Gaseous Time Projection Chamber for Radioactive Material Screening

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Motivation

- Surface radioactivity measurement is key to low background experiments
- Sensitive surface measurement is not as widely available

CUORE: Neutrinoless double $\beta$ decay bolometer array

( alpha from detector surface)

PandaX-4T: dark matter liquid xenon detector

(Radon emanation)
The gaseous TPC

The gaseous TPC to measure particle energy and track

- Sample inside the TPC, high detection efficiency
- Combine energy and track information to identify particle type and source
- Easy to realize a large measuring area (~2000cm²), shorten measuring time

All the features help improve the sensitivity of measurement
Detector overview

The gaseous TPC design (construct with low background materials)

Diagram of gas system
Circular purify the working gas (for a long term stable run)
Simulation for background study

Geometry of the gaseous TPC simulation

敏感体积: \(60 \times 40 \times 10 \text{ cm}^3\)

气体: 一_bar Argon+5\% isobutane

背景能量谱的不同来源

（Alpha背景来自\(^{238}\text{U}\)、\(^{232}\text{Th}\)和\(^{222}\text{Rn}\)）

背景能量谱的组成部分

（Alpha背景来自argon气体，readout平面，field cage和cathode）
Detector response simulation and track reconstruction

Mock signals after detector response simulation

The background energy spectrum after detector response simulation

BiPo coincident event from Geant4 simulation

β

a low energy cut to filter out the β tracks

α
Number of hits (cut ~50% readout plane background)

Track origin points (cut almost all field cage and cathode background)

The cosine of θ (cut readout plane background and half of gas background)

After all cuts

Signals: ~ 68% reserved

Background: suppressed from 4.8 to 0.26 (counts per day)
Measurement sensitivity

The energy spectra of backgrounds after suppression

Sensitivity analysis of the gaseous TPC (90%C.L)

<table>
<thead>
<tr>
<th>measurement time (day)</th>
<th>background events (counts)</th>
<th>sensitivity (μBq·m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.26</td>
<td>82</td>
</tr>
<tr>
<td>3</td>
<td>0.77</td>
<td>43</td>
</tr>
</tbody>
</table>
Prototype TPC

Field cage and readout plane

The Micromegas readout module
(20 x 20 cm²)
Read out with 64 Y strips and 64 X strips
The preliminary test of prototype TPC($^{241}$Am)

$^{241}$Am source: 3mm dot

Signals collected from the prototype TPC

Track reconstruction

Hit map of the origin source
Summary

- Surface contamination control is a critical part of low background experiments and surface radioactivity measurement is desirable.

- We propose a low-background, large-area (about 2000cm²), and high-efficiency gaseous TPC with Micromegas readout for measurement of surface radioactivity.

- With the energy and track recorded by the TPC, TPC background can be further suppressed.

- The sensitivity of surface alpha measurement will be better than 100 μBq/m² at 90% C.L. of one day measurements.

- A prototype TPC is constructed to verify the detector’s design and the analysis protocol.
Thanks for your attention!
Backup
Simulation for background study

<table>
<thead>
<tr>
<th>Material</th>
<th>Gaseous argon</th>
<th>Acrylic</th>
<th>Oxygen-free copper</th>
<th>Stainless steel</th>
<th>Readout plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}$</td>
<td>$1.8 \times 10^{-3}$</td>
<td>0.088</td>
<td>0.38</td>
<td>1.7</td>
<td>45 nBq.cm$^{-2}$</td>
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<tr>
<td>$^{232}\text{Th}$</td>
<td>$0.4 \times 10^{-3}$</td>
<td>4.63</td>
<td>0.51</td>
<td>2.74</td>
<td>14 nBq.cm$^{-2}$</td>
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<tr>
<td>$^{222}\text{Rn}$</td>
<td>0.01 mBq.m$^{-3}$</td>
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<td>$^{40}\text{K}$</td>
<td></td>
<td>0.09</td>
<td>4</td>
<td>13.95</td>
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<tr>
<td>$^{60}\text{Co}$</td>
<td></td>
<td></td>
<td>0.2</td>
<td>1.03</td>
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<tr>
<td>$^{137}\text{Cs}$</td>
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<td>0.16</td>
<td>2.36</td>
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<tr>
<td>$^{39}\text{Ar}$</td>
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<td>1022</td>
</tr>
</tbody>
</table>

**Sensitivity volume:** $60 \times 40 \times 10 \text{ cm}^3$

**Readout plane (Microbulk Micromegas):** $58.03 \times 38.55 \text{ cm}^2$, 0.1mm thick

**Cathode:** $60 \times 40 \text{ cm}^2$, 2mm thick

**Field cage:** A 4 cm thick acrylic frame

**ssVessel:** $80 \times 60 \times 15 \text{ cm}^3$, 1cm thick

**Sample:** $55 \times 35 \times 0.01 \text{ cm}^3$