

Testing feasibility of SrI2(Eu) scintillation detector for low-energy neutrino detection

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Abstract

The possibility to use the SrI2(Eu) scintillator for detection of tritium neutrino with energy below 20 keV is suggested. SrI2(Eu) scintillator has a record light yield up to 120 photons/keV that in combination with high photon detection efficiency photodetectors would enable the detection threshold below 1 keV. The compact modular setup of SrI2(Eu) scintillation detectors to register sub-keV energy deposition from neutrinos interactions is considered. Each individual detector module comprises four small scintillators with attached SiPM arrays packed together in a light-tight plastic case. The main drawback of SiPM, the high dark current rate (DCR), which is exponentially dependent on temperature, can be suppressed at negative operating temperatures. The experimental tests of SiPMs were performed over a wide temperature range from +20°C to -65°C, that show the DCR reduction for about three orders. To further suppress the effect of DCR, a time coincidences of the signals in each detector module were implemented. The light collection of SrI2(Eu) scintillators with SiPM read-out was studied using several γ -ray sources. The optimal operating conditions were examined to provide a minimum energy detection threshold. The normalized light collection achieves 26.3 photoelectron/keV in all range of measured energies. The performed tests with low energy γ -ray sources confirmed that constructed SrI2(Eu) modules are suitable for high-resolution X- and γ -rays spectroscopy.

Full Text

Preamble

Testing feasibility of SrI2 (Eu) scintillation detector for low-energy neutrino detection*

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The possibility to use the SrI2 (Eu) scintillator for detection of tritium neutrino with energy below 20 keV is suggested. SrI2 (Eu) scintillator has a record light yield up to 120 photons/keV that in combination with high photon detection efficiency photodetectors would enable the detection threshold below 1 keV. The compact modular setup of SrI2 (Eu) scintillation detectors to register sub-keV energy deposition from neutrinos interactions is considered. Each individual detector module comprises four small scintillators with attached SiPM arrays packed together in a light-tight plastic case. The main drawback of SiPM, the high dark current rate (DCR), which is exponentially dependent on temperature, can be suppressed at negative operating temperatures. The experimental tests of SiPMs were performed over a wide temperature range from +20 °C to -65 °C, that show the DCR reduction for about three orders. To further suppress the effect of DCR, a time coincidences of the signals in each detector module were implemented. The light collection of SrI2 (Eu) scintillators with SiPM readout was studied using several γ -ray sources. The optimal operating conditions were examined to provide a minimum energy detection threshold. The normalized light collection achieves 26.3 photoelectron/keV in all range of measured energies. The performed tests with low energy γ -ray sources confirmed that constructed SrI2 (Eu) modules are suitable for high-resolution X- and γ -rays spectroscopy.

Keywords

Tritium neutrino, scintillation detector, light yield, energy resolution

INTRODUCTION

with use of the compact photodetectors like silicon photomultiplier (SiPM). The choice of SiPM is driven by several factors. Thus, PMTs photocathodes are contaminated with the ³³K radioactive isotope, which can potentially lead to false event identification. Silicon photodetectors avoid the problem with the radioactive contamination. The small size and relatively low cost of SiPMs allow the design of photodetector arrays with the required sizes and configurations.

Finally, commercial SiPMs can achieve a Photon Detection Efficiency (PDE) of up to 50%, which is generally higher than quantum efficiency of traditional PMTs. The main drawback of SiPMs is high thermal noise of around 100 kHz/mm at room temperature. However, this issue is less crucial

for the CsI(pure) detectors operating at cryogenic temperatures. For example, at liquid nitrogen temperatures, the noise level drops by several orders of magnitude to 0.2 Hz/mm [8].

Development of experimental setups with extremely low energy detection thresholds is a crucial task of modern neutrino physics. For example, in coherent neutrino-nucleus scattering, the energy deposition in detectors is expected to be around or significantly below 1 keV. Similar energies would be detected in experiments with neutrinos from the beta decays of various radioisotopes. Thus in experiment SATURNE [1] with a tritium source to search for the neutrino magnetic moment, the neutrino energy E_ν does not exceed 18 keV and the electron recoil energy T_e in the detector will be less than 1 keV.

