The JUNO large PMT readout electronics

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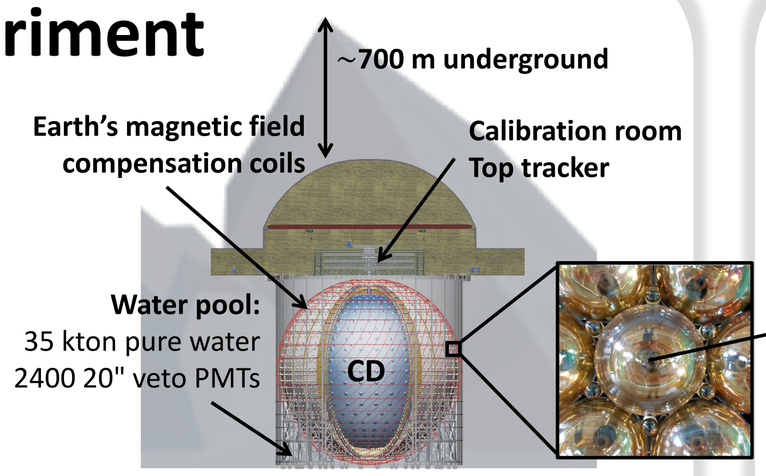
The JUNO experiment

The 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 China [1, 2].



Extensive **neutrino physics and astrophysics program:**

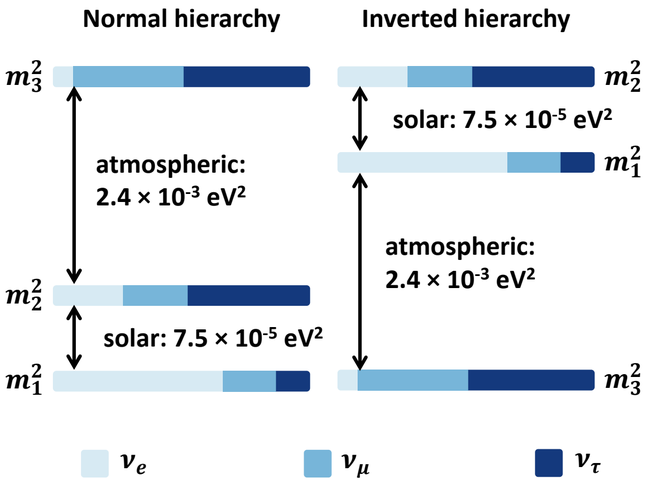
- **Reactor $\bar{\nu}_e$: 60 IBD/day**
- Supernovae burst: 5000 IBD + 2300 ES in 10 s (@ 10 kpc)
- DSNB: 2-4 IBD/yr
- Solar ν: O(10^3)/yr
- Atmospheric ν: O(10^2)/yr
- Geo-ν: ~400/yr

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

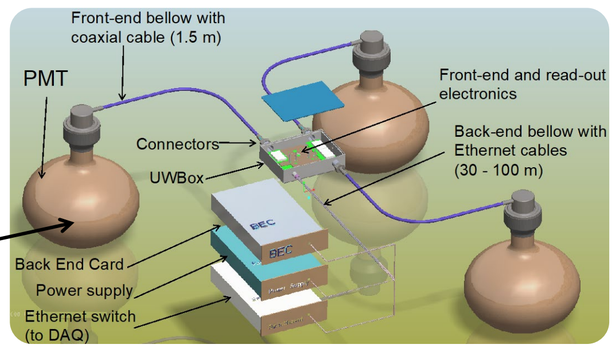
CD PMT system:
17612 20" Large-PMTs
25600 3" Small-PMTs
photocoverage > 75%

Main **physics goals**:

- **neutrino mass hierarchy** determination @ 3σ in 6yr
- measurement of three **oscillation parameters** with sub-percent precision



Large-PMT readout electronics



Total components:

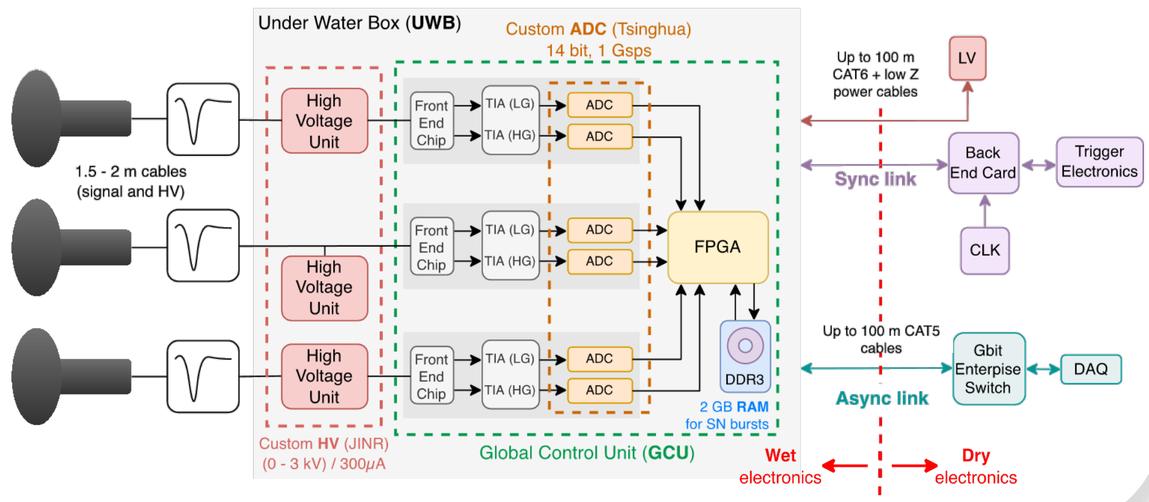
- 20012 L-PMTs
- 6670 GCUs
- 138 BECs
- 7 RMUs
- 1 CTU

3 PMTs connected to 1 UWBox;
48 GCUs connected to 1 BEC via the **synchronous** link and to 1 switch via the **asynchronous** link.

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
- **Reliability**: 0.5 % failure rate over 6 yr
- System **synchronization**: 8 ns clock

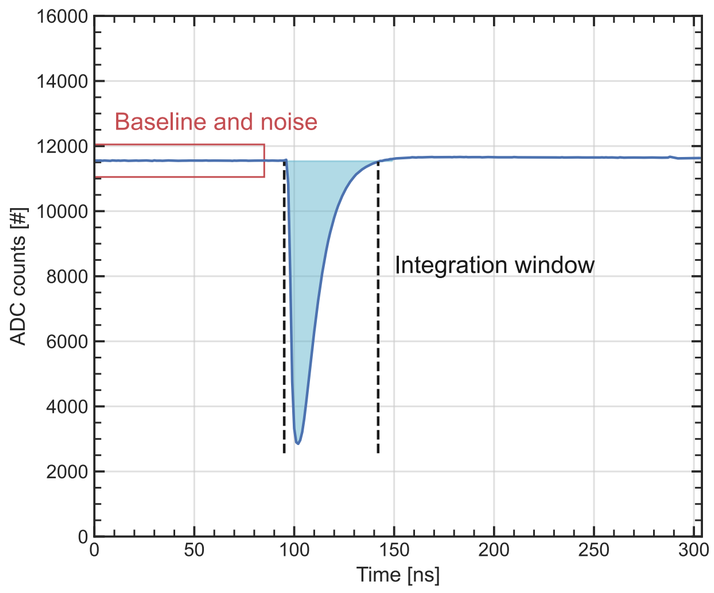


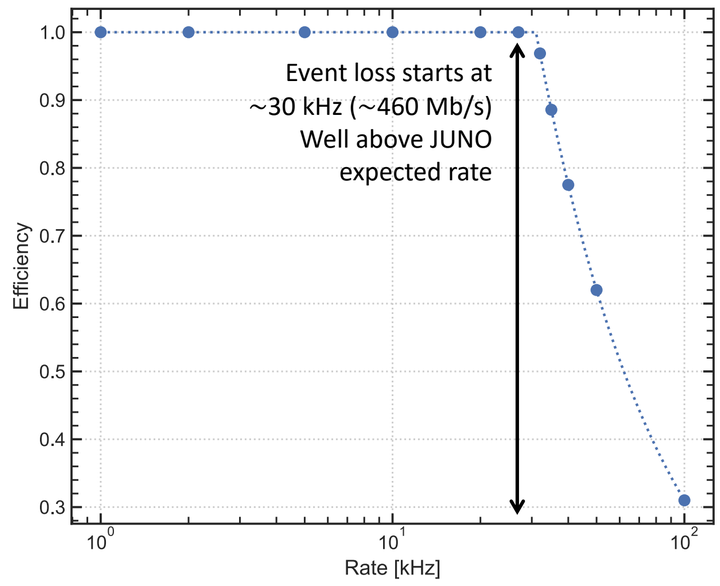
Mass testing of the Large-PMT readout electronics at Kunshan production site

