NEUTRONS FOR SCIENCE at GANIL

X. Ledoux on behalf of the NFS collaboration

Outline

1. The Spiral-2 and NFS facilities
2. First neutron spectra measured at NFS
3. First experiments

The Neutrons For Science facility

NFS is one of the experimental areas of SPIRAL-2 at GANIL (Caen)

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 characteristics

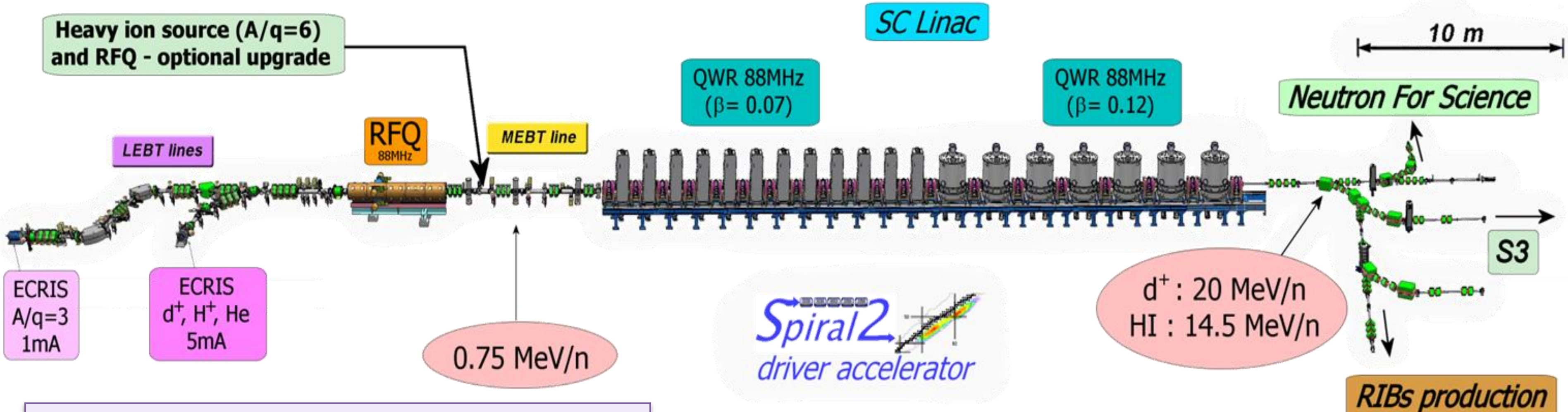
- Well collimated pulsed neutron beam
  - F<1 MHz
  - Burst duration 1 ns
  - Flight path from 4 to 30 m

→Good energy resolution

- Energy spectra :
  - Continuous up to 40 MeV (d + thick converter)
  - Quasi mono-energetic up to 31 MeV (p + thin lithium converter)
- Irradiation station
  - Neutron induced reaction
  - Ion induced reaction
- Ion beam delivered by the LINAC of SPIRAL-2
  - Proton : 2 – 33 MeV
  - Deuteron and Helium : 2 – 20 MeV/u
  - I = 5 mA

