AIP Conference Proceedings

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Jianglai Liu and UCNA Collaboration

Citation: AIP Conference Proceedings **1182**, 674 (2009); doi: 10.1063/1.3293897
View online: http://dx.doi.org/10.1063/1.3293897
View Table of Contents:
http://scitation.aip.org/content/aip/proceeding/aipcp/1182?ver=pdfcov
Published by the AIP Publishing

Measuring Neutron Beta Decay “A” Parameter Using Ultracold Neutrons

Jianglai Liu

W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125, USA
Representing the UCNA Collaboration

Abstract. The UCNA experiment is designed to measure the neutron decay beta asymmetry (the “A” parameter) to very high precision (<0.5%), using the ultracold neutron (UCN) source at the Los Alamos National Lab. After a successful commissioning run in 2007, data were taken in 2008 which will lead to a 1% measurement of *A*. In this talk, I will discuss major improvements we made in 2008, and report the status of data analysis.

Keywords: UCN, neutron beta decay, A parameter
PACS: 12.15Ff,12.15Hh,13.30Ce,23.40Bw

INTRODUCTION

In polarized neutron decays, the angular distribution of the outgoing electrons is given by

$$dW(E_e,\theta) = F(E_e)(1+AP\beta\cos\theta)\,, \tag{1}$$

where E_e is the electron energy, β is the electron velocity relative to c, P is the polarization of the neutron, θ is the angle between the neutron spin and the electron momentum, and $F(E_e)$ is the electron energy spectrum for unpolarized neutrons. A is the so-called beta asymmetry, or the “A” parameter. To first order, A is related to the ratio of the nucleon axial to vector coupling constant g_A/g_V as

$$A = \frac{-2\lambda(1+\lambda)}{1+3\lambda^2}, \lambda = -|\frac{g_A}{g_V}|\,. \tag{2}$$

Therefore, a measurement of A allows a direct determination of λ, a fundamental constant which has no first principle prediction in the standard model. A precise determination of λ also provides stringent constraints to the standard model [1].

Before 2007, all data on A were made with cold neutron beams. The consistency among these experiments is not very good [2], and PDG quotes a 1.1% uncertainty to A [1]. The UCNA experiment is designed to measure the A parameter using ultracold neutrons, which has very different systematics compared to cold neutron experiments, with an aim to elucidate the experimental situation.

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[1] E.g., a combination of λ and the neutron lifetime gives determination of the CKM matrix element V_{ud} independent of nuclear models.

[2] PDG [1] has a reduced χ^2 of 2.3 (for 3 degree-of-freedom). The quoted uncertainty has a χ^2 penalty factor.

CP1182, *Intersections of Particle and Nuclear Physics,*
Proceedings of the 10th International Conference, edited by M. L. Marshak

UCNA

The details of experimental setup of UCNA are explained in [2, 3]. We used the solid deuterium source at the Los Alamos Neutron Science Center. UCN are polarized by a 7 T primary polarizer, coupled to an adiabatic fast passage (AFP) spin flipper that allows us to control the spin state of UCN. Polarized UCN enter the superconducting spectrometer (SCS), and are confined in an electropolished Cu trap with Be-coated ultrathin Mylar endcaps. A 1-T field is oriented along the decay trap axis, along which decay electrons spiral toward one of the two identical beta detector packages. Each beta detector package consists of a multiwire proportional chamber (MWPC) backed by a plastic scintillator, with scintillation lights measured by four phototubes. MWPC provides position determination, and beta scintillator provides triggers as well as energy determination. Each MWPC has a thin front and back mylar windows which separate chamber gas (neopentane) from spectrometer vacuum [4]. The asymmetry in the two detectors as a function of energy, averaged over the two polarization states, leads to a determination of A (Eqn. 1).

Summary of Results from 2007

In 2007, at the end of the commissioning run, we took 62 hours of beta decay data. The extracted A from this measurement is $A = -0.1138 \pm 0.0051$ [2], consistent with the world data so far with a 4.5% uncertainty. The left three columns in Table 1 summarize the major uncertainty budget for this measurement. We note that the uncertainty of neutron polarization was statistics limited. The lack of extensive source calibration resulted into a rather large uncertainty related to detector linearity. The corrections to the backscattering and angle effects (angle-dependent energy loss through windows), both related to the windows in the spectrometer, relied purely on Monte Carlo, and assigned uncertainties reflect the confidence we had on the Monte Carlo.

TABLE 1. Major uncertainty budget in 2007 and expected uncertainties in 2008.

