PAUL SCHERRER INSTITUT


Uwe Filges

# Neutron Optics and 3D printing Developments at PSI

BRIDGE2023 18th-20th October 2023

# Outline

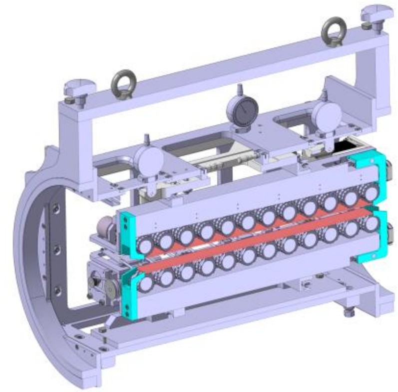
(1) Introduction SINQ

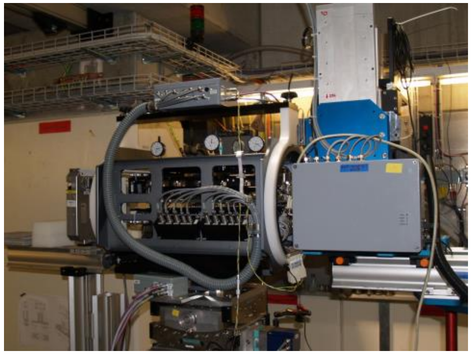
(2) SINQ Neutron Guide Upgrade in 2017-2020

(3) Focusing optics in Sample environment

(4) Adaptive Optics Developments

(5) 3D printing of borated materials





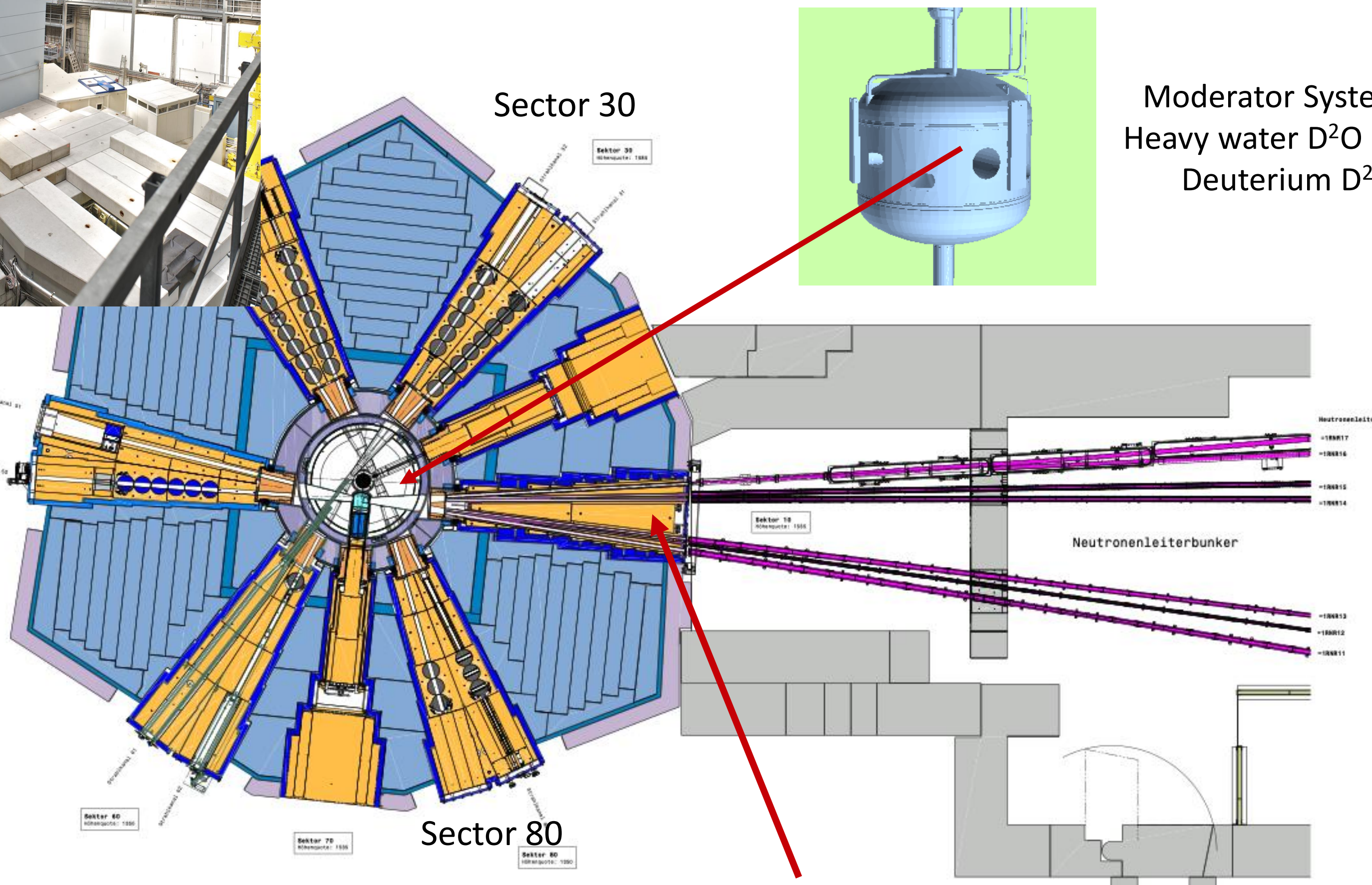
Full adaptive Optics

New in-pile Section – Guide bundle

FOCUS guide (up to 25 cm in heigth)

# SINQ – Guide and Moderator System

Moderator System:
Heavy water $D^2O$ and
Deuterium $D^2$




Sector 30

Sector 50
short cold beamlines

Thermal beam ports
Sector 30,40,80

Sector 80

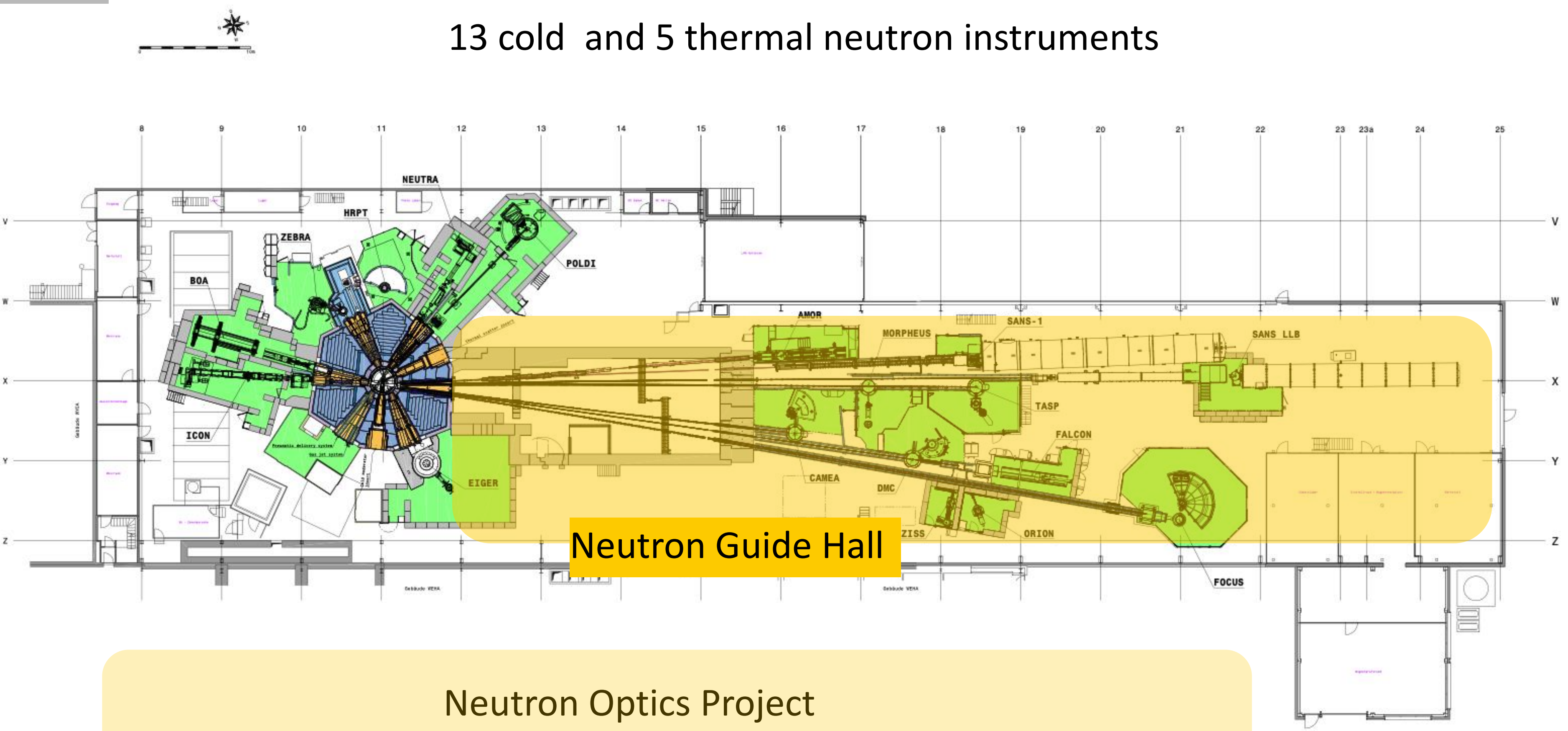
Sector 10
7 Neutron Guides (up to 70 m long)

