Slow Liquid Scintillator for Scintillation and Cherenkov Light Separation

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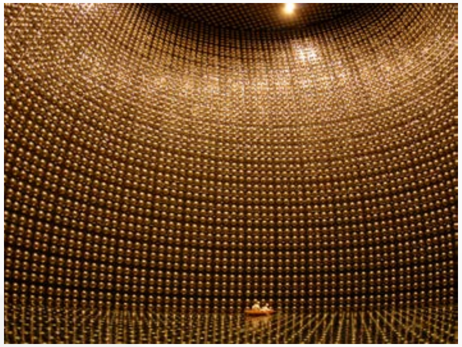
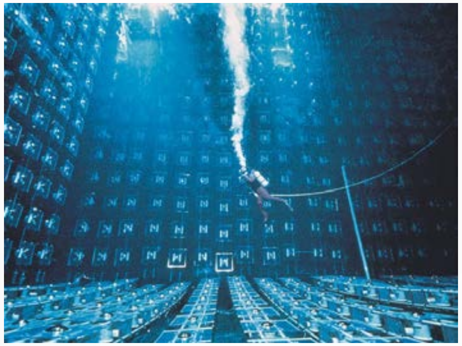
Different neutrino detectors

Water/Heavy water detector

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



Super Kamiokande



IMB

SNO

etc.

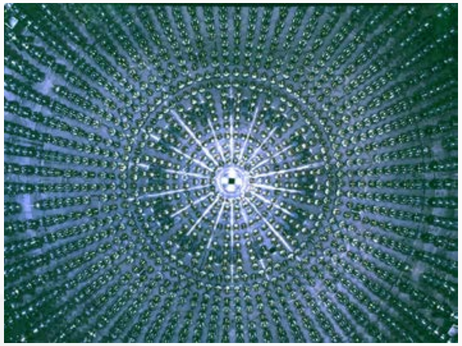
Different neutrino detectors

Liquid scintillator detector

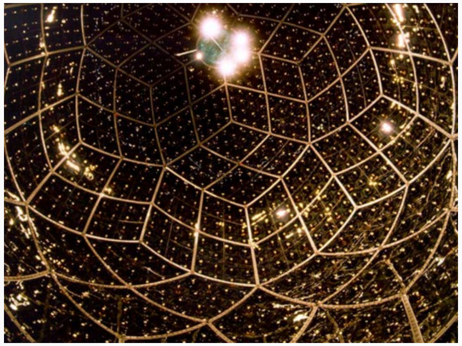
✓Low detection threshold.

✓High light yield and energy resolution.

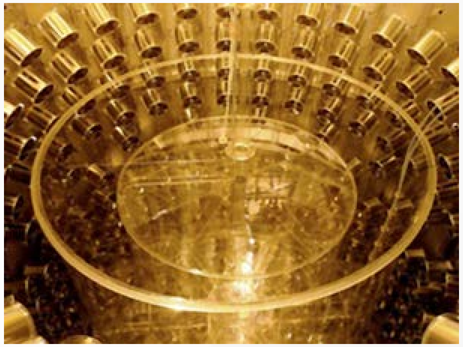
✗ No direction information.



Borexino



KamLAND

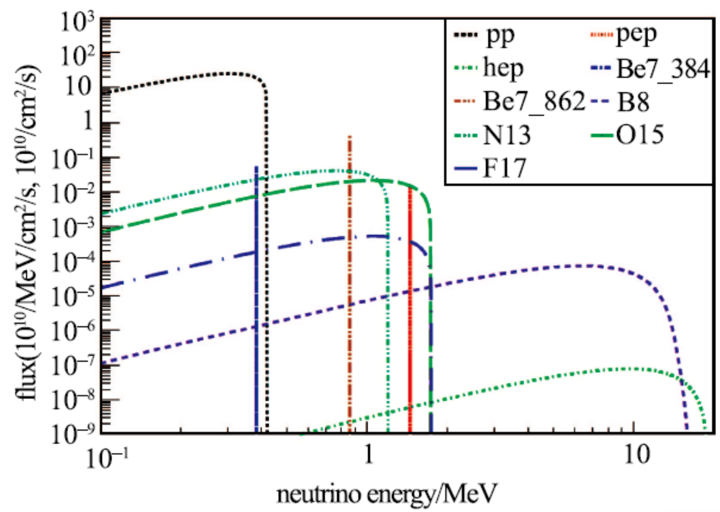


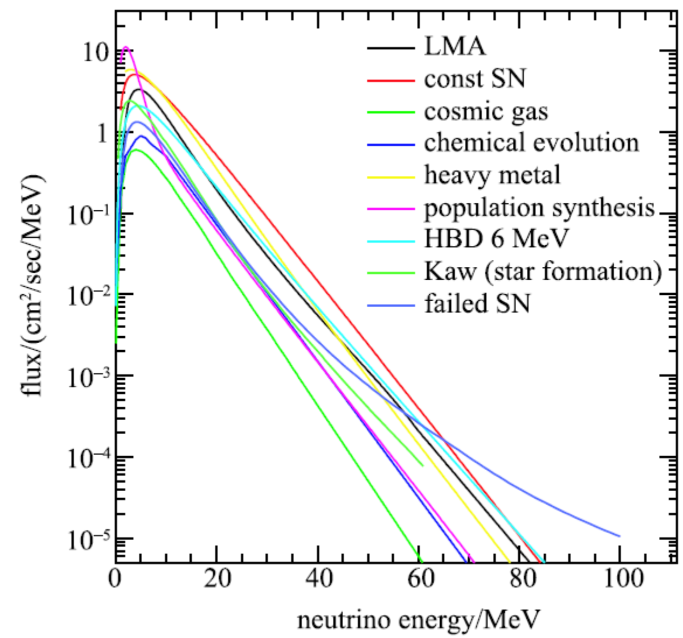
Double Chooz

etc.

