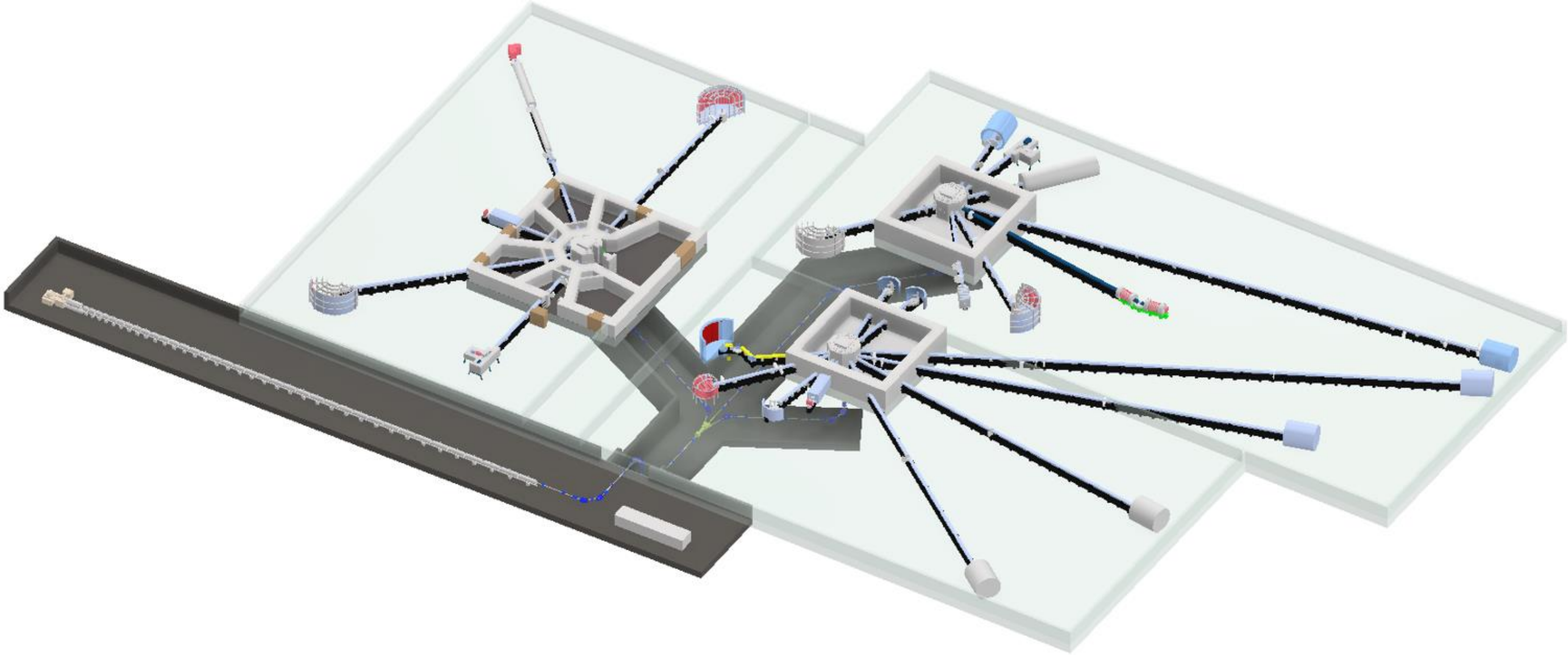


Options for an Epithermal and Fast Neutrons Target Station at HBS

Dr. Eric Mauerhofer, M.Eng. Norberto Schmidt

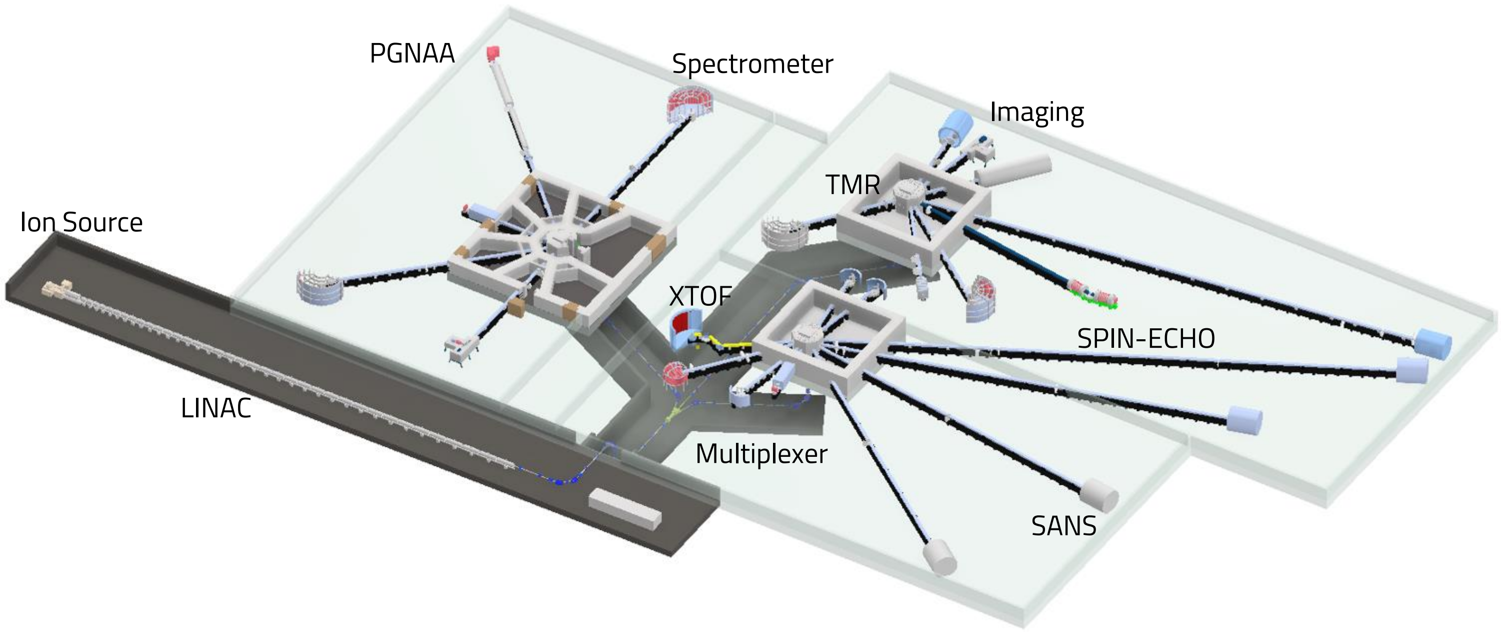
01.12.2022 | 6th Joint Workshop of RIKEN RAP and JCNS

Summary

High Brilliance Neutron Source

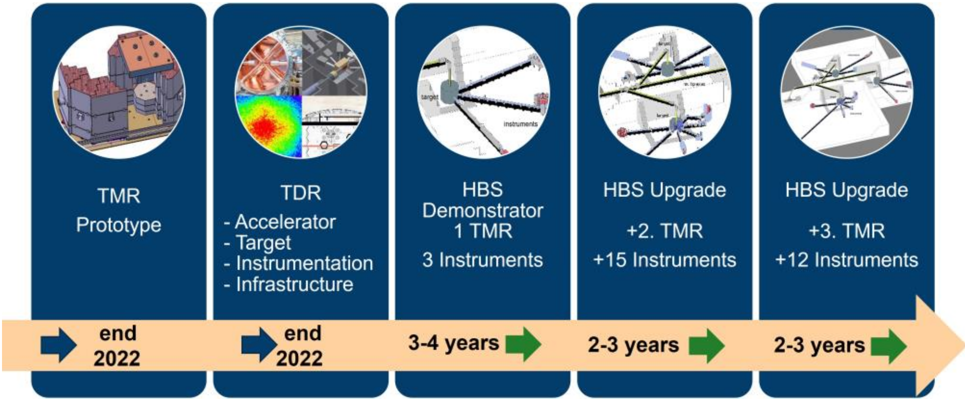
Accelerator:

- Average Power: 100 kW
- Proton Energy: 70 MeV
- Duty Cycle: 1.6 %
- Proton Current: 89.3 mA
- Neutron target: Tantalum



