Concept of KamLAND2 DAQ system

May 25, 2021 TIPP2021 (online)
KamLAND

Kamioka Liquid scintillator Anti-Neutrino Detector
- KamLAND Zen 800 phase is running since Jan. 2019.

![Diagram of KamLAND detector components](image)

- **Inner detector**
  - 17-inch PMT × 1325
  - 20-inch PMT × 554

- **Liquid scintillator 1kton**

- **Inner balloon 1.9mφ**

- **Stainless steel tank 18mφ**

- **Outer detector**
  - 20-inch PMT × 140

- **Mineral Oil**

- **Outer balloon 13mφ**

- **Pure water 3.2kton**
Neutrino physics @ KamLAND

**Geo neutrino**
(Neutrino Geoscience 2019, H. Watanabe)

**7Be solar neutrino**
(PR C 92, 055808 (2015))

**Neutrino-less double β decay**
(TAUP2019, Y. Gando)

**Gravitational Wave**
(Astro. Phys. Journal, 909;116 (2021))
Neutrino physics @ KamLAND

SNEWS:
SuperNova Early Warning System
International collaboration of experiments
- Super-K (Japan)
- LVD (Italy)
- Ice Cube (South Pole)
- KamLAND (Japan)
- Borexino (Italy)
- Daya Bay (China)
- HALO (Canada)
KamLAND → KamLAND2

**Major backgrounds for 0ν2β decay**
- 2ν2β decay
- Cosmic μ spallation backgrounds

**2ν2β decay**

![Graph showing 2νβ and 0νβ decay]

Q = 2.467MeV

To improve energy resolution is the only one solution!

**Cosmic μ spallation backgrounds**

- Likelihood (dE/dX, dL and dT)
- 3-fold tagging (μ, ¹⁰C and neutron).

Q = 3.6MeV
τ₁/₂ = 19s
**KamLAND → KamLAND2**

**Major backgrounds for 0ν2β decay**
- 2ν2β decay
- Cosmic μ spallation backgrounds

<table>
<thead>
<tr>
<th>Gain of light yield</th>
<th></th>
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<tbody>
<tr>
<td>High Q. E. PMT</td>
<td>&gt; 1.9</td>
</tr>
<tr>
<td>Light collecting mirror</td>
<td>&gt; 1.8</td>
</tr>
<tr>
<td>High light yield LS</td>
<td>&gt; 1.4</td>
</tr>
<tr>
<td>Scintillation balloon</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>&gt; 5</td>
</tr>
</tbody>
</table>

- Increase light yield & improve energy resolution!!
- Target $<m_{\beta\beta}>$ sensitivity ~ 20 meV / 5 years
Challenges for electronics

- **Cosmic \(\mu\) spallation backgrounds**
  - Spallation on \(^{136}\text{Xe}\) induce serious backgrounds.
  - Number of surrounding neutrons is a key for tagging.

  "High neutron detection efficiency"

- **Supernova neutrinos**
  - Time profile of the number of neutrinos is a probe of supernova explosion mechanism.

  "High event rate tolerance"

**Betelgeuse (200pc)**

Maximum instantaneous event rate ~ 1MHz
Current limitation

- Cosmic $\mu$ spallation backgrounds
  - Trigger decision become difficult under overshoot.

- Supernova neutrinos
  - Buffer will be full at around 300$\mu$s with event rate of 1MHz.
How to overcome

- Cosmic $\mu$ spallation backgrounds
  - Trigger decision become difficult under overshoot.

  "Digital BaseLine Restorer (BLR)"

- Supernova neutrinos
  - Buffer will be full at around 300$\mu$s with event rate of 1MHz.

