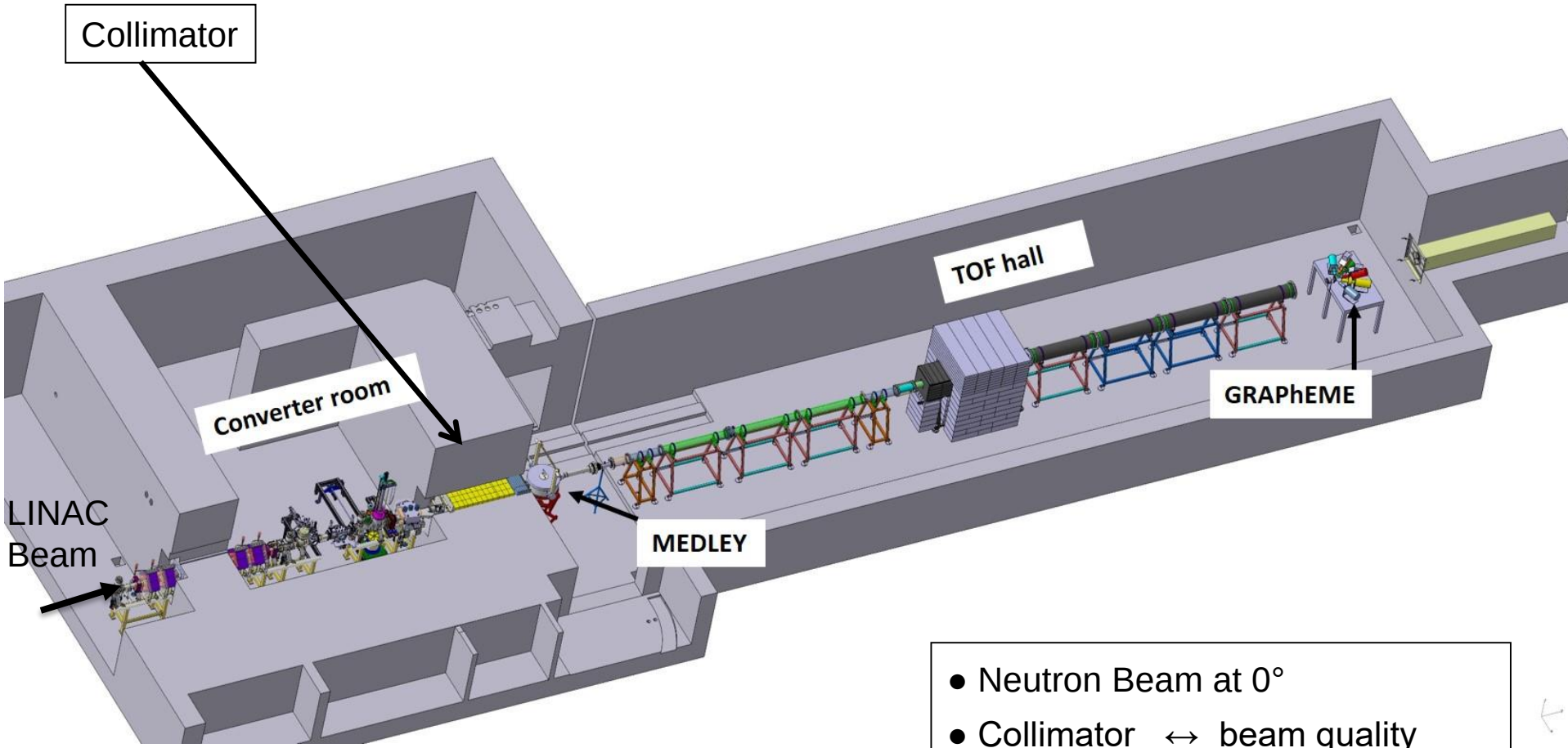
First results of the Neutrons For Science Facility

X. Ledoux on behalf of the NFS collaboration

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

NFS layout

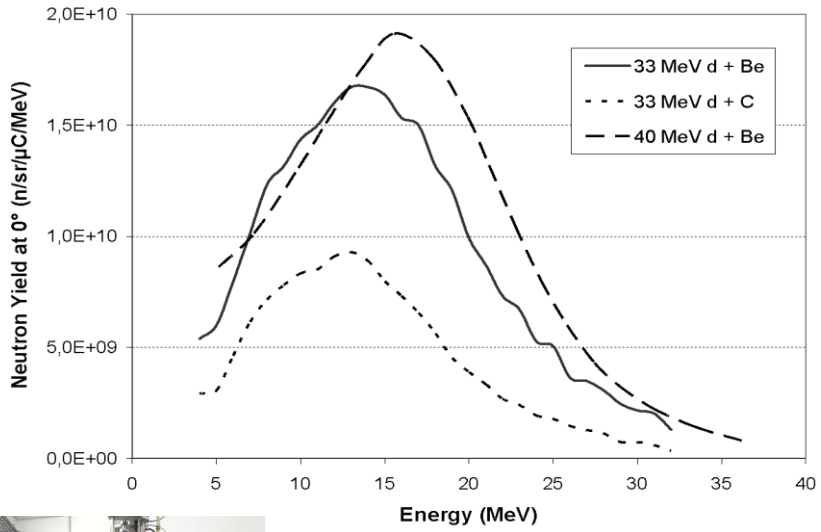


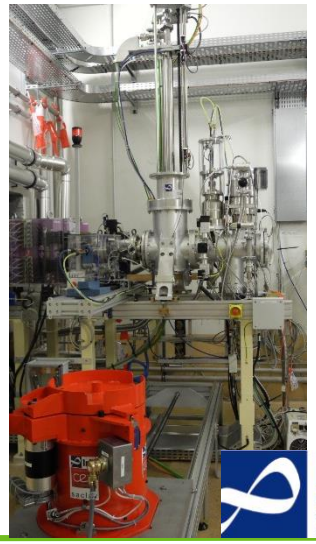
- Ion and neutron induced reactions
- Beam line extension
- Irradiation station (n, p, d)