**18 Neutron instruments are positions around the Neutron source 360 deg (8 sectors)**

# SINQ Instrumente (14 user + 4 inhouse instruments)

Diffraction | Spectroscopy | SANS + Ref. | Imaging

13 cold and 5 thermal neutron instruments

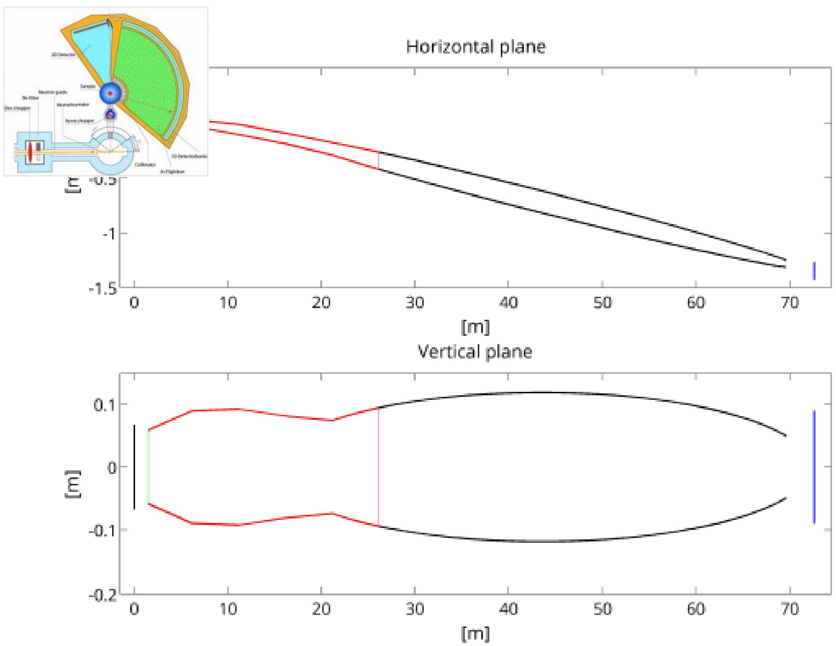



Neutron Optics Project

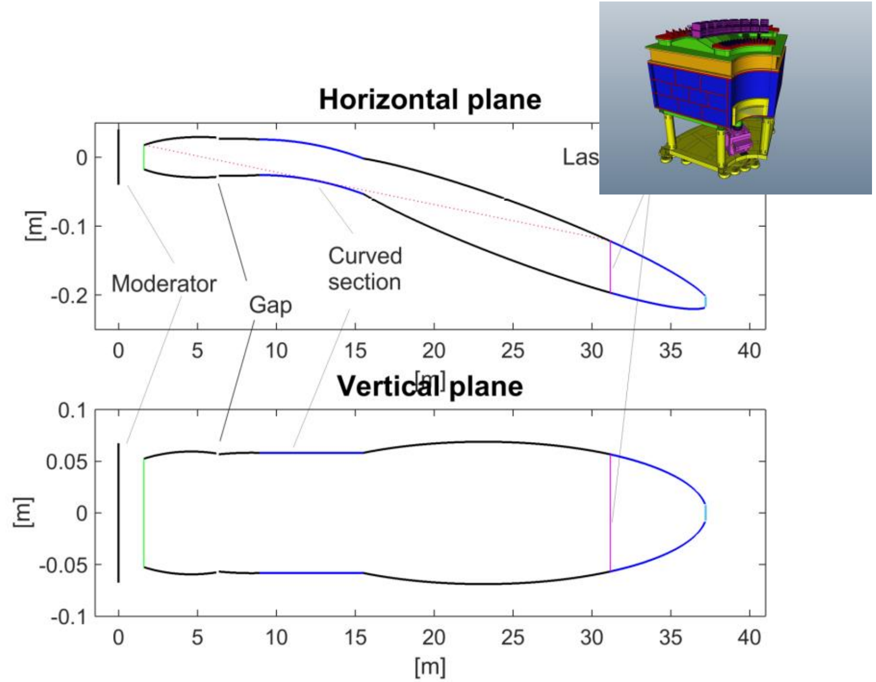
Neutron Guide Upgrade in 2017-2020 (Upgrade of 11 Instruments)

# Upgrade of SINQ guide system

- replacement of the 340 m long old guide system (m=2/m=1) in the neutron guide hall (includes re-positioning/adaption of shutters, filters, vacuum systems and beam monitors)
- Improving the scientific conditions at the instrument side (redesign of few instrument areas)
- Improving the shielding along the guides (reducing the neutron background)



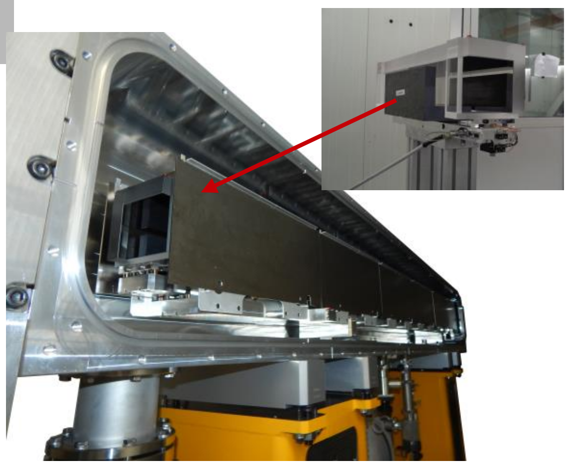

FOCUS – High Intensity by High Divergence



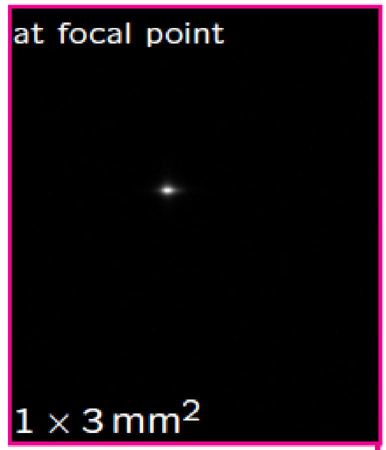

CAMEA – Advanced Triple-Axes Instrument

# Instrument AMOR – Selene Guide

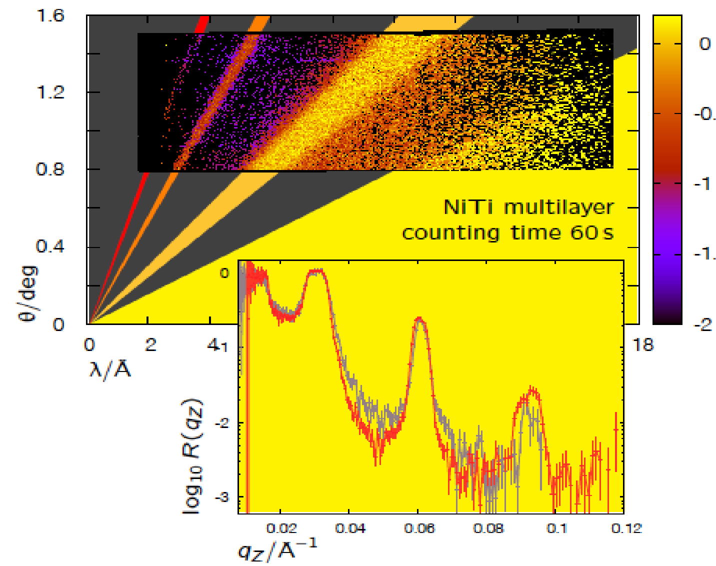
First neutron optics worldwide which can focus the beam to a spot of < 1 x 3 mm$^2$ **over 30 m**



