# New 1-ton neutrino detector at CJPL-I: equipment upgrades and performance

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On Behalf of JNE

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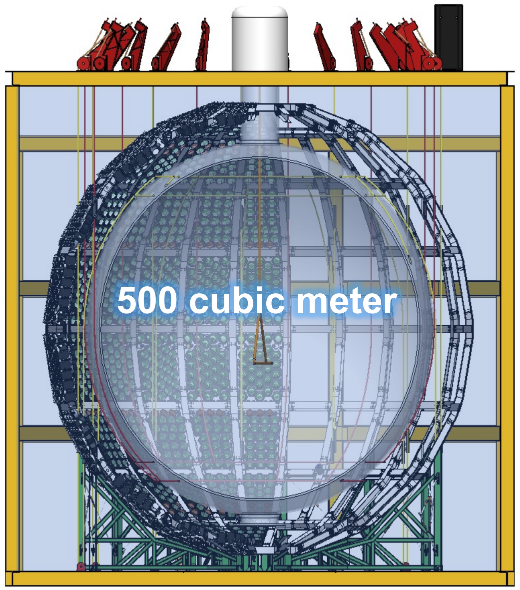
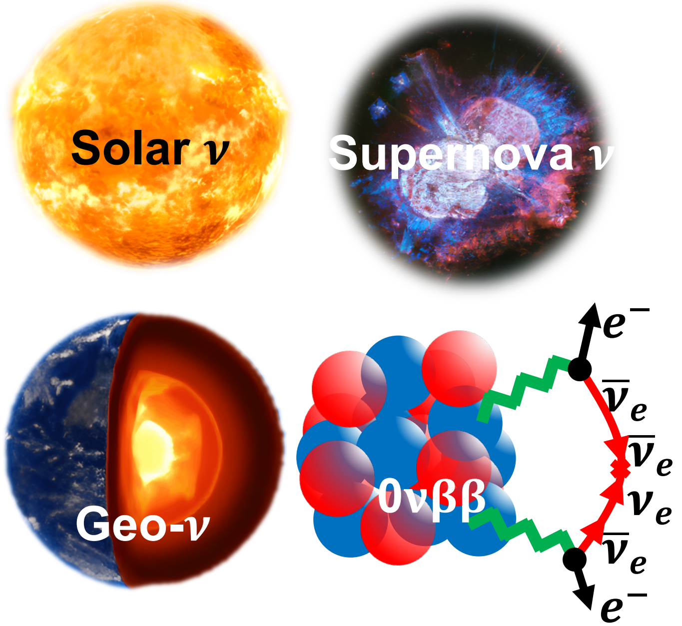
# Motivation

- The 1-ton detector is a prototype for the future 500t detector.
  - Testing MCP-PMTs and self-developed electronics system
  - Testing reconstruction algorithm
- The 1-ton detector has capability for some physics study.
  - Background measurement
  - Muon flux and muon induced neutron yield measurement




**Prototype**

| | | 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 | $(4.67 \pm 1.35) \times 10^{-8}$ | - |

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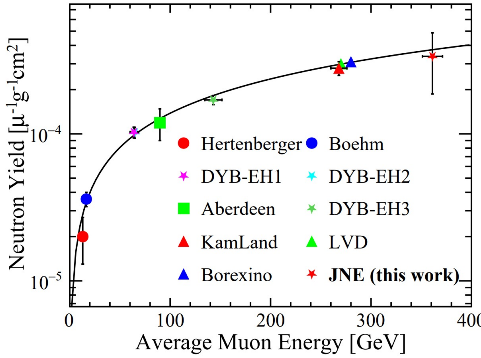


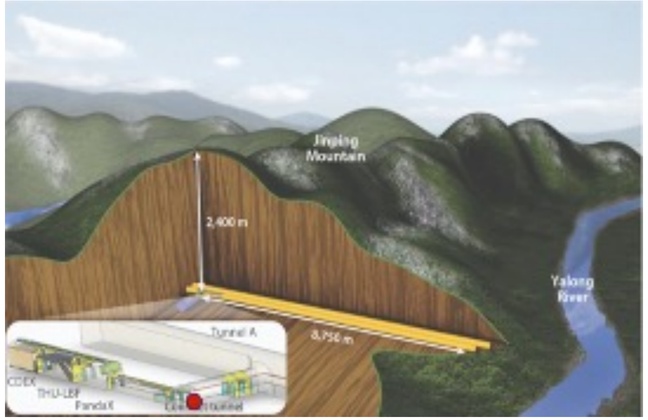

DOI:10.1103/PhysRevD.110.112017

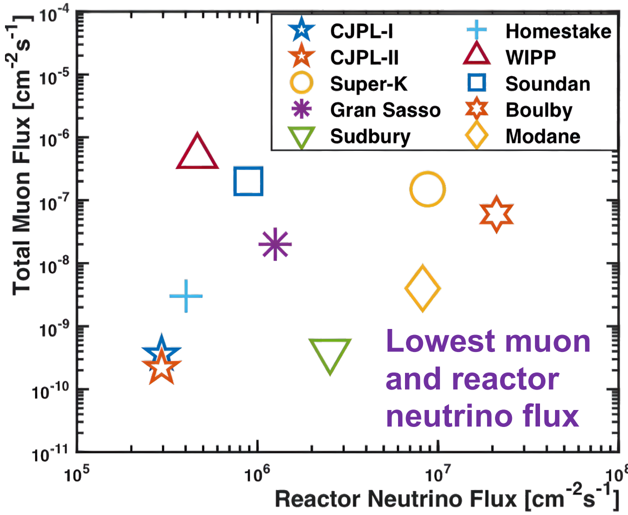
# Outline

- **Experimental Site**
- Detector Structure
  - Target
  - MCP-PMT
  - Electronics System
- Calibration and Reconstruction
  - Time and Energy Calibration
  - Event-by-event Direction Reconstruction
- Prospect

