ESS Test Beamline: Measuring the first neutrons of the new facility and characterizing the ramp-up

Thawatchart Chulapakorn, Robin Woracek, Irina Stefanescu, Douglas Di Julio, Masatoshi Arai

European Spallation Source (ERIC), Lund, Sweden

25 September 2025

Outline

- ❑ Overview of TBL Layout
- ❑ First Beam-on-Target
- ❑ Brightness measurement
- ❑ Early activities
- ❑ Early science

Test beamline (TBL)

Team

Thawatchart Chulapakorn
TBL Lead Scientist

Christofer Svensson
TBL Lead Engineer

Samuele Andreucci
TBL Installation Package Leader

Jason Morin
TBL Instrument Operations Engineer
(started in May)

Robin Woracek
Former TBL Lead Scientist

Alejandro Tobias Quispe Mamani
Former TBL Lead Engineer

Gabor Lazslo
Former TBL Lead Engineer

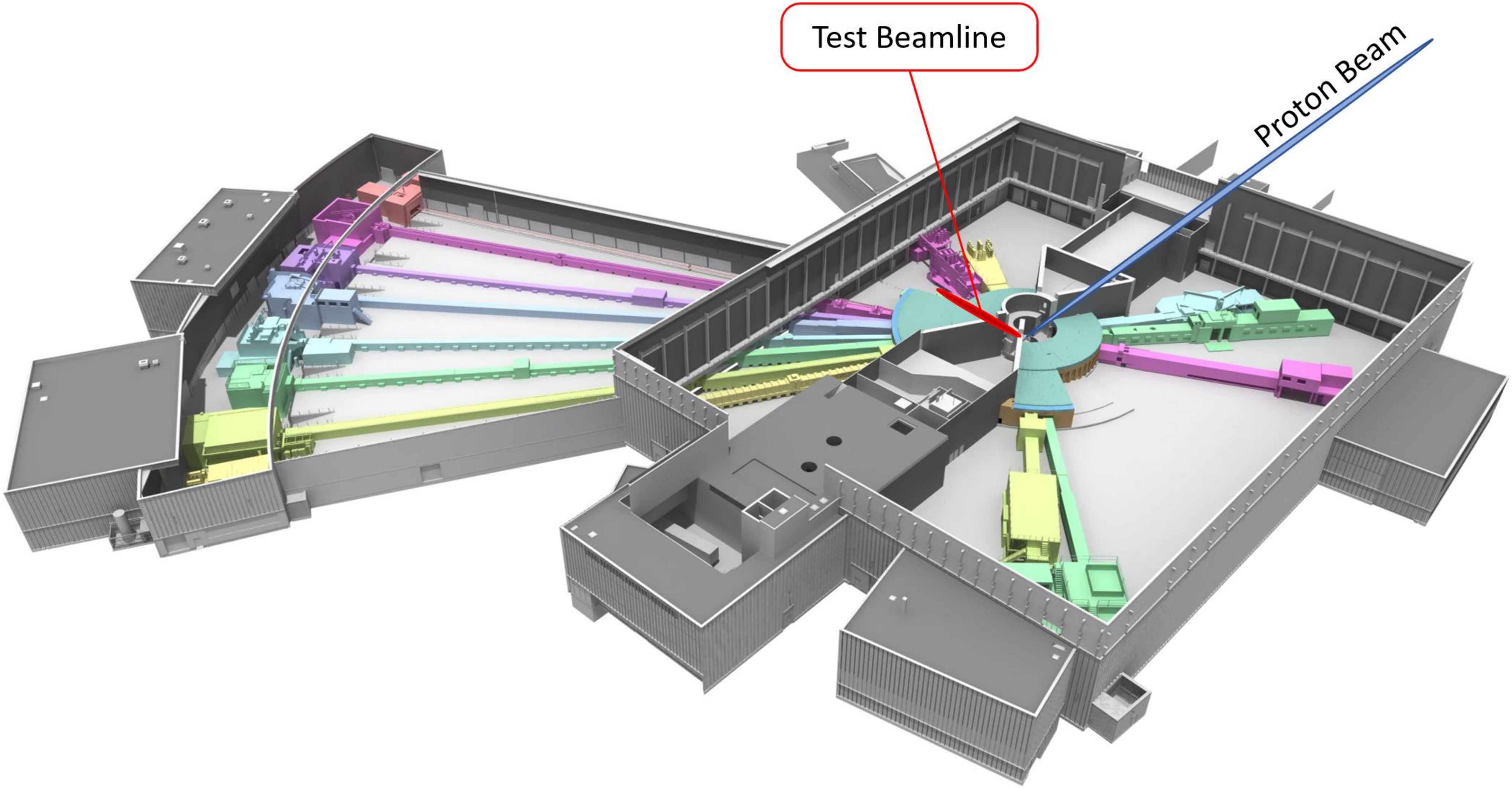
Michaela Eriksson
Former Mechanical Engineer

Mary-Ellen Donnelly
Former IOE

Nicolas Breton
Former Mechanical Engineer

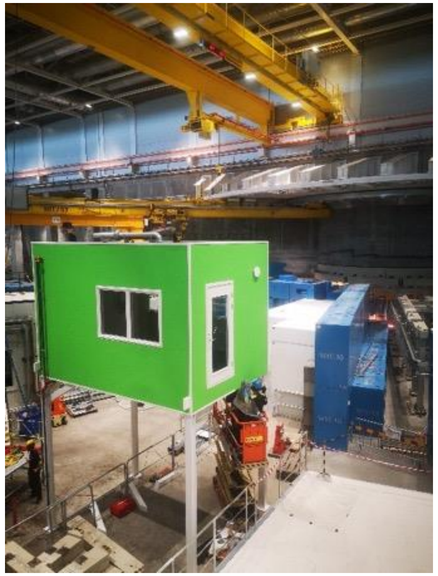
Overview

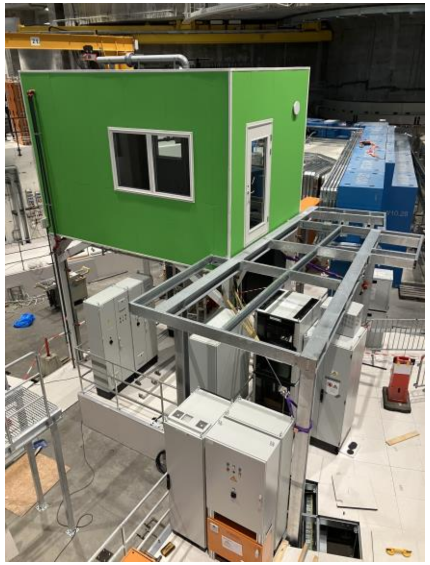
Location in Facility: W11 (North Sector)




2022

2023

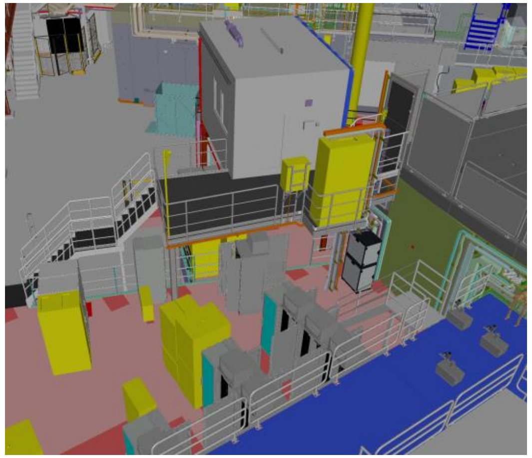



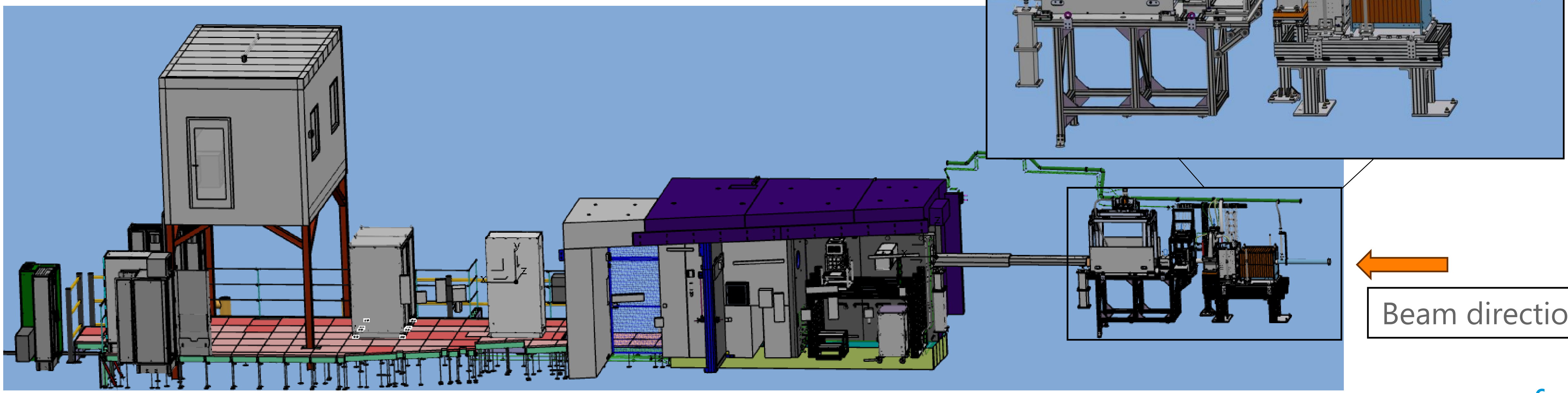


2024

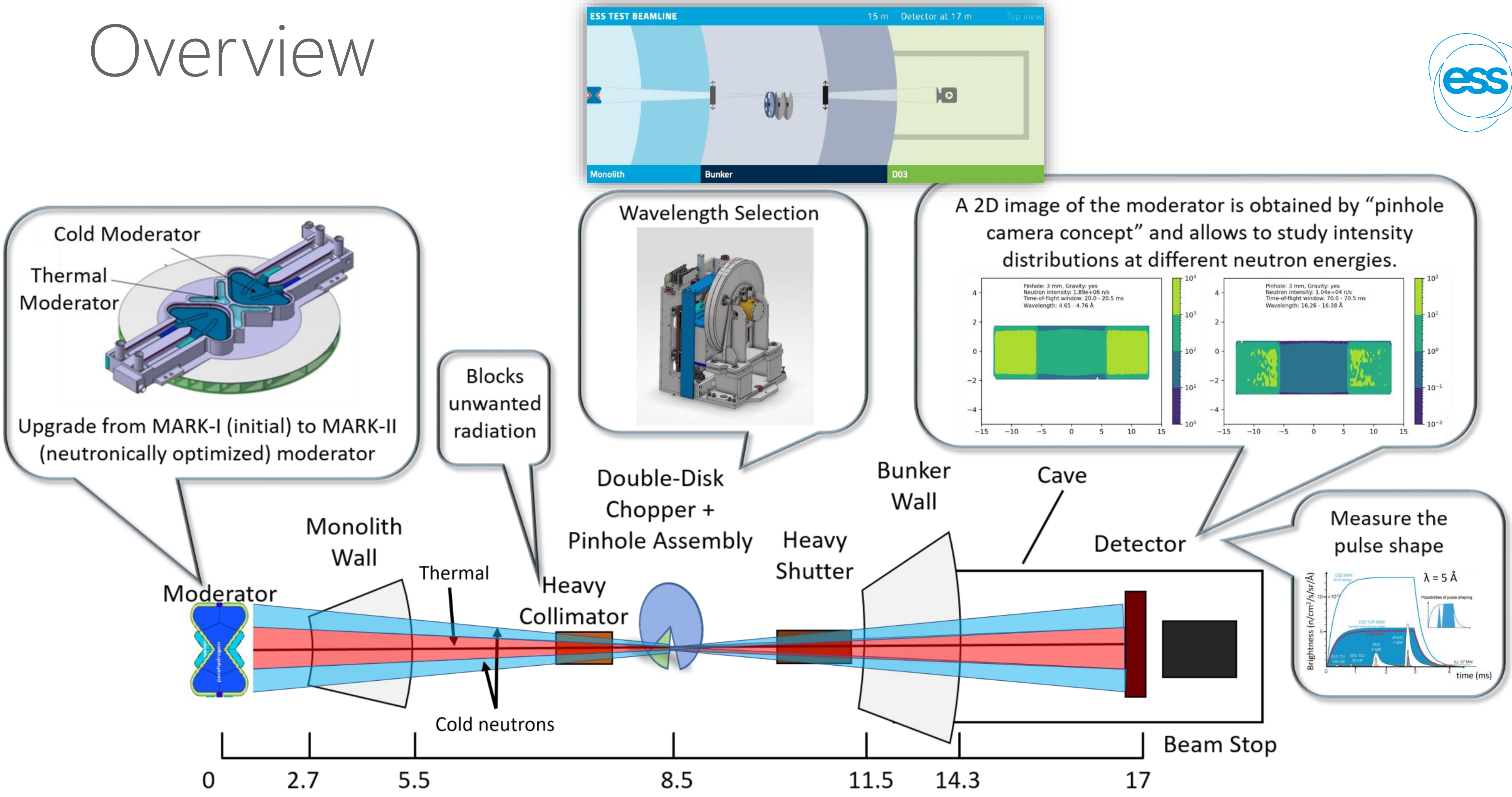
2025

Layout TBL overview





Overview


ESS TEST BEAMLINE
15 m
Detector at 17 m
Monolith
Bunker
D03
Cold Moderator
Thermal Moderator
Upgrade from MARK-I (initial) to MARK-II (neutronically optimized) moderator
Blocks unwanted radiation
Wavelength Selection
A 2D image of the moderator is obtained by "pinhole camera concept" and allows to study intensity distributions at different neutron energies.
Measure the pulse shape
λ = 5 Å
time (ms)
Moderator
Monolith Wall
Thermal
Cold neutrons
Heavy Collimator
Double-Disk Chopper + Pinhole Assembly
Heavy Shutter
Bunker Wall
Cave
Detector
Beam Stop
0
2.7
5.5
8.5
11.5
14.3
17

Cave

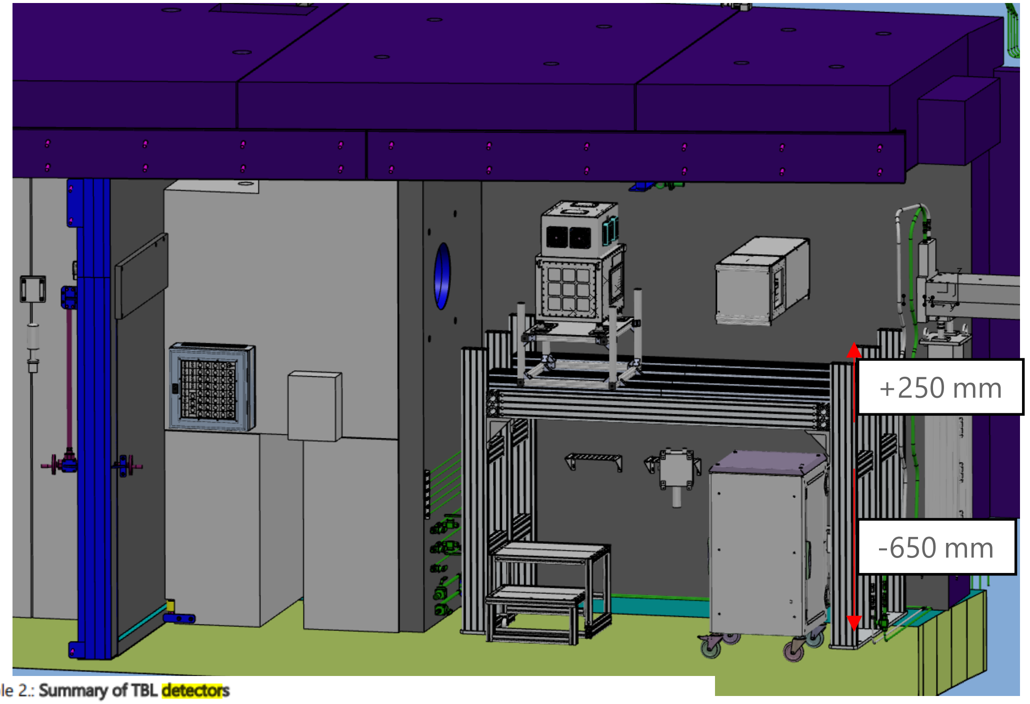
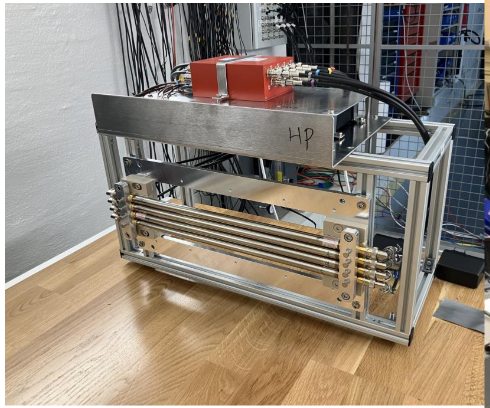


Table 2.: **Summary of TBL detectors**

Detector	**He-3**	**nGEM**	**CMOS**	**TimePix3**	**Multi-Blade**
Type	Gas-filled	Micropattern	Scintillator – optical camera (Frame-based)	Scintillator – optical camera (Event-mode)	Multi Wire Proportional Chamber (MWPC)
Neutron Converter	He-3	^{10}B	Scintillators (^{6}LiF, Gadox, etc.)	Scintillator pending (^{6}LiF, Gadox, etc.)	^{10}B
Active Area	312mm × 50.8mm	100mm × 100mm	Up to 280mm × 280mm	Up to 260mm × 260mm	260mm × 140mm
Spatial resolution (mm)	3 mm	0.8mm × 0.8mm	Between 20µm and several hundred µm	Between 5µm and several hundred µm	~ 0.5 mm x ~ 3.5 mm
Time resolution (µs)	10	0.015	10,000 (100 Hz full frame readout)	0.001	< 10
Efficiency @2Å	10 - 63.6	~10%	Scintillator pending		~40%
Count rate capacity	100 kHz	10 MHz	100 Hz	20 MHz	several kHz per mm2

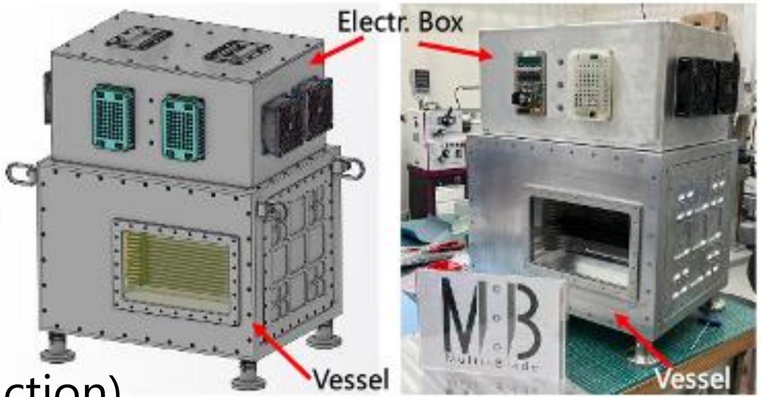
Detectors at TBL

He-3 tubes
1st use for BoT



nGEM (ToF)
2nd use for BoT

Camera (Gated-imaging)
Low-resolution ToF



Multiblade
(imaging/diffraction)

