Experimental report

07/09/2022

Proposal: **3-07-400** **Council:** 10/2020

Title: Search for mirror neutrons via neutron transmission through a beam stop

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples:

Instrument	Requested days	Allocated days	From	To
PF1B	21	16	24/08/2021	09/09/2021

Abstract:

This experiment aims to detect mirror neutrons via neutron survival through a beam stop with a super-imposed magnetic field up to 15 T. It should notably be able to decide about the existence or absence of an effect with parameters of mass splitting and mixing angle predicted within a recent model of neutron - mirror neutron oscillations.

Experimental report for experiment 3-07-400:
Search for mirror neutrons via neutron transmission through a beam stop

Experimental team: E. Blackburn, T. Forgan, F. Lafont, V. Nesvizhevsky, T. Soldner, O. Zimmer

Introduction:

This experiment had the goal to detect neutrons transmitted through a beam stop placed in a strong magnetic field. A positive signal would be interpretable as being due to transitions between ordinary neutrons (n) and mirror neutrons (n') of a hypothetical parallel world, made of mirror particles that were suggested to globally restore the parity violation observed in our world of ordinary particles. The role of the magnet was to vary the mass splitting of the two energy eigenstates, by virtue of the magnetic interaction of the neutron. Its maximal settable field value of 16 T changes the mass splitting without field by 1 μeV. Any splitting smaller than 1 μeV would thus become detectable, provided that the mixing between n and n' states is sufficiently large. Since the magnetic field would for one spin state increase the splitting whereas for the other it would decrease it, the use of polarized neutrons offers the possibility to detect the effect as a flipping ratio, which is very sensitive and avoids the need for absolute measurements.

Experimental setup:

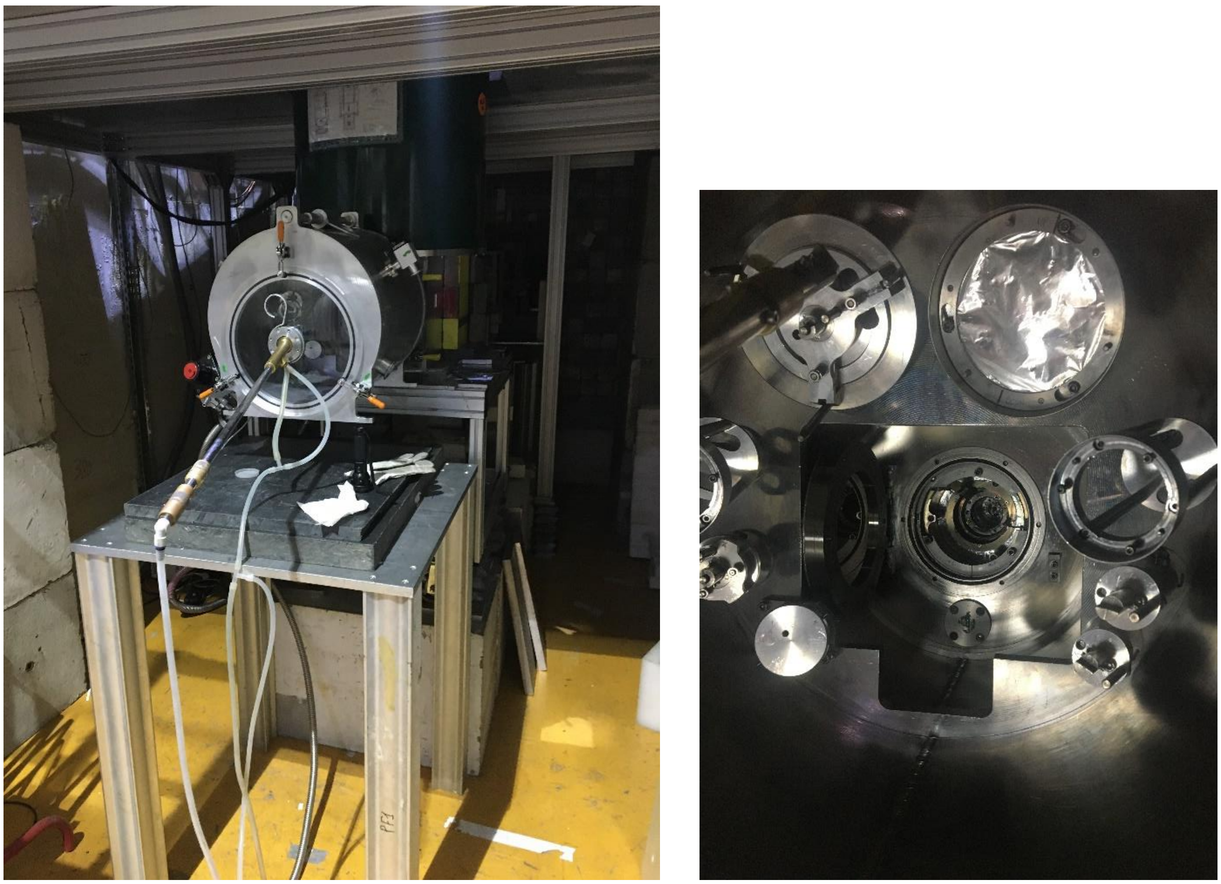
The superconducting magnet was installed in the experimental zone of PF1B (see photo). Its longitudinal field guided the neutron polarization, which was provided by the new "solid-state" polarizer in the casemate of PB1B. A resonance spin flipper allowed us to invert the neutron polarization with respect to the magnetic field. The mirror neutron experiment took advantage of an existing collimation system connecting the casemate with the experimental zone, which was also used in the subsequent experiment BRAND on neutron beta decay. Designed to deliver a clean, divergent beam to the experiment, it met the needs of both experiments. In its final configuration, a He3 detector was placed with its active volume at 92 cm behind the B4C beam stop situated in the center of the magnet. The size of the detector was at this distance sufficient to cover the full divergence of the beam incident on the beam stop.

