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# EDM: Neutron electric dipole moment measurement

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**Abstract:** An **e**lectric **d**ipole **m**oment (EDM) of the neutron would be a clear sign of new physics beyond the standard model of particle physics. The search for this phenomenon is considered one of the most important experiments in fundamental physics and could provide key information on the excess of matter versus antimatter in the universe. With high measurement precision, this experiment aims to ultimately achieve a sensitivity of $10^{-28}$ ecm, a 100-fold improvement in the sensitivity compared to the state-of-the-art. The EDM instrument is operated by an international collaboration based at the Technische Universität München.

## 1 Introduction

The electric dipole moment of the neutron can be interpreted as a probe to investigate the evolution of the early Universe, less than $10^{-11}$ s after the big bang and complementary to experiments at CERN and also beyond the reach of accelerator experiments. In the Neutron Guide Hall East, a new instrument to search for the neutron EDM is currently being commissioned (Altarev, Chesnevskaya, et al., 2012).

The EDM experiment is based on a Ramsey resonance measurement applied to trapped ultra-cold neutrons (UCN) in the simultaneous presence of strong electrostatic fields. UCN will be provided by a superthermal source based on solid deuterium, placed in beam the tube SR-6. The UCN are guided from the source to the experiment in a circular neutron guide through a superconducting polarizer magnet with 3 T strength and a spin-flipper in the center. The guide leads the polarized UCN adiabatically into a magnetically stabilized environment, where two cylindrical traps with 50 cm diameter and 10 cm height are placed. A small magnetic field of $\sim 1\ \mu$T with a stability error of $10^{-9}$ over 300 s and a homogeneity of $10^{-4}$ is provided over the volume of the UCN storage chambers. The typical duration

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of the Ramsey experiment is 250 s. A deviation of the Larmor precession due to the electrostatic field would be an indication for an EDM. While the UCN source will provide the required neutron density of 1000 per $cm^3$ in the instrument, the stability and homogeneity of the applied fields is critical to understand systematic issues.

A dominating systematic issue to achieve this precision is the quality of the magnetic environment. Currently, it provides an extended volume $\sim 0.5$ $m^3$) of 100 pT or less absolute field and a temporal stability of $< 3$ fT in 300 s without any active measures. This is smaller than the average magnetic field in between stars in the milky way.

The shielding factor against external distortions of $6\times10^6$ at 1 mHz and $> 10^8$ at 1 Hz (Altarev et al., 2014; Altarev, Bales, et al., 2015; Altarev, Fierlinger, et al., 2015). Inside this volume, magnetic fields of up to few $\mu$T can be applied vertically and horizontally with a homogeneity of better than up to $10^{-4}$ relative precision (Altarev, Fierlinger, et al., 2012). During the commissioning phase, the volume is used for optical magnetometry and precision spin-clock measurements, as well as for the comparison of precision magnetometers. Systems for magnetic field monitoring are 186 fluxgate magnetometers, 32 scalar and vector Cs atomic vapor magnetometers, 2 $^{199}$Hg magnetometers, $^{129}$Xe and $^{3}$He magnetometers and 9 LTc SQUID sensors with liquid helium and dry operation. These systems operate simultaneously inside the environment with different bandwidths and spacial resolutions. Combined, the setup has below 1 fT resolution for variations in the magnetic field relevant for an EDM measurement. Spin-polarized noble gases are prepared using SEOP techniques directly at the facility. To apply electrostatic fields, a bipolar 200 kV source with active stabilisation on Pockels effect is implemented. For the simulation of neutron transport and spin tracking with extreme precision, also to resolve geometric phase effects, a dedicated package for GEANT4 (a particle-tracking toolkit from CERN) has been developed (Atchison et al., 2005).

The instrument is a joint activity of several institutions, currently including ILL, JCNS, MLZ, MSU, PTB, TUM, UC Berkely, UIUC, UMich (see Fierlinger & Paul (2013)).

Other optional measurements inside the instrument include:

- Ramsey-measurements with trapped ultra cold neutrons
- Probing the isotropy of the Universe and its invariance under Lorentz transformations via clock comparison measurements with polarised gases (Altarev, Baker, Ban, Bison, et al., 2009; Altarev et al., 2010, 2011)
- Measuring new forces at short distances: search for dark matter candidates (axions etc.)
- Measuring possible transitions from neutrons to mirror-neutrons (Altarev, Baker, Ban, Bodek, et al., 2009; Bodek et al., 2009)
- Precision magnetometry and magnetometer development
- Ultra low field NMR
- Magnetic material screening on pT level
- Biological studies, e.g. cell growth

## 2 Technical Data

The EDM facility consists of a magnetically shielded room, surrounded by 180 fluxgate magnetometers and 24 coils for external field compensation. The magnetically shielded room consists of an outer and an inner room, which can be used independently or slided into each other. Experiments with $2 \times 2 \times 2.8$ m dimension can be placed inside the shields in pre-assembled state through a door of $2 \times 2$ m. The furniture inside is non-magnetic and either 3D-printed or made from wood, external equipment can be degaussed on-site. Stable current sources with ppm stability over $> 1000$ s can provide DC magnetic fields with up to 5 μT.


