LANL nEDM experiment

Searches for Electric Dipole Moments: From Theory to Experiment

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Outline

- Purpose and goal
- UCN source and its upgrade
- LANL nEDM experiment
  - Overview
  - North Beamline characterization
  - Vacuum chamber, precession chamber, UCN valves, …
  - Magnetically shielded room
  - B0 coil
  - Magnetometry
- Status and plans

LANL nEDM Collaboration

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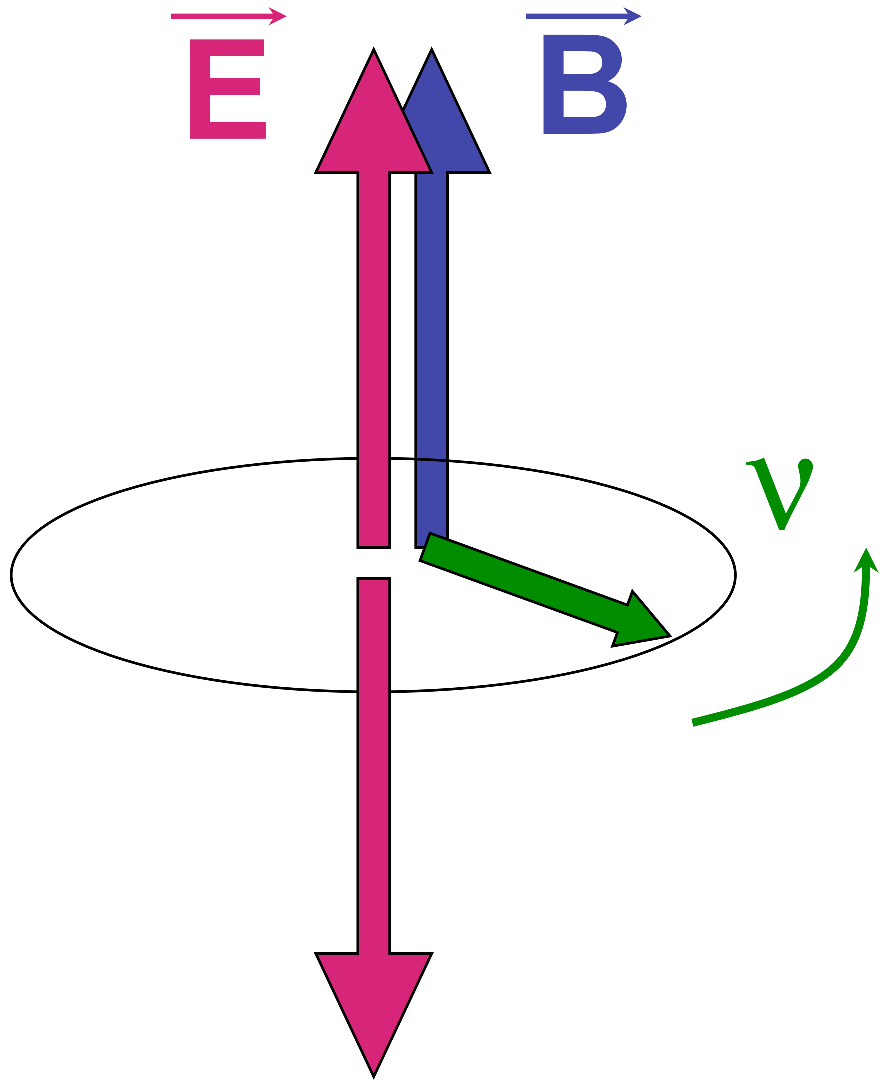
LANL nEDM: concept

- A neutron EDM experiment with a goal sensitivity of $\delta d_n \sim O(10^{-27})$ e-cm based on the proven room temperature Ramsey's separated oscillatory field method could take advantage of the existing LANL SD2 UCN source.
    - nEDM measurement technology for $\delta d_n \sim O(10^{-27})$ e-cm already exists. The systematic uncertainty of the recent PSI results was 2×10^{-27} e-cm.
    - The successfully upgraded LANL UCN source has been shown to provide the UCN density required for an nEDM experiment with $\delta d_n \sim O(10^{-27})$ e-cm.
- Such an experiment could provide a venue for the US nEDM community to obtain physics results, albeit less sensitive, in a shorter time scale while development for the nEDM@SNS experiment continues.

nEDM measurement principle



$$\nu = \left(2\mu_n B \pm 2d_n E\right)/h$$

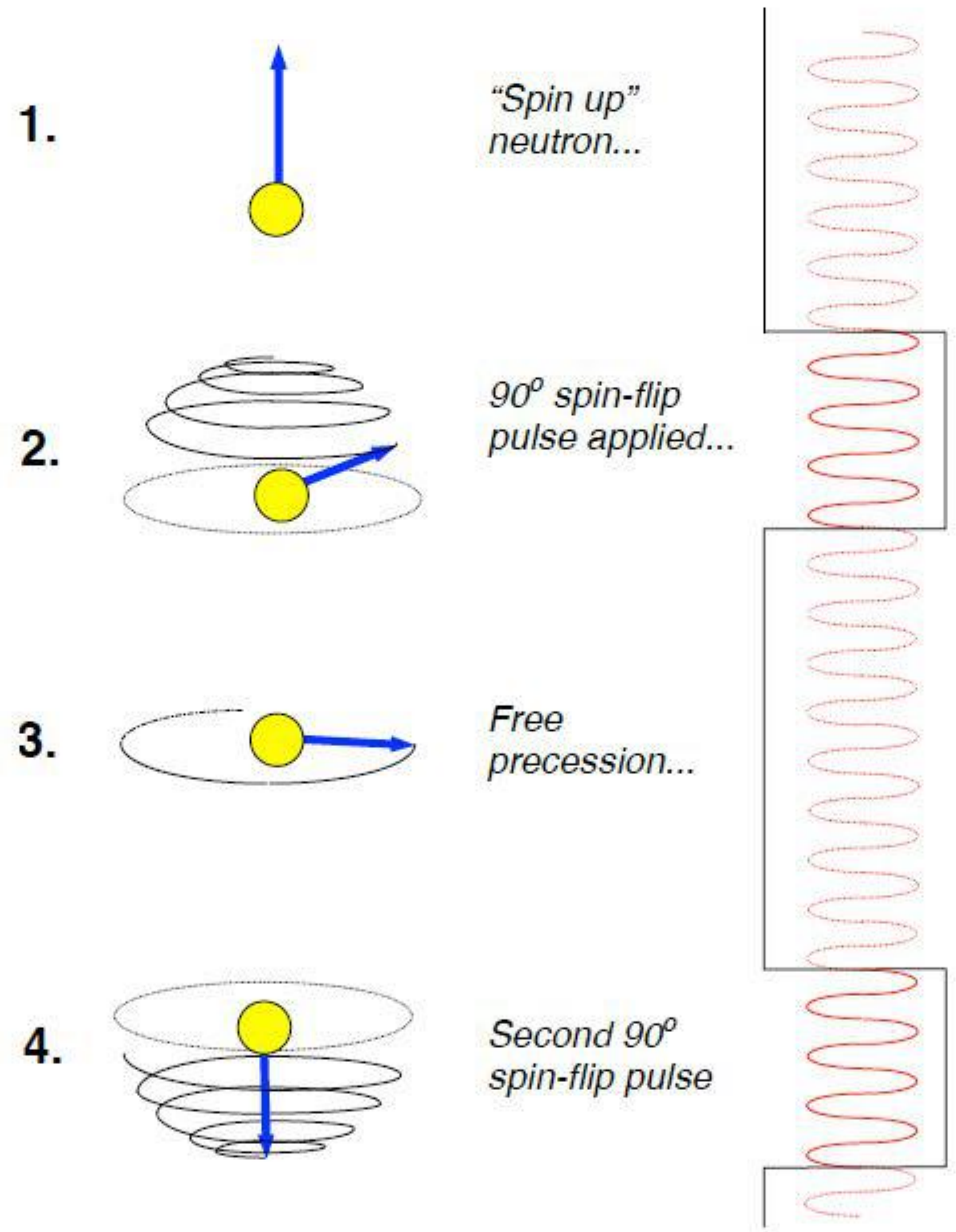
$$\Delta\nu = 4d_n E/h$$

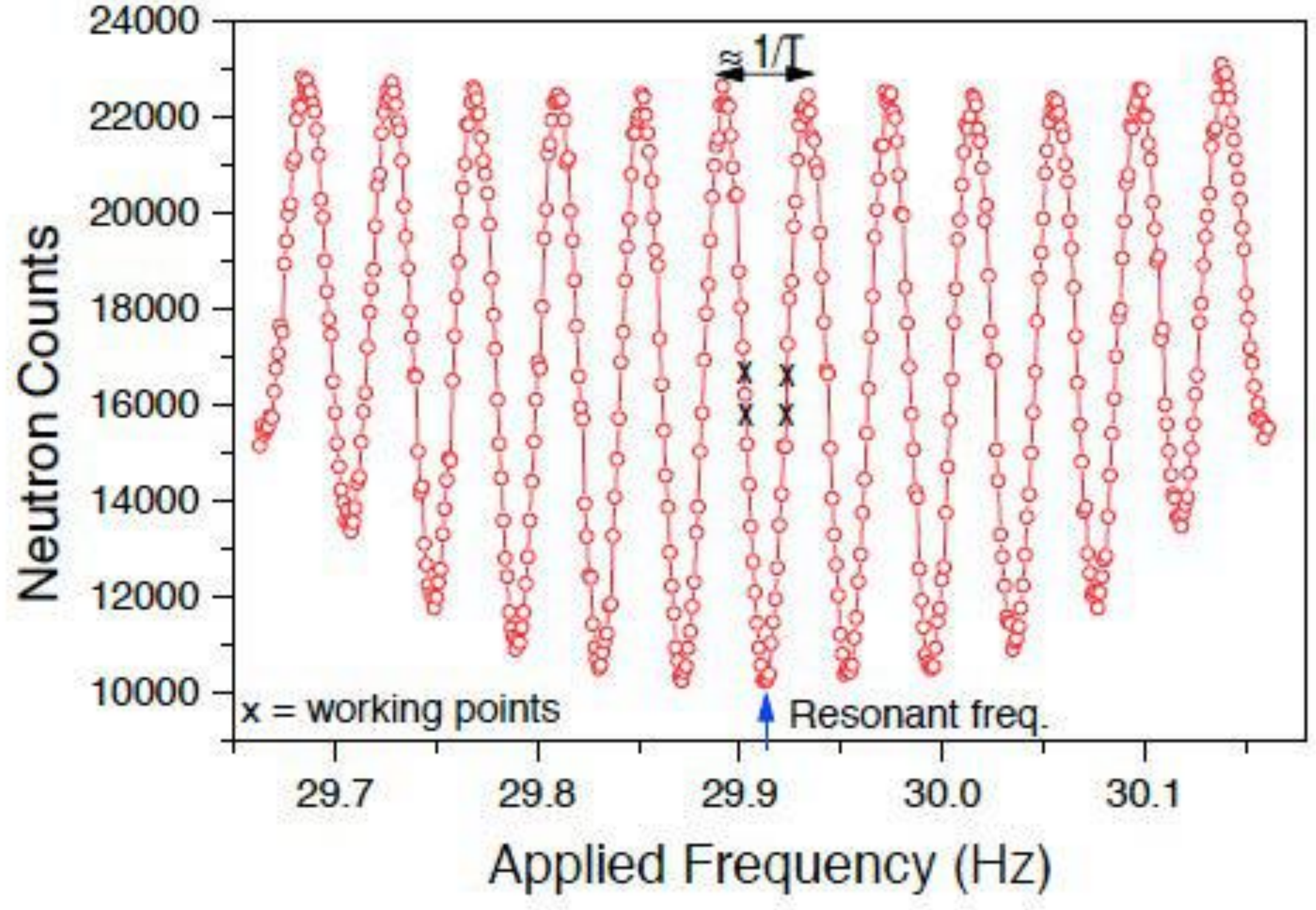
$$\delta d_n = h\frac{\delta\Delta\nu}{4E}$$

For B ~ 1 μT, ν = 30 Hz.

For E = 10 kV/cm and $d_n = 3\times10^{-27}$ e-cm, $\Delta\nu$=0.03 μHz.

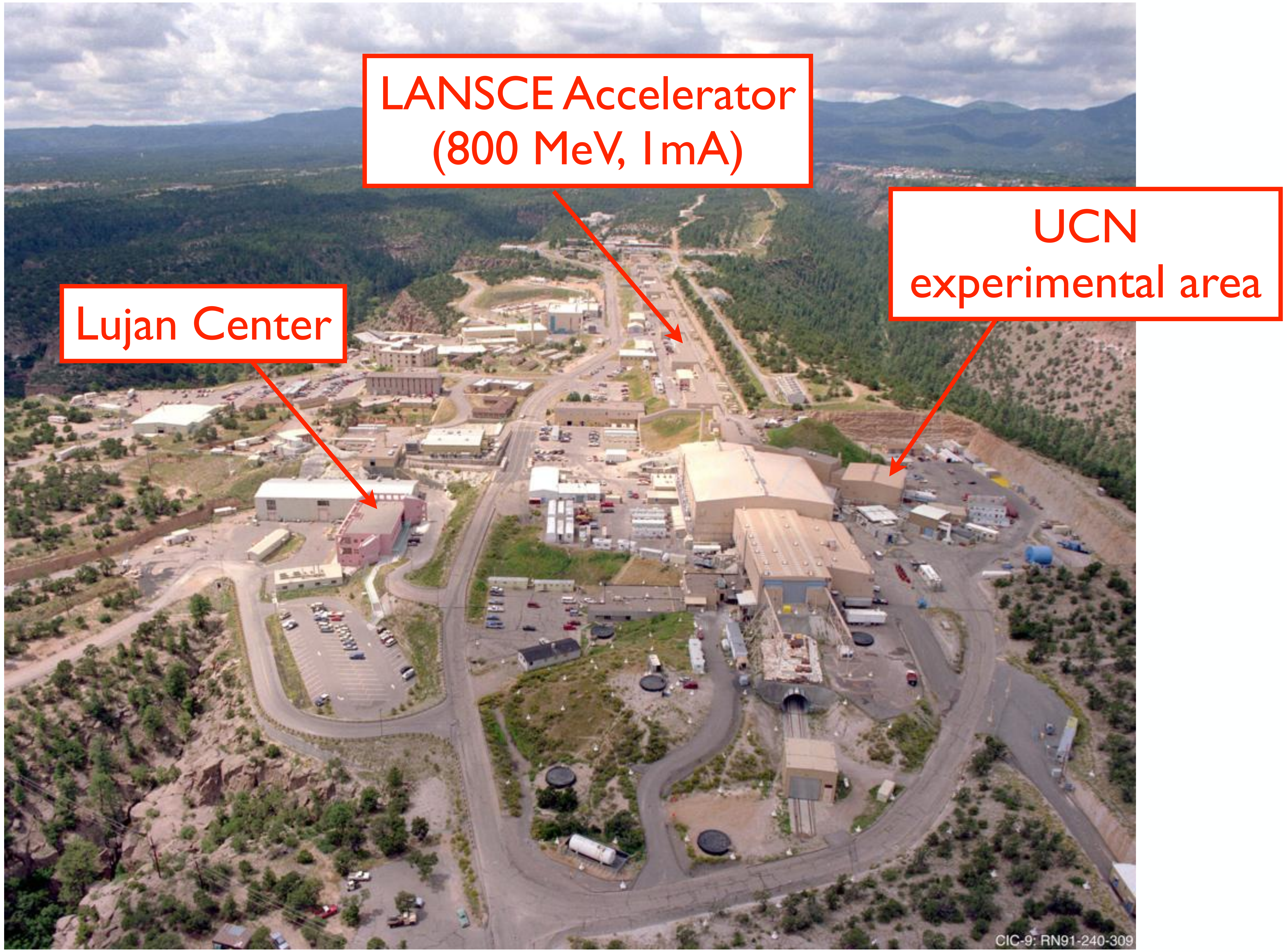
Ramsey method of separated oscillatory fields



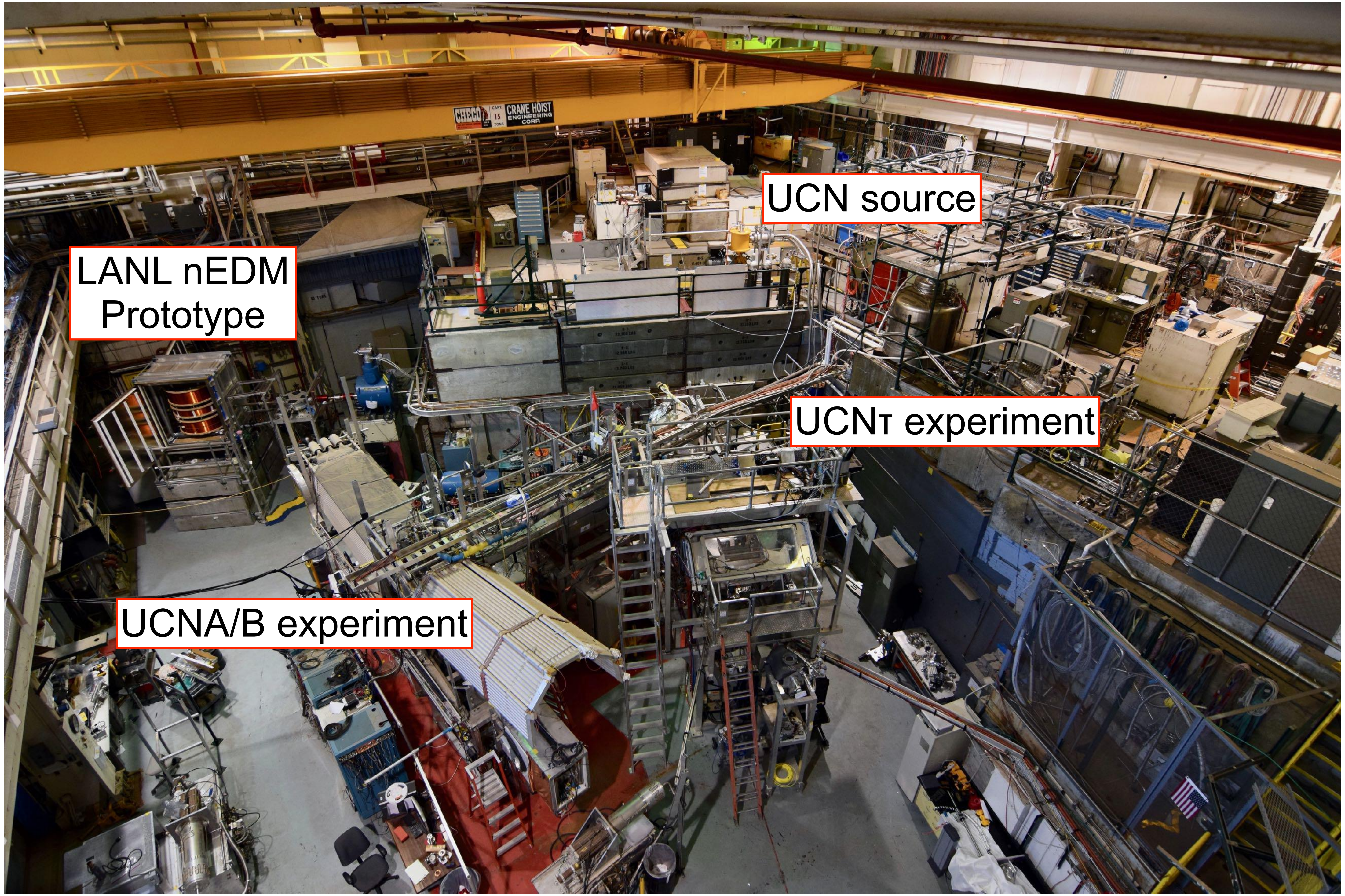


Baker et al, NIMA 736, 184 (2014) (arXiv:1305.7336)

