



BRAND—A detection system for β -decay correlation measurement

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ABSTRACT

The BRAND experiment aims at the search of Beyond Standard Model (BSM) physics via measurement of exotic components of the weak interaction. For this purpose, eleven correlation coefficients of neutron β -decay will be measured simultaneously. The BRAND detection system is oriented for the registration of charged products of β -decay of polarized, free neutrons. With the measurement of the four-momenta of electron and proton, the complete kinematic of the decay will be determined. Moreover, the transverse spin component of the electron, which is the crucial observable to probe BSM exotic components of weak interaction, will be measured via Mott scattering. The electron detection system features both tracking and energy measurement capability. It is also responsible for the determination of the electron spin orientation. A challenging detection of low-energy protons from the β -decay is performed with a system, which involves the acceleration and subsequent conversion of protons into bunches of electrons. To test the feasibility of the proposed experimental techniques, a small-scale prototype setup was installed at the cold neutron beam facility PF1B at the Laue-Langevin Institute (ILL) in Grenoble, France. In this contribution, the preliminary results of the commissioning run are presented with an emphasis on the performance of individual parts of the detection system.

1. Introduction

A free neutron decay is a suitable tool to probe the details of weak interactions. Besides the interaction components foreseen in Standard Model (SM) also the possible extension Beyond Standard Model (BSM) are accessible. Precision study of polarized/unpolarized neutron decay correlation coefficients is one of the well known methods [1]. The BRAND experiment will simultaneously measure 11 of these correlation coefficients [2]. Seven of them: H , L , N , R , S , U and V , are sensitive to the transverse polarization of emitted electrons. The measurements of five of them (H , L , S , U , V) were never attempted experimentally before. This will be achieved with the event-by-event reconstruction of the kinematics of the decay products. Dedicated detectors will measure four-momenta of protons and electrons, whereas the neutrino energy and momentum will be evaluated from conservation laws. For analysis of the electron spin orientation, the Mott scattering process will be used. With the measurement accuracy of 5×10^{-4} of the transverse electron polarization related coefficients, the new limits for possible scalar and tensor contributions will be established.

It is foreseen that the BRAND measurements will be interpreted in the framework of effective field theories (EFT) which provide the common formalism both for high and low energy fundamental research (see [2] and references therein).

2. BRAND-0: The initial phase experiment

To test the principle of the BRAND project, a small scale prototype setup was installed at the polarized cold neutron beam facility (PF1B), ILL. The data have been taken in September–October, 2021. Fig. 1 presents a cross-section of the experimental apparatus. The three units of proton detector were installed in vicinity of the polarized neutron beam passing through the evacuated decay chamber. The electron detection system is located outside the decay chamber. β particles, to be detected, have to leave the decay chamber through a very thin aluminium coated Mylar window ($13 \mu\text{m}$) reinforced with the Kevlar mesh. They are registered in the combined tracker-spectrometer-Mott polarimeter. It consists of (i) a Multi-Wire Drift Chamber (MWDC)

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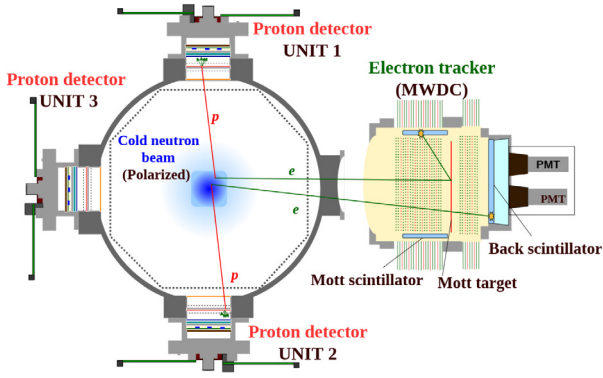


Fig. 1. BRAND test setup, ILL 2021. (See text for details).

