Status of the Veto System of JUNO (extra info)

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IPHC/IN2P3/CNRS

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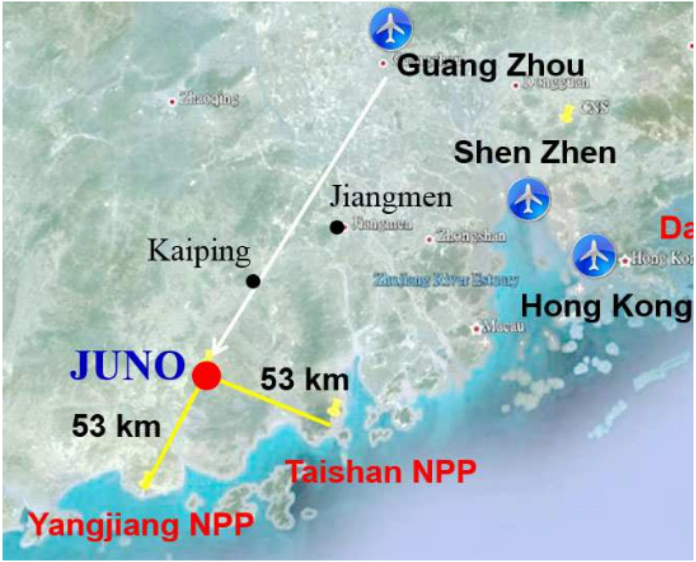
General info on JUNO

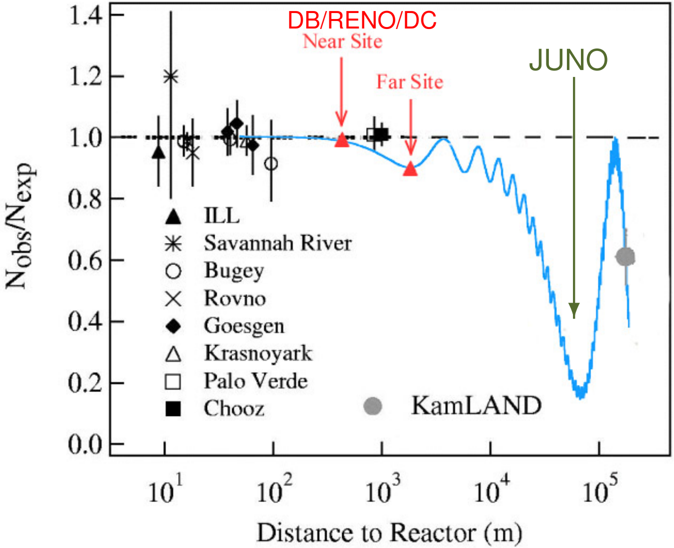
Introduction to the Jiangmen Underground Neutrino Observatory



J. Phys. G **43** (2016) no.3, 030401

- JUNO located 53 km from Taishan and Yangjiang NPP
  - TAO@JUNO planned in Taishan NPP
- Baseline optimized for Neutrino Mass Ordering determination
  - many other topics in reach
- First experiment to see both Δm^2 from ν oscillations

Introduction to the Jiangmen Underground Neutrino Observatory



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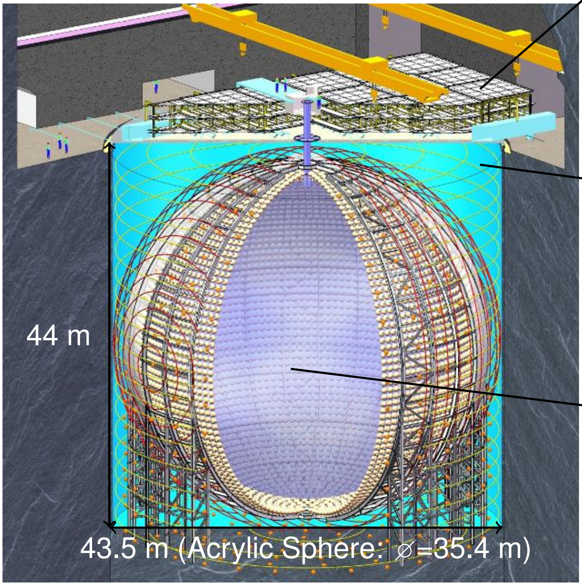
The JUNO Detector



Top Tracker (TT)

- Precise μ tracker
- 3 layers of plastic scintillator
- $\sim$ 60% of area above WCD

Water Cherenkov Detector (WCD)

