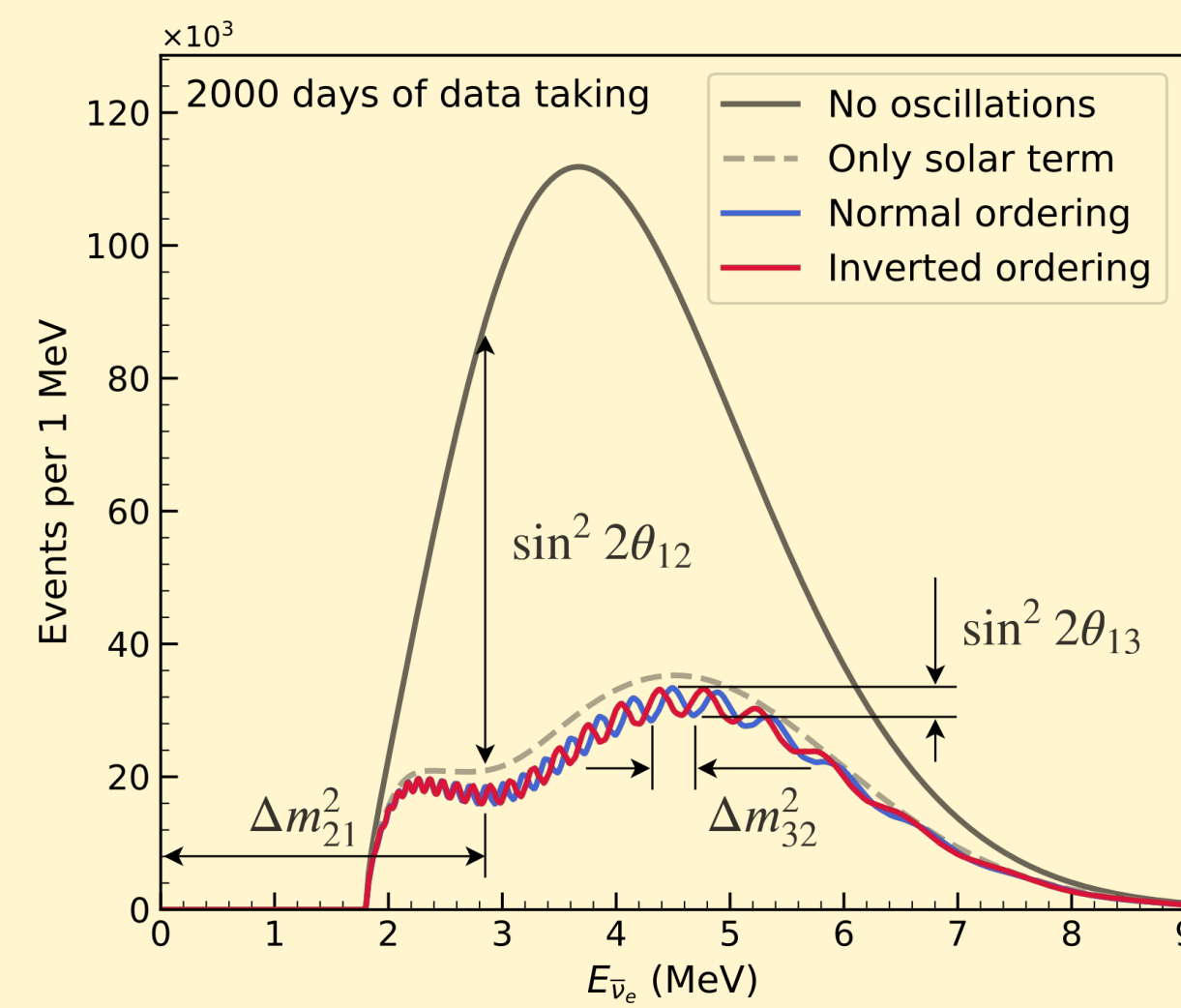
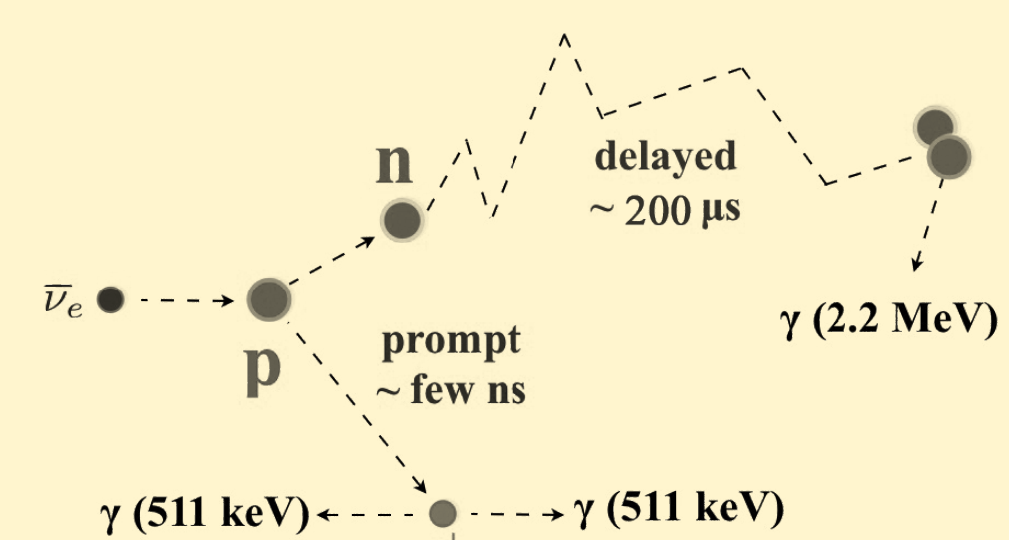


