Research and Development of JinPing Neutrino Experiment (JNE)

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On behalf of JNE
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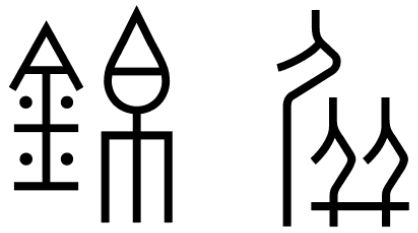
What is JinPing?

JinPing

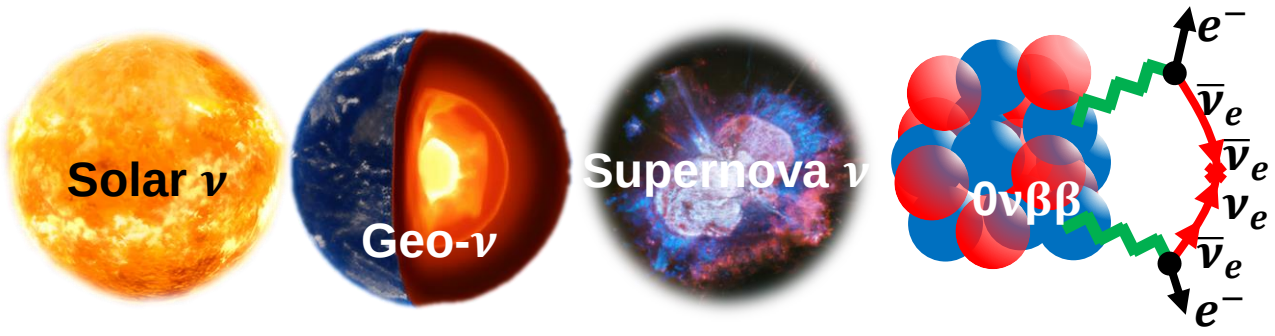
=



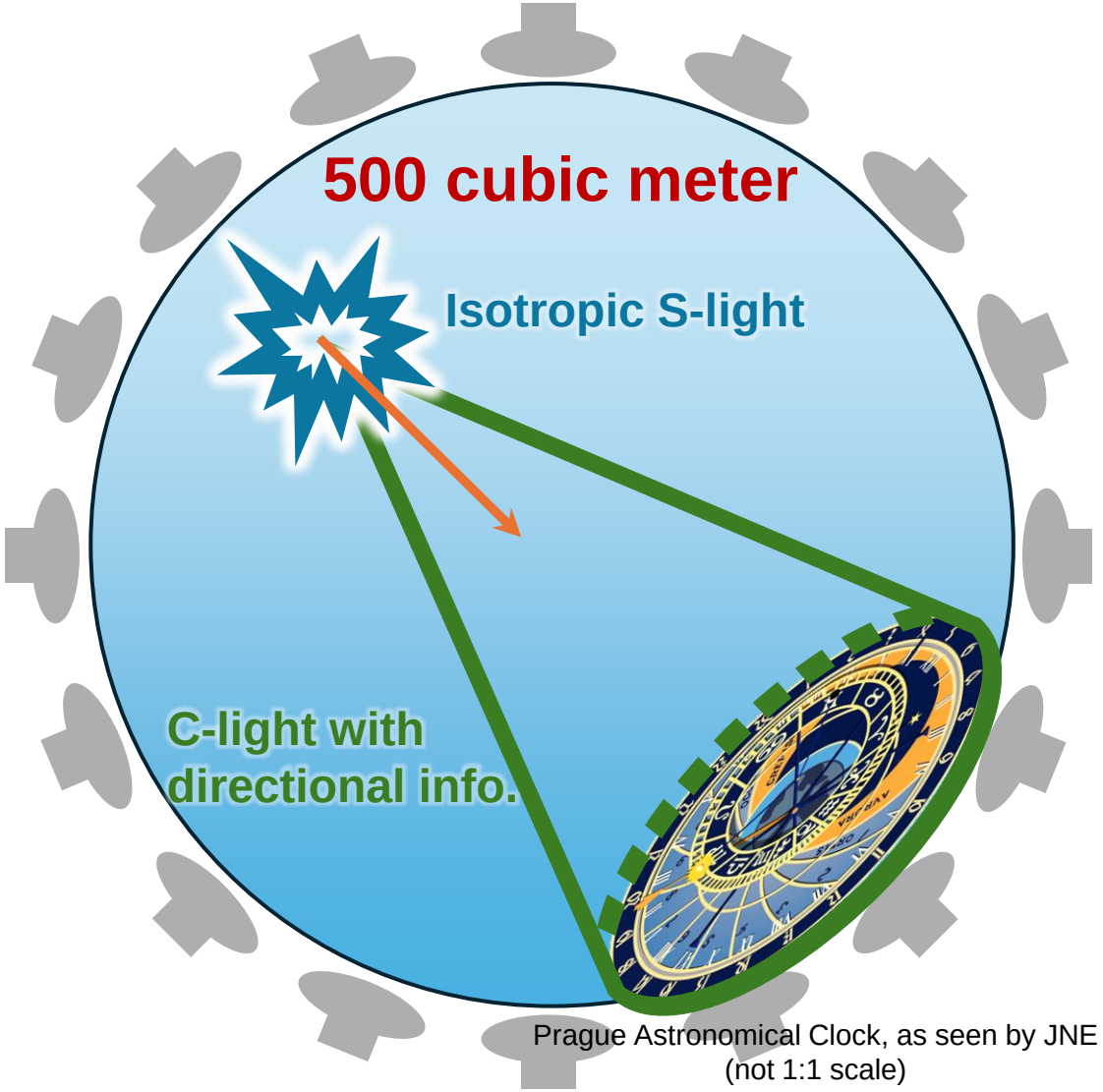
- A screen of brocade.
- Refers to a woman's residence, the boudoir.

What is JNE?

- Solar neutrino observatory at China JinPing underground Laboratory(CJPL)

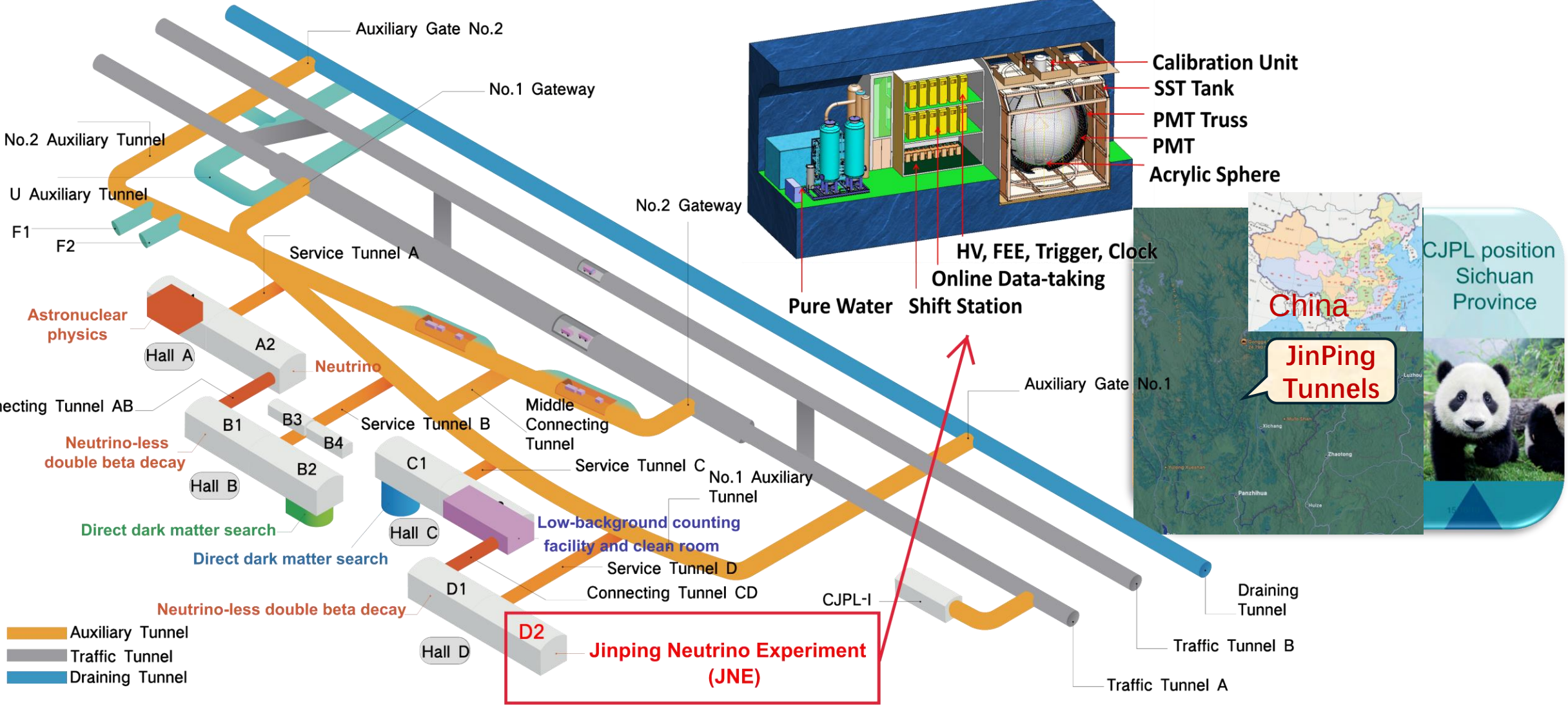


- Using Cherenkov light(C-light) and scintillation light(S-light) separation techniques to study MeV-scale neutrinos



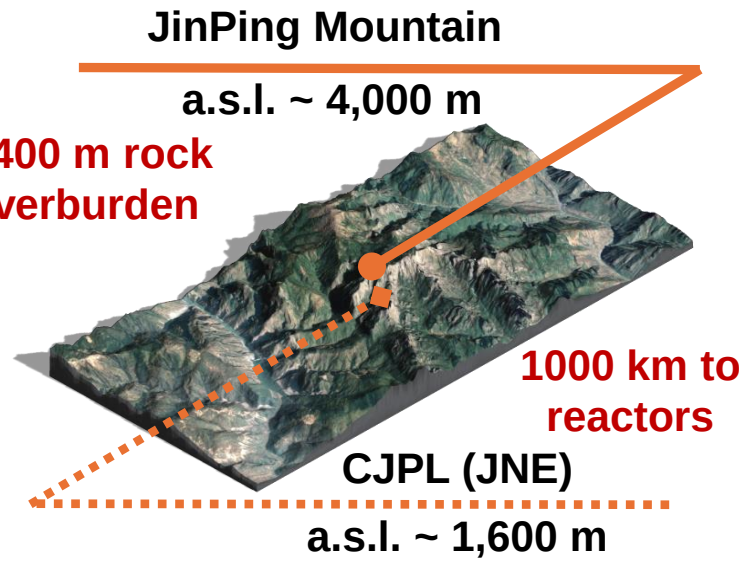
Prague Astronomical Clock, as seen by JNE
(not 1:1 scale)

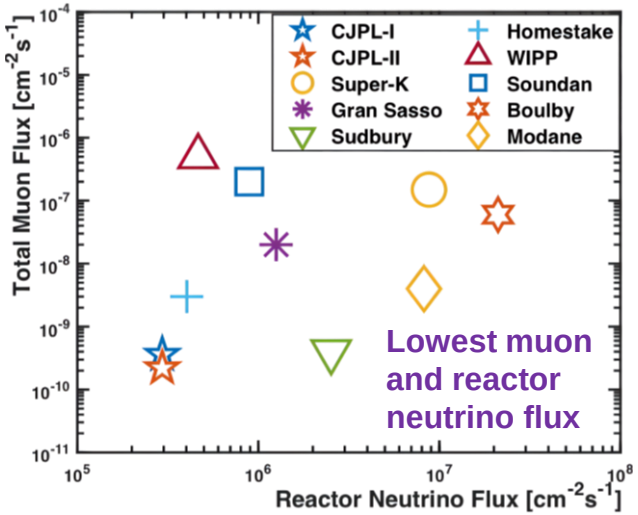
Where is JNE?


