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n2EDM

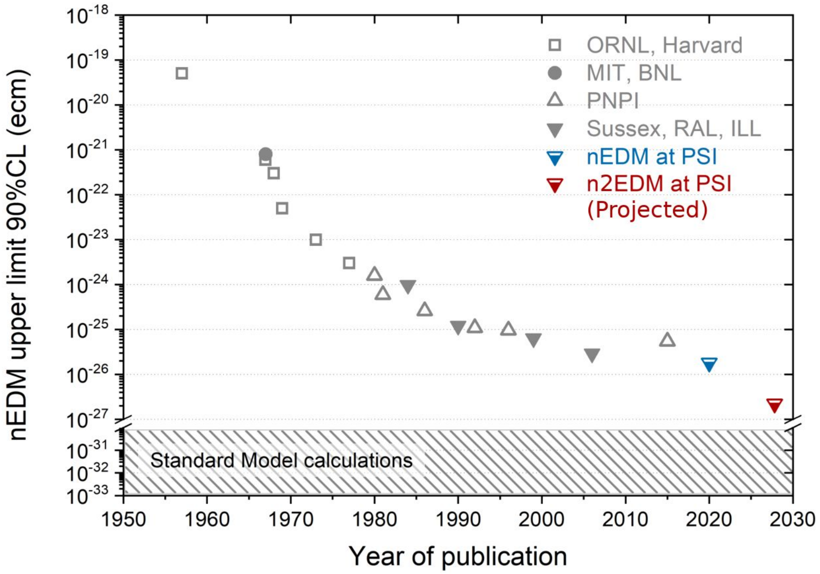
Cornelis B. Doorenbos :: on behalf of the nEDM collaboration :: Paul Scherrer Institute

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

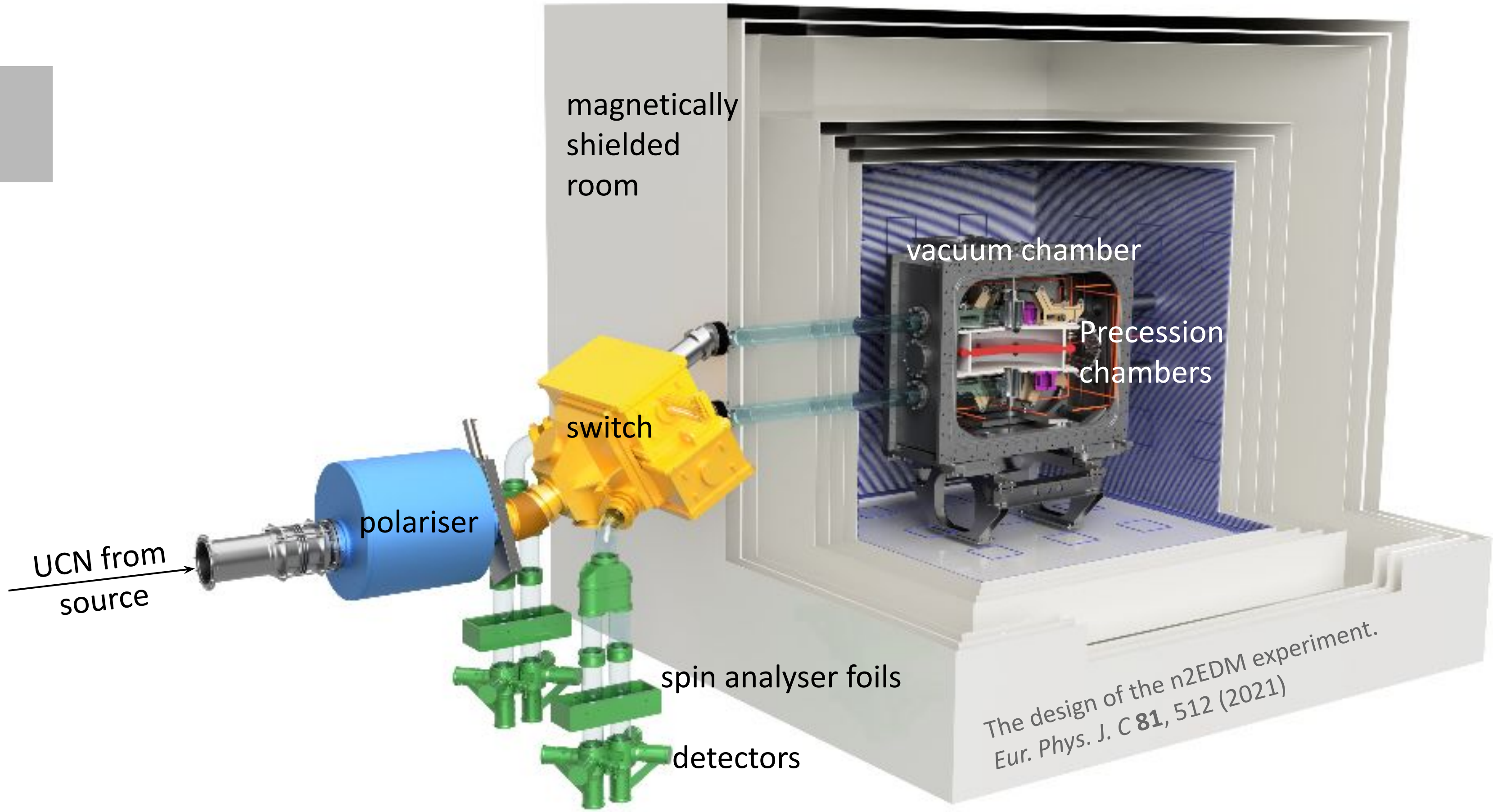
Neutron Delivery Systems 2023 :: ILL, Grenoble

Goal of the n2EDM experiment

- Electric dipole moments (EDMs) can help to understand matter-antimatter asymmetry of the Universe
- We search for the neutron EDM using stored ultracold neutrons (UCN). **Sensitivity: 10^{-27} e cm**
- Method: to measure precession frequency under (anti)parallel **E** and **B** fields $h\nu = 2\mu_n B \pm 2d_n E$
- Limited by:
  - UCN statistics
  - Systematics, magnetic field uniformity

