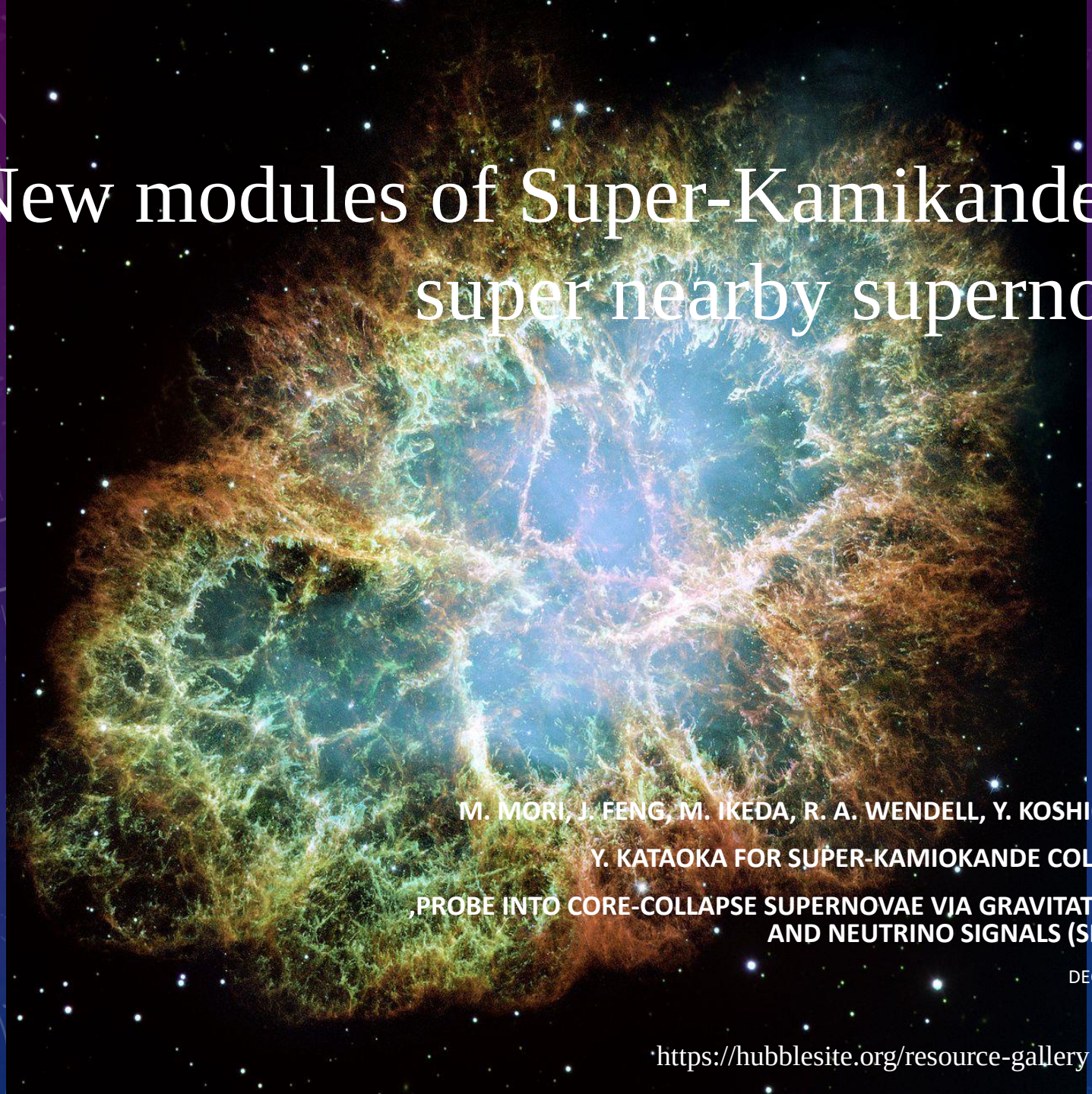
New modules of Super-Kamikande for super nearby supernovae



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Y. KATAOKA FOR SUPER-KAMIOKANDE COLLABORATION

,PROBE INTO CORE-COLLAPSE SUPERNOVAE VIA GRAVITATIONAL-WAVE AND NEUTRINO SIGNALS (SNEGWV2021)

DECEMBER 1TH, 2021

ONLINE

https://hubblesite.org/resource-gallery

Overview

- Neutrino is a good probe for the core of supernovae
- Super-kamiokande can detect more than some of thousands of events from galactic supernovae.
- However, if supernovae are too close, they may be beyond the ability of the Super-Kamiokande DAQ.

Keywords

- Supernova, Super-kamiokande, Neutrino, Betelgeuse

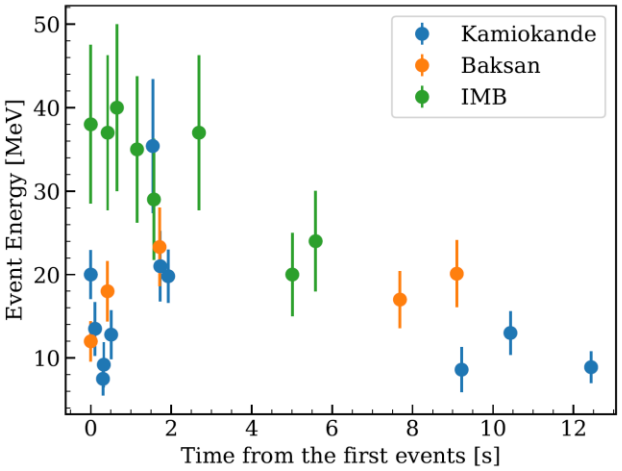
Supernova

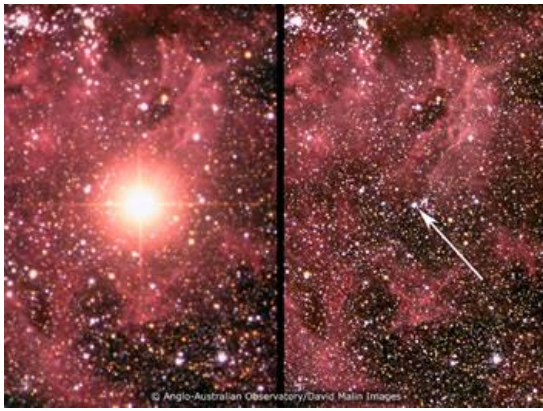
- 8 times heavier stars than the sun happen huge explosion
- Complicated phenomenon in which neutrino plays a main role.
  - ➢We are waiting for neutrino observations
- Energy of 10^{53}erg is released as neutrino
  - ➢ Only one observation in 1987 (SN1987A)

