GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

TOF-DONES
The Spanish nuclear physics community proposal for a neutron time of flight facility

D. Cano-Ott

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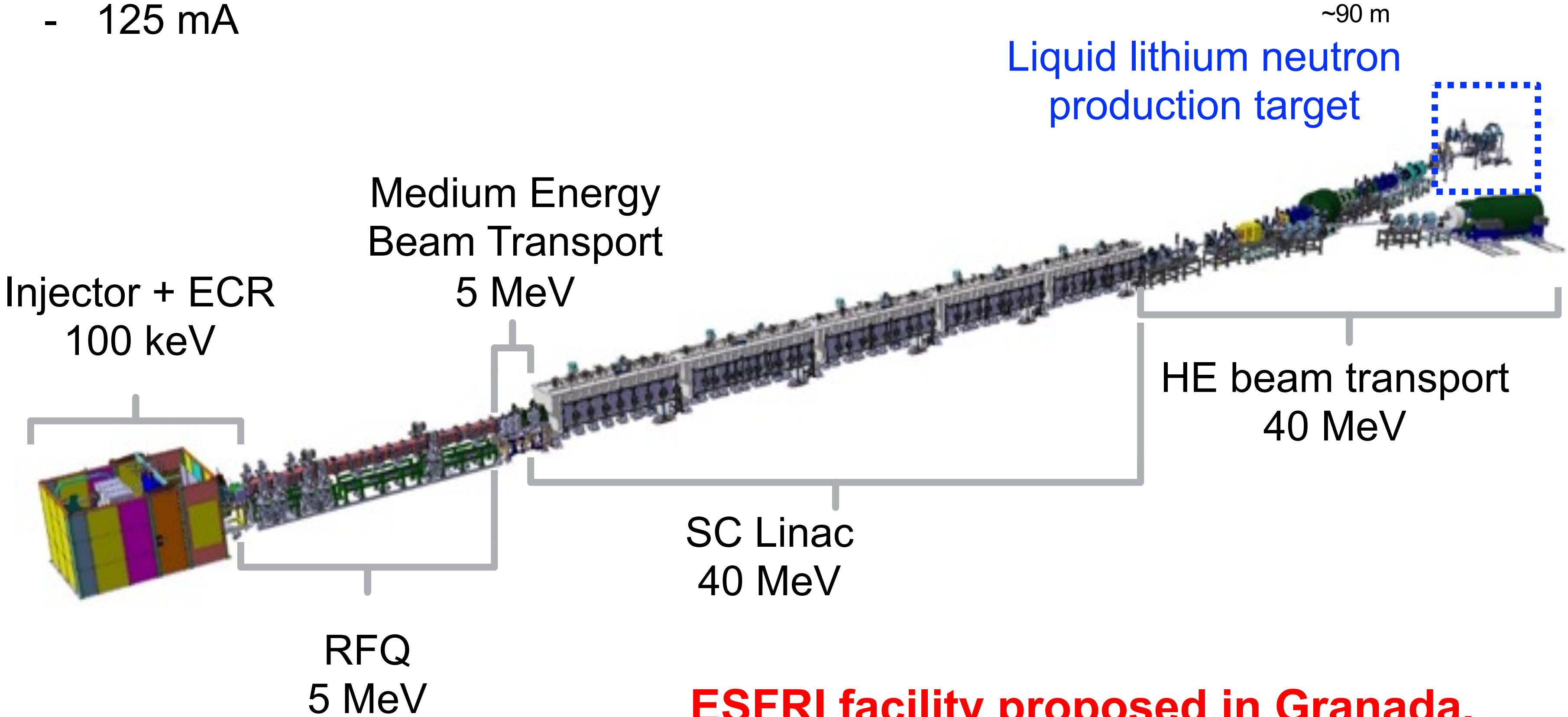
on behalf of the Spanish Nuclear Physics Network
fNUC@DONES study group

FNUC RED TEMÁTICA DE FÍSICA NUCLEAR

IFMIF – DONES Users workshop, 26th – 27th of September 2022

Demo Oriented NEutron Source - DONES

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



ESFRI facility proposed in Granada.

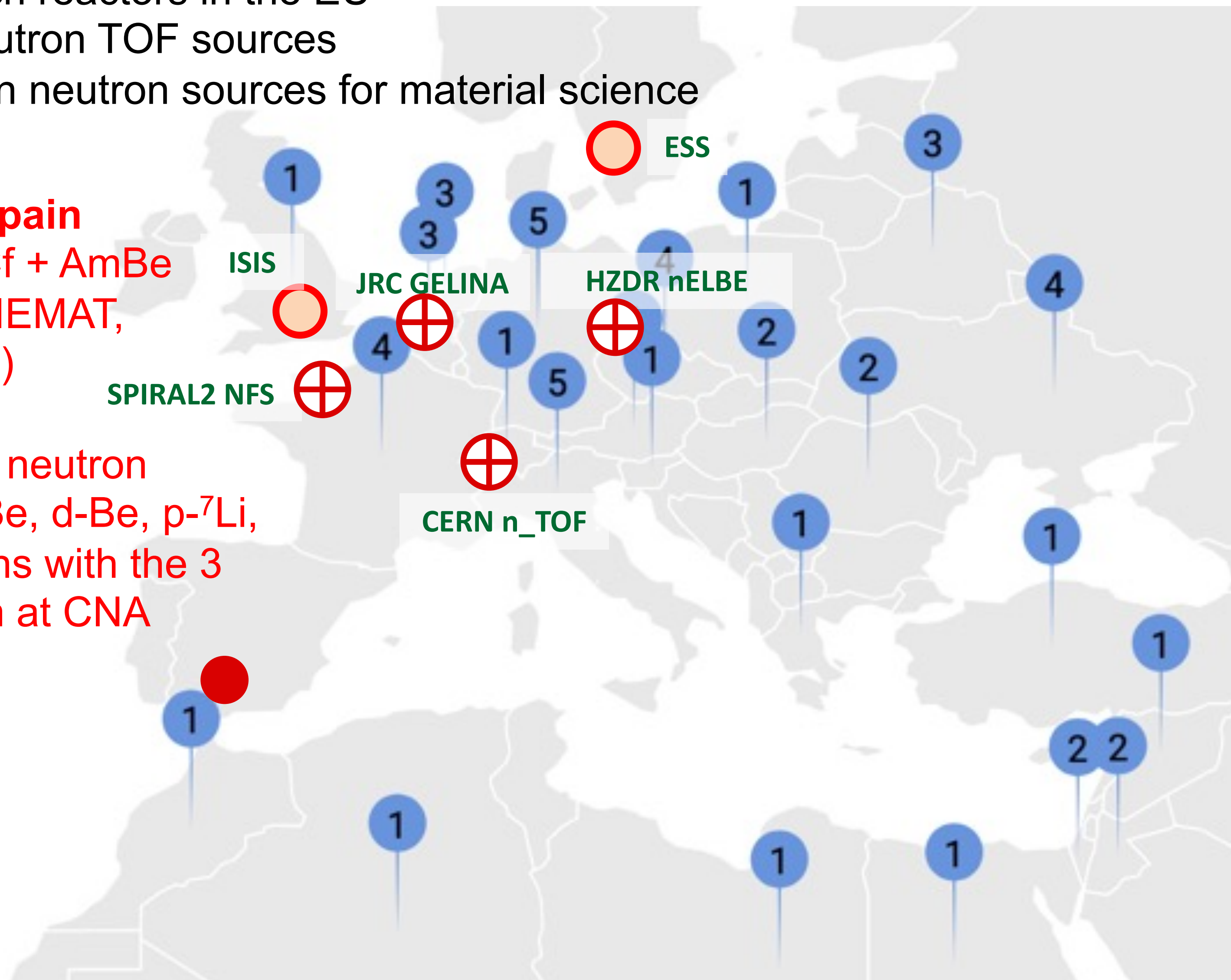
Neutron sources in Europe

33 research reactors in the EU
4 large neutron TOF sources
2 spallation neutron sources for material science

Spain

Strong ^{252}Cf + AmBe sources (CIEMAT, universities)

HISPANoS neutron source: p-Be, d-Be, p-^{7}Li, d-d reactions with the 3 MV tandem at CNA



fNUC @ DONES study group

Home Work packages Library News Calendar Contact

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

fNUC RED TEMÁTICA DE FÍSICA NUCLEAR — IFMIF DONES GRANADA

Welcome to the Spanish nuclear physics network - fNUC @ DONES web site

The **Spanish nuclear physics network fNUC** has promoted a study group for exploring the **nuclear physics opportunities at IFMIF-DONES**. The group has been structured as follows:

- **Coordination**: D. Cano-Ott (CIEMAT), A.M. Lallena (Univ. Granada)
- Work package 1. **Facility and simulations** (E. Mendoza - CIEMAT)
- Channel the discussions with the DONES design team. Simulations of neutron beams. Two possible measuring stations will be considered: one after the test cell and one using a parasitic pulsed deuteron beam (kicker + buncher) for producing neutrons on a secondary target (d+d, d+t, d+C…) or induce reactions (transfer, fission…)
- Work package 2. **Fundamental nuclear physics** (C. Guerrero – Univ. Sevilla)
- Collecting all the proposals from the different members of the community.
- Work package 3. **Applications** (C. Domingo – IFIC)
- Collecting all the proposals from the different members of the community

The **experimental program** could cover experiments and applications with:

- continous high energy (tens of MeVs) and moderated neutron beams.
- Pulsed neutron beams.
- Continous deuteron beams.
- Pulsed deuteron beams.
- Radioisotopes produced in situ at different irradiation stations.

User login

Username *

Password *

- Create new account
- Request new password

Log in

Navigation

Biblio

DONES irradiation calculator

Calendar

What could we do at DONES?

fNUC@DONES collected **30 Expressions Of Interest** received from the different groups for experiments with **continuous (see A. Letournaux talk)** and **pulsed neutron beams**.

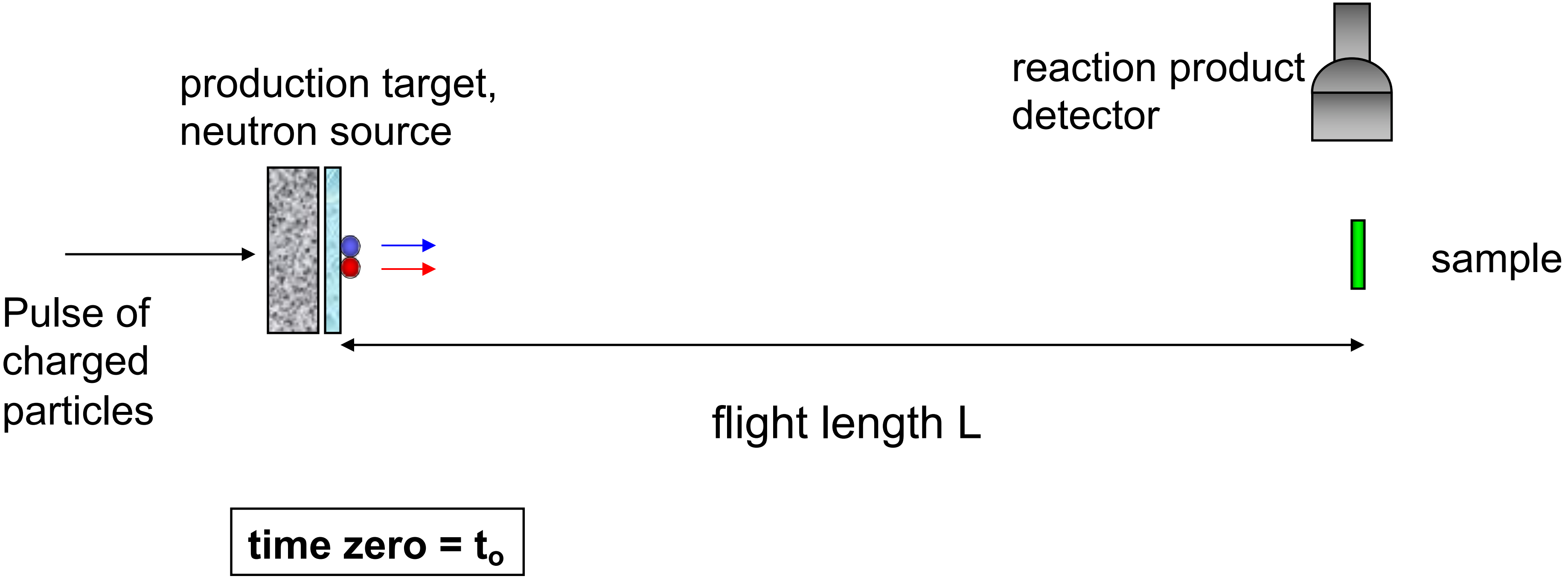
I. Fundamental nuclear science

- Nuclear reaction studies
- Nuclear structure studies
- Calibration and development of instrumentation
- Let our imagination fly…

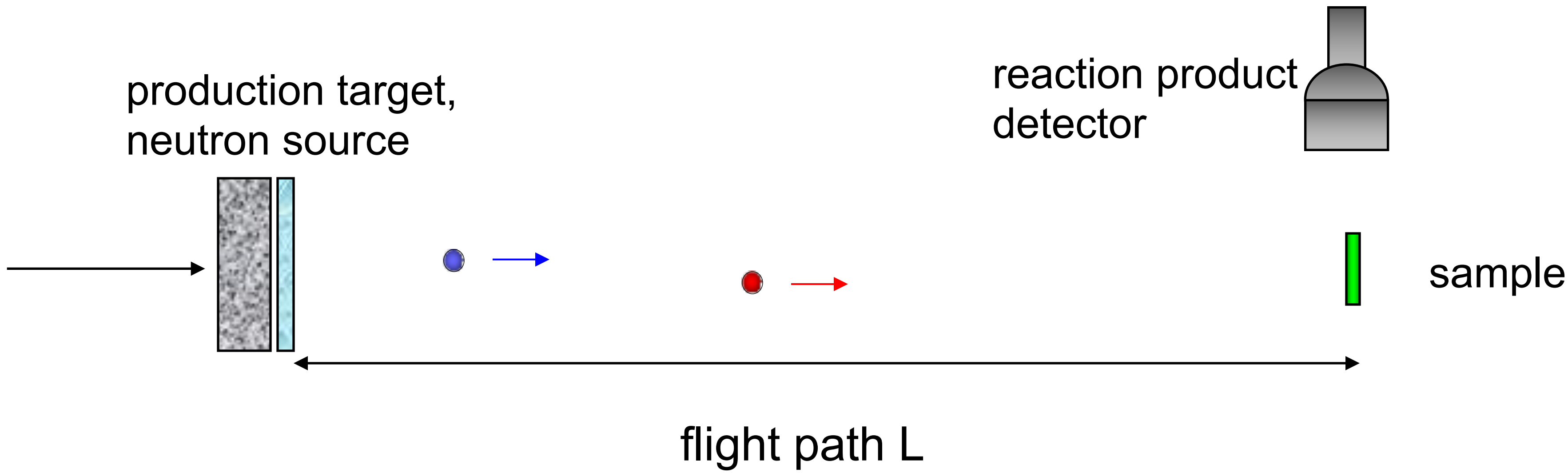
II. Nuclear physics & industrial applications

- 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

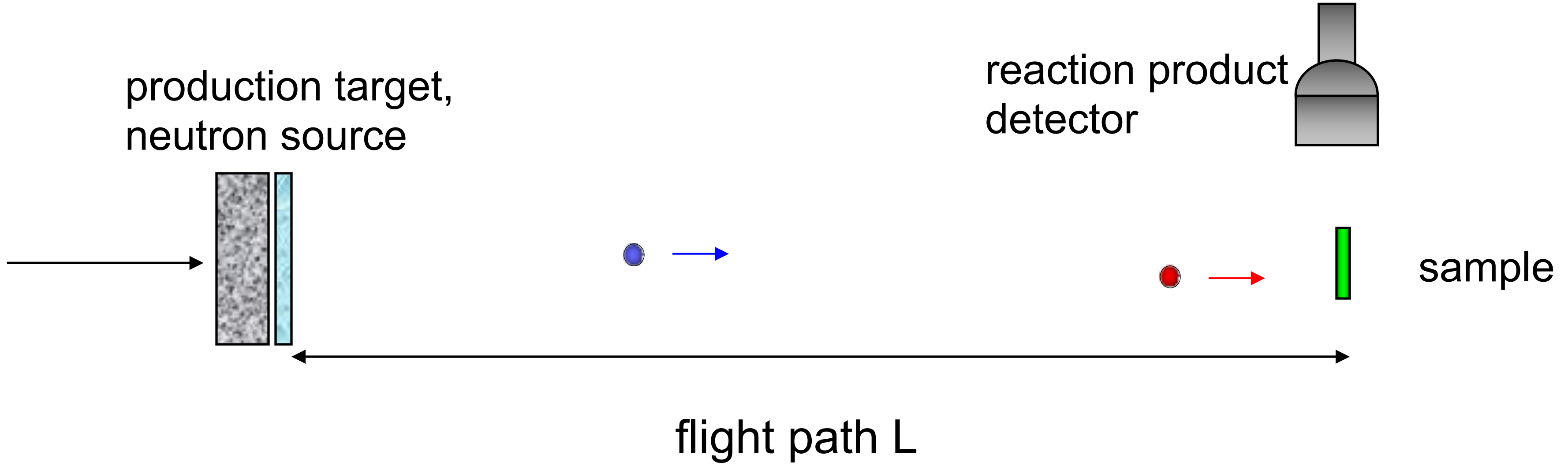
Why pulsed neutron beams? The Time – Of – Flight technique



