FRM II
Forschungs-Neutronenquelle
Heinz Maier-Leibnitz

MLZ
Heinz Maier-Leibnitz Zentrum

ANTARES
NEUTRON IMAGING

… and other neutron imaging facilities

Michael Schulz

MLZ is a cooperation between:

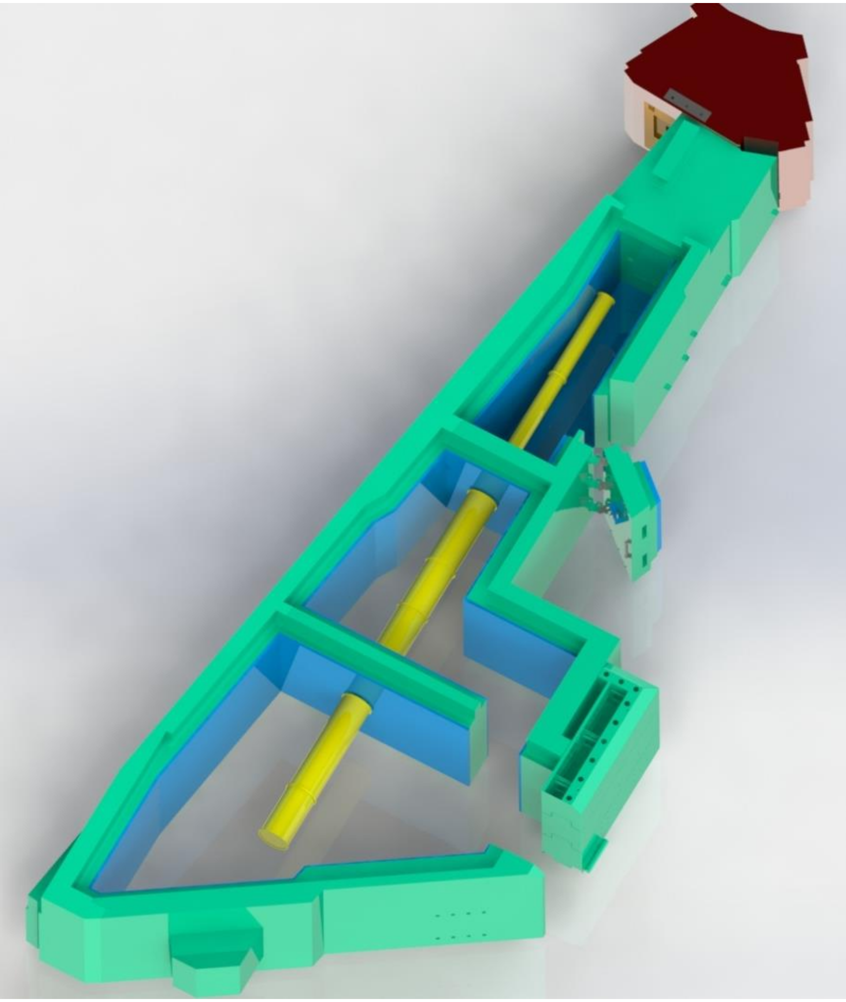
JÜLICH FORSCHUNGSZENTRUM

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

TUM
Technische Universität München

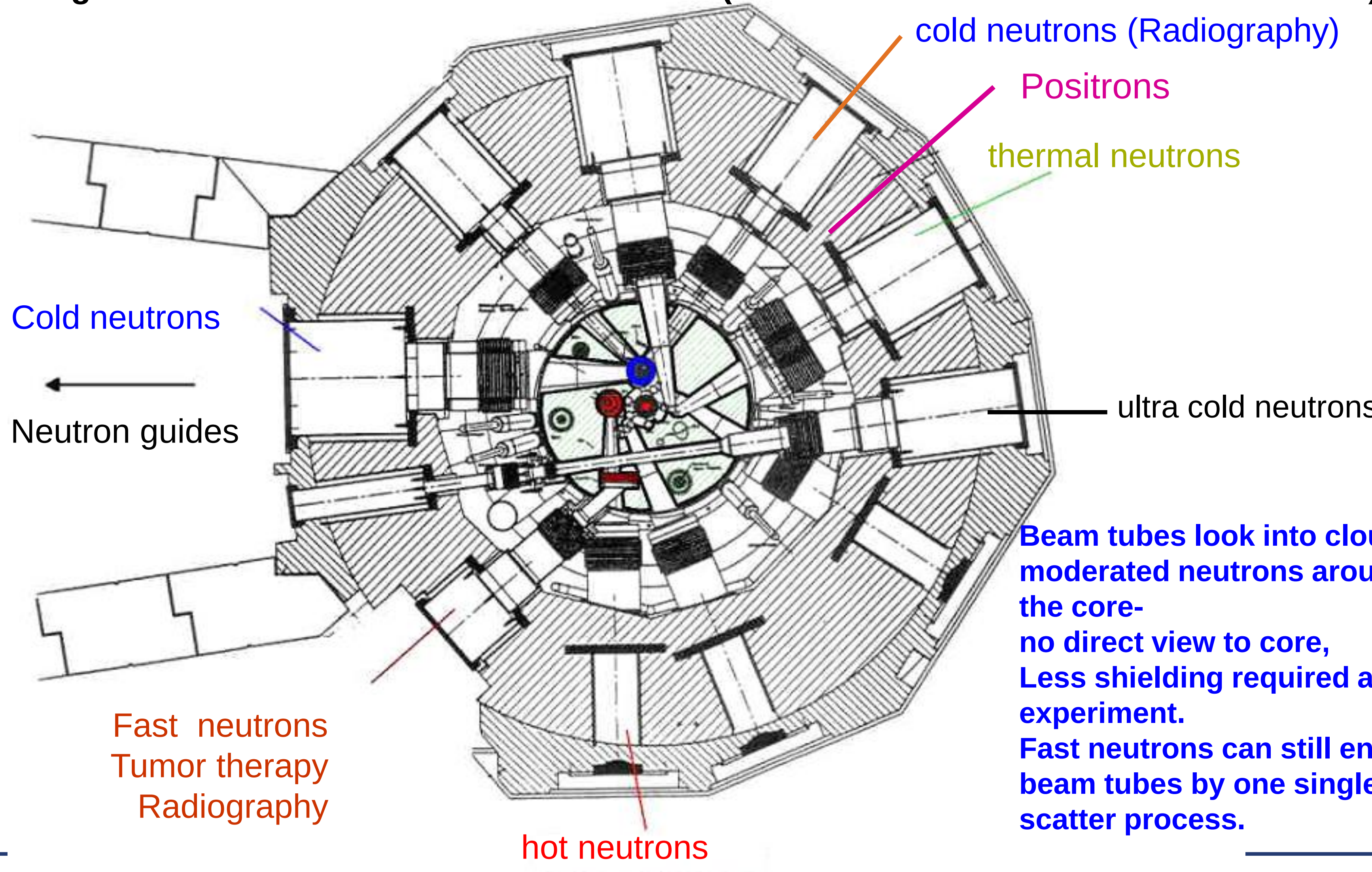
Outline

- Neutron production & interaction
- ANTARES: neutron imaging at a reactor
  - Beam line overview
  - Basic components
  - Advanced setups
- ODIN: neutron imaging
  at a spallation source



Modern reactor design:

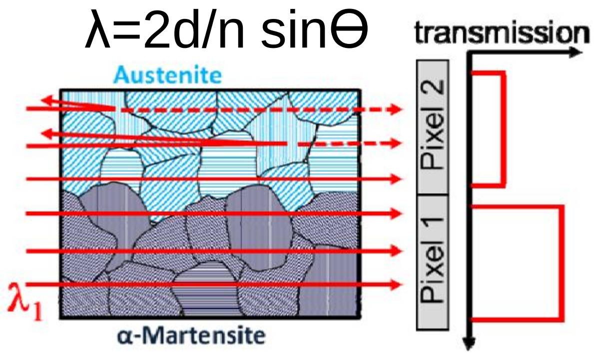
Tangential beam tubes at the FRM II reactor (First introduced 1967 at the ILL Reactor)

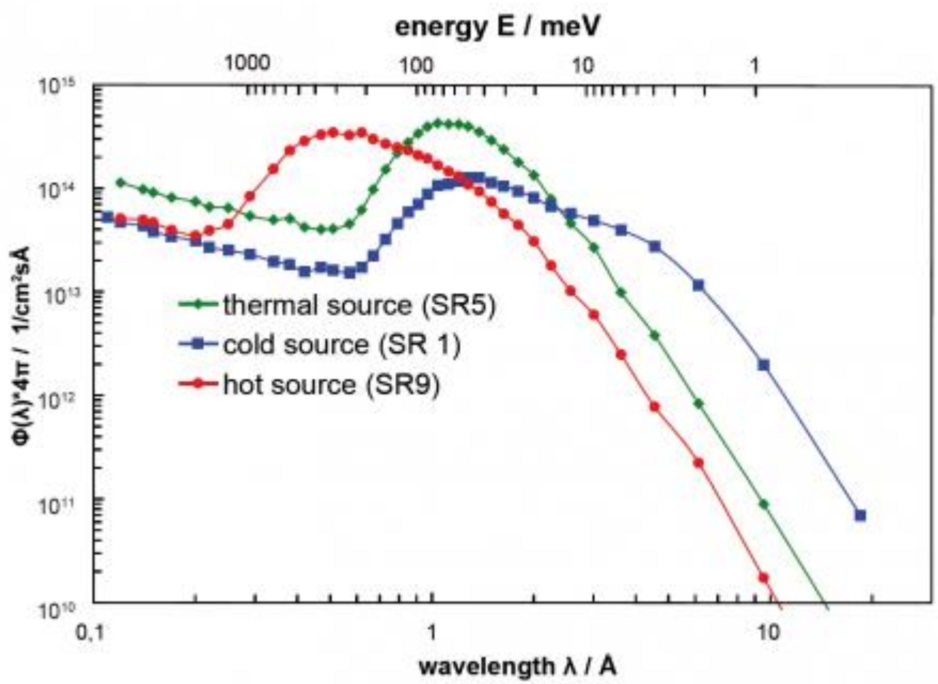


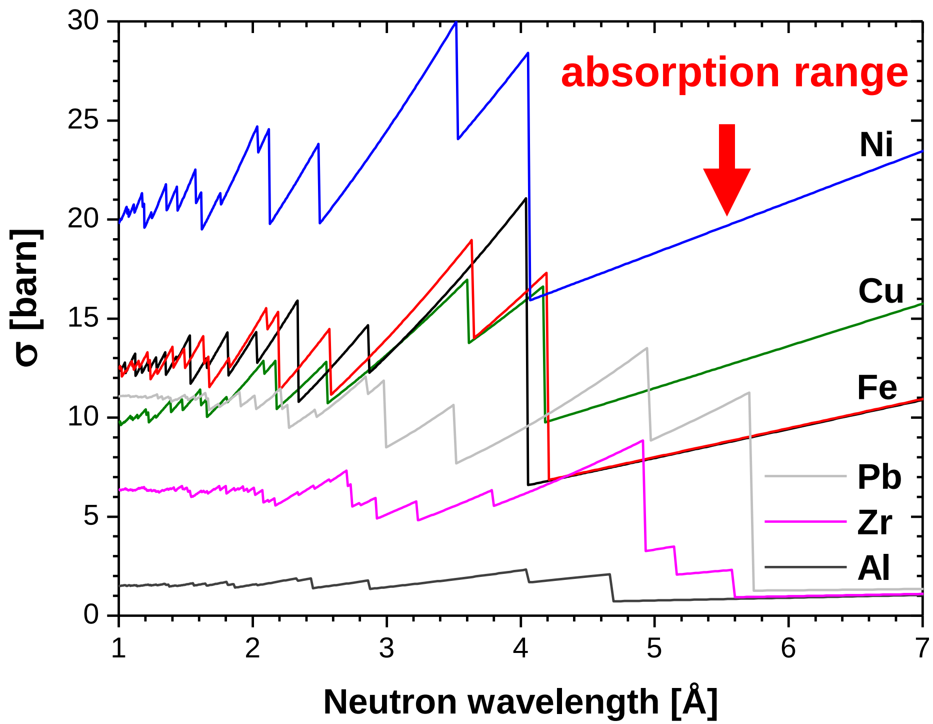
Beam tubes look into cloud of moderated neutrons around the core-
no direct view to core,
Less shielding required at experiment.
Fast neutrons can still enter beam tubes by one single scatter process.