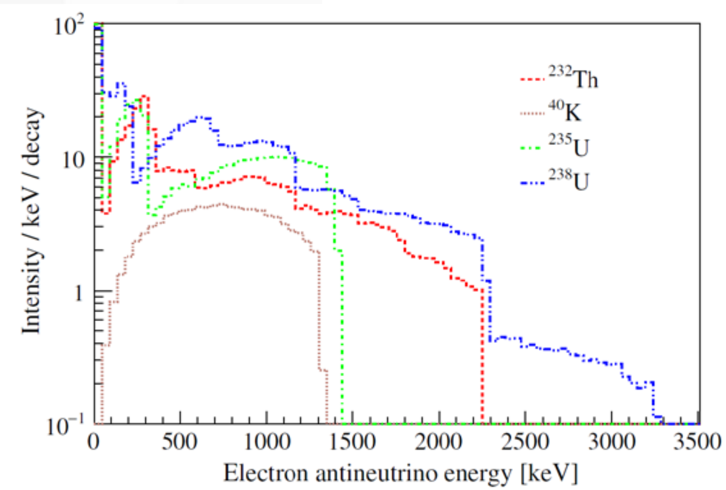
A new type of neutrino detector

Energy window @ Jinping neutrino experiment: 1 ~ 20 MeV





Geoneutrino



Solar neutrino

Supernova relic neutrino

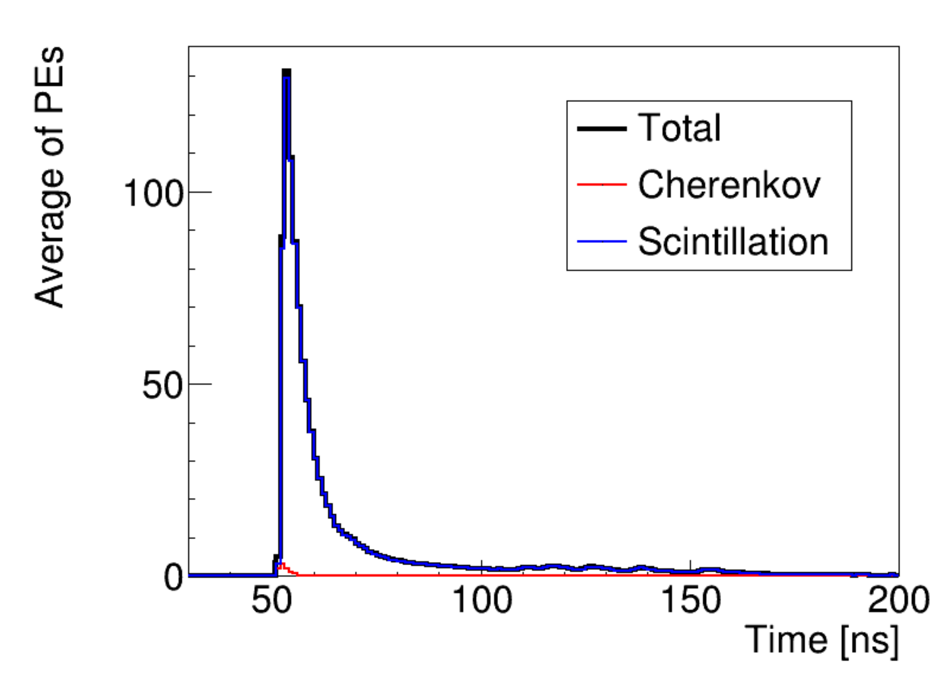
A new type of neutrino detector

Water Cherenkov detector for Jinping?

- Direction information is important for solar or supernova neutrinos detection
- Light yield ~ 150 photons/MeV (@300~600nm)

Liquid scintillator for Jinping?

- Light yield (~10000 photons/MeV) is adequate.
- Absorption and reemission of Cherenkov photons.
- Fast time constant.
- Hard to separate Cherenkov light and reconstruct the direction.

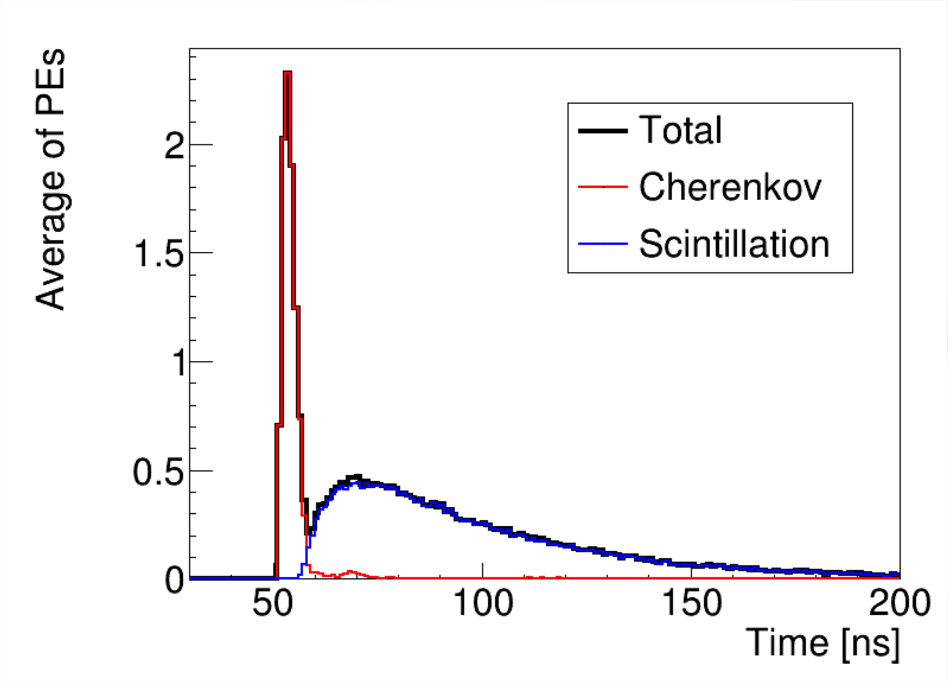


PE arrival times of a 20 m diameter sphere LS detector, simulated by Geant4.

