Beta-asymmetry measurement with the TRIUMF neutral atom trap

B. Fenker, M. Mehlman, D. Melconian, and P.D. Shidling

Along with collaborators at the TRIUMF Neutral Atom Trap (TRINAT), we have taken data for a measurement of the polarized beta-asymmetry parameter in ^{37}K. The apparatus uses a magneto-optical trap (MOT) to confine and cool neutral ^{37}K atoms and optical pumping to achieve spin-polarization of 99%. The trapped atoms, localized in space and nearly at rest, undergo positron decay and the angular distribution of decay positrons with respect to the spin-polarization axis provides the experimental signature. Furthermore, the polarization is precisely measured using techniques described in our other report. Compared to our 2012 run, we have implemented a number of technical improvements resulting in an increased number of trapped atoms, a longer trap lifetime, and improved detector performance. With these improvements we have collected data with enough statistics for a 0.3% precision measurement. This measurement will be used to constrain physics beyond the Standard Model.

Using a newly developed high-power Titanium-carbide target, TRIUMF was able to deliver more than twice the yield of ^{37}K than during our previous run. Additionally, our own technical improvements increased the trapping and cooling efficiency of the MOT. As a result, we increased the number of trapped atom to almost 9000 and increased the MOT lifetime from 1s in 2012 to 4s in 2014.

The main detectors in the experiment are a pair of plastic scintillators coupled via light guides to photomultiplier tubes (PMT). These record the full energy of the positron but have no position information and are very sensitive to a large gamma-ray background from positrons annihilating in the apparatus. To both provide position information and suppress this background, each scintillator is placed directly behind a thin double-sided silicon-strip detector. The low efficiency of these detectors for detecting gamma-rays suppresses their background and the segmentation provides position sensitivity. A typical positron energy spectrum with and without the coincidence requirement is shown in the Fig. 1. In our run last year, we continuously monitored the gain of each PMT using a stabilized LED. This allows us to measure and correct for any drifts in gain over the roughly three weeks during which the data was taken. Additionally, we added a forced-air cooling system to the silicon detector to combat the heating induced by the AC magnetic fields of the MOT. Operating the silicon detectors at a lower temperature directly reduces the noise inherent in these detectors. Also, in 2012, half the strips on one of these detectors were not functioning which resulted in large complications in the analysis and therefore a significant systematic uncertainty in how best to approach this problem. We have fixed this issue and therefore eliminated this large systematic for the 2014 data set. Finally, we have added position sensitivity to the shake-off electron micro-channel plate. This detector provides an extremely clean signal that a detected beta-decay occurred from within the trap rather than after escaping the trap and perhaps depolarizing. The position sensitivity shown in Fig. 2 has demonstrated that very few of these electrons miss the detector, which confirms that this is not a significant source of systematic uncertainty.

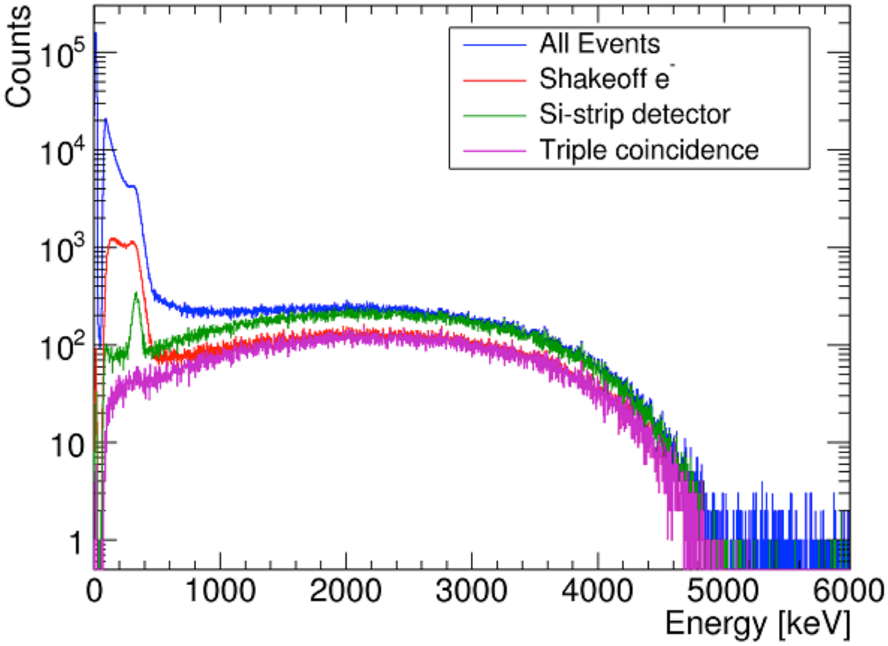

FIG. 1. Positron energy spectrum in the plastic scintillator. Requiring a coincidence with the sake-off electron detector (green) eliminates background from untrapped atoms and requiring a silicon-strip detector coincidence (green) reduces the gamma-ray background. Final analysis is done with the three-fold coincidence (magenta).

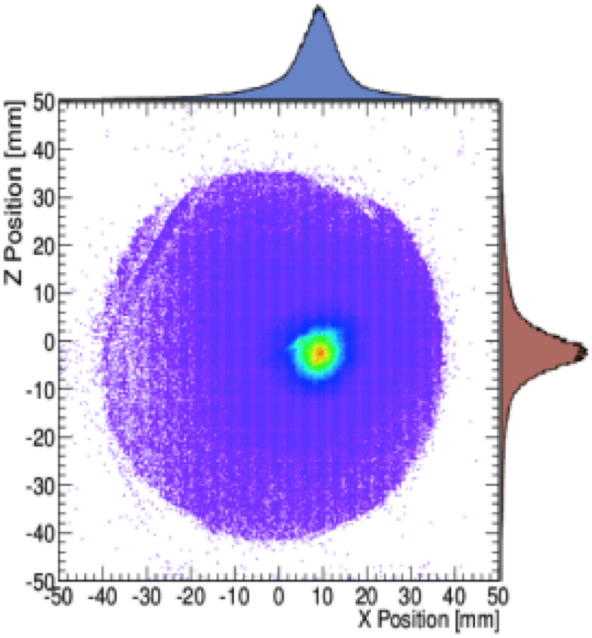

FIG. 2. Position spectrum of atomic electrons shaken off from the recoiling daughter nucleus as a result of the sudden change in nuclear charge. That few events events are registered near the detector edges confirms that the possible systematic effect from electrons missing the detector is quite small.

With the upgrades and larger number of atoms, the current data set has a higher statistical sensitivity and better control over systematic uncertainties. The total statistical uncertainty is expected to be about 0.3%, half as large as the 2012 data set. We have also reduced all the main sources of systematic uncertainty. The proper functioning of all regions of the silicon detectors has already been discussed and having more trapped atoms allows a more precise determination of trap parameters such as size and average velocity. Also, the larger number of trapped atoms has resulted in a very clean polarization signal which allows a much more precise measurement than before and is discussed in our other report. Combining systematic and statistical uncertainties, we expect the final uncertainty to be $\lesssim 0.5\%$, making it the most precise determination of the beta-asymmetry in a nucleus and of similar precision to measurements in the neutron. The results will be used to constrain possible Standard Model extensions and in particular search for a possible $V + A$ (vector + axial-vector) component in the charged weak interaction.