AXEL
high pressure xenon gas TPC
for neutrinoless double beta decay search

Kiseki Nakamura | Kyoto Univ.
For the AXEL group

1. AXEL project
2. Fundamental studies
3. Prototype detector
4. Future prospect
5. Summary
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**AXEL experiment**

- High pressure xenon gas TPC for $0\nu\beta\beta$ search
  - High energy resolution: **0.5% (FWHM) @2.5MeV**
    - gaseous xenon + electroluminescence
  - Large mass: **1ton (φ3×2.5m, 10atm)**
  - BG discrimination: **pixel readout** (15mm pitch)

- Similar idea as NEXT experiment
- We introduce a new idea for signal readout (ELCC)
EL readout idea: **ELCC**

**ELCC**
- In the cell hole, electrons are collected and accelerated, then electroluminescence photons are generated.
- Photons are detected by MPPC(SiPM) in each cell.

**Merit of ELCC**
- Uniform response in wide area.
- Rigid structure (--> large size).

![Diagram of ELCC setup]
- Anode electrode
- PTFE insulator w/ holes(\(\phi 4\text{mm}\))
- Mesh electrode
- MPPC photon detector array
What we want to observe

• 0νββ signal
  • energy: integrated FADC
  • track: waveforms (pixel readout TPC)

10atm
Xe100%
15mm pitch
1μs sampling (~1mm)
Tracking strategy

- energy resolution 0.5% --> reject non-2.5MeV
- tracking --> reject α, γ (98%: compton)

10atm, Xe100%, 15mm pitch, 1μs sampling (~1mm)
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Electric field simulation (FEMM)

- Line of electric field are collected
- Uniformity of EL yield is 0.47% (sigma)

\[ \frac{dN_{ph}}{dx} = 70(E/p - 1.0)p \]
MPPC linearity

- Check large and long pulse photon response (~$10^5/5\mu s$)
- Saturation was observed
  - “simultaneous hit” and “decrease of bias voltage”
- After correction, expected residual fluctuation is 0.11%

\[ N_{obs} = \frac{p_0N_{pmt}}{1 + k\tau + Gp_0N_{pmt}} \]
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Overall view

- Kyoto Univ. 3F (welcome!)

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<table>
<thead>
<tr>
<th>Name</th>
<th>filter class</th>
<th>filter num</th>
<th>filter flow</th>
<th>overall flow</th>
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<tbody>
<tr>
<td>CLL25 [Matsusada]</td>
<td>10000</td>
<td>4</td>
<td>7 m³/min</td>
<td>64 times/h</td>
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</table>
Prototype detector

• Detection volume
  • 6*6*6cm³
  • 5.7g (4atm Xe)

• Sensor
  • WLS coated MPPC x64
  • VUV-PMT x2

• Electric field
  • EL: 2.4kV/cm/atm
  • drift: 50V/cm/atm
Event sample

- waveforms of MPPC and PMT
  - EL light & scintillation light are observed

MPPC: 65MHz 12bit 2Vpp

PMT: 100MHz 14bit 2Vpp
γ-ray measurement ($^{57}$Co 122keV)

- Fiducial cut
  - veto region: outer 28 MPPCs
γ-ray measurement ($^{57}$Co 122keV)

- Time dependence correction
- Impurities decrease EL gain
- Gas circulation system is now under construction
**γ-ray measurement (\(^{57}\text{Co} 122\text{keV}\))**

- EL-gain correction
  - Photon num of 30keV γ-ray for “each cell”
    - One MPPC(red) selection is too strict, so blue MPPCs are allowed
    - EL crosstalk suppression structure is under designing

\[ \sigma = 0.065 \quad \text{vs} \quad \sigma = 0.016 \]
γ-ray measurement ($^{57}\text{Co}$ 122keV)

- Hit volume correction
  - strong correlation was obtained
  - (recombination is seen ? )
Energy resolution

- Four peaks are observed
- FWHMs are evaluated by Gaussian fitting

<table>
<thead>
<tr>
<th></th>
<th>Kα</th>
<th>Kβ</th>
<th>escape</th>
<th>full</th>
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<tbody>
<tr>
<td>energy</td>
<td>29.8keV</td>
<td>33.6keV</td>
<td>92.3keV</td>
<td>122keV</td>
</tr>
<tr>
<td>photon #</td>
<td>6605</td>
<td>7516</td>
<td>18711</td>
<td>24710</td>
</tr>
<tr>
<td>FWHM</td>
<td>7.9%</td>
<td>8.7%</td>
<td>5.6%</td>
<td>4.7%</td>
</tr>
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</table>
Energy resolution estimation at Q

- Estimated resolution is 1~3.6% (FWHM) @ 2.5 MeV
  - Several factors for the target

- We plan to improve energy resolution by
  - VUV-MPPC
  - Gas circulation
  - Crosstalk suppress
  - Etc...

