An Overview of the n2EDM Experiment at PSI

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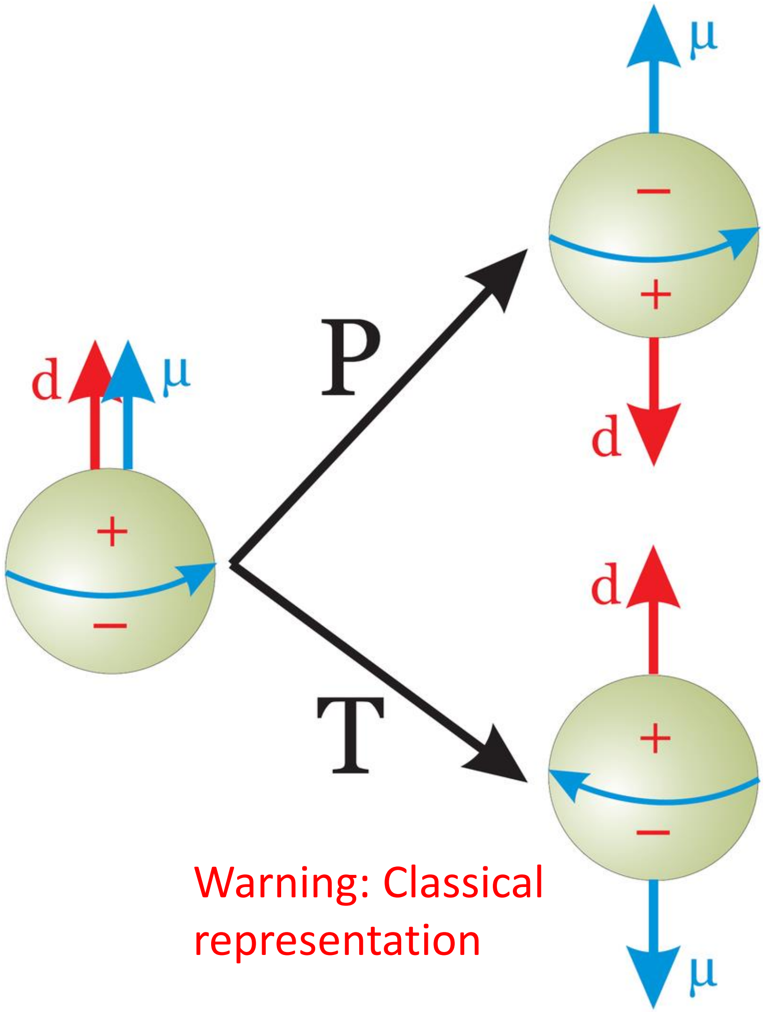
Baryon asymmetry of the Universe

CP violation in the Standard Model

Weak sector: CKM matrix

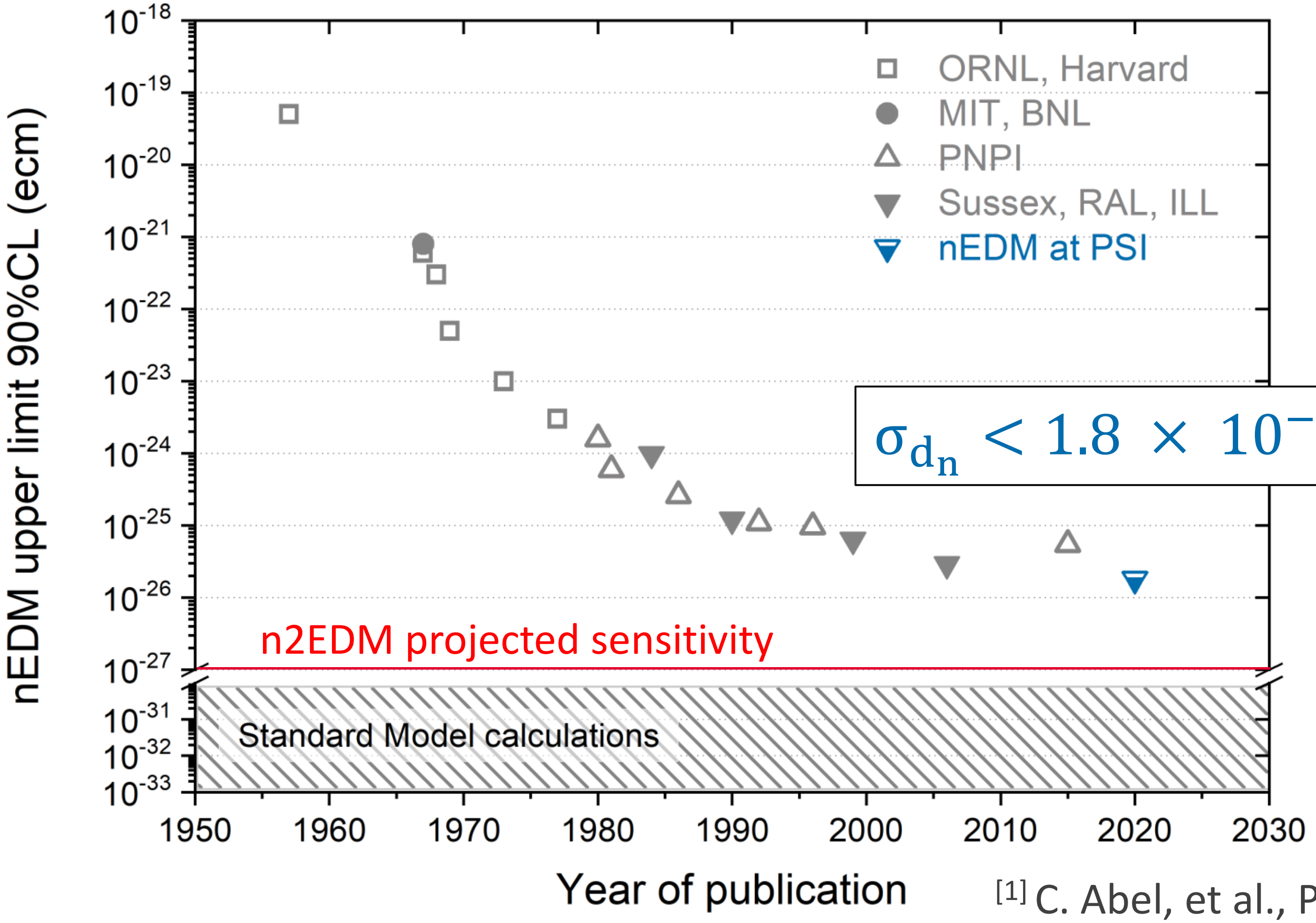
Strong sector: QCD-Lagrangian, θ

Non-zero EDM direct probe of beyond standard model physics



Warning: Classical representation

Neutron EDM sensitivity over time



$\sigma_{d_n} < 1.8 \times 10^{-26} e \cdot cm$ (90% C.L.)[1]

[1] C. Abel, et al., Phys. Rev. Lett. 124, 081803 (2020)

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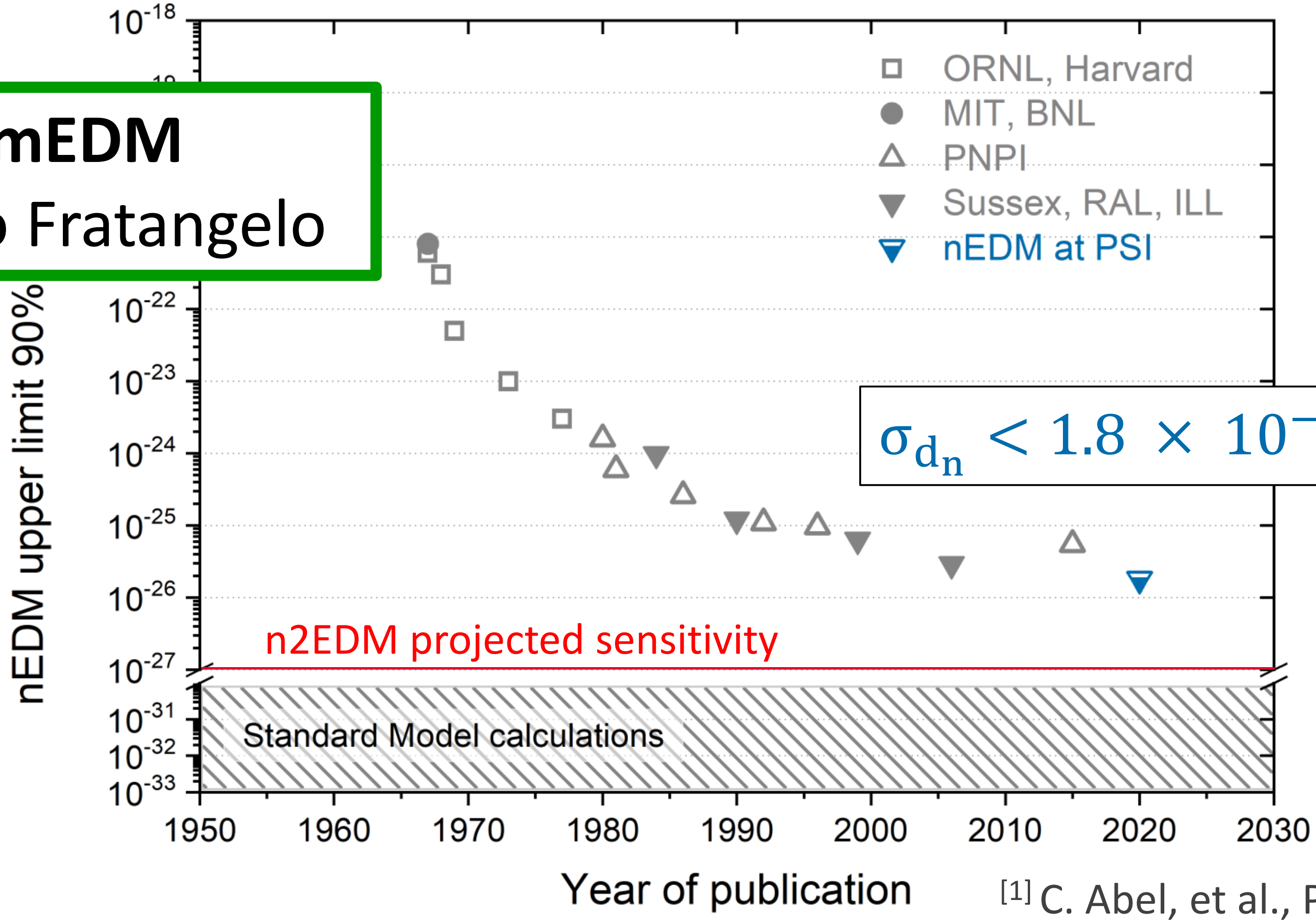

BeamEDM
Anastasio Fratangelo

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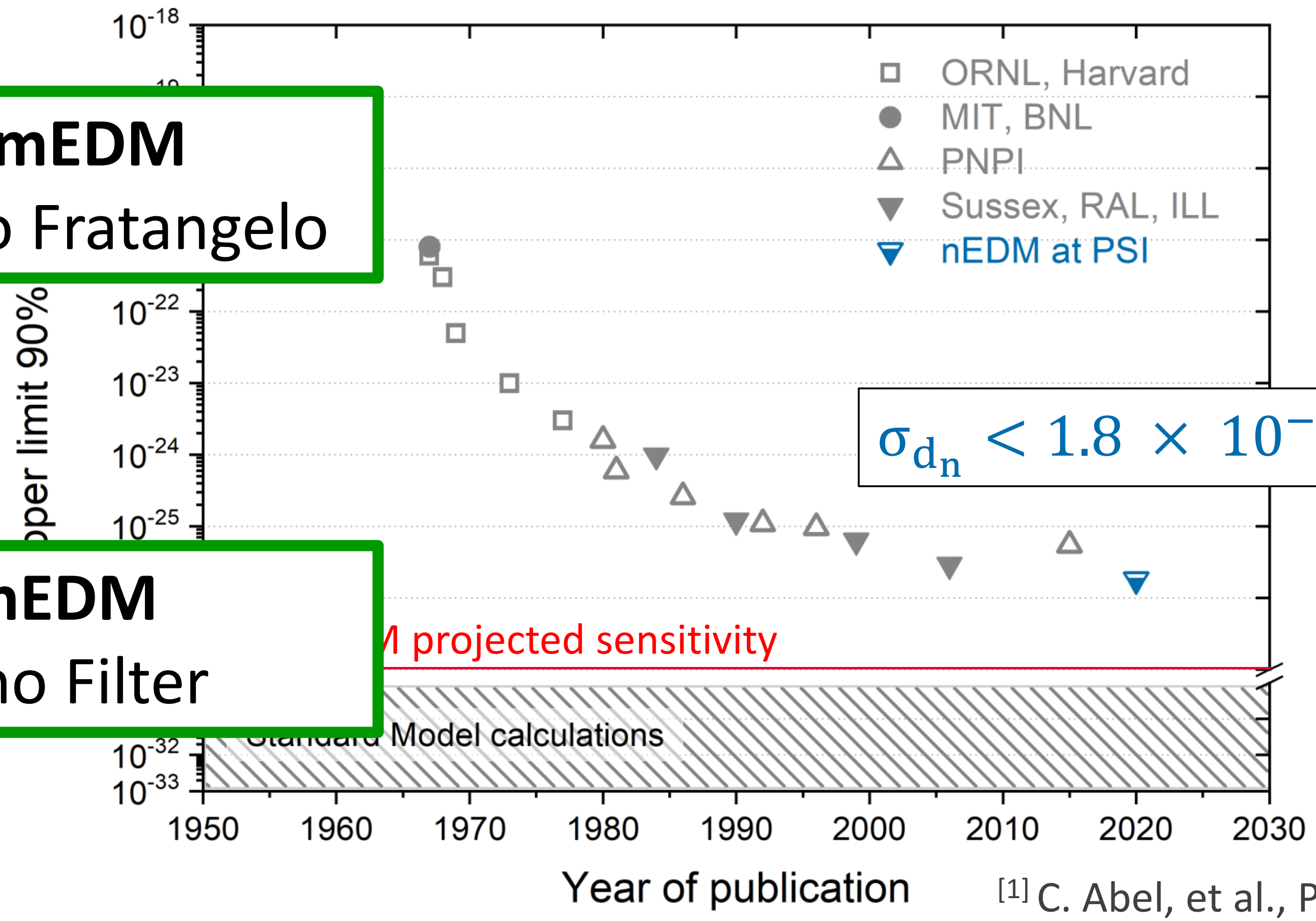

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PanEDM
Hanno Filter

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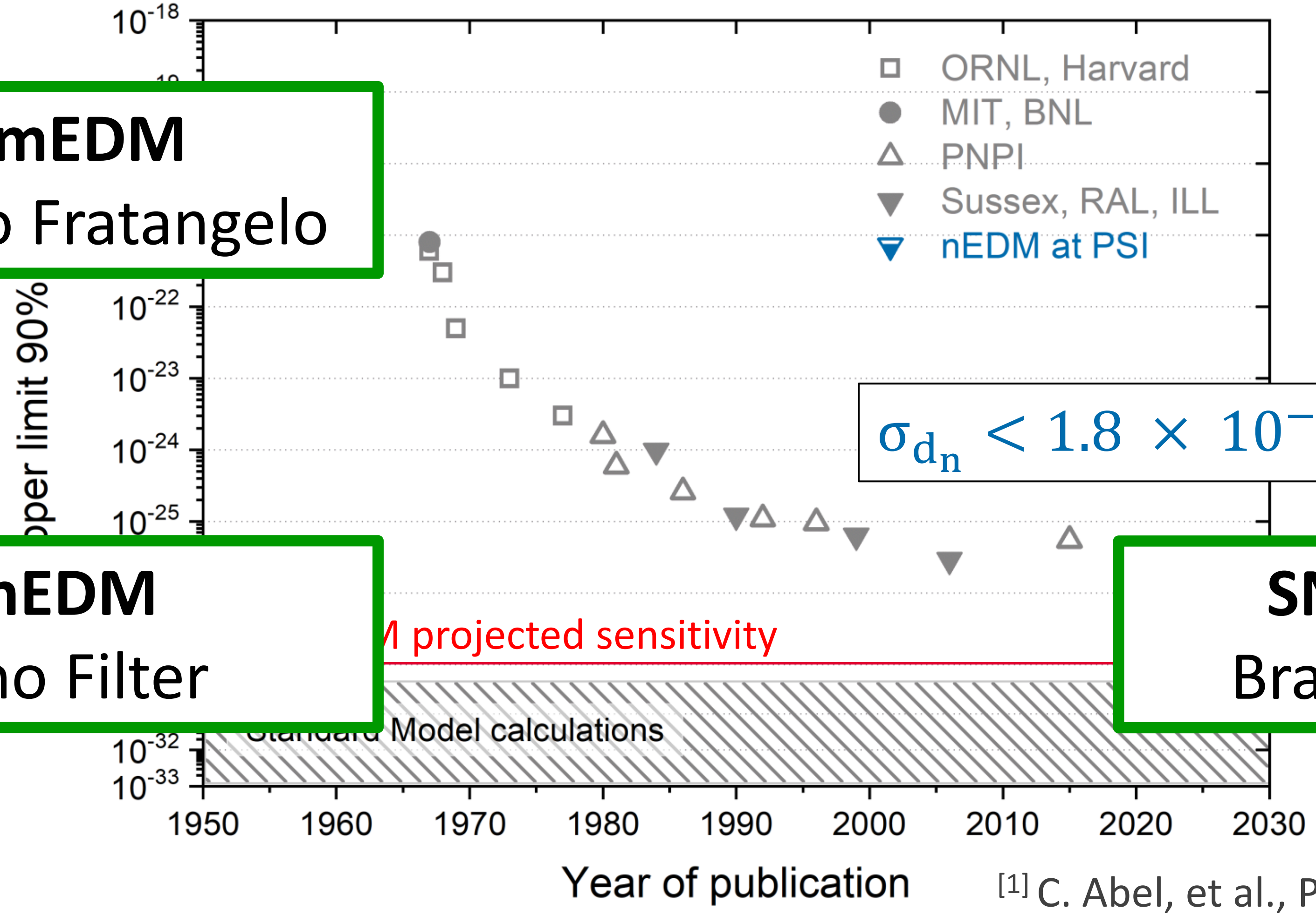

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Brad Plaster

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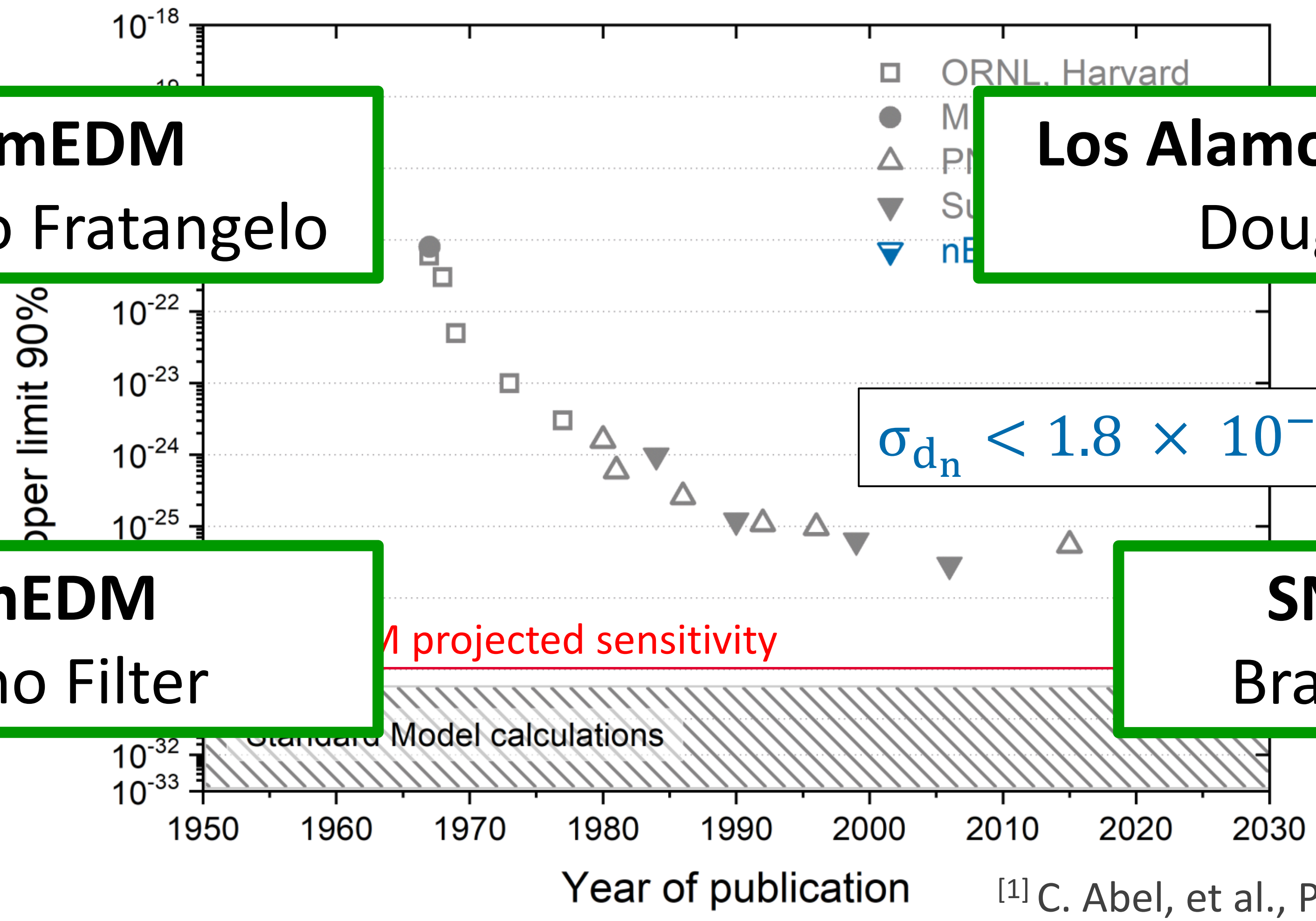

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Los Alamos neutron EDM
Douglas Wong

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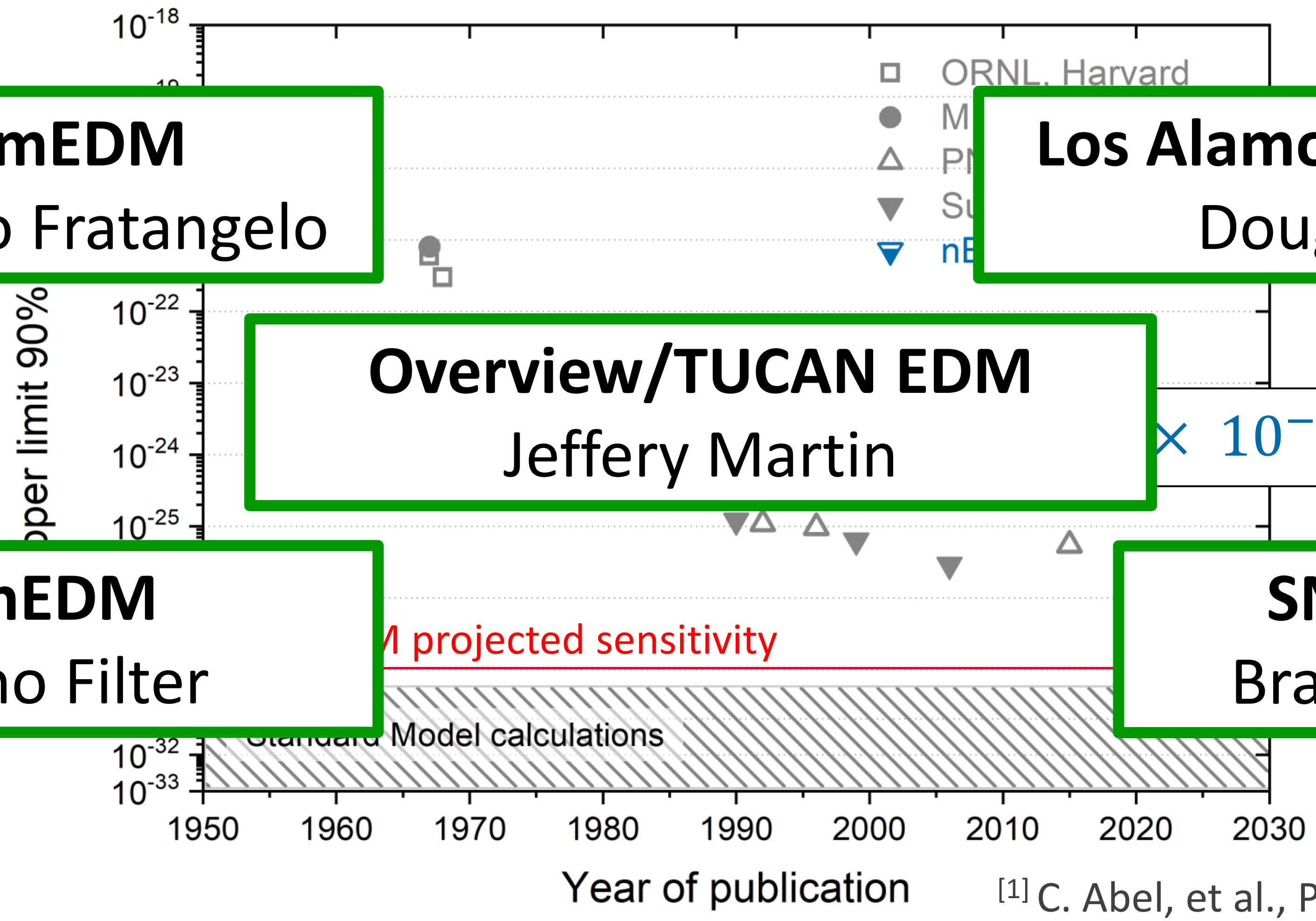

BeamEDM
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Los Alamos neutron EDM
Douglas Wong

Overview/TUCAN EDM
Jeffery Martin

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PanEDM
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SNS EDM
Brad Plaster

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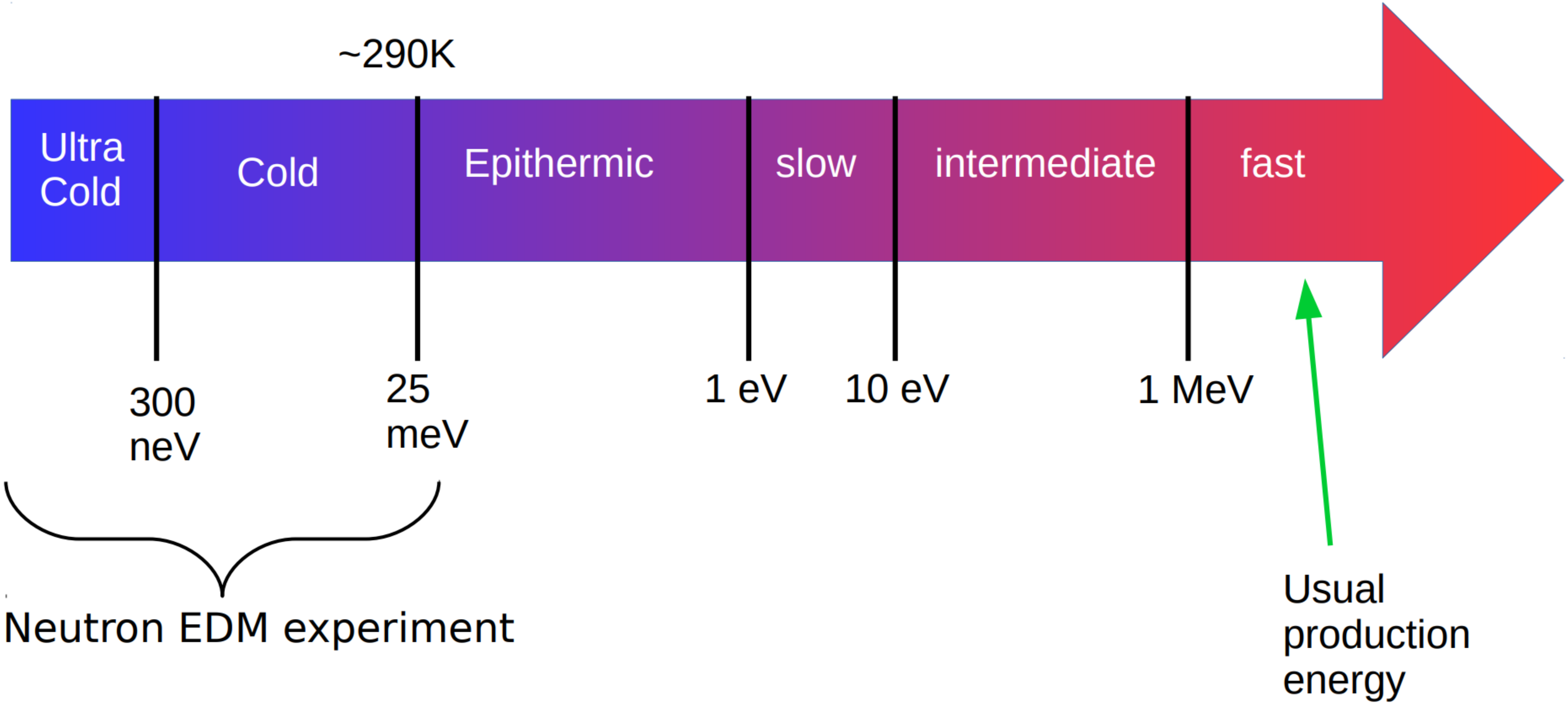
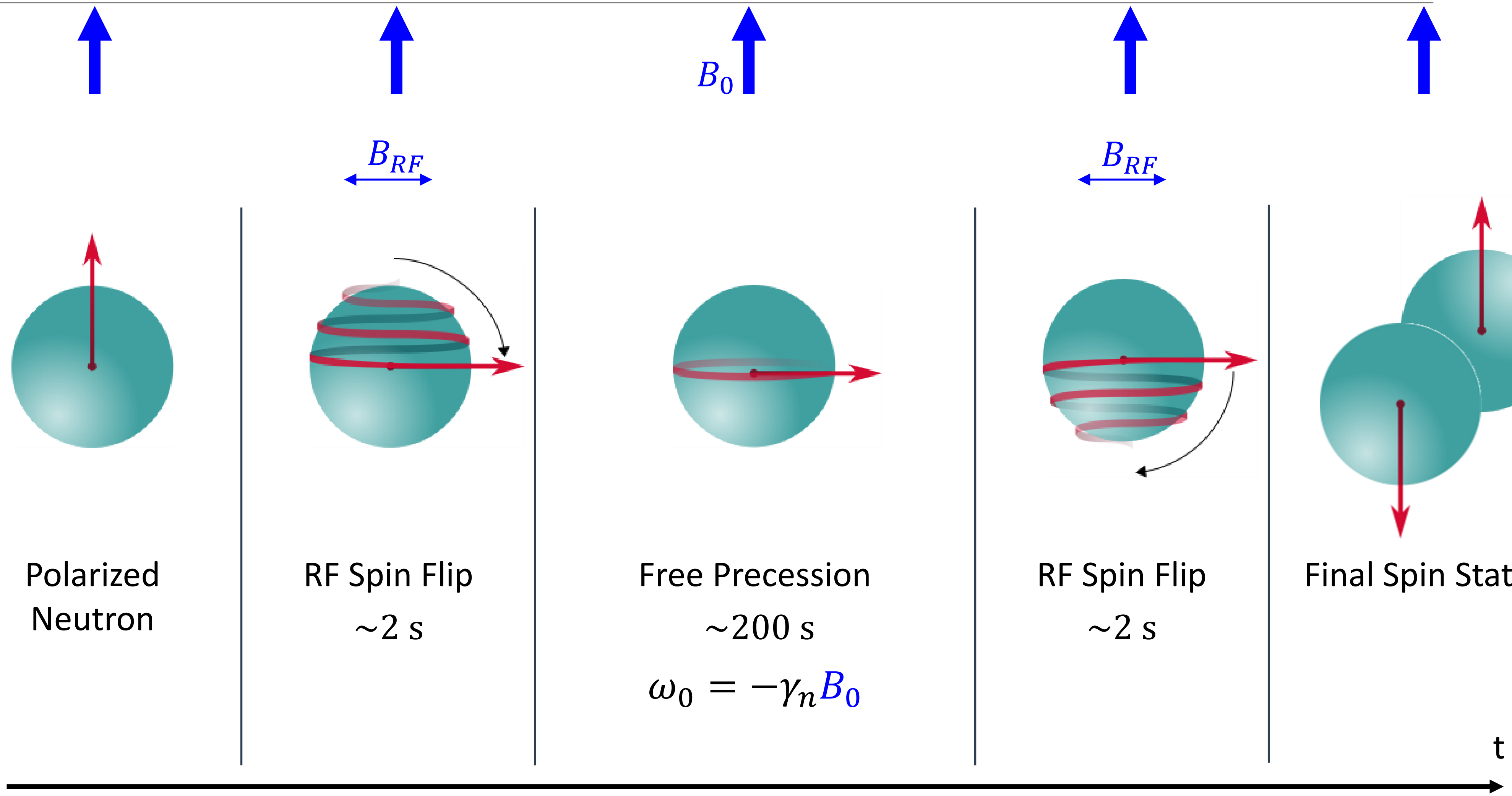
Ultra cold neutrons (UCN)