3 Target-Moderator-Reflector (TMR) Stations:

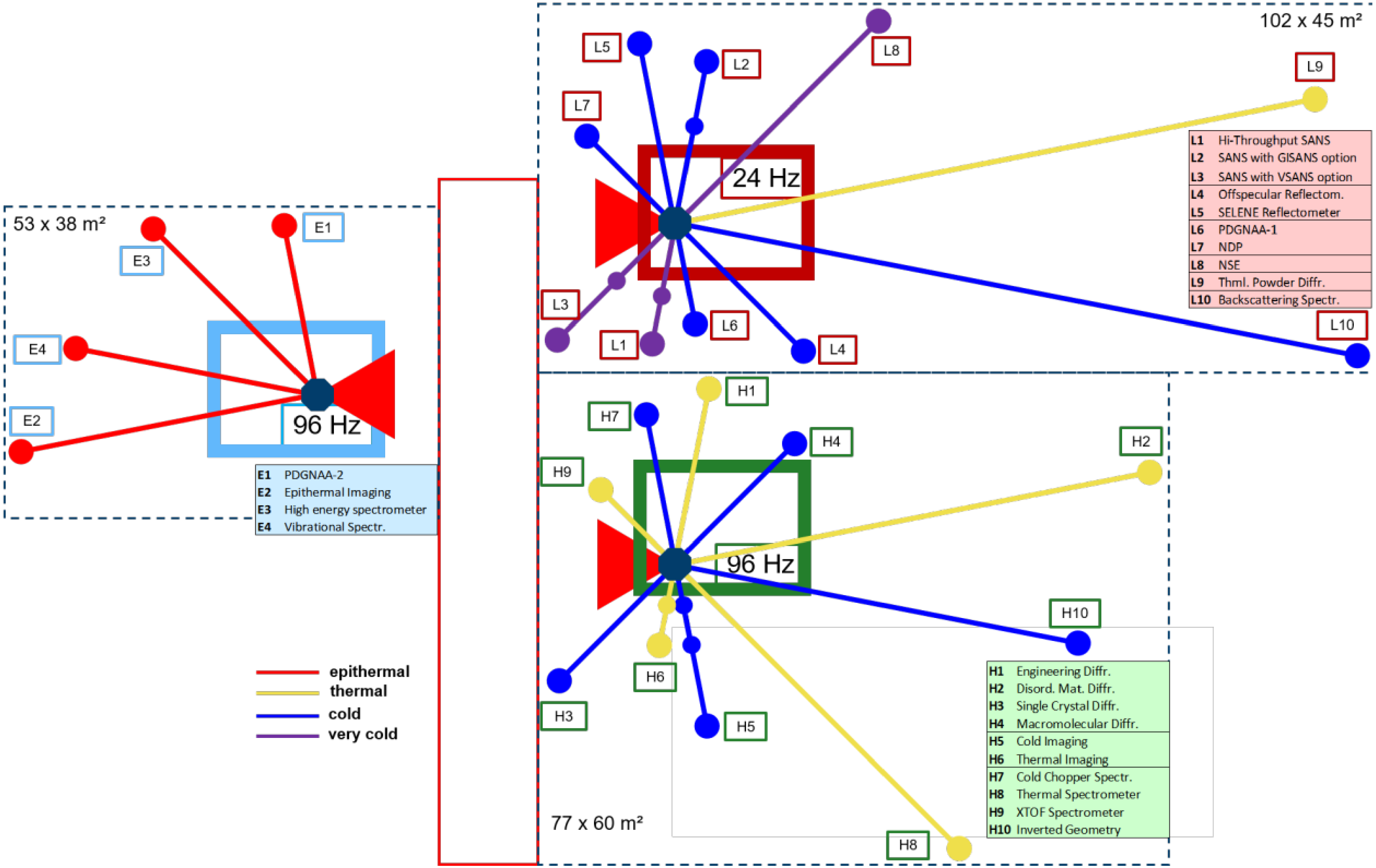
Frequency [Hz]	Period [ms]	Duty cycle [%]	Pulse width [μs]	Purpose
24	41.7	1.60	667	Long pulse, cold neutrons
96	10.4	1.60	167	Medium pulse, thermal neutrons
96	10.4	1.60	167 (down to 10)	Short pulse, epithermal neutrons



High Brilliance Neutron Source

Instruments investigated for the Technical Design Report (TDR)

- 3 Analytics Instruments
- 5 Diffractometers
- 5 Large Scale Structure Instruments
- 7 Spectrometers
- **5 Imaging Instruments**



High Brilliance Neutron Source

TMR Source Simulations → **Virtual Sources Generation** → **Instruments Simulations**

PHITS — Particle and Heavy Ion Transport code System

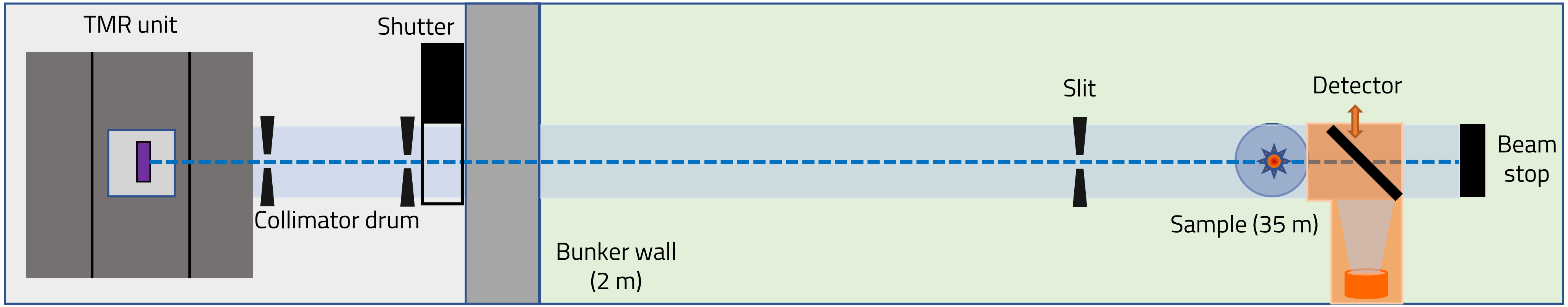
KDSource

VITESS   McStas

TMR Source Simulations
- Cold
- Thermal
- Epithermal
- Fast

Virtual Sources Generation
- Machine learning algorithms
- Resampling from the original sources

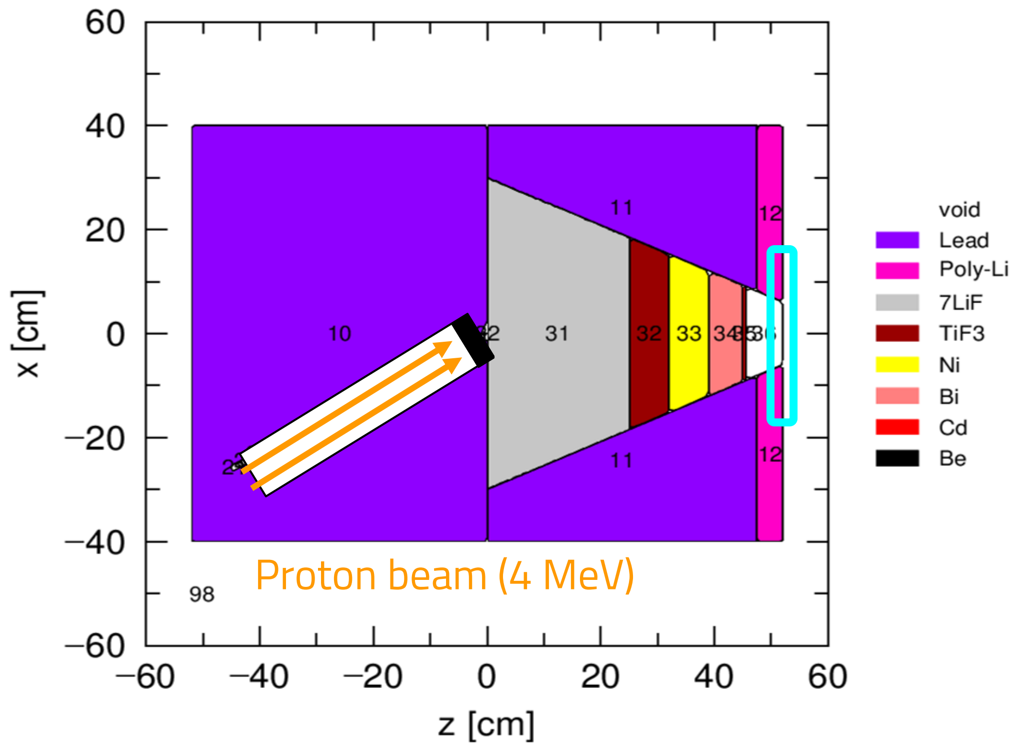
Instruments Simulations
- Flux at the sample
- Field of view (FOV)
- Collimation (L/D)
- Spatial distribution
- TOF distribution
- Frame overlap



Schematic side view of the Epithermal Neutron Imaging Instrument at the HBS

Background and Previous Works

- We took as reference the design of BNCT instruments, because they require a high epithermal flux
- At the beginning, we tested the ^{7}LiF as moderator for our epithermal TMR unit



xz view of the BNCT facility

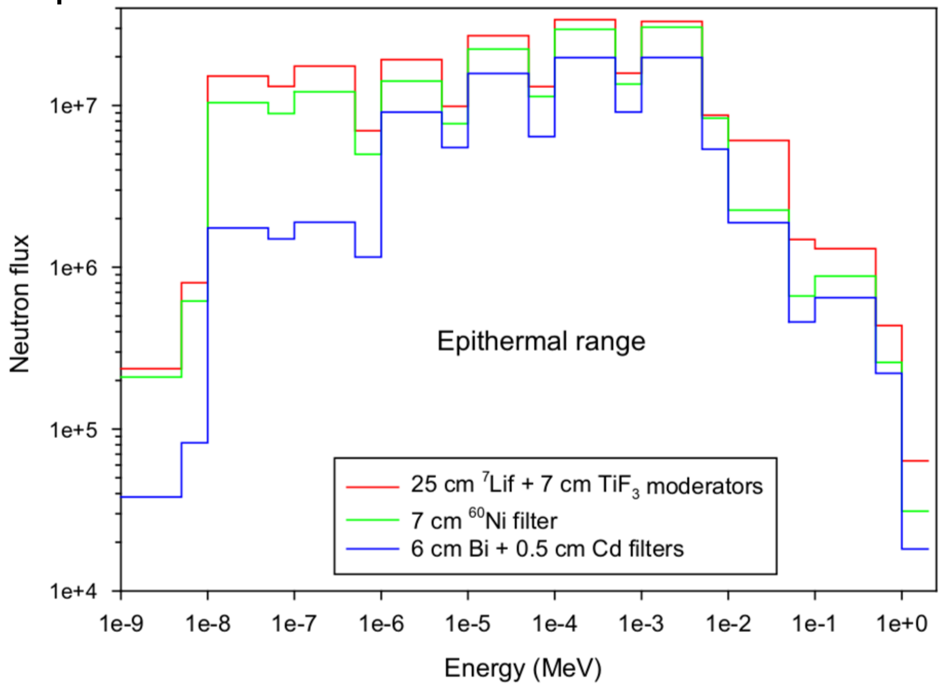
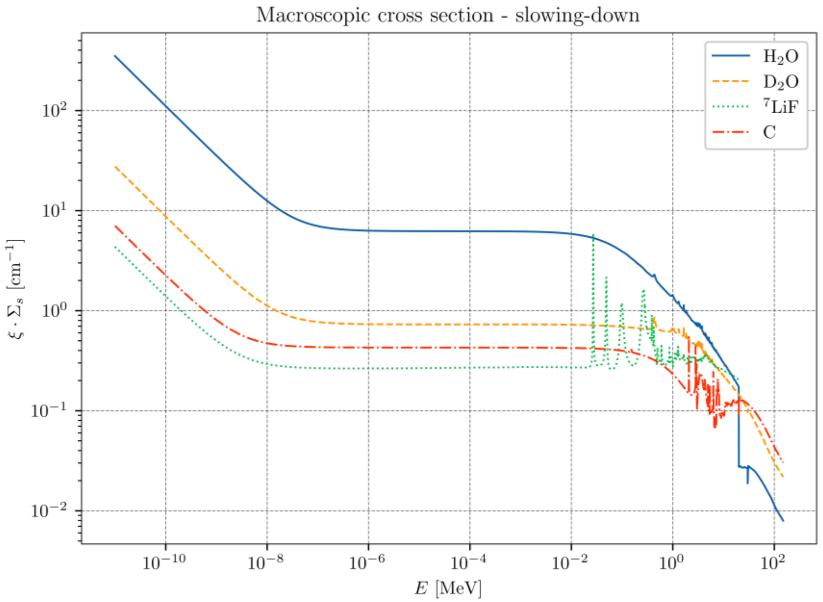


