JUNO Top Tracker

João Pedro Athayde Marcondes de André
for the JUNO Collaboration

IPHC/IN2P3/CNRS

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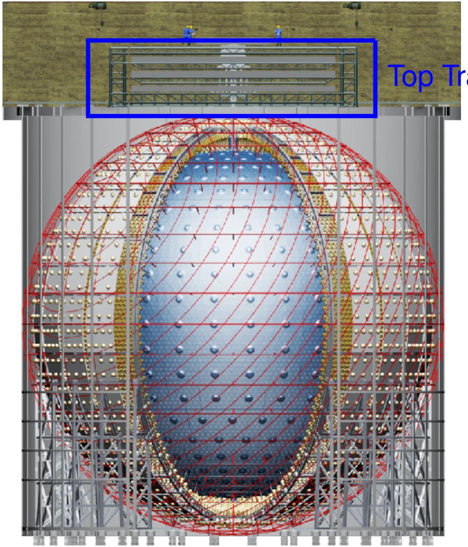
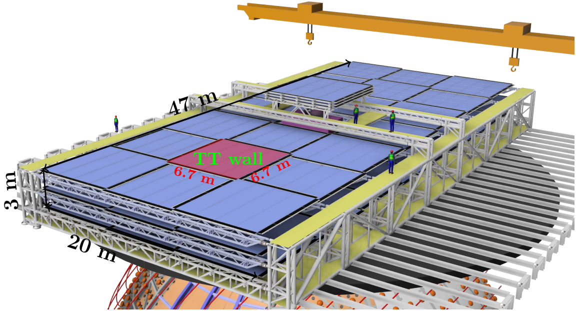
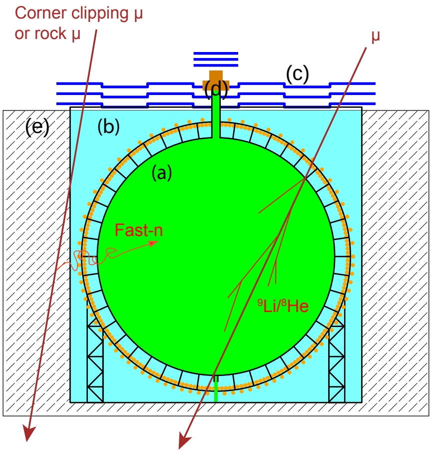
JUNO, "The JUNO experiment Top Tracker," Nucl. Instrum. Meth. A **1057** (2023), 1686800 [arXiv:2303.05172]

The JUNO Detector

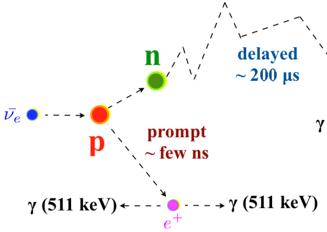




Cosmogenic background



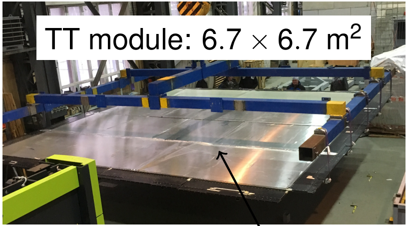
- Inverse Beta Decay (IBD) – 57.4/day in JUNO
  - Main channel to detect reactor antineutrinos

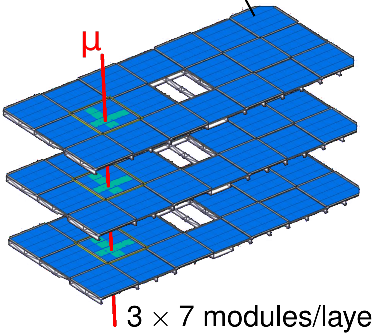


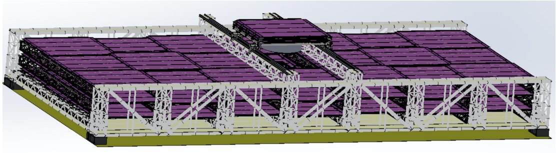
- Cosmogenic bkg. hard to distinguish from IBD
  - ^{9}Li & ^{8}He have decays with $e^- + n$
    - ★ ∼167 (^{9}Li + ^{8}He) per day; $\sim 1/2$ decay w/ $e^- + n$
  - As IBD has prompt-delayed signature
  - Tagged using parent μ
  - JUNO needs good muon tracking capabilities
- Fast-n can also be issue,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