Ramsey's method of separated oscillatory fields



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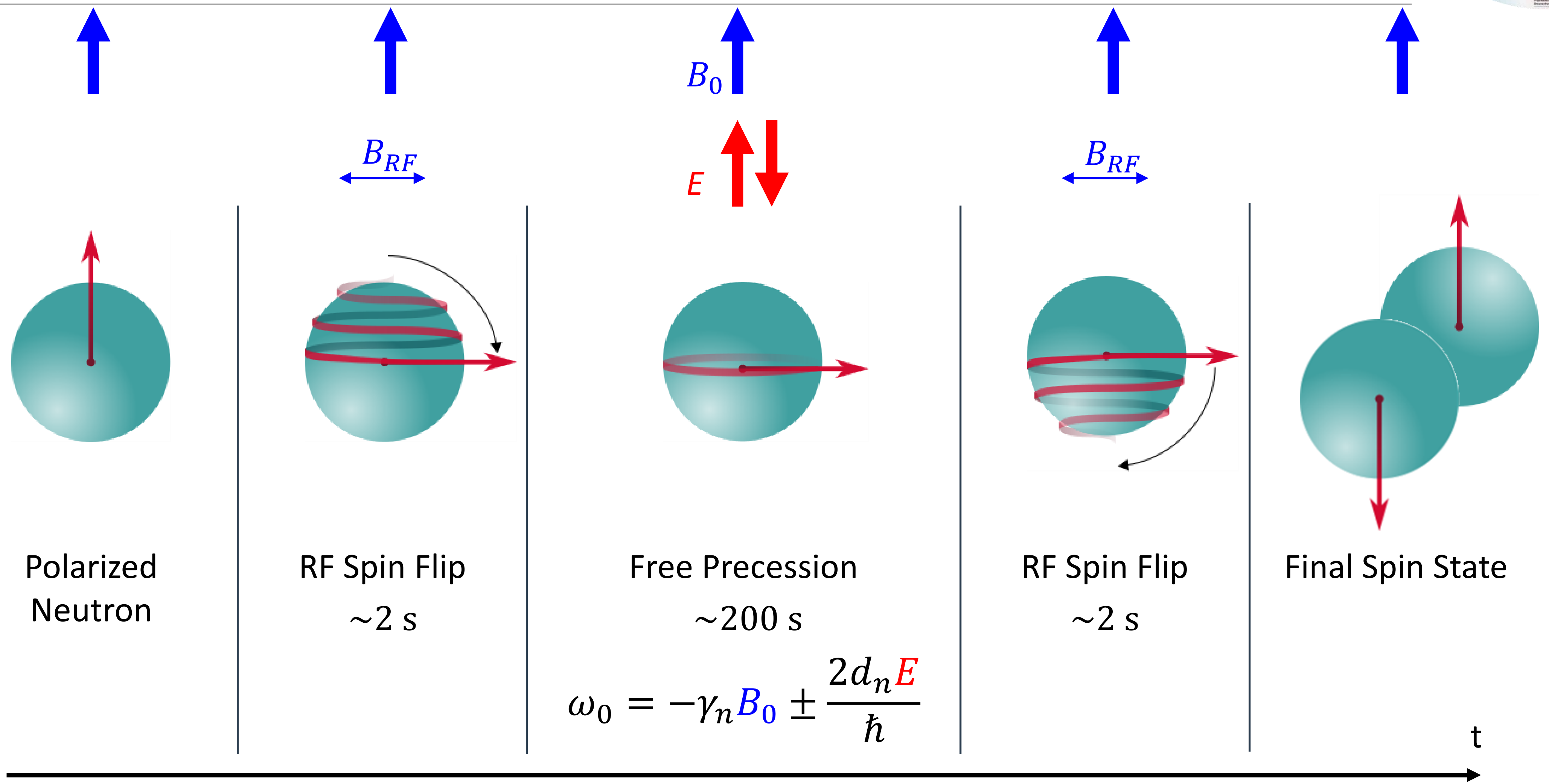

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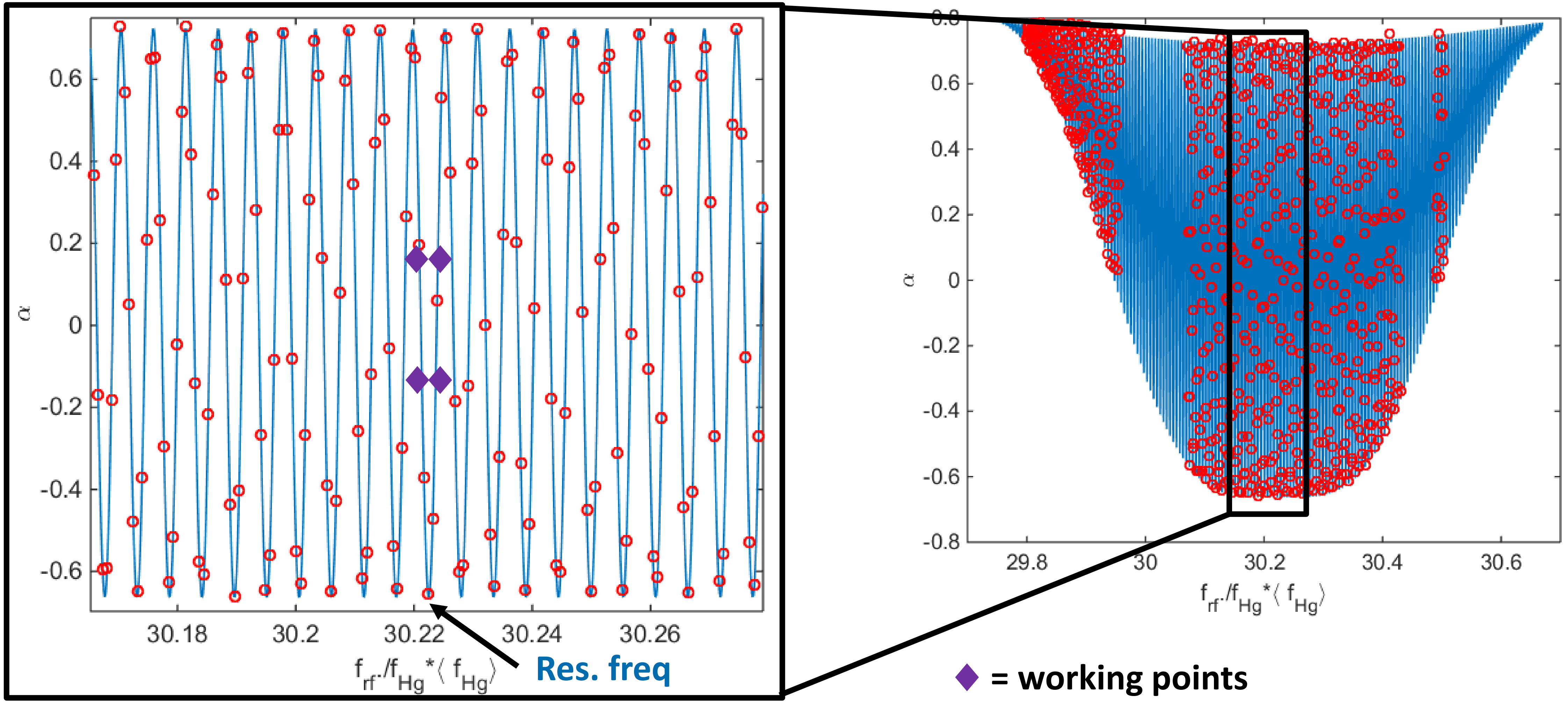


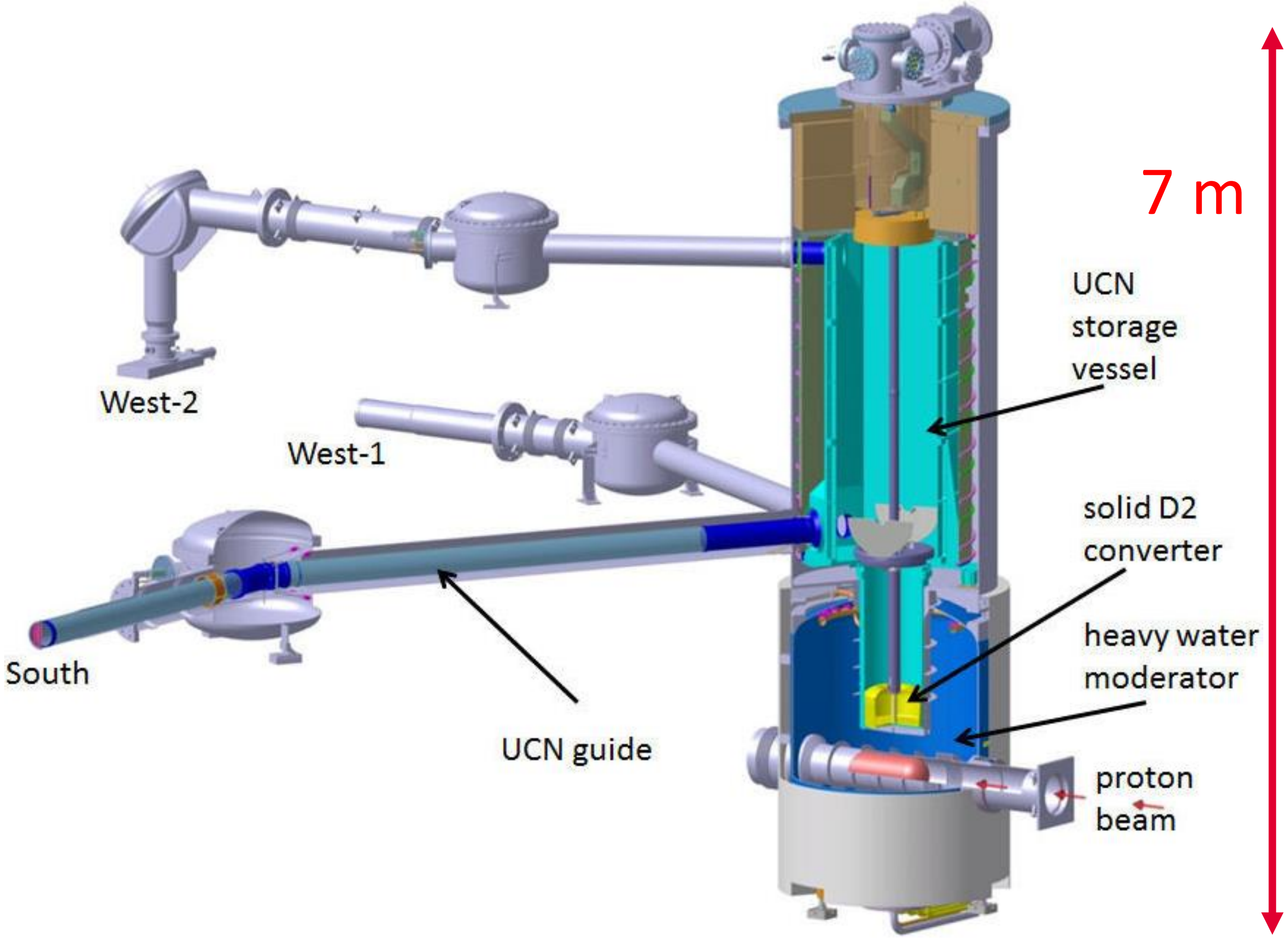
PSI UCN source

Proton beam: 590 MeV, 2.2 mA on spallation target

Pulsed for 8 s every 5 minutes

Neutrons moderated to UCN

Extracted to experiment



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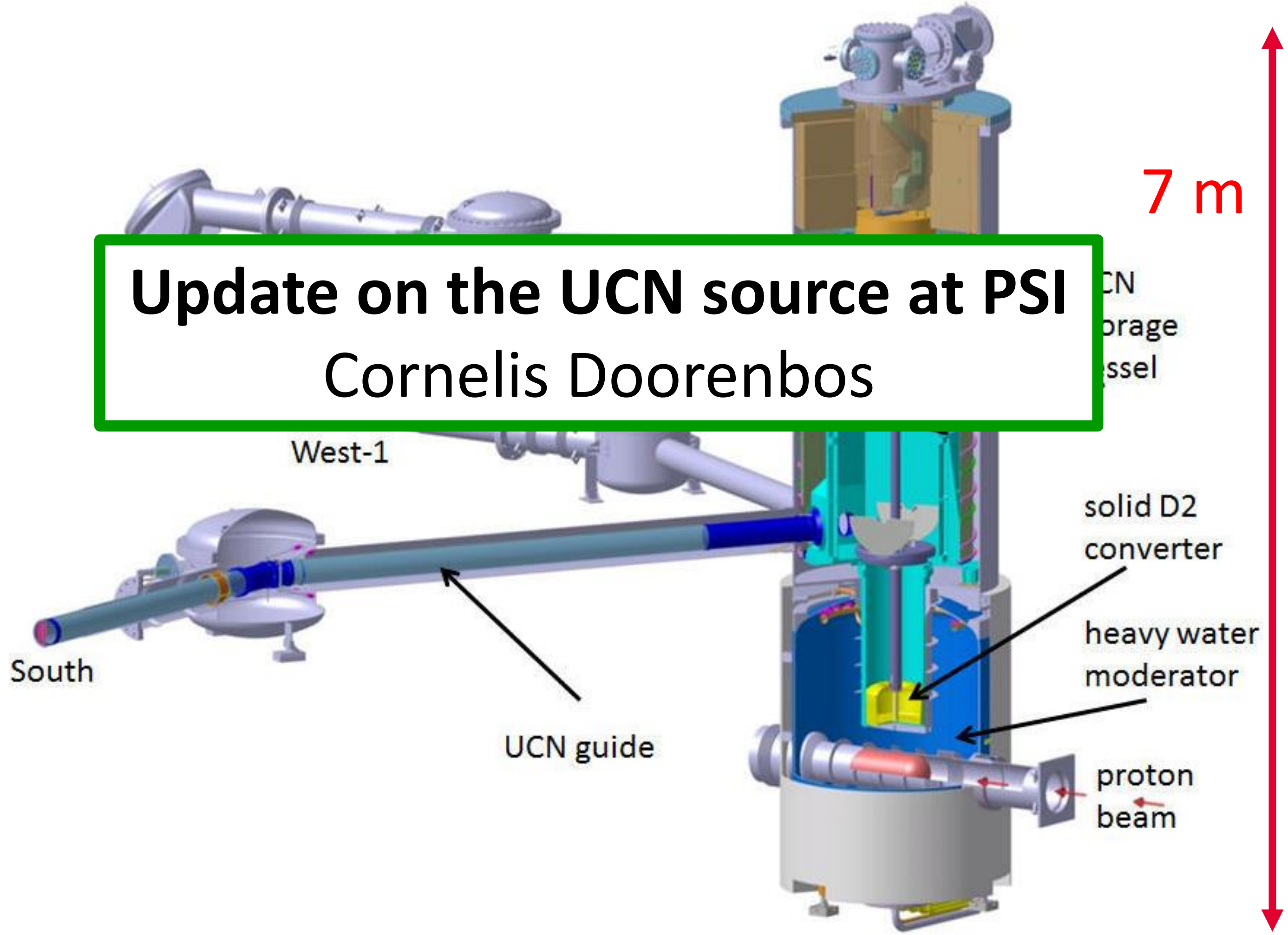
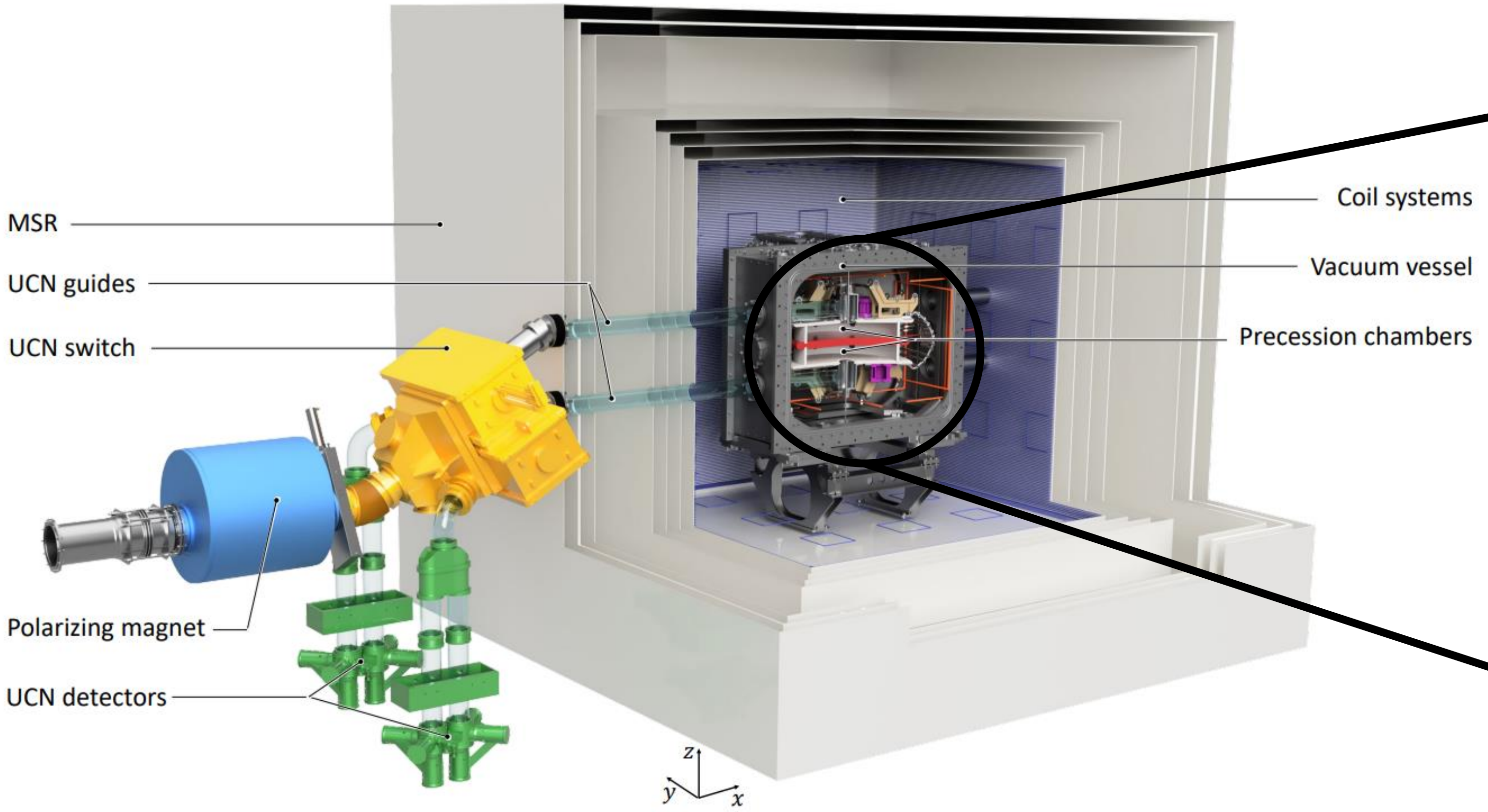
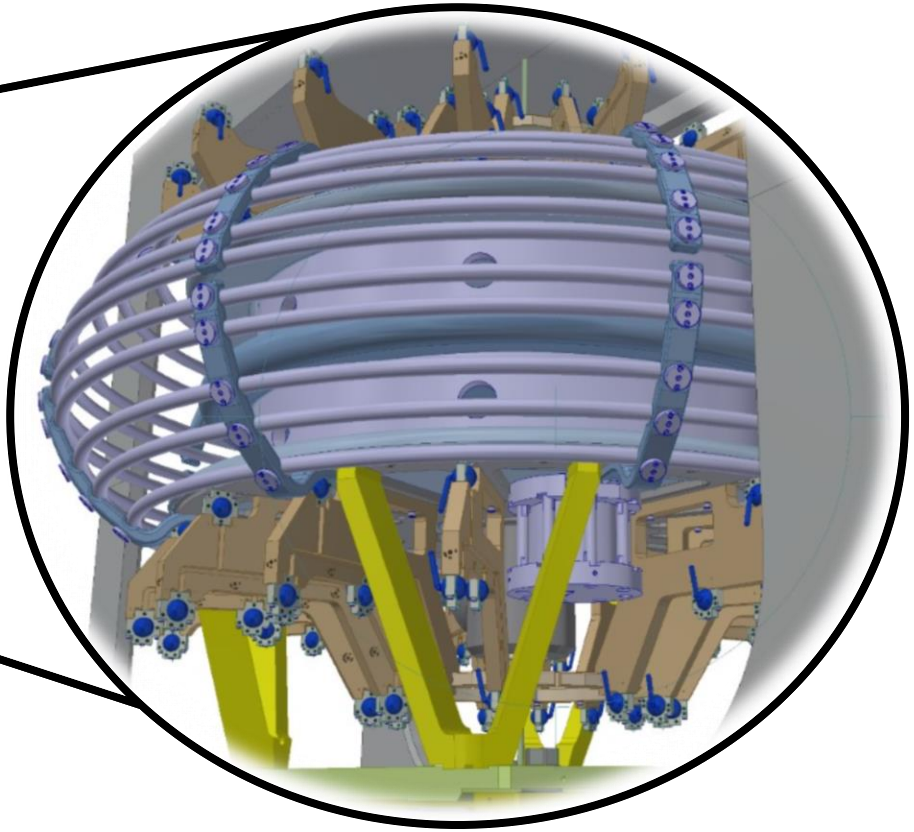


Experimental setup – n2EDM





Active magnetic shield (AMS)

Noisy magnetic environment

Active compensation coils: 3 homogenous fields, 5 first order gradients

50 km of cables

7 kW (typ. 2 kW) power

Approx. 1 µT homogeneity on MSR

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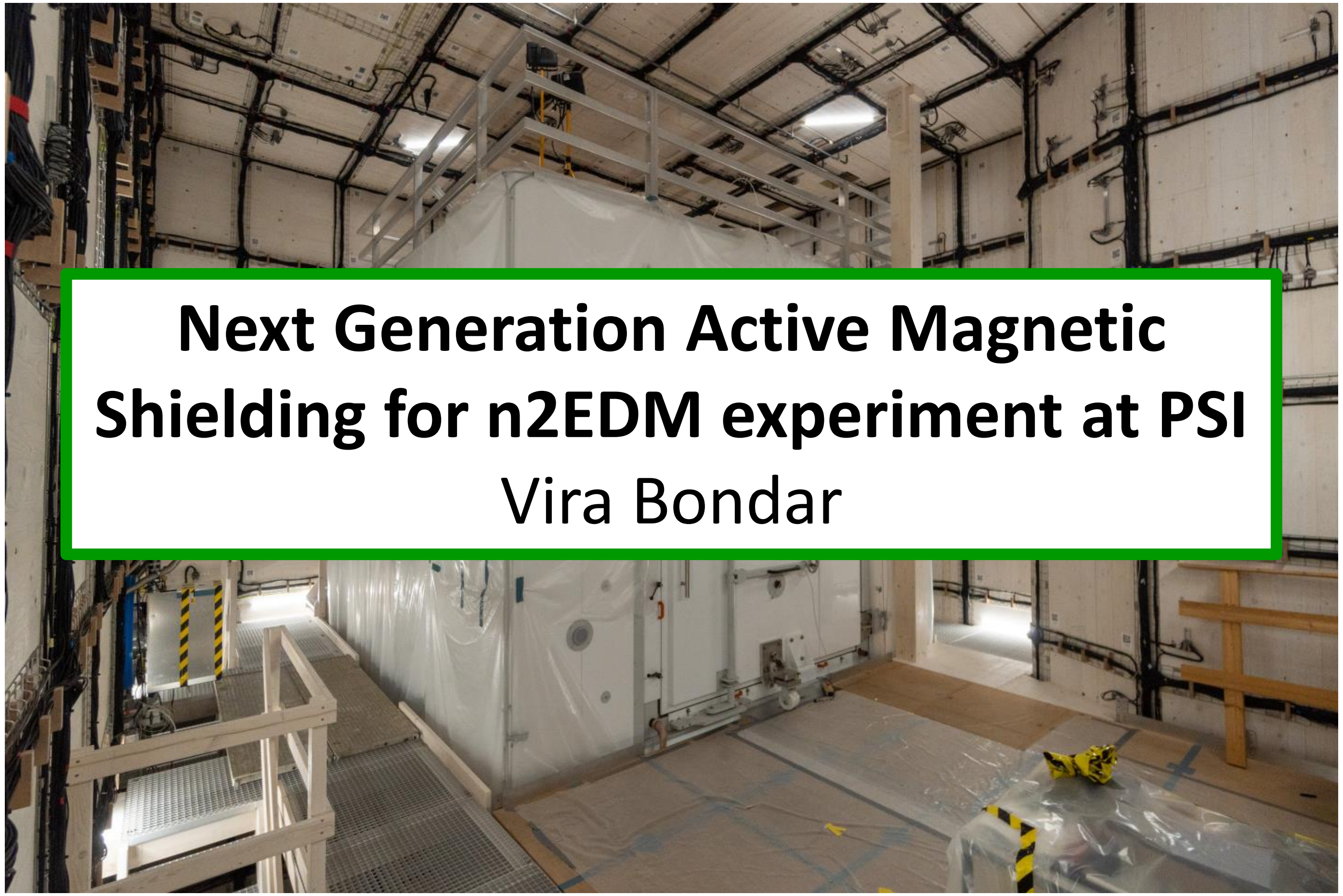
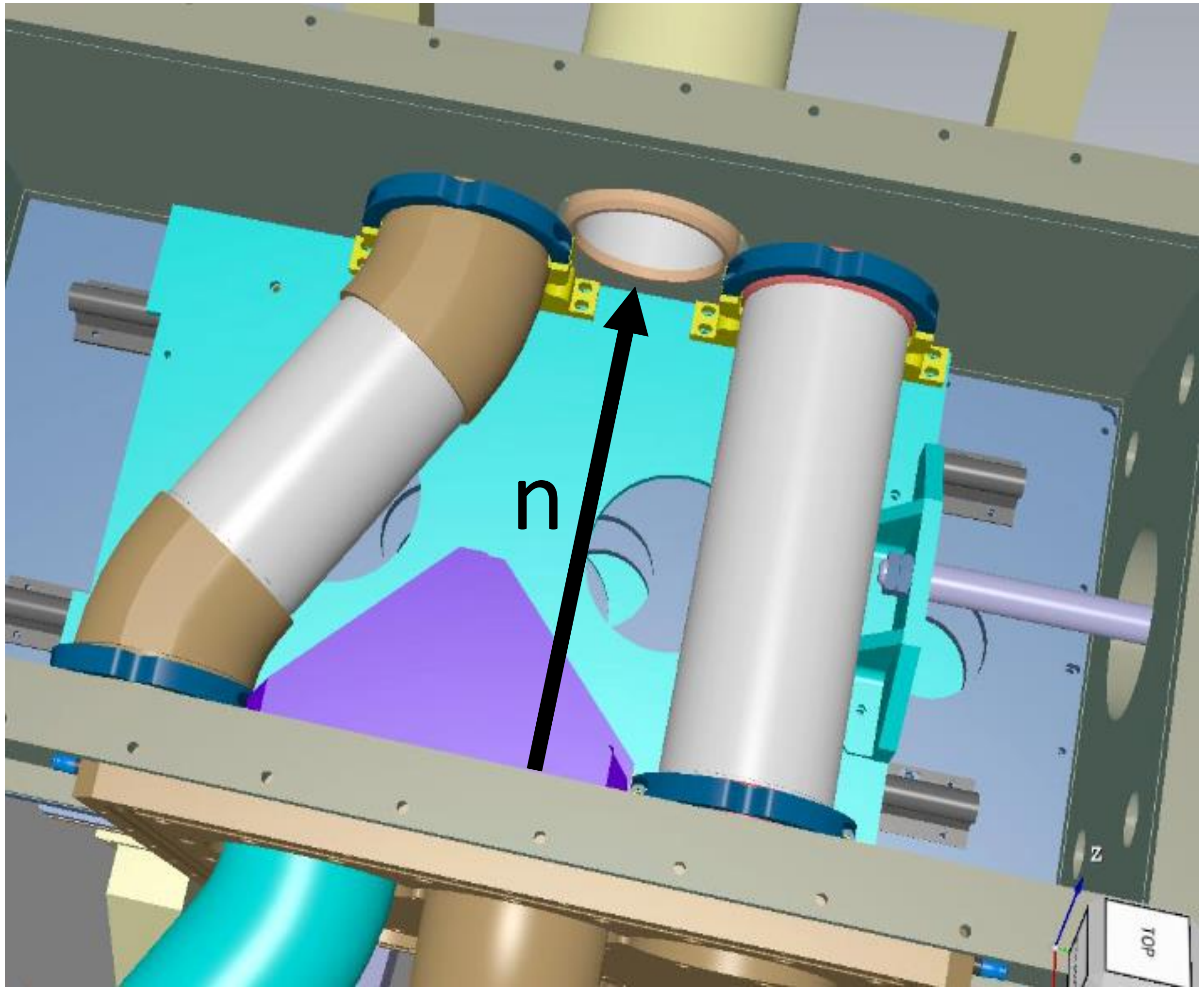
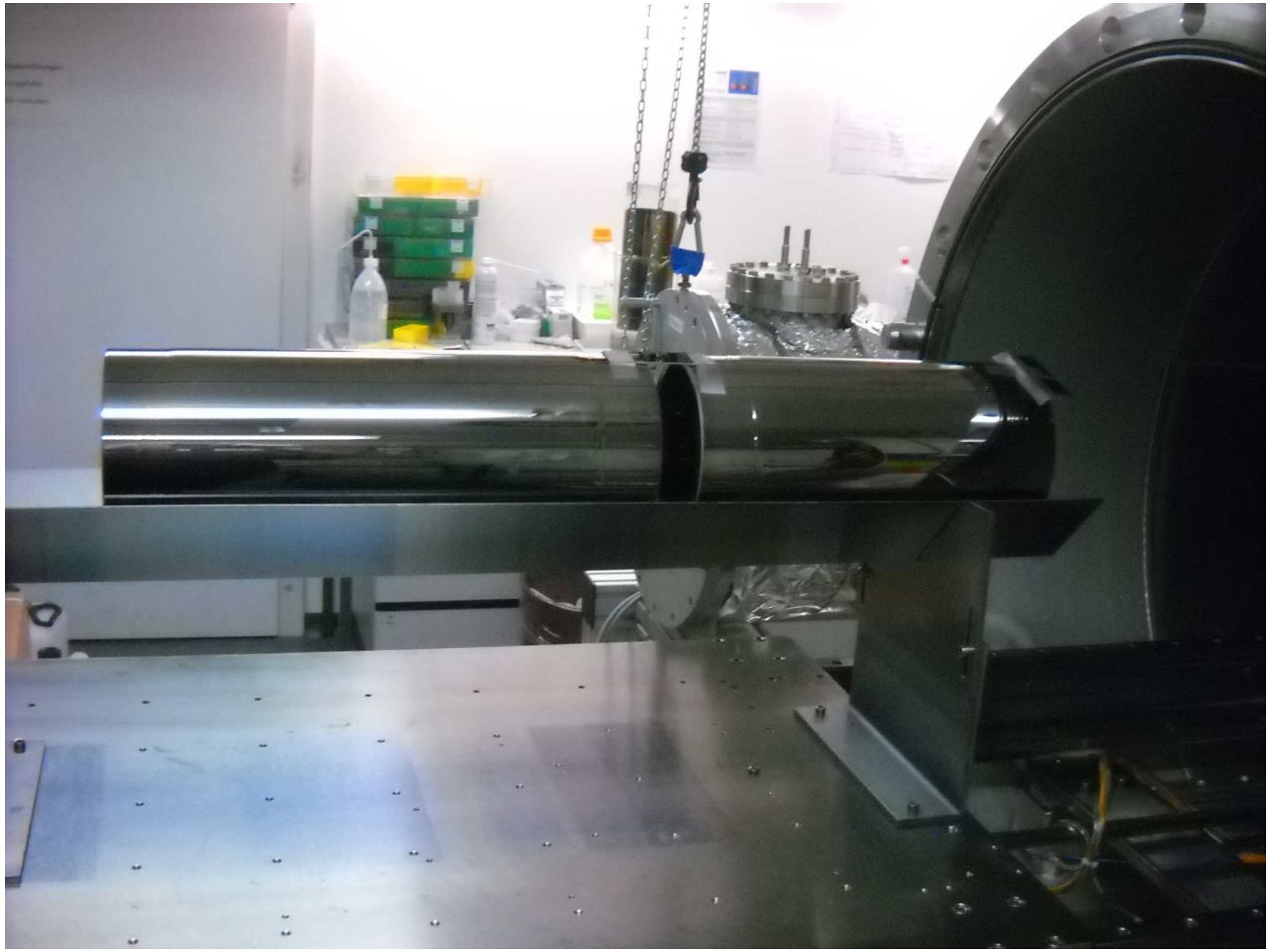


