Daya Bay Muon System

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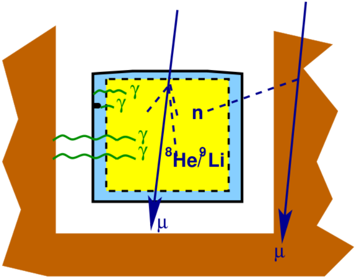
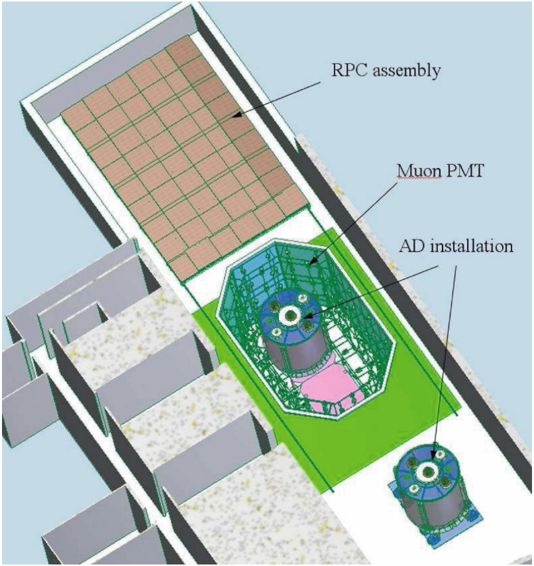
On behalf of Daya Bay Collaboration

Background Sources



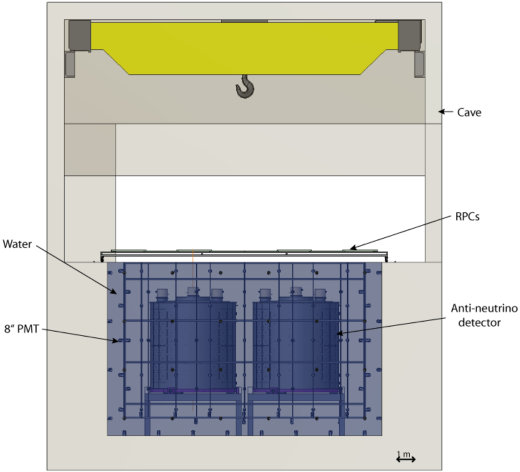
- Accidental background
  - Natural radioactivity in the materials and around rock
  - Untagged neutrons
- Fast neutron: $n_{fast} + p \longrightarrow p + n^*$
  - Recoil proton generates the prompt signal
  - Capture of the thermalized neutron provides the delayed signal
- ^{9}Li/^{8}He from cosmic 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

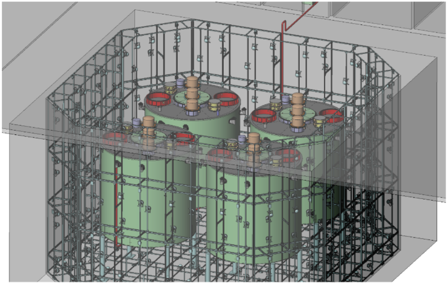


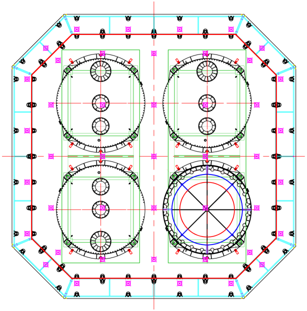
- Water Cherenkov detector: the Anti-Neutrino Detectors are immersed in a water pool with 2.5 m water in all directions.
  - Inner muon veto
  - Outer muon veto. Seperated by Tyvek reflectors from inner veto.
- RPC system: multiple layers of resistive plate chambers on top of pool