Jiangmen Underground Neutrino Observatory (JUNO):

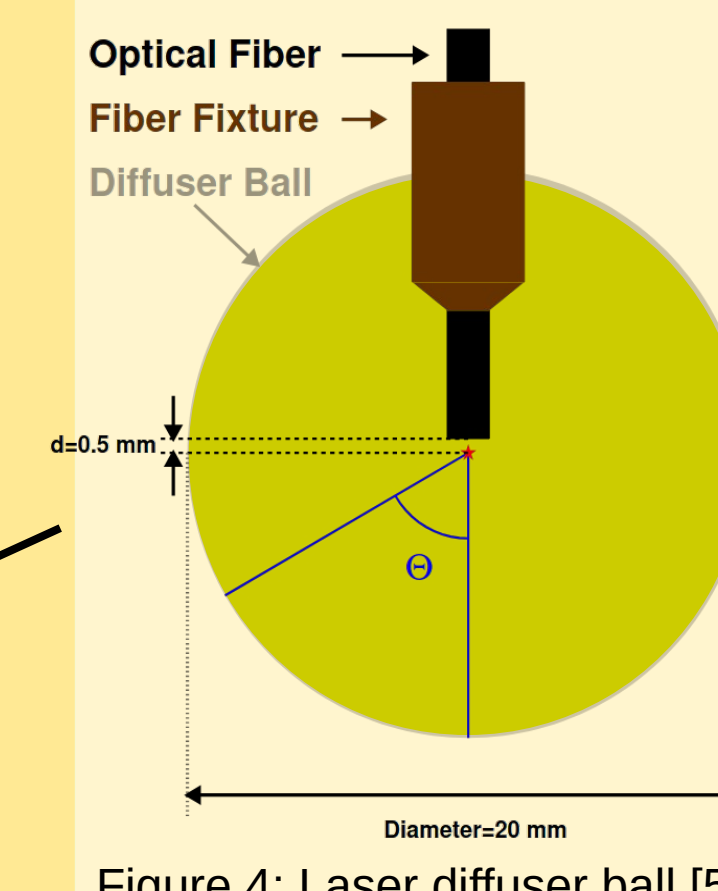
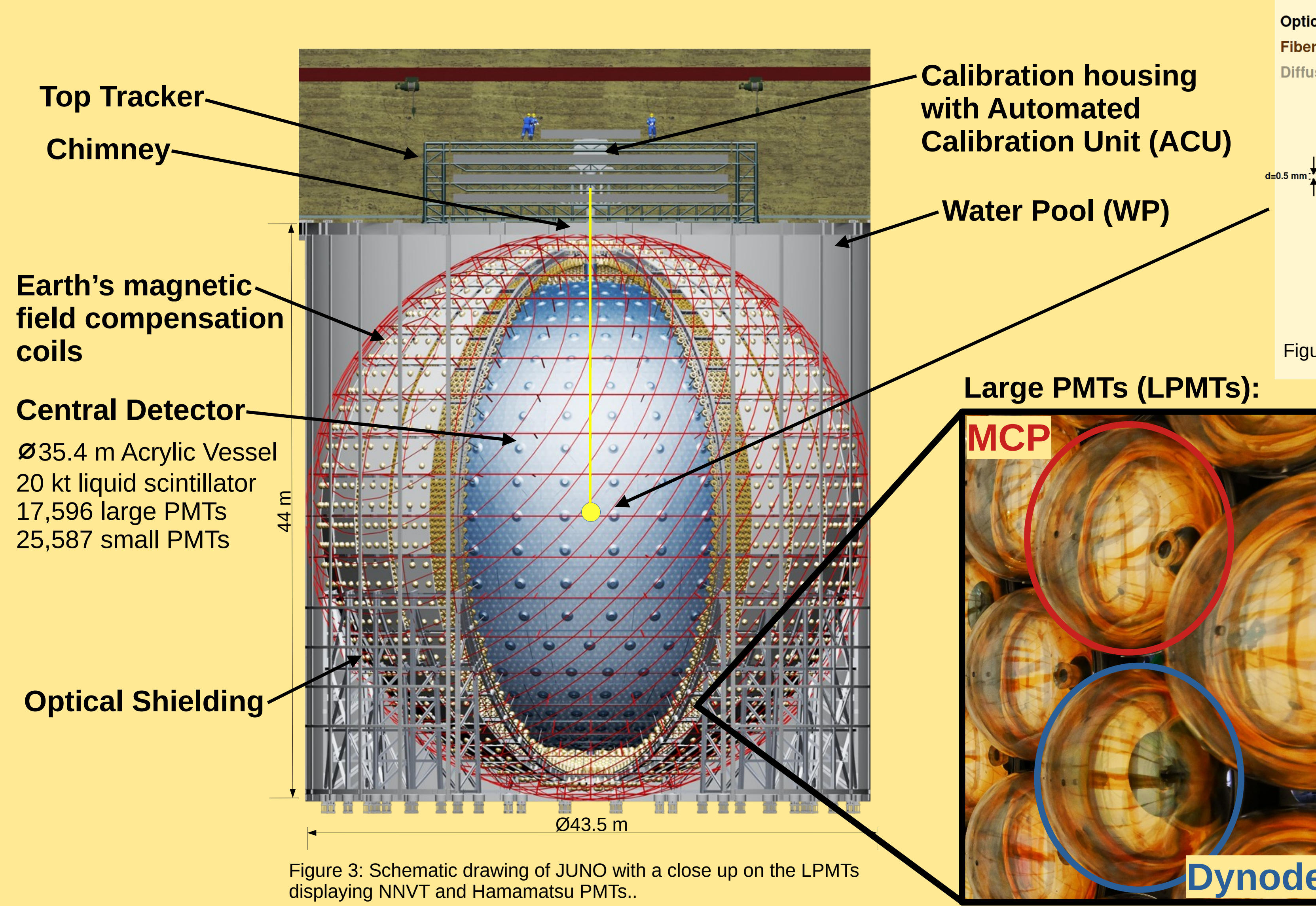
- 20 kt spherical liquid scintillator detector, located in southern China.
- 650 m overburden reduces cosmic muons induced backgrounds.
- Main Physics goal: Determine the neutrino mass ordering (NMO) by measuring the reactor electron anti-neutrino spectra at a 52.5 km baseline.
- Physics data taking started on 26th August 2025 after successful commissioning.
- First results with world leading solar oscillation parameter precision and initial detector performance released in November 2025 [1],[2].

