様　式　C－19、F－19－1、Z－19　(共通)

科学研究費助成事業　　研究成果報告書

令和　元 年　 6 月　 3 日現在

機関番号：１２６０１
研究種目：基盤研究(C)（一般）
研究期間：2016～2018
課題番号：１６Ｋ０５３７１

研究課題名（和文）Search for false signals in underground dark matter detectors

研究課題名（英文）Search for false signals in underground dark matter detectors

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交付決定額（研究期間全体）：（直接経費）　　3,700,000円

研究成果の概要（和文）：本研究課題は、地下深くの暗黒物質探索実験に影響を与える可能性のある周期的バックグラウンドとなる要因の直接測定を目的としたものだが、成功裏に完了した。
その目的を達成するために、いくつか粒子検出器を建設し、それらを神岡ニュートリノ実験施設に設置した。これらの検出器で、地下における熱中性子束と高速中性子束、およびラドンガスの活性度を1年間にわたり測定した。
取得した実験データにより、よく知られているDAMA / LIBRAコラボレーションが主張するダークマター観測結果に対して別の説明を与えることができるバックグラウンドについて調査・評価を行った。

研究成果の学術的意義や社会的意義
本課題研究により取得された実験データを使った結果は、学術誌に掲載発表された。
これらのデータは、私たちの宇宙の約25%を構成する暗黒物質の起源を理解するために役に立つ。また、これらの結果は新しい物理の探索を目的とした新規の地下実験の計画のためにも利用することができる。本課題研究の期間中、私たちは地元のエンジニアリング会社と協力し、検出器のコンポーネントの製造に必要なサポートを得て、検出器を建設した。大学と産業の間のこのような協力は、神岡のような継続的な人口減少が進む遠隔地でも最先端の研究を続けることを可能にする。

研究成果の概要（英文）：The research project aimed at direct measurement of possible sources of periodic background that may affect search for the Dark Matter at deep underground laboratories was successfully completed. For that purpose, we constructed several particle detectors and installed them at the Kamioka neutrino observatory. The detectors were used to measure the thermal and fast neutron flux, and the radon gas activity underground for a 1-year period. The acquired experimental data are being used to study backgrounds that could give an alternative explanation to the well-known Dark Matter observation claim made by the DAMA/LIBRA collaboration.

研究分野：Direct Dark Matter search

キーワード：Dark Matter　underground laboratory　NaI(Tl) detector

１．研究開始当初の背景

Dark matter (DM) constitutes 85% of the total matter in the Universe and it is most likely to be composed of Weakly Interacting Massive Particles (WIMPs). A direct WIMPs search is a well-established field which utilizes wide range of experimental techniques and target materials. Many experiments aimed at detection of weak periodic signals from DM particles rely heavily on periodicity of observed signals as evidence for their DM origin (Figure 1). It is possible; however, that these periodic "signals" originate from unidentified sources of background, e.g. neutrons that may produce nuclear recoils identical to that from WIMPs. All dark matter experiments are located deep underground in order to reduce neutron flux produced by cosmic muons. However, at such depths, fast neutrons produced in (α,n) reactions on light nuclei make a significant contribution to the total neutron flux (Figure 2) which makes neutron flux dependent on decay rate of α–emitters such as ^{222}Rn ($T_{1/2}$ = 3.8d), and it's daughter nuclei (^{218}Po, ^{214}Po). This effect was already observed by a direct measurement of the thermal neutron flux deep underground. Therefore, it is reasonable to assume that these seasonal neutron-flux variations may create variations in number of nuclear recoil events in DM detectors not protected by large external buffers, such as DAMA/LIBRA. In order to understand how these neutron-flux variations may affect the "signal" detected by DAMA/LIBRA type NaI(Tl) detectors several measurements will be made simultaneously at the Kamioka mine (rock overburden is a 1000m).

