EPJ Web of Conferences **146**, 10014 (2017) DOI: 10.1051/epjconf/201714610014
ND2016

Beta-spectroscopy of long lived nuclides with a PIPS detector-setup

Alexander R. Domula[a], Jan Thurn, and Kai Zuber

TU Dresden, Institute for Nuclear- and Particle Physics, Zellescher Weg 19, 01069 Dresden, Germany

Abstract. Several applications in modern nuclear physics, research and engineering are limited by a lack of precise knowledge in spectral shape data for beta-decays. Specifically the interest aims to study spectral data for forbidden decays with respectively long half-lives, which is one of the central activities of our group. For the investigation of those rare beta-decays the group operates a setup of six PIPS detectors in a vacuum chamber built out of low-radioactivity materials. In the long term the setup will be used as low-background-detector for the investigation of rare beta-decays. In order to reduce the measuring-background a muon veto was installed. The characterization of the setup in the energy-range from 20..1000 keV using conversion-electrons is described. A set of useful calibration-nuclides was established to determine energy calibration and efficiencies.

1. Introduction

The study of beta-spectral-shapes was of great interest in the 1950 to the 70-ties. The present work aims for new precision measurements, especially for forbidden decays. On the one hand the relevance of the exact spectral-shape rised up again due to huge improvements in experiments like Ultra-Low-Background (ULB) experiments – on the other side theoretical models came to a state where experimental data of spectral shapes is needed as input for new achievements [1,2].

At the ‘Institute of Nuclear- and Particle physics’ (IKTP) at TU-Dresden a Low-Background PIPS-detector (Passivated Implanted Planar Silicon) setup was installed for precise spectral shape measurements especially for investigation of forbidden decays with a maximum Beta-Endpoint-Energy of $E_\beta \approx 1\,\mathrm{MeV}$. Thus forbidden beta decays with the corresponding Q-values have a comparable high log-*ft*-value those are associated to long-lived nuclides [3]. The condition for the necessary sufficient counting statistics is fulfilled with an activity above the detector-specific detection-limit and can be served by a reasonable number of source-nuclei. In order to get minimal statistical uncertainties due to the energy-loss in the sample itself the sample-layer also needs to be as thin as possible. The bigger the area of the sample-surface and the detector-efficiency, the better both requirements can be met. A high-resolution-detector with a sufficient efficiency is achieved with an array of PIPS-detectors. In comparison to magnetic spectrometers, which achieve a brilliant resolution in this field, an array of PIPS-detectors enables the capability to measure a necessarily extended-area-sample with the coverage of the full energy range at once.

2. Experimental setup

PIPS-detectors are flat, disc-shaped semiconductor-diodes, which are commercially available as detectors for direct ionising particles with an active area of up to $2'000\,\mathrm{mm}^2$. In the active-volume with thicknesses of up to $d = 1\,\mathrm{mm}$ electrons with an energy up to $E_{e-} \approx 860\,\mathrm{keV}$ deposit their full energy [4]. Thus the full-energy-peak-efficiency (FEP-efficiency) decreases for higher electron energies, hence PIPS-detectors are limited to a maximum energy of $\sim 1500\,\mathrm{keV}$ for precise shape-measurements, as retrieved from estimations with Monte-Carlo Simulations.

To provide a good efficiency for a big sample-surface the discussed setup provides six *CANBERRA* (*PD-1000-300*) PIPS-detectors with an active surface of $300\,\mathrm{mm}^2$ each. The active volume has a nominal thickness of $1000\,\mu\mathrm{m}$ (Fig. 1). For a proper spectroscopy of direct ionising particles one wishes an active detector-volume without entrance-window to prevent any energy-loss of the investigated particles. The ion-implanted front-contact with a maximum thickness of 50 nm is a special feature of the used PIPS detectors in order to provide a minimal entrance radiation-window. Thus the present detectors are not protected with a light-tight foil, the thickness of the entrance-window is given by the implantation contact only.