NMO Determination:

- Reactor anti-neutrinos detection via:



- Designed energy resolution of 3% at 1 MeV.
- NMO sensitivity of 3σ after 6 years [3] and sub-percent precision on oscillation parameter.



Laser system for PMT calibration:

- Laser: FQSS266-Q4-1k 266 nm UV laser or 420 nm.
 - Plastic (PTFE) diffuser ball for uniform light distribution.
 - ACU can deploy diffuser along the central Z-axis of CD.
 - Weekly calibration: external trigger with 50 Hz rate.
- Performance:**
- Timing precision <1 ns, with a stability of 1%.
 - Light intensity tunable.

Large 20" PMT (LPMT) system:

- LPMTs and small PMTs (sPMTs) combined geometrical coverage 78%.
- **12,657 MCP** PMTs - GDB6201 Northern Night Vision Technology Co.
- **4,939 Dynode** PMTs - R12860-50 Hamamatsu Photonics K.K.

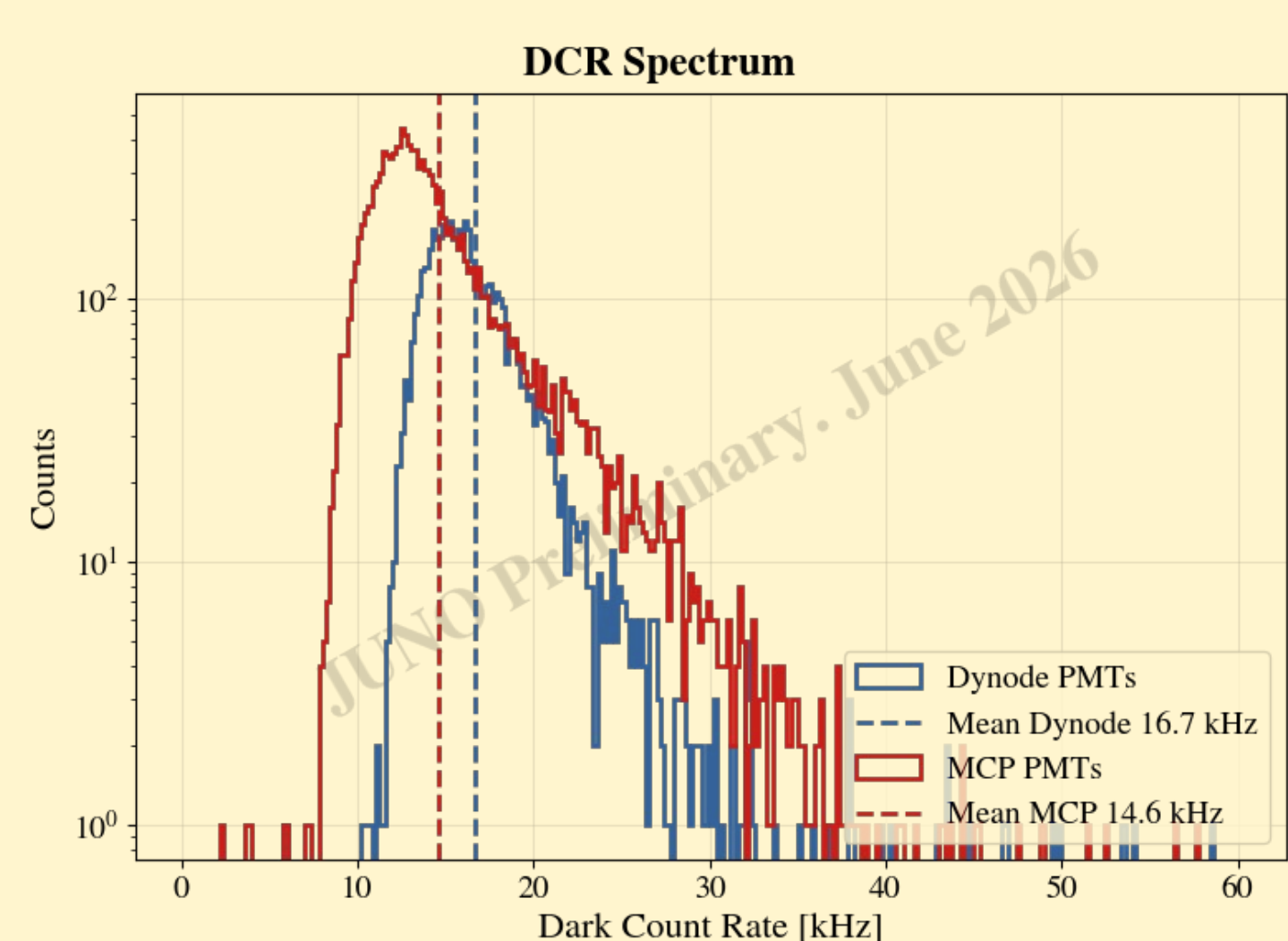
LPMT characteristics:

	MCP PMTs	Dynode PMTs
Photon detection efficiency [%]	30.1	28.5
Transit Time spread [ns]	7.0	1.3
Risetime Falltime [ns]	4.9 17.3	6.9 10.2

Table 1: JUNO LPMT main parameters for qualified PMTs from mass PMT testing [6].

