

Test of Time Reversal Symmetry using polarized ^8Li at TRIUMF-ISAC

J. Murata¹²³, H. Baba³, J.A. Behr⁴, M. Hata¹, Y. Hirayama⁵, M. Ikeda¹, D. Kameda³, H. Kawamura³⁶, R. Kishi¹, C.D.P. Levy⁴, Y. Nakaya¹, K. Ninomiya¹³, M. Nitta¹, N. Ogawa¹, J. Onishi¹, R. Openshaw⁴, M. Pearson⁴, E. Seitabashi¹, Y. Totsuka¹, T. Toyoda¹, M. Uchida⁷

1. Department of Physics, Rikkyo University, Tokyo 171-8501, JAPAN

2. Department of Physics and Astronomy, University of British Columbia,
Vancouver, BC V6T 1Z1, CANADA

3. Nishina Center, RIKEN, Saitama 351-0198, JAPAN

4. TRIUMF, Vancouver, BC V6T 2A3, CANADA

5. KEK, Tsukuba, Ibaraki 305-0801, JAPAN

6. Cyclotron and Radioisotope Center, Tohoku University, Miyagi 980-8578, JAPAN

7. Department of Physics, Tokyo Institute of Technology, Tokyo 152-8550, JAPAN

E-mail: jiro@rikkyo.ac.jp

Abstract. A new experimental project called MTV (Mott Polarimetry for T-Violation Experiment), is running at TRIUMF. It aims to achieve the highest precision test of time reversal symmetry in polarized nuclear beta decay by measuring a triple correlation (R -correlation), motivated to search a new physics beyond the standard model. It is because the CKM predicts negligible effects on the u - d quark system. In this experiment, the existence of non-zero transverse electron polarization is examined utilizing the analyzing power of Mott scattering from a thin metal foil. Backward scattering electron tracks are measured using a multi-wire drift chamber event-by-event for the first time. The tracking device eliminates the largest systematic effect, which has been limiting the sensitivity of previous studies. The MTV experiment was commissioned at TRIUMF-ISAC in 2009 using an 80% polarized ^8Li beam at 10 Mpps resulting in 3.6% precision on the R -parameter, after performing a feasibility test at KEK-TRIAC in 2008 using an 8% polarized beam at 100 kpps yielding 41% statistical precision. In 2010, a physics production run is scheduled, aiming to reach below 0.1% precision. In this document, the preparation status for the 2010 run and results from the commissioning run are described.

1. Introduction

Time reversal symmetry is one of the most fundamental symmetries in nature, and its violation is considered equivalent to CP -violation under the CPT -theorem. Almost all the CP -violating phenomena that have been observed for K -meson and B -meson systems are considered to be consistent with the Cabbibo-Kobayashi-Maskawa (CKM) mechanism. On the other hand, it is becoming clear that the amount of CP -violation predicted by the CKM is insufficient to explain quantitatively the observed large asymmetry between the amounts of matter and anti-matter in our universe. Therefore, it is widely believed that there must be large $CP(T)$ -violating phenomena outside of the CKM mechanism. The present study is one of the attempts searching for such a “large” T -violation beyond

the CKM in nuclear beta decay. CKM predicts negligible effects for normal nuclear systems [1]. On the other hand, models based on physics beyond the standard model predict detectable CP -violating effects, i.e. T -violating effects in the normal nuclear system. Therefore, observation of a non-zero CP -(T)-violating effect is direct evidence for new physics beyond the standard model.

T -violation has been tested in many microscopic systems as listed in Table I. There are two categories of T -violation; one is not only T -violating but also parity violating, and the other one is parity conserving. In the present study, we are aiming to explore the T - and P - violating phenomena. In Table I, experimental results on measurements of a triple correlation named “ R -correlation”, are listed for various systems [2-6].