Auxiliary Gate No.2
No.1 Gateway
No.2 Auxiliary Tunnel
U Auxiliary Tunnel
F1
F2
Service Tunnel A
No.2 Gateway
Astronuclear physics
Hall A
A2
Neutrino
Connecting Tunnel AB
B1
B3
B4
Service Tunnel B
Middle Connecting Tunnel
Neutrino-less double beta decay
B2
Hall B
C1
Service Tunnel C
No.1 Auxiliary Tunnel
Direct dark matter search
Hall C
Low-background counting facility and clean room
Direct dark matter search
Service Tunnel D
D1
Connecting Tunnel CD
Neutrino-less double beta decay
CJPL-I
D2
Hall D
Jinping Neutrino Experiment (JNE)
Auxiliary Tunnel
Traffic Tunnel
Draining Tunnel
Calibration Unit
SST Tank
PMT Truss
PMT
Acrylic Sphere
HV, FEE, Trigger, Clock
Online Data-taking
Pure Water
Shift Station
Auxiliary Gate No.1
Draining Tunnel
Traffic Tunnel B
Traffic Tunnel A
China
JinPing Tunnels
CJPL position
Sichuan Province

Why is JNE?

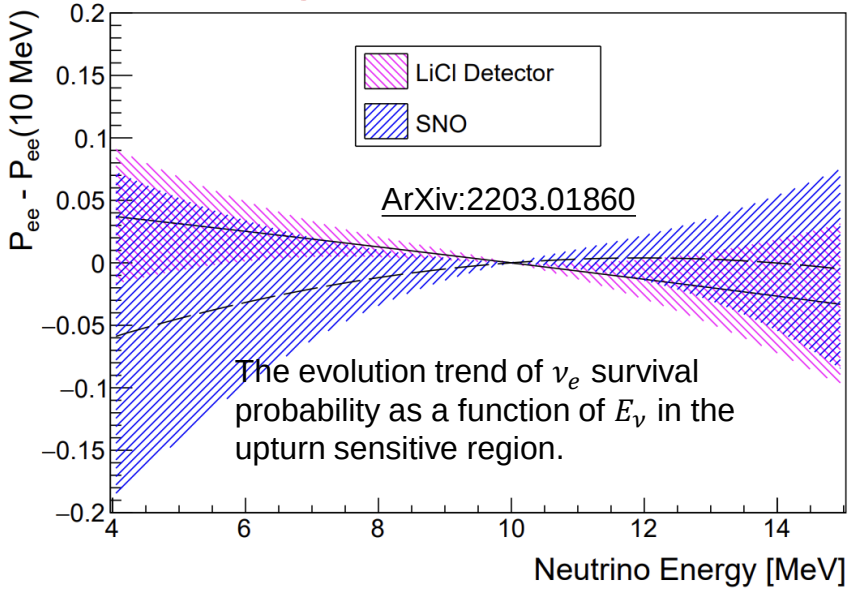
- **Lowest cosmogenic** and **reactor neutrino backgrounds**
- Extensive experience in the **oil-based** and **water-based slow liquid scintillator(LS) - LiCl aqueous solution**
  - High cross-section $\nu_e + {}^7\mathrm{Li} \rightarrow {}^7\mathrm{Be} + e^- (+\gamma)$
  - High natural abundance of Li-7: 92%
  - High solubility: 80 g LiCl in 100 g water
  - Spectrometer for ν_e and $\overline{\nu_e}$
- **Event-by-event direction reconstruction and particle identification(PID)**
- **Good chance for solar, geo, and supernova neutrinos**

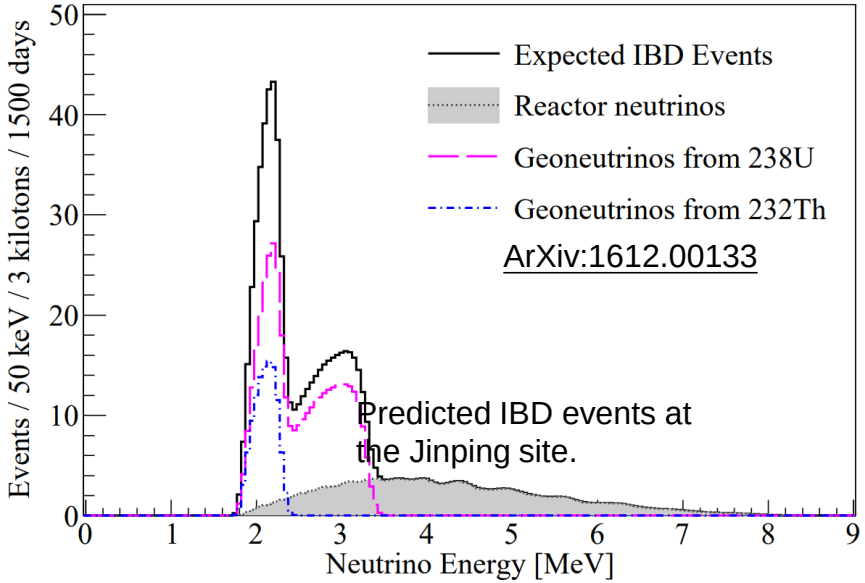


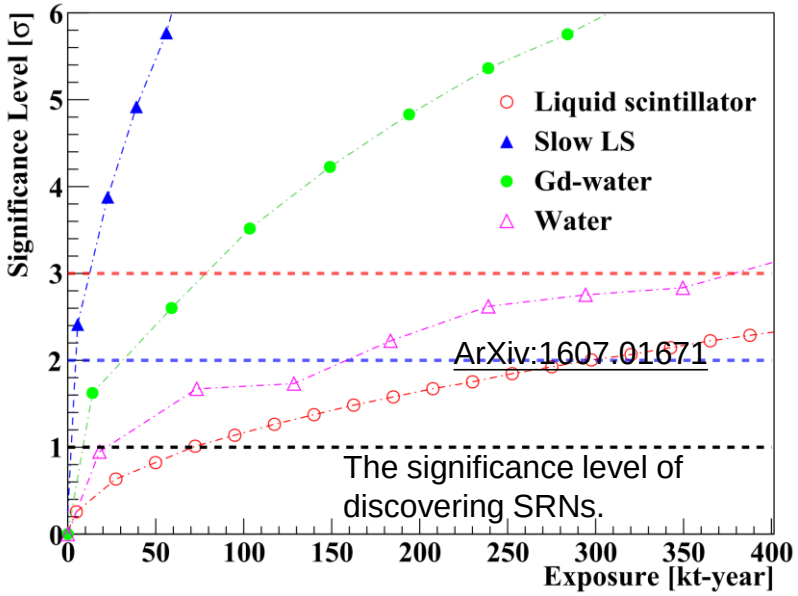


Why is JNE?

- Charged current on Li-7 has an advantage than ν_e ES in measuring solar neutrino upturn effect
- JNE is very sensitive to Qinghai-Tibet plateau crust neutrinos
- Have the capability for PID to suppress atmospheric neutrino neutral current background







JNE Timeline

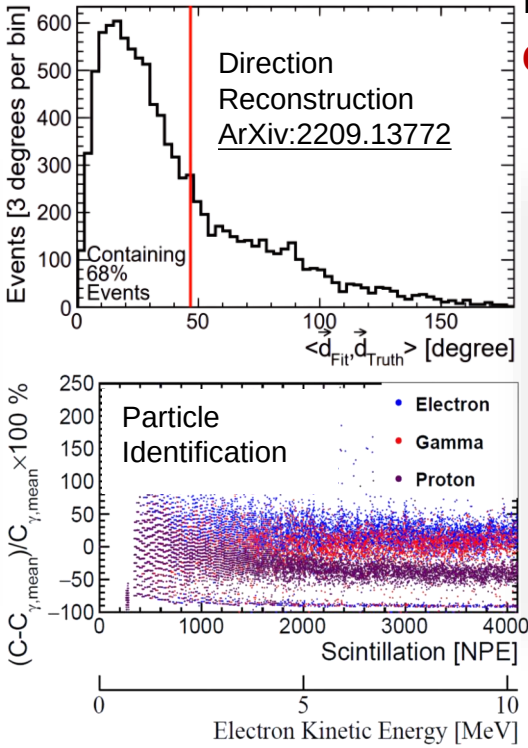
- Structure design of the **multi-hundred ton detector**
- Event-by-event direction reconstruction & PID
- Novel 8-inch MCP-PMT study
- FADC and readout design and testing

