Magnet use and design

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NEUTRONS FOR SOCIETY

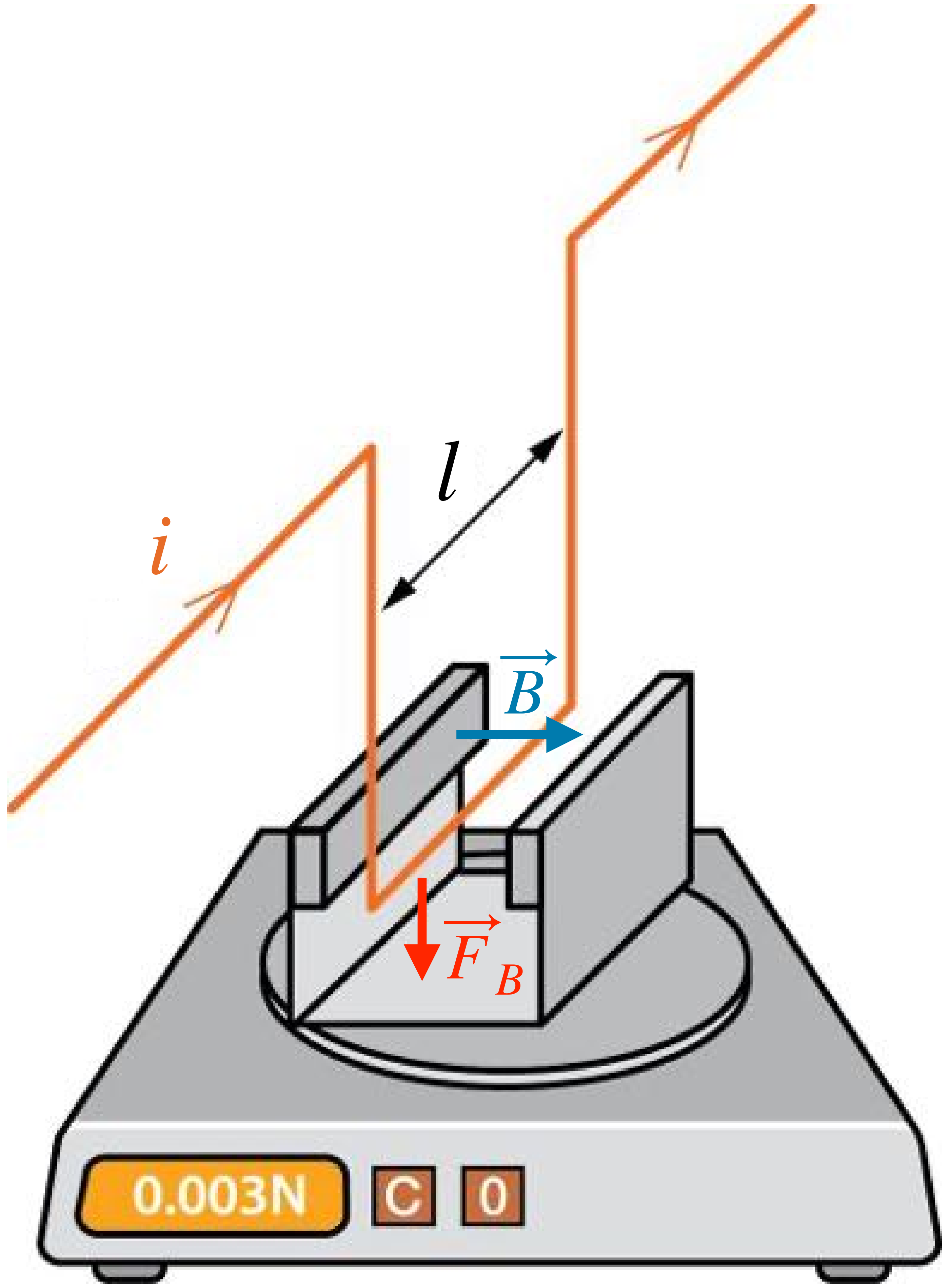
Magnet use and design

- Definition of a magnetic field
- Low-T_c superconducting magnets
- High-T_c superconducting magnets
- Resistive pulsed field magnets
- Safety aspects

Magnet use and design

- Definition of a magnetic field $\vec{B}$
  - When a particle of charge q moves at a velocity $\vec{v}$, we observe:
    - a Lorentz magnetic force $\vec{F}_B$ exerted on the charged particule which is proportional to both v and q.
    - the amplitude and direction of $\vec{F}_B$ depend on $\vec{v}$ and $\vec{B}$.
    - $\vec{F}_B$ vanishes when $\vec{v}$ is parallel to $\vec{B}$.
    - $\vec{F}_B$ is perpendicular to the plane $(\vec{v}, \vec{B})$ and its amplitude is proportional to $sin(\theta)$ where θ is the angle between $\vec{v}$ and $\vec{B}$.

$$\vec{F}_B = q\vec{v} \wedge \vec{B}$$

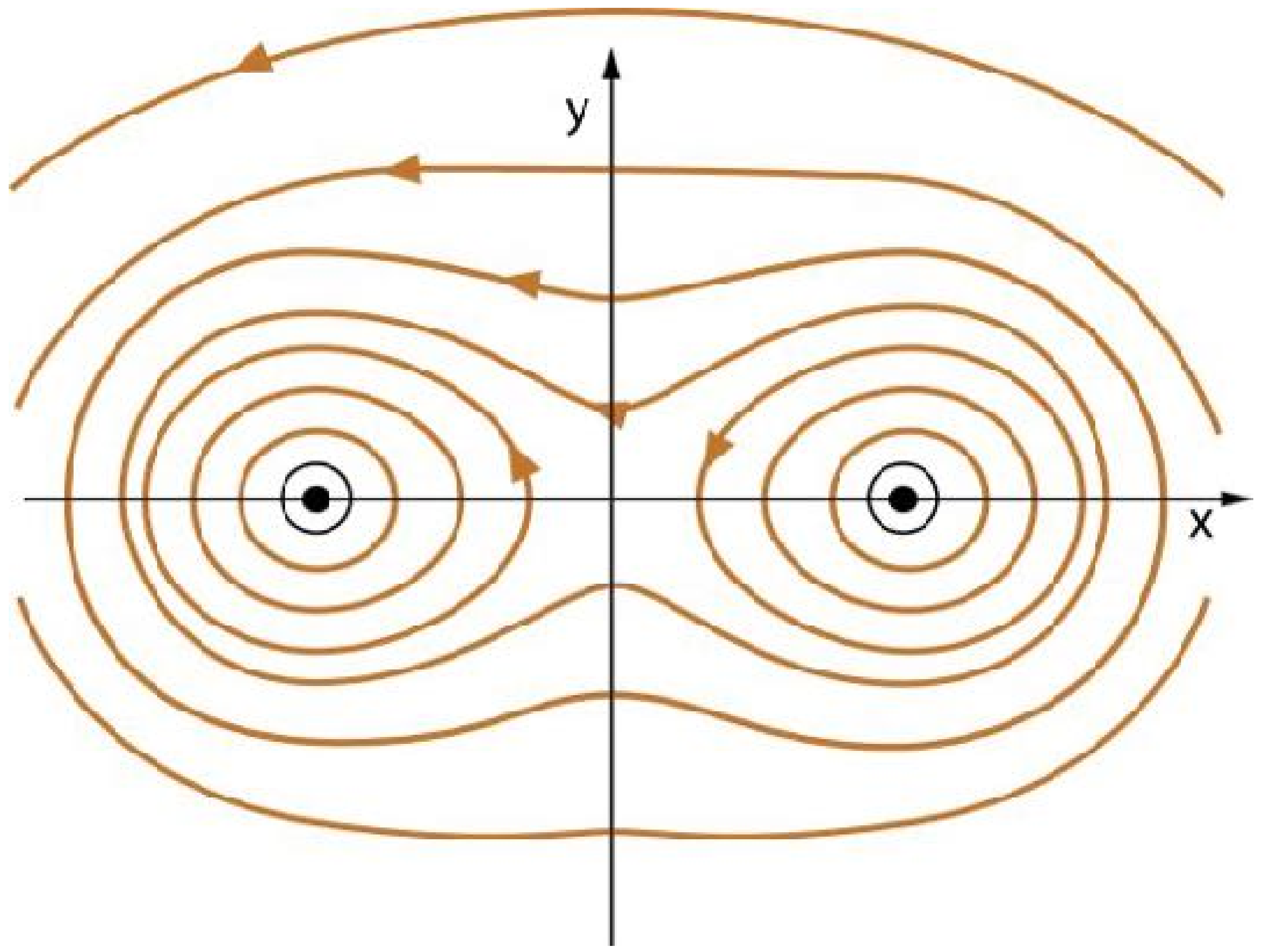


$$\vec{F}_B = i\vec{l} \wedge \vec{B}$$

NEUTRONS FOR SOCIETY

Magnet use and design

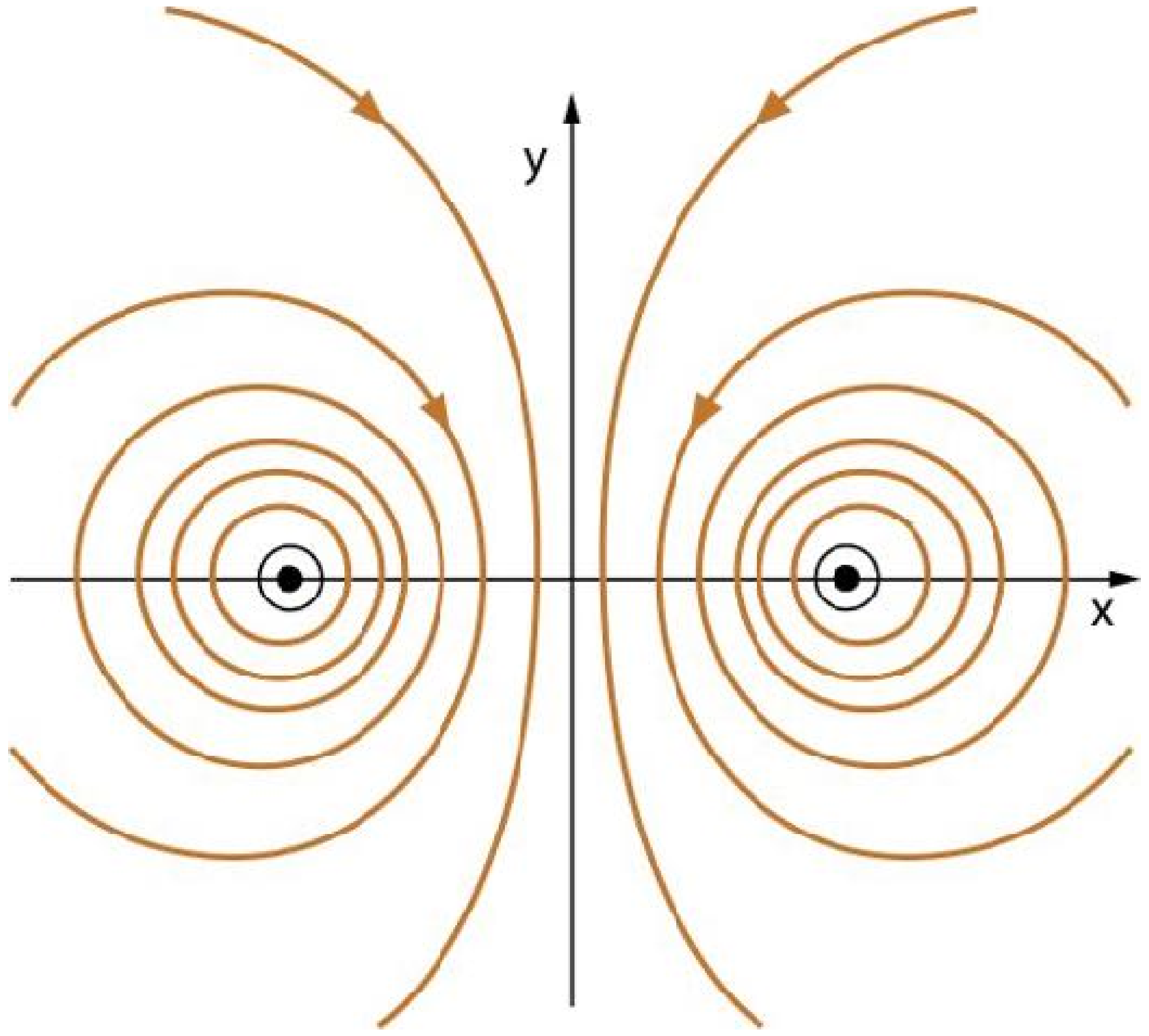
- Magnetic field created by long straight wires