- 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

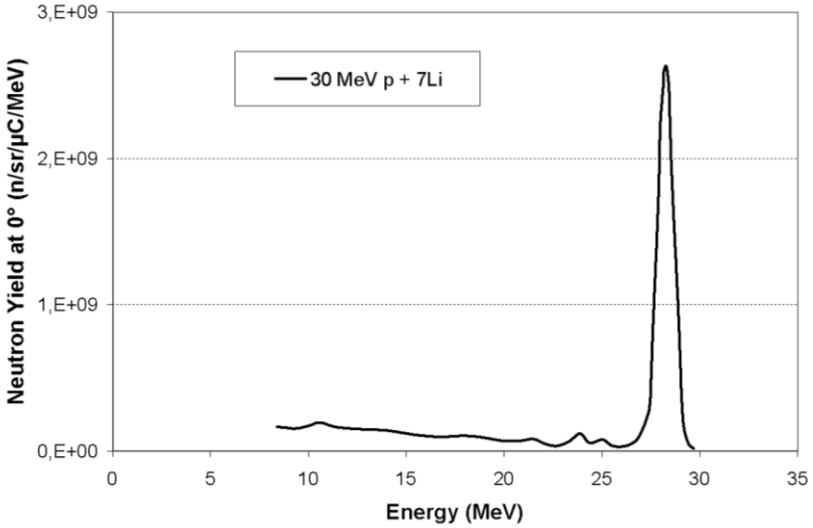




40 MeV d + Be at 50 µA

Rotating converter
thick target C or B (8mm)
P< 2 kW

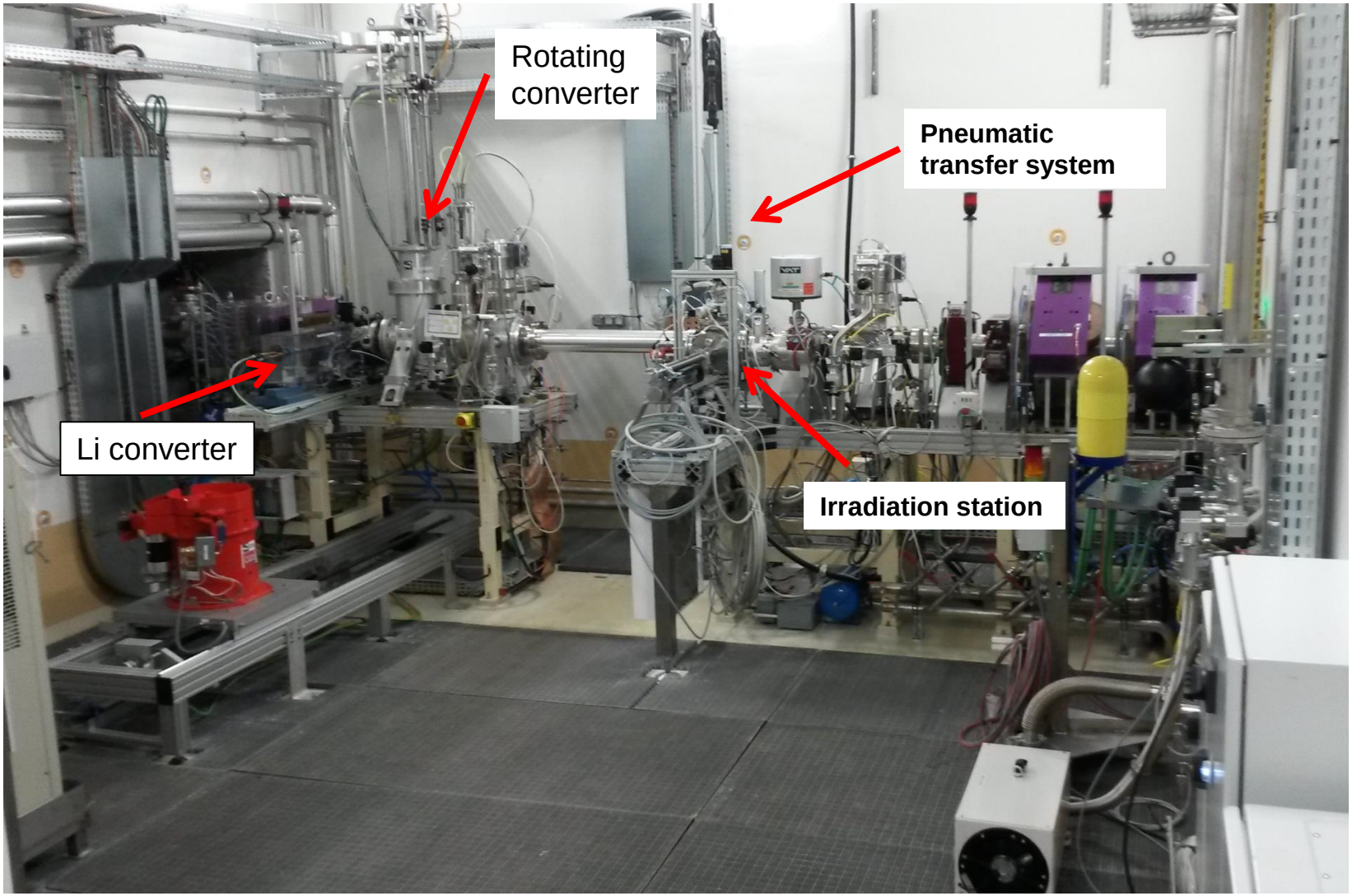
Quasi-monoenergetic spectrum
E_n = up to 31 MeV



p + Li (1mm) at 20 µA

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

NFS: The converter room



NFS: The TOF area

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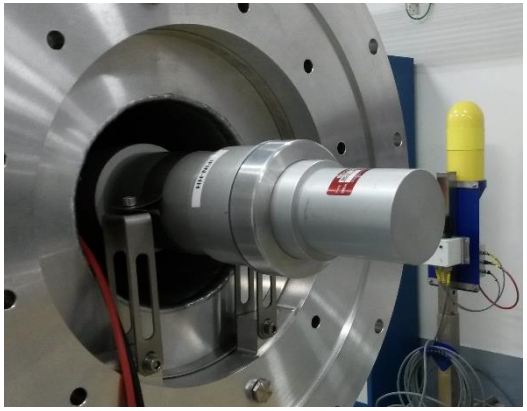
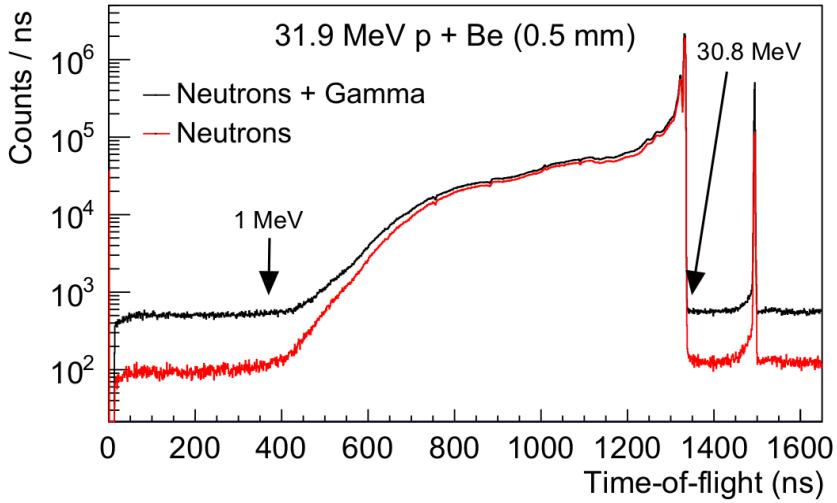
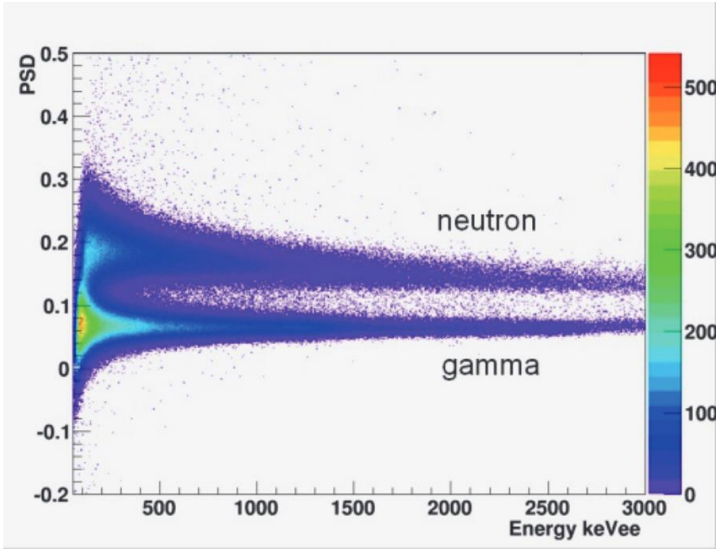
Neutron spectra measurements: E> 2 MeV