Muon System Requirements

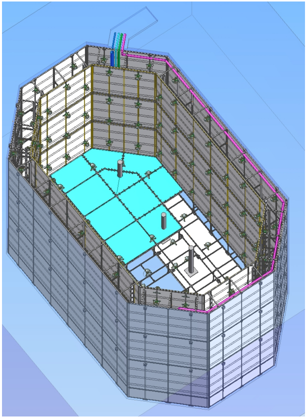
Item	Requirement	Justification
Thickness of water shield	$\geq$2 m	Attenuate fast neutrons and γ rays from rock
Total efficiency for muons	$\geq$99.5%	Reduce fast-neutron background to a level below ^{9}Li/^{8}He
Uncertainty of efficiency	$\leq$0.5%	Maintain fast-neutron uncertainty well below that of ^{9}Li/^{8}He
Random veto deadtime	$\leq$15%	Avoid undue impact on statistical precision
Position resolution	0.5$\sim$1 m near AD	Study radial dependence of cosmogenic background
Timing resolution	$\pm$2 ns (Cherenkov) $\pm$25 ns (RPCs)	Allow spatial reconstruction of muon Limit random veto deadtime from false coincidences to O(1%)

Water Pool Geometry

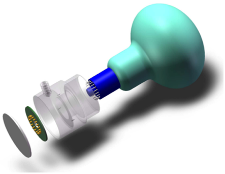


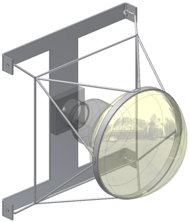


Inner and outer veto separated by Tyvek panels



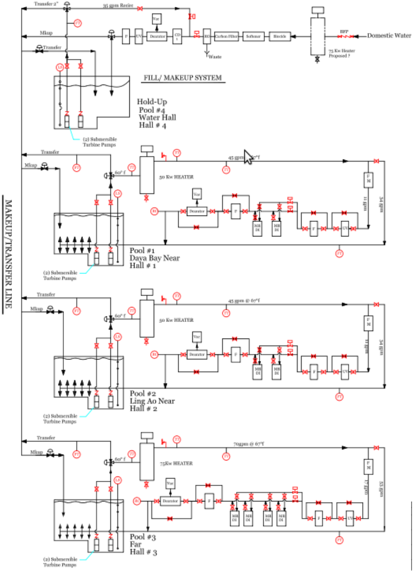
Water Pool PMT





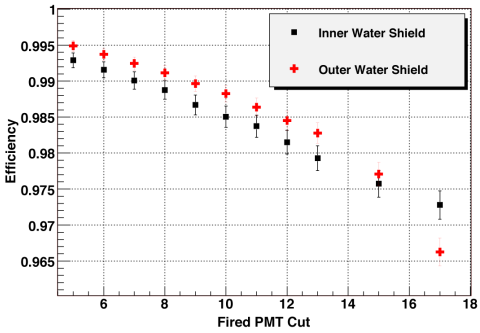
- Potted & encapsulated base
- Holder based on MiniBooNE design
- 8" PMTs: ∼1000 in all, 2/3 new, 1/3 recycled MACRO PMTs
- Inner water shield: 1 PMT/8 m^2
- Outer water shield: 1 PMT/6-7 m^2

Water Conditioning System



- DYB Far pool: $2560\,\mathrm{m}^3$
- DYB Near pool: $1600\,\mathrm{m}^3$
- 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.

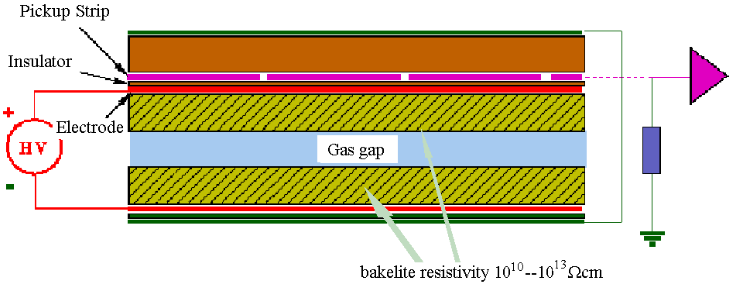
Water Pool Veto Efficiency



- Simulation result with conservative assumptions: $\lambda_{att} = 30\,\text{m}$, Reflectivity ∼80%, Singles Rate=50 kHz/PMT, Dead time fraction ≤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