parallel currents
- attract -

$$B = \frac{\mu_o i}{2\pi r}$$

i=2.5 A, r=1 cm
➜ 50 µT
i.e. Earth field
but very localised

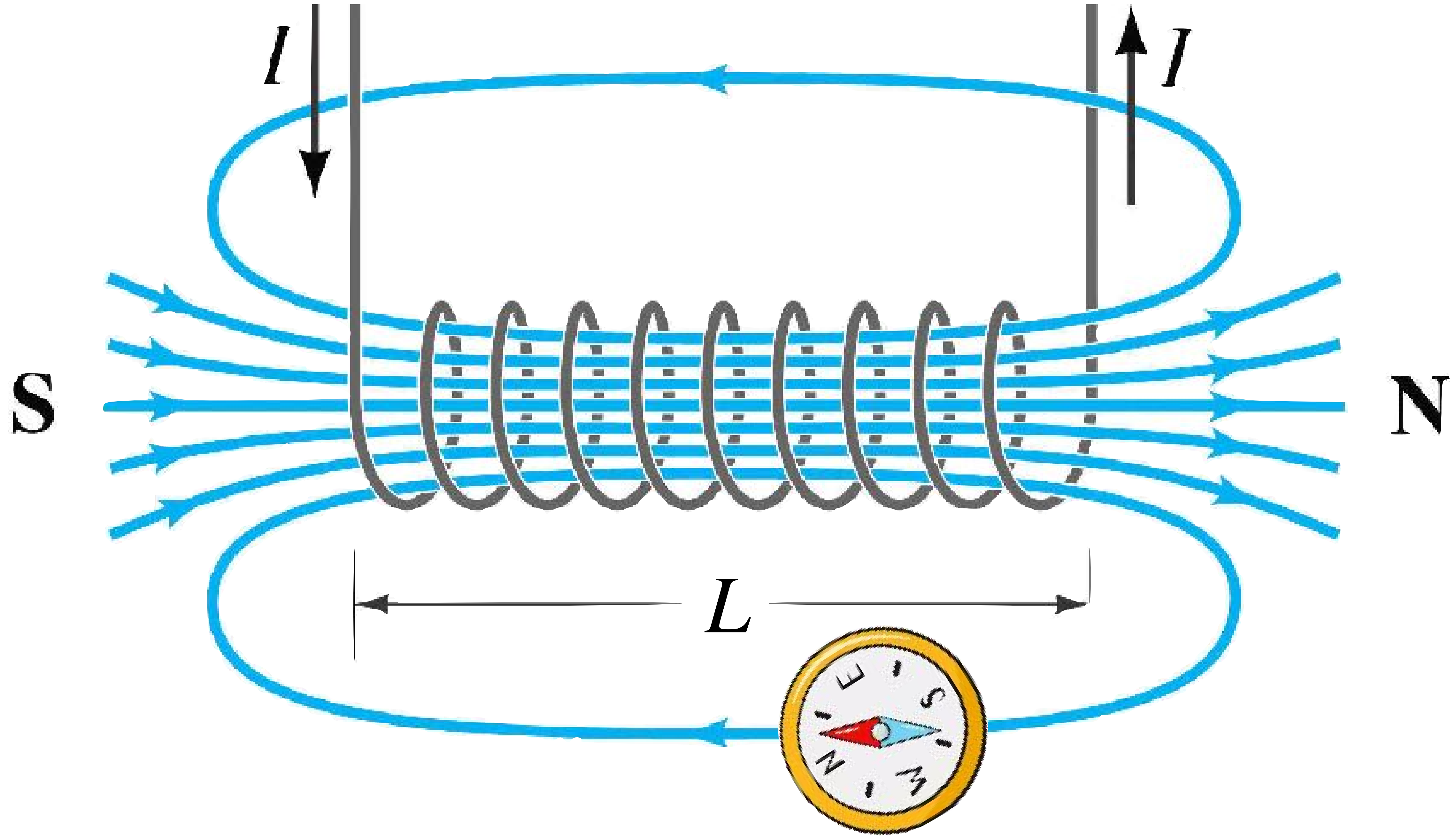


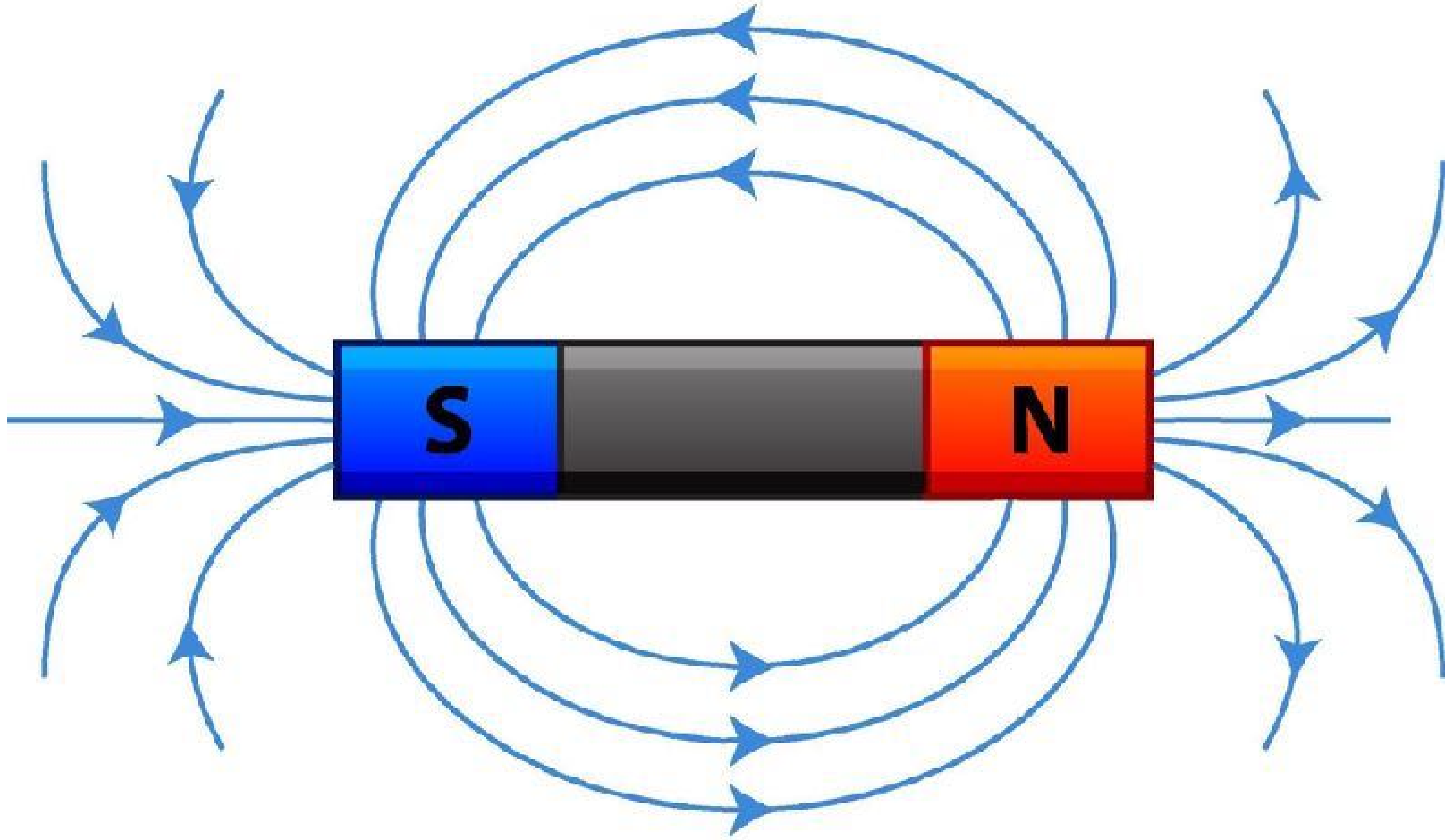
anti-parallel currents
- repel -

NEUTRONS FOR SOCIETY

Magnet use and design

- Magnetic field created by a long solenoid

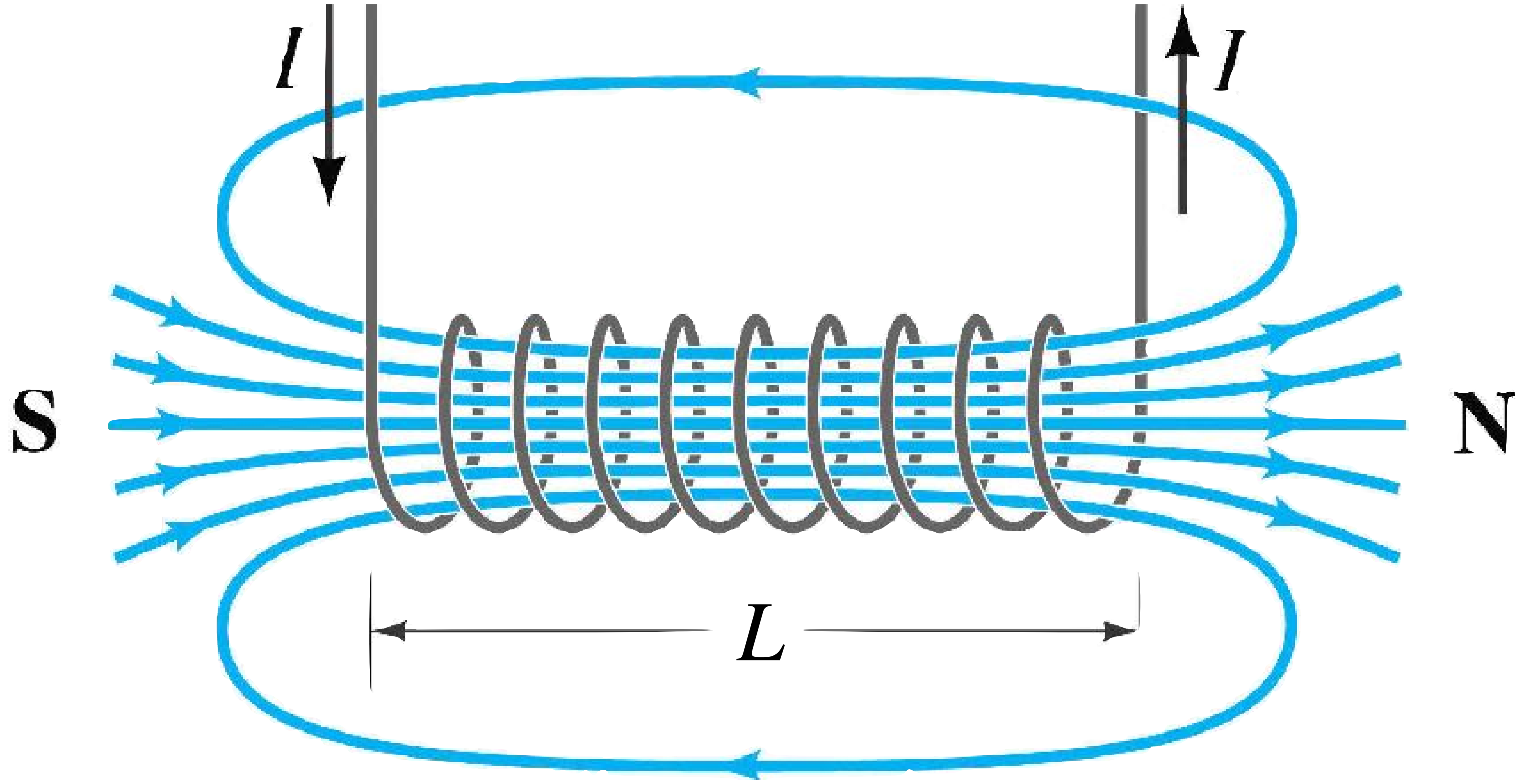




Magnet use and design

- Magnetic field created by a long solenoid

$$B = \frac{\mu_o N I}{2\sqrt{L^2 + R^2}}$$



L=5 cm, radius R=1 cm
➜ 1 T with i=1624 A

but 88 kW of heat
generated with
a good Cu wire

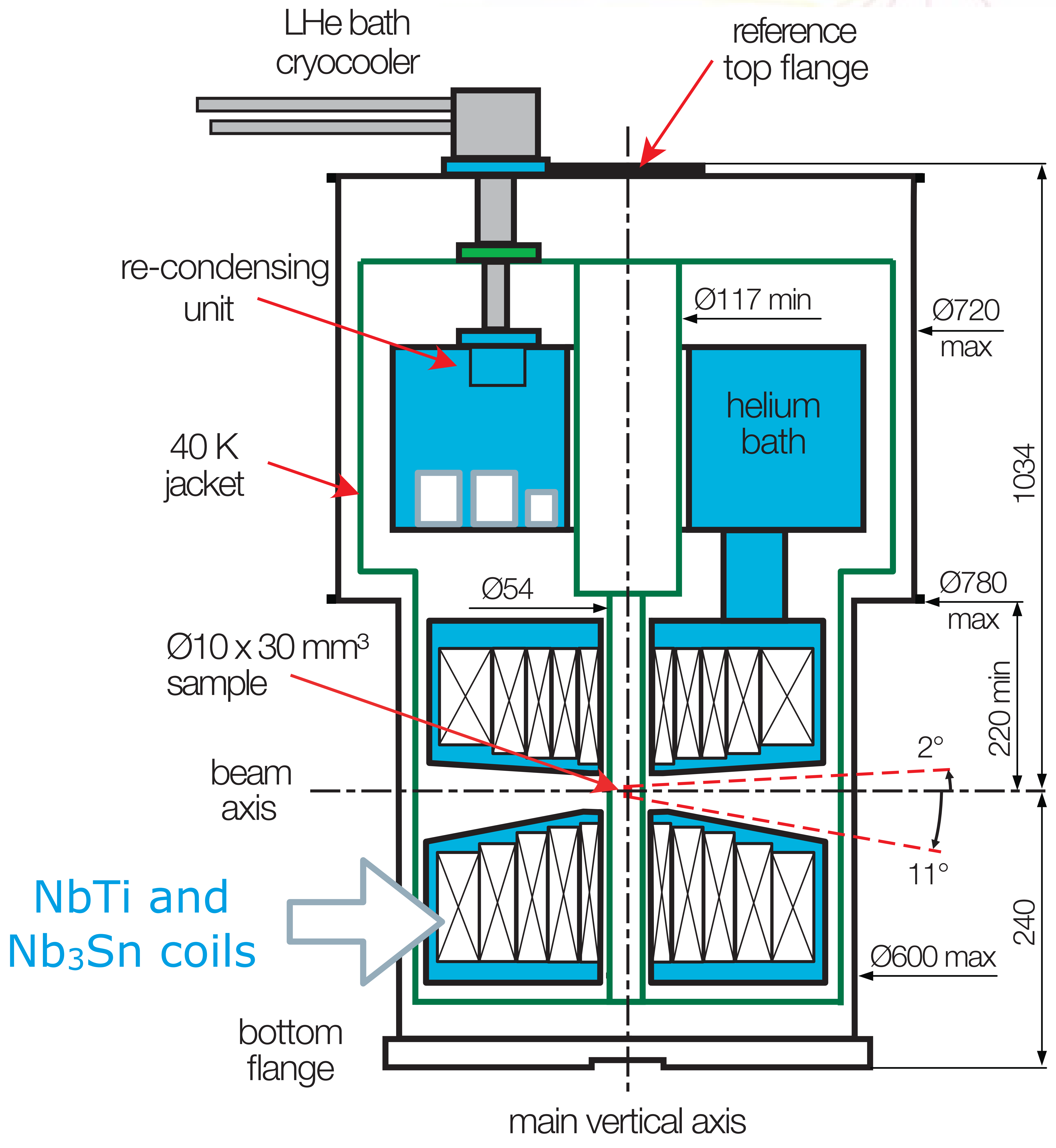
- Impossible! -

NEUTRONS FOR SOCIETY

Low-T_c magnets

for neutrons & x-rays

- Vertical field
  - up to 15 T
  - dry or wet cryostat
  - zero boil-off option
  - split geometry (rings or not)
  - symmetric or asymmetric
  - self-shielded or not
  - 40 mK dilution insert
  - 2 T dysprosium booster



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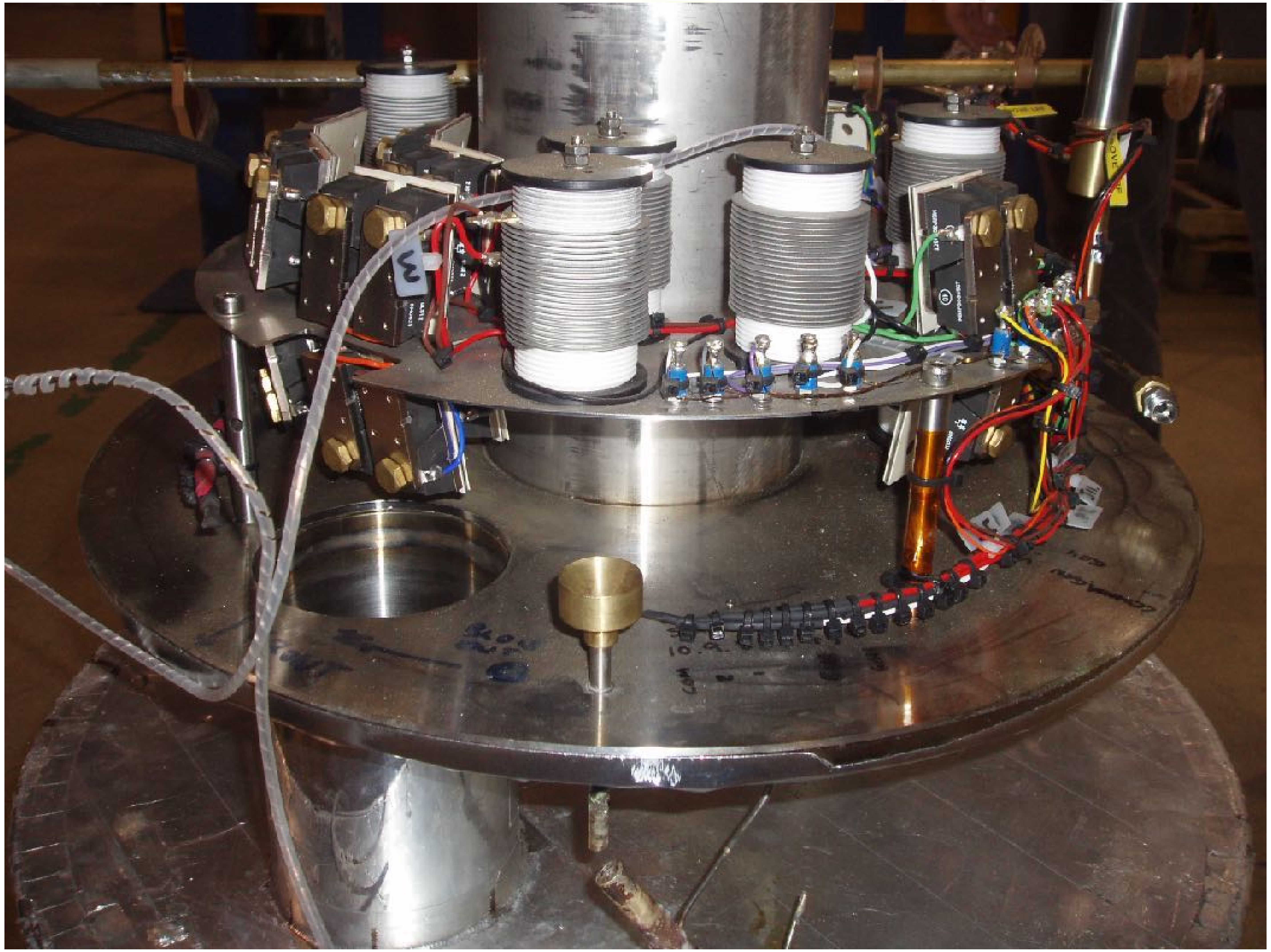

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radial access

⬇

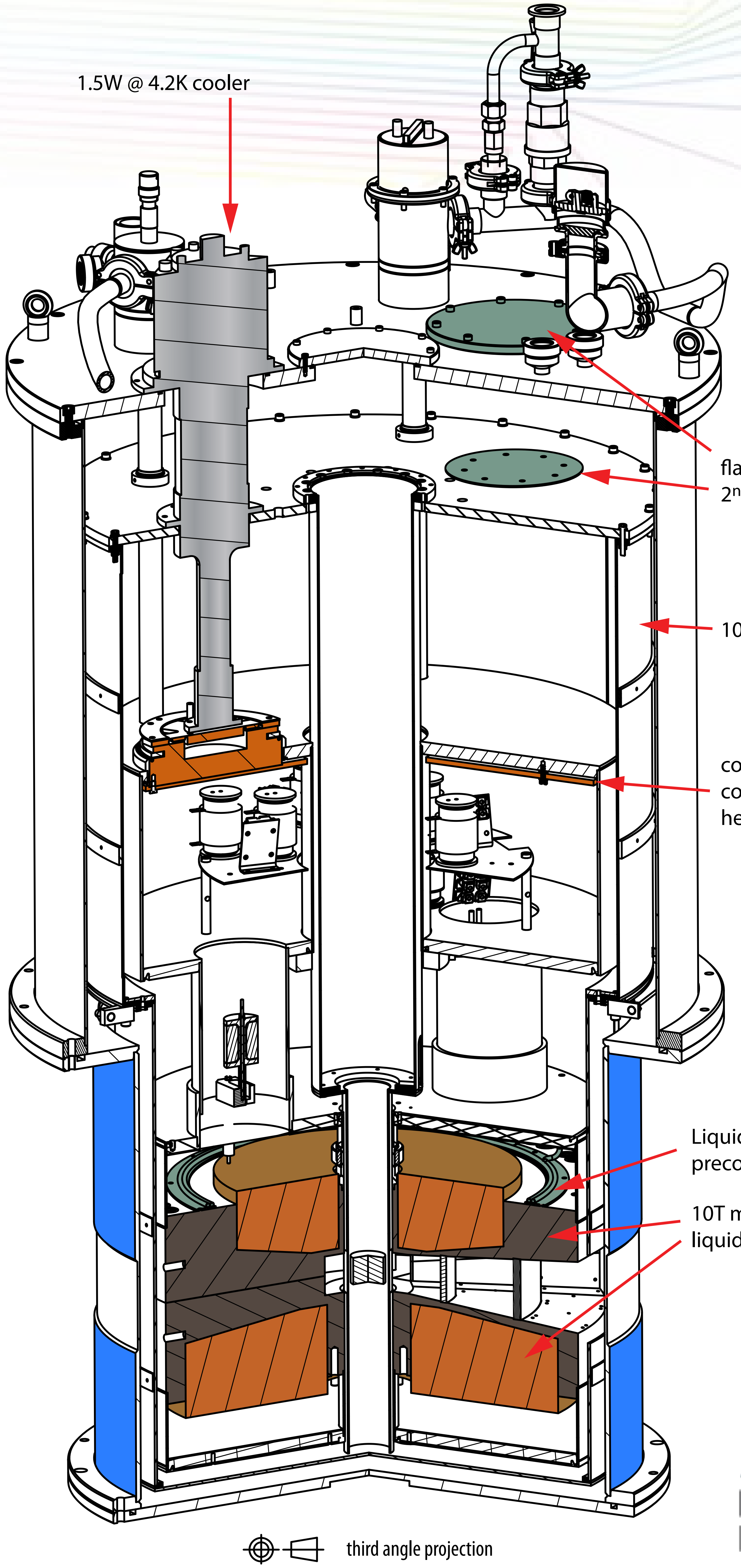
split pair geometry

⬇

13.4 T in coils
to reach 10 T at
sample position

⬇

1069 kN
attraction force



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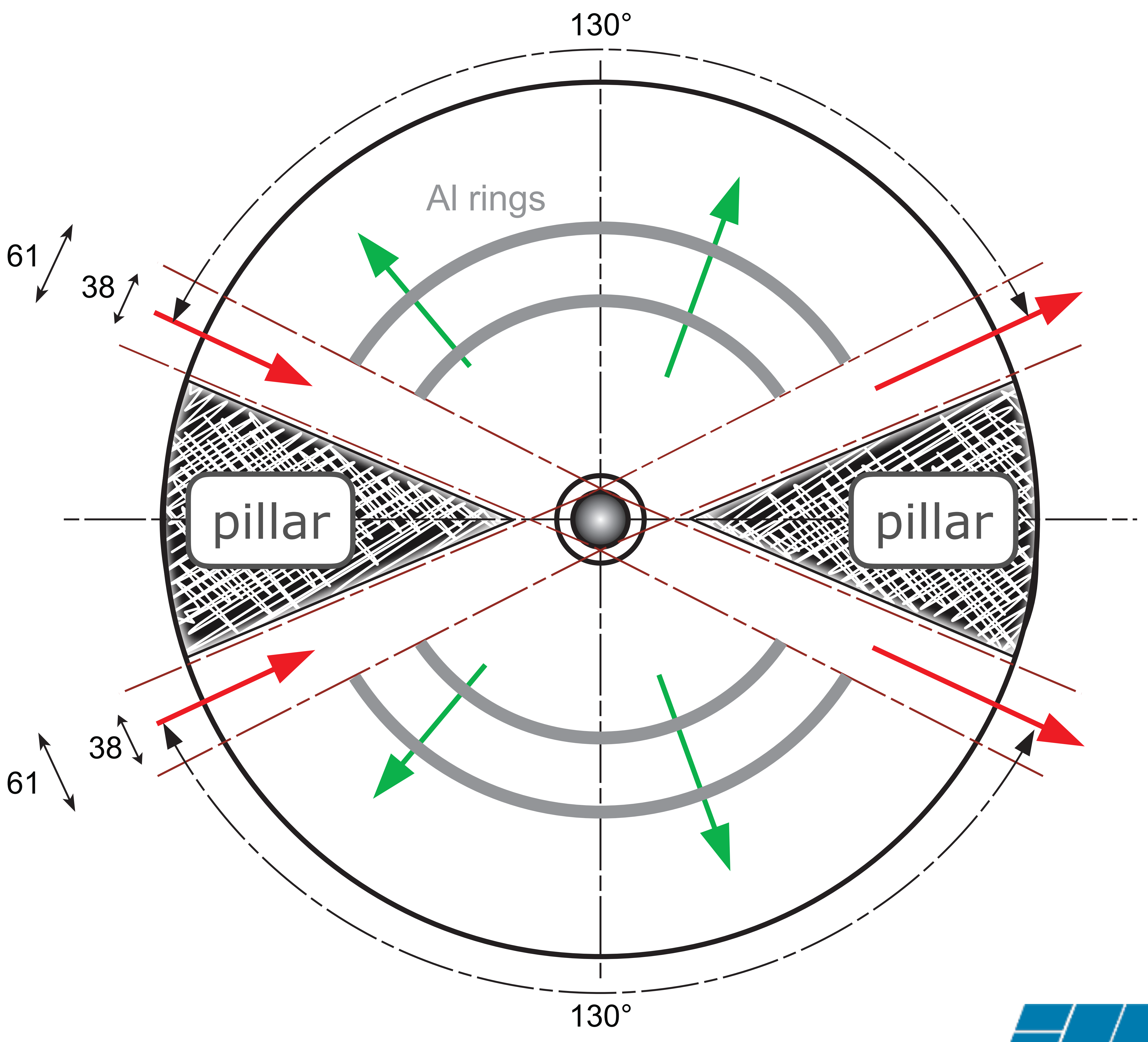