System	Correlation	Results	Experiment
$\bar{\Lambda}_0 \rightarrow \pi^- + \bar{p}$	$\vec{J}_\Lambda \cdot (\vec{p}_p \times \vec{\sigma}_p)$	$(94 \pm 60) \times 10^{-3}$	CERN '72 [2]
$^{19}\bar{Ne} \rightarrow ^{19}Fe + \bar{e}^- + \bar{\nu}_e$	$\vec{J}_{Ne} \cdot (\vec{p}_e \times \vec{\sigma}_e)$	$(79 \pm 53) \times 10^{-3}$	Princeton '83 [3]
$^8\bar{Li} \rightarrow ^8Be + \bar{e}^- + \bar{\nu}_e$	$\vec{J}_{Li} \cdot (\vec{p}_e \times \vec{\sigma}_e)$	$(-0.9 \pm 2.2) \times 10^{-3}$	PSI '03 [4]
$\bar{\mu} \rightarrow \bar{e}^- + \nu_e + \bar{\nu}_\mu$	$\vec{J}_\mu \cdot (\vec{p}_e \times \vec{\sigma}_e)$	$(-3.7 \pm 7.7) \times 10^{-3}$	PSI '05 [5]
$\bar{n} \rightarrow p + \bar{e}^- + \bar{\nu}_e$	$\vec{J}_n \cdot (\vec{p}_e \times \vec{\sigma}_e)$	$(8 \pm 15) \times 10^{-3}$	PSI '09 [6]

Table I: Present decay results on T -violating and P -violating triple correlation “ R ”.

Definition of the R -correlation can be found in the following beta decay rate function [7].

$$\omega(<\vec{J}>, \vec{\sigma} | E_e, \Omega_e) dE_e d\Omega_e = \frac{F(\pm Z, E_e)}{(2\pi)^4} p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e \quad (1)$$

$$\times \xi \left\{ 1 + b \frac{m}{E_e} + \frac{\vec{p}_e}{E_e} \cdot \left(A \frac{<\vec{J}>}{J} + G \vec{\sigma} \right) + \vec{\sigma} \cdot \left[N \frac{<\vec{J}>}{J} + Q \frac{\vec{p}_e}{E_e + m} \left(\frac{<\vec{J}>}{J} \frac{\vec{p}_e}{E_e} \right) + R \frac{<\vec{J}>}{J} \times \frac{\vec{p}_e}{E_e} \right] \right\}$$

Existence of a non-zero value of the R parameter implies non-zero transverse electron polarization perpendicular to the parent nuclear polarization direction. From Table I, it can be seen that the finest precision was obtained by a radioactive nuclear beta decay experiment performed at PSI [4] using polarized ^8Li , with the result $R = (-0.9 \pm 2.2) \times 10^{-3}$. The relatively high precision was mainly due to good statistics.

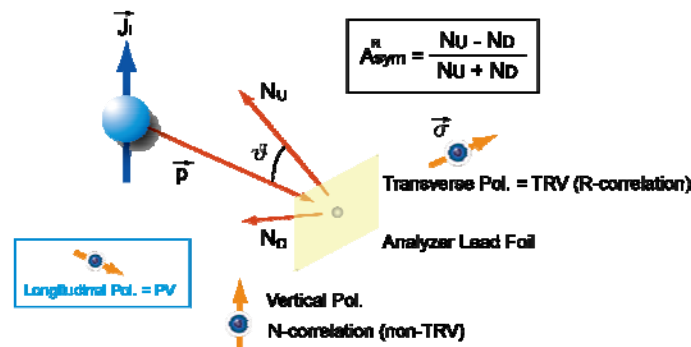


Figure 1. Detection principle of the transverse polarimetry.

The present study is testing the same T -violating correlation using the very high beam intensities and polarization of ^8Li at TRIUMF, combined with electron polarimetry using the analyzing power of Mott scattering, as shown in Figure 1. The electron transverse polarization in the horizontal direction can be extracted from the measured value of the backward scattering up and down asymmetry using the known analyzing power.

2. Experimental Setup

In the MTV experiment, a planar drift-chamber is used to track both initial electron tracks and backward scattering tracks (V-tracks), considering the maximum figure of merit at around 110 degrees. A schematic view of the experimental setup is shown in Figure 2. At TRIUM-ISAC, optically pumped polarized ^8Li beam, at 28 keV with 10^7 pps and 80% polarization, is implanted on the surface of a 10 μm thick aluminium stopper, which is placed between permanent spin holding magnets producing about 500 Gauss. The spin relaxation time is 2.3 sec. The stopper is in vacuum within an FRP tube. Beam polarization is monitored by plastic asymmetry scintillation counters surrounding the stopper, set outside the FPR tube. Emitted electrons enter the drift chamber through a 400 μm thick aluminium window. A fraction of order 10^{-4} of the electrons are backwardly scattered by a 10 μm gold (or 100 μm lead) analyzer foil, set behind the drift chamber. Electron energy is measured using stopping plastic scintillation counters.

