SiPM and Read-Out Electronics for JUNO-TAO Central Detector

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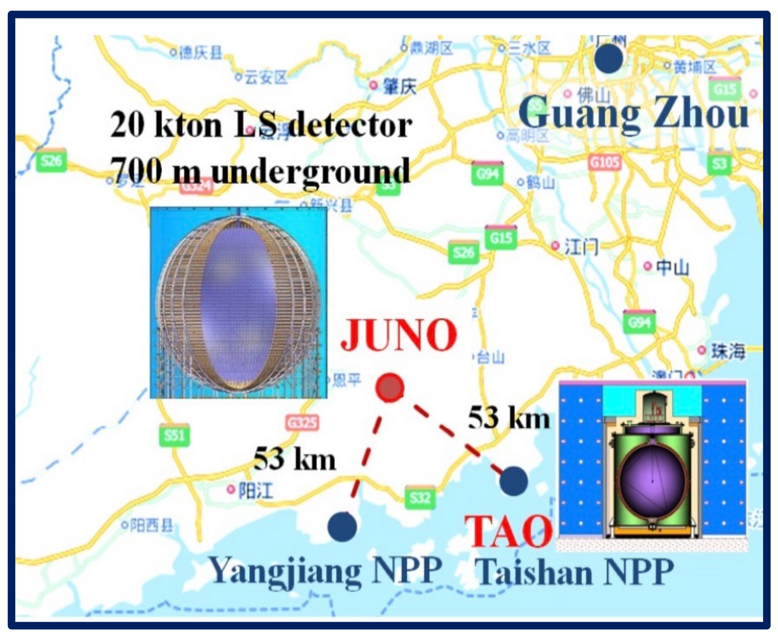
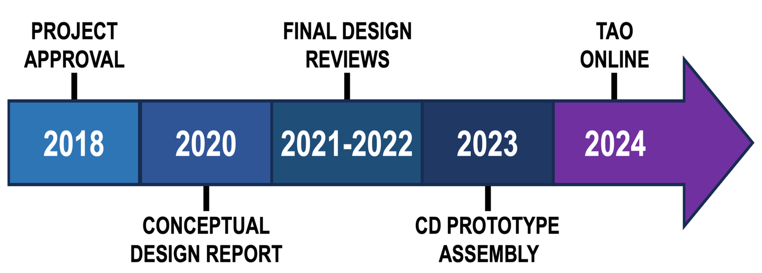
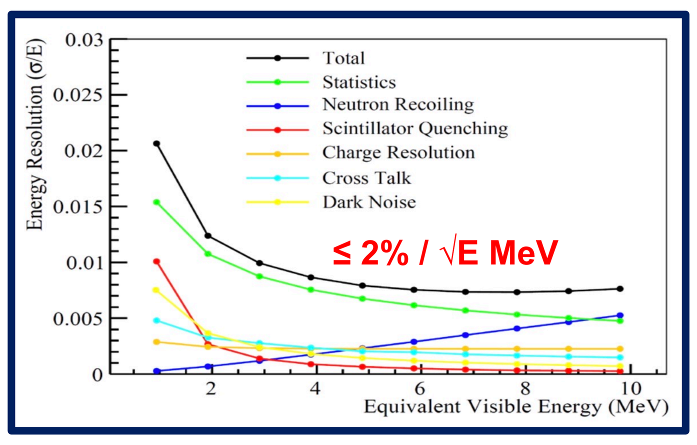
JUNO-TAO EXPERIMENT

The **T**aishan **A**ntineutrino **O**bservatory (**TAO**) is a satellite experiment of the **J**iangmen **U**nderground **N**eutrino **O**bservatory (**JUNO**)

- TAO consists of a spherical ton-level **G**adolinium-**d**oped **L**iquid **S**cintillator (**Gd-LS**) detector (1.8 m diameter) at ~30 m from a reactor core of the Taishan Nuclear Power Plant (4.6 GW) in Guangdong, southern China, expected to start collecting data in 2024. **[1]**
- By means of 10 m² SiPM (~ 4100 arrays of >50% PDE) covering the spherical LS, the reactor antineutrino spectrum will be measured with a sub-percent energy resolution (≤ 2% / √E MeV). The detector operates at -50°C to lower the dark/thermal noise of the SiPMs.

