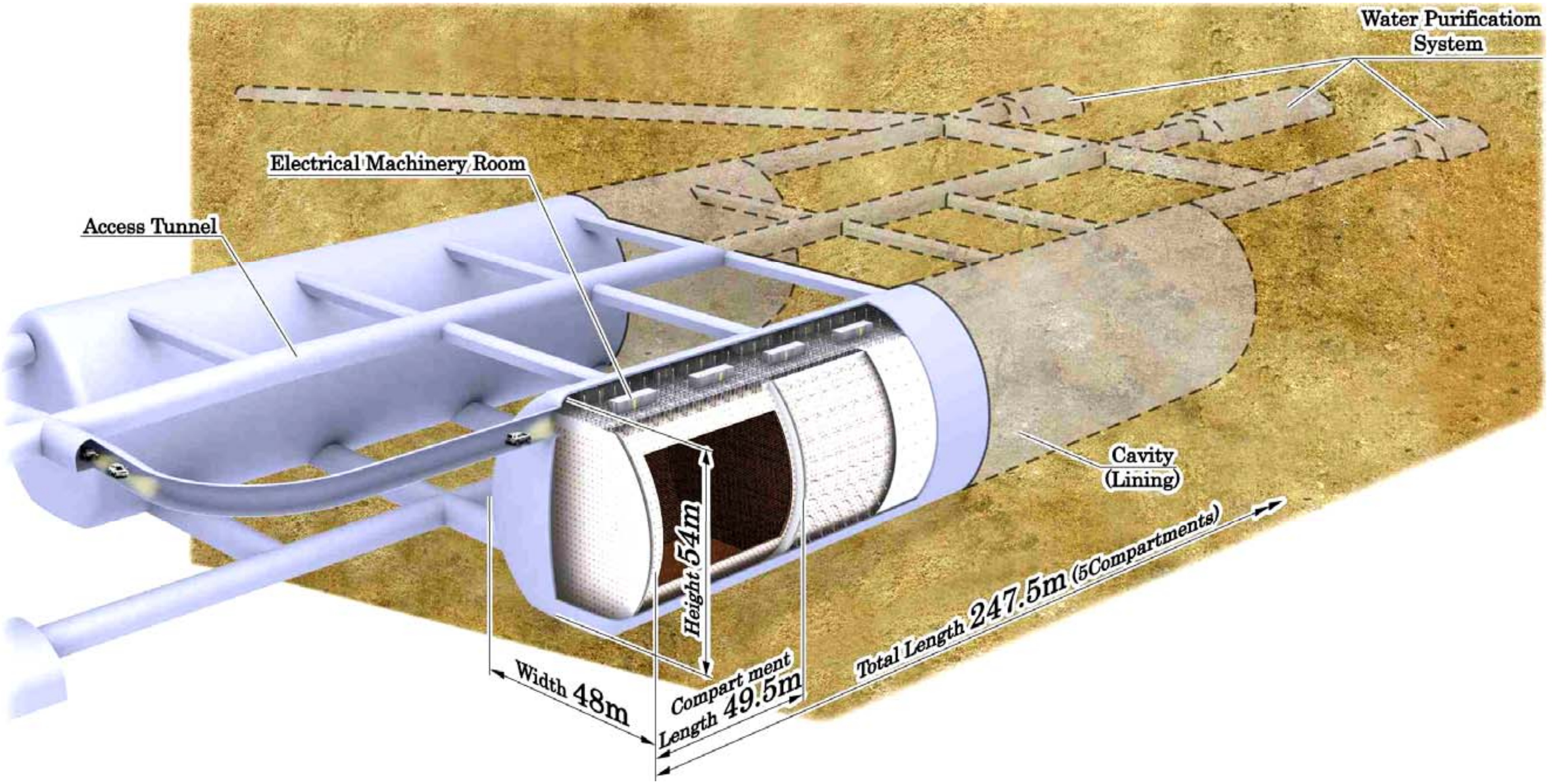
Baseline design of the DAQ system for the HK detector

Yoshinari Hayato (Kamioka, ICRR)

Introduction

of photo sensors : ~ 100,000 (in total)
# of compartments : 10

➔ # of photo sensors ~ 10,000 Similar to SK



Similar design to SK is expected to work

~ good working example for the baseline design

Introduction

Requirements for the online/DAQ system are
(slightly) different from the "accelerator" based experiment.

- Rare events (nucleon decay, super nova etc.)
  can happen "at any time".
- (Natural) neutrino beam is always there.
- Order of the events is also important.
  - Electron generated by decay of μ
    might be misidentified as the product of ν_e scattering.
  - Low energy events might be generated by spallation products

- Keep the detector running "**all the time**" without dead-time.

  Dead-time needs be minimized
  Dead-time should be recorded.