SN1987A information

Distance:51.2 kpc
Number of events: Detector

- 11: Kamiokande(2.14 kton)
- 8: IMB [2]
- 5: Baksan [3]

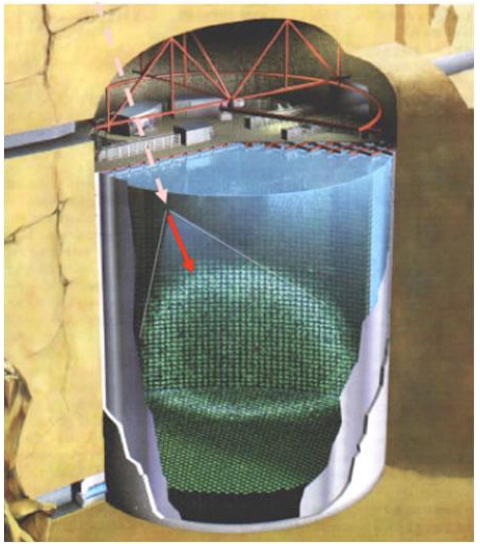




[1]Hirata et al. 1987
[2]Bionta et al. 1987
[3]Alekseev et al. 1987

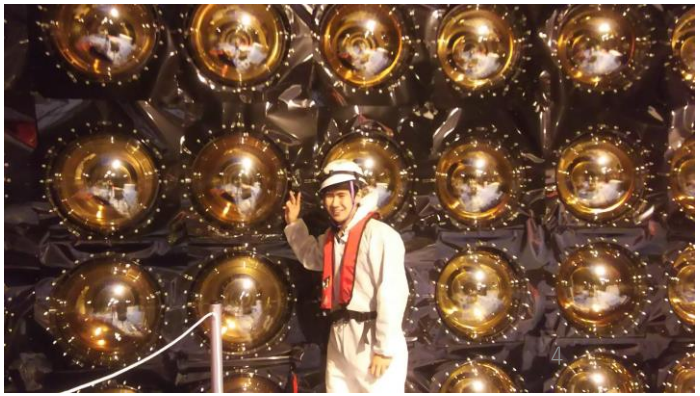
Super-Kamiokande(SK)

- Water Cherenkov detector in the Gifu prefecture.
  - Height: 41.4 m
  - Diameter: 39.3 m
  - Inner dector: 32.5 kton
  - Number of PMTs:11,129
  - Energy threshold: 5MeV
- Various neutrino studies
  - atmosphere, solar , accelerator…



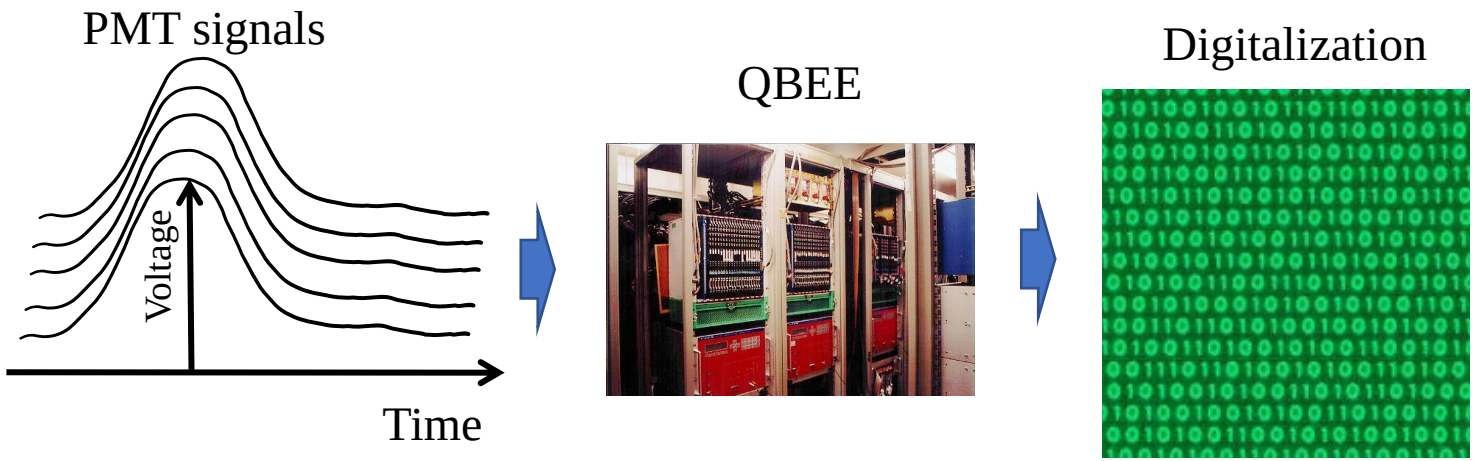
http://www-sk.icrr.u-tokyo.ac.jp

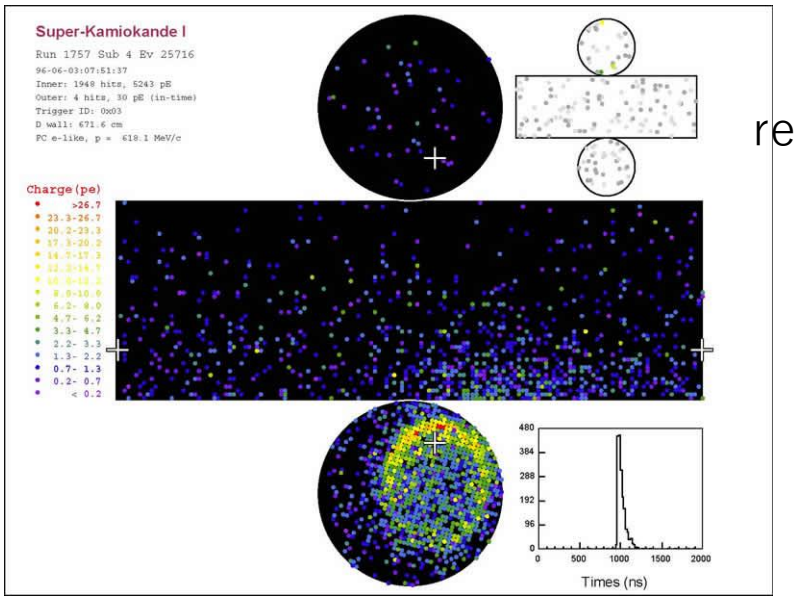
- Monitoring supernovae for 24 hours
  - If galactic supernovae happen, it is predicted to detect from 2,000 to 7,000 events.