Detectors based on liquid scintillator EJ309



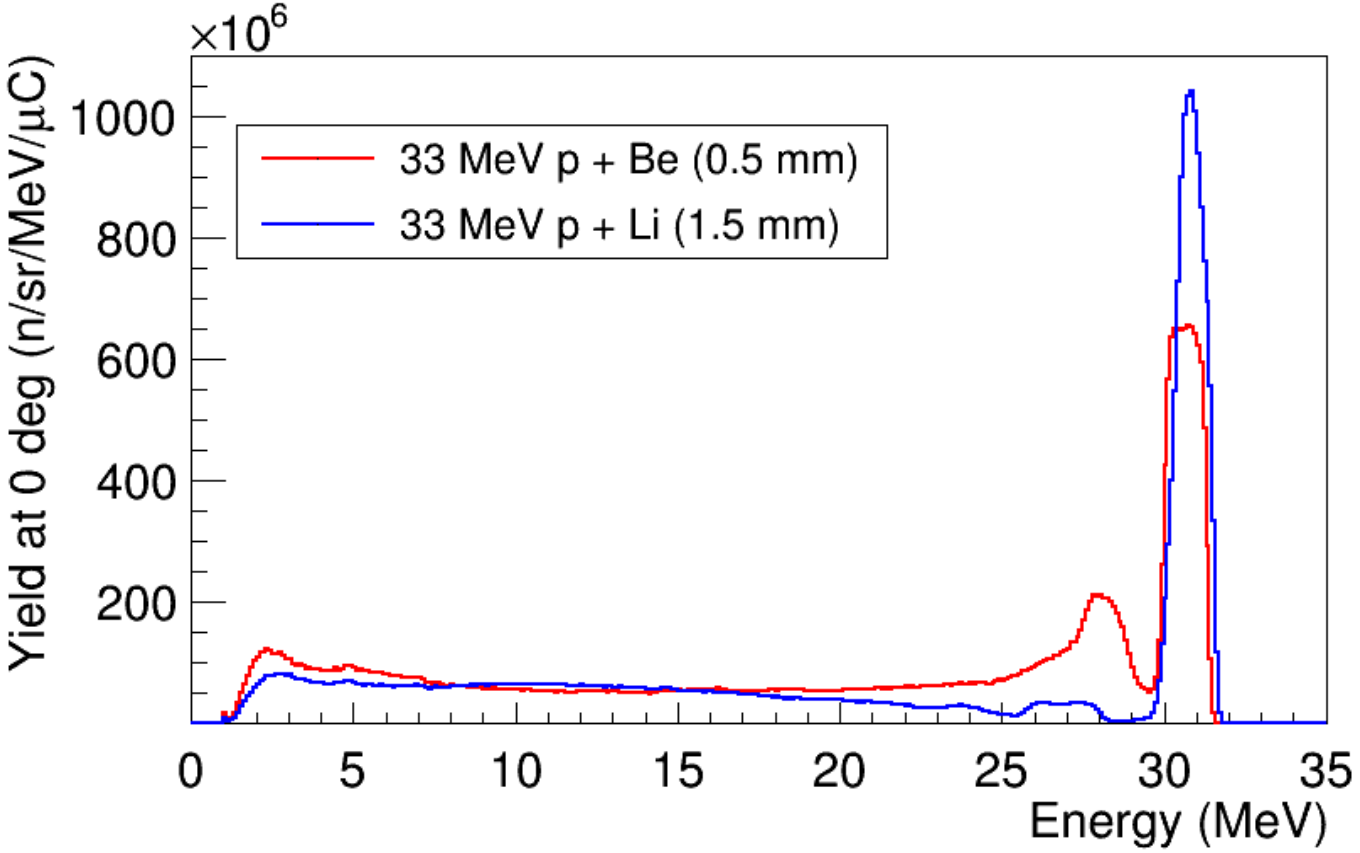
- Neutron spectrum and flux measurement by the TOF technique
- n-γ discrimination by pulse shape analysis
- EJ309 cell (2 inches in diameter, 3 inches in length)
- Placed in the beam pipe downstream of the rotating converter (15 to 30 m)





