The LPMT Global Trigger System of JUNO Central Detector

Jianmeng Dong, Guanghua Gong

Tsinghua University, Beijing

On behalf of the JUNO collaboration

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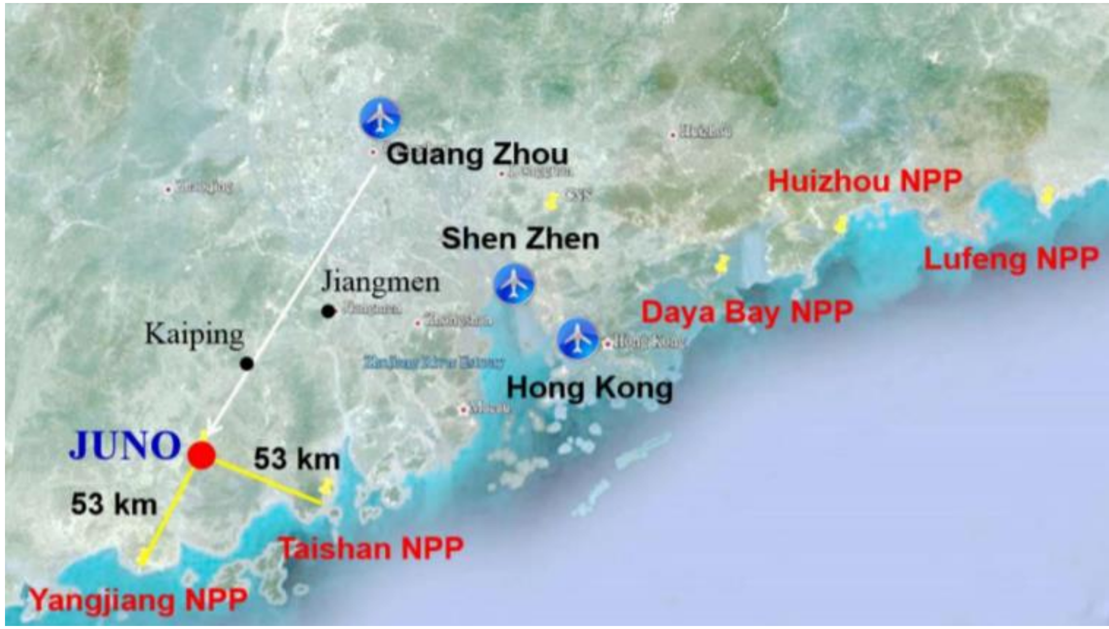
Outline

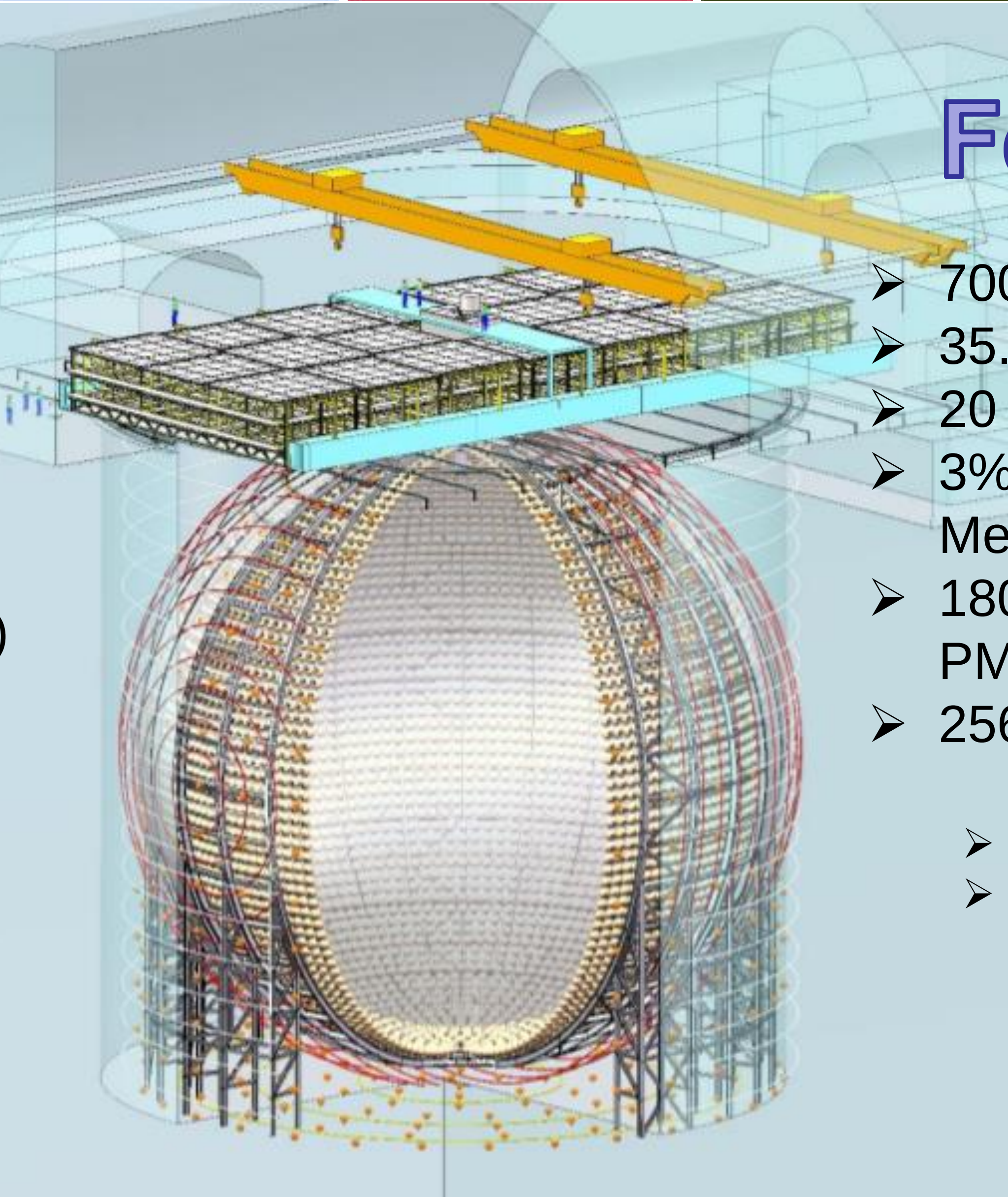
- ➢ Introduction of the JUNO experiment
- ➢ Trigger strategy of the Central Detector (CD)
- ➢ Current structure of the global trigger system
- ➢ Components gallery of the global trigger system
- ➢ Status and Plans



Jiangmen Underground Neutrino Observatory

Purposes

- Main task:
  - Determine the neutrino mass hierarchy
  - Measure 3 (Δm_{21}^2, Δm_{32}^2, θ_{12}) of the 6 neutrino oscillation parameters accurately (< 1% precision)
- Other purpose:
  - Supernova neutrinos
  - Geo-neutrinos
  - Solar neutrinos
  - Atmospheric neutrinos
  - ……



