UCNs and the nEDM experiment

Ultracold neutron source at the PSI

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Neutron electric dipole moment measurement

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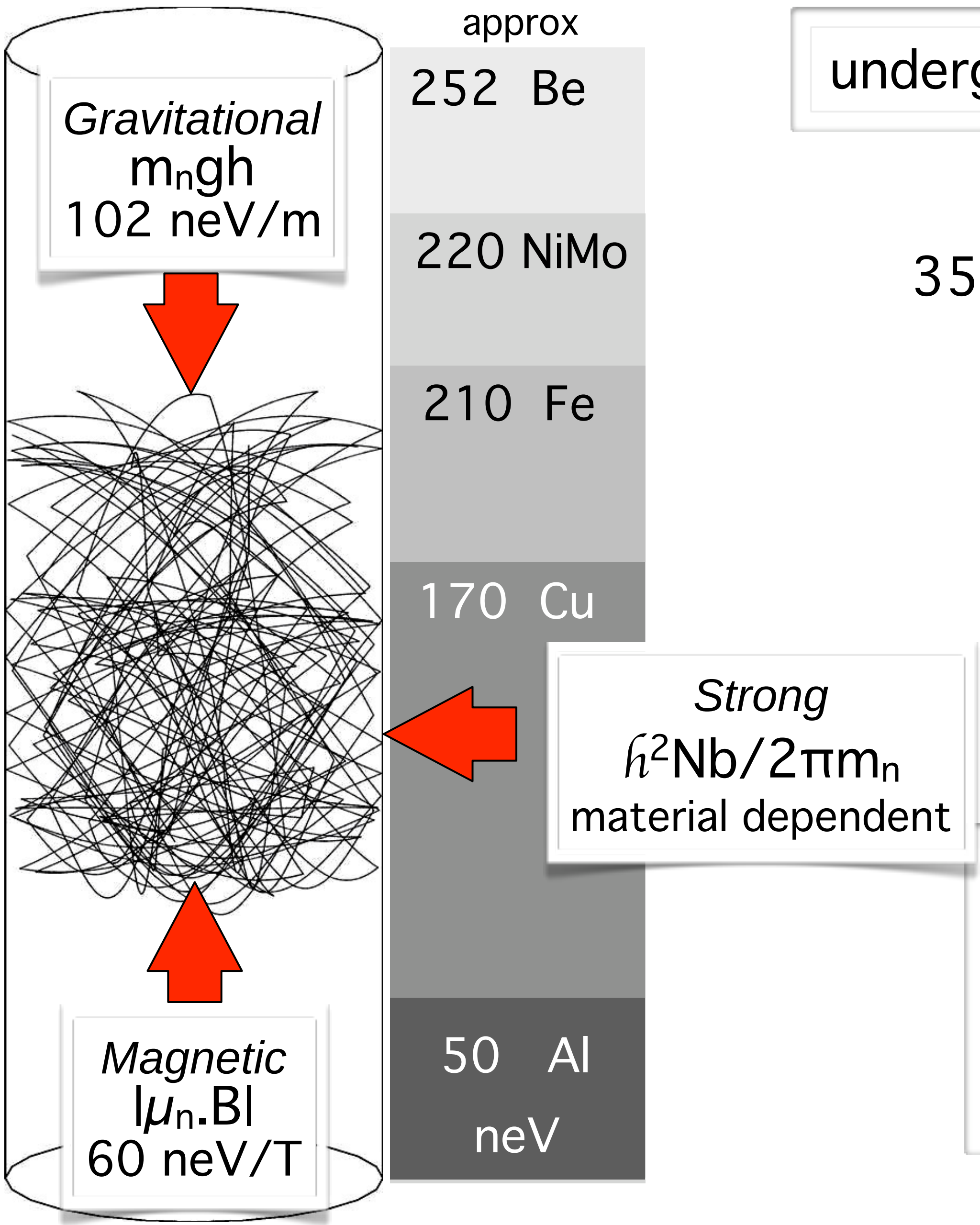
Zema Chowdhuri for the
PSI UCN project team
and the
nEDM collaboration

PAUL SCHERRER INSTITUT

The PSI ultracold neutron source

Ultracold neutrons



undergo total reflection from certain materials

350 neV ↔ 8 m/s ↔ 500 Å ↔ 3 mK

Neutrons with E_{kin} < 350 neV

- are easily confined
- can be easily polarized

well suited to
high precision measurements
to test Standard Model
predictions

Production of UCNs in solid $^2H_2$

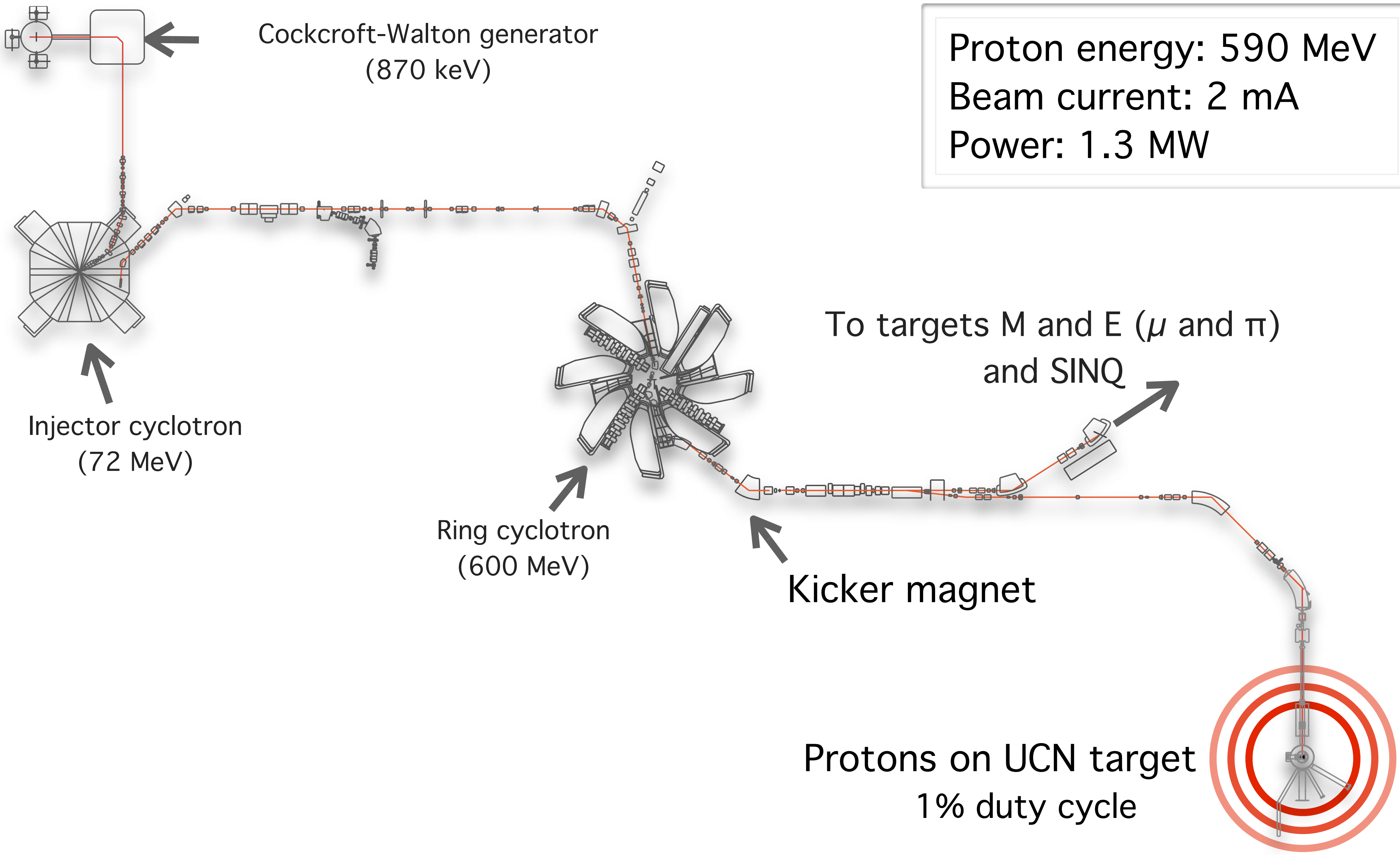
Two popular ways of downscattering cold/thermal neutrons to UCN range:

interaction with superfluid ^4He below 0.6K
interaction with solid $^2H_2$ around 5K