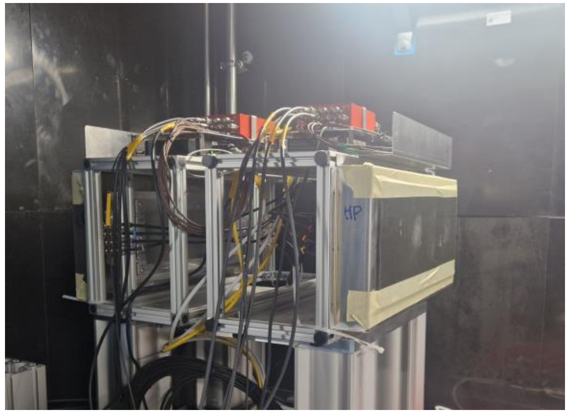
LumaCam
(ToF imaging/diffraction)

Detectors-overview

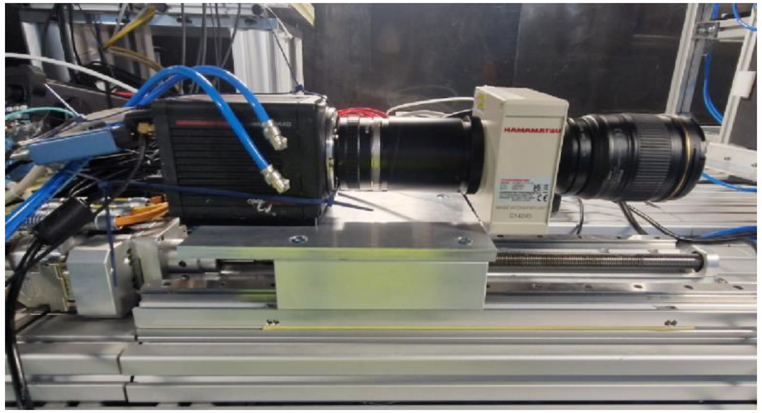
Table 2.: **Summary of TBL detectors**

Detector	**He-3**	**nGEM**	**CMOS**	**TimePix3**	**Multi-Blade**
Type	Gas-filled	Micropattern	Scintillator – optical camera (Frame-based)	Scintillator – optical camera (Event-mode)	Multi Wire Proportional Chamber (MWPC)
Neutron Converter	He-3	^{10}B	Scintillators (^{6}LiF, Gadox, etc.)	Scintillator pending (^{6}LiF, Gadox, etc.)	^{10}B
Active Area	312mm × 50.8mm	100mm × 100mm	Up to 280mm × 280mm	Up to 260mm × 260mm	260mm × 140mm
Spatial resolution (mm)	3 mm	0.8mm × 0.8mm	Between 20μm and several hundred μm	Between 5μm and several hundred μm	~ 0.5 mm x ~ 3.5 mm
Time resolution (μs)	10	0.015	10,000 (100 Hz full frame readout)	0.001	< 10
Efficiency @2Å	10 - 63.6	~10%	Scintillator pending		~40%
Count rate capacity	100 kHz	10 MHz	100 Hz	20 MHz	several kHz per mm2

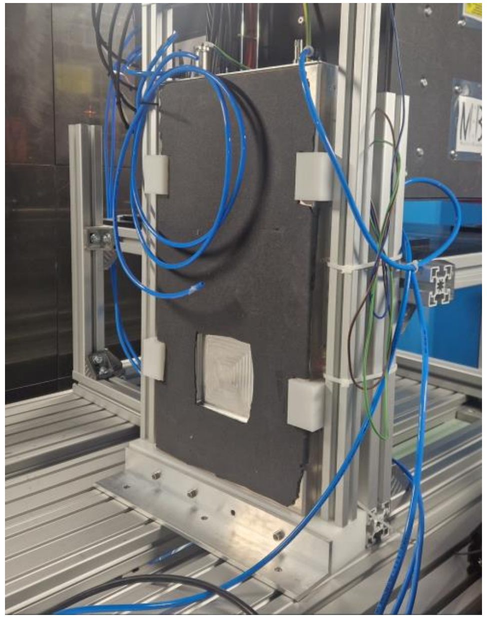
Multi-blade



He-3



CMOS



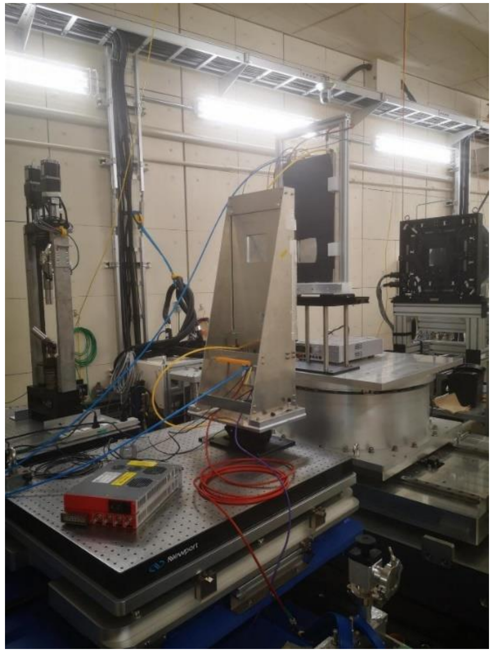
nGEM

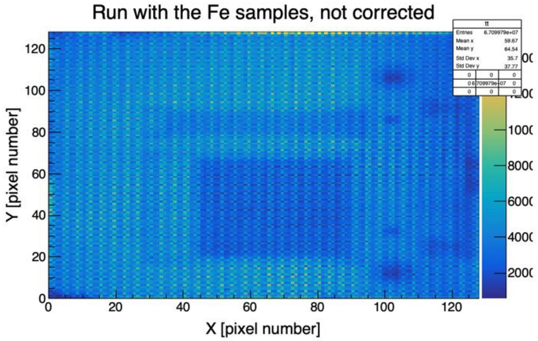
LumaCam

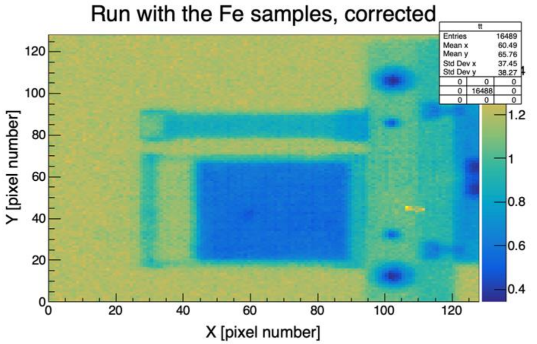
Test at other facilities

nGEM

RADEN (BL22), J-PARC



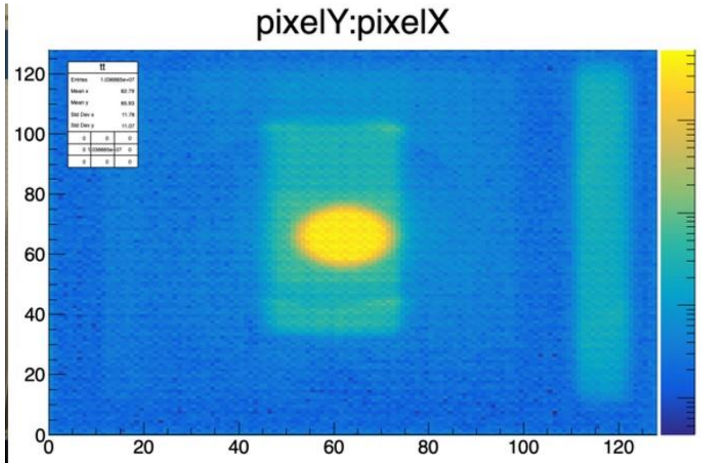


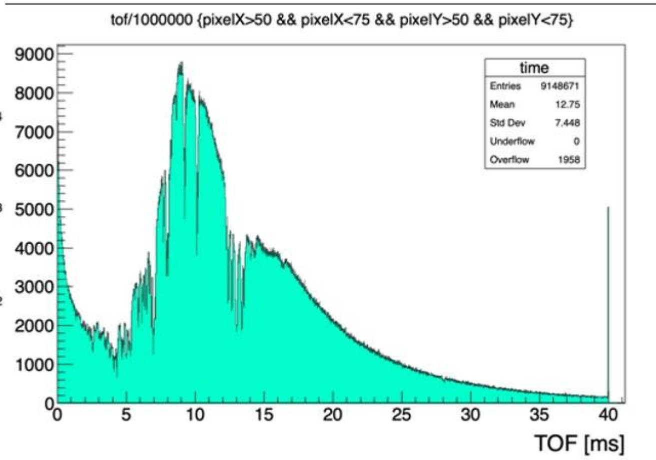


2D image + ToF

NOBORU (BL10), J-PARC

Beam through slit

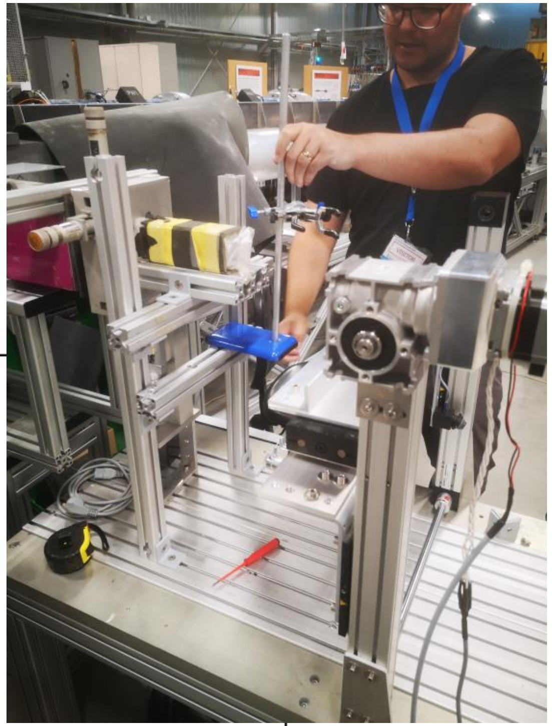




Test at other facilities

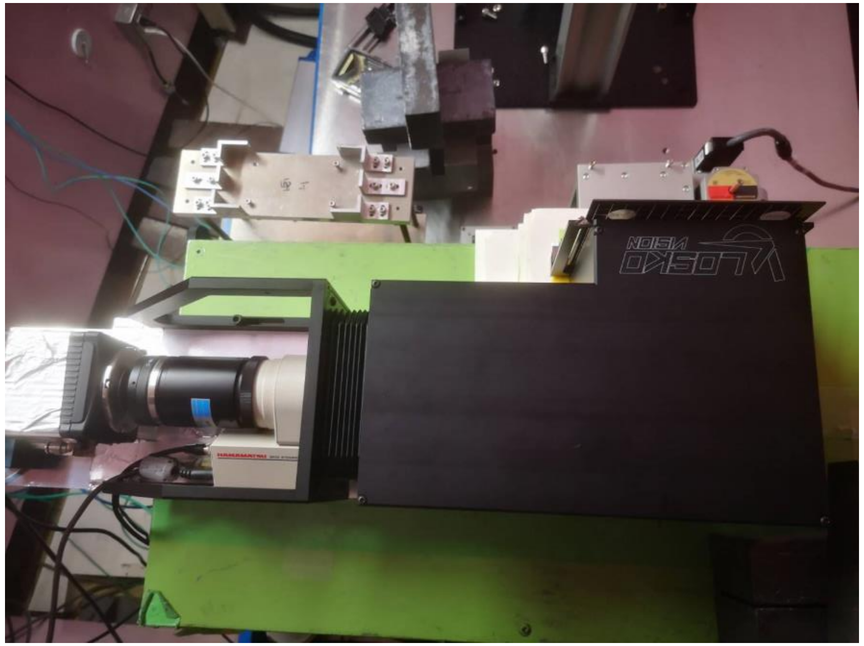
CMOS

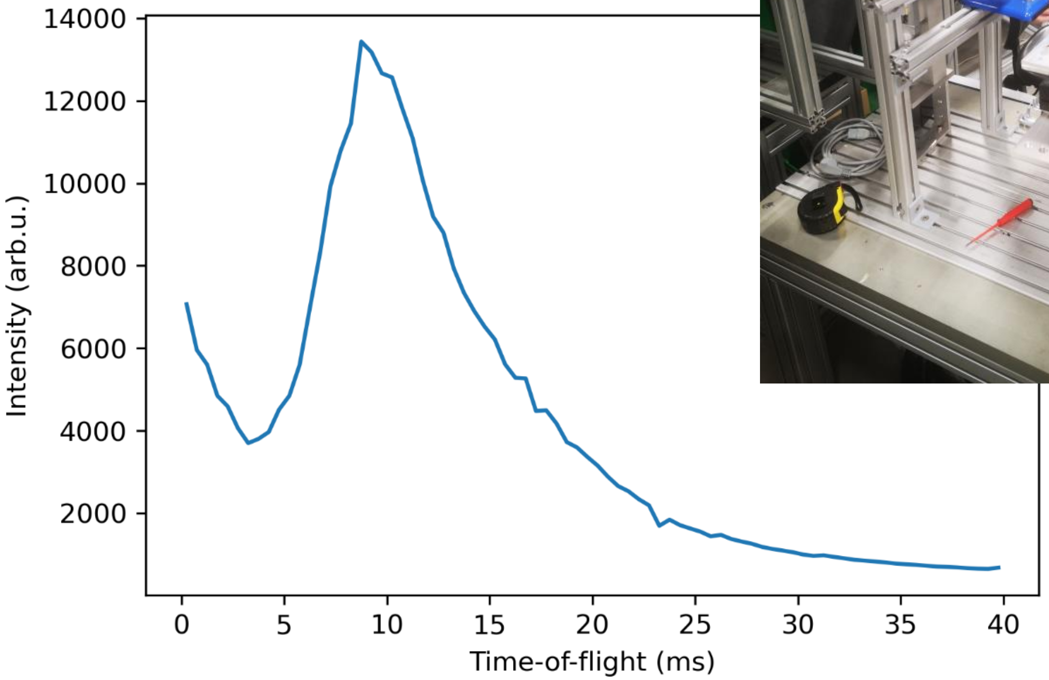
TU Delft



Gated-camera

- Each frame will be gated for just 5 ms (with intensifier)
- One can obtain ToF spectra for individual pixels

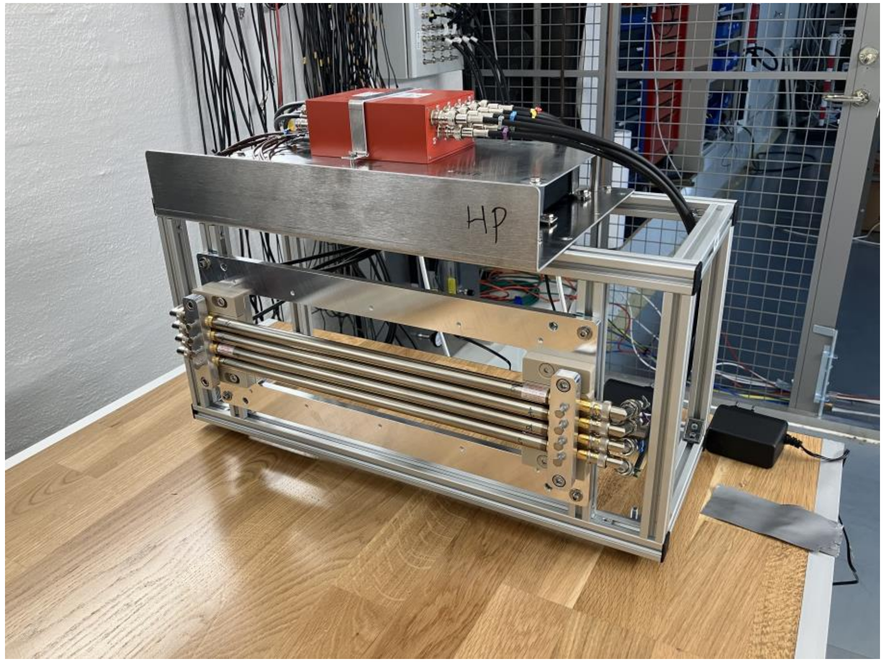


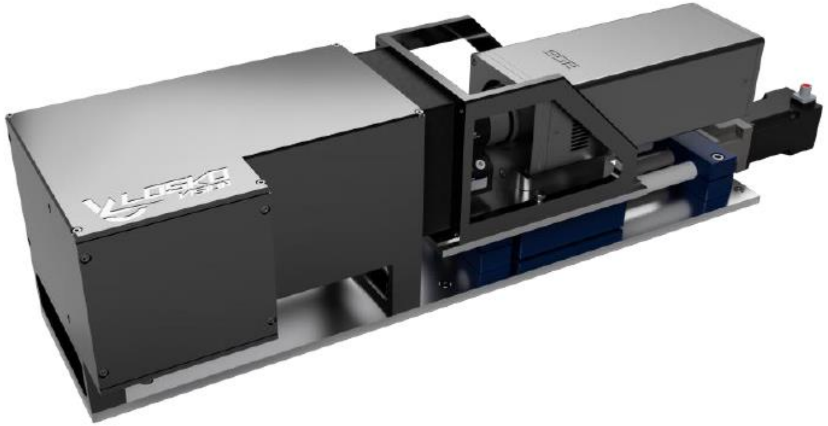


NOBORU (BL10), J-PARC

(To be) tested at other facilities

He-3 – Efficiency calibration at CRISP in December 2025
nGEM – Retest at CRISP in December 2025
Lumacam – NOBORU in December 2025





Outline

- ❑ Overview of TBL Layout
- ❑ First Beam-on-Target
- ❑ Brightness measurement
- ❑ Early activities
- ❑ Early science

