Development of a low alpha emitting $\mu$-PIC for NEWAGE direction-sensitive dark matter search

Takashi Hashimoto
Outline

• NEWAGE
• Background study for NEWAGE
• Background reduction
  • A prototype of Low α μ-PIC ($10 \times 10 \text{cm}^2$)
  • $30 \times 30 \text{cm}^2$ Low α μ-PIC
• Development of a surface α ray detector using TPC
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• NEWAGE

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  • A prototype of Low $\alpha\mu$-PIC ($10 \times 10\text{cm}^2$)
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• Development of a surface $\alpha$ ray detector using TPC
NEWAGE (NEw generation WIMP search with an Advanced Gaseous tracker Experiment)

- Direction-sensitive dark matter search experiment
- Detection nuclear track by gaseous detector
- NEWAGE using $\mu$-TPC

Expected angular distribution

M = 80 GeV
$\sigma = 0.1$ pb

Hatch:DM signal
Fill:neutron BG

@Galaxy
Detector

『μ-TPC』 @Kamioka mine

- Detection volume: $30 \times 30 \times 41 \text{ cm}^3$
- Gas: CF$_4$(0.1 atm)

μ-TPC: Electrons hit the GEM-CF$_4$ gas mixture

- μ-TPC: anode pitch 400μm, gas gain $\sim 10^3$
- GEM: pre-amplifier, gas gain $\sim 10$

Drift Cage 41 cm PEEK
Direction-sensitive limit

RUN14

- period: 2013/7/20～8/11, 10/19～11/12
- live time: 31.6 days
- fiducial volume: 28×24×41 cm$^3$
- mass: 10.36 g
- exposure: 0.327 kg·days

SD 90% C.L. upper limits and allowed region

- Obtained limit: 557pb@200GeV
- Our limit is still not very good
- Background understanding and reduction are necessary
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  • 30 × 30 cm² Low α μ-PIC
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Background study

Goal
Understanding the measured energy spectrum

- For understanding the measured energy spectrum
  - Measurement of contamination of U/Th in NEWAGE detector components using a HPGe
  - Simulation using U/Th measurement result

A : ambient neutrons and γ-rays,
B : Radon in Gas,
C : U/Th-chain in μ-PIC.
Material screening
Measurement sample

- μ-PIC
- polyimide(PI)(800μm, 100μm) reinforced with glass clothes
- glass clothes
- plating solution(CuSO₄)
- GEM(LCP+copper)

LCP: liquid Crystal Polymer

cross-section view of μ-PIC

plating solution(CuSO₄)

A

100μm

B

800μm

A

100μm

dissolving only PI 100μm using NaOH,KOH

PI reinforced with using glass clothes (L: 800μm,R:100μm)
Measurement result

<table>
<thead>
<tr>
<th></th>
<th>$^{238}$U [ppm] middle stream†</th>
<th>$^{238}$U [ppm] upper stream</th>
<th>$^{232}$Th [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI 100μm</td>
<td>0.39 ± 0.01</td>
<td>0.38 ± 0.01</td>
<td>1.81 ± 0.07</td>
</tr>
<tr>
<td>CuSO₄</td>
<td>&lt;0.01</td>
<td>&lt;0.1</td>
<td>&lt;0.06</td>
</tr>
<tr>
<td>Glass cloth</td>
<td>0.84 ± 0.03</td>
<td>0.91 ± 0.02</td>
<td>3.48 ± 0.12</td>
</tr>
<tr>
<td>GEM</td>
<td>&lt;0.022</td>
<td>&lt;0.17</td>
<td>&lt;0.12</td>
</tr>
</tbody>
</table>

†: assumption of radioactive equilibrium

- GEM and plating solution (CuSO₄) are pure
- Glass cloth in PI 100μm has high radioactivity

<table>
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<th>$^{238}$U [μBq/cm²] middle stream†</th>
<th>$^{232}$Th [μBq/cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI 100μm</td>
<td>68.5 ± 1.5</td>
<td>102.1 ± 2.3</td>
</tr>
<tr>
<td>Glass cloth</td>
<td>64.5 ± 0.1</td>
<td>86.8 ± 1.1</td>
</tr>
<tr>
<td>(PI)-(Glass cloth) Calculation</td>
<td>4.0 ± 1.5</td>
<td>15.3 ± 2.6</td>
</tr>
</tbody>
</table>

$\text{ppm} = 10^{-6} \times \text{g/g}$

U/Th in the PI 100um can be explain by U/Th of glass cloth
We simulated using Geant4

- α-rays from U/Th-chain are generated from the glass cloth in PI 100µm (orange mesh region: \( t = 87 \pm 6 \) µm)
- α-rays from PI 800µm are negligible, because α-rays can’t pass through PI 100µm
Simulation result

- systematic error
  - Uncertainty of glass thickness
  - Uncertainty of gas gain in GEM
- 150-400 keV region can be explained by TPC events
- 50-150 keV region is explained by gap events

Main BG source is glass cloth used to reinforce the PI insulator
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• **Background reduction**
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Development of Low $\alpha\mu$-PIC

- The main background source is glass clothes in PI 100$\mu$m.
- We need to make a $\mu$-PIC with low radioactive materials (Goal: 1/100).

New material

<table>
<thead>
<tr>
<th>Sample</th>
<th>$^{238}$U [ppm]</th>
<th>$^{232}$Th [ppm]</th>
<th>備考</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI100$\mu$m</td>
<td>0.39±0.01</td>
<td>1.81±0.04</td>
<td>Current $\mu$-PIC material</td>
</tr>
<tr>
<td>PI+epoxy</td>
<td>$&lt; 2.98\times10^{-3}$</td>
<td>$&lt; 6.77\times10^{-3}$</td>
<td>New material</td>
</tr>
</tbody>
</table>

- New materials is 100 times as pure as current materials.
- Low $\alpha\mu$-PICs were created.

