Deep underground atmospheric neutrino and cosmic ray detector at CJPL

周宁 上海交通大学

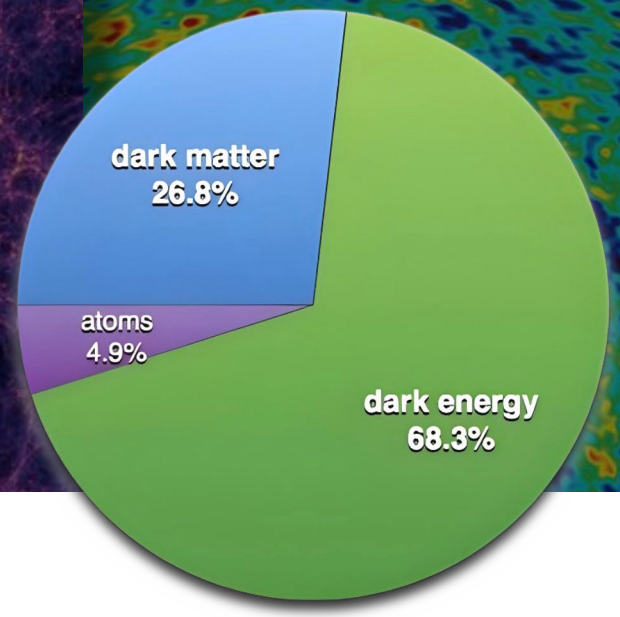
on behalf of PandaX Collaboration

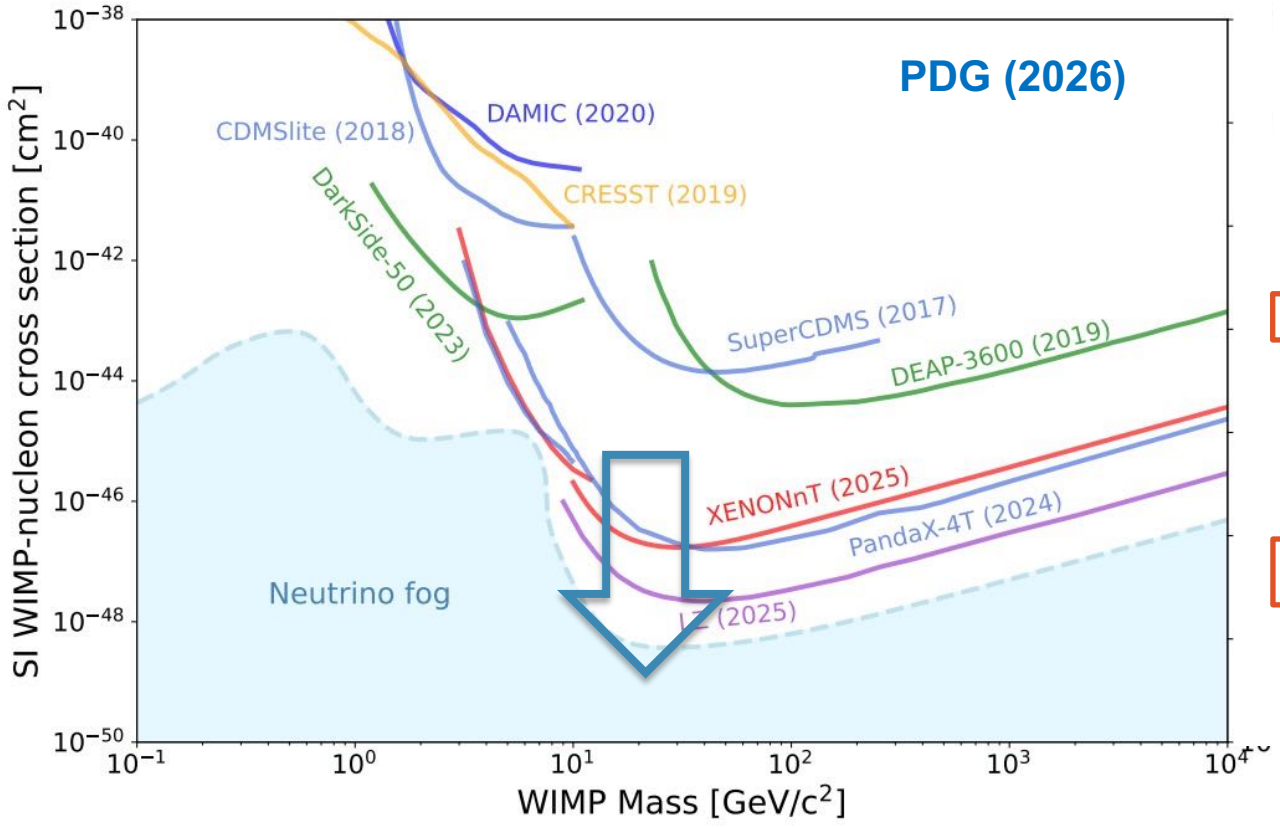
高能物理大会, 广州, 2026/07/16

Dark Matter

Physical nature?

Interaction with normal matter?

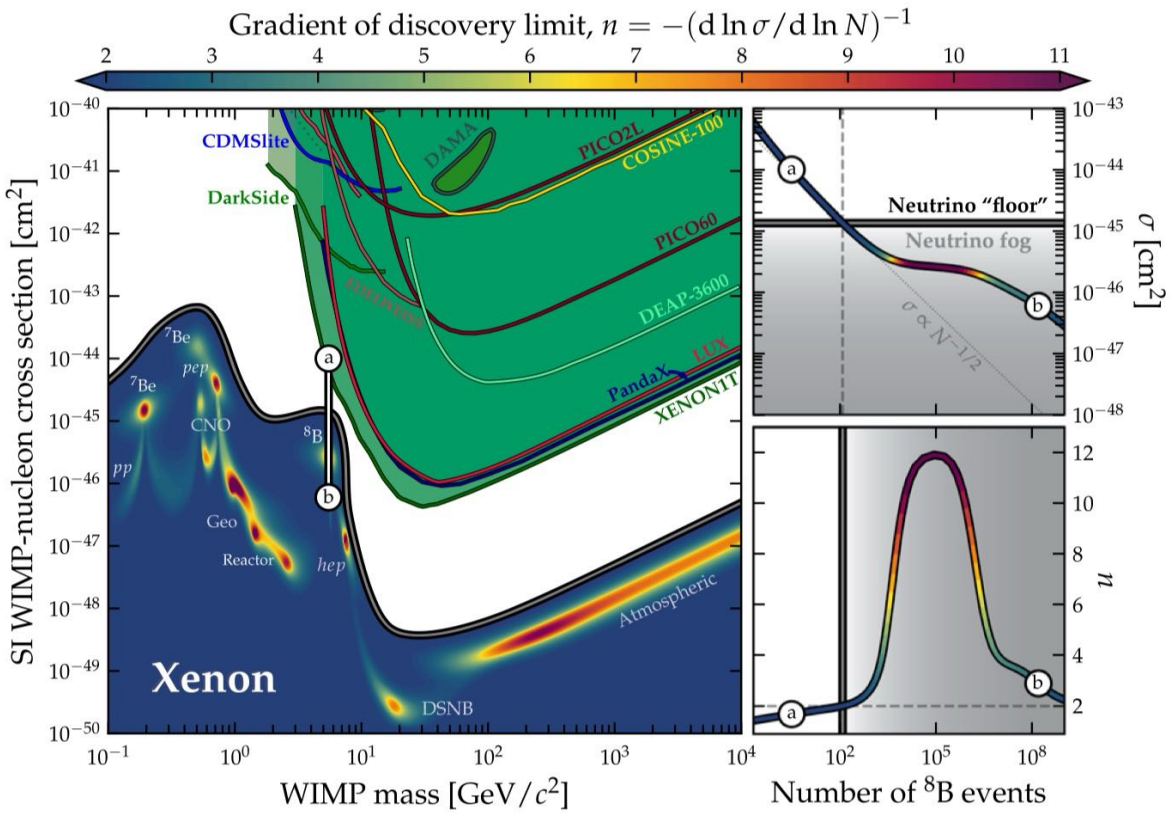




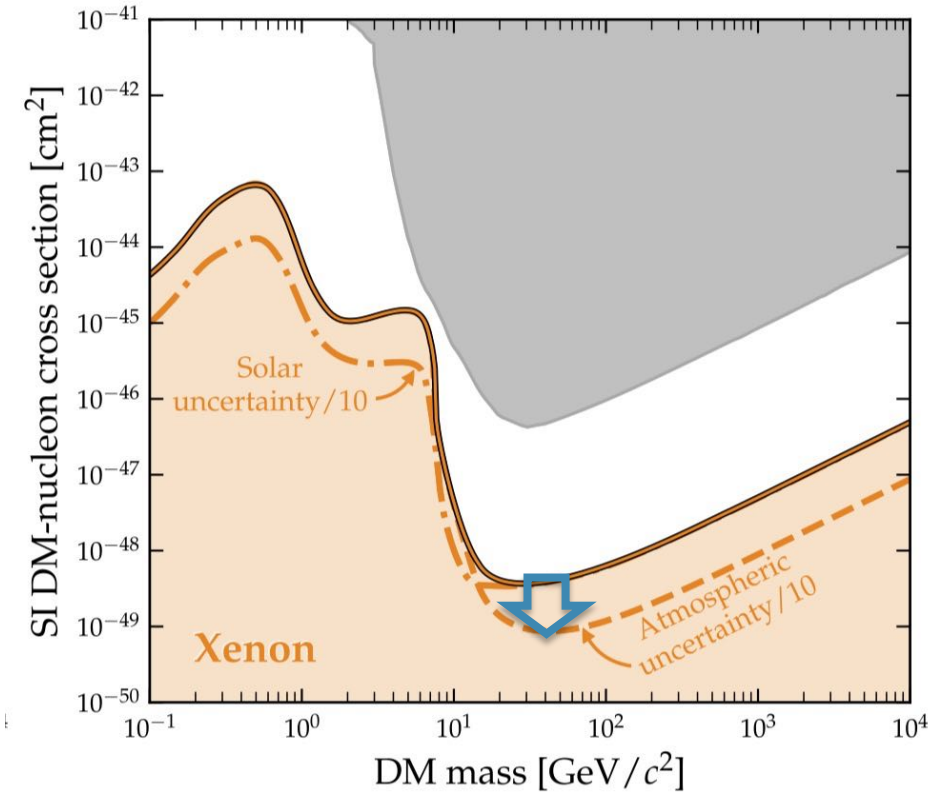
Experiment	Target	Fiducial mass [kg]	Cross section [cm^2]	DM mass [GeV]	Ref.
Spin independent high mass (>5 GeV)					
LUX-ZEPLIN	Xe	5500	2.2×10^{-48}	40	[117]
PandaX-4T	Xe	2480	1.6×10^{-47}	40	[118]
XENONnT	Xe	4000	1.7×10^{-47}	30	[119]
SuperCDMS	Ge	12	1.0×10^{-44}	46	[120]
DarkSide-50	Ar	20	1.9×10^{-43}	10	[121]
DEAP-3600	Ar	2000	3.9×10^{-45}	100	[122]
Spin independent low mass (<5 GeV)					
DarkSide-50 (ionisation only)	Ar	20	1.4×10^{-42}	2	[121]
PandaX-4T (ionisation only)	Xe	3100	1.3×10^{-43}	3.5	[123]
PandaX-4T	Xe	3100	1.6×10^{-42}	3	[124]
XENONnT	Xe	4000	3.2×10^{-42}	3	[125]
SuperCDMS (CDMSlite)	Ge	0.6	2×10^{-40}	2	[126]
CRESST	$CaWO_4$ - O	0.024	1×10^{-39}	2	[127]
CRESST	Si	0.0035	4.5×10^{-32}	0.15	[128]
CRESST	Al_2O_3	0.0006	1.0×10^{-32}	0.1	[129]
DAMIC	Si	0.3	1×10^{-40}	4	[130]
NEWS-G	Ne	0.3	1×10^{-38}	2	[131]

