The LANL nEDM Experiment

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Los Alamos National Laboratory

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ECT* workshop | Neutron Electric Dipole Moment: from theory to experiment

LA-UR-22-27810

Outline

- Purpose and goal
- UCN source and its upgrade
- nEDM experiment overview
- North Beamline characterization
- Vacuum chamber
- Magnetically shielded room
- B0 coil
- Magnetometry
- Status and plans

LANL nEDM Collaboration

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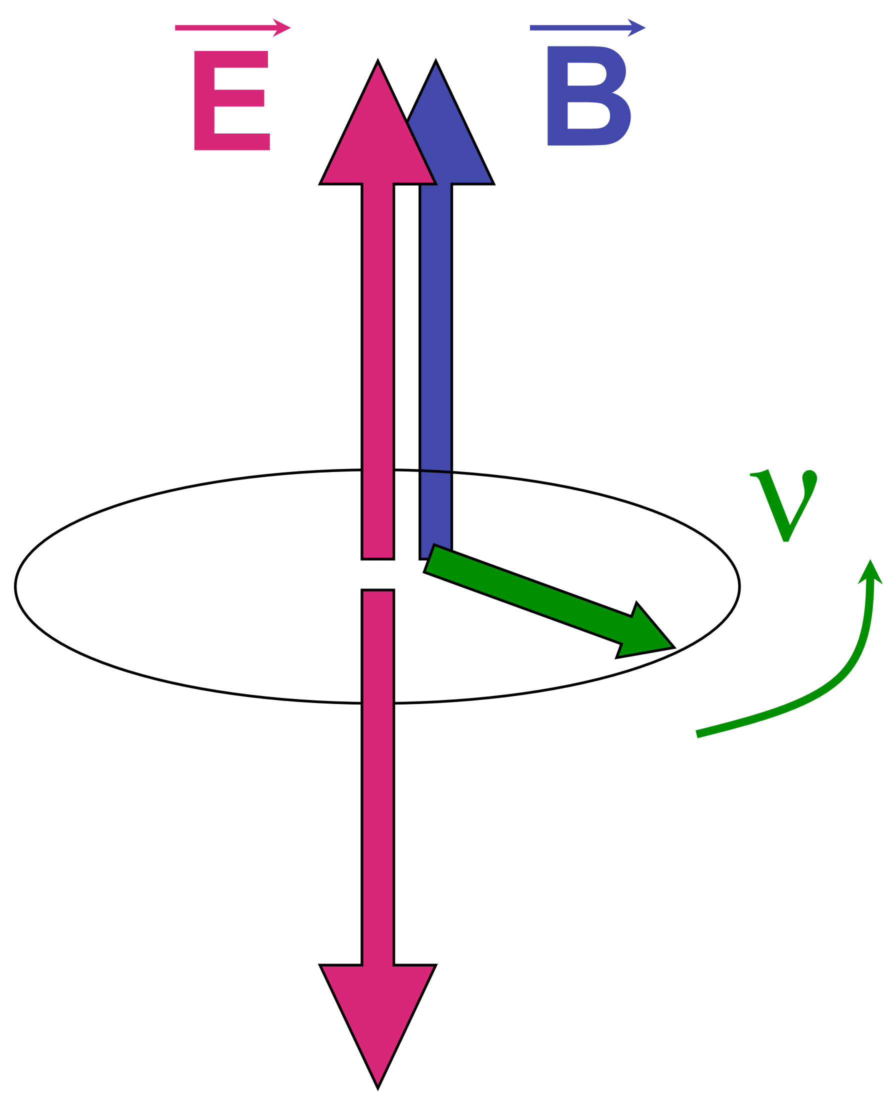
LANL nEDM: concept

- A neutron EDM experiment with an uncertainty of $\delta d_n \sim O(10^{-27})$ e-cm based on 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



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

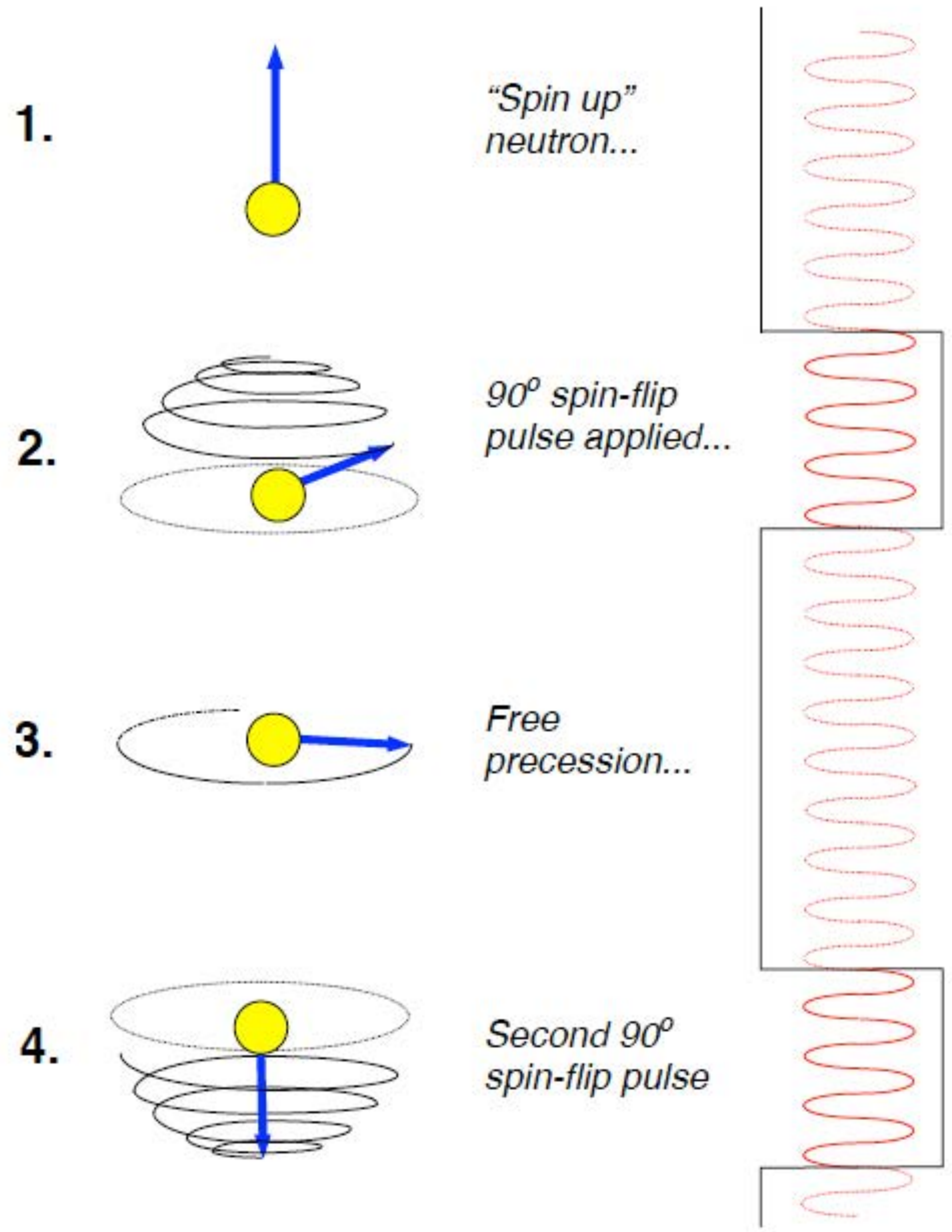
$$\Delta\nu = 4d_n E/h$$

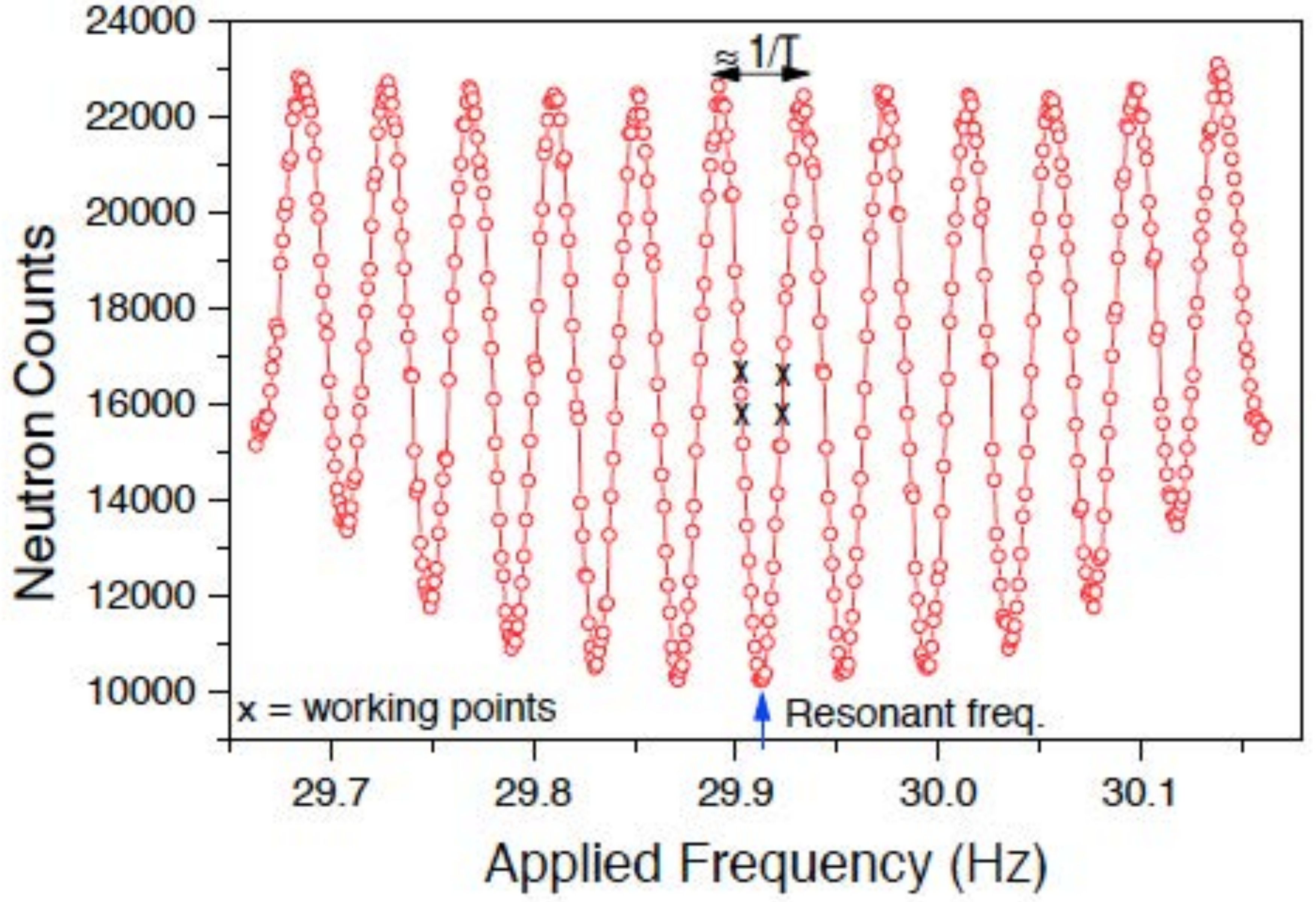
$$\delta d_n = h\frac{\delta\Delta\nu}{4E}$$

For B ~ 1 μT, ν = 30 Hz.

For E = 10 kV/cm and d_n = 3×10^{-27} e-cm, Δν=0.03 μHz.

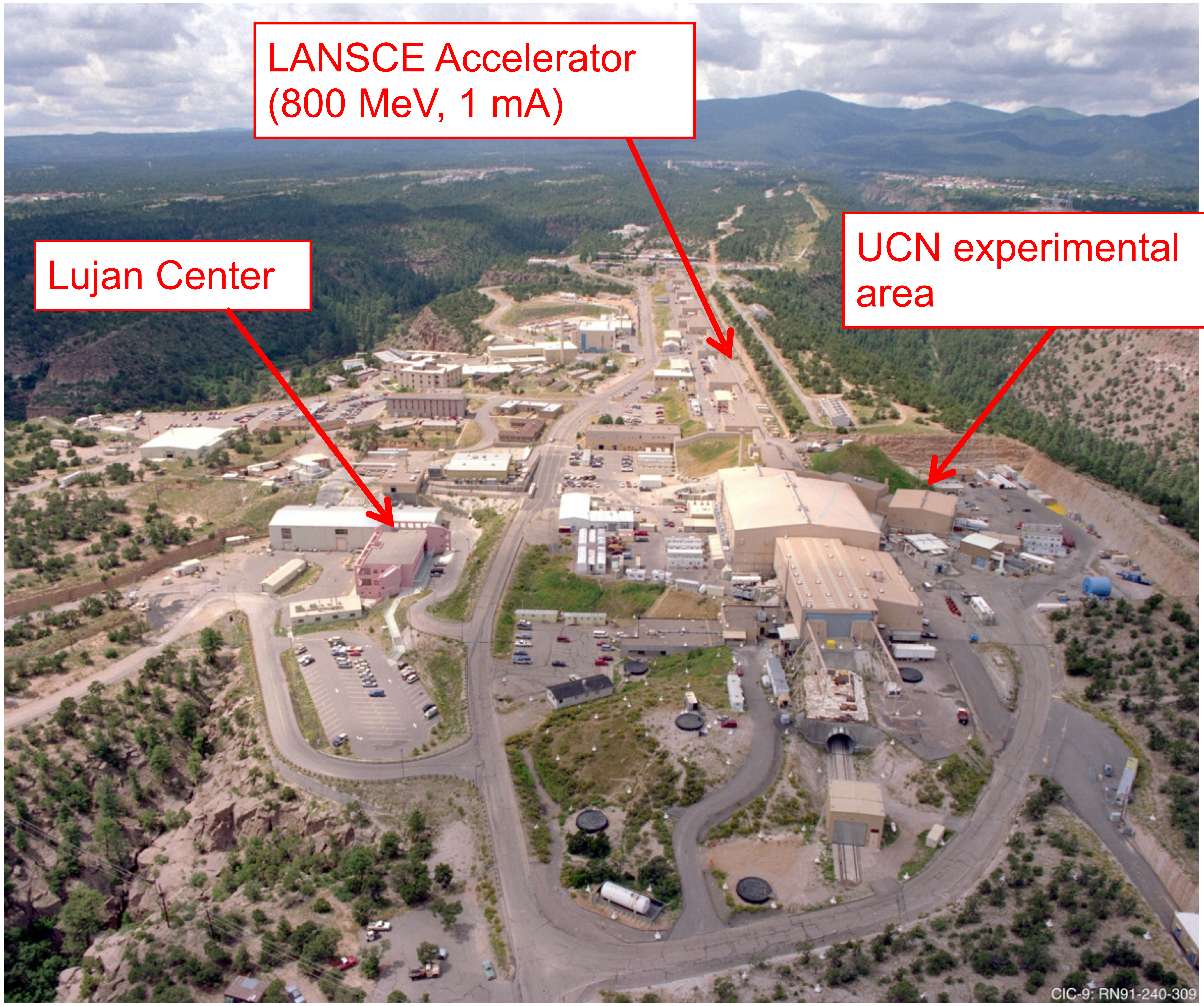
Ramsey method of separated oscillatory fields



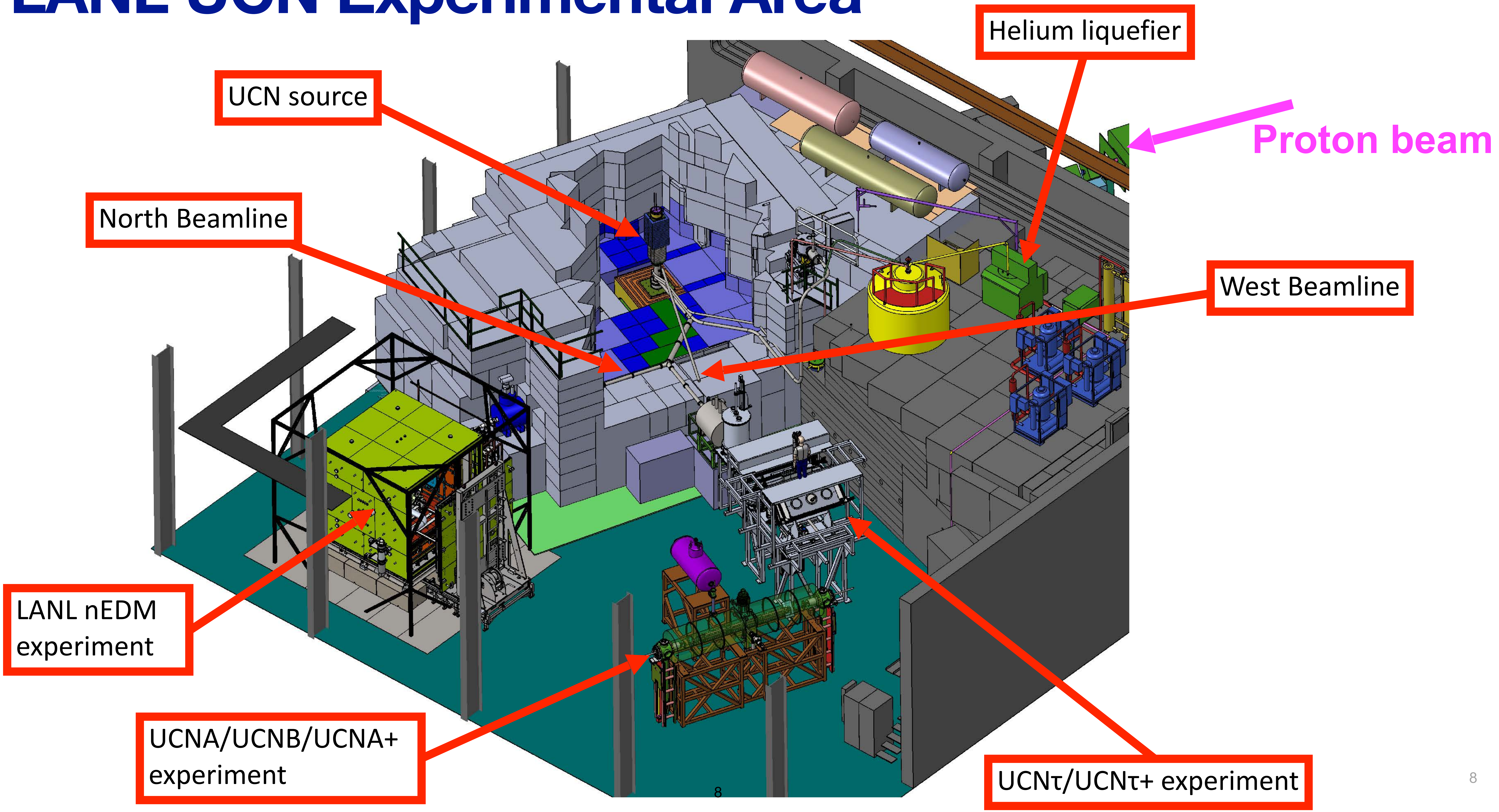


Baker et al, NIMA 736, 184 (2014) (arXiv:1305.7336)

Los Alamos Neutron Science Center (LANSCE)