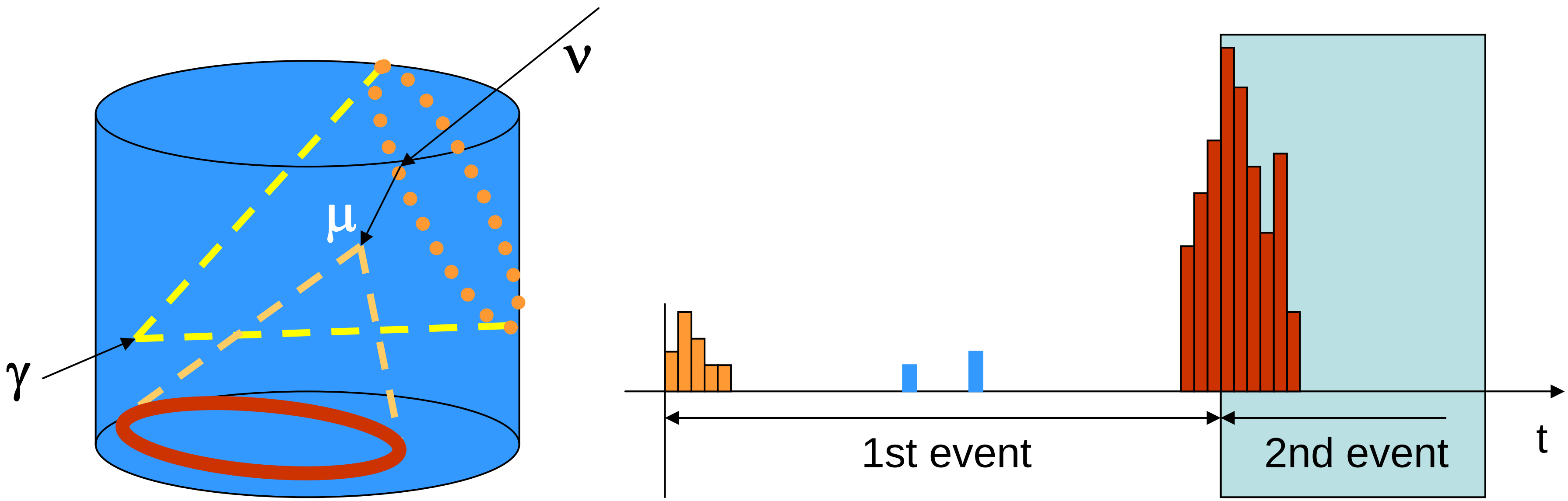
  1) Dead-time (down time) due to the equipment trouble / maintenance
  2) Dead-time due to the limitation of the DAQ/online system

- Triggered by the detector (system) itself.
- Condition of the detector is necessary to be recorded.

Introduction

If one want to detect very low energy events,
trigger rate gets extremely high.
(This depends on the radio activity in the water
and isolation from the surrounding rock.)

- Example of a very low energy event:
  2.2 MeV γ (from neutron capture) generates only a few ~ several hits.



Due to a trigger generated by a small activity,
"real high energy ν event" can be split into two.

Baseline design

Record all the hits from PMTs including dark noise.

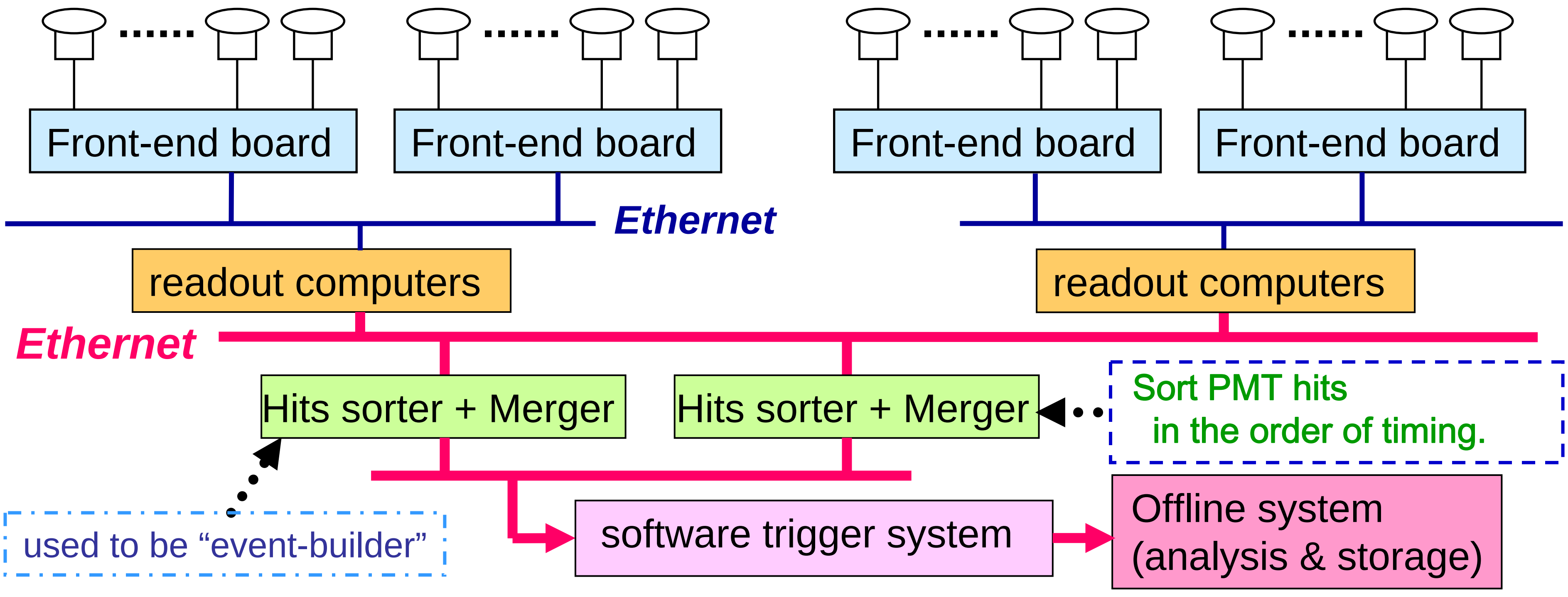
Then, apply the "software" trigger and define an event.

Assume 10kHz dark rate and data size of 6bytes/PMT hit

~600MB/sec for a detector with 10k PMTs.

