IFMIF DONES for non fusion applications

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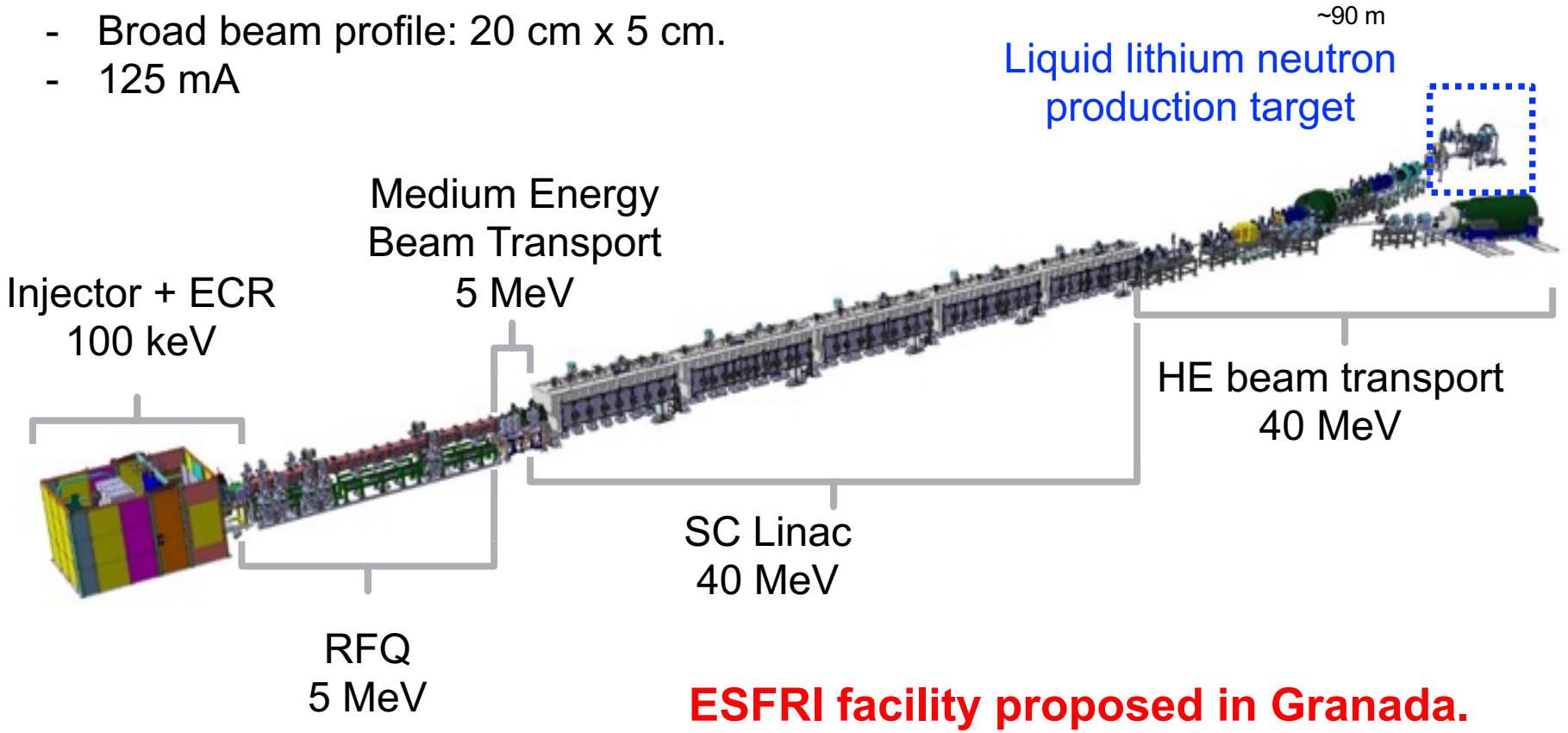
on behalf of the Spanish Nuclear Physics Network
fNUC@DONES study group

Demo Oriented NEutron Source - DONES

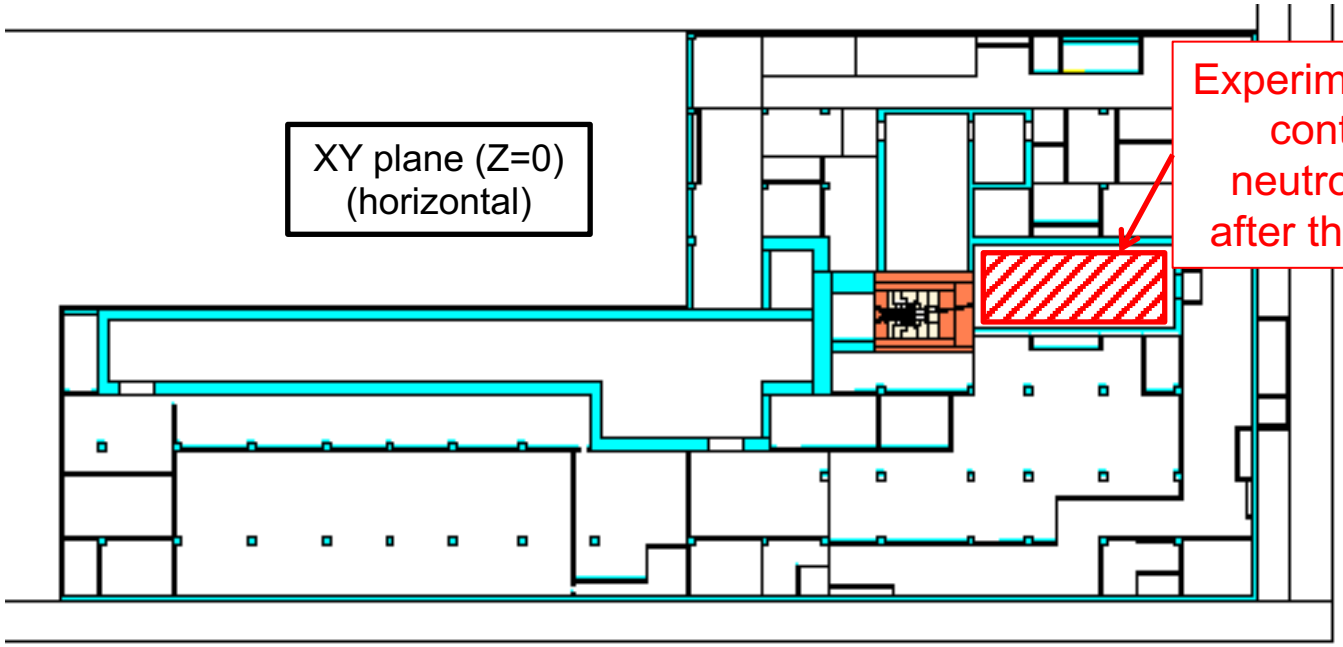
One of the most powerful accelerators in the world:

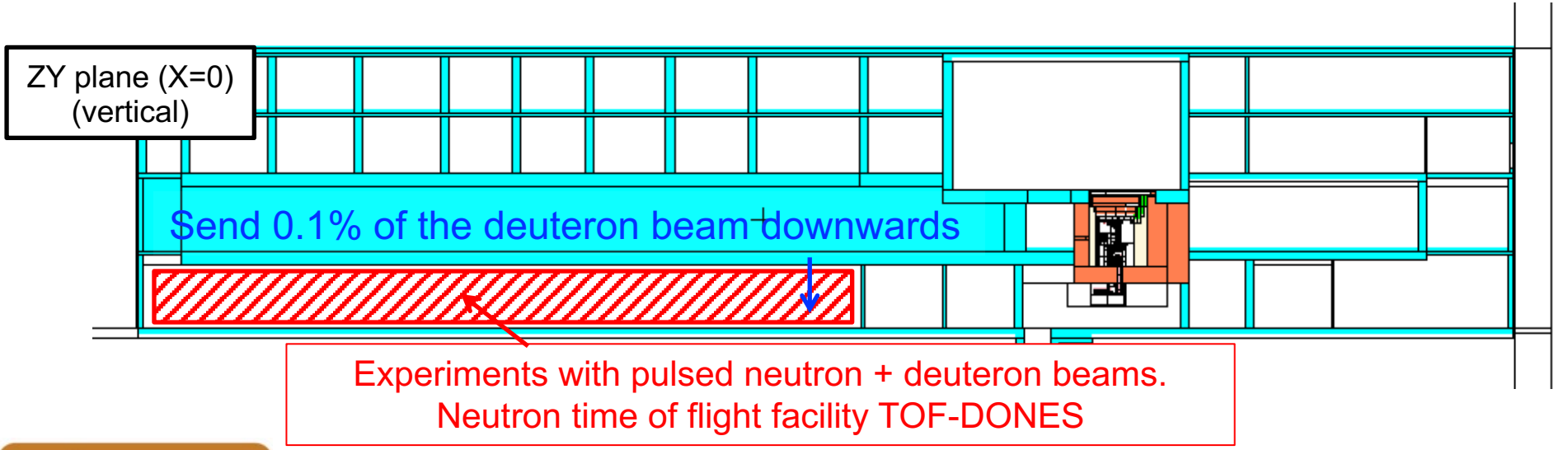
- 40 MeV deuterons.
- Broad beam profile: 20 cm x 5 cm.
- 125 mA



ESFRI facility proposed in Granada.

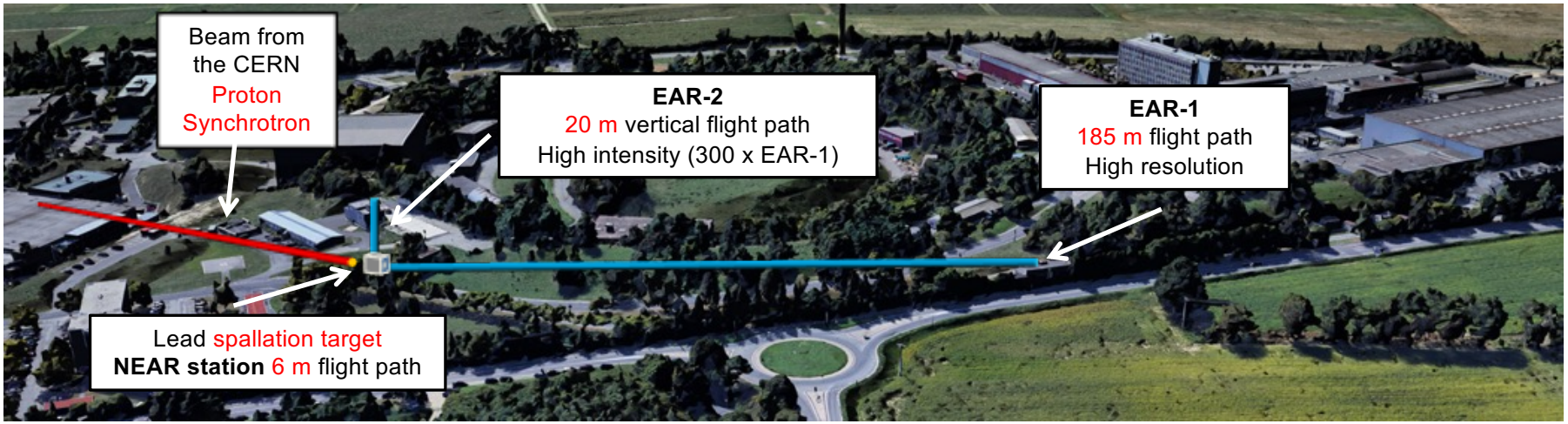
The DONES facility





Spanish experience with neutron beams

Spanish institutions form **20% of the collaboration** and are **leading 20% of the experiments. Large experience** in neutron physics and nuclear instrumentation (FAIR, n_TOF and ISOLDE @ CERN…)



- Experiments at **ILL-Grenoble** and other experimental reactors.
- First Spanish proposals at the new **Neutrons For Science (NFS) facility** at SPIRAL-2 (France).

What could we do at DONES?

Experiments with **continuous** and **pulsed neutron beams**.

I. Fundamental nuclear physics

http://fnuc-at-dones.es/

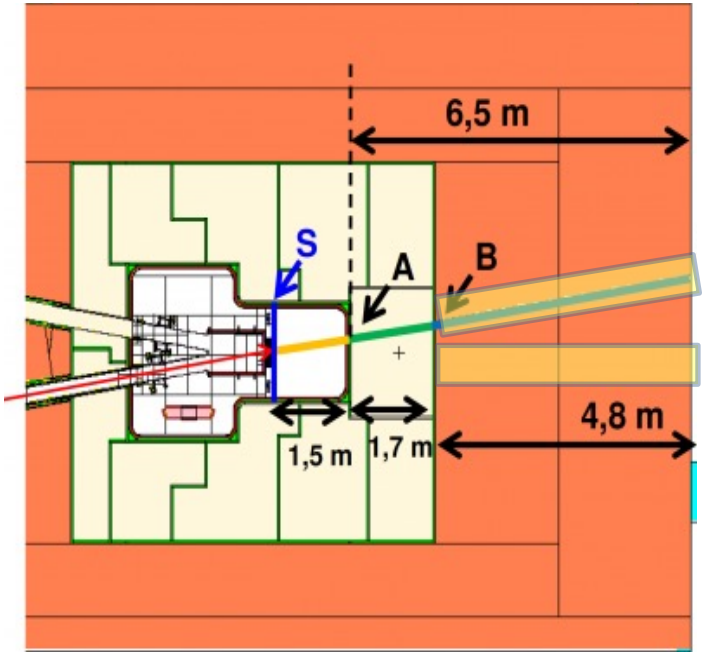
- Nuclear reaction studies
- Nuclear structure studies
- Calibration and development of instrumentation

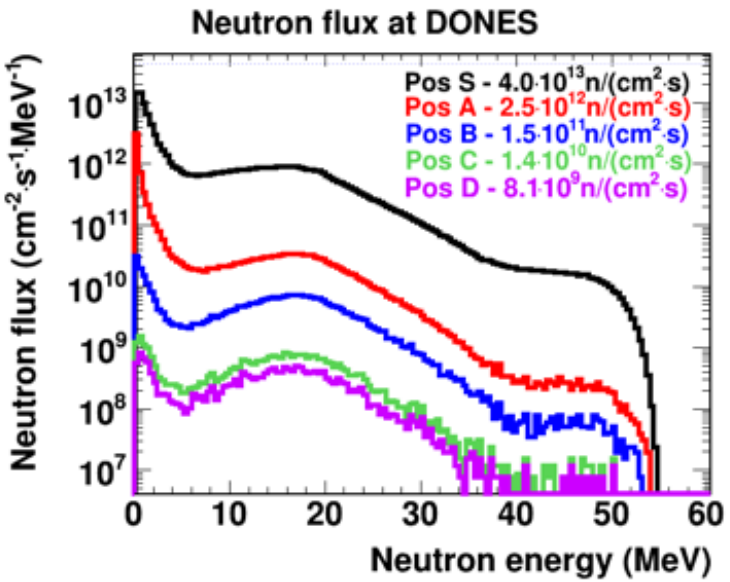
II. Nuclear physics & industrial applications

- Nuclear data for nuclear technologies: fission, fusion, space, medical applications
- Radiobiology
- Material science
- Neutron imaging
- Isotope production for various purposes (medical, radiotracers, industry…)
- Irradiation of electronics
- Irradiation of plant seeds
- R&D on cargo inspection and homeland security

