

First IFMIF-DONES Users workshop 26-27/09/2022

Perspectives for Neutron Scattering techniques at DONES

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Outline

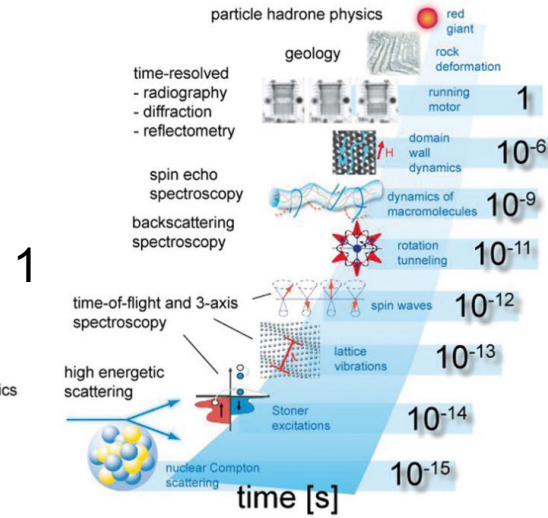
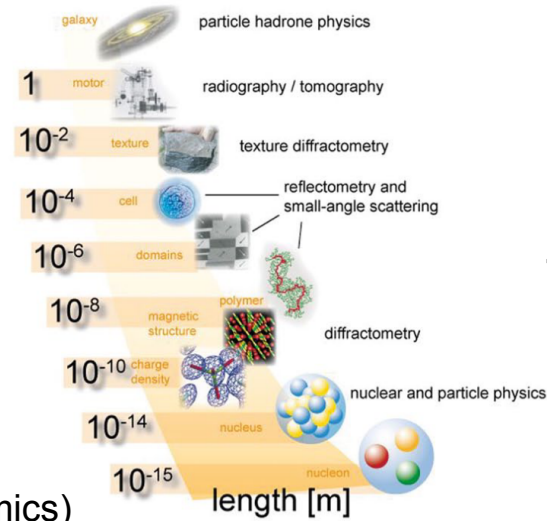
- The landscape of Neutron Scattering in Europe
- My experience in Neutron Scattering:
 - Design of the ANNI beamline for ESS
- Possibilities of Neutron Scattering at IFMIF-DONES
 - Complementary Applications Hall R160
 - Beam Extraction to other experimental areas



The Landscape of Neutron Scattering

Fields of interest:

- From biology to chemistry, magnetism, soft matter and nuclear&particle physics, to art&heritage conservation.
- Large synergies with industry



Types of experiments / instruments:

- Diffractometry (structure) / spectroscopy (dynamics)
- TOF in pulsed modes (typical frequencies in the range 10 – 300 Hz)
- Monochromator crystals / polarization (do not need pulsation)
- Complementary: PGAA and neutron imaging/tomography

The Situation of Neutron Scattering in Europe

Europe is leading in the field of Neutron Scattering: 70 % share of publications in the past 20 years.

Large Scale Facilities:

ILL, the flagship of Neutron Scattering for 50 years. Reactor shut-down planned at the end of this decade. Hosting ~40 instruments.

ESS. Accelerator-based, pulsed source with high brilliance. Will host up to 15-22 instruments.

National or regional neutron sources:

- Many reactor based sources have either already shut-down or will do in the near future.
- Compact Accelerator-based Neutron Sources (CANS) are on the road.

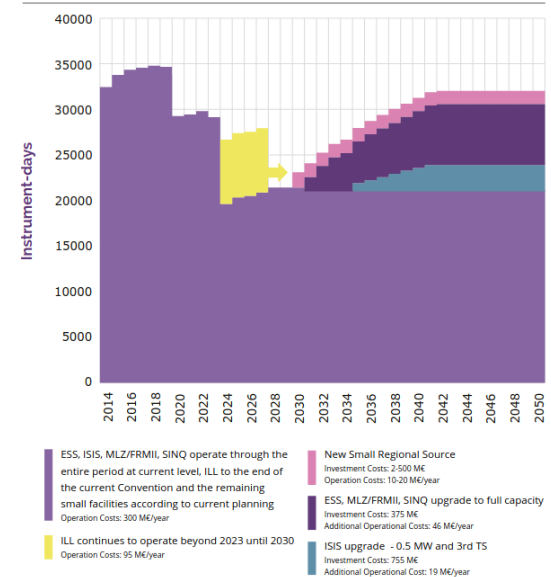
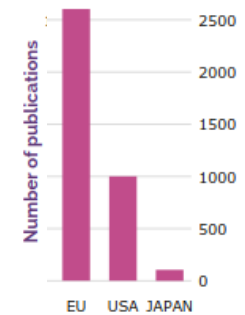
!! Not enough neutron supply for the Neutron Scattering Community in the next decade.