Features

- 700m underground
- 35.4m diameter of the CD
- 20 kt Liquid scintillator
- 3% energy resolution (@ 1 MeV)
- 18000 LPMTs for CD, 2000 PMTs for water pool
- 25600 SPMTs

  - LPMT: 20'' Large PMT
  - SPMT: 3'' small PMT

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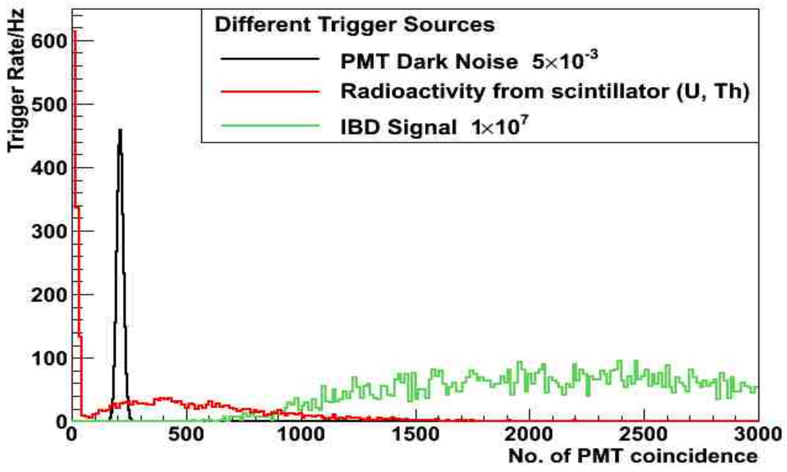
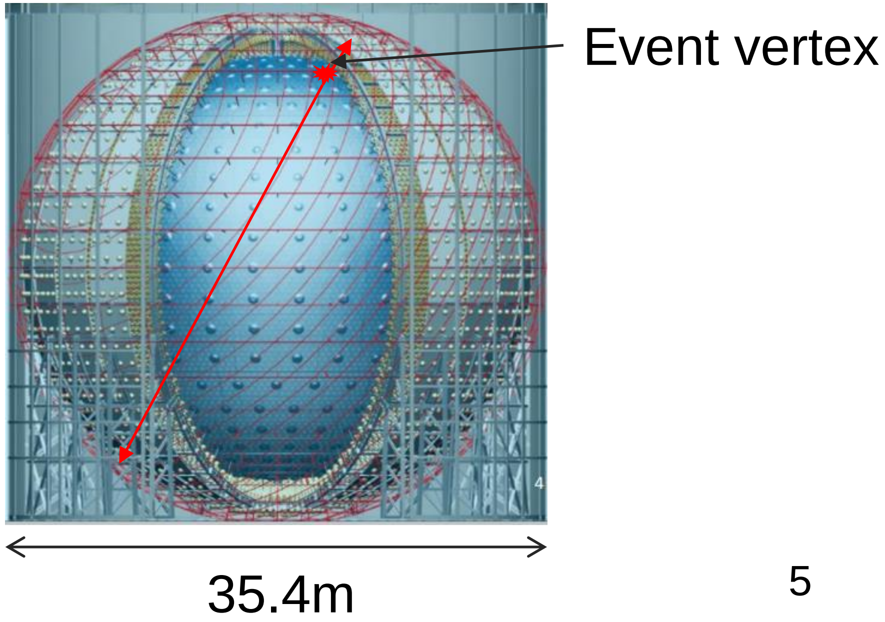
Trigger Strategy of LPMTs

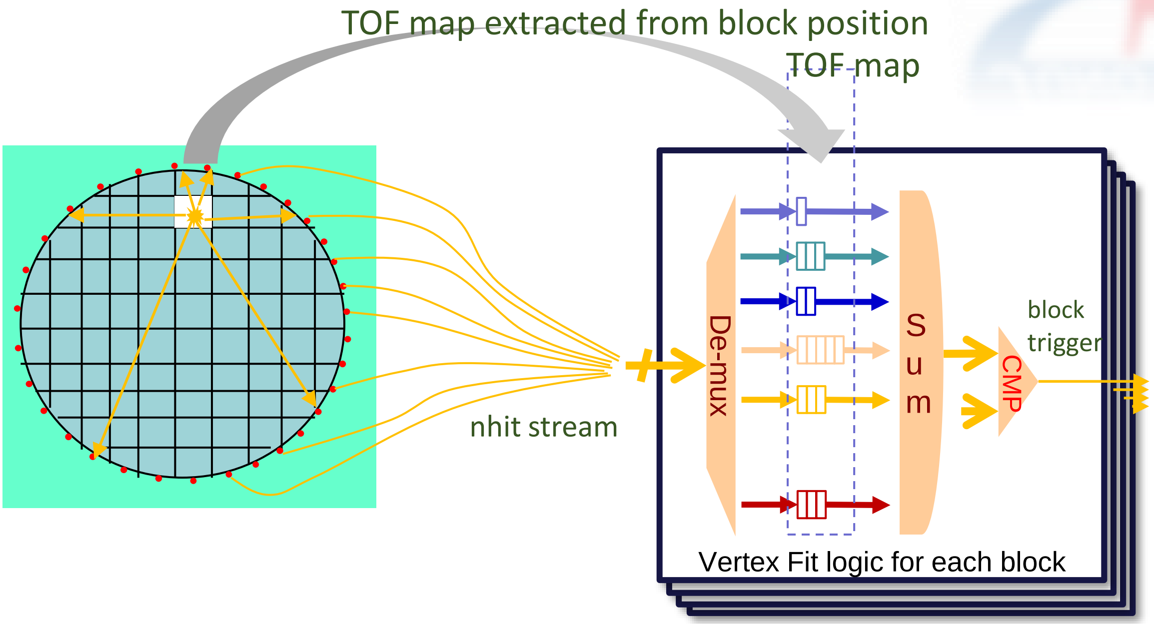
- According to simulation, nhit (multiplicity) trigger is good enough for Inversed Beta Decay (IBD) and atmospheric events.
  - Need to use full hit information.
  - With threshold 500, the PMT Dark Noise and more than 70% radioactive background can be cut efficiently.
- Trigger window:
  - Large size of the CD leads to big Time of Flight (TOF) difference;
  - If the reaction vertex is at the edge, the maximum TOF difference will be more than 200 ns;
  - Need to use wide trigger window (~300 ns) to cover full information of the same event.
- Dark count rate of the PMT:
  - Considering the event rate, the DCR (50 kHz) will be dominant.
  - With wide trigger window, high nhit threshold is needed to reject PMT dark noise, while some low energy events are cut too.