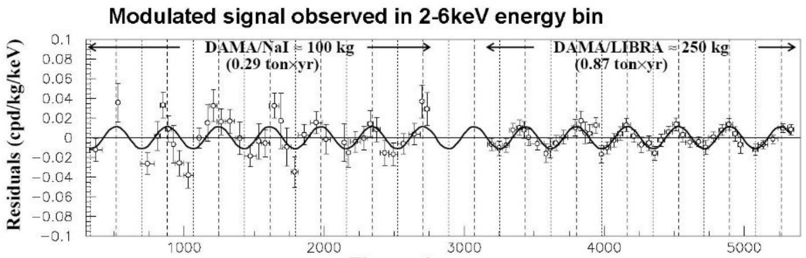


Figure 1

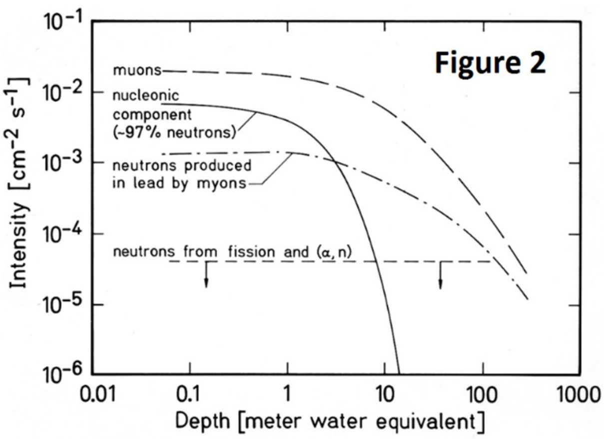


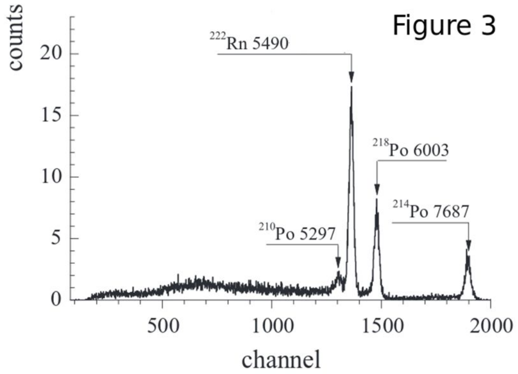
Figure 2

- Low energy events down to a few keV (where DM signals were reported) will be detected in two ultra-pure 5-inch NaI(Tl) detectors placed into an ultra-low background shielding (a 25cm of lead + 10cm of OFHC copper).
- Radon activity variations in the underground air will be measured using radon gas detectors and 2-inch NaI(Tl) detector sensitive to the γ–rays (609 and 1120keV) from the ^{214}Bi decay.
- Thermal and fast neutron fluxes will be measured by two separate detectors.

２．研究の目的

The purpose of these measurements is to find possible correlations between several keV signals in NaI(Tl) detectors, the radon activity in the mine air and the neutron flux. Combined information obtained from all these measurements may help to understand origin of the periodic background.

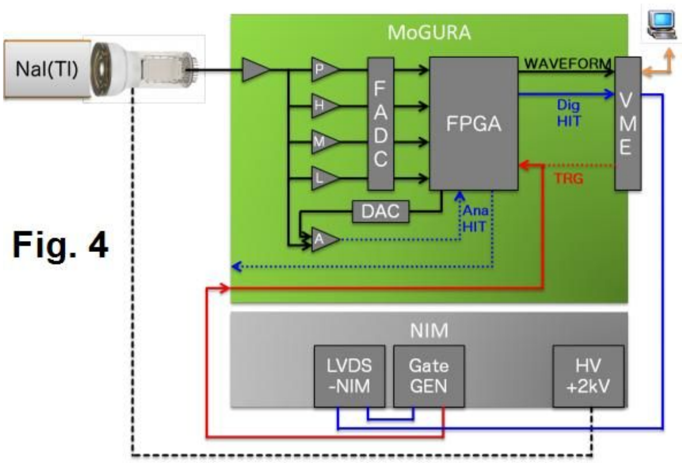
E.g. the thermal neutron flux is expected to originate from deeper layers of rock (moderated in the rock, and the ground water), while fast (several MeV) neutrons from boundary layers only. A large volume liquid scintillator (doped with ^{6}Li) detector will be used to detect fast neutrons using a delayed coincidence method with τ≈20μs (prompt signals are produced by proton recoils from the fast neutron scattering, and delayed signals from the thermal n+^{6}Li capture). The fast neutron energy information allows, for example, monitoring of moderating properties of the rock (due to seasonal changes of the water content). A high sensitivity and high energy resolution radon gas detector (Figure 3) will be used to identify 5490keV α–particles from decay of ^{222}Rn in the air.