JUNO Top Tracker (TT): Overview

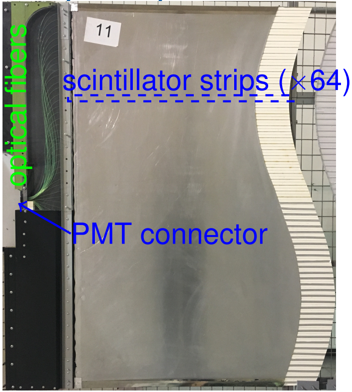
- TT refurbished from OPERA Target Tracker
  - TT modules are delivered to JUNO site in 2018!
- 62 walls measuring (6.7×6.7) m^2 of plastic scintillator available
- Walls distributed in 3×7 horizontal grid in 3 layers $\rightarrow$ cover $\sim$ 60% of surface above WCD
- Upgrades needed on several systems: electronics, mechanical structure, ...

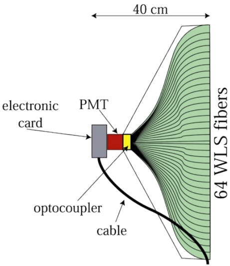


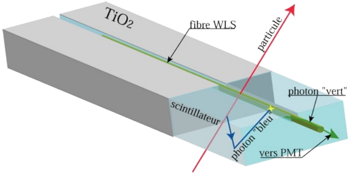




Detection principle



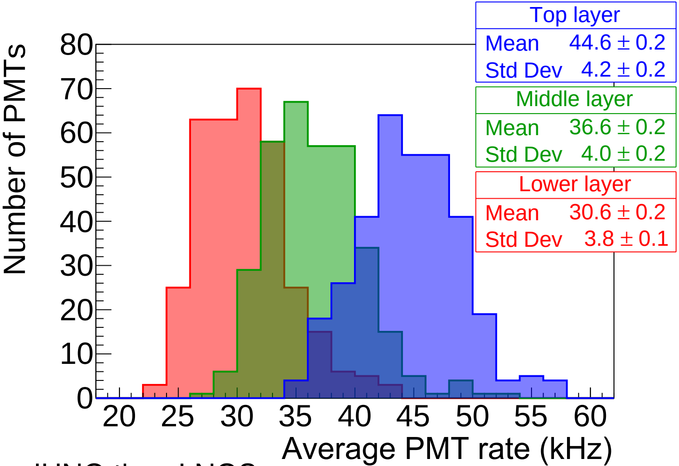




- Charged particle crosses scintillator strip → scintillation light
- Light captured by optical fibers and guided to MA-PMT
- Signal from PMT processed by electronics