# Experimental Site

- The China Jinping Underground Laboratory (CJPL) is located in Sichuan province, China.
  - Low reactor neutrino rate and low muon rate
  - Granite, low natural radioactivity background
  - Suitable for neutrino experiment


DOI:10.1088/1674-1137/41/2/023002

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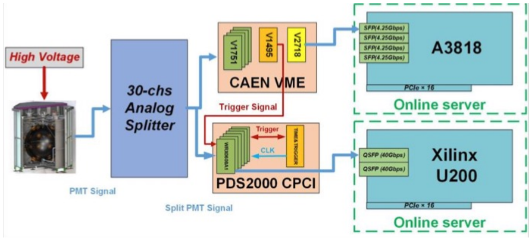
# Detector Structure

Outer

Electronics




Water and steal shielding

MCP-PMTs

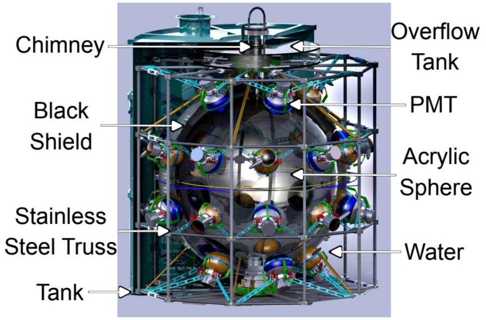
Acrylic sphere

Target: water / LS / LiCl

Inner

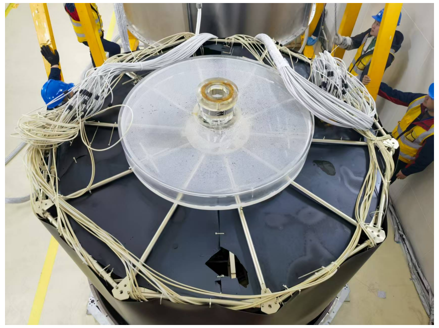
# Equipment Upgrade

- 30PMTs




2017 - 2024.6

- Filled with pure water
- Installed light shielding cylinder



2024.9

- Changed PMTs

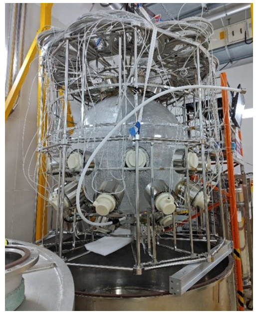
2025.5

- New liquid scintillator
- New Electronics system
- ……

Future

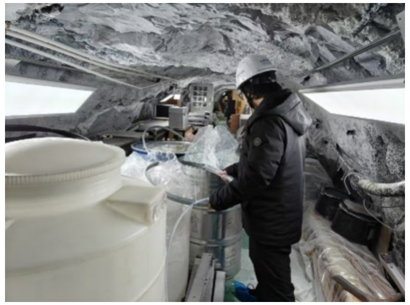
Old 1-ton detector | Dry run | Water | LS | Dry run | Water

2024.6



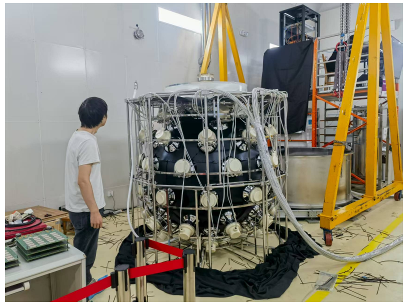
- Replaced with 60 MCP-PMTs
- Removed lead shielding