Los Alamos Neutron Science Center (LANSCE)

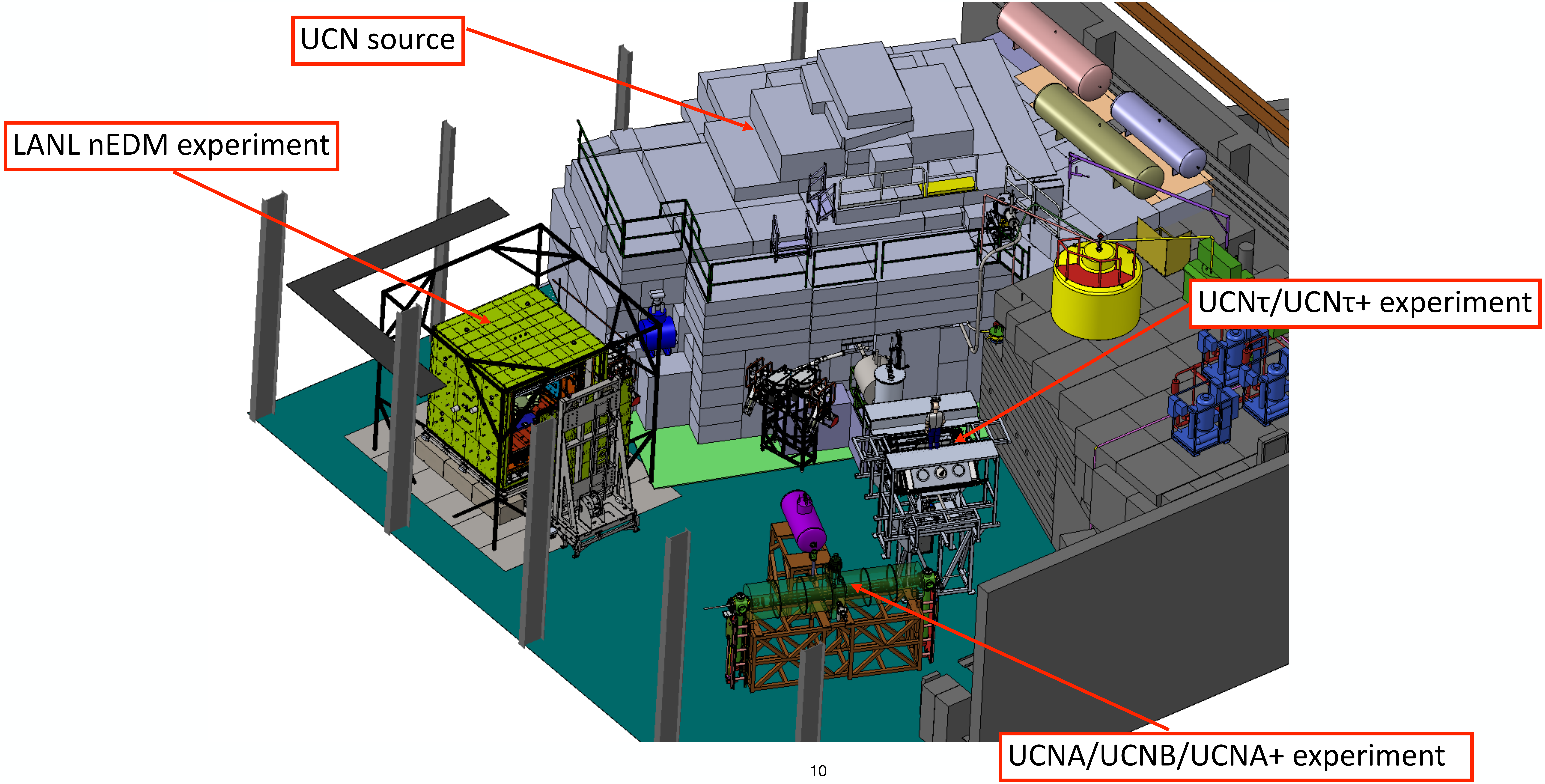


LANL UCN Experimental Area (2018)

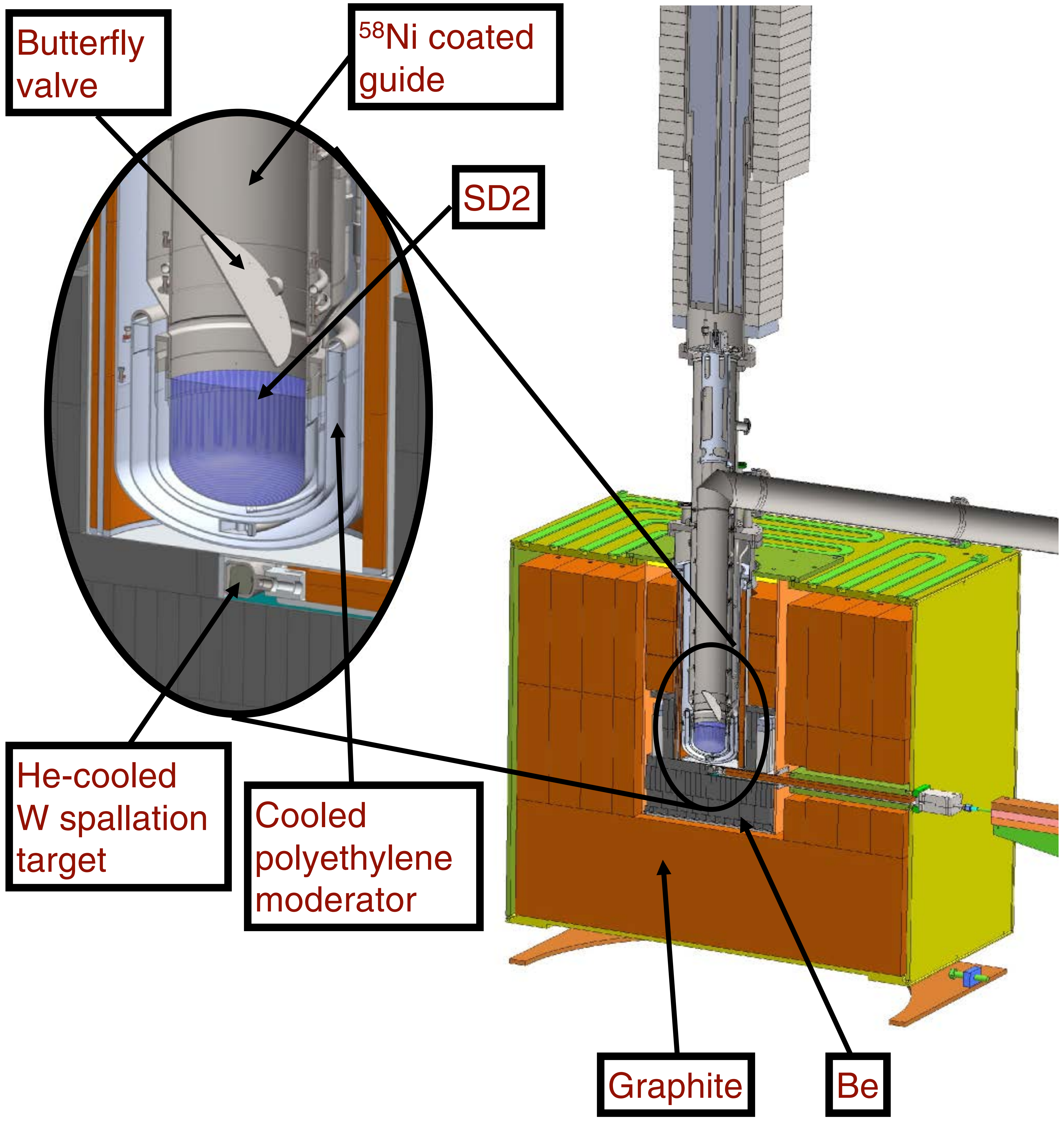


LANL UCN Experimental Area (2022)

LANL UCN Experimental Area (2022)



LANL UCN source



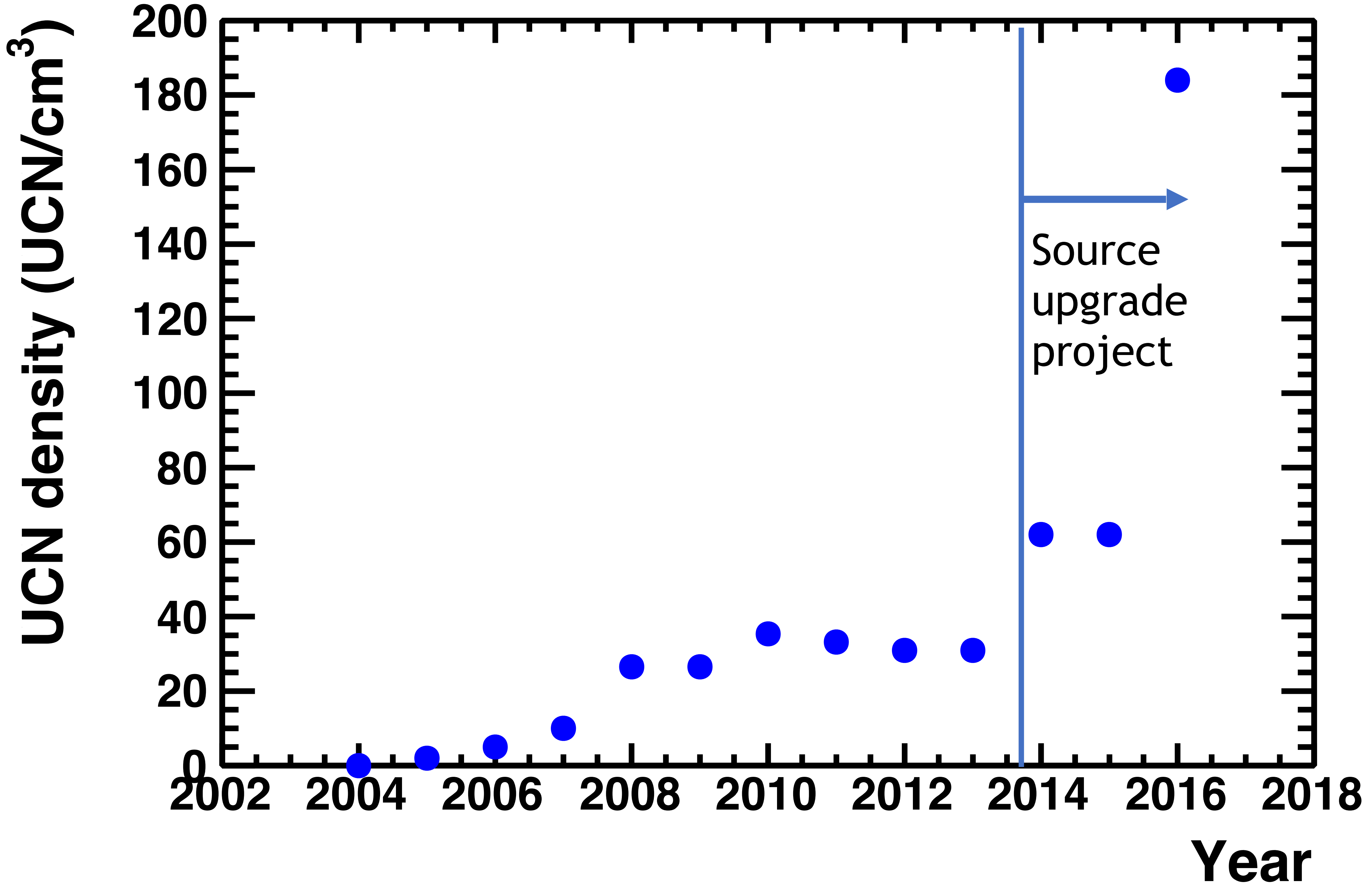
Spallation neutrons from W target
K.E. ~ 2 MeV

Thermal neutrons in Be and graphite moderator
K.E. ~ 25 meV

Cold neutrons in polyethylene cold moderator
K.E. ~ 6 meV

Ultracold neutrons in SD2 converter
K.E. ~ 100 neV

UCN density measured at the exit fo the biological shield using vanadium foil

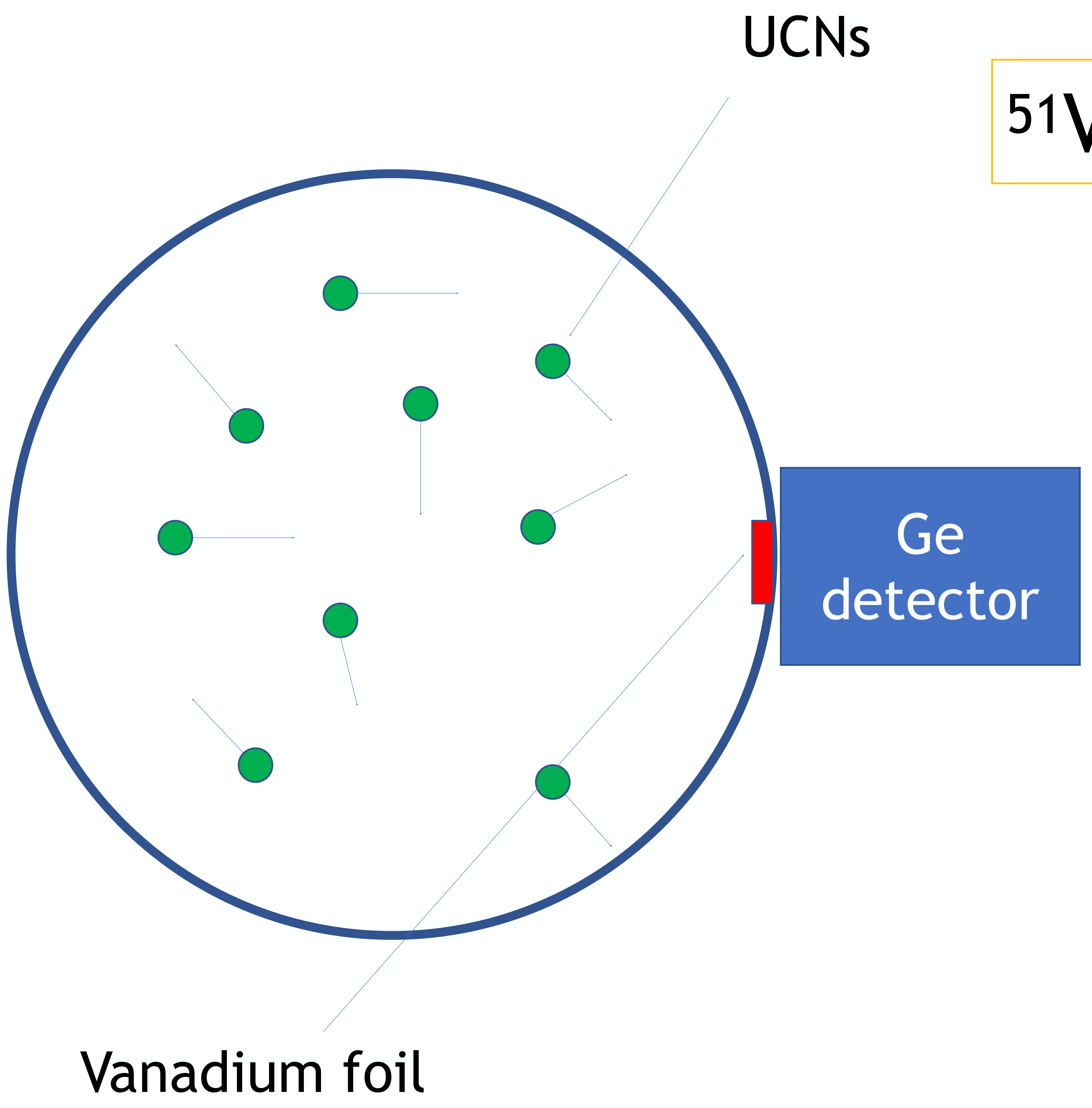


An upgrade of the UCN source (FY14-17) more than quadrupled the UCN output by:

1. increasing the average beam current
2. replacing the UCN source insert with one optimized for CN moderation and UCN transport.

[Ito et al. PRC 97, 012501(R) (2018).]

UCN density measurement based on vanadium activation



$$^{51}V + n \rightarrow {}^{52}V \rightarrow {}^{52}Cr + \beta + \gamma \ (1.4 \text{ MeV})$$

- Detecting the 1.4 MeV gammas with a Ge detector determines the UCN capture rate by the vanadium foil.
- The Ge detector can be calibrated (for the efficiency and solid angle product) by placing a calibrated ^{60}Co source at the location of the vanadium foil.
- UCN density can be determined from:

