Measurements at NFS

X. Ledoux and the NFS collaboration

Outline

- SPIRAL-2
- The NFS facility
- Measurements at NFS
- Study of the pre-equilibrium process in neutron induced reaction

Neutrons For Science

- **NFS is one of the two facilities of the LINAG Experimental Area**

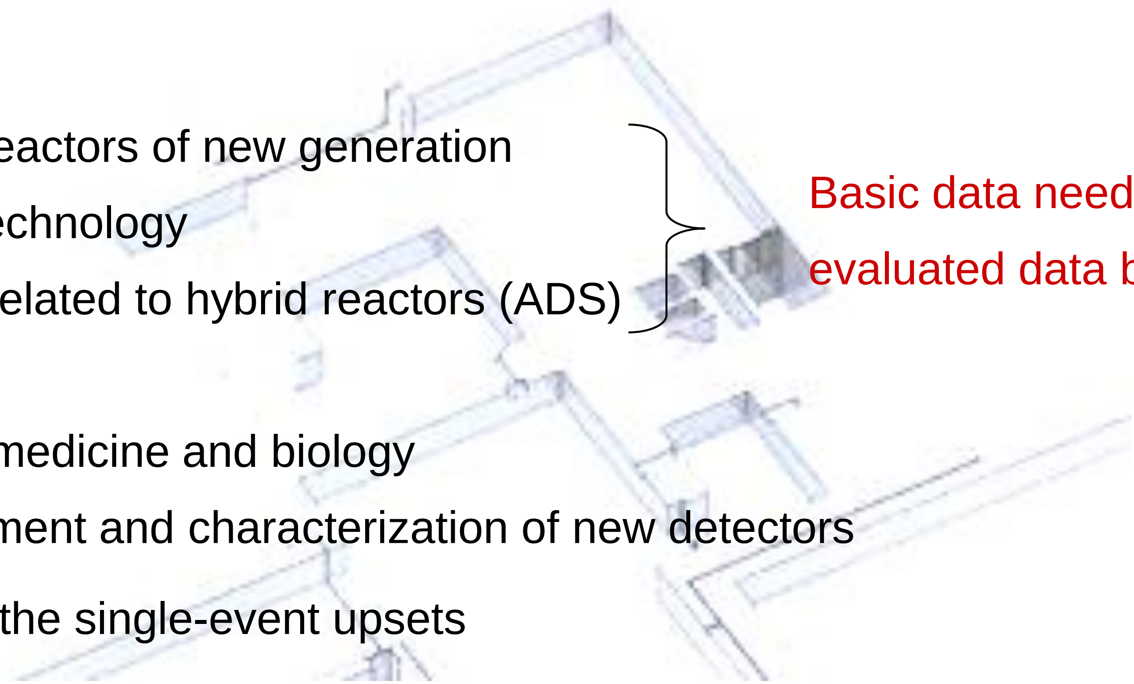
- **Use of the LINAG's beams to produce neutrons between 1 and 40 MeV**

- **The NFS is composed of :**
  - A neutron beam in a Time-Of-Flight area
  - An irradiation box (p, d , HI and n induced reactions)

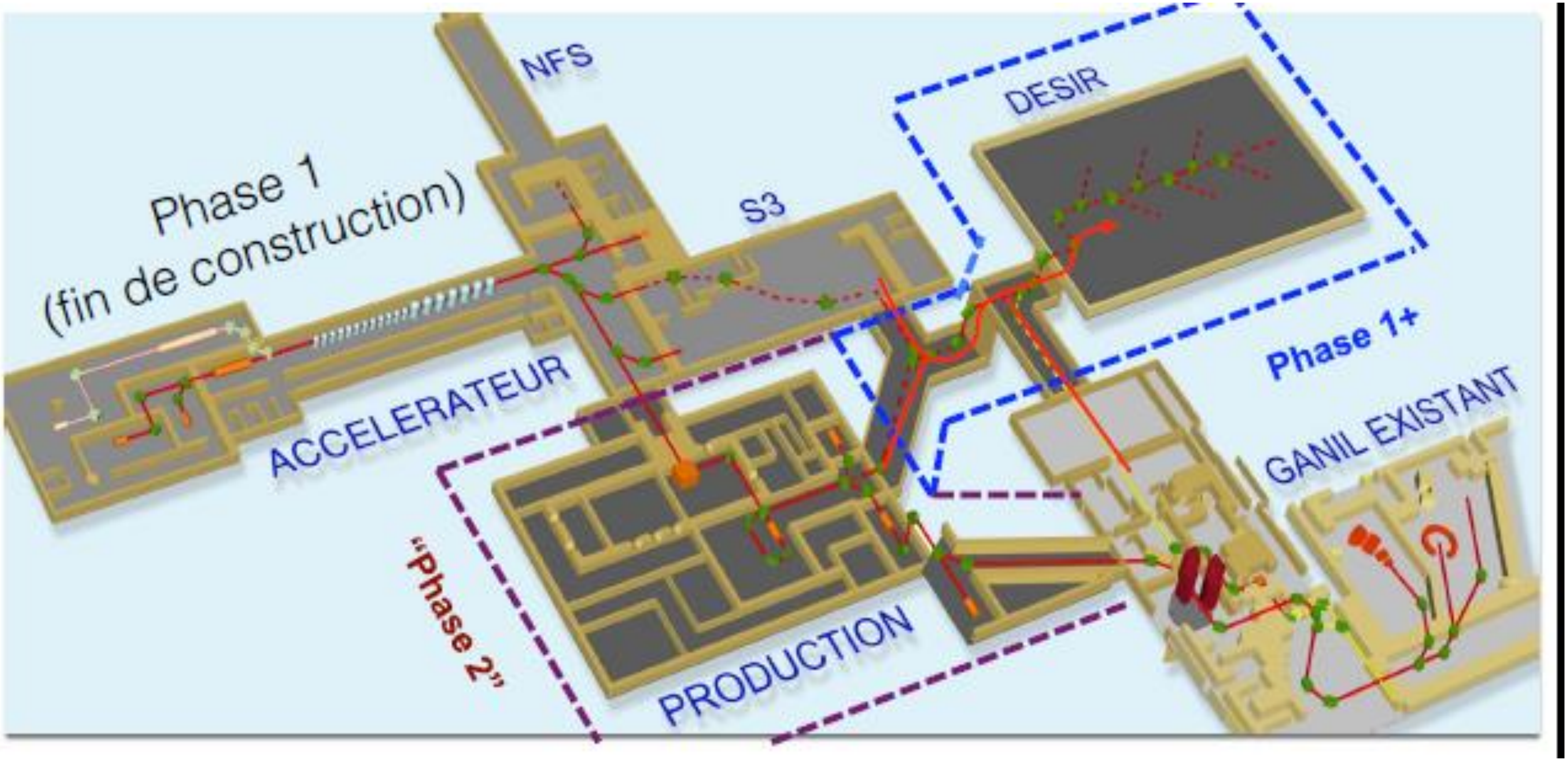
- **Physics case**
  - Fission reactors of new generation
  - Fusion technology
  - Studies related to hybrid reactors (ADS)

  } Basic data needed for evaluated data bases

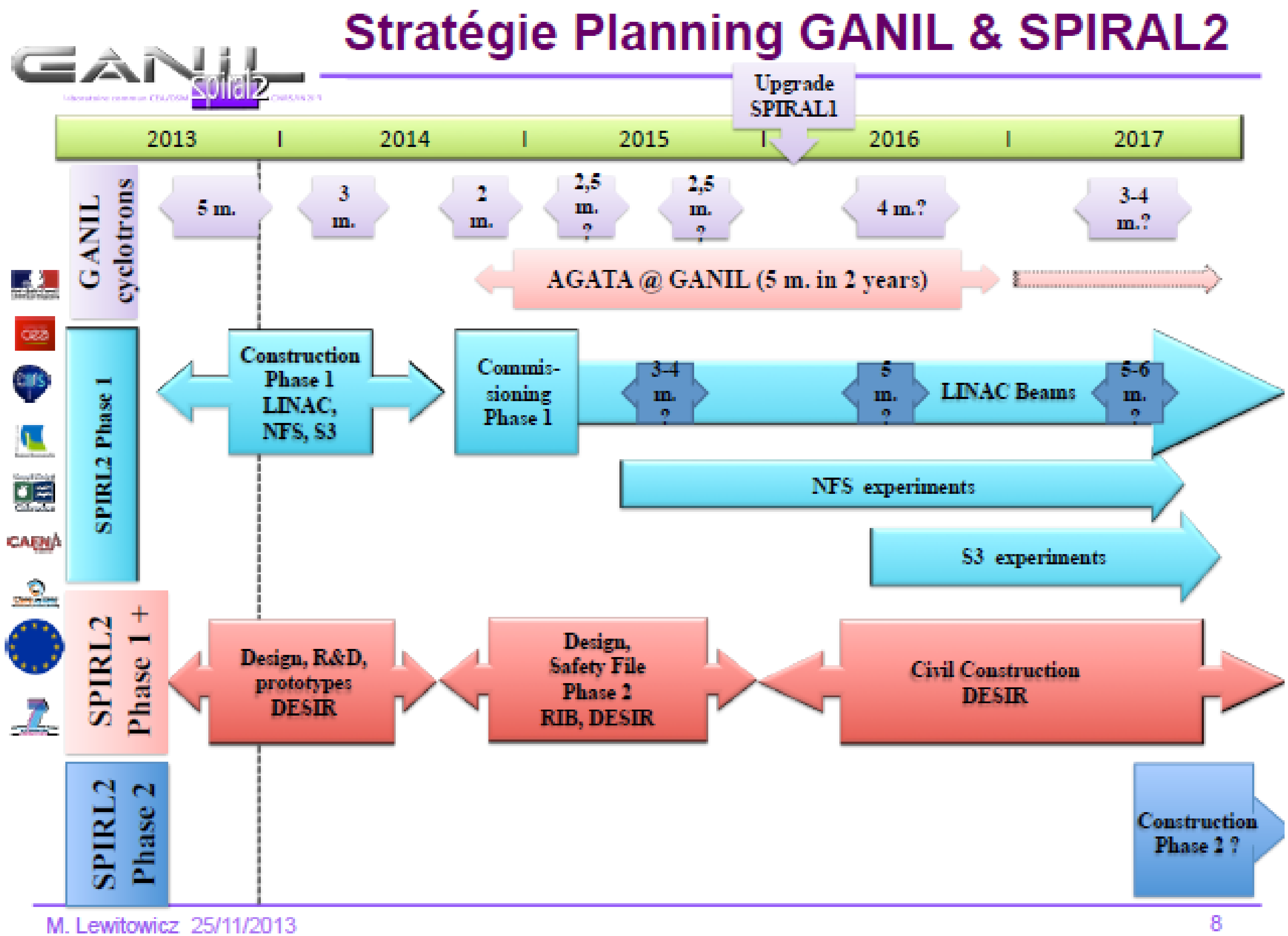
  - Nuclear medicine and biology
  - Development and characterization of new detectors
  - Study of the single-event upsets