To achieve energy thresholds below 1 keV, detectors based on noble gases at temperatures near 0 K are primarily considered [2, 3]. Another approach involves cryogenic germanium semiconductor detectors [3–5]. Additionally, traditional organic scintillators with high light yield, such as NaI(Tl), NaI(Na), CsI(Tl) are very attractive to construct a large scale detectors due to their availability and relative cheapness. In recent years, many studies focused on pure cesium iodide (CsI(pure)) scintillator to construct the detectors with sub-keV energy thresholds. CsI(pure) light yield reaches up to 120 photons/keV at temperatures below 100 K [6] that requires a liquid nitrogen (LN₂) temperature for the operation. In one of recent works [7], a normalized light yield of approximately 33 p.e./keV was obtained for a small CsI(pure) detector prototype with a cryogenic photomultiplier tube (PMT) readout.

Additional improvement of light collection can be achieved

In the past few years a number of tests were performed with small CsI(pure) scintillators coupled to SiPMs at LN₂ temperature.

Thus miniature CsI(pure) detector with two SiPMs readout [9] revealed a record light collection of about 43 p.e./keV. Larger sizes of scintillators would certainly reduce the light collection efficiency due to the light absorption in the crystals. It is especially problematic for CsI(pure) UV emission spectrum with the average wavelength of about 350 nm. The problem could be partially solved by coating the SiPM matrices by wavelength shifter [10]. For relatively large 5x5x5 cm crystal the light collection achieved 21 p.e./keV at nominal SiPM operation voltage and 30 p.e./keV at extreme overvoltage. In the last case, the signal amplitude is dominated by contribution from parasitic crosstalk of SiPM pixels that provides unrealistic 123 p.e./keV light collection. Note, that crosstalk is a general problem of SiPM operating at cryogenic temperatures [11]. Also, the performance of * This study was conducted within the framework of the scientific program some SiPM types can be unstable at these temperatures due of the National Center for Physics and Mathematics, section 8 «Physics of charge carrier freeze-out in semiconductors [8]. hydrogen isotopes». Stage 2026-2027. † Corresponding author,

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In spite of the excellent light yield of CsI(pure) at LN2 tem-

perature, this scintillator has an inherent disadvantage associated with its internal radioactivity, mainly due to the presence of radioisotope Cs [12, 13]. Additionally, CsI(pure) detector for γ -spectroscopy as would be shown below. The emission spectrum lies in UV region, which does not properly use of four SrI2 (Eu) crystals in a single module with a total align with SiPM PDE maximum. To overcome the mentioned total mass of about 100 g and overall dimension of 30x30x25 makes this detector effective for both hard X-rays and 71 drawbacks, other low-background scintillators with comparable light yields at elevated operating temperatures can be considered. One of the most attractive scintillators for such measurements is SrI2 (Eu) (Europium-doped Strontium Iodide). It

A. Structure of neutrino detector has superior light yield of up to 120 photons/keV at room temperature and nice proportionality of light yield across a wide range of deposited energies [14-16]. This advanced tritium neutrino detector will consist of a few (up to seven) vertically placed individual layers, each representing a energy resolution, significantly surpassing traditional materials separate mini-detector with its own readout system. In a similar like NaI(Tl). The best SrI2 (Eu) samples have energy resolution below 3% for the 662 keV Cs gamma line that is a factor of 2 better than for NaI(Tl).

The outer and inner circles contain 10 and 6 detector modules. Comparing to CsI(pure), SrI2 (Eu) demonstrates less internal radioactivity [17] and appears to be more suitable for low background measurements. The SrI2 (Eu) emission spectrum peaks at 420 nm and nicely aligns with the maximum spectral sensitivity of SiPMs. These unique properties are attached to each module.