Applications with continuous neutron beams

Applications

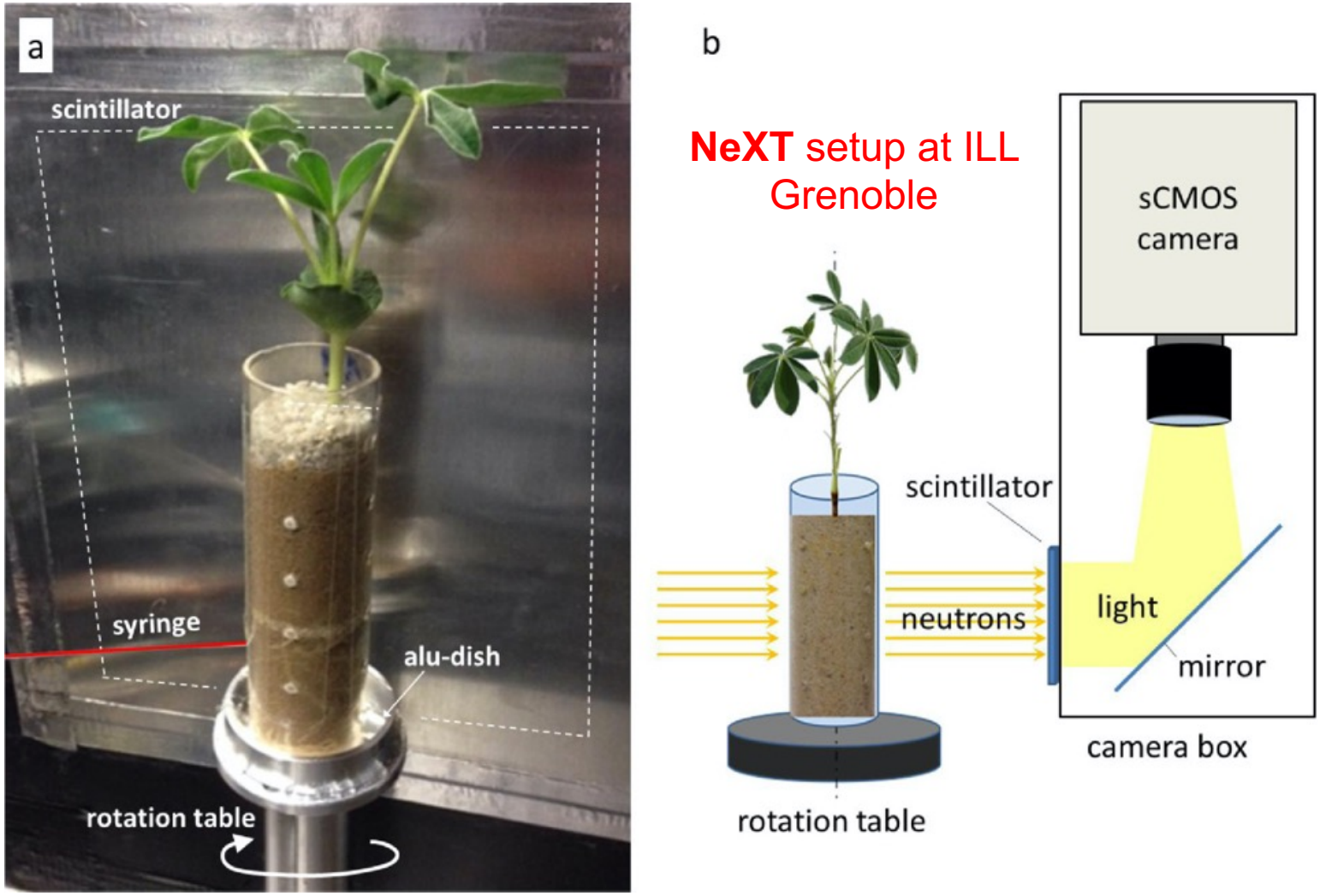




Neutron beam crossing the Sample irradiation module (HFTM):

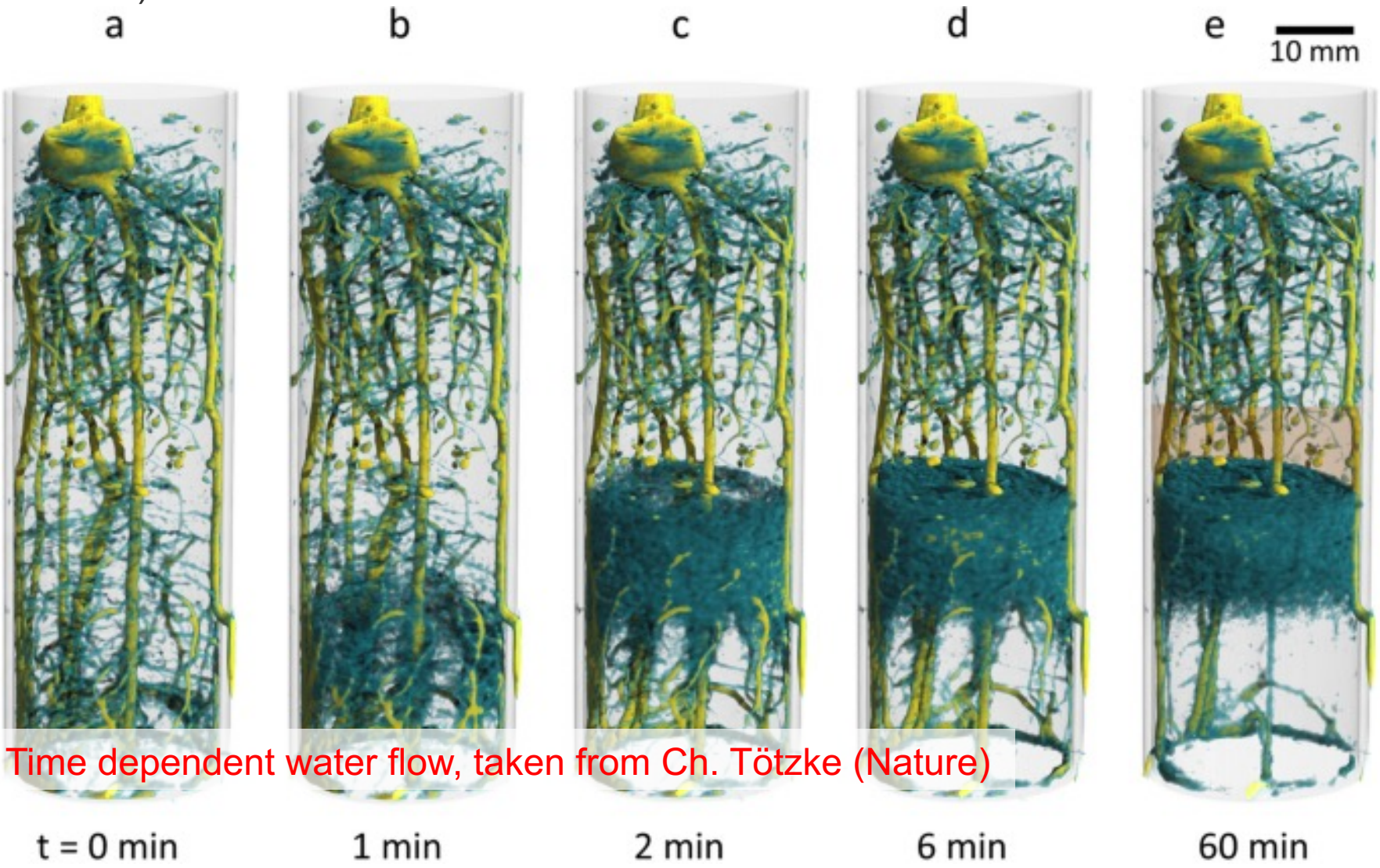
- **Production of isotopes.** A large variety of isotopes for applications (medical, radiotracers…) and science.
- **neutron imaging** with continuous cold neutron beams for science and industry.
- Material composition analysis via **neutron activation techniques.**
- **Irradiation of electronics**. Single event effects, sensor calibration & development.
- **Radiobiology**. Irradiation of cell cultures. DNA damage. Impact on radiotherapy, space missions…
- **Irradiations of seeds** (for inducing valuable mutations).

