

PAUL SCHERRER INSTITUT

PSI



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Commissioning of the ultracold neutron guide system for the n2EDM experiment at PSI

Swiss Physical Society annual meeting 2023

Basel

The n2EDM experiment

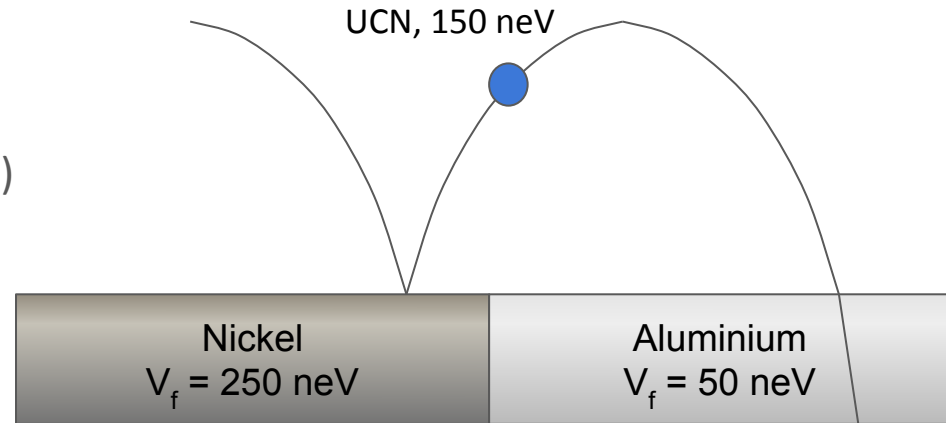
- Search for the neutron electric dipole moment (nEDM) using stored ultracold neutrons (UCN).

- Statistical sensitivity:
$$\sigma(d_n) = \frac{\hbar}{2\alpha|E|T \sqrt{N}}$$

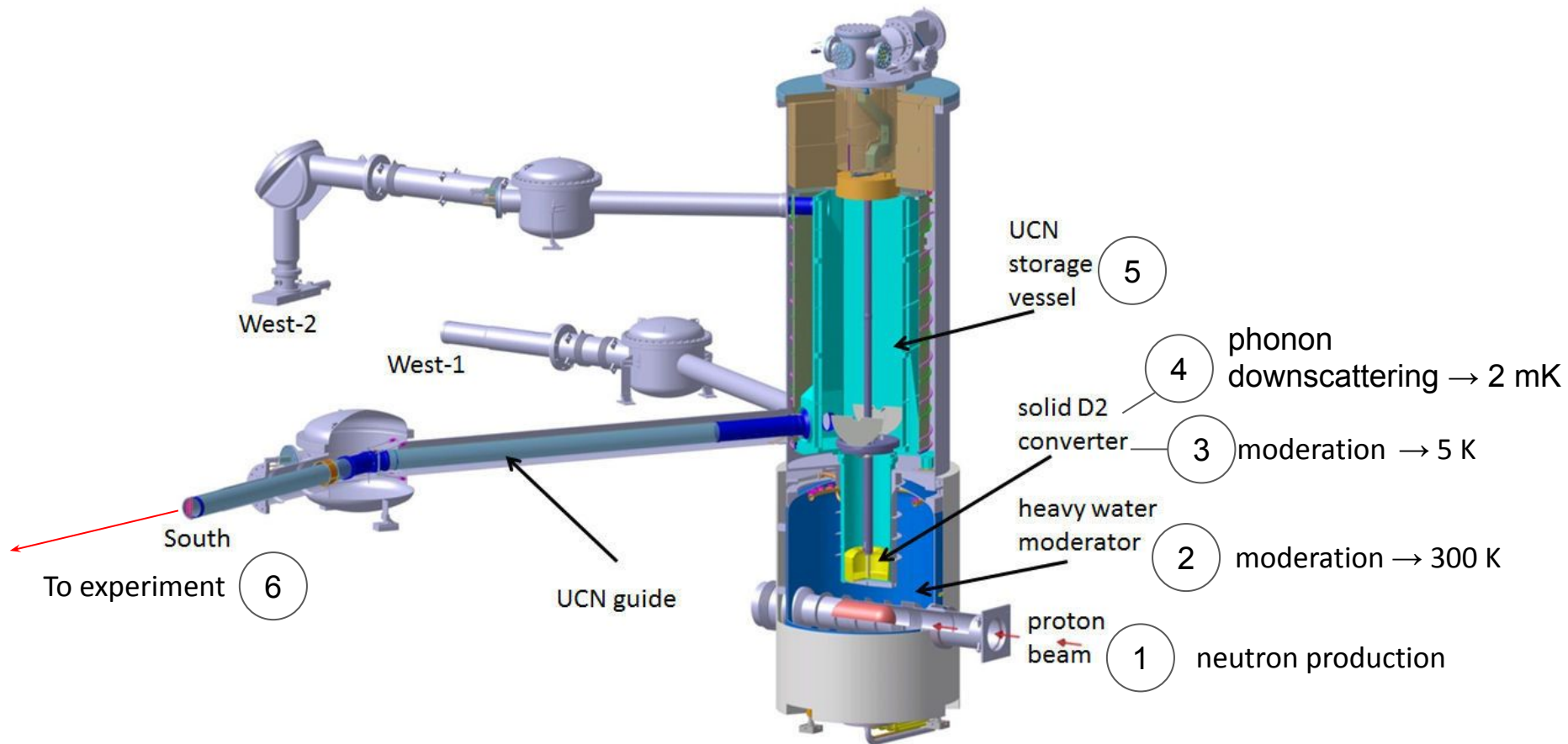
- We need a good UCN transport system!

UCN are storable neutrons

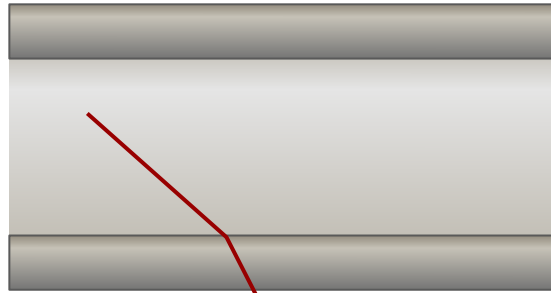
- Ultracold
 - $E_{\text{kin}} < 300 \text{ neV}$ $T \sim 2 \text{ mK}$ $v \sim 5 \text{ m/s}$
- Material interactions: Fermi potential (V_f) approximates strong force
 - If $E_{\text{kin}} < V_f$
 - Reflection under all angles
 - Storable
- Magnetic traps ($dV/dB = \pm 60 \text{ neV/T}$)
- Gravity traps ($dV/dh = 102 \text{ neV/m}$)