UCN Switch



UCN guides



USSA/UCN detectors

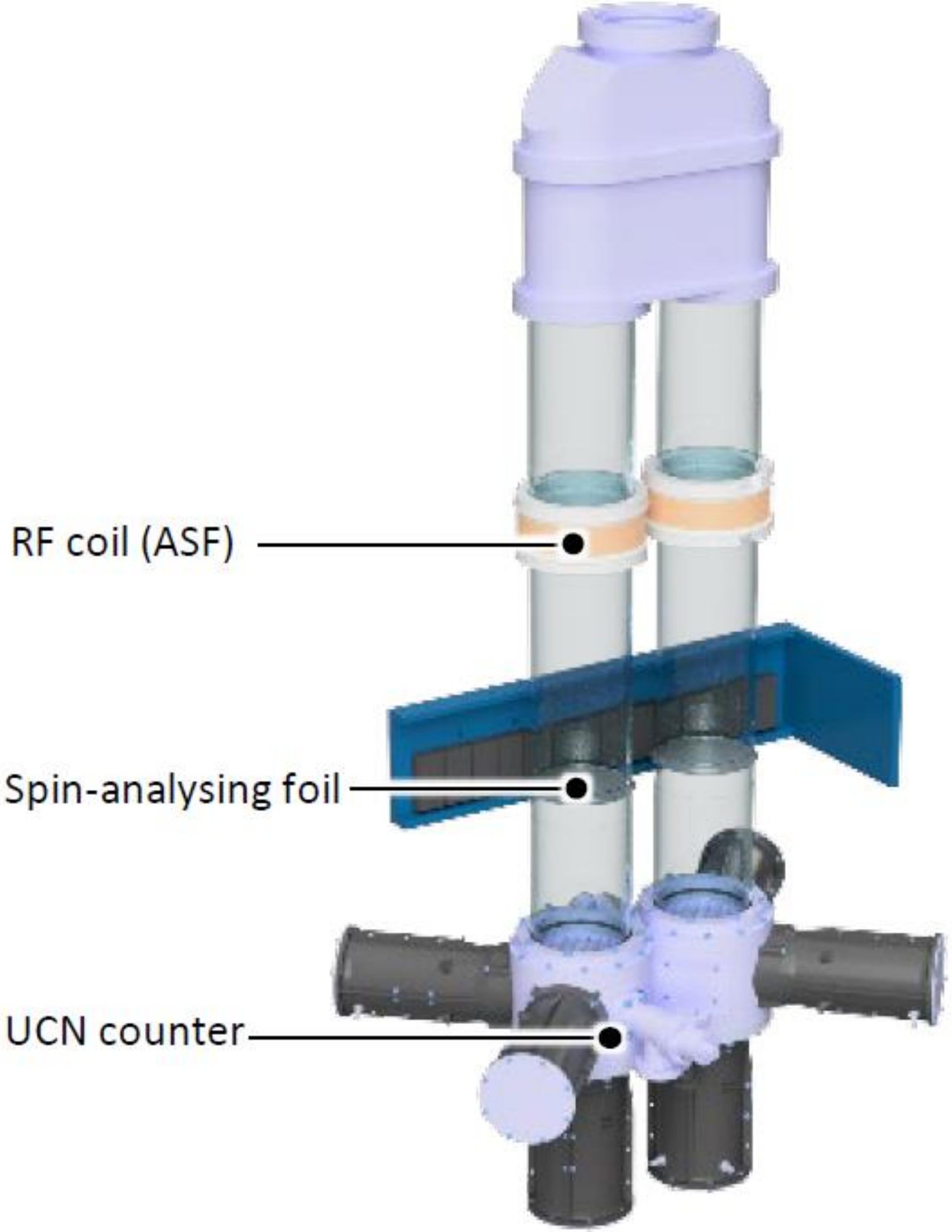
USSA for each UCN volume

Simultaneous neutron spin discrimination

UCN counters: fast gaseous detector

Gas mixture of ^{3}He and CF_4

Process: neutron capture produces proton and triton, creating scintillation of CF_4



Magnetically shielding room (MSR)

6 layers mu-metal

1 layer aluminium

Internal shielded volume ~ 25 m^3

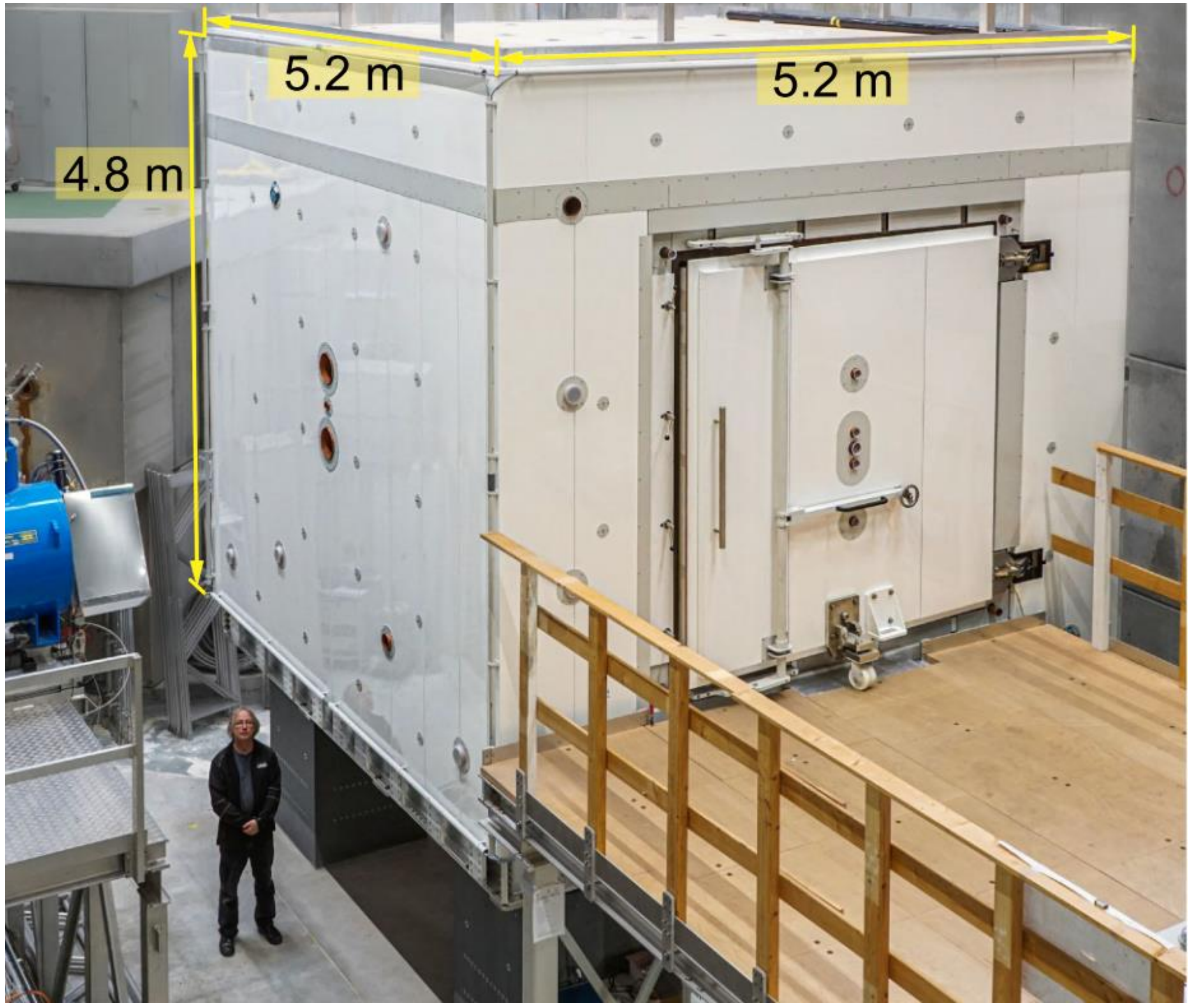
Remanent magnetic field < 100 pT @ central 1 m^3

87 openings, largest 220 mm diameter

Door clearance 2 m x 2 m

Shielding factor 100,000 @ 0.01 Hz[2]

[2] N.Ayres, et al., Review of Scientific Instruments 93, 095105 (2022)



Coil system

Installed on inner mu-metal layer

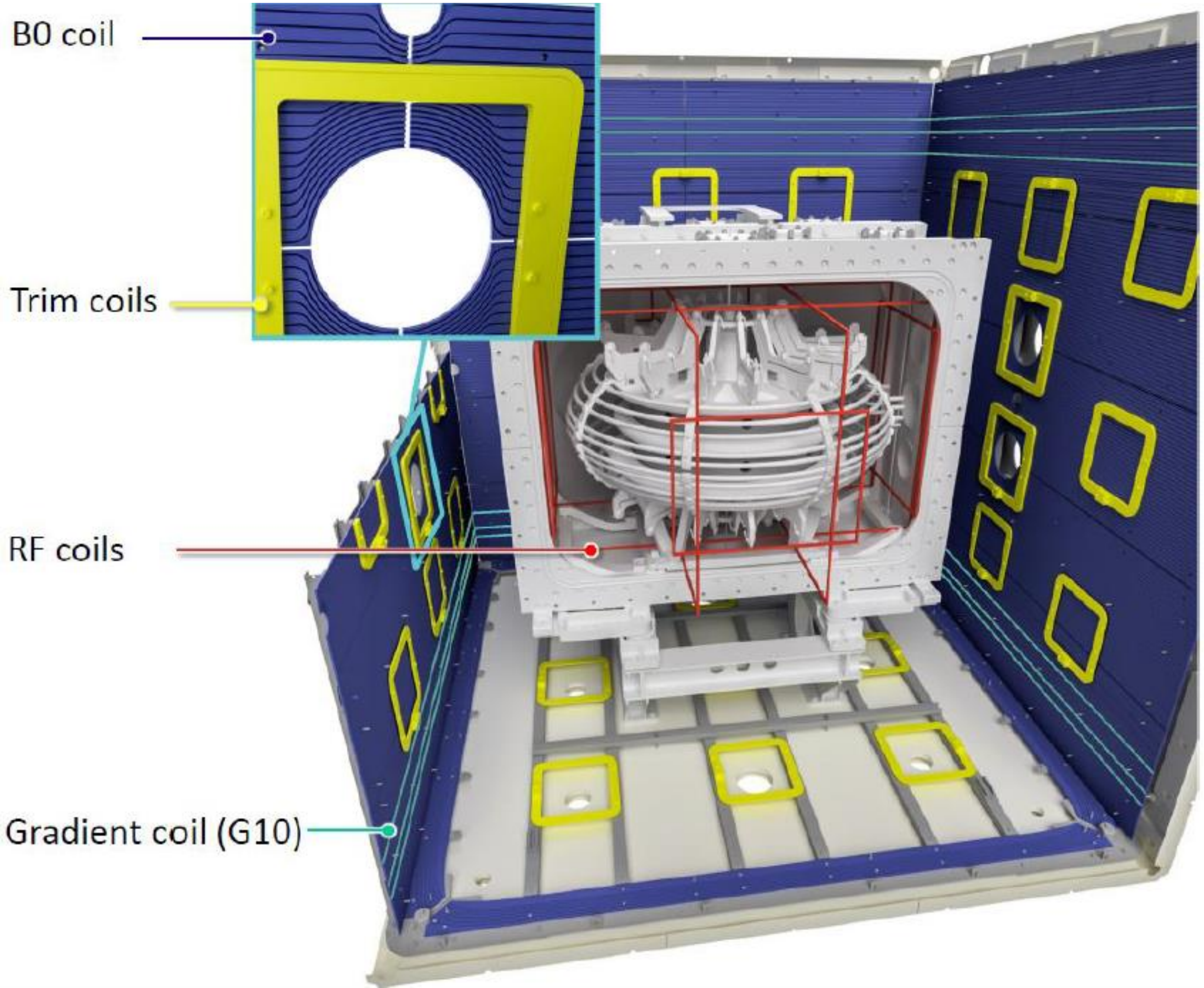
B_0 coil + 56 trim coils + 7 gradient coils

8 RF coils on vacuum tank

$B_0 = 1\ \mu T$

Field uniformity < 170 pT

Top-bottom resonance matching
< $|0.6|$ pT/cm



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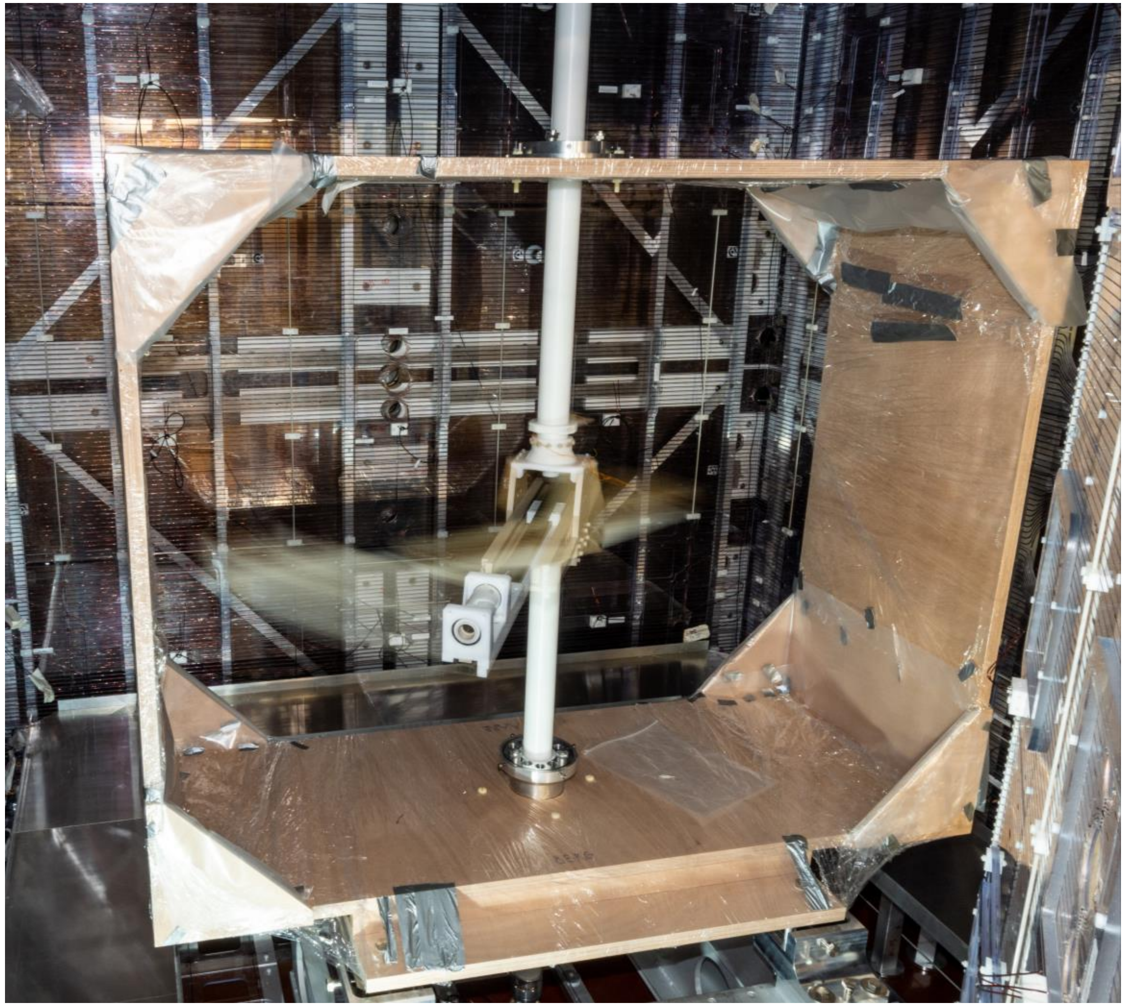
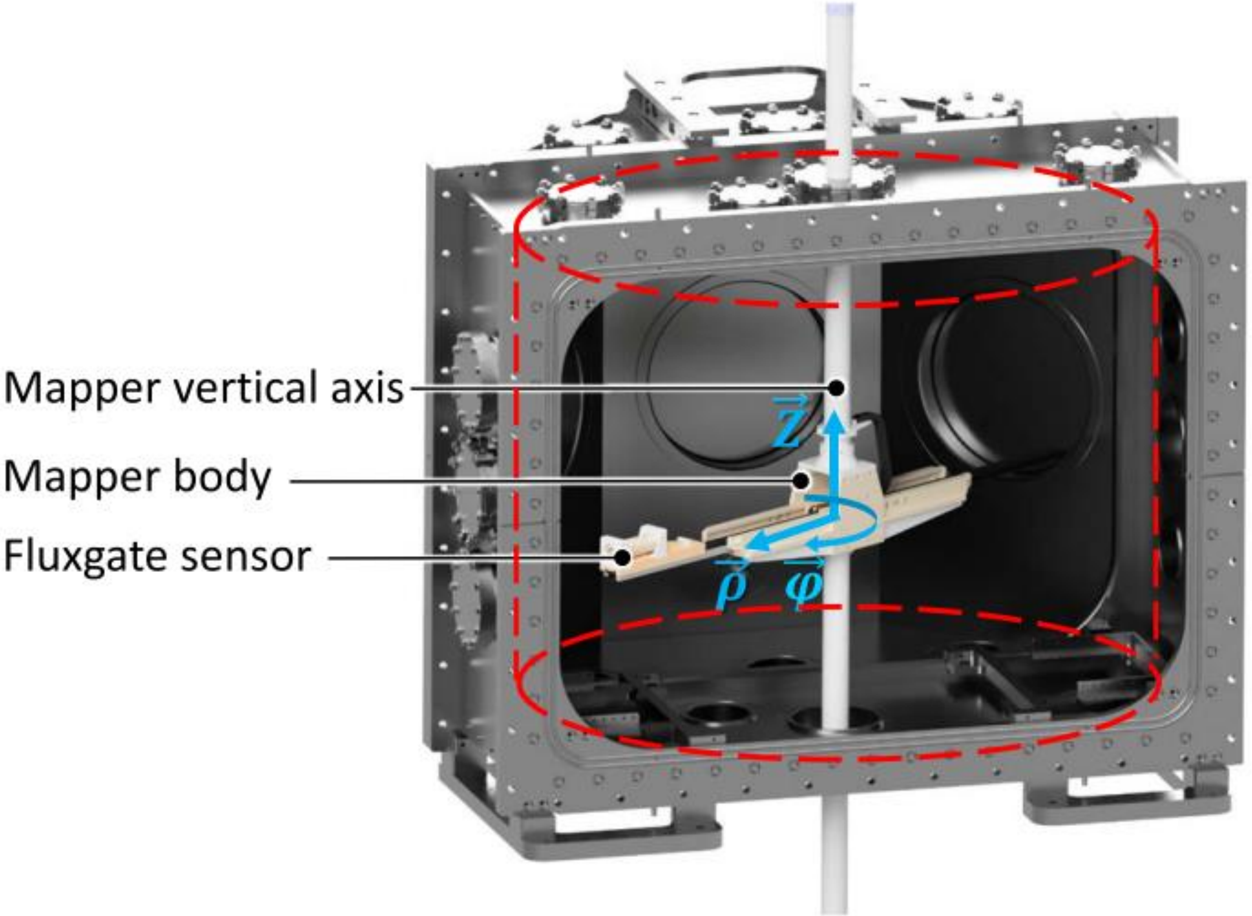
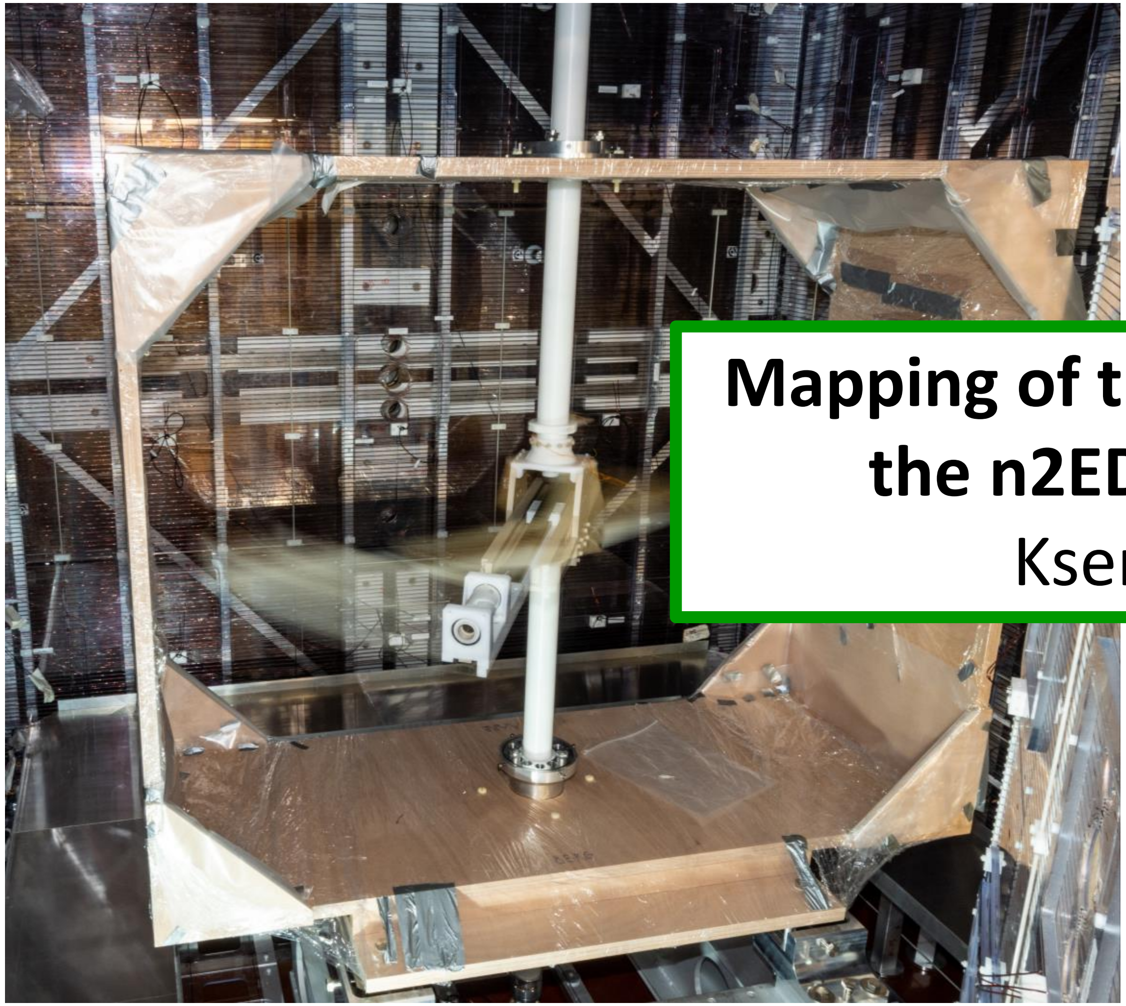
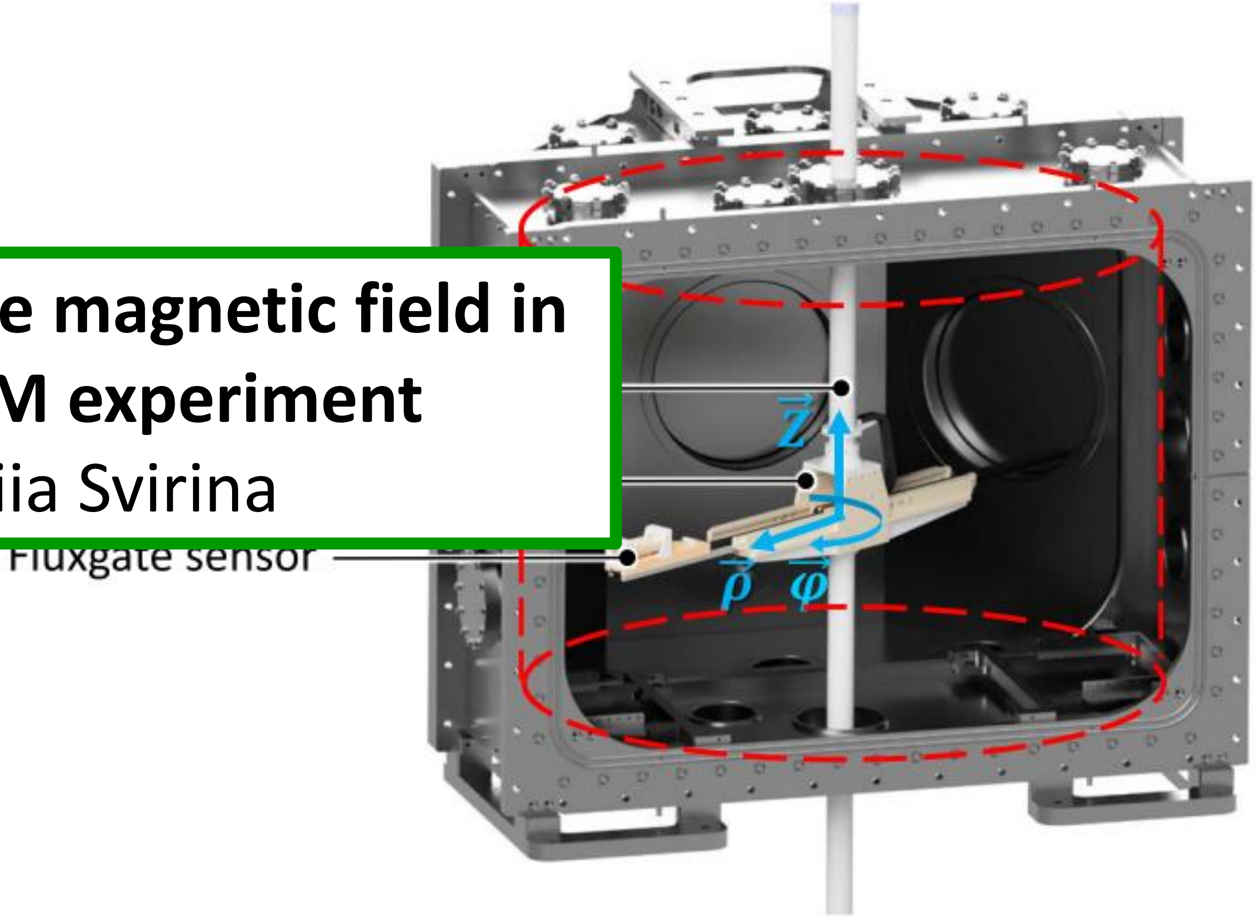




