Hyper-K Latest updates (Activities in Japan)

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1. Recent news (in Japan)
2. Slight update of the timetable
3. Update of the sensitivity
   ~ Accelerator based long baseline experiment ~
4. Status of the photo sensor R&D in Japan
5. Status of the DAQ R&D (in Japan)

1. Recent news

- Selected one of the ***27 'top projects'*** out of 192
  in 'Japanese master plan for large scale research projects'
  by Science Council of Japan

Report (In Japanese) : http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t188-1.pdf

Excerpts (summary translated in English)

No.	Scien-tific Field No.	Project Name	Project Summary	Scientific Significance	Social Value	Project Duration	Financial Requirement (1billion yen)	Implementing Institution, or Affiliation of Proposer
85	23-2	Nucleon decay and neutrino oscillation experiment with an advanced large detector	The project aims to construct a one million ton-scale water Cherenkov detector, Hyper-Kamiokande, to succeed Super-Kamiokande and to perform world-leading neutrino and nucleon decay research in conjunction with the J-PARC accelerator facility.	The project will explore CP violation (matter-antimatter asymmetry) in neutrinos in order to help understand the evolution of the universe. Additionally, with the world's best nucleon decay searches it also aims to establish the unification of elementary particles and their forces.	Addressing profound questions concerning the elementary structure and evolution of the universe appeals directly to the inherent intellectual curiosity mankind harbors for comprehension of its origins and future. Additionally, dramatic advances in neutrino research with a world-leading project in Japan represent society's dreams for a rich program in basic science.	2015 to 2038	Total:1,880 Construction of Hyper-Kamiokande 800, Operating cost of Hyper-Kamiokande 450, Operating cost of J-PARC 600, Neutrino monitor 30	Lead by the Institute for Cosmic Ray Research, University of Tokyo and the High Energy Accelerator Research Organization. Participation from domestic and foreign universities and research institutions is anticipated.

- We had MEXT review (interview) in March.

2. Current status in Japan

Budget for the R&D was approved

1) Grant-in-Aid for Scientific Research on Innovative Area.
(5 years from 2013 to 2017)
Includes both Hyper-K R&D and T2K/J-PARC improvements.

Build a test (small) detector
to test the new equipment and components
to be used in the HK detector
and to confirm the detector stably works as a `system’.

Surface of the tank (water shielding liners),
water system,
photo sensors,
signal read out system and
calibration system
have to be confirmed to work.