36 High precision optics were adjusted together (Selene 1 & 2)

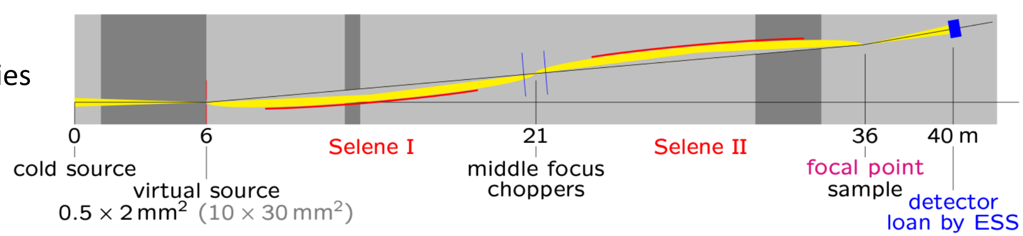



Beam focusing



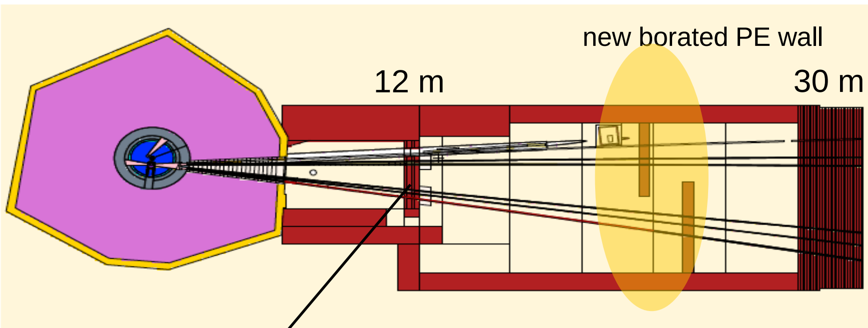

Reference sample was measured within 60 seconds (gain factor 30)

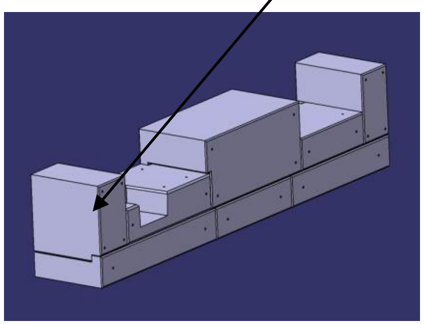
Two Montel optics in series



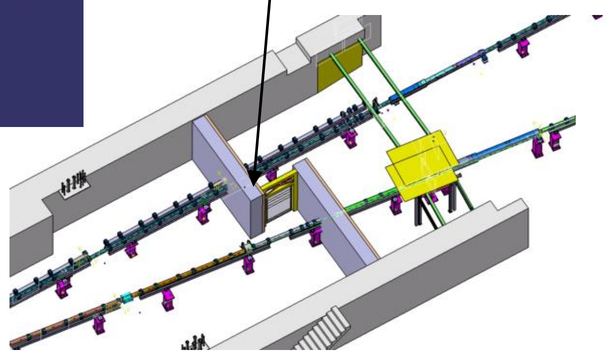
# New Shielding Concept in the Neutron Guide Bunker

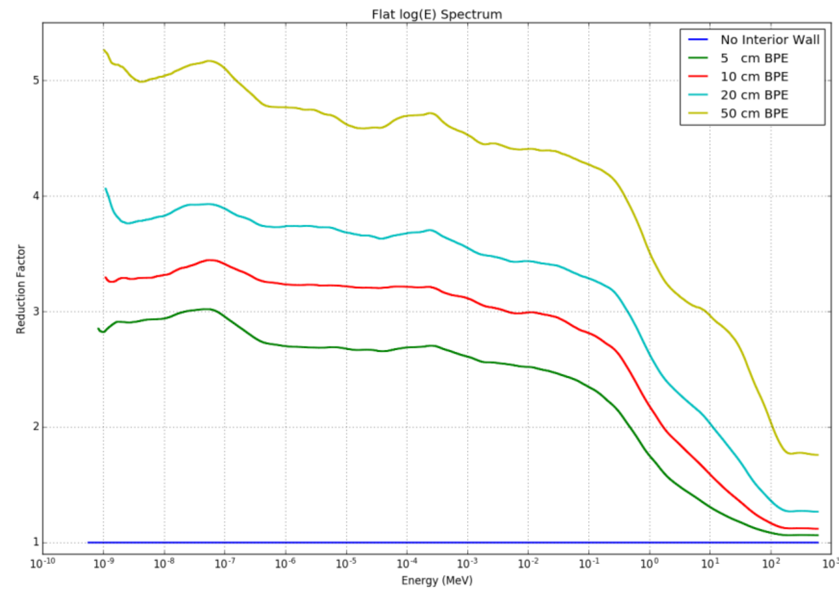
50 cm borated PE & 10 cm Steel reduces significantly the n-background (5-6 times)