!! Many countries will lose access to a reliable neutron source for experiments (lack of beamtime).

Medium sized facilities are needed for testing and first-insight experiments before being accepted for performing experiments in the highly demanded instruments of ESS.

Also, as spaces for training of new researchers and for new instrument and detector design and testing.

The Low Energy Accelerator-driven Neutron Sources (LENS) Report of 2020 encourages the design and development of intermediate size facilities, specially pointing to countries such as Spain or Italy.



Figures from *Neutron Scattering Facilities in Europe, present status and future perspectives (2016)*



My experience in Neutron Scattering

The ANNI¹ beamline proposed for ESS

An instrument for particle physics:

Neutron decay rate and correlations (testing Standard Model)

Measuring neutron properties (e.g charge, electric dipole momentum, etc)

Nuclear physics experiments

(e.g. NPDGamma ($^1\text{H}(n,\gamma)^2\text{H}$) and NDTGamma ($^2\text{H}(n,\gamma)^3\text{H}$) at SNS ORNL)

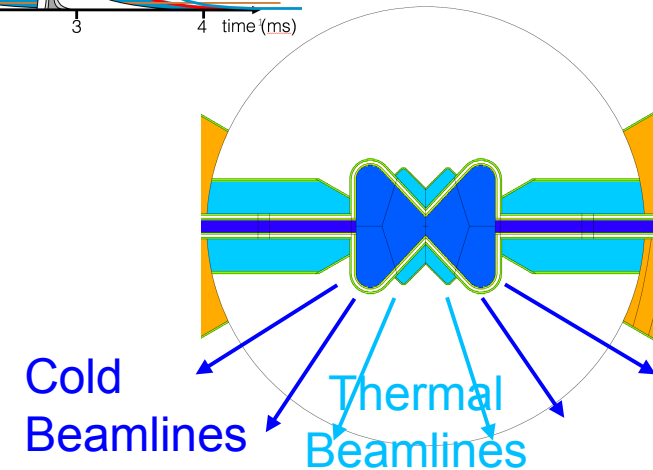
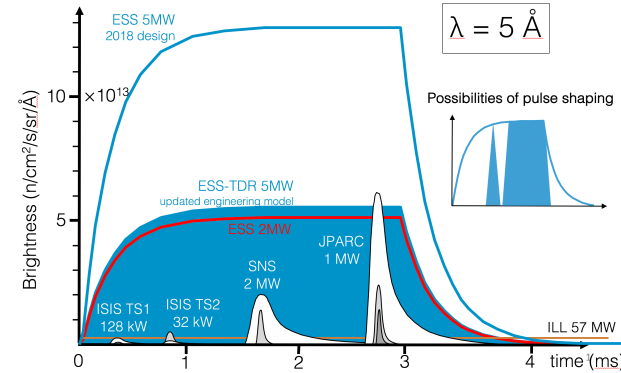
¹T. Soldner et al. EPJ Web of conferences 219, 10003 (2019)

My experience in Neutron Scattering

ESS

ESS has a high brilliance moderator and provides a large flux to the beamlines. The beam is pulsed with a frequency of 14 Hz and pulse length is 3 ms.

The moderator has a flat butterfly-like geometry. The instruments point towards a cold moderator (para-H₂ at 20 K) or a thermal moderator (H₂O at 300 K).



