Update on ^{3}He spin filter developments in Europe

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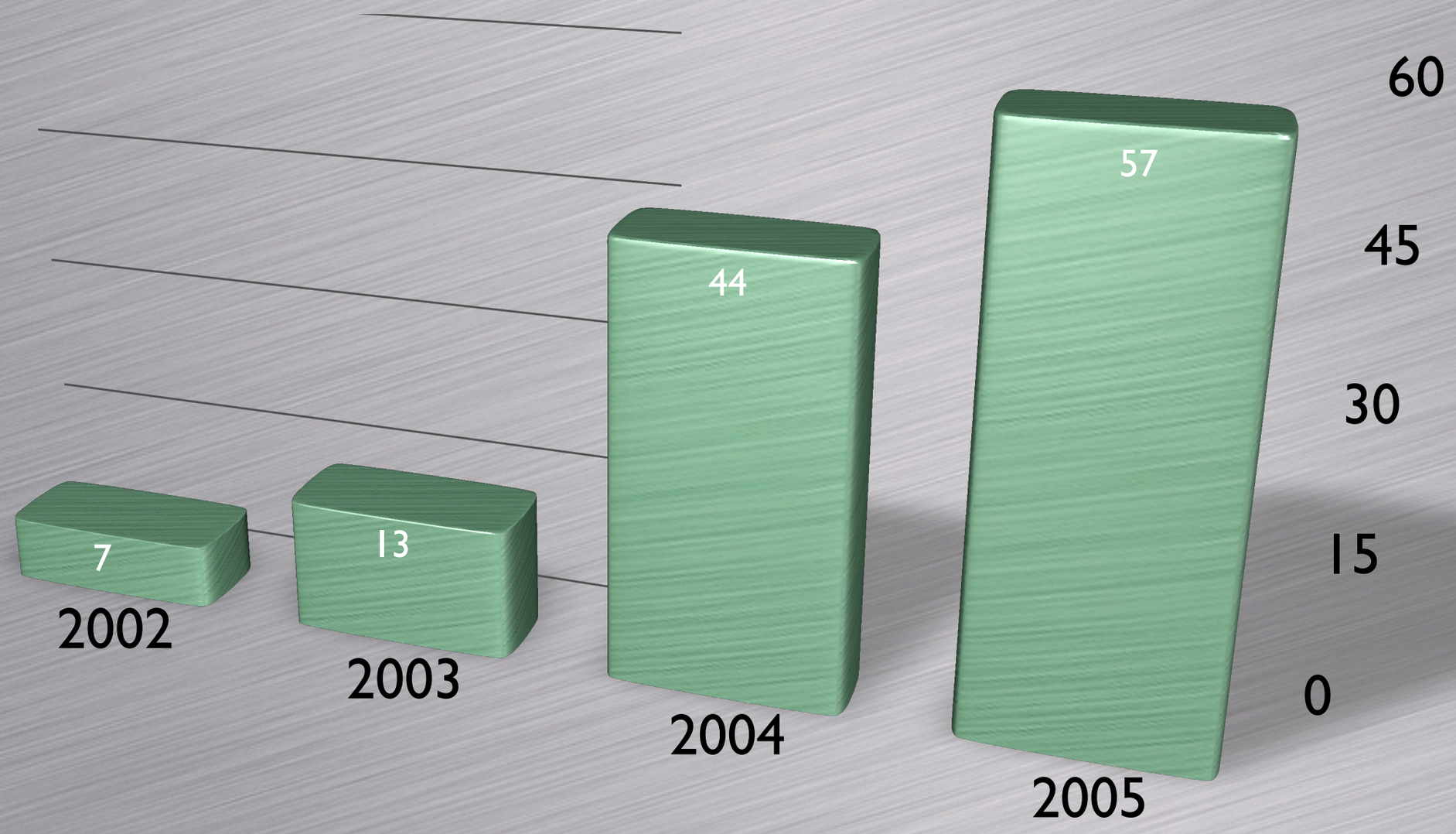
^{3}He Neutron spin filters

Production for scheduled experiments (bar.l)



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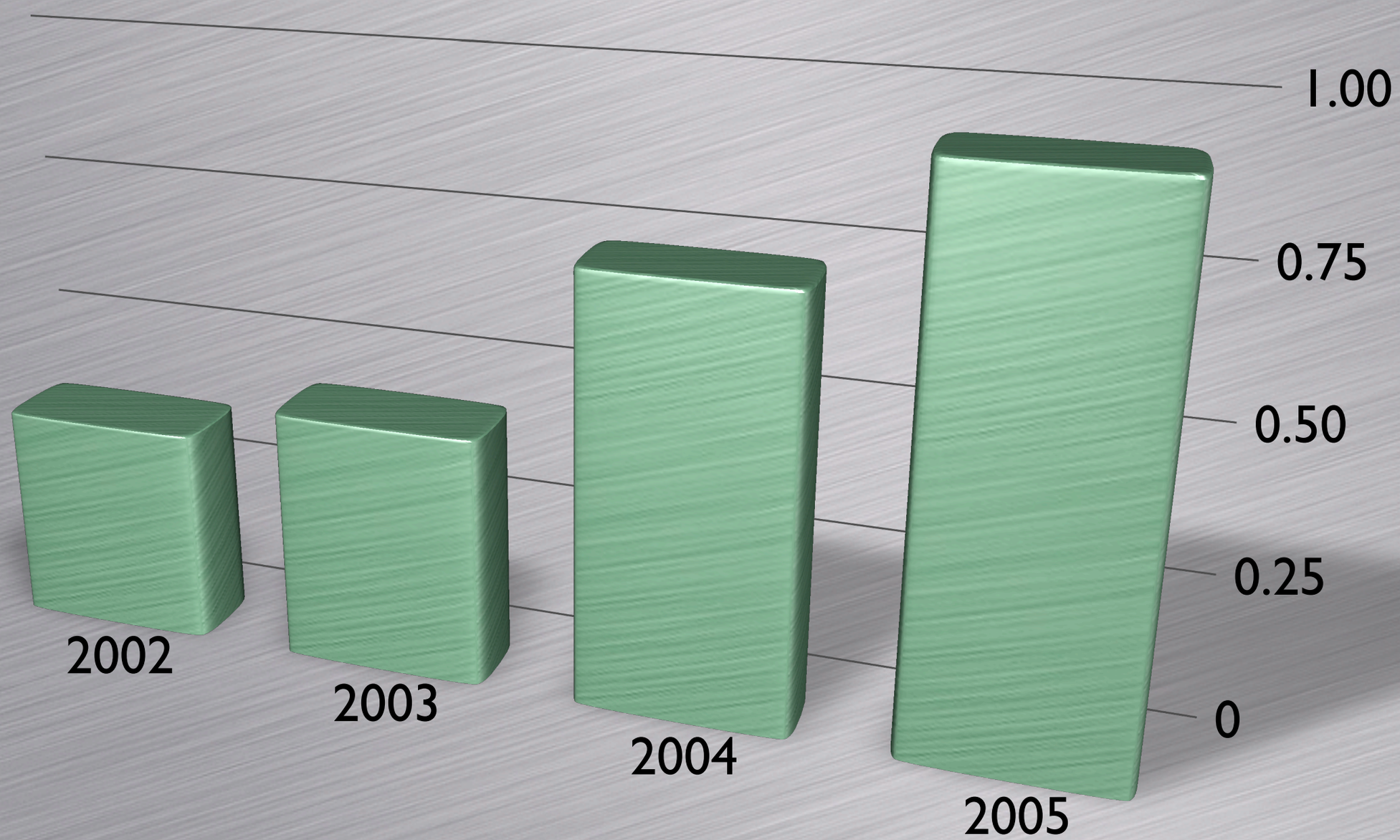
Average quantity of polarised ^{3}He per cell (bar.l)



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polarising the gas…

SEOP

- gas polarised directly at the desired pressure
- long spin exchange time constant
- low production rate
- safety issues on instr.
- low investment cost

MEOP

- gas polarised at low pressure (≈ 0.6 mbar)
- short metastability exchange time constant
- high production rate
- scaled for a facility
- high investment cost

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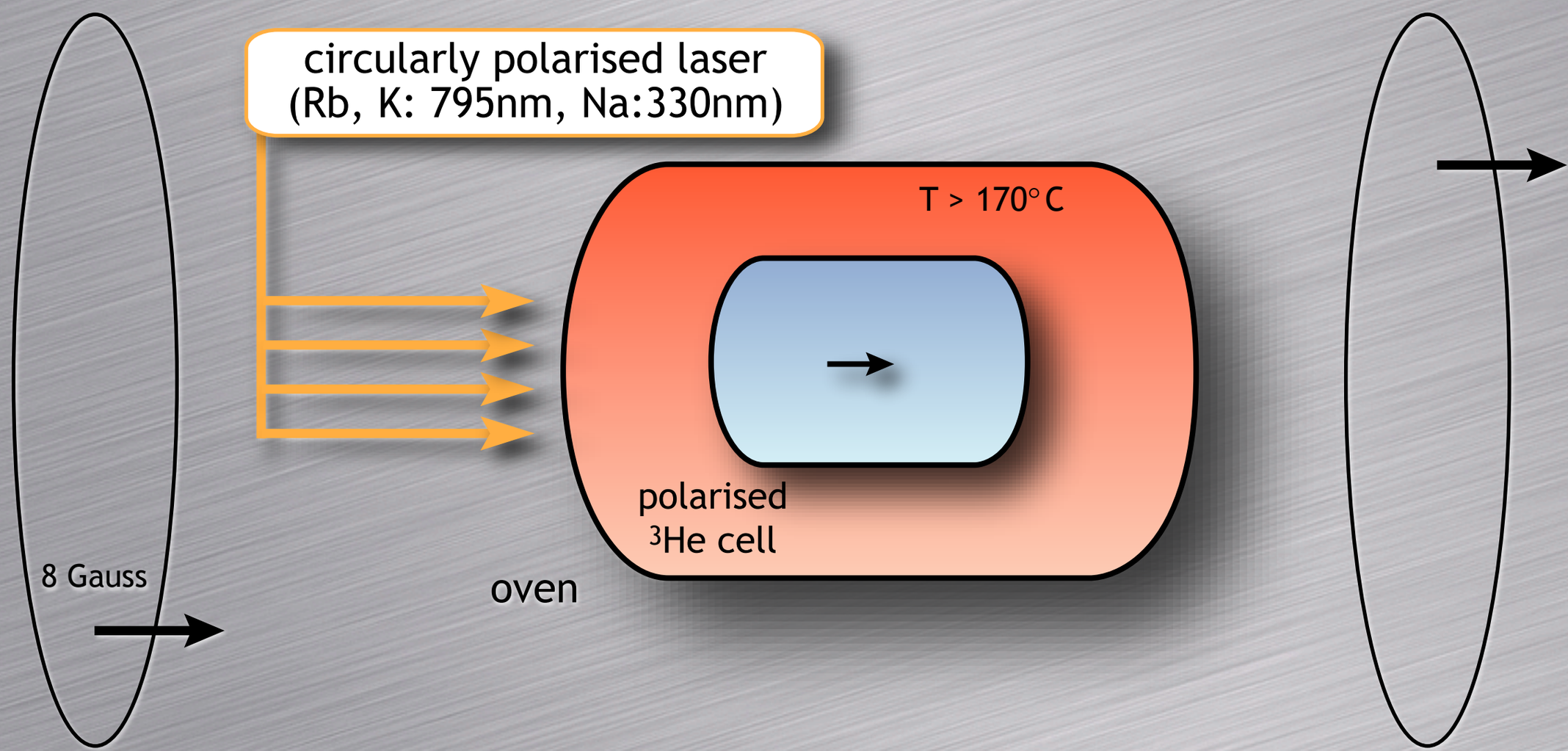
Spin Exchange Optical Pumping (SEOP)

