Neutron Instrumentation

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Neutron instrumentation

- What do we measure and need?
- Neutron guides & shielding
- Measuring techniques
- Sample environments
- Neutrons detectors
- Data acquisition system

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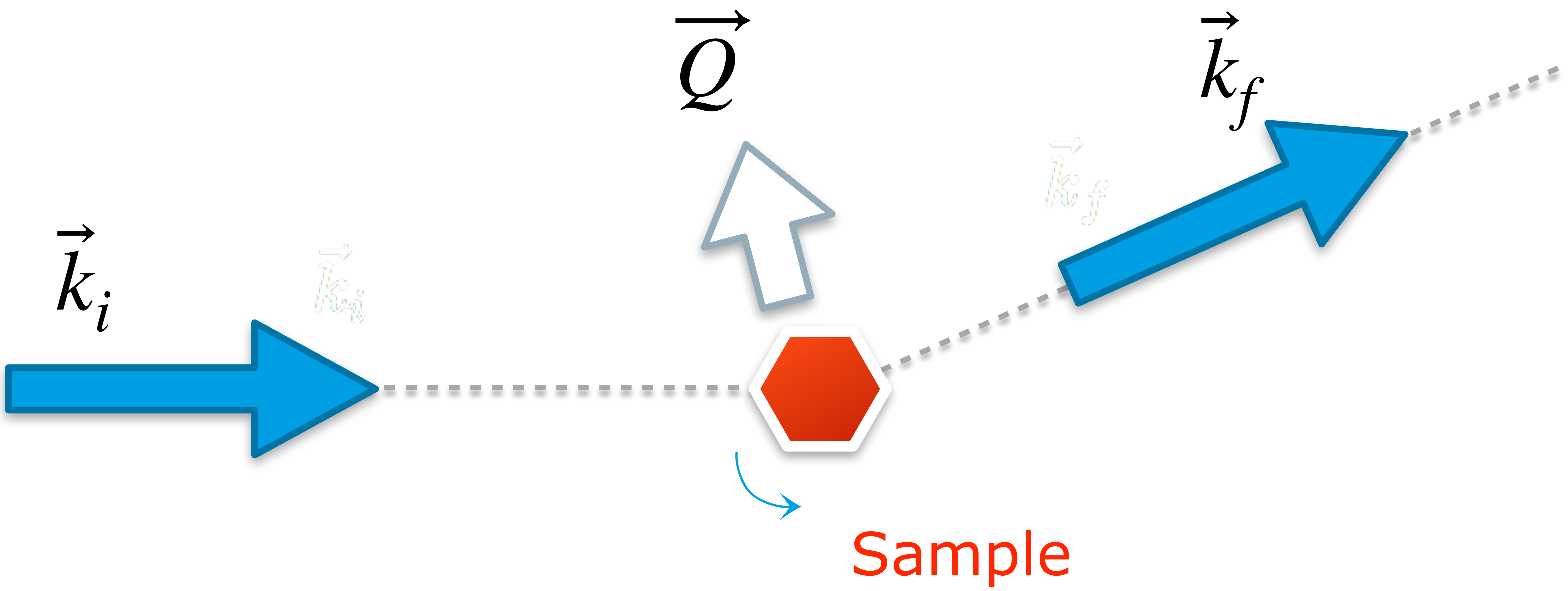
What do we measure and need?

Elastic scattering: $\|\vec{k}_i\| = \|\vec{k}_f\|$

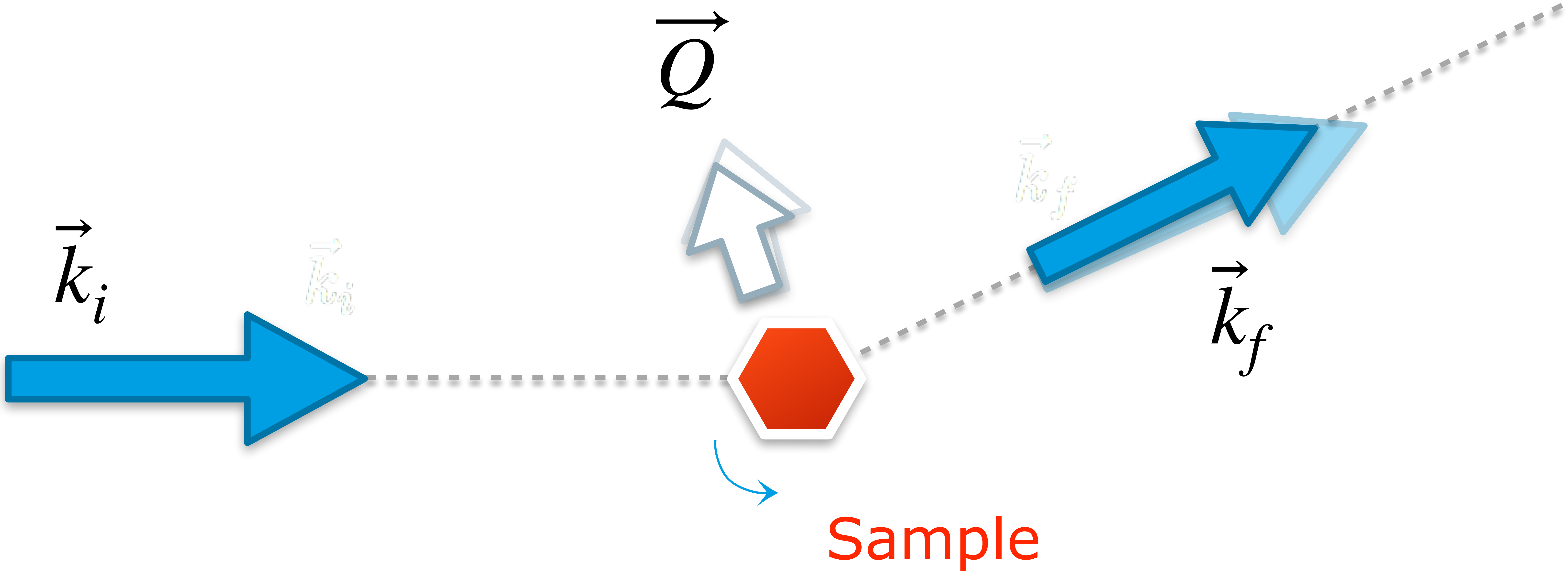


Intensity vs wave-vector transfer

$$\vec{Q} = \vec{k}_f - \vec{k}_i$$

What do we measure and need?

Inelastic scattering: $\|\vec{k}_i\| \neq \|\vec{k}_f\|$

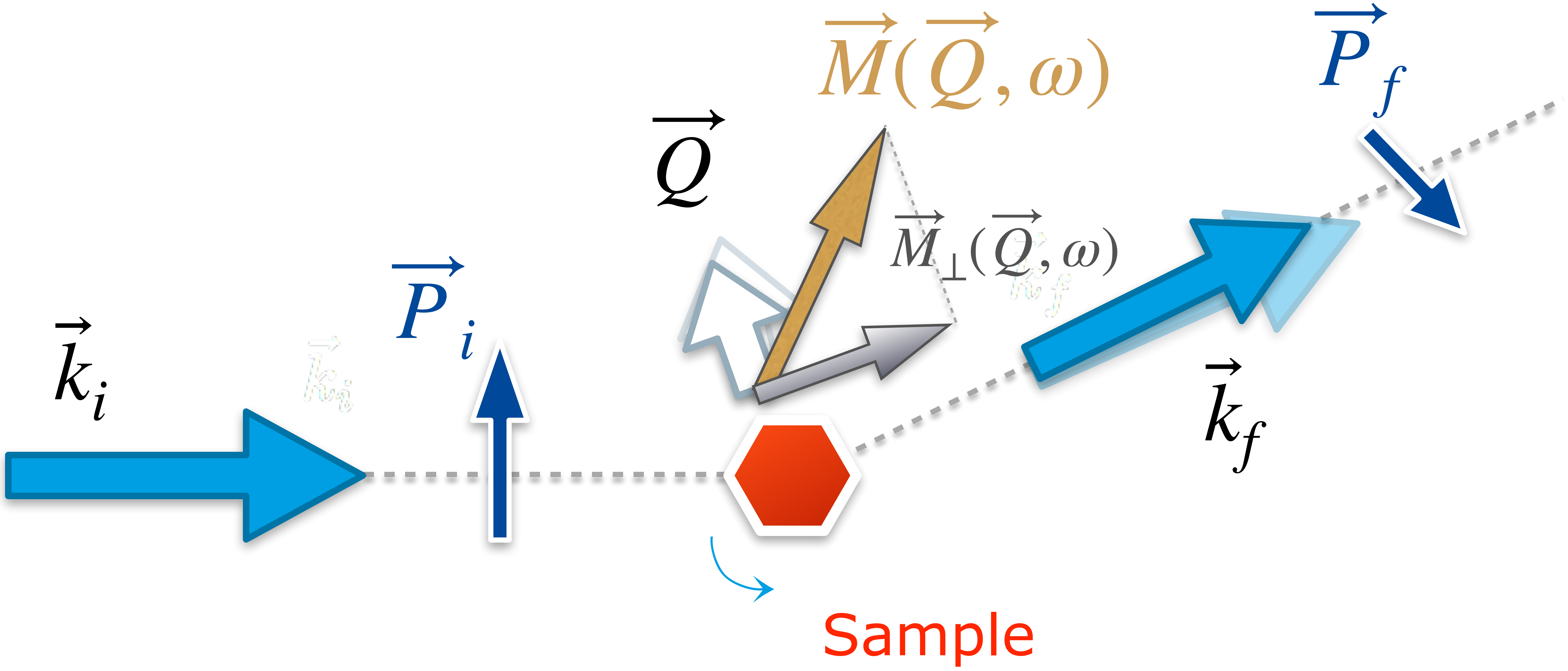


Intensity vs wave-vector & energy transfer

$$\vec{Q} = \vec{k}_f - \vec{k}_i, \; \hbar\omega = E_f - E_i$$

What do we measure and need?

Polarised neutron scattering



In general, the polarisation of a neutron beam will change both in magnitude and direction upon scattering from a magnetic material.

What do we measure and need?

Polarised neutron scattering

- We measure an intensity:

$$I\,(\overrightarrow{Q}, \overrightarrow{P}_i, \hbar\omega) \quad \text{where} \quad \overrightarrow{Q} = \vec{k}_f - \vec{k}_i,\ \hbar\omega = E_f - E_i$$

- and components of the scattered polarisation $\overrightarrow{P}_f$ for each direction of the incident polarisation $\overrightarrow{P}_i$:

$$\mathrm{P}_{i,j} = \frac{P_i\ \mathbb{P}_{i,j}\ + P_j^{\dagger}}{\|\overrightarrow{P}_f\|} \ \text{with}\ (i,j) \in \{x, y, z\}$$

Neutron instrumentation

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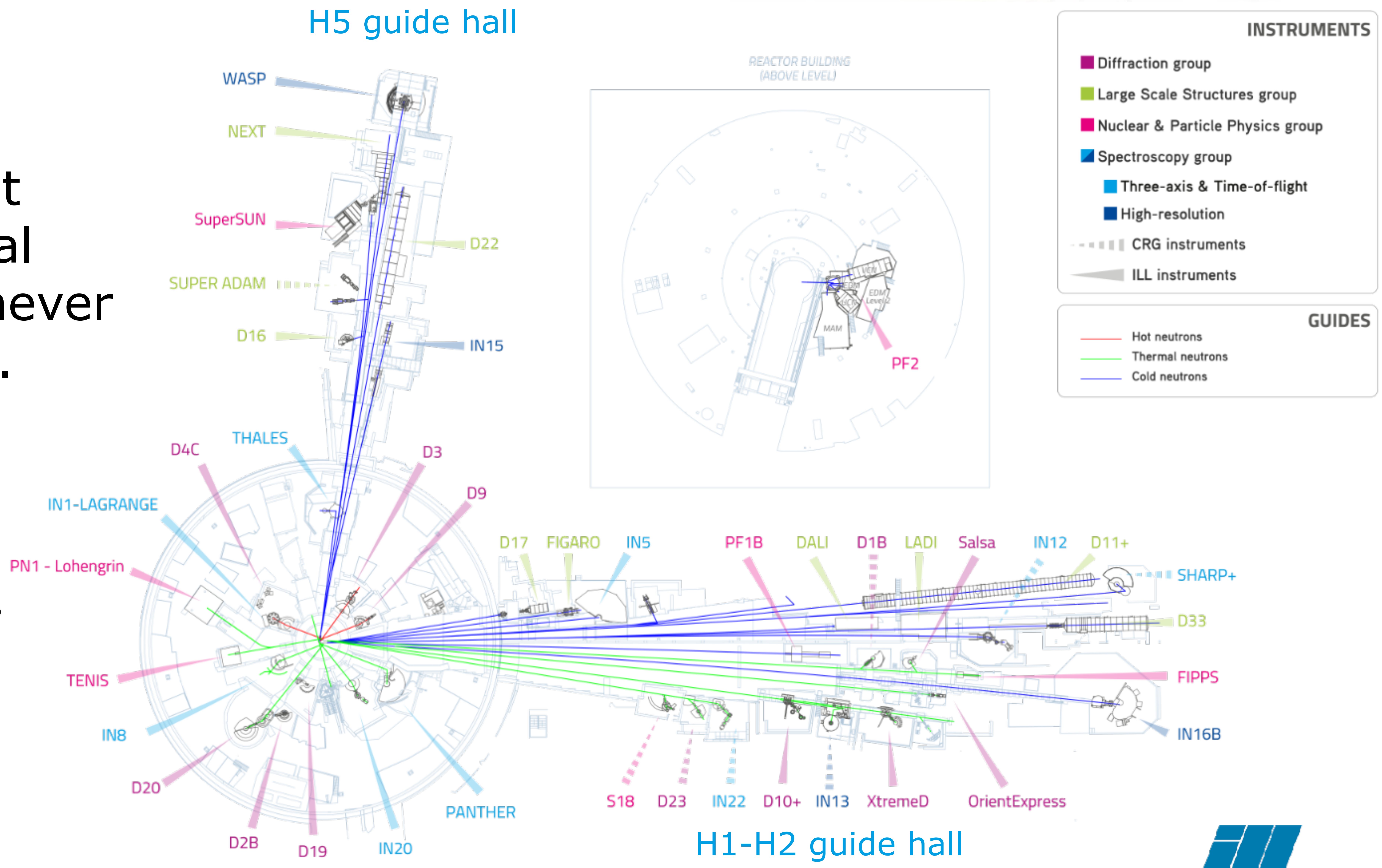
Guides

Constructibility

- a real instrument has to fit in a real space, and will never be large enough.
- thermal, cold, hot neutrons?
- wide-band, monochromatic?
- beam size, divergence, resolution?

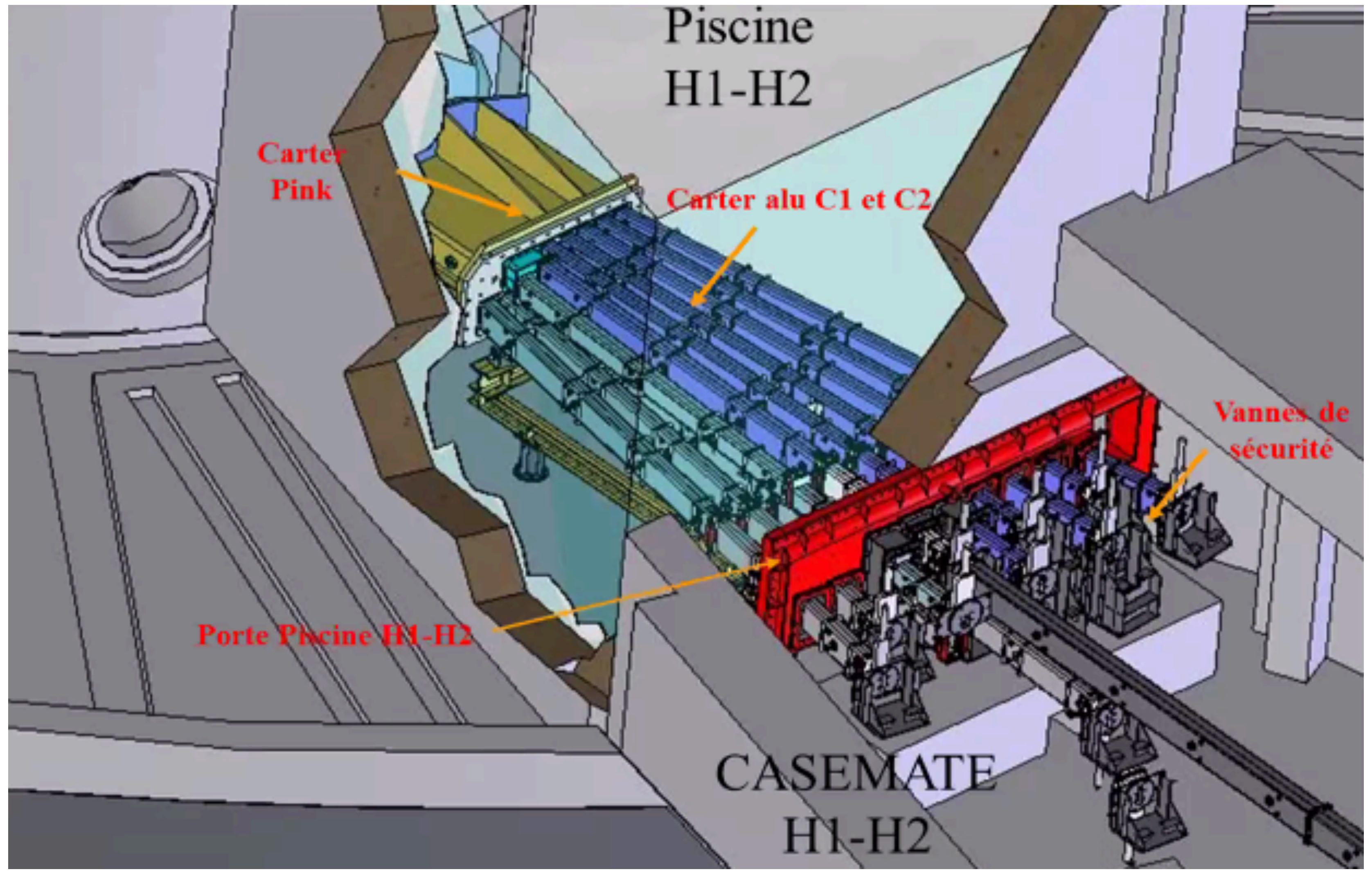


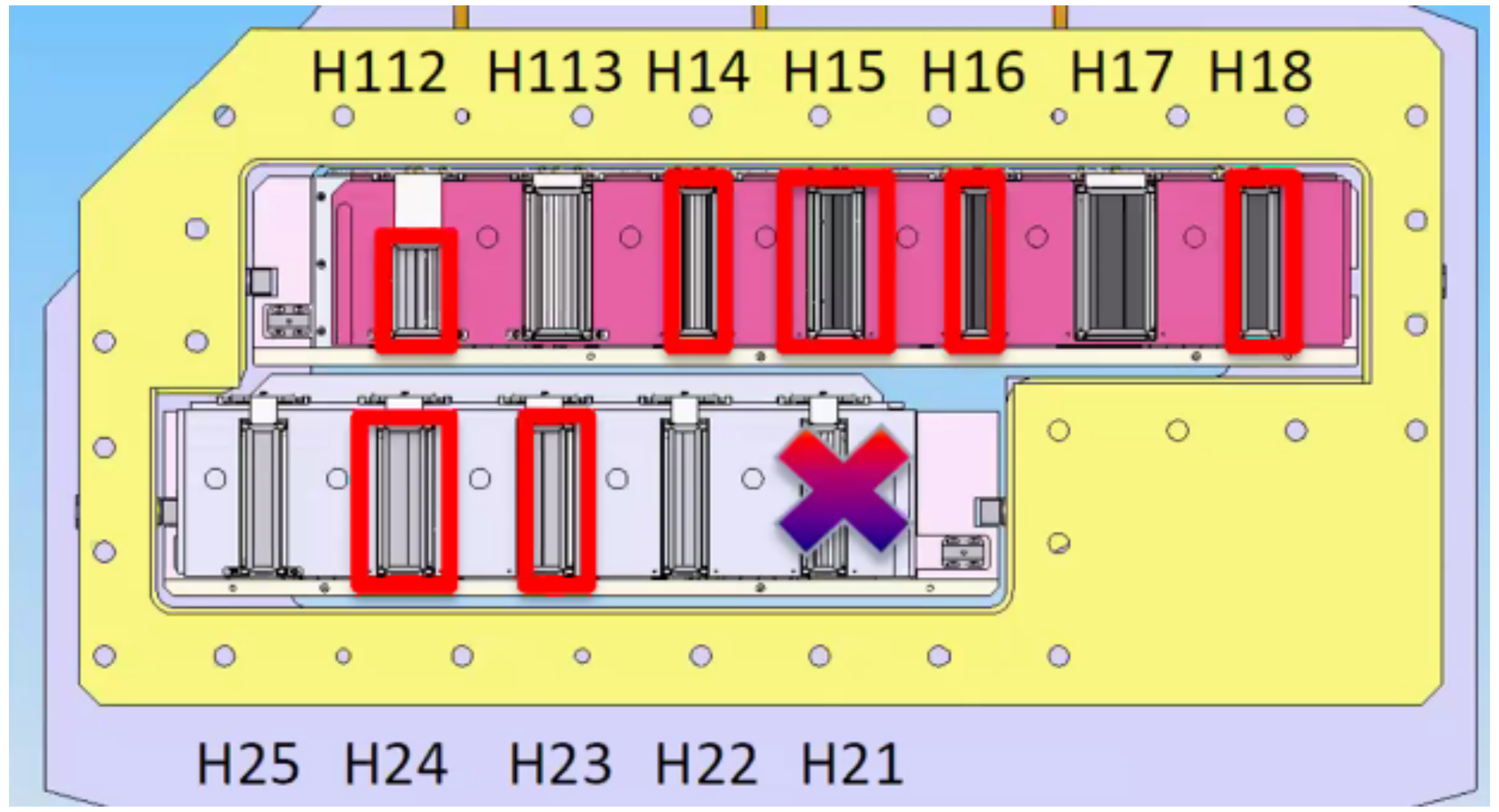
Neutron guides

H1-H2 major upgrade in 2022

- A guide is made up of sections joined together
- Glass is cheap and sufficiently thick to hold the vacuum
- Curved guides eliminate fast neutrons ($R \approx \mathrm{km}$)
- Guides can split, focus, collimate, polarise…

