SPIRAL-2 FOR NEUTRON PRODUCTION

X. Ledoux and the NFS collaboration

Outline

- The SPIRAL-2 facility
- The Neutrons For Science Facility

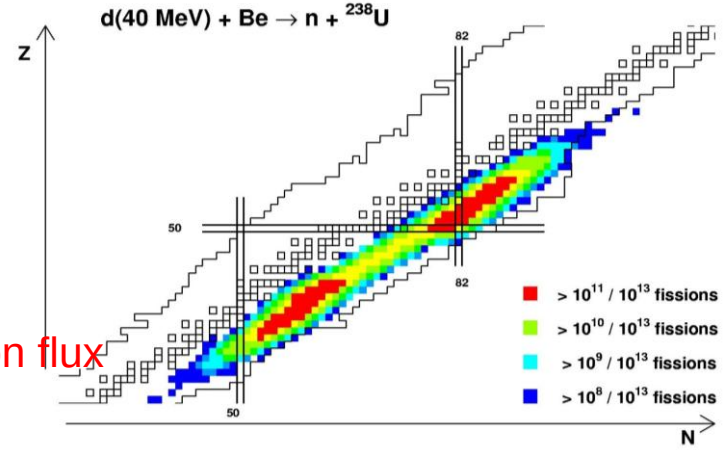
OUTLINE

- SPIRAL-2
- The Neutrons For Science facility

The SPIRAL-2 project

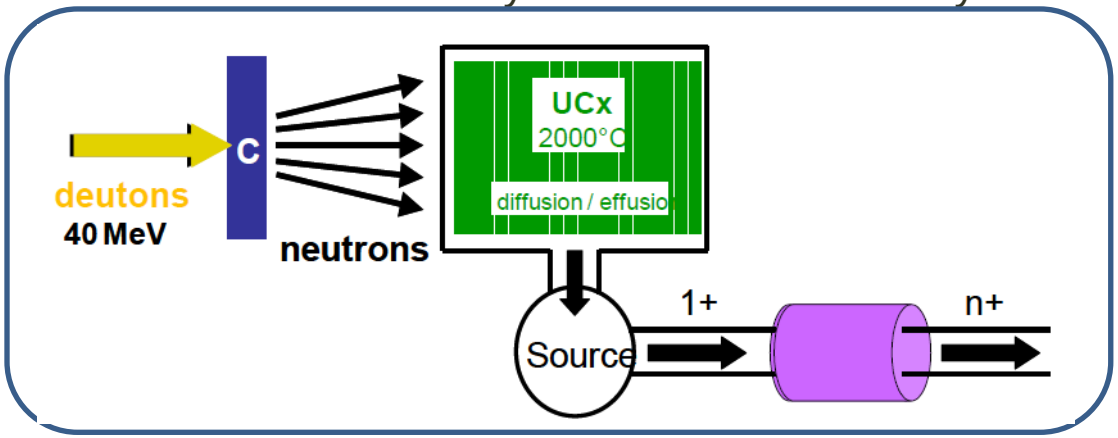
Main objectives:

- Increasing the RIB production by a factor 10 to 1000
- Extend the range of beams nuclei Z>40 A>80



Technique :

- Primary beam of high intensity to produce high neutron flux
- Neutron induced fission of 238U
- UCx target
- Post-Acceleration of secondary beam with the CIME cyclotron



Linear accelerator: p and d up to 5mA, HI up to 14,5 MeV/A

Neutron production reactions

Goal for RIB : 5.10^{13} fissions/s

- 2,3 kg of ^{238}Uranium in an Uranium Carbide target
- Neutron production : 40 MeV d + Carbon

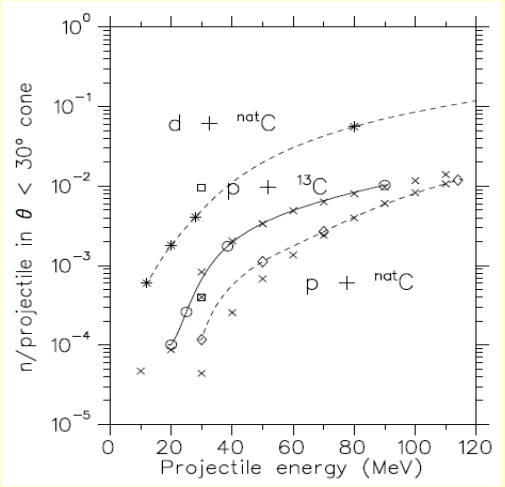
Deuteron is more efficient than proton

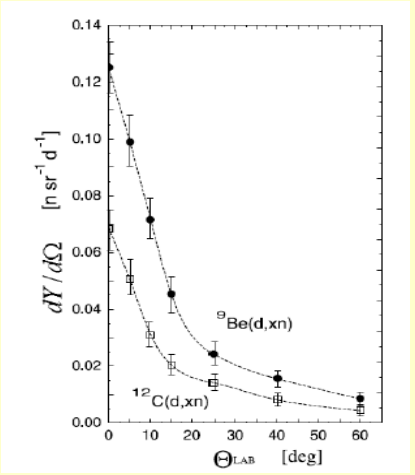
Neutron yield :

- increases with the projectile energy
- peaked at forward angle

Several converters can be used :

- Lithium : liquid target
- D2O : tritium production, radiolyse
- Be : Chemical toxicity
- C : High melting point

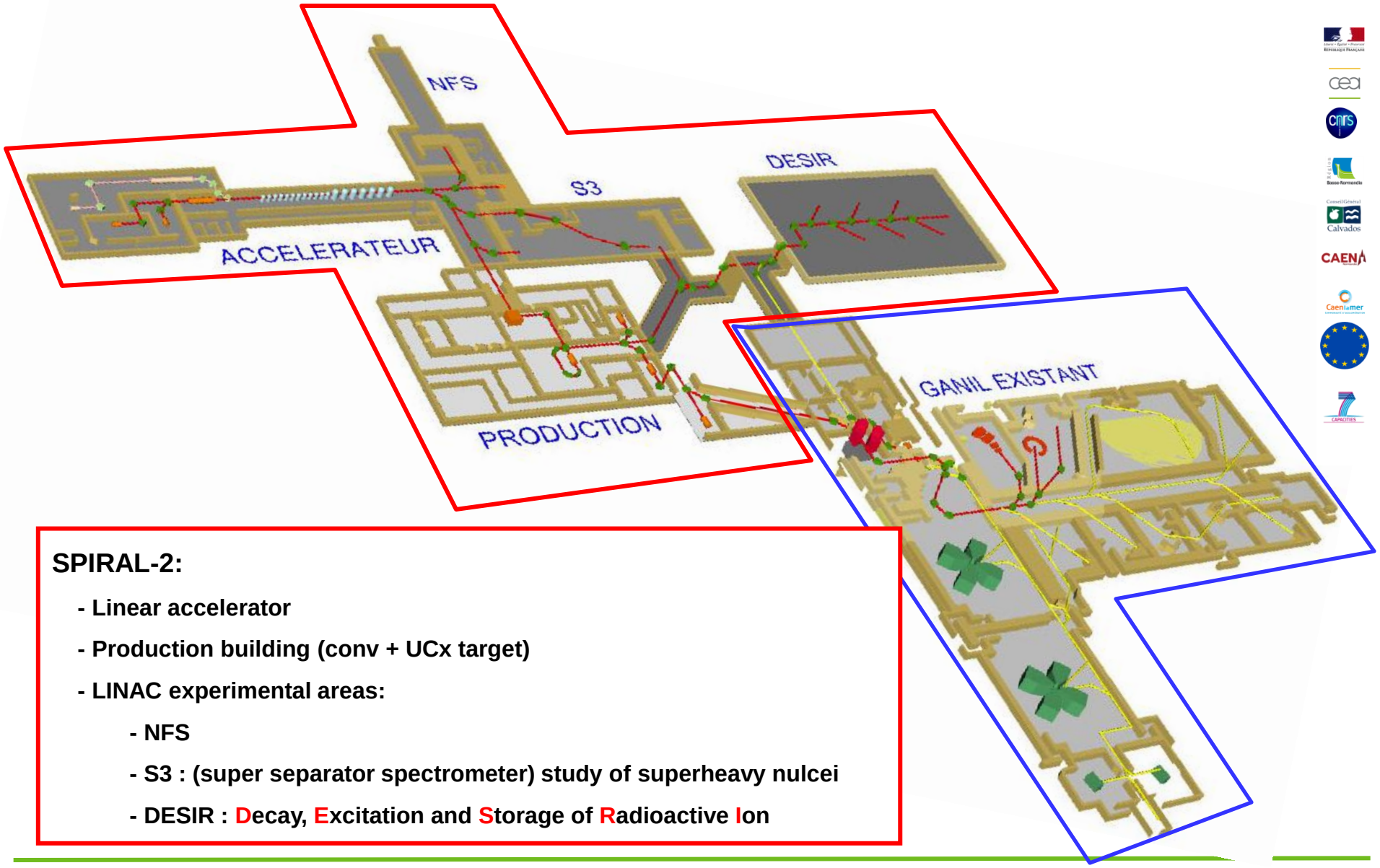




SPIRAL-2 phase 2 :

