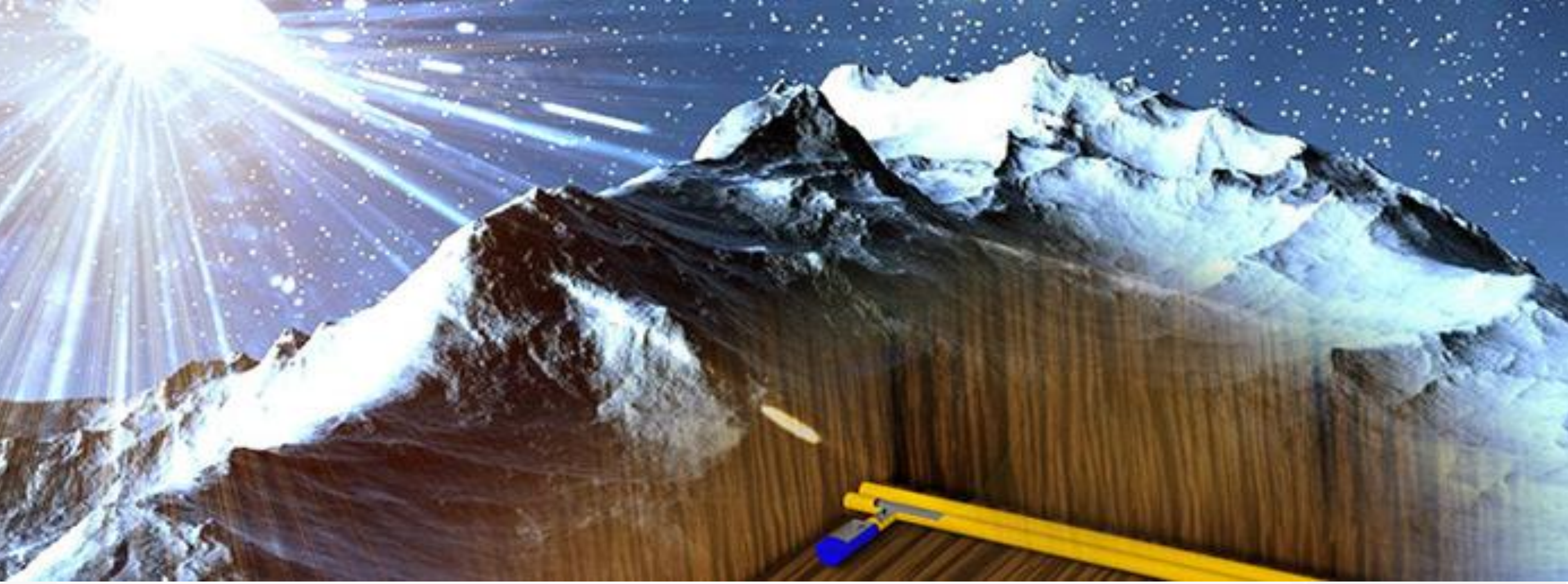

Research on Liquid Scintillator Cherenkov Detector for Neutrino Physics

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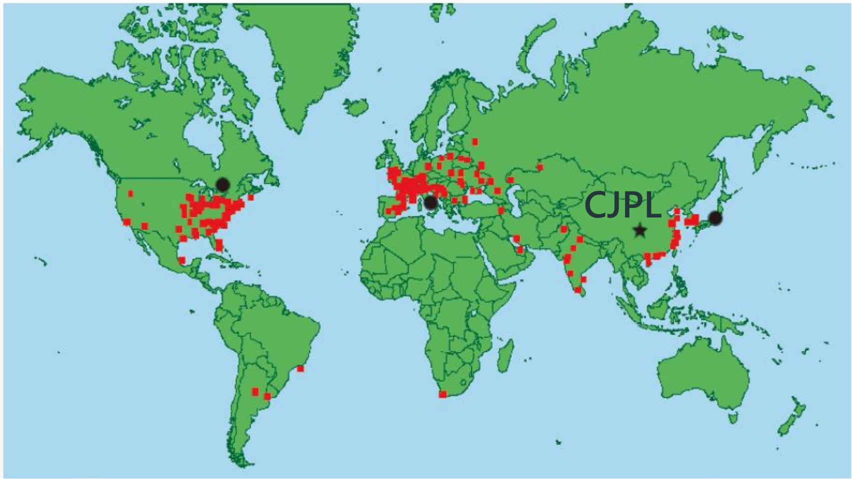
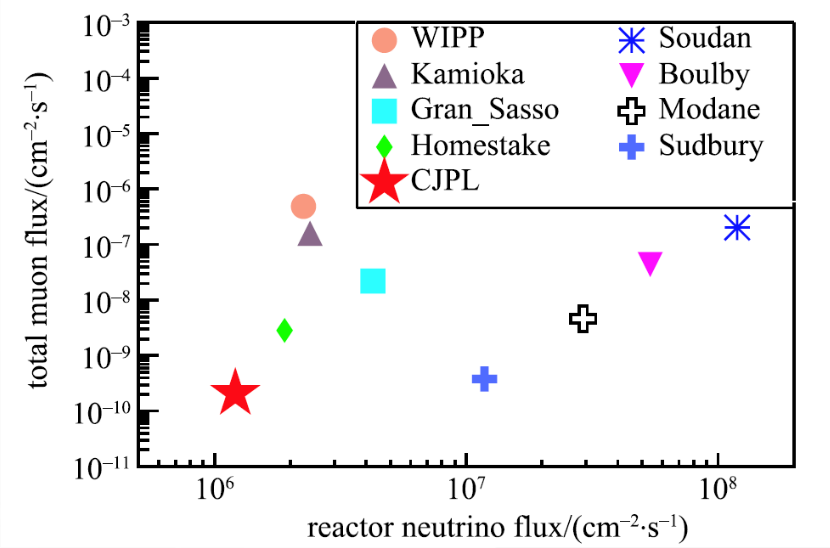
2018/01/30 at AFAD 2018

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



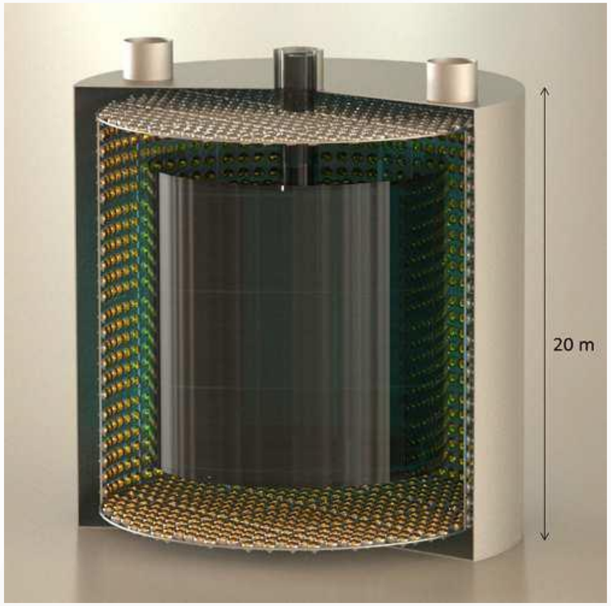
World map with all the nuclear power plants in operation and under construction.