A new type of neutrino detector

Slow liquid scintillator detector!
separate Cherenkov light
and scintillation

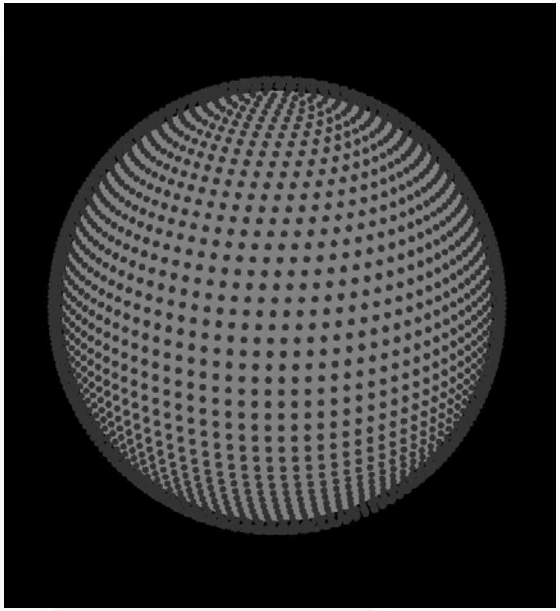
- Suppress the absorption and reemission of Cherenkov light
- Lengthen the time constants
- Enhance the light yield



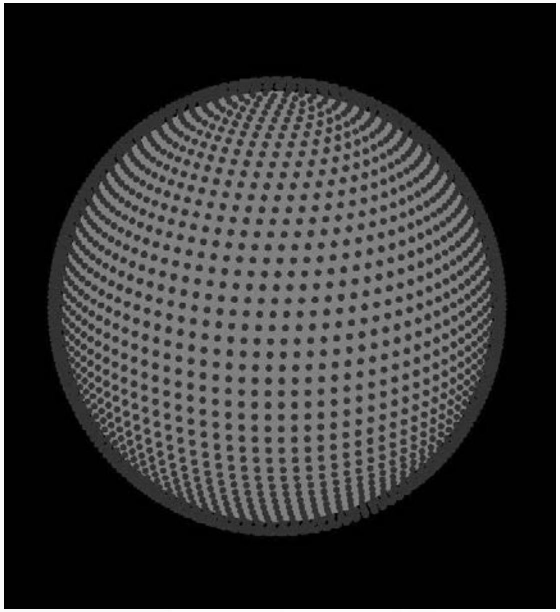
PE arrival times of a 20 m diameter sphere LAB detector, simulated by Geant4.

A muon Monte-Carlo event

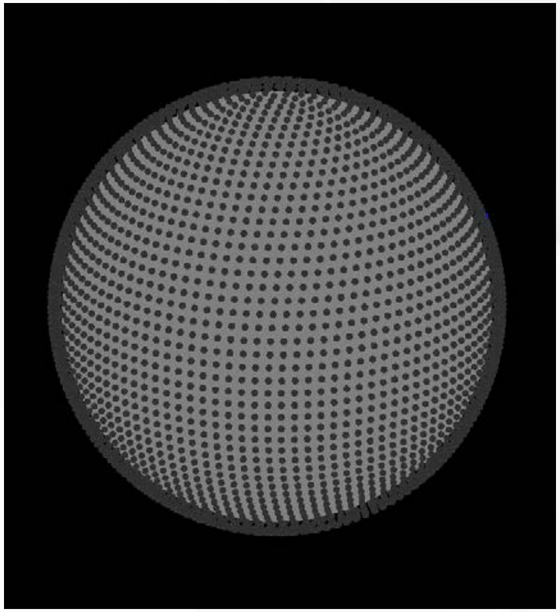
Water



Slow LS



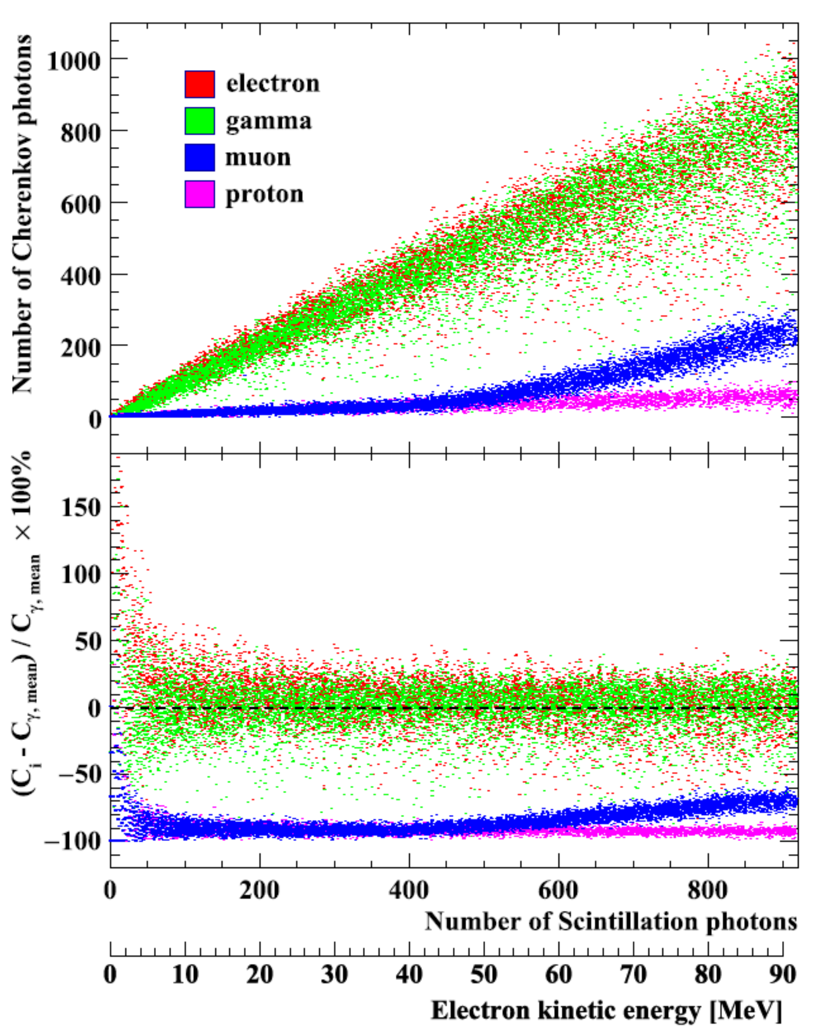
LS



A new type of neutrino detector

Particle Identification in LAB [1]

