Experimental report

18/10/2018

Proposal: **3-07-374** **Council:** 4/2017

Title: New Neutron Electric Dipole MomentSearch using a Beam

Research area: Nuclear and Particle Physics

This proposal is a new proposal

Main proposer: **Florian PIEGSA**

Experimental team: Florian PIEGSA
Estelle CHANEL
Marc SOLAR

Local contacts: Torsten SOLDNER
Valery NESVIZHEVSKY

Samples:

Instrument	Requested days	Allocated days	From	To
PF1B	21	21	08/03/2018	29/03/2018

Abstract:

We are proposing a new neutron electric dipole moment search using a (pulsed) beam, which has been recently described [Piegsa, Phys. Rev. C 88 (2013) 045502]. The final full-scale experiment is intended for the ESS, however, an important proof-of-principle investigation will need to be performed at a high-intensity neutron instrument like PF1b at ILL. Hence, for the investigation of important systematic effects, feasibility studies, component testing, and subsequent production runs, we plan to apply for a considerable amount of beam time in the coming years.
For this year we would like to apply for 3 weeks of beam time, to gather experience with the neutron beam and our prototype setup currently under development in our laboratories at the University of Bern (Switzerland). The important milestone of this measurement campaign will consist of determining/evaluating the (future) statistical sensitivity of the concept.

Experimental Report: New Neutron Electric Dipole Moment Search using a Beam (3-07-374)

E. Chanel[1], M. Solar[1], T. Soldner[2], F.M. Piegsa[1,*]

1. Laboratory for High Energy Physics and Albert Einstein Center for Fundamental Physics, University of Bern, Switzerland
2. Institute Laue-Langevin, Grenoble, France
* florian.piegsa@lhep.unibe.ch

Time period: 08/03/2018 - 29/03/2018

The measurement of the neutron electric dipole moment (EDM) is considered to be one of the most important fundamental physics experiments at low energy and presents a very promising route for finding new physics beyond the standard model of particle physics, i.e. new sources of CP-violation which could explain the observed matter-antimatter asymmetry in the universe. Recently, a novel concept has been proposed to measure the neutron EDM with a cold pulsed neutron beam instead of the established use of stored ultracold neutrons (Piegsa, Phys. Rev. C **88** (2013) 045502). The technique relies on the fact that one can distinguish between the effect due to a neutron EDM and the main systematic false effect (relativistic v×E effect) by performing a time-of-flight Ramsey measurement. The related phase shift of the Ramsey pattern is given by:

$$\Delta\varphi = \frac{8d_nE}{\hbar}T + \frac{4\gamma_nEL}{c^2}\sin\alpha$$

Here, d_n is the neutron EDM, E is the strength of the applied electric field, L is the length of the experiment, and T is the neutron time-of-flight. The innovative method can ultimately lead to a highly competitive result with different susceptibilities on possible systematic effects. The present manuscript reports on our first beam time with a prototype setup. The corresponding experiments are part of a planned long-term research activity of the Bern University group at PF1b at the ILL (compare letter-of-intent submitted by F. Piegsa and discussed by the College 3 Subcommittee on 21/04/2015). PF1b represents the ideal facility for these studies, since it provides a high-intensity polarized cold neutron beam with a large beam cross section and all necessary infrastructure. The findings of these investigations are essential for a later design of the full-scale experiment, intended for the upcoming European Spallation Source in Sweden. Additionally, the results of this beam time were presented in a talk at the “Particle Physics at Neutron Sources” conference at ILL in May 2018. Presently, the group at Bern receives funding for this project via an ERC Starting Grant by the European Research Council and via the Swiss National Science Foundation.

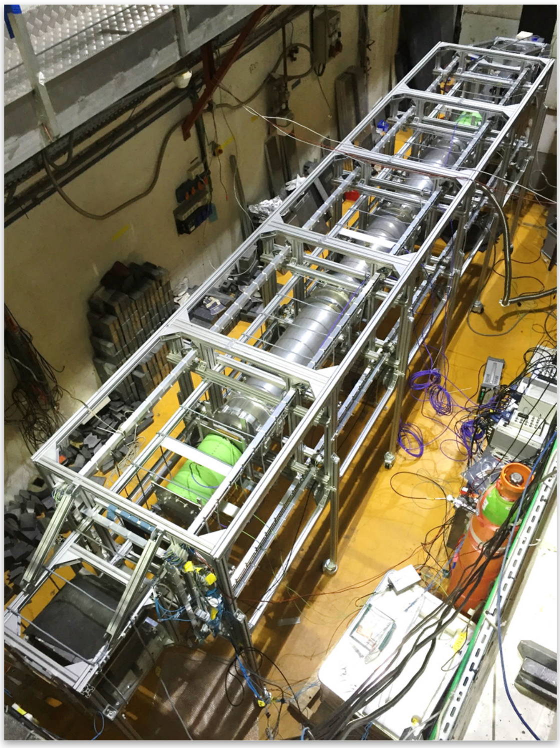

Fig.1 Installation of the Beam EDM prototype experiment at the PF1b beam line at ILL. The length of the setup is approximately seven meters. The neutron beam exits the wall at the experimental site in the lower left corner of the image. The high-rate neutron detector is located at the upper right corner of the image. The green coils are the neutron resonance spin flippers. They are separated by 4 m. Between the coils the 3.5 m long aluminum vacuum pipe is installed.

