Neutrons for Science at SPIRAL-2

X. Ledoux and the NFS collaboration

Outline

- Description of NFS
- Physics case
- IFMIF/DONES

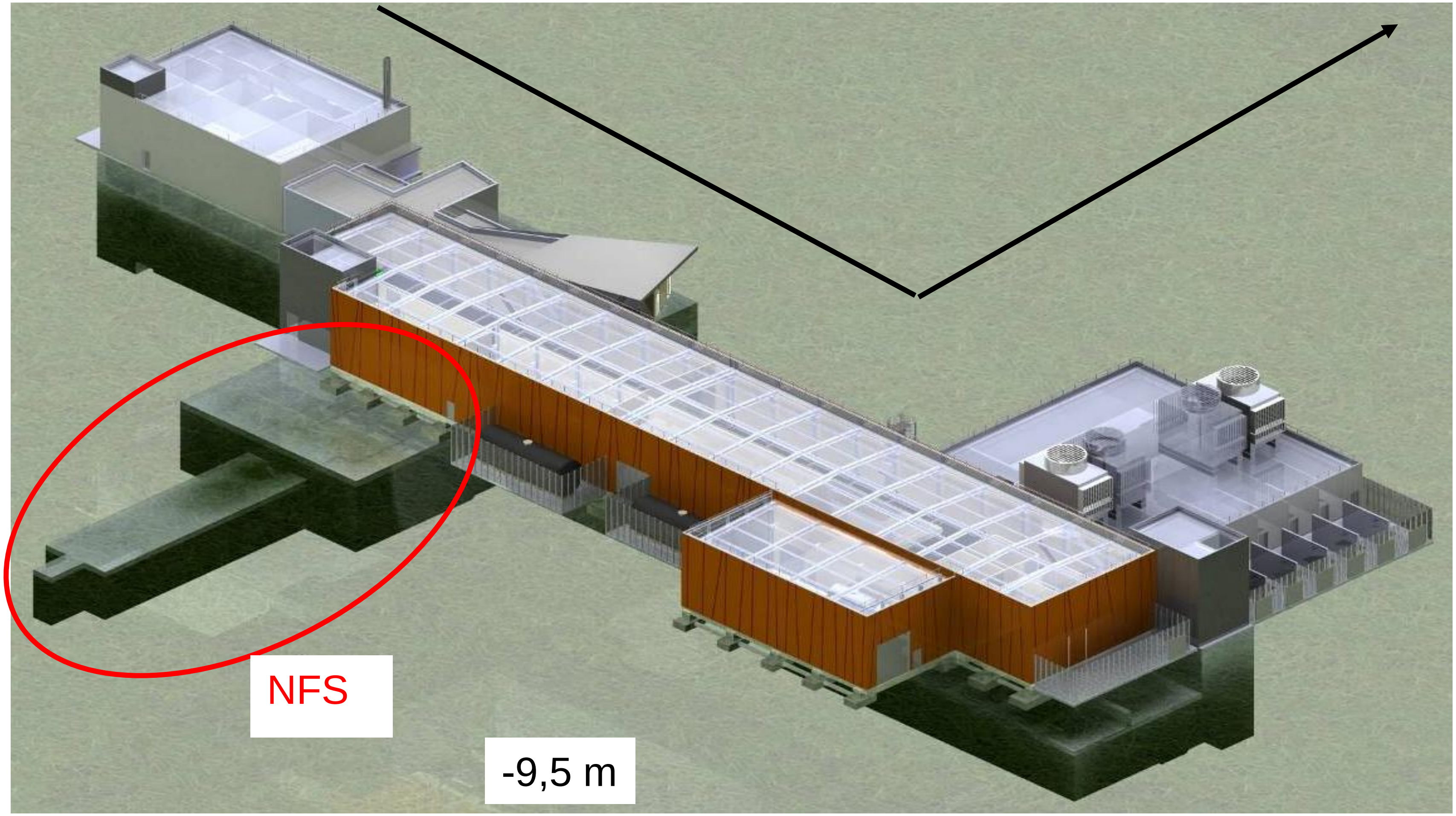
The neutrons for science facility

- ❑ **NFS is one of the two facilities of the LINAG Experimental Area**
- ❑ **Neutron beam between 100 keV and 40 MeV**
- ❑ **Irradiation station for n, p, d and ions induced reactions**

