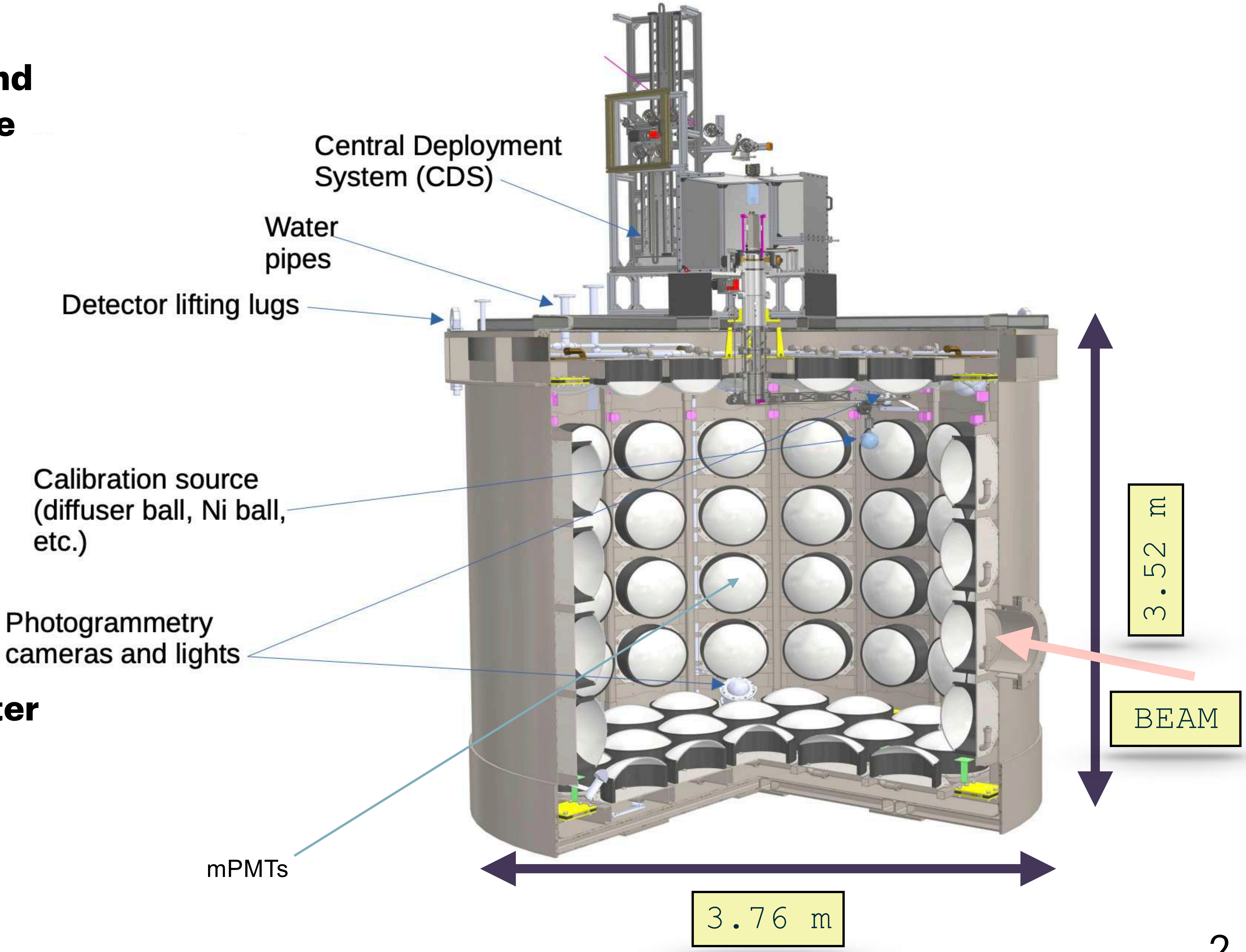
WATER CHERENKOV TEST EXPERIMENT AT CERN: PRELIMINARY RESULTS FROM A NEW GENERATION OF MULTI-PMT MODULES

TIPP 2026 | Mohit Gola, 02/02/2026 | TRIUMF/UVIC

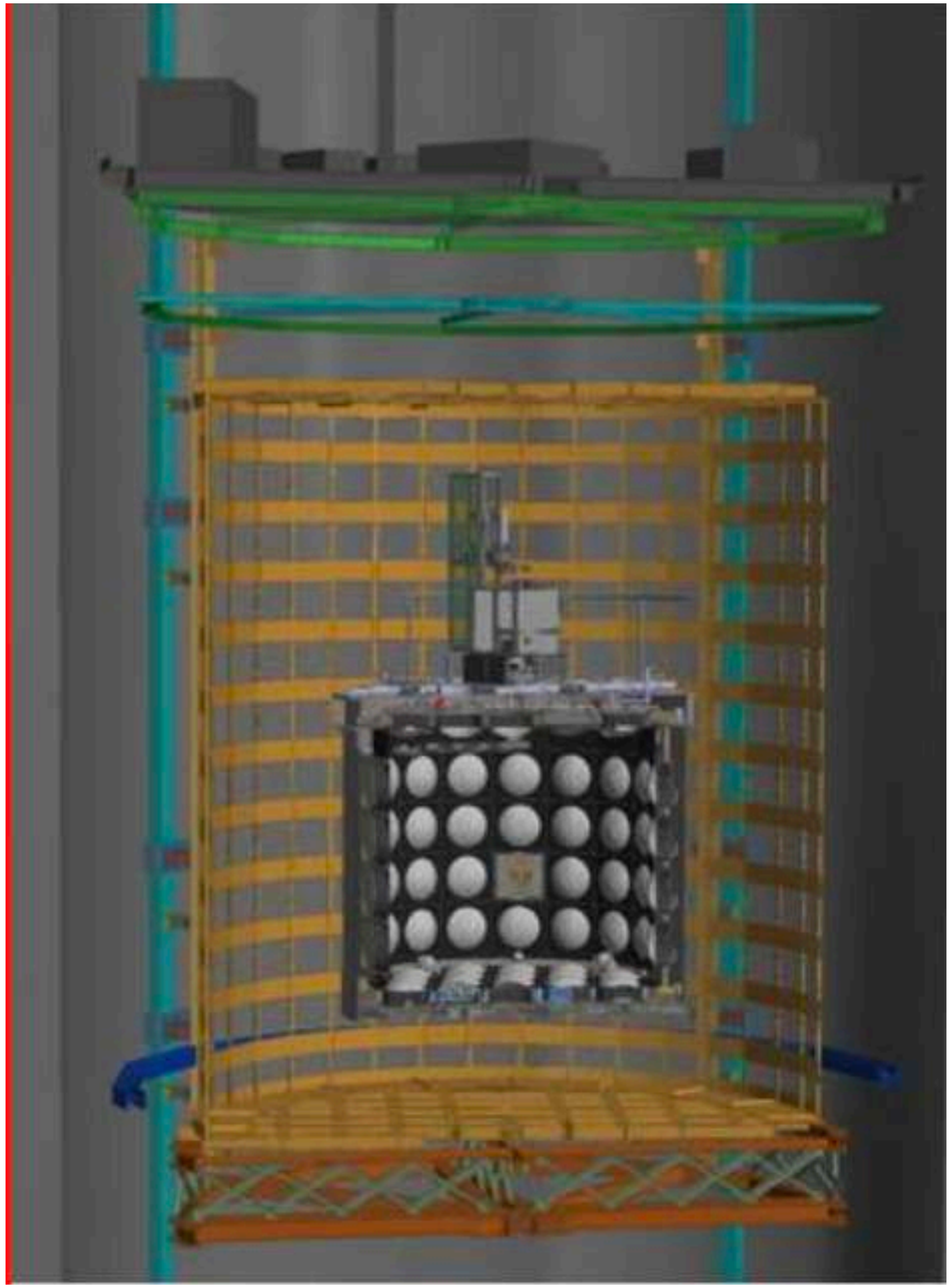
THE WATER CHERENKOV TEST EXPERIMENT (WCTE)

- 40-ton water Cherenkov Detector.
- Testbed for water Cherenkov detector systems and new calibration techniques that will be used in the Intermediate Water Cherenkov Detector (IWCD).
- Instrumented with 97 mPMTs
  - 93 IWCD mPMTs
  - 4 Far Detector (FD) mPMTs
- Operated in CERN T9 (East Hall) beam line
  - Interested in e,π,μ,p,γ in the 0.2-1.2GeV/c range
- Operations in both pure water and Gd-loaded water mode
  - First beam run: Oct. 19 - Nov. 27, 2024
  - Second beam run: Mar. 19 - Jun. 11, 2025



MOTIVATION : (WCTE ⟶ IWCD)

- Hyper-Kamiokande (HK) builds on Super-Kamiokande and Tokai to Kamioka (T2K) to discover CP violation and measure neutrino oscillation parameters precisely.
- The IWCD sits near the neutrino source to study neutrinos before they oscillate.
- WCTE uses primarily the same photosensors and calibration systems as IWCD.
- Size is ~1/2 the height and ~1/2 the diameter of the IWCD inner detector.
- Opportunity to establish event reconstruction and calibration for an IWCD-size detector using mPMT photosensors
- Measurements of the interaction of charged particles in water to reduce the uncertainty of neutrino detection for HK
- The mPMT assembly procedure has been refined to facilitate the production of approximately 270 additional mPMTs for IWCD.
- WCTE provides experience for installation, operation and data analysis.