NEUTRONS FOR SOCIETY

Low-T$_c$ magnets

for neutrons & x-rays

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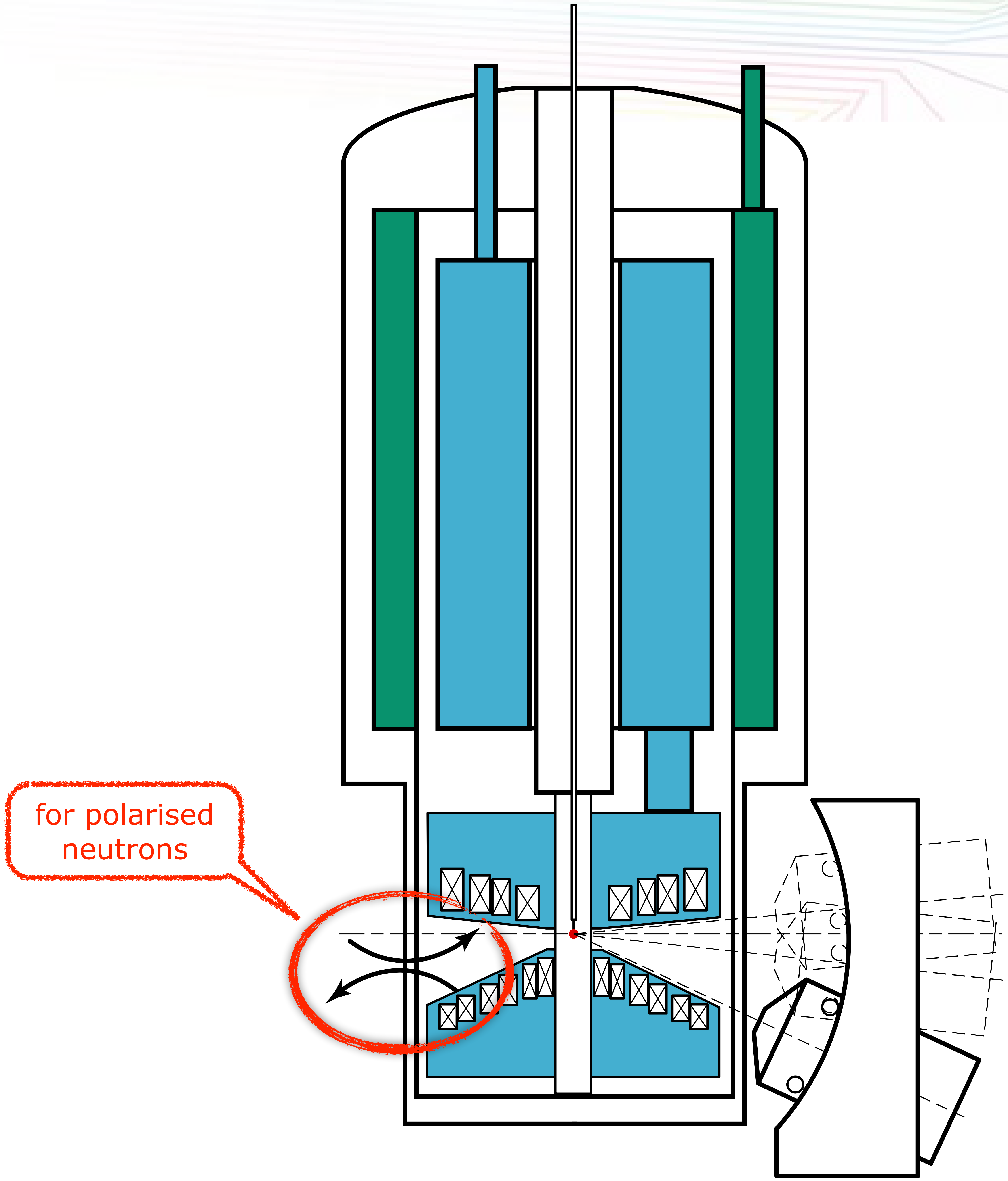

NEUTRONS FOR SOCIETY

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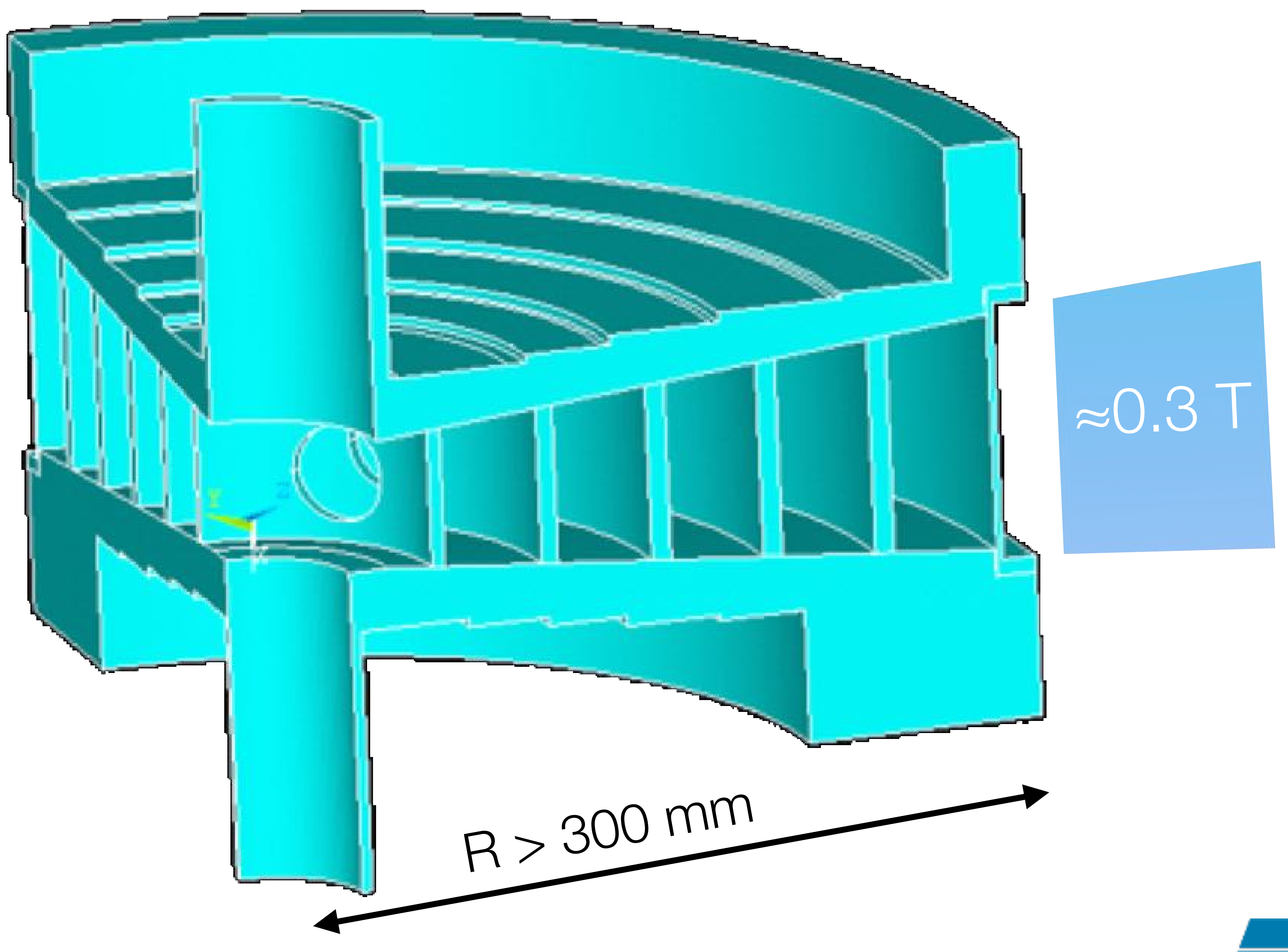
10T non-shielded magnet



NEUTRONS FOR SOCIETY

Low-T_c magnets

for neutrons & x-rays

10T actively shielded magnet

- Vertical field
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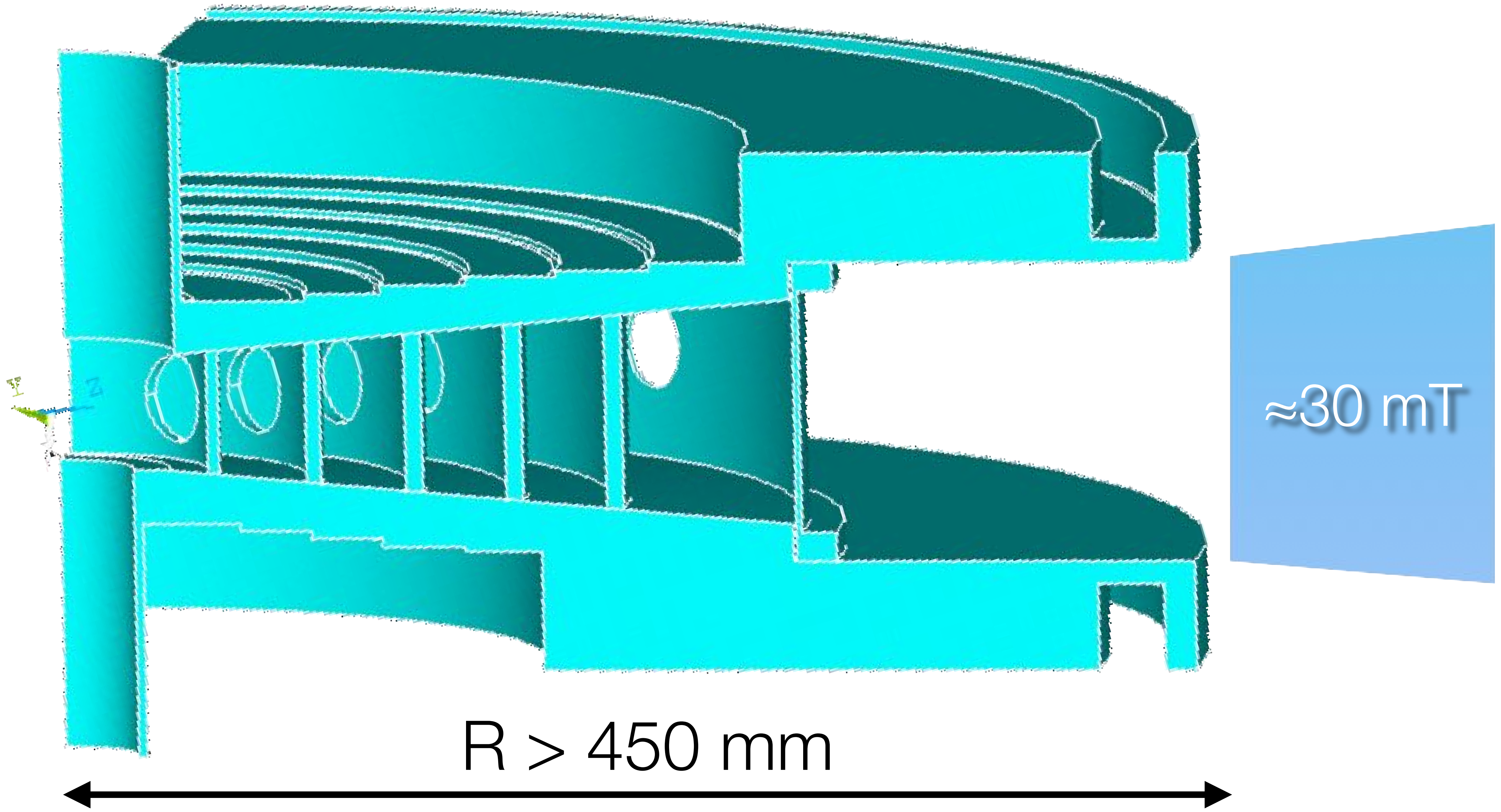
  - dry or wet cryostat
  - zero boil-off option
  - split geometry (rings or not)
  - symmetric or asymmetric
  - self-shielded or not
  - 40 mK dilution insert
  - 2 T dysprosium booster



NEUTRONS FOR SOCIETY

Low-T_c magnets

for neutrons & x-rays

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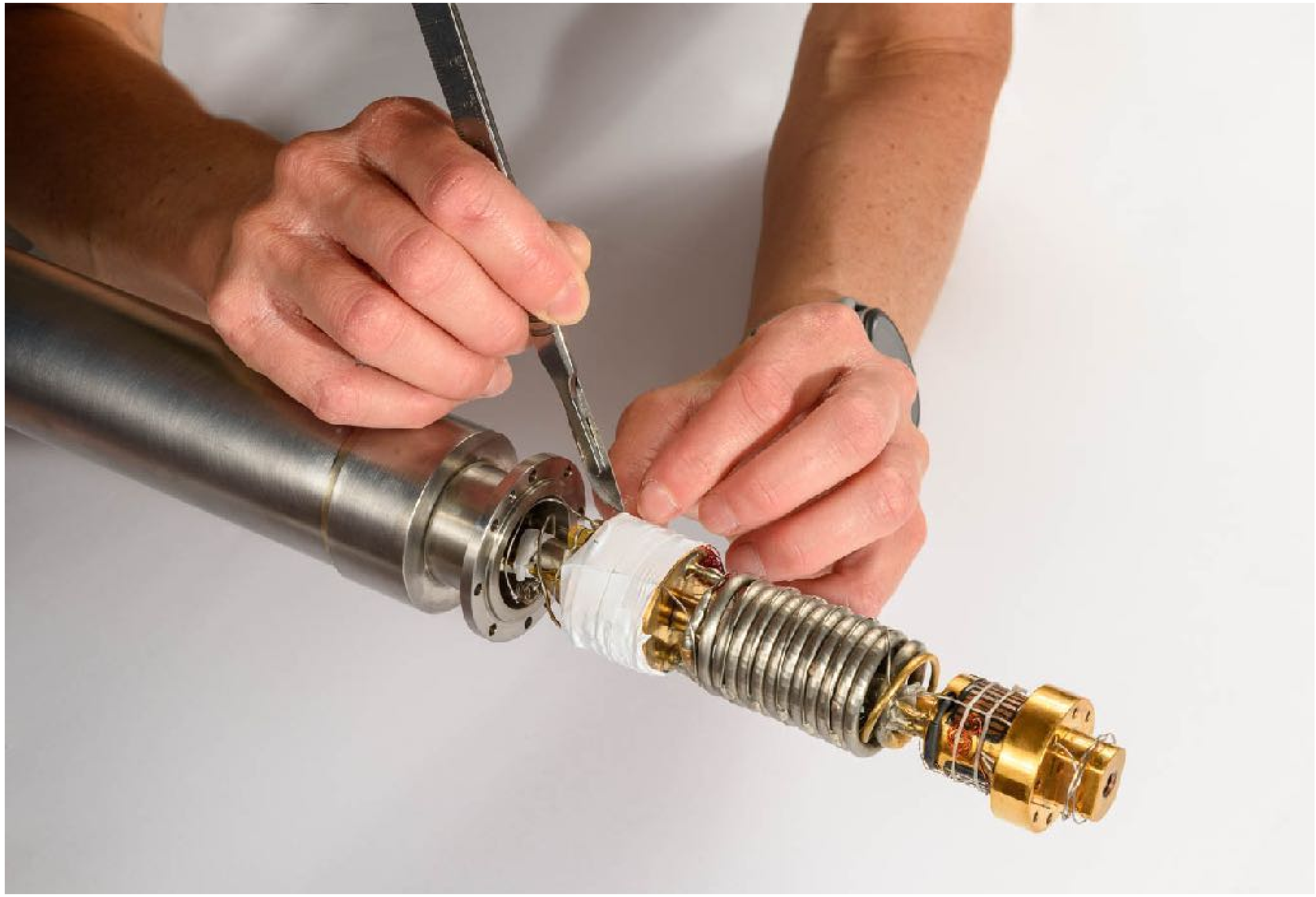