2. Current status in Japan

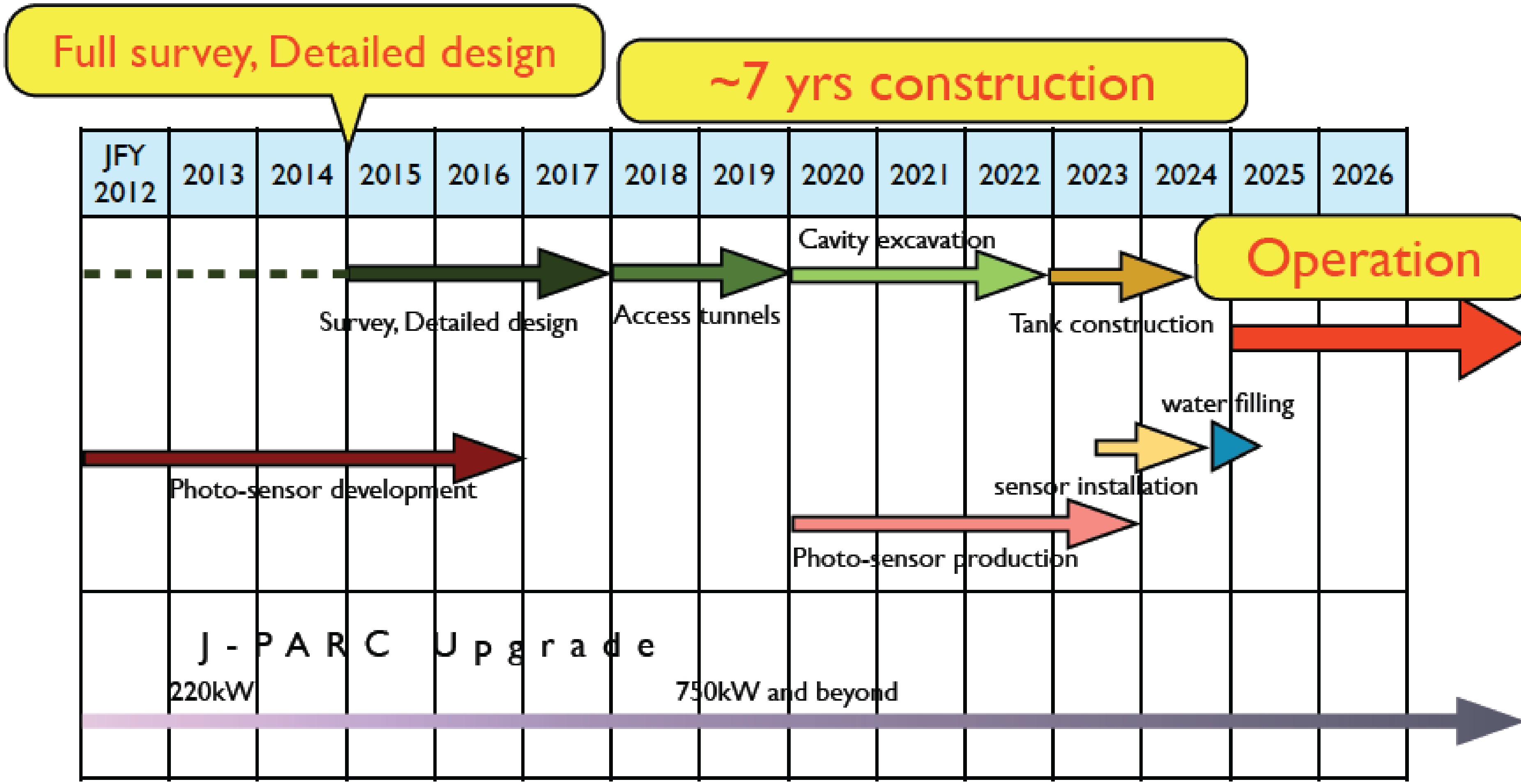
Budget for the R&D was approved

2) Japan/US Cooperation Program
in the Field of High Energy Physics.

For various R&D for the new neutrino detectors
(both near and far detectors)
and J-PARC accelerator / T2K beamline improvements.

Example : R&D of the FPGA-based TDC for
QTC-TDC based front-end electronics
is (just) started as a project in 2014.

3. Timeline (slight update)



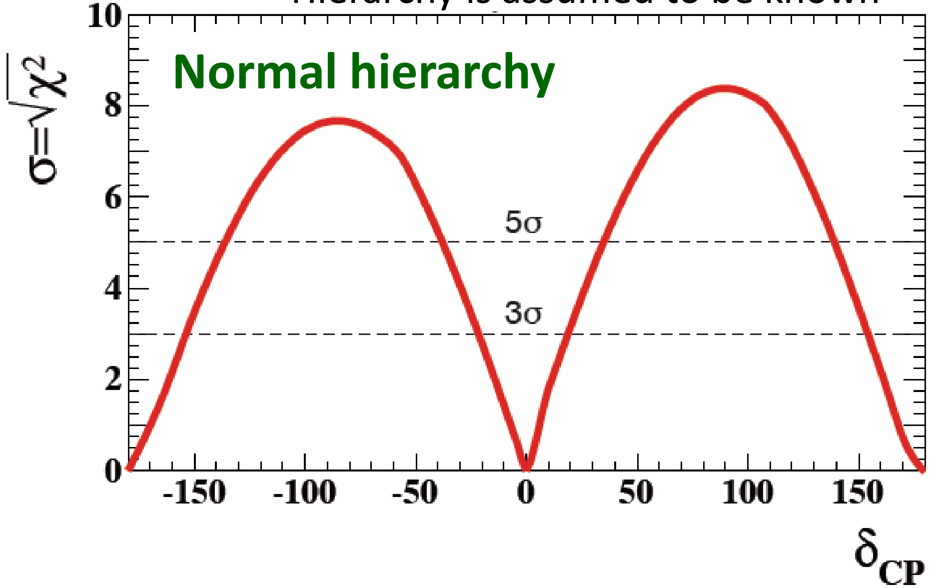
-2015 Full survey, Detailed design (3 years)
-2018 Excavation start (7 years)
-2025 Start operation

4. Updated sensitivity ~ LBL J-PARC & HK ~

Revised systematic errors ~ Determination of CP δ

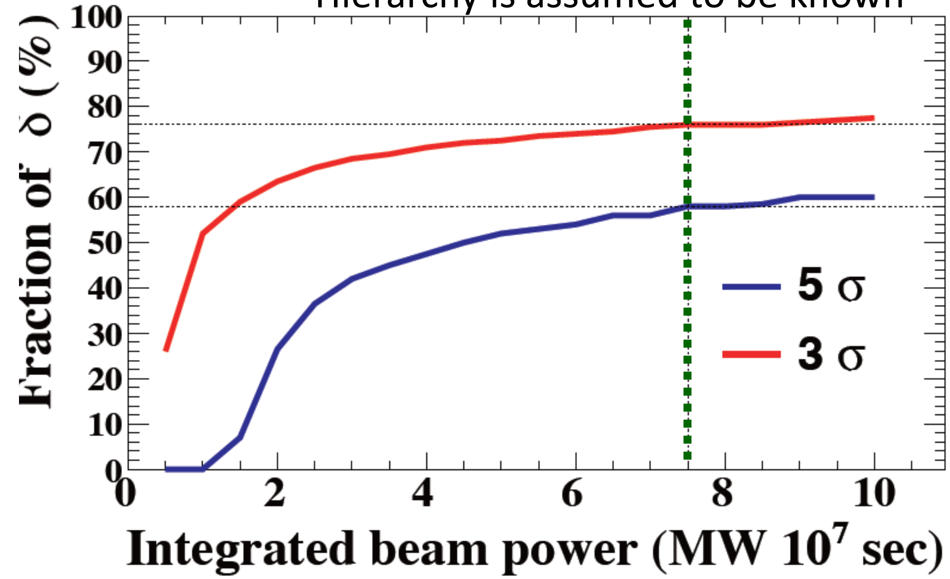
Sensitivity ~ Exclusion of sin δ = 0

(7.5 x 10⁷ MW·sec)



Fraction of δ

~ Exclusion of sin δ = 0



Exclusion of sin δ = 0

76% of δ at 3σ level and 58% of δ at 5σ level

with realistic systematic error estimations.