H1-H2 beamtube
▼
guide hall

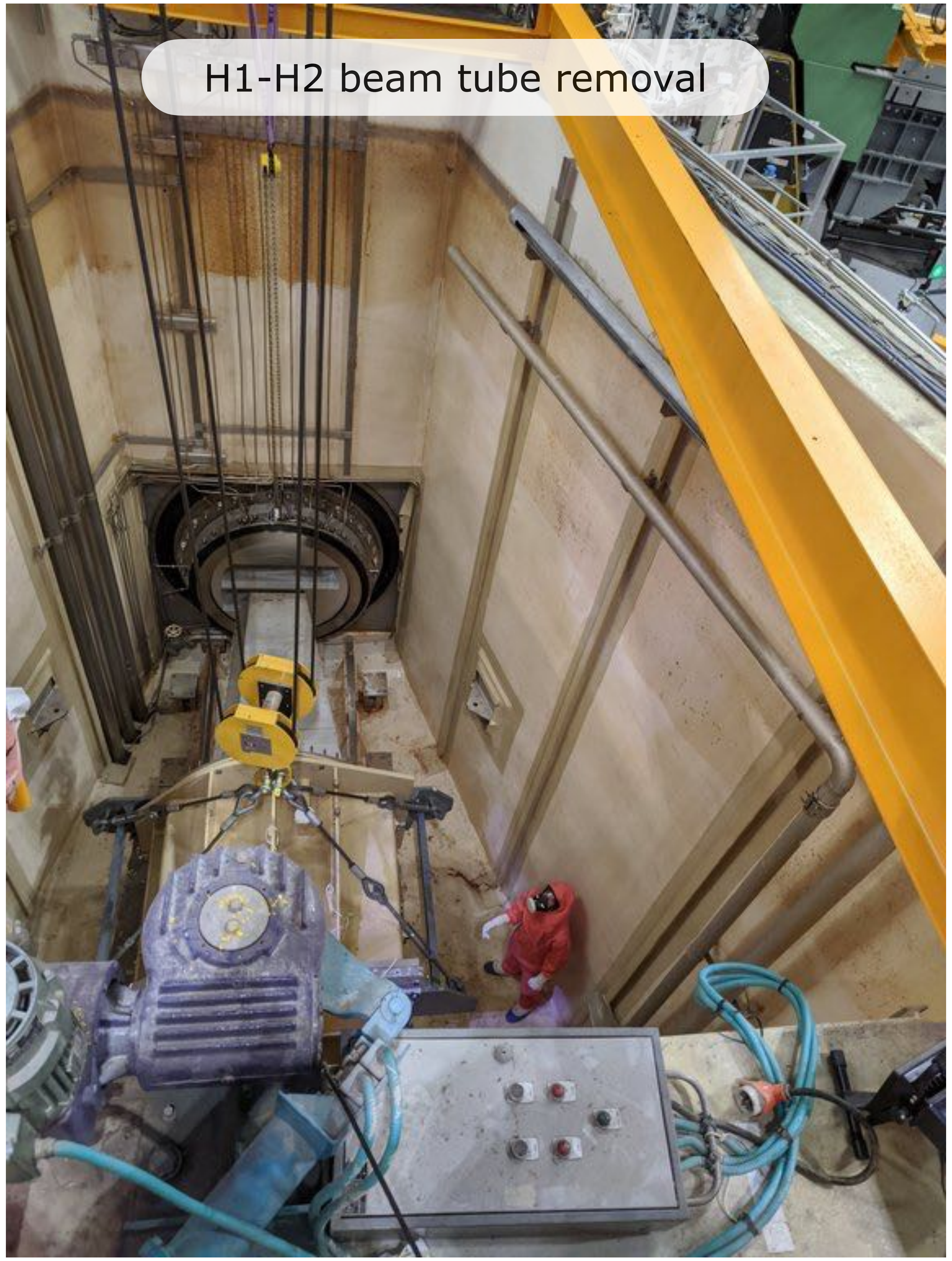




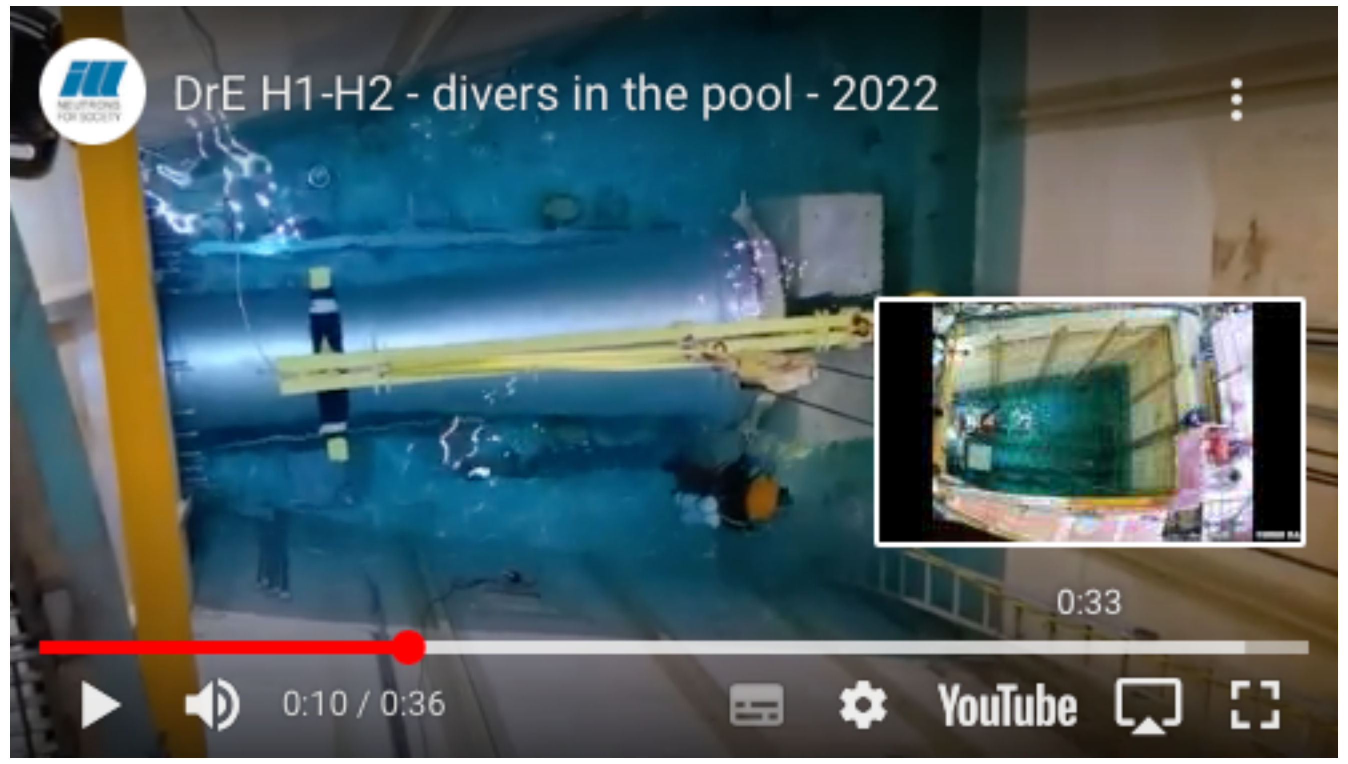
H1 ► cold

H2 ► thermal

Neutron guides



https://www.ill.eu/users/instruments/modernisation-programmes/ill2023



Neutron guides

H5 major upgrade in 2014

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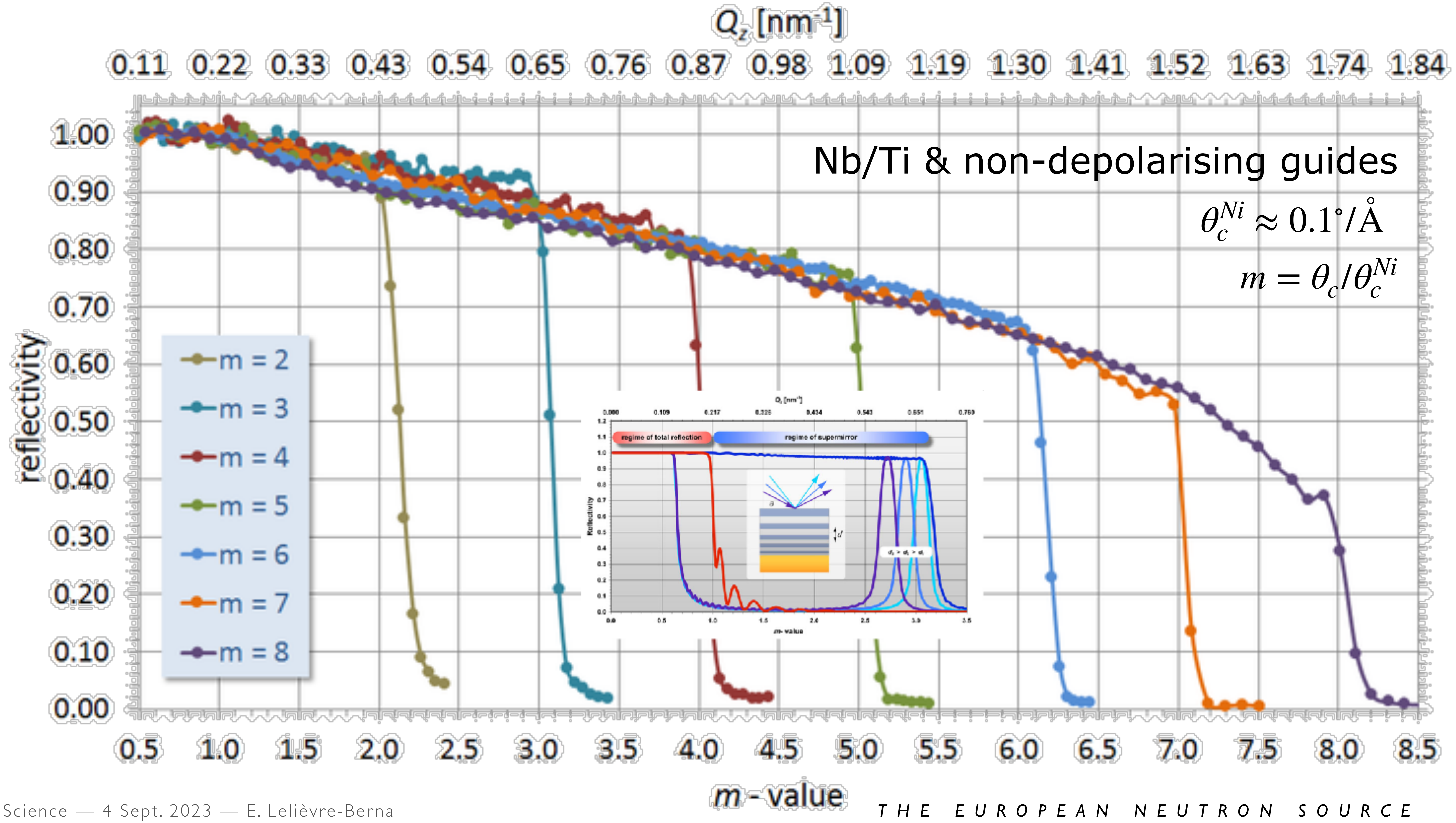
Neutron guides

H5 major upgrade in 2014

Neutron guides

e.g. supermirrors from Swiss Neutronics



Neutron guides

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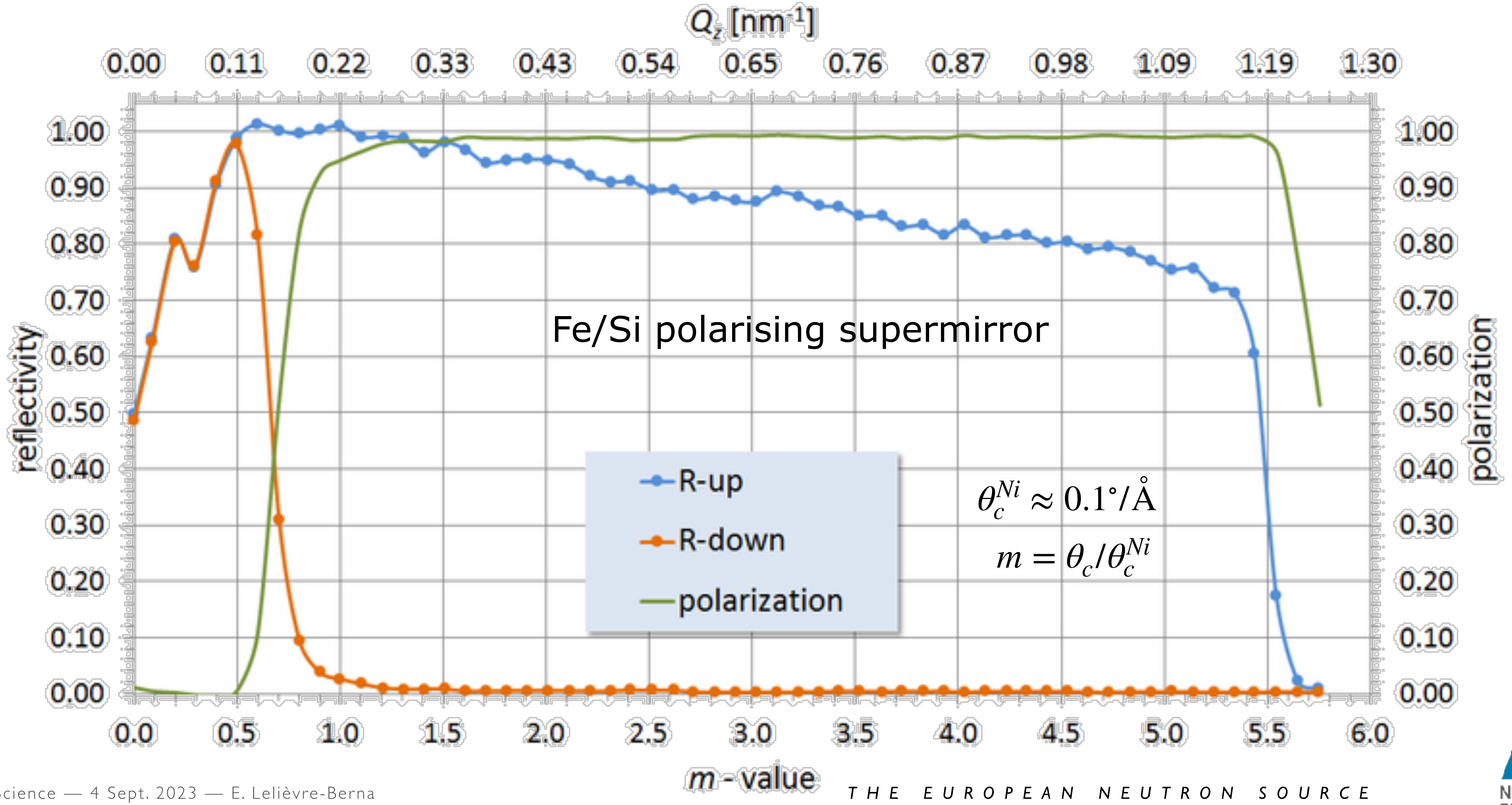
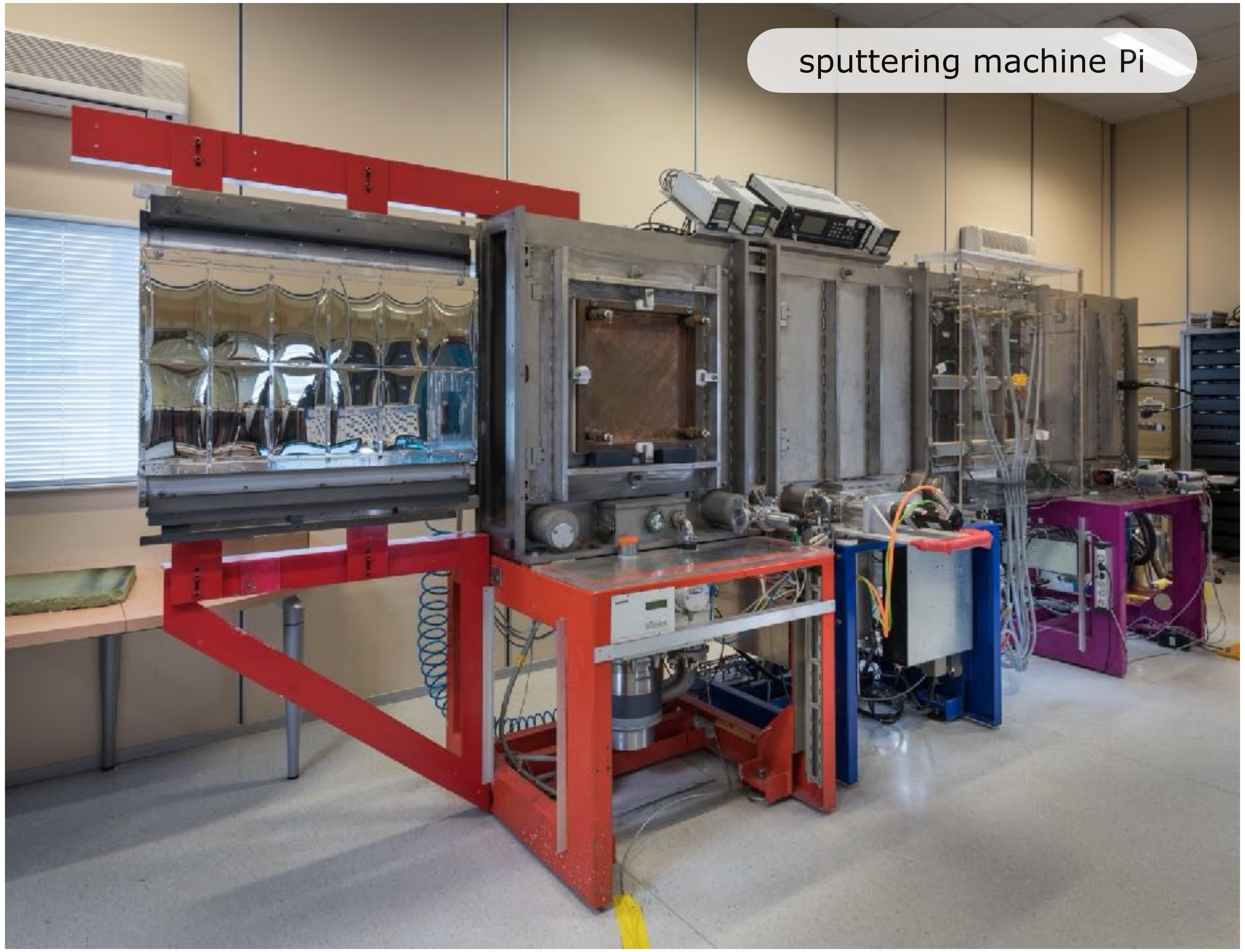
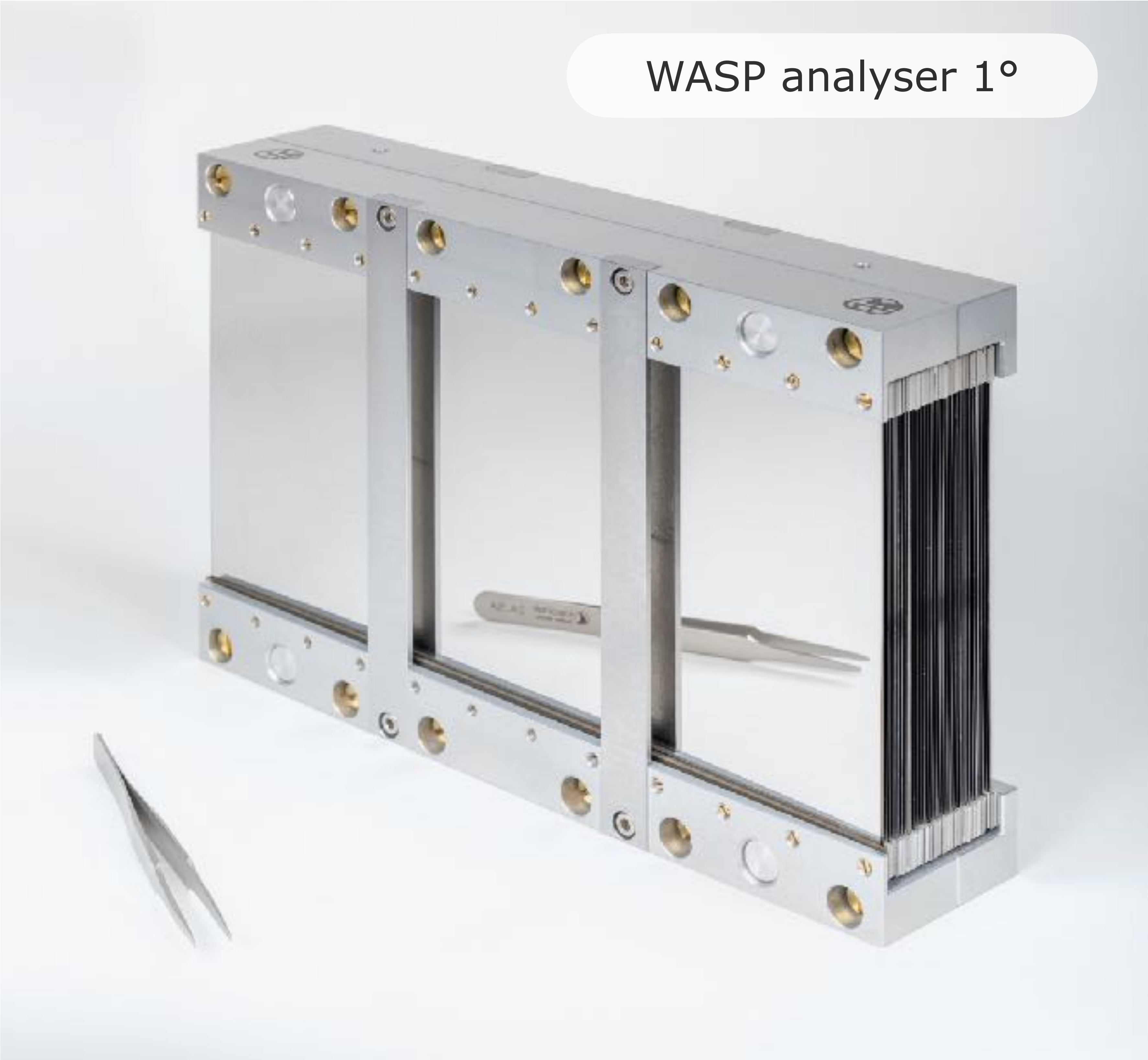