- Light yield ~1000 photons/MeV
- PMT quantum efficiency ~10%
- Optical attenuation
- Quenching effect

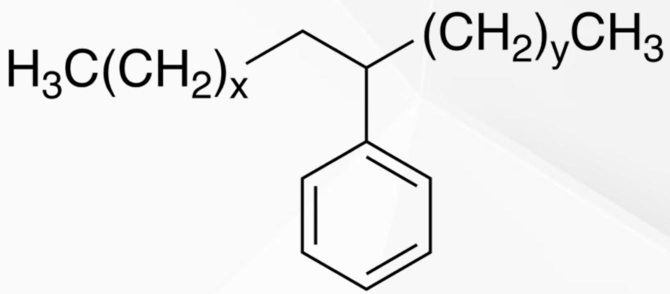


[1] Wei H, Wang Z, Chen S. Discovery potential for supernova relic neutrinos with slow liquid scintillator detectors[J]. Physics Letters B, 2017.

Candidates of slow liquid scintillator

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, such as RENO and Daya Bay.

Candidates of slow liquid scintillator

Two candidates of slow liquid scintillator in this work:

- Candidate A: pure LAB (Linear alkyl benzene)
- Candidate B: 0.07 g/L PPO + 13 mg/L bis-MSB dissolved in LAB

PPO: 2,5-Diphenyloxazole
bis-MSB: 1,4-Bis(2-methylstyryl) benzene

Candidate A | Candidate B

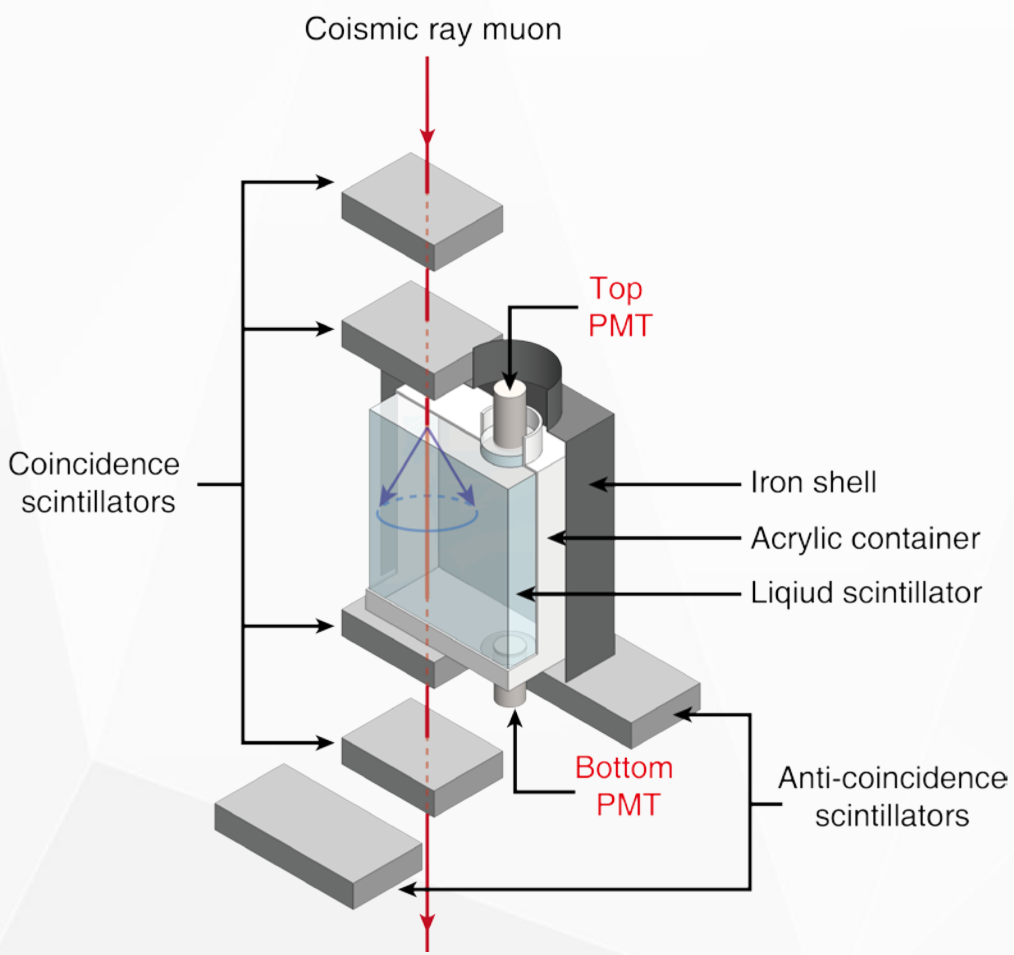
Water/Heavy water style

- ✓ Energy and direction information
- × Poor light yield and energy resolution
- × High energy detection threshold