Schematic view of a SEOP station



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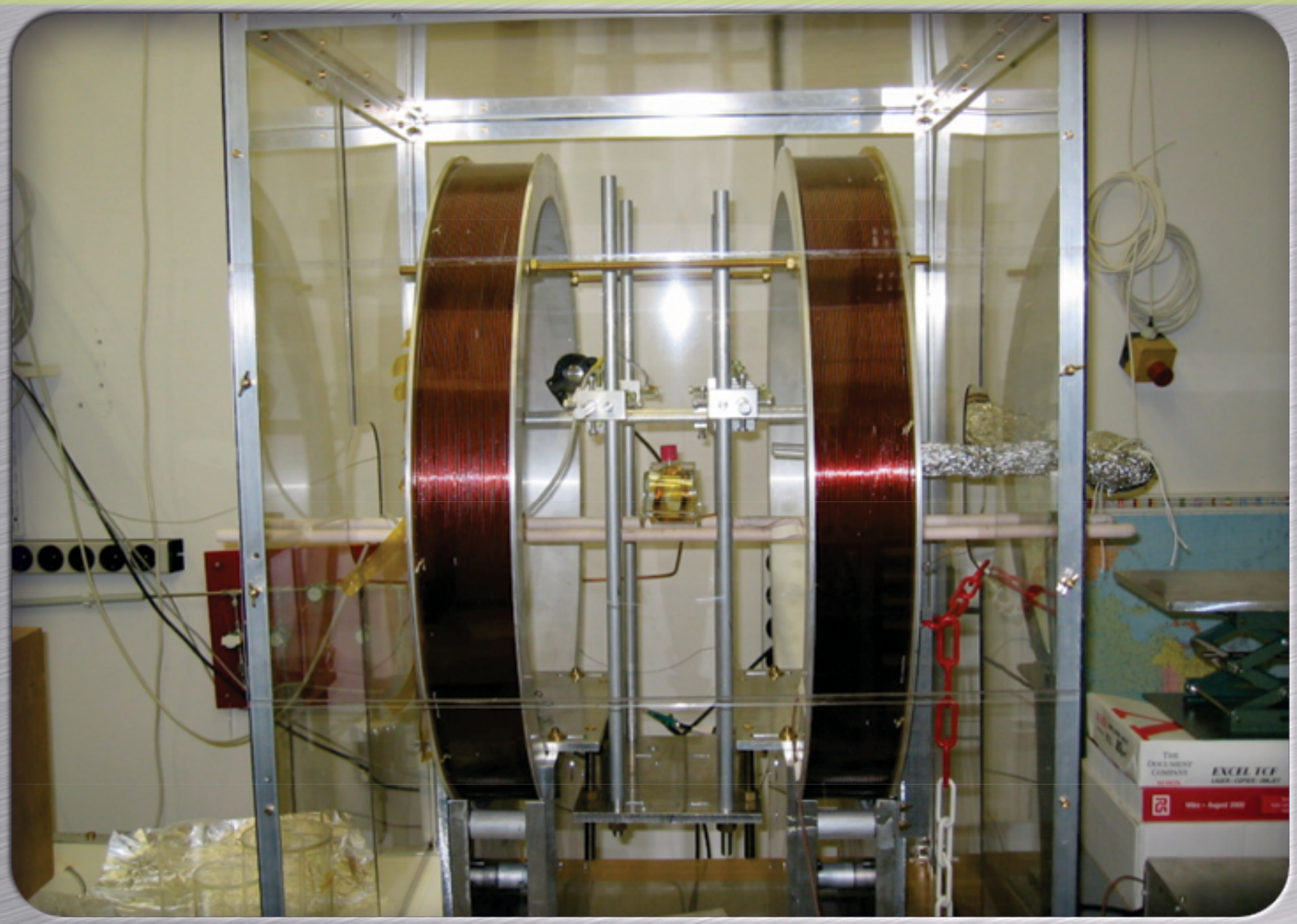
Spin Exchange Optical Pumping (SEOP)



FZJ SEOP station: 62% polarisation (Rb-^{3}He)

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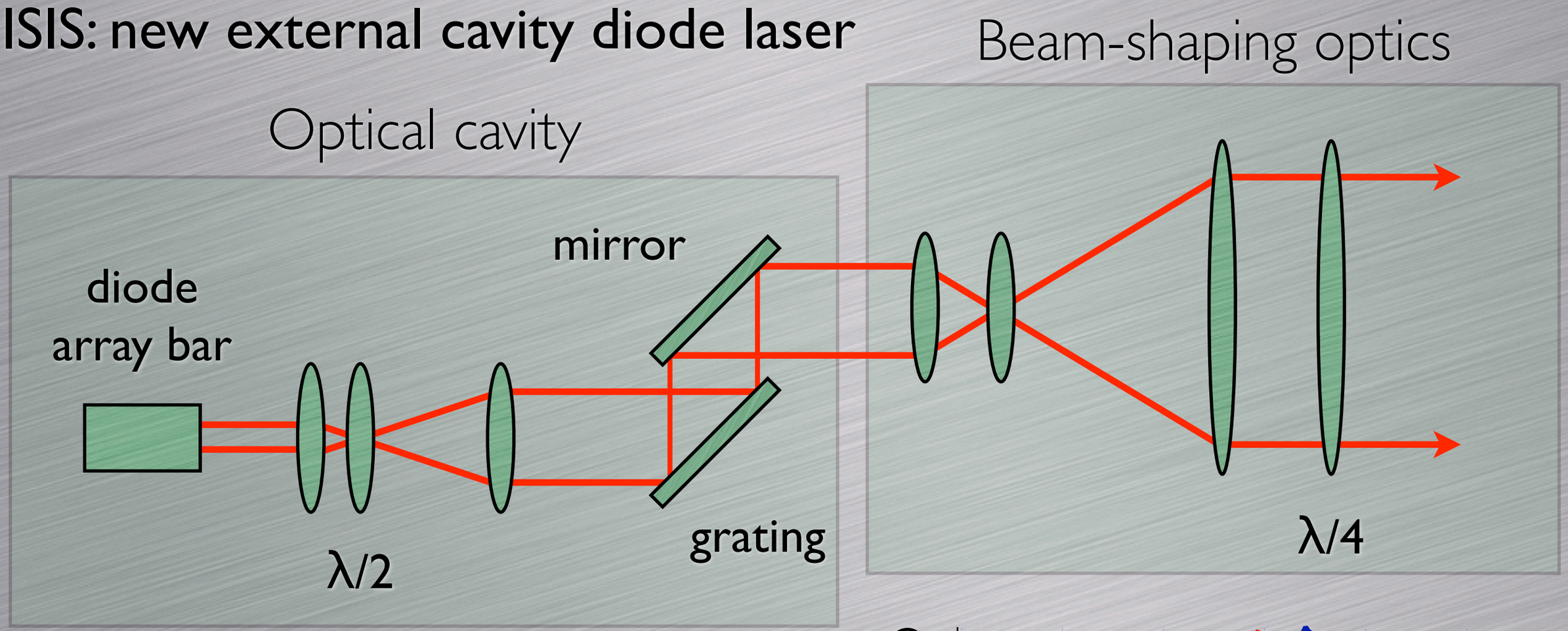
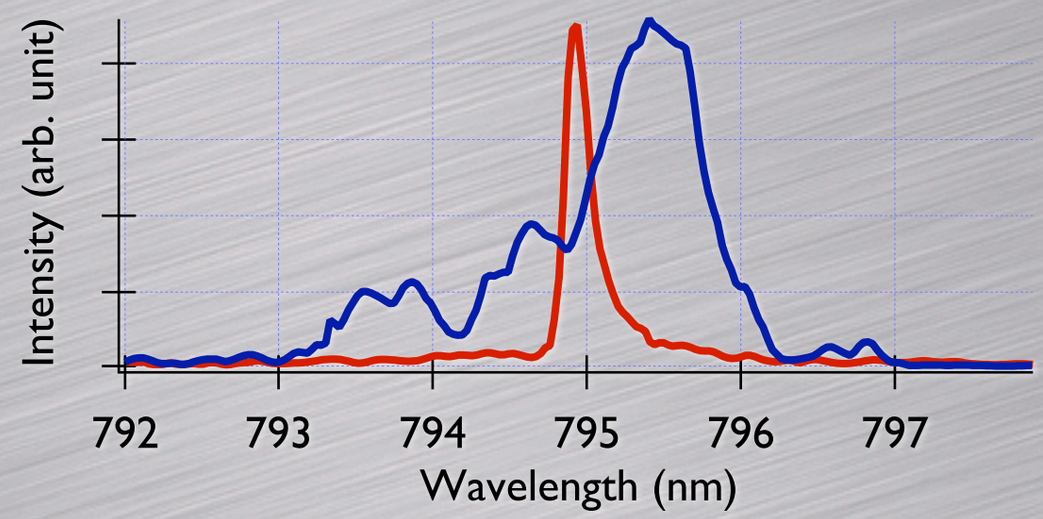
Spin Exchange Optical Pumping (SEOP)

ISIS: new external cavity diode laser



30W FAP 2nm FWHM replaced with 50W Quintessence diode in ECDL 0.12nm FWHM



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Spin Exchange Optical Pumping (SEOP)

- ILL has started the construction of a SEOP station (ECDL laser and diagnostic equipment for cell testing >30k€).
- At present: 63% with bad cell ($T_1 \approx 34h$)
- Our aim is to build a compact magneto-static cavity connected to a SEOP station in a low or large stray-field environment (D3, D23,…?)

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Spin Exchange Optical Pumping (SEOP)

- Rb-^{3}He: 60-65% routinely achieved but one must be patient (time constant ≈13h) !

$$P_{^3He}^{t\to\infty} = P_{Rb}\frac{\kappa_{SE}\left[Rb\right]}{\left(1+X\right)\kappa_{SE}\left[Rb\right]+\Gamma_{wall}}$$

- K-Rb-^{3}He: better efficiency (time constant ≈5h), project not started in Europe yet
- Na-Rb-^{3}He: development postponed, even better efficiency expected…
- Maximum ^{3}He polarisation achieved ≈75%

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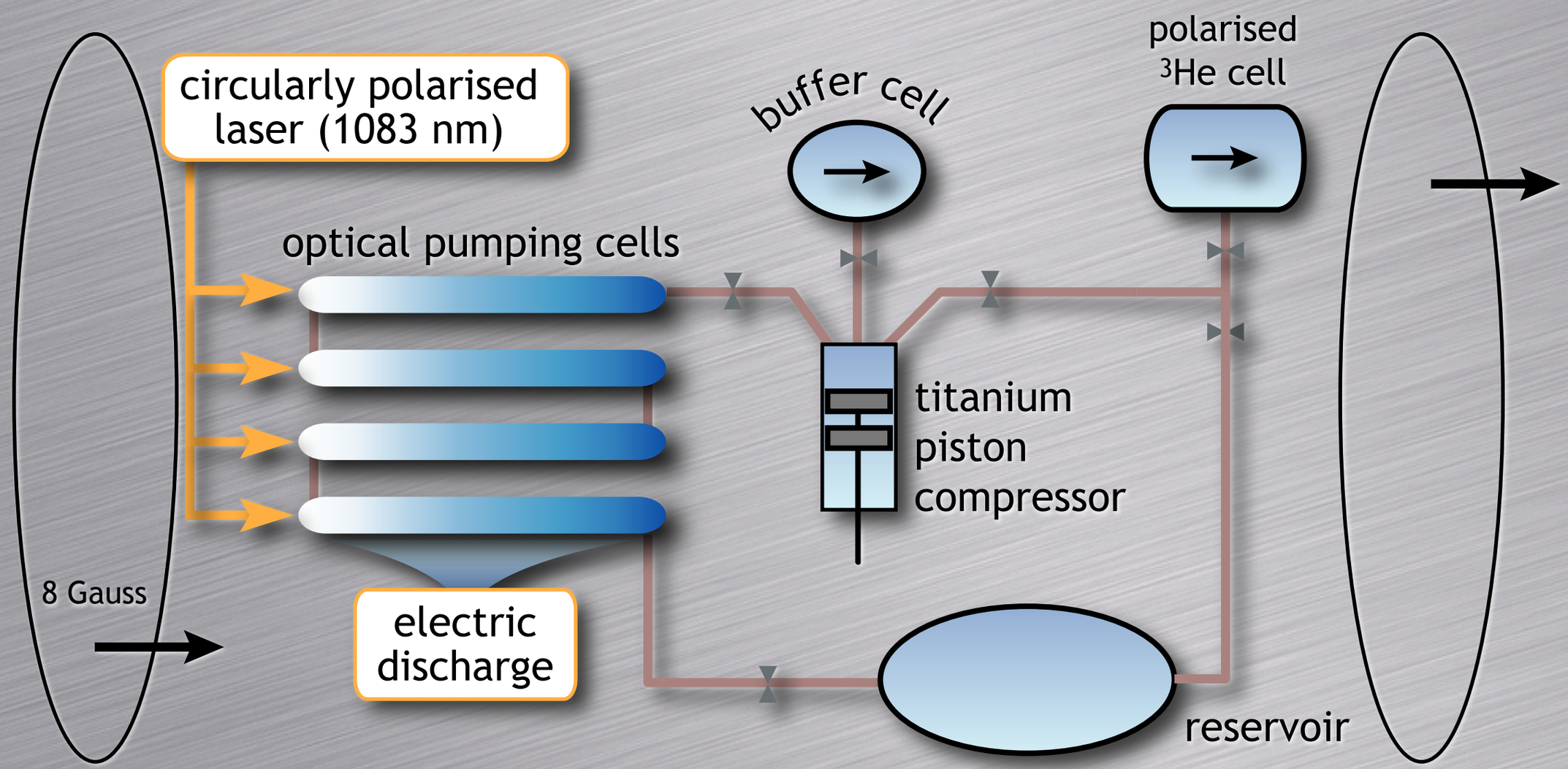
^{3}He Neutron Spin Filters