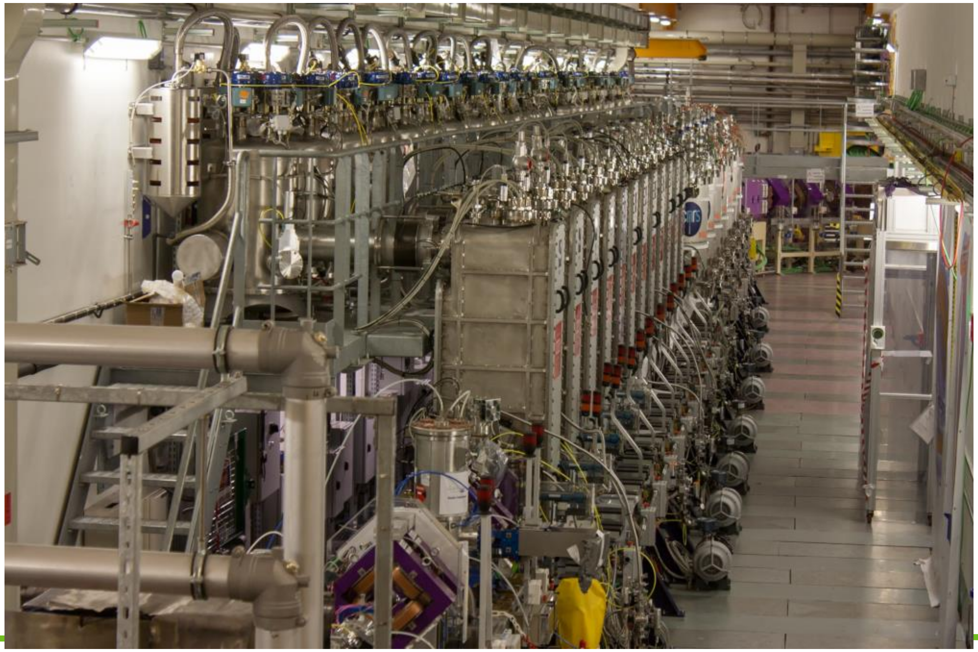
SPIRAL-2 phase 1 building

The Linear Accelerator of SPIRAL-2

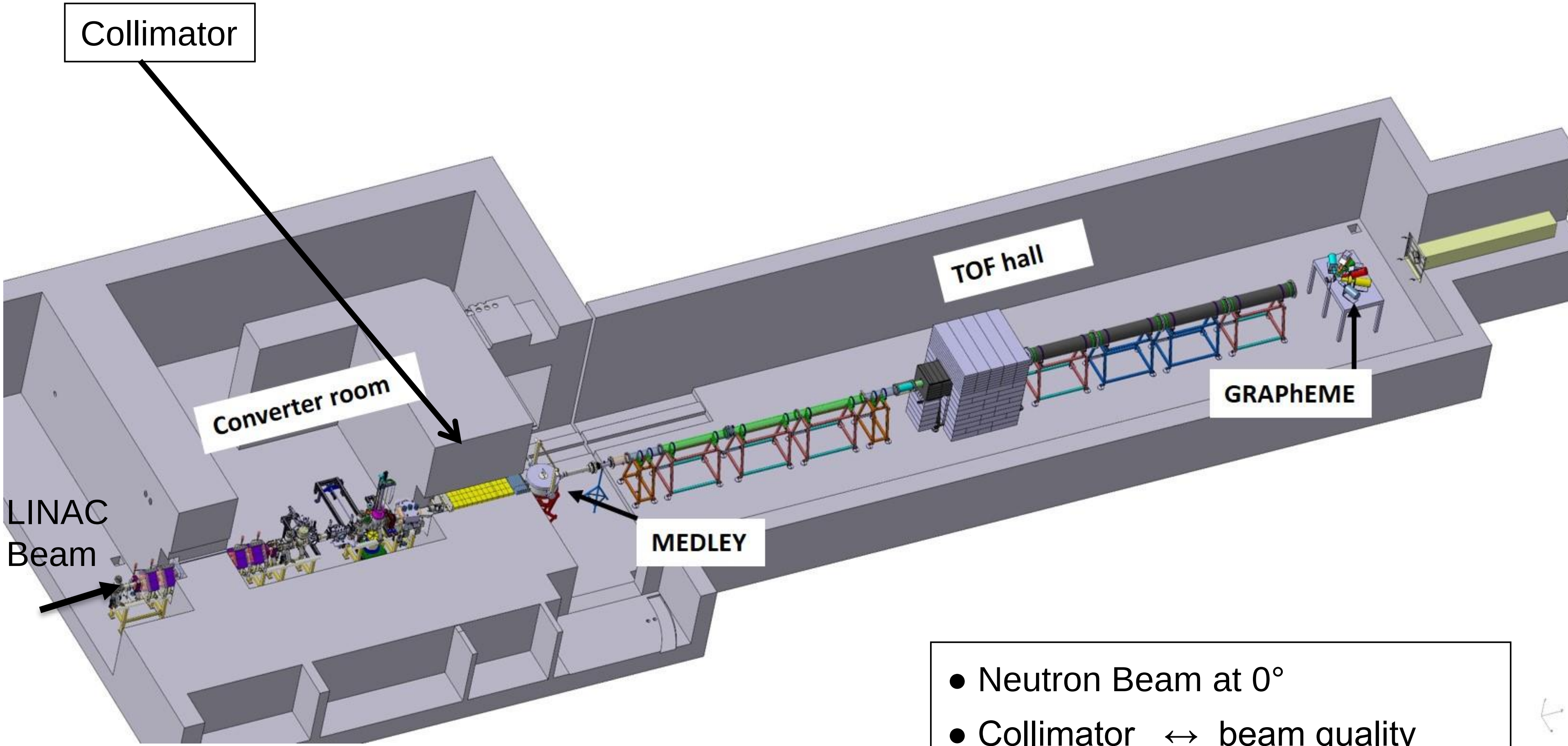


Total length: 65 m (without HE lines)
Slow (LEBT) and Fast Chopper (MEBT) RFQ (1/1, 1/2, 1/3) & 3 re-bunchers
12 QWR beta 0.07 (12 cryomodules) 14 (+2) QWR beta 0.12 (7+1 cryomodules) 1.1 kW Helium Liquifier (4.5 K) Room Temperature Quadrupoles Solid State RF amplifiers (10 & 20 KW)

RFQ frequency F = 88MHz



NFS layout

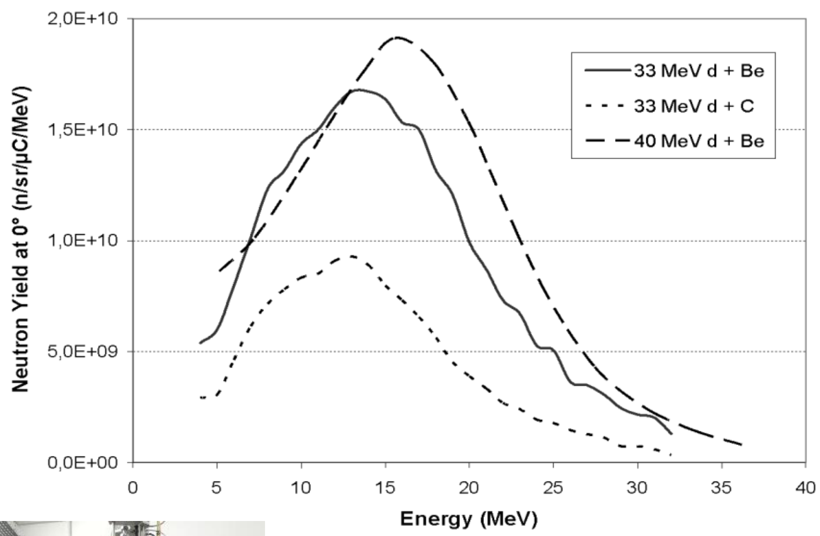


- Ion and neutron induced reactions
- Beam line extension
- Irradiation station (n, p, d)

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

Neutron production reaction

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



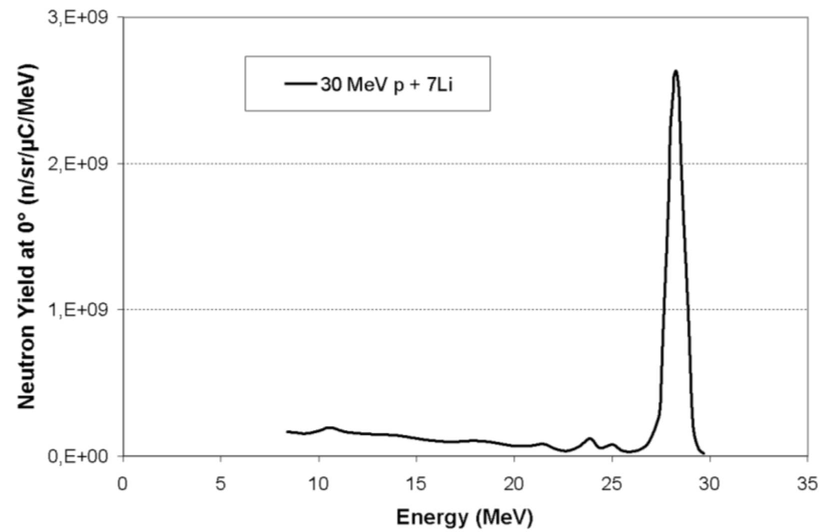
40 MeV d + Be at 50 µA

Rotating converter

thick target C or B (8mm)