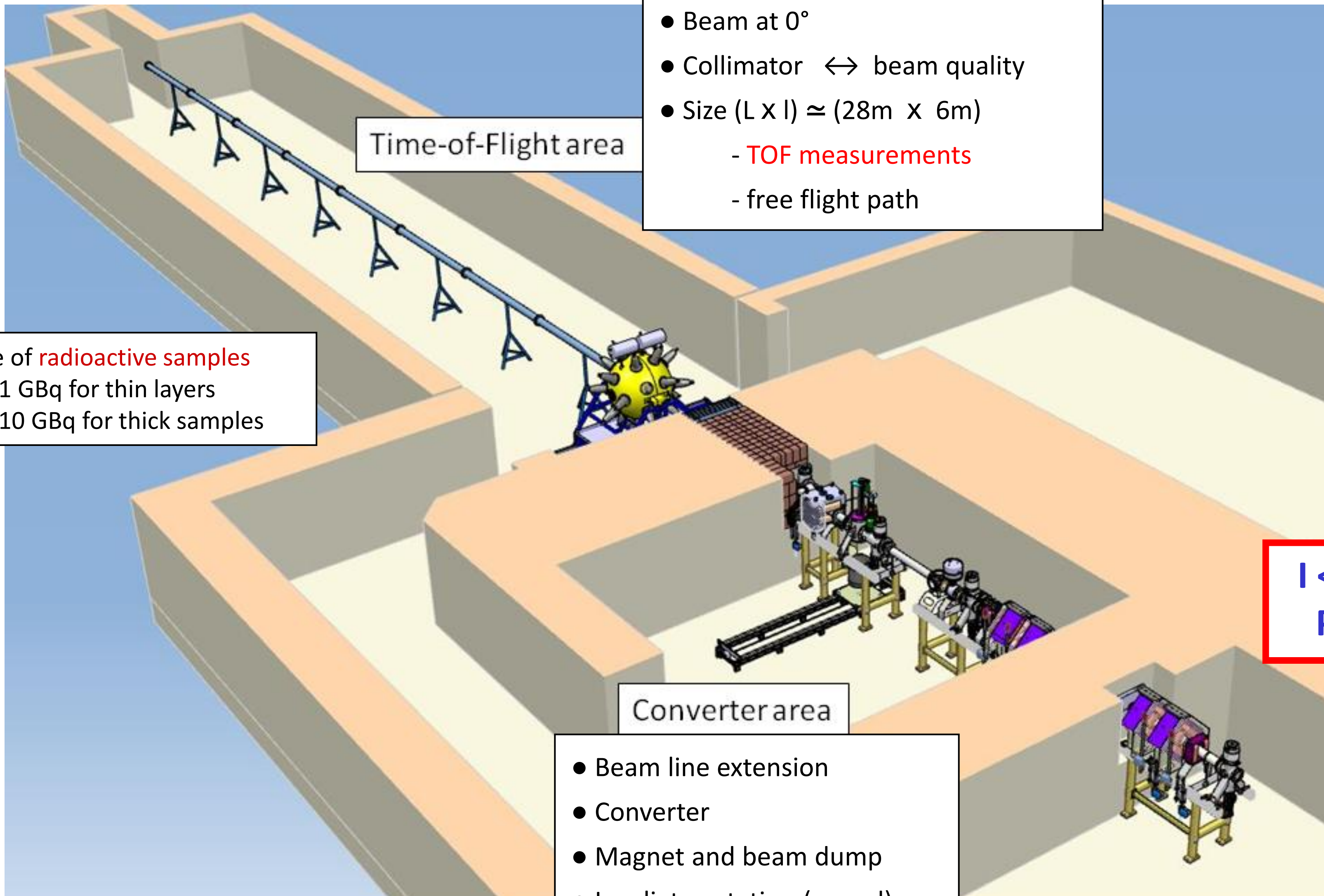
- Fundamental physics
- Fission reactors of new generation
- Fusion technology
- Studies related to hybrid reactors (ADS)
- Nuclear medicine
- Development and characterization of new detectors
- Radioisotopes production for medical applications
- Biology
- Study of the single-event upsets

} Basic data needed for evaluated data bases

SPIRAL2 phase 1 building



The NFS facility



- 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

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

I < 50 µA
P < 2 kW

NFS: The converter room

NFS: the TOF area

Continuous neutron spectra

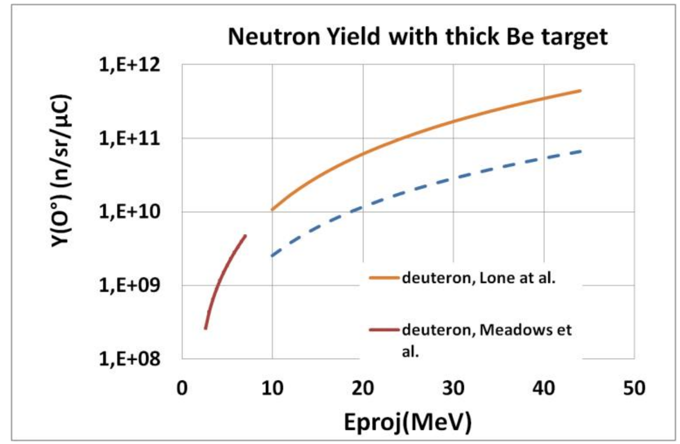
Thick converter (6 to 10 mm)