$$R = \frac{1}{4} v A \rho$$

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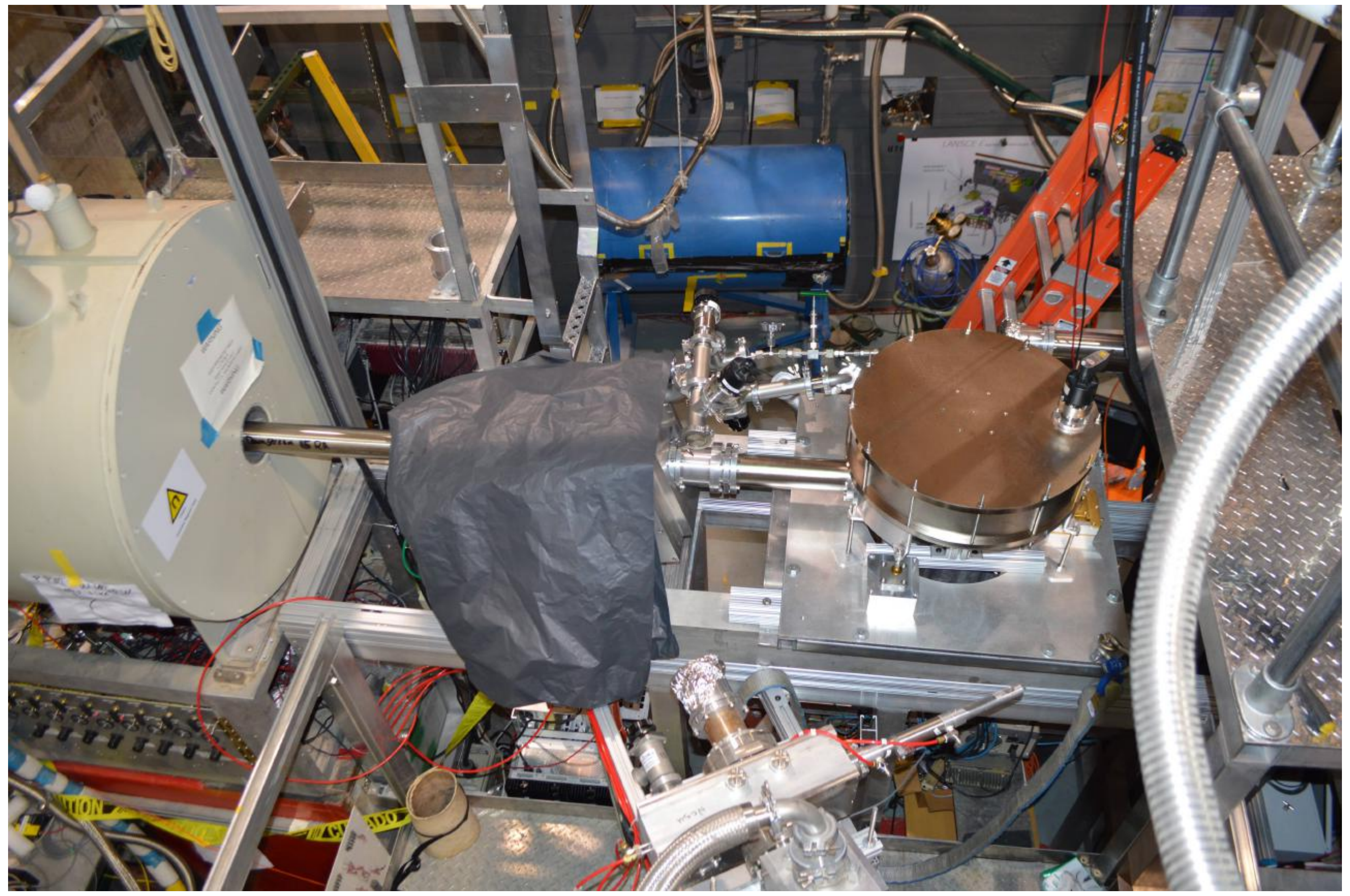
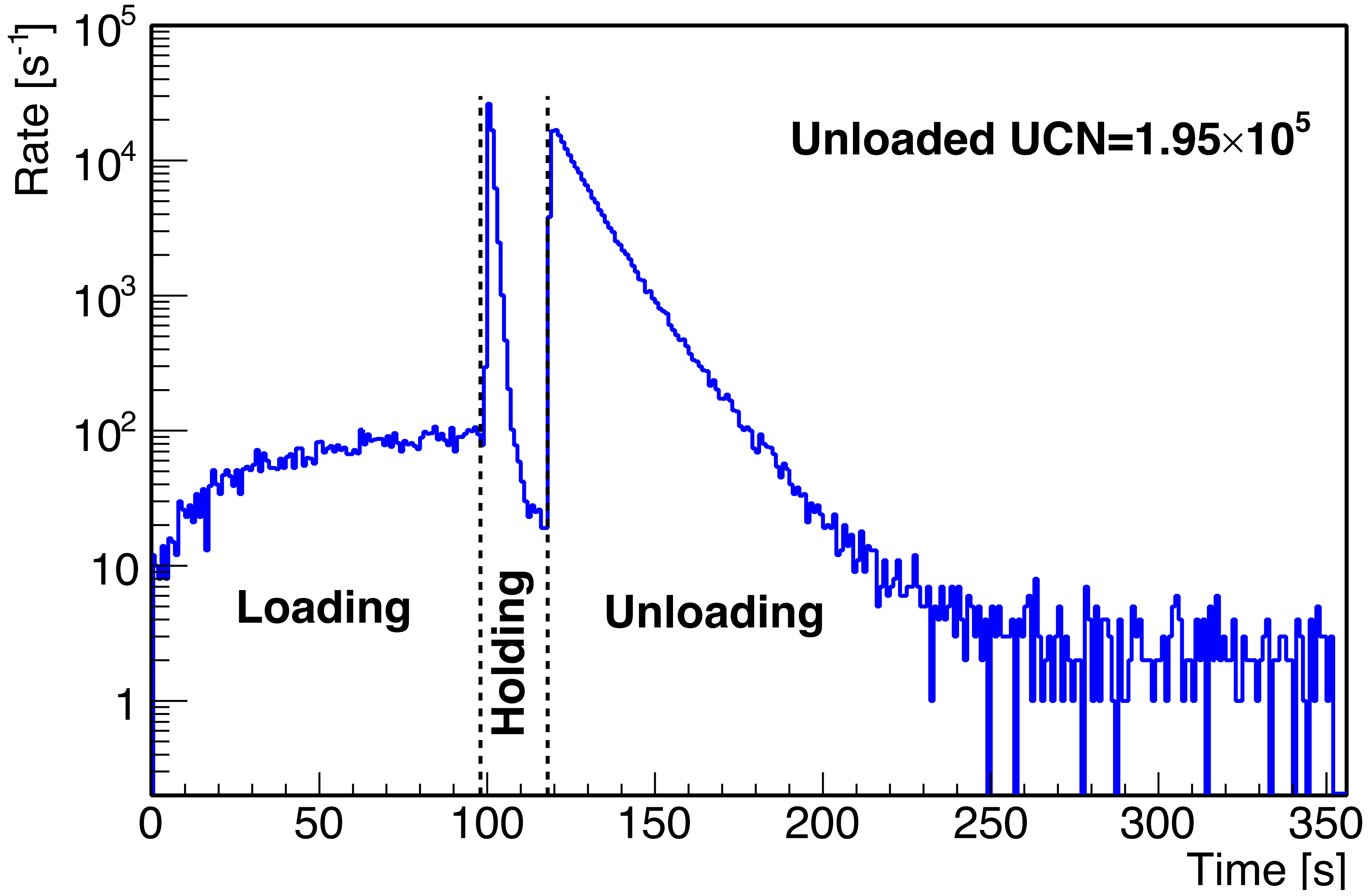
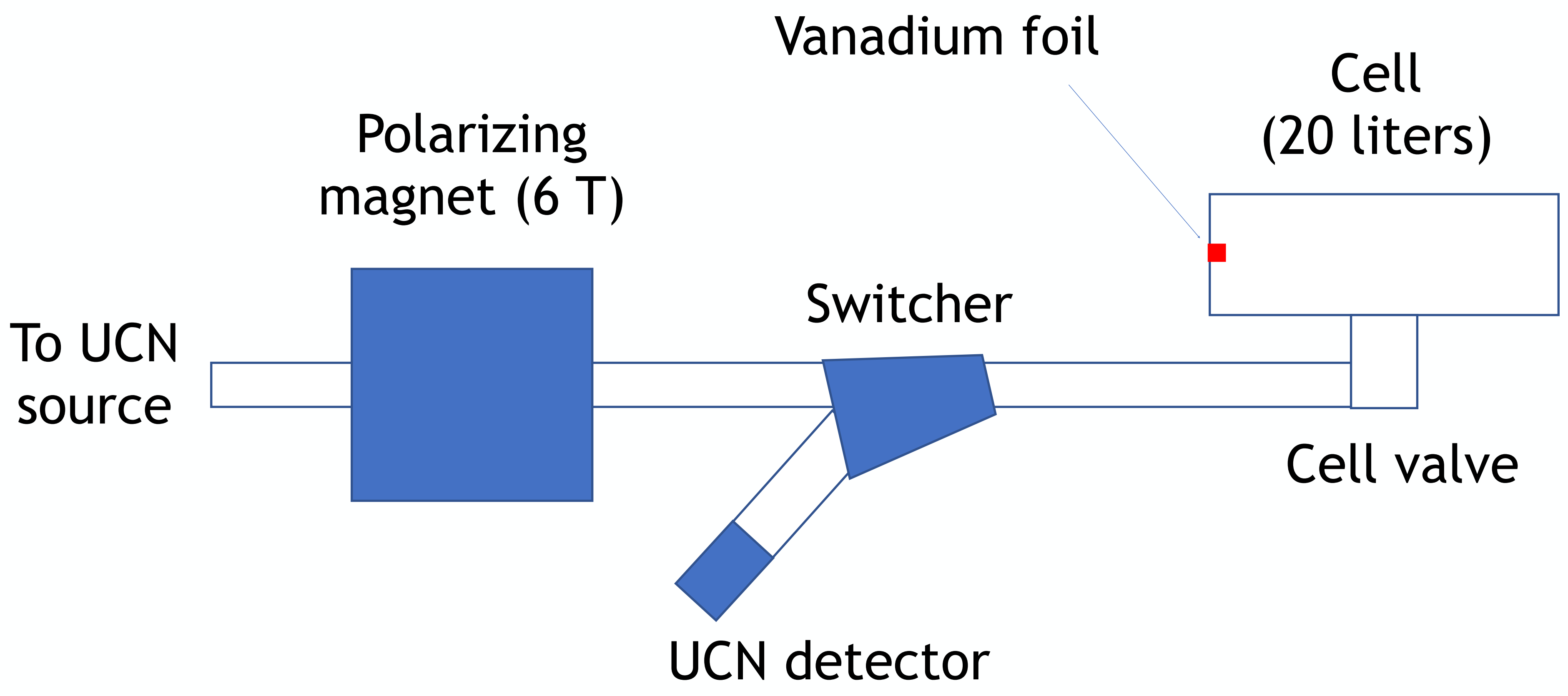
Polarized UCN density in a dummy nEDM cell on the West Beamline







Polarized UCN density (E < 170 neV) at t=0

- 12 UCN/cc from the fill and dump measurement (was 2.5 UCN/cc before the source upgrade)
- 36 UCN/cc from vanadium foil activation measurement

The difference can be attributed to loss in the switcher and the finite detection efficiency.

Estimated statistical sensitivity of an nEDM experiment

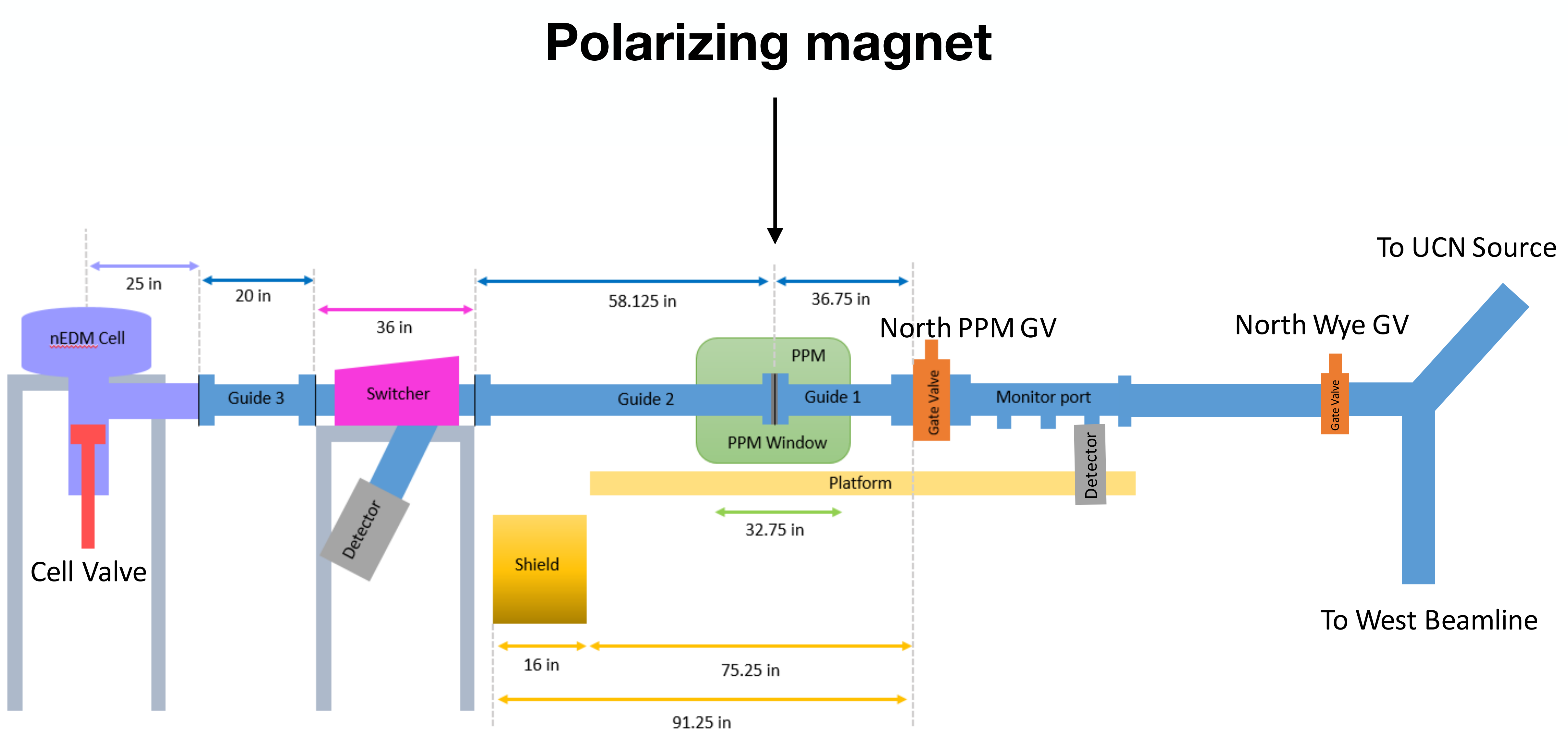
Parameters	Values
E(kV/cm)	12.0
N(per cell)	39,100
T_{free} (s)	180
T_{duty} (s)	300
α	0.8
σ/day/cell (10^{-26} e-cm)	5.7
σ/day (10^{-26} e-cm) (for double cell)	4.0
σ/year (10^{-27} e-cm) (for double cell)	2.1
90% C.L./year (10^{-27} e-cm) (for double cell)	3.4

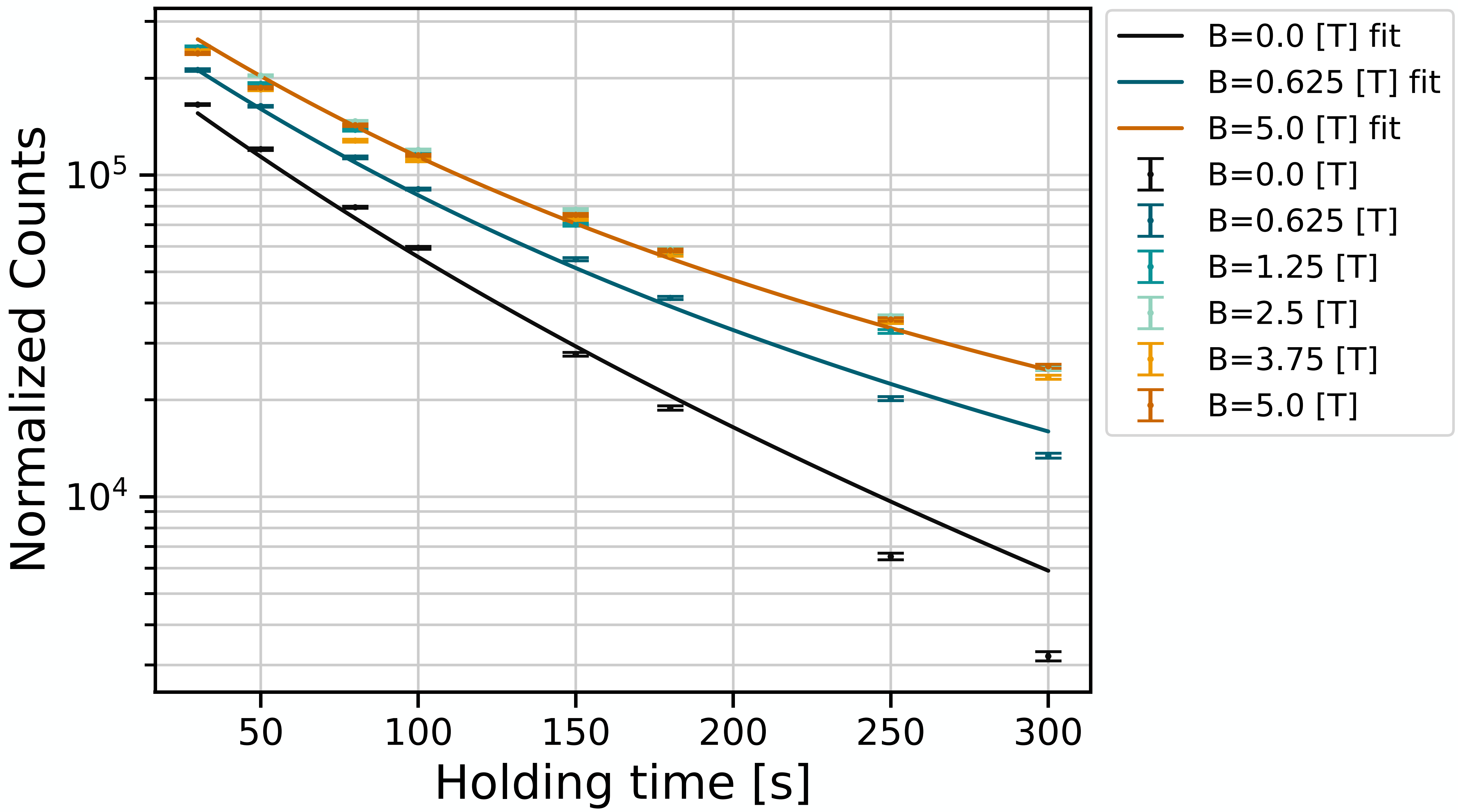
This estimate is based on the following:

- The estimate for E, T_{free}, T_{duty}, and α is based on what has been achieved by other experiments.
- The estimate for N is based on the actual detected number of UCN from our fill and dump measurement at a holding time of 180 s. Further improvements are expected (new switcher and new detector).

* "year" = 365 live days. In practice, it will take 5 calendar years to achieve this with 50% data taking efficiency

Neutron transport and storage test

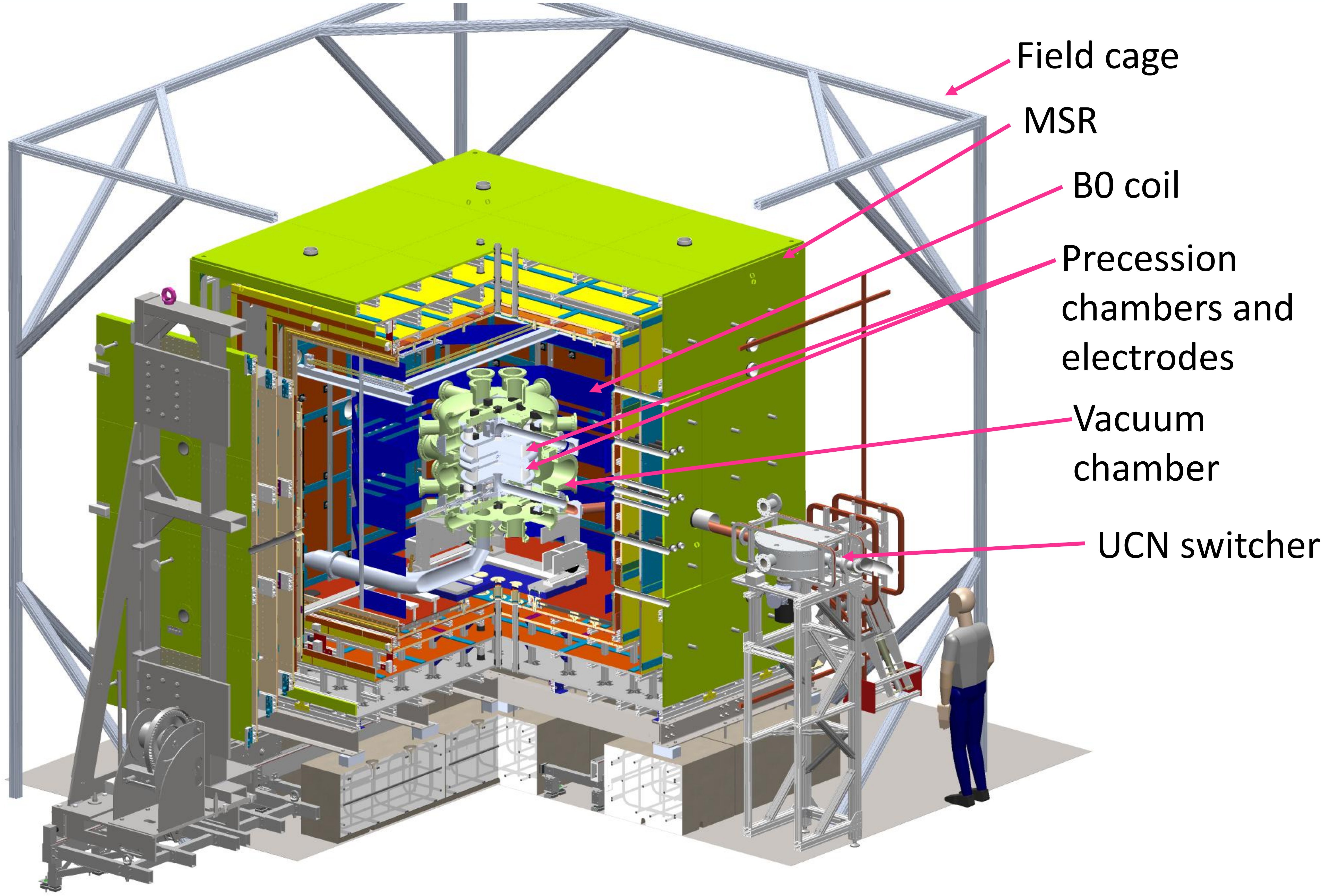




Measurement corresponds to ~60,000 detected UCN @ 2000 Hz GV rate after 180 s when a dPS coated cell wall was used with the new switcher