Super-Kamiokande data flow

- Signals from PMTs are digitalized with QBEE and then reconstructed as an event with computers.



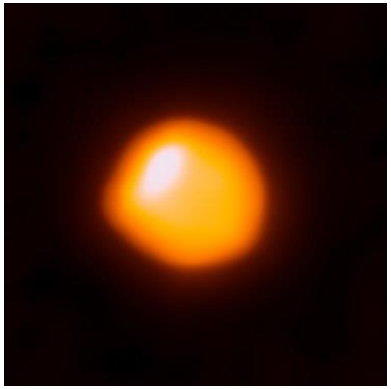


Event estimation from Betelgeuse

- Kamiokande-II detected 11 events from SN1987 A.
- Estimate how many events SK will detect from Betelgeuse.

$$11\text{events} \times \left(\frac{167000\ \text{ly}_{\text{SN 1987A}}}{480\sim640\ \text{ly}_{\text{Betelgeuse}}}\right)^2 \times \left(\frac{32.5\ \text{kton}_{\text{SK}}}{2.14\ \text{kton}_{\text{K-II}}}\right)$$

$$\approx 10\times10^6\sim20\times10^6\text{events for just 10 seconds}$$

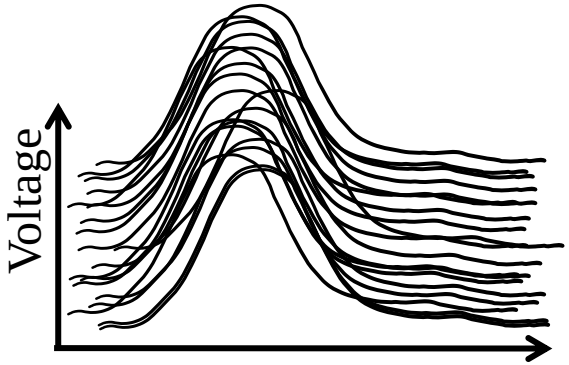


Betelgeuse
ALMA/E. O'Gorman/P. Kervella

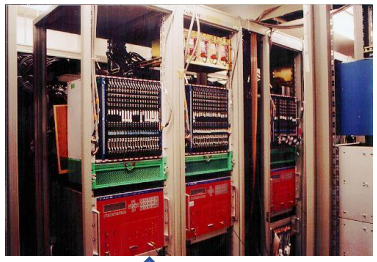
Limitation of data-acquisition

- QBEE cannot process such a high-rate event.
- Because buffer memories on QBEE overflows.
- SK cannot reconstruct events

