Design and first tests of a unique, superconducting multipole magnet for the ultracold neutron trap PENeLOPE

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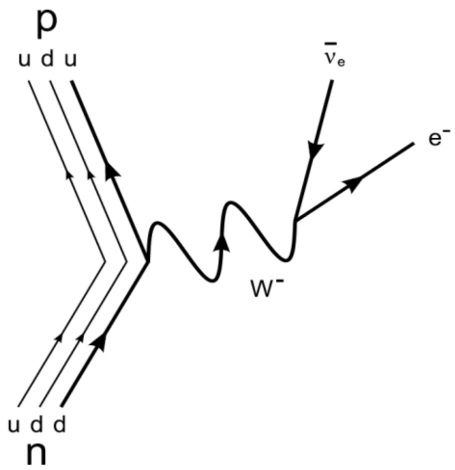
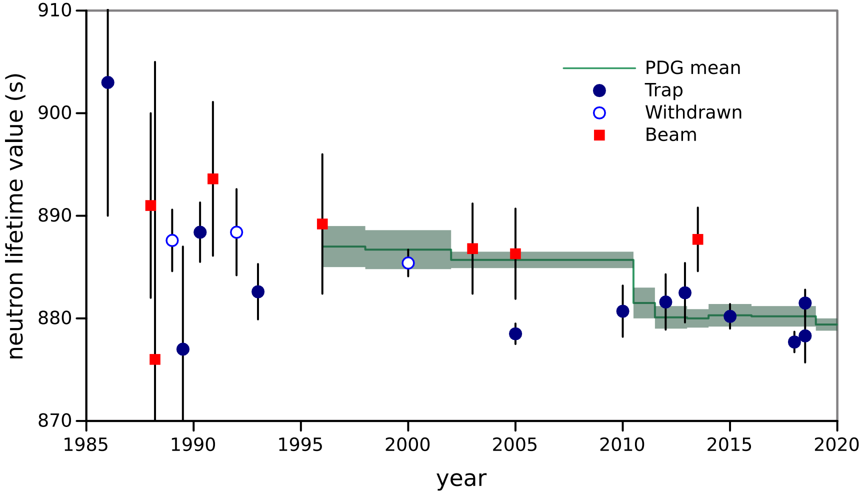
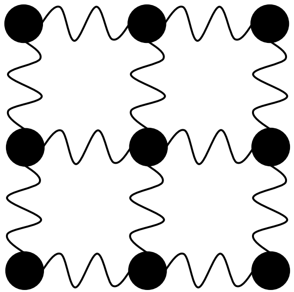
The Goal: measure neutron lifetime with 0.1s precision

- τ_n = 879.4 ± 0.6 s
- Precise measure of weak-interaction parameters
- Impacts formation of elements in early universe
- Difficult measurement, many discrepancies, especially between “beam” and “trap” methods
  - Are there exotic neutron decays?



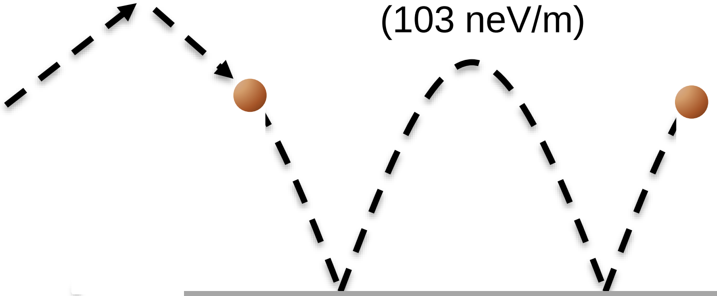


The Tool: ultracold neutrons



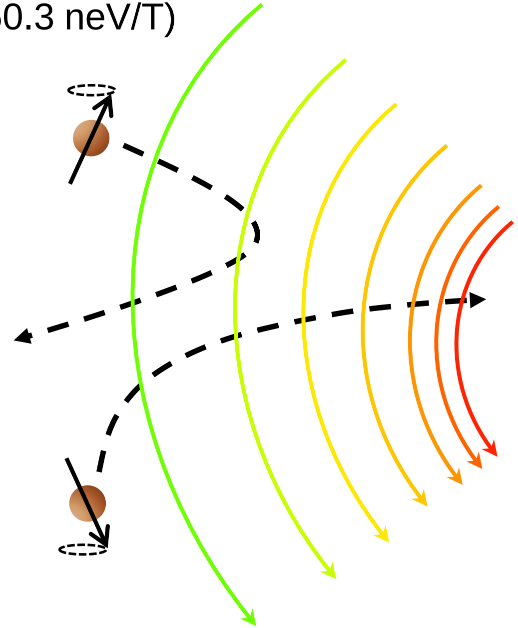
Conversion of cold neutrons to ultracold through phonon-scattering
1 meV → 100 neV

Influenced by gravity
(103 neV/m)



Totally reflected by many materials
(Fe: 209 neV, Ni: 245 neV)

Interact with magnetic field (60.3 neV/T)



