

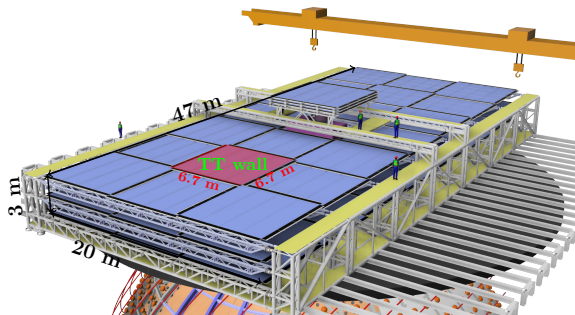
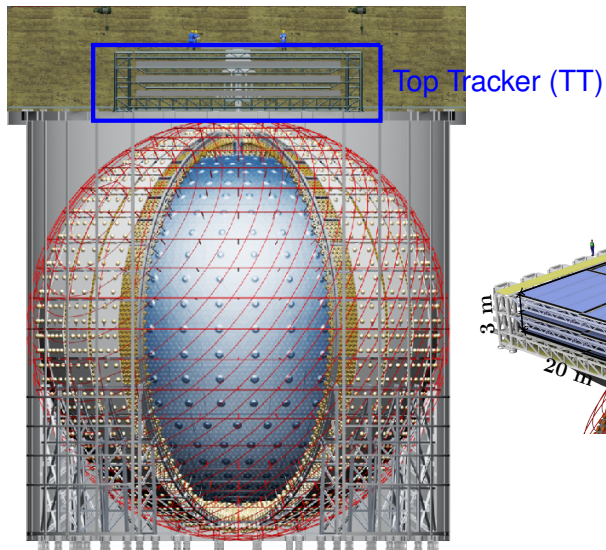
## JUNO Top Tracker installation

João Pedro Athayde Marcondes de André & Jacques Wurtz  
for the JUNO Collaboration

IPHC/IN2P3/CNRS

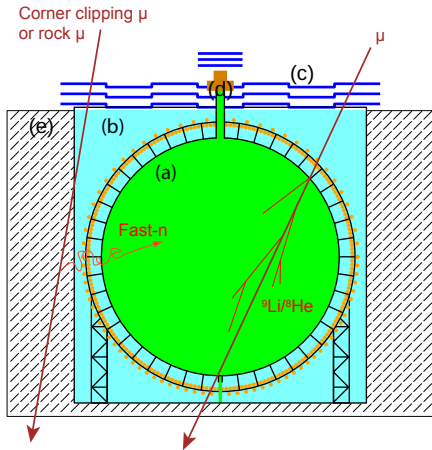
July 22<sup>nd</sup>, 2025

# The JUNO Detector

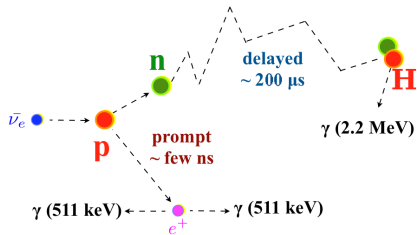




# Cosmogenic background



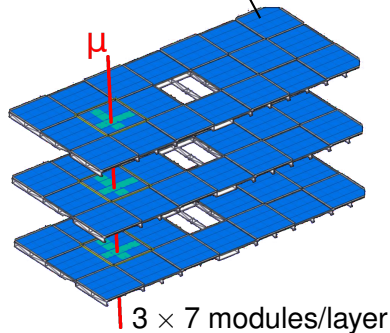
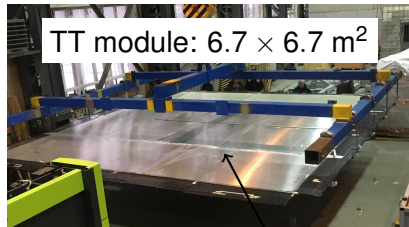
- Inverse Beta Decay (IBD) – 57.4/day in JUNO
  - Main channel to detect reactor antineutrinos



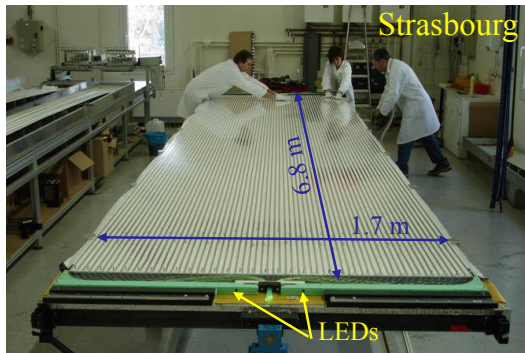
- Cosmogenic bkg. hard to distinguish from IBD
  - ${}^9\text{Li}$  &  ${}^8\text{He}$  have decays with  $e^- + n$ 
    - ★  $\sim 167$  ( ${}^9\text{Li} + {}^8\text{He}$ ) per day;  $\sim 1/2$  decay w/  $e^- + n$
  - As IBD has prompt-delayed signature
  - Tagged using parent  $\mu$
  - JUNO needs good muon tracking capabilities
- Fast-n can also be issue, but lower rate expected
  - Control it with good  $\mu$  tracking outside CD

# JUNO Top Tracker (TT): Overview

- Full description: JUNO, “The JUNO experiment Top Tracker,” Nucl. Instrum. Meth. A **1057** (2023), 1686800 [arXiv:2303.05172]
- TT refurbished from OPERA Target Tracker
  - ▶ TT modules are delivered to JUNO site in 2018!
- 62 walls measuring  $(6.7 \times 6.7)$  m<sup>2</sup> of plastic scintillator available
- Walls distributed in  $3 \times 7$  horizontal grid in 3 layers  $\rightarrow$  cover  $\sim 60\%$  of surface above WCD
- Upgrades needed on several systems: electronics, mechanical structure, ...
- And now installed in JUNO!



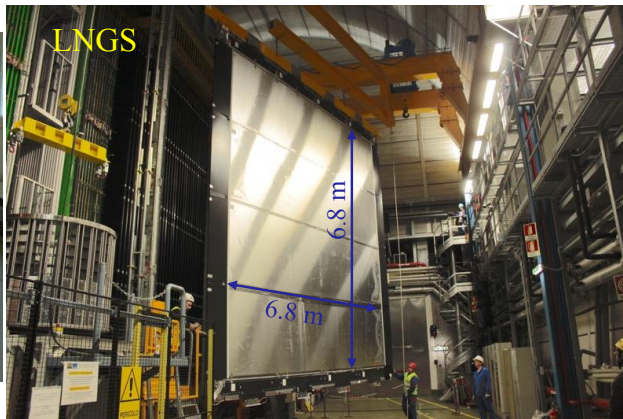
# The Top Tracker before JUNO



during module assembly (2004-2006)