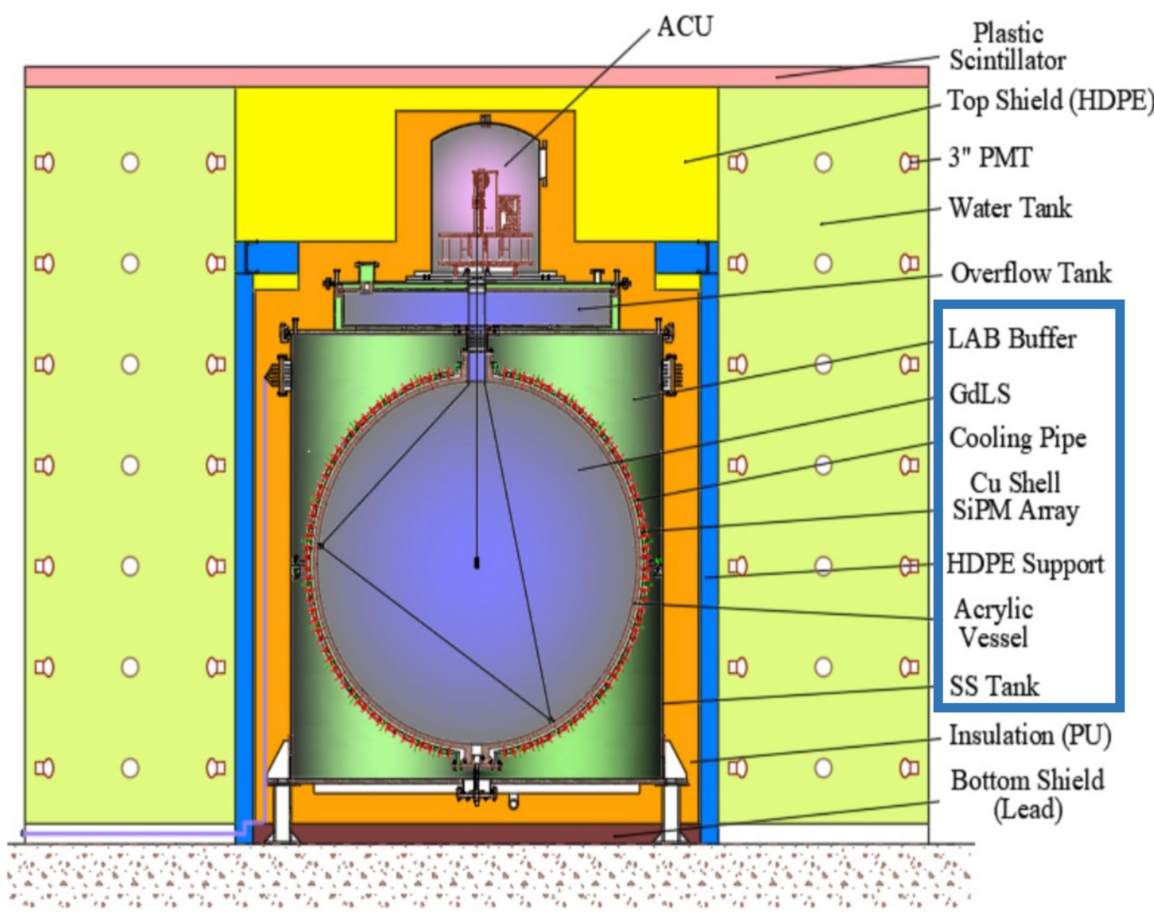






MOTIVATION

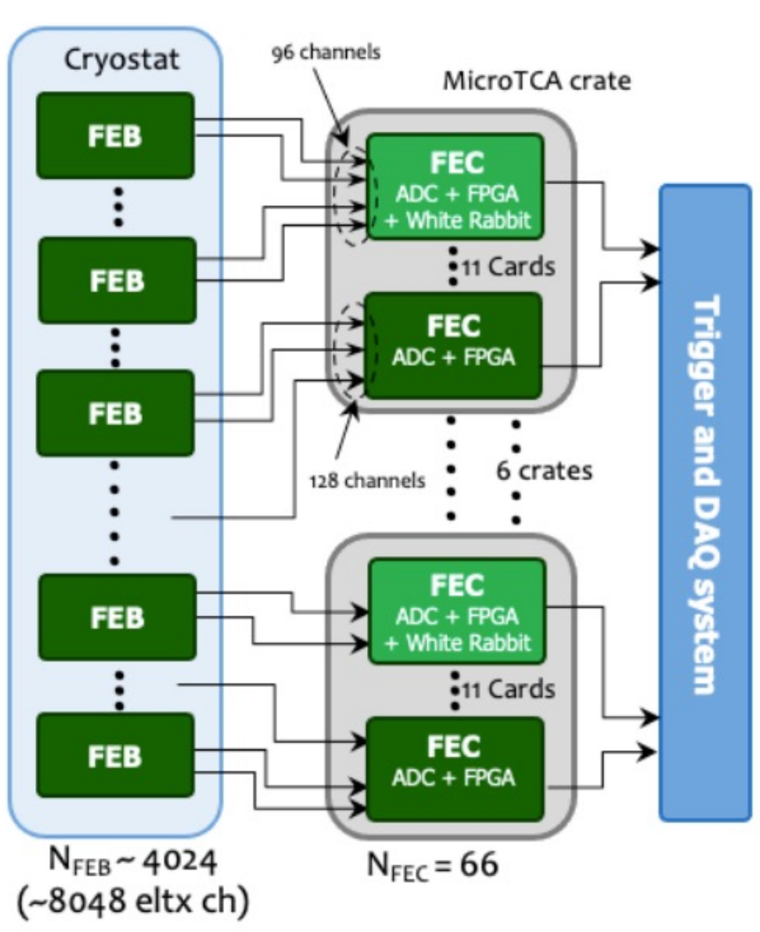
- ✓ Provide a reference spectrum for the JUNO neutrino mass-hierarchy measurement.
- ✓ Provide a benchmark measurement to test nuclear databases.



CENTRAL DETECTOR (CD):

- Acrylic Sphere (d=1.8m, 20mm-thick) filled with 2.8t Gd-LS
- Copper Shell (d=1.886m, 12mm-thick) with SiPM tile support
- SS Tank (d=2.09m, 10mm-thick) filled with 3.2t LAB/Gd-LAB