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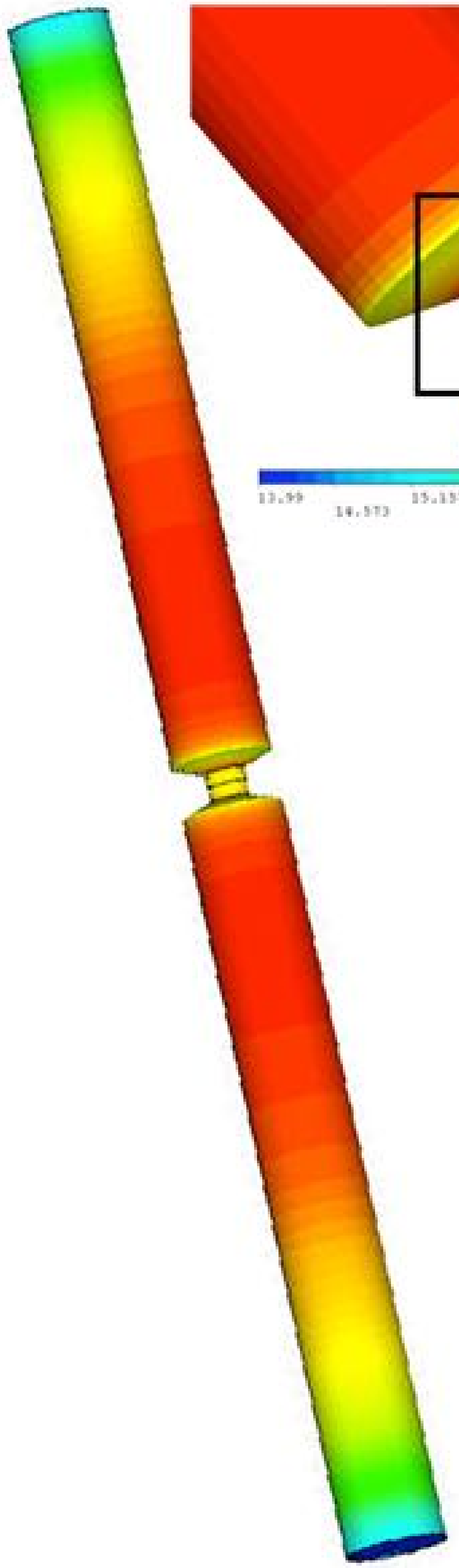
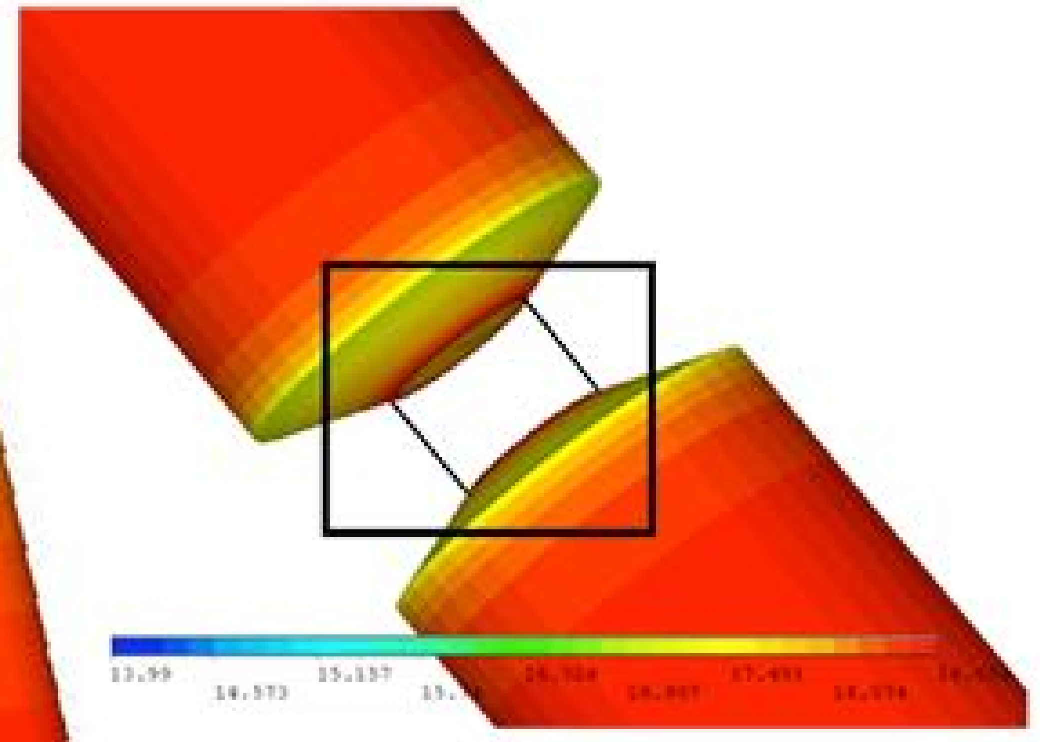
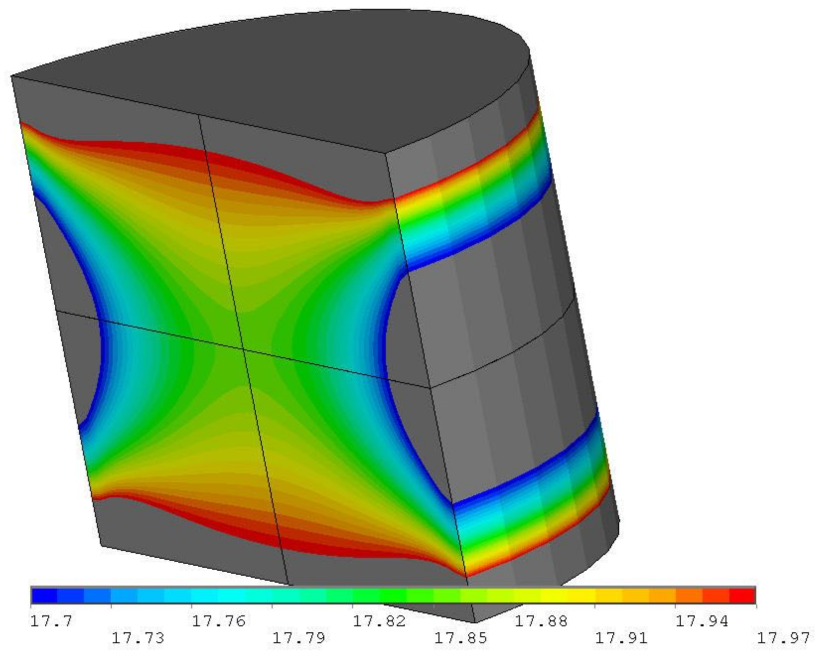






4 mm gap
Ø6 mm
+2.8 T

NEUTRONS FOR SOCIETY

Sample alignment

Align crystals remotely inside magnets

- Goniostick
  - non-magnetic
  - ±7° sample tilting
  - ±0.02° reproducibility
  - ±10 mm vertical tuning
  - ±180° vertical rotation
  - fits inside >Ø36 mm bore magnets

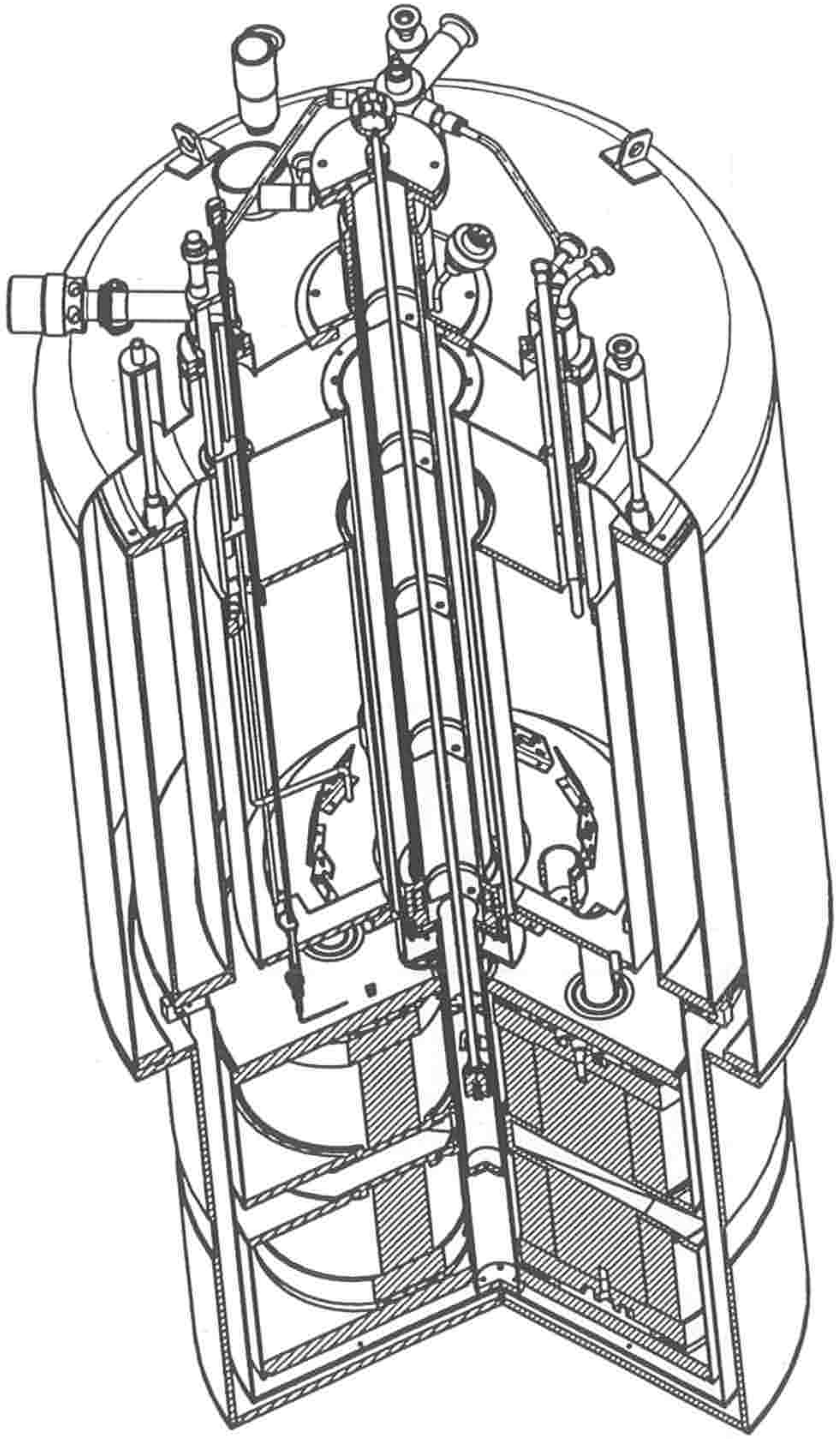
J. Neutron Research **19** (2017) 27

NEUTRONS FOR SOCIETY

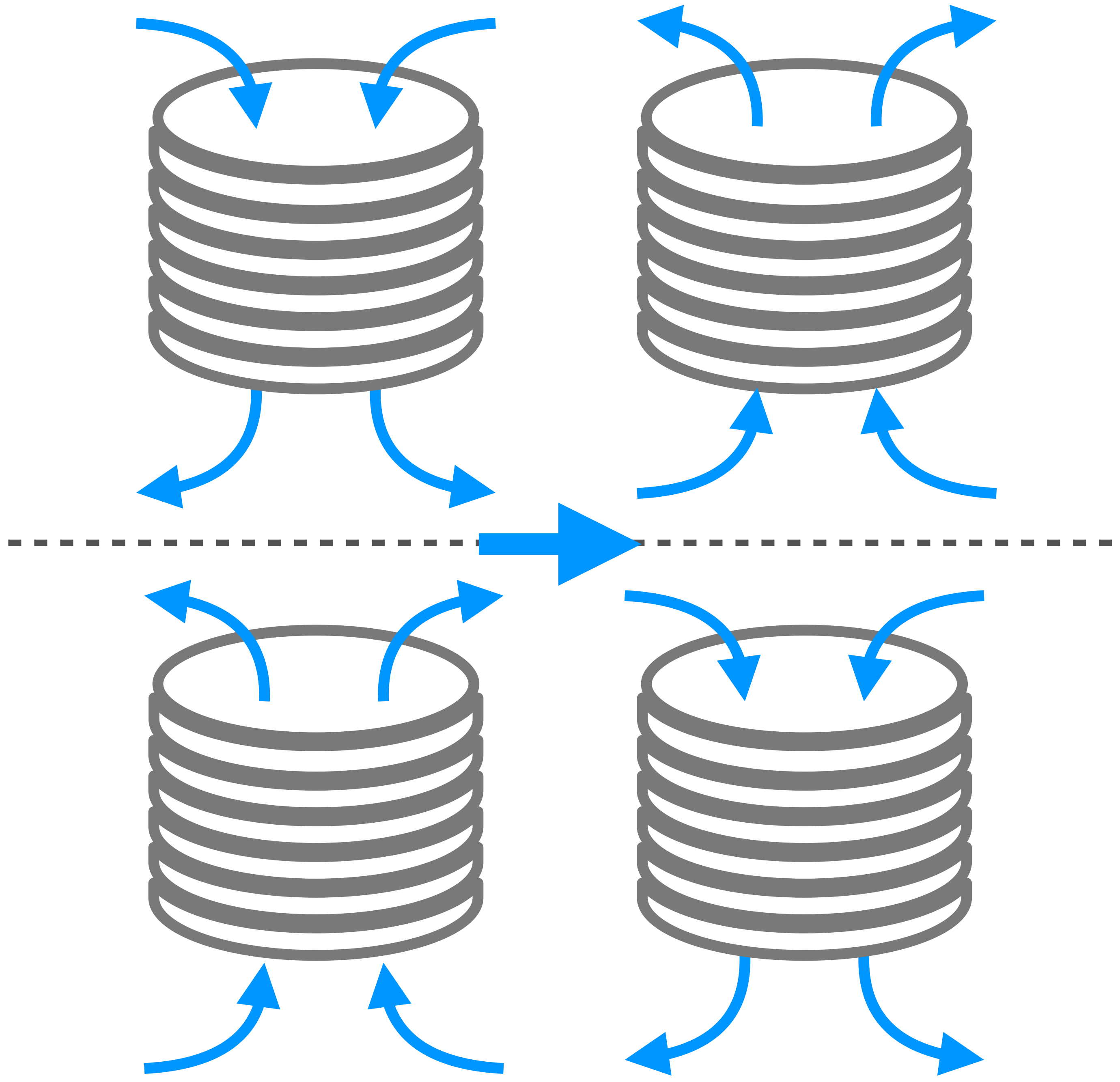
Low-T$_c$ magnets

for neutrons & x-rays

- Horizontal field
  - up to 17 T
  - split or conical
  - top or bottom loading
  - zero boil-off option
  - self-shielded or not
  - 40 mK dilution insert or 100 mK dilution refrigerator



4 T magnet with 4 coils



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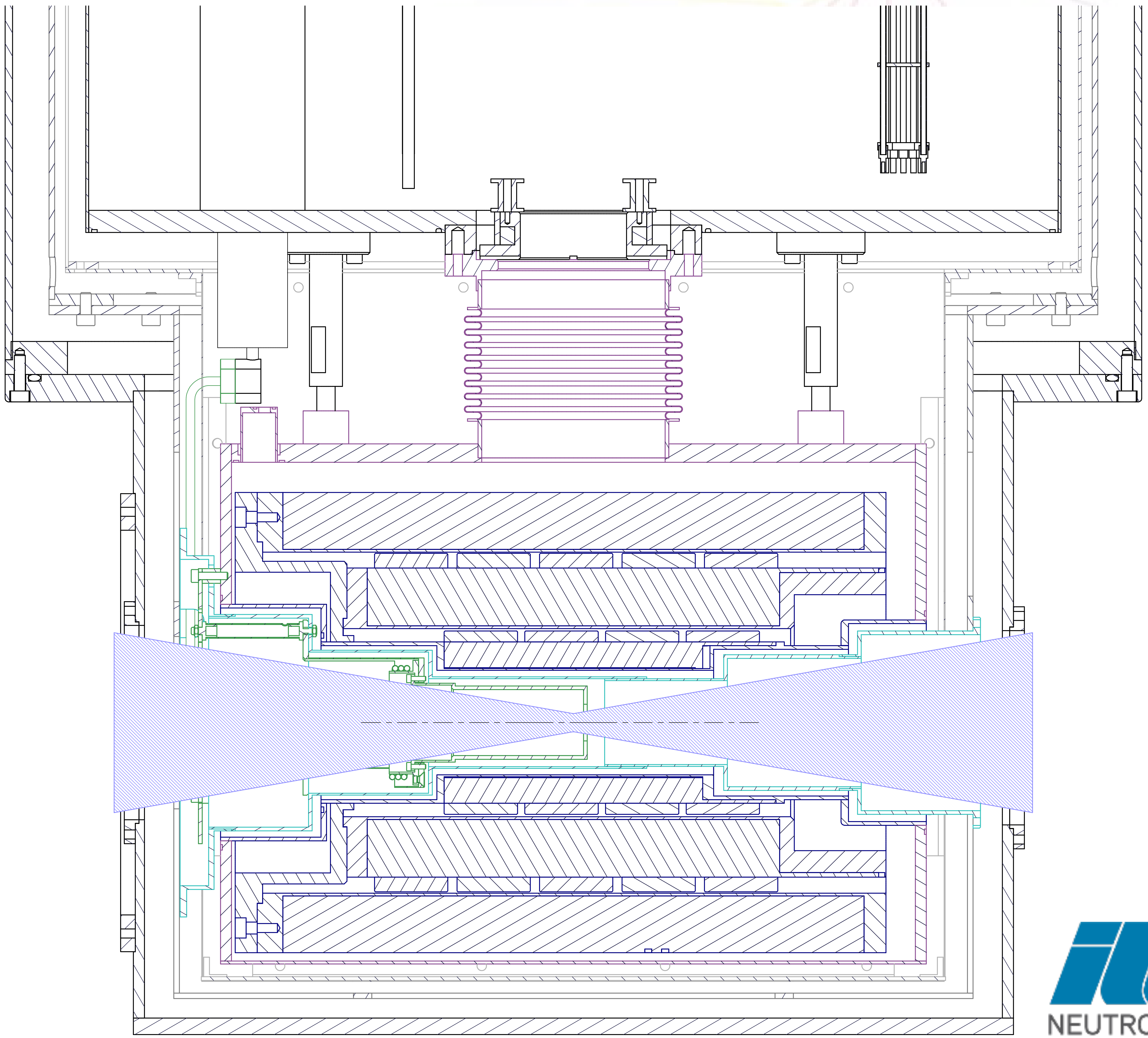