Experiments:

After installation of the magnet in the beamline, preparatory experiments were performed to optimize various experimental parameters. For neutron polarization analysis behind the magnet, an aperture with 1.4 mm diameter was first installed in the center of the magnet (later replaced by a fully opaque beam stop). A He3 spin filter (15 cm long, 1.02 bar initially polarized to 74%) installed 2.5 m behind the magnet with appropriate guide fields, followed by a neutron detector, was then used to set all magnetic fields, optimizing the flipping ratio of neutron counts with the spin flipper switched on and off, respectively. Afterwards, flipping ratios were measured for various settings of the field of the main magnet between 1 and 16 T, and for the magnetic field direction inverted (for which one expects to observe the same results). The measured flipping ratios in the range of 175 at 16 T and still 65 at 1 T demonstrated an excellent neutron polarization, which was more than sufficient to perform the main experiment.

A study of the count rate dependence as a function of the neutron detector distance from the magnet operated at its highest field used in the main experiment (16 T) allowed us to observe any reduction of detector efficiency due to the field. No significant negative effect was found, even if the detector was placed much closer to the magnet than needed to accept the full beam divergence (of potentially converted mirror neutrons in the main experiment).

A gold foil activation was performed to determine the neutron flux in the center of the magnet. This number is a necessary input in the data analysis.



Photographs of the experiment taken during installation. Left: the magnet with attached service chamber for exchange of the beam stop in the center of the magnet (normally it is used for exchange of samples in that location). In the final configuration of the experiment, the detector and its shielding were located on the table behind the magnet. Right: view into the service chamber; the various tools surround the central bore giving access to the magnet.

Since backgrounds crucially influence the quality of the experiment, a large fraction of the beam time was spent to understand and possibly reduce the detected count rates by appropriate shielding measures. These studies were started early on, first by doing measurements with a heavily shielded detector without neutron beam, to determine a potentially lowest achievable level of ambient background at the detector location in the experimental zone. A count rate of about 0.03 per second was thus achieved.

The detector (ILL's multi-tube monitor type, used with 15 bars of He3 to make it opaque for the cold spectrum of PF1B) was carefully characterized at PF1B and in complementary tests at a test beam of the detector group. Its voltage (1.4 kV) and the trigger level for neutron detection (250 mV) were chosen to keep backgrounds low, at an affordable tradeoff of 10% in neutron detection efficiency.

After all preparatory experiments requiring a neutron beam were finished, the aperture in the magnet was replaced by a 7 mm thick disk of 41 mm diameter, made of sintered B4C of natural isotopic composition. The exchange was performed with the magnet kept cold, using the tools in an attached, and evacuated service chamber (see photo).

The shielding of the whole beamline including the detector was gradually reinforced while monitoring the effect on the detected count rates. Measurements in the configuration of the main experiment were performed, determining flipping ratios in the sequence flipper off/on/on/off (at each setting for 10 seconds), to eliminate linear drifts. Data were taken for the magnet set to field values of 16 T, -16 T, 3 T, 6 T, and 11 T, at typical count rates of about 0.2 per second.