Liquid scintillator style

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

Apparatus



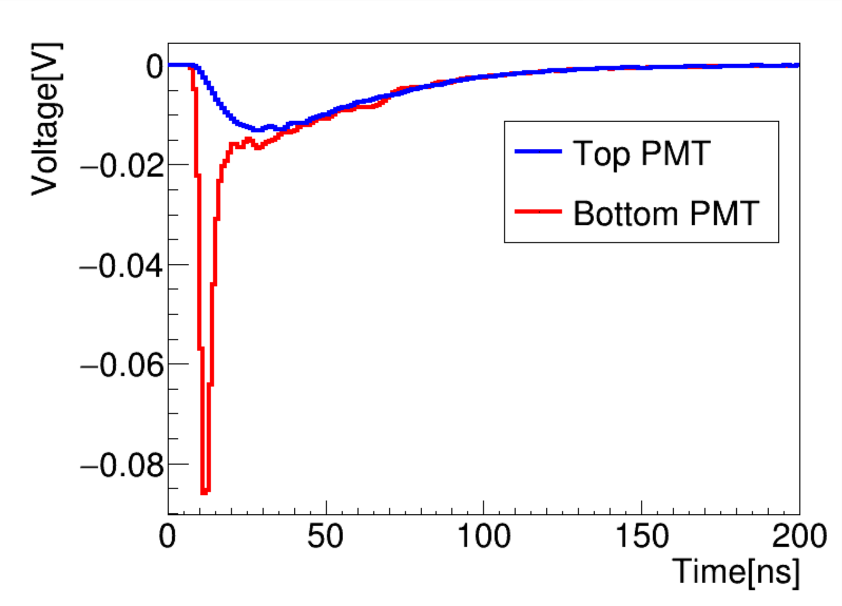
Once a single vertically-going muon fly into the detector,

- 4 coincidence scintillators: trigger
- 2 anti-coincidence scintillators: no trigger
- Top PMT: scintillation
- Bottom PMT: both scintillation and Cherenkov light

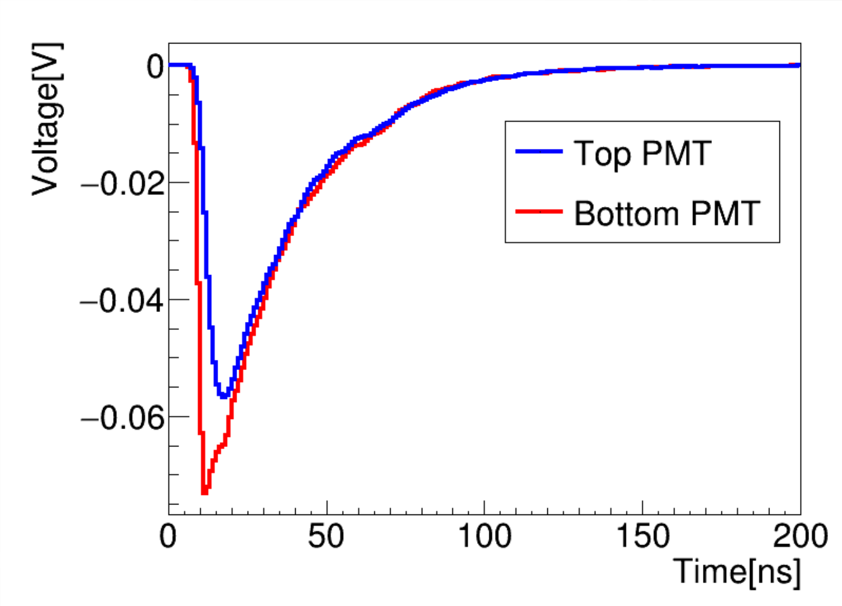
Electronics readout waveform

- A CAEN 10 bit 1 GHz flash ADC for waveforms readout.
- Focus on the waveforms of top and bottom PMT.

Candidate A:



Candidate B:



Time profile

Fit function:

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

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

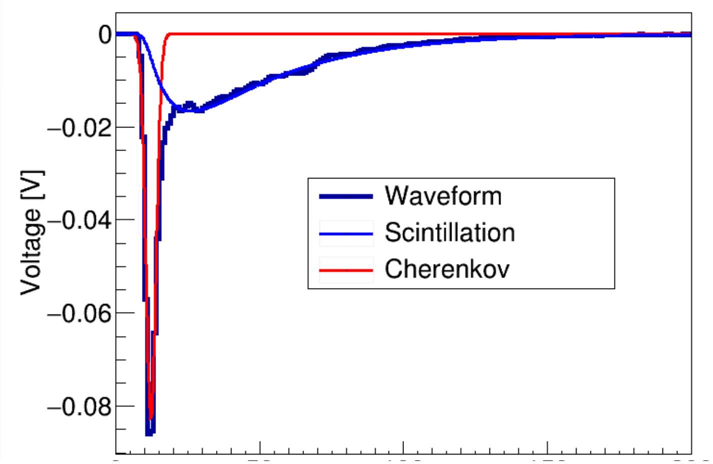
$$n(t) = \frac{\tau_r + \tau_d}{\tau_d^2}\left(1 - e^{t/\tau_r}\right) \cdot e^{t/\tau_d}$$

Candidate A:

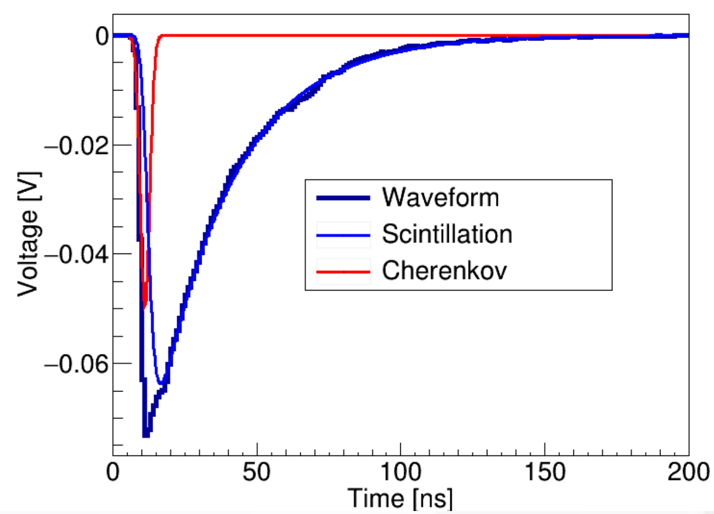
$$\tau_r = (7.7 \pm 3.0)\ \text{ns}$$
$$\tau_d = (36.6 \pm 2.4)\ \text{ns}$$

Candidate B:

$$\tau_r = (1.7 \pm 0.12)\ \text{ns}$$
$$\tau_d = (26.6 \pm 0.19)\ \text{ns}$$



A



B

Light yield

Light yield was estimated by

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

- D: Number of photoelectrons, from waveform
- ε: Detection efficiency, from Monte-Carlo simulation
- E_{vis}: Total visible energy deposit, from Monte-Carlo simulation

