Latest results from the *a*SPECT experiment

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/72

The *a*SPECT retardation spectrometer measures the $\beta - \bar{\nu}_e$ angular correlation coefficient a in the β-decay of the free neutron. This measurement can be used to determine the ratio $\lambda = \frac{g_A}{g_V}$ of the weak coupling constants, as well as to search for physics beyond the standard electroweak model. In spring/summer 2013 *a*SPECT had a successful beam time at the Institut Laue-Langevin (ILL), Grenoble/France. The goal of this beam time is to improve the current uncertainty of a from $\frac{\Delta a}{a} \sim 5\%$ to about 1%. To achieve this goal the systematic uncertainties of *a*SPECT have to be understood accordingly. This is achieved via systematic tests, measurements of a with different systematic parameter settings during the beam time and measurements afterwards, like the work-function fluctuations of electrodes or the magnetic field ratio of our spectrometer. Sophisticated simulations of our spectrometer are used to understand and reduce the systematic uncertainties further.

1 Motivation

The β-decay of the free neutron is an ideal system to search for physics beyond the standard model. Its daughter nucleus, the proton, is the simplest possible, so no complicated nuclear corrections are necessary. Further, the system is overdetermined, which opens the possibility to determine one parameter of the standard model, λ, by measuring different correlations. With this complementarity a reduction of the systematic uncertainties of the parameter, as well as a test of the standard model itself is possible.

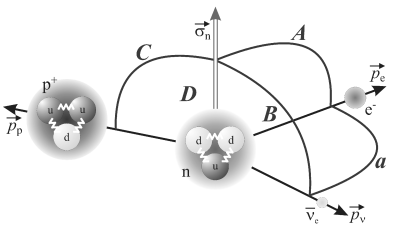

Figure 1: Graphical representation of the important angular correlations in the β-decay of the free neutron.

One of these correlations is the $\beta - \bar{\nu}_e$ angular correlation coefficient a. It describes the angular distribution between the emitted electron and electron-antineutrino and is linked to λ by $a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}$. For further information about the physics of the

neutron, the reader is referred to [1].

2 The *a*SPECT Experiment

*a*SPECT is a MAC-E-filter (**M**agnetic **A**diabatic **C**ollimation combined with an **E**lectrostatic potential). In the following an overview of the measurement principle of a MAC-E filter and the systematic of *a*SPECT is given.

2.1 Measurement Principle

A schematic of the experimental setup of *a*SPECT can be seen in Fig. 2. The neutrons are collimated and guided through the Decay Volume (DV) at high magnetic field (B = 2.2 T). The protons from decays in the DV are adiabatically guided by the magnetic field to a region of 0.44 T, the Analysing Plane (AP). This adiabatic change of the magnetic field causes a momentum transfer from transversal momentum to longitudinal momentum, known as the inverse magnetic mirror effect. Between the electrodes in the DV and the AP a voltage is applied, which acts as a retardation voltage for the protons. This retardation potential performs the energy analysis of the protons. The resolution of a MAC-E filter is determined by the ratio of the magnetic field in the DV and in the AP, in case of *a*SPECT the resolution is about 20 %.

Protons with enough kinetic energy to overcome the potential barrier in the AP are accelerated by typically -15 kV and are detected by a silicon-drift-detector [2]. In this way *a*SPECT measures the integral recoil spectrum of the protons with high precision. This spectrum can be used to determine a and therefore λ with high precision.

For a detailed description of *a*SPECT the reader is referred to [3, 4].

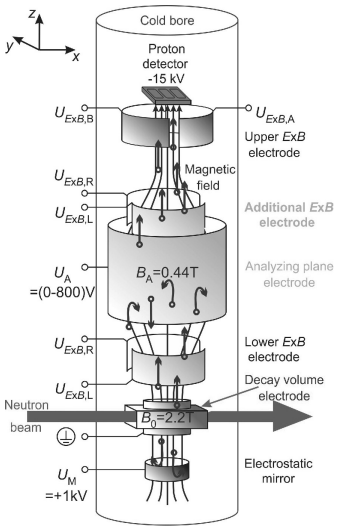

Figure 2: Schematic of the spectrometer *a*SPECT.

2.2 Beam Times and Improvements

*a*SPECT has had several beam times in the past, leading to significant improvements of the system and finally a successful beamtime in 2013. In the following a short overview of these improvements is given. A data acquisition system (DAQ) with logarithmic amplification has been designed and tested to avoid any saturation effects, as seen in 2008. The vacuum has been improved by better cleaning procedures, exchange of materials in the UHV system and the installation of additional turbo molecular and getter pumps. Further, the edges of our electrode system have been smoothed and the whole system has been recoated to reduce field emission. Also an additional dipole electrode has been installed to remove trapped charged particles from a penning-like trap in our spectrometer. These improvements proved to solve the problematic of discharges in the spectrometer and to reduce the background to a sufficiently

low level to determine a with $\frac{\Delta a}{a} \sim 1$ %. The system has been further improved by a new neutron collimation made of conductive boron nitride. Furthermore, a system to measure the beam profile inside of the DV has been designed for investigations of the so-called edge effect with high precision. This system also allows ti introduce radioactive sources into the DV, for alignment and background studies. The DV and AP have been redesigned out of flat electrode plates to obtain well-defined surfaces, which is important to determine the exact potential inside the electrodes.