Fast neutron imaging



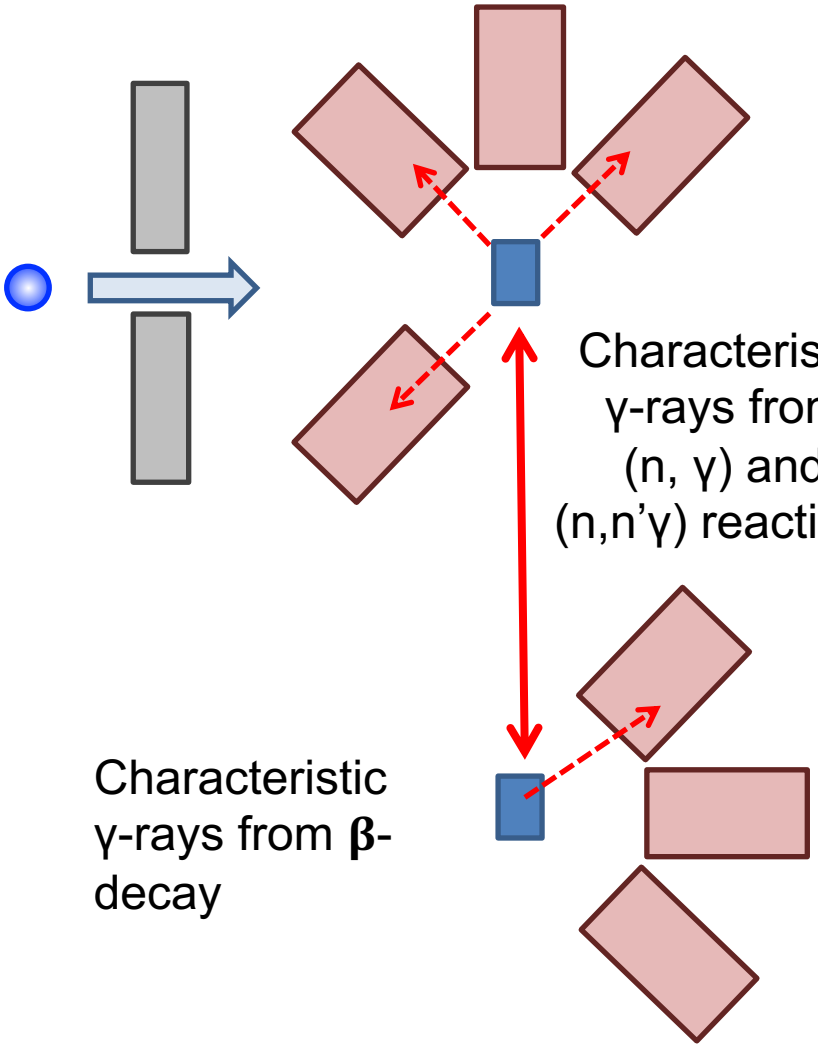
Ch. Tötzke et al.,High-Speed Neutron Tomography at ILL," Opt. Express **27,** 28640 (2019)

3D imaging (by rotating the sample) and 4D (in steps of a few seconds - minutes).



Time dependent water flow, taken from Ch. Tötzke (Nature)

Prompt and Decay Gamma neutron Activation Analysis



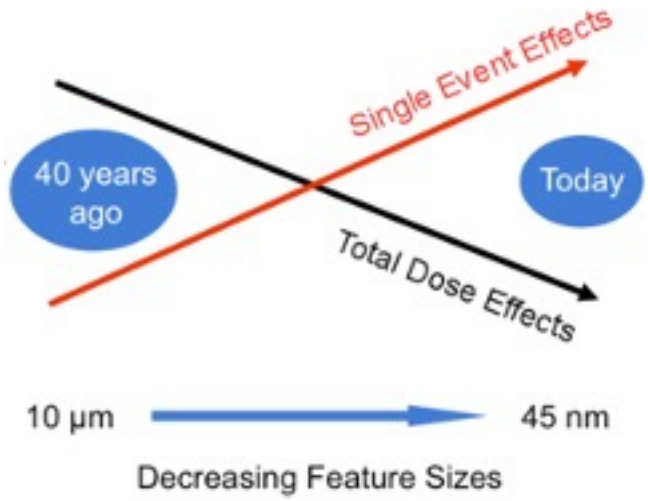
A non-destructive technique:

Irradiation wit thermal or fast neutrons. Detection of the characteristic γ-rays from:

- (n,n'γ) and (n, γ) reactions during the irradiation - Prompt Gamma Neutron Actitation (PGNA)
- From the **β**-decay – Decay Gamma Neutron Activation.

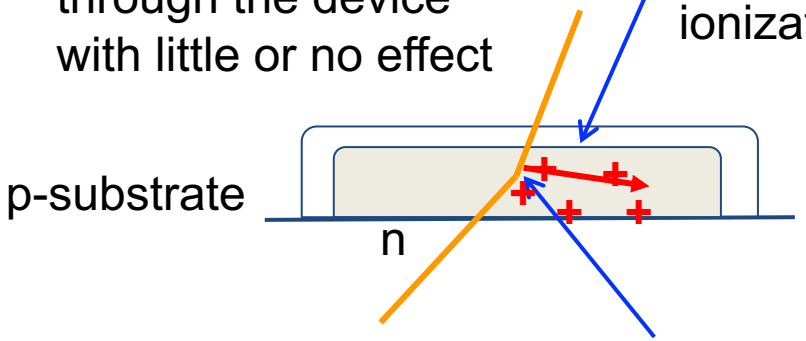
High sensitivity: materials in the mass range from picograms to miligrams.

Electronics: SE-effects, sensor calibration & development



Most neutrons pass through the device with little or no effect

Short-range recoil produces ionization



Few neutrons make nuclear reactions $^{28}Si(n,p)$, $^{28}Si(n,d)$, $^{28}Si(n,\alpha)$, etc

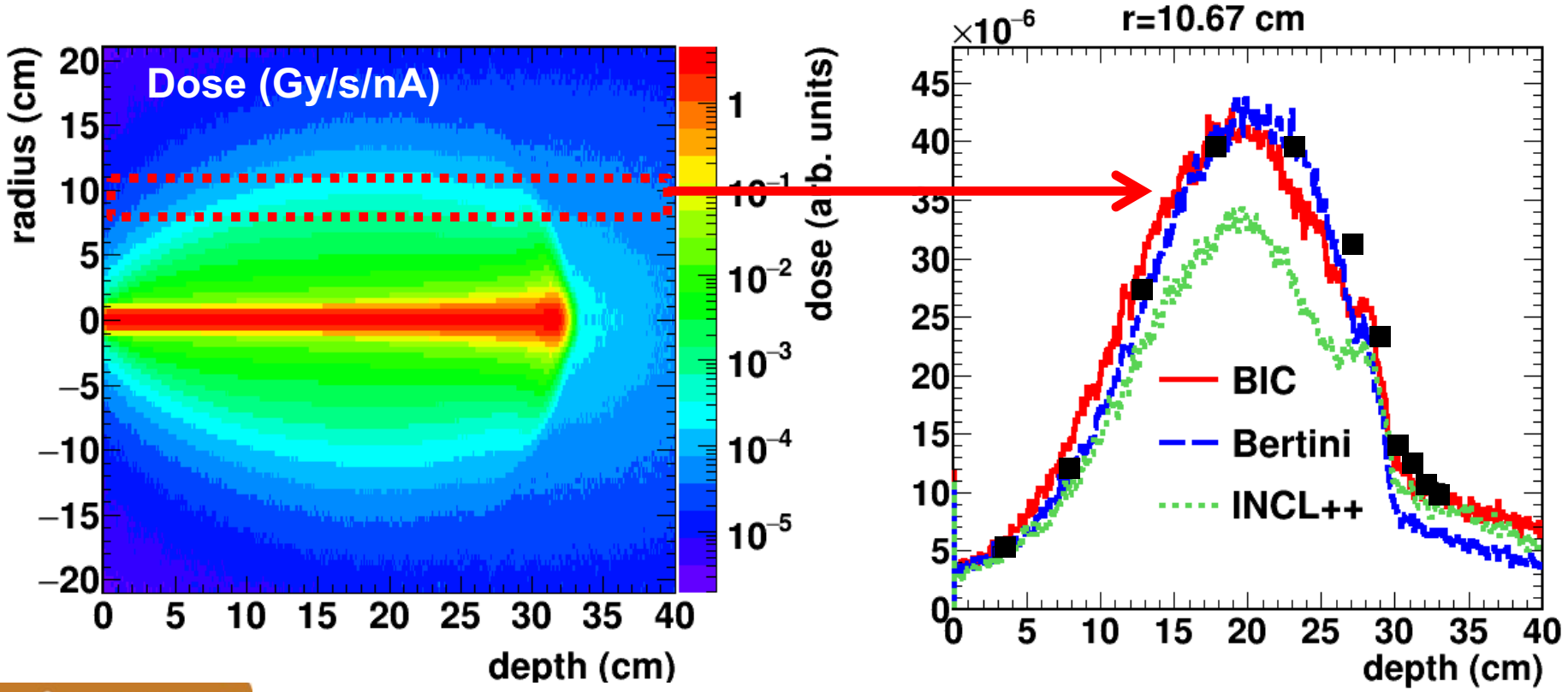
Use the continuous high energy neutron beam (and deuterons if possible) to:

- Induce and study Single Event effects (SE-effects) in semiconductors.
- Develop neutron dosimeters based on semiconductors.
- Calibration many different types of sensors.

Irradiation of cell cultures

Impact of radiation on living cells. Improve the knowledge of relative biological effectiveness of radiation. Impact of neutrons in the far from field dose in a proton therapy treatment.

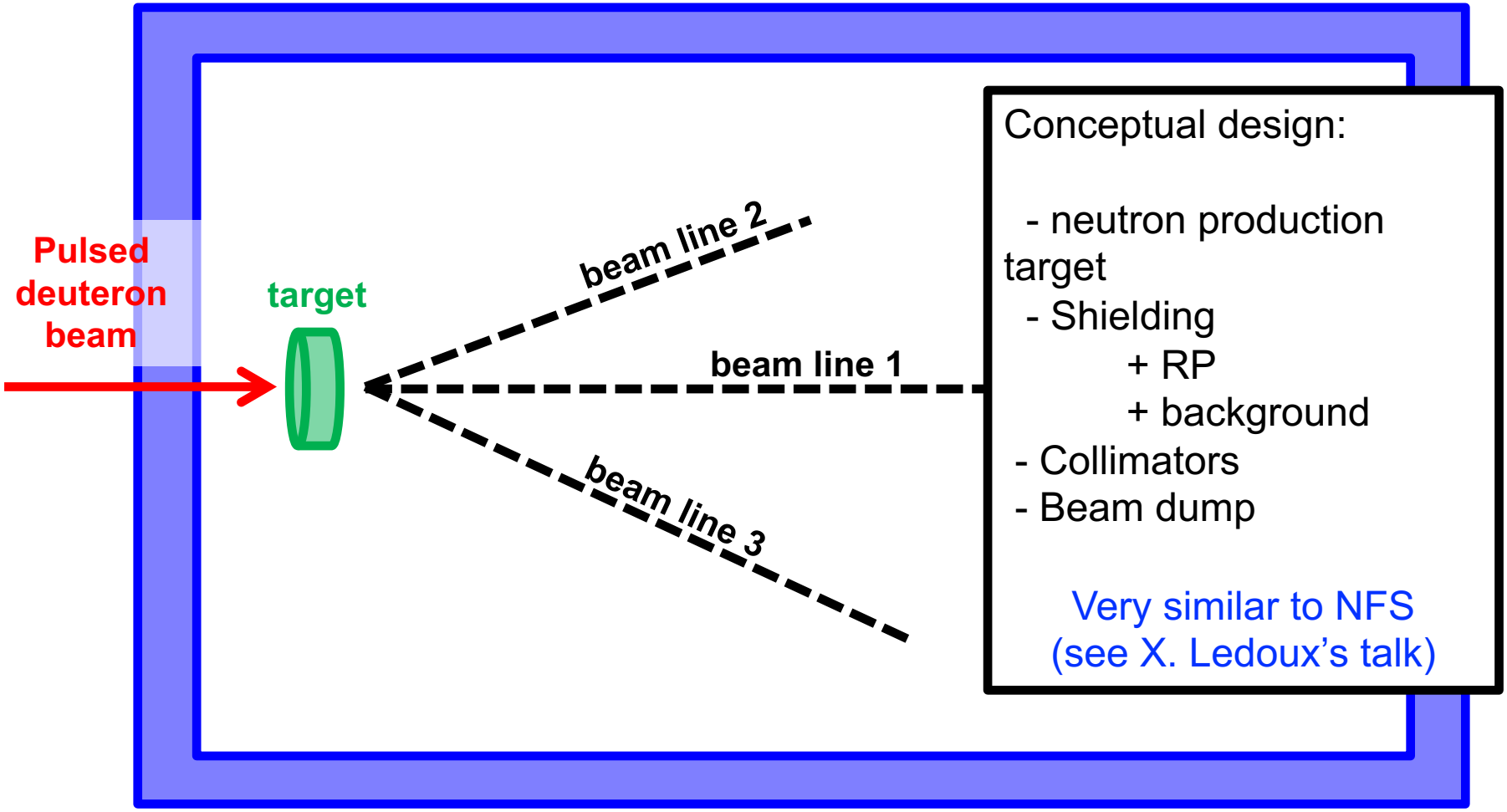
- Experiments for the determination of **cell survival rate**, **DNA damage**, **chromosomic aberrations** ... Use of gold nanoparticles GNP.