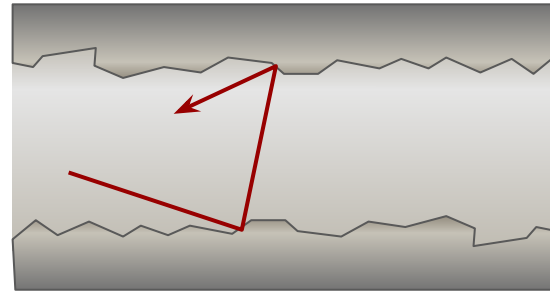
UCN Source at PSI



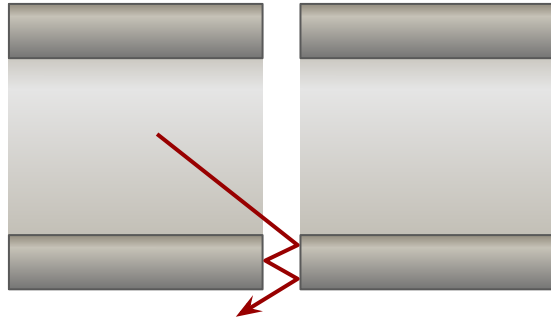
Requirements for UCN guides



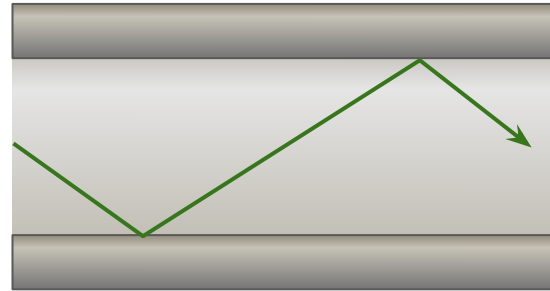
Fermi potential



Smoothness

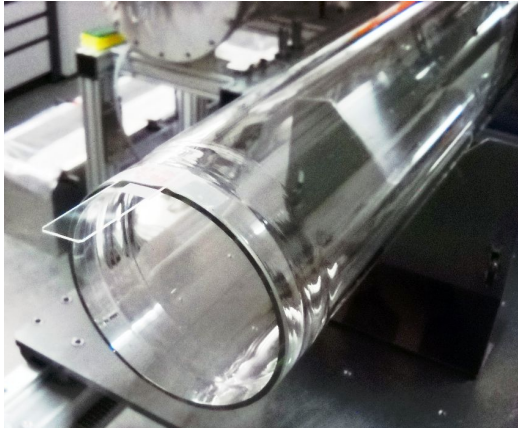


Gaps between guides



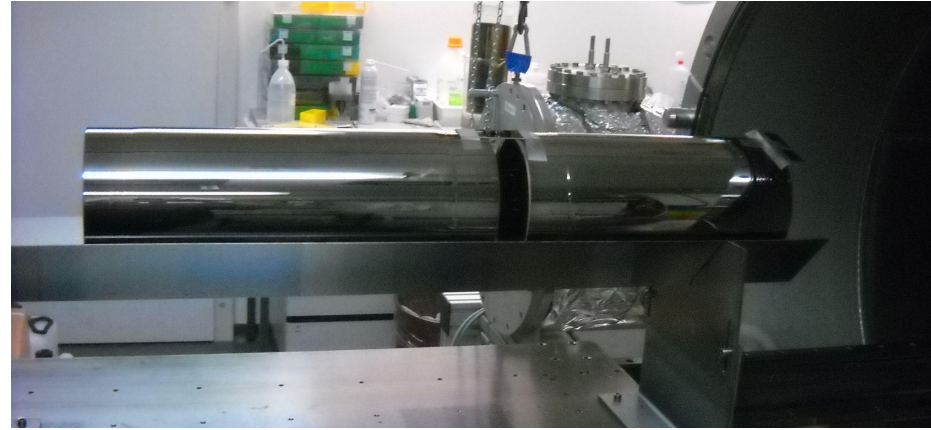
Required transmission:
90 % for 1m guide

UCN guides



Glass guides

- smooth
- Inner diameter: 13 cm
- Length: varies, up to 125 cm

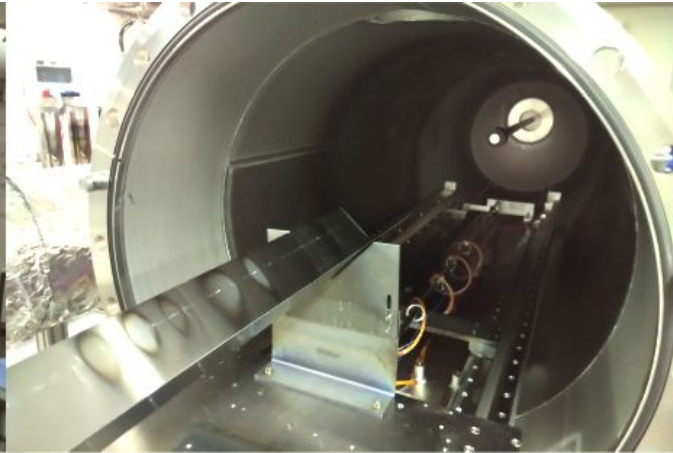
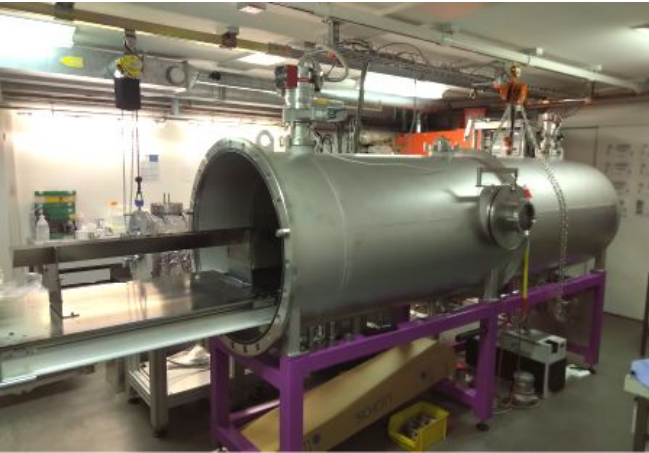


NiMo coating (85:15 mass ratio),

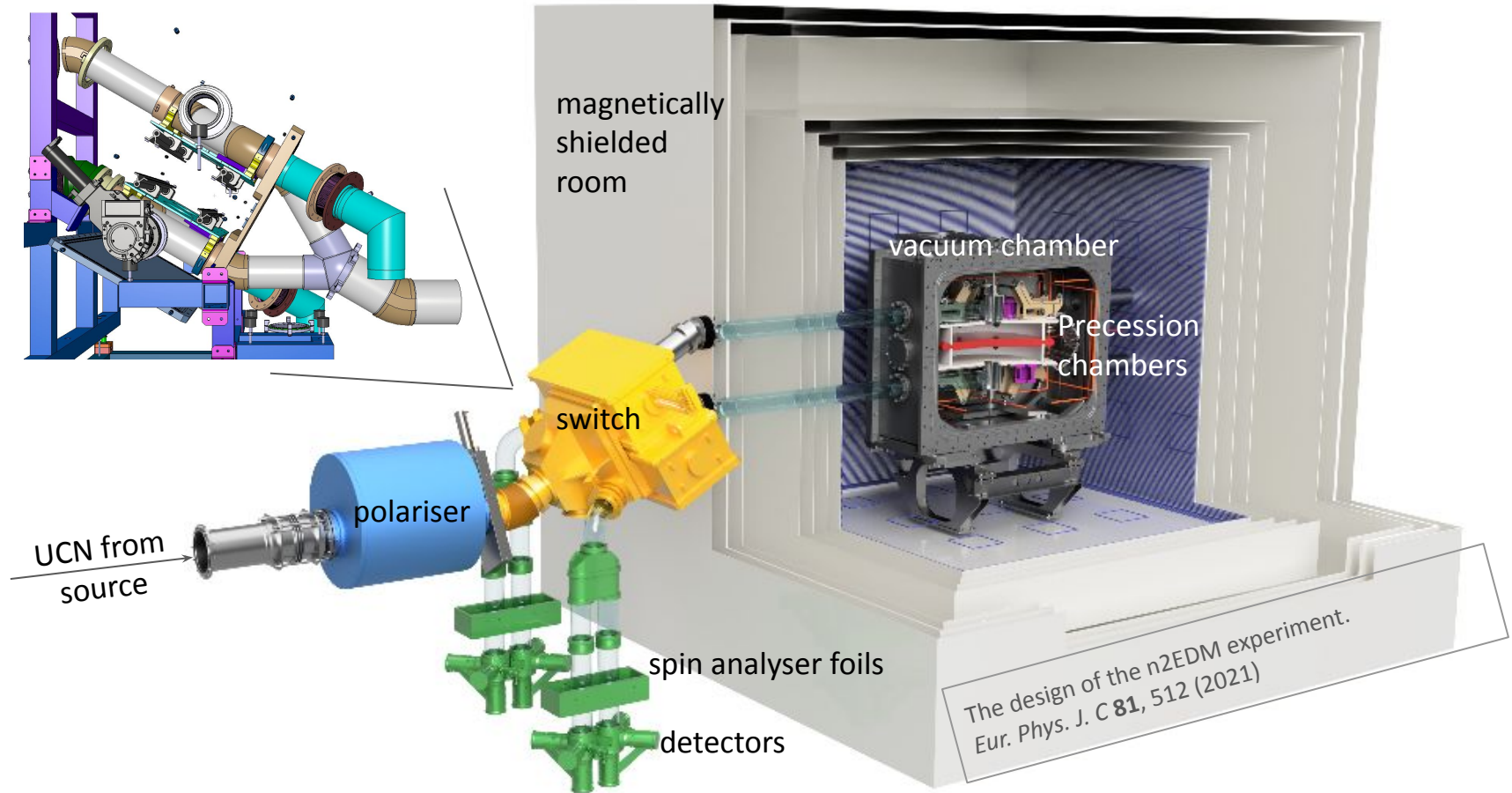
- $V_f = 220$ neV
- Ni: high fermi potential, but ferromagnetic
- Mo: reduces Curie temperature well below room temperature

