Experimental report

19/09/2022

Proposal: 3-07-399 **Council:** 10/2020

Title: BRAND: Search for BSM physics at TeV scale via the transverse polarization of electrons emitted in neutron decay - beam time extensio

Research area: Physics

This proposal is a new proposal

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Samples: neutron decay

Instrument	Requested days	Allocated days	From	To
PF1B	14	7	29/09/2021	06/10/2021

Abstract:

The basic goal of the proposed project is the construction of the apparatus and carrying out of data taking in an innovative experiment measuring simultaneously as many as 11 correlation coefficients in the decay of polarized neutrons. Five from them (H, L, S, U, V) would be measured for the first time. The ultimate goal of the project is the determination of the correlation coefficients H, L, N, R, S, U and V with the accuracy of about 5x10^{-4}, and providing complementary and competitive information respectively to ``classical'' neutron decay experiments (correlation coefficients a, b, A, B, D) and to ongoing and planned high-energy experiments (like eg. CMS at LHC) searching for not existing in the Standard Model but theoretically possible scalar and tensor couplings. The request for additional 2 weeks of beam time is a result of a rearrangement of the orginal plans imposed by a substantial delay in delivery of the beam time allocated within the proposal 3-07-384: the first (out three) weeks will begin on September 21, 2020. The requested beam time will be devoted for taking data necessary for complition of ongoing PhD projects.

Report for experiments 3-07-384, 3-07-399 and DIR-229

“Search for BSM physics at TeV scale by exploring the transverse polarization of electrons emitted in neutron decay – the BRAND project”

Beam time allocation and measurement schedule

Partial allocation of the beam time at PF1B beam line and agreements with other experiments led to effectively two runs: (1) in Fall 2020 and (2) in Fall 2021.

1) The first run covered the period 21/09/2020 – 28/09/2020 with about 4 days for setting up and diagnostic measurement of the beam while the remaining 5 days were devoted for tuning the prototype detectors and collection of sample data. This run is a part of the experiment 3-07-384. A sketch of the test setup and a photo of the setup inside the PF1B cave is shown in Fig. 1.
2) The second run covered the period of four weeks: 15/09/2021 – 13/10/2021 and encompasses formally three experiments: 3-07-384, 3-07-399 and DIR-229. The first week was devoted to setting up the polarized beam and measurements of the neutron polarization. The next two days were used for setting up of the BRAND test setup and mapping of the guiding field. The remaining time was used for tuning all prototype detectors and taking samples of data in various triggering modes. Essential elements of the setup are illustrated in Fig. 2.

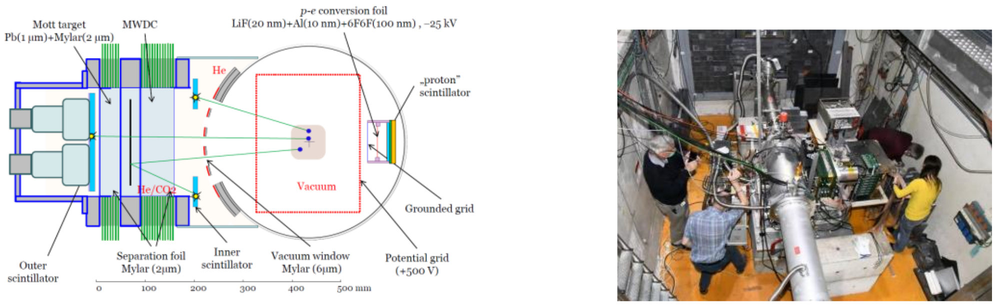

Fig. 1: Left: Layout of the test experiment for run 1.: Cross section in the plane perpendicular to the beam axis. Right: Test setup inside the PF1B cave.