Neutrino fog

- **CEvNS from neutrinos can mimic dark matter signals**
  - Solar and atmospheric neutrinos
- **The key: precise measurement of neutrino flux**

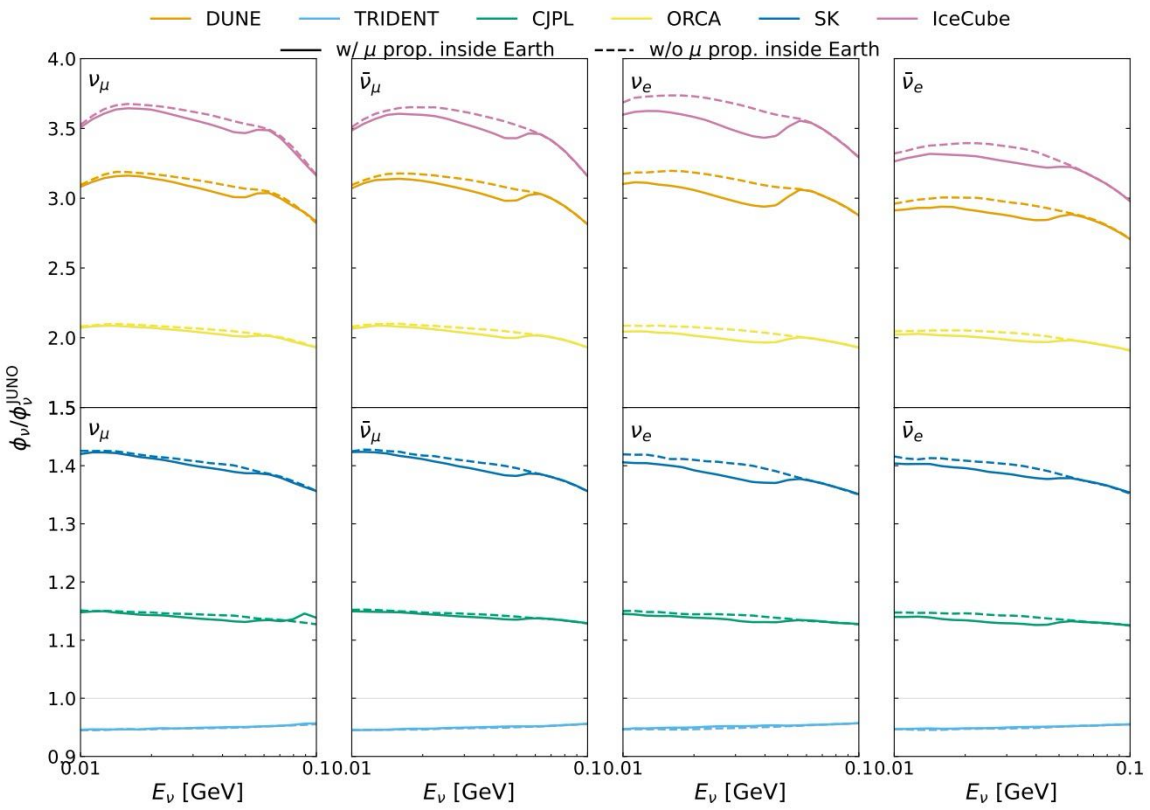


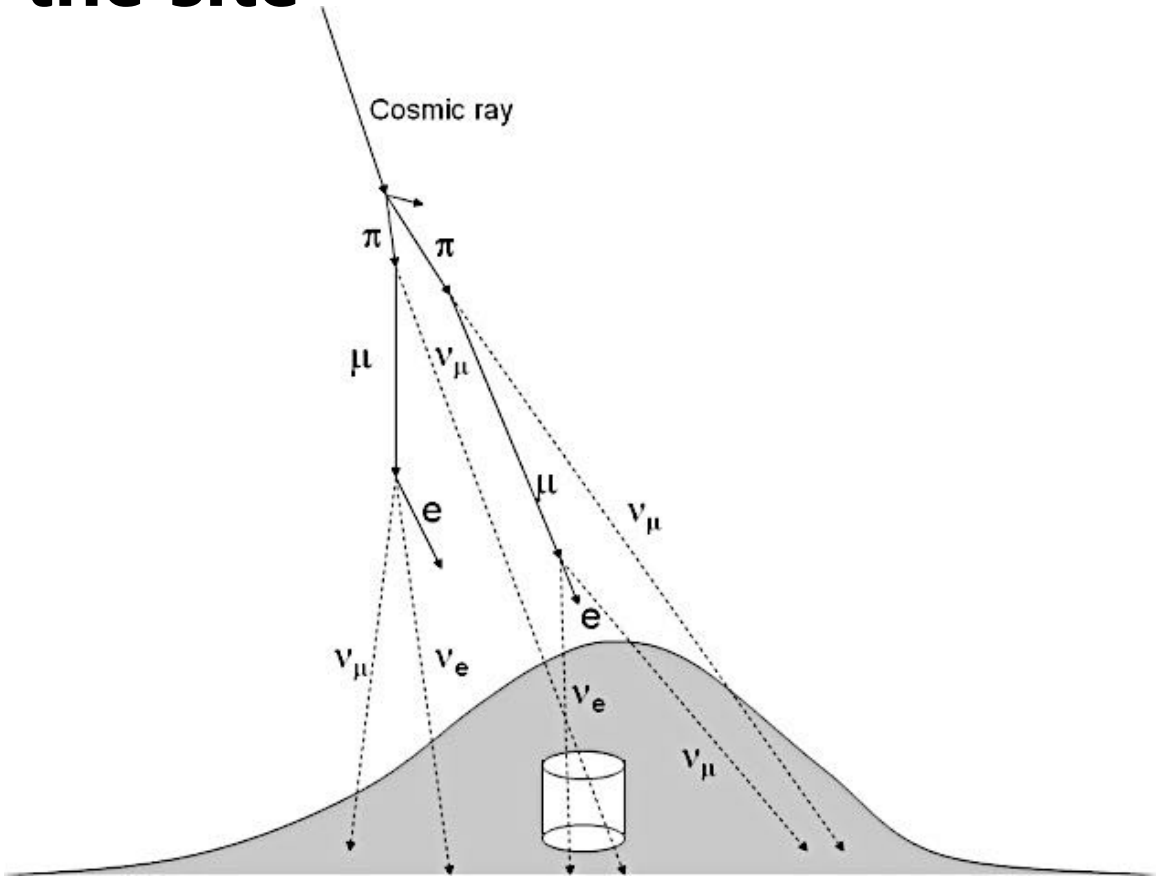
O'Hare, **PRL** 127, 251802 (2021)



Atmospheric neutrinos

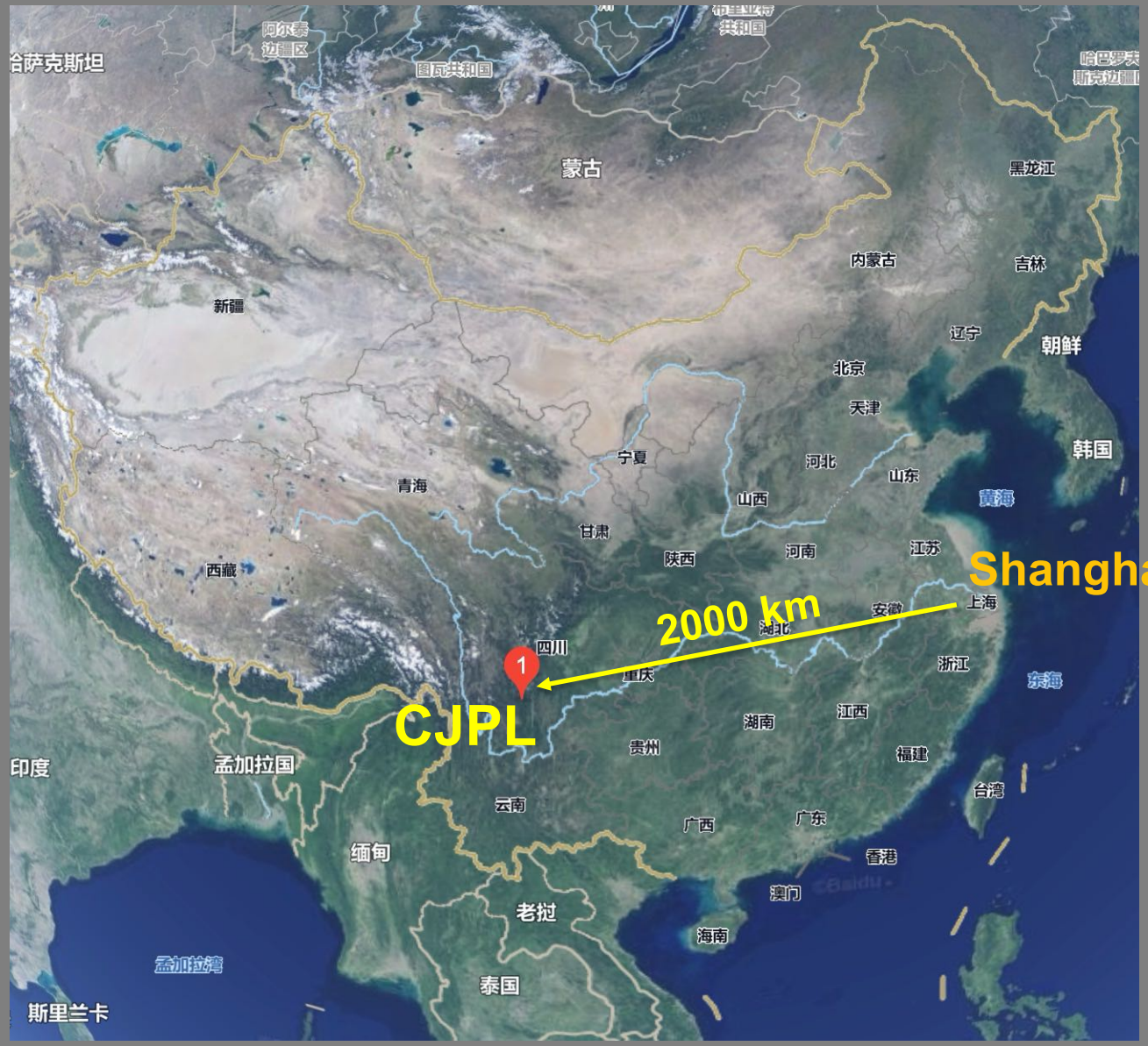
- **Non-uniform flux**
  - Vary significantly across geographic regions
- **The key: in-situ measurement on the site**