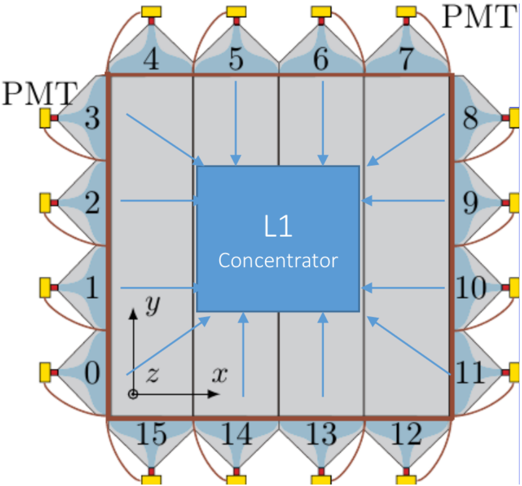
PMT rate

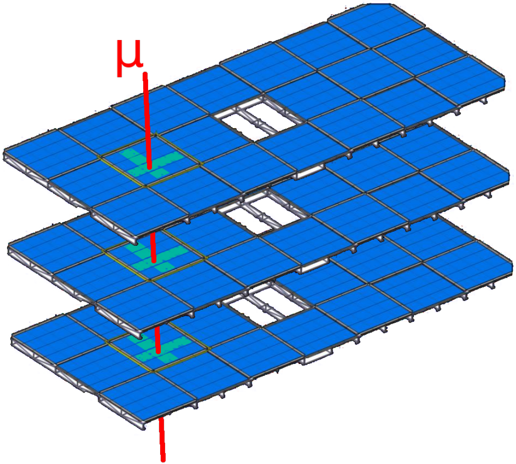
Isotope	Activity (Bq/kg)	
	LNGS	JUNO site
^{40}K	26 ± 2	1340 ± 50
^{238}U	1.8 ± 1	110 ± 10
^{232}Th	1.5 ± 1	105 ± 10



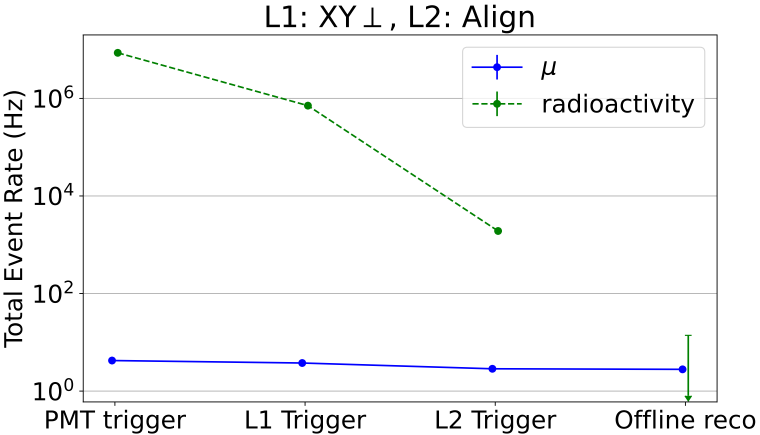
- Rock $\sim 100\times$ more radioactive in JUNO than LNGS
- Singles rate @ PMT for JUNO from radioactivity from rock
- Need to reject online most of this background (reduce dead time & data size)

L1 and L2 trigger views



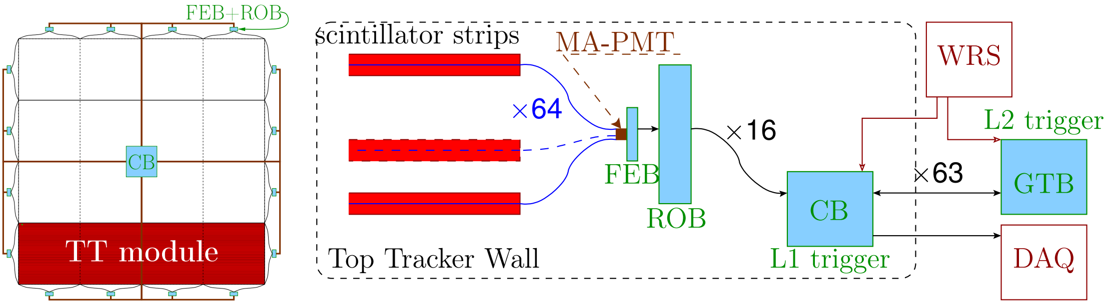


Estimated TT trigger rate



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

TT Electronics: Schematic View



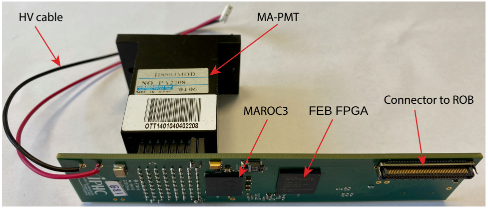
Front-End Board (FEB): PMT interface and part of the PMT readout.