Letter of Intent
ArXiv:1602.01733

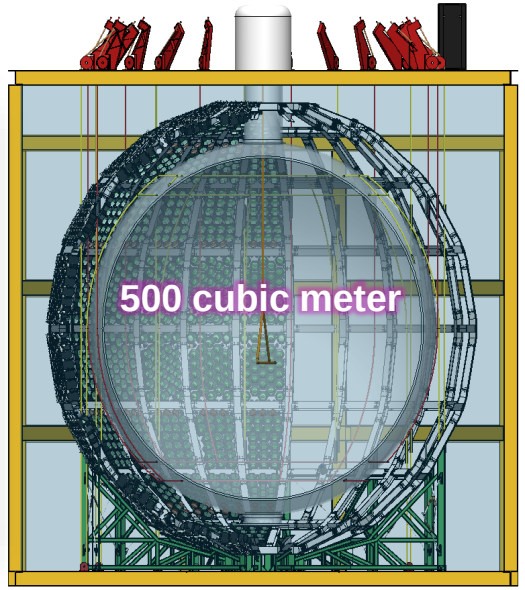
Multi-hundred ton detector data taking

2015 **2017** **2023** **2024** **2026**

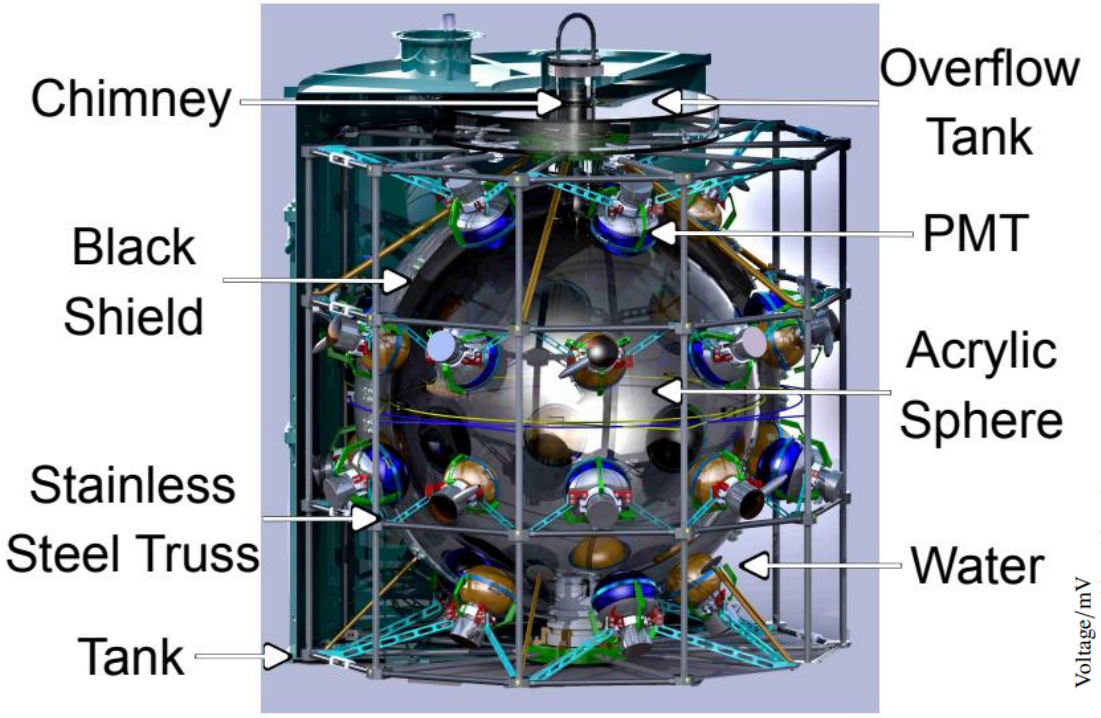
1-ton Prototype data taking



Multi-hundred ton detector **construction begins**



1-ton Prototype

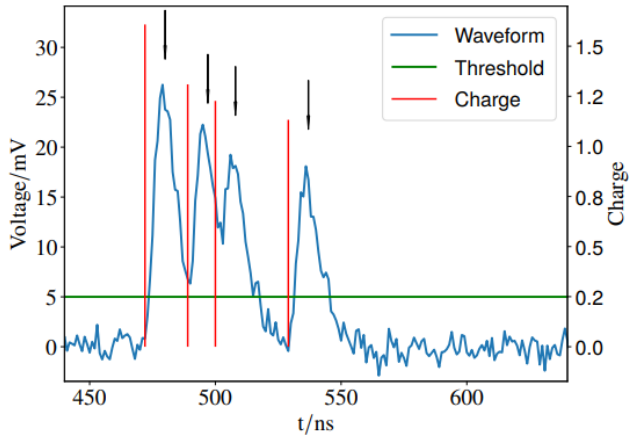


1-ton prototype at CJPL-I
Running for ~6 years
Upgrade: 30 PMTs → 60 MCP-PMTs

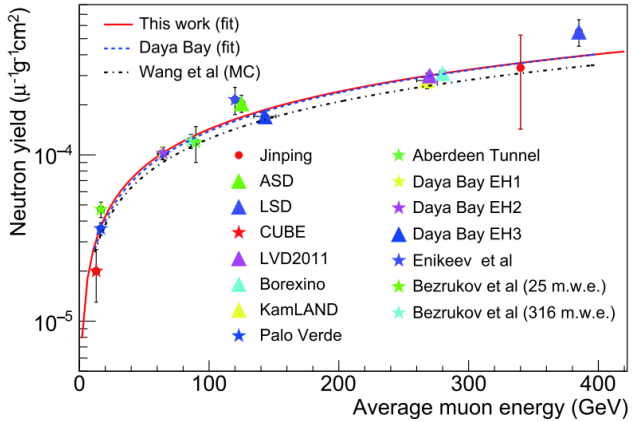
ID: #669, PMT single PE response
ID : #1128, Muon flux of CJPL
ID : #1169, 1-ton Upgrade
ID : #1214, Waveform analysis

Background measurement

		PMT	LS
Decay rate [Bq/g]	^{214}Bi	-	$(1.59 \pm 0.20) \times 10^{-8}$
	^{208}Tl	$(1.64 \pm 0.47) \times 10^{-3}$	-
	^{212}Bi	-	$<(1.01 \pm 0.20) \times 10^{-9}$
	^{40}K	$(1.24 \pm 0.35) \times 10^{-2}$	-
Contamination level [g/g]	^{238}U	-	$(1.28 \pm 0.16) \times 10^{-12}$
	^{232}Th	$(1.12 \pm 0.32) \times 10^{-6}$	$<(2.49 \pm 0.50) \times 10^{-13}$
	^{40}K	$(4.67 \pm 1.35) \times 10^{-8}$	-



Waveform analysis, total reflection reconstruction



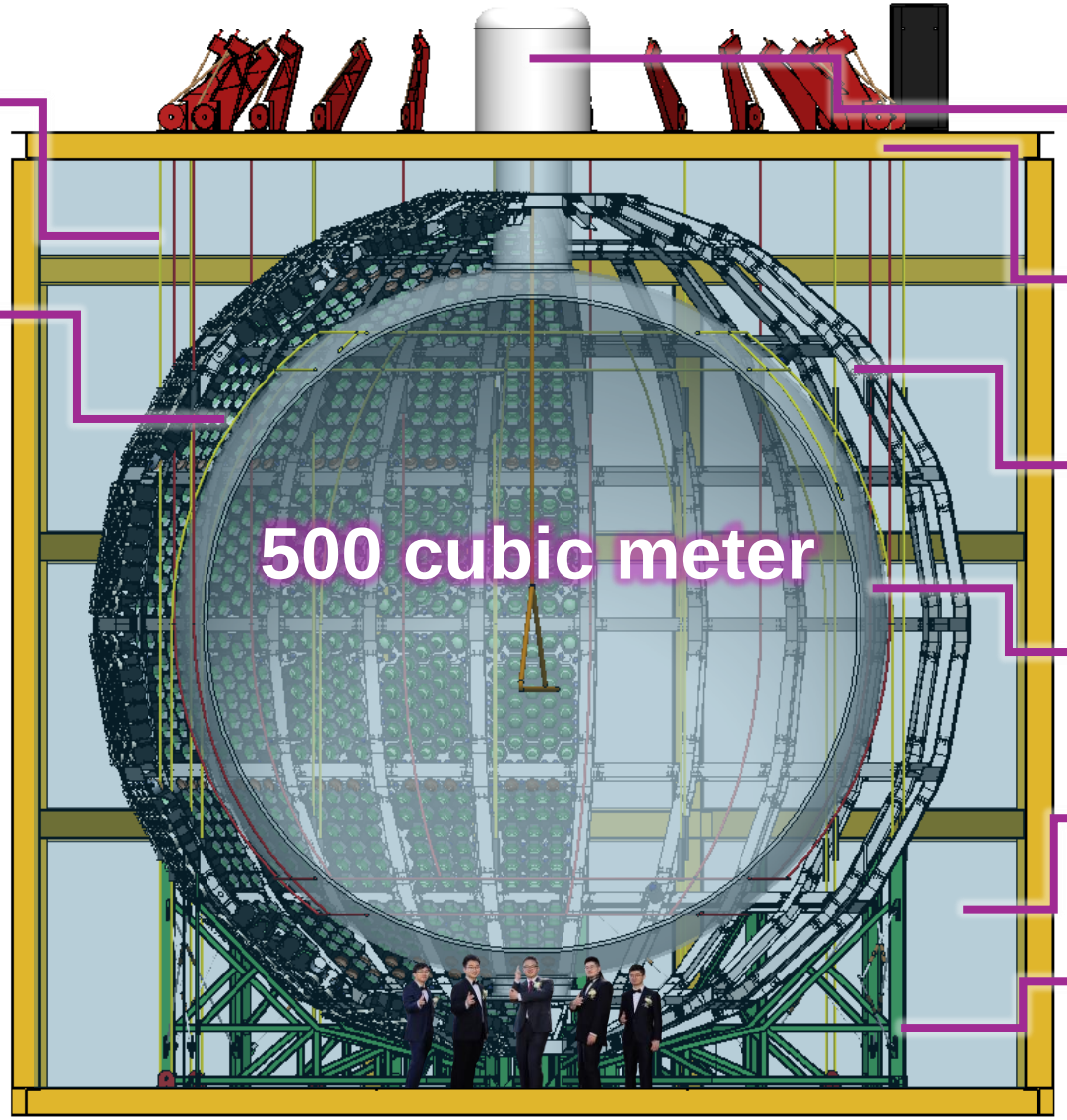
Muon flux and muon-induced neutron yield

Multi-hundred ton Detector

Rope System
holding-up and holding-down

8-inch MCP-PMT
+Light Concentrator
~4000, ~50% Coverage


Prague Astronomical Clock



Calibration Unit

Stainless Steel Tank(SST)
14.5 m *12.9 m *13.2 m

SST PMT Truss
Inner diameter(ID): 12.16 m

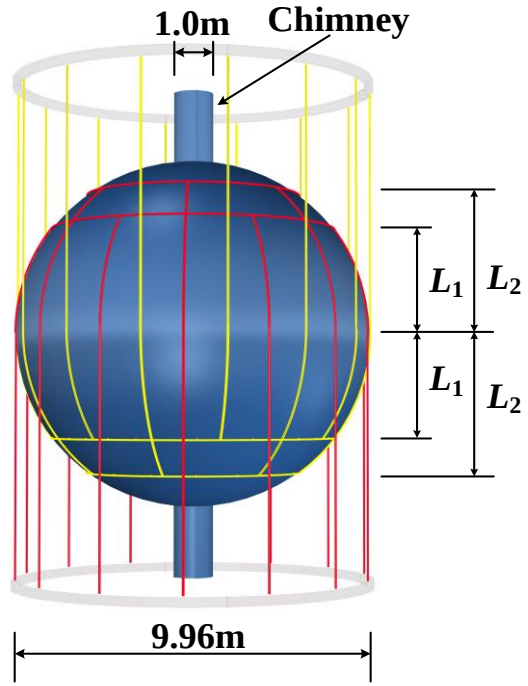
Acrylic Vessel
ID: 9.96 m, Thickness: 5 cm

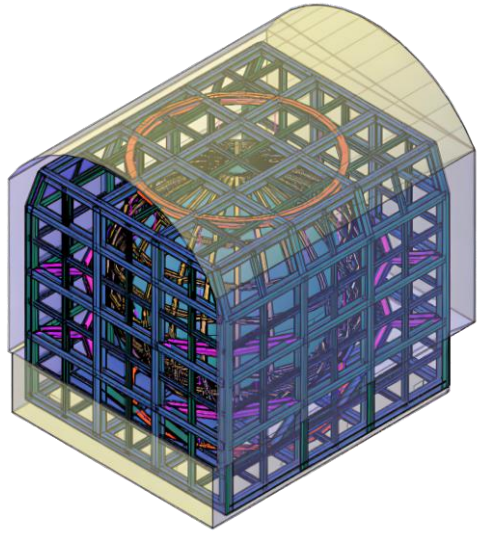
Shieling Material
Water and SST (or lead)