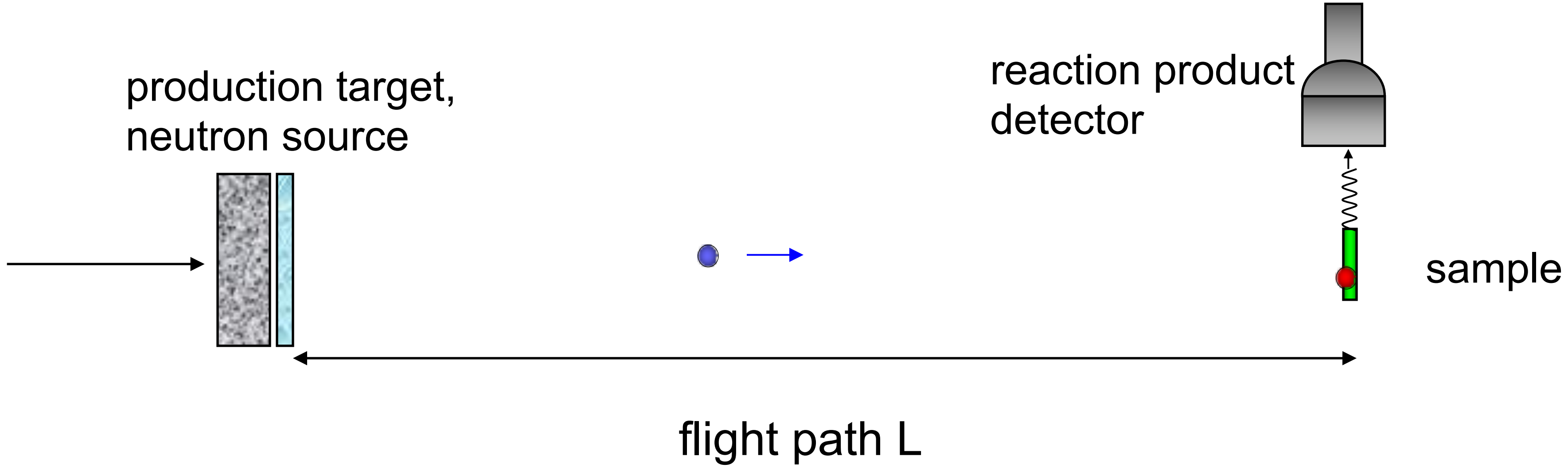
Time – Of – Flight technique



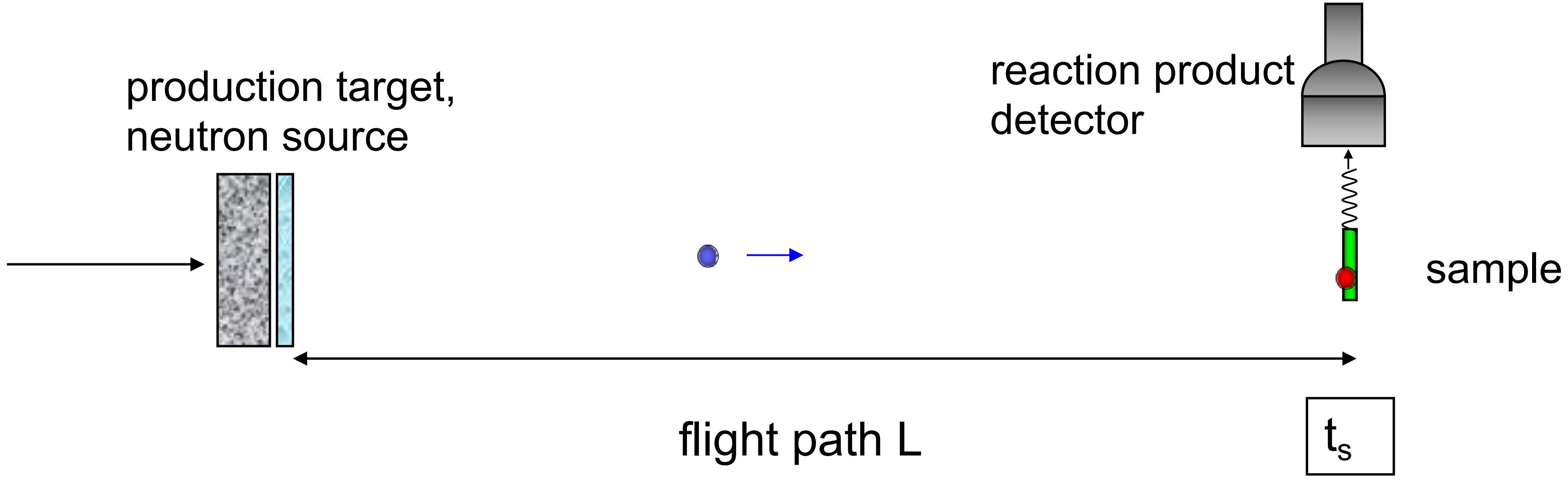
Time – Of – Flight technique



Time – Of – Flight technique

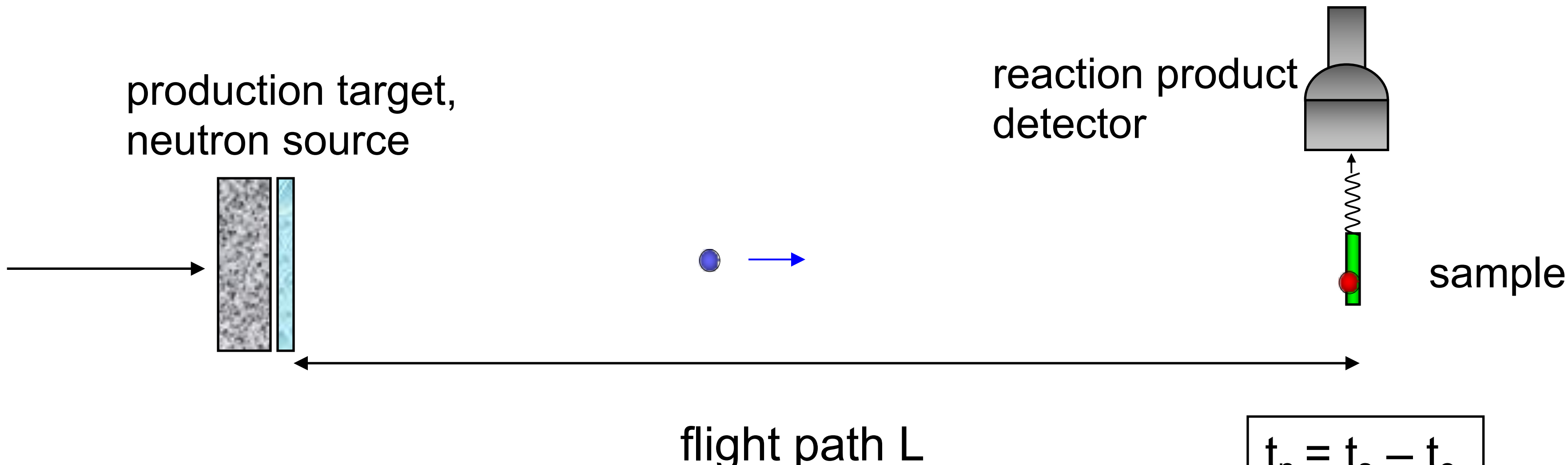


Time – Of – Flight technique



$t_n = t_s - t_o$

Time – Of – Flight technique

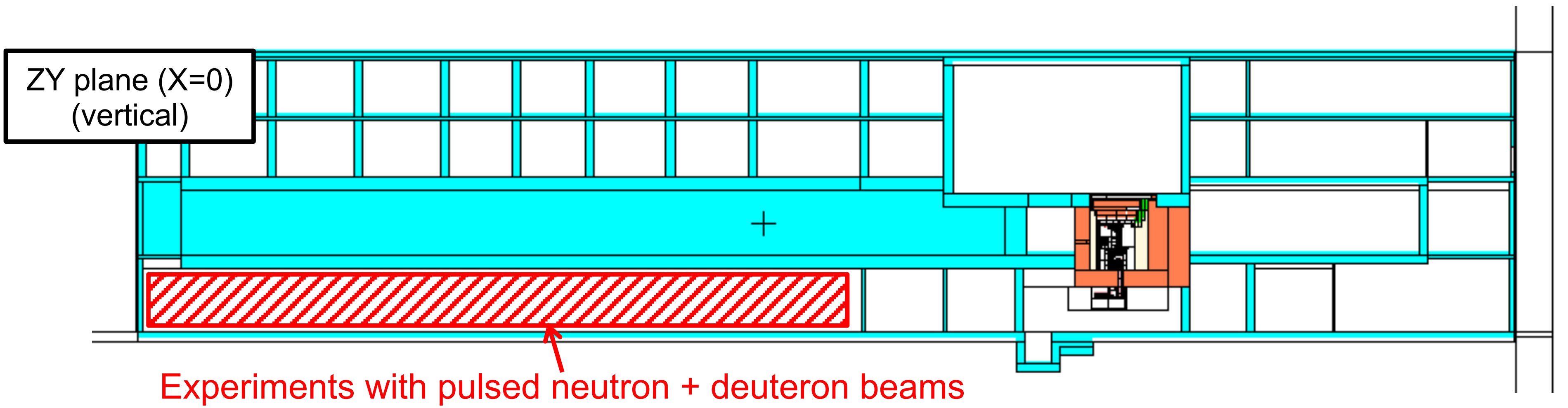


$$t_n = t_s - t_o$$

Kinetic energy of the neutron by time-of-flight

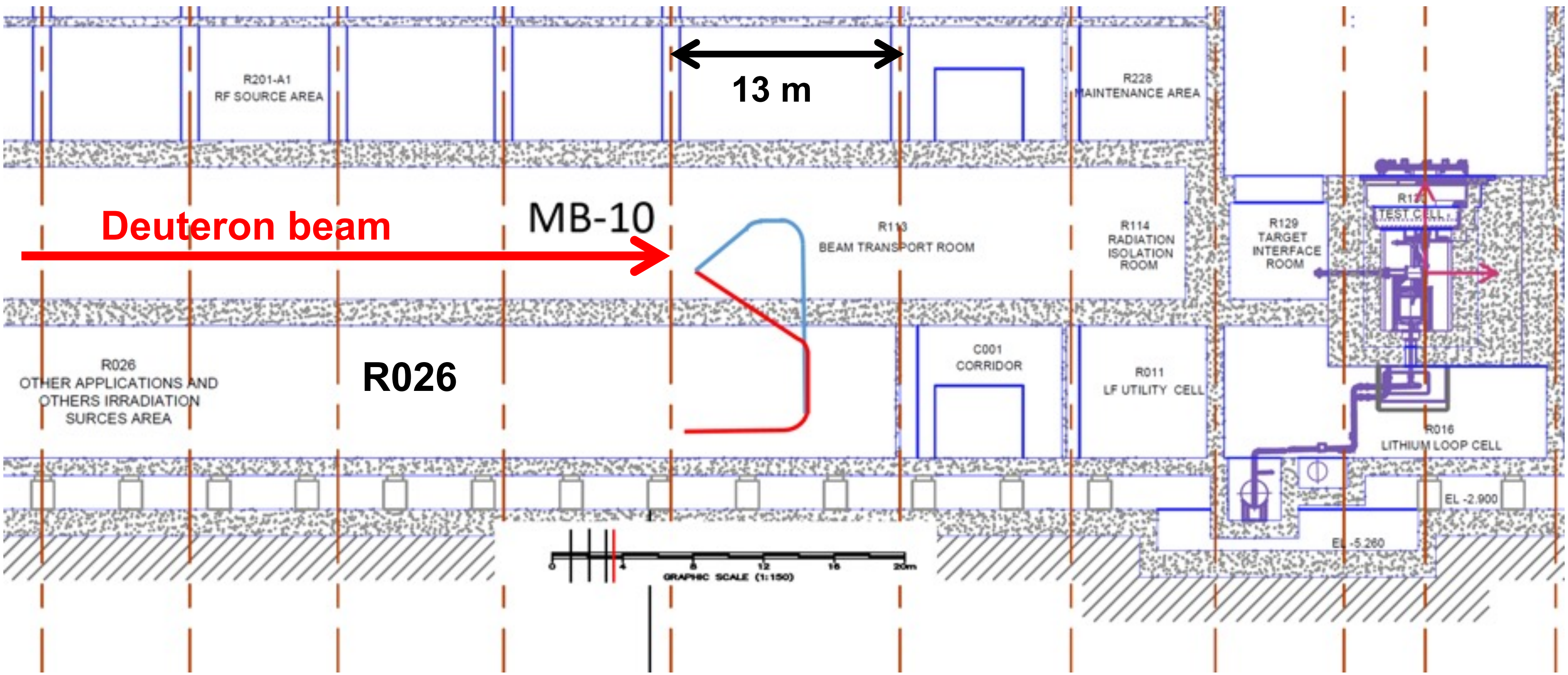
$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1 - \left(\frac{v_n}{c}\right)^2}} - 1 \right) \qquad v_n = \frac{L}{t_n}$$

The DONES facility



Dimensions of R026:
~ 60 x 36 x 8 m

Extraction of the pulsed deuteron beam



Extraction of the 40 MeV deuterons with kicker (1/1000 duty cycle or less)

The TOF-DONES pulsed neutron beam

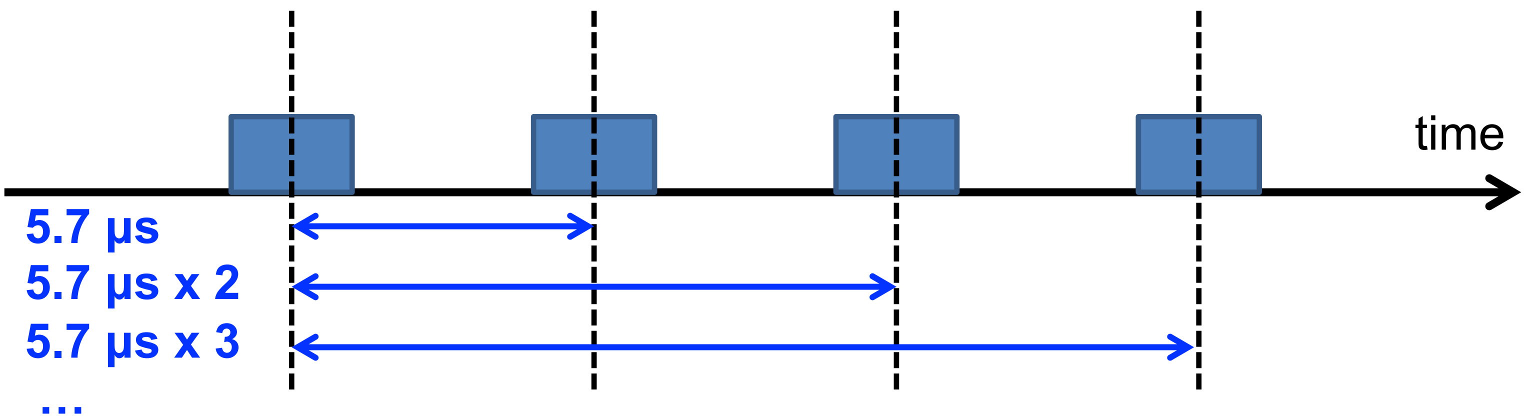
Structure of the deuteron pulses: 5.6 ns width, 125 mA, 5.7 μs separation

For TOF-DONES:

Parasitic experiment: extraction 1/1000 or less of the of the primary beam, producing a secondary beam of 125 μ A):

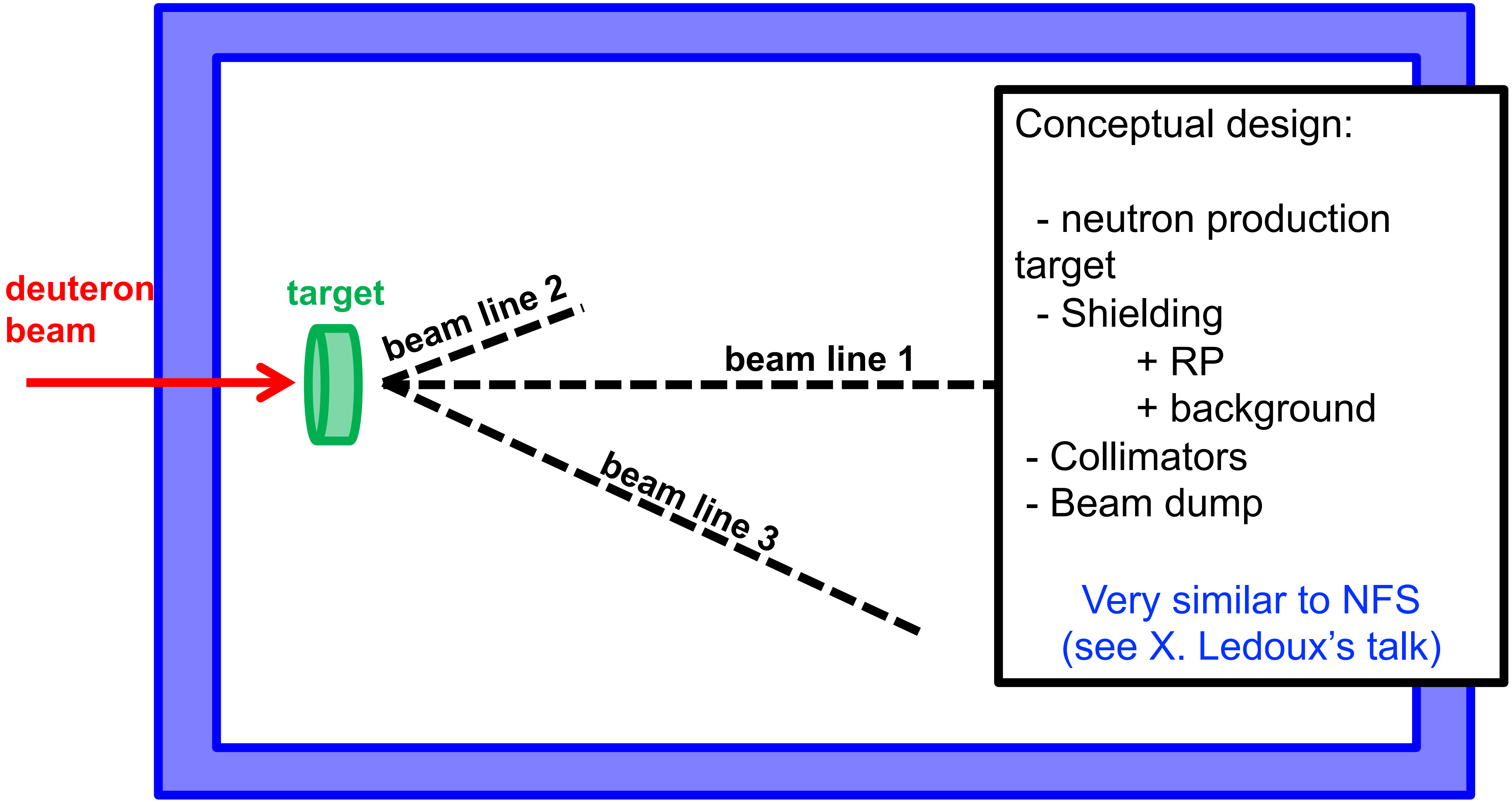
→ **0.1% duty cycle max**.