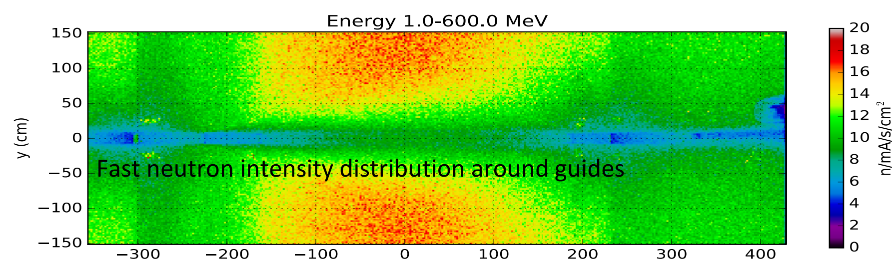



Use of new developed borated mineral cast



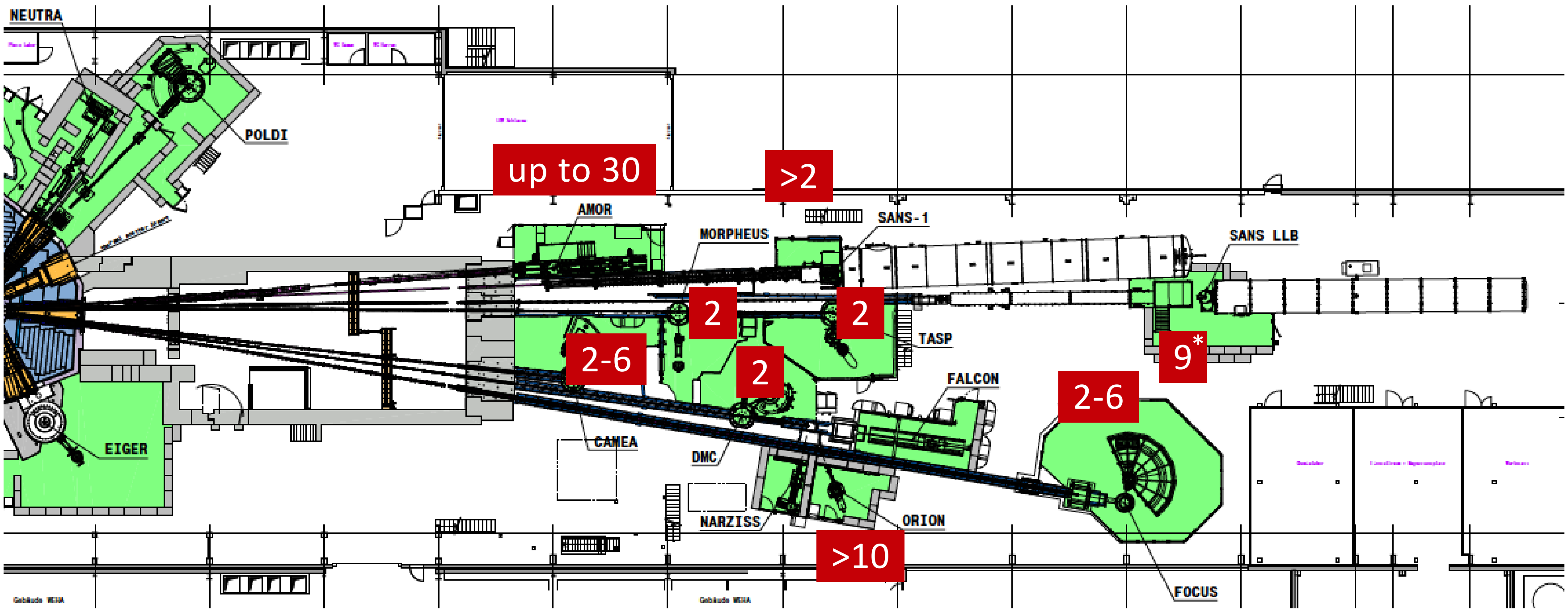



Background reduction depending from BPE wall thickness



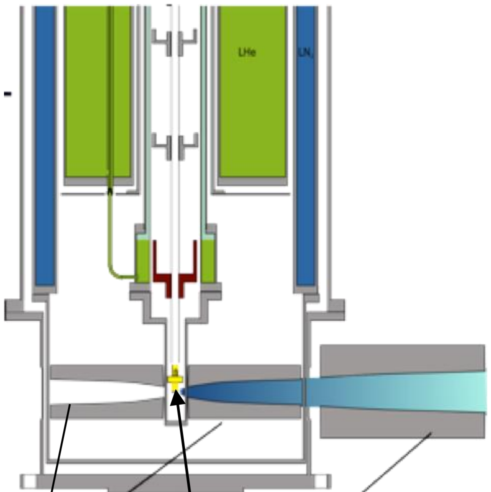
# Performance after Guide Upgrade

All instruments/guides have at least an intensity gain of a factor 2 (in comparison to 2018).
Instruments with elliptic neutron guides are performing better – up to factor 30.




* Gain factor is in comparison to SANS-2 (2018)

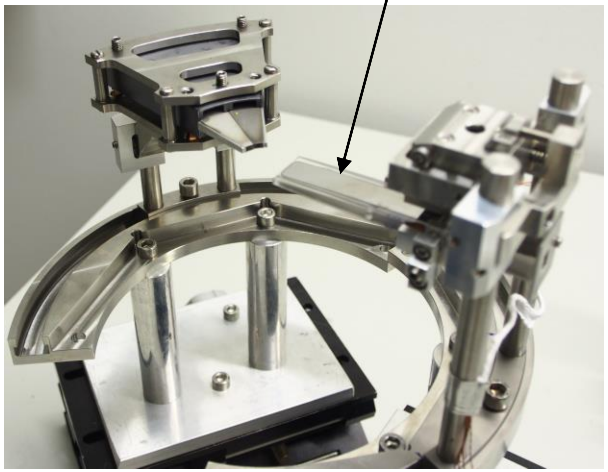
# Focusing Optics inside sample environment




Optics inside sample environment

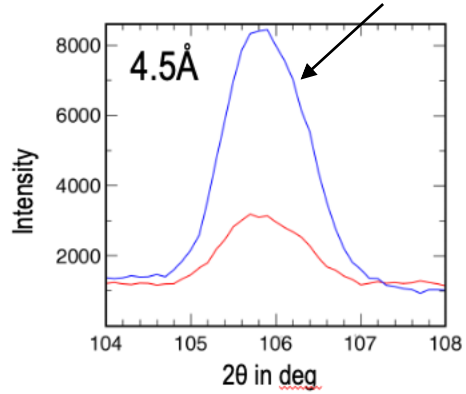
Prefocusing optics

elliptic cryo-lens

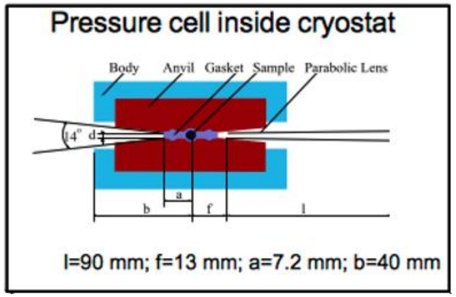


Used Focus – DeFocus Setup at DMC

with optics




Sample $Mg(BD_4)_2$ measured at DMC



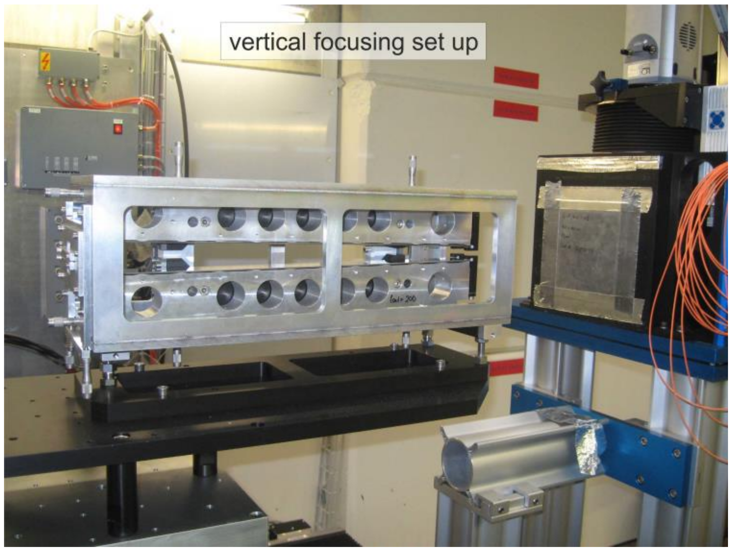

- focusing neutrons inside the pressure cell (vert. opening about 1.3 – 2.1 mm)
- pressure cell 100kbar operated at <5K - 300K
- alignment requirements for the lens holder: 0.1mm vertical; tilting < 0.03deg

Focus / Defocus Setup - s/n gain factor > 3 can be reached

# Focusing Optics – Adaptive Optics

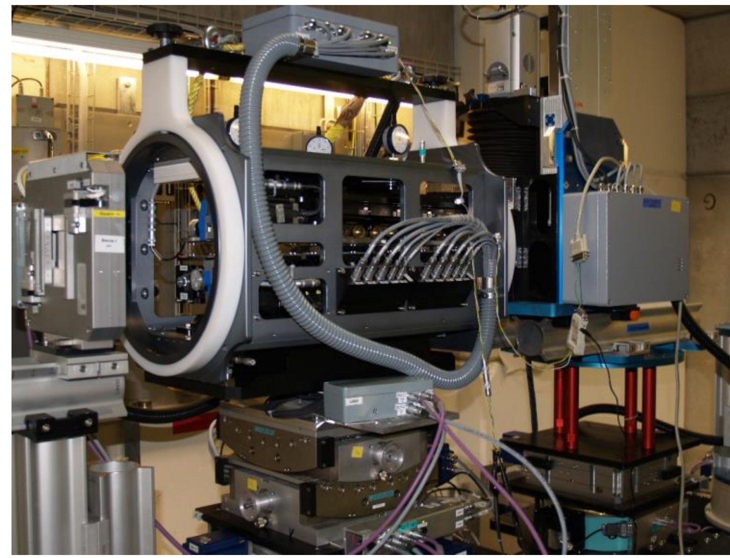
A flexible neutron focusing device for sample sizes about 1 $mm^2$

Quasi- adaptive Optics




Within ***few minutes*** a new lens setup can be arranged (by hand).

Adaptive Optics with 16 different lenses on one device



Within ***few seconds*** a new lens setup can be adjusted (automatically).