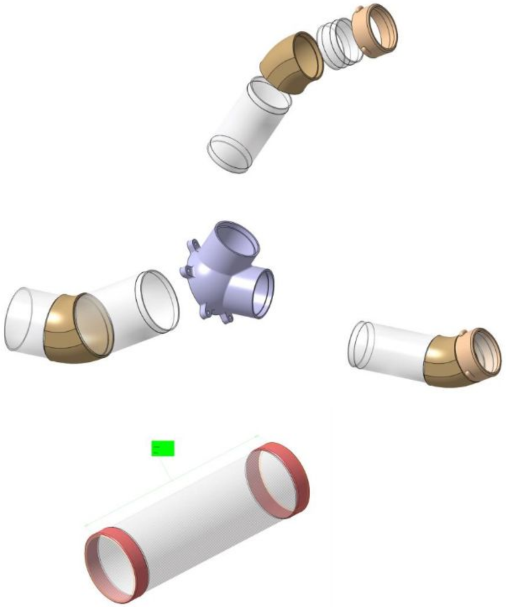


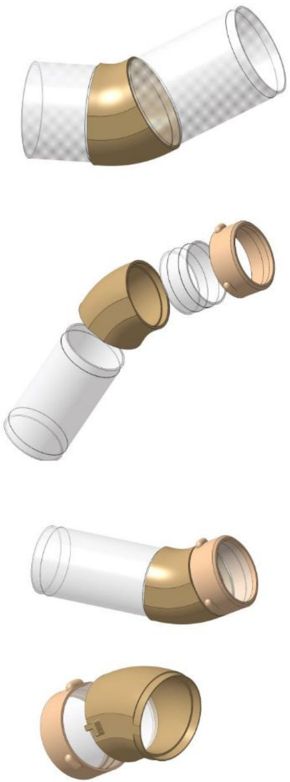
The n2EDM experiment

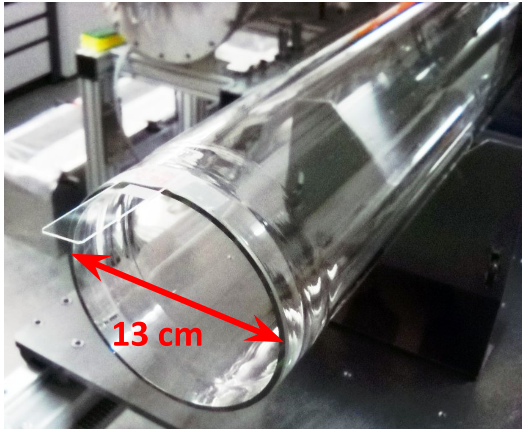


The guide system

Aluminium (complex shapes)
Borosilicate glass
NiMo coated
Lengths: 25 to 125 cm

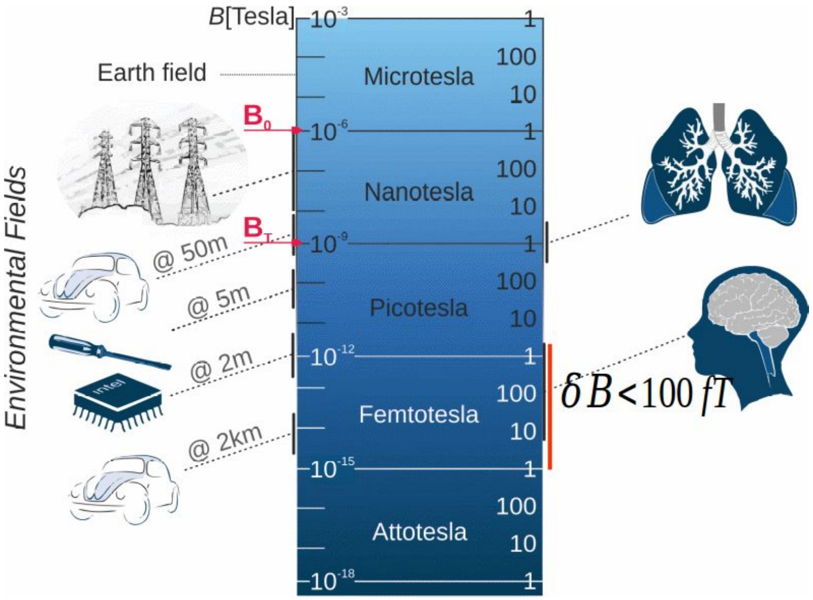






Requirements for UCN guides

- 90% transmission, normalised to 1 m
- Homogeneous magnetic field
  - Field stability (30 fT)
  - Accurate magnetometry (30 fT)
  - Limit on local magnetic impurities
    - 10 nA m^2
    - 16 pT @ 5 cm