2025.1



- Filled with liquid scintillator
- Calibrated the detector

2025.6

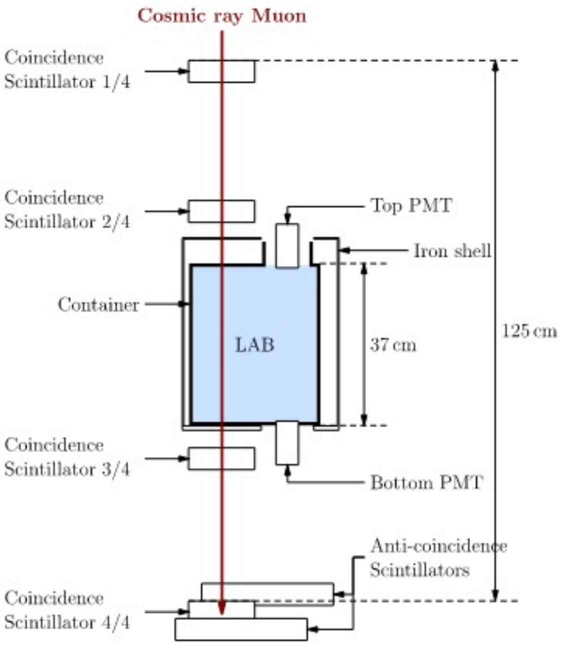


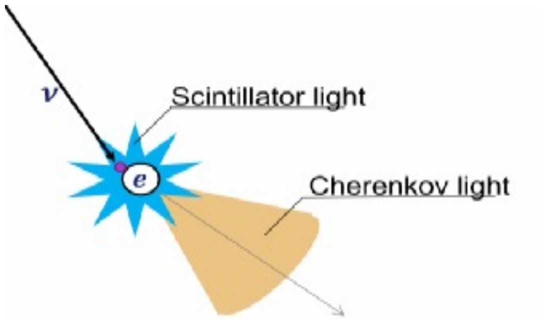
- Installed light shielding sphere

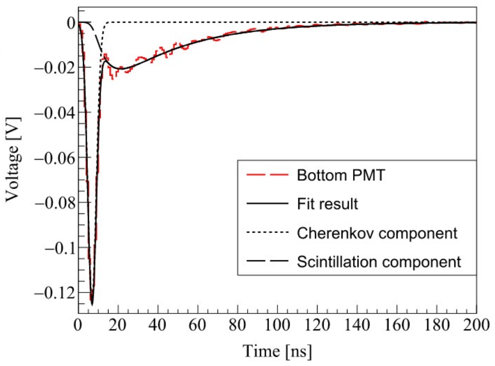
2025.8

# Target (Slow LS & LiCl aqueous solution)

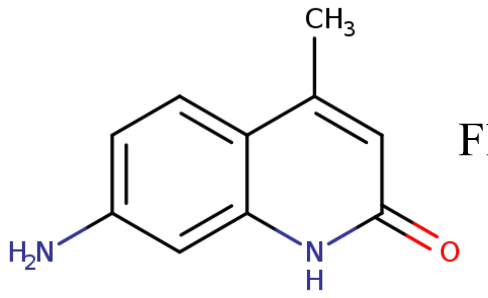
- The properties of Slow LS and LiCl aqueous solution has been studied
  - Slow LS: separating scintillation and Cerenkov light
  - LiCl aqueous solution: detecting solar neutrino spectrum & separating CS light



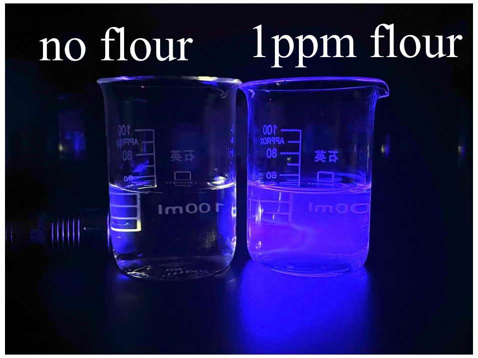




20L detector structure and bottom PMT waveform




Flour: Carbostyril-124




- Large cross section
- High natural abundance
- High transparency

LiCl aqueous solution sample



DOI:10.1016/j.nima.2016.05.132

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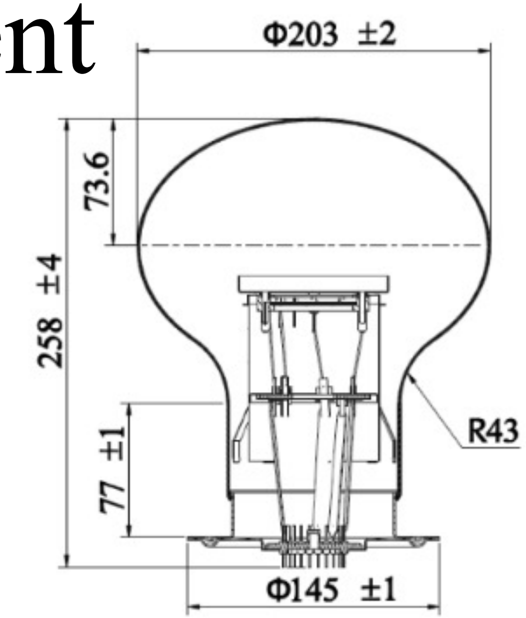
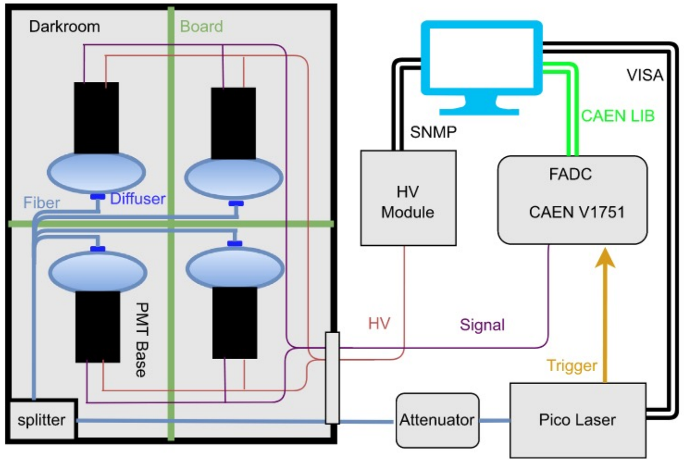
# MCP-PMT Performance Measurement

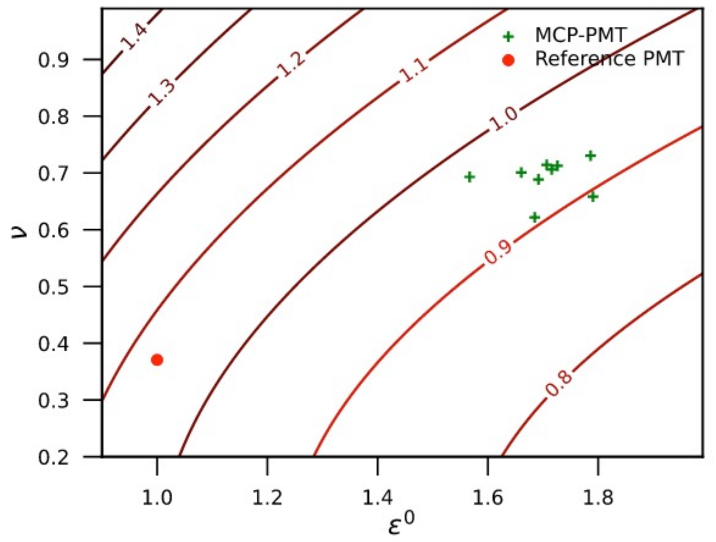



- Jointly developed by NNVT and Tsinghua
- Parameters of MCP-PMTs have been measured with a testing system.
  - High QE, low TTS, low DR and low background
  - Better photon detection efficiency boost