The weight of the scintillator makes the SrI2 (Eu) scintillator excellent not only for γ -spectroscopy, but also for detecting ultra-low energies, in SrI2 (Eu) crystals in full detector of 11.2 kg. Parameters of particular, sub-keV energy depositions from neutrino typical SrI2 (Eu) crystal are presented in table 1. To suppress thermal noises of SiPMs full detector will be placed in a refrigerator with

the operational temperature between -60°C and -80°C . The extremely low energy threshold, for example, for the scintillation detector of tritium neutrinos in the SATURNE experiment

1. Physical and scintillation parameters of SrI2 (Eu) . The concept of such detector and the performance of its individual scintillator modules will be considered.

CONCEPT OF LOW THRESHOLD SCINTILLATION DETECTOR FOR TRITIUM NEUTRINO

Light Yield (photons/MeV) Temperature Coefficient (%)

- C) Energy Resolution (FWHM) @ 662 keV Primary Decay Time (μs) Emission Peak (nm) Refractive Index Effective Atomic Number (Z) Hygroscopicity

80,000–120,000 -0.12 2.6–4.0%

The SATURNE experiment [1, 18] is being developed at the National Center for Physics and Mathematics (NCPM) in Sarov, Russia, and will search for neutrino electromagnetic interactions, including the neutrino magnetic moment. Since each detector layer consists of 16 modules with 64 SrI2 (Eu) crystals, it requires 64 readout channels. Each channel includes a current amplifier of SiPM with a sensitivity of 10 MCi. The tritium neutrino source [19] is a set of 149 signal and an analog-to-digital converter (ADC). A commercial tubular element, in which tritium is in a chemically bound 64-channel ADC will allow each layer to function as an independent state on titanium. At the initial stage of experiment, these independent mini-neutrino detector with its own data acquisition system will form the cylinder with the inner diameter of about 300 mm both. The scintillation detector will be situated in the inner part of this cylinder. The 12-bit analog-to-digital converters with the sampling rate limited active volume necessitates the maximal packing density of 62.5 MS/s and additionally includes noise filters and differential amplifiers of detector elements. At the same time, these elements must be read out by photodetector arrays of SiPMs with a printed circuit board. The recorded by the ADC waveforms are a reasonable density of readout channels. These factors motivated the development of a modular structure of the detector. Note that operation of the SrI2 (Eu) detector at a relatively high temperature above -100°C allows the use of commercial cooling systems such as medical refrigerators and avoids detector modules would allow to construct

different geometry of 162 merous problems associated with cryogenic systems. At the

SiPM arrays and individual readout is attached to each module. The modules of the layer are mounted on a copper disk to ensure acceptable thermal conductivity. An inner hole is intended for the cooling system and signal cables. Right - a scheme of the neutrino detector that includes seven adjacent layers. Each layer is readout its own analog-to-digital converter and can be considered as independent part of full detector.

same time, the thermal noise of SiPM will be several orders of 192 the impermeability of the construction. For this purpose the magnitude higher compared to the LN₂ temperature. It would 193 plastic container is covered by waterproofing varnish. The 165 require and additional approaches in SiPM noise suppression 194 most problematic issue is humidity insulation of the optical 166 as time coincidence of signals in SrI2 (Eu) crystals. The noise 195 contact between the scintillator and SiPM array. Ordinary op167 suppression methods developed are described in detail below. 196 tical grease can not guarantee the water-tightness, while the The proposed structure of the neutrino detector ensures its 197 optical glue causes damage to the SiPM arrays if module re169 modularity and scalability, which allows further improving 198 pair is needed. Therefore, the optical contact is provided by 170 the sensitivity of the detector by increasing the number of lay- 199 a transparent double-sided acrylic tape. A dedicated study 200 showed that in this case, light collection is deteriorated by 171 ers of detector modules. 201 approximately 10-15% compared to optical grease. This is 202 a reasonable price for the ability to reassemble the detector 203 modules.

B. Design of detector modules Note, that the polishing of the SrI2 (Eu) crystals and assem205 bly of detector modules is performed in a dry atmosphere in The structure of individual detector module is shown in 174 figure 2 [Figure 2: see original paper].