5. Recent updates of the photo sensor R&D

~ For better performance and reduction of cost ~

1) higher QE (from 22% to ~30%)

    Reduction of # of sensors ~ reduction of cost

2) Better timing response

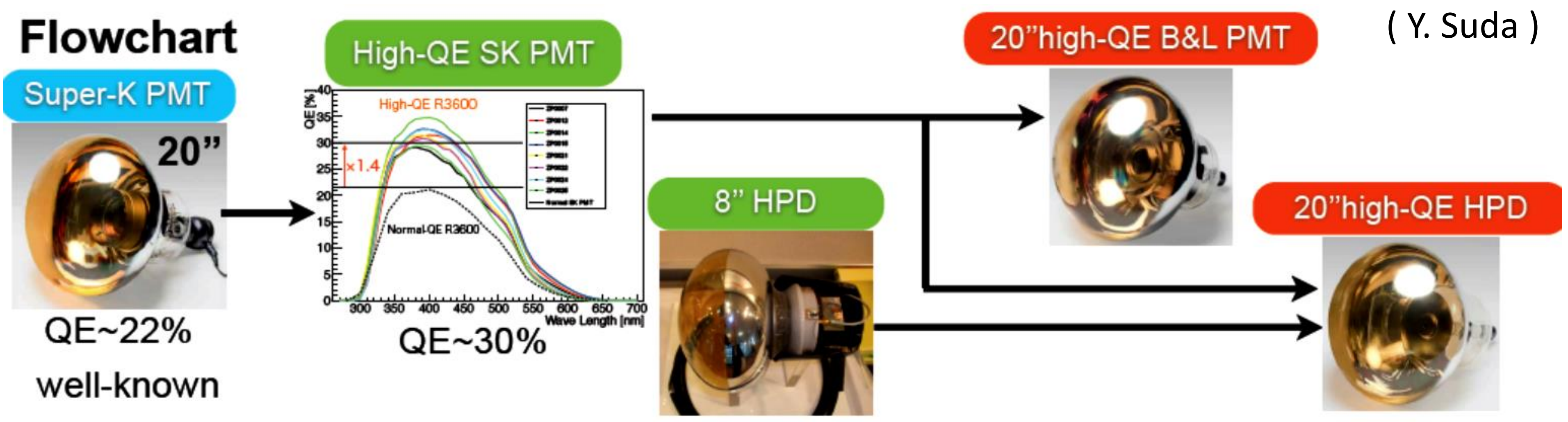
    Improvements in the accuracy of the vertex reconstruction

We are testing 2 types of new photo sensors,

20” high QE Box-Line PMT and

20” high QE Hybrid Photo Detector.

Following 5 pages are from the presentation for TIPP 2014 by Suda-san.



5. Recent updates of the photo sensor R&D

New 20” Prototypes

20” high-QE box&line PMT

20” high-QE HPD
(w/ 5mmΦ AD)

Note

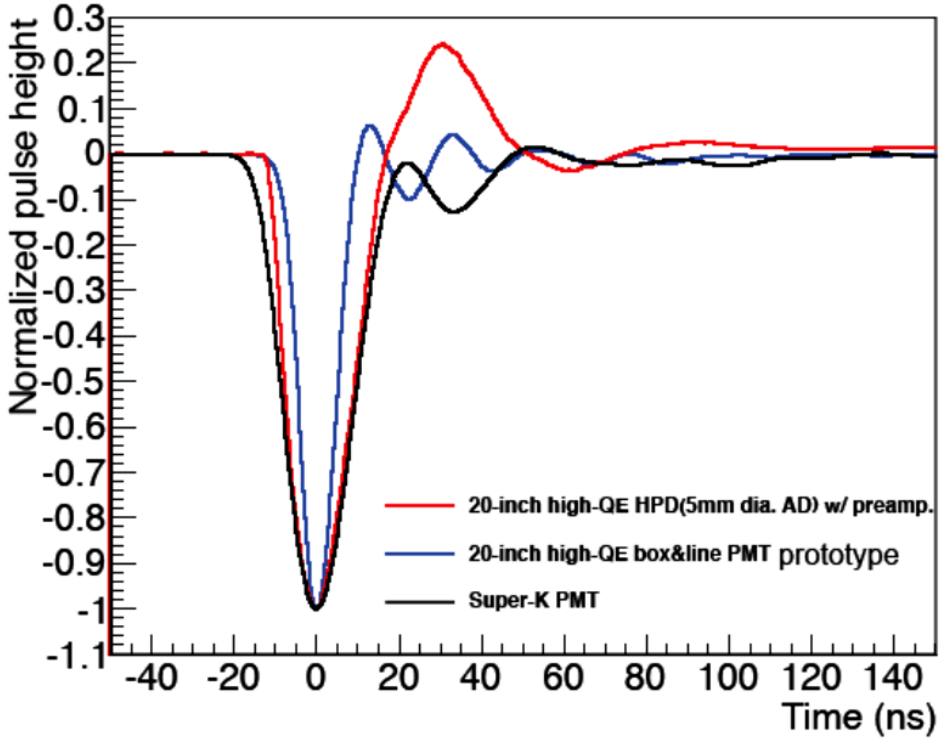
- AD used for the evaluation is smaller size, same as 8” HPD
- 20” HPD w/ 20mmφAD (with good efficiency in final design) will be later measured with coming new preamplifier.