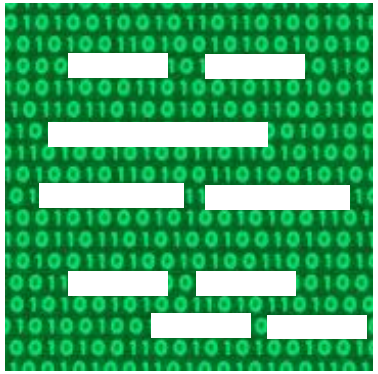
Many PMT signals

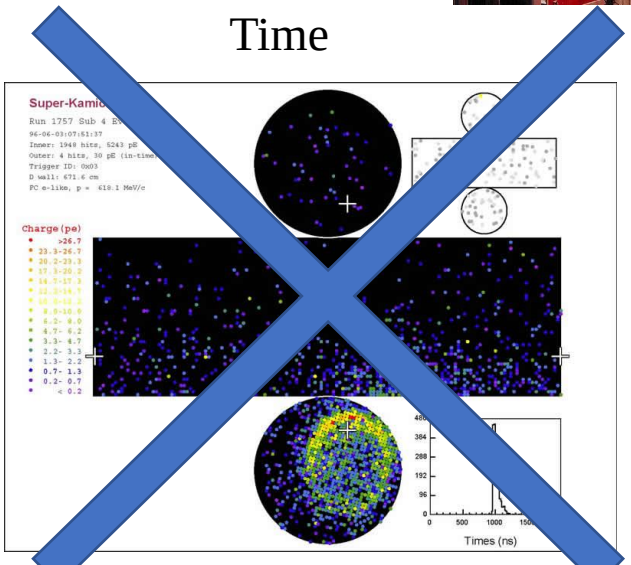


QBEE



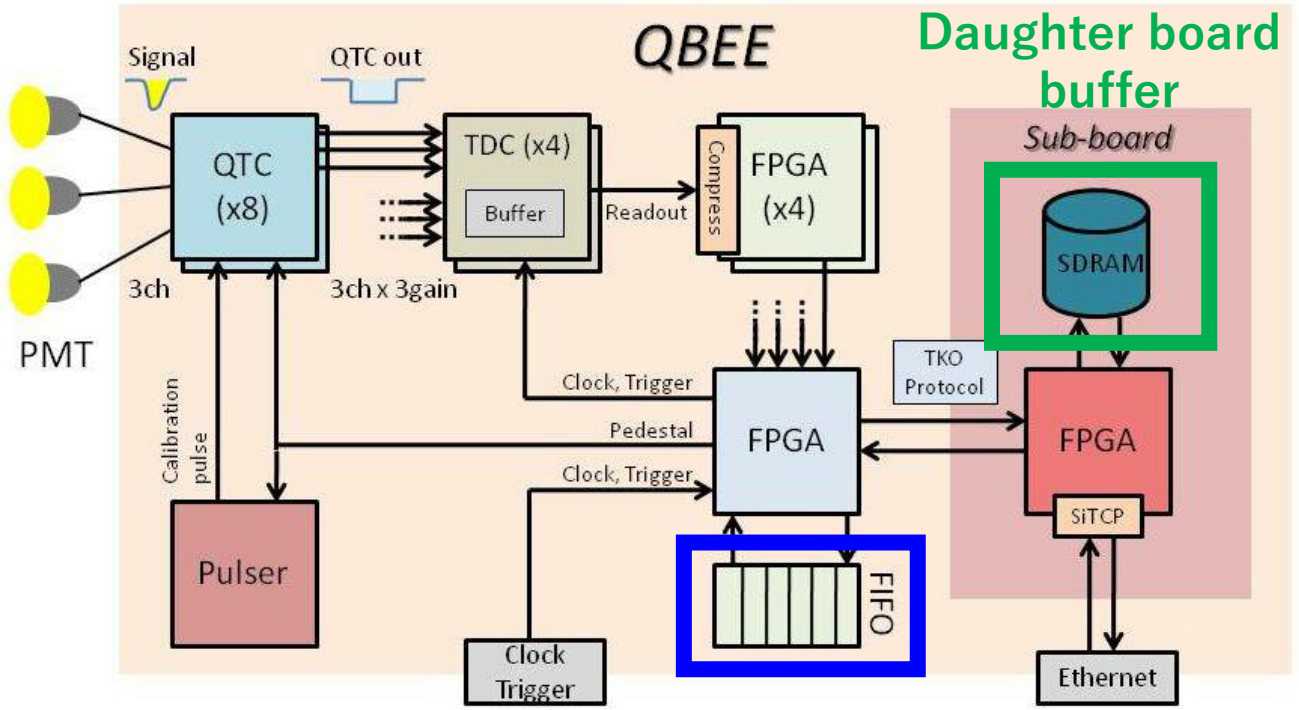
Lack of information





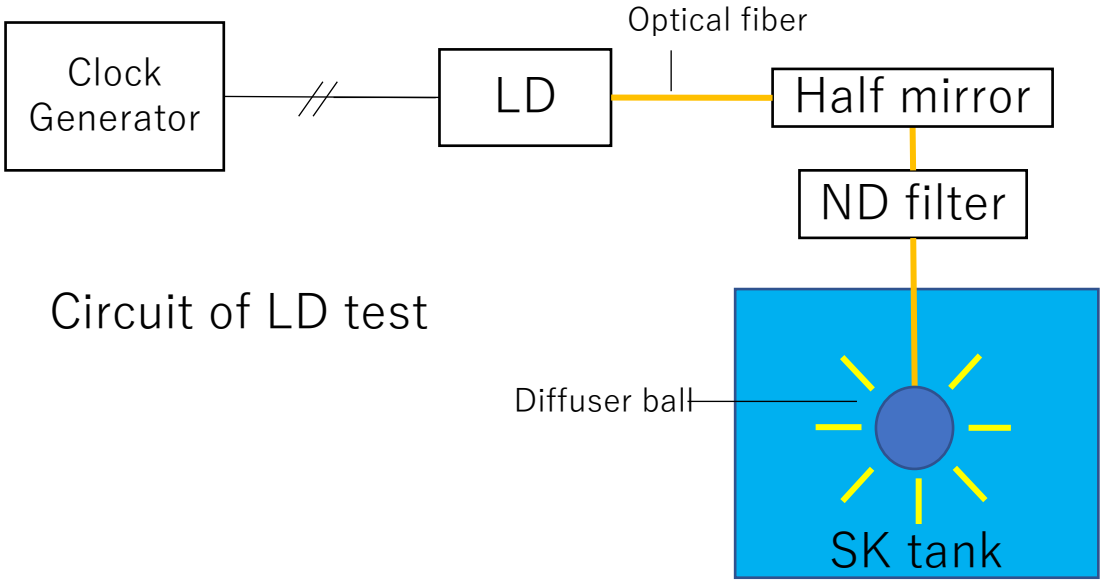
QBEE overflow

- There are two types of buffers on QBEE
  - FIFO buffer
    - Stores information while digitalization on FPGA.
  - Daughter board buffer
    - Stores information before transmission through the Ethernet.
- The overflow happen on these memories.