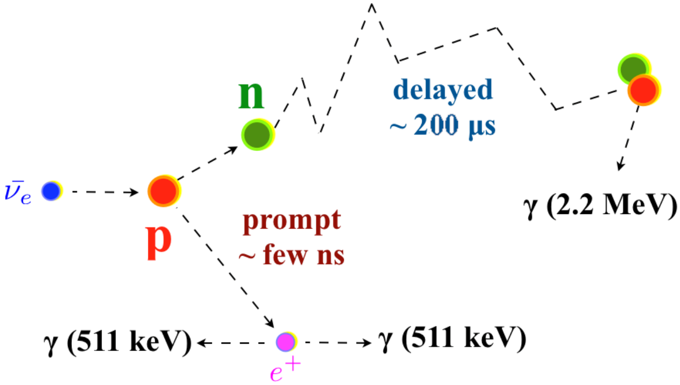
- 35 kton ultra-pure water
- 2.4k 20" PMTs
- High μ detection efficiency
- Protects CD from external radioactivity

Central Detector (CD) – $\bar{\nu}$ target

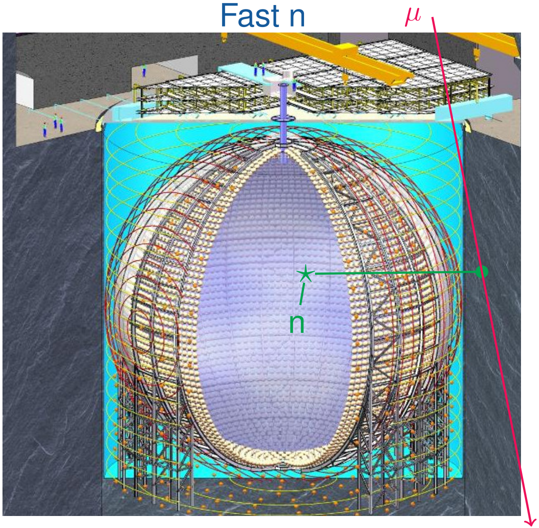
- Acrylic sphere with 20 kton liquid scint.
- 18k 20" PMTs + 26k 3" PMTs
- 3% energy resolution @ 1 MeV

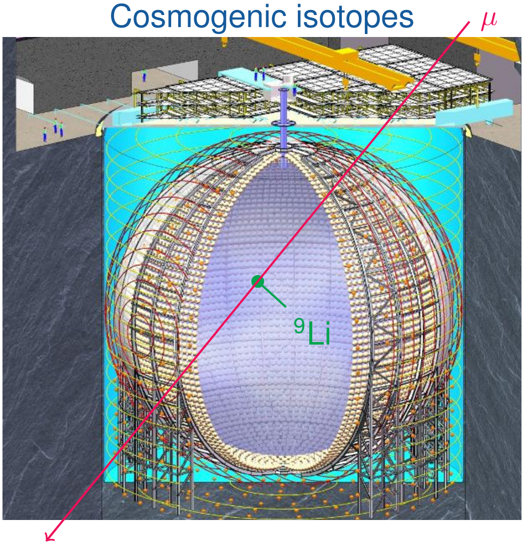
Measuring Reactor $\bar{\nu}_e$

- $\bar{\nu}_e$ detected via IBD: $\bar{\nu}_e + p \rightarrow n + e^+$
  - IBD used since discovery of $\bar{\nu}$
  - Prompt+delayed signal $\Rightarrow$ large background suppression
  - Expected event rate: 73/day (IBD-like in FV)



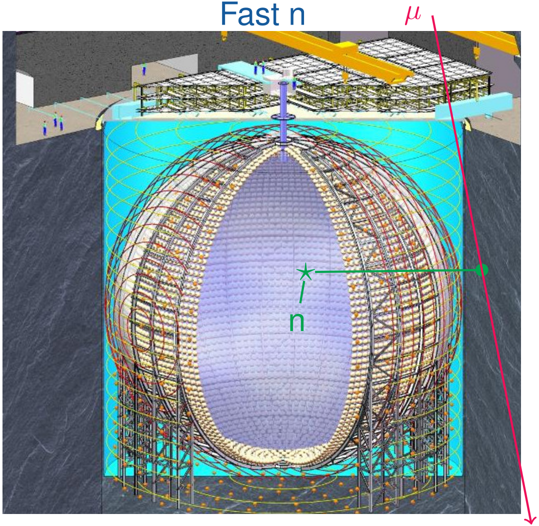
Measuring Reactor $\bar{\nu}_e$: μ-Induced Backgrounds