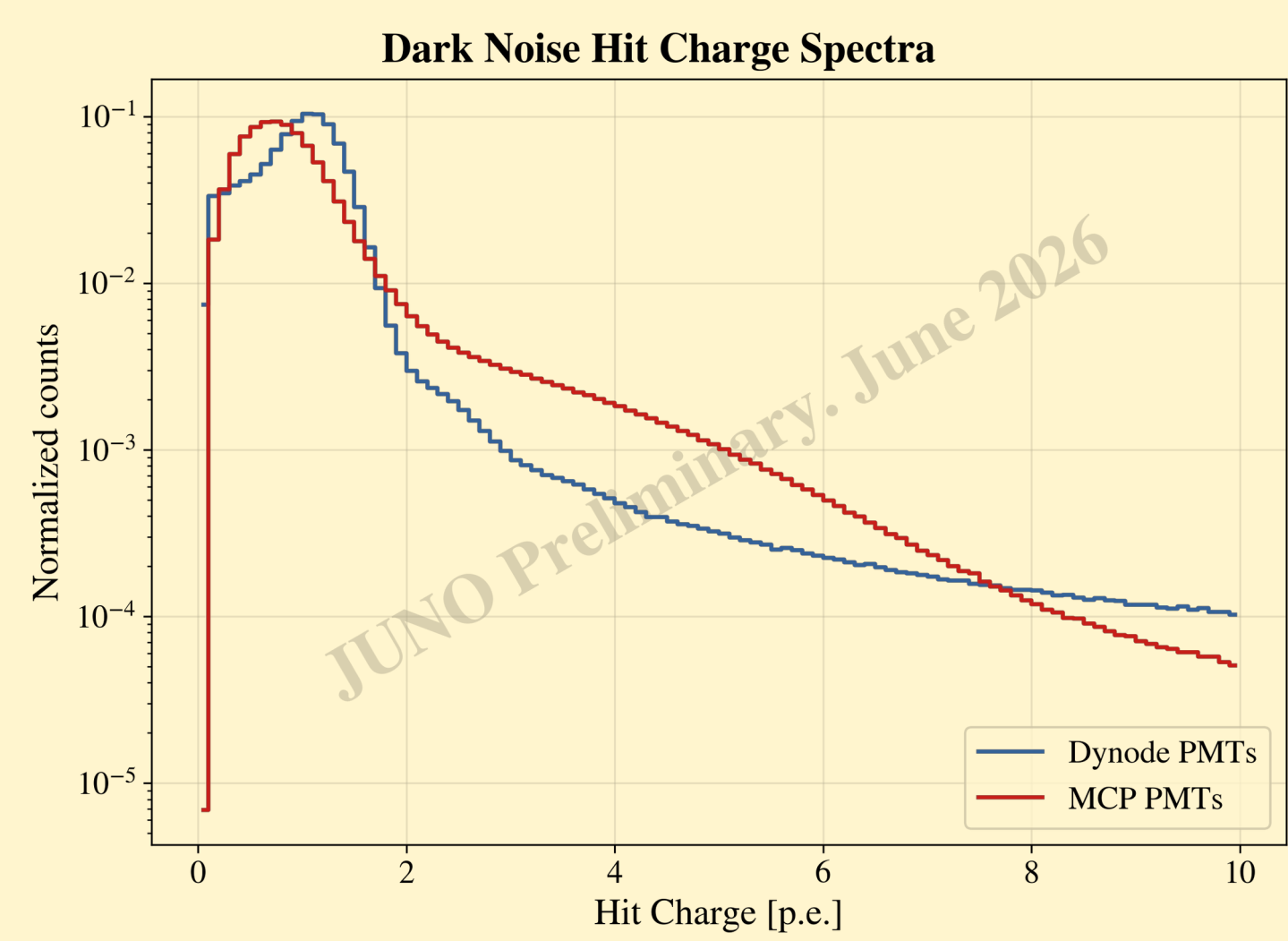
Dark count rate (DCR) from periodic trigger:

- Run-by-run DCR to be subtracted for the reconstruction.
- Mean **Dynode** DCR is higher than mean **MCP** DCR.
- Changes in the High Voltage (HV) or detector settings can lead to shifts in the DCR observed.
- in ranges [14.6,21.7] kHz for **MCP** and [16.7,23.1] kHz for **Dynode**.
- The mean HV has been lowered from 1597 V to 1541 V for **MCP** and 1754 V to 1705 V in **Dynode** PMTs to elongate PMT lifetime.



Dark Noise (DN) Hit Charge:

- Run-by-run DN hit charge distribution from periodic trigger.
- The DN hit charge stability is monitored to be compared with gain from weekly laser calibrations.
- After severe sPMT flashers in January 2026 the relative DN hit charge evolution has been used in the daily gain interpolation, till the next laser calibration run was taken.



Gain Calibration from external laser trigger:

- The single p.e. response per PMT $S_1(q)$ is used to define the gain.
 - The measured PMT response can be expressed as $S_{ideal}(q) = \sum_{n=0}^{\infty} P(n, \mu) S_n(q)$ with the probability $P(n, \mu)$ to detect n p.e. for a mean laser occupancy μ .
- Mean Gain:** $G_m = \int q S_1(q) dq$