- We also plan to make a larger detector
Upgrades

- Long field cage
  - For 511keV $\gamma$-ray
- New VUV-sensitive MPPCs
  - instead of WLS-painted MPPC
  - operation test with $^{57}$Co seems OK
- Gas circulation
  - pump (last component) is now vacuum test
- EL crosstalk suppression
  - designing
Our goal is ....

- $0\nu\beta\beta$ discovery !!!
  - or exclude inverted hierarchy

- Expected event rate
  - 0.5 count/year/ton ($m_{\beta\beta}=10\text{meV}$)
  - We need ton scale detector
  - BG rate requirement in ROI $< \sim 1$ count/year

<table>
<thead>
<tr>
<th>volume</th>
<th>mass</th>
<th>MPPC #</th>
<th>purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>0.216L</td>
<td>~10g</td>
<td>64 ELCC test (122keV, 511keV)</td>
</tr>
<tr>
<td>next (2016~2017)</td>
<td>~200L</td>
<td>~10kg</td>
<td>~2000 2.5MeV demonstration enriched $^{136}\text{Xe}$</td>
</tr>
<tr>
<td>next2 (2018~)</td>
<td>~2000L</td>
<td>~1ton</td>
<td>~31000 $0\nu\beta\beta$ search</td>
</tr>
<tr>
<td>future (202X~)</td>
<td>~18000L</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Next prototype detector

- **Purpose**
  - energy resolution @ 2.5MeV (Q value)
  - establish large size technique
  - tracking ability
  - BG observation

- **Status**
  - readout board --> Tanaka’s poster
  - structure: designing with Geant4
  - clean room: constructed large size
  - gas system: considering safety devices
  - etc...
Most serious BG for AXEL

• γ-ray from $^{214}$Bi is our enemy
• chamber mass : 25 ton
• expected BG is 1000 cts/year

\[ R_{BG} = M \times C \times \frac{N_A}{M_{238U}} \times \frac{\ln 2}{T_{1/2}^{238U}} \times \Omega \times B \times R = \sim 1000 \text{ counts/year} \]

- Mass $\sim 25 \times 10^6$ g
- Contamination $2.9 \times 10^{-12}$ g/g
- Avogadro # $6.02 \times 10^{23}$
- solid angle $\sim 0.1$
- branching ratio 0.0157
- photoab. ratio 0.02

atomic weight 228

half life $4.468 \times 10^9$
• Geant4 + diffusion
• Two blobs detected
• 1/10 reduction will be expected
  • (still remain 100 cts)

<table>
<thead>
<tr>
<th>Signal Efficiency [%] (with BG 10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 atm Xe25%+He75%</td>
</tr>
<tr>
<td>84.6  75.8  73.0  71.0</td>
</tr>
<tr>
<td>30 atm Xe50%+He50%</td>
</tr>
<tr>
<td>80.5  77.4  73.9  67.1</td>
</tr>
<tr>
<td>30 atm Xe75%+He25%</td>
</tr>
<tr>
<td>77.6  73.2  69.2  59.5</td>
</tr>
<tr>
<td>30 atm Xe100%</td>
</tr>
<tr>
<td>64.7  60.5  51.4  36.7</td>
</tr>
</tbody>
</table>

particle.root (entry=0)
/home/axel/AKEL_anal/Geant4/NP5000L/03.2/Onlab_gas_30atmXe100_1e3 axel@hanaro 2015/10/08 11:42:01
G4evt=0, seed=1=5675, seed2=54321
nRuns=3000, nparticles=2, ele_num_totals=103236
E=374.6 x=(686.6,174.2,1123.3) y=(0.110,0.638,0.771)
E=2004.1 x=(686.6,174.2,1123.3) y=(0.110,0.638,0.771)
W=22.1eV, fan=1.03
diffusion: L=0.0195302, T=0.0654811 cm/cm*0.5
attachment=0.00
path_length=120.4mm
blob: r=10mm, n=100
left: 209, 230, 235, 237 ... 464, 500, 503, 645, 477 right
subcluster: 6, 9, 0, 0, 0 keV

2.5 5 7.5 10 [mm]
Pressurized water shield

• Concept
  • Similar structure to KamLAND-Zen
  • Thickness : 37.3mm \(\rightarrow\) 3mm (ex. EXO achieved 1.37mm)
    • or thinner thickness like balloon
  • BG will be 10 counts/year

• Plan
  • pressure test for various materials
  • construct small system
Summary

• AXEL project
  • $0\nu\beta\beta$ search using high pressure xenon gas TPC with high energy resolution, large mass and tracking ability
  • New readout idea: ELCC (electric field simulation is OK)
  • Linearity for $1e5/5\mu s$: correction fluctuation is 0.12% (OK)

• Prototype detector
  • Energy resolution: 1~3.6%(FWHM) at Q (many improvements are ongoing)
  • Long size + VUV-MPPC result will come soon (511keV)

• Future prospects
  • We started making large size detector --> Tanaka’s poster
  • $\gamma$-ray BG from $^{214}$Bi in the chamber (heaviest component) will be reduced by tracking and water shield: 1000->100->10