It comprises four SrI2 (Eu) crystals, read out by 206 a plexiglass glove box. 175 four photodetector arrays.

Each crystal has dimensions of 176 15\$×15×\$25 mm and mass of 25 g, with a total active mass

III. READOUT OF DETECTOR MODULES 177 of one module 100

- g. Each crystal is wrapped in polytetraflu178 oroethylene (PTFE) reflector tape from all sides except the

A. Performance of photodetectors 179 side used for light readout. The SrI2 (Eu) crystal length of 25 180 mm was chosen to be transparent to its own emission light 181 [20]. The 15\$×15mm\$scintillatorcross – section,fitstosizes209Toensurethehighestcollectionefficiencyofthelightfrom182ofusedSiPMarrays. Every mm . Geometri- 211 quested.

Currently, one of the best commercial SiPM optical factors (ratio of SiPM active area to the transverse crystal dimensions with high PDE is Hamamatsu MPPC S14161-3050HS2 185 size) leads to 25 percent light loss. The maximum PDE of the Hamamatsu MPPC The mechanical design of the detector modules is based on 214 exceeds 50% at a light wavelength of 420 nm. Main parameters of a four-cells plastic honeycomb structure manufactured using 215 types of the selected SiPM matrices are shown in table 2 The second important parameter that limits the energy dependence of the DCR is the Dark Current Rate (DCR), which is 190 with board of SiPM arrays is shown. Since the SrI2 (Eu) scintillator is mainly caused by SiPM thermal noises. Together with PDE, the DCR is the principal limiting factor, especially in the detection of low energy events.

one of the ends. Crystals are placed in a plastic honeycomb structure. Right - assembled module with board of SiPM arrays.

First, number of events in spectrum reflects the DCR, i.

e. the

3050HS-04 SiPM array for $T = 25^\circ$

C. 240 individual peaks equals to the amplitude (or charge) of single photoelectron signals. This allows for immediate calibration Number of channels $16 (4 \times$

- 4) 242 of the amplitude scale in absolute units and the derivation of Effective area per channel (mm^2) 243 signal amplitudes as the number of photoelectrons (see section IV for details). Third, the ratio of the number of events Spectral response (nm) 245 with an amplitude greater than the amplitude of a single photoelectron to the number of a single-photoelectron events is PDE @ λ_p (%) 247 an estimate of X-talk probability.

Gain (typ.) 2.5×10^6 The thermal noise spectra were collected for SiPMs in a Breakdown voltage VBR (V) VBR Temp. Coeff. (mV/°C)

- C) 249 wide temperature range. The experimental setup incorporated Dark count per channel (kcps) 250 two cooling systems: a standard commercial freezer with a

minimum temperature of -35°C and a medical-grade freezer 252 capable of cooling down to -65°C

C. All DCR measurements 220 tion of rare events. As mentioned above, DCR drops sharply 253 were obtained using a detection threshold close to 0.5 photoelectron amplitude. 221 with decreasing operating temperature from 10 Hz/ mm^2 at 254 electron amplitude. 222 room temperature to below 1 Hz/ mm^2 at LN2 temperature. 255 The dependence of DCR on the operating temperature for 223 Since the SrI2

(Eu) neutrino detector is planned to operate at 256 the Hamamatsu MPPC array is presented in figure 4 [Figure 4: see original paper] in a 224 a relatively high temperature above -100°C , the DCR is ex- 257 logarithmic scale. Several measurements at various operat2 225 pected to be several tens of Hz/mm . Such relatively high 258 ing voltages are presented. The MPPC manufacturer recom226 DCR value would require the development of additional ap- 259 mends an overvoltage of 2.7 V above the breakdown voltage. 227 proaches to suppress the contribution of thermal noises in the 260 To test the effect of overvoltage on the DCR, data were also 228 false event rate, such as the time coincidence of the SiPM 261 collected at overvoltages of 2.2 V and 3.2 V, i.