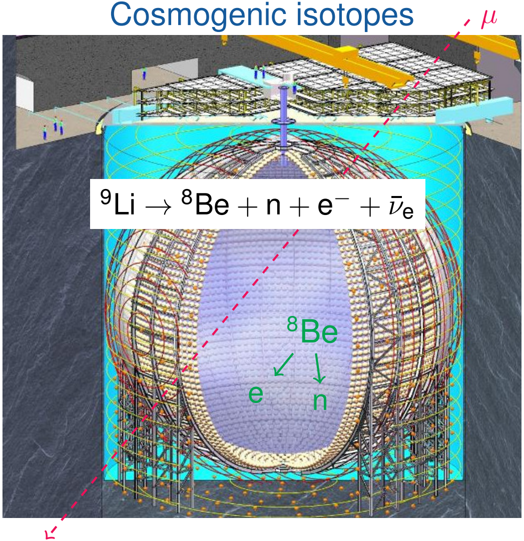


Measuring Reactor $\bar{\nu}_e$: μ-Induced Backgrounds

Fast n



Cosmogenic isotopes



71/day (IBD-like in FV)

JUNO μ Veto

- Goal: remove cosmogenic-induced IBD-like events
- Veto criteria:
  1. if μ tagged and direction known, reject events within 3 m of μ for 1.2 s
  2. if μ tagged in CD (WCD) but direction unknown, reject events for 1.2 s (1.5 ms)

$\Rightarrow$ Need to track μ well to avoid full detector veto!
  - 99% of μ expected to be in category 1
  - If cannot reco. μ (ie, 100% in category 2) $\Rightarrow$ 100% detector downtime

- Tracking μ going to rock also important to experimentaly evaluate fast n rate

<table>
<tr><th>Selection</th><th>IBD efficiency</th><th>IBD</th><th>Geo-νs</th><th>Accidental</th><th>^{9}Li/^{8}He</th><th>Fast n</th><th>(α, n)</th></tr>
<tr><td>-</td><td>-</td><td>83</td><td>1.5</td><td>$\sim 5.7 \times 10^4$</td><td>84</td><td>-</td><td>-</td></tr>
<tr><td>Fiducial volume</td><td>91.8%</td><td>76</td><td>1.4</td><td rowspan="3">410</td><td>77</td><td rowspan="5">0.1</td><td rowspan="5">0.05</td></tr>
<tr><td>Energy cut</td><td>97.8%</td><td rowspan="3">73</td><td rowspan="3">1.3</td><td rowspan="3">71</td></tr>
<tr><td>Time cut</td><td>99.1%</td></tr>
<tr><td>Vertex cut</td><td>98.7%</td><td>1.1</td></tr>
<tr><td>Muon veto</td><td>83%</td><td>60</td><td>1.1</td><td>0.9</td><td>1.6</td></tr>
<tr><td>Combined</td><td>73%</td><td>60</td><td colspan="5">3.8</td></tr>
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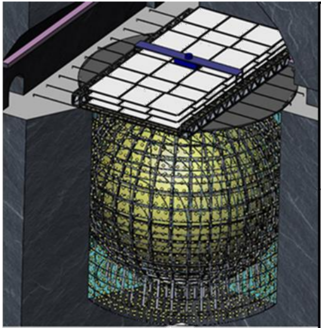
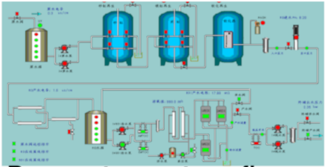
Table 2-1: The efficiencies of antineutrino selection cuts, signal and backgrounds rates.