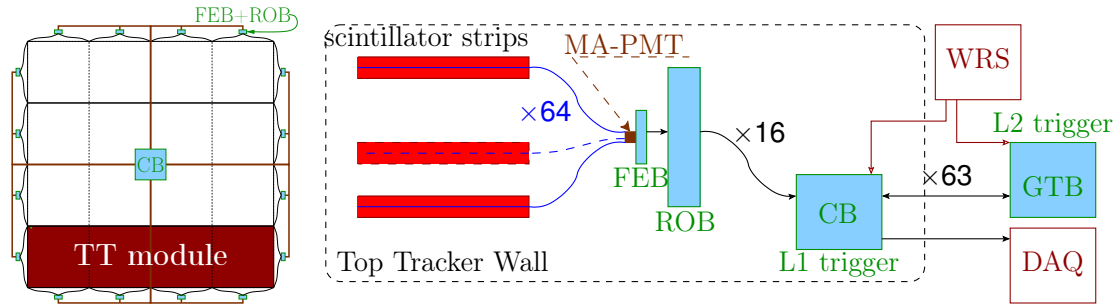
May 2025

M. Dracos IPHC-IN2P3/CNRS/UNISTRA



during TT dismounting from OPERA detector

# TT Electronics: Schematic View



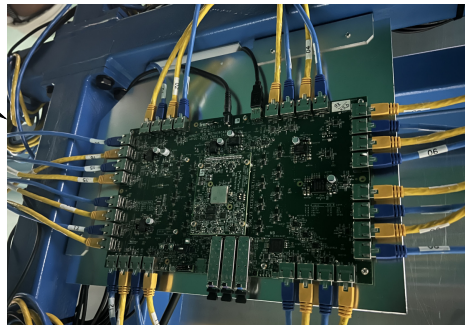
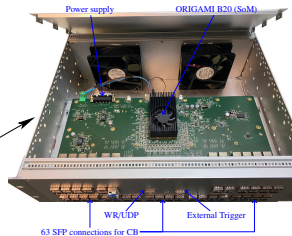
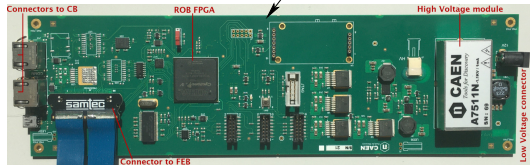
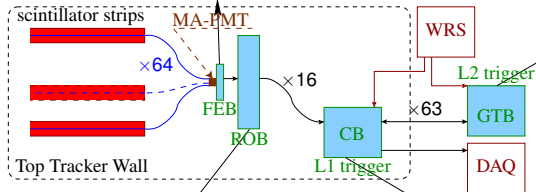
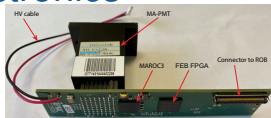
**Front-End Board (FEB):** PMT interface and part of the PMT readout.

**Read-Out Board (ROB):** slow control, power supply, and finish PMT readout.

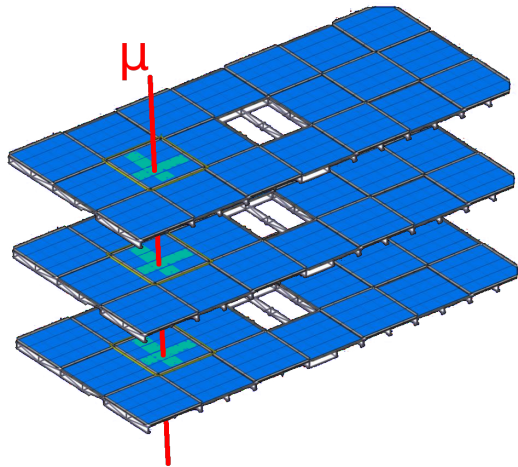
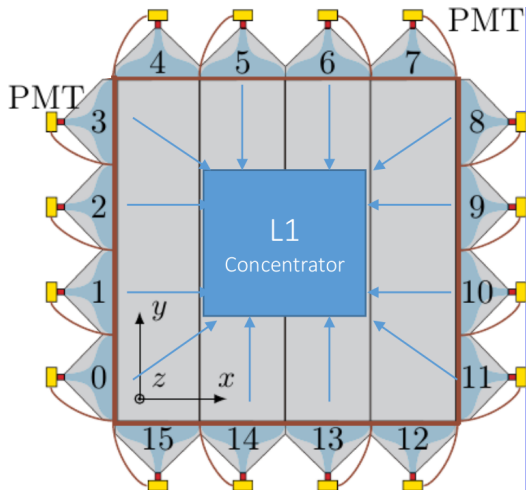
**Concentrator Board (CB):** gathers hits related to each wall, and create L1 trigger. Also time-stamps of all hits with a nanosecond precision.

**Global Trigger Board (GTB):** combine information of all L1 triggers from CB and produce a L2 trigger.

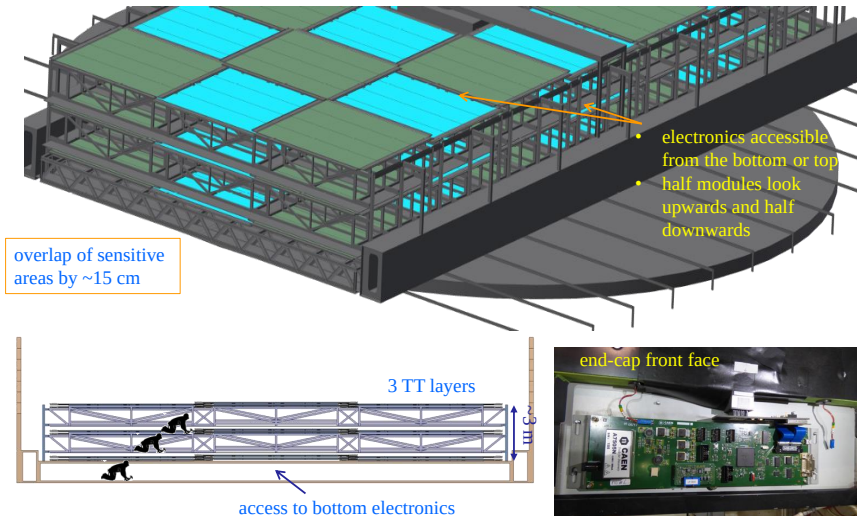
# TT Electronics



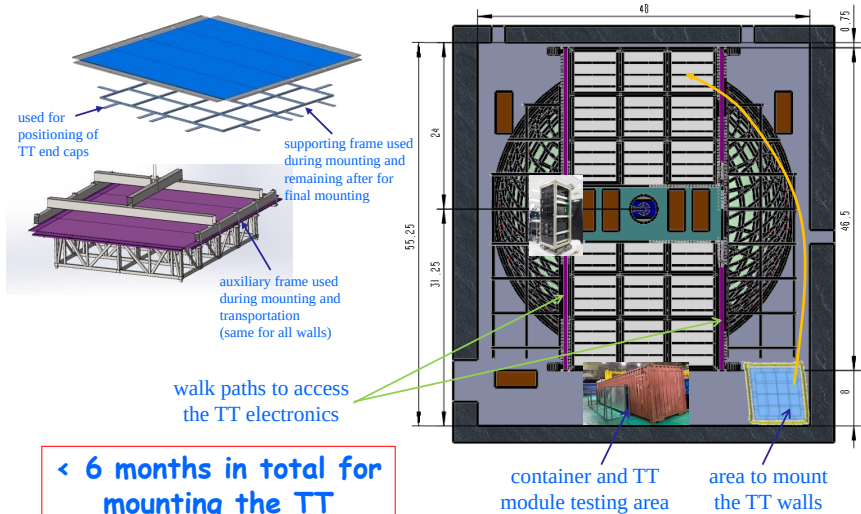
# L1 and L2 trigger views



# Top Tracker



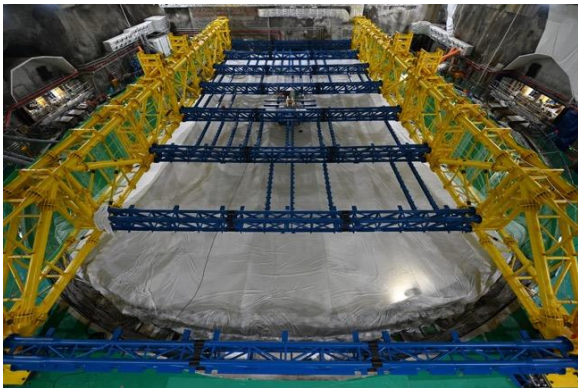
# Top Tracker mounting



< 6 months in total for mounting the TT



# The Bridge on Top of JUNO



- Solid bridge on top of JUNO to install TT
- TT layers spaced by  $\sim 1.5$  m (3 m total height) need to be supported by bridge
- Keep possibility to access TT electronics
- Work to be done in parallel with other activities

# The Bridge on Top of JUNO at the start of the installation



# And now concretely...

- 7 TT containers in China since 2017.
- In a warehouse near JUNO site and brought back to SAB when needed, cleaned and sent in the underground.



very compact packaging...