Summary of important parameters of the MCP-PMTs.

| Parameters | Value | Criteria | Notes | Section |
|---|---|---|---|---|
| $\overline{Q}/Q_0$ | 1.8 ± 0.1 | | Entire-sample to main-peak gain ratio | 3.2 |
| $\nu_0 = \sigma_{Q_0}/Q_0$ | 0.25 ± 0.02 | | Peak resolution | 3.2 |
| $\nu = \sqrt{s_Q^2}/\overline{Q}$ | 0.69 ± 0.03 | | Sample resolution | 3.2 |
| $N^{1e}/N^{hit}$ | 0.59 ± 0.02 | | Main-peak fraction | 3.2 |
| P/V | 5.9 ± 1.4 | >5 | Peak-to-valley ratio | 3.3 |
| $t_r$/ns | 3.71 ± 0.15 | <4 | Rise time | 3.4 |
| $t_f$/ns | 15.6 ± 1.8 | <20 | Fall time | 3.4 |
| $\sigma_{SER}$/ns | 1.63 ± 0.06 | | Shape parameters of SER | 3.4 |
| $\tau_{SER}$/ns | 7.2 ± 1.1 | | | |
| TTS/ns | 1.73 ± 0.08 | <1.8 | Transit time spread | 3.5 |
| DCR/kHz | 5.8 ± 1.6 | ~5 | Dark count rate | 3.6 |
| $P_{pre}$ | 1E−6 ± 6E−6 | <0.001 | Pre-pulse probability | 3.7 |
| $P_{after}$ | 0.009 ± 0.005 | <0.048 | After-pulse probability | 3.7 |
| $\epsilon^0$ | 1.71 ± 0.06 | >1.6 | Relative PDE | 3.8 |



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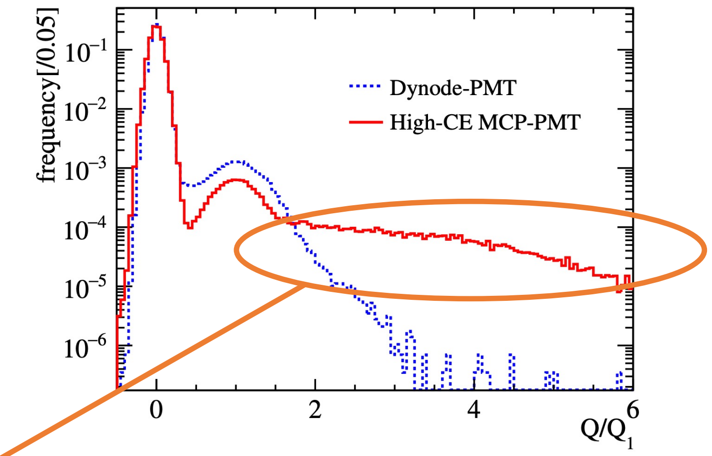
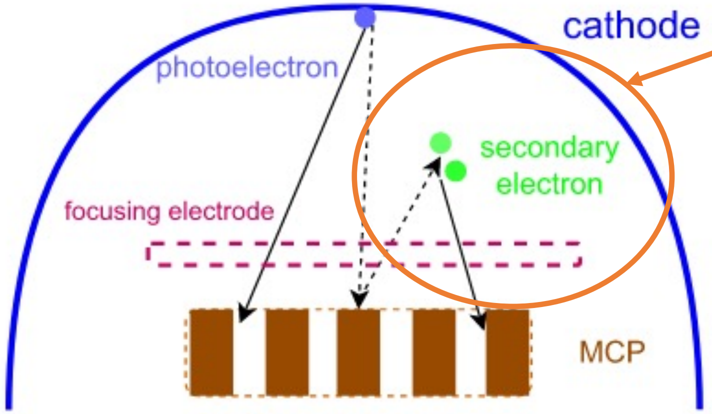
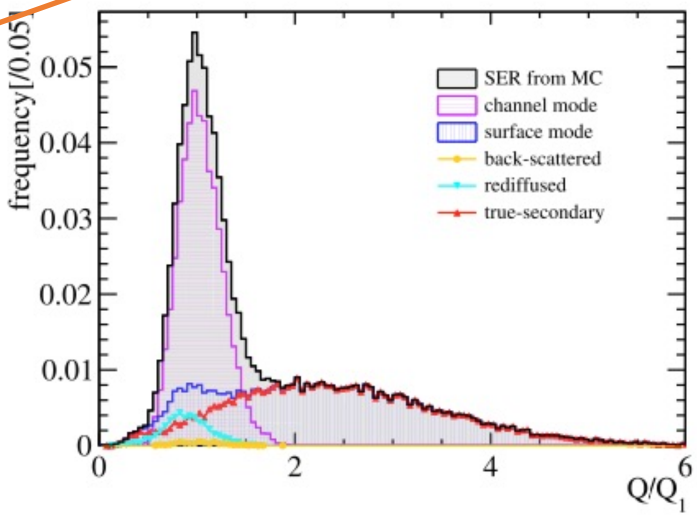
# Single Electron Charge Spectra of MCP-PMT

- The long tail structure in single electron charge spectra has been studied.
  - The long tail structure is caused by secondary electrons emission.
  - Using a Gamma-Tweedie mixture distribution to fit the single electron charge spectra.