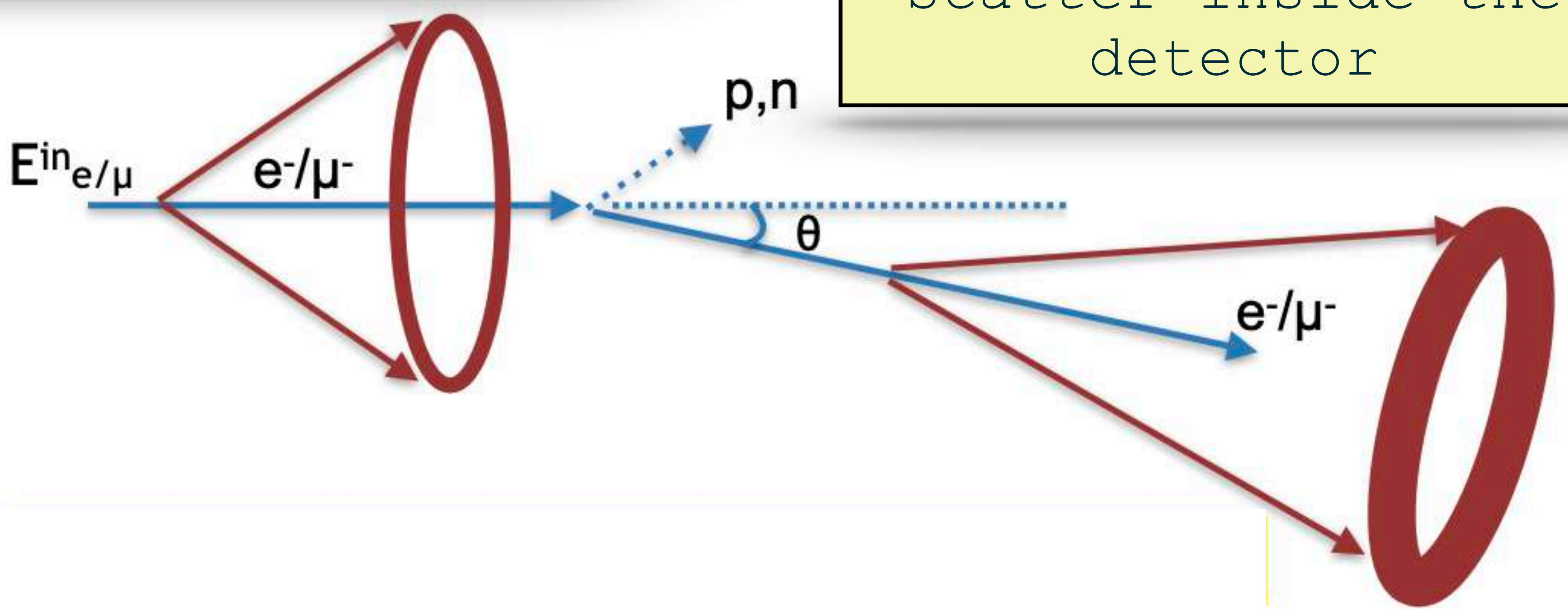


Charged Lepton Scattering

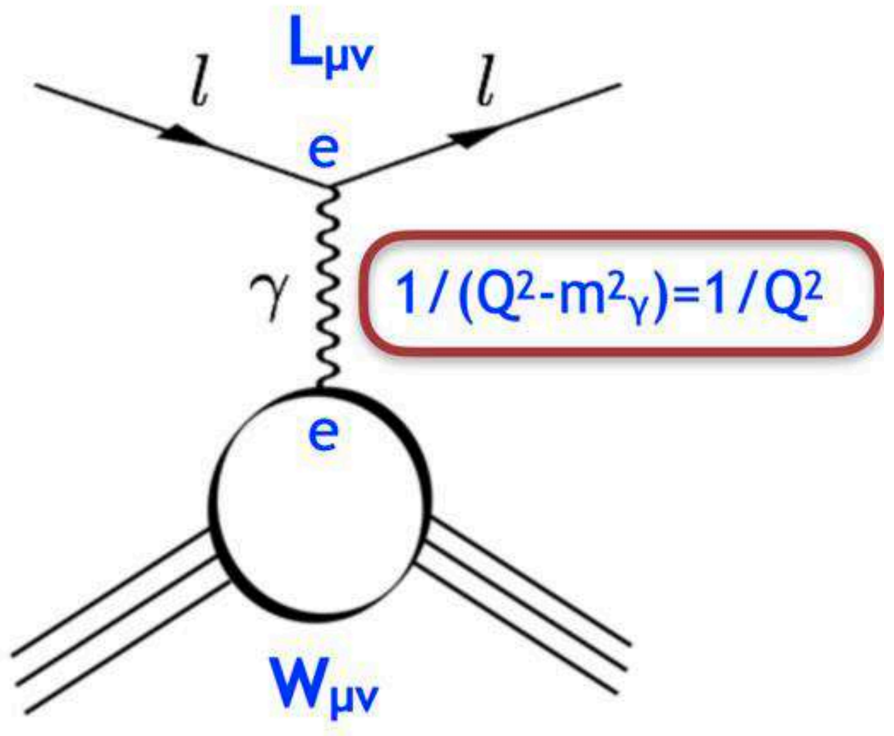
- ⭐ **Measure the scattering of beam electrons and muons in water to provide constraints on neutrino-nucleus interaction.**
- ⭐ **Signature in WCTE is an event with two rings**

Beam electron enters

Scatter inside the detector

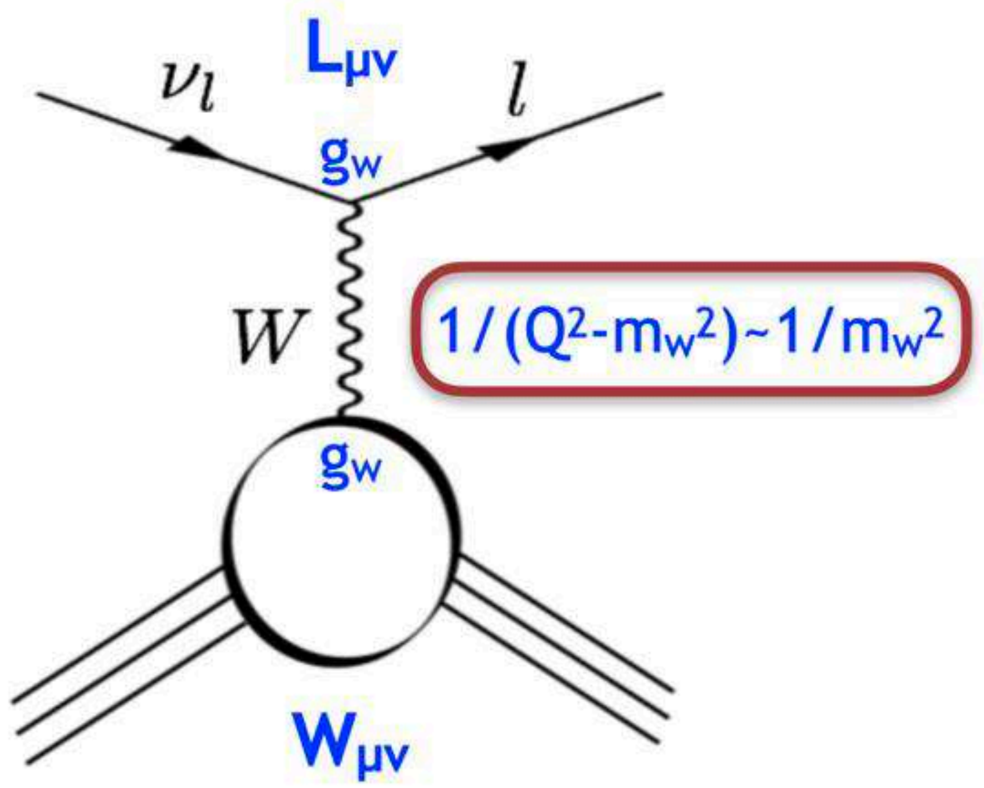


Charged Lepton Scattering



$$\frac{d\sigma_{eA}}{d\Omega_{e'}dE_{e'}} = \frac{\alpha^2}{Q^4}\frac{E'_e}{E_e}L_{\mu\nu}W^{\mu\nu}_A$$