# TT wall assembly



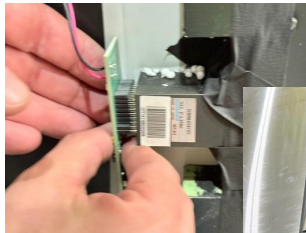
supporting "table" assembly



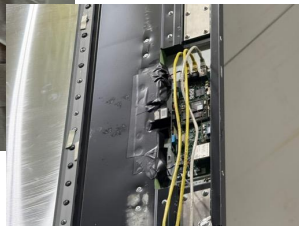
extracting modules from the container



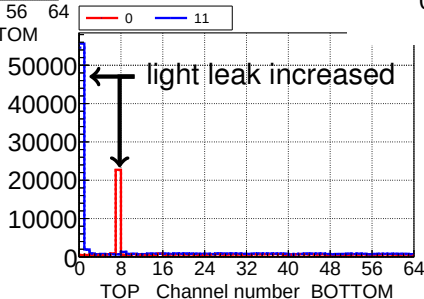
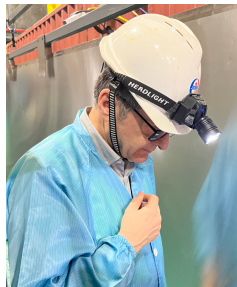
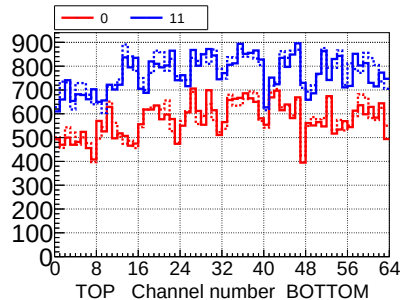
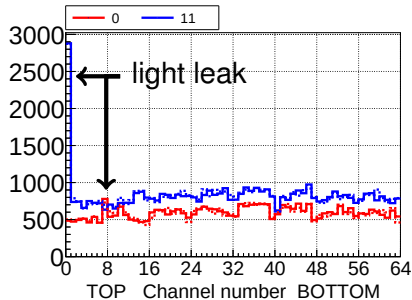
storage structure for testing



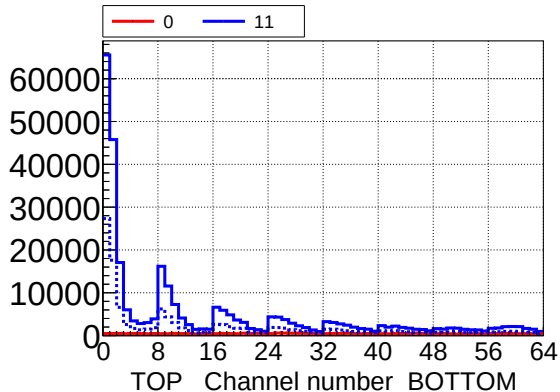
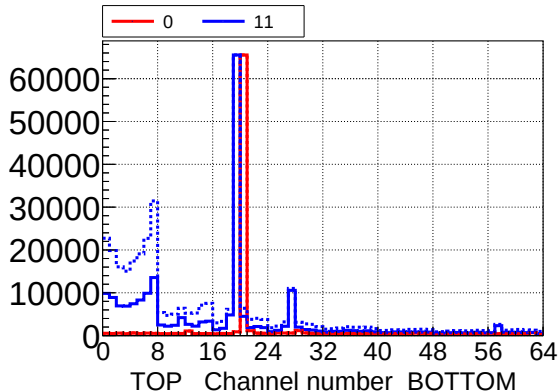
replacement of old  
electronics and search  
for light leaks



# Testing & Fixing modules

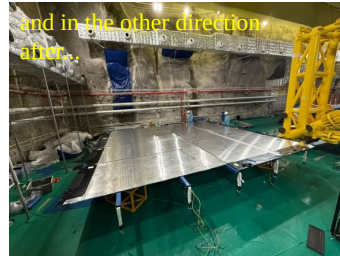
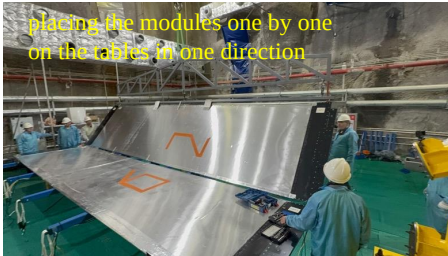
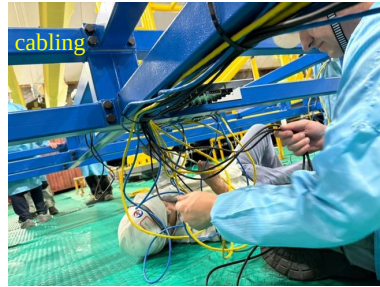
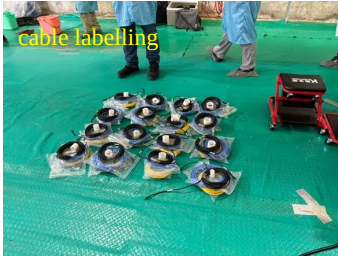


## Testing & Fixing modules: other types of light leaks



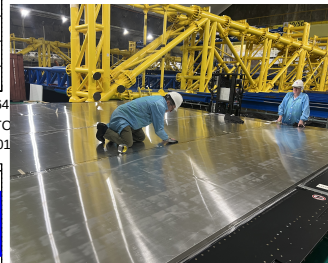
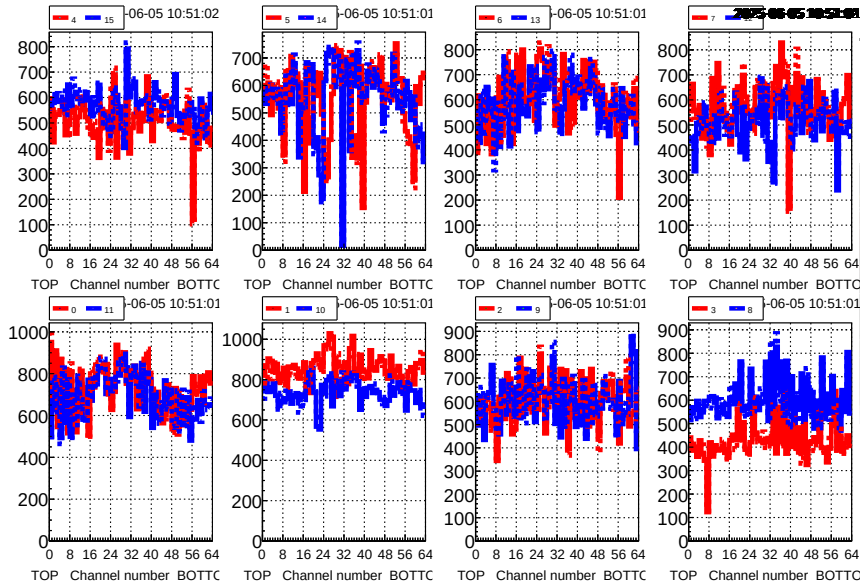
- Several different topologies of light leaks
- Some types of light leak might affect multiple channels of same PMT at once