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

Quasi-mono-energetic spectra

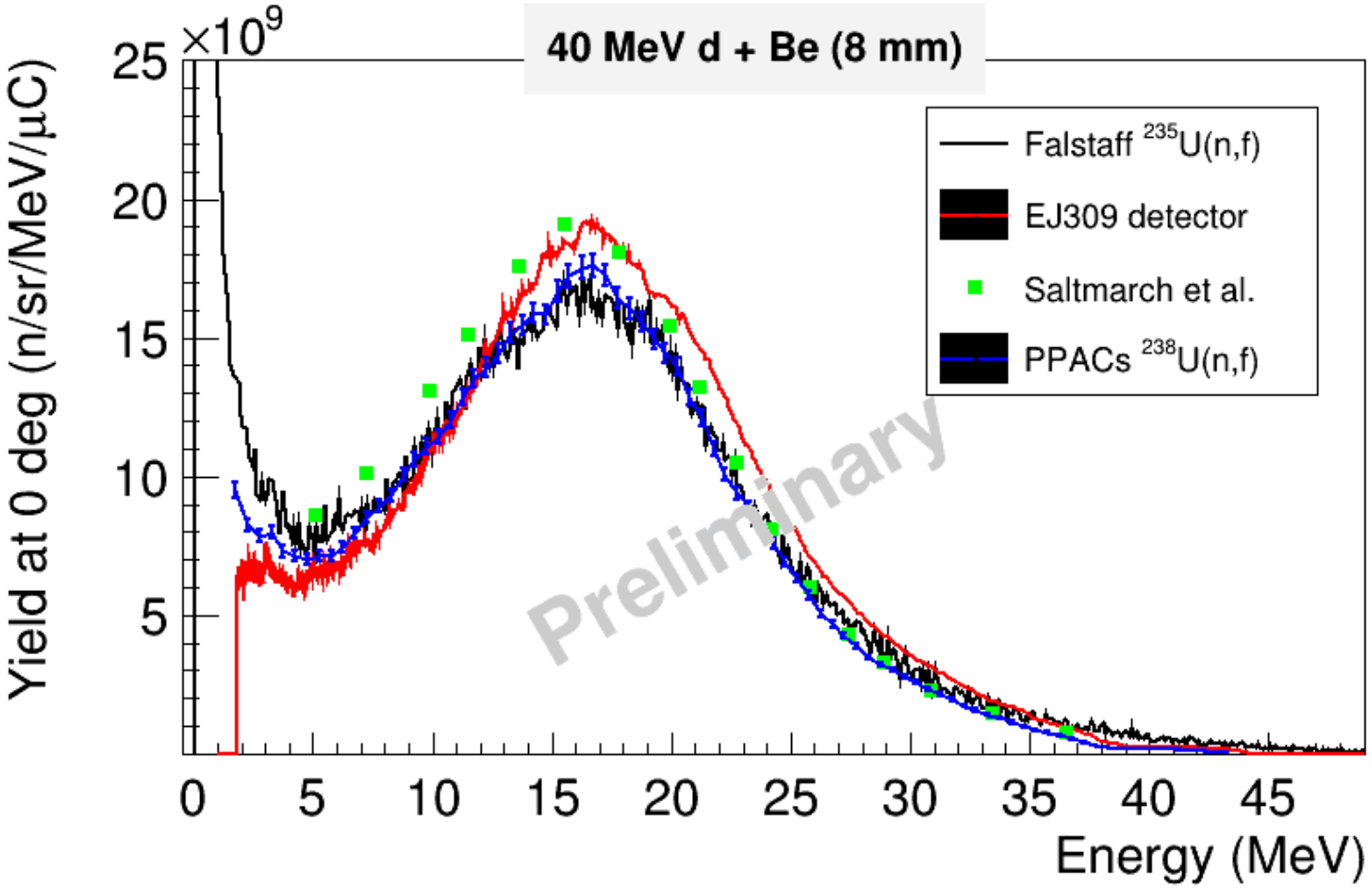


33 MeV p + Li (1,5 mm)

Neutron yield in the mono-energetic peak 1,2 10^9 n/sr/µC

at 20 µA and d=500cm → Φ = 10^5 n/s/cm^2

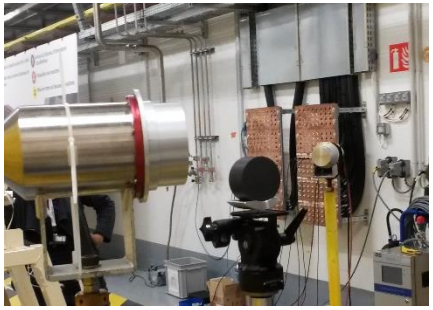
Continuous spectrum

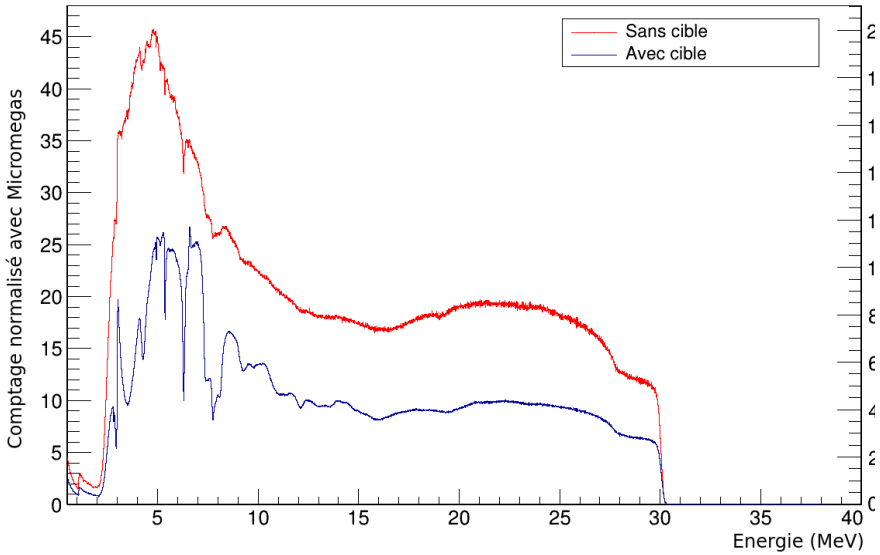


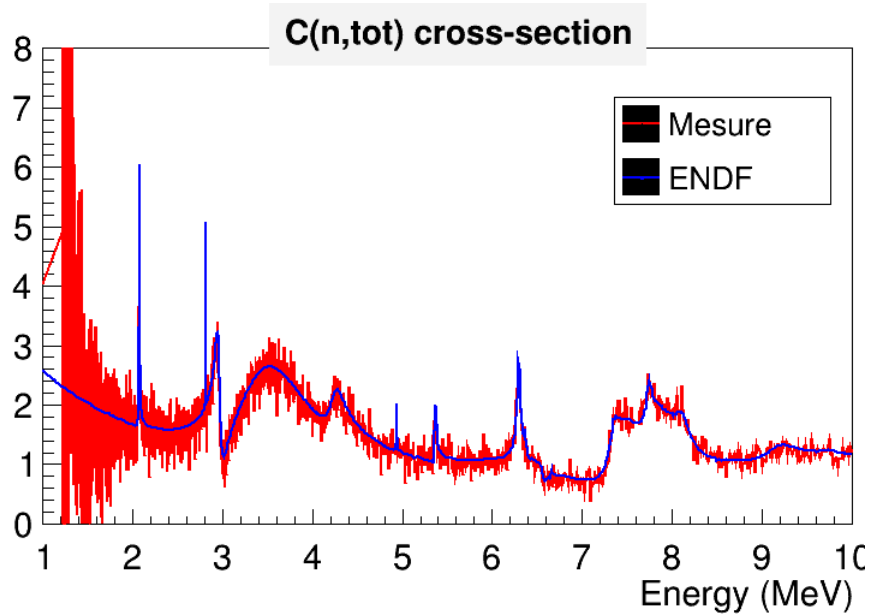
Transmission measurement

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

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





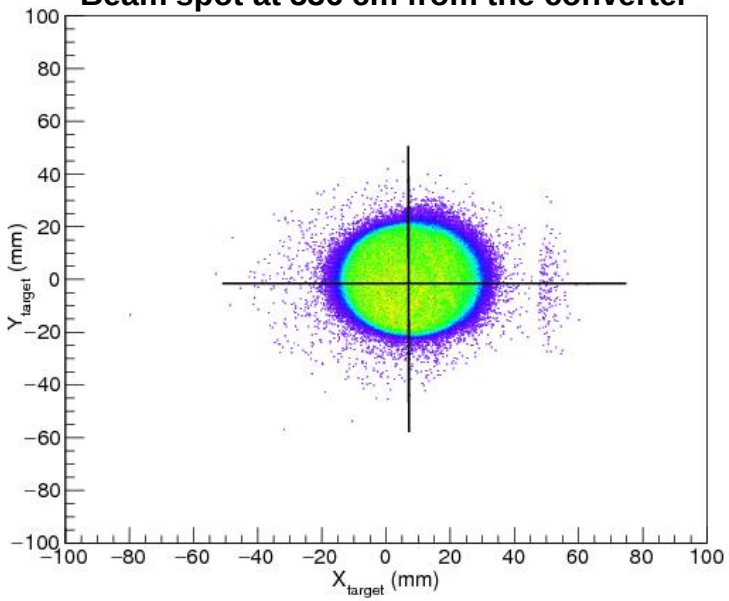


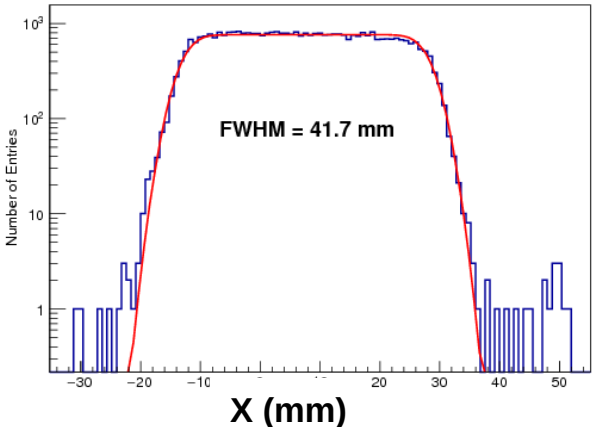
$$\frac{\Delta E}{E} = \gamma(\gamma+1)\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

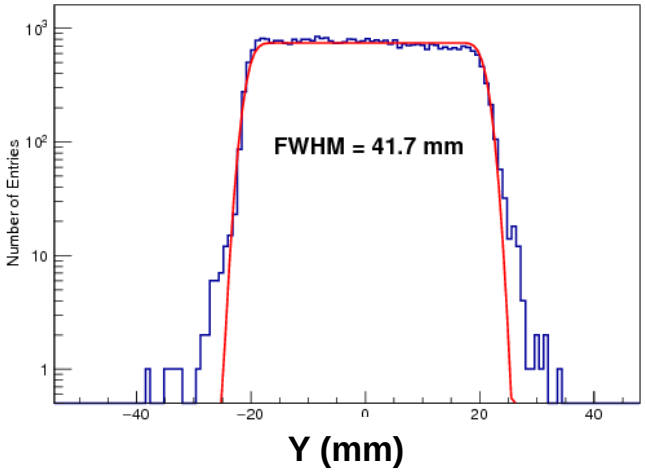
Neutron beam profile

- The beam has a conical shape :
  - r=21 mm at 5 m downstream from the collimator
  - r=28 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







1. The NFS facility
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3. First experiments

PAC 2020 to 2022

- NFS accepted experiments

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
E832	Deuteron activation of natMo - focus on short-lived products	E. Simeckova, NPI, Rez	4
E833	Pygmy dipole resonance in 140Ce using the (n,n'g) reaction at NFS	M. Vandebrouck, CEA Saclay	23
E835	Measurement of the neutron induced activation in materials	V. Blieanu, CEA Saclay	3
