Current status on the recent limits of millichaged particles based on germanium technology

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This article gives a review of the latest constraints on millicharged particles, as investigated by several research collaborations worldwide. Particular focused on the findings from experiments utilizing germanium (Ge) detector technology, including TEXONO, GEMA and CDMS. The review aims to summarize and compare the results of these collaborations to showcase the collective understanding of the current experimental landscape in the search for millicharged particles.

Introduction

The unsolved issue in physics is quantization of charge with several theories reported its cause, such as higher-dimensional theories, grand unified theories as well as magnetic monopoles. Various experiments had given astrophysical constraints on millicharged particles[1]. Charge quantization verification involves searching for particles with very small charges (δ_e, where $\delta \ll 1$) or finding non-zero charges in neutrinos. As shown in figure, it is illustrated that γ-rays from nuclear reactors (around 10 MeV), while those between 15 MeV, dominates (χ_q - $\bar{\chi}_q$) pair production (FIG. 1). The nuclear reactor's core, producing 1 GW thermal power, emits approximately 10^{20} photons per second in the MeV order. When the interaction of photons with electrons happens, it generates around 2.3 10^{18} δ^2 millicharged particles per second at core of nuclear reactor. At core, the Compton process primarily produce millicharged particles. Whereas Bremsstrahlung effect is one of the main mechanism in the production of relativistic millicharged particles caused by interaction of high-energy cosmic rays with nuclei present in the Earth's atmosphere. So by investigating cosmic rays one can study the limits of millicharged particles, which are very tough to find due to their energy loss being proportional to δ^2. These are basically low ionizing particles (LIP) which loses less energy than unit charge particles while maintaining similar conditions. Low-threshold point contact Ge detector is best tool for the detection, but the range of mass for these particles remained uncertain.

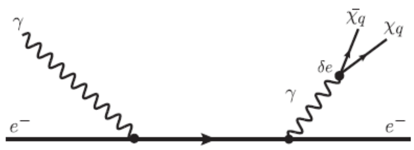
1.png


FIG. 1: Schematic diagram showing the production of millicharged particle - anti particle pair (χ_q - $\bar{\chi}_q$) via Compton process [2].

Experimental Overview

TEXONO based at KSNL, utilizes Ge detectors with low energy thresholds and high resolution for neutrino and dark matter research. TEXONO has set a notable limits on dark matter interactions, neutrino millicharge and magnetic moments. In 2014, TEXONO compared their data, collected over a periods when reactor is operational, with $\nu_e - A(\delta Q)$ using the Multi-Configuration Relativistic Random-Phase Approximation (MCRRPA). TEXONO reported a limit on neutrino millicharge $|\delta Q| < 2.1 \times 10^{-12}$ at 90% C.L with superimposing the 2σ band. with no direct proof for δQ-induced atomic interactions [3]. In 2019, they reported an excluded regions for millicharged particles, improving limits for light-χ_q of mass $(m_{\chi q}) < 4 \times 10^{-4}\mathrm{GeV}/c^2$ and

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presenting a plots for dark sector millicharged particles. The exclusion plot for $m_{\chi q}$ and δ spanned $10^{-6}\,\mathrm{GeV}/c^2$ to 1 GeV/c^2. An excluded spectrum plotted for $m_{\chi q} = 1\,\mathrm{keV}$ and $\delta = 1.06 \times 10^{-7}$ [2].

GEMMA focuses on study of antineutrino-electron scattering at facilty of Kalinin Power Plant with 1.5 kg high-purity Ge detector. The detector is equipped with shielding to reduce background noises. In 2012, the collaboration has set upper limits on neutrino magnetic moments and used this to report an upper limit on neutrino millicharge, reaching $|\delta Q| < 2.7 \times 10^{-12} e_0$ at 90% C.L., where e_0 is the electron charge [4]. They had planned to lower the detection threshold with GEMMA-II by reducing the threshold from 2.8 keV to 1.5 keV whereas GEMMA-III targeted as low as 350 eV. These significant upgrades are expected to improve the upper limits on neutrino millicharge to $|\delta Q| \sim 9.4 \times 10^{-13} e_0$ and $|\delta Q| \sim 5.5 \times 10^{-13} e_0$, respectively [5].

CDMS-II experiment which is located in the Soudan underground laboratory, reported the first direct limit on LIP in 2015. The study focused on relativistic fractionally charged particles with a charge less than $e/6$ (where e is the electron charge). CDMS operated in a tower configuration, using five towers of detectors, specifically towers 2 and 4 are for the LIP searches. The experimental setup involves nineteen Ge and eleven Si detectors, kept below 50 mK. The collaboration presented an plot with 90% C.L., indicating vertical intensity of LIP versus inverse electric charge in units of $1/e$. The collaboration team focuses to enhance sensitivity to charges $\lesssim e/20$ using SuperCDMS detectors [6,7].

Conclusion

Millicharged particles are very important for exploring particles beyond the standard model. Experiments worldwide are focused on searching for these particles, with neutrino-based experiments delivering promises since neutrinos are prime candidates for millicharged particles. Ge-based collaboration are working to lower its detection thresholds and this improvement is expected to set new limits in the near future.

Acknowledgments

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