Ramping-up phase

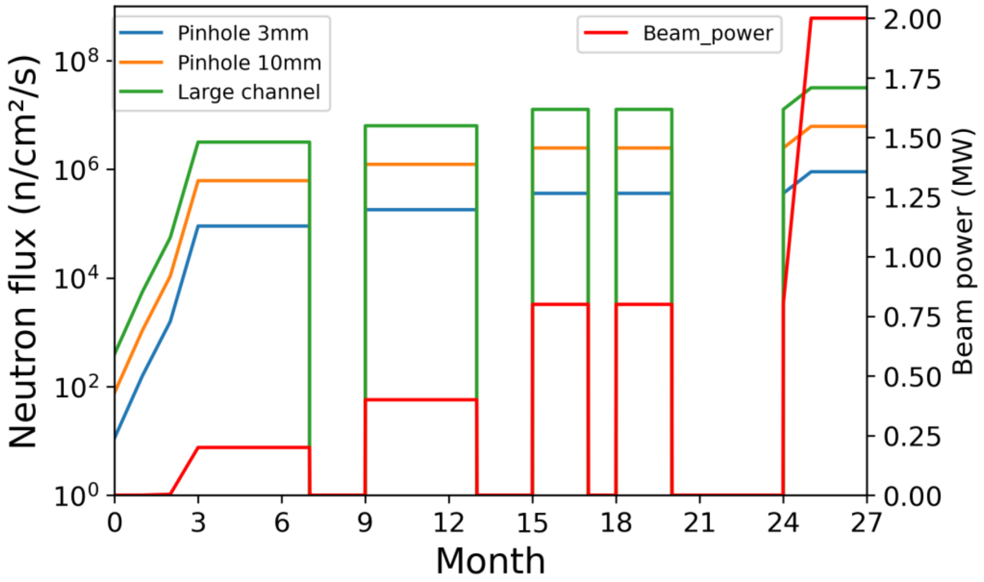
Neutron flux on TBL at BOT

Neutron flux (n/cm2/s) @5MW (2 GeV)

- 3mm pinhole: ~ 2.25×10^{6} n/cm2/s
- 10mm pinhole: ~1.54×10^{7} n/cm2/s
- 30mmX25mm channel: ~7.88×10^{7} n/cm2/s

Thermal/cold flux (Up to Year)	< 0.5	< 1	< 2	>2
Beam energy	~800 MeV			
Power	0.2 MW	0.4 MW	0.8 MW	2 MW
Neutron Flux 3mm (n/cm2/sec)	8.98E+04	1.80E+05	3.60E+05	8.98E+05
Neutron Flux 10mm (n/cm2/sec)	6.15E+05	1.23E+06	2.46E+06	6.15E+06
Neutron Flux 30mm x 25mm (n/cm2/sec)	3.15E+06	6.31E+06	1.26E+07	3.15E+07

HC Plan: Facility ramp-up schedule



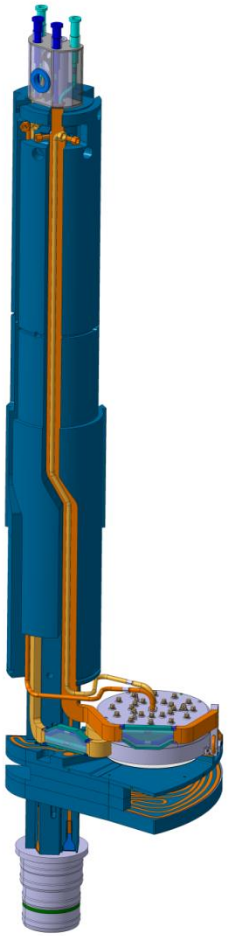
During 1st beam commissioning (short pulses)

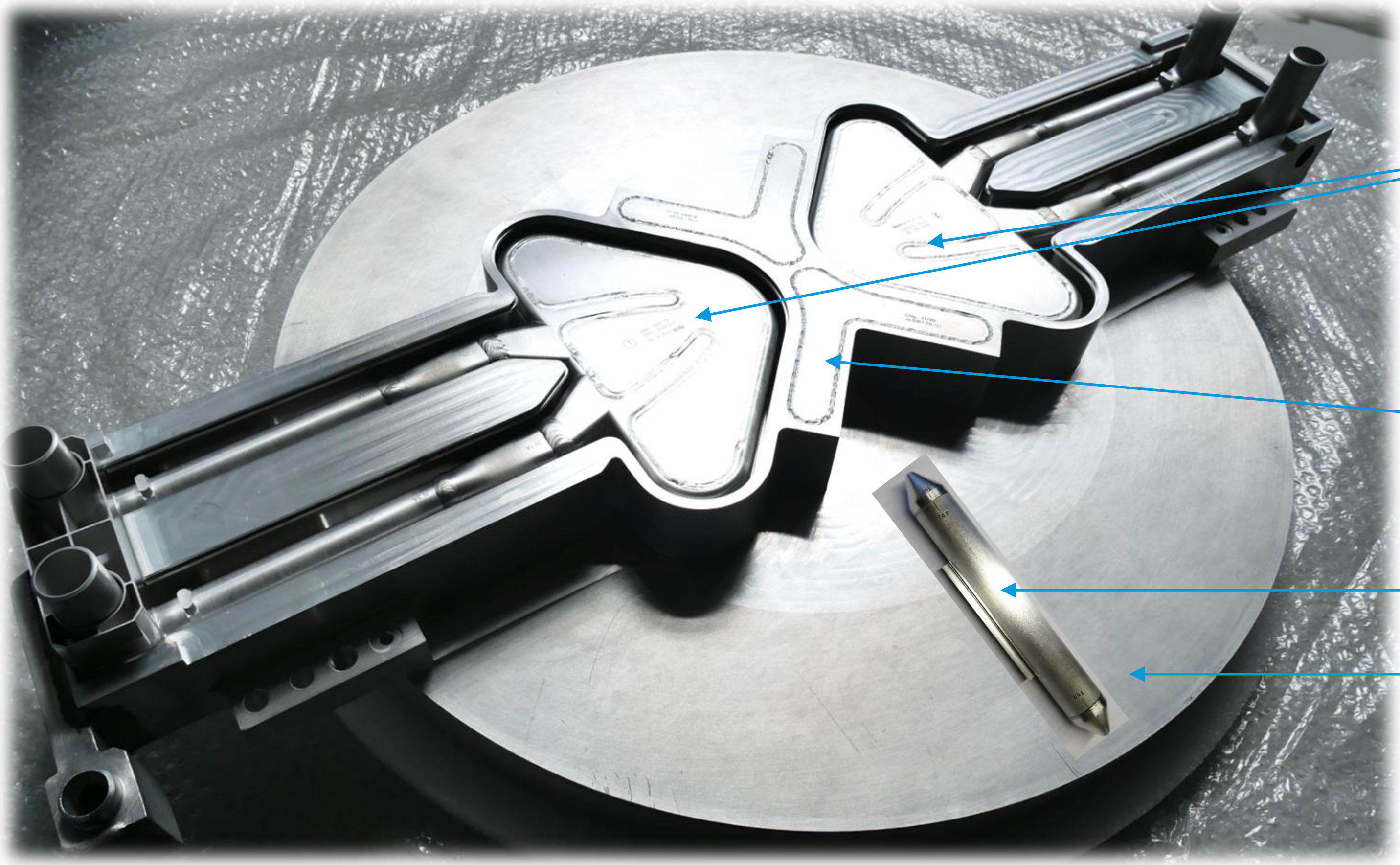
- At BoT, 5µs at 6.25mA at 1Hz would be only **25 W**; which translates into a flux (very ROUGH estimate) ~**11 n/cm²/s** to **~ 394 n/cm²/s** at TBL in current configurations.
- Within 0.5 year, 2.86ms at 6.25mA at 14Hz would be **200kW**; which translates in a flux (very ROUGH estimate) of ~**9×10^{4} n/cm²/s** to **~ 3×10^{6} n/cm²/s** at TBL in current configurations.

ESS moderator (BF2/MARK-1)

The goal of this step is to make an as built model of the moderator

First generation of para-Hydrogen Moderators (BF2) – upper Moderator Plug

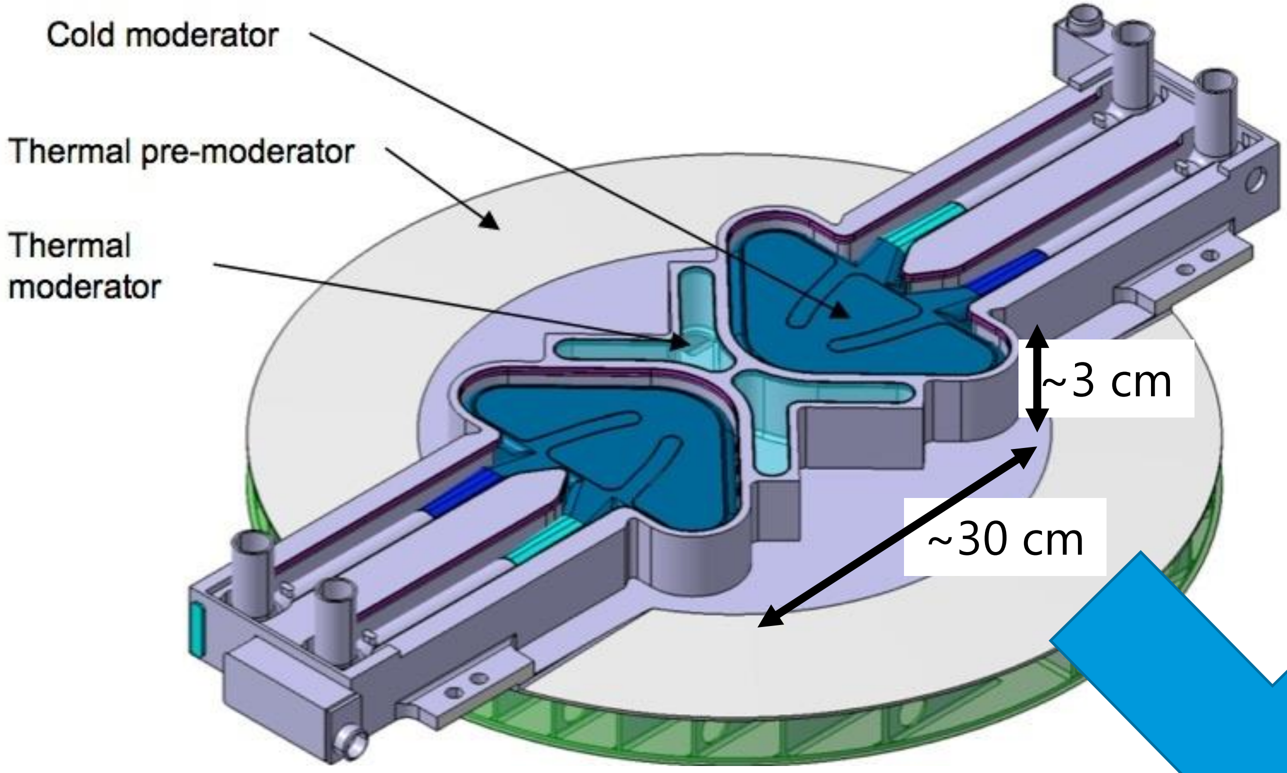


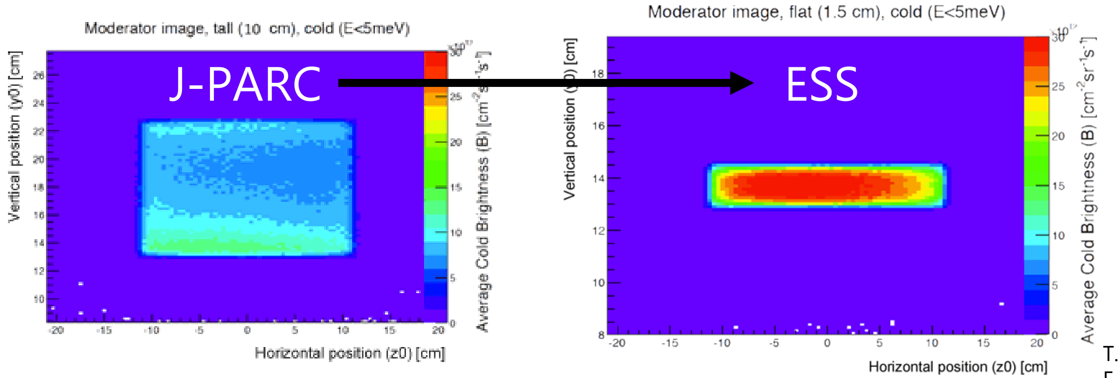


(courtesy FZJ)

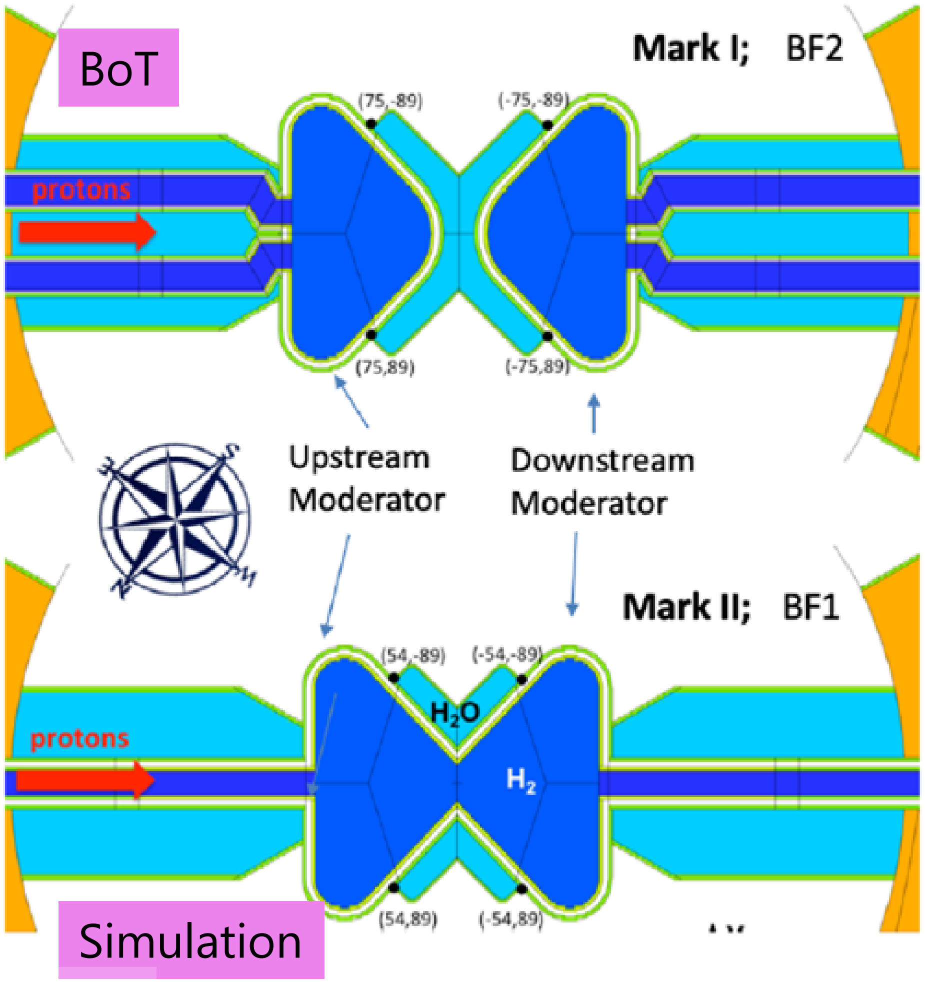
ESS moderator

Moderator





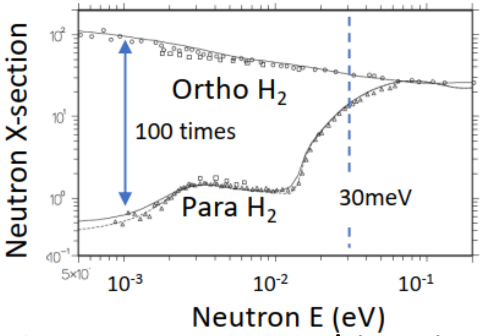
MARK-I: current moderator
MARK-II: (neutronically optimized moderator)



T. Kai, *et al.*, NIMA 523.3 (2004): 398-414.
F. Mezei *et al.*, J. Neu. Res., 17.2 (2014): 101-105.

ESS moderator

Asymmetric and focusing effect



Courtesy: Masatoshi Arai

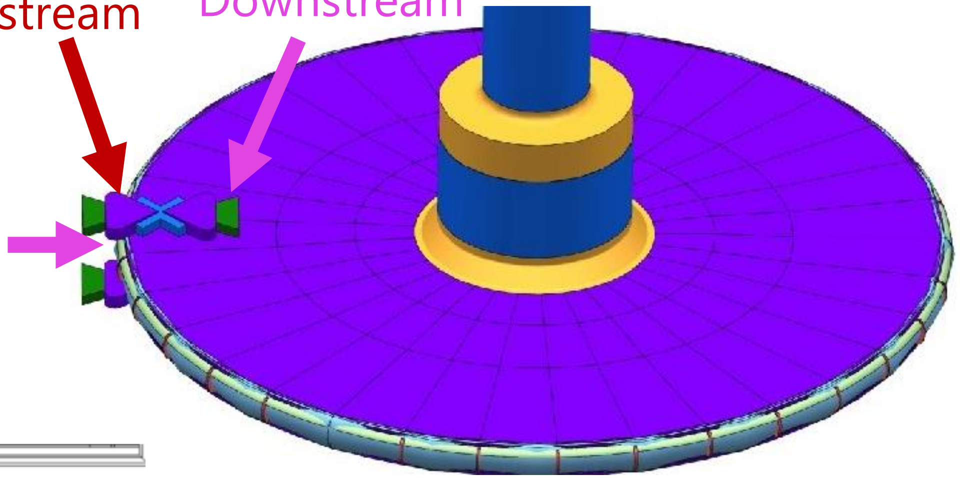
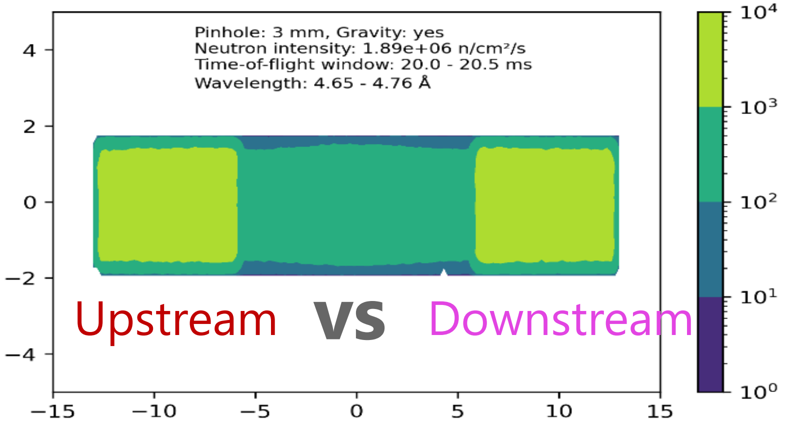
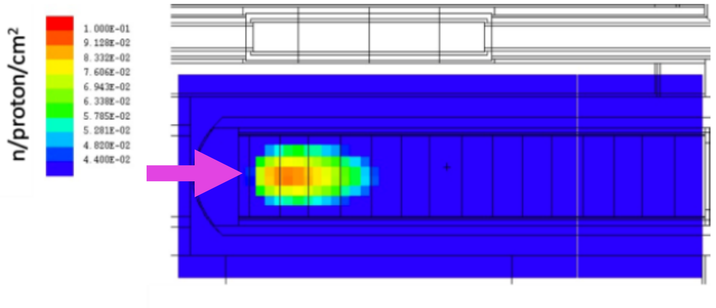


