AXEL
A Xenon ElectroLuminescence detector for high-energy-resolution $0\nu\beta\beta$ search

Kiseki Nakamura | Kyoto Univ.
High pressure Xe gas TPC for $0\nu\beta\beta$ search

- High energy resolution: 0.5% (FWHM) @2.48MeV
- Large mass: 1 ton ($\phi 2 \times 1.7 m$, 30 atm)
- BG discrimination: pixel readout (7.5mm pitch)

(DirectionaDM search)
High energy resolution

**Ionization process**
- W-value = 22.1eV
- Fano-factor = 0.13
- => 0.25%(FWHM) @2.5MeV
- proven by Xe gas

**Multiple process**
- Use ElectroLuminescence (EL)
- proportional to the electric field
- amplification fluctuation is small

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![Energy resolution graph](image)

- $E_\gamma = 662$ keV
- 100 atm
- NIMA396 (1997) 360
Conventional EL readout (NEXT)

- energy @ opposite PMT
- tracking @ SiPM
- position dependence
- deflection of mesh

New EL readout (ELCC @AXEL)

- energy & tracking @ ELCC
- no position dependence
- no deflection of mesh
- robust structure
- need performance check
Electroluminescence

Produced photons ($N_{ph}$)
- proportional to $E/p$
- threshold process
- $dN_{ph}/dx = 70(E/p - 1.0)p$
  (UV photons/e cm drift)

Detected photons (Gain)
- $\text{Gain} = N_{ph} \times \text{eff}_{\text{collect}} \times \text{PDE}$
- Gain=100 (30atm) is enough to keep high energy resolution

<table>
<thead>
<tr>
<th>$E$ [kV/cm]</th>
<th>P [atm]</th>
<th>eff$_{\text{collect}}$ [%]</th>
<th>PDE [%]</th>
<th>Gain</th>
<th>E$_{\text{res}}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>1</td>
<td>12.9</td>
<td>30</td>
<td>3</td>
<td>0.47</td>
</tr>
<tr>
<td>32</td>
<td>10</td>
<td>12.9</td>
<td>30</td>
<td>30</td>
<td>0.28</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
<td>12.9</td>
<td>30</td>
<td>96</td>
<td>0.26</td>
</tr>
</tbody>
</table>

*only Gain effect is considered
**EL demonstration by UV-PMT**

**Setup**
- 1 atm Xe
- UV-PMT (H3178-51Q)
- detection size: 28x28x55mm

**energy resolution (FWHM)**
- 13.8% @30keV (fit right edge)
- 1.5% @2.5MeV (converted)

**Escape peak**
- 29.8keV

**241Am**
- 59.5keV
Prototype detector: outside

- Gas system (we need pump with high pressure for gas circulation)
- Chamber 10L, <10atm
- Temperature controller
- Electronics
Prototype detector: inside

- Wire w/o soldering
- 32ch MPPC
- Wave length shifter
- Anode holes
- PTFE
- MPPC drift top
- Anode holes 1.6kV
- GND mesh
- Drift top 2kV
- 7.5mm
Data acquisition

- record waveform (32ch)
- 65MHz 12bit 2Vpp
Tracking demonstration (α-ray)

- Detect EL light
  - OK!
- Track width is too large?
  - large Diff$_{tra}$ --> High Pressure
  - blurred at WLS --> UV-MPPC

\[
\begin{align*}
\text{gas: } & \text{ Xe 1atm} \\
E_{\text{anode}} &= 1.6kV/0.5cm \\
E_{\text{drift}} &= 0.4kV/6cm \\
\text{Diff}_{tra} &= 0.34cm/\sqrt{\text{cm}}
\end{align*}
\]
- Detect γ-ray
  - OK!
- Bad energy resolution
  - WLS efficiency is small (< 0.5) and not uniformity
  - small size (32ch) and low pressure (1atm) ---> w/o fid-cut
  - ---> need UV-MPPC, large size (64ch), high pressure

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gas : Xe 1atm
$E_{anode}=1.6kV/6cm$
$E_{drift}=0.4kV/0.5cm$

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$^{57}$Co
122keV

![Graph showing photon count]
Plan of prototype detector

- Goals
  - Measure energy resolution using 662keV gamma-ray
  - Measure rejection power of α-ray by tracking