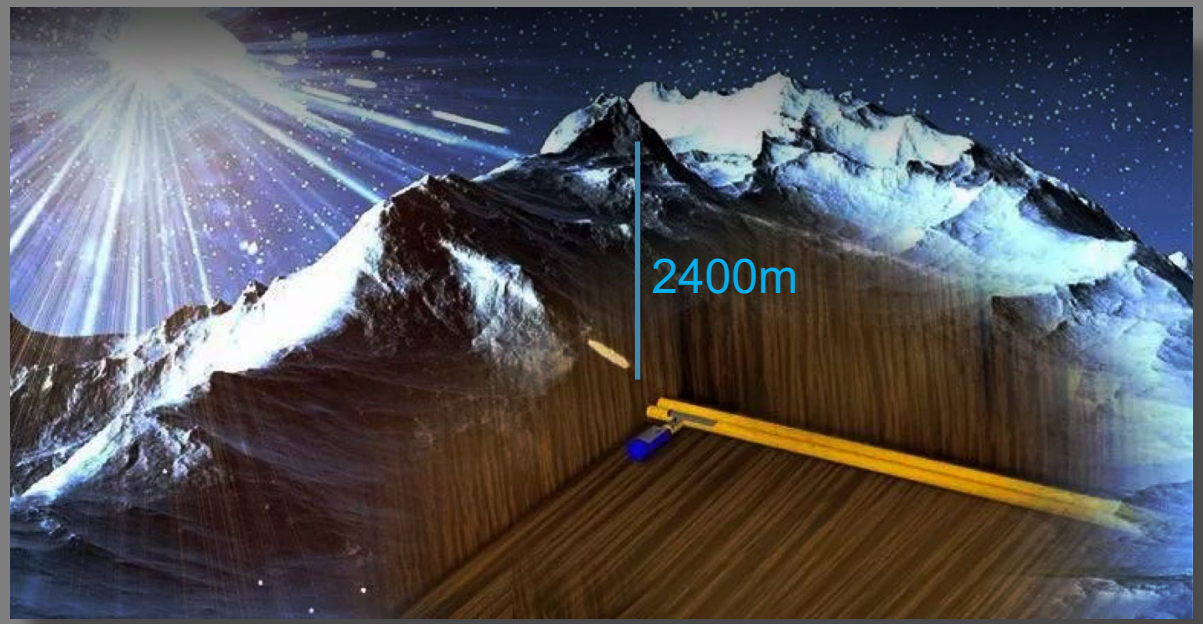




J. Cheng, Y.-F. Li, L.-J. Wen, **arXiv:**2607.08310

China Jinping Underground Laboratory





PandaX development

- Increasing the detector sensitive target volume
- Lowering radioactive background

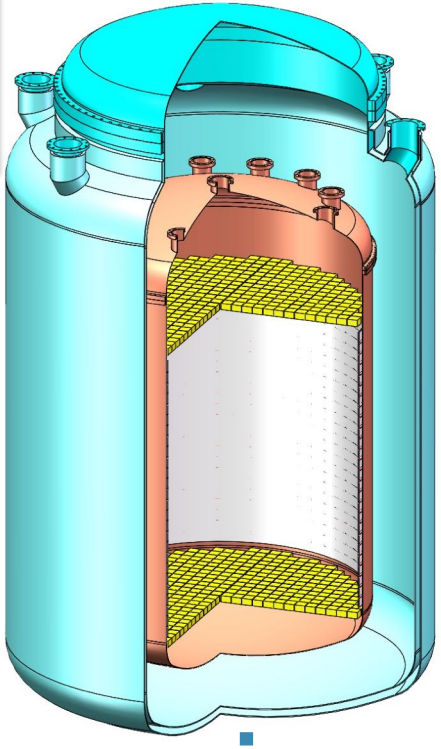
PandaX Start

PandaX-I
120kg

PandaX-II
580kg

PandaX-4T
(3.7 tonne)

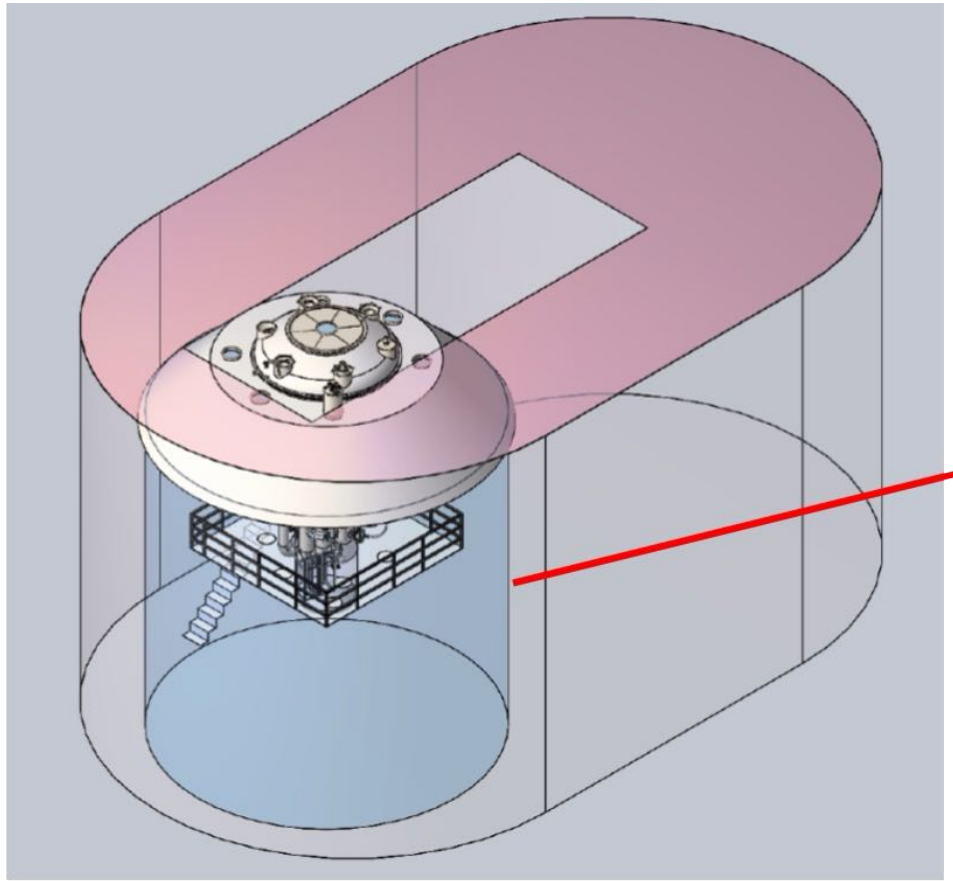
PandaX-xT



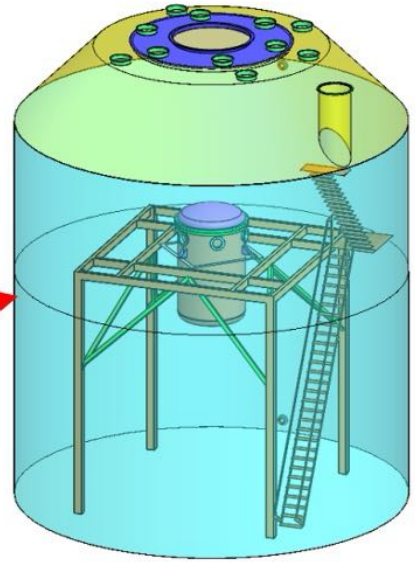
2009 | 2010-2014 | 2015-2019 | 2020-2026 | 2027-

900m³ water shielding

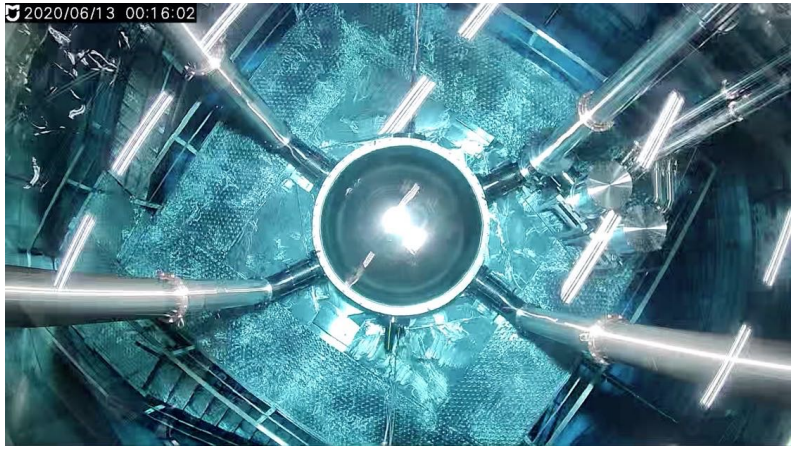
- **Current 900m³ high purity water tank**
  - PandaX-4T detector in the center



大型常温纯净水屏蔽总装置示意图



内屏蔽体装置示意图

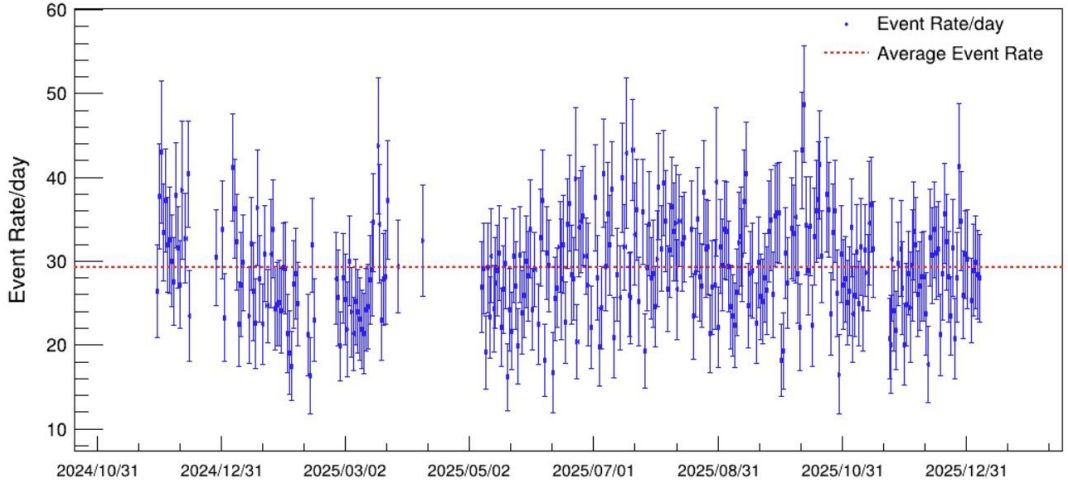


Water Cherenkov veto for PandaX-4T

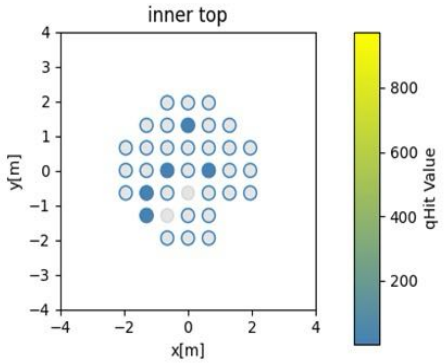
- **Two layers of 8-inch MCP PMTs from NNVT in water shielding**
  - Inner layer (2m radius) and Outer layer (5m radius)
- **Data taking: from 2024/07 to 2026/04**

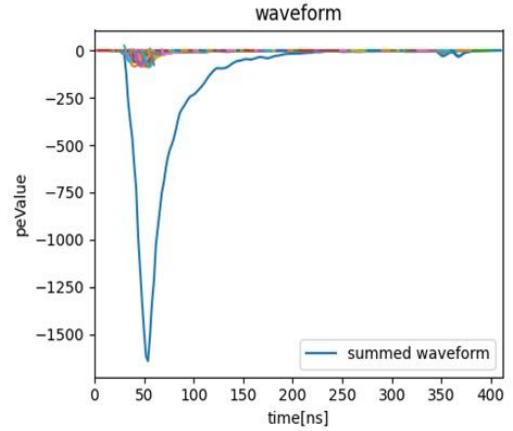
Tagging muons and neutrons

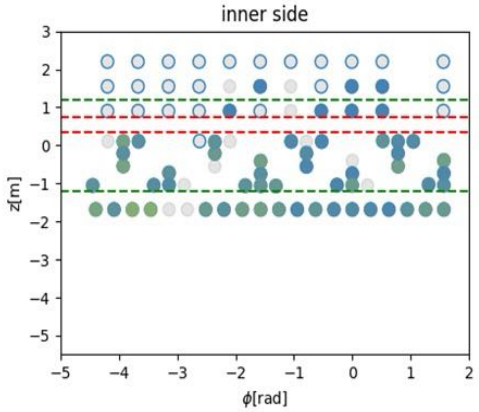
- **~30 muons detected per day**
  - 83.2 ± 2.7 (stat) /m²/year
  - the largest muon detector at CJPL