Neutron spectrum

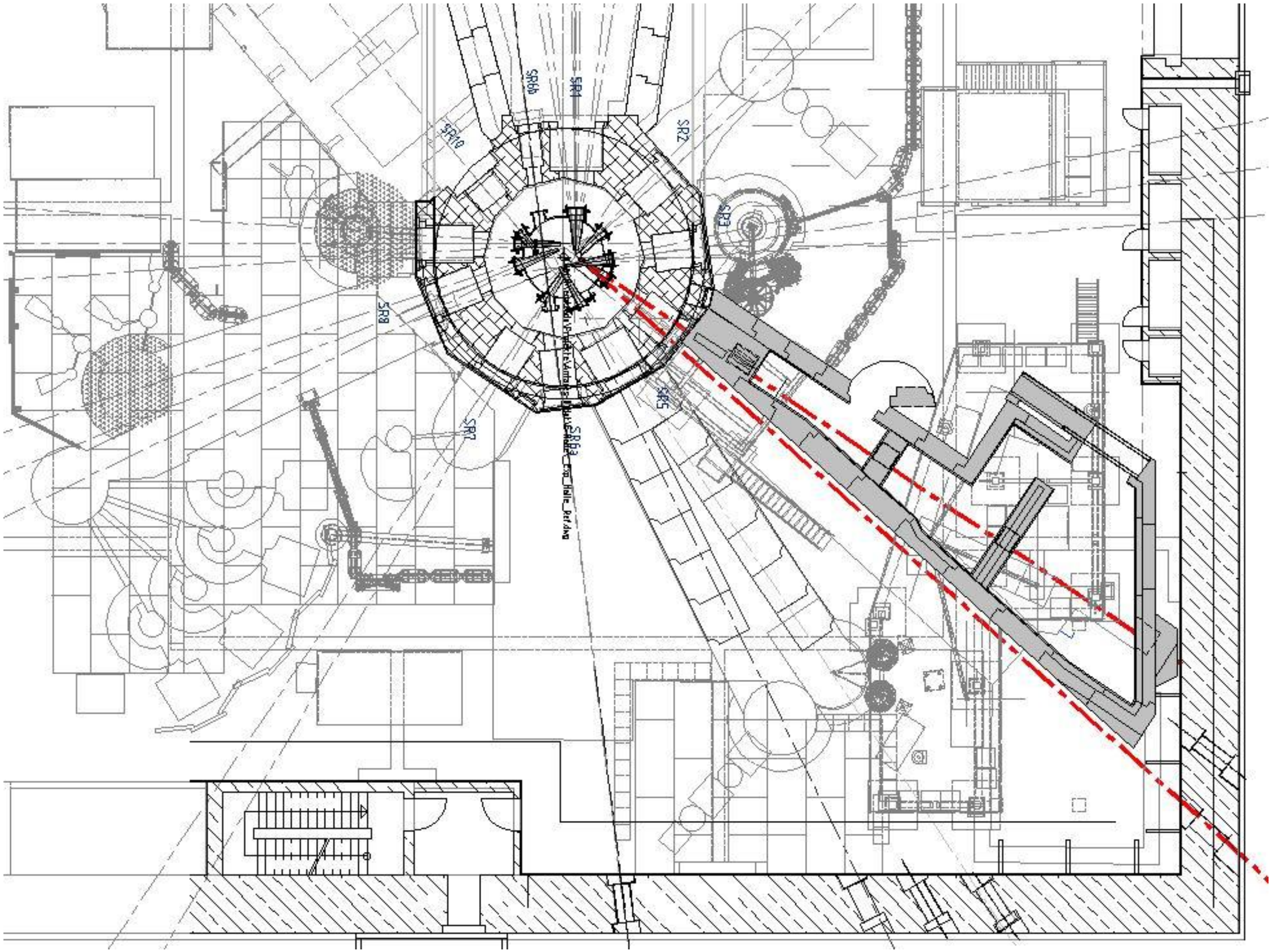
- Cold, thermal, hot, (fission) sources
- General 1/v law
- Plus Bragg edges
- Beam Hardening effects







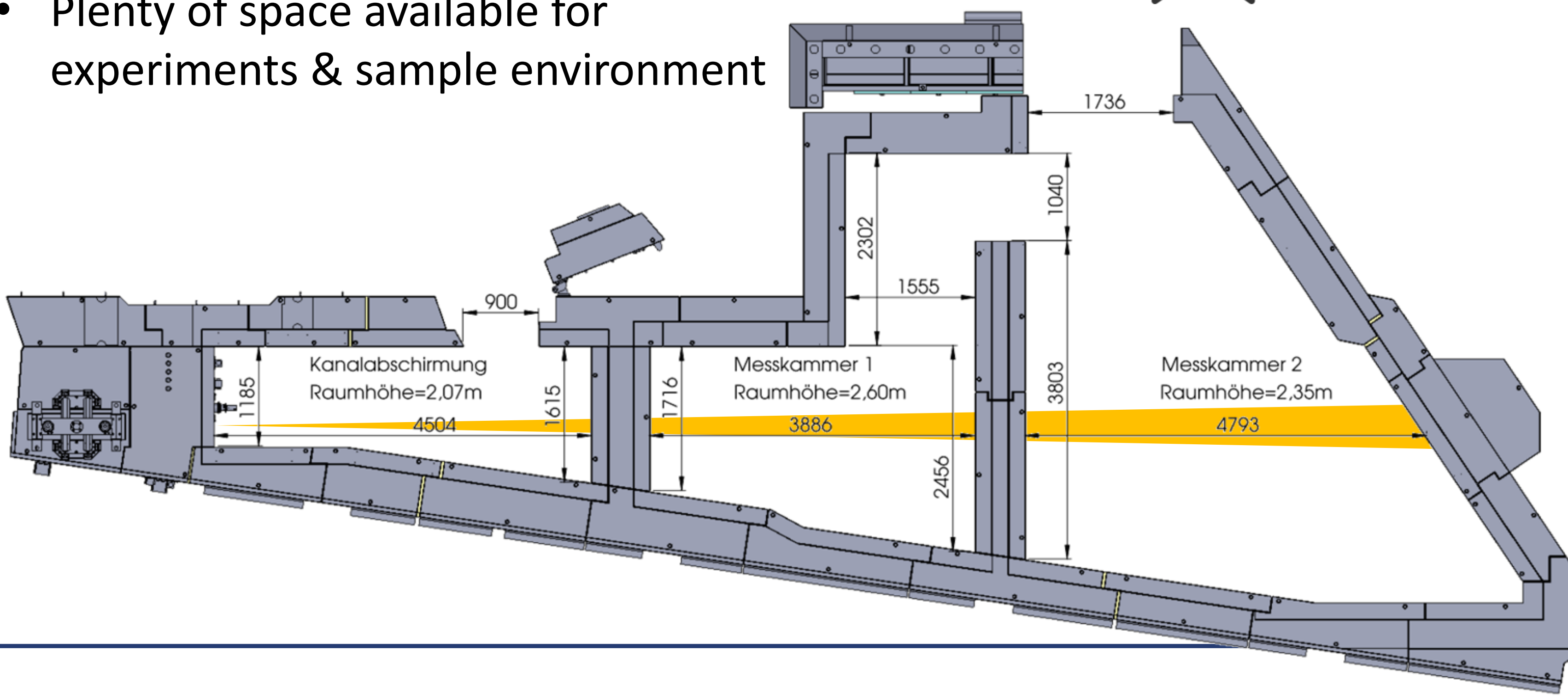
ANTARES beamline



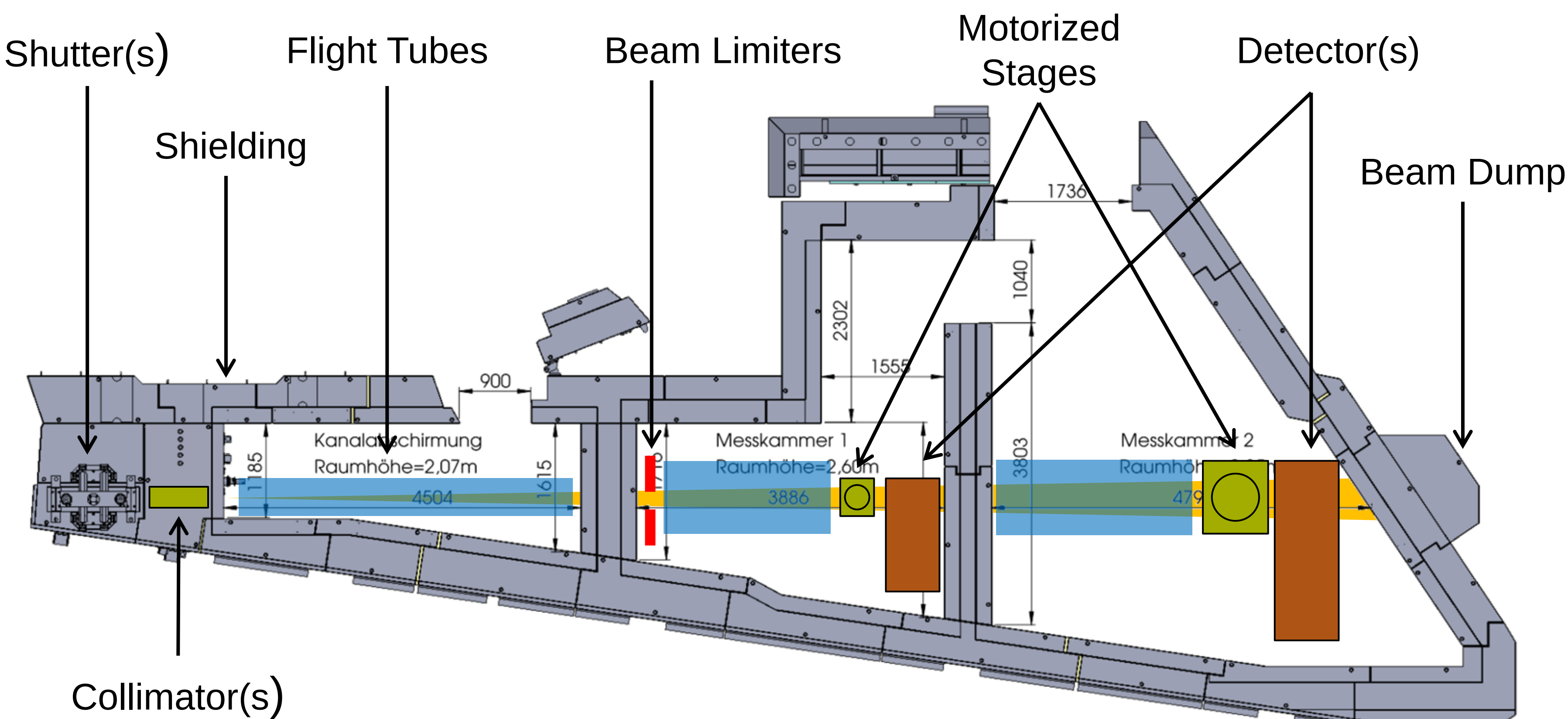
ANTARES Beam Line Concept

- 3 chambers
- Beam fully accessible along flight path
- High flexibility
- New & light shielding material (only 500t)
- Plenty of space available for experiments & sample environment