Taken from the presentation at TIPP 2014 by Suda-san.

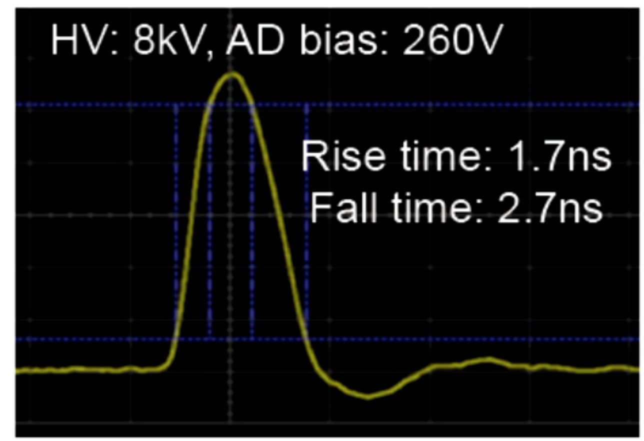
5. Recent updates of the photo sensor R&D

Waveforms

- Box&line PMT and HPD are faster than Super-K PMT



8” HPD w/o preamp.



	HPD	B&L PMT	SK PMT
Rise time (ns)	7.4	6.2	10.6
Fall time (ns)	11.5	6.3	13.1
Pulse width (ns)	25.5	16.7	31.4

HPD itself has very fast response.

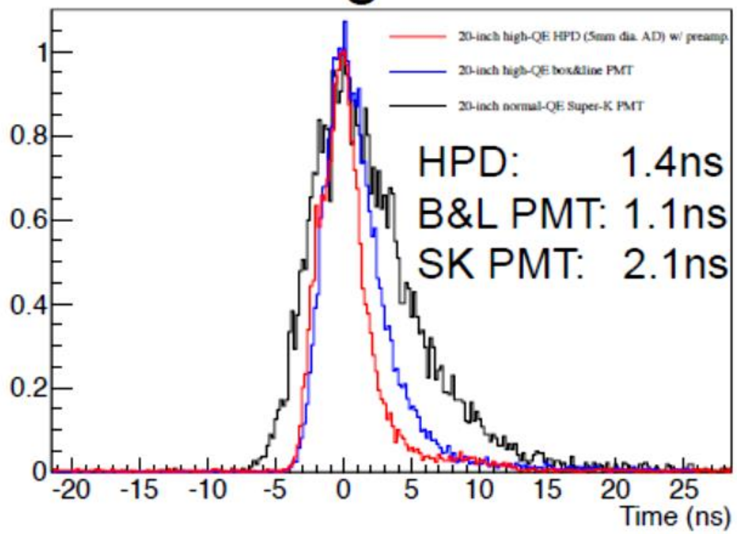
Preamplifier R&D to get a fast response is ongoing.

Taken from the presentation at TIPP 2014 by Suda-san.

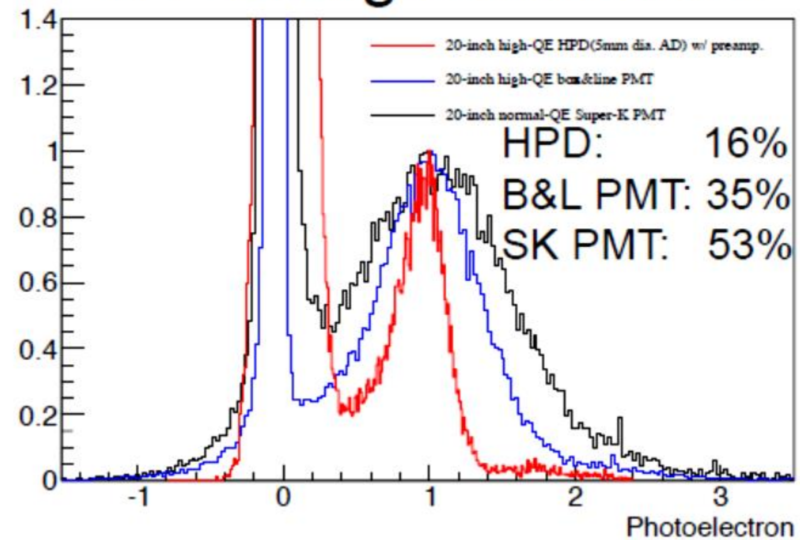
5. Recent updates of the photo sensor R&D

Timing & Charge

1PE timing distribution



1PE charge distribution



	20" HPD (8" HPD)	**B&L PMT**	**SK PMT**
Timing resolution σ (ns)	1.4 (1.1)	1.1	2.1
FWHM (ns)	3.4 (3.3)	4.1	7.3
1PE resolution σ/μ	16% (12%)	35%	53%
Peak to Valley ratio	3.9 (5.2)	4.3	2.2