$\alpha = e^2/4\pi$



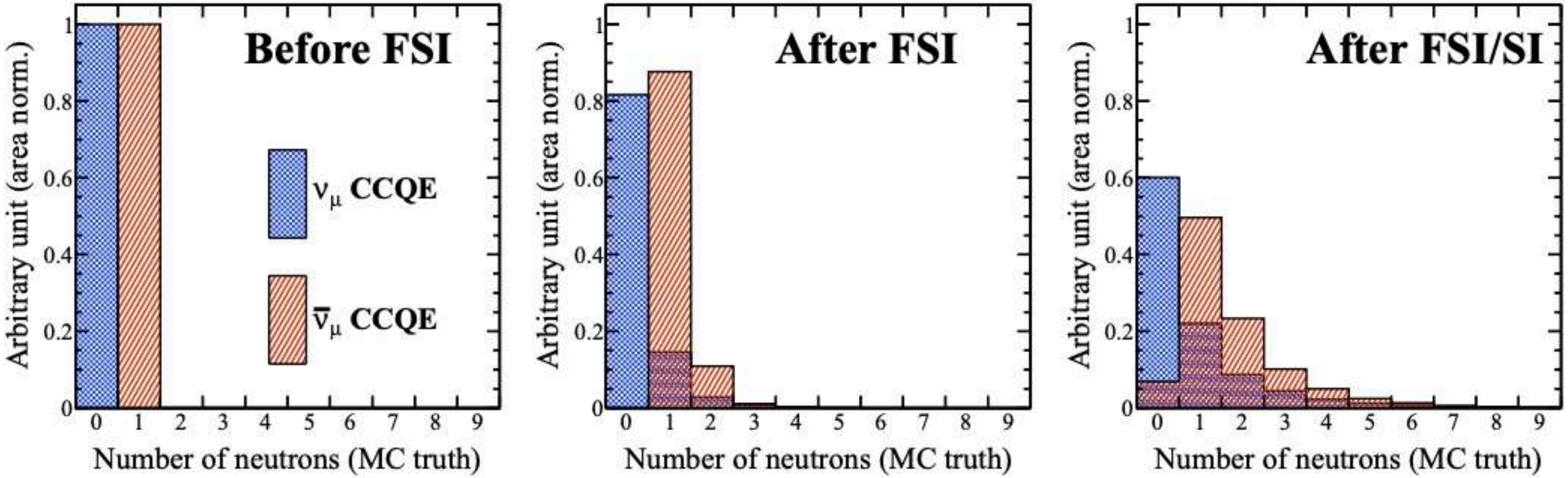
CCQE Neutrino Scattering

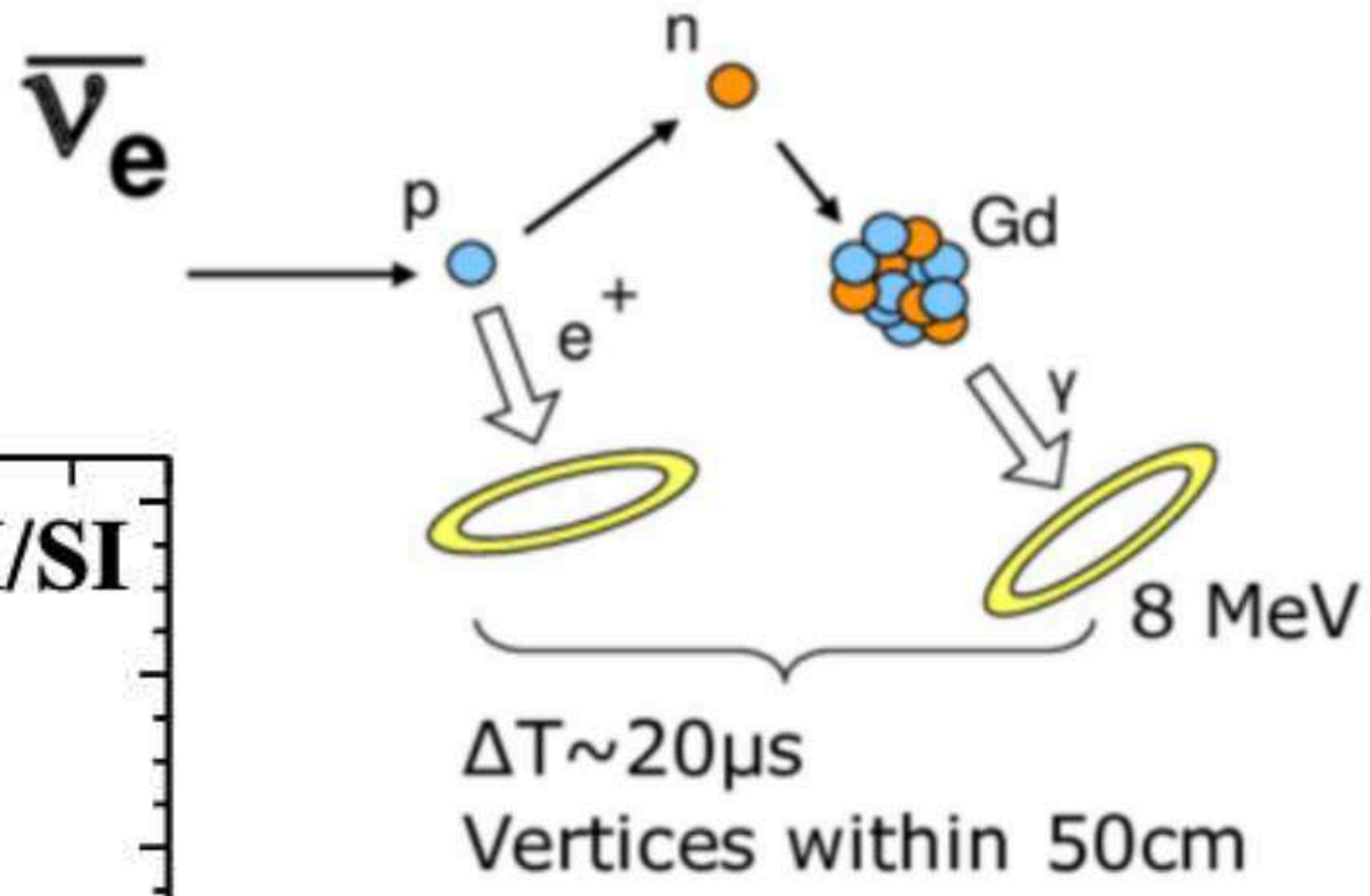
$$\frac{d^2\sigma}{dE'd\Omega'} = \frac{1}{16\pi^2}\frac{G_F^2}{2}L_{\mu\nu}W^{\mu\nu}$$

$G_F \sim g_W^2/m_W^2$

Gadolinium Doping

- ⭐ Antineutrino interactions tend to produce neutrons, while neutrinos tend to produce protons
- ⭐ In water Cherenkov detectors, it is challenging to separate neutrinos and anti-neutrinos (no magnetic field)
- ⭐ The capability to tag antineutrinos vs. neutrinos with neutron detection is limited by the secondary production of neutrons
- ⭐ WCTE will measure secondary neutron production

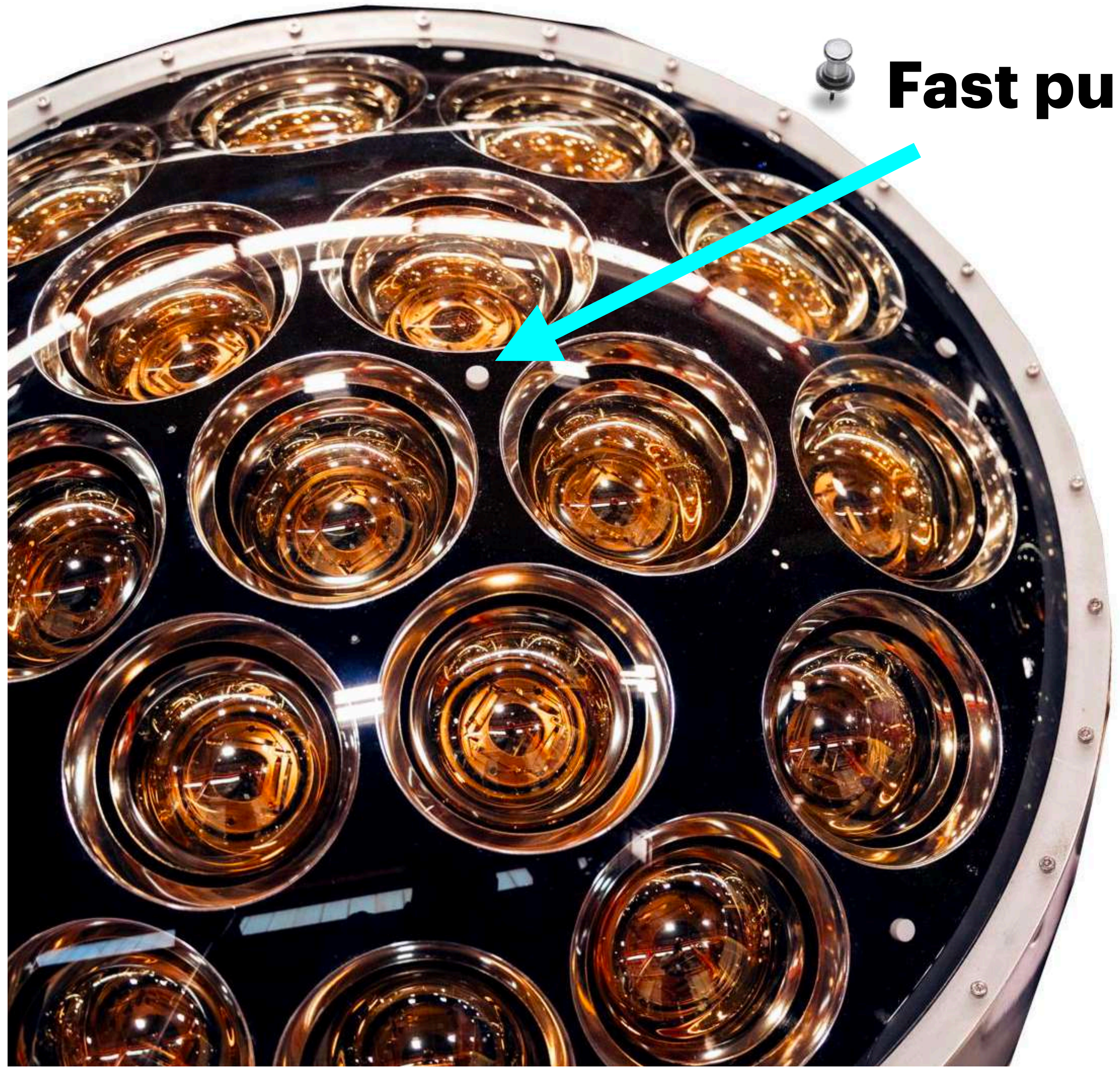




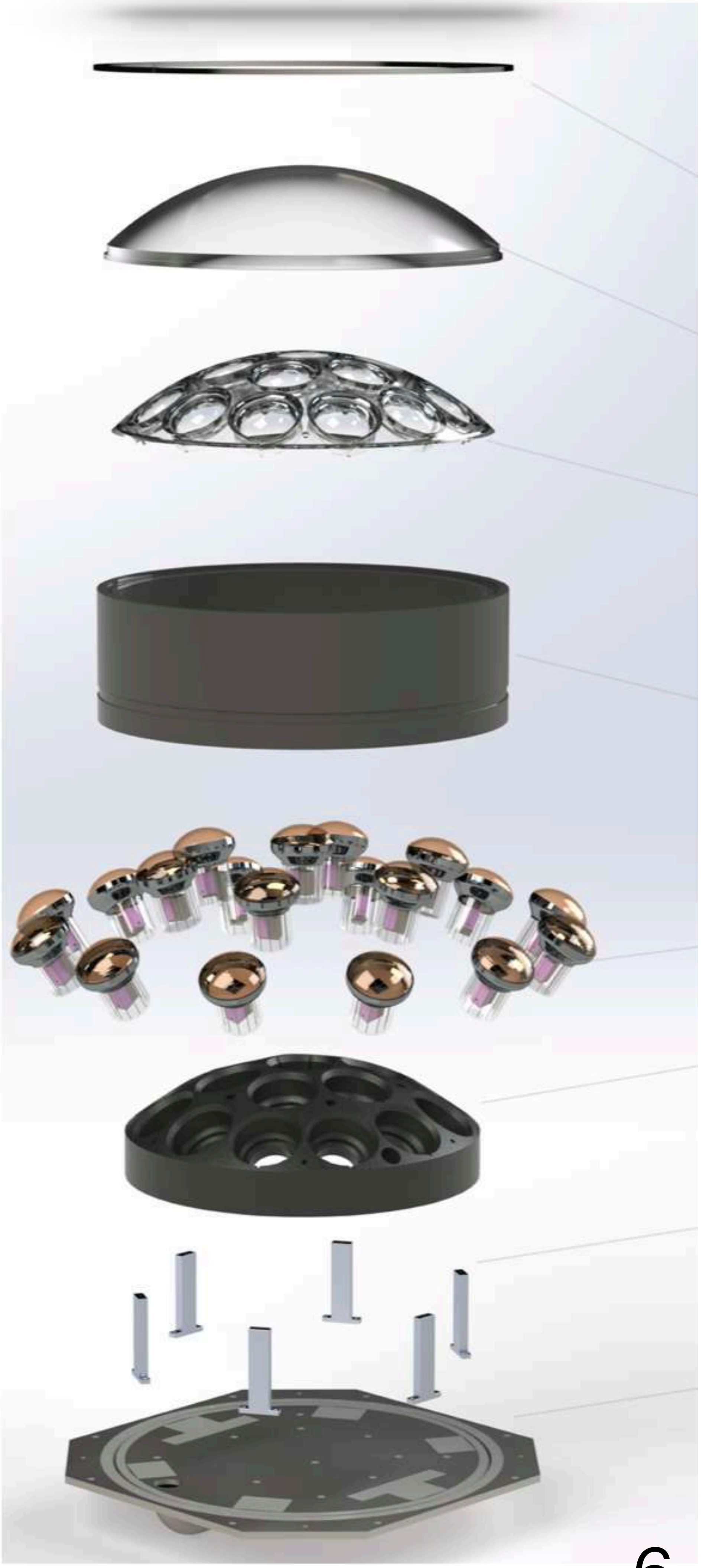
Neutron production in CCQE interactions in T2K