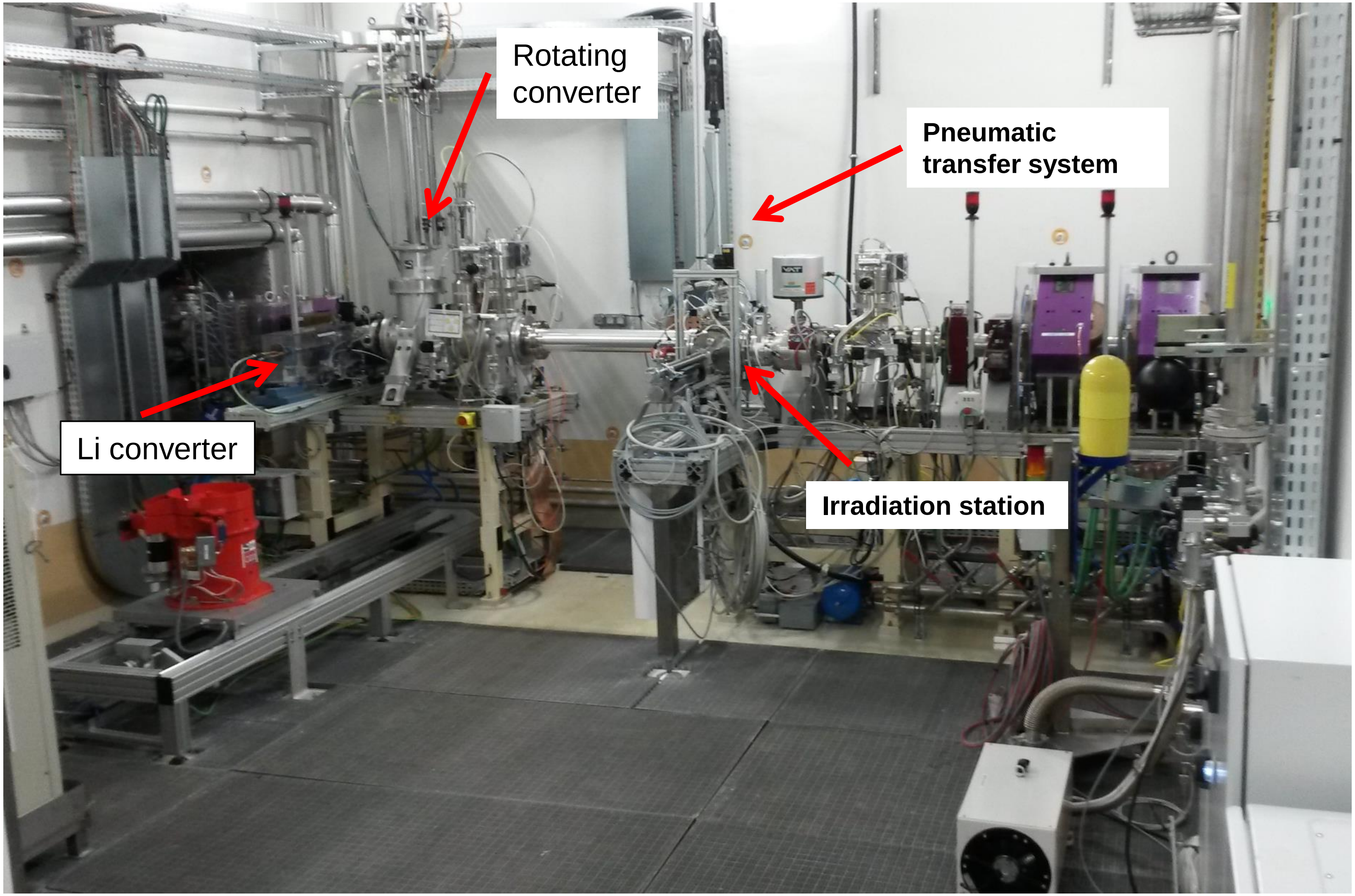
P< 2 kW

Quasi-monoenergetic spectrum
E_n = up to 31 MeV



p + Li (1mm) at 20 µA

NFS: The converter room



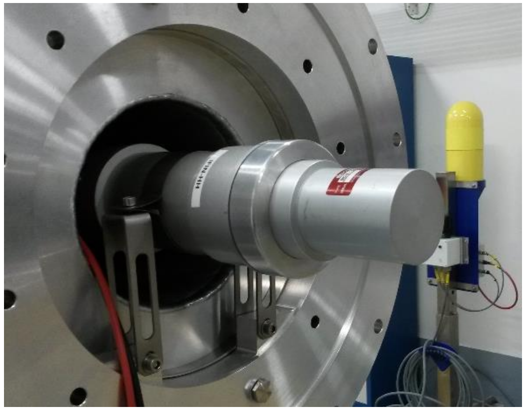
NFS: The TOF area

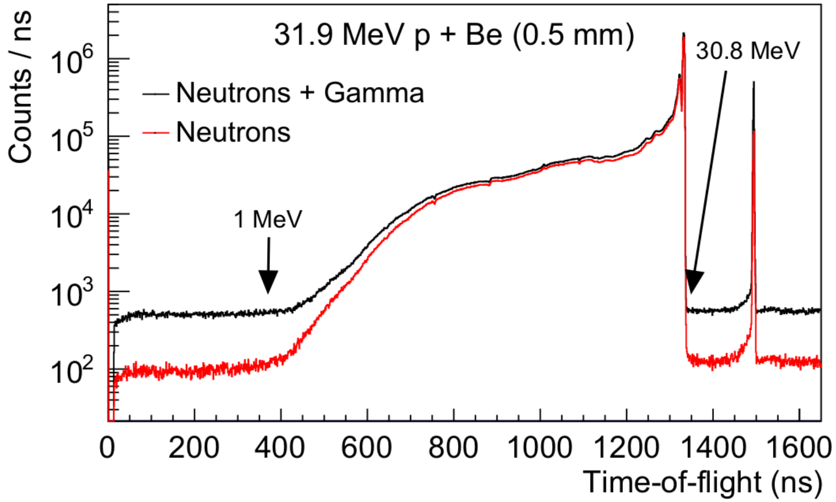
NFS commissioning

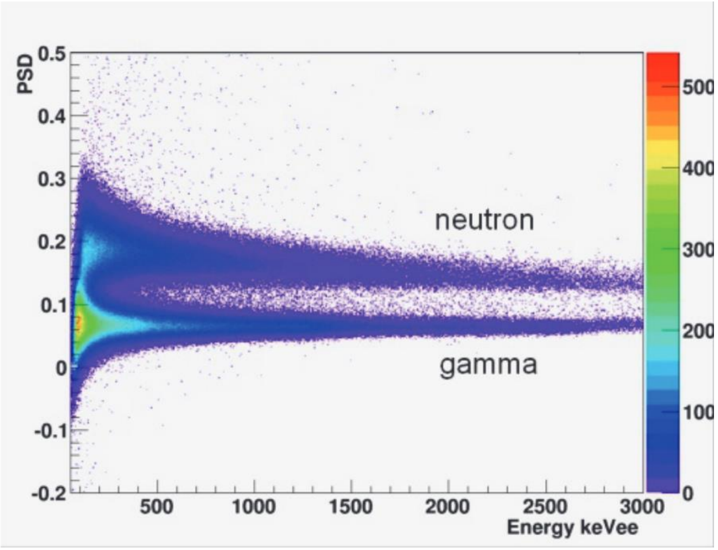
- December 2019 : First proton beam at 33 MeV in the converter cave
- September 2020 to December 2020: First neutron beams
  - First quasi-mono-energetic neutron beam: 33 MeV p + Li and Be
  - Continuous neutron beam 31,9 MeV p + Be (8 mm)