My experience in Neutron Scattering

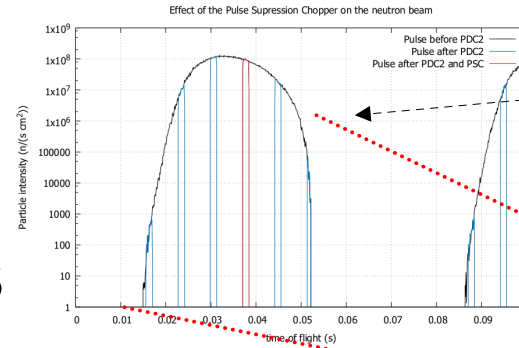
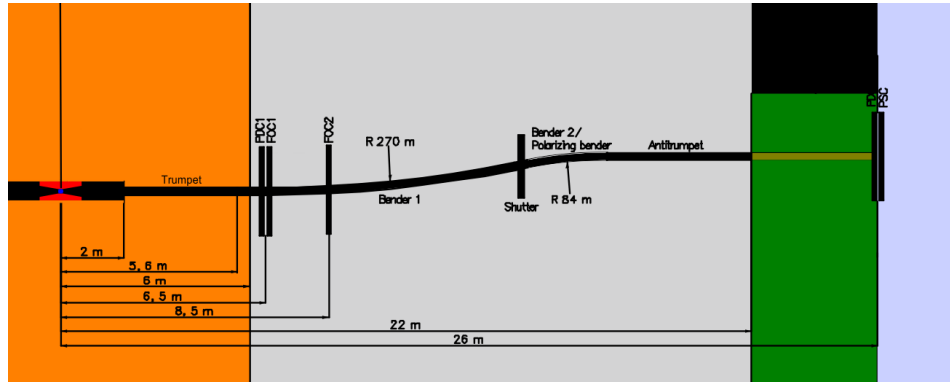
The ANNI beamline proposed for ESS

The instrument comprises a bent guide and a set of choppers to define the time structure of the neutron pulse.

The goal in most experiments at the ANNI beamline is to have a well defined beam position and length within a detection volume. The pulsed structure of the beam is perfect for such goal.

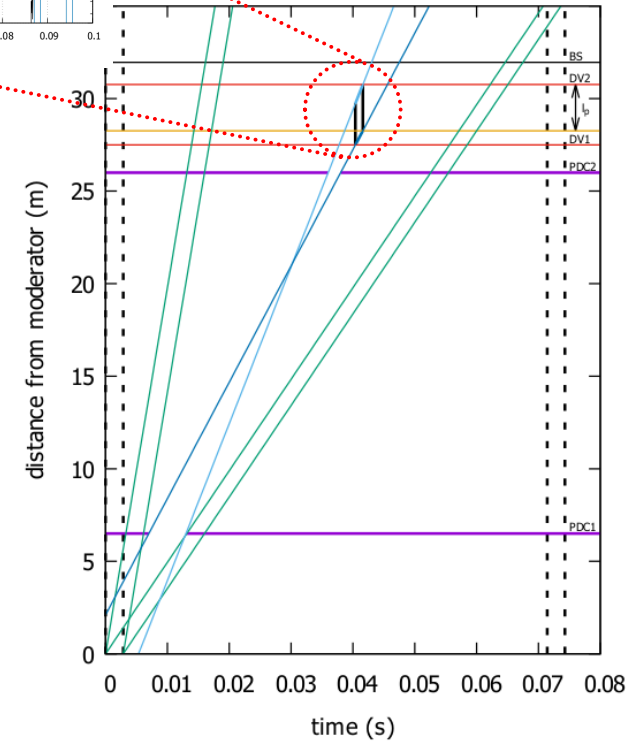
High energy resolution is not needed in this case (whereas this is fundamental in other applications)

Simulations run with the McStas Code.



Neutron beam pulse with and without applying pulse definition choppers (PDC)

Pulse definition for 1 pulse



Possibilities of Neutron Scattering at IFMIF-DONES: Complementary Applications R160 Hall

For Neutron Scattering experiments, low energy neutrons are needed:

Thermal neutrons (20-100 meV)

Cold neutrons (5-20 meV)

Very cold neutrons (0-5 meV)

Neutrons from the TC have energies around the tens of MeV

→ A moderator device is needed

Complementary Applications R160 Hall

Previously discussed ideas included inserting the moderator inside the wall:

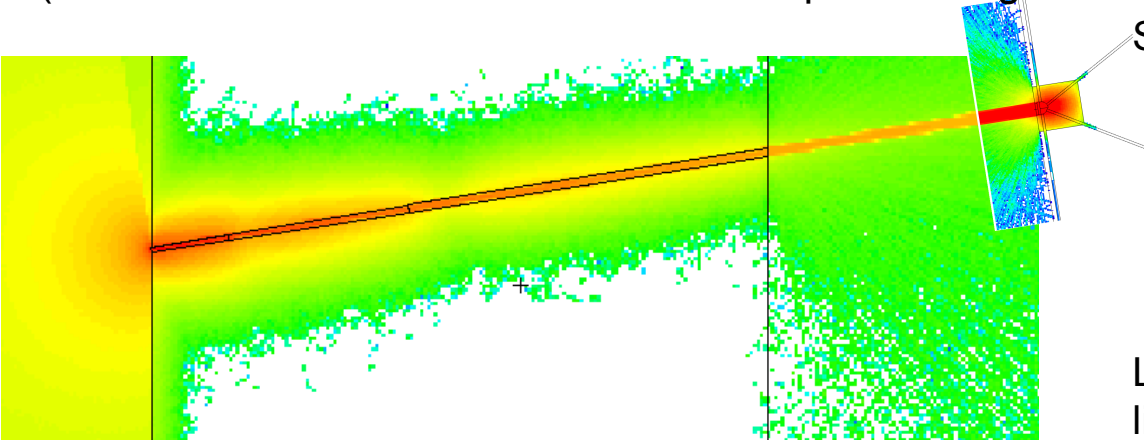
- This allows a single beamline with high brilliance
- But also with large fast neutron contamination

By moving the moderator outside the wall:

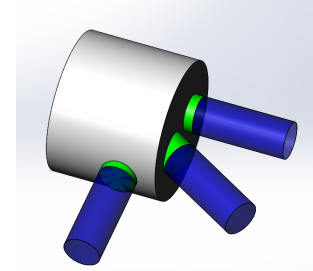
- Multiple beamlines can be extracted
- Also they can be oriented off the duct direction (avoiding partly the fast neutron contamination)

Neutrons from the Hot Cell through the duct (+6 m concrete wall)

(MCNP v6.2 simulations of neutron transport: through the duct + moderator & beamports)



Some Previous designs (report)



Last designs based on Low Dimensional Moderators, like the ESS

Complementary Applications R160 Hall

Low Dimensional Moderator

1D Lineal Moderator

(one or two beamlines max, cold or thermal)

Maximizes brilliance

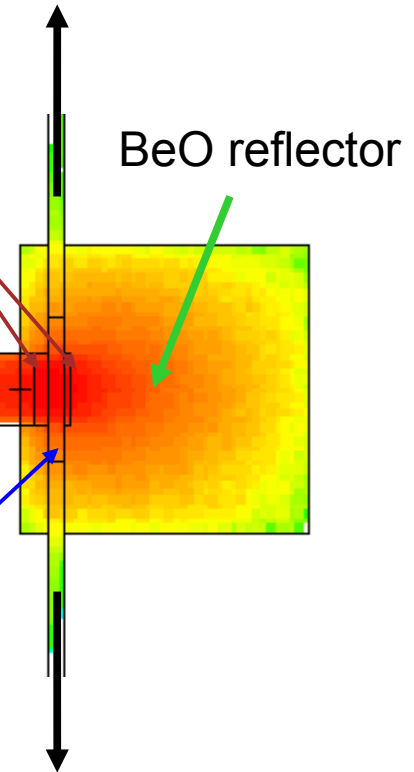
We have obtained brilliances around $3 \cdot 10^8$ n/cm²/s/sr for cold neutrons (5-20 meV)

Larger brilliance / more difficult to integrate in the R160 Hall (limited beamline lengths / lower resolution if TOF / lower collimation)

Thermal moderator (H₂O at 300 K)

Neutron beam from the TC

Cold moderator (para-H₂ at 20 K)



Complementary Applications R160 Hall

Low Dimensional Moderator

2D Flat Moderator

Allows multiple extraction points

→ Many experiments running on parallel)

4 cm height

2 cm depth pre-moderator (H₂O)

