Characterization of the JUNO Large-PMT readout electronics

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On behalf of the JUNO collaboration

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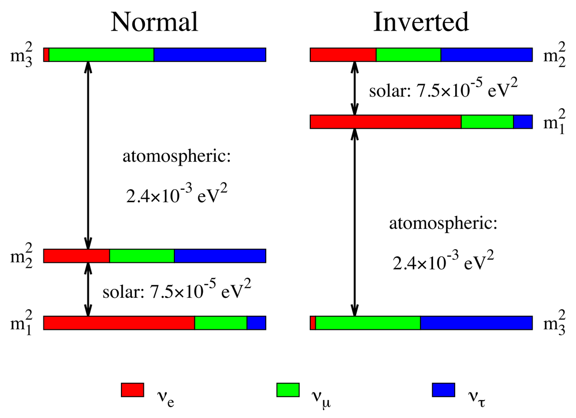
Jiangmen Underground Neutrino Observatory

JUNO is a neutrino medium baseline experiment with an expected unprecedented energy resolution of 3% at 1 MeV, under construction in southern China.

Extensive **neutrino physics & astrophysics program** [1]

- Reactor $\bar{\nu}_e$: 60 IBD/day
- SN burst: 5000 IBD + 2300 ES (@ 10 kpc)
- DSNB: 2-4 IBD/year
- Solar ν: O(100)/year
- Atmospheric ν: O(100)/year
- Geo-ν: ~400/year