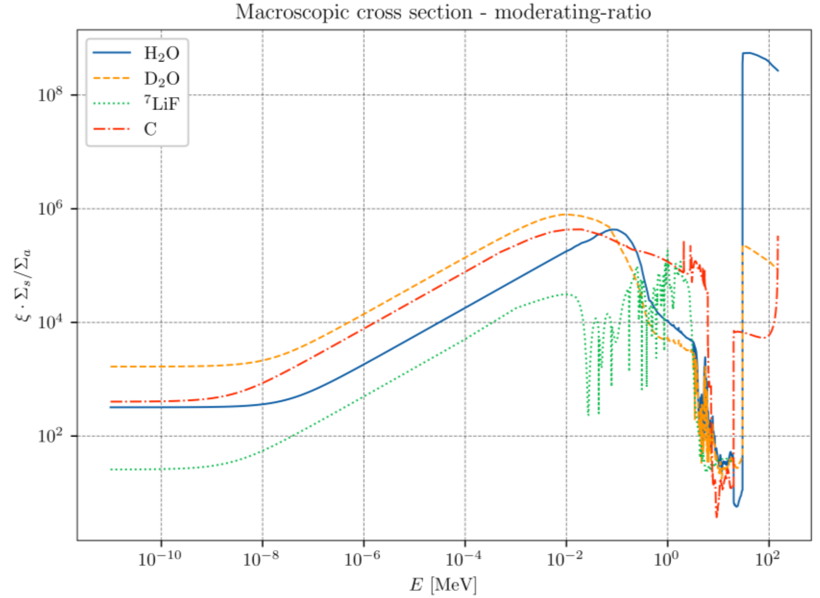
Fig. 9 The neutron spectra at the exit of the facility.

Fantidis, J. G., & Nicolaou, G. (2018). Optimization of beam shaping assembly design for boron neutron capture therapy based on a transportable proton accelerator. Alexandria engineering journal, 57(4), 2333-2342.

But we realized that, because of the high radiation levels close to the target, **the ^{7}LiF alone will melt**

Background and Previous Works





According to Beckurts (1964) and Carpenter (1977), the neutron beam current following a source pulse at large energies is:

$$J(E,t) \propto \frac{1}{2E}\frac{Y^{2/\gamma}e^{-Y}}{\Gamma(2/\gamma)}, Y = \frac{\xi\ \Sigma_s\ v\ t}{\gamma}$$

$$\xi = 1 - \frac{\alpha \ln(1/\alpha)}{1-\alpha}, \alpha = \left(\frac{A-1}{A+1}\right)^2$$

$$\gamma = 1 - \frac{0.5\ \alpha \ln(1/\alpha)^2}{1 - \alpha - \alpha\ln(1/\alpha)}$$

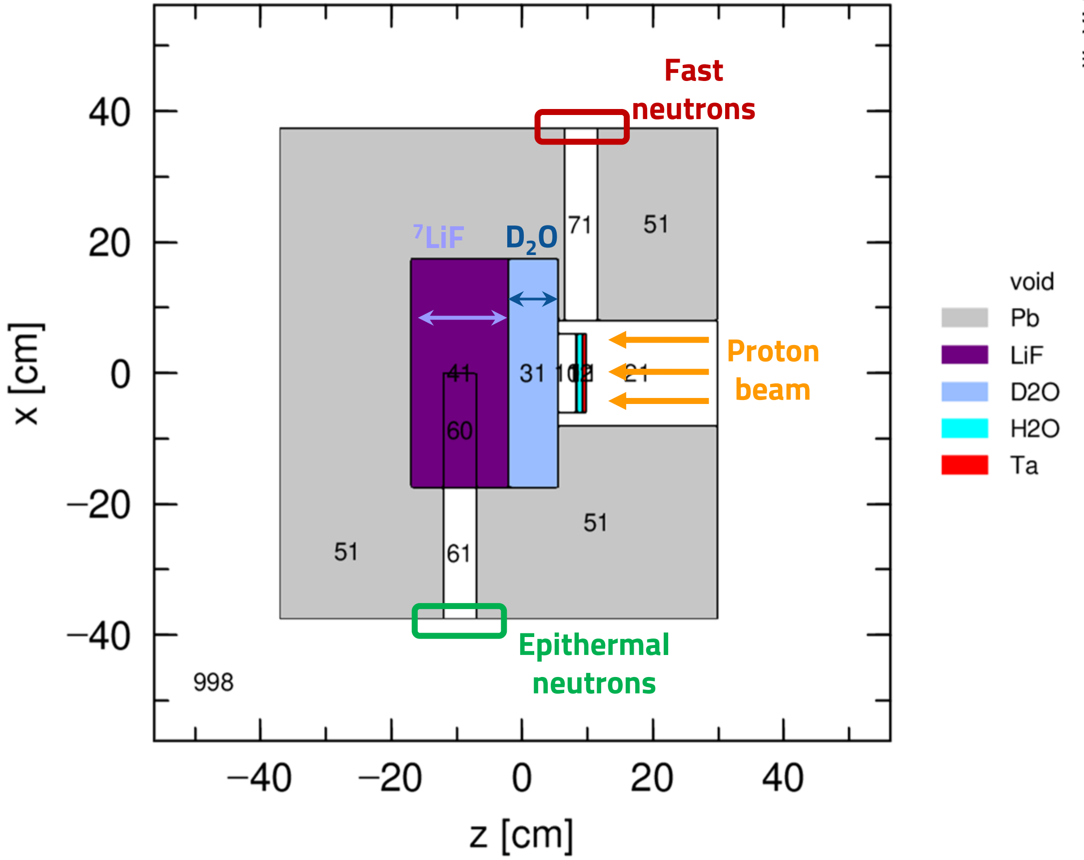
For energies above 1 eV:

$$< J(E) > \propto \frac{1}{\xi\ \Sigma_s\ E}, < t > = \left(1 + \frac{2}{\gamma}\right) \cdot \left(\frac{\gamma}{\xi\ \Sigma_s\ v}\right)$$

It's useful to define the slowing-down power as $\xi\ \Sigma_s$,
and the moderating-ratio as $\xi\ \Sigma_s/\Sigma_a$