- e. 0.5 V be229 signals discussed below. 262 low and above the recommended value. As can be seen, the To characterize the SiPMs, the dark current rate and cross- 263 dark current rate varies from 29 kHz/mm² at room temper2 at -65°

C. Different overvoltage values 231 talk (X-talk) values were studied using the SiPM thermal 264 ature to 41 Hz/mm 232 noise spectra collected at different temperatures. 234 trum for SiPM thermal noise signals. Individual peaks cor- 267 in good agreement with the expected exponential behavior.

Note that increasing the overvoltage will improve the PDE 235 respond to different number of thermally activated pixels of 268 236 SiPM array or, equivalently, to different number of photo- 269 value, but at the cost of a significant increase in X-talk, see, This results in a significant fraction of 237 electrons. This spectrum allows us to find three parameters. 270 for example, [10].

ADC channels

DCR (Hz/mm)

pixels of SiPM (to different number of photoelectrons). A four-Gaussian fit was applied to precisely identify the average positions of these peaks. Each group of three parameters represent the amplitude, mean position, and standard deviation of the corresponding Gaussian component.

Counts

Temperature ($^{\circ}\text{C}$) dependencies for Hamamatsu arrays correspond to different over-voltages of 2.2, 2.7 and 3.2

V. DCR values for room and -65° C temperatures are shown numerically.

events with multiple photoelectron signals generated by ther- 278 noise level of silicon photomultipliers is reduced to below mal noise, and should be avoided in detectors with ultra-low 279 one Hz/mm² [8]. As shown above, the DCR at -65° C is two 273 threshold. Measured at -65° C and nominal voltages, X-talk 280 orders of magnitude higher. Therefore, additional noise sup274 value is about 7% for all tested MPPC arrays. 281 pression techniques are required. One of the most effective 282 methods is the use of time coincidences of the signals in each 283 event.

It can potentially suppress the detection of random thermal noises by several orders of magnitude.

B. Time coincidence trigger scheme

This approach is implemented in the readout of each detector module. The operating temperature of -65°C is significantly higher than the liquid nitrogen temperature, at which the thermal number of SiPM arrays in a single detector module allows

The presented readout encoding scheme preserves the number of readout channels equal to the number of SrI2 (Eu) crystals in the detector module, but requires a specific event selection to trigger ADC recording in case of double coincidence of appropriate signal combination. For this purpose, a dedicated trigger scheme with four coincidence circuits was implemented, as shown in 5 (bottom). An event firing one of the crystals triggers two adjacent SiPM groups and coincidence of these two signals generates the ADC trigger for the event recording. Since one detector module uses four coincidence circuits, the trigger signals are fed to the common OR-circuit. Taking into account the measured DCR and a coincidence time of the order of one microsecond, the trigger frequency from random thermal noise is estimated to be several tens of hertz for one detector module if the detection threshold is set to about 0.5 photoelectrons. This trigger rate is rather comfortable for the data acquisition by ADC.

PERFORMANCE OF SRI2 (EU) DETECTOR

Discriminator

The characteristics of the detector module were studied using SrI2 (Eu) crystals manufactured by the A.

N. Nikolaev Institute of Inorganic Chemistry (NIIC SB RAS, Novosibirsk, Russia).

Since the crystal growth technology is currently under development, crystals may exhibit variations in impurity levels and activator distribution. Therefore, the following results are presented for a high-quality specimen. Hamamatsu MPPC S14161-3050HS-04 photodetectors were used for light readout, and signal waveforms were recorded by a 12-bit ADC with a 16 ns sampling rate.

The examples of such waveforms are presented in figure for module. The colors represent four SiPM groups with individual readout for the low (left panel) and high (right panel) energy design readout. Half of SiPM array of one crystal is combined with 6 positions in scintillator. Small peaks at left picture correspond to the other half of the SiPM array of the adjacent crystal. Bottom - correspond to the detection of single photoelectrons. The widths of scheme of event trigger with four coincidence circuits to suppress these single electron signals of about $0.5\ \mu\text{s}$ is determined by the thermal noises. An event firing one of the crystals

triggers two 338 the terminal capacitance of MPPC array. It can be seen that adjacent SiPM groups of different colors (see left picture) and gen- 339 the full pulse width from the SrI (Eu) scintillator is approximately 2 erates the ADC trigger signal for event recording. 340 mately 10 μ s. Therefore, the signal charge was also integrated 341 over 10 μ s.