2 Moderators (halves of Semicircle)

- 4 cm radius for thermal moderator

- 5 cm radius for cold moderator

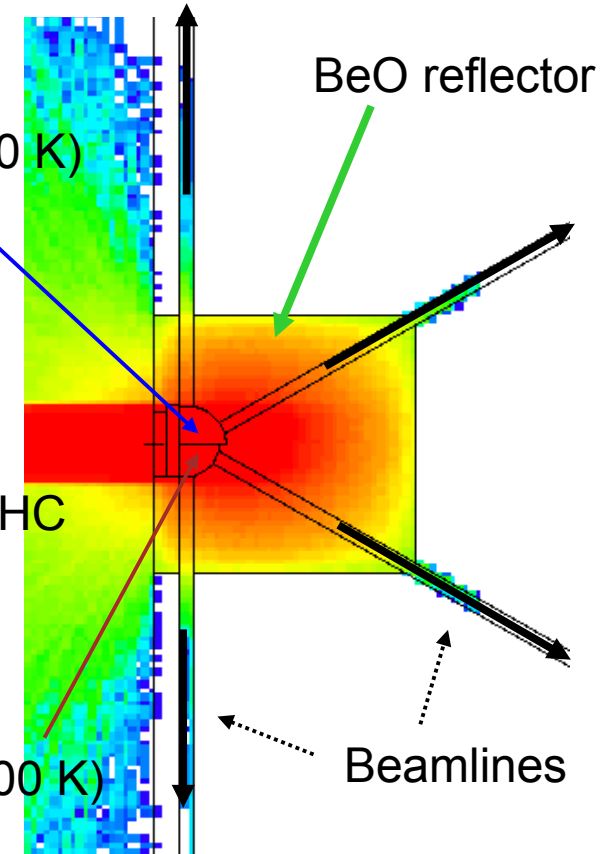
Cold moderator (para-H₂ at 20 K)

Neutron beam from the HC

Thermal moderator (H₂O at 300 K)

BeO reflector

Beamlines



Complementary Applications R160 Hall

Low Dimensional Moderators

2D Flat Moderator (Allows multiple extraction points → Many experiments running on parallel)

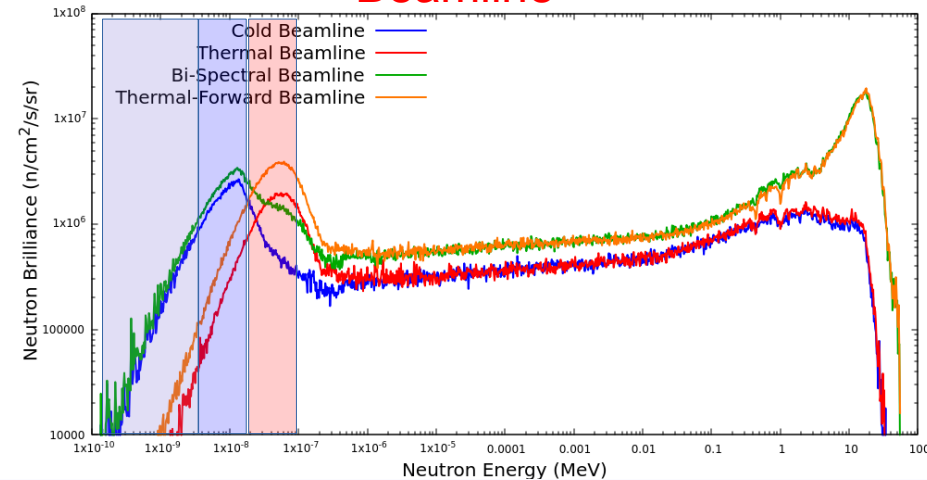
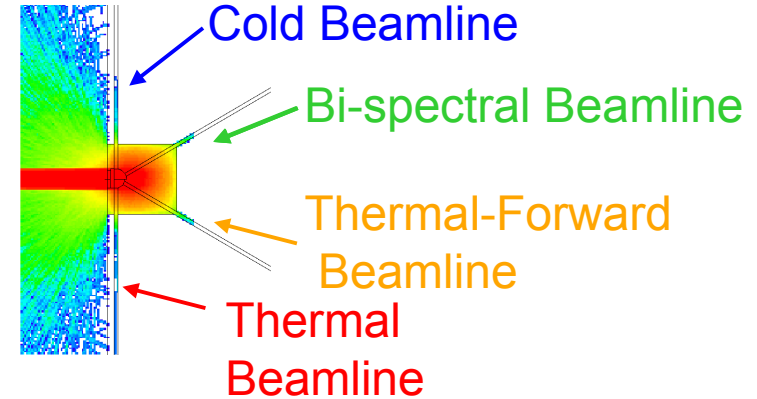
Lower brilliance

We have obtained brilliances:

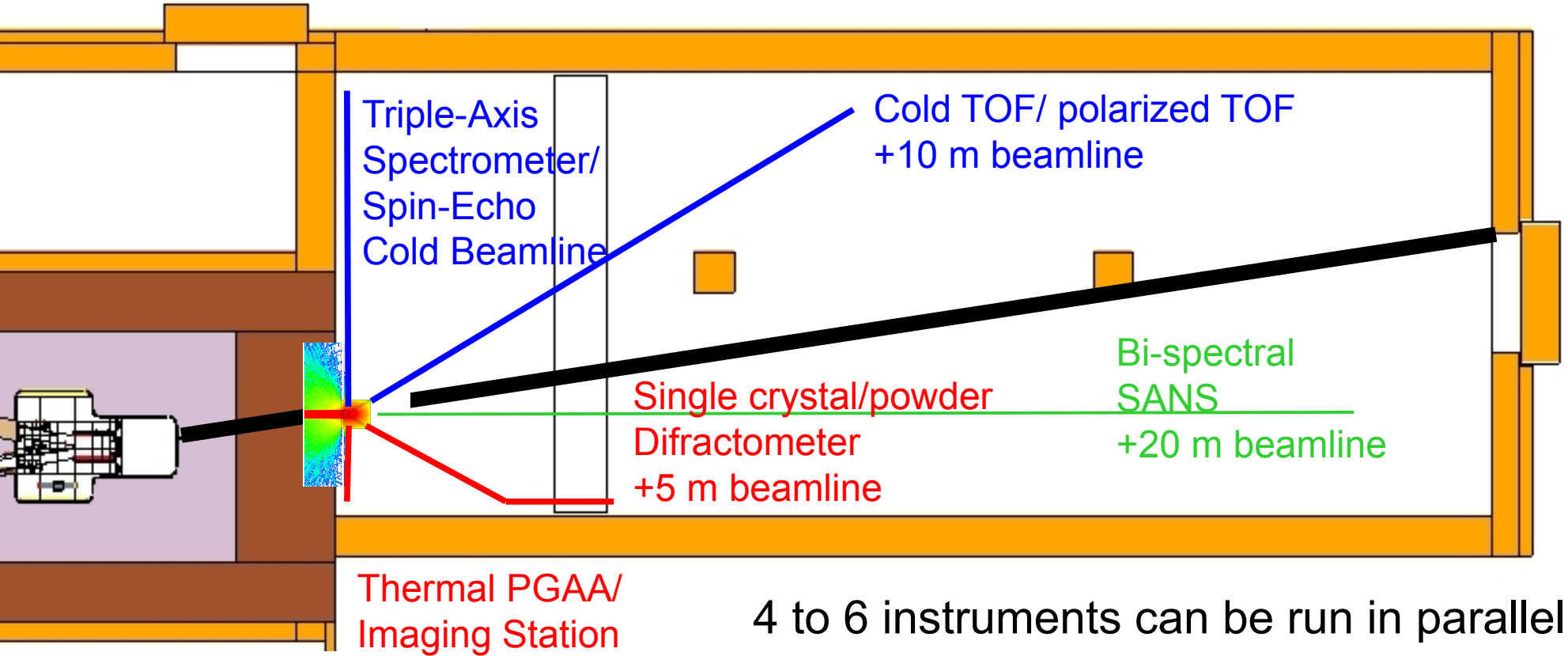
- $\sim 1.5 \cdot 10^8$ n/cm²/s/sr for cold neutrons (5-20 meV)
- $\sim 2.2 \cdot 10^8$ n/cm²/s/sr for thermal neutrons (20-100 meV)
- $\sim 3.2 \cdot 10^8$ n/cm²/s/sr for a bi-spectral (0-100 meV)

For comparison, cold brightness from ILL yellow book is $3.3 \cdot 10^{12}$ n/cm²/s/sr

→ 4-4.5 orders of magnitude below ILL



Complementary Applications R160 Hall



Possibilities of Neutron Scattering at IFMIF-DONES: 1% Deuteron Beam Extraction

Secondary neutron source:

With 1.25 mA 40 MeV d onto C \rightarrow $\sim 6E13$ n/s (fast neutrons)

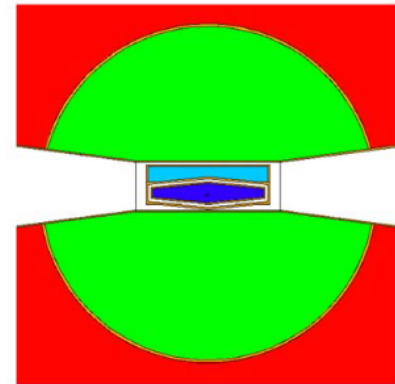
With 1.25 mA 40 MeV d onto Be \rightarrow $\sim 5.6E14$ n/s (fast neutrons)

Moderators for such targets can be designed using MCNP, profiting from neutron production cross sections in the TENDL19 database.