- Cryogenic System, at -50°C to reduce SiPM thermal noise
- Front-End Electronics (FEE)

FRONT-END ELECTRONICS



ANALOG SIGNALS **DIGITAL SIGNALS**

❄ **FEB (Front End Board)**
inside the cryostat

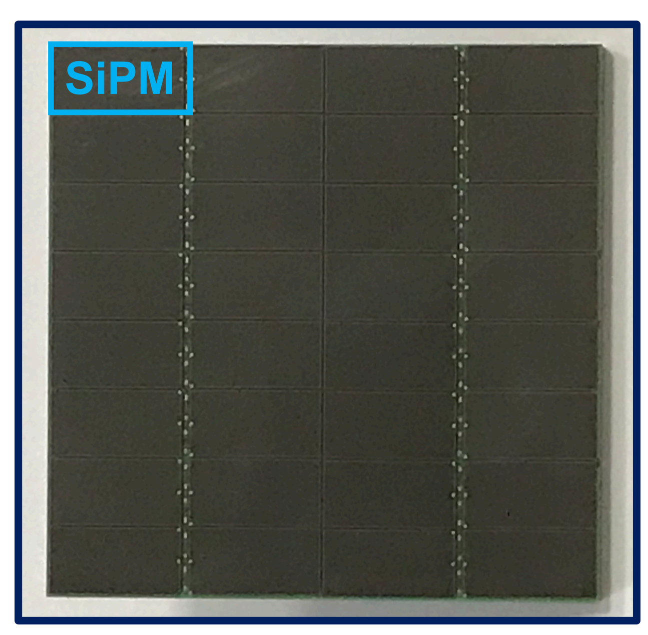
- 4024 tiles, 4024 FEBs
- 2 channels on 1 FEB/tile
- Total 8048 channels
- Analog signals from FEB transferred to FEC via differential pairs, ~ 4 m inside the SS tank, ~14 m outside the tank