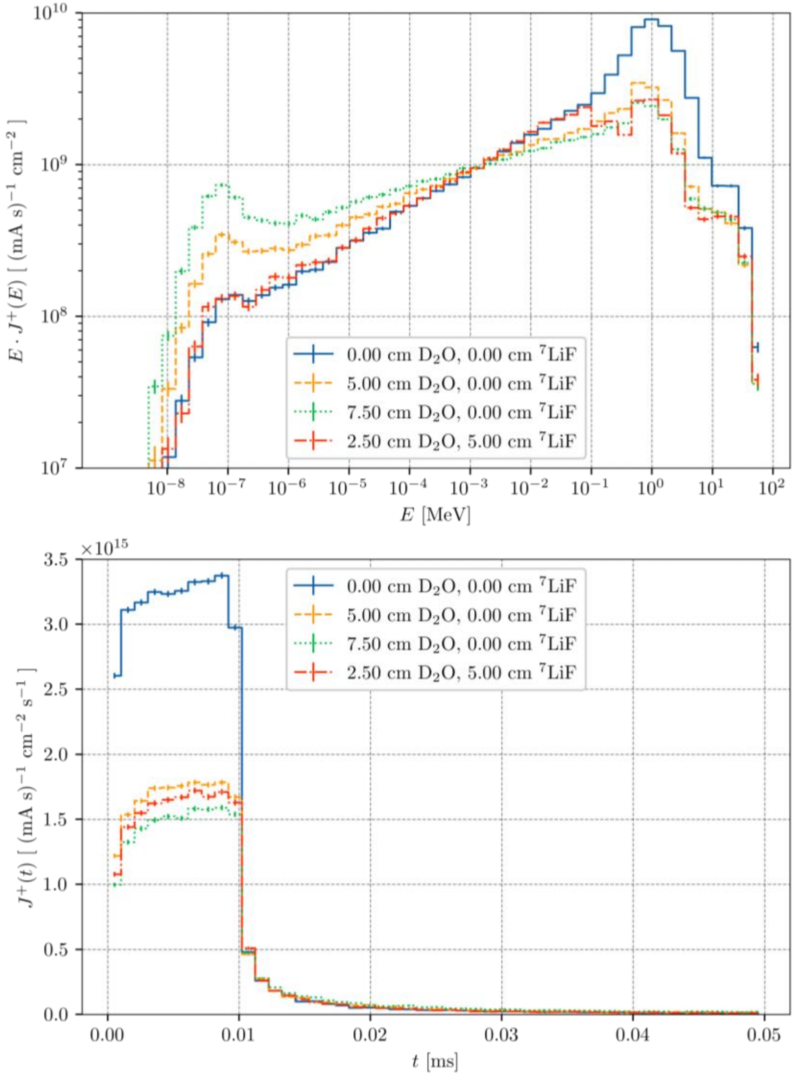
Simulations description

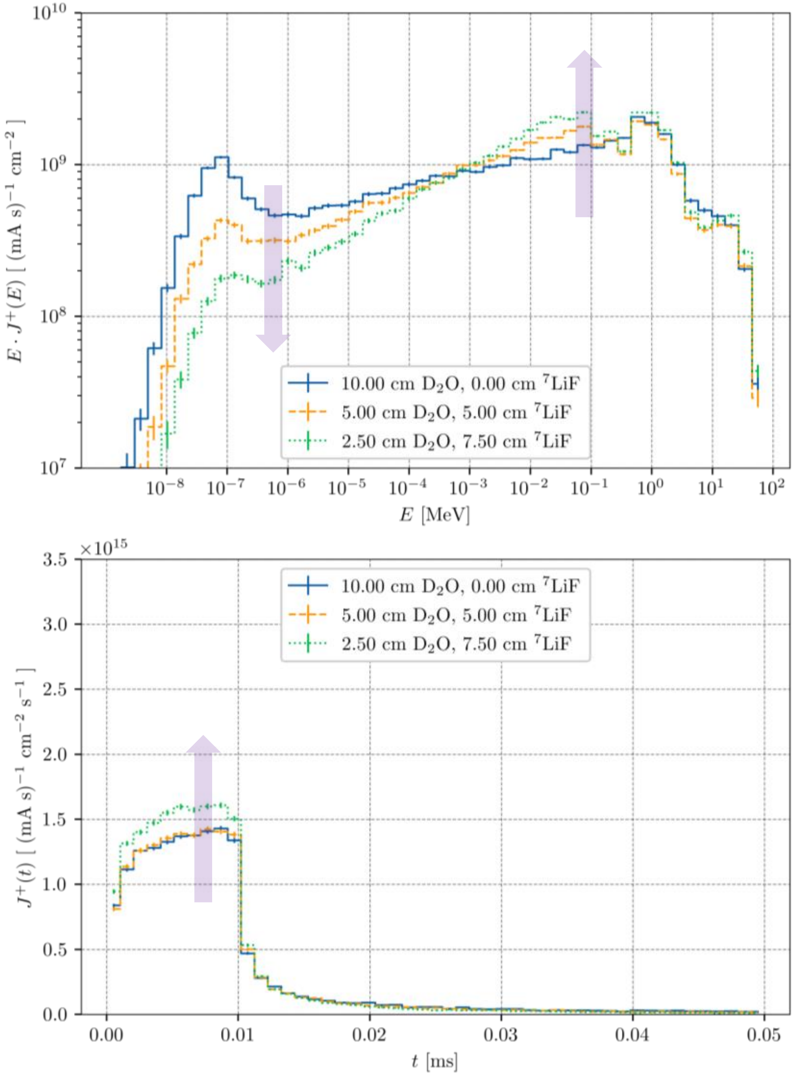
- Pb reflector, rectangular, 20 cm thickness in all directions
- One fast channel (5 cm diameter) looking directly to the target
- One epithermal channel (5 cm diameter) looking to the moderator
- A pre-moderator layer of D_2O, and a moderator layer of ^7LiF
- D_2O thickness: between 2.5 and 17.5 cm
- ^7LiF thickness: between 0 and 15 cm
- Tallies: dump-files to save all the particles that cross-out the epithermal and fast channels



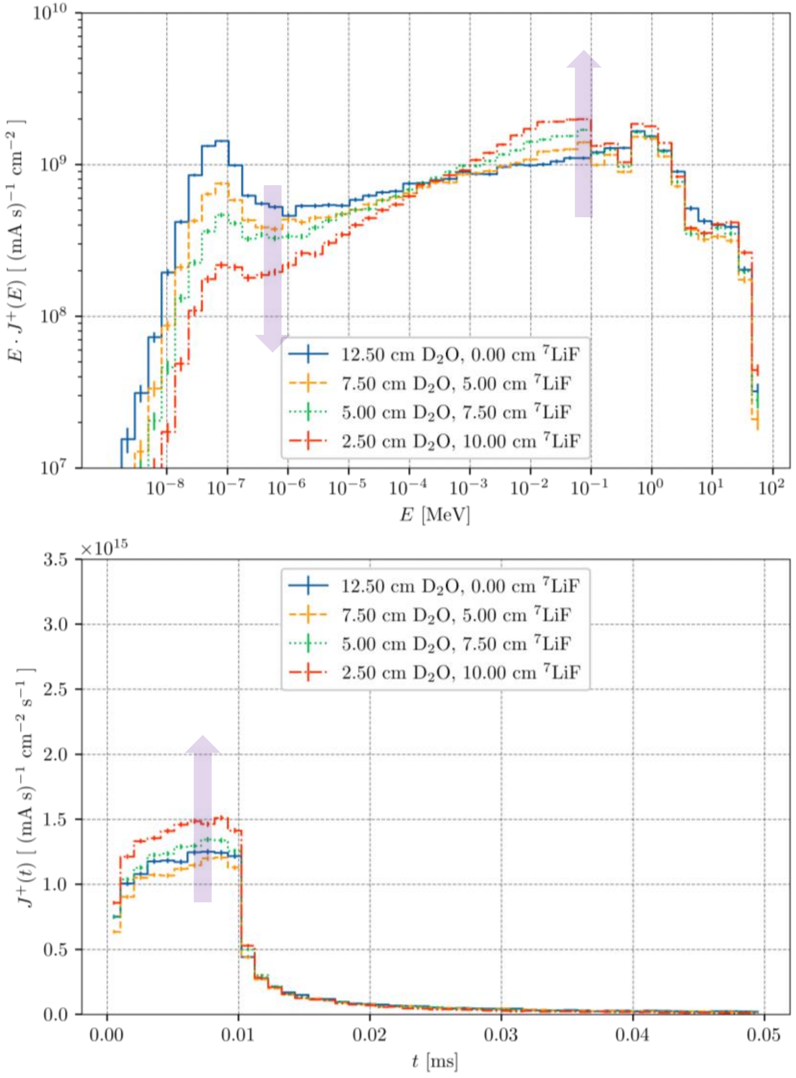
- Monte Carlo code: PHITS 3.27
- Nuclear library: JENDL-4.0
- Proton pulse width: 10 μs

