New Neutron Electric Diople Moment Search using a Beam

The search for the neutron electric dipole moment (nEDM) is considered to be one of the most important fundamental experiments for searches beyond standard model physics. The existence of the neutron electric dipole moment violates parity P and time-reversal T symmetries, if CPT theorem is valid then also CP symmetry. This new source of CP violation could explain the observed matter-antimatter asymmetry in the universe, which are explained through various beyond standard model theories.

The search for a finite neutron electric dipole moment remains a top priority. It has become a worldwide endeavour being conducted by various research teams, all of which are seeking measurements with improved sensitivity. These groups all intend to use or are planning to use ultracold neutrons (UCN). The advantage of using UCN is that they can be stored for long periods, giving much longer measurement/interaction times. However, prior to using UCN, searches for the neutron electric dipole moment were performed with cold neutron beams. This method proved limiting due to the relativistic vxE effect. This effect arises due to the neutron moving through an electric field sensing an effective magnetic field which produces as a false neutron electric dipole moment signal.

The following is a proposed new concept that would overcome this limitation enabling beam measurements to compete with the sensitivity goals of the UCN experiments. In order to achieve this, the vxE effect is directly measured with a high intensity pulsed cold neutron beam [Piegsa, Phys. Rev. C 88 (2013) 045502]. A beam with the required intensity for such a measurement will soon come online at the European Spallation Source (ESS), currently under construction in Sweden. Pulsed sources offer the advantage of gathering neutron energy dependent information at full beam intensity. In this case using a spectroscopic method known as Ramsey oscillatory fields allows separation of velocity dependent and independent effects acting on the neutron spin precession frequency. Thus, the issue of the vxE effect is overcome and the additional spin contribution from a non-zero neutron electric dipole moment can be distinguished. Hence, this technique describes a unique and complementary approach, with different systematics than standard UCN experiments.

The full-scale experiment at the ESS is planned to consist of a 50 m long producing high sensitivity to the neutron electric dipole moment. This experiment has several challenging aspects: magnetic field stability, vacuum, high voltage, neutronics etc. In order to work towards this final experiment, a smaller version of approximately 5 m will be demonstrated to check feasibility and accuracy while also investigating potential systematic effects. Presently this experiment receives funding by the Swiss National Science Foundation and starting by April 2017 also by the European Research Council.

Currently a number of beam times have been carried out at the Swiss Spallation Neutron Source (SINQ) at the Paul Scherrer Institute (PSI) in September 2017 and October 2018 as well as at ILL PF1b in March 2018 [**ILL user report**]. This has lead to development and optimisation of the apparatus. The most recent beam time at PSI, enabled us to perform our first measurement of the neutron electric dipole moment. The apparatus is shown in Figure 1. However, these measurements where performed over a period of only 12 hours with low statistics. The SINQ beamline also suffers for low polarization especially at long neutron wavelengths. In order to test the full potential of this experiment, a further beam time at ILL on the PF1b beamline would enable high-statistics and high-accuracy measurements. ILL represents the ideal facility for our experiment, providing a high intensity polarized cold neutrons beam with large cross section and all necessary infrastructure. The previous beam neutron electric dipole moment measurements achieved a sensitivity of $3 \times 10^{-24}\ ecm$ (90% CL) [Dress et al., Phys. Rev. D 15 (1977) 9]. We would be able to achieve a more accurate measurement and exceed this sensitivity during the upcoming full reactor cycle. The sensitivity equation for the neutron electric dipole moment is given as: $d_{\sigma_n} = \frac{2\hbar}{\eta\tau E\sqrt{N}}$, where η is the visibility of the Ramsey fringe, E is the electric field, N is neutron count, and τ represents the interaction time interval. We plan to operate at $E = 100\ kV/cm, \eta\ = \ 0.75, \dot{N} = 1MHz, \tau\ =\ 10\ ms$ at PF1b, giving us a sensitivity of $9.88\ \times\ 10^{-24}\ ecm\ (90\%\ CL)$ per day, continuous measurement. We propose to perform 3 weeks of neutron electric dipole moment data taking, thereby exceeding the previous sensitivity limit for a neutron beam experiment.

An additional week of measurements dedicated to the searches for an axion-like particle can also be performed. The existence of an axion field would be detectable as an oscillating neutron electric dipole moment, [Abel et al., Phys. Rev. X 7 (2017) 4]. The advantage compared to previous measurement is that the high frequency data collection allows us to probe phase space not yet experimentally measured. The axion measurement does not use the chopper, but instead only the wavelength selector to maximise our sensitivity region by switch through various velocities.

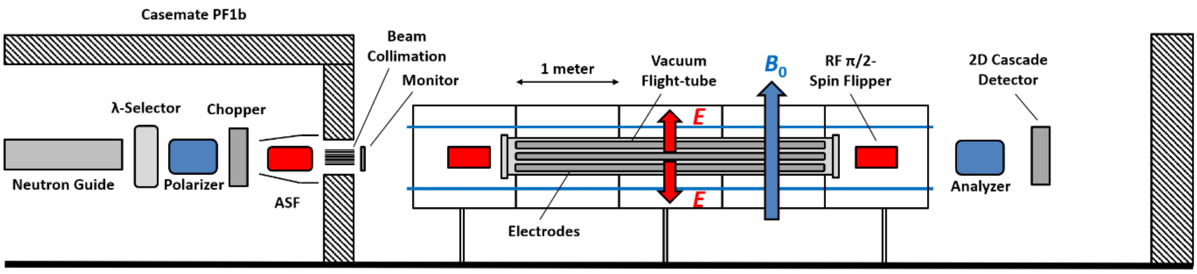


*Figure 1: Experimental setup of the proposed Ramsey beam apparatus installed at PF1b. The Ramsey apparatus will be mounted in an aluminium frame with an edge length of 1 m. Electrodes are installed in the vacuum pipe, with the central electrode set to 100 kV.*

The previous measurements at ILL informed us on beam characteristics, neutron detector behaviour, and magnetic field stability. The major upgrade we require for the next beam time is the introduction of a passive magnetic shielding. External time dependent magnetic field gradients where present of order 10 $\mu T$. The shielding is required otherwise large changes in the magnetic field could induce a false neutron electric dipole moment, limiting our sensitivity.

| Task | Weeks dedicated |
|---|---|
| Setup of experiment in beamline | 1 |
| Characterisation/systematic checks | 1 |
| EDM measurement | 3 |
| Radiation/safety checks | 1 |
| Axion measurement | 1 |

*Table 1: Proposed schedule for PFb1.*

Hence, for the upcoming reactor cycle in January/February 2020 we would request a full cycle. This would give us required measurement time to achieving a new sensitivity limit. The axion measurement only require a week of data taking which would allow us to measure axion phase space not currently explored. If possible we would also request a week before the start of the reactor cycle to setup the experiment in the beam line to give more measurement time, if not possible then an additional week to setup the experiment would be required. As previous mentioned the axion measurement does not use a chopper, therefore, we would require access to the casemate to remove it. This access and radiation measurements that are required to take place would mean an additional week to our schedule.