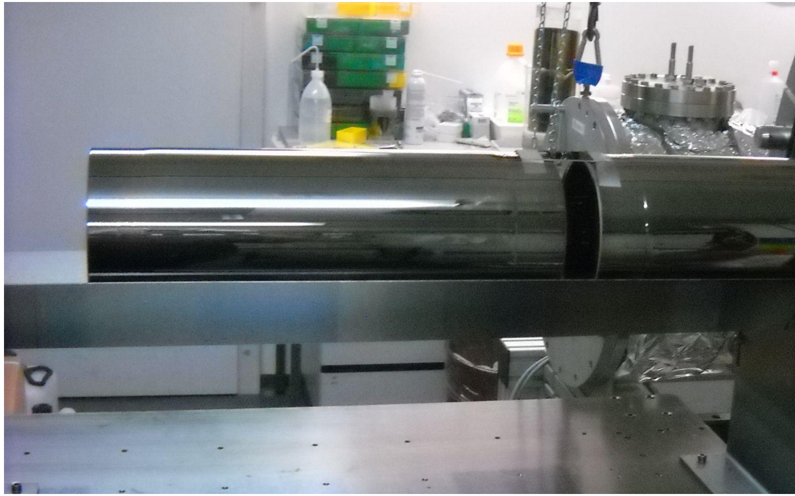


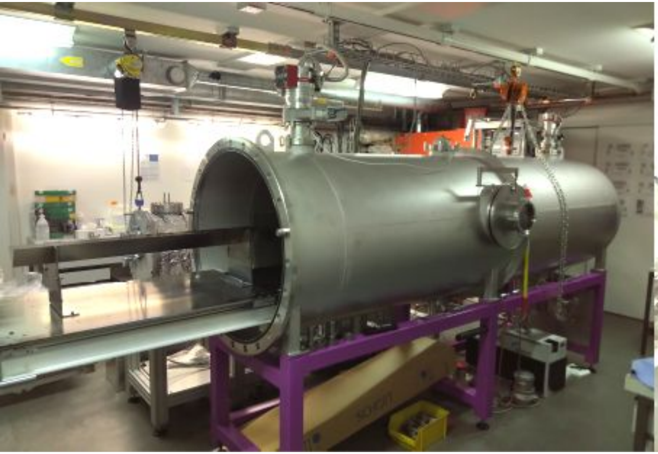
Coating

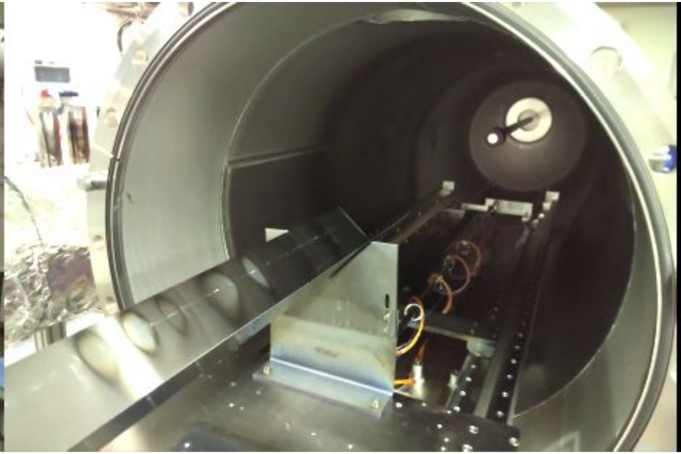
In house DC magnetron sputtering facility

High purity NiMo sputter targets

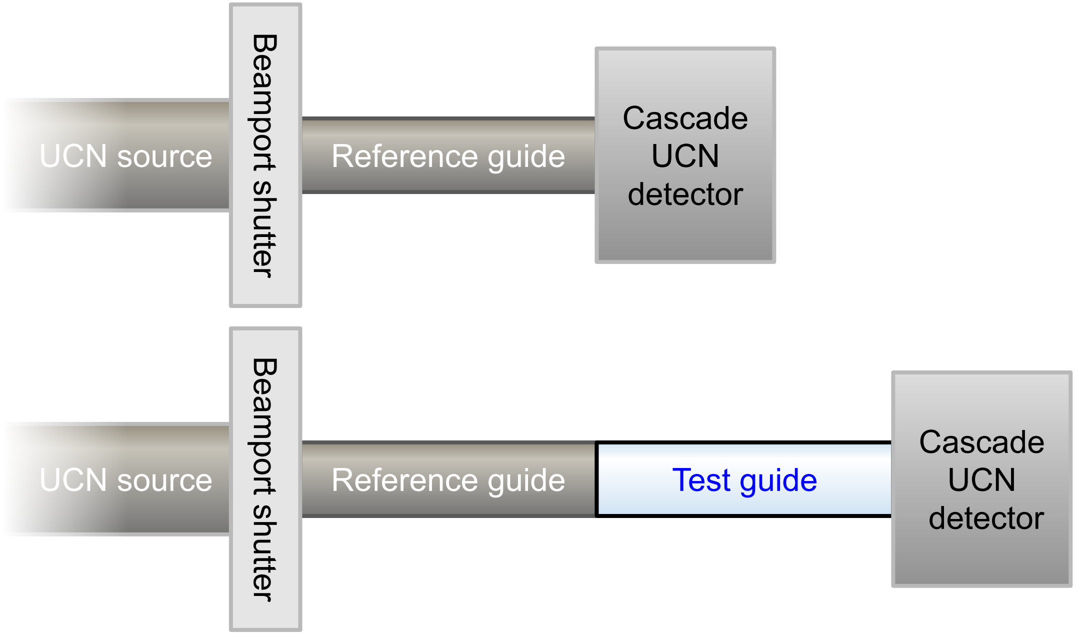
- 85:15 mass ratio
- V_F = 220 neV (CN reflectometry confirmed)
- Curie temperature << room temperature