Ex-situ

- 19 x 3′′ PMTs in a single module
- All readout electronics are housed inside the vessel, with a single cable/connection exiting the unit
- Advantages over 20′′ PMTs:
  - Granularity and improved timing resolution
  - Fast pulsed LEDs for calibration purposes
- mPMT Production Experience:
  - ~100 modules/5 months, it gives on average 5/week
  - In-situ assembly variant will be used for IWCD production

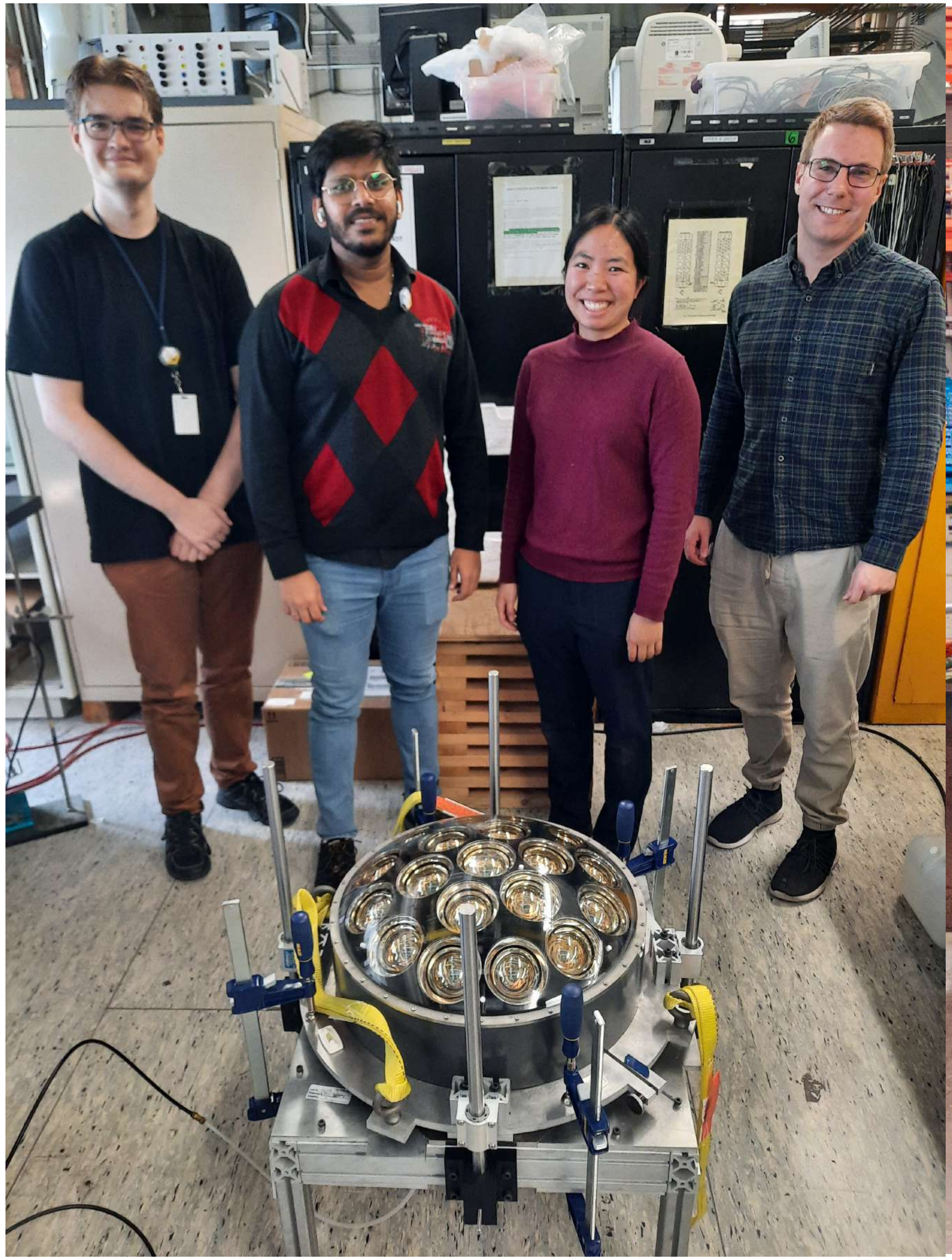


In-situ



First mPMT Produced at TRIUMF

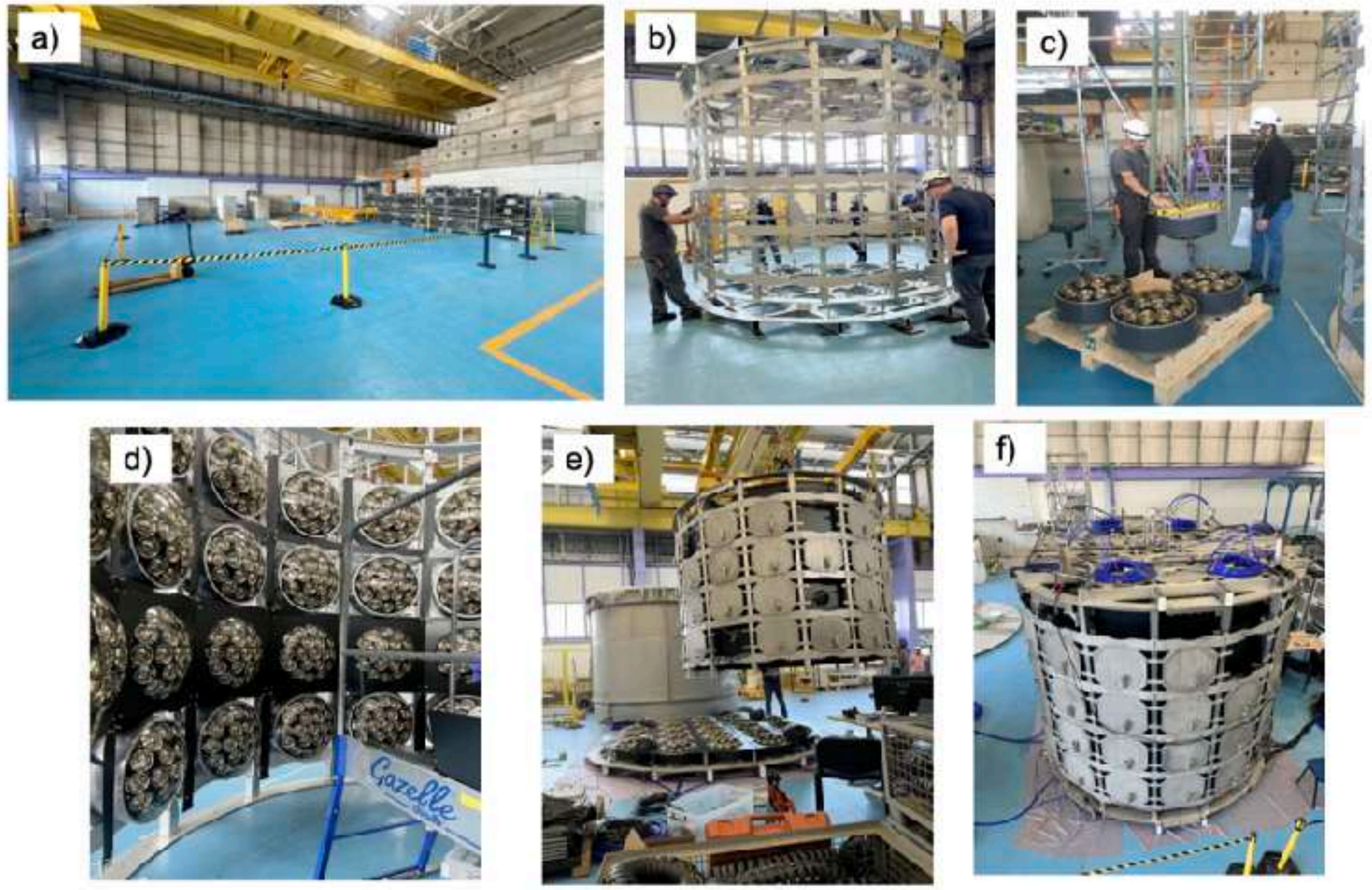
Half way through the TRIUMF production of mPMTs