In detection efficiency estimation:

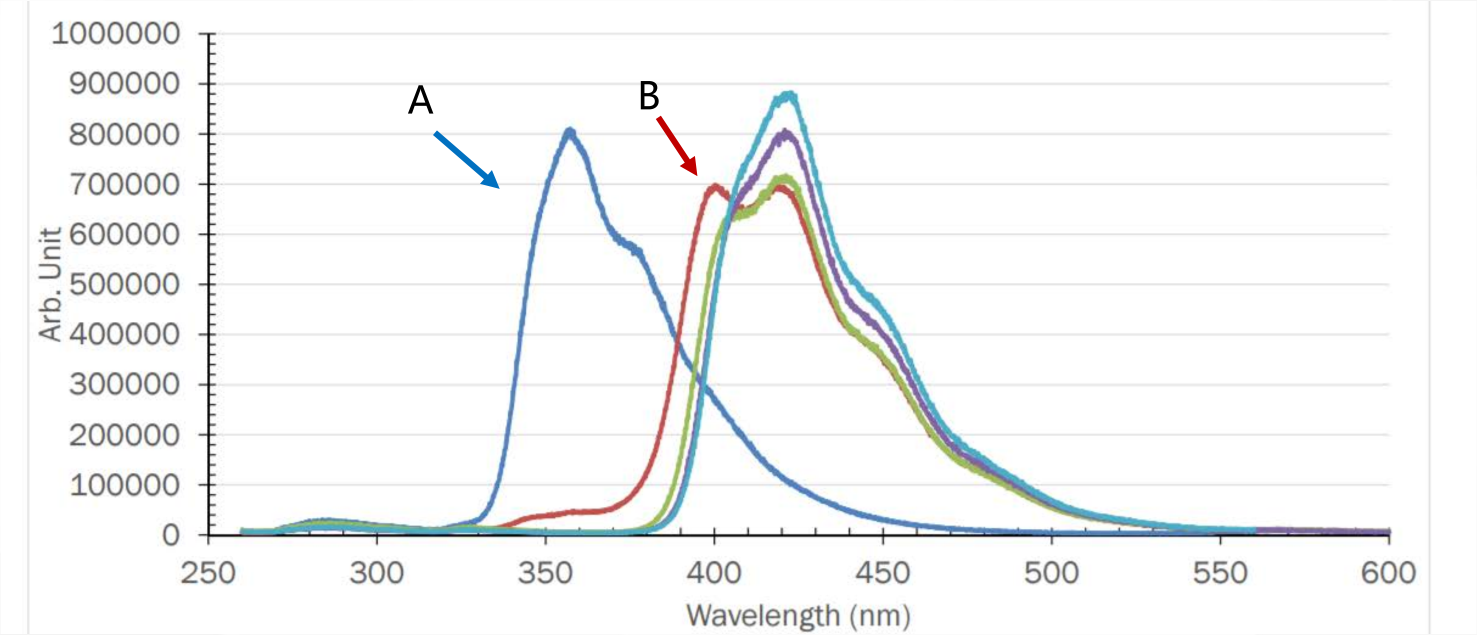
- Modified muon energy spectrum
- Quenching effect
- Quantum efficiency fluctuation
- Uncertainly of reflectivity of optical surface
- Attenuation length

A: $(1.01 \pm 0.12) \times 10^3$ photons/MeV
B: $(3.39 \pm 0.44) \times 10^3$ photons/MeV

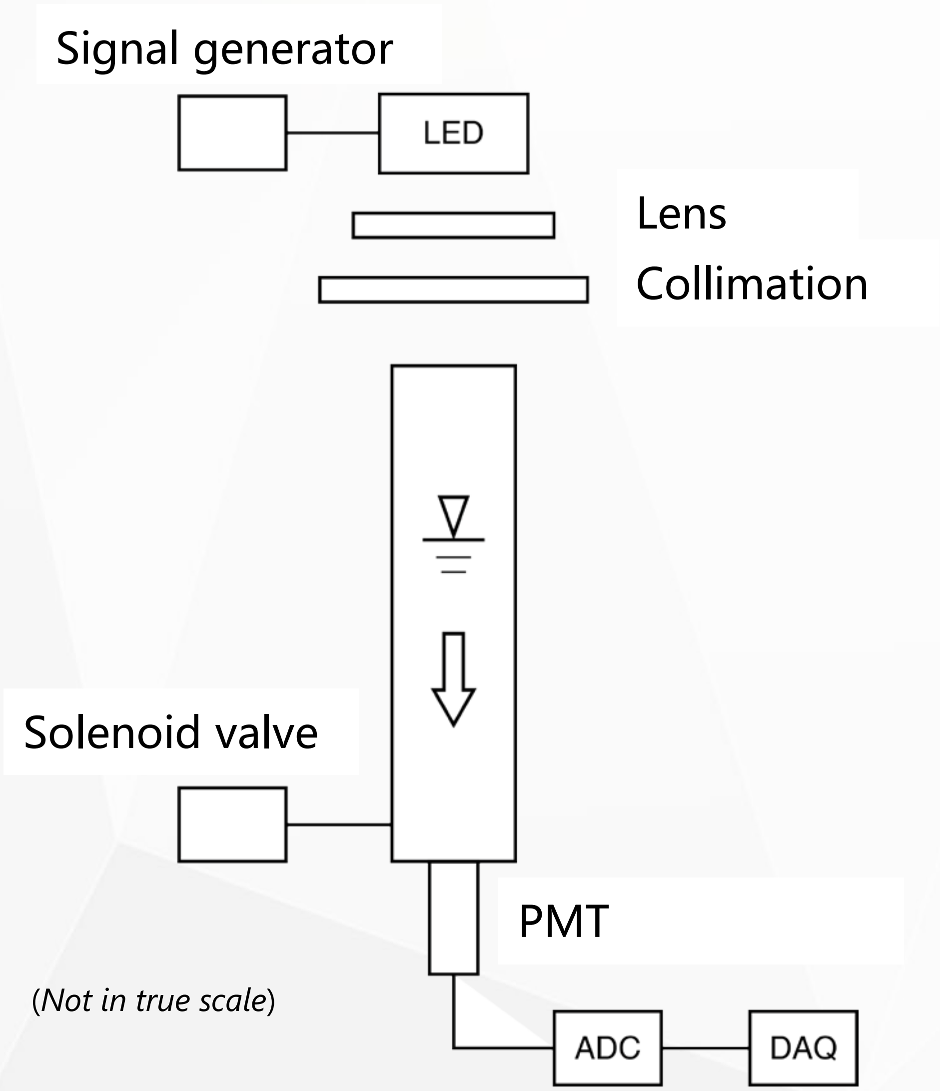
(preliminary result)