The main aim of the three-weeks-long beam time at PF1b (proposal no. 3-07-374) was to perform characterization measurements of the cold neutron precision Ramsey spectrometer presented in Fig. 1. The apparatus has been fully developed in the

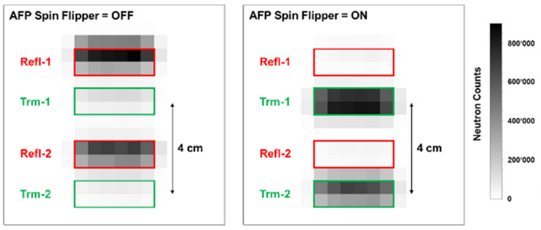

Fig. 2 Detector counts in 10 seconds at a wavelength of 0.48 nm for the two adiabatic spin flip device states (off and on). The detector has an active area of 100×100 mm² divided into 16×16 pixels. The two beams cause four beam spots behind the spin analyzer – reflected (red box) and transmitted (green box) beam of the upper and lower beam, respectively. The employed detector was purchased by the company CDT.

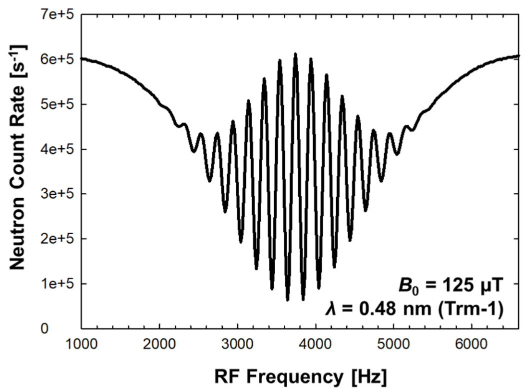

Fig. 3 "Classic Ramsey" signal of one of the four detector beam spots (upper beam, transmission) at a wavelength selector setting of 0.48 nm. The presented result is obtained by scanning the frequency of the spin flippers close to the neutron Larmor resonance frequency. The entire curve was measured within approximately one hour (10 sec per point).

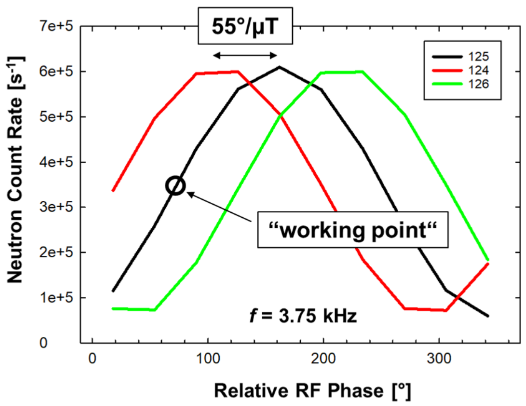

Fig. 4 Ramsey phase-scan at 3.75 kHz for three different static magnetic field setting of 124, 125, and 126 μT. The phase shift of the sinusoidal pattern is about 55°/ μT.

laboratories at the University of Bern. It consists of a non-magnetic structure made from aluminum profiles which supports all neutron beam elements (collimator, apertures, spin flippers, vacuum beam pipe, spin analyzer, and neutron detector) as well as all magnetic field coils. During this beam time, it was not planned for the high-voltage electrodes to be installed. Even without an electric field, a multitude of investigations of the performance of Ramsey apparatus could already be conducted.

To perform systematic studies an adiabatic spin flip device and a neutron velocity selector were installed in the casemate of PF1b. Further, the beam was split in two parallel well-collimated sub-beams using apertures (upper and lower beam) each with a size of 1 (height) × 4 (width) cm², with a center-to-center distance of 4 cm. In front of the position sensitive detector capable of high-rates, the two sub-beams were spin analyzed by means of two sets of spin polarizer blades (silicon wafers coated with m=5 FeSi multi-layers, one spin state gets reflected the other transmitted). This results in four well-separated beam spots on the detector – a reflected and a transmitted spot for each sub-beam. An image of a typical detector intensity pattern is presented in Fig. 2. This four beam pattern allows for normalization of the beam intensity to compensate for slight fluctuations of the neutron output of the reactor. The two sub-beams will in later experiments pass between three electrodes – two ground electrodes and a central high-voltage electrode. Hence, the upper and lower beam will experience opposite electric fields and thus can be used to compensate for common-mode noise and drifts. This is equivalent to a UCN neutron EDM experimental setup with two precession chambers.