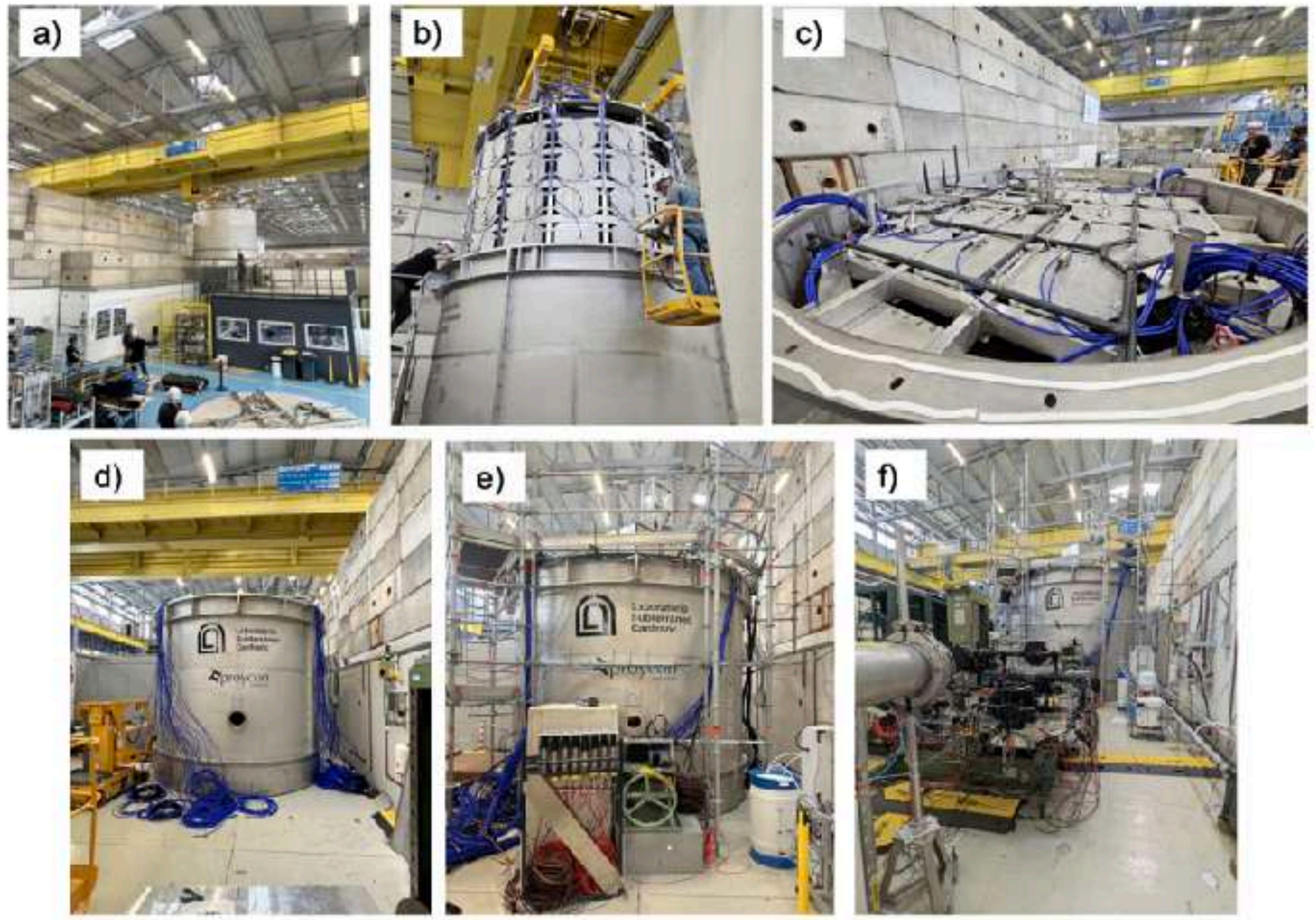


WCTE TIMELINE

Detector assembly and installation
Jul.-Oct. 2024

1st detector commissioning
Oct.-Nov. 2024



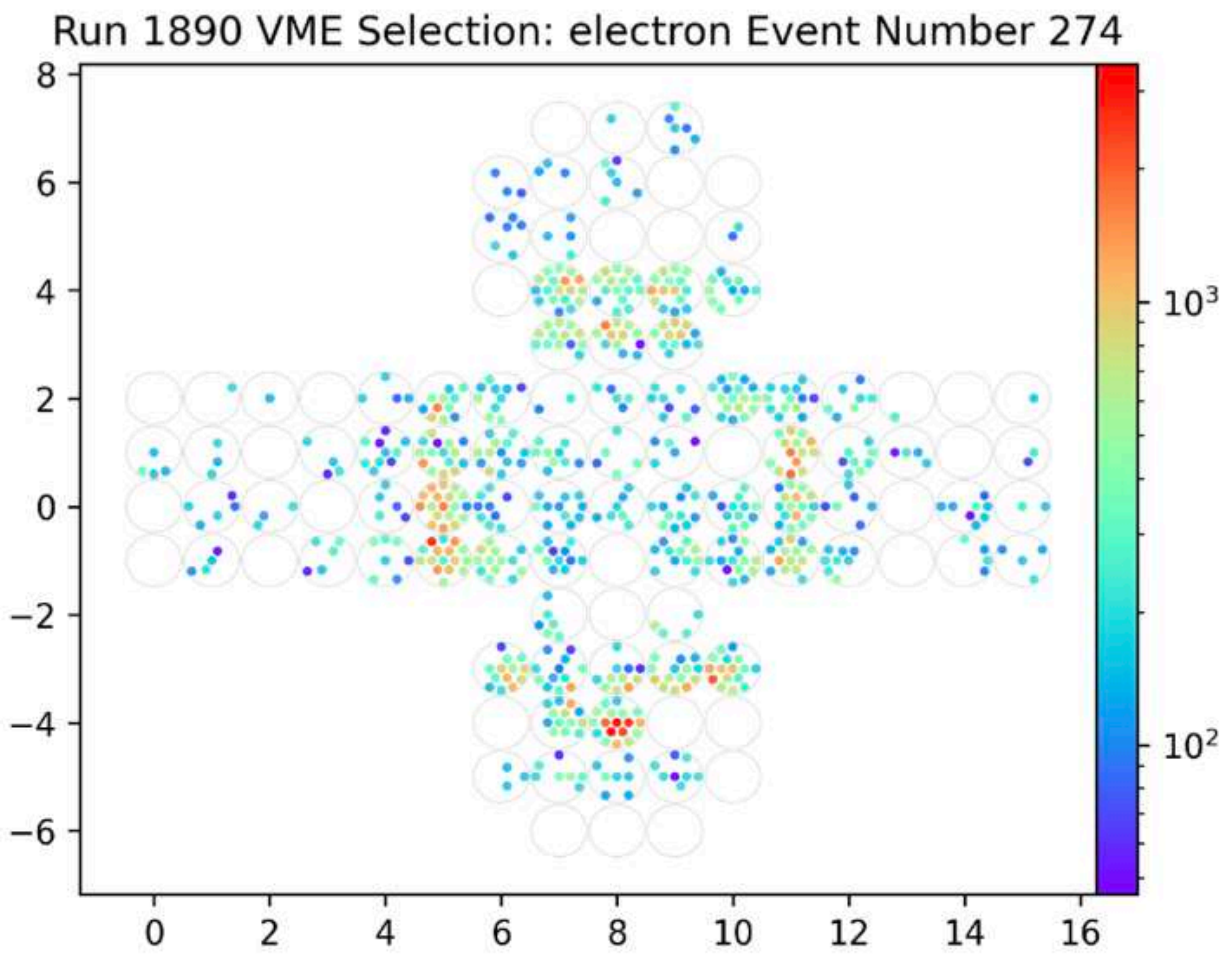


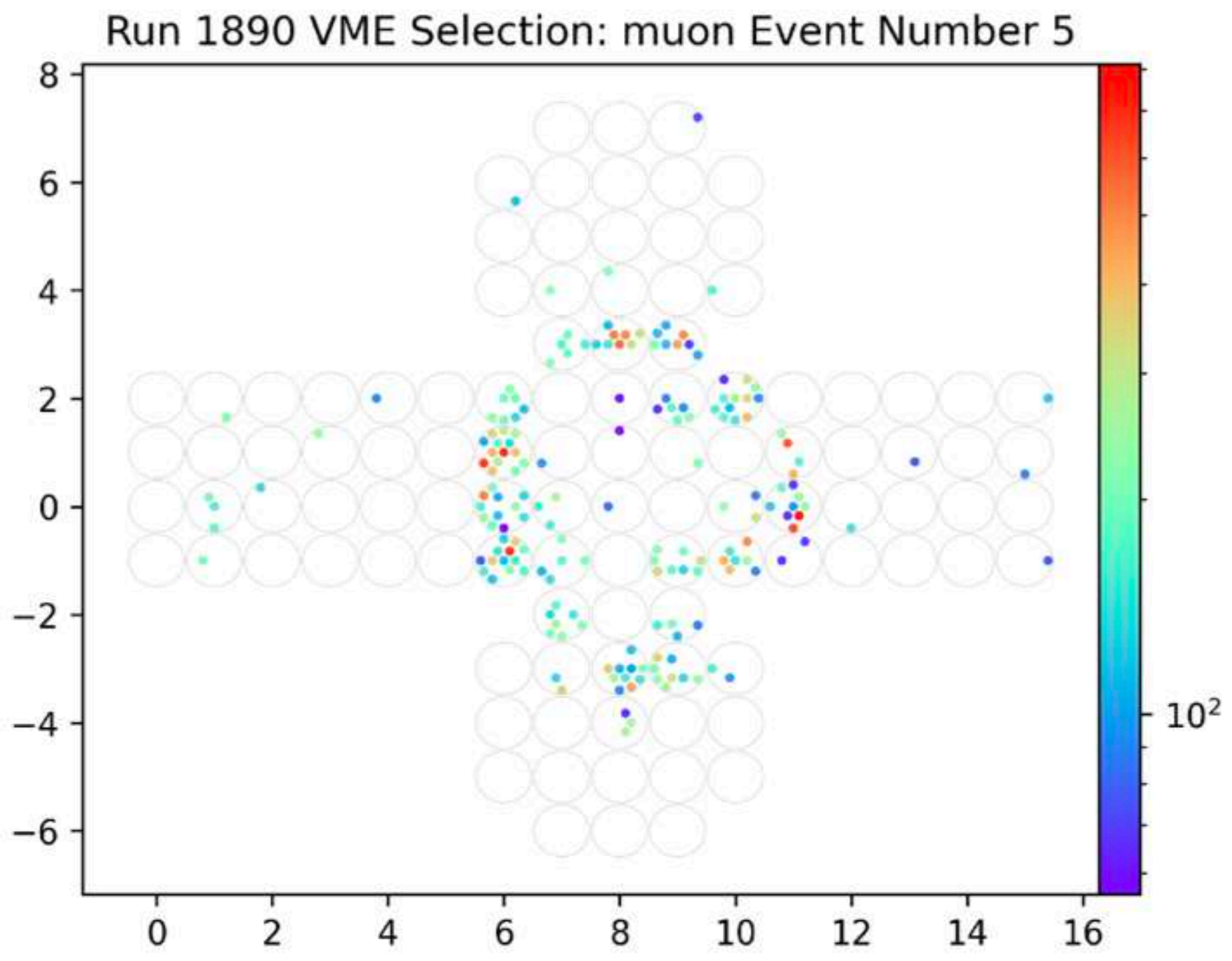
WCTE TIMELINE

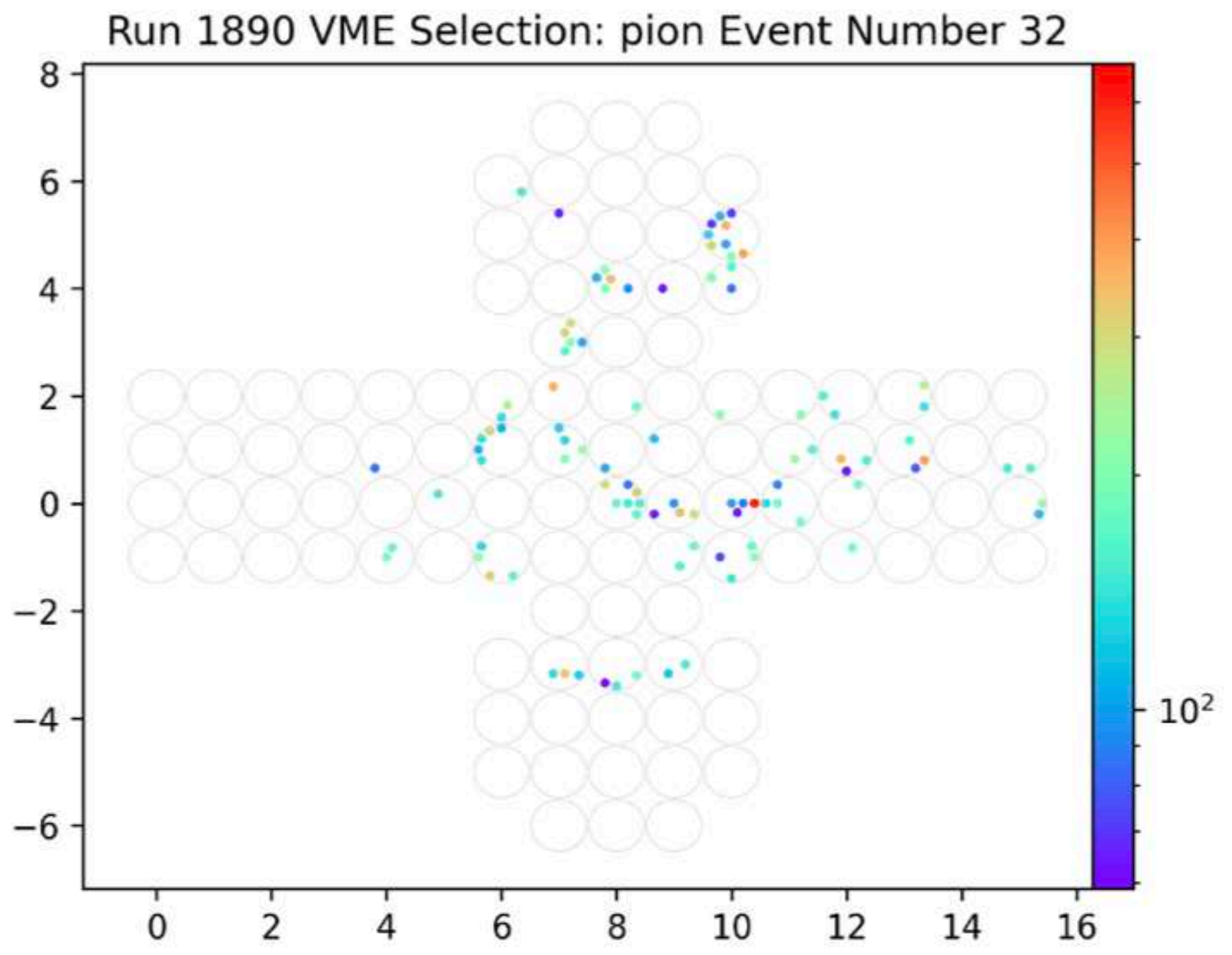
2nd detector commissioning, Mar. 2025

Data taking in pure water April - May 2025

Data taking in Gd water (0.03%), May 2025







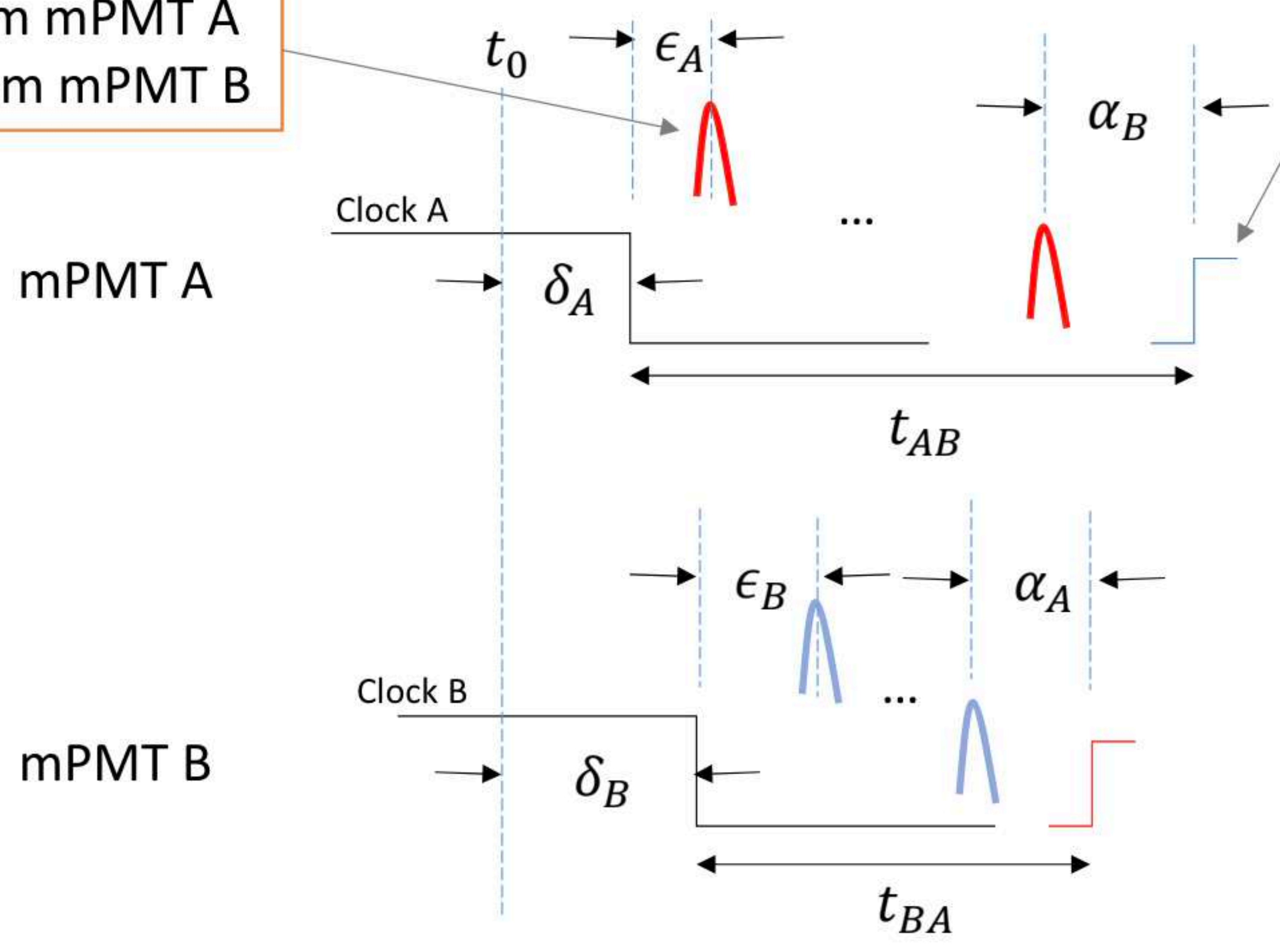
WCTE TIMELINE

Decommissioning and disassembly, June 3, 2025 - June 30, 2025




- **Each mPMT contains 3 fast-pulsing LEDs**
  - **Ex-situ: two 15-degree collimators, one diffuse**
  - **In-situ: two 30 degree collimators, one diffuse**
  - **Wavelengths: 365 nm, 405 nm, 470 nm**
- **Idea: Pulse a given LED, record the time at which this happens, and record the time at which a signal is seen in a PMT receiving the light**
- **The MCCs give us phase-locked mPMT clocks**
  - **This allows one to estimate timing offsets that are inherent in the electronics and the PMTs**

Red pulse emitted from mPMT A
Blue pulse emitted from mPMT B



Red signal received by mPMT A
Blue signal received by mPMT B

$$t_{AB} = d_{AB}\frac{n}{c} + (\delta_B - \delta_A) + \epsilon_A + \alpha_B$$

Note the degeneracy: equations are unchanged by offset to all ϵ provided the negative of that offset is applied to all α. The degeneracy is removed by applying weak priors on ϵ and/or α. One mPMT is used as a reference and a strong prior is applied for δ_{ref}.