Wong et al., NIMA 1050, 168105 (2023)

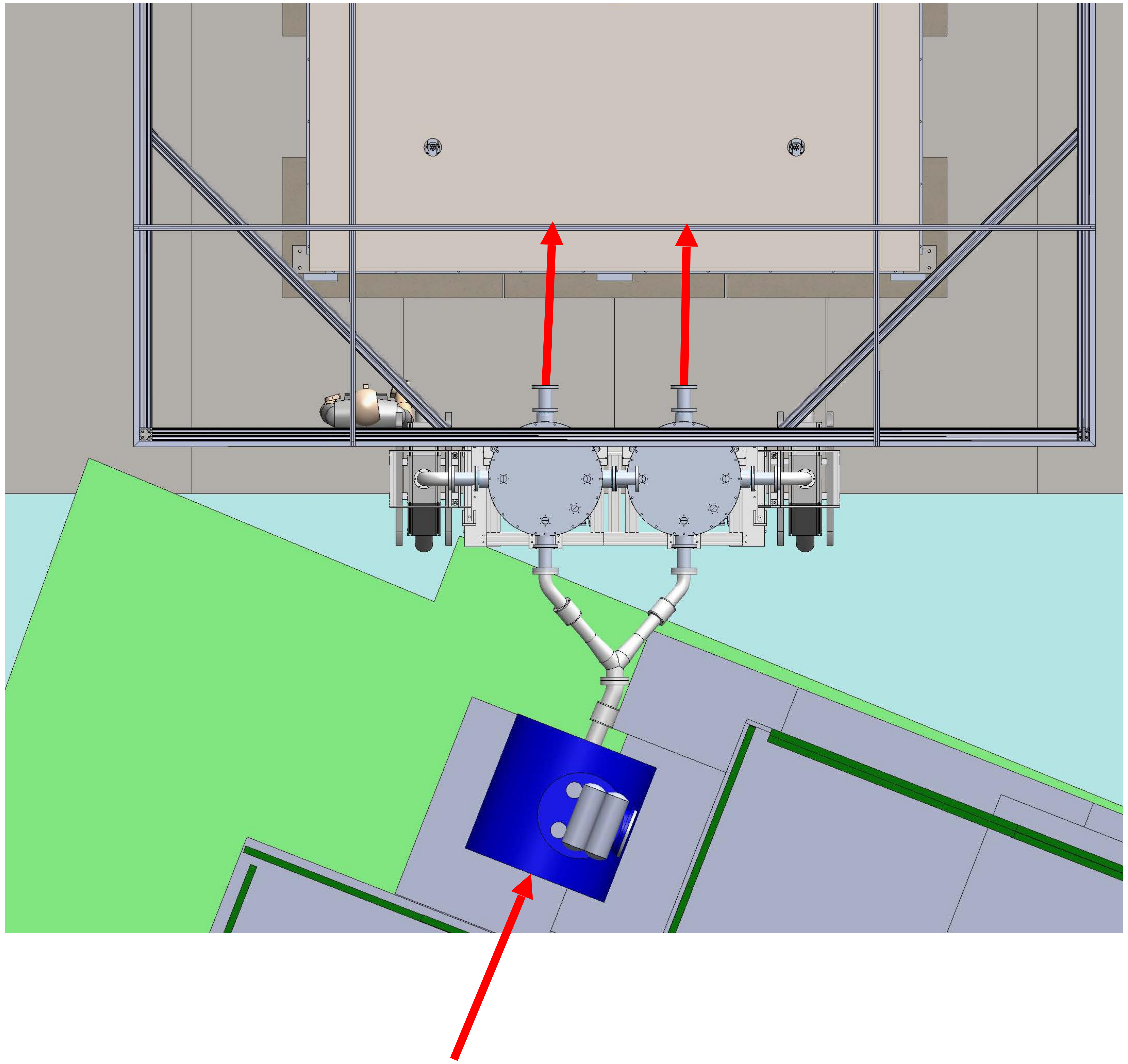
Apparatus Overview

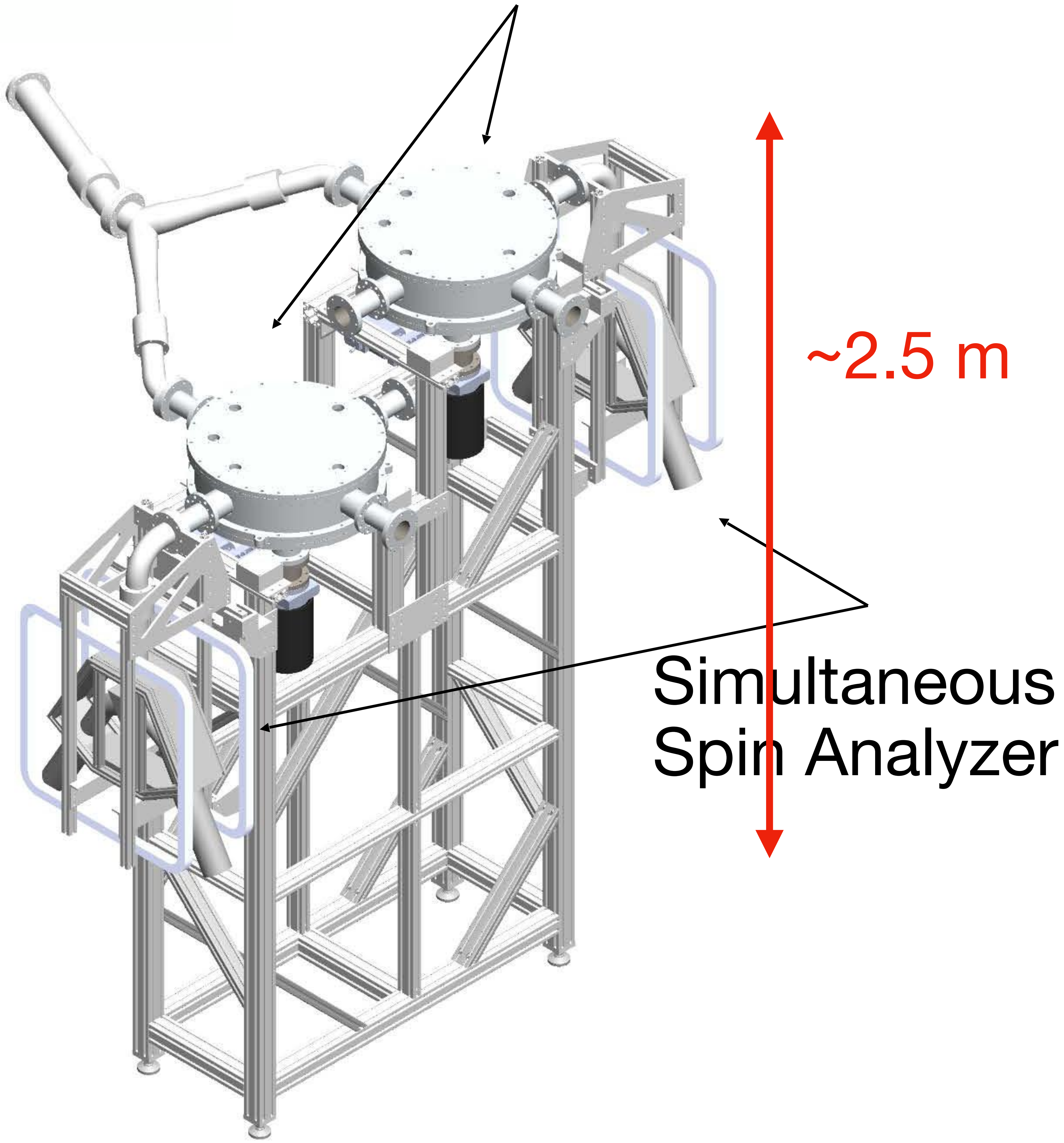


Selected features

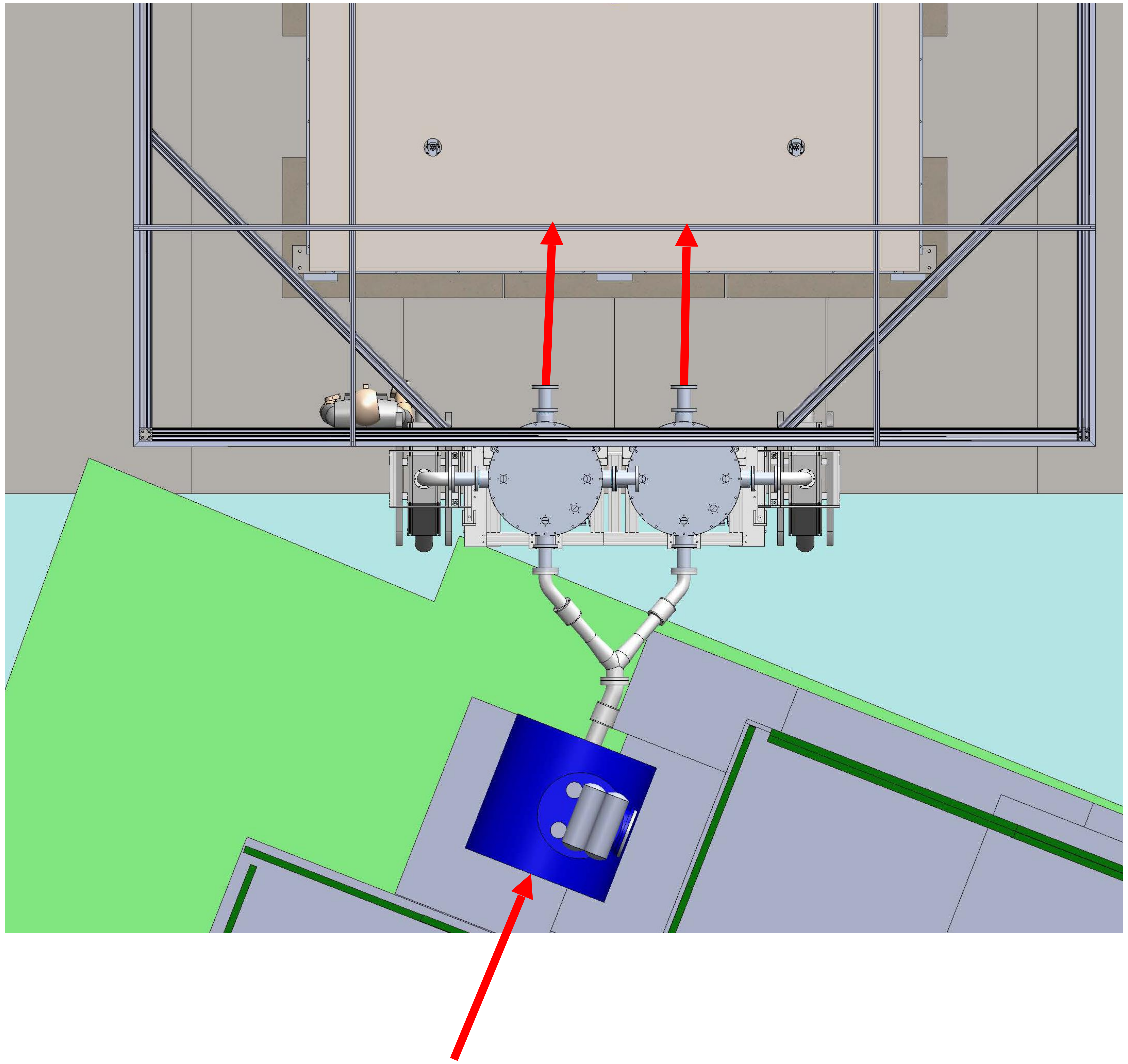
- Ramsey's separated oscillatory field method at RT
- Double precession chamber
- Simultaneous spin analysis
- MSR
    - 4 layer mu-metal + 1 layer RF shield
    - Outer dimension: 3.5 m x 3.5 m x 3.5 m
    - Inner dimension: 2.4 m x 2.4 m x 2.4 m
- Magnetometry:
    - 199Hg comagnetometer
    - 199Hg external magnetometer inside the HV electrode
    - Atomic external magnetometers
- Demonstrated UCN density
- Sensitivity goal: δdn = 3×10^{-27} e-cm in one live year

