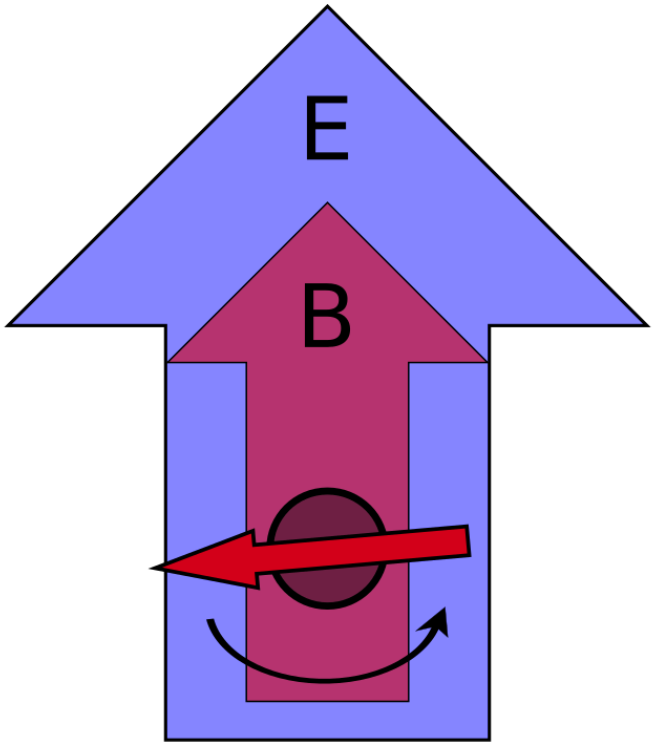
Overview of the n2EDM Experiment

Dieter Ries
dieter.ries@psi.ch

nEDM2023 workshop

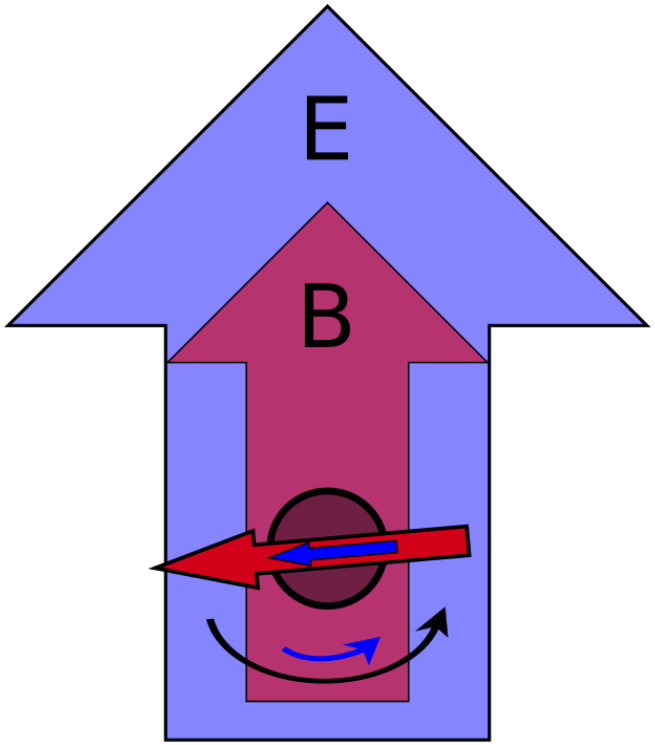
November 6, 2023

How do we measure an EDM?



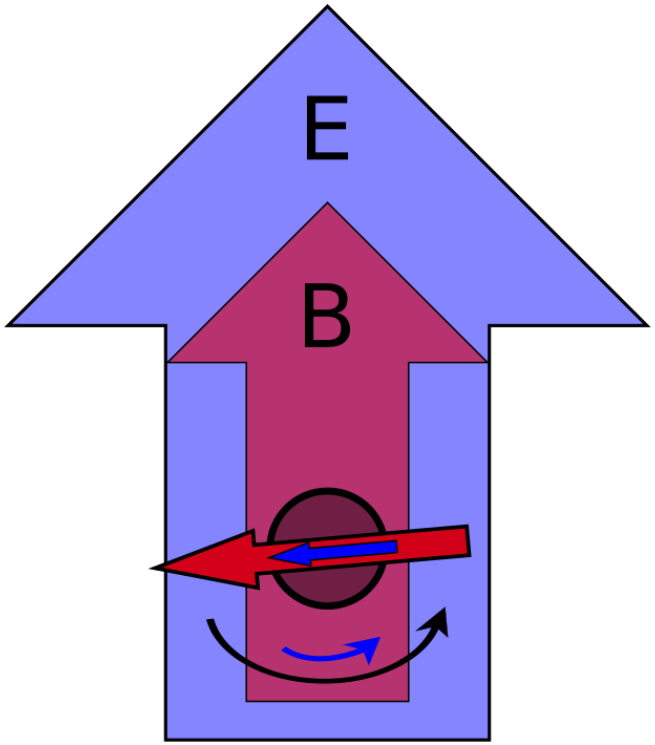
$$2\pi f = \frac{2\mu}{\hbar} B$$

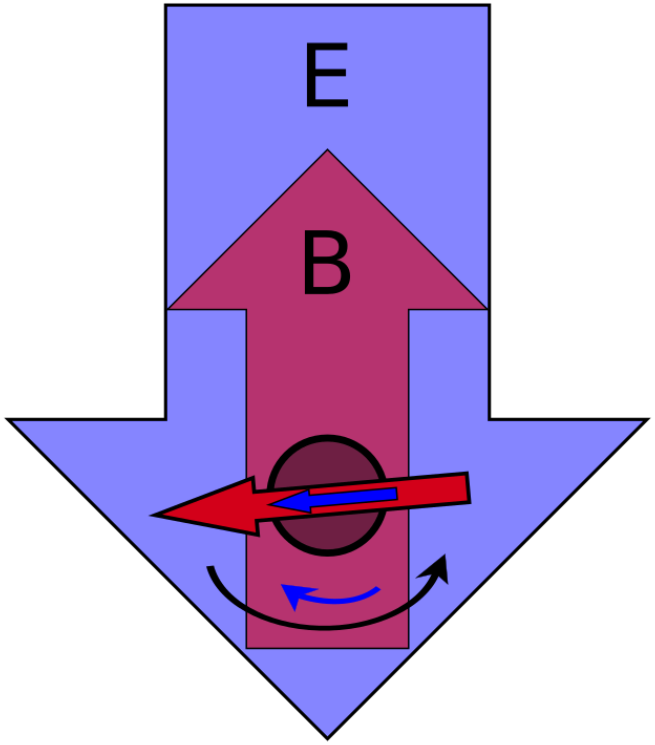
How do we measure an EDM?



$$2\pi f = \frac{2\mu}{\hbar}B + \frac{2d}{\hbar}E$$

How do we measure an EDM?





$$2\pi f = \frac{2\mu}{\hbar}B + \frac{2d}{\hbar}E$$

$$2\pi f = \frac{2\mu}{\hbar}B - \frac{2d}{\hbar}E$$

How do we measure an EDM?

$$f(\uparrow\uparrow) - f(\uparrow\downarrow) = \frac{2}{\pi\hbar} dE$$

How do we measure an EDM?

$$f(\uparrow\uparrow) - f(\uparrow\downarrow) = \frac{2}{\pi\hbar} dE$$

'Never measure anything but frequency!'

Arthur Schawlow

Caveat

$$2\pi f(\uparrow\uparrow) = \frac{2\mu}{\hbar}B + \frac{2d}{\hbar}E$$
$$2\pi f(\uparrow\downarrow) = \frac{2\mu}{\hbar}B - \frac{2d}{\hbar}E$$

$$f(\uparrow\uparrow) - f(\uparrow\downarrow) = \frac{2}{\pi\hbar}dE$$

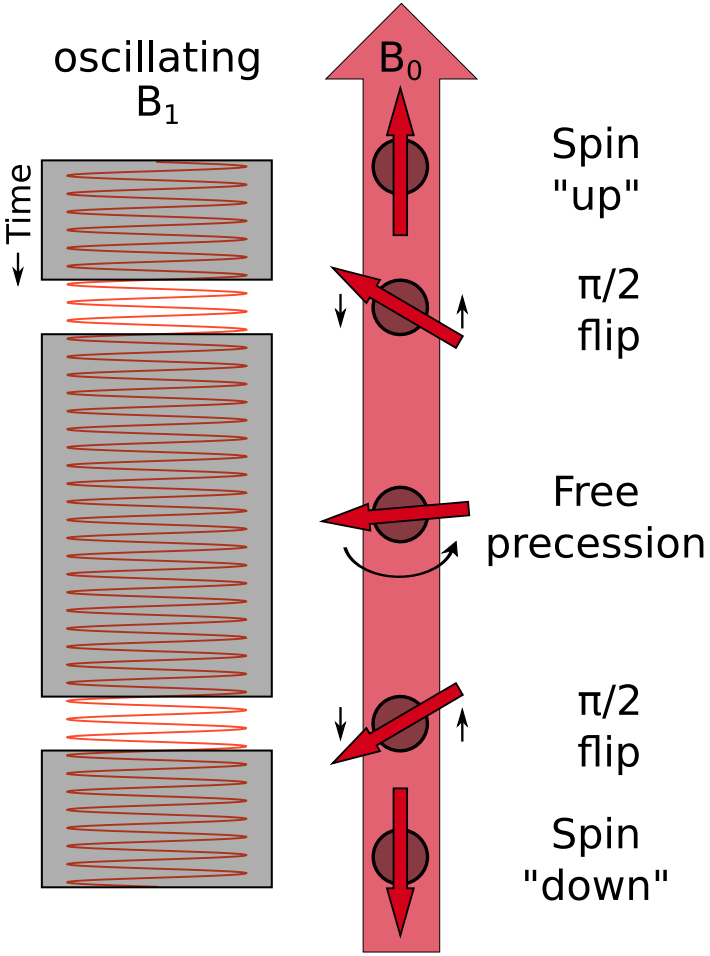
Caveat

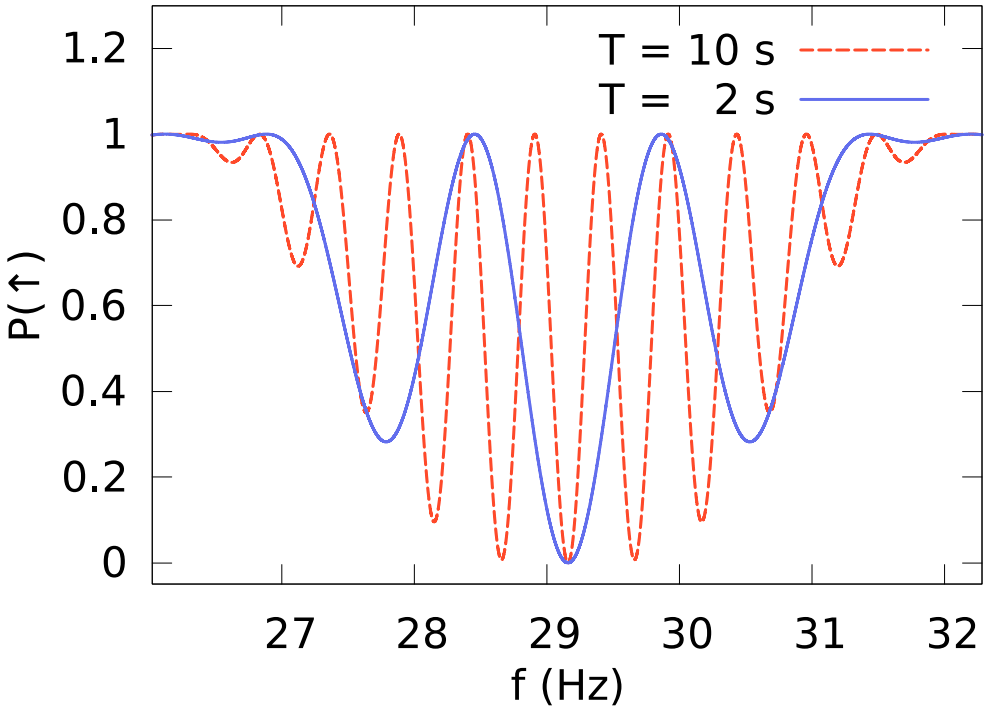
$$2\pi f(\uparrow\uparrow) = \frac{2\mu}{\hbar}B + \frac{2d}{\hbar}E$$
$$2\pi f(\uparrow\downarrow) = \frac{2\mu}{\hbar}B - \frac{2d}{\hbar}E$$

$$f(\uparrow\uparrow) - f(\uparrow\downarrow) = \frac{2}{\pi\hbar}dE$$

only if: $\frac{2\mu}{\hbar}(B(t \mathrel{\hat{=}} \uparrow\uparrow) - B(t \mathrel{\hat{=}} \uparrow\downarrow)) = 0$