Light collection tests of SrI2 (Eu)-SiPM detectors were per288 the appropriate configuration of photodetectors to arrange the 343 formed with 241 Am, 55 Fe and 57 Co sources of gamma-rays, 289 time signal coincidence in each scintillator without increas- 344 which cover the energy range from a few keV to about 120 290 ing the number of readout channels. The simplest solution 345 keV. Depending on the activity of the gamma source, the 291 to implement the time coincidence of signals is to divide the 346 data acquisition took from around a minute (57 Co) to twelve 292 SiPM array in each crystal into two equivalent parts with in- 347 hours (55 Fe). The light yield estimation was done in several 293 dependent signal readout. However, such basic configuration 348 steps. The initial step involved calibration of the ADC scale 294 results in doubling of the number of electronic readout chan- 349 in photoelectrons (p.e.) using a few photoelectron peaks from 295 nels. To avoid this drawback, a method for encoding the read- 350 the SiPM noise spectrum (see figure 3 [Figure 3: see original paper]). The four observed 296 out channel was developed using the structure of a detector 351 peaks were fitted by the superposition of four Gaussian func297 module consisting of four SrI2 (Eu) crystals. Namely, half of 352 tions, with the i -th peak characterized by p $3i-3$ (number of 298 SiPM array of one crystal was connected in parallel with the 353 events), p (mean), (standard deviation, σ) $pa3i-2$ 299 other half of the SiPM array of the adjacent crystal. 354 rameters. Based on this fit, the photoelectron conversion fac300 The SiPMs are organized into four distinct groups, as indi- 355 tor was determined to be 1 p.

e. = 30100 ± 300 ADC chan301 cated by different colors in figure 5 [Figure 5: see original paper] (top). Each SiPM group is 356 nels as the average distance between fitted peaks. Note that 302 readout by a single electronic channel. And the fired SrI2 (Eu) 357 during acquisition of the noise spectrum an additional $10 \times$ 303 crystal is uniquely identified by the combination of two sig- 358 gain was implemented to improve the sensitivity of ADC. 359 As a result, the correct photoelectron conversion factor is 304 nals in different readout channels.

Discriminator

Trigger

Discriminator

Discriminator

single p.

e. peaks

Counts

corresponding to the 122 keV gamma line from ^{57}Co decay. Full signal width is about $10 \mu\text{s}$.

ADC channels 241 Am amplitude spectrum. The left cluster of peaks corresponds to gamma energies of 13.9 keV, 17.8 keV, and 20.7 keV, while the right peak indicates the dominant 59.5 keV gamma line from alpha decay. Each group of three parameters in p0 – p8 range represents the amplitude, mean, and standard deviation of a Gaussian component.