New strategy for SPIRAL-2 construction



- SPIRAL-2 Phase 1 : LINAC + NFS + S3
- SPIRAL-2 Phase 1^+ : Phase 1 + DESIR (3 tunnels and 2 beam lines from S3 and SPIRAL-1)
- SPIRAL-2 Phase 2 : Phase 1^+ + production building


Stratégie Planning GANIL & SPIRAL2
Upgrade SPIRAL1
2013
2014
2015
2016
2017
GANIL cyclotrons
5 m.
3 m.
2 m.
2,5 m. ?
2,5 m. ?
4 m.?
3-4 m.?
AGATA @ GANIL (5 m. in 2 years)
SPIRL2 Phase 1
Construction Phase 1 LINAC, NFS, S3
Commis-sioning Phase 1
3-4 m. ?
5 m. ?
LINAC Beams
5-6 m. ?
NFS experiments
S3 experiments
SPIRL2 Phase 1 +
Design, R&D, prototypes DESIR
Design, Safety File Phase 2 RIB, DESIR
Civil Construction DESIR
SPIRL2 Phase 2
Construction Phase 2 ?
M. Lewitowicz 25/11/2013
8

Neutron spectra provided at NFS

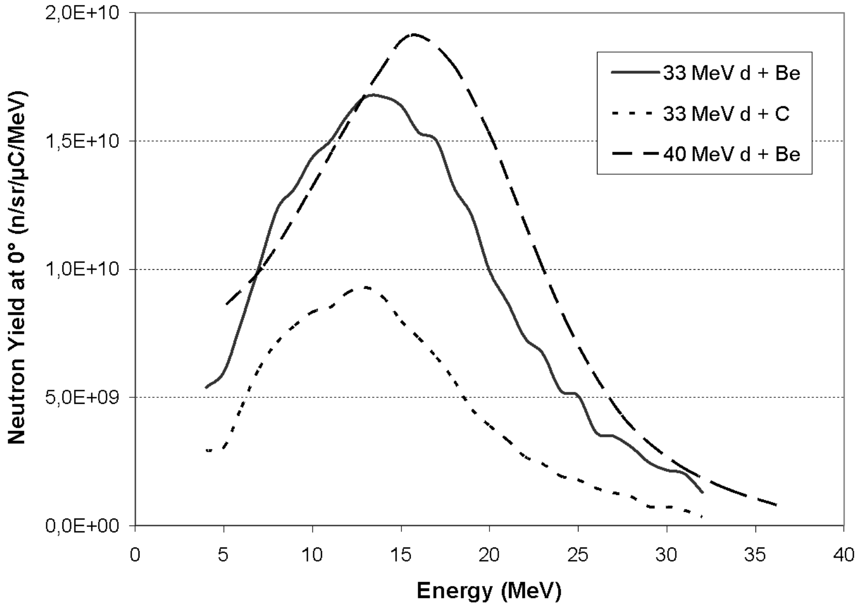
Characteristics of the beams the LINAG :

- 40 MeV deuteron and 33 MeV proton
- I_{max} = 5 mA
- Pulsed beam F_0 = 88 MHz T=11 ns Burst width = 200 ps

Continuous spectrum :

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

thick converter (1cm)



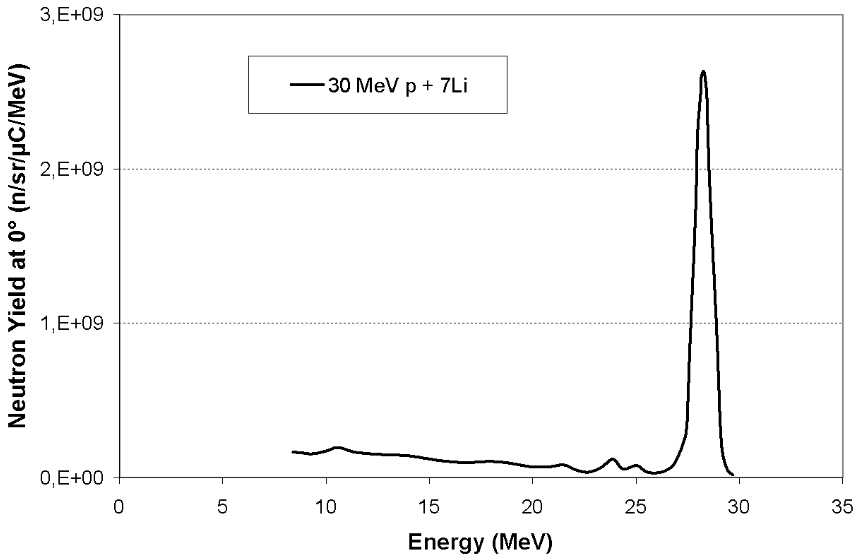
J. P. Meulders et al., Phys. Med. Biol. (1975)vol 20 n°2, p235

M. J. Saltmarsh et al., NIMA145 (1977) p81-90

Quasi-monokinetic beam :

E_n = up to 31 MeV

Thin converter (1-3 mm)