３．研究の方法

- The KamLAND Mogura DAQ electronics (Figure 4) that provides a flexible environment for detecting pulses of different durations (up to 10μs) and amplitudes is used in this project. Operation of the Mogura DAQ electronics is supported by Dr. Y. Takemoto (The University of Tokyo) who is one of system developers and research collaborator of the PI. The DAQ system is installed at the underground clean room and is being used by the PI and Dr. Takemoto for evaluation of radio-pure NaI(Tl) crystals developed by the KamLAND-PICO group. Background rates achieved in currently available NaI(Tl) detectors are equal to 2-3 events/day/keV/kg which is sufficient for this project. The ultra-low background 5-inch NaI(Tl) crystals developed by the KamLAND-PICO group are coupled with new 4-inch ultra-low background Hamamatsu R13444X PMTs. These PMTs are developed by joint efforts of the KamLAND-PICO group and Hamamatsu Photonics K. K. by using already existing ultra-low background Hamamatsu R11065-20 3-inch PMT as a prototype. The ultra-low background shielding for NaI(Tl) detectors was constructed at the same underground clean room. The shielding is connected to a permanent source of boiled off nitrogen gas to avoid the radon induced background.

Fig. 4



- Radon detectors

Large air-ion-pulse ionization chambers are used for ^{222}Rn measurements in the air. Two units were produced together with research collaborators Dr. A.M. Gangapshev, Dr. V.V. Kuzminov, and Dr. V.V. Kazalov from Baksan Neutrino Observatory (BNO), Institute for

Nuclear Research, Russian Academy of Sciences. Detector components were produced partially in Russia. In addition to radon gas detectors, 2-inch NaI(Tl) is used to monitor intensity of 609 keV γ–rays from the ^{214}Bi decay.

- **Fast neutron detectors**

The fast neutron detector is made of acrylic container viewed by 2 pairs of fast 5-inch Hamamatsu R1250 photomultipliers. A stable liquid scintillator based on pseudocumene (83%), surfactant (17%), PPO (5g/L), and LiBr·H2O is used. A delayed coincidence method allows to identify fast neutrons where prompt signals are produced by recoiled protons from the fast neutron scattering, and delayed signals come from products of the thermal neutron capture on ^{6}Li. Only charged particles with a very short stopping range are produced in the $^6Li + n \longrightarrow {}^3H + {}^4He + 4.78MeV$ reaction which improves the neutron detection efficiency.

- **The thermal neutron detector**

A thermal neutron detector with a large detection area is made of a thin scintillating layer of ^{6}LiF+ZnS(Ag) which is insensitive to γ-rays. The thermal neutron capture on ^{6}Li results in a bright light emission (1.6×10^5 photons per neutron capture) that is detected using three 5-inch Hamamatsu R1250 photomultiplier and recorded by the CAEN DAQ.

４．研究成果

Within the framework of the project, we acquired experimental results that were published in academic journals. The data can help to understand origin of the Dark Matter that composes about 25% of our Universe. These results can be also used for planning of new underground experiments aimed at search for new physics.

５．主な発表論文等

〔雑誌論文〕（計２件）

１． A.Kozlov et.al. , Detectors for direct Dark Matter search at KamLAND, Nuclear Instruments and Methods in Physics Research A, https://doi.org/10.1016/j.nima.2019.05.080

２． A.Kozlov, D.Chernyak, A large area detector for thermal neutron flux measurements at the KamLAND site, Nuclear Instruments and Methods in Physics Research A 903 (2018), Pages 162-169, https://doi.org/10.1016/j.nima.2018.07.006

〔学会発表〕（計２件）

１． A.Kozlov, Status of direct Dark Matter search experiment at KamLAND, Low Radioactivity Techniques 2019, 2019
２． A.Kozlov, Detectors for direct Dark Matter search at KamLAND, 15th Vienna Conference on Instrumentation, 2019

〔図書〕（計０件）

〔産業財産権〕
○出願状況（計０件）

名称：
発明者：
権利者：
種類：
番号：
出願年：
国内外の別：

○取得状況（計０件）

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取得年：
国内外の別：

〔その他〕
ホームページ等

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研究者番号（8 桁）：

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研究協力者氏名：
ローマ字氏名：

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