- High intensity deuteron beam I=5mA, E=40 MeV → 200kW
- Carbon converter on rotating wheel

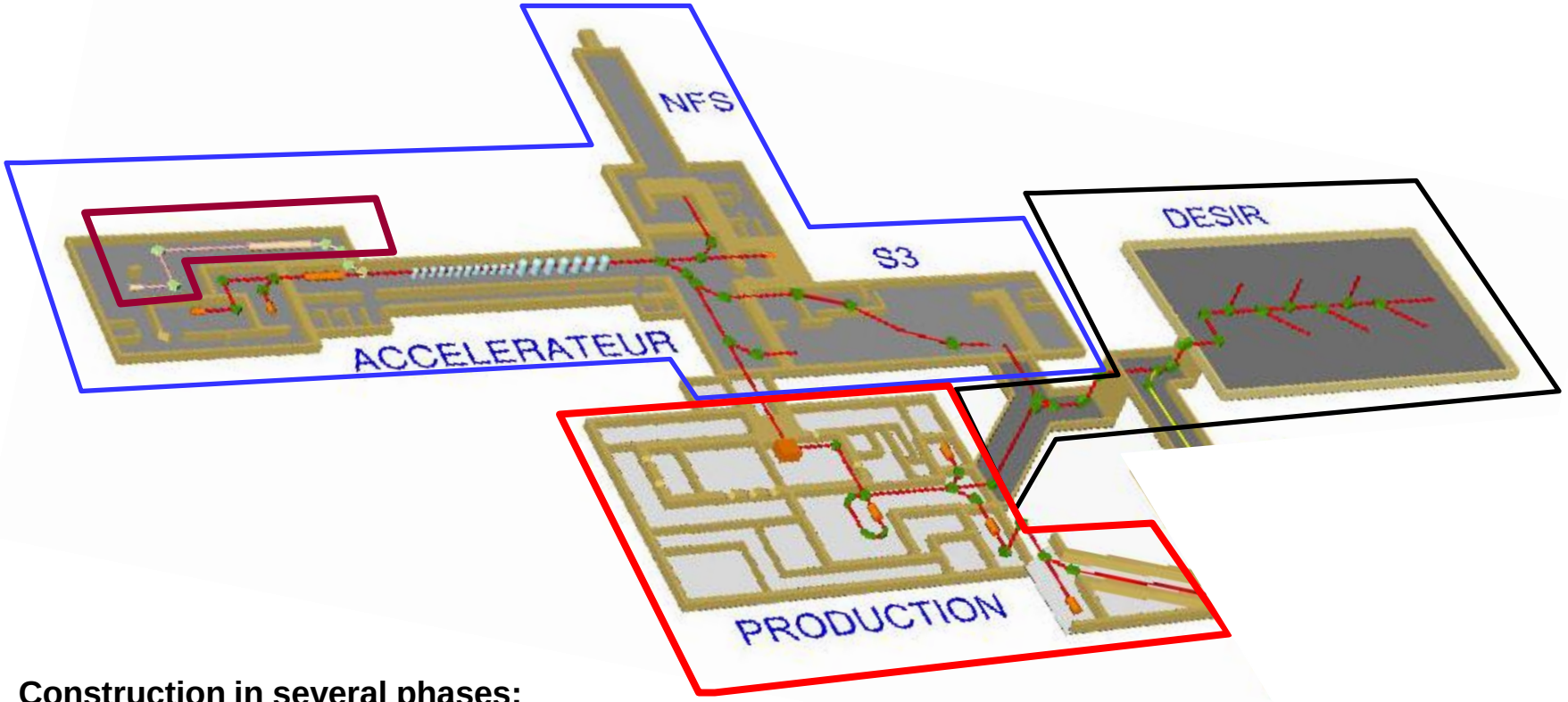
GANIL/SPIRAL 2 facility



SPIRAL-2:

- **Linear accelerator**
- **Production building (conv + UCx target)**
- **LINAC experimental areas:**
  - **NFS**
  - **S3 : (super separator spectrometer) study of superheavy nulcei**
  - **DESIR : Decay, Excitation and Storage of Radioactive Ion**