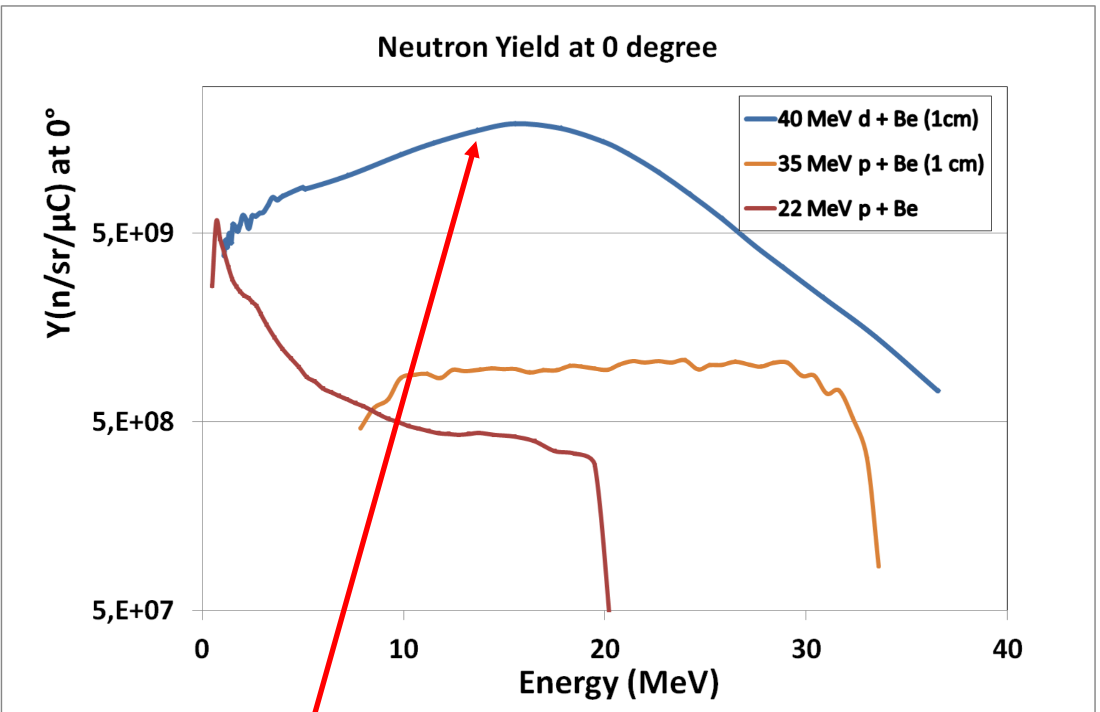
Proton or deuteron beam

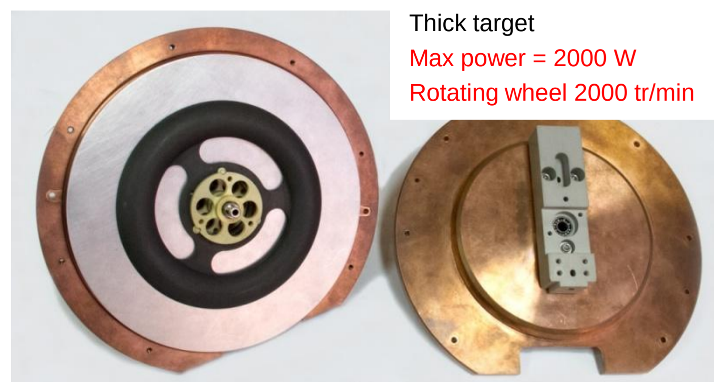
I_{max}=50 µA at E=40 MeV

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





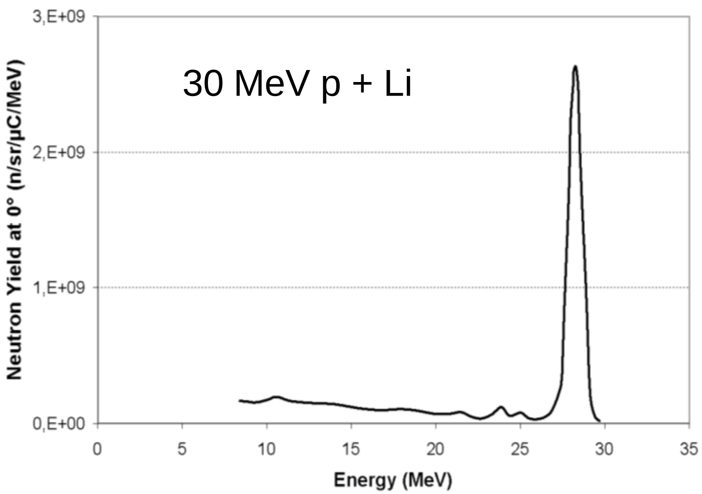


Thick target
Max power = 2000 W
Rotating wheel 2000 tr/min

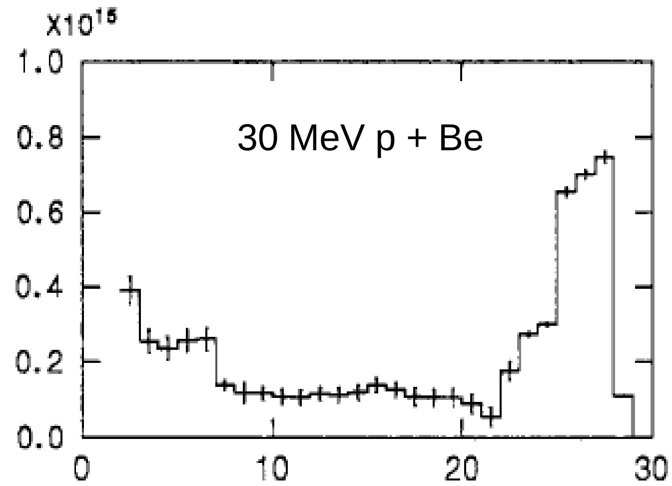
Similar to IFMIF spectrum

Quasi-mono-energetic neutron spectra