C. J. Batty et al.,NIM **68** (1969) p273-276

⇒ Similar to IFMIF spectrum

Neutron flux in the TOF area

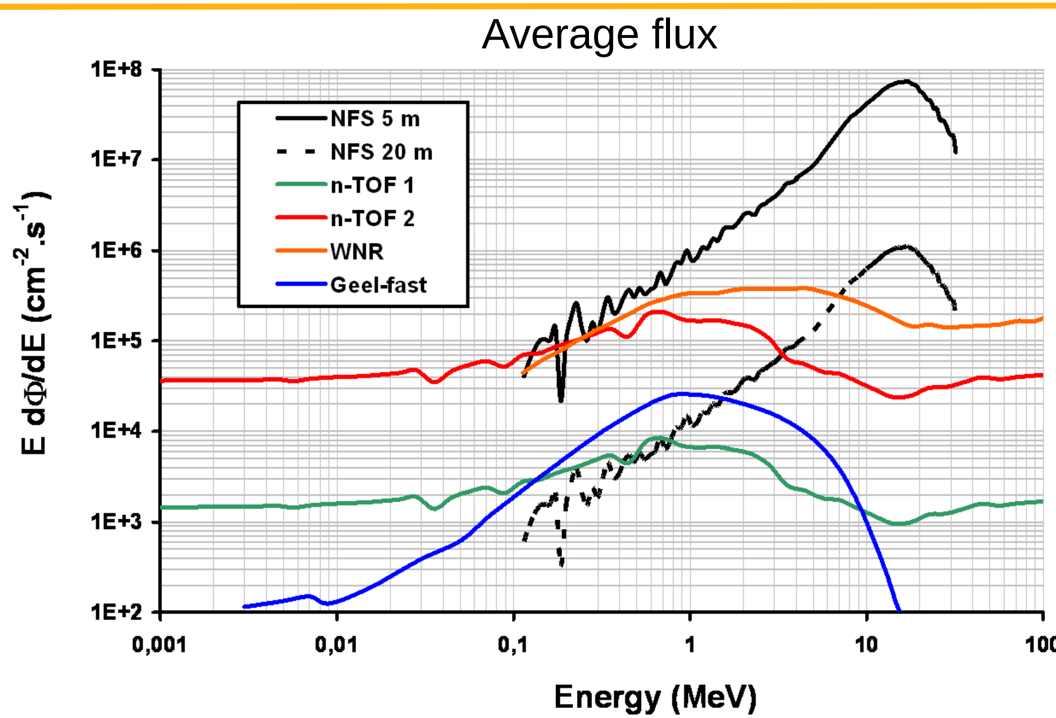
NFS : 40 MeV d + Be

WNR : Los Alamos

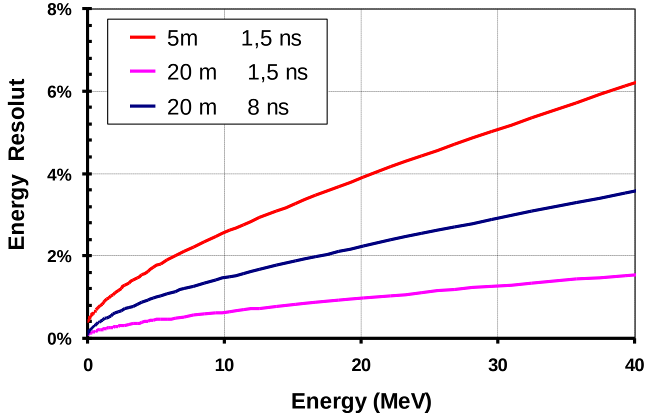
n-TOF 2 : CERN

n-TOF 1 : CERN

GELINA : Geel

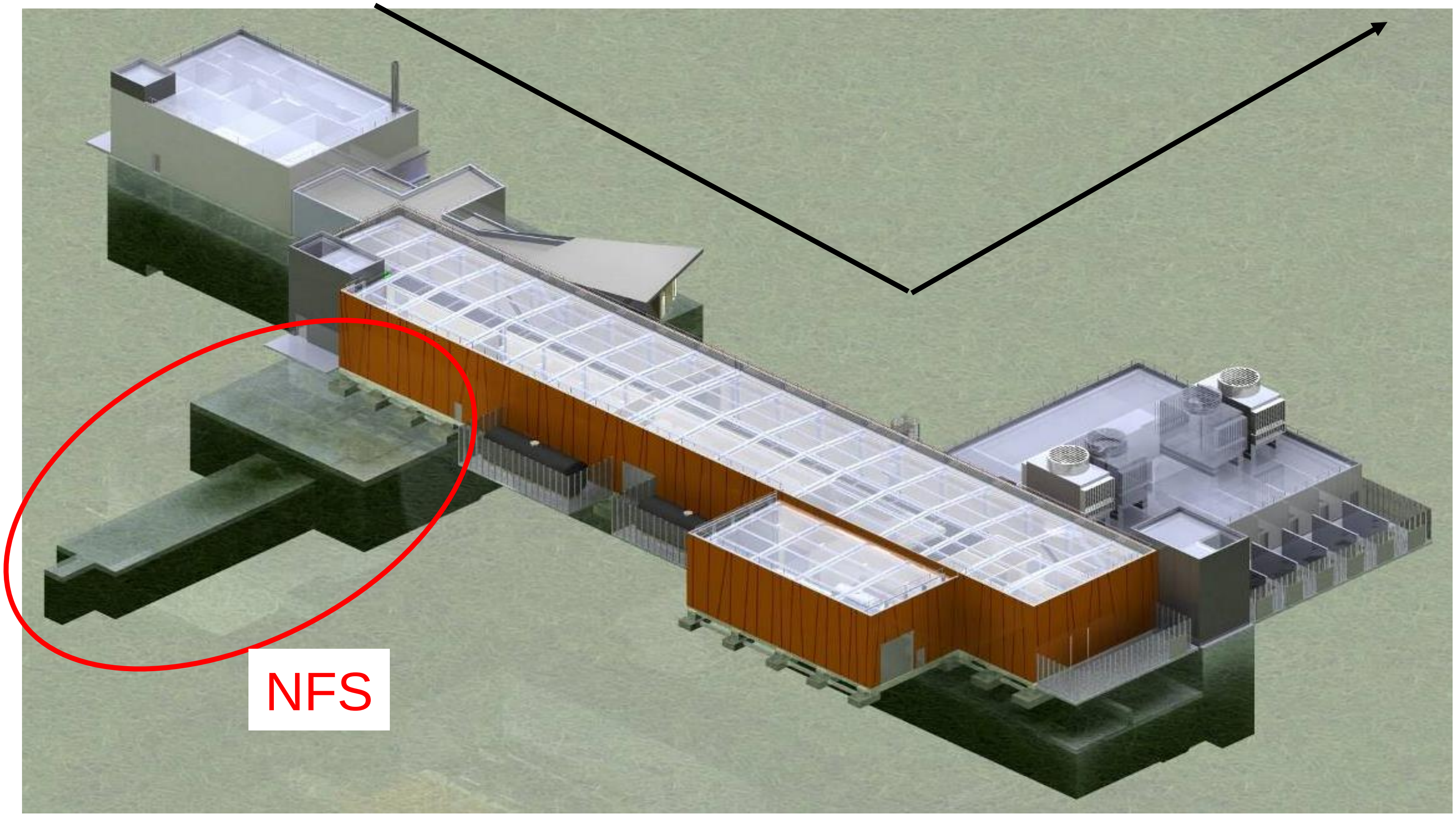


- E_n: from 0,1 MeV to 40 MeV
- Good energy resolution
- Reduced γ flash
- Low instantaneous flux