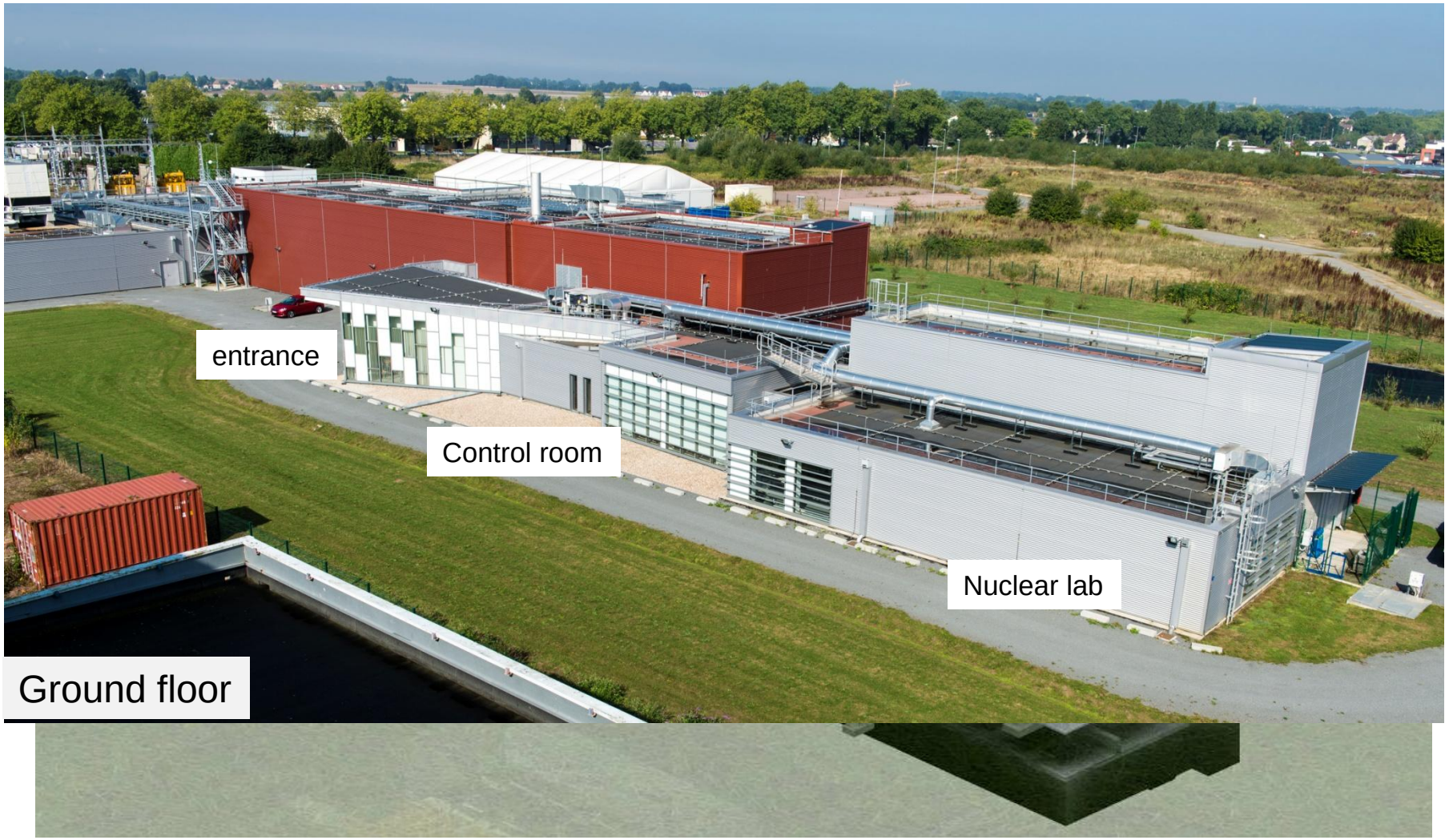
SPIRAL 2 construction phases



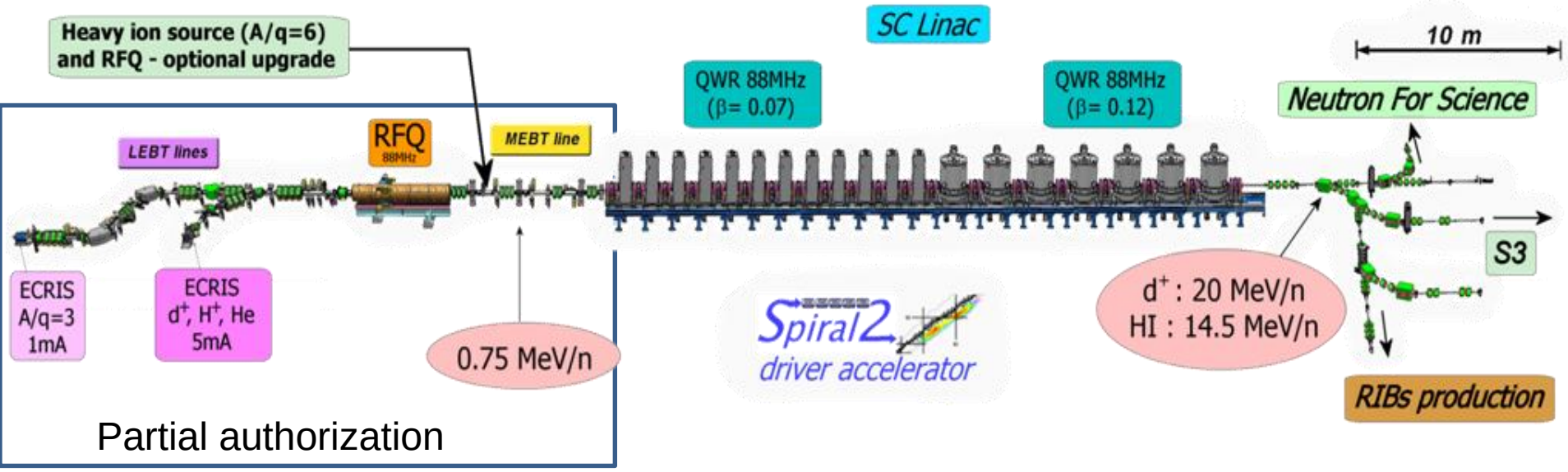
Construction in several phases:

Phase 1 : LINAC + NFS + S3	**Built**
Phase 1+ : DESIR	**Funded, call for tender for construction**
Phase 1++ : RFQ Q/A = 1/7	**Not yet funded**
Phase 2: Production building	**Standby**

SPIRAL-2 phase 1 building



The Linear Accelerator

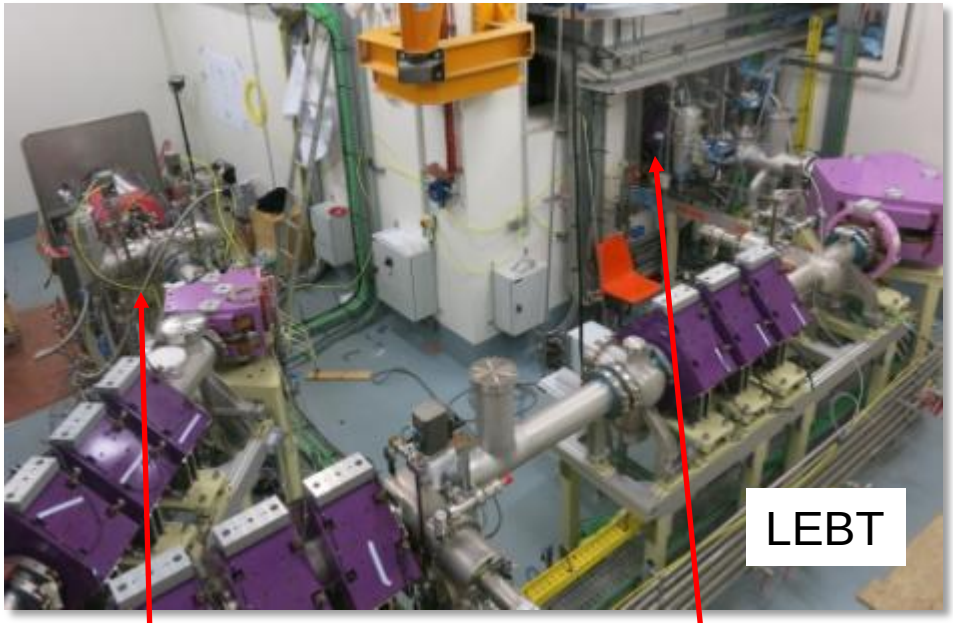


Total length: 65 m (without HE lines)
Slow (LEBT) and Fast Chopper (MEBT) RFQ (1/1, 1/2, 1/3) & 3 re-bunchers
12 QWR beta 0.07 (12 cryomodules) 14 (+2) QWR beta 0.12 (7+1 cryomodules) 1.1 kW Helium Liquifier (4.5 K) Room Temperature Quadrupoles Solid State RF amplifiers (10 & 20 KW)

RFQ frequency F = 88MHz

	Q/A	I (mA)	Energy (Mev/u)	CW max beam Power (KW)
Protons	1/1	5	2 - 33	165
Deuterons	1/2	5	2 - 20	200
Ions	1/3	1	2 - 14.5	45
Ions (option)	*1/6*	*1*	*2 - 8*	*48*