Metastability Exchange Optical Pumping (MEOP)

Schematic view of a MEOP station



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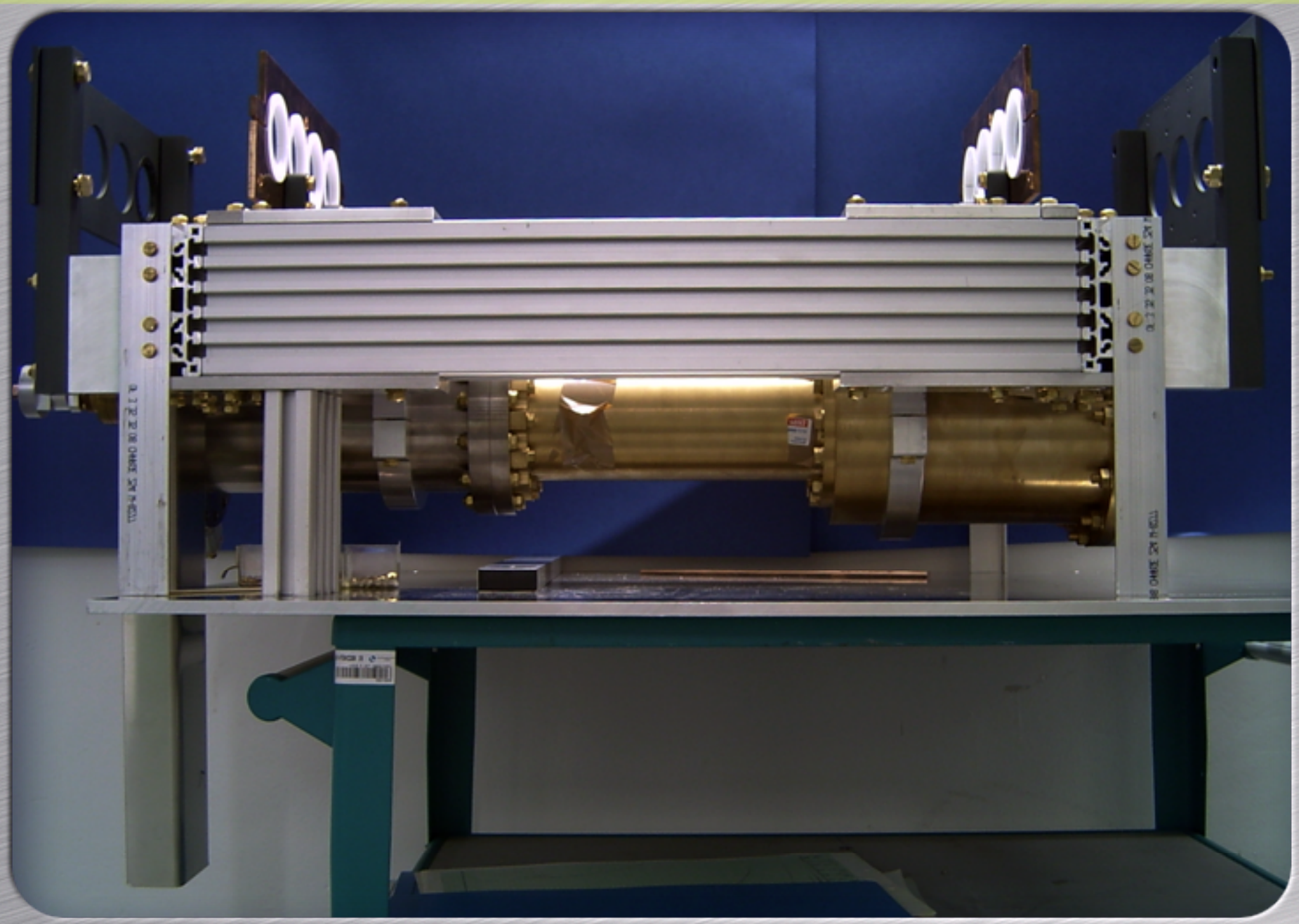
Metastability Exchange Optical Pumping (MEOP)



FZJ MEOP station under construction

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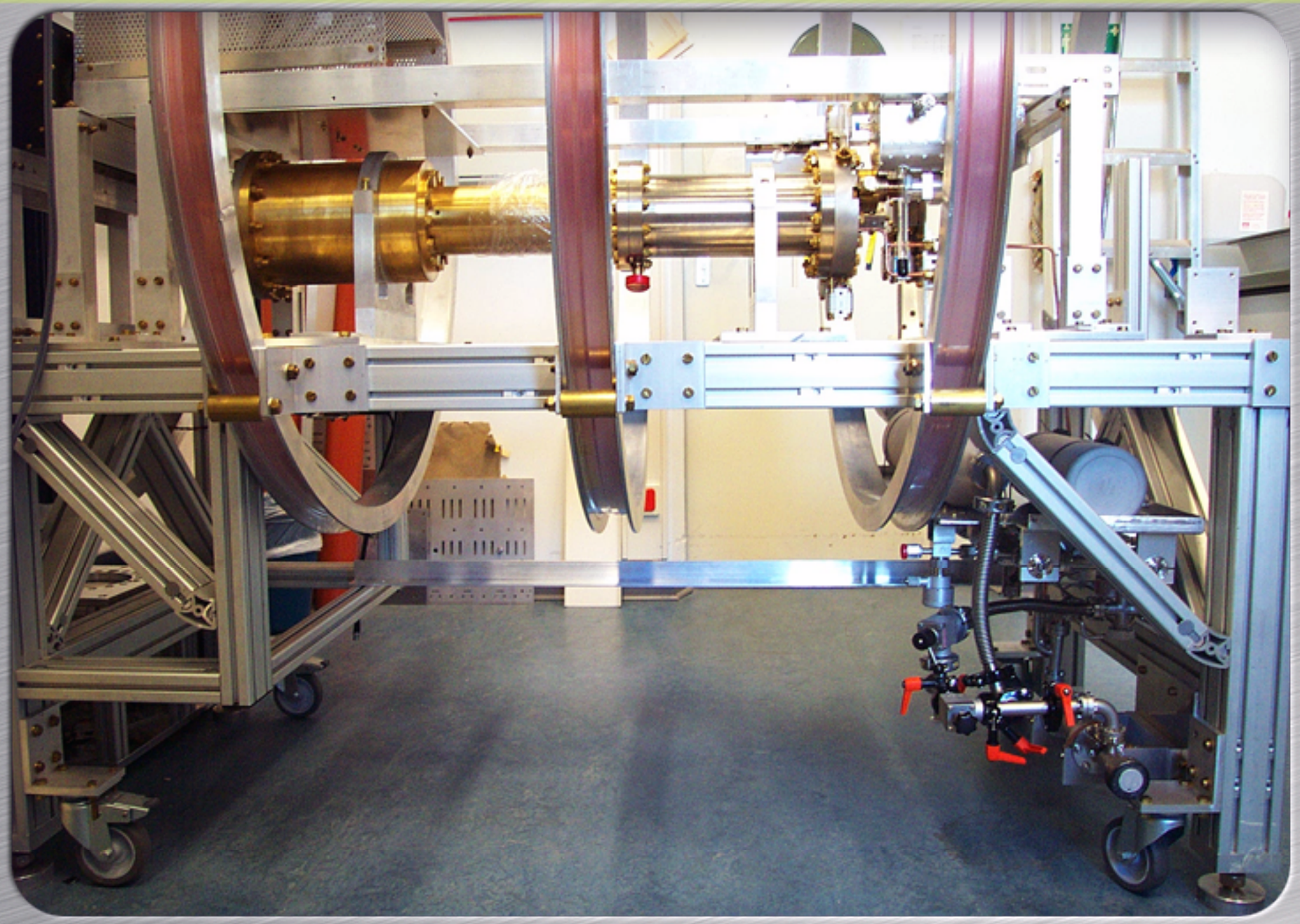
Metastability Exchange Optical Pumping (MEOP)



HMI MEOP station under construction

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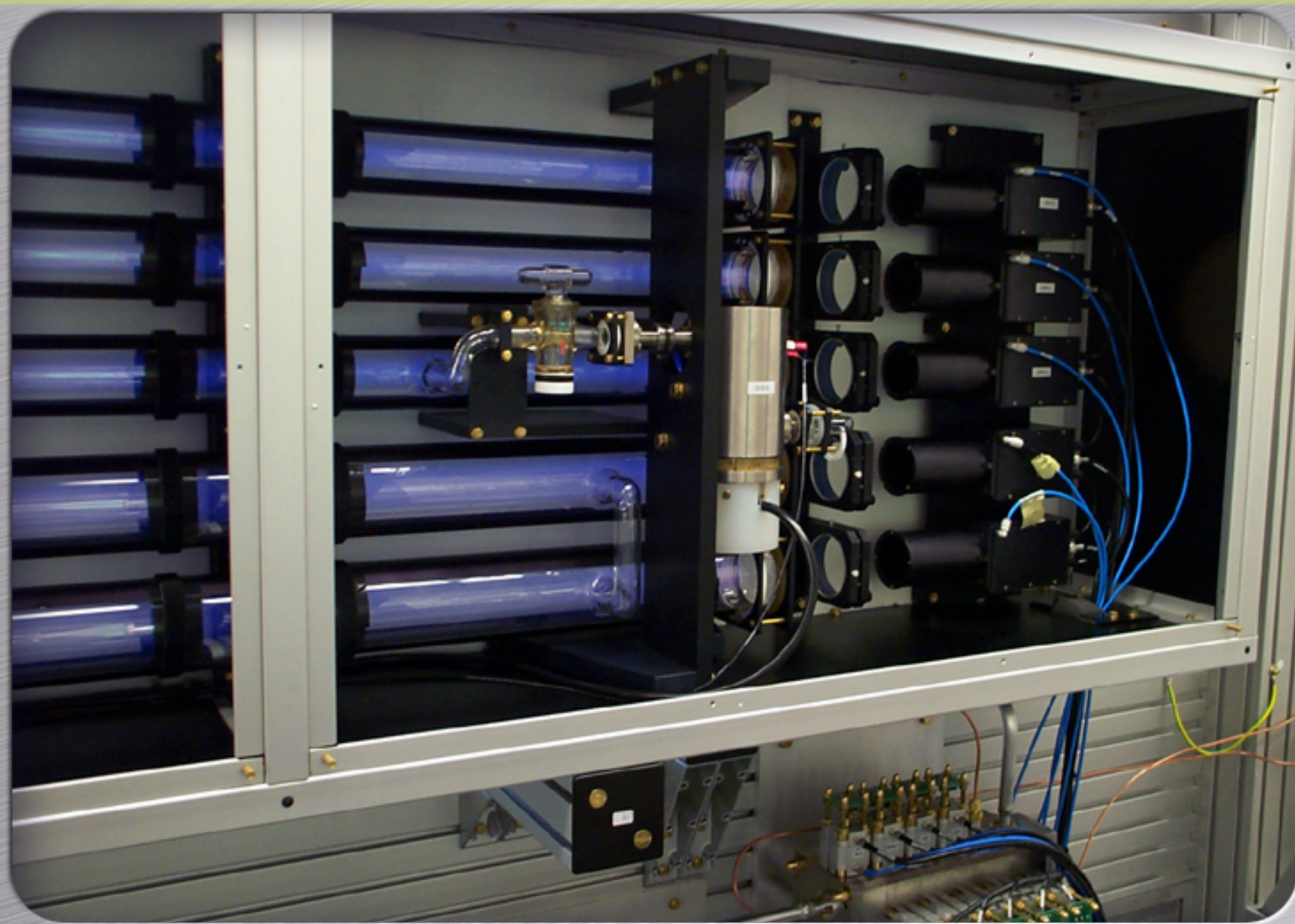
Metastability Exchange Optical Pumping (MEOP)