The static magnetic field in our setup is oriented vertically and we typically work at a field of about 125 μT. The field is actively stabilized to the nT-level using an array of fluxgates. In Fig. 3 a typical Ramsey pattern obtained by scanning the frequency of our resonance spin flippers is presented. Alternatively, the frequency of the resonance spin flippers is kept constant and only their relative phase is scanned. This so-called phase-scan has the advantage that one performs all measurements at the resonance frequency, compare Fig. 4. Instead of performing an entire phase-scan, we also conducted fast repetitive measurements at a single working point (point of steepest slope of the curve). This allows to determine the overall stability and therefore sensitivity of the Ramsey apparatus for a broad range of time scales. This is presented in an Allan-Standard-Deviation (ASD) plot in Fig. 4. This

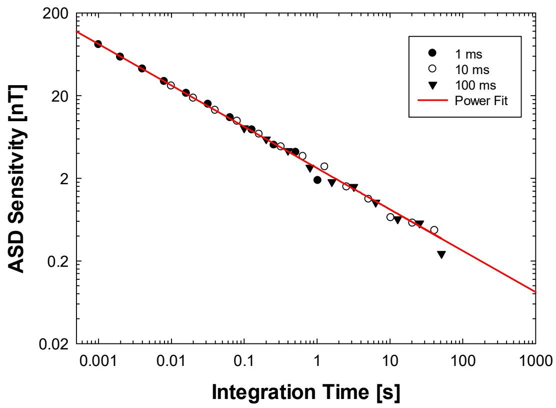

Fig. 4 ASD plot of the stability/sensitivity of our Ramsey apparatus as a function of the measurement/integration time. The red line indicates the improvement in sensitivity due to Poisson statistics.

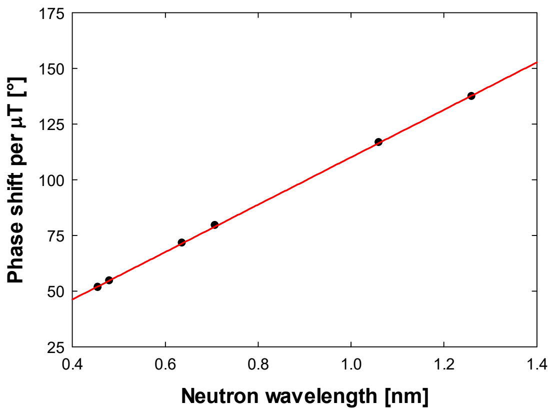

Fig. 5 Phase shift per one microtesla as a function of the neutron wavelength (of the upper beam).

yields a sensitivity of the apparatus of about 2 nT (0.2 nT) at a measurement time of 1 s (100 s). As expected for Poisson statistics the sensitivity improves with the square root of the measurement time. However, the plot ends at about 100 s since on this time scale we started to experience magnetic field gradient drifts on the order of a few nT. These field changes probably have their origin in magnetic fields produced by neighboring instruments/cryostats and could not be entirely compensated by our setup. Hence, in the next beam time we plan to add an additional passive magnetic field shield, i.e. a layer of mu-metal.

In another measurement we have determined the phase shift of the Ramsey signal due to a one microtesla change of the main magnetic field. Fig. 5 presents the obtained data as a function of the neutron wavelength. This plot summarizes the gist of our concept, namely measuring a (pseudo)magnetic field effect as a function of the neutron energy. In this case it is a real field change, later it will be a pseudomagnetic field due to the neutron EDM. The slope of the linear fit of 106° per nm-wavelength is very close to the expected value.

In conclusion, the beam time was very successful and delivered several important results. Firstly, we can well separate the two sub-beams on our detector, which is capable of standing the high neutron rates at PF1b. Secondly, the detected count rate statistic is enough to perform all measurements of the future R&D and physics program. Thirdly, the Ramsey patterns (classic and phase-scan) look as expected. And finally, our Ramsey apparatus allows for high-precision magnetic field measurements down to the sub-nanotesla regime within only a few seconds of measuring time. This gave us valuable insights on how to further upgrade and develop our setup.

In the next beam time, we plan to employ and characterize the high-voltage electrodes (currently in production) and the aforementioned passive magnetic shield (currently under design). Eventually, this will allow us to take first real neutron EDM data with our apparatus.