe and Cu samples irradiated



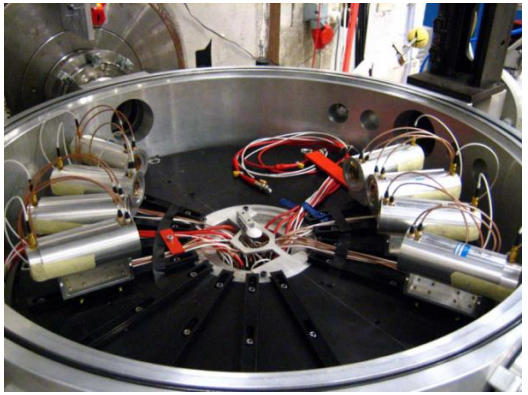
● Good agreement between production cross section of 62Zn and recommended values ->**proves the validity of the method**



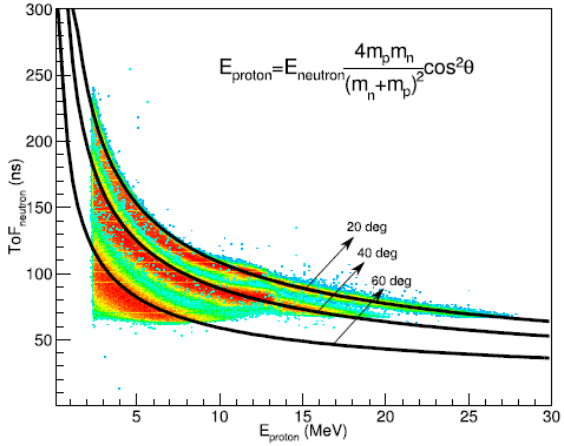
● **natFe(p,x) 54mCo measure for the first time** the production cross section of the **short-lived isomeric state of 54Co**

E800: Ion Production Studies with Medley at the NFS facility

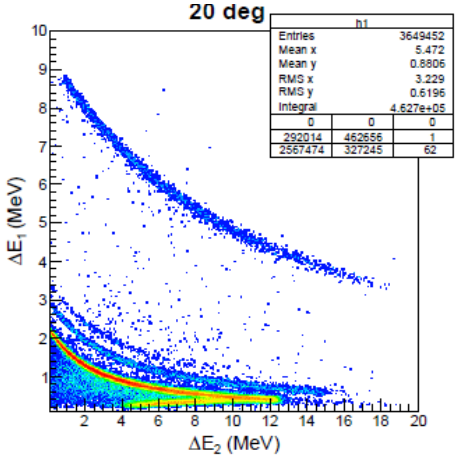
- **Neutron-Induced Light charged particles emission with MEDLEY**
  - 8 **Si-Si-CsI** telescopes
  - Double-differential **cross sections** :
  - **Cancer therapy and dosimetry** (H,C,O, Ca...)
  - **Radiation effects** in microelectronics (Si, O)
  - Energy applications: **Gen-IV or fusion reactors** (building materials, fuel, coolants, etc)



- **Setup tested in fall 2020 and September 2021**
  - High **particle-identification capability**
  - Simultaneous measurement of **charged-particles energy and neutron ToF** (digital



Identification E-ΔE technique



- FIRST NFS by the end of this week

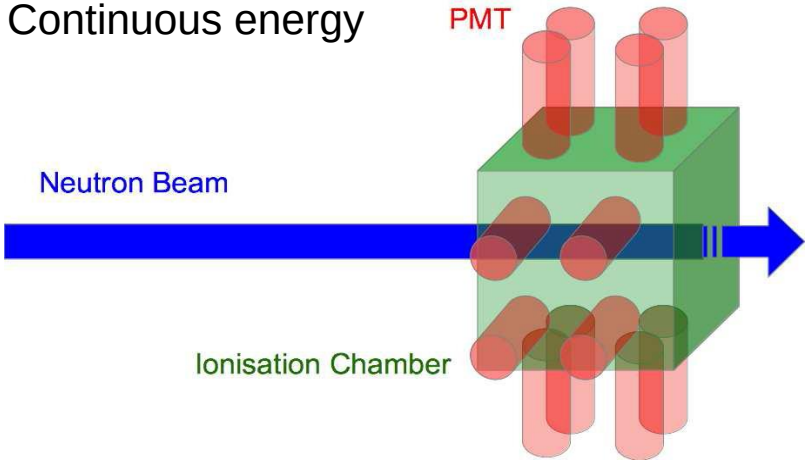
E811: Study of the (n,α) reactions of interest for nuclear reactors - the SCALP Project