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.

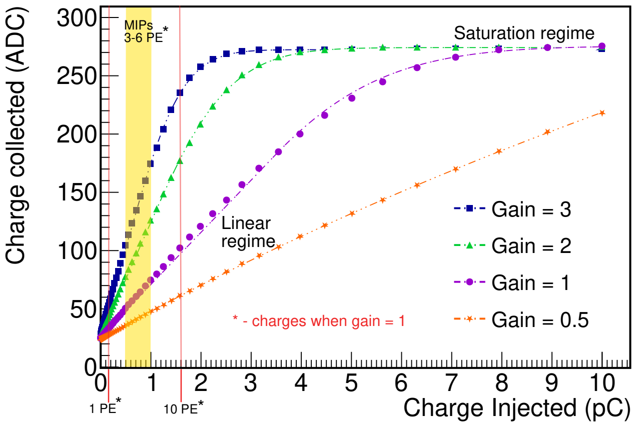
Global Trigger Board (GTB): combine information of all L1 triggers from CB and produce a L2 trigger.

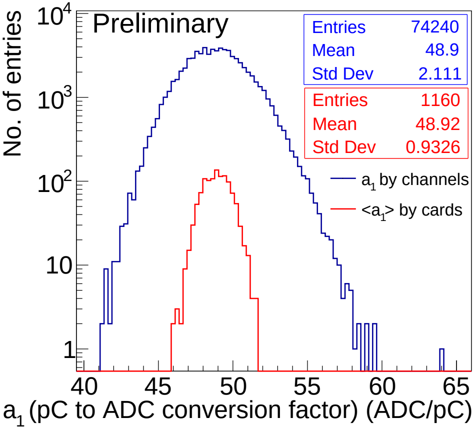
TT Electronics Status: FEB



- 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



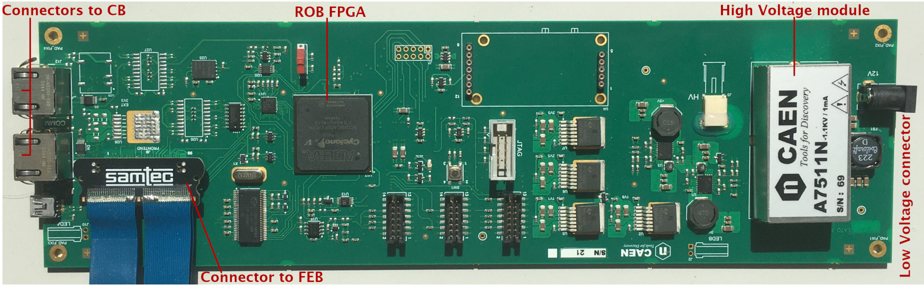


$$f(x) = \begin{cases} a_0 + a_1 x & , x \leq b \\ a_{00} + a_2\left(1 - e^{-a_3 x^{a_4}}\right) & , x > b \end{cases}$$

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

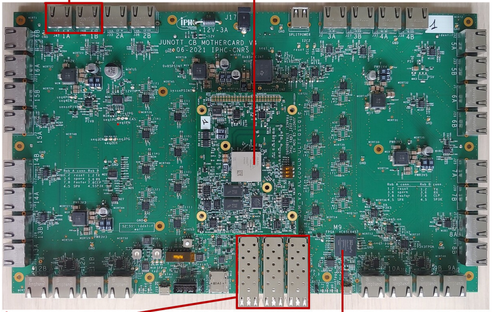
- Charge measured using MAROC3 Wilkinson
- Good homogeneity between FEBs