Sources and LEBT and RFQ



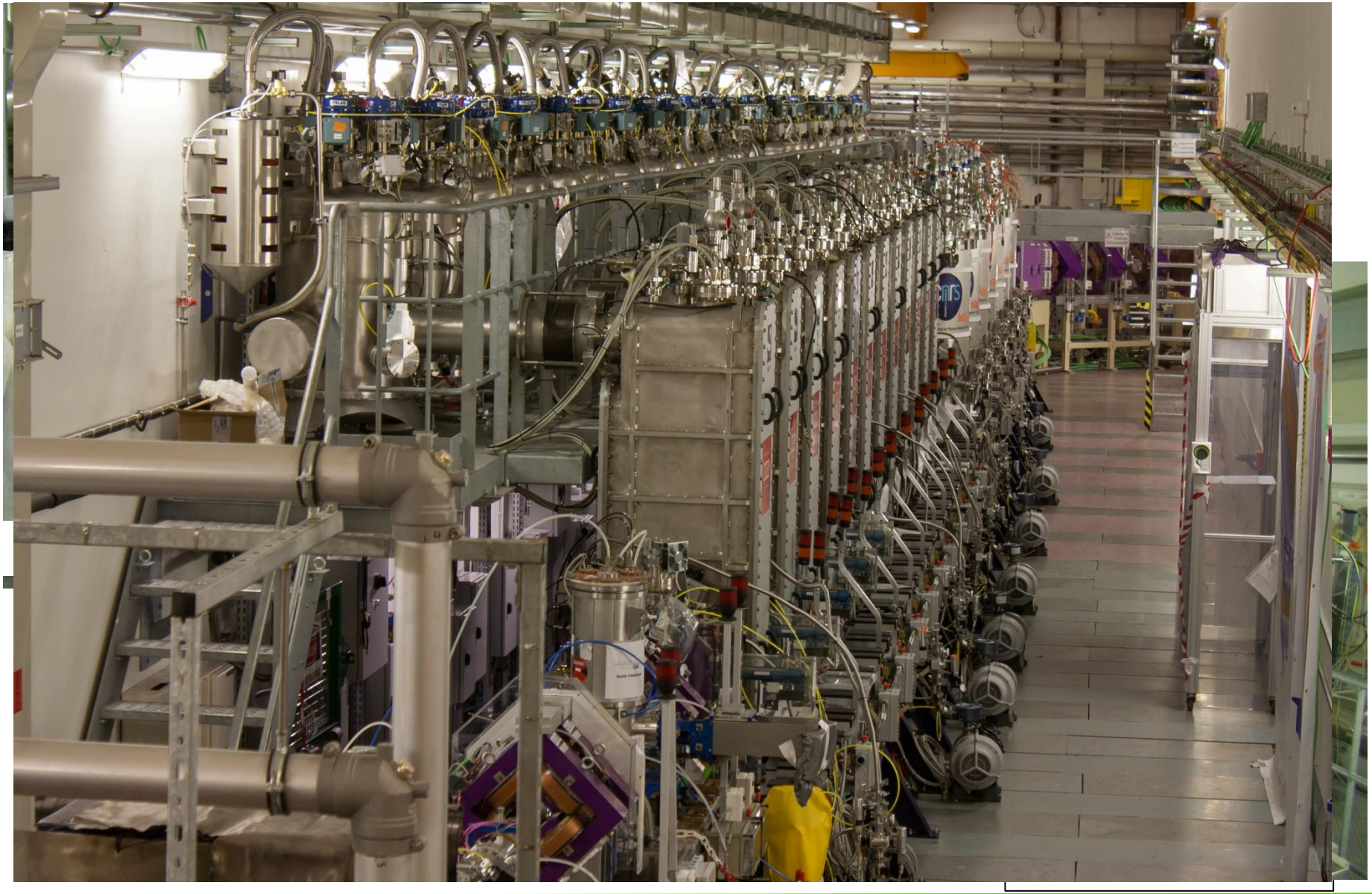
ECRIS A/Q=3
First beam (230 μA Argon 9+) July 10, 2015

ECRIS A/Q=2
First beam (2mA H^+) Dec. 19th, 2014

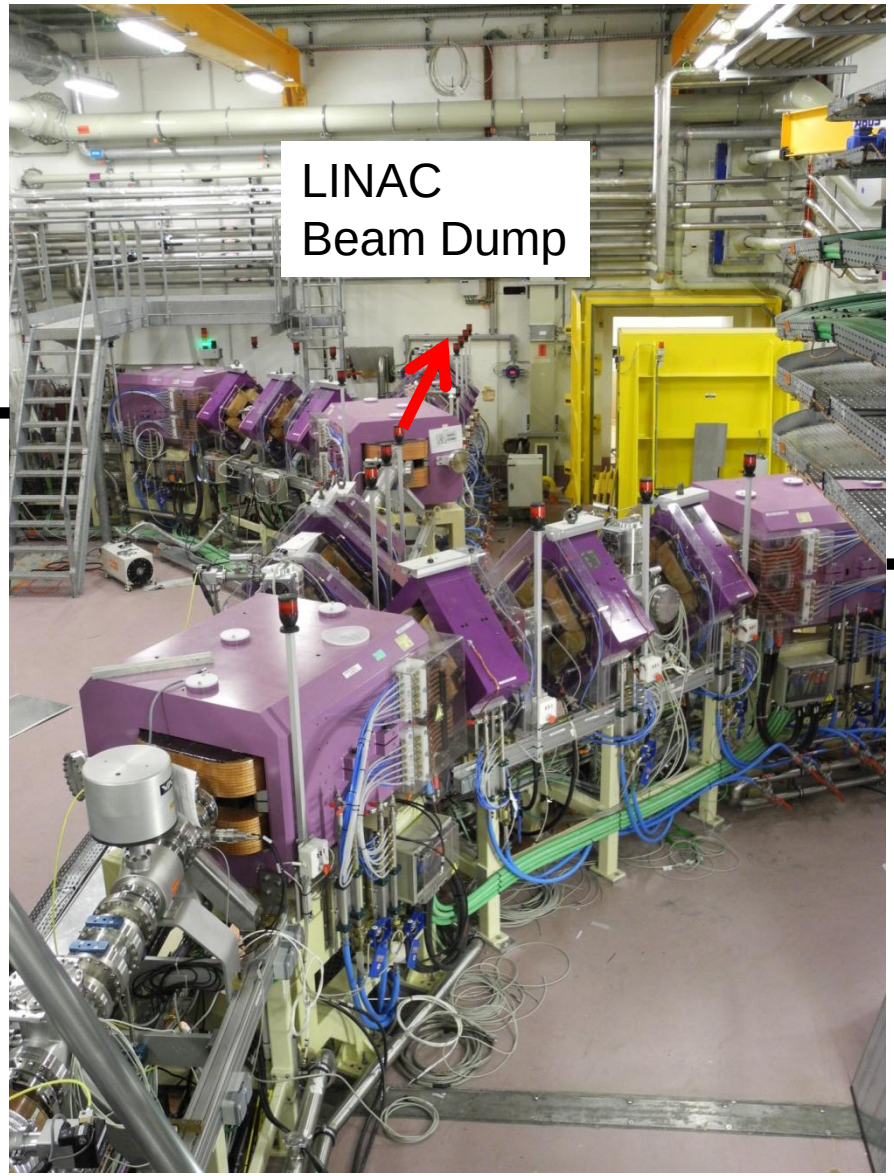
RFQ: First beam (H+) Dec 3rd, 2015

RFQ Commissioning with beam :
- **A/Q=1 (protons) with 5 mAe CW**
- **A/Q=2 ($^4He^{2+}$) with 1,3 mAe CW**
- **A/Q=3 ($^{18}O^{6+}$) with 600 µAe**

The LINAC



High Energy Beam Line



NFS

To S3 and
Production Building

- SPIRAL-2
- The Neutrons For Science facility

The Neutrons For Science facility

- Pulsed neutron beam
- Continuous spectrum : d + thick converter
- QMN spectra : p + thin converter
- Neutron energy range 1-40 MeV
- Measurements by activation method