UCN transport and analysis system



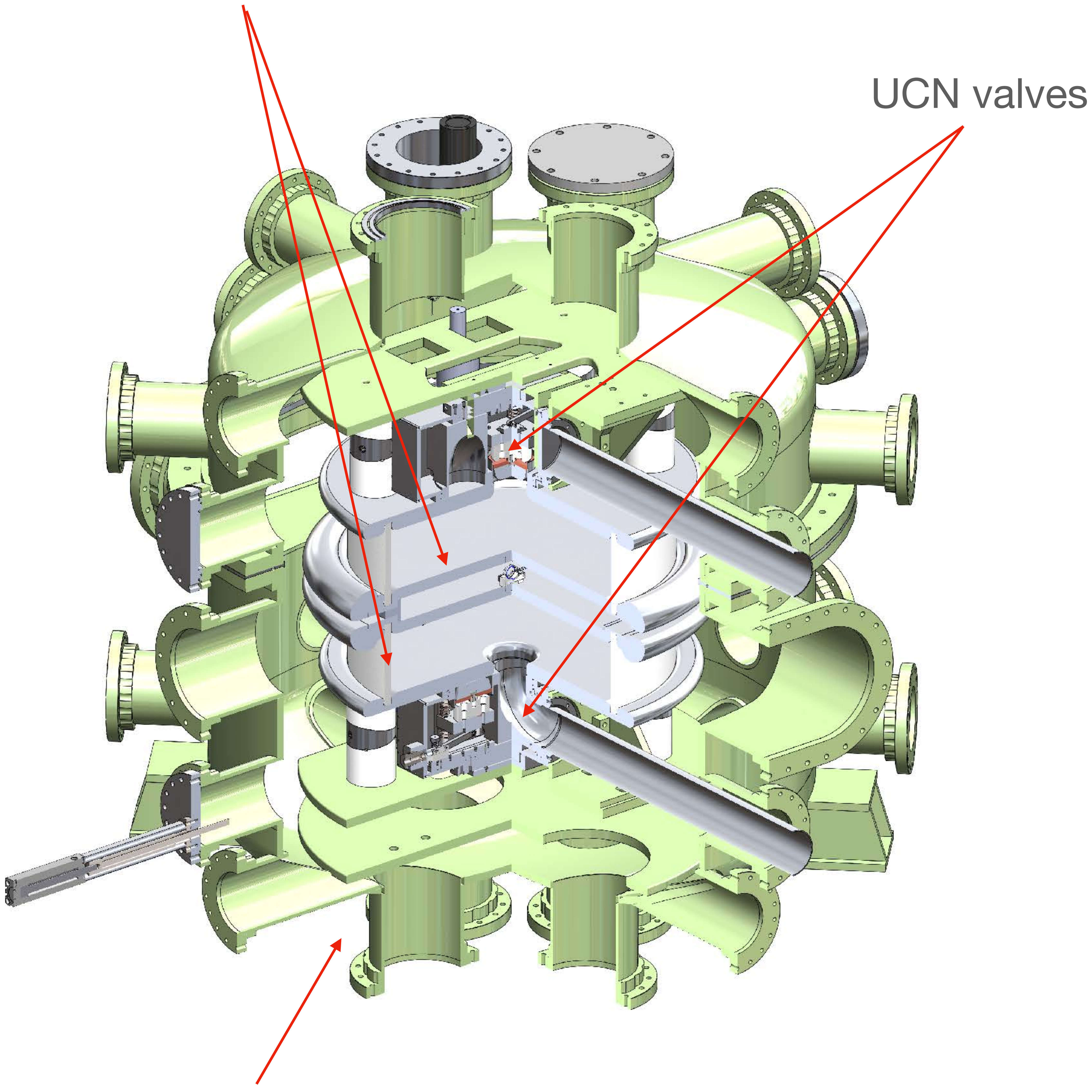


UCN transport and analysis system



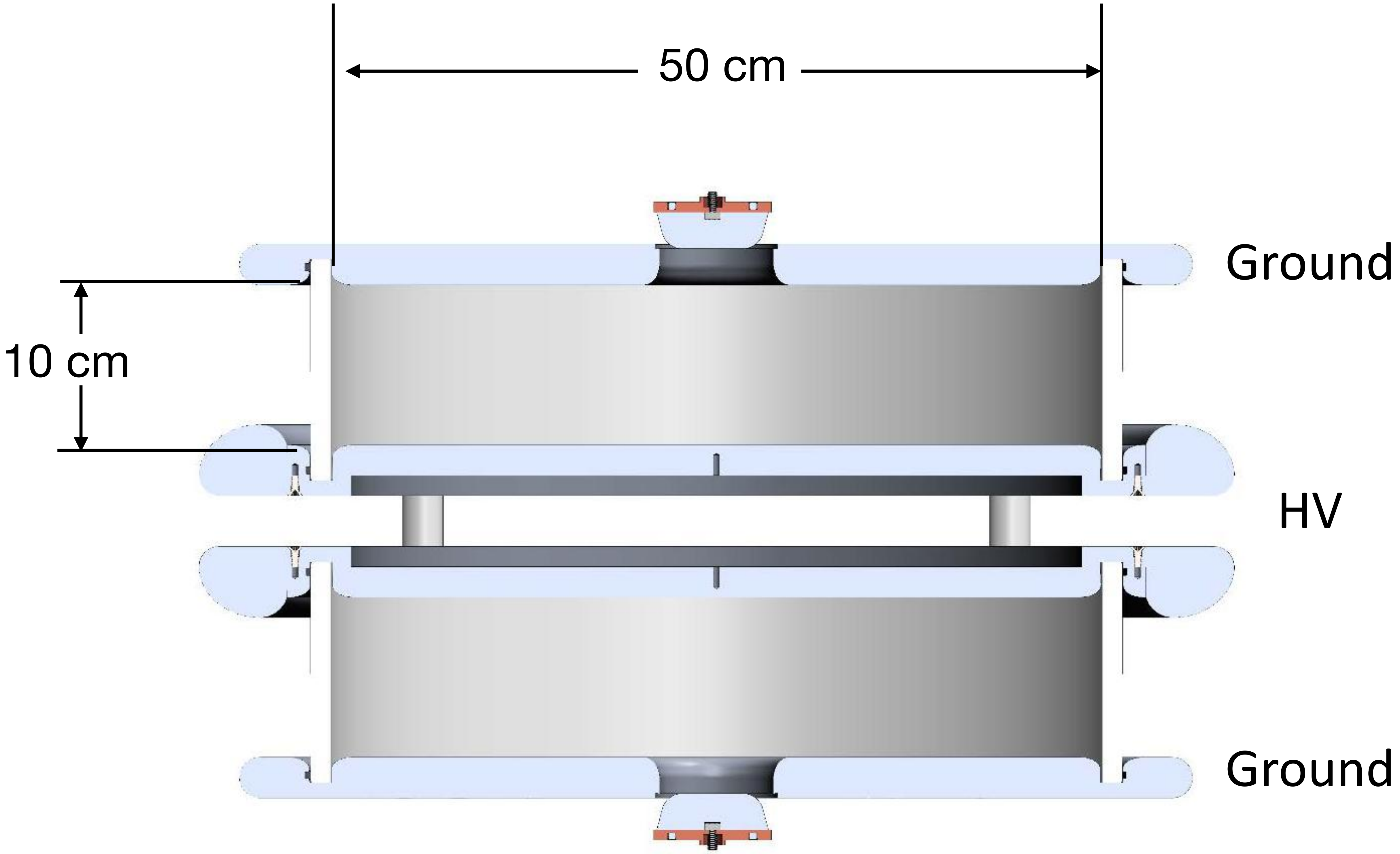
Switchers being installed

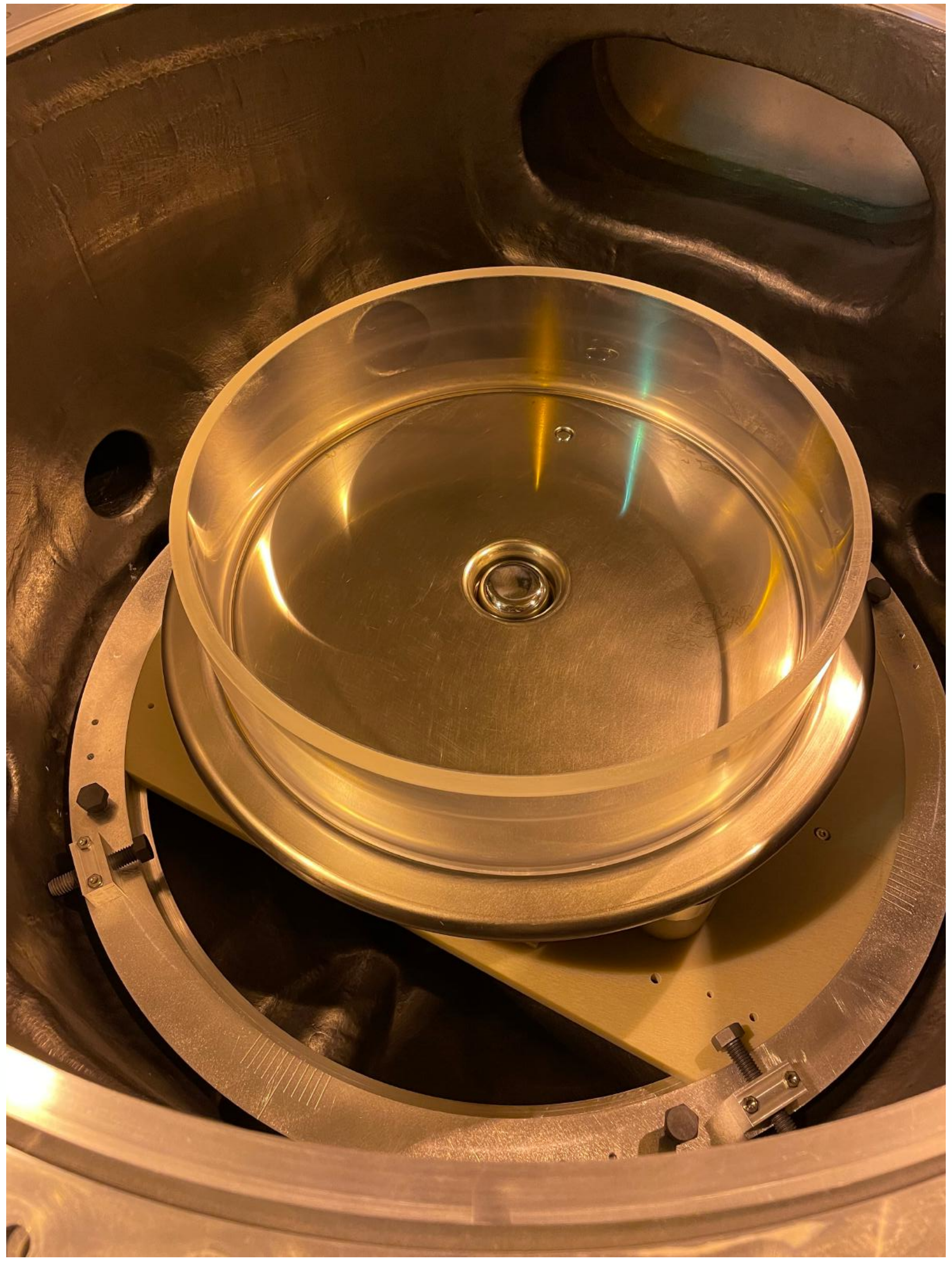
Vacuum chamber and internal design



Non-magnetic vacuum chamber

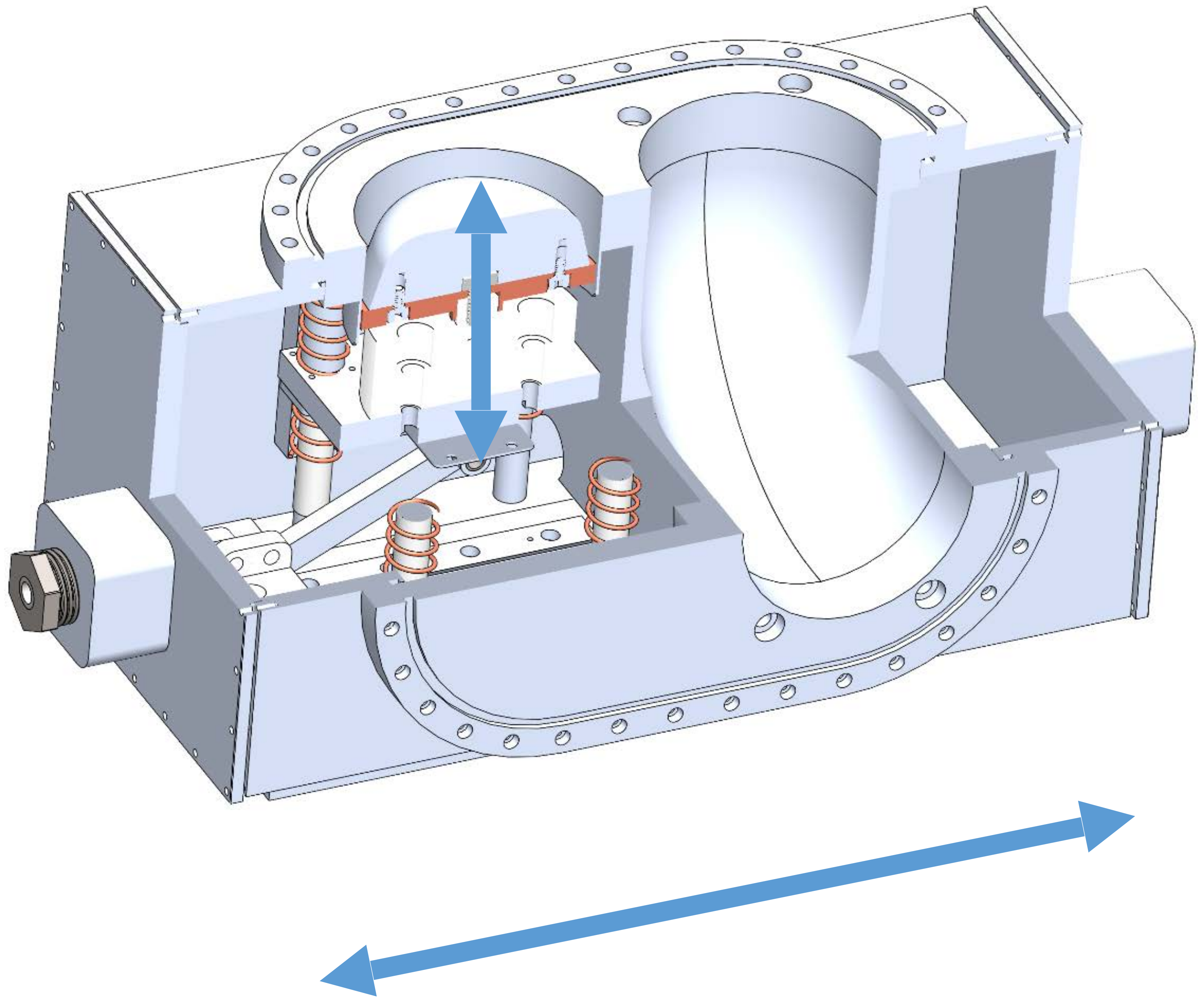
Electrodes and precession chamber

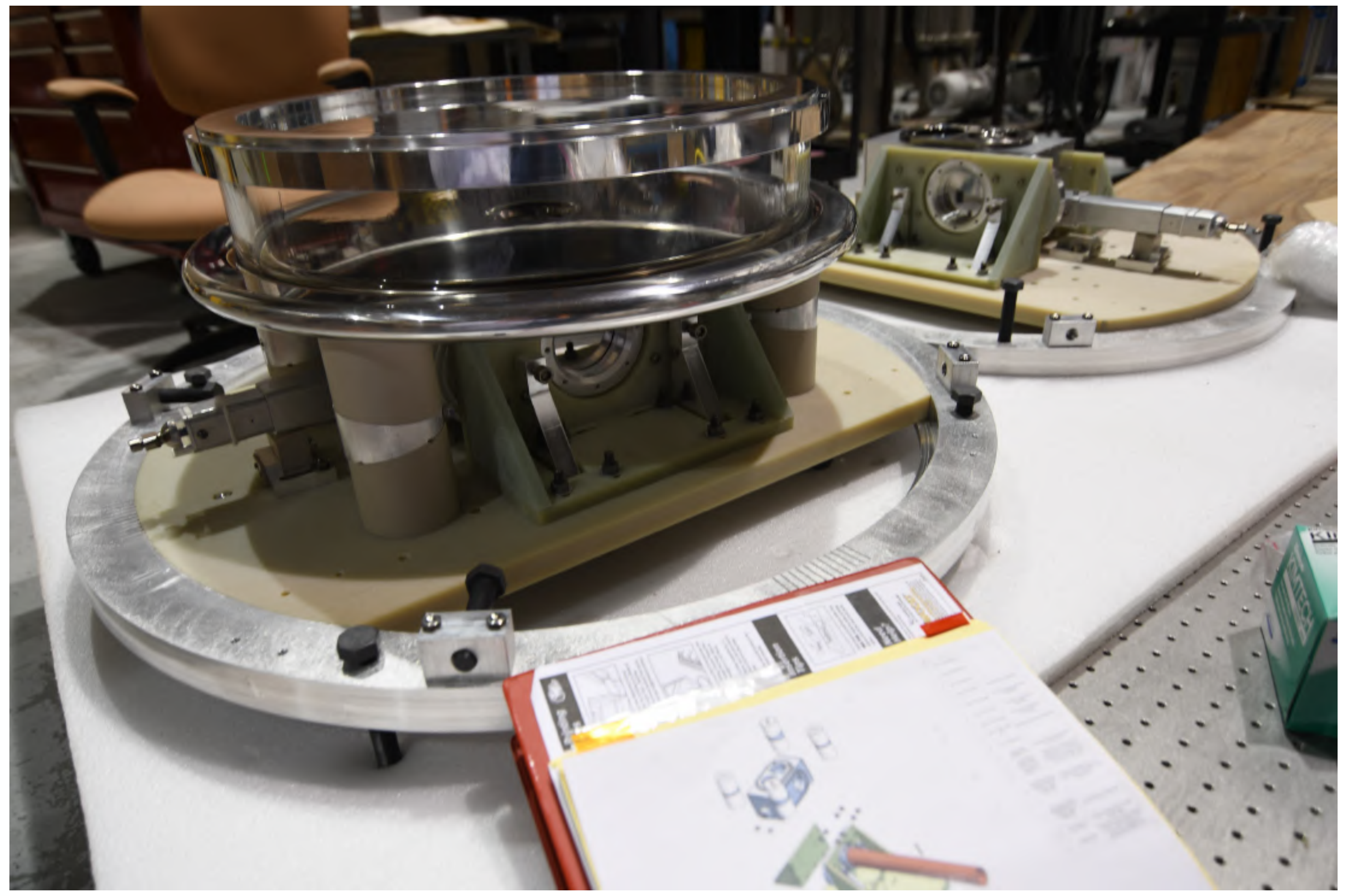


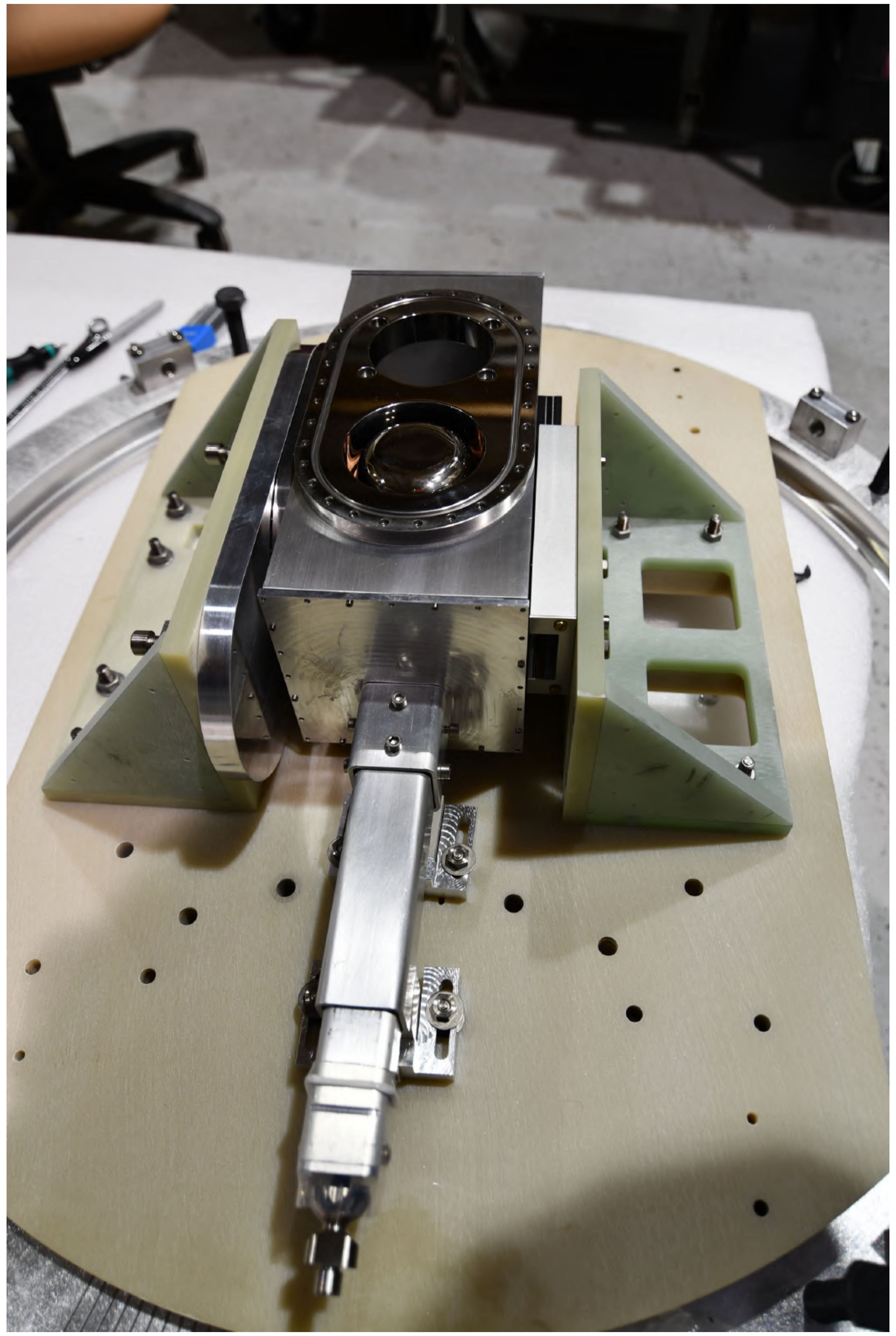


Precession chamber walls: dPS coated PMMA
Electrodes: NiMo coated aluminum -> DLC coated aluminum