→ Repetition rate: 175/n kHz (n = 1, 2, 3 …)



Conceptual design of TOF-DONES

- Dimensions of R026 → ~ 60 x 36 x 8 m



Neutron production

We have investigated different possibilities for producing neutrons in a secondary target of the TOF DONES time-of-flight facility:

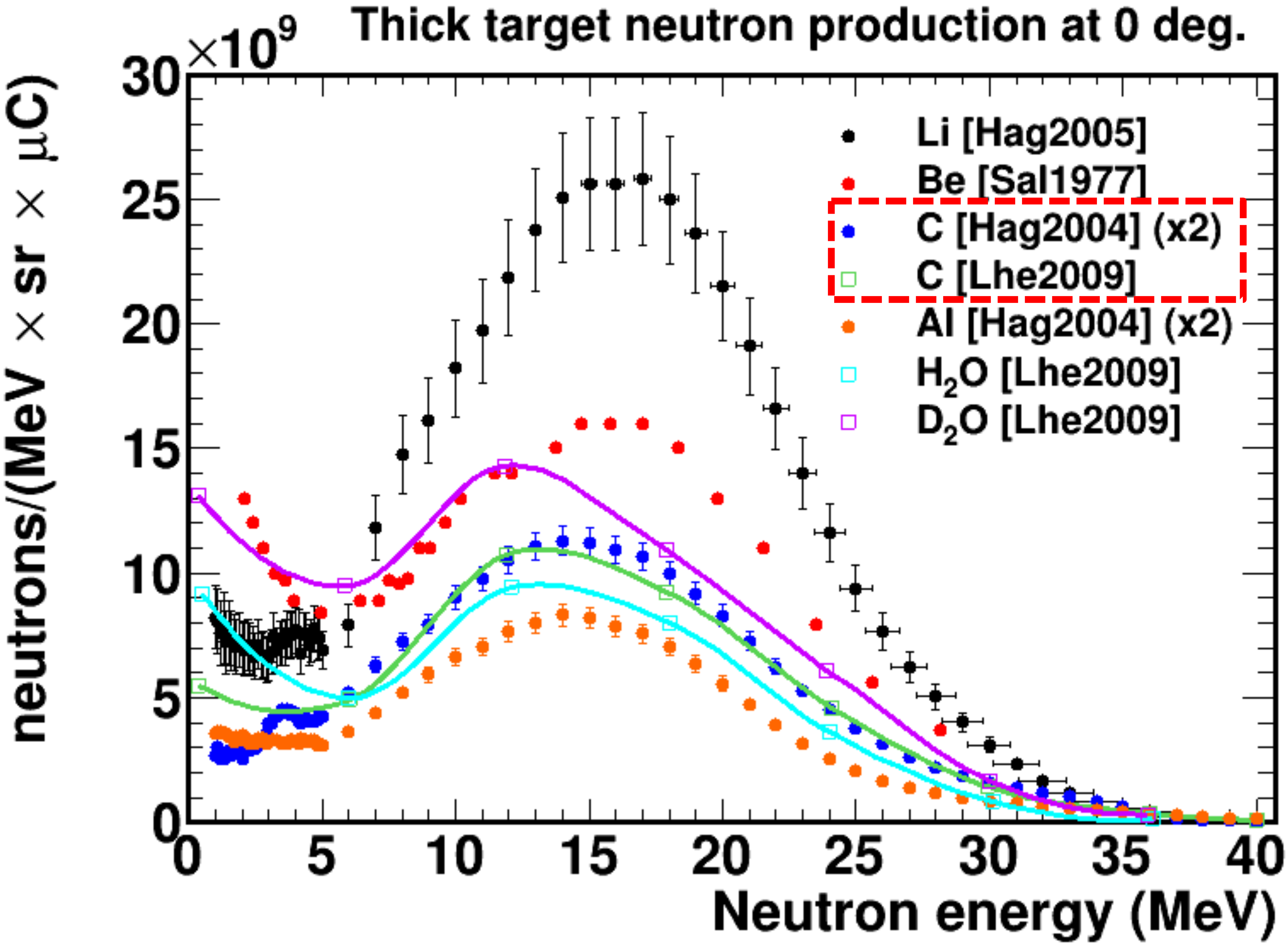
- Thick target neutron production yields and energy spectra at forward angles
- Nuclear data for 40 MeV deuterons from the EXFOR database.

Programmed (d,xn) **realistic event generators based on experimental data**.

Target	Reference	EXFOR entry	neutron yield (forward) (n/(sr·μC))
Li	[Hag2005]	http://www-nds.iaea.org/EXFOR/E1986.002	$4.52 \cdot 10^{11}$ (11%)
Be	[Sal1977]	http://www-nds.iaea.org/EXFOR/C1832.003	$3.09 \cdot 10^{11}$ (15%)
C	**[Hag2004]**	**http://www-nds.iaea.org/EXFOR/E1985.002**	**$2.02 \cdot 10^{11}$ (--%) (*)**
C	**[Lhe2009]**	**http://www-nds.iaea.org/EXFOR/E1985.002**	**$1.85 \cdot 10^{11}$ (12%)**
Al	[Hag2004]	http://www-nds.iaea.org/EXFOR/E1985.003	$1.44 \cdot 10^{11}$ (--%) (*)
H_2O	[Lhe2009]	http://www-nds.iaea.org/EXFOR/O1746.004	$1.64 \cdot 10^{11}$ (15%)
D_2O	[Lhe2009]	http://www-nds.iaea.org/EXFOR/O1746.003	$2.82 \cdot 10^{11}$ (12%)

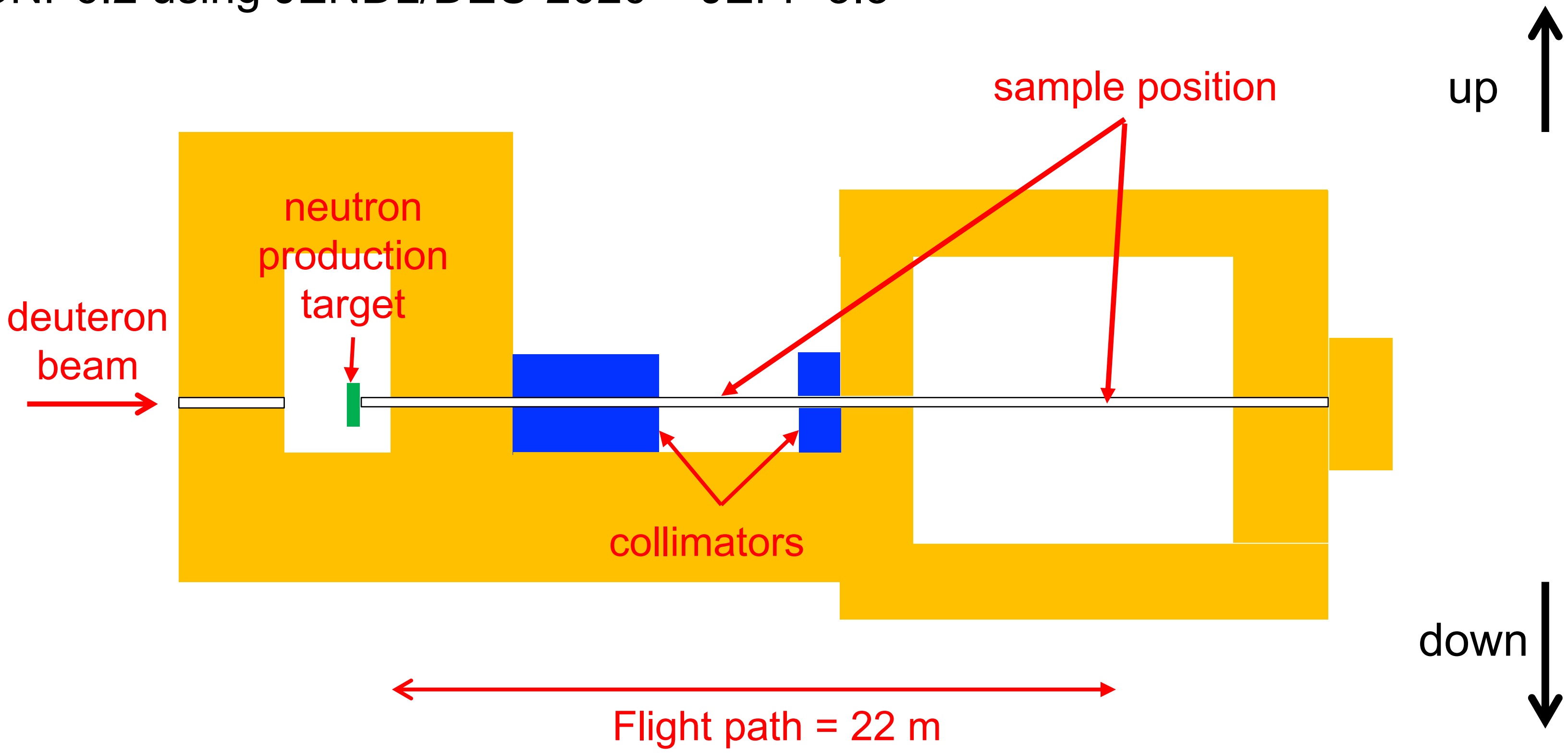
(*) The values for C and Al from Hagiwara have been multiplied by a factor of 2 following the recommendation from the evaluator

Neutron production by 40 MeV deuterons

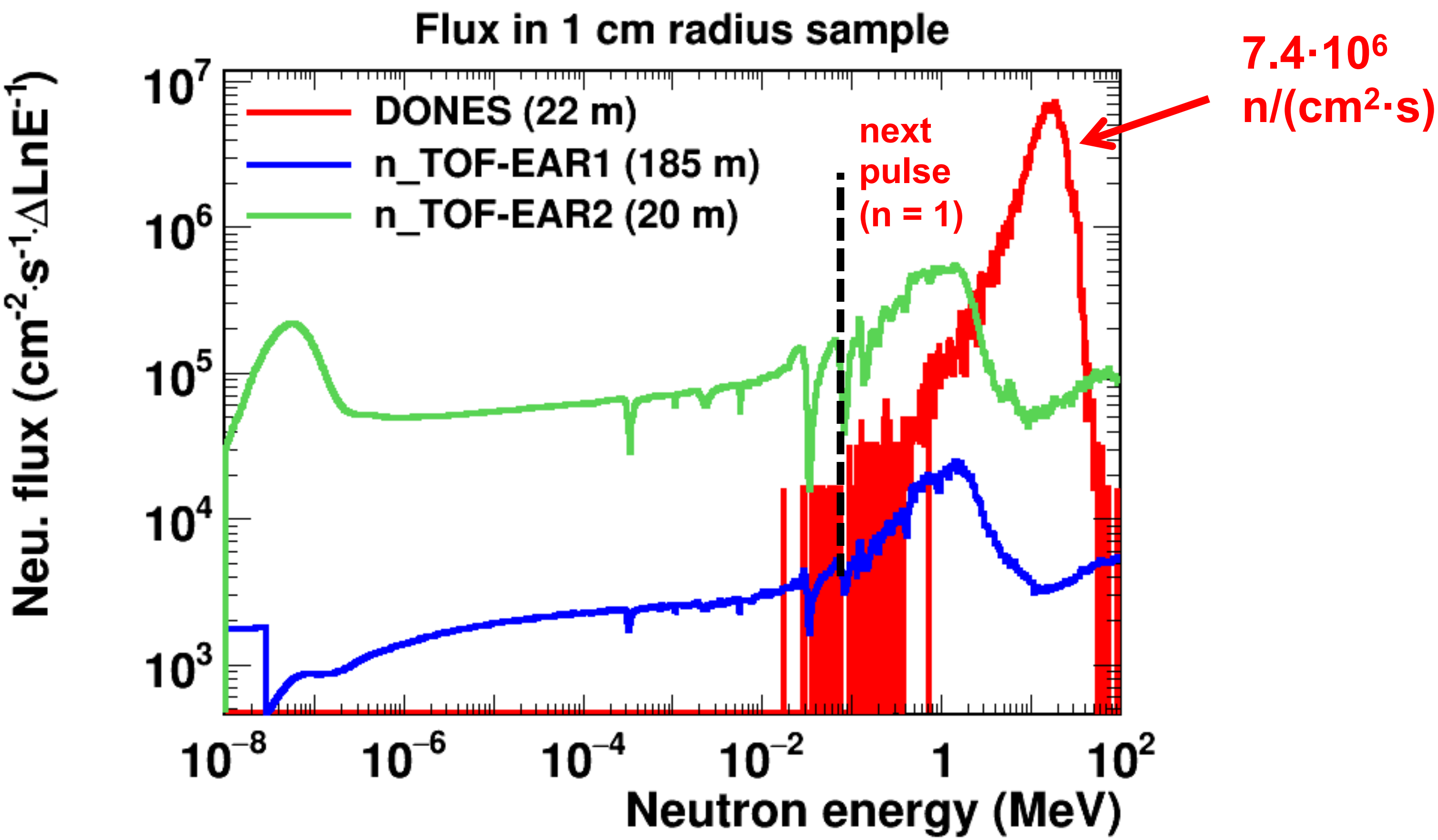


Simulations of TOF DONES

Deuteron beam: 5 cm radius + uniform distribution of the neutrons.
Collimators: 7.1 + 4.6 cm radius (first) and 3.7 cm radius (second).
Time-of-flight distance: 22 m
Yellow: concrete – blue: collimators (iron + borated polyethylene)
MCNP6.2 using JENDL/DEU-2020 + JEFF-3.3