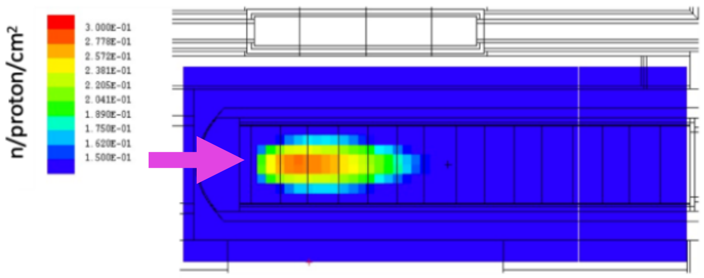
Image at TBL by 'pinhole imaging'



Projected range



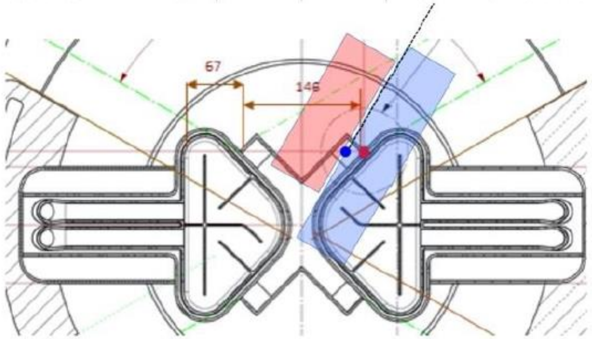
800 MeV



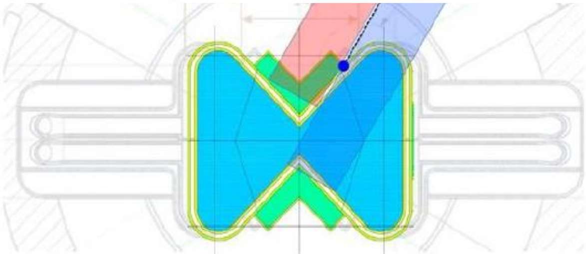
2 GeV

Moderator

MARK-1



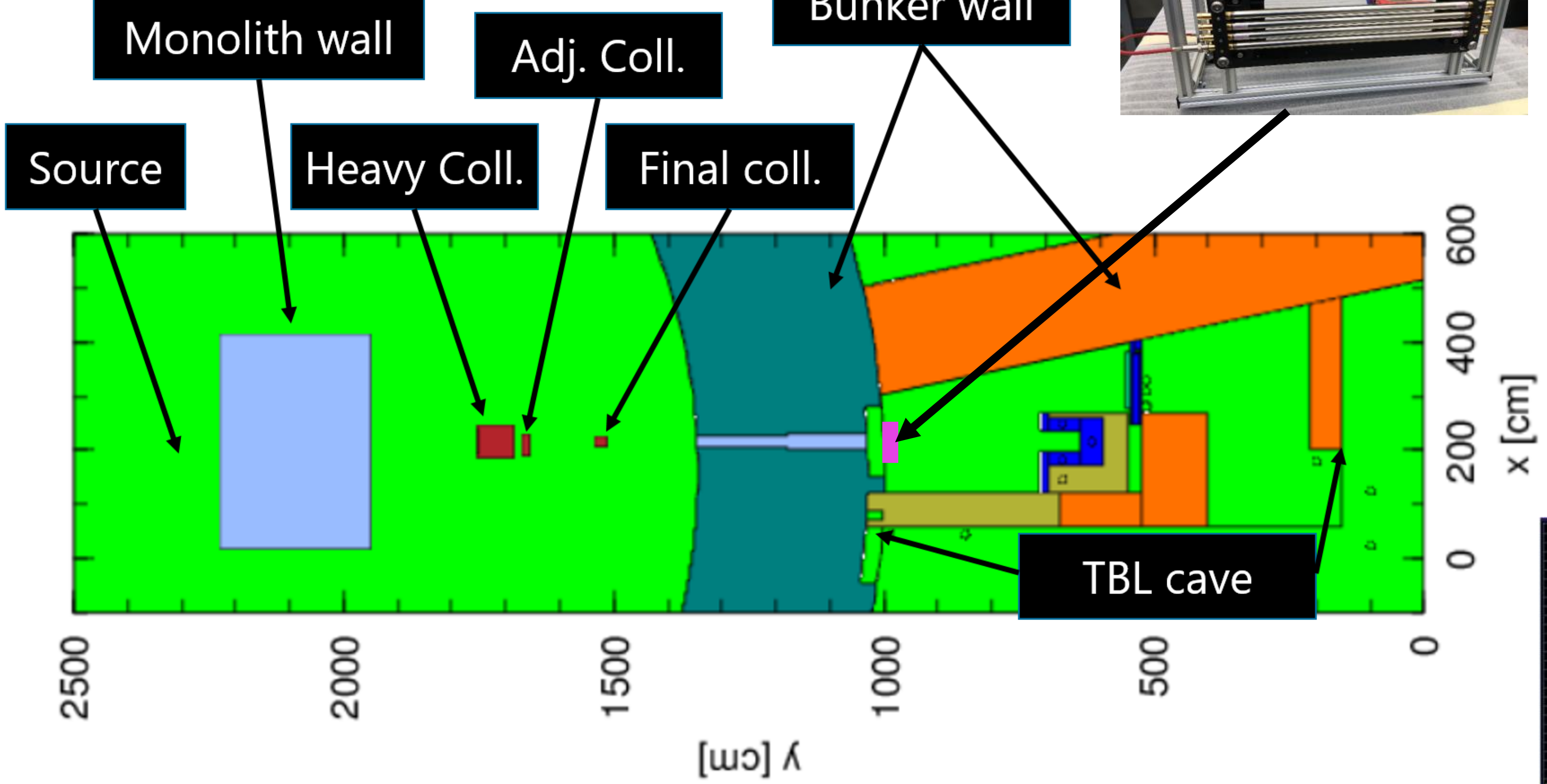
MARK-2

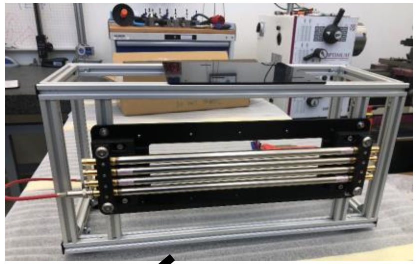


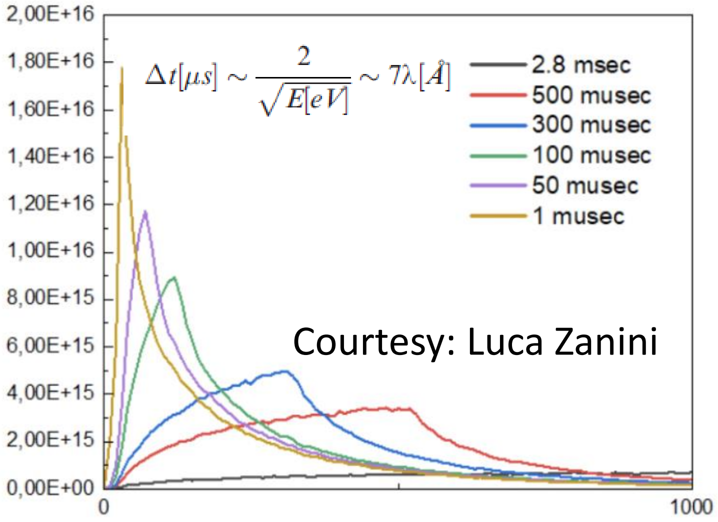
Test 1: Validation of Neutron Production

He-3 tubes (63.6% efficiency @1.6Å)

Located close to the bunker wall

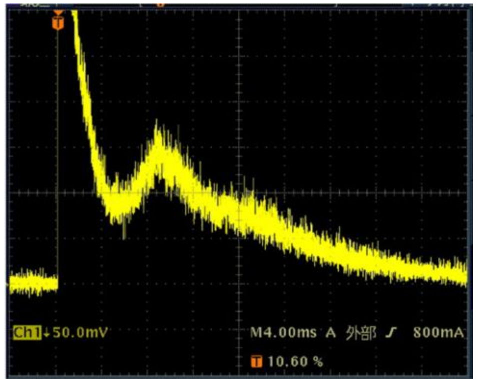






Expected result: 1D tof spectrum

Minimum result: 0D neutron counts



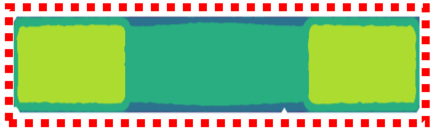
Proton beam 800 MeV, 5 μs pulse width @1Hz, 25 W
Neutron flux ~ 400 n/cm^2/s

F. Maekawa *et al.*, *NIMA*, **620** (2010) 159-65.

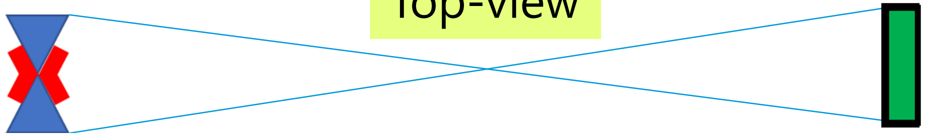
Outline

- ❑ Overview of TBL Layout
- ❑ First Beam-on-Target
- ❑ Brightness measurement
- ❑ Early activities
- ❑ Early science

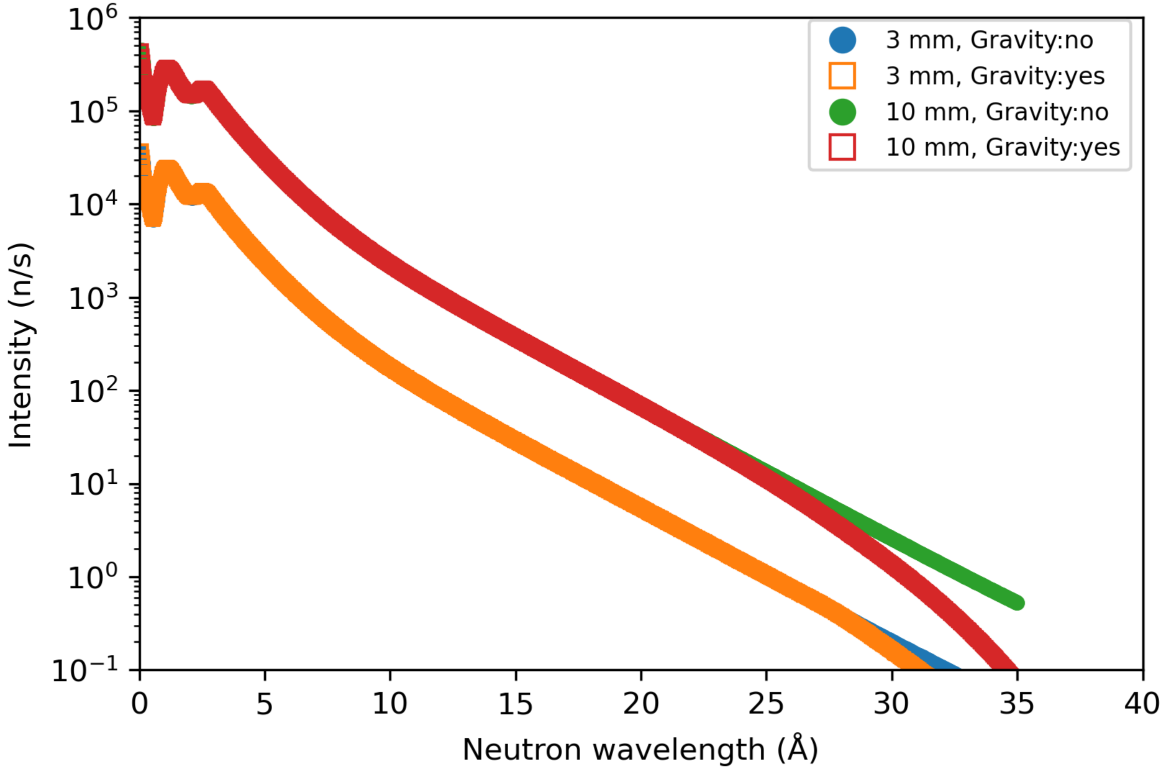
Neutron spectrum



Top-view



Complete detector view

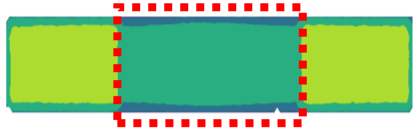


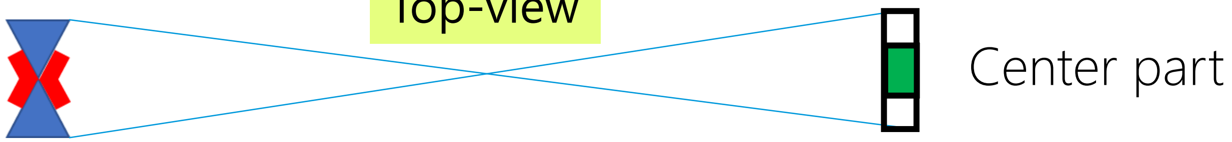
Thermal and cold (0.1 - 25 Å) flux: 3.39e+06 n/s/cm² at pinhole 3 mm

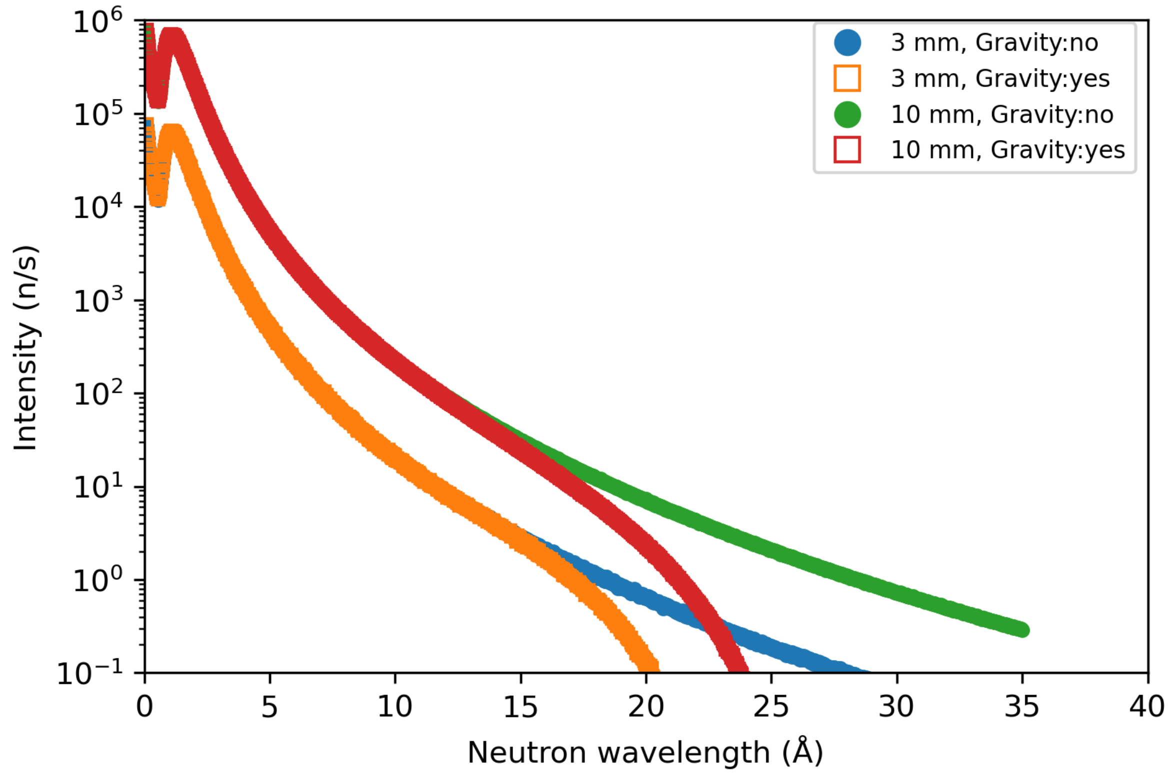
Thermal and cold (0.1 - 25 Å) flux: 4.16e+07 n/s/cm² at pinhole 10 mm

No difference in spectrum shape for different pinhole size

Neutron spectrum





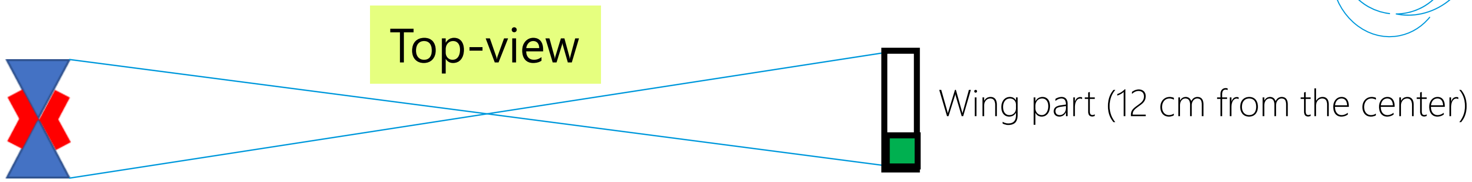


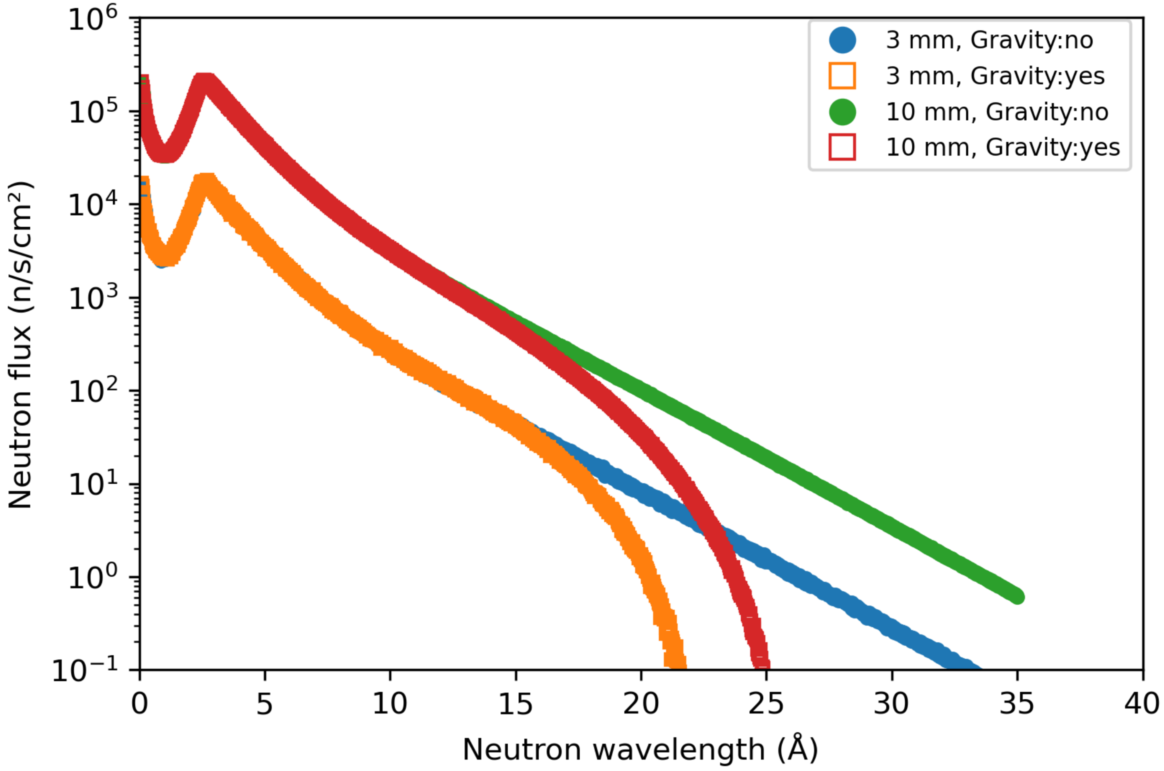
Thermal and cold (0.1 - 25 Å) flux: 4.90e+06 n/s/cm² at pinhole 3 mm

