nEDM at LANL

Workshop on Electric and Magnetic Dipole Moments

Takeyasu Ito
Los Alamos National Laboratory
September 15, 2020

LANL nEDM Collaboration

T. Chupp*, S. Clayton, C. Cude-Woods, S. Currie, T. Hassan, T. Ito, M. Makela, C. Morris, C. O'Shaughnessy, A. Saunders, W. Uhrich, A. Urbaitis,
Los Alamos National Laboratory

C. Swank
California Institute of Technology

T. Chupp, F. Hills, A. Tewsley-Booth
University of Michigan

J. Chen, F. Gonzales, C. Hughes, C.-Y. Liu, J. Long, A. Reid, W. Snow, D. Wong
Indiana University

J. Brewington, W. Korsch, M. McCrea, P. Palamure, B. Plaster
University of Kentucky

N. Sachdeva
Northwestern University

R. Pattie Jr.
East Tennessee State University

S. Stanislaus
Valparaiso University

T. J. Bowles and B. Heckel
University of Washington

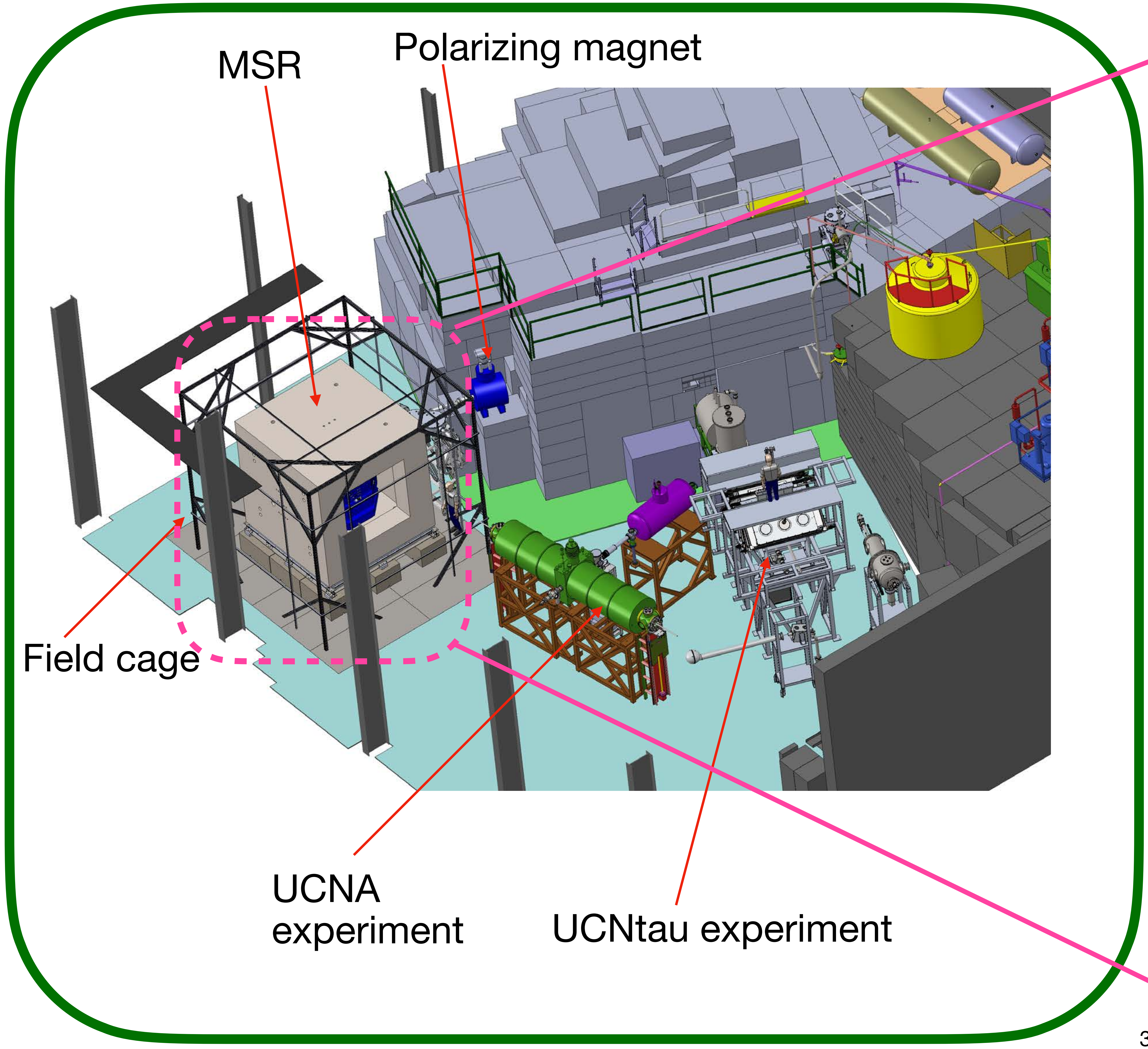
S. K. Lamoreaux
Yale University

E. Sharapov
Joint Institute of Nuclear Research

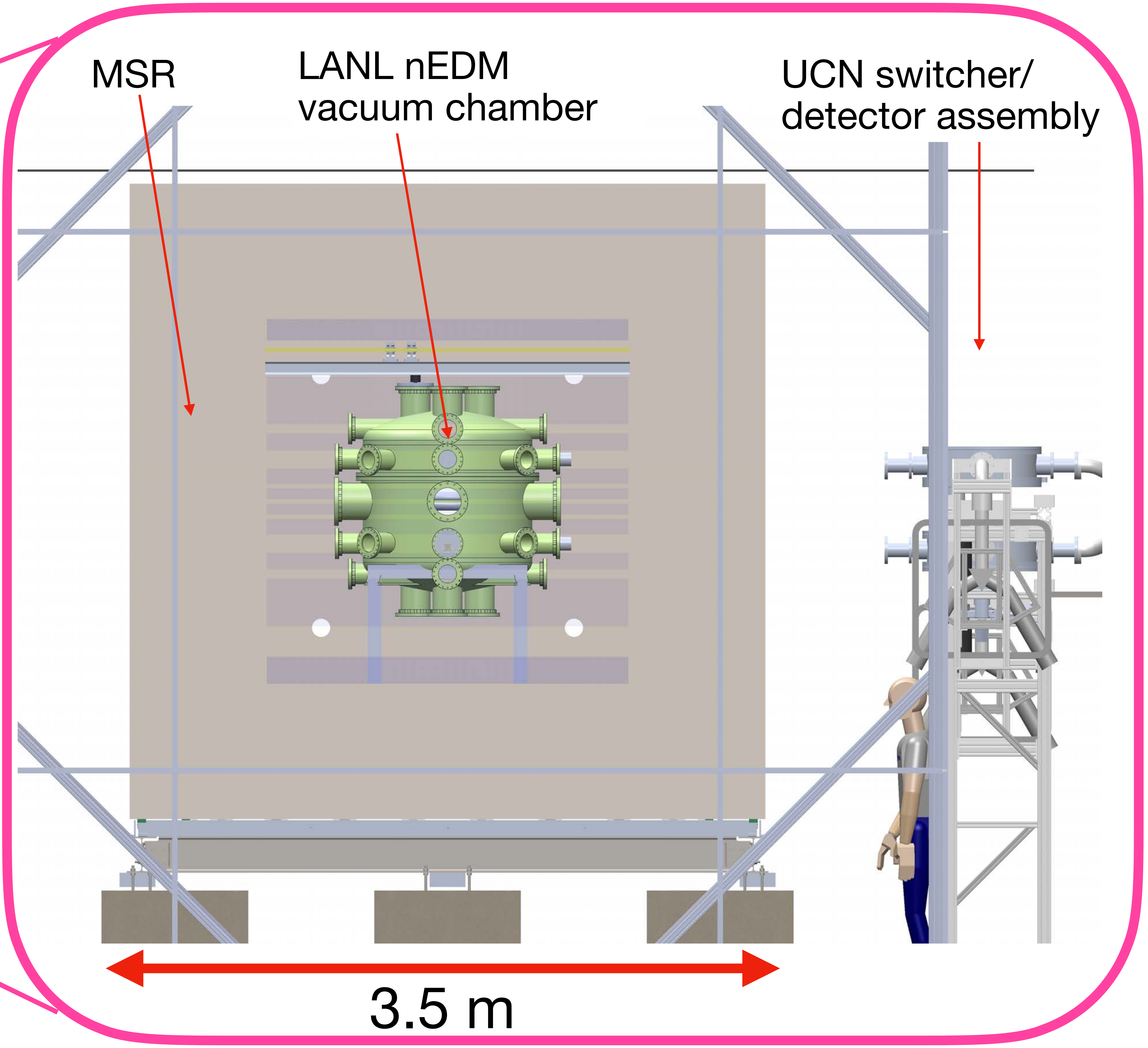
* 2020 LANL Rosen scholar

Apparatus overview

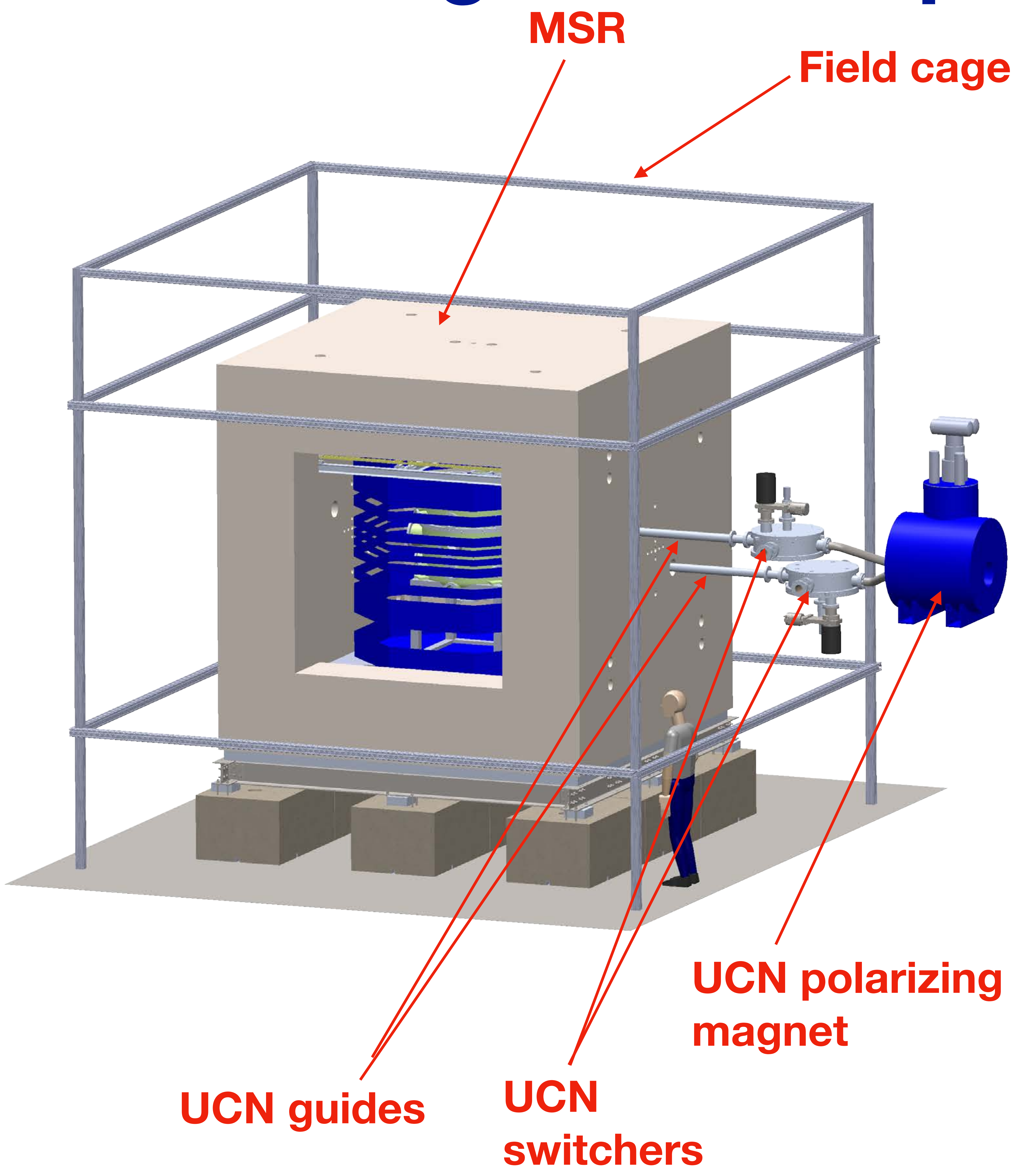
TA-53 Area B (UCN Experimental Hall)