# TT wall assembly



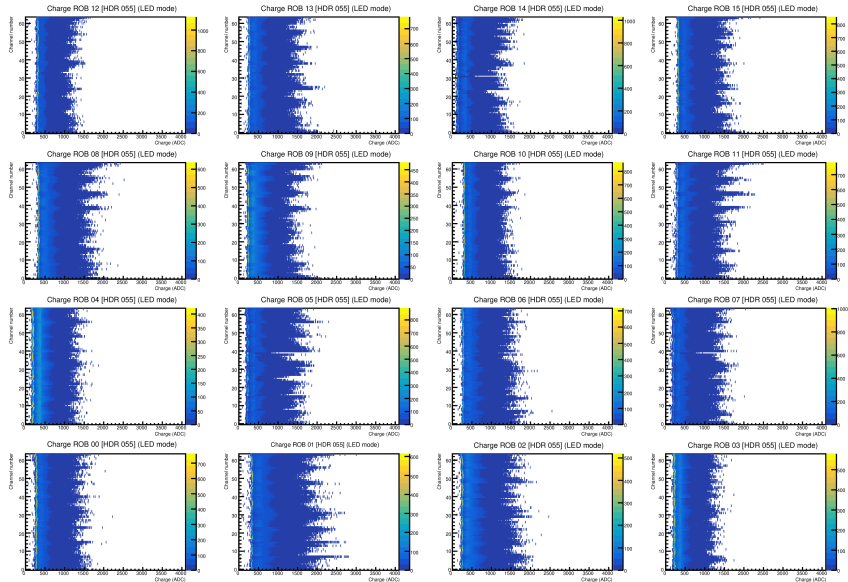


# Final test of wall after assembly: TRT

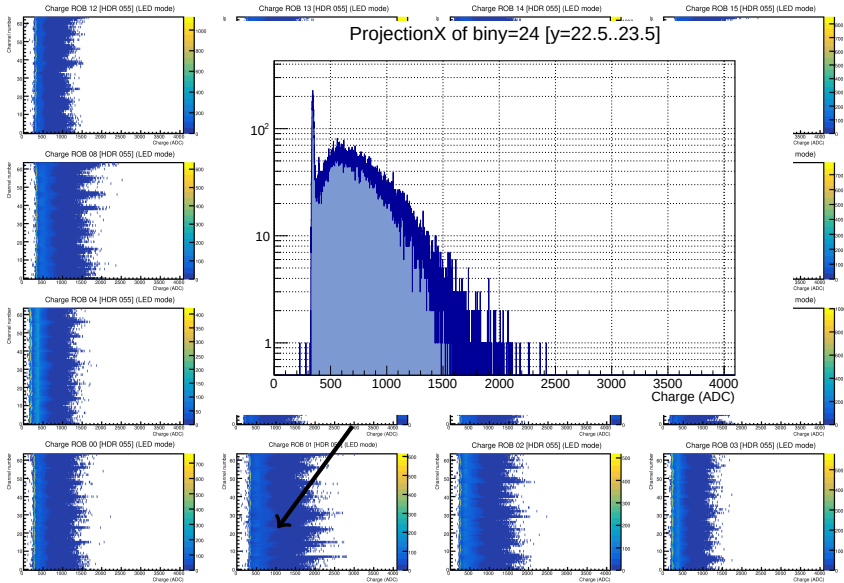




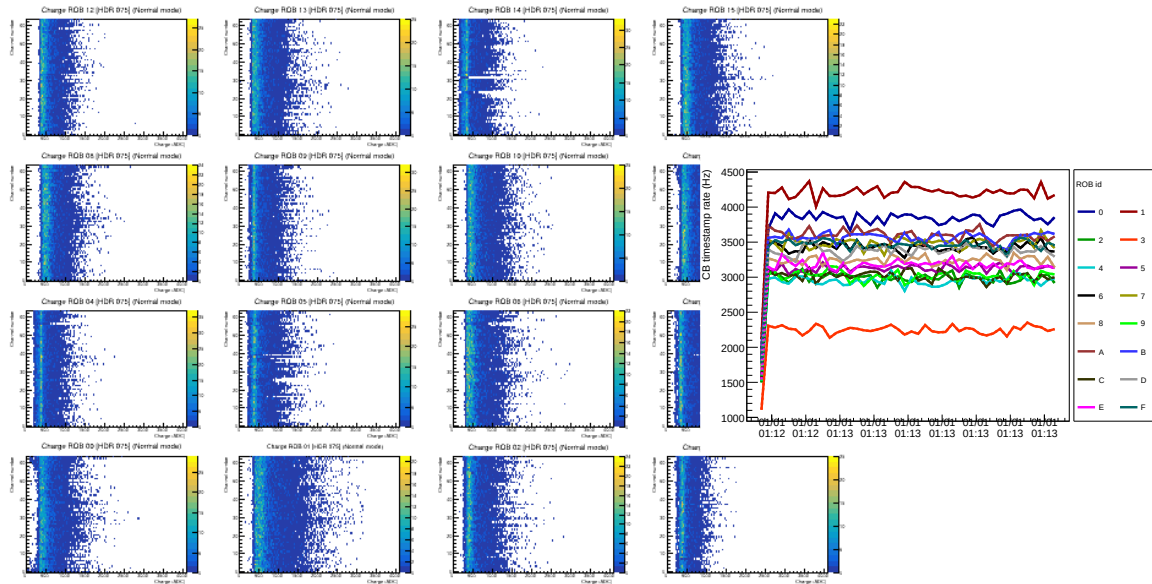
# Final test of wall after assembly: LEDs



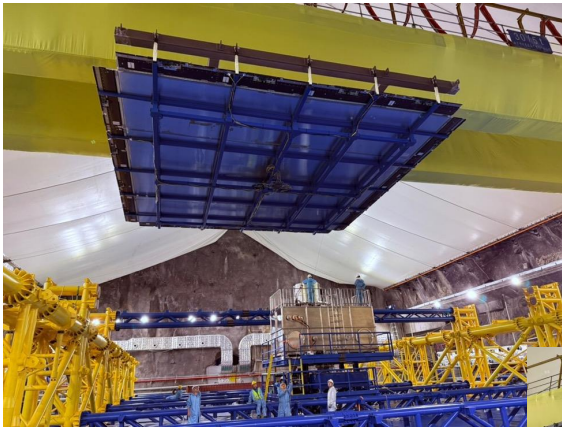
## Final test of wall after assembly: LEDs



# Final test of wall after assembly: 'Regular' data



# TT wall assembly



moving the wall at the  
right position

... just few mm above  
the installed beams...