SST Supporting Legs

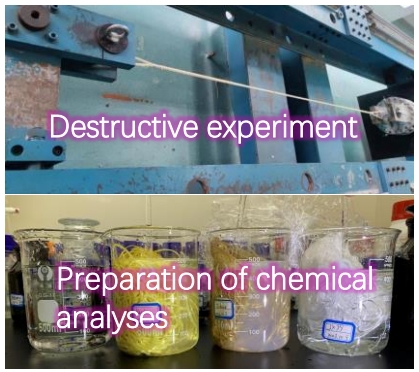
Central Detector

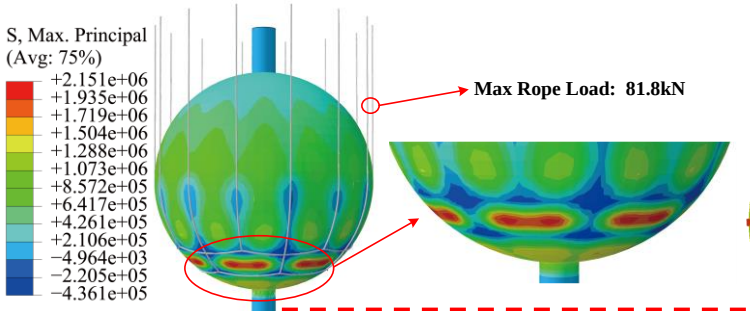
- 9.96 m spherical acrylic vessel, 500 cubic meter(Water, LS, or Doped LS)
- Rope to hold the acrylic vessel
- **Density difference to water: ±20%(Gravity or buoyancy)**
- Low background
- High strength, low creeping, water compatibility
- Mechanical analysis of the SST framework has been finished
- Finite element software ABAQUS is adopted





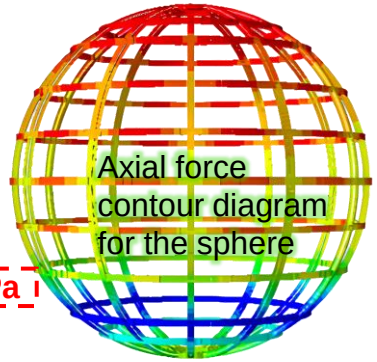
SST Frame

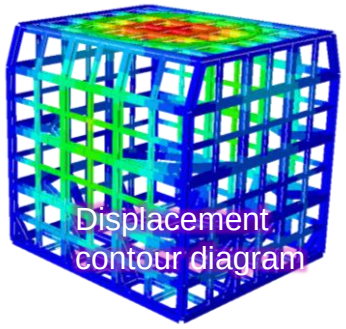




Max Principal Stress: 2.15 MPa

ArXiv: 2406.12899





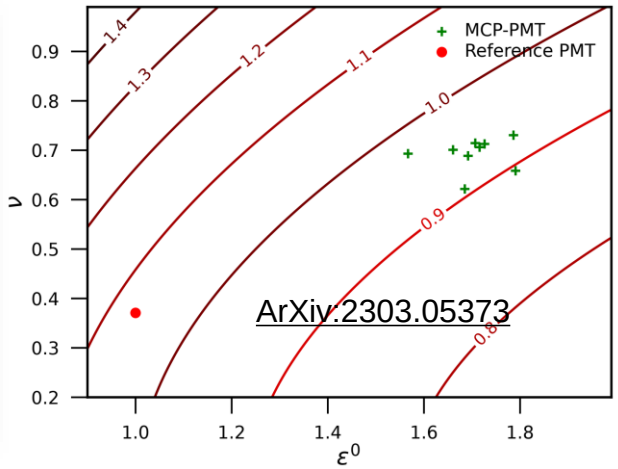
MCP-PMTs & Electronics

~4,000 novel 8-inch MCP-PMTs

- U、Th: <4e-8 g/g，K-40: <4e-9 g/g
- High QE: ~30%
- Good TTS: <1.8 ns

600 MCP-PMTs have been produced.

ID: #1228, MCP-PMT testing

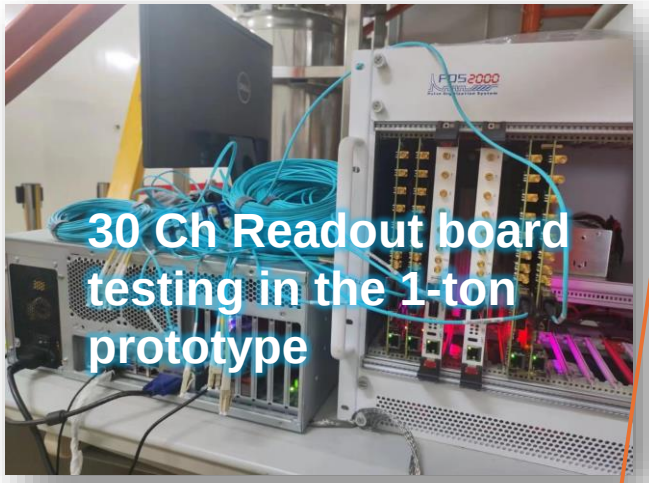


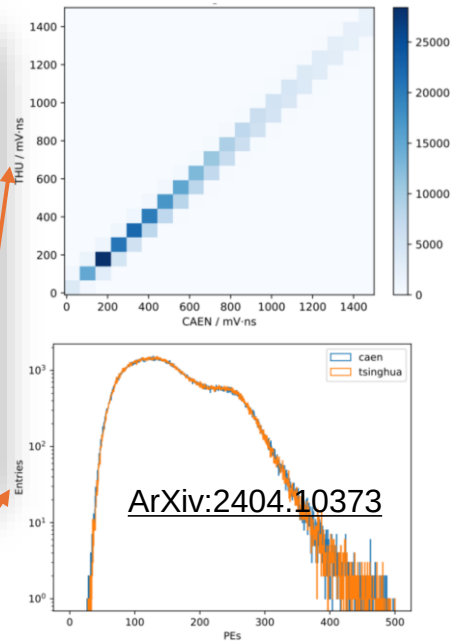
Mean square deviation and relative photon detection efficiency distribution of PMT charge spectra

FADC for PMT waveform readout

- 350 mW/ch, 12-bit, 1 GSps
- Readout board, Bandwidth 300 MHz, 40Gbps

The whole system will be tested on the one-ton prototype this year.





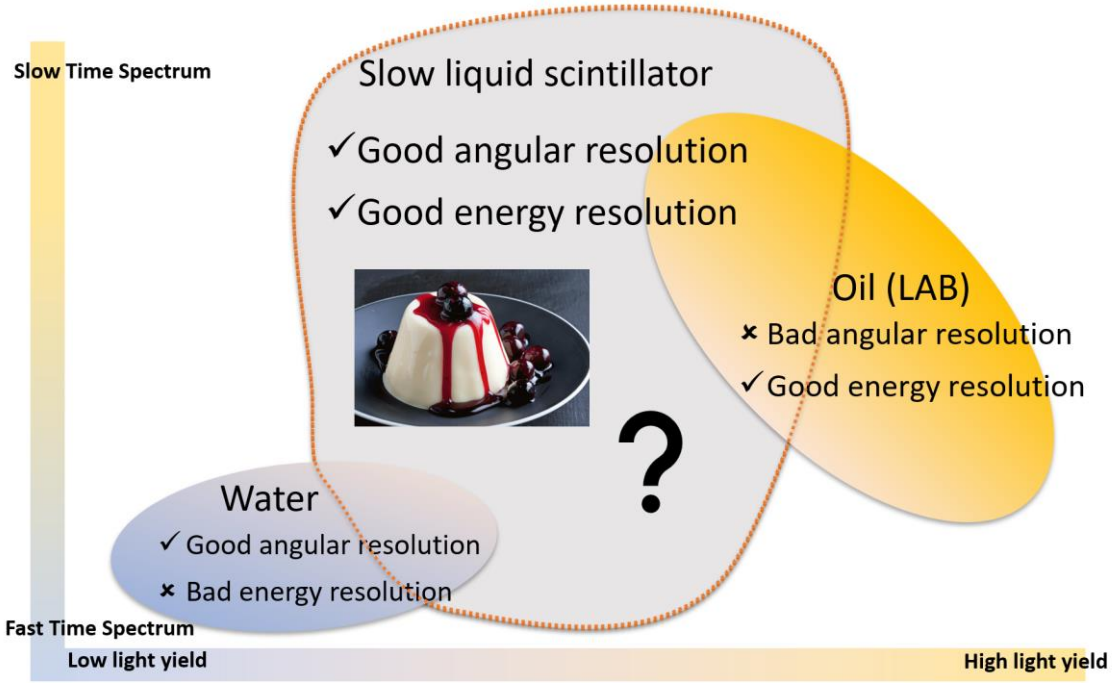
Charge spectrum(top) and PE spectrum(bottom) comparison between THDAQ system and CAEN DAQ system

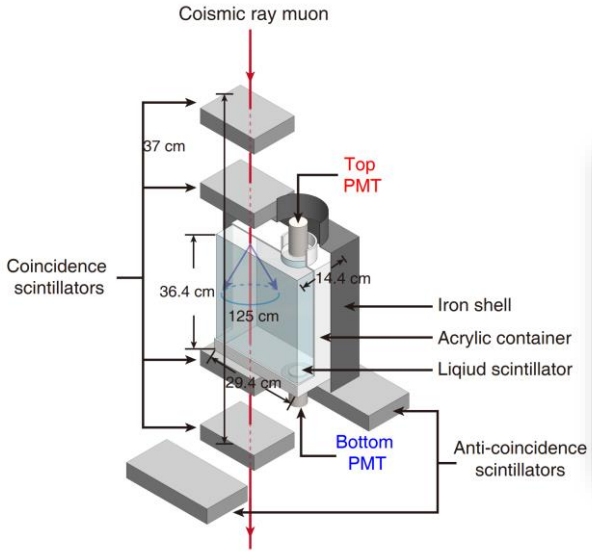
Slow Liquid Scintillator

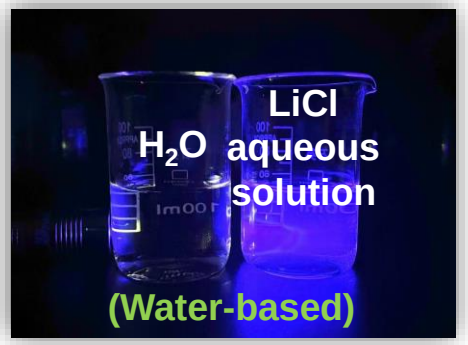
- Have good angular resolution and energy resolution
- **Reduce the interference of S-light**

  → Get direction

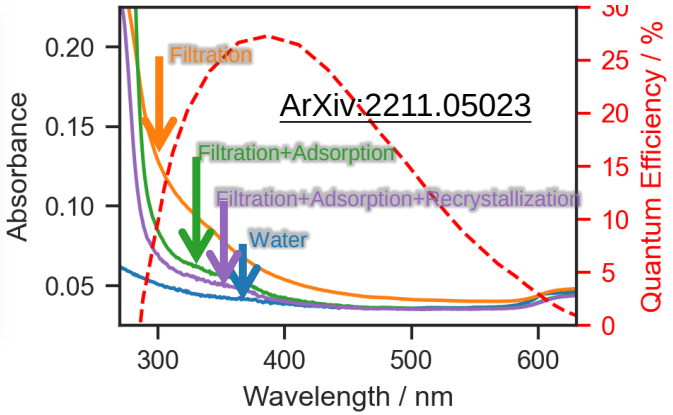
  - Control the S-light yield(**water-based LS**)
  - Control the emission speed(**oil-based LS**)