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 (initially we will run without it)
  - 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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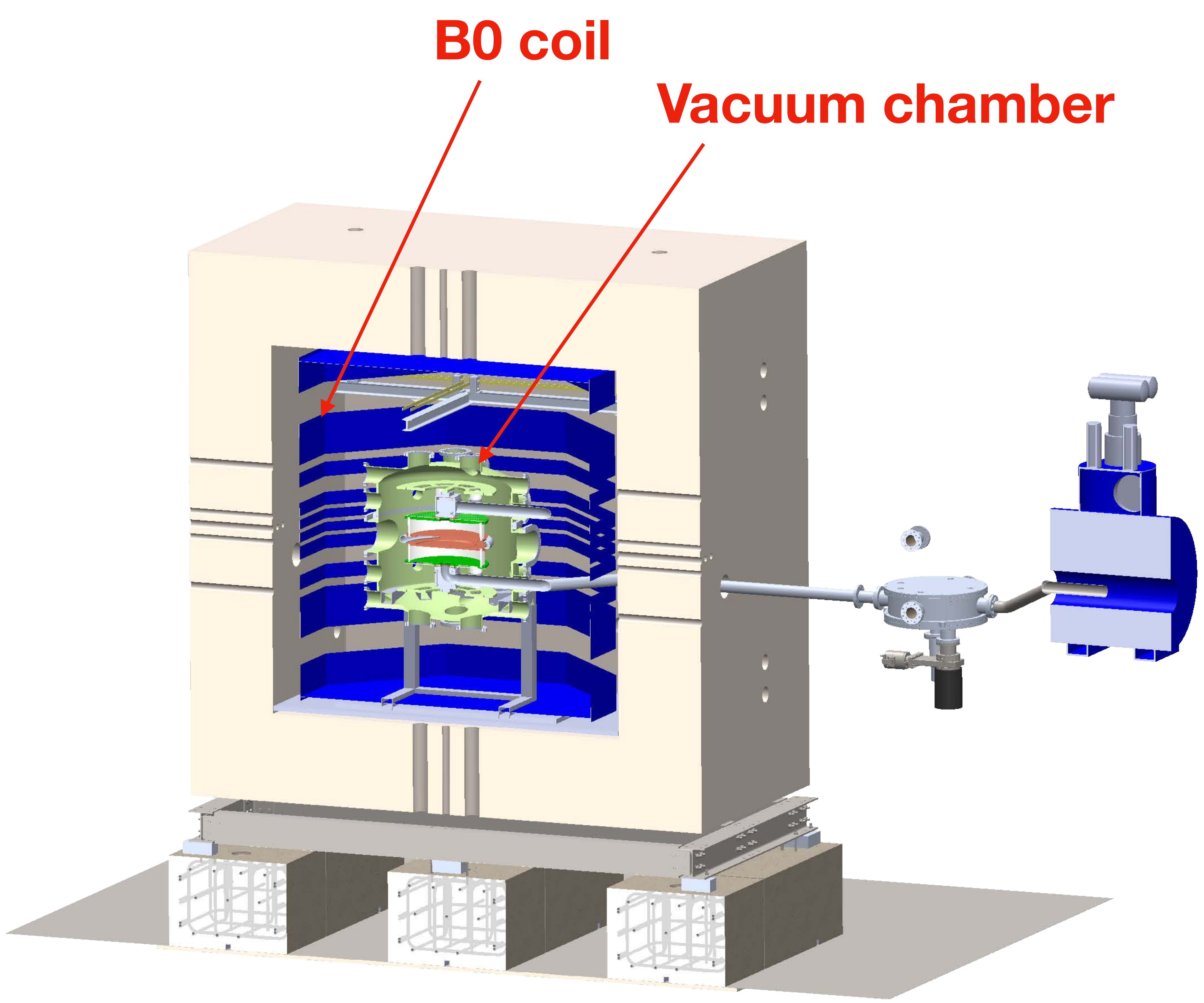

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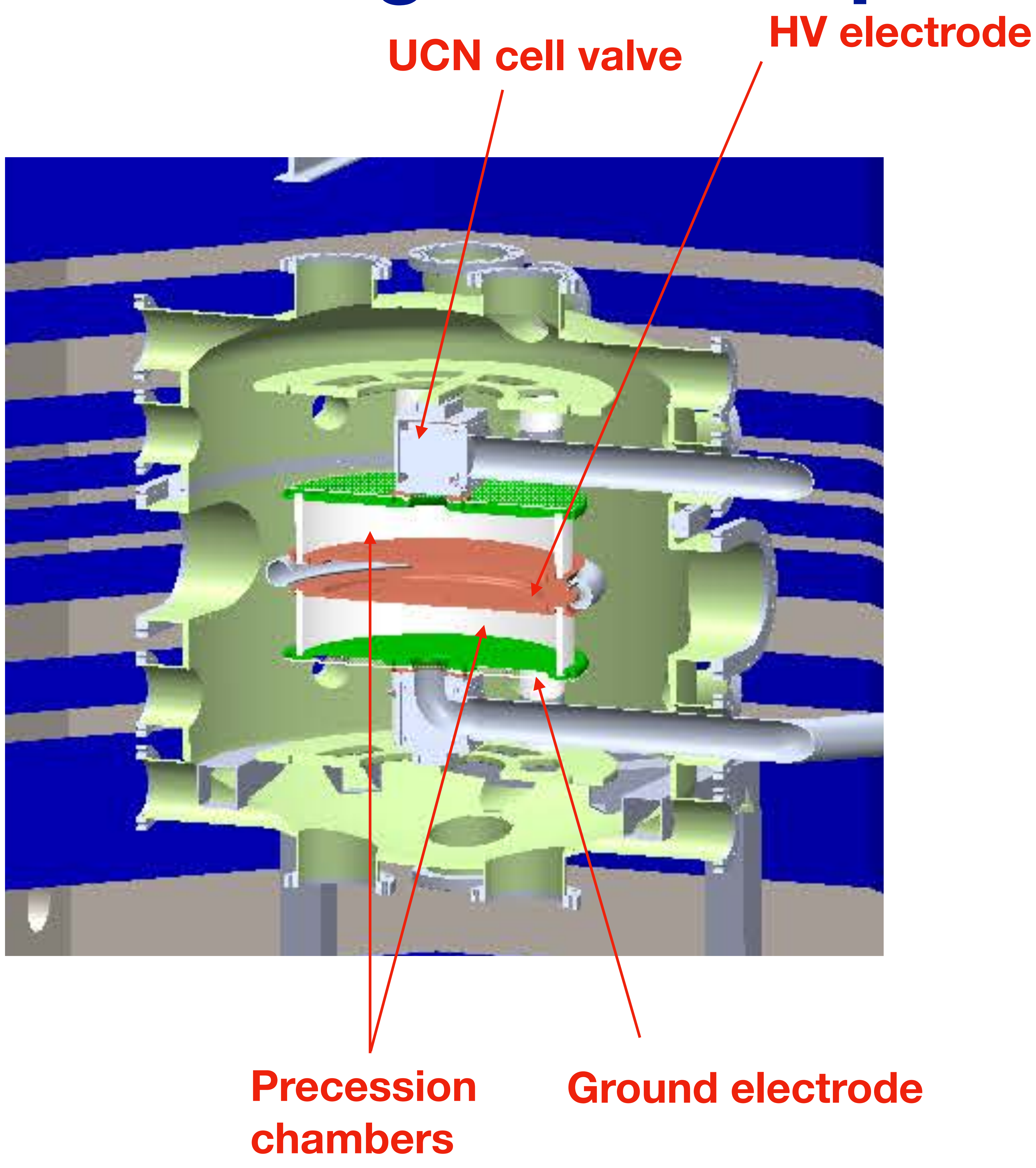

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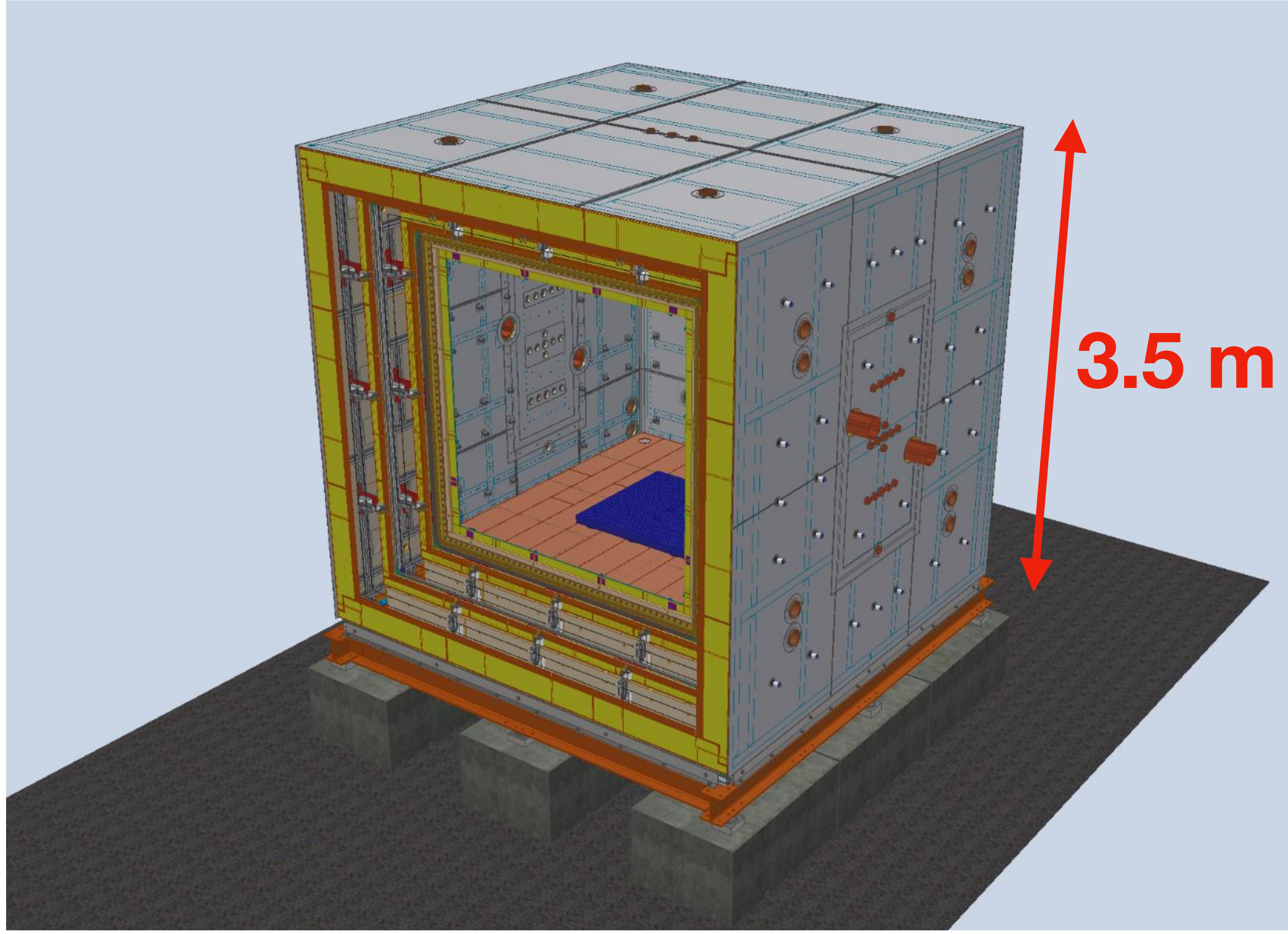
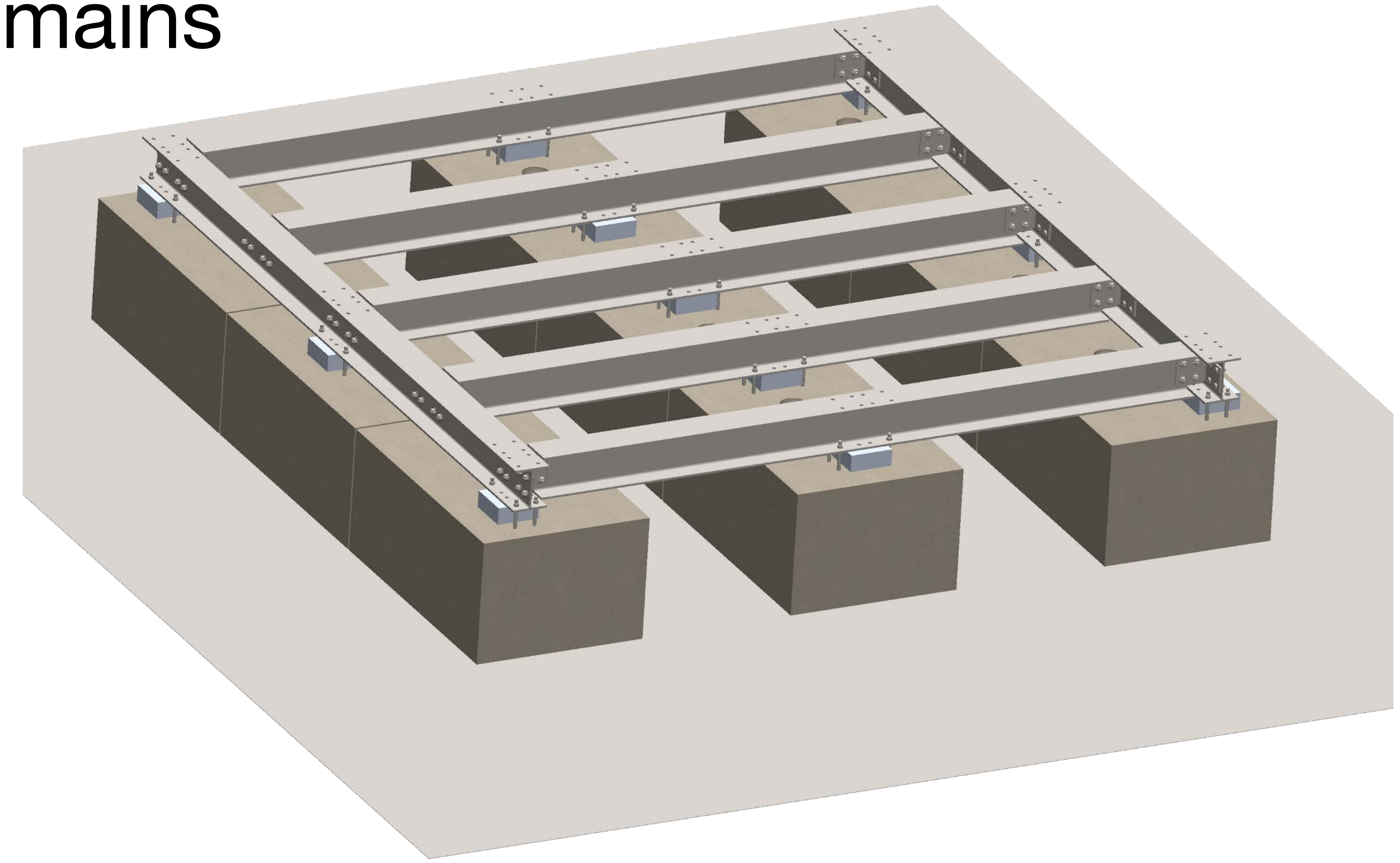
MSR design + design of the support structure



