SEARCH FOR LIGHT NEUTRAL BOSONS IN THE TREK/E36 EXPERIMENT AT J-PARC

A Dissertation

by

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ABSTRACT

Search for Light Neutral Bosons in the TREK/E36 Experiment at J-PARC

(August 2020)

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The Standard Model (SM) represents our best description of the subatomic world and has been very successful in explaining how elementary particles interact under the influence of the fundamental forces. Despite its far reaching success in describing the building blocks of matter, the SM is still incomplete; falling short to explain dark matter, baryogenesis, neutrino masses and much more. The E36 experiment conducted at J-PARC in Japan, allows for sensitivity to search for light $U(1)$ gauge bosons, in the muonic K^+ decay channel. Such $U(1)$ bosons could be associated with dark matter or explain established muon-related anomalies such as the muon $g-2$ value, and perhaps the proton radius puzzle. A realistic simulation study was employed for these rare searches in a mass range of 20 MeV to 100 MeV. Currently, about $\sim 8\%$ of the data has been analyzed and upper limits for the A' branching ratio $\mathcal{B}r(A')$ have been extracted at 95% CL.

Dedicated to my parents.

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I would like to acknowledge...

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CHAPTER 1
INTRODUCTION

The TREK/E36 experiment was conducted at the Japan Proton Accelerator Research Complex (J-PARC), with physics data-taking occurring from September to December 2015, and has been decommissioned as of March 2016. TREK/E36 was part of the TREK program at J-PARC, where TREK stands for Time Reversal Experiment with Stopped Kaons. The primary goal of the TREK/E36 experiment was to provide a high precision electroweak measurement in order to test lepton universality, which is expressed as an identical coupling constant of the charged lepton family (e, μ, and τ). Lepton universality is a staple of the Standard Model (SM) and any violation of this would be clear evidence of New Physics (NP) beyond the SM.

Data analysis of two-body leptonic decays of stopped kaons K_{l2} is currently being performed in order to provide a precise measurement of the decay width ratio $R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ to test lepton universality. Due to the $V - A$ structure of charged current couplings, the ratio R_K is helicity-suppressed in the SM and is therefore sensitive to beyond SM physics. The K_{l2} decay width is calculated as

$$\Gamma(K_{l2}) = g_l^2 \frac{G^2}{8\pi} f_K^2 m_K m_l^2 \left(1 - \frac{m_l^2}{m_K^2}\right)^2 \tag{1.0.1}$$

where g_l is the coupling constant of the lepton current, G is the Fermi constant, f_K is the kaon form factor and m_K and m_l are the kaon and lepton masses respectively. The SM value for R_K is very precise because to a first approximation the strong interaction dynamics from equation 1.0.1 cancel

$$
\begin{aligned}
R_K^{SM} &= \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} \\
&= \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r) \\
&= (2.477 \pm 0.001) \times 10^{-5} \qquad (1.0.2)
\end{aligned}
$$

where δ_r represents radiative corrections, detailed calculations of which were carried out in. Thus the SM value for R_K^{SM} has been calculated to high accuracy ($\Delta R_K/R_K \sim 0.4 \times 10^{-4}$) thereby making it possible to search for NP effects by conducting a precise measurement of R_K.