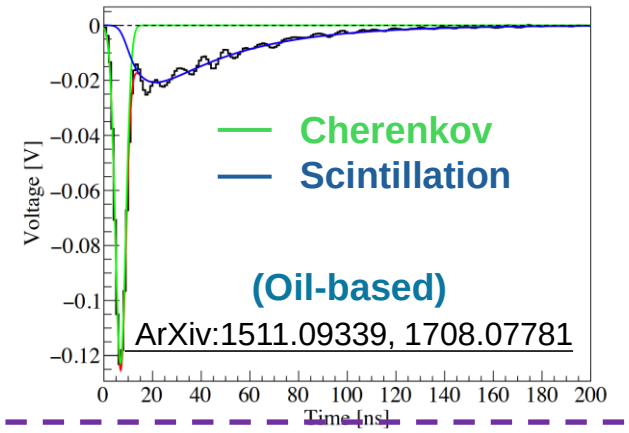






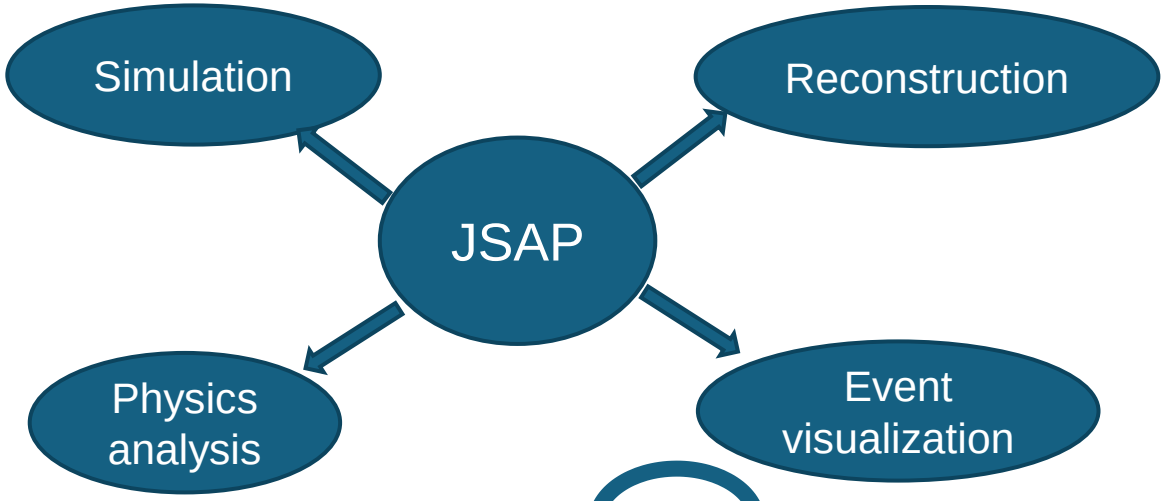
ID: #1125, LiCl aqueous solution

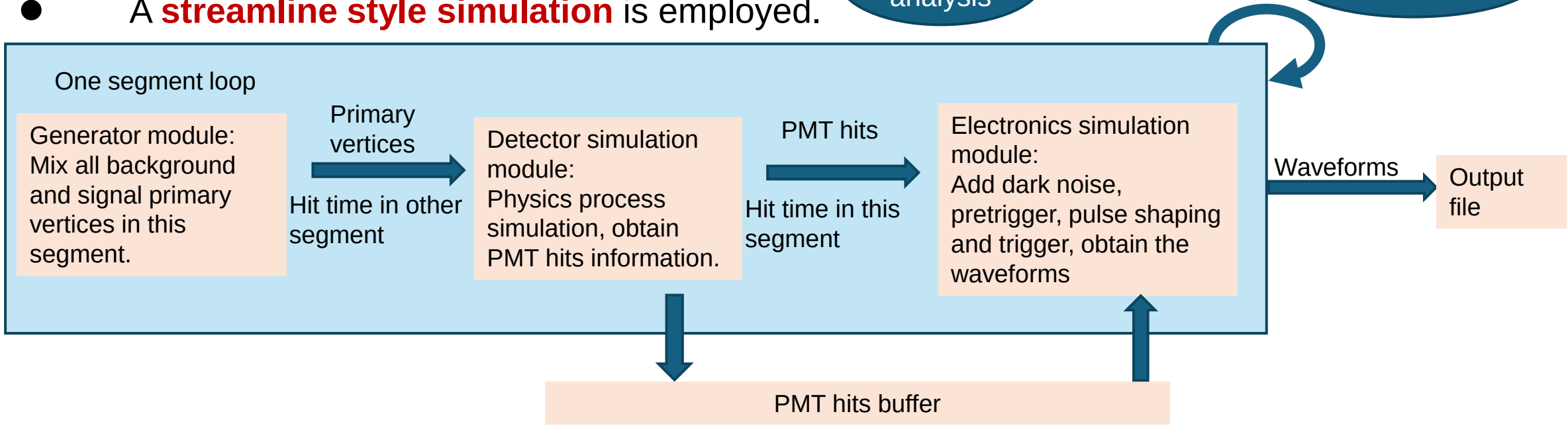




Jinping Sim. & Ana. Package

- JSAP uses **Geant4** and **GDML** for studying various detector geometries like spherical and cylindrical detectors.
- Electronics and trigger simulations are included, offering waveform readout.
- A **streamline style simulation** is employed.





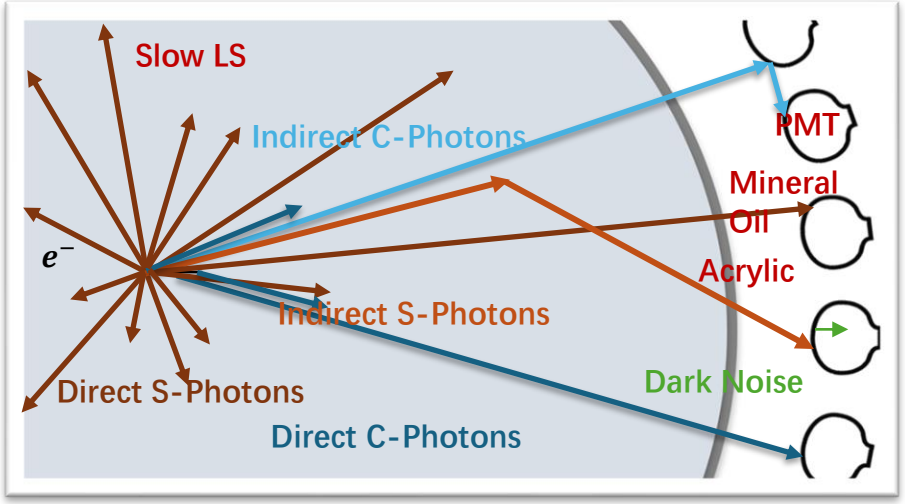
Reconstruction

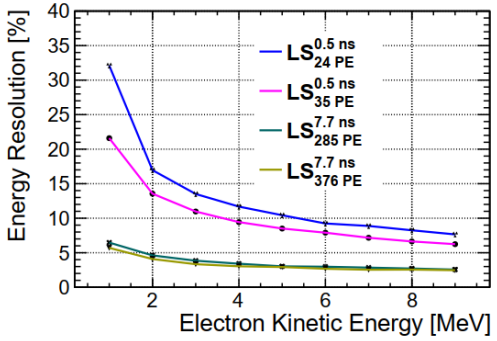
- Reconstruct both Cherenkov light and scintillation light
- Event-by-event **direction**, energy, position reconstruction
- C-light emission capability ranking:

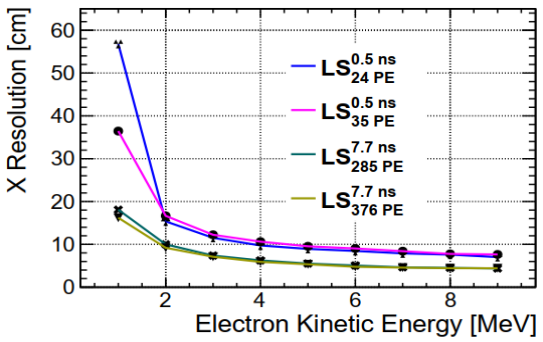
  e > γ > p ≈ α

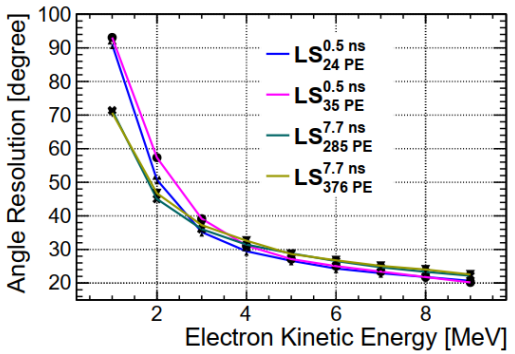
  Particle identification

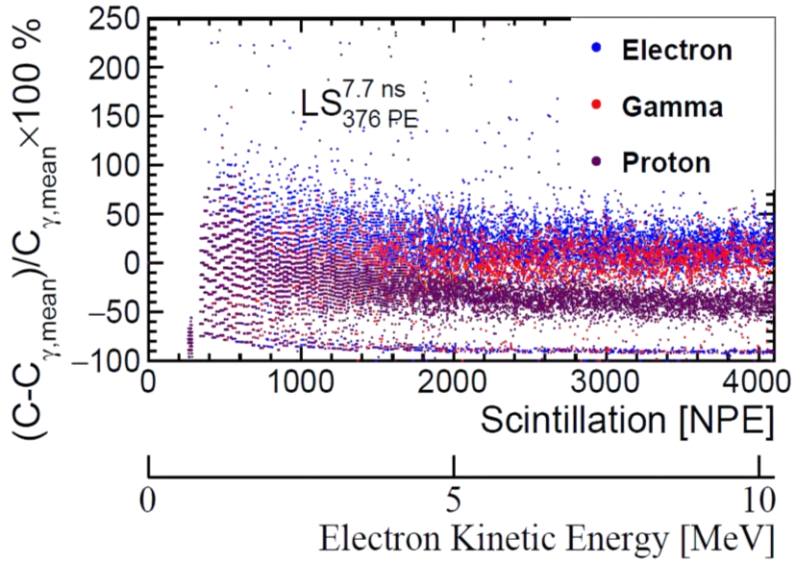
Guide liquid scintillator development, ArXiv:2209.13772









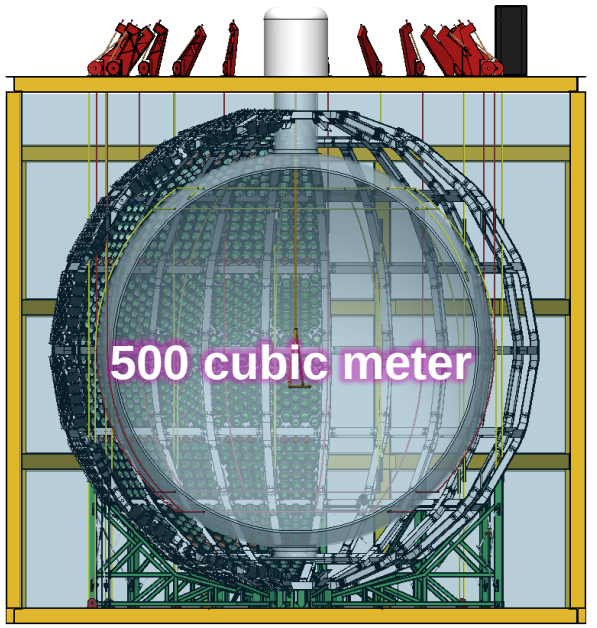


Summary

- Multi-hundred ton solar neutrino observatory at CJPL-II will be constructed by **2026**.