Using linear moderator – only one or 2 beamlines in opposite directions

(moderator brilliance estimates from ¹, neutron yield from Be(d,n) at 40 MeV from ²):

- Brilliances can go up to the order of $6.2 \cdot 10^{10}$ n/cm²/s/sr
- We would be only two orders of magnitude below ILL



¹ L. Zanini et al 2018 J. Phys.: Conf. Ser. 1021 012009

² PhD Thesis J. Morrell, U. California, Berkeley (2021)

1% deuteron Beam Extraction

It was proposed to extract 1.25/0.125 mA (1 % to 0.1 %) at 1.75 to 0.175 MHz (single pulses)

This pulse structure is too fast for Neutron Scattering experiments.

Quick example: Thermal neutrons have a speed of 2200 m/s.

In a 10 m length instrument, if we want a resolution of $\Delta\lambda/\lambda \sim 0.01$, a pulse widens by 90 us.

For cold neutrons (5 meV), that would be 200 us.

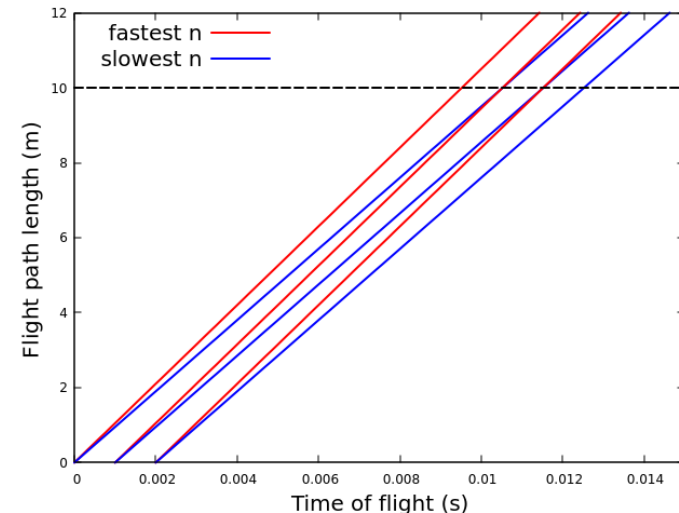
Just to avoid frame overlap, frequency should go below 5 kHz.

All this does not consider pulse duration, specially moderating times and the tails of the pulses.

Lower resolution and larger experiments would benefit if an even lower frequency was used

Typical figures for Neutron Scattering instruments are:

- Pulse length: 10 us – 10 ms
- Frequency: 10-300 Hz



Example for a 5 meV ($v \sim 1000$ m/s) neutron beam with 5% resolution in a 10 m instrument. Maximum frequency without frame overlap would be 1 kHz

1% deuteron Beam Extraction

In order to be used for Neutron Scattering purposes:

Assume the beam as continuous (same as at R160):

Chop it afterwards (depending on instrument needs) → Better for slow instruments (e.g. SANS)

Use monochromators for energy selection instead of TOF (e.g. Triple-Axis Spectrometers)

Use for applications with no time-structure demand → PGAA & Imaging

Change pulse structure:

Extracting a bunch made of 10^4 consecutive pulses at 175 Hz (1 %) and pulse length = 57 μ s

→ Acceptable for thermal neutrons

Extracting a bunch made of 10^5 consecutive pulses at 17.5 Hz (1 %) and pulse length = 0.57 ms

→ Better for cold neutrons



Conclusions

The Neutron Scattering Community is in need of medium-sized neutron sources

There are real possibilities of installing a suite of neutron scattering instruments at IFMIF-DONES

At the R160 Hall, right after the HC: using Low Dimensional Moderators (1D or 2D), brilliances around $3 \cdot 10^8$ n/cm²/s/sr can be achieved. This is enough for a regional source. Further research towards specific instrument needs can improve the figures.

Exploring the possibility of using the 1% d beam, additional neutrons can be produced using C,Be targets, with high output. First estimates of moderator brilliance could reach $6 \cdot 10^{10}$ n/cm²/s/sr, around the size of national sources.

In this case, however, special care should be pointed towards the pulse structure.



Thank you for your attention!