Preliminary results



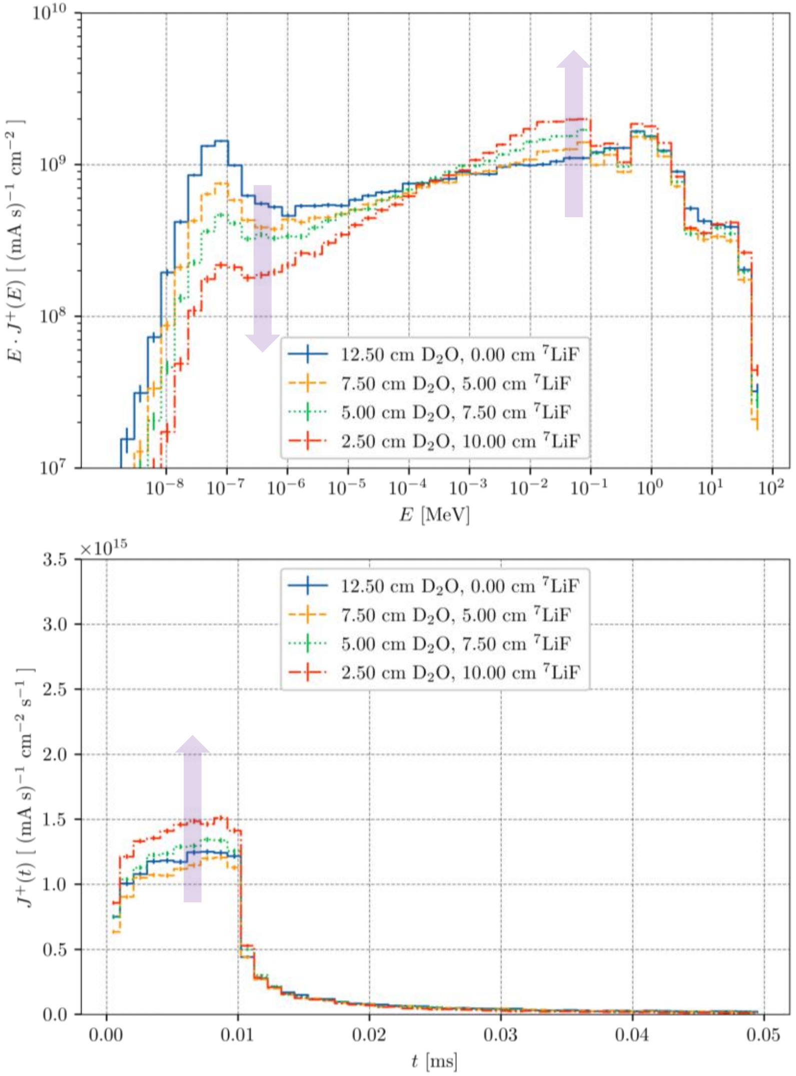


Total thickness: 10.0 cm

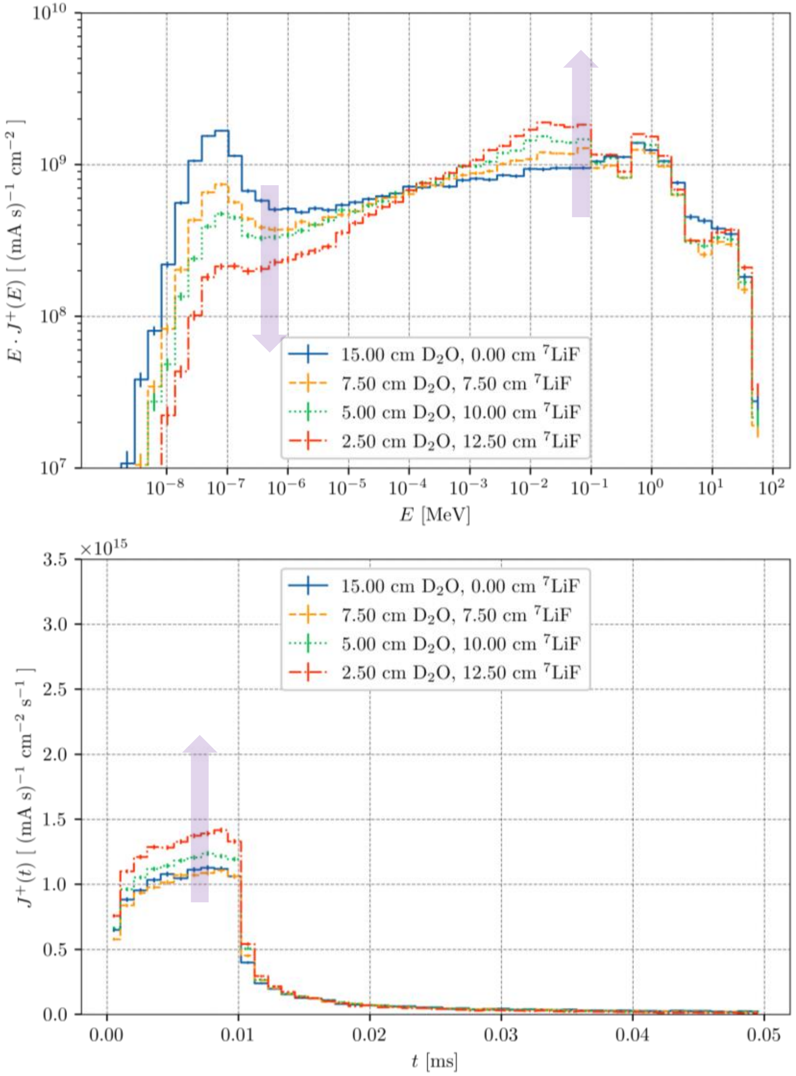


Total thickness: 12.5 cm

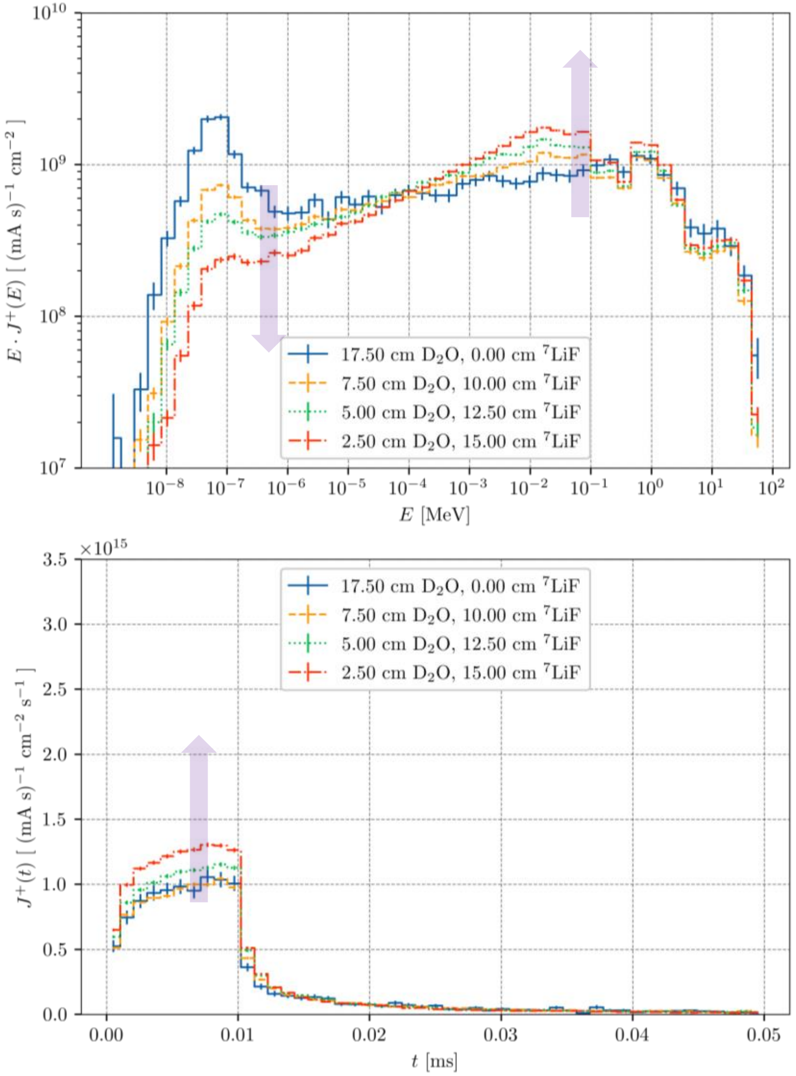
Preliminary results



Total thickness: 12.5 cm

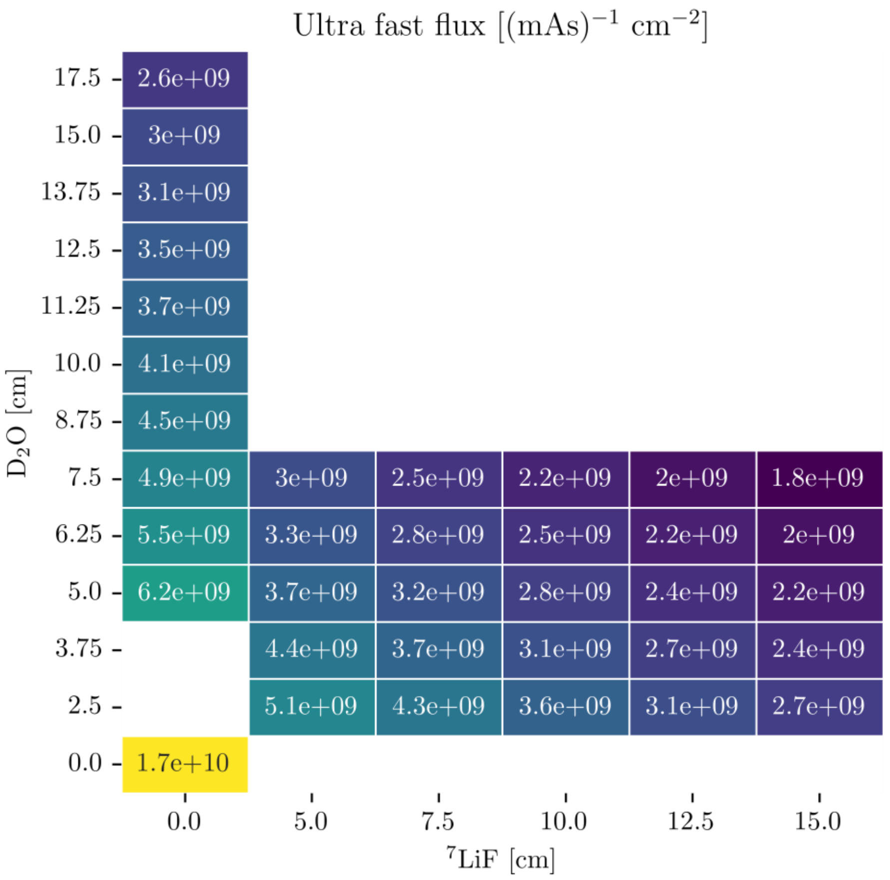


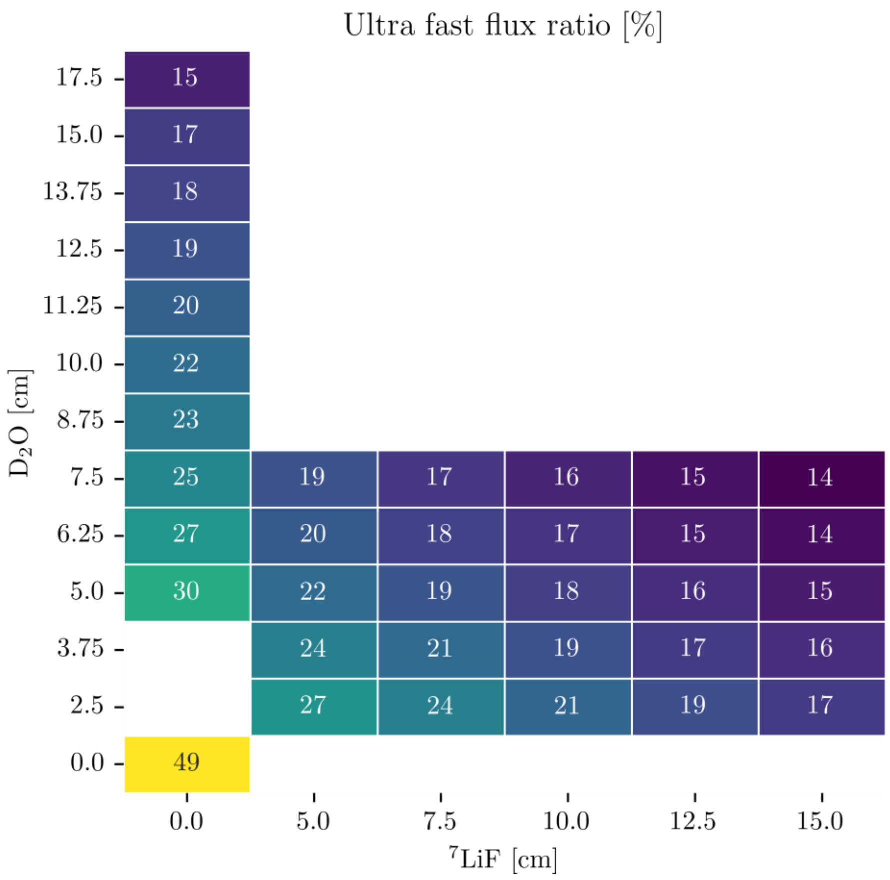
Total thickness: 15.0 cm