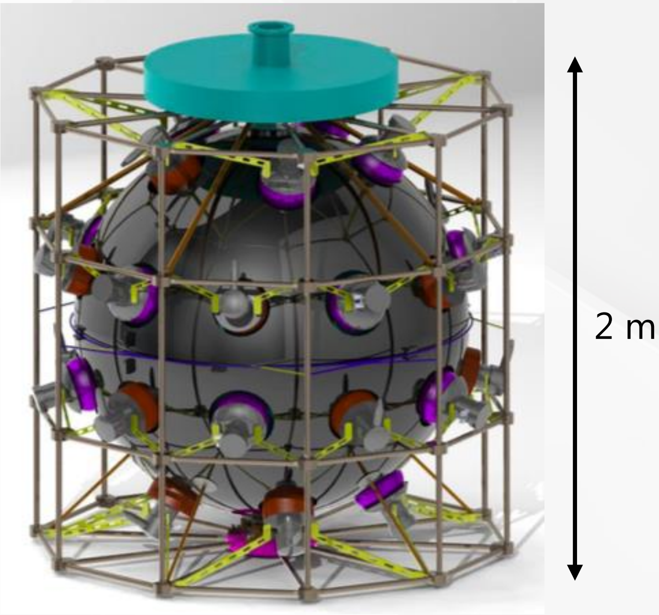
Muon flux vs reactor neutrino background flux for various underground labs in the world.

Jinping Neutrino Experiment

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



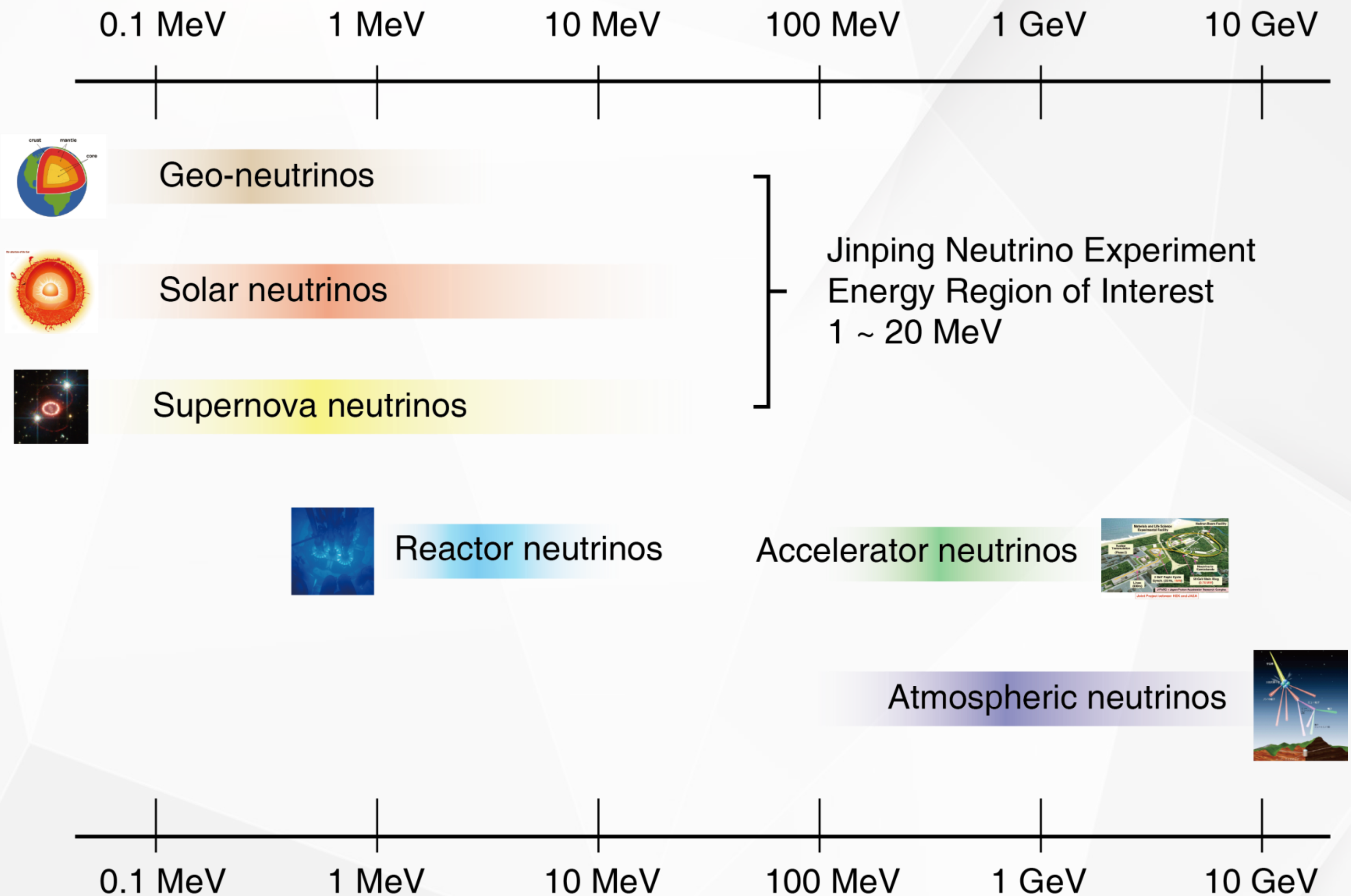
The conceptual design for a cylindrical neutrino detector at Jinping. Spherical inner vessel is also an option.



One ton prototype detector design.

This detector is running now.

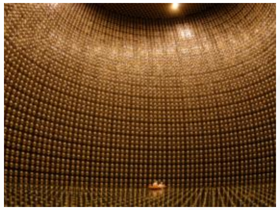
Neutrino physics



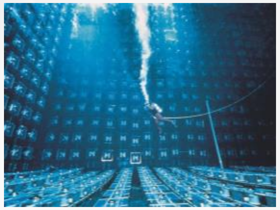
Different neutrino detectors

Water/Heavy water detector

- ✓ Measuring both energy and direction.
- × Poor light yield and energy resolution.
- × High energy detection threshold.



Super Kamiokande



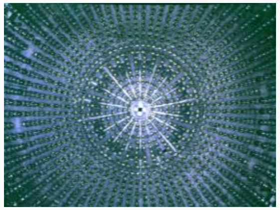
IMB

SNO

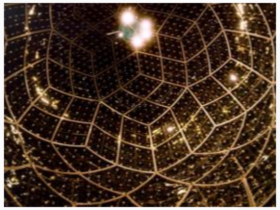
etc.

Liquid scintillator detector

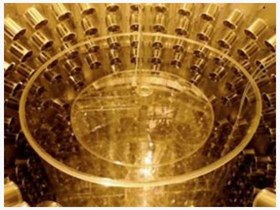
- ✓ Low detection threshold.
- ✓ High light yield and energy resolution.
- × No direction information.