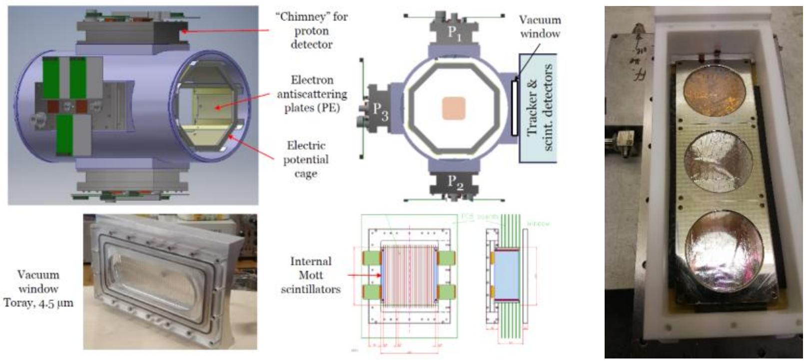

Fig. 2: Left and middle: Layout of the test experiment for run 2. Right: p-e converter foils inside the proton detector insulator.

Immediate experimental goals and their realization

An immediate goal of the above runs was to test the performance of all important prototypes of the future BRAND components in real experimental conditions and identify weak points of the proposed setup. The efforts were focused on the following components:

1) **Beam geometry, polarization**. For the test measurements we collimated the beam with two rectangular apertures (60x60 mm^2) according to the standard PERKEO setup. In the first run, the guiding field wasn’t setup and only a crude beam intensity profile was measured giving the thermal equivalent capture flux of 6.3×10^8 $n\cdot cm^{-1}s^{-1}$ in the profile center. In the second run, the guiding field for longitudinal polarization was applied and mapped on site using a single axis Hall probe (SS496B). All three components were mapped along five axes parallel to the beam central axis. Evaluation of the field maps is in progress. The field maps will be used for calculation of the corrections of the neutron spin deviation from momentum direction. Polarization measurement revealed $P_L = 0.98 \pm 0.01$ at maximum intensity around $\lambda = 0.5$ nm. This time the beam intensity gave the thermal equivalent capture flux of 4.0×10^8 $n\cdot cm^{-1}s^{-1}$. The polarization is sufficient for the BRAND project while the beam intensity is 30% below expectation.