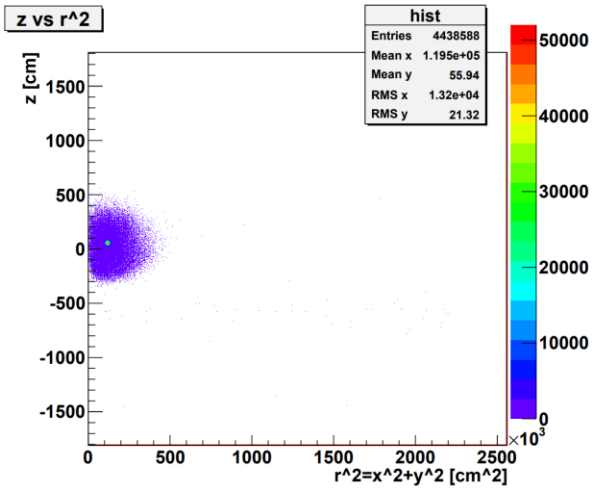


Test method

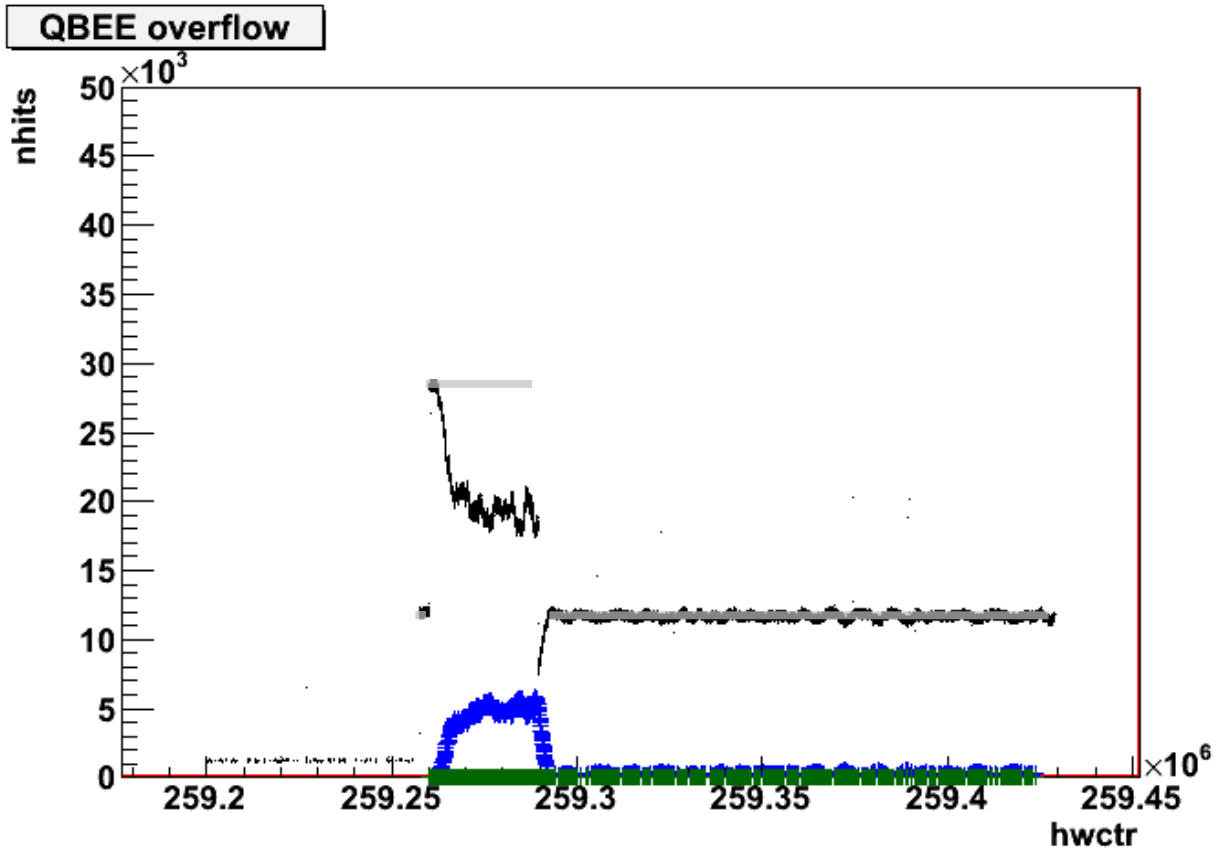
- We carried out LD test to check QBEE overflow.
- LD test:
  - A test that we light a laser diode (LD) in the tank and reproduce SN bursts.
- Event rate: 60 M events (maximum) fro 10 seconds



Circuit of LD test



QBEE overflow without Veto module

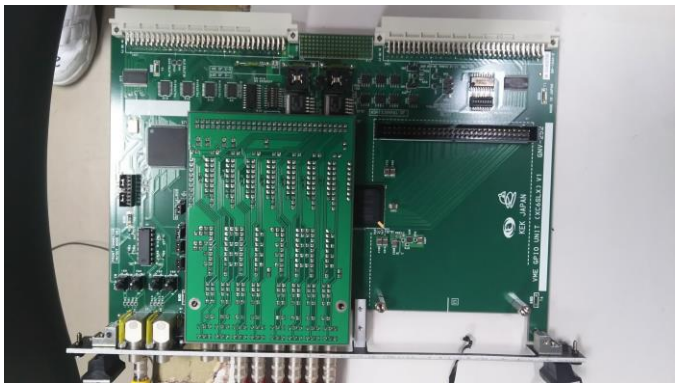


- 30 M burst
- Blue markers: FIFO buffer overflow
- Green markers: DB buffer overflow
- Grey lines: true burst shape

New modules

- Concept:
  - Records the number of hits from supernovae without dead time and prevents QBEE from overflowing.
- Developed two types of modules
- SN module
  - Records only the number of hits
  - Issues triggers to inform Veto module of SN bursts.
- Veto module
  - Decreases events to prevents QBEE from overflowing