FRM2 MEOP station: 70% polarisation in cells (1M€)

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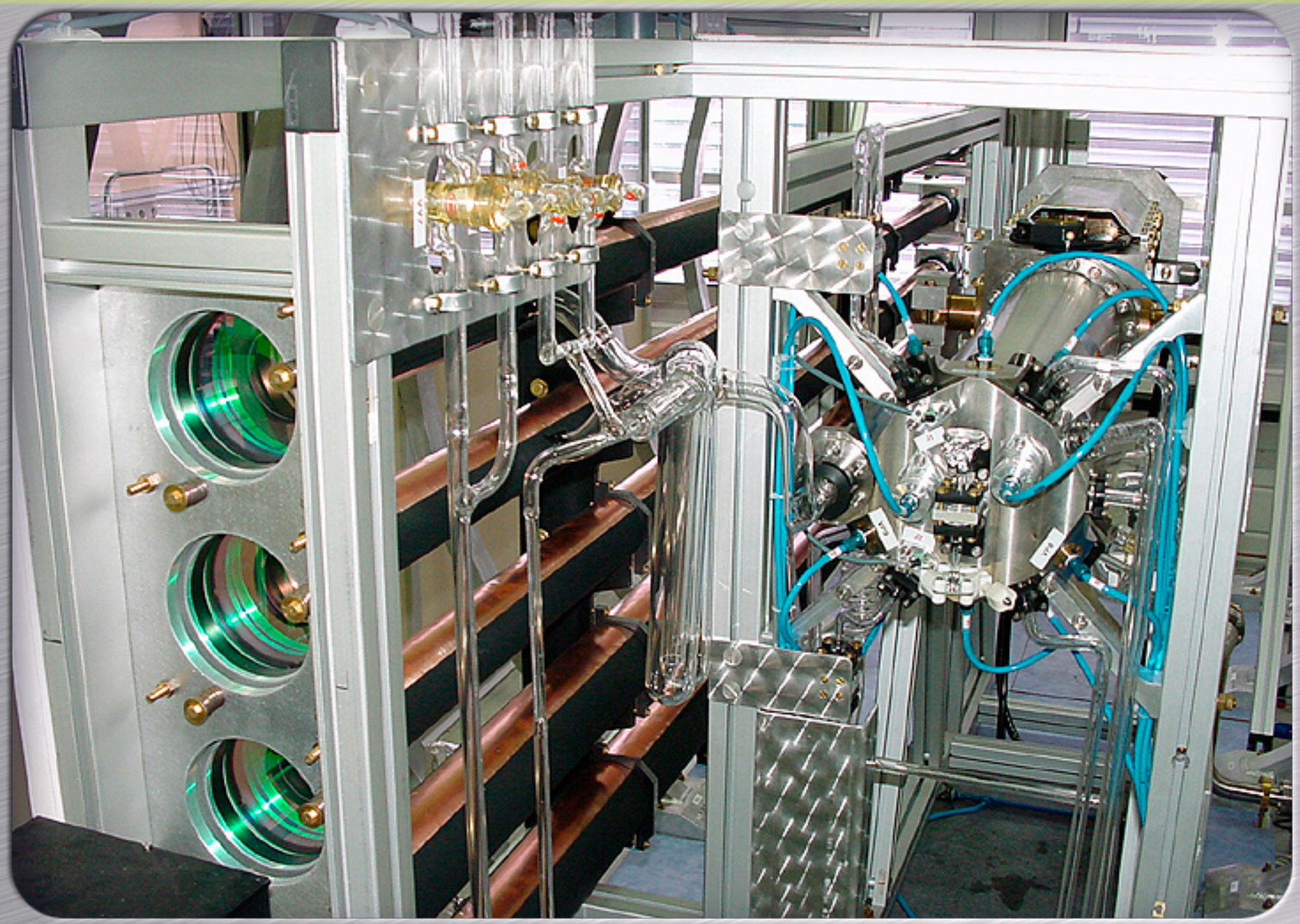
Metastability Exchange Optical Pumping (MEOP)



ILL MEOP station: 70% polarisation (0.8M€)

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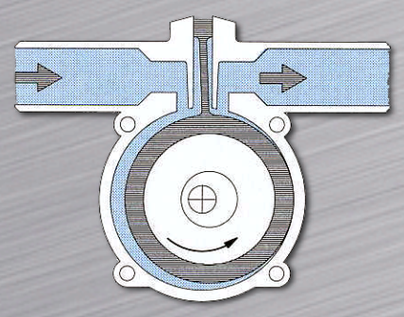
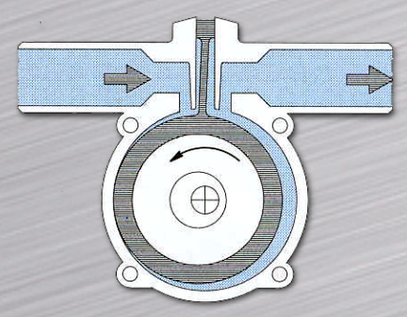
Metastability Exchange Optical Pumping (MEOP)

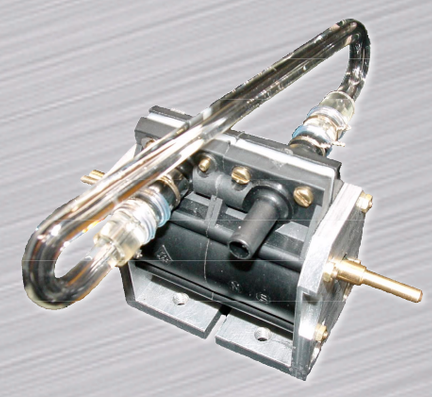
- Piston compressor (ILL, FRM-2): polarisation preserving (loss < 0.5% absolute polarisation)

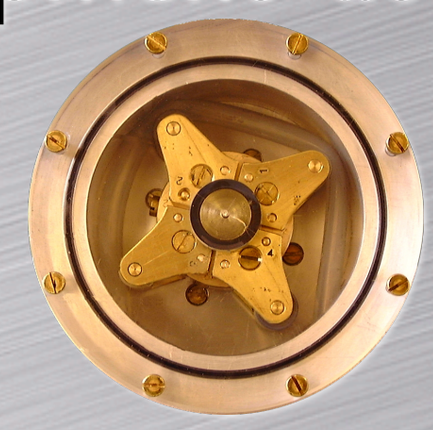
  45 min for polarising 3 bar.l of gas at 70%

- Other compressors: rotary diaphragm (coffee machine), peristaltic pumps in development at ISIS









- 1083 nm Yb-fibre lasers commercially available (e.g. Keopsys - up to 10 W)

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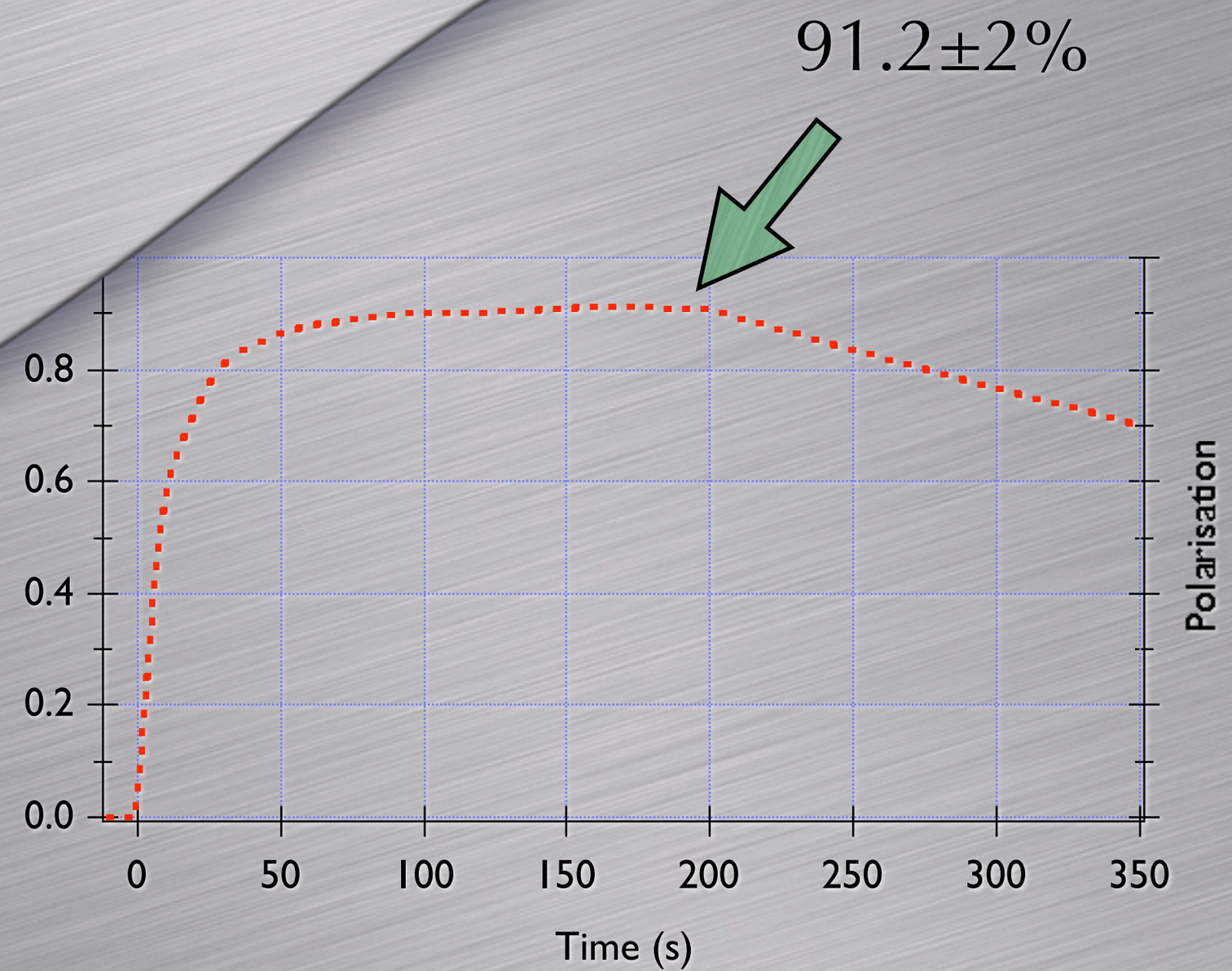
Metastability Exchange Optical Pumping (MEOP)

- At Mainz, M. Wolf got a polarisation greater than 90% in a cell of 2 liters (see PhD)



10W laser
p = 0.65mbar
80% after 29s

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^{3}He Neutron Spin Filters

on neutron beams

- The main difficulty resides in the ability to preserve the ^{3}He polarisation on the beam line.

$$\frac{1}{T_1} = \frac{1}{T_{wall}} + \frac{1}{T_{field}} + \frac{1}{T_{dipolar}} = \gamma \frac{S}{V} + \frac{1.7\,10^4}{p} \left(\frac{1}{B_r} \frac{\partial B_r}{\partial r} \right)^2 [\mathrm{bar.cm^2.h^{-1}}] + \frac{p}{830} [\mathrm{bar^{-1}.h^{-1}}]$$

- The wall relaxation scales with the surface to volume ratio, and depends strongly on the quality of the inner surface of the container,
- A very homogeneous magnetic field must be applied over the volume of the container ($\approx 10^{-4}$ cm^{-1}),
- The ^{3}He pressure must be optimised.