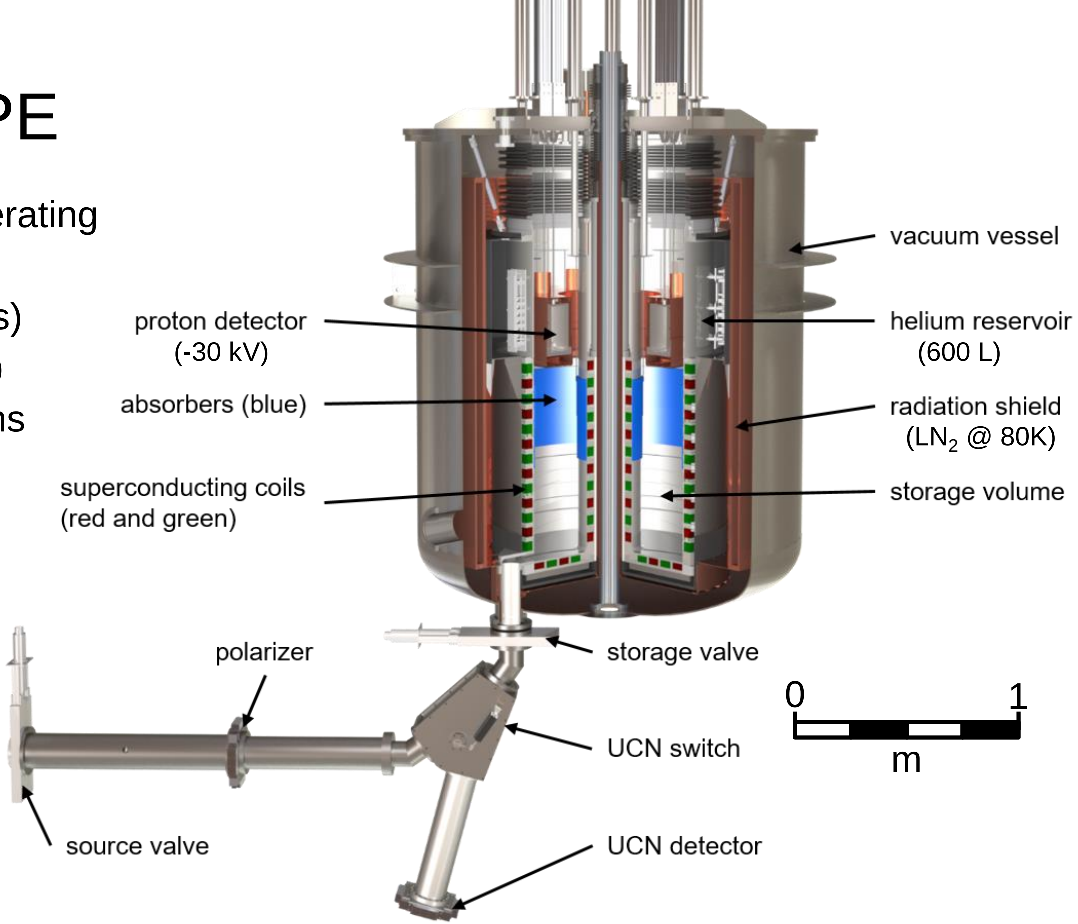
Can be trapped for several minutes!

The Apparatus: PENeLOPE

Precision Experiment on Neutron Lifetime Operating with Proton Extraction

- Fill ultracold neutrons in experiment (~300s)
- Ramp up superconducting magnet (~100s)
- Detect decay protons from trapped neutrons
- Ramp down magnet (~100s)
- Count remaining neutrons (~200s)

Magnet and cryostat built by Bilfinger Noell (Würzburg, Germany)



Challenging magnet requirements

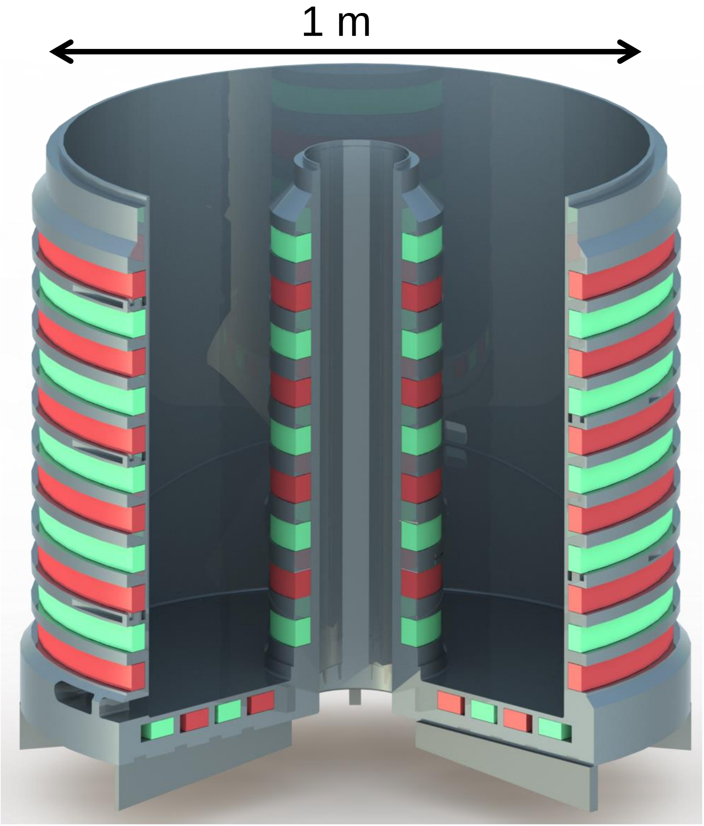
Large volume (> 600L)