UCN transmission measurements



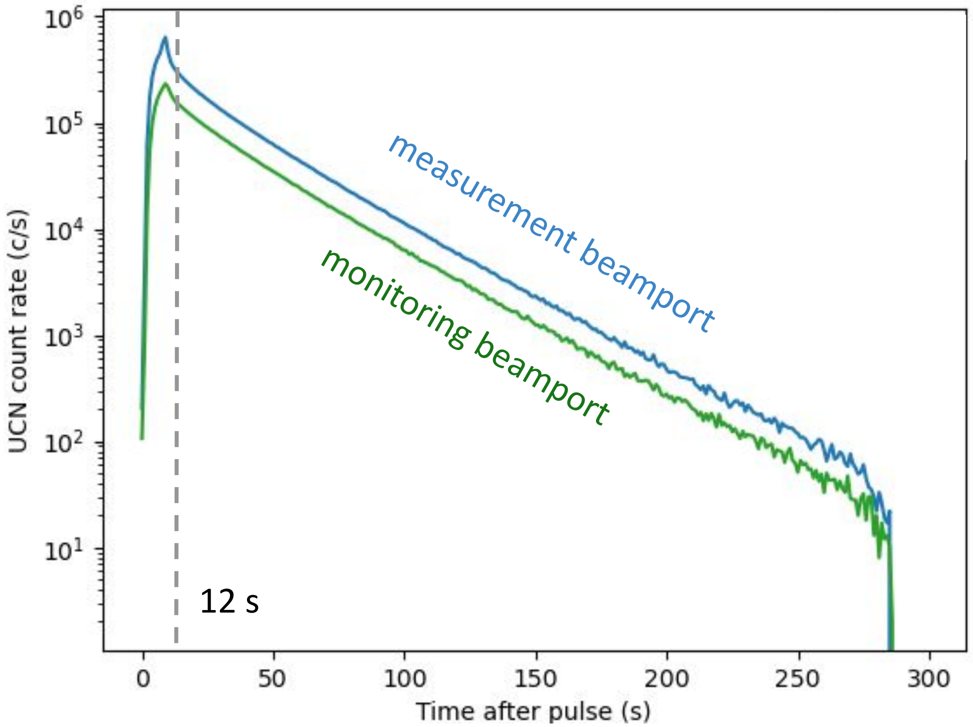
Reference setup

Test setup

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

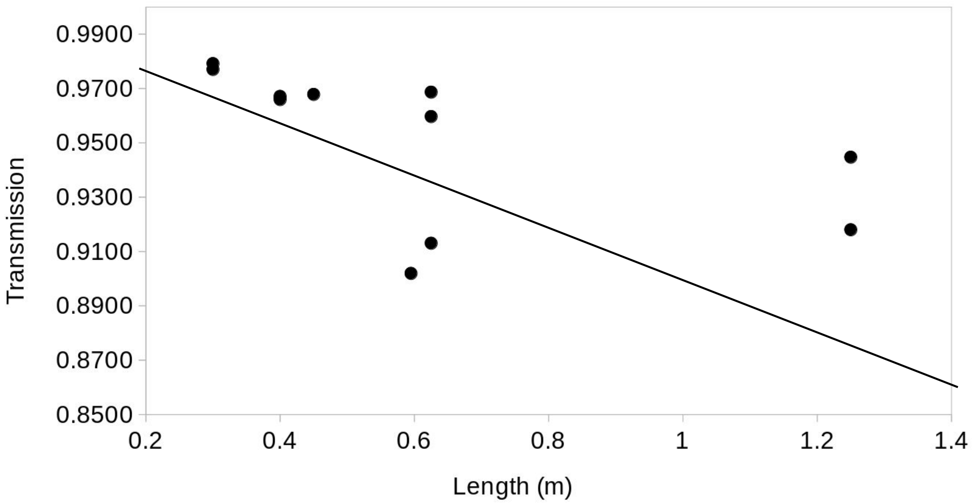
UCN transmission measurements

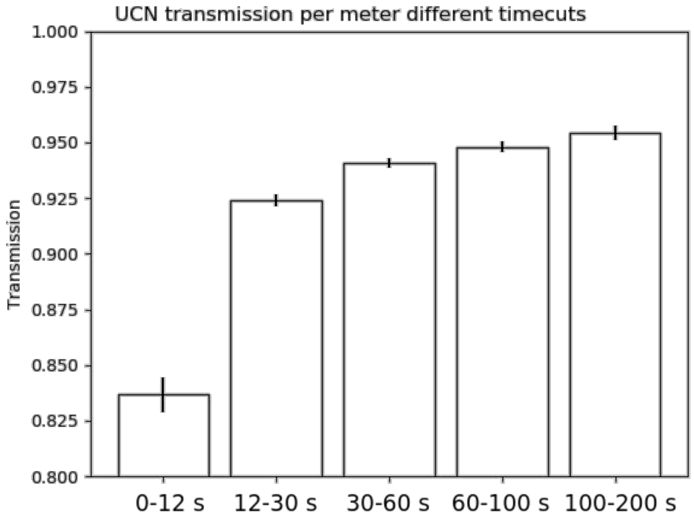
- Pulsed UCN source
  - 8 s proton beam on spallation target
  - UCN production
  - Fill storage volume
  - Drain into experiment
- Region of interest: 12-200s
  - not all neutrons before 12s are storable
- Normalisation using second beamport at same height