Borexino



KamLAND

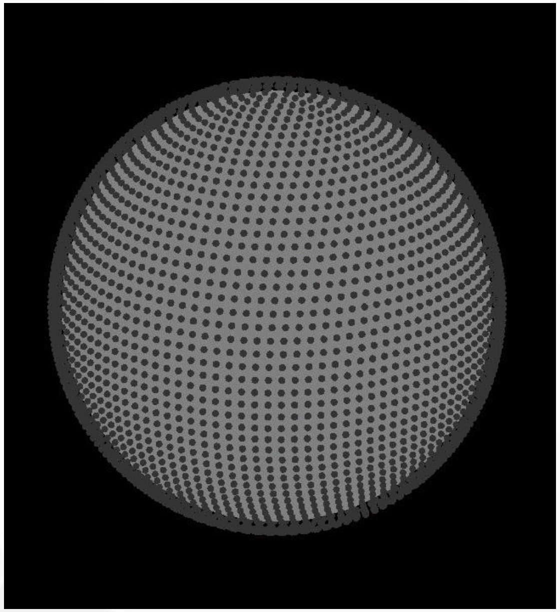


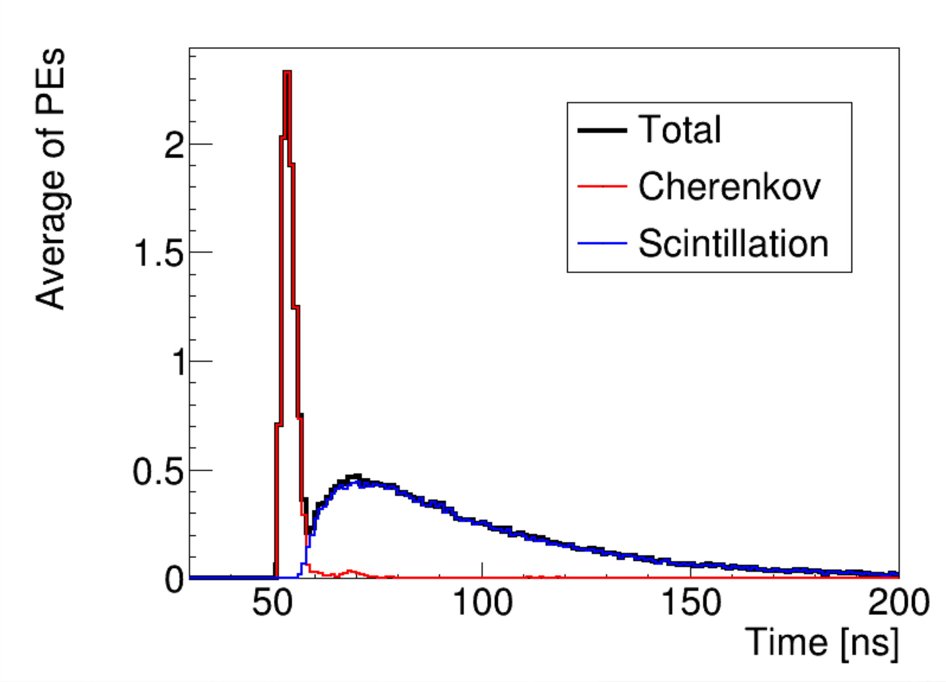
Double Chooz

etc.

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

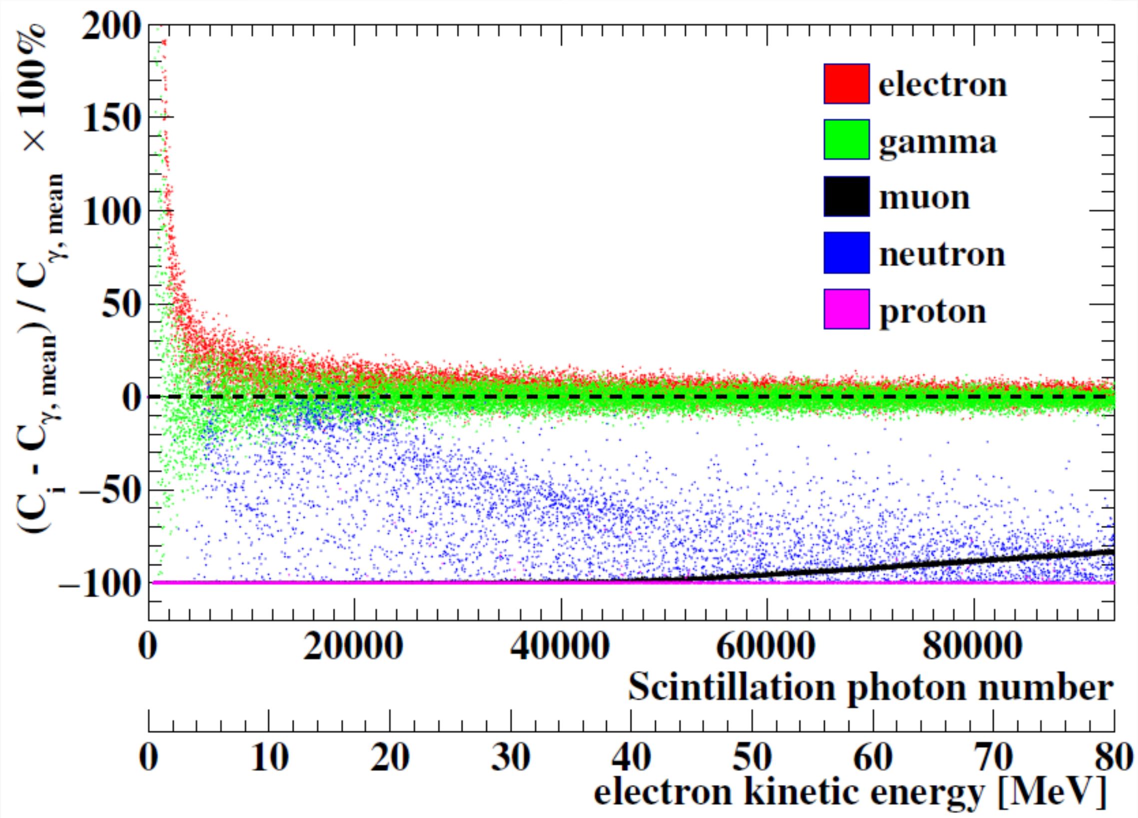




PE arrival times of a 20 m diameter spherical slow LS detector, simulated by Geant4.

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

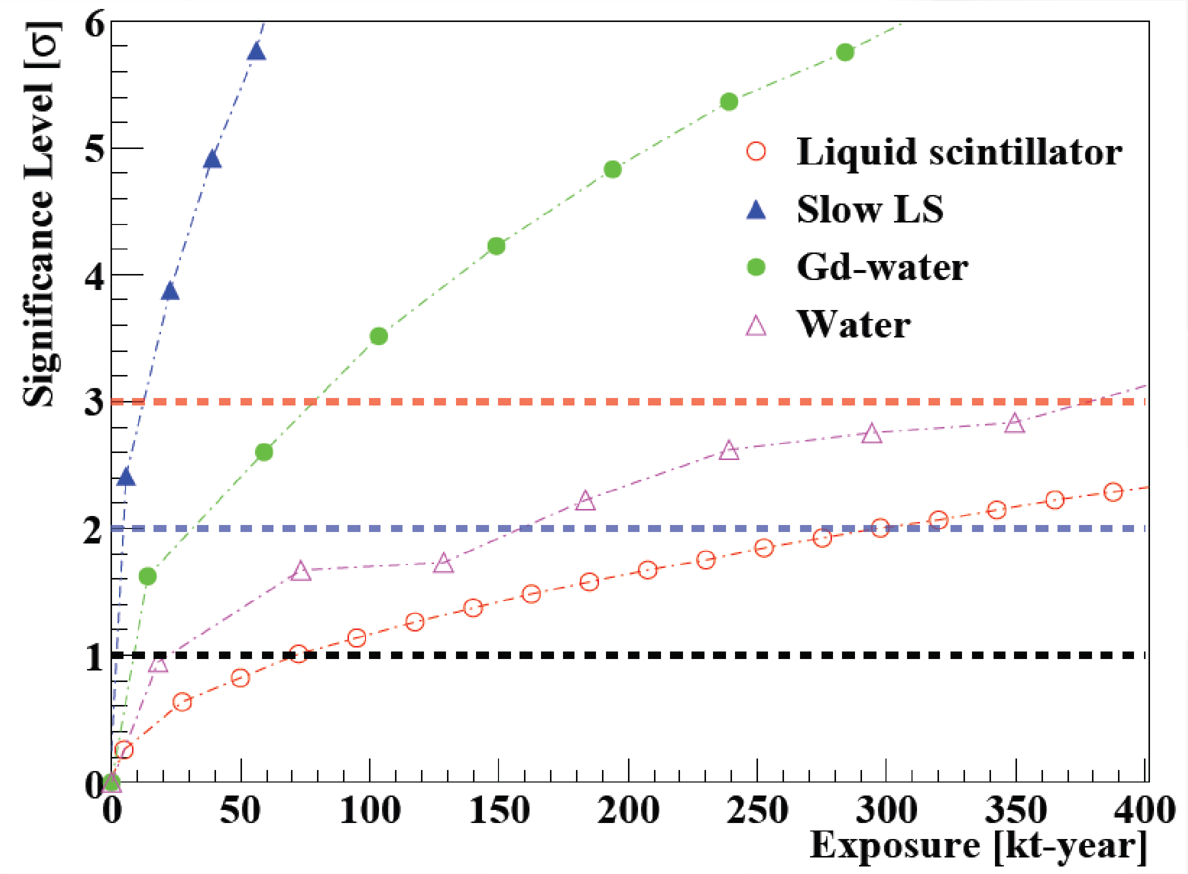


- Particle identification: Suppress fast neutron background, atmosphere CC and NC background, even suppress part of gamma background