Thermal and cold (0.1 - 25 Å) flux: 5.40e+07 n/s/cm² at pinhole 10 mm

More **thermal** spectrum when detecting at the center part of the beam

Neutron spectrum



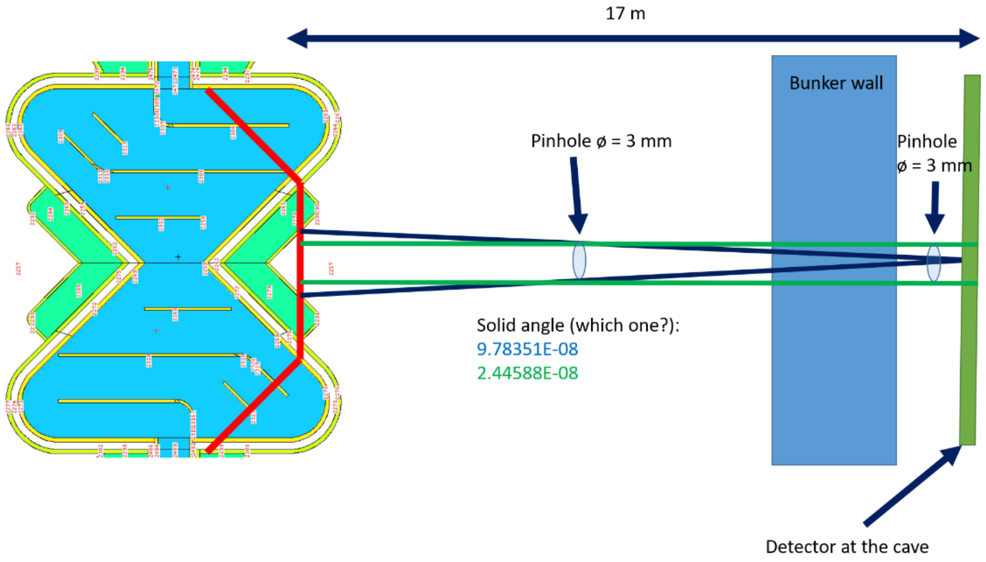


Thermal and cold (0.1 - 25 Å) flux: 2.52e+06 n/s/cm² at pinhole 3 mm

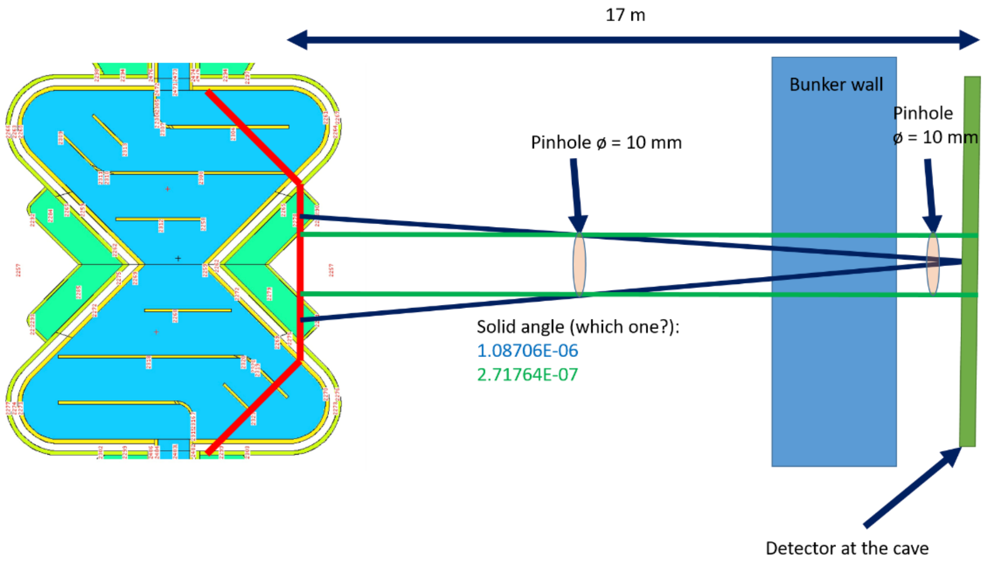
Thermal and cold (0.1 - 25 Å) flux: 3.09e+07 n/s/cm² at pinhole 10 mm

More **cold** spectrum when detecting at the wing part of the beam

Test 2.1: Validation of Moderator Brightness



Should refer to what have been done at FP12 (LANSCE)
P.-N. Seo *et al.*, *NIM A*, **517** (2004) 285–294.



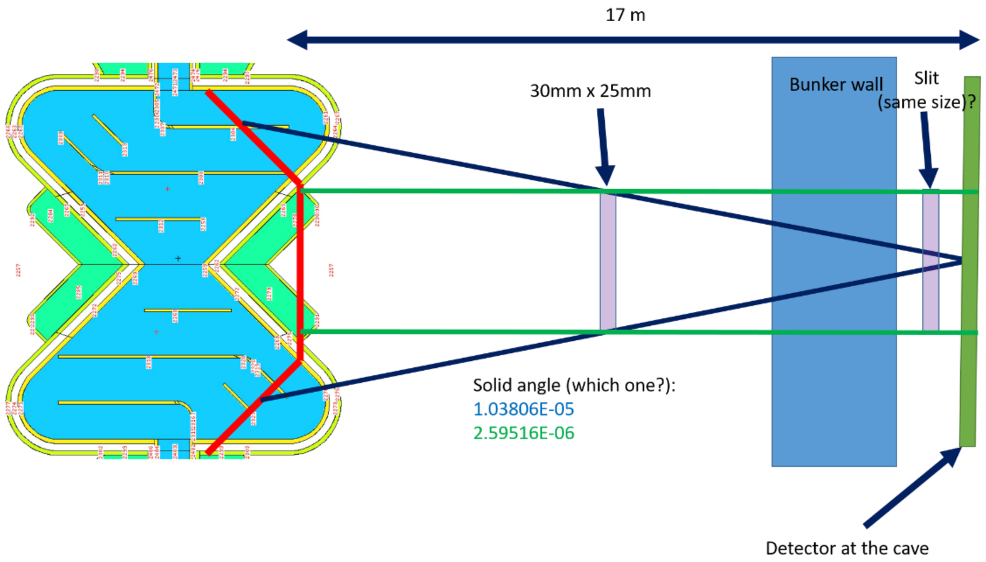
Proton beam 800 MeV, 5-50 μs pulse width @1-14Hz, 25W - 4kW
Neutron flux ~ 400 – 1E5 n/cm^2/s

		n/sr/p over a 3x6 cm2 area
Cold brightness	<20 meV	3.58E-03
Thermal brightness	20 – 100 meV	2.56E-03

Using larger channel

Brightness: μs-pulse vs ms-pulse

2nd pinhole/slit to define detection area



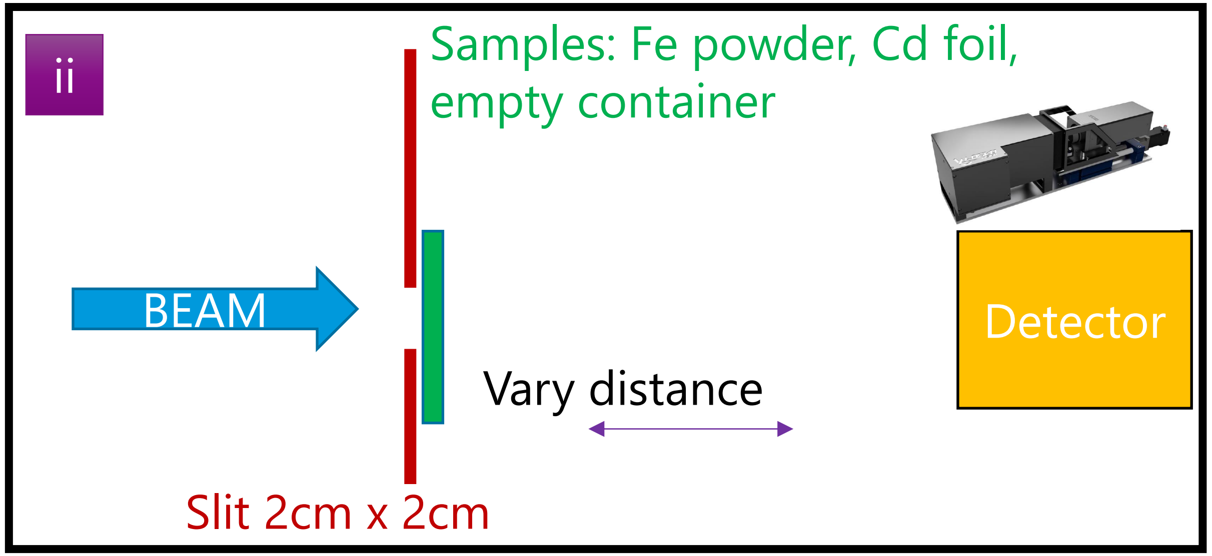
Outline

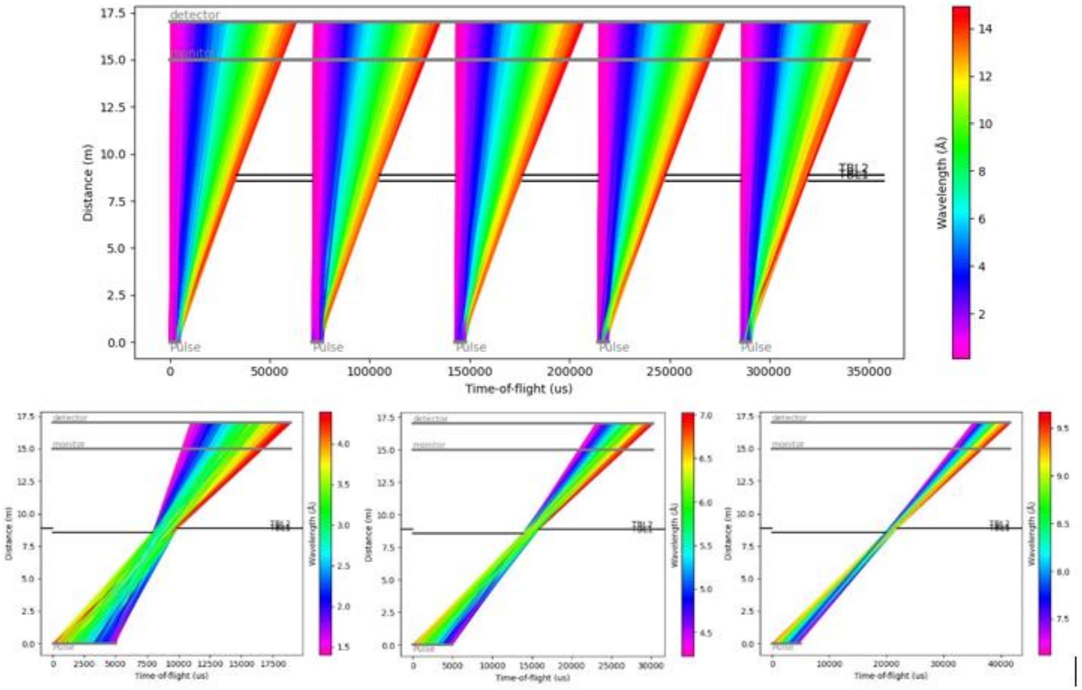
- ❑ Overview of TBL Layout
- ❑ First Beam-on-Target
- ❑ Brightness measurement
- ❑ Early activities
- ❑ Early science

Beam power > 100s W

Calibrations

1) Alignments: Collimators (pinholes) using in-bunker beam monitor
2) Energy selection: filters (Fe, HDPE, Bi-sc, Cd, sapphire-sc, Si-sc
3) T0 verification: Observe prompt pulse (> 3 ms)
4) Flight path: standard powder Bragg edge (short pulse)
5) Chopper phasing





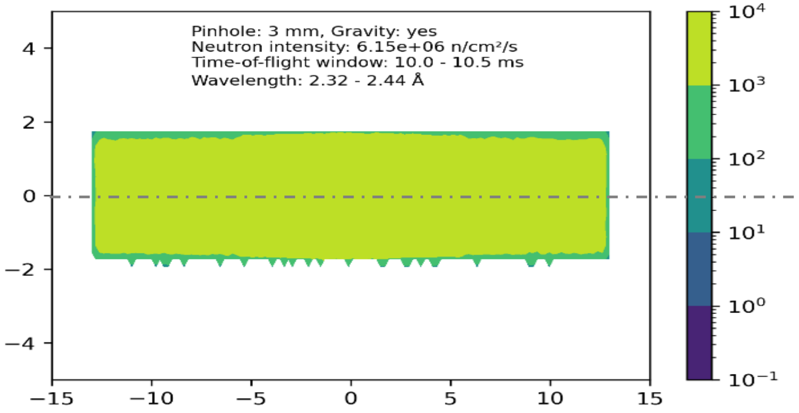
Test 3.1: Beam profile (spatial and ToF)

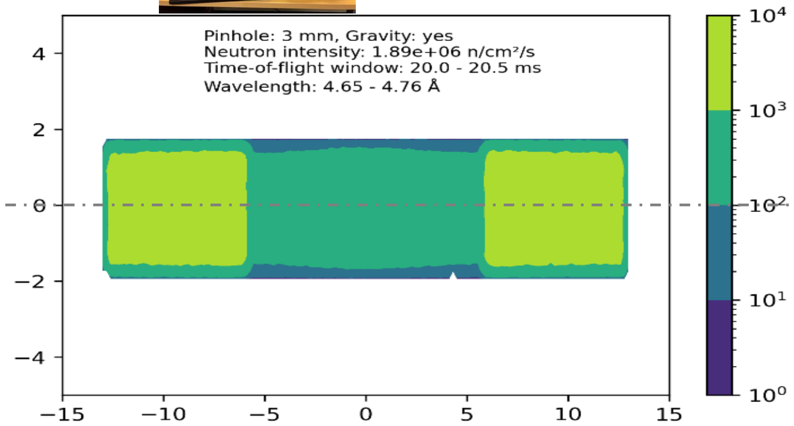
Beam power > kW

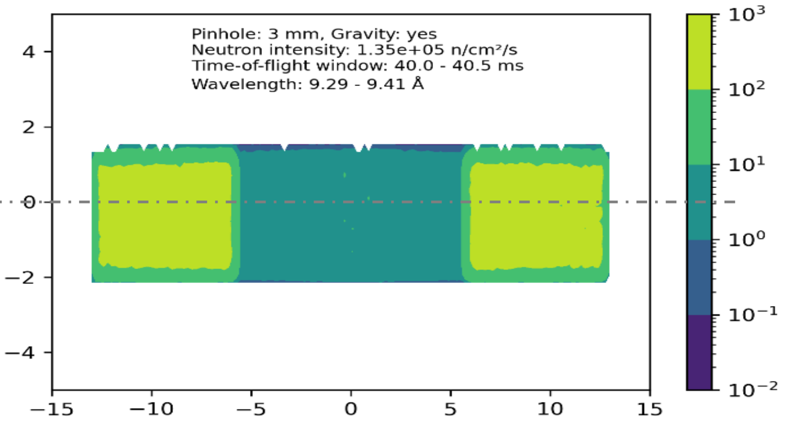
2D images taken by 'pinhole setup' ➔ Wavelength-selective image

LumaCam

ToF imaging (gating intensifier)