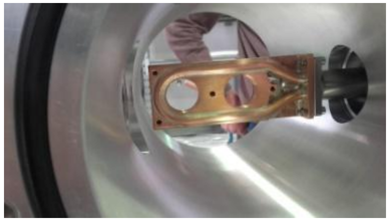
p+^{7}Li → n + ^{7}Be   Q= -1.64 MeV

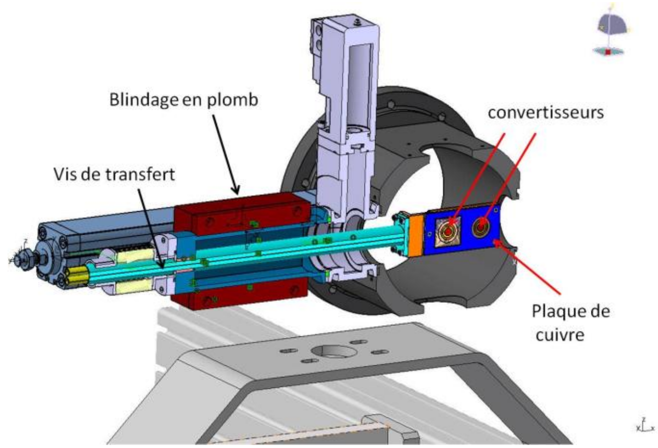


p+^{9}Be → n + ^{9}B   Q= -1.85 MeV

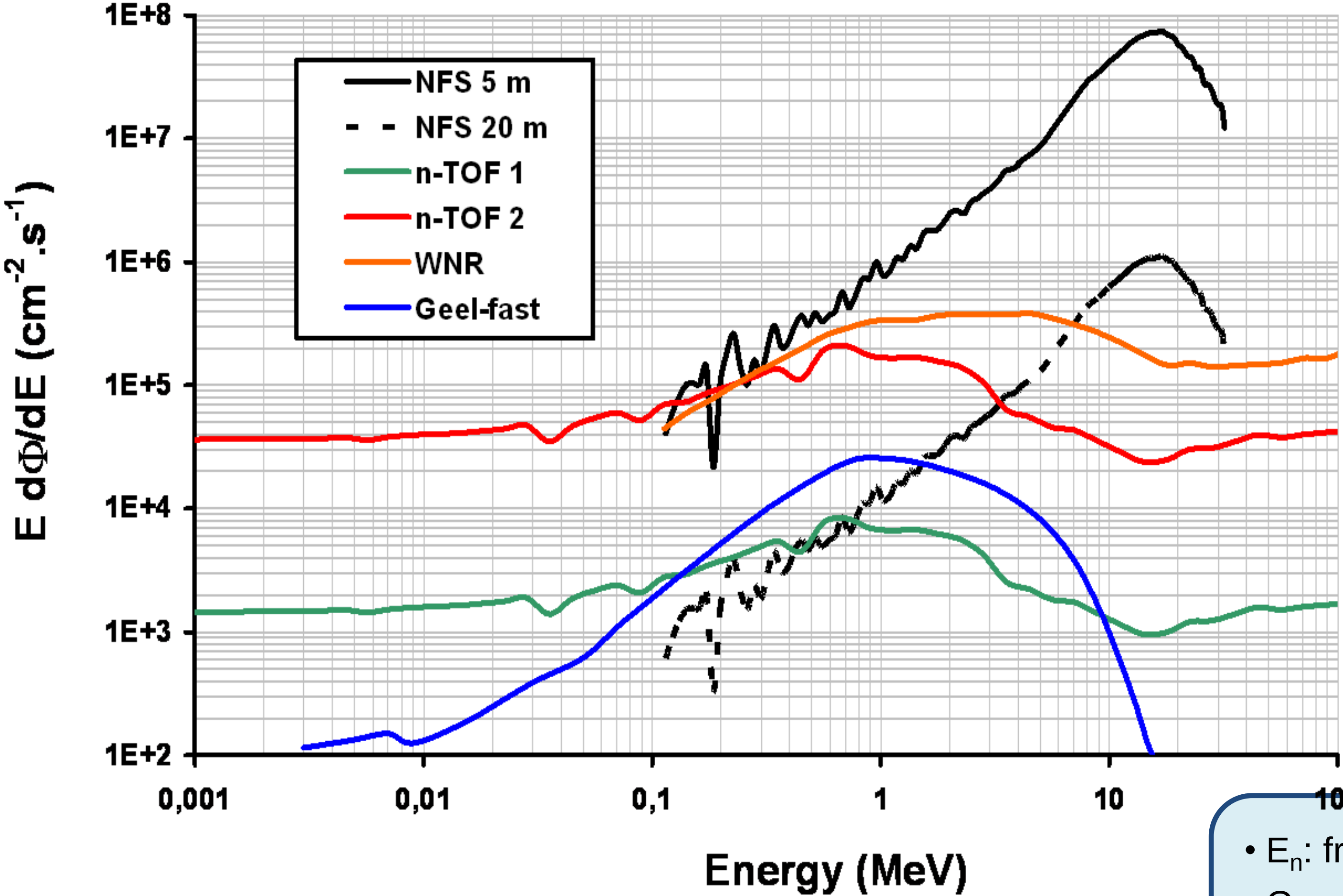


Lithium foil on cupper frame cooled by water cooling





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

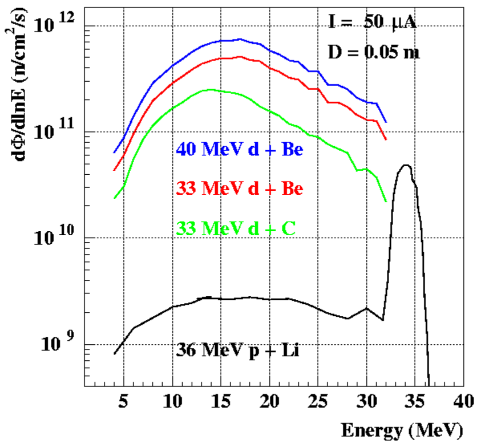
Complementary to the existing facilities