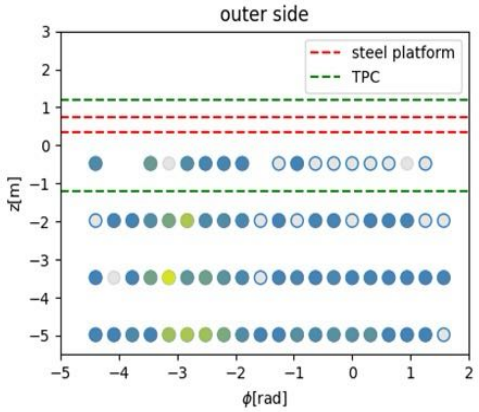


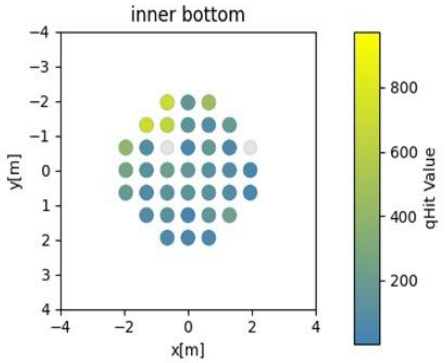
- **Neutron veto calibration with AmBe source**
  - 500 μs time window: 53.9%

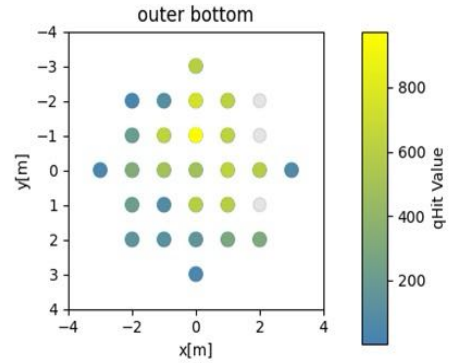






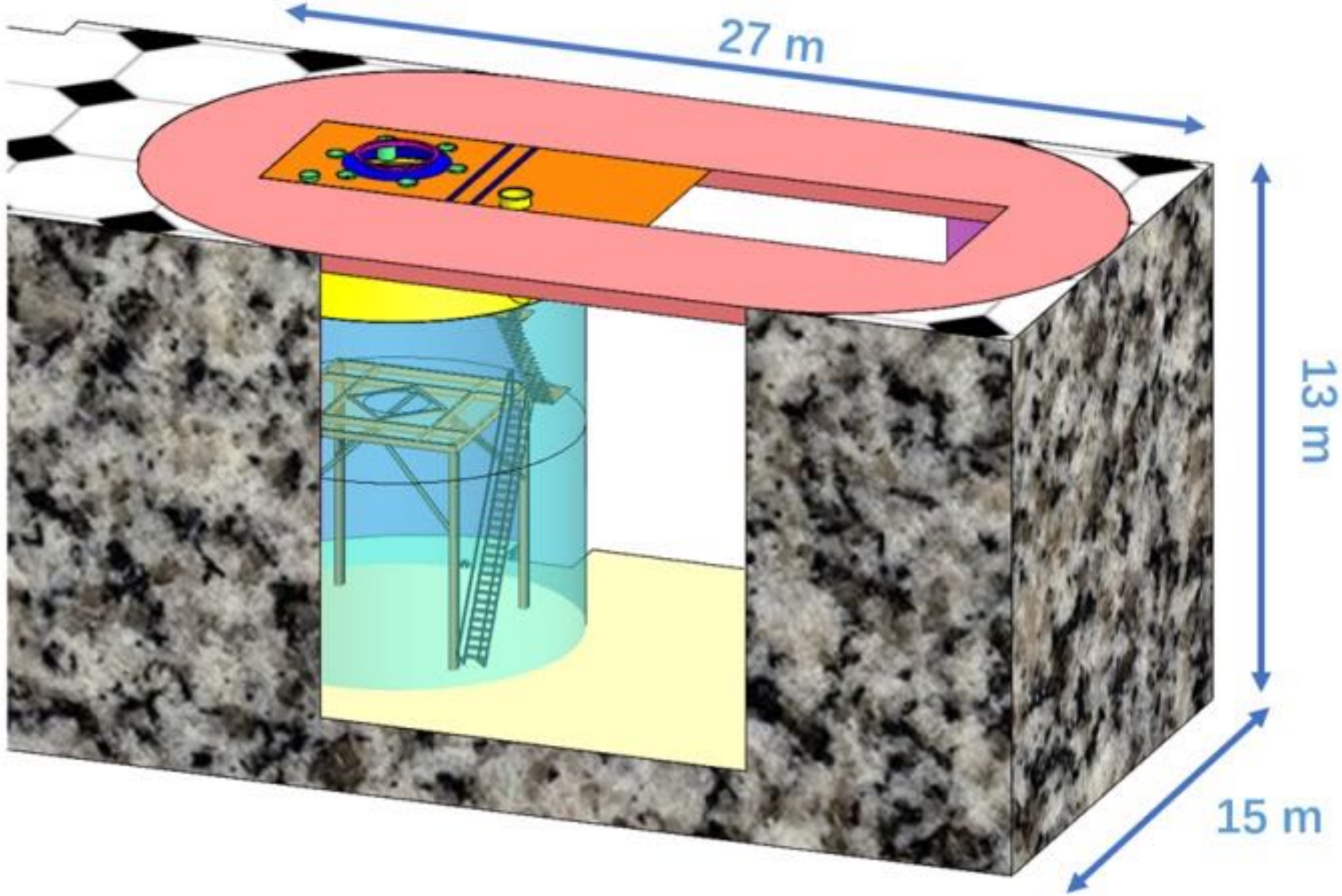






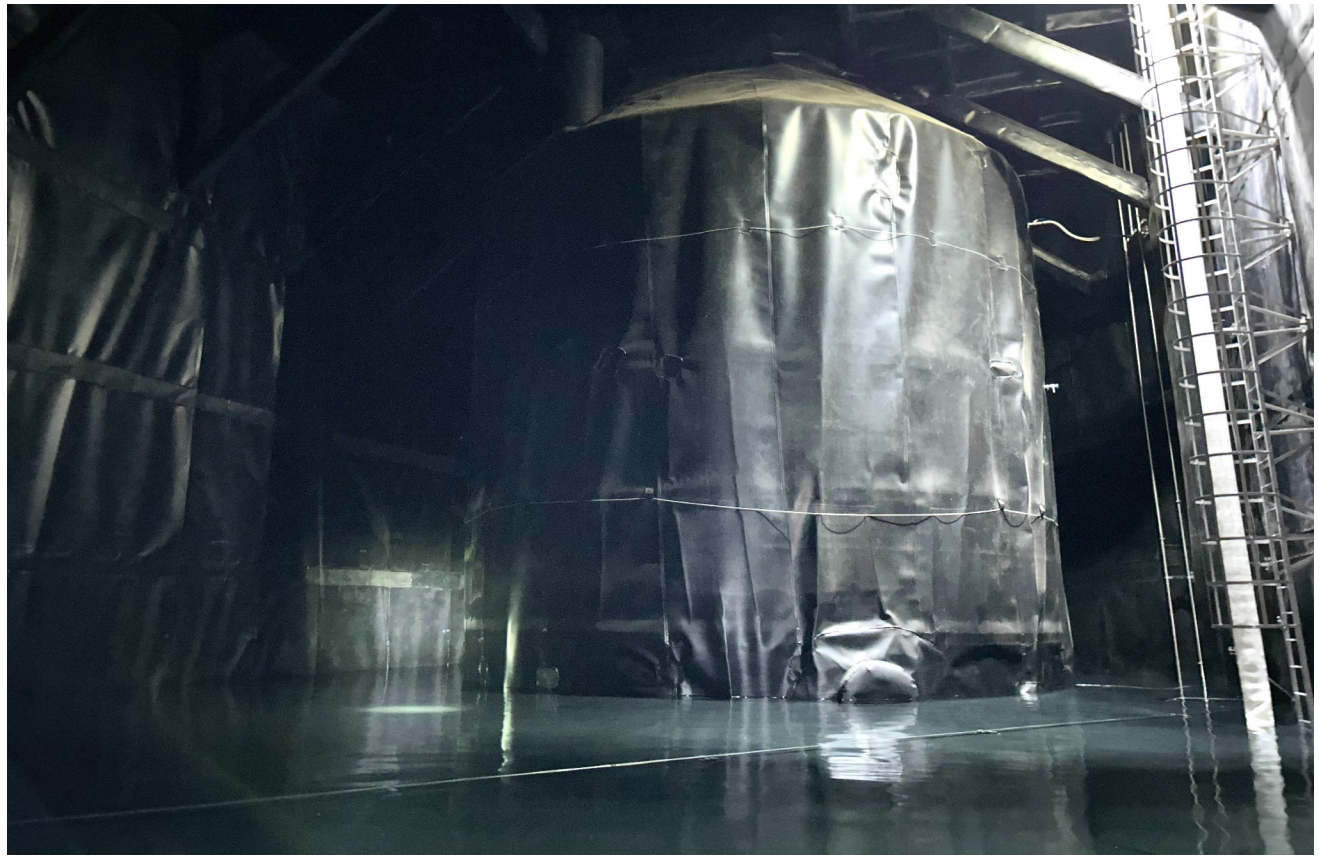
极深地下极低辐射本底屏蔽平台

- 国家重大科技基础设施项目“极深地下极低辐射本底前沿物理实验设施”的建设内容之一
  - 4500m^3 water shielding



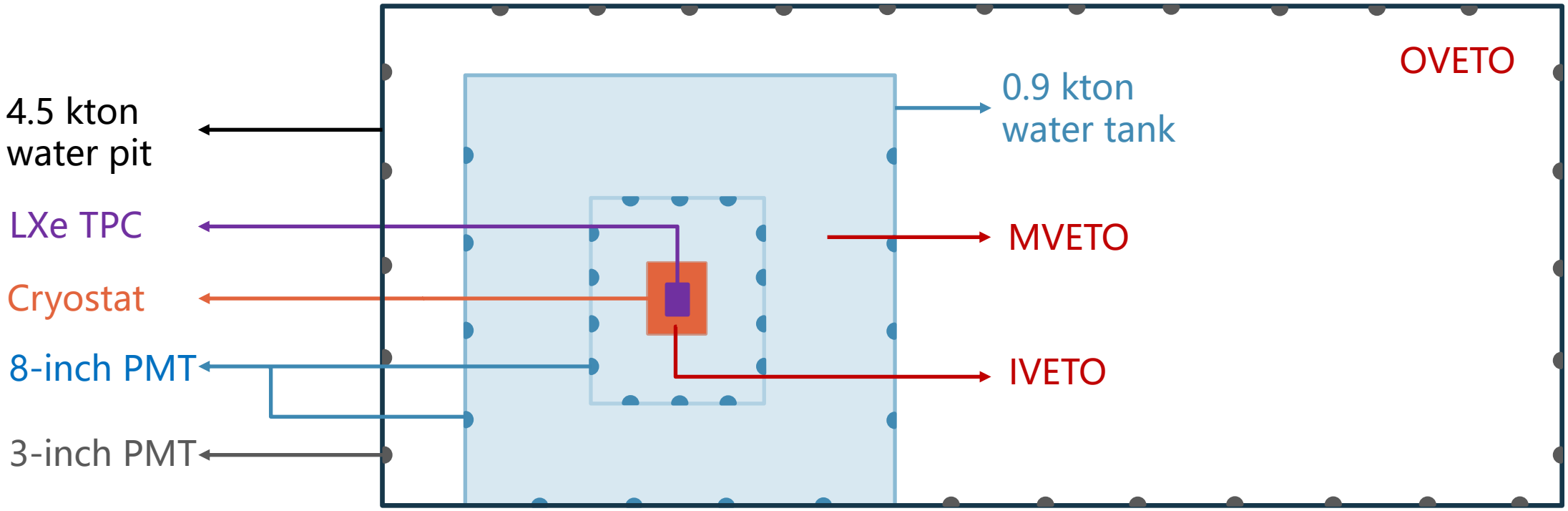
4500m³ water shielding

- **采用双层水屏蔽方案**
  - 外屏蔽体采用PE膜进行防水覆盖，内屏蔽体采用不锈钢罐体
- **2025年9月完成验收**



Atmospheric neutrino and muon detector

- **4500 m^3 water pit, mount 3-inch PMT arrays on the side wall**
  - Measure atmospheric neutrino flux in-situ at CJPL
  - Tag cosmic-ray muons