PLB 769 (2017) 255

Liquid Scintillator Cherenkov Detector for Neutrino physics

- Improvement for SRN detector



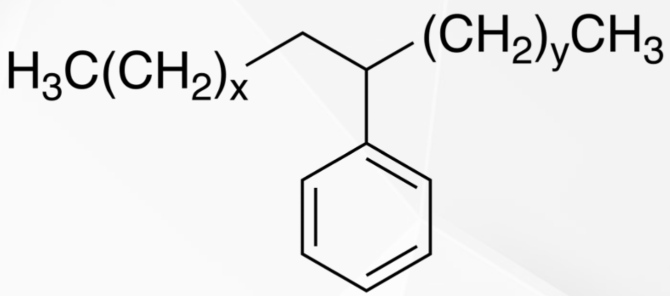
PLB 769 (2017) 255

Slow liquid scintillator candidates

Linear alkyl benzene (LAB):

An important ingredient of slow liquid scintillator

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



($C_6H_5C_nH_{2n+1}$, n: 10~16)

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.

Low concentration

High concentration

Water/Heavy water style

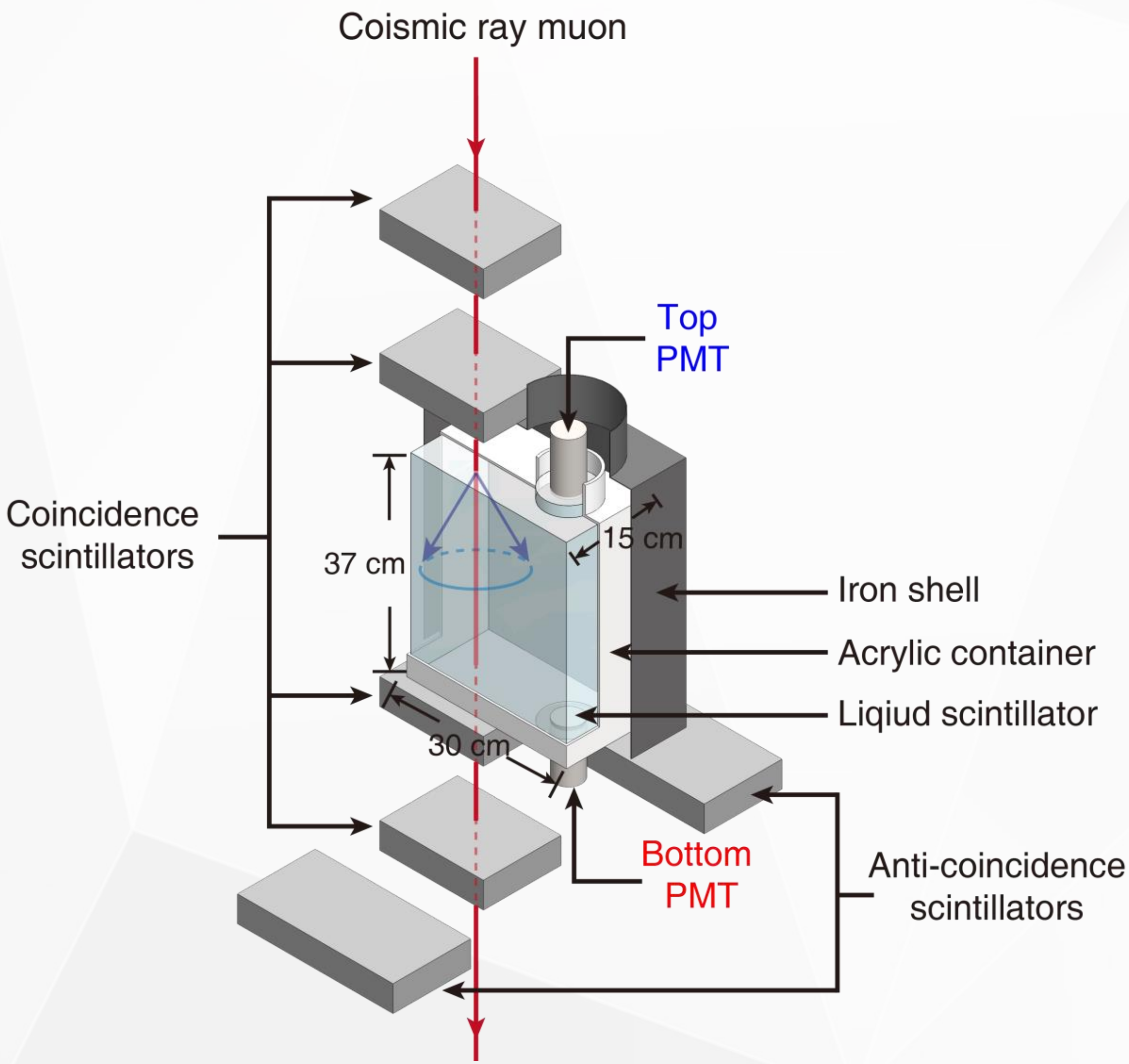
- ✓ Energy and direction information
- ✗ Poor energy resolution
- ✗ High energy detection threshold

Liquid scintillator style

- ✗ No direction information
- ✓ High energy resolution
- ✓ Low detection threshold