better suited to accelerator-based sources like ours

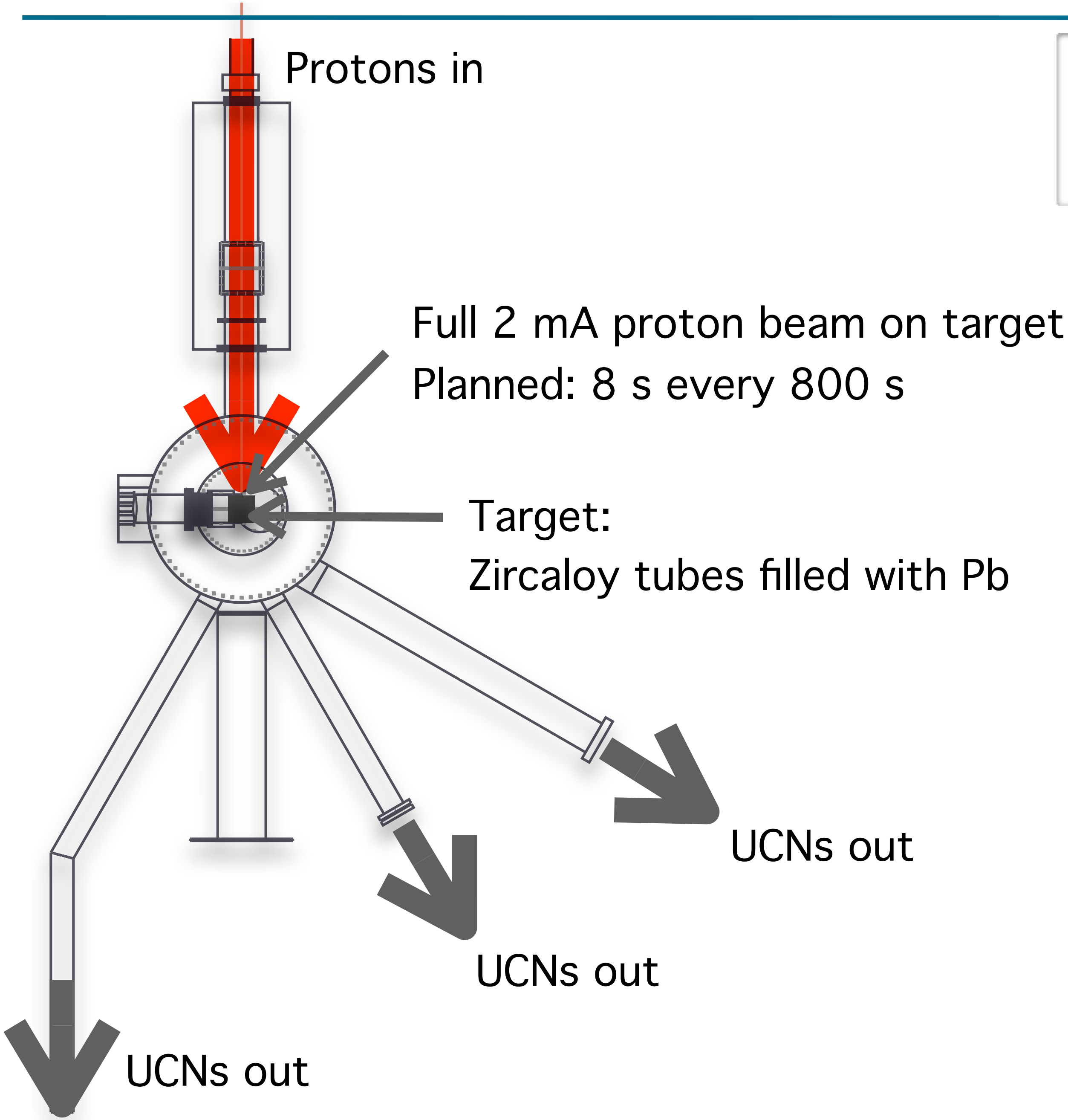
PSI UCN production beamline

Proton energy: 590 MeV
Beam current: 2 mA
Power: 1.3 MW

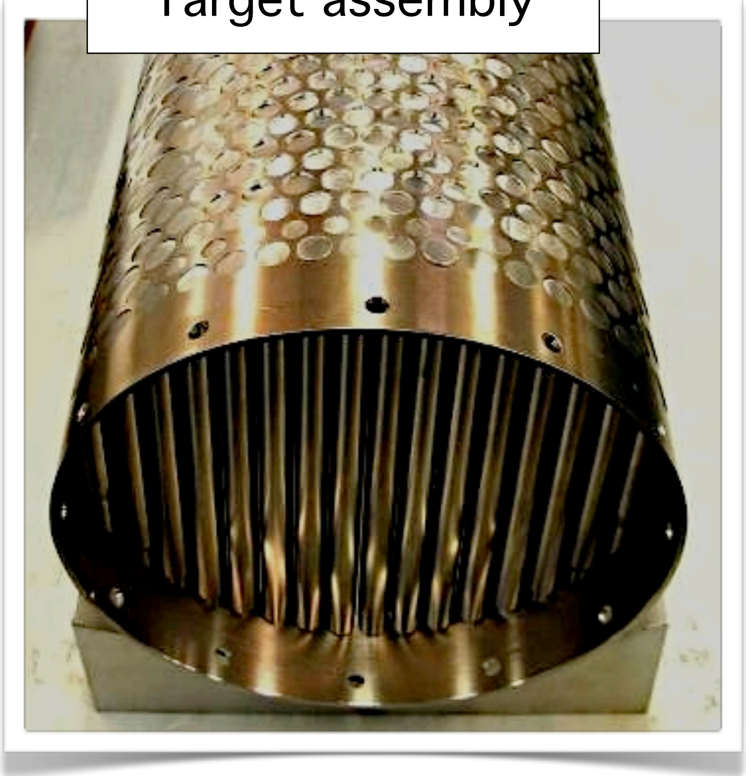


Target and source layout

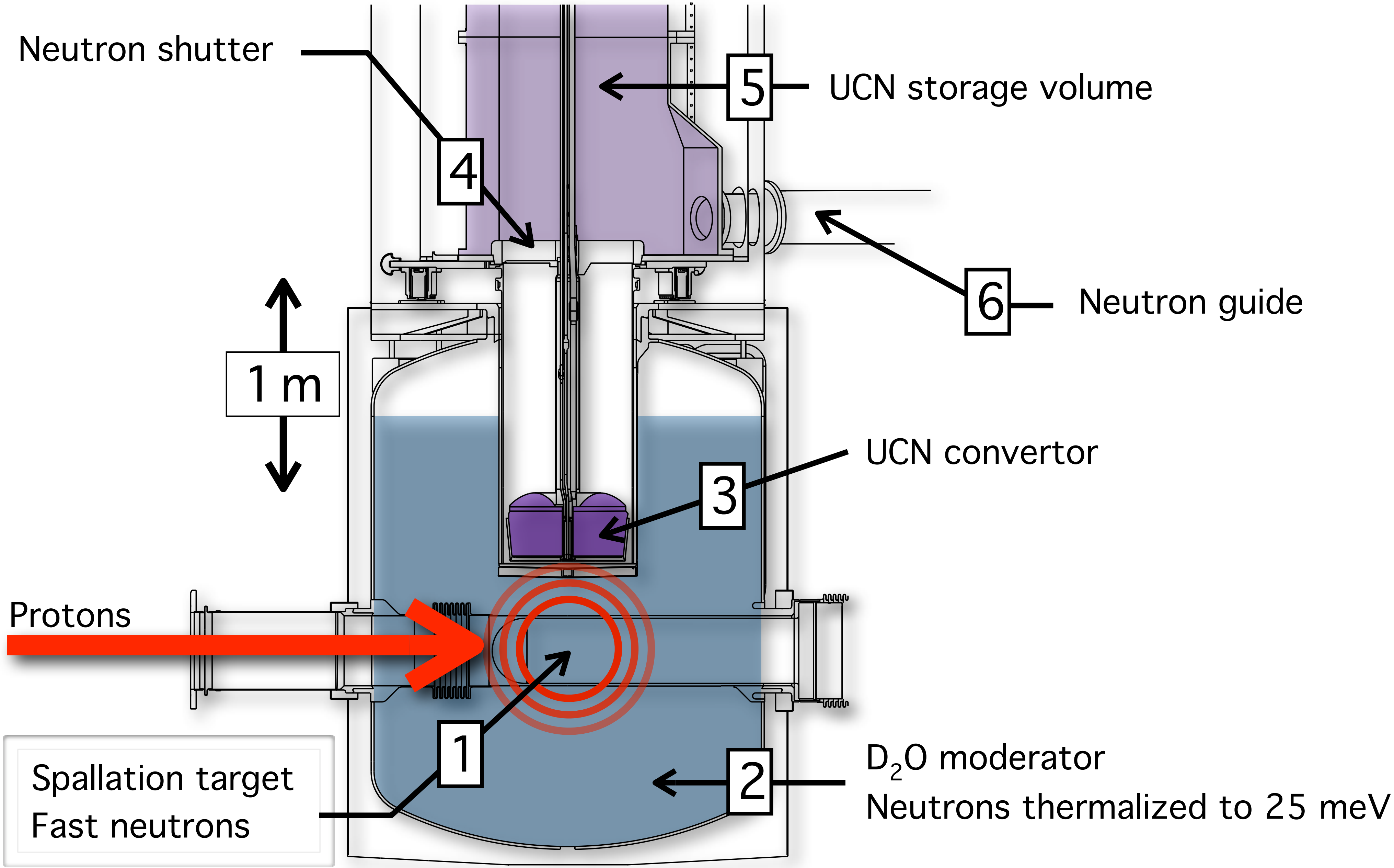
Neutrons per proton: about 8
Mean neutron energy: 2 MeV