→ Complementary to the existing facilities

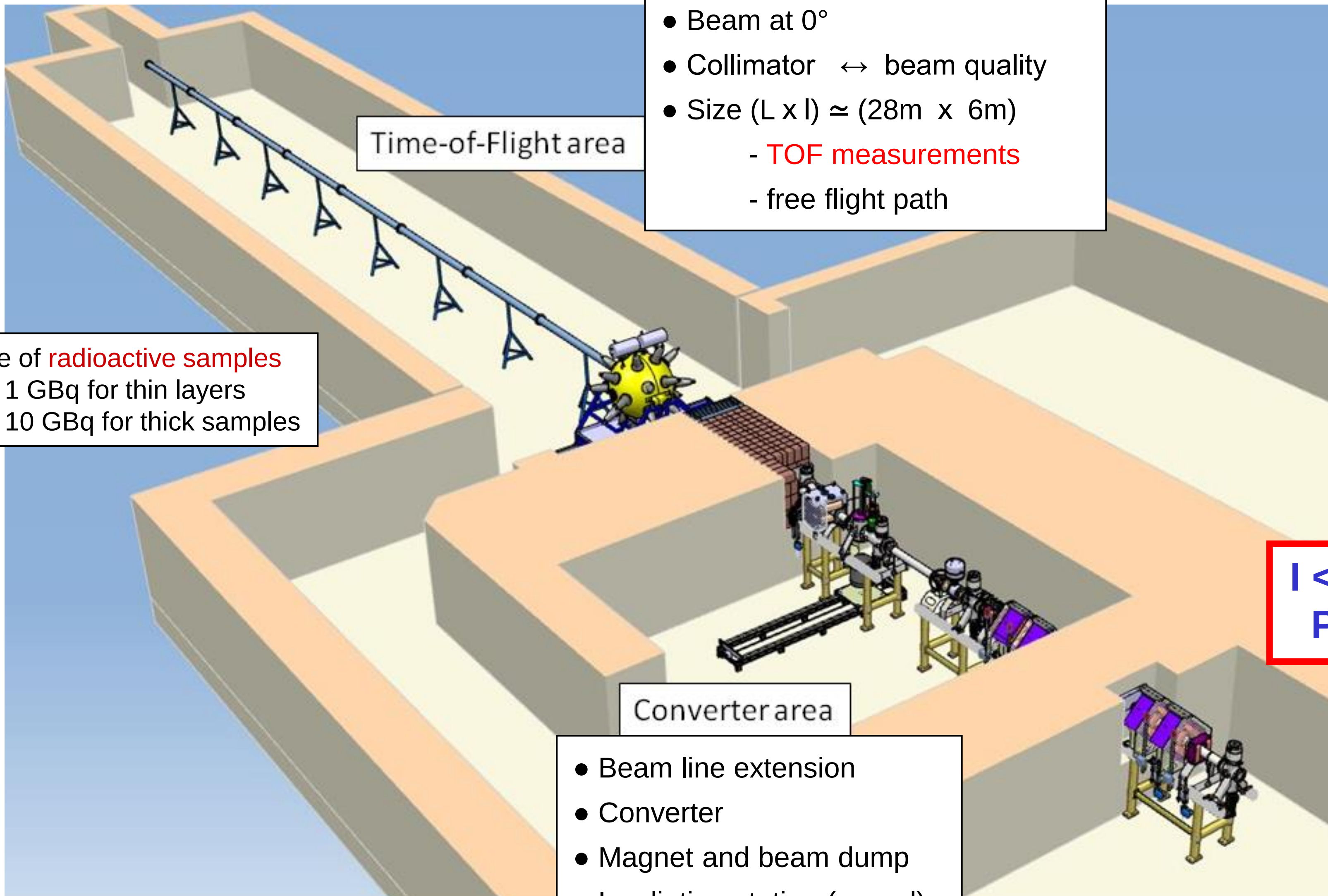
SPIRAL2 phase 1



Description

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

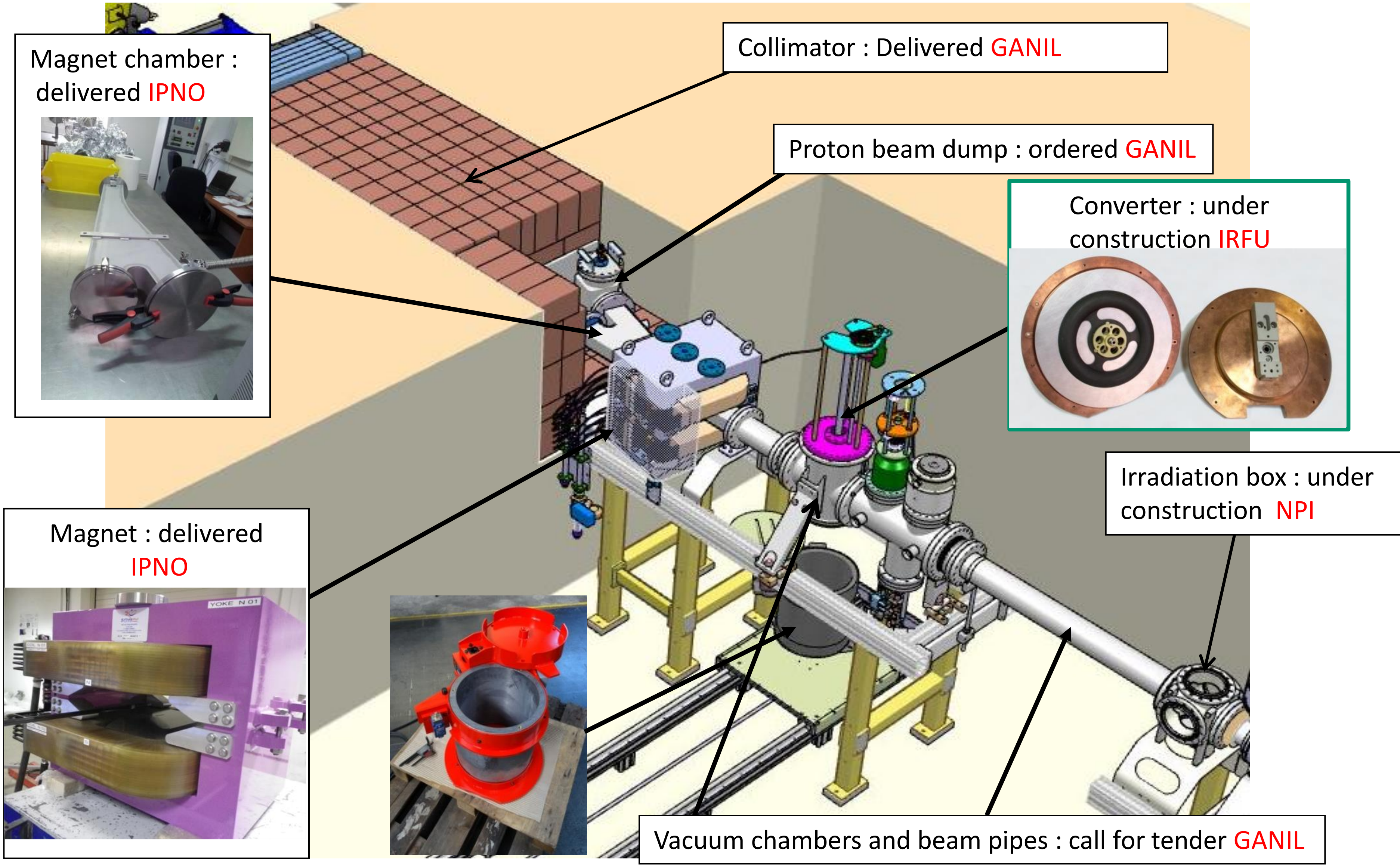
Use of radioactive samples
A< 1 GBq for thin layers
A< 10 GBq for thick samples



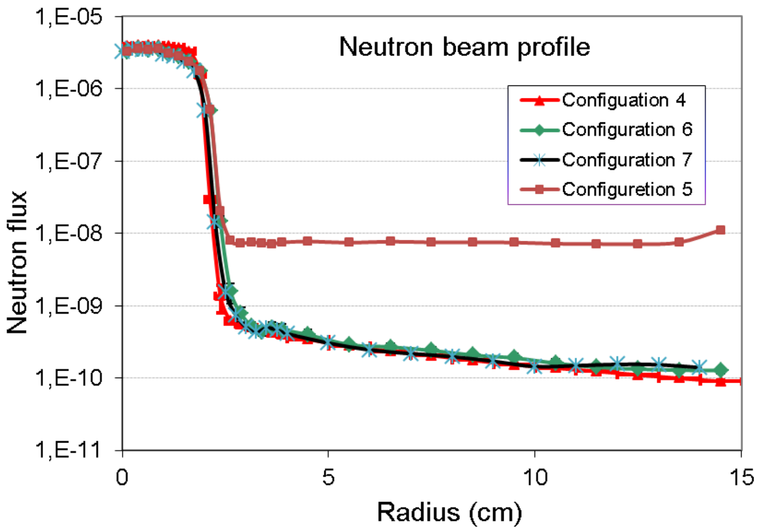
I < 50 µA
P < 2 kW

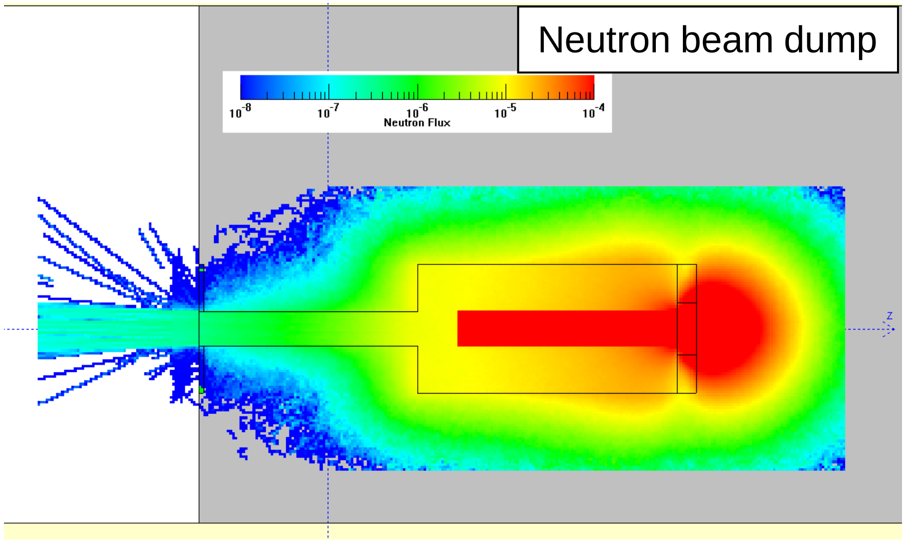
- Beam line extension
- Converter
- Magnet and beam dump
- Irradiation station (n, p, d)

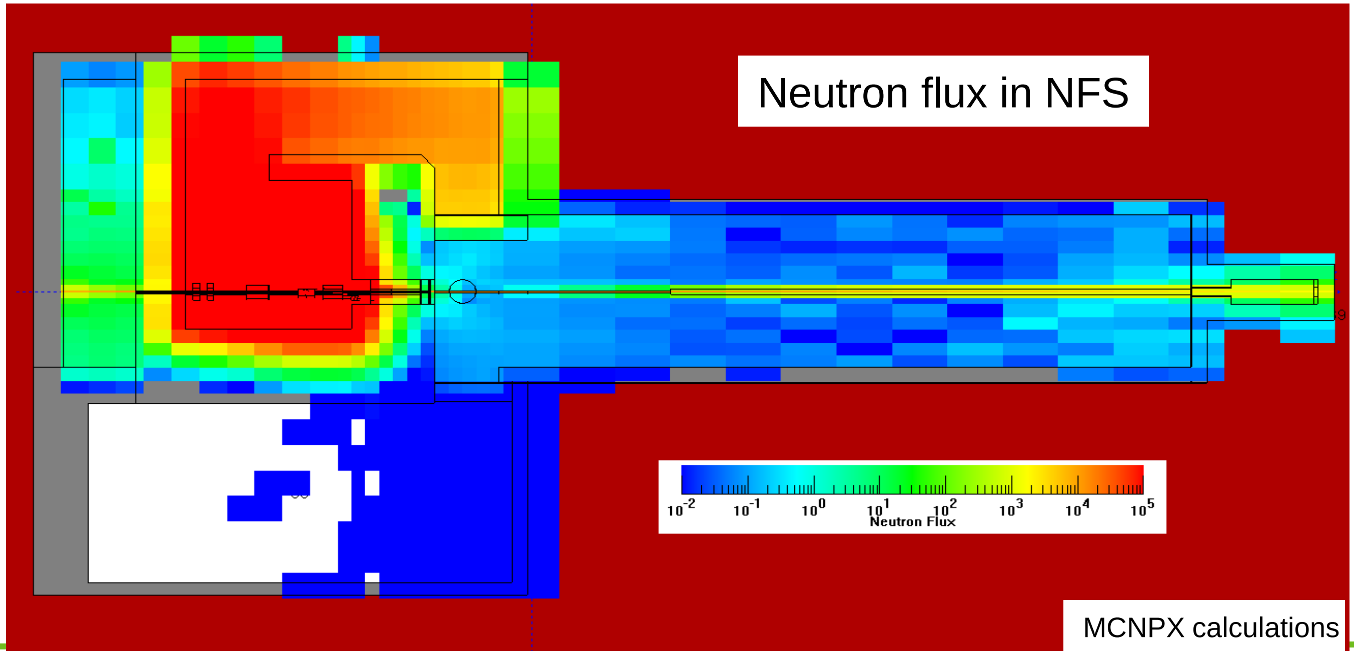
NFS components



Calculation for beam profile and neutron background







CEA/DAM/DIF

Physics case

Neutron induced fission

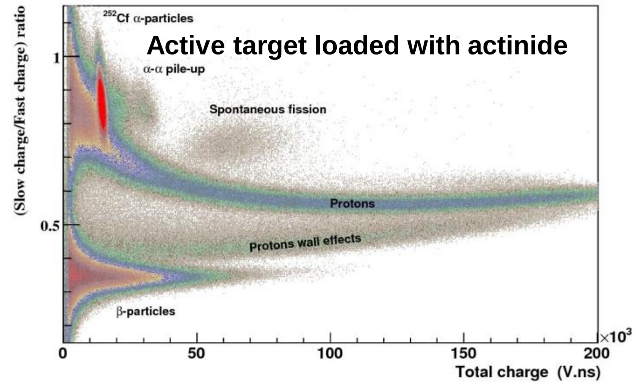
- Need of data for fast neutron essentially for minor actinides