Coating

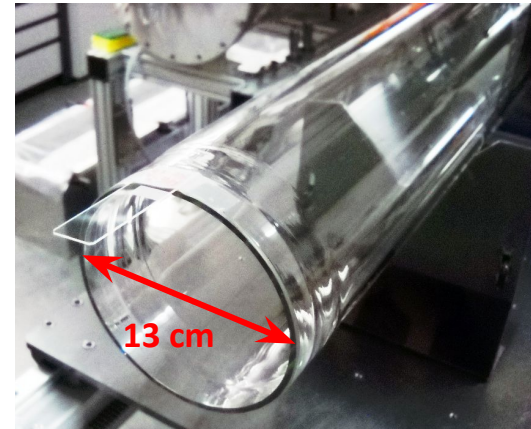
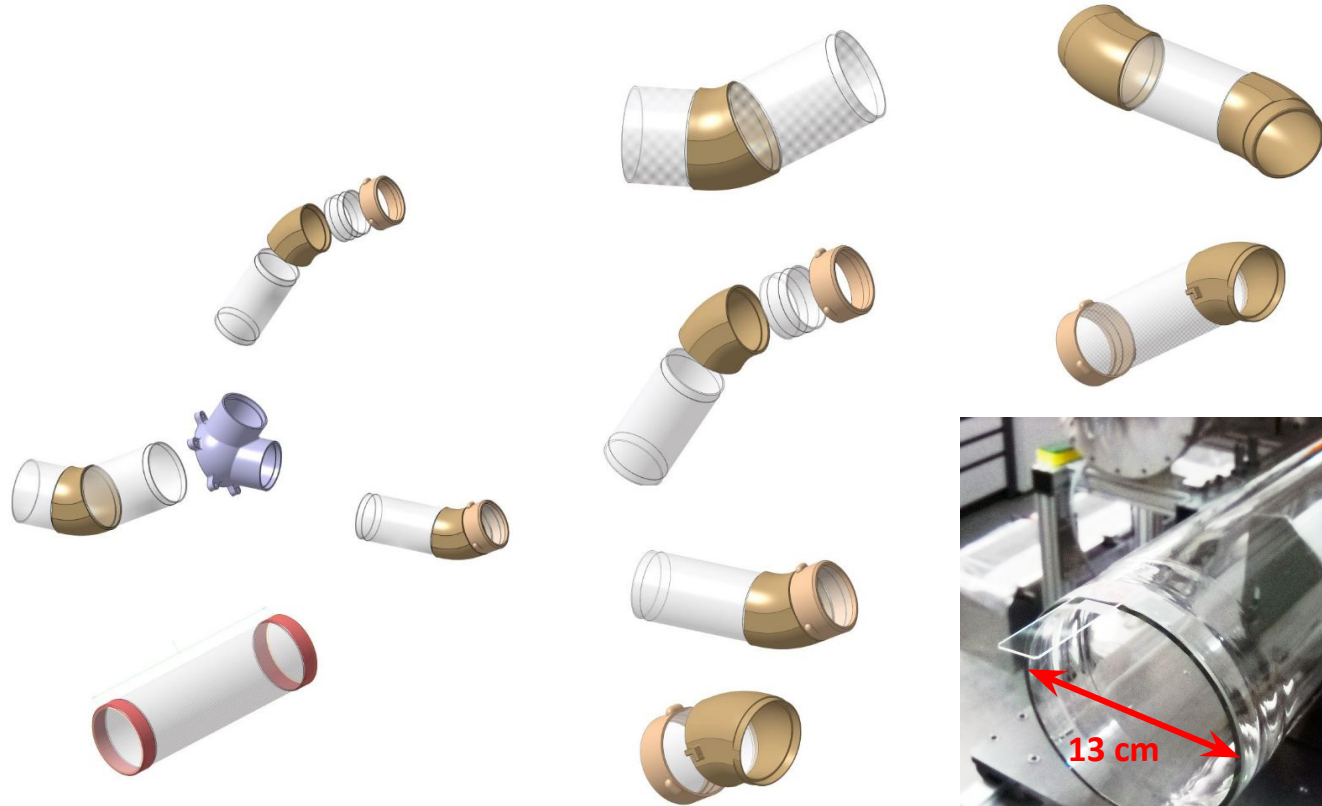
In house, DC magnetron sputter coating facility