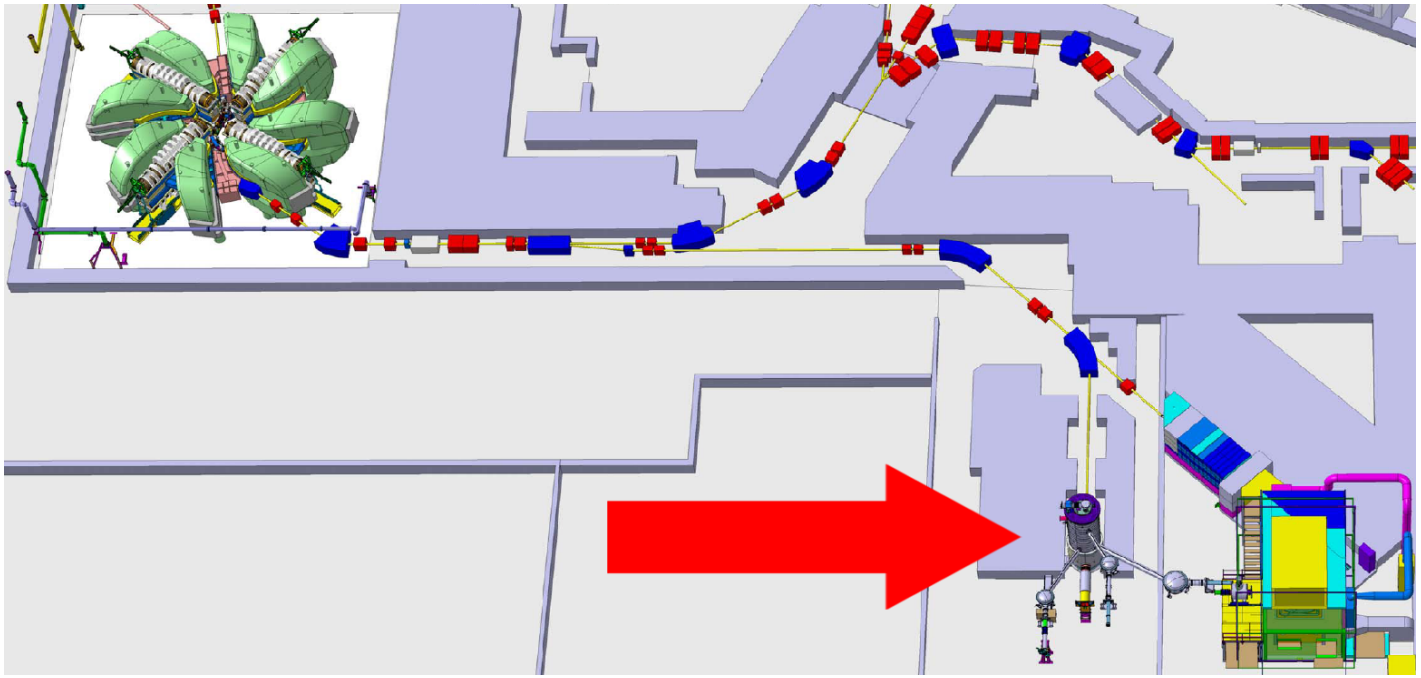
Ramsey's method of separated oscillatory fields

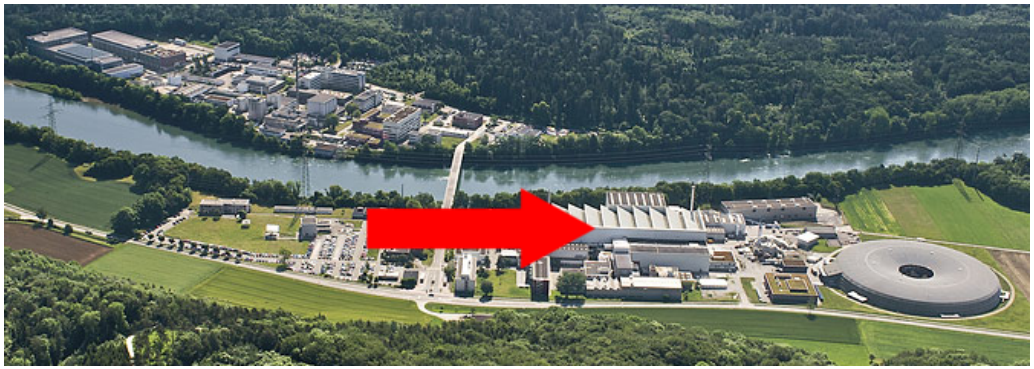




- Precision spectroscopy
- Atomic clocks
- EDM measurements

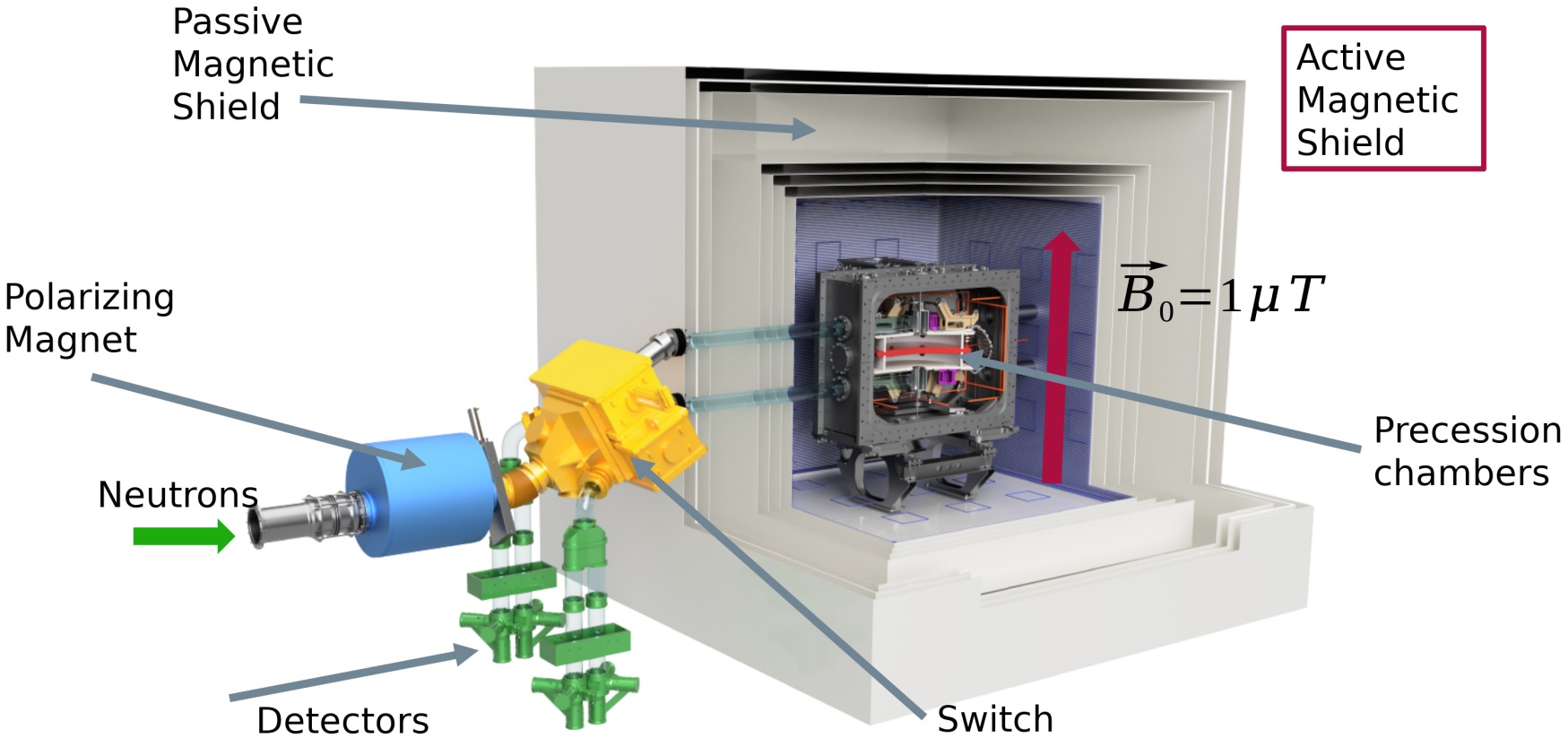
n2EDM at Paul Scherrer Institute





- Paul Scherrer Institut, Villigen, Switzerland
- 590 MeV proton accelerator
- up to 2.4 mA beam current

n2EDM Overview



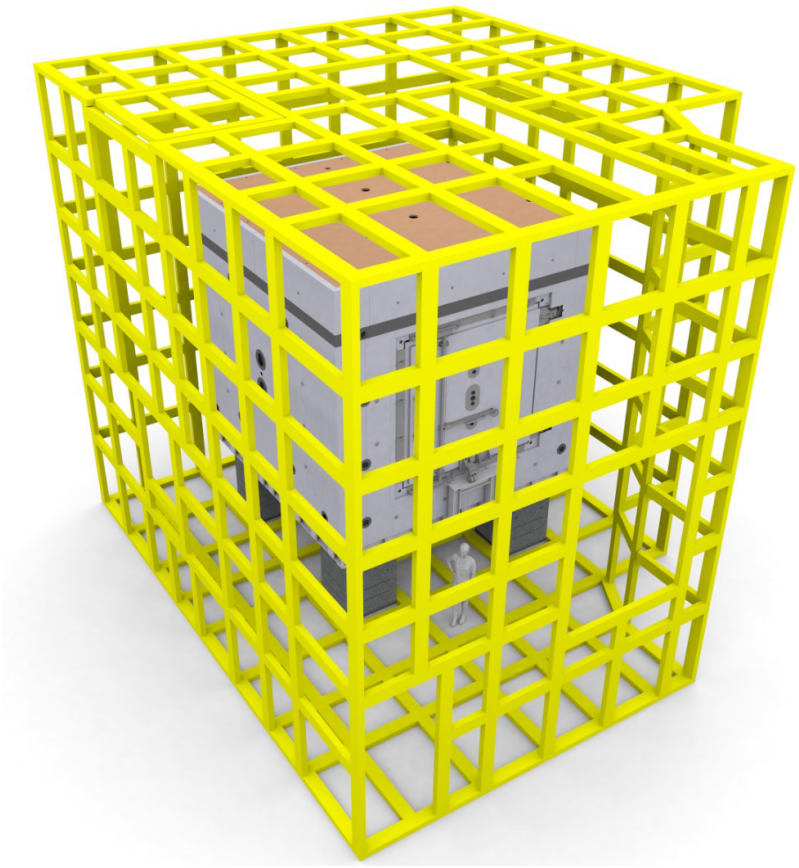
Polarizing Magnet

5 T superconducting solenoid

200 mm warm bore

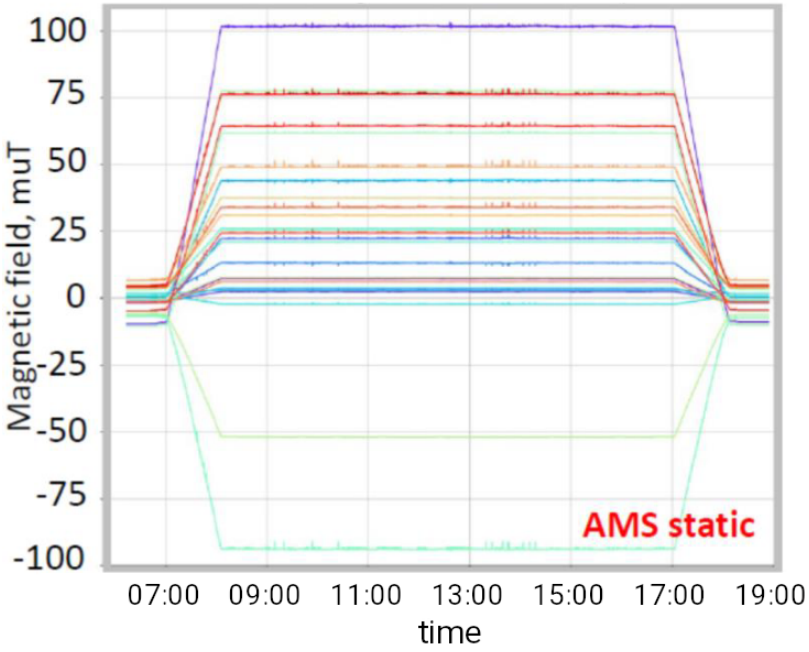
Active Magnetic Shielding

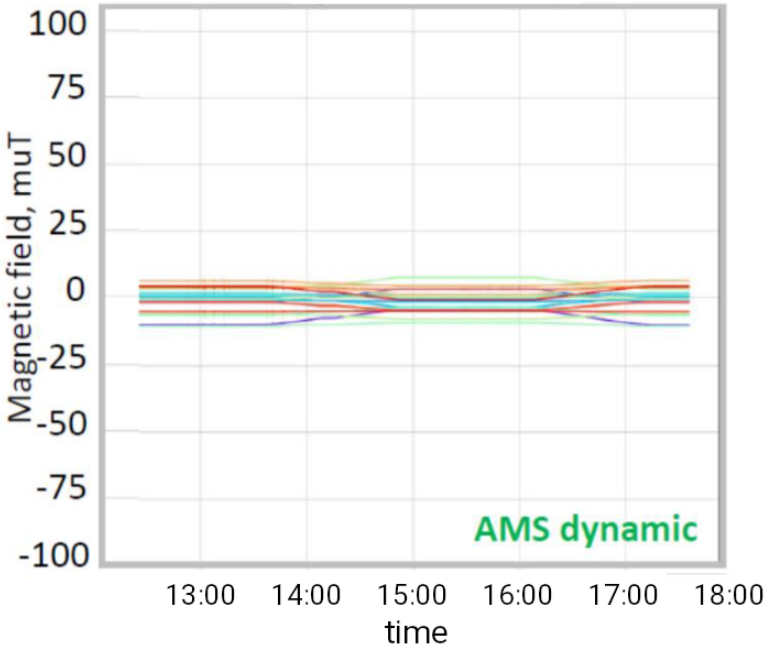
- 8 independent Coils
  - 3 currents each
- 490 wire paths
- 55 km wires
- 3.2 t of wire
- 780 m cable trays
- Several kW heat