Assembly of the cells, valves, …

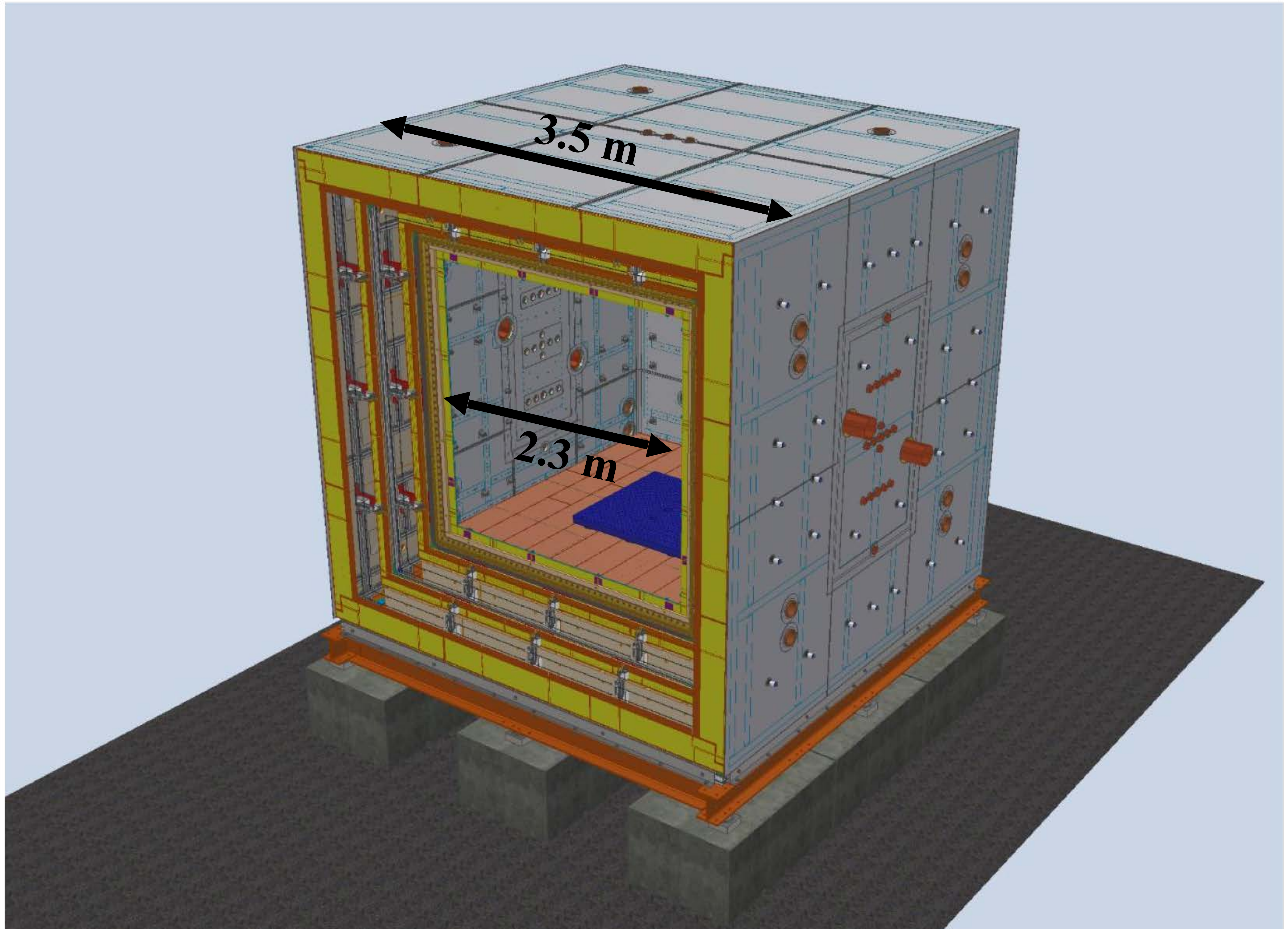






Magnetically shielded room

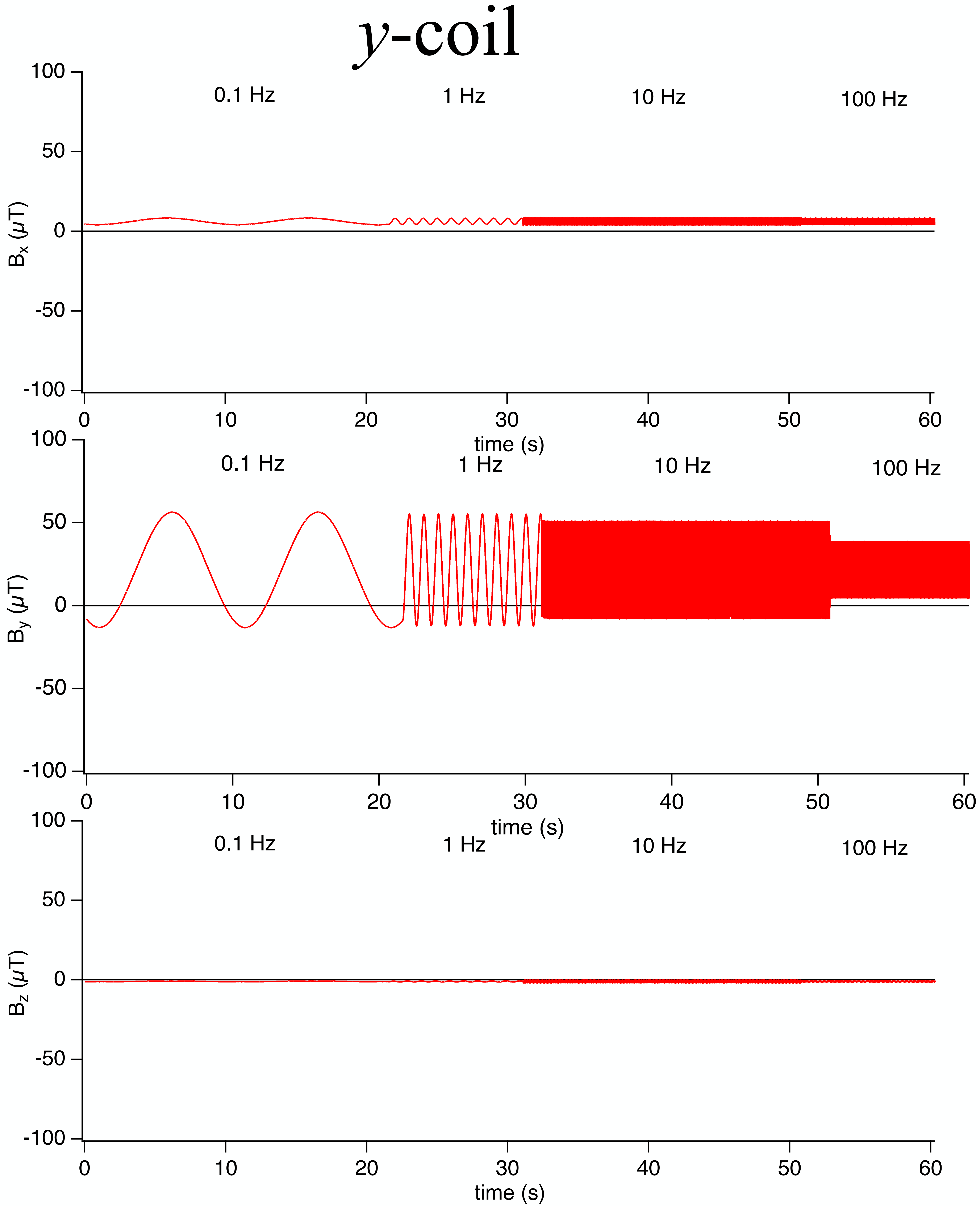
4 μ-metal + 1 Cu layers



Design performance

Frequency (Hz)	SF
0.01	100,001
0.1	100,001
1	1,000,001
10	10,000,001
100	10,000,001

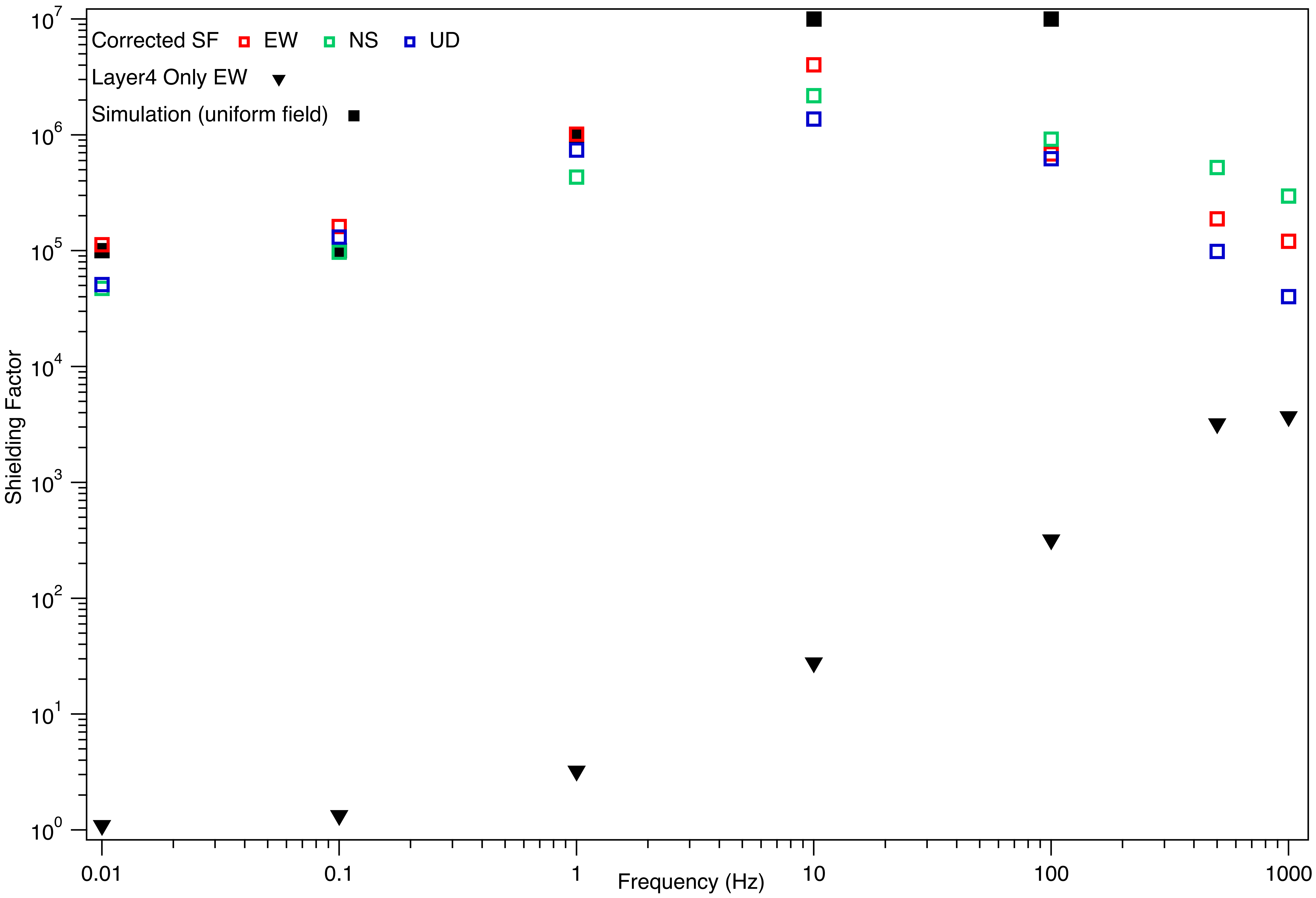
Field cage characterization



Installation of MSR in progress

Layer 1, outer and inner cladding, lighting, pneumatic system for door have been installed (mid January 2022)

Measured shielding factor

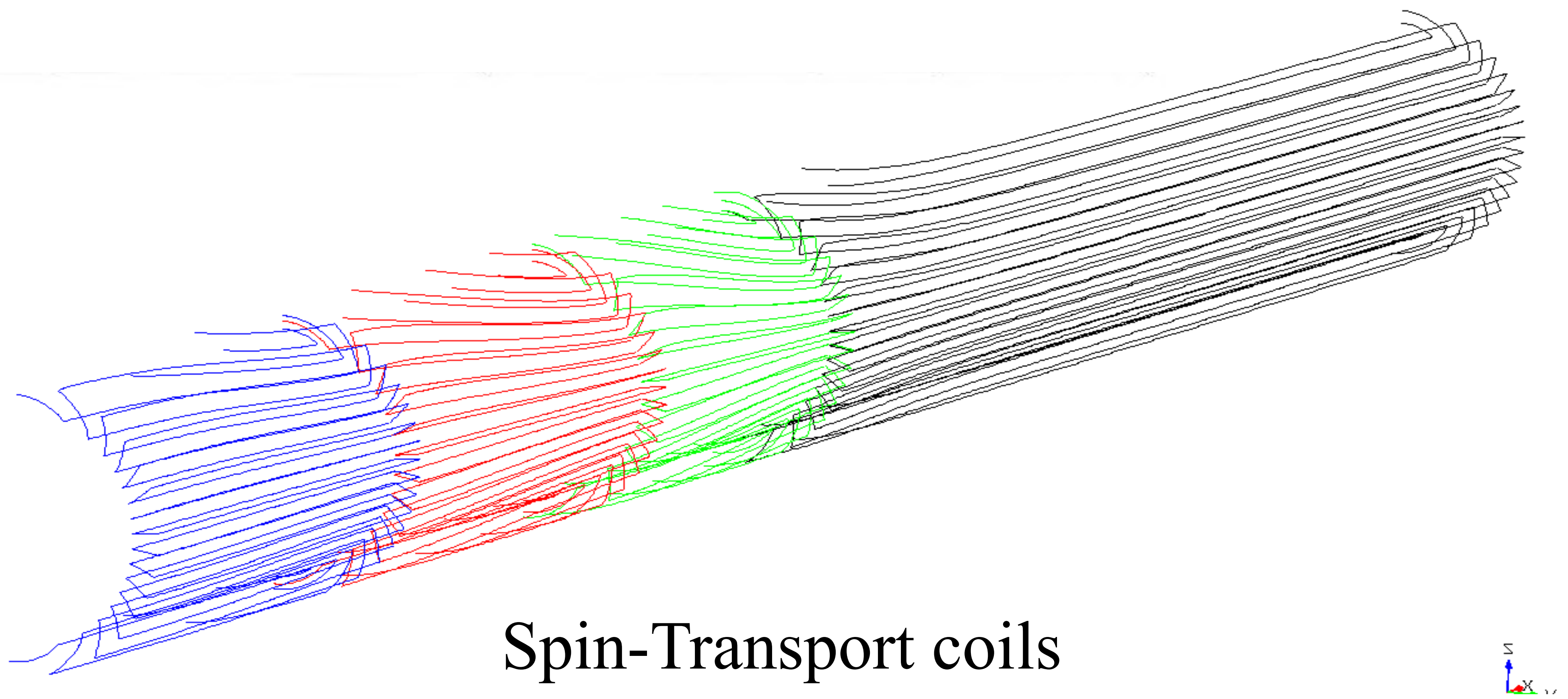


Residual field inside the MSR

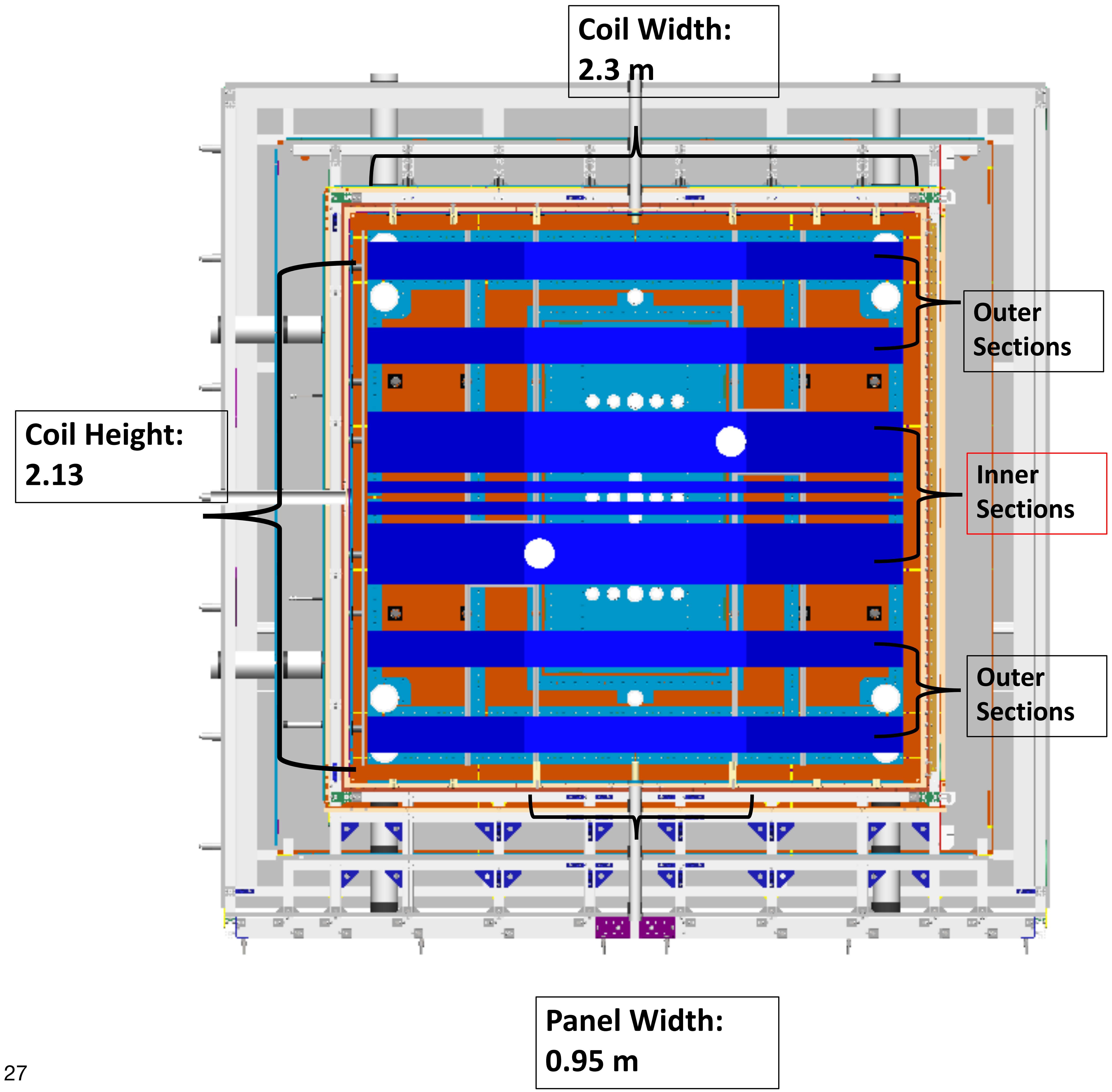
Point	x (cm)	y (cm)	z (cm)	Absolute Field (nT)	Specified (nT)
1	−40	−39	23	0.64	< 1
2	0	−39	23	0.51	< 1
3	40	−39	23	0.45	< 1
4	−40	39	−23	0.52	< 1
5	0	39	−23	0.41	< 1
6	40	39	−23	0.93	< 1

B0 coil design

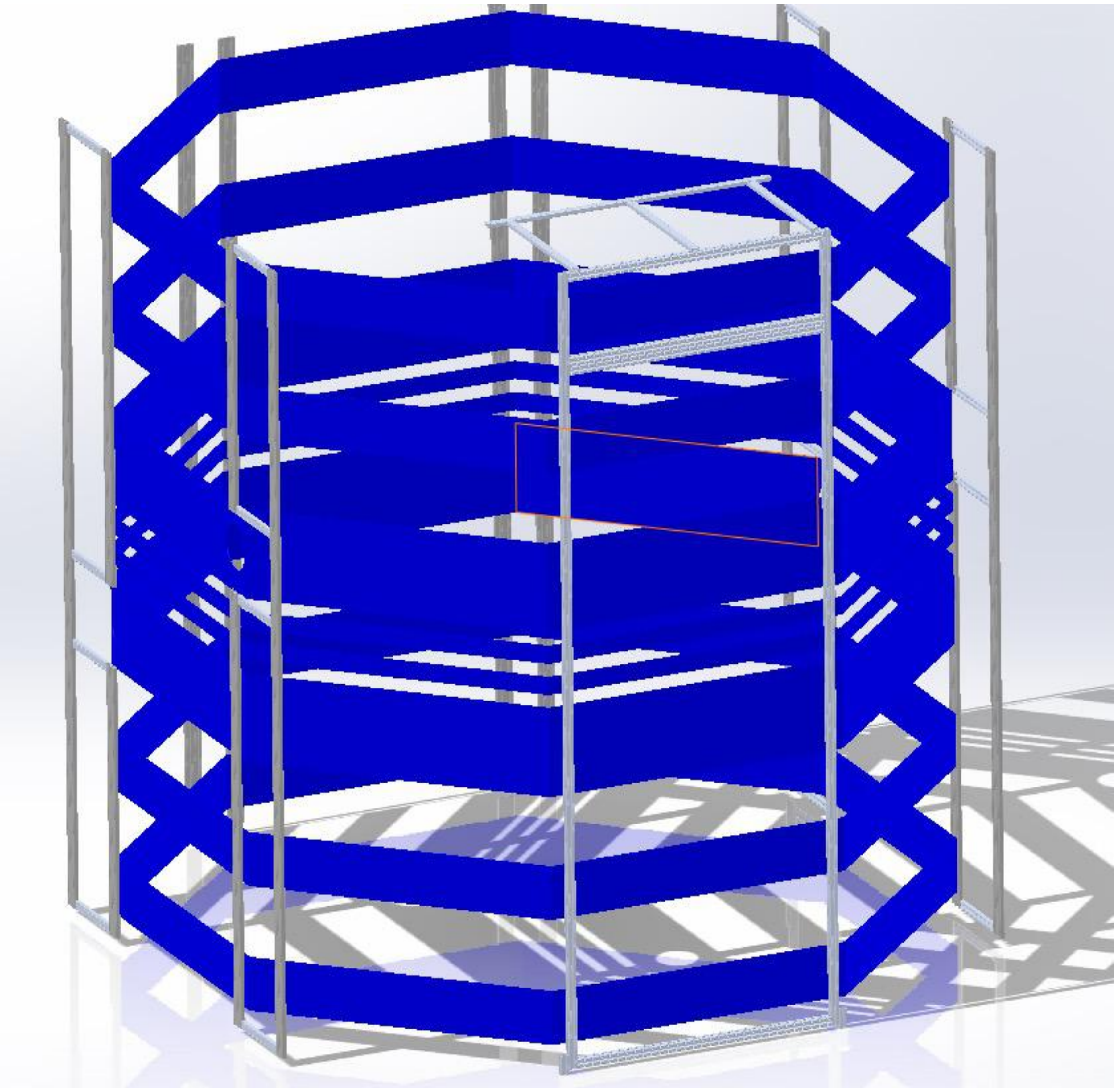
- Octagon-shaped multi-gap solenoid
- Spin-transport coil interface
- Modelled gradient: $\left|\frac{\partial B_z}{\partial z}\right| < 0.1\ \mathrm{nT/m}$
  - Specifications: $\left|\frac{\partial B_z}{\partial z}\right| < 0.3\ \mathrm{nT/m}$ inside each cell (the difference between the cells < 10 pT)