Trigger Strategy, Vertex Fitting Logic (VFL)

- Use pre-defined vertex
  - Divide the CD into several cubes. Each cube stands for a vertex.
- Compensate TOF for each vertex
  - According to the position, delay the PMT hit information for different steps.
- Reduce the trigger window
  - With 50ns trigger window, the PMT dark noise can be removed from 0.2MeV events [1]

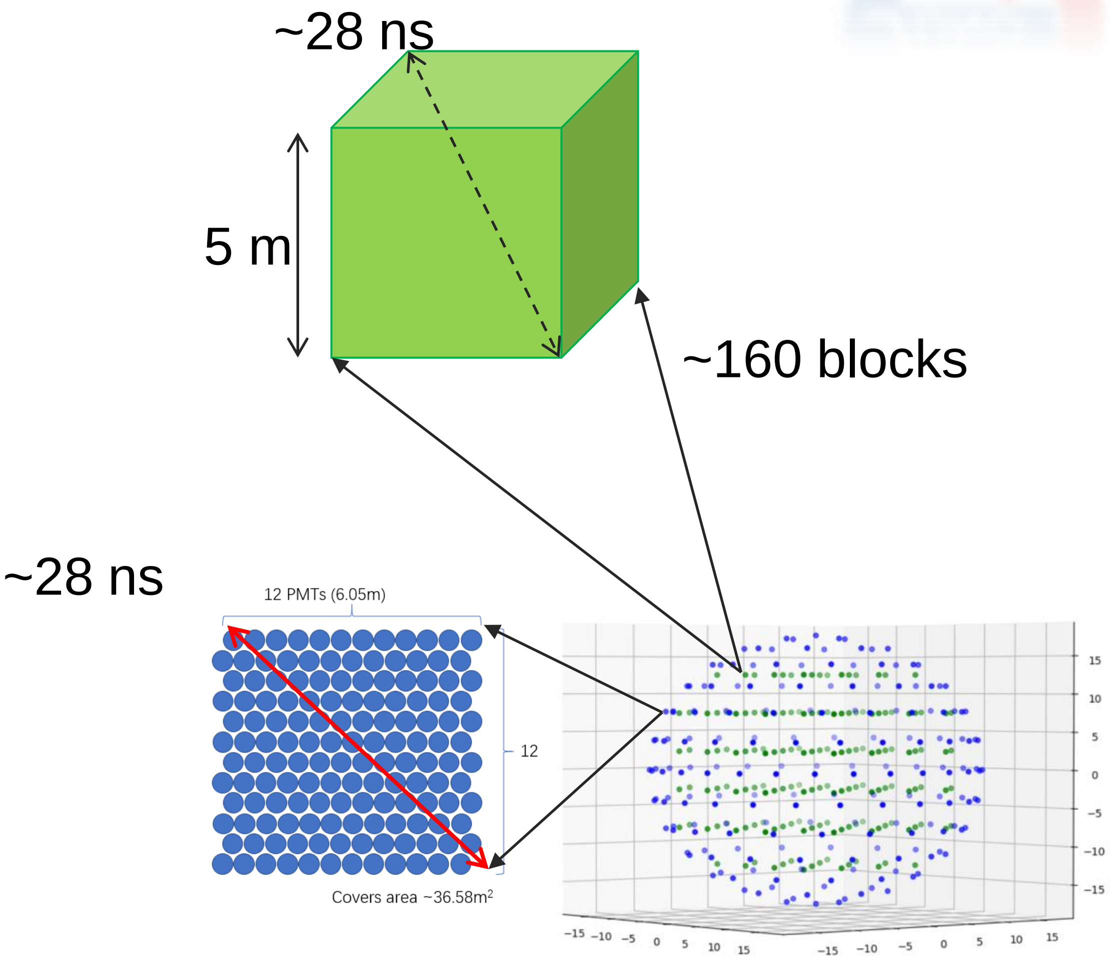


- The further the PMTs locate, the less delay steps are needed.
- Delay steps will be configured as parameter of each block.
- Each block generates a trigger accept.
- All outputs of the blocks are or-ed to generate global trigger.

[1] The global trigger with online vertex fitting for low energy neutrino research, G. Gong, H. Gong, ICALEPCS2015, Melbourne, Australia.

Size of the vertex blocks and PMT groups

- Vertex blocks:
  - The vertex doesn't need to be very accurate;
  - TOF difference within a block should be less than 50 ns;
  - Less blocks make hardware implementation easier.
- PMT groups:
  - Not possible to compensate for each PMT; Divide the PMTs into groups.
  - TOF difference within a group should be less than 50 ns.



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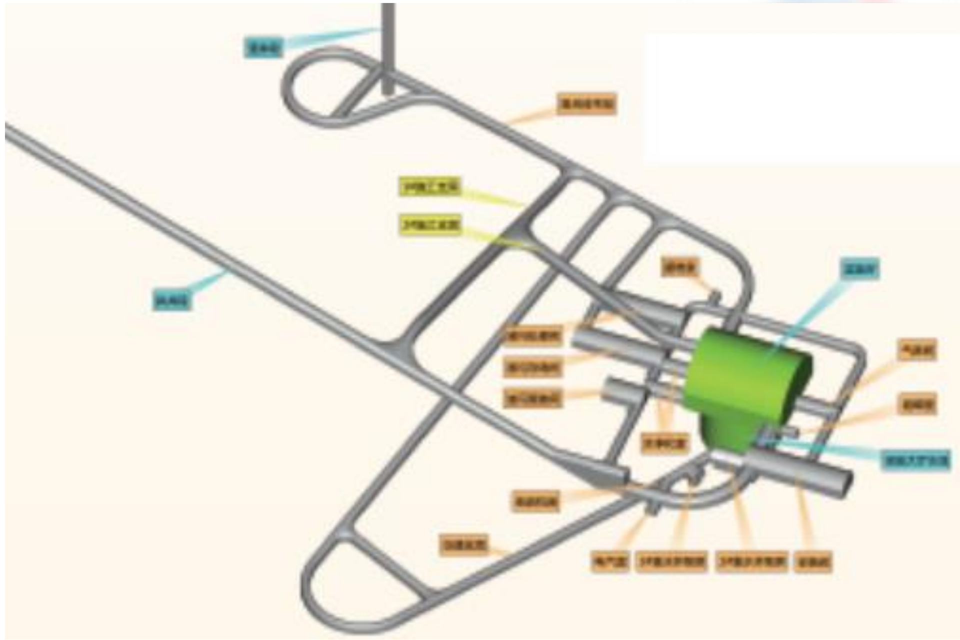
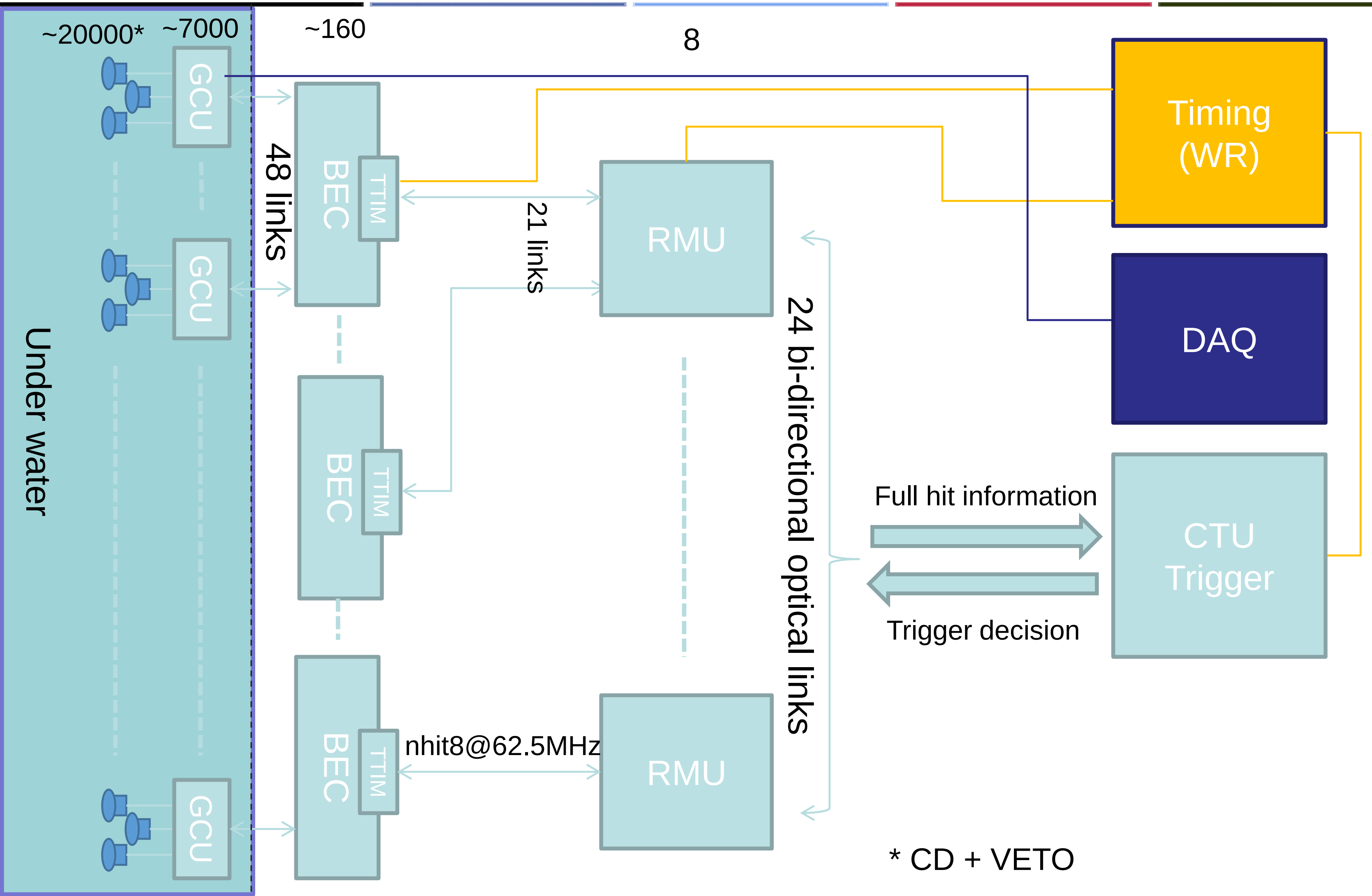