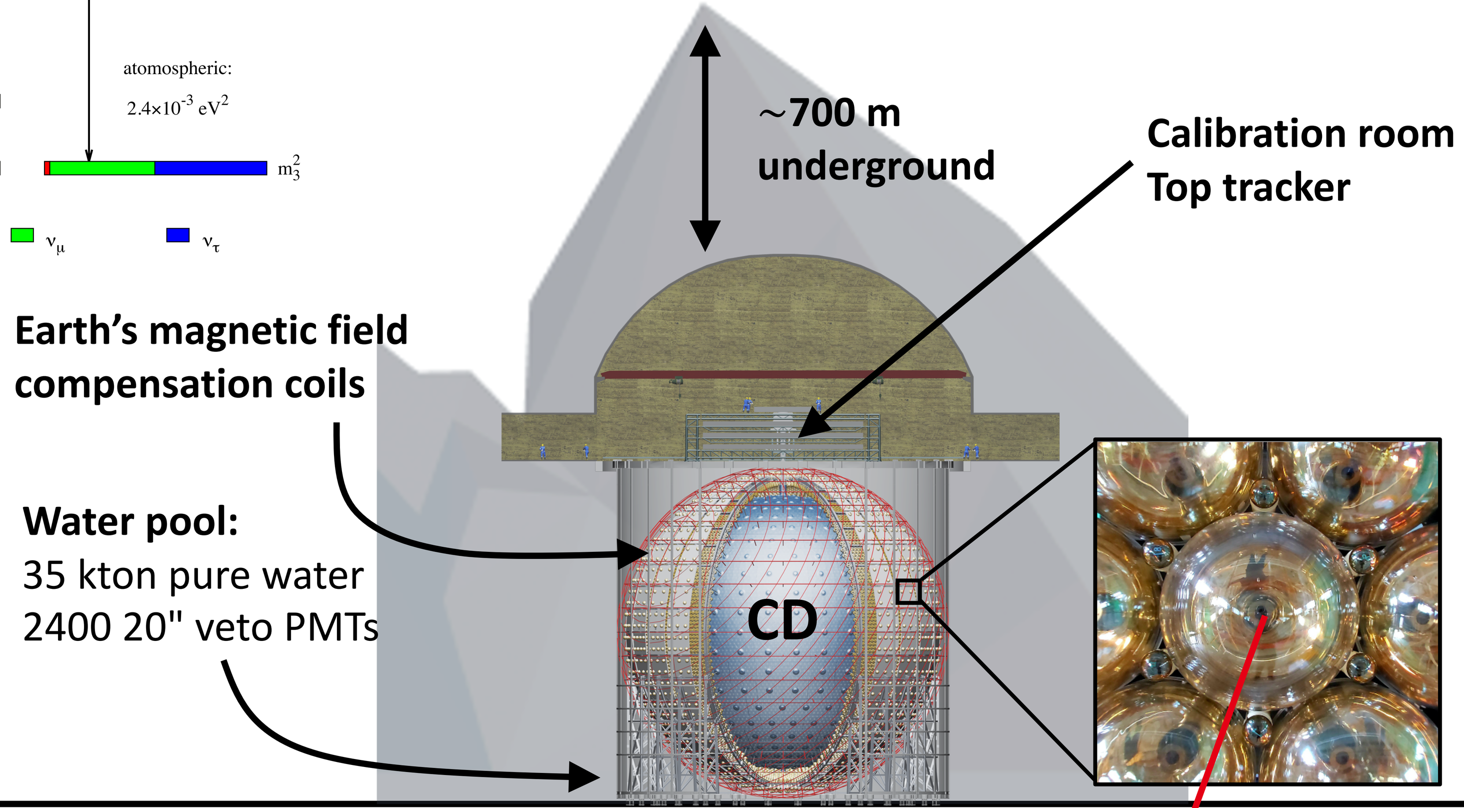


Main physics goals:

- neutrino mass ordering determination @ 3σ in 6 years
- measurement of three oscillation parameters with sub-percent precision

Central detector (CD): 20 kton liquid scintillator (LS) inside an acrylic vessel (AV) (⌀ 35.4 m), supported by a stainless steel latticed shell

PMT system: ~18000 20" (Large-)PMTs, ~25600 3" (small-)PMTs, photocoverage > 75%, ~1300 pe/MeV expected