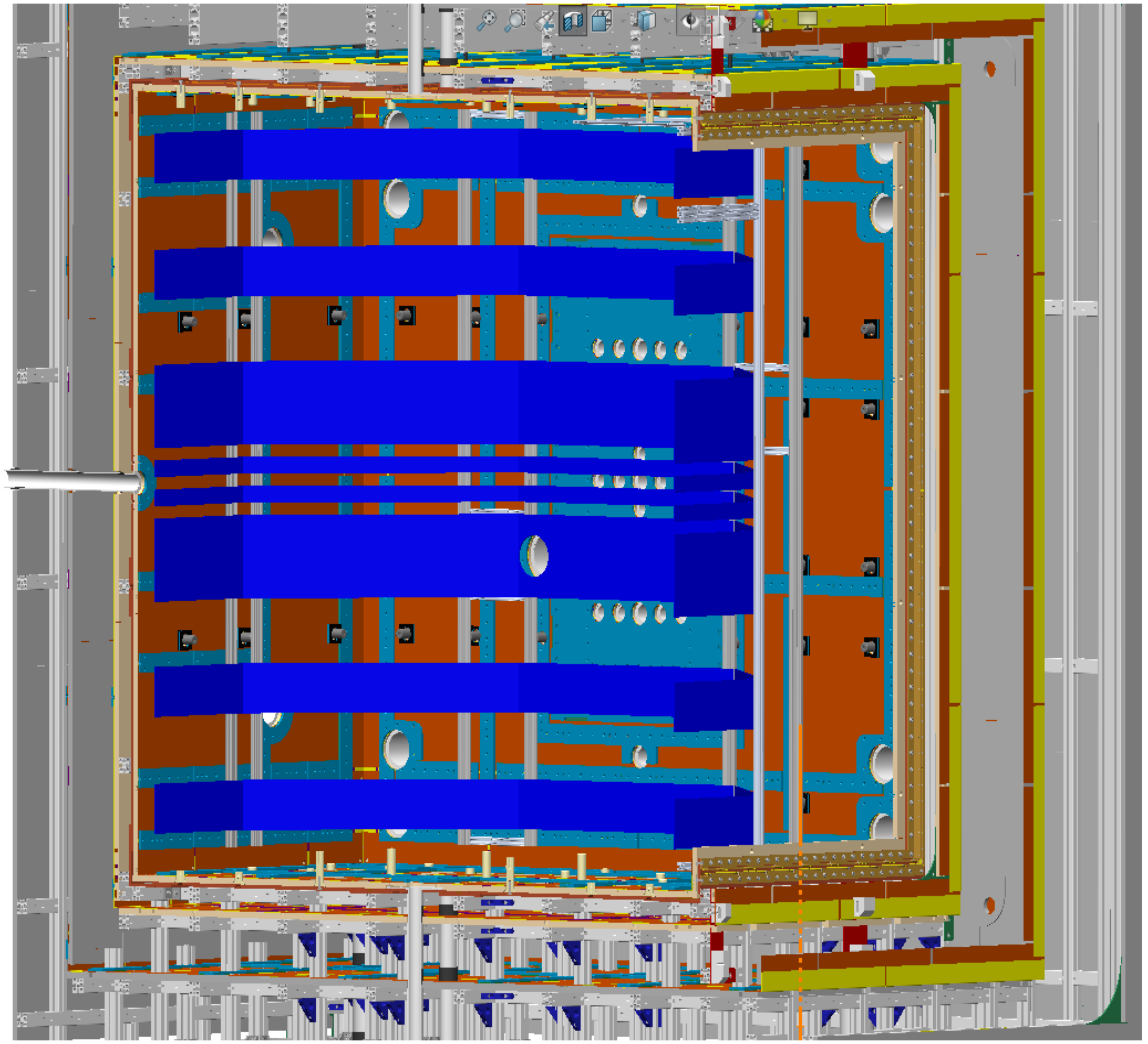
Spin-Transport coils
Double Layer Modified Cos θ



B0 coil system

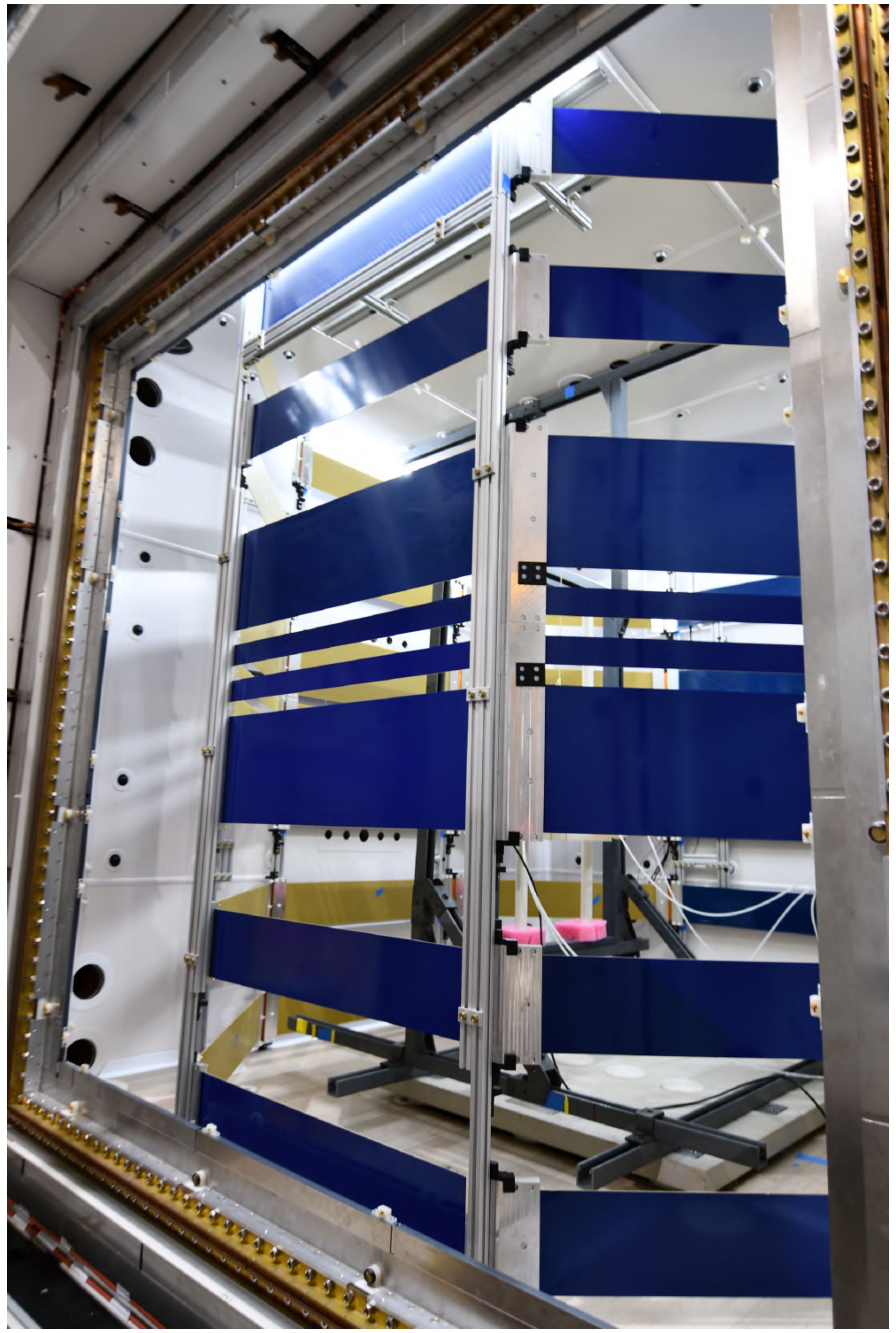


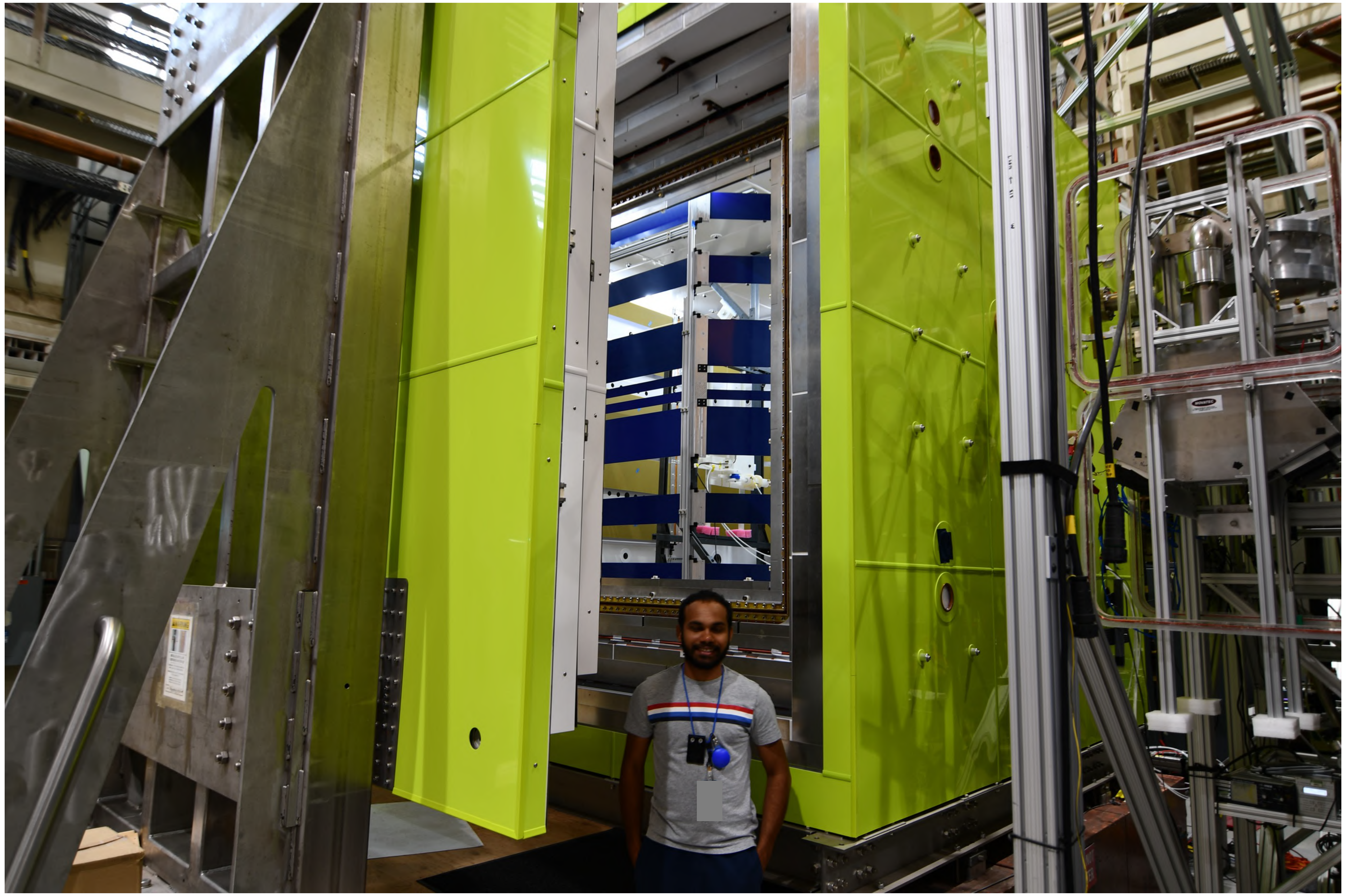
Bo coil and the frame



Bo coil sitting inside the MSR

B0 coil system

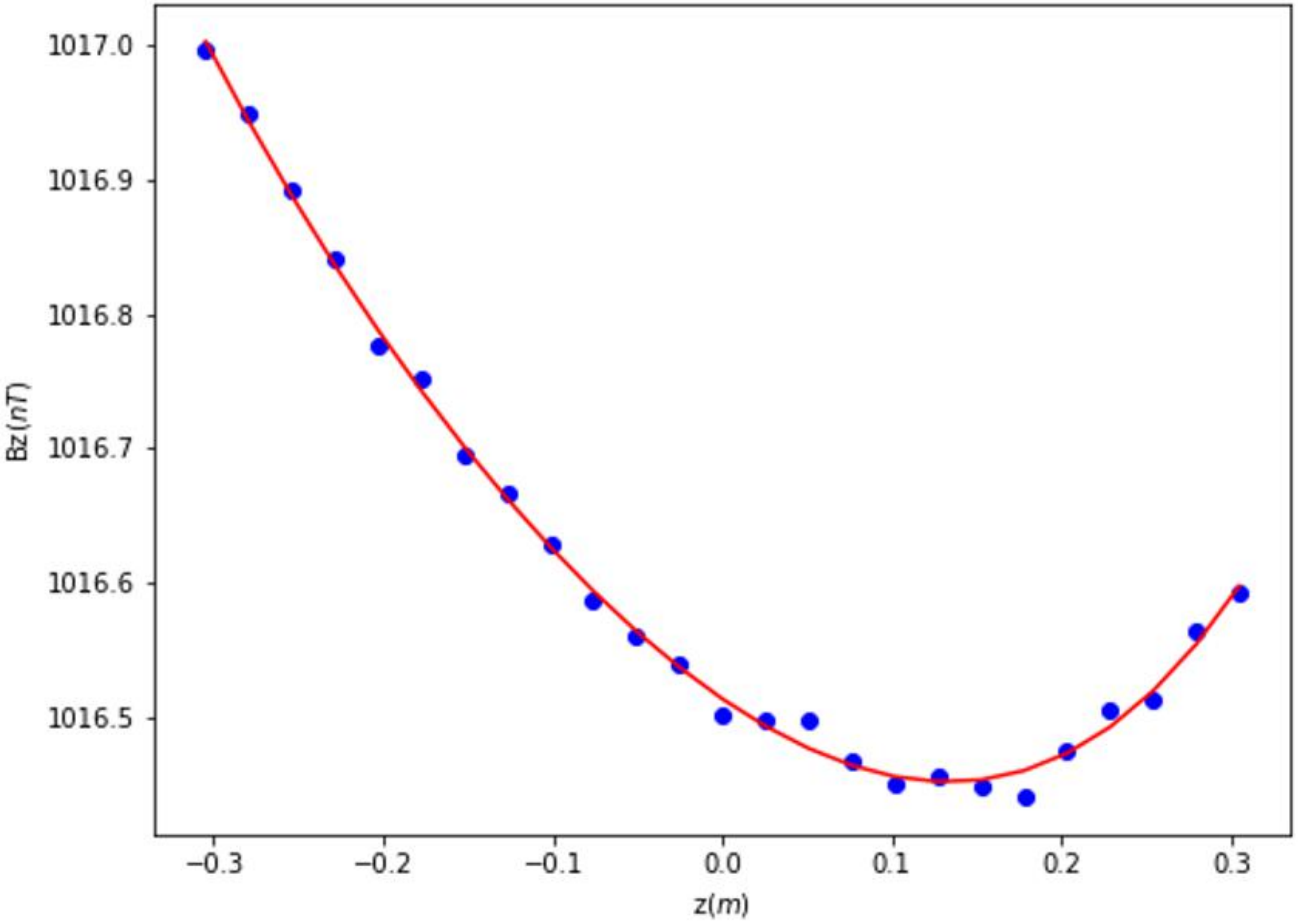




B0 field measurement

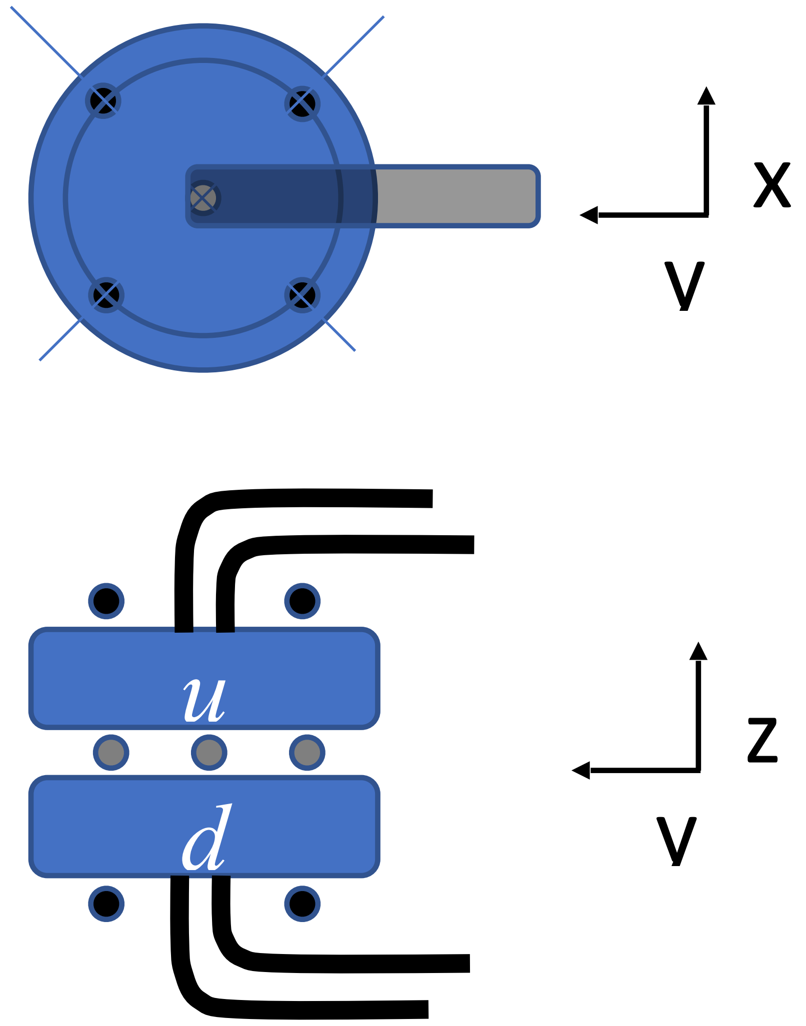
- Gradient goal for CY22:
  - 10 nT/m for 200 s T2*

(Ultimate goal: 0.1 nT/m)



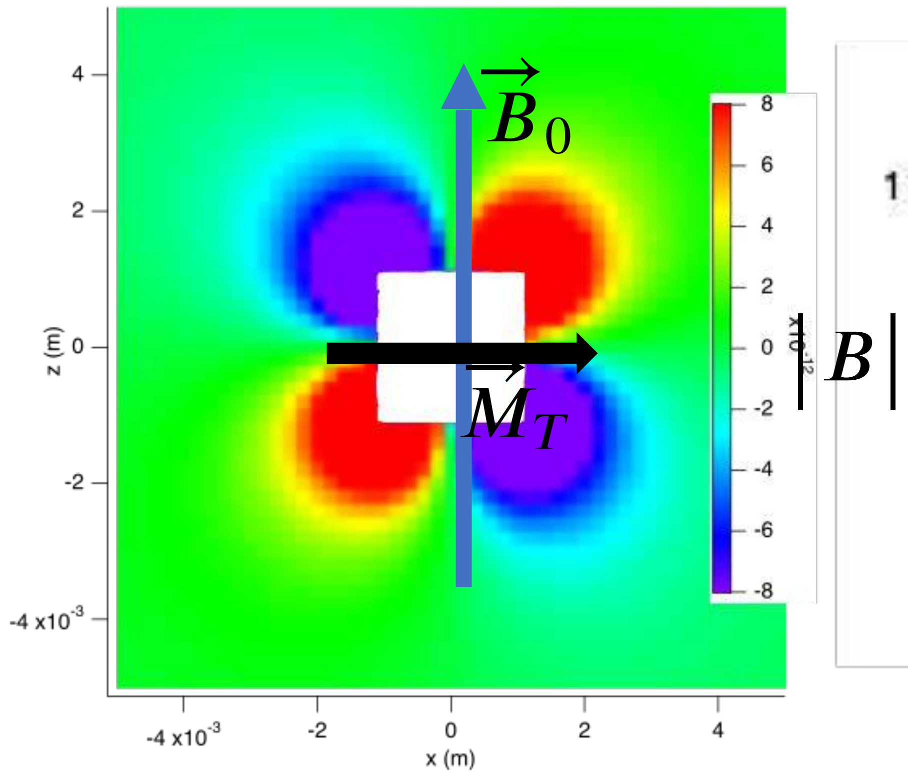
Magnetometers

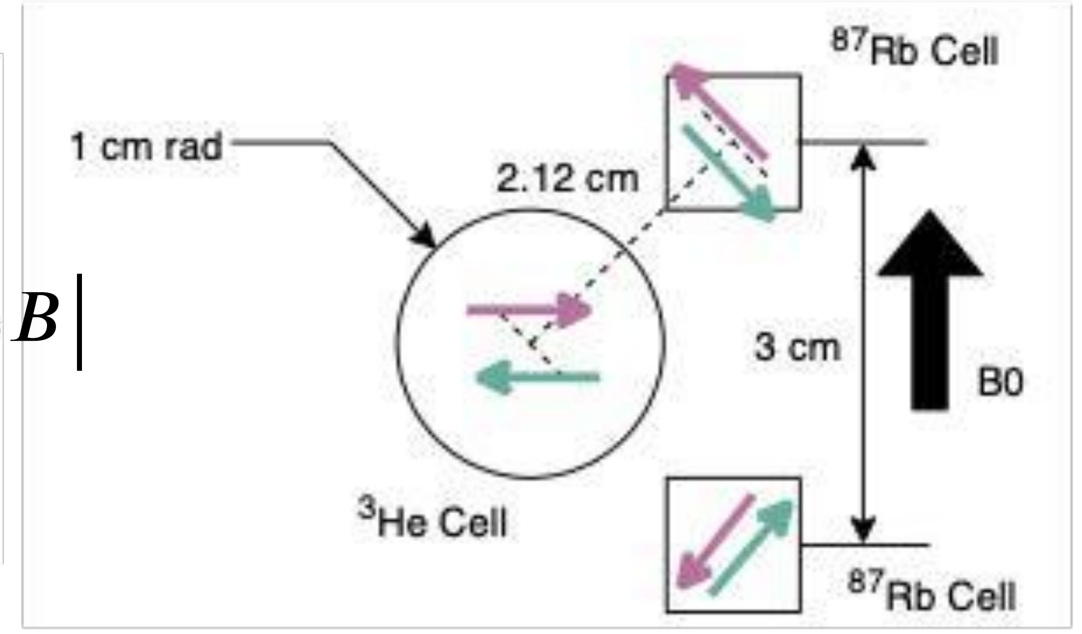
Up to 13 external magnetometers (inside vacuum) monitor B_0, gradients