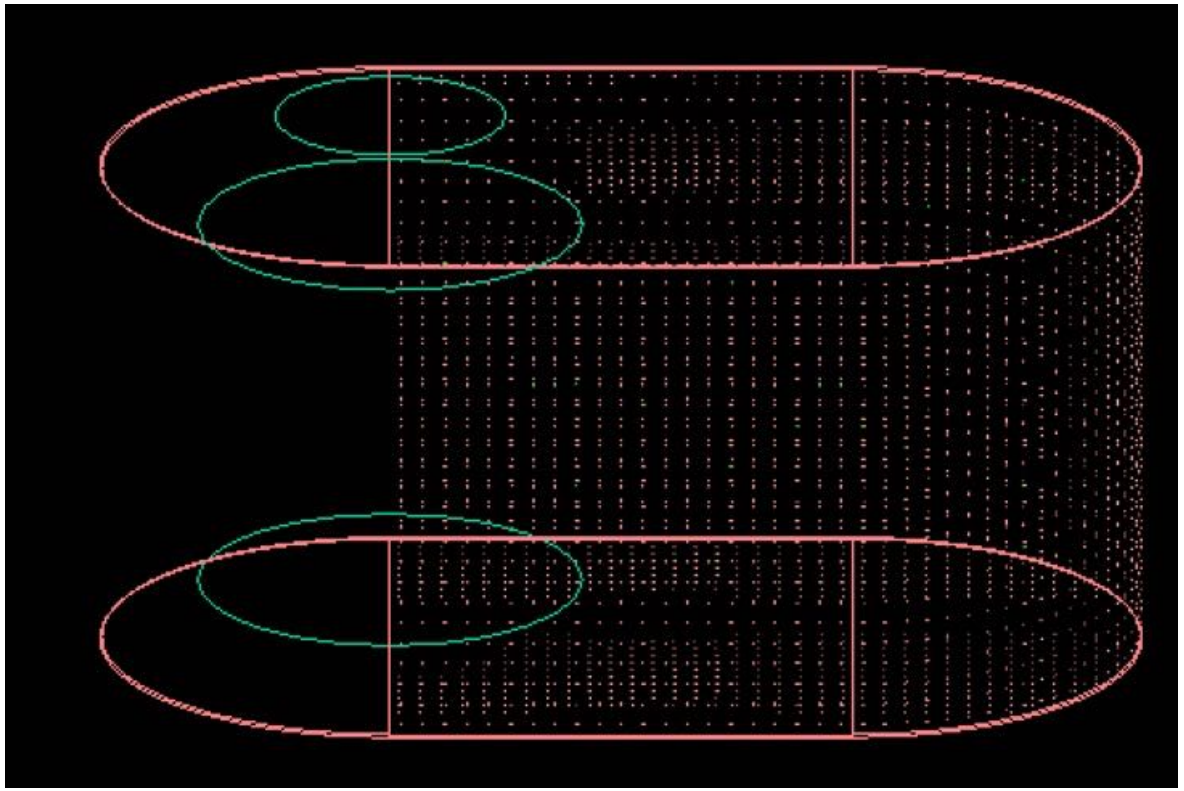


3-inch PMTs

- **4000 3-inch PMTs donated by Prof. Jenny Thomas (UCL)**
  - HZC(XP82B2FNB), formerly-used in CHIPS detector (5kton water Cherenkov detector)
  - 2300 of them to be used in this project

3-inch PMTs

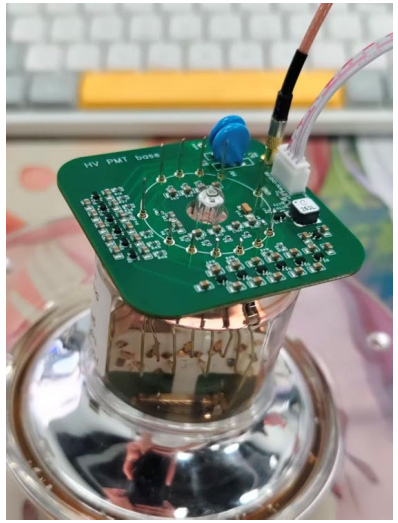
- **Plan to have additional ~2000 PMTs from NVT**
  - NVT(N2034)
- **Goal: 50cm PMT spacing**

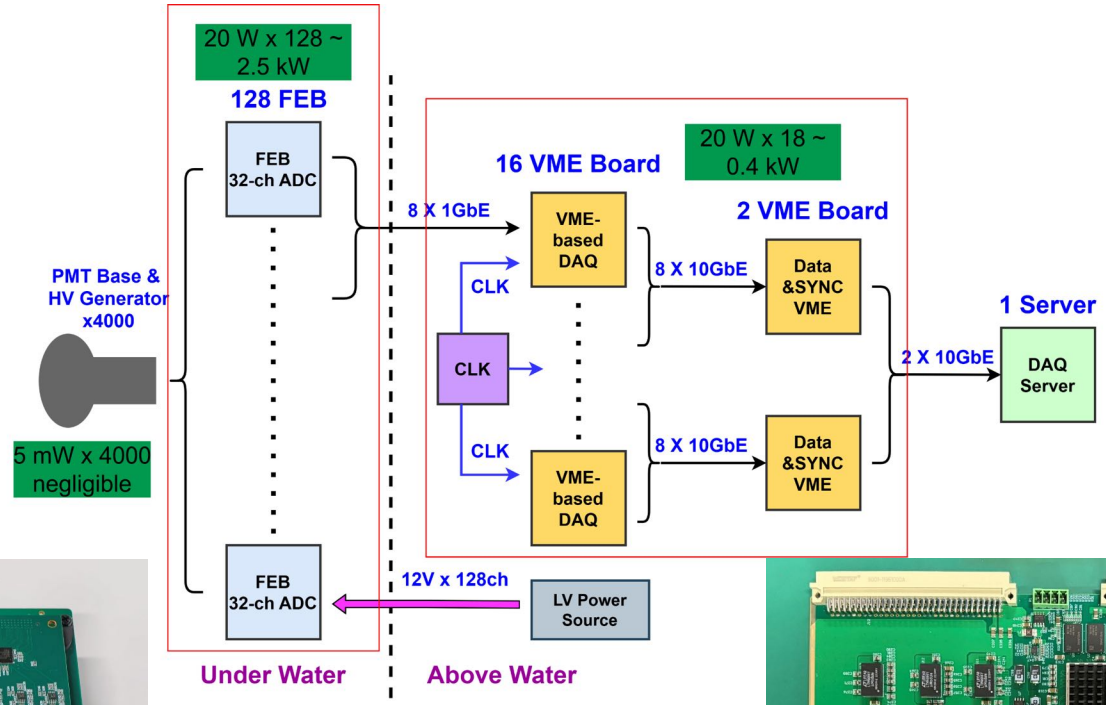


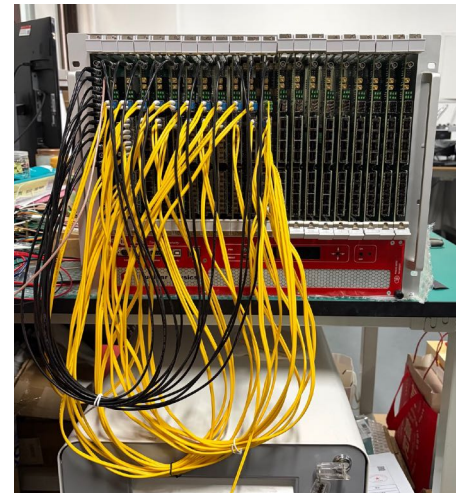
NVT
北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO., LTD

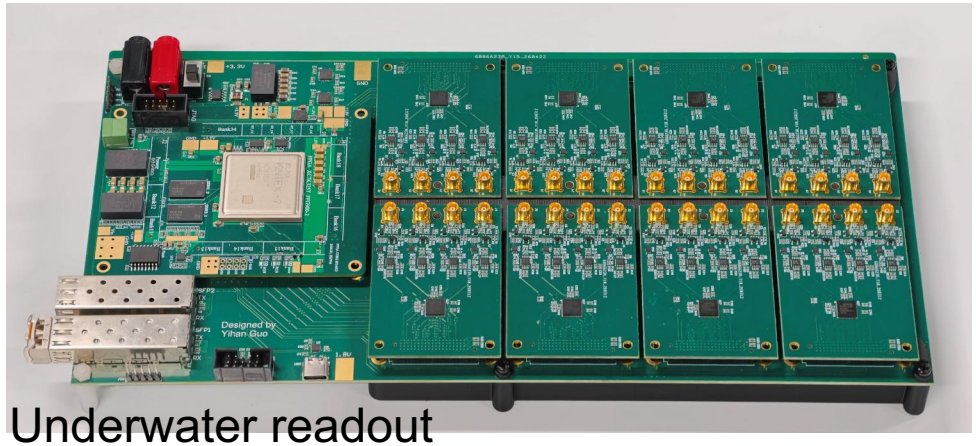
PMT readout electronics

- **Under-water: 4000 PMT (with base and HV) + 128 FEBs**
- **Above-water: 18 VME Board + 1 DAQ Server**