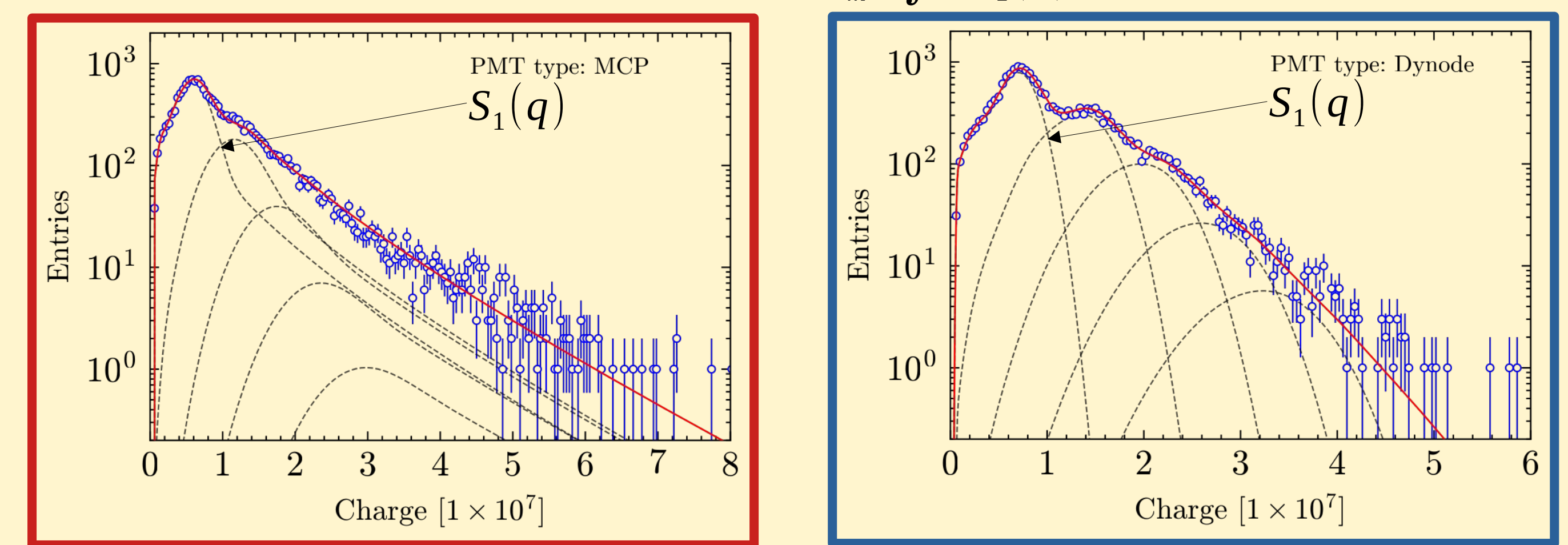


Figure 7: Fitted charge spectra for MCP (left) and Dynode (right) PMTs extracting the single p.e. response from laser data [2]. Dashed lines show the individual contribution up to 5 p.e.

Gain evolution:

- Mean Gain changes with HV changes and threshold changes.
- **MCP** mean gain drops caused by sPMT flashers in winter 2025/26.
- Daily gain interpolation is linear interpolation of laser runs, following DN hit charge evolution if sPMT flasher after calibration run.