❄ **FEC (Front End Controller)**
outside the cryostat

- 258 ADC boards --> 66 FECs
- ADC is on FEC, used to digitize analog SiPM signals from the FEBs
- FPGA & Power boards in μTCA.4 crate
- Q/T information is extracted with FPGA (waveform analysis)

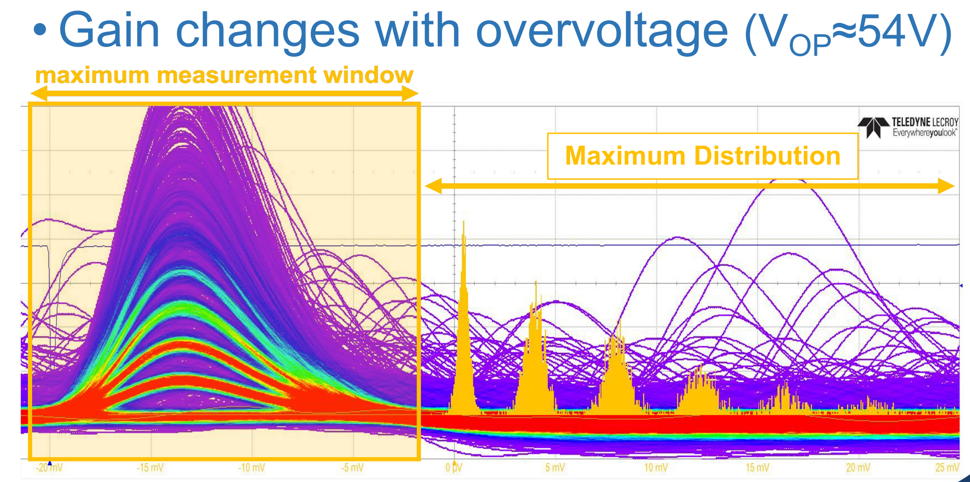
Silicon-PM TILE

- ❑ **S**ilicon **P**hoto-**M**ultipliers (**SiPMs**) are single-photon-sensitive devices based on arrays of many small **S**ingle **P**hoton **A**valanche **D**iodes (**SPADs**, working in Geiger Mode).
- ❑ The output charge of the SiPM is the sum of all the charges generated by the fired SPADs, and it is proportional to the number of detected photons.



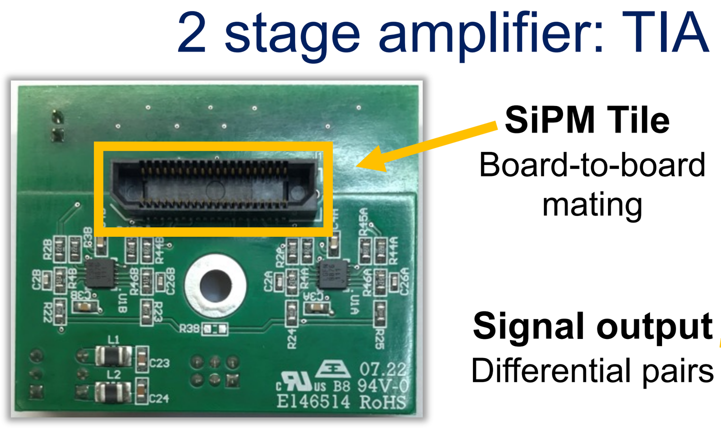
HAMAMATSU
S16088: SiPM TILE **[2]**

- 12,782 SPADs x SiPM (75 μm pixel pitch)
- 8x4 array of 12x6 mm² SiPMs (5x5 cm²)
- 10 m² / 25 cm² ≈ 4000 SiPM tiles
- Each SiPM tile splitted in 2 channels (series/parallel connections on the FEB)
- Gain changes with overvoltage (V_{OP}≈54V)

