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Unrecognized backscattering in low energy beta spectroscopy

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Abstract

We present studies on electron backscattering from the surface of plastic scintillator beta detectors. By using a setup of two detectors coaxial with a strong external magnetic field—one detector serving as primary detector, the other as veto-detector to detect backscattering—we investigate amount and spectrum of unrecognized backscattering. These are events where only one detector recorded a trigger signal. The implications are important for low energy particle physics experiments.

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Keywords: Beta spectroscopy; Electron backscattering; Neutron decay

1. Introduction

In the β-decay of the free neutron in proton, electron, and anti-neutrino, $n \rightarrow pe^-\bar{\nu}_e$, a number of interesting questions of particle physics and cosmology can be addressed [1]. These studies provide clean data and uncertainties due to nuclear structure do not arise. Main observables are correlations (emission asymmetry parameters) between neutron spin and the momenta of the decay products, or correlations between two of the latter. They are determined by measuring the emission direction of electrons and protons (e.g. Refs. [2–5]). Due to their small mass, electrons may be scattered from nuclei at large angles leading to electron backscattering out of the detector [6]. As generally in low-energy beta spectroscopy, this induces a systematic effect for neutron decay experiments since energy and angle dependent losses may falsify the asymmetry signal [7–9], a problem that has been discussed for many years now. In this paper, we present a method to directly determine the effect.

At present and in the near future, there will be several spectrometers employing a magnetic field to precisely measure neutron decay parameters, such as aSPECT, PERKEO III, and a PNPI experiment in Europe, and UCNA, aCORN, abBA, Nab, and PANDA in the US [1,10,11]. Therefore it is of great interest to study electron backscattering in the framework of these experiments, to investigate how backscattering can be suppressed, and to determine the size of possible systematic effects. Especially for plastic scintillators that are widely used in these studies almost no data are available in the low energy range [8].

2. Experimental setup

We will focus on the rather simple setup of the electron spectrometer PERKEO II [12]. This is a quite general approach since many of the newly proposed experiments have a similar design. It features a strong magnetic field ($B_{max} = 1.03\,T$) applied across a polarized neutron beam. The field is slightly decreasing and guides the electrons generated in neutron decay onto two opposite detectors. In this way, a $2 \times 2\pi$ detection system is realized and no particles can miss the detectors (Fig. 1). This configuration is ideally suited to study backscattering effects from a primary detector which can be registered in the secondary detector on the opposite side ("veto detector"). The spatially varying magnetic field B also lowers electron backscattering considerably due to the magnetic mirror

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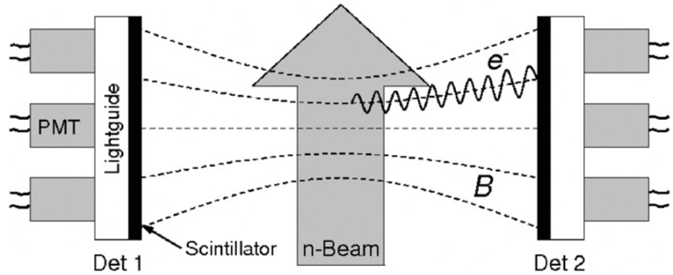

Fig. 1. The experimental setup of PERKEO II to study electron backscattering. Electrons from neutron decay are guided onto the detectors (plastic scintillator) by the magnetic field.

effect: The magnetic flux enclosed by the electron trajectories is an adiabatic invariant, $p_t^2/B = \mathrm{const.}$, with the transversal momentum p_t. An electron moving in an increasing field can therefore be reflected. Many electrons scattered out of the detector are thereby returned to the same scintillator where they depose their remaining energy.

The detectors consist each of a large area plastic scintillator ($190 \times 130\,\mathrm{mm}^2$, 5 mm thick, Bicron BC 404, pulse width 2.2 ns), coupled to a 30 mm thick plexiglass light guide and six photomultiplier tubes (Hamamatsu R5504 mesh PMTs). These are read out by charge integrating ADCs (analogue to digital converter) to measure the energy. A trigger is generated, when at least two of the six photomultiplier signals of one detector have passed the discriminator threshold. The trigger probability is 90% at about 100 keV. Every trigger signal is sent to an individual TDC (time to digital converter) channel to determine which of the detectors were hit and to register timing information. A detailed description of the experimental setup can be found in Ref. [13].