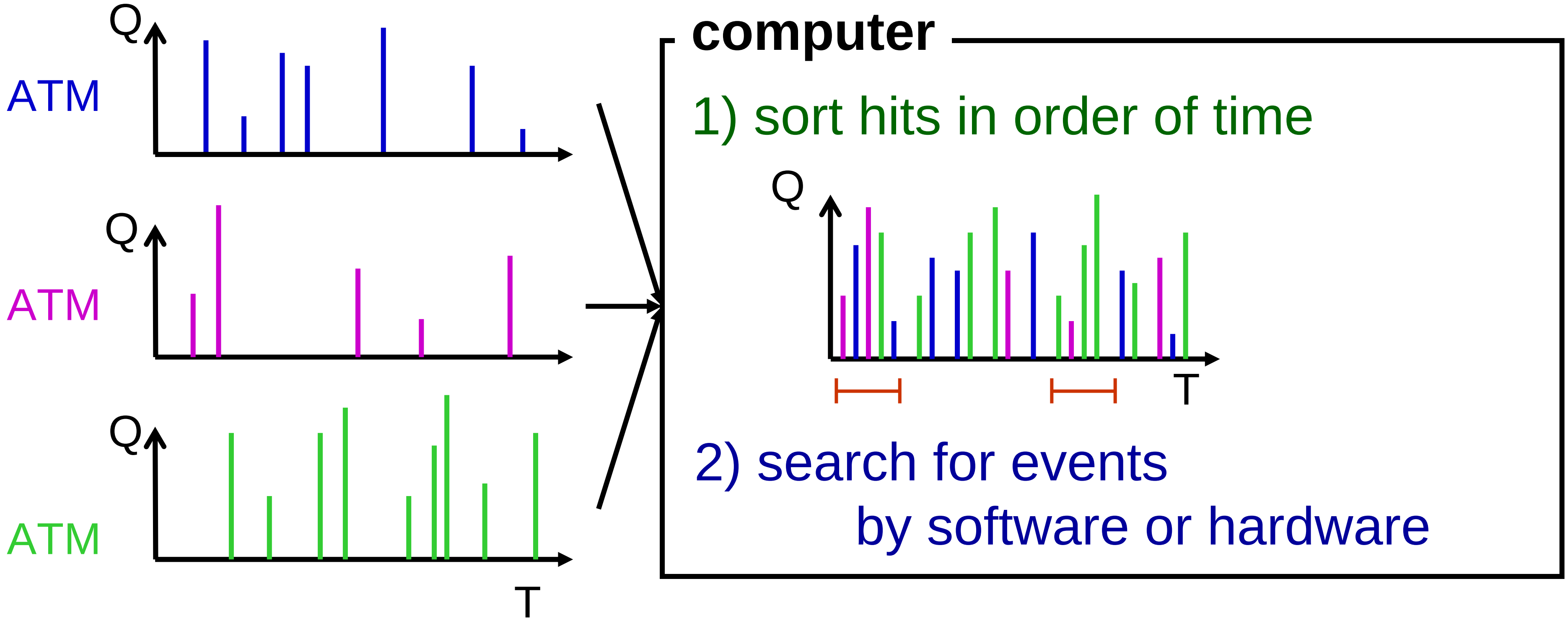
(Typical dark rate of 20 inch PMT is 3~5kHz.)

- **Schematic diagram**



Hit data reduction scheme with the software trigger

Readout all the PMT hits and sort them in the order of timing.



Possible to change the gate width of each event category

- Shorter gate width for low energy events
- Longer for higher energy to contain decay electron
- Use GPS information for the accelerator beam etc..

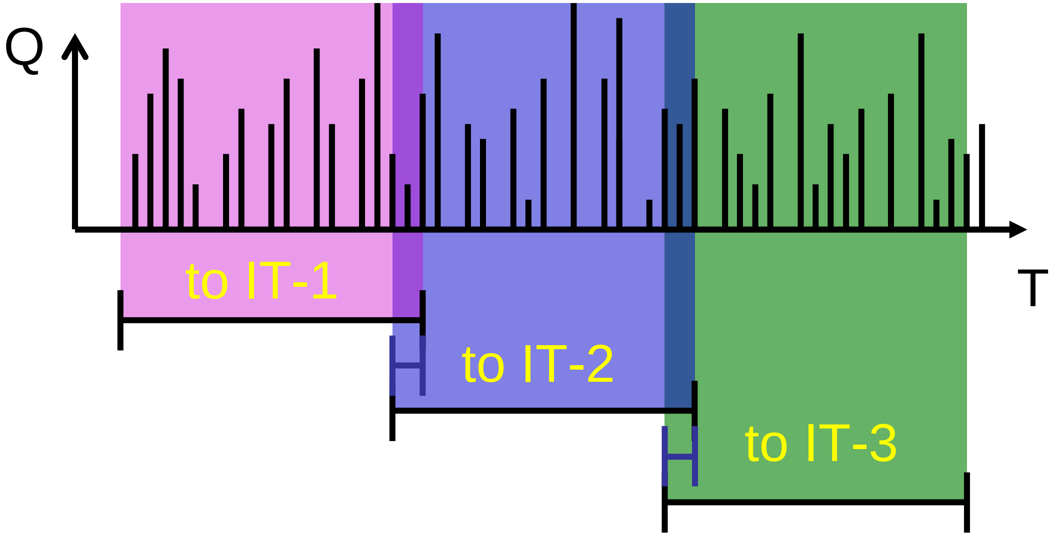
Hit data reduction scheme with the software trigger

It is not possible to handle all the data by one CPU core.

Need to process the data using multiple CPU cores.

But we don’t know when an event happens.

There must be some overlaps in distributing the data.