Mapper vertical axis
Mapper body
Fluxgate sensor
$\vec{z}$
$\vec{\rho}$
$\vec{\varphi}$

Coil system





Mapping of the magnetic field in the n2EDM experiment

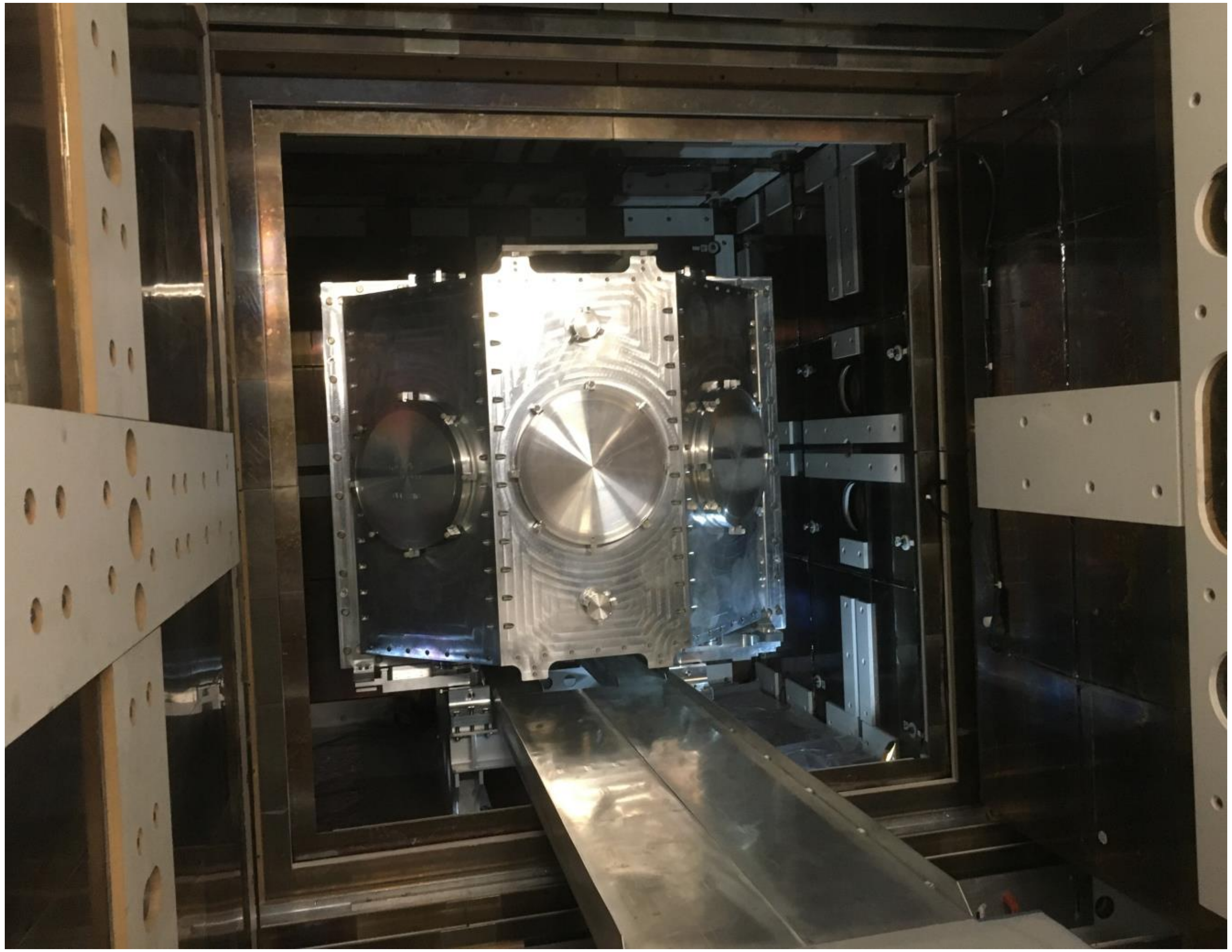
Kseniia Svirina

Vacuum tank

Non-magnetic aluminium vacuum tank

Internal volume: 1.6 m x 1.6 m x 1.2 m

Ultimate pressure: $\sim 10^{-6}$ mbar



Cesium magnetometers

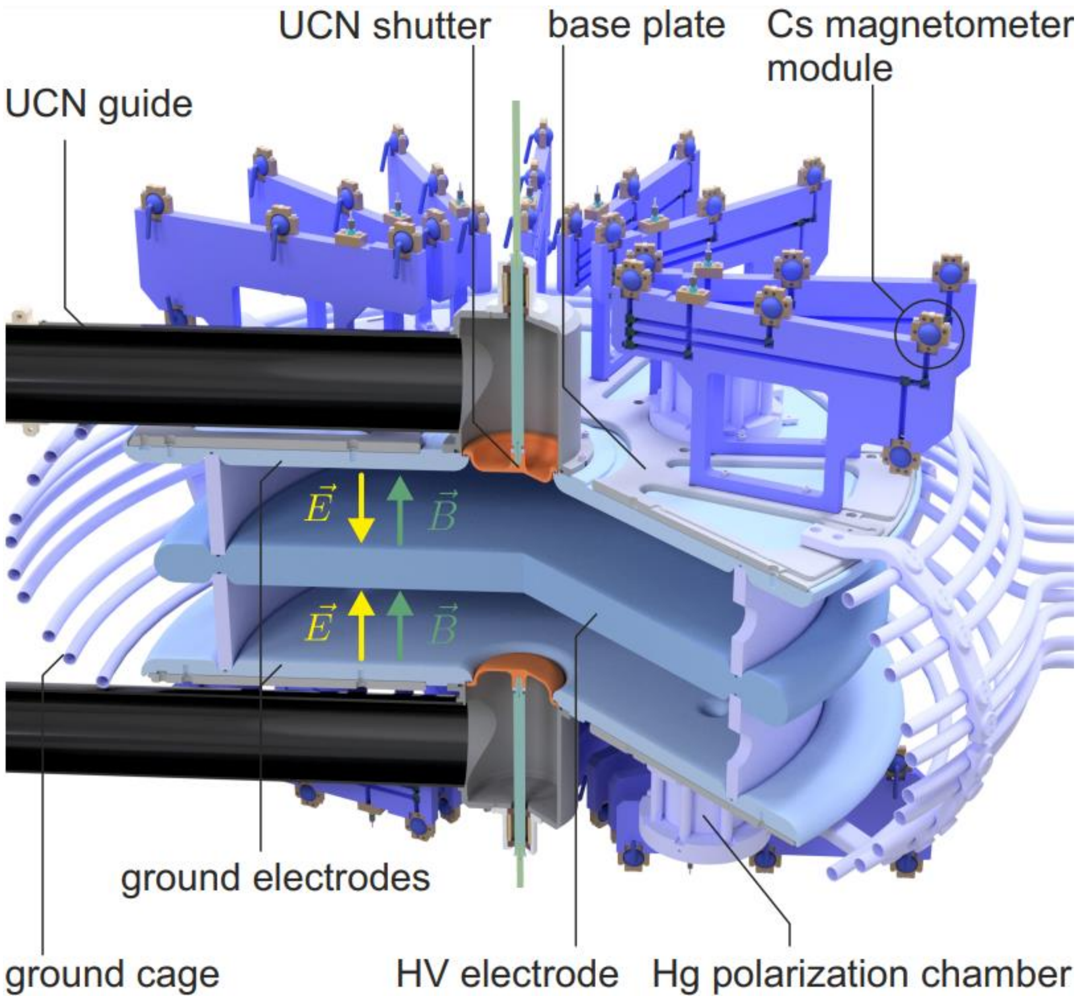
Optically pumped magnetometers

114 Cs magnetometers: position optimize for extraction of gradient components

Goal accuracy < 5 pT

Position placement ± 0.5 mm

Characterise in 4 layer mu-metal shielding

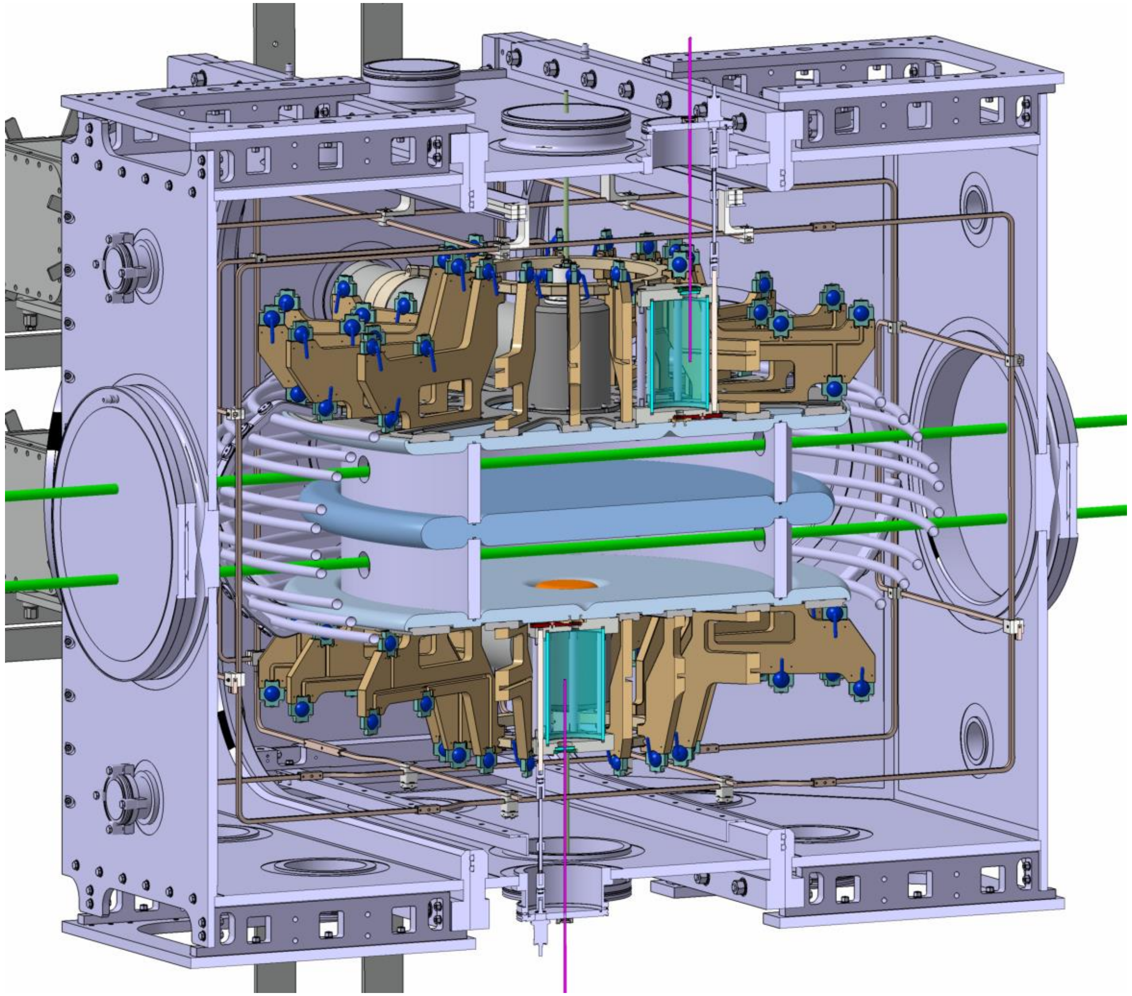


Mercury magnetometers

Co-magnetometer measures volume averaged magnetic field

Hg^{199} polarized via optical pumping of the $6^1\mathrm{S}_0 \rightarrow 6^3\mathrm{P}_1$

PMT measures intensity modulation of a horizontal light beam



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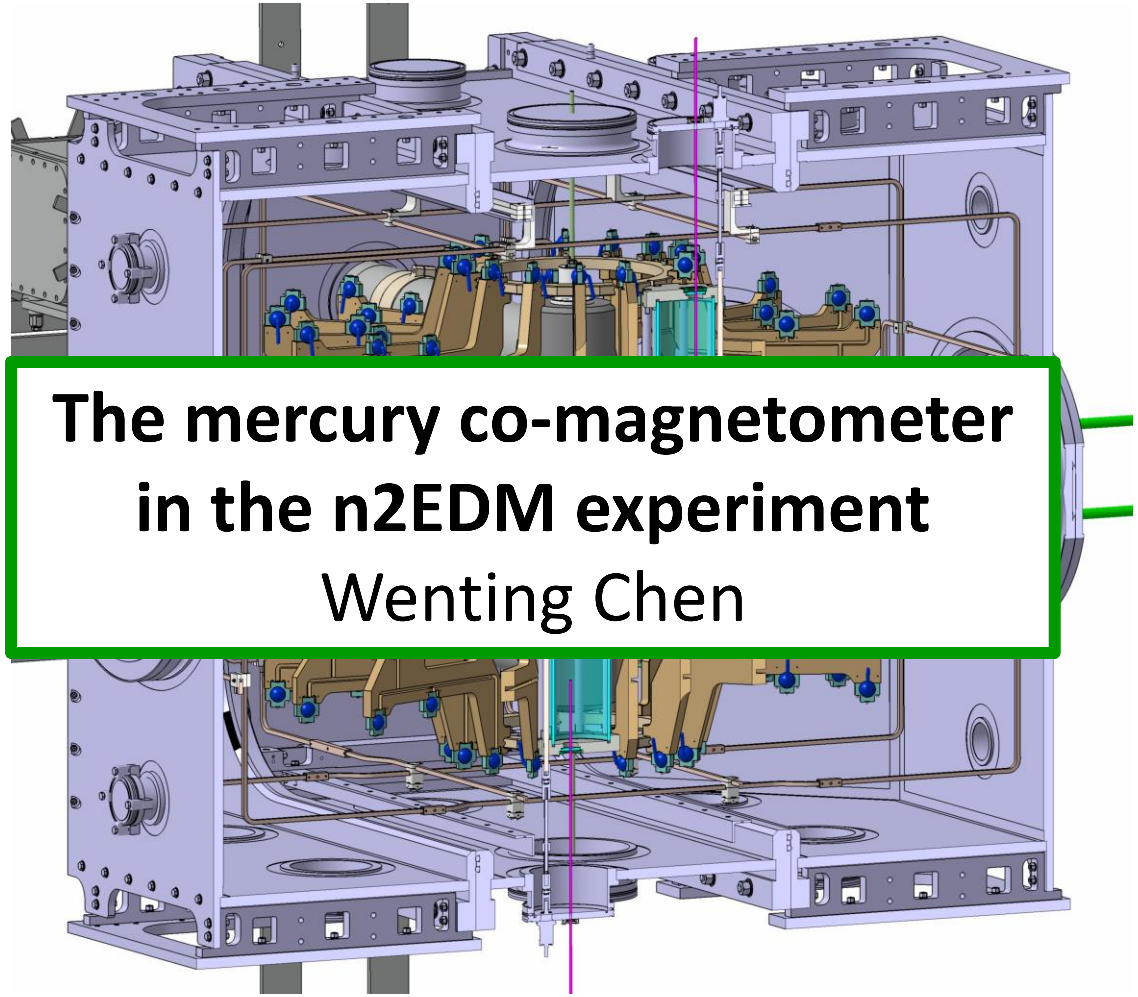
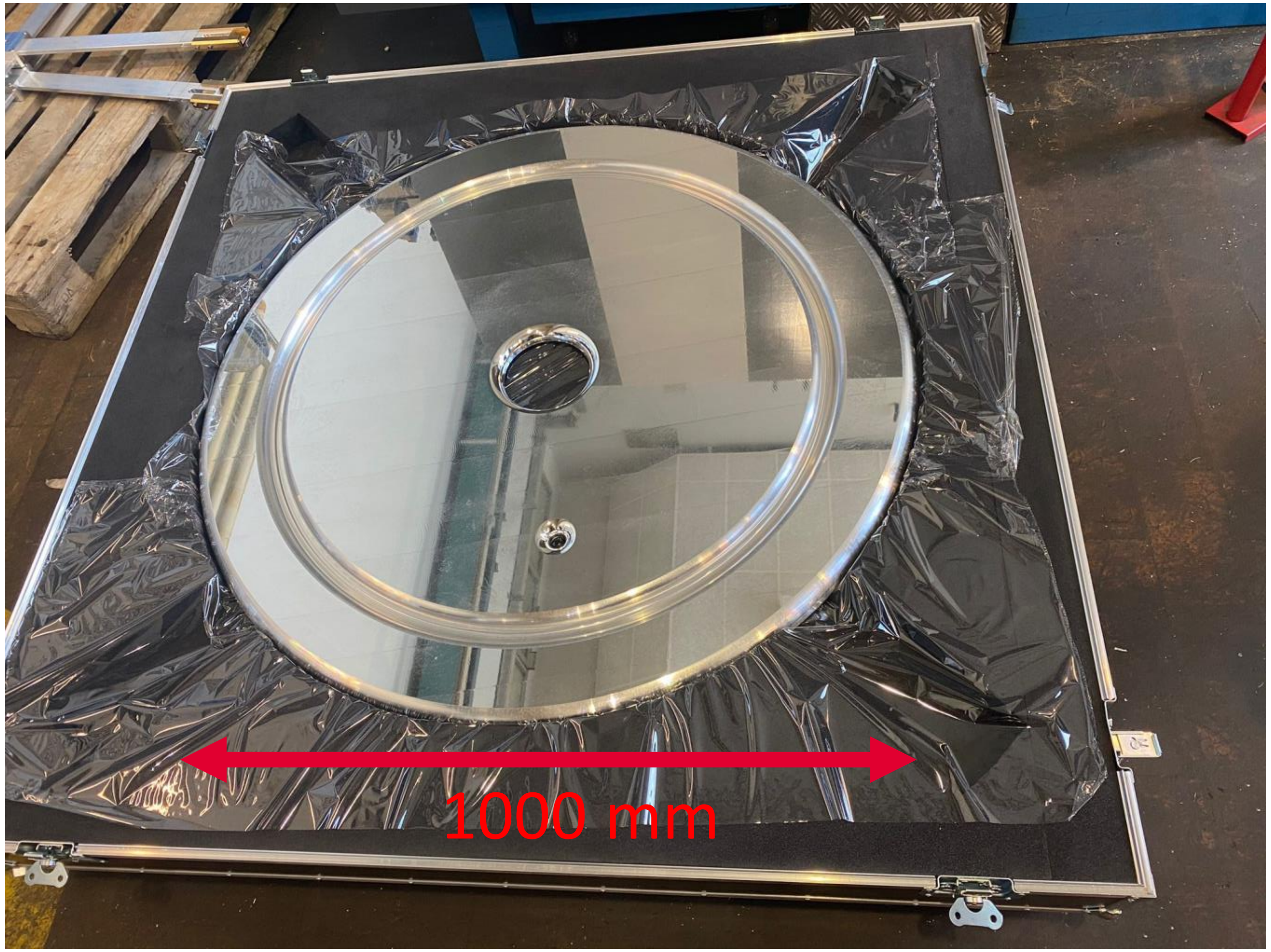
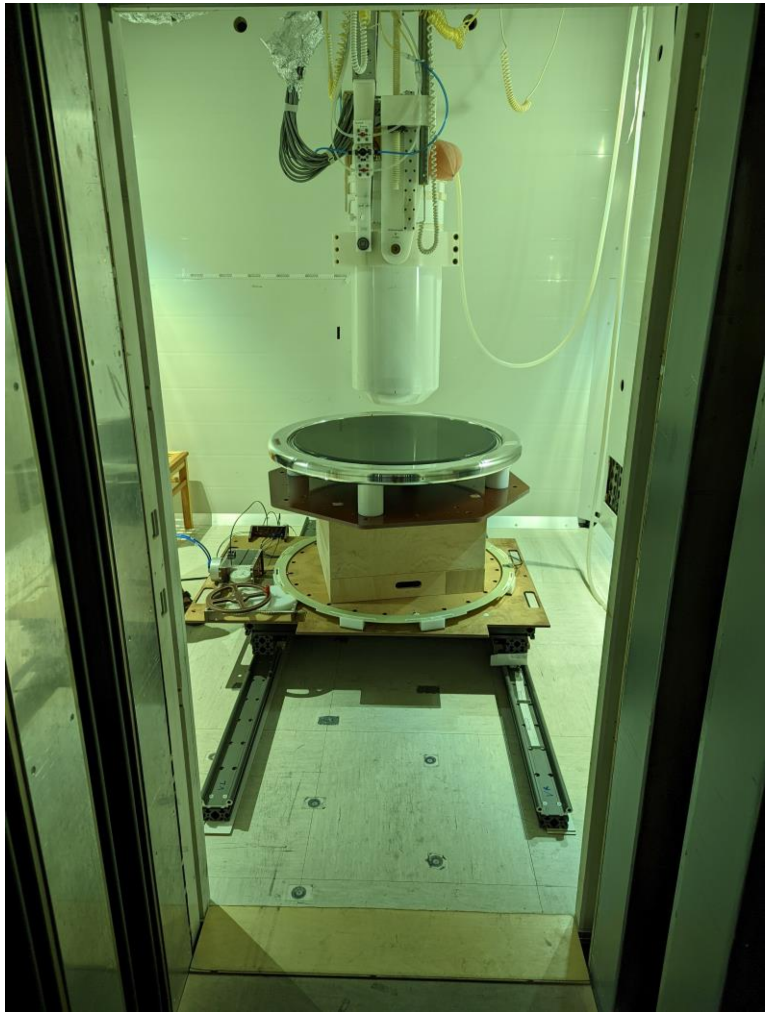
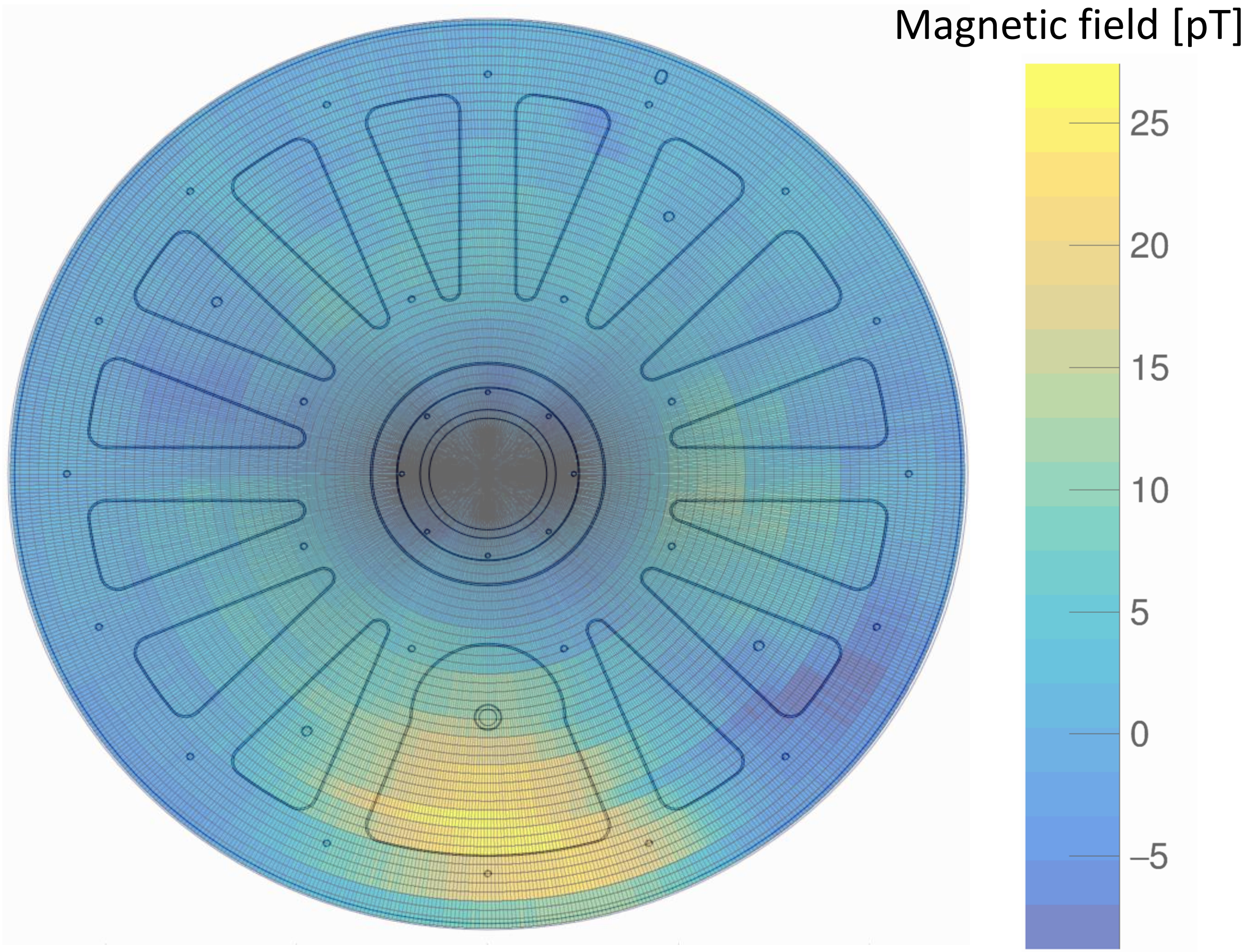


Ramsey chamber electrodes



Electrode magnetic scanning at PTB





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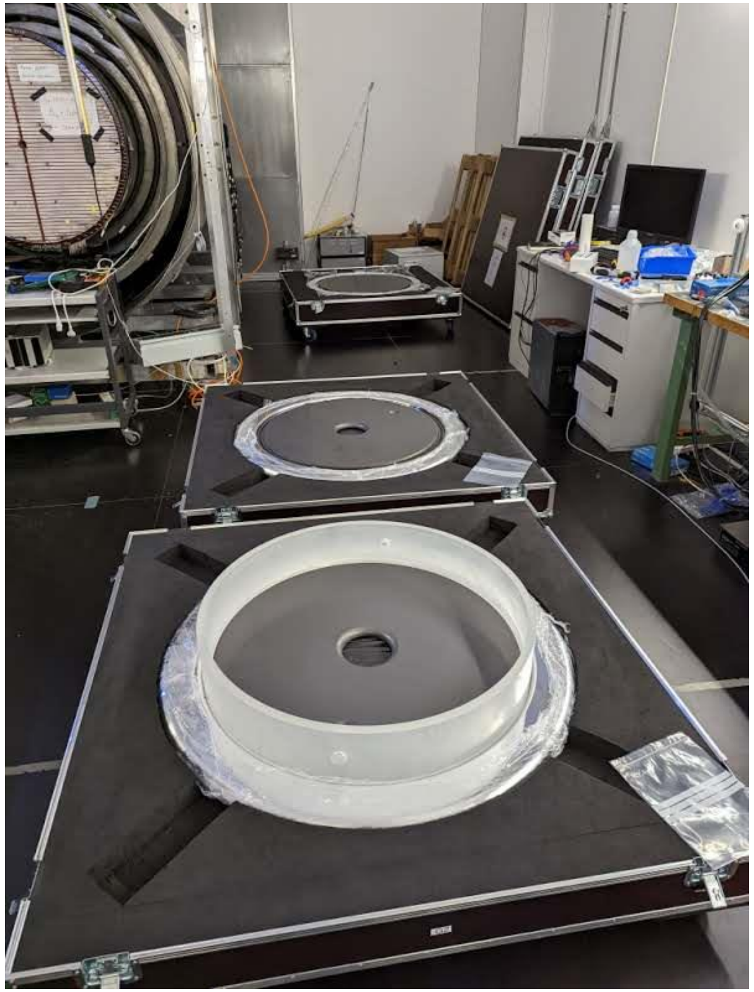
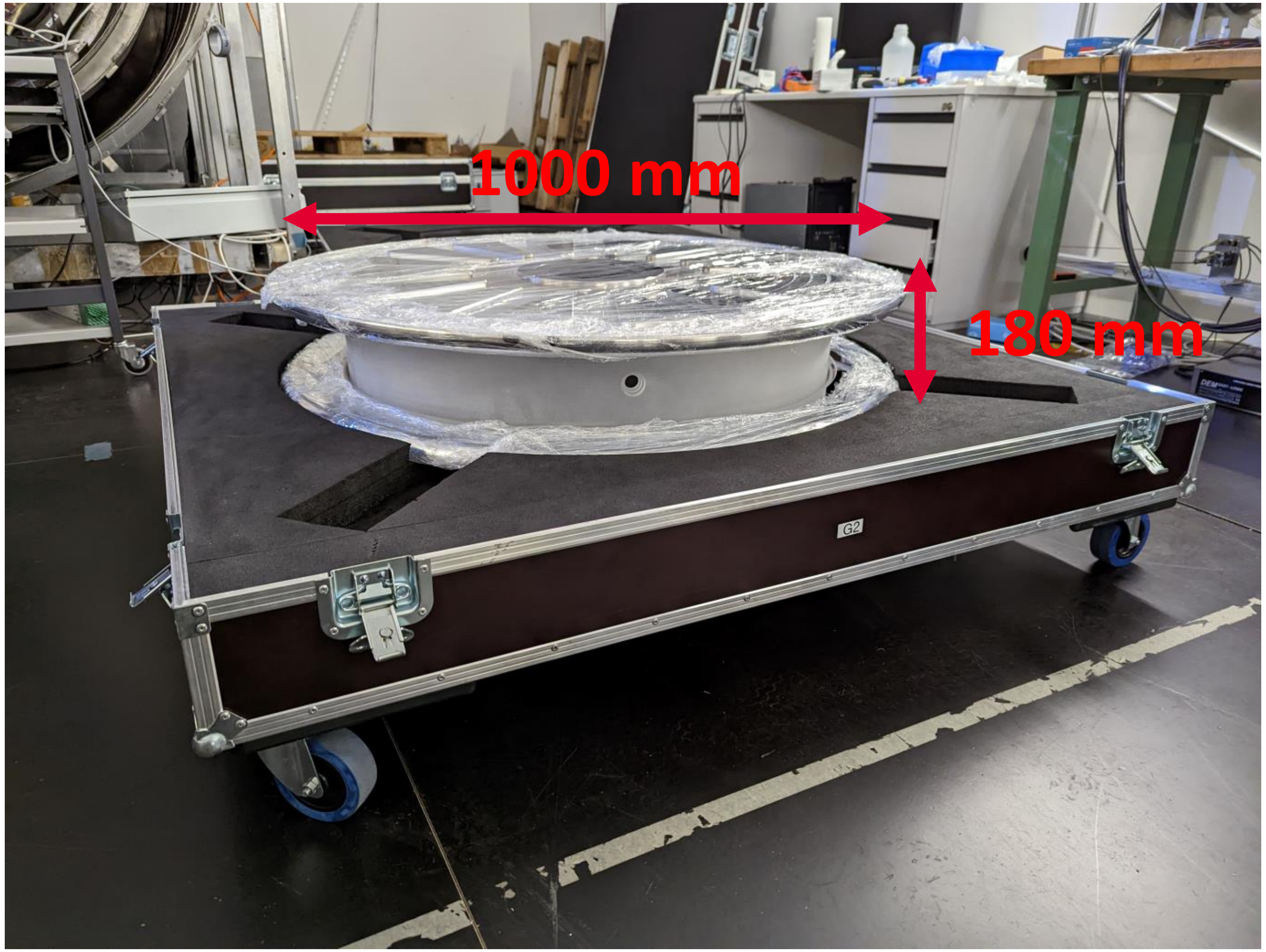