Measurements by activation method

1- Sample irradiation in the converter room

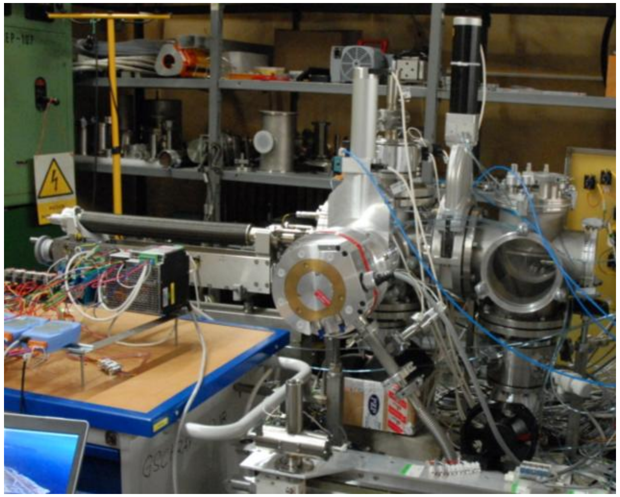
Neutron irradiation

Φ ≈10^{11} n/cm²/s

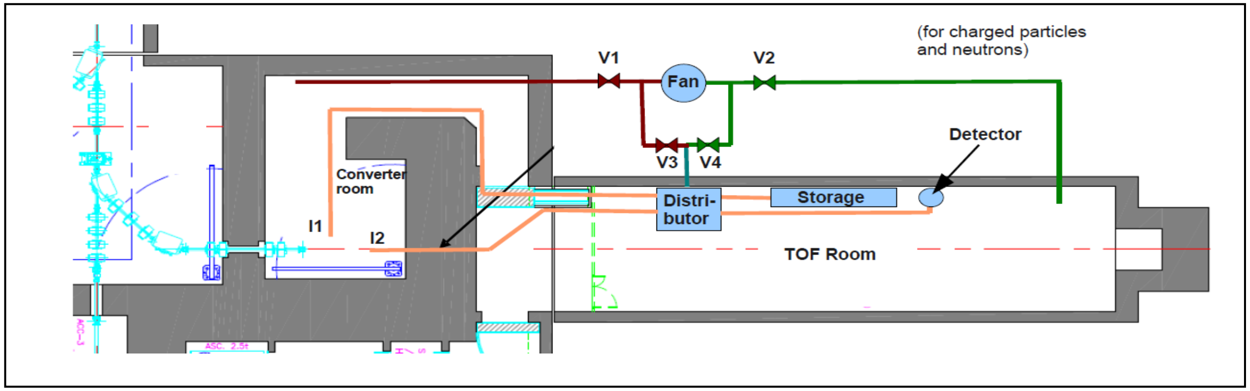


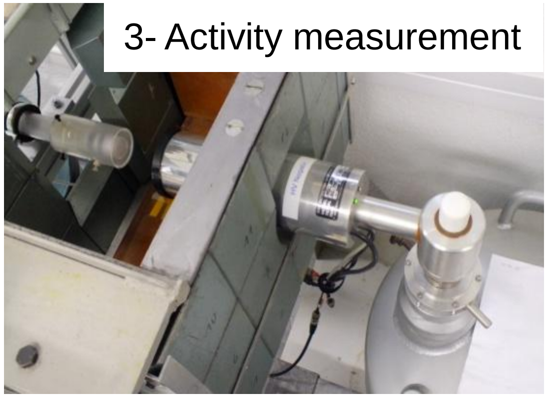
or

ion induced reactions



2- Transfer of sample to TOF room





Cross-section measurements by activation method
Study of radioisotope production

Physics case and first experiments

LoI and proposals for Day-One experiments at NFS

In blue : new proposals presented during the NFS workshop

- 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*

  SCALP - Scintillating ionization Chamber for ALpha particle Production in neutron induced reaction, G. Lehaut

- 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

  Measurements of prompt fission neutron energy spectra for fast neutron induced fission on major and minor actinides, A. Sardet

  Measurement of prompt fission gamma-ray spectra in fast neutron induced-fission of actinides, J.M. Laborie

  Gamma-rays spectroscopy and lifetime measurements at NFS, A. Dijon

- 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

  Measurement of cross-sections of deuteron-induced reactions on Ni and Zn, J. Grinyer

- Biology :

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

  R&D for the production of radioisotopes for medical applications at NFS, G. De France

  Investigation of ^{211}At and ^{64}Cu medical radioisotope production at NFS, J. Grinyer

- Detector development :

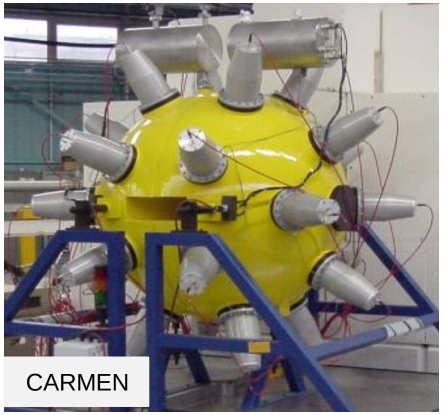
  LoI_29 : Neutron spectrometer characterization for LMJ project, *B. Rossé*

  Characterization of neutron signal in Si-CsI telescope and measurement of the absolute neutron detection efficiency, E. Bonnet

Study of (n,X) reactions

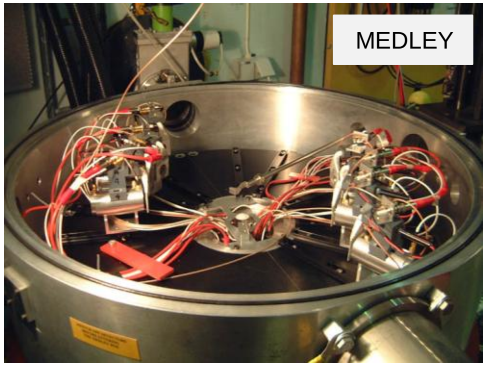
❑ (n,xn) reactions

- Main part of the cross-section
- Accurate measurements up to 40 MeV of :
  - cross-section
  - neutron multiplicity
- 4π neutron detector
- (n,n'γ)-technique (GAINS)



❑ (n,LCP)

- Gazes and default production
- Energy deposition in therapy
- Composite particle prediction → no model works
- Double differential measurements (MEDLEY)
- Few data exits between 20 and 50 MeV