- Plan

<table>
<thead>
<tr>
<th></th>
<th>num</th>
<th>type</th>
<th>pressure</th>
<th>γ source</th>
<th>others</th>
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<tbody>
<tr>
<td>current</td>
<td>32ch</td>
<td>visible</td>
<td>1atm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015/03</td>
<td><strong>64ch</strong></td>
<td>visible</td>
<td>1atm</td>
<td>241Am(60keV)</td>
<td>put UV-PMT to get z pos.</td>
</tr>
<tr>
<td>2015/04</td>
<td>64ch</td>
<td><strong>UV</strong></td>
<td>1atm</td>
<td>241Am(60keV)</td>
<td></td>
</tr>
<tr>
<td>2015/05</td>
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<td>UV</td>
<td>3atm</td>
<td>57Co(122keV)</td>
<td></td>
</tr>
<tr>
<td>2015/06</td>
<td>64ch</td>
<td>UV</td>
<td><strong>10atm</strong></td>
<td>137Cs(662keV)</td>
<td></td>
</tr>
</tbody>
</table>

UV-MPPC (3rd gen.) will be marketed from FY2015.
- low Cross talk (new)
- low after pulse (already done)
- PDE@178nm: 20~30%
Motivation

• Linearity is very important to obtain high energy resolution.
• Many photons (~$10^5$) may come in long time (~5μsec).

Experiment

• Linearity would depend on pixel size and recovery time.
• MPPC is studied by comparing PMT.
Motivation

- PDE is very important basic performance.
- There is no result of PDE in high pressure Xe gas.

Experiment

- Mini chamber filled with high pressure Xe gas.
- UV-MPPC detect scintillation from $\alpha$ (UV-PMT as a reference)
We start to think about background
Signal estimation

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

- Expected event rate
  - 0.5 count/year/ton ($m_{\beta\beta} = 10\text{ meV}$)
  - We need several tons of $^{136}\text{Xe}$...

- BG rate requirement in ROI < $\sim 1$ count/year
Comparison of $0\nu\beta\beta$, $e$, and $\alpha$

- Event topology by tracking
  - $\alpha$ BG is well rejected
  - $\gamma$ BG with 2.5MeV photoelectric absorption is difficult to reject perfectly.
  - (multi site events such as Compton scattering can be rejected)
γ-ray BG around the ROI

- Energy resolution of 0.5%
  - γ-ray from $^{208}$Tl can be rejected
  - γ-ray from $^{214}$Bi interacting photoelectric absorption can be serious BG
Rate of $^{214}\text{Bi} \gamma$-ray

- Attenuation length of 2.5MeV $\gamma$-ray
  - 140cm in 30atm Xe -> self shielding is not effective
  - 20cm in water -> external BG stop by water shield

- Materials of detector must be checked
  - Vessel is the most heavy component (10ton : copper)
  - EXO uses clean copper for vessel : U < 5ppt 95% U.L.

$$R_{BG} = M \times C \times \frac{N_A}{M_{238U}} \times \frac{\ln 2}{T_{1/2}^{238U}} \times \Omega \times B \times R = 643 \text{ counts/year}$$

- Mass $\sim 10 \times 10^6$ g
- Contamination $5 \times 10^{-12}$ 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 $4.468 \times 10^9$
How to deal with $^{214}\text{Bi}$?

- Improve energy resolution
  - Energy difference between 0νββ and γ from $^{214}\text{Bi}$ is 0.44%
  - Intrinsic energy resolution is 0.25%
- Put some shield “in” the vessel
  - Pressure vessel become huge
- Make clean vessel
  - Purifying copper
- Make light vessel
  - Titanium is strong and light (NEXT group’s approach)
  - Need 2 ton --> still need purification
- --> We noticed rejection of high energy γ is not so easy
Pressurized water shield

• Merit
  • Greatly reduce the mass inside the water shield (~30kg)
  • Clean (<0.1ppt U, ILIAS UKDM)
  • Work as active veto (need PMT for high pressure)
  • Liquid is easy high pressure (in addition, it’s safe)
  • Cheap

• Next to do
  • check MPPC ($10^5$ ~100kg) BG
  • Geant4 simulation
Summary

• AXEL experiment
  • high pressure Xe gas TPC for 0νββ search
  • aim to search $m_{\beta\beta} = 10\text{meV}$

• R & D
  • prototype detector for demonstration
  • check MPPC linearity
  • performance of UV-MPPC in high pressure Xe gas

• We start to think about BG
  • $^{214}\text{Bi}$ is our enemy
  • pressurized water shield seems to be good