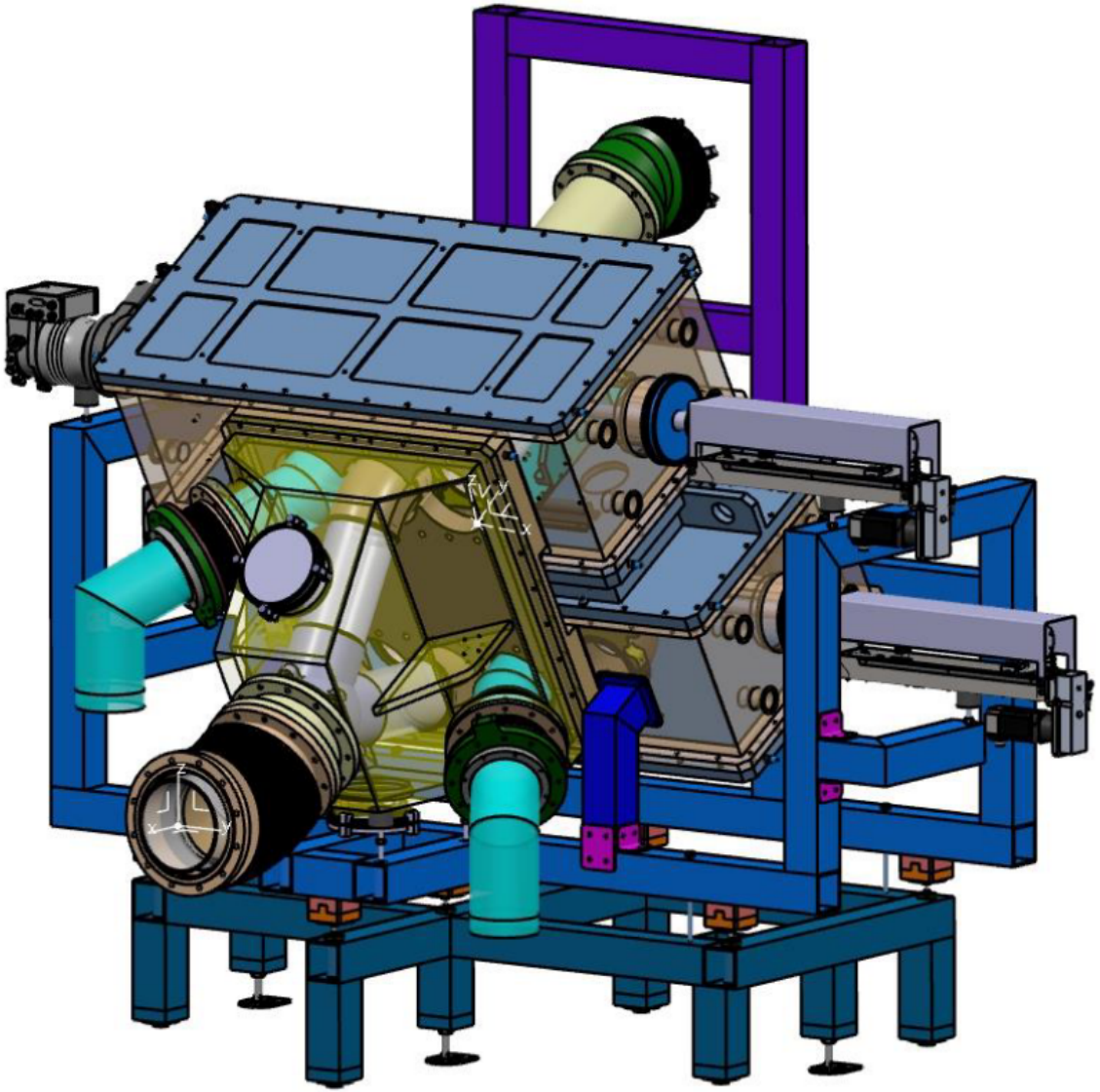
Artistic AMS

Fluxgate readings outside the MSR





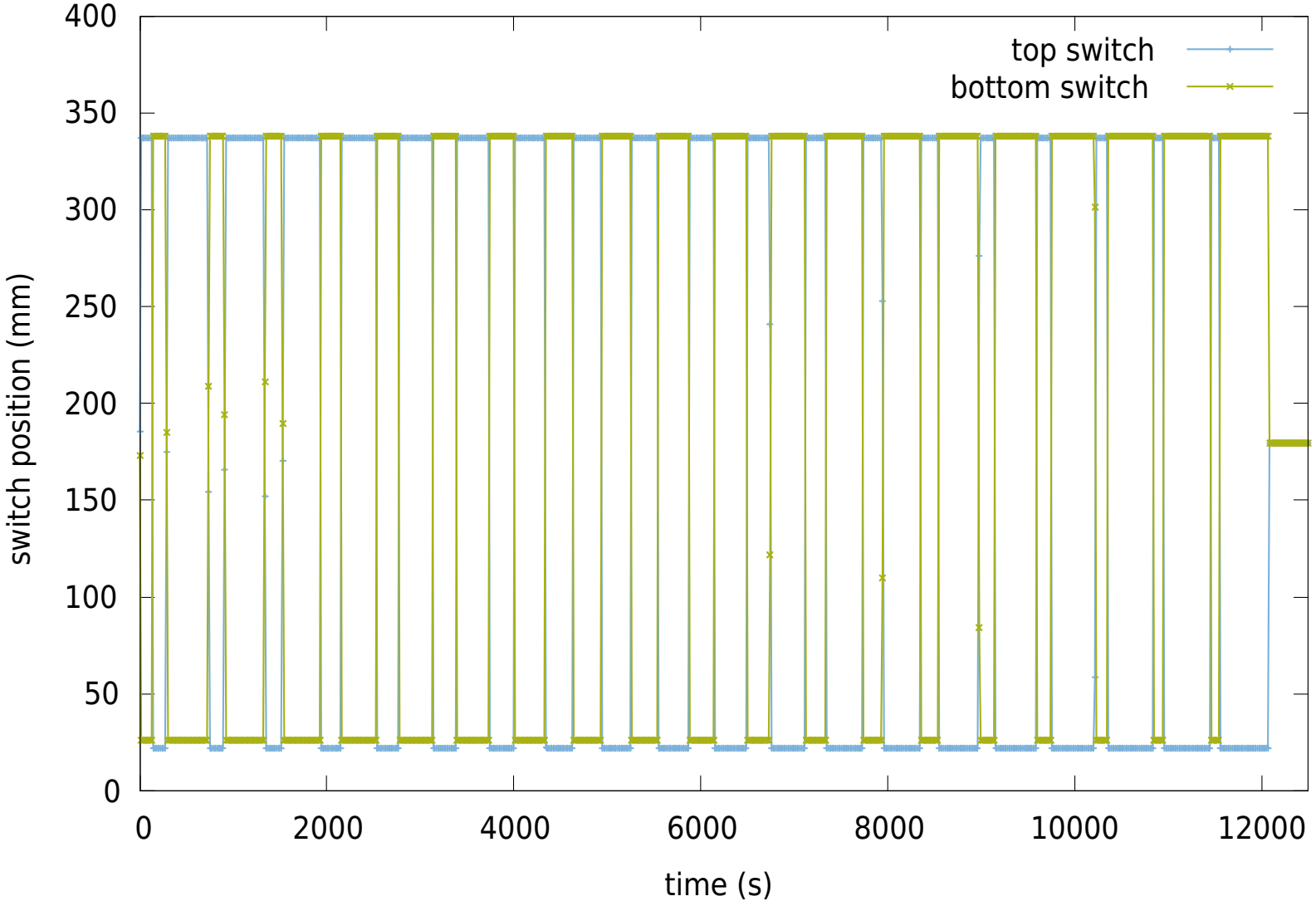
UCN Switch



UCN Switch

UCN Switch

UCN Switch Performance

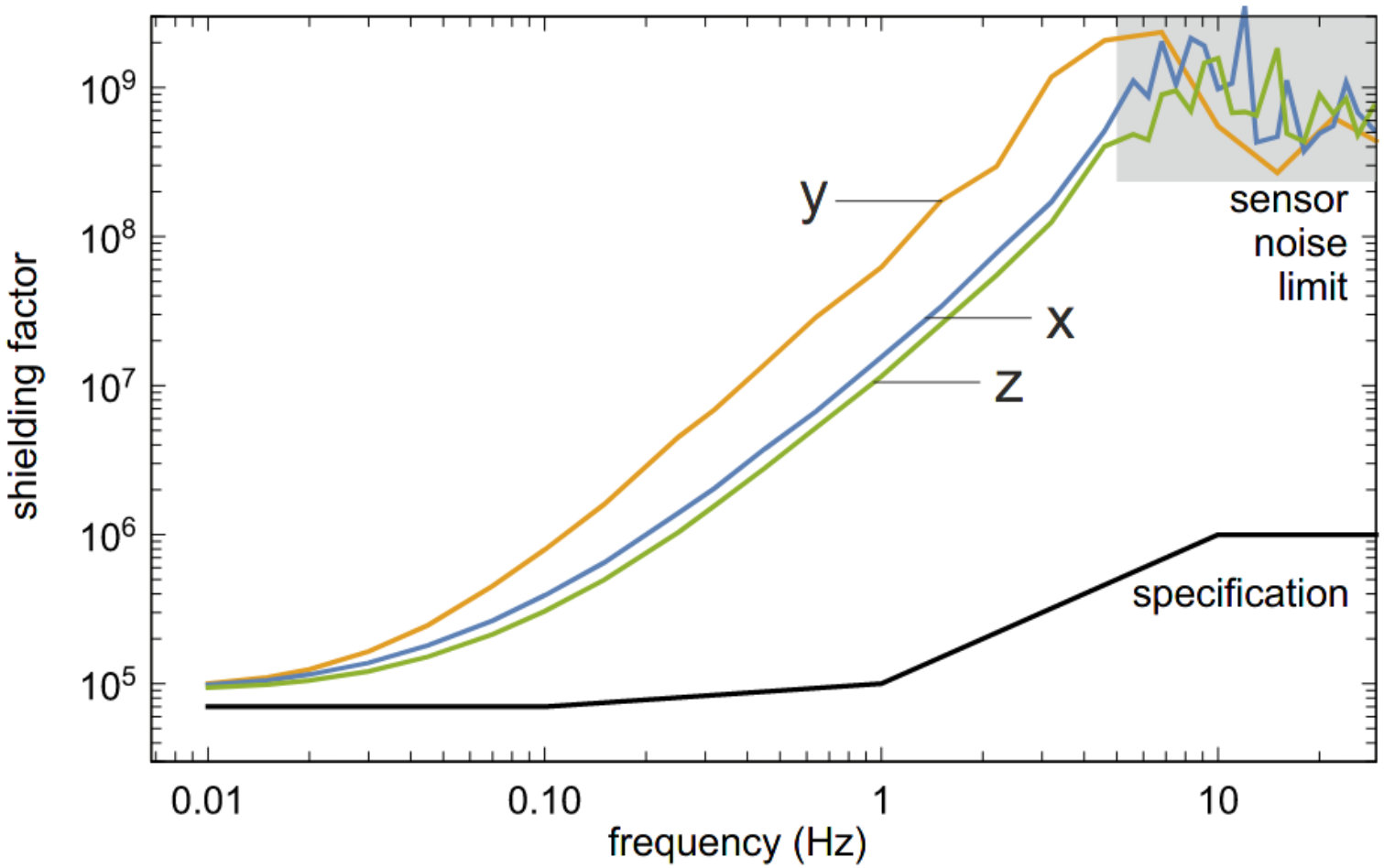


Magnetically Shielded Room

$< 100\,\mathrm{pT}$ in inner m^3 shielding factor 10^5 at $0.01\,\mathrm{Hz}$

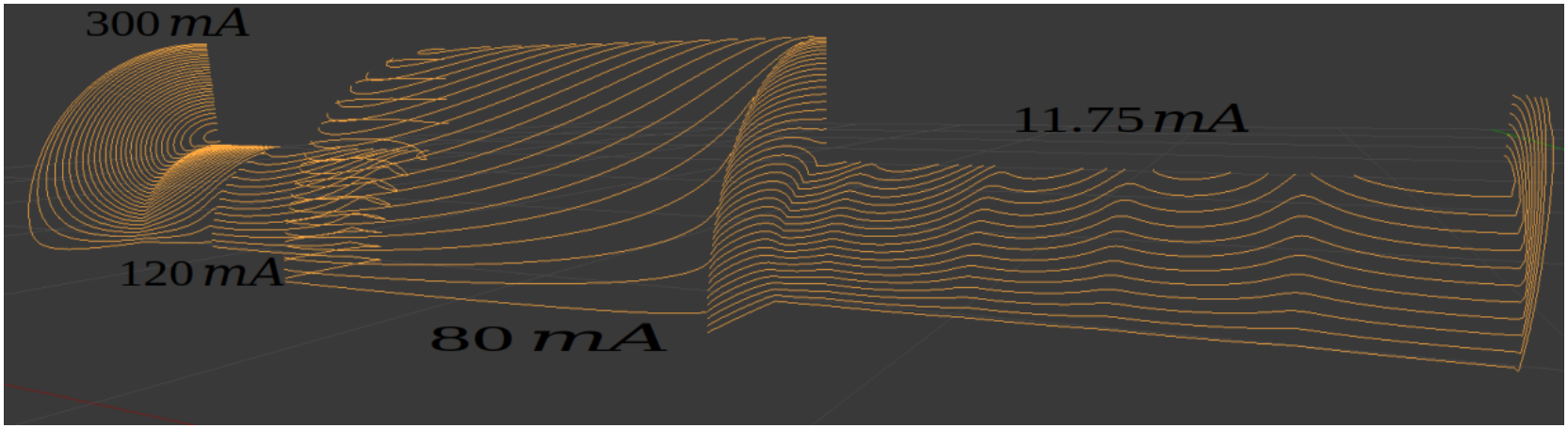
MSR in Thermal Shell / AMS