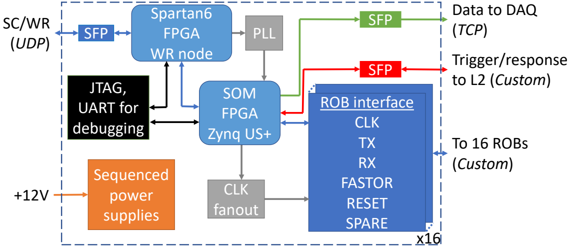
TT Electronics Status: ROB



- 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

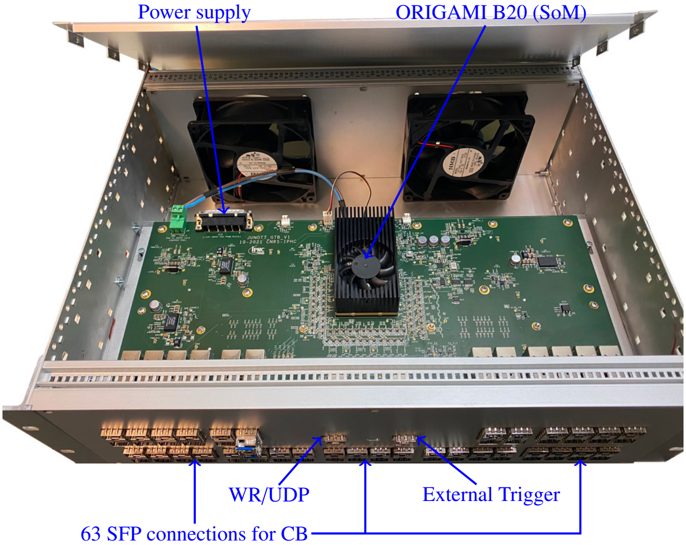
TT Electronics Status: CB





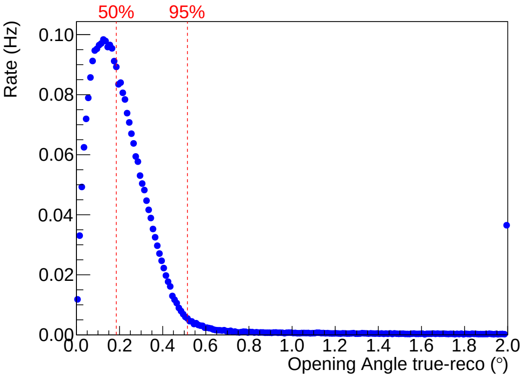
- Connections to all 16 ROBs of same wall (2 RJ-45 cables/ROB)
- Optical connections components outside wall
- Timestamping & event selection done in separate FPGAs
  - Easier to implement WR node on Spartan6 using UDP
  - TCP connection used to transfer data with Zynq Ultrascale
- To be shipped to China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

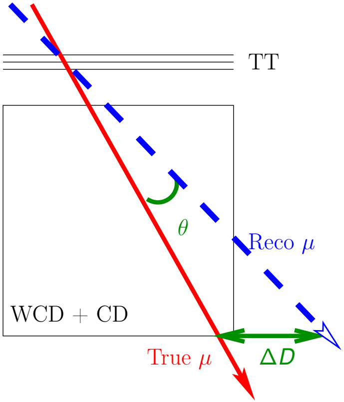
TT Electronics Status: GTB



- 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 μ reconstruction capabilities