Steep field gradient at walls

- Alternating multipole, high repelling forces (1 MN)
- High current density (> 300 A/mm^2)
- Thin support structure (10 mm)

Fast ramping (< 100 s)

Warm bore



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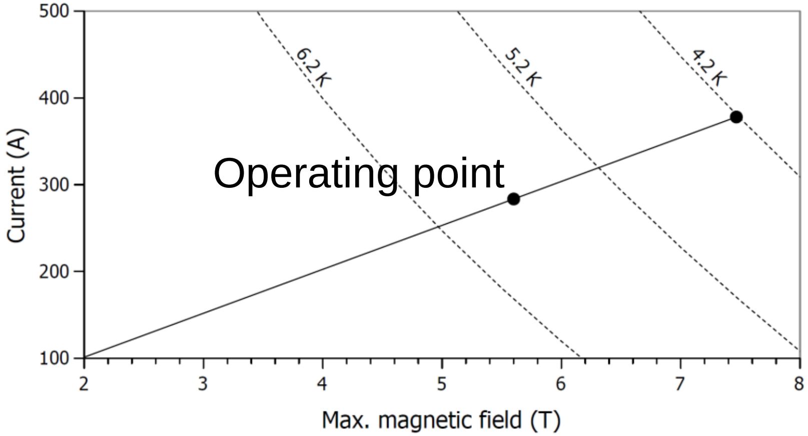
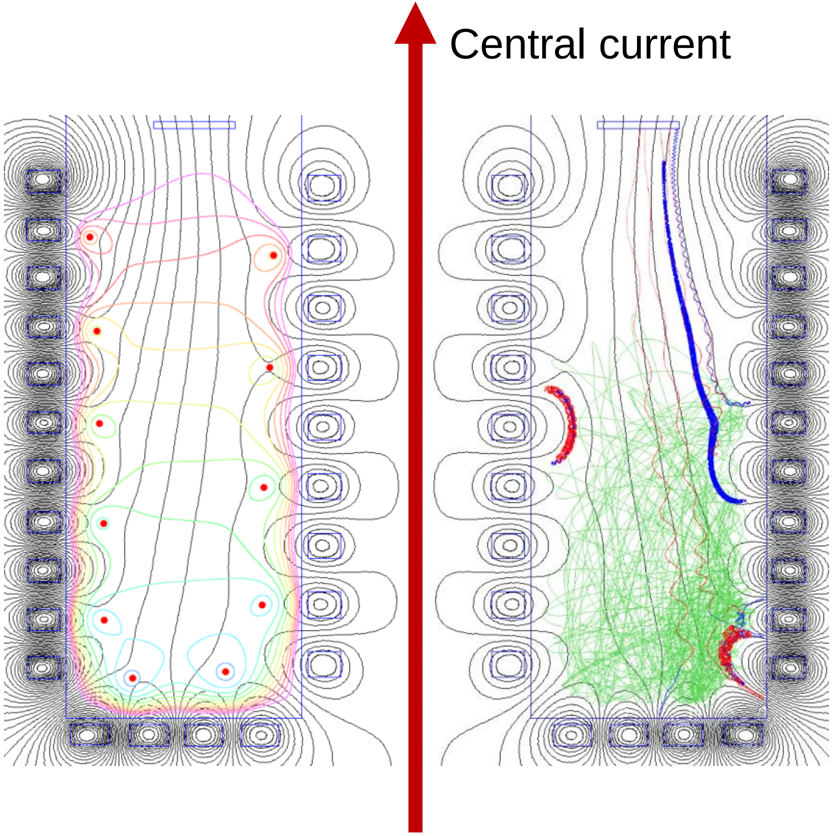
Optimized magnet design

Layout with 24 coils maximizing
- trapping potential (115 neV)
- probability of decay protons reaching detector

Tradeoff between current density and max. field
(0.9 mm Supercon VSF-SSCI NbTi wire, Cu/SC 1.5)
Strong normal-conducting current (> 10 000 A)
through center to cancel zero-field regions