Current Trigger/Timing System Scheme



- GCU: Global Control Unit
- BEC: Back-End Card
- TTIM: Trigger/Timing Interface Mezzanine
- RMU: Reorganizing and Multiplexing Unit
- CTU: Central Trigger Unit
- WR: the White Rabbit system; provide sub-ns synchronization
- DAQ: the Data Acquisition system

Trigger Data flow

- The GCU counts the PMTs hit every clock cycle (62.5MHz), and generates 2 bits nhit data (from 0 to 3).
- The BEC collects 48 GCUs' data and sum the hit PMTs number after compensate the cable length. The nhit data is 8 bits (up to 144). The data rate from BEC(TTIM) to RMU is 8b*62.5MHz = 500Mbps.
- Each RMU has 21 links with the TTIM and 3 links with the CTU. So the input data bandwidth is 500Mbps*7*3 = 3.5Gbps*3. The RMU will not process the incoming data.
- The CTU receives all the nhit data, use the VFL modules to make trigger decision. The trigger decision is sent back to the GCU through the RMU -> the BEC.

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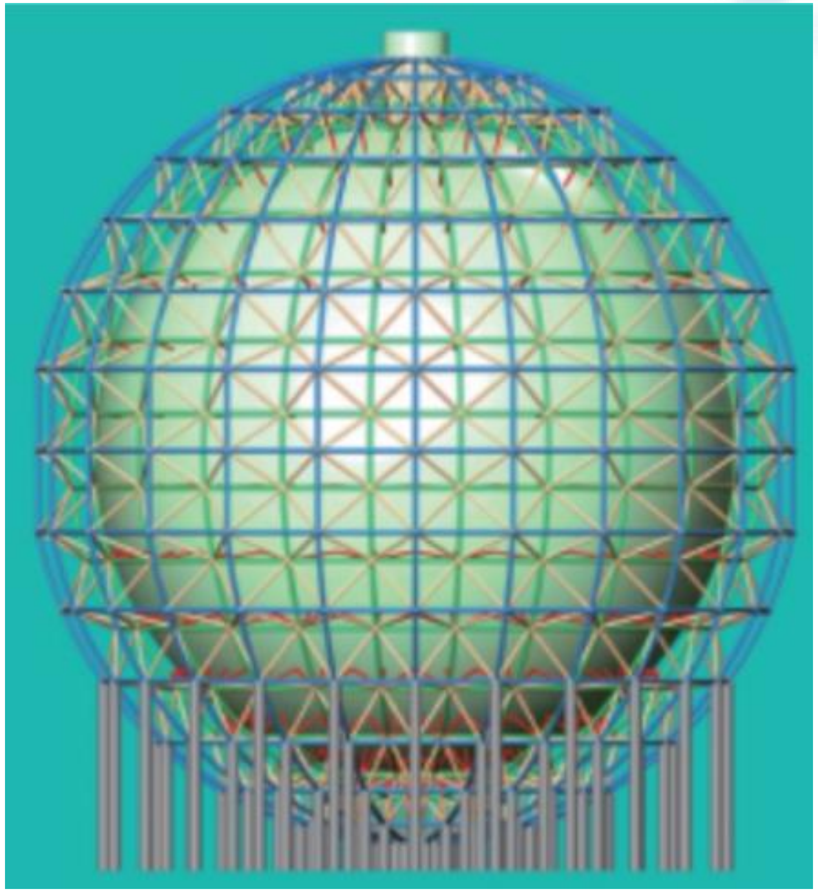
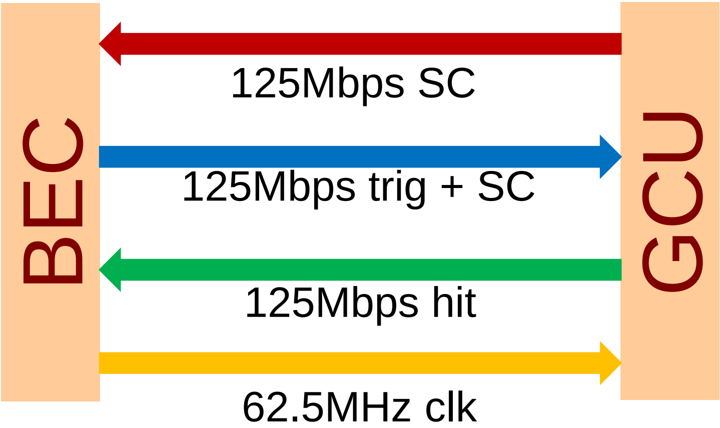