E838	Shedding new light on the structure of 56Ni using (n,3n) reaction at NFS	E. Clément, Ganil	22
E856	Study of neutron induced reactions on 239Pu	G. Bélier, CEA-DAM	42
E858	GARROS - Gas production in iron by neutrons	A. Prokofiev, Uppsala University	22
E859	238U(n, 2ng) and (n, 3ng) reaction cross sections measurements	M. Kerveno, IPHC, Strasbiurg	31

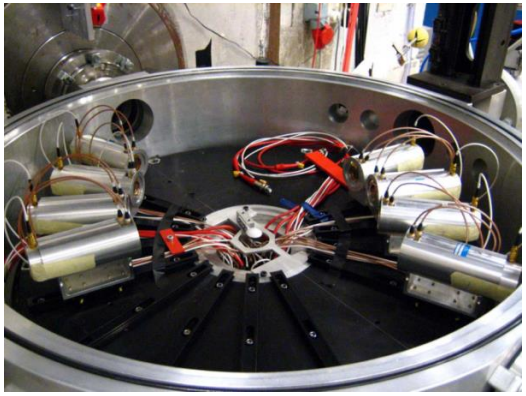
1 UT = 8h

E800: Ion Production Studies with Medley at the NFS facility

Spokesperson : D. Tario, Uppsala University

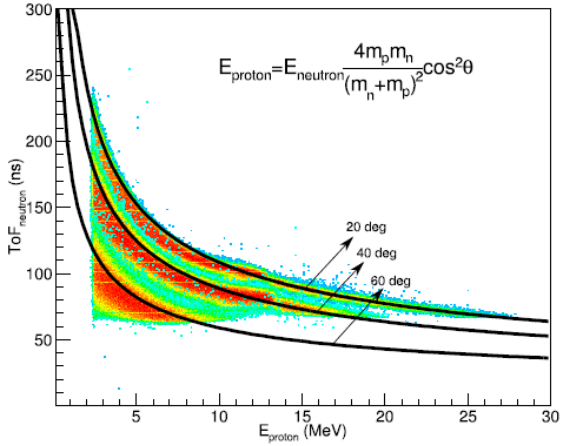
- **Neutron-Induced Light charged particles emission with MEDLEY**
  - 8 **Si-Si-CsI** telescopes
  - Double-differential **cross sections** :
  - **Cancer therapy and dosimetry** (H,C,O, Ca...)
  - **Radiation effects** in microelectronics (Si, O)
  - Energy applications: **Gen-IV or fusion reactors**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

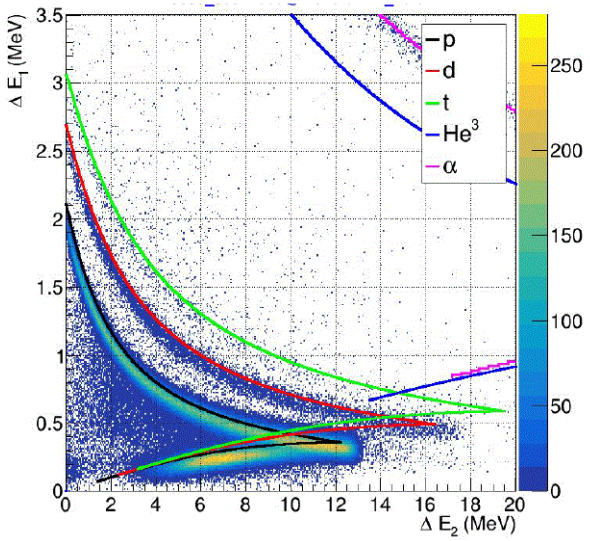
- **Experiment performed in fall 2021 and 2022**
  - High **particle-identification capability**
  - Simultaneous measurement of **charged-particles energy and neutron ToF** (digital



Accepted experiments with MEDLEY

- **LIONS (Light ION production Studies with Medley) - 21/22**
- **GARIC (GAs pRoduction In Chromium by neutrons) - 22/23**
- **GARROS (Gas pRoduction in iROn by neutronS) -**
- **FISHES (FISsion versus Hydrogen Elastic Scattering)**