➽ <u>detachable cells ? optical pumping on the beam line ? local filling ?</u>

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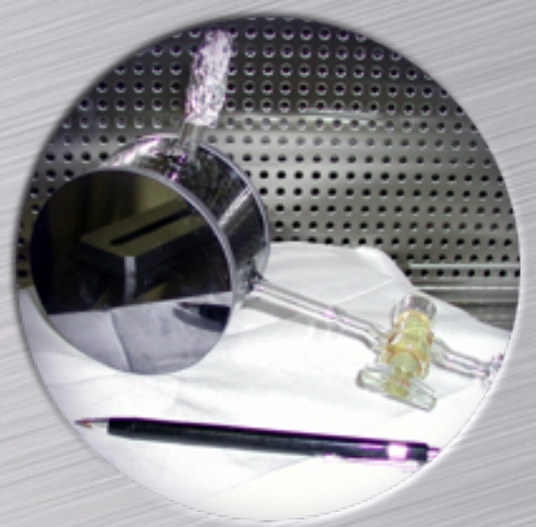
^{3}He Neutron Spin Filters

on neutron beams

- ^{3}He containers must:
  - not depolarise the gas,
  - be transparent to neutrons (and light for SEOP),
  - produce low diffuse background,
  - cover appropriate solid angles.

➽ Use of Pyrex, Quartz glass, single-crystalline Si windows…



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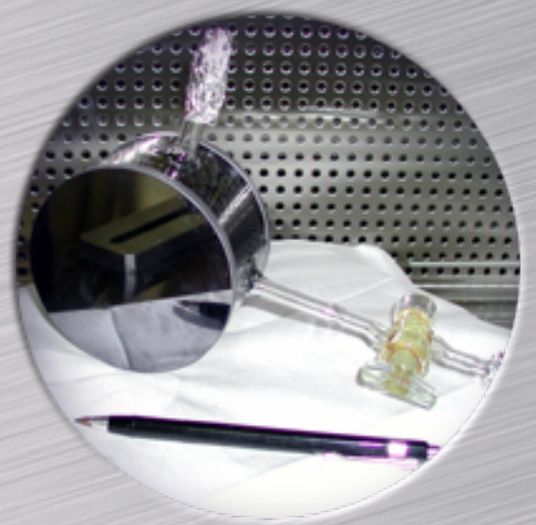
^{3}He Neutron Spin Filters

on neutron beams

- Sealed cells for SEOP
  - glassblowing from Ø15mm GE180, filled with Rb (+ K, Na), N_2 and ^{3}He
  - cells must be replaced with new ones after several weeks of use

- Valve-sealed cells for MEOP
  - GE224, GE180, Si-windowed Pyrex cells, … all Cs coated
  - valves must be checked regularly



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^{3}He Neutron Spin Filters

on neutron beams

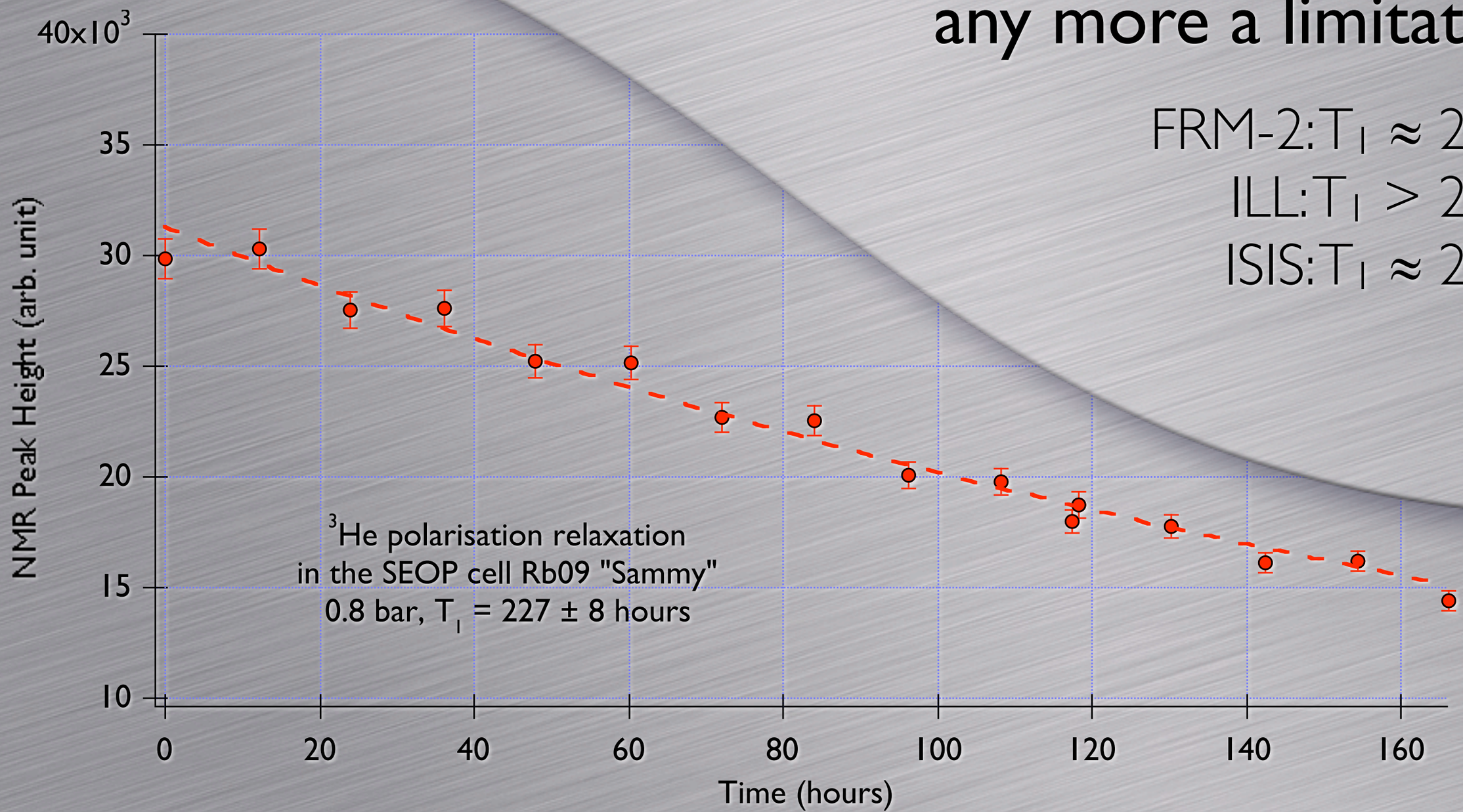
The wall relaxation is not any more a limitation

FRM-2: $T_1 \approx 267$h

ILL: $T_1 > 240$h

ISIS: $T_1 \approx 230$h

...



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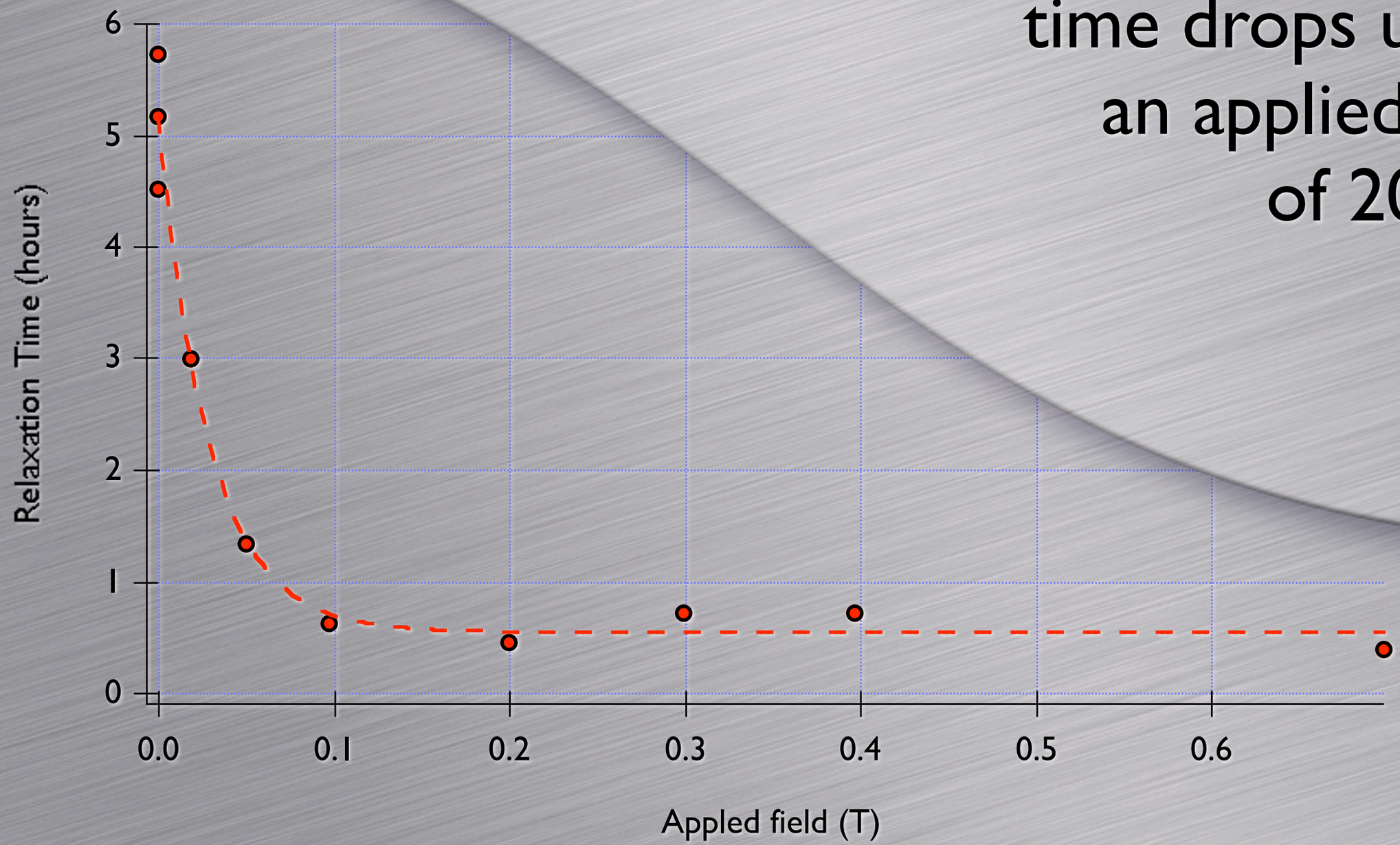
^{3}He Neutron Spin Filters

on neutron beams

- But the relaxation time drops under an applied field of 200G !