Conclusions

n2EDM representants next generation experiment

Sensitivity goal improvement of order magnitude

Commissioning of the experiment currently underway

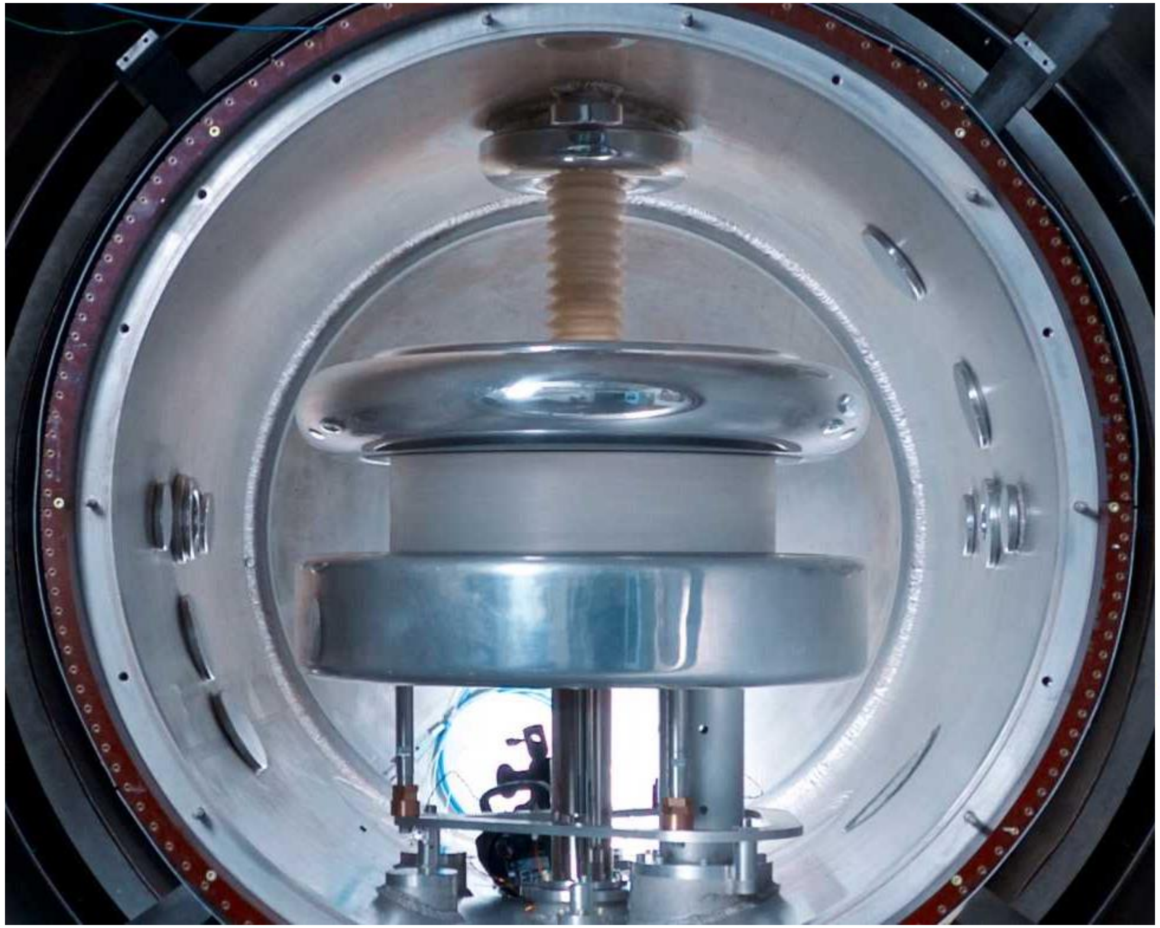
Plan for first UCN's with Ramsey apparatus in the next year

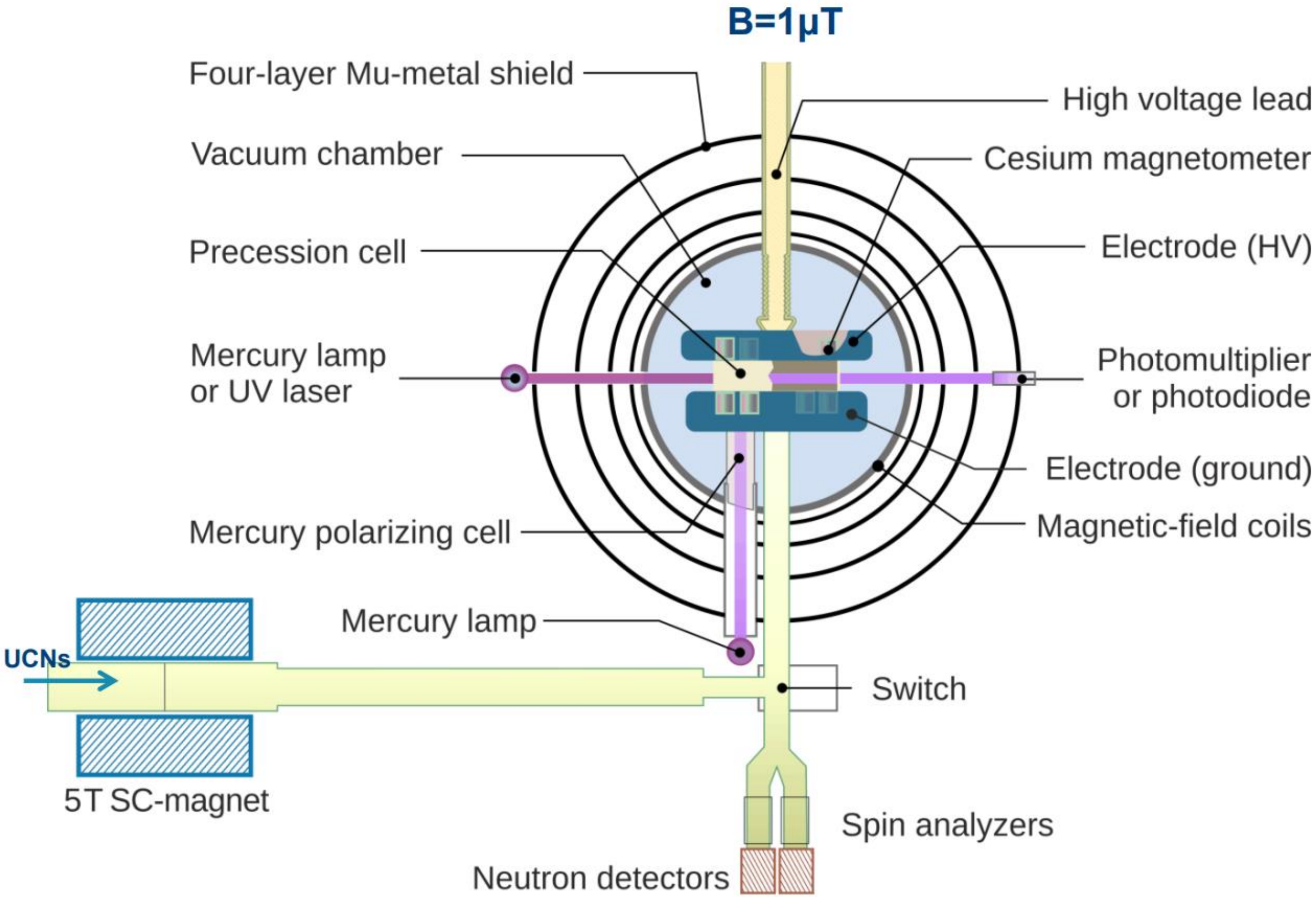
Thanks for your attention

Backup slides

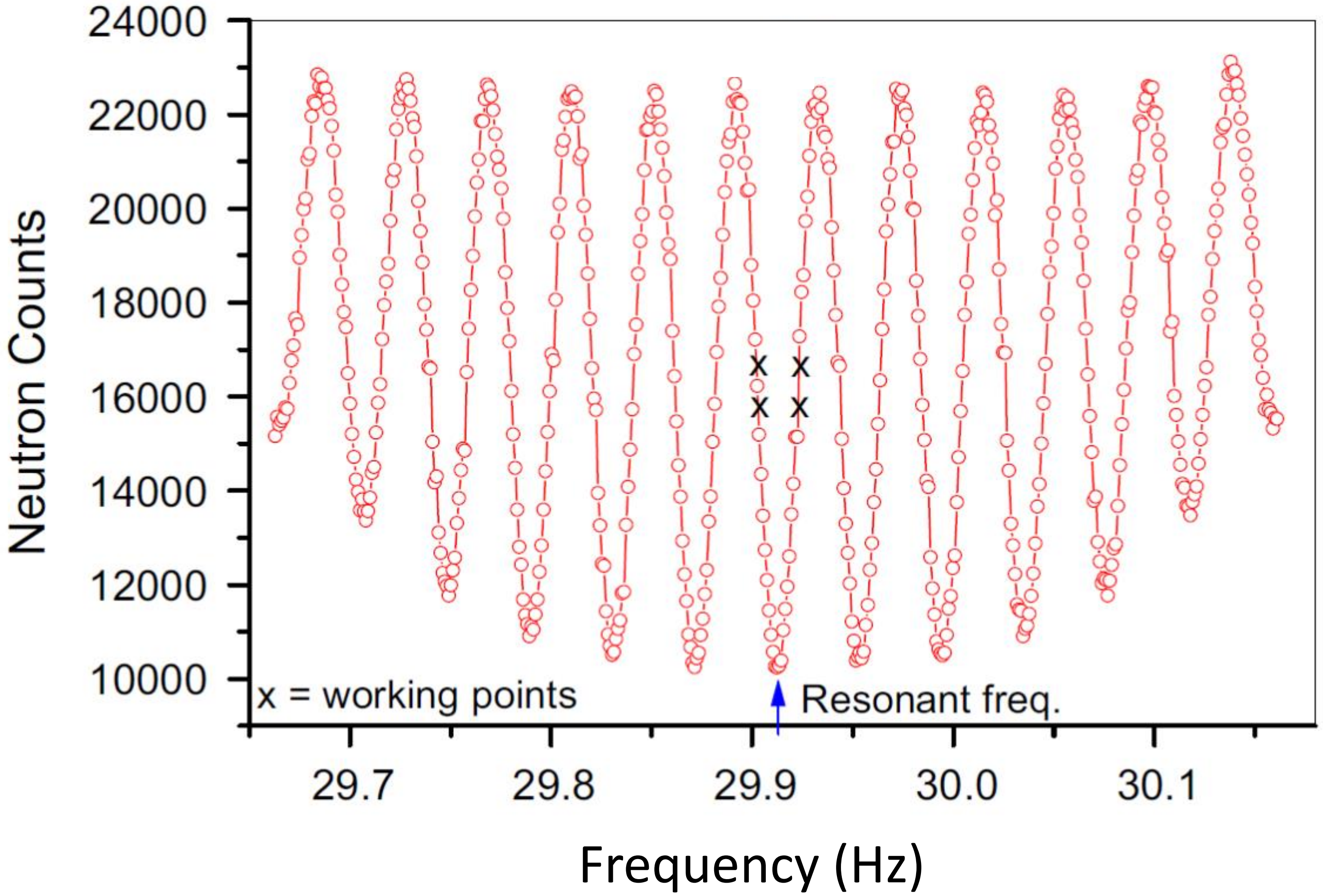
The collaboration

Previous experiment – nEDM





Ramsey's method of separated oscillatory fields



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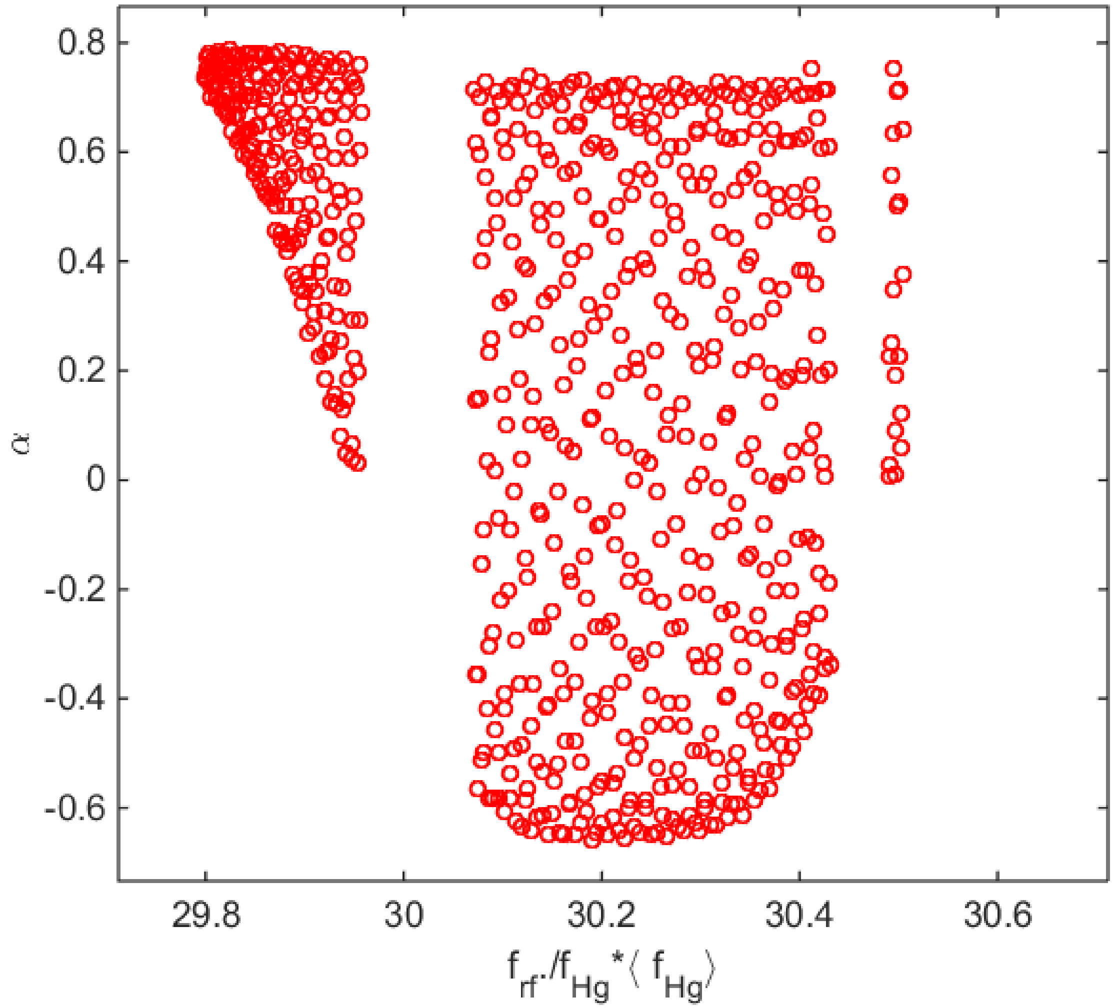

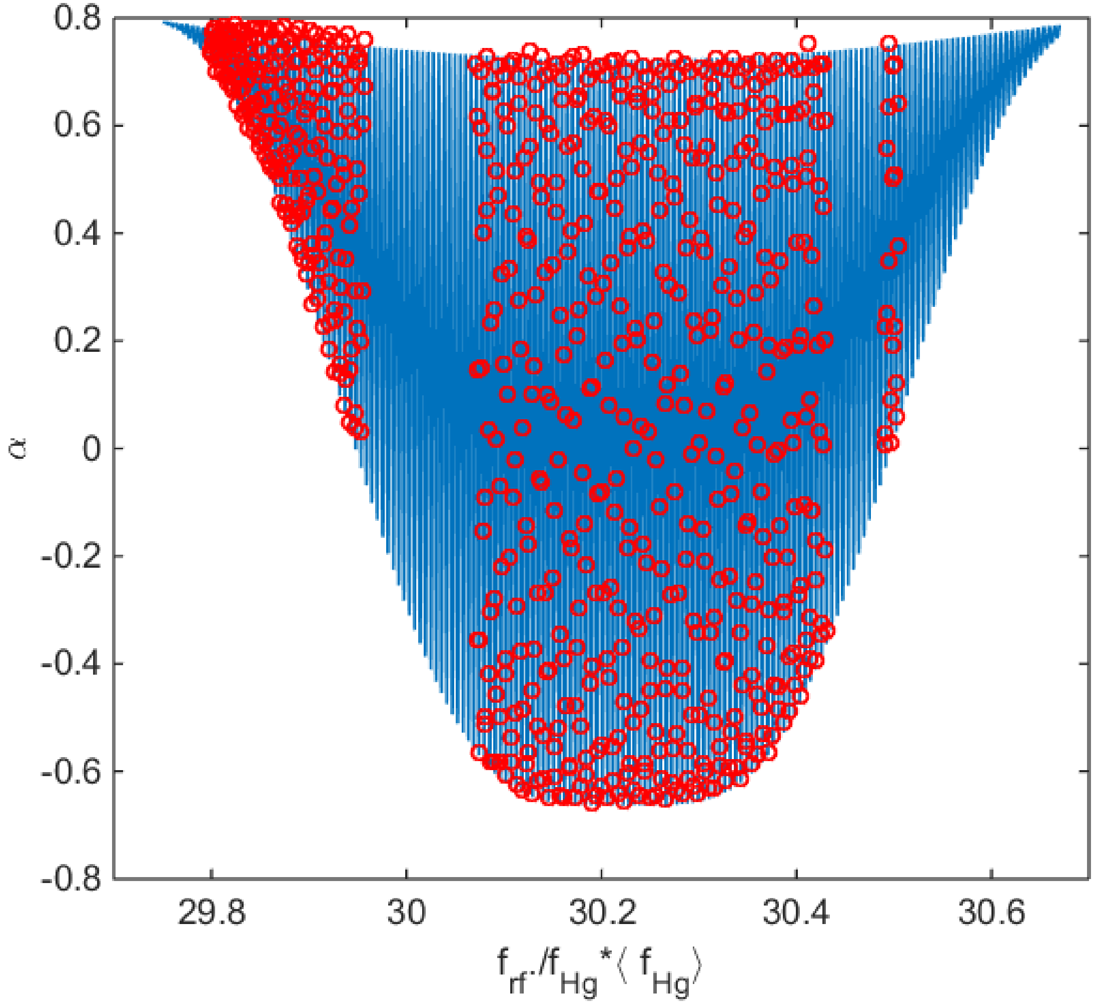

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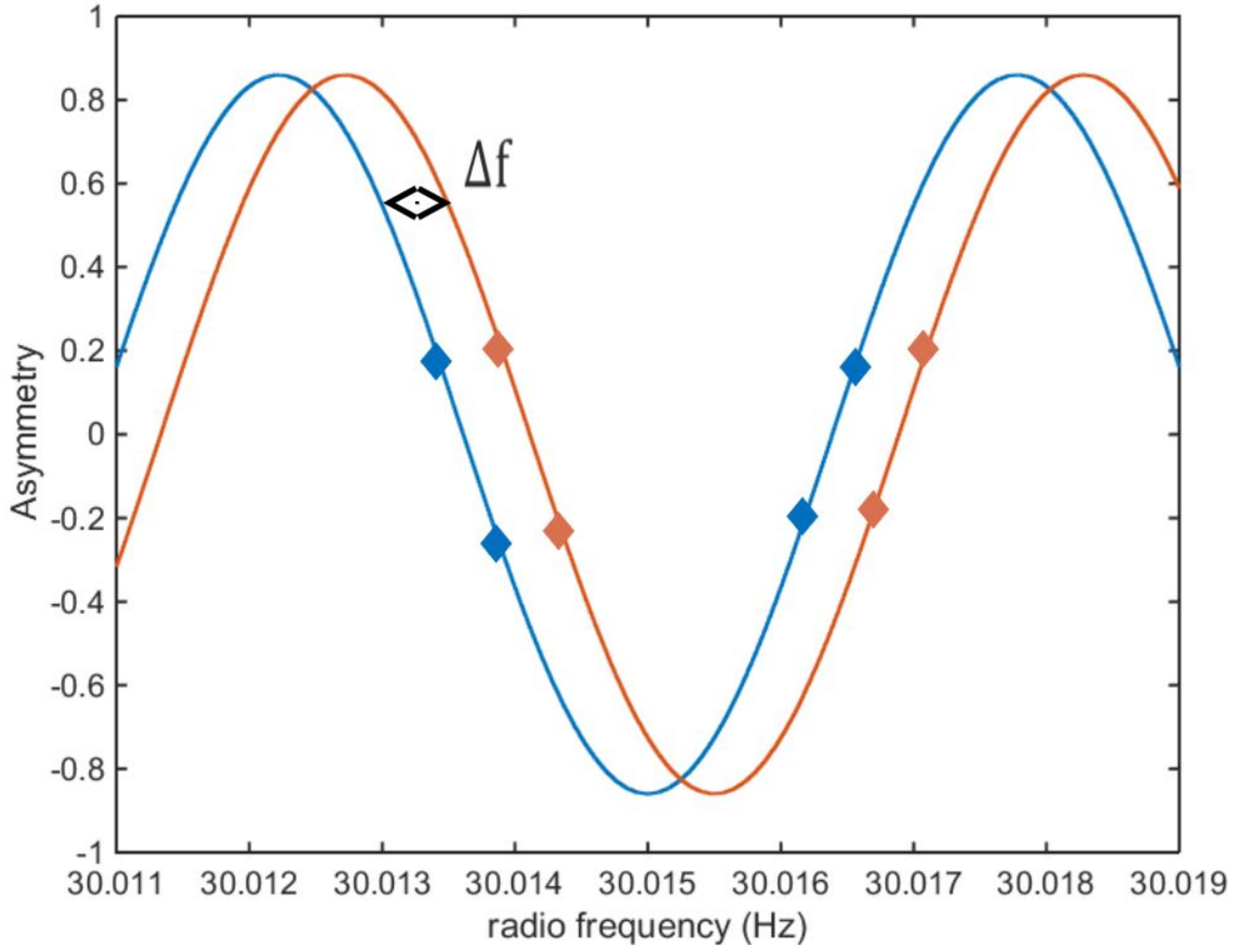
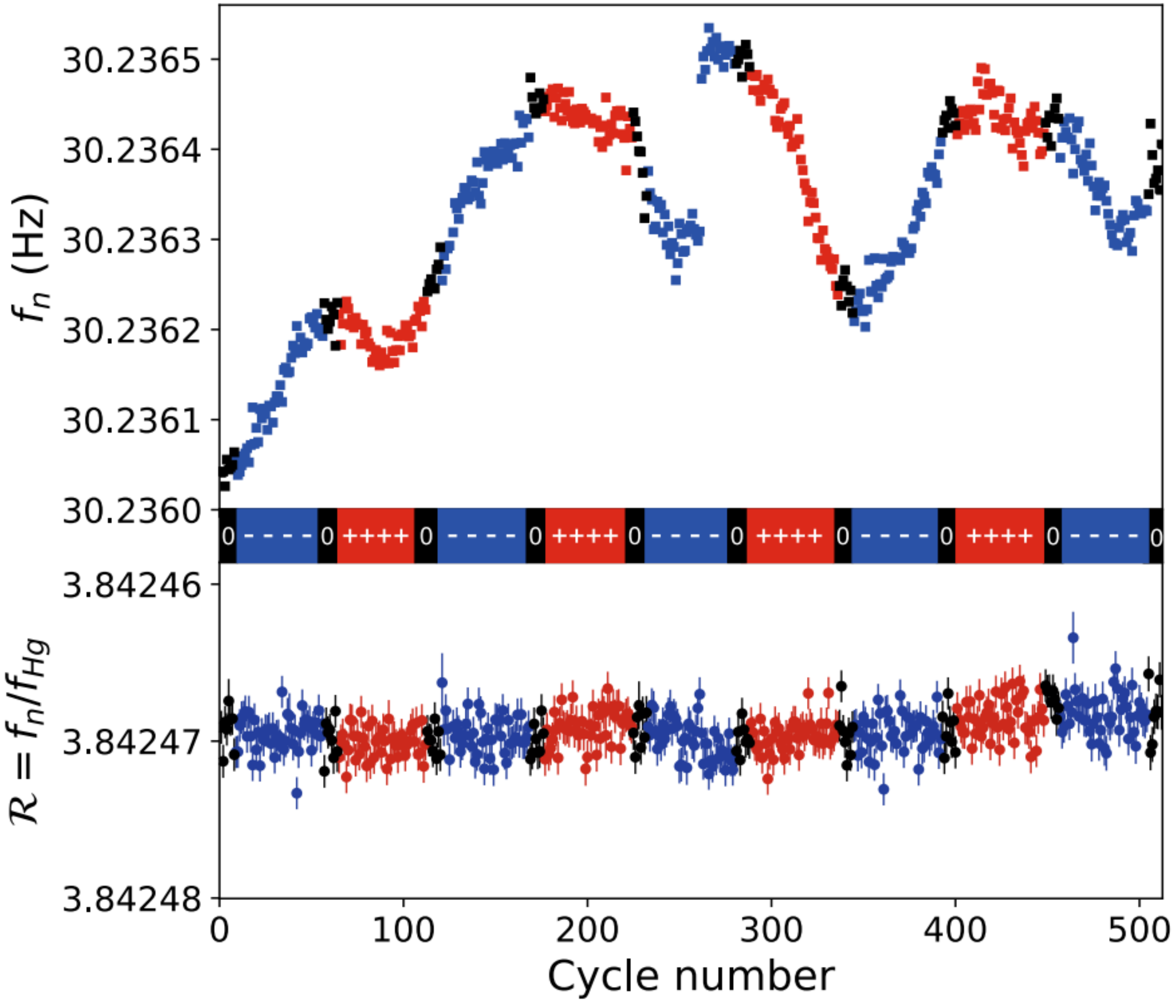


nEDM data sequence



Experimental comparison

	nEDM 2016	n2EDM
Chamber	DLC and dPS	DLC and dPS
Diameter D	47 cm	80 cm
N (per cycle)	15,000	121,000
T	180 s	180 s
E	11 kV/cm	15 kV/cm
α	0.75	0.8
$\sigma(f_n)$ per cycle	9.6 μHz	3.2 μHz
$\sigma(d_n)$ per day	11×10^{-26} e cm	2.6×10^{-26} e cm
$\sigma(d_n)$ (final)	9.5×10^{-27} e cm	1.1×10^{-27} e cm