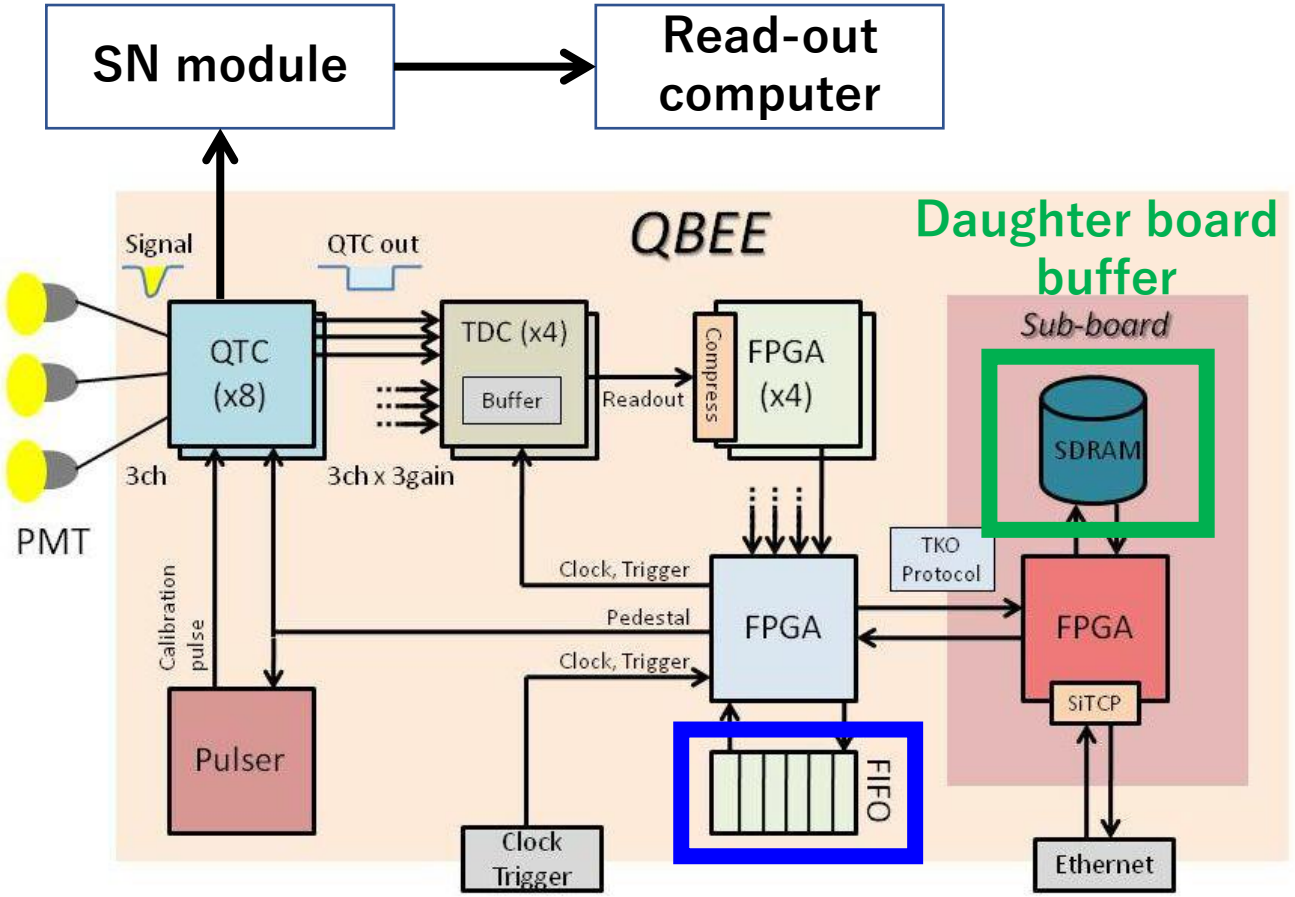
SN module



Veto module

SN module detail

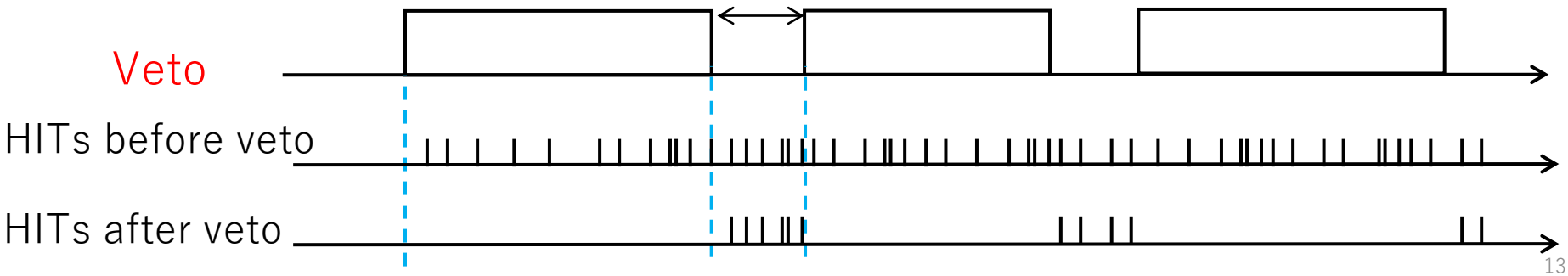
- SN module read out the number of hits a circuit on the QTC of QBEE.
- This circuit is located upstream of the buffers so is not influenced by overflowing.



Veto module detail

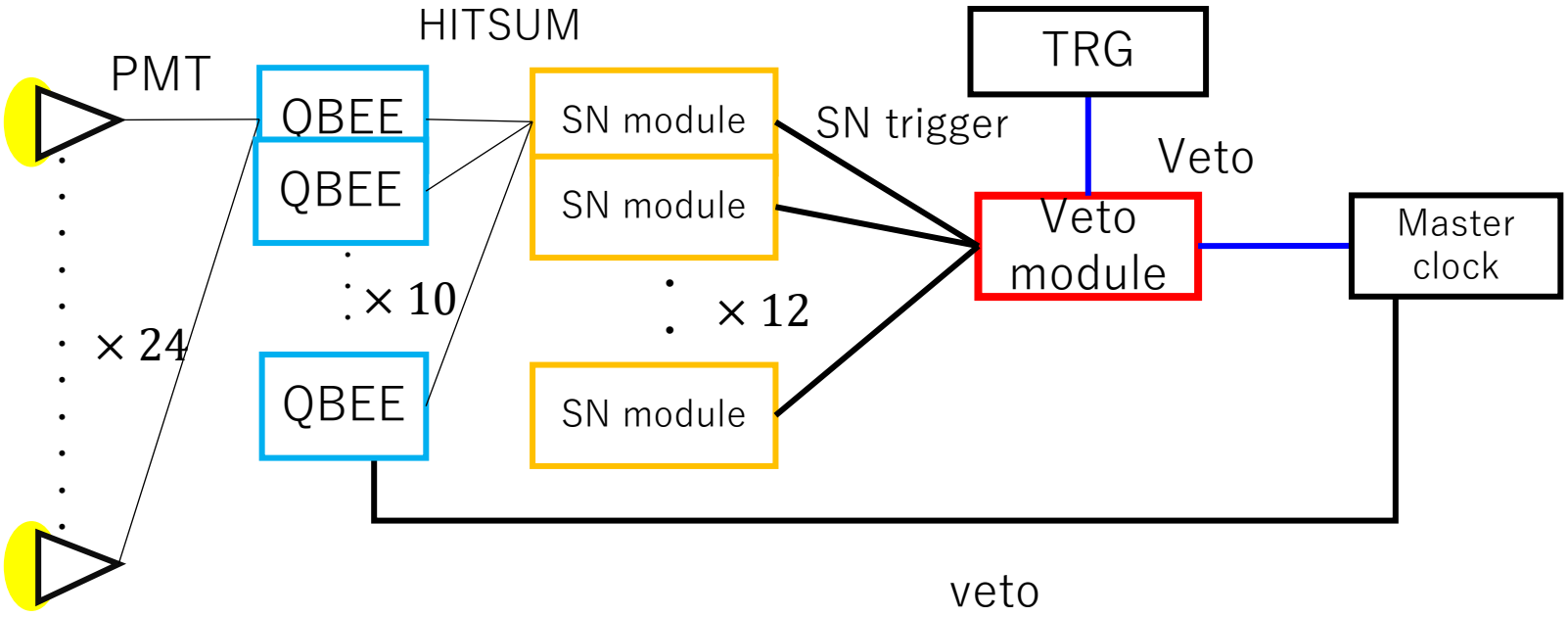
- Veto module is connected to 12 SN modules.
- receives SN triggers from SN modules.
- According to the number of SN triggers, Veto module issues periodical veto signals.
- Three veto conditions to record as many events as possible.