Total thickness: 17.5 cm

Preliminary results

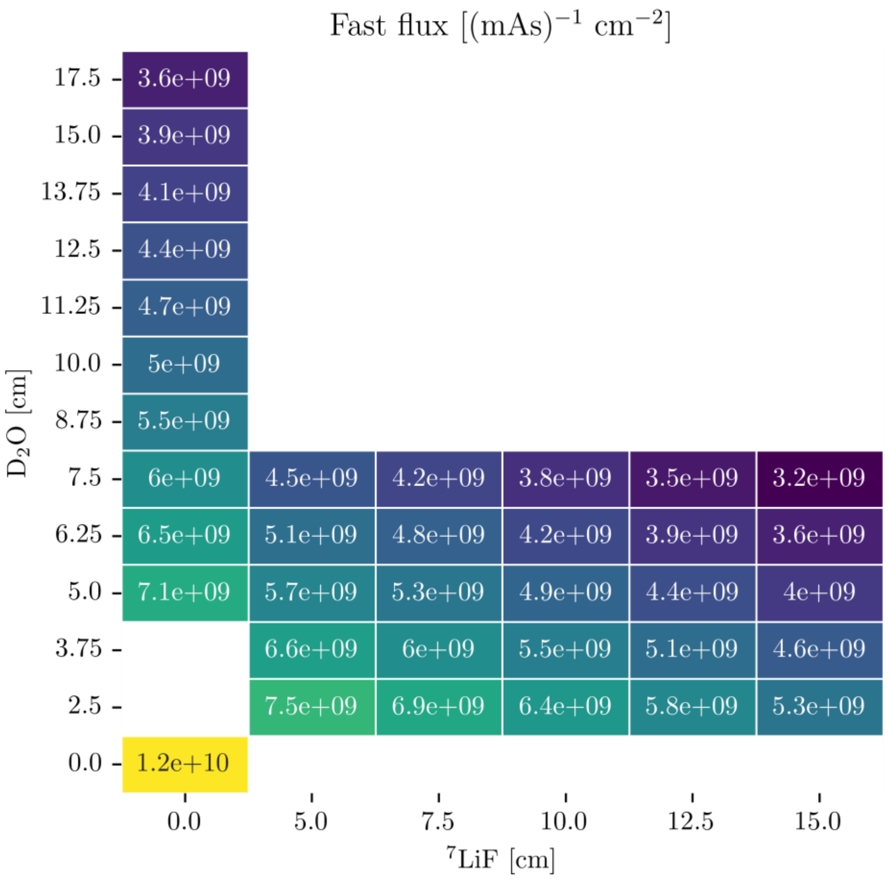


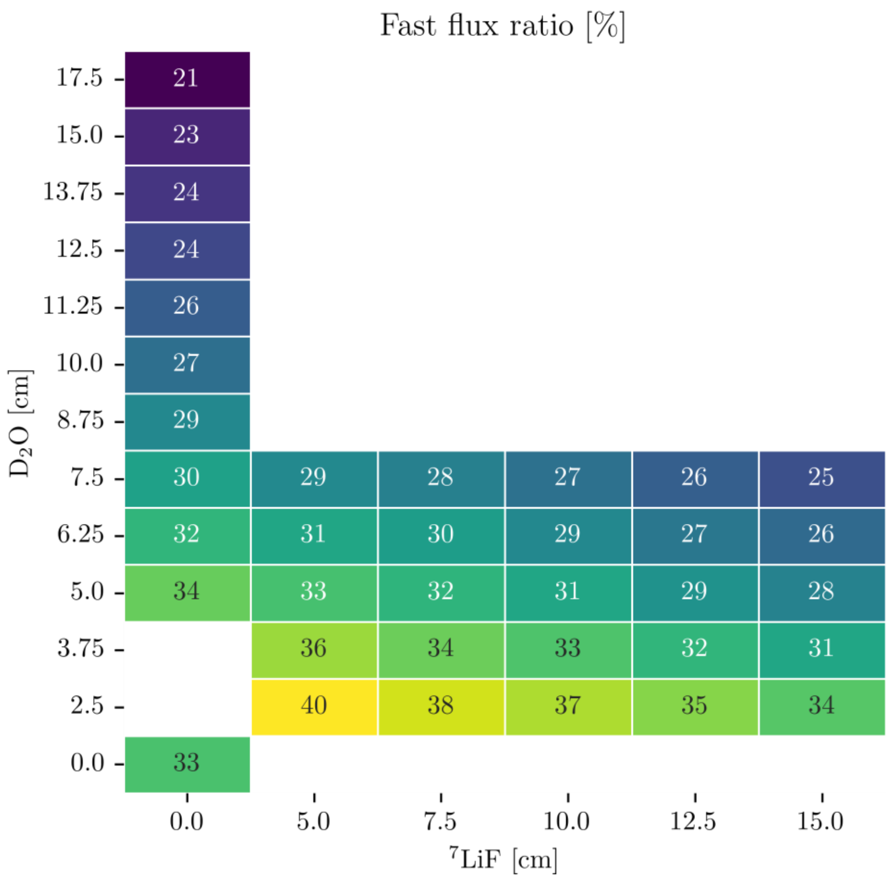


Group name	Range
Ultra fast	0.5 – 70 MeV
Fast	10 keV – 0.5 MeV
Resonance	2 eV – 10 keV
Epithermal	500 meV – 2 eV
Thermal	0 – 500 meV

Increasing the thickness of D_2O or ^{7}LiF has the same effect for ultra fast neutrons