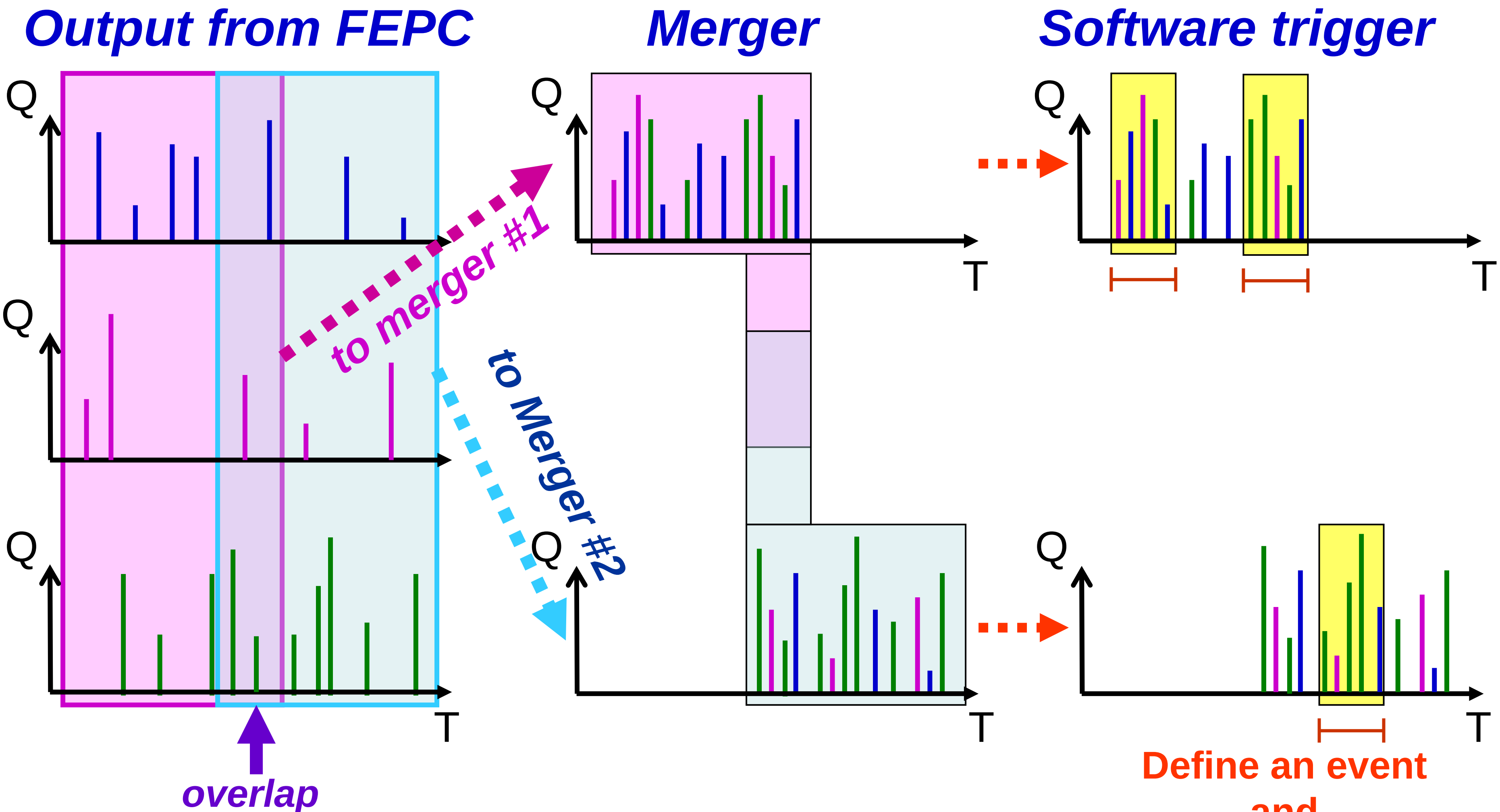


But same event will be produced

if an event occurred in the overlap region.

Need to reject overlapping event after the software trigger.

Hit data reduction scheme with the software trigger



Define an event
and
keep the selected hits.

1 segment corresponds to **~20ms** (1280 HW triggers)

1 overlapping period corresponds to **~ 1ms** (64 HW triggers)

Event selection criteria

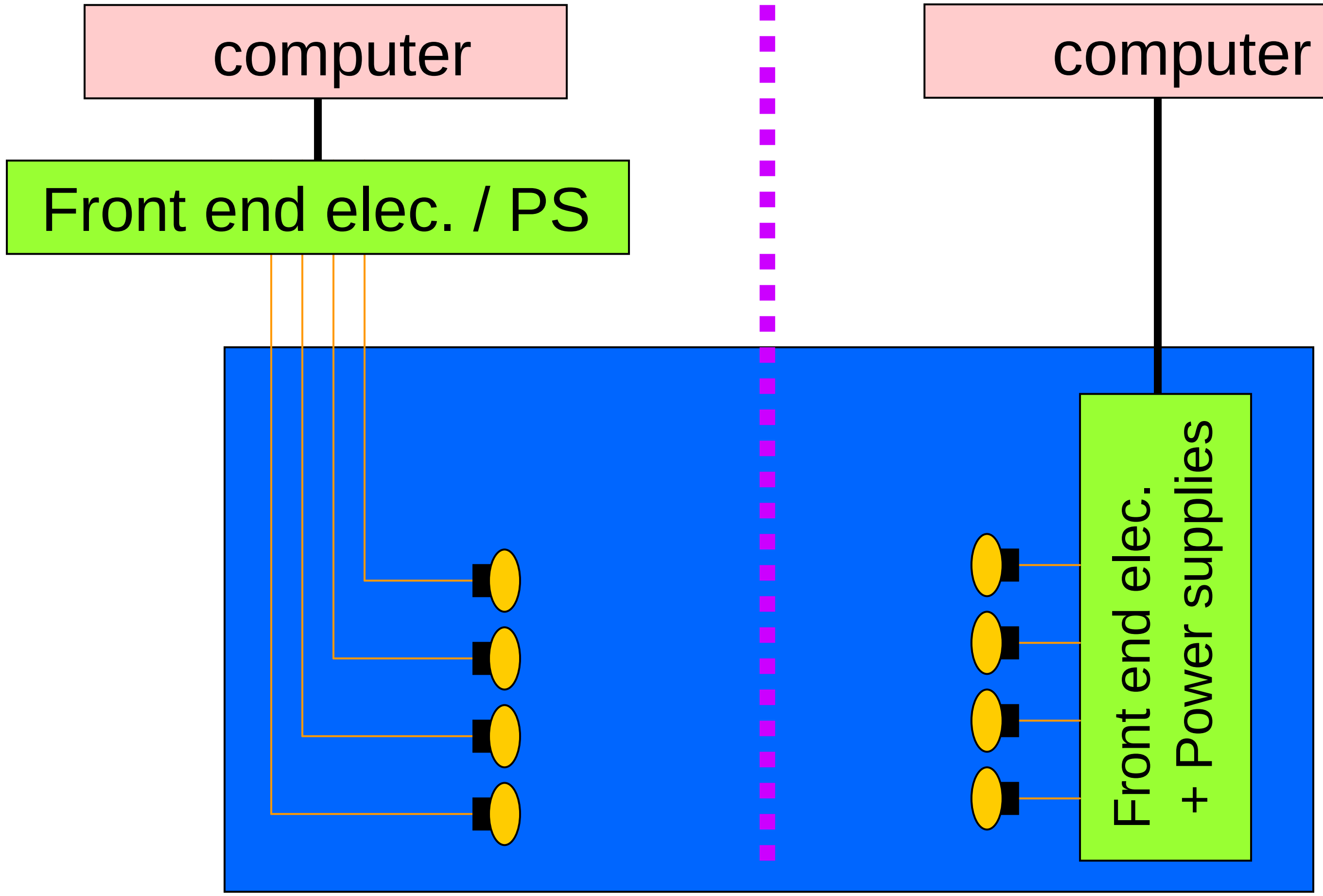
- **# of hits within 200ns**
- **Neutrino beam timing**