# TT wall assembly



first installed TT wall



first installed TT wall



some  
accessibility  
issues

# Survey of TT wall positions



- Measure module position at some reference points available in each module
- Need to be done as the installation advances as new walls cover walls below it
- Positions measured within expectation – larger deviations in middle due to sag

# Many other activities

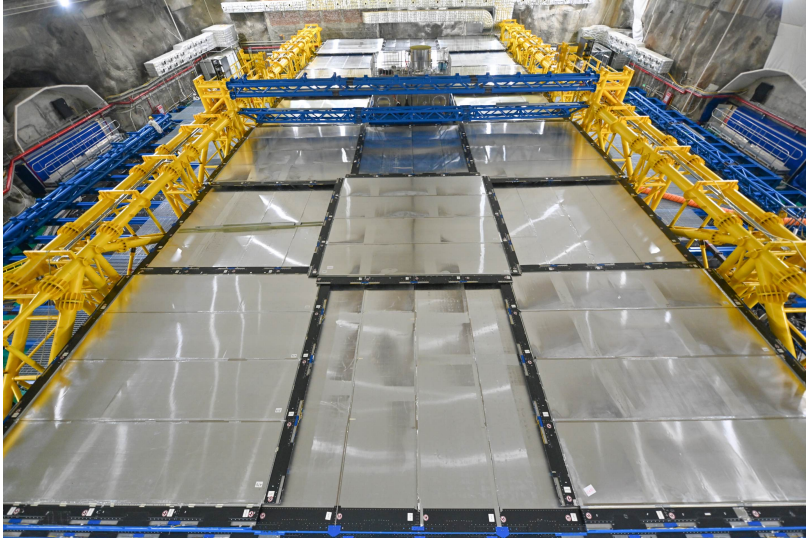




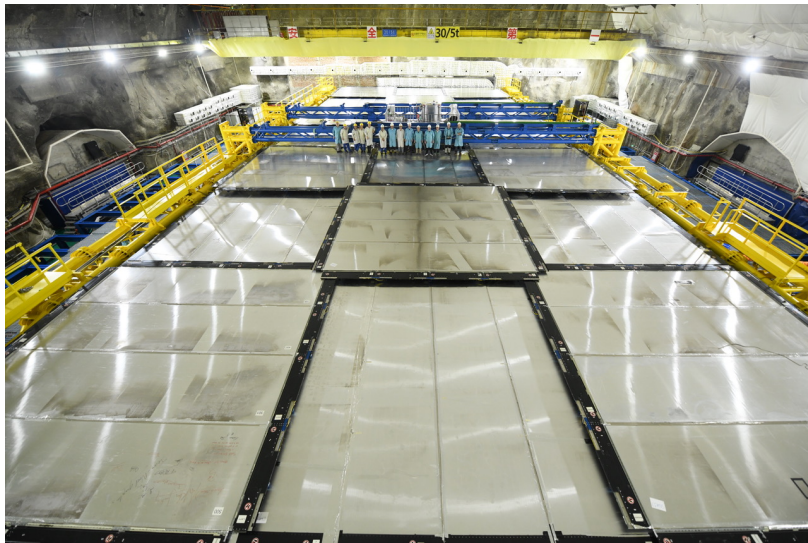




## Second TT Layer installed



# Third TT Layer and walls on top of Chimney installed

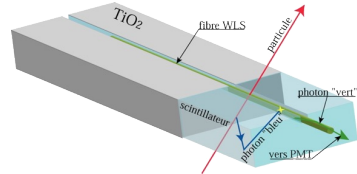
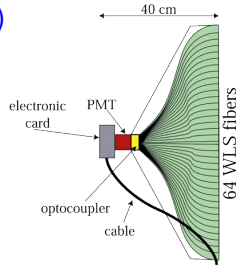
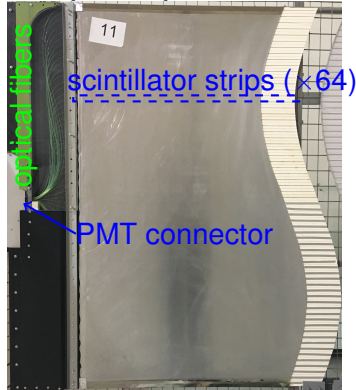


# Summary

- Top Tracker modules refurbished from OPERA Target Tracker
  - ▶ All modules equipped with new Electronics
  - ▶ Looked for and fixed light leaks in all modules
- Assembled TT walls and installed all 63 walls on top of the JUNO WCD
  - ▶ After assembly all walls have been retested & new light leaks have been fixed
  - ▶ Afterwards walls placed in detector!
- Since last FCPPL/N meeting we have fully installed the Top Tracker!
- Commissioning of Top Tracker getting started
  - ▶ Stay tuned for results in our meeting next year!

# Backup

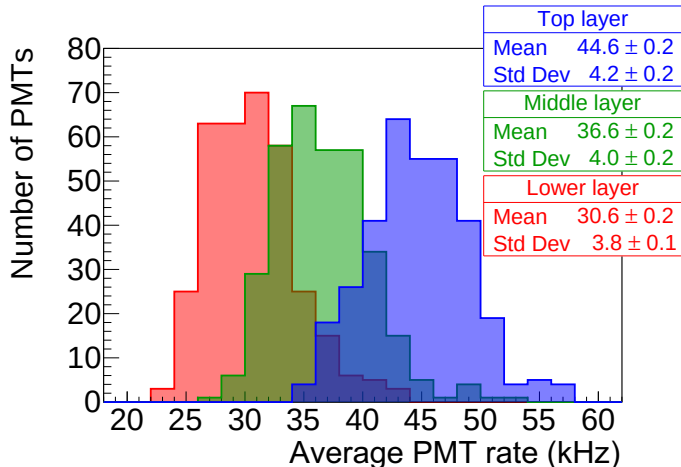
# Detection principle



- Charged particle crosses scintillator strip  $\rightarrow$  scintillation light
- Light captured by optical fibers and guided to MA-PMT
- Signal from PMT processed by electronics

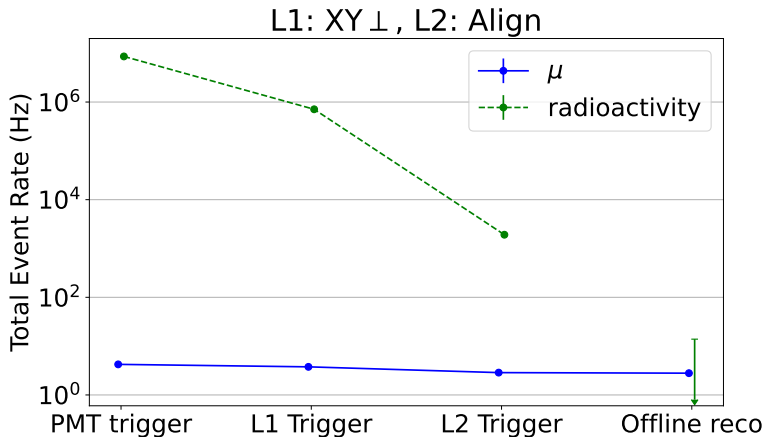
# PMT rate

| Isotope           | Activity (Bq/kg) |               |
|-------------------|------------------|---------------|
|                   | LNGS             | JUNO site     |
| $^{40}\text{K}$   | $26 \pm 2$       | $1340 \pm 50$ |
| $^{238}\text{U}$  | $1.8 \pm 1$      | $110 \pm 10$  |
| $^{232}\text{Th}$ | $1.5 \pm 1$      | $105 \pm 10$  |