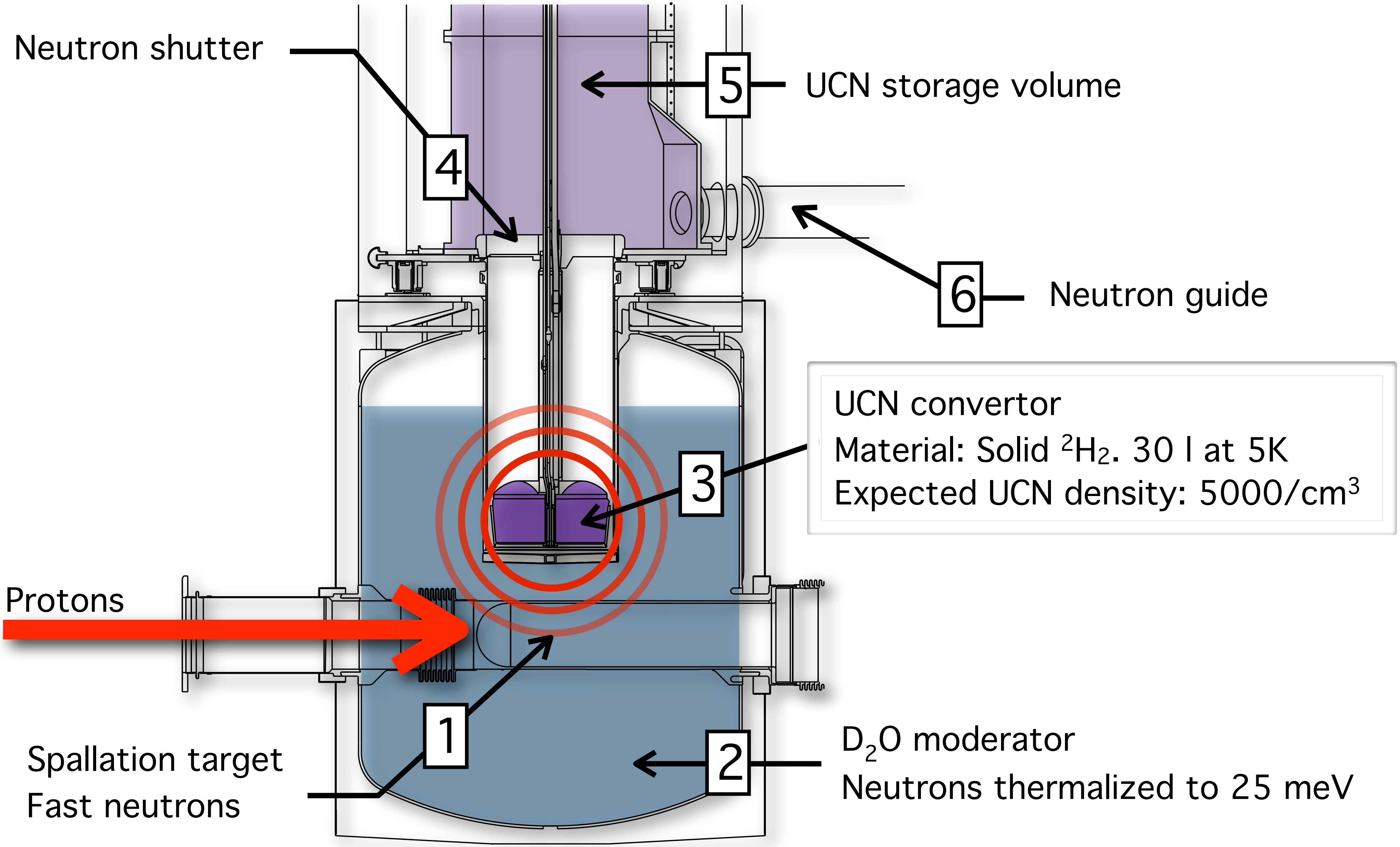
Target assembly



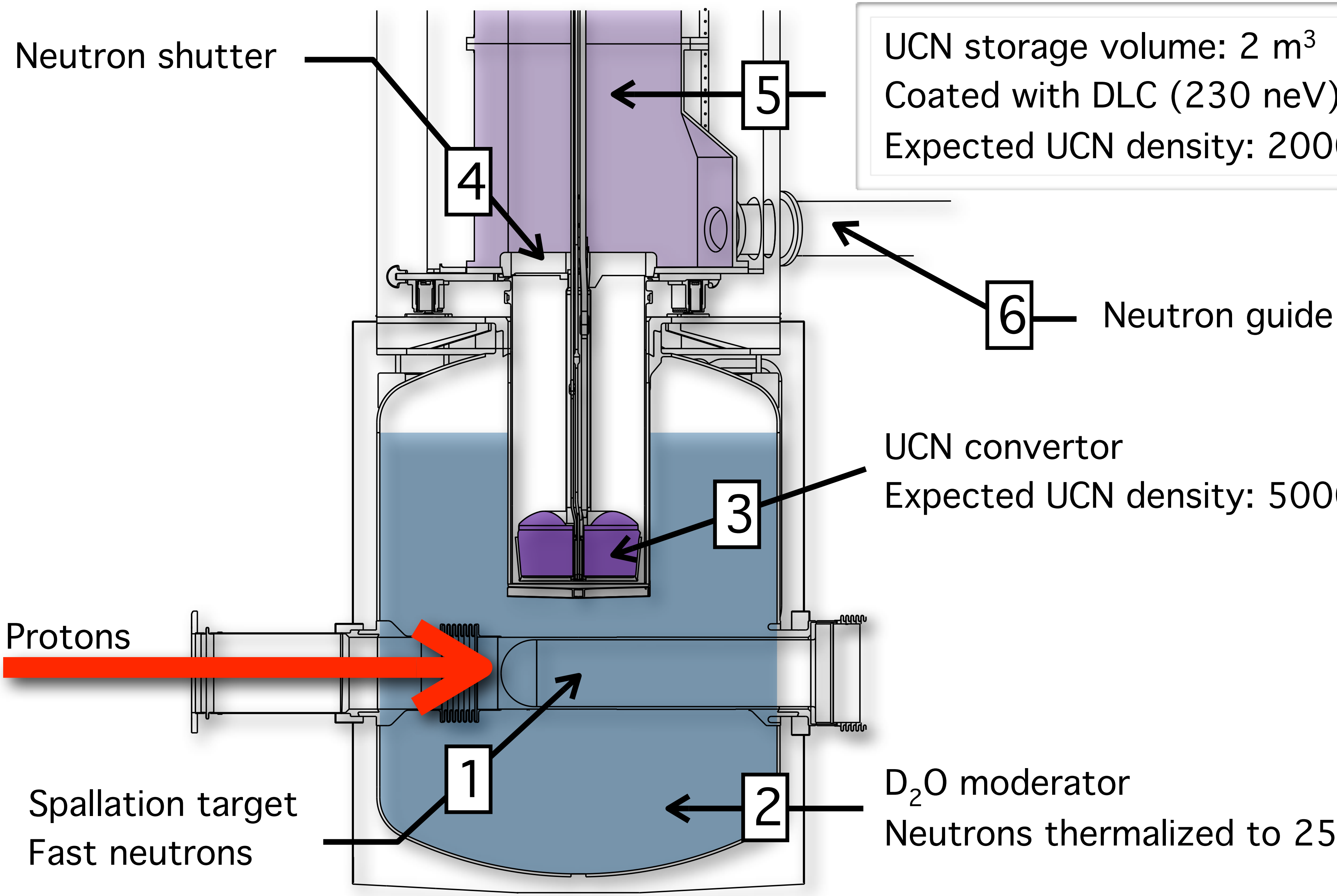
UCN source assembly



UCN source assembly

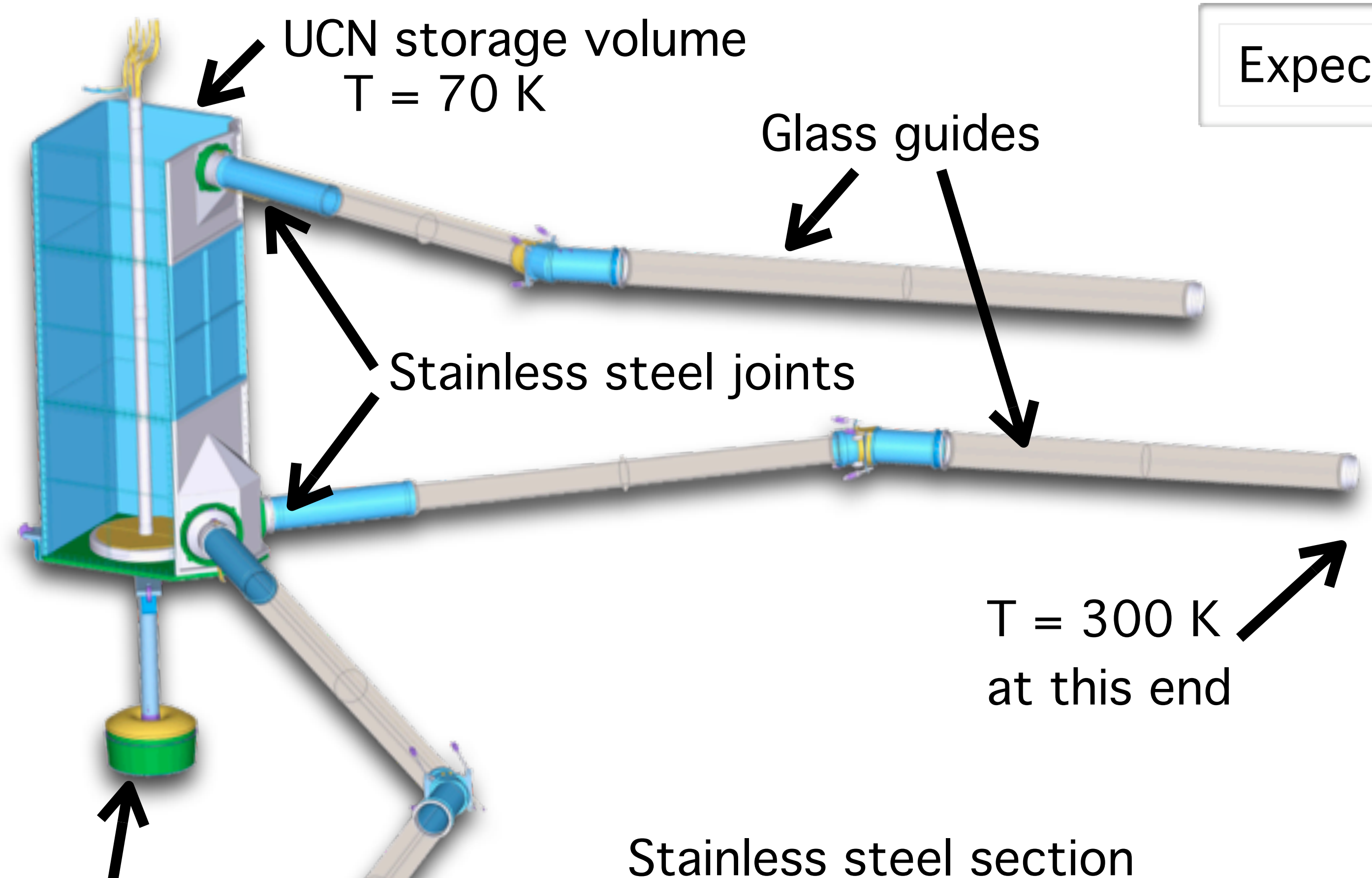


UCN source assembly



UCN storage volume: 2 m^3
Coated with DLC (230 neV)
Expected UCN density: 2000/cm^3