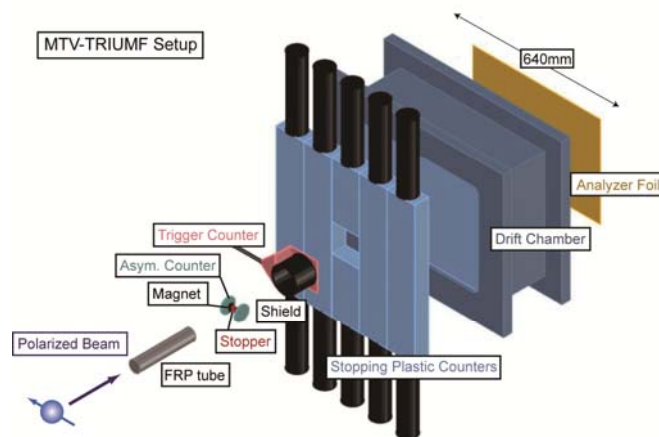


Figure 2. MTV Experimental Setup (Stretched view).

A Level-1 trigger is generated with the plastic scintillation counter logic. Real V-track events, which can be considered to be scattered at the analyzer foil, contributed only 0.2% of the Level-1 triggered events in an offline analysis. The dominant background events come from scattering by the materials such as the chamber wall, windows, wires and gas. In order to reduce the DAQ triggering rate, we developed an FPGA based Level-2 triggering system, performing online hitt pattern recognition using all the anode signals from the drift chamber.

3. Experiment at KEK-TRIAC 2008

The MTV project was first commissioned at KEK-TRIAC in 2008, using 8% polarized ^8Li beam at 178 keV/u with 10^5 pps. At TRIAC, a tilted foil technique was used to produce the beam polarization, using 20 sheets of $3\mu\text{g}/\text{cm}^2$ polystyrene. The first test experiment was performed in April 2008 using unpolarized ^8Li beam at 10^4 pps, confirming V-tracking ability using the drift-chamber-based Mott polarimeter, as shown in Figure 3. After building the Level-2 triggering system, physics data taking was performed in September 2008, using vertically polarized beam at 10^5 pps. We accumulated about 6×10^5 V-tracking events for this MTV-TRIAC measurement.

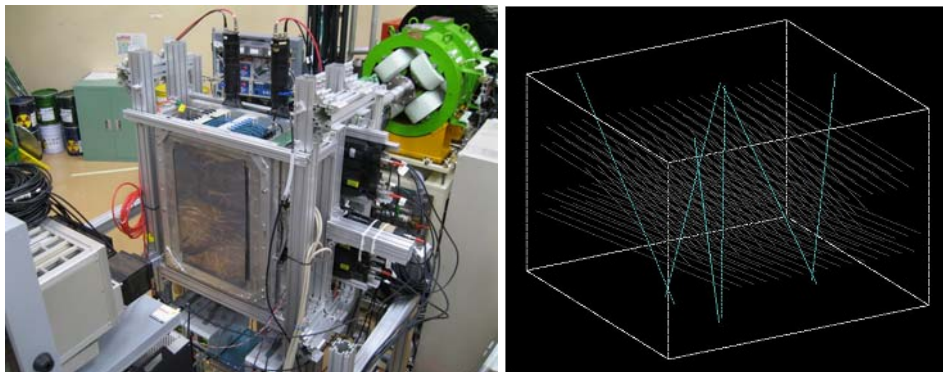


Figure 3. (Left) MTV-experimental setup at KEK-TRIAC 2008.
(Right) Event display of the V-tracks observed at KEK-TRIAC.

Figure 4 shows the backward scattering angular distribution of the Mott scattering at MTV-TRIAC for beam spin up and down settings. The beam polarization direction was changed by rotating the setting angle of the tilted foils every 5 minutes. The result, $R = -0.020 \pm 0.41_{\text{stat}} \pm 0.024_{\text{sys}}$ was obtained [8].