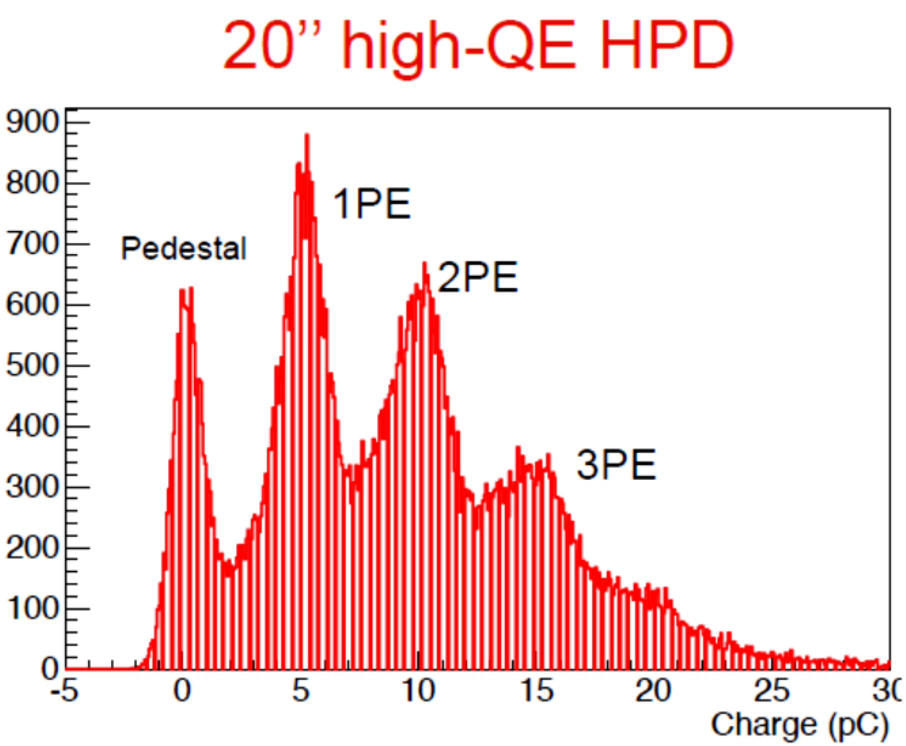
HPD calculated timing resolution FWHM: 0.75ns (20mmφ AD w/o preamp)

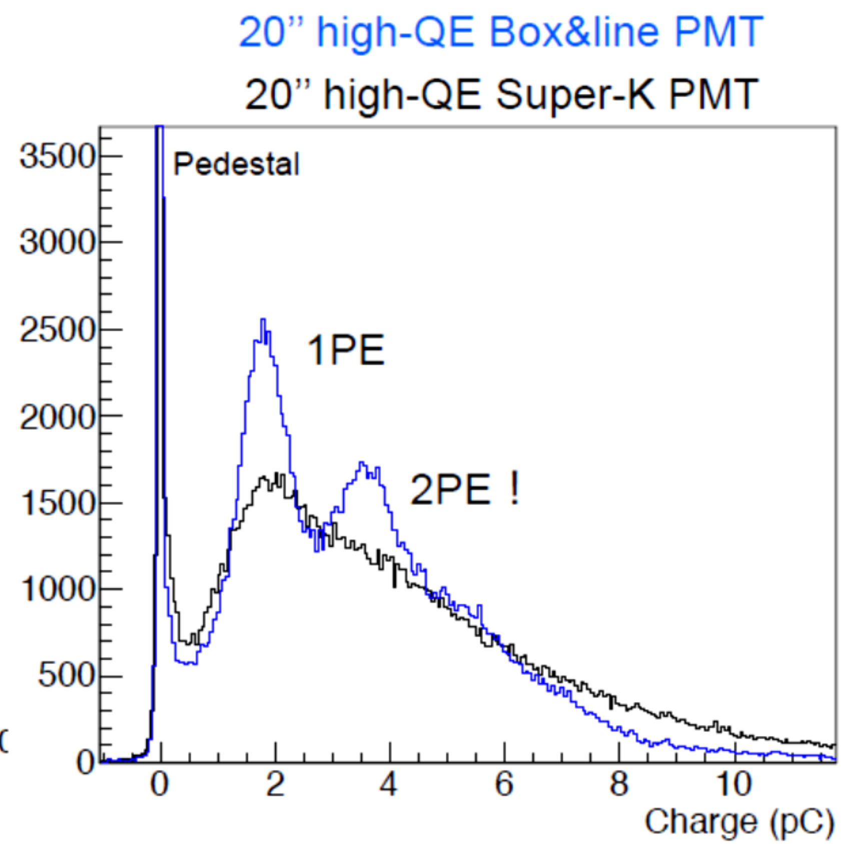
- Both box&line PMT and HPD show better timing and charge resolution than Super-K PMT

Taken from the presentation at TIPP 2014 by Suda-san.