  - Flux and spectrum measurement
- July 2020: First He-4 beam
- September 2021: First deuteron beam
- September to December 2021: First experiments
  - E800 : LIONS
  - E811 : SCLAP
  - E807 : SCONE
  - E799 : Excitation function in proton induced reactions

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)



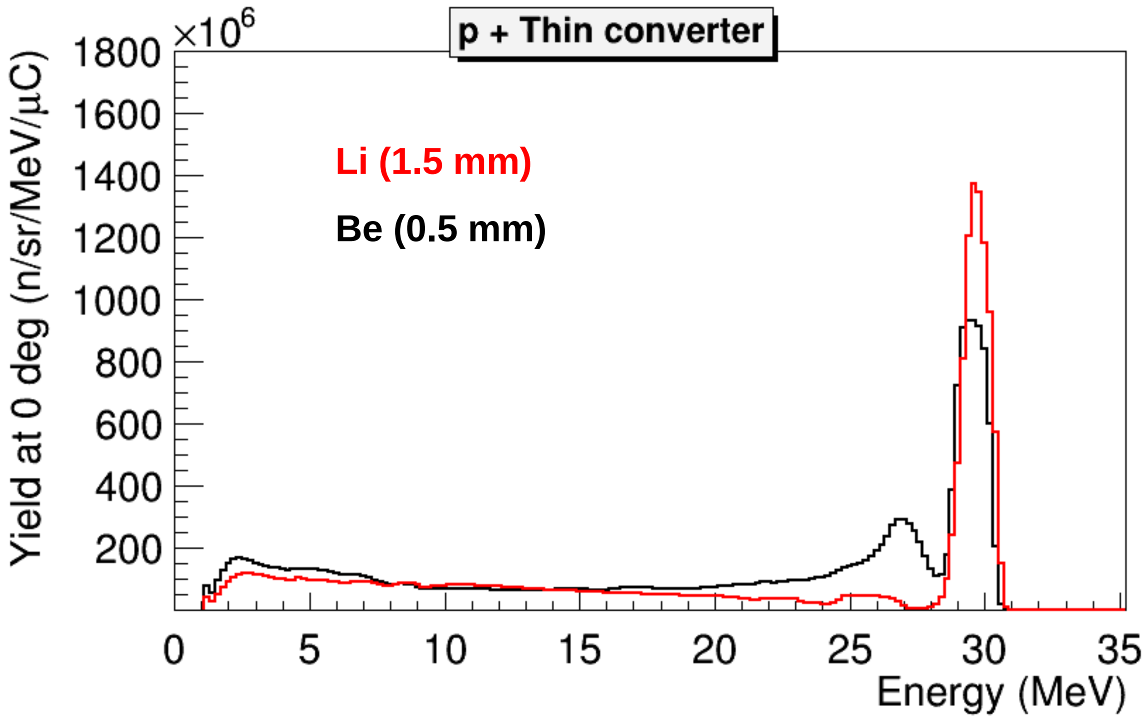




- ❑ Adaptation of the SCINFUL code:
  - Light response of EJ309 included
  - Efficiency determination

Eth ≈ 1 MeV

Protons @ 31.9 MeV on thin converters



Peak ratio (E>28.5 MeV) / total (E>2 MeV):

