Experimental report

15/02/2021

Proposal: **3-14-403** **Council:** 4/2019

Title: Search for neutron-mirror neutron oscillations in low magnetic field with a beam experiment

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples:

Instrument	Requested days	Allocated days	From	To
PF2 EDM	48	48	11/08/2020	28/09/2020

Abstract:

We propose to search for neutron-mirror neutron oscillations with a beam experiment, covering a wide range of magnetic field (from 50 to 1100 micro Tesla). In this range, only weak, indirect constraints exist and oscillations as short as (0.005-0.15) s are not excluded yet. We propose to probe oscillations with oscillation time up to 8 s at 3 sigma confidence level. For this experiment, we will reuse an existing ensemble of a 5-meter long solenoid and a mumetal shield. This ensemble is characterised.

Search for neutron-mirror neutron oscillations in low magnetic field with a beam experiment

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1. Timeline of the experiment

We could access PF2 most of the summer to install the coil, the extension of the platform and the beamguide system, see figure 1. During this period we could benefit from a large technical support that we would like to acknowledge. An on-site magnetic field map was done in mid-July and the simulation of the experiment was updated with the actual shape of the magnetic field before the experiment started. We could also fine tune the setting of the compensation coil to homogenize the main magnetic field. The detector and the associated gas filling system was installed just before the beginning of the cycle.

Figure 1. Pictures of the setup at the nEDM beamline. Left: Picture of the beamguide entering the main coil. The geometry on this side was constrained by the available space on the platform. Right: the beamguide exiting the main coil and the detector standing on a custom-made extension of the PF2 platform.

The first ten days were dedicated to detector tests. First of all, the optimal gas admixture (CF4 and He3 pressure) was established since this detector was still in its commissioning phase. This admixture has in particular to be adjusted taking into account the gamma background. Secondly, some efforts were needed to get a stable lossless DAq system with the strong flux at the PF2/EDM beam.

The data taking to search for neutron-mirror neutron oscillation started August the 21rst. We took five and seven scans for each direction of the main magnetic field. This statistics is sufficient to achieve the minimum science reach of the proposal.

In the proposal, we evaluated the expected count rate to be 160 000 s^{-1} which was a "safe" evaluation. The DAq was designed and tested to handle a rate of 400 000 s^{-1}. We used the new beam-tubes recently purchased by PF2 which proven to be of very good quality. The measured count rate was 280 000 s^{-1}.

2. Preliminary results and data analysis strategy

The detector, a gas detector where CF4, a scintillating gas, is cohabiting with He3 has 3 photo-multipliers (PMTs). The three signals where sent to 2 DAq systems. A first one, developed at LPSC [1], was mainly used for the online analysis since it gives efficiently access to the number of triple coincidences (same event seen by the 3 PMTs). The second DAq system, named FASTER, was developed at the LPC [2] and is designed to reach the best neutron / background discrimination at the cost of a need for off-line treatment of the data plus the need to transfer and store a large amount of data (20 Tb in total for the oscillation search data). The data-set was transferred to the french computing center.

During the experiment, the on-line analysis was focusing on two aspects :

- Checking the Faster data to ensure that the detector was properly working without drift and that there was no data loss. This task was ensured by the LPC team which was on site before the start and during most of the experiment.
- Checking on the achieved statistics and looking at the fluctuations. This task was done by the LPSC team.

The off-line analysis of this data-set is the PhD topic of W. Saenz in LPC under the supervision of T. Lefort. The following pictures are thus provided by W. Saenz and are preliminary.

The status of the neutron / background discrimination can be seen in figure 2. It is based on the maximum of the amplitude of the signal (vertical axis in 2) called *Amp*, and a shape parameter QDC/Amp (horinzontal axis in 2) where *QDC* is the integrated amplitude over 20-60 ns (threshold based). The parameter space was divided into 19 zones (18 are shown, zone 19 is for any event outside all the other 18 zones). Zone number 9 has a very pure UCN content (background contamination to be evaluated) while zone number 10 has a higher background contamination while still containing mainly UCNs. This approach allows us to do the analysis using only counts from zone 9, only counts from zone 10, and of course the counts from both zones. Also the time stability of known backgrounds can be studied : in zone number 2 to 6 we found betas and gammas, while zone 16 are Cerenkov events and zone 15 are pile-up events. We are still investigating the background to get the full picture.