**Long tail structure,**
**caused by secondary electrons emission**



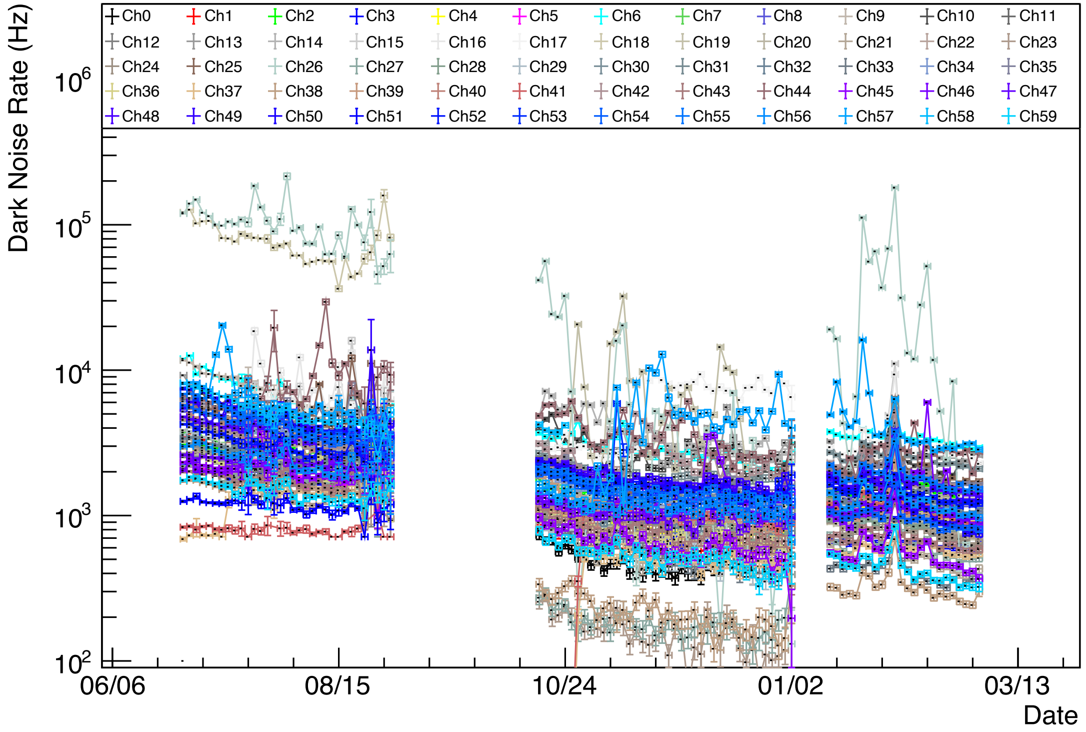

- Poisson: different modes
- Gamma: single mode
- Poisson-Gamma compound → Tweedie



DOI:10.1016/j.nima.2024.169626

# MCP-PMTs’ Dark Noise Evolution

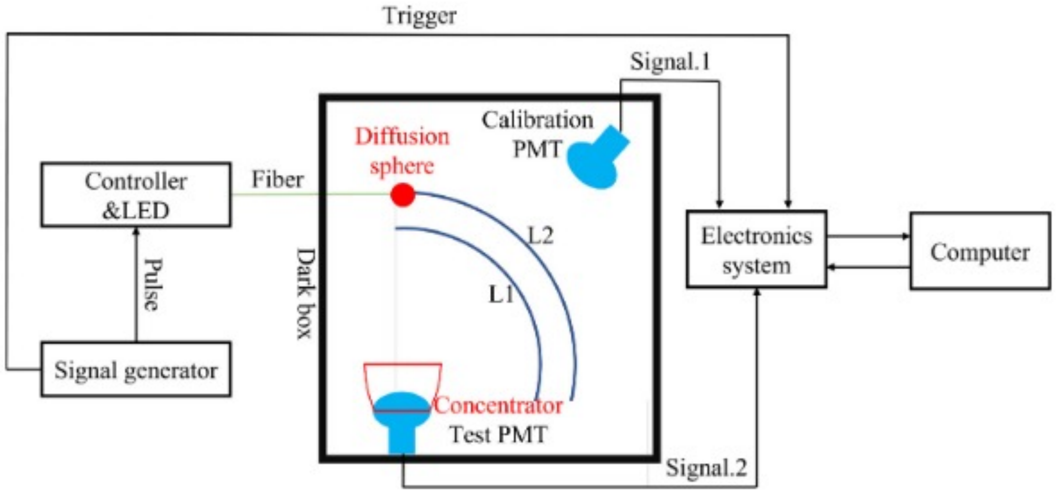
- We measured the dark noise rate of the MCP-PMTs
  - The dark noise rate is 1.1kHz (2025.3)
  - The rate decreases over time, dropping to 1/3 within 8 month.
  - We plan to study the reason of the decrease.