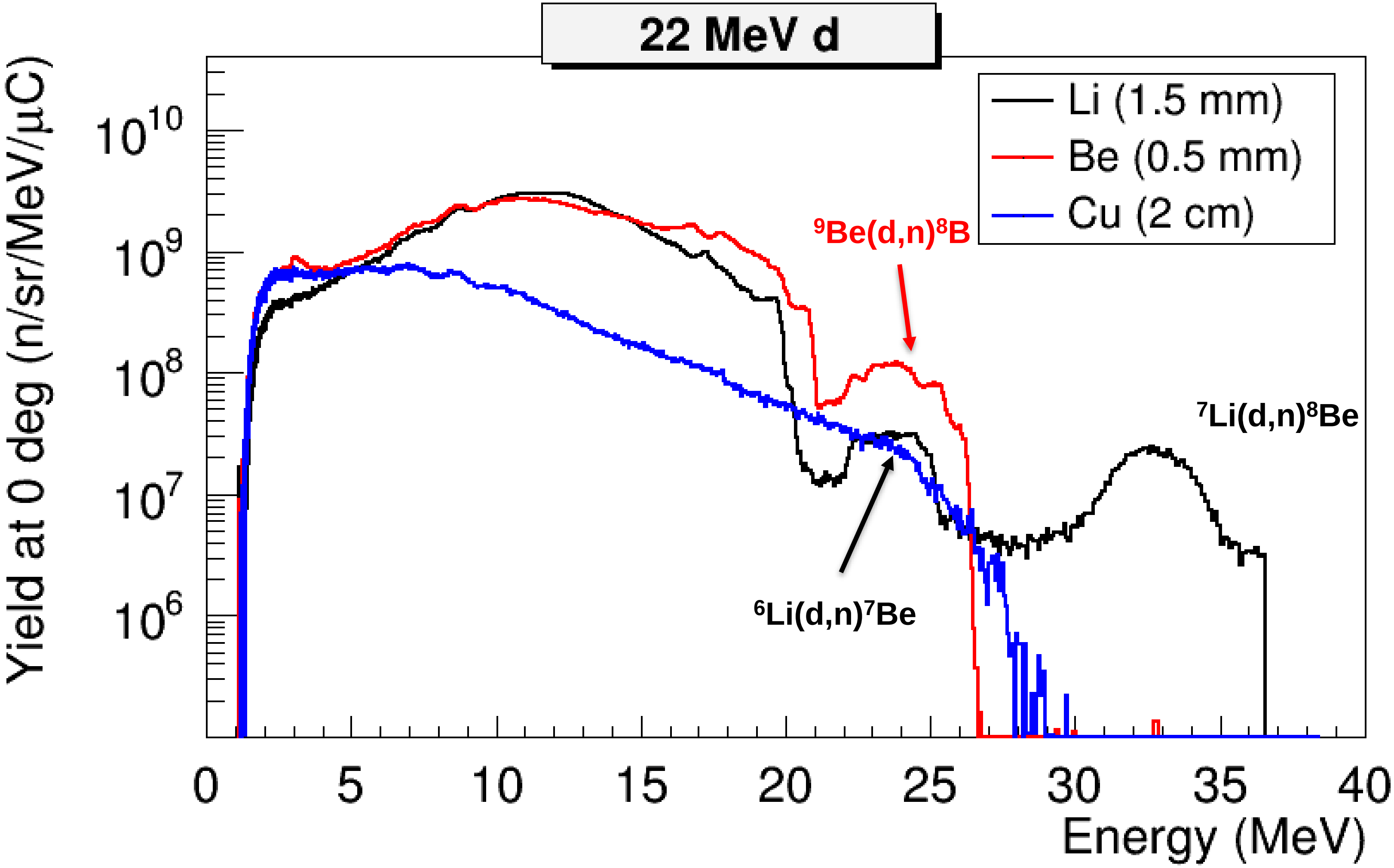
p + Li (1,5 mm) : 51%

p + Be (0,5 mm) : 32%

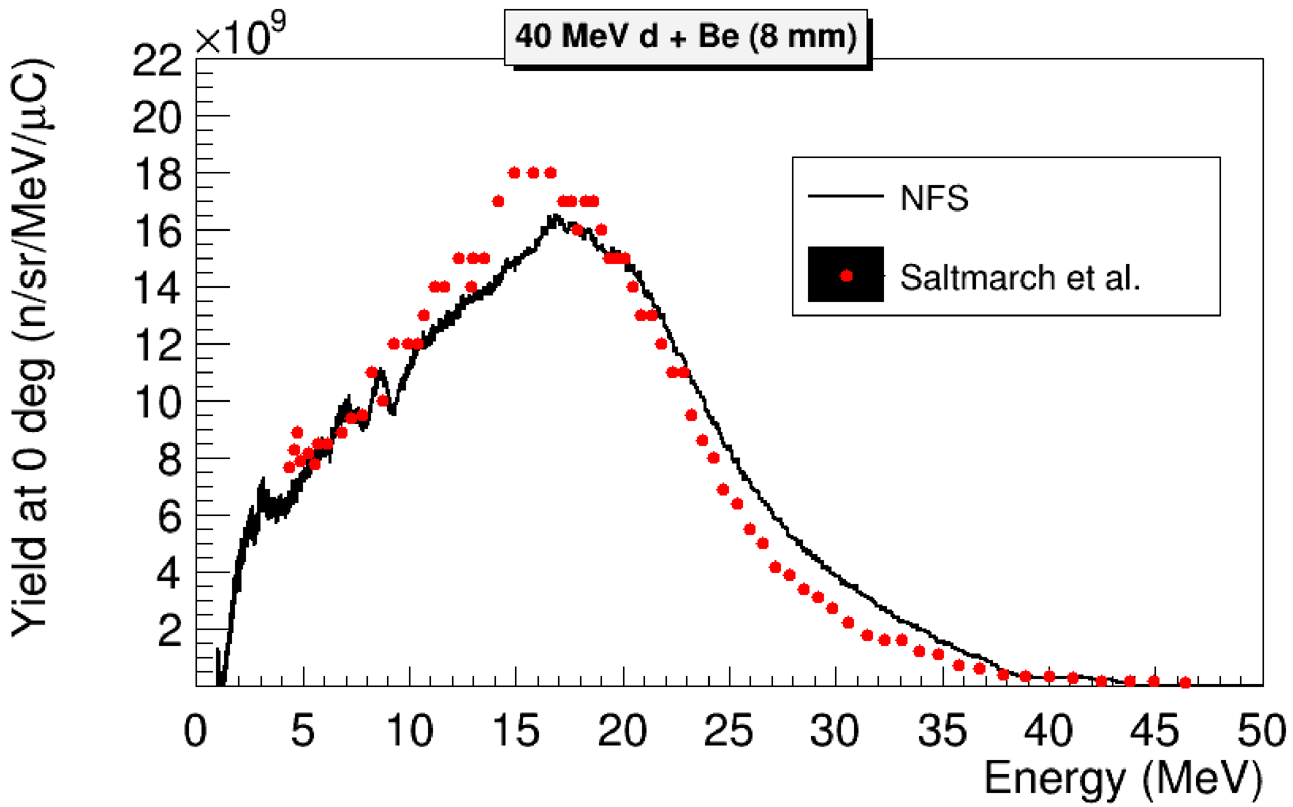
31,9 MeV p beam at 20 µA →

E MeV	Flux at 5 m
5	$1{,}7.10^4$ n/cm²/MeV/s
10	5.10^3 n/cm²/MeV/s
20	$2{,}3.10^4$ n/cm²/MeV/s
30	$1{,}2.10^5$ n/cm²/MeV/s