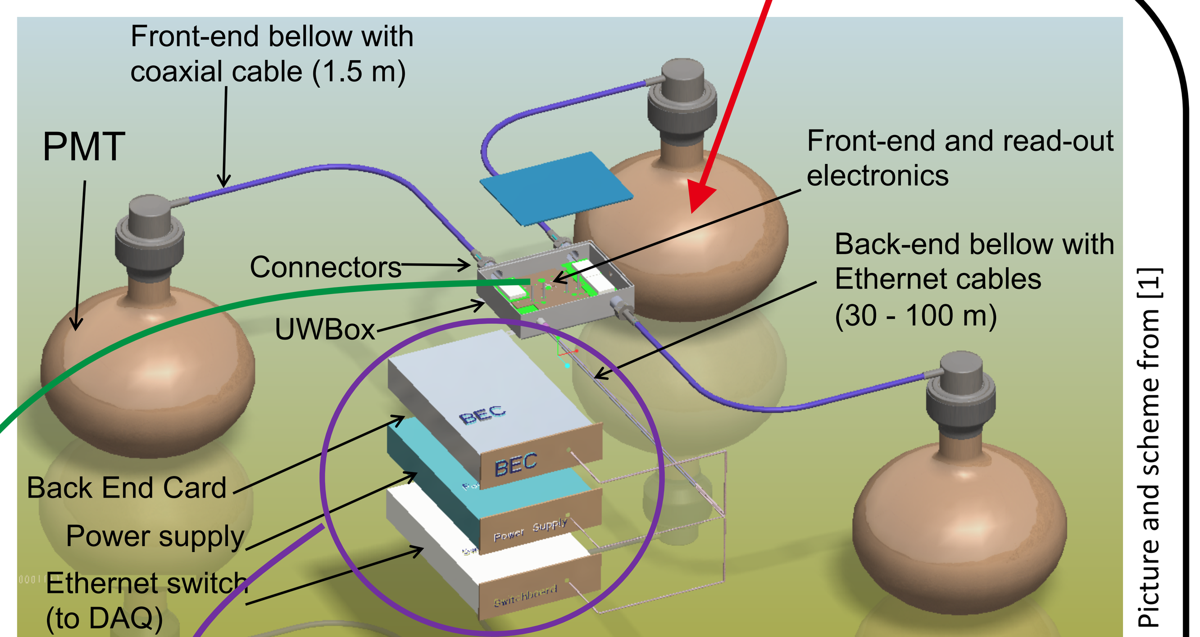


Large-PMT readout electronics

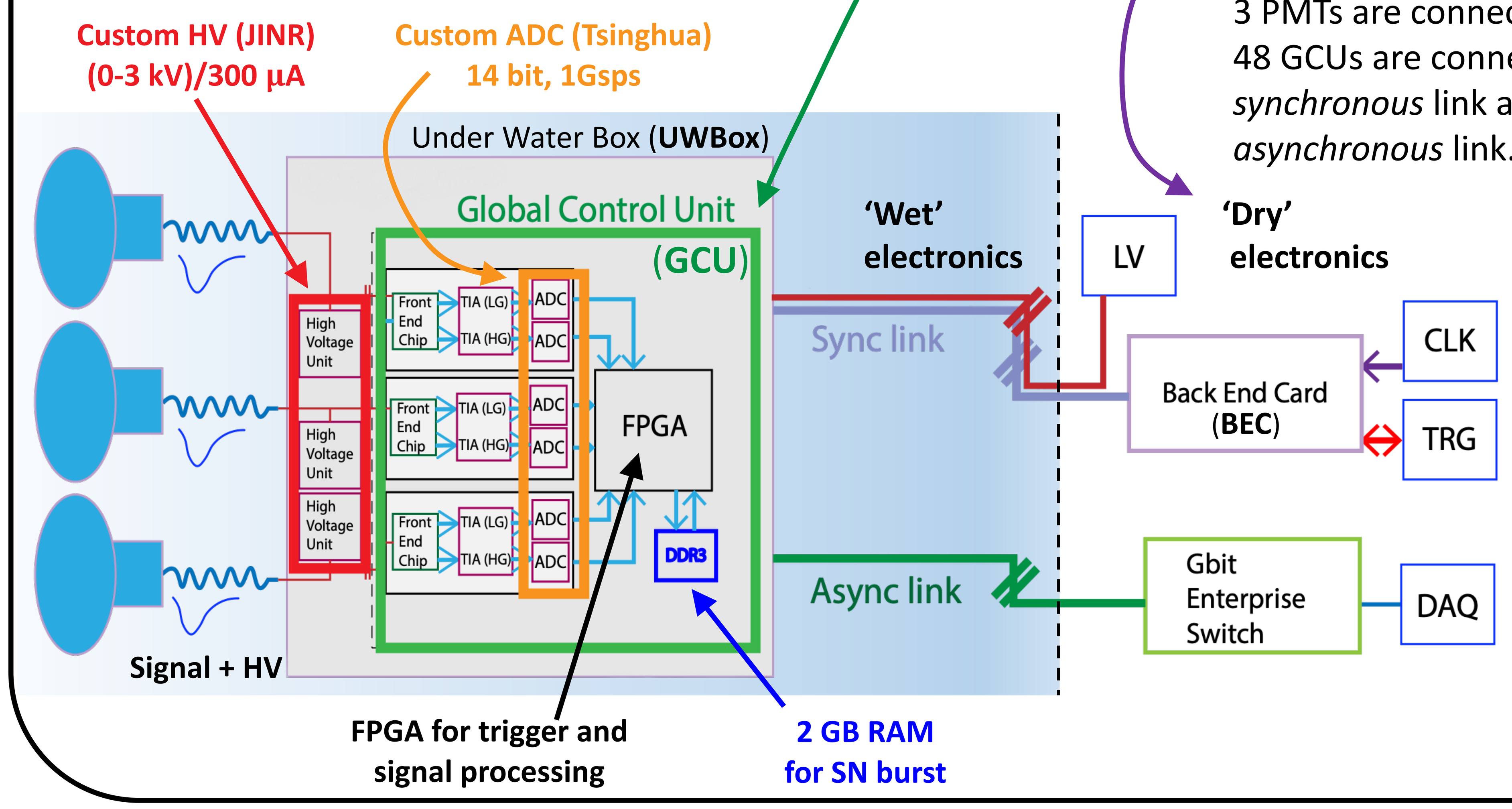
Main tasks: digital conversion of the analog signals from the PMTs, local trigger generation, charge reconstruction, timestamp tagging, temporary storage in local FPGA memory, data transfer to DAQ.

Electronics specifications [1,3]

- Waveform sampling: 1 GS/s
- Wide dynamic range: 1-1000 pe
- Acquisition rate up to 10 kHz
- High reliability over time (~6 years)



3 PMTs are connected to 1 UWBox/GCU; 48 GCUs are connected to 1 BEC through the *synchronous* link and to 1 switch through the *asynchronous* link.