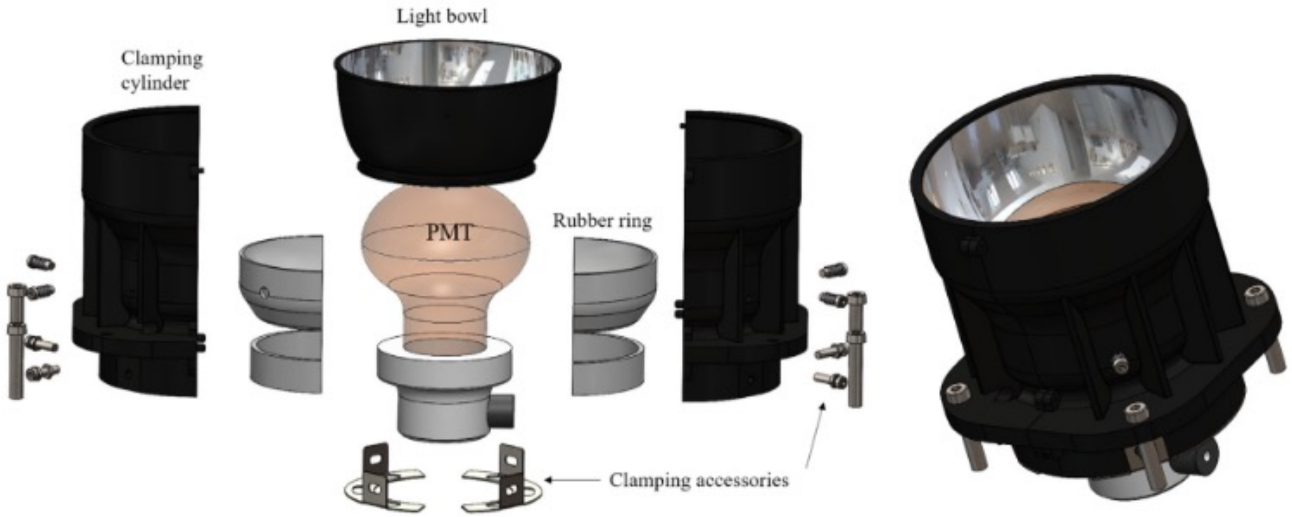


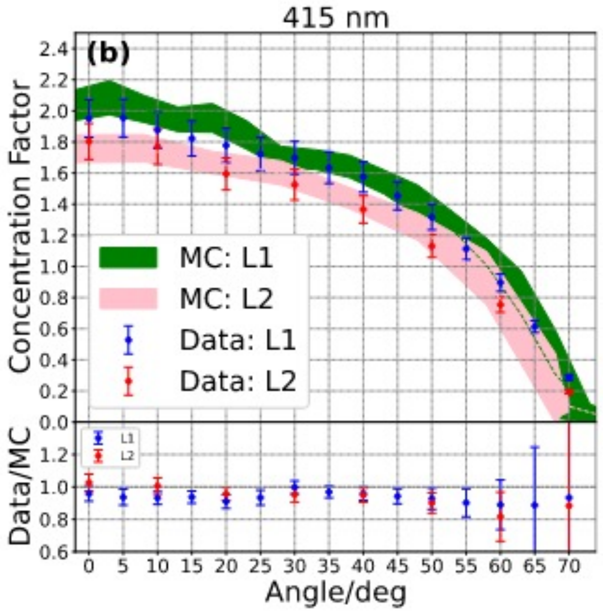

dry run phase water phase LS phase

# MCP-PMT + Light Concentrator

- Further enhancement of photon detection efficiency for the future 500-ton detector
  - 40% improvement when $\theta_{incident} < 30°$
  - TTS only increased by $< 0.3$ns



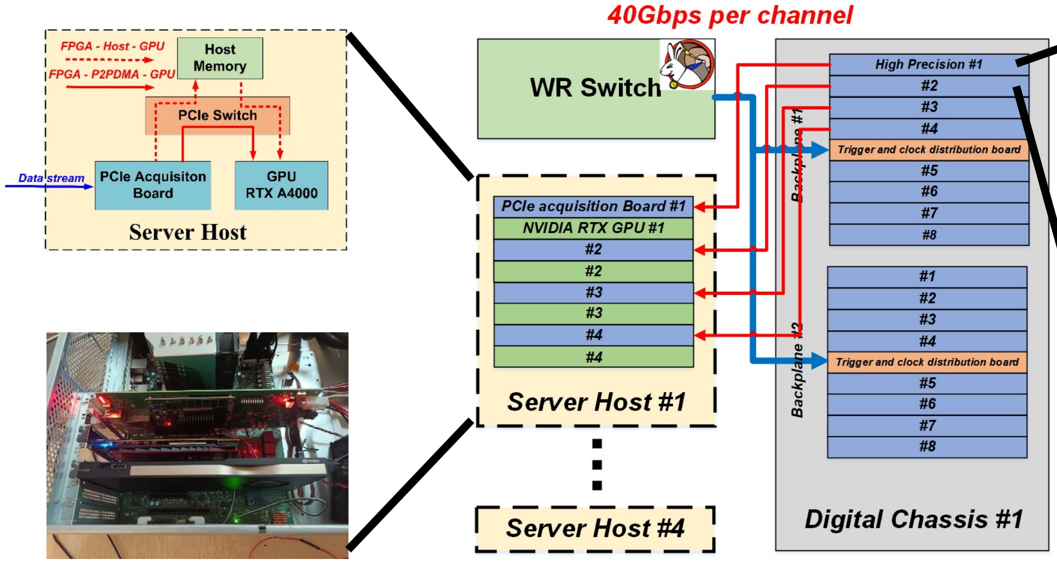

DOI:10.1016/j.nima.2025.170755



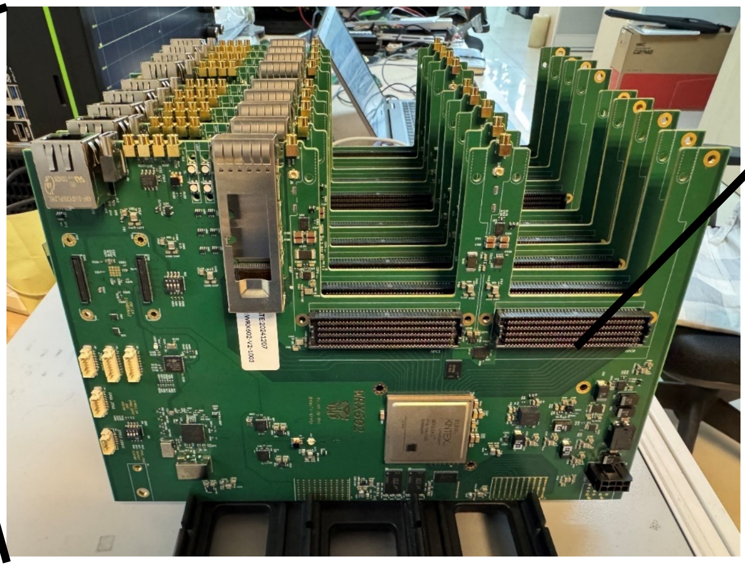
**For more details, see Shuai's poster #219**