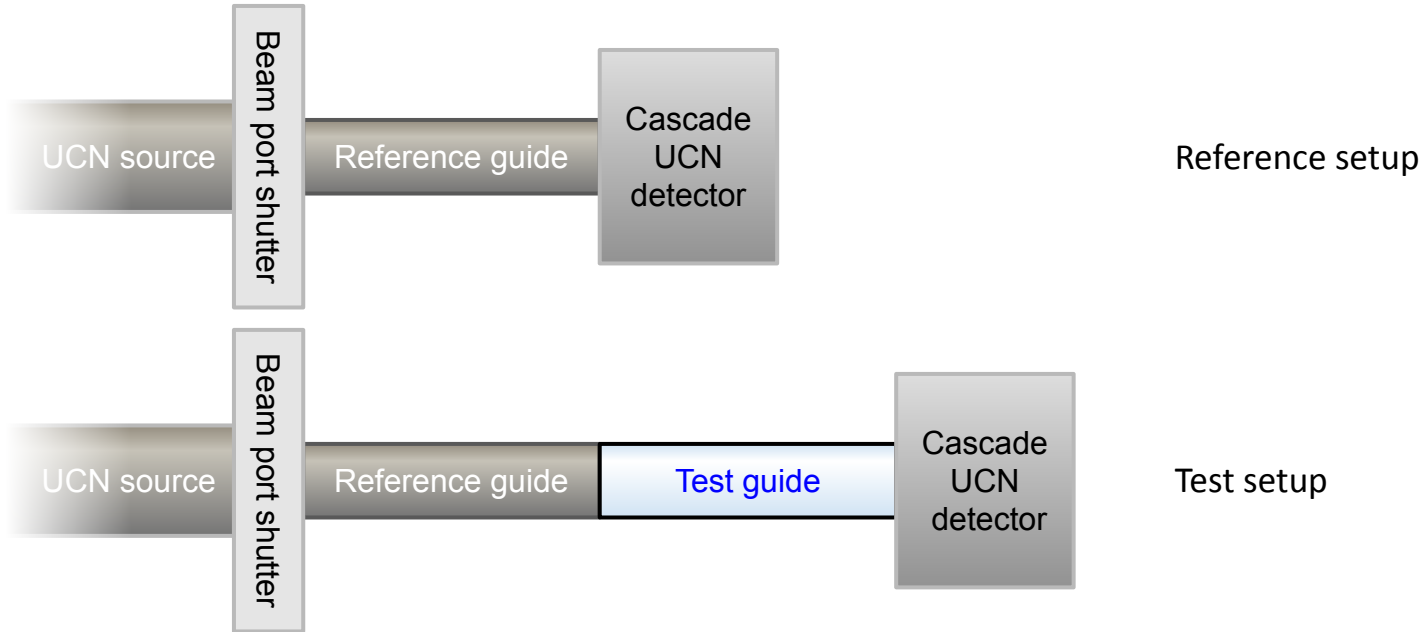
The n2EDM experiment



The guide system



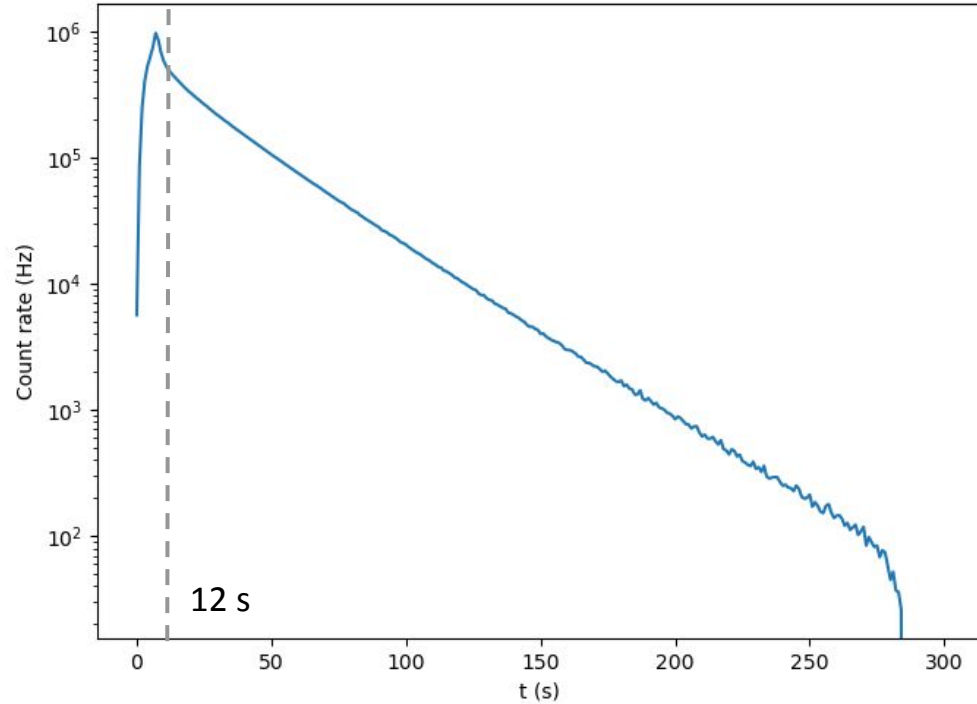
UCN transmission measurements



$$\text{Transmission} = \frac{\text{normalised UCN counts in test setup}}{\text{normalised UCN counts in reference setup}}$$

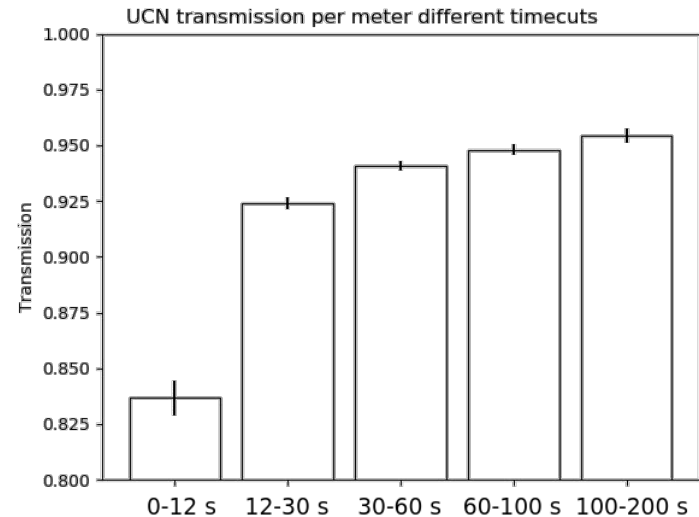
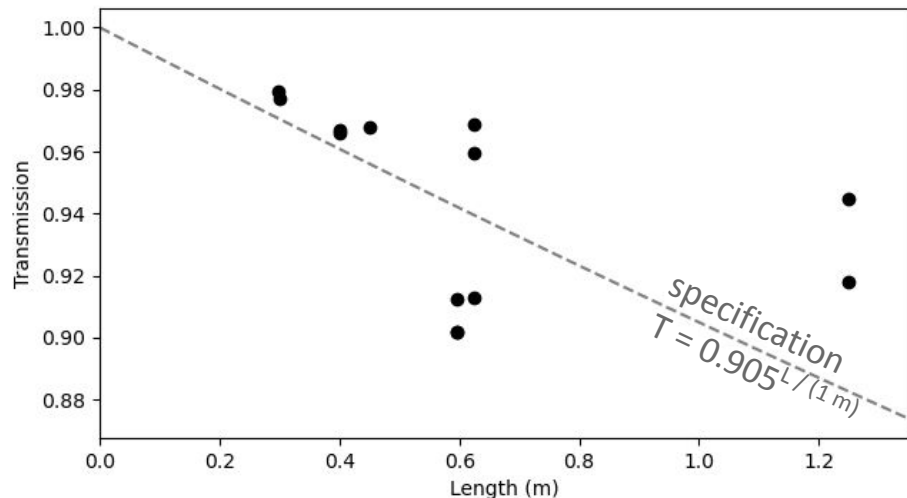
UCN transmission measurements

- Region of interest: 12-200s
- not all neutrons before 12s are storable



UCN transmission measurements, results

- UCN guides not equal in transmission
- Transmission is UCN energy spectrum dependent (higher transmission for lower energies)