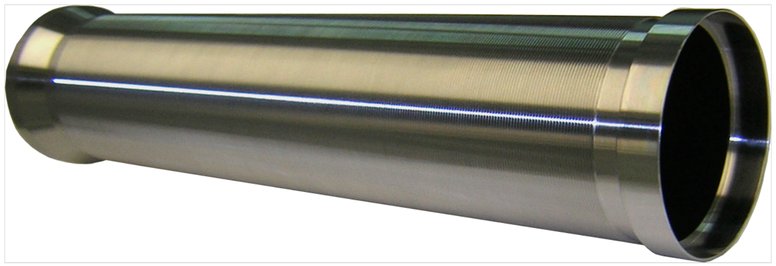
UCN guide system



Expected UCN density: 1000/cm^3

Compare with ILL: 40/cm^3
Factor of 25 increase

Stainless steel section



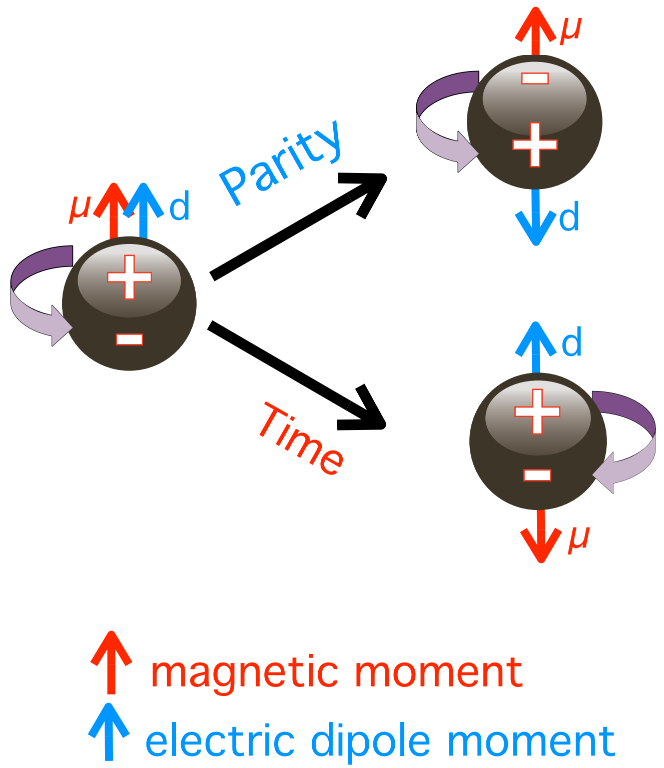
Glass guide coated with Ni-Mo

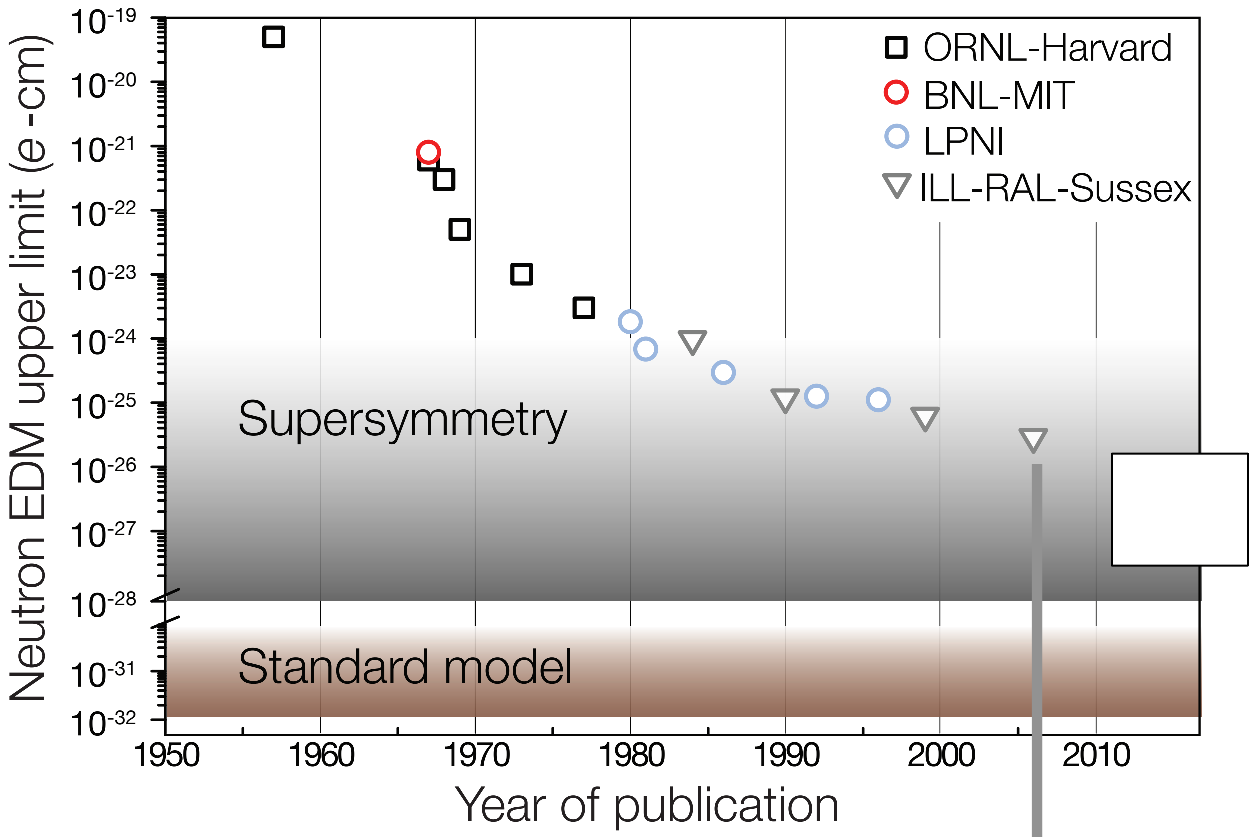
Measured transmission efficiency > 98% per meter

Search for a neutron EDM

Search for a neutron EDM

A nonzero particle EDM violates P, T and, assuming CPT conservation, also CP





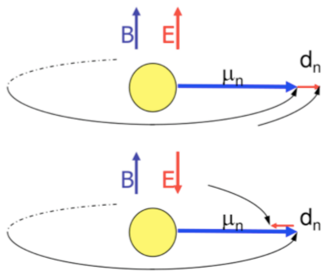
Baker et al., PRL 97 (2006) 131801

$|d_n| \leq 2.9 \times 10^{-26}$ e·cm (90% C.L.)

Experimental technique

Measure Larmor precession frequency of polarized neutrons in a magnetic field.

Look for a change in the frequency caused by an electric field.



$$h\nu_{\uparrow\uparrow} = 2\mu_n B + 2d_n E$$

$$h\nu_{\uparrow\downarrow} = 2\mu_n B - 2d_n E$$

$$h(\nu_{\uparrow\uparrow} - \nu_{\uparrow\downarrow}) = 4d_n E$$

Ramsey technique of separated oscillatory fields

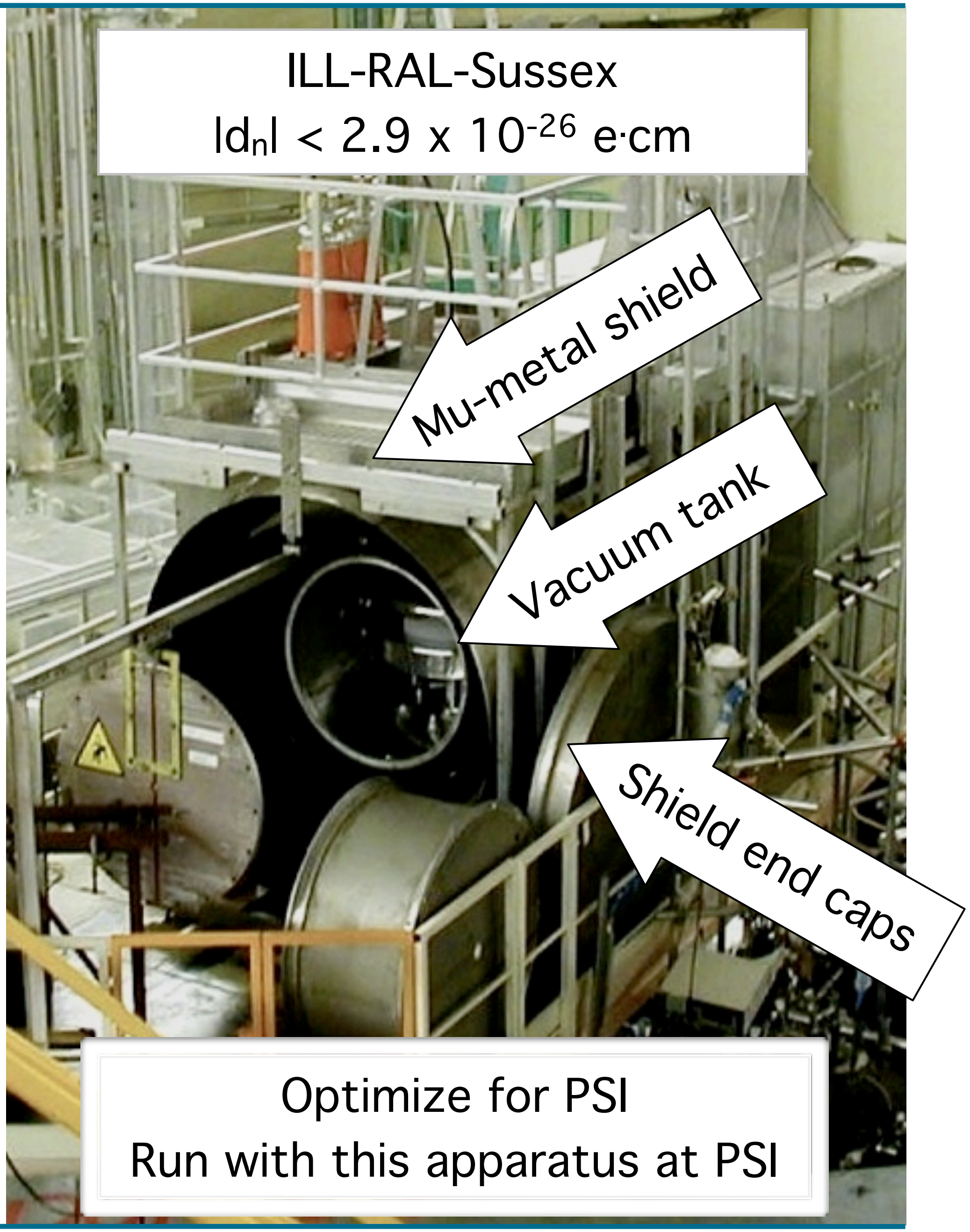
Statistical sensitivity is given by:

$$\delta d_n = \frac{\hbar}{2\alpha\, T \cdot E \cdot \sqrt{N}}$$

visibility (α), precession time (T), electric field (E), number of neutrons (N)

