Daya Bay Muon System

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On behalf of Daya Bay Collaboration
Background Sources

- Accidental background
  - Natural radioactivity in the materials and around rock
  - Untagged neutrons
- Fast neutron: $n_{\text{fast}} + p \rightarrow p + n^*$
  - Recoil proton generates the prompt signal
  - Capture of the thermalized neutron provides the delayed signal
- $^9\text{Li}/^8\text{He}$ from cosmic muons
  - Long half life (0.18 s/0.12 s), hard to reject from muon tagging.
  - $\beta-$neutron cascade decay mimic inverse beta decay.
Purpose of Muon System

- Shield the antineutrino detectors from natural and cosmogenic background. Attenuate rock radioactivity and fast neutrons.
- To register the presence of a cosmic ray muon and measure its time and position with respect to candidate events.
- The water also regulates the temperature of the antineutrino detectors.
Muon System

- Water Cherenkov detector: the Anti-Neutrino Detectors are immersed in a water pool with 2.5 m water in all directions.
  - Inner muon veto
  - Outer muon veto. Seperated by Tyvek reflectors from inner veto.

- RPC system: multiple layers of resistive plate chambers on top of pool
<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of water shield</td>
<td>≥2 m</td>
<td>Attenuate fast neutrons and γ rays from rock</td>
</tr>
<tr>
<td>Total efficiency for muons</td>
<td>≥99.5%</td>
<td>Reduce fast-neutron background to a level below $^9$Li/$^8$He</td>
</tr>
<tr>
<td>Uncertainty of efficiency</td>
<td>≤0.5%</td>
<td>Maintain fast-neutron uncertainty well below that of $^9$Li/$^8$He</td>
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<tr>
<td>Random veto deadtime</td>
<td>≤15%</td>
<td>Avoid undue impact on statistical precision</td>
</tr>
<tr>
<td>Position resolution</td>
<td>0.5~1 m near AD</td>
<td>Study radial dependence of cosmogenic background</td>
</tr>
<tr>
<td>Timing resolution</td>
<td>±2 ns (Cherenkov) ±25 ns (RPCs)</td>
<td>Allow spatial reconstruction of muon Limit random veto deadtime from false coincidences to O(1%)</td>
</tr>
</tbody>
</table>

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Water Pool Geometry

Inner and outer veto separated by Tyvek panels
Water Pool PMT

- Potted & encapsulated base
- Holder based on MiniBooNE design
- 8” PMTs: ~1000 in all, 2/3 new, 1/3 recycled MACRO PMTs
- Inner water shield: 1 PMT/8 m²
- Outer water shield: 1 PMT/6-7 m²
- **DYB Far pool**: 2560 m³
- **DYB Near pool**: 1600 m³
- **Requirement**: attenuation length for Cherenkov light be on the order of the pool dimension or larger.
- **Initial purification units** include: biocide feeder, water softener, filters, and a reverse osmosis (RO) unit.
Simulation result with conservative assumptions: $\lambda_{\text{att}} = 30\,\text{m}$, Reflectivity $\sim 80\%$, Singles Rate$=50\,\text{kHz}/\text{PMT}$, Dead time fraction $\leq 1\%$

- Inner veto require $>11$ PMTs: 98% tagging eff.
- The baseline water shield muon trigger uses an OR of a multiplicity trigger for inner and outer shields.
RPC system
RPC Module Structure

- RPC is composed of two resistive plates with gas flowing between them.
- Bakelite plates, RPC operated in streamer mode.
- The RPCs are constructed from a new type of phenolic paper laminates, the surface quality of these plates is improved compared to that of other bakelite plates.
RPC Arrangement

- 4 layers of RPC module
- Each module slightly larger than $2 \times 2$ m, overlap to exclude dead region

RPC support structure
RPC Readout Scheme

- Readout: strips of 25 cm (spatial resolution requirement \(\sim 50\) cm) pitch of zigzag design, the effective width of the strip is 6 cm, the effective length of 8 m does not degrade the signal.
- Four layers, “x”, “y” readouts alternate
Gas mixture:  
\[ \text{Ar/R134A/Isobutane/SF}_6 = 65.5/30/4/0.5\% \]

- Small fraction of \( \text{SF}_6 \) is essential for avoiding very large amount of charge delivered in the gas per single streamer.

- Electronic bubbler system monitors the chamber gas flow.
Single layer efficiency > 95%, singles rate < 0.5 Hz/cm², dark current < 5 µA/m²
### Muon Veto Efficiency

<table>
<thead>
<tr>
<th>Layers</th>
<th>( \geq 1 )</th>
<th>( \geq 2 )</th>
<th>( \geq 3 )</th>
<th>( \geq 4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>99.75%</td>
<td>90.25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>99.987%</td>
<td>99.275%</td>
<td>85.74%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>99.999%</td>
<td>99.952%</td>
<td>98.598%</td>
<td>81.45%</td>
</tr>
</tbody>
</table>

- RPC requirement: hits in 3 out of 4 layers.

<table>
<thead>
<tr>
<th></th>
<th>Pool Only</th>
<th>Pool + RPC</th>
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<tbody>
<tr>
<td>Near</td>
<td>98.85±0.12%</td>
<td>99.43±0.09%</td>
</tr>
<tr>
<td>Far</td>
<td>98.81±0.12%</td>
<td>99.44±0.08%</td>
</tr>
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</table>

- Muon track length in water.
- Red histogram shows the events which miss both inner and outer water shield vetos.
- Most inefficient muons are short tracks from outer water shield (far away from AD).
The Daya Bay muon system consists of Water Cherenkov detector and RPC system.

99.5% muon veto efficiency is achievable.

Currently, PMT potting and RPC bear chamber testing are under progress.

RPC module assembly at IHEP is almost finished.

Installation for the near hall is underway.
Backup slides
A special installation platform shown above will be manufactured.

This tool can help people to get access to the front end panel of the RPC module.
Muon Reconstruction

- Distribution of reconstructed position minus true position.
- Preliminary results show that a resolution of $\sim 40$ cm can be achieved from inner water shield.