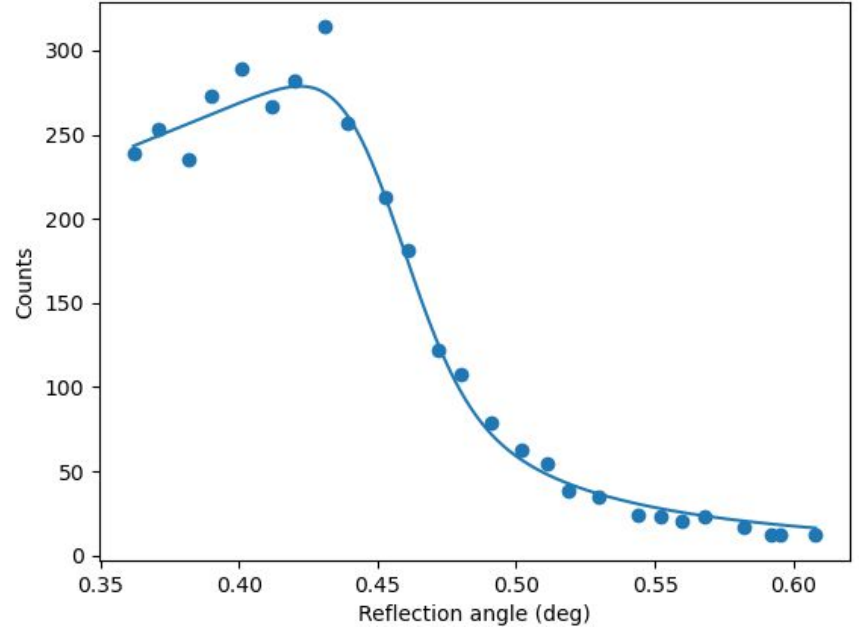
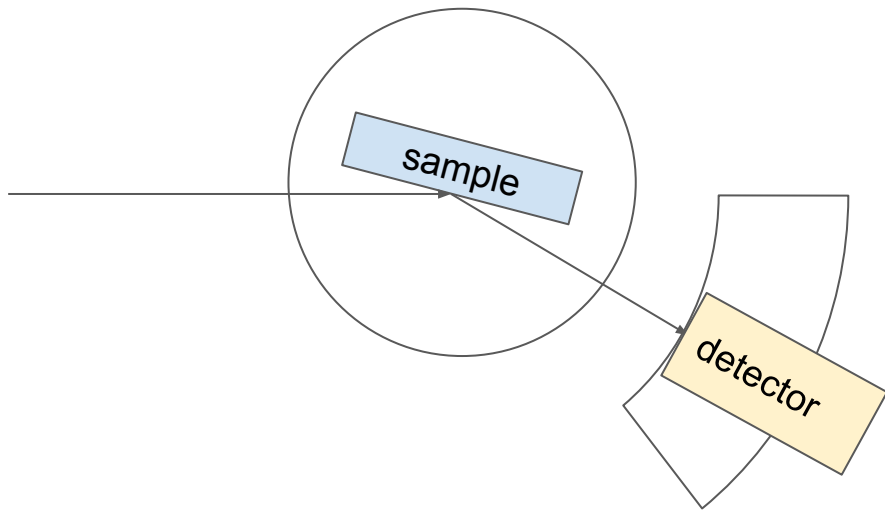


Measurement of V_F

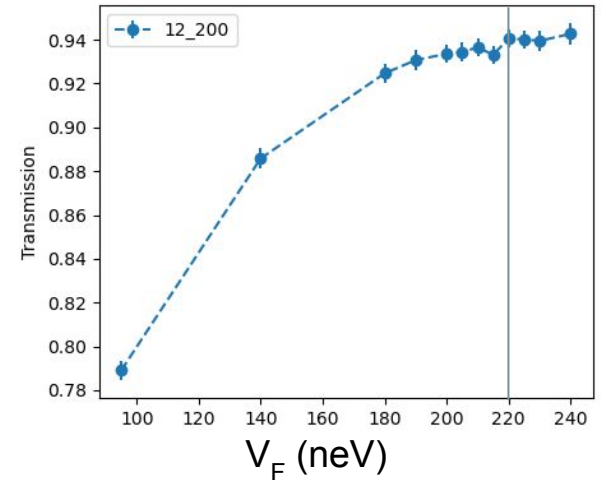
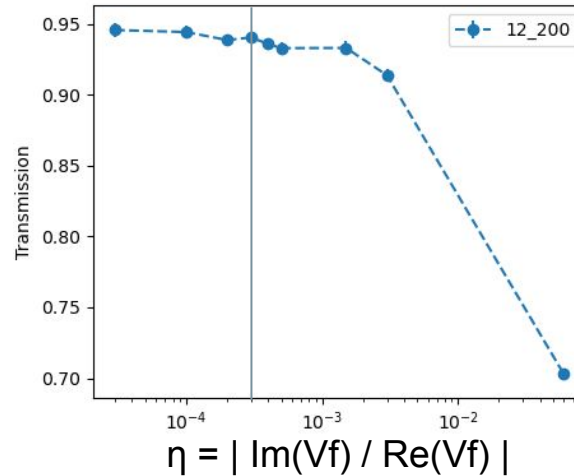
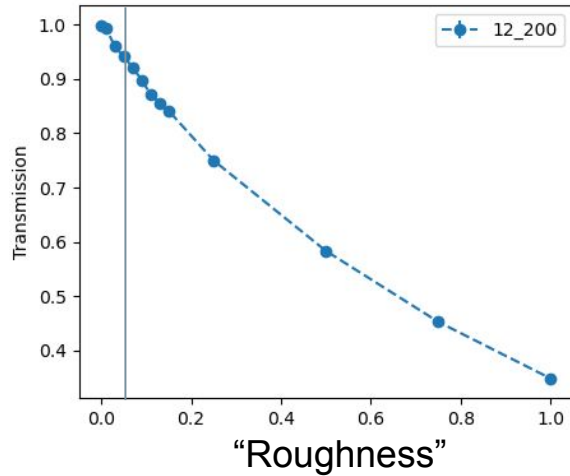
Reflectometry

Confirmed that for our NiMo coating

$$V_F = 220$$



UCN transport simulations

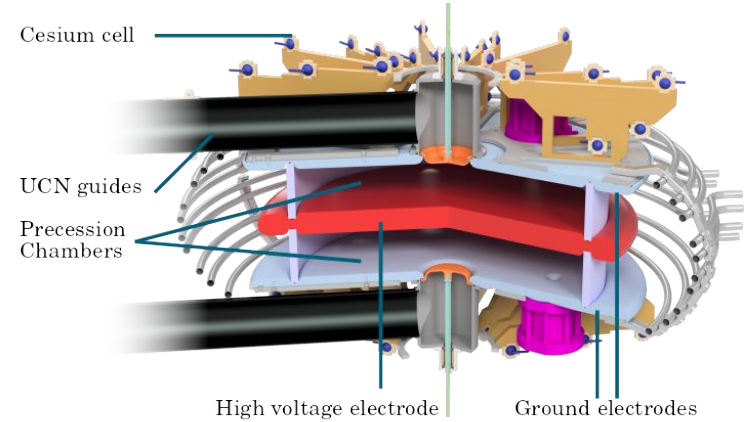


- Simulation of the transmission measurements, from source to detector
- Diffuse scattering fraction ("roughness") explain differences (Lambert model)
- Not caused by coating, intrinsic to guides
- Not sensitive to the other parameters

The MCUCN simulation code for ultracold neutron physics
Nucl. Inst. and Meth. A, Vol. 881, p. 16-26.
<https://doi.org/10.1016/j.nima.2017.10.065>

Checking for magnetic dipoles

- Guides closest to precession chamber
- Limit for magnetic contamination:
 - 16 nA m²
 - 25 pT at 5 cm distance
 - 2 million times lower than geomagnetic field
- The guides fulfil the specifications

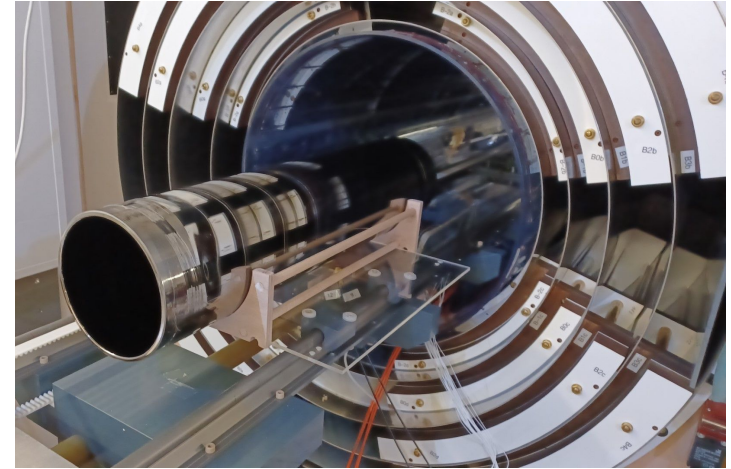
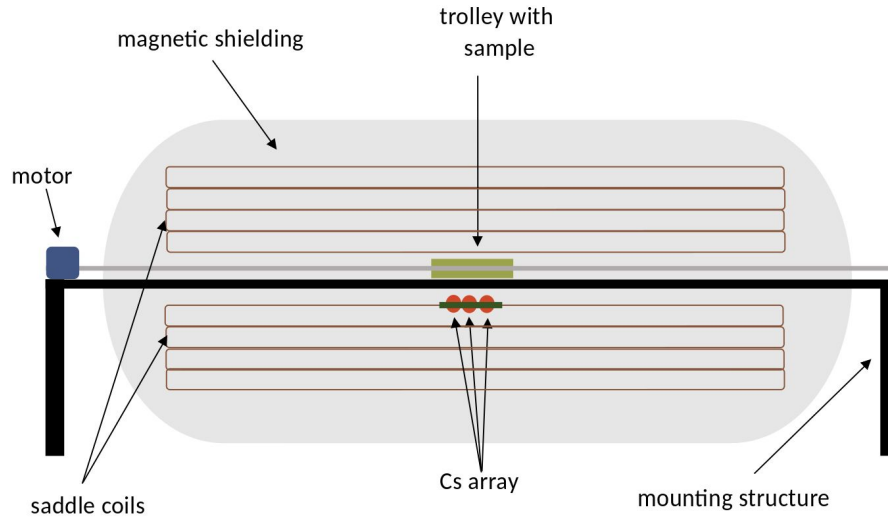