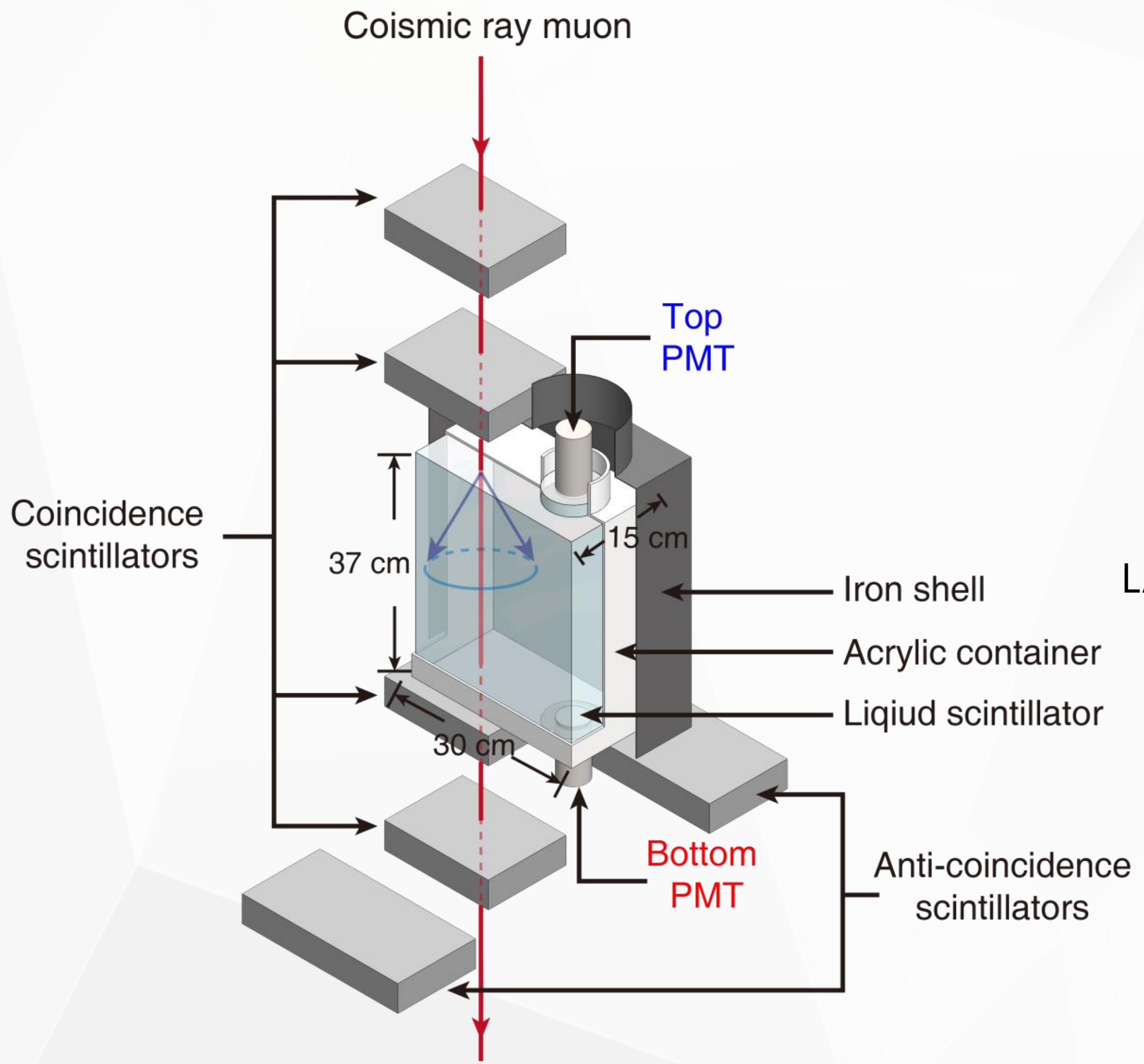
Scintillation Cherenkov light separation

Apparatus for researching on the light yield and time constants

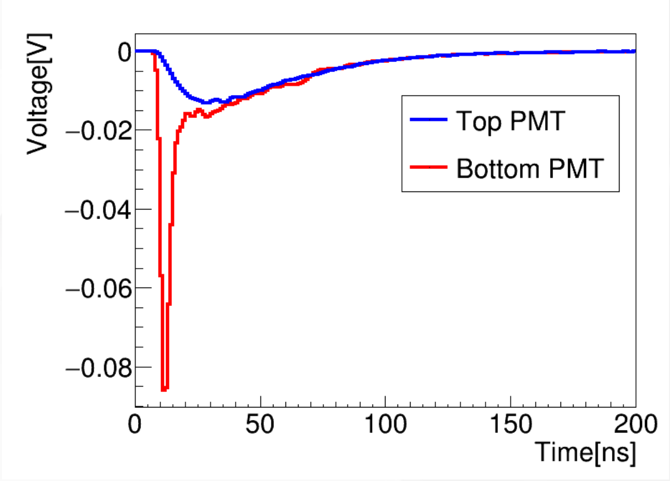


- Trigger by cosmic ray muon
- Container with Low reflectivity inner surface
- Bottom PMT can see both Cherenkov light and scintillation light
- Top PMT can only see scintillation light
- Scintillation light is expected up-down symmetric

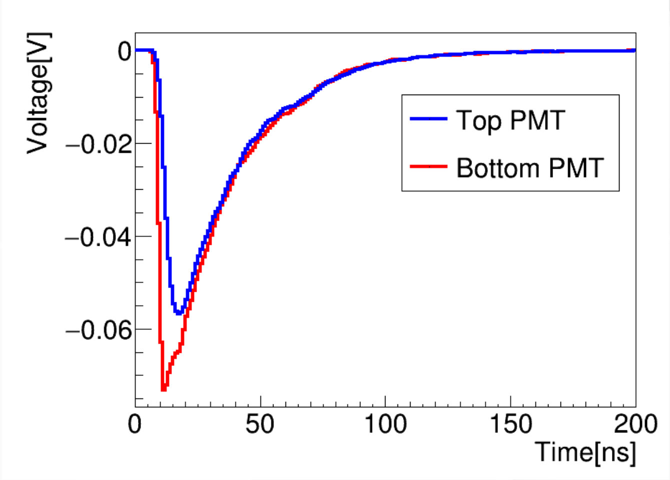
Scintillation Cherenkov light separation



Pure LAB



LAB + 0.07 g/L PPO + 13 mg/L bis-MSB



Time profile and light yield

- Time profile: fit the average waveform with

$$f(t) = [A_C \cdot \delta(t - t_0) + A_S \cdot n(t - t_0)] \otimes \mathrm{gaus}(t)$$

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

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

τ_r : Rising time constant

τ_d : Decay time constant

- Light yield was estimated by

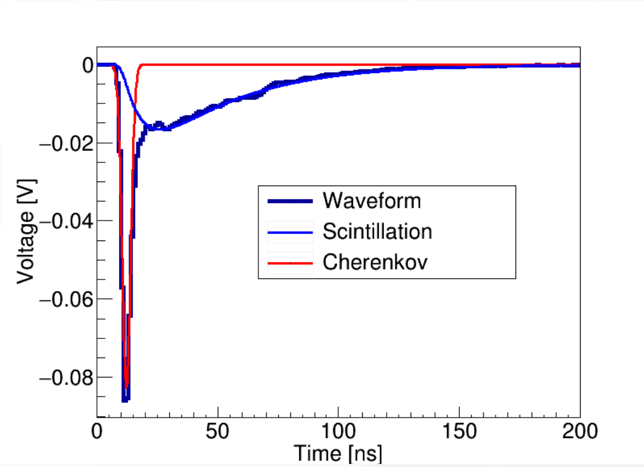
$$L = \frac{D}{\varepsilon E_{vis}}$$

D : Number of photoelectrons, from fit result of waveform

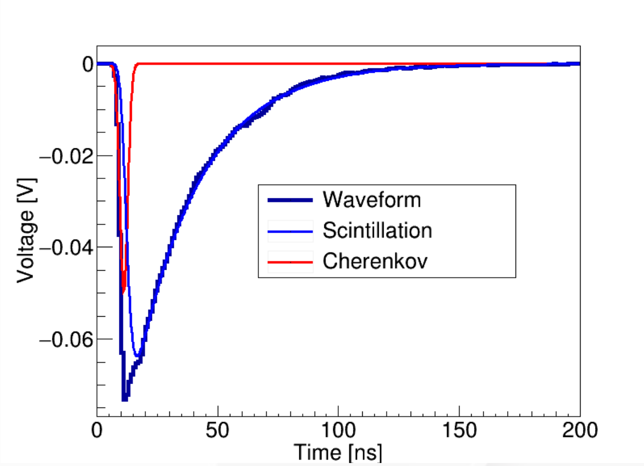
ε : Detection efficiency, from Monte-Carlo simulation