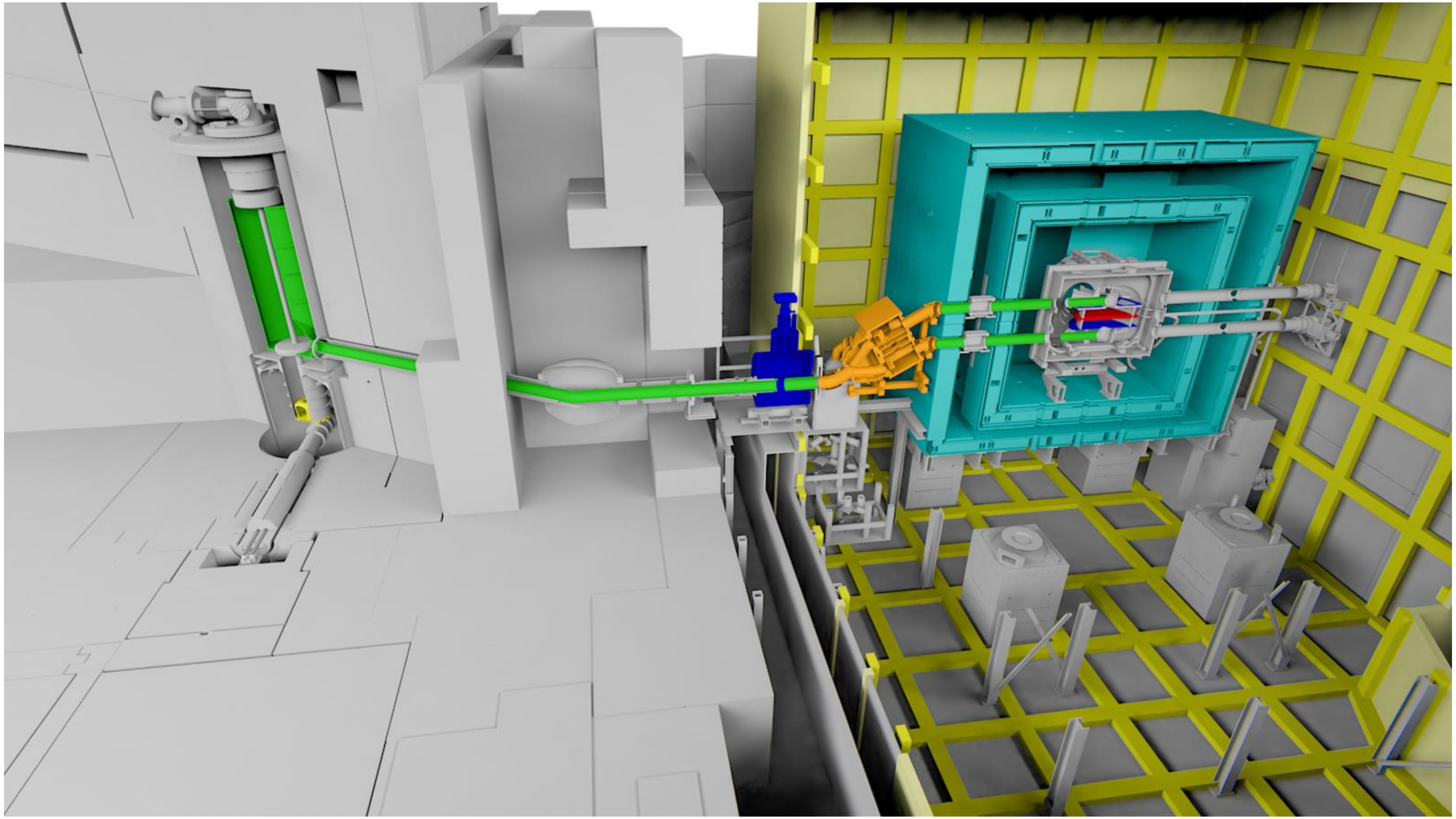
n2EDM systematic effects

Systematic effect	(10^{-28} e cm)
Uncompensated gradient drift	1
Quadratic $v \times E$	1
Co-magnetometer accuracy	1
Phantom mode of order 3	3
Phantom mode of order 5	3
Dipoles contamination	3
Total	6

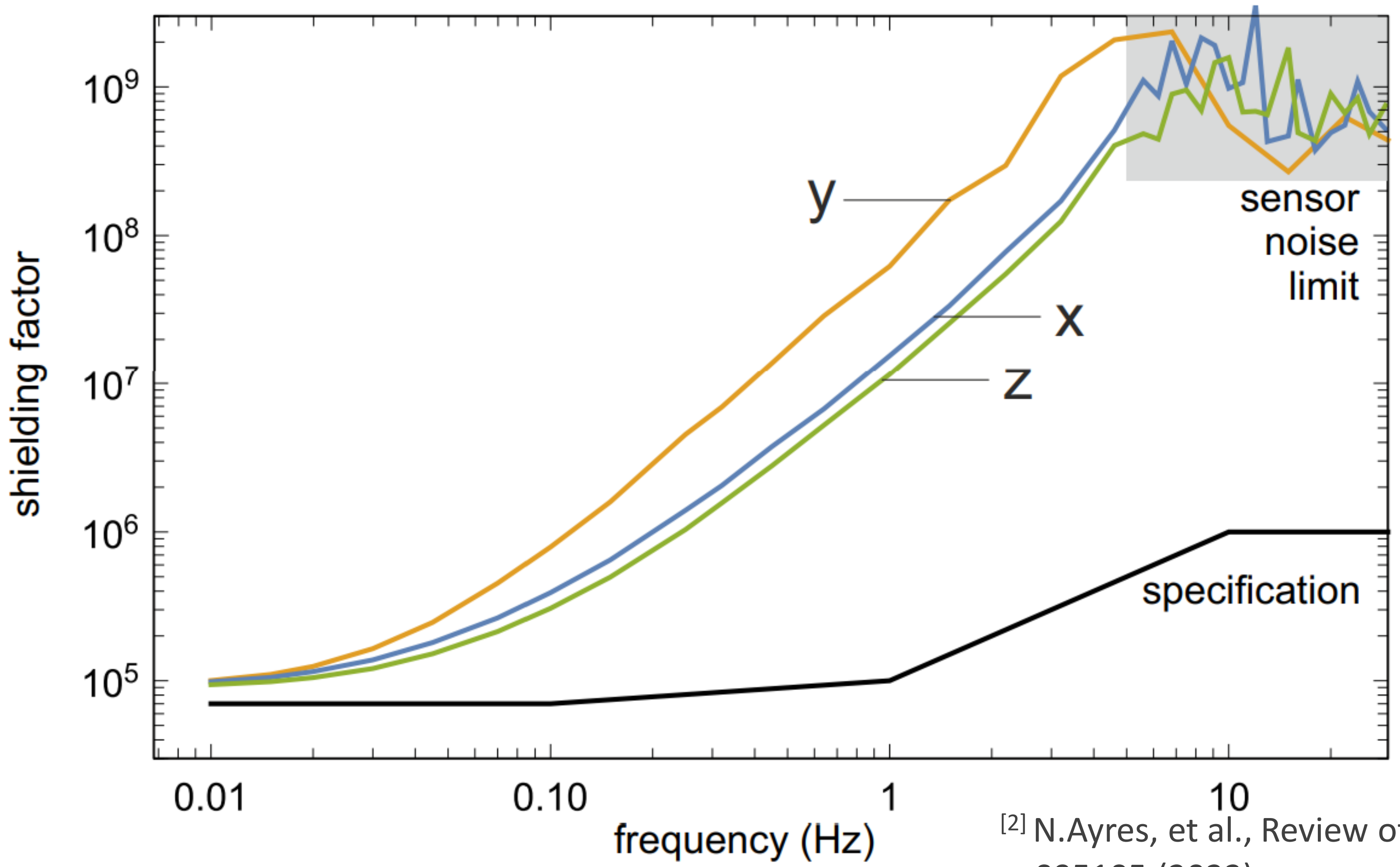
Magnetic field requirements

Related to statistical errors	
(B-gen) Top-Bottom resonance matching condition	$-0.6\,\mathrm{pT/cm} < G_{1,0} < 0.6\,\mathrm{pT/cm}$
(B-gen) Field uniformity in the chambers	$\sigma(B_z) < 170\,\mathrm{pT}$
(B-gen) Field stability on minutes timescale	< 25 fT
(B-meas) Precision Hg co-magnetometer, per cycle, per chamber	< 25 fT

Experimental setup – n2EDM

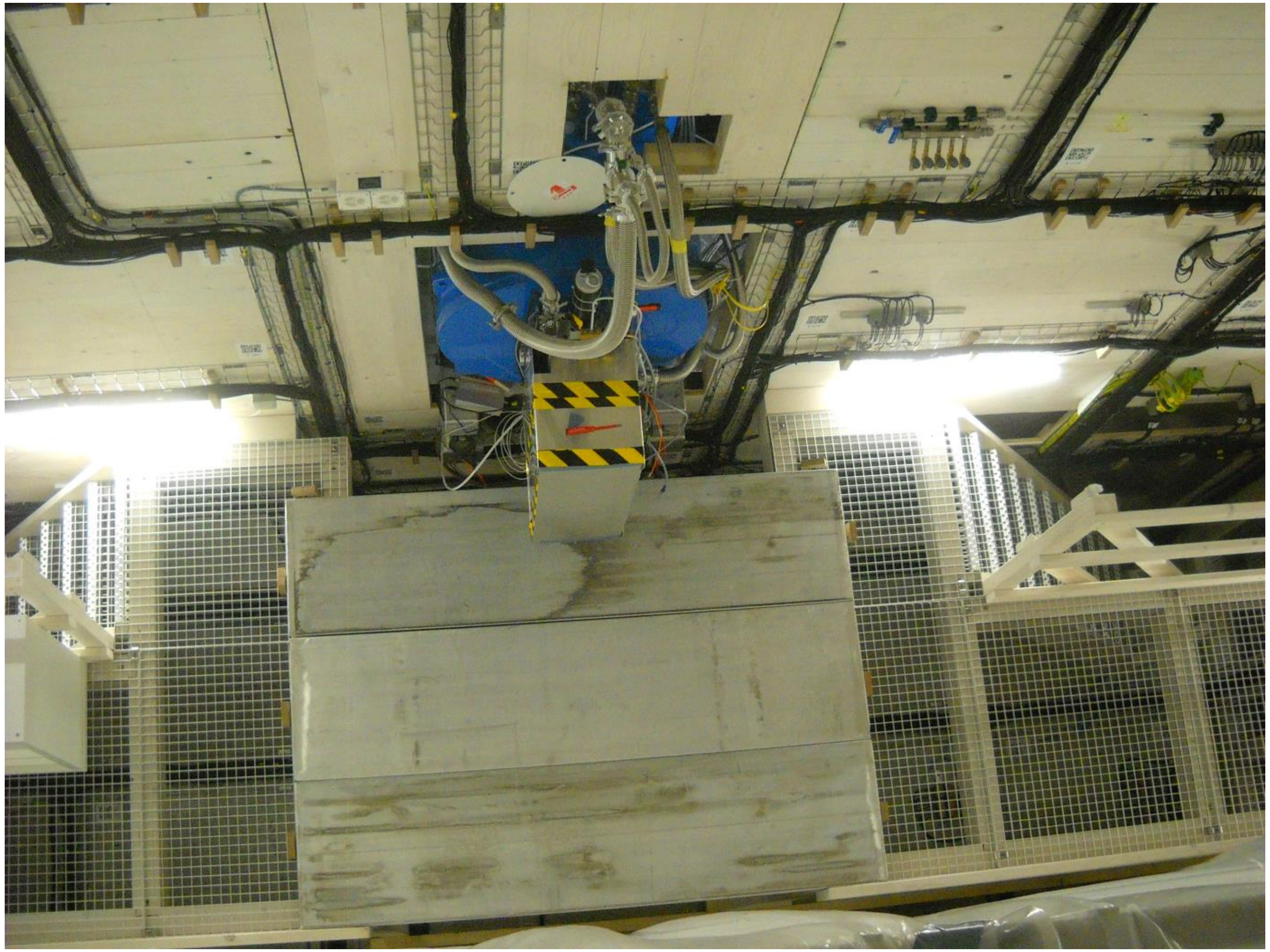


MSR shielding factor



[2] N.Ayres, et al., Review of Scientific Instruments 93, 095105 (2022)

Polarizing magnetic



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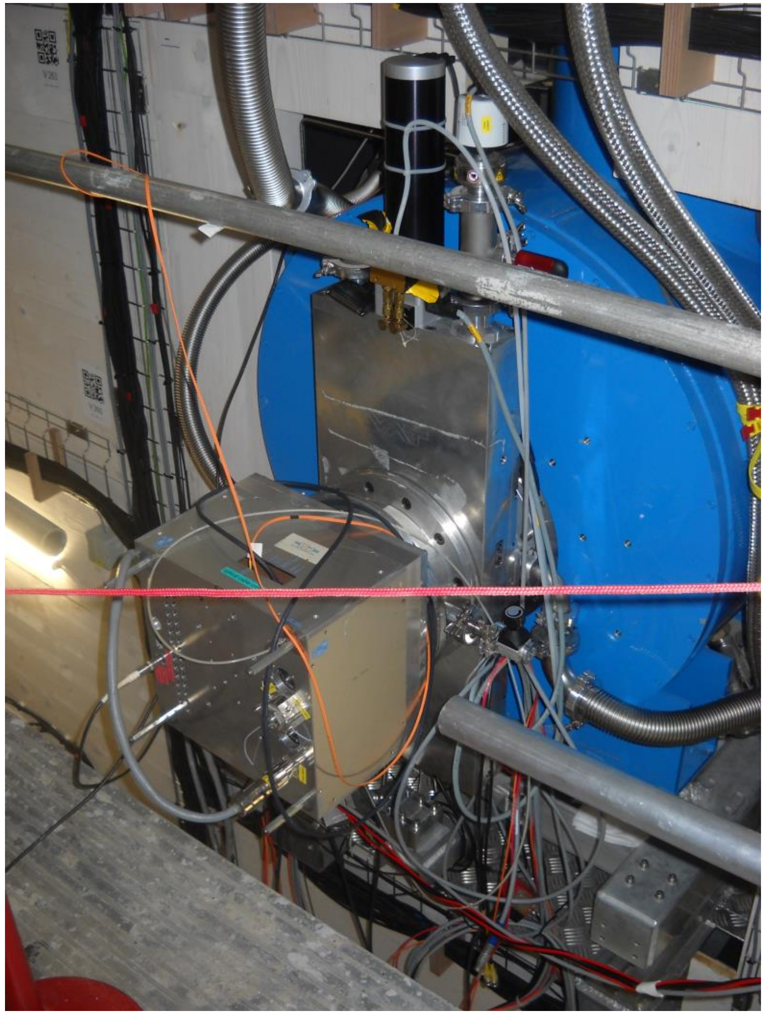
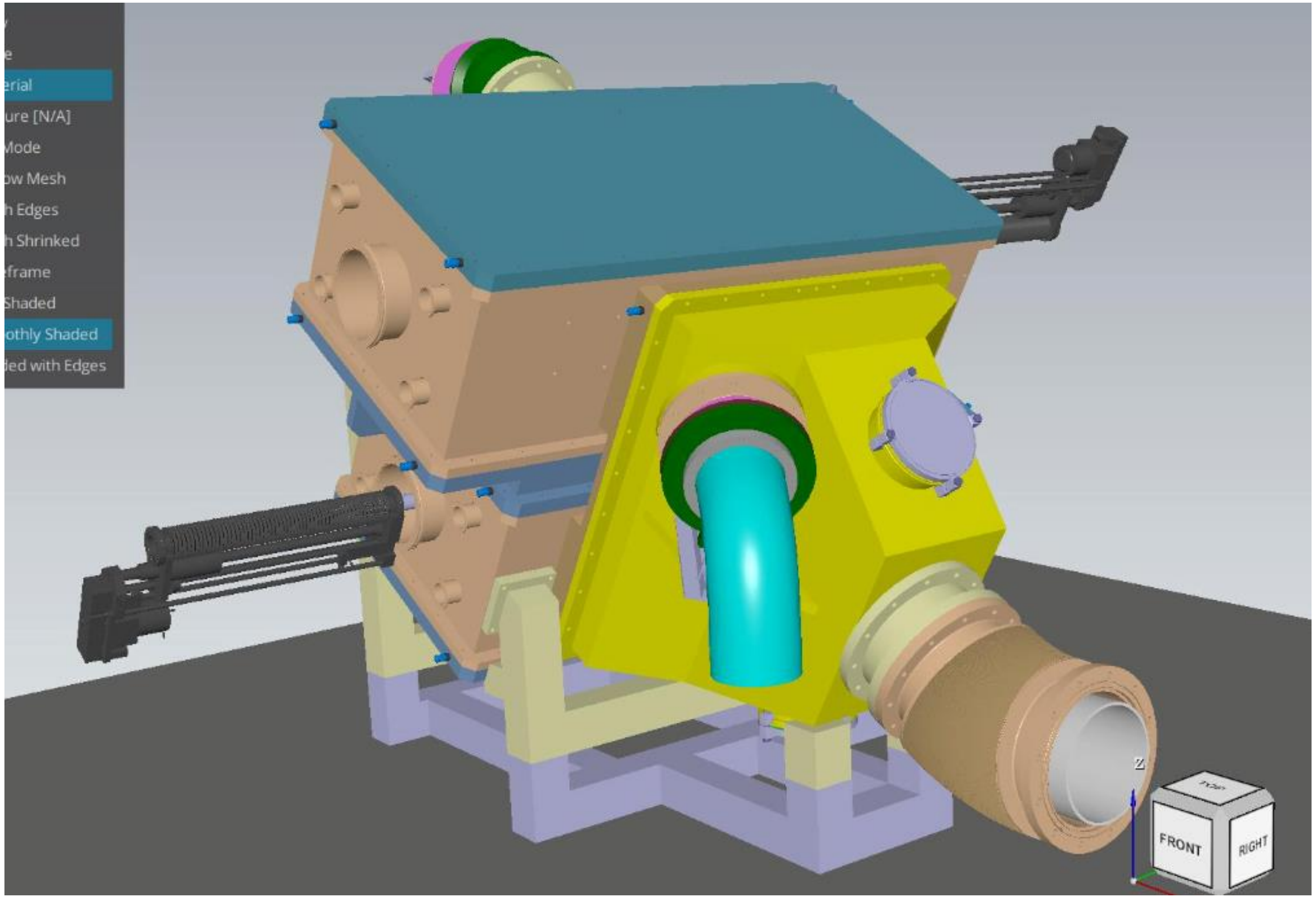


UCN switch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ure [N/A]
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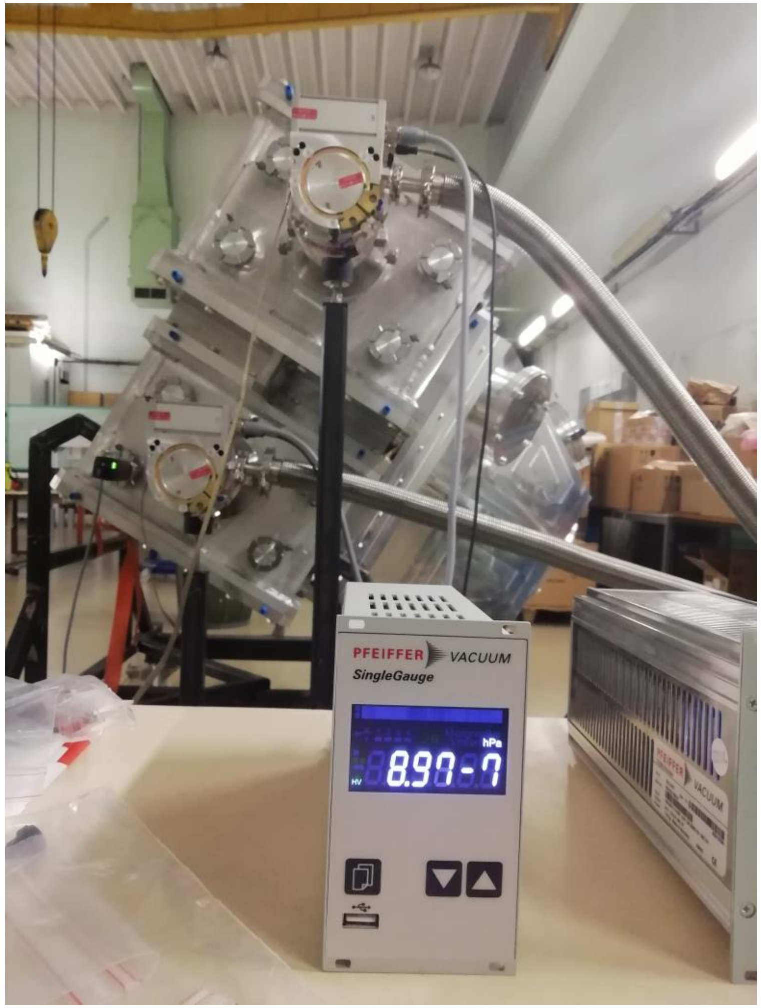
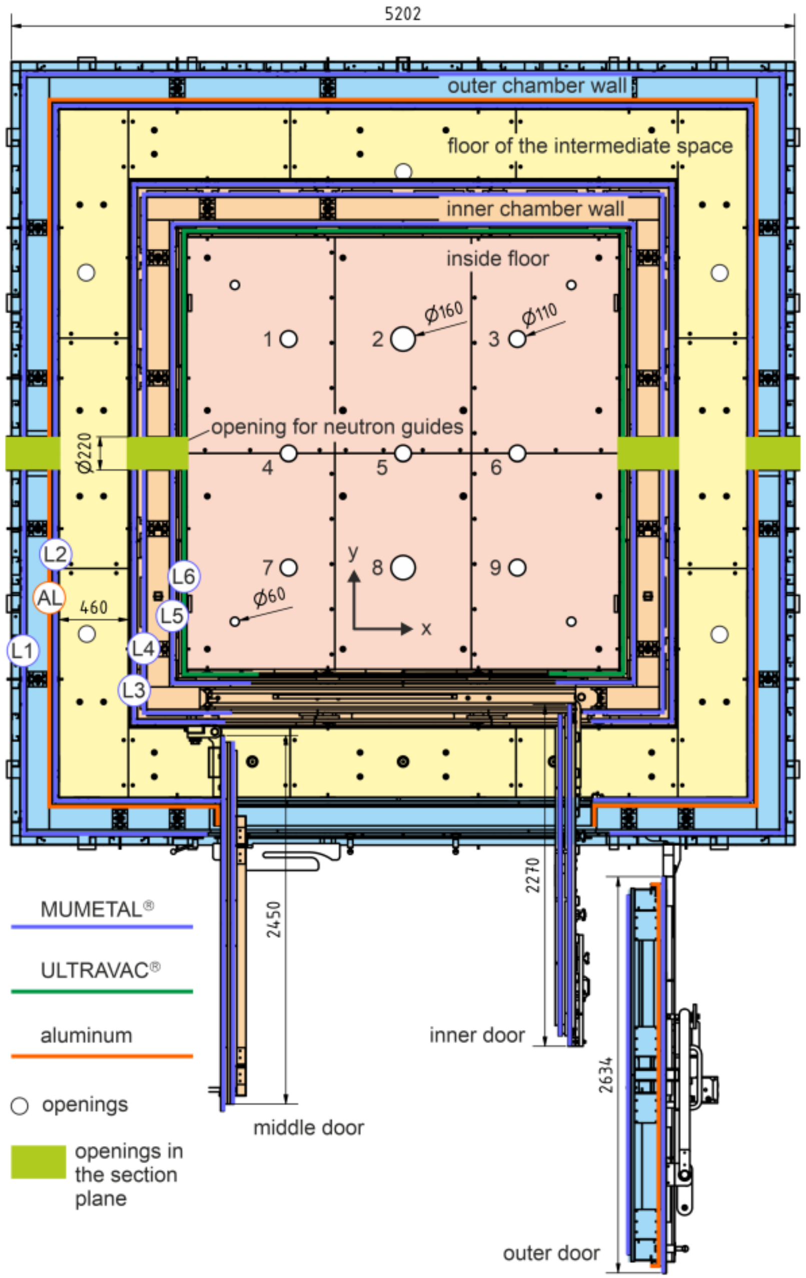
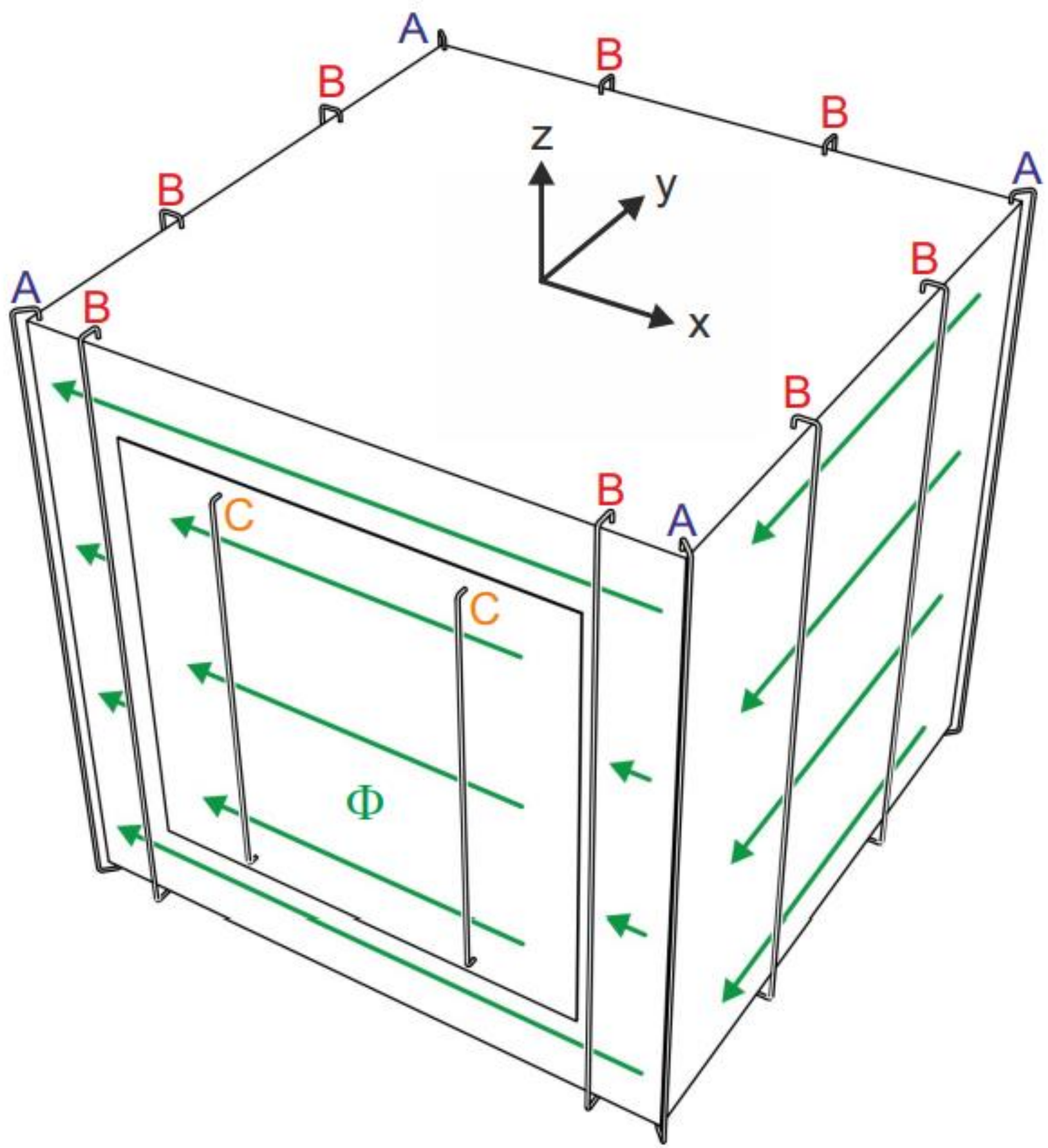
ded with Edges
FRONT
RIGHT
TOP


PFEIFFER VACUUM
SingleGauge
8.90-7
hPa


5202
outer chamber wall
floor of the intermediate space
inner chamber wall
inside floor
Ø160
Ø110
1
2
3
opening for neutron guides
Ø220
4
5
6
L2
L6
AL
460
L5
L1
L4
L3
7
8
9
Ø60
y
x
MUMETAL®
ULTRAVAC®
aluminum
openings
openings in the section plane
2450
2270
2634
inner door
middle door
outer door