- Non-magnetic, high density aggregate precast foundation blocks, minimize transmission of exterior impact vibration
- Stainless steel frame, supports the load without deflection. Bolted construction to avoid welds that can create magnetic domains



- Shielding factor = 10^5 @ 0.01 Hz
- 4 μ-metal layers + 1 Cu layer
- Outer dimension: 3.5 m x 3.5 m x 3.5 m
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- To be delivered in August 2021

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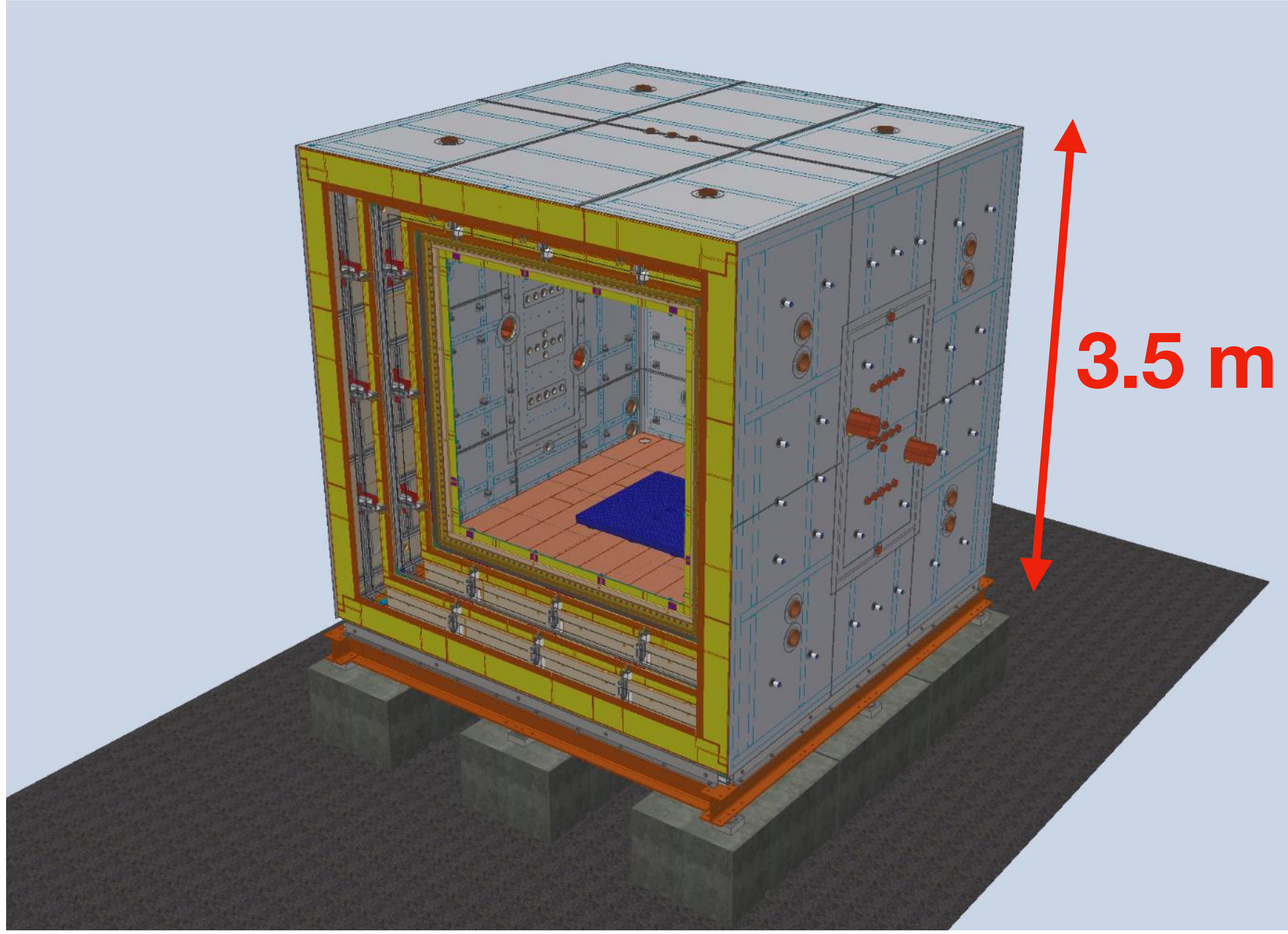