Neutron guides

supermirrors produced at the ILL

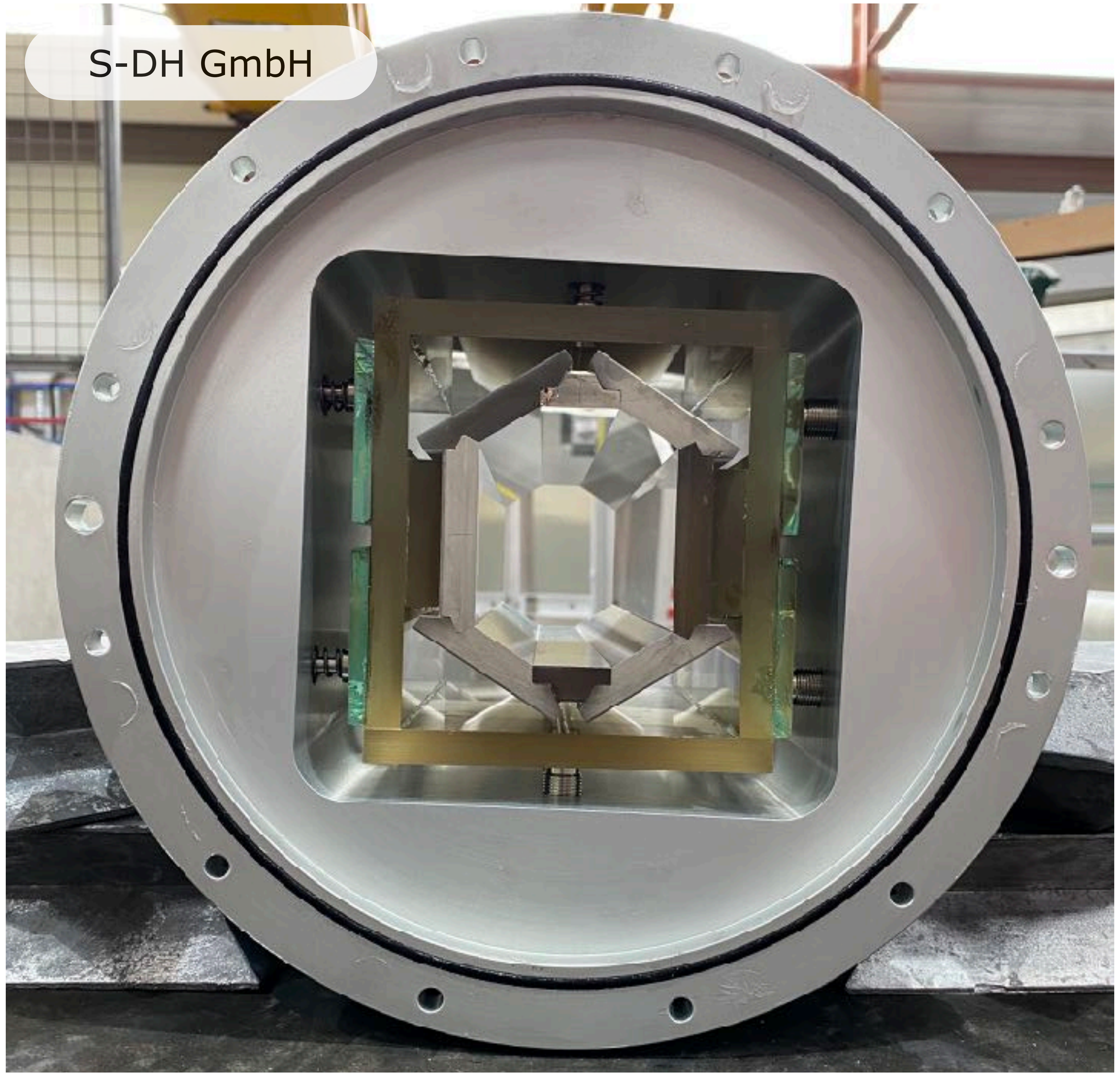


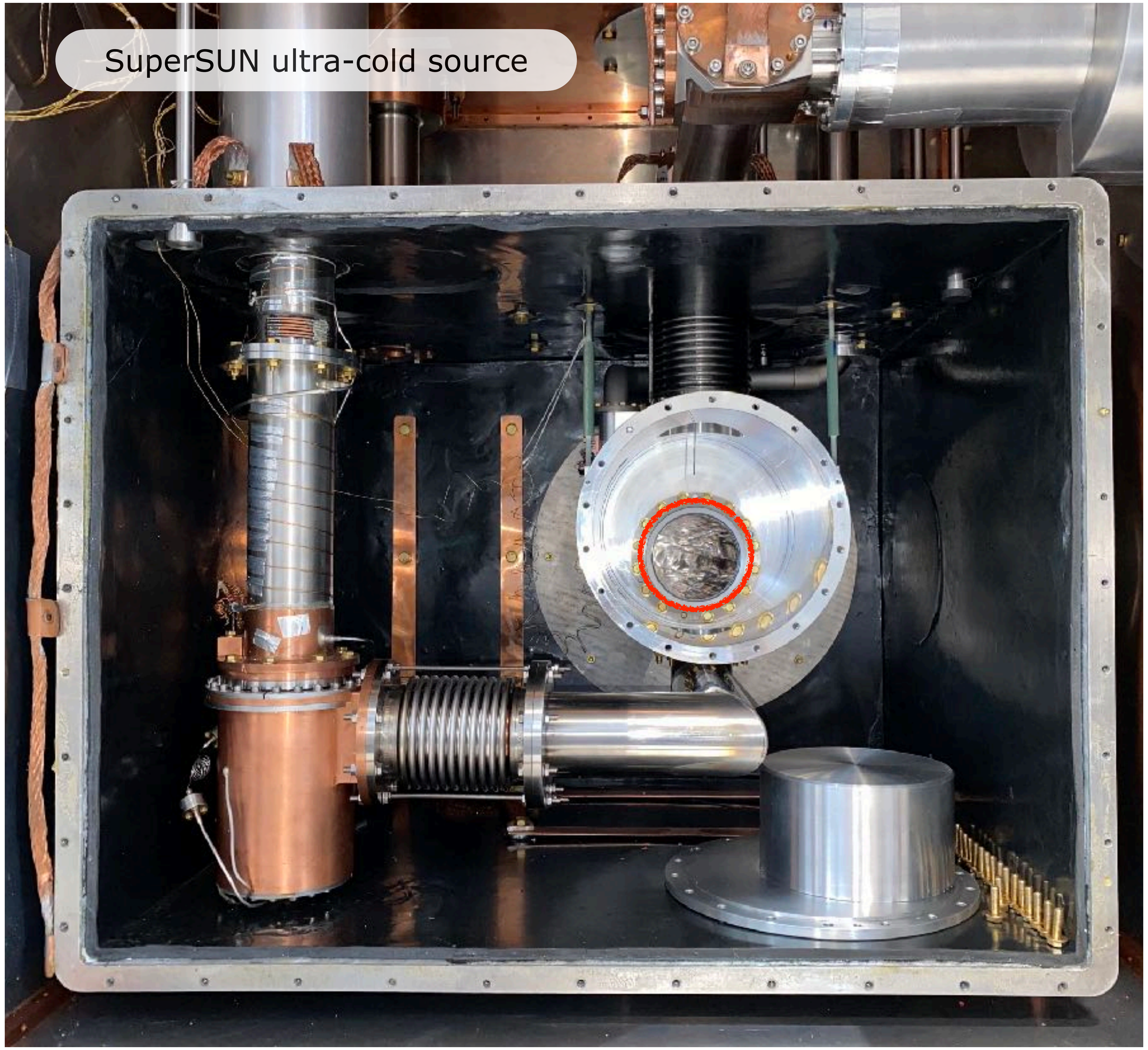


3300 double-sided m=3.2 Co/Ti/Gd mirrors for covering 90°

Neutron guides

of the ultra-cold neutron source

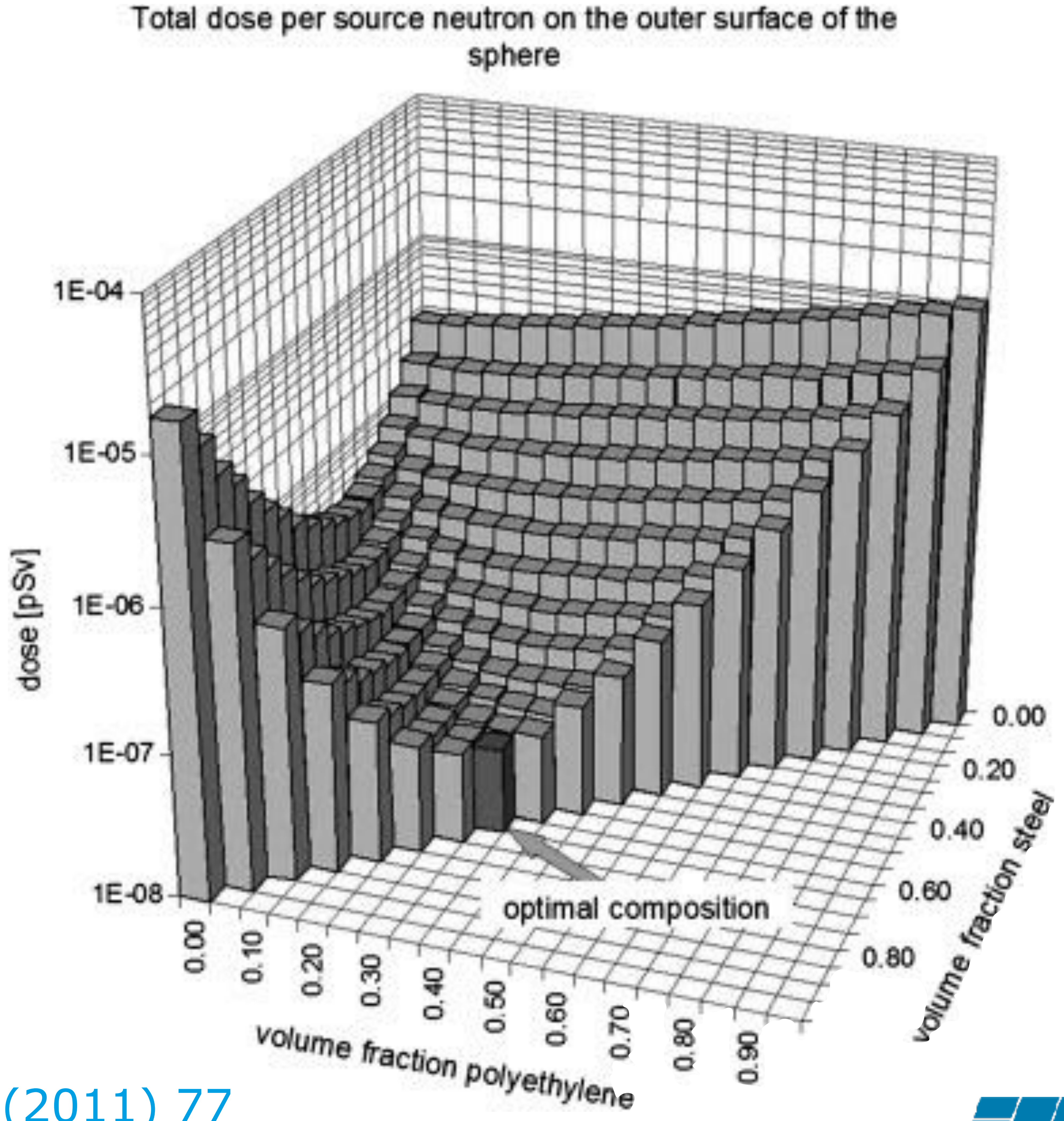




Shield against neutrons & gammas

- Hydrogeneous
  - concrete, wax, polyethylene
- Boron, ^{6}Li, Cd, Gd/GdO
- Lead, Iron (soft steel)

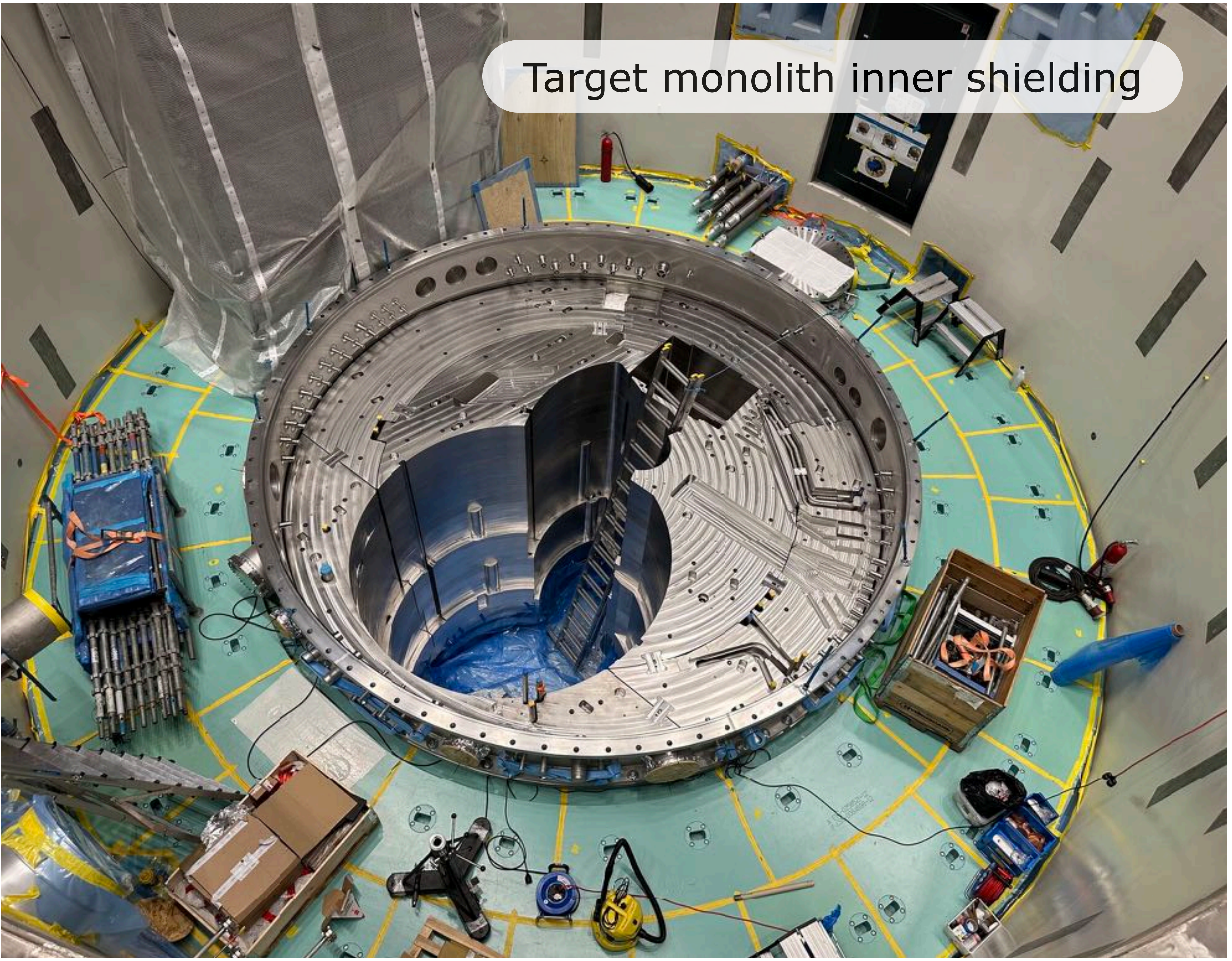
- Number of collected neutrons x30 since 2000 at ILL. The shielding efficiency must continuously be improved (to save space)

