Research on Liquid Scintillator Cherenkov Detector for Neutrino Physics

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Jinping Neutrino Experiment

- Equipped in the China Jinping Underground Laboratory (CJPL)
- Located in Sichuan province, China
- 2400 meters under Jinping mountain, 950 km from reactors

World map with all the nuclear power plants in operation and under construction.

Muon flux vs reactor neutrino background flux for various underground labs in the world.
Jinping Neutrino Experiment

- Total fiducial target mass of 2000 tons for solar neutrino physics
- Equivalently, 3000 tons for geo-neutrino and supernova neutrino physics

The conceptual design for a cylindrical neutrino detector at Jinping. Spherical inner vessel is also an option.

One ton prototype detector design. This detector is running now.
# Neutrino physics

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Neutrino Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>Geo-neutrinos</td>
</tr>
<tr>
<td>1</td>
<td>Solar neutrinos</td>
</tr>
<tr>
<td>10</td>
<td>Supernova neutrinos</td>
</tr>
<tr>
<td>100</td>
<td>Jinping Neutrino Experiment Energy Region of Interest (1 - 20 MeV)</td>
</tr>
<tr>
<td>1 GeV</td>
<td>Reactor neutrinos</td>
</tr>
<tr>
<td>10 GeV</td>
<td>Accelerator neutrinos</td>
</tr>
<tr>
<td>100 MeV</td>
<td>Atmospheric neutrinos</td>
</tr>
<tr>
<td>1 GeV</td>
<td>10 GeV</td>
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<tr>
<td>10 GeV</td>
<td></td>
</tr>
<tr>
<td>10 GeV</td>
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</tbody>
</table>
Different neutrino detectors

Water/Heavy water detector
✓ Measuring both energy and direction.
✗ Poor light yield and energy resolution.
✗ High energy detection threshold.

Liquid scintillator detector
✓ Low detection threshold.
✓ High light yield and energy resolution.
✗ No direction information.
Liquid Scintillator Cherenkov Detector

- Slow liquid scintillator instead of traditional LS
- Slower time constants, separate Cherenkov and scintillation light by time
- Suppress the absorption and reemission of Cherenkov light

PE arrival times of a 20 m diameter spherical slow LS detector, simulated by Geant4.
Liquid Scintillator Cherenkov Detector for Neutrino physics

- Both direction and energy measurement
- For solar neutrino,
  - Possible to use solar direction correlation
  - Possible to increase energy resolution and probe low energy solar neutrinos

![Graph showing discrimination of particles based on scintillation photon number and electron kinetic energy.](image)

- Particle identification:
  - Suppress fast neutron background, atmosphere CC and NC background, even suppress part of gamma background

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• Improvement for SRN detector
Slow liquid scintillator candidates

Linear alkyl benzene (LAB):
An important ingredient of slow liquid scintillator

- Non-flammable
- Non-toxic
- Favorable optical properties
- Low cost

LAB is now used in several neutrino detectors as the solvent of LS, such as RENO and Daya Bay.
### Slow liquid scintillator candidates

- However, the light yield of pure LAB (~1000 photons/MeV) is not high enough.
- PPO (2,5-Diphenyloxazole) and bis-MSB (1,4-Bis(2-methylstyryl) benzene) could be the scintillation solute and wavelength shifter.

<table>
<thead>
<tr>
<th>Low concentration</th>
<th>High concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water/Heavy water style</td>
<td>Liquid scintillator style</td>
</tr>
<tr>
<td>✓ Energy and direction information</td>
<td>✗ No direction information</td>
</tr>
<tr>
<td>✗ Poor energy resolution</td>
<td>✓ High energy resolution</td>
</tr>
<tr>
<td>✗ High energy detection threshold</td>
<td>✓ Low detection threshold</td>
</tr>
</tbody>
</table>
Scintillation Cherenkov light separation

Apparatus for researching on the light yield and time constants

- Trigger by cosmic ray muon
- Container with Low reflectivity inner surface
- **Bottom PMT** can see both Cherenkov light and scintillation light
- **Top PMT** can only see scintillation light
- Scintillation light is expected up-down symmetric
Scintillation Cherenkov light separation

[Diagram showing a setup with a cosmic ray muon passing through scintillation panels labeled 'Top PMT' and 'Bottom PMT', with measurements of 37 cm and 30 cm.]

- Coincidence scintillators
- Iron shell
- Acrylic container
- Liquid scintillator
- Anti-coincidence scintillators

Graphs showing voltage over time for Pure LAB and LAB + 0.07 g/L PPO + 13 mg/L bis-MSB.
Time profile and light yield

- Time profile: fit the average waveform with

\[ f(t) = [A_c \cdot \delta(t - t_0) + A_s \cdot n(t - t_0)] \otimes \text{gaus}(t) \]

where \( n(t) \) is the scintillator time profile:

\[ n(t) = \frac{\tau_r + \tau_d}{\tau_d^2} \left( 1 - e^{t/\tau_r} \right) \cdot e^{t/\tau_d} \]

\( \tau_r \): Rising time constant
\( \tau_d \): Decay time constant

- Light yield was estimated by

\[ L = \frac{D}{\varepsilon E_{vis}} \]

\( D \): Number of photoelectrons, from fit result of waveform
\( \varepsilon \): Detection efficiency, from Monte-Carlo simulation
\( E_{vis} \): Total visible energy deposit, from Monte-Carlo simulation
Low concentration would have slower time constant (lead to better separation ability) and lower light yield.
Emission spectrum

- Black line is the transmissivity of a 10mm depth UV-transparent acrylic.
- If use acrylic, adding bis-MSB is a good choice. It matches the acrylic transmission spectrum.
The LED is not monochromatic, use a two exponential formula

\[ I = I_1 e^{-x/L_1} + I_2 e^{-x/L_2} \]

- \( I_1 \): long wavelength component
- \( I_2 \): short wavelength component

(9.37 ± 0.44) m for LAB + 0.07 g/L PPO + 13 mg/L bis-MSB
One ton prototype

Jinping one ton prototype detector is currently running at CJPL

• Understand the property of detector
• Study the technology of liquid scintillator
• Measure the in-situ cosmic ray flux, neutron flux at CJPL and PMT background
One ton prototype structure

Steel support structure

Acrylic vessel, filled with slow liquid scintillator
\((\text{LAB} + 0.07 \text{ g/L PPO} + 13 \text{ mg/L bis-MSB})\)

Stainless steel tank

8 inch Hamamatsu R5912 PMTs (15 low background glass and 15 normal glass, 30 totally)

Shielding sphere

Buffer water filled between tank and acrylic vessel
One ton prototype running status

Online real time event display (animation)
A cosmic ray muon candidate event

Trigger ID: 218936
Possible muon incident direction
Exit
One ton prototype running status

- Running with slow liquid scintillator since July 31, 2017.
- Now doing studies about underground background and Slow LS.

PMT gains are set uniformly

PMT dark noise has settled down to 5k-10k
Summary

• The lowest cosmic-ray muon and reactor neutrino flux at CJPL, ideal to carry out low-energy neutrino experiments.
• Jinping Neutrino Experiment is expected to improve the present studies on solar neutrinos, geo-neutrino and supernova neutrino.
• Slow liquid scintillator would be used aiming at the separation between Cherenkov and scintillator light.
• One ton prototype detector will enable us to have a better understanding for the performance of slow liquid scintillator.
Thank you for your attention.