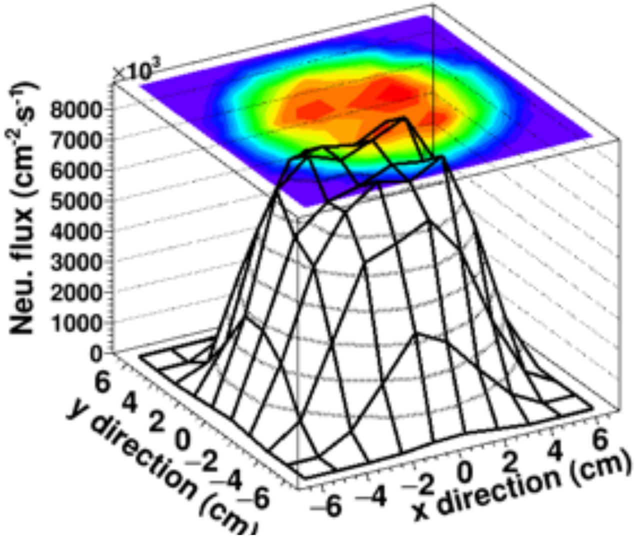


Neutron flux of TOF DONES

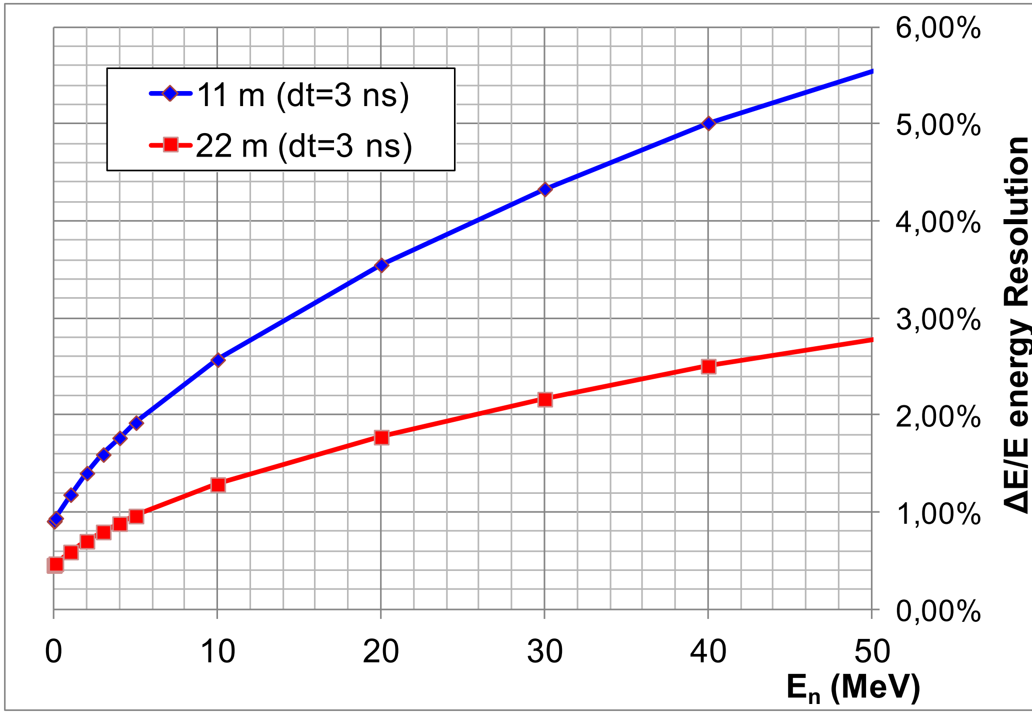


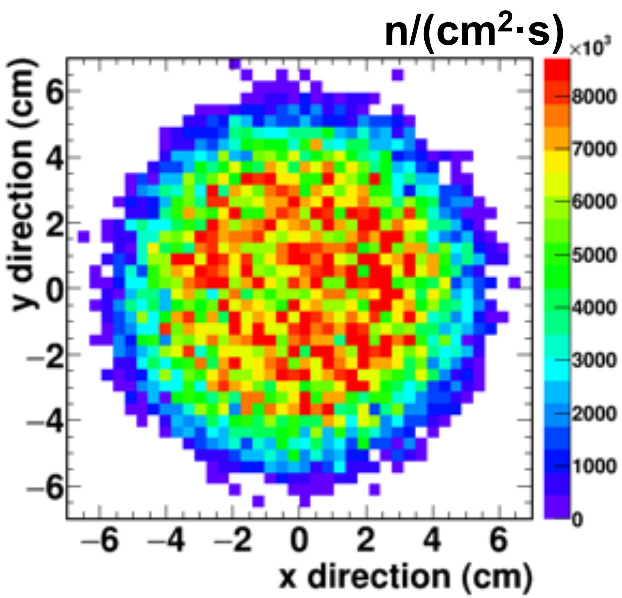
Neutron flux per unit lethargy at the sample position (22 m) compared with n_TOF (capture collimator). n_TOF has 0.83 pulses per second. A duty cycle of 10^{-3} has been assumed for DONES.

Beam profile & energy resolution



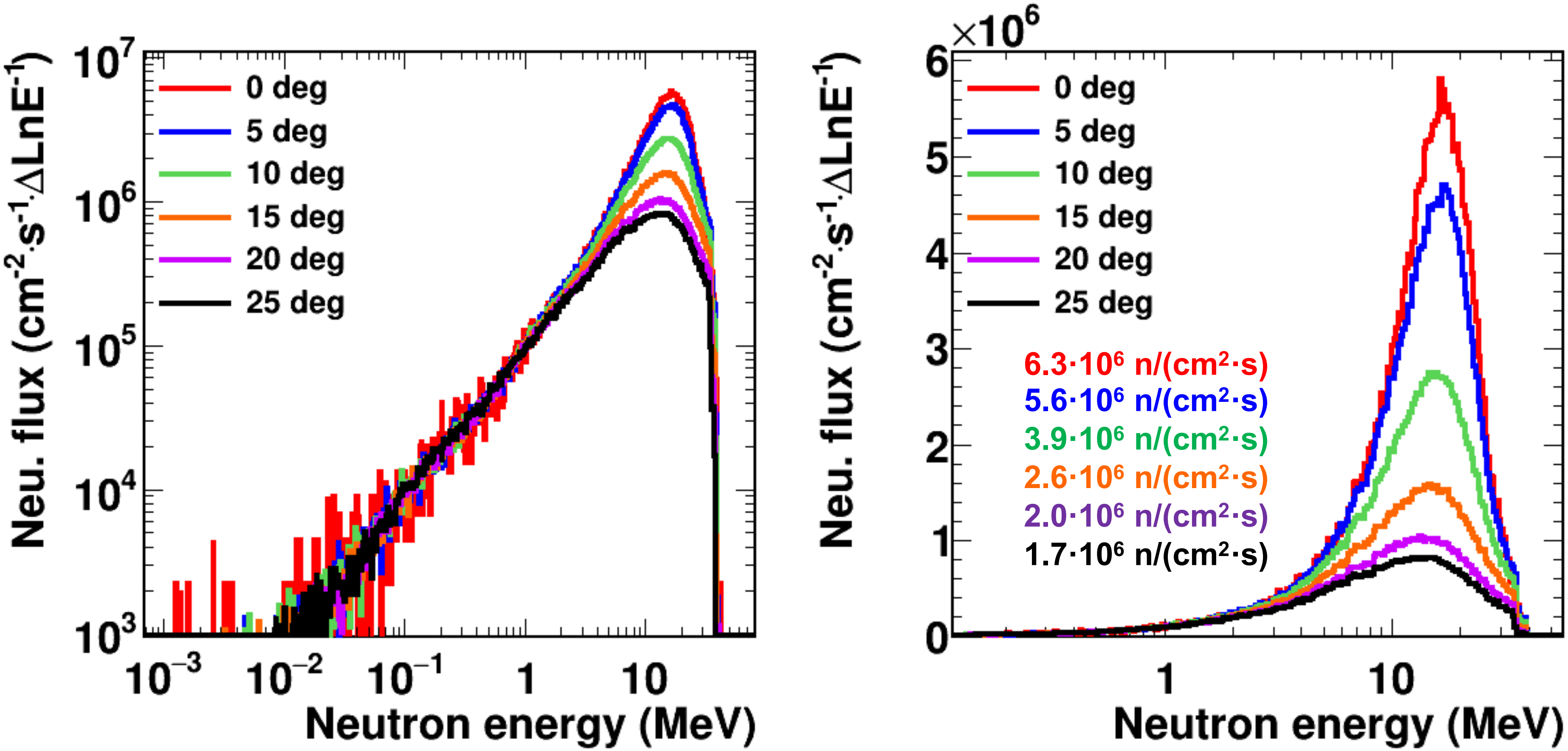
Neutron energy resolution at different flight paths.





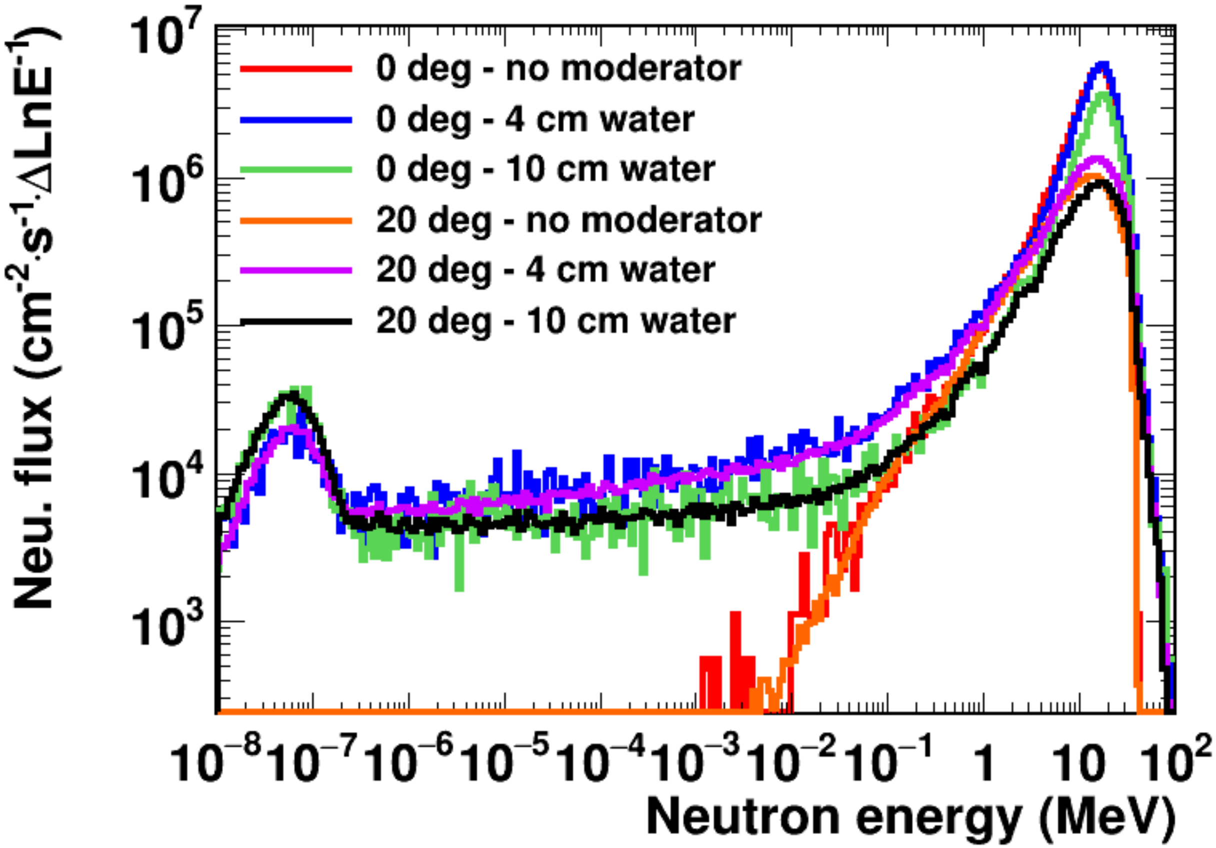
Beam profile at the sample position (22 m).

Neutron flux at different angles



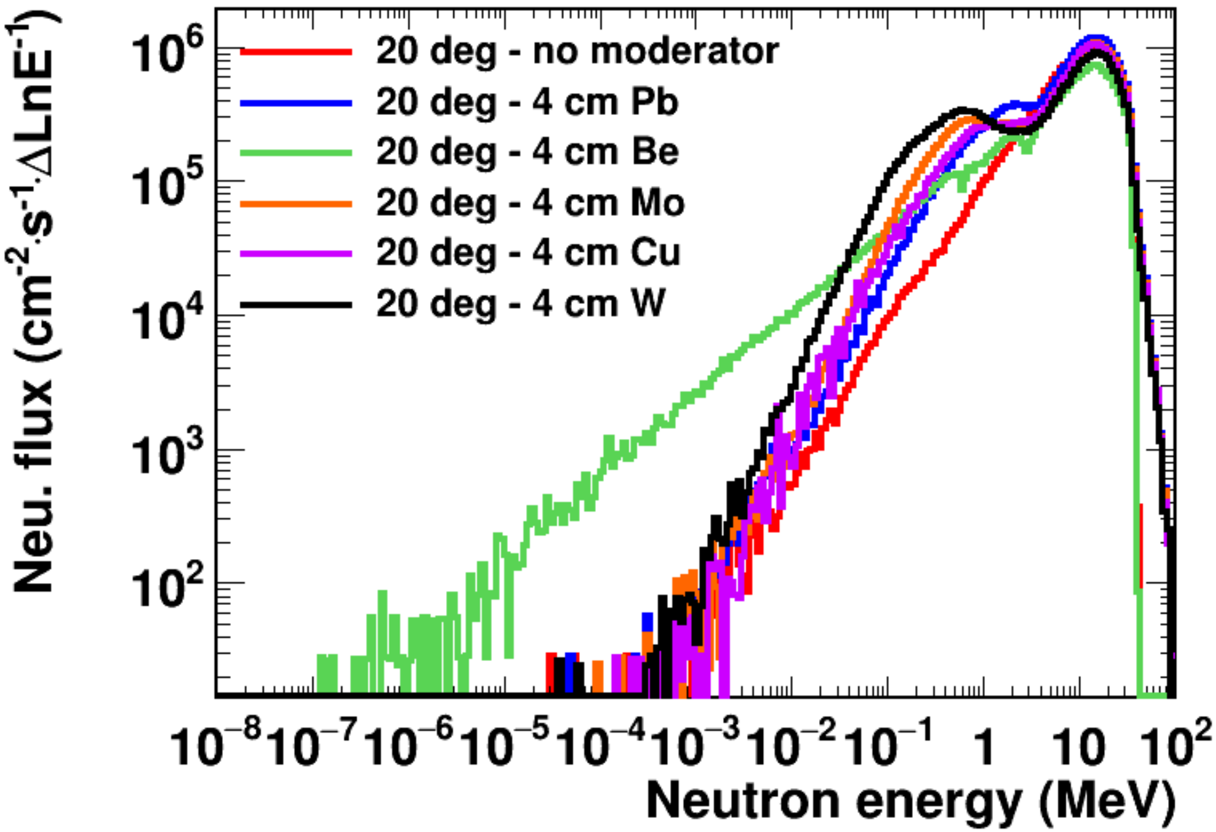
Neutron flux at **20 m TOF distance**, as a function of the neutron energy, at different angles generated by a 40 MeV deuteron beam of 125 μA impinging on a thick graphite target.

Moderation of the neutron beam



We have investigated the possibility of *moderating* the neutron beam → not straightforward, water/polyethylene … are not good moderators for 15 MeV neutrons.
(In the picture: 20 m TOF distance + 125 μA deuterons on thick graphite)

“Degradation” of the neutron beam



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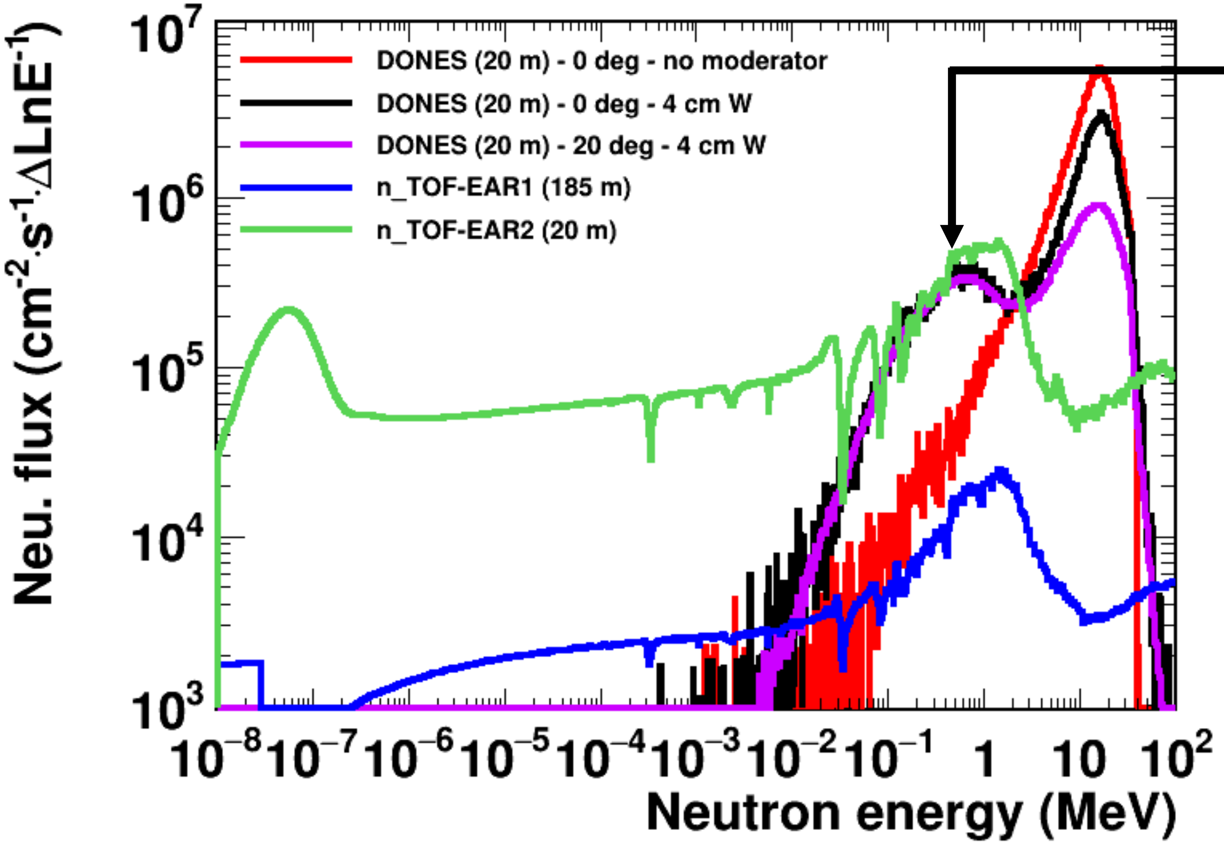