$$t_{BA} = d_{BA}\frac{n}{c} + (\delta_A - \delta_B) + \epsilon_B + \alpha_A$$

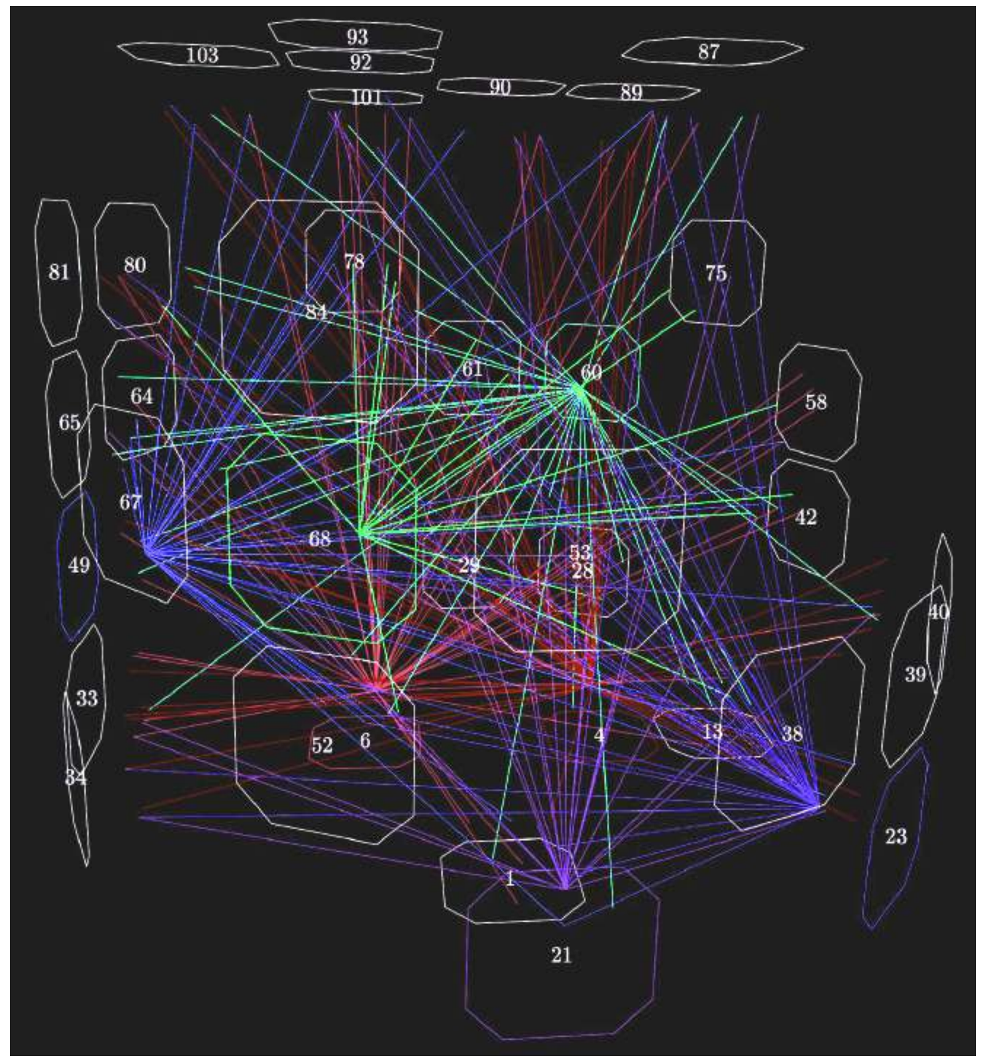
δ_i: mean mPMT_i clock delay wrt reference
ϵ_{il}: mean LED_ il pulse emission delay
α_{jk}: mean PMT_ jk response delay

Tx mPMT = i, Rx mPMT = j
n mpmts, index i or $j = 0, \dots, n-1$
m pmts per mpmt, $k = 0, \dots, m-1$
w leds per mpmt, $l = 0, \dots, w-1$

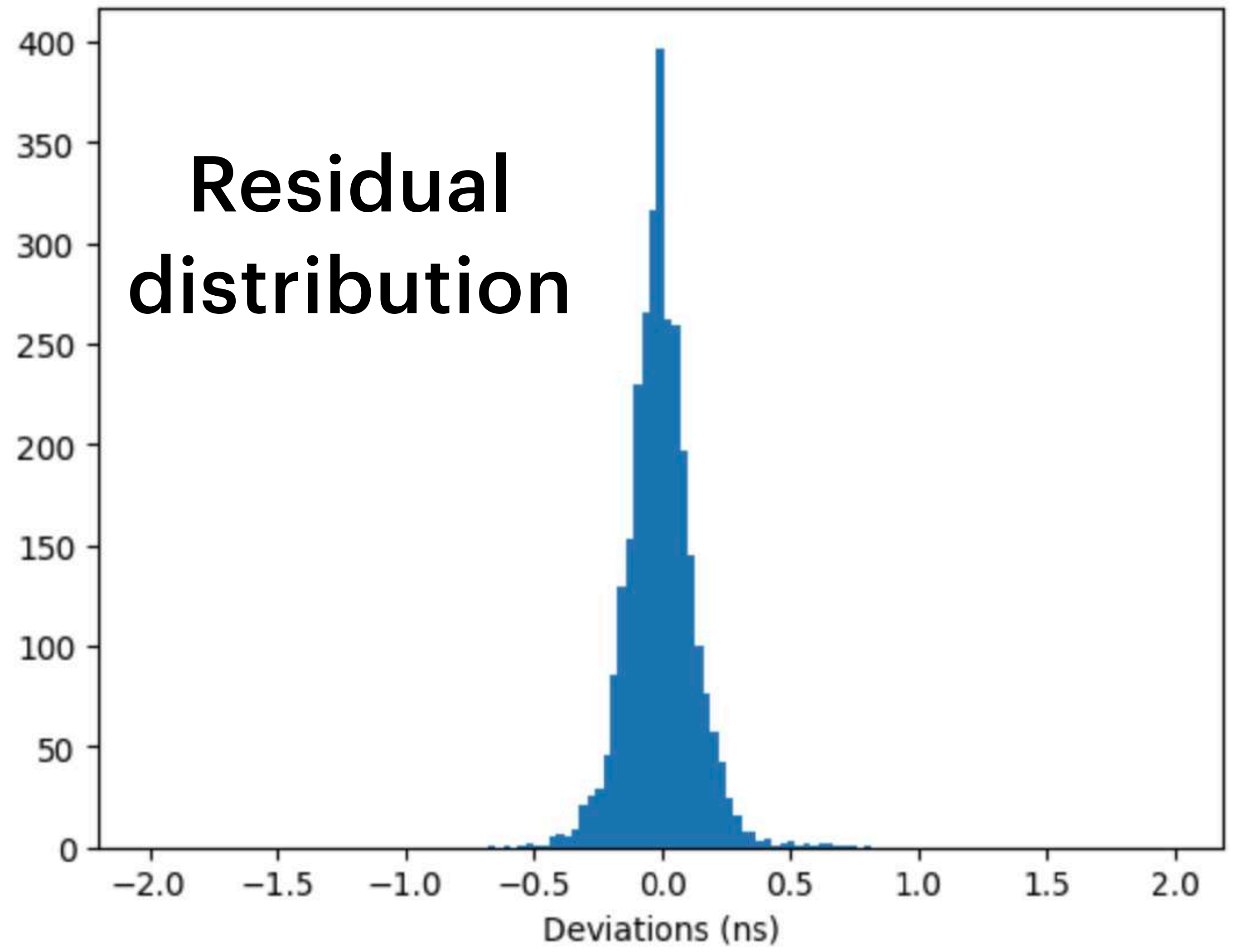
$$t_{iljk} = d_{iljk}\frac{n}{c} + (\delta_j - \delta_i) + \epsilon_{il} + \alpha_{jk}$$

Quantities of interest

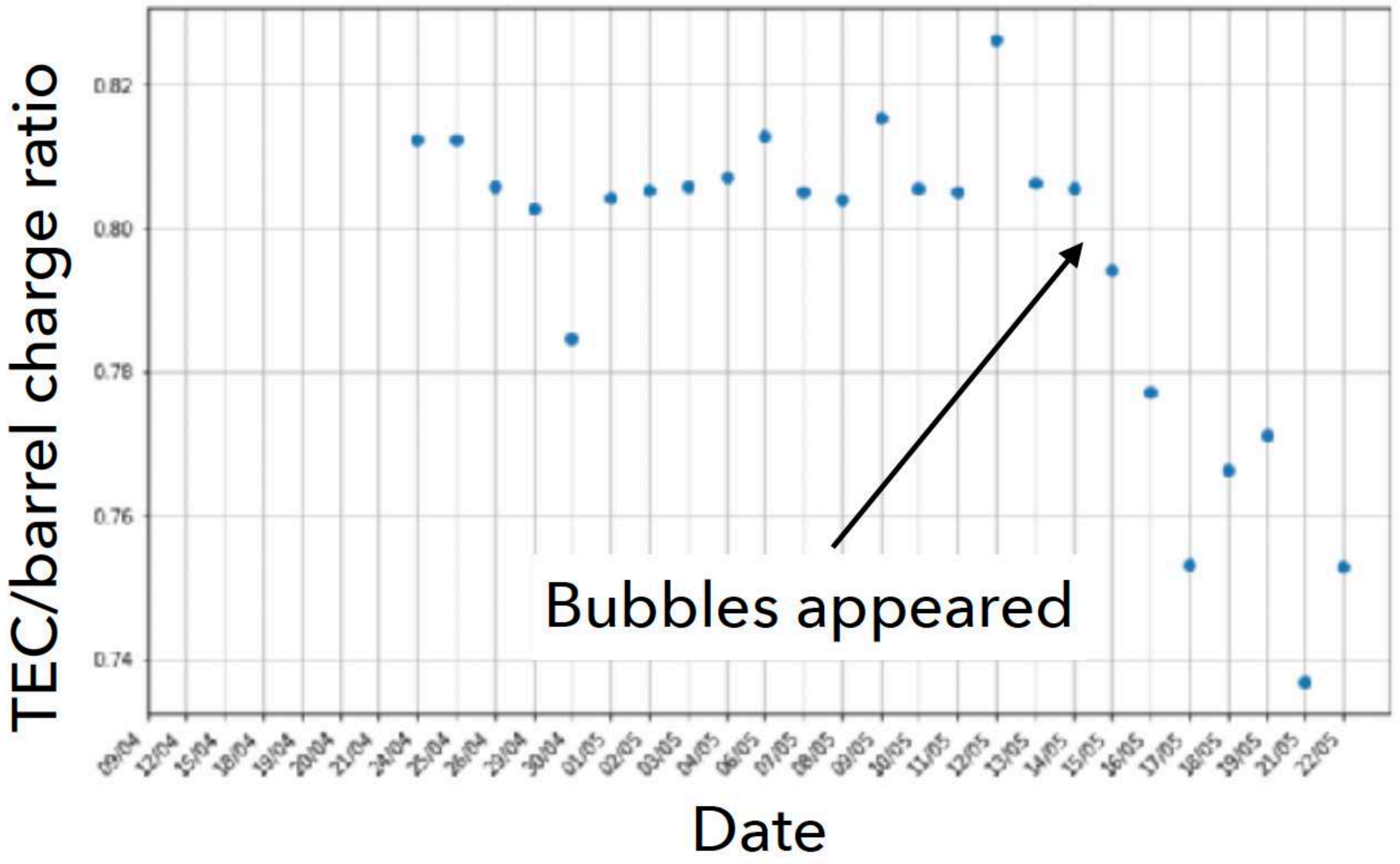
TIMING CALIBRATION



Solve the system of linear equations to extract the timing delays in the system



After calibration, can look at difference between predicted timing (based on geometry) and calibrated arrival time