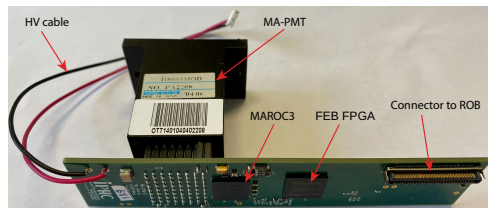
- Rock  $\sim 100\times$  more radioactive in JUNO than LNGS
- Singles rate @ PMT for JUNO from radioactivity from rock
- Need to reject online most of this background (reduce dead time & data size)

# Estimated TT trigger rate



- 4 orders of magnitude of background noise rejected due to L1 & L2 triggers
- Remaining background rejected with at reconstruction stage

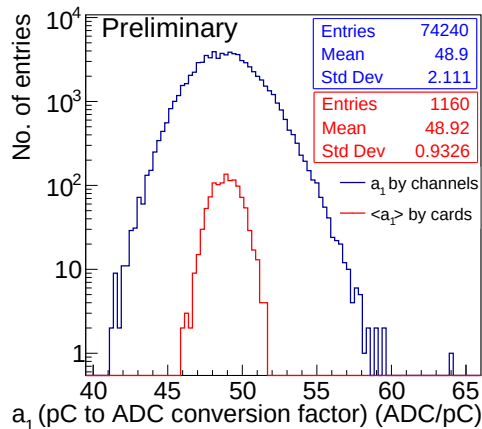
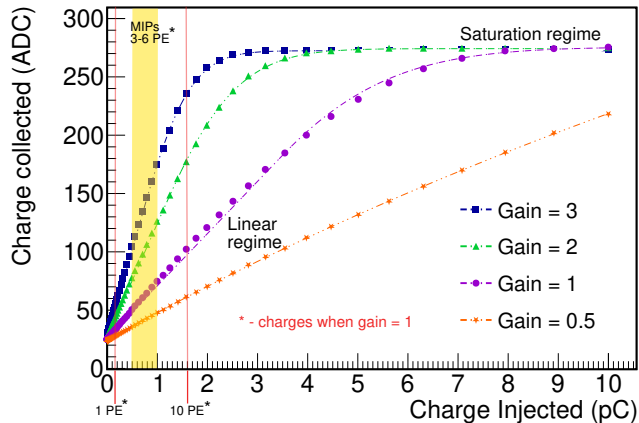
# TT Electronics Status: FEB



- FEB uses MAROC3 ASIC for PMT readout
- FEB passed final design review in 2019
- Produced & tested all cards
  - 992 needed, 1200 produced, 1134 passed tests
- Cards already on JUNO site
- Data taking already tested and working



# TT Electronics Status: FEB mass testing

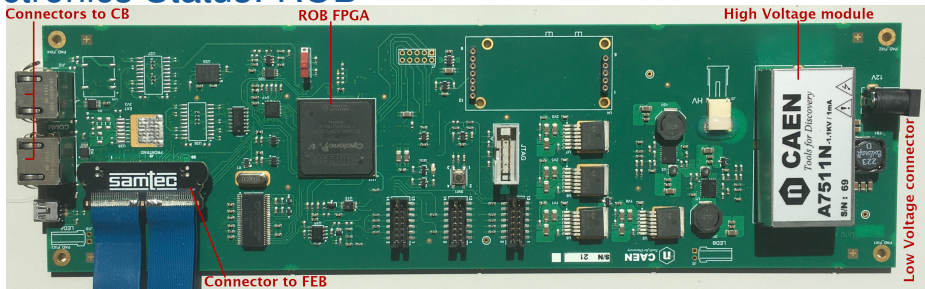


- Charge measured using MAROC3 Wilkinson
- Good homogeneity between FEBs

$$f(x) = \begin{cases} a_0 + a_1 x & , x \leq b \\ a_{00} + a_2 \left(1 - e^{-a_3 x^{a_4}}\right) & , x > b \end{cases}$$

$$a_5 = a_3 b^{a_4}$$

# TT Electronics Status: ROB

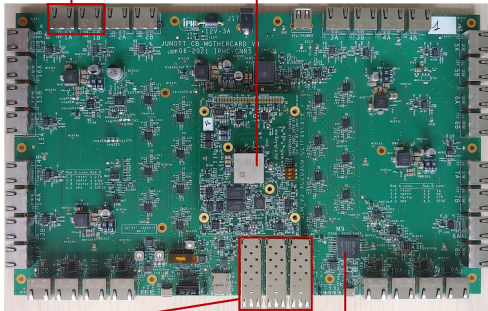


- Extra option for charge readout from MAROC3 using FADC on ROB
  - ▶ Faster than MAROC3 Wilkinson, with better granularity
  - ▶ Uses MAROC3 output as input for ADC → MAROC3 samples charge in same way in both cases
- Passed final design review in March/2021
- Finalizing tests of full acquisition chain
- ROBs have been shipped to JUNO site this year
  - ▶ 992 cards required, 1020 available