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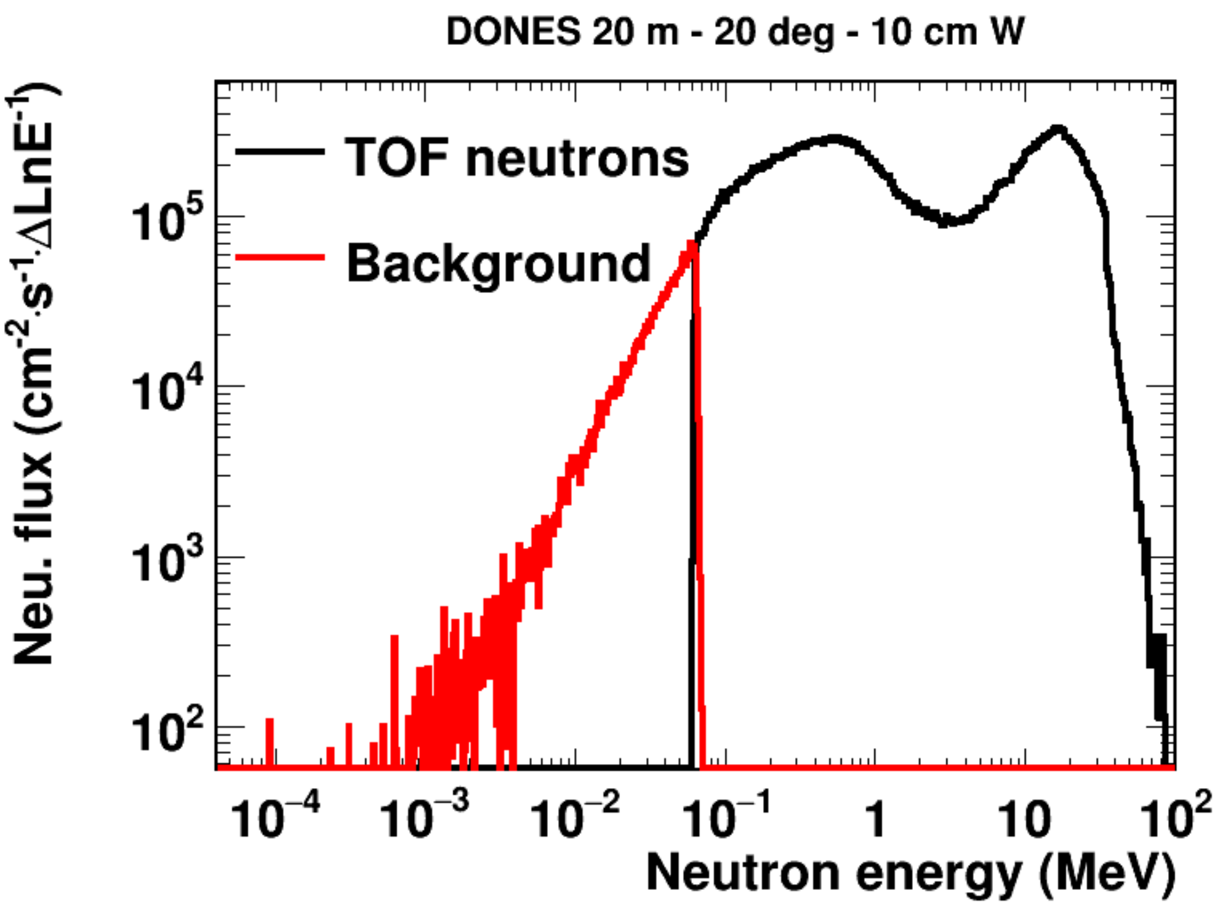
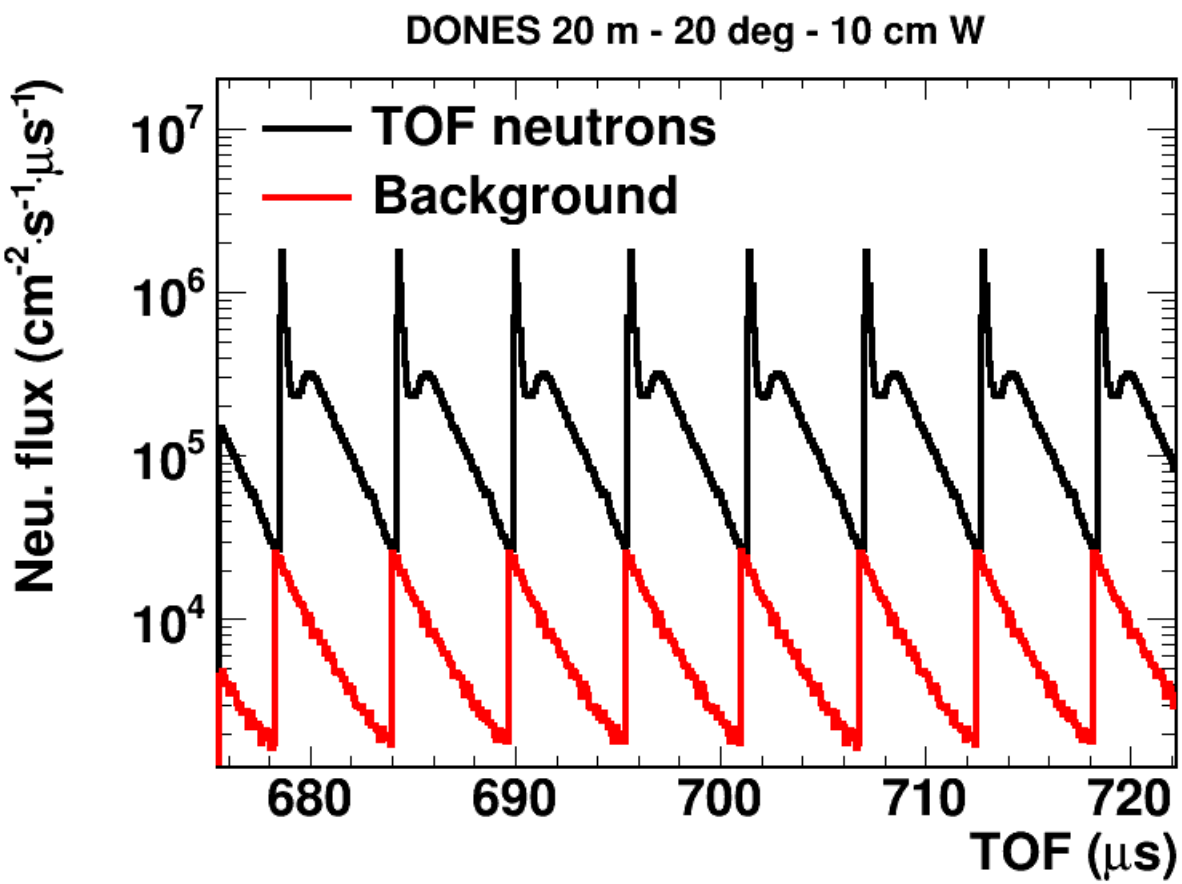
Time structure of the neutron beam



In the neutron beam, there will be some neutrons coming with the desired TOF-Energy relation (black) and other neutrons from other pulses → background (red). In the picture, n = 1 and the distance between pulses 5.7 μs (175 kHz).

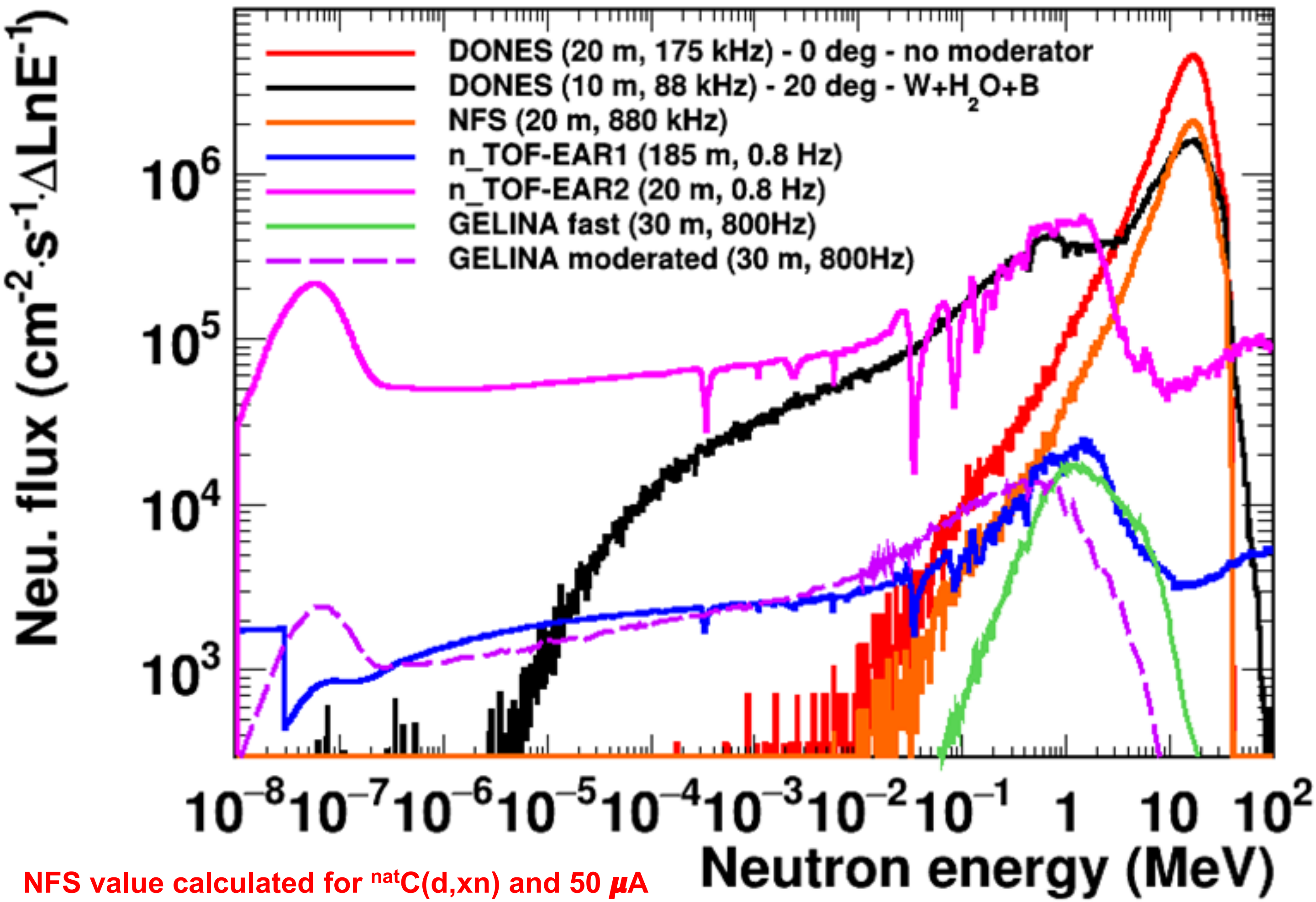
Time structure of the neutron beam



In the neutron beam, there will be some neutrons coming with the desired TOF-Energy relation (black) and other neutrons from other pulses → background (red). In the picture, n = 1 and the distance between pulses 5.7 μs (175 kHz).

Comparison of TOF-DONES with other facilities

20 m TOF distance + 125 μA deuterons (duty cycle 1/1000) on thick graphite



NFS value calculated for $^{nat}C(d,xn)$ and 50 *μ*A

TOF-DONES preliminary concept

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

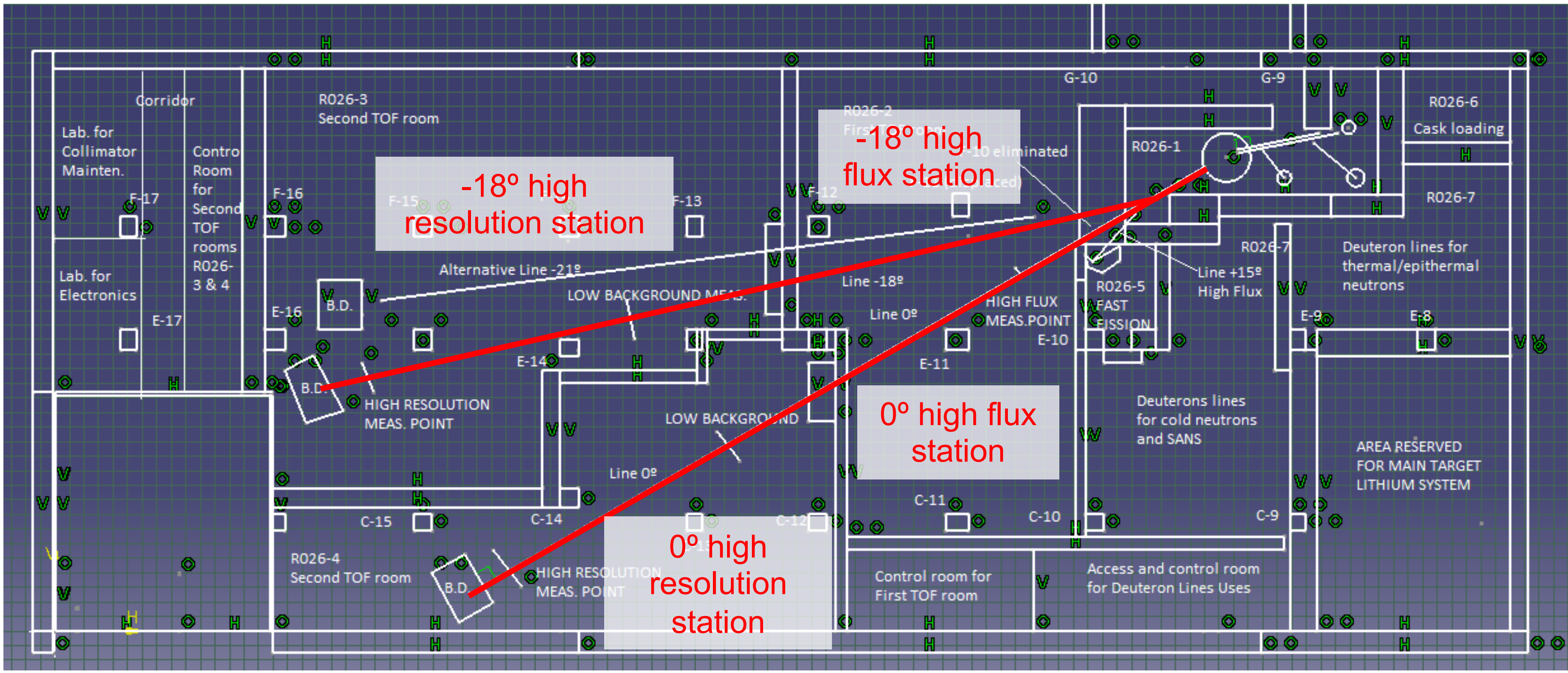


Image courtesy by P. Ortego / SEA Ingeniería p.ortego@seaingenieria.es

TOF-DONES experimental program

Broad experimental program on neutron induced reaction cross section measurements for nuclear technologies, astrophysics, fusion, particle and astro-particle physics

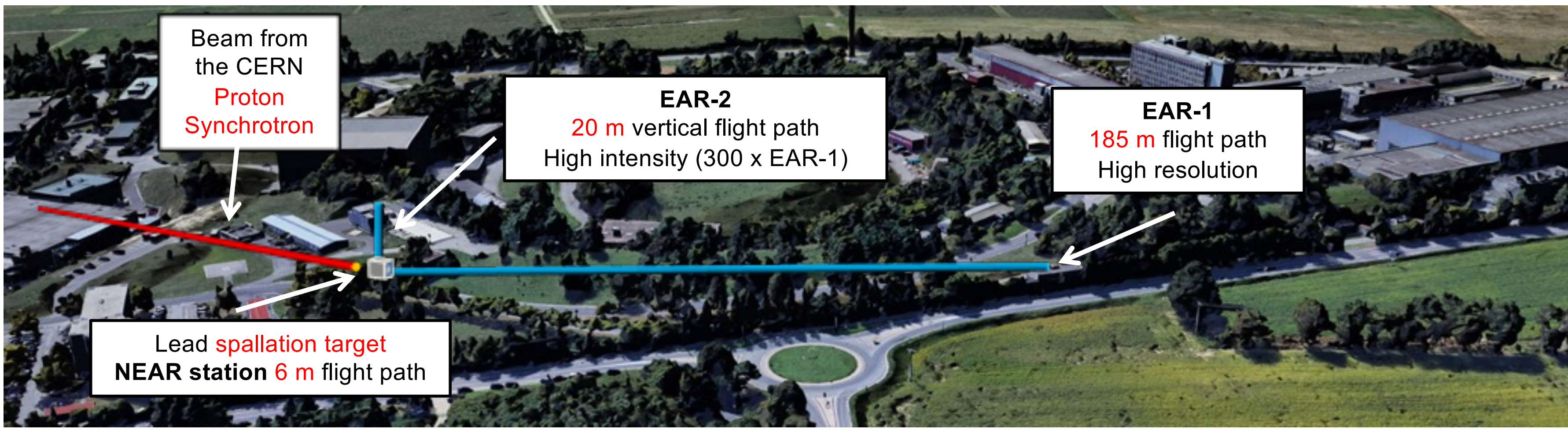
- (n,el) - elastic
- (n,γ) - capture
- (n,n'γ) -inelastic
- (n,xn) – neutron multiplication
- (n,f) - fission
- (n,p), (n,d), (n,t), (n,α)… - charged particle production
- Reaction studies with **pulsed deuteron beam**: cross sections, radiobiology, isotope production…
- **Nuclear data relevant for fusion!**

There is a program that requires decades of beam time (thee is room for complementary facilities like 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.