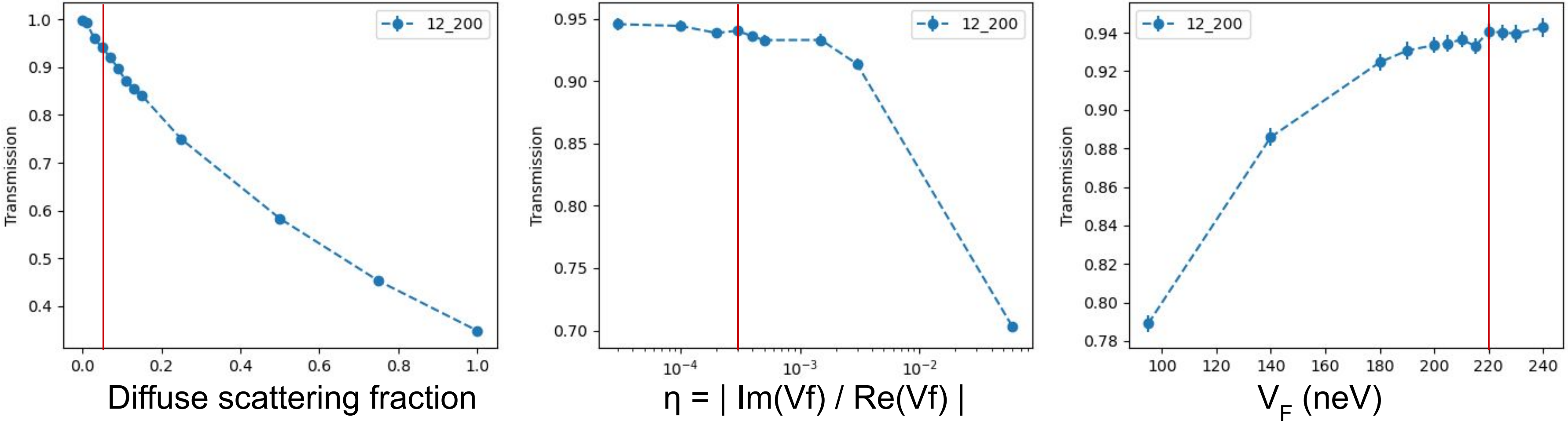
UCN transmission measurements, results

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





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

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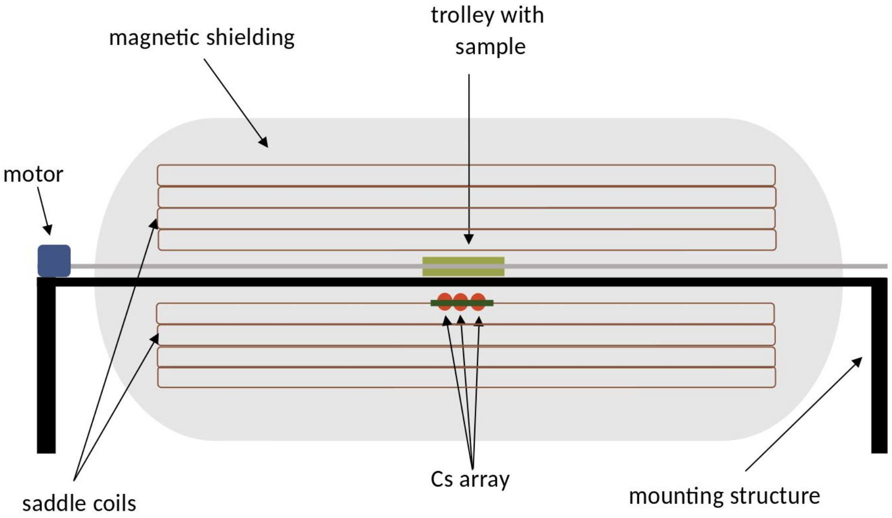
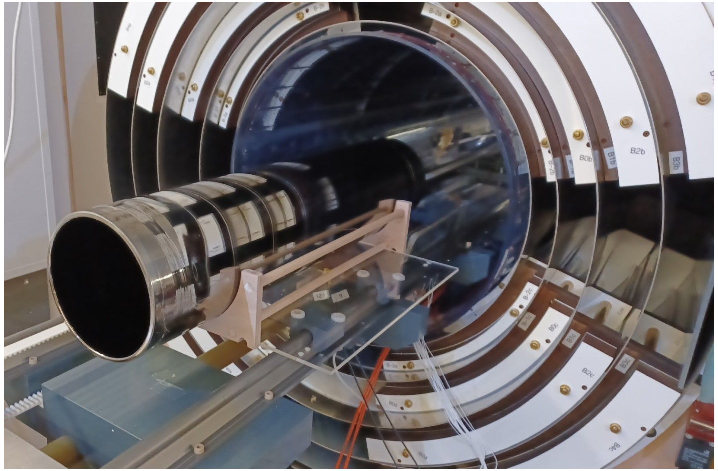
Checking for magnetic dipoles

- All components degaussed
- Can components be magnetised?
- We check for dipoles:
  - After degaussing (intrinsic dipoles)
  - After magnetisation with 30 mT magnet (areas that can be magnetised)

Checking for magnetic dipoles

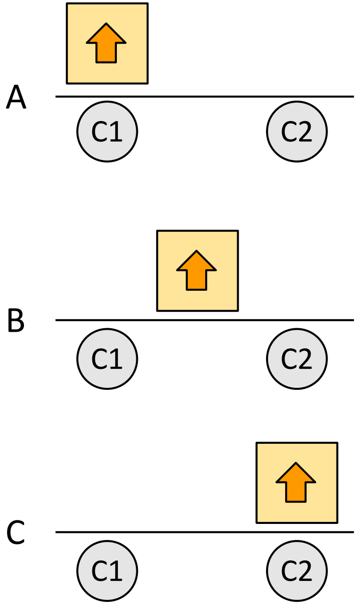


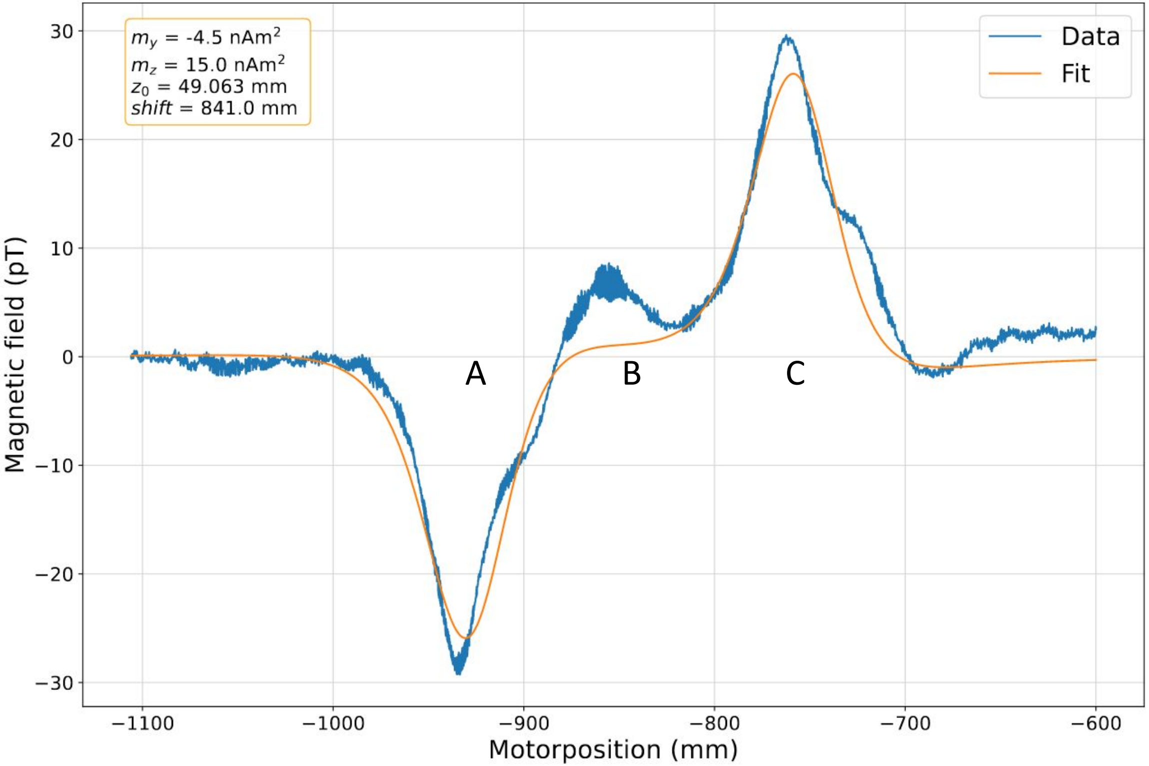


- Vertical B_0 field: 2.6 uT
- Sample driven past Caesium magnetometers
- Quantity of interest: ΔB between Cs magnetometers
- Sensitive to dipoles of 1 nA m^2 (1 pT level)