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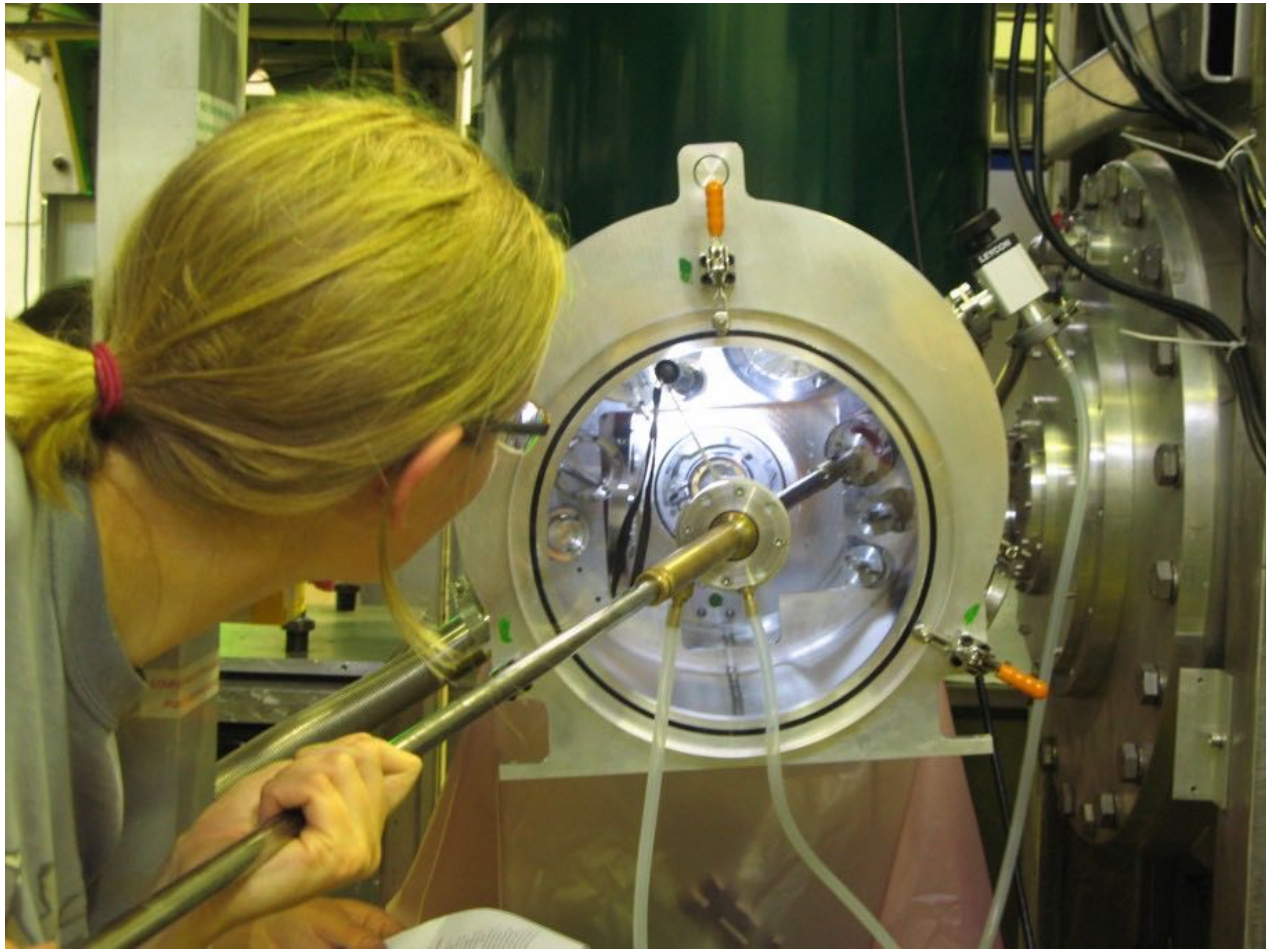


NEUTRONS FOR SOCIETY

Low-T_c magnets

Ancillary equipment

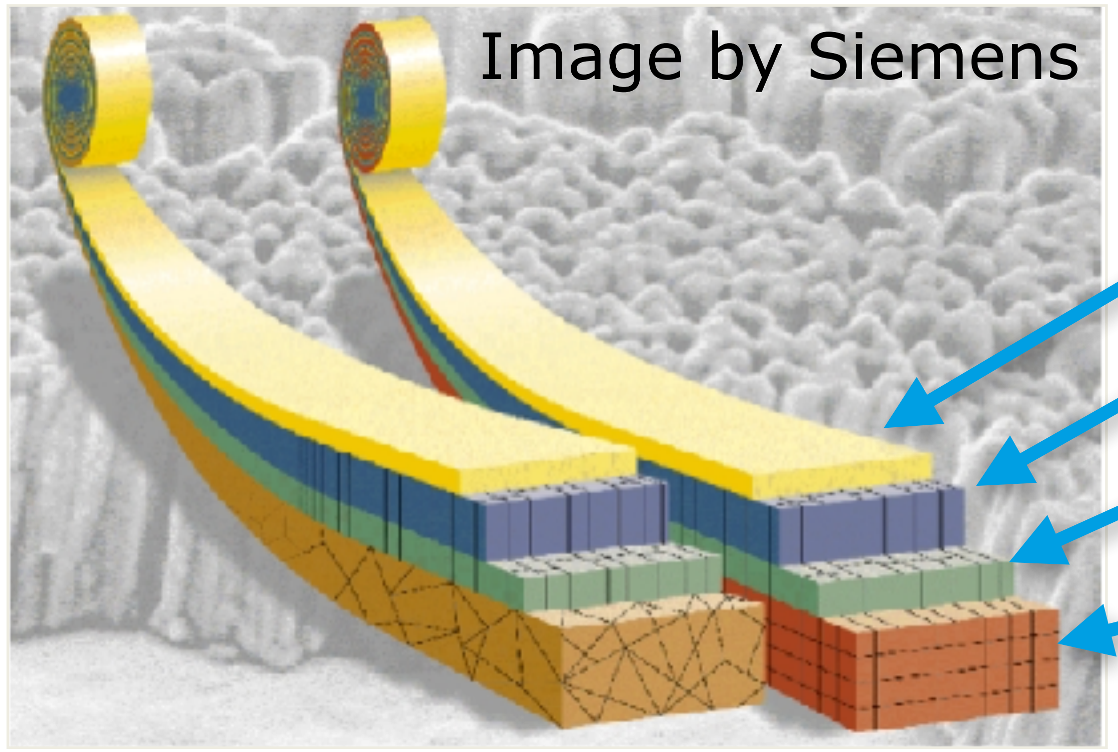
- Power supply
  - typically 125 A / 10 V
  - limiting slopes
  - persistent switch control
  - auto-run-down
- Liquid He level monitor
  - low-level alarm
- Pressure regulator
  - atmospheric pressure in the bath

NEUTRONS FOR SOCIETY

High-T_c magnets

for neutrons & x-rays

- Practical superconductors for high-field magnets

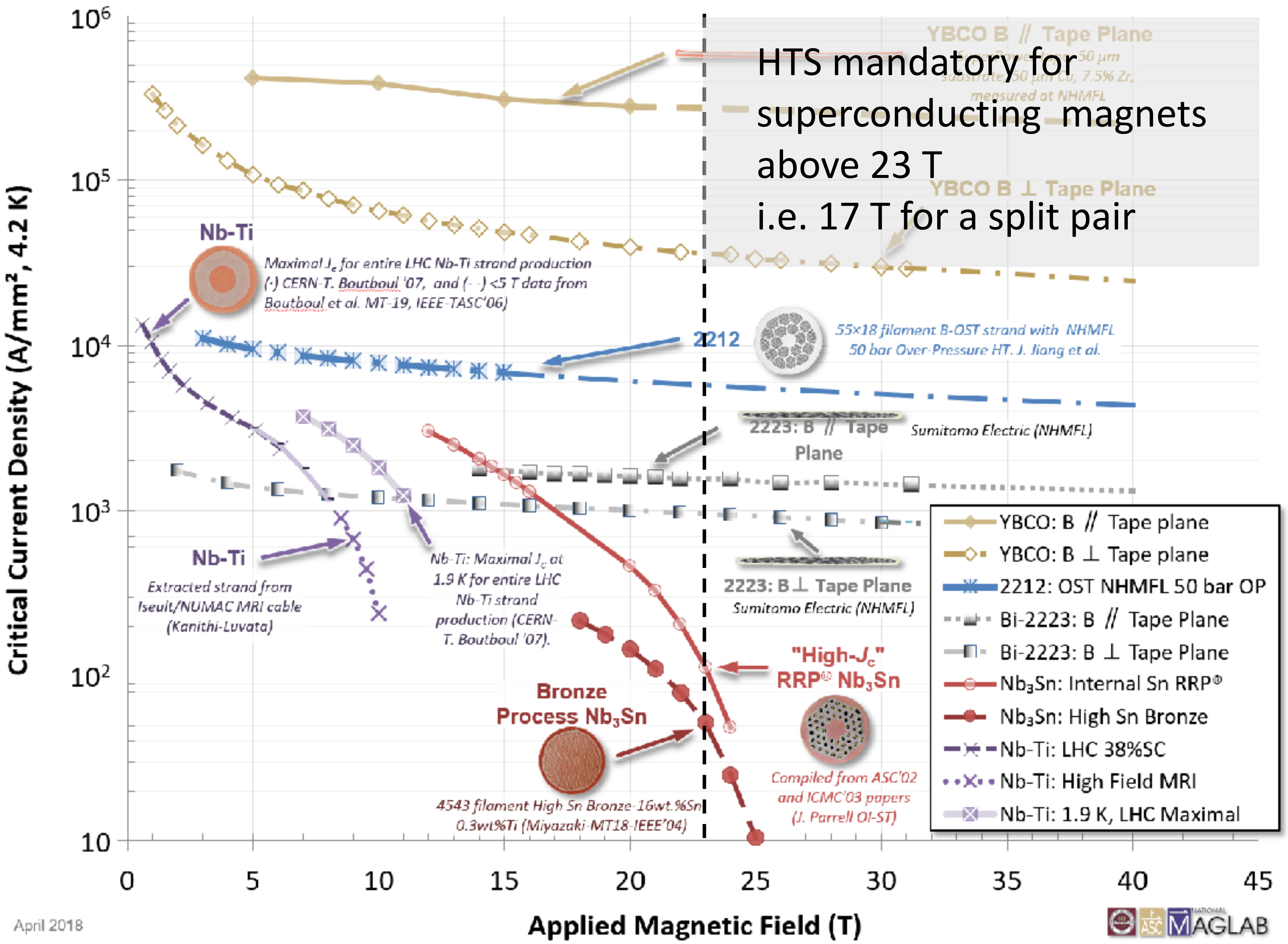


Shunt 4 - 100 µm

REBCO 1 – 4 µm

Buffer (small)

Substrate 30 – 100 µm

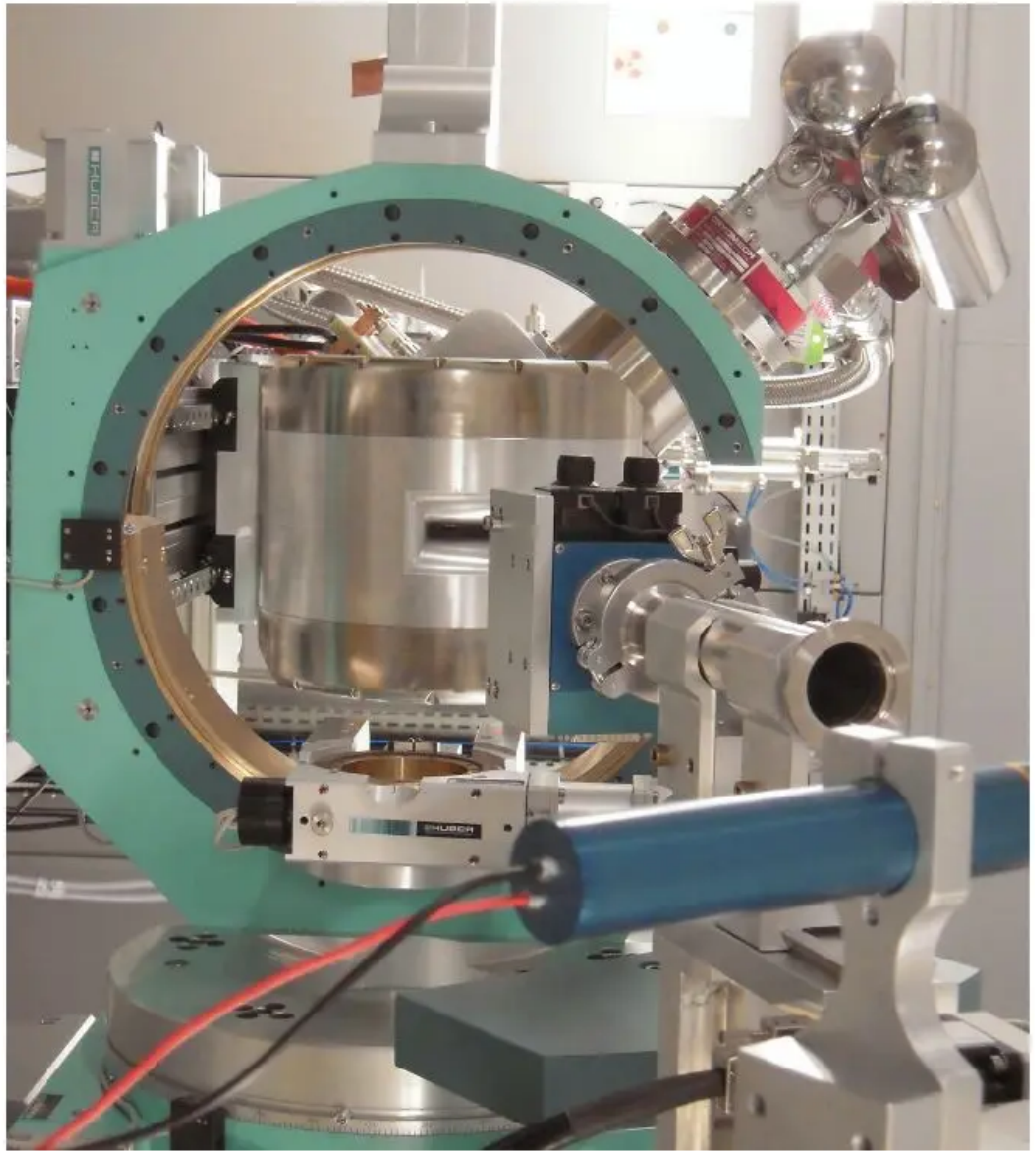


HTS mandatory for superconducting magnets above 23 T
i.e. 17 T for a split pair

High-T_c magnets

for neutrons & x-rays

- 1G high-T_c tape
  - dry or wet cryostat
  - rotatable or not
  - cold or warm bore
  - for diffraction, magnetic scattering, magnetic circular dichroism, etc.
- 2G high-T_c tape coming…
  - compact coils
  - higher fields expected



NEUTRONS FOR SOCIETY

High-T_c magnets

for neutrons & x-rays

- 3 Tesla high-T_c 1G coils
  - magnetic yoke
  - ±16° conical access
  - transverse and longitudinal field
  - Ø81 mm warm bore
- 12 Tesla high-T_c 1G coils
  - +11°/-2° vertical access to 30 mm
  - 2x130° horizontal access to 10 mm
  - 1.5-300 K sample temperature

High-T_c magnets

for neutrons & x-rays

- 3 Tesla high-T_c 1G coils
  - magnetic yoke
  - ±16° conical access
  - transverse and longitudinal field
  - Ø80 mm warm bore
- 12 Tesla high-T_c 1G coils
  - +11°/-2° vertical access to 30 mm
  - 2x130° horizontal access to 10 mm
  - 1.5-300 K sample temperature

High-T_c magnets

Ancillary equipment

- Power supply
  - typically 250 A / 5 V
  - limiting slopes
- Magnet monitor
  - high-T and high-V alarms
  - auto-run-down
- Pressure regulator
  - to maintain an atmospheric pressure in the bath

Pulsed field magnets

for neutrons & x-rays

- Produced by EMFL labs in EU
- Ex: available at ILL through collaboration with CNRS/LNCMI Toulouse