ANTARES
NEUTRON IMAGING

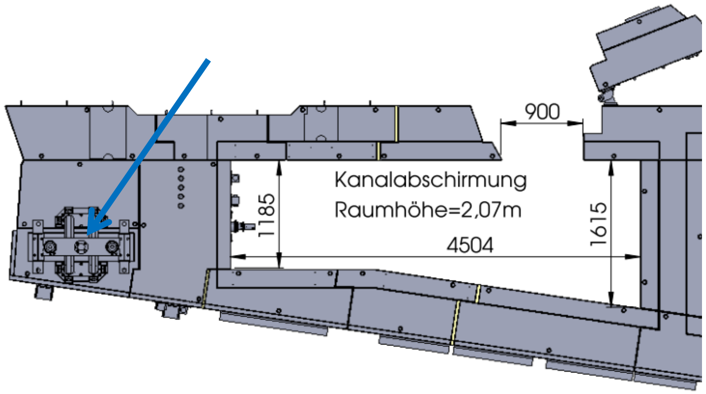


Main Components of ANTARES



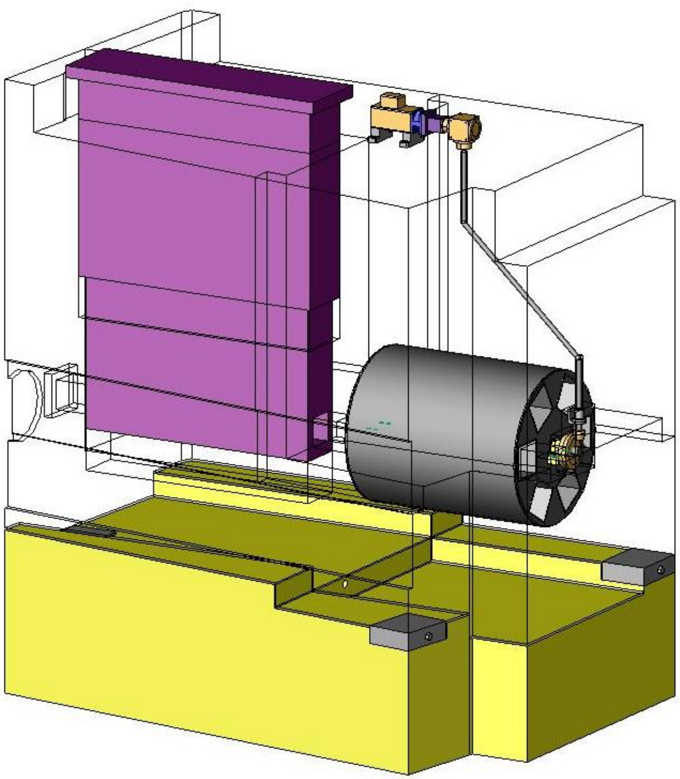
optional:
- Beam Filters
- Monochromator / Selector

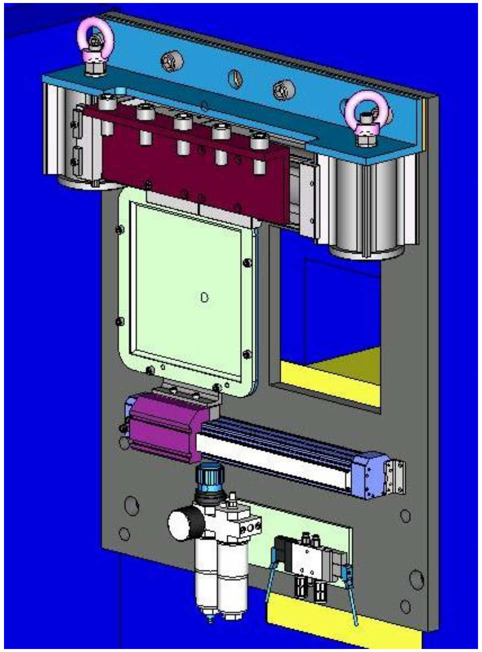
plus:
- Access Control
- Media Supply (electricity, gas, water, …)
- IT (network, storage, servers, software, …)



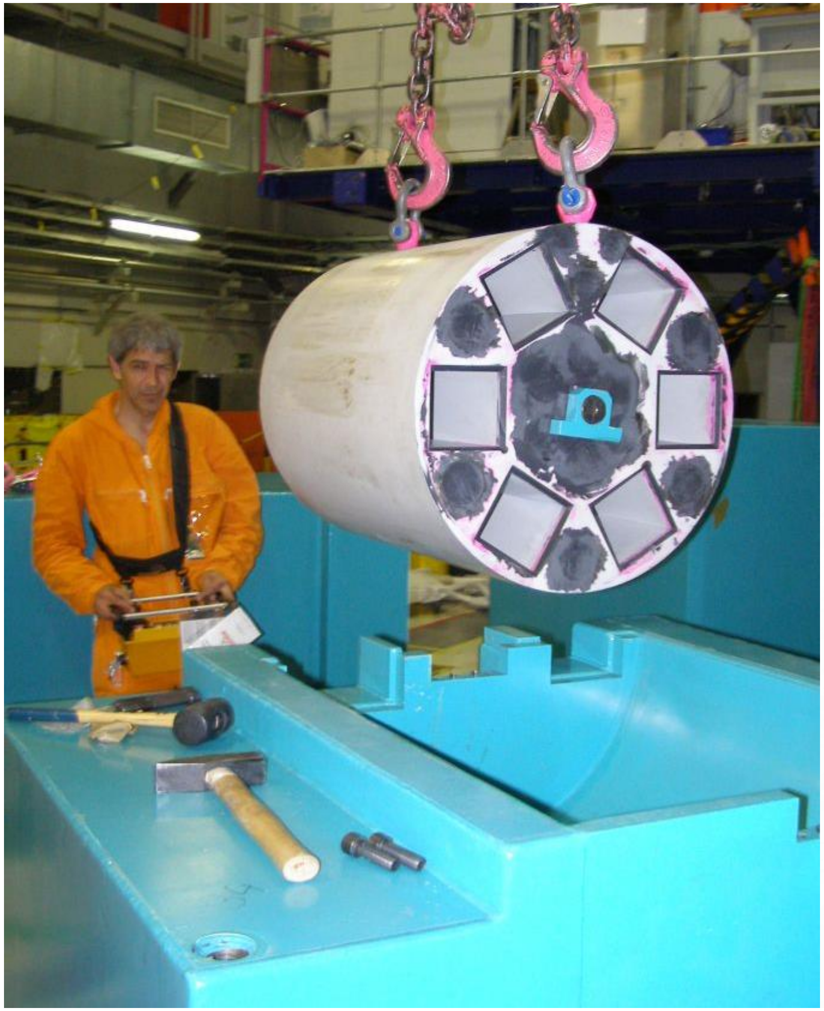
Shutters

- Stop full beam for access of cave
- One shutter must be fail-safe!
- Additional fast shutter (B_4C) to reduce sample activation (closed after each image)

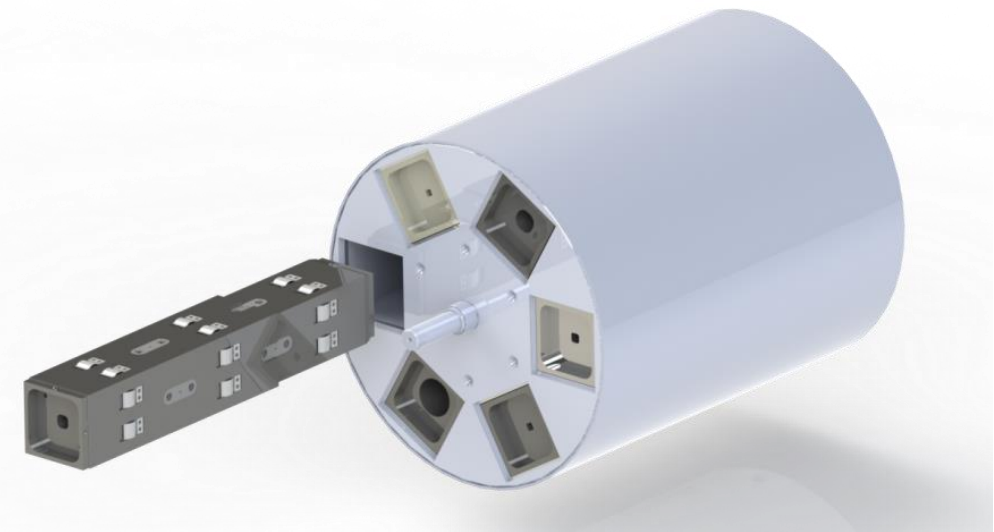




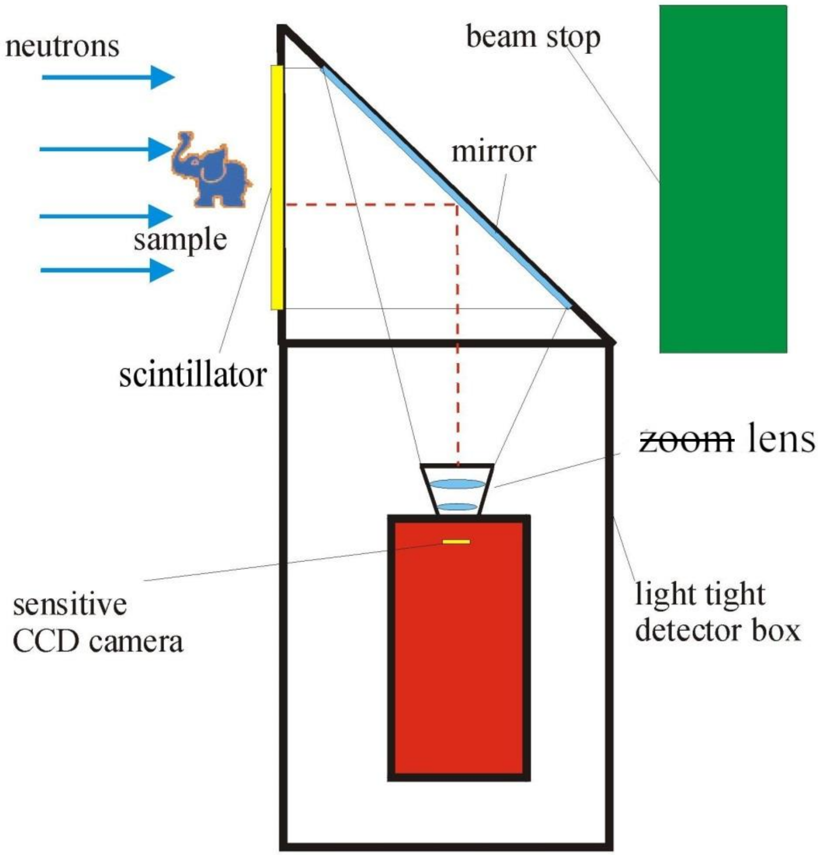
Collimators



- Massive for beam tube instruments to stop background
- Material with low activation (i.e. borated steel)
- Machined by spark erosion
- Pinhole sizes: 2, 4.5, 9, 18, 36, 71mm