  ADS, GEN IV reactors

  Cross-section measurements

  Neutron, gamma multiplicity and spectra

  Fragment yields



- NFS short flight path → High flux

  Small samples (α emitters)

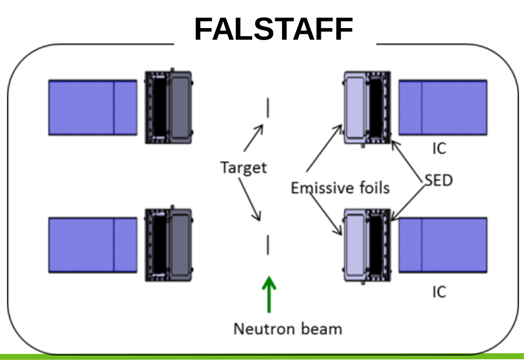
  Coincidence measurements

Maximal activity
1 GBq for thin sample
10 GBq for thick target

- Complementary to surrogate reactions

  Limited to 10 MeV

  Model dependence



- Study of the fission process

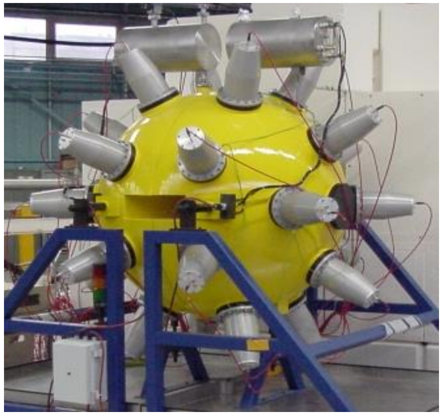
  Continuous spectrum → continuous excitation energy

  Coincidence experiment

  (A,Z) fragment distribution

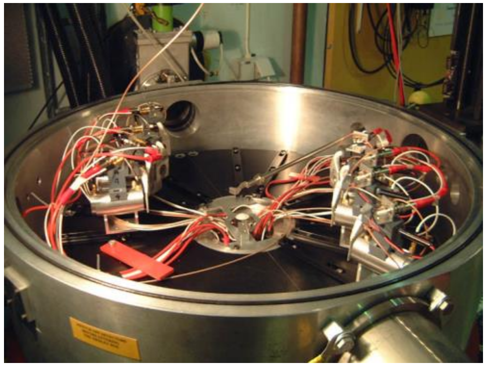
Isotopes usable at NFS
^{232}Th
^{233}U
^{235}U
^{237}Np
^{238}U
^{239}Pu
^{241}Am
^{242}Am
^{243}Am
^{245}Cm
^{234}U
^{236}U
^{240}Pu
^{242}Pu
^{244}Pu
^{246}Cm
^{247}Cm
^{248}Cm
^{231}Pa
^{241}Pu
^{249}Cf
^{251}Cf

(n,X) cross section measurements



- **(n,xn) reactions**
  - Maximum σ in the NFS energy range
  - Neutron multiplication
- **In-beam γ-ray spectroscopy**
  - White source and quasi-monokinetic spectrum
  - (n,2n), (n,np), (n,α) reactions
  - Use of large Ge array for γ-γ coincidence measurements

- **(n,LCP)**
  - Gazes and default production
  - Energy deposition in therapy
  - Composite particle prediction → no model works

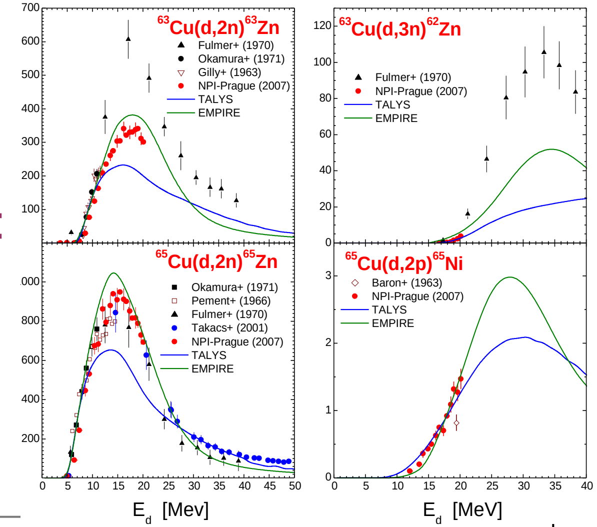


- **Double differential measurements (n,xn), (n,LCP)**
  - Few data exits between 20 and 50 MeV
  - Use of existing detection set-ups

Proton and deuteron induced reactions

Measurement of reaction cross-sections by activation technique :

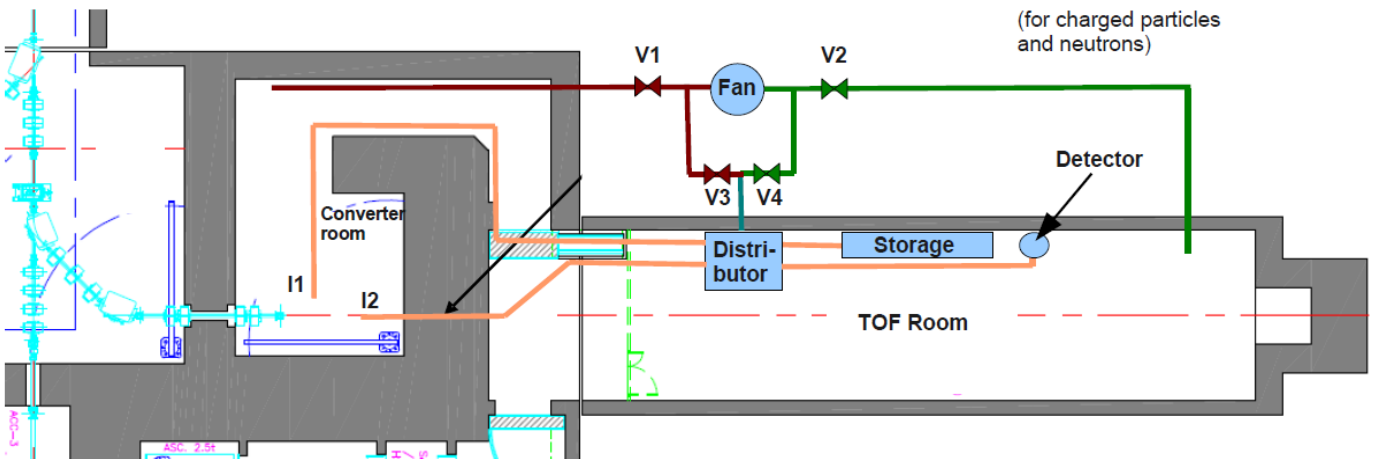
- data for IFMIF facility design
- improvement of reaction model



NFS opens a possibility to extend the activation experiments :

- high intensities
- high deuteron energies
- isotopes with short half lives can be studied.

Pneumatic transfer system of samples between the converter room and the TOF area: KIT



Letters of Intents for Day-One experiments at NFS

- **Neutron induced reactions studies :**
  - LoI_13 : Study of pre-equilibrium process in (n,xn) reaction, *X. Ledoux*
  - LoI_14 : Comparison between activation and prompt spectroscopy as means of (n,xn) cross section measurements, *M. Kerveno*
  - LoI_20 : Direct measurement of (n,xn) reaction cross sections on ^{239}Pu, *G. Bélier*
  - LoI_21 : Light-ion production studies with Medley, *S. Pomp*

- **Fission :**
  - LoI_15 : Fission fragment distributions and neutron multiplicities, *D. Doré*
  - LoI_22 : Fission fragment angular distribution and fission cross section measurements relative to elastic *np* scattering with Medley, *S. Pomp*
  - LoI_28 : Study of the fission process and fission cross-section measurements, G. Bélier

- **Cross-section reaction measurements by activation technique :**
  - LoI_16 : Proton and deuteron induced activation reactions, *P. Bem*
  - LoI_24 : Neutron-induced activations reactions, *A. Klix*

- **Biology :**
  - LoI_23 : Response of Mammalian cells to neutron exposure, *C. Hellweg*

- **Detector development :**
  - LoI_29 : Neutron spectrometer characterization for LMJ project, *B. Rossé*

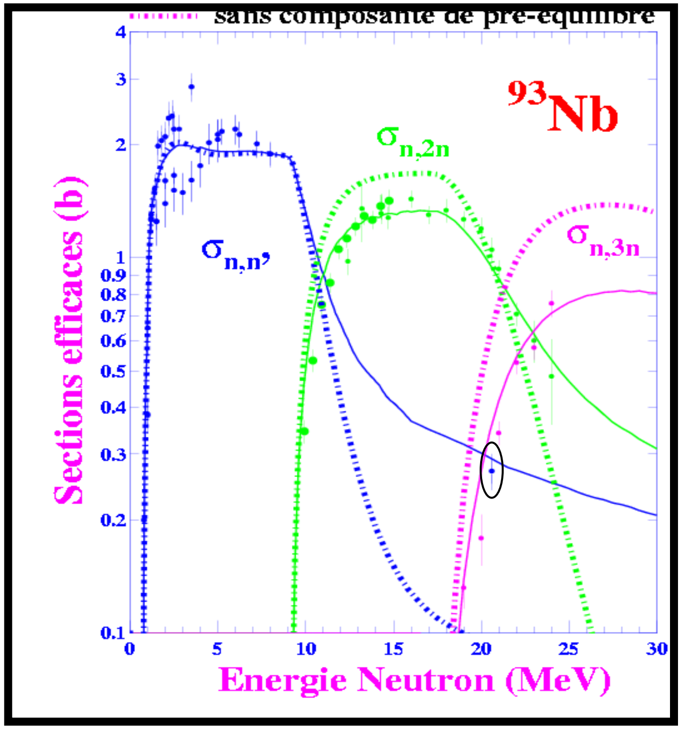
Study of pre-equilibrium process in (n,xn) reaction

X. Ledoux, G. Bélier, M. Dupuis, C.Varignon

CEA, DAM, DIF

F-91297 Arpajon

Study of pre-equilibrium process in (n,xn) reaction



Importance of (n,xn) reactions

-Accelerator Driven System

- Fusion technology

- Nuclear medicine

- Represent the main part of reaction cross-section of non fissile nuclei at low energy.