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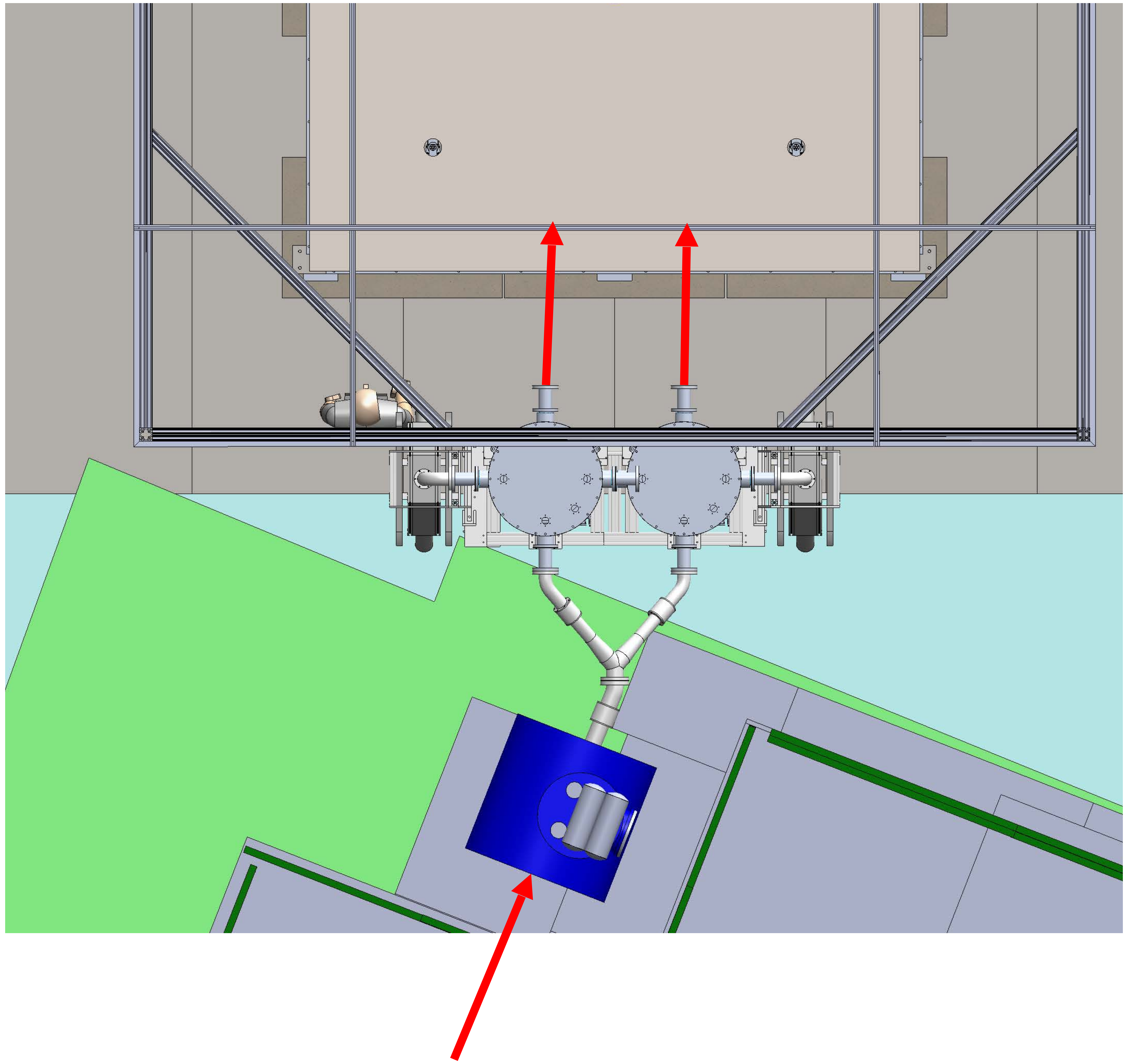
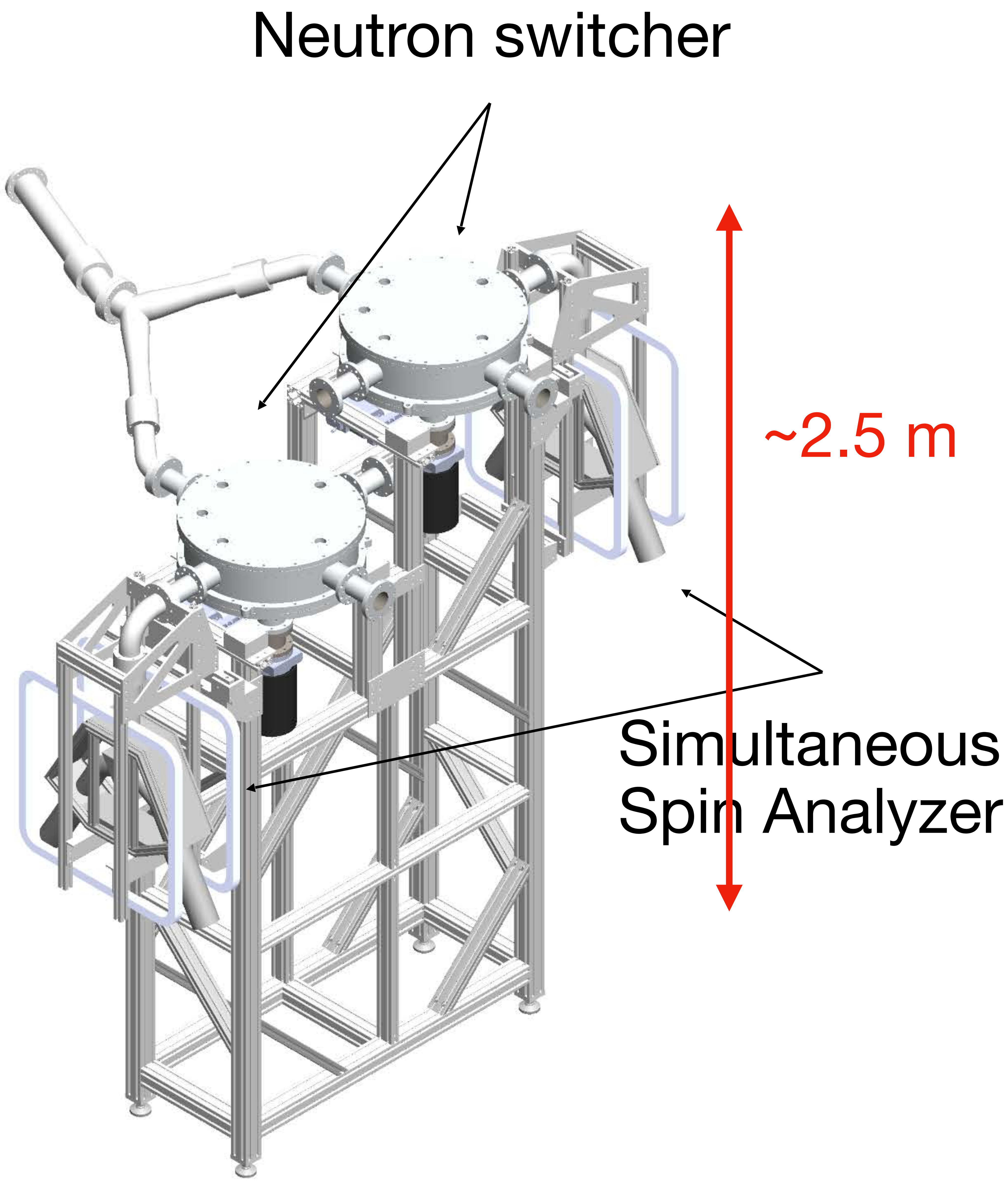
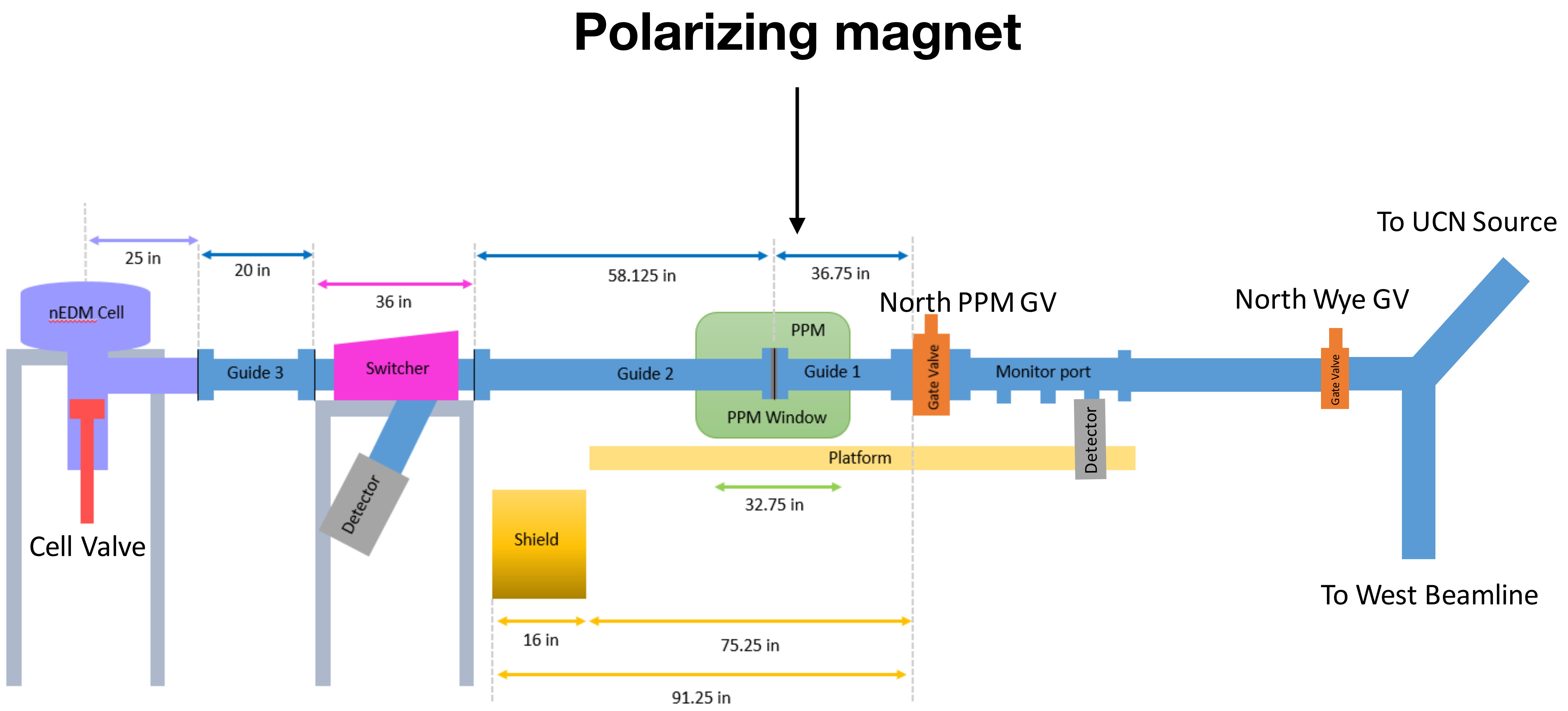
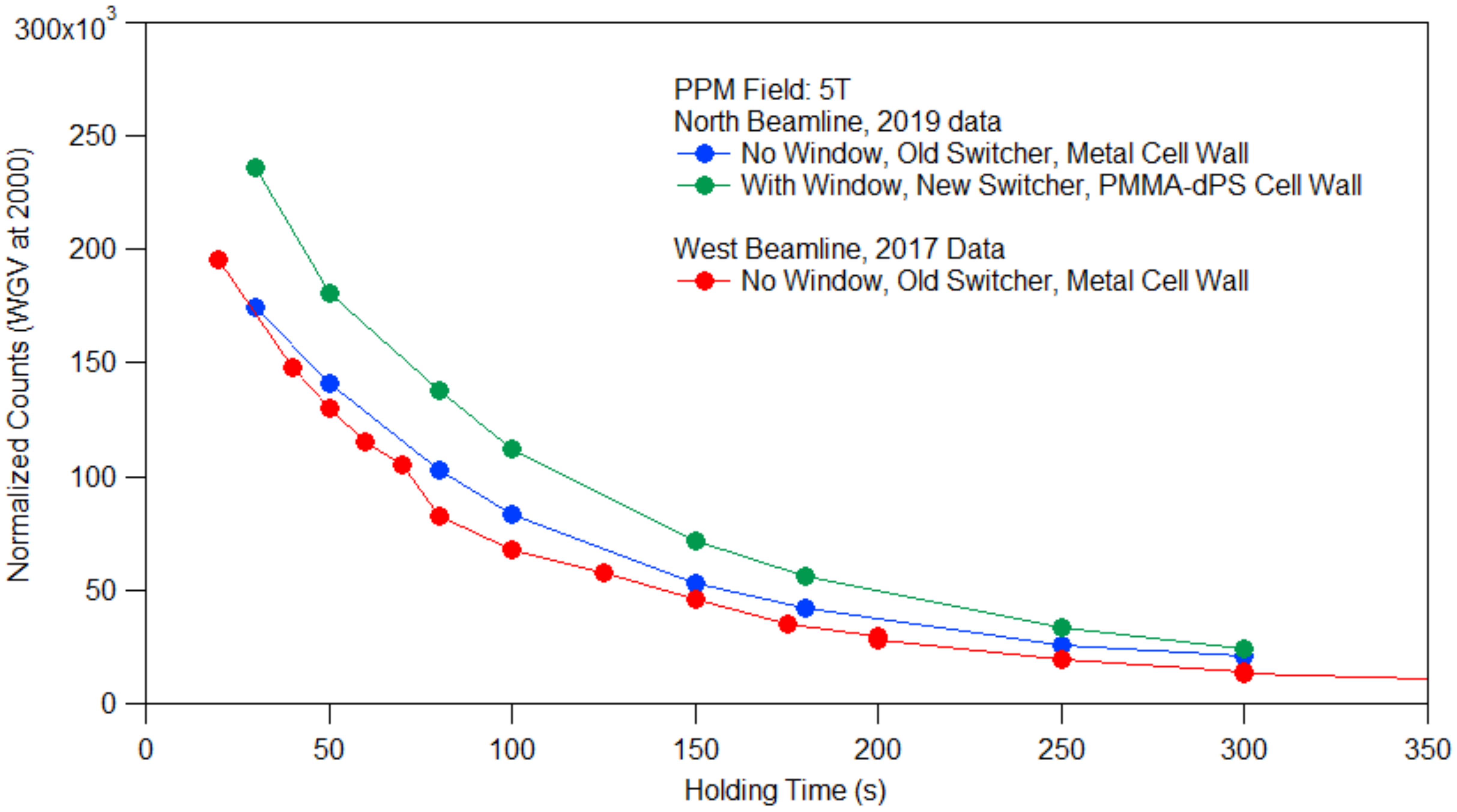
Beam line design