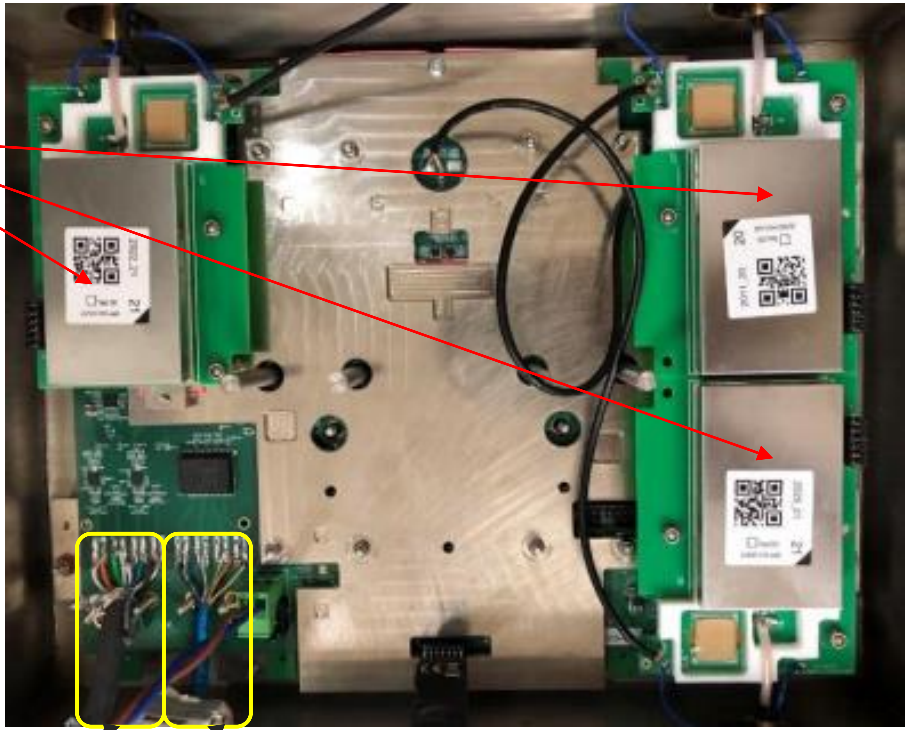
GCU, Global Control Unit

- Designed by IHEP and INFN Padua

GCU in box

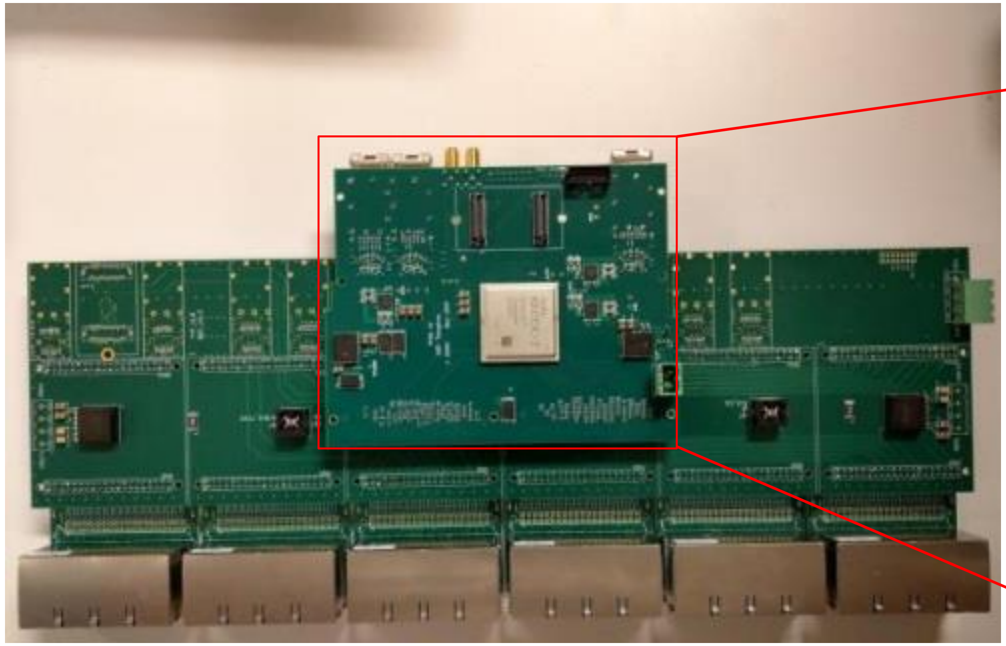
Cat5e FTP cable (considering change to Cat6)





BEC and TTIM, Back-End Card and Trigger/Timing Interface Mezzanine

- BEC is designed by ULB, Brussels.
- TTIM is designed by Tsinghua University.