Summary

- Our goal: to search for nEDM with 10^{-27} e cm sensitivity
- Our requirements
 - Transmission per meter > 90 %
 - Magnetic contamination: < 25 pT
- Most guides we produce satisfy these requirements



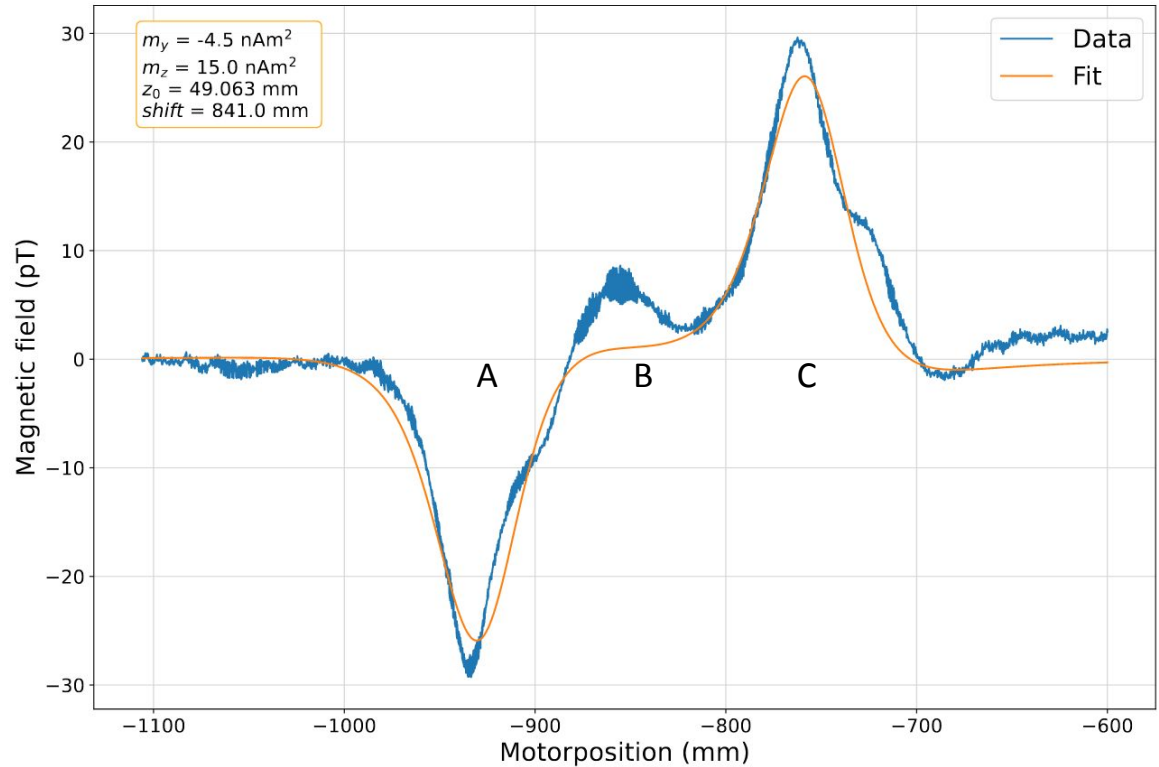
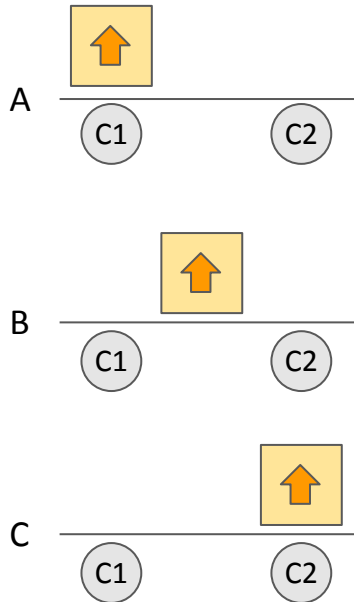
Checking for magnetic dipoles



- Vertical B_0 field: 2.6 μT
- Sample driven past Caesium magnetometers
- Quantity of interest: ΔB between Cs magnetometers
- Sensitive to dipoles of 1 nA m^2 (1 pT level)

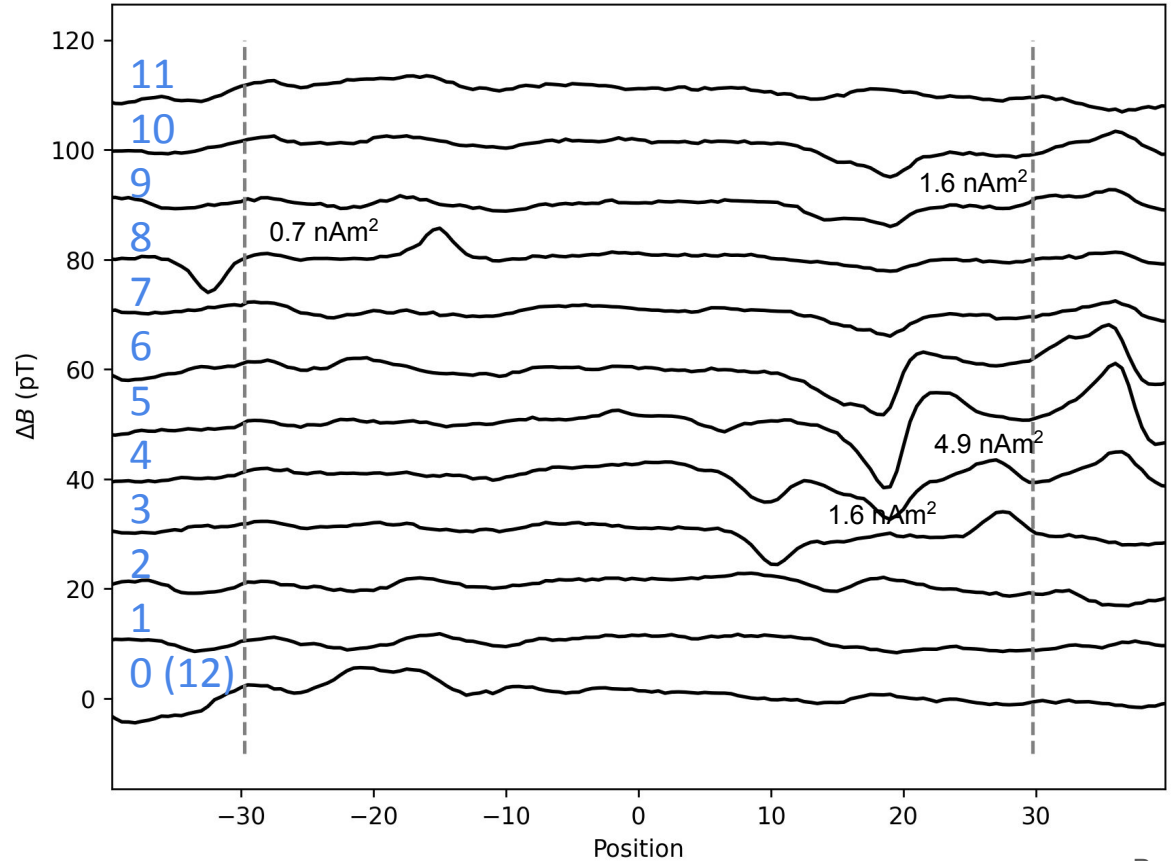
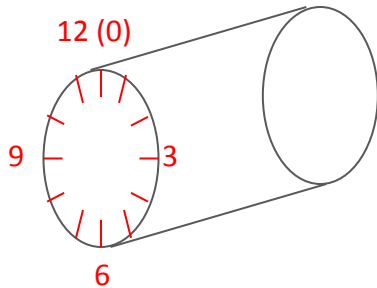
Example dipole signal