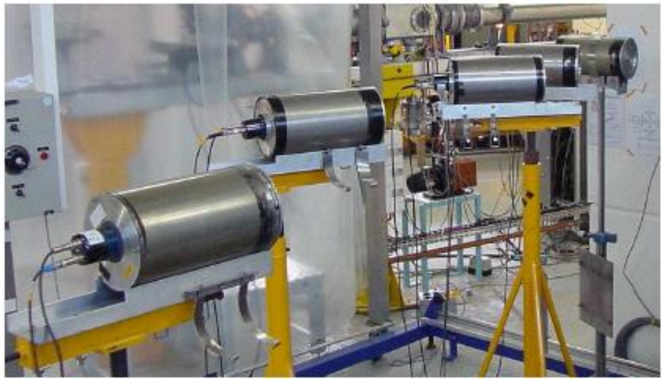


❑ Advantage of NFS

- High flux
- Collimated neutron beam
- Energy range and energy resolution

Neutron induced fission

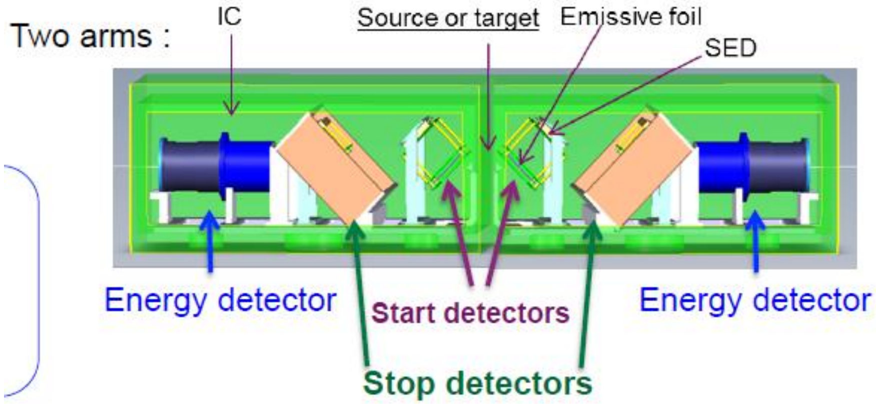
- Need of data for fast neutron essentially for minor actinides **(ADS, GEN IV reactors)**
  - Cross-section measurements
  - Neutron, gamma multiplicity and spectra
  - Fragment yields → residual heat in the reactors



- Study of the fission process
  - fission fragment mass and charge distributions
  - ff kinetic energy (deformation energy, scission conf)
  - neutron multiplicity (deformation energy)
  - Need of data below the 2nd chance fission and beyond

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

- Experimental set-ups
  - Fission chambers, active targets
  - MEDLEY, FALSTAFF,....

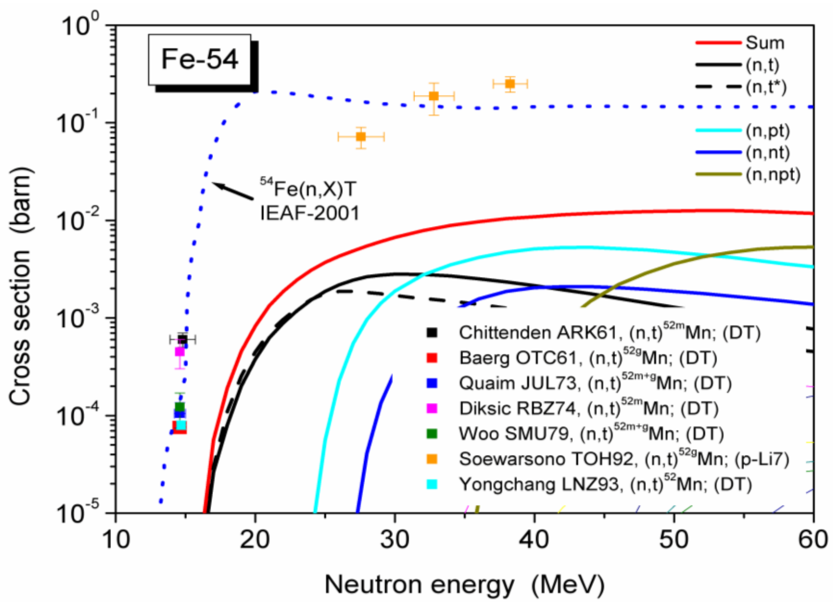


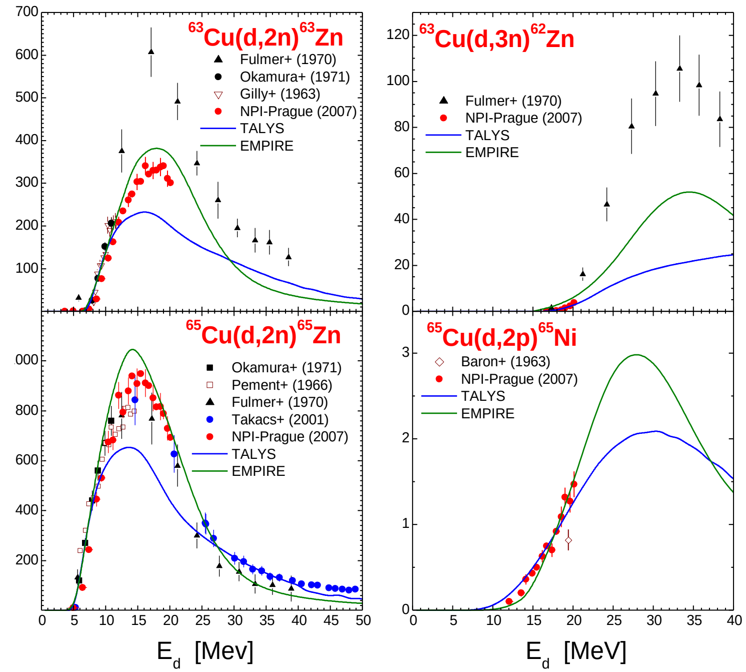
- Advantage of NFS
  - High flux
  - Energy resolution
  - Use of actinide samples

Neutron, 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.