Application: DMC, Poldi or FOCUS (Factor 2 in intensity gain can be reached)

Collaboration project with Riken (Masako Yamada talk)

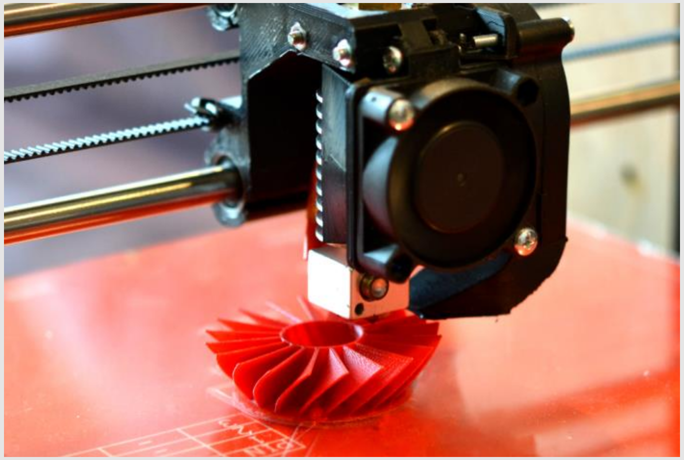
PAUL SCHERRER INSTITUT

# Introduction to 3D printing

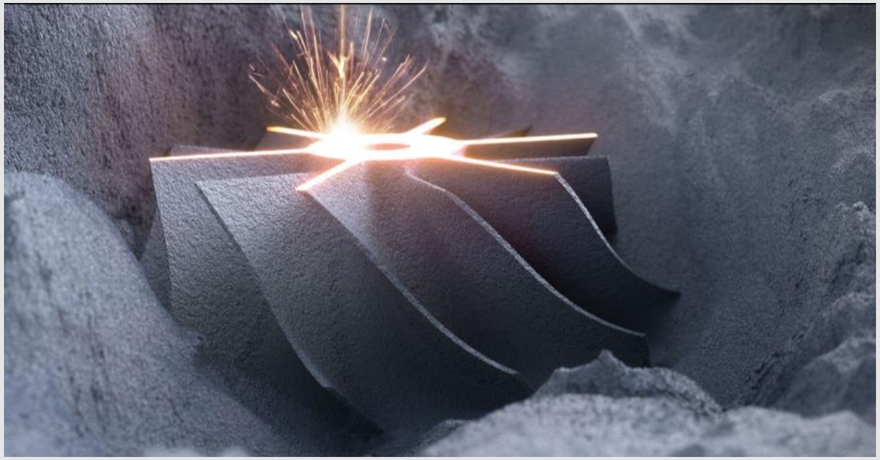

- 3D printing technology has improved a lot in precision, shape and surface quality
- industrial use is more and more established
- many new material composition (filaments) are developed (also borated)
- presently PSI is using borated Aluminium (BORAL) and borated PE (B4C or BN)
  ➡ limitations in machining and availibility / for use in cold sample environment

# 3D printing technology

**plastics**



**metals**



EBM – Electron Beam Melting

FDM – Fused Deposition Modeling

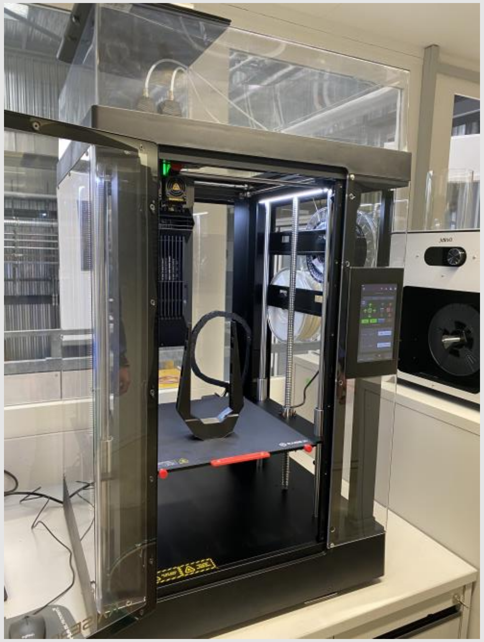
MJP – Multi Jet Modelling

SLS – Selective Laser Sintering

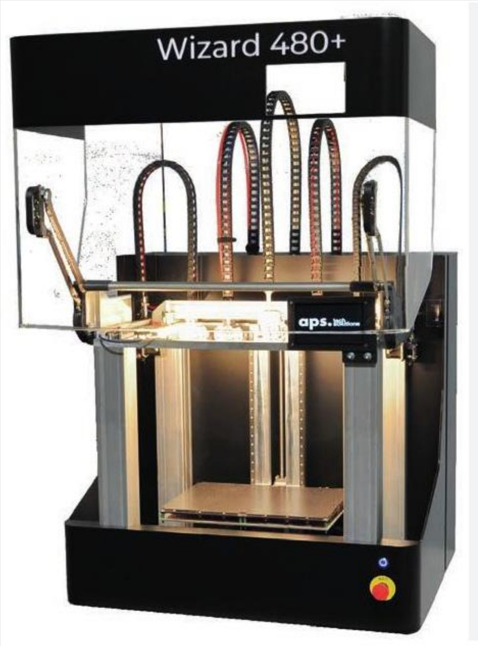
presently we are focused on plastics using FDM printers

# FDM Printers at PSI

- different FDM printers are available at PSI



Precision FDM printer




Expert FDM printer

max. object size: 255 mm x 300 mm x 605 mm
precision: up to 10 µm
2 extruder heads
min. layer height: < 10 µm

max. object size: 400 x 255 x 370 mm
precision: up to 20 µm
4 extruder heads, endless fiber (carbon, copper …)
open source software

# PSI Filament developments

Commercial available B4C filament (AddNorth) based on a nylon/polyamid matrix
(B4C enrichment is 25 wt%)

- complicated printing properties (warping, … ) and not suited for low temperature devices (deformation)

PSI filament production line

Boron-nitrite composition (BN up to 30 wt%)

Boron-carbide compostion (B4C up to 40 wt%)
- with and without **additional carbon fiber**

Gadox compostion (10 wt%)

KEK-PSI collaboration project

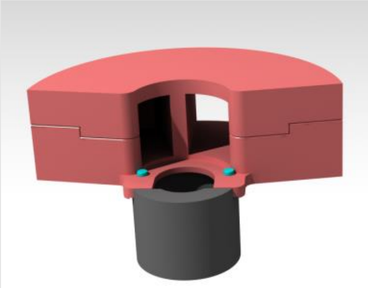
All absorbing materials are placed in a polylactid matrix (special PLA).

Neutron Shielding proberties are identical to BORAL (B4C enrichments of 20 – 35 wt%)

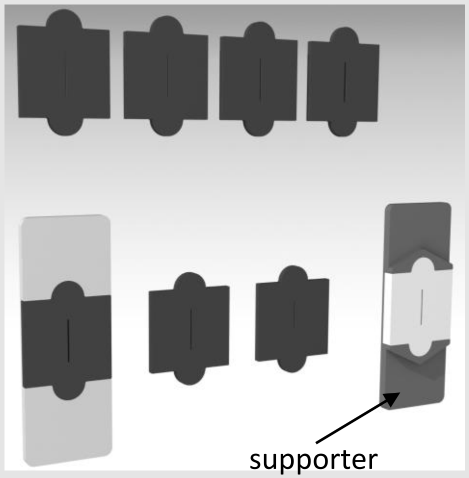
# Applications

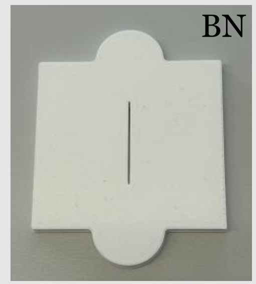
- all kinds of slite/aperture systems (2D and 3D) – can be also used at very low temperatures (< 5 K)
- Linear and radial collimators / double collimators
- Neutron traps
- very thin foils
- Flight tubes
- Chopper discs
- Neutron guide shielding

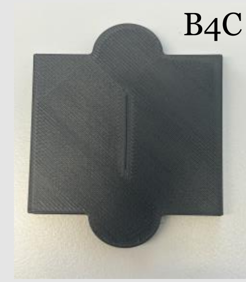

Radial collimator


Neutron trap

# Standard slite/aperture systems

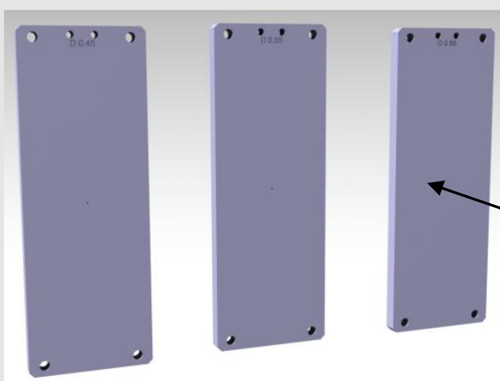


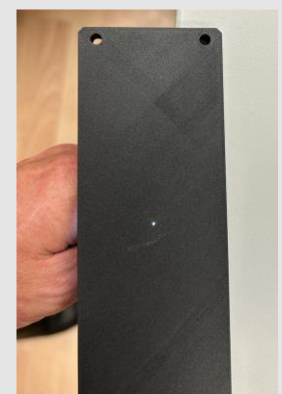




Apertures – opening can be 0.1 mm (slite width)