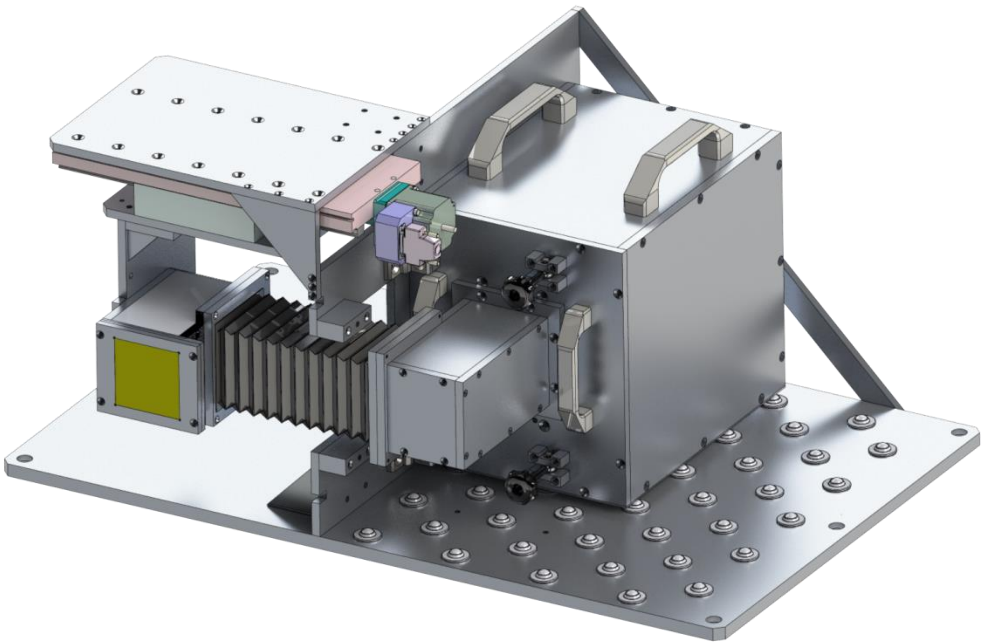


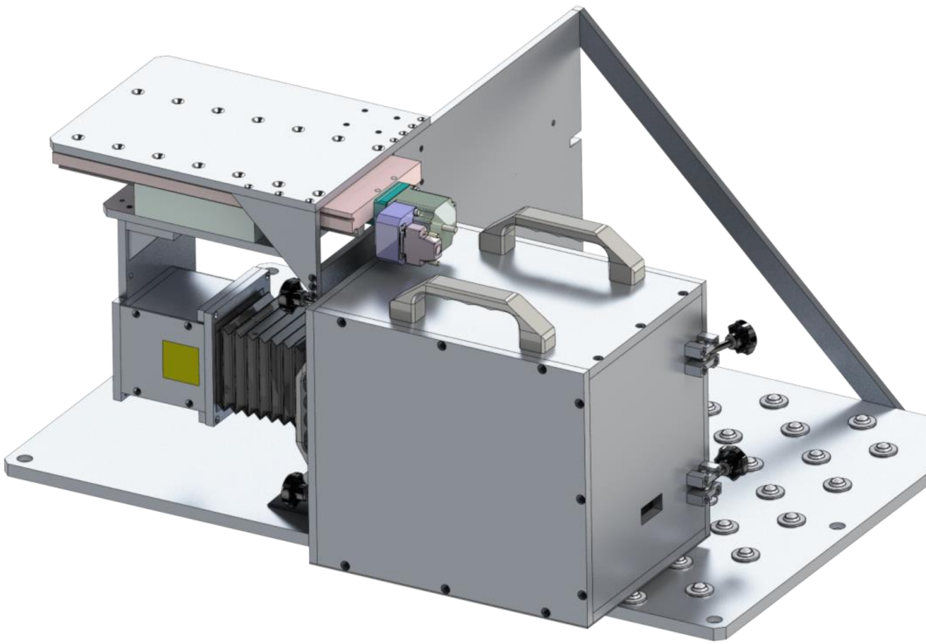
Detectors – Camera Based Systems



- General principle: scintillator – camera – mirror
- Cooled scientific CCD / CMOS for reduced / negligible dark current
- Surface mirror with > 99% reflectivity
- High end optics: SLR or custom made

High resolution detector

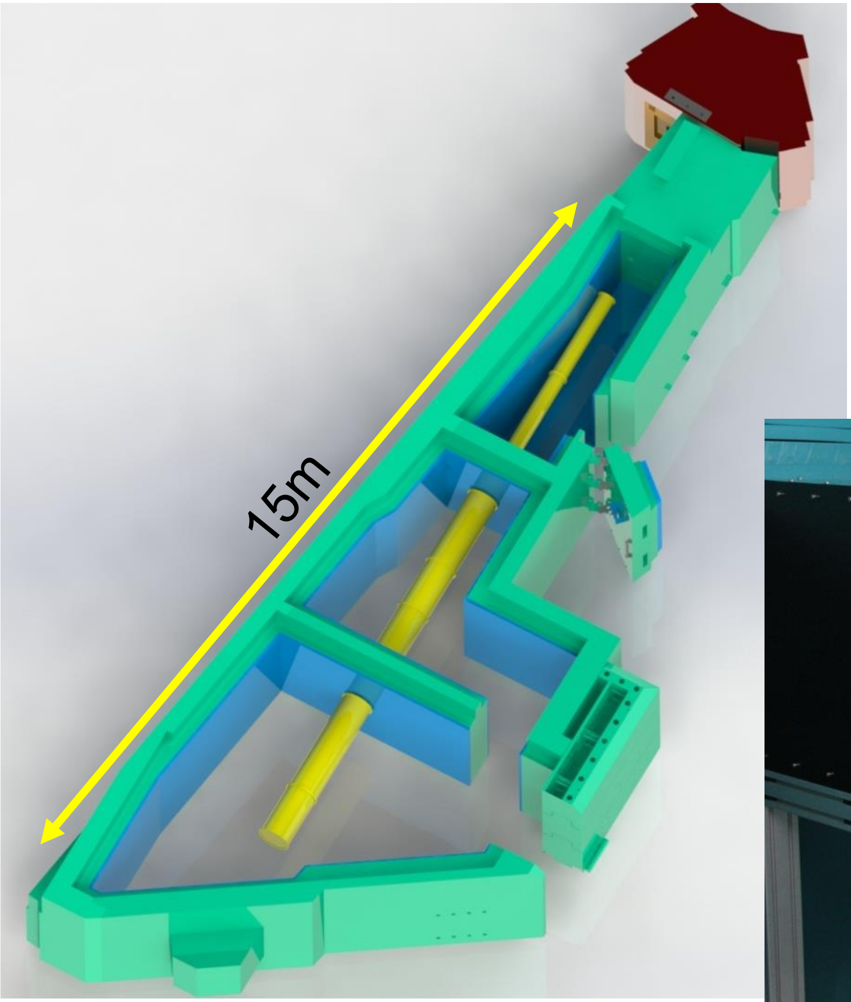


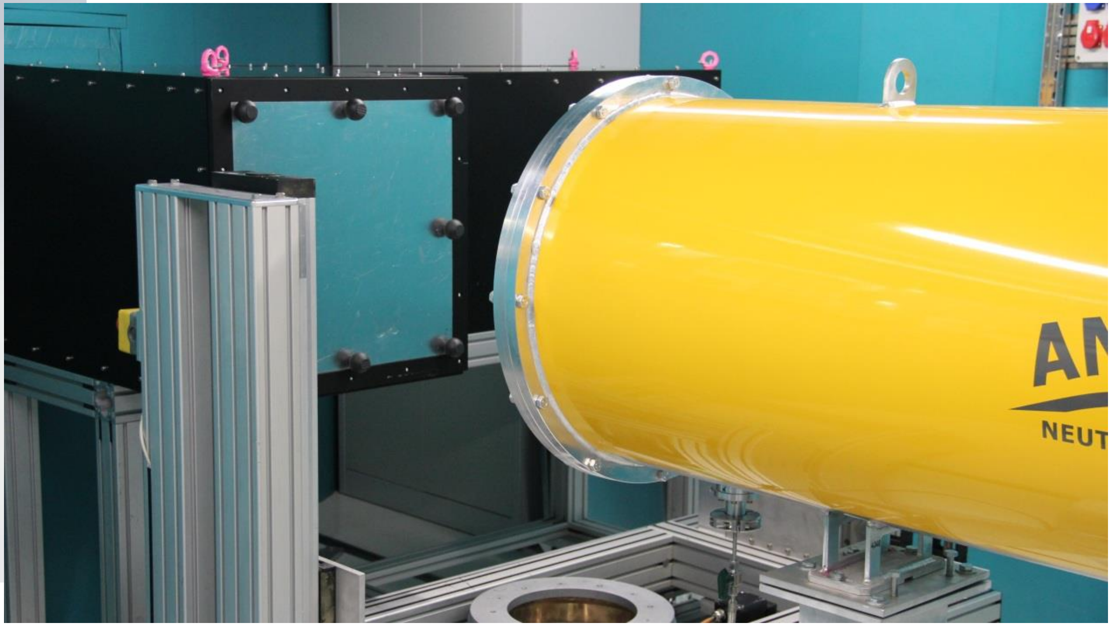


- Adjustable FOV (14mm ... 60mm)
- Smallest pixel size 6.5µm
- One or two mirror configuration
- 10/20µm Gd_2O_2S scintillator
- Camera shieled with 5cm Pb
- Autofocus

Flight Tubes

- Intensity loss in air ~8% per m (depens on moisture)
- Flight Tubes with thin Al windows
- Penumbra must not touch the tubes
- He filled or evacuated (danger!)
- Flexible arrangement desired



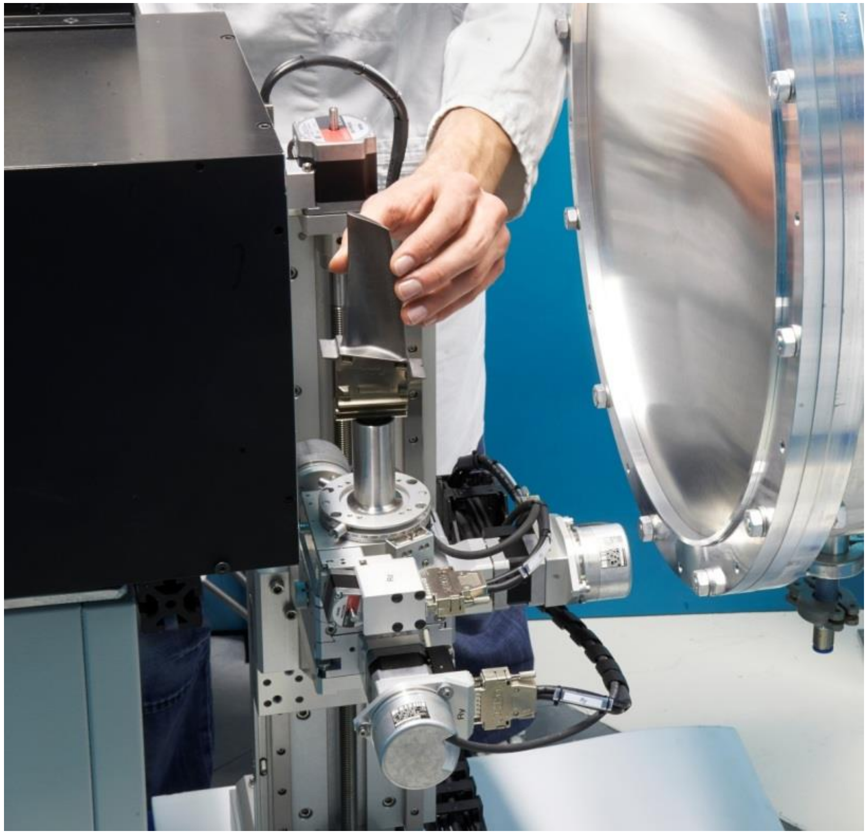


Beam Limiters

- Absorb most of the unused beam area before the sample position
- Reduced background at sample position
- Neutron absorber: BorAl, BN or B_4C (B: low gamma energy ~500keV)