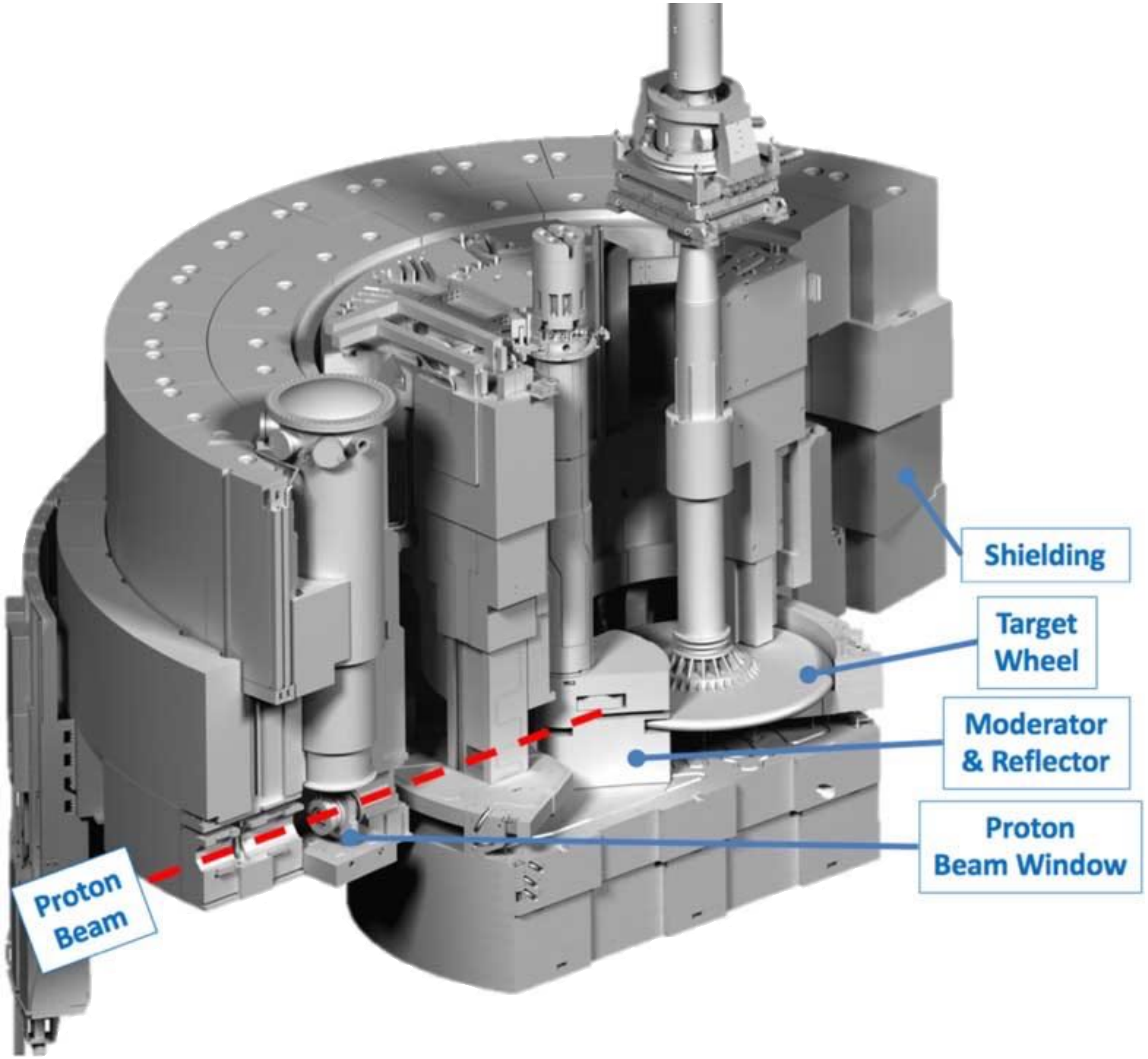


Calzada *et al.* NIMA 651 (2011) 77

Neutron guides & shielding

Neutron guides & shielding





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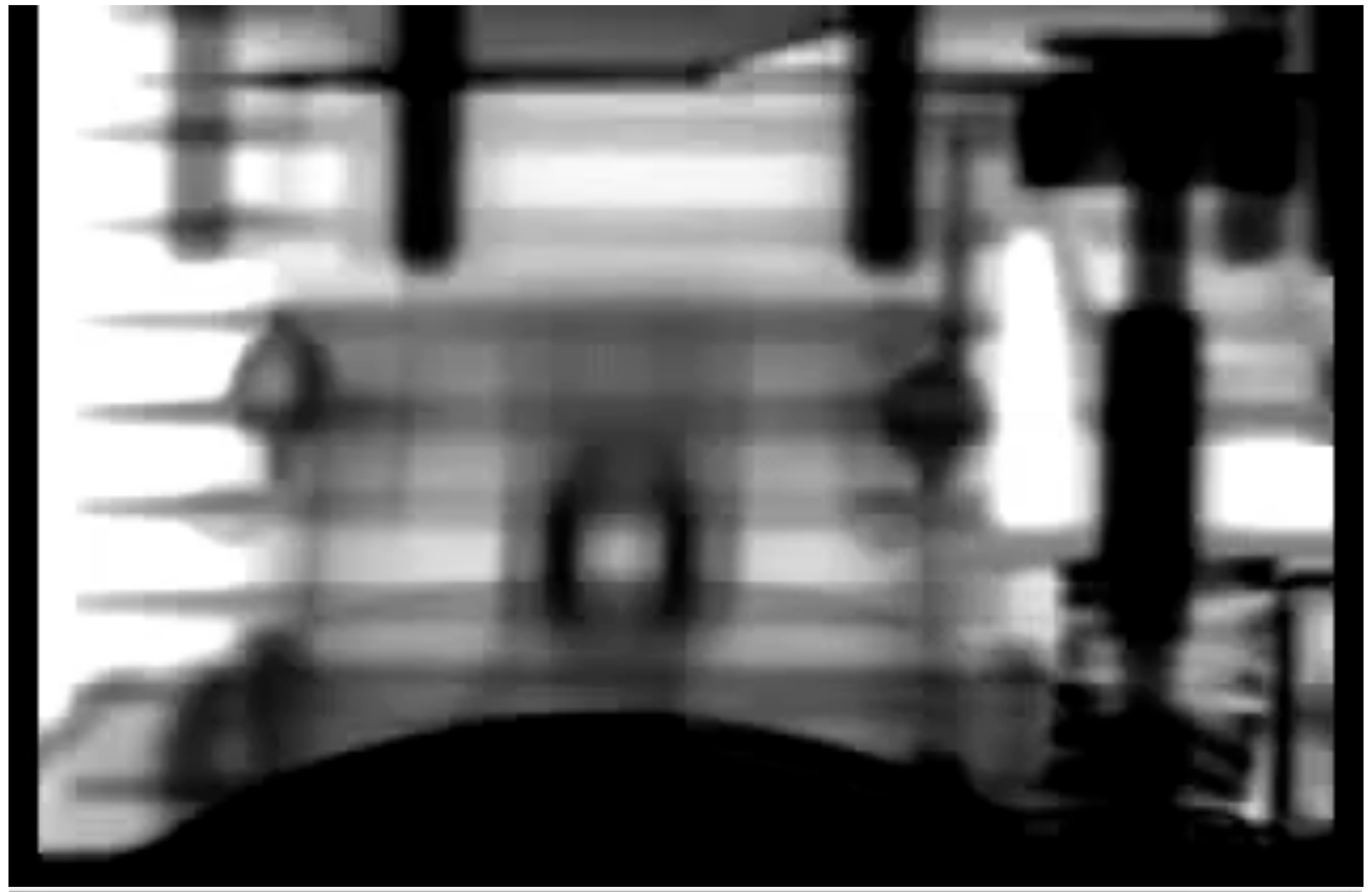
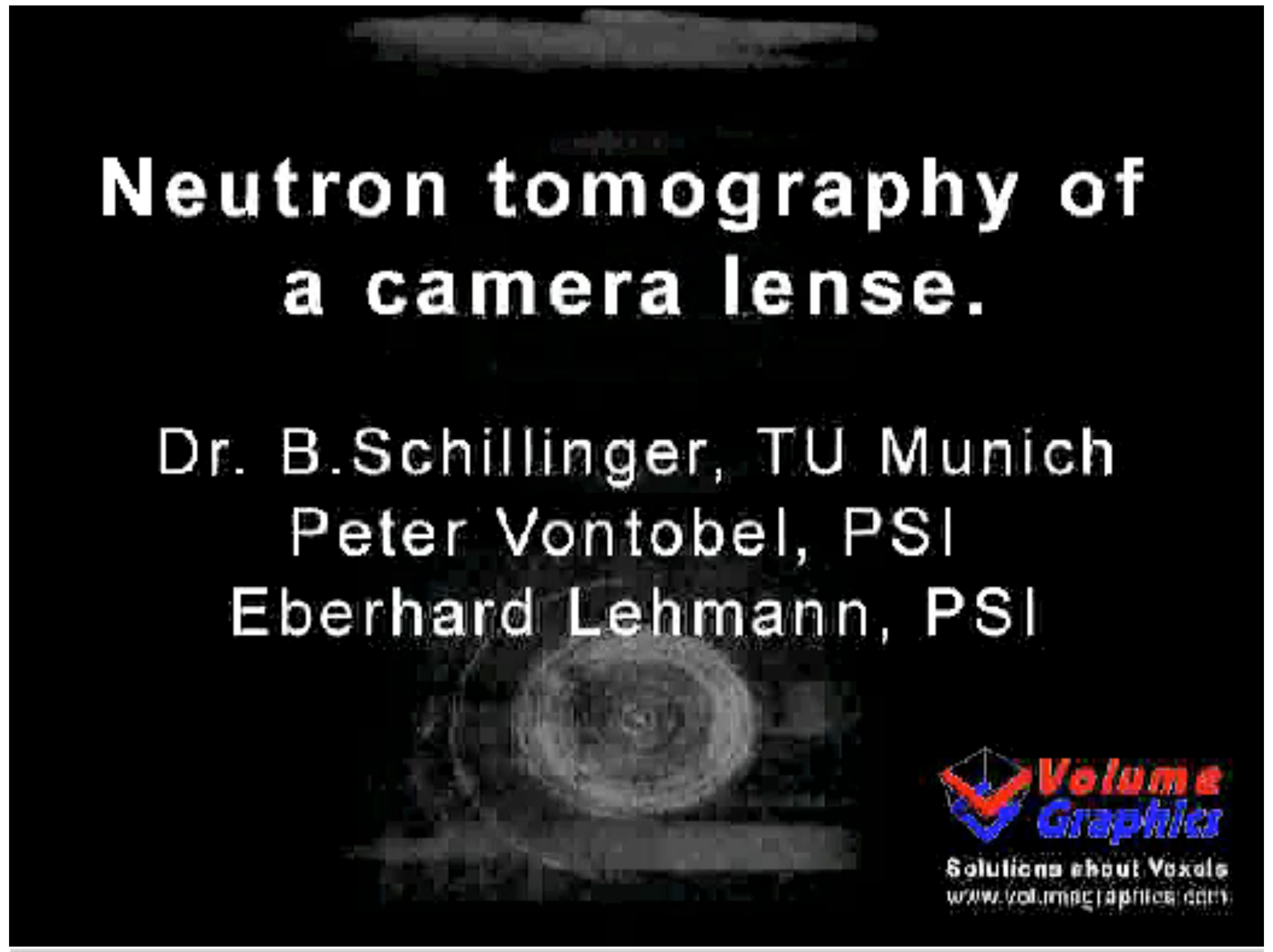
Measuring techniques

Neutronography



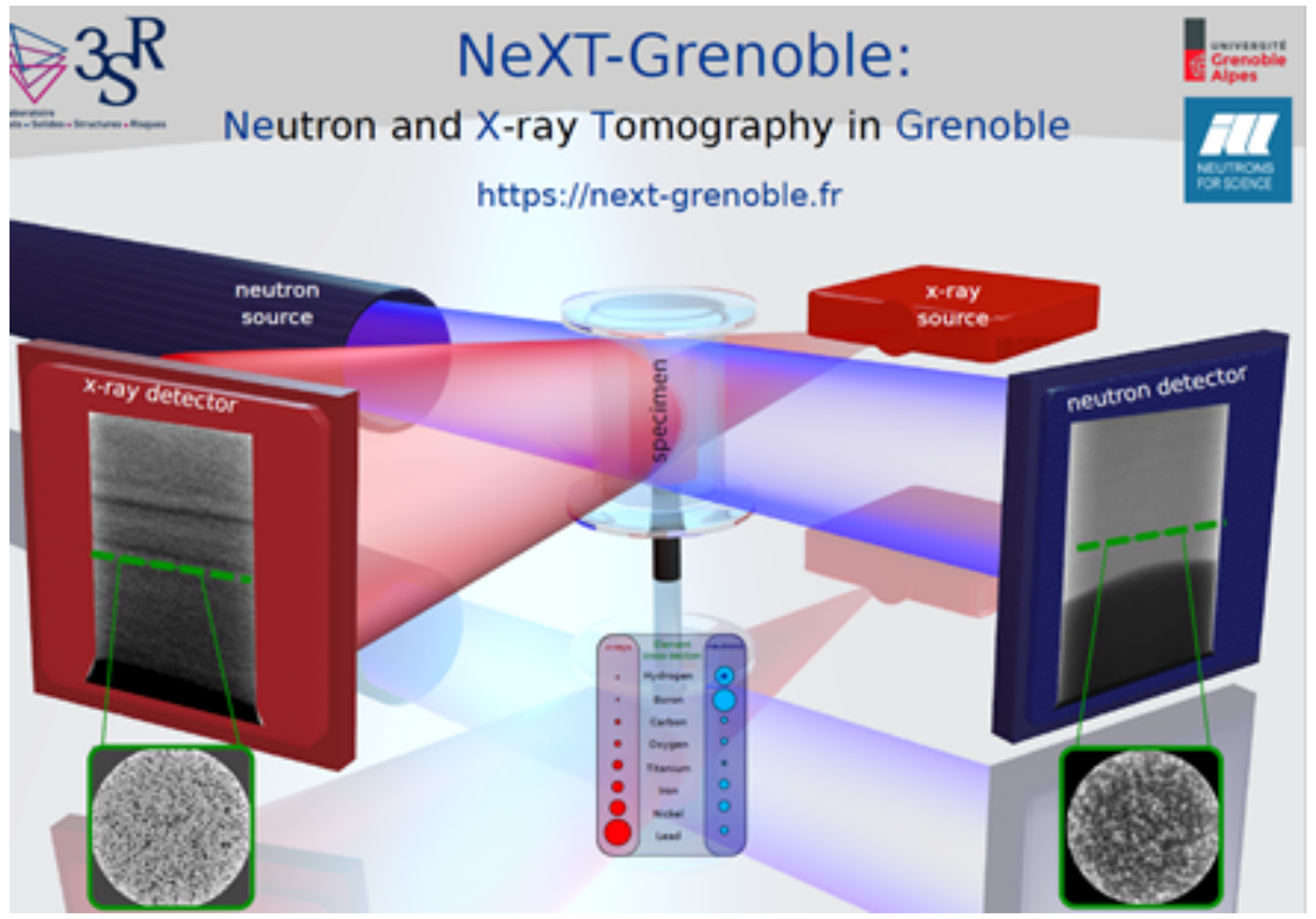


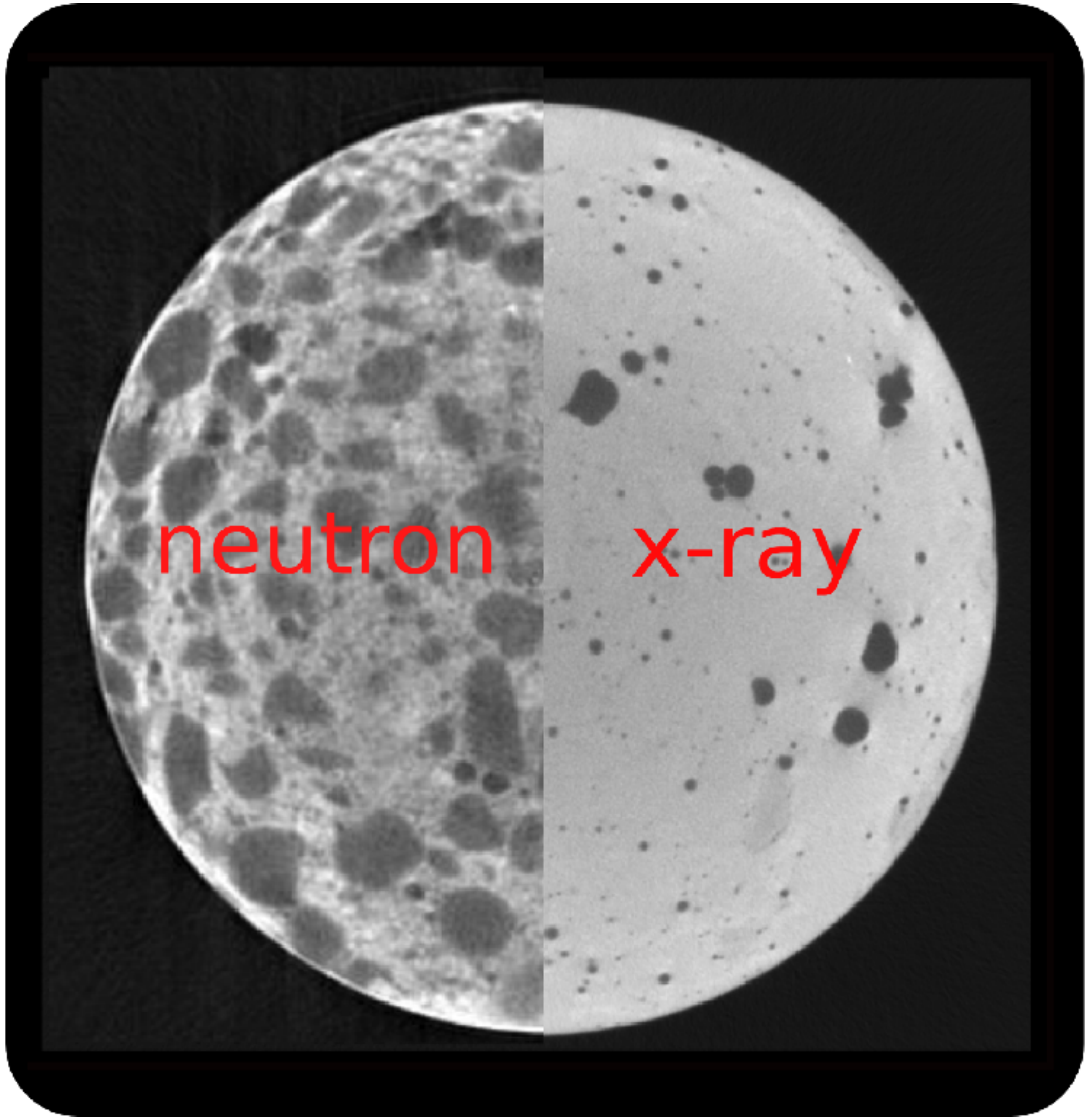
5 µm resolution — complementary to x-rays

Measuring techniques

Tomography

- Neutrons spec.
  - 1 µm resolution
  - 1 ms images
  - 1 s tomography
- Neutrons + X-ray
  - 10 µm resolution

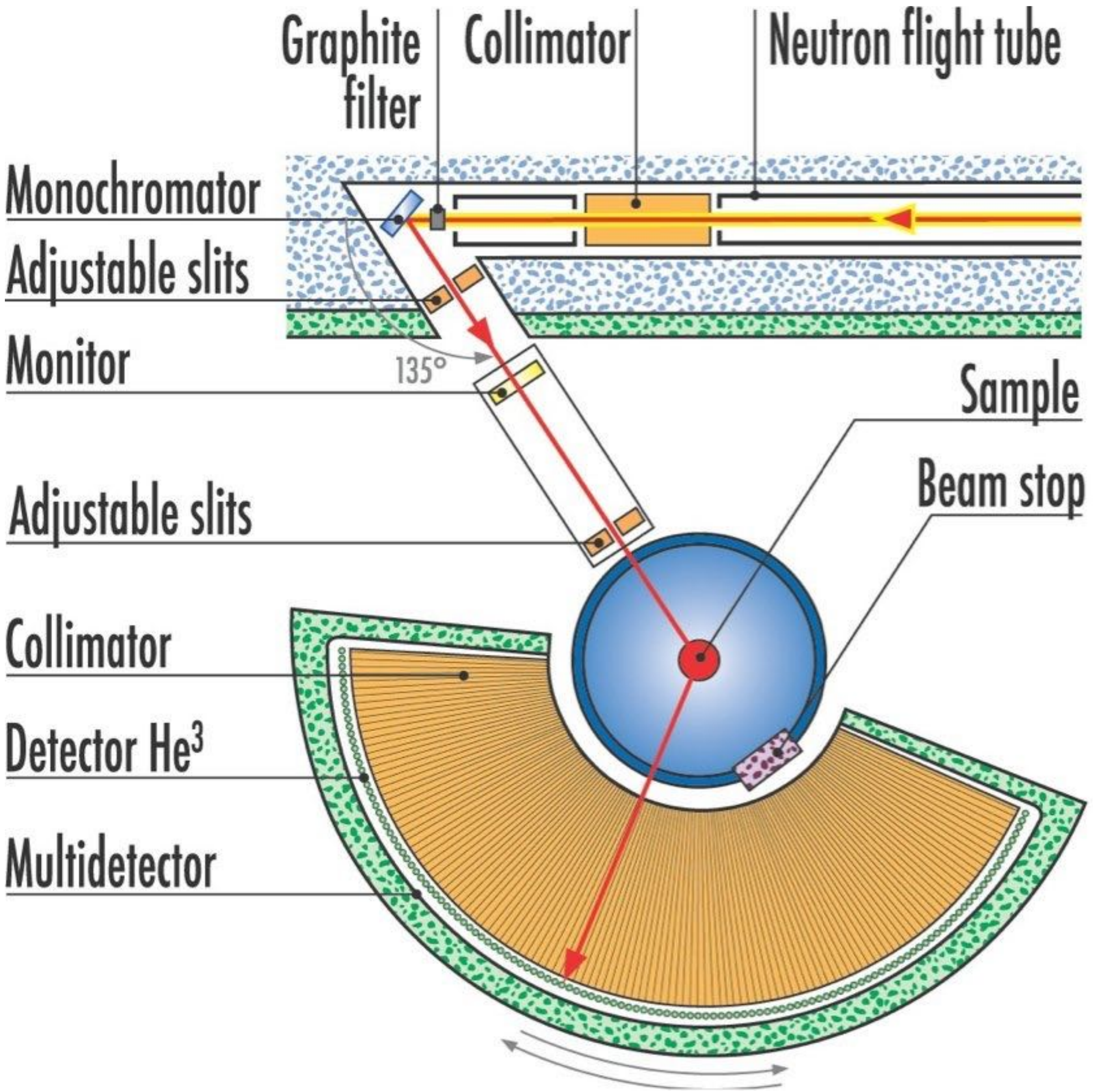




Measuring techniques

Elastic scattering

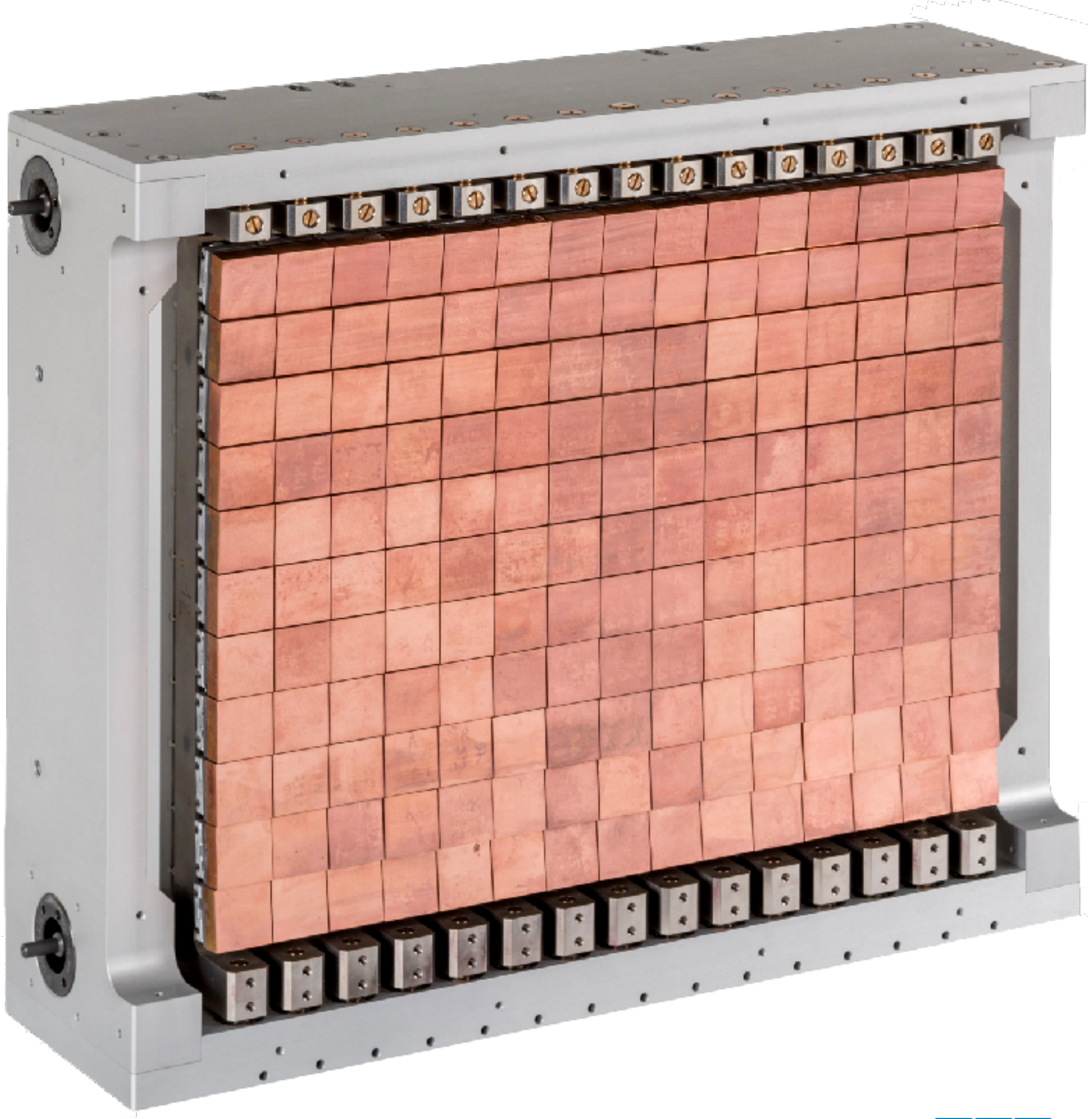
- Powder diffraction
  - collimator, filter
  - focusing monochromator
  - (spin polariser)
  - slits, monitor
  - collimators
  - detectors



Measuring techniques

Monochromators

- Array of single crystals
  - To select energy (and polarisation)
  - Cu, Si, HOPG, Heusler, Diamond…
  - Flat, focusing vertically (diff.), vertically and horizontally (spec.)
  - Controlled mosaic distribution by plastic deformation of Cu crystals at high-temperature