  Ø8 mm sample

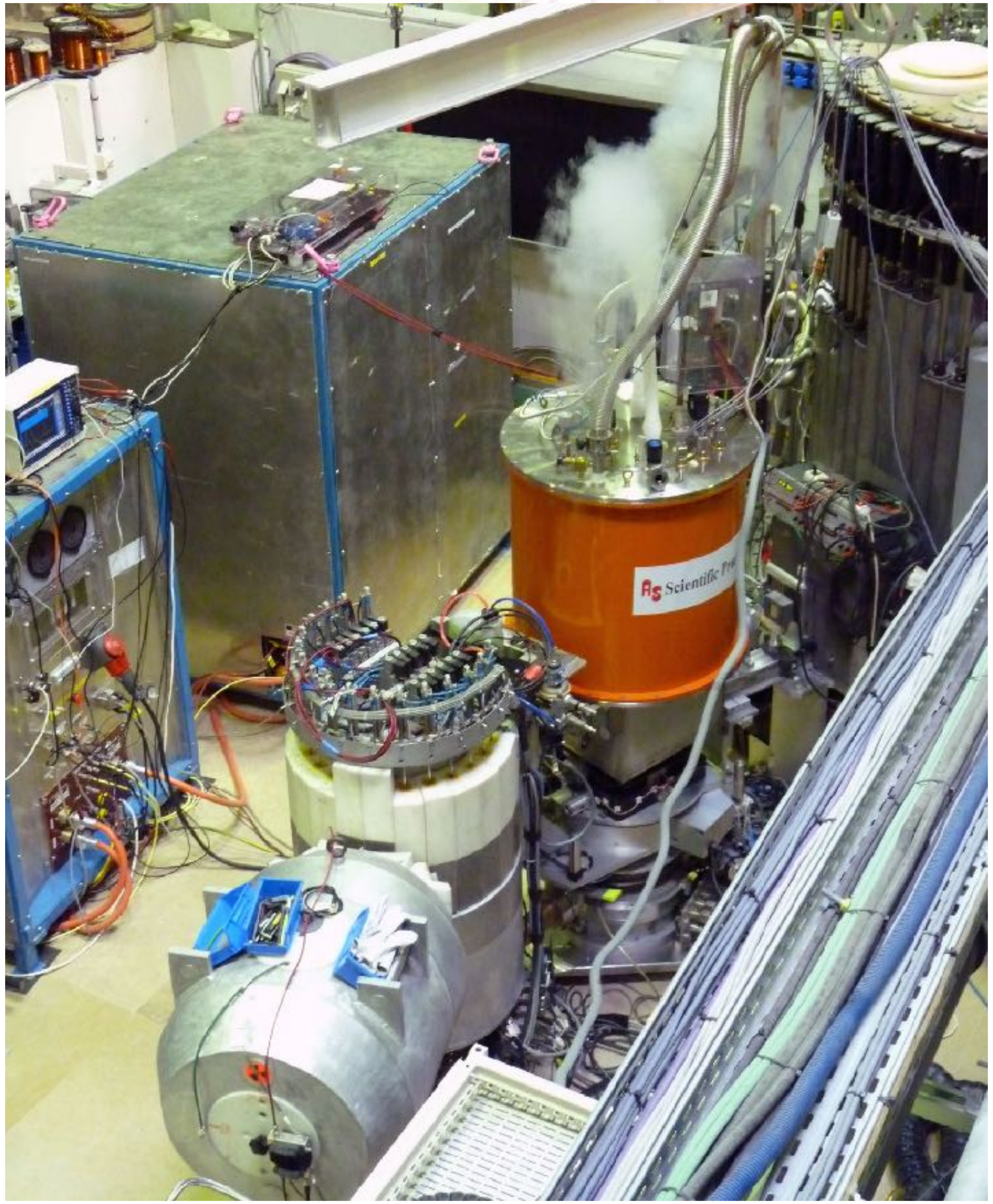
  2 K base temperature

  ±15° incident horizontal access

  ±30° outgoing horizontal access

  ±7° outgoing vertical access

  … and 1.000 L liquid N_2 / day at 40 T



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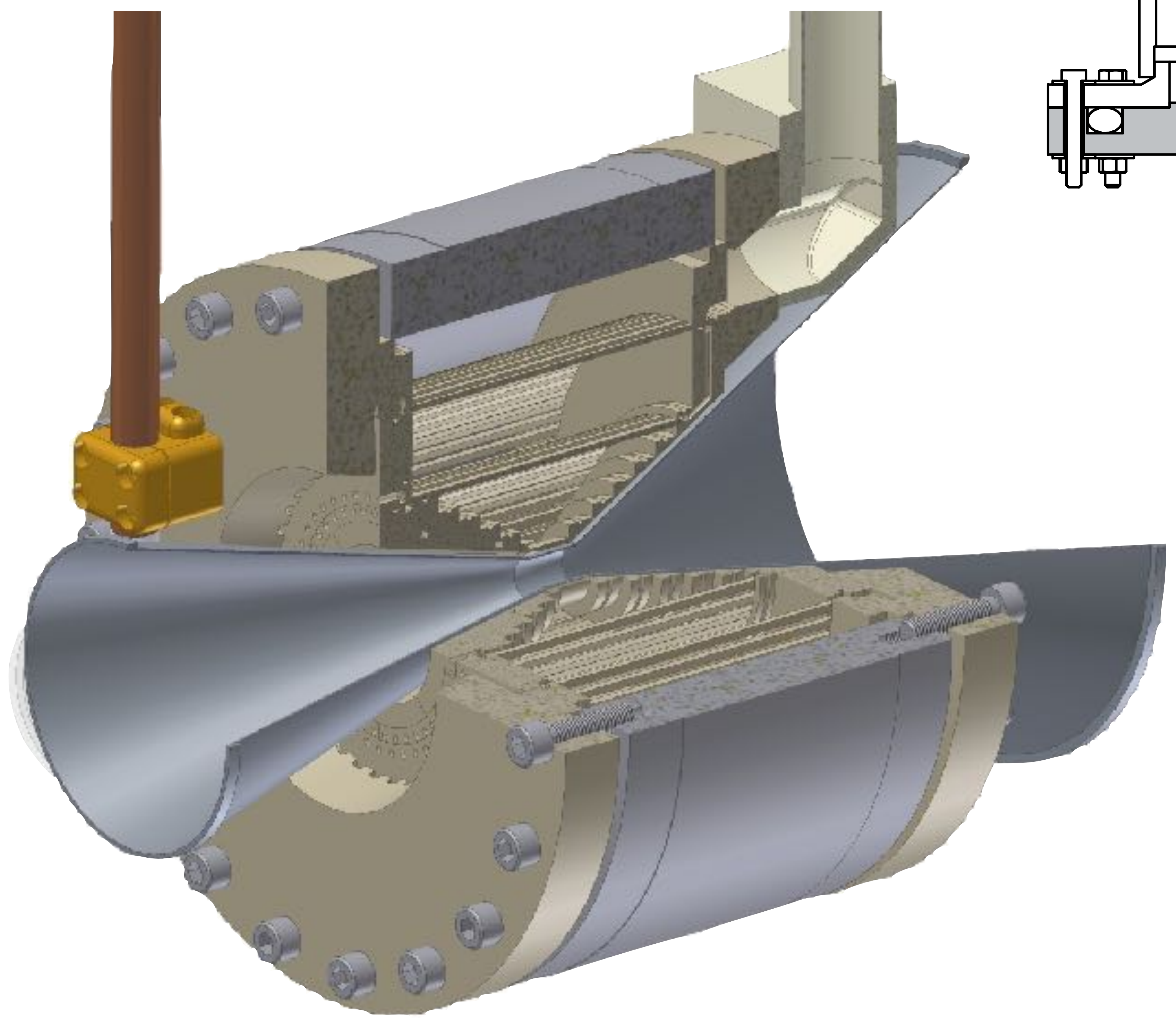
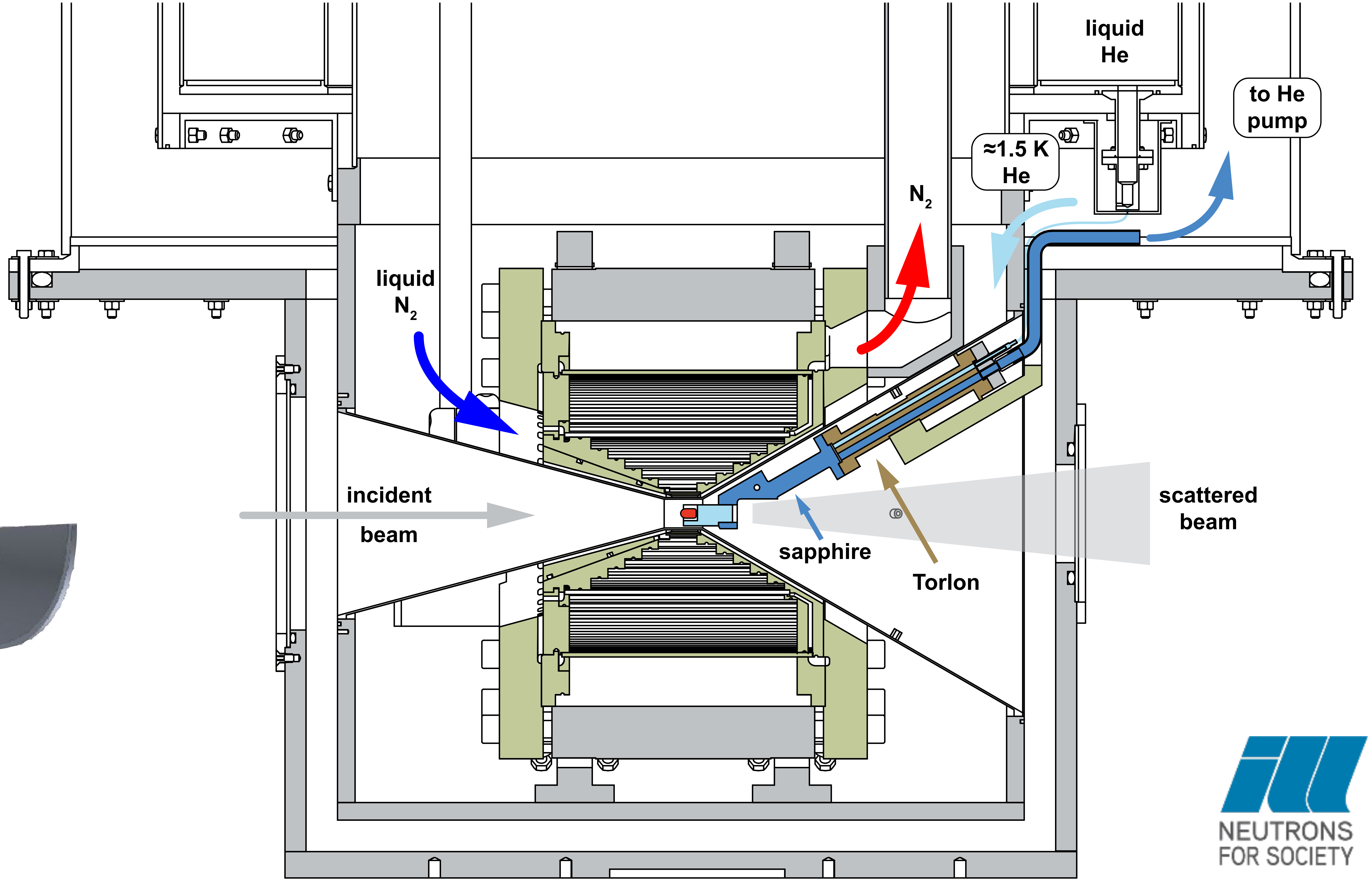
NEUTRONS FOR SOCIETY

Pulsed field magnets

Ex: 40 T with 1.1 MJ power supply





NEUTRONS
FOR SOCIETY

Pulsed field magnets

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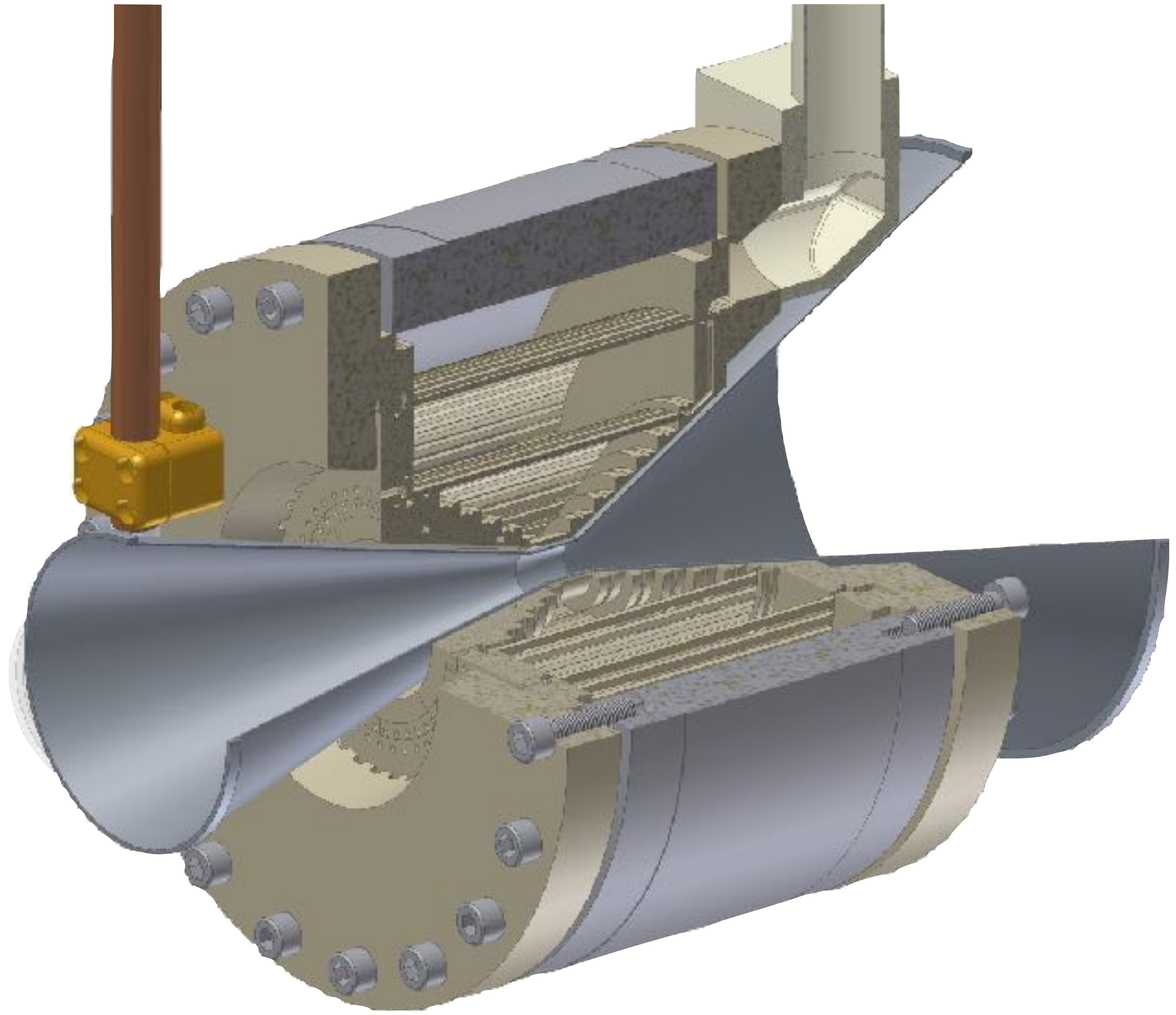
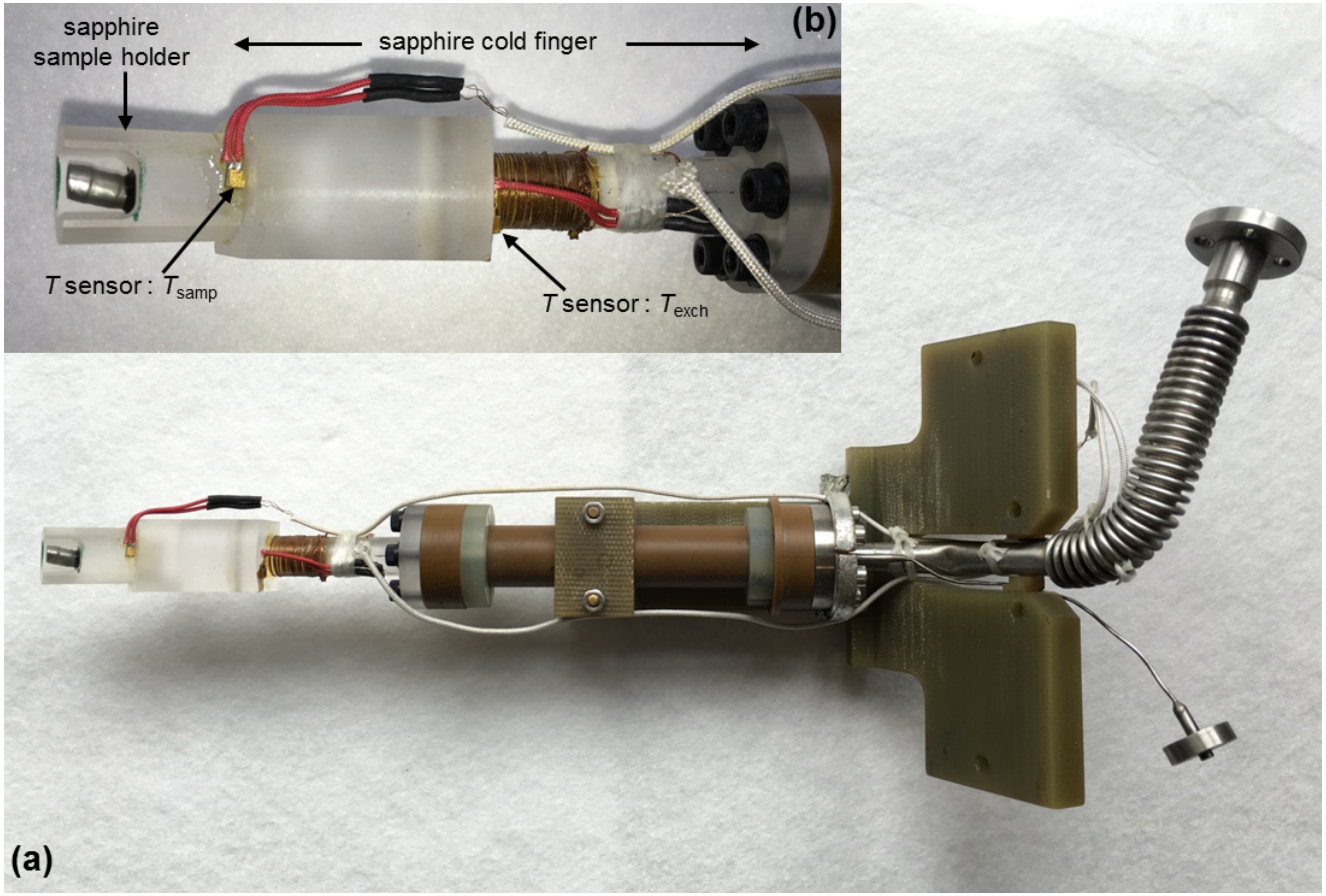