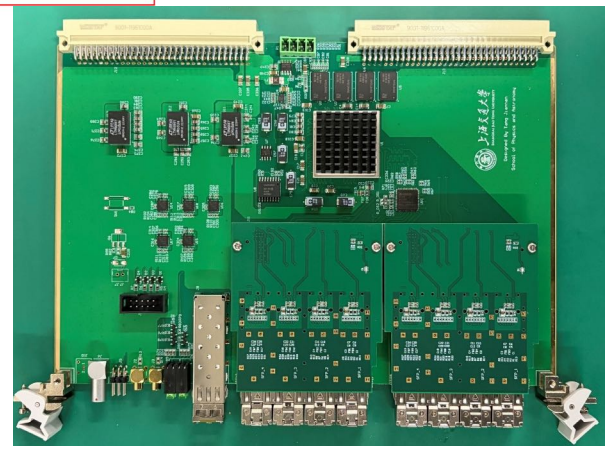








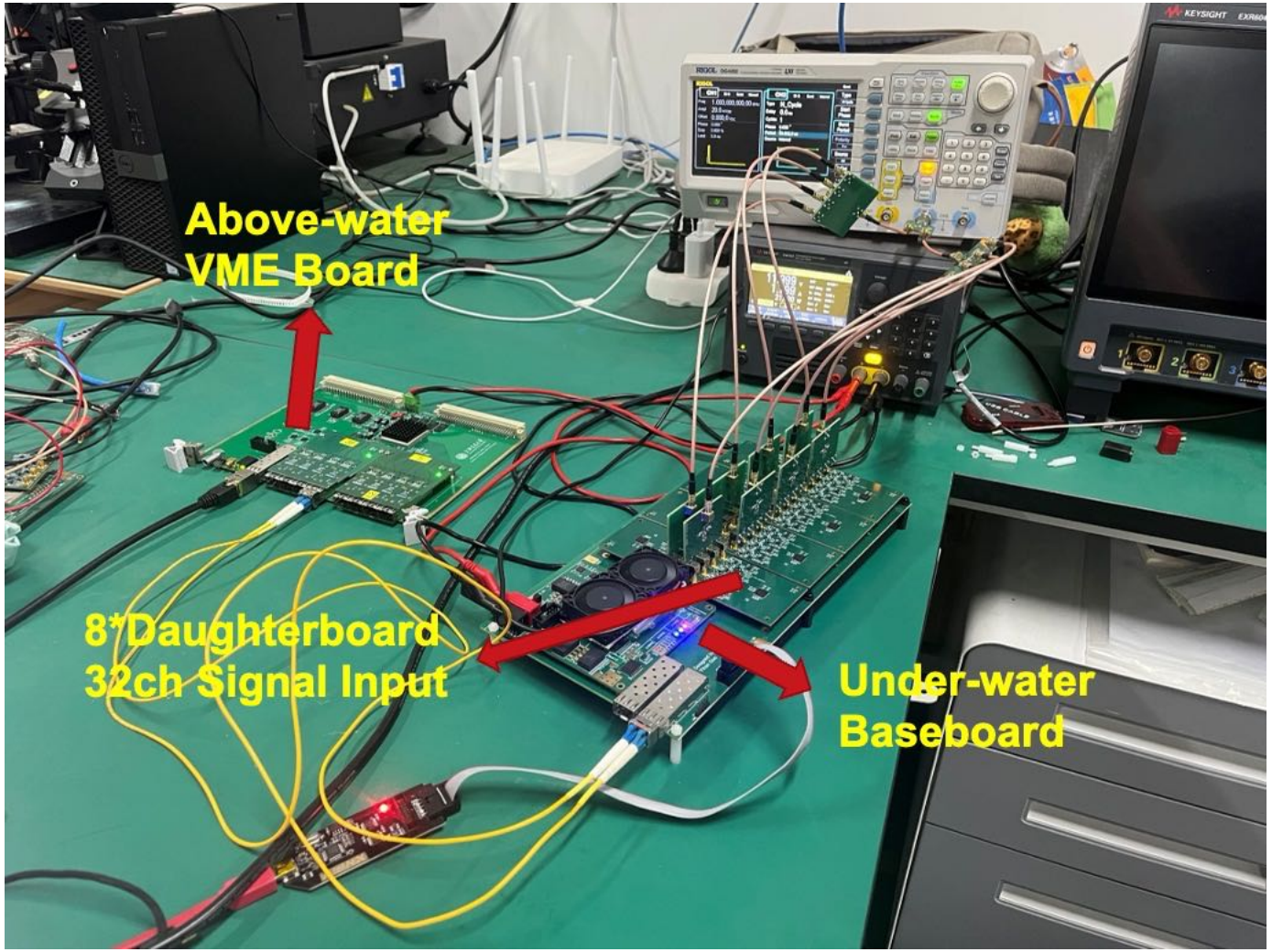
Underwater readout

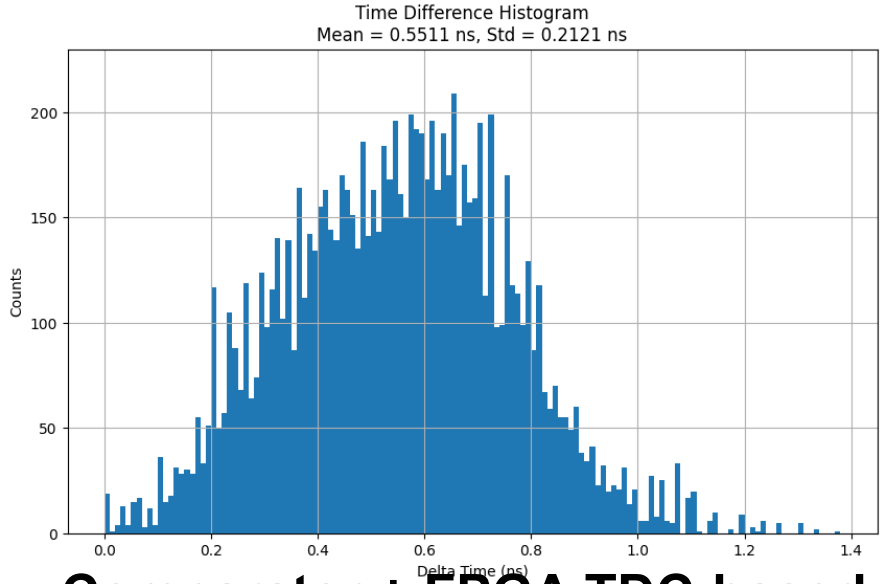


Above water readout

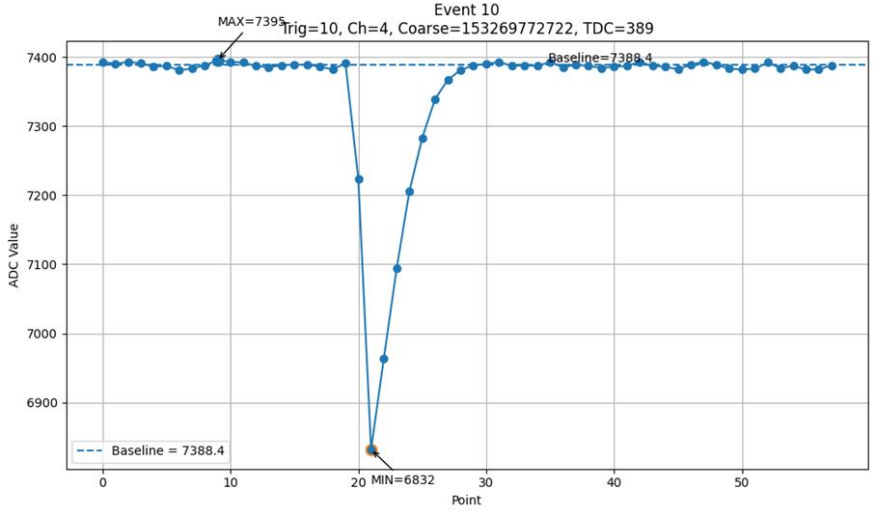
PMT readout electronics

- **Integration test**





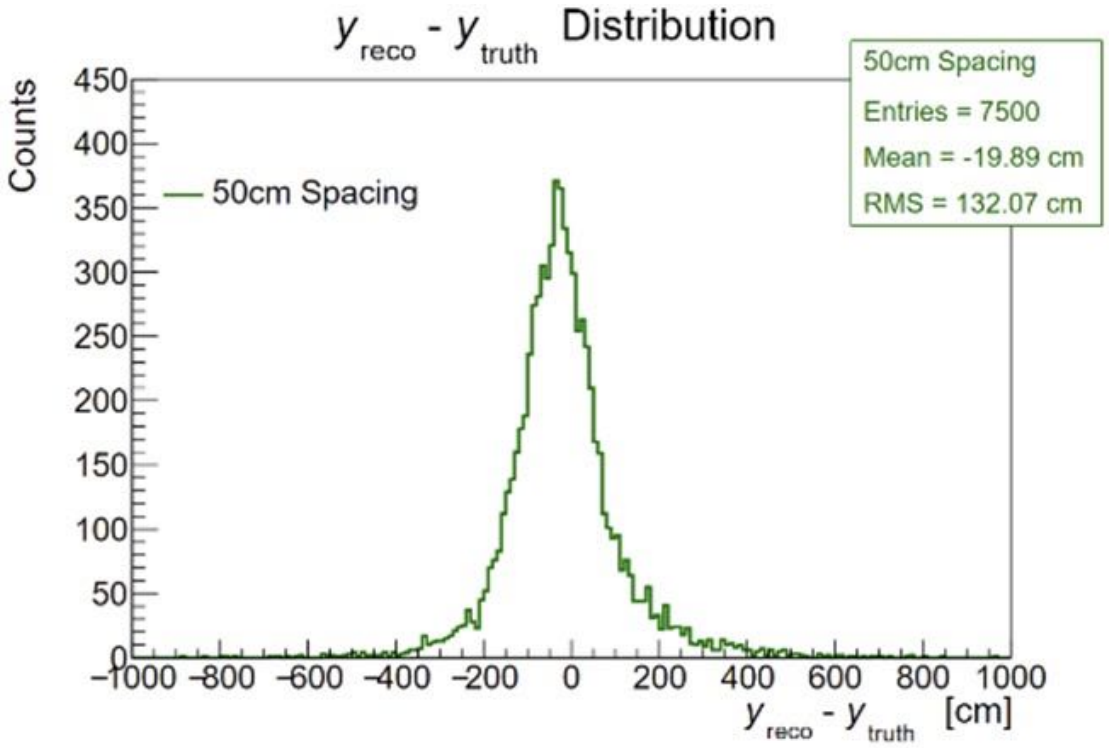
Comparator + FPGA TDC-based
timing precision: 0.2121ns

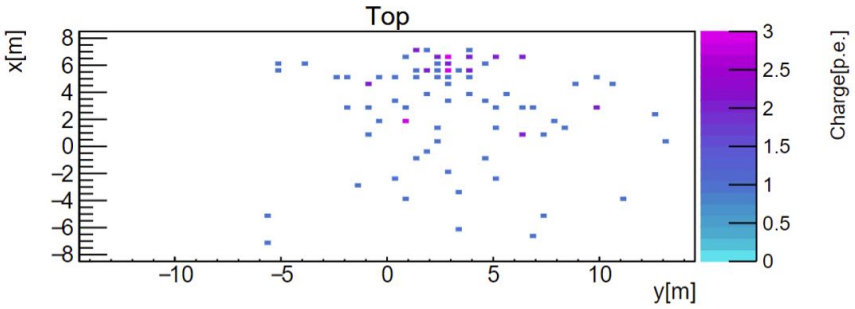


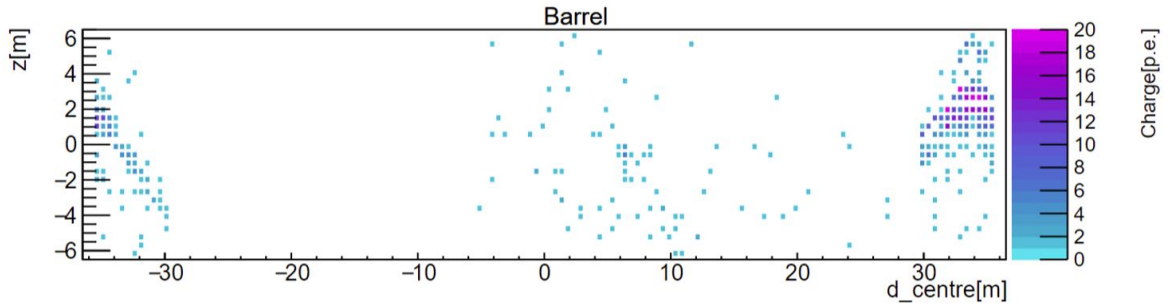
Measured waveform of a single event

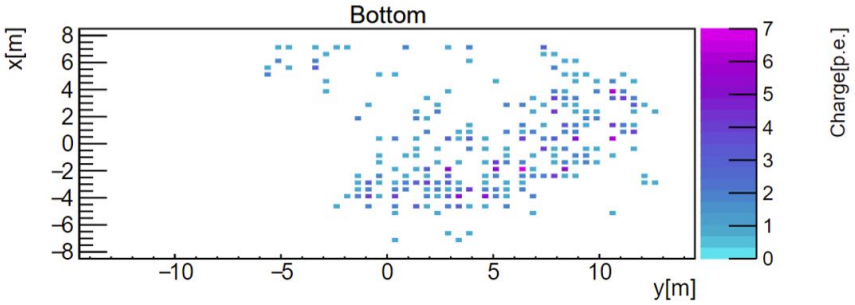
Atmospheric neutrino simulation

- **Neutrino simulation**
  - Flux() → GENIE → Geant4 detector (WCSim)
- **Reconstruction: GNN-based algorithm**
  - Position resolution: <1.5m