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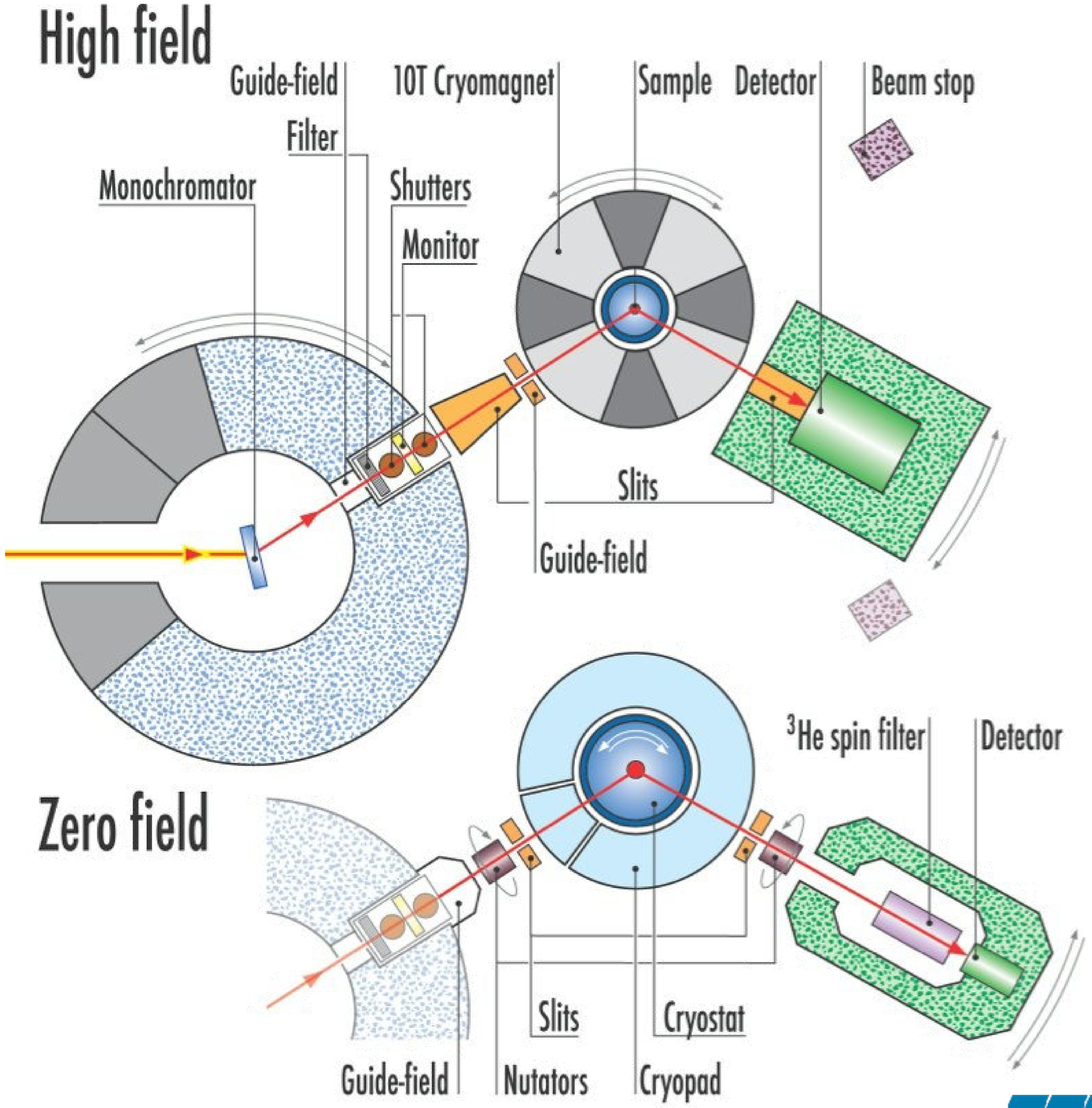
Measuring techniques

Elastic scattering

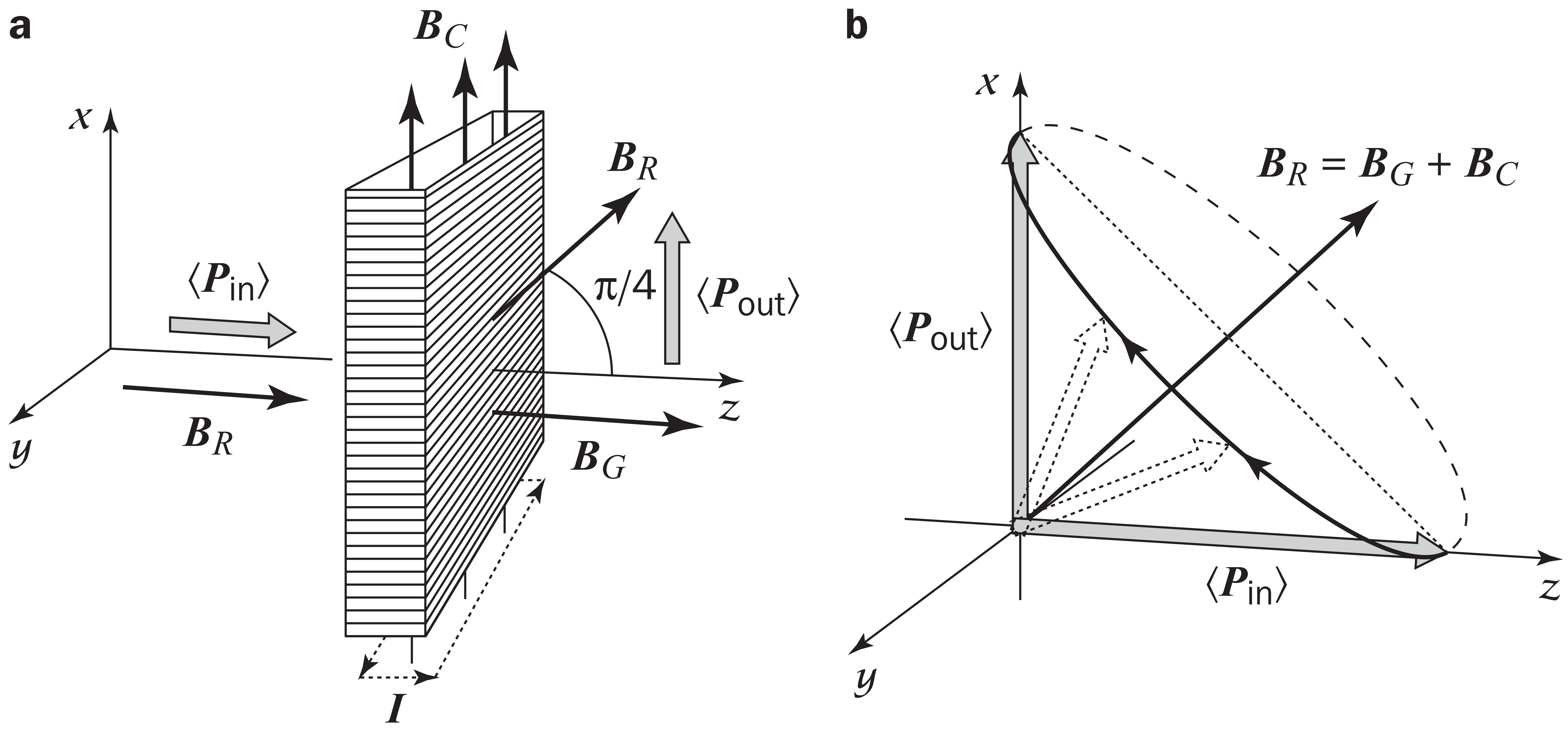
- Crystal diffraction
  - (polarising) monochromator
  - harmonic filters
  - monitor, (spin flipper)
  - collimation, slits, (cradle)
  - (polarimeter & spin analyser)
  - single or PSD detector



Measuring techniques

Spin flippers

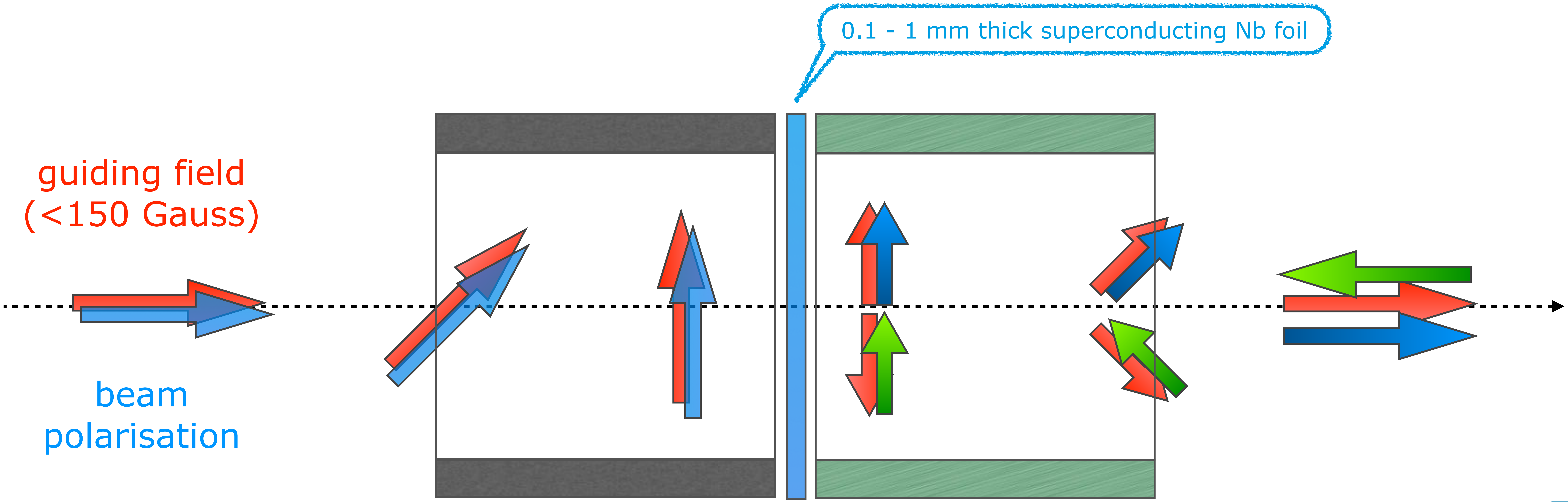
- Mezei's flipper: sensitive to environmental magnetic fields, neutron wavelength dependent, for cold and thermal neutrons only



Measuring techniques

Spin flippers

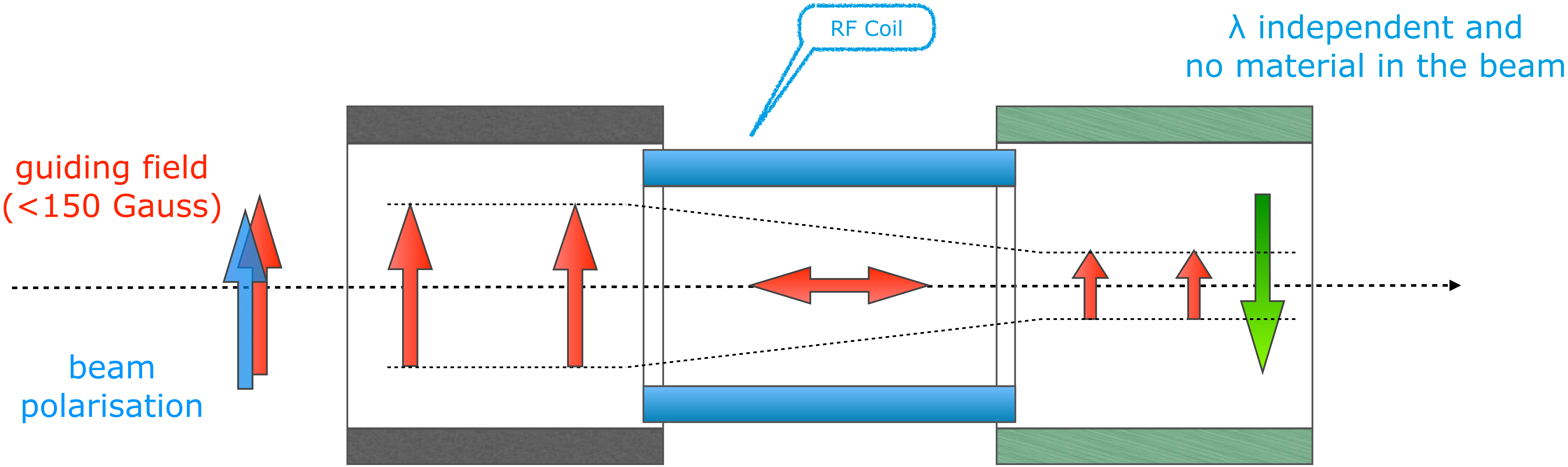
- Cryoflipper (Tasset’s flipper): neutron wavelength independent, 99.9% efficiency down to 0.3 Å, operates in up to 400 G stray fields



Measuring techniques

Spin flippers

- RF flipper: in the rotating frame of the neutron, the polarisation follows the effective field and rotates adiabatically.



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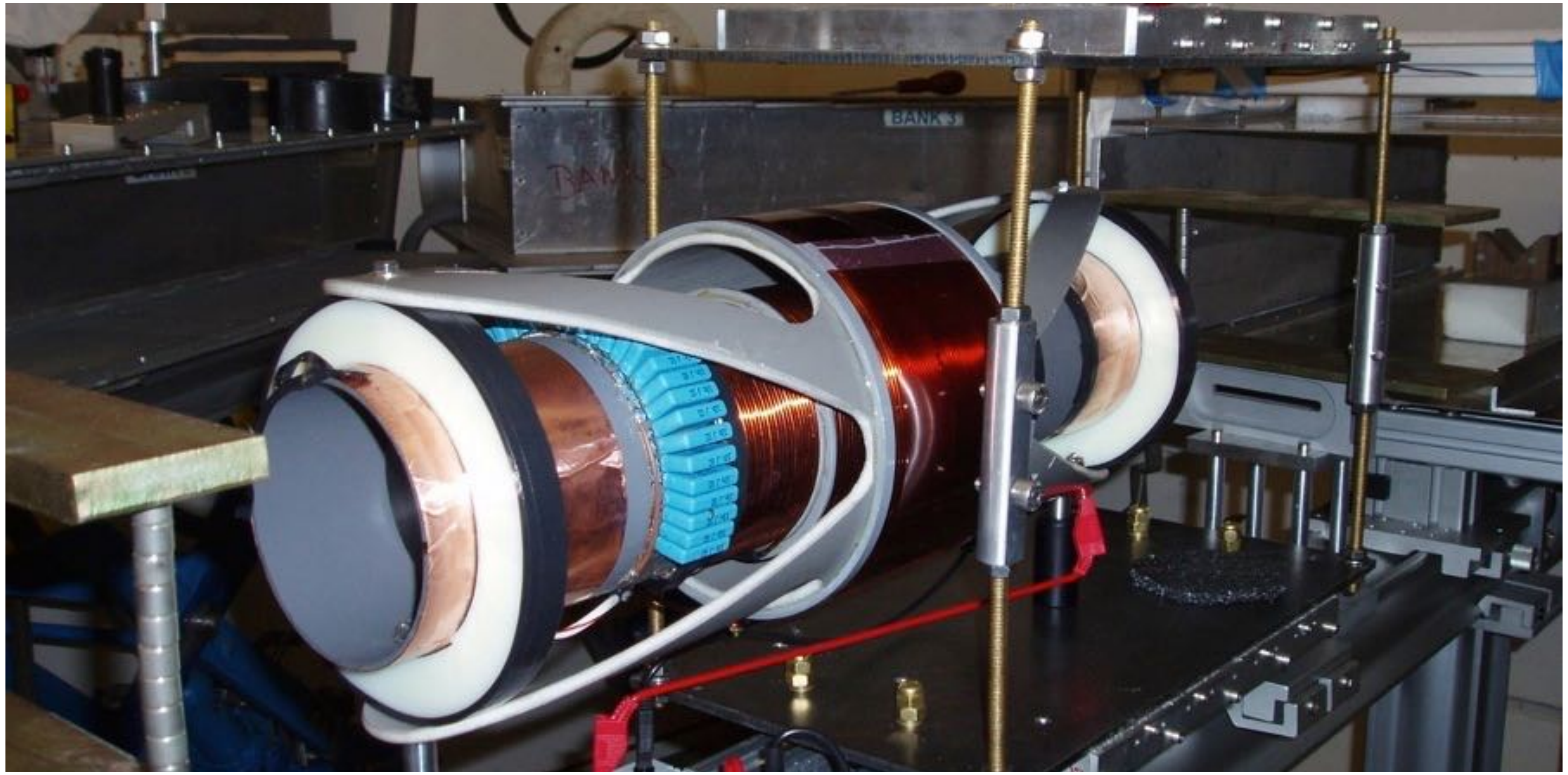


λ independent

no material
in the beam

Measuring techniques

Spin polariser & flipper

- ^{3}He spin filters are characterised by their opacity:

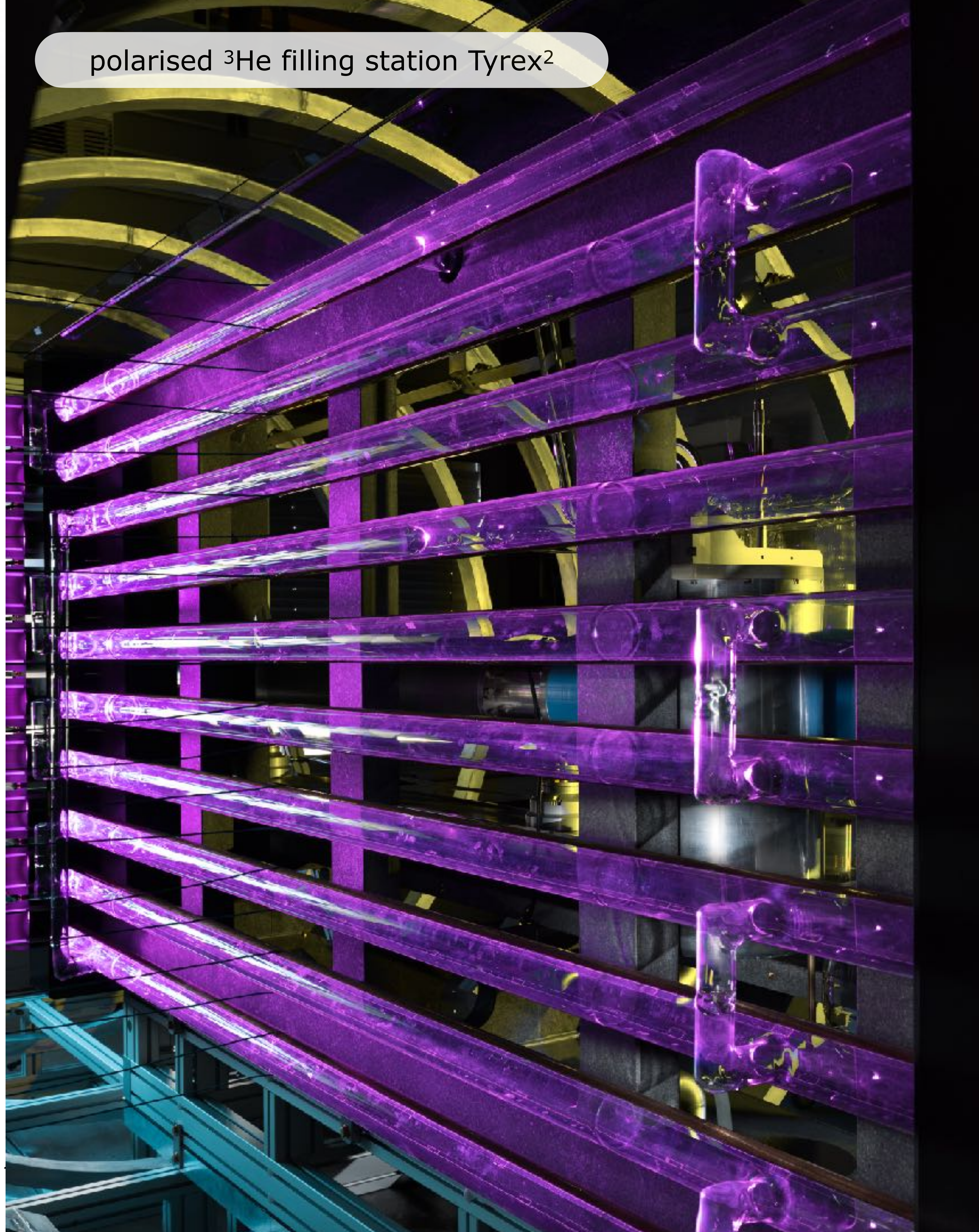
$$\mathcal{O} = N \ell \, \sigma_{\upharpoonleft\downharpoonright} \simeq 0.0732 \, p[\text{bar}] \, \ell[\text{cm}] \, \lambda[\text{Å}]$$

- The total transmission and polarising efficiency are:

$$T_n \propto \cosh\left(\mathcal{O} P_{^3\text{He}}\right)$$

$$P_\epsilon = \tanh(\mathcal{O} P_{^3\text{He}})$$

polarised ^{3}He filling station Tyrex[2]