SN triggers	Clocks with enough SN triggers	scaling ratio
8	8	1/2
10	200	1/3
10	2000	1/4

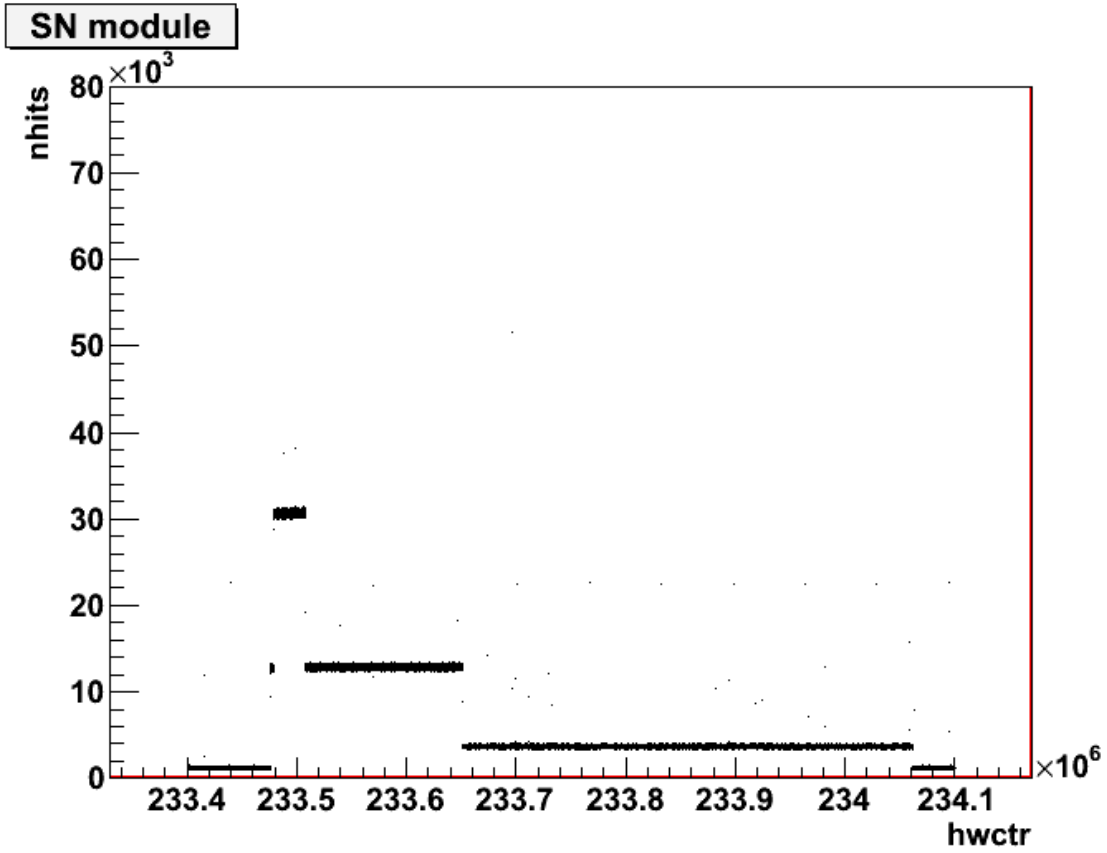


Setup of new modules

- QBEEs are connected to 24 PMTs
- SN modules are connected to 10 QBEEs
- Veto module is connected to 12 SN modules
- Finally, Veto module sends veto signals to all QBEEs