5. Recent updates of the photo sensor R&D

Multi-PE Distribution



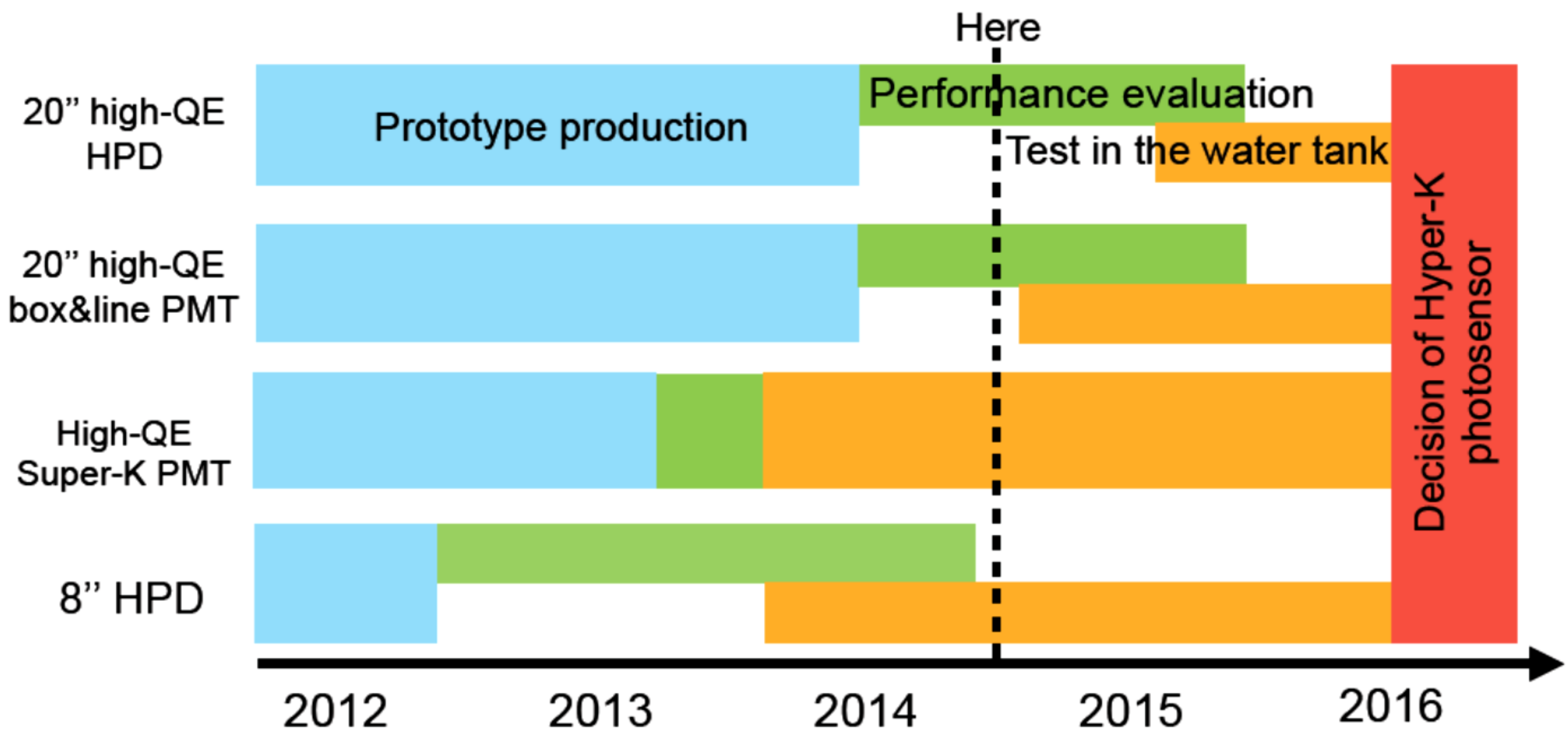


Multi-photoelectron peaks are clearly seen

Taken from the presentation at TIPP 2014 by Suda-san.

5. Recent updates of the photo sensor R&D

Schedule



- Development of 20" HPD is still ongoing
  - Preamplifier for large AD size, Low capacitance AD
- In this summer, 20" high-QE box&line PMT will be installed in the tank

Taken from the presentation at TIPP 2014 by Suda-san.