- 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

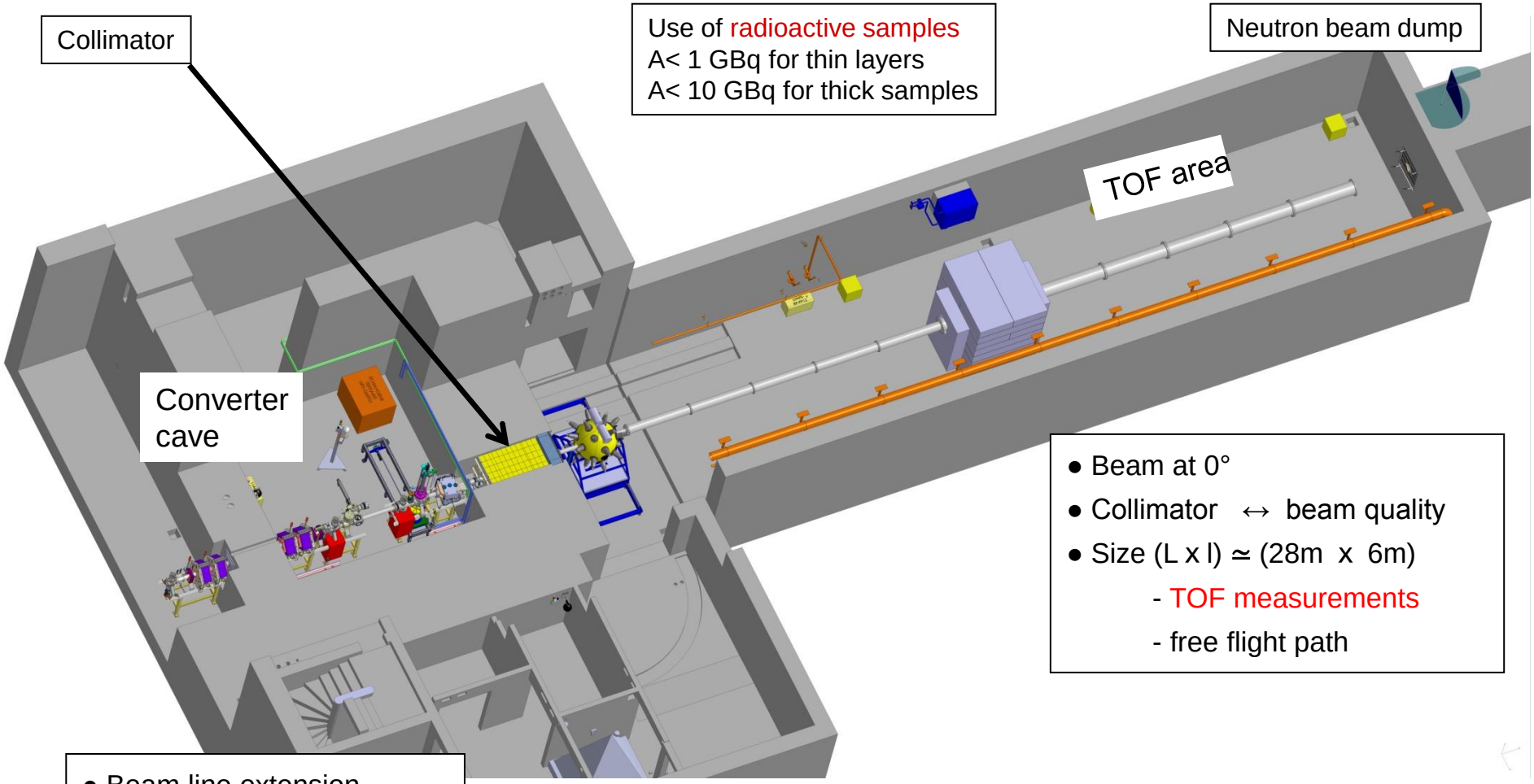
50 physicists

15 laboratories

8 partners

First PAC in 2016, 7 experiments accepted

NFS layout



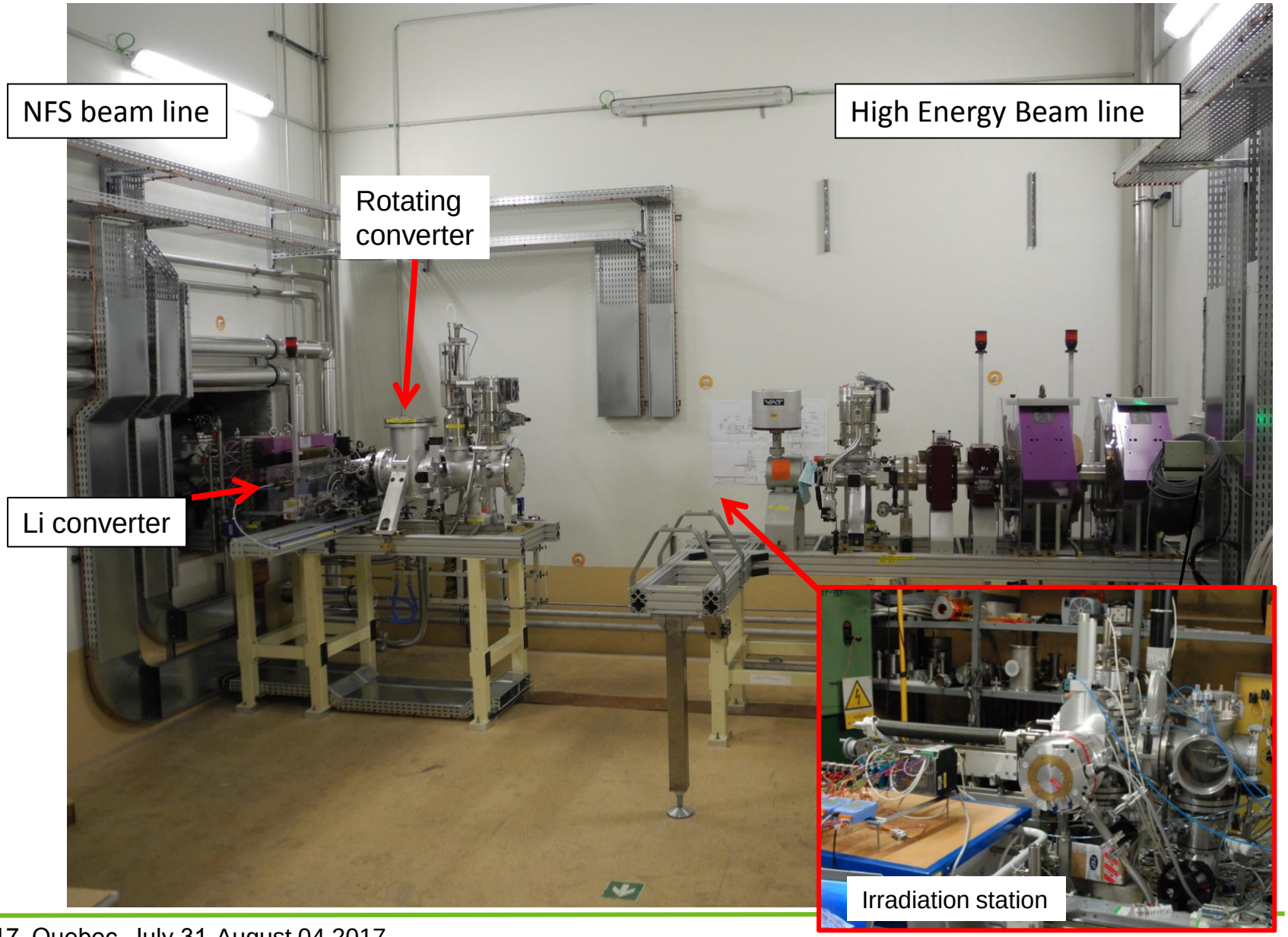
Use of radioactive samples
A< 1 GBq for thin layers
A< 10 GBq for thick samples