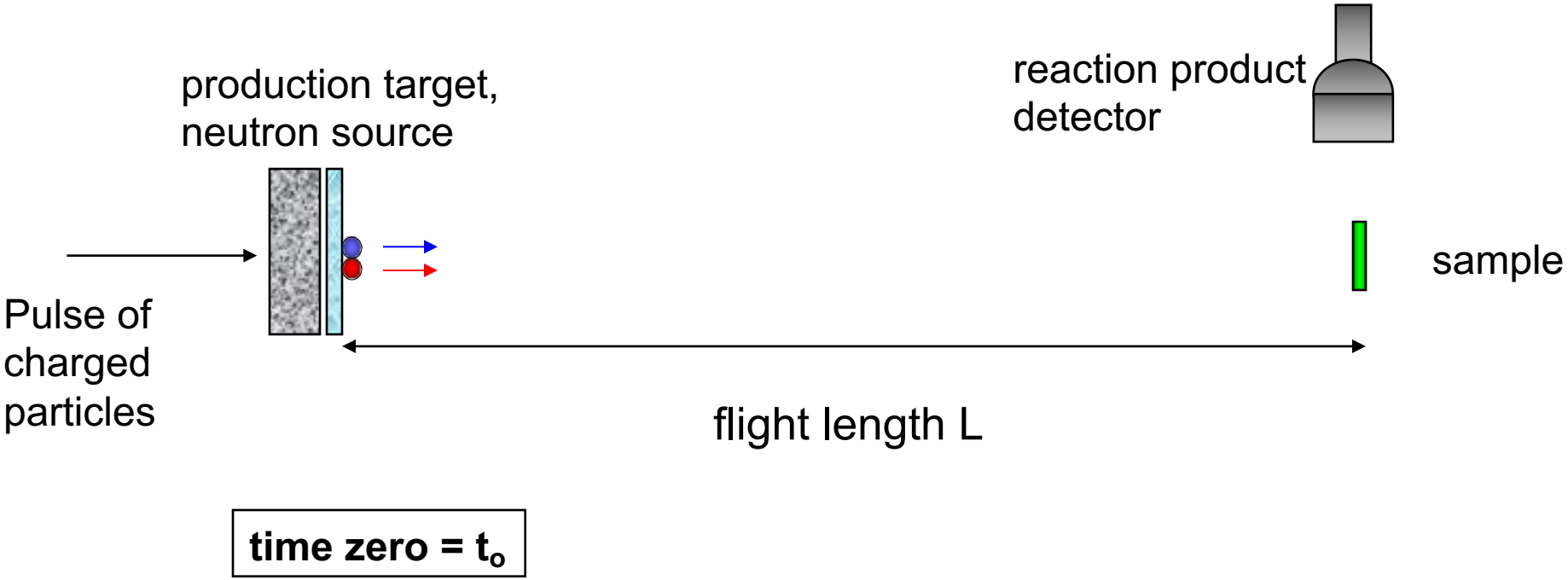
Applications with pulsed neutron beams

The TOF-DONES neutron time of flight facility

Use of ~5 ns broad deuteron pulses at a 175 kHz repetition rate. Requires only 0.1 % of the IFMIF DONES beam beam.