E_{vis} : Total visible energy deposit, from Monte-Carlo simulation

Pure LAB

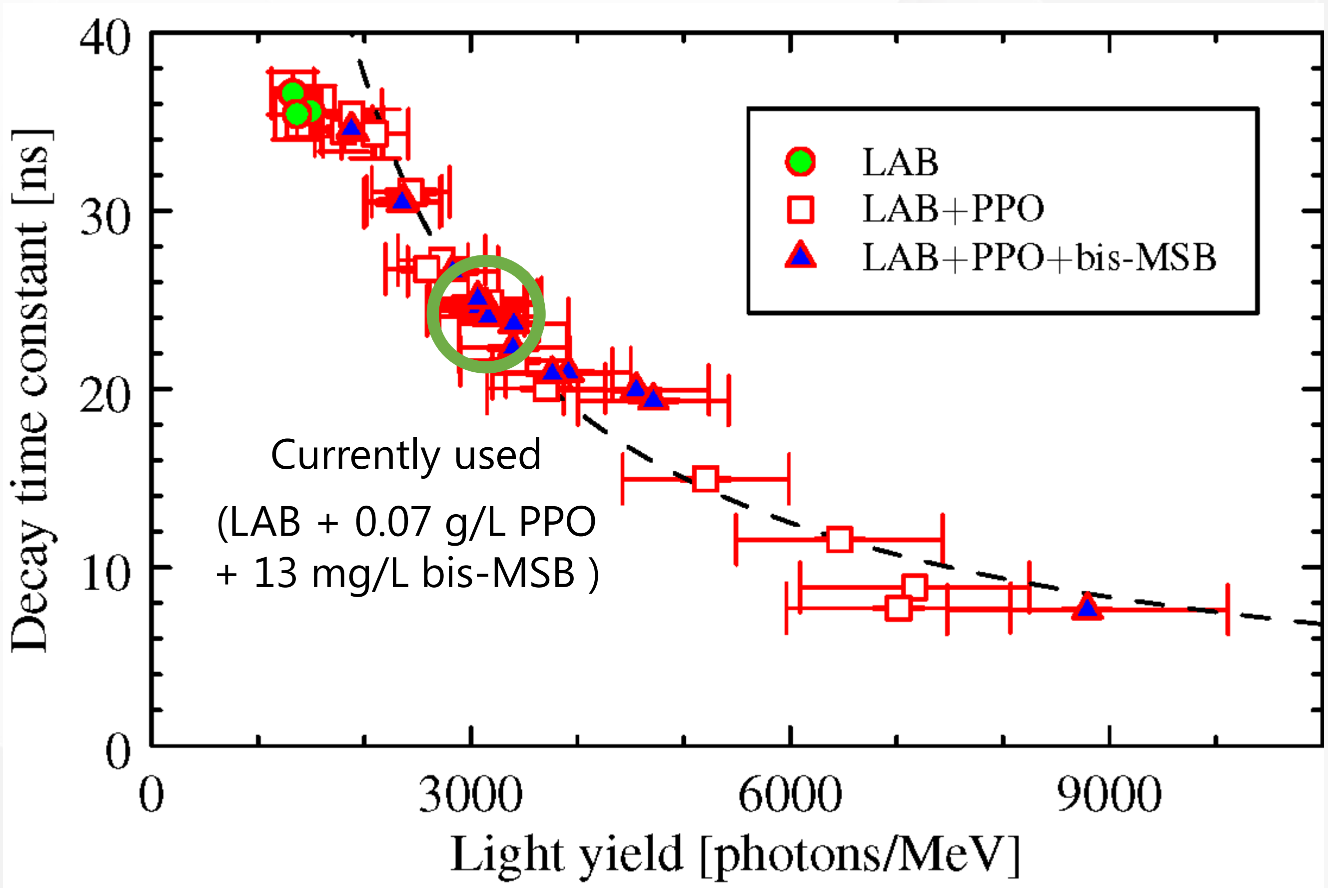


LAB + 0.07 g/L PPO + 13 mg/L bis-MSB



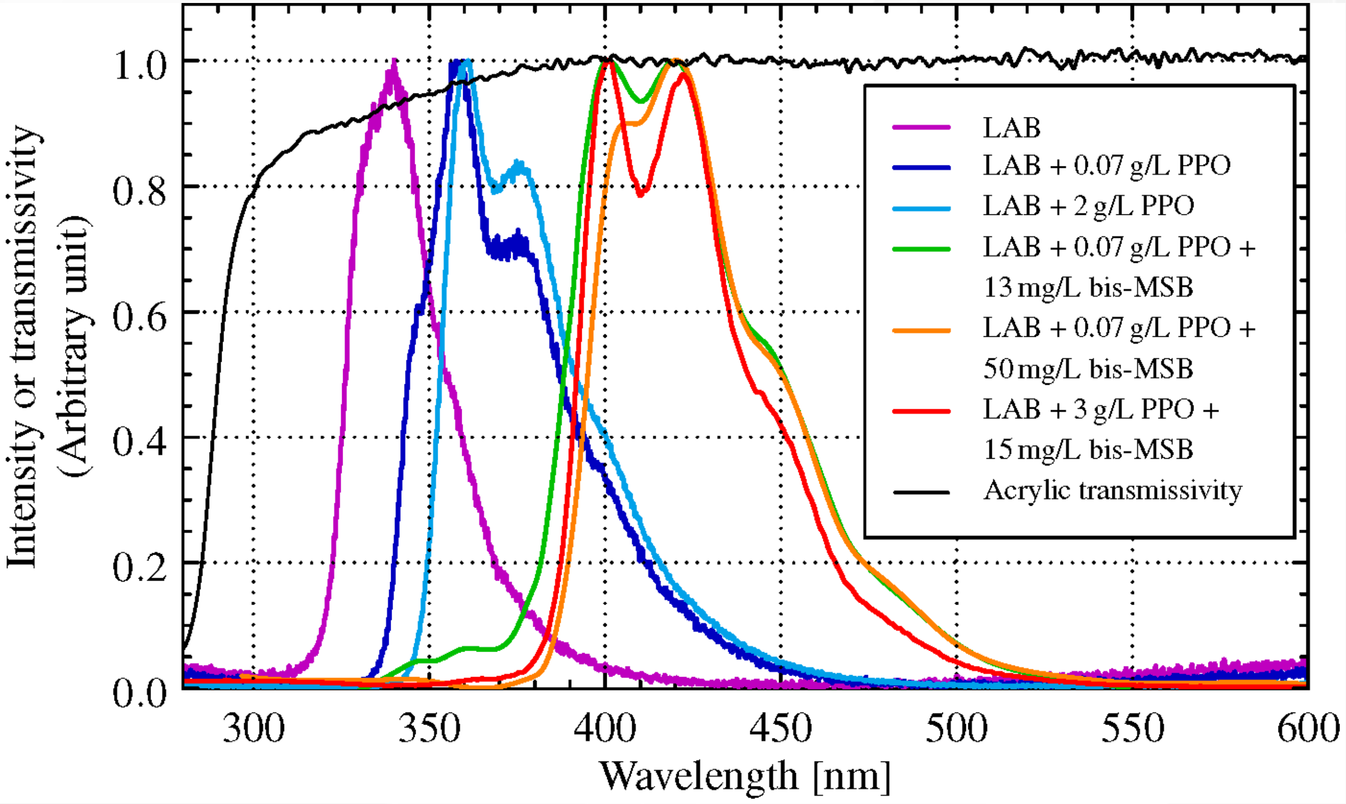
Time constant vs light yield

Low concentration would have slower time constant (lead to better separation ability) and lower light yield