LANL UCN Experimental Area



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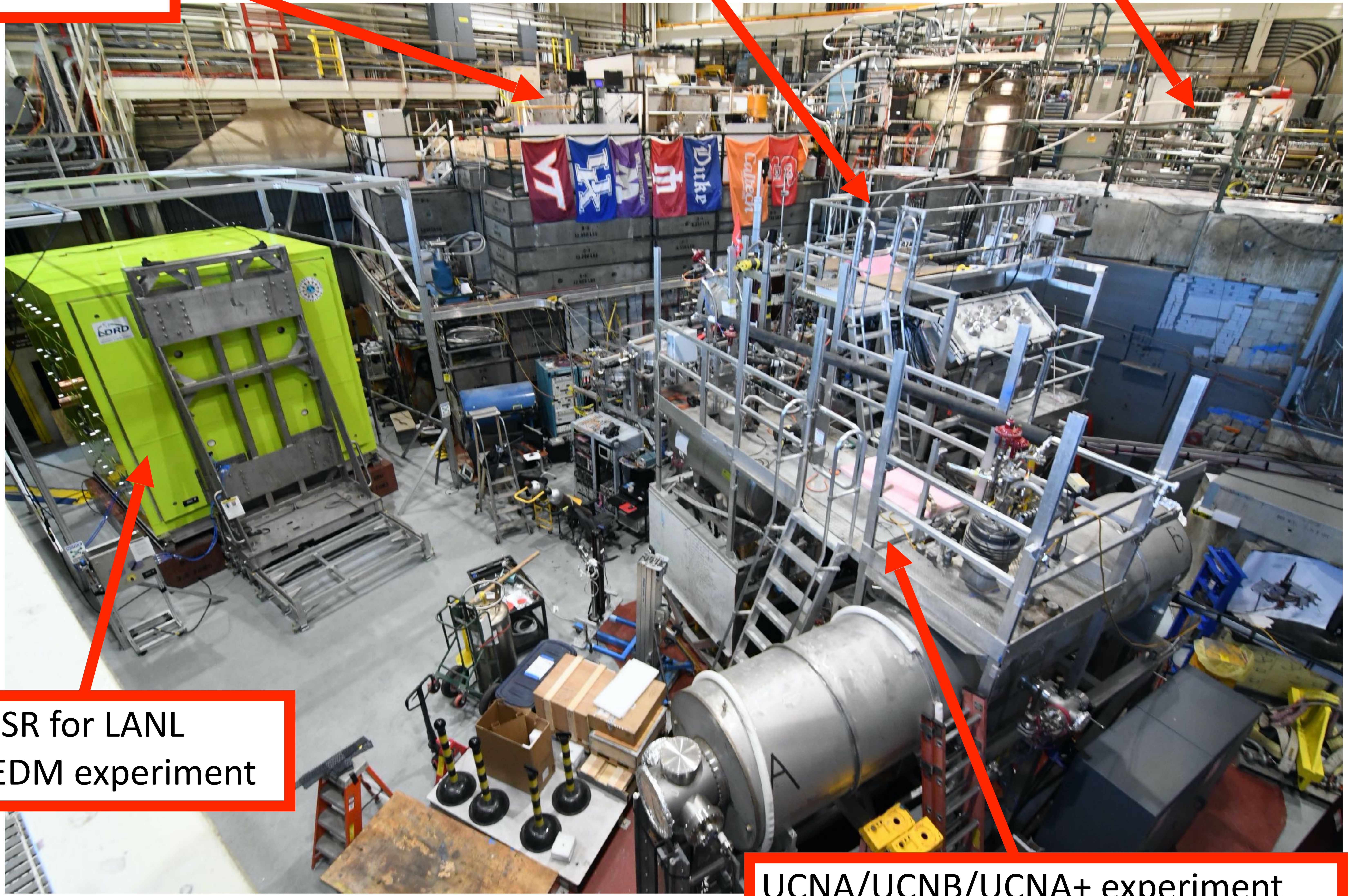
LANL UCN Experimental Area



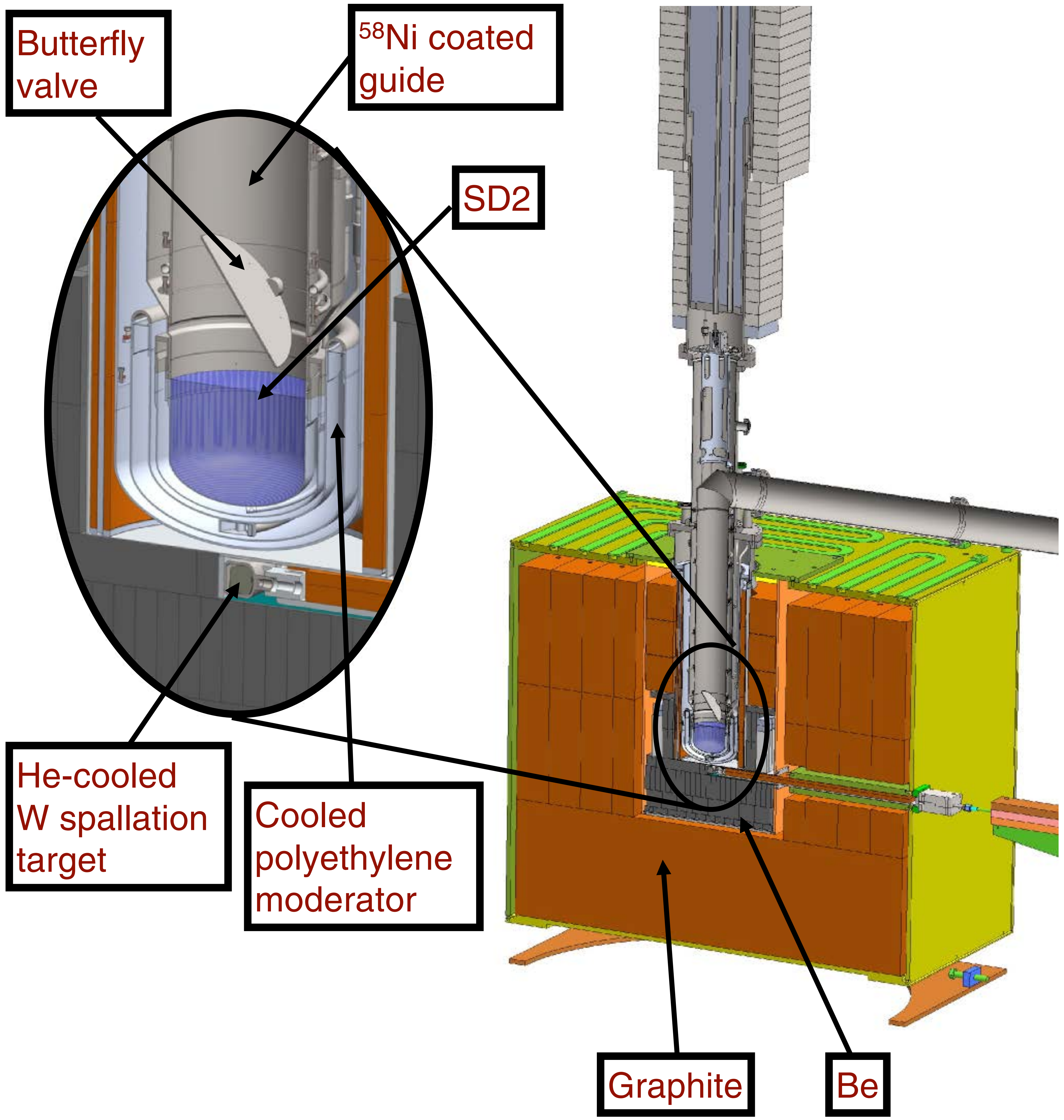
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

U.S. DEPARTMENT OF ENERGY Office of Science

NSF

THE GLENN T. SEABORG INSTITUTE

LANL UCN source



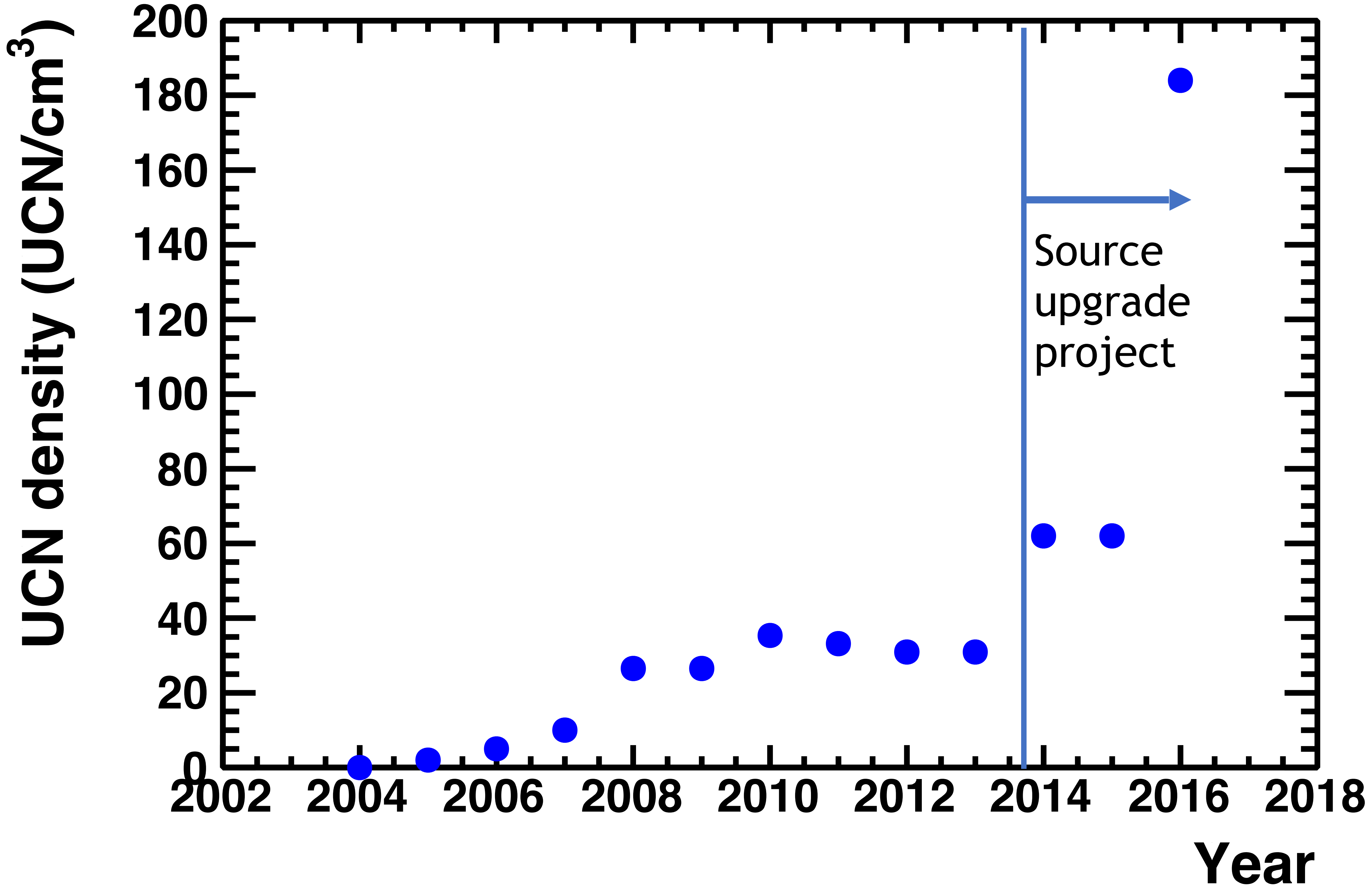
Spallation neutrons from W target
K.E. ~ 2 MeV

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

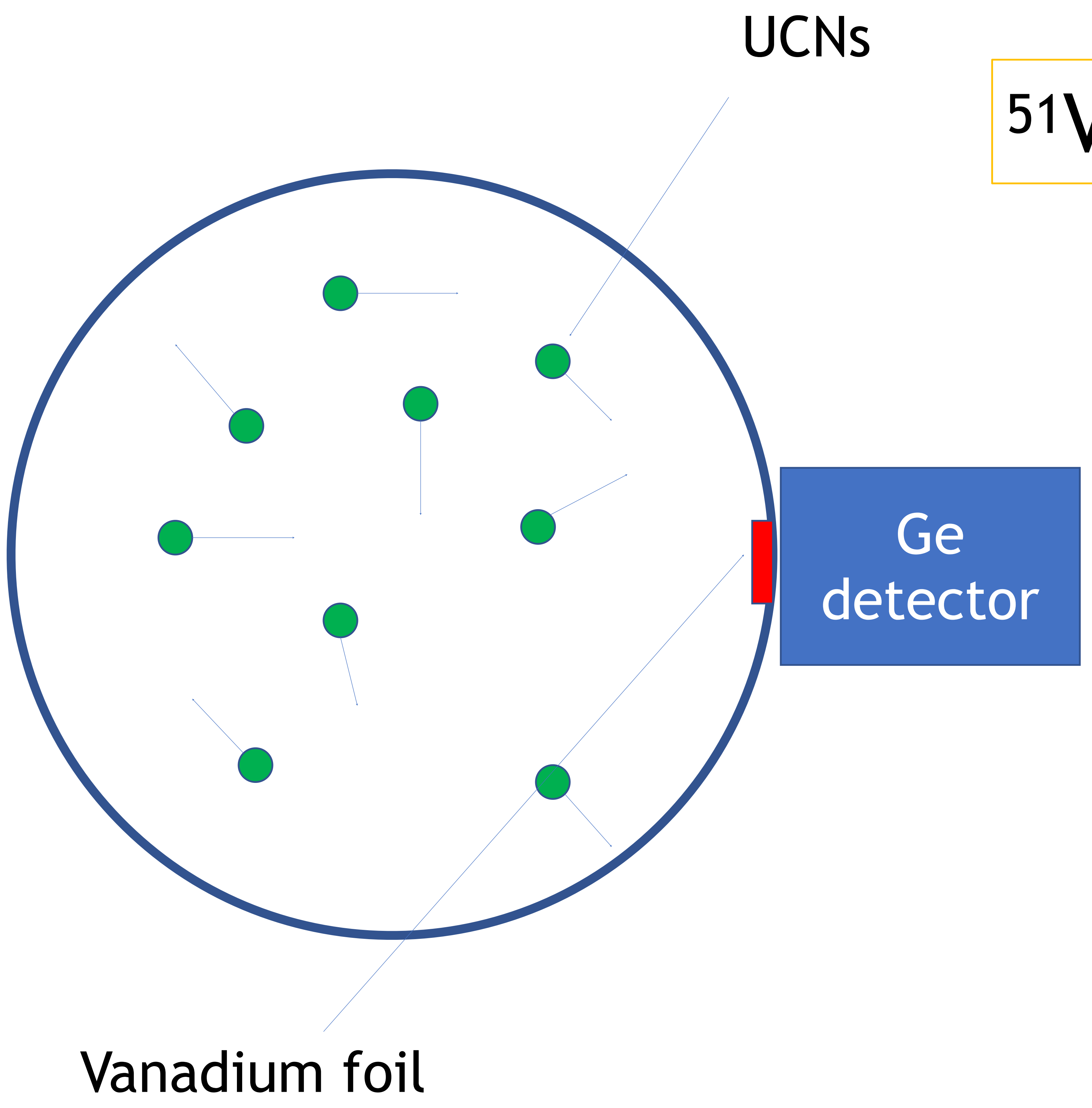


An upgrade of the UCN source (FY14-17) more than quadrupled the UCN output by:

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

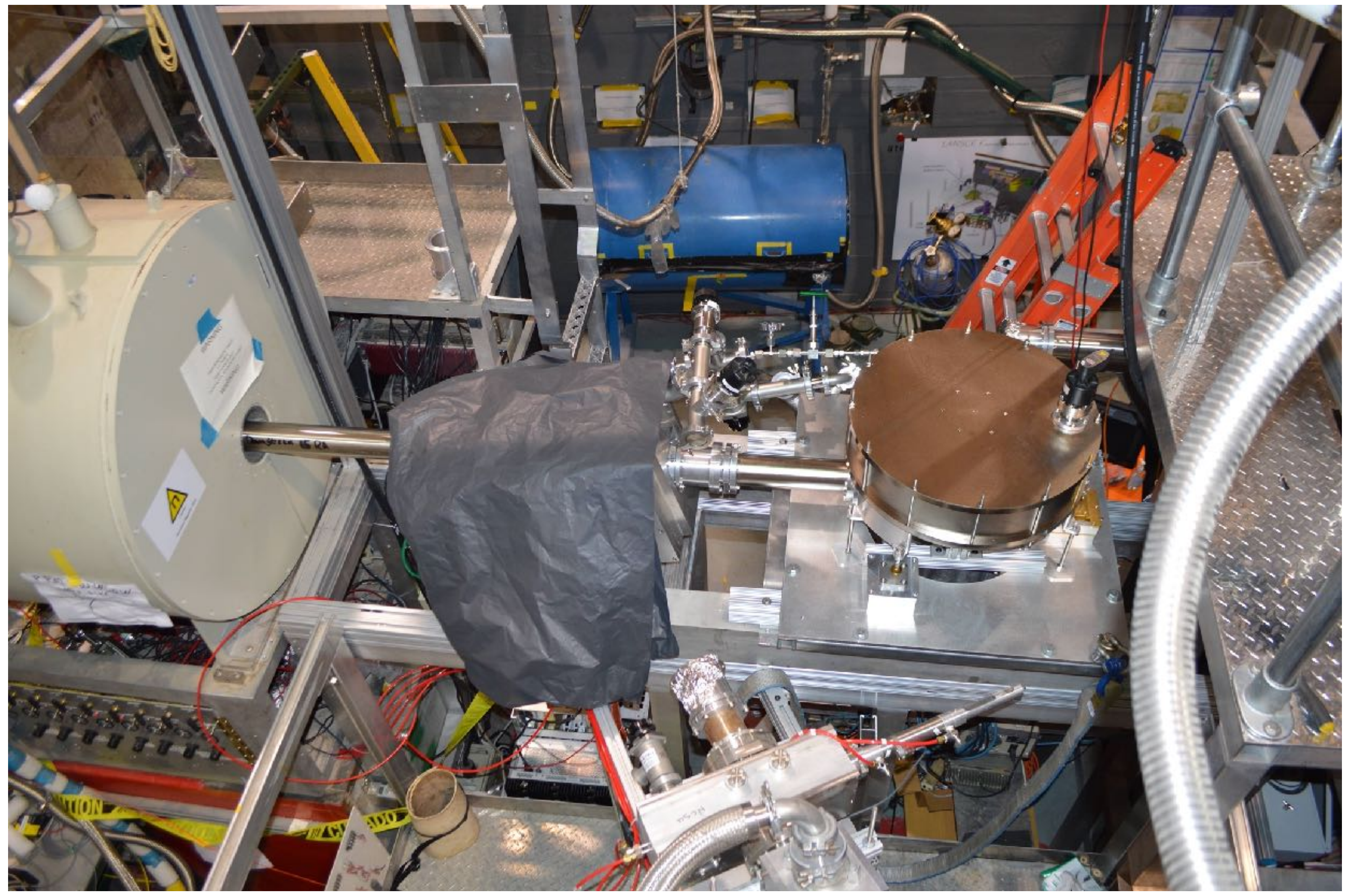


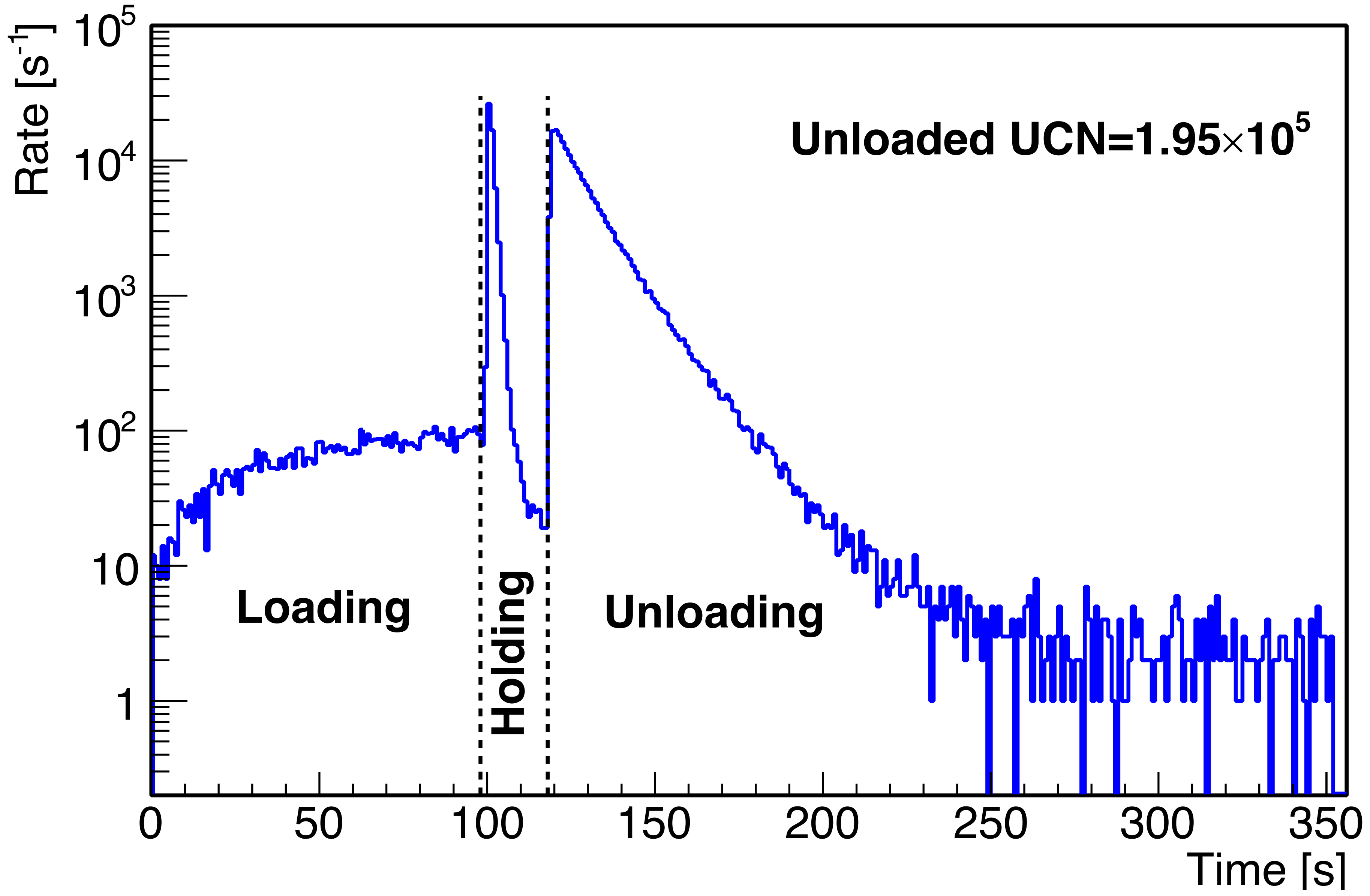
$^{51}V + n \rightarrow {}^{52}V \rightarrow {}^{52}Cr + \beta + \gamma\ (1.4\ \text{MeV})$