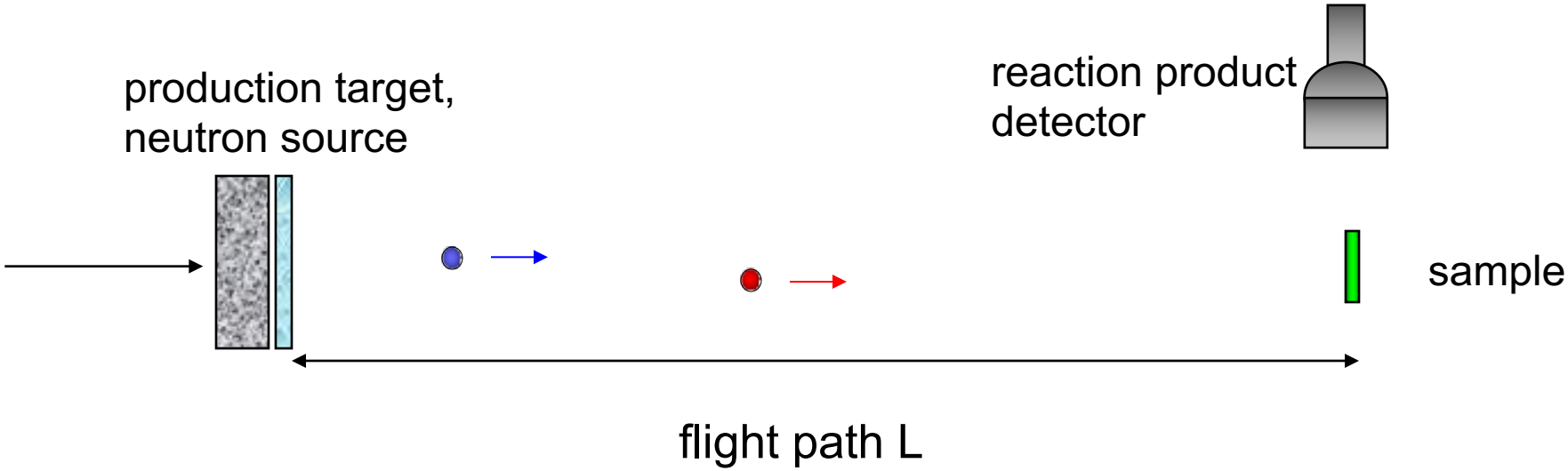


Time – Of – Flight technique

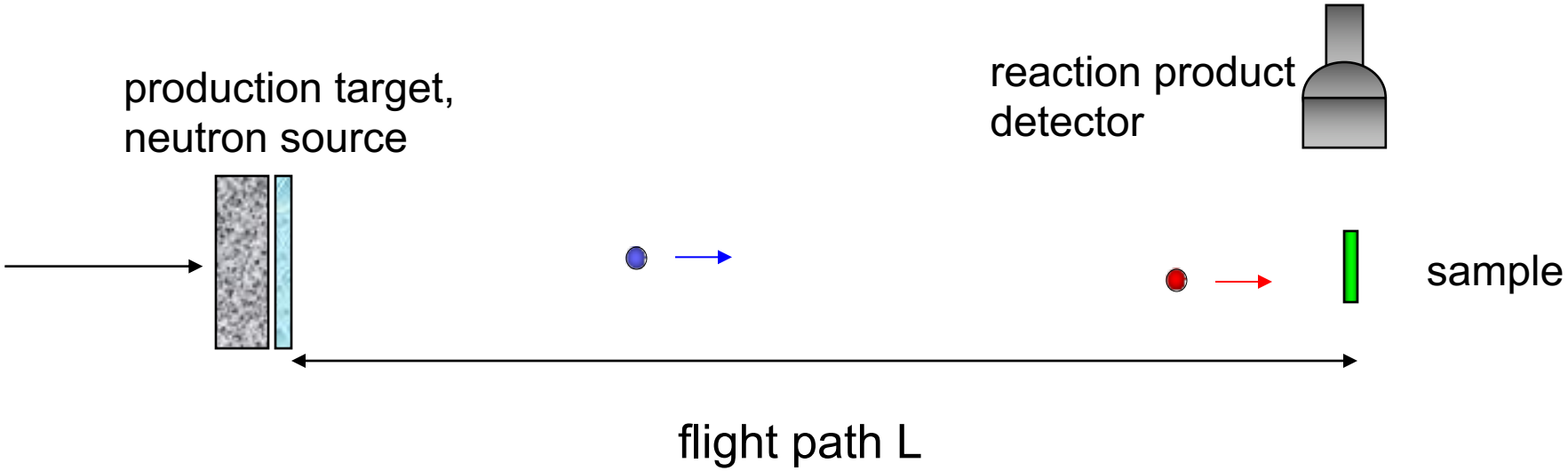


time zero = t_o

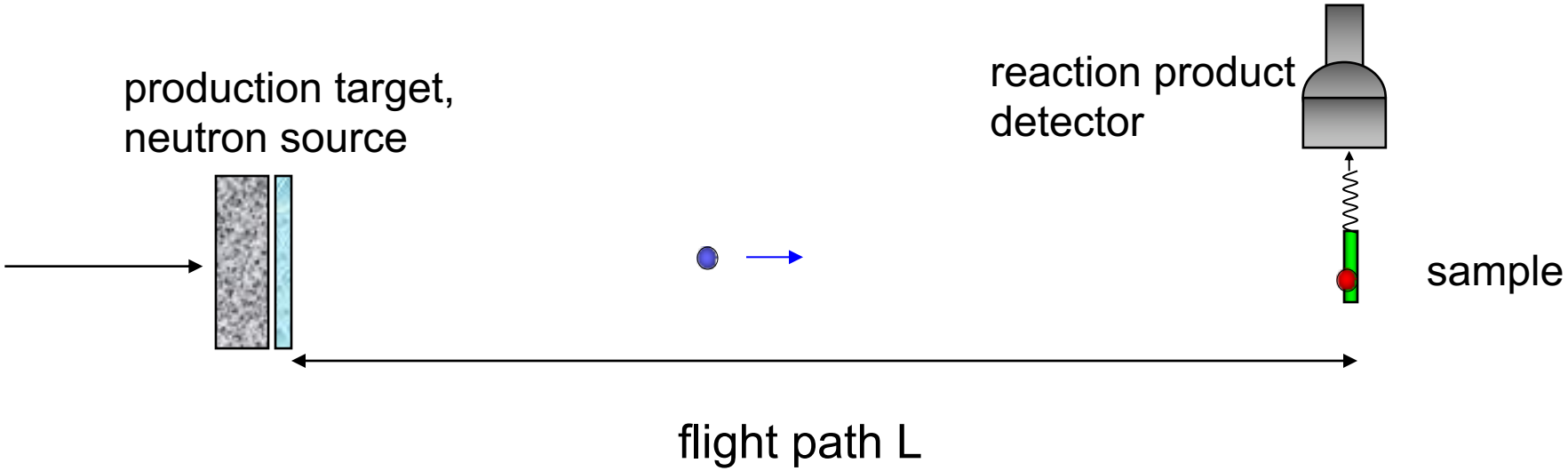
Time – Of – Flight technique



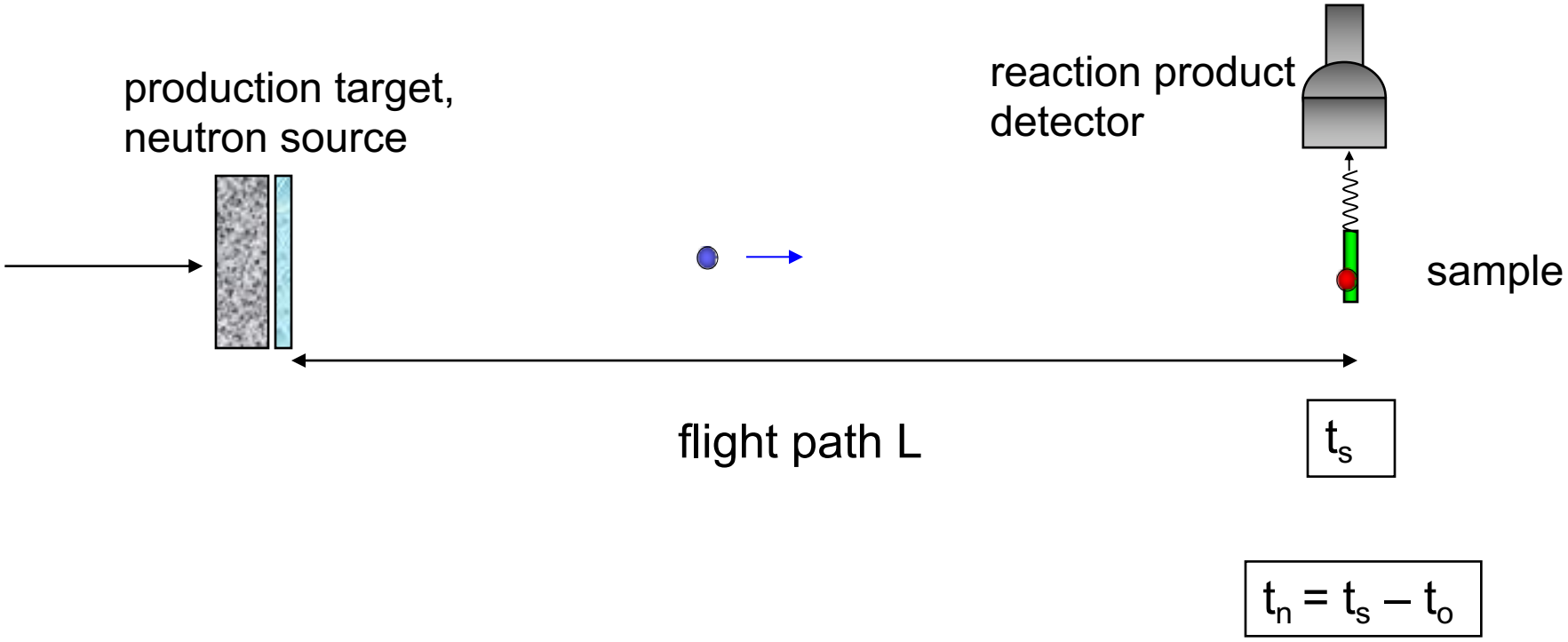
Time – Of – Flight technique



Time – Of – Flight technique

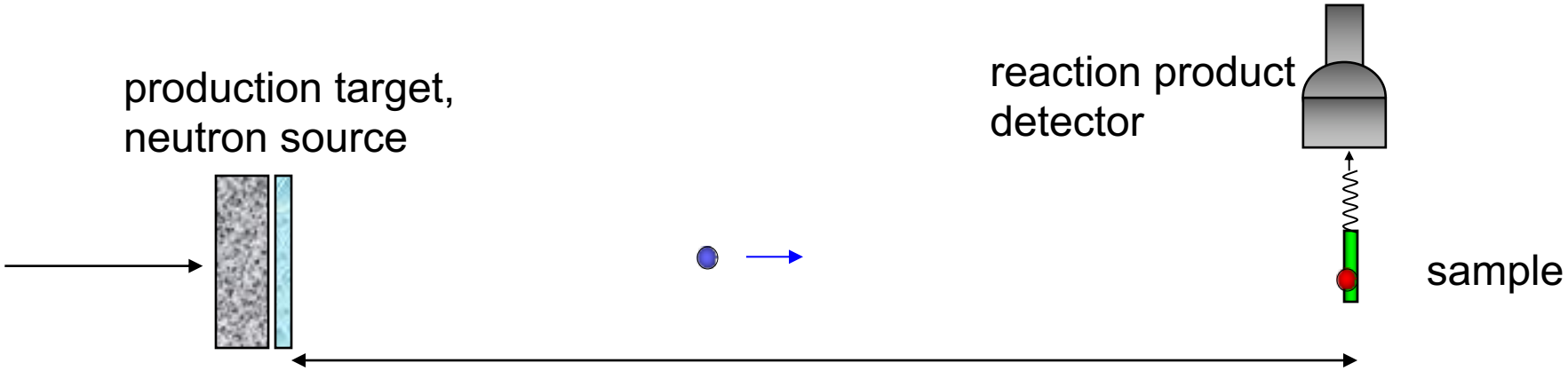


Time – Of – Flight technique



$$t_n = t_s - t_o$$

Time – Of – Flight technique



$t_n = t_s - t_o$

Kinetic energy of the neutron by time-of-flight

$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1 - \left(\frac{v_n}{c}\right)^2}} - 1 \right)$$

$$v_n = \frac{L}{t_n}$$

The TOF-DONES preliminary concept

Included in the “Identification of Complementary Experiments in R026 and Preliminary Safety Implications”.