Example dipole signal

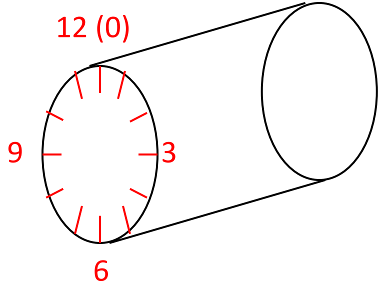
- PEEK (plastic)
- Signal: C2 - C1

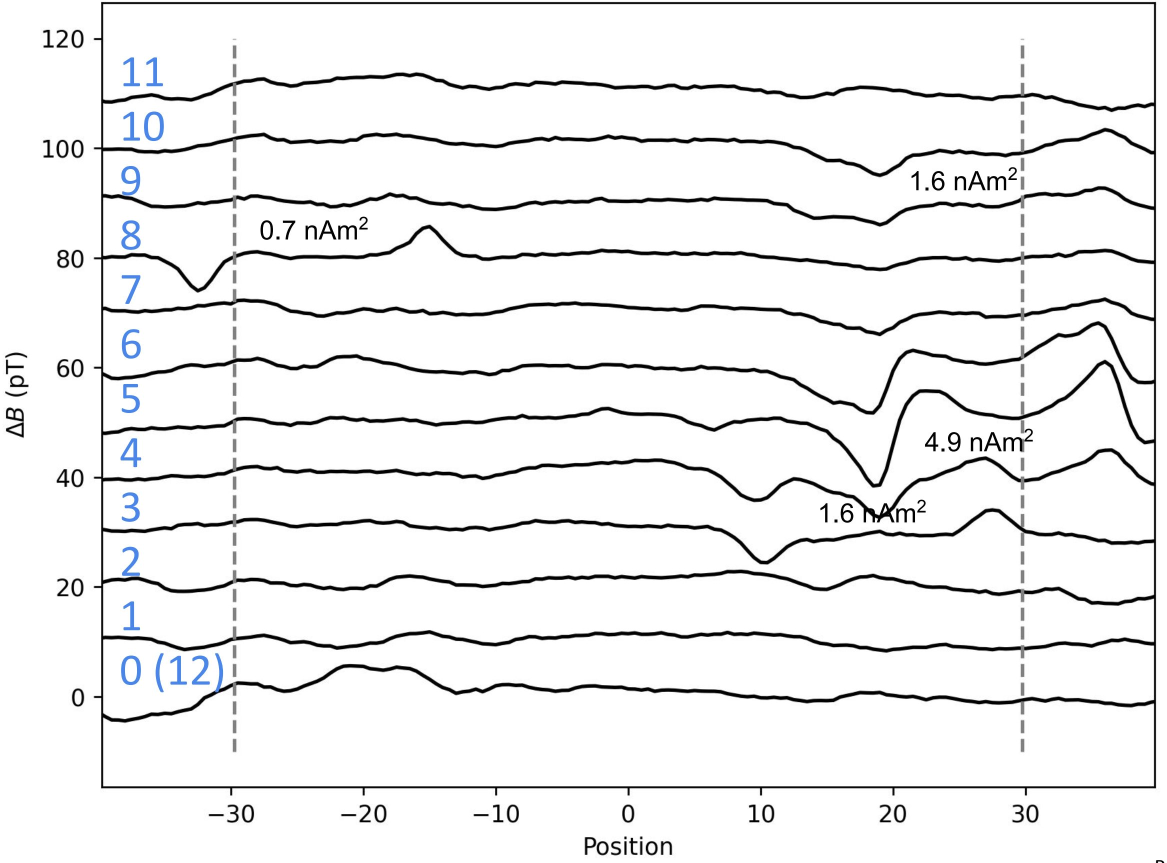




UCN guide dipole scan

Max allowed dipole strength:
10 nAm^2
16 pT





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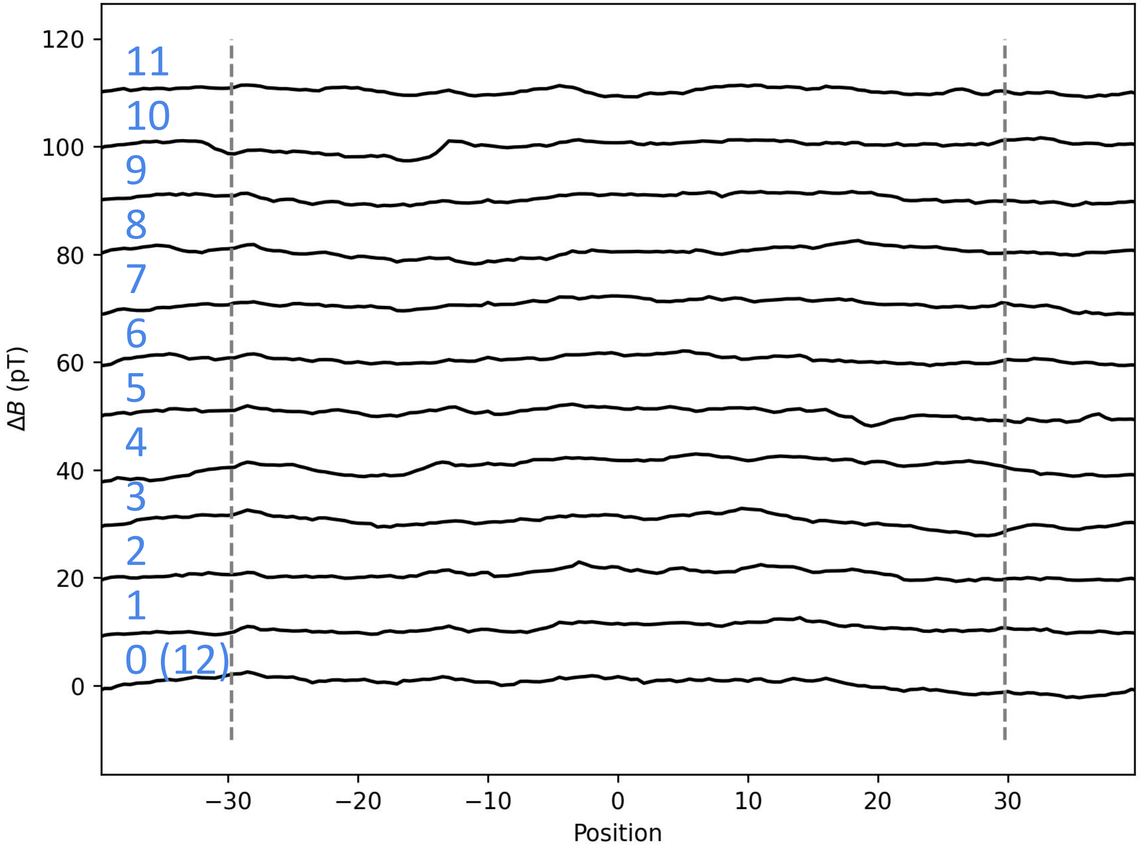
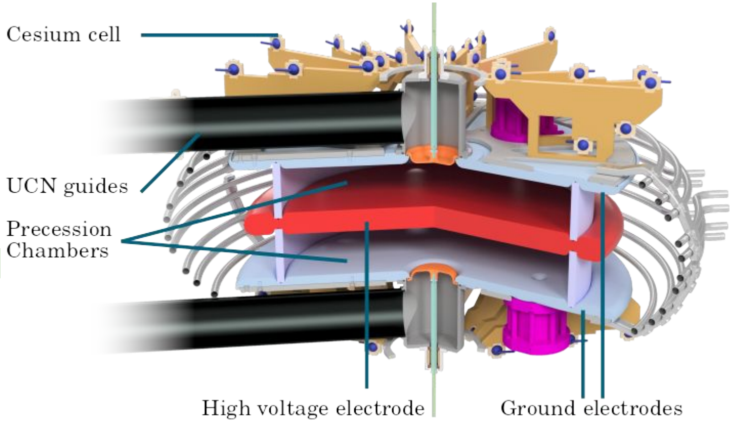
UCN guide dipole scan, degaussed