Front end electronics + Power supply for photo sensors

☆ Where to put the front end electronics
and power supplies for photo sensors?

1）On the detector (tank)

2）Close to the photo sensors



Front end electronics + Power supply for photo sensors

☆ Where to put the front end electronics
and power supplies for photo sensors?

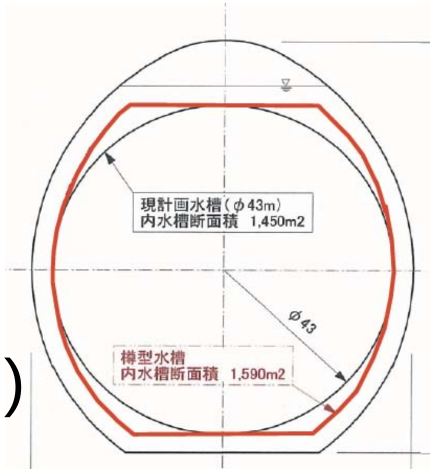
1）On the tank

2）Close to the photo sensors

Why we think about this option seriously?

- Design of the tank ~ egg shape
  Difficult to bring up huge number of cables

One idea is to place the cable
when the supporting structure
is constructed.
(If reliable, cheap and easy
water-tight connector is available)



- Handling of the cables around the exit
  from the detector is not so simple.
  (Cable holes will be the inefficient / dead regions.)

Front end electronics + Power supply for photo sensors

☆ Where to put the front end electronics
and power supplies for photo sensors?

1）On the tank

2）Close to the photo sensors

Why we think about this option seriously?

- Cable length from the photo sensor ~ 100m
  (SK is 70 or 75m)
  Cable is not cheap
  Signal will be degraded
  Difficult to match impedance = signal reflections
- Hybrid PMT, gain is lower and need to amplify

Problem **＊＊Can not repair once installed＊＊**

Fault tolerant circuit / configuration

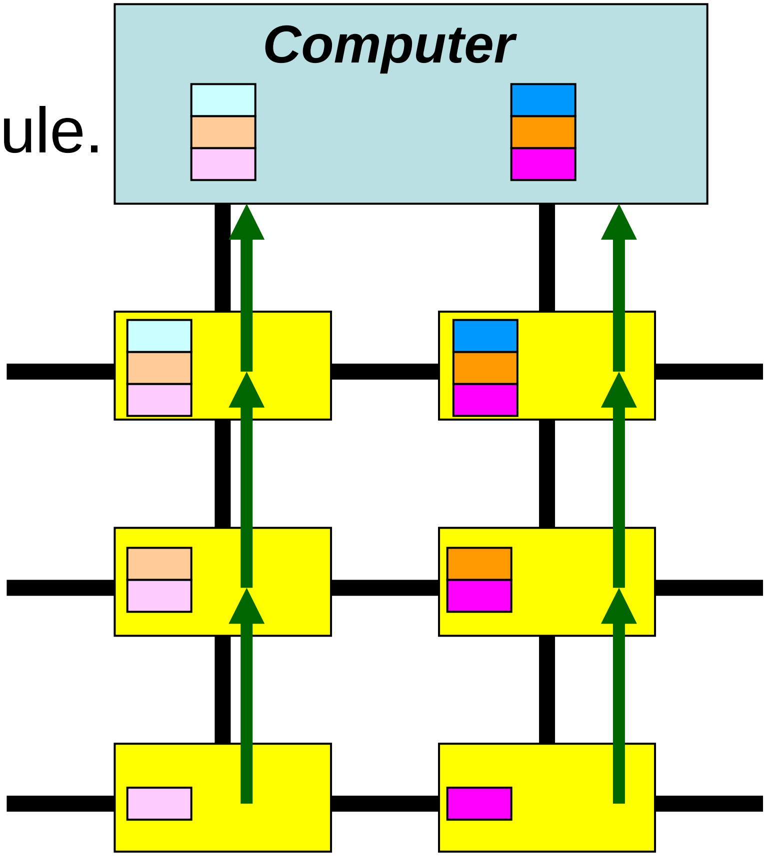
Reliable water tight connectors are expensive

Thermal design (heat flow), noise (grounding) etc.