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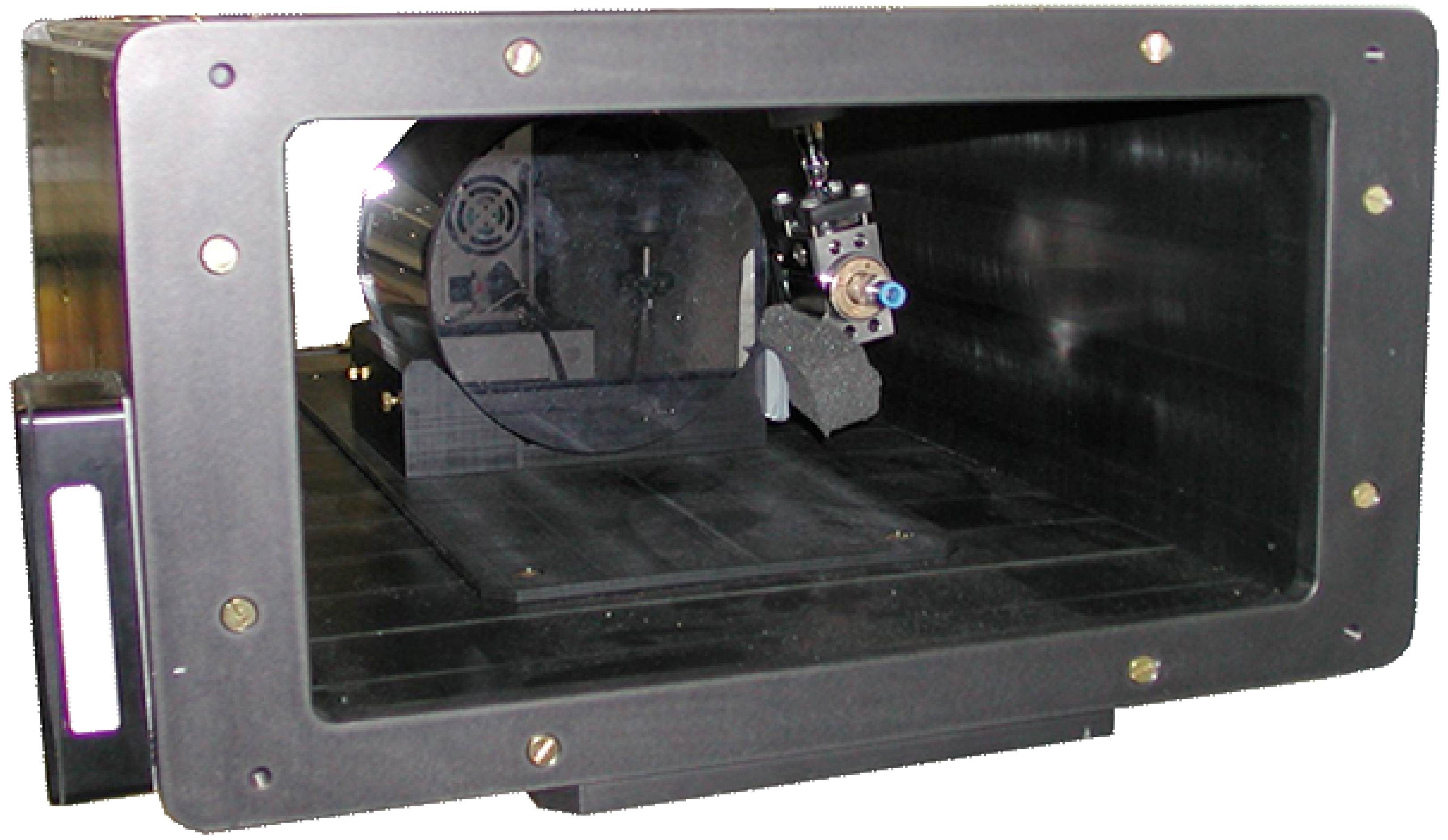
Banna-shaped Quartz cell

Quartz cell

Si-windowed cell



magneto static cavity

Measuring techniques

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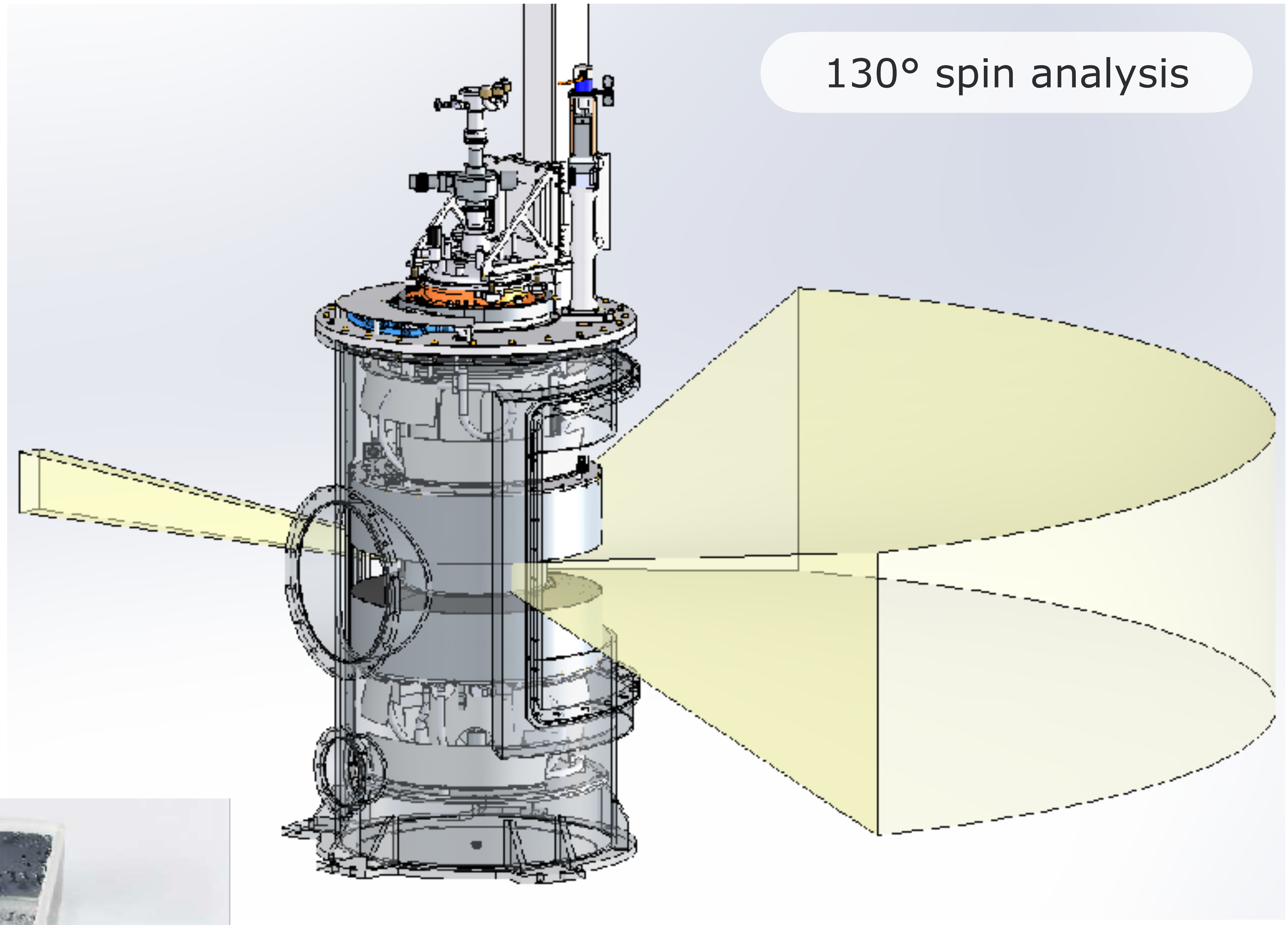
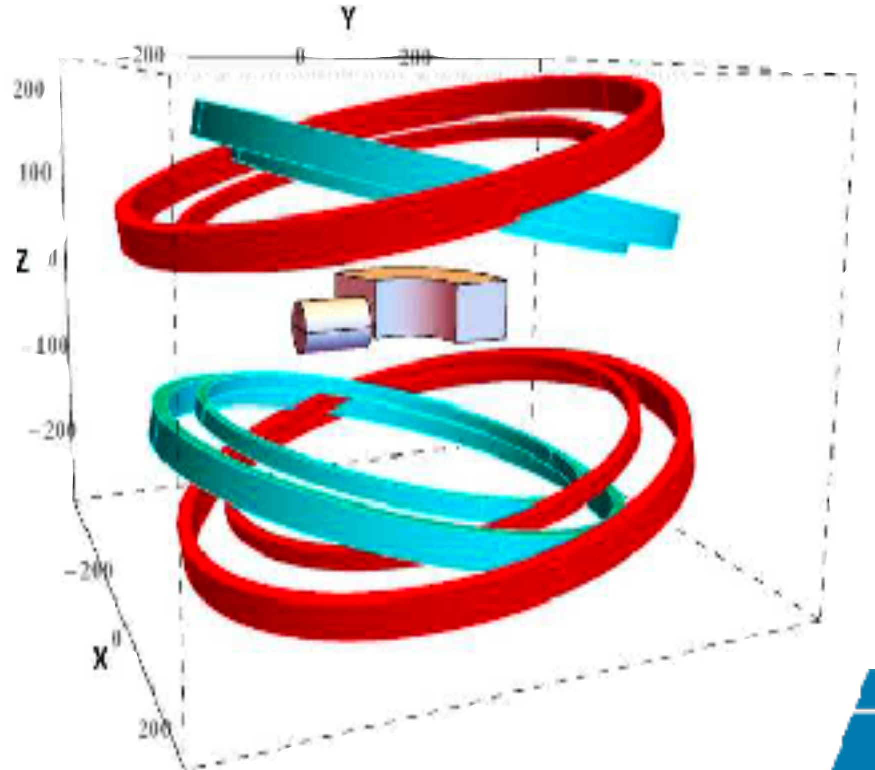




Measuring techniques

Manipulation of the beam polarisation (polarimeter)

- Cryopad:

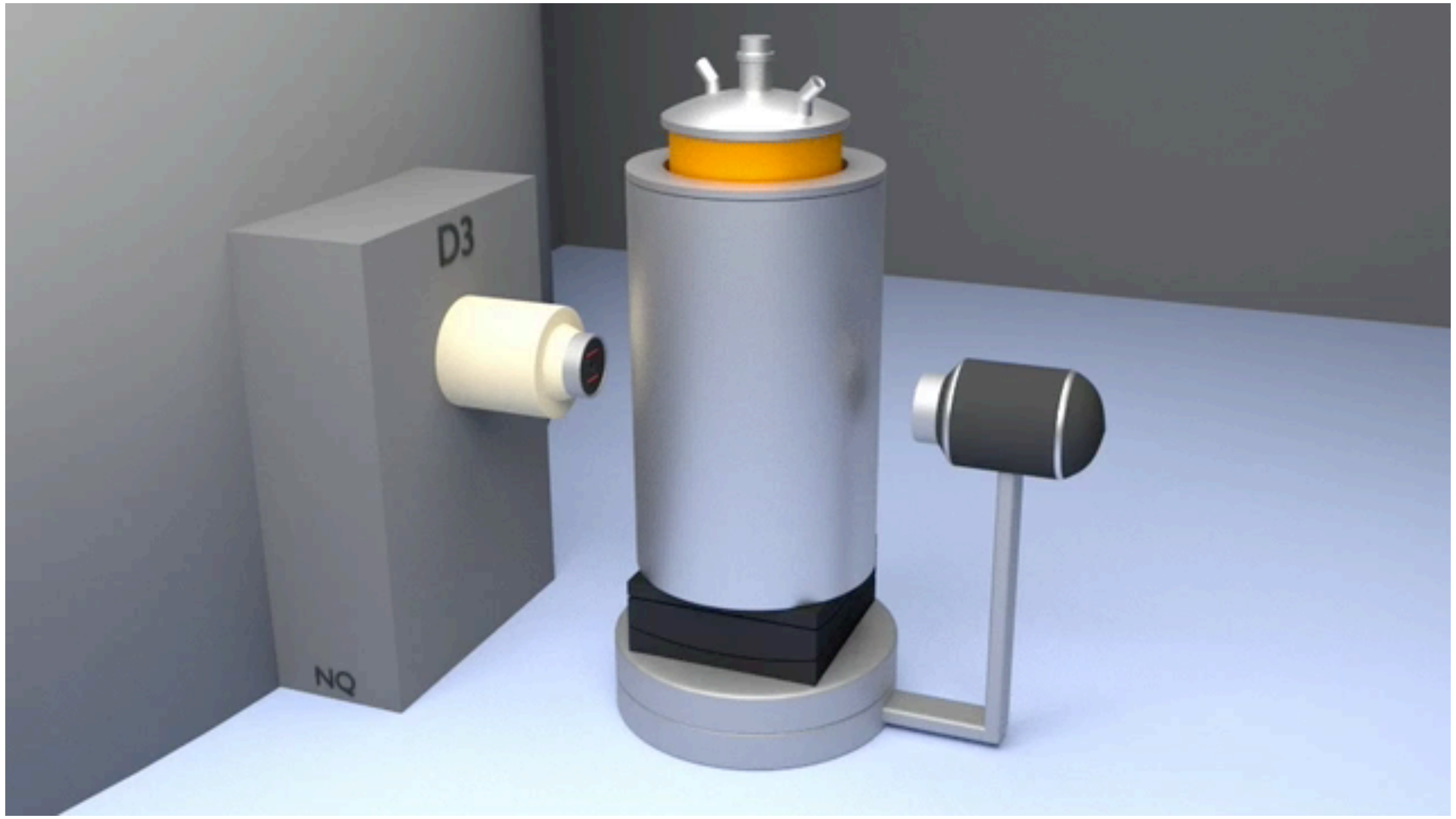
  Cryogenic

  Polarisation

  Analysis

  Device

- sample in zero field
- manipulates the beam polarisation vector before and after the sample



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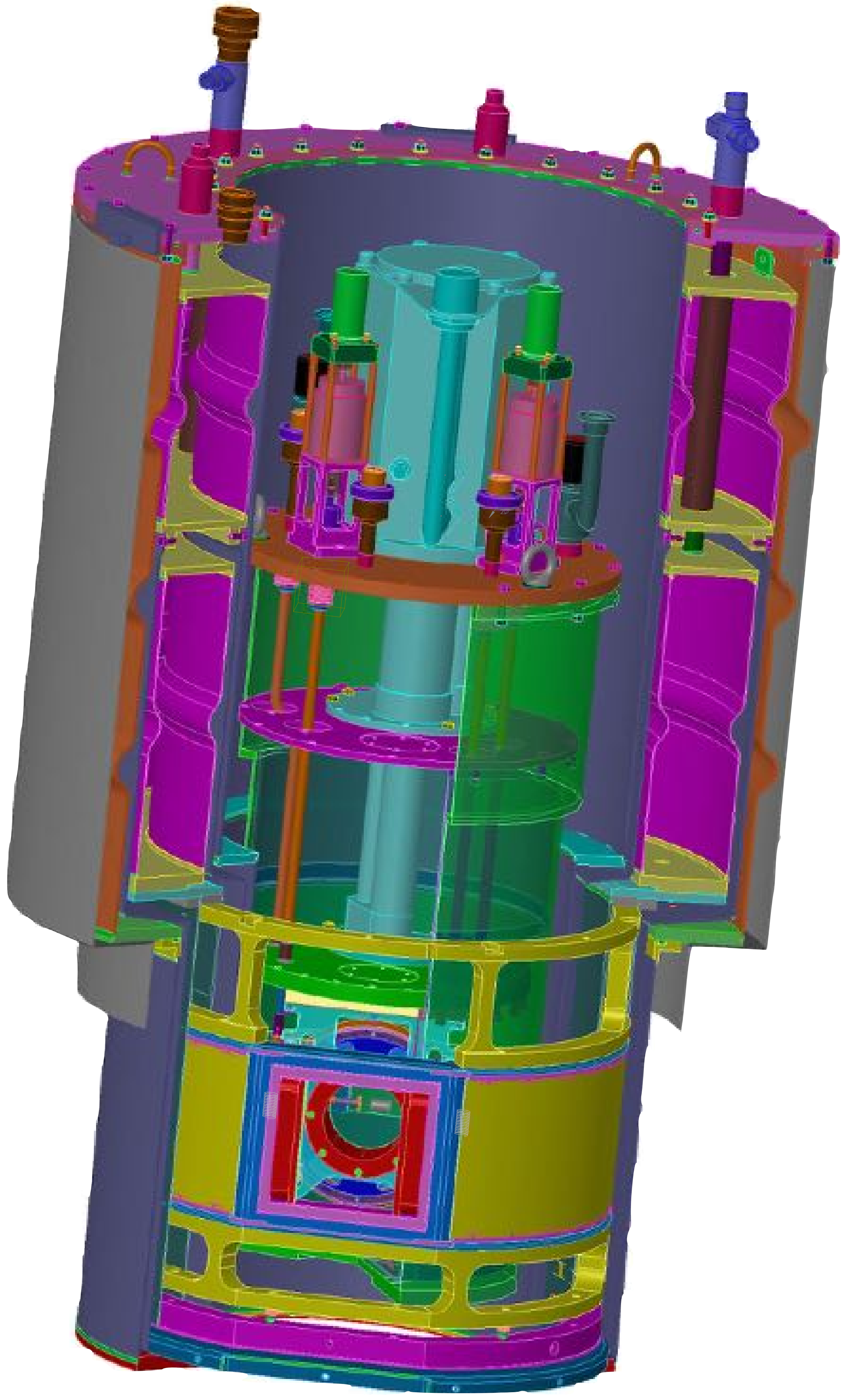


Measuring techniques

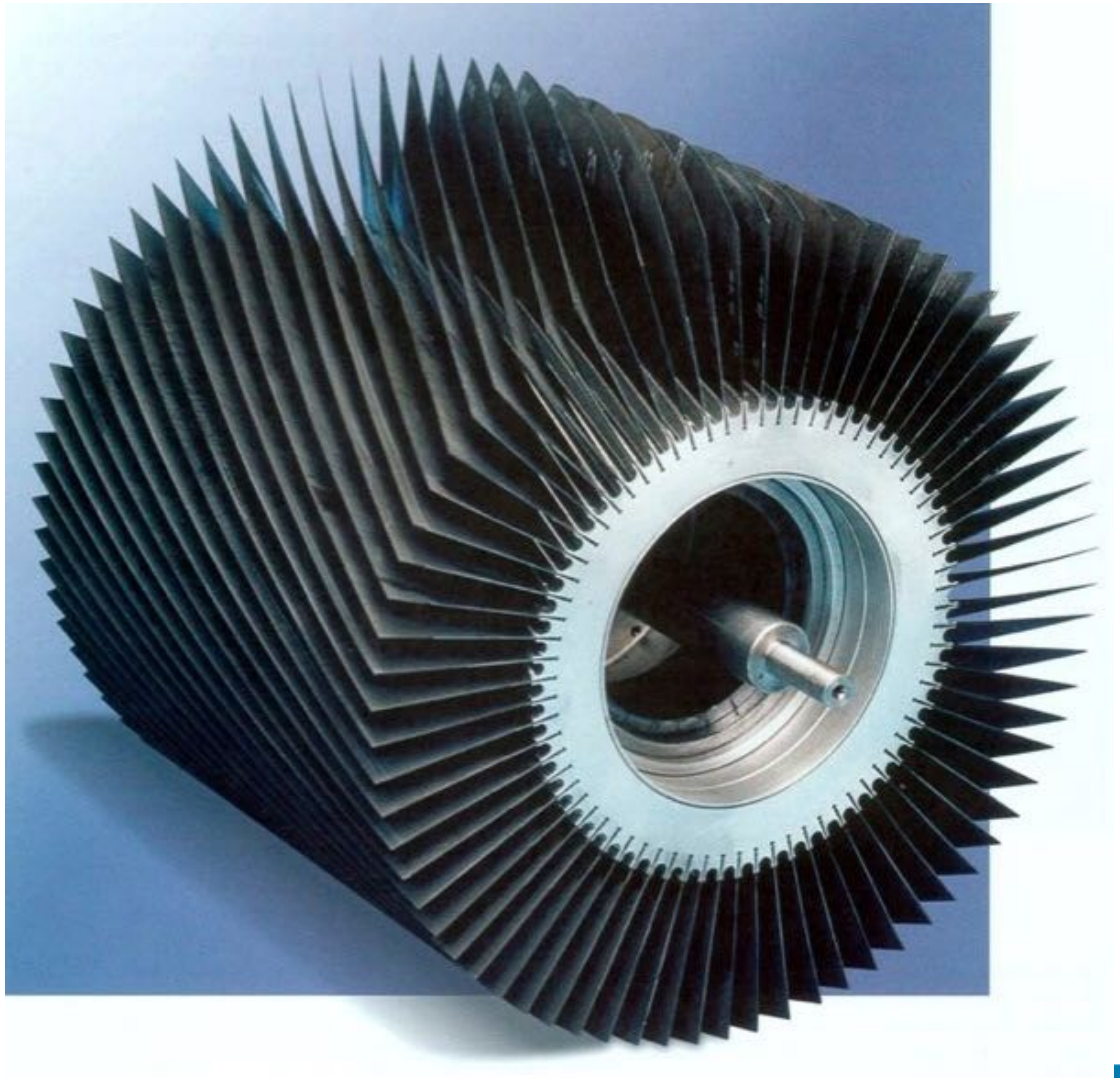
Elastic scattering

- Small angle neutron scattering (SANS)
  - velocity selector, (polariser + flipper), filter, (choppers in TOF mode), collimators, slits, detector(s) in evacuated chamber

Measuring techniques

Velocity selectors

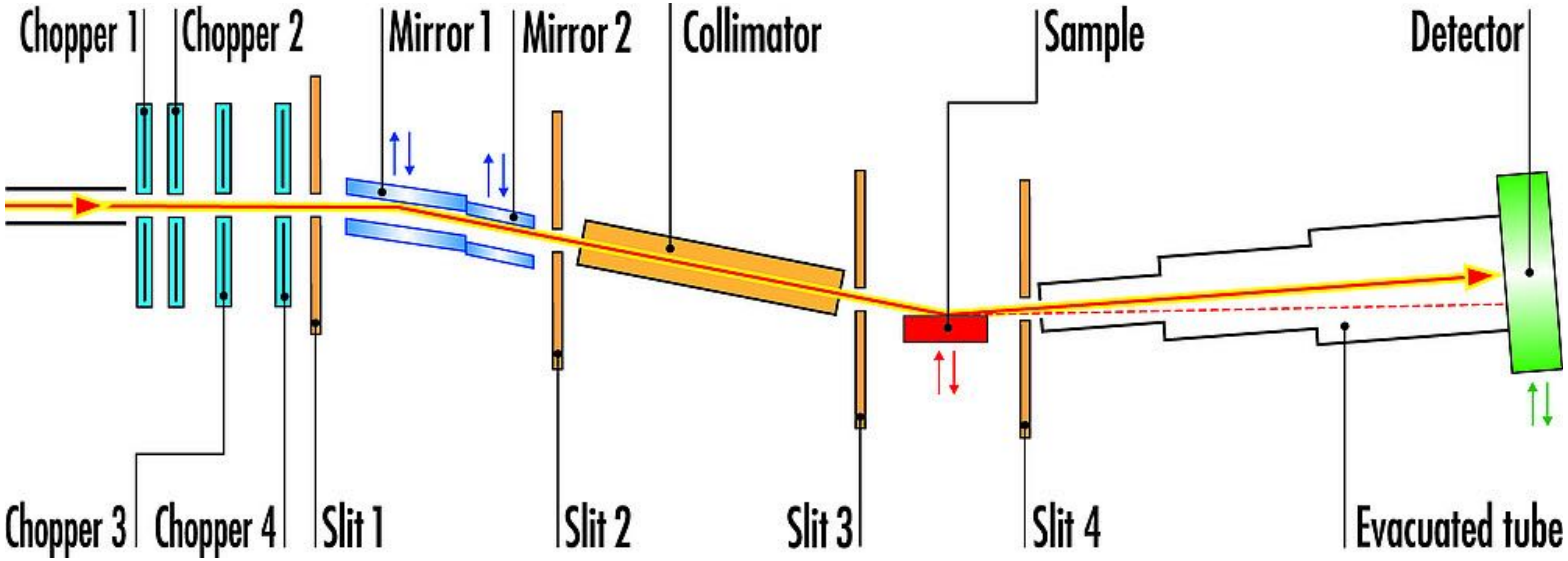
- Large Δλ/λ: typically 10 to 12% fwhm resolution
- High transmission: from 75 to 95%
- Rotation frequency: from 1 to +5 kHz
- Multi-disc or multi-blade