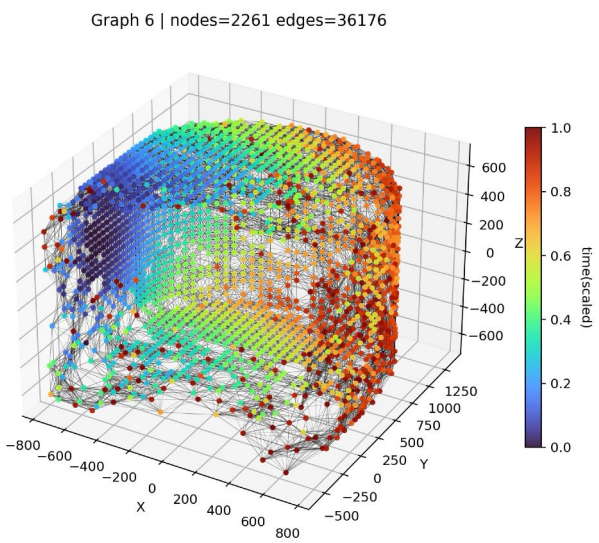


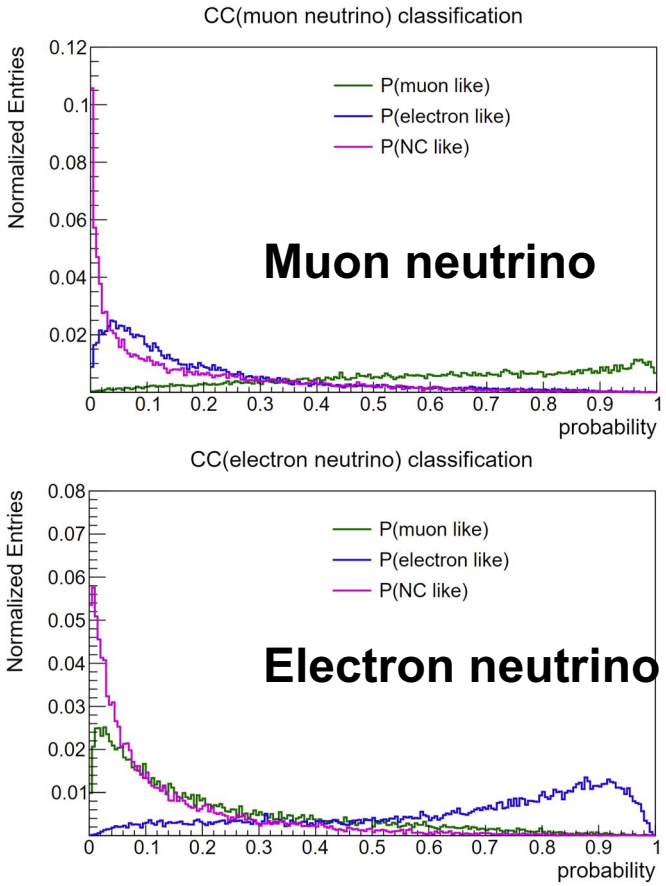


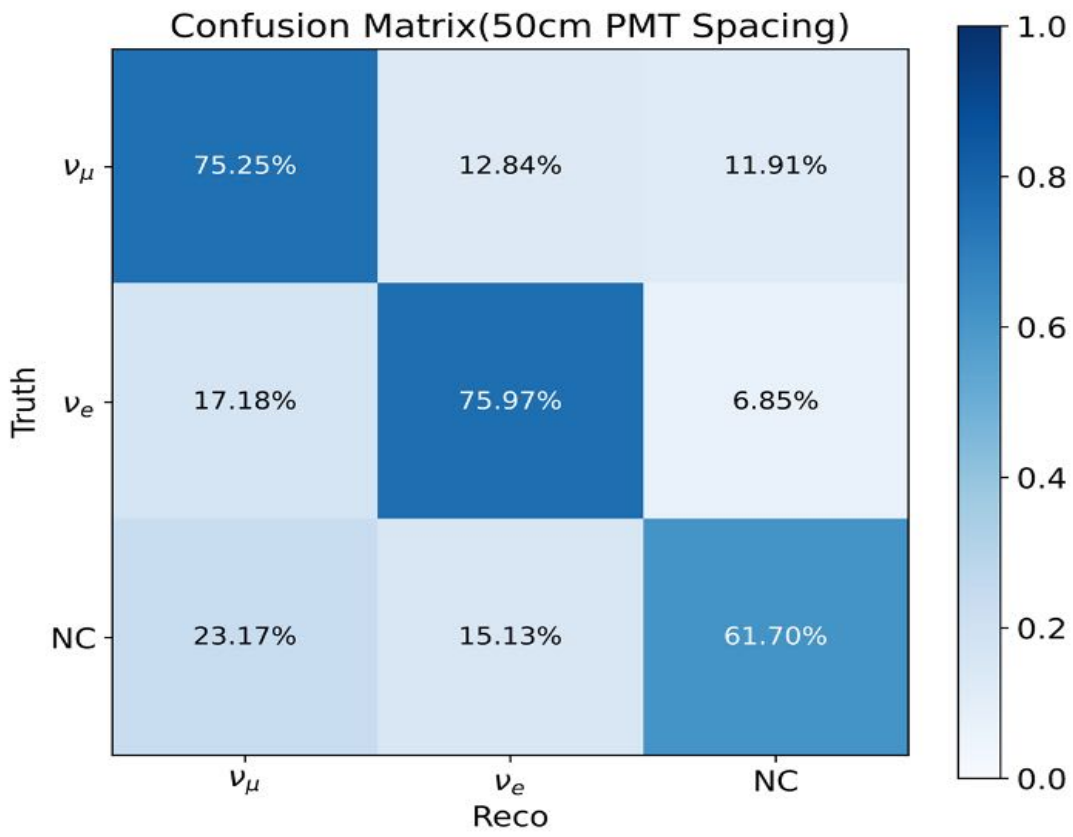


Atmospheric neutrino simulation

- **Particle identification**
  - Expecting 75% precision for ν_e/ν_μ identification

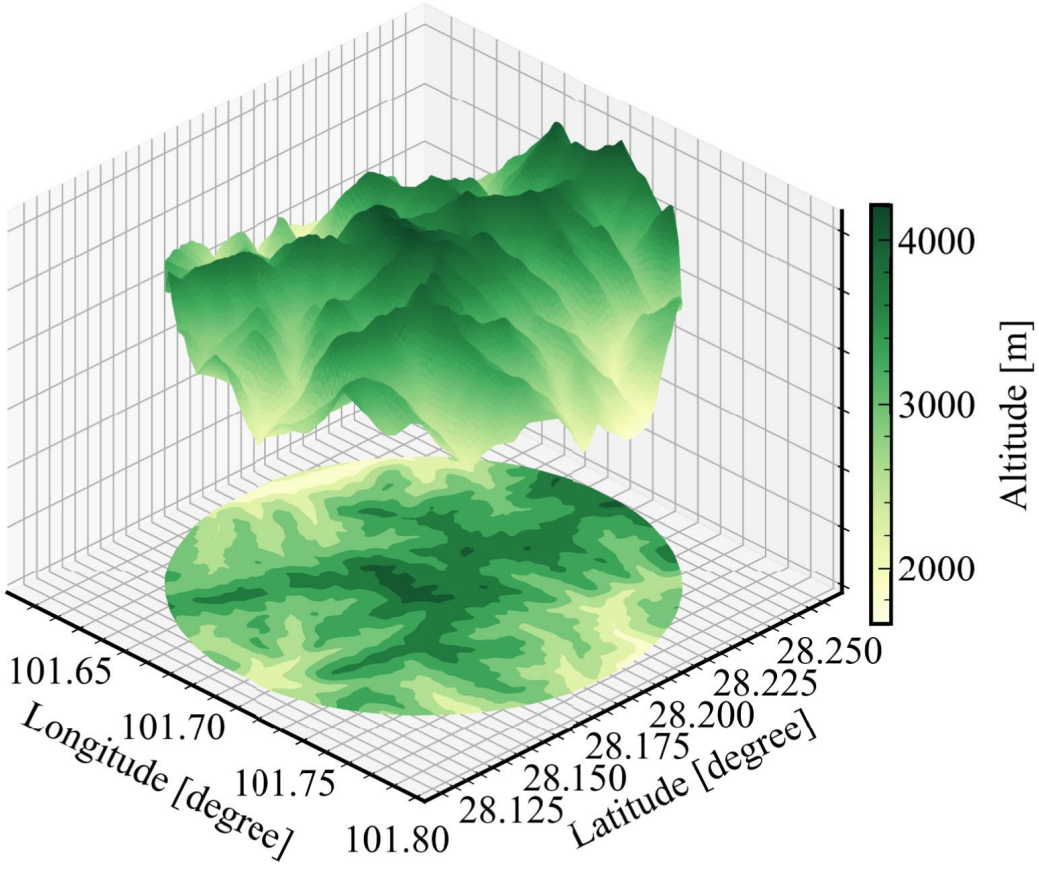


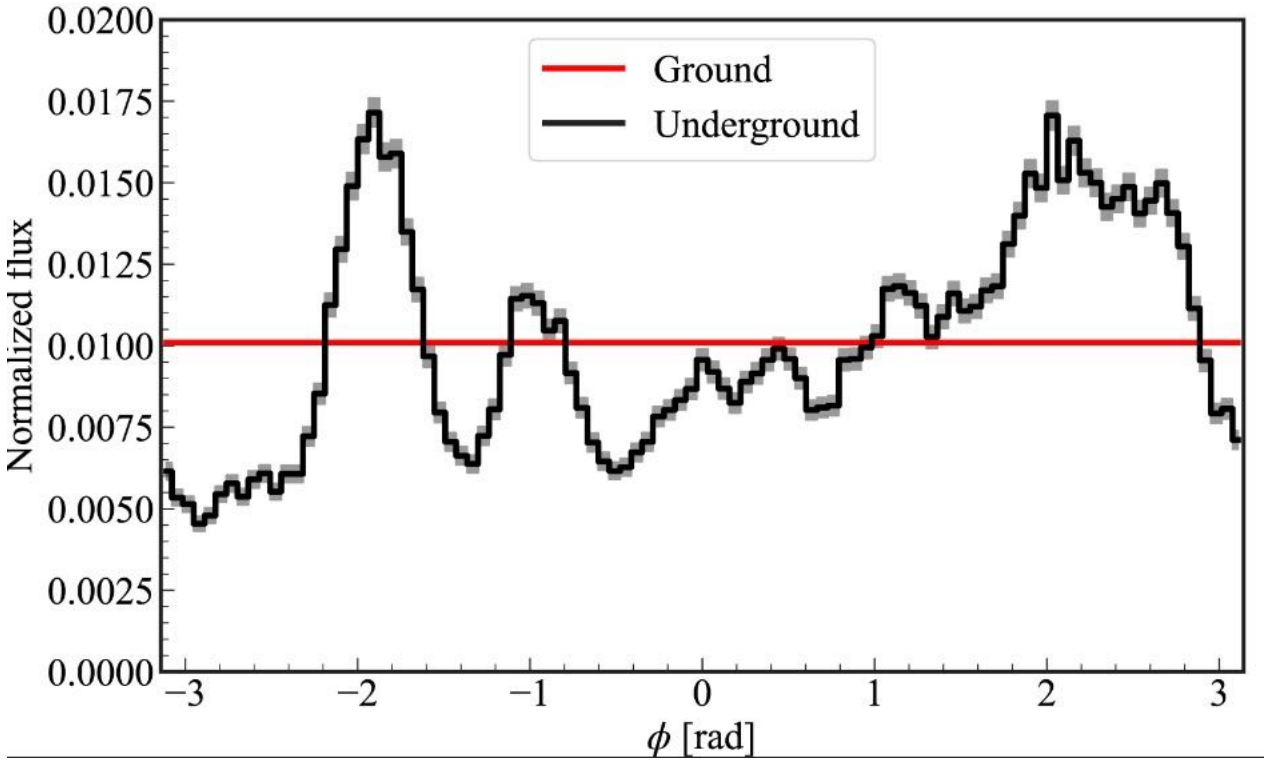




Cosmic-ray muons at CJPL

- **2400m overburden**
  - only high energy muons can reach the lab
- **Mountain structure: muon flux non-uniformity**