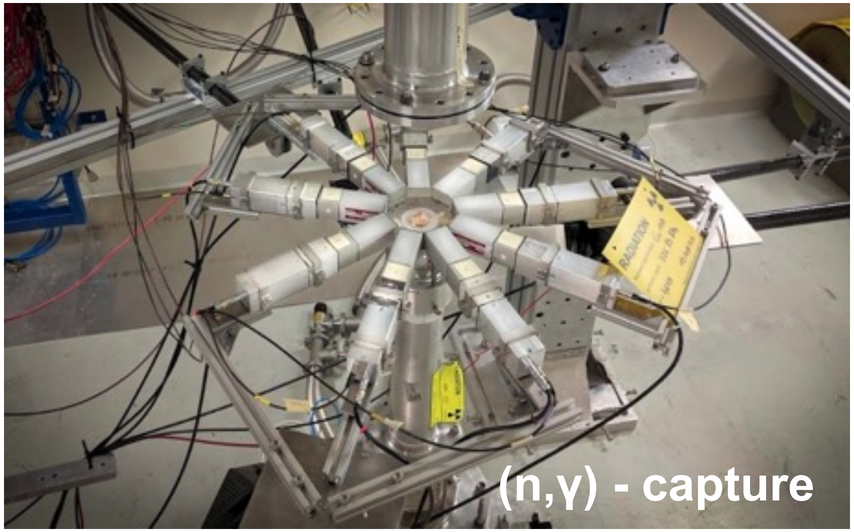
Spanish experience with neutron beams

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).

"Spanish" detectors at n_TOF

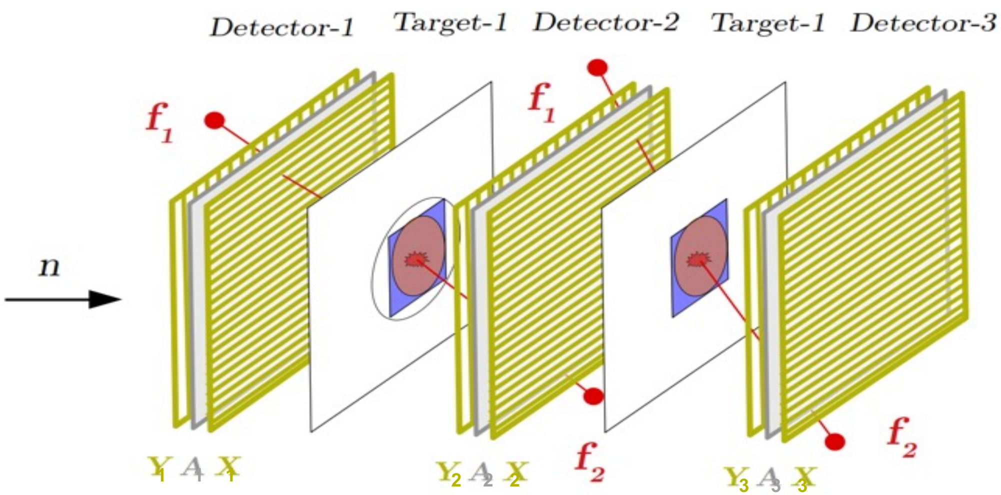


sTED
segmented
total energy
detector
CIEMAT

iTED γ-ray Compton imager
IFIC - Valencia

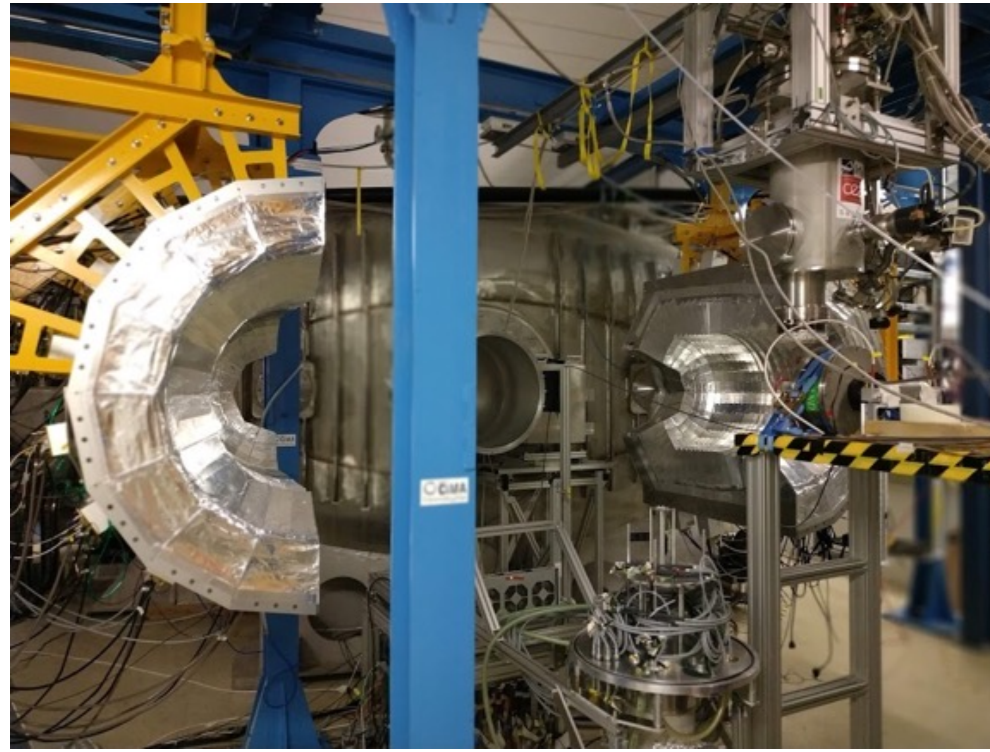
(n,f) - fission

Developed by IPN – Orsay and the
Universidad de Santiago de Compostela

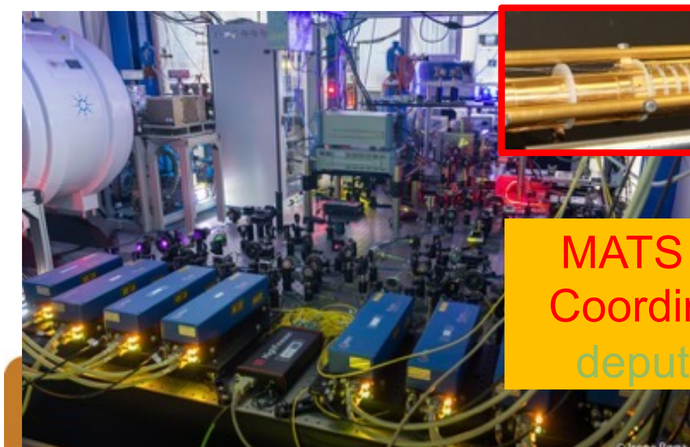


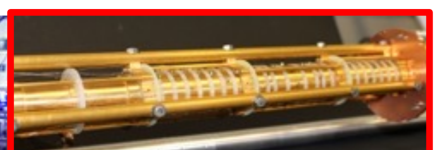
Construction of nuclear instrumentation (FAIR)

MONSTER neutrón detector
Coordinator CIEMAT

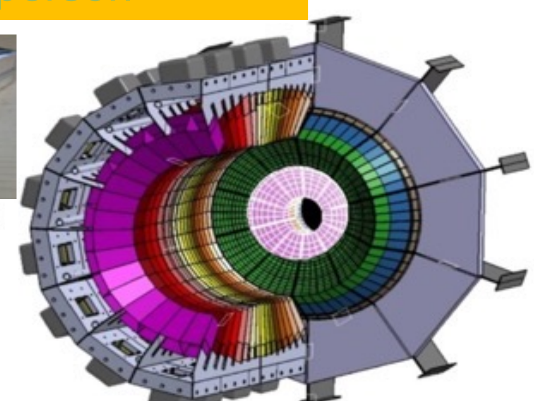


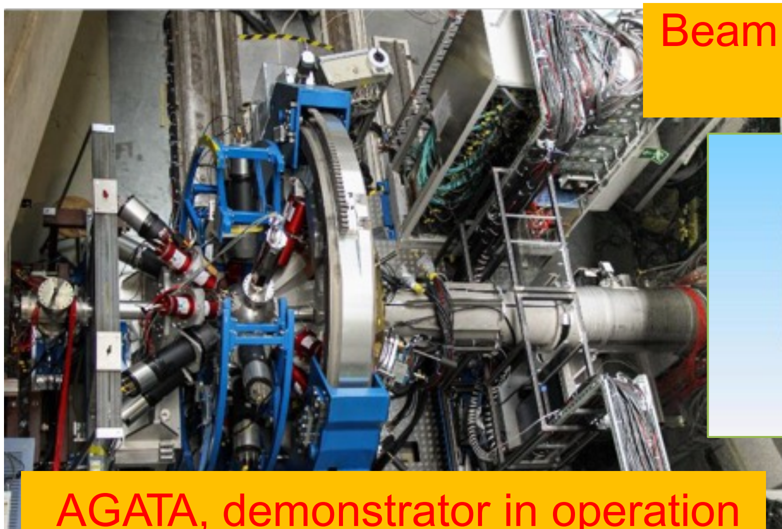
CALIFA Detectors (USC; Uvi, IEM)
Coordinator USC
R^3B spokesperson



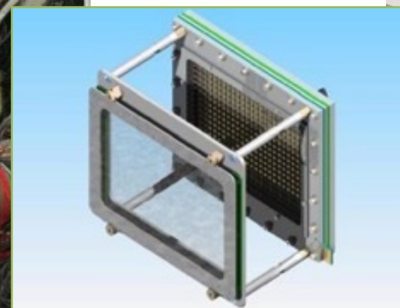


MATS Preparation trap
Coordinator U. Granada
deputy spokesperson

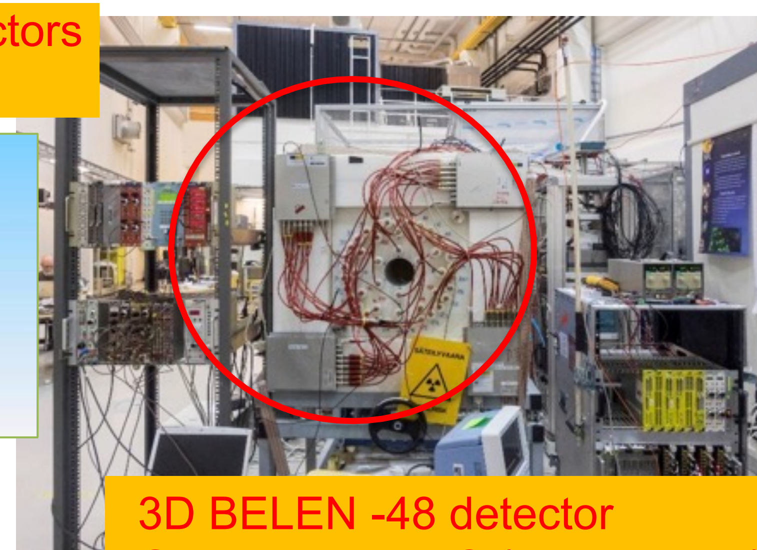




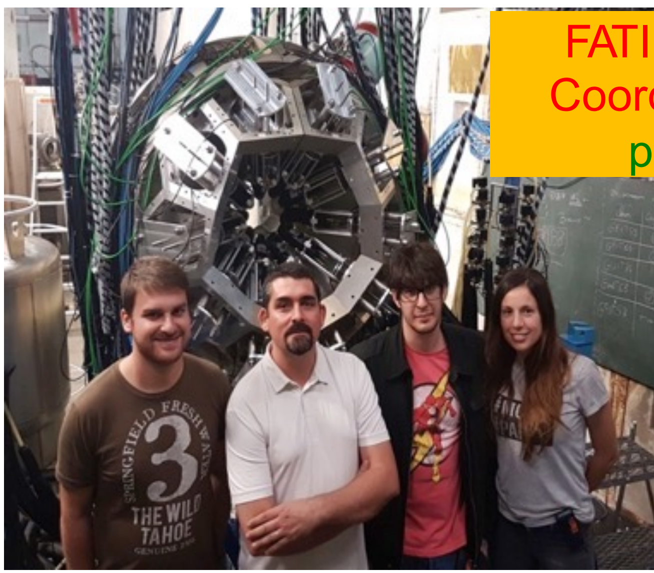
Beam tracking detectors
Univ. Sevilla



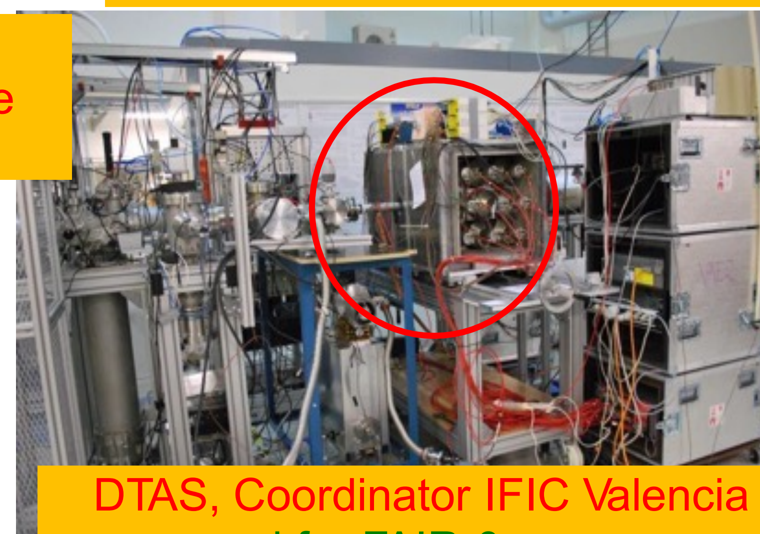
AGATA, demonstrator in operation
Coordinator IFIC Valencia



3D BELEN -48 detector
Coordinator UPC (in operation)



FATIMA array, in operation
Coordinator U Complutense
proposed for FAIR-0



DTAS, Coordinator IFIC Valencia
proposed for FAIR-0

The role of Spain in the international nuclear data community

- **Coordination** of the last 4 nuclear data European Projects (> 30 institutions): NUDATRA (FP-6), ANDES (FP-7), CHANDA (H2020) and SANDA (2020).
- Participation in the ENSAR and ENSAR2 **European nuclear physics projects**.
- Participation in the different **transnational access programs**: previous projects + EUROLABS.
- Spain will host the next largest nuclear data conference in the world: **Nuclear data for science and technology 2025 (Madrid).**

Summary and conclusions

IFMIF DONES offers unique and superb scientific and technological possibilities.

- **Spain lacks of intense neutron sources** for fundamental and applied research.
- The construction of an additional neutron TOF facility (TOF-DONES) would lead to one of **world's highest intensity neutron TOF line** for nuclear physics.
- The neutron spectrum could be tailored for covering a large amount of different experiments.

The Spanish Nuclear Physics community has the necessary **expertise** and **skills** for making the facility a great success!

At a very reduced cost we would:

- Provide the Spanish and international scientific community with an **world leading high intensity neutron source** for a broad range of experiments and applications.

- Boost largely the IFMIF-DONES **scientific production**.

