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Alpha-ray imaging chamber based on a micro-TPC in a low radioactivity structure

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Abstract. An α -ray imaging chamber has been developed based on a gaseous micro-timeprojection chamber with a low- α emission μ -PIC in a low radioactivity structure. The detector offers the advantage of position sensitivity, which allows to image the α -ray contamination for the sample. It measures the α -ray rate in the sample region and a background region at the same time, thus that the net α rate from the sample can be evaluated efficiently by subtracting these rates from each other. In this work, the measurement results for several samples using the detector is provided.

1. Introduction

For astrophysics underground experiments are an issue radioactive impurities such as uranium and thorium in the detector components. Especially α -ray-emitting impurities from radon decaying in the air above the material contaminate the material surface. The α -rays from the impurities staying at a depth of a few micron and a few tens of microns of material surface are referred as "surface α -ray" with a peak energy and "bulk α -ray" with a continuous energy spectrum, respectively.

To estimate the radioactive impurities in the detector materials, the XMASS group measured ²¹⁰Pb and ²¹⁰Po in the bulk of copper by using a commercial α -ray detector (Ultra-Lo 1800, XIA) [1]. The alpha detector has an energy resolution of 4.7% at 5.3 MeV and a mechanism to reduce the background by waveform analysis, and thus its sensitivity is ~ 10⁻⁴ $\alpha/\text{cm}^2/\text{hr}$. However, it has no position sensitivity.

A sample such as a micro pattern gas detector board does not have a uniform radioactive contamination. For example the impurities can be in a particular location due to the manufacturing process. Therefore, a position-sensitive α -ray detector is required in order to determine the site and perhaps the process associated with the sample's contamination.

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2. The alpha-ray imaging chamber

2.1. Detector construction

An α -ray imaging chamber [2] has been developed based on a gaseous micro-time-projection chamber using a low- $\alpha \mu$ -PIC, in which the glass cloth is replaced by a new material with less radioactive contamination [3].

In the detector, the gas volume is $(35 \text{ cm} \times 35 \text{ cm}) \times 31 \text{ cm}$ and filled with CF₄ gas (99.99% purity or better), which was also used in NEWAGE-0.3a [4]. It was selected because of its low diffusion properties. The pressure was set at 0.2 bar as a result of the optimization between the expected track length (~8 cm for α ray with 5 MeV) and detector stability. The typical gas gain of a μ -PIC was 10^3 at ~ 500 V. As the drift plate, an oxygen-free copper plate with its surface electro-polished to a roughness of 0.4 μ m and a size of (35 cm × 35 cm) × 0.1 cm was used. The drift plate had an opening with a size of 9.5 cm × 9.5 cm as a sample window. A copper mesh made of 1-mm- ϕ wire with 1-cm pitch (aperture ratio of 0.81) was set on the drift plate to hold the sample in the window area. The electric field is formed by a drift plate biased at -2.5 kV and copper wires with 1 cm pitch connected by a register chain.



Figure 1. Alpha ray track event display (a). Alpha-ray contamination map for the source (b). The dashed line is the edge of the sample window.

2.2. Performance estimate

The detector performance has been estimated using a ²¹⁰Po surface α -ray source (5.3 MeV), where the radioactivity was measured to be $1.49 \pm 0.01 \ \alpha s^{-1}$ for 4.8–5.8 MeV by using the XMASS Ultra-Lo 1800 [1]. The energy resolution is estimated to be ~ 6.7%(σ) at 5.3 MeV α -ray-equivalent.

The α -ray track is reconstructed as shown as Fig. 1 (a). The black circle is data and the red line is fitting. The blue point is the emission position, where the track orientation (i.e., whether the track was upward or downward) can be determined from the signal waveform. The selection efficiency for downward going events was estimated to be 0.964 ± 0.004 for 3.5 MeV α -ray events. Fig. 1 (b) shows an obtained α -ray image from the source. The position resolution was estimated by using events originating from the four edges of sample region and was determined to be $\sim 7 \text{ mm} (\sigma)$. The detection efficiency of $\sim 20\%$ was estimated by calculating a ratio of the event rate to the source activity, where the copper mesh aperture ratio (~ 0.81) and the good-track event selection efficiency (~ 0.4) were included.

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2.3. Sample screening

We measured α -ray from several samples using this α -ray imaging chamber. The energy threshold was set to 2 MeV in this work. The results are listed to Table. 1. In previous work [2], the α rate of a standard μ -PIC was estimated to be $(3.57 \pm 0.35) \times 10^{-1} \alpha/\text{cm}^2/\text{hr}$. This estimate was consistent with the result from High Purity Germanium detector. The Achilles-Vynilas (polyvinyl chloride sheet) is a candidate for use of a new field-cage structure with a high resistance, transparency for visible light, and less radioactive impurities. The sample α rate has be also measured to be $< 2.4 \times 10^{-2} \alpha/\text{cm}^2/\text{hr}$ (90%CL) [5].

It was found that the printed circuit board for μ -PIC installation emits α -rays because it has a glass cloth with uranium and thorium impurities. The alpha rate for its sample was measured to be $(1.16 \pm 0.11) \times 10^{-1} \alpha/\text{cm}^2/\text{hr}$ [2]. We will have to replace this circuit board with one that does not have this problem to improve our imaging chamber's sensitivity. As a candidate to place this printed circuit board, a copper-printed Kapton sheet was measured. The α rate for this new sample was measured to be $< 2.1 \times 10^{-3} \alpha/\text{cm}^2/\text{hr}$ (90%CL).

Sample	Size (cm)	Live time (hr)	α rate $(\alpha/\mathrm{cm}^2/\mathrm{hr})$
μ-PIC	5×5	75.9	$(3.57 \pm 0.35) \times 10^{-1} [2]$
Achilles-Vynilas sheet	10×10	139.5	$< 2.4 \times 10^{-2} (90\% \text{ C. L.}) [5]$
Print circuit board	10×10	176.8	$(1.16 \pm 0.11) \times 10^{-1} [2]$
Copper-printed Kapton sheet	10×10	297.9	$< 2.1 \times 10^{-3} (90\% \text{ C. L.})$

3. Upgrade prospection

In order to improve the sensitivity, we have following plans.

- Use a cooled charcoal system to reduce radon exposure in the chamber: α -ray events from the radon progeny currently dominate the alpha event sample.
- Replace of new materials: the print circuit board and low- $\alpha \mu$ -PIC has yet had radioactive impurities.
- Improve the tracking algorithm and DAQ: the track reconstruction should be improved and evened out for alpha events in all directions; direction dependent efficiency is a common issue in strip gas TPCs.

The detector sensitivity would be improved to better than $10^{-4}\alpha/\text{cm}^2/\text{hr}$ if all the above measures could be implemented.

4. Conclusion

The α -ray imaging chamber is a unique detector that allows us to see where alpha contamination is concentrated on a sample. The current detector can measure alpha rates down to $\sim 10^{-3} \alpha/\text{cm}^2/\text{hr}$. Reducing the background to the measurement arising from the materials in the imaging chamber itself with the improvements outlined above is expected to increase its sensitivity by another of magnitude.

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