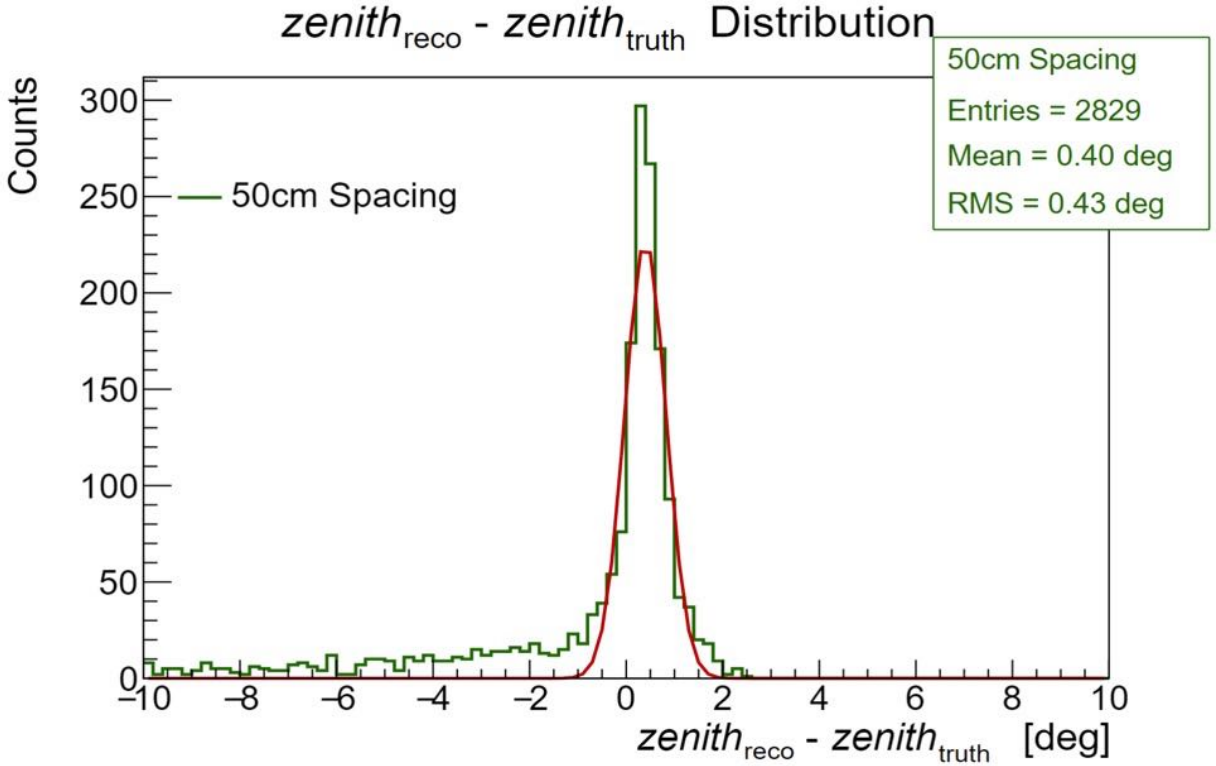


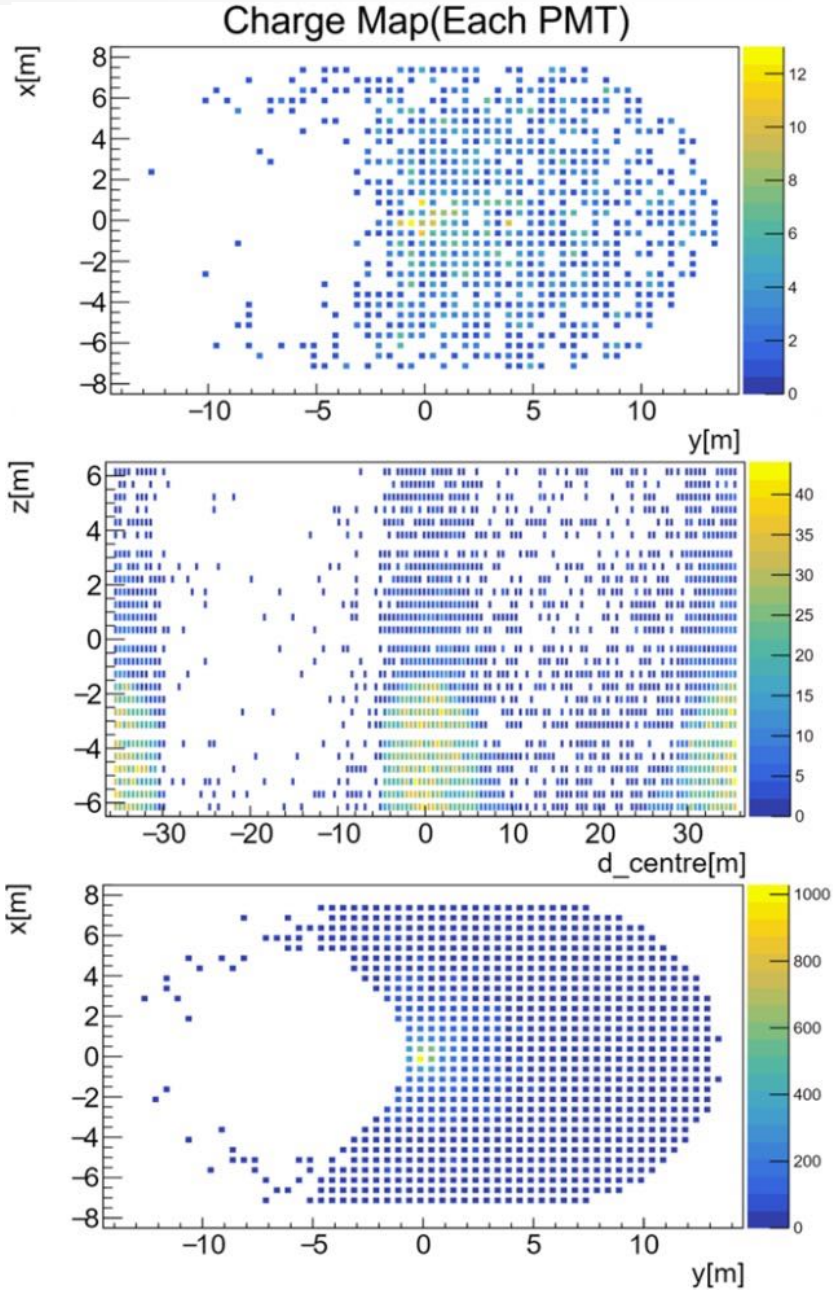


P. Zhang et. al., **Astroparticle Physics** 172 (2025) 103147

Cosmic-ray muon simulation

- **Simulation: WCSim+GENIE**
- **Reconstruction: GNN algorithm**
  - Angular resolution: expecting <2 degs





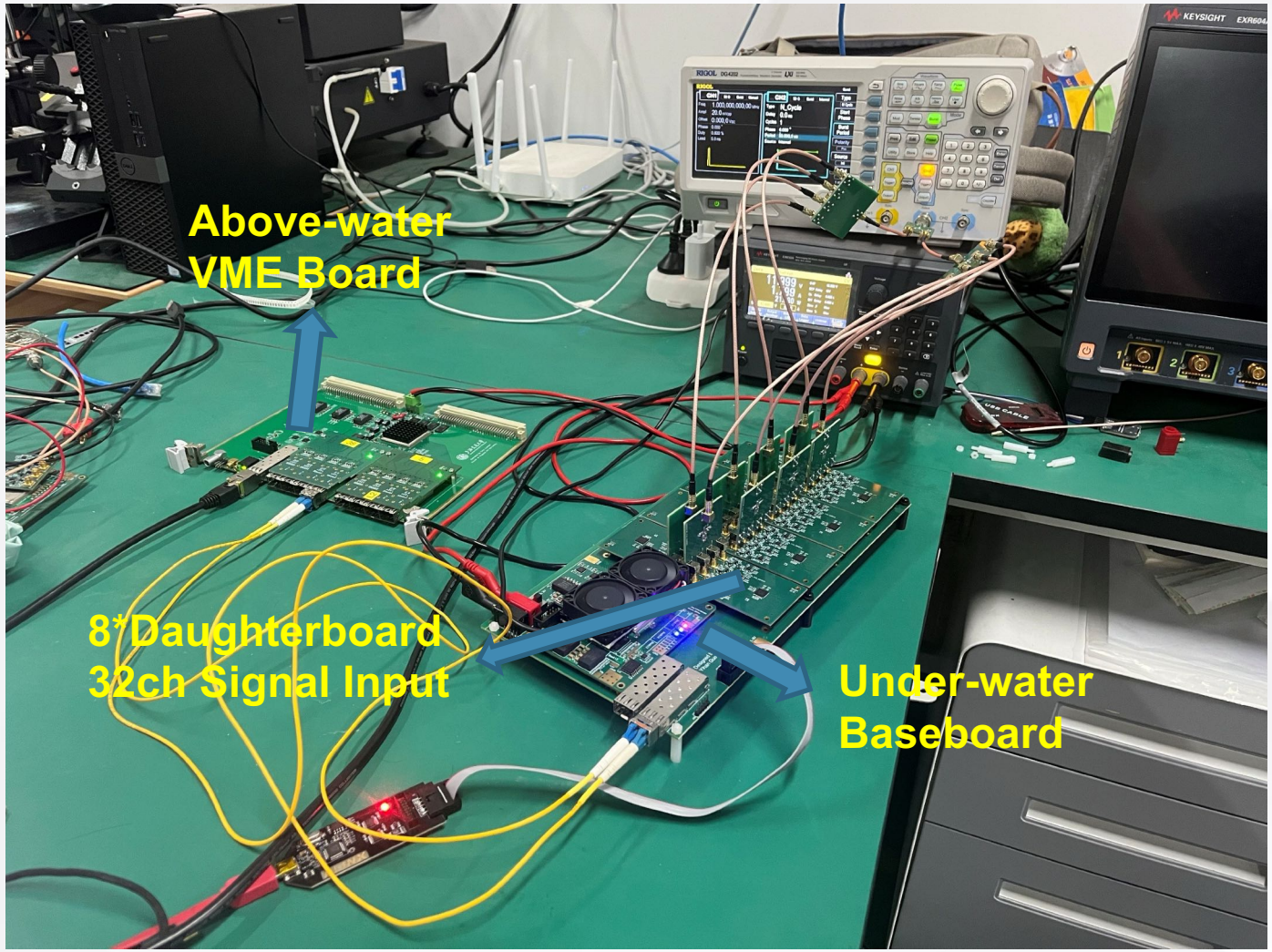
Summary

- CJPL provides a unique location for atmospheric neutrino and cosmic-ray muon measurement
- The existing 4500m^3 water shielding can be converted into such a detector
- To provide important info for dark matter searches, cosmic-ray physics and mountain imaging.

THANK YOU

Night view @ CJPL

Integration Test



- **Input:**
  - 640 mVpp, **8 ns** pulse width, **20 kHz** event rate
  - Split into 32 channels using custom 1-to-32 splitter board
  - Equivalent input per channel: **20 mVpp**
- **Signal transmission path:**
  - 32-ch Input → **8*4ch ADC** → **Under-water FEB** → 10G Optical Fiber → **Above-water VME Board** → Gigabit Ethernet → **PC**
- **Test items:**
  - Timing precision: **Comparator + FPGA TDC** threshold crossing
  - Timing precision: **ADC-based** threshold crossing
  - Long-term stability test