Network configuration ~ Front end electronics

- In SK, each QBEE is directly connected to PC via switch.
- If we use the same scheme,
  network switch will be the source of single point failure.
- Connect neighboring modules and form grid
  to send data and commands.

  - Each module sends data
    to one of the neighboring module.
  - Transmit received data
    after adding its own data.



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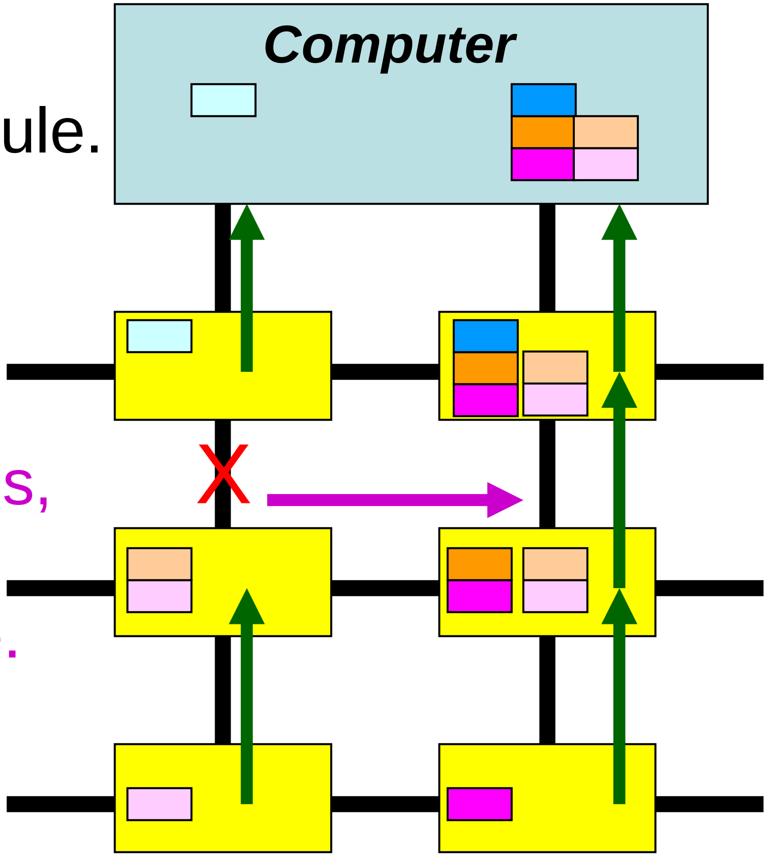
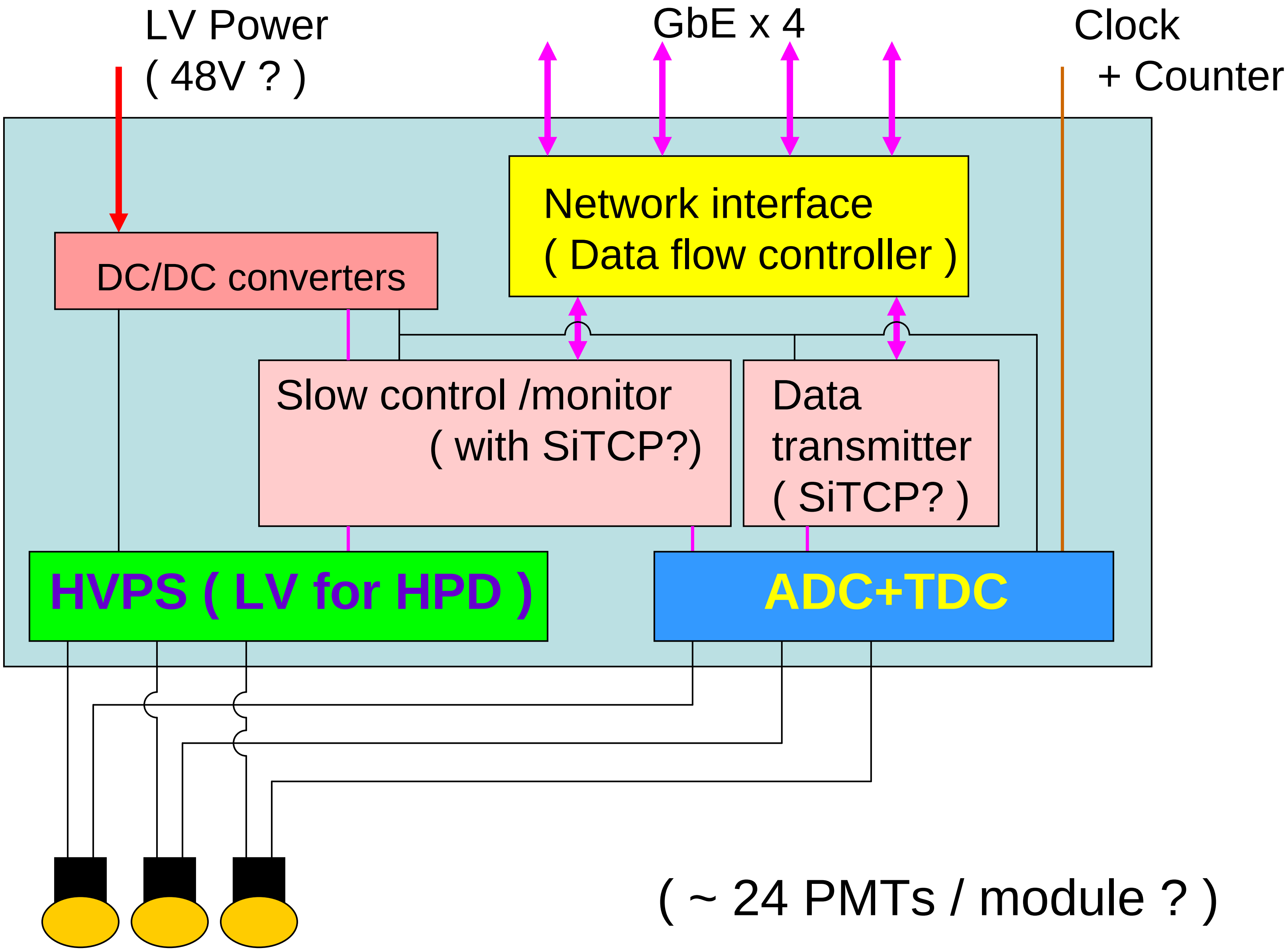
  to send data and commands.