Slot holder used at any beamline at SINQ



Circular holes printed with a diameter of 0.45 mm

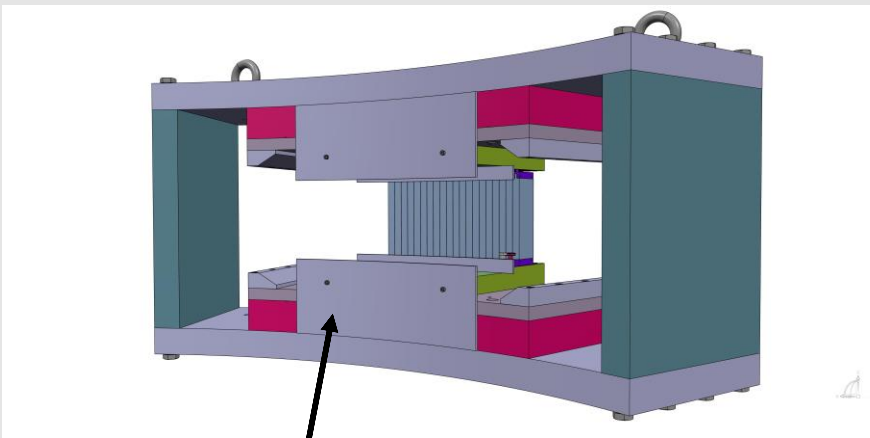


Needs special engineering modelling (how edges are modelled) and calibration/tunning of the printer system

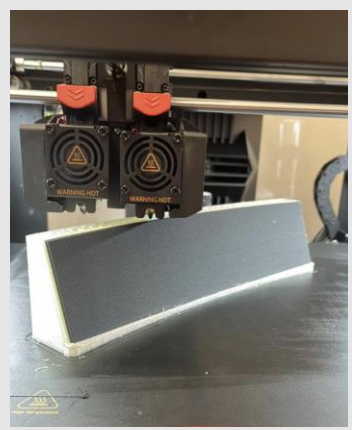
PAUL SCHERRER INSTITUT PSI

# Advanced slite/aperture systems

## Polarisation Analyser for MAGiC at ESS



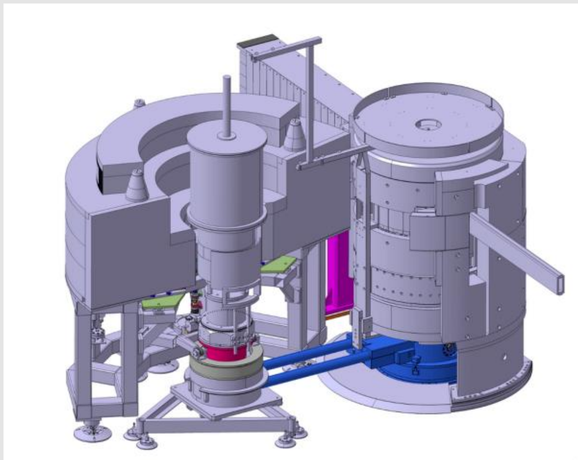
3D printed aperture plates with a curvature of 50 cm , thickness 3 mm, heigth 12 cm, with slot holes , B4C Filament



Printing Technology:

- Aperture plate was fully integrated into a water-soluble support material
- without support material it would tip over

# 3D aperture system for a pressure cell experiment at DMC



Cold powder diffratometer DMC at SINQ

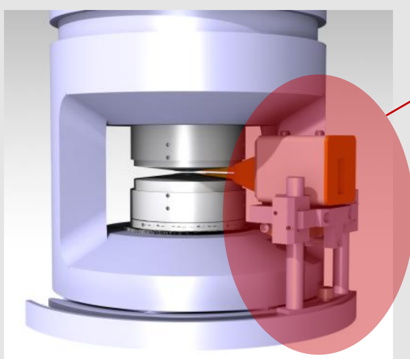
Sample size is very small (about 10 mm$^2$)

⬇

Low signal-to-noise is many times a problem

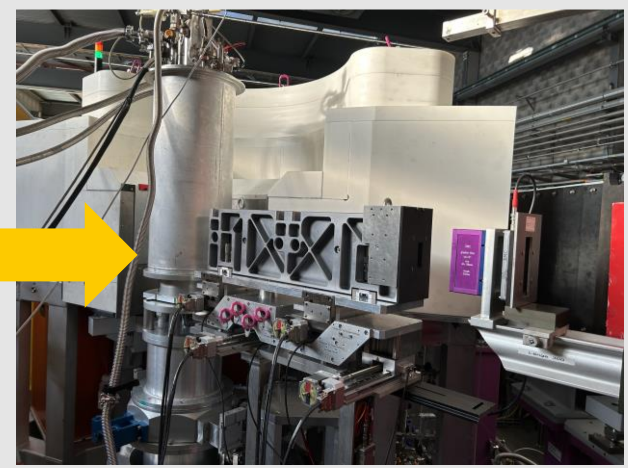
Pressure cell is positioned inside a cryostate

Up to 100 kbar



3D printed aperture system

Paris-Edinburgh pressure cell

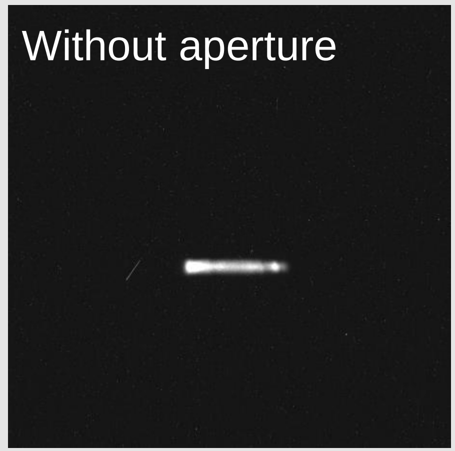


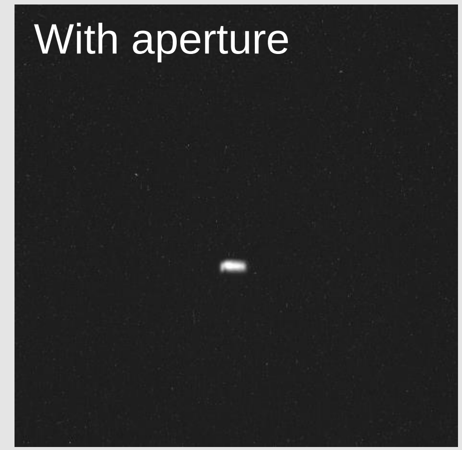
Previous experiments were done with a slit outside of the PE-cryo system.