# Electronics System

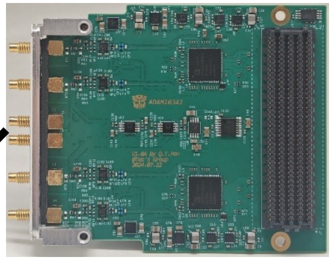
- To meet the experimental requirements, a new self-developed electronic system has been designed.
  - 350 mW/ch, 12-bit, 1 GSps
  - Readout board, Bandwidth 300 MHz, 40Gbps
  - Higher accuracy FADCs are being developed and tested




JNE triggerless readout system



WRX602



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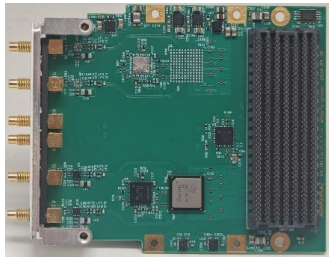


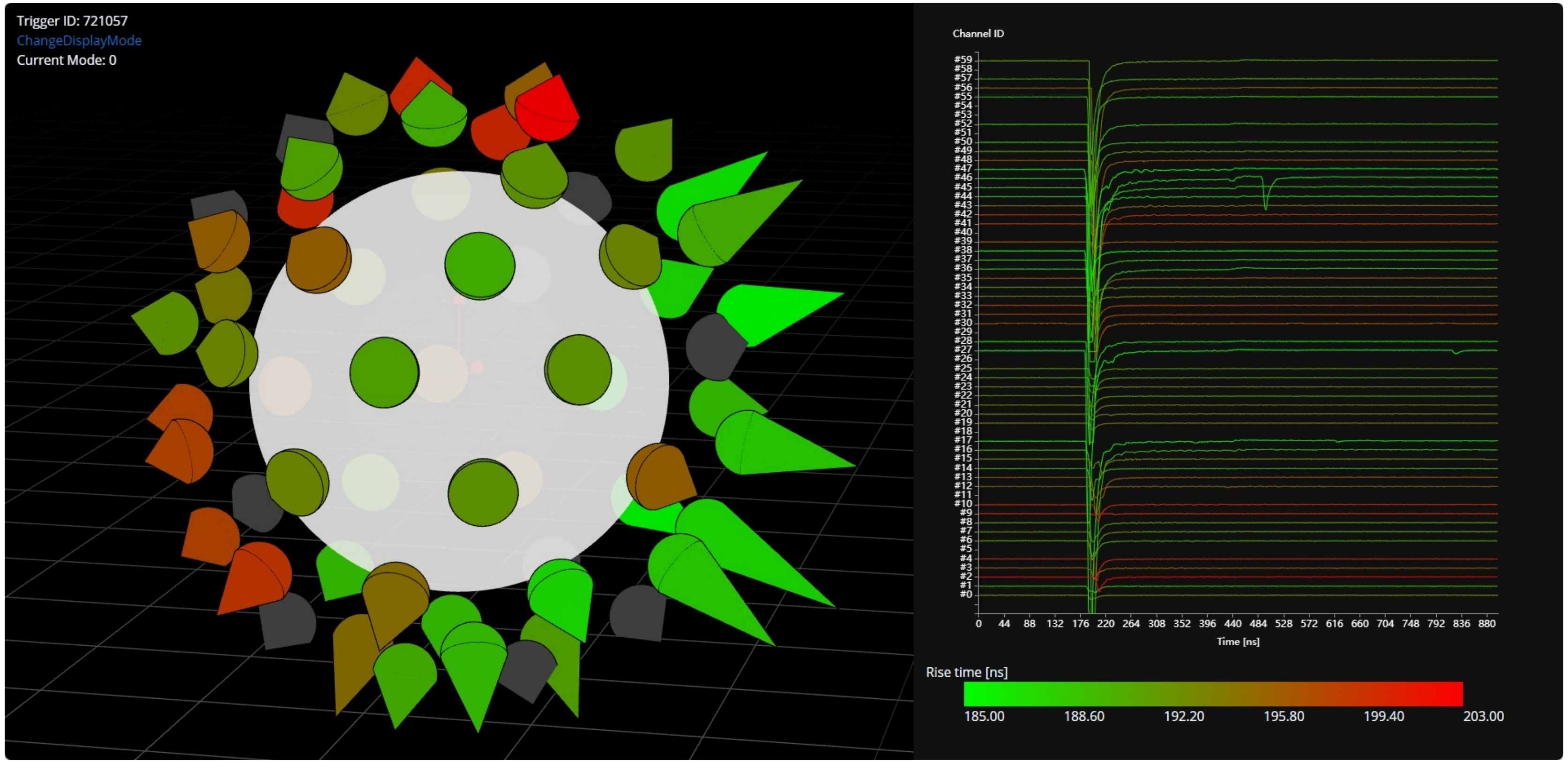
ADAM105A2



DOI:10.1016/j.nima.2025.170211

# Event Display

- An event display program based on JavaScript.
  - Real-time event visualization
  - Real-time detector status monitoring



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# Time and Energy Calibration

- Time Calibration:
  - Defined residual, and minimize the residual through iteration.
- Energy Calibration:
  - Hang radioactivity source in the center of the detector.