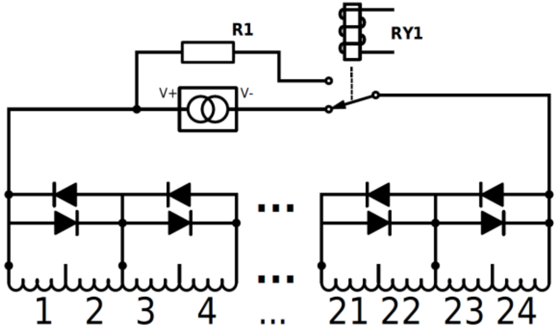


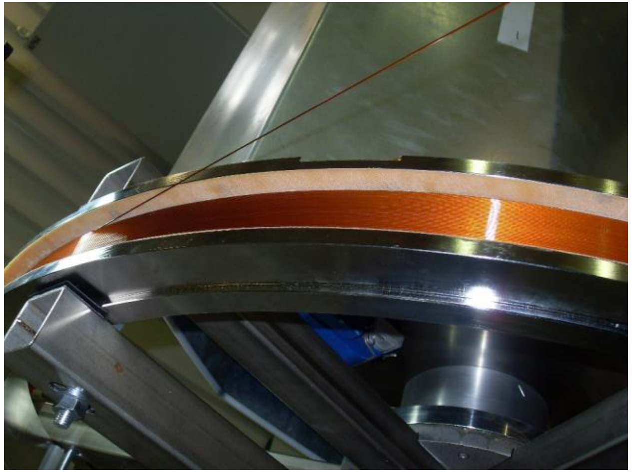


Magnet construction

Winding with defined pre-tension to avoid detachment
Deep-penetration laser welding
Single coils quenching lead to rapid load changes, high inductive voltages

- Coils are bridged pair-wise with liquid-helium-cooled diodes
- Careful design of wiring between paired coils





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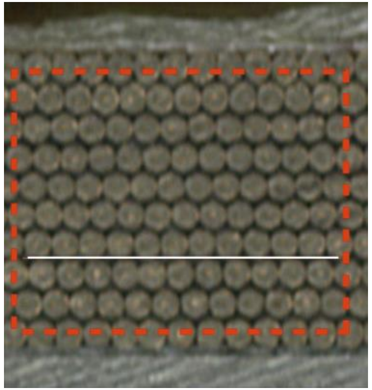
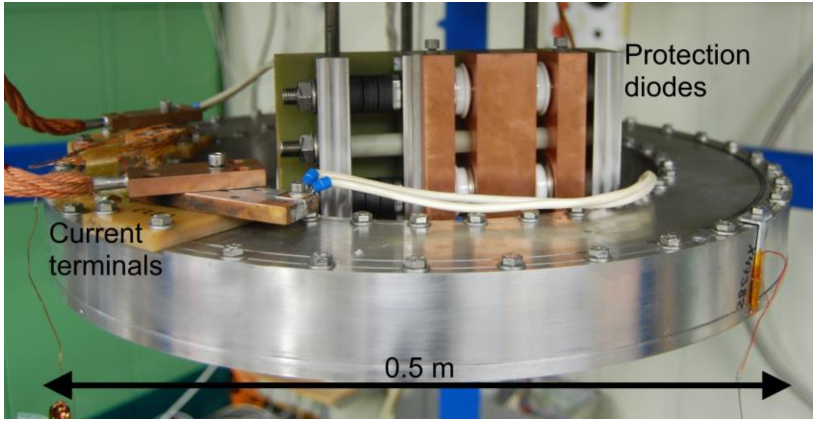
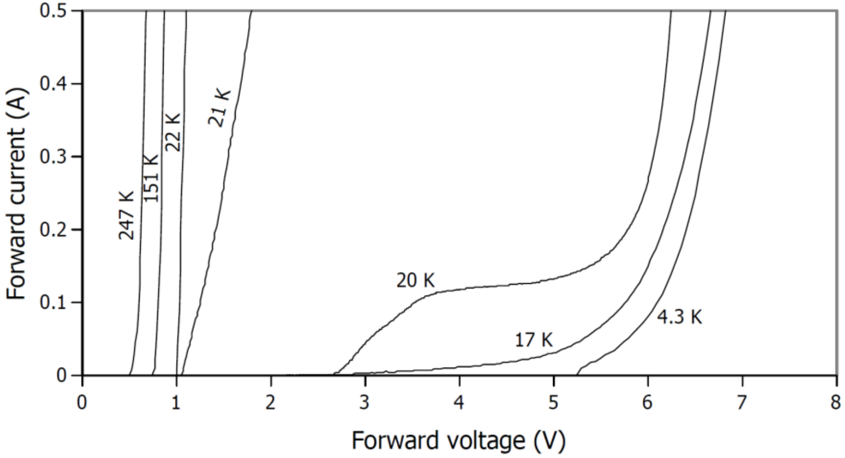
Prototype tests

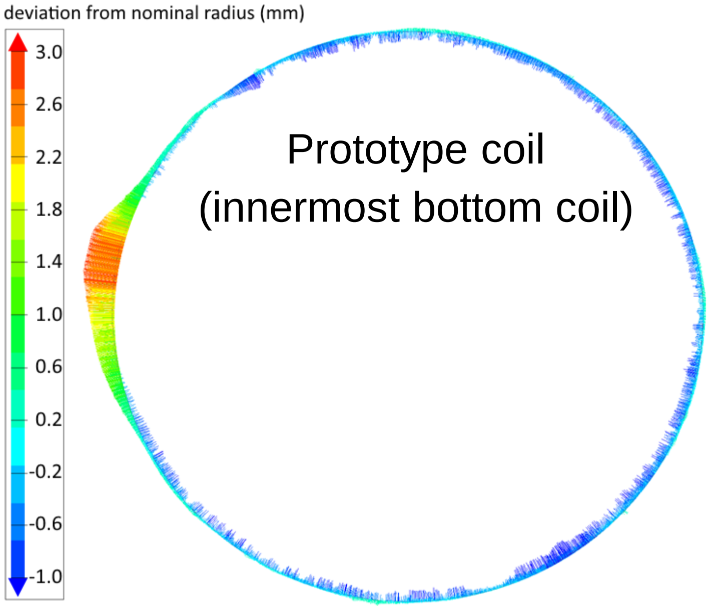


Packing density
80%



Protection diodes (Dynex DS502ST)