# TT Electronics Status: CB

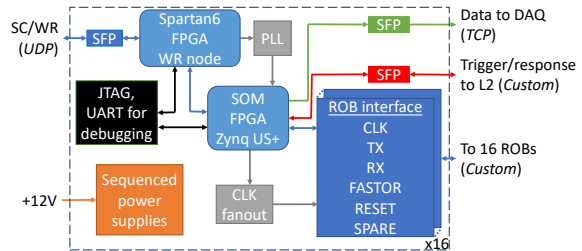
Connectors to ROB

SOM FPGA



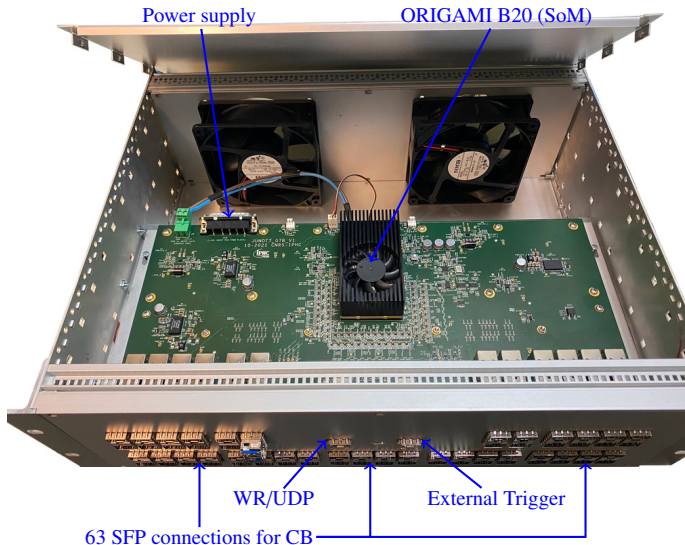
Optical connections to DAQ/WRS/GTB

Spartan6 FPGA



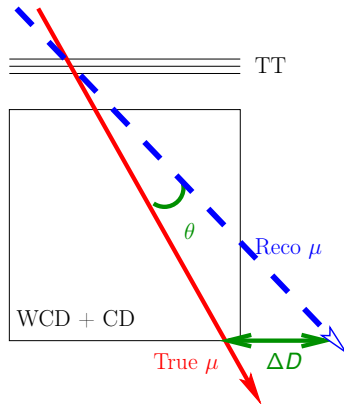
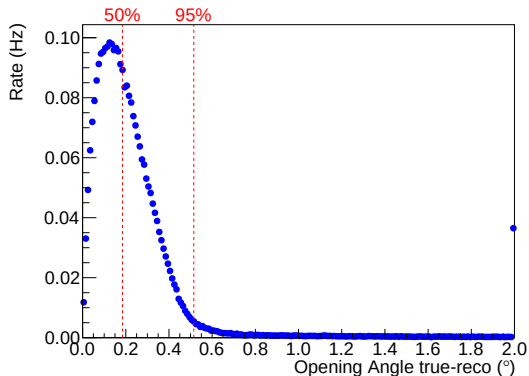
- Connections to all 16 ROB's of same wall (2 RJ-45 cables/ROB)
- Optical connections components outside wall
- Timestamping & event selection done in separate FPGAs
  - ▶ Easier to implement WR node on Spartan6 using UDP
  - ▶ TCP connection used to transfer data with Zynq Ultrascale
- To be shipped to China this month
  - ▶ 63 cards needed, 80 produced

# TT Electronics Status: GTB



- 1 optical connection for each of 63 CBs
- Same WR implementation as on CB
- 2 GTBs already produced, to be sent to China this month.
- Firmware under development
  - ▶ Basic functionalities & communication working
  - ▶ Trigger algorithm being developed

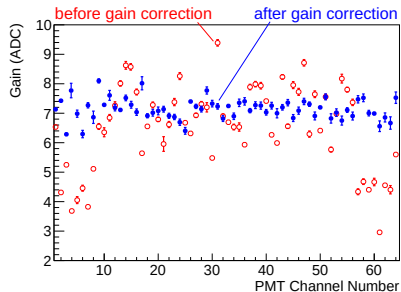
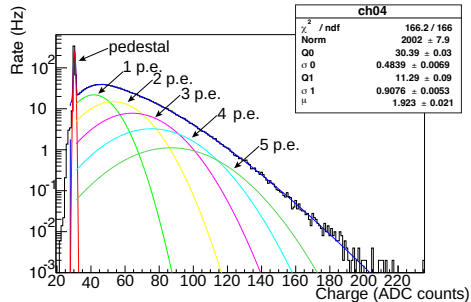
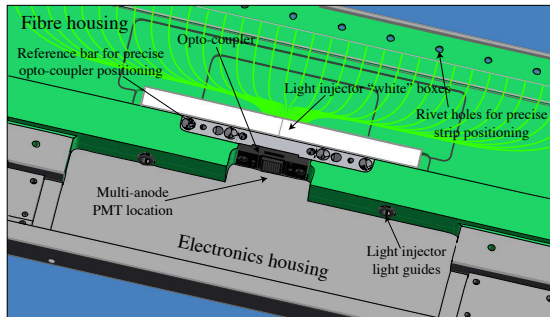
# TT $\mu$ reconstruction capabilities



- Median resolution to track  $\mu$  of  $0.2^\circ$
- Projected to the bottom of WCD, corresponds to median  $\Delta D = 20$  cm
- Excellent  $\mu$  tracking capabilities to help veto  $\mu$  and associated cosmogenics
- Also provides well reconstructed  $\mu$  sample for CD + WCD tuning/calibration

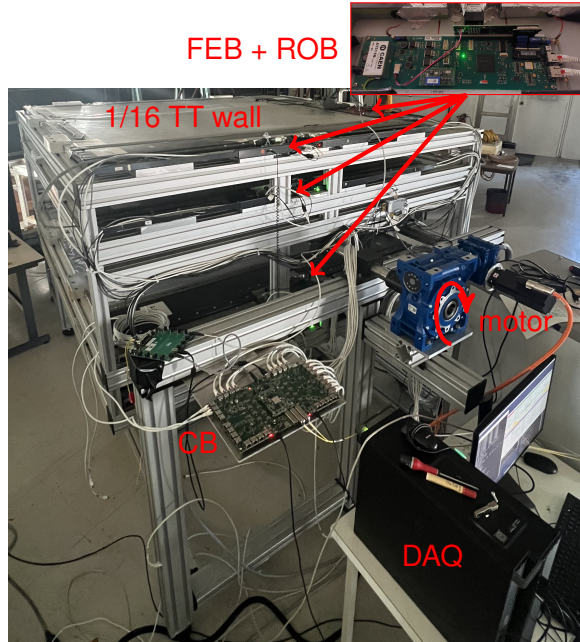
# TT data acquisition modes & calibration

- Trigger rate mode available to check light leak
- Pedestal mode available to adjust PMT pedestal
- LED mode available to calibrate PMT gain & adjust gain for each channel
  - ▶ MAROC3 has separate pre-amplifier/channel
- Self-trigger mode used for regular data taking

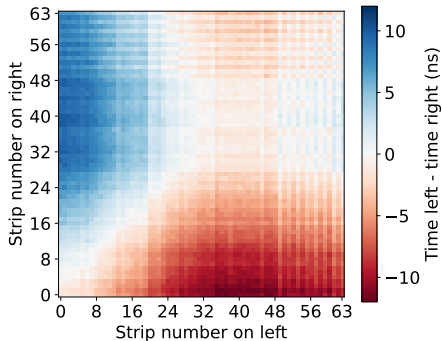


# TT Prototype

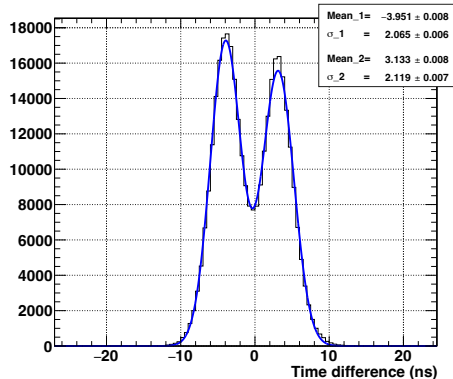
- TT prototype in Strasbourg
  - ▶ build with a quarter of a TT module
  - ▶ 4 X – Y layers (TT has 3)
  - ▶  $8 \times (\text{FEB} + \text{ROB})$  and 1 CB
- Perfectly adapted to test new TT Electronics Cards
  - ▶ FEB & ROB tested in with close to real conditions
  - ▶ Testing of some L1 & L2 trigger algorithms in small scale also possible



# TT Prototype: testing timing of JUNO electronics



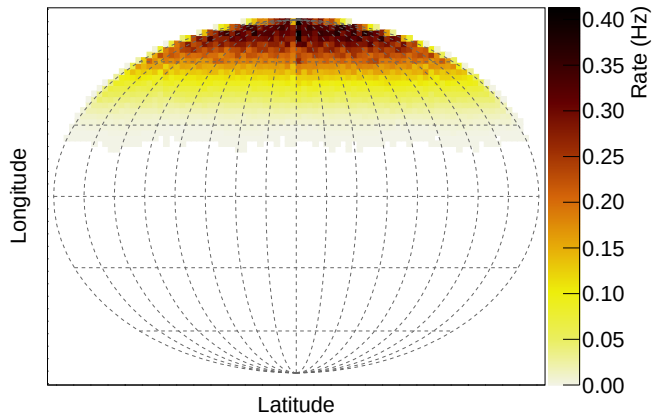
- Due to size of modules, time for light propagation to PMT not negligible
- Impact will be larger on JUNO
- Not negligible to reach  $\mathcal{O}(\text{ns})$  resolution
  - ▶ Pattern expected from fiber lengths