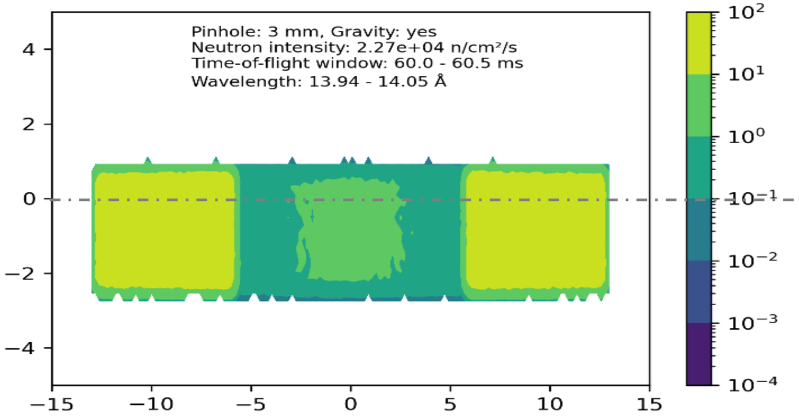


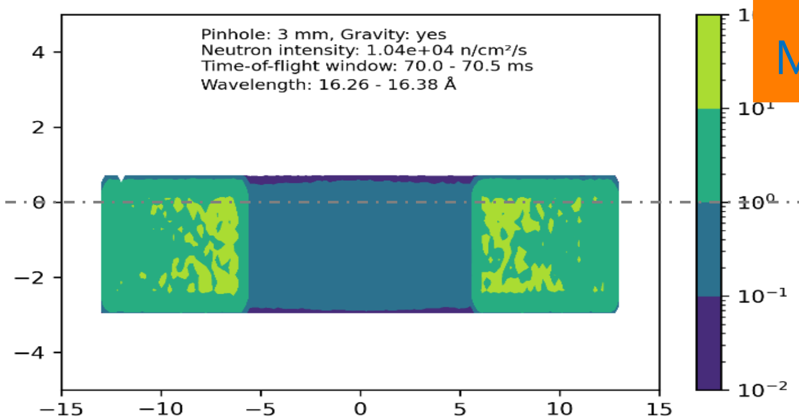


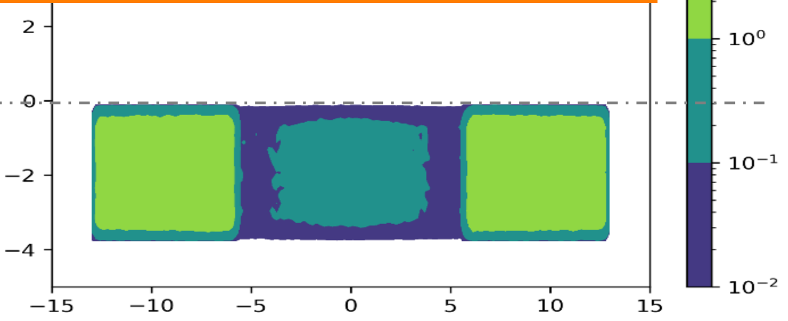


Expected result: 2D-tof up to 8 Å

Minimum result: tof 3 regions





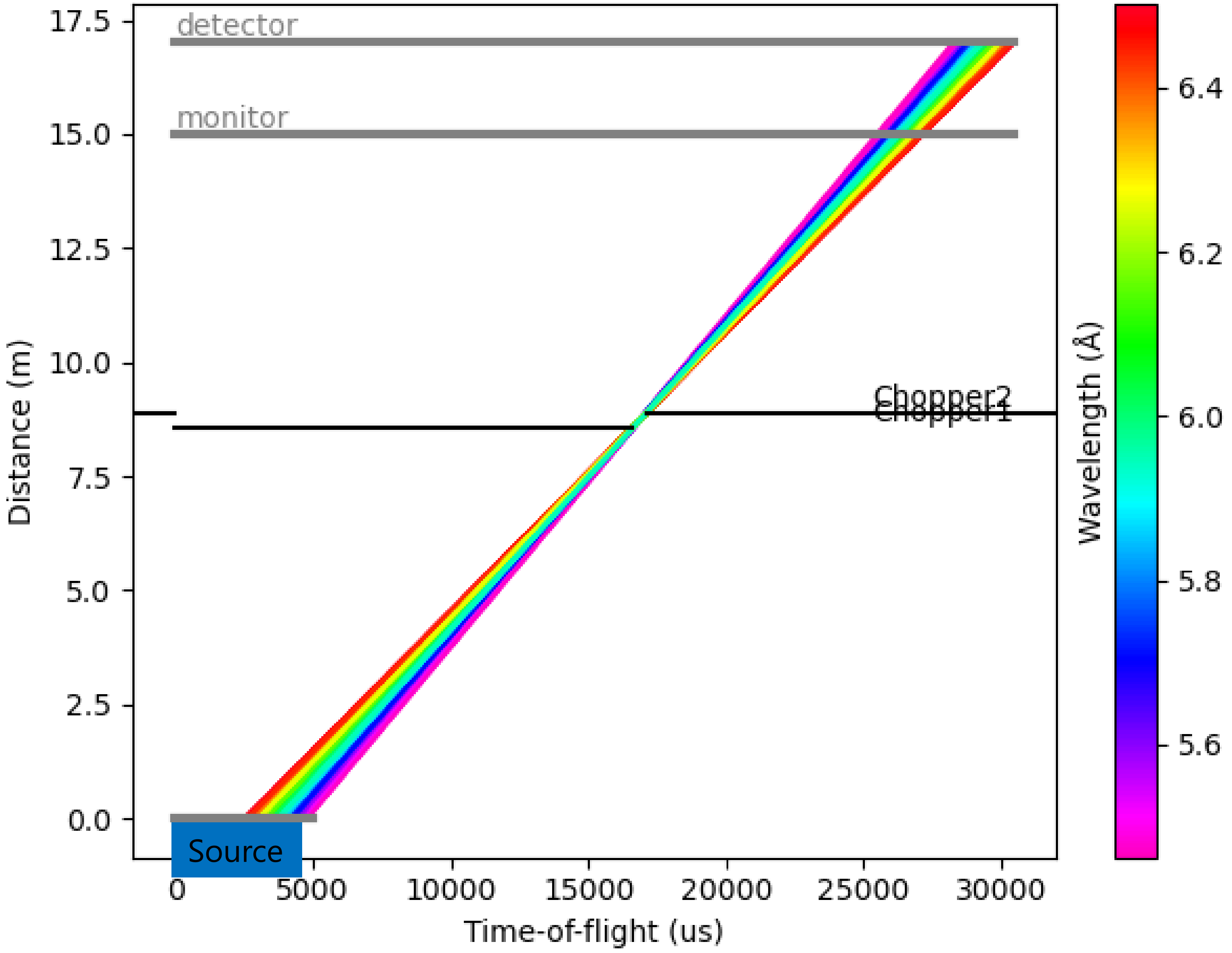


Δλ flight path ~0.7Å

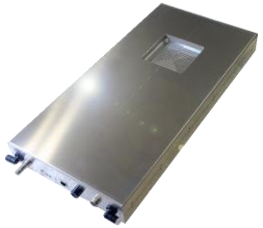
Test 3.2: ToF imaging

Beam power > tens kW

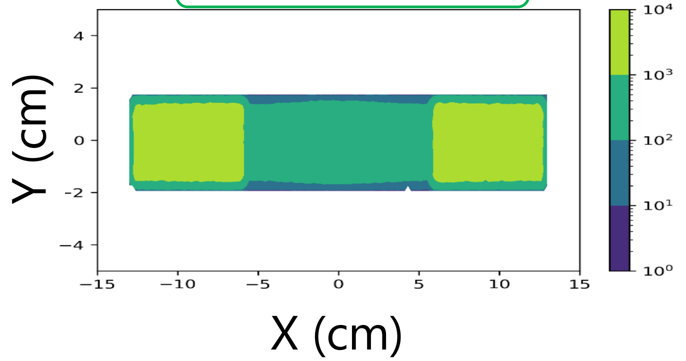
Effective small opening achieved by double-disc chopper



Using chopper to create distinct wavelength bands

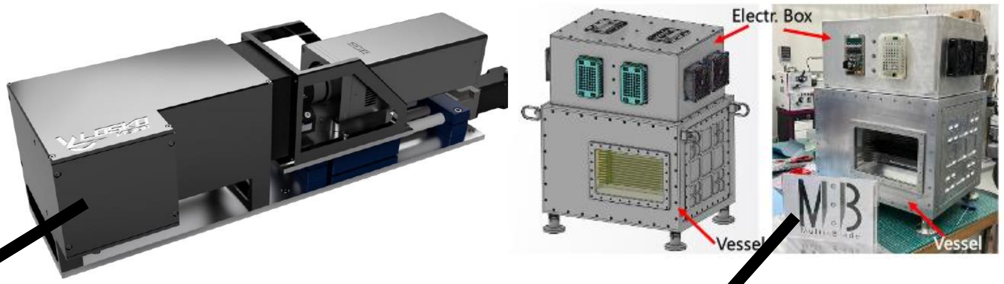


$5.5Å - 6.5Å$



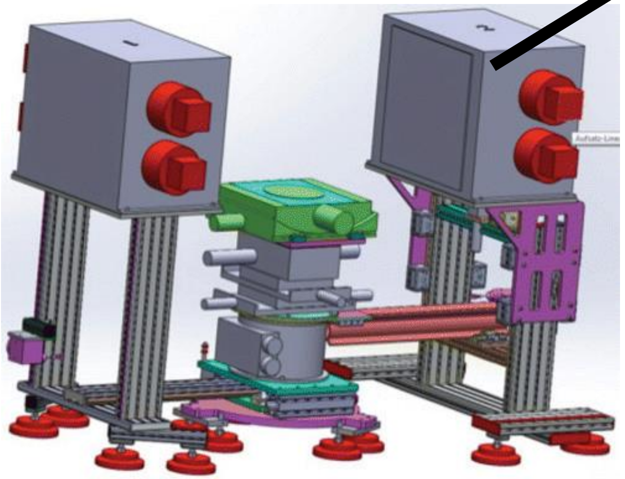
Projection of "Butterfly" moderator

Test 4: Pulse-shape



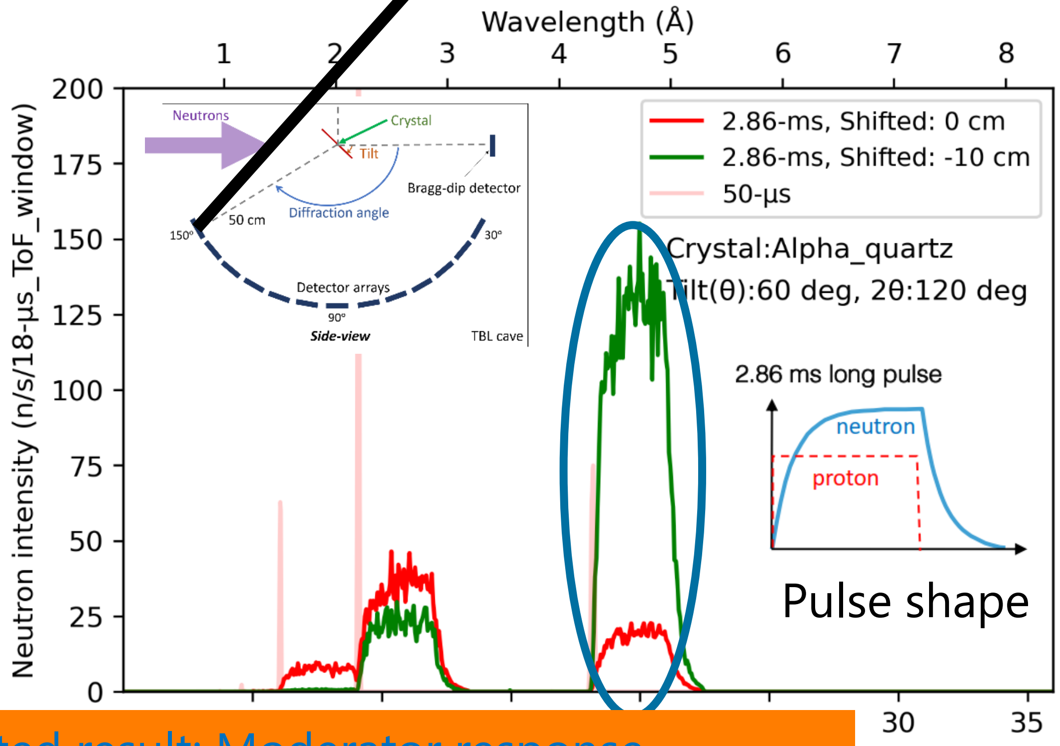
Beam power > hundreds kW

This calibration is to ensure the pulse shape of ESS neutron production. A large lattice powder (e.g. mica) will be used to diffract beam at larger angles. The setup is under development, but we foresee *Laue diffraction*, using LumaCam detector, same as the flight path calibration (but larger FoV).



Setup similar to FALCON (HZB) (no backward camera)

Another setup will be employed like conventional *Bragg diffraction* using MB/nGEM at a fixed angle. This setup needs more space compared to the above. The detector will be placed under the table and faced tilting to sample.



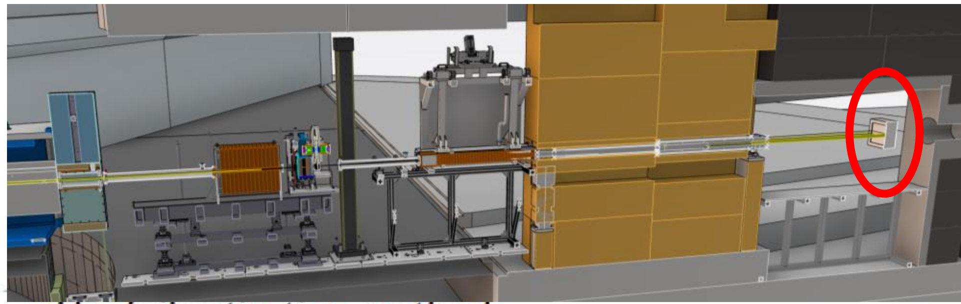
Expected result: Moderator response

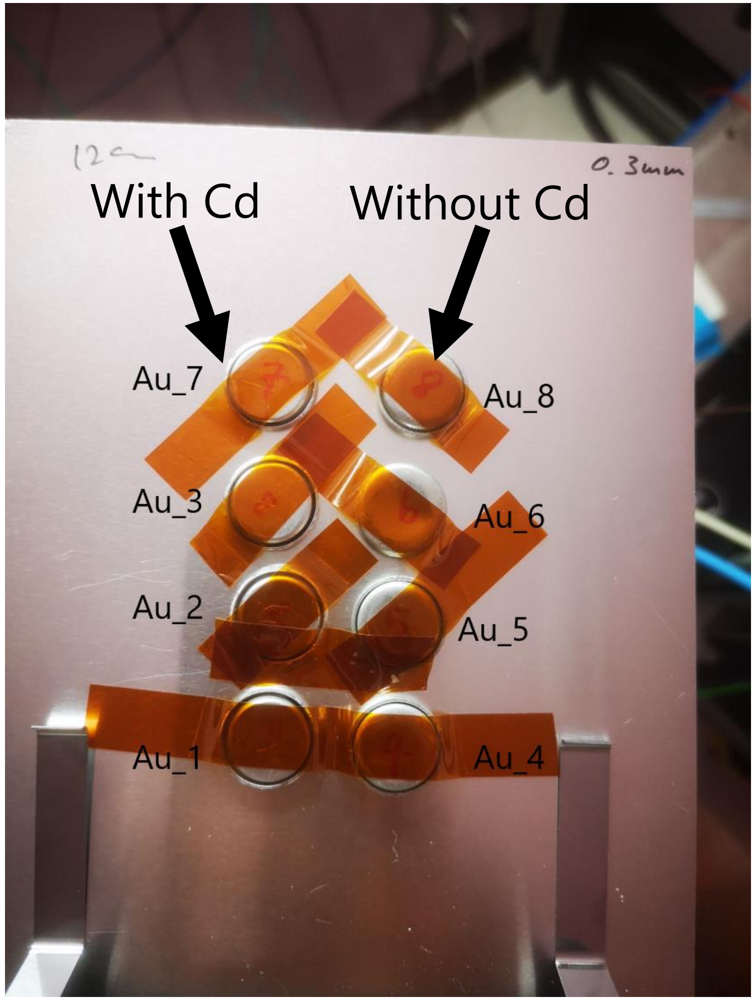
Minimum result: 2.86-ms pulse shapre

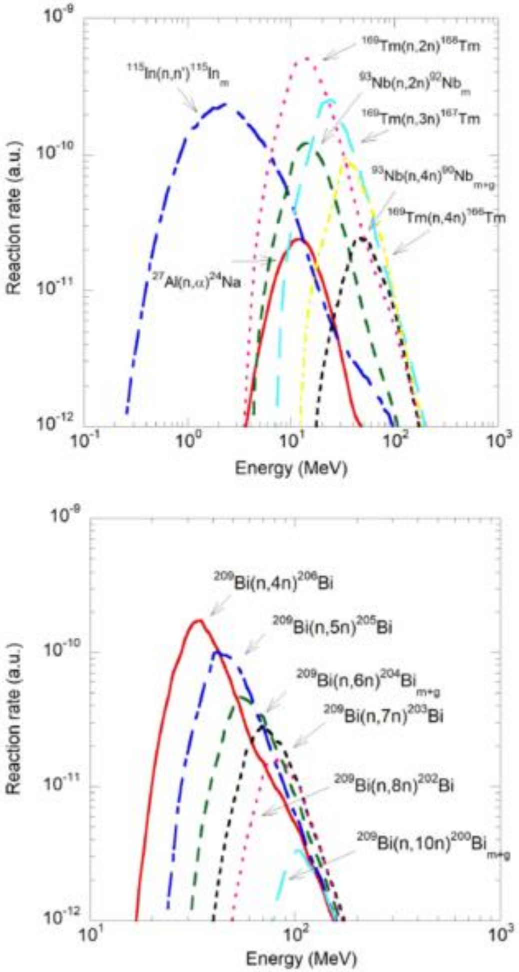
Test 5: Flux (up to 200 MeV)

Long-pulse

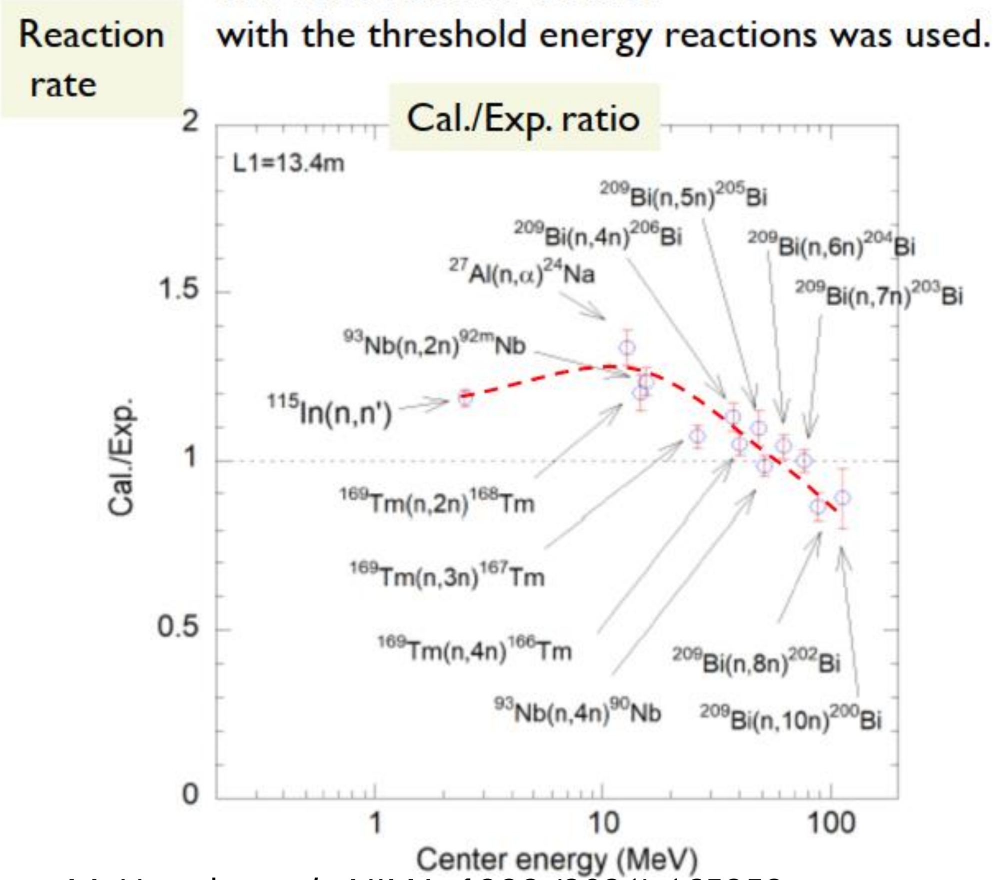
Beam power > kW







The foil activation method with the threshold energy reactions was used.