For a given detector-surface and detection-efficiency the detection-threshold is mainly influenced by the measuring-background. In order to achieve a minimal background-level the setup was shielded actively and passively for ionising radiation from natural radioactivity and cosmic rays. Particular attention was paid on a low intrinsic radioactivity of construction materials to reach a possibly low BG-impact.

Thus the PIPS-detectors were installed inside a counting chamber made of ultra-pure copper, which enables the opportunity to lower the air-pressure in the

[a] e-mail: alex_do@gmx.net

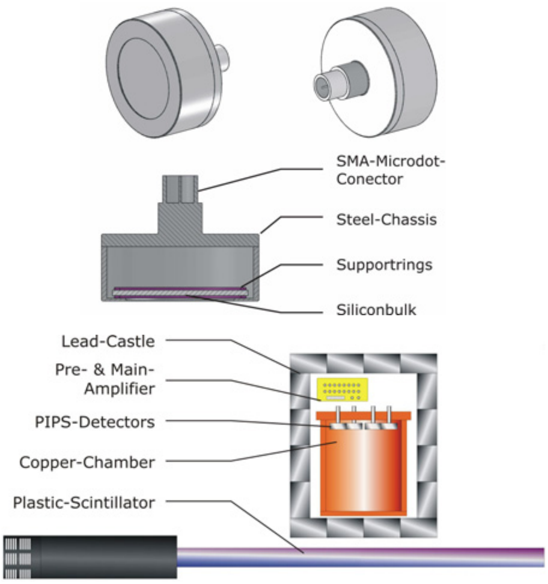

Figure 1. The PIPS-detectors are installed into an evacuated counting-chamber, made from ultrapure copper. To reduce ionising radiation from natural, environmental radioactivity the chamber is housed into 10 cm of lead. Underneath a plastic-scintillation-detector is installed in order to reduce the cosmic-ray-background, which is mainly given by atmospheric muons.

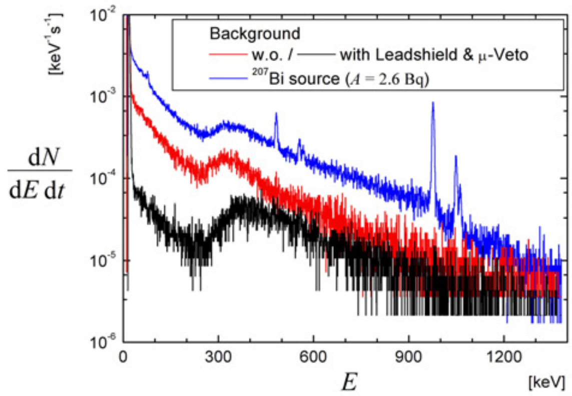

Figure 2. Passive and active BG-reduction lead to a peak-sensitivity of 1.3 mBq ($E \approx 1200$ keV) to 2.7 mBq ($E \approx 350$ keV). Whereas the passive shielding mainly reduces the BG in the lower energy-region up to 300 keV, the muon interaction which shows up in the region around 350 keV with a Landau-shaped peak is efficiently reduced by anti-coincidence-cuts. The conversion-electron-spectra were retrieved for energy-, resolution-, and FEP-efficiency-calibration.

space between sample and detector down to ~ 1 mBar. The chamber with the direct coupled pre-amplifiers was housed into 10 cm of lead. Underneath the setup a 10 mm plastic-scintillator was installed in order to suppress BG which is caused due to atmospheric muons (Fig. 1/Fig. 2).

All of the PIPS-detectors are coupled to a *mesytec MSI-8* pre- & main-amplifier-system with 5 cm cables almost directly on the outside of the chamber. The modular system biases the connected detectors with the high-voltage (*iseg 203M*), amplifies and shapes the detector-signal where the output signals have an energy-proportional pulse-height. Those signals from the PIPSs and the veto-detector are acquired with a *FAST-Comtec MPA-4* multiparameter-system, which allows a coincidence-/anticoincidence analysis.