Total components:

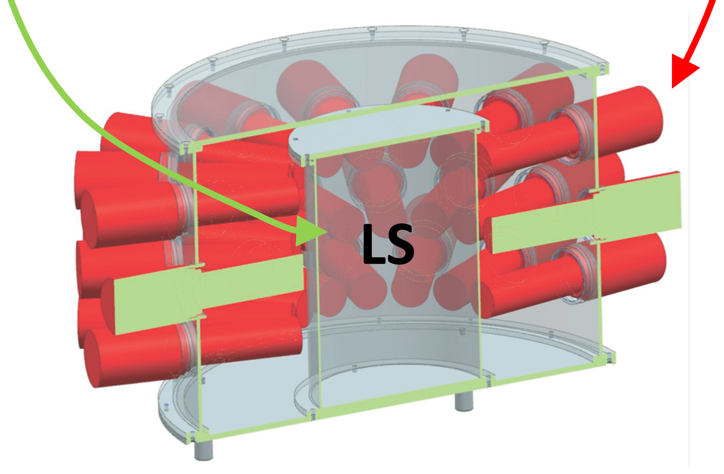
- ~18000 LPMTs
- ~6000 GCUs
- ~125 BECs
- 1 Global Trigger Unit

GCUs are the key component in the processing of Large-PMT signals: a thorough characterization is required.

Tests of the Large-PMT readout electronics at LNL[(*)]

Setup

- 20 l liquid scintillator (LS)
- 13 boards (GCUs)
- 39 channels (37 active) with PMTs
- 1 back-end card (BEC)
- 3 plastic scintillator bars to trigger cosmic muons

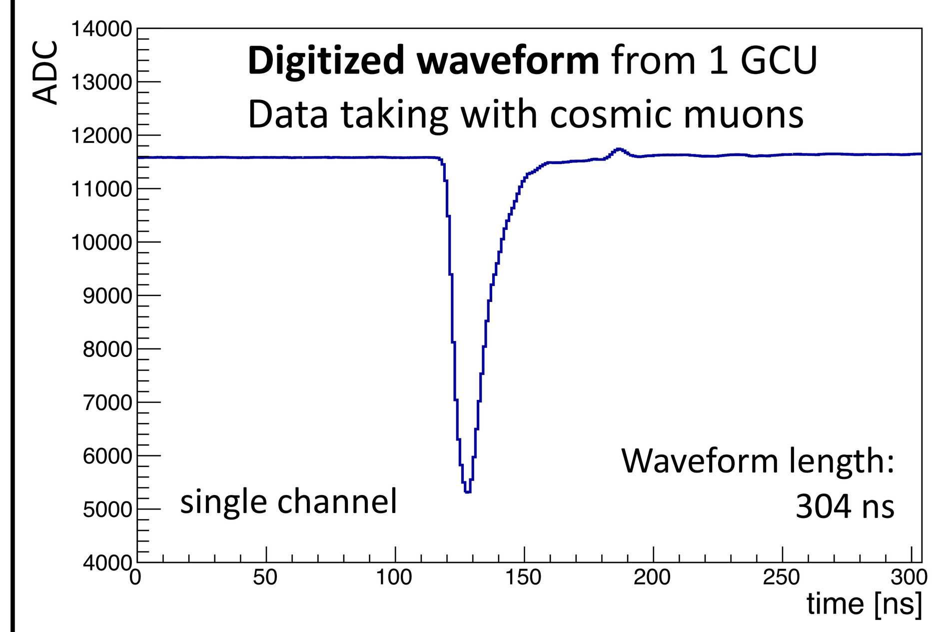


Note: the PMTs used in this setup are not JUNO's PMTs.

Next step: complete the synchronous link chain with the Global Trigger Unit and test the whole electronic chain.