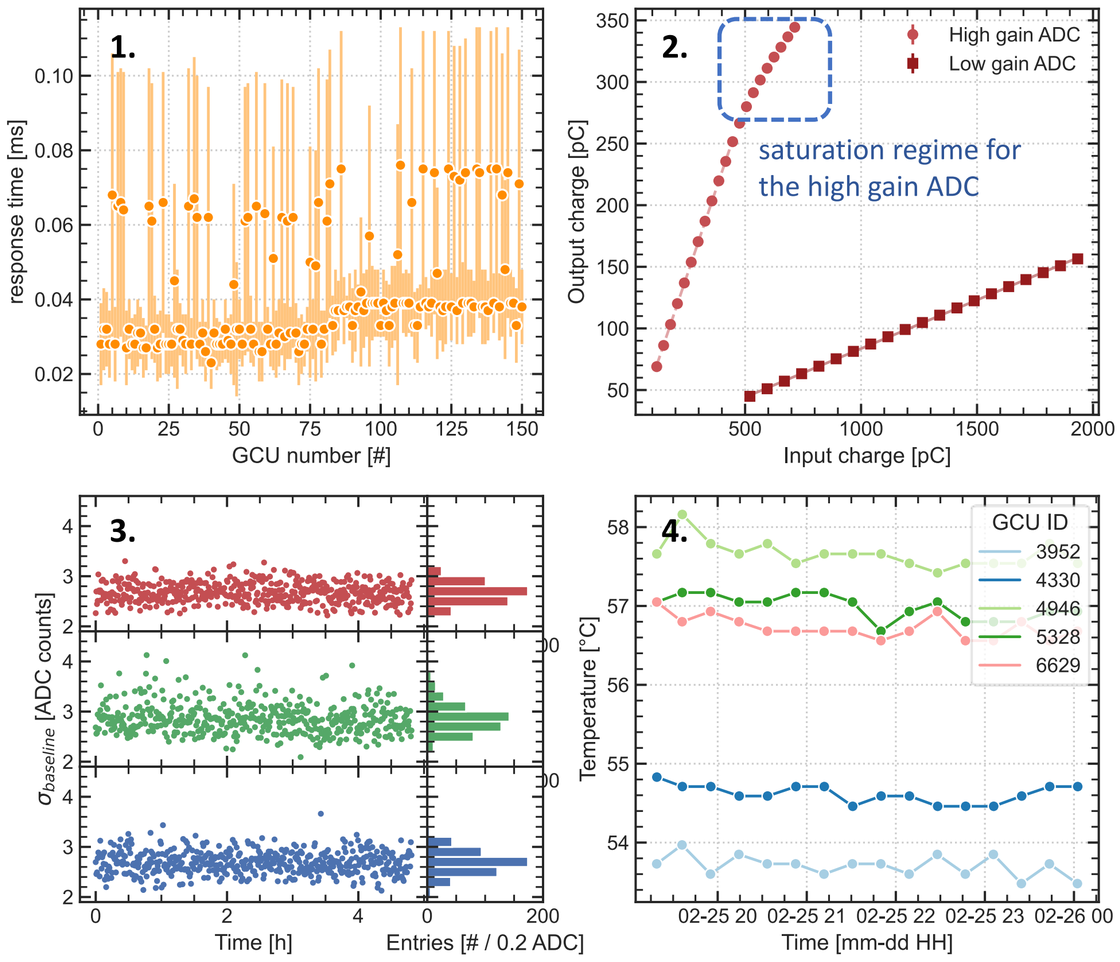
Integration tests in Kunshan, China:
simultaneous mass **testing** of **344 GCUs** at production site. Each day 60 GCUs are exchanged.

Waveform digitization:
304ns-waveform generated by the **integrated calibration circuit**. Waveform length and position of waveform can be changed online via IPbus protocol [4].

Bandwidth measurement:
external pulser at 1-100 kHz frequency, data acquisition from 3 channels of 1 GCU, fixed packet size 1 evt = 5.12 kb.
Efficiency measurement (acquired/expected events).







Test protocol:

1. **Ping test:** to check performances of connection of the GCU to the network; send 100 56-byte packets in 1 second to each GCU.
2. **Linearity test**: calibration of each channel, evaluate gain for High gain and Low gain ADCs; short runs at various test pulse amplitude.
3. **Stability test**: check stability of parameter over time: baseline, baseline sigma, integrated charge; long run at fixed test pulse amplitude.
4. **Slow control monitoring:**
   - FPGA temperature
   - HVU temperature
   - PMT high voltage
   - internal voltages and currents

   quantities are read through the asynchronous link via IPbus protocol [4].
5. **DDR3:** check storage capabilities and event loss rate.

References:
[1] JUNO Collaboration, *JUNO Physics and Detector*, 2021, arXiv:2104.02565
[2] JUNO Collaboration, *Neutrino Physics with JUNO*, J. Phys. **G43**, 3, 2016
[3] JUNO Collaboration, *JUNO CDR*, 2015
[4] C. Ghabrous Larrea et al., *IPbus: a flexible Ethernet-based control system for xTCA hardware*, JINST **10** (2015) no.02, C02019