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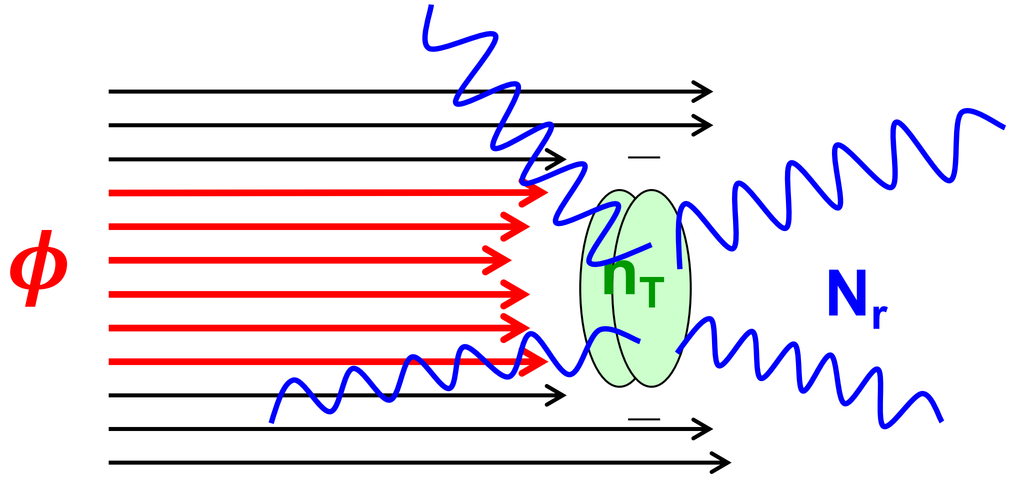
Spare slides

Measurement of energy dependent neutron induced reaction cross-sections



$$\sigma_x(E)[barn] = \frac{N_x(E)[reactions \cdot s^{-1}]}{n_T\,[atoms \cdot barn^{-1}] \cdot \phi(E)[neutrons \cdot s^{-1}]}$$

Energy range of the TOF measurements

	10 m	20 m	30 m	40 m	50 m	60 m
n = 1	16 keV	**64**	144	250	400	580
n = 2	4	**16**	36	64	100	144
n = 3	1.8	**7.1**	16	28	44	64
n = 4	1	**4**	9	16	25	36
n = 5	0.64	**2.5**	5.8	10	16	23
n = 10	0.16	**0.64**	1.44	2.5	4	5.8
n = 20	0.04	**0.16**	0.36	0.64	1	1.44
n = 50	0.0064	**0.025**	0.058	0.10	0.16	0.23
n = 100	0.0016	**0.0064**	0.0144	0.025	0.04	0.058

TOF-energy (in **keV**) of the neutrons at the time of overlapping with the next pulse, at the sample position → minimum neutron energy for TOF measurements.

1. Neutron production

We have investigated different possibilities for producing neutrons in a secondary target of the TOF DONES

- Thick target ne
- Nuclear data fo

Programmed (d,x

Target	Referen	ron yield d) (n/(sr·µC))
Li	[Hag200	10^{11} (11%)
Be	[Sal1977	10^{11} (15%)
C	[Hag200	0^{11} (--%) (*)
C	[Lhe2009	10^{11} (12%)
Al	[Hag200	0^{11} (--%) (*)
H_2O	[Lhe2009	10^{11} (15%)
D_2O	[Lhe2009	10^{11} (12%)

(*) The values … wing the recommendation from the evaluator

The neutron flux, in n/(cm²·s), at forward angles, can be obtained from (n=1):

$$F = \frac{0.0125 \cdot Y}{d^2}$$

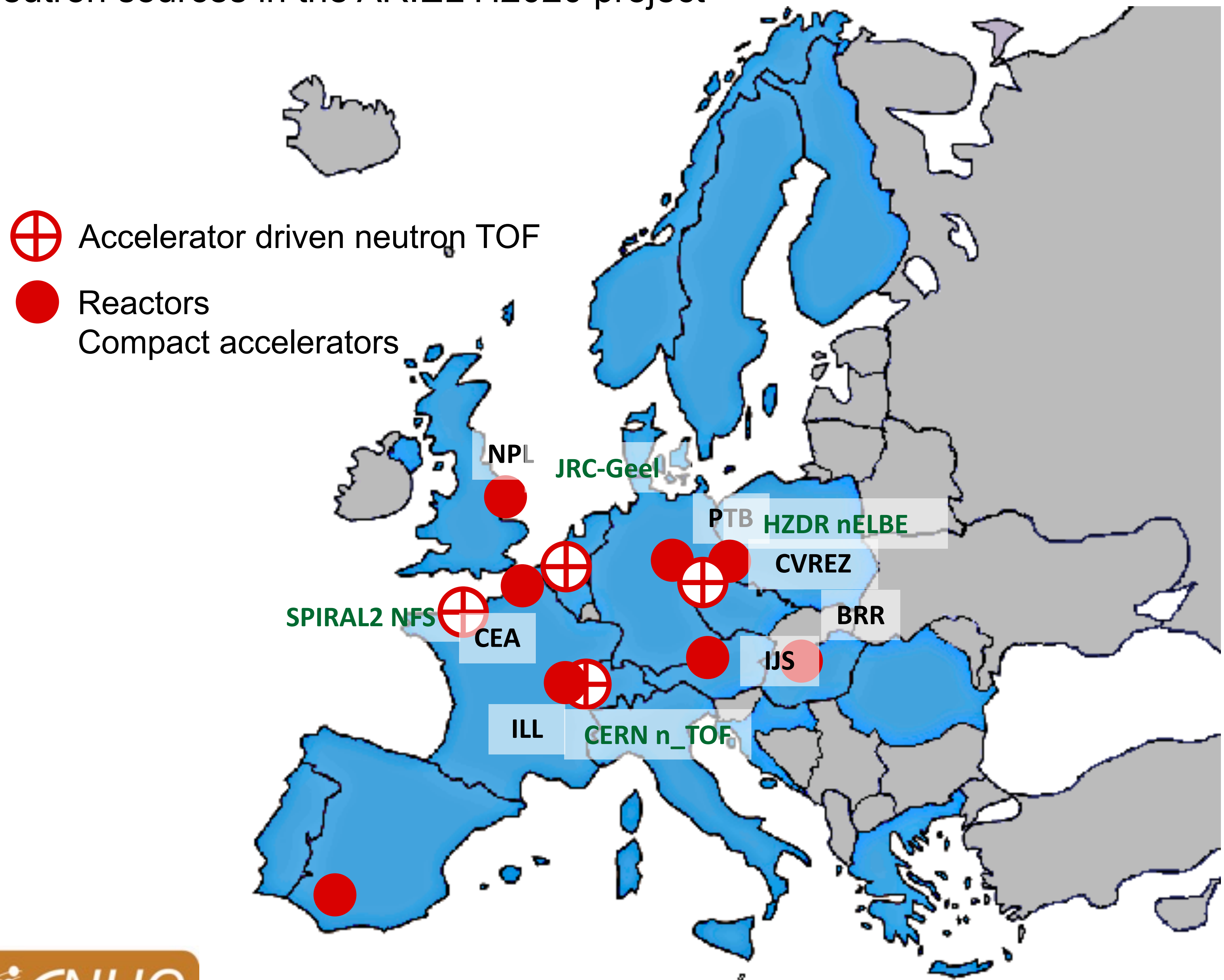
where:

- *d* is the time-of-flight distance, in meters.
- A duty cycle of 10^{-3} has been considered.
- *Y* are the values on the right column.

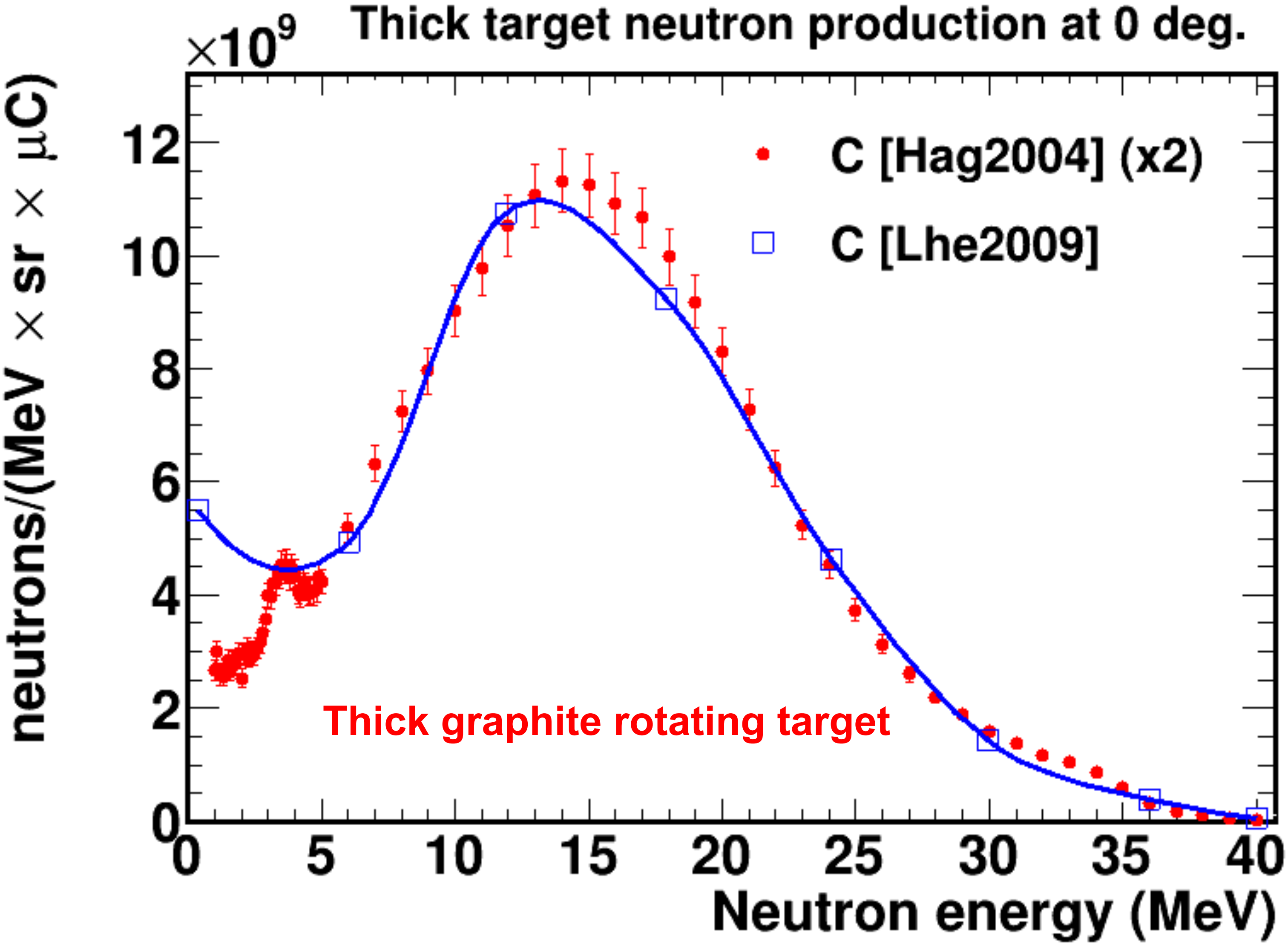
Graphite (~$2\cdot10^{11}$ n/(sr·µC)):

1 m → $2.5\cdot10^{9}$ n/(cm²·s)
10 m → $2.5\cdot10^{7}$ n/(cm²·s)
20 m → $6.2\cdot10^{6}$ n/(cm²·s)
40 m → $1.6\cdot10^{6}$ n/(cm²·s)
60 m → $6.9\cdot10^{5}$ n/(cm²·s)

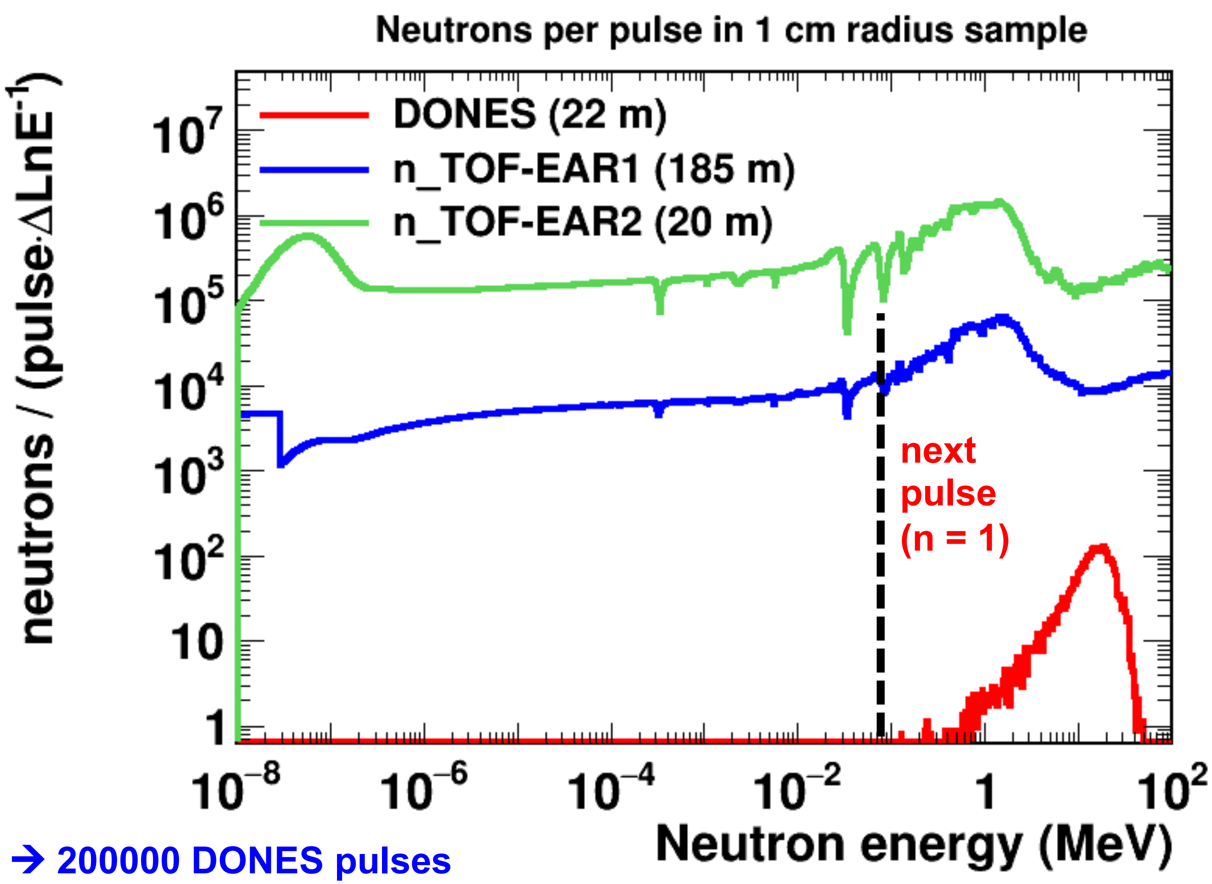
Neutron sources in the ARIEL H2020 project



Neutron production by 40 MeV deuterons



Neutron fluence of TOF DONES



1 n_TOF pulse → 200000 DONES pulses

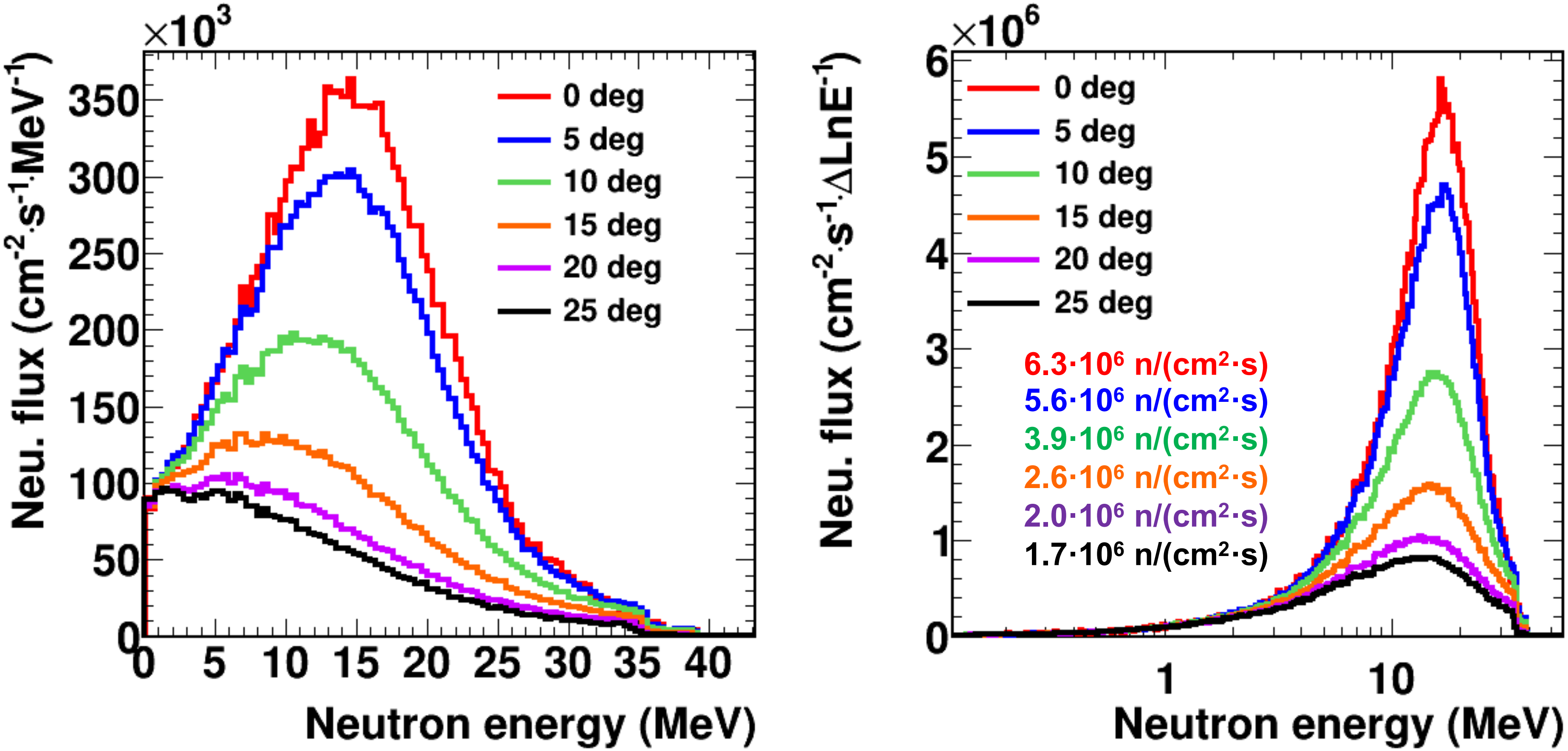
Neutrons per pulse and per unit lethargy at the sample position (22 m) compared with n_TOF (capture collimator). For DONES we have assumed a duty cycle of 10^{-3} and $1.75 \cdot 10^{5}$ pulses per second (175 kHz).