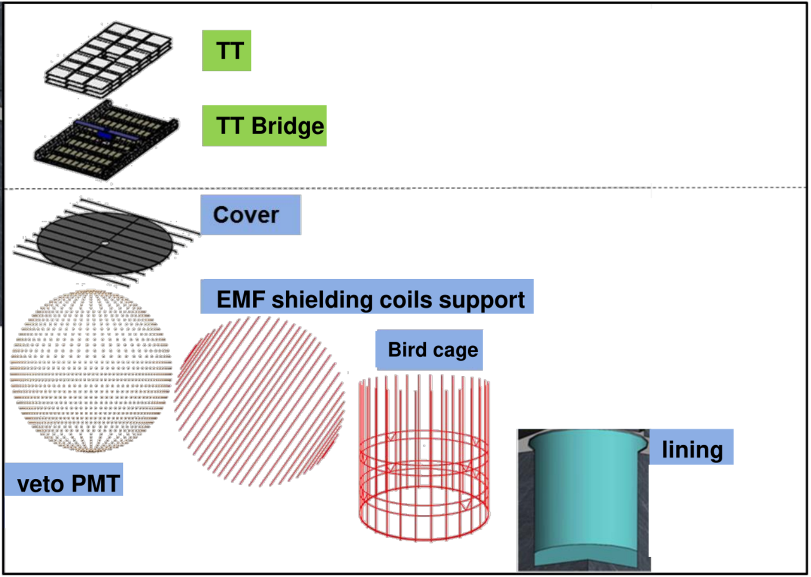
JUNO Water Cherenkov Detector

Water Cherenkov Detector overview

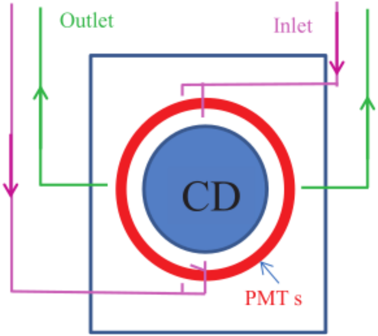


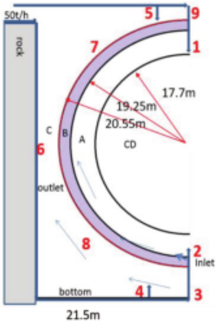


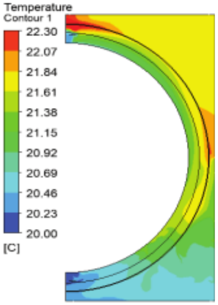
Pure water system, flow rate: ~100 t/h



Pure water system







- Water circulation keeps water quality
- Keep acrylic sphere at (21 ± 1) °C
- Prevent Rn diffusion to CD
- Company for installation already selected (Shenzhen Ultrapure)
- Will starting installing pipes still this year
- 100 t/h system ready in 2021

Pure water system: flowchart

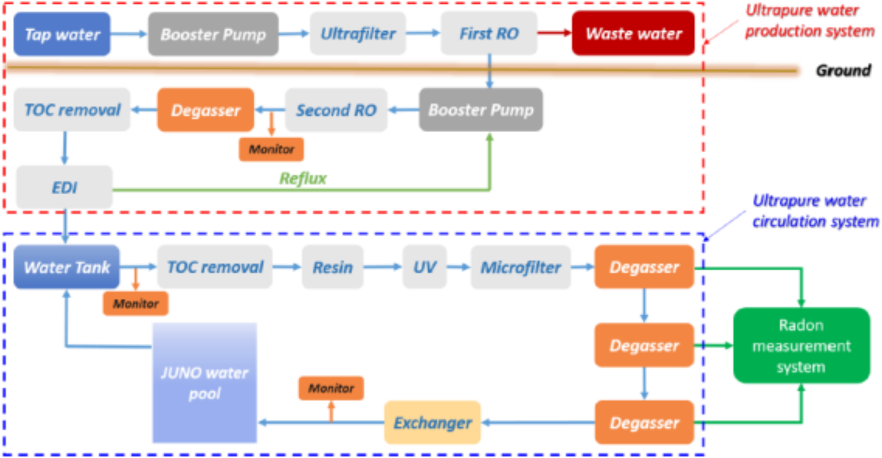


Figure 6: The flow chart of JUNO pure water system

Water Pool Liner

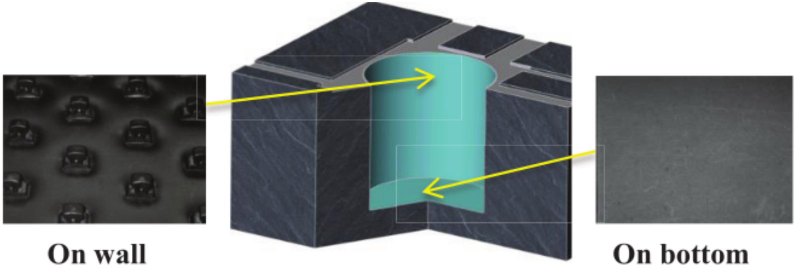
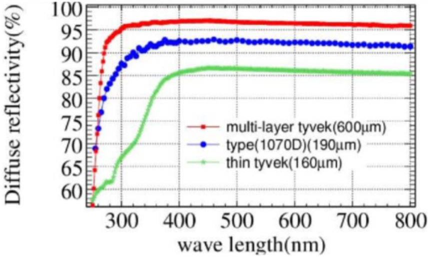


Figure 2: HDPE liner. Left: the StudLiner. Middle: the pool. Right: the smooth liner.

- High Density PolyEthylene plate (HDPE) used to separate rock and ultra pure water
  - Keep water clean
  - Prevent Rn diffusion from rock
- Finishing to test installation procedure

Tyvek



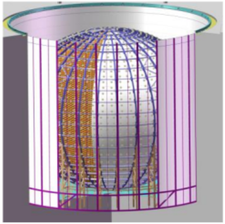
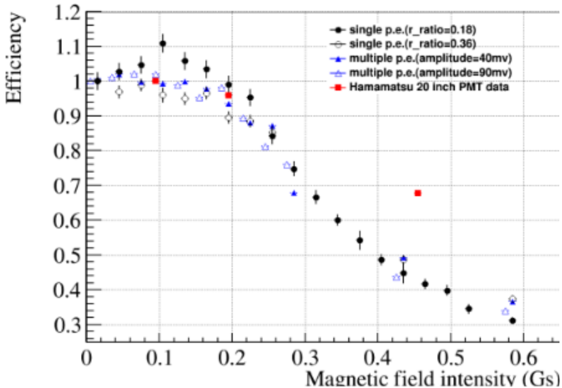
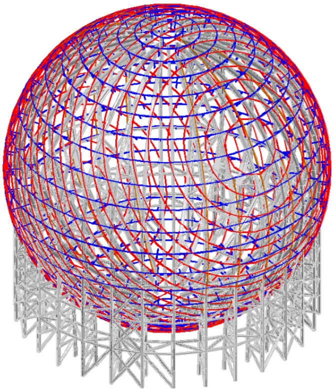