Deuteron beam @ 22 MeV



Deuteron beam @ 40 MeV



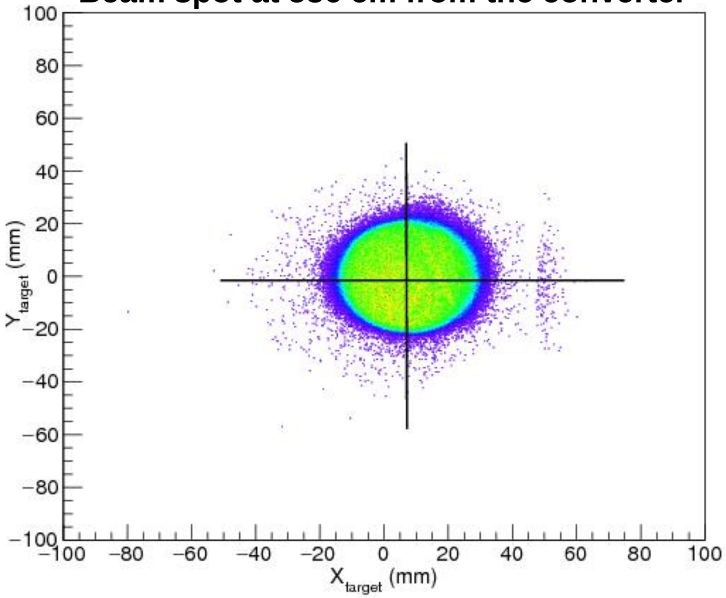
40 MeV d beam at 50 µA →

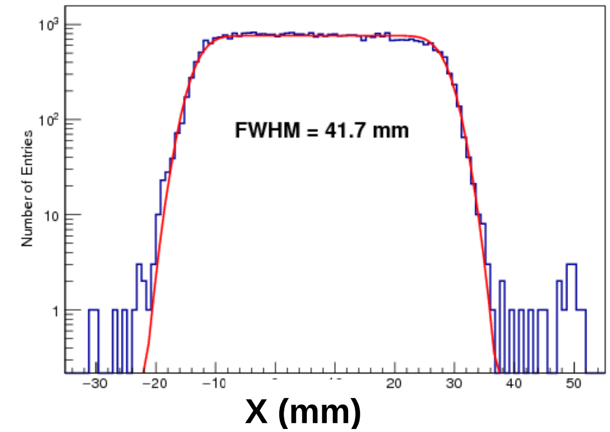
E MeV	Flux at 5 m
0-40	8.10^{7} n/cm²/s
5	2.10^{6} n/cm²/MeV/s
14	5.10^{6} n/cm²/MeV/s
30	6.10^{5} n/cm²/MeV/s

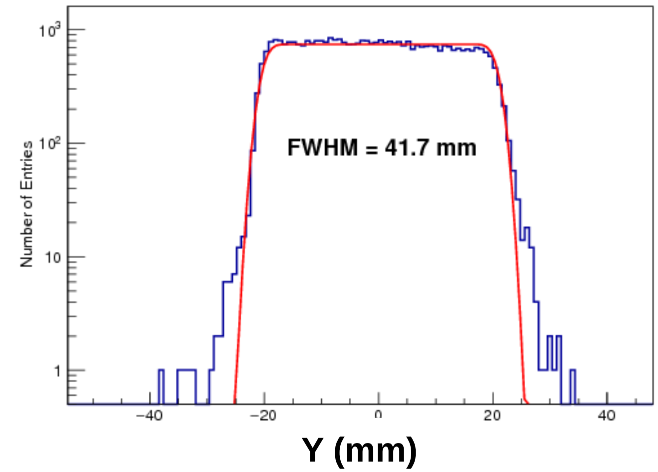
Neutron beam profile

- The beam has a conical shape :
  - r=21 mm at 5 m downstream from the collimator
  - r=55 mm at 29 m
- Beam profile measurement :
  - PPAC detector with U238 sample (IJCLab)
  - Graphchromic film at 29 m

Beam spot at 536 cm from the converter







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

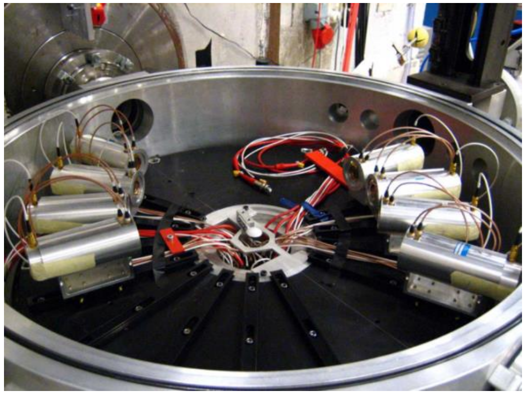
- 3 Letters of Intents

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

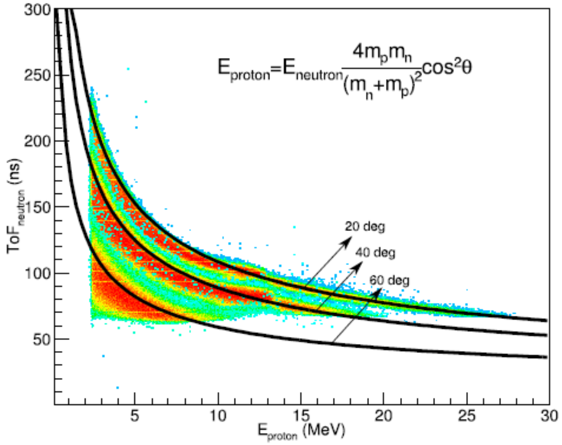
E800: Ion Production Studies with Medley at the NFS facility

Spokesperson : A. Prokofiev, Uppsala University

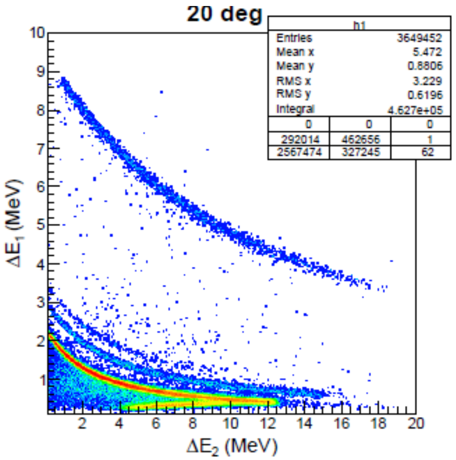
- **Neutron-Induced Light charged particles emission with MEDLEY**
  - 8 **Si-Si-CsI** telescopes
  - Double-differential **cross sections** :
  - **Cancer therapy and dosimetry** (H,C,O, Ca...)
  - **Radiation effects** in microelectronics (Si, O)
  - Energy applications: **Gen-IV or fusion reactors**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