M. Harada *et al.*, *NIMA*, **1000** (2021) 165252.

Need to find Bi, Dy, Ta foils

Expected result: Flux - Whole range

Minimum result: Thermal/cold flux (< Cd)

Outline

- ❑ Overview of TBL Layout
- ❑ First Beam-on-Target
- ❑ Brightness measurement
- ❑ Early activities
- ❑ Early science

What do we actually want to do?

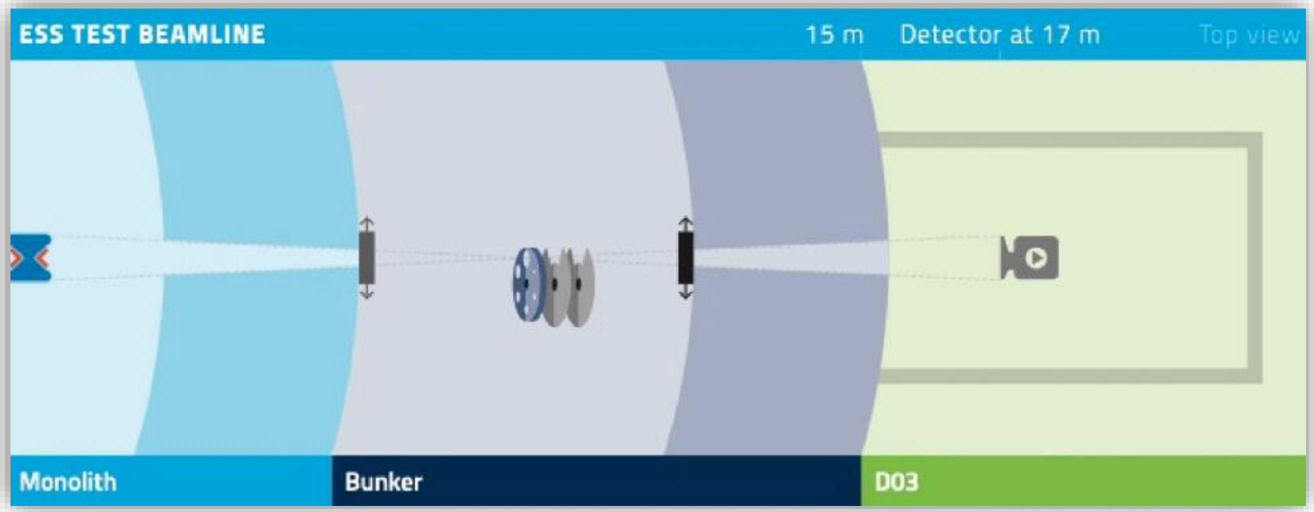
Scope

The Test Beamline (TBL) will be used to **verify that ESS is successfully producing slow neutrons** that will be used for scientific investigations.

The TBL design consists of a changeable pinhole and a double-disk chopper. The modular designs allows for future upgrades.

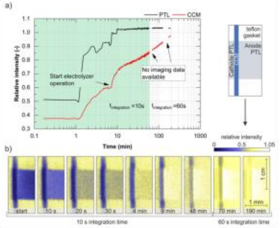
The goal of the TBL is to characterize/support:

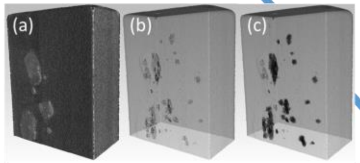
- Characterization of the ESS moderator system
- Be a benchmark to other beam ports
- Proton beam stability/Moderator stability
- Spatial distribution of neutron beam
- Characterize neutron spectrum
- Pulse-shape of cold-thermal neutrons
- Detectors and data processing systems
- Sample (e.g. single crystal) alignment
- Simple imaging and diffraction experiments



What can we do at TBL?

Operando Hydrogen storage
Hydrogen Blistering - corrosion

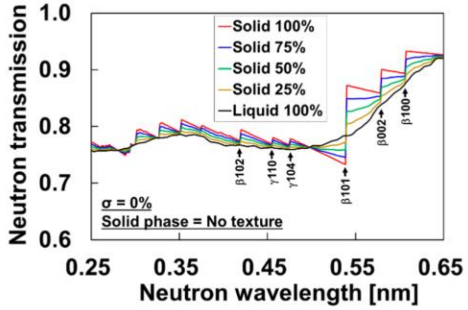




Acta Mater., **2014**, *78*, 17.

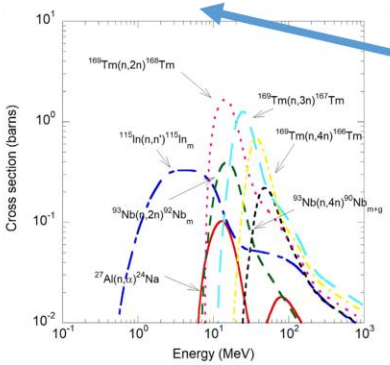
J. Electrochem. Soc., **2020**, *167*, 144509.

Low-resolution tof transmission of liquids

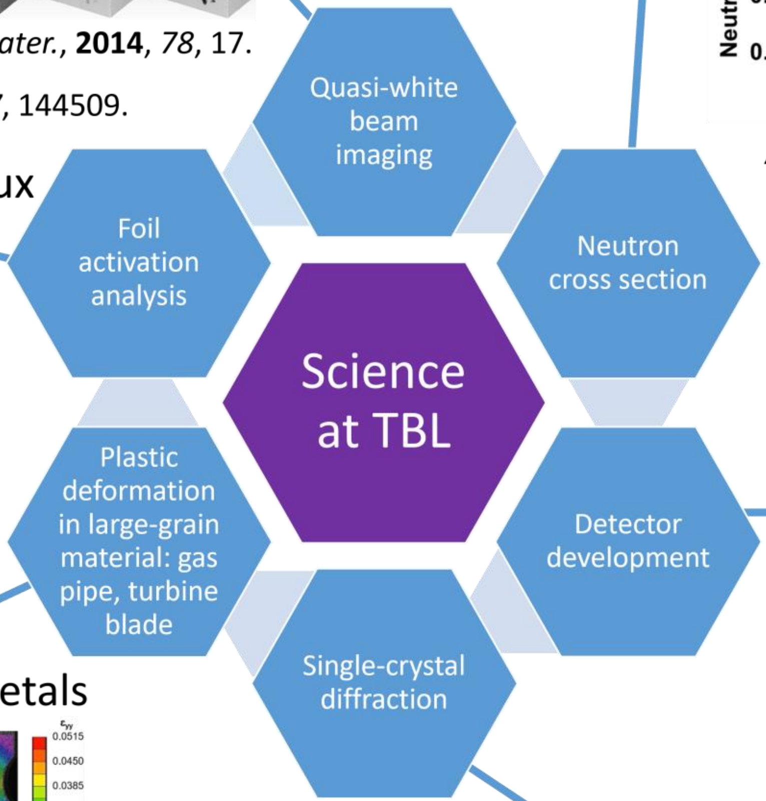


Appl. Sci. **2021**, *11*, 5988.

Access to Fast Neutron Flux

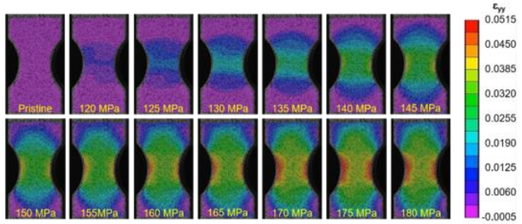


NIM A, **2021,** *1000*, 165252.



Calibrated with neutron monitor

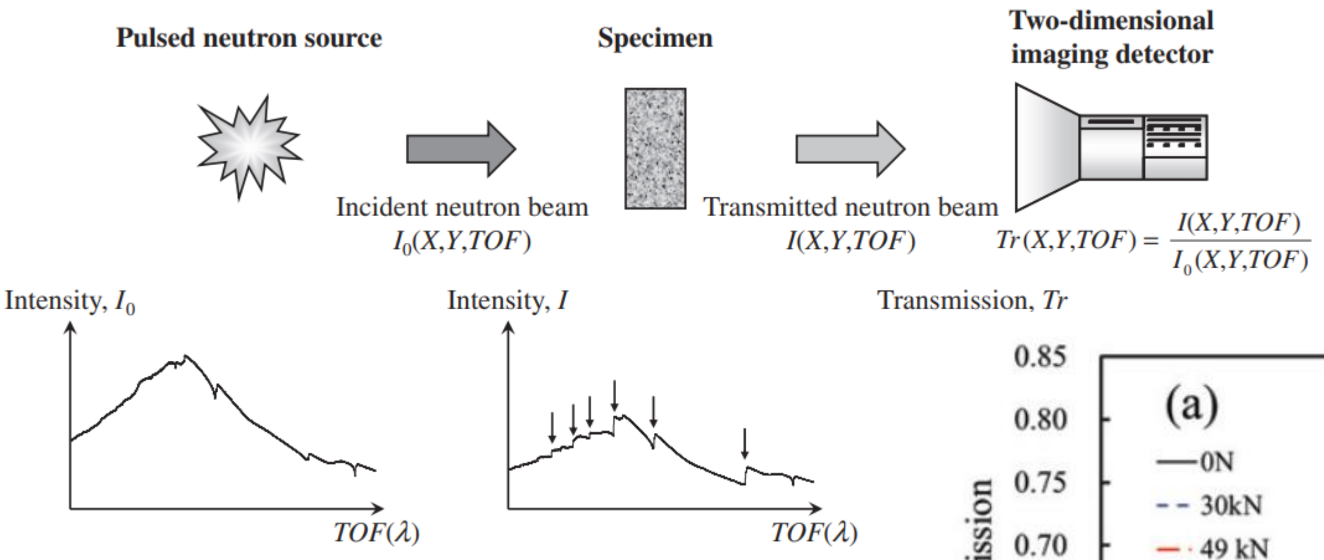
Extinction effects in metals

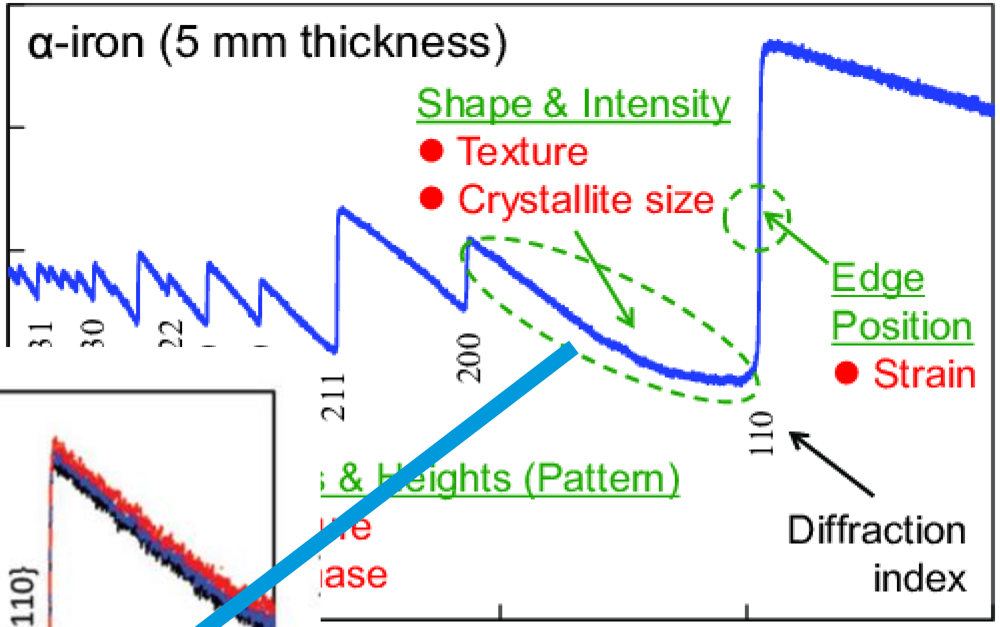


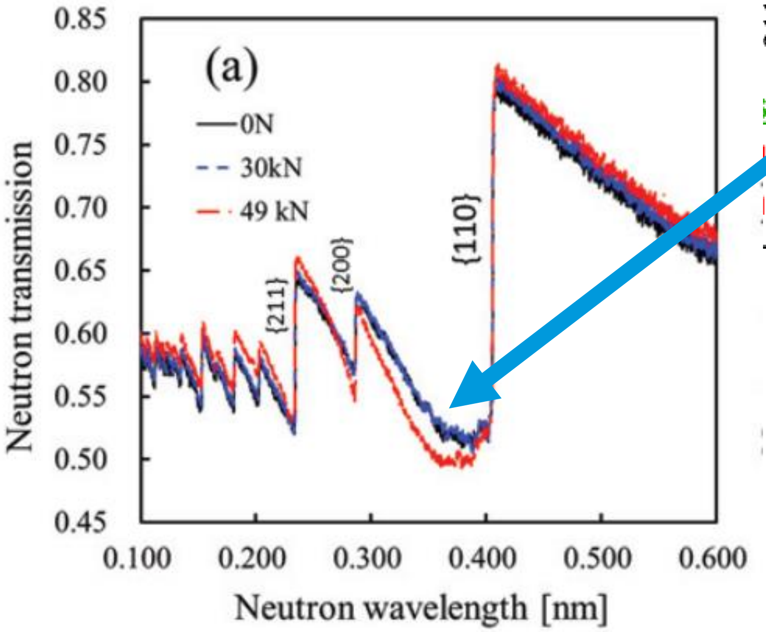
In Preparation

Single-crystal alignment
Validate ESS pulse shape

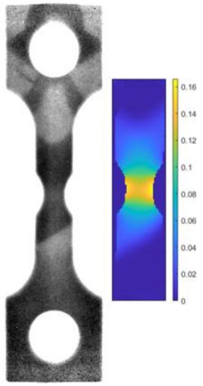
Neutron imaging: Bragg-edge







$$\varepsilon_{hkl} = (d_{hkl} - d_{hkl}^{0})/d_{hkl}^{0}$$



The sudden change in transmission is caused by ***less elastic coherent scattering*** right-after Bragg condition at a specific wavelength

A. Steuwer *et al.*, *Physica Status Solidi A*, **185** (2001) 221.
H. Sato *et al.*, *Materials Transactions*, **52** (2011) 1294.

ToF-imaging: Mechanical properties

Tran van Khanh

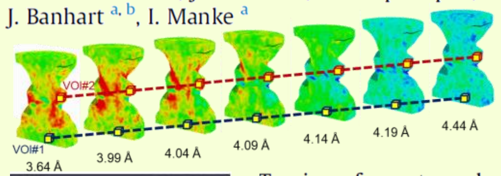
Spectral Neutron Imaging

2018-2023

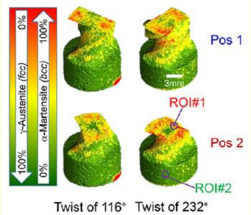
ongoing

Spectral neutron tomography

K.V. Tran [a, b, c, **], R. Woracek [d, *], N. Kardjilov [a], H. Markötter [a, h], A. Hilger [a], W. Kockelmann [e], J. Kelleher [e], S.B. Puplampu [f], D. Penumadu [f], A.S. Tremsin [g], J. Banhart [a, b], I. Manke [a]

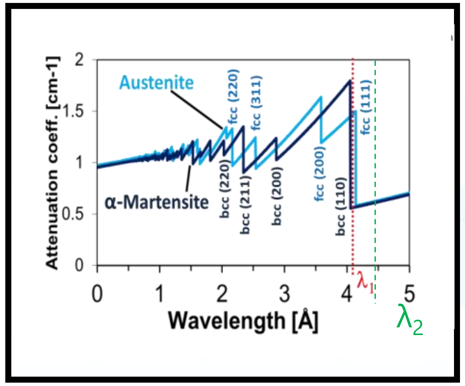


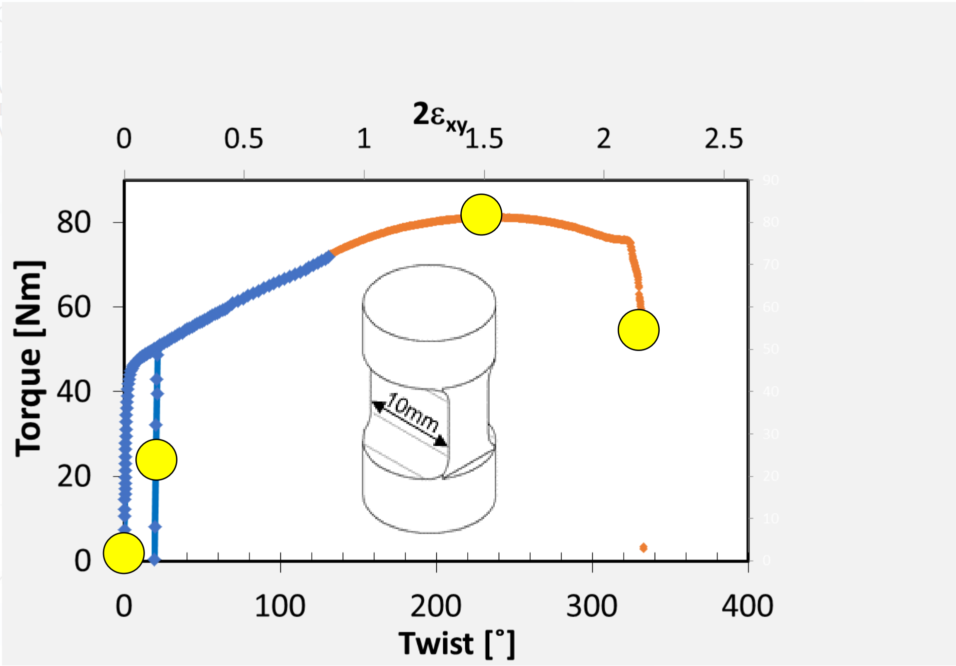
3D phase distributions in a complex geometry using neutron tomography

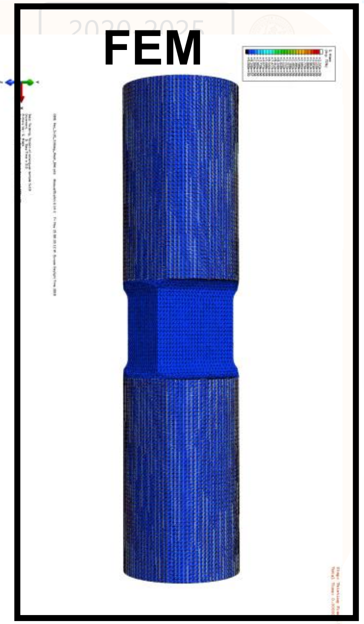


Torsion of a rectangular bar: Complex phase distribution in 304L steel revealed by neutron tomography