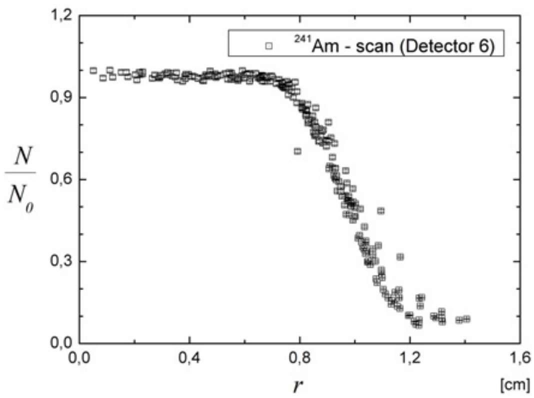

Figure 3. To retrieve a relative thickness profile of the active volume the detector was scanned with a collimated ^{241}Am-source. A relative intensity-profile N/N_0 was retrieved for different scanning-points in the distance r to the detector-center. The intensity-profile which is shown is influenced by the clear cylindrical-shape of the active-volume and Gaussian beam-profile with an FWHM of approx. 2.5 mm.

3. Detector characterisation

Precision measurements of spectral shapes need a very good knowledge of detector properties and characteristics, not least to get a reliable response matrix and to give estimations for uncertainties.

With the use of mono-energetic conversion-electrons the detectors energy- and resolution-calibration as well as the Full-Energy-Peak-efficiency were determined. Therefore a set of suitable calibration sources was evaluated. As PIPS-detectors are sensitive to electron and X-rays due to their thin entrance-window, a proper attention was paid on non-interfering X-ray and conversion-lines. In the end a set of ^{137}Cs, ^{207}Bi, ^{133}Ba and ^{242}Pu was assorted to calibrate the detectors with the corresponding K-conversion-lines in the energy-range from 23.158 keV to 1059.805 keV.

Moreover the detectors were characterised for the size of their active volume and the entrance-window. The latter was investigated with an X-ray-Fluorescence-Analysis (XFA) scan where the front-contact was analysed as implanted silver-ions. The thickness-profile of the active volume was scanned with a collimated ^{241}Am-source (Fig. 3). The results show that PIPS-detectors have a well defined active volume, which can be precisely manufactured by ion-implantation.

Based on the input from the manufacturers data-sheets and the results from detector-characterisation a Monte-Carlo-model was created with the use of PENE-LOPE 2014 [5]. The FEP-values from the experimental characterisation were reproduced by the simulation.

4. Summary and outlook

In order of precise beta-spectral-shape-measurements a low- background counting-chamber, equipped with

DOI: 10.1051/epjconf/201714610014

PIPS-detectors was set up at IKTP / TU-Dresden. With detectors of the maximum bulk-size, which is commercially available. A calibration technique with conversion-electrons was successfully evaluated and used for energy-, FWHM- and FEP-efficiency calibration.

Moreover the detectors were characterised for the shape of their active volume and their radiation entrance-window. The results from these measurements in combination with the data from the manufacturers data-sheets were used as input for a Monte-Carlo-model. The latter will be used for unfolding of beta spectra in future experiments.

References

[1] X. Mougeot, Phys. Rev. C **91**, 055504 (2015)
[2] G.A. Lukyanchenko, Phys. of At.. Nuc. **78**(14), 1621–1623 (2015)
[3] J. Suhonen, *"From Nucleons to Nucleus"*, Springer-Verlag Berlin – Heidelberg (2007)
[4] A. Flammersfeld, Naturwissenschaften **33**, 280 (1946)
[5] F. Salvat, *"PENELOPE-2014 – A Code System for Monte Carlo Simulation of Electron and Photon Transport"* – Workshop Barcelona, Spain 29 June-3 July (2015) (NEA/NSC/DOC(2015)3)