Data taking

- laser
- cosmic muons
- calibration sources
- internal test pulser

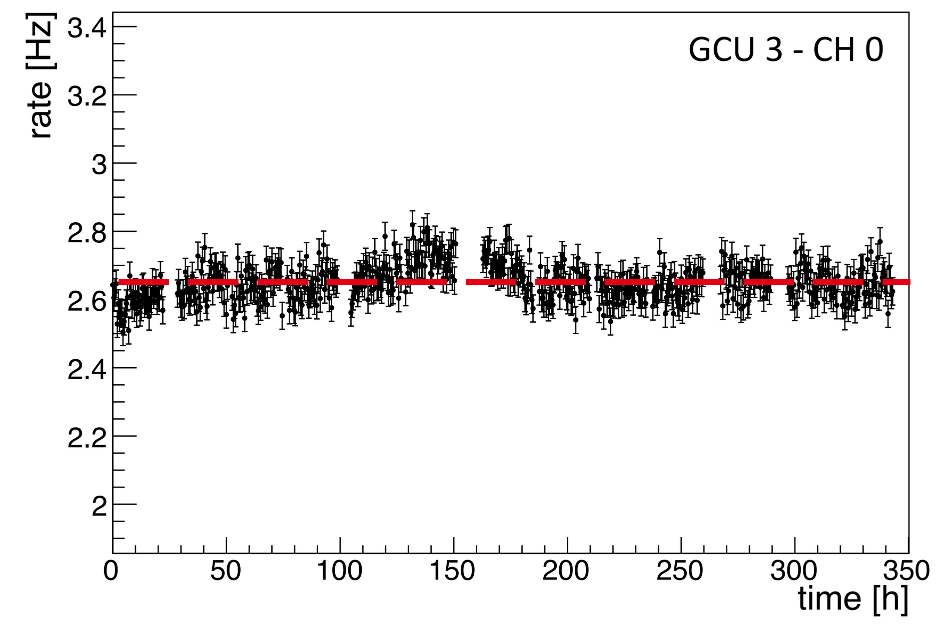


Waveform properties to check:

- baseline
- noise
- integrated charge
- packet size validity
- timestamp validity

Trigger rate stability

- with cosmic muons (external trigger)
- 13 1-day-long runs over 14 days
- almost 350 consecutive hours of runtime

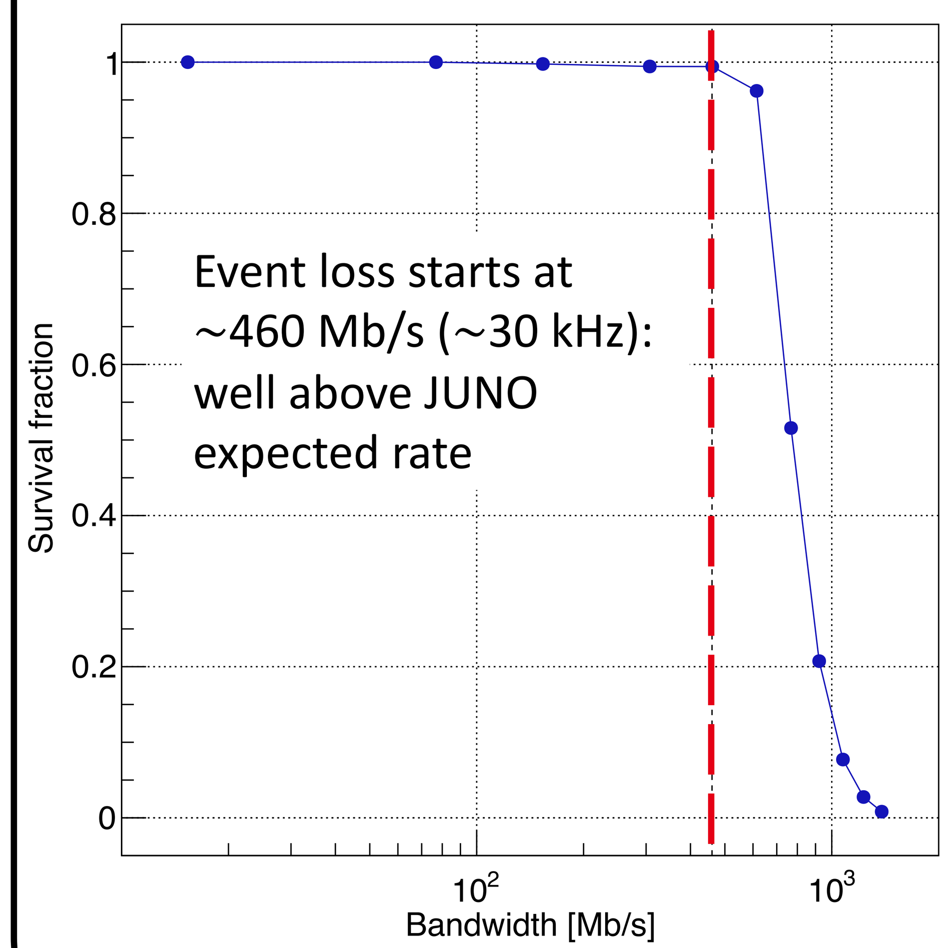


Measured cosmic muon rate ≃ 2.65 Hz. During the test, we verified that all 13 GCUs stayed **synchronized** over the whole data taking period.