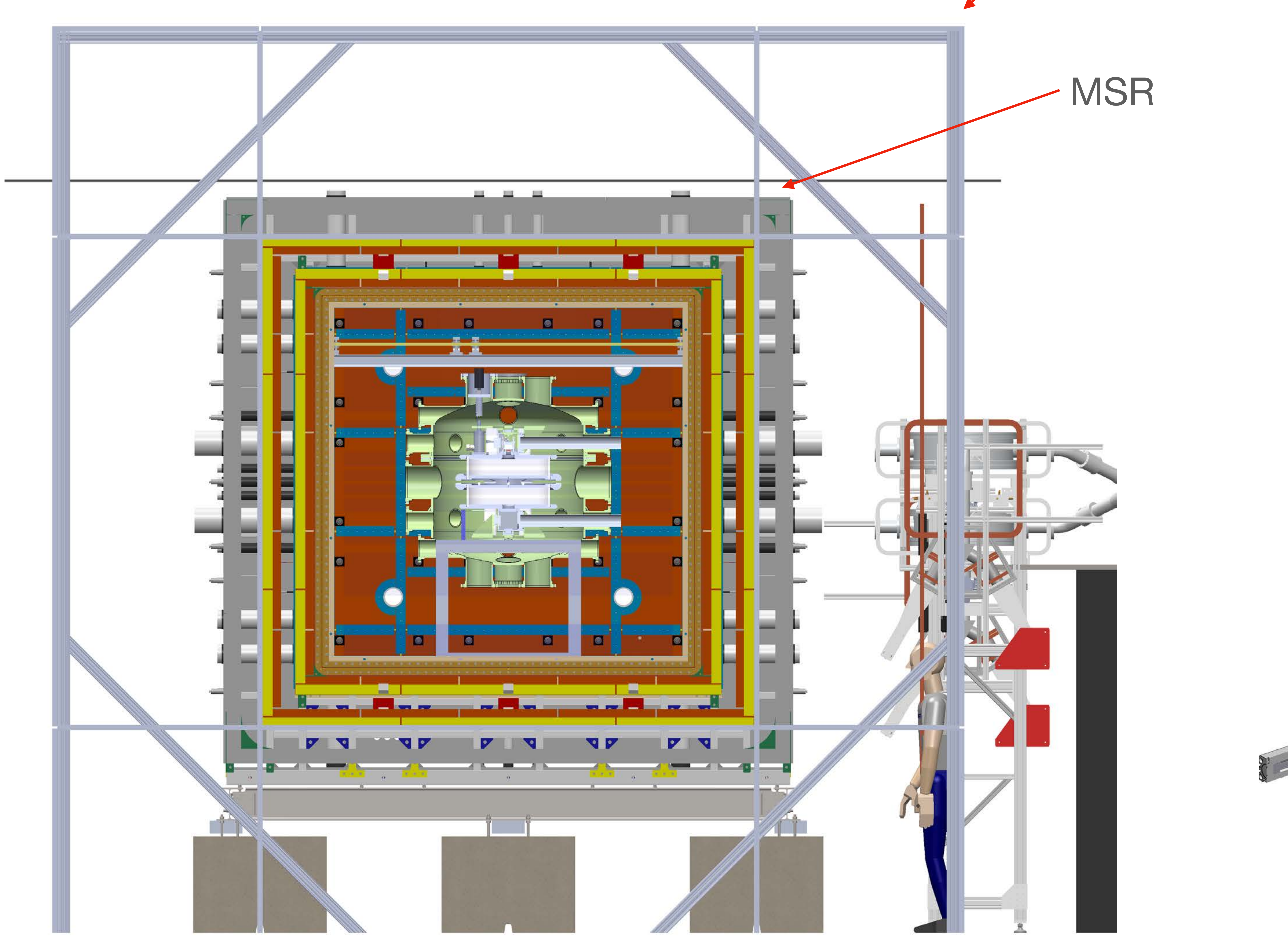
Neutron transport and storage test

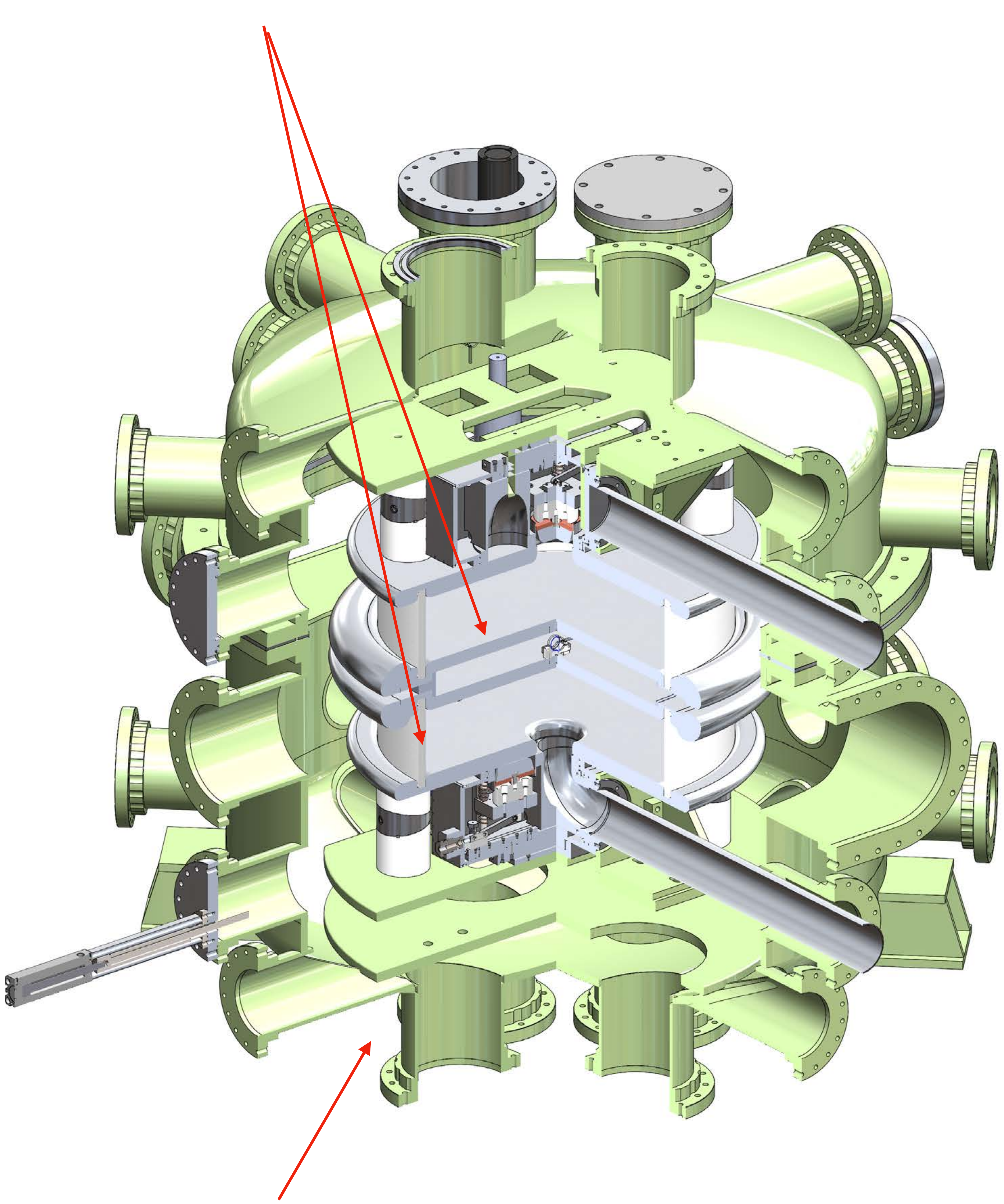




Measurement corresponds to ~70,000 detected UCN @ 2000 Hz GV rate after 180 s when a dPS coated cell wall was used with the new switcher

Experiment design



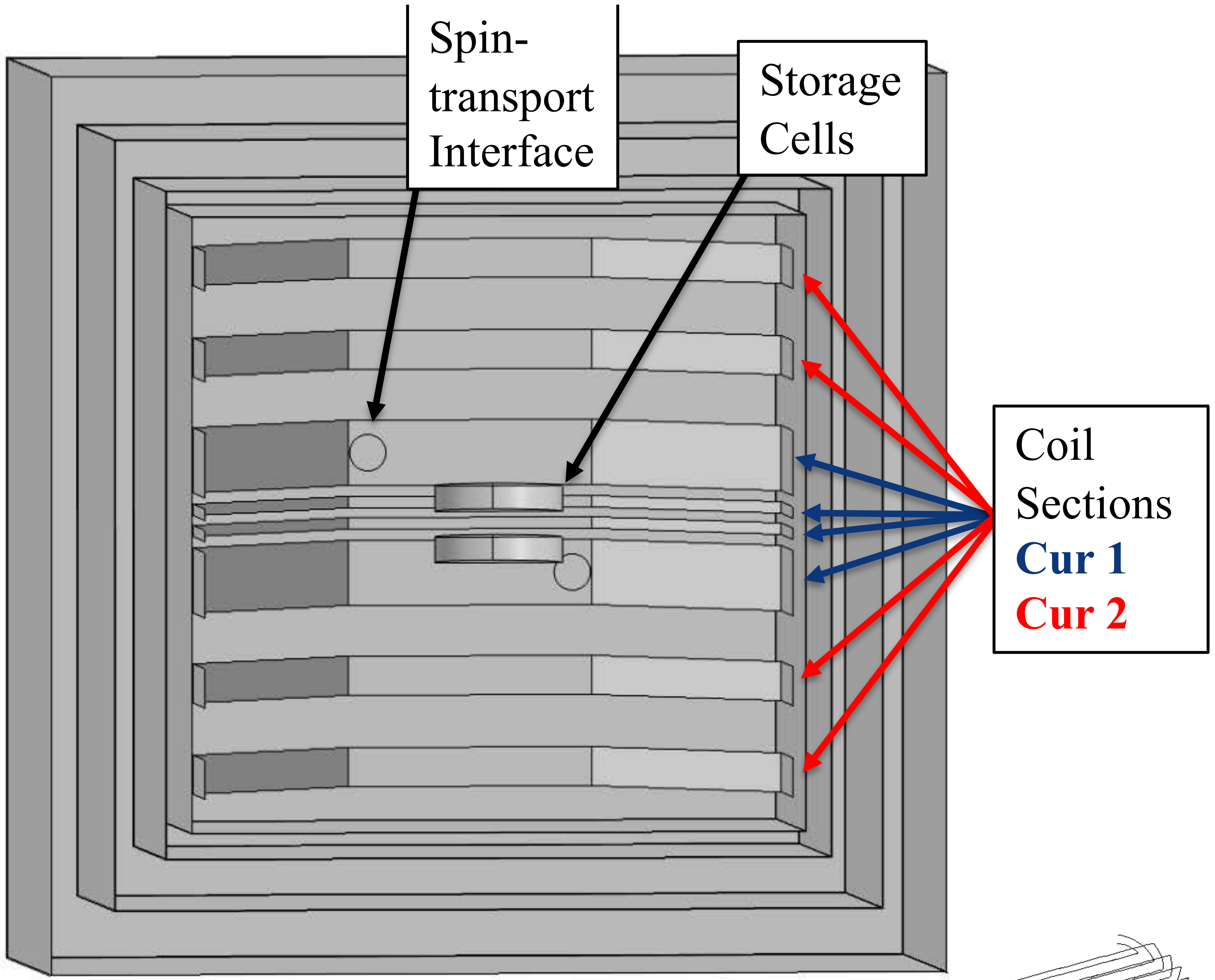


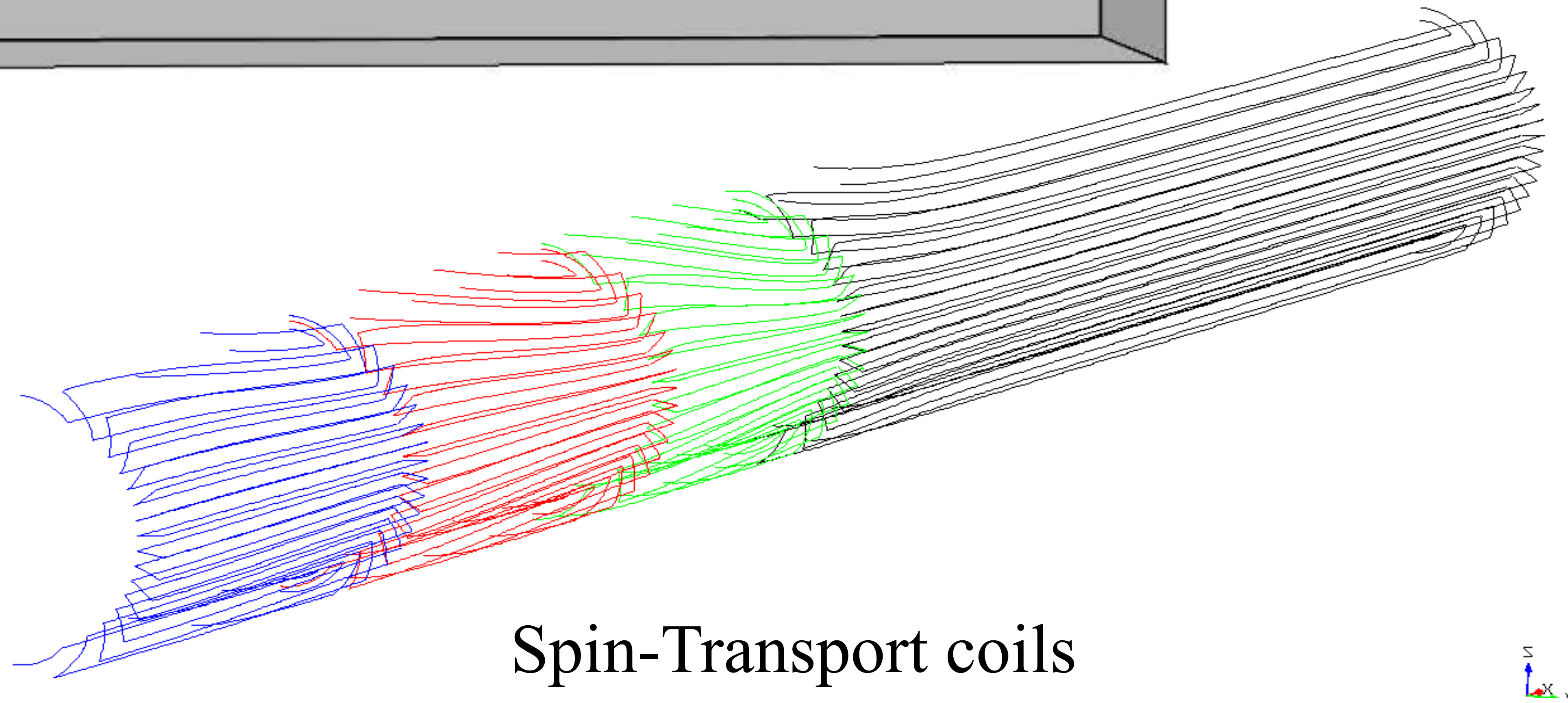
Magnetic field cage

- Produces magnetic field to cancel the ambient field
- Plan
    - ✓ Assemble
    - Characterize the performance
    - Dissemble to allow installation of the MSR
    - Assemble again.
    - Use the field generated by the field cage for MSR performance evaluation.

