PROCEEDINGS OF SCIENCE

Commissioning and the first observation of ISAI, Investigating Solar Axion by Iron-57, experiment.

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ISAI is an experiment of solar axion search dedicated for axion-nucleus interaction. An event-triggered monolithic Silicon On Insulator (SOI) X-ray pixel detector cooperated with position sensitive anti-coincidence timing counter observes a 14.4 keV γ-ray as a converted signal of solar axion by ^{57}Fe isotope. Because the background from radioactivity in detector defines the axion sensitivity, we had developed a rigid-flexible circuit board to separate the pixel sensor and the peripheral electrical components having major radioactivities. Two timing triggers from the pixel detector and the anti-coincidence counter are recorded by a high time resolution DAQ system so that background induced by cosmic-ray or environmental radiation can be rejected in the offline analysis. We will present the experimental apparatus, the commissioning and the first background observation using the half detector without the anti-coincidence measurement.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08-01.09.2023
University of Vienna

*Speaker

PoS(TAUP2023)086

1. Introduction

Strong CP problem has been unsolved issue in the Standard Model in particle physics for over forty years. A CP violating term in Lagrangian of quantum chromodynamics which can induce a neutron dipole moment [1]. However, the term is unnaturally highly suppressed $\lesssim 10^{-10}$ by the interpretation of the latest measurement [2]. The most promising solution is to introduce a global chiral $U(1)$ symmetry proposed by Peccei-Quinn symmetry [3] which breaks spontaneously and a Nambu-Goldstone boson, known as axion, appears. Original Peccei-Quinn symmetry thought to break in an energy scale f_a of electroweak but it was ruled out by experiment. At present, invisible axions have a much larger energy scale, so called KSVZ [4] axion and DFSZ axion [5] models, have been studied theoretically and searched experimentally. Axion can interact with photon, electron and nucleon in our interest with the coupling constant g_{an}.

The Sun would be a powerful axion source and an experimental scheme of solar axion search using an isolated axion-nucleon interaction was proposed [6]. ^{57}Fe nucleus in core of the Sun could be thermally excited and emit a monochromatic 14.4 keV axion via axion-nucleon interaction, and the axion could excite ^{57}Fe nucleus on the earth and emit monochromatic 14.4 keV γ by the de-excitation. The expected rate of absorption can be $R = 3.0 \times 10^2$ day^{-1} kg$^{-1}(\frac{10^6 \text{ GeV}}{f_a})^4 C^4$, where $C = -1.19(\frac{3F-D+2S}{3}) + (D+F)\frac{1-z}{1+z}$. The D and F are the reduced matrix elements for the SU(3) octet axial vector currents can be obtained from hyperon semileptonic decays,S characterizes the flavor singlet couplingand $z = m_u/m_d \sim 0.56$ in the first order calculation. Experimentally, the R can be measured by $R = N_{sig}/(M\eta\epsilon)$, where N_{sig} is detected number of signal, M is the mass of ^{57}Fe, η is the probability of γ-ray emission from ^{57}Fe and ϵ is detection efficiency of 14.4 keV photon. Several observations were conducted and got null results [7–9]. Current upper limit, $g_{an} \leq 3.0 \times 10^{-6}$ which is corresponding to the axion mass $m_a < 145$ eV at 95% C.L. by [9].

2. ISAI experiment

Investigating Solar Axion by Iron-57 (ISAI) is an experiment dedicated measurement of an interaction between the axion and nucleus without introducing the other interactions. Fig. 1 shows a schematic drawing of the detector and the readout system composed of two X/γ-ray detector modules, a position sensitive cosmic-ray anti-coincidence counter in the climate chamber.

XRPIX [10], a monolithic pixel sensor for X-ray imaging equipped with a 10 μs timing resolution has been developing for a future X-ray astronomy satellite mission. XRPIX7, in the series number of XRPIX, is used in the ISAI experiment to detect a 14.4 keV γ of the axion signal and has the largest detection area of 21.9 mm $\times$ 13.8 mm with 300 μm thickness. It is comprised of 608 $\times$ 384 pixels which pixel size is 36 μm square. Each pixel has a correlation double sampling circuit with low readout noise for the output of signal pulse height and a comparator associated with a trigger circuit enables to cooperate with external detector for background rejection by an anti-coincidence technique. The signal from XRPIX is readout and digitized by SEABAS board [11].