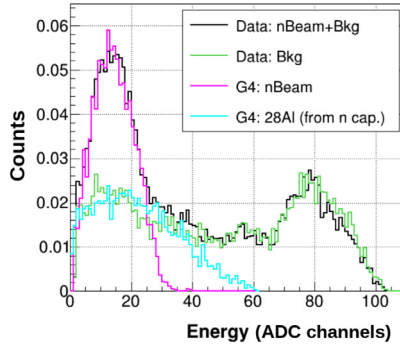


Fig. 2. Energy spectrum detected in the Back scintillator. Component of electrons from neutron decay (black) is superimposed on the background (green). Simulations with Geant4 reproduce the β spectrum (magenta) and the background component originating from neutron capture in Al (blue).

of low effective thickness, (ii) a thin (2 μm) Pb coated Mylar film (4 μm) working as a Mott scattering target, installed in the active volume of MWDC, (iii) a plastic scintillator (Back scintillator) for energy measurement of the electrons unaffected by the Mott foil, (iv) two plastic scintillators (Mott scintillators) for registration and energy measurement of electrons scattered by the Mott foil. The scintillator detectors provide as well the trigger signals for DAQ. Ref. [3] gives detailed description of electron detector. The idea of prototype tracker for BRAND experiment was adopted from the miniBeta project [4,5].

Low energy of emitted protons (< 750 eV) in β -decay makes them very difficult for direct detection. To overcome this problem, the technique developed by [6] has been applied. Protons are first accelerated in the external electric field (up to 25 kV) and then converted into a bunches of secondary electrons. For this aim a thin LiF layer is used. Electrons ejected from the conversion foils are subsequently accelerated by the same electric potential and detected in a thin plastic scintillator, providing information about the hit position of the original proton. From known time-of-flight and the trajectory, their energy can be calculated. Thus, registering the proton-electron coincidence permits the vertex reconstruction and unambiguous identification of β -decay events. For a detailed description of the methods used for the proton detection see [7].

3. Results

Fig. 2 shows the energy spectrum registered in the Back scintillator. The component from the β spectrum of neutron decay (black line) is superimposed on the broader distribution identified as a background

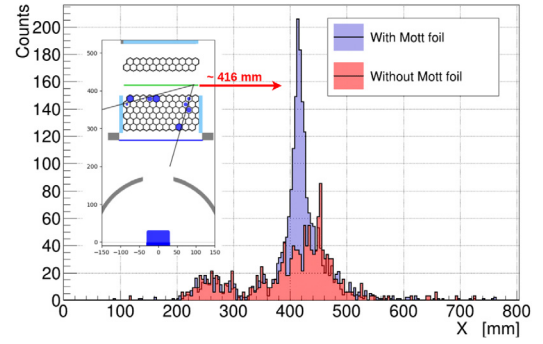


Fig. 3. Vertex distributions of V-tracks for Mott scattered electrons when the Mott target is on (magenta) and off (red).

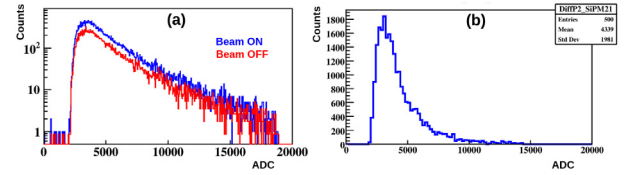


Fig. 4. Typical ADC spectra of the proton detector: (a) neutron beam ON/OFF spectrum (blue/red, respectively), (b) background subtracted spectrum of protons.

(green line). The β spectrum is well reproduced by the simulations performed with the Geant4 toolkit (magenta line), where full geometry of the setup, electronic response and dominant physical processes were implemented. Low energy background component (blue line) is identified by the Geant4 simulation as a neutron capture process at Al components of the setup.

To extract the transverse polarization component of β particles, it is crucial to identify and track the Mott-scattered electrons. For this aim the V-shaped tracks in the MWDC are searched for. Fig. 3 shows vertex distribution of such V-tracks, which are attributed to the Mott-scattered electrons. The position of the purple peak at $X = 416$ mm reproduces the position of the Mott target inside the tracker. The distribution plotted with the red color presents the background (normalized for corresponding measurement time) registered when the Mott target was removed.

In Fig. 4 the preliminary spectra registered in the proton detectors are shown. Events being candidates for proton signals are indicated. Analysis of the collected data is still ongoing. The preliminary results achieved until now are promising.

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