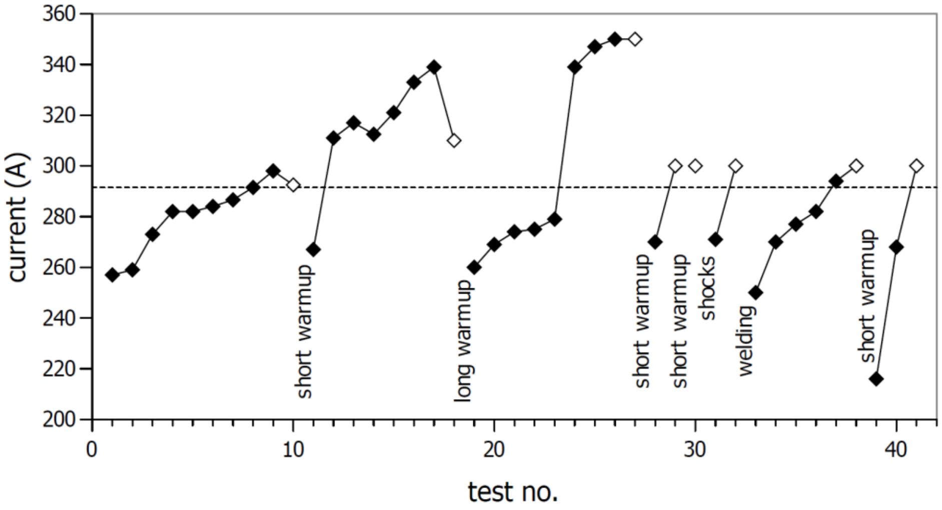
Coil tests: prototype coil

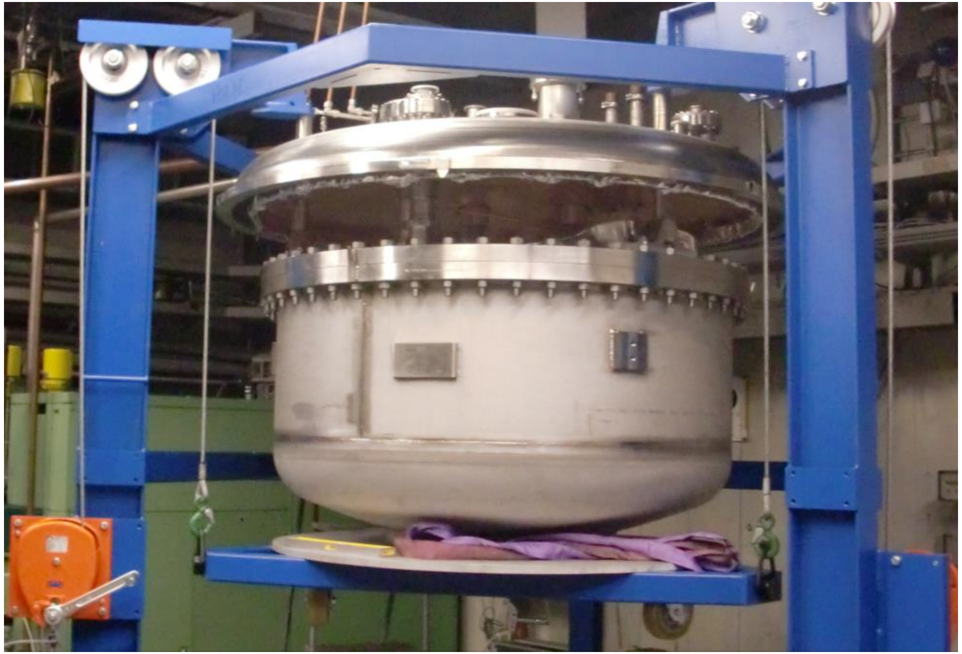
CoTEx: 1000 L liquid-helium bath cryostat to test individual coils

Records temperatures and voltages during training

Prototype coil:

- Reached 120% of nominal current, 280% of nominal ramp rate
- Little training required