  "RFSoC" transfer speed 76.8 Gbps
  "DDR4" on-board buffer 4 GB
DAQ overview

- Pipeline
- High scalability

Monitoring & Control

Front-End
~2000 ch
0.5Gbps/FEE

Readout
× 13
5Gbps/computer

Trigger
× 4
16Gbps/computer

Event Builder
0.7Gbps
## Event rate & Data rate

<table>
<thead>
<tr>
<th>Event rate</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dark noise</strong></td>
<td>20kHz</td>
</tr>
<tr>
<td><strong>Cosmic μ</strong></td>
<td>0.3Hz</td>
</tr>
<tr>
<td><strong>Supernovae</strong></td>
<td>1MHz (~1s)</td>
</tr>
</tbody>
</table>

- **Dark noise**
  \[1 \text{GSPS \times 16bit \times 100ns \times 20kHz} = 32 \text{ Mbps}\]

- **Cosmic μ**
  \[1 \text{GSPS \times 16bit \times 10\mu s \times 0.3Hz} = 48 \text{ kbps}\]

- **Nearby Super novae**
  \[1 \text{GSPS \times 16bit \times 100ns \times 1MHz} = 1.6 \text{ Gbps}\]
Front-End Electronics

<table>
<thead>
<tr>
<th></th>
<th>KamLAND</th>
<th>KamLAND2</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-board buffer</td>
<td>64 MB</td>
<td>4 GB</td>
</tr>
<tr>
<td>Transfer speed</td>
<td>12.8 Gbps</td>
<td>76.8 Gbps</td>
</tr>
</tbody>
</table>
Front-End Electronics

**RFSoC** (XCZU29DR-1FFVF1760E)
- High speed ADC and DAC
- Large number of Digital Signal Processors (DSP)
- Fine tunable digital BLR

**Key Features**
- **ADC**
  - Resolution: 12 bit
  - Max sample speed: 2.058 GSPS
- **Logic cell**: 930300
- **DSP slice**: 4272

**Diagram**
- **Analog circuit**
  - BNC ×16
  - H-gain amp.
  - L-gain ADC

- **DSP**
  - H-gain RFADC
  - Digital BLR
  - RFDAC

- **L1 trigger**
  - Delay Discri.
  - Data frame generator

- **Data transfer**
  - 10GbE
  - SFP+ 512Mbps
  - DDR4 4GB

**RFSoC** (XCZU29DR-1FFVF1760E) is a high-speed electronic system with features such as high-speed ADC and DAC, a large number of Digital Signal Processors (DSP), and fine tunable digital BLR.
DAQ control

- Address=tcp://127.0.0.1:5555
- Type=push
- Method=bind
- Name=Sampler

Plugin
- Development based on J-PARC E16 experiment
- Redis API
- Key-Value store
  https://github.com/redis/redis

FairMQ
- Asynchronous message processing
- Various transports (TCP/IP, in-process, inter-process)
- Independent process (FairMQDevice)
- StateMachine
  https://github.com/FairRootGroup/FairMQ
## Trigger

<table>
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<th>KamLAND</th>
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<tbody>
<tr>
<td>L1 : 1 p.e. detection (hardware)</td>
<td>L1 : 1 p.e. detection (hardware)</td>
</tr>
<tr>
<td>L2 : Hit based hardware trigger</td>
<td>L2 : Time-charge based software trigger</td>
</tr>
<tr>
<td>Special trigger to detect neutrons after cosmic $\mu$.</td>
<td>Waveform from all of hit channels to be recorded.</td>
</tr>
</tbody>
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**Conceptual study is ongoing based on MC**

### KamLAND

- NHits (Hit Based trg)
- Cosmic $\mu$
- Radioactivity

### Hit timing

- Row
- TOF subtracted

- Number of Hit
- Entries: 2512060
- Overflow: 64
Development status

FEE

☑ Recording waveform with a time window of 34 $\mu$s.

Long enough for cosmic $\mu$ events!
Development status

FEE

- Recording waveform with a time window of 34 µs.
- Data acquisition of 1MHz events for 1s.

![Graph showing time to fill up the buffer vs. hit rate.]

- DDR4 4GB (estimation)
- 1MB URAM + AXI4-Stream interconnect (measurement)

Hit rate [kHz] vs. Time to fill up the buffer [ms]
Summary

- KamLAND2 is planned to improve the energy resolution.

- Challenges for electronics are,
  - to achieve higher rejection efficiency of spallation backgrounds
  - to acquire data of supernova events.

- High speed processing is one of the important subjects.

Key for implementation
- RFSoC, DDR4 and 10GbE on FEE
- Network design and data processing with FairMQ
- Time-charge based software trigger

Next step
- Operation of KamLAND2 prototype detector around end of this year.