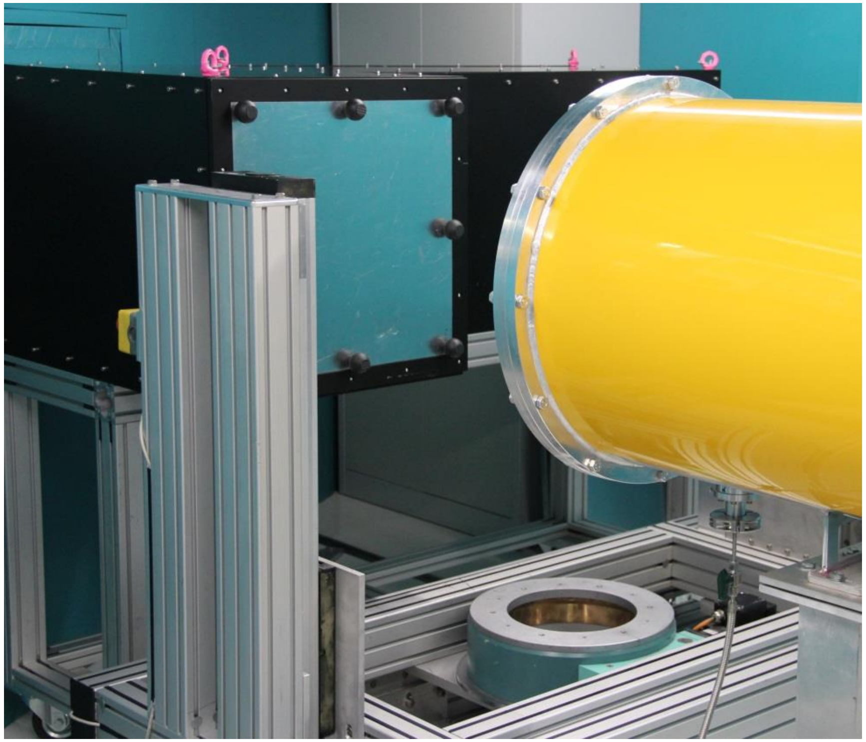
Motorized Stages

- High precision / high load capacity
- X,y,phi, (+ optional goniometers)



10kg

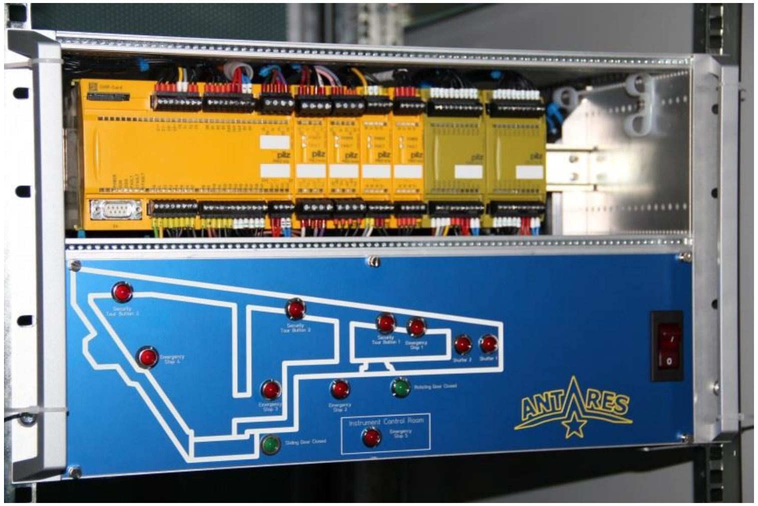
500kg

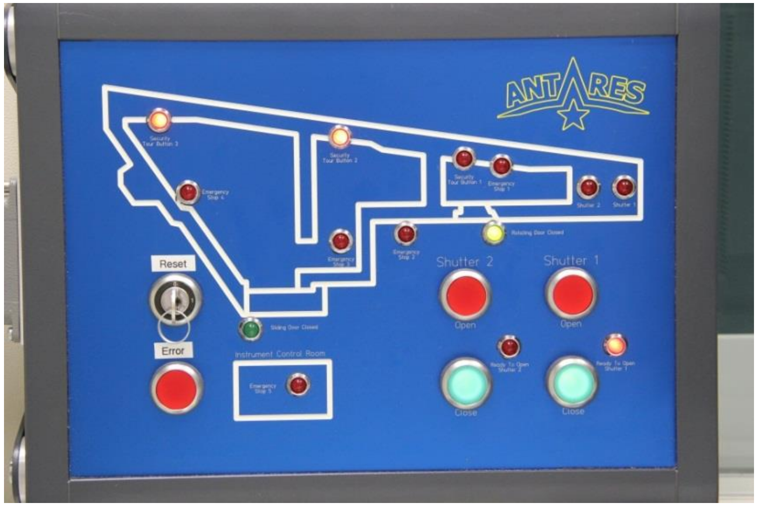


Additional things…

- A place to work

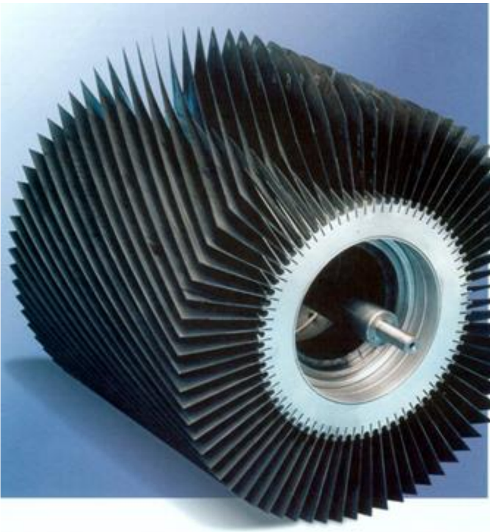
Additional things…

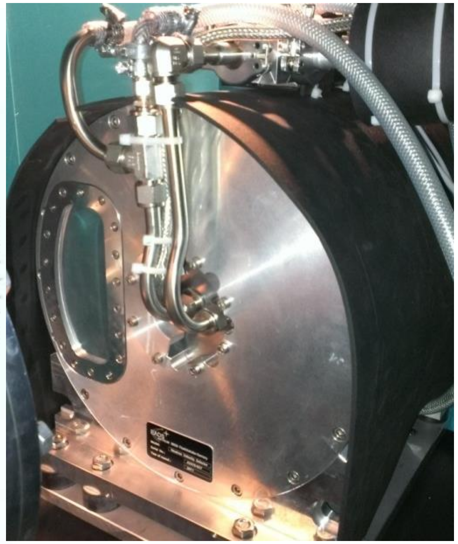




- Racks for electronics
- Safety access control
- IT: (File server, Computers for reconstruction / visualization / Instrument control)

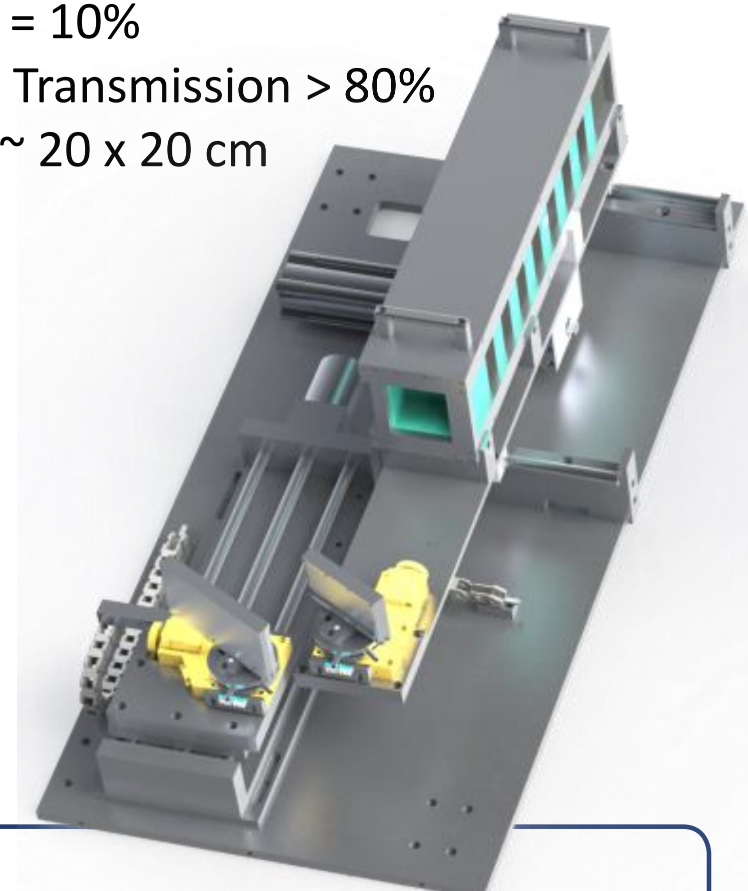
Monochromatization





Astrium Neutron Velocity Selector

- 144 lamellae
- λ_{min} = 2.95Å
- $\Delta\lambda/\lambda$ = 10%
- Peak Transmission > 80%
- FOV ~ 20 x 20 cm



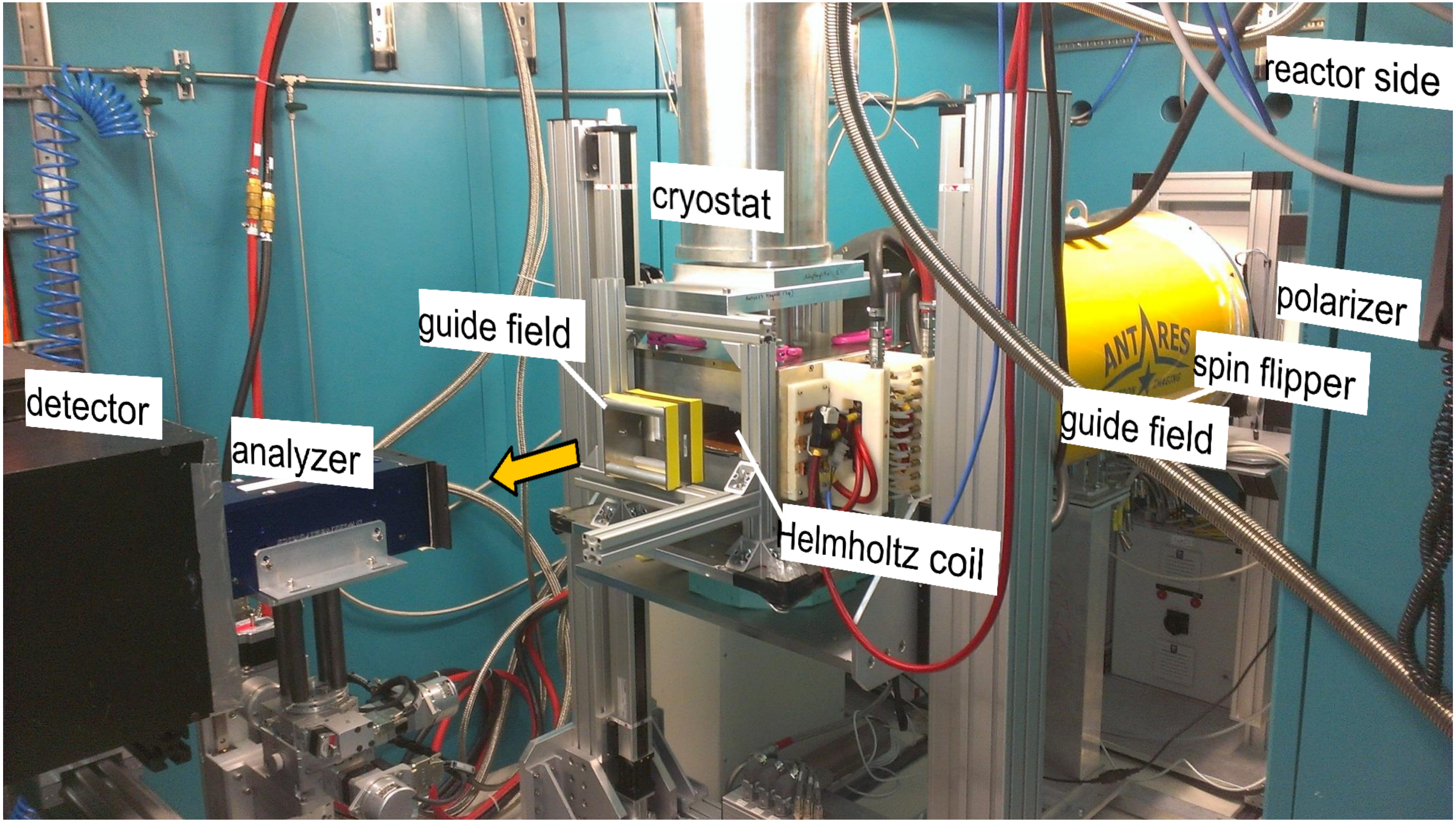
Double Crystal Monochromator

- Pyrolytic graphite (002) crystals
- Mosaicity 0.7°
- $\Delta\lambda/\lambda$ = 1% .. 3%
- Wavelength band: 1.4 … 6.0Å