B_0 Coil Design (U. Kentucky)

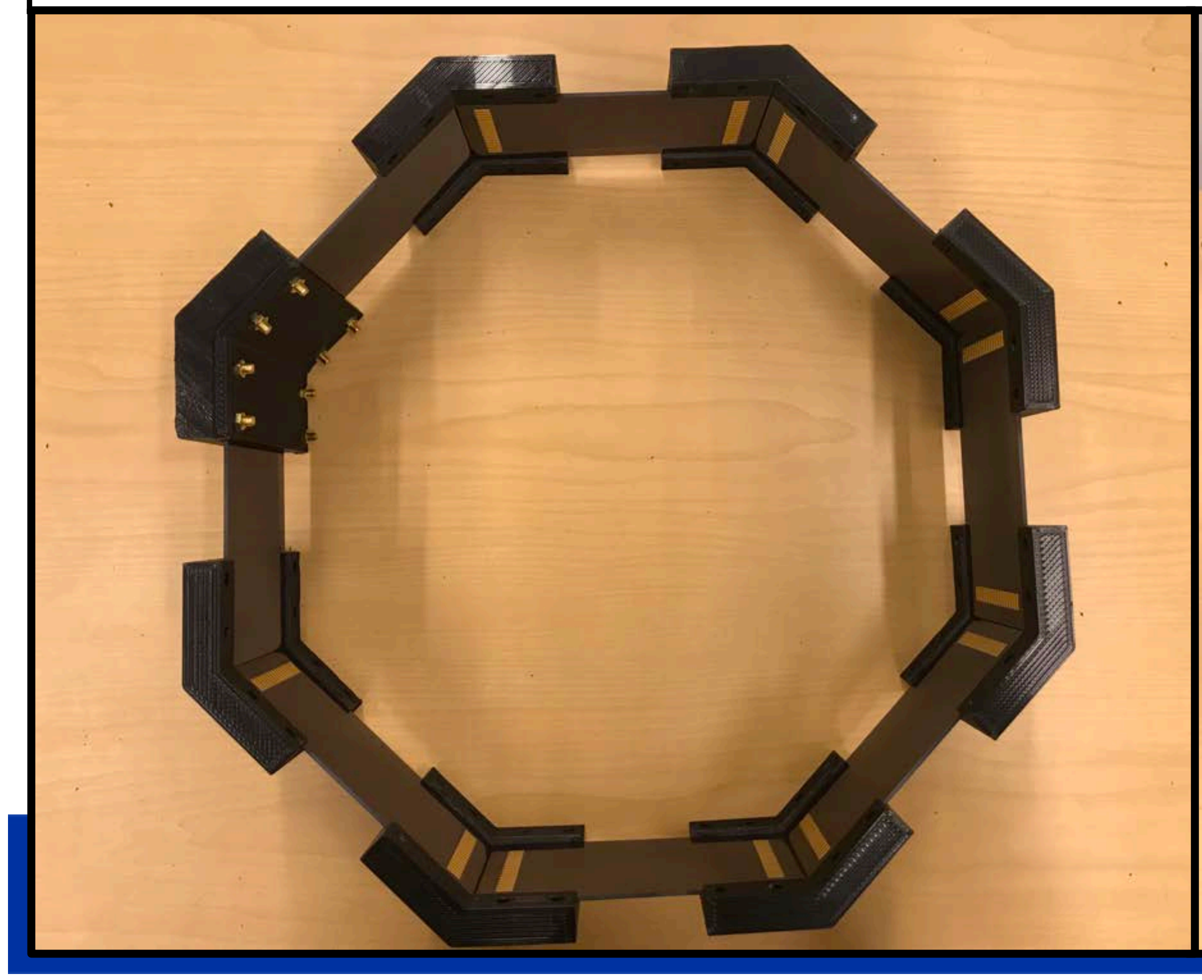
- Octagon-shaped multi-gap solenoid
- Spin-transport coil interface
- Modelled gradient: $\frac{\partial B_z}{\partial z} < .1\ \mathrm{nT/m}$
  - Specification is $< .3\ \mathrm{nT/m}$





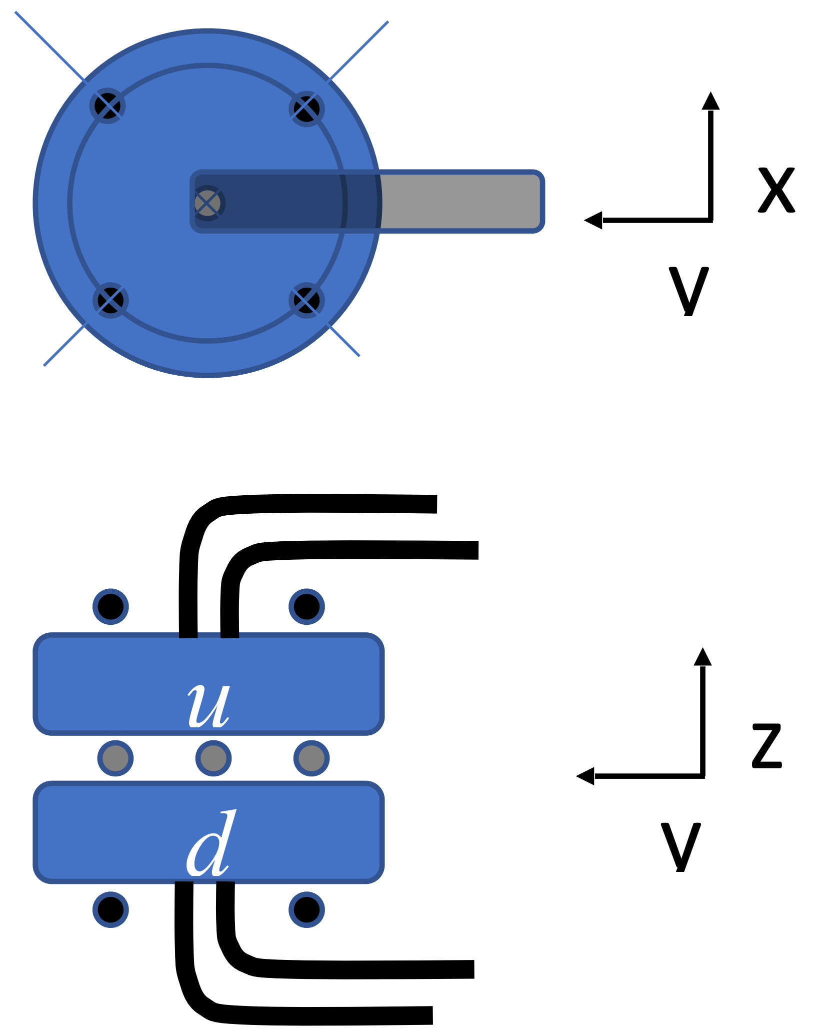
Spin-Transport coils
Double Layer Modified Cos θ

B_0 Prototyping—PCB panels with 3D printed connectors

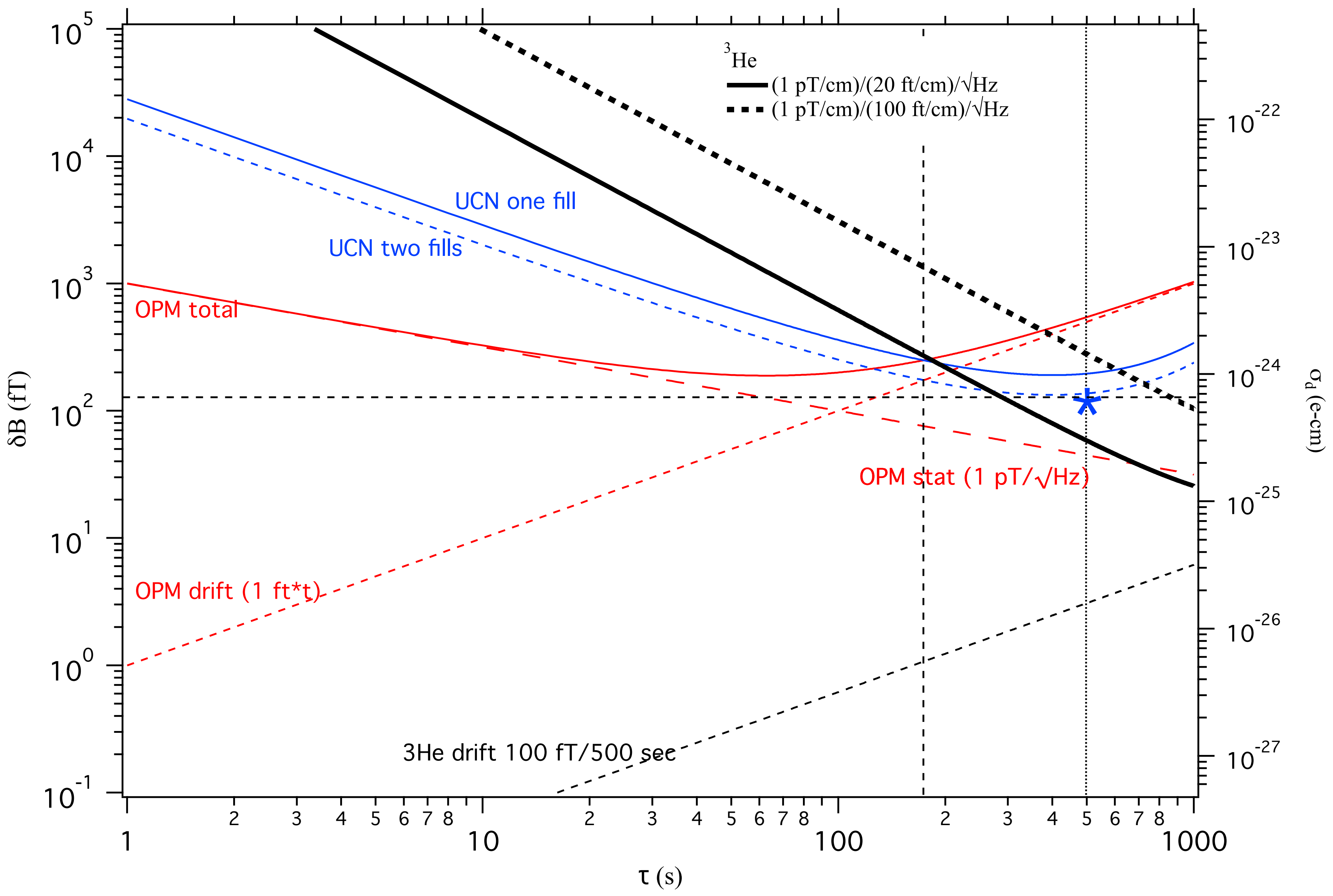
Top View	Side View
	

Magnetometers (U. Michigan)