ILL-RAL-Sussex

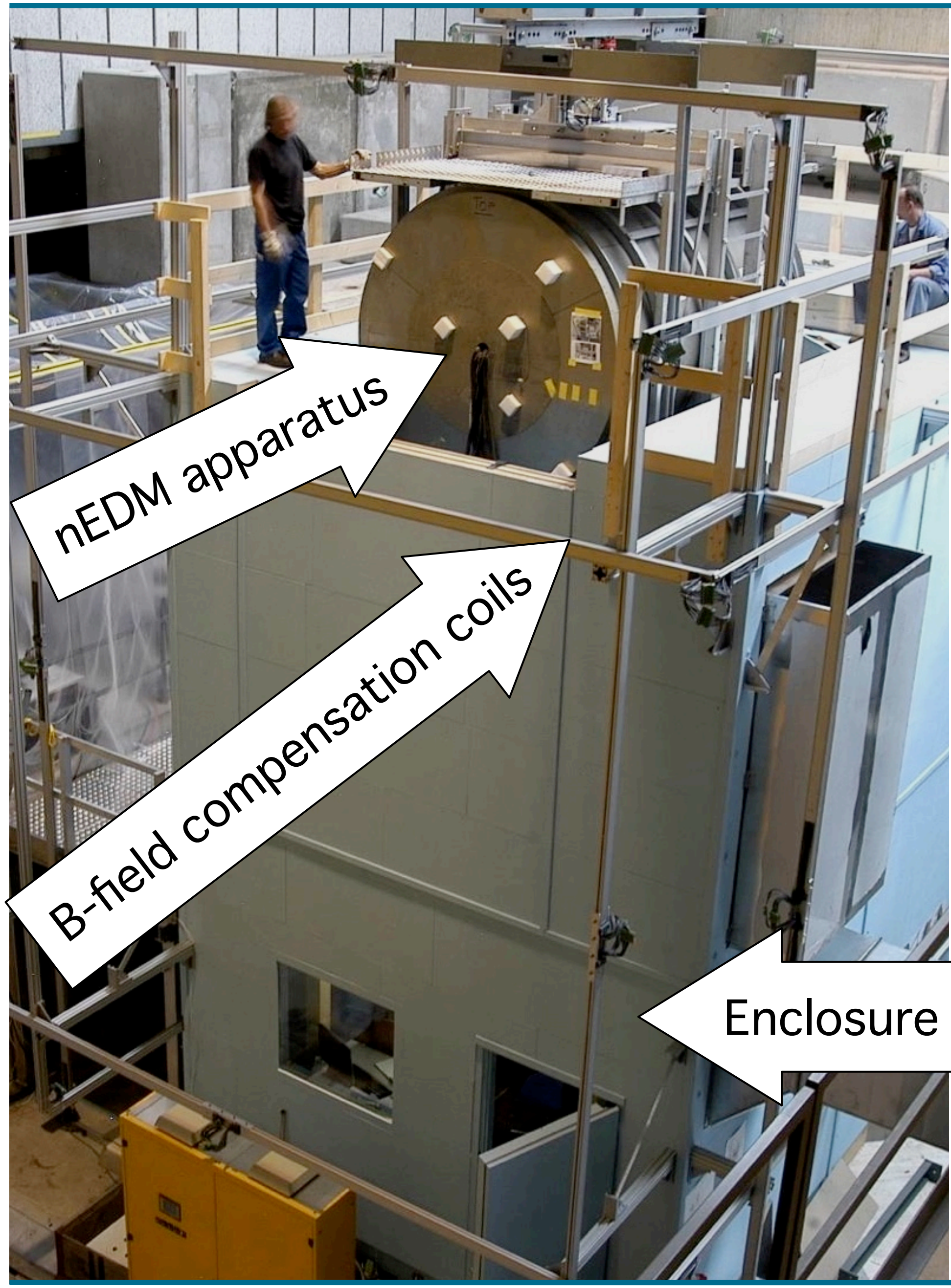
$|d_n| < 2.9 \times 10^{-26}$ e·cm



Optimize for PSI

Run with this apparatus at PSI

Set-up at PSI

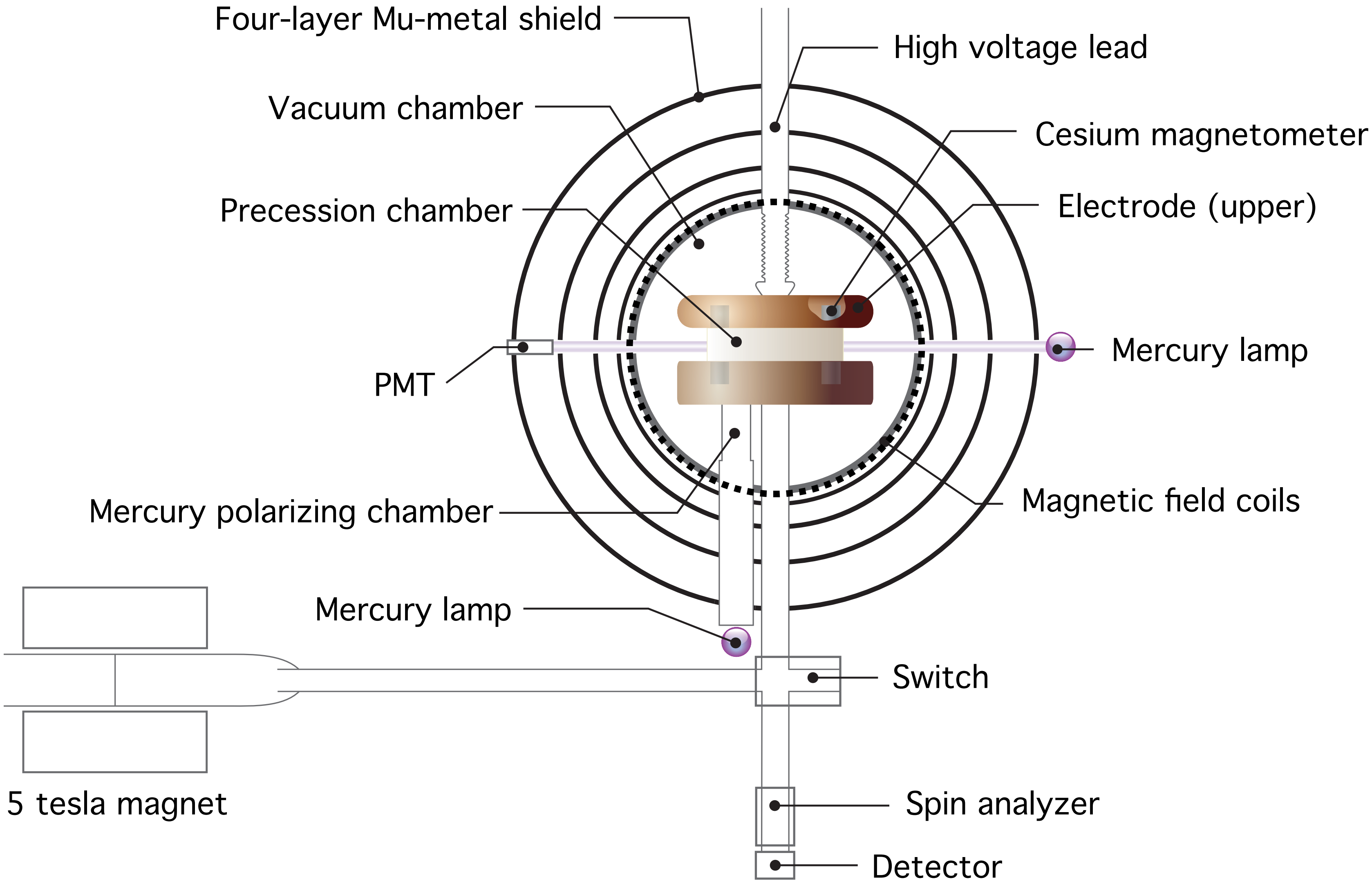


Modified
ILL-RAL-Sussex apparatus

- 25x more neutrons
- better magnetic field control
- better control of systematics