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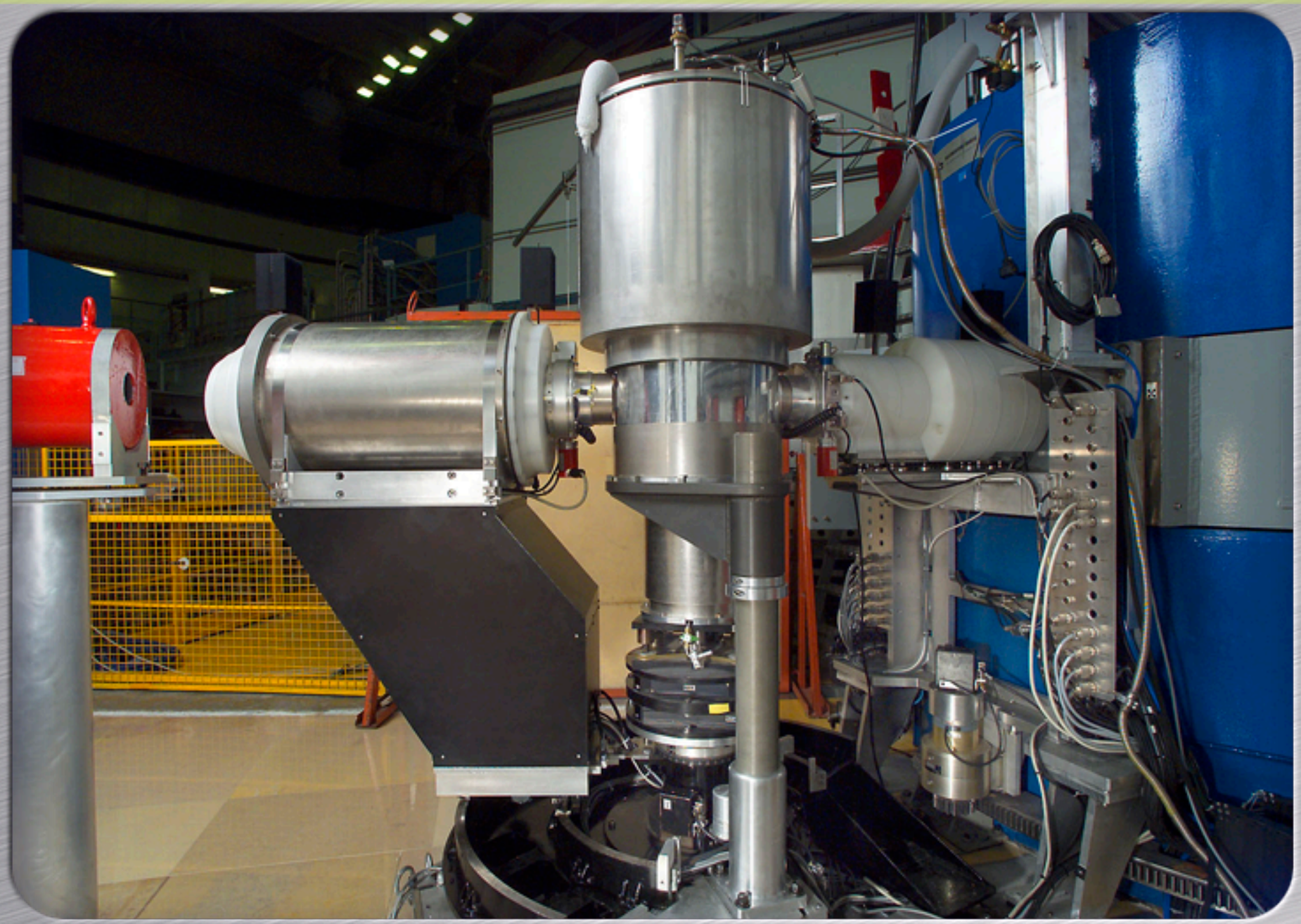
^{3}He Neutron Spin Filters

in low-field environment



adiabatic transport of the neutron polarisation

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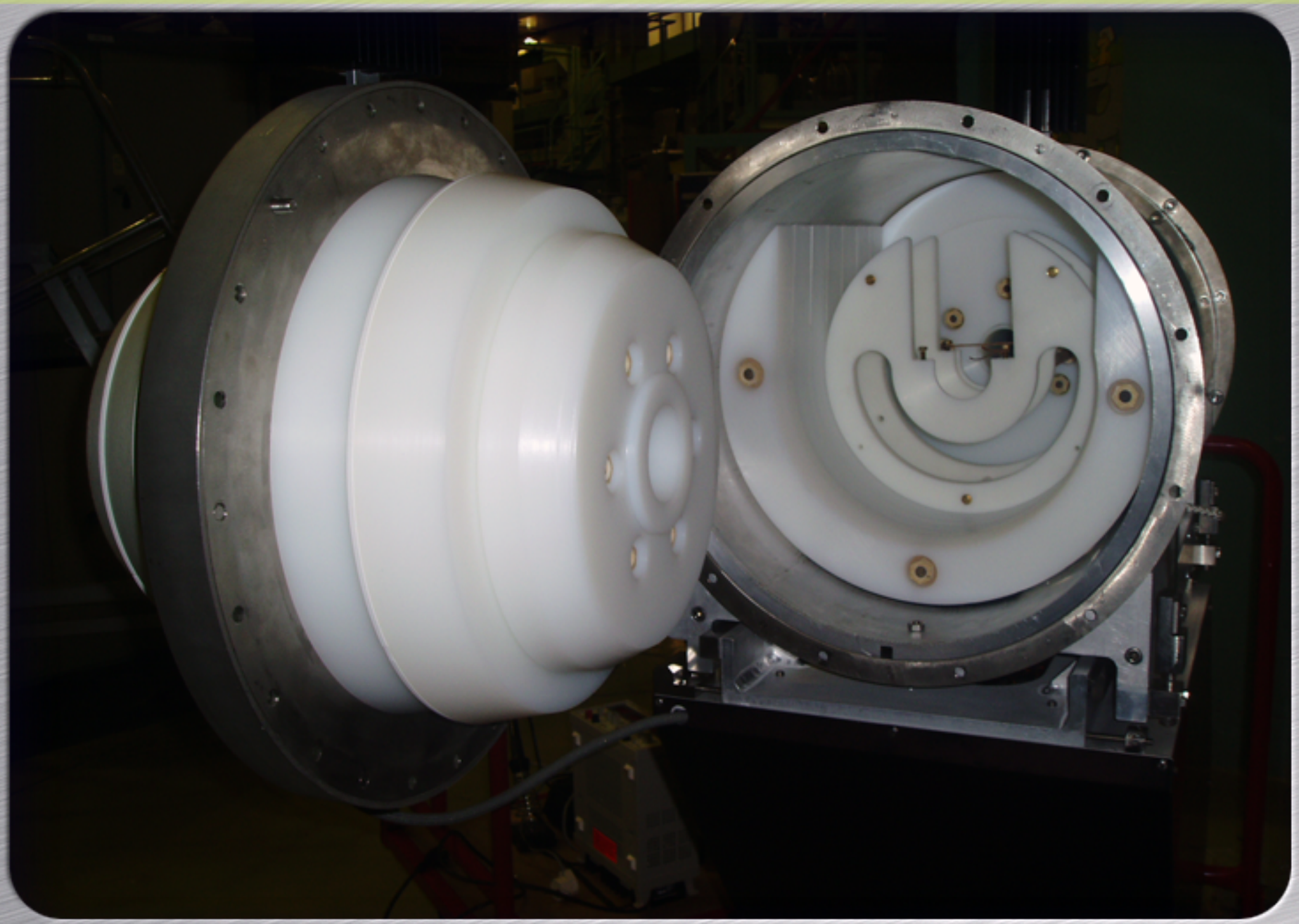
^{3}He Neutron Spin Filters

in low-field environment



cells replaced in Earth field w/o polarisation loss

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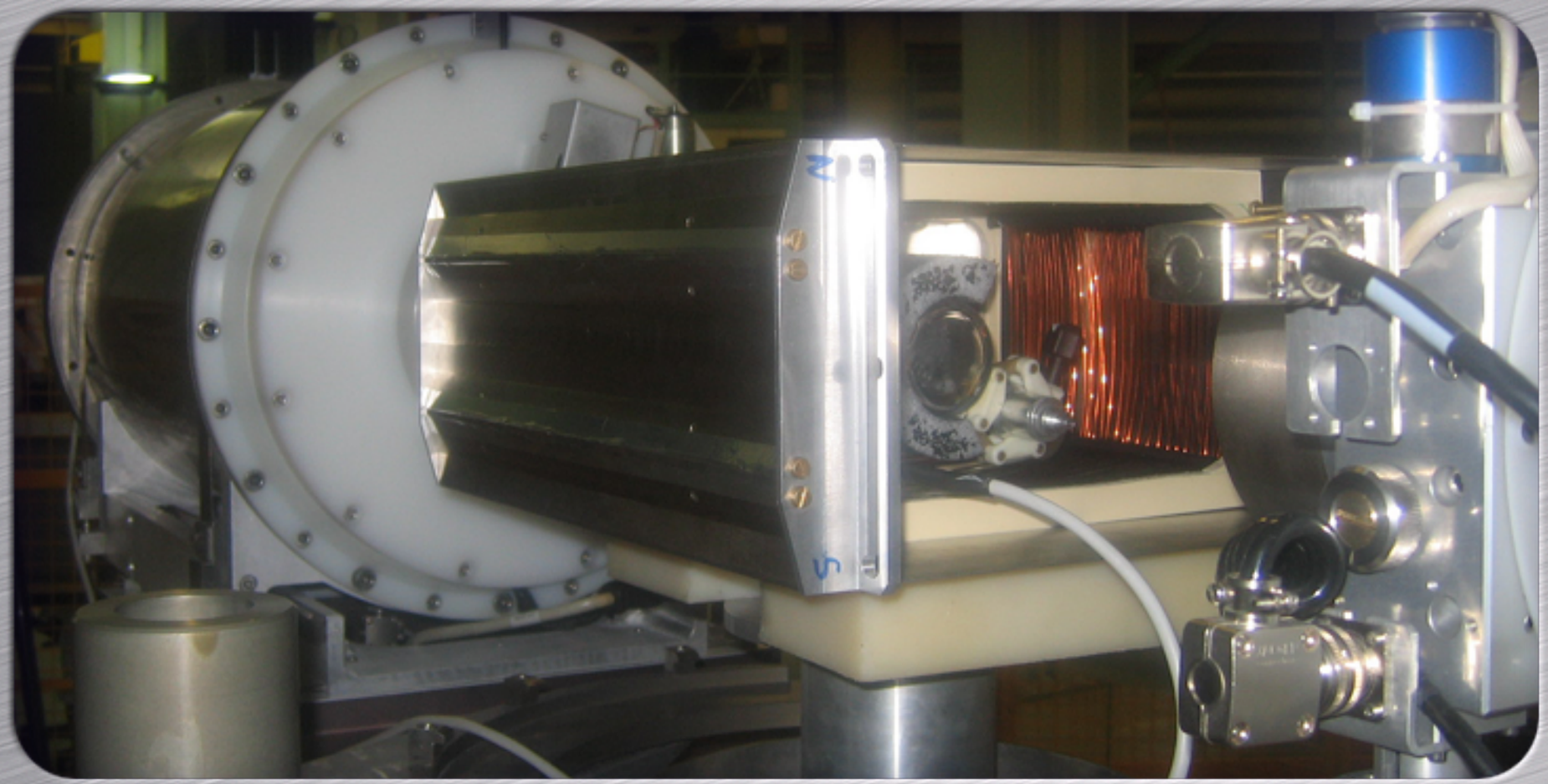
^{3}He Neutron Spin Filters

in low-field environment



The "Magic-Box": a wide-band polariser-flipper !

A simple magneto-static cavity providing long relaxation times including an RF coil used to flip the polarisation of the gas with less than 10^{-5} polarisation loss per flip.