A G10 rigid circuit board on which bare XRPIX chip is implemented can be a major background (BG) source as indicated in the previous study [12]. To reduce the BG, we had developed a rigid-flexible circuit board composed of a thin 2-layers of polyimide flexible circuit board sandwiched

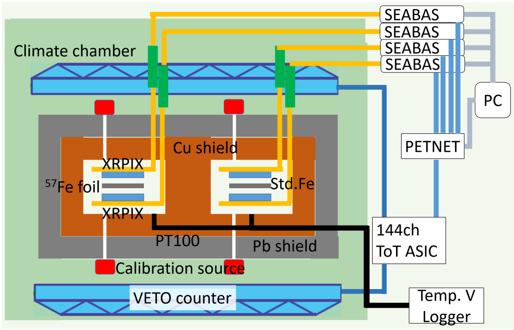

Figure 1: Schematic drawing of ISAI detector.

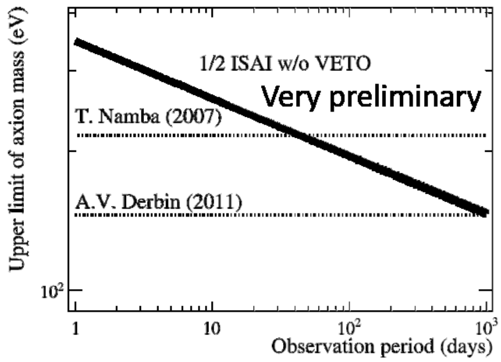

Figure 2: Very provisional sensitivity of the half ISAI detector without anti-coincidence using result of the first background study to identify the possible improvements for the full experiment.

by two 2-layers of G10 rigid circuit board and electrically connected in each layer internally. It enables to arrange the chip inside of hermetic BG shield and the G10 board in the outside. A 95% enriched ^{57}Fe foil for the signal detector and a standard Fe foil for the background detector, modularized exactly same configurations, are sandwiched by two XRPIX7's, respectively. Each module except for G10 rigid board is shielded by oxygen free copper of 5 mm and lead of 50 mm thickness, respectively.

Two plastic scintillator detectors are placed on top and bottom of the lead shield, and synchronized the timing to the XRPIX7 for anti-coincidence measurement of cosmic rays and environmental radiation. Timing information of XRPIXs and scintillators is input to the PETNET board [13], originally developed for Compton-PET hybrid camera.

The detection efficiency and gain can be monitored by an irradiation area where the calibration source placed on top and bottom of the lead shield through the 1 mm ϕ pin-holes during the observation. The other area can be used for a fiducial area of axion measurement. Also, temperature by embedded PT100 inside of the lead shield and supplied voltages are monitored.

3. Commissioning and the first background observation using half ISAI detector without anti-coincidence measurement

There is a problem in XRPIX7 that if cannot operate with full depletion; however, this is resolved in the latest XRPIX10. Though reason of the issue is under investigation, we confirmed the chip works under the moderate bias voltage of 10 V. The provisional detection efficiency is estimated to be a 2% by a ratio of collimated radiation fluxes of XRPIX and the Amptek XR100SDD whose efficiency provided in the specification sheet. The first module comprises of a standard Fe foil sandwiched two XRPIXs was assembled and shielded as a corresponding "half ISAI" detector for the commissioning rehearsal and the understanding background without the timing veto by the plastic scintillator detector. We measured the background for 10.07 days of live time and obtained a very preliminary BG rate of $\sim$ 4.3 counts/day/2.8keV(FWHM) at 14.4 keV. Using the rate, we estimate an axion sensitivity of half ISAI detector shown in Fig. 2 using the values $M = 127$ mg, $\eta = 0.105$, ϵ =2.0 %, $z = 0.56$, nuclear structure parameters $C = -0.27$, $D = 0.77$, $F = 0.48$, $S = 0.45$ and assuming null signal.

4. Summary

The ISAI is an experiment dedicated measurement of g_{an} without introducing the other interactions. We conducted the first background observation using the corresponding half ISAI detector without the anti-coincidence measurement. Further studies of background reduction by both the improved passive and the active shield, better understanding for the efficiency and countermeasure of the recovery are progressing. We will improve the sensitivity and start the observation using fully implemented ISAI detector in next year.

We thank S. Moriyama and T. Namba for useful discussions for the experiment. This work was supported by Japan Society for the promotion of Science (JSPS), KAKENHI Grant-in-Aids for Scientific Research, Grant Number JP 16H00945, 21K18151, 22H04572, 21H05461, 21H04493 and JSPS Research Fellow, Grant Number JP 22J00064.

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