- **Novel 8-inch MCP-PMT**, low background, fast, high QE.
- ADC chips and waveform readout electronics under design and testing.
- Explored the option with **LiCl aqueous solution**.
- Successfully developed a reconstruction algorithm based on slow LS, capable of **direction reconstruction and particle identification**.

- Rich physics with MeV-scale neutrinos at CJPL-II, see http://jinping.hep.tsinghua.edu.cn



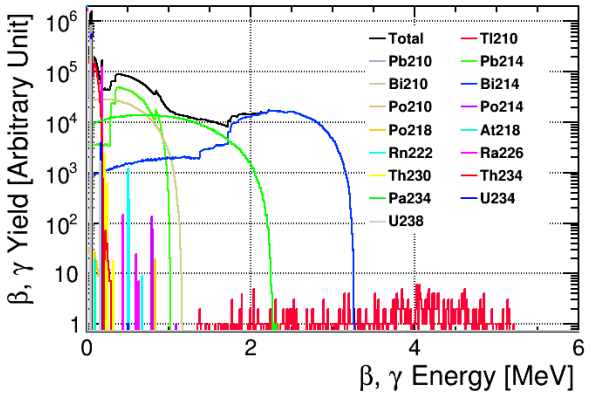

Thank
You !

What's More

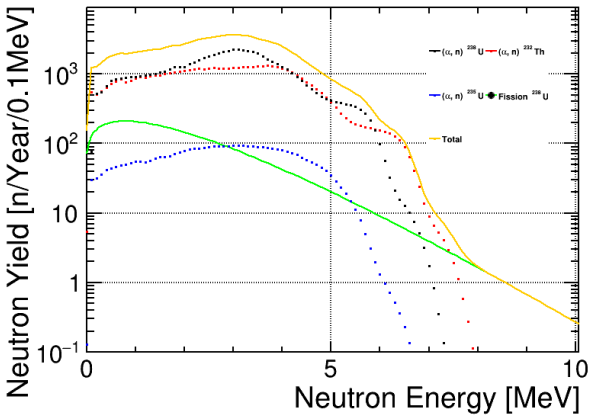
Backup

Radiogenic Background Shielding

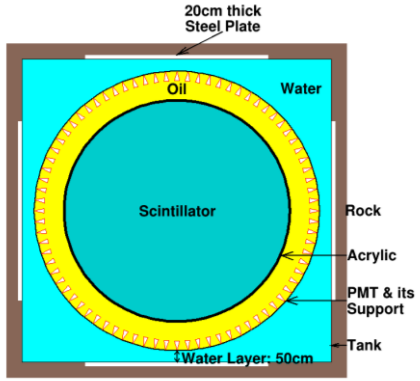
- Radiogenic background
  - β, γ background
  - Neutron-related background
    - (α, n) neutron
    - ^{238}U Self-fission
- Working flow
  - background spectrum → simulation for different shielding plans → background rates → determine the best shielding detector plan
- The best shielding plans
  - 50cm Water
  - 7m×7m×20cm Steel plate
  - Boron-doped PE PMT encapsulation



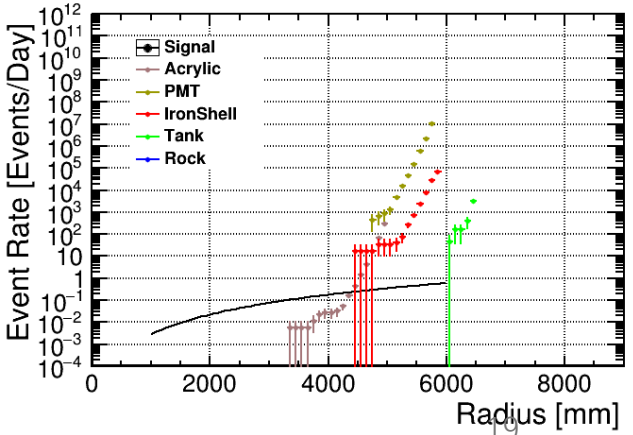
β, γ spectrum from ^{238}U



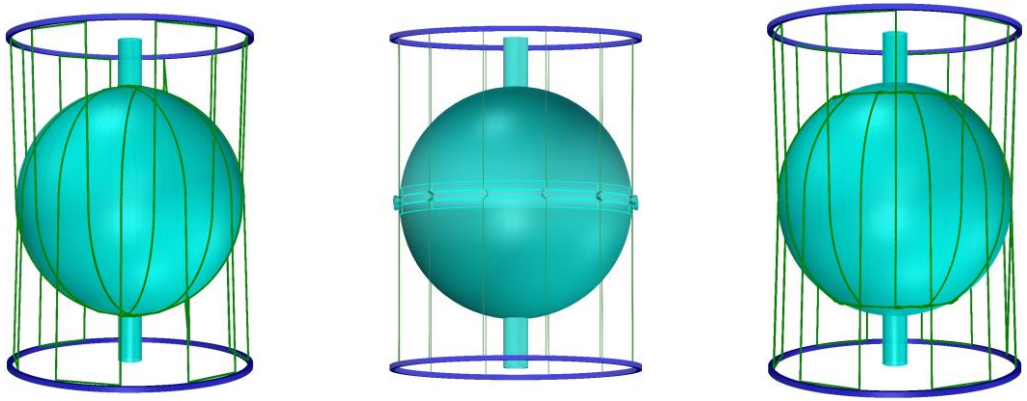
Neutron spectrum of PMT glass



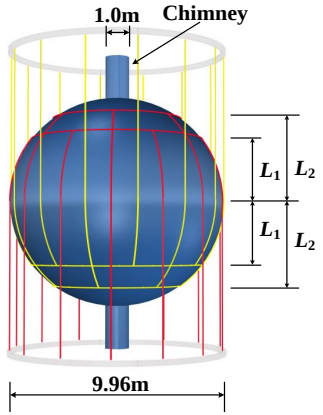
The best shielding plan



Background rates for the best shielding plan

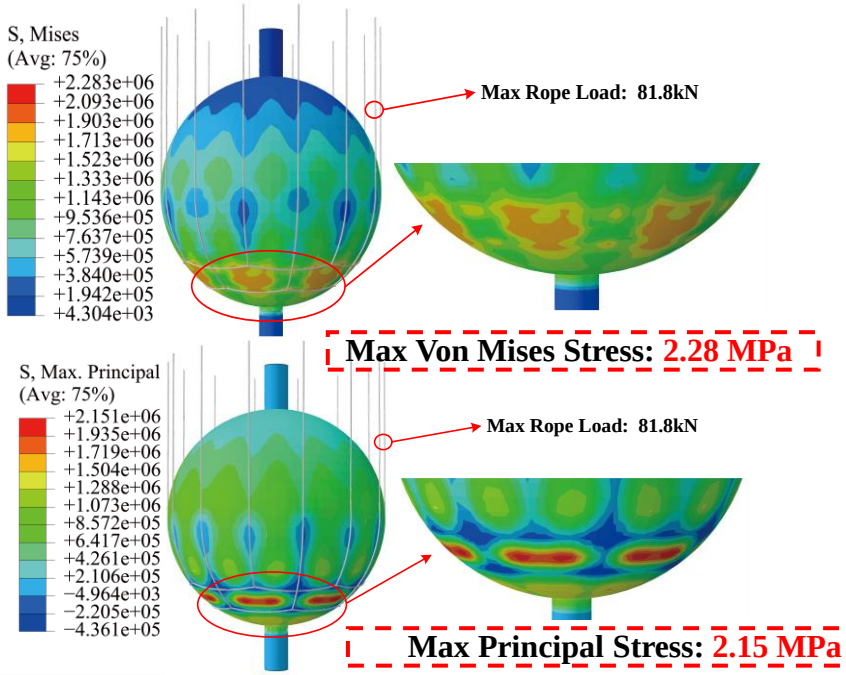


Scheme 1 Scheme 2 Scheme 3



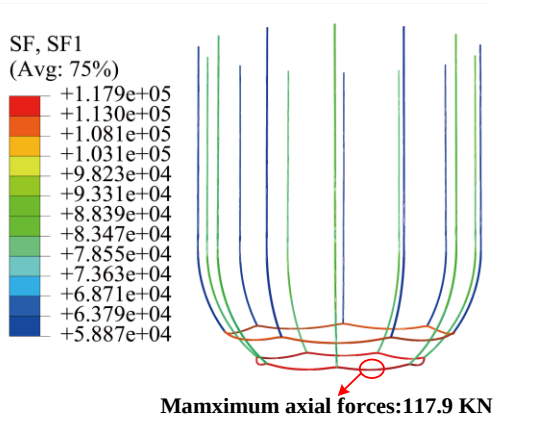
- Double loop
- Double chimney structure
- Diameter 9.96 m, shell thickness 50 mm
- Volume 500 m^3
- Rope diameter 35mm

Final Scheme

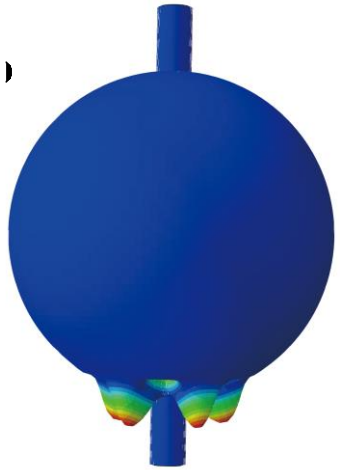


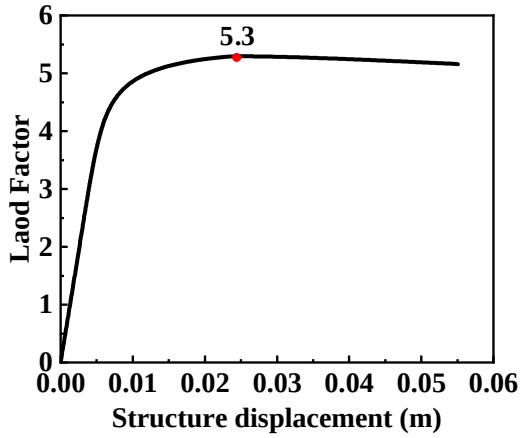
Max Von Mises Stress: 2.28 MPa

Max Principal Stress: 2.15 MPa



Max Rope Axial Force: 117.9 kN





Linear Buckling Analysis Safety Factor 14.72

Risk Analysis Safety Factor 5.3

Rope diameter analysis | Rope Young's modulus analysis | Shell Thickness analysis