6. Recent updates of the DAQ R&D

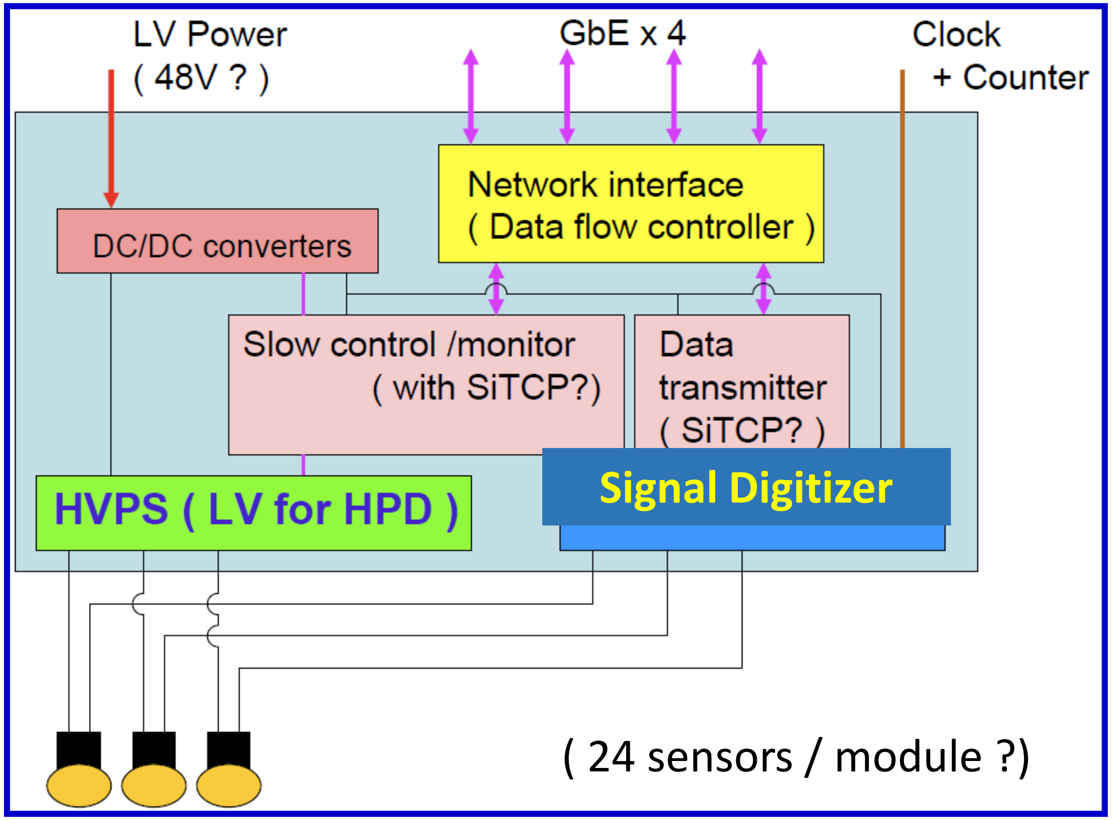
Baseline design

Hardware trigger less DAQ system ~ record all the hits ~

Digitize all the photo sensor signals above threshold (~ ¼ photo electrons) and read out by a computer.

Key components

- Self triggering & dead-time free signal digitizers
- HV (LV) for photo-sensors
- Intelligent network interfaces
- Front-end module in the water



6. Recent updates of the DAQ R&D

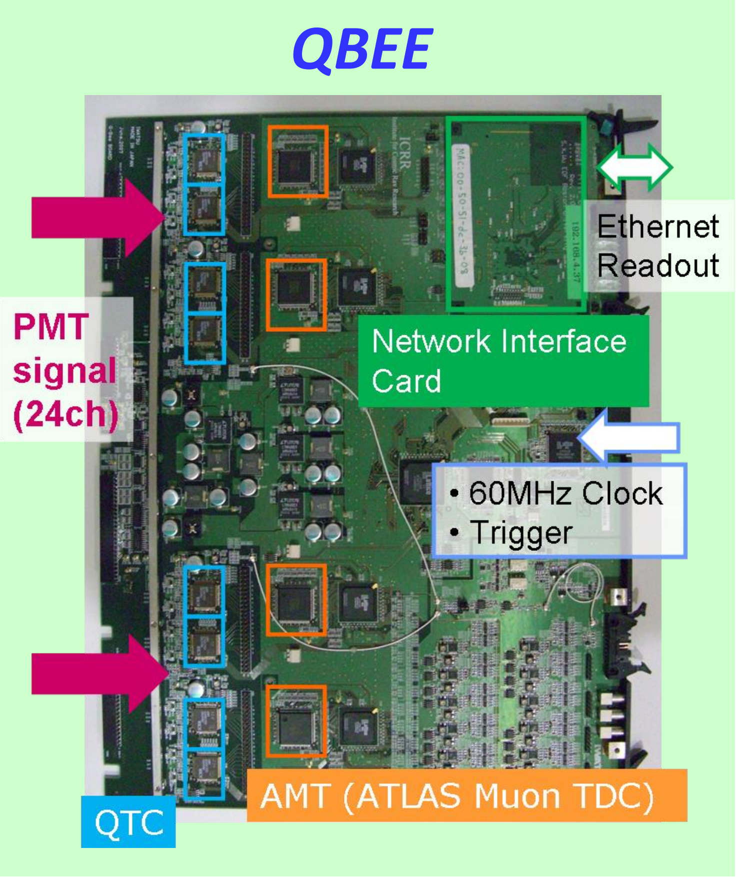
Baseline design

Hardware trigger less DAQ system ~ record all the hits ~
Digitize all the photo sensor signals above threshold
(~ ¼ photo electrons) and read out by a computer.

Possible configurations
of the front end module

- QTC (ADC) + TDC
  Similar to the current SK ~ QBEE
- FADC
  Proposed by the Canadian group

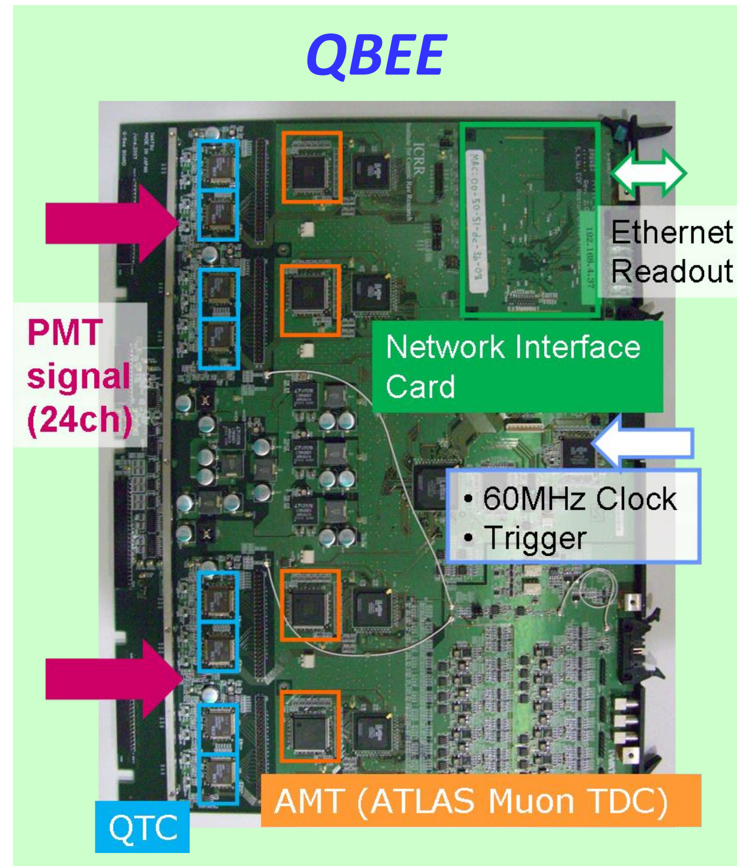
In Japan, we have started R&D
to develop a test module
with QTC & FPGA based TDC.