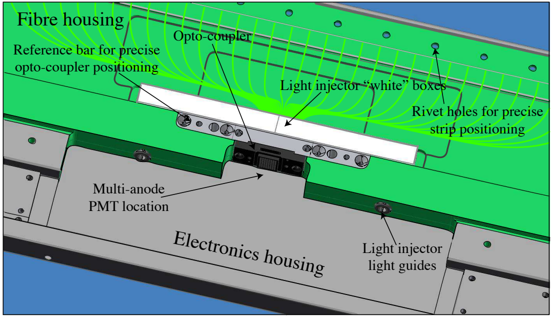


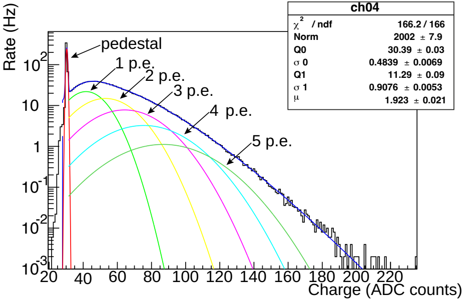


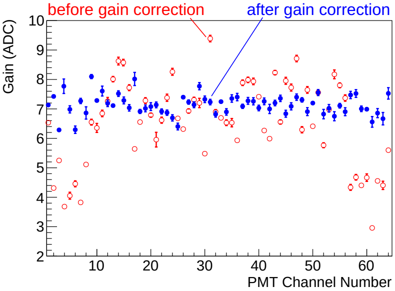
- Median resolution to track μ of 0.2°
- Projected to the bottom of WCD, corresponds to median $\Delta D = 20$ cm
- Excellent μ tracking capabilities to help veto μ and associated cosmogenics
- Also provides well reconstructed μ sample for CD + WCD tuning/calibration

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

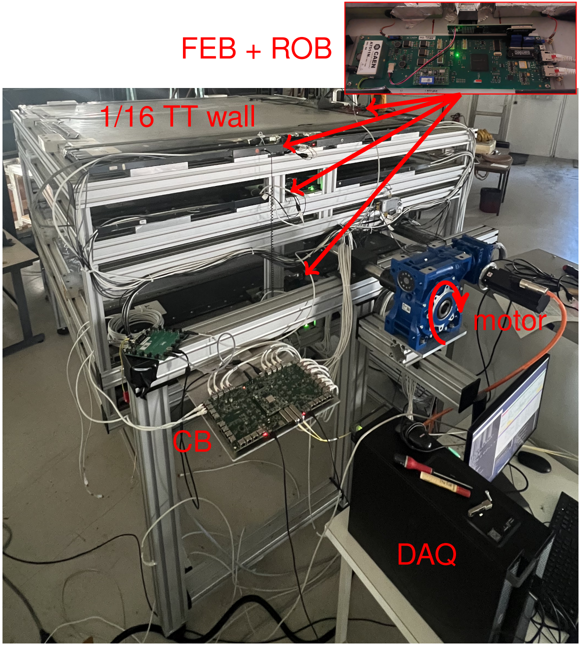




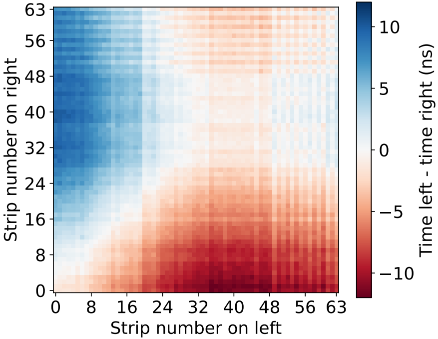


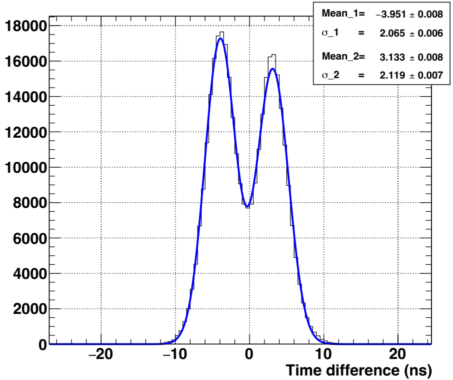
TT Prototype

- TT prototype in Strasbourg
  - build with a quarter of a TT module
  - 4 X – Y layers (TT has 3)
  - 8×(FEB + 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