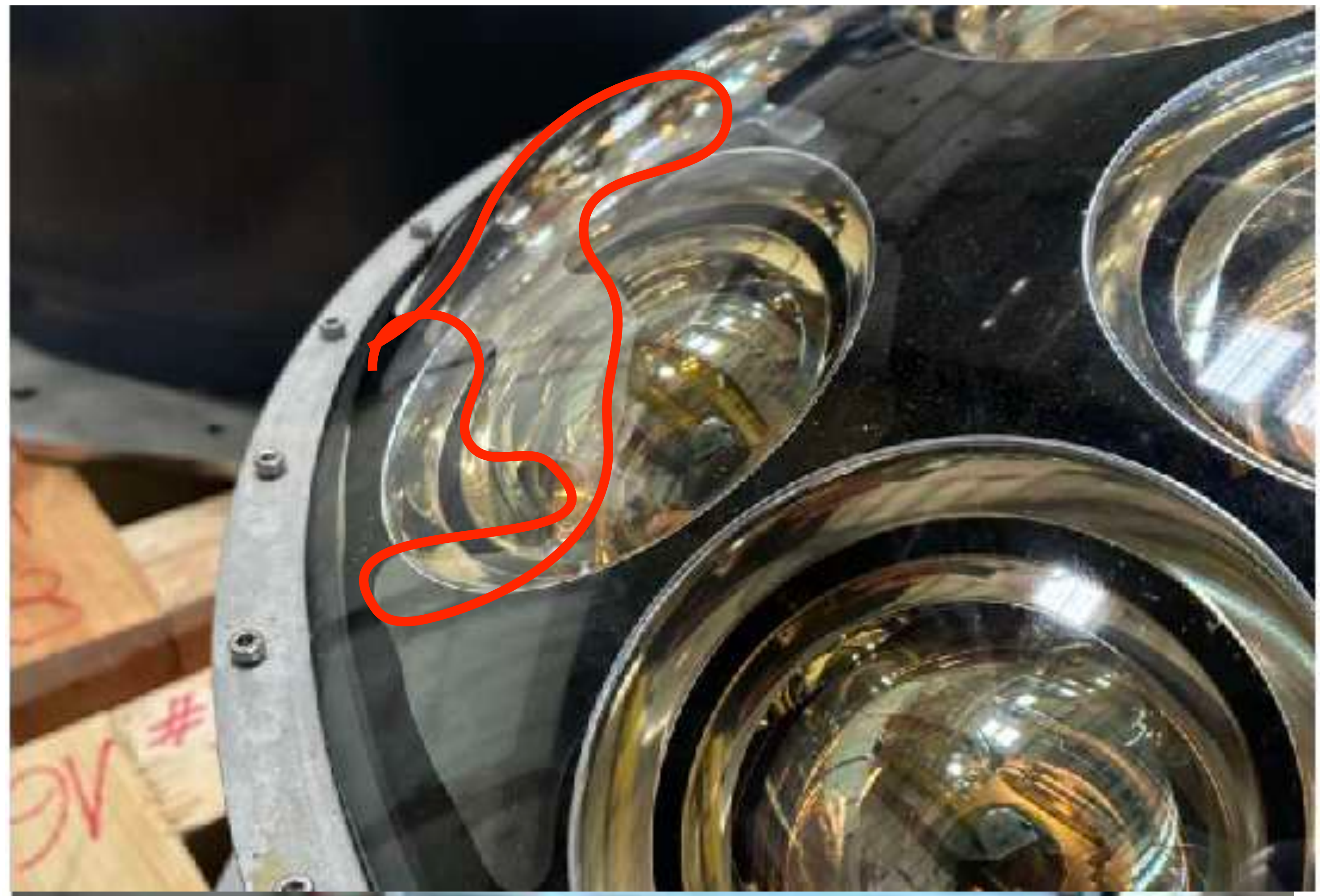


LED data are taken several times a day, and have been useful for identifying occasional clock synchronization issues and change in detector operational conditions (e.g. bubbles on mPMTs)

Demonstrated that using internal LEDs in each mPMT allows for accurate and efficient timing calibration, an approach now adopted for the full IWCD detector.

MPMT EXPERIENCE

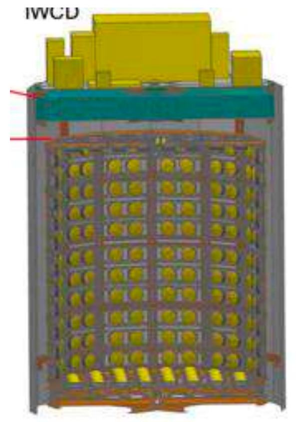
- 83 working mPMTs in WCTE at the start of 2025 run
  - 93 mPMTs installed, 10 mPMTs had problems (of these at least 50% can be trivially fixed)
  - Gel delamination was observed only in in-situ mPMTs; none was observed in ex-situ or repaired in-situ mPMTs.
- The leading hypothesis is that it is caused by the thermal shrinkage of the gel due to the lower operational temperature



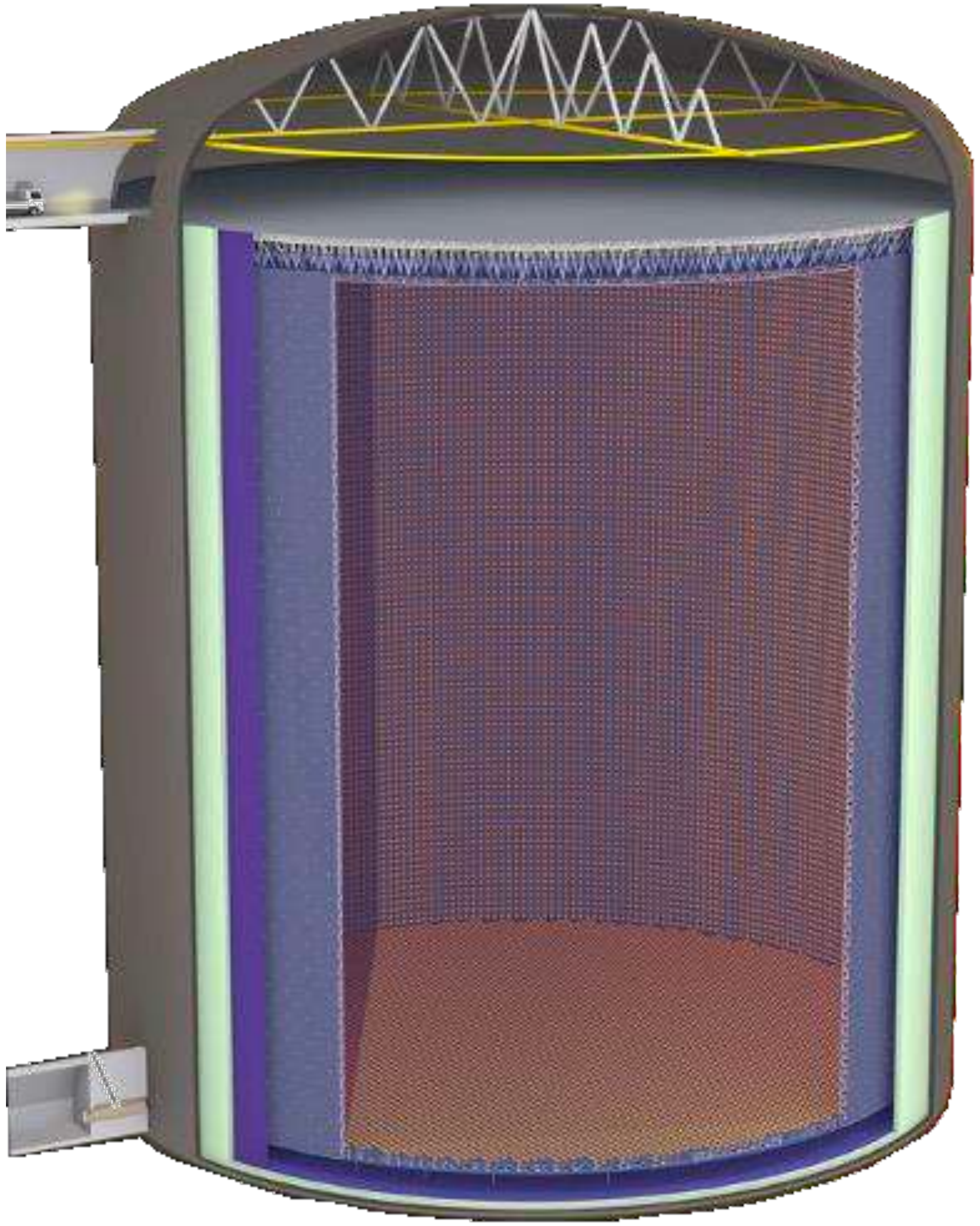
Solution:

- Confirmed that we can reproduce gel delamination by placing the mPMT at temperatures of 15 °C.
- Mechanical compression is required to push the gel toward the dome.
- A couple of methods have been tested and are under finalisation.

WCTE



IWCD



Hyper-Kamiokande