In 2013 a beam time of 100 days took place with the improved system. This run includes 40 days of pure data taking. During these days no discharges occurred and a sufficiently low background has been observed. No saturation effects in the DAQ have been observed and an additional DAQ without a shaper, but with a high resolution FlashADC has been tested. With a statistical sensitivity of about 1.3 % per day and detector pad (a 3 pad detector was used) many in-depth systematic tests of the system were possible. The analysis of the data and the systematics is currently ongoing.

3 First Results

A thorough investigation of the systematic uncertainties is necessary to achieve the goal of aSPECT of $\frac{\Delta a}{a} \sim 1$ %. One of the main contributions to the systematic error is the uncertainty of the transmission-function of the MAC-E filter. The transmission-function is a function of the ratio of the magnetic field in the AP region and the DV region, as well as the potential difference between AP and DV electrodes [3]

$$f_{Trans} = f\left(\frac{B_{AP}}{B_{DV}}, \Phi_{AP} - \Phi_{DV}\right).$$

3.1 Magnetic field ratio

The magnetic field ratio $r_B = \frac{B_{AP}}{B_{DV}}$ has to be know to a level of $\frac{\Delta r_b}{r_b} \leq 10^{-4}$, which corresponds to an error contribution of $\frac{\Delta a}{a} \sim 0.1\%$ [4]. To achieve this level of precision a nuclear magnetic resonance system (NMR) has been designed, since a standard hall probe can not reach the required precision under lab conditions. The measurement of the magnetic field ratio took place immediately after the beam time at the beam place. The NMR system measured the magnetic field in the DV and AP simultaneously, determining the ratio of the magnetic fields. A small drift has been observed over time for the magnetic field in the single regions, as well as systematic influences of surrounding materials. However, the ratio of the magnetic field stays stable at a level of $\frac{\Delta r_b}{r_b} < 10^{-4}$, see Fig. 3. This is more than sufficient for our goal of $\frac{\Delta a}{a} \sim 1\%$.

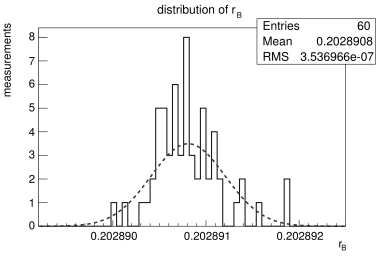

Figure 3: Histogram of the distribution of the r_B values for different settings and over time. The dashed line shows a Gaussian fit to the measured data.

3.2 Potential difference

An accuracy of the retardation potential for the decay protons $U_A = \Phi_{AP} - \Phi_{DV}$ of ~ 10 mV corresponds to an error in a of $\frac{\Delta a}{a} \sim 0.1\%$ [4]. The determination of the potential difference between the AP electrode and the DV electrode is not a trivial task. The retardation voltage is applied by a stable power supply (FUG HCN 0,8M 800) and measured by a precision digital multimeter (Agilent 3458A). However, the applied potential seen by the decay protons is changed by the shape of the electrode, field leakage from outside of the electrode and the work function of the surface material of the electrode.

The shape of the potential due to the electrode design can be simulated. The field leakage can be simulated and measured partially by changing the voltage difference between the electrode and its surrounding during the beam time. The work function, more precisely, the surface contact potential, has to be measured afterwards using eg. a Kelvin Probe. In Fig. 4 a scan of the surface contact potential at air of one of the aSPECT electrodes is shown. Clearly three different areas of different contact potential can be distinguished. These 'patches' are caused by the different crystal orientations of the gold coating of the electrodes [5]. The scanning of the electrodes with a Kelvin Probe is ongoing. First results show an average fluctuation across an electrode of 19 mV and differences of the average between different electrodes of 35 mV. The surface contact potential does not reflect the potential fluctuations, as seen by the protons, which have to be determined by simulations of the electric potential inside the electrodes. But these first results can be used for a worst case scenario, since a fluctuation of 54 mV in the retardation voltage corresponds to $\frac{\Delta a}{a} \sim 0.5\%$, which is compatible with an overall precision of $\frac{\Delta a}{a} \sim 1\%$.

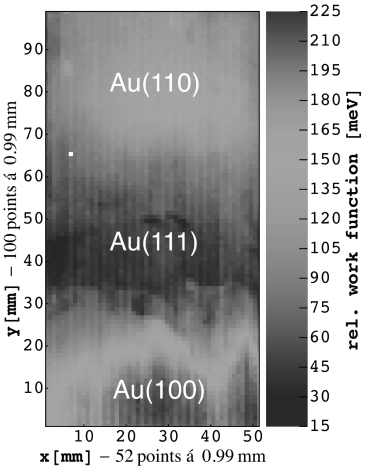

Figure 4: Scan of the surface contact potential with a Kelvin Probe of one of the aSPECT electrodes. For more details see text.

Acknowledgements

This work has been supported by the joint priority program 1491 of the Deutsche Forschungsgemeinschaft and the Austrian Science Fund, project HE2308/9-1, HE2308/9-2, ZI816/1-1, ZI816/4-1, SO1058/2-1 and I534-N20, the University of Mainz, the ILL and the Technische Universität Vienna.

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