Figure 4: Left: reflectivity of different Tyveks . Right: effect drawing of Tyvek.

- Cover all surfaces to water pool with tyvek → increase light collection
- Use same as for Daya-Bay
- Preparing for bidding

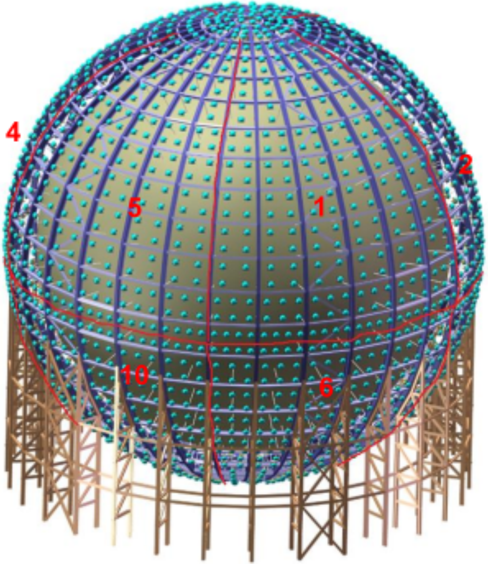
EMF compensating coils

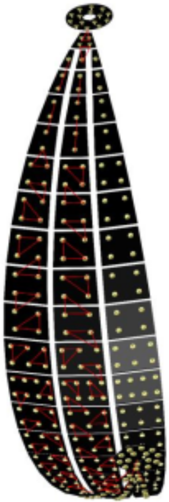




- @ JUNO site geomagnetic field is $B \approx 45\ \mu$T
- 16 pairs shielding coils
- EMF coils set to compensate geomagnetic field $\rightarrow$ residual $B < 5\ \mu$T
- Ready for production

WCD PMTs



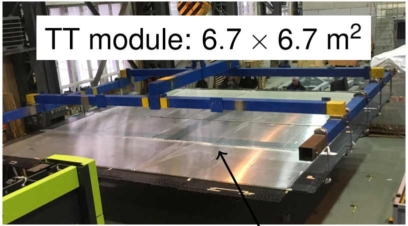


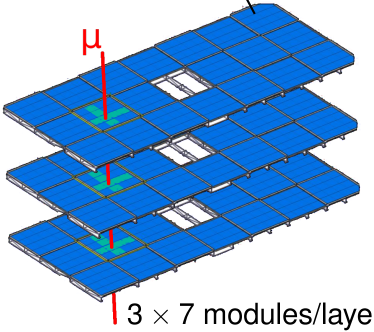
- Same 20” PMTs as in CD, placed around acrylic sphere
- 2400 PMTs divided with 44% on top, and 56% on bottom

JUNO Top Tracker

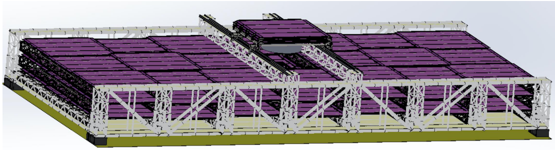
JUNO Top Tracker (TT): Overview

- TT refurbished from OPERA Target Tracker
  - 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
  - Monitoring of aging of detector essential
  - Upgrades needed on several systems: electronics, mechanical structure, ...
- Very precise μ tracking
  - Detector granularity 2.6×2.6 cm^2 in X–Y
  - 3 Layers separated by 1.5 m
  - $\Rightarrow$ 0.2° median resolution for μ tracks!