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

Spokesperson : E. Simeckova, NPI, Rez

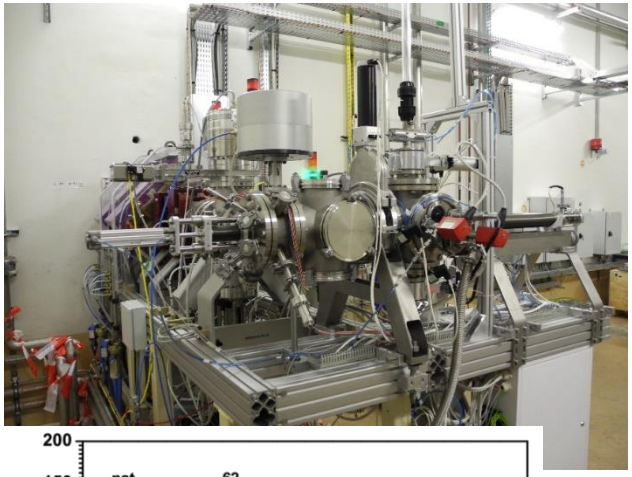
Measurement of reaction cross-sections by activation technique :

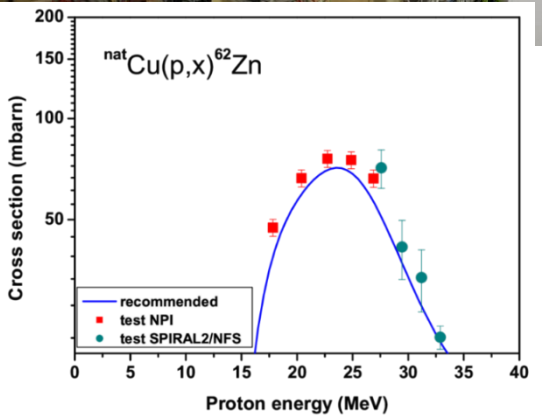
- data for IFMIF facility design
- improvement of reaction model

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

Commissioning : Irradiation station tested in December 2019

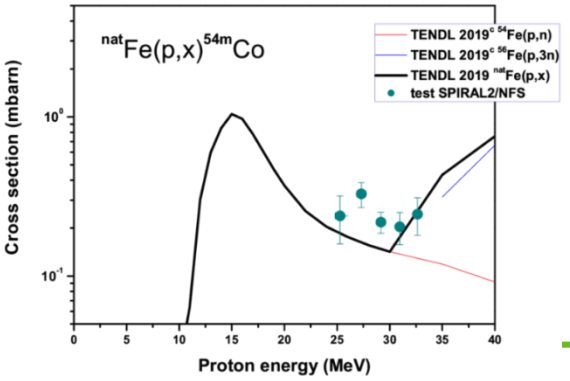
- **33 MeV proton** beam
- **80 nA** beam intensity
- **Fe and Cu samples** irradiated





● 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**



Experiment E799 performed in October 2021

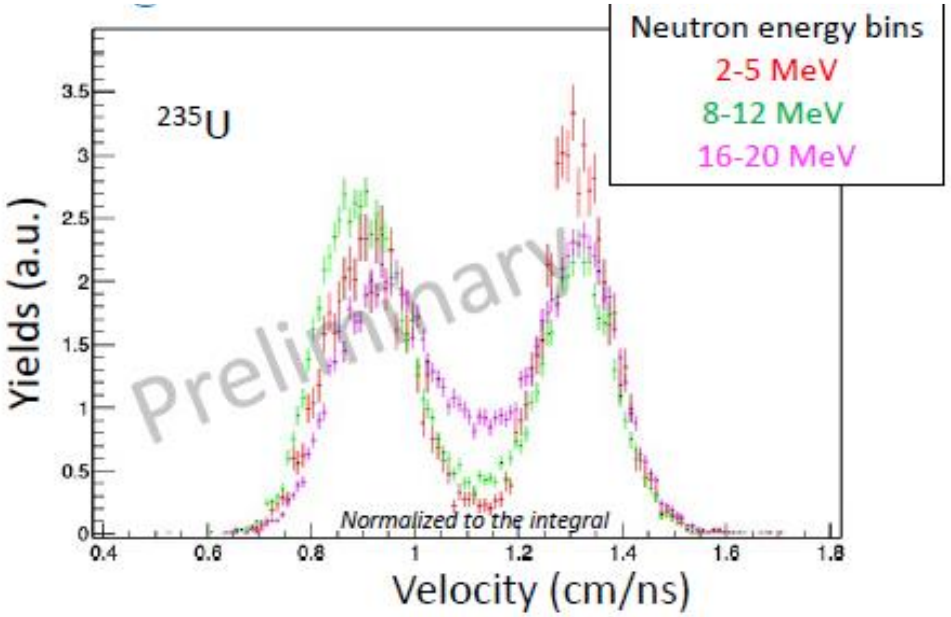
Following experiment E832 : "Deuteron activation of natMo - focus on short-lived products" performed in October 2022

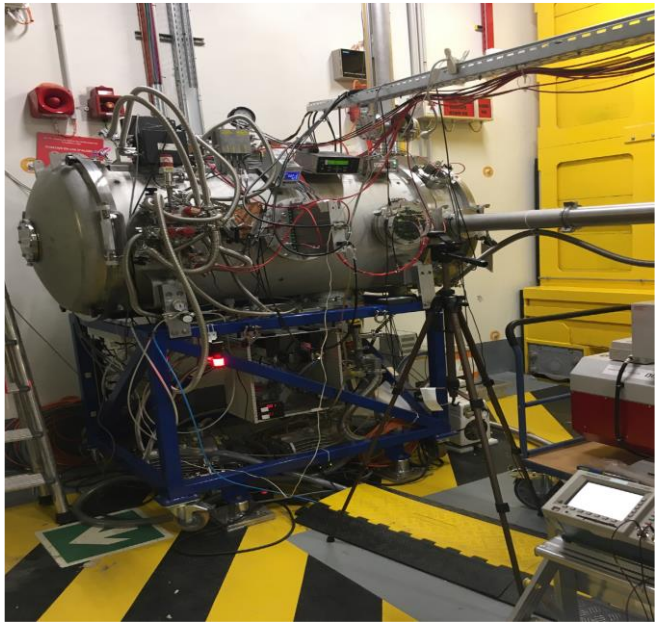
E814: ^{235}U Fission fragment study with FALSTAFF at NFS

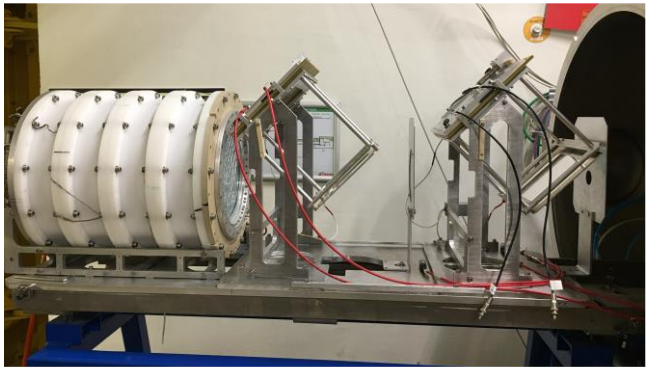
Spokesperson : D. Doré, CEA-IRFU

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







(n, 2-3nγ) cross sections measurements @ SPIRAL2/NFS

Spokesperson : M. Kerveno, IPHC Strasbourg

Study of (n, 2-3n γ) reactions @SPIRAL2/NFS

PAC 2021

LoI-9 :
Check the feasibility of the prompt γ-ray spectroscopy method at 30 m from the neutron source.