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

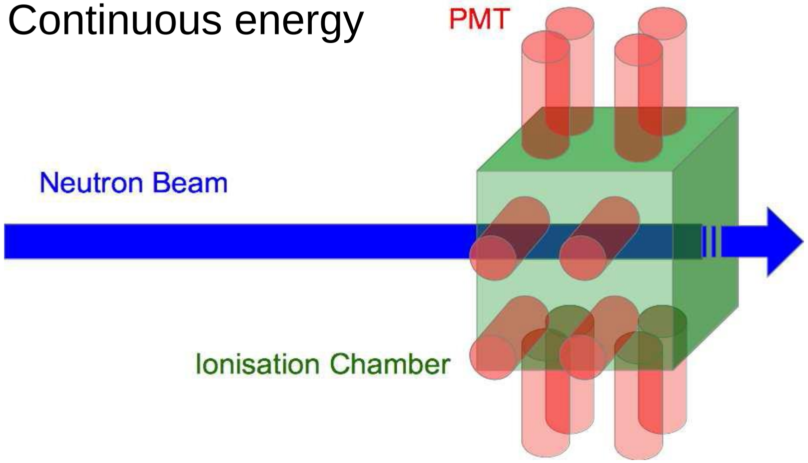
Spokesperson : J. F. Lecolley, LPC Caen

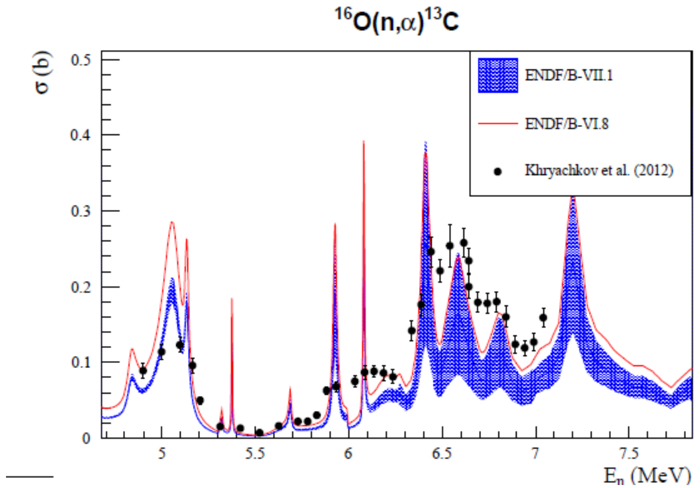
Goals : XS measurement in 7MeV-20MeV range with an uncertainty better than 5%

Active target

Scintillating Ionization chamber

Continuous energy





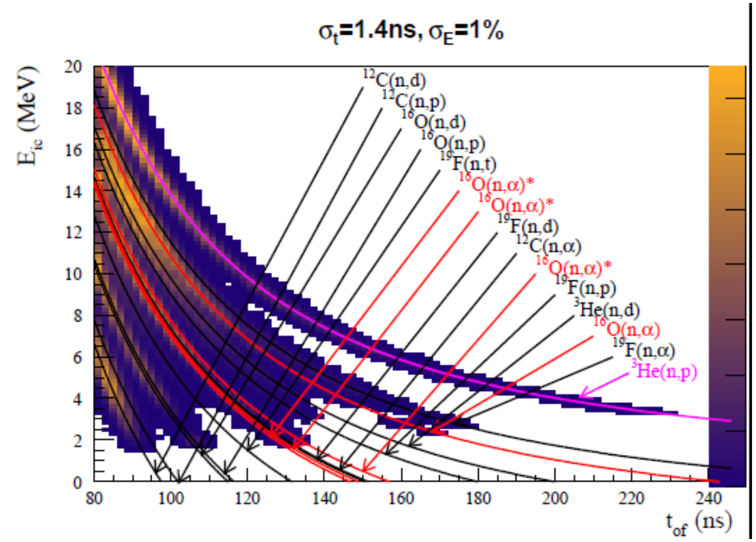
Target composition :

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

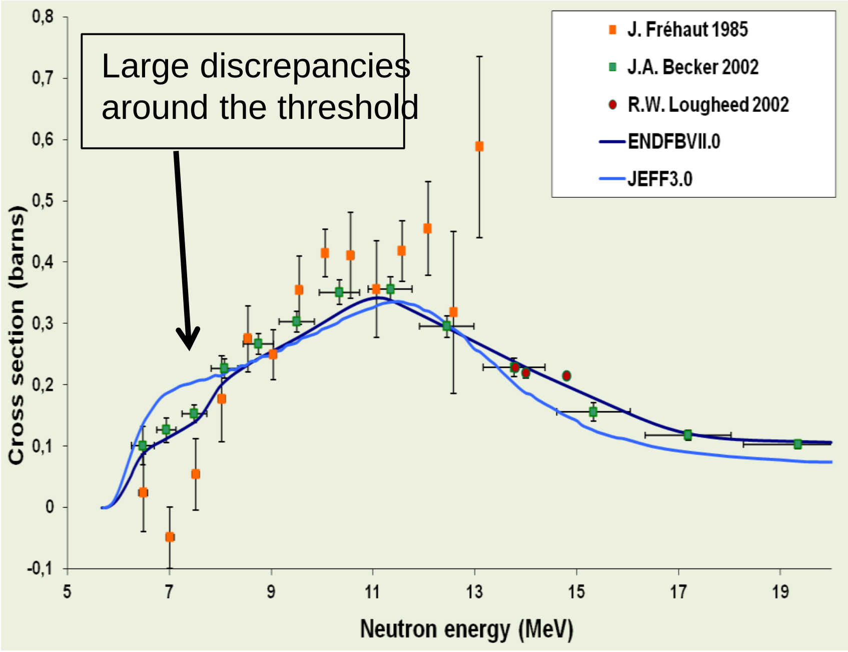
Spokesperson : G. Bélier, CEA-DAM-DIF

- (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 :

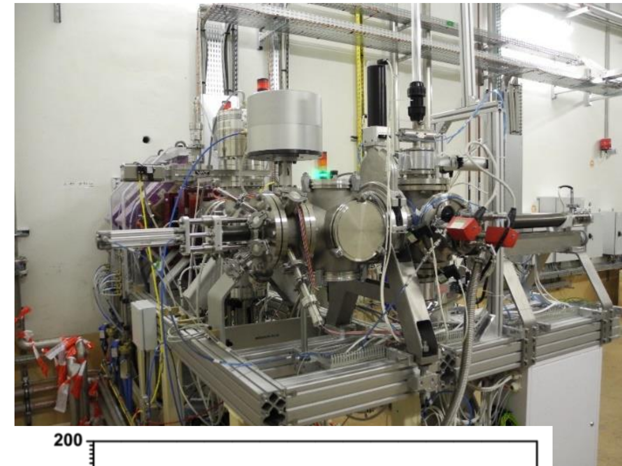
- ❑ Veto fission (fission chamber)
- ❑ 4π neutron detector SCONE
- ❑ 6 MeV<En< 20 MeV