Compared to solid state detectors, which have backscattering probabilities p_{BS} of up to 80% (NaI, [6]), plastic scintillators have the lowest p_{BS} in beta spectroscopy due to their low average atomic number Z. But with $p_{\mathrm{BS}} \approx 8\%$ ($p_{\mathrm{BS}} \approx 4\%$ for normal incident) this probability is still quite high [6] and has to be considered in the analysis of precision measurements.

In the experiments listed above, backscattering enters in an integral way, i.e., integrated over different angles of incidence θ on the detector. In PERKEO II, the maximal angle $\theta_{\max}$ is around 45° as the decreasing magnetic field increases the electron momentum component parallel to the field lines. Most electrons hit the detector near $\theta_{\max}$. Overall, the influence of the magnetic field reduces the backscattering probability to below 5%.

3. 2-Trigger backscattering

Whenever a trigger signal occurs, the ADCs of both detectors are read out simultaneously. With 180 ns, the integration time is much higher than the average time the backscattered electrons need to cover the distance between the detectors (800 mm), and we always obtain the full energy information of the event by summing up both detectors. *2-trigger backscattering* occurs when an event generates a trigger both in the primary and the secondary detector. This allows to determine the chronological order of the two signals by using the timing information of the TDC. If its time resolution is smaller than the minimal flight time between the detectors, this assignment can be done without any uncertainty.

Fig. 2 shows the timing measurement of 2-trigger backscattering: The well separated peaks correspond to events where detector 1 (left) or detector 2 (right) was hit first. The separation is a measure of the system's time resolution which is given by the TDC-channel width of 0.8 ns. In between the peaks, where no first detector can be assigned properly, there are less than 0.2% of the backscatter events. Combined with the backscatter probability of below 5%, this fraction is negligible. The energy of the backscattered electrons is not distributed uniformly into primary and secondary detector (Fig. 3): Independent

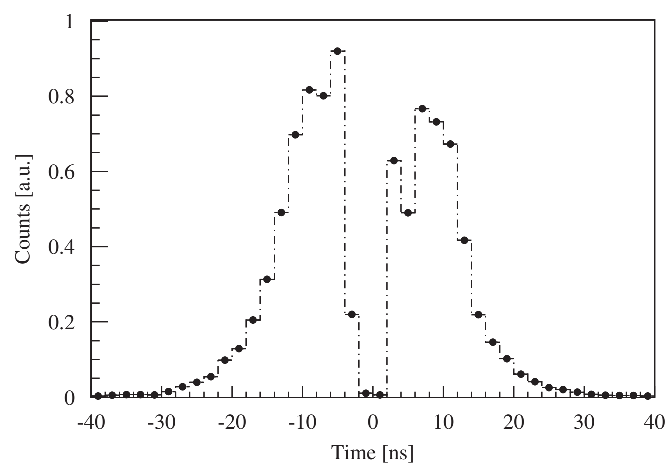

Fig. 2. Timing measurement of 2-trigger backscattering. The plot shows the time difference between triggers of detectors 1 and 2. Events where detector 1 triggered first are in the left peak. The peaks are well separated.

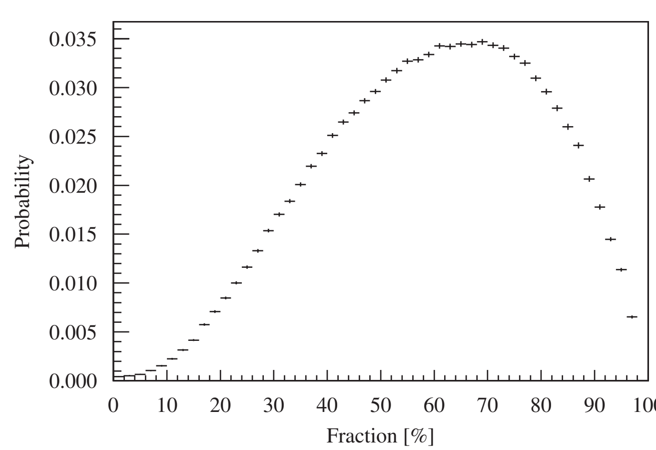

Fig. 3. Measurement of the probability that a backscattering event deposits a particular fraction of its energy in the primary detector. The distribution is asymmetric, i.e. there is a strong preference to depose more energy in the primary detector.