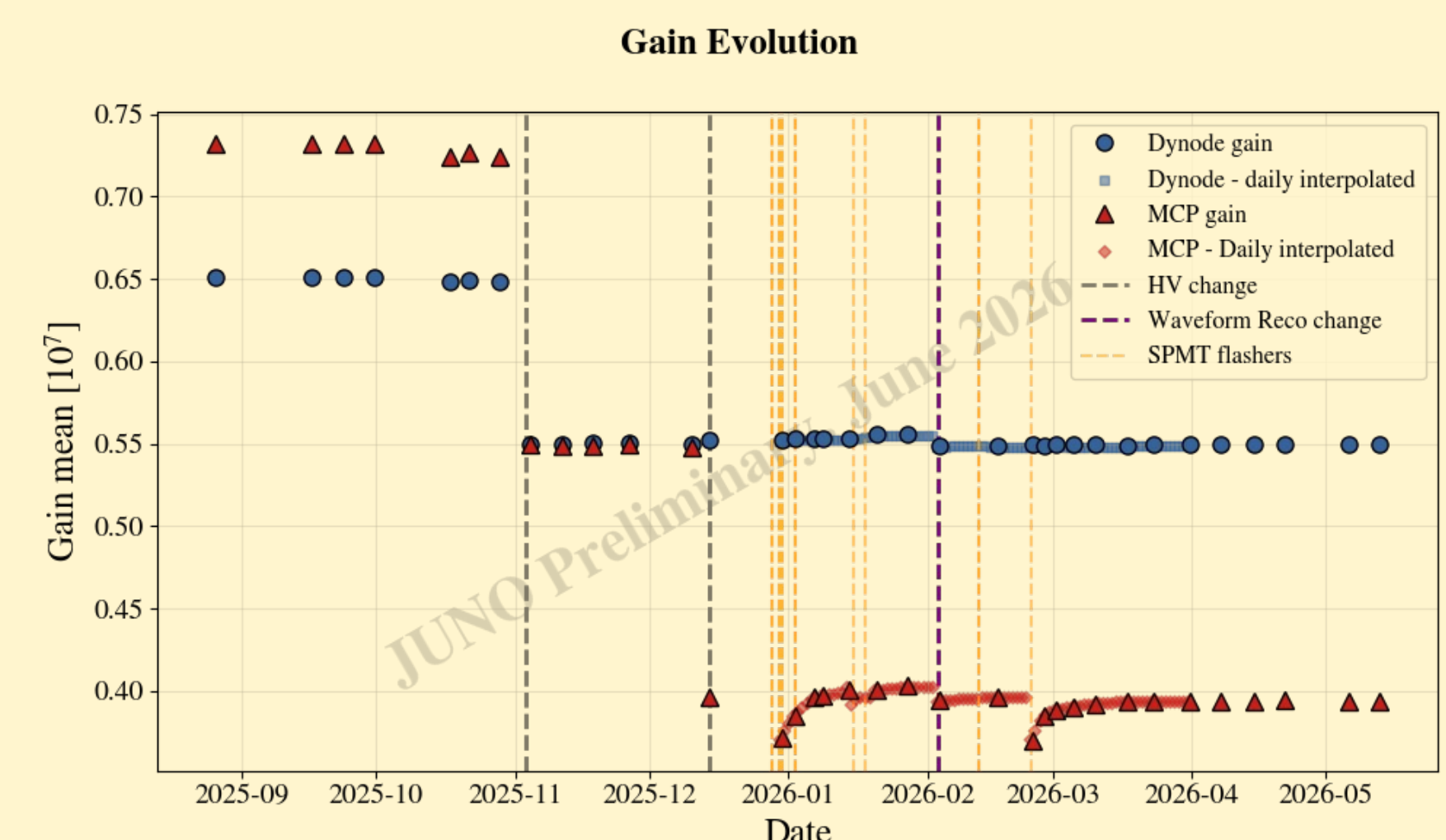


Figure 8: Evolution of the mean gain over time, the solid markers show the weekly gain calibration results, daily interpolation is shown by squares and diamonds.

Timing Calibration from external laser trigger:

- **Transit Time** defined as $TT_i = HitTime_i - ToF_i - t_0 \rightarrow$ **TimeOffset**: maximum of TT
- **HitTime**: First time the waveform of i^{th} PMT exceeds threshold.