Here, the dominant systematic error source was the dependence of the V-tracking asymmetric efficiency on the counting rate. Under such an effect, a change in the beta emission angular distribution can be a source of a fake asymmetry which cannot be cancelled by flipping the beam polarization. The size of this effect is evaluated using beam intensity dependence on the obtained real events. Therefore, the systematic error can be reduced in a higher statistics measurement.

Although the result at MTV-TRIAC was not the finest precision result compared to past studies at PSI, it could be said that this was the first result from a systematics-free study from an event-by-event tracking measurement in a nuclear system. It is because a simple counter type experiment without tracking cannot avoid a systematic effect of solid angle changing due to beta asymmetric emission to the beam polarization.

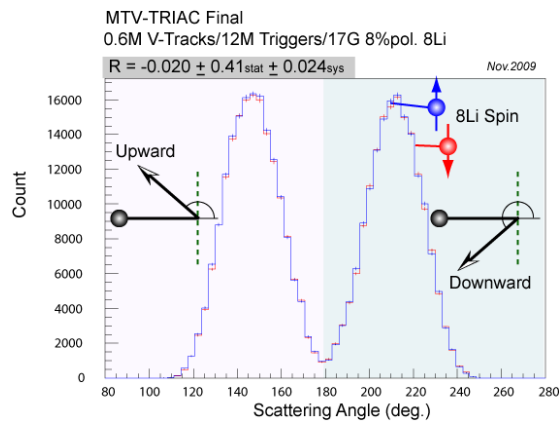


Figure 4. Result of Mott scattering angular distribution from the MTV-TRIAC 2008.

4. Experiment at TRIUMF 2009

The MTV project at TRIUMF was proposed in 2008. After conducting the KEK-TRIAC experiment, we moved the whole experimental setup to the low energy polarized beam line at TRIUMF. At the so-called “OSAKA” beam line, a horizontally polarized 28 keV beam at 10^7 pps with 80% polarization is available. After commissioning a hot 100MBq ^{90}Sr source, the first test beam MTV-Run I was performed in November 2009, as shown in Figure 5. The main purpose of the MTV-Run I was to check the statistical advantage compared to KEK-TRIAC. For this reason, the beam intensity dependences of the triggering rate, data taking rate and V-track recording rate were studied. Although

offline analysis is still underway, we have confirmed a statistical precision of about 3% for the Run-I 70% analyzed data.

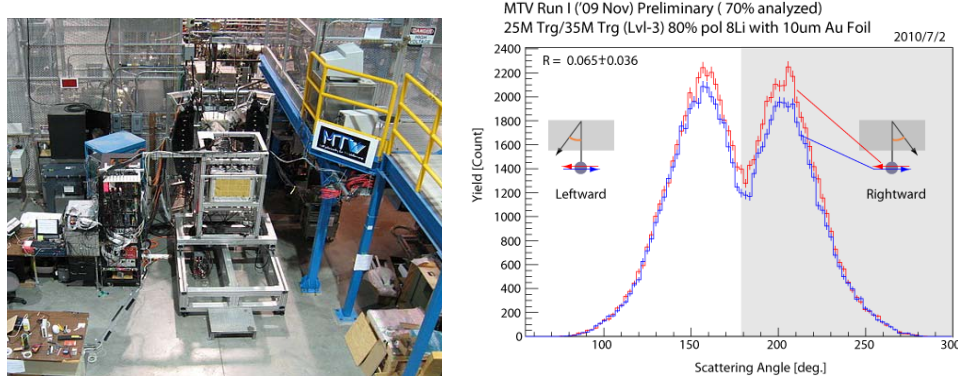


Figure 5. (Left) MTV-Run I experimental setup at TRIUMF-ISAC 2009.
(Right) MTV-Run I result on Mott scattering angular distribution.