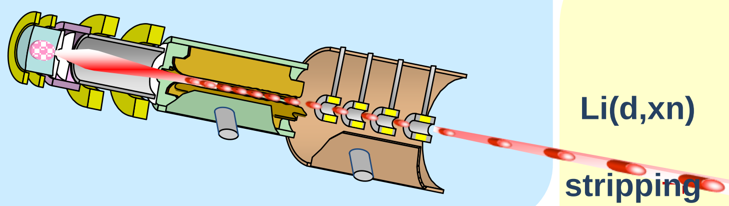




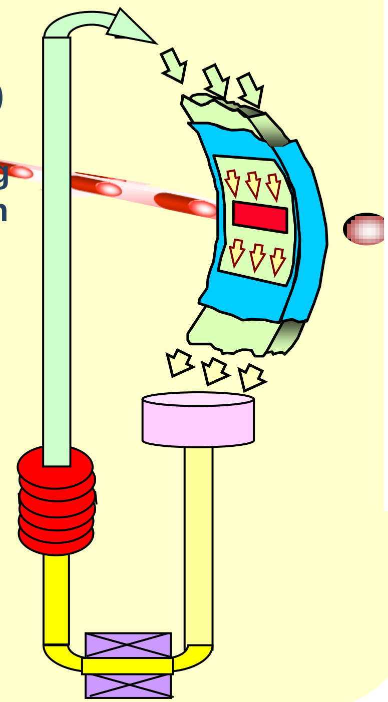
Nuclear physics experiments at IFMIF

Accelerator

Deuterons: 40 MeV 125 mA (5 MW)

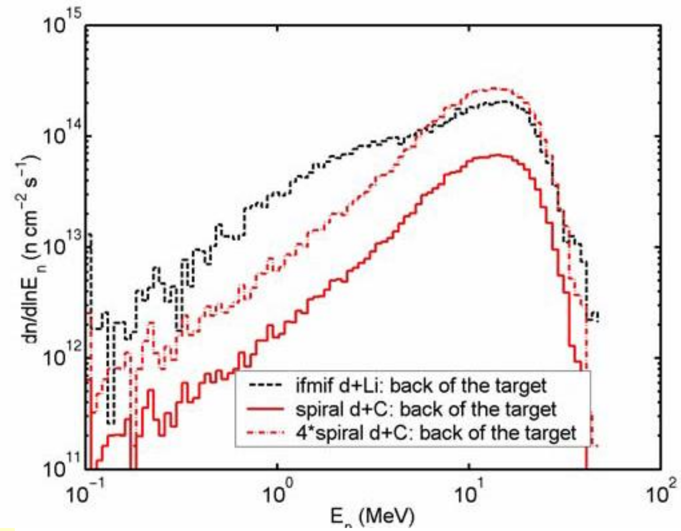


Lithium Loop (Target)



Deuterons at 40 MeV
collide on a liquid
Li screen
flowing at 15 m/s

Courtesy: A. Ibarra, P. Barabaschi, A. Moeslang,
J. Knaster, R. Heidinger for the IFMIF Team



- Neutron energy spectrum similar to NFS
- Very high flux 10^{18} n/s/m^2

→ ≈1000 times higher than at NFS

Very interesting tool for physics

Characteristics of a neutron facility

- Main characteristics :
  - Energy range
  - High neutron flux
    - Samples of small mass (enriched, radioactive)
    - Small cross-section measurements
    - Low efficiency detection set-up

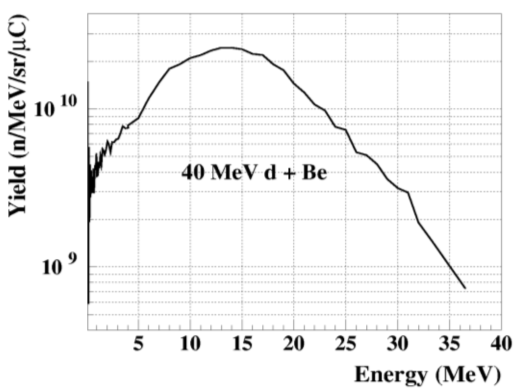
- Important parameters :
  - Neutron energy measurement
    - Differential measurement
    - Excitation functions measurement
  - Neutron and photon background
    - Use of photon and neutron detectors
    - Use of fissile targets

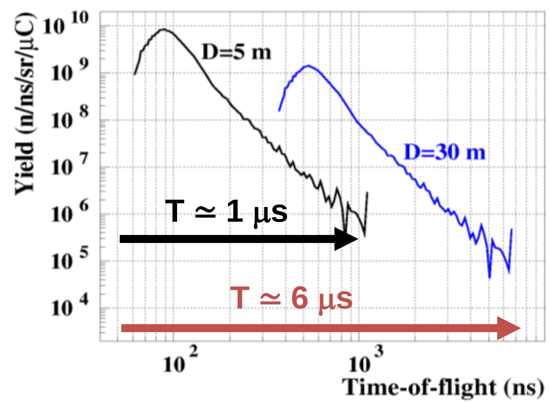
Energy measurement

Neutrons are not mono-energetic

E measurement by time-of-flight ⇒ Pulsed beam

- **The energy range is defined by the beam frequency and the flight path:**





100keV<E<40MeV

L= 5 m ⇒ **T≈1 μs**

- **The energy resolution is defined by the time resolution and the flight path**