- **Time of flight (ToF)**: Calculated flight time of light between diffuser and PMT i .
- t_0 : Reference time of laser in waveform window taken by external monitor PMT.
- TT_i fitted with PMT Response and wavelength-dependent Scintillation Component.

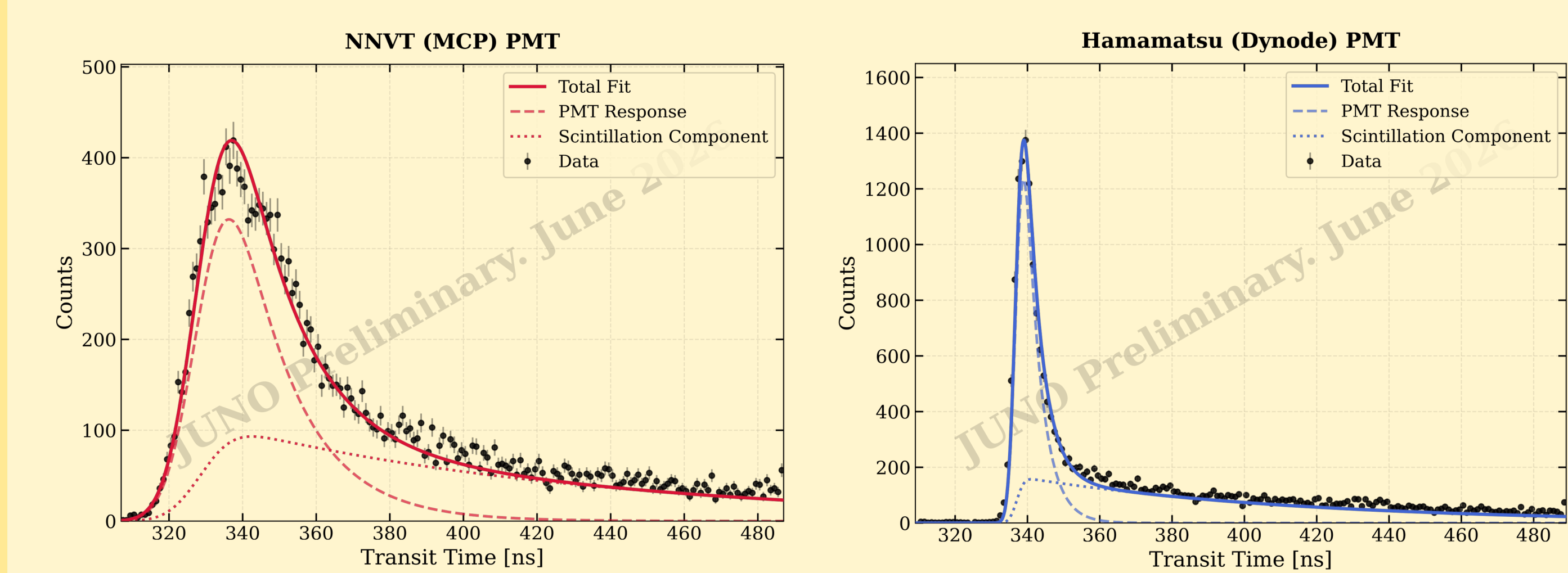


Figure 9: Example fit of the transit time distribution of 420 nm Laser to determine the timing offset per PMT.