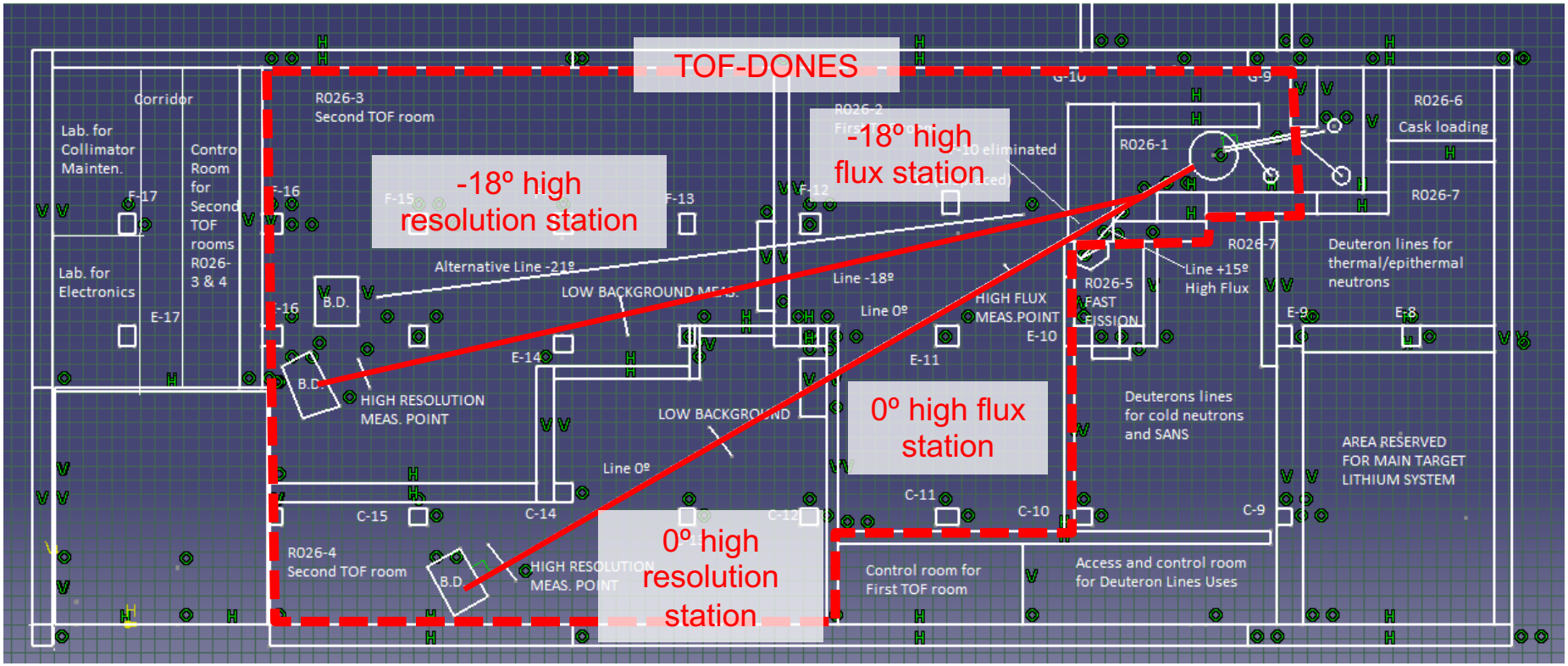
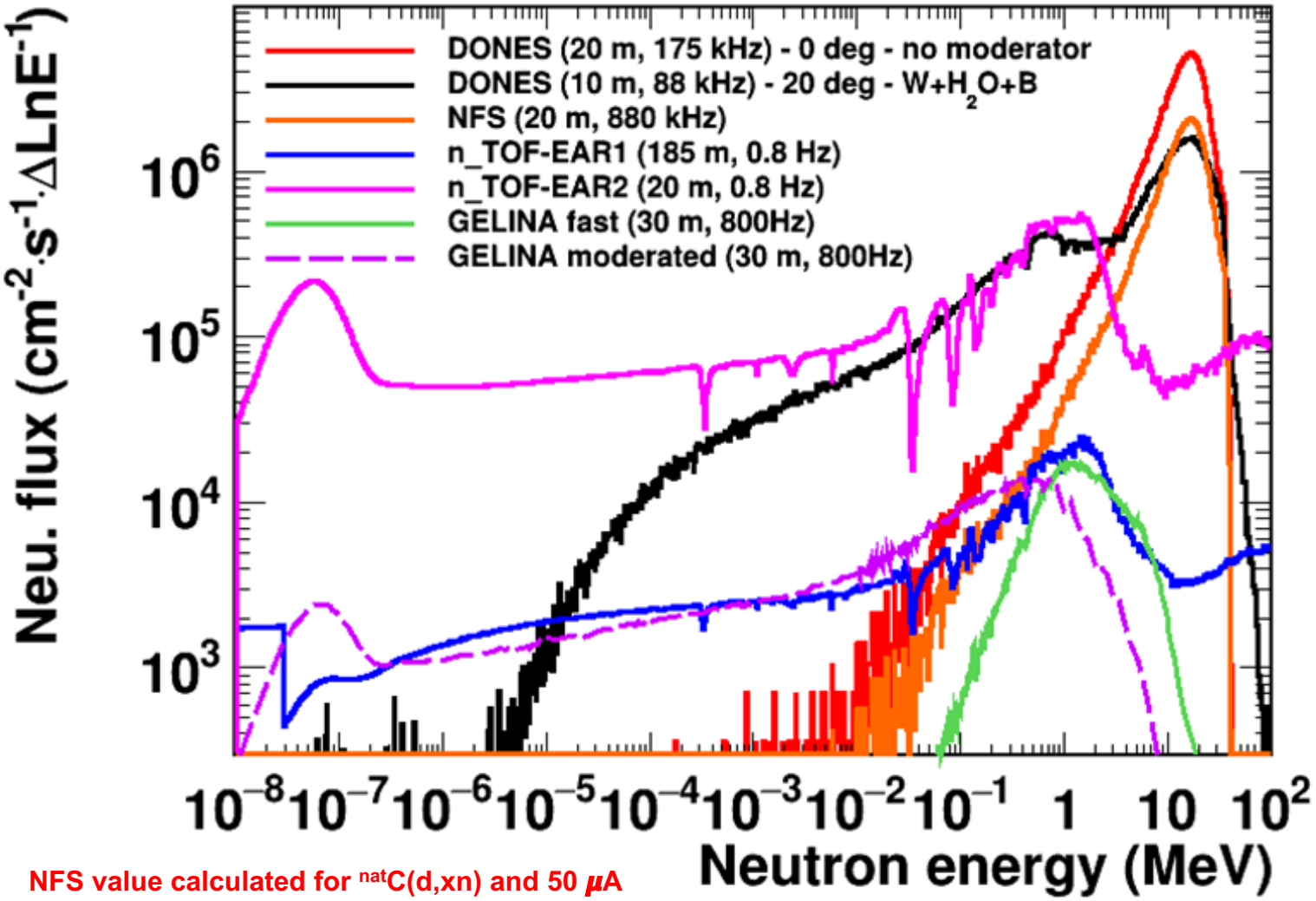


Image courtesy by P. Ortego / SEA Ingeniería p.ortego@seaingenieria.es

Comparison of TOF-DONES with other facilities

20 m TOF distance + 125 μA deuterons (0.1% of the IFMIF-DONES beam) on thick graphite



NFS value calculated for ^{nat}C(d,xn) and 50 μA

The TOF-DONES experimental program

Answering the question of "**what happens when a given material (isotope) is bombarded with a neutron?**":

- **How probable is the reaction as a function of the neutron energy?**
- **What are the secondary particles emitted?**

Very important for nuclear technologies (fission and fusion), astrophysics, astro-particle physics, dosimetry, space missions, cancer treatments…

There is a huge experimental program to be covered. The identified priorities require already **decades of beam time** (n_TOF, NFS, nELBE, GELINA):

- 52 isotopes listed in the **High Priority Request List** for nuclear technologies (also for fusion).
- Over **35 (n,γ) prioritary cross section measurements** for astrophysics.

Non fusion applications and industry

IFMIF-DONES could **boost** the Spanish (and international) **nuclear science** and **science industry**. It will also offer important **business opportunities**:

- Engineering: design and construction.
  - Shielding/target materials.
  - Mechanics.
  - Vacuum technologies.
  - Superconducting magnets.
  - Cryogenics.
  - Electronics (power, low power).
- Nuclear instrumentation and detectors.
- Information technologies (data acquisition, data centres, hardware).

Opportunities for the science business:

- Neutronic characterisation of materials (isotopic identification, activation…)
- Radiation hardness of electronics.
- Production of isotopes for various applications.
- Development of detectors, sensors and realisation of tests/calibrations.
- Education and training.

Summary and conclusions

IFMIF DONES offers unique and superb scientific and technological possibilities.

- **Cover a lack of high intensity neutron sources in Spain** for fundamental and applied research.
- Offer vey **high intensity** and **high energy** neutron beams:
    - **Continuous beams** for applications.
    - Pulse beams at the TOF-DONES facility, which would be one of **world's highest intensity neutron TOF line** for nuclear physics.

- Opportunities for science industry: contributing to its **construction** and for developing **new high end products**. Neutrons are and will be even more important in the context of the ***nuclear renaissance*** experienced worldwide.
- Boost largely the IFMIF-DONES **scientific production.**
- Be a unique place for **educating and training** young scientists, engineers and technicians**.**

The Spanish Nuclear Physics community has the necessary **expertise** and **skills** for contributing to the facility's success!