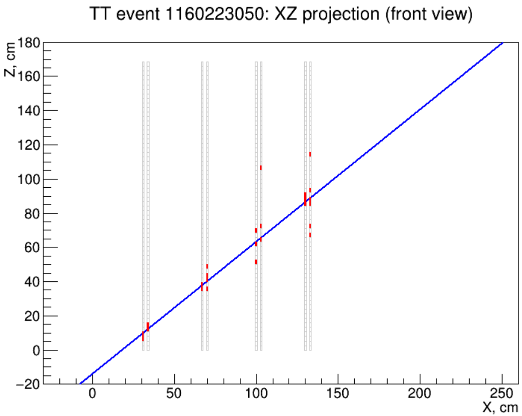


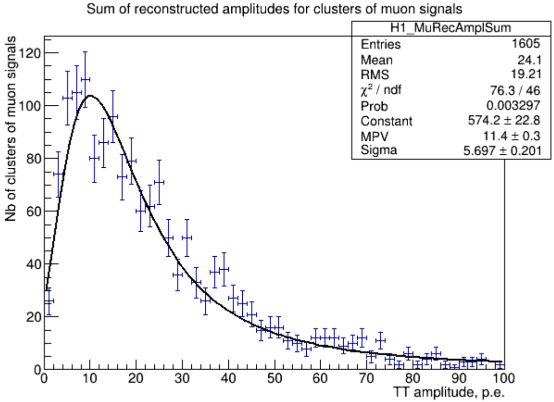
3×7 modules/layer



TT Modules Already Delivered at Detector Site!

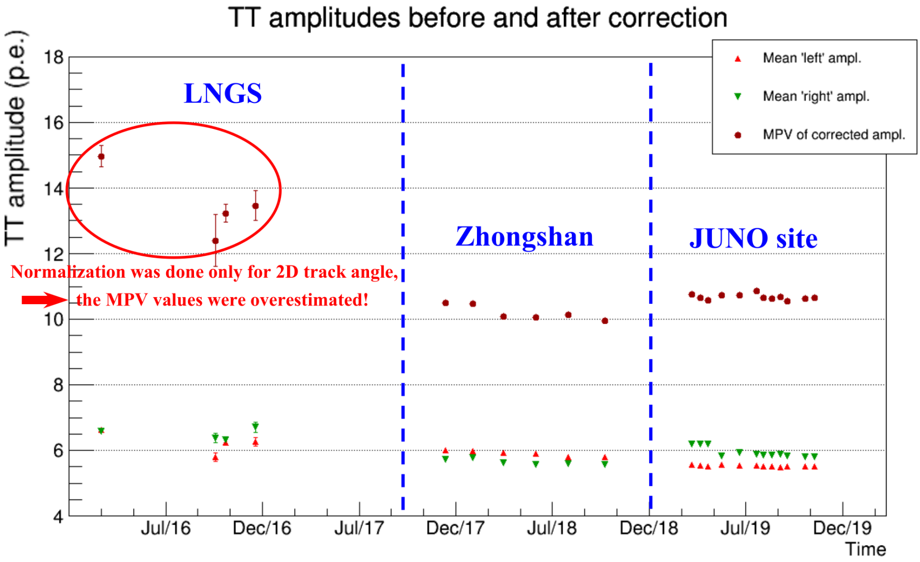
TT Monitoring in PMT Testing Hall



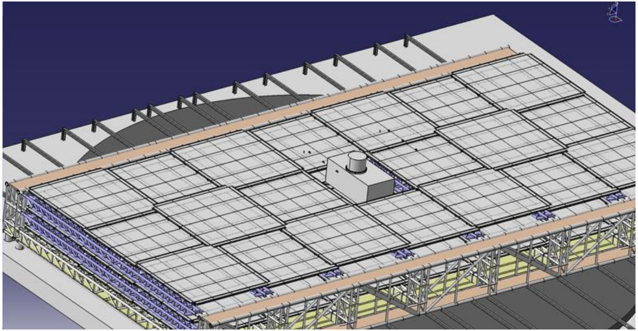


- Use old electronics to take atm. μ data from TT modules in containers during storage
- No significant aging observed up to now