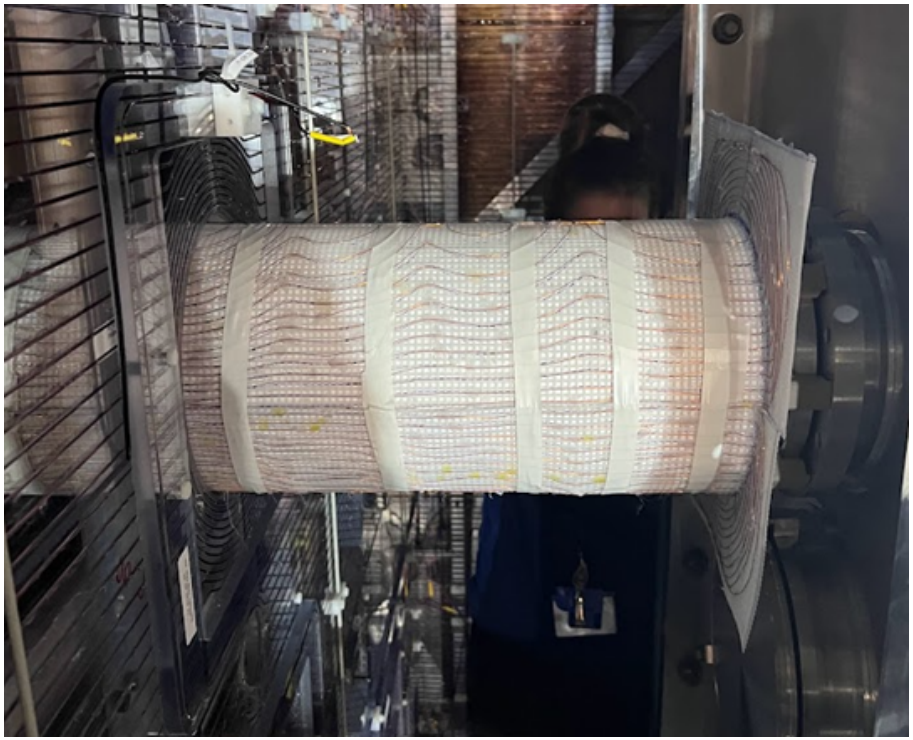
MSR Performance



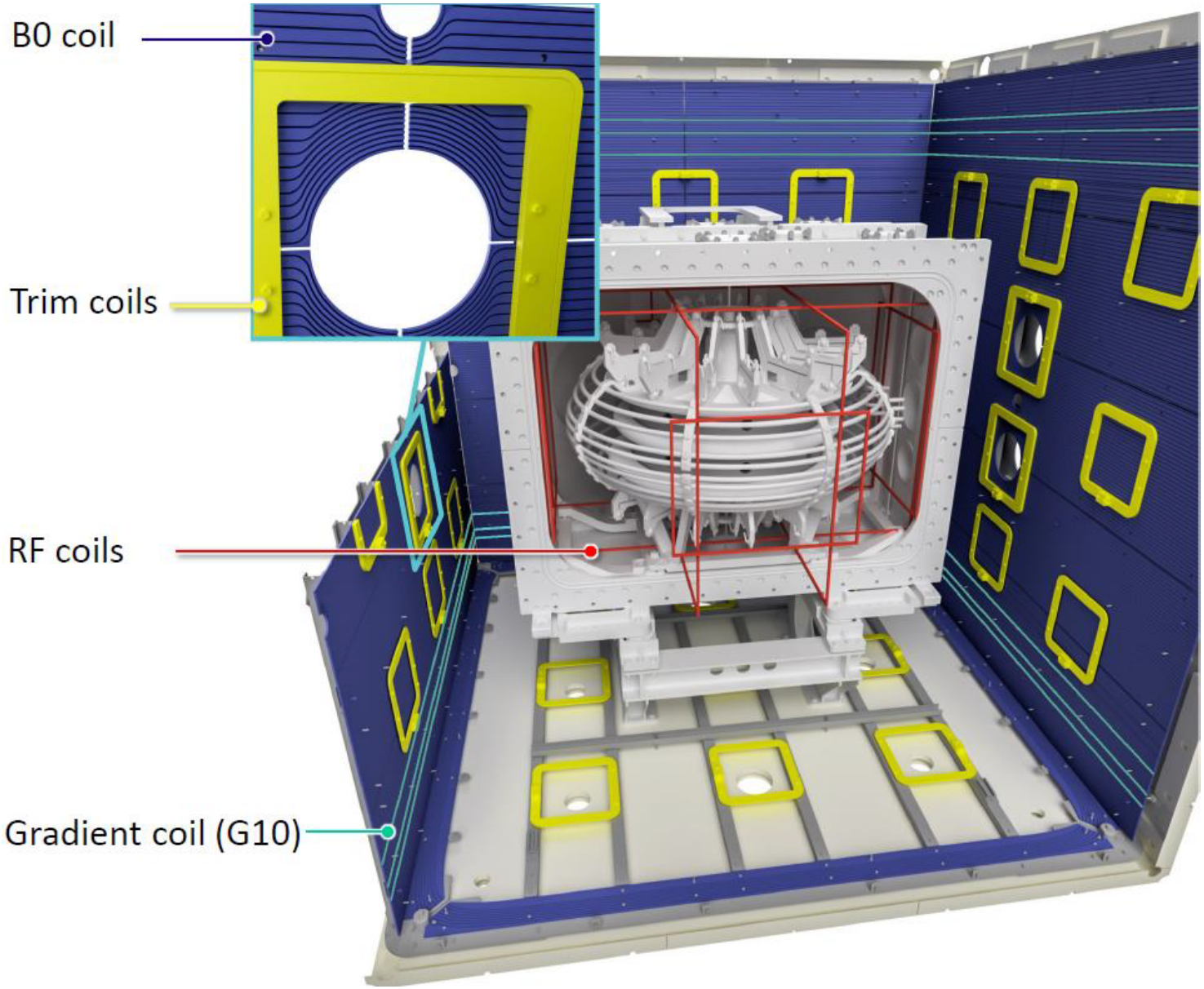
Rev. Sci. Instrum. 93, 095105 (2022) arXiv:2206.10714

Spin Guiding Field

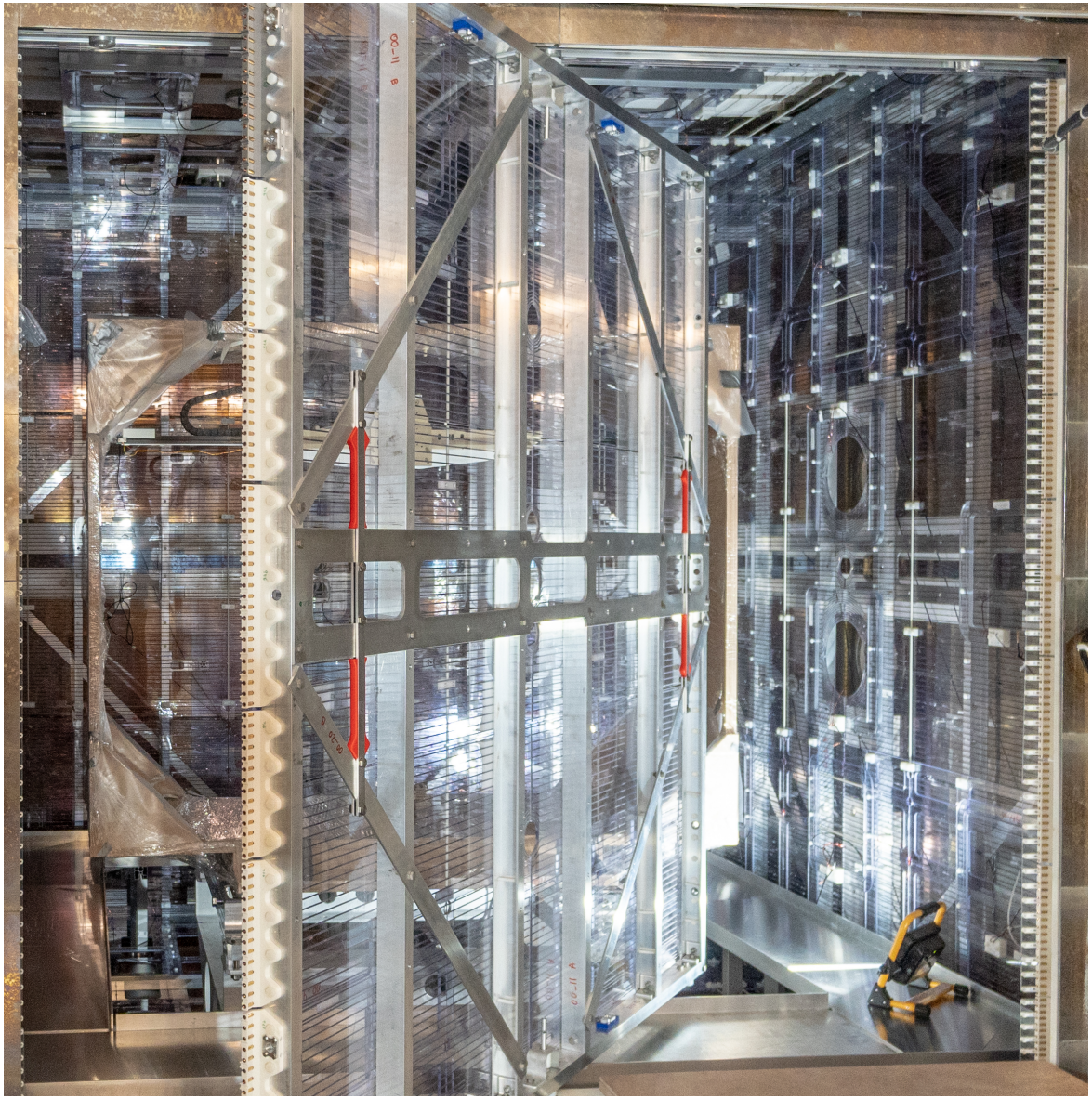




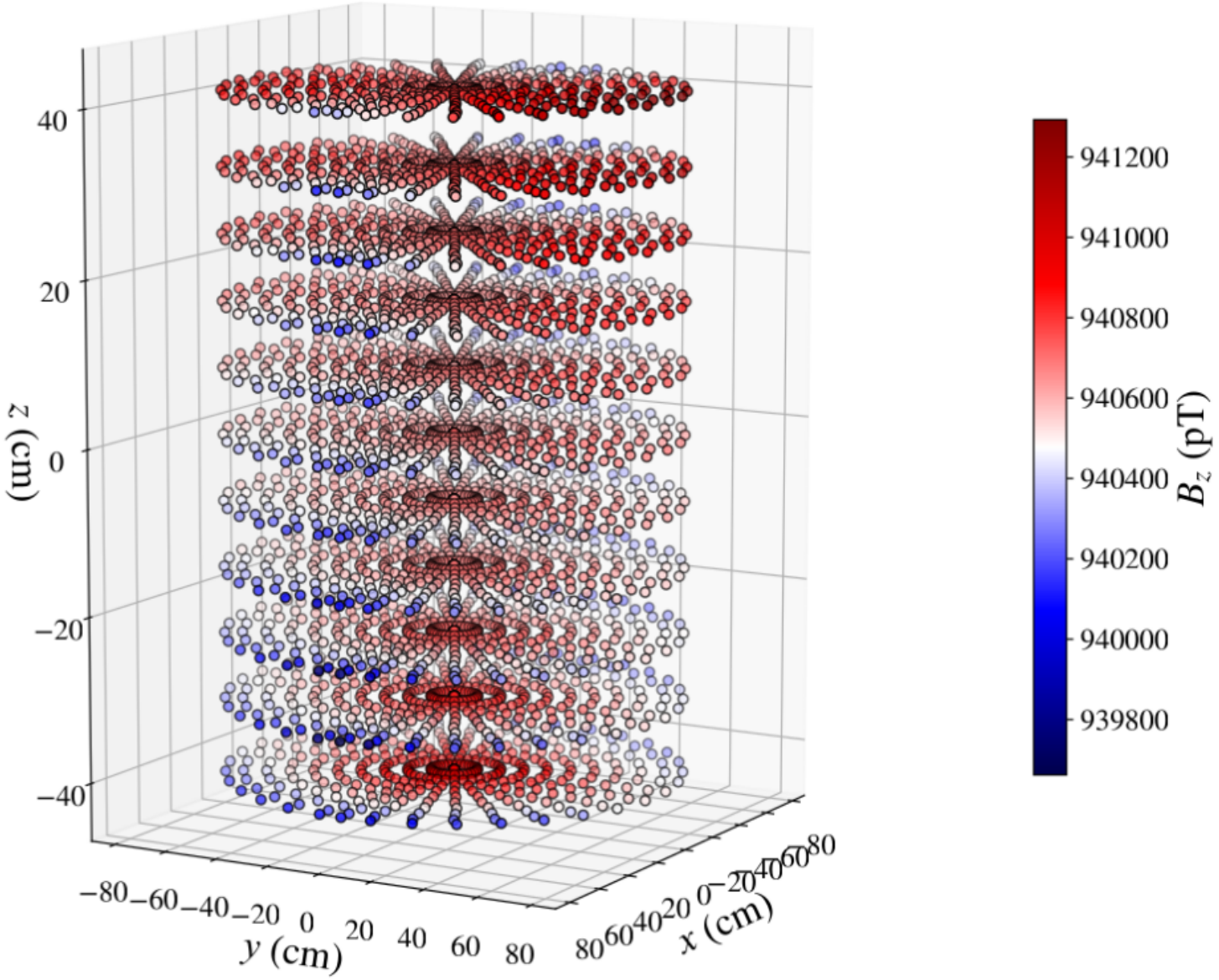
B0 and Trim/Gradient Coils



B0 and Trim/Gradient Coils



B0 Homogeneity



Magnetic Field Performance

Requirements for B field generation (TDR 2021)