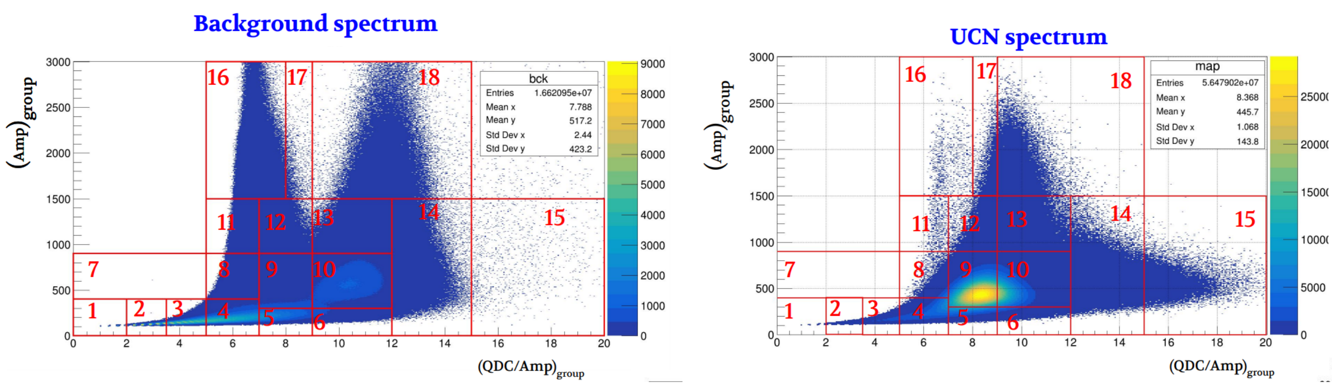

Figure 2. Pulse shape analysis based neutron/background selection, status as of January 2021. The upper figure shows a "background spectrum" taken with only CF4 inside the detector, while the lower picture shows a similar measurement taken with CF4+He3 inside the detector.

We took the data according to an A-B-B-C pattern. Each run consisted of:

- Request the beam and ramp the magnetic field to a value A.
- Measure for 44 s
- Ramp the magnetic field to a value B

- Measure for 88 s
- Ramp the magnetic field to a value C
- Measure for 44 s

Figure 3 shows a typical run. One can see two issues. First, a general linear drift that can be corrected for using the ratio $R = \frac{N_{B+B}}{N_A + N_C}$ where N_{B+B} is the total number of neutrons counted while the magnetic field was at the value B (resp. A and C). Since A, B and C were chosen such as A<B<C or C<B<A, this ratio is also strong against a possible (but experimentally excluded by some dedicated tests) linear change in detector efficiency correlated with the applied magnetic field. The size of the magnetic step between A and B and B and C was chosen using the simulation of the experiment taking into account the inhomogeneities of the magnetic field measured on-site.

The second issue is due to non statistical fluctuations of the neutron flux. As an example, the reduced Chi-square of the linear fit in figure 3 is 2.2. We could not find any periodicity of those additional fluctuations but they are significant as soon as we are looking at timescales longer than 0.5 s. We believed we need more data to conclude on this issue and a new proposal will be submitted.

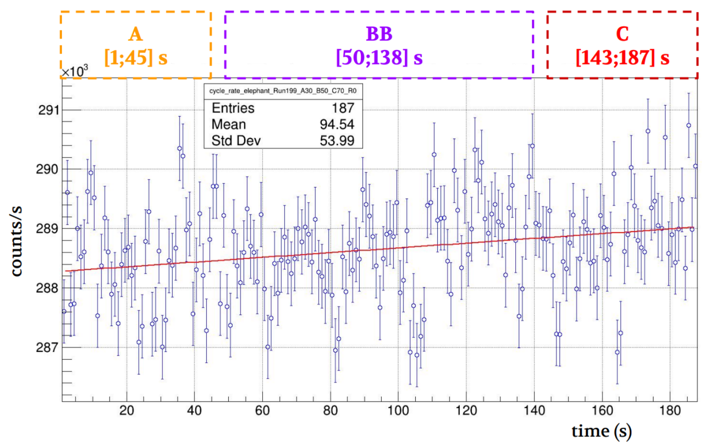

Figure 3. Typical 190 s run.

3. Conclusion

In conclusion, we would like to report on a successful experiment that is still being analysed. The statistical sensitivity is expected to be limited by the fast fluctuations of the neutron flux, reducing the sensitivity by a factor somewhere between 2 and 3. Also the count rate was higher than expected and the science reach does not seem compromised as far as we can tell.

References

[1] O. Bourrion et al., Nucl. Instrum. Meth. A 821 (2016).

[2] D. Etasse, B. Carniol, C. Fontbonne, J.M. Fontbonne, J. Hommet, H. Plard, J. Poincheval, T. Charentre, and D. Cussol. Faster, http://faster.in2p3.fr/.