Nuclear reaction models :

- Optical model

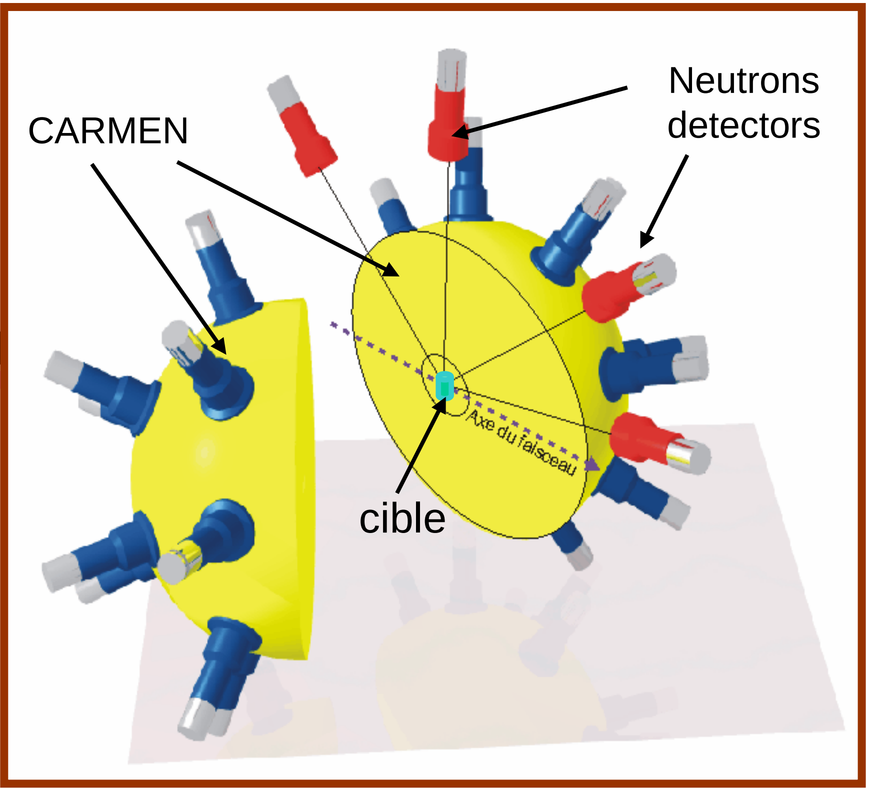
- Pre-equilibrium process absolutely needed for reliable integral data prediction

- Evaporation models

Existing double differential cross-sections data: Sum of the channels where at least one neutron is emitted.

Experience description

Measurement of (n,xn) double differential cross section in Coincidence with neutron multiplicity.



Method :

- measurement of energy and angle of one neutron
- count of the (x-1) neutrons emitted simultaneously.

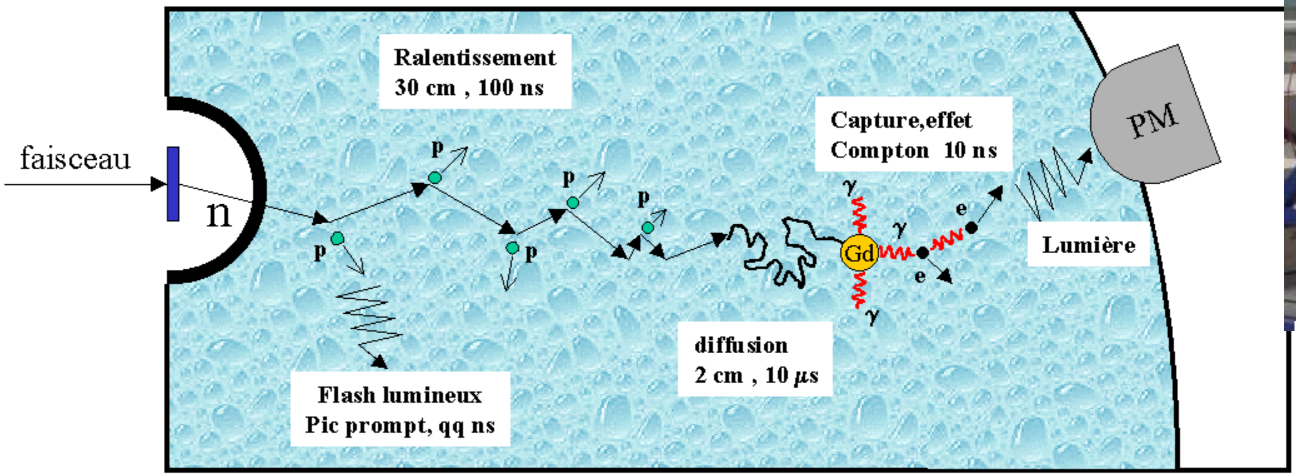
Realisation :

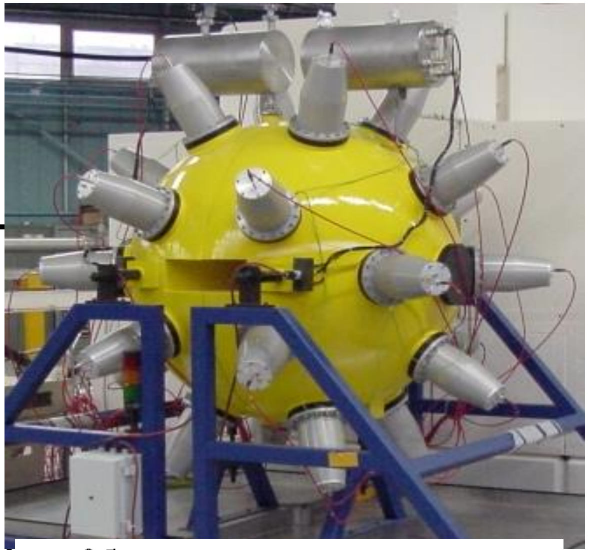
- Neutron beam
- NE213 neutrons detector at angle θ,
- 4π detector with high efficiency to detect the (x-1) other neutrons (CARMEN).

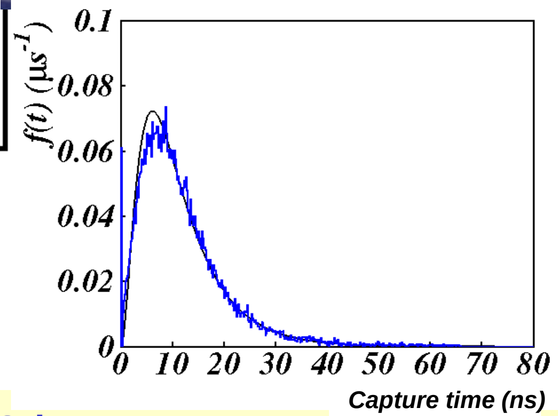
CARMEN

4 π neutron detector of high efficiency (ε = 85 % for fission neutrons)

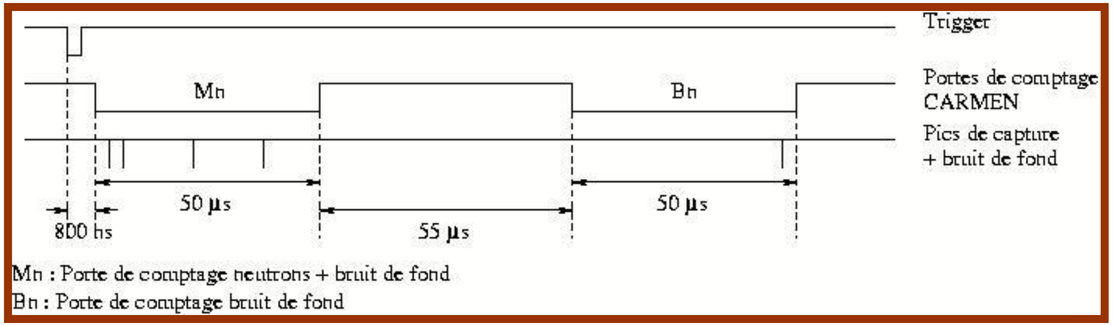
- Two hemispheres (r=60 cm)
- 950 liters of liquid scintillator (C_9H_{12}) loaded with Gd (0.5 %)
- 24 phototubes in the liquid.