Neutron beam dump

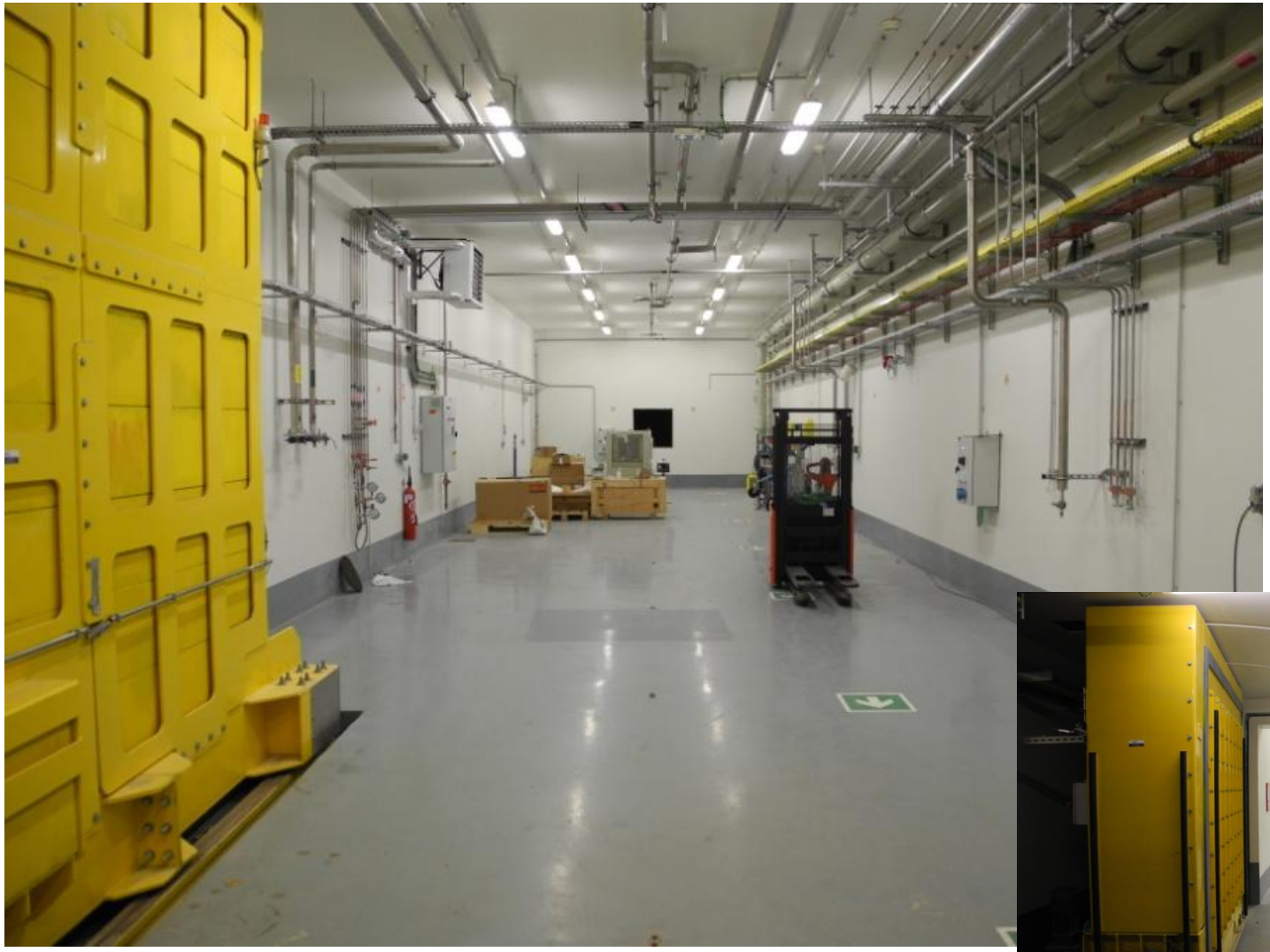
- Beam at 0°
- Collimator ↔ beam quality
- Size (L x l) ≃ (28m x 6m)
  - TOF measurements
  - free flight path

- Beam line extension
- Converter
- Magnet and beam dump
- Irradiation station (n, p, d)

NFS: The converter room

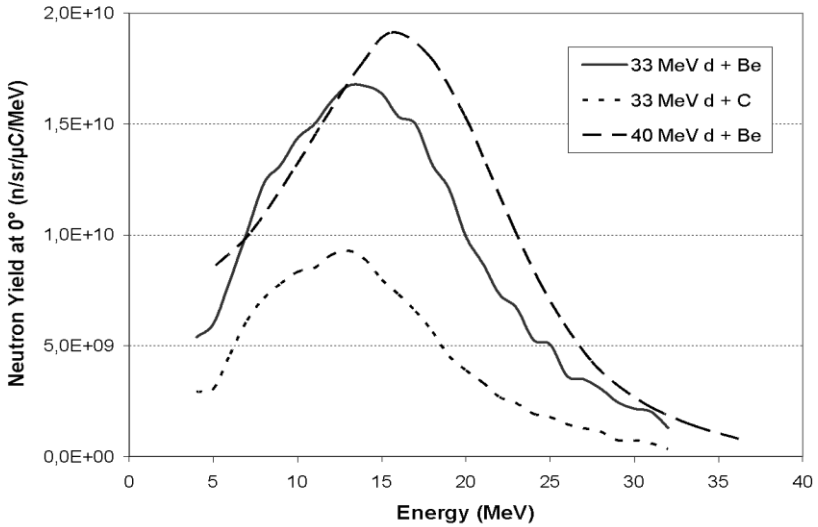


NFS: The TOF area

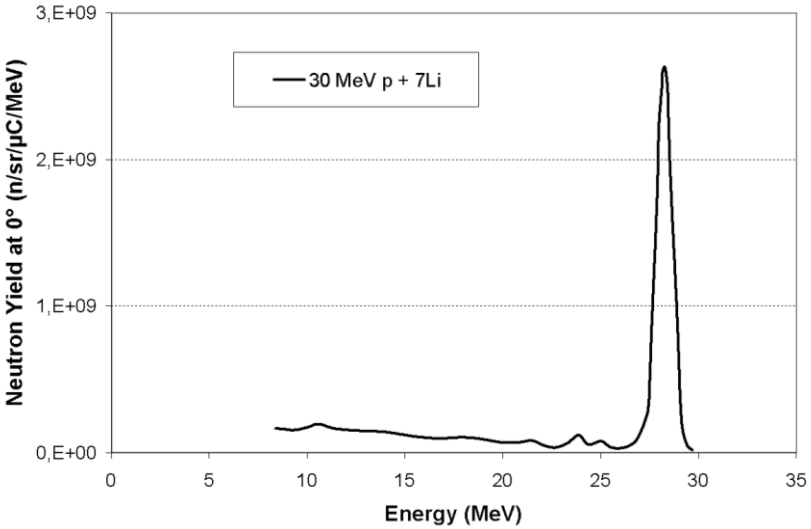


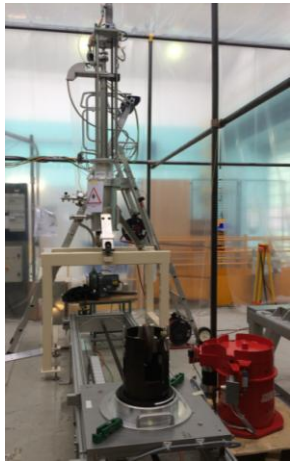
Neutron Spectra

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



Quasi-monoenergetic spectrum
E_n = up to 31 MeV





40 MeV d + Be at 50 µA

Rotating converter

thick target C or B (8mm)