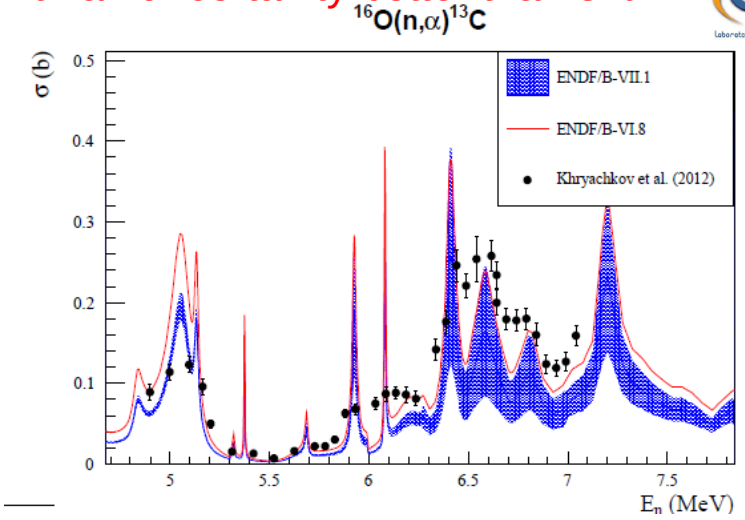
Goals : XS measurement in 7MeV-20MeV range with an uncertainty better than 5%

Active target

Scintillating Ionization chamber

Continuous energy





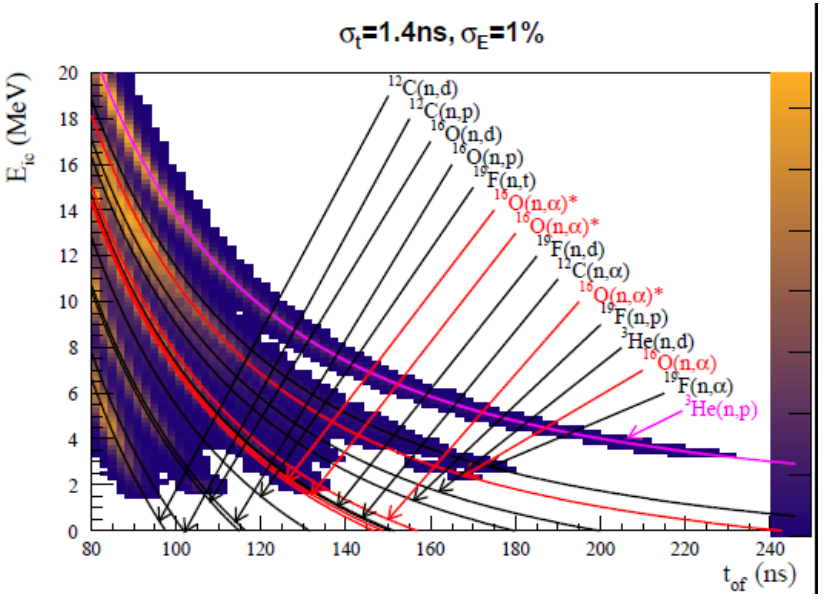
Target composition :