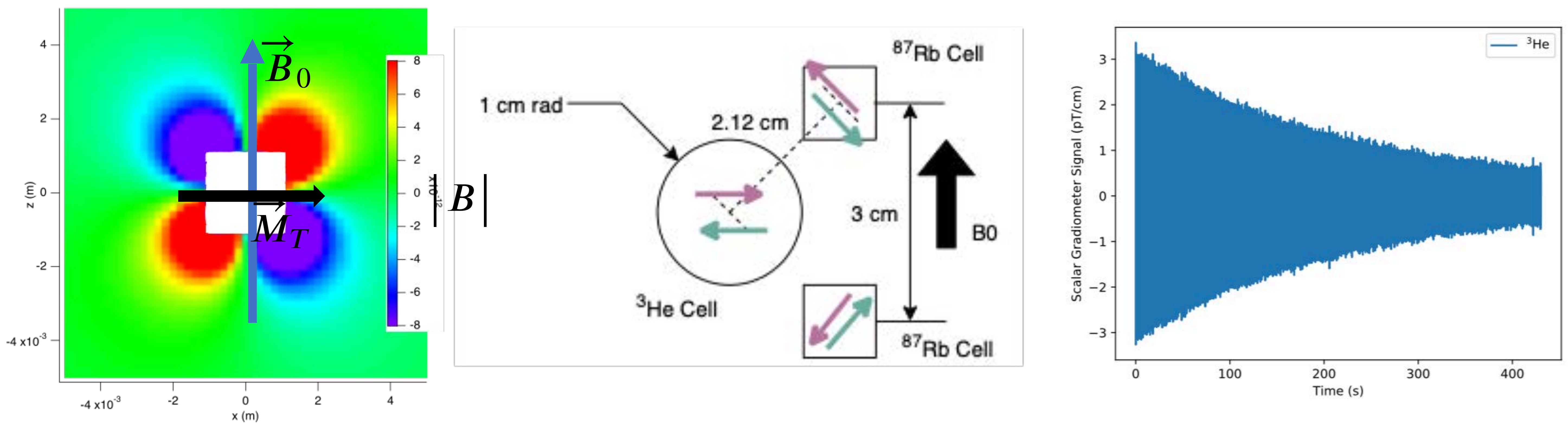
Up to 13 external magnetometers (inside vacuum) monitor B_0, gradients



OPMs (optically pumped ^{87}Rb magnetometers

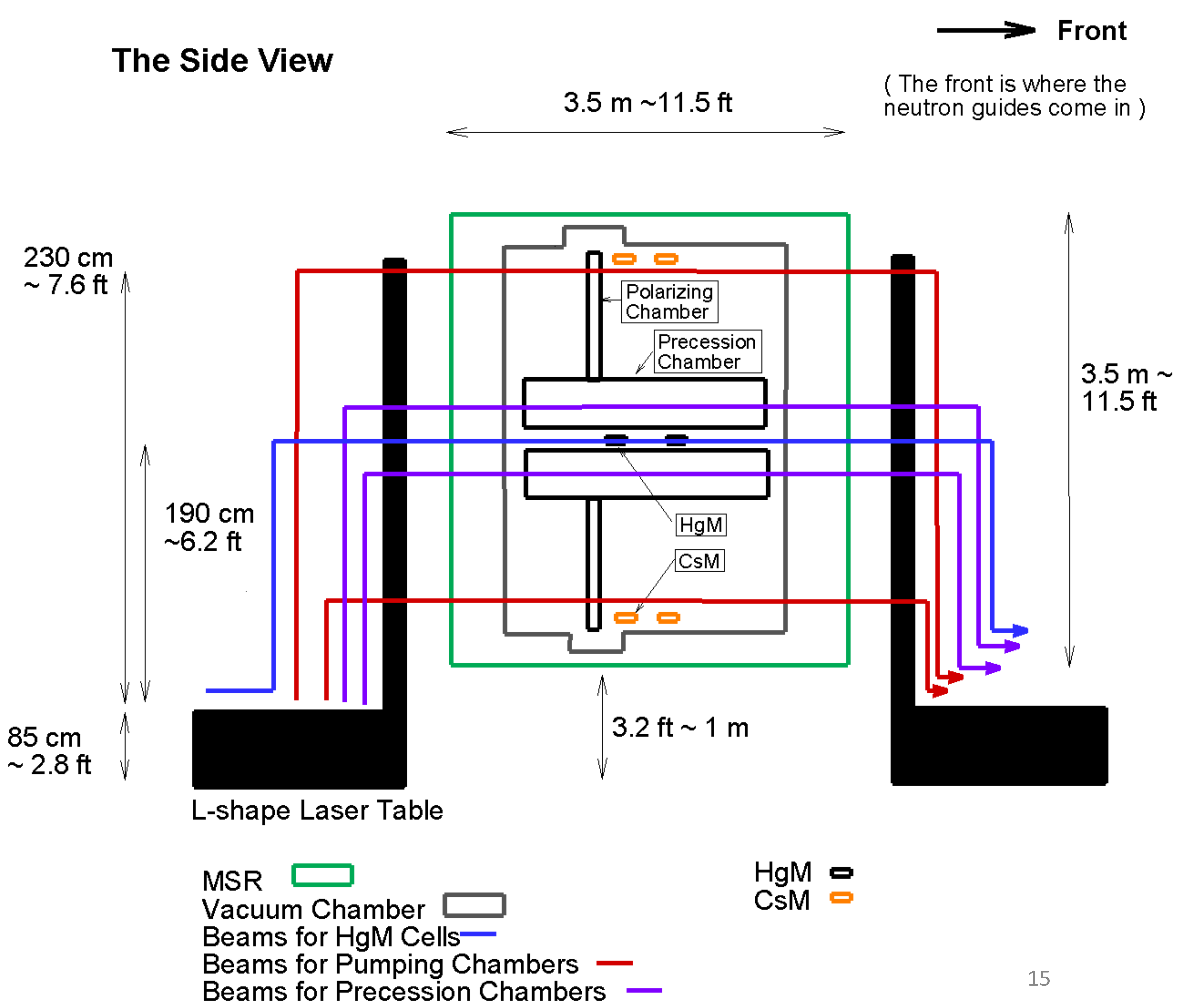


Nuclear spin magnetometers: Hg, ^{3}He (UM/Twinleaf)



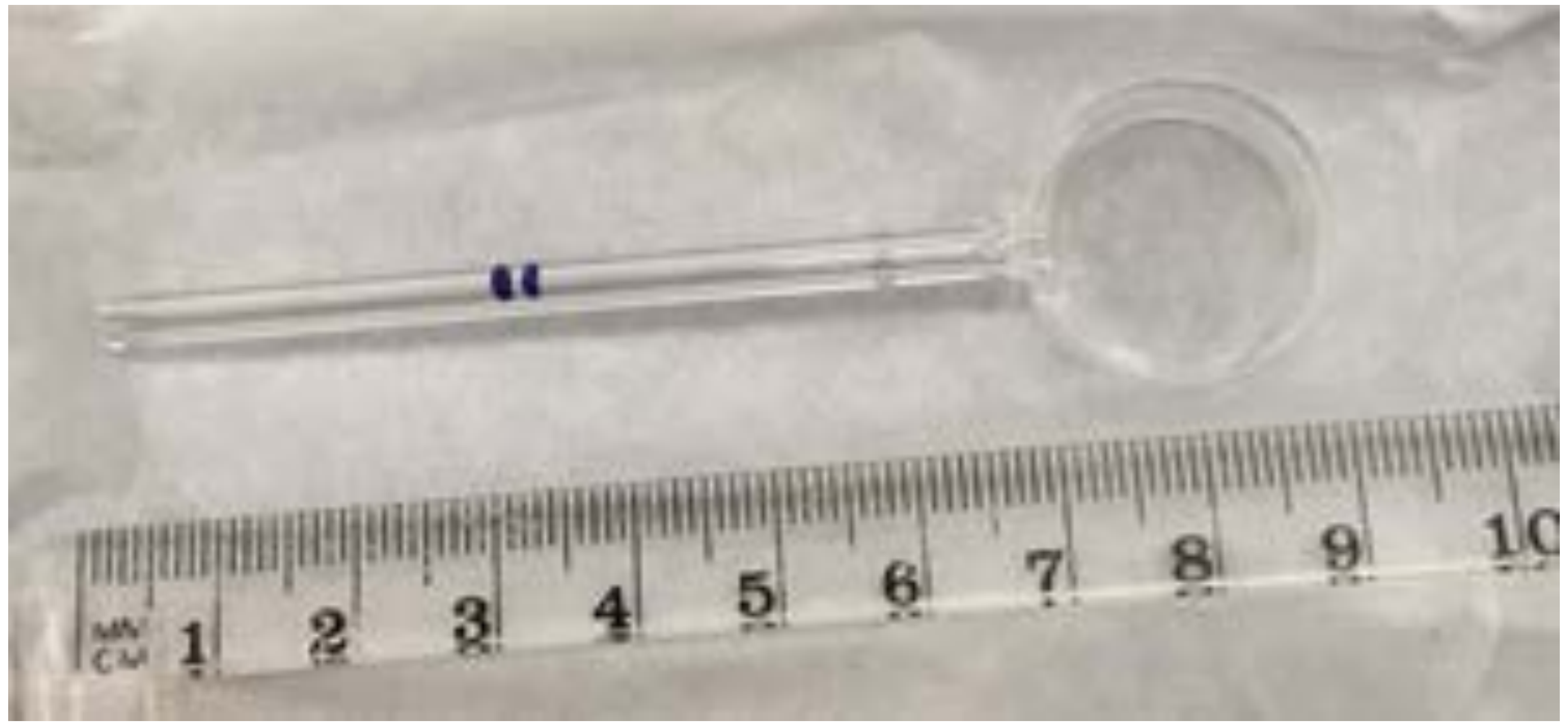
Hg-199 as co-magnetometer and magnetometers (Indiana U, UW)

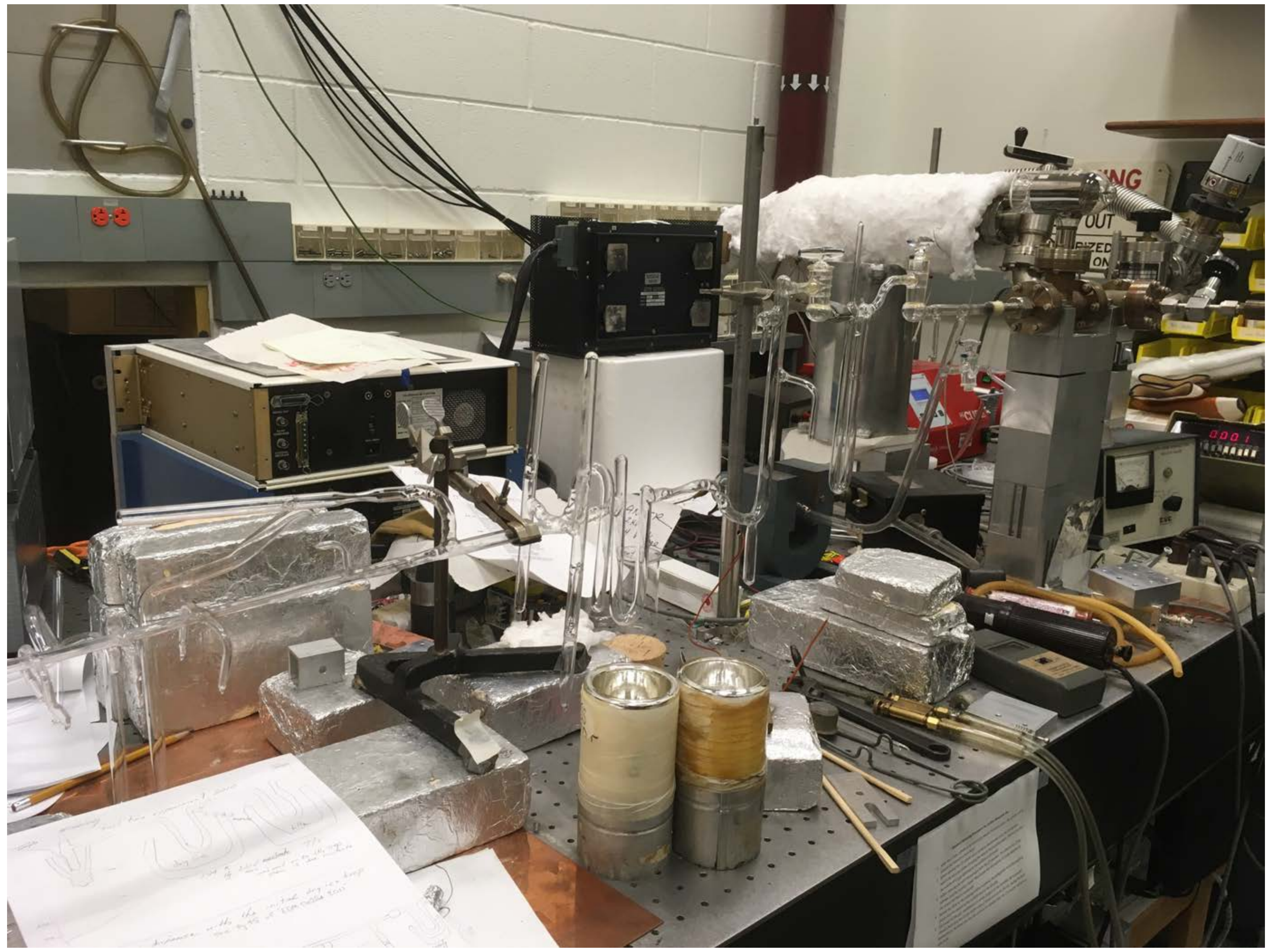
- nEDM@LANL has two precession chambers.
- Hg atoms are optically pumped in the polarizing chamber and then are transferred to the precession chamber to monitor the magnetic field.
- 5 Hg magnetometers(HgMs) are inside the HV electrode.
- All the pump beams come in from the side of MSR.
- The laser beams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