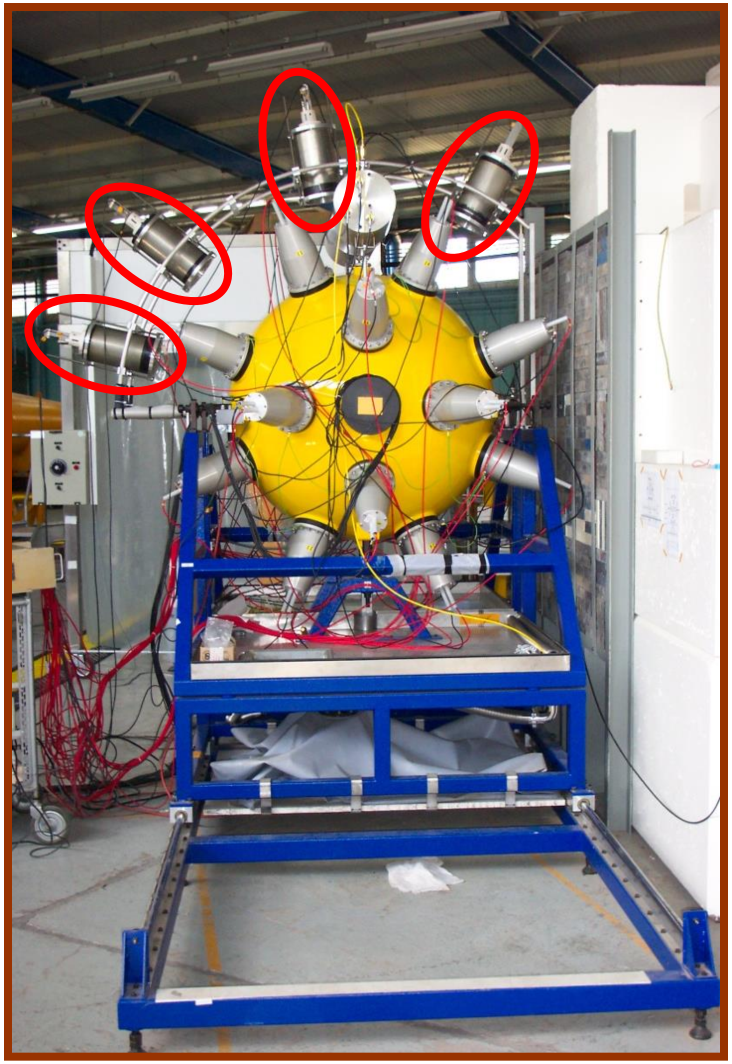
CARMEN measures the neutron multiplicity event by event.

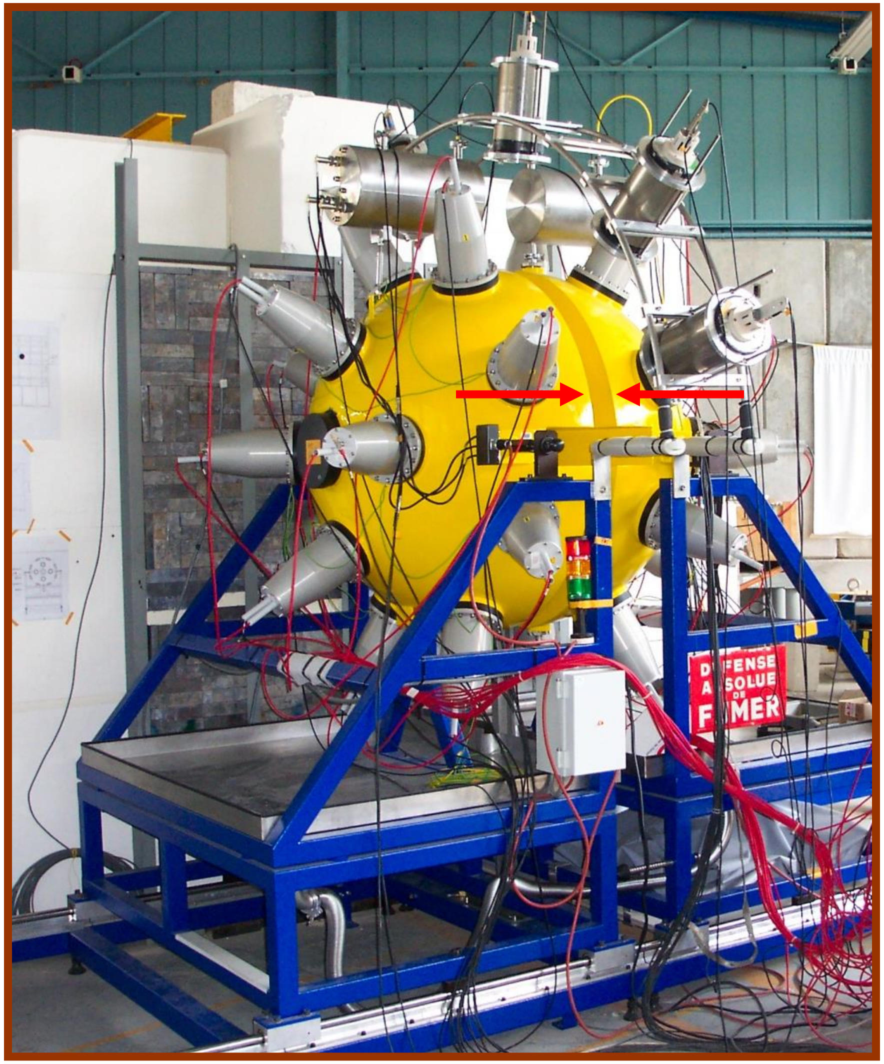


Other use :

- σ(n,2n), σ(n,3n) measurement
- fission studies ($\bar{\nu}$, E_{gamma})
- α ratio

Experimental Set-up

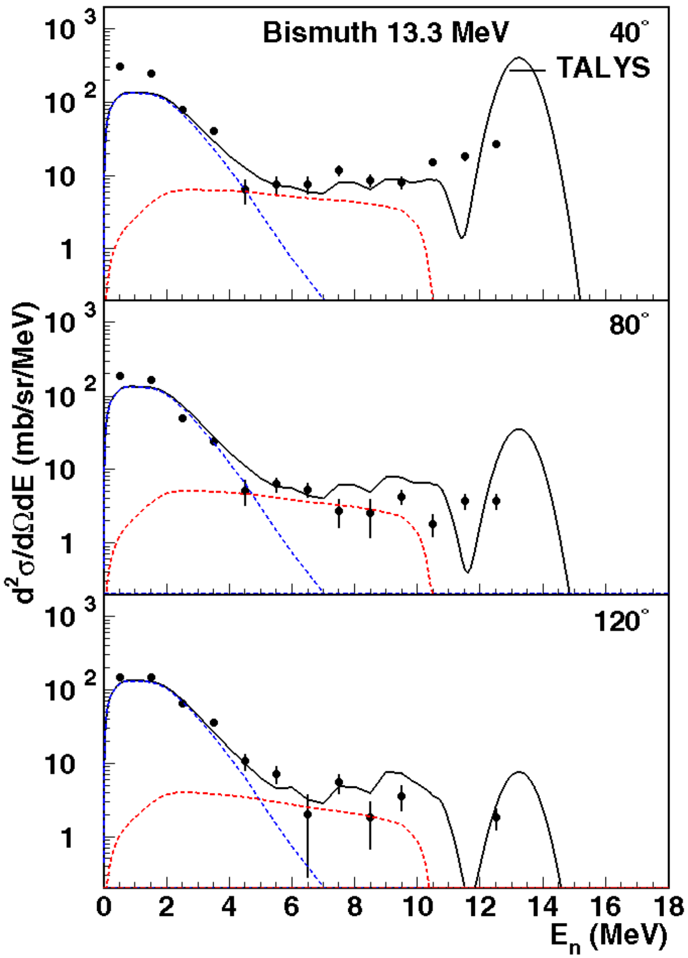




Results at 13.3 MeV

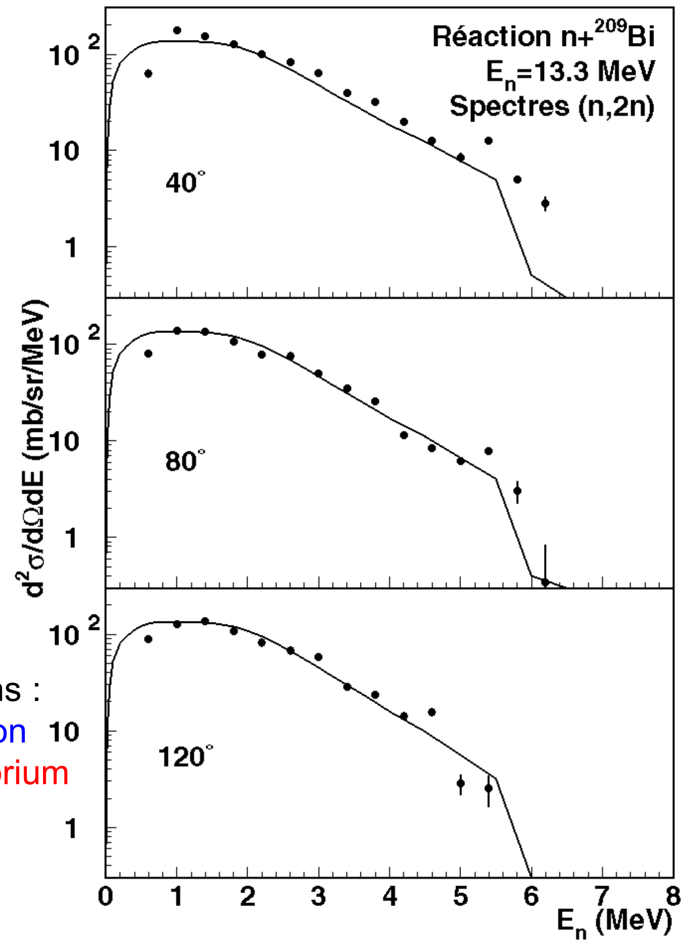
Experiment at CEA/DIF, I. Lantuéjoul Thesis