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

Energy resolution for 40MeV neutron:

Δt = 1 ns

L = 5 m ⇒ ΔE/E < 6%

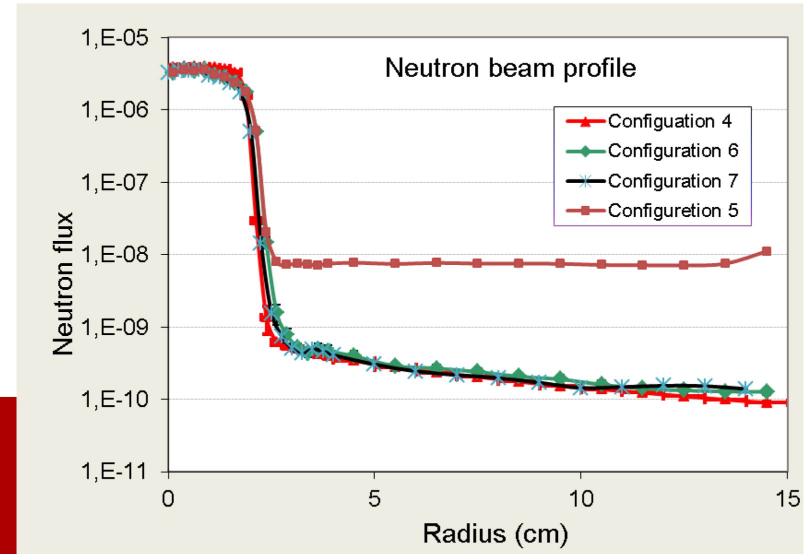
L = 20 m ⇒ ΔE/E < 2%

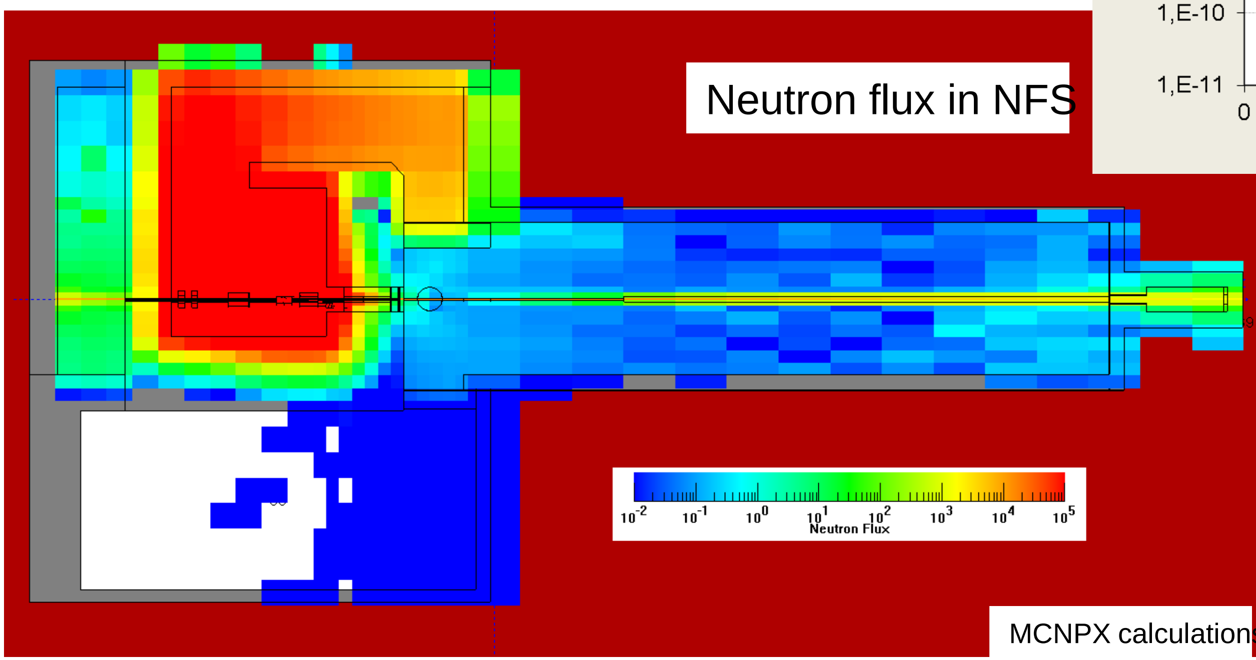
Δt = 7 ns

L=20m ⇒ ΔE/E < 5%

Neutron and photon background

- **Neutrons are produced in 4 π → Shielding for the detection set-up**
  - Detector shielding
  - Collimator → Beam profile
  - Neutron beam dump → Background
- **Very intense neutron flux :**
  - Photon background from activation
  - Choice of the materials





Summary

❑ NFS:

- **Characteristics:**
  - White and quasi-mono-energetic spectra in the 1-40 MeV range
  - Neutron beams with high flux and good energy resolution
  - Measurements by activation reactions (n, p, d)
- **Physics case**
  - Fission studies : σ, fragments, yields, neutron and gamma multiplicities
  - (n,xn) and (n,lcp) reactions: σ and $d^2\sigma/dEd\Omega$
  - Deuteron and proton induced reactions
  - Detector development, Biology

❑ IFMIF/DONES:

- **Powerful tool for nuclear physics**
  - Energy range
  - Very high flux
- **To increase the interest :**
  - Pulsed beam → F < 1MHz
  - Experimental area(s) with very efficient shielding