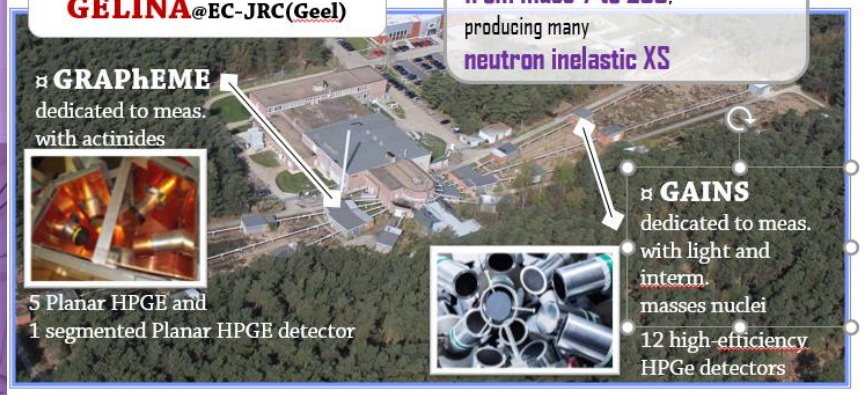
Questions :
- How well is the beam defined at 30 m (after the second collimation)?
- How are the backgrounds (n & γ) conditions?
- How to deal with low γ-flash for tof measurement in the Fission Chamber?

	09/2021	11/2022
Detectors	3 HPGe	3 HPGe, Fission chamber (3 ^{238}U), 1 LaBr3
Acquisition syst.	FASTER	FASTER
sample	^{nat}W @ 28.936 m Thick. =0.2 mm, m=41.2 g	^{nat}W @ 29.2 m Thick. =0.2 mm, m=41.2 g
Beam d + Be	~16μA ; E_d = 40 MeV; F=440 ; 220 kHz	~7.5 μA ; E_d = 40 MeV; F=880 ; 440; 220 kHz (Be target fixed)
effective UT	~1	~25 (11 parasitic mode @220 kHz)

Collaboration IPHC/CNRS (Fr) – EC-JRC Geel (Be)– IFIN-HH (Ro)
has developed two germanium arrays at EC-JRC-GELINA
for (n,xn γ) cross sections measurements
using the **prompt γ-ray spectroscopy method**

Neutron Time of flight facility
GELINA@EC-JRC(Geel)

30 nuclei for nuclear reactor interest **from mass 7 to 238**,
producing many
neutron inelastic XS



Conclusions :

- Beam size and halo as expected (following MCNP simulations) ✓
- Special care has to taken when (re)mounting the second collimator to guarantee the alignment !
- No major problem identified with background at this stage of th analysis. ✓
- tof measurements possible with HPGe ✓
- For tof measurement with FC, special care must be taken for the calibration of the time spectrum, but possible. Additional work is needed to confirm the neutron flux. !

GANIL spiral2

PAC 2022
December 8th, 2022 (remotly)

E859_22

^{238}U(n, 2nγ) and (n, 3nγ) reaction cross sections measurements

Spokesperson: **Maëlle Kerveno**
E-mail: maelle.kerveno@iphc.cnrs.fr
Co-spokesperson : Greg Henning

ACCEPTED

Collaboration:
IPHC, Strasbourg : Ph. Dessagne, G. Henning, M. Kerveno, N. Dari Bako
EC-JRC/Geel : A. Plompen, C. Paradela, A. Oprea
IFIN-HH Bucharest : C. Borcea, M. Boromiza, A. Negret, A. Olacel
ESRIG, University of Groningen : N. Kalantar, M. Kavatsyuk
CEA/DAM, Bruyeres le Chatel : M. Dupuis

Pygmy dipole resonance (PDR) in 140Ce using the (n,n'γ) reaction at SPIRAL2-NFS

Spokespersons: Marine VANDEBROUCK (CEA Saclay Irfu/DPhN) and Iolanda MATEA (IJCLab)

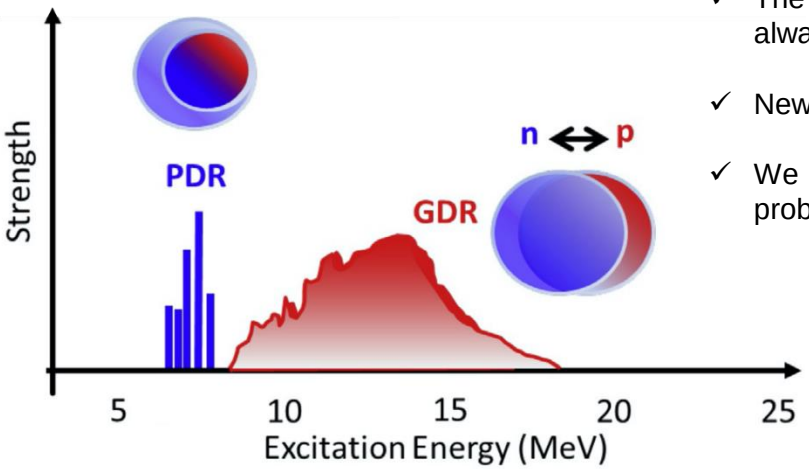
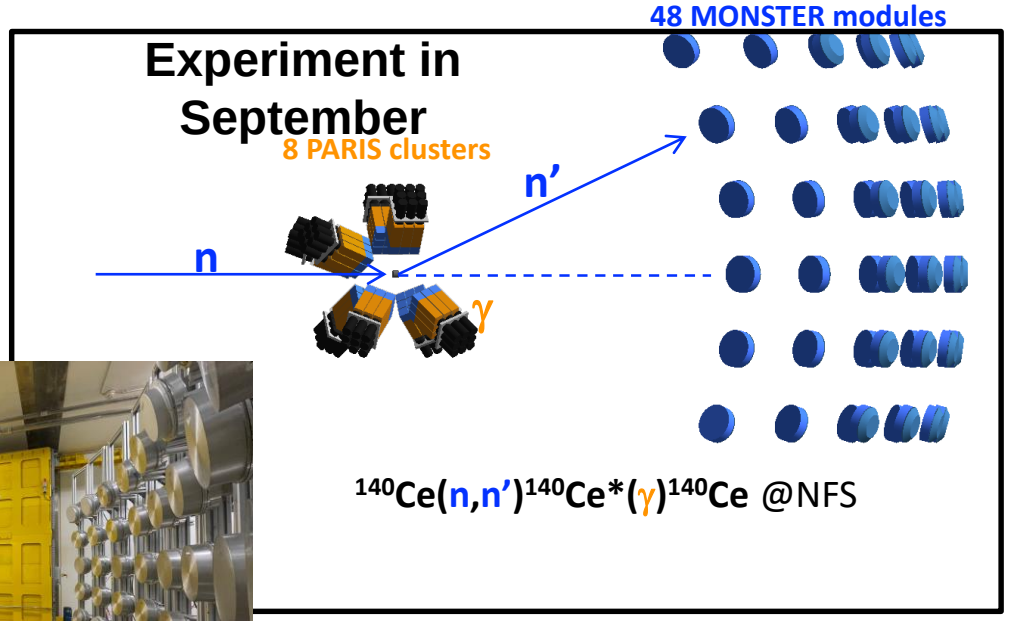