- PEEK (plastic)
- Signal: C2 - C1

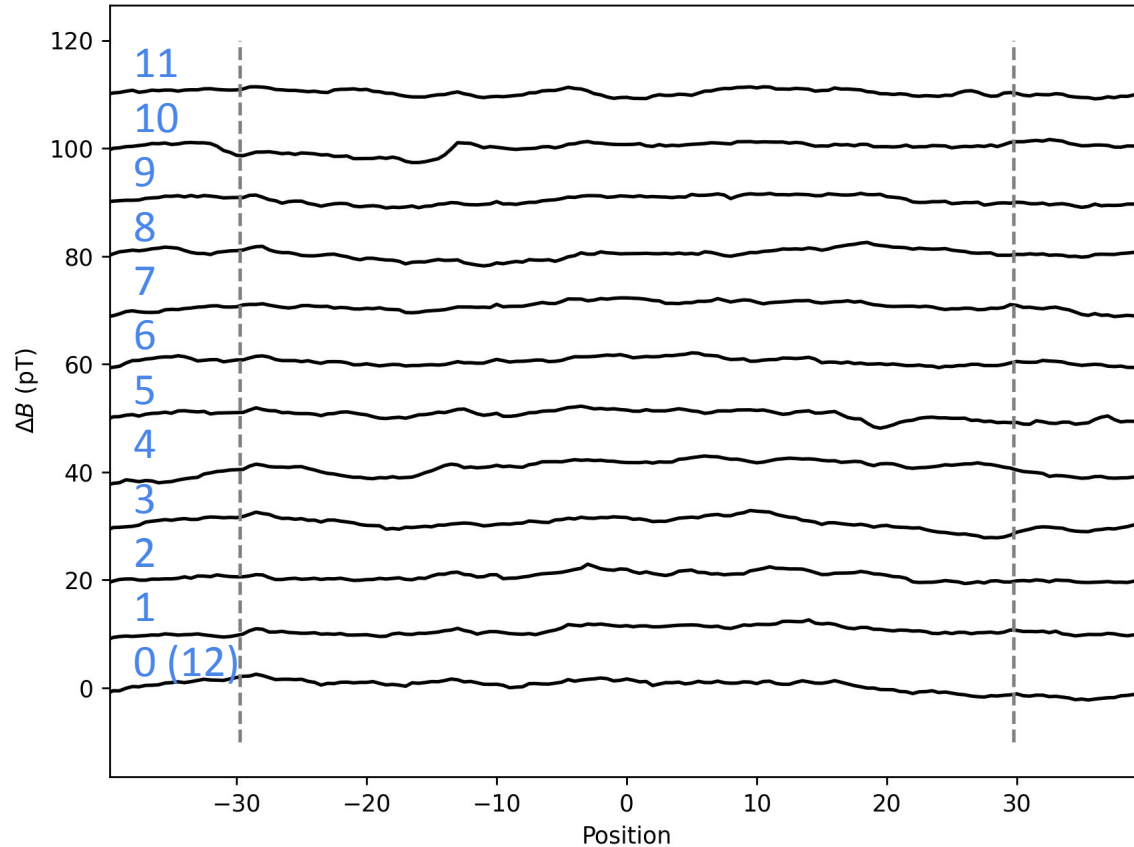


UCN guide dipole scan

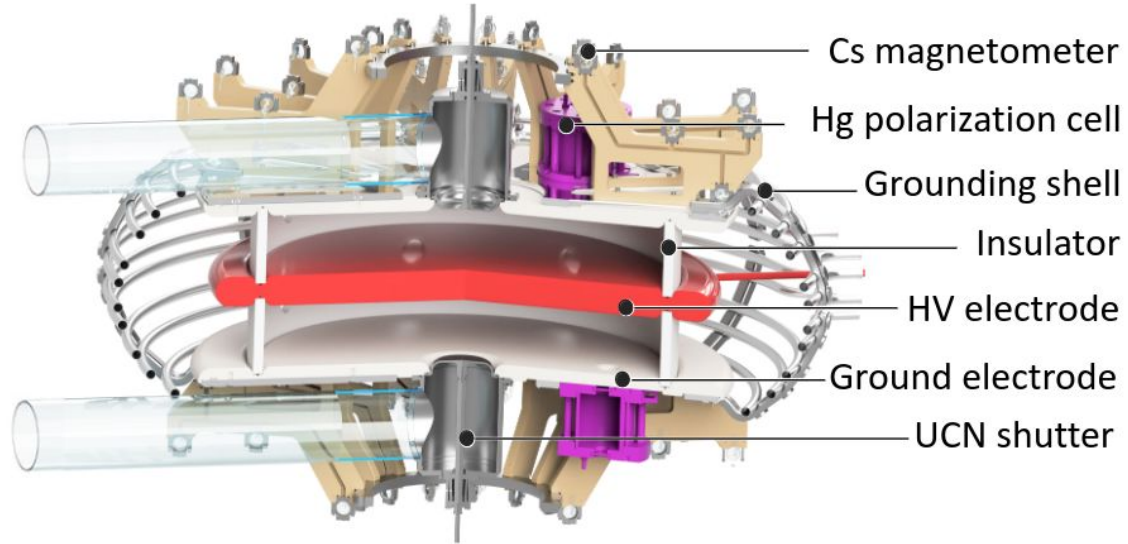
Max allowed
dipole strength:
10 nAm²
16 pT