Oxygen → CO_2

Scintillation → CF_4

Normalization → ^3He

→ A lot of Channels to distinguish →



Experiment scheduled by Oct 2021

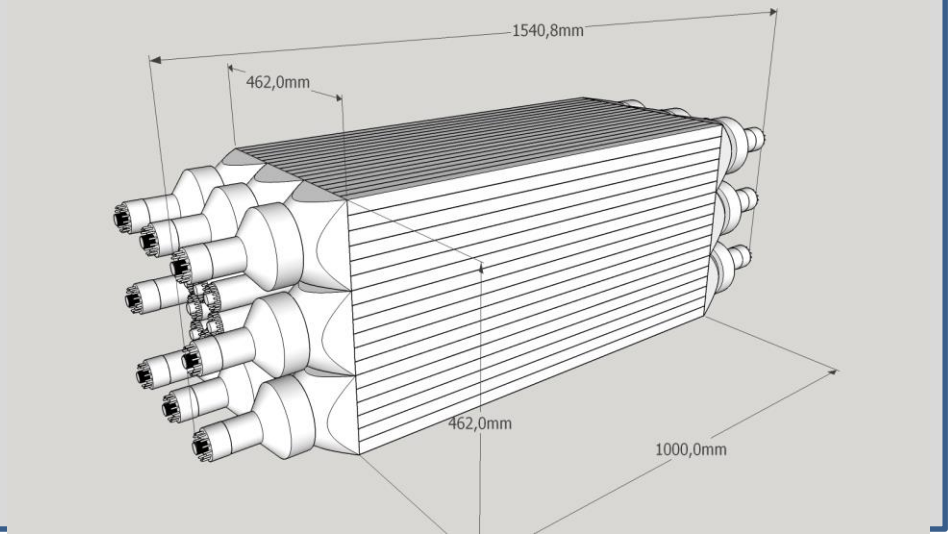
E807: Study of the (n,xn) and (n,f) reaction for U238

Spokesperson : G. Bélier, CEA-DAM-DIF

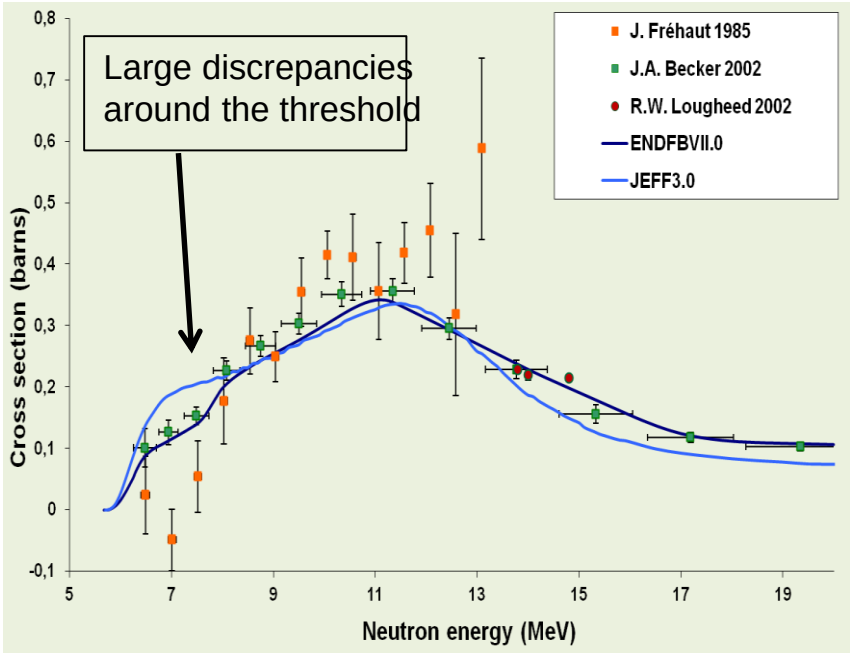
- (n,xn) reaction are important channels in the 5-50 MeV range
- (n,xn) cross-section measurement of actinide is very difficult:
  - radioactive sample
  - prompt neutron fission

Experimental technique :

- ❑ Veto fission (fission chamber)
- ❑ 4π neutron detector SCONE
- ❑ 6 MeV<En< 20 MeV



Next Step : ^{239}Pu(n,2n)



Conclusion

- NFS produces intense beams of neutrons
  - Quasi-mono-energetic and continuous spectra
  - Neutron Yields in agreement with published data
  - Good time resolution
  - Ion induced reaction cross-section measurement successfully tested
  - Test of (n,lcp) production with MEDLEY successful
  - Some of the results are published
- Next steps : perform the 4 experiments scheduled before the end of the year
- The NFS facility fulfil the expected characteristics
- But the accelerator still lacks reliability to achieve experiments in good conditions