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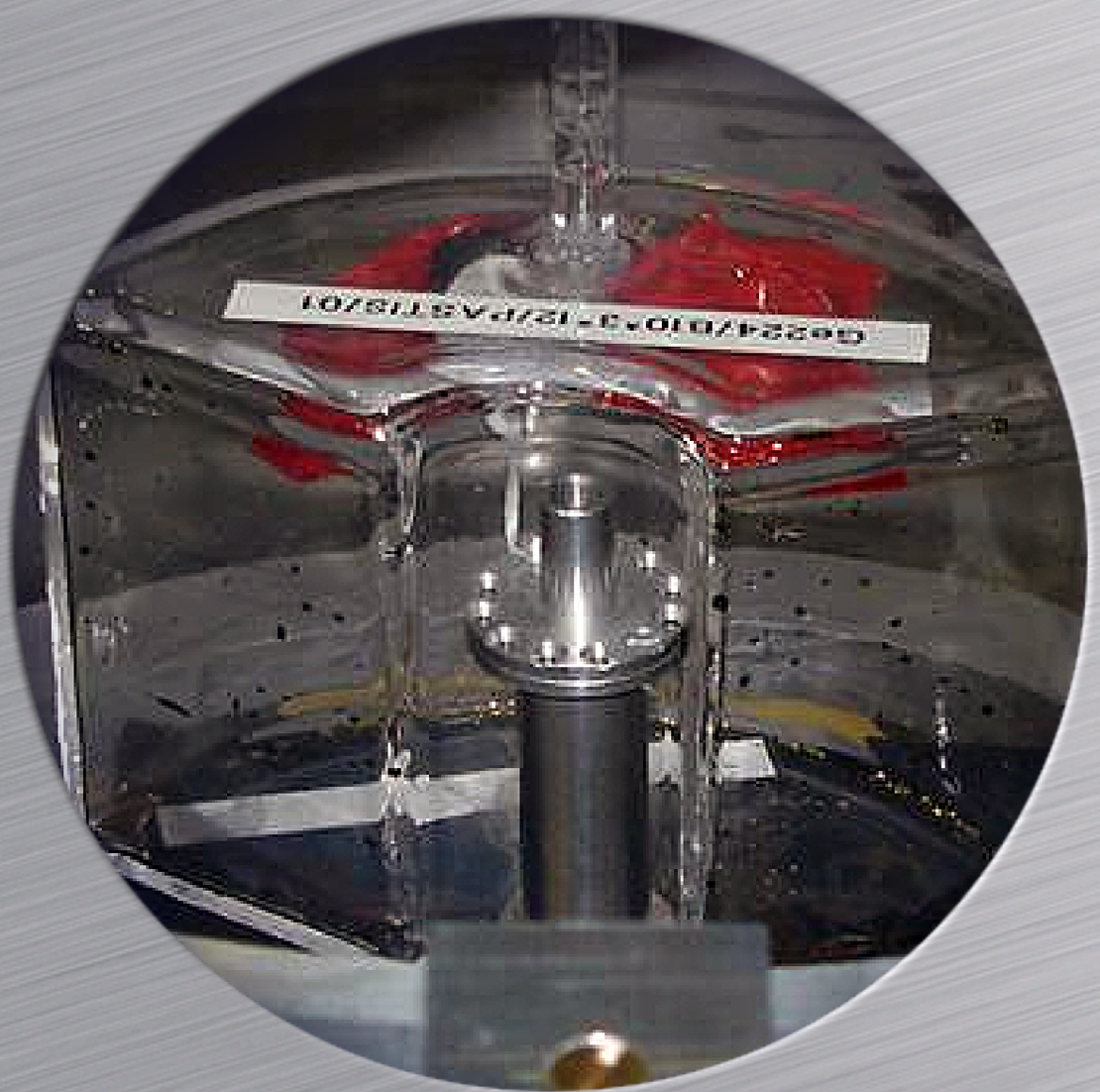
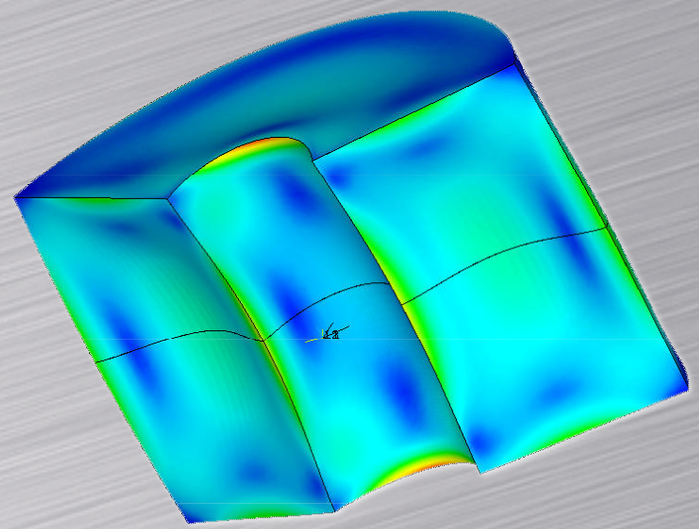
^{3}He Neutron Spin Filters

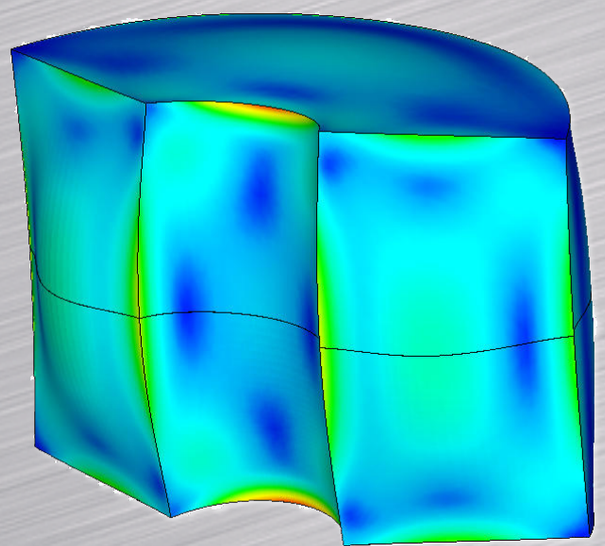
in low-field environment

- ILL has started the development of PASTIS (XYZ method applied to thermal neutrons)



$\Delta p = -1$bar





$\Delta p = +2$bar

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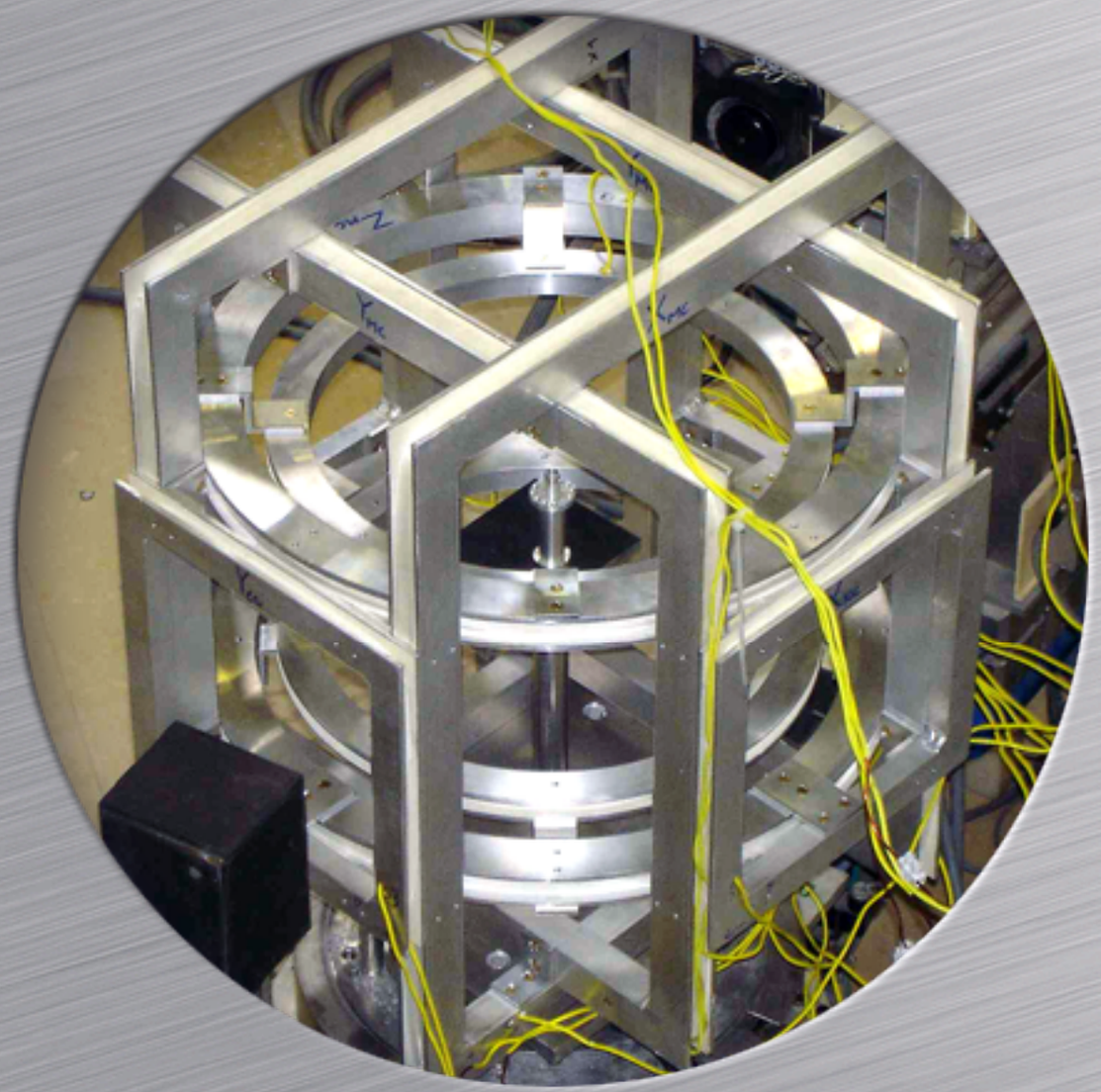
in low-field environment

- ILL has started the development of PASTIS (XYZ method applied to thermal neutrons)



The best field homogeneity was obtained by using nuclear magnetic resonance free induction decay (FID).

With the applied field rotated toward X,Y and Z every 5min, one obtains $T_1 \approx 100h$.

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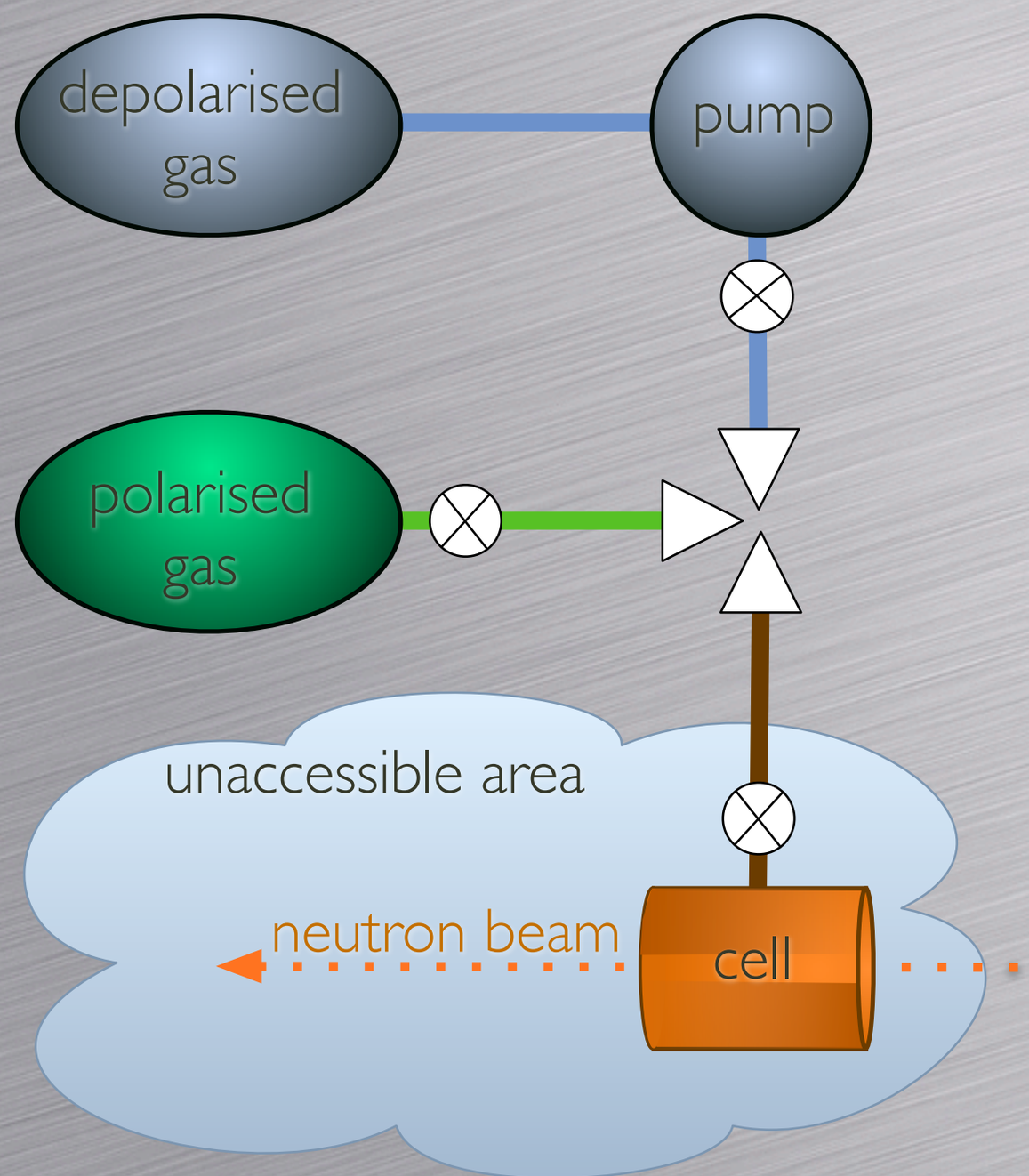
in mid-field environment



- The gas is polarised with Tyrex (MEOP)
- The cell is filled with freshly polarised gas directly on the instrument (local filling).
- We use a pipe and a valve which are both polarisation preserving.