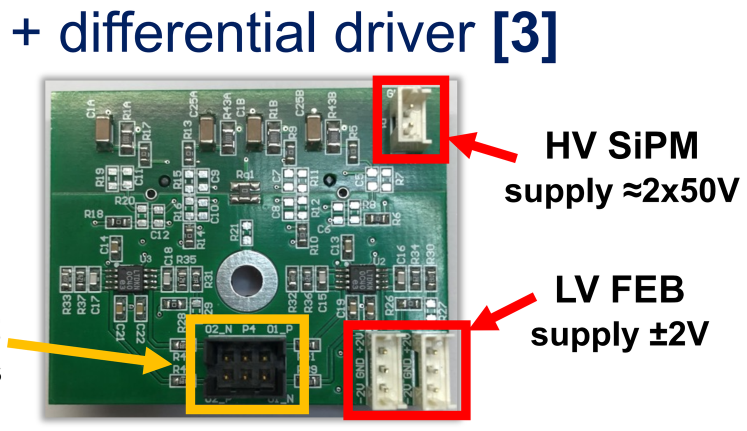


FRONT-END BOARD

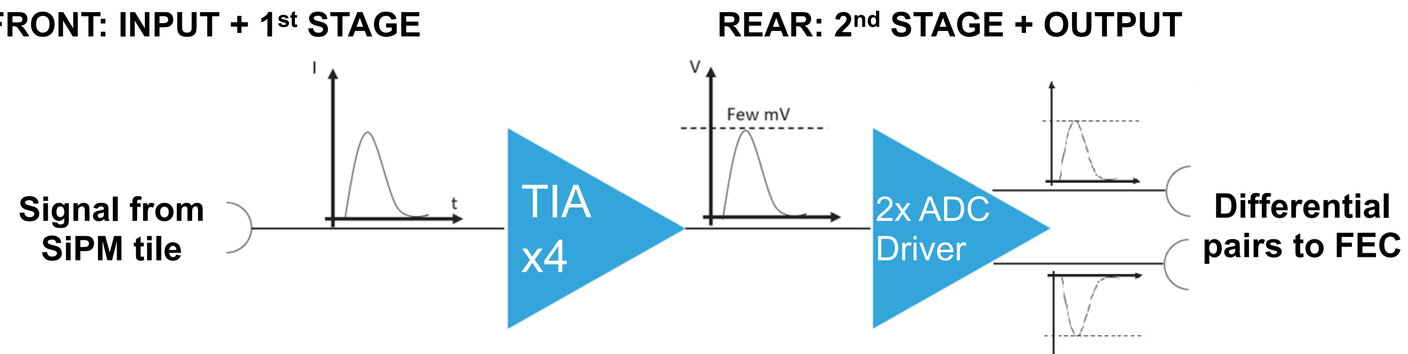
Planar version with aramid PCB (low background)
2 stage amplifier: TIA + differential driver **[3]**