Emission spectrum

- Measured by an RTI fluorescence spectrometer
- Excited at 260 nm.



Attenuation length

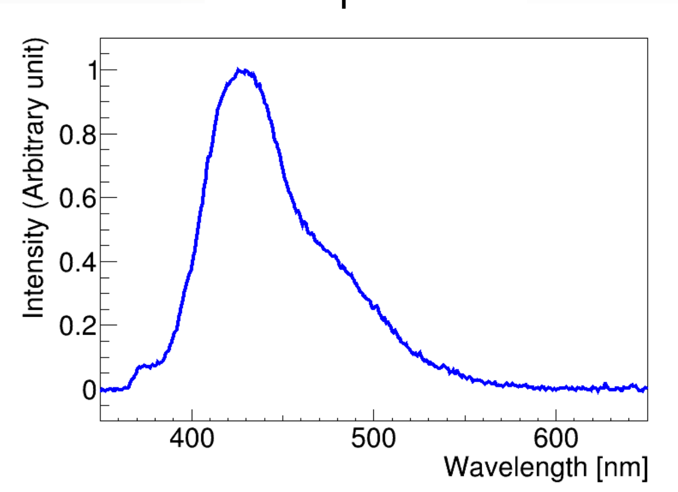


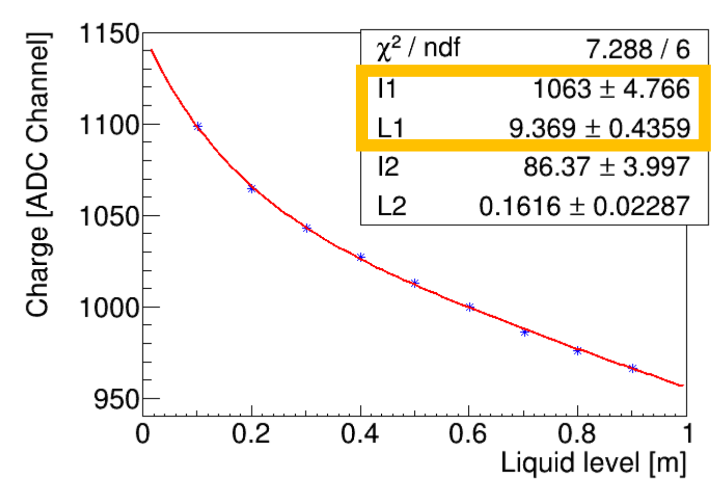
(*Not in true scale*)

- An LED on the top
- Adjust the liquid level
- Measure the charge integral on PMT
- Fit the relationship between liquid level and charge integral

Attenuation length

LED spectrum





Fit result of candidate B

- The LED is not monochromatic, the intensity of light should be the weighted average of LED spectrum,

$$I(x) = I_0 \int f(\lambda) \mathrm{e}^{-x/L(\lambda)} \mathrm{d}\lambda$$

- Try to 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
Fit result indicates that long wavelength component domains.

A: (19.52 ± 0.39) m
B: (9.37 ± 0.44) m

Summary and outlook

Two candidates of slow liquid scintillator in this work:

- Candidate A: pure LAB
- Candidate B: 0.07 g/L PPO + 13 mg/L bis-MSB dissolved in LAB

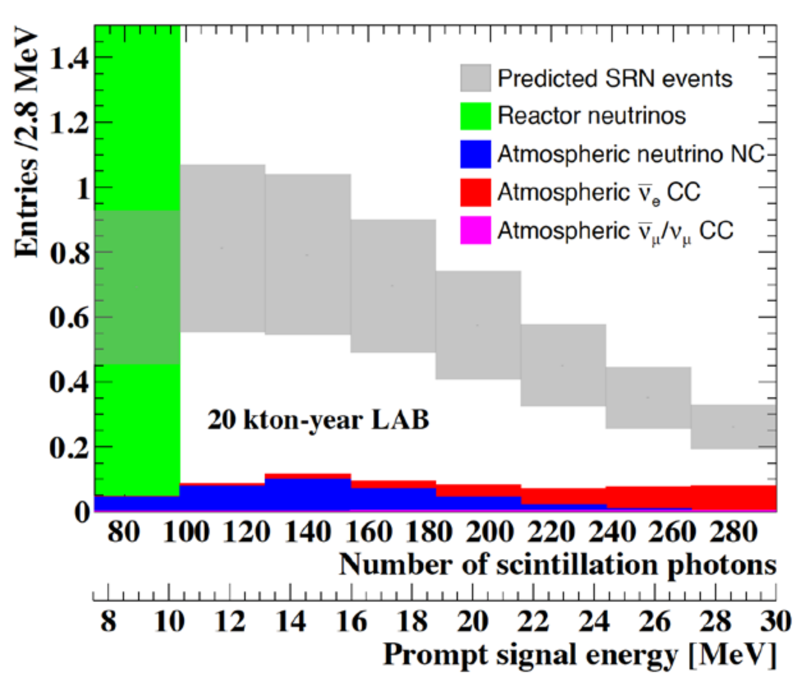
	Rising time constant (ns)	Decay time constant (ns)	Light yield (photons/MeV)	Attenuation length (m)
Candidate A	7.7 ± 3.0	36.6 ± 2.4	$(1.01 \pm 0.12) \times 10^3$	19.52 ± 0.39
Candidate B	1.7 ± 0.1	26.6 ± 0.2	$(3.39 \pm 0.44) \times 10^3$	9.37 ± 0.44