  - Each module sends data
    to one of the neighboring module.
  - Transmit received data
    after adding its own data.
  - If one of the modules
    or network ports fails,
    send data to
    the other available module.



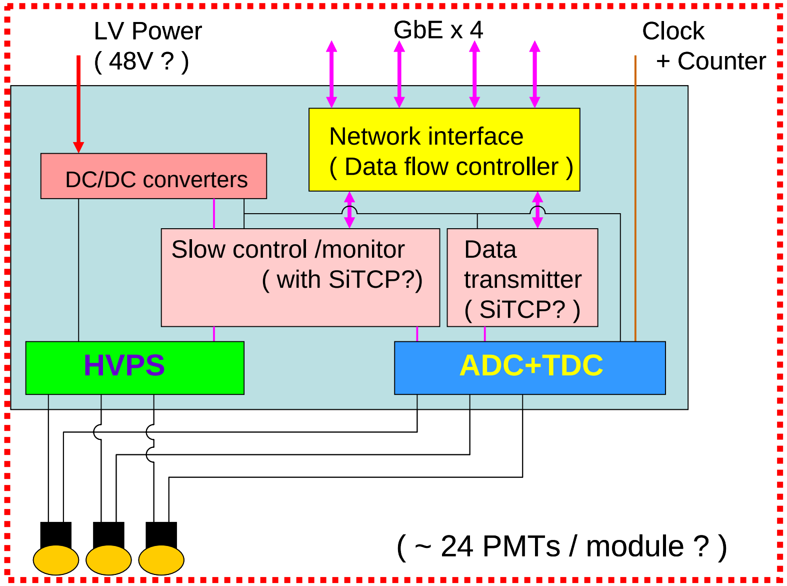
Front end electronics + High voltage system

Schematic diagram（ example ）



Front end electronics + High voltage system

R&D items of the front end module



- Connection of the cables
  Water proof connectors
- Water proof cases
  Need shock protection?
- Heat flow / cooling
- Grounding issues
  Noise problems
- R&D or selection of the long life HV supply module
- R&D to control HV control / voltage and current monitor
- Noise shield between HVPS and ADC
- R&D of ADC (QTC?) and TDC etc….

☆ Assume to use electrical connections (not optical)

☆ For Hybrid PMT, HV and ADC/TDC might be embed in the sensor and functions may be slightly different.

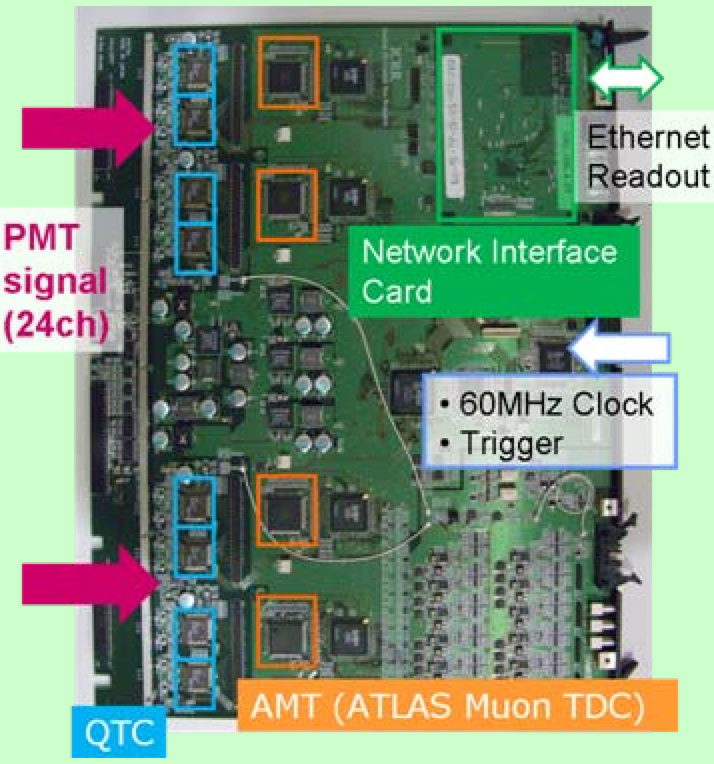
Front end electronics + Power supply for photo sensors

Required performance for ADC / TDC ~ similar to QBEE (SK)

Performance of QTC for SK

- **Built-in Discriminator**
  ¼ p.e. (~ 0.3 mV)
- **Processing Speed**
  ~1usec/HIT
- **High Sensitivity for single p.e.**
- **Charge Response**
  RMS Resolution:
  ~ 0.05p.e. (<25p.e.)
- **Timing Respons**
  0.3ns (1p.e.⇔ -3mV) (RMS)
  0.2ns (>5p.e.)
- **Wide Charge Dynamic Range**
  0.1 ~ 1250p.e. (0.2~2500pC)