TT Monitoring in PMT Testing Hall

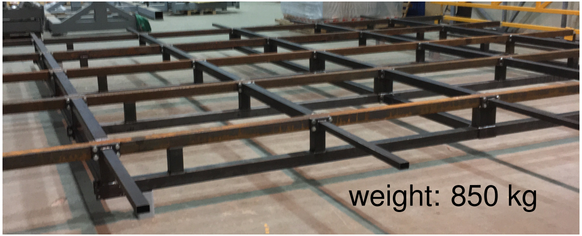


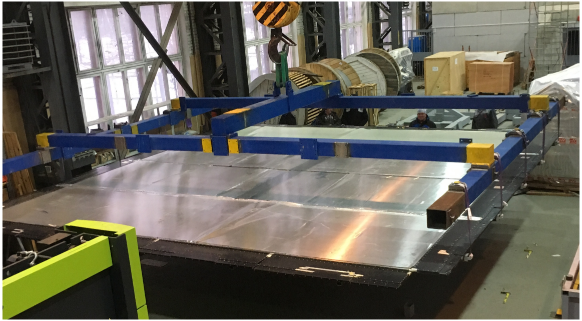
TT Mechanical Structure



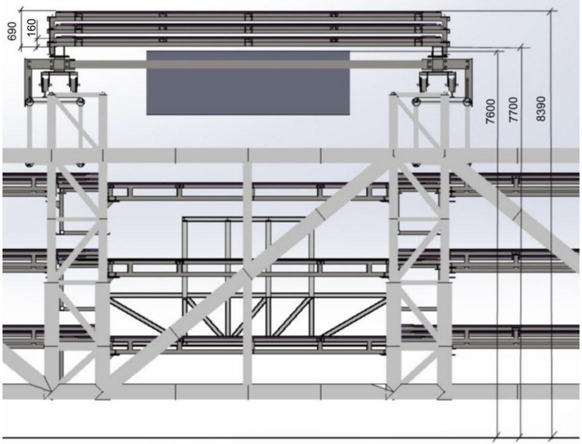
- TT modules are flexible
- In OPERA modules placed vertically
  $\rightarrow$ no supporting structure needed
- In JUNO, horizontal placement requires strong structure to avoid sagging
- Easy access to electronics needed
- Final design review completed
  - TT wall supporting structure
  - TT chimney structure
  - TT bridge
- Ready to start mass production

TT Mechanical Structure

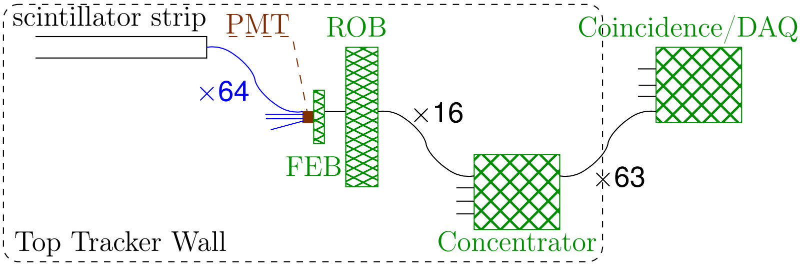




Supporting structure above Chimney



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.

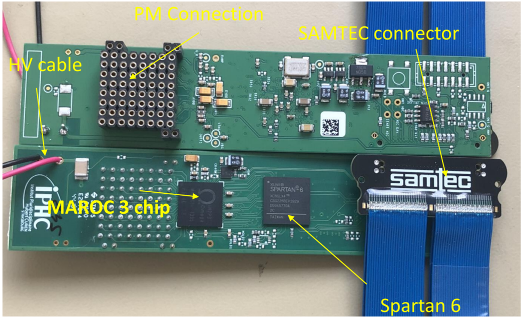
- Charge readout by FEB/ROB takes 8-15 μs
- Permanent Fast OR Trigger

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

Coincidence Board: combine information from all L1 triggers to produce a L2 trigger.

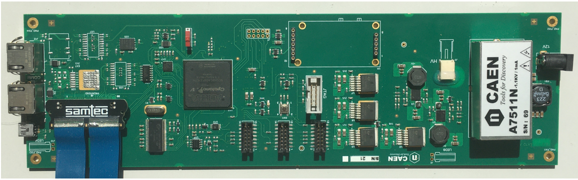
TT Electronics: Front End Board and Read Out Board

FEB



- Design validated by collaboration
- 1200 cards produced and tested
  - 1st pass of testing ended on July 2020
  - 97% passed tests
  - Cards that did not pass being repaired
- ∼1000 cards needed for TT

ROB



- Test of integration with FEB and Concentrator on-going
- To be reviewed by collaboration in 2020
- Production should start just after passing review

TT Electronics: Concentrator and L2 Trigger Boards

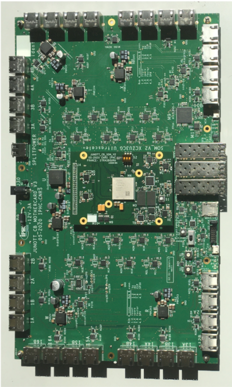
- Concentrator Board is divided on a motherboard + SOM card
  - both cards developed @IPHC
  - SOM → Xilinx Ultrascale+ FPGA
    - ★ 16 layers, >600 FPGA pins routed, DDR4 2x8Gb @ 1GHz
- Extensively tested V2 prototype
- Have just received V3 prototype
  - This should be final version
  - Finish testing by end 2020
  - Production of 80 CB expected in 2021

- Just started design of L2 Trigger Board based on Concentrator Board
- Only 1 TT L2 trigger card needed for JUNO, will be ready for data taking

CBv2 (2019)