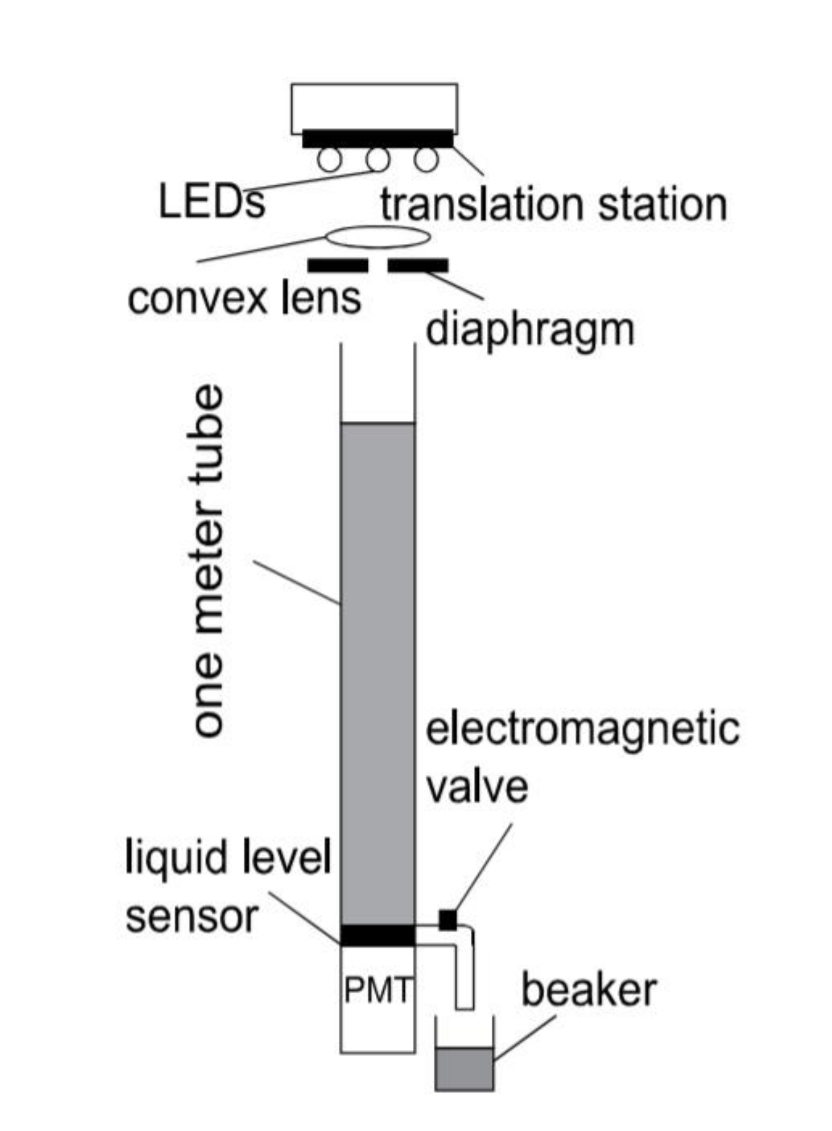


Emission spectrum

- 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.