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



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

Spokesperson : E. Simeckova, NPI, Rez



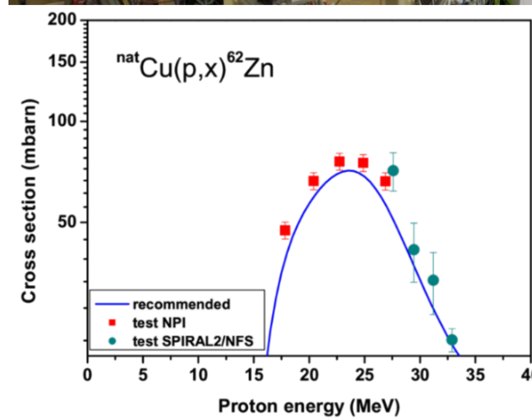
Measurement of reaction cross-sections by activation technique :

- data for IFMIF facility design
- improvement of reaction model

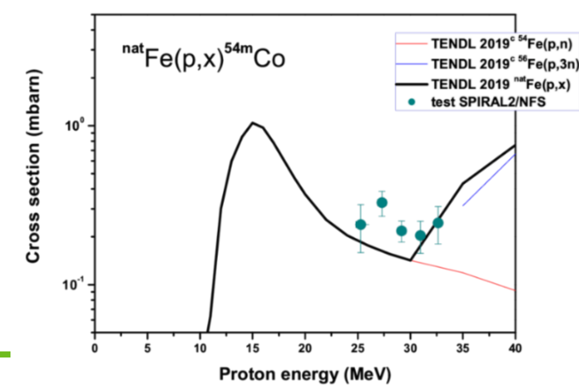
Goal: measure the ^{58m}Co and ^{58g}Co alimentation

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** in



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

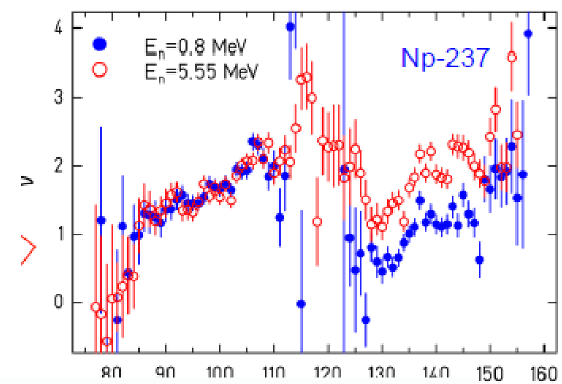
E814: ^{235}U Fission fragment study with FALSTAFF at NFS

Spokesperson: D. Doré (CEA/IRFU)

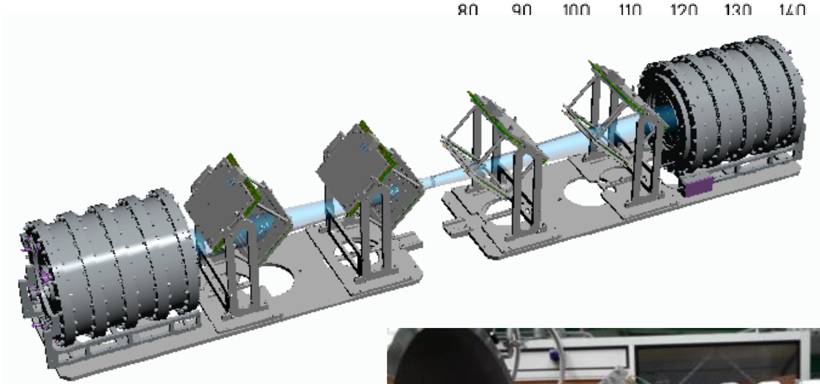
FALSTAFF : Four Arm cLover for the Study of Actinide Fission Fragments

Perform experiments in the fast domain to characterize actinide fission fragments

- Neutron Sawtooth Curve
- Important piece of information about scission
  - Excitation energy sharing
  - Shell effects
  - Energy balance



Many models exist but not predictive enough



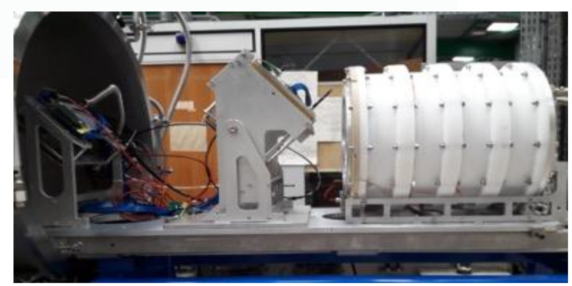
Actinides to study:
^{235,238}U,^{239}Pu,^{237}Np, ^{232}Th, ^{233}U

Detection of fragments in coincidence

Kinetic energy

Post-masses (after n evap) → EV method good energy resolution 1 %

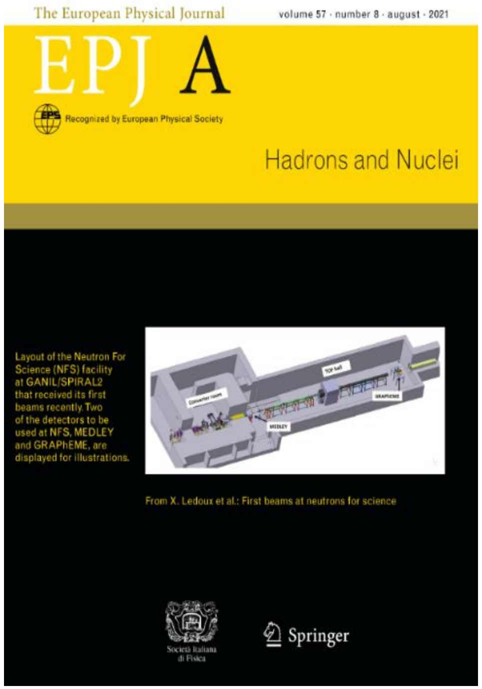
Pre-masses (before n evap) → 2V method TOF measurement time resolution < 150ps



Each arm is composed of Ionization chamber (E) and SED detector (v)

Summary

- Neutrons for Science characteristics :
  - Collimated neutron beam
  - Quasi-mono-energetic and continuous spectra
  - Light ion beam
  - Irradiation station for neutrons and ion induced reactions
- Physics cases of the proposed Experiments :
  - Lcp particle production
  - Fission process
  - n,xnγ reactions
- Everyone can propose an experiment
  - 2 PAC session per year
  - GANIL web site “proposing an experiment” and contact me
- NFS is in the European Projects (Transnational Access):
  - ARIEL
  - RADNEXT



Thank you for your attention