- Field uniformity in chambers: $\sigma(B_z) < 170\,\mathrm{pT}$
- Top-Bottom gradient: $-0.6\,\mathrm{pT\,cm^{-1}} < G_{1,0} < 0.6\,\mathrm{pT\,cm^{-1}}$
- Reproducibility of order 5 gradient: $\sigma(G_5) < 20\,\mathrm{fT\,cm^{-1}}$

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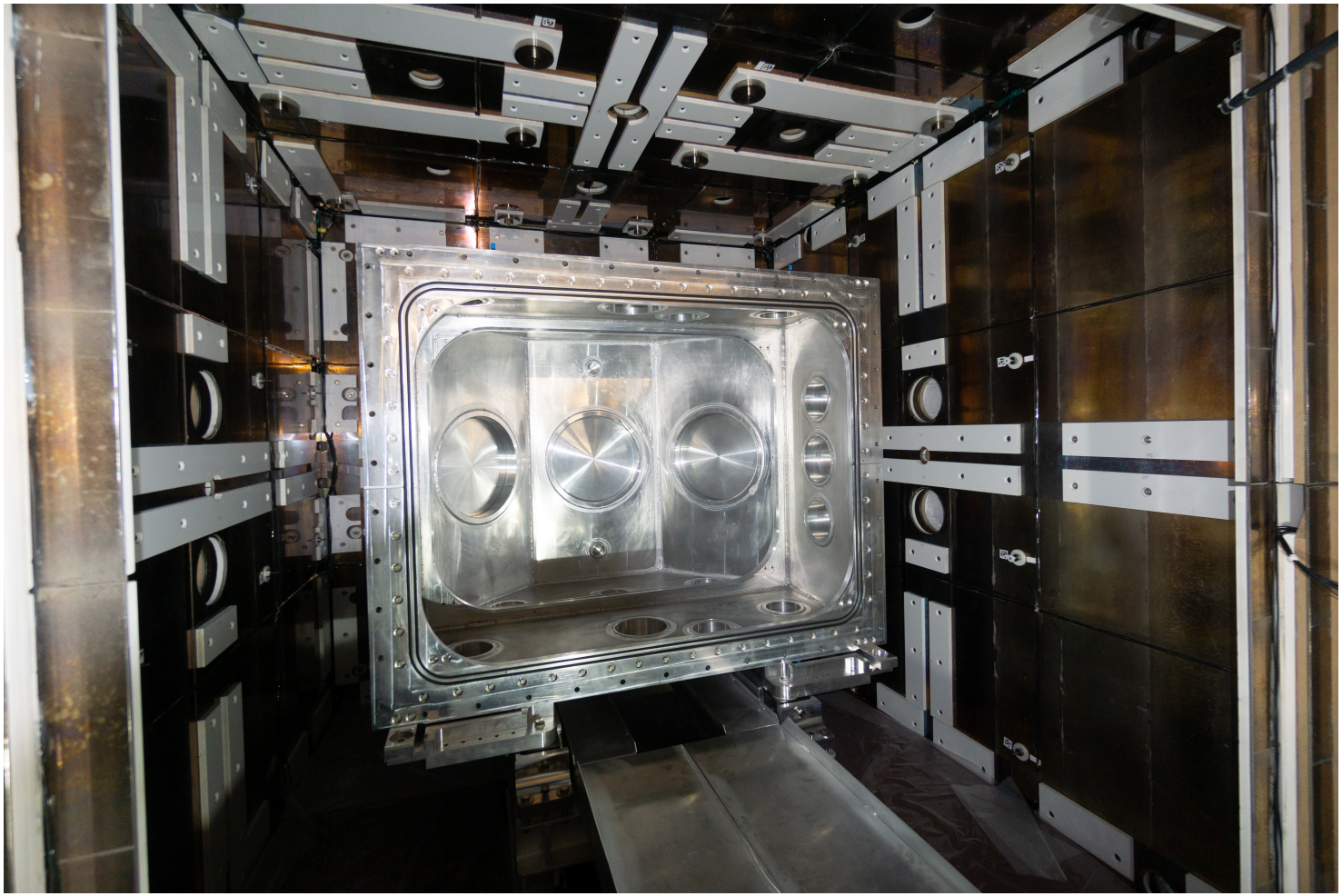
Measured parameters:

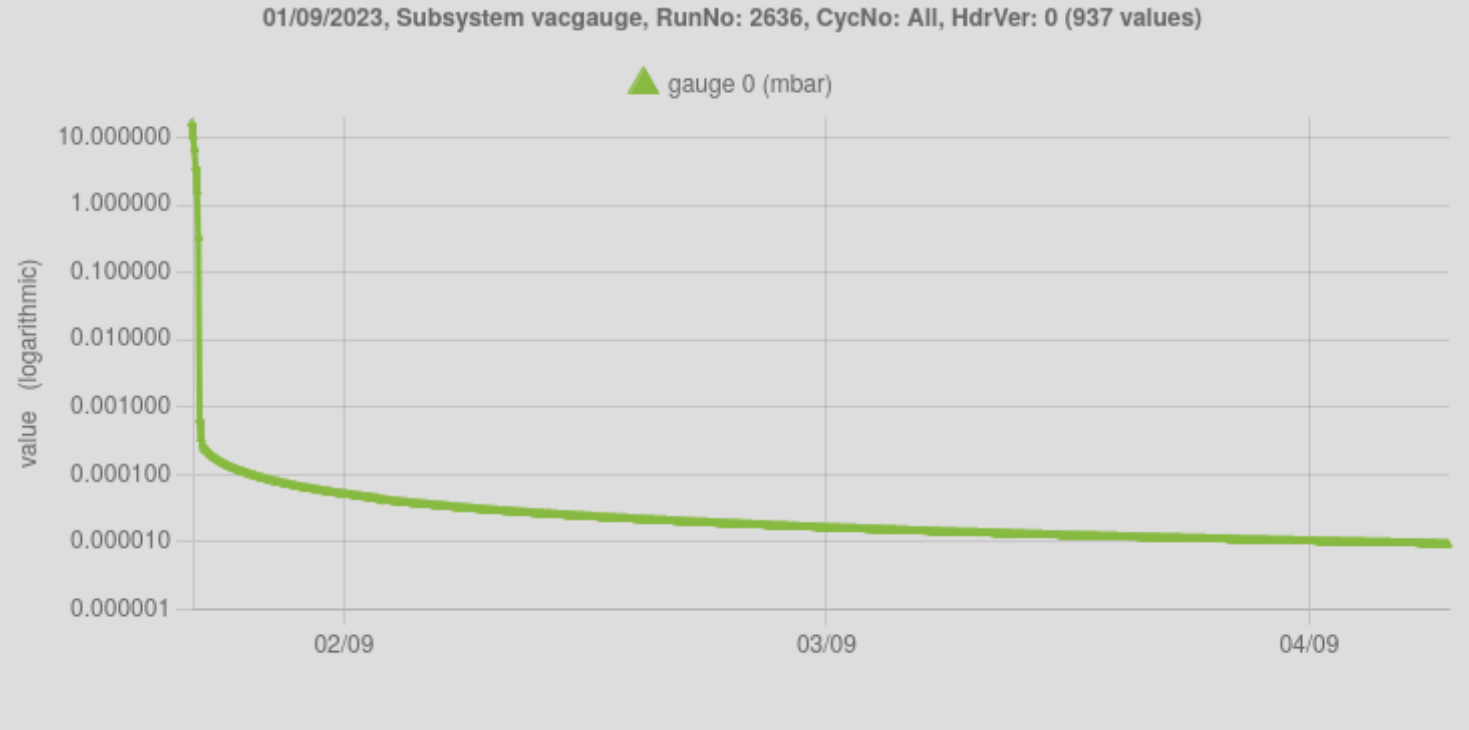
- Field uniformity in chambers: $\sigma(B_z) = 49\,\mathrm{pT}$ ✓
- Top-Bottom gradient: $G_{1,0} = (0.35 \pm 0.25)\,\mathrm{pT\,cm^{-1}}$ ✓
- Reproducibility of order 5 gradient: $\sigma(G_5) = (3.5 \pm 4.3)\,\mathrm{fT\,cm^{-1}}$ ✓