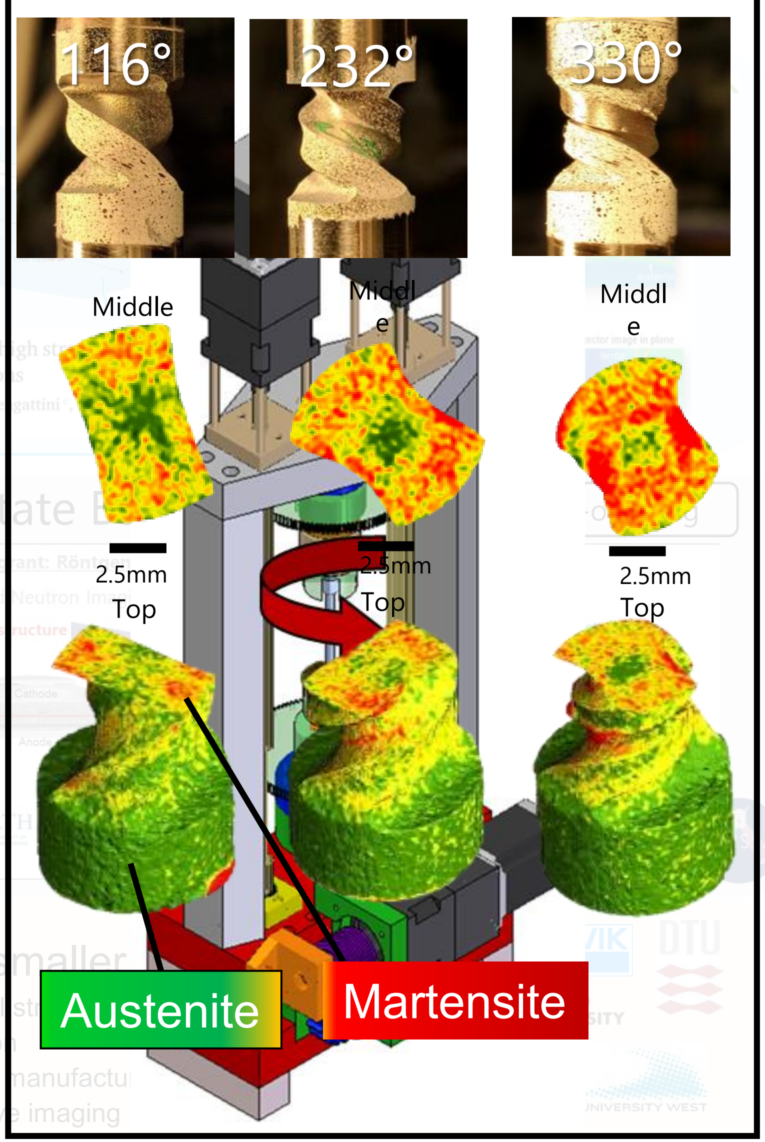
Khanh Van Tran [a,b,c,*], Robin Woracek [d], Nikolay Kardjilov [a,*], Henning Markötter [a,g], Daniel Abou-Ras [a], Stephen Puplampu [e], Christiane Förster [a], Dayakar Penumadu [e], Carl F.O. Dahlberg [f], John Banhart [a,b], Ingo Manke [a,b]



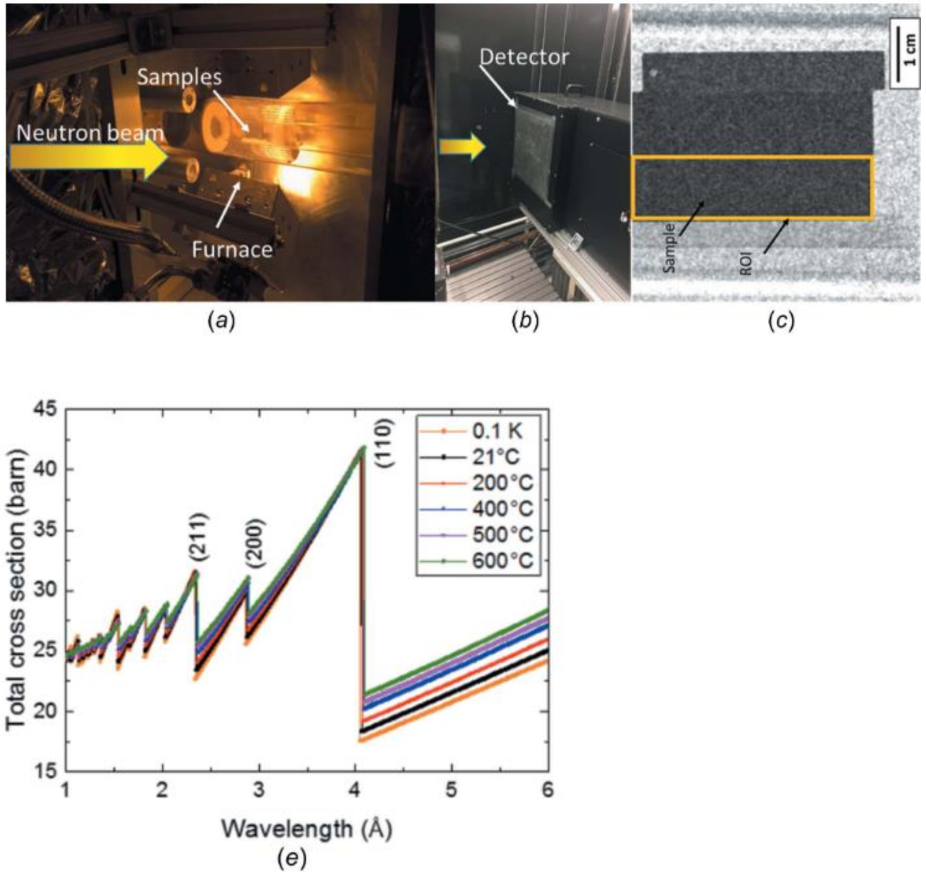




Diffraction Contrast Tomography



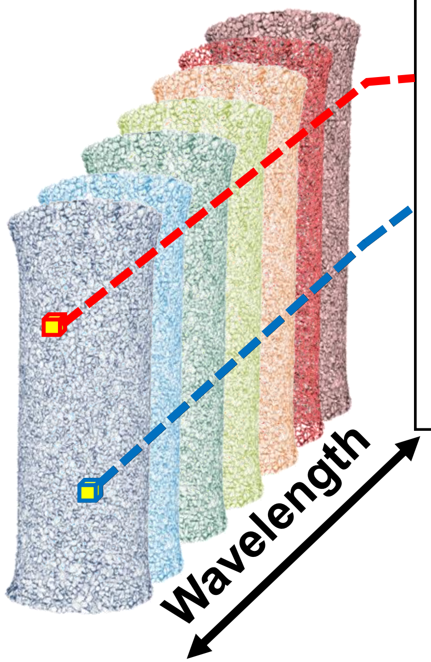
ToF-imaging: Temperature effect

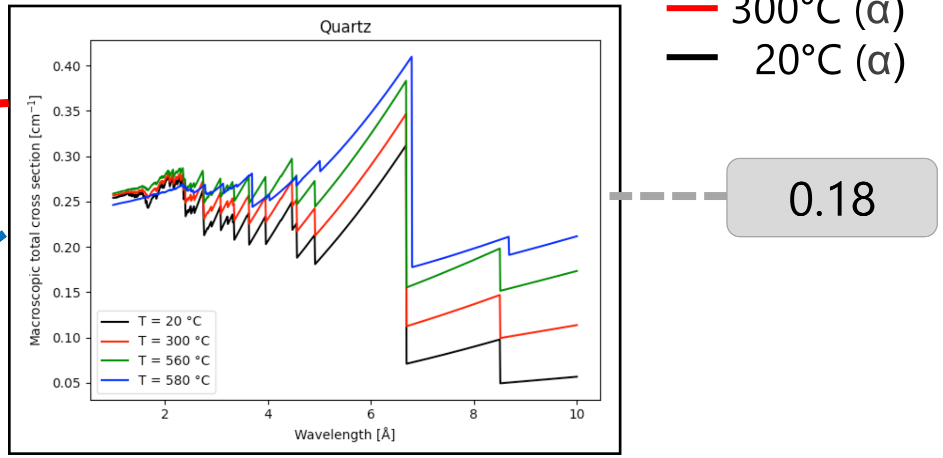


Al-Falahat *et al.*, *J. Appl. Cryst.*, **55** (2022) 919–928.

Pulsed Source

'Hyper-Spectral' Tomography





Macroscopic Neutron Cross Sections!

- Crystallographic Phase (Texture, Strain)
- Much improved quantification of material compositions
- Thermography (Temperatures)

NCrystal : a library for thermal neutron transport

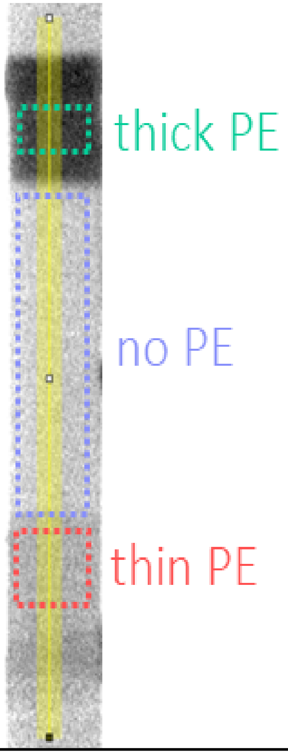
Tran, Woracek et al. MATER TODAY ADV 9 (2021)

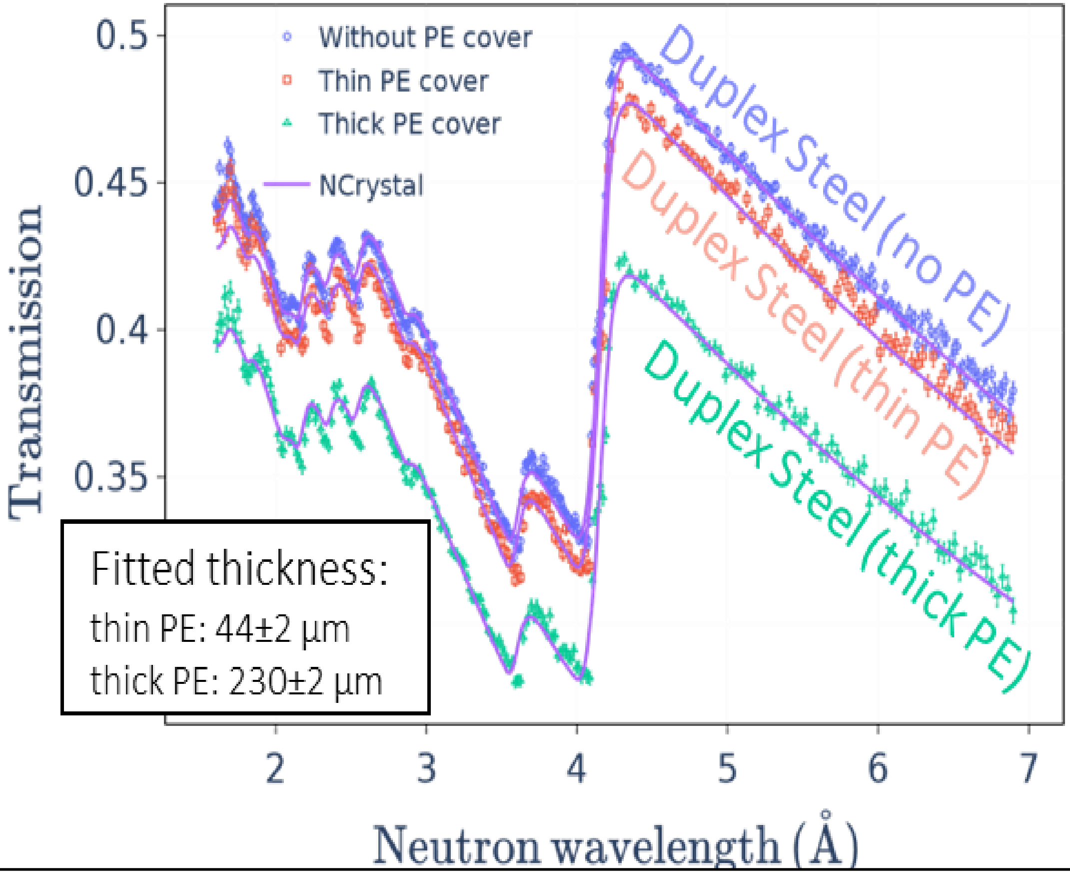
ToF-imaging: H-embrittlement


David Lindblom   Shuqi Xu

Example: Duplex-Stainless steel + PE sheets

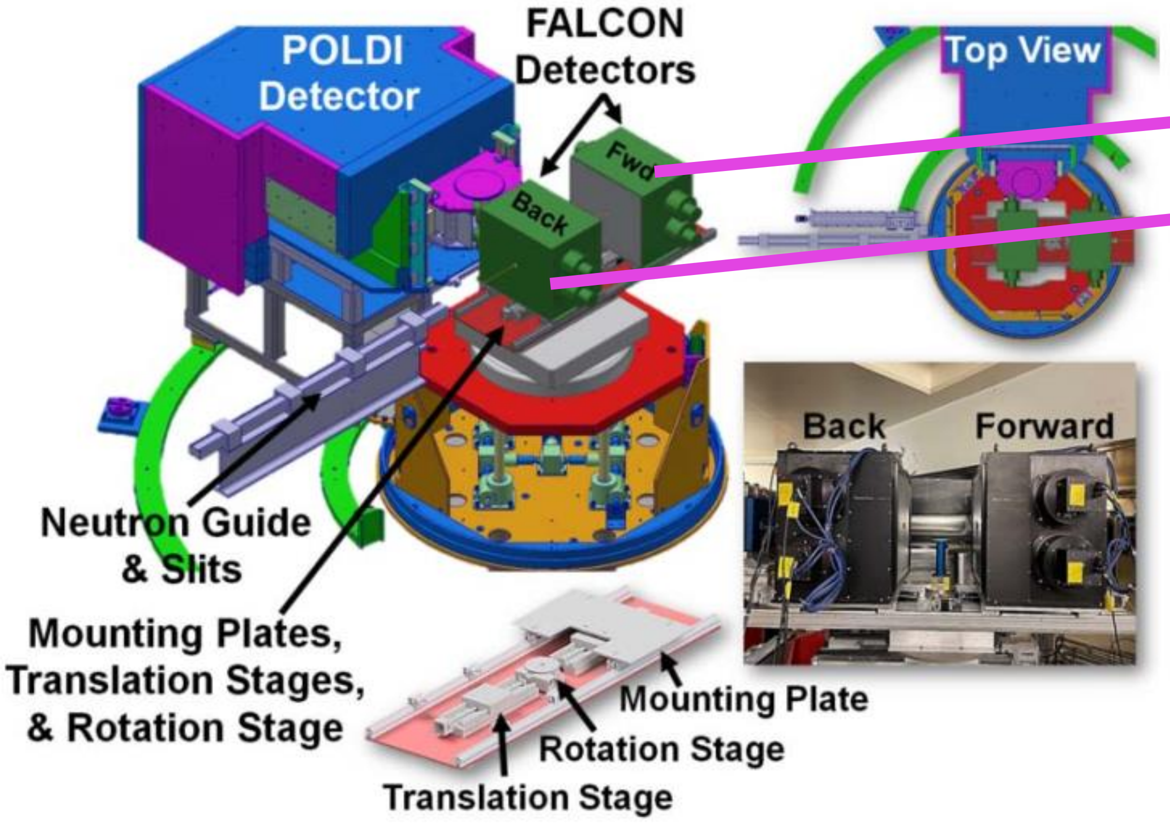
NCrystal : a library for thermal neutron transport

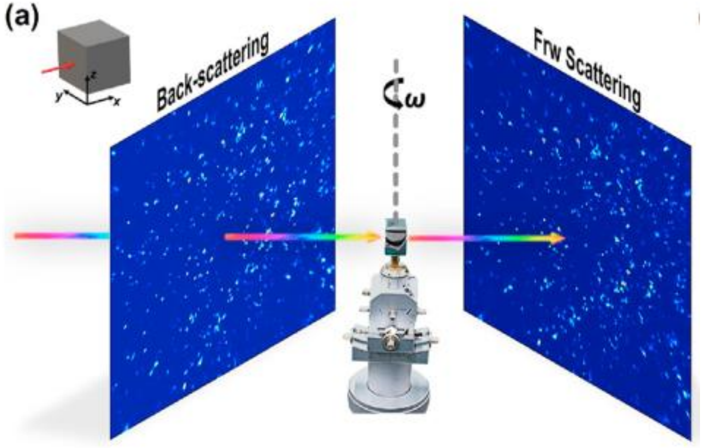




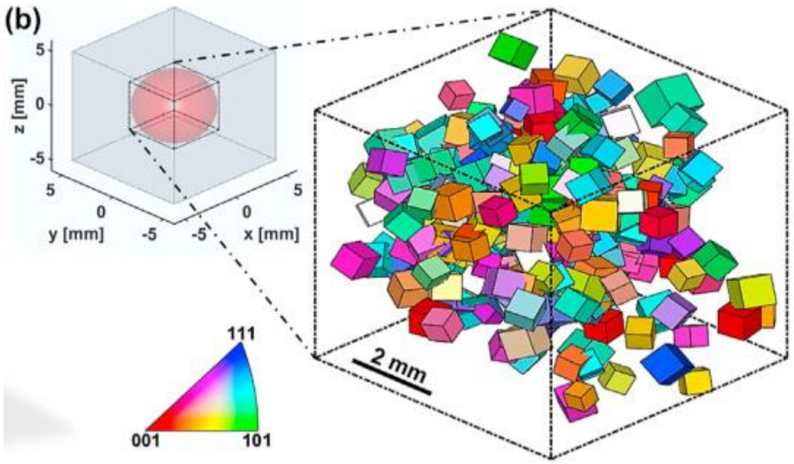
Single crystal alignment/measurements

Neutron imaging + diffraction





Map grain size and orientation



S. Samothrakitis *et al.*, *J. Appl. Cryst.*, **56** (2023) 1792–1801.
S. Samothrakitis *et al.*, *Mater. Today Adv.*, **15** (2022) 100258.

2025-09-08

Cold-commissioning

Thank you

Contacts:

thawatchart.chulapakorn@ess.eu (science)
christofer.svensson@ess.eu (engineer)
samuele.andreucci@ess.eu (installation)
jason.morin@ess.eu (beamline operation)