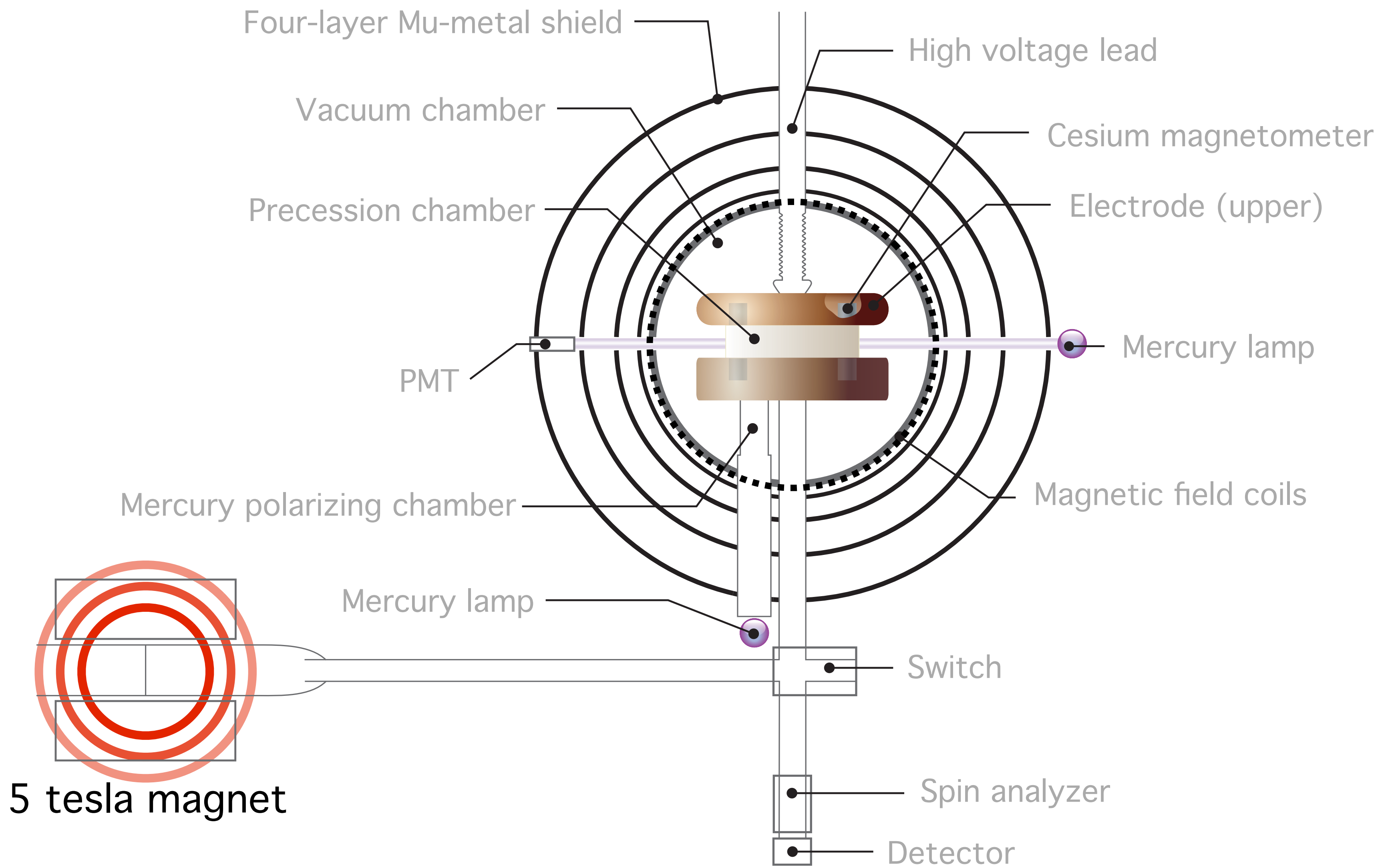
Goal for first round: 5×10^{-27} e·cm

Neutron EDM apparatus



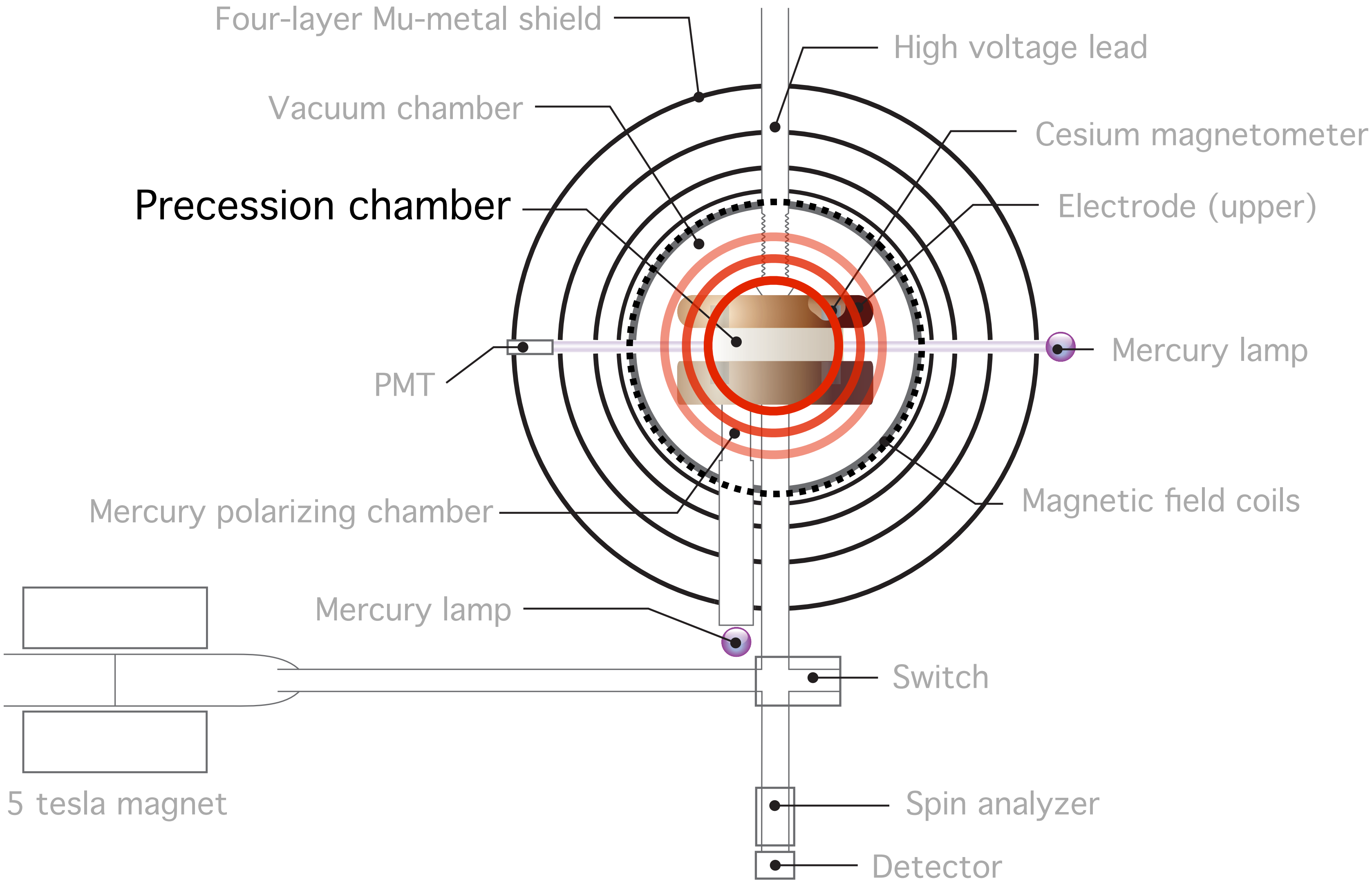
nEDM measurement procedure

UCNs from the source are polarized



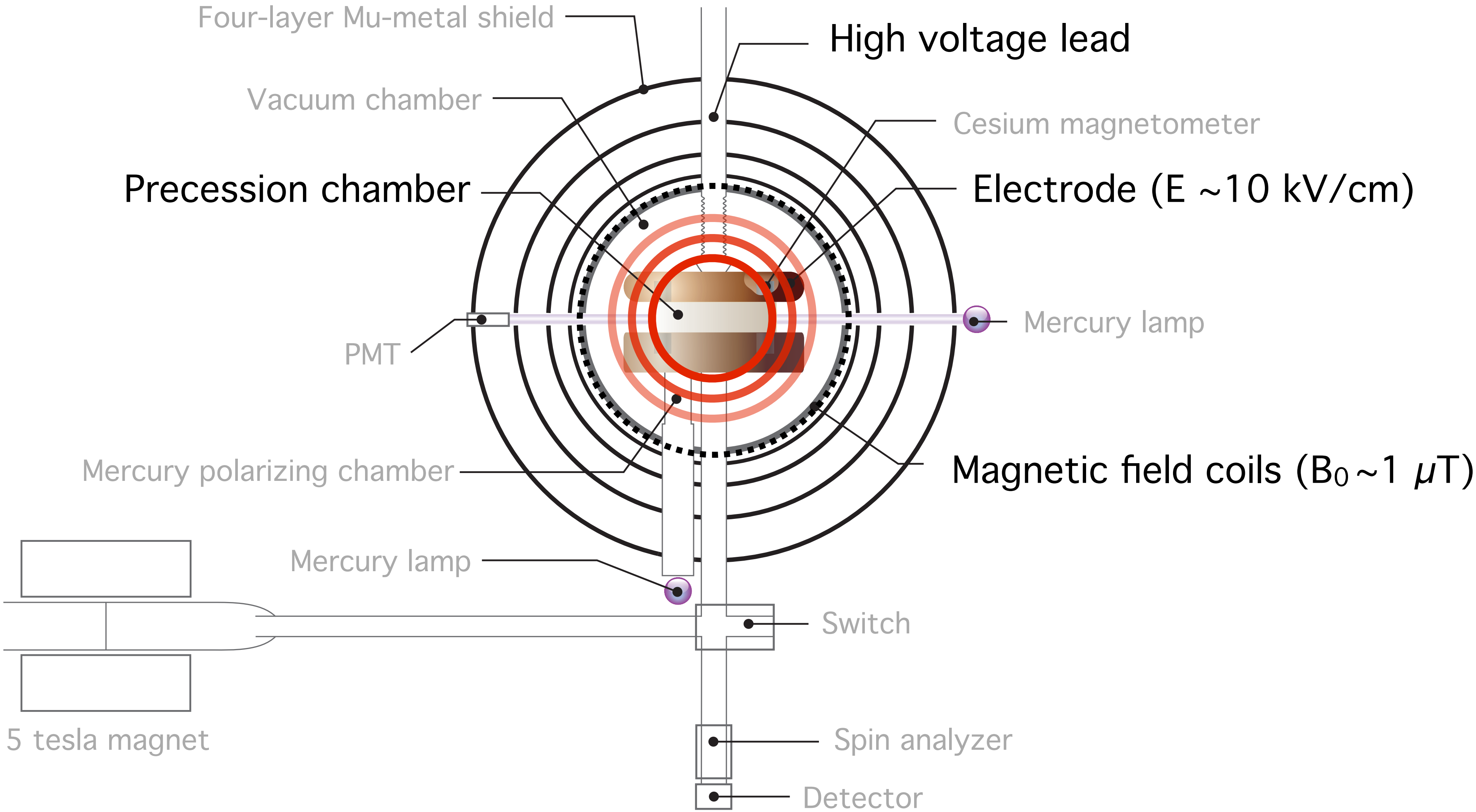
nEDM measurement procedure

The precession chamber is filled



nEDM measurement procedure

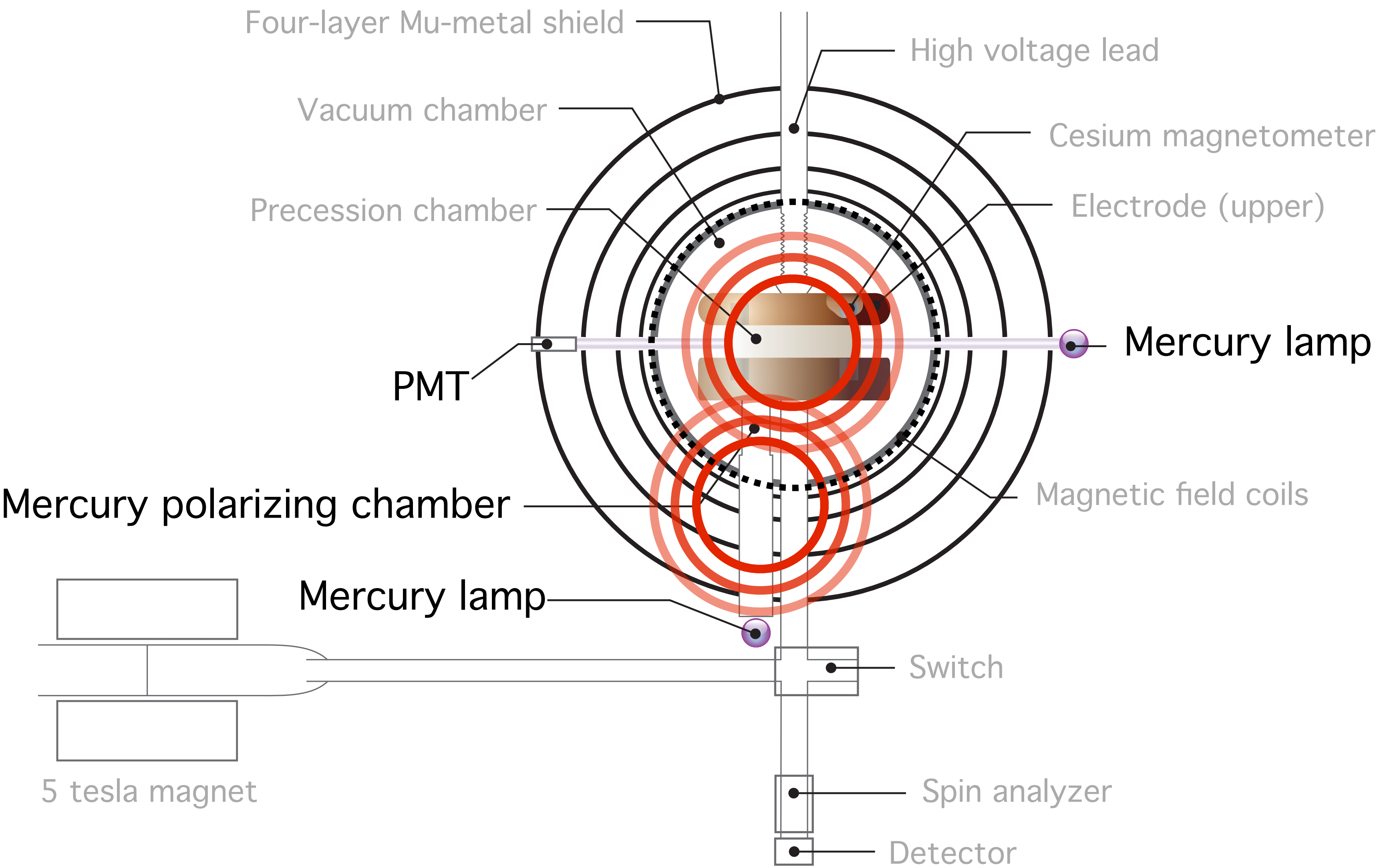
The precession chamber is filled



nEDM measurement procedure

Polarized mercury is let into the chamber

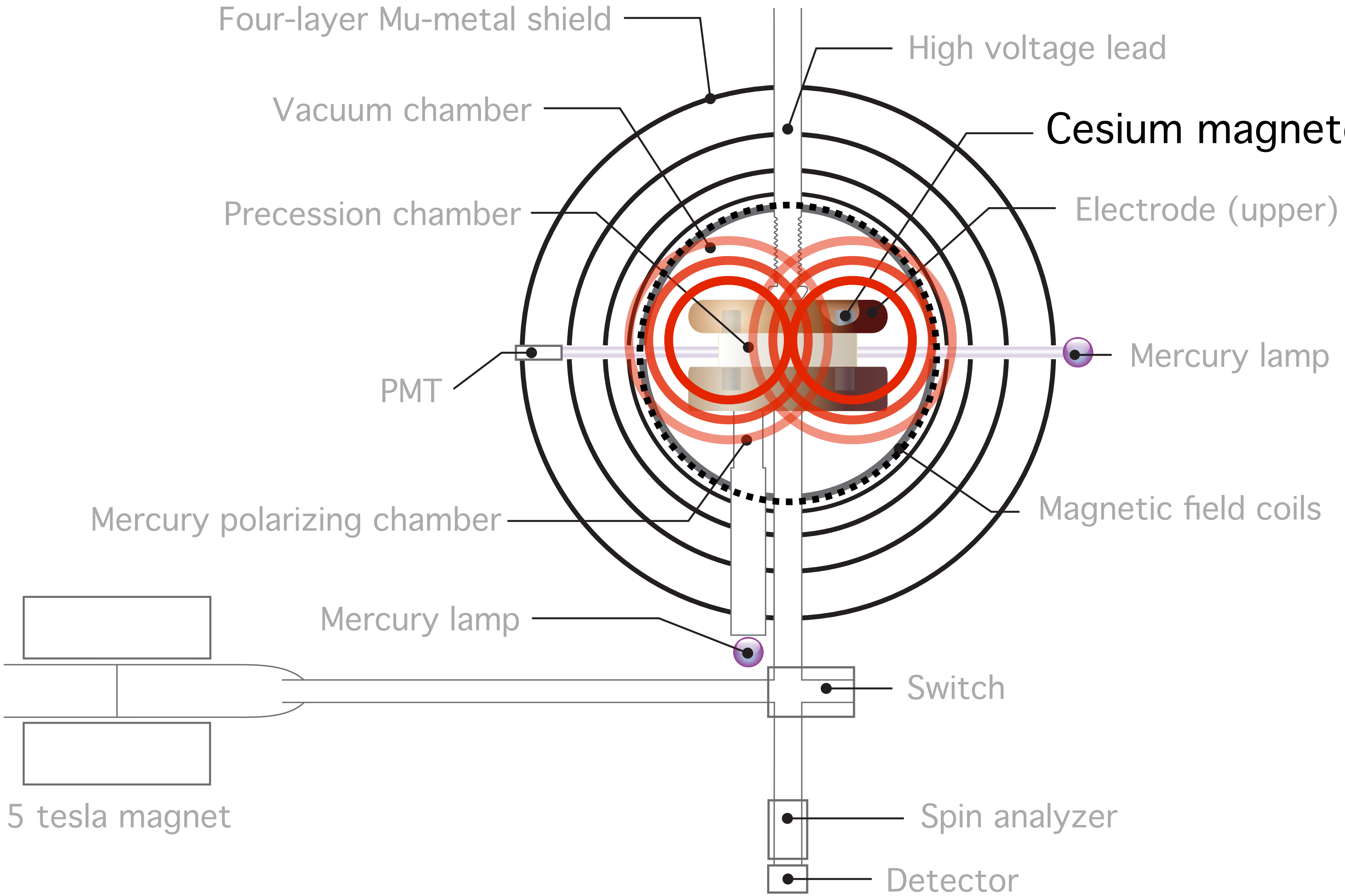
Co-habiting magnetometer



nEDM measurement procedure

Cesium magnetometers

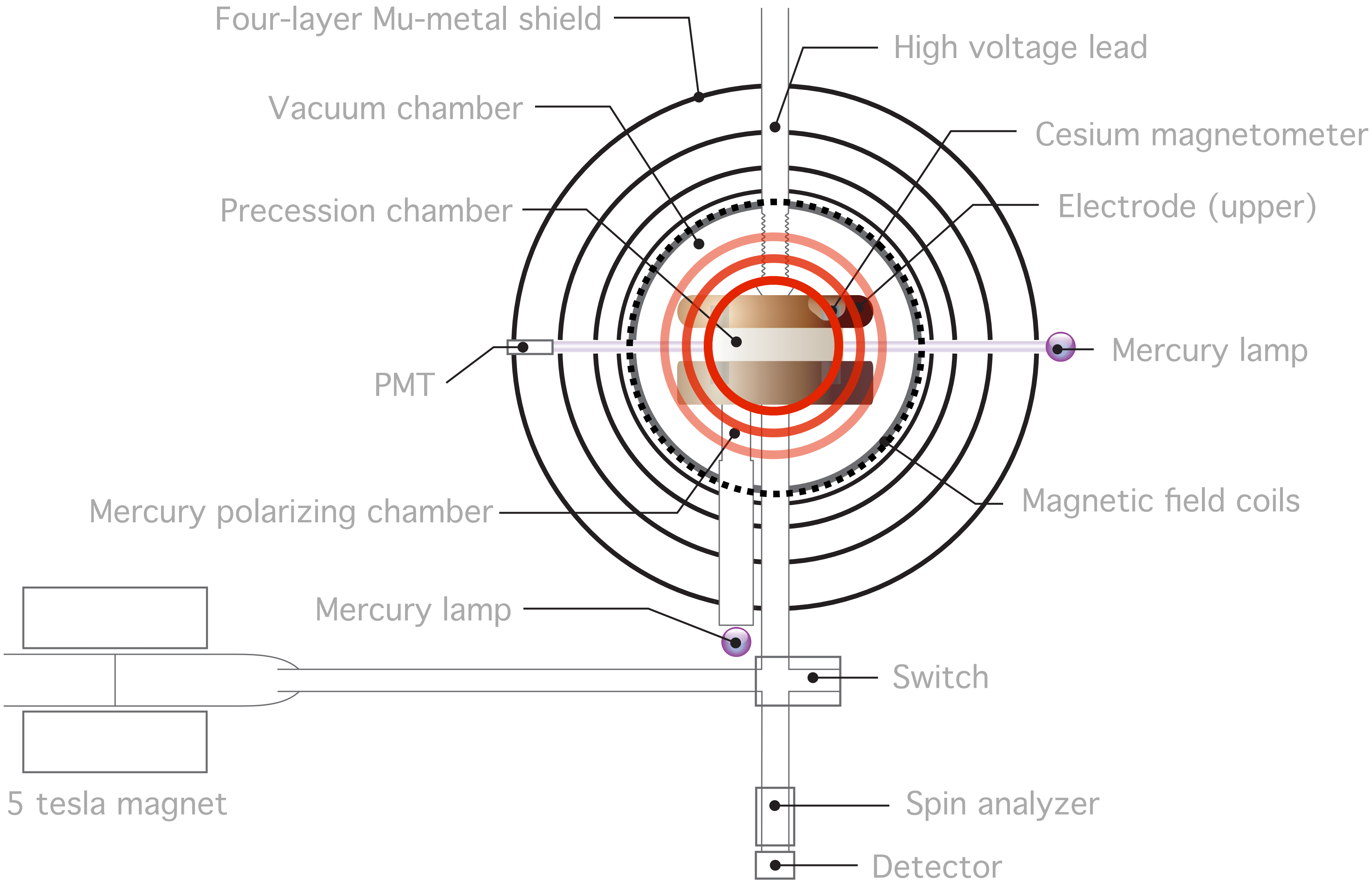
Field gradient information



nEDM measurement procedure