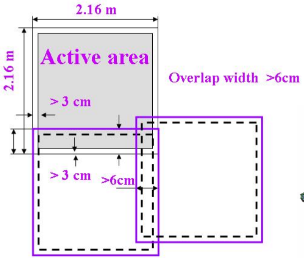
RPC Module Structure

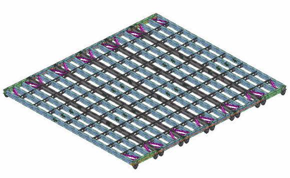


- RPC is composed of two resistive plates with gas flowing between them.
- Bakelite plates, RPC operated in streamer mode.
- The RPCs are constructed from a new type of phenolic paper laminates, the surface quality of these plates is improved compared to that of other bakelite plates.

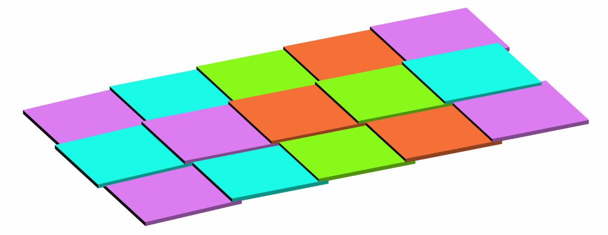
RPC Arrangement

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

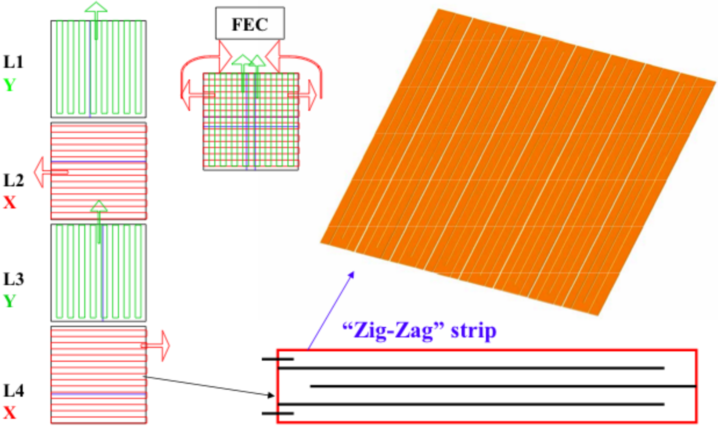




RPC support structure

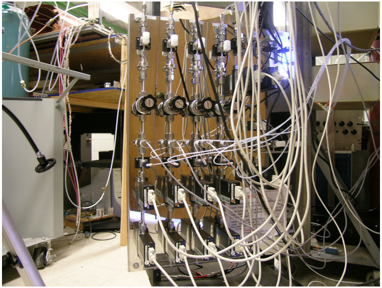


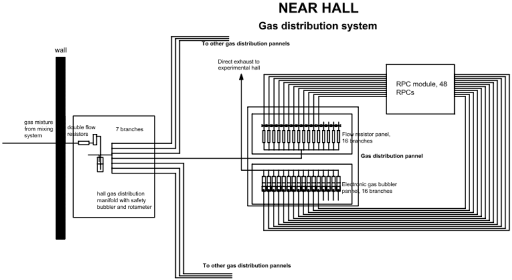
RPC Readout Scheme



- Readout: strips of 25 cm (spatial resolution requirement ∼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