5. Future

The MTV Run-I confirmed that the MTV detector has the potential to explore time reversal symmetry to the highest precision. In order to achieve it, we have developed a new fast DAQ system with buffering TDC readout having a data taking rate of 50kHz, much faster than the 1kHz rate of the MTV-TRIAC experiment and the MTV Run-I. In addition, a low detection efficiency problem due to aging of drift chamber wires has been fixed by re-wiring all the anode and field wires. The MTV project is going to perform physics data taking MTV Run-II in 2010 and 2011 with the improved performance. The expected sensitivity is shown in Figure 6.

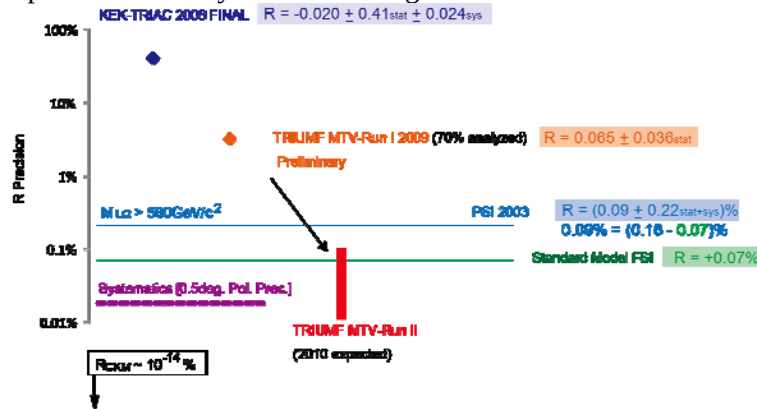


Figure 6. Summary of physics sensitivities.

A dominant systematic effect comes from a physics correlation, defined as the N -correlation in (1). The standard model prediction for the N -correlation is large compared to the size of the final state

interaction for the R -correlation. Indeed, $R_{\text{FSI}} = A \frac{\alpha Z_F m_e}{p_e} \approx 0.7 \times 10^{-3}$ and

$N_{\text{SM}} = -\frac{m_e}{E_e} A \approx 30 \times 10^{-3}$ is predicted in a first order calculation for ^8Li [7]. If the Mott polarimeter is

misaligned in the direction perpendicular to the parent nuclear polarization, sizable false effects can be produced by the N -correlation. For this reason, we are going to install a new forward beam polarimeter designed to determine the beam polarization direction with 0.5 degrees precision, which

can reduce the systematic effect to be no larger than 0.02%. In addition, the electron energy dependence on the R -correlation is also going to be measured in order to look the possible appearance of an electromagnetic final state interaction for the first time, assuming its electron momentum dependence. It is necessary because our statistical precision is expected to be below 0.1%, as shown in Figure 6. All the beam related effects such as absolute value of polarization, spot position etc., are only needs to be considered as systematic corrections, just after observing a non-zero value of the R -parameter.

In summary, we are aiming to achieve below 0.1% precision in the Run-II measurement, which is about the size of the final state interaction. In order to make a precision measurement of electron momentum for the final state interaction evaluation, and to improve the detector symmetry to avoid systematic effects originating from the asymmetric geometry, we have started to build a next generation V-tracking cylindrical drift chamber (CDC). A quantitative study of the sizable T -violating correlation, using the MTV-CDC, is planned in the very near future in order to distinguish between new physics and the standard model effect in the expected non-zero signal. This work is supported by KAKENHI (21684012).

6. References

- [1] P. Herczeg and I.B. Khriplovich, Phys. Rev. D56 (1997) 80
- [2] W.E. Cleland *et al.*, Nucl. Phys. B40 (1972) 221
- [3] M.B. Schneider *et al.*, Phys. Rev. Lett. 51 (1983) 1239
- [4] R. Huber *et al.*, Phys. Rev. Lett. 90 (2003) 202301
- [5] N. Danneberg *et al.*, Phys. Rev. Lett. 94 (2005) 021802
- [6] K. Bodek *et al.*, AIP Conf. Proc. 842 (2006) 805
- [7] J.D. Jackson *et al.*, Nucl. Phys. A4 (1957) 206, Phys. Rev. 106 (1957) 517; N. Severijns *et al.*, Rev. Mod. Phys. 78 (2006) 991
- [8] H. Kawamura, "Study of time reversal symmetry in polarized nuclear beta-decay using tracking detector", doctoral thesis, Rikkyo Univ. (2010)