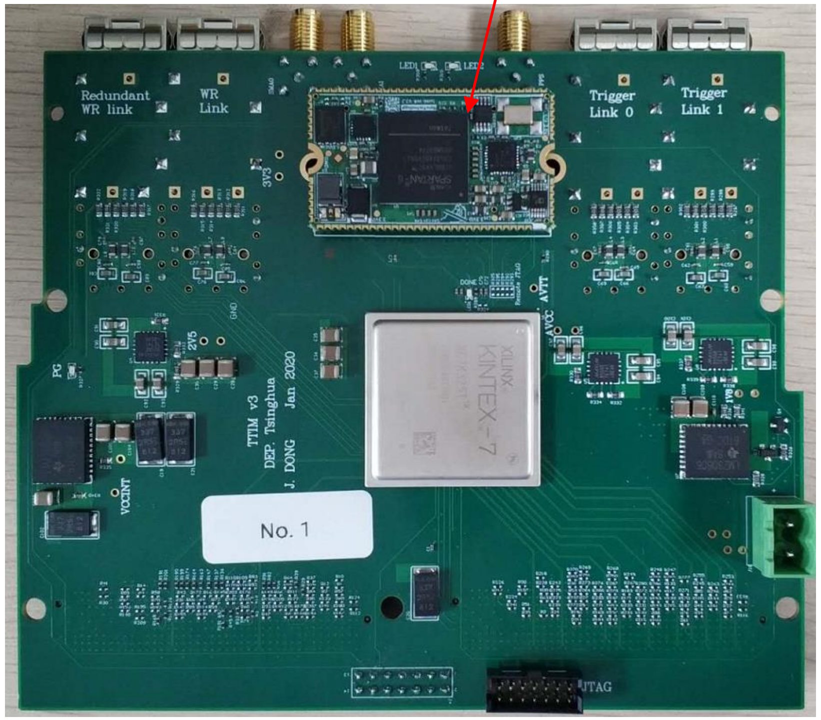


48 ports connects with the GCU

Link with WR

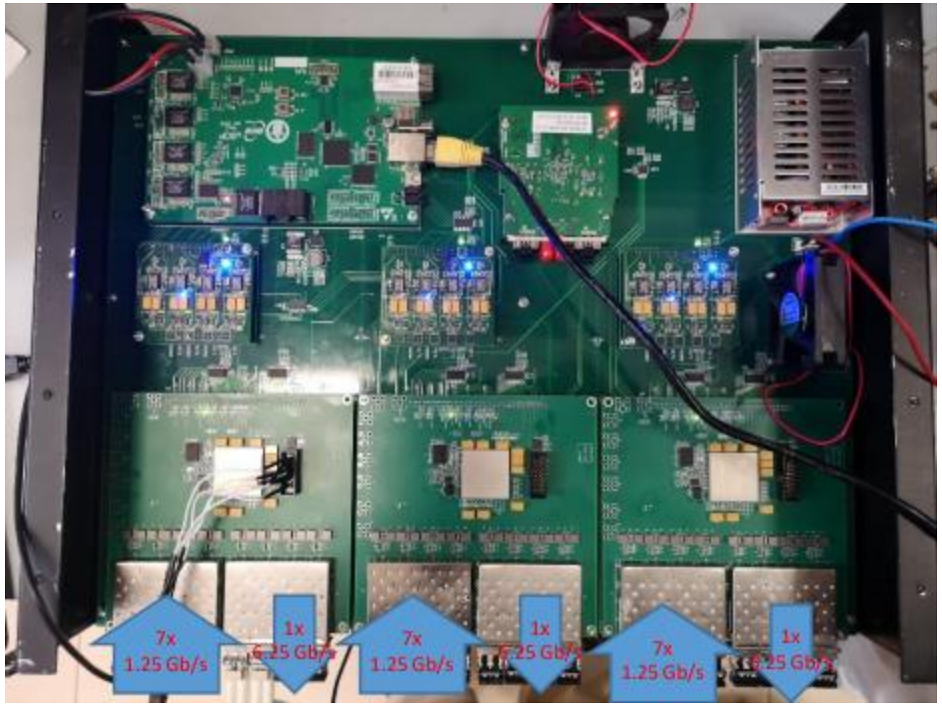
Mini-WR

Link with RMU



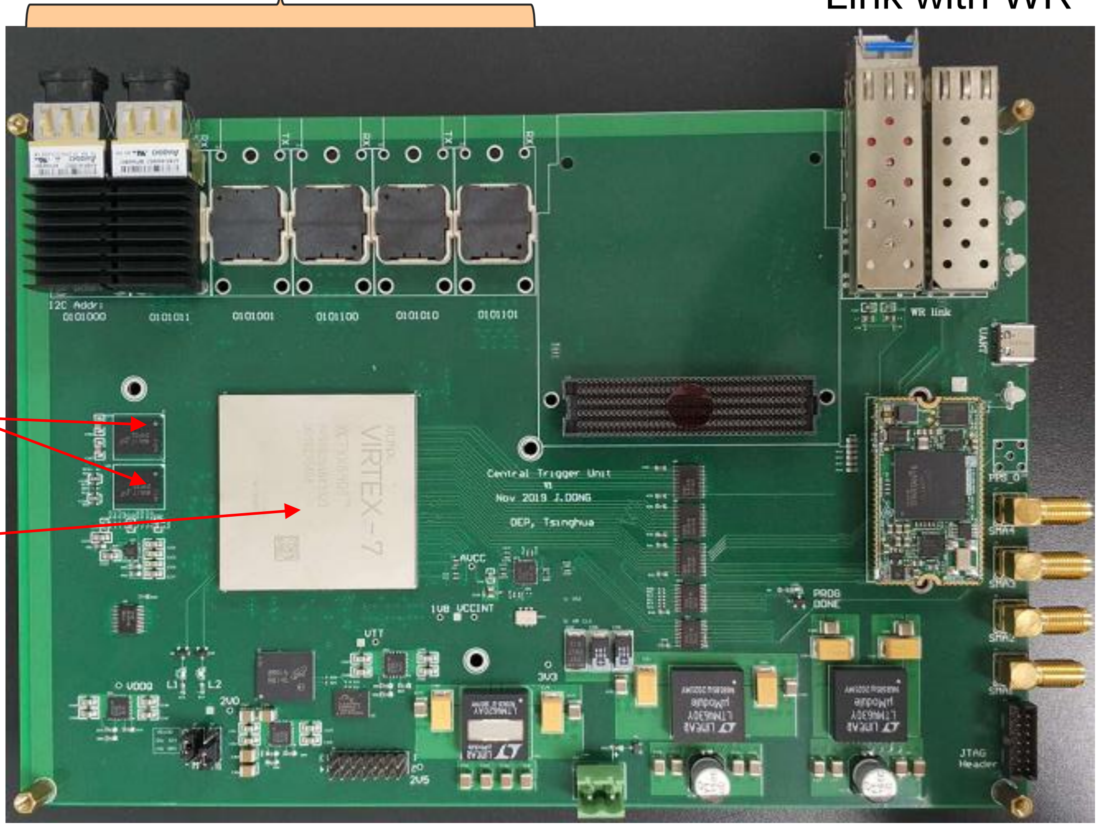
RMU, Reorganizing and Multiplexing Unit

- Designed by INFN Roma Tre.



CTU, Central Trigger Unit

- Designed by Tsinghua University



- Large FPGA to implement VFLs;
- Plenty of optical links to receive full hit information;
- Connects to WR system to get time and clock;
- Interface with calibration system;
- DDR storage for future complex trigger algorithm update.

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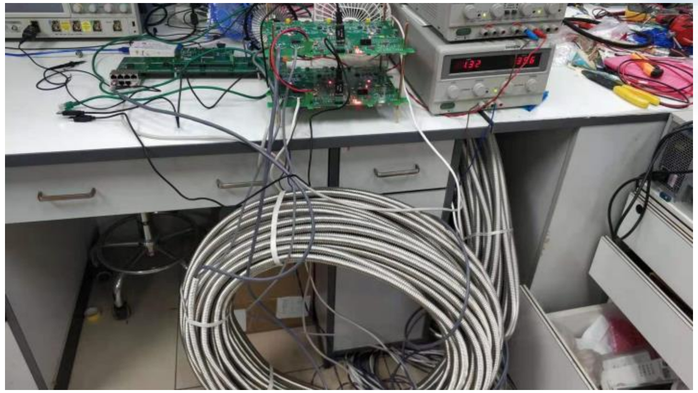
Current status

- All hardware is verified;
- Firmware of the GCU, TTIM and RMU has beta version released and is under testing;
- The CTU firmware is still under developing;
- Joint test of trigger and DAQ system is running.