(n,xn) spectra



CARMEN
Filter

(n,2n) spectra



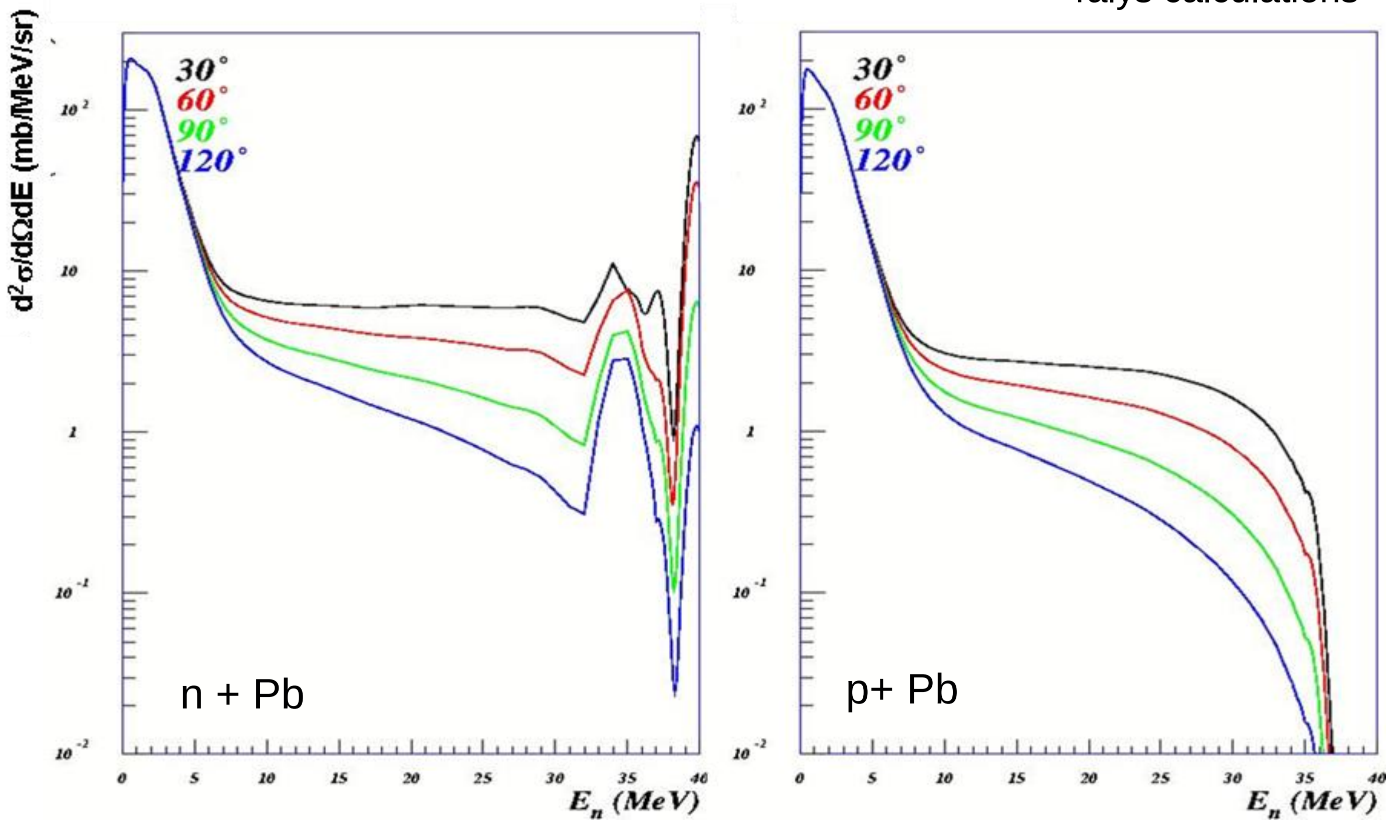
Talys calculations :
Blue : evaporation
Red : pre-equilibrium

Experiment at NFS

Quasi-monokinetic neutron beam at 31 MeV

Well collimated neutron beam

Talys calculations



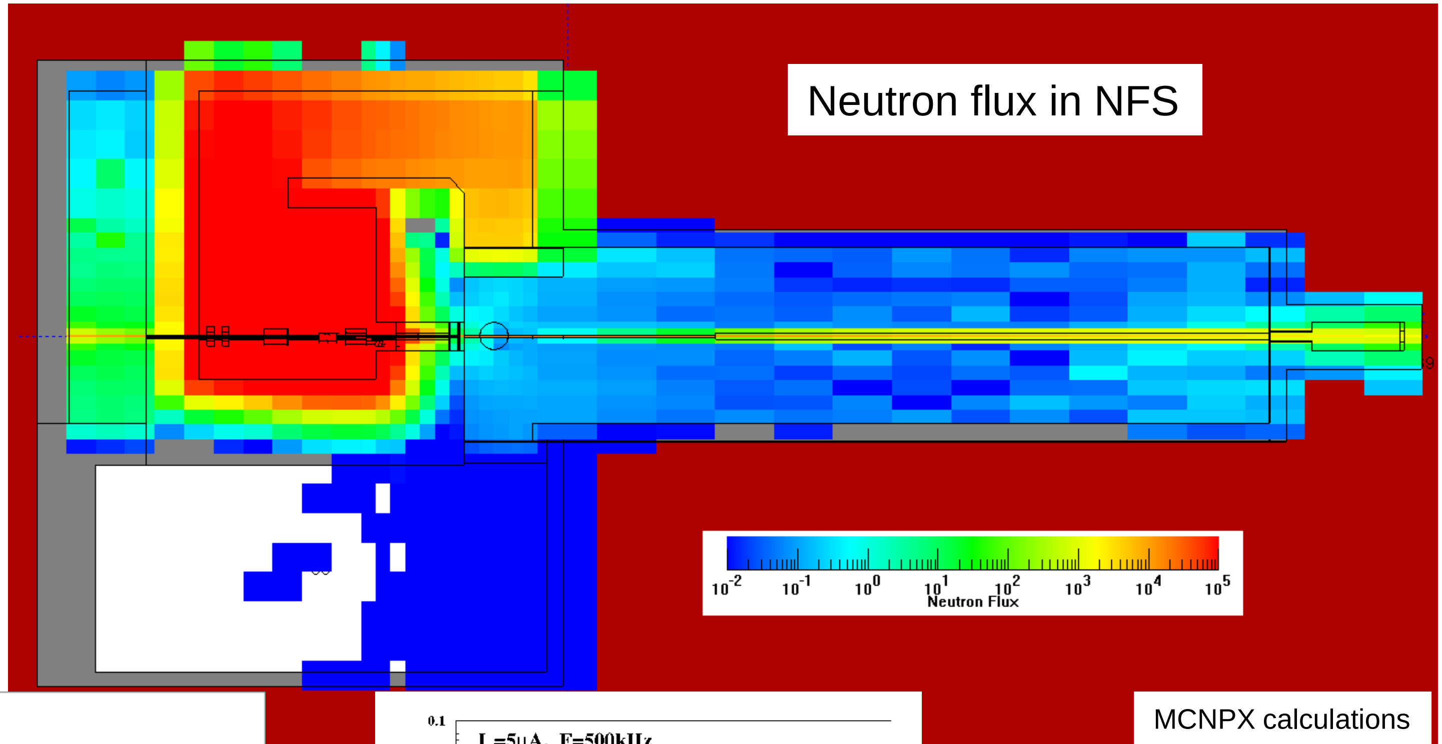
Increase of pre-equilibrium process effect

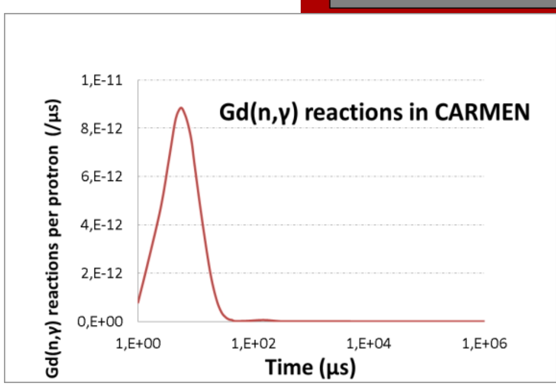
Opening of (n,3n) and (n,4n) channels

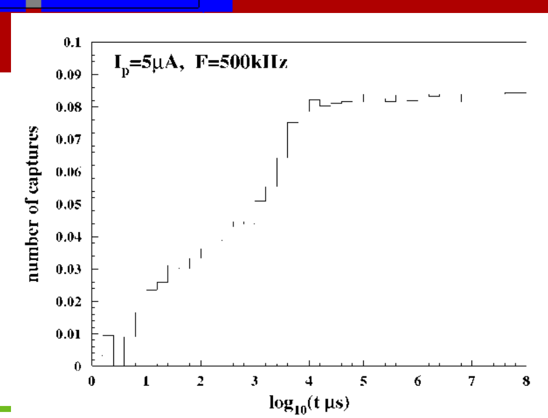
Background simulation

Neutron production reaction : 33 MeV p + ^{7}Li

Beam characteristics : F=500 kHz and I=5µA







Neutron capture in 50 µs < 0,1

Summary

NFS will be a very powerful tool for physic with neutrons

Technical issues :

- 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)

Physics case :

- Fundamental and applied research
- Fission and fusion technology
- Material studies
- Detector development
- Biology

First experiment in 2015

SPIRAL2 phase 1+ physics workshops

« DESIR and S^3-LEB »

24th-26th March 2014

« S^3 »

26th-28th March 2014

« NFS »

31st March -1st April 2014

Maison d'hôtes du GANIL