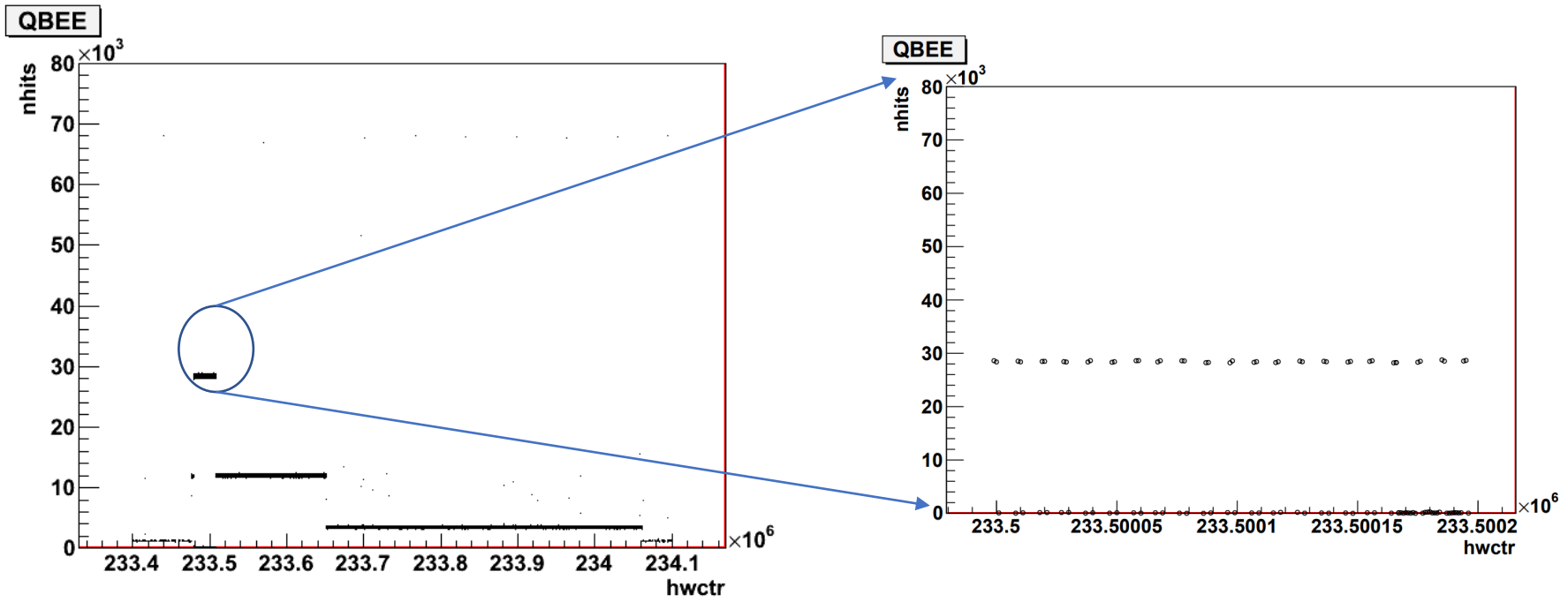


LD burst through SN module



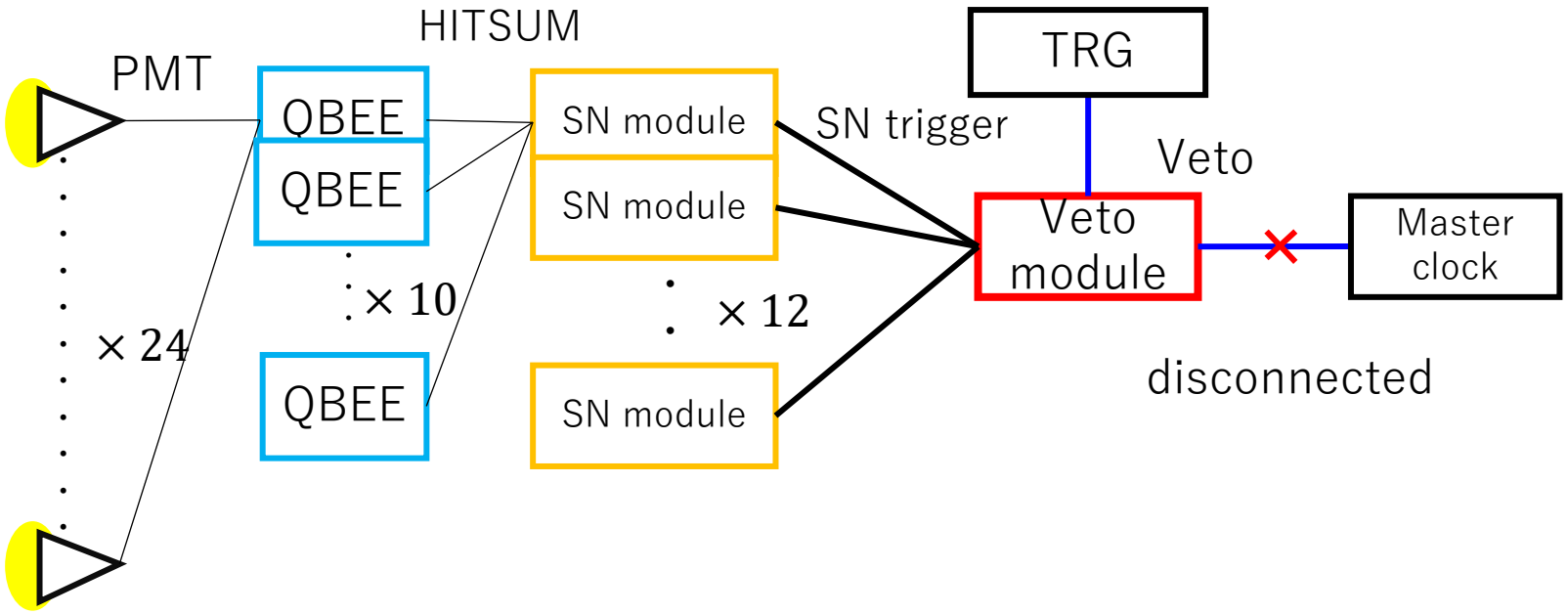
- SN module reproduces the shape of the burst.

Prevent overflow with Veto module



- Veto module can prevent QBEE from overflowing.
- We can observe a periodic structure of veto signals.

Long term test



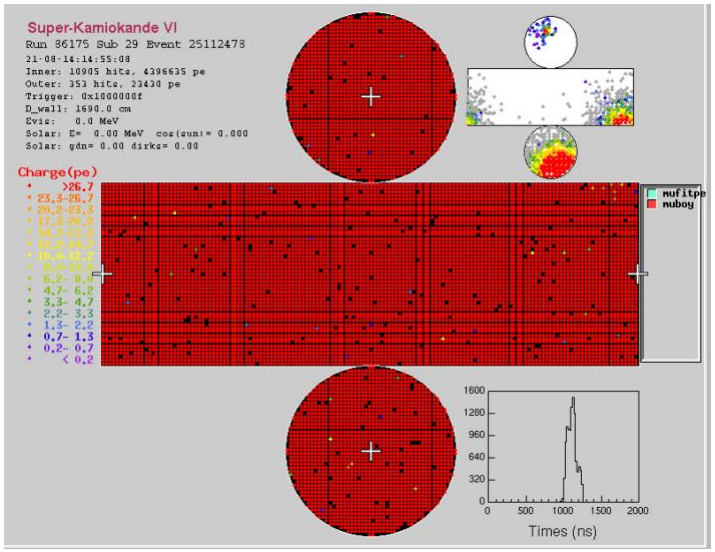
- New modules have been installed and we are doing a long term test to confirm they do not affect normal operation.

Accidental veto

The number of times Veto module is triggered

June in 2021	July	August	September	October	November
0	1	7	1	6	1

Very high muon



- Veto module accidentally issues some veto signals a month.
- The causes are very high muons and electrical troubles.
- The total dead time is about 1 ms in the half year

Summary

Summary

- Very close supernovae such as Betelgeuse can make SK DAQ overflow.
- To overcome the problem, we developed the new modules (SN module and Veto module).
- Confirmed that new modules provide dead-time free observation, prevent from overflowing and have no influence on normal operation.

To do

Develop analysis methods and simulation for the new modules.