- Prototype rotated  $90^\circ$
- Clear separation between left/right going  $\mu \rightarrow 2$  ns timing resolution
  - ▶ Selected clean  $\mu$  & apply all corrections for timing

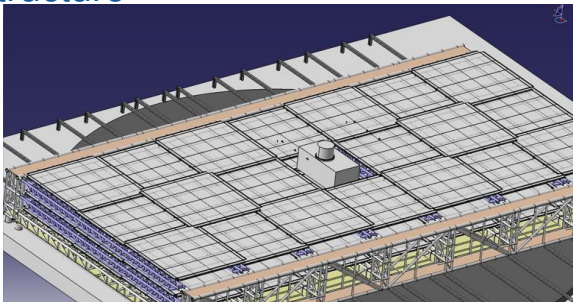


# TT Prototype is also a telescope for muons



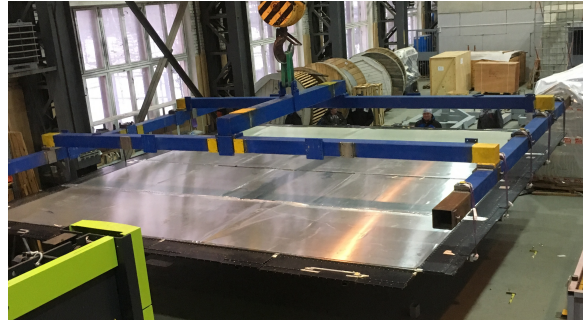
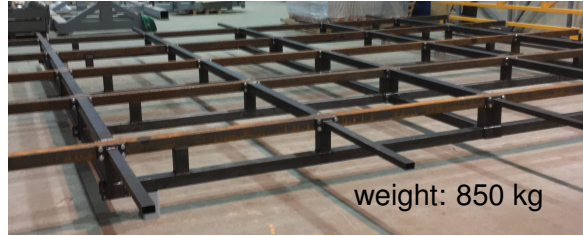
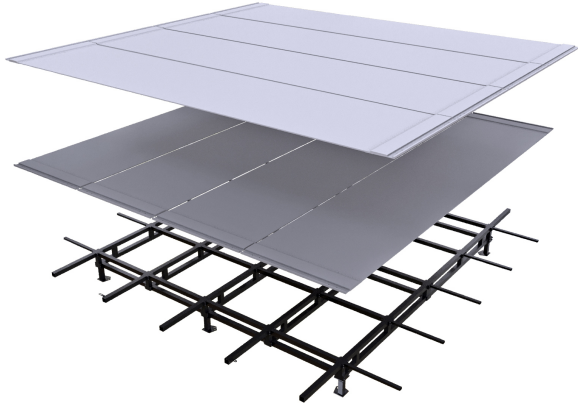
- Prototype at 0° (“looking up”)
- Measured atmo.  $\mu$  flux @ Strasbourg
- JUNO reconstruction working well
- New reconstruction algorithms under development

# TT Mechanical Structure

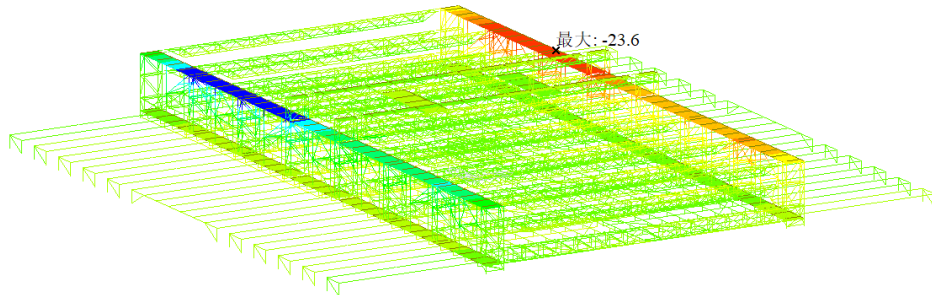


- TT modules are flexible
- In OPERA modules placed vertically → no supporting structure needed
- In JUNO, horizontal placement requires strong structure to avoid sagging
- Easy access to electronics needed
- Will be constructed in China soon
  - ▶ Everything ready, but need to make sure enough space available on JUNO site

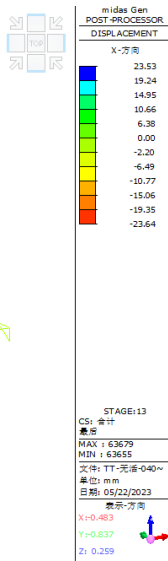
# TT Mechanical Structure for TT modules



# TT bridge deformation studies



- Made by company producing bridge in collaboration with IHEP
  - ▶ Calculated for each step during mounting bridge
- Changed order of mounting bridge to minimize deformation
  - ▶ Now lateral deformations controlled to 2.36 cm

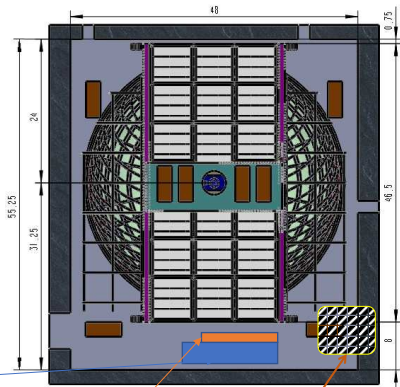


# TT installation



TT Container  
(~70 modules)

Preparation of the modules  
before installation in the TT  
walls (replacement of  
electronics, light leaks,  
cleaning, etc.)

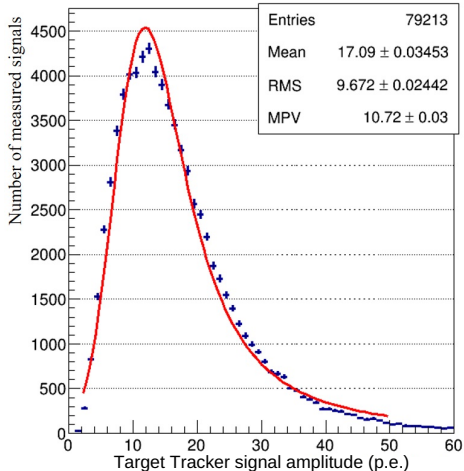
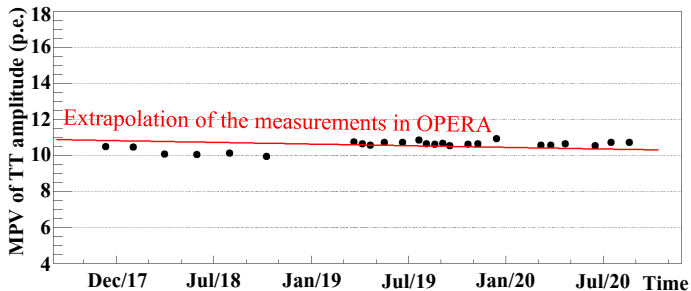


area for TT walls  
mounting  
10\*10m

- Expect to test & mount 1 wall per day

# TT Scintillator Monitoring

- Use old electronics to take atm.  $\mu$  data from TT modules in containers during storage
- Geometry in various storage sites can affect slightly the result of monitoring
- About  $(1.7 \pm 0.2)\%$  light yield loss per year
- Stopped since end 2020



# PMT channel vs strip conversion