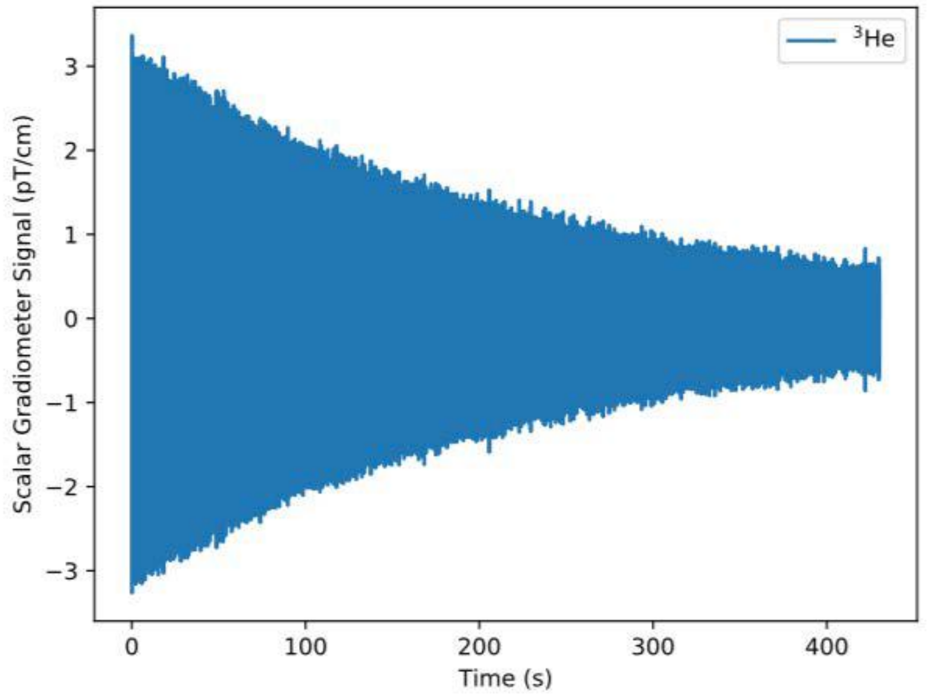


OPMs: optically pumped alkali (Cs, Rb) magnetometers

Nuclear spin magnetometers: Hg, ^{3}He (UM/Twinleaf)

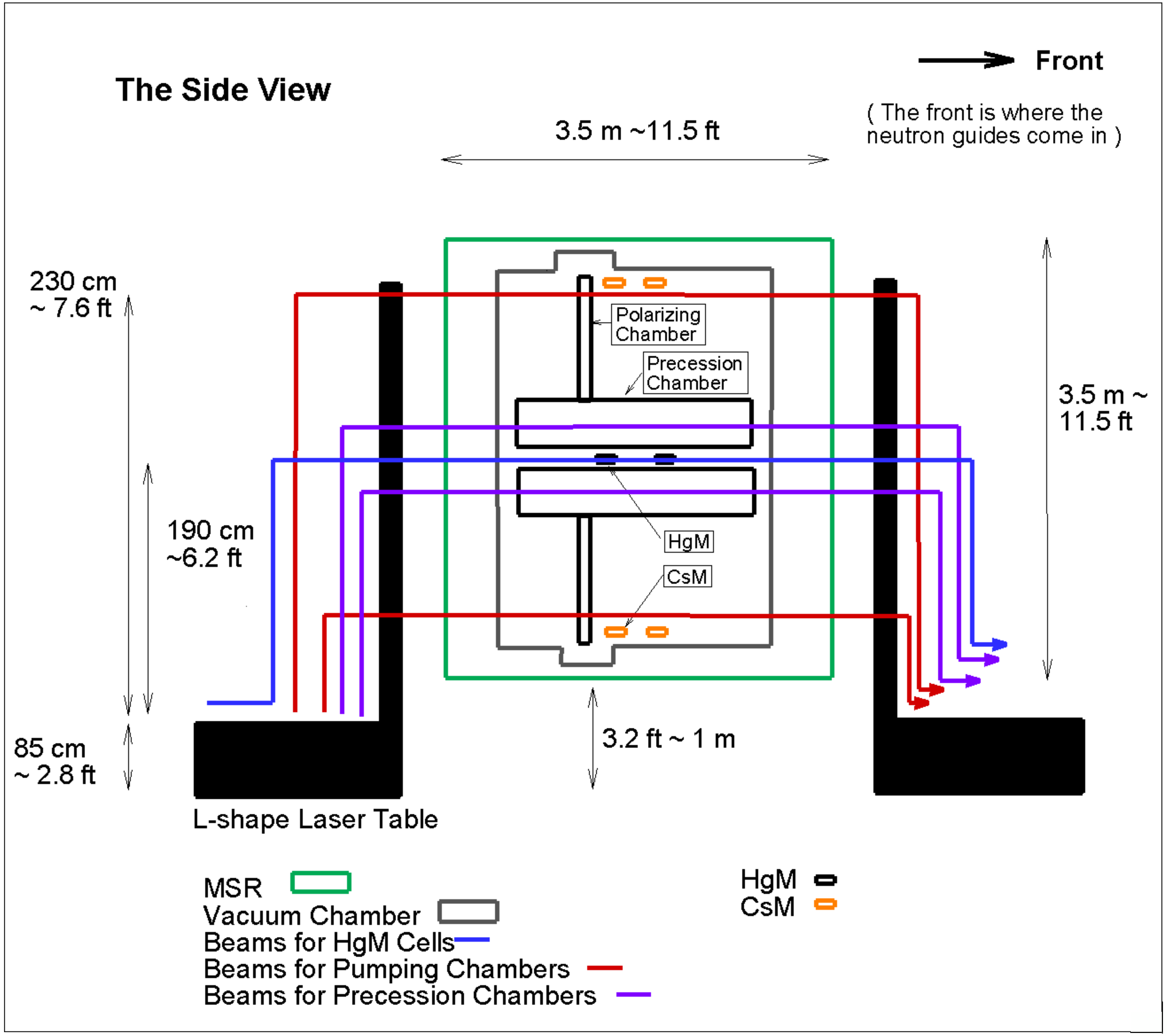




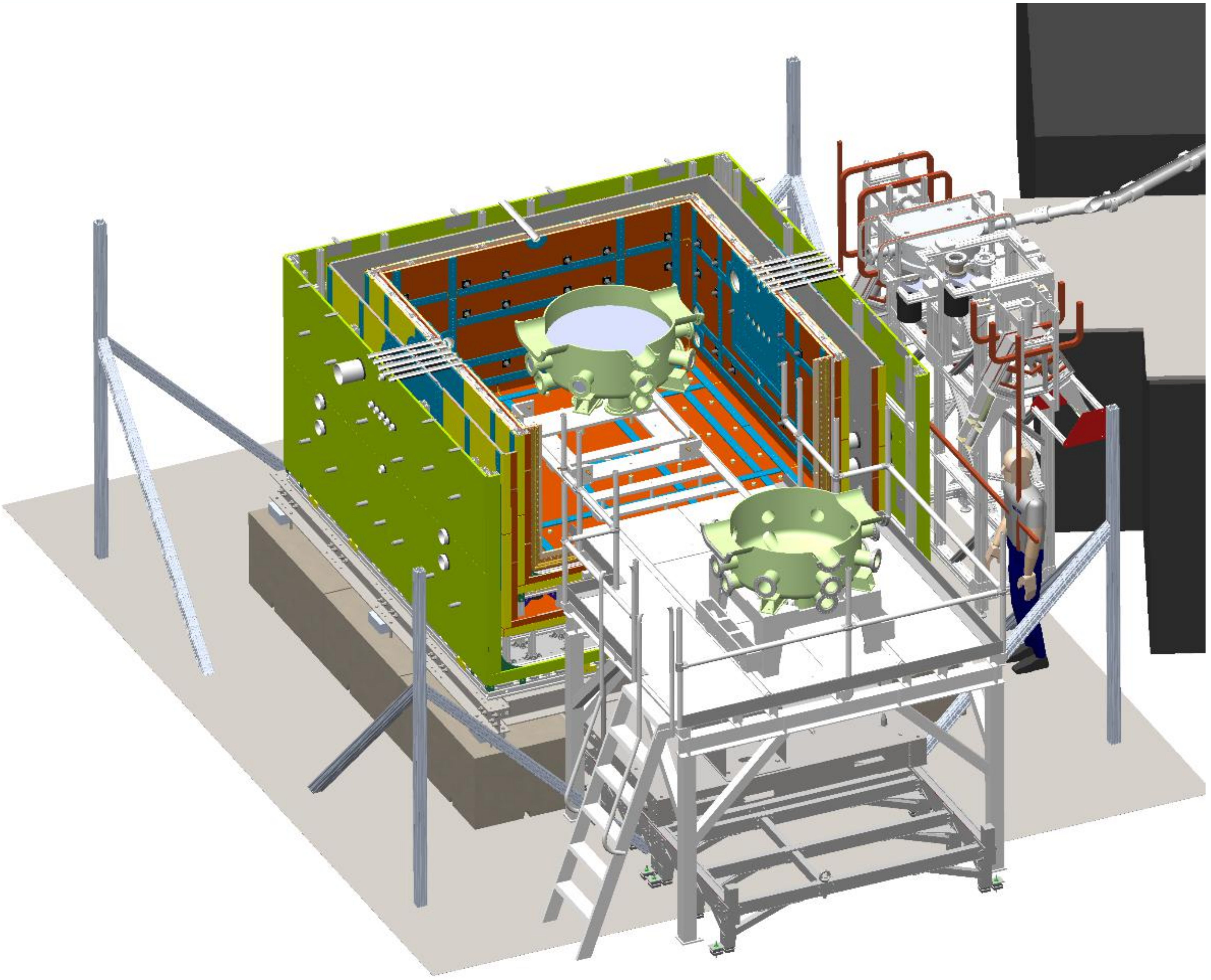


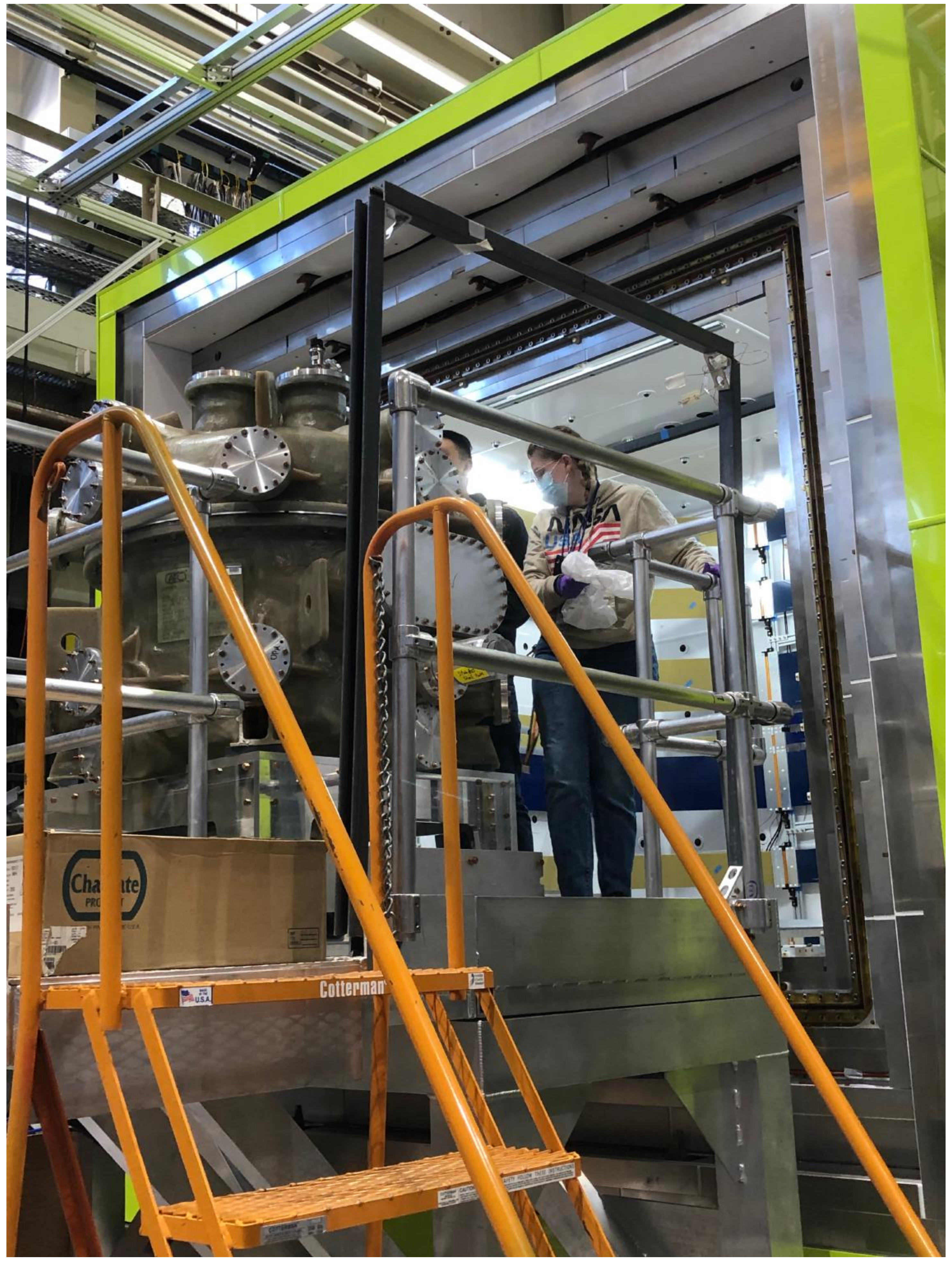
Hg-199 as co-magnetometer and magnetometers

- nEDM@LANL has two precession chambers.
- Hg atoms are optically pumped in the polarizing chamber and then are transferred to the precession chamber to monitor the magnetic field.
- 5 Hg magnetometers(HgMs) are inside the HV electrode.
- All the pump beams come in from the side of MSR.
- The laser beams for the top precession chamber and the pumping chambers will raise up to 7.6 ft and 6.2 ft from the optic table.
- The HgM cell is currently in experimental development.



Vacuum chamber installed in the MSR





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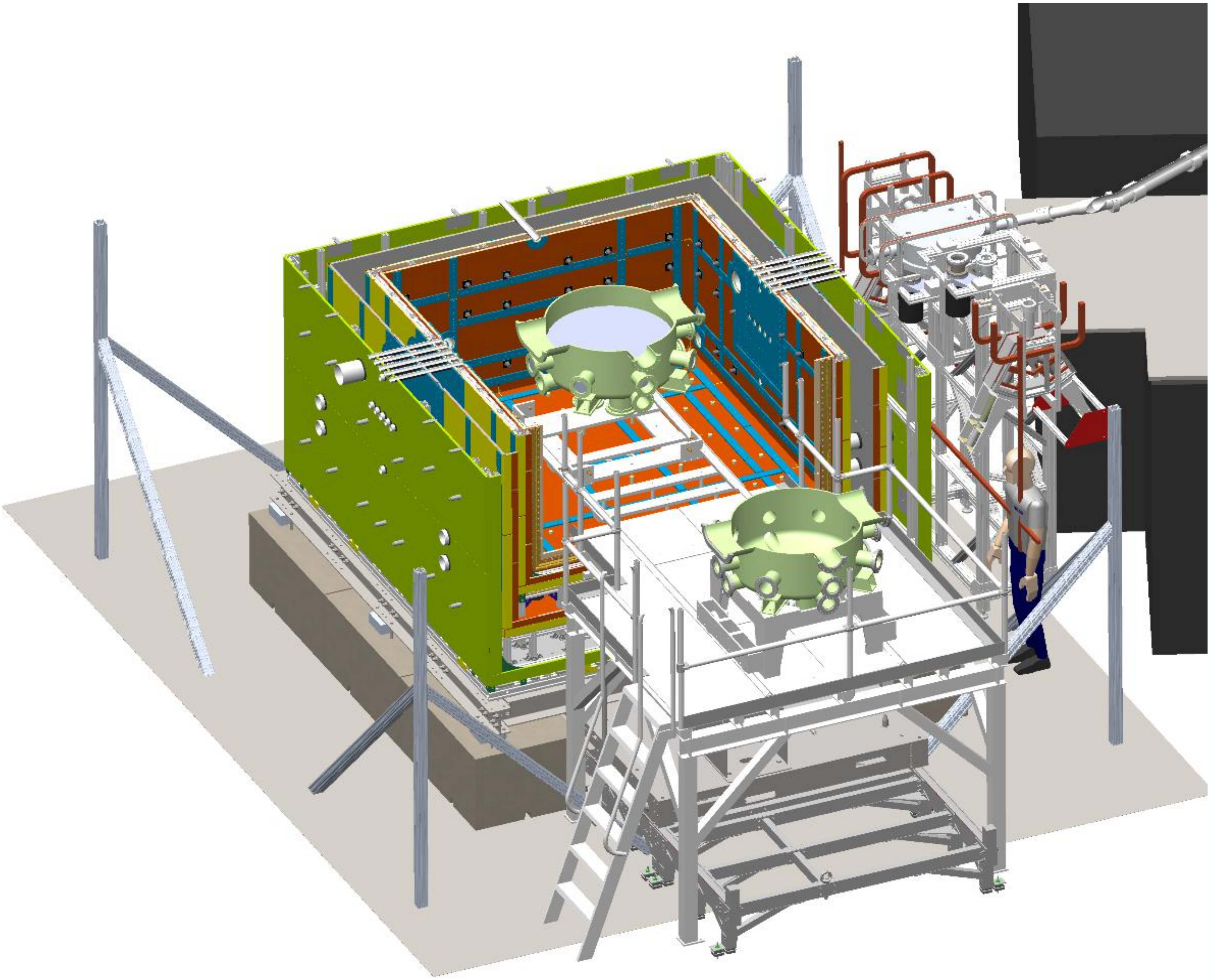

Status and plans

- MSR was delivered in January 2022. It meets basic performance requirements. More detailed characterization is necessary.
- Precession chambers and UCN valves were assembled.
- Engineering run started in December 2022.
  - UCN transport and storage
  - Spin transport
- Characterization and improvements of the apparatus will continue this year.