Temperature analysis | Rope position analysis | Rope failure analysis | … … …

ν_e CC, ES, and $\bar{\nu}_e$ detection

1. CC process for ν_e:

$$\nu_e + {}^7\mathrm{Li} \rightarrow {}^7\mathrm{Be} + e^- (+\gamma)$$

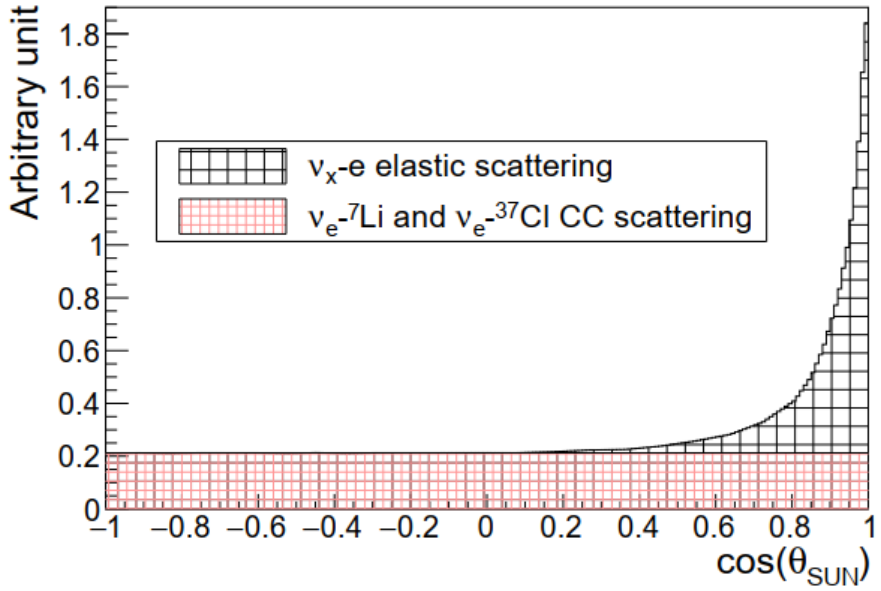
Measure neutrino energy

1. Elastic scatter on e^-:

2. Delayed coincidence for

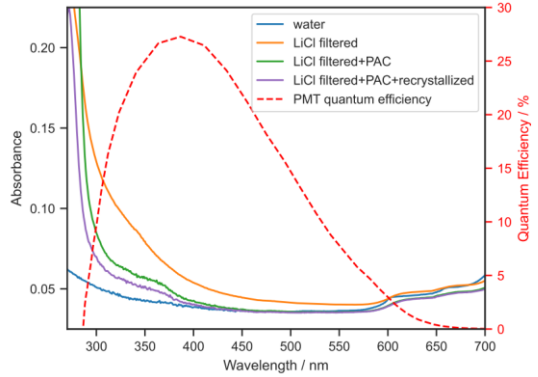
$$\bar{\nu}_e + p \rightarrow n + e^+$$

with neutron capture on H, Li6, and Cl35 measure $\bar{\nu}_e$ energy



Spectrometer for ν_e and $\bar{\nu}_e$
Good chance for solar, geo, and supernova neutrinos

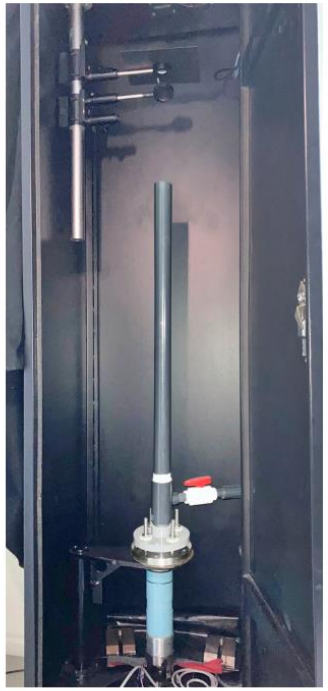
LiCl Water Solution



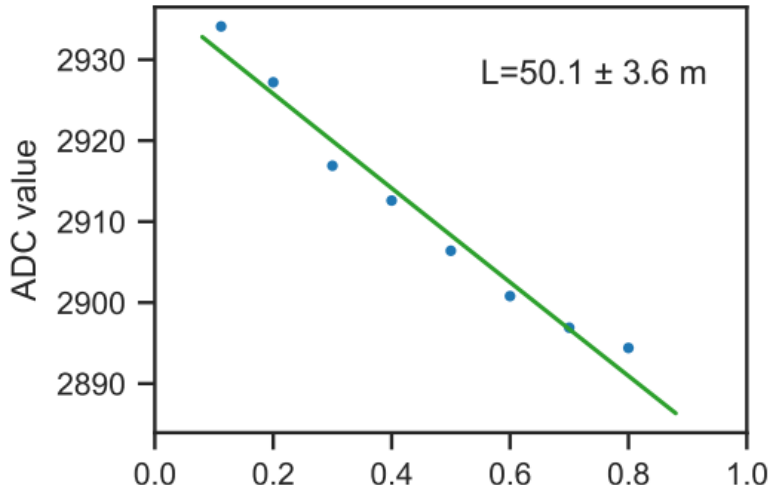
LiCl water solution

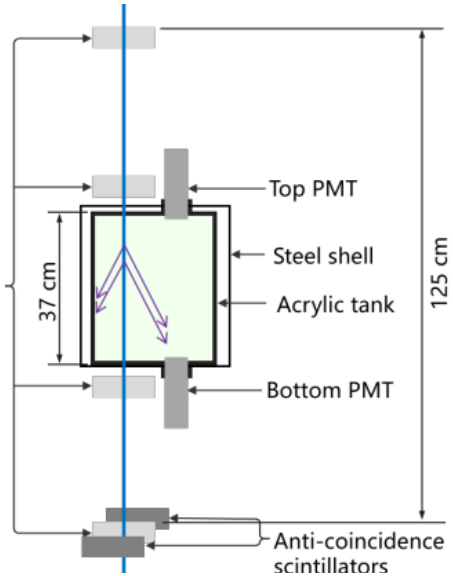
Ideal for solar neutrino upturn effect study

1. Attenuation length at 430 nm is greater than 50 meters
2. C124 can be added to enhance light yield



(b)

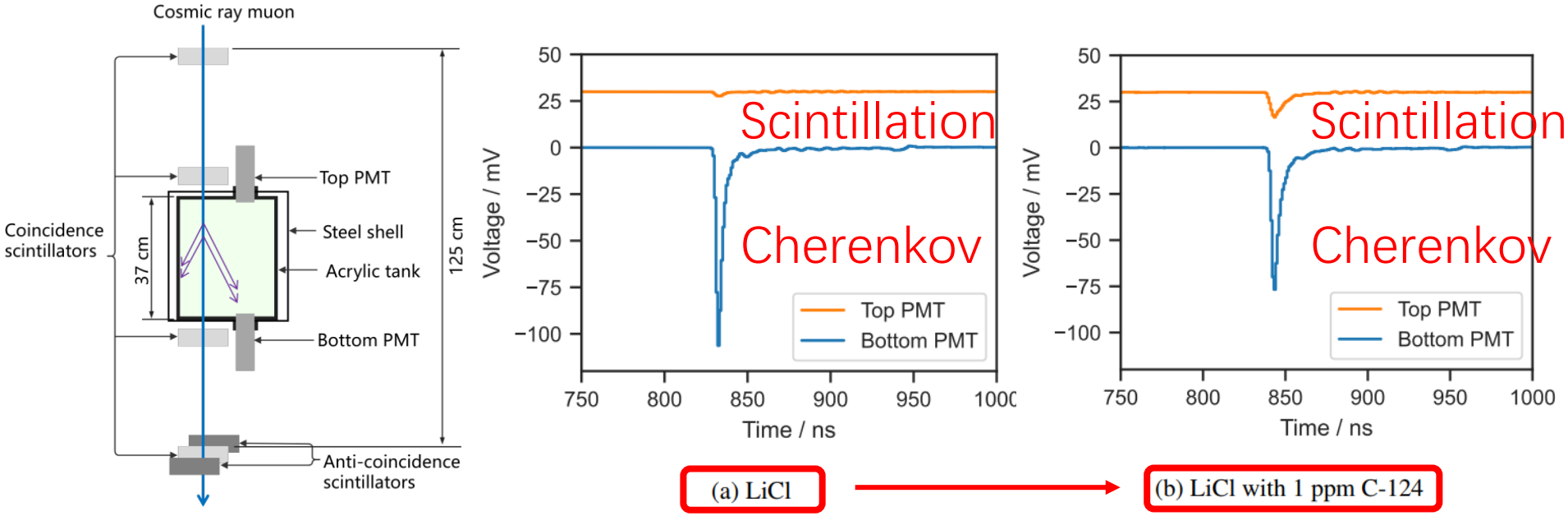




	Top PMT PEs	Bottom PMT PEs
Water	0.76 ± 0.08	15.8 ± 1.5
Saturated LiCl solution	0.54 ± 0.08	17.2 ± 1.5
Saturated LiCl solution with 1 ppm C-124	3.7 ± 0.4	16.0 ± 1.6

LiCl aqueous solution with carbostyril

Light yield verification with a muon telescope

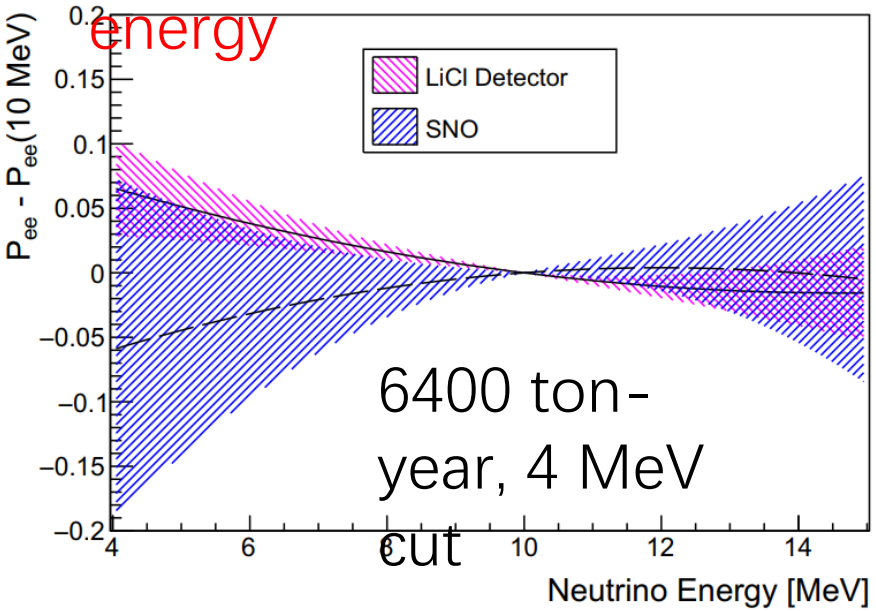


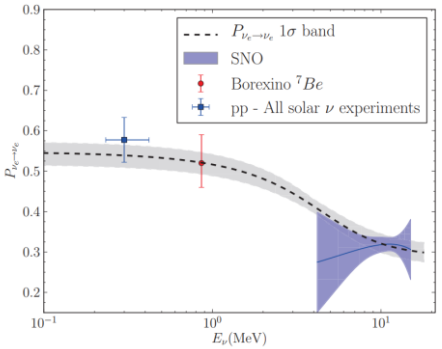
3.7 PE detected from isotropic scintillation