P< 2 kW

p + Li (1mm) at 20 µA

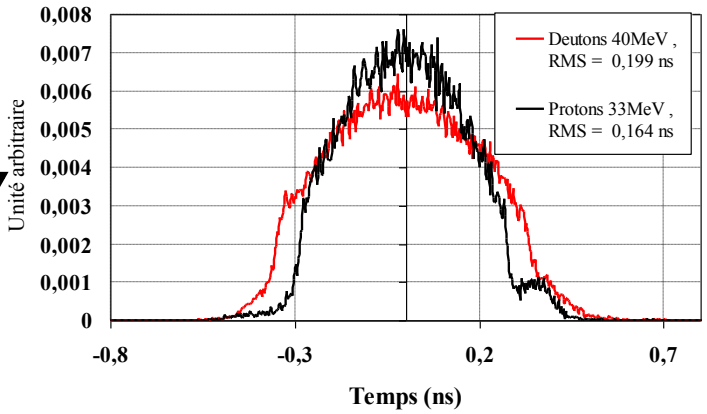
Energy resolution

Neutron energy measured by time-of-flight

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

Time resolution: $$\Delta t = \sqrt{(\Delta t_d)^2 + (\Delta t_b)^2}$$

Profils temporels sur la cible de NFS



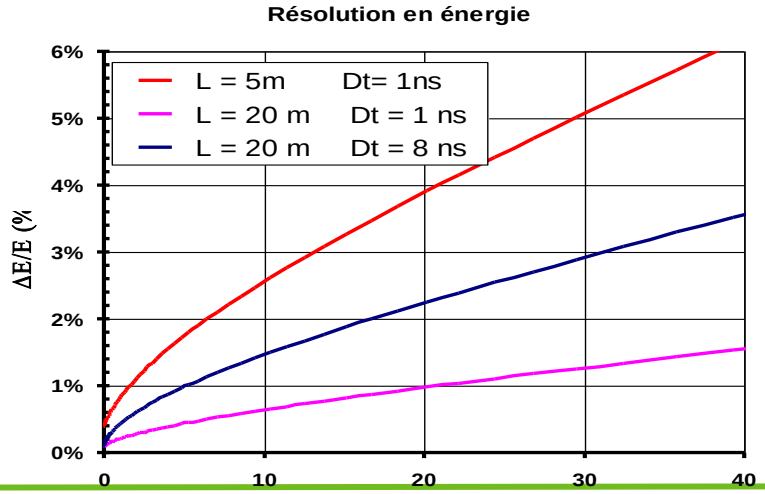
Δt < 1 ns at the converter point

Long flight path
+
good time resolution

Good energy resolution

L = 20 m & Δt = 1 ns ⇒ ΔE/E < 2%

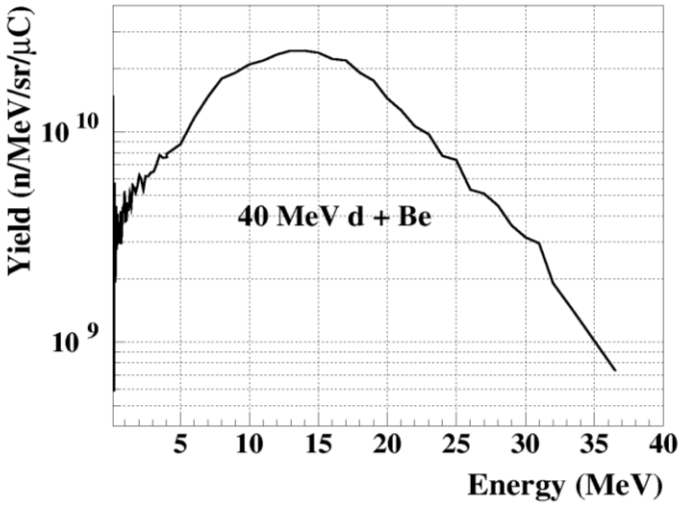
L=20m & HPGe ⇒ ΔE/E < 5%



Contact: xavier.ledoux@cea.fr

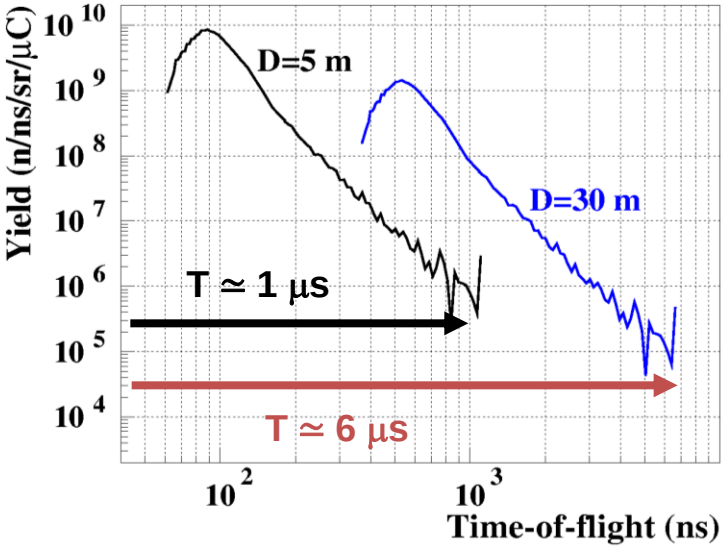
Beam repetition rate

Requirement: differentiation of 2 neutrons with the ToF **t** and **t+T**



F_{LINAG} = 88 MHz

T_{LINAG} = 11 ns



Take only one burst over N (f = F_0/N)

- **Single bunch selector**
- **I = I_{max} / N, with I_{max}= 5mA**

L(m)	E_{th} (MeV)	T(μs)	N	I_{max}(μA)
5	0.1	1	100	50
30	0.1	6	600	8

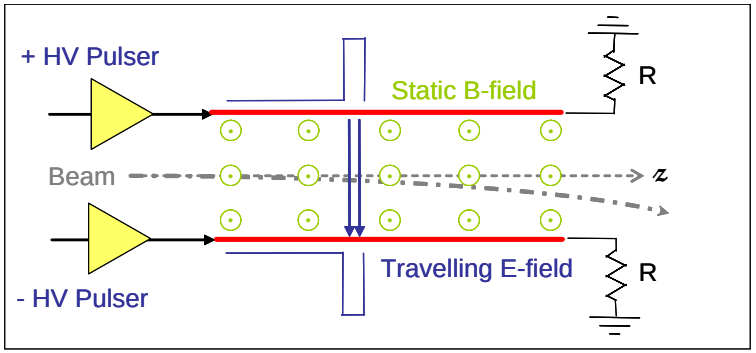
Contact: xavier.ledoux@cea.fr

The single bunch selector

Objective:

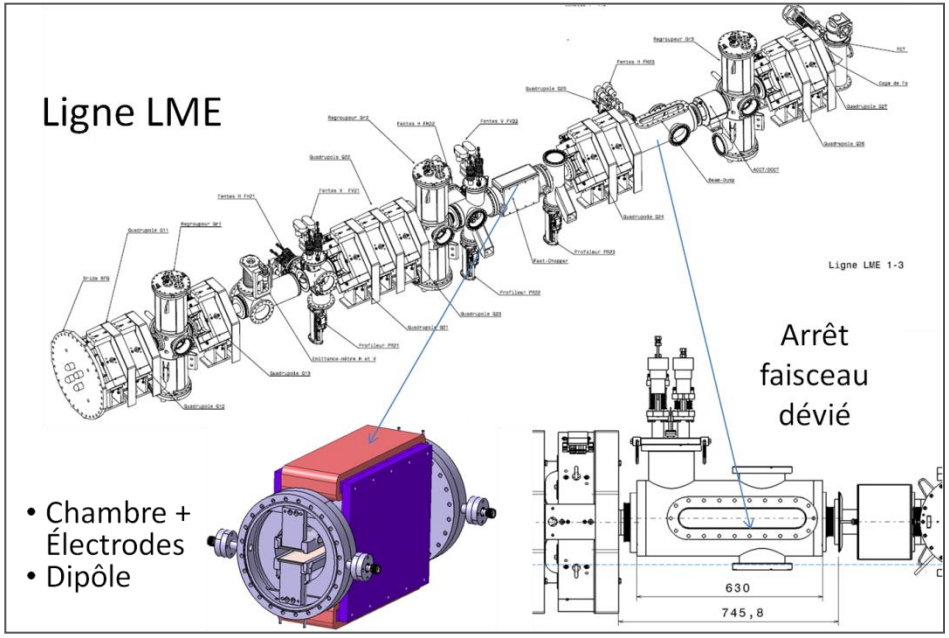
Select 1 bunch over N, N>100 $F_{NFS}=F_{linac}/N$

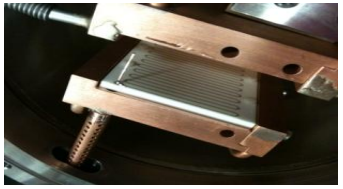
LINAG frequency = 88 MHz -> T=11ns

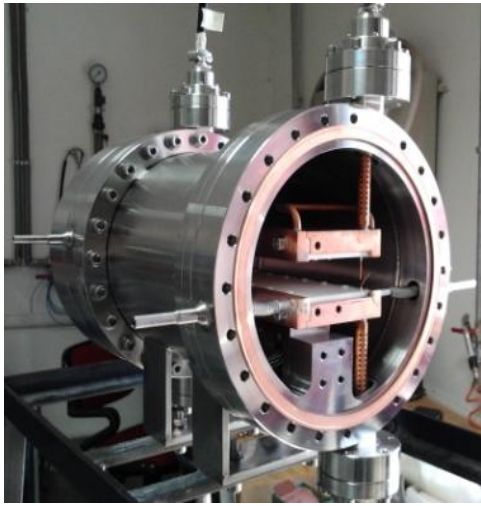


Single bunch selector:

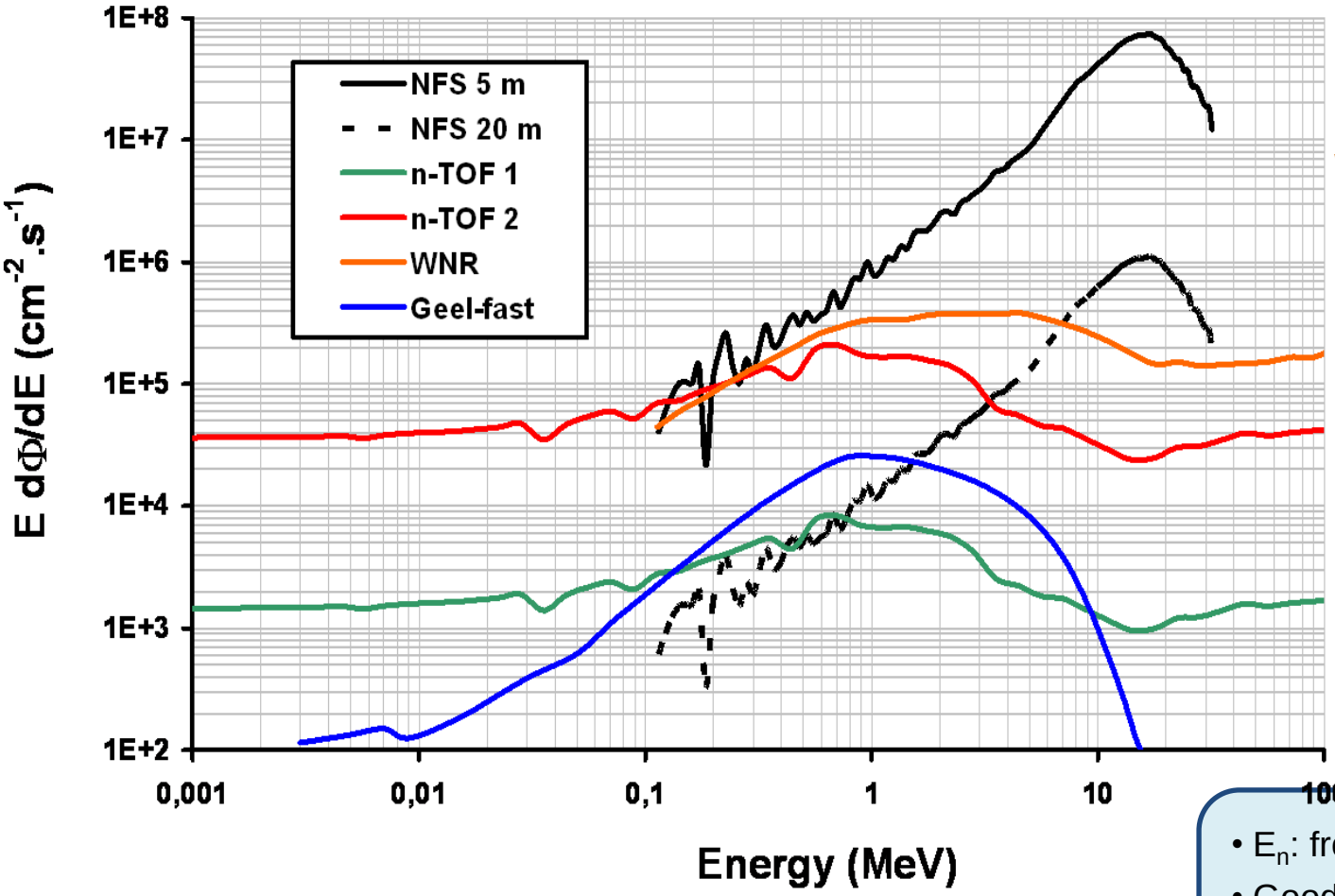
- Middle energy beam line
- Magnet to deflect the beam to a beam dump
-Travelling electric field to deviate one burst over N to the LINAG







Comparison with other Neutron TOF facilities



NFS : 40 MeV d + Be

WNR : Los Alamos

n-TOF 2 : CERN

n-TOF 1 : CERN

GELINA : Geel

- E_n: from 0,1 MeV to 40 MeV
- Good energy resolution
- Reduced γ flash
- Low instantaneous flux

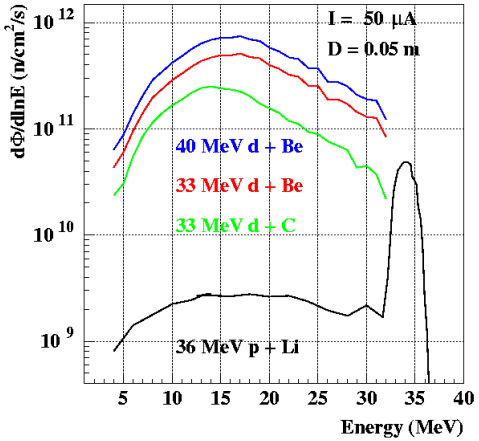
Complementary to the existing facilities

Measurement by activation method

1- Sample irradiation in the converter room

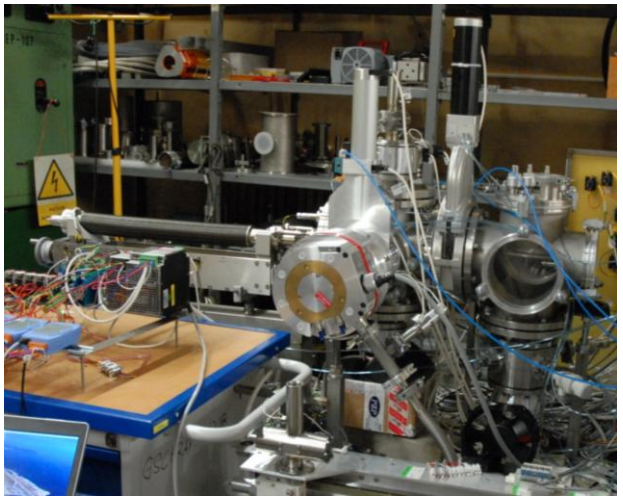
Neutron irradiation

- Spectrum similar to IFMIF
- $\Phi > 10^{11}$ n/s/cm^2

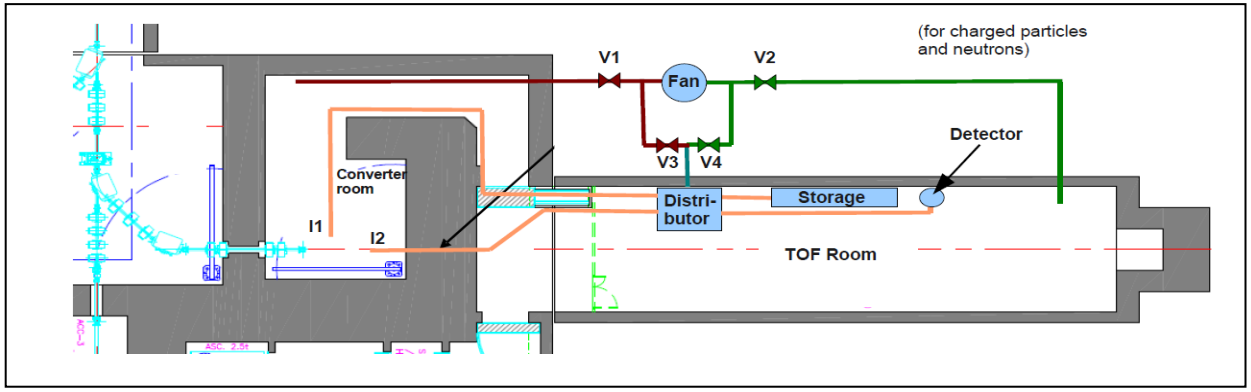


or

ion induced reactions



2- Transfer of sample to TOF room



3- Activity measurement

Cross-section measurements by activation method
Study of radioisotope production

Timeline

- 19th Dec 2014 : First proton beam delivered by the source
- 3th Dec 2015 : First beam accelerated through the RFQ
- 9th of June 2016 : NFS experiments @ GANIL PAC
- Next step : cooling of the LINAC
- Final authorization (deuteron beam + LINAG) expected by end of 2017
- Start of LINAC commissioning
- NFS commissioning : → as soon as the LINAG's beam is available
- First experiment : 2018 - 2019

Summary

SPIRAL-2:

- Phase 1 is built
- H^+, $^4He^{2+}$ and $^{16}O^{8+}$ accelerated in the RFQ
- Proton and deuteron beams of the LINAC are well suited for neutron production

NFS:

- NFS will be a very powerful tool for physics
- White and quasi-monokinetic spectra in the 1- 40 MeV range
- Neutron beams with high flux and good energy resolution
- Complementary to the existing n-tof facilities
- Measurements by activation reactions (n, p, d)