Pulsed field magnets

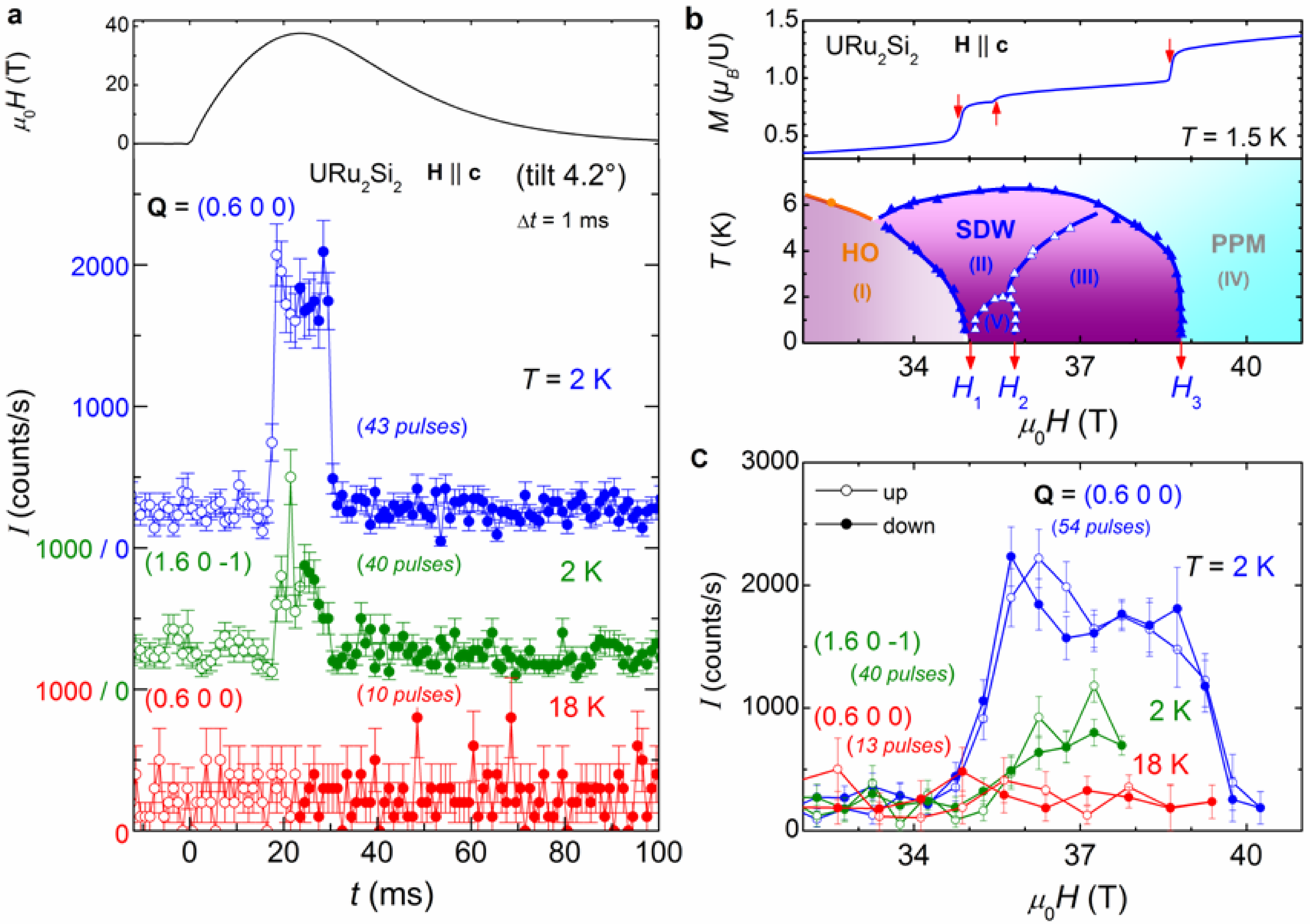
Ex: 40 T with 1.1 MJ power supply

- Field induced spin-density waves in URu_2Si_2

43 pulses to 40T
i.e. 6.5 hours

40 pulses to 40T
i.e. 6 hours

10 pulses to 40T
i.e. 1.5 hours

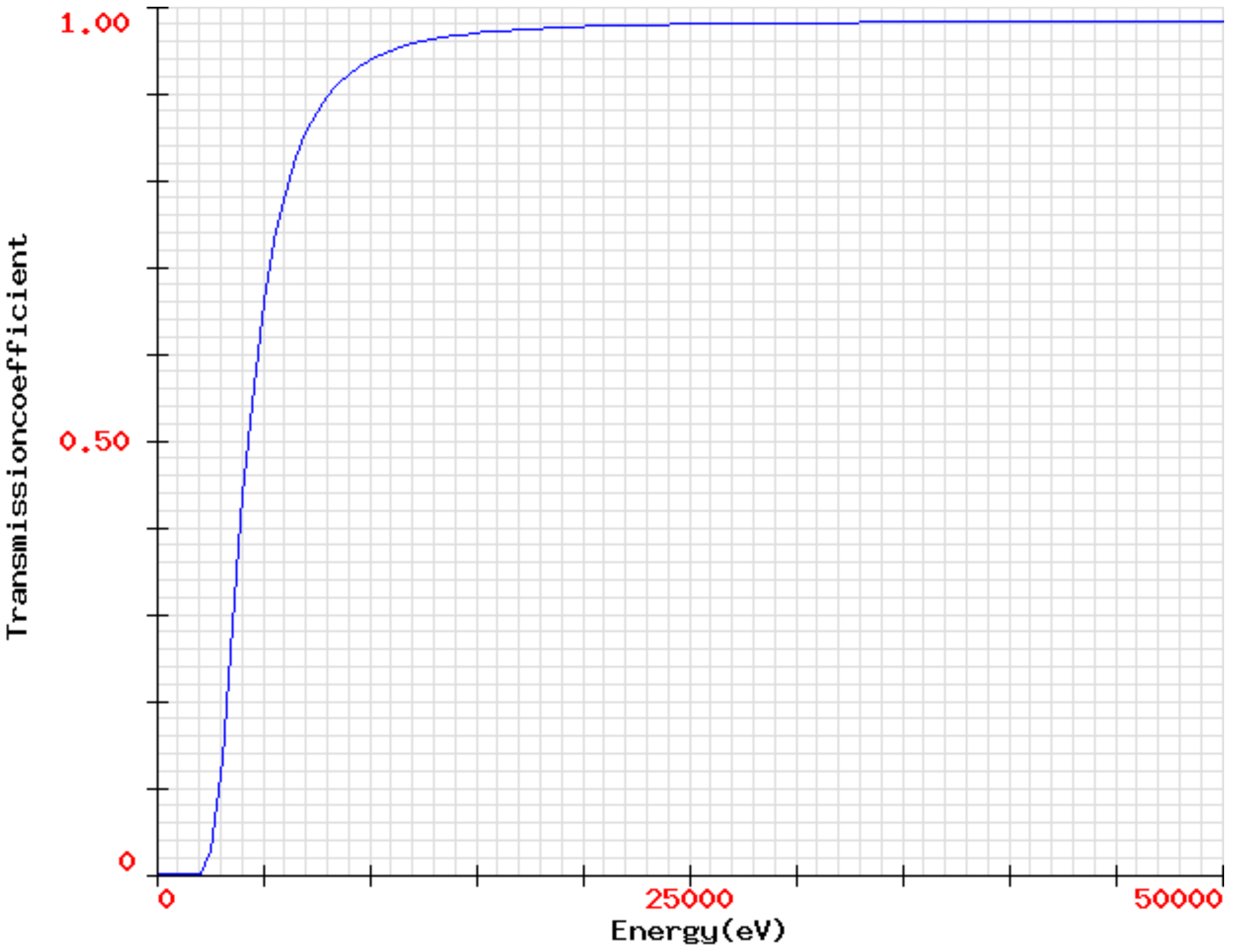


Nature Commun. **7** (2016) 13075

NEUTRONS FOR SOCIETY

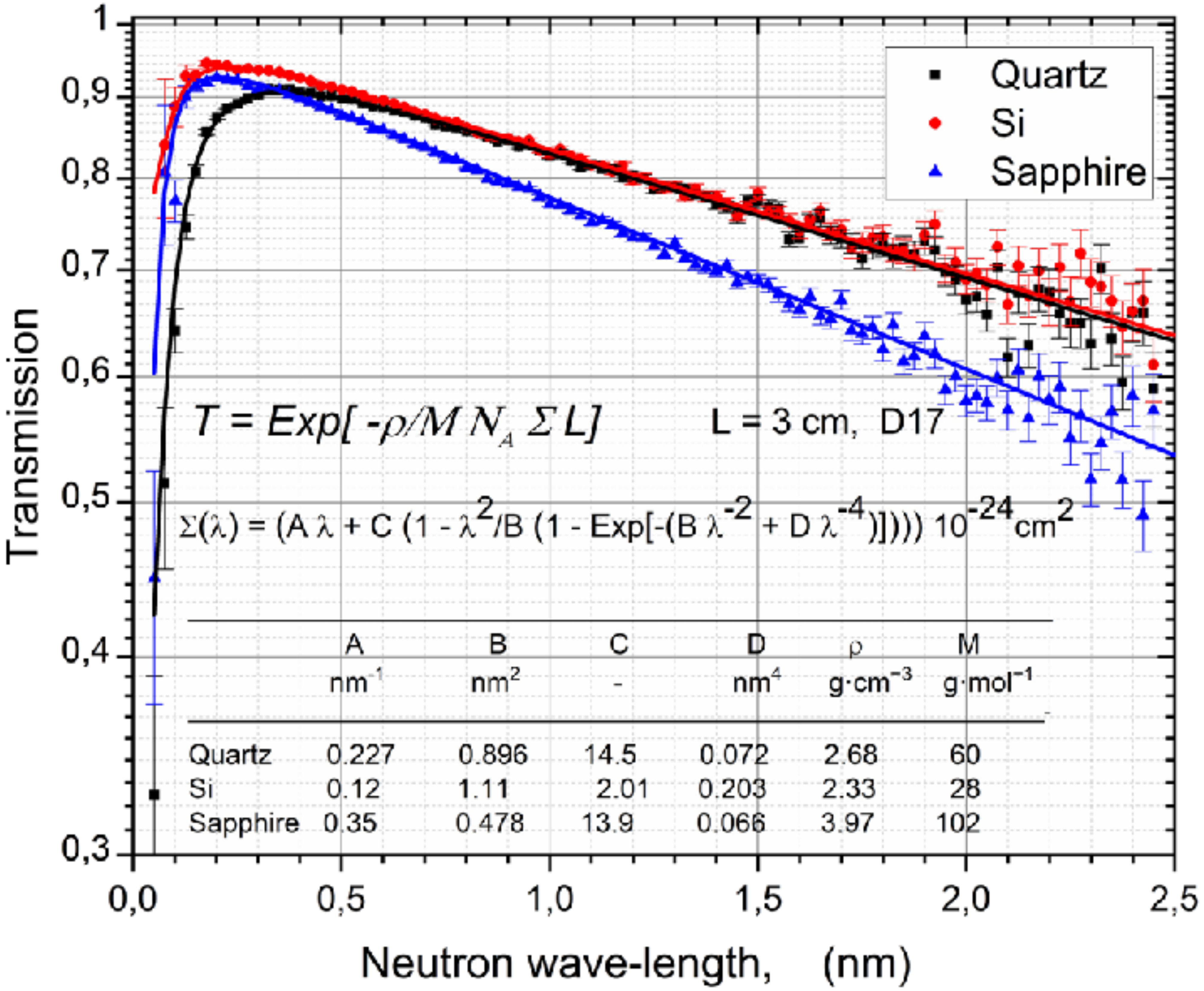
Magnet use and design

Windows



Beryllium windows for x-rays

BM05 webpage



Sapphire or Silicon windows for neutrons

Rev. Sci. Instrum. 90, 085112 (2019)

Safety aspects

Magnetic fields on beamlines

- Known biophysical effects
  - dizziness, nausea, metallic taste
  - change in blood flow in limbs and brain function, in heart function
  - limit of 2 T for the head, 8 T for the body
- Indirect effects

0.5 mT limit
pacemakers, implants…

3 mT limit
no ferromagnetic material

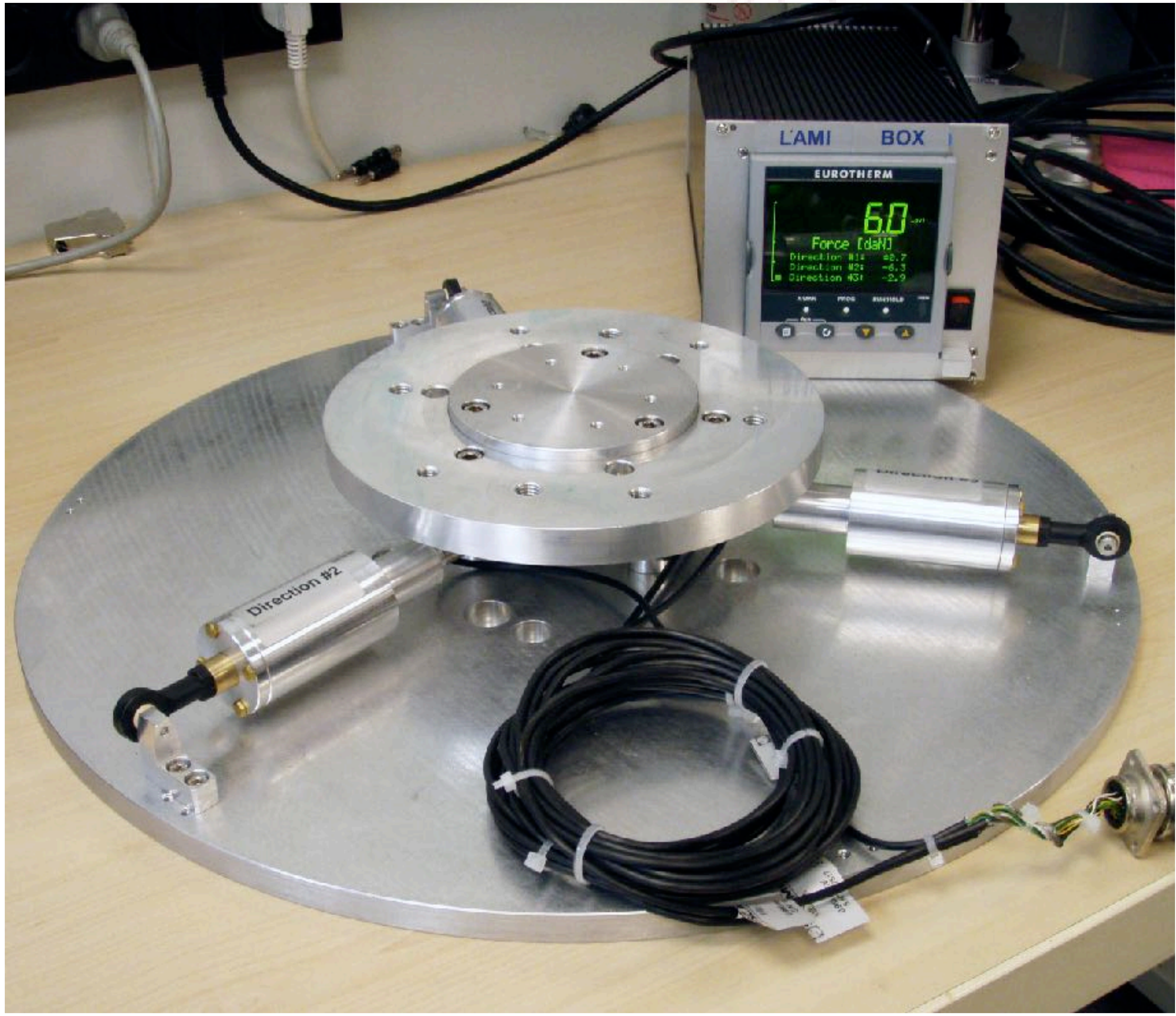
contact current,
spark discharge

NEUTRONS FOR SOCIETY

Safety aspects

Magnetic fields on beamlines

- Use non-magnetic materials
  - don’t trust companies! They mix magnets and magnetic materials
  - most stainless steels are magnetic, use 304 or 316L
  - welds may become magnetic!
  - brass, copper, aluminium, CuBe, sapphire, ceramics…