Measuring techniques

Specular & off-specular scattering

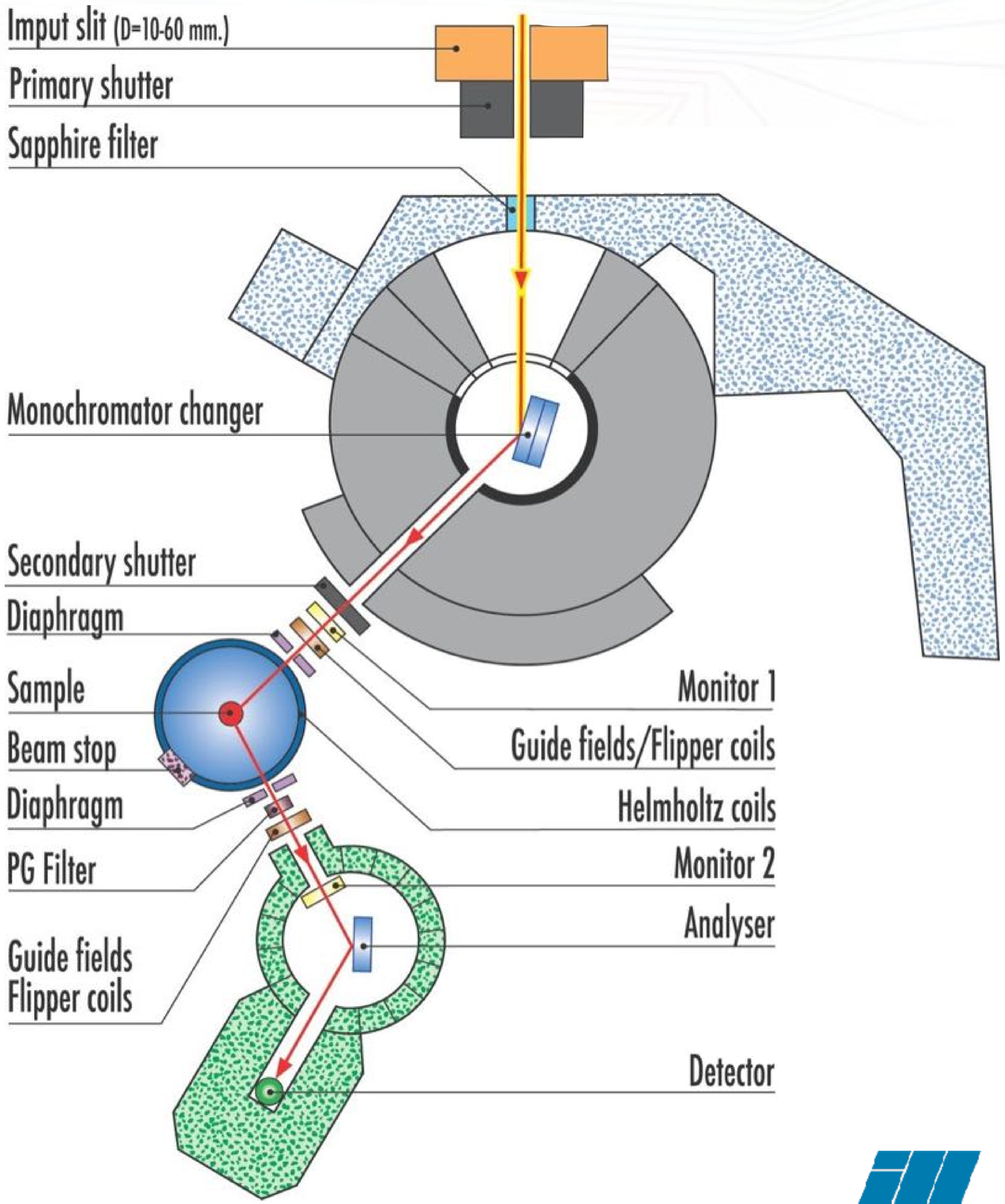
- Horizontal or vertical reflectometry
  - monochromator or choppers (TOF mode), (polariser + flipper), monitor, collimator, slits, detector in evacuated chamber



Measuring techniques

Inelastic scattering

- Three-axis spectroscopy
  - collimator, (filter, velocity selector)
  - (polarising) monochromator
  - slits before (and after) sample
  - (spin) analyser
  - single or PSD detector
  - very low neutron background



Measuring techniques

Inelastic scattering

- "Two-axis" spectroscopy
  - collimator, (filter, velocity selector)
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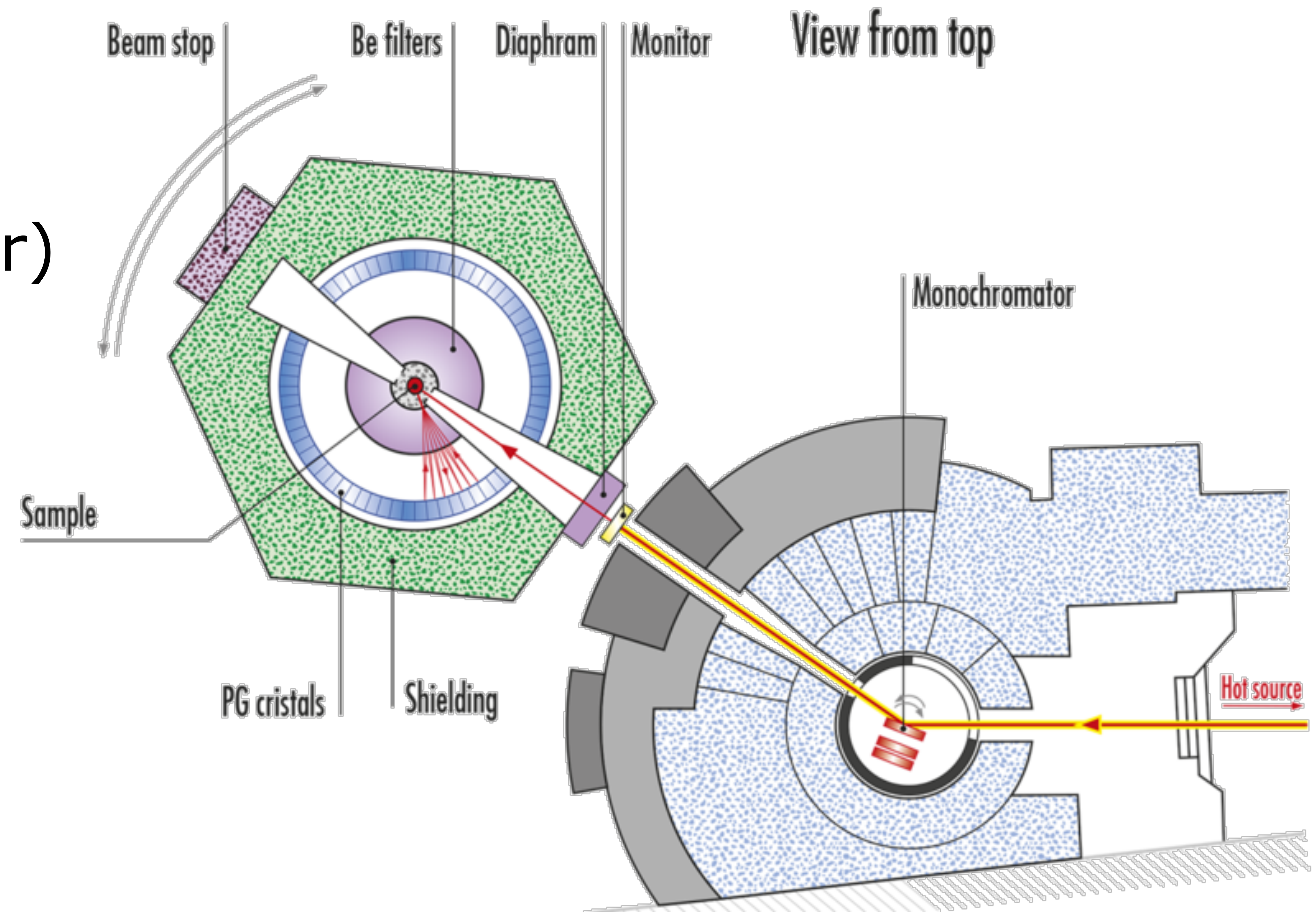


Scientific
113ILHV49 – IN14

Measuring techniques

Inelastic scattering

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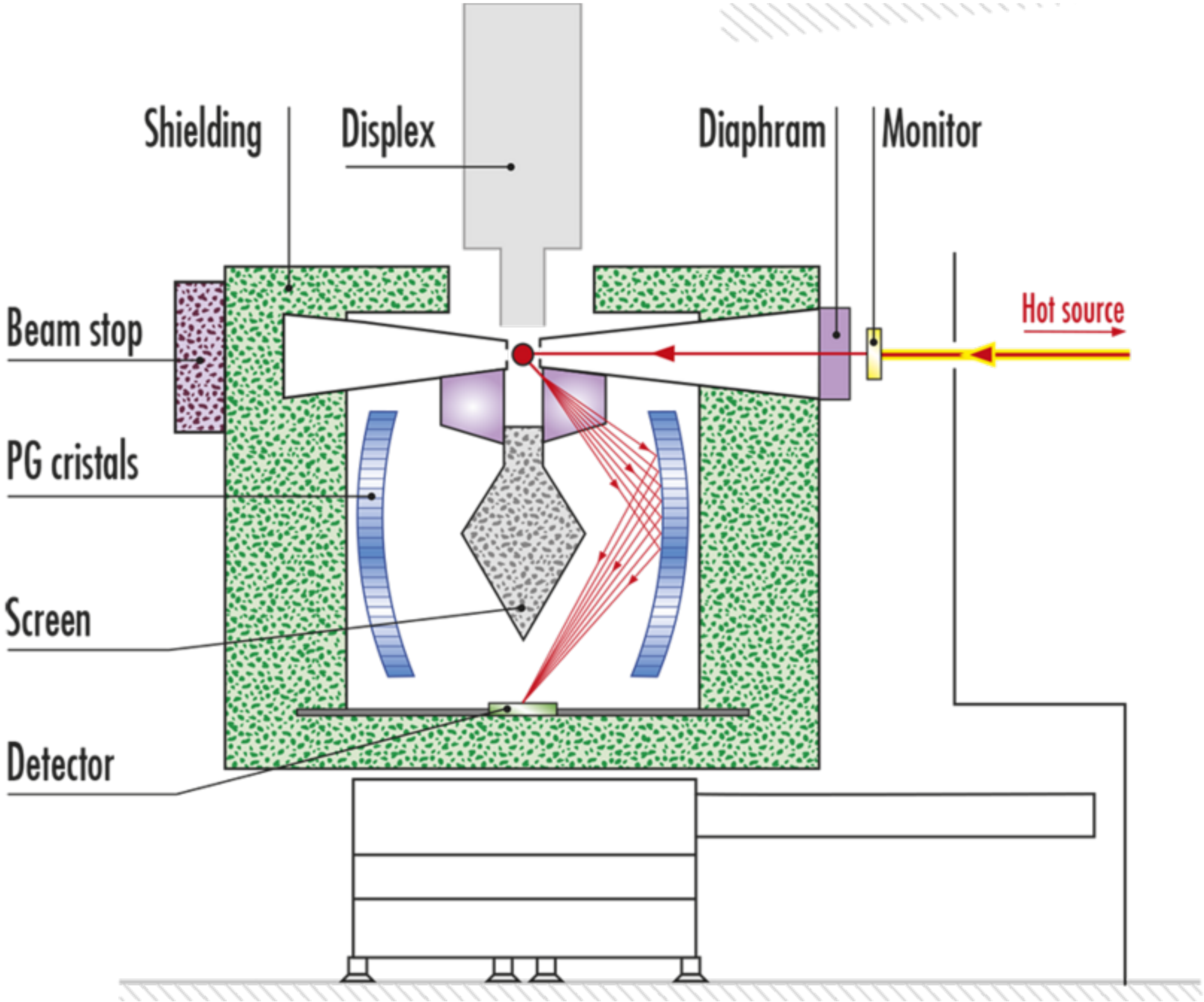
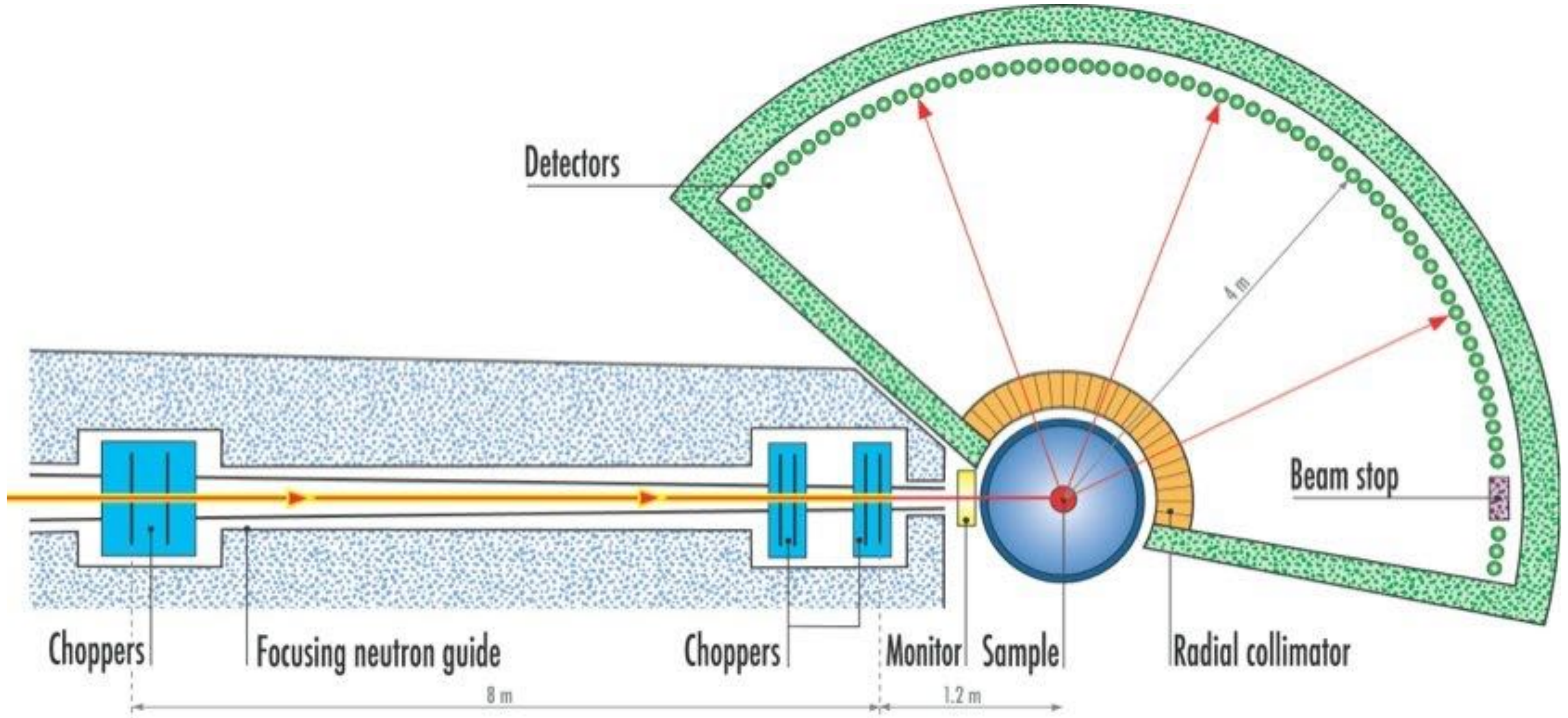
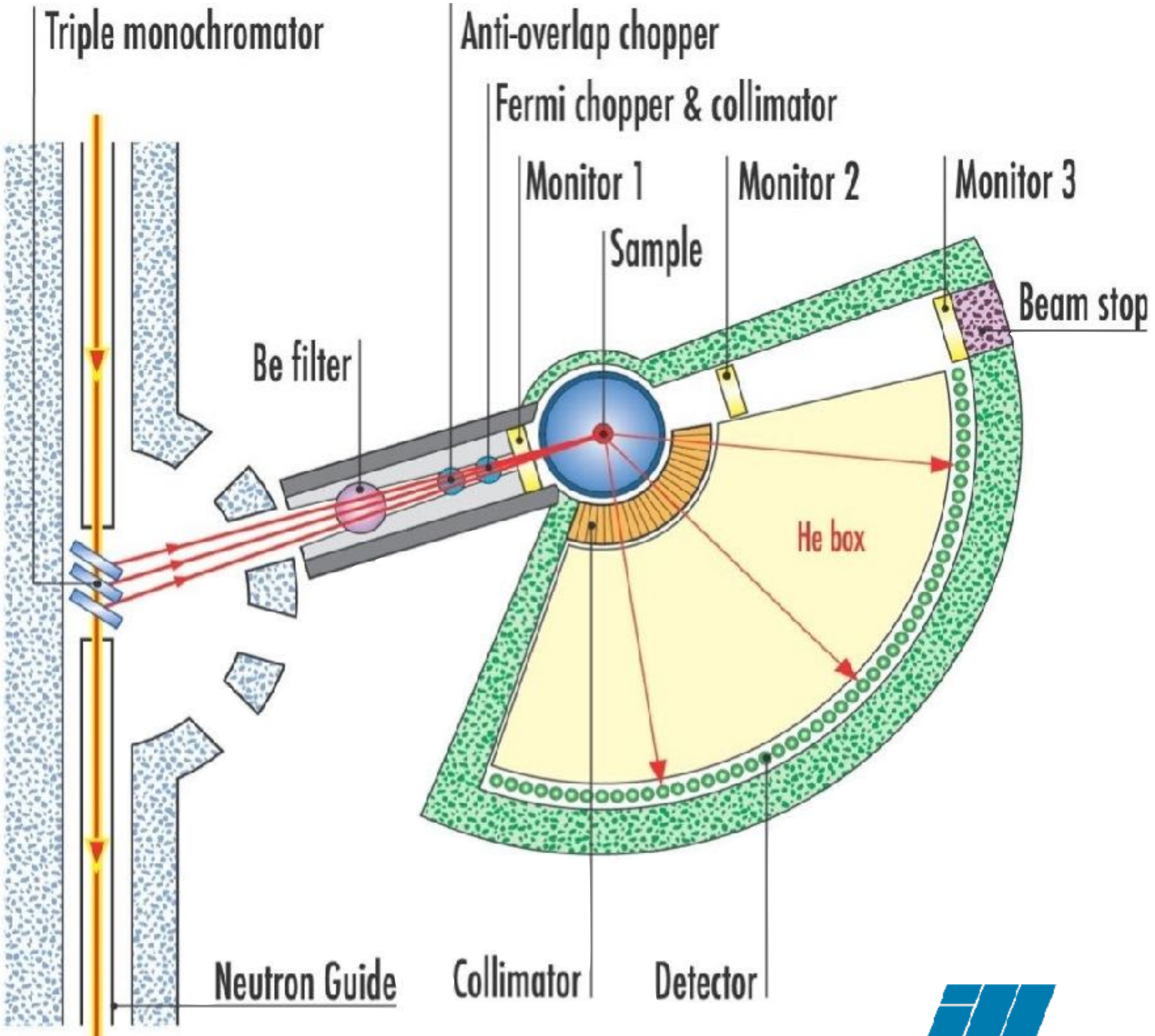