Characterisation of guides

- Guides closest to precession chamber
- #1
  - Magnetised: 9 nAm^2
  - Degaussed: Below detection threshold
  - Transmission: 0.902
- #2
  - Magnetised: 5 nAm^2
  - Degaussed: Below detection threshold
  - Transmission: 0.922



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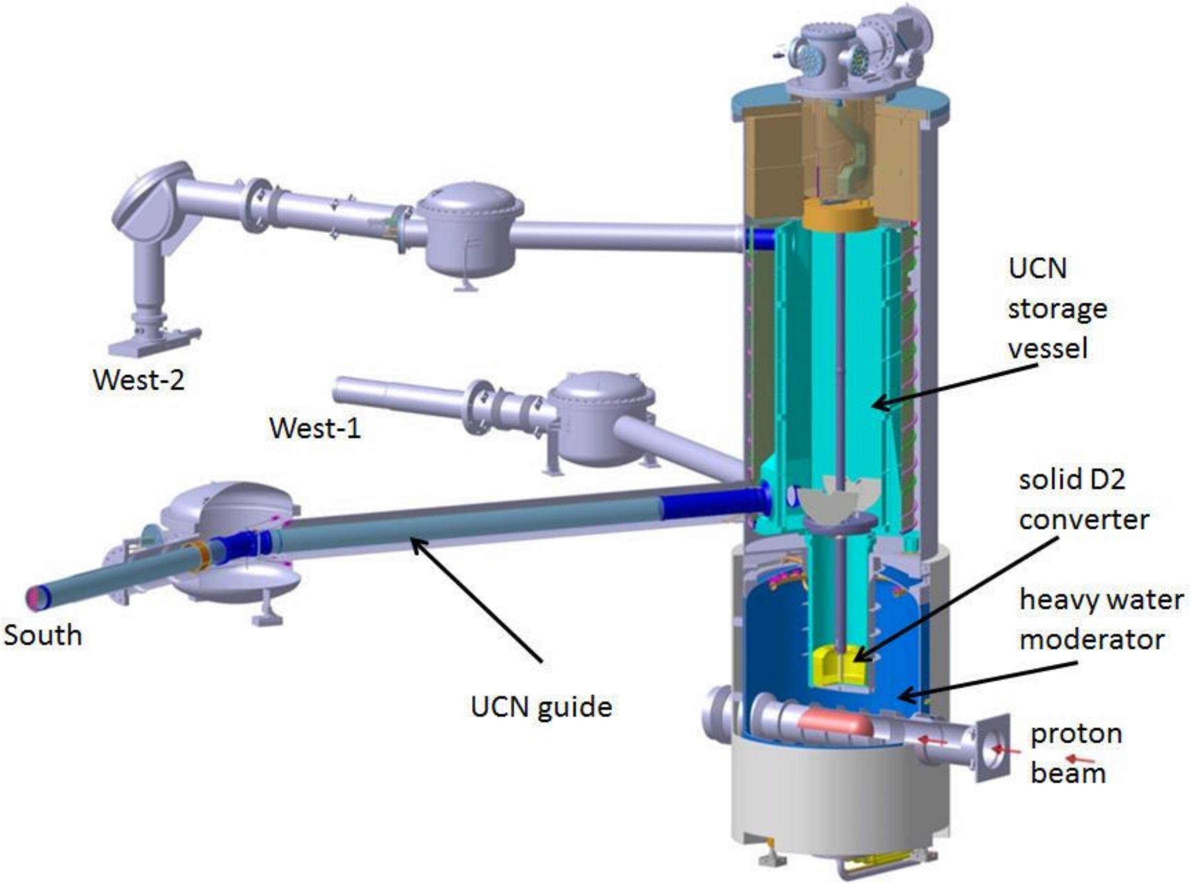
Summary