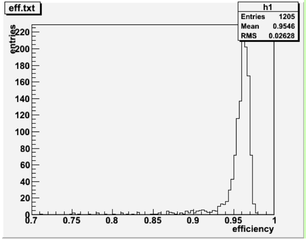
RPC Gas System

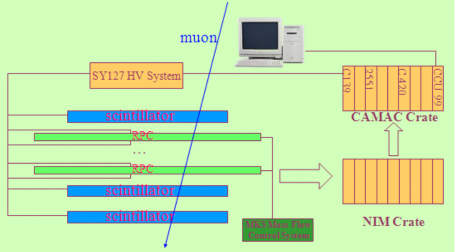


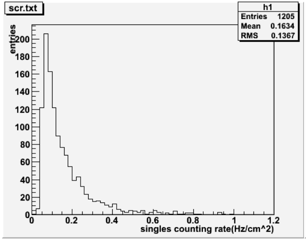


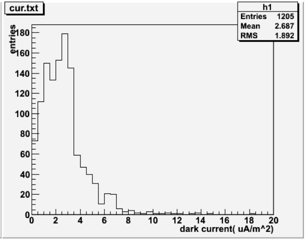
- Gas misture: Ar/R134A/Isobutane/SF_6 $= 65.5/30/4/0.5\%$
- Small fraction of SF_6 is essential for avoiding very large amount of charge delivered in the gas per single streamer.
- Electronic bubbler system monitors the chamber gas flow.

RPC Bare Chamber Test









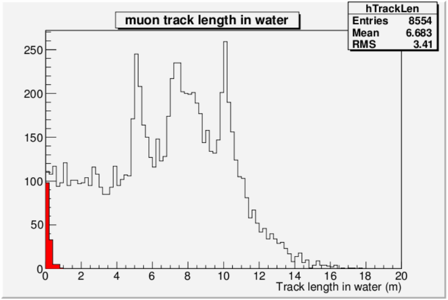
- Single layer efficiency > 95%, singles rate $< 0.5\,\text{Hz/cm}^2$, dark current $<5\,\mu\text{A/m}^2$

Muon Veto Efficiency

Layers	≥1	≥2	≥3	≥4
1	95%			
2	99.75%	90.25%		
3	99.987%	99.275%	85.74%	
4	99.999%	99.952%	98.598%	81.45%

	Pool Only	Pool+RPC
Near	98.85±0.12%	99.43±0.09%
Far	98.81±0.12%	99.44±0.08%

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



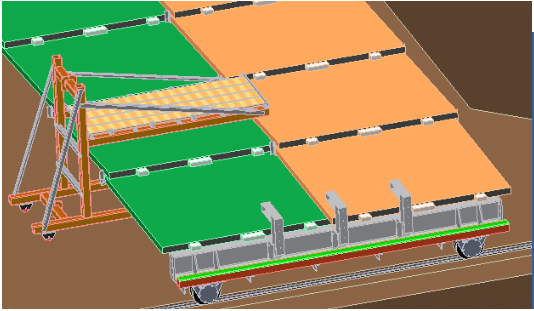
- Muon track length in water.
- Red histogram shows the events which miss both inner and outer water shield vetos.
- Most inefficient muons are short tracks from outer water shield (far away from AD).

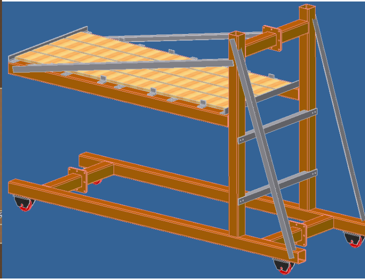
Summary and Schedule

- 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

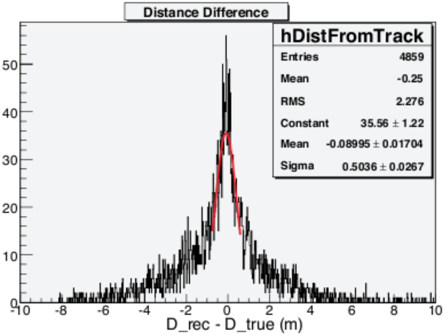
RPC Installation





- 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 ~40 cm can be achieved from inner water shield.