$A = \{(m,i) | \text{Event } m. \text{ trigger. PMT } i\}$

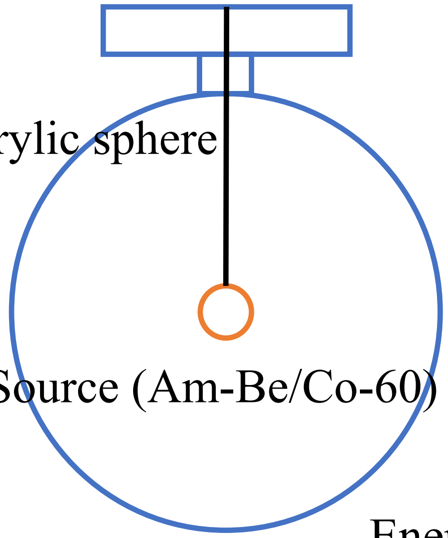
$$Res = \sum_{(m,i)\in A} (R_{mi} - t_m - T_i - TOF_i)^2$$

time deviation

rise time

reconstruction time

Time calibration




| Vertex | Source | $E_{eff}$ MeV | E MeV | $E_{rec}$ MeV | Nonlinearity |
|---|---|---|---|---|---|
| $^{60}Co$ | $^{60}Co$ Calib | 1.258 | 2.506 | $2.930 \pm 0.010$ | $1.169 \pm 0.004$ |
| $^{40}K$ | PMT | 1.461 | 1.461 | $1.728 \pm 0.020$ | $1.183 \pm 0.013$ |
| n-H | AmBe Calib | 2.223 | 2.223 | $2.737 \pm 0.001$ | $1.2312 \pm 0.0004$ |
| $^{208}Tl$ | PMT | 2.614 | 2.614 | $3.281 \pm 0.005$ | $1.238 \pm 0.004$ |
| n-C | AmBe Calib | 4.343 | 4.945 | $6.081 \pm 0.033$ | $1.230 \pm 0.007$ |

Need to be studied

Energy Calibration



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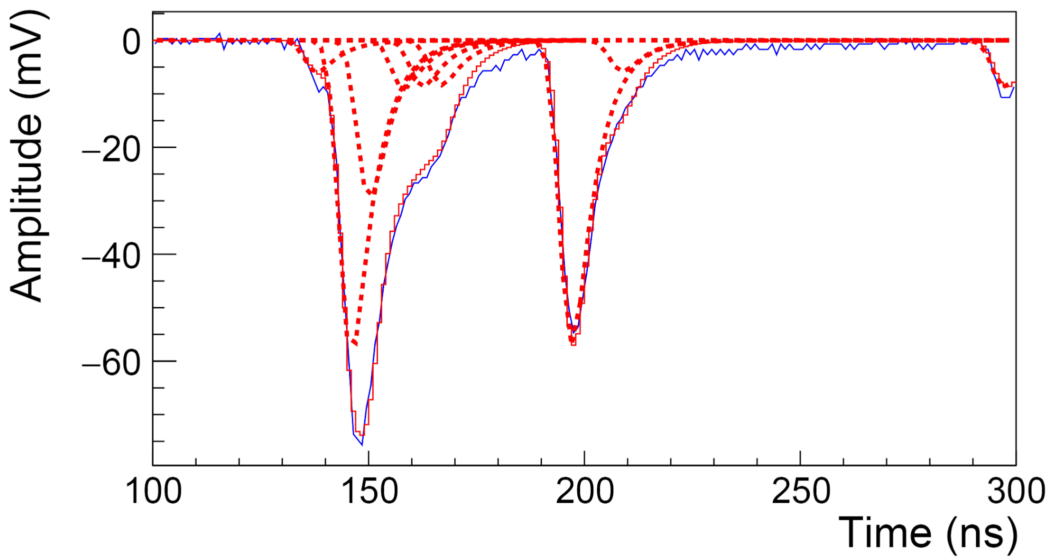
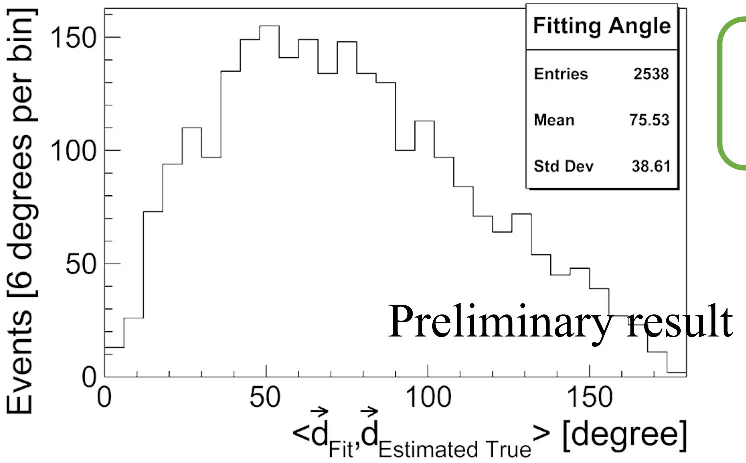
# Event-by-event Direction Reconstruction

- From waveform analysis to event reconstruction.
  - Obtain PE number and each PE time from waveform
  - Scintillation and Cerenkov light are reconstructed separately, for direction and energy reconstruction.




$$\mathcal{L}\left(n_i^{\mathrm{Obs}}, t_{ij} \middle| E, x, y, z, t_{\mathrm{event}}, \vec{d}_{\mathrm{Fit}}\right) = \prod_{i}^{N_{\mathrm{PMT}}} P_i^{\mathrm{C}} \prod_{j}^{n_i^{\mathrm{Obs}}} P_{ij}^{\mathrm{T}}$$

Known quantities Fit parameters Probability of the Charge and Time




**QiscinT** Algorithm

DOI: 10.1088/1748-0221/18/02/P02004



**For more details, see Yutao's poster #471**

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# Prospect

- Studying performance of new technology
  - Stability of MCP-PMTs
  - Sampling rate of self-developed electronics system

  ……
- Testing new liquid scintillators
  - Slow LS
  - LiCl aqueous solution

  ……
- Studying experiment hall's background
  - Muon flux measurement using different targets
  - Environment background

  ……

# Thanks for Attention!