12.3 PE for Cherenkov

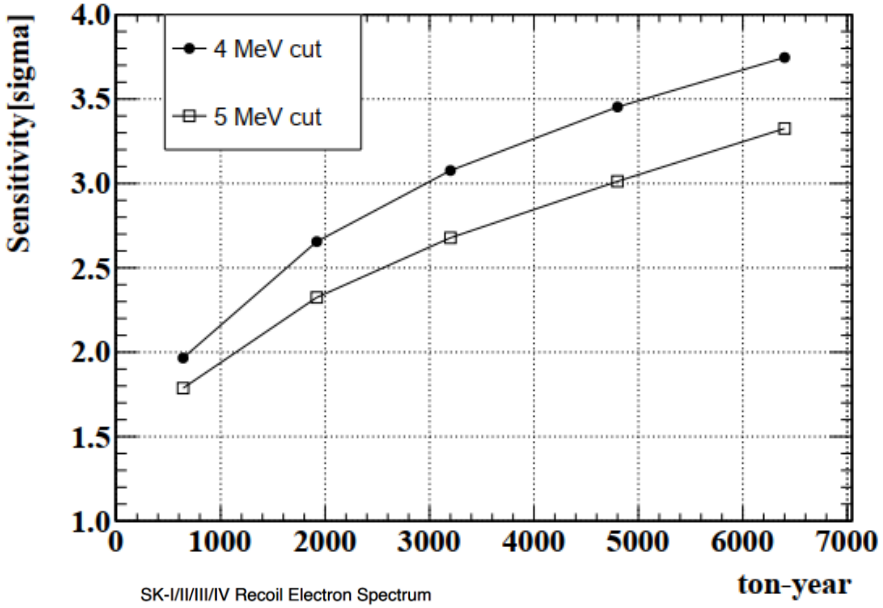
Solar Neutrino Physics with LiCl Solution

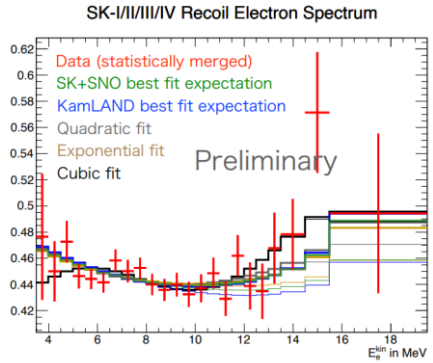
Solar neutrino survival probability-average vs energy





Upturn discovery sensitivity versus exposure



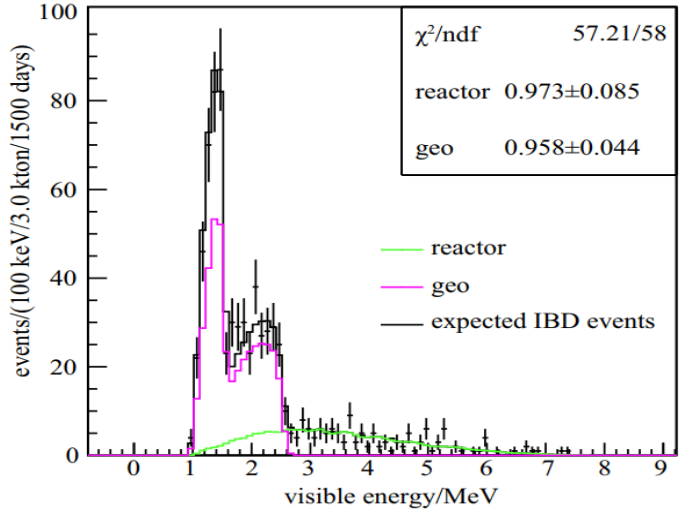


Slightly favors up-turn, though need more data

Geo Neutrino and Supernova Relic Neutrinos

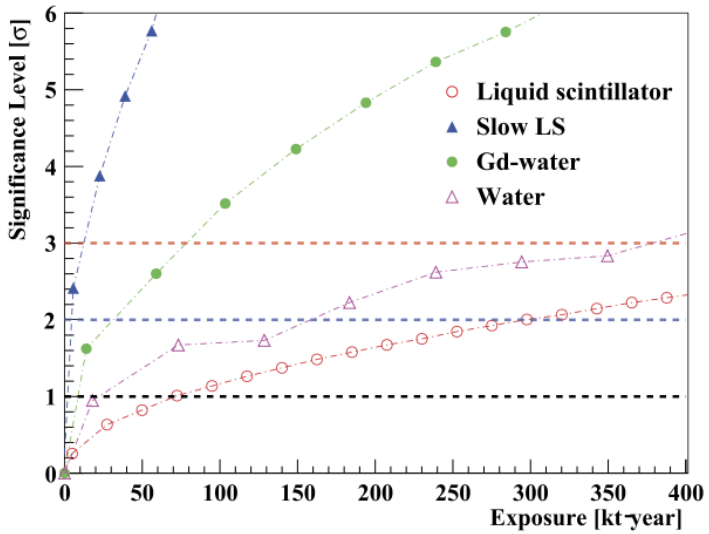
With prompt-delayed signal detection:

Expect tens of geoneutrinos in 5-10 years with the 500-ton detector



With Cherenkov-scintillation liquid scintillator:

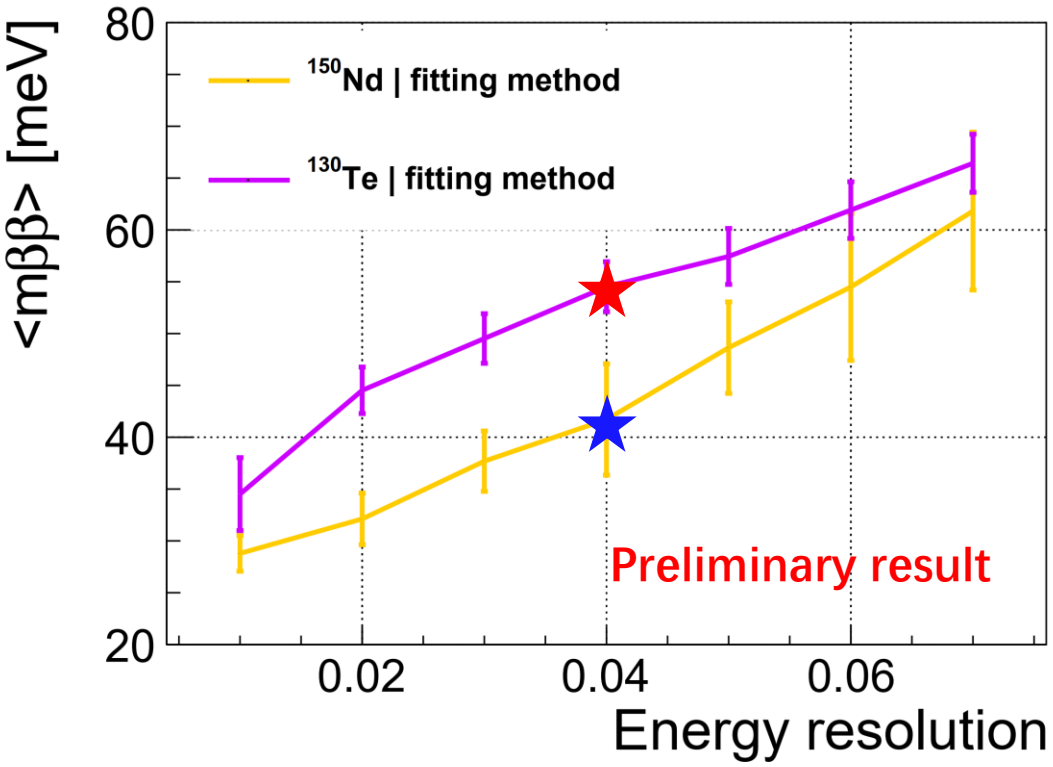
Expect a few golden candidate supernova relic neutrinos in 5-10 years with the 500-ton detector

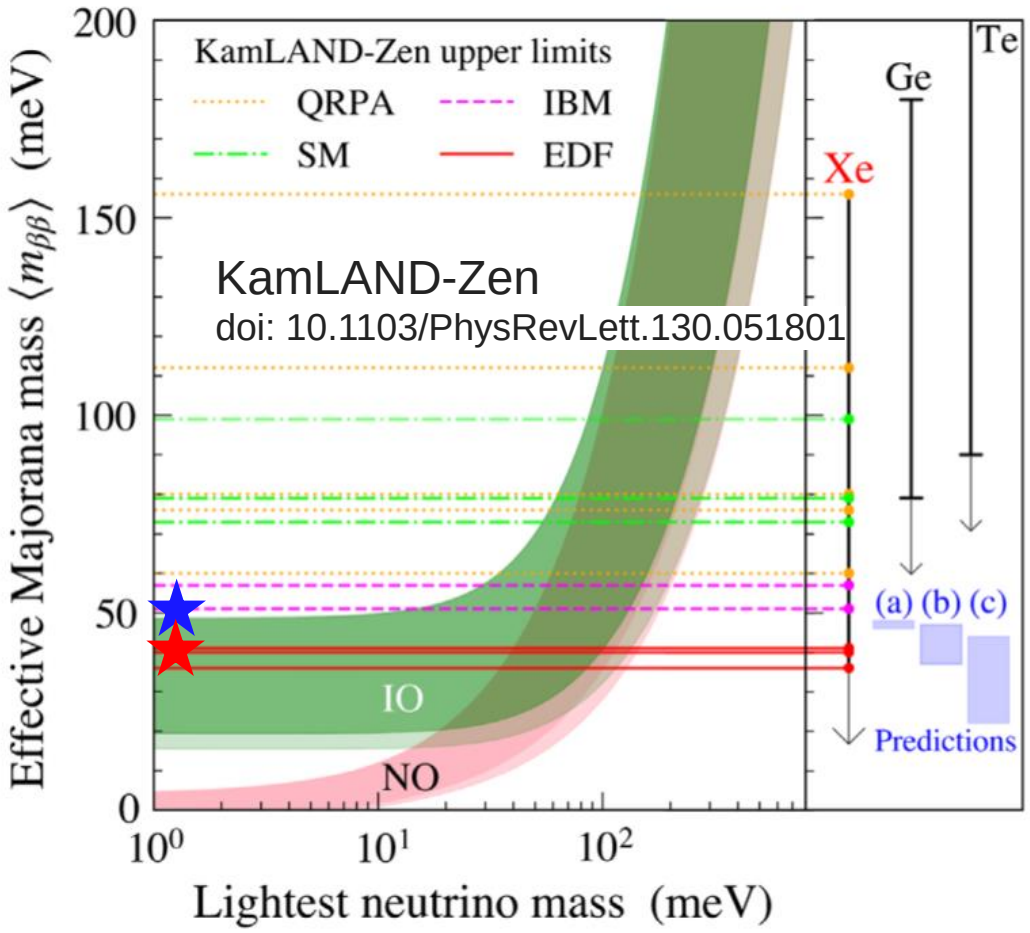


Expect an improvement better than this figure. Work in progress.

Neutrino effective mass of Nd-150 vs. Te-130

Natural Nd/Te doping of 10%, i.e. 2.85t Nd-150 / 17.25t Te-130 | Runtime = 1yr





Calculation of $G\_0\nu$ versus $M\_0\nu$ ($QRPA$) for $<m\beta\beta>$ used taken from doi:. 10.1142/s0217732313500211