PAUL SCHERRER INSTITUT PSI

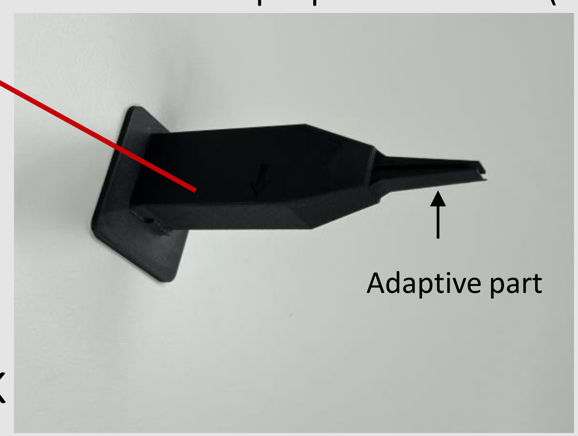
# Pressure Cell Experiment at DMC with ballistic aperture with adaptive nozzle

Direct beam was reduced by factor 40 (CCD camera measurement)



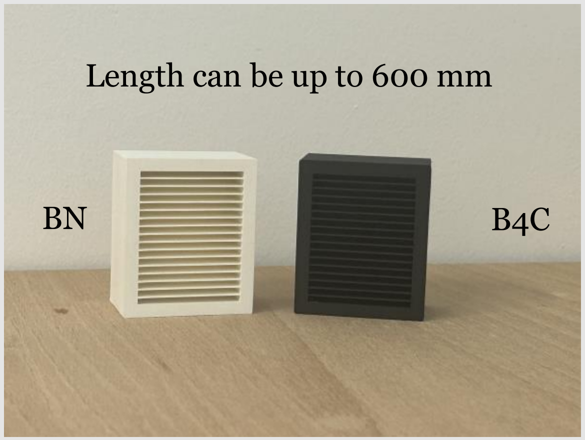

Beamsize at sample position: 2 mm (H) x 5 mm (W)




Results shown by Masako Yamada

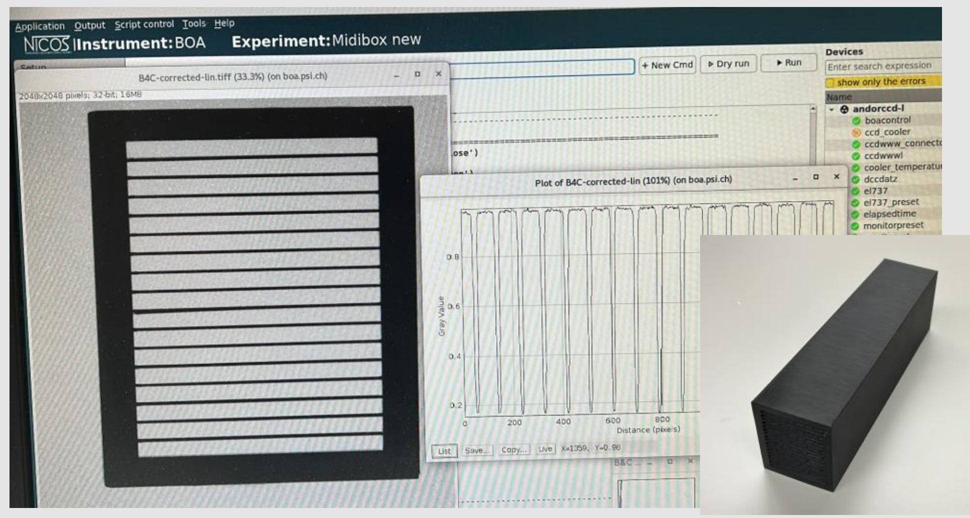
System was cooled down to 3-5 K

# Linear and double collimators




Linear collimators with 0.4 mm wall thickness

40 minutes collimators (length 205 mm, cross section 50 mm x 40 mm) are made and tested at the BOA beamline at SINQ



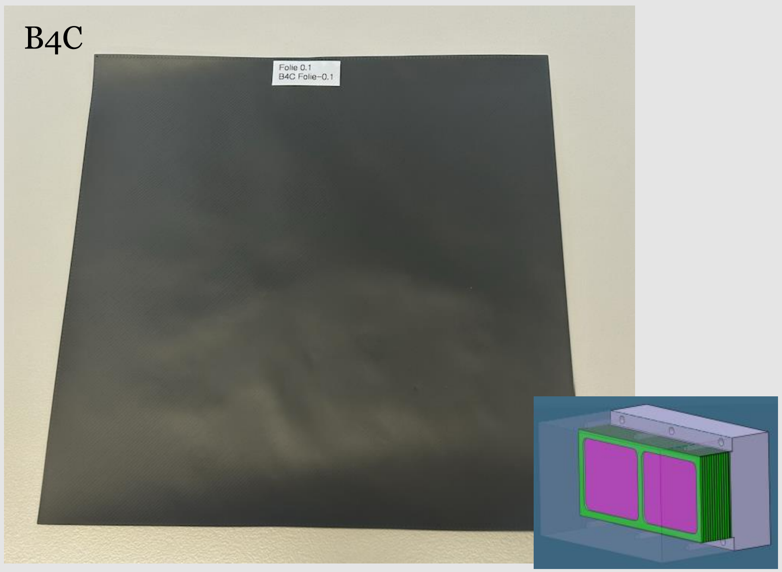

Neutron image of the B4C linaer collimator (BOA beamline)


Double collimator – channel size 3 mm x 3 mm

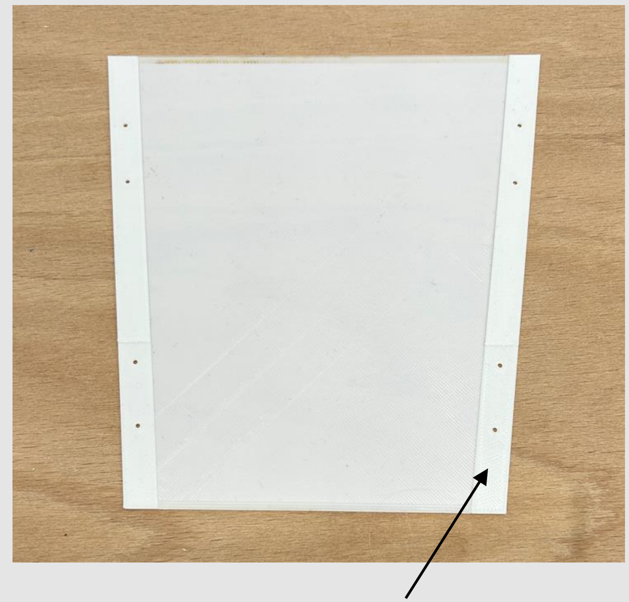
- wall thickness is related to the nozzle size (minimum wall thickness of 0.25 mm was realized)

# Foil developments (1)

- wall thickness is limited to 0.25 mm if printing of the full object will be done in one step
- can be used inside reflecting optics or collimator assemblies




Thin foils – thickness 100 µm (size 200 mm x 200 mm)



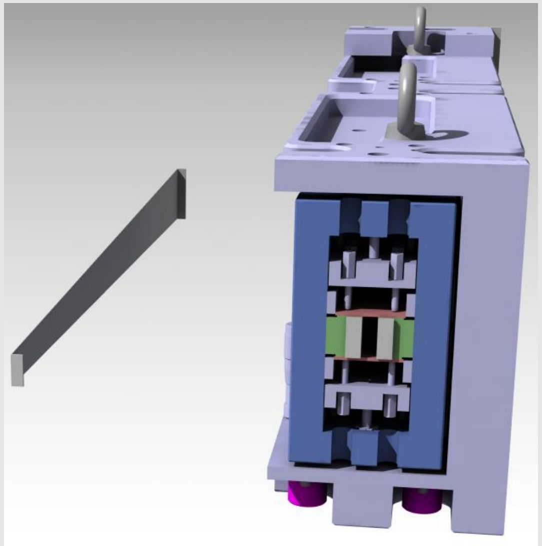
Stable clamping frame

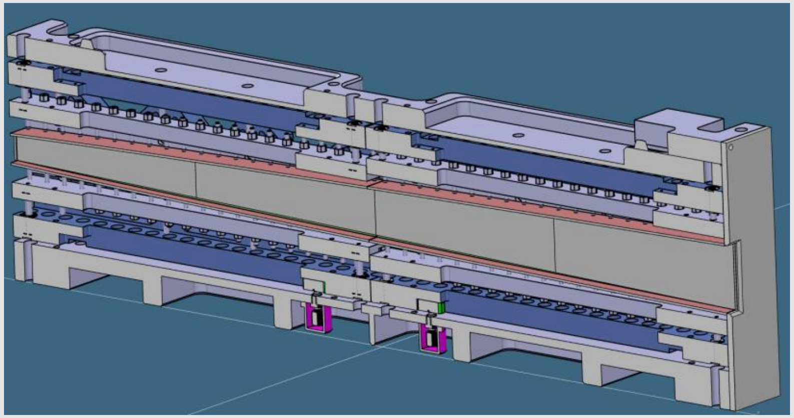
- foils are very robust – can be easily stretched
- in addition foils can be printed in a stable clamping frame (no waves afterwards)
- negative effect: the neutron absorption goes down with thin walls -> Gd filament as alternative (10-20 times better in absorption)

# Special Foils for Optics

Double focusing reflecting optics was built for DMC

Depending from the experiment only vertical focusing is requested





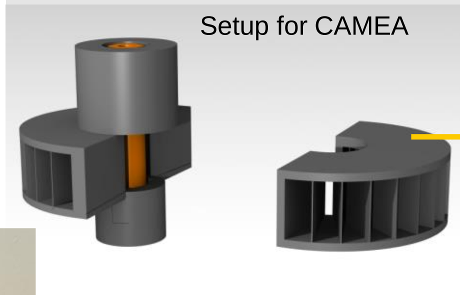
Foil is mounted inside of the optics


The foil is 800 mm long and 0.3 mm thick. The DMC Experiment has shown that the horizontal focusing can be masked completely.