Preliminary results

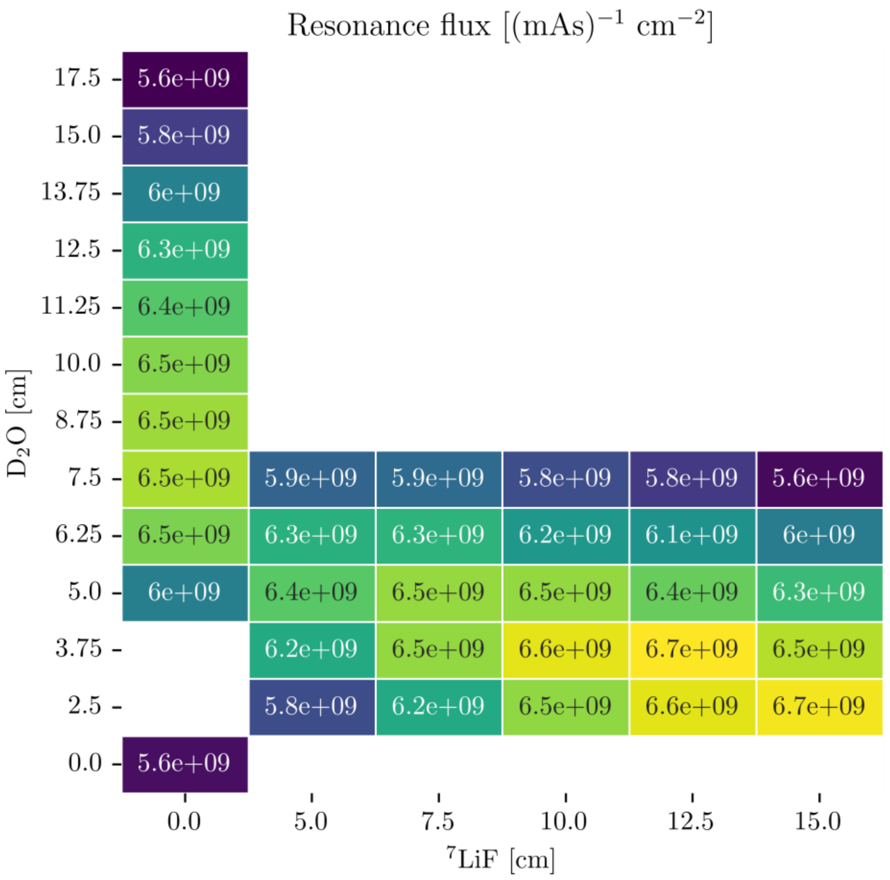


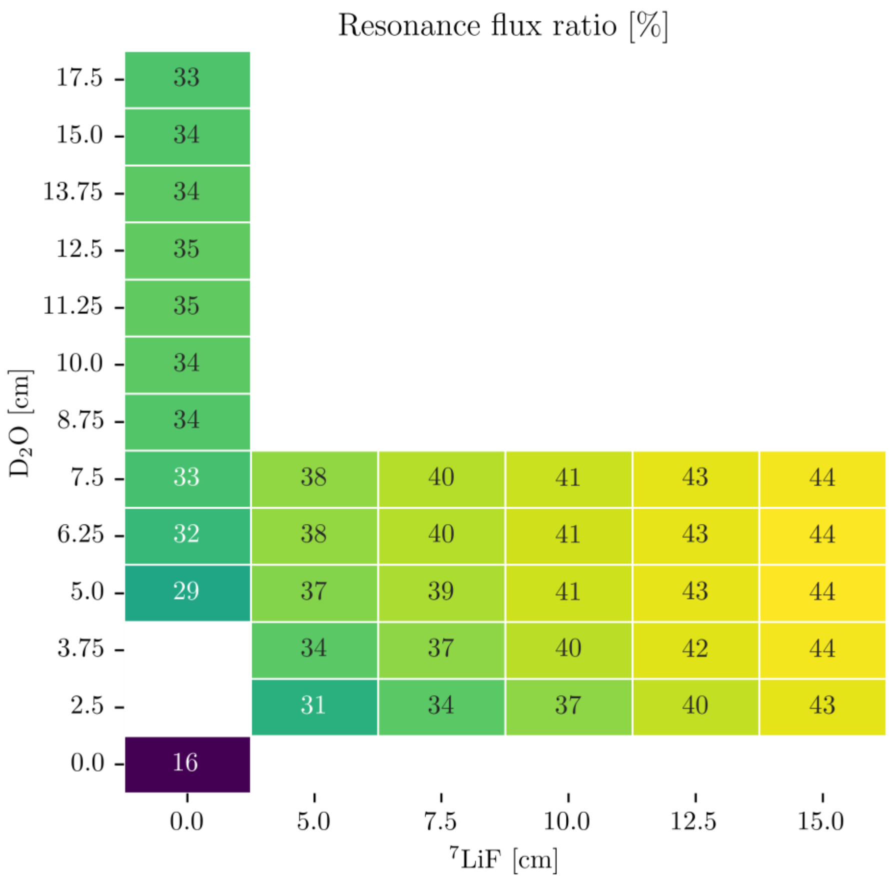


Group name	Range
Ultra fast	0.5 – 70 MeV
Fast	10 keV – 0.5 MeV
Resonance	2 eV – 10 keV
Epithermal	500 meV – 2 eV
Thermal	0 – 500 meV

Increasing the thickness of ^{7}LiF has less effect than D_2O for fast neutrons

Preliminary results

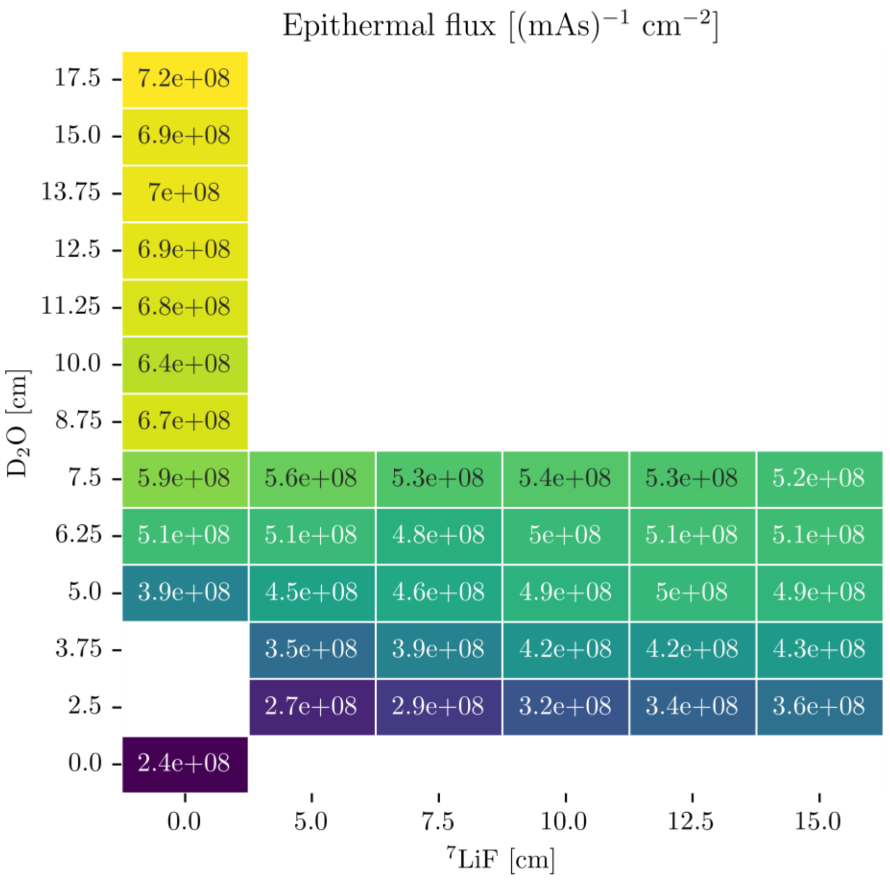


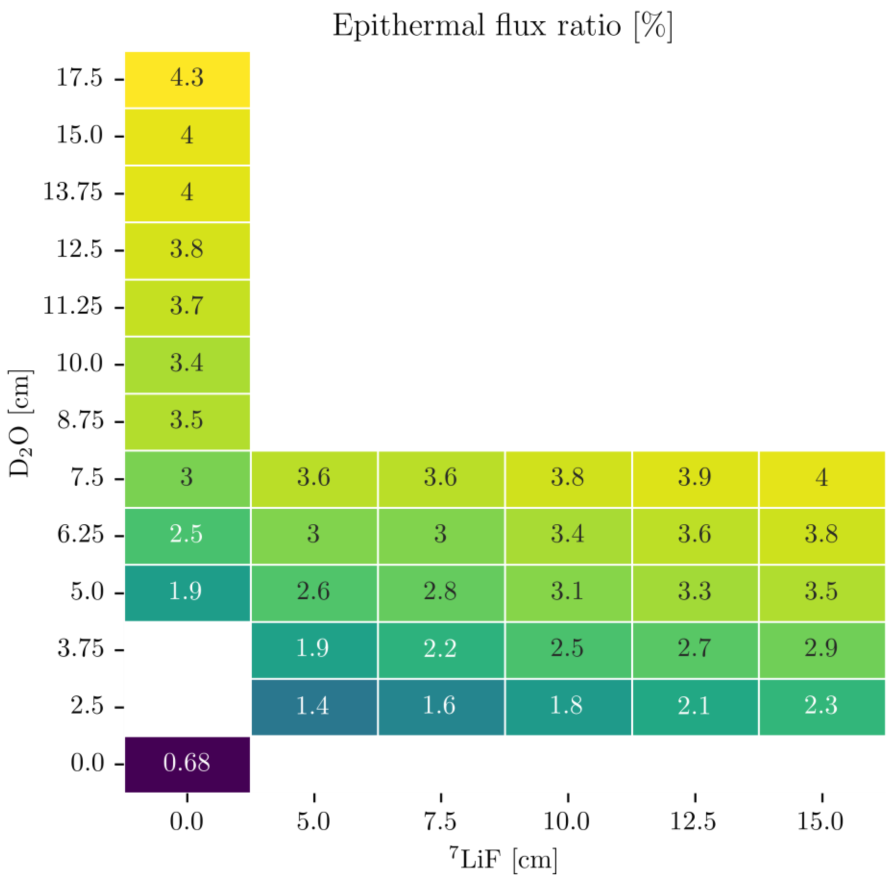


Group name	Range
Ultra fast	0.5 – 70 MeV
Fast	10 keV – 0.5 MeV
Resonance	2 eV – 10 keV
Epithermal	500 meV – 2 eV
Thermal	0 – 500 meV

For resonance neutrons, it seems there is an optimal combination for ^{7}LiF and D_2O