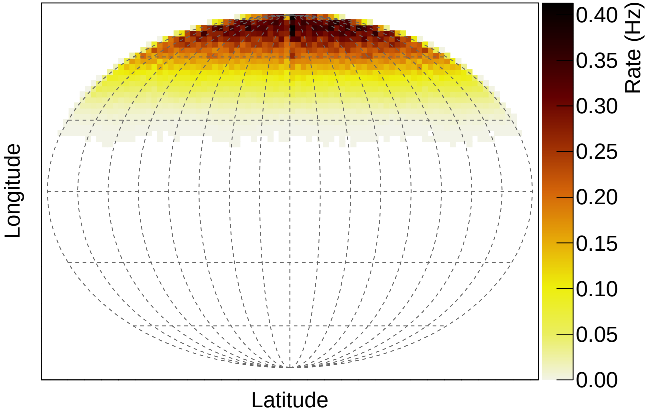




- Due to size of modules, time for light propagation to PMT not negligible
- Impact will be larger on JUNO
- Not negligible to reach $\mathcal{O}$(ns) resolution
  - Pattern expected from fiber lengths

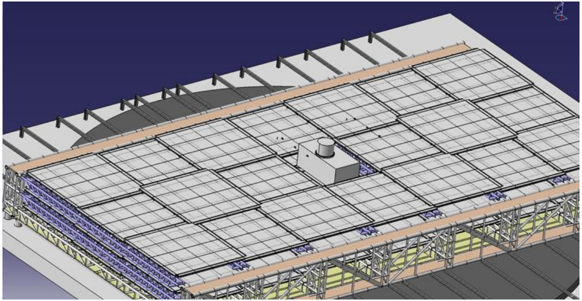
- Prototype rotated 90°
- Clear separation between left/right going $\mu \rightarrow$ 2 ns timing resolution
  - Selected clean μ & apply all corrections for timing

TT Prototype is also a telescope for muons



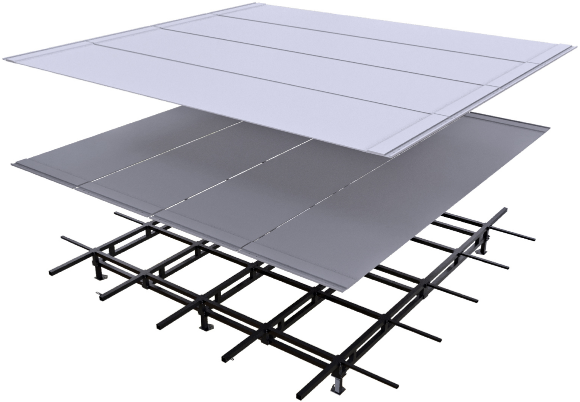
- Prototype at 0° (“looking up”)
- Measured atmo. μ flux @ Strasbourg
- JUNO reconstruction working well
- New reconstruction algorithms under development

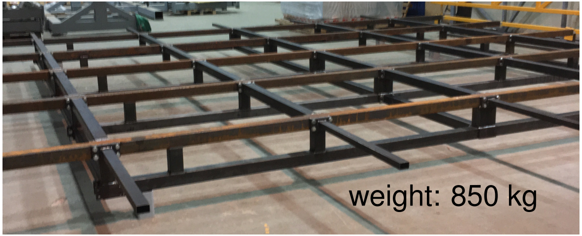
TT Mechanical Structure

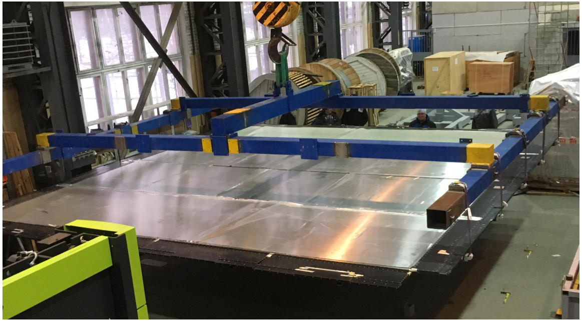


- TT modules are flexible
- In OPERA modules placed vertically → no supporting structure needed
- In JUNO, horizontal placement requires strong structure to avoid sagging
- Easy access to electronics needed
- Will be constructed in China soon
  - Everything ready, but need to make sure enough space available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