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in mid-field environment

Scheduled experiments
on the reflectometer D17

- The gas is polarised with Tyrex (MEOP)
- The cell is filled with freshly polarised gas directly on the instrument (local filling).
- We use a pipe and a valve which are both polarisation preserving.

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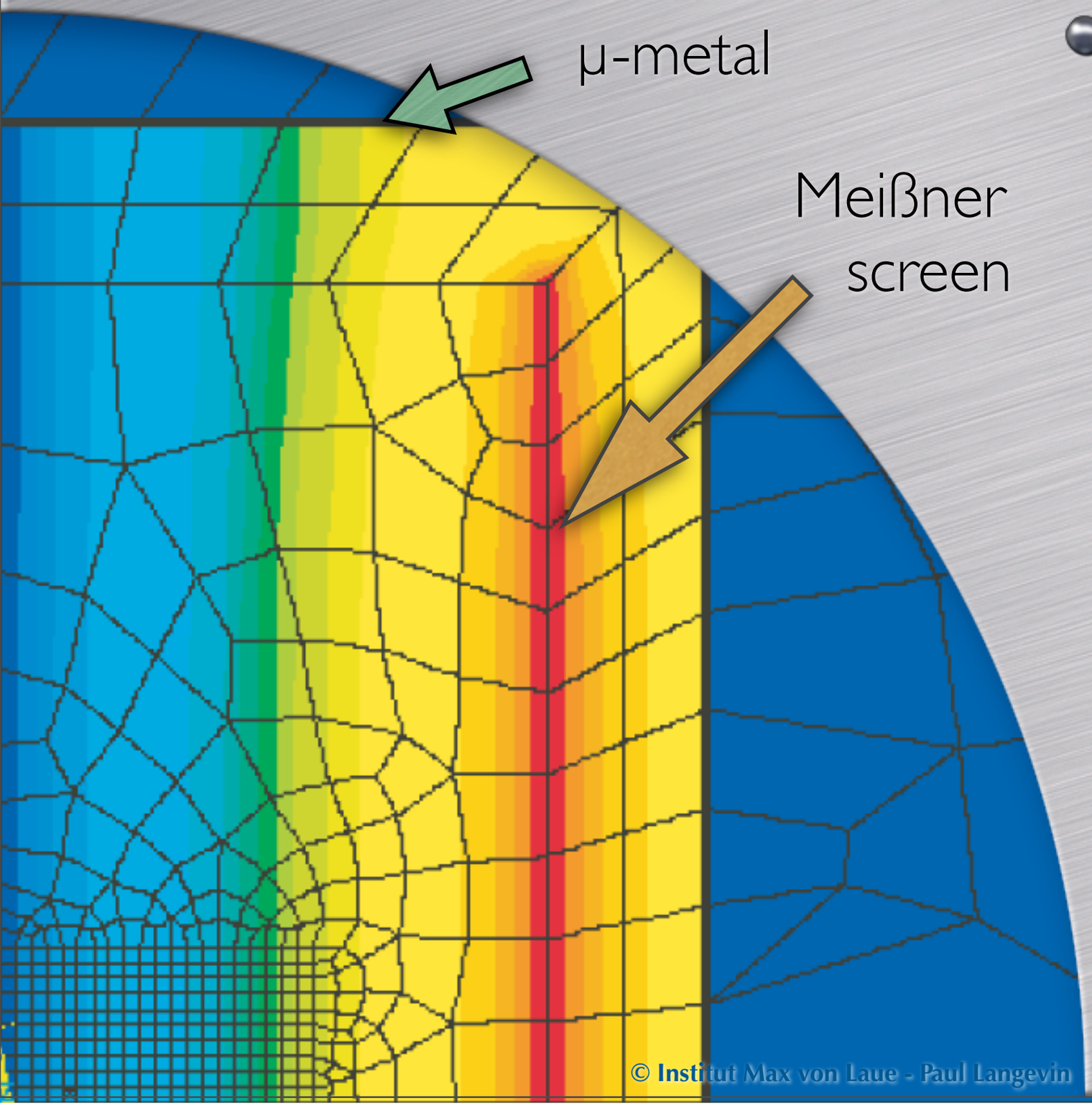
^{3}He Neutron Spin Filters

in high-field environment



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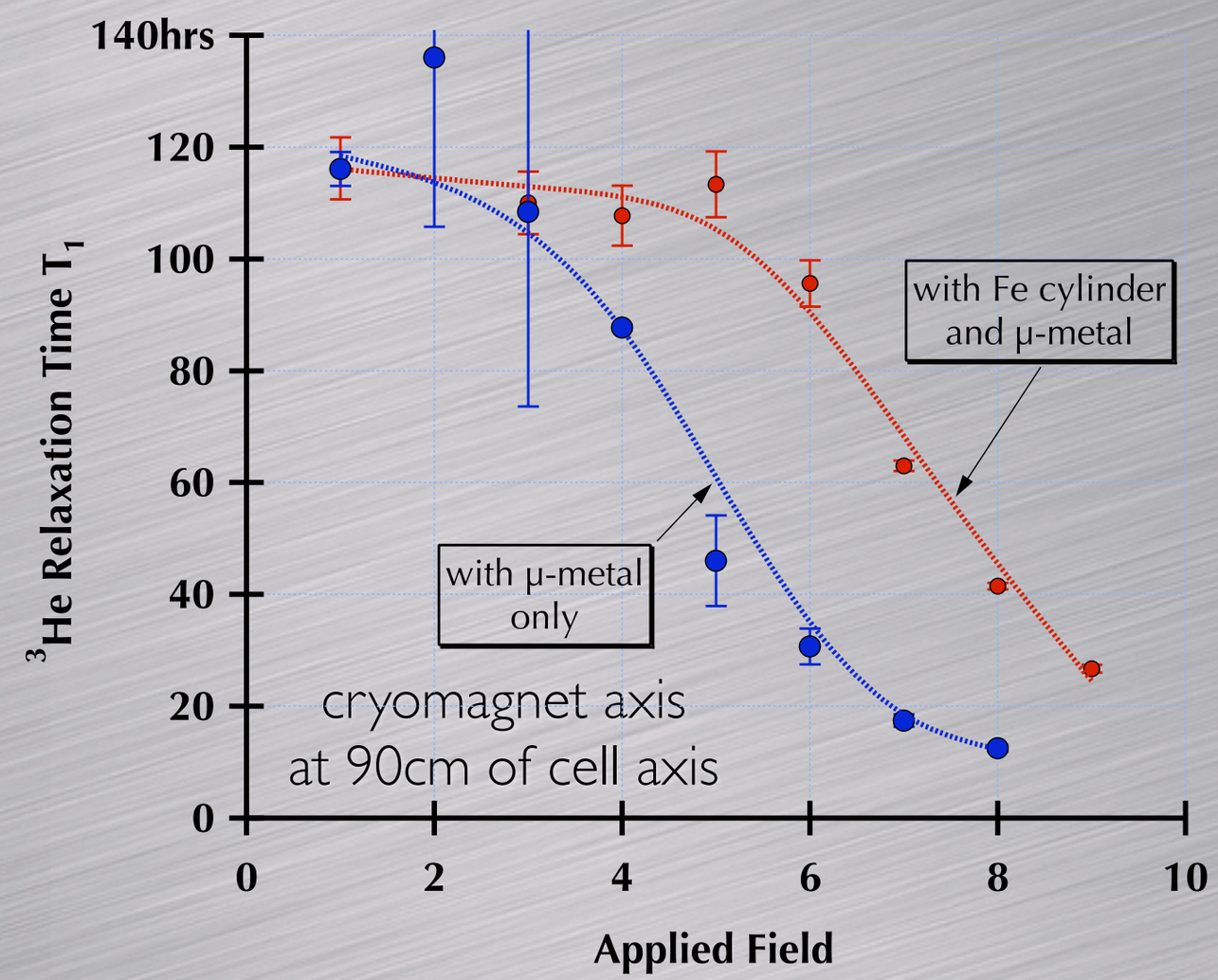
- <u>Cryopol</u>:
  - homogeneous magnetic field trapped in a superconducting cylinder (85 Gauss),
  - magnetic field loop closed with the μ-metal,
  - secondary field screen necessary for high stray fields (up to 500 Gauss).

^{3}He Neutron Spin Filters

in high-field environment

- Cryopol prototype:
  - good ^{3}He relaxation up to 200 G



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^{3}He Neutron Spin Filters

for HYSPEC ?

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^{3}He Neutron Spin Filters

for HYSPEC ?

- Polariser
  - 0.5 bar.l polarised with a MEOP station (local filling required for optimising the opacity)
  - optical and polarising functions decoupled

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^{3}He Neutron Spin Filters

for HYSPEC ?

- Polariser
  - 0.5 bar.l polarised with a MEOP station (local filling required for optimising the opacity)
  - optical and polarising functions decoupled
- Analyser (low stray field ☞ K. Andersen talk)
  - 60° horizontal access, ±7.5° vertical access
  - cell located at 4cm from the sample axis
  - about 3 bar.l polarised in 2 hours
  - 20k€ for the ^{3}He cell and compensated XYZ coils
  - 1M€ for the MEOP station (used about 3 hours/day)

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^{3}He Neutron Spin Filters

for HYSPEC ?

- Polariser
  - 0.5 bar.l polarised with a MEOP station (local filling required for optimising the opacity)
  - optical and polarising functions decoupled
- Analyser (high stray field)
  - 60° horizontal access, ±7.5° vertical access
  - cell located at about 90cm from the sample axis
  - about 40 bar.l polarised in 2 days
  - cost for the cell ? cost for the magnetostatic cavity ?
  - 1M€ for the MEOP station (used continuously)

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^{3}He Neutron spin filters

Conclusion:

HYSPEC ^{3}He polariser: an obvious and easy option

HYSPEC ^{3}He analyser: still a big challenge with high fields!

MEOP station on the market , SEOP must be developed.

NSF-JRA Collaborators (and friends)...

CEA: *L.-P. Regnault, E. Ressouche,…* ***FRM-2:*** *G. Borchert, S. Masalovich,…*

FZJ: *A. Ioffe, R. Müller,…* ***HMI:*** *A. Rupp, S. Nünighoff…* ***ISIS:*** *C. Frost, S. Parnell,…*

ILL: *K. Andersen, E. Babcock, E. Bourgeat-Lami, R. Chung, Y. Gibert, D. Jullien,*

A. Petoukhov, S. Pujol, F. Tasset, M. Thomas, X. Tonon,… ***LKB:*** *P.-J. Nacher, G. Tastevin,…*

and ***"Observers"*** *at* ***IUCF, KEK, NIST, SNS, UMich***

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