Figure extracted from A. Bracco *et al.* Prog. Part. Nucl. Phys. 106 (2019)

- ✓ The use of different reactions to excite the PDR showed different responses, not always compatible with the neutron skin picture
- ✓ New probes are necessary to resolve the complexity of the PDR structure
- ✓ We propose to use neutron inelastic scattering reaction at SPIRAL2-NFS as a new probe

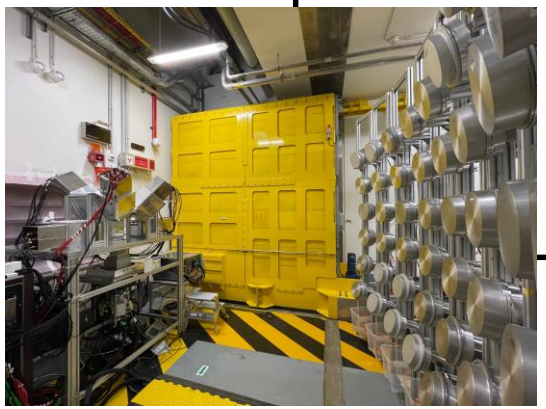


GDR (Giant Dipole Resonance)

- oscillation of neutrons against protons
- exhausts ~ 100% of the dipole strength

PDR (Pygmy Dipole Resonance)

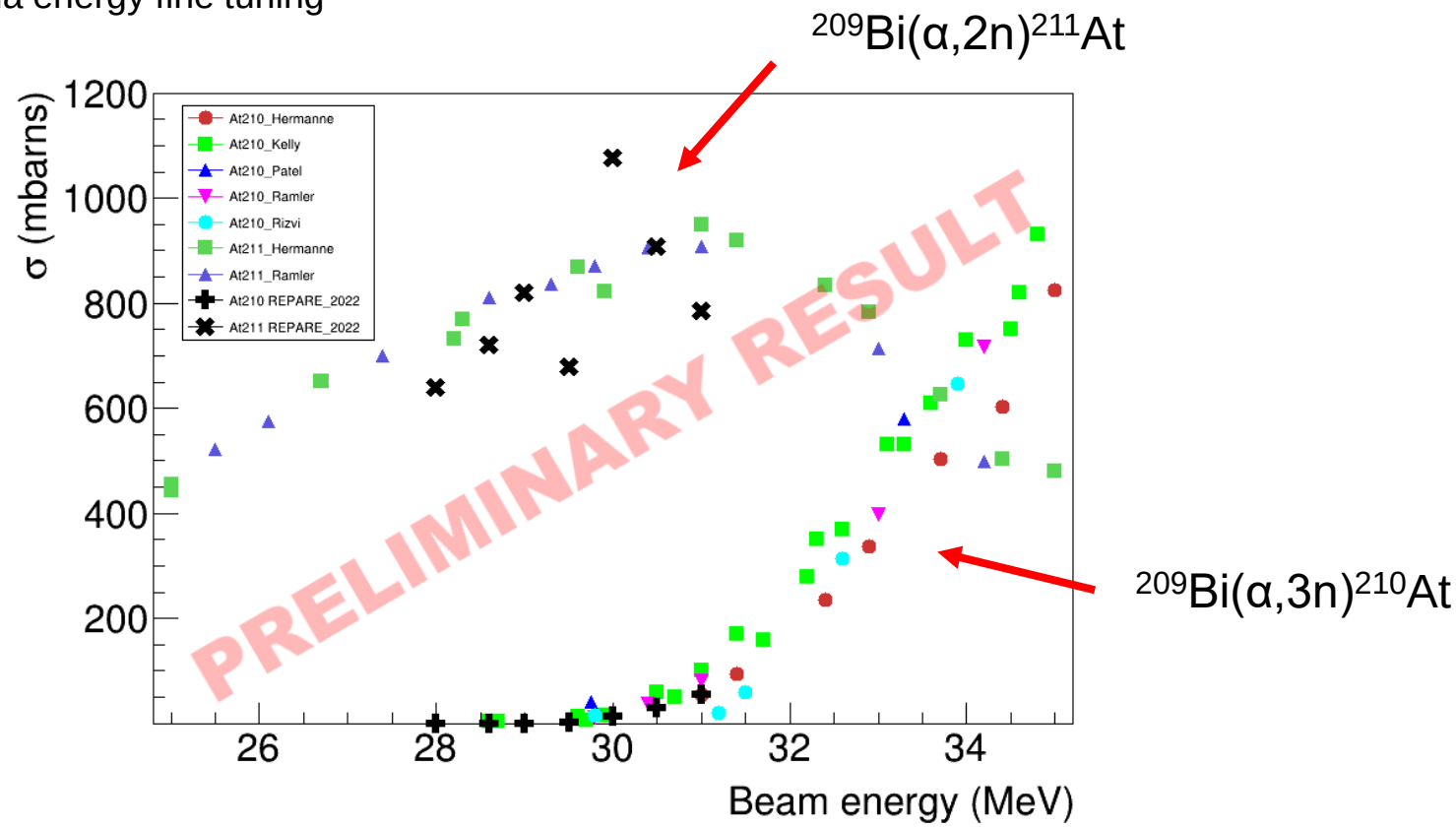
- oscillation of a neutron skin against a symmetric proton/neutron core
- small additional dipole strength at lower energy



$^{209}Bi(\alpha,3n)^{210}At$ excitation function

Goal: produce ^{211}At (α emitter, $T_{1/2}$ = 7.2 h) by $^{209}Bi(\alpha,2n)$ and minimize the production of ^{210}At

- $^{209}Bi(\alpha,3n)^{210}At$ excitation function close to the energy threshold
- Irradiation station + pneumatic transfer system
- Alpha energy fine tuning



Summary

- Neutrons for Science is now operational

- 7 Experiments and 3 tests have already been performed
  - Lcp particle production
  - Fission process
  - n,xnγ reactions
  - P and d induced reaction cross-section measurements

- Everyone can propose an experiment
  - 1 PAC session per year: next PAC in November
  - GANIL web site “proposing an experiment” and contact me

- NFS is in the European Projects (Transnational Access):
  - ARIEL
  - RADNEXT