Figure 1: Magnetic field compensation system of the EDM experiment in the Neutron Guide Hall East. The active external compensation can provide compensation of variable external magentic field sources from outside with 24 correction coils and 180 magnetic field probes by a factor of $\sim$5−10, in addition to the passive shielding of $6 \times 10^6$ at mHz (Copyright by FRM II, TUM).

### 2.1 External compensation

- Size 9 x 6 x 6 m
- Number of coils: 24
- Number of magnetometers: 180
- Field $<$ 5 μT (DC)
- Active feedback frequency: 10 Hz (max.)
- Mulitpolarity: dipoles at distance $>$ 10 m

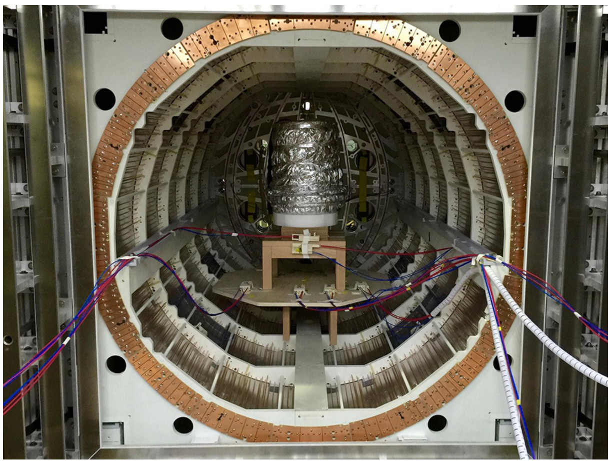

Figure 2: NMR field coil with field monitoring (Copyright by A. Eckert / Photographie).

### 2.2 Outer shield

- Inner dimension: h = 2.3 m, w = 2.5 m, l = 2.8 m
- Residual field: $<$ 0.5 nT in 1 $m^3$
- Damping factor: 279 at 0.01 Hz, $>$ 10000 at 10 Hz

### 2.3 Inner shield

- Inner dimension: h = 1.5 m, w = 1.5 m, l = 2.1 m
- Residual field: $< 0.1$ nT in 0.5 $m^3$
- Damping factor: 6.000.000 at 0.001 Hz, $> 10^8$ at 1 Hz

### 2.4 Available magnetometry

- Fully optical Cs magnetometers ($< 30$ fT in 40 s resolution)
- $^{199}$Hg magnetometers ($< 20$ fT in 100 s)
- SQUID magnetometers and gradiometers with 1 fT/$\sqrt{Hz}$ resolution
- SEOP polarisation of $^3$He and $^{129}$Xe at the experiment

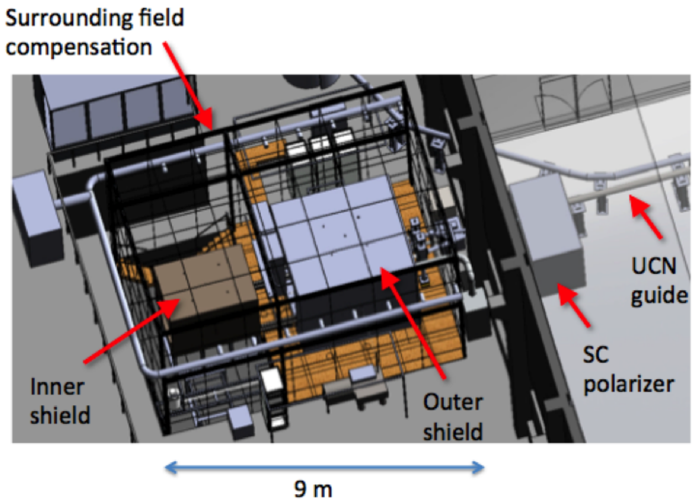


Figure 3: Schematic drawing of the installation. The UCN guide from the reactor is passing a superconducting (SC) polarizer to supply perfectly polarized UCN into the EDM measurement chambers, which are placed inside the outer shield. The inner shield contians the stable field coil and can be guided into the outer shield on rails, to provide the stable magnetic field and the pulses for the Ramsey experiment.

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