BEC <-> GCU link test

BEC <-> RMU <-> CTU link test

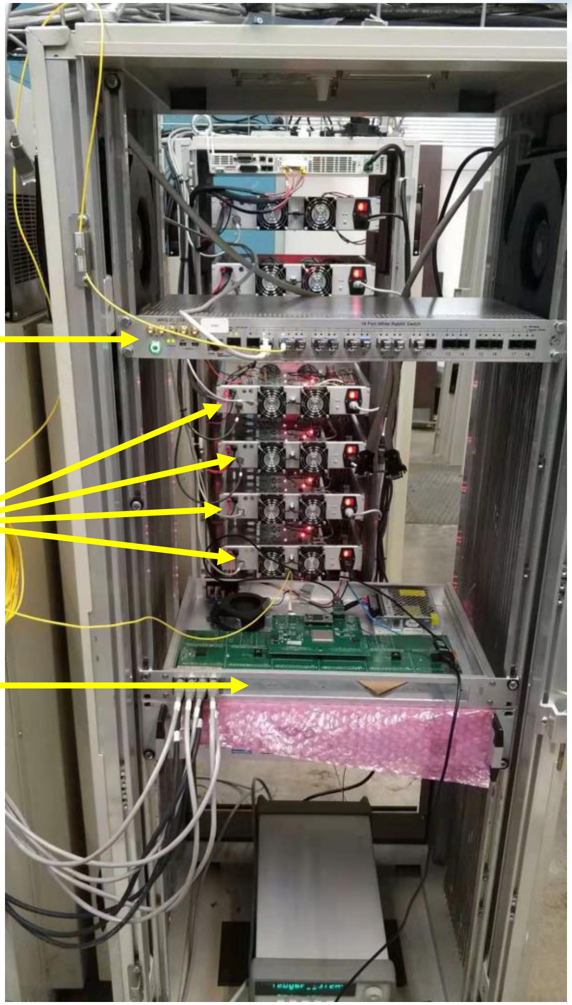
Joint test in Legnaro, Italy

48 PMTs. Currently 39 are running with 13 GCUs

WRS

GCU

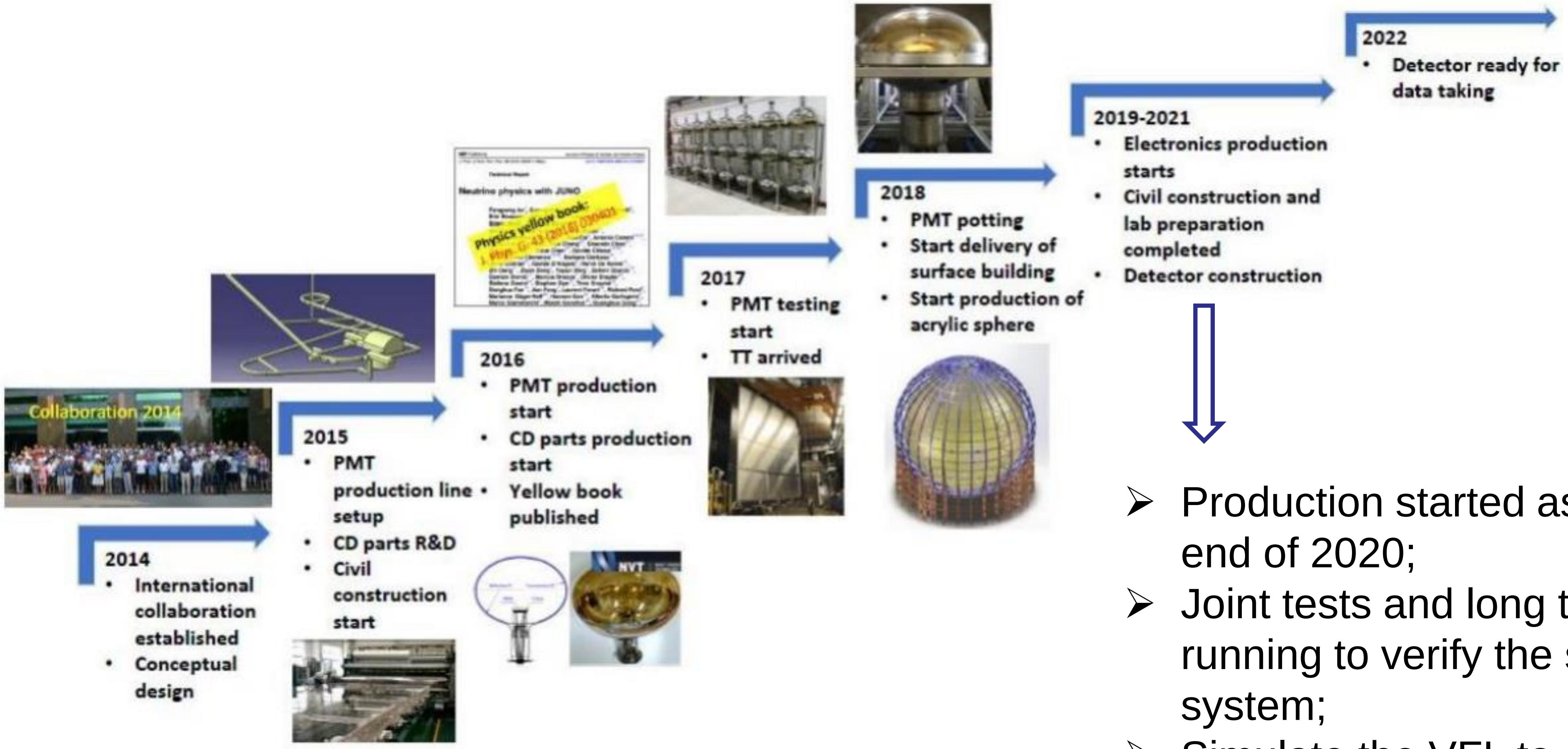
BEC



Currently the system is triggering with the BEC. The GCU sends the hit information to the BEC and the BEC calculates the nhit, generates trigger then sends to the GCU. The waveform is read out by the DAQ software.

The RMU and CTU will add to this setup very soon.

Plans



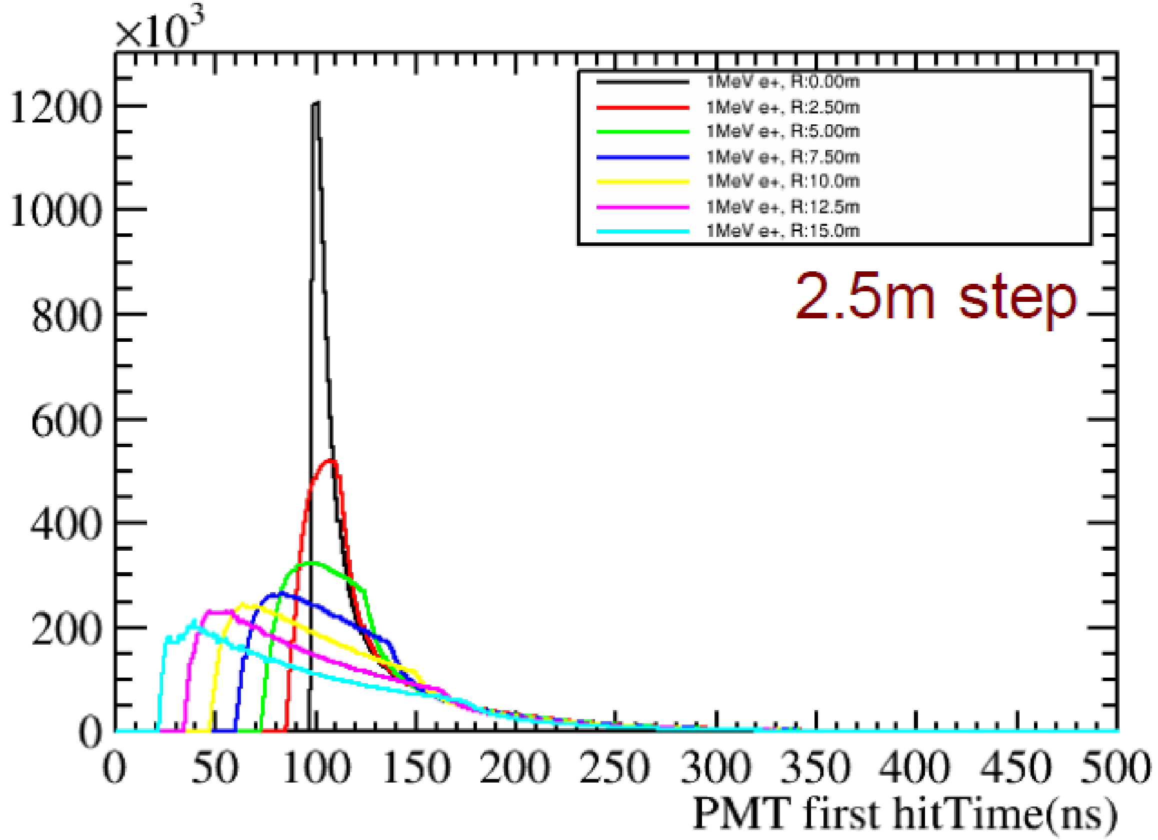
- ➢ Production started as planed, by the end of 2020;
- ➢ Joint tests and long term tests keep running to verify the stability of the system;
- ➢ Simulate the VFL to optimize the block number and delay steps parameter.