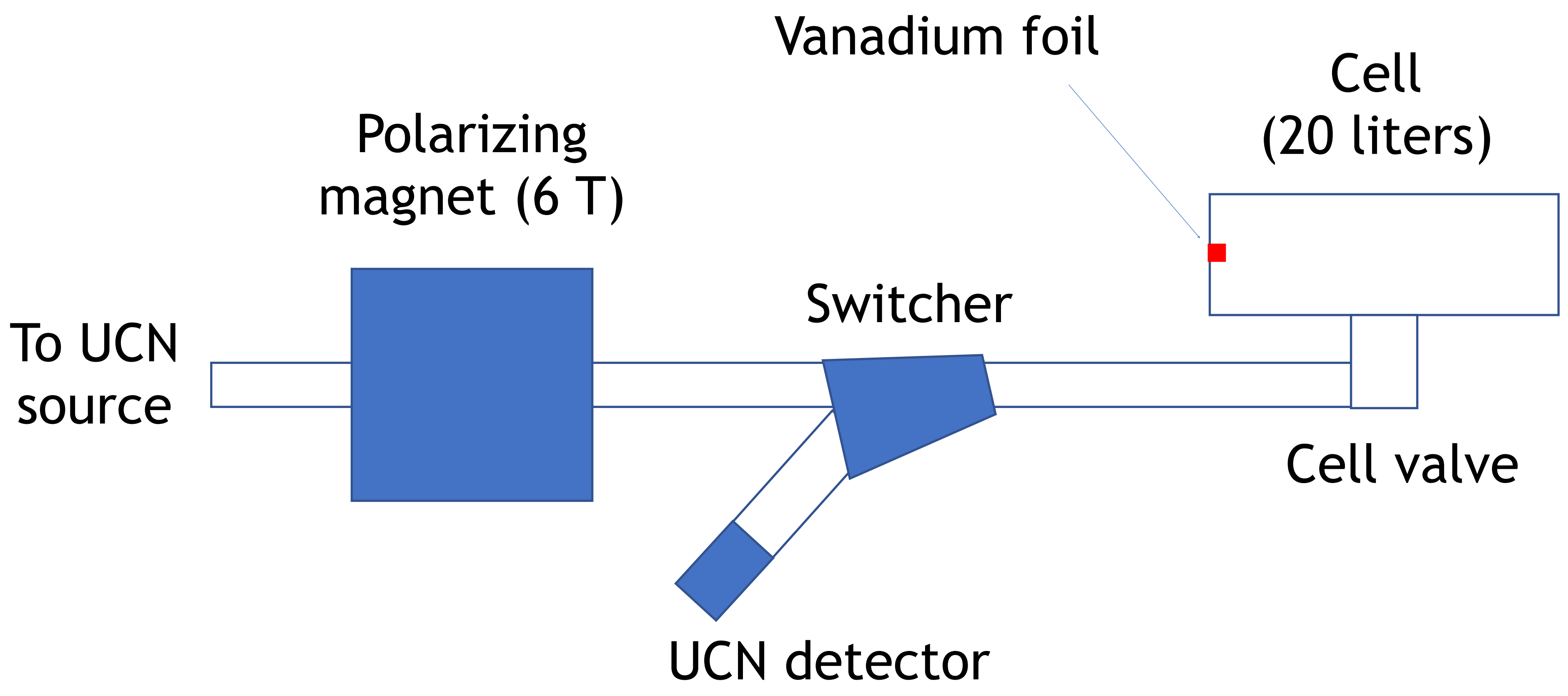
- Detecting the 1.4 MeV gammas with a Ge detector determines the UCN capture rate by the vanadium foil.
- The Ge detector can be calibrated (for the efficiency and solid angle product) by placing a calibrated ^{60}Co source at the location of the vanadium foil.
- UCN density can be determined from:

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

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

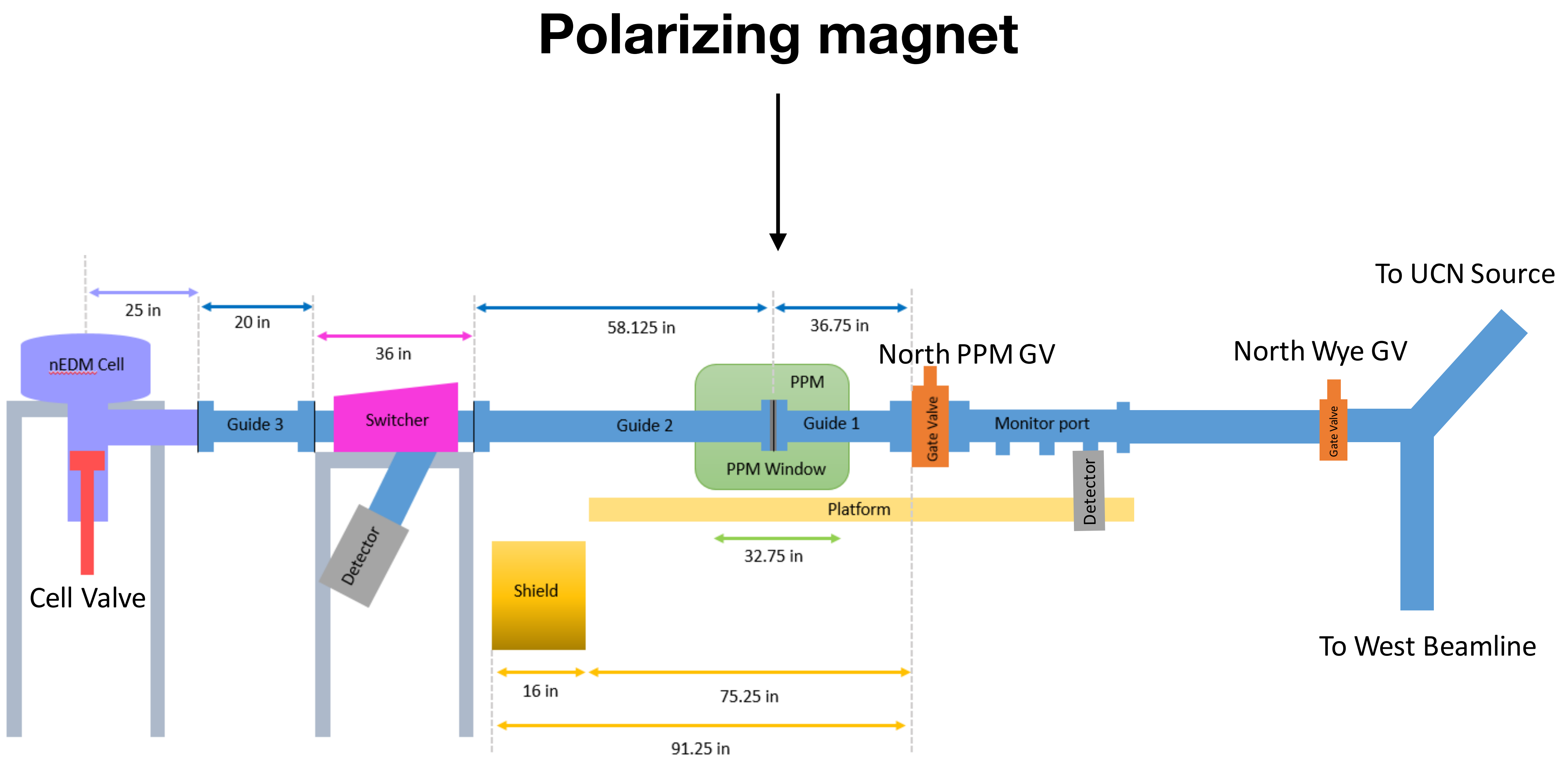
$$\delta d_n = \frac{\hbar}{2\alpha E T_{free}\sqrt{N}}$$

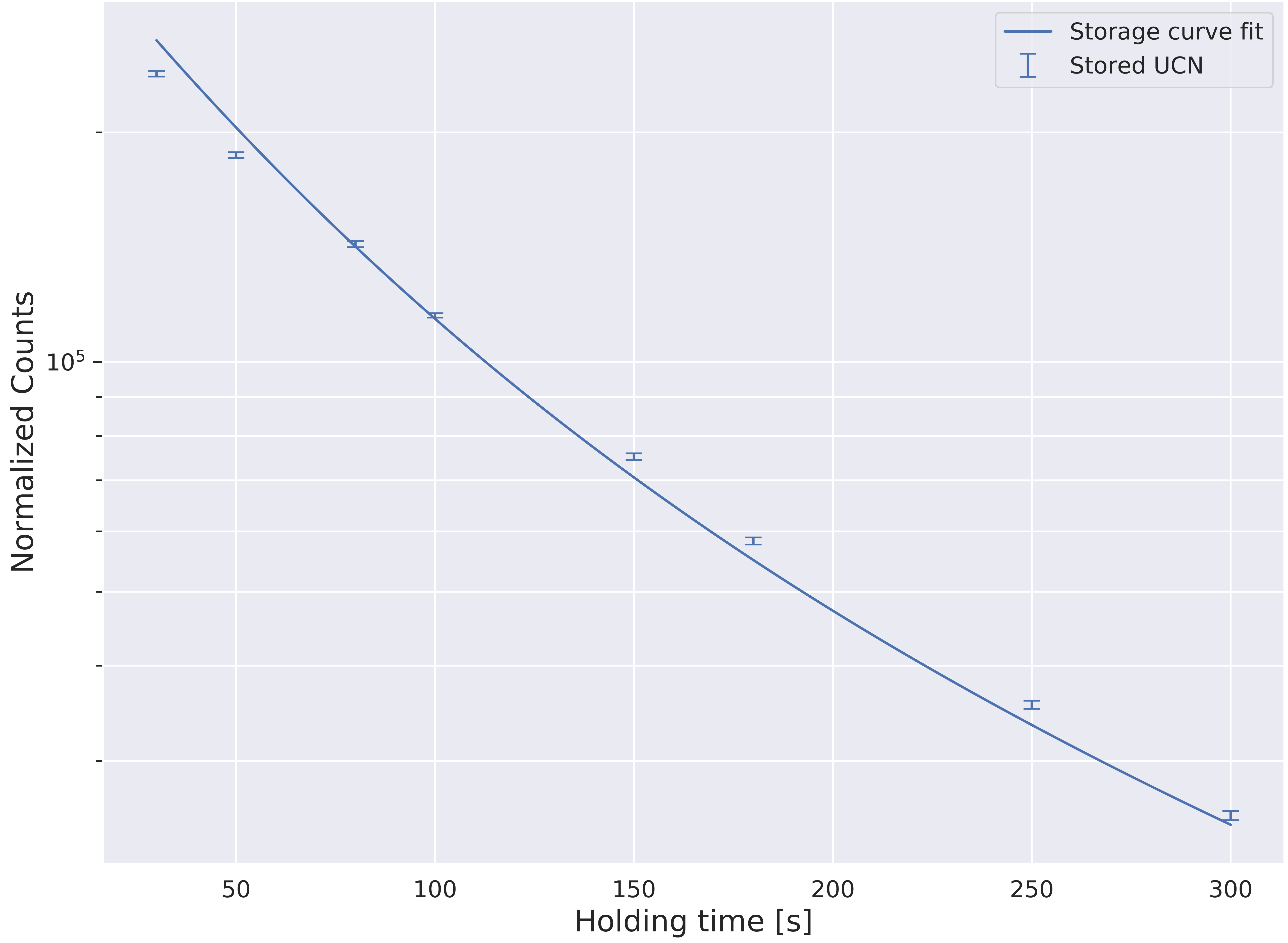
This estimate is based on the following:

- 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 on the North beam line

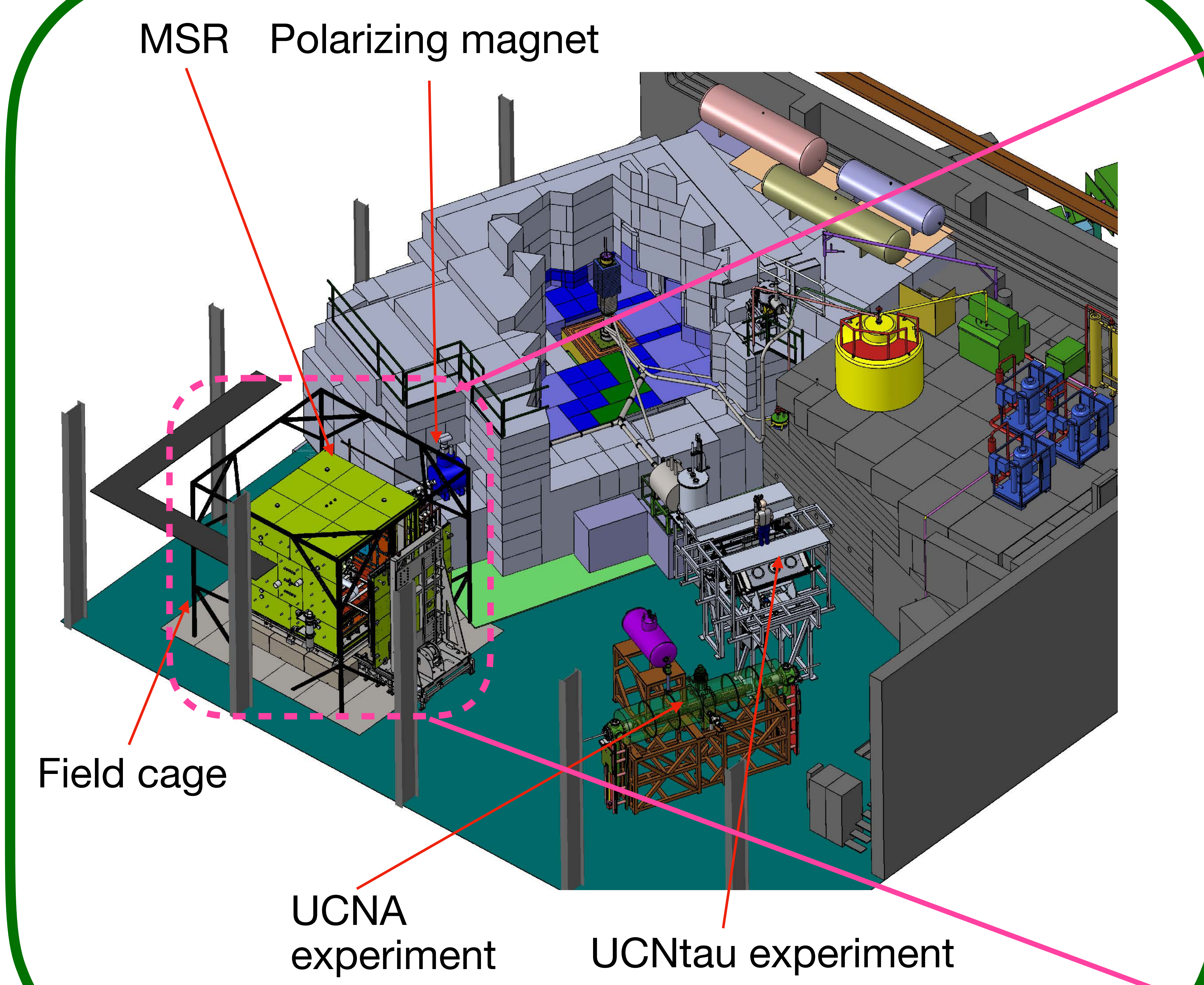




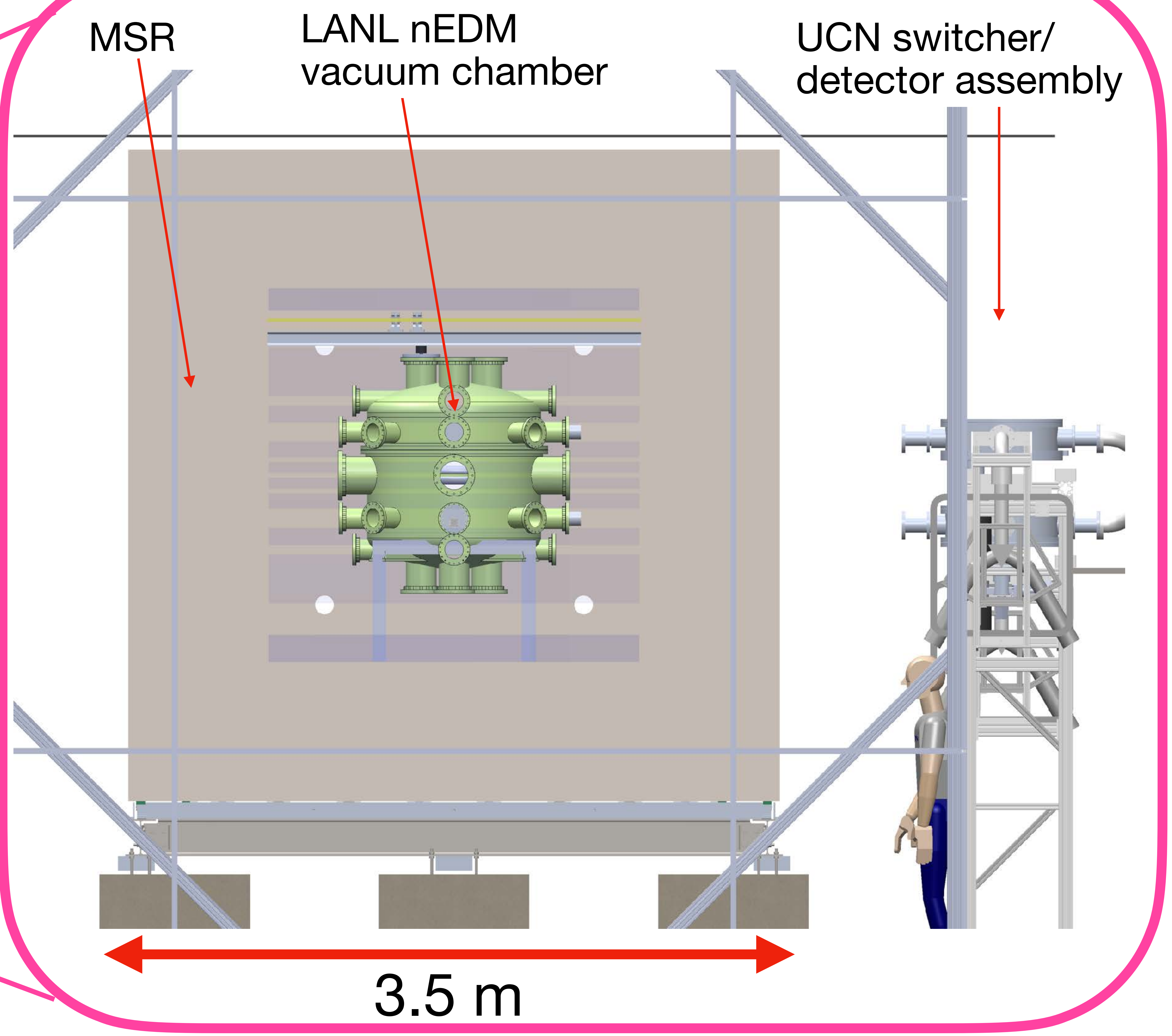
Measurement corresponds to ~60,000 detected UCN @ 2000 Hz GV rate after 180 s when a dPS coated cell wall was used with the new switcher

Apparatus overview

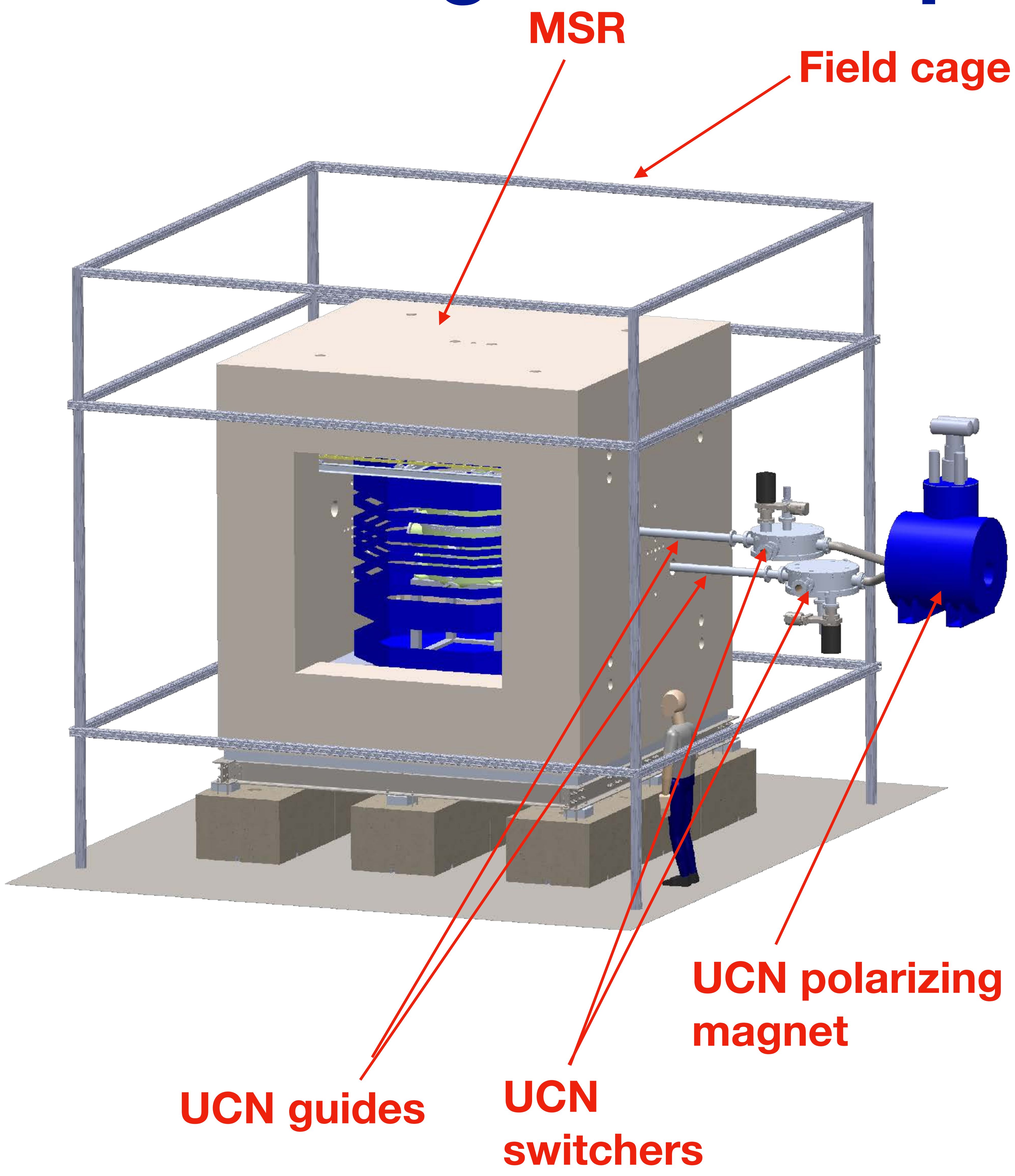
TA-53 Area B (UCN Experimental Hall)



LANL nEDM experiment



Overall design of the experiment



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: $\delta d_n \sim 3\times10^{-27}$ e-cm in one live year

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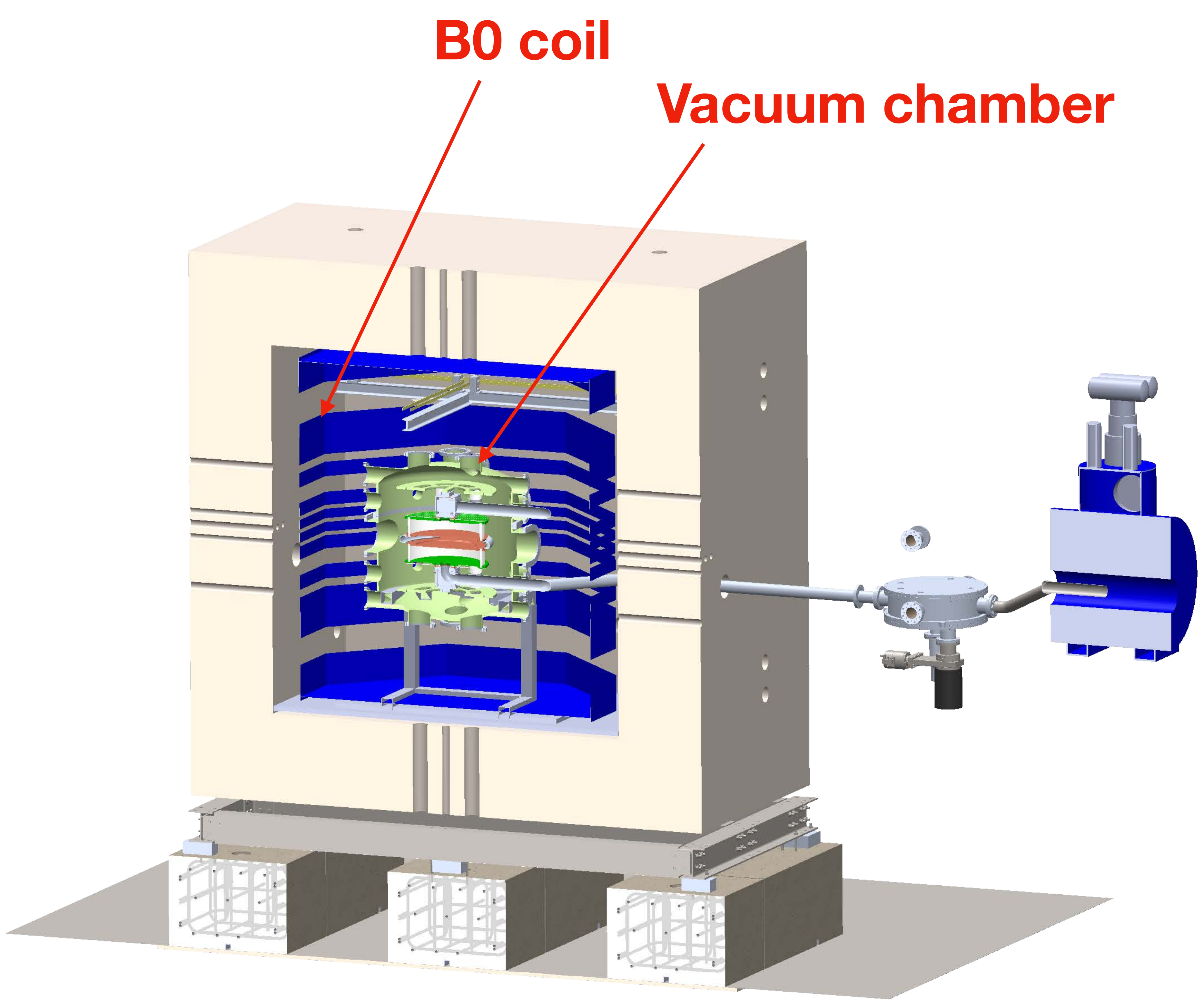

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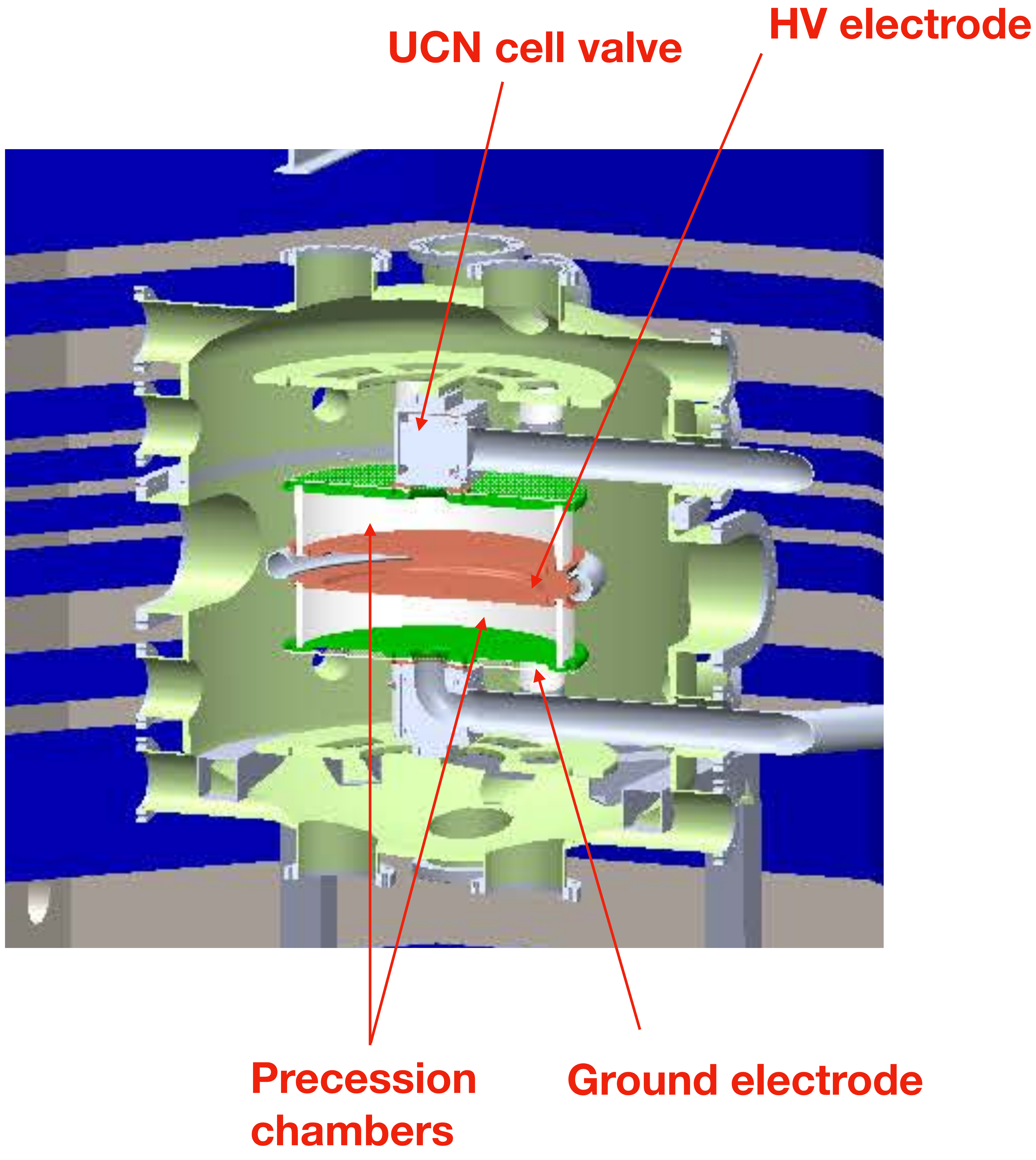

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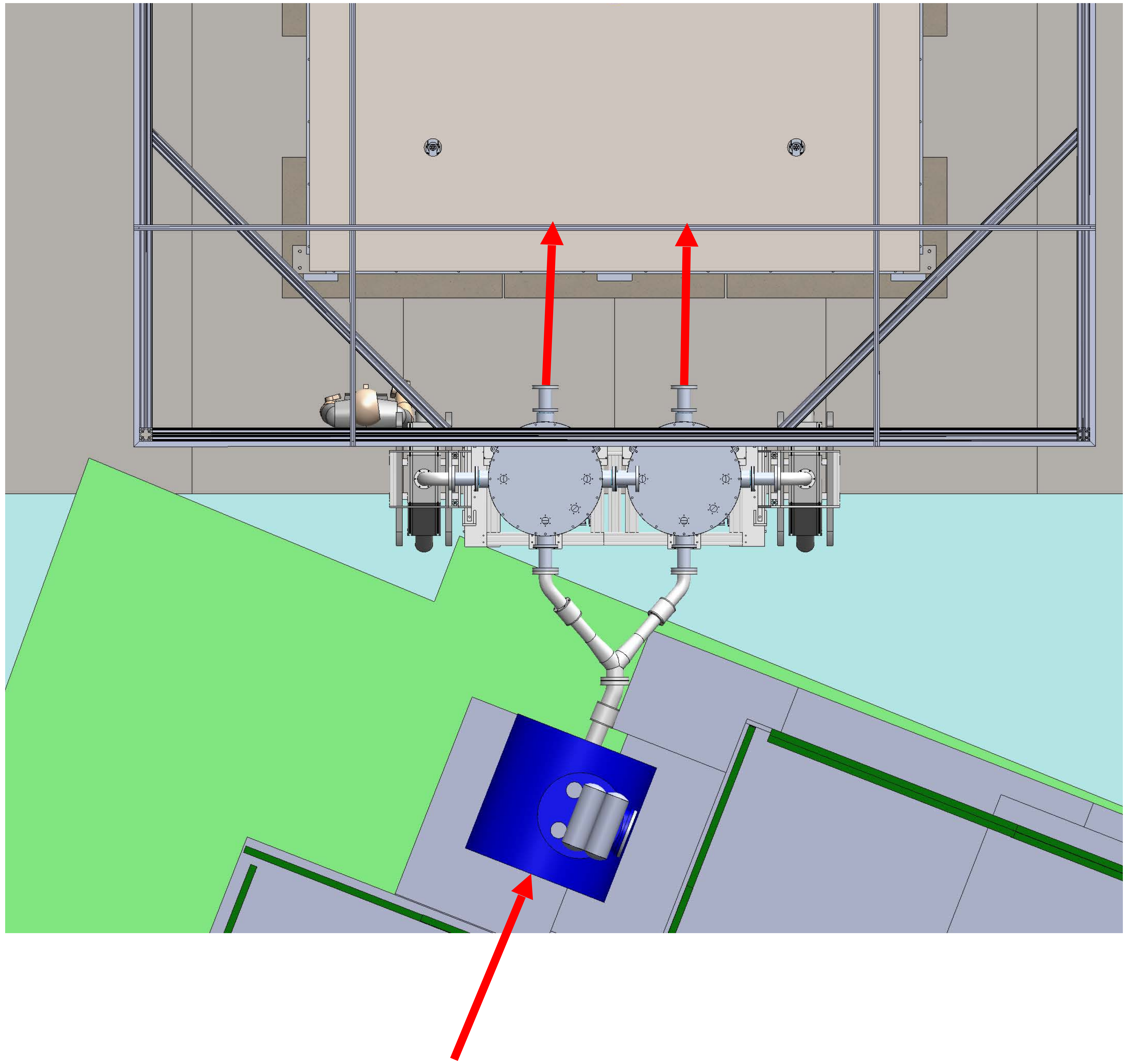
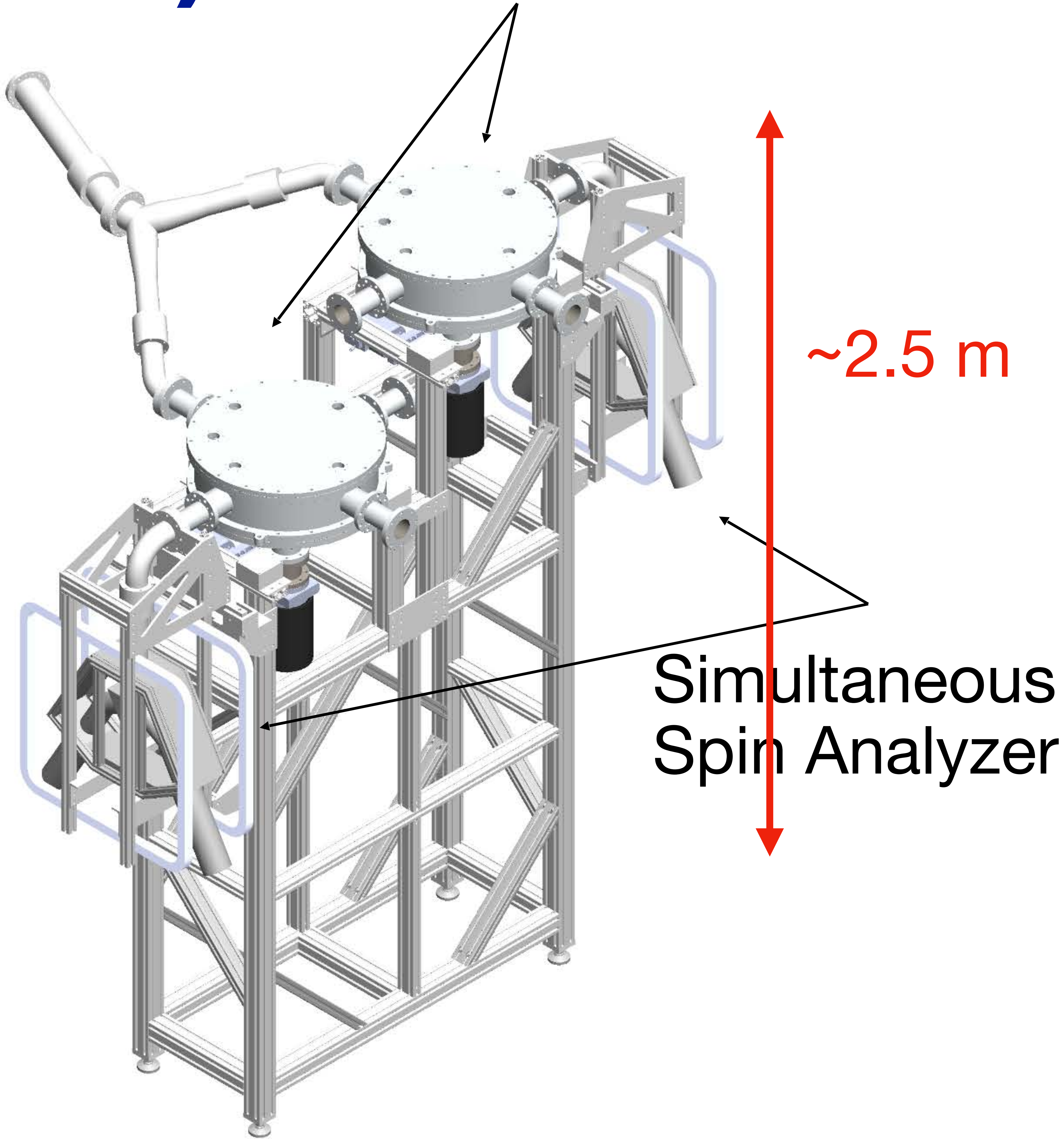
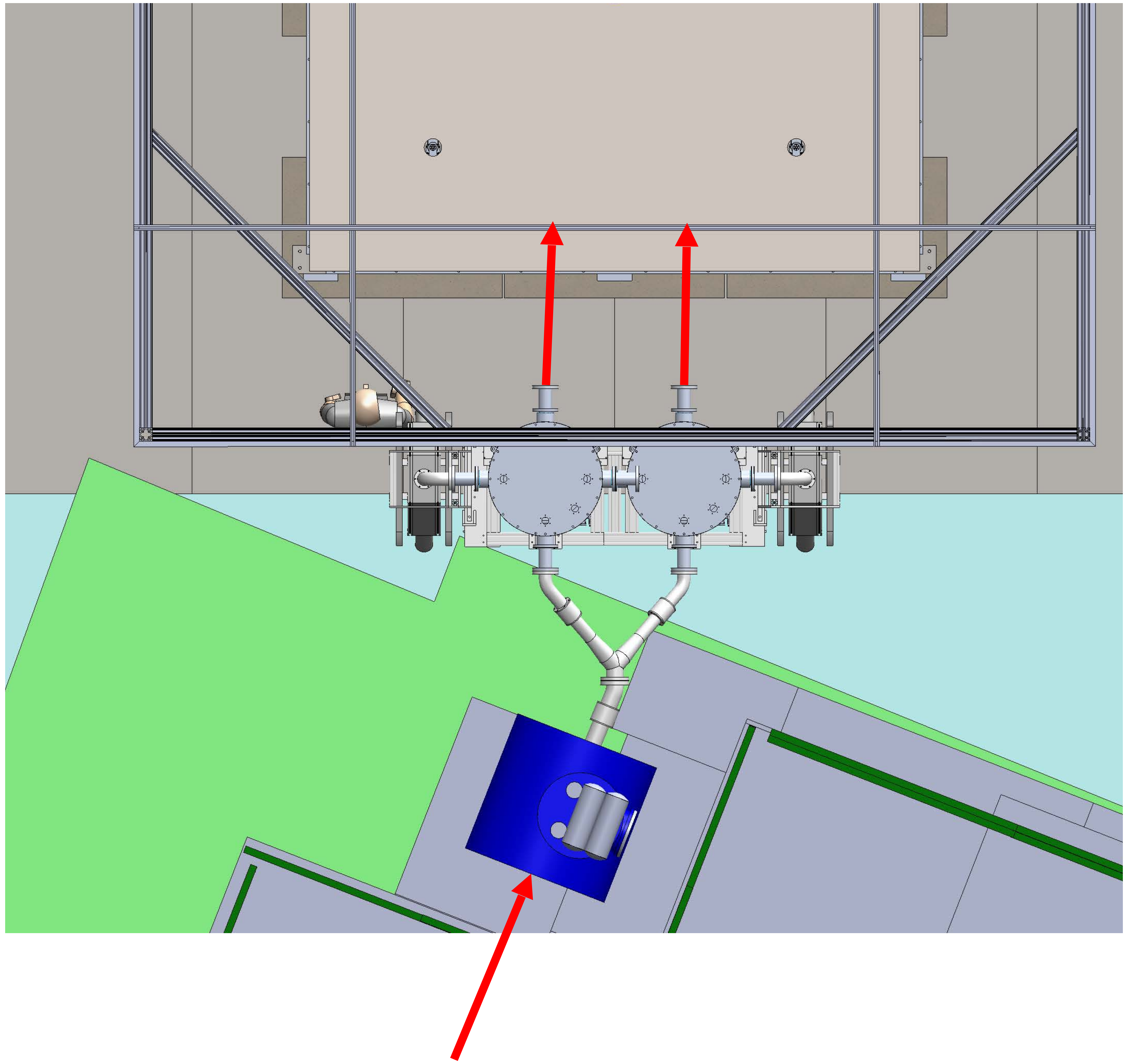
UCN transport (LANL, Indiana)



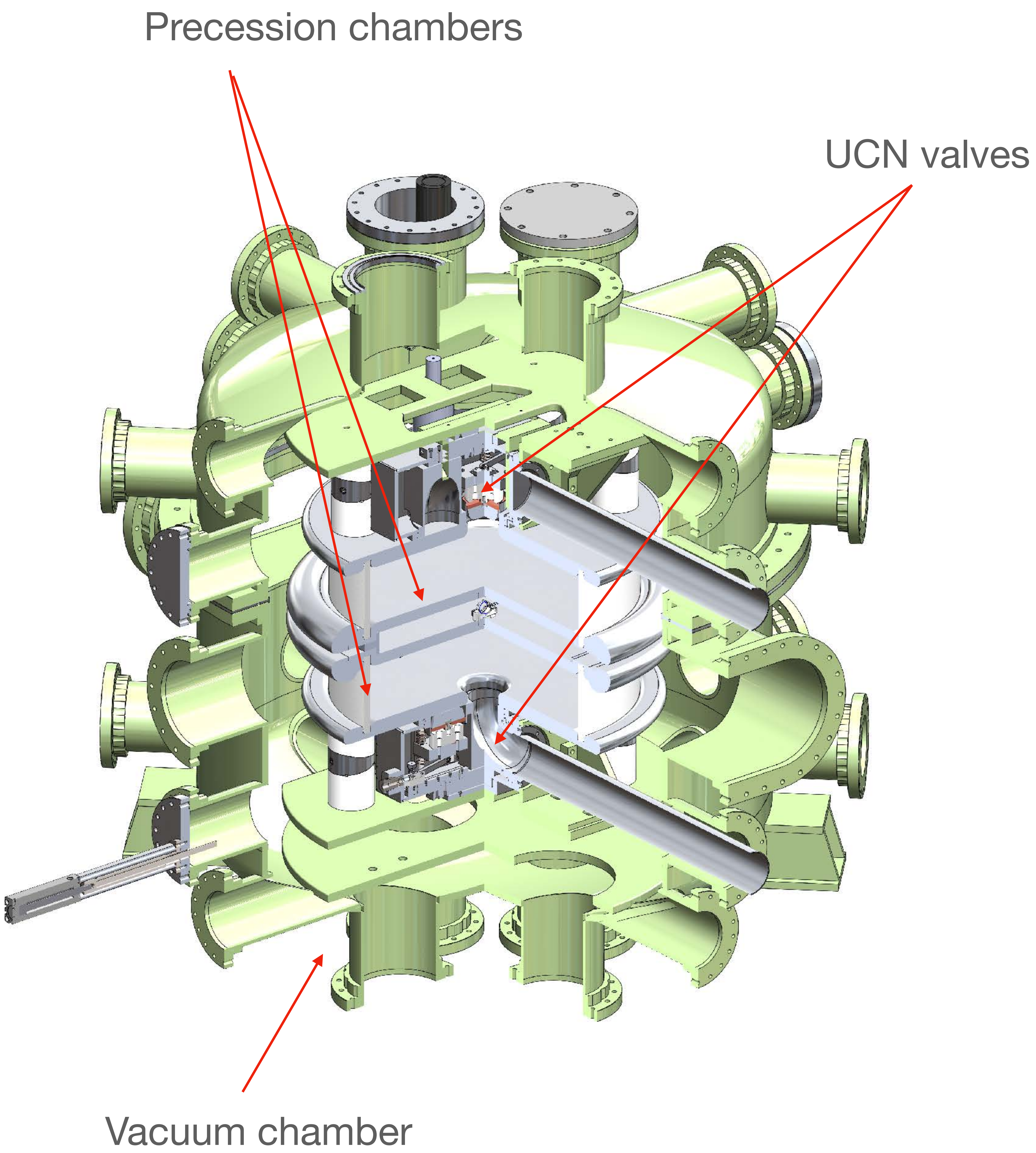


UCN transport



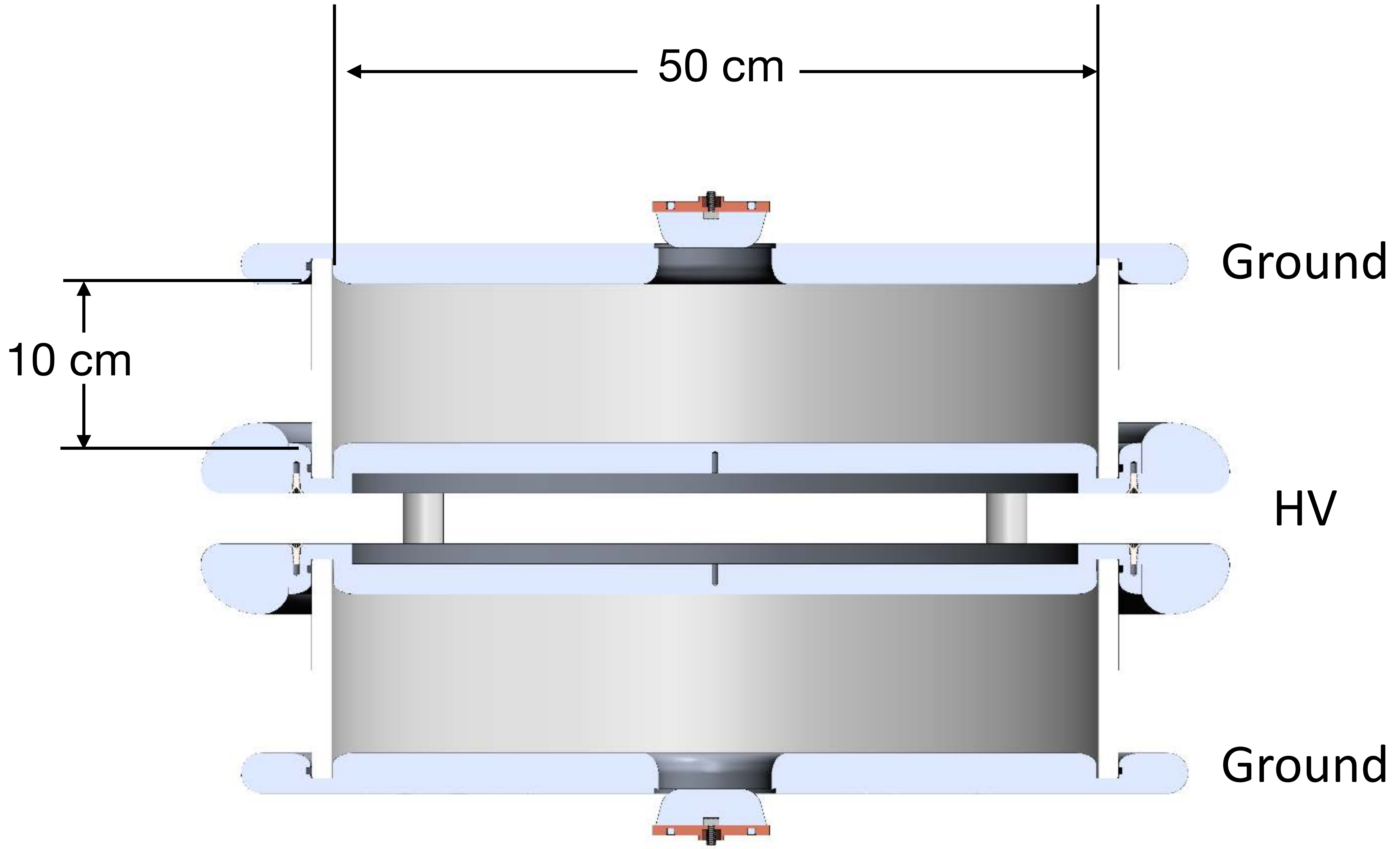
Switchers being installed

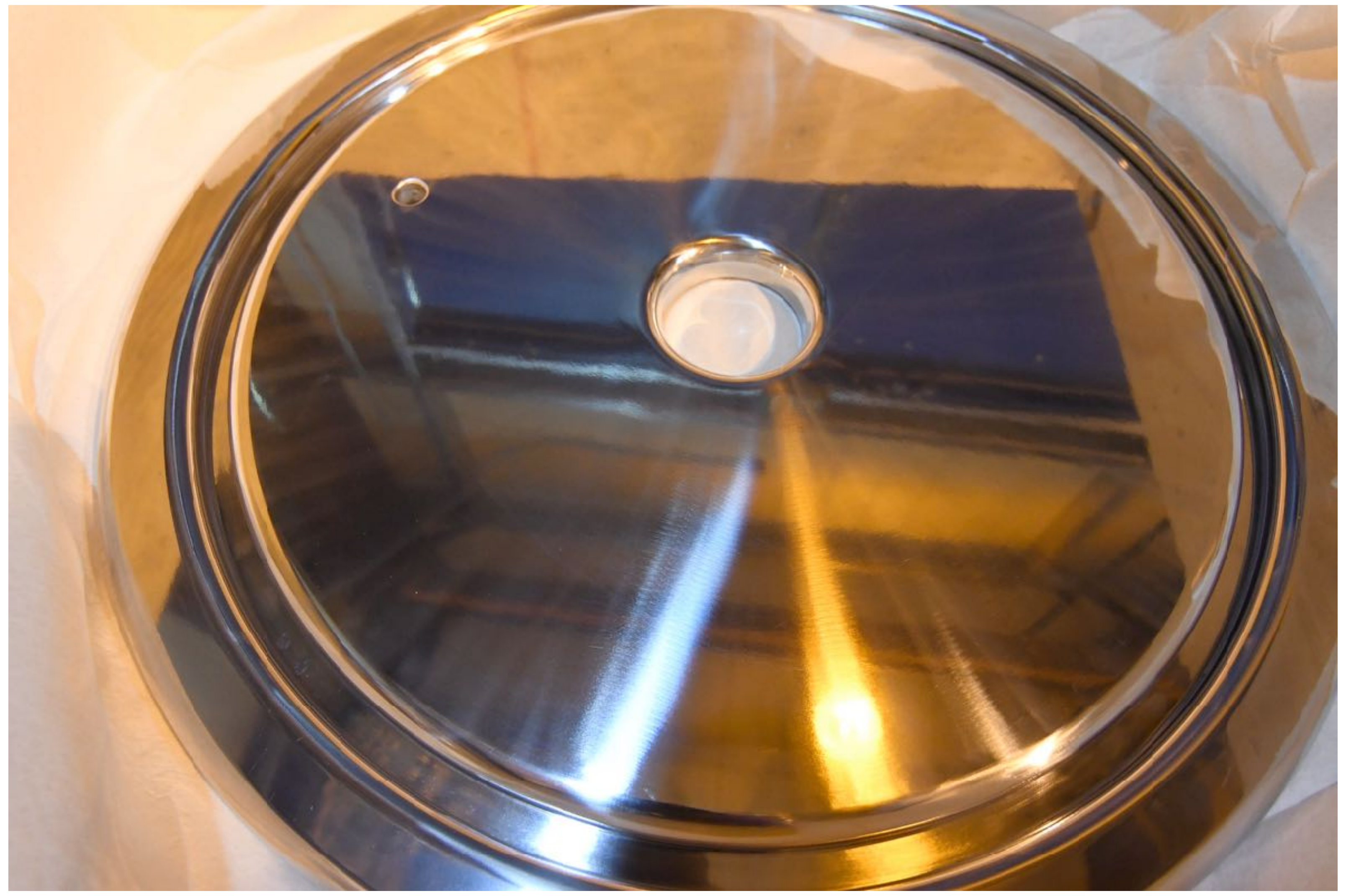
Vacuum chamber and internal design



Non-magnetic vacuum chamber

Electrodes and precession chamber



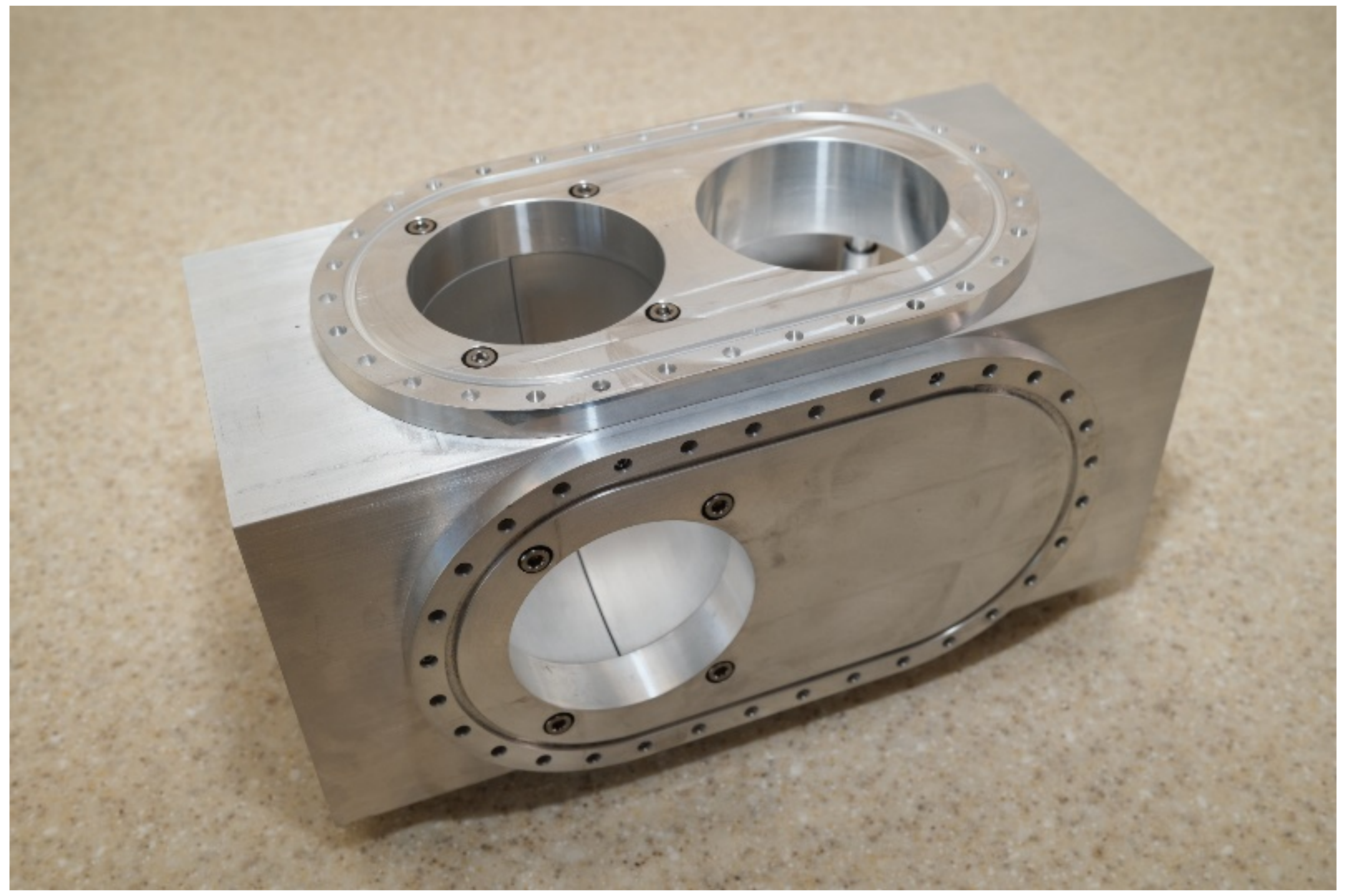


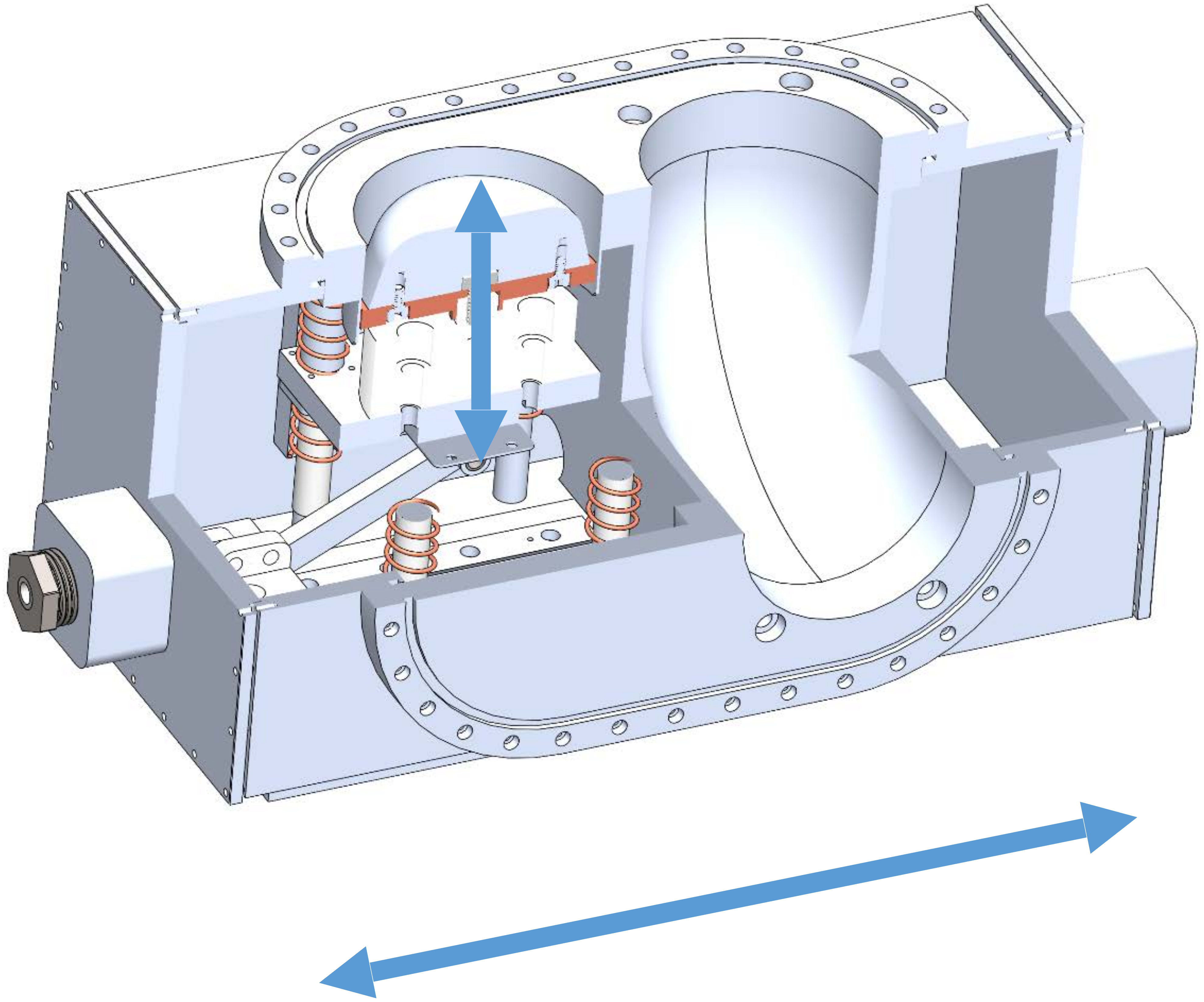
Ground electrode

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

UCN valves

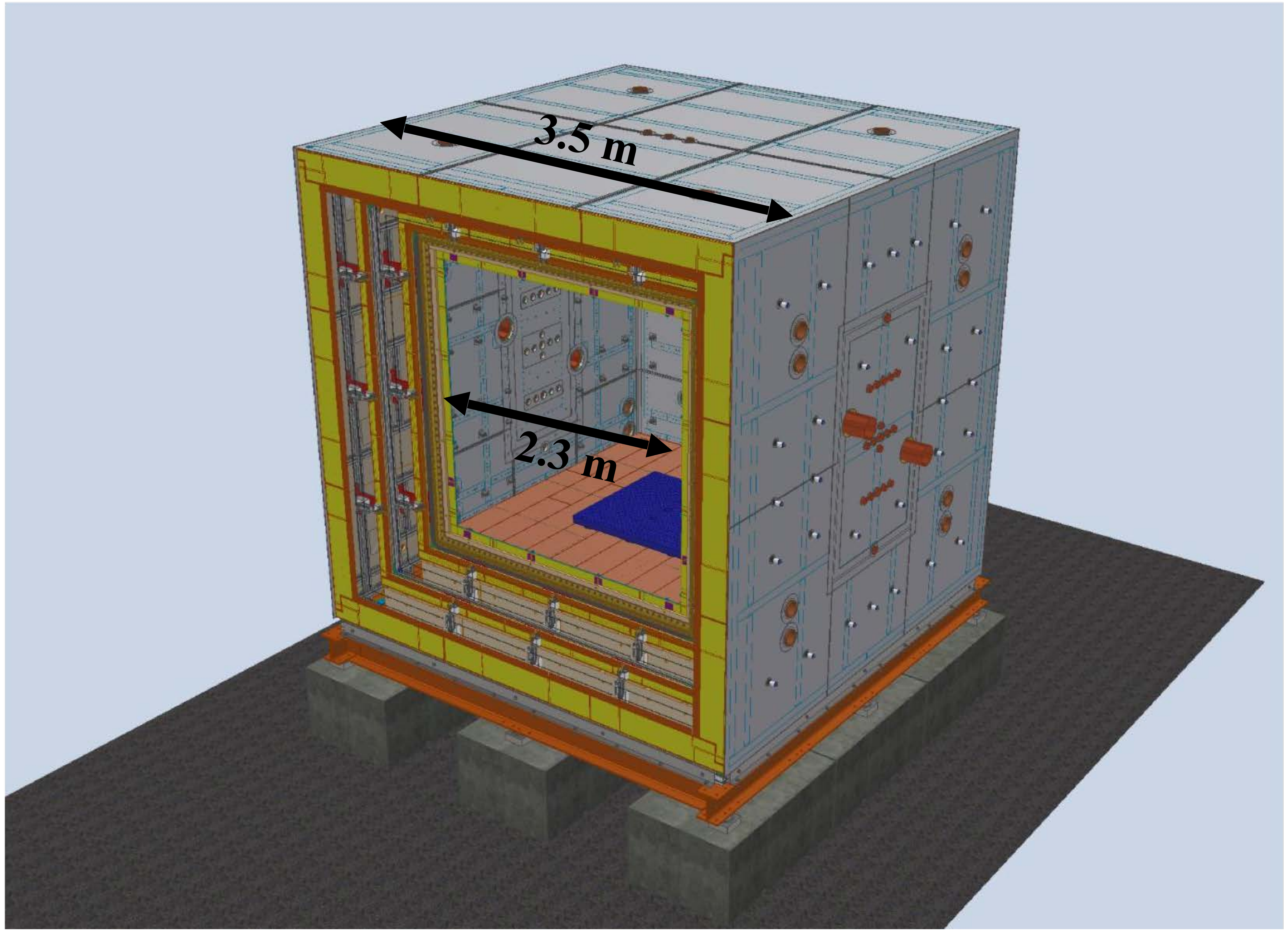
- Valve box similar to a gate valve
- Slides between transport section and valve plug
- Valve plug closes on a linkage
- Components have been fabricated and test fit





Magnetically shielded room (LANL, Indiana U.)

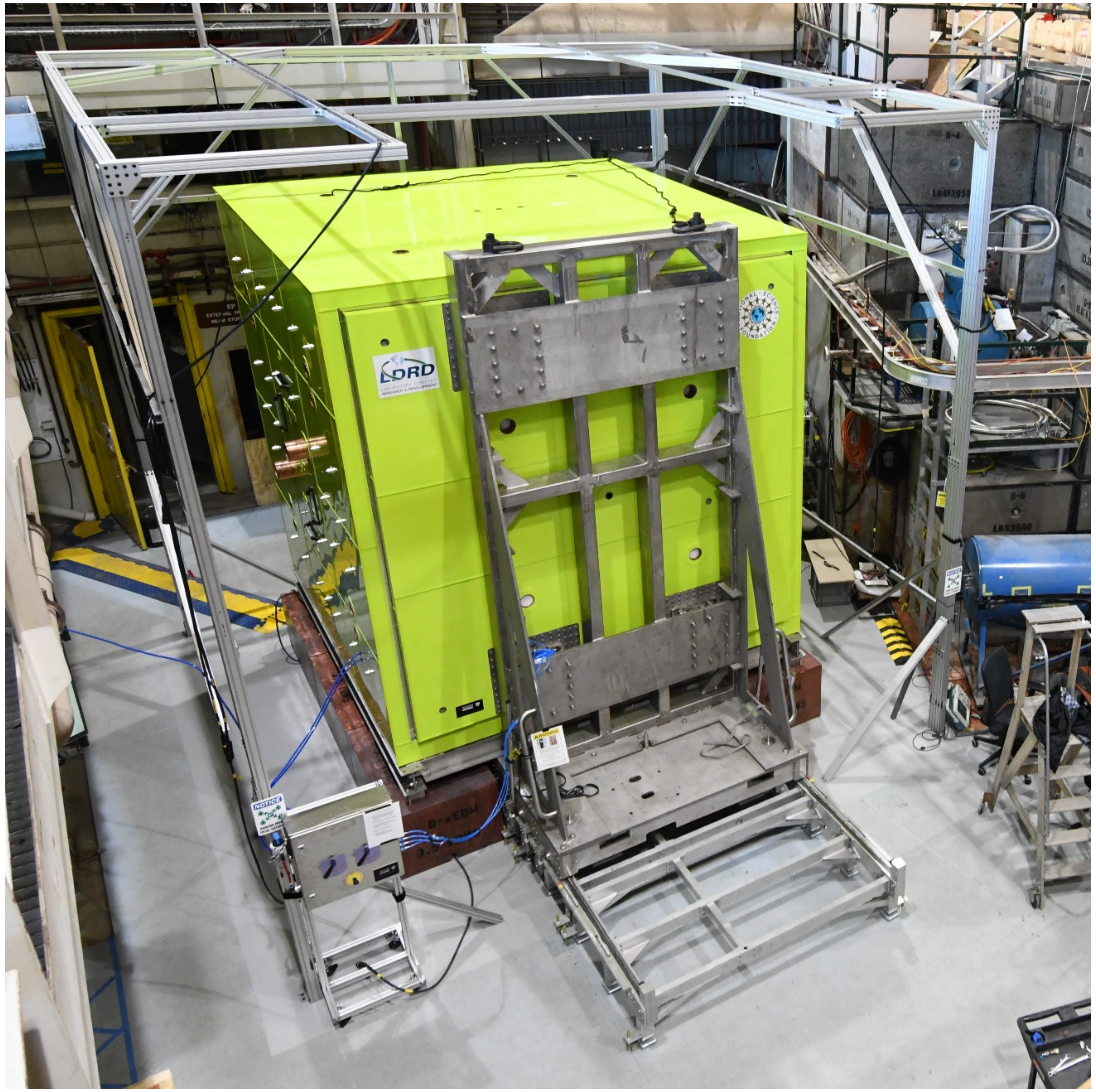
4 μ-metal + 1 Cu layers



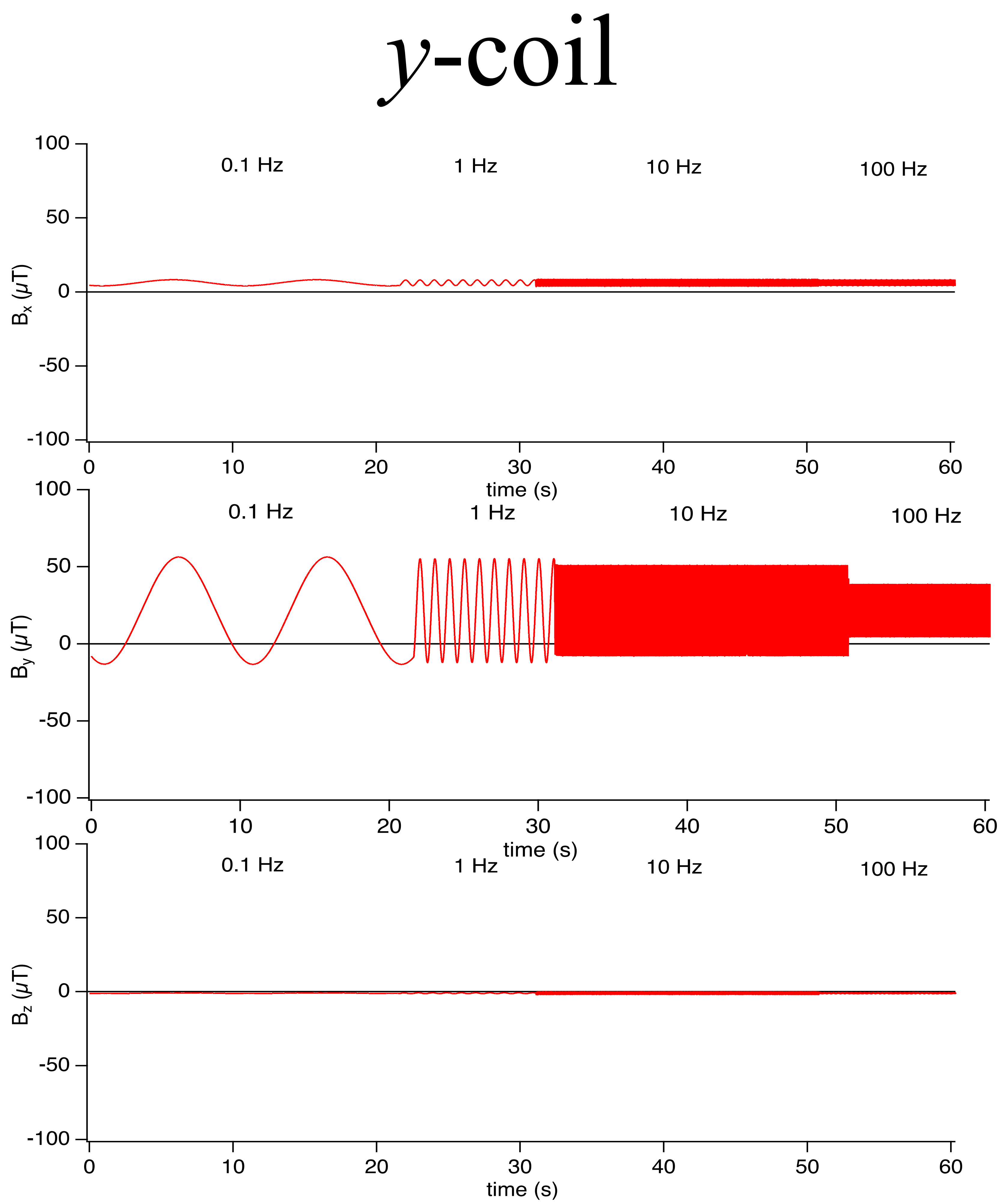
Design performance

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

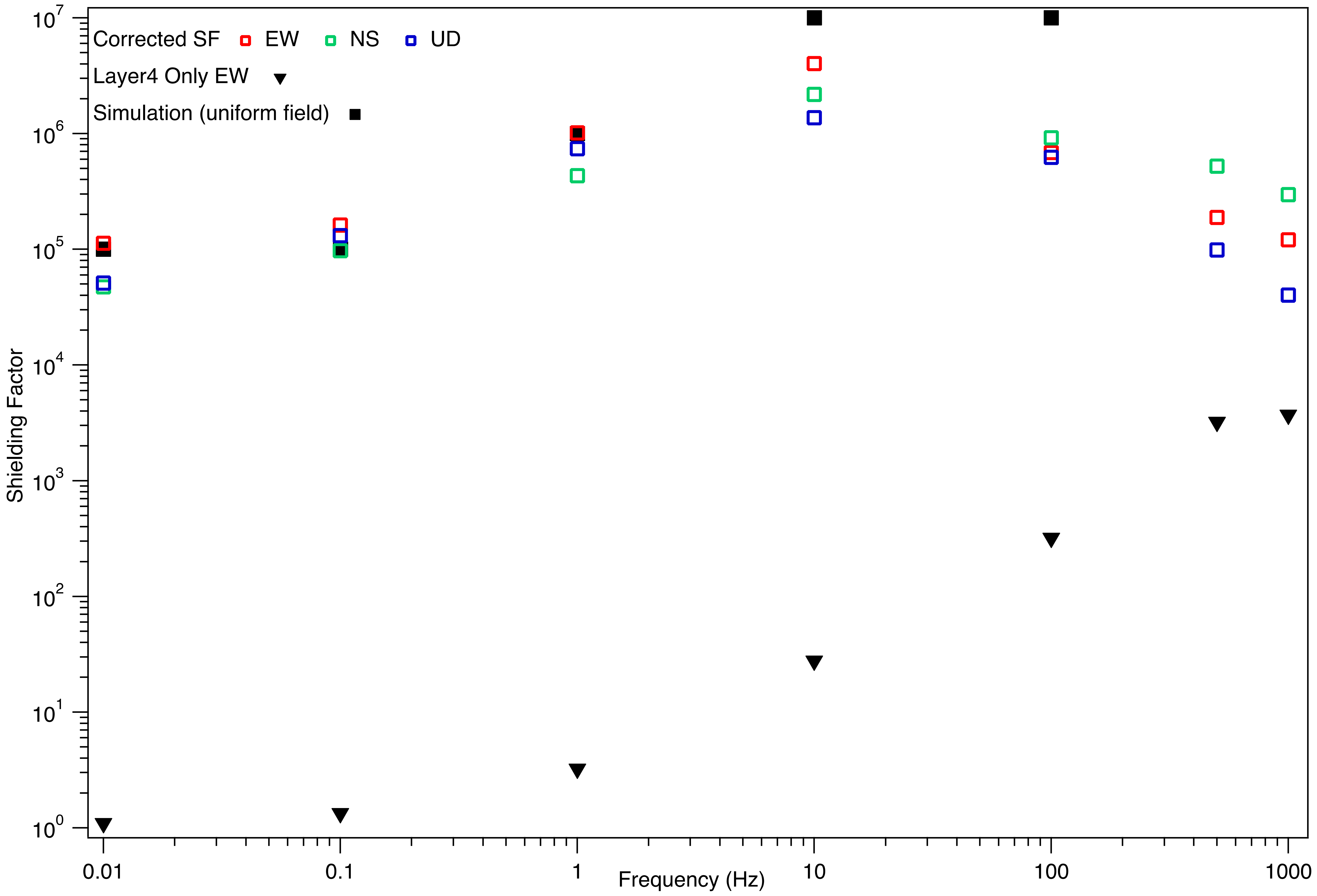
Magnetically shielded room



Field cage: MSR evaluation and cancellation of external fields

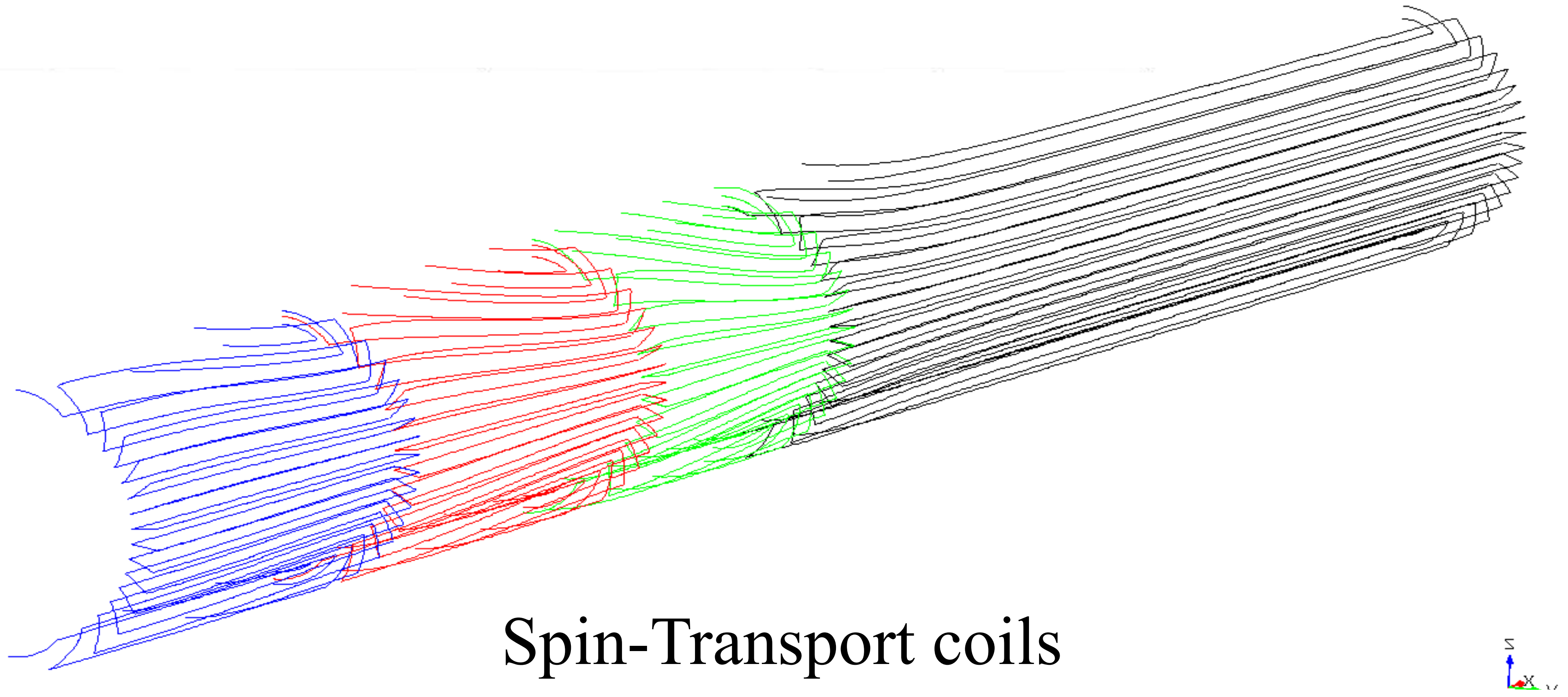


Shielding factor

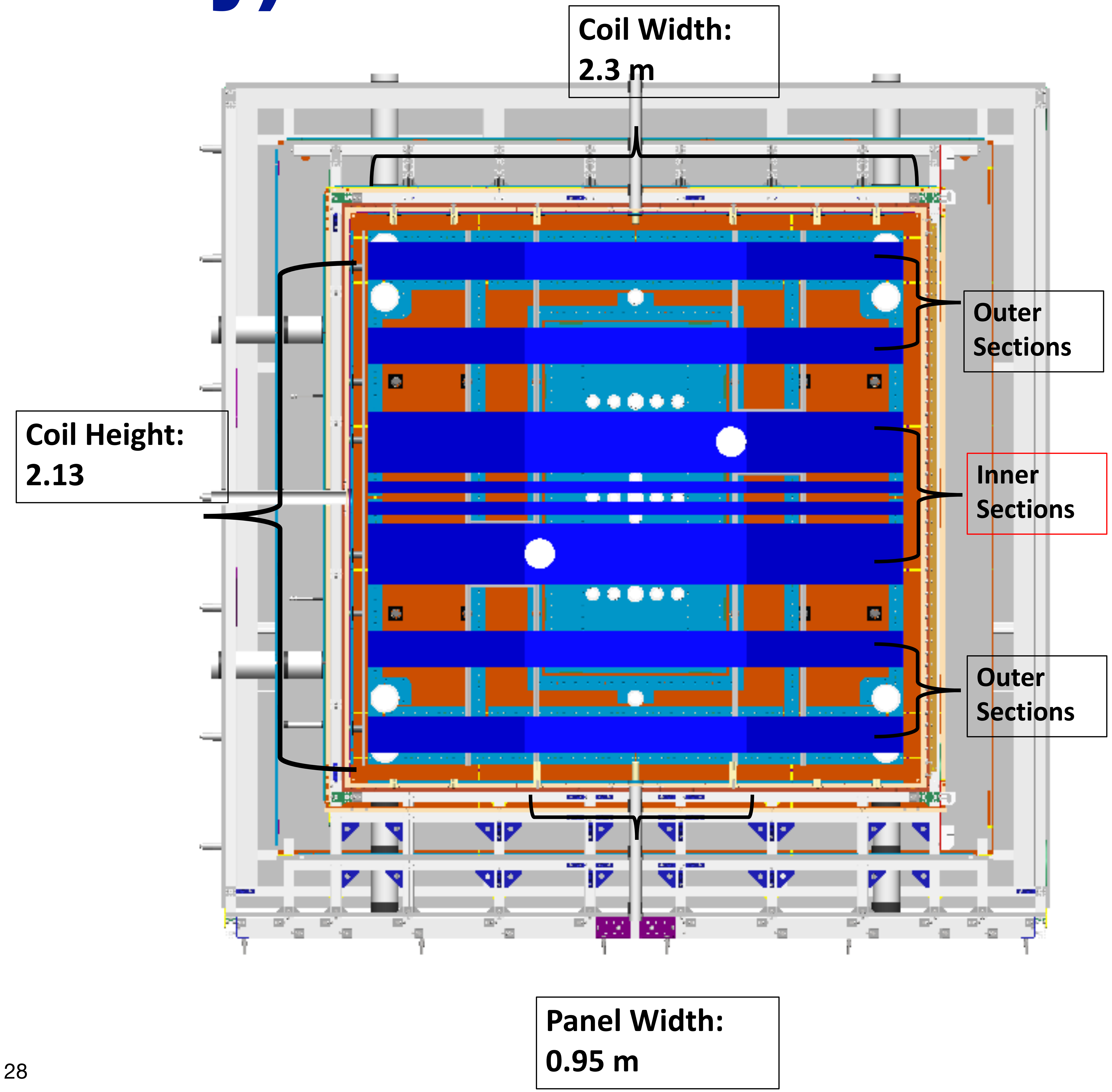


B0 coil design (U. Kentucky)

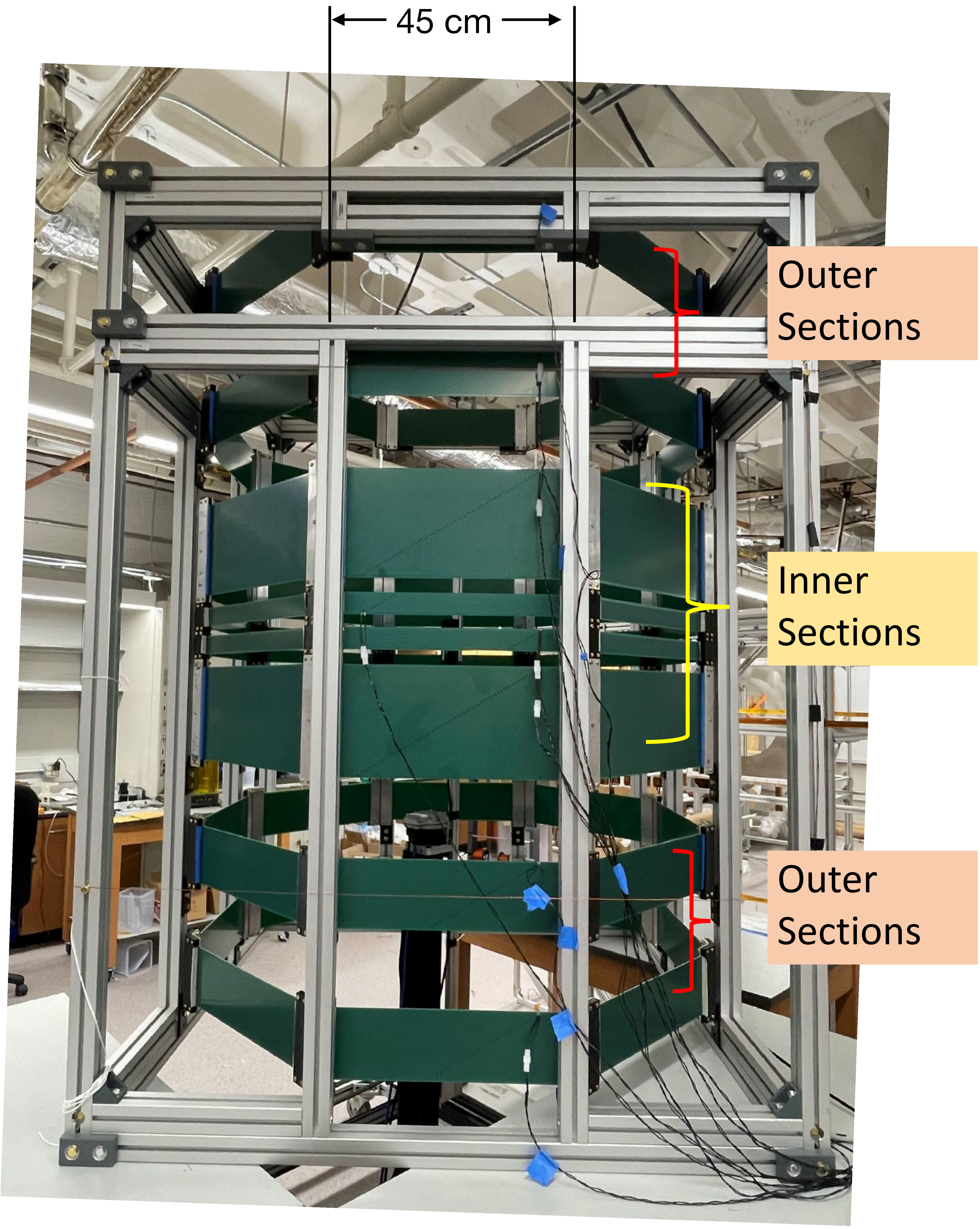
- Octagon-shaped multi-gap solenoid
- Spin-transport coil interface
- Modelled gradient: $\left|\frac{\partial B_z}{\partial z}\right| < 0.1\ \mathrm{nT/m}$
  - Specifications: $\left|\frac{\partial B_z}{\partial z}\right| < 0.3\ \mathrm{nT/m}$ inside each cell (the difference between the cells < 10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



Spin-Transport coils
Double Layer Modified Cos θ



Half scale B0 coil prototype tested inside an MSR

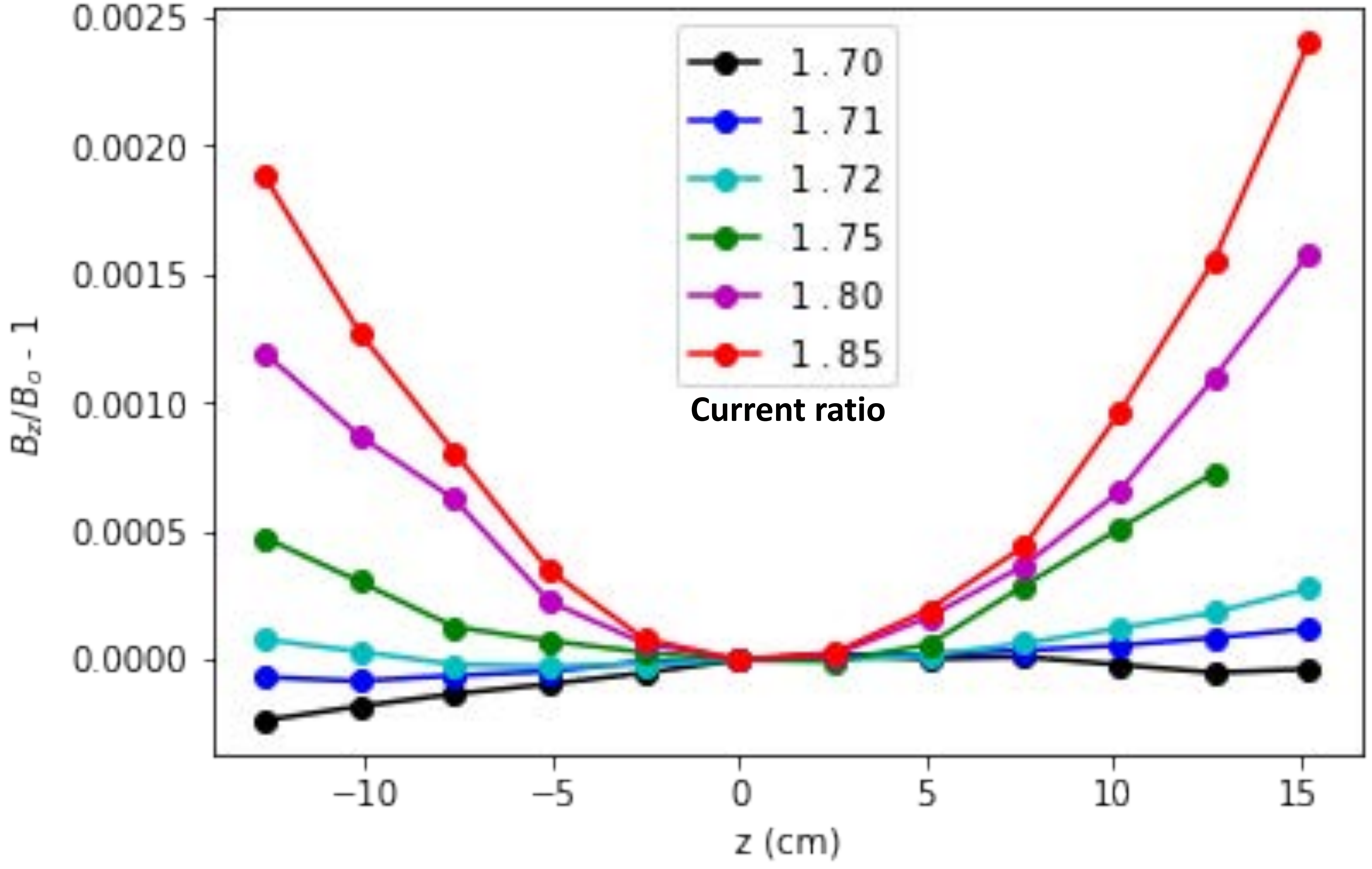


Half scale B0 coil prototype tested inside an MSR

- Tuning the current ratio between outer and inner coil sections to make $\frac{\partial B_z}{\partial z}$ gradient smaller
- Change the current in the z shim coil to fine tune the $\frac{\partial B_z}{\partial z}$ gradient further

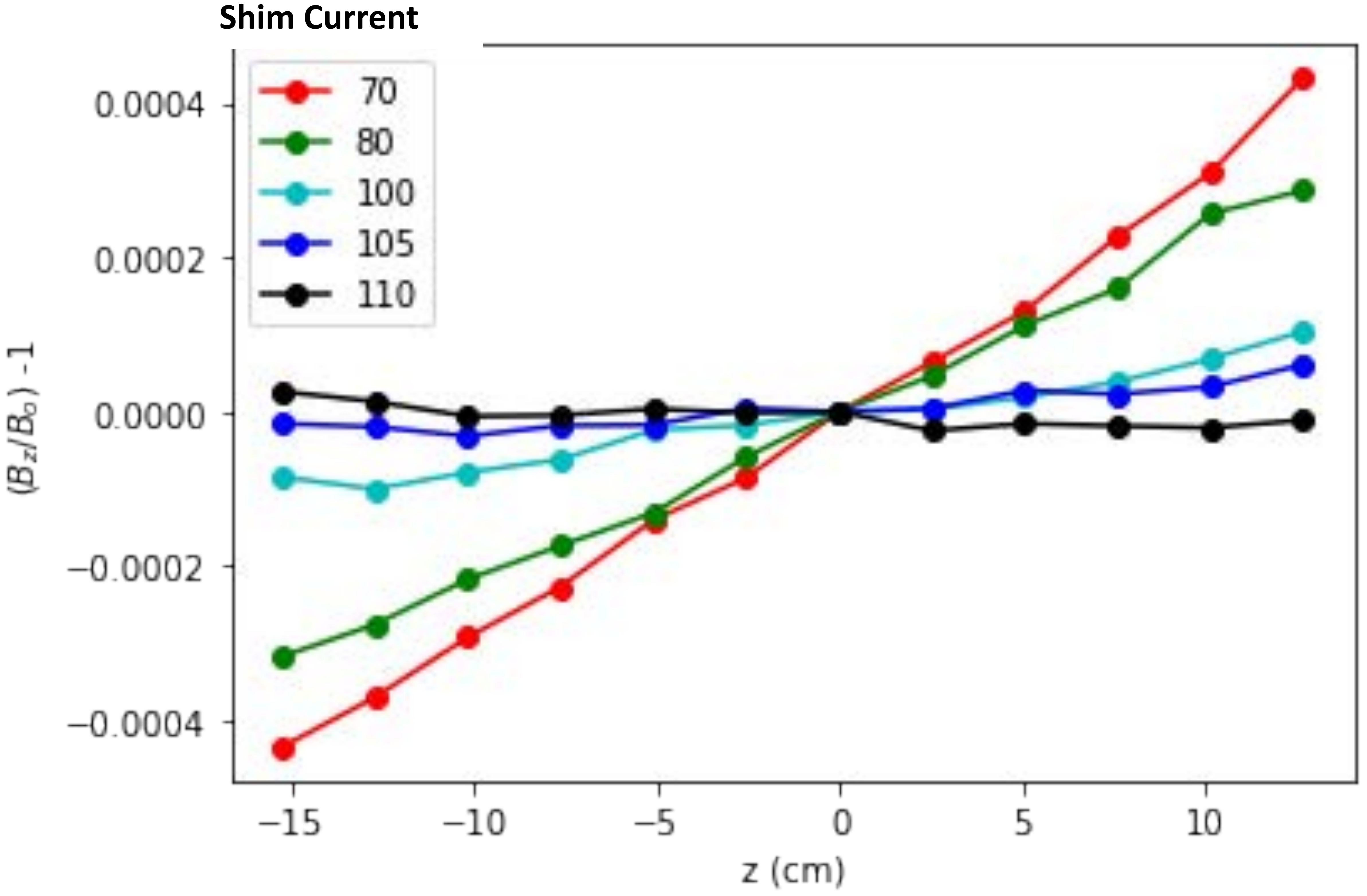
Tuning current ratio with $B_o \cong 2.9\ \ \mu\text{T},\ I_{inner} = 100\ mA$

$I_{shim} = 100\ mA$



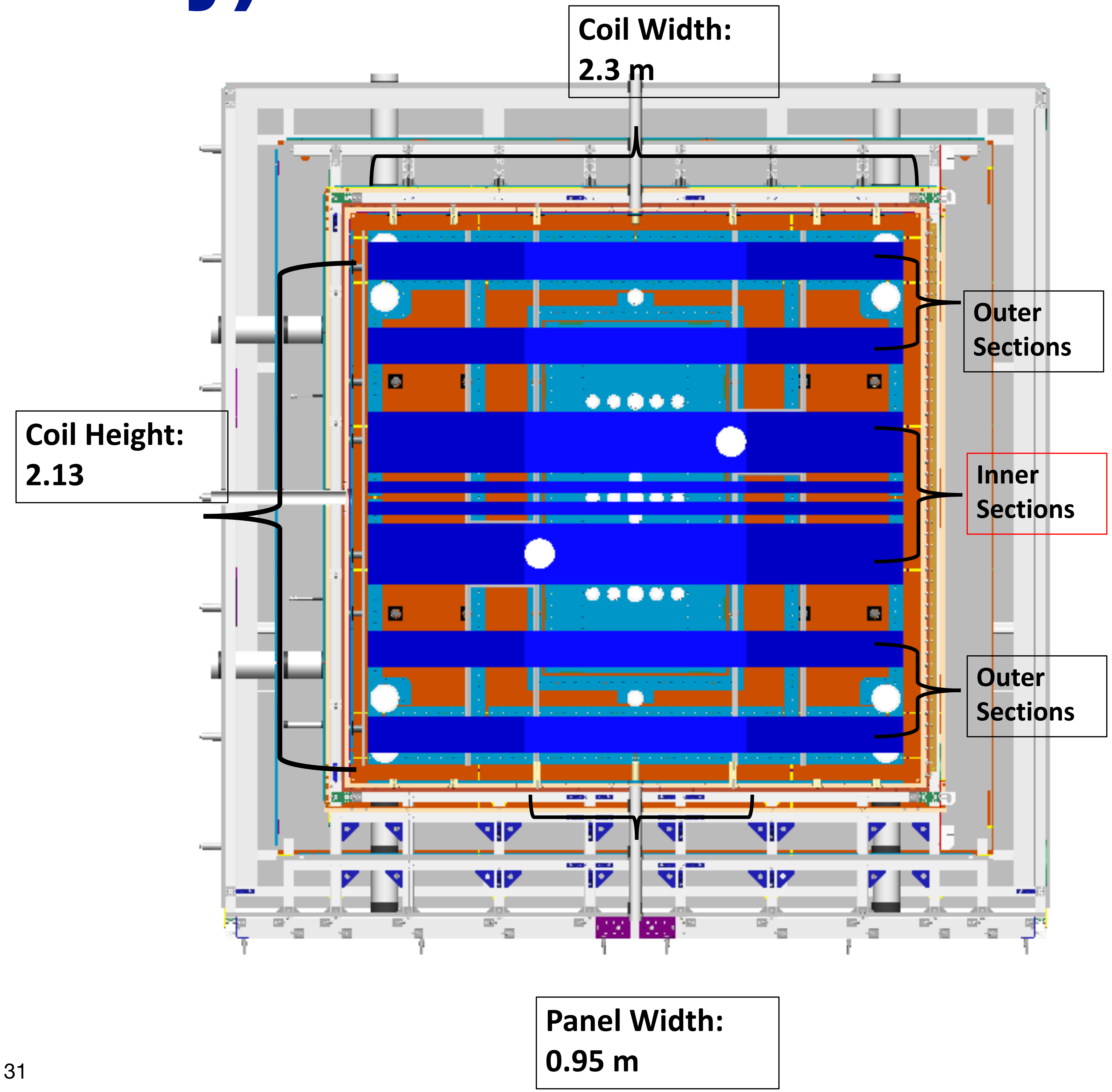
Tuning shim coil current with $B_o \cong 2.9\ \ \mu\text{T}, I_{inner} = 100\ mA$

$I_{outer}/I_{inner} = 1.71$



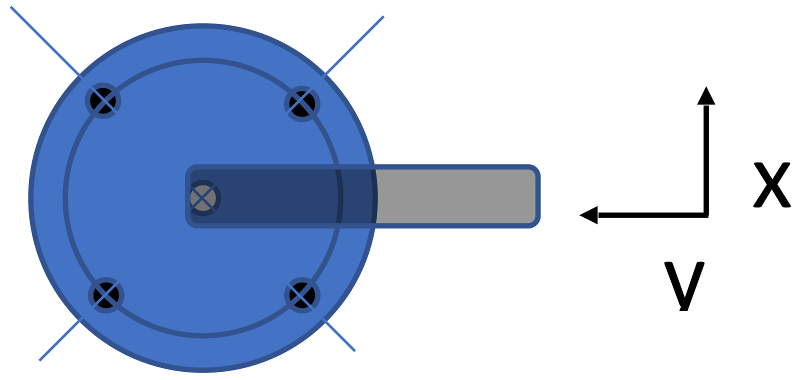
B0 coil status (U. Kentucky)

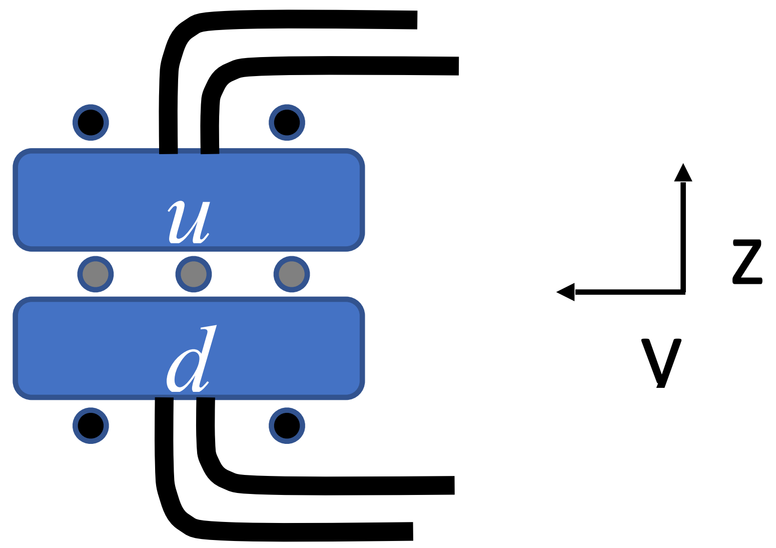
- The full scale B0 coil has been installed in the MSR.
- The work to characterize the performance of the B0 coil is on hold to give priorities to other tasks.



Magnetometers (U. Michigan)

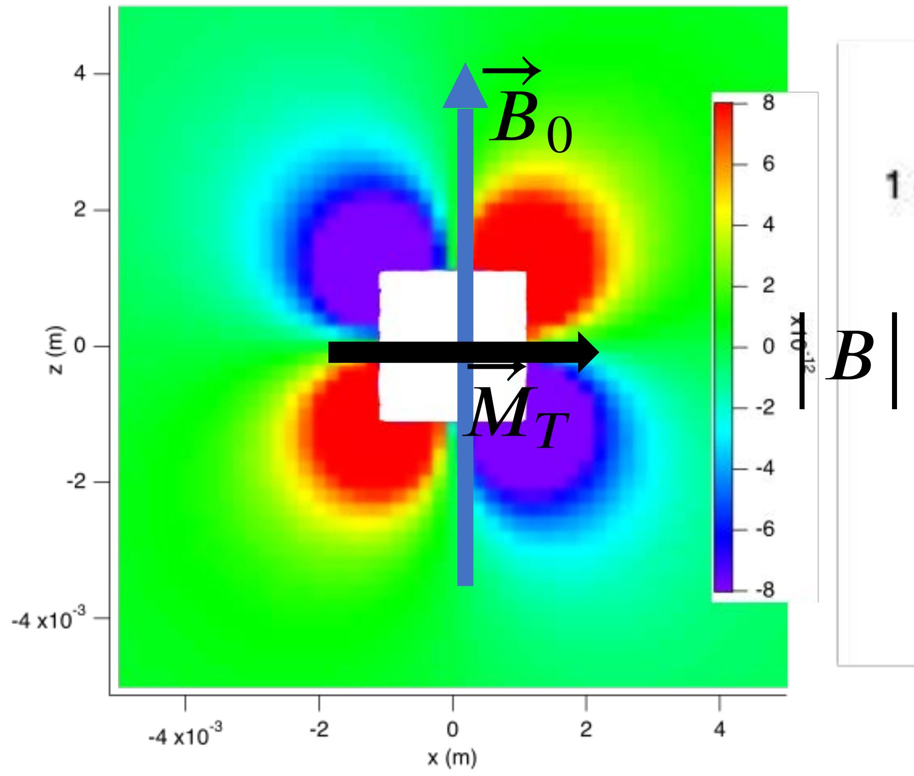
Up to 13 external magnetometers (inside vacuum) monitor B_0, gradients

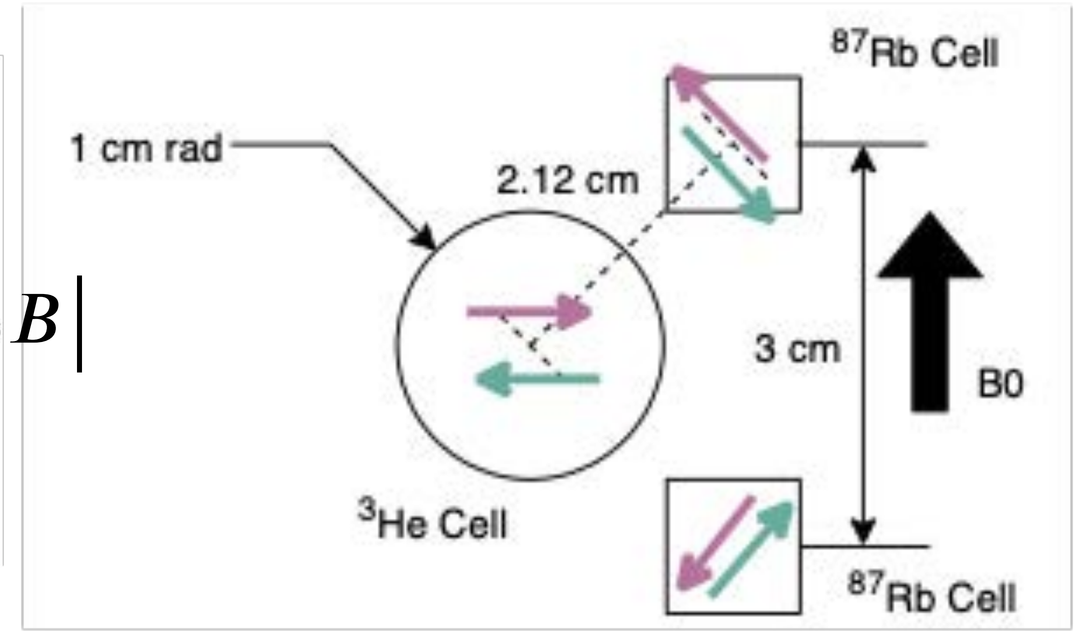


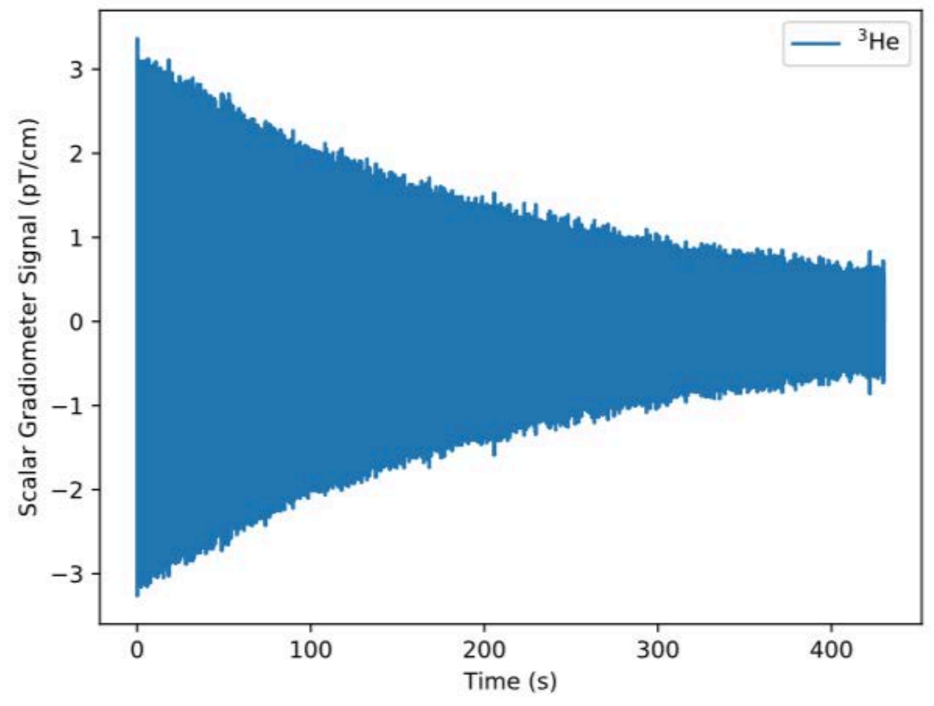


OPMs: optically pumped alkali (Cs, Rb) magnetometers

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

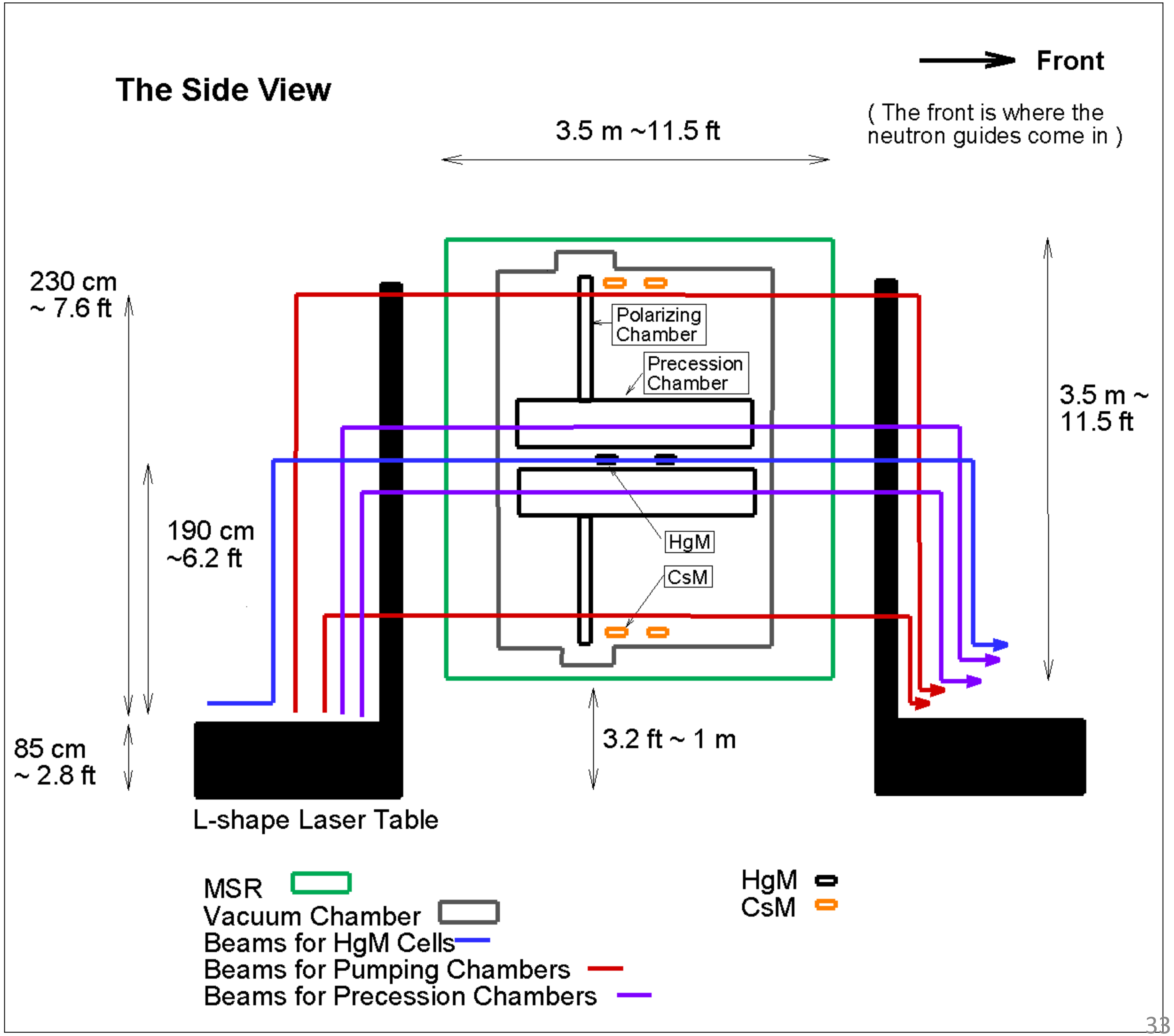






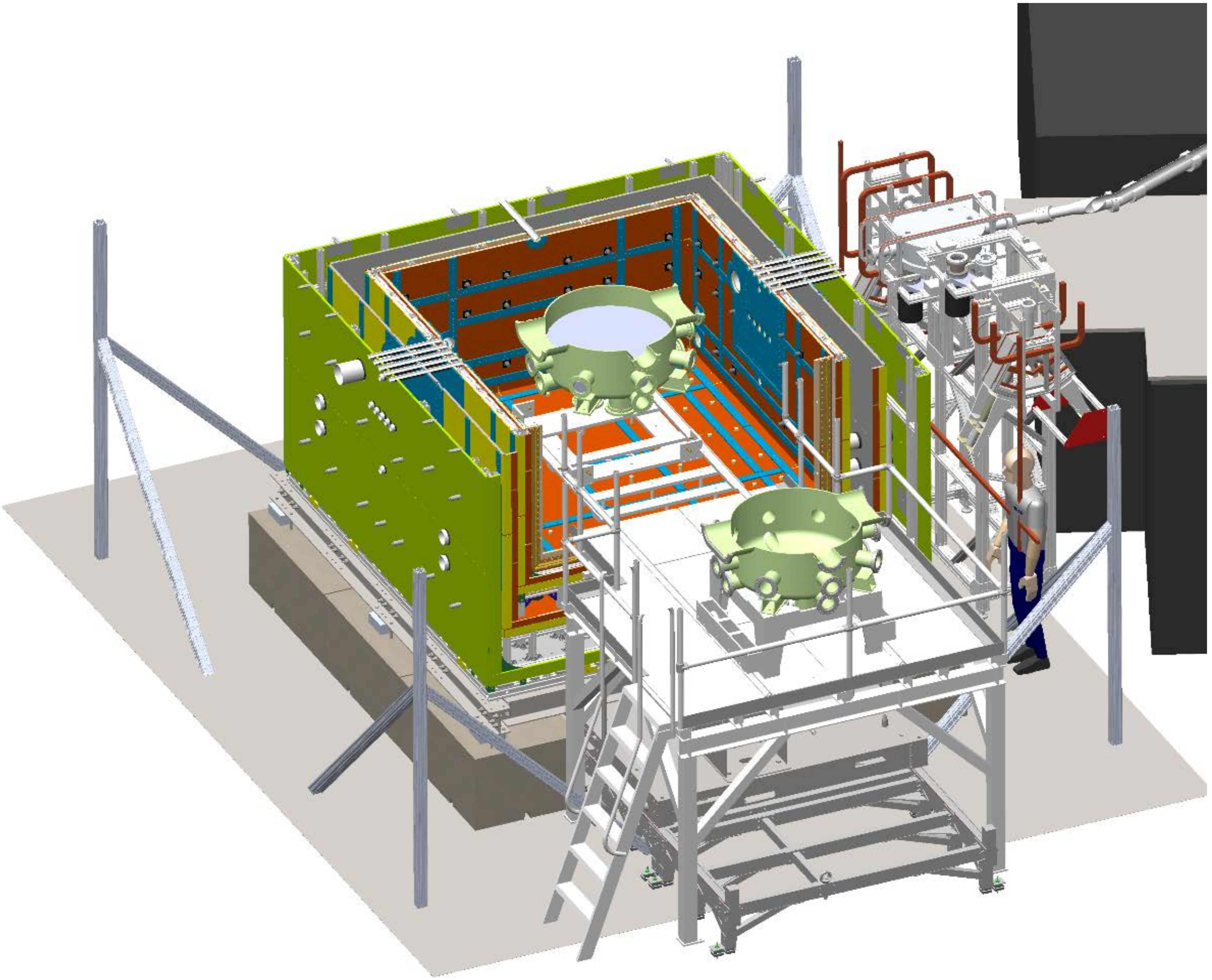
Hg-199 as co-magnetometer and magnetometers (Indiana U, UW)

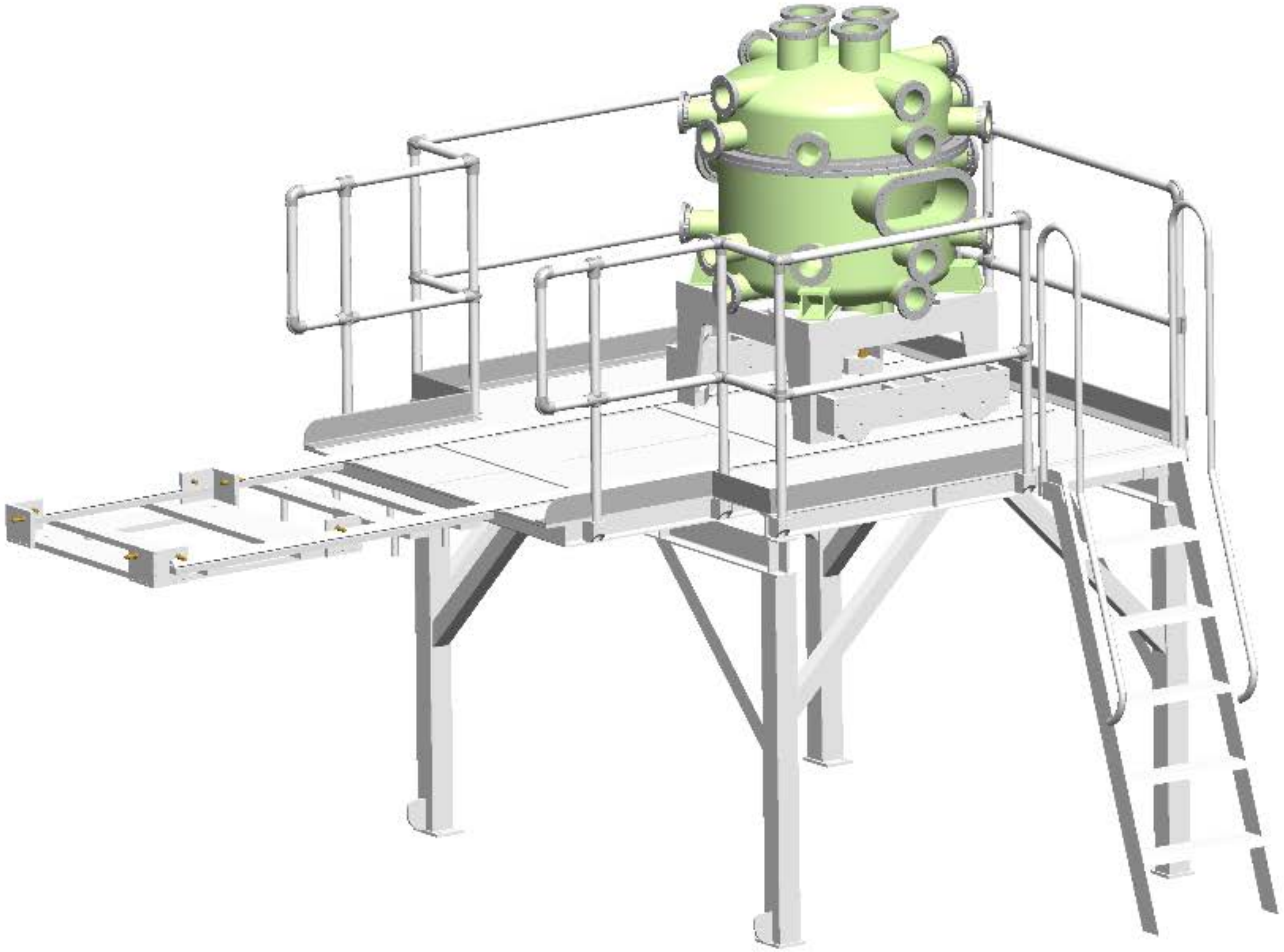
- nEDM@LANL has two precession chambers.
- Hg atoms are optically pumped in the polarizing chamber and then are transferred to the precession chamber to monitor the magnetic field.
- 5 Hg magnetometers(HgMs) are inside the HV electrode.
- All the pump beams come in from the side of MSR.
- The laser beams 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.



Installation platform (Indiana U.)

- To be delivered to LANL early August





Status and plans

- MSR was delivered in January 2022. It meets performance requirements. More detailed characterization is necessary.
- nEDM apparatus is being assembled.
- We plan to start an engineering run this summer.
    - We will start with confirming UCN transport and storage.