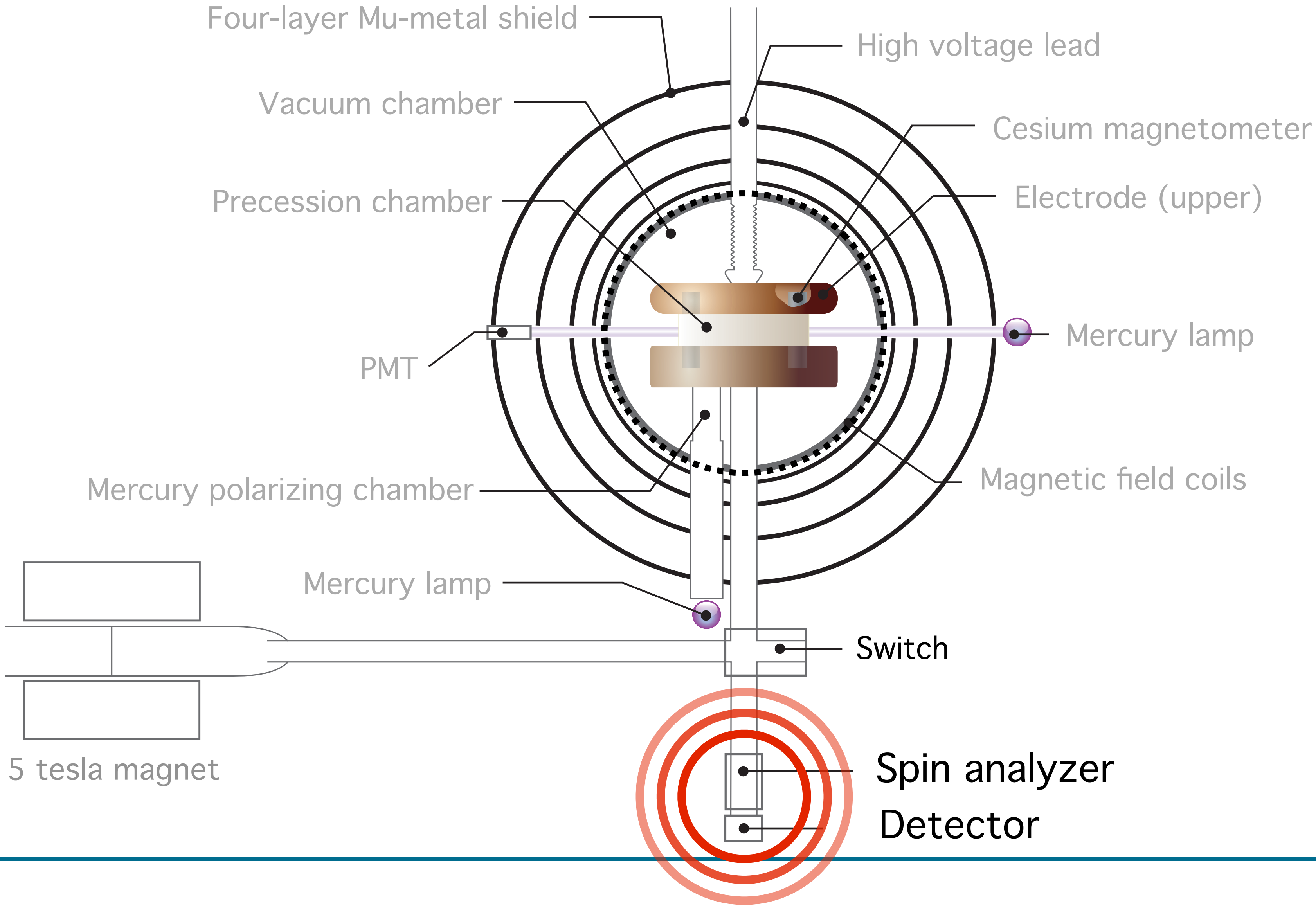
Perform Ramsey procedure

Precession is induced

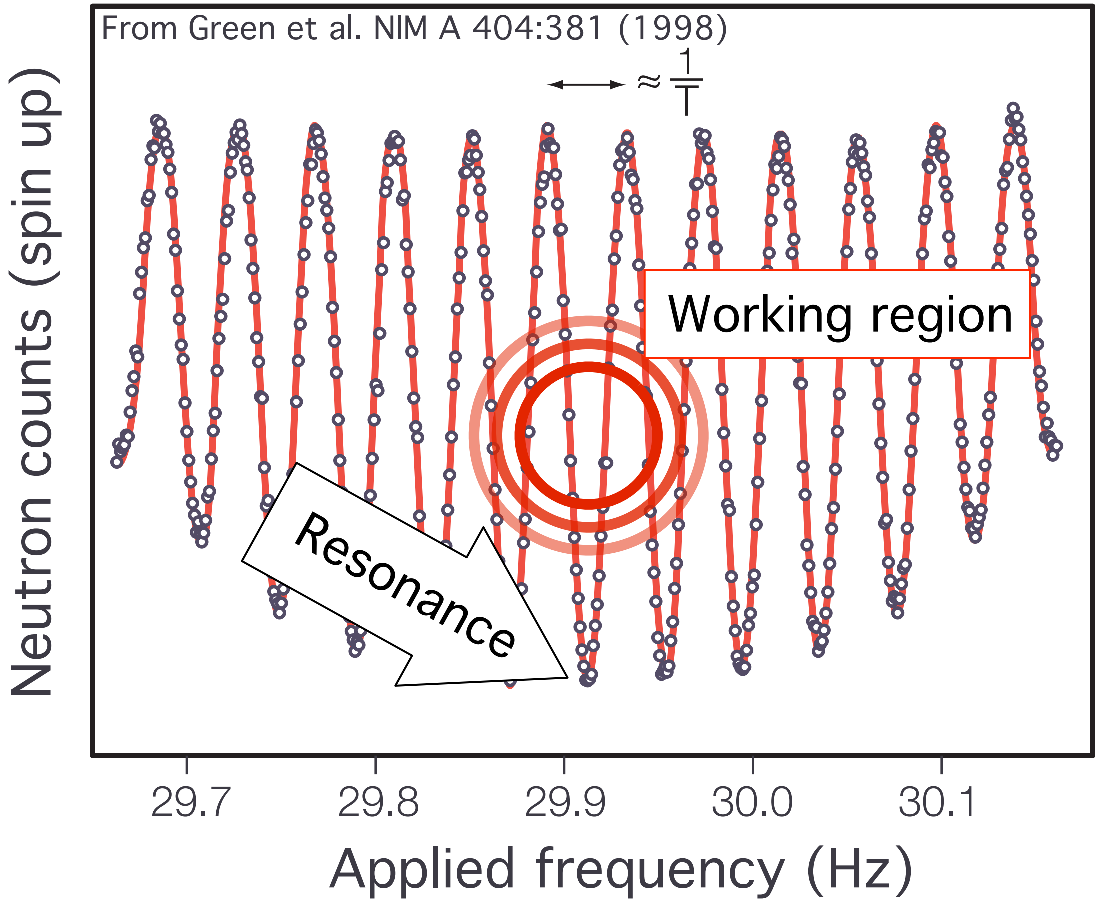


nEDM measurement procedure

The UCNs are let out and counted according to polarization



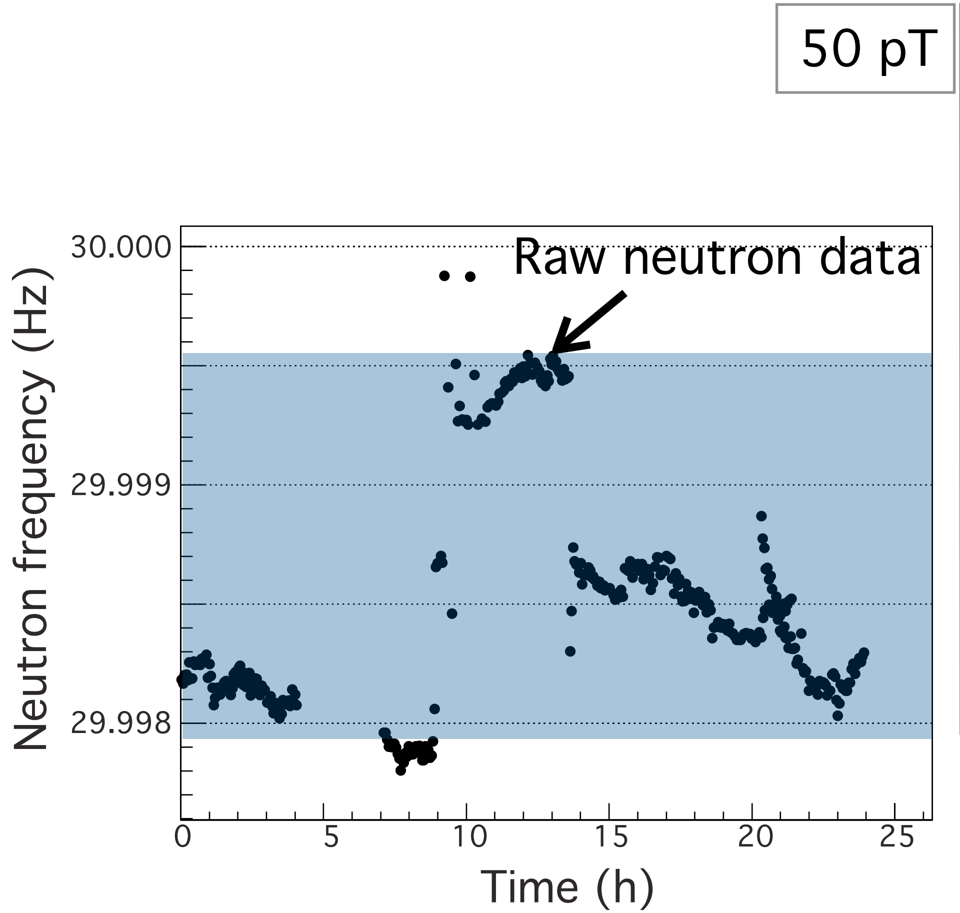
Ramsey resonance curve



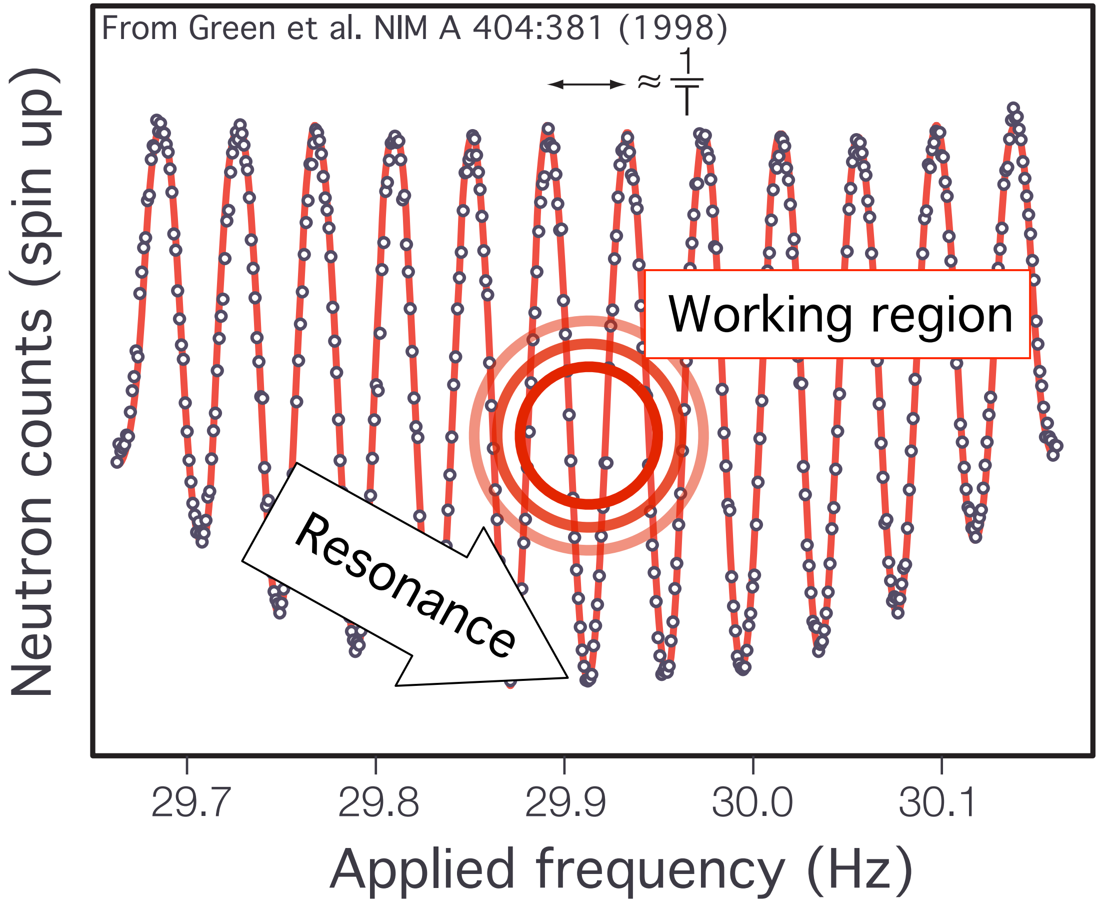
Plot resonance frequency

Alternate the electric field every few cycles

Look for frequency shifts



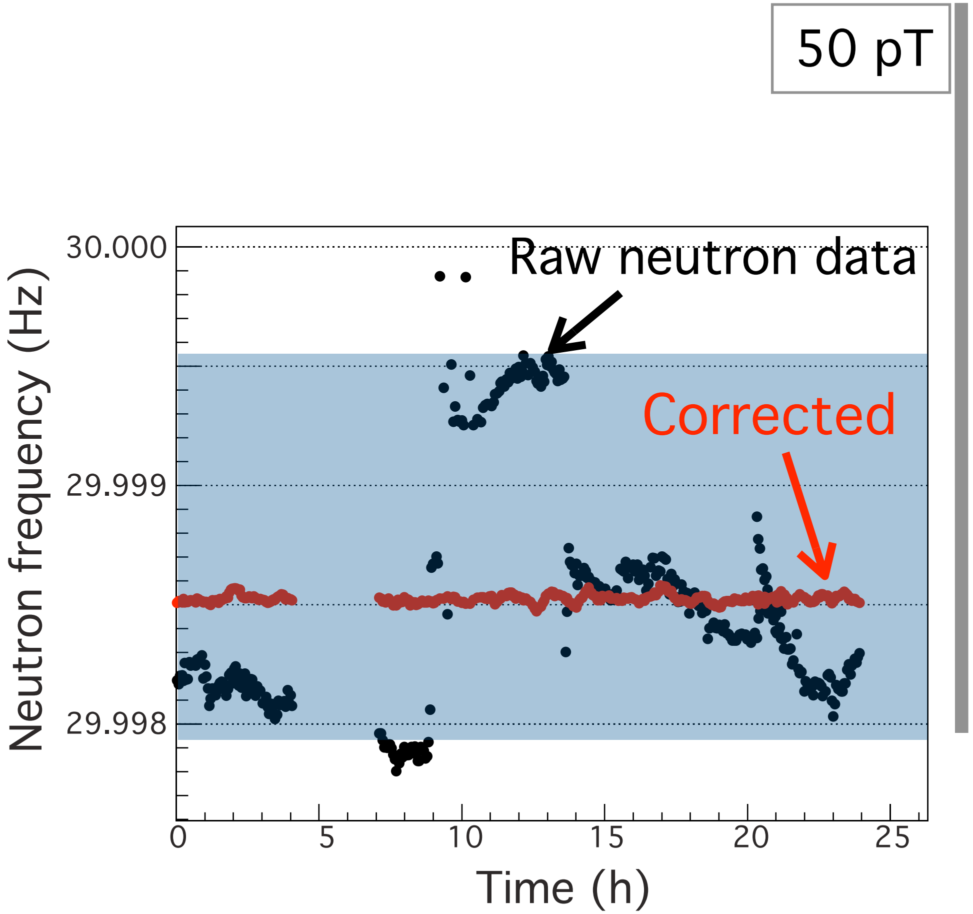
Ramsey resonance curve



Alternate the electric field every few cycles

Look for frequency shifts

Correct for magnetic field drift



Systematic errors (in 10^{-27} e·cm)

Effect	Shift*	σ*	σ (at PSI)
Door cavity dipole	-5.6	2.0	0.1
Other dipole fields	0.0	6.0	0.4
Quadrupole difference	-1.3	2.0	0.6
v×E translational	0.0	0.03	0.03
v×E rotational	0.0	1.0	0.1
Second-order v×E	0.00	0.02	0.02
ν_{Hg} light shift (geo phase)	3.5	0.8	0.4
ν_{Hg} light shift (direct)	0.0	0.2	0.2
Uncompensated B drift	0.0	2.4	0.9
Hg atom EDM	-0.4	0.3	0.06
Electric forces	0.0	0.4	0.4
Leakage currents	0.0	0.1	0.1
ac fields	0.00	0.01	0.01
Total	-3.8	7.2	1.4

*Baker et al., PRL 97 (2006) 131801

Status and outlook

PSI UCN source is being commissioned

UCNs by the end of 2010

nEDM experiment will be ready to use these UCNs

Sensitivity goal: 5×10^{-27} e-cm in 2012

New experiment n2EDM is in the works

Goal: 5×10^{-28} e-cm (2012 - 2015)

The neutron EDM collaboration

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