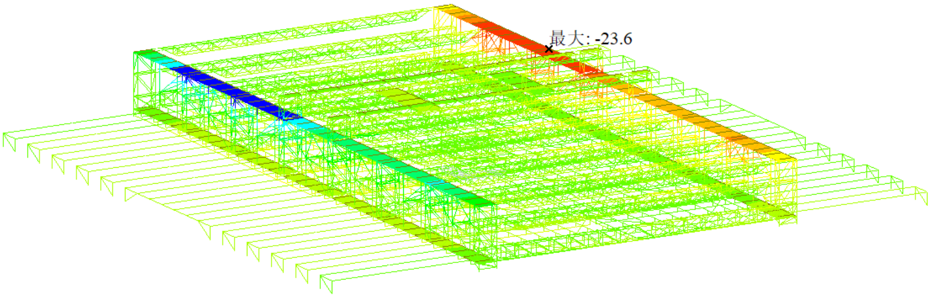
TT Mechanical Structure for TT modules







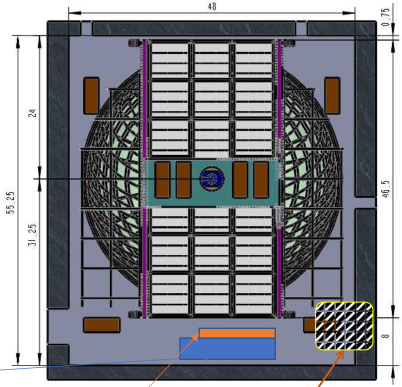
TT bridge deformation studies



- 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)



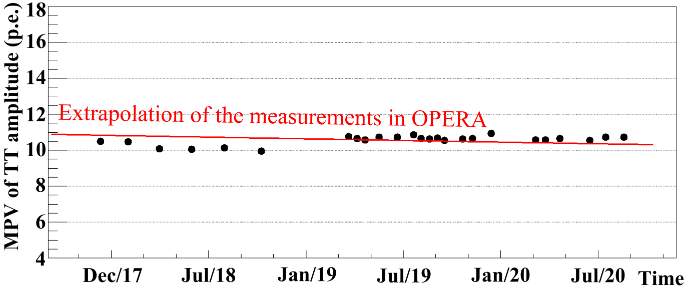
Preparation of the modules before installation in the TT walls (replacement of electronics, light leaks, cleaning, etc.)

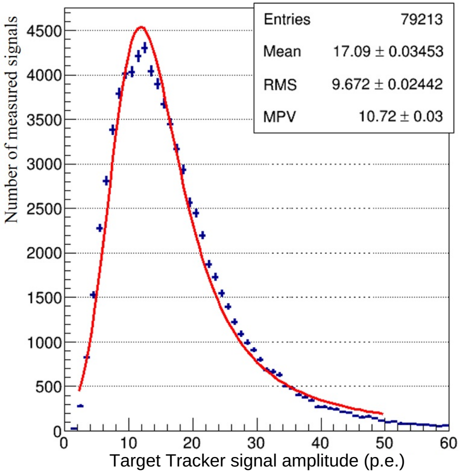
area for TT walls mounting 10*10m

- Expect to test & mount 1 wall per day

TT Scintillator Monitoring

- Use old electronics to take atm. μ 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





Summary

- JUNO Top Tracker is a part of the JUNO Veto system
  - Precise μ tracking is essential for rejection of cosmogenic background
    - also allows to study cosmogenic background spectrum
  - Helps tuning reconstruction of CD/WCD
- TT modules have been on JUNO site since 2018
- Top Tracker preparation is being completed
  - Mechanical structure defined, ready for production
  - All electronics produced and either already in China or to be send there this month
    - Firmware still being finalized
    - Tests ongoing using prototype @ IPHC
  - Installation procedure defined
- Top Tracker installation expected to start this year!