QBEE

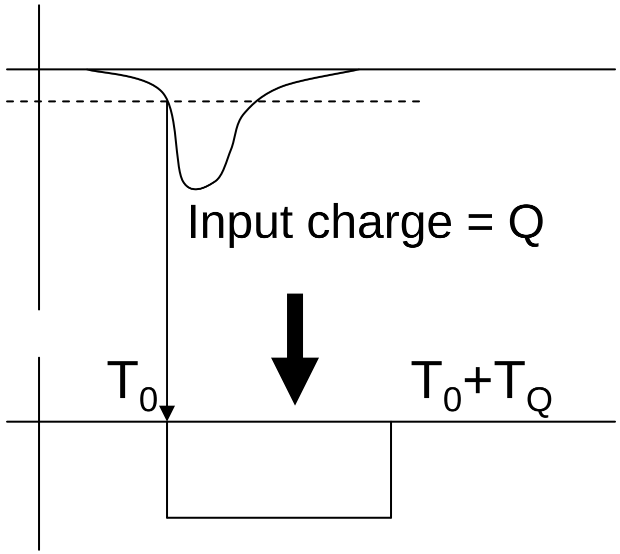


~1 W/channel

Actual implementations ~ Digitization

Use QTC (charge to time converter)
with multi-hit continuous readout TDC (AMT)

QTC converts charge to the digital signal
whose signal width is linear to the input charge



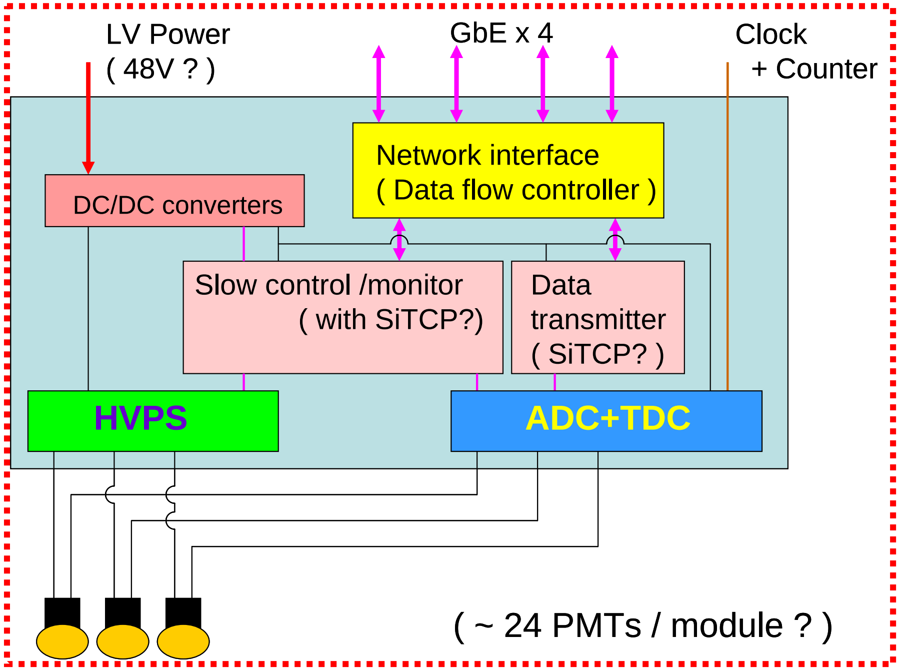
T_0 : Timing of the input analog signal

T_Q : Width of the signal
linear to the input charge Q

Usually, there are small dead-time after each hit (integration gate)
and thus, it is not completely “dead-time” free.

- Digitize all the hits from all PMTs
and readout everything using the computers

Summary ~ R&D items



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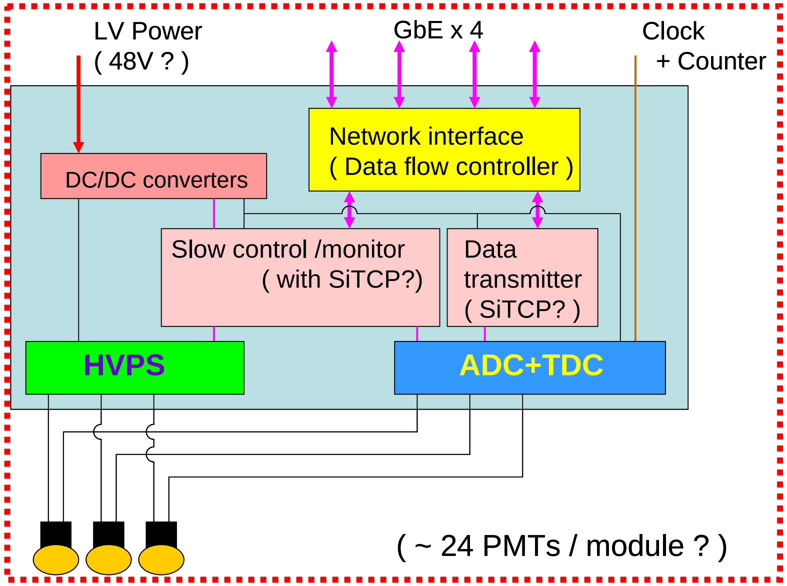
in the sensor and functions may be slightly different.

backups

Front end electronics + High voltage system
short term work (**this year**)

- Connection of the cables
  - Water proof connectors
- Water proof cases
  - Need shock protection?
- Heat flow / cooling
- Grounding issues
  - Noise problems



→ Put existing QBEE for SK in the case
Check water proof and heat flow

QBEE input/output
PMT inputs (24ch)
Timing/trigger clock
Network
LV power supply

Actual implementations ~ Digitization

Allowed maximum width of the signal
constraints the dynamic range.
(if it is too long, channel dead-time will be longer)

➡ QTC developed for SK has 3 ranges per channel
to cover 0.2 ~ 2500 p.e.
(i.e. 3 output per channel from QTC)

Selection of the gain (range) can be done
after the TDC.
(# of TDC channels = 3 x # of PMTs)

Charge integration gate 400 ns
Processing time 900 ns
= channel dead-time ~ 500ns
But this will not cause serious problems
in the large water Cherenkov detectors.

Actual implementations ~ Digitization timing chart