A
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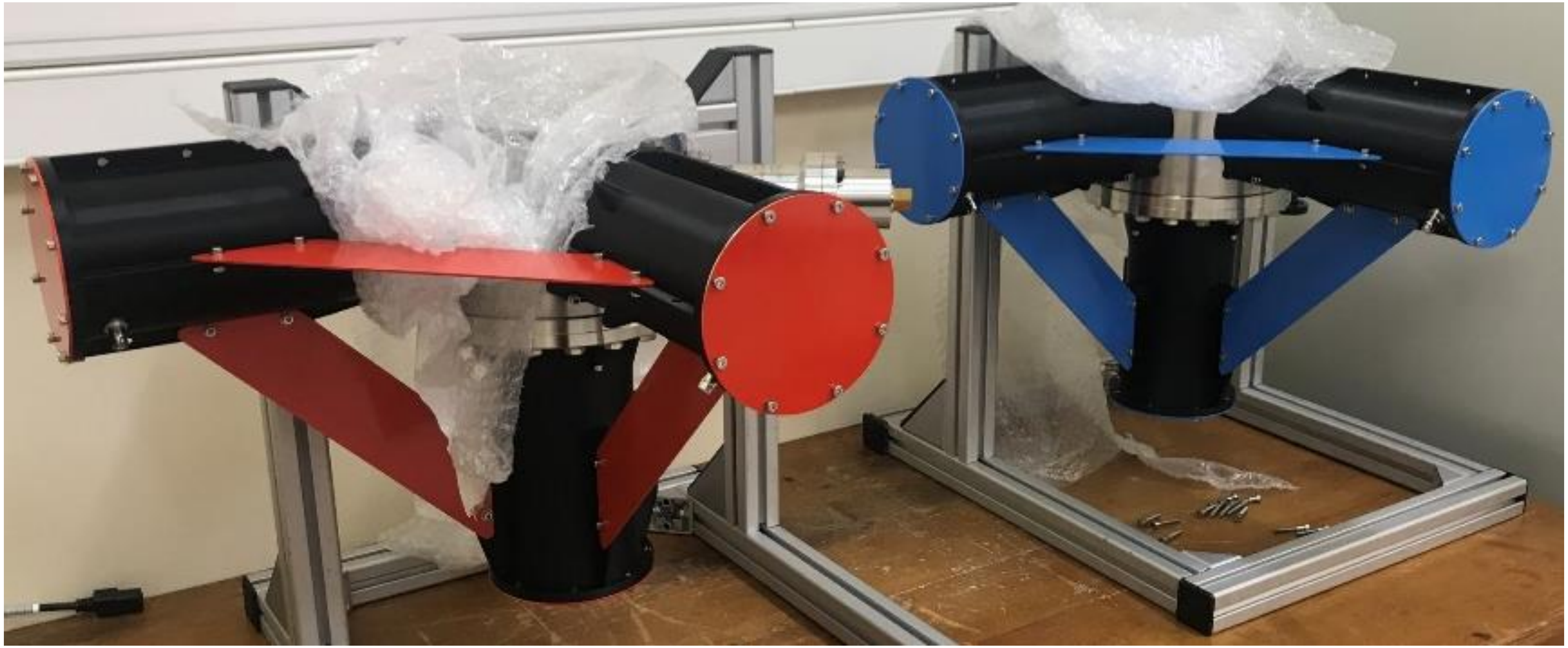
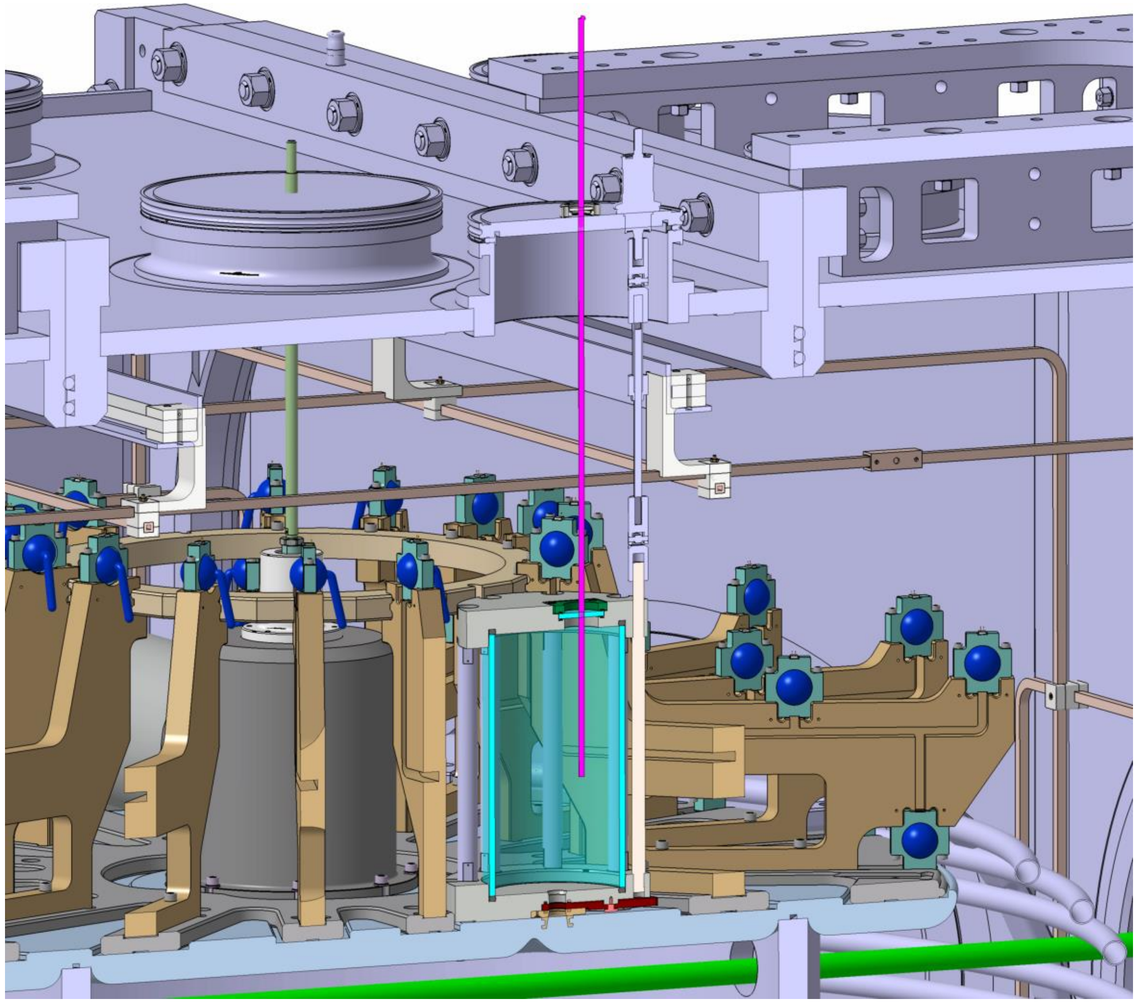
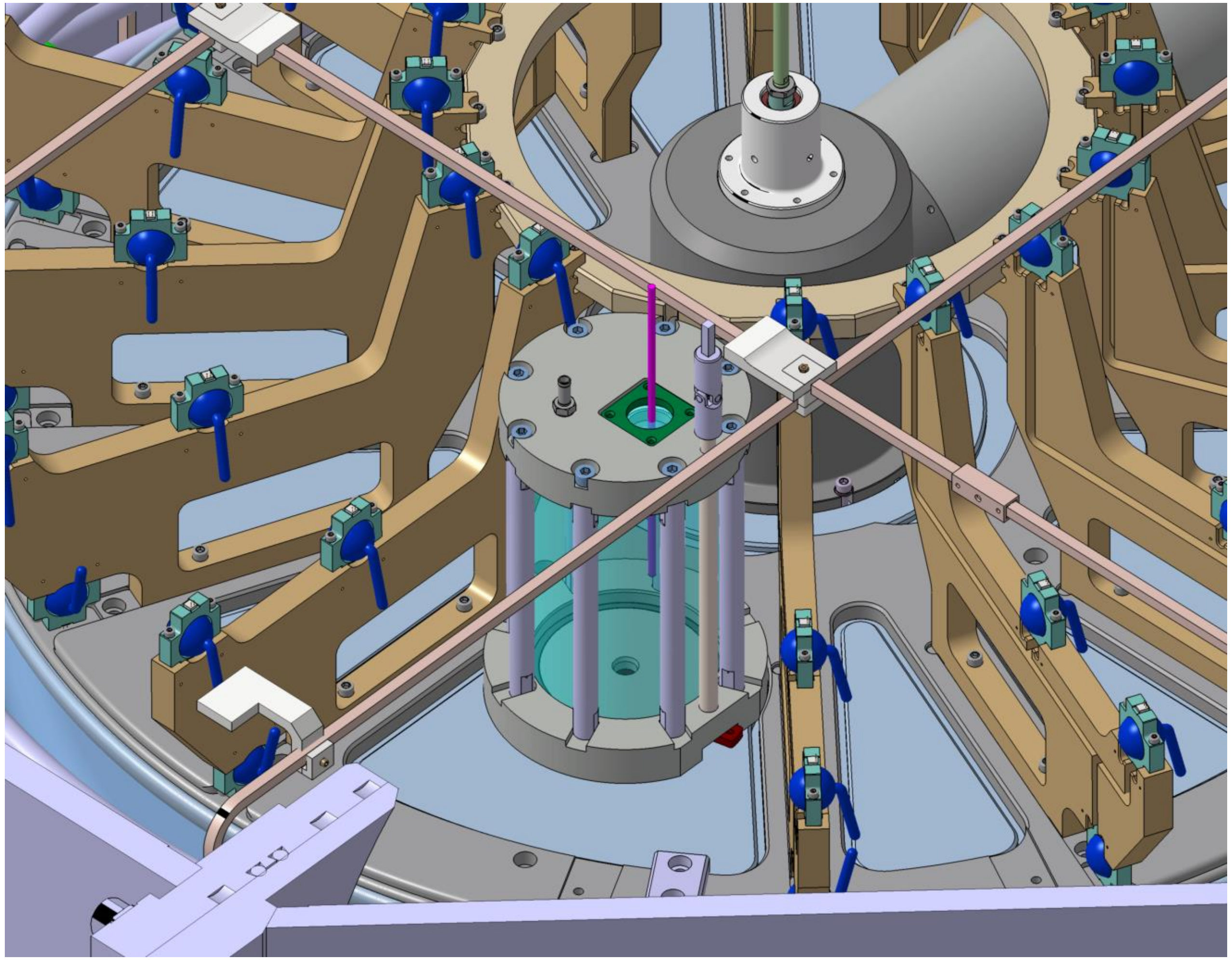
UCN detectors

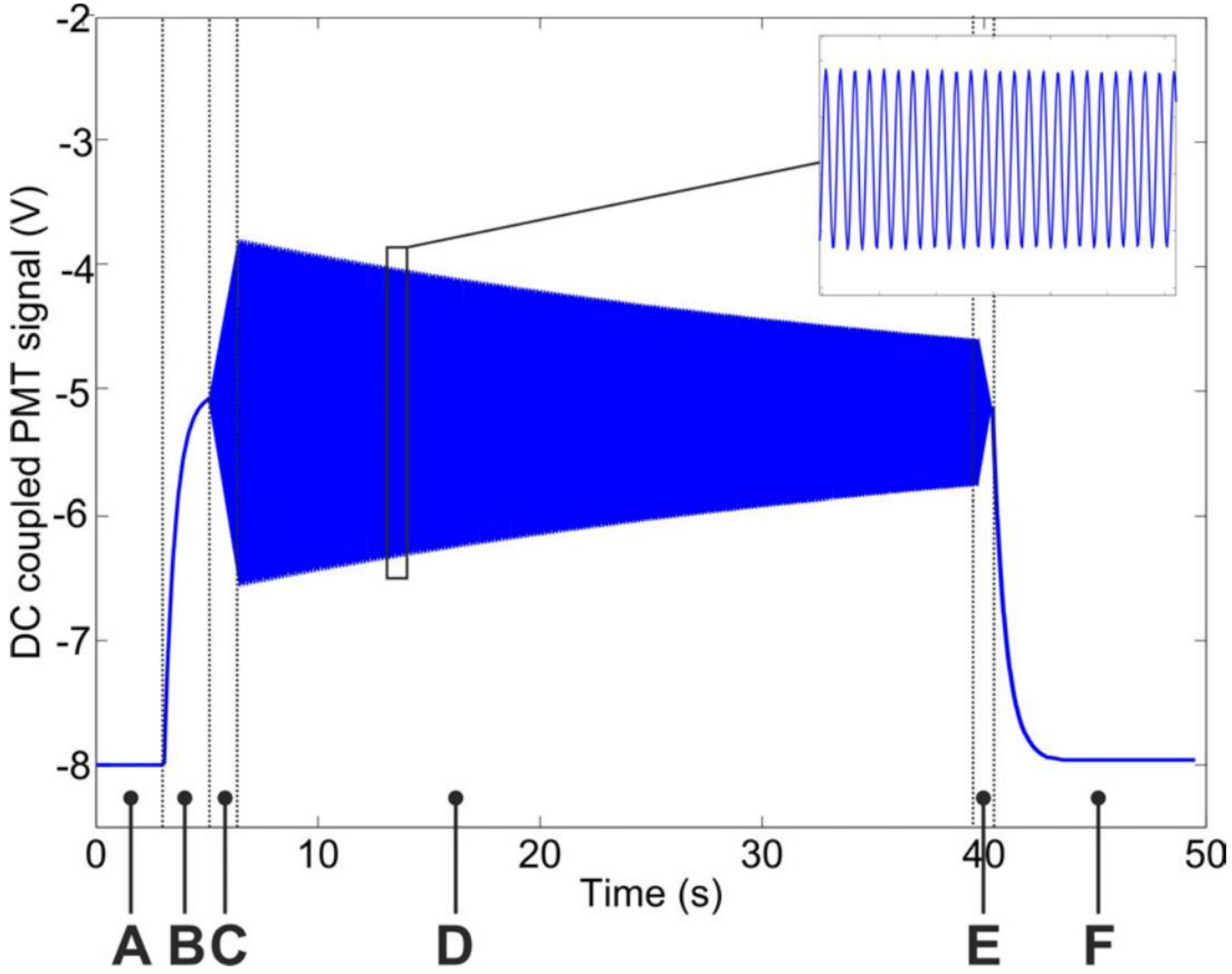


Mercury magnetometers



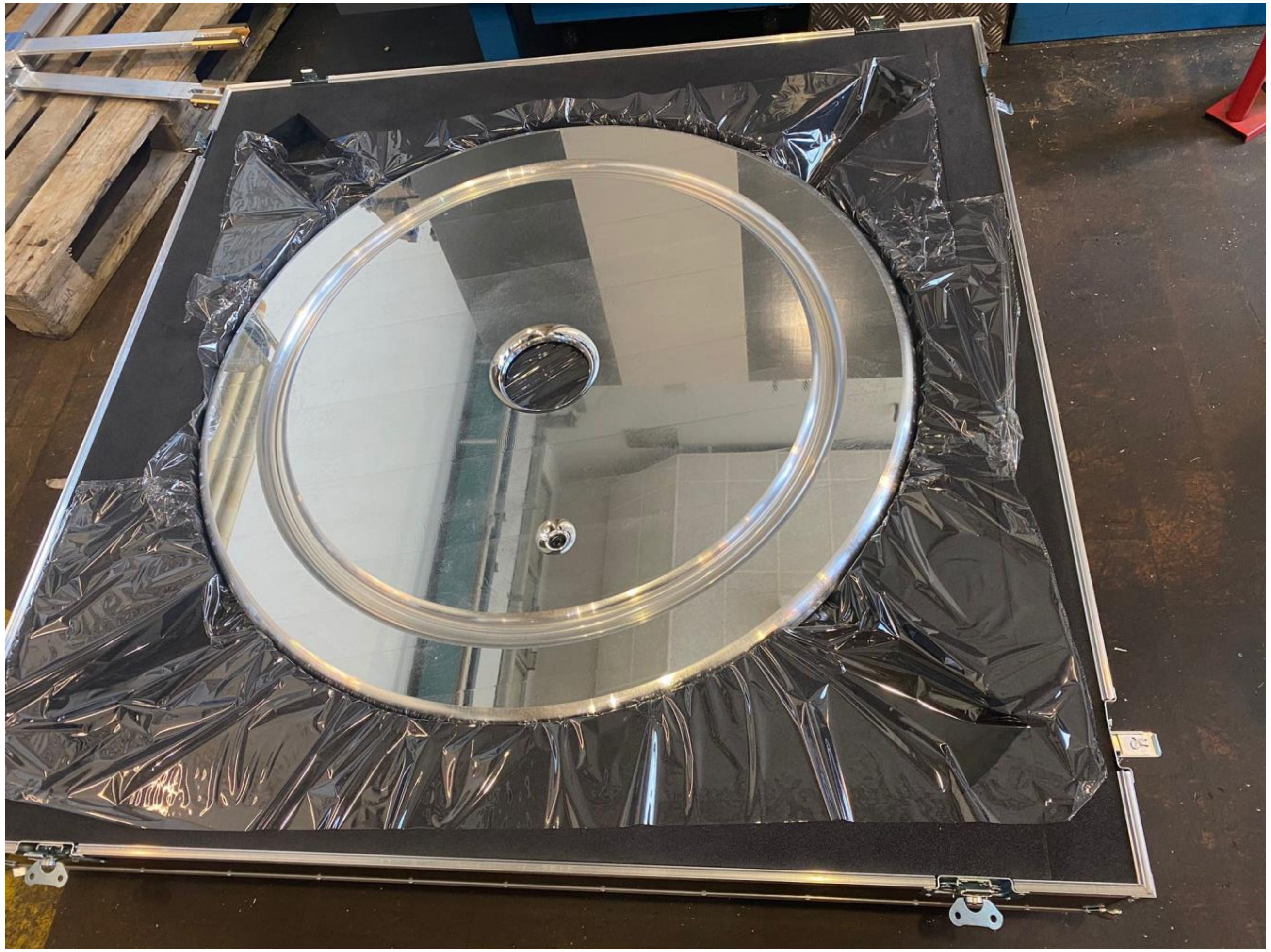


Typical mercury signal

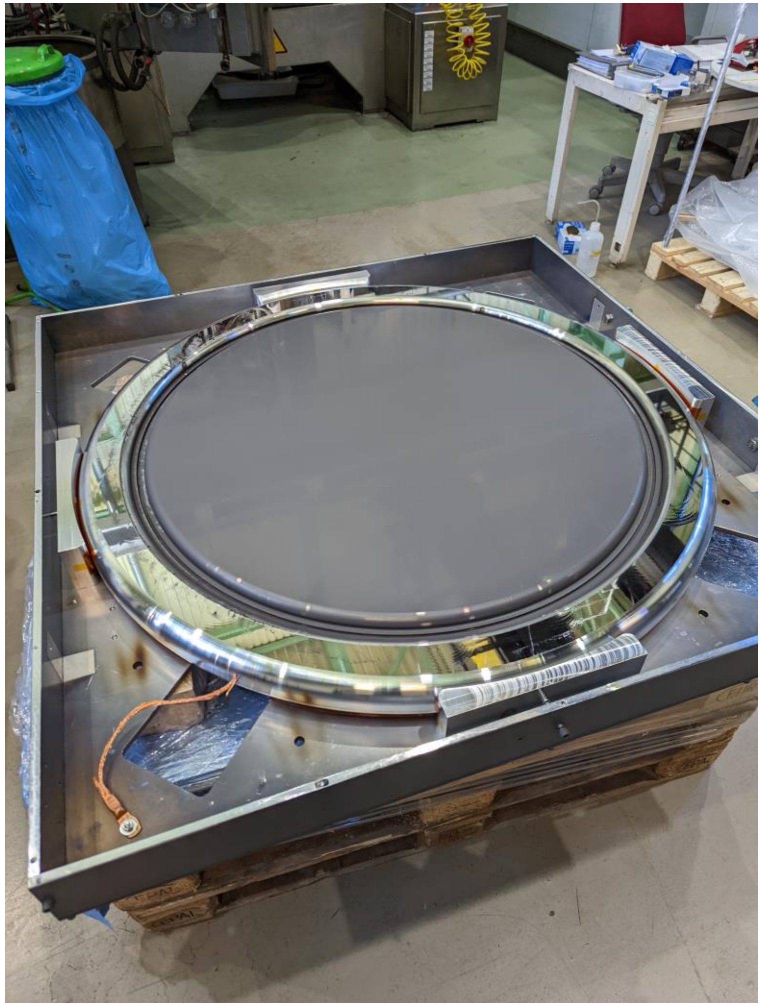


UCN Switch

Finished ground electrode



DLC coated electrode



Magnetic restrictions

- Hg and UCN occupy the same volume
- As the Hg is thermal, it can sample many more gradient fields then the UCN
- This leads to Hg induced false EDM on the neutrons:

$$d_{Hg\rightarrow n}^{false} = -\frac{\hbar\left|\gamma_n\gamma_{Hg}\right|}{2c^2}\sum_{l=1}^{\infty} G_{l,0}\langle x\Pi_{x,l,0} + y\Pi_{y,l,0}\rangle$$

- These gradient fields are characterised, offline and online, but puts limits on induced dipole fields of nearby components
- Hence the Ramsey chamber requires dipole field < 20 pT @ 5 cm