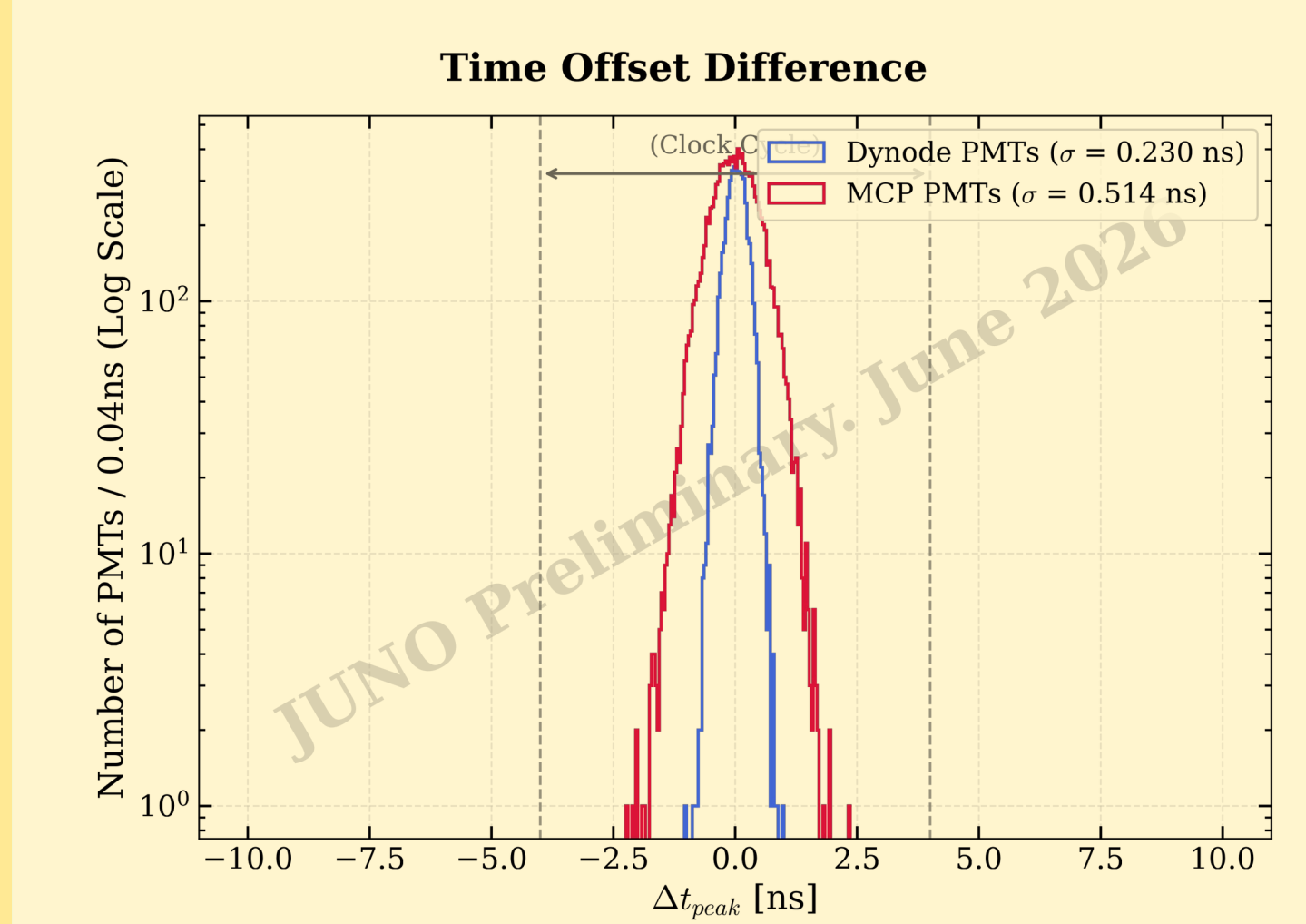


Figure 10: Time Offset Difference of consecutive calibrations for NNVT and MCP PMTs.

- Time offset differences per PMT for consecutive runs shows:
- Resolution of the distribution is <1 ns \rightarrow Sub-ns agreement of consecutive weekly calibration constants.
 - Excellent timing stability of $>99.8\%$ from comparing weekly calibrations.