Vacuum Tank

Vacuum Tank

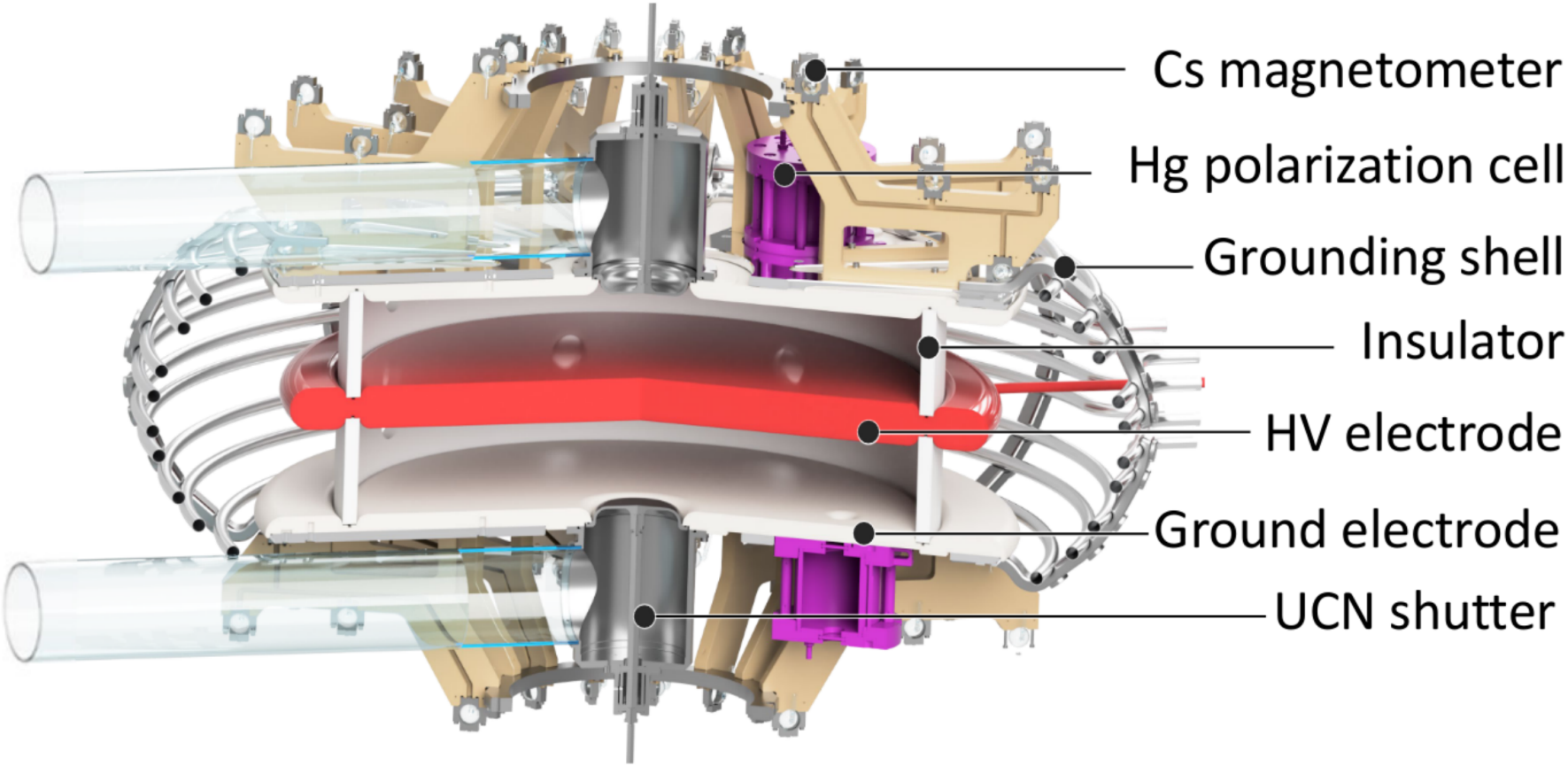


Vacuum

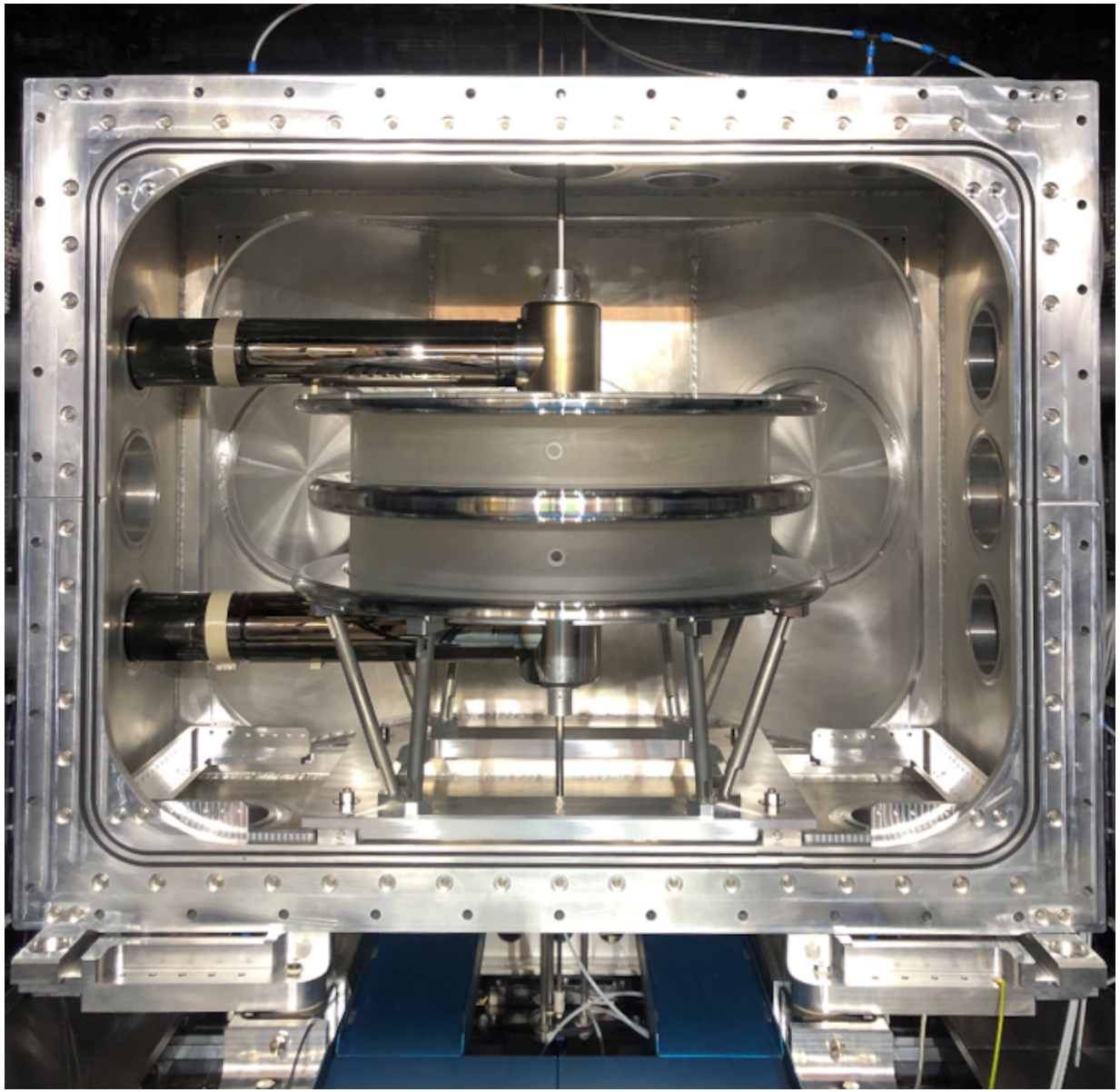


Non-magnetic aluminium construction
Final pressure $< 1 \times 10^{-6}$ mbar

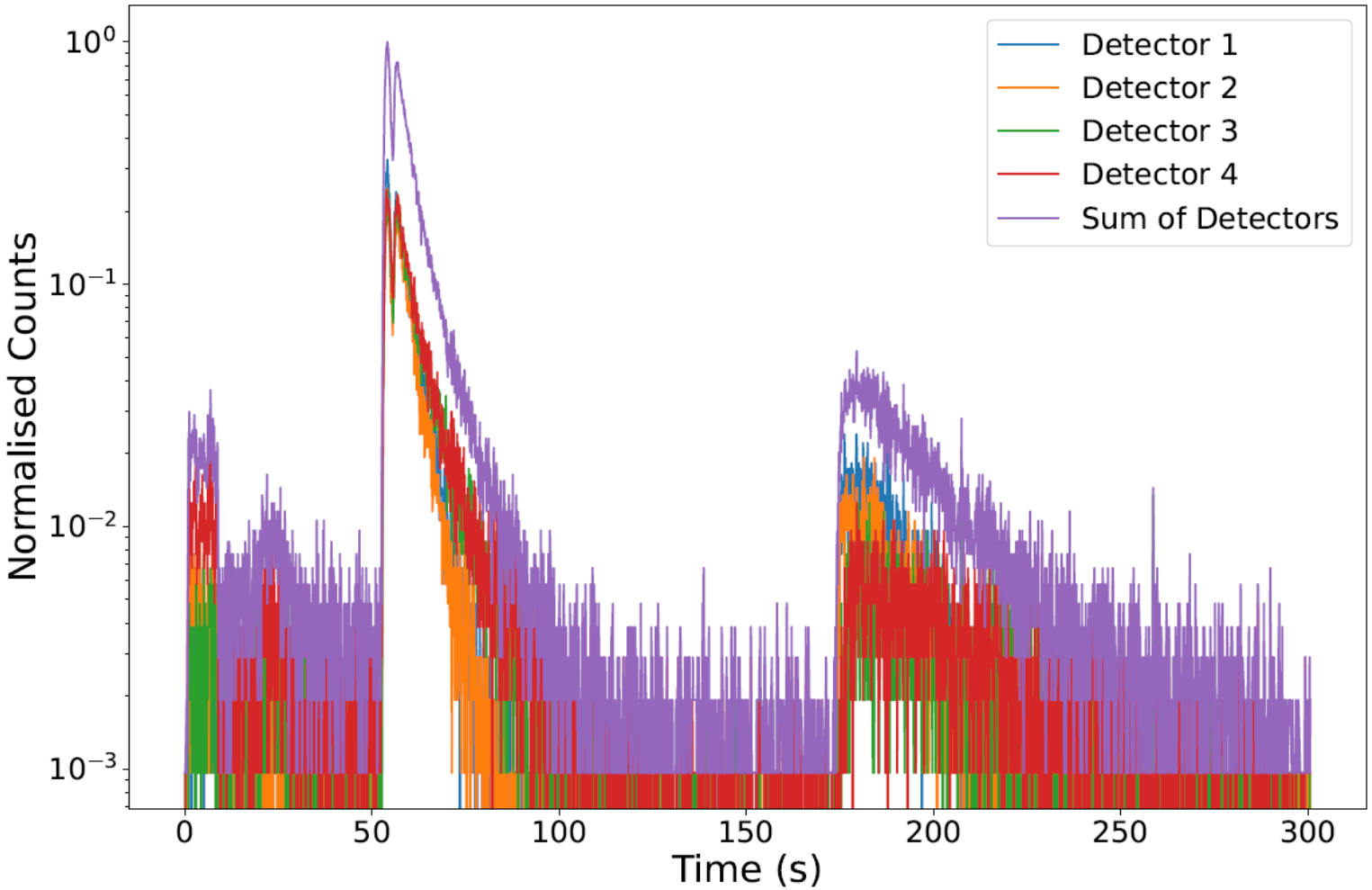
Precession Chambers



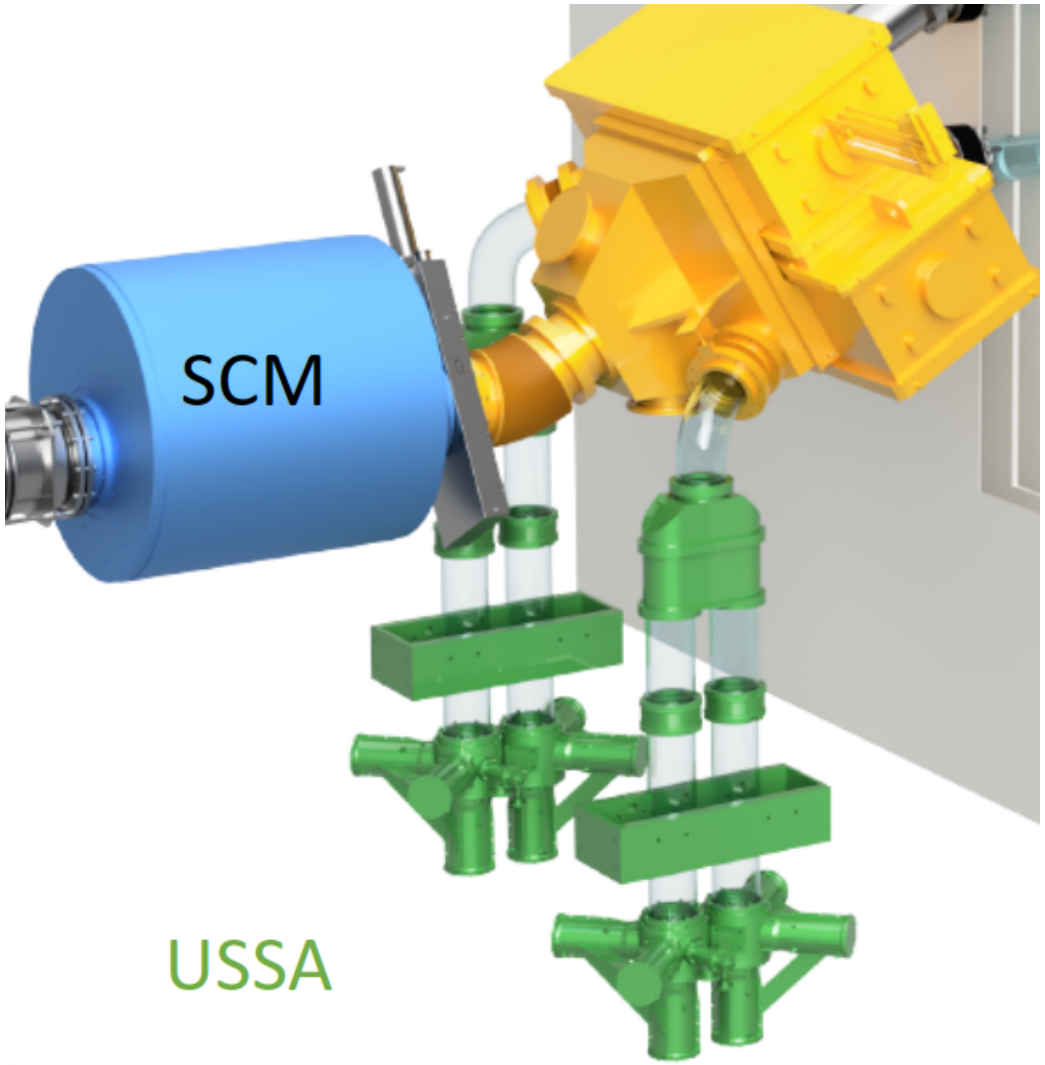
Precession Chambers



July 8 2023


Detector 1
Detector 2
Detector 3
Detector 4
Sum of Detectors
Normalised Counts
10^0
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300
Time (s)