Applications:

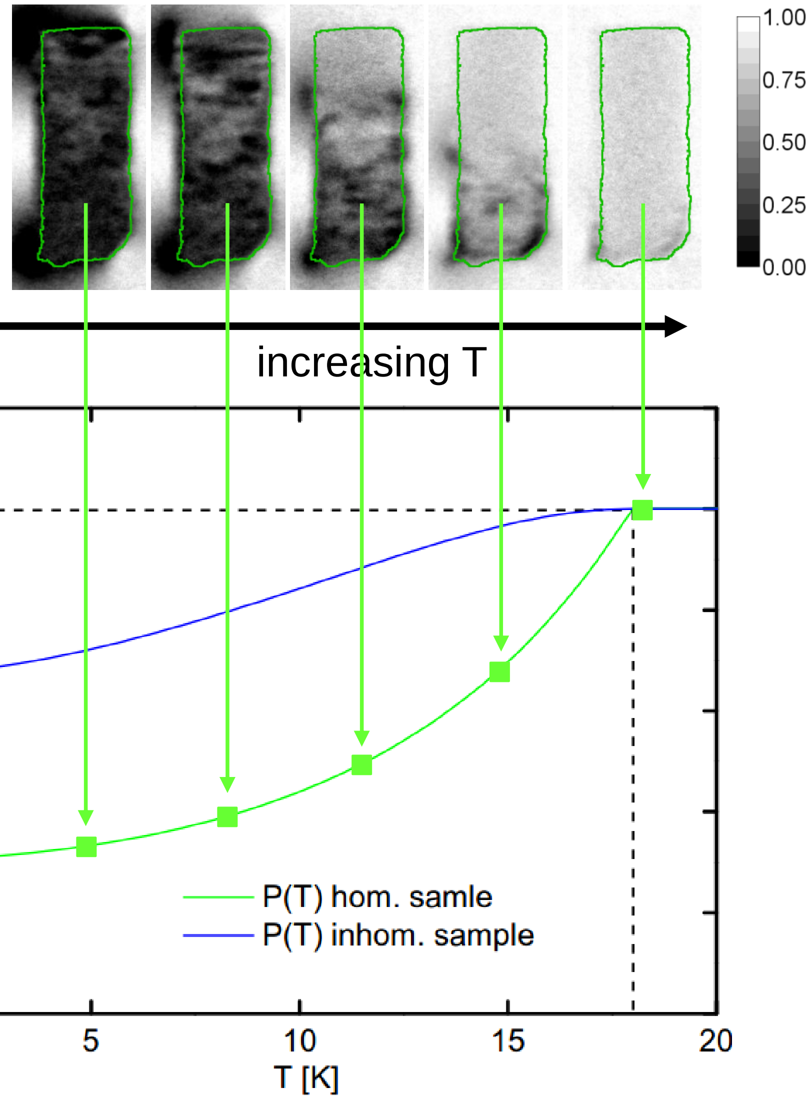
- Bragg Edges
- Texture

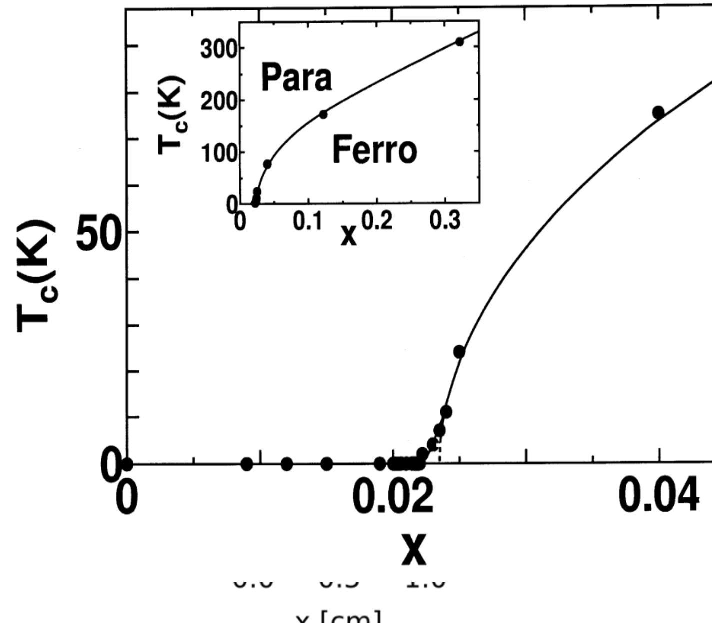
Setup for Depolarization Imaging



$Pd_{1-x}Ni_x$

depolarization

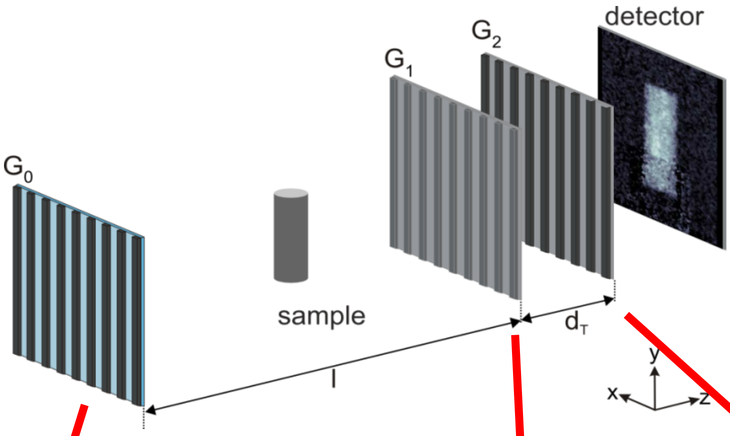


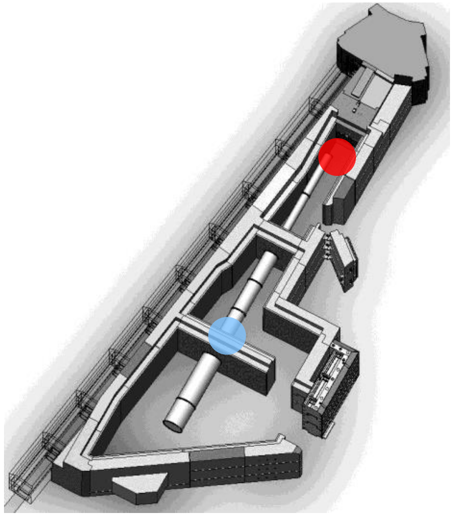


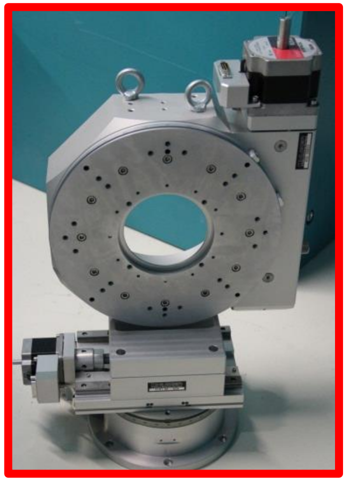
T = 8K

M. Schulz, *et.al.*
J.Phys. Conf., **211** (2010) 012025

Neutron grating interferometer at ANTARES



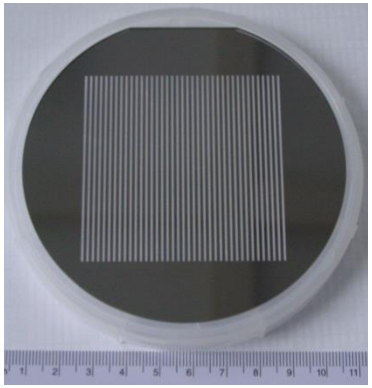


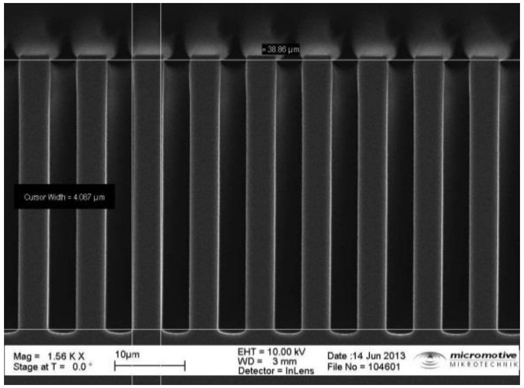


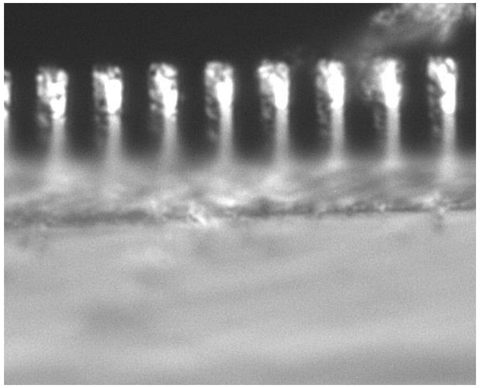
Absorption grating
p_0=1.6 mm

Phase grating
p_1=7.98 µm

Analyzer grating
p_2=4.0 µm

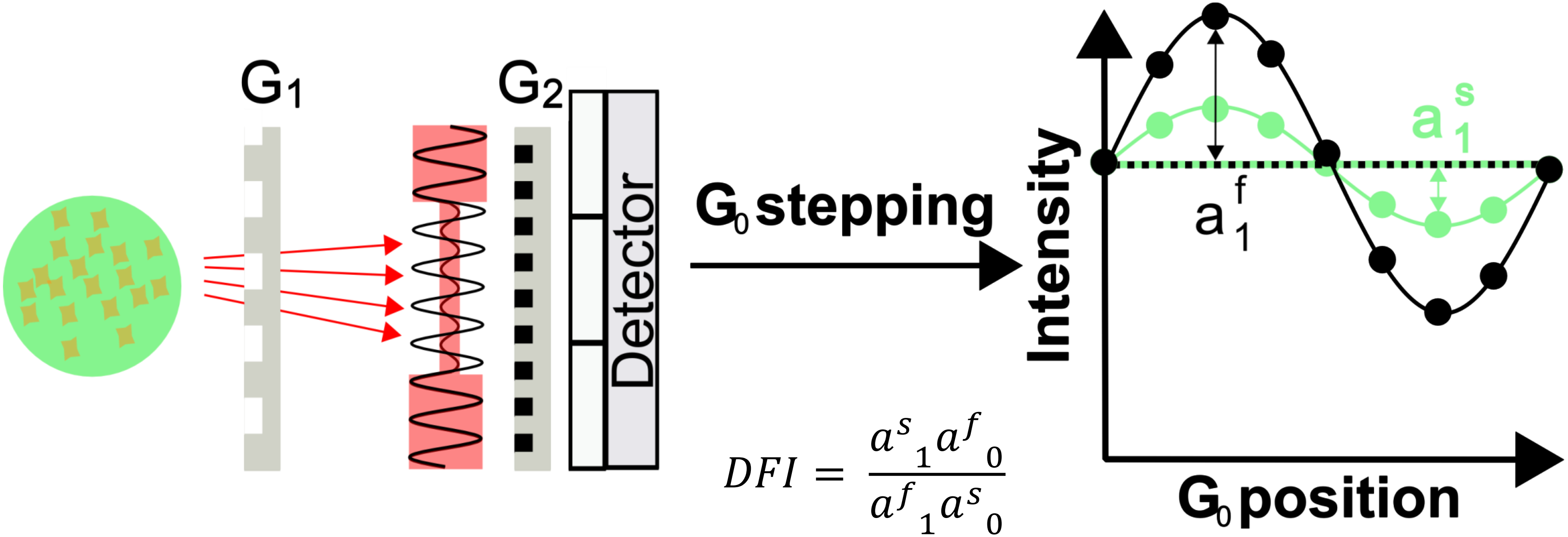






The nGI setup

- Setup generates neutron interference pattern at detector:



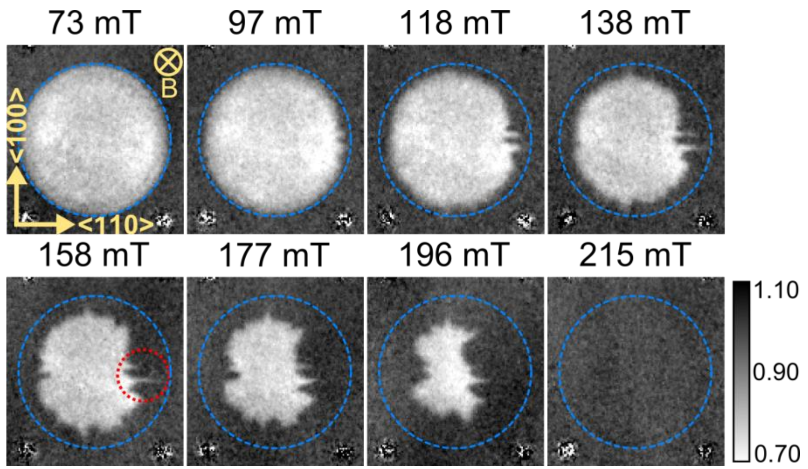
$$DFI = \frac{a^s{}_1 a^f{}_0}{a^f{}_1 a^s{}_0}$$

- Scattering at µm structures locally degrades interference pattern
- Degradation of interference pattern mapped in the DFI

→ DFI = spatially resolved USANS scattering map

Applications:

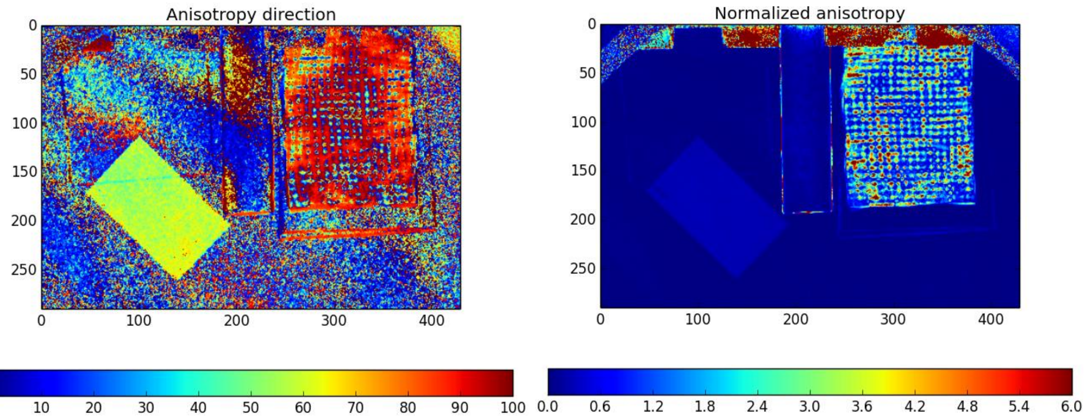
- Material differentiation and testing for µm inhomogeneities
- Investigation of µm domain structures and nucleation in ferromagnets, superconductors, multiferroics, etc.
- Examples:



Domain expulsion in the IMS of superconducting Nb in increasing field after FC to 4 K. In the white regions islands of flux line lattice coexist with field free Meissner phase.

- Under development:

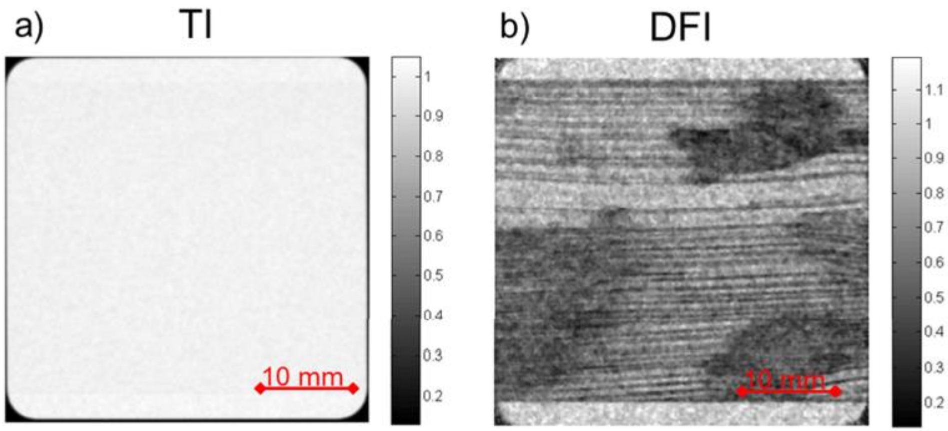
  Probing for micrometer anisotropies



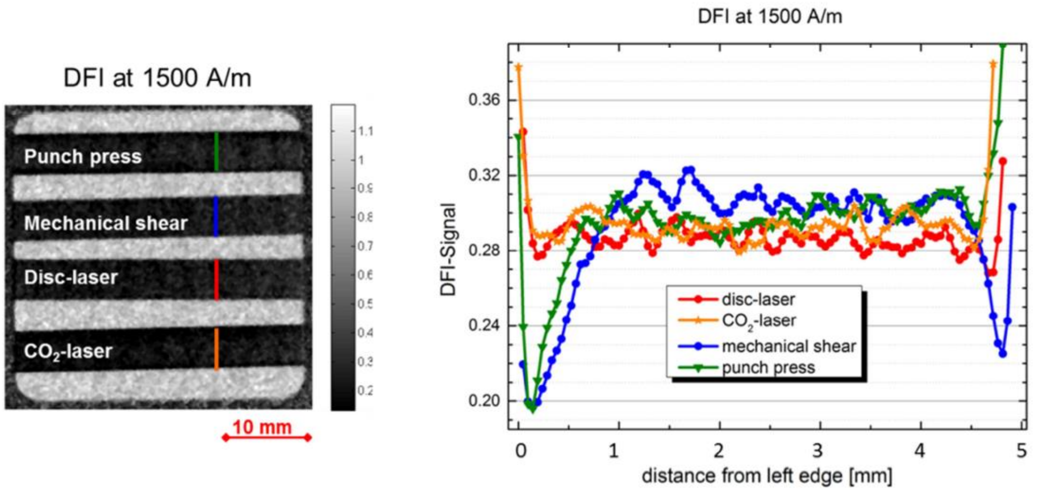
Direction and magnitude of anisotropy in a µm neutron absorption grating, a brass rod and a glass fiber mat (from left to right)

Electric steel

- Transmission image (TI) and dark field image (DFI)
- DFI visualizes domain walls **inside the material**
- Investigate how machining affects magnetic properties



TI and DFI of a grain oriented electric steel (t = 300 µm)
B. Betz et al., Physics Procedia 69, 399-403 (2015)



DFI and DFI-profiles of several not oriented electric steels
Betz et al., Physics Procedia 69, 399-403 (2015)

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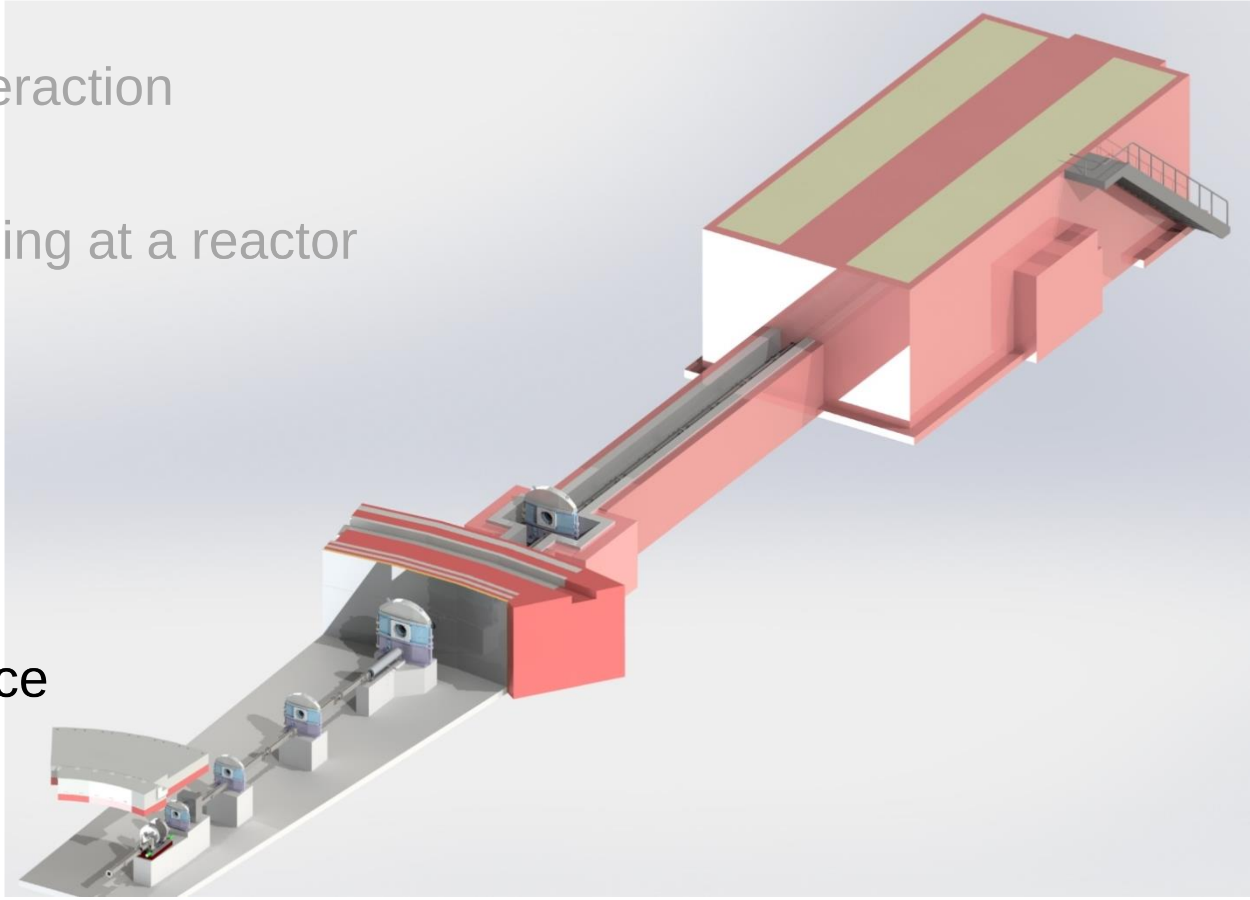
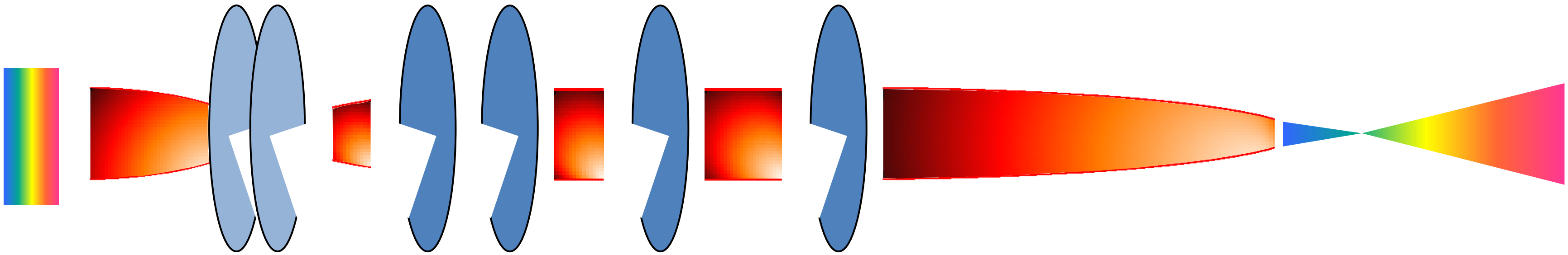