Preliminary results

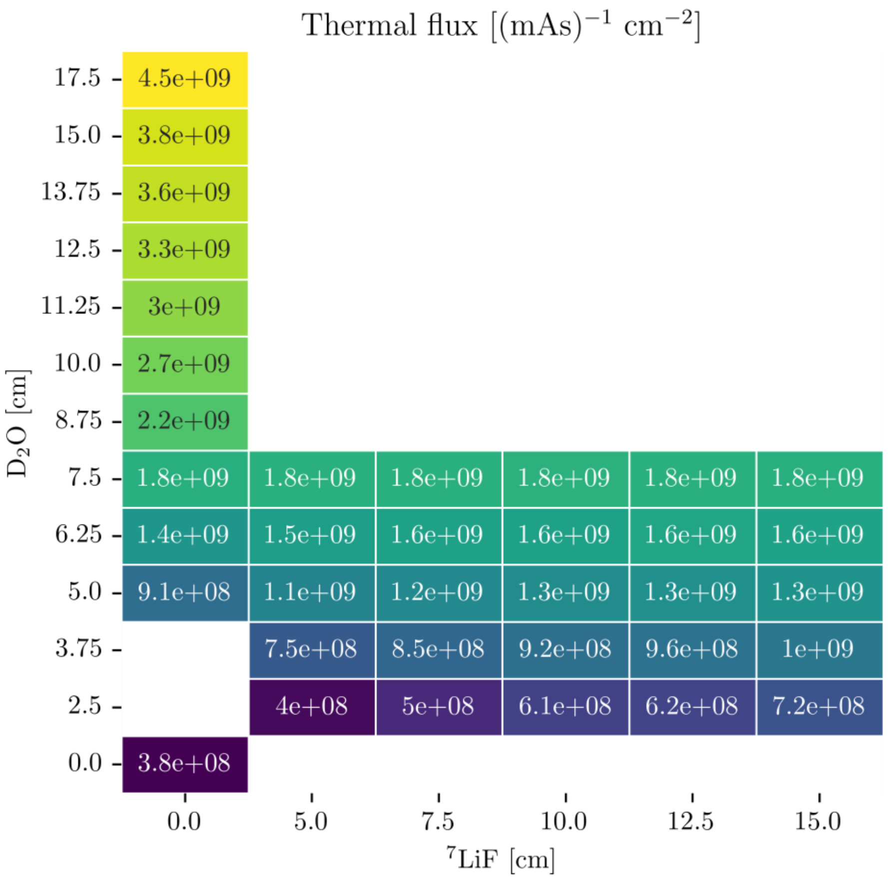


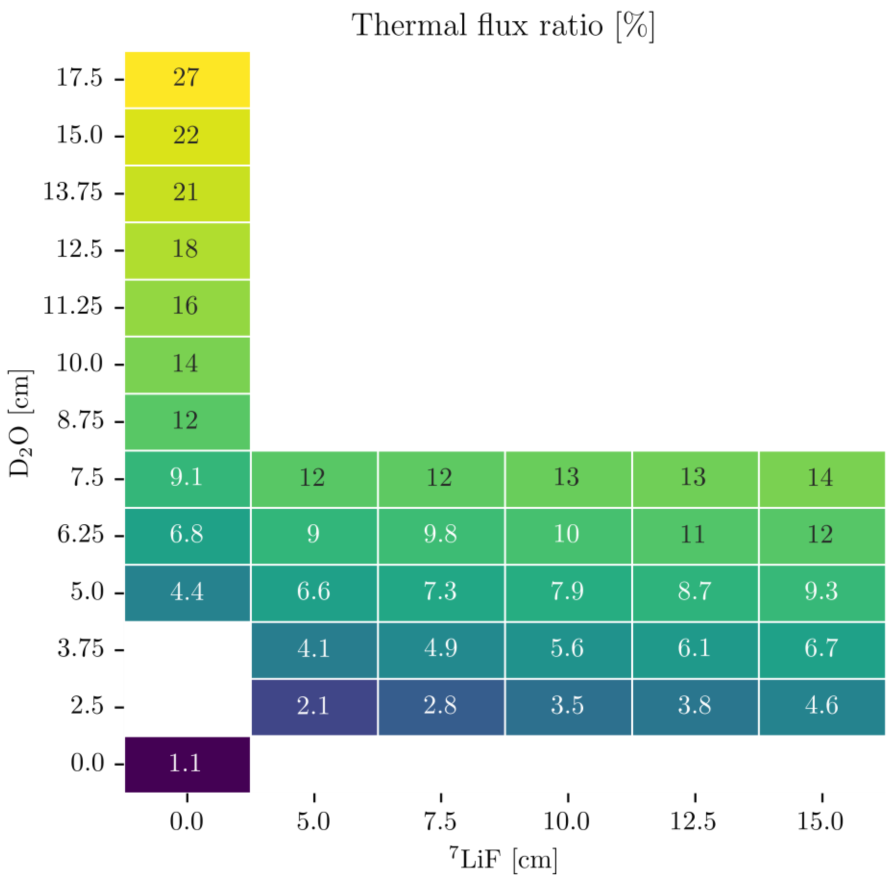


Group name	Range
Ultra fast	0.5 – 70 MeV
Fast	10 keV – 0.5 MeV
Resonance	2 eV – 10 keV
Epithermal	500 meV – 2 eV
Thermal	0 – 500 meV

The thickness of ^{7}LiF is neglectable for epithermal neutrons

Preliminary results





Group name	Range
Ultra fast	0.5 – 70 MeV
Fast	10 keV – 0.5 MeV
Resonance	2 eV – 10 keV
Epithermal	500 meV – 2 eV
Thermal	0 – 500 meV

The thickness of ^{7}LiF is neglectable for thermal neutrons

Conclusions and Future Work

1) For the resonance flux, it seems there is an optimal combination between D_2O as pre-moderator and ^7LiF as moderator

2) For the epithermal flux, more studies are required:

   a) Test with other pre-moderators (Light water? Graphite?)

   b) Test with other moderators (Light water poisoned with boron?)

   c) Change the starting position of the channel (Re-entrant geometry? Height?)

   d) Design a removable epithermal moderator/filter (Inside the fast channel?)

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ZEA-1:
Y. Bessler
R. Hanslik
R. Achten
F. Löchte
M. Strothmann

- Engineering

IKP-4:
O. Felden
R. Gebel
A. Lehrach
M. Rimmler
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- Nuclear physics

INM-5:
B. Neumaier

- Radio isotopes

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/ HIM
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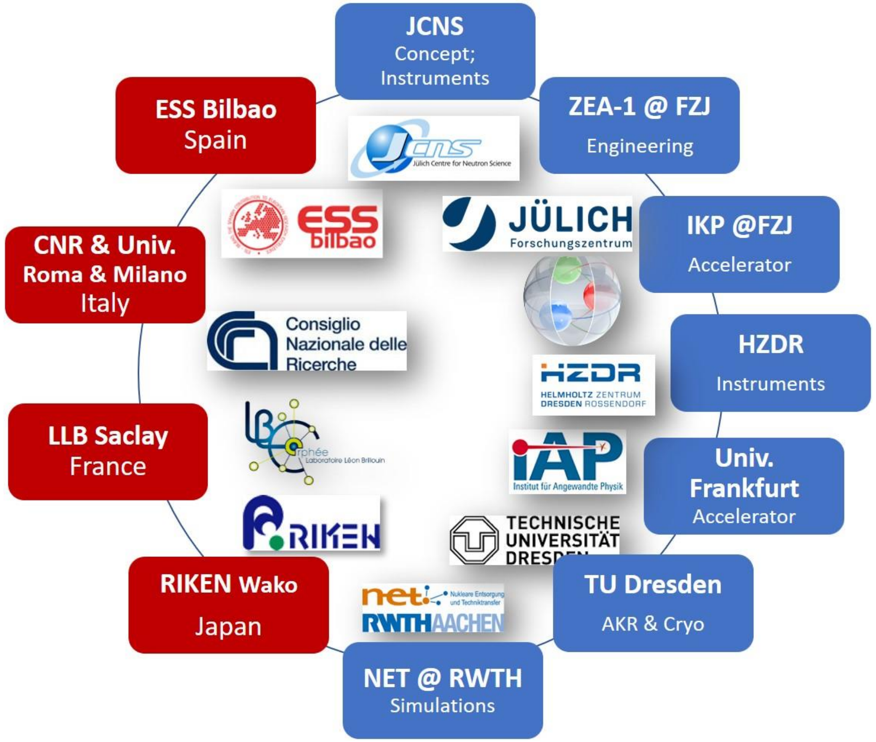
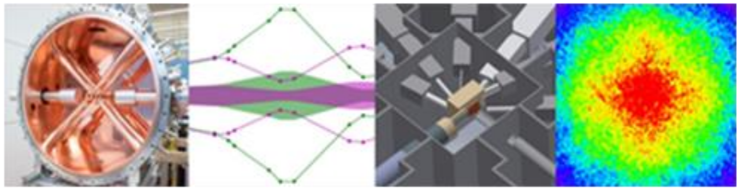
W. Barth

- Accelerator



HBS Innovationpool Project



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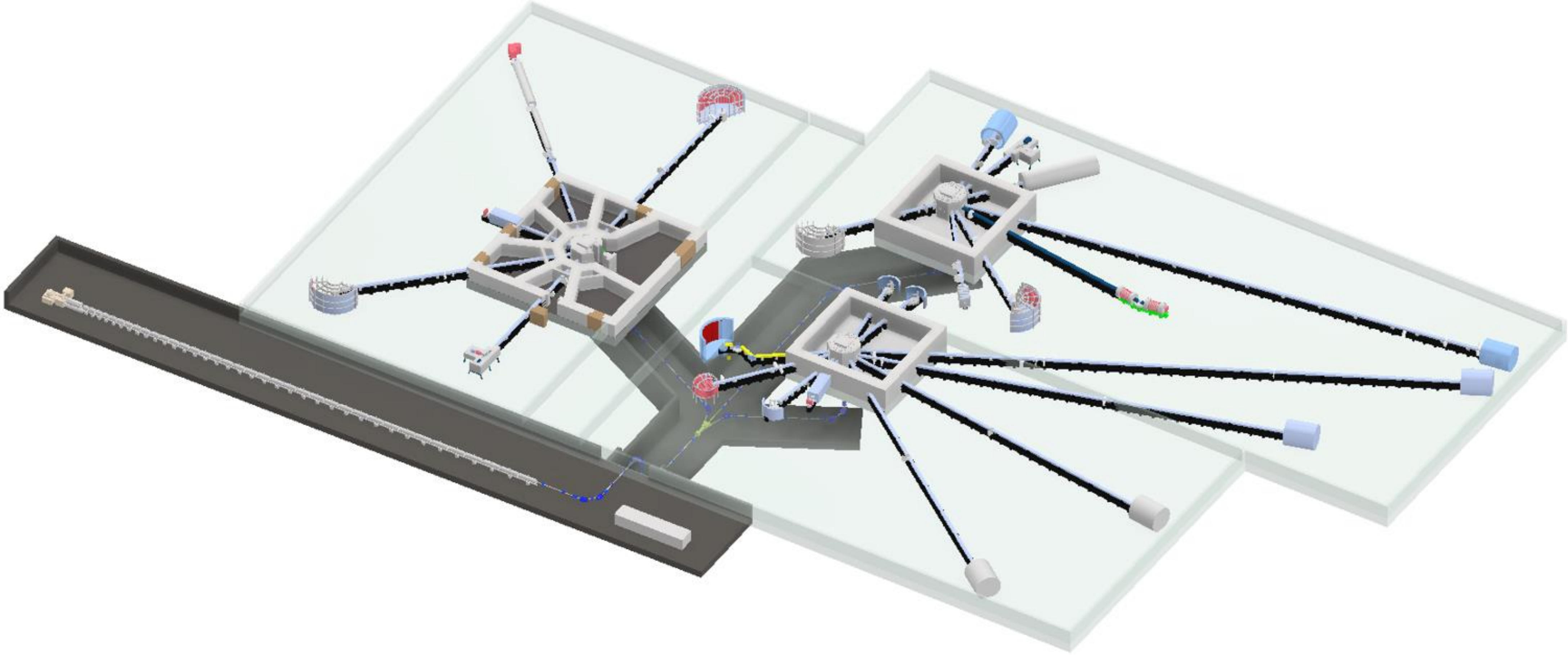

Thanks all for your attention!

Questions?