Attenuation length

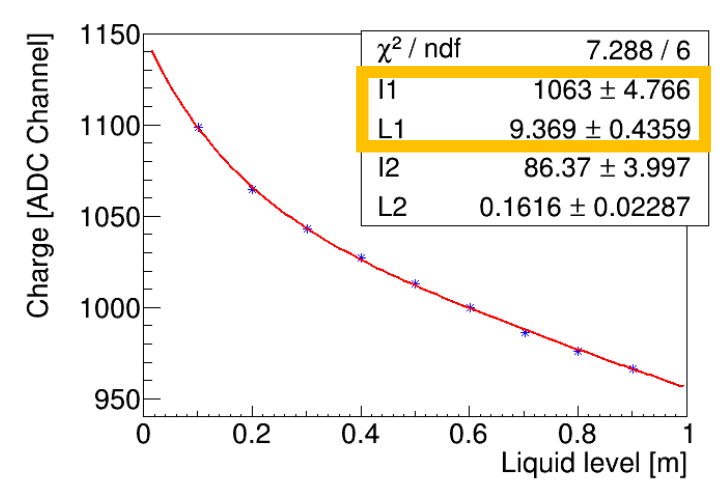


- The LED is not monochromatic, use a two exponential formula

$$I = I_1 e^{-x/L_1} + I_2 e^{-x/L_2}$$

I_1: long wavelength component

I_2: short wavelength component

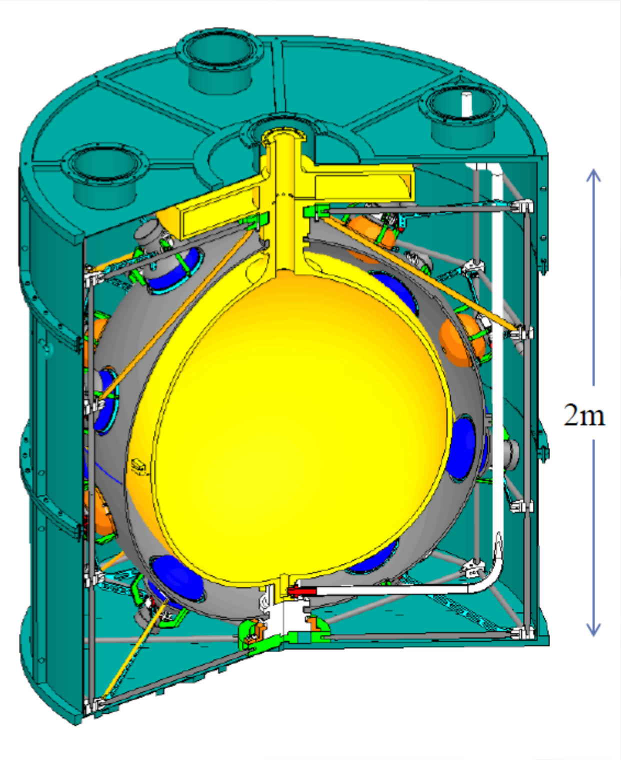


(9.37±0.44) m for LAB + 0.07 g/L PPO + 13 mg/L bis-MSB

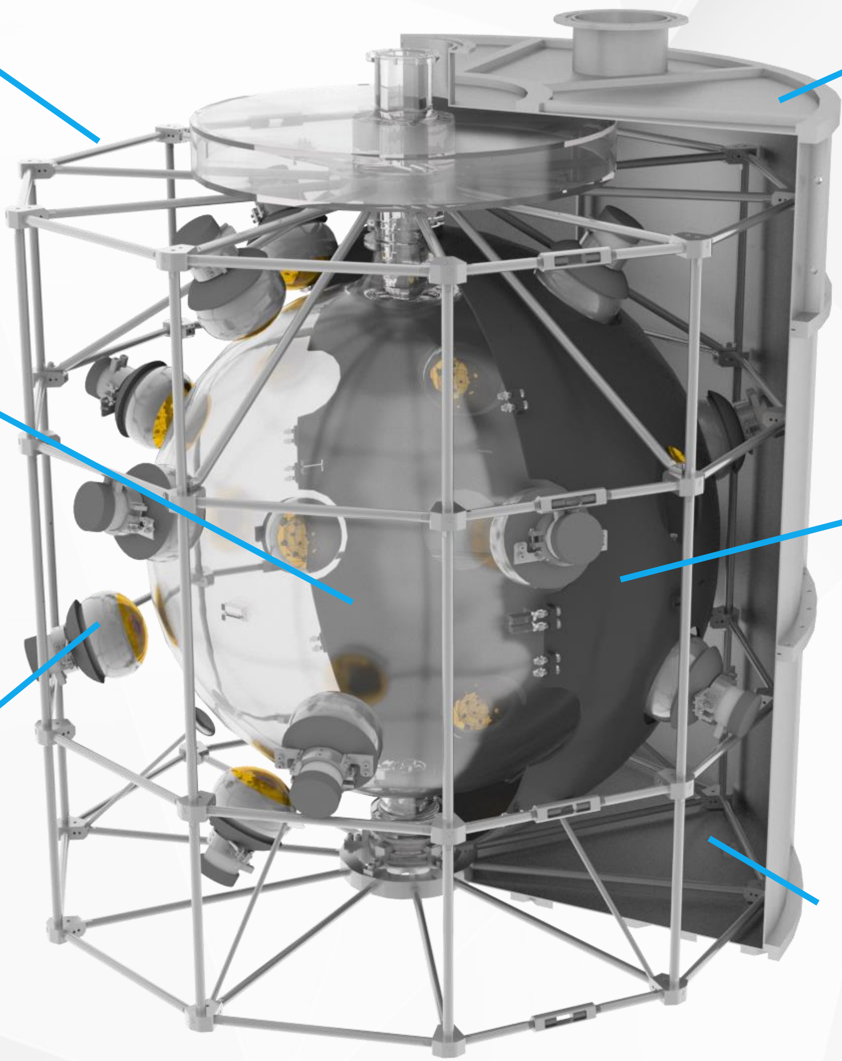
One ton prototype

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

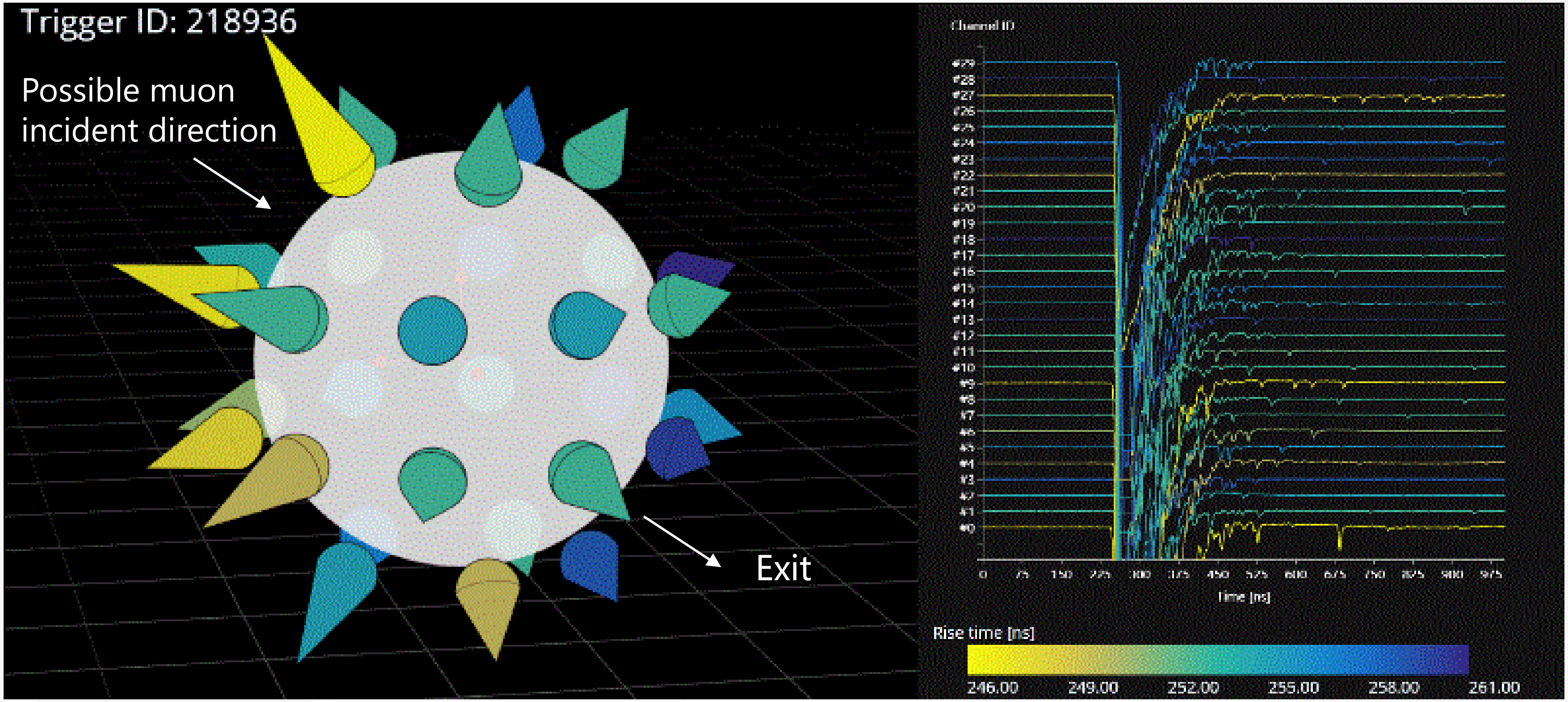


One ton prototype structure



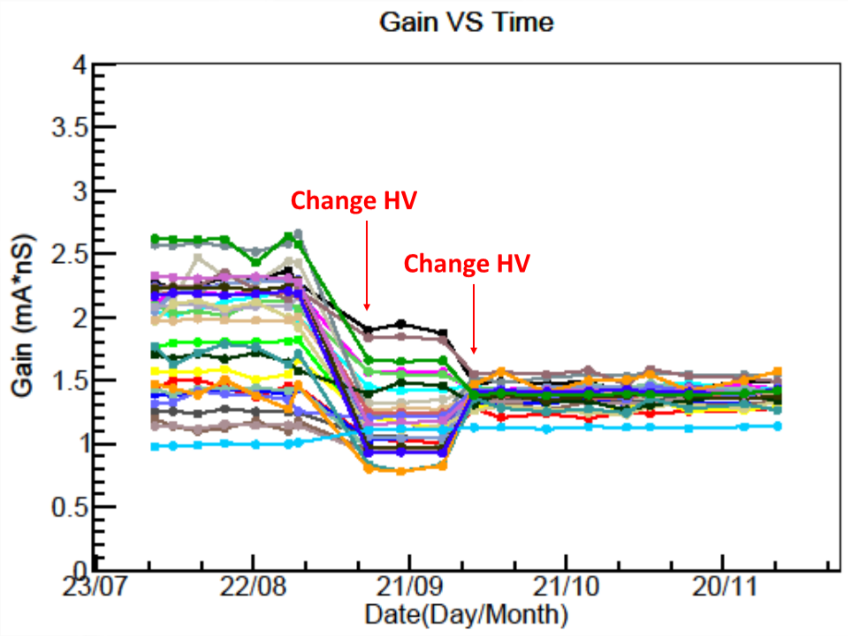
One ton prototype running status

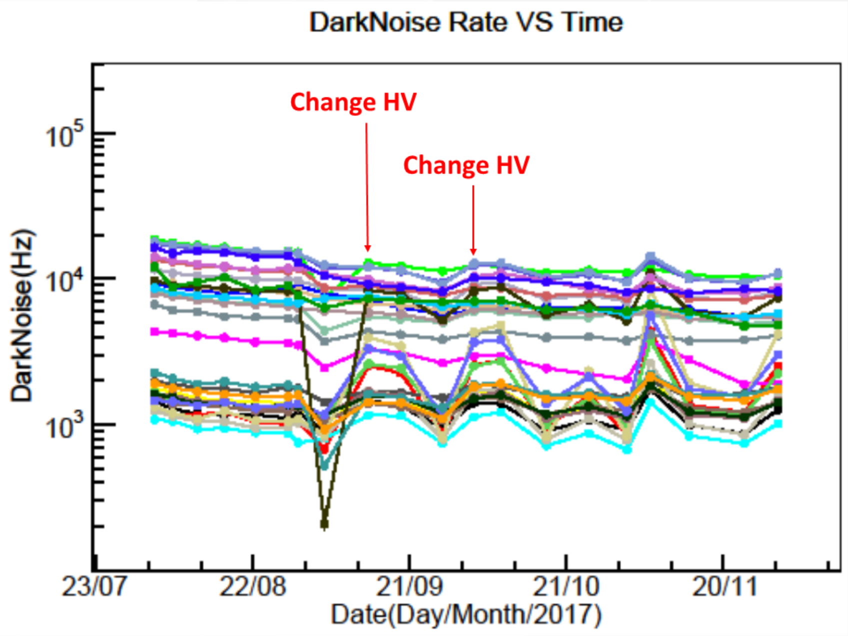
Online real time event display (animation)
A cosmic ray muon candidate event



One ton prototype running status

- Running with pure water from May 8, 2017 to July 27, 2017.
- 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.

END

Thank you for your attention.