FRONT: INPUT + 1st STAGE



REAR: 2nd STAGE + OUTPUT

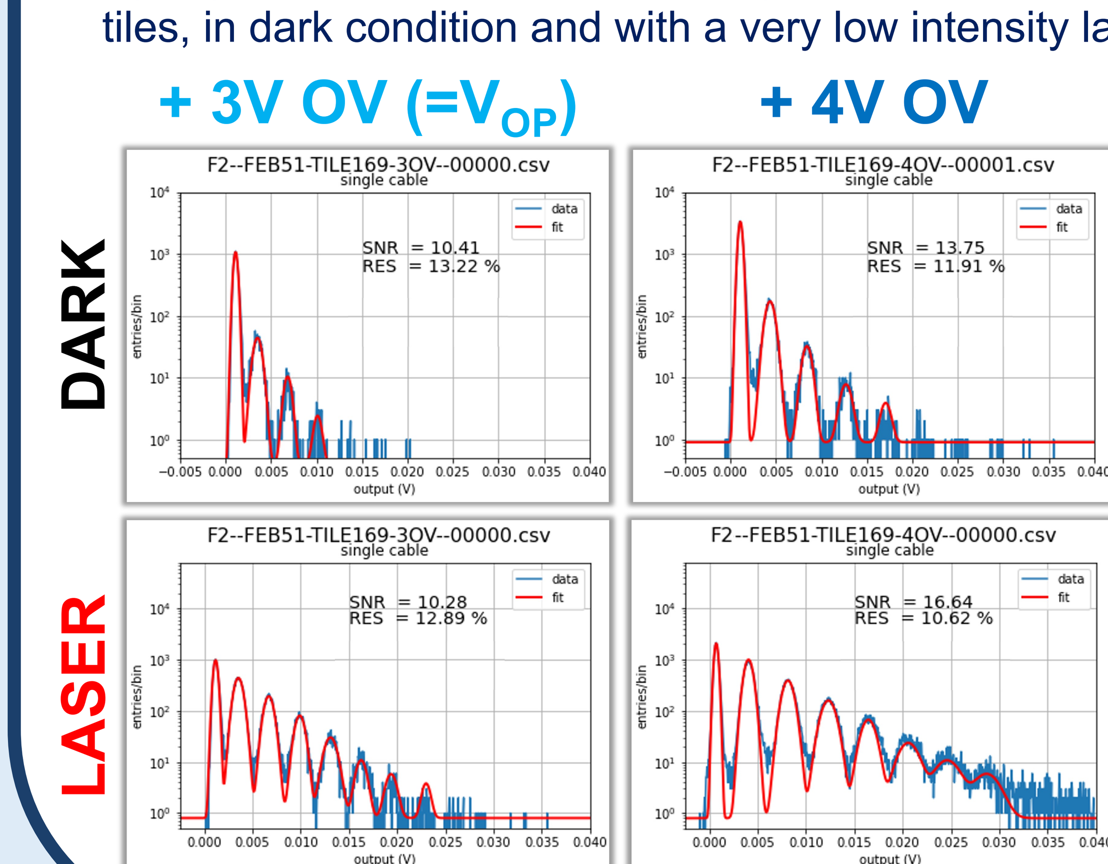


- Single p.e. amplitude ≈ 15 mV ➡ p.e. channel dynamic range: 1–125 p.e.
- FEB needs ±80 mA at +2.2V and -2.2V @ -50°C ➡ 0–2V linearity range
- Shaping time ≈ 500 ns
- Recovery time < 5 μs
- SiPM gain adjustment with overvoltage (G≈4x10⁶ @ V_{OP})

CHARACTERIZATION

4 figures of merit with specific requirements defined in TAO CDR:
SNR > 10 **RES < 15%** **XTLK < 20%** **DCR <100 [Hz/mm²]**

100 pre-production FEBs tested with pulse electrical source (linearity, gain) and with SiPM tiles, in dark condition and with a very low intensity laser source (λ=407nm) @ -50°C



- RES, SNR, XTLK: Gaussian fit over maximum histograms ➡ results as the requirements
- DCR: Count of events (normalized with time and area)
  - ➡ ~25 [Hz/mm²] @ +3 OV
  - ➡ ~32 [Hz/mm²] @ +4 OV

About the same for all FEBs and Tiles; into datasheet range @ -50°C:

Typ. 2000 / Max. 6000 (Typ. 13.9 / Max. 41.7)	cps/ch. (cps/mm²)

$DCR_{@25°C}$ ≈ 4e³ x DCR@-50°C

CONCLUSIONS

- High resolution measurement of the reactor antineutrino spectrum
- Design of the TAO readout front-end electronics reported
- Preliminary tests demonstrating the fulfillment of the TAO requirements
- Automatic data acquisition by means of ADC boards with FPGA controller
- JUNO-TAO 1:1 prototype ready at the end of the 2023 and online in 2024

REFERENCES

1. TAO Conceptual Design Report: A Precision Measurement of the Reactor Antineutrino Spectrum with Sub-percent Energy Resolution, arXiv:2005.08745 (2020)
2. HAMAMATSU Photonics, Specification Sheet MPPC (S16088), Doc. No. K30-I50549 (2022)
3. S. Sanfilippo *et al.* (2022) Performance of the SiPMs operated at low temperature for the JUNO-TAO detector, J. Phys.: Conf. Ser. 2374 012123

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