Neutron flux at different angles (thick target)

	10 m	20 m	30 m	40 m	50 m	60 m
θ = 0º	$2.5 \cdot 10^7$	$6.3 \cdot 10^6$	$2.8 \cdot 10^6$	$1.6 \cdot 10^6$	$1.0 \cdot 10^6$	$7.0 \cdot 10^5$
θ = 5º	$2.2 \cdot 10^7$	$5.6 \cdot 10^6$	$2.5 \cdot 10^6$	$1.4 \cdot 10^6$	$8.9 \cdot 10^5$	$6.2 \cdot 10^5$
θ = 10º	$1.6 \cdot 10^7$	$3.9 \cdot 10^6$	$1.7 \cdot 10^6$	$9.7 \cdot 10^5$	$6.2 \cdot 10^5$	$4.3 \cdot 10^5$
θ = 15º	$1.1 \cdot 10^7$	$2.6 \cdot 10^6$	$1.2 \cdot 10^6$	$6.6 \cdot 10^5$	$4.2 \cdot 10^5$	$2.9 \cdot 10^5$
θ = 20º	$7.8 \cdot 10^7$	$2.0 \cdot 10^6$	$8.7 \cdot 10^5$	$4.9 \cdot 10^5$	$3.1 \cdot 10^5$	$2.2 \cdot 10^5$
θ = 25º	$6.7 \cdot 10^7$	$1.7 \cdot 10^6$	$7.4 \cdot 10^5$	$4.2 \cdot 10^5$	$2.7 \cdot 10^5$	$1.9 \cdot 10^5$

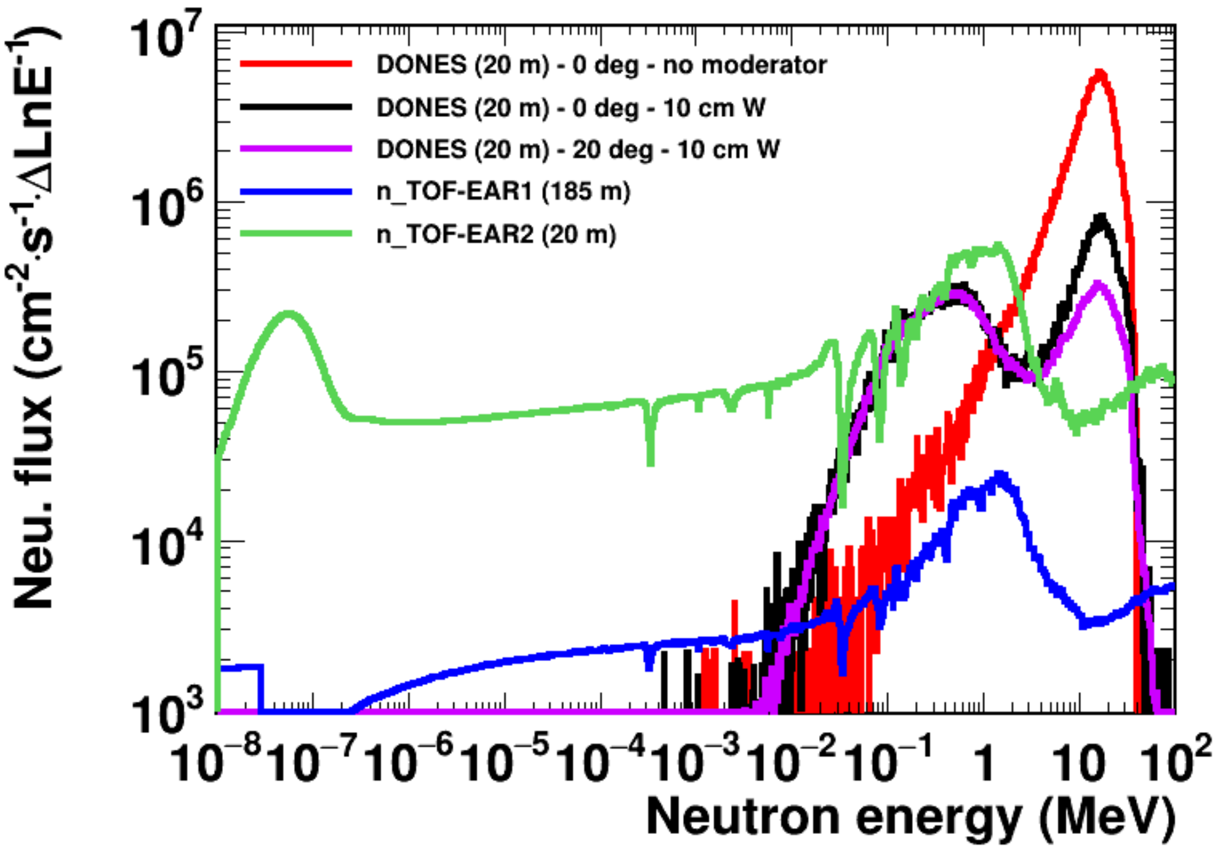
Neutron flux, in **$n/(cm^2 \cdot s)$**, at different angles and TOF distances, generated by a 40 MeV deuteron beam of **125 μA** impinging on a thick graphite target.

Neutron flux at different angles



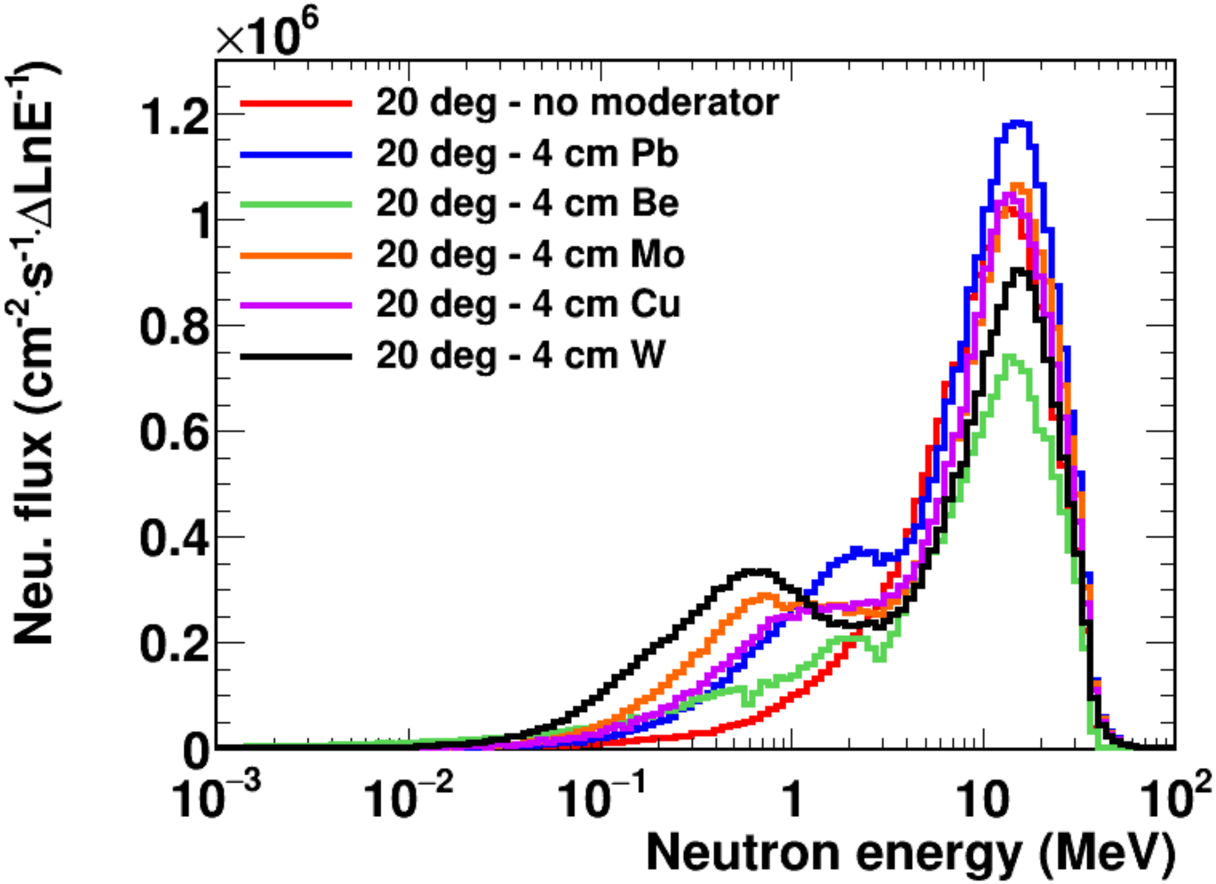
Neutron flux at **20 m TOF distance**, as a function of the neutron energy, at different angles generated by a 40 MeV deuteron beam of 125 μA impinging on a thick graphite target.

“Degradation” of the neutron beam



We have investigated the possibility of *moderating* the neutron beam → not straightforward, water/polyethylene … are not good moderators for 15 MeV neutrons.
(In the picture: 20 m TOF distance + 125 μA deuterons on thick graphite)

“Degradation” of the neutron beam



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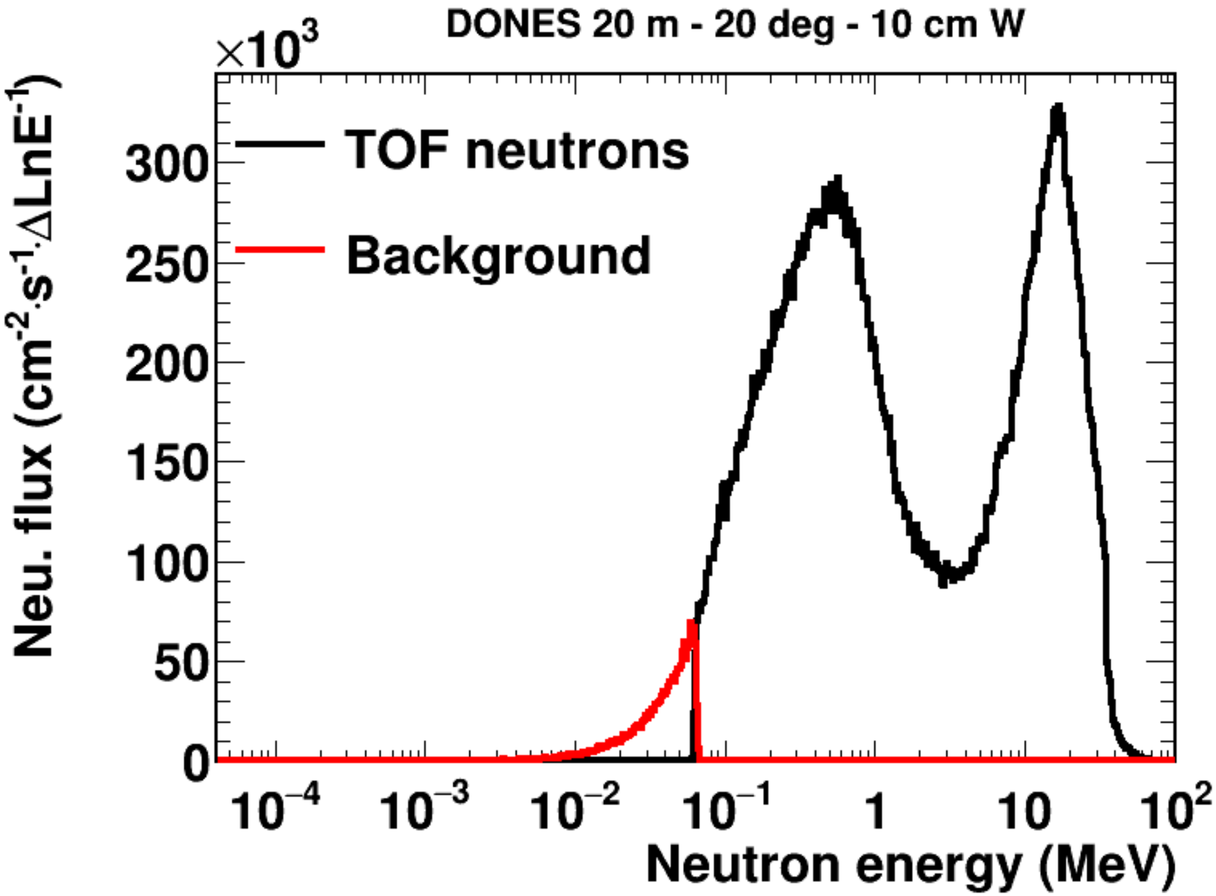
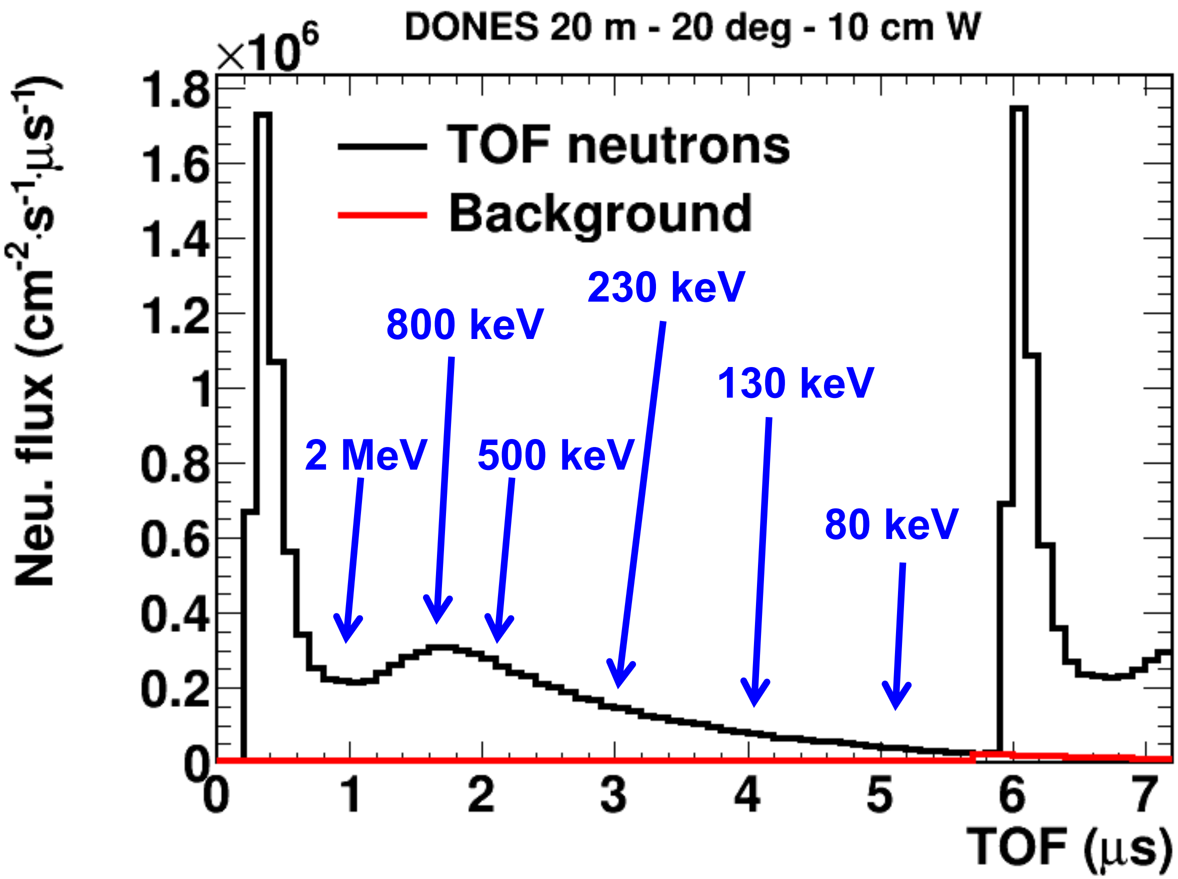
Time structure of the neutron beam



In the neutron beam, there will be some neutrons coming with the desired TOF-Energy relation (black) and other neutrons from other pulses → background (red). In the picture, n = 1 and the distance between pulses 5.7 μs (175 kHz).

Time structure of the neutron beam



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TOF-DONES experimental program

- Irradiation of targets
- In-beam production/excitation of isotopes via (n,f), (n,xn), (n,n'γ)
- γ-ray, neutron and charged particle spectroscopy.