- Our goal: to search for nEDM with 10^{-27} e cm sensitivity
- Our requirements
  - Transmission per meter > 90 %
  - Dipoles < 10 nA m^2
- All the guides we have are sufficient to guarantee the design sensitivity of n2EDM

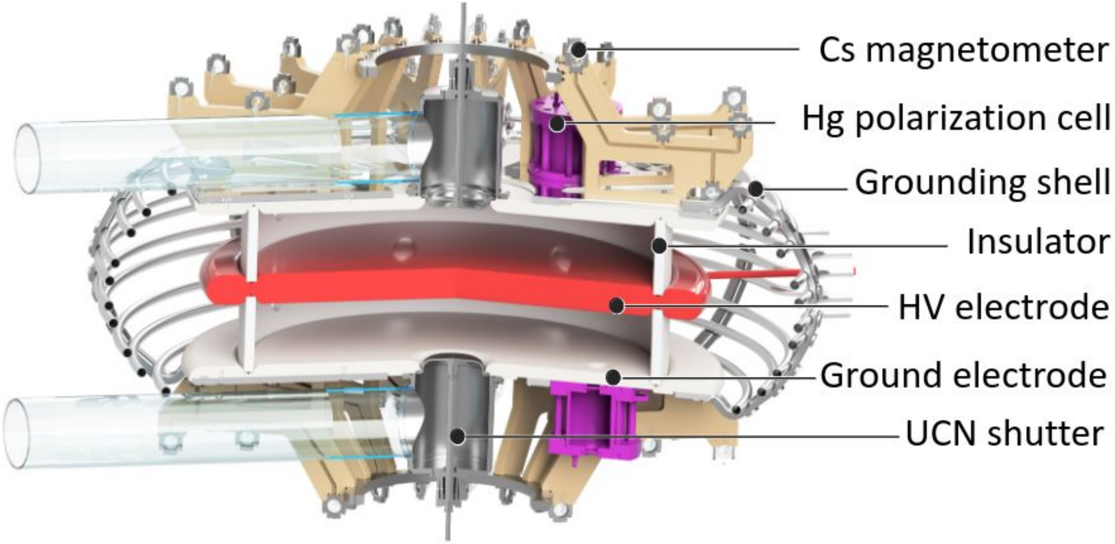
n2EDM

Swiss National Science Foundation

UCN Source


West-2
West-1
South
UCN guide
UCN storage vessel
solid D2 converter
heavy water moderator
proton beam

The precession chambers



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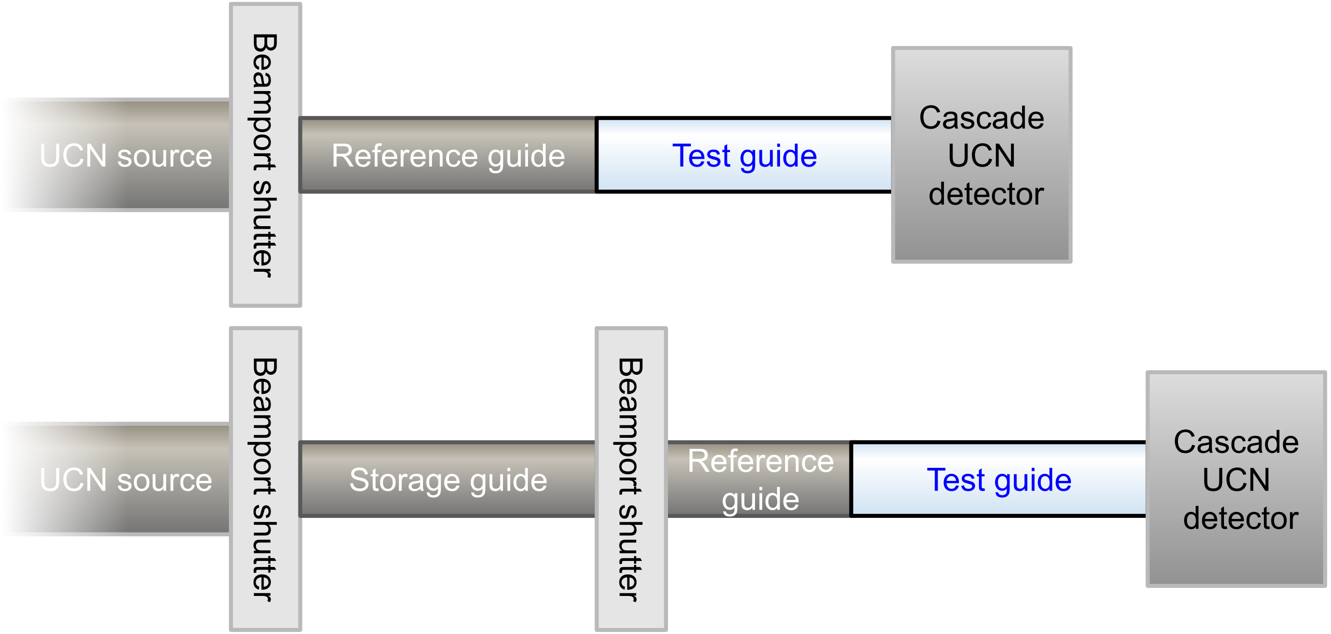
UCN transmission measurements



Direct measurement

Pre-storage meausrement

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	< 30 fT
(B-meas) Precision Hg co-magnetometer, per cycle, per chamber	< 30 fT
Related to systematical errors	
(B-gen) Gradient stability on the timescale of minutes	$\sigma(G)[5\mathrm{min}] < 50$ fT/cm
(B-meas) Accuracy mercury co-magnetometer per chamber	< 100 fT
(B-meas) Accuracy on cubic mode (Cs magnetometers)	$\delta \acute{G}_3 < 20\,\mathrm{fT/cm}$
(B-gen) Reproducibility of the order 5 mode	$\sigma(\acute{G}_5) < 20\,\mathrm{fT/cm}$
(B-meas) Accuracy of the order 5 mode (field mapper)	$\delta \acute{G}_5 < 20\,\mathrm{fT/cm}$
(B-gen) Dipoles close to the electrode	< 20 pT at 5 cm
(E-gen) Relative accuracy on E field magnitude	$< 10^{-3}$