Cross section view of a new material:
A prototype of Low α µ-PIC production in 2016

- A new type µ-PIC, by replacing top layer of PI with a new material
- A prototype (10×10cm²) was successfully created
  - The anode electrodes are placed in the cathode electrodes
Performance check of the Low $\alpha$ $\mu$-PIC

Requirement: The same level with gas gain of standard $\mu$-PICs

Detector
- Anode 256ch x cathode 256ch
- Cathode readout
- Recorded pulse height using MCA

Detector diagram:
- Source
- Vacuum vessel
- Capton films
- $\mu$-PIC
- Drift mesh
- 1 cm
- Cathode readout

Pre-amp: 2V/pC
MCA
Gas gain of Low $\alpha$ $\mu$-PIC is almost same as standard $\mu$-PIC
- Error bar: Position dependence of gas gain
- A difference between two slope of gain curve is under investigation
  - difference of electric field structure
  - difference of a height of anode electrode

Measurement result

<table>
<thead>
<tr>
<th>Condition</th>
<th>Standard $\mu$-PIC(100$\mu$m)</th>
<th>Low $\alpha$ $\mu$-PIC(80$\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Ar:C}_2\text{H}_6$</td>
<td>9:1,1atm</td>
<td></td>
</tr>
<tr>
<td>Drift V</td>
<td>-500 V</td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>$^{55}\text{Fe}$</td>
<td></td>
</tr>
</tbody>
</table>

graphical representation of gas gain vs. voltage

- Standard $\mu$-PIC
- LA $\mu$-PIC

Condition:
- $\text{Ar:C}_2\text{H}_6 = 9:1,1\text{atm}$
- Drift V: -500 V
- Source: $^{55}\text{Fe}$
30×30 cm² Low α μ-PIC production in 2017

- Low α μ-PICs with a detection area of 30×30cm² was very successfully created
  - alignment control is very good (< 1 μm)

- We confirmed gas amplification
- We will check the performance of a 30 × 30cm² LA μ-PIC
- This will be installed DM searching detector in 2017 summer
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• Development of a surface $\alpha$ ray detector using TPC
Surface $\alpha$ ray detector

We want to measure $\alpha$-rays from a surface of standard and Low $\alpha$ $\mu$-PICs

- Commercially available detector: UltraLo-1800
- We developed a surface $\alpha$ ray detector using $\mu$-TPC
  - We already have $\mu$-TPC and DAQ
- $\alpha$-rays expected from HPGe measurement
  - Standard $\mu$-PICs: $0.1 \, \alpha/cm^2/h$ <- This work
  - Low $\alpha$ $\mu$-PICs: $< 10^{-4} \, \alpha/cm^2/h$ <- Goal

Sensitivity of UltraLo-1800: $10^{-4} \, \alpha/cm^2/hr$

$\mu$-TPC@Kamioka mine
Surface α ray detector

- Merit of μ-TPC:
  - position sensitive measurement
  - measurement of a insulator sample
- Sample region: 10×10 cm²

Sample: Standard μ-PIC(5×5cm² 4 pieces)
Event display

Gas : CF4 @ 0.2 atm

- nhit : 35
- path length = 7.81 cm
- FADCsum = 1818

- We can obtain tracks every 400μm pitch
  - Recording address of all hit strips
- Energy information is groped down to 4 channels and their waveforms are recorded by FADC(100MHz)
Measurement samples

Sample: Standard μ-PIC (5 × 5cm² 4 pieces)
Gas: CF4 @ 0.2 atm
Live time: 3.16 days
Event selection: nhit ≥ 4, Energy > 500 keV

- Comparing data and SRIM simulation, we verified taking α ray
- We can see the image of samples
Measurement samples

Sample: Standard μ-PIC (5 × 5cm² 4 pieces)
Live time: 3.16 days
Event selection: nhit ≥ 4, Energy > 500 keV

- Sample region: 0.157 ± 0.005 events/cm²/h
- BG (Outside of sample region): 0.119 ± 0.002 events/cm²/h

\[0.157 ± 0.005\] events/cm²/h
\[0.119 ± 0.002\] events/cm²/h

• (Sample region) – (BG) = 0.038 ± 0.005 events/cm²/h
• Detection efficiency of α-ray from sample: 0.55 ± 0.05
  • Considering uncertainty of gas pressure

\[0.07 ± 0.01\] α/cm²/h

α-rays expected from HPGe measurement:

→ α-rays from sample: \[0.07 ± 0.01\] α/cm²/h

0.1 α/cm²/h

• The cause of difference between two measurement results is under investigation
NEWAGE: Direction-sensitive dark matter search experiment

Background study

• Understanding: Main BG source is glass clothes used to reinforce the PI insulator
• Reduction: Development of Low $\alpha$ $\mu$-PIC

Performance check of Low $\alpha$ $\mu$-PICs

• We obtained gas gain using $10 \times 10$ cm$^2$ low $\alpha$ $\mu$-PIC as same as a current $\mu$-PIC
• Next step is performance check of $30 \times 30$ cm$^2$ low $\alpha$ $\mu$-PIC
• We will start DM search using Low $\alpha$ $\mu$-PIC at Kamioka main in 2017

Development of a surface $\alpha$ ray detector using $\mu$-TPC

• Sample region: $10 \times 10$ cm$^2$
• BG level: $0.119 \pm 0.002$ events/cm$^2$/h
• In near future, We want to measure $\alpha$-rays from a surface of Low $\alpha$ $\mu$-PICs