Spin Analysis

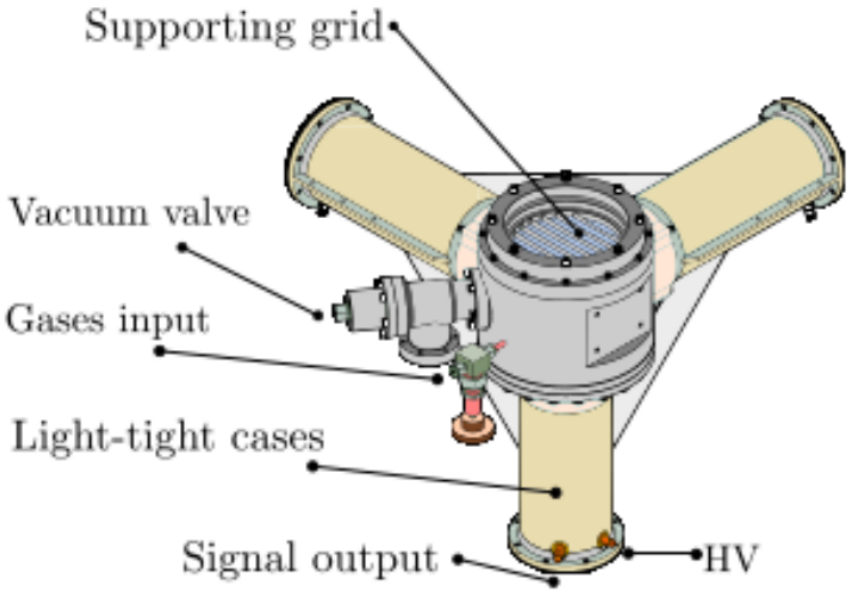


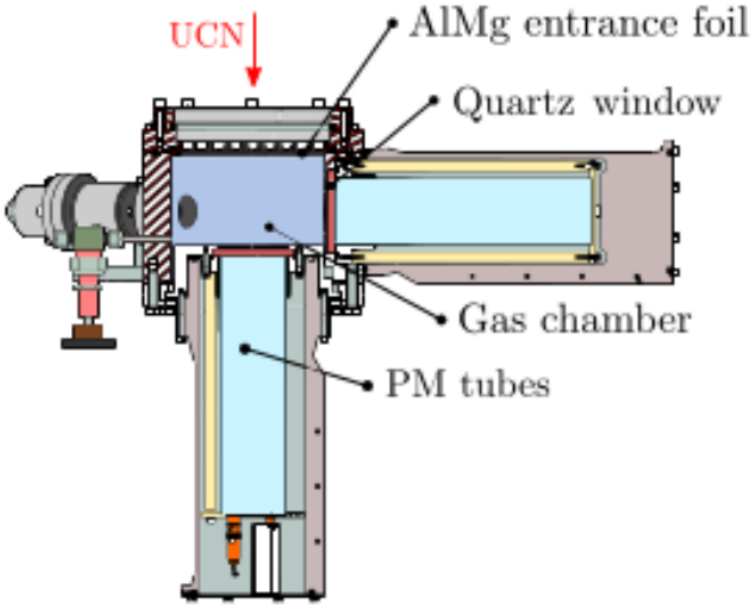
Spin Analysis Performance

	red	blue	yellow	white
frequency (kHz)	80	70	90	90
capacitor (nF)	19.2	25.6	15	14.7
amplitude (mV)	321	308	354	366
I_RF opt (A)	0.5	0.5	0.5	0.5
I_HC (A)	1.5	1.5	1.5	1.5
sup factor	0.037	0.039	0.0479	0.053

UCN Switch and Spin Analyzers

UCN Detectors

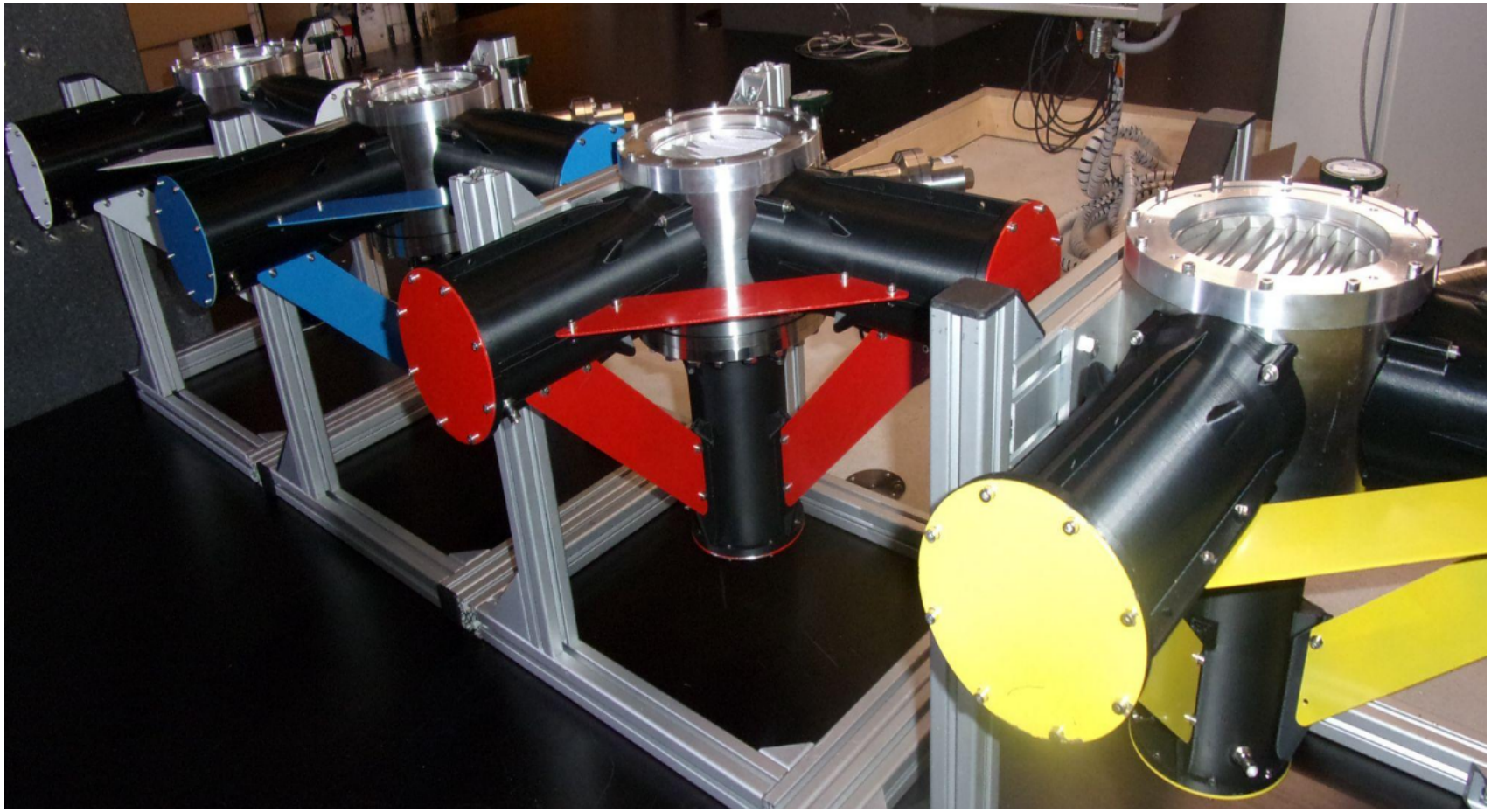




25 mbar ^{3}He

500 mbar CF_4

UCN Detectors



DAQ

Stable, modular, omnipurpose DAQ — 3100 runs on disk

Online Analysis

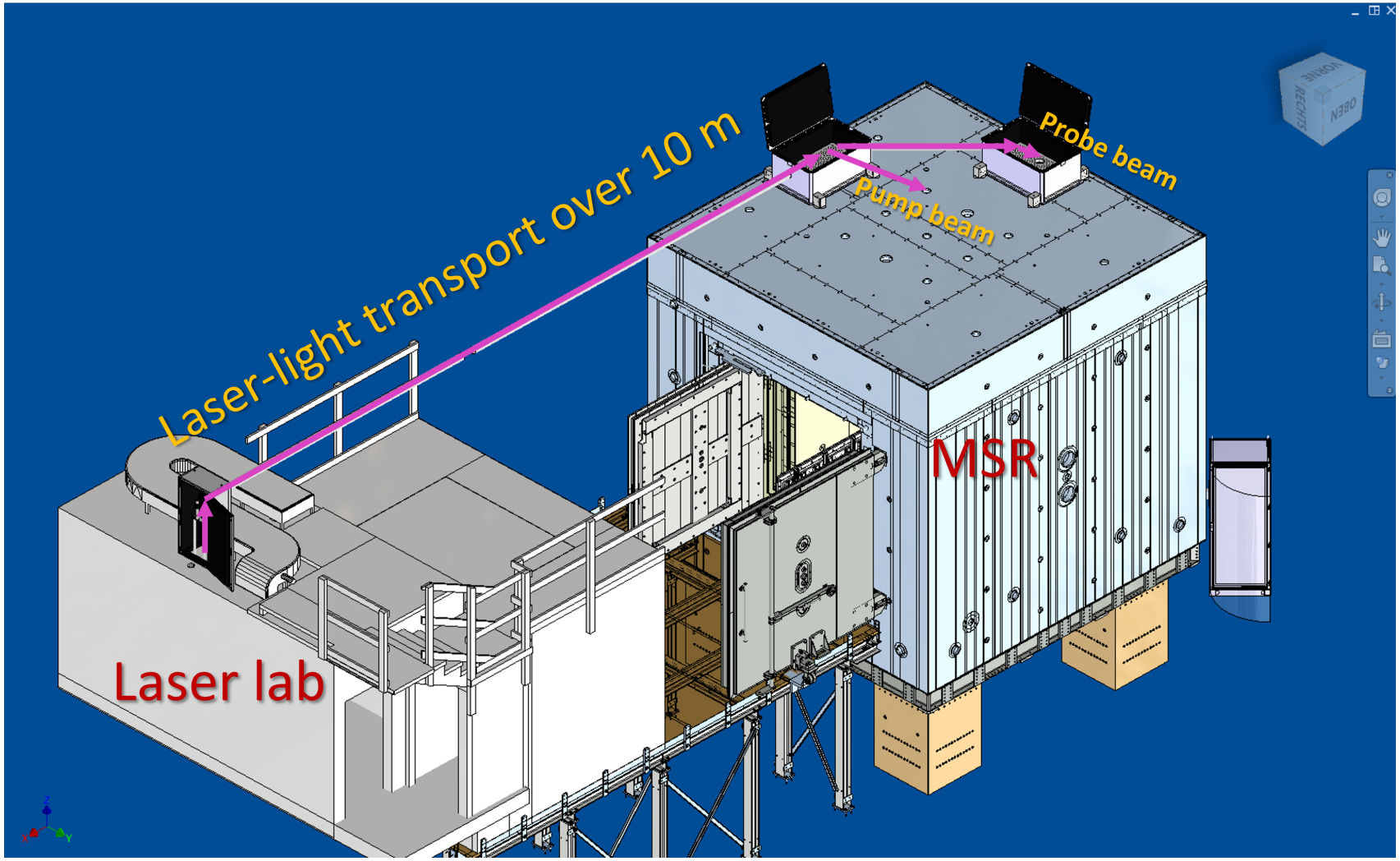
Automatic analyses for standard measurements:

- Count integration
- exponential fits
- ...

Upcoming:

- Hg fit
- Ramsey fit
- Data collection for blinding

Hg Co-Magnetometer

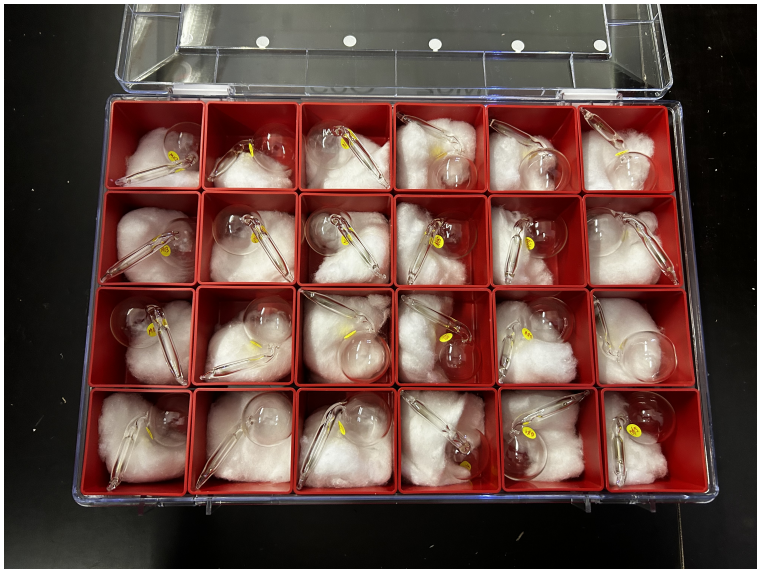


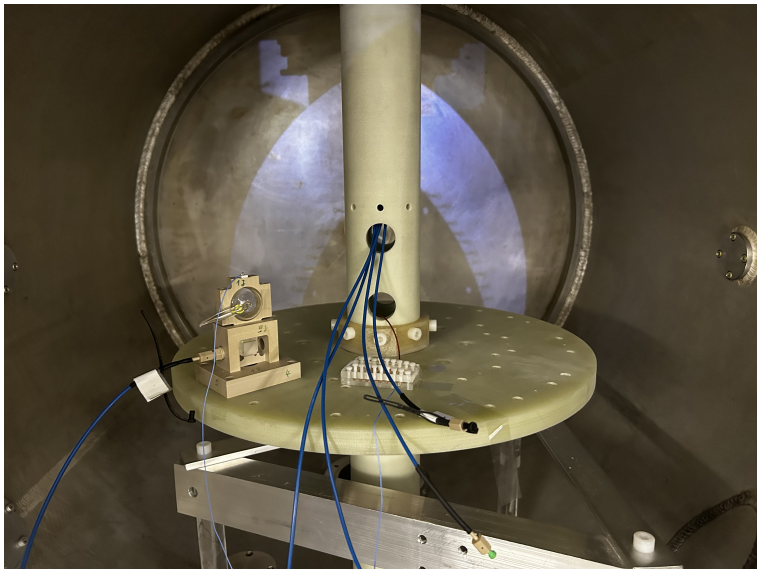
Hg Co-Magnetometer Laser

High Voltage

- Electrodes ✓
- Ground shell designed and built
- Feedthrough designed and built
- Ballast resistor designed and built
- Working on getting 200kV PSU for initial HV tests