2) **Vacuum windows**. The polarized cold neutron beam is guided in vacuum. The charged decay products will be observed in a section of the beam line called a decay chamber. While the recoiling protons will be detected directly in the decay chamber, electrons have to pass a thin vacuum window into a gas tracker (Multi-Wire Drift Chamber) with ambient pressure. The window must be made with low Z materials and its thickness should be less than 10 μm in order to mitigate energy loss and depolarization of electrons. Challenging is the total size of the window: in one m long decay chamber it should cover about 1.5 m^2 at the rest gas pressure of about 10^{-5} mbar. We tested two types of window segments: (i) self-supporting 18×200 mm^2 and (ii) Kevlar thread reinforced 90×200 mm^2 pieces made of Toray polyamide and Al-metalized Mylar. General conclusions are positive but further research must be continued. Among others two layer windows with differential pumping are considered.
3) **Electron tracker**. In the test measurements, a copy of the miniBETA MWDC spectrometer was applied. It provides *xy*-position (across wires) from drift time with accuracy of about 0.5 mm. Z-position is obtained from asymmetry of the signal height measured at both wire ends. The achieved accuracy of about 5 mm was achieved in the first run while the second run delivered two times worth precision. The reason for this degradation is not known yet. It may have to do with significantly higher electronic noise level experienced in the second run.
4) **Main scintillator**. To detect direct decay electron a plastic scintillator is being used. The role of this detector is not only triggering data acquisition but also provide precise energy information. This is why light yield and collection is of primary importance. In the test setup, a plastic scintillator disk with diameter of 200 mm and thickness of 10 mm was read out by four Photonis XP3330 PMTs.
5) **Mott scintillators**. The backscattered electrons from the Mott target are being registered by plastic scintillator of the same type as for direct decay electrons. In the first run, four 100×100×10 mm^3 pieces read out by Photonis XP3330 PMTs were arranged externally to the tracker. They performed correctly, however, the geometrical limitations made them inefficient with respect to the acceptance and angular settings. In the second run, plastic scintillator plates of 200×100×10 mm^3 were installed inside the tracker allowing for optimal detection geometry, however, the small size of the prototype tracker prevented guiding scintillation light towards external PMTs. Instead, an array of SiPMs Hamamatsu S14116-6050HS (14 sensors at each short side of the scintillator) was applied. The analysis of the Mott scattering events collected within the second run are still in progress.
6) **Proton detectors**. BRAND experiment assumes using conceptually novel recoiling proton detectors. They should measure time-of-flight in the free drift region (accuracy better than 1 ns) and hit position with accuracy of about 10 mm. Moreover the sensitivity of proton detectors to decay electrons should be heavily suppressed. The prototype proton detector utilizes conversion of protons accelerated to about 25 keV into a bunch of secondary electrons ejected from a thin (approx. 10 nm) LiF layer, subsequent acceleration to about 25 keV each and detection in a 25 µm thick plastic scintillator. Scintillation light will be measured with an array of SiPM sensors and the hit position deduced using the light sharing method. In the first run, a prototype detector was constructed with one 50 mm diameter converter foil and a readout structure consisting of 18 SiPM sensors distributed on a triangular mesh. The whole detector including front end electronics and active cooling was installed in the decay chamber. The detector was operated at high voltage of 16 kV as higher potential led to breakdowns. The collected sample of data in the self-triggering mode clearly shows an excess of counts with beam on and with increasing voltage. More investigations could not be performed due the lack of beam time. For the second beam time the proton detector was redesigned such that the front end electronics was located outside vacuum chamber and cooling was applied only to sensors. Three units were assembled utilizing three 50 mm diameter converter foils each. All three detectors were supplied from a common HV power supply. This was one of the main source of difficulties as it turned out that the custom HV plugs did not perform correctly. It was realized post factum that the insulating silicone glue did not harden correctly and contained plenty of small air bubbles. Provisional patching and operating detectors one by one in a sequence allowed to reach the desired voltage of 25 kV in two units, however, the duration of such a state was limited to about 1 hour. The collected samples of data are still being analyzed and a number of additional laboratory tests are underway in order to localize and fix problems.
7) **Front end electronics**. The BRAND apparatus relies on fully customized front end electronics servicing the gas tracker, and scintillation detectors read out by both traditional PMTs and SiPM sensors. Additionally, all pulse height information is converted to time encoded in the pulse length (interval between leading and trailing edges of square form standard LVDS signals). In the first run, the front end electronics worked correctly with performance close to the requirements. In the second run, however, the effective resolution of all channels was worse by a factor of two. The origin of this effect is not known yet. We speculate that it can be due to observed generally higher noise level. This, in turn, may be related to experienced grounding problems. This hypothesis will be verified in the off-line test in the lab.
8) **Triggering scenarios**. Triggering of DAQ is an important issue for BRAND scenarios. Detection of an electron (direct or Mott scattered) starts a clock necessary for both pulse height and detection time measurements

of all acquired channels and is crucial for Time-of-Flight of the recoiling protons. Moreover, in order to suppress detection of Compton background the prompt coincidences between electron scintillators and gas tracker are required. The event acquisition window of about 10 μs and sample transient storage depth of 500 ns is needed to accomplish full acquisition of required signals. It is planned to construct an ultimate trigger system using modern LPGA based modules. In the test runs, such functionality wasn't possible. Instead a simple custom triggering board was constructed and operated together with CAEN VX1190 TDC modules. This allowed only for software scintillator-gas tracker coincidences and for significantly reduced dynamical range (down to 1.8 μs instead of 10 μs). Additionally, in the second run, the trigger board was accidentally damaged. "In-fly" repair recovered its main functionality, however, the level of performance was not clear.