6. Recent updates of the DAQ R&D

Basic requirements of the front-end module

- **Built-in Discriminator**
  ¼ p.e. (~ 0.3 mV)
- **Charge integration gate**
  ~ 400 ns
- **Processing Speed**
  ~1 usec / hit
- **High Sensitivity for single p.e.**
- **Charge Response**
  Resolution: ~ 0.05p.e. (<25p.e.)
- **Wide Charge Dynamic Range** (*)
  0.1 ~ 1250p.e. (0.2~2500pC)
- **Timing Response**
  0.3ns (1p.e. ⇔ -3mV) (RMS)
  0.2ns (>5p.e.)
- **TDC lowest bit**
  0.52 ns
- **Low power consumption**
  ~< 1W / channel



(*) QTC has 3 charge ranges
to cover wide dynamic range
(1 : 7 : 49)

6. Recent updates of the DAQ R&D

R&D of the new front end module

1) Use spare QTC chips for SK

(We don't have many but sufficient for the tests.)

2) Use new FPGA based TDC developed in FNAL by Jinyuan-san.

AMT3 chip (used in QBEE) has been discontinued.

The first buffer of AMT3 was not sufficient and ringing of the PMT signal may fill up the buffer.

Data bus throughput is not sufficient to read out all the hits at maximum rate.

This TDC is now under development for muon experiment in FNAL.

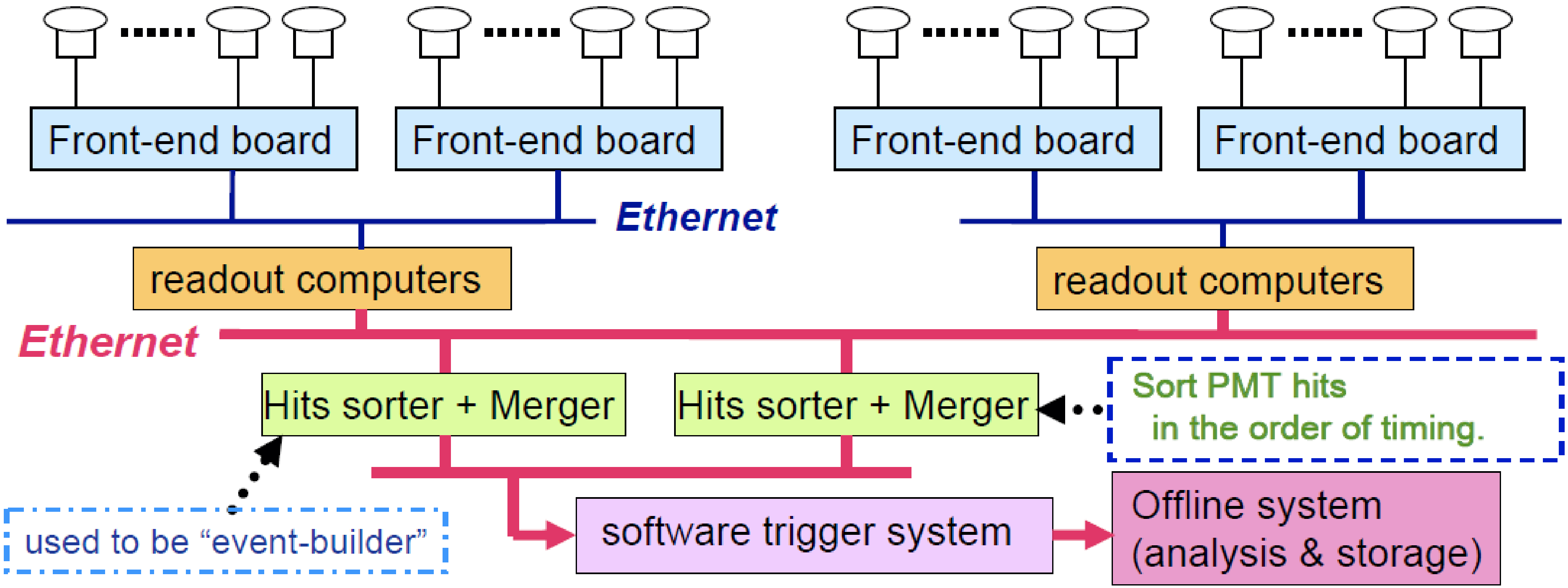
From this summer, evaluation of this TDC will be started.

Once this TDC is confirmed to