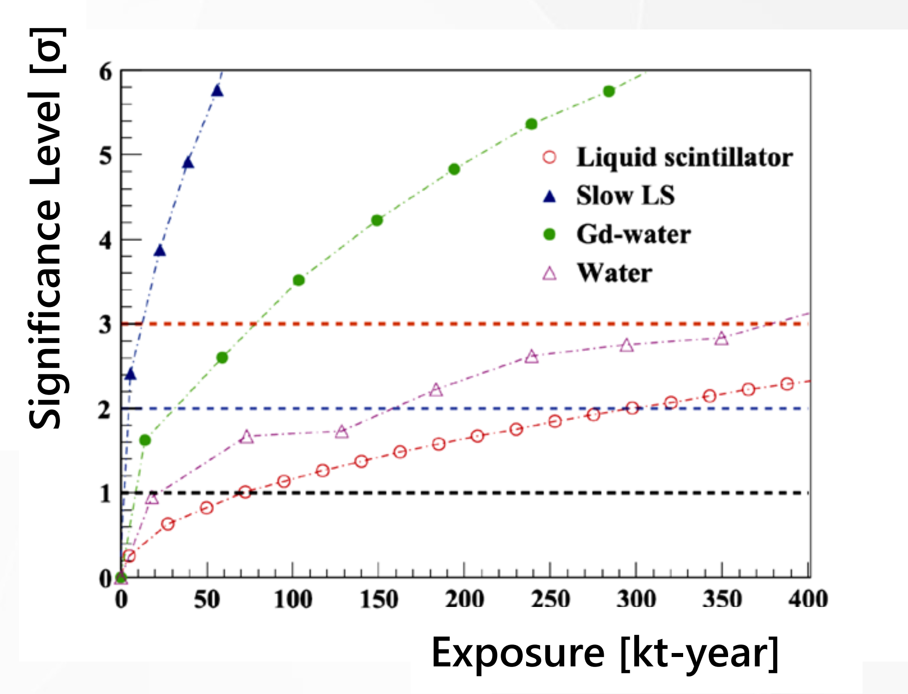
- PPO and bis-MSB result in the absorption and reemission of Cherenkov light, the should be tested carefully.
- Research more slow LS candidates in the future.
- A monochromatic light source is necessary for a precise attenuation length measurement.
- The attenuation length should be increased for a kiloton scale detector.

Opportunity of slow liquid scintillator

Opportunity: Discovery potential for supernova relic neutrinos [1]

- Suppress atmosphere neutrino CC and NC backgrounds by particle identification
- Enough sensitivity to make a discovery of super nova relic neutrinos @ kiloton-scale LAB detector at Jinping



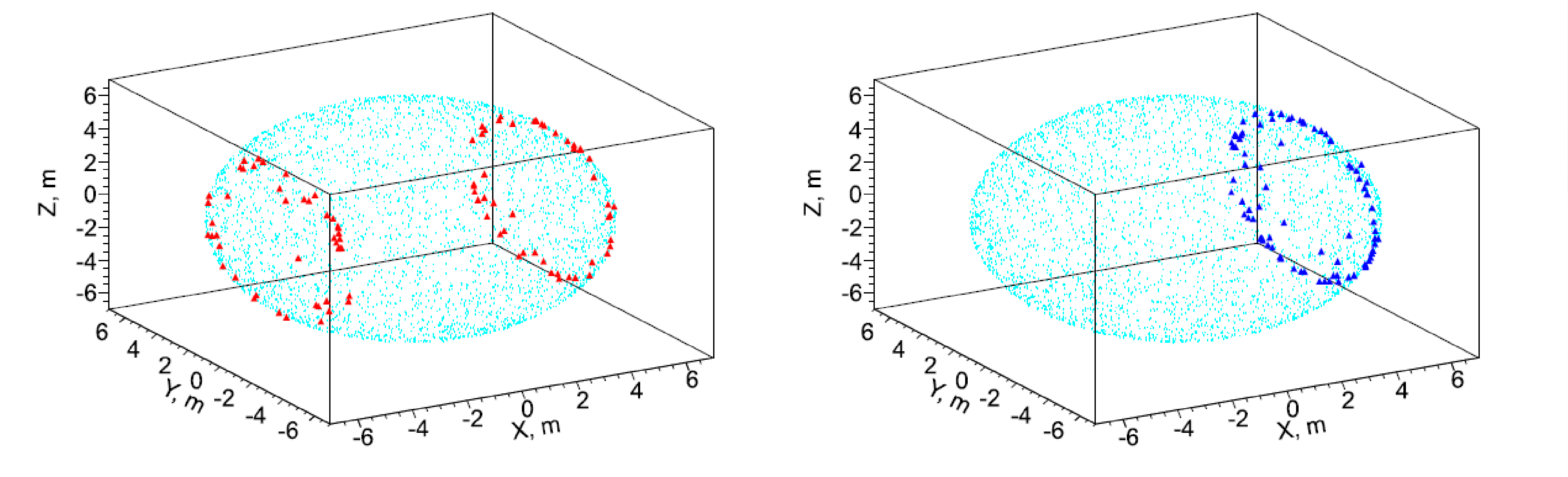


[1] Wei H, Wang Z, Chen S. Discovery potential for supernova relic neutrinos with slow liquid scintillator detectors[J]. Physics Letters B, 2017.

Opportunity of slow liquid scintillator

Opportunity: Double-beta decay experiment [2]

- Discriminate ^{8}B solar neutrino background events from 0νββ decay events by spherical harmonics analysis



[2] Elagin A, Frisch H J, Naranjo B, et al. Separating double-beta decay events from solar neutrino interactions in a kiloton-scale liquid scintillator detector by fast timing[J]. NIMA, 2017, 849: 102-111.

END

THANKS