Encountered problems and difficulties

1) It is fair to say that both preparation of the experimental apparatus and conduction of measurements were severely affected by COVID-19 pandemic. Long periods of closed labs and workshops and heavily delayed delivery of components made the experiments difficult, especially with respect to the time needed for systematic laboratory tests of subsystem. Some of planned solutions could not be realized in time and must have been postponed for the next steps of the project. Time constraints for two PhD theses enforced somewhat risky experiment planning in order to generate samples of physics data rather than systematically validate the experimental components.
2) The first on site test measurement was additionally affected by very short beam time available. Practically, for testing of prototype detectors and electronic boards using neutrons only 5 days were available. Nevertheless, useful data samples were acquired for further off-line analysis.
3) In the second run, we experienced a number of technical problems. One of them was persistently increased noise level (as compared to the first run). The current hypothesis is that in the complicated electrical and electronic circuits we generated not identified ground loops. Also the accident leading to partial destruction of the trigger board might have had negative consequences on the rest of electronics. This hypothesis will be checked in the post factum laboratory tests.
4) Lack of alpha particle calibration source necessary for the gain balance of multiple SiPM channels had far going consequences: the data of proton detectors must have been collected with unbalanced gains and not calibrated energy vs. pulse height relation leading to badly controlled hit position estimation. The reason for this difficulty was an unfortunate coincidence of general ILL regulations and an accidental absence of the person responsible for radioactive source service at neutron beams. In the future, a satisfactory solution of this problem must be established.

Conclusions and planning

Despite the above mentioned difficulties it is fair to say that no principal obstacle among all proposed solutions was found. It seems that all the encountered deficiencies can be mitigated by known techniques and methods. The analysis of rich experimental material is ongoing. Partial results are being published and presented in a number of specialized workshops and conferences. It is expected that the analysis process will continue still a couple of months. After that an exhaustive publication summarizing the achievements and conclusions is planned. It is also planned that a number of technical papers dedicated to novel solutions will be published, too. The project will be continued. It got a substantial funding from the National Science Center, Poland. Before applying for the beam time at ILL the BRAND collaboration needs to resolve the identified problems and construct a full scale detector segment. Meanwhile, short beam time periods for testing particular components are not excluded.

References

1. "*BRAND exploring transverse polarization of electrons emitted in neutron decay – Feasibility demonstration experiment*", K. Bodek, J. Choi, L. De Keukeleere, K. Dhanmeher, M. Engler, G. Gupta, A. Kozela, K. Lojek, K. Pysz, D. Ries, D. Rozpedzik, N. Severijns, T. Soldner, N. Yazdandoost, A.R. Young and J. Zejma: (EXA2021) EPJ Web of Conferences 262, 01014 (2022)
2. "*Search for BSM physics with neutron beta decay in the BRAND project*", D. Rozpedzik, K. Bodek, J. Choi, L. De Keukeleere, K. Dhanmeher, M. Engler, G. Gupta, A. Kozela, K. Lojek, K. Pysz, D. Ries, N. Severijns, T. Soldner, N. Yazdandoost, A.R. Young and J. Zejma: (PANIC2021) PoS 432 (2022)
3. "*Mott polarimeter for electrons from neutron decay in BRAND experiment*", K. Dhanmeher, K. Bodek, J. Choi, L. De Keukeleere, M. Engler, G. Gupta, A. Kozela, K. Lojek, K. Pysz, D. Ries, A. R. Young, D. Rozpedzik, N. Severijns, T. Soldner, N. Yazdandoost and J. Zejma: PoS (PANIC2021) 099, (2022)
4. "*BRAND - A detection system for n-decay correlation measurement*", K. Dhanmeher, K. Bodek, J. Choi, L. De Keukeleere, M. Engler, G. Gupta, A. Kozela, K. Lojek, K. Pysz, D. Ries, A. R. Young, D. Rozpedzik, N. Severijns, T. Soldner, N. Yazdandoost, J. Zejma: (15th Pisa Meeting on Advanced Detectors) May 22-28, 2022
5. "*Search for Time Reversal Violation in Free Neutron Decay*": K. Bodek, J.Choi, K. Dhanmeher, L. De Keukeleere, M. Engler, G. Gupta, A. Kozela, K. Łojek, K. Pysz, D. Ries, A. R. Young, D. Rozpędzik, N. Severijns,T. Soldner, N. Yazdandoost and J. Zejma: (INPC2022), oral presentation
6. "*BRAND - Probing weak interaction in neutron beta decay using recoil proton related correlation coefficients*", G. Gupta, K. Bodek, J. Choi, L. Keukeleere, K.Dhanmeher M. Engler, A. Kozela, K. Lojek, K. Pysz, D. Ries, D, Rozpedzik, N. Severijns, T. Soldner, N. Yazdandoost, A.R. Young, J. Zejma: (EuNPC 2022), poster, accepted