PAUL SCHERRER INSTITUT

# Pilot experiment with a 3D printed collimator system on CAMEA at SINQ

Use of a clamp pressure cell – up to 17 kbar

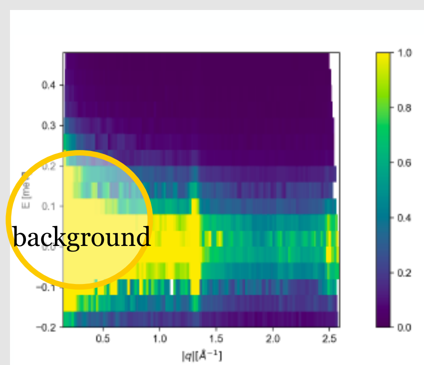



Design of the collimator system

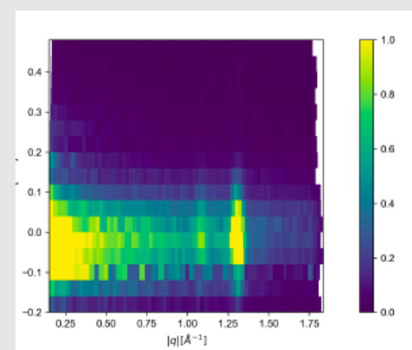
Printed collimator system including holder and get loss channel (neutron trap)

Used at 10 and 150 K

Radial collimator plus the a dedicated shielding was developed and printed.


**Without** collimator system



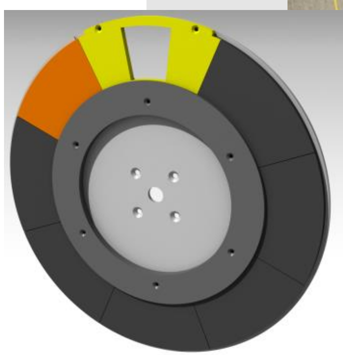

**With** collimator system

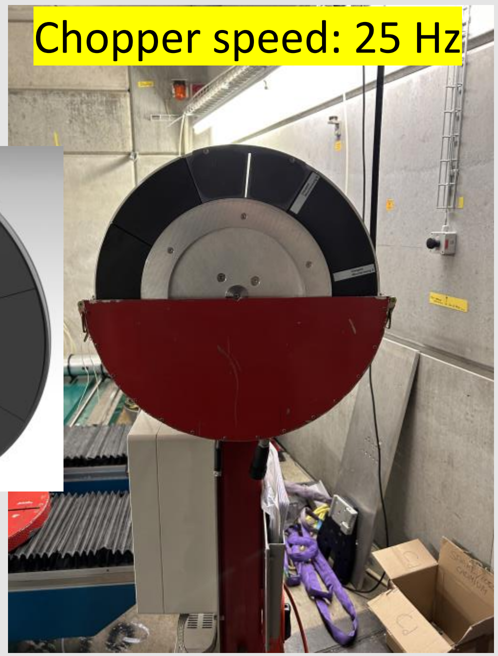
Strong background reduction (up to factor 4-5)

# Chopper disc for NEUTRA (Imaging Beamline)

Absorping part was made out of 7 segments (outer disc diameter is about 55 cm)

Chopper speed: 25 Hz





Mobile chopper system at SINQ with 3D printed absorption plate (9 mm B4C filament)

Neutron imaging measurements

B4C plastic is very homogenous

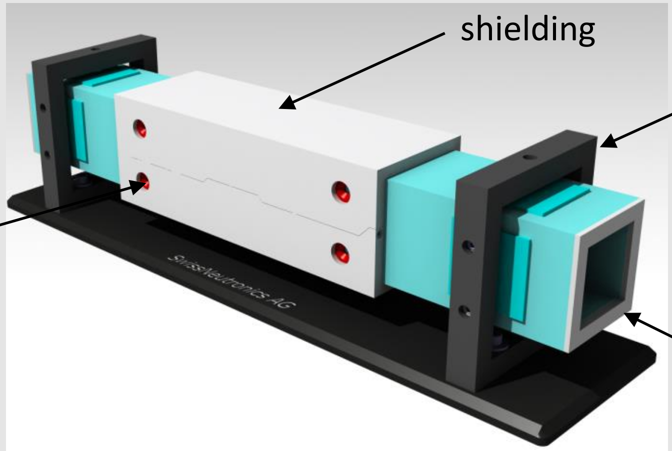
Disc transmission was measured with epithermal neutrons at NEUTRA

**User Case: TOF imaging with epithermal neutrons at Neutra.**

In this case the hydrogen content in the filament is useful (neutron moderation)

# Neutron Guide Shielding

Collaboration project with SwissNeutronics

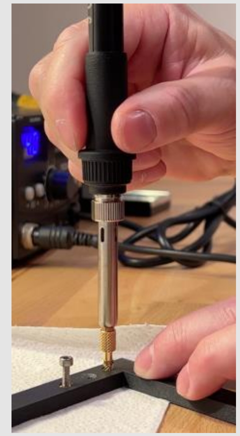



SNAG guide model with 3d printed shielding components (BN or B4C material can be used)

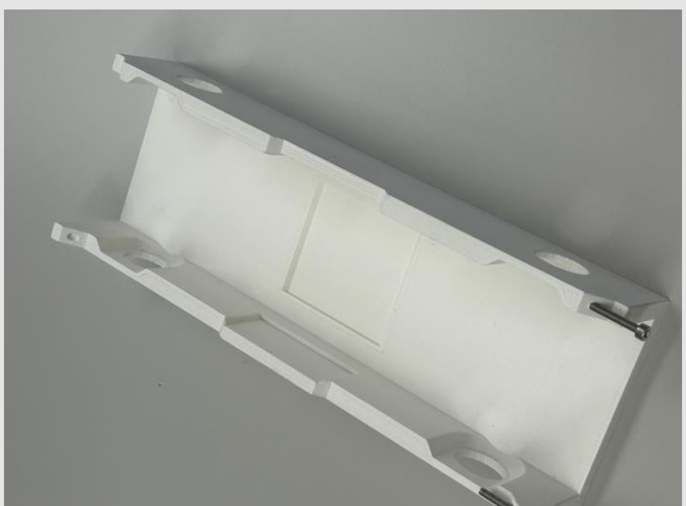
- thermal/epithermal/fast neutrons are leaking out of the guide system and can produce neutronic background and strong gamma radiation

- guide geometries can be complex and also the guide holder frames (made out of aluminium) are producing gammas with an energy of 1.8 MeV which have to be shielded

# Neutron Guide Shielding



Screw threads can be built (melt) in within few seconds



Fiducials and outer glass plates can be easily integrated

Shielding pieces can be screwed (simple assembling)

Shielding walls can be have different fill grades (20 to 100%)

PAUL SCHERRER INSTITUT PSI

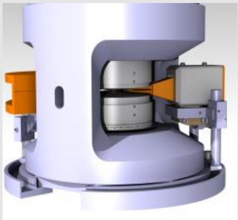
# Summary

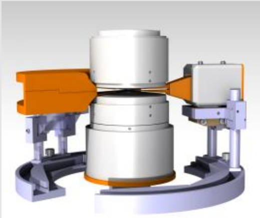
High precision 3D printing is possible

Engineering has to be adapted to 3D printing requirements

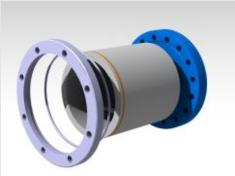
Simple systems can be realized in short time (few hours)

Dedicated devices (collimators, apertures) for sample environment can be realized





Flight tubes are under development



Filament development is essential to improve wall properties (e.g. B-10 or Li-6 filaments)

# Swiss Spallation Neutron Source SINQ


**Thank you for your attention.**