Thanks!

Backups

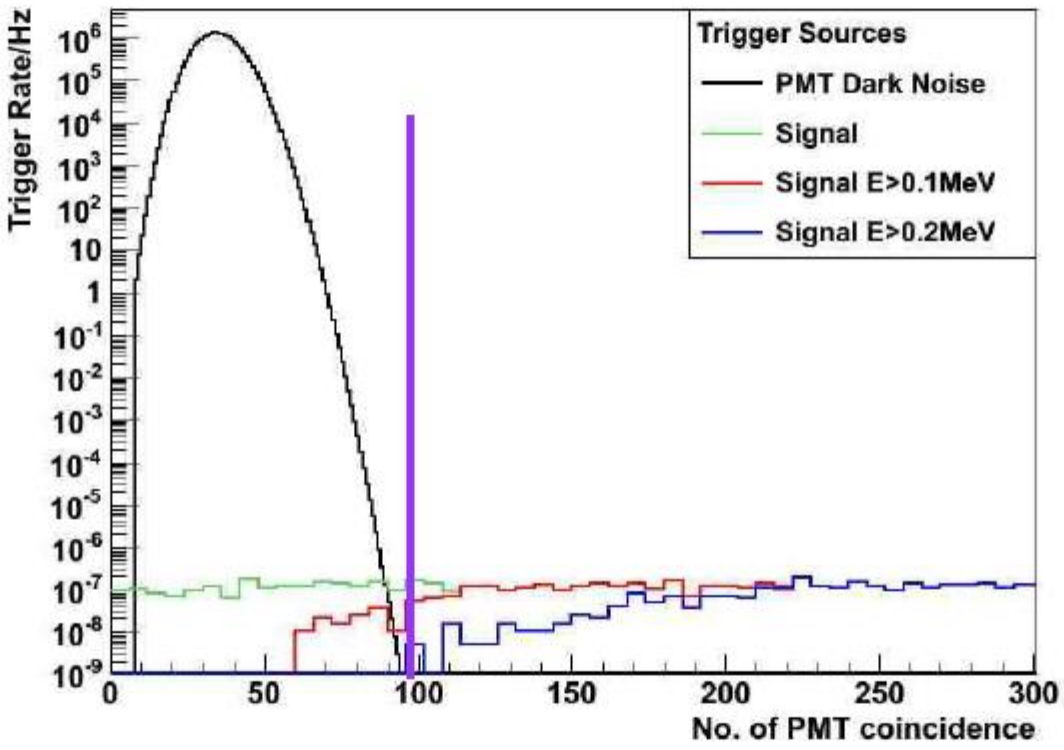
PMT hit time distribution

hit time in ns

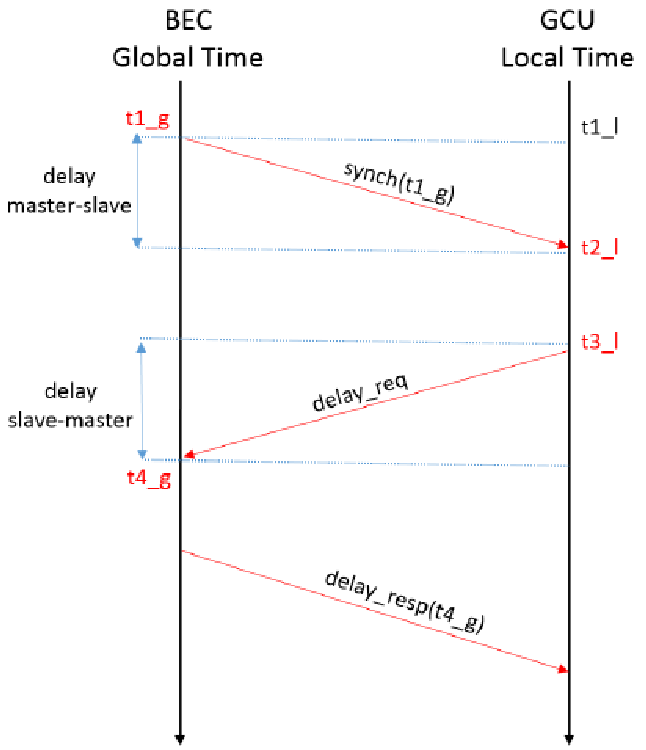


When the vertex locates at the edge of the CD, PMT hit time spread in a duration up to 300ns.

Trigger rate simulation with 50ns trigger window



BEC-GCU synchronizing procedure [1]



- Initiate by BEC: send long-frame command (contain global time);
- SYNC received by GCU: matched GCU ID, sub-addr of long-frame is x09;
- Delay_req from GCU: long-frame with sub-addr x19;
- Delay_rsp by BEC: send the timestamp when received the delay_req to GCU

$$offset = \frac{(t_{1\_g} - t_{2\_l}) + (t_{4\_g} - t_{3\_l})}{2}$$

Assume delay_ms = delay_sm

delay_ms = delay_sm $= \frac{(t_{4\_g} - t_{3\_l}) + (t_{2_l} - t_{1\_g})}{2}$

delay_ms includes logic delay and cable delay.

!

Set the “total delay” as delay_t (constant), the coarse delay of GCU as delay_c, then:

delay_c = delay_t – delay_ms – delay_logic

The BEC will get each GCU’s hit information with same time-stamp.

[1] Nanoseconds Timing System Based on IEEE 1588 FPGA Implementation, D. Pedretti, M. Bellato, et. all, IEEE Transaction on Nuclear Science, June 2018

GCU installation

GCU Under Water Box

20 inch PMT