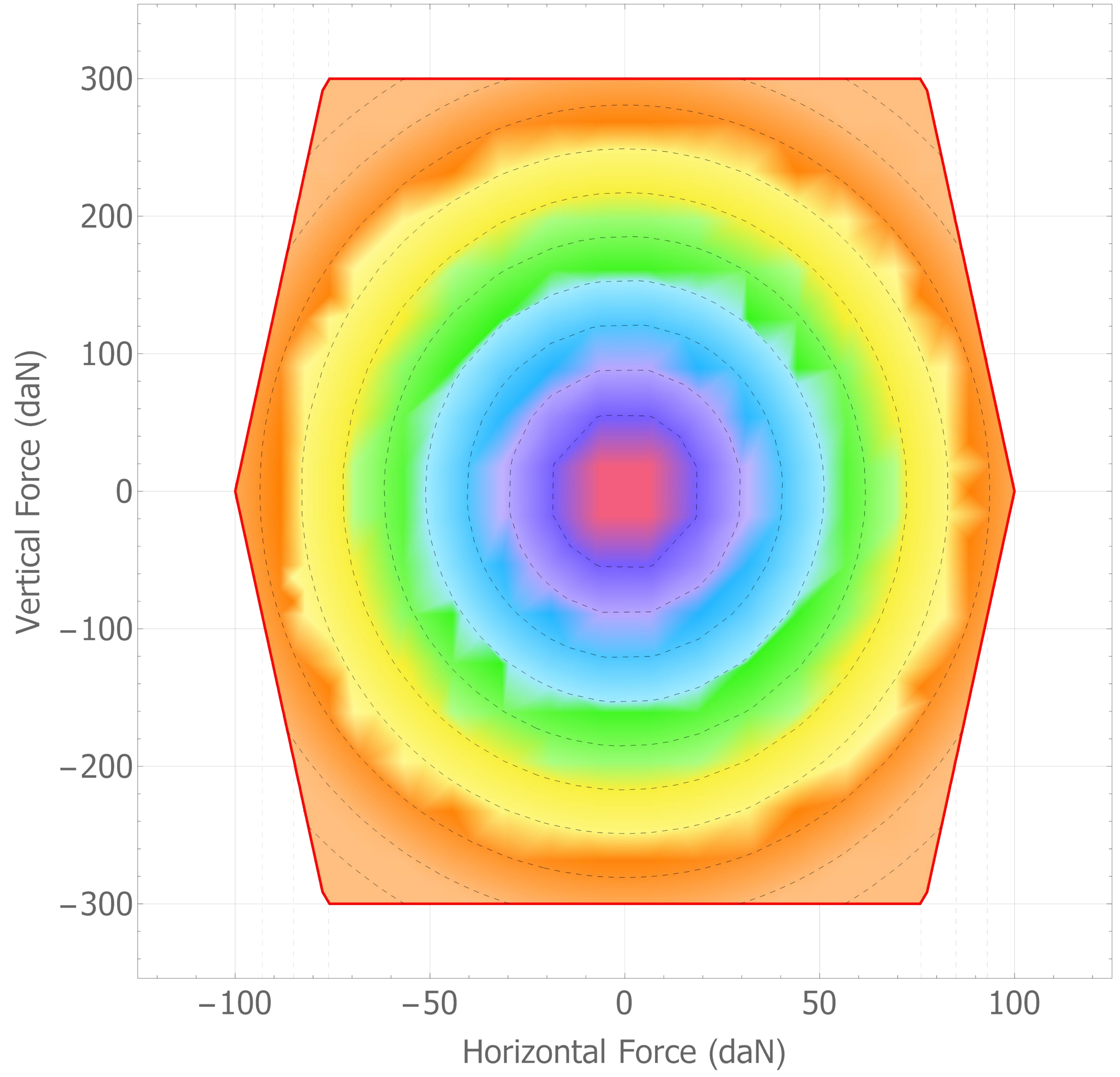


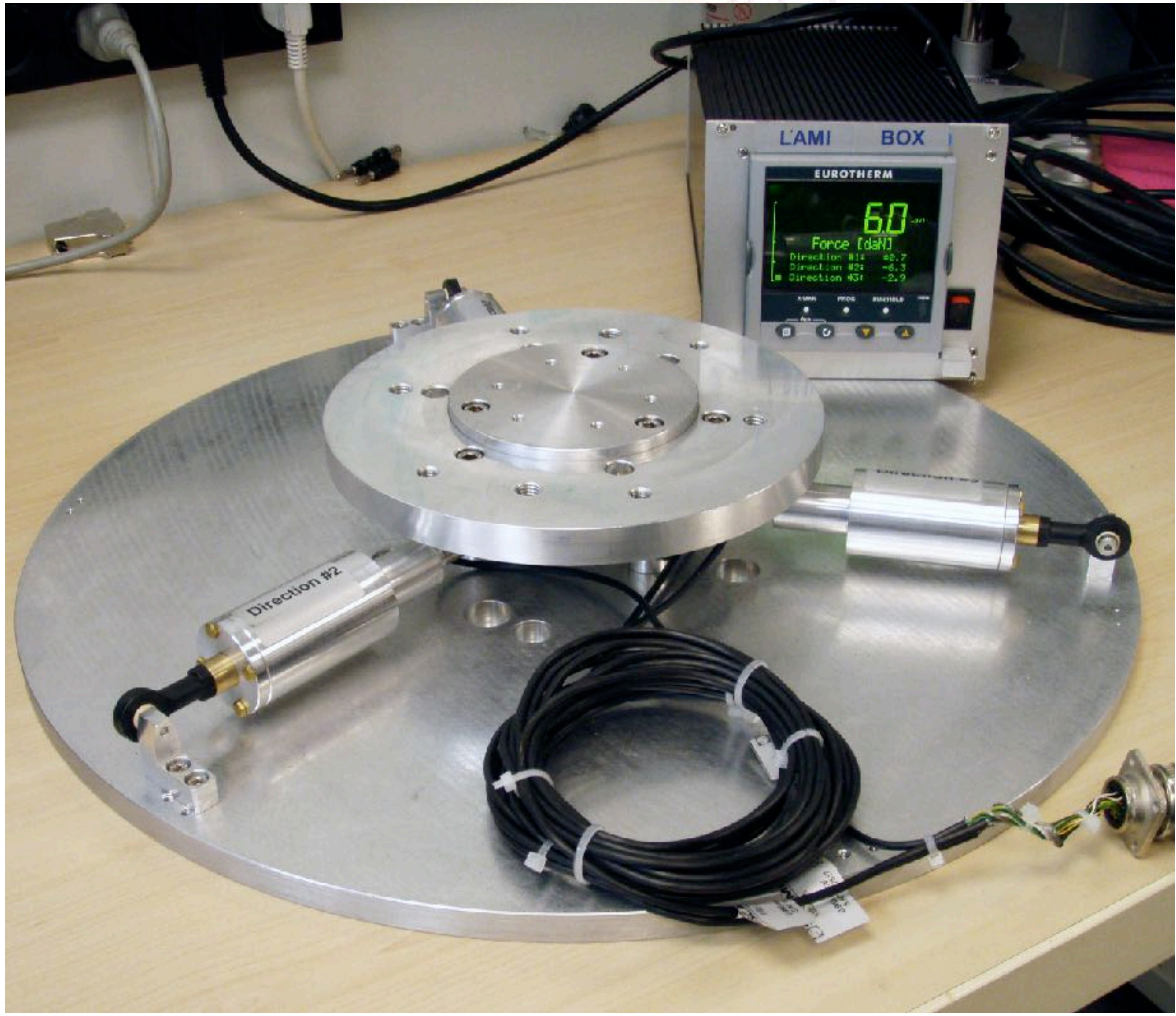
NEUTRONS FOR SOCIETY

Safety aspects

Magnetic forces on beamlines

$F_v + 13\ F_h < 1300$ daN





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Safety aspects

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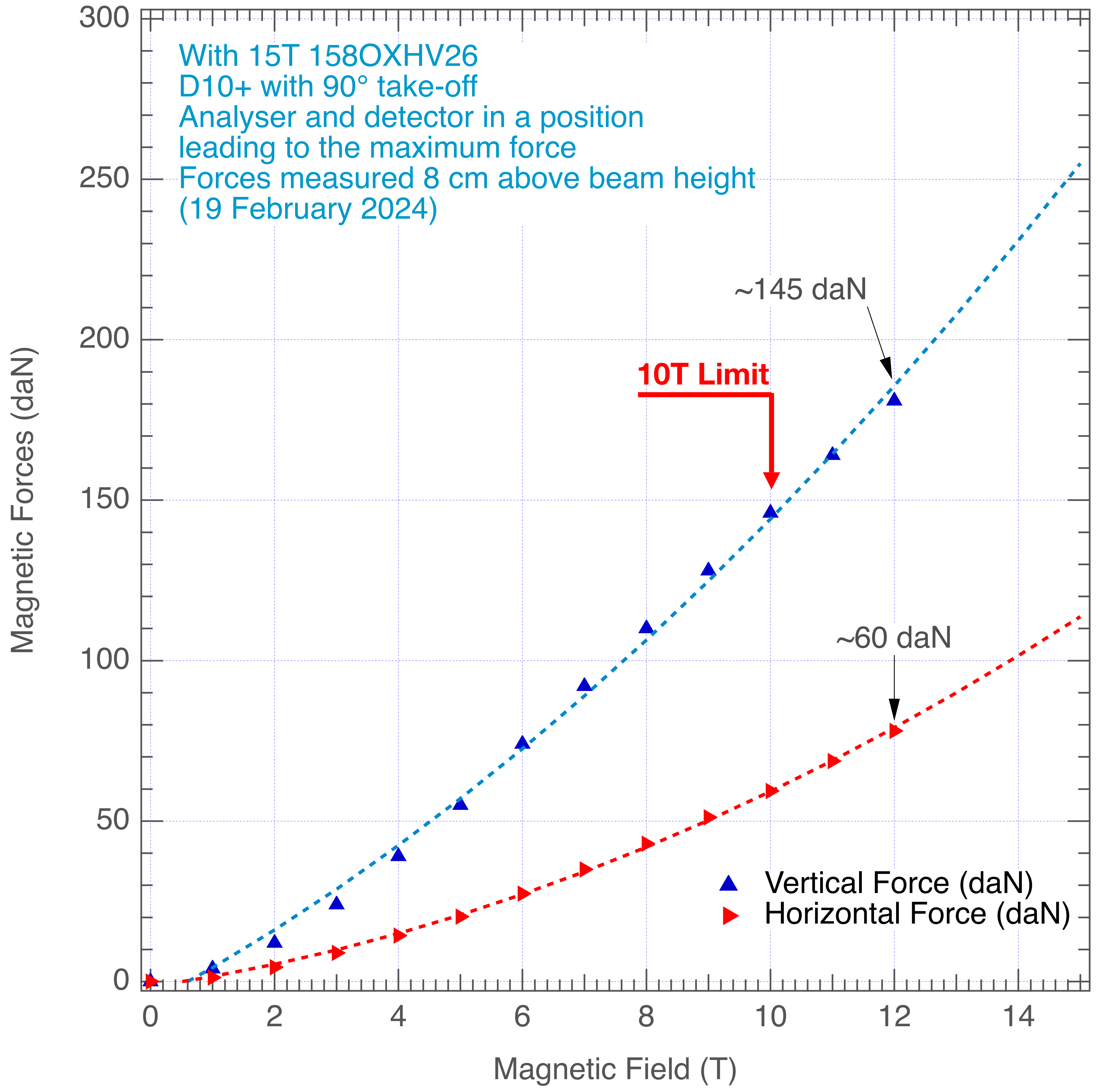
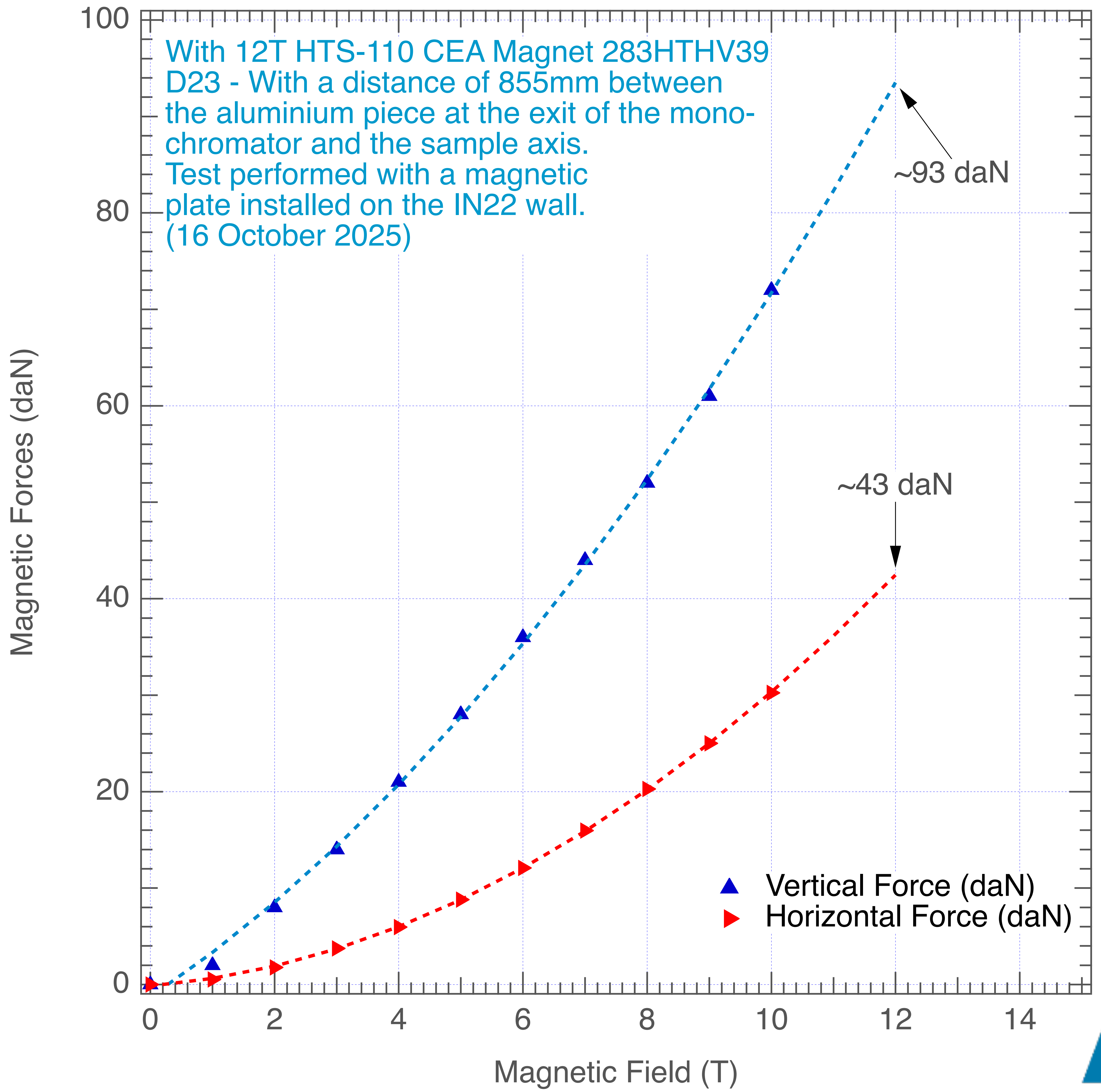


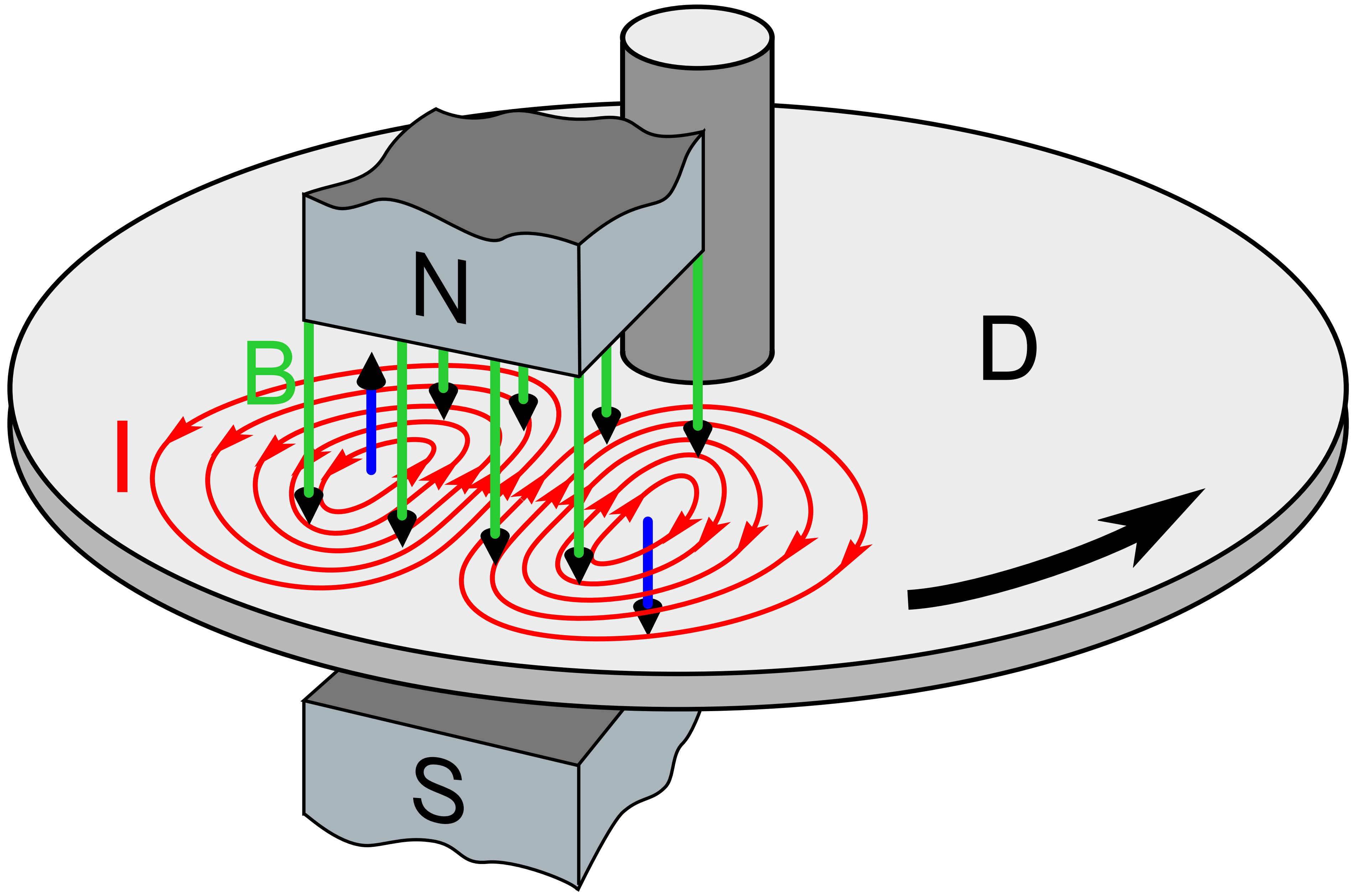


NEUTRONS FOR SOCIETY

Safety aspects

Eddy currents in choppers (Foucault's current)

- Choppers are metallic
  - the field induces circular electric currents in the rotating disc
  - the field, acting on the sideways moving electrons, creates a Lorentz force opposite to the velocity of the disc



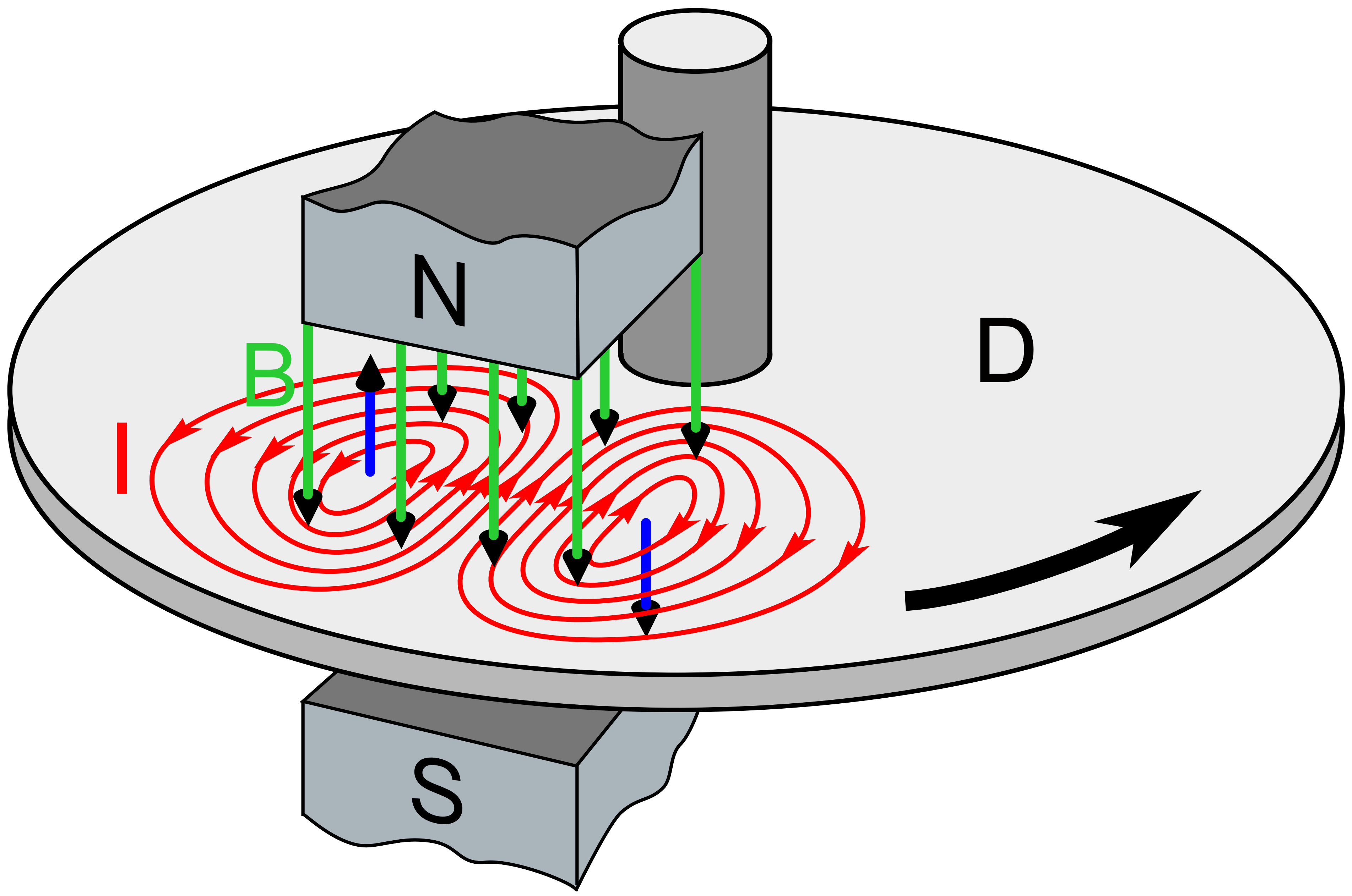
➜ The disc is braked and heats up

NEUTRONS FOR SOCIETY

Safety aspects

Eddy currents in choppers (Foucault's current)

- Example
  - 10 T magnet on IN5 at ILL
  - sample to disc: 1230 mm
  - low speed: 5100 rpm (85 Hz)
  - phasing impossible above 5.2 T
  - temperature increased by 15°C and was still heating



➜ magnetic shield required

NEUTRONS FOR SOCIETY

Many Thanks
for your Attention

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FOR SOCIETY

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