UCN guide dipole scan, degaussed

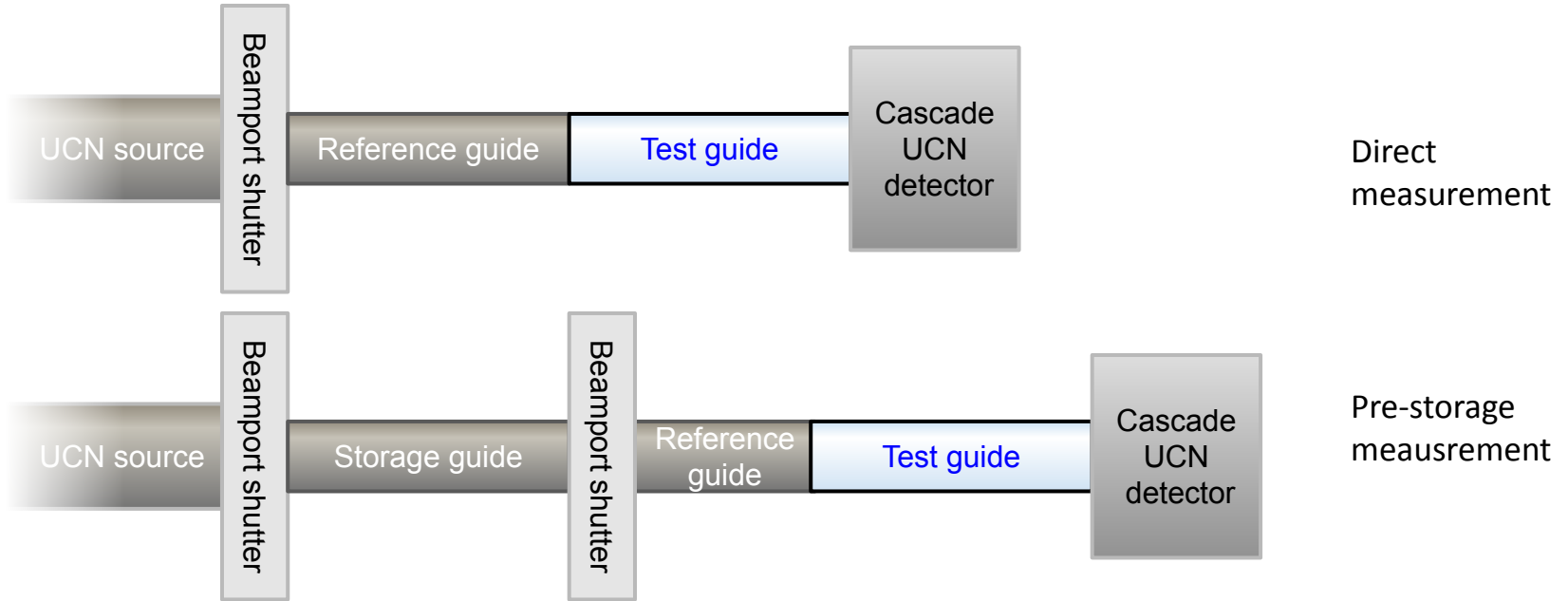


The precession chambers



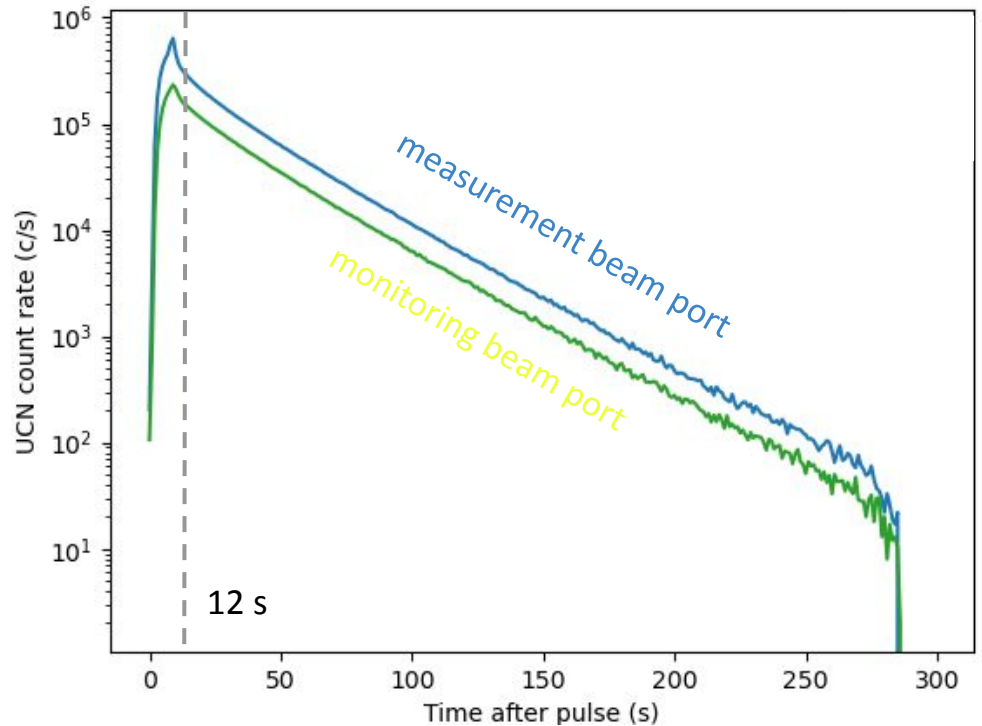


UCN transmission measurements



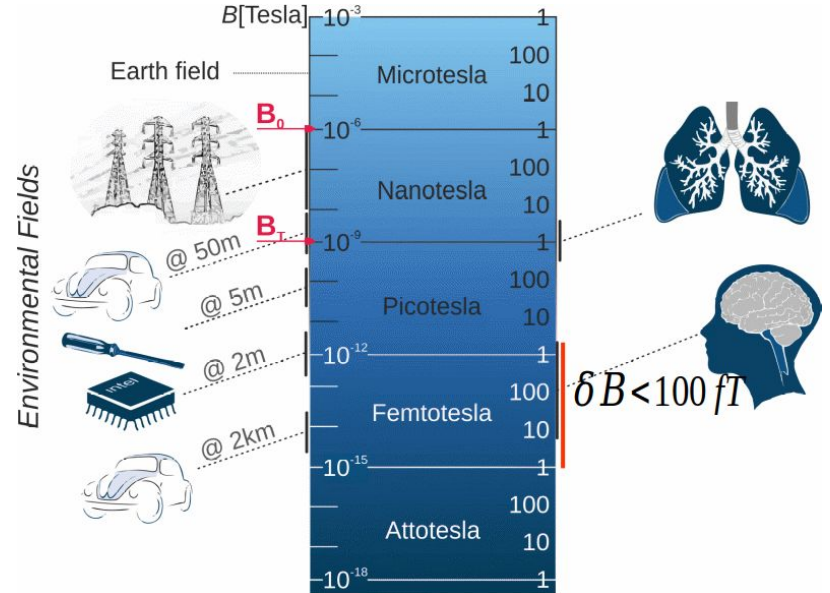
UCN transmission measurements

- Pulsed UCN source
 - 8 s proton beam on spallation target
 - UCN production
 - Fill storage volume
 - Drain into experiment
- Region of interest: 12-200s
 - not all neutrons before 12s are storable
- Normalisation using second beam port at same height



Requirements for UCN guides

- 90% transmission, normalised to 1 m
- Homogeneous magnetic field
 - Field stability (30 fT)
 - Accurate magnetometry (30 fT)
 - Limit on local magnetic impurities
 - 10 nA m²
 - 16 pT @ 5 cm



Related to statistical errors	
(B-gen) Top-Bottom resonance matching condition	$-0.6 \text{ pT/cm} < G_{1,0} < 0.6 \text{ pT/cm}$
(B-gen) Field uniformity in the chambers	$\sigma(B_z) < 170 \text{ pT}$
(B-gen) Field stability on minutes timescale	$< 30 \text{ fT}$
(B-meas) Precision Hg co-magnetometer, per cycle, per chamber	$< 30 \text{ fT}$

Related to systematical errors	
(B-gen) Gradient stability on the timescale of minutes	$\sigma(G)[5\text{min}] < 50 \text{ fT/cm}$
(B-meas) Accuracy mercury co-magnetometer per chamber	$< 100 \text{ fT}$
(B-meas) Accuracy on cubic mode (Cs magnetometers)	$\delta \dot{G}_3 < 20 \text{ fT/cm}$
(B-gen) Reproducibility of the order 5 mode	$\sigma(\dot{G}_5) < 20 \text{ fT/cm}$
(B-meas) Accuracy of the order 5 mode (field mapper)	$\delta \dot{G}_5 < 20 \text{ fT/cm}$
(B-gen) Dipoles close to the electrode	$< 20 \text{ pT at } 5 \text{ cm}$
(E-gen) Relative accuracy on E field magnitude	$< 10^{-3}$