Bandwidth measurement

- external pulser at fixed rates: 1-100 kHz
- data acquisition from 3 channels of 1 GCU
- fixed packet size: 1 event = 5.12 kb
- survival fraction:

$$\frac{\textit{\# of events acquired by all 3 channels}}{\textit{\# expected events}}$$



bandwidth [Mb/s] = *rate* [evt/s] × × *packet_size* [kb/evt] × (# *channels*)

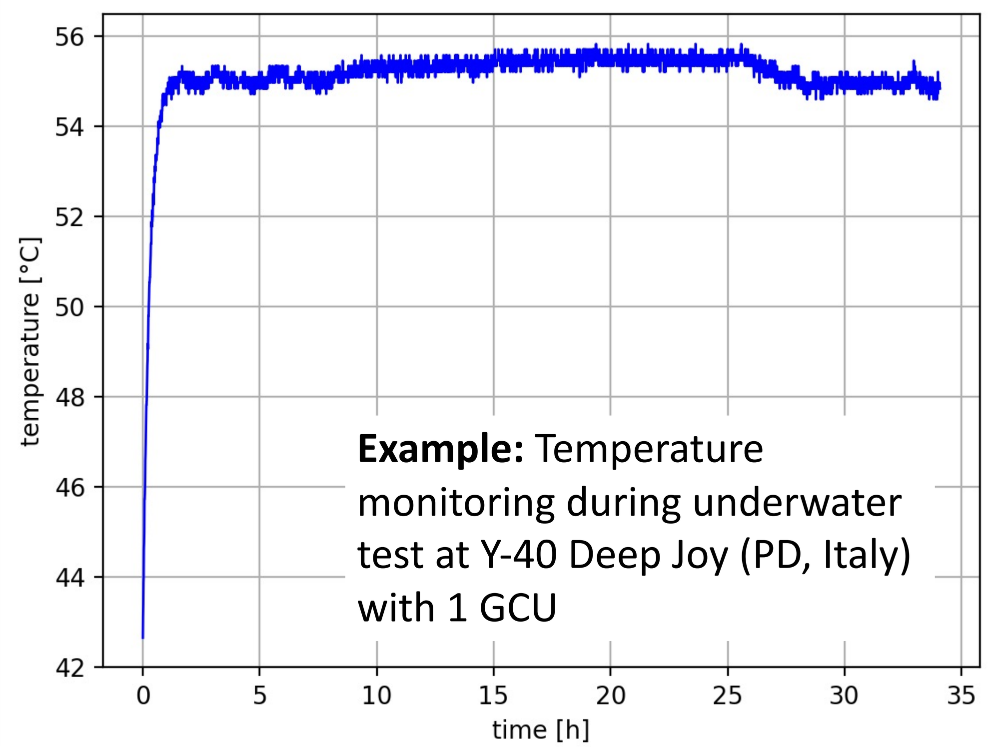
Future tests and upcoming large-scale integration test

Tests with a laser:

- check linearity of the ADCs
- timing measurements: check temporal synchronization of the GCUs

Slow control:

- check parameters:
  - temperatures
  - internal voltages
  - internal currents
- check connection with HVUs



Integration test in Kunshan, China: development of a test protocol to test ~270 GCUs at the same time during production cycle

- check network connection
- slow control monitoring
- use of internal test pulser:
  - long run to check stability over time
  - short runs at different amplitudes to check linearity

References:

[1] JUNO Collaboration, *JUNO Physics and Detector*, 2021, arXiv:2104.02565

[2] JUNO Collaboration, *Neutrino Physics with JUNO*, J. Phys. G43, 3, 030401 (2016) [arXiv:1507.05613]

[3] JUNO Collaboration, *JUNO CDR*, 2015, arXiv:1508.07166 (chapter 7)

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