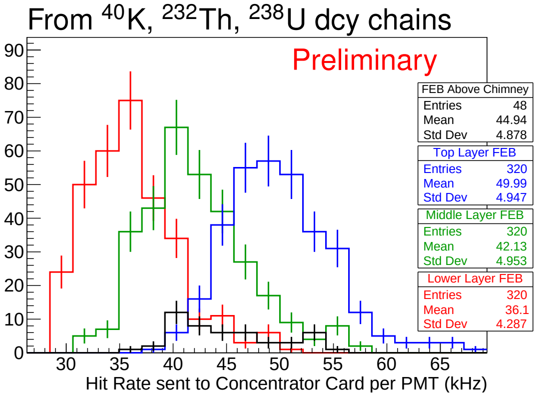
FPGA – IPHC SOMv1

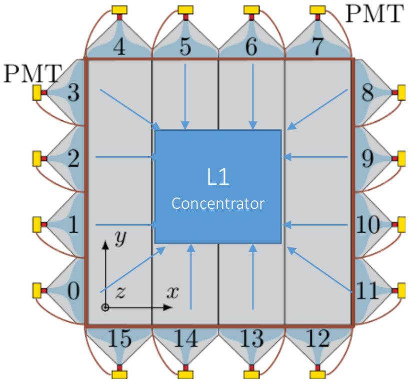
CBv3 (2020)



FPGA – IPHC SOMv2

TT Trigger Overview





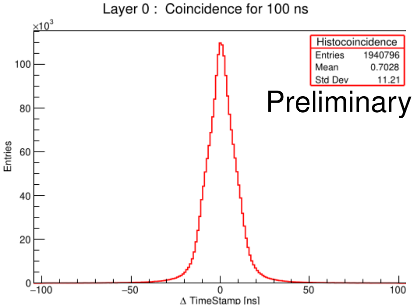
- Natural radioactivity @JUNO site is 100× larger than @OPERA site
- Need to quickly **reject** radiation (but not μ!) to reduce dead time
- L1 trigger: acts at "wall" level, looks for X–Y coincidences
- L2 trigger: looks at the whole detector (looks for global alignment)

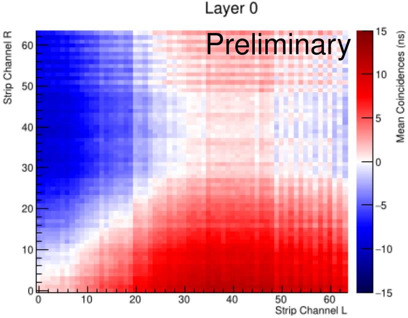
TT Prototype

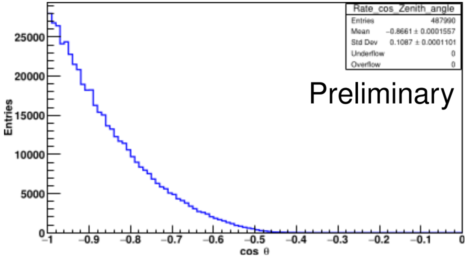
- TT prototype in Strasbourg
  - build with a quarter of a TT wall
  - 4 X – Y layers (instead of 3 as in TT@JUNO)
- Perfectly adapted to test new TT Electronics Cards
  - FEB & ROB tested in with close to real conditions
  - Testing of some L1 & L2 trigger algorithms in small scale also possible

TT Prototype: data

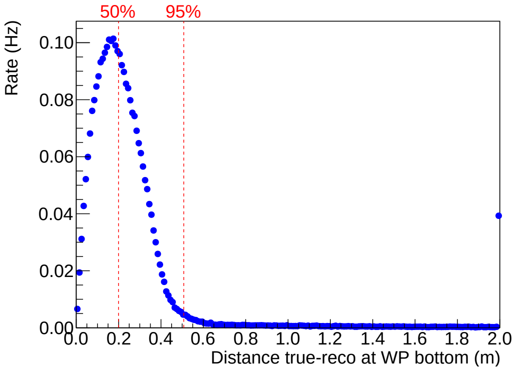
- Put in place full calibration procedure
- XY coincidence in 1 plane: $\sim$500 Hz $\rightarrow$ 1 evt/min/cm^2
- Reconstructed coincident events using JUNO software
- On-going work to tune simulation & improve reconstruction

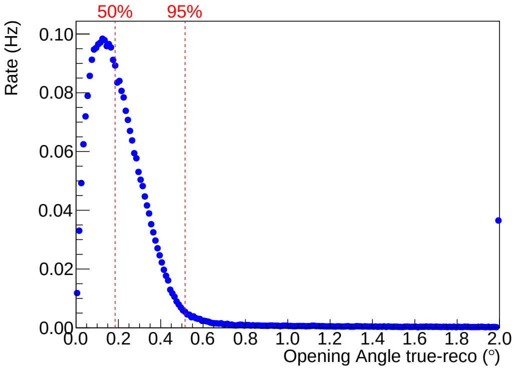






TT reconstruction quality





- Median resolution: 20 cm at bottom of WP or 0.2° angular resolution
- 95% of events within: 50 cm at bottom of WP or 0.5° angular resolution