Caesium Magnetometer Array





> 100 cells in production / qualification / testing

Qualification Measurements

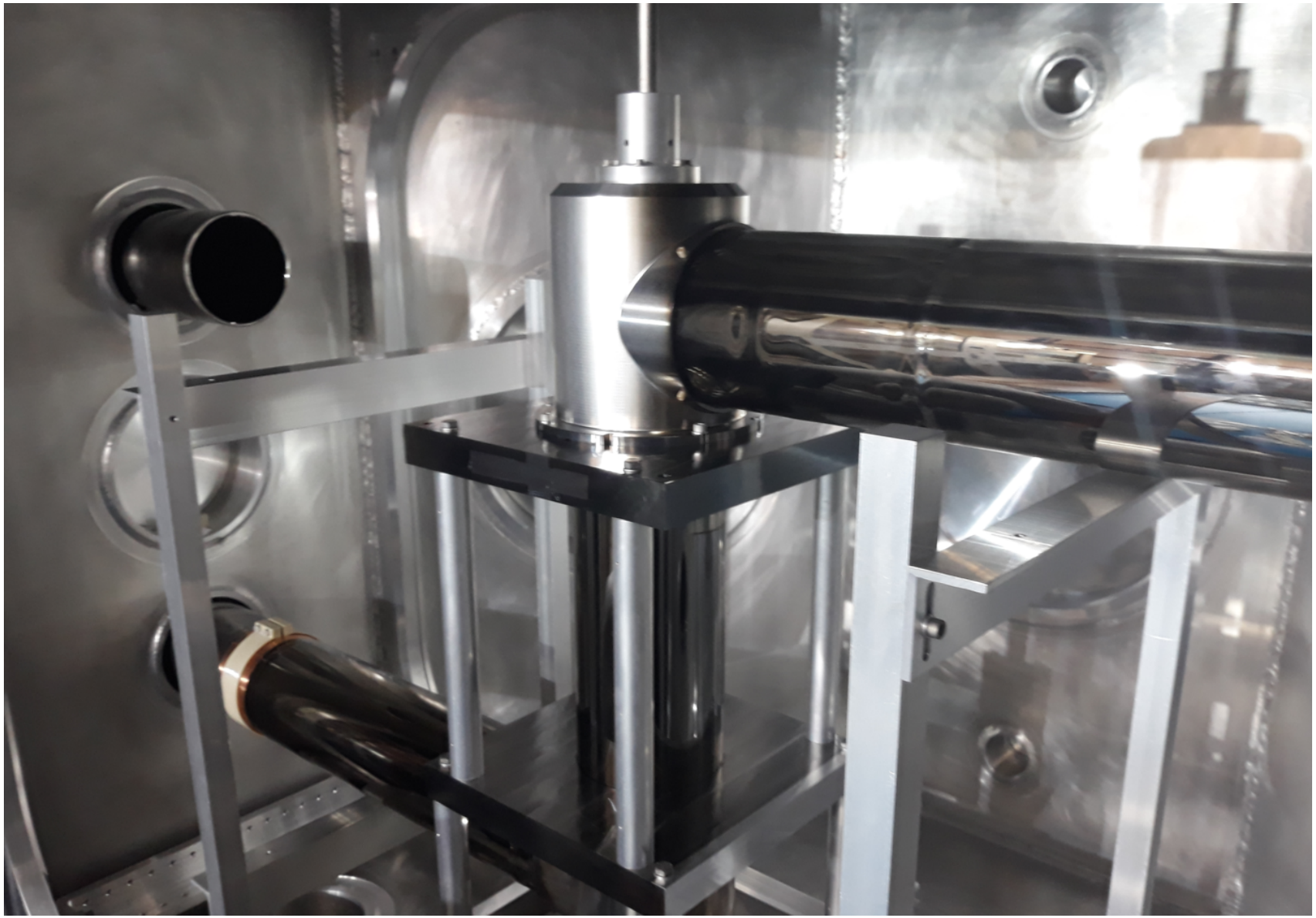
Done:

- UCN transport: ✓
- Basic storage parameters (filling, emptying etc.) ✓
- USSA performance: ✓
- Switch position reproducibility ✓
- Spin transport: (✓)

Ongoing/upcoming:

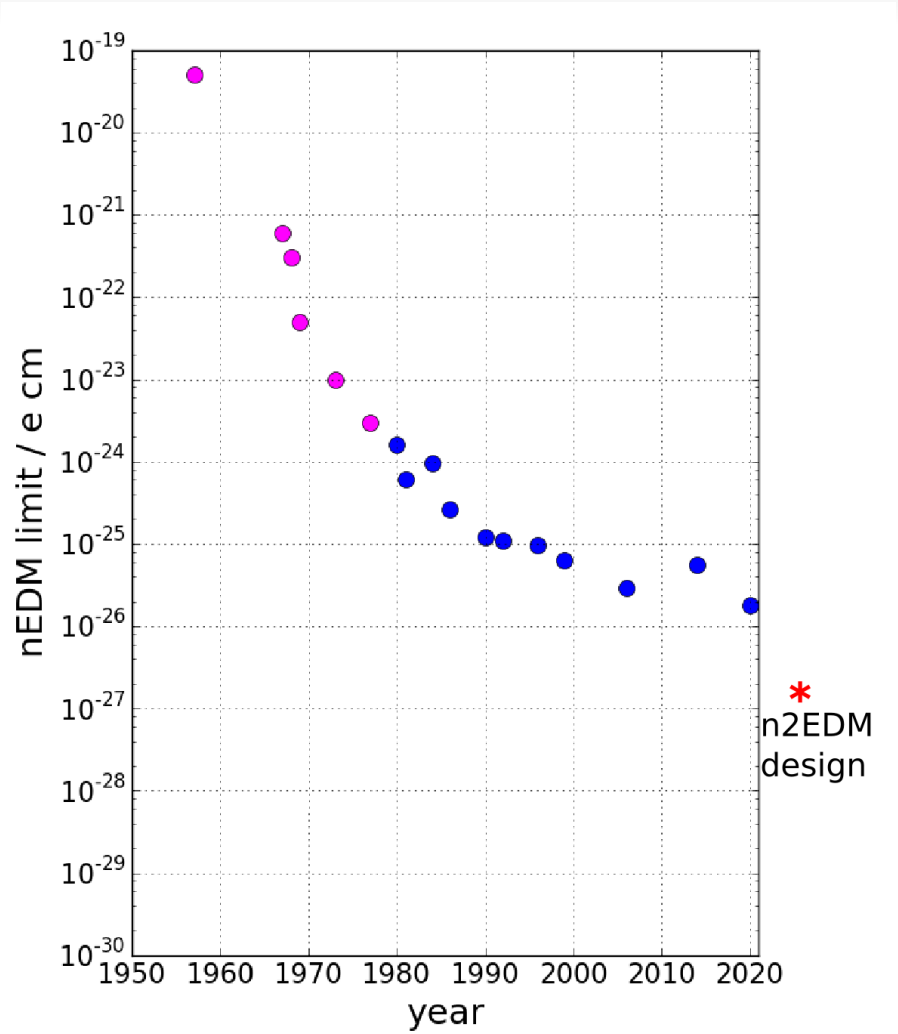
- UCN storage performance
- Spinflips / Ramsey
- Spin transport

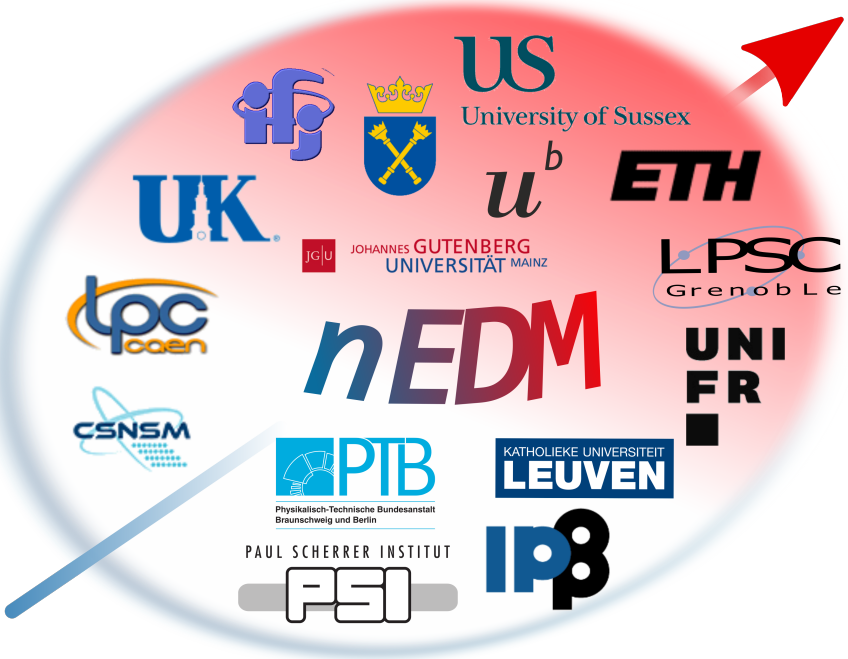
UCN Transport Qualification

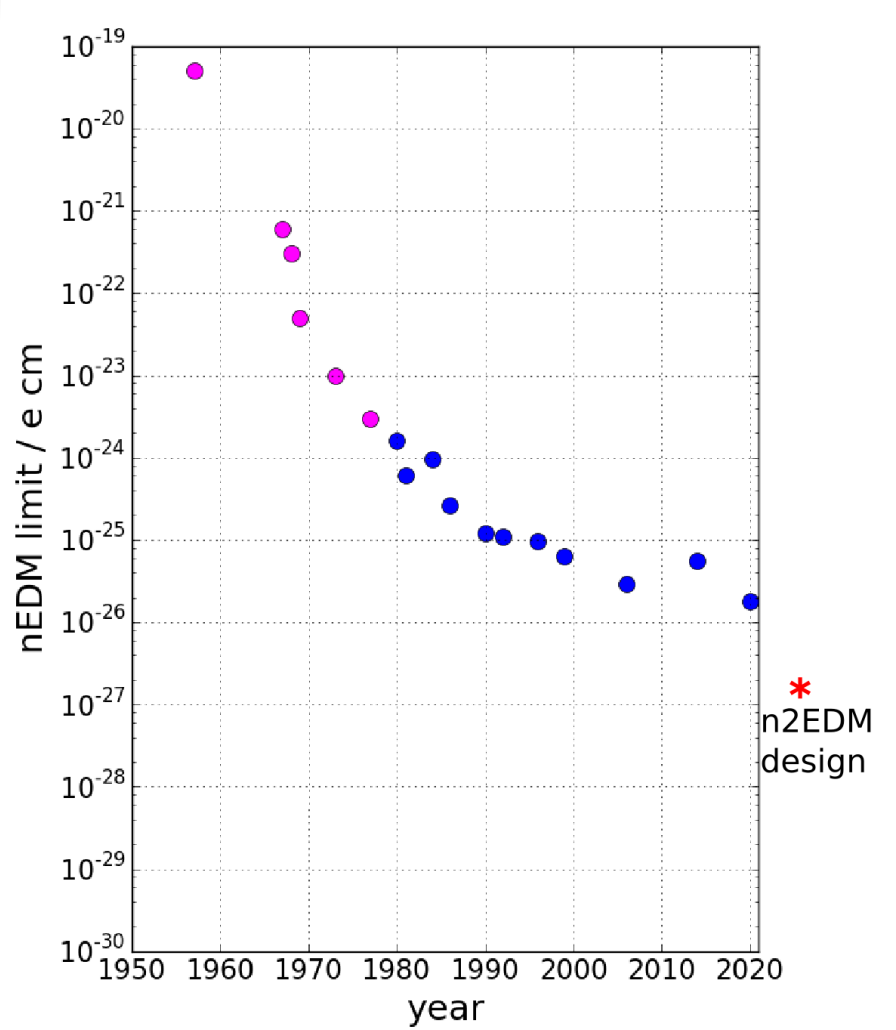


Status

- n2EDM has entered “commissioning with neutrons” phase
- Neutron optics / switch / shutters, DAQ / control, spin analysing detectors, spin transport coils already working, being optimized.
- Up next: Spin flippers, Hg co-magnetometry, Cs vapor magnetometers, high voltage.
- Stay tuned for the first Ramsey measurements and EDM results!


nEDM limit / e cm
year
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
10^-26
10^-27
10^-28
10^-29
10^-30
1950 1960 1970 1980 1990 2000 2010 2020
*
n2EDM
design


US
University of Sussex
UK
ETH
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
LPSC
Grenoble
nEDM
UNI FR
CSNSM
PTB
Physikalisch-Technische Bundesanstalt Braunschweig und Berlin
KATHOLIEKE UNIVERSITEIT LEUVEN
PAUL SCHERRER INSTITUT
PSI
IPB



Thank you for your attention!

Backup