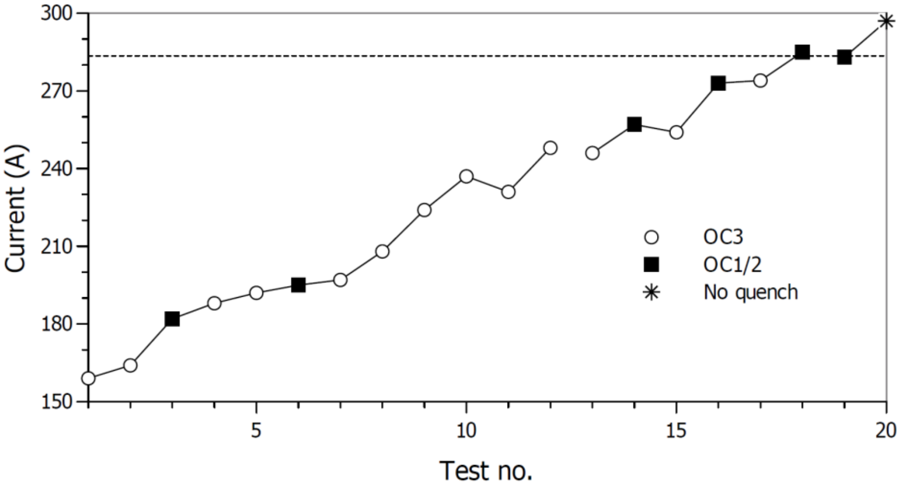


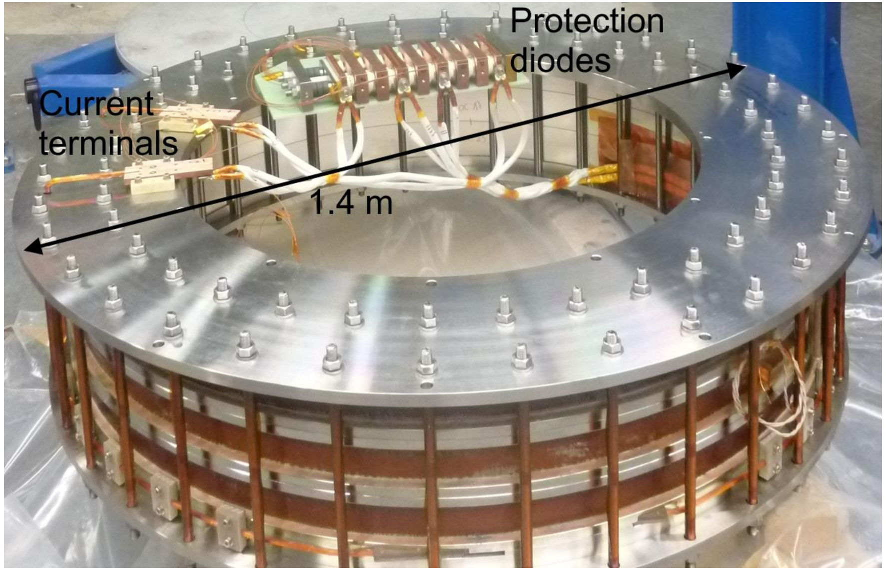


Coil tests: outer coils

Stack of three outer coils:

- 105% nominal current, nominal ramp rate
- Extensive training required

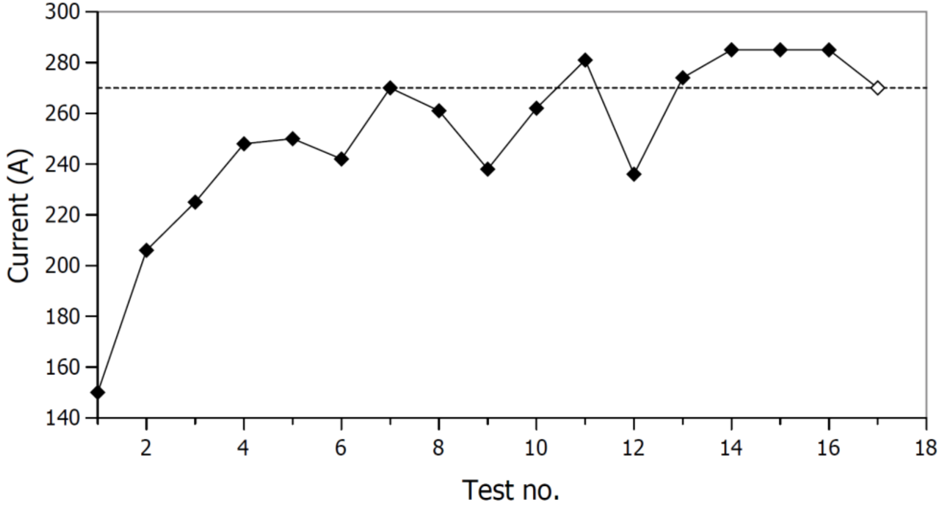


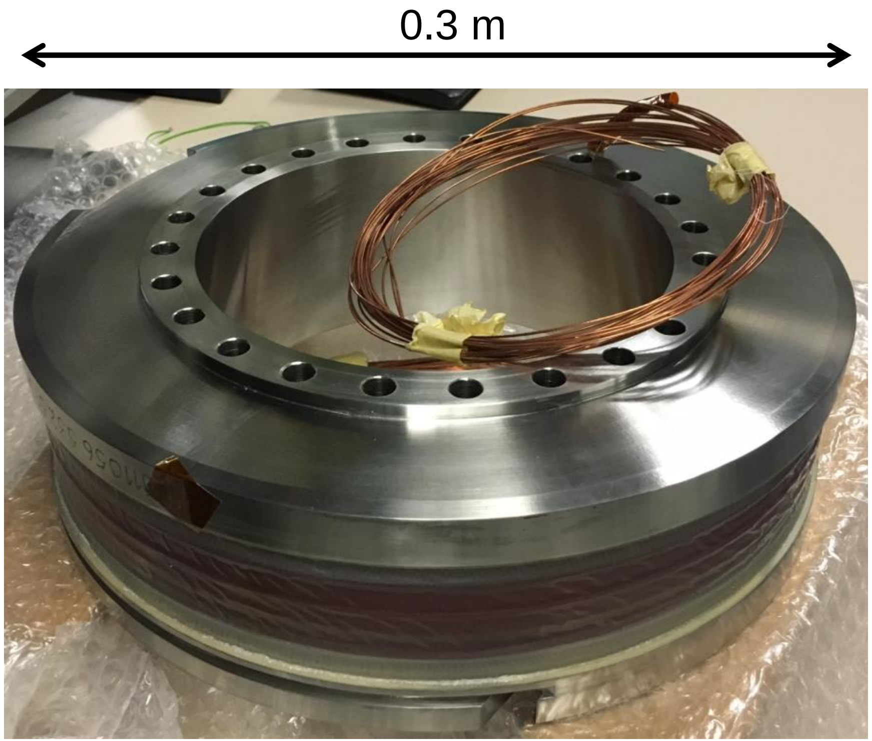


Coil tests: inner coil

Single inner coil:

- Reached nominal current, nominal ramp rate
- Irregular training, unstable above nominal current

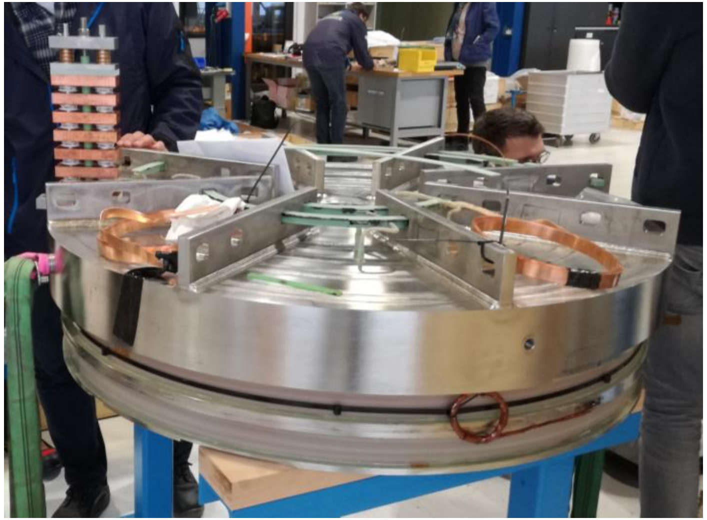


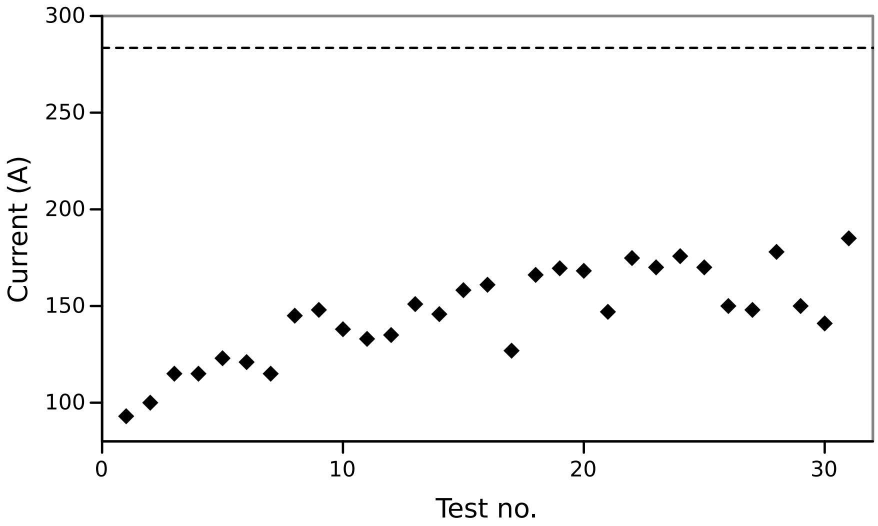


Coil tests: partially completed magnet

Bottom coils + 2 inner coils + 2 outer coils:

- Reached only 64% of nominal current



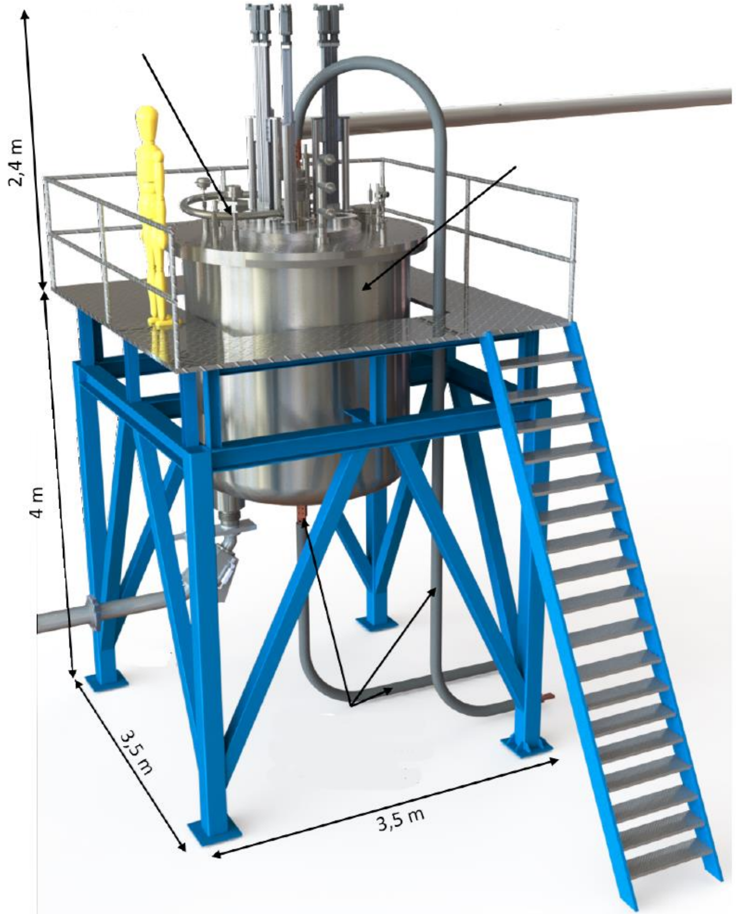


Status

Magnet completed

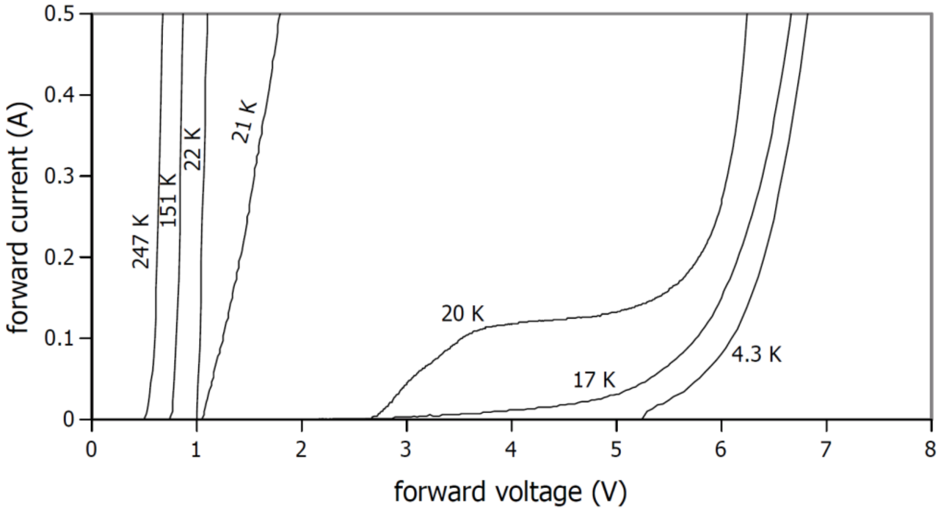
Cryostat delivery end of year

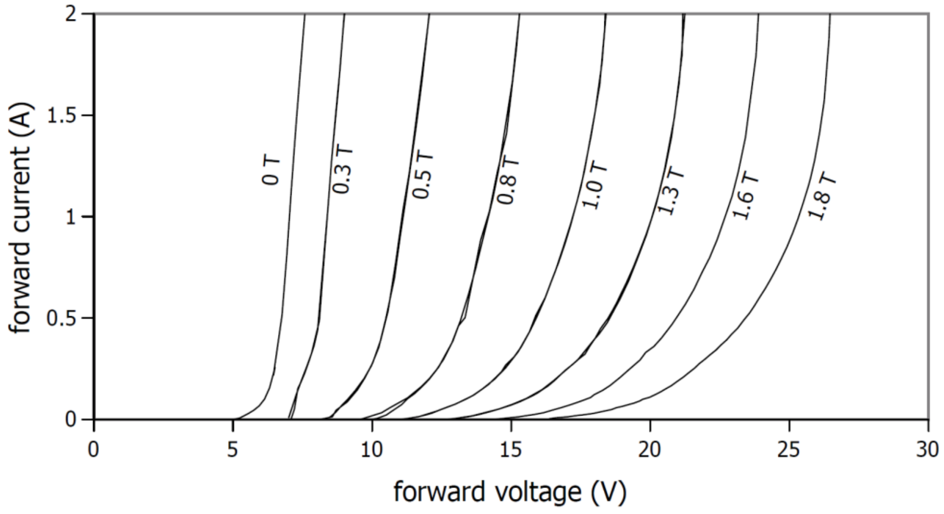
Commissioning without ultracold neutrons in 2020



Thank you for your attention

Diode characterization





In transverse magnetic field

Quench data outer coils