Magnetic scanning @ PTB

After electrode cleaning

Transportation to PTB

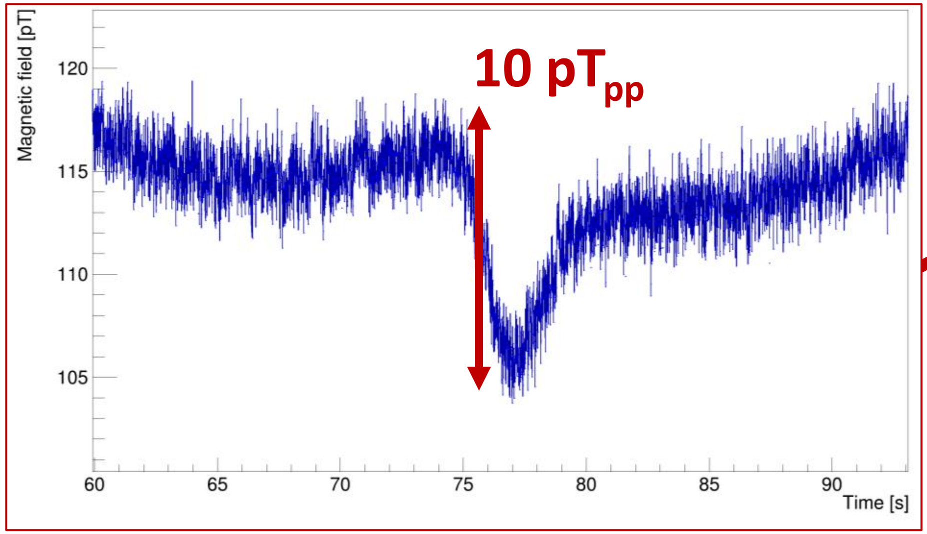
Approximate timeline is for March/April

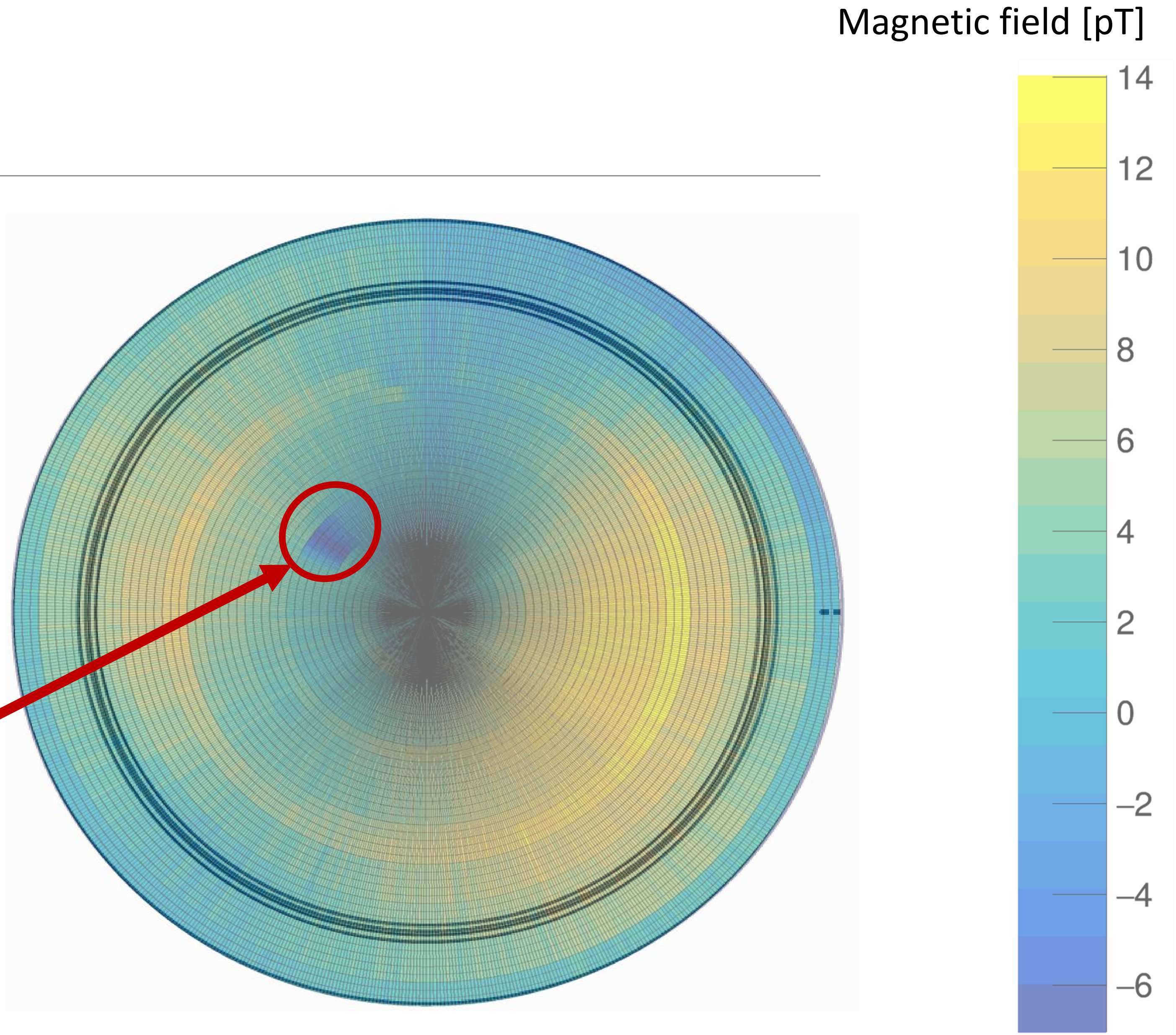
Followed by DLC coating in Dortmund

Electrodes then returned to further scanning

HV electrode – front

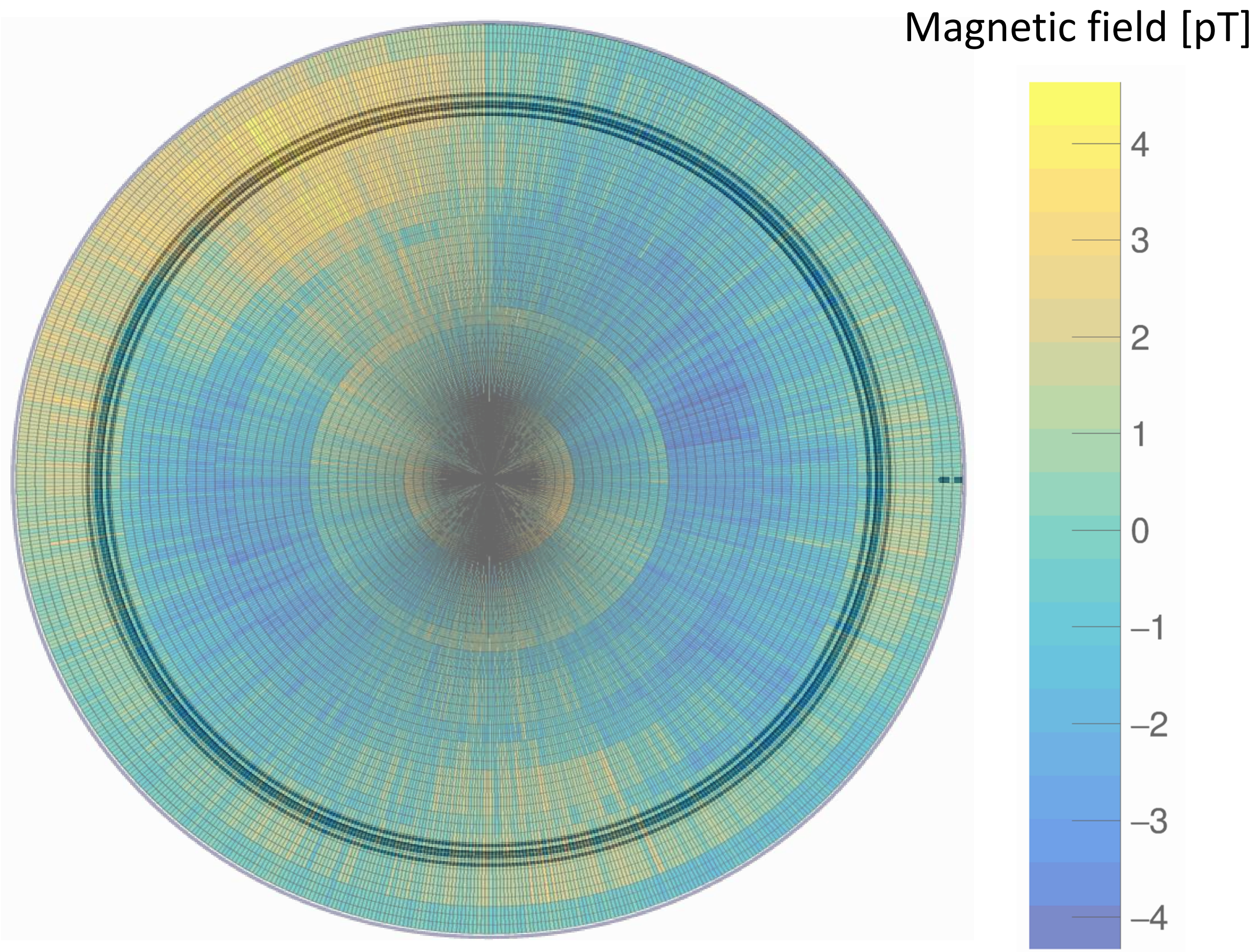
Dipole degaussed: 10 pT





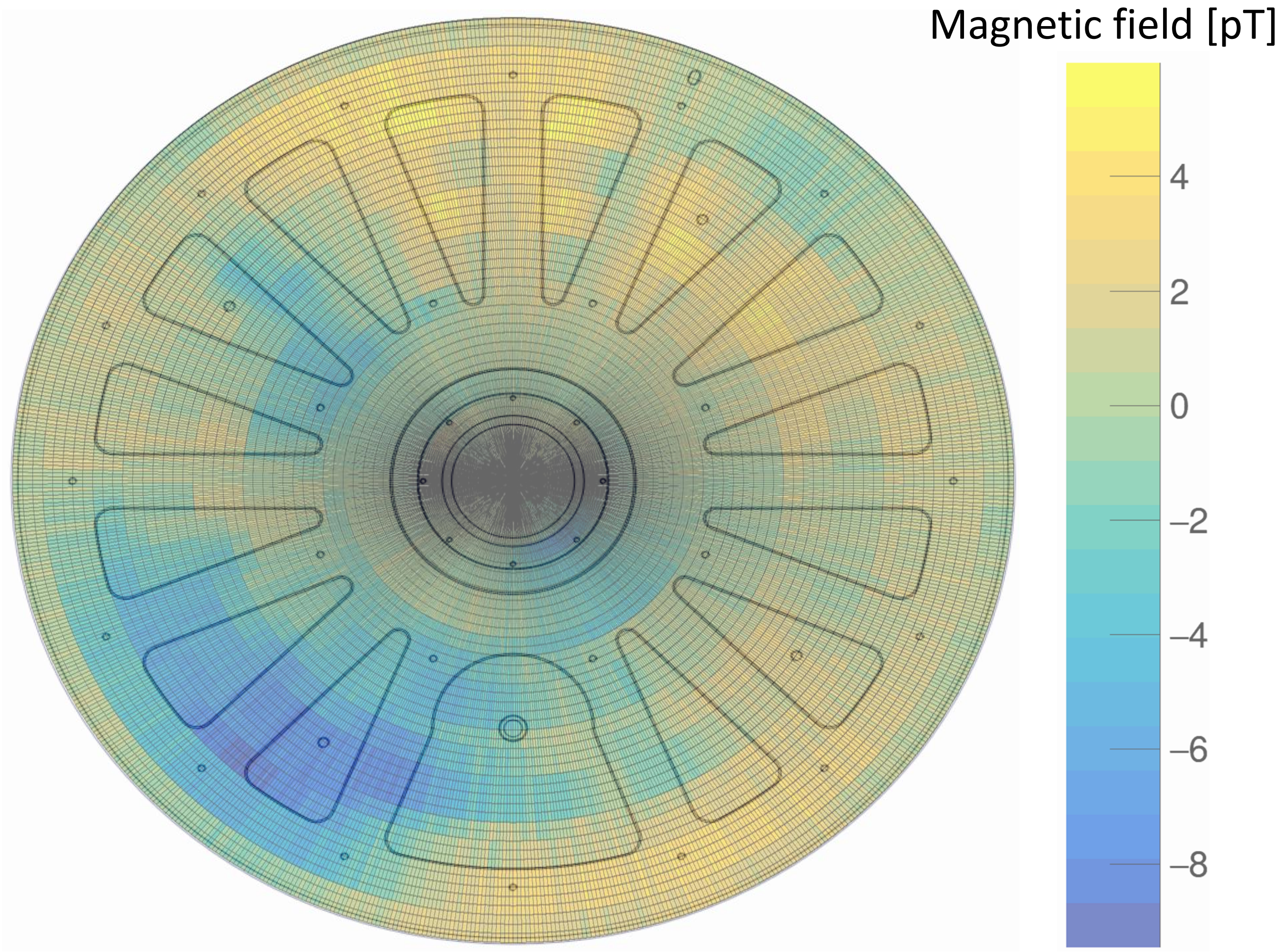
HV electrode – back

Dipole: < 4 pT



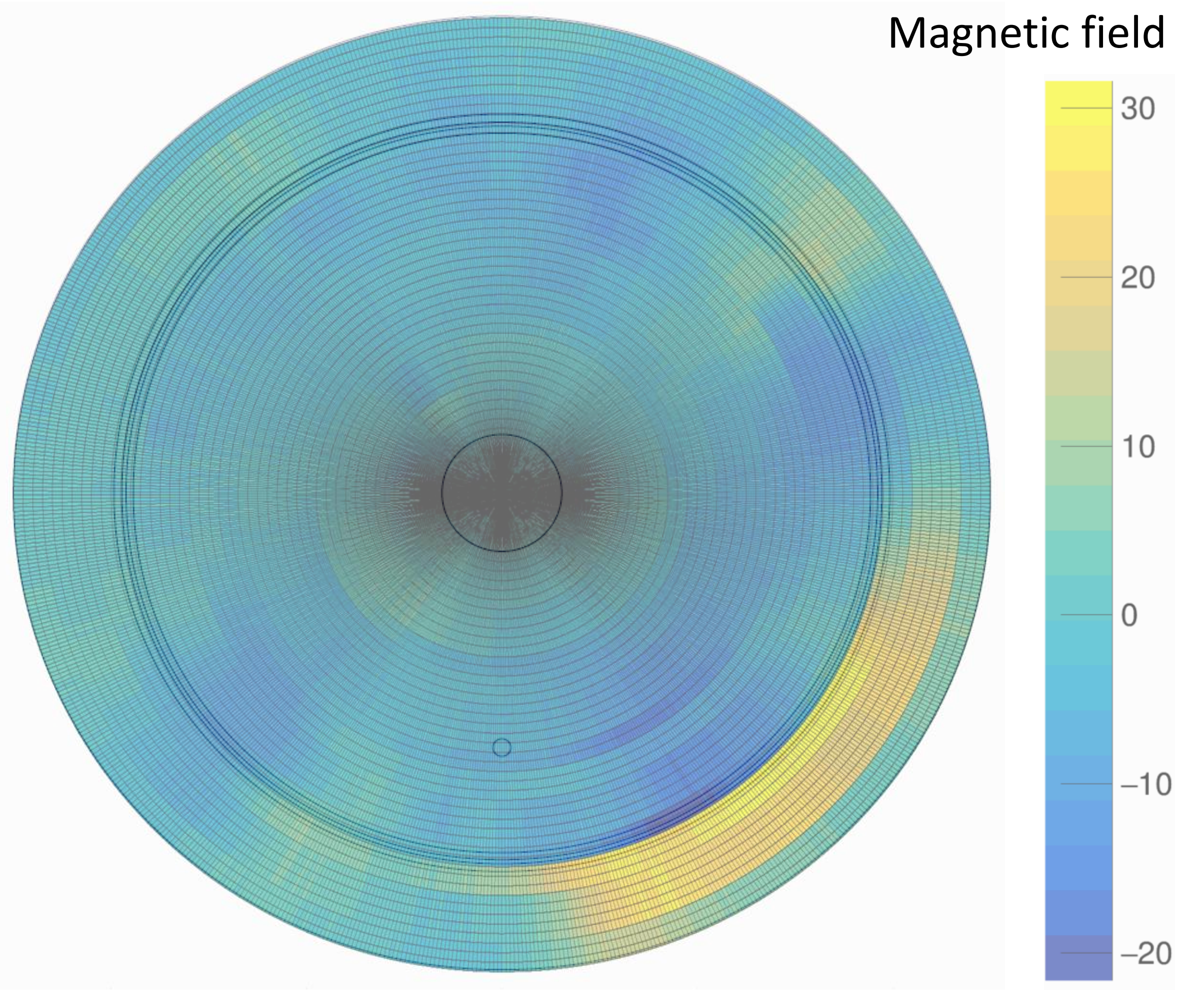
G2 electrode – back

Dipole: < 6 pT



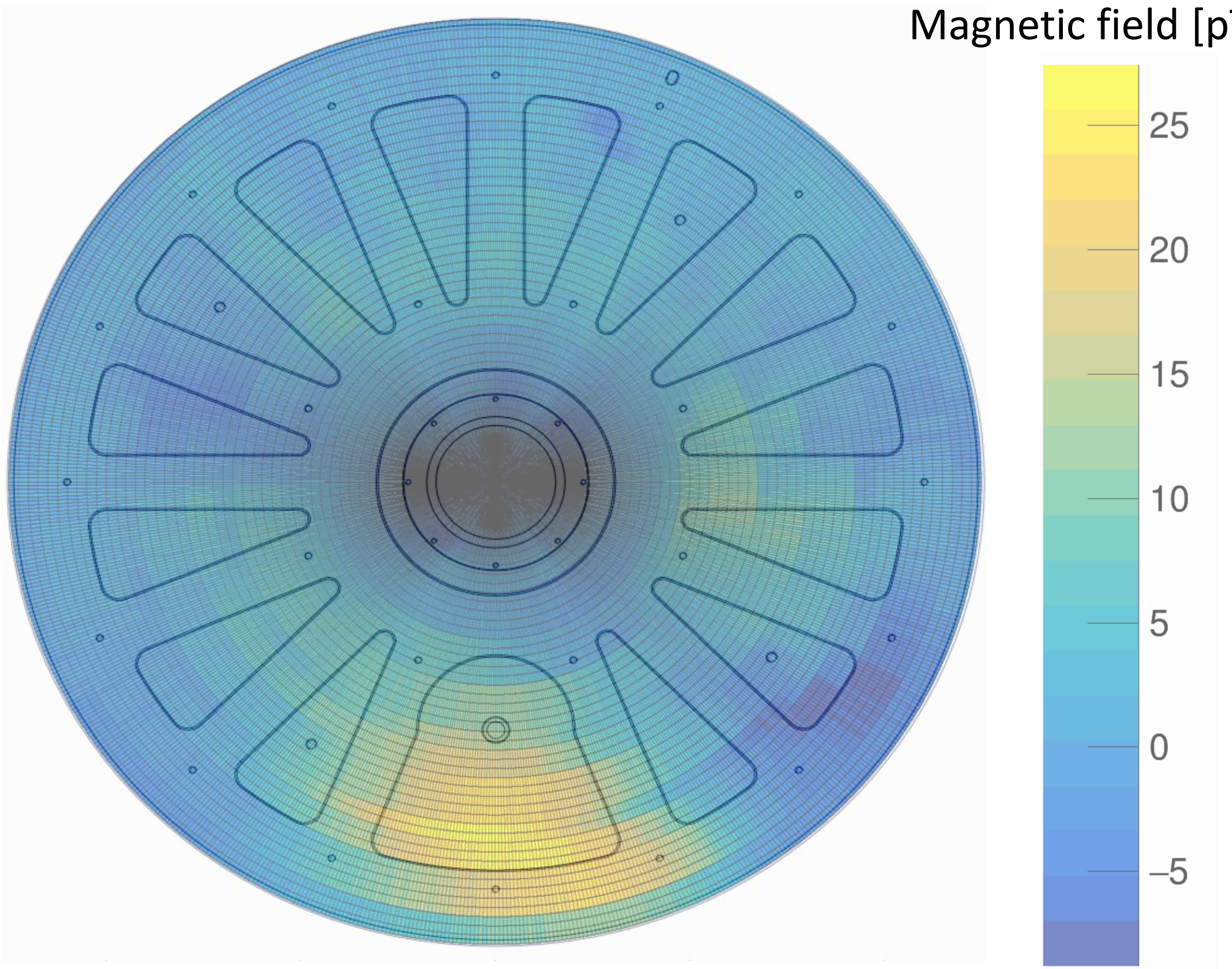
G2 electrode – front

Dipole: < 30 pT



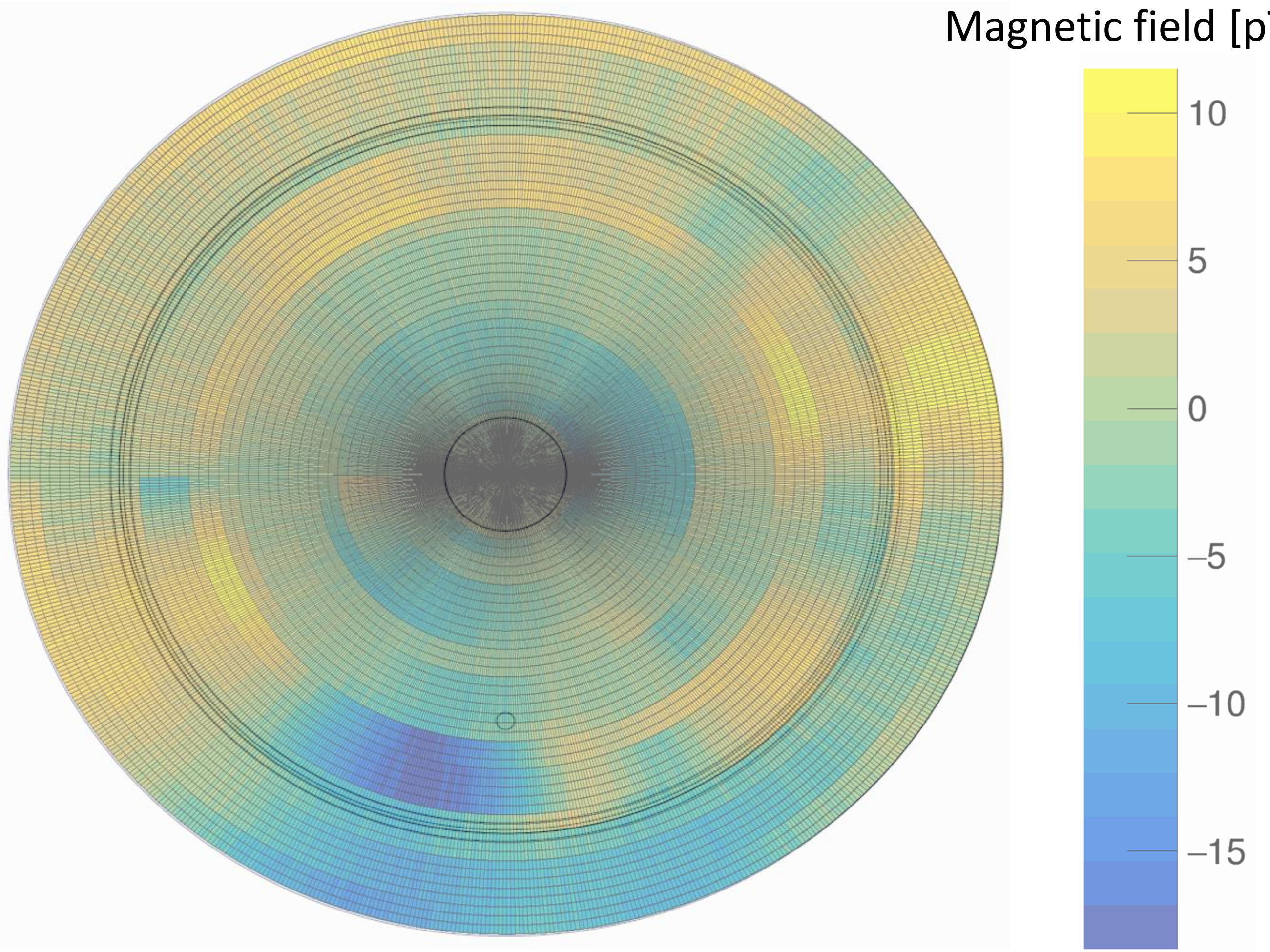
G1 electrode – back

Dipole: < 26 pT

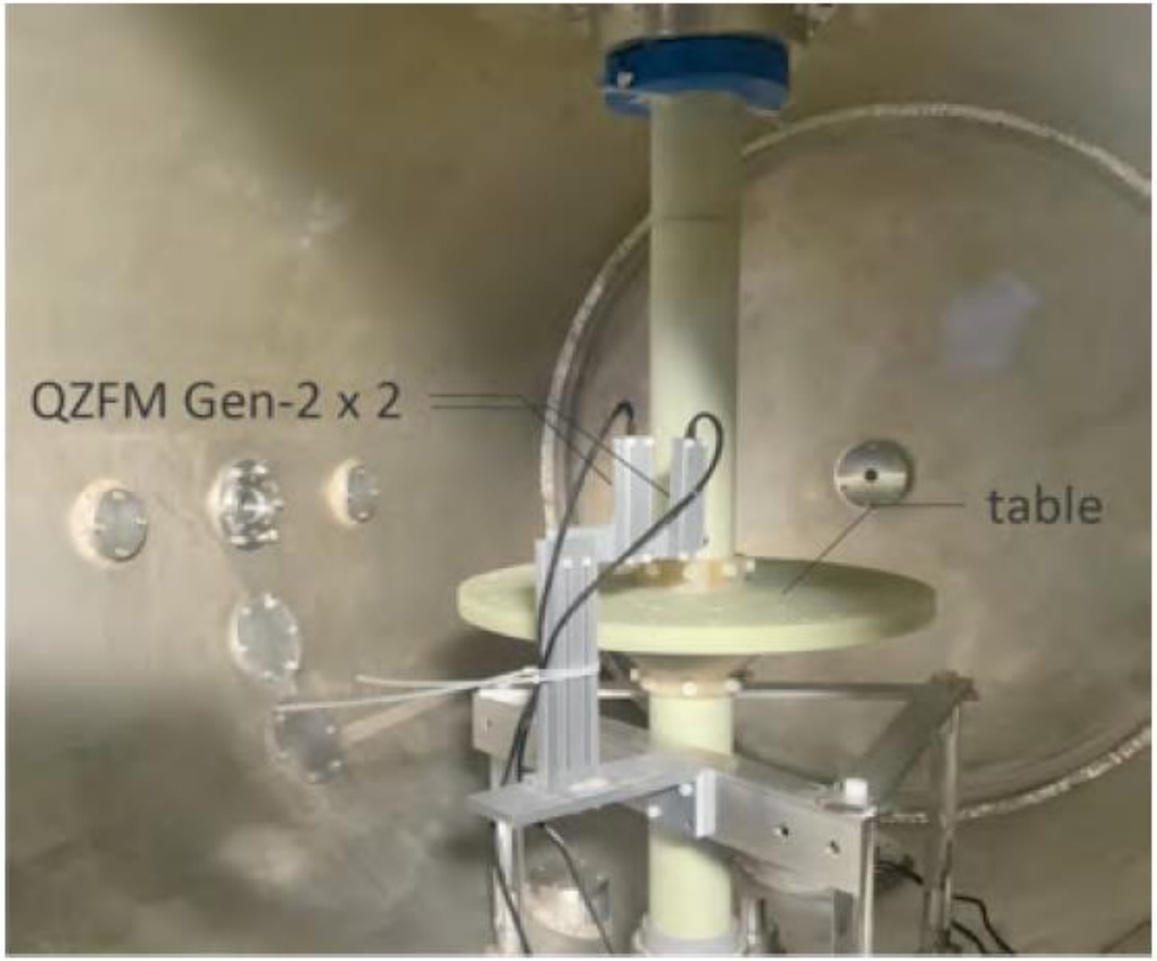


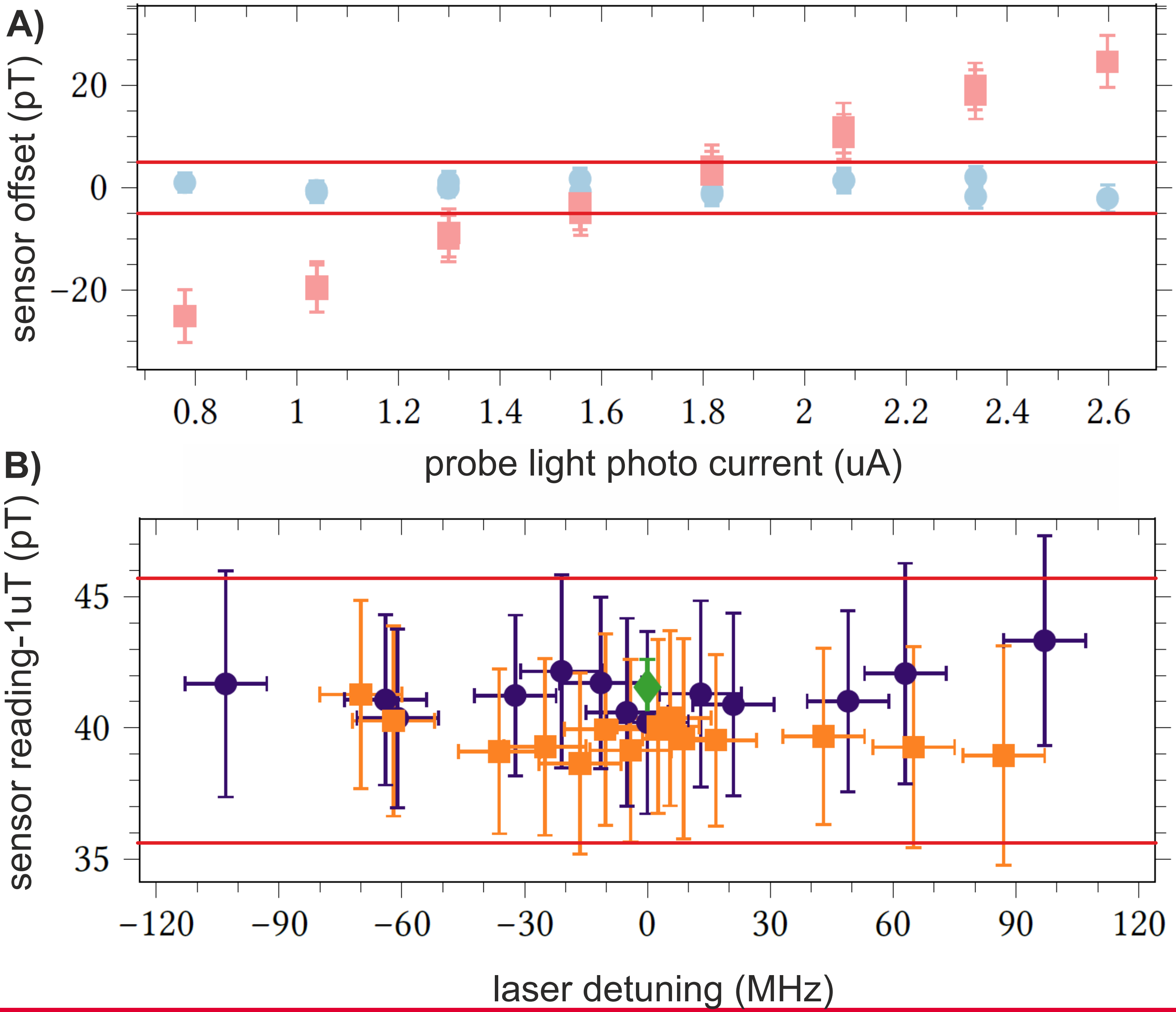
G1 electrode – front

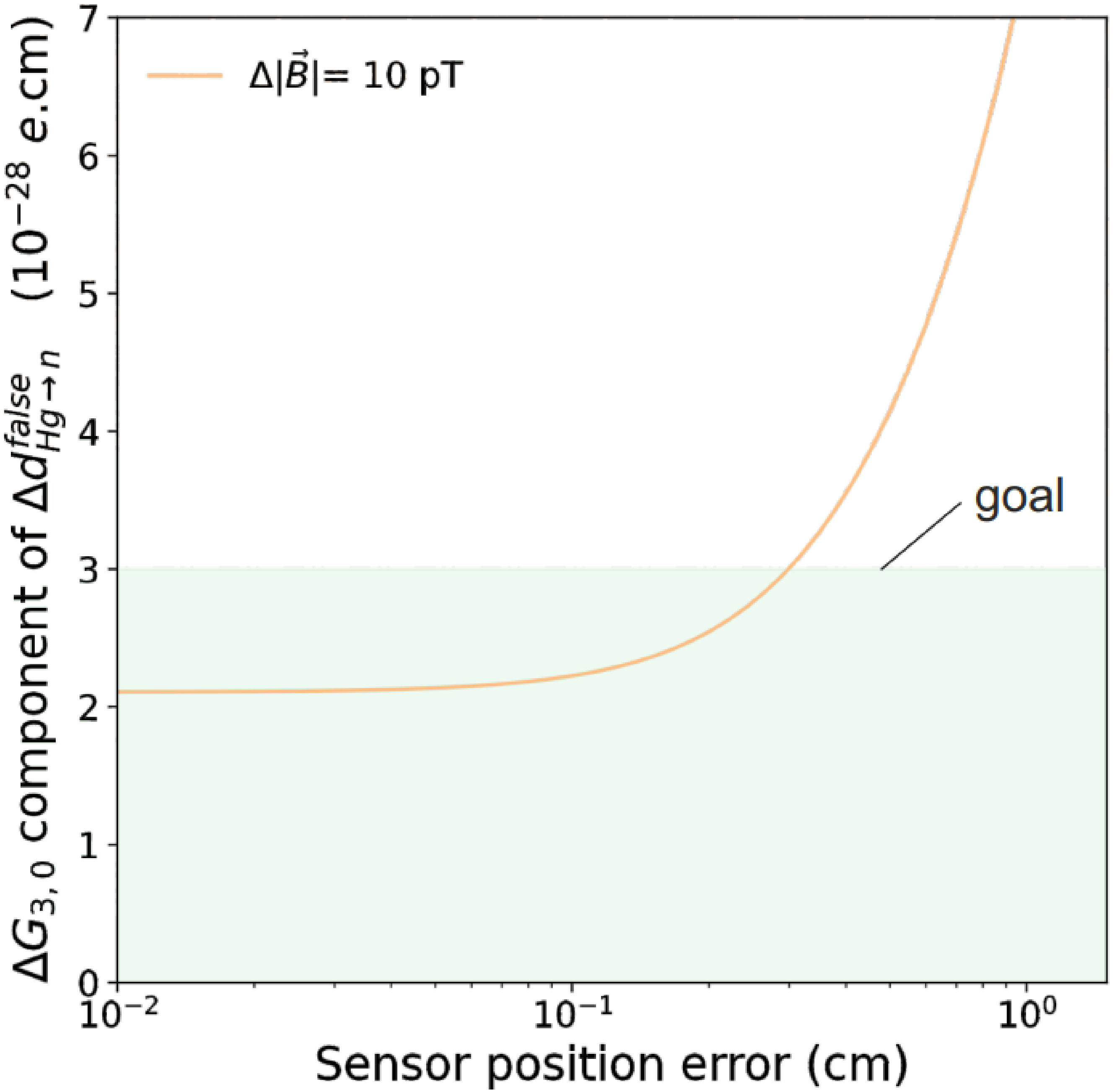
Dipole: < 11 pT



Caesium magnetometers

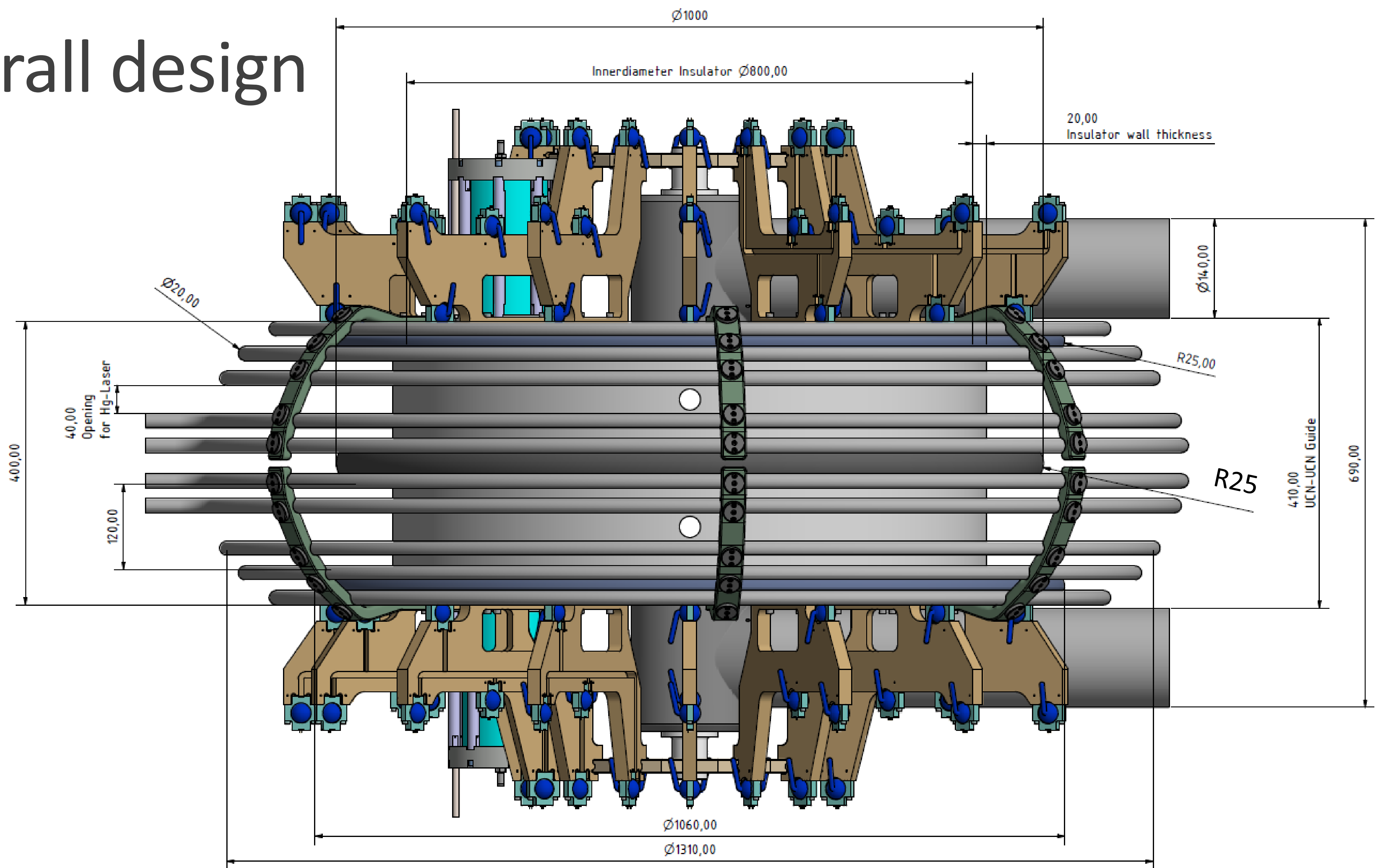



A)
sensor offset (pT)
20
0
−20
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
probe light photo current (uA)
B)
sensor reading-1uT (pT)
45
40
35
−120
−90
−60
−30
0
30
60
90
120
laser detuning (MHz)



$\Delta|\vec{B}|$= 10 pT
goal
$\Delta G_{3,0}$ component of $\Delta d^{false}_{Hg\to n}$ $(10^{-28}$ e.cm)
Sensor position error (cm)
0
1
2
3
4
5
6
7
10^{-2}
10^{-1}
10^{0}

Overall design



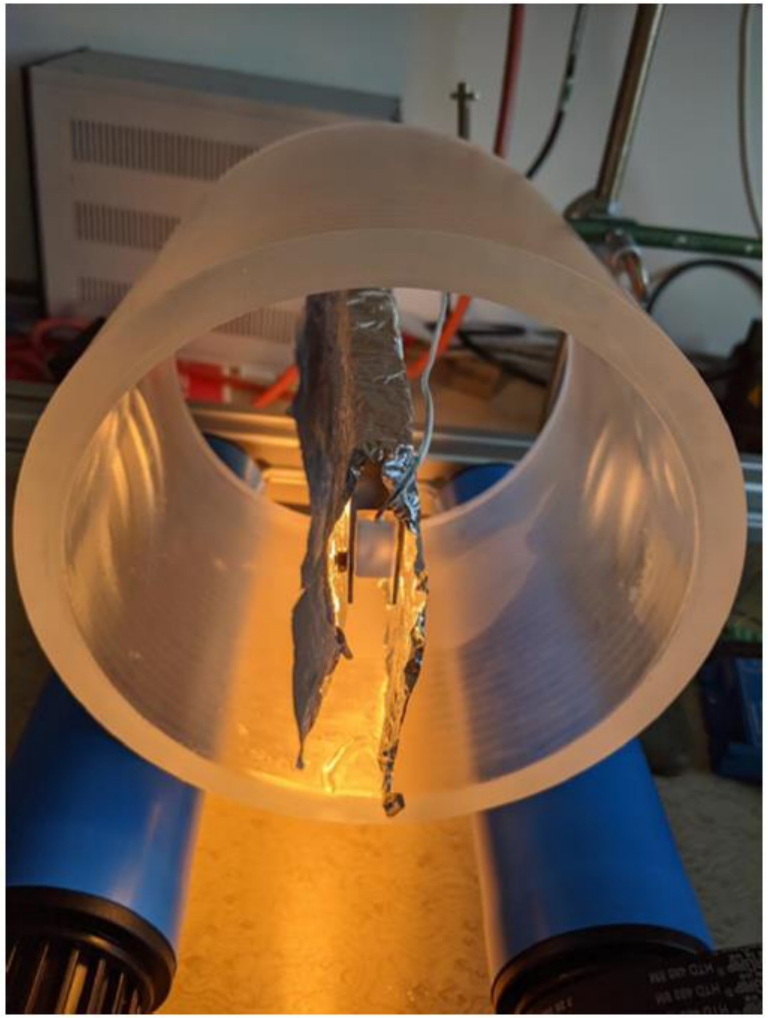
Insulator ring

500 mm insulator rings produced

These have co-centricity of inner and outer surfaces – 0.06 mm

Magnetic scans show one spot ~3 pT, overall less then 1.5 pT

Soon begin production of 800 mm rings



HV feedthrough

Prototype constructed

Tested up to +/- 180 kV

Pressure test: $<10^{-5}$mbar

Feedthrough -> electrode connection is still in design, however, prototypes tested

Connector to be made flexible