378 Mn $K\alpha$ X-ray emission line. Due to the low source activity, 1 p.

e. = 3010 ± 30 ADC channels. 362 trum from Am gamma source. It shows characteristic 380 ing the same time period and is included for comparison. The 363 emission lines at 13.9 keV, 17.8 keV, 20.8 keV, and 59.5 keV. 381 background exhibits a flat behavior in the region of interest, 364 Due to the limited energy resolution the lower-energy peaks 382 enabling reliable Gaussian peak fitting as demonstrated from 365 (13.9-20.8 keV) are partially resolved. Therefore, a triple- 383 the fit parameters. The figure 8 [Figure 8: see original paper] (right) presents the energy Co, showing the dominant 122.1 keV gamma 366 Gaussian function to resolve the overlapping peaks was used, 384 spectrum of 367 as shown in the left panel of the histogram. The fitting pa- 385 line and the 14.4 keV nuclear transition line, with correspond368 rameters follow the same convention as for the noise spec- 386 ing Gaussian fit parameters presented near each photopeak. 369 trum analysis (see figure 3), with coefficients corresponding 387 In table 3 LY and energy resolution results for tested samples 370 to the amplitude, mean position, and standard deviation of 388 are demonstrated. 371 each Gaussian component. The right panel in figure 7 [Figure 7: see original paper] dis- 389 The energy dependence of the light yield for all used 372 plays the Gaussian fit results for the well-resolved 59.5 keV 390 gamma-ray peaks is presented in figure 9 [Figure 9: see original paper] (top). The SrI (Eu) 373 photopeak. The light yield was determined to be 26.0 by an- 391 detector exhibits excellent linearity in light output across the 374 alyzing the 59.5 keV photopeak. Similar procedure was ap- 392 measured energy range (5.9–122.1 keV). The systematic un241 375 plied for other low-energy gamma lines of 393 certainty in the peak positions was estimated from the stan376 377 source (blue histogram), featuring the characteristic 5.9 keV 395 the light yield data provides an average value of 26.3 ± 0.5

Counts

Counts

ADC channels

ADC channels

Energy (Isotope) LY (p.e./keV) Resolution $\sigma E / E$ (%) 5.9 keV (55 Fe) 23.3 ± 4.5 19.47 ± 0.54 13.9 keV (241 Am) 26.3 ± 2.2 8.51 ± 0.16 14.4 keV (57 Co) 28.5 ± 2.3 8.13 ± 0.20 17.8 keV (241 Am) 25.9 ± 1.9 7.48 ± 0.13 20.8 keV (241 Am) 26.8 ± 2.0 7.32 ± 0.21 59.5 keV (241 Am) 26.0 ± 1.0 3.75 ± 0.01 122.1 keV (57 Co) 26.2 ± 0.7 2.61 ± 0.01

p.e./keV. The bottom panel of figure 9 shows the energy resolution ($\sigma E / E$) as a function of gamma-ray energy. The results follow the expected dependence, consistent with the theoretical resolution function, where experimental

$E(\text{keV})$

ally acquired p0 equals 29.5%. Notably, the achieved resolution made it possible to separate closely spaced 241 Am lines at 13.9 keV, 17.8 keV and 20.8 keV (see Fig. 7), which is a challenging task for scintillation detectors due to their typically limited energy resolution at low energies.

Light Yield (p.e./keV)

$\$ \$2 / \text{ndf}$

1.607 / 6 26.29 ± 0.4921

significantly deviates from the background profile. Right - 57 Co spectrum. The left peak indicates a gamma energy of 14 keV, and the right peak corresponds to the 122 keV gamma line.

$\$ \$2 / \text{ndf}$

Energy (keV) 8.668 / 6 0.2955 ± 0.005535

CONCLUSION

Energy (keV)

SrI2 (Eu) detector for all used gamma lines.

A novel concept for a low temperature scintillation detector utilizing SrI2 (Eu) crystals is proposed for tritium neutrino detection. The SrI2 (Eu) scintillator demonstrates extremely separation of closely spaced Am gamma lines in the high light yield of up to 120 photons/keV, which potentially energy range below 20 keV. The use of four SrI2 (Eu) crystals enables to lower the energy detection threshold to hundreds in a single module with an overall dimension of 30x30x25 eV. Additionally, SrI2 (Eu) offers other crucial advantages: 425 mm also might allow this detector to be effective for high low intrinsic radioactivity and optimal matching of its spectral resolution X- and γ -rays spectroscopy. emission peak with photon detection efficiency of commercially available silicon photomultipliers. SrI2 (Eu) can operate at a convenient temperature of about -65 C, where the DCR of SiPMs is low enough to suppress thermal noises by application of time coincidence

technique. Systematic measurements of the prototype detector module's performance using 420 different gamma sources demonstrate consistent light yield of about 26.3 p.e./keV. The obtained energy resolution allows

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