ESS - A European Big Science Project

- 5 MW accelerator (3GeV protons)
- Cost Book construction cost of 1.843 **B€** (2013)
- Cost Book annual operations cost target of 140 **M€** (2013)
- 22 “public” instruments (15 included in the construction budget)

Civil Construction

Imaging at ESS



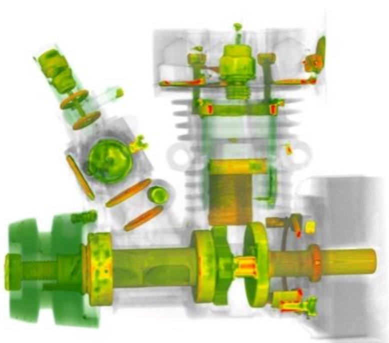
standard neutron imaging

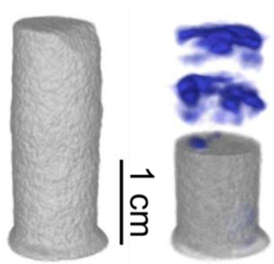
depolarization imaging

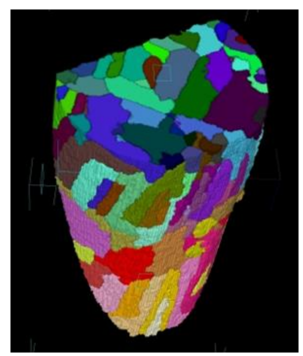
dark field and phase imaging

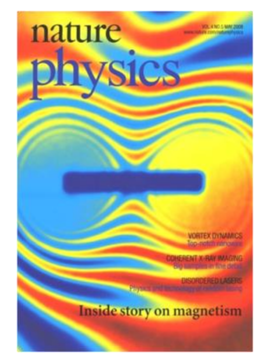
quantitative magnetic imaging

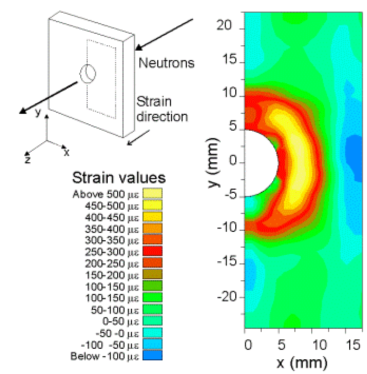
stress and strain imaging









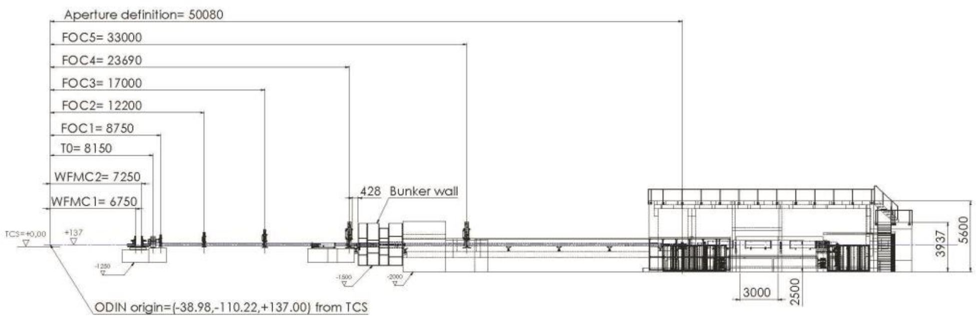


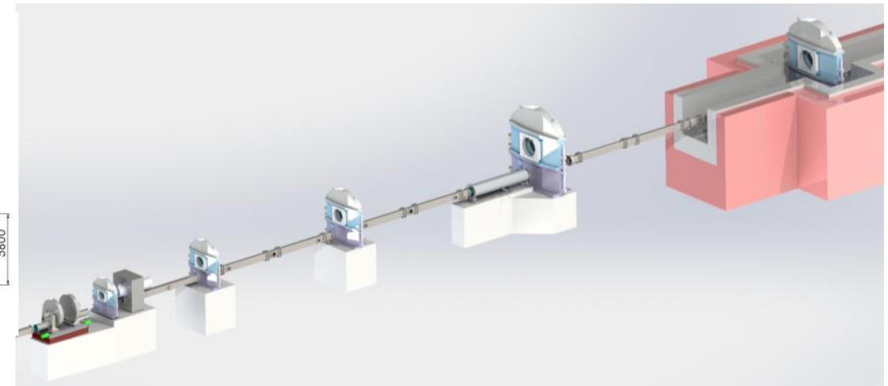
$\Delta\lambda/\lambda$ not required — *10 %* — *10 %* — *1 %* — *0.5 %*

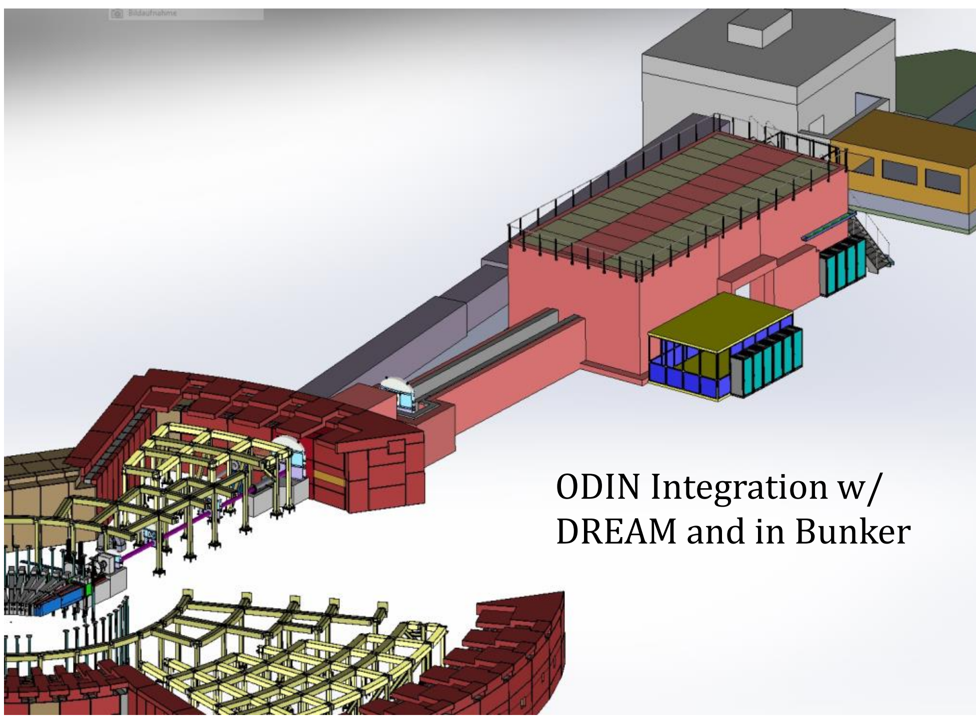
✓ Can be realized with sophisticated Chopper System

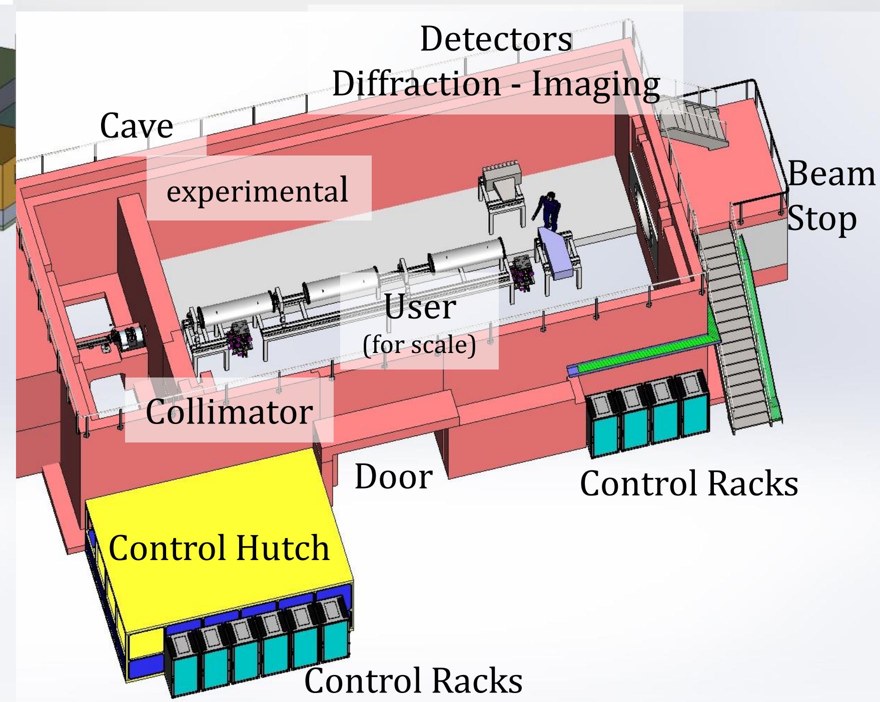
ODIN Overview

- **O**ptical and **D**iffraction **I**maging with **N**eutrons: Neutron radiography and ToF imaging with variable wavelength resolution
- ODIN will be the only imaging instrument installed during the first round
- It will be a “day-1” instrument: first neutrons planned for 2021
- Joint project of PSI and TUM (lead institution)
- Budget 11.6M€.


Aperture definition= 50080
FOC5= 33000
FOC4= 23690
FOC3= 17000
FOC2= 12200
FOC1= 8750
T0= 8150
WFMC2= 7250
WFMC1= 6750
428 Bunker wall
3937
5600
3000
2500
ODIN origin=(-38.98,-110.22,+137.00) from TCS




ODIN Integration w/
DREAM and in Bunker


Detectors
Diffraction - Imaging
Cave
experimental
Beam
Stop
User
(for scale)
Collimator
Door
Control Racks
Control Hutch
Control Racks

Thank You!