Measuring techniques

Inelastic scattering

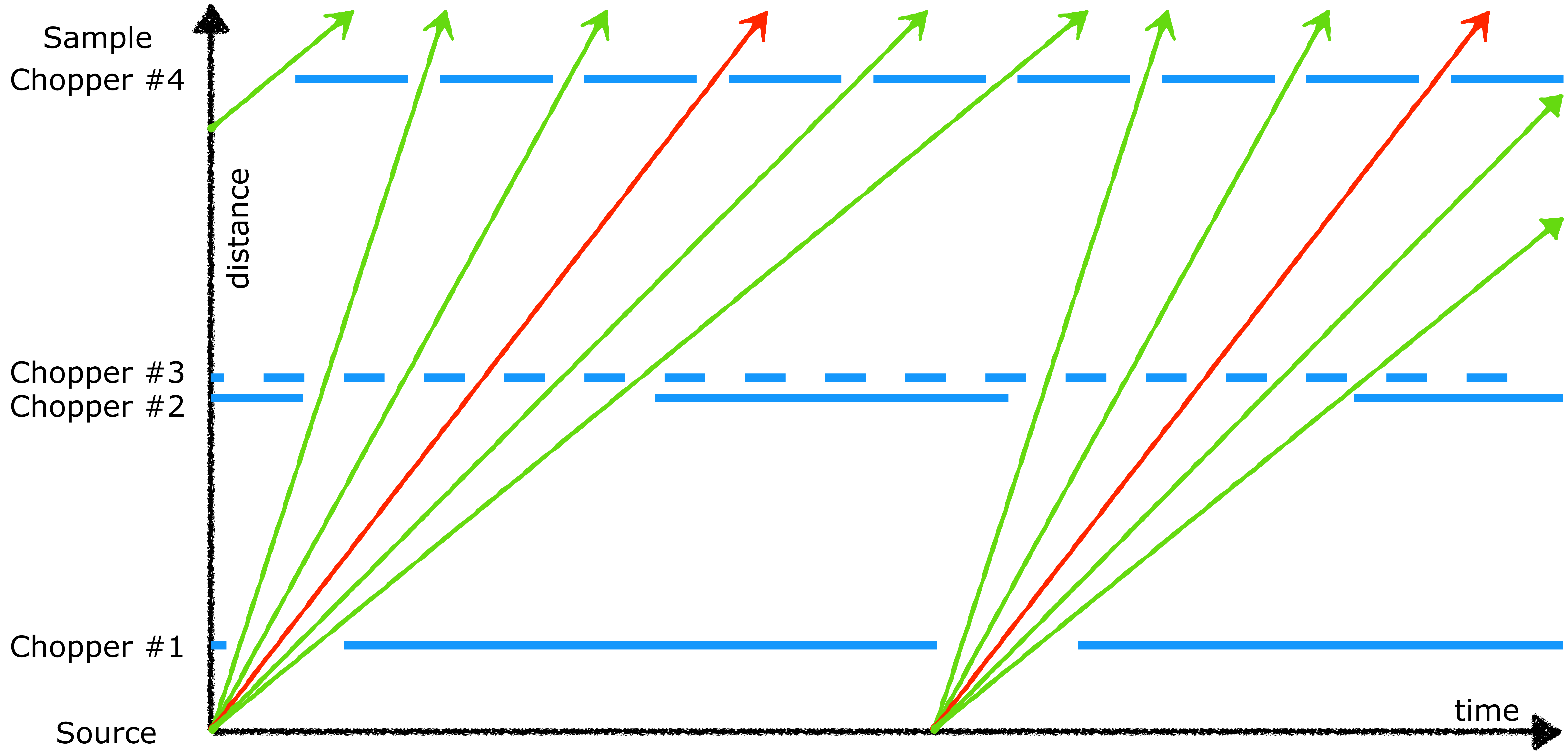
- Time of flight spectroscopy
  - choppers, monitor, collimator
  - (monochromator, filter, choppers)





Measuring techniques

Choppers - Time of flight technique



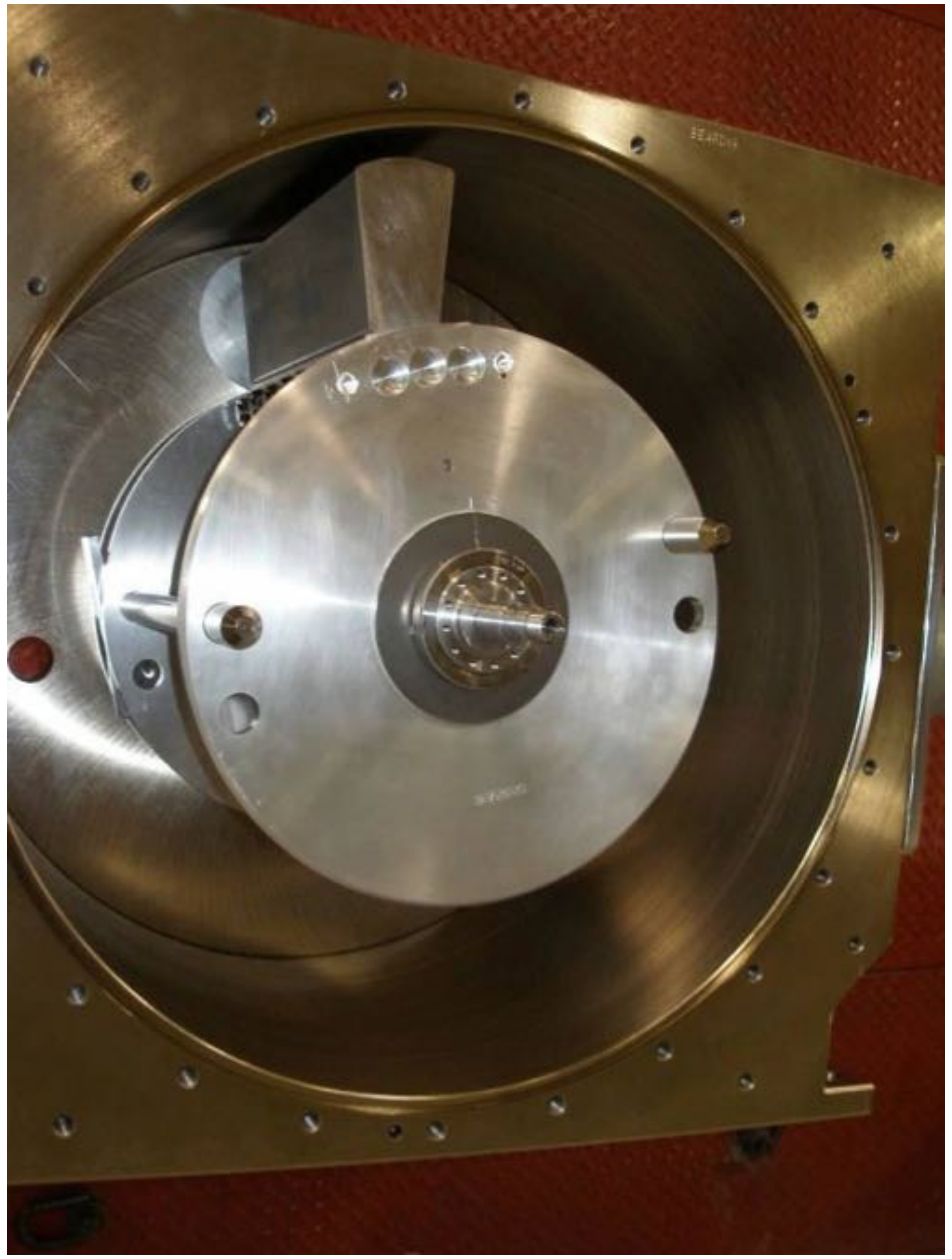
Repetition rate multiplication by M. Russina & F. Mezei NIM A **604** (2009) 624

Measuring techniques

Choppers - Time of flight technique

- T0 choppers to stop fast neutrons (pulsed sources)
- Bandwidth-limiting choppers (prevent frame overlap)
- E_0 or Fermi choppers to transmit a very narrow bandwidth of neutrons (e.g. to define E_i)

assembled T_0 chopper unit



T_0 single-blade rotor

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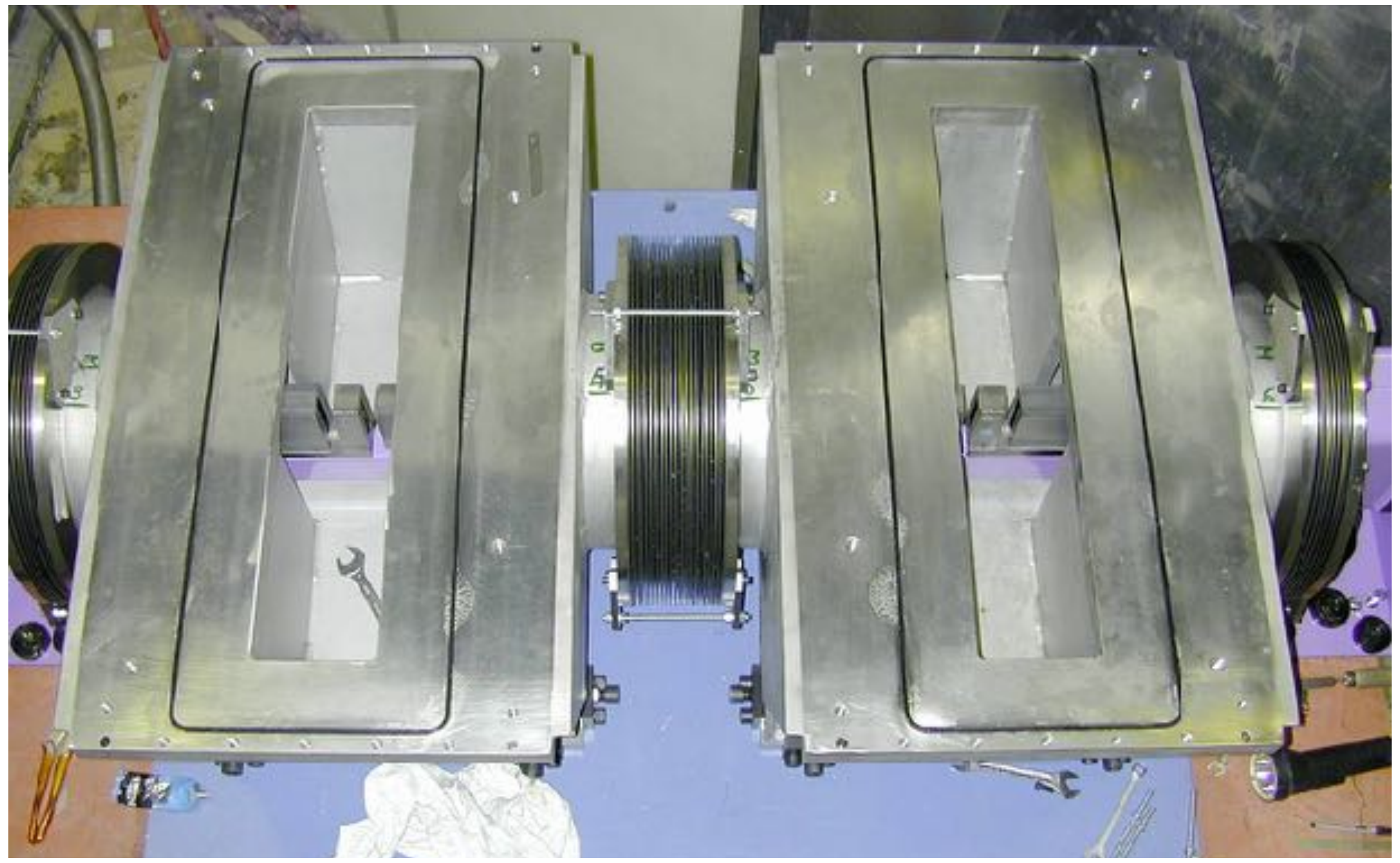
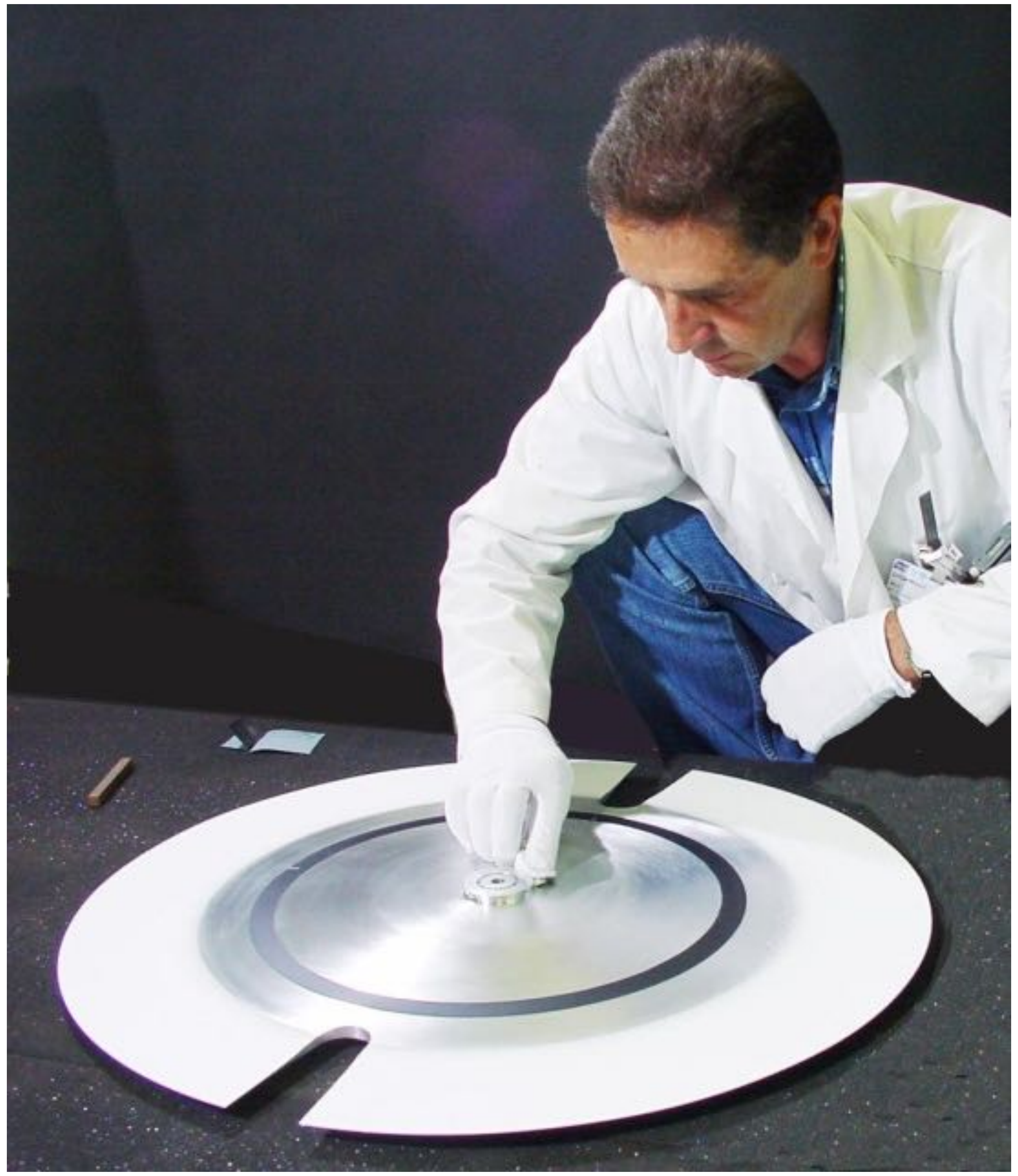


IN5 chopper housings

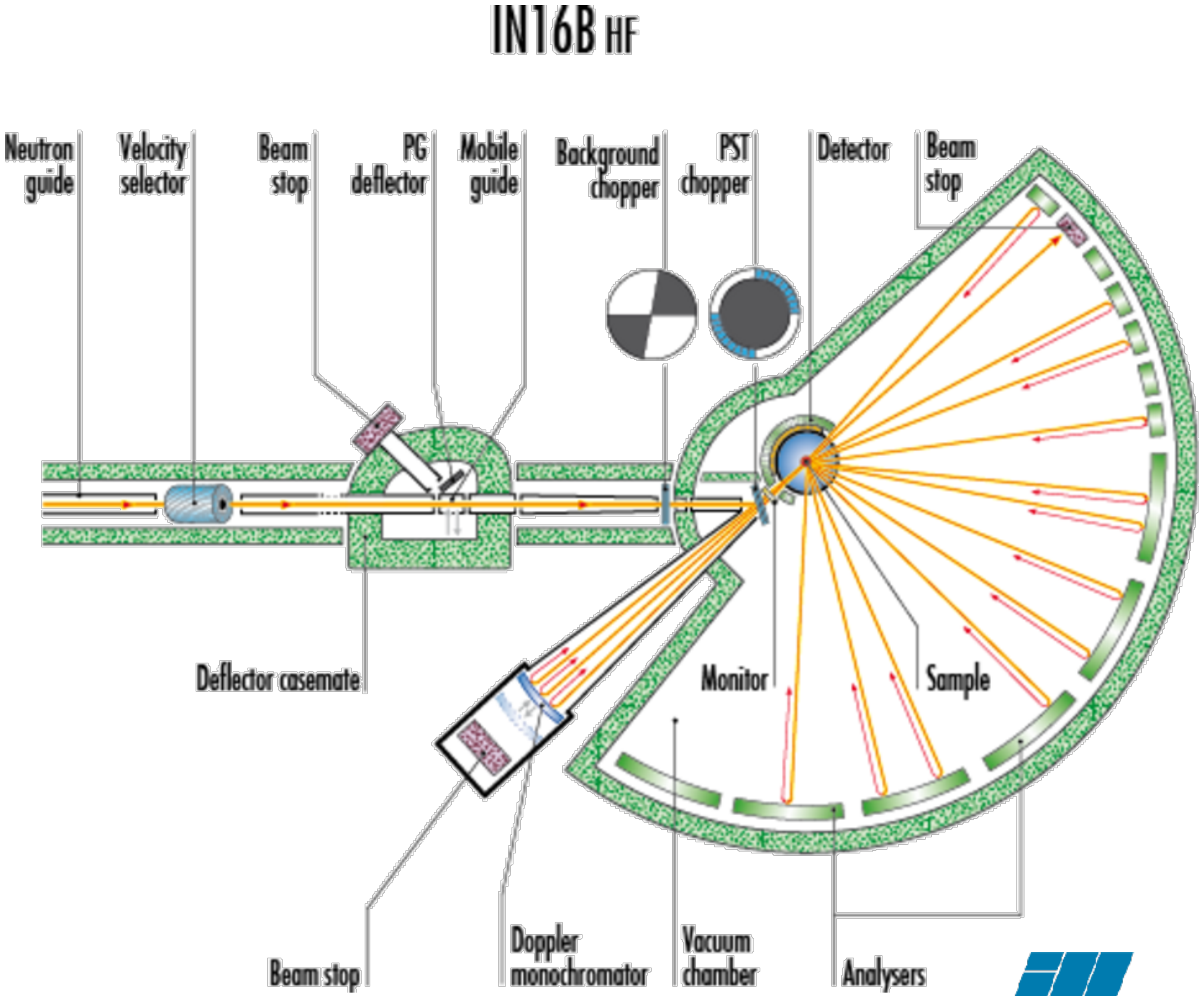


IN5 chopper disc

Measuring techniques

Quasi-elastic scattering

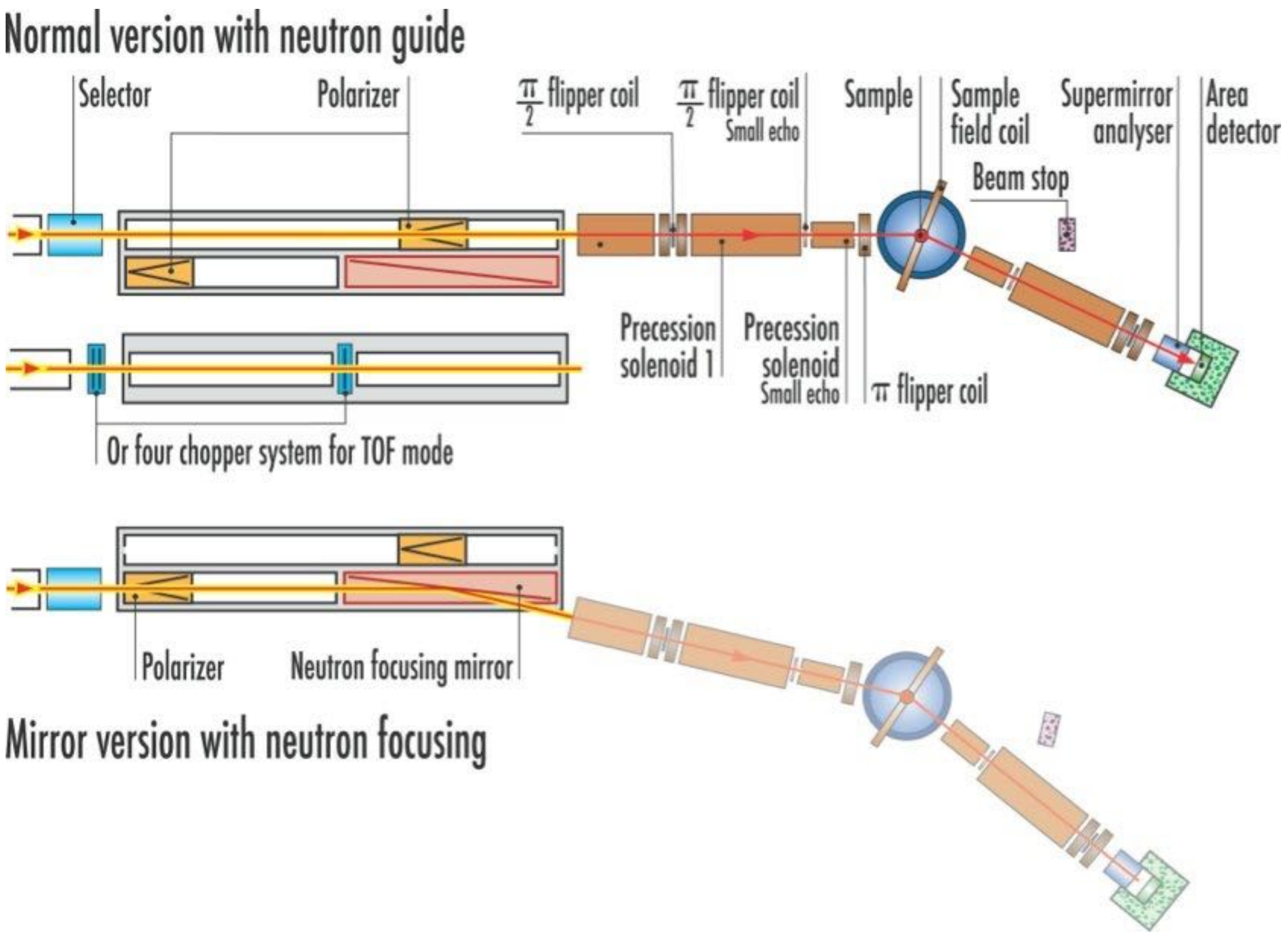
- Backscattering
  - velocity selector
  - background and phase space transformation choppers
  - Doppler monochromator
  - analysers
  - position sensitive detector (PSD)



Measuring techniques

Quasi-elastic scattering

- Neutron spin echo
  - velocity selector
  - polarising supermirrors
  - precession solenoids
  - π and π/2 flippers
  - spin analyser, PSD detector
  - choppers for TOF mode



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