	2007		2008	
	Correction	Uncertainty	Correction	Uncertainty
Statistical	n/a	4%	n/a	<0.8%
Polarization	0	1.3%	0	<0.7%
Linearity	0	1.5%	0	<0.5%
Angle Effects	−1.6%	0.5%	−0.8%	<0.3%
Backscattering	1.1%	0.4%	0.5%	0.2%
Background	0	0.2%	0	<0.2%
Total		4.5%		<∼1.2%

UCNA Updates in 2008

In 2008, we made major improvements in order to improve the precision from all fronts. Compared to 2007, we collected a factor of 30 more beta decay events. Not only does this reduce the statistical uncertainty significantly, more statistics also allow us to study systematic effects more thoroughly.

UCN Depolarization. The depolarization measurements interleaved in beta decay measurements [3] have significantly improved statistics in 2008. In addition, many dedicated measurements were made to study the systematics in such a measurement [4]. Based on preliminary analysis so far, the uncertainty on UCN polarization has been reduced to 0.7% under very conservative assumptions.

Beta Detector Response and Linearity. We used detected light variation from neutron beta end point to map out the position response function for each individual phototube, as shown in the left panel in Fig. 1. Such a map is used to correct for the apparent light output event by event. The right panel of Fig. 1 shows the corrected light for a given tube for different sources as a function of vertex radius. The light from a given source becomes independent of the position, clearly demonstrating the validity of this procedure. Varying intensity LED sources (one for each scintillator) were used to illuminate scintillators frequently to keep track of the relative nonlinear responses from phototube to phototube. we employed multiple beta sources [5] in dedicated calibration runs to determine the absolute nonlinearity. Currently we are finalizing the energy reconstruction procedure.

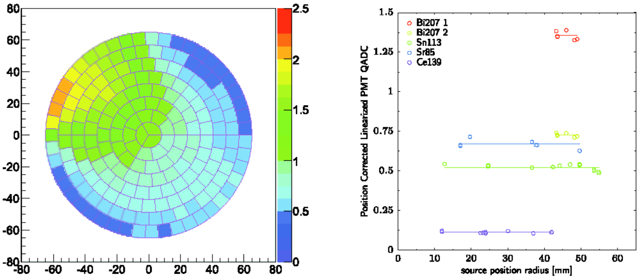

FIGURE 1. Left: position response function for a given phototube extracted from the neutron beta end point in each pixel. Right: position corrected ADC values for the same phototube for various beta sources.

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[3] A normal beta decay run cycle consists of three different types of runs: a beta decay run with a given polarization (1 hour), a background run (10 minutes, by turning off UCN beam), and a UCN depolarization run (5 minutes). The amount of depolarized neutron was measured with a ^{3}He UCN detector upstream of the main polarizer. After loading the spectrometer with UCN with a given polarization, the right spin neutrons were "cleaned" by draining into the ^{3}He detector, whereas the wrong spin neutrons were trapped downstream of the main polarizer. Some seconds later, the spin flipper changed state, allowing wrong spin neutrons to flip spin and being "unloaded" and detected by the ^{3}He detector.

[4] Particularly the amount of right spin neutron during the "unloading" phase. See footnote #3.

[5] We used ^{113}Sn, ^{85}Sr, ^{207}Bi, ^{114m}In, ^{139}Ce, and ^{109}Cd, which cover the entire energy range of neutron beta spectrum

Decay Trap and Detector Windows Systematics. To study the systematics due to the decay trap window and detector windows (the backscattering and angle effects), the spectrometer geometry was changed several times during the run, as summarized in Table 2. By varying the "weight" of decay trap window and detector windows, we can use different observables to calibrate the Monte Carlo. With thinner windows in 2008 (except geometry B) and a calibrated Monte Carlo, we expect to cut down both the corrections and the uncertainties to backscattering and angle effects by roughly a factor of two, compared to 2007.

TABLE 2. Summary of different SCS geometry in 2007-2008.

Geometry	Decay Trap Windows (μm)	MWPC Windows (μm)	Beta Events (M)
2007	2.5	25	0.8
A	0.7	25	10
B	12.7	25	10
C	0.7	6	4
D	none	6	calibration only

UCN-induced Background. Capture gamma rays of UCN on Cu could produce (irreducible) UCN-induced background. We put a constraint on such a background in a special setup by placing a 1/4-inch acrylic piece outside the decay trap to block the decay electrons ("beta blocker") from UCN [6]. Preliminary analysis of the beta blocker measurement sets an upper limit of 0.2% to the UCN-induced background relative to normal beta decay rate.

Summary and Outlook. The projected uncertainty budget in 2008, due to all improvements described above, are summarized in the right two columns in Table 1. As the data analysis progresses, some of the uncertainty could get reduced further. We are on track to a $\sim$1% measurement of A.

ACKNOWLEDGMENTS

The author would like to acknowledge the contributions of the members of the UCNA collaboration. The UCNA experiment is supported in part by the Department of Energy, National Science Foundation, and Los Alamos National Laboratory LDRD.

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[6] Since the Cu gammas can also make Compton electrons in the beta blocker, we varied the position of the beta blocker relative to the decay trap to produce a lever arm for subtracting such a Compton component.