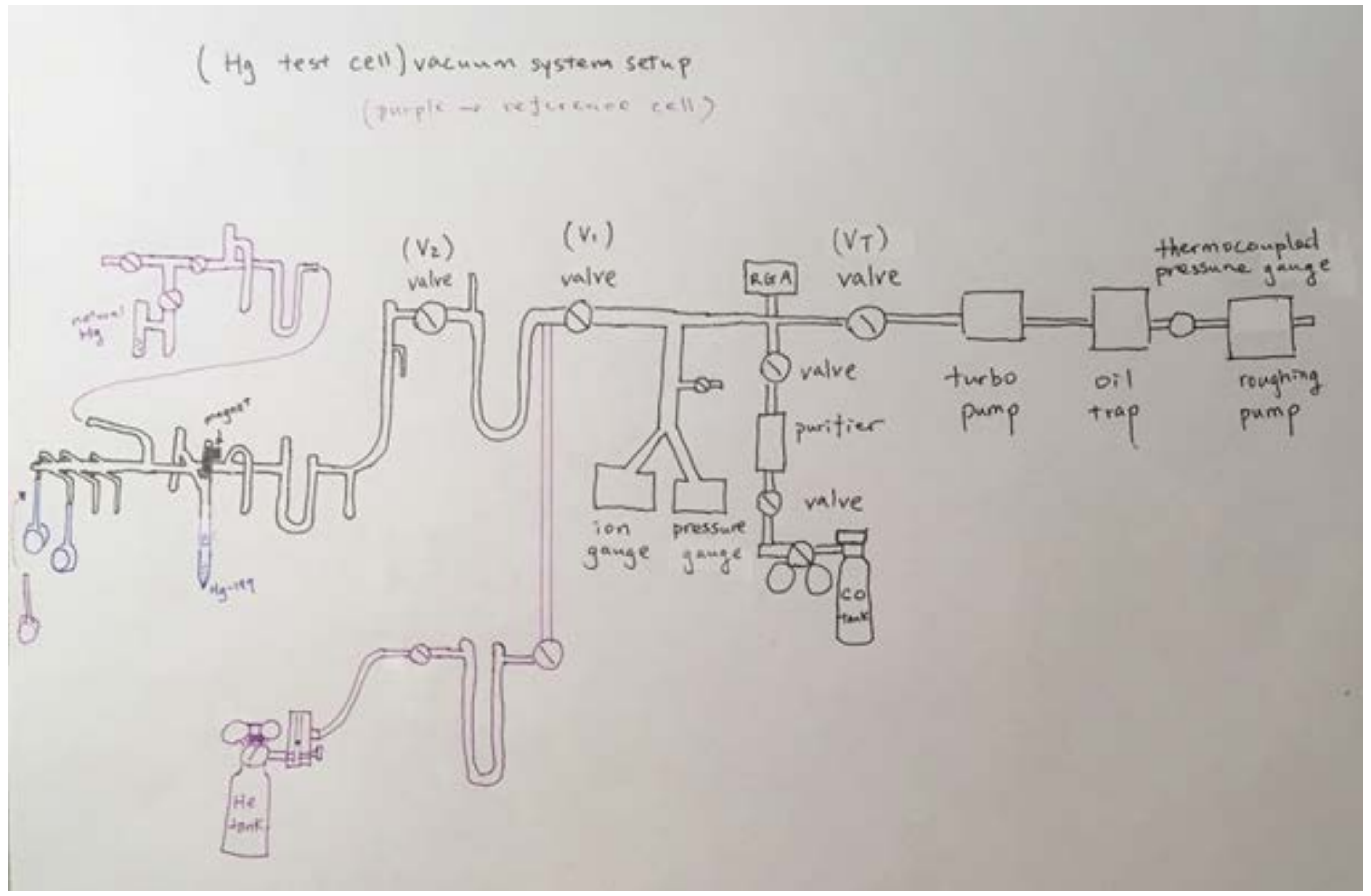


The development of HgM cells

- The long (~120s) and stable coherence time of the cell is required to precisely measure the magnetic field
- The coherence time is dominated by the excess of liquid Hg and the quality of the wall coating.
- Form an atomically uniform layer as the wall coating with various chemicals.







Schedule

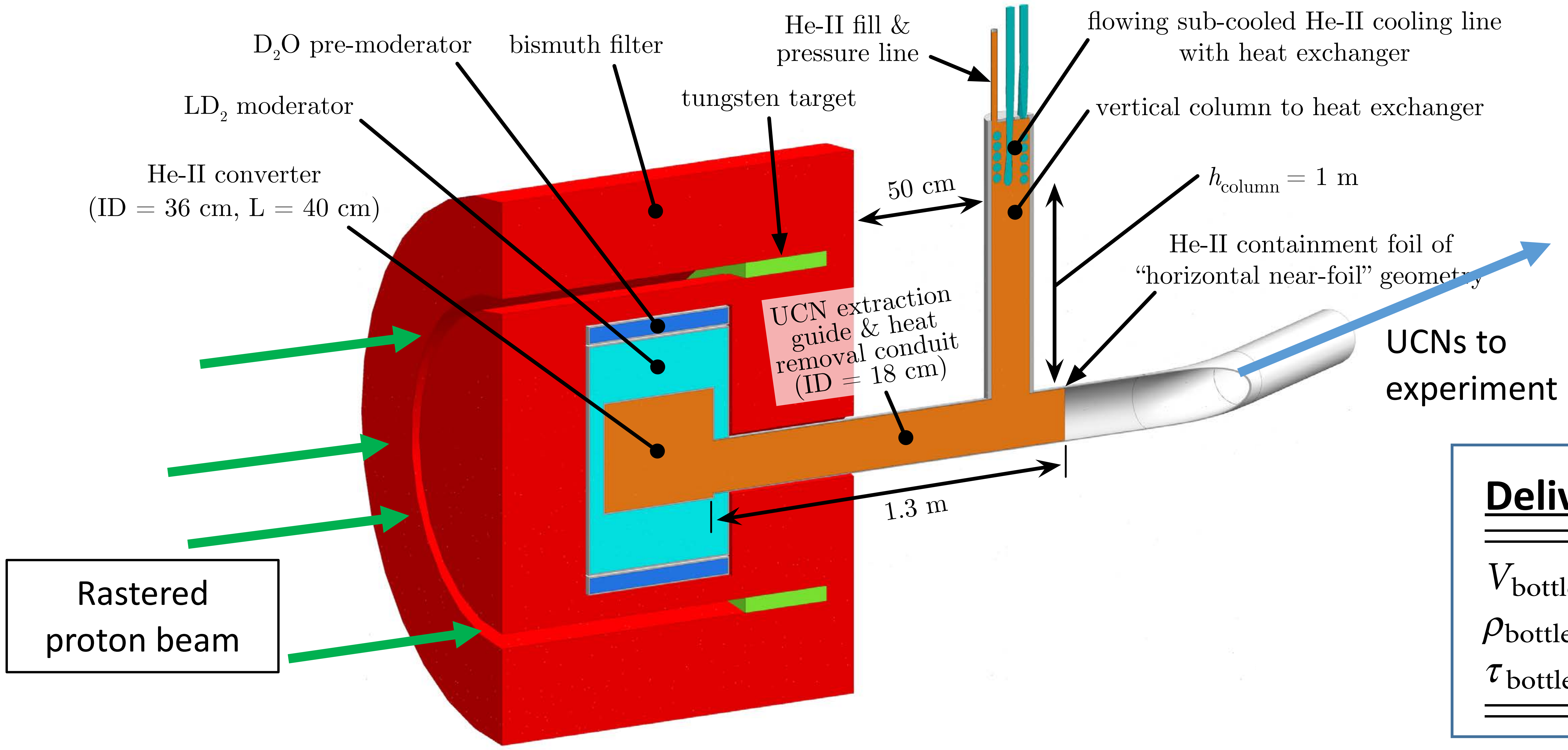
- Remainder of CY 2020:
  - Field cage evaluation
  - Continued study of UCN transport and storage
  - Testing of UCN spin analyzer
  - Fabrication of components for the experiment
  - Prepare the area for MSR installation
- CY 2021
  - Test precession chambers and UCN valves with UCN on the test port
  - MSR installation and characterization
  - B0 coil characterization in MSR
- CY 2022
  - Install the precession chambers inside the MSR
  - Start engineering run/commissioning

My personal view on future development needs

- Impressive advancement by the PSI collaboration in understanding and controlling of systematic effects (in particular those associated with magnetic field non-uniformity).
- Great progress on SNS nEDM.
- To go beyond the experiments that are currently running or being developed, we will need stronger sources of neutrons.
- I would like to see US invest in developing next generation UCN sources.
    - Much higher UCN density will make it possible to use different experimental approaches (eg. smaller cells).
    - Will also benefit other experiments that use UCN

Example: Next-generation inverse-geometry spallation-based SF^{4}He UCN source

- Take 1 MW proton beam (@ 800 MeV studied) and 100 W cooling at 1.6K sub-cooled helium technology (e.g. common at LHC, JLab and SNS).
- Use 40 L of superfluid helium (He-II) for production volume
- Optimized "inverse geometry" spallation target design with cold LD_2 moderator and thermal D_2O pre-moderator.
- Rastered proton beam on ring-shaped target to distribute heat loads to allow edge-water cooling
- Find that can produce 1.8E9 UCN/s in the 40L production volume.



Physics model published in:

K.K.H. Leung, G. Muhrer, T. Hügle, T.M. Ito, E.M. Lutz, M. Makela, C.L. Morris, R.W. Pattie, A. Saunders, A.R. Young
J. Appl. Phys. 126, 224901 (2019)
doi:10.1063/1.5109879

*^{58}Ni cut-off potential & unpolarized

Delivered equilibrium UCN density to external bottle:

V_{bottle} (l)	5	50	500	5×10^3	5×10^4
ρ_{bottle} ($\times 10^4$ UCN cm^{-3})*	1.12	1.11	1.05	0.80	0.31
τ_{bottle} (s) (Filling time)	0.11	1.1	10	80	315

- If continue to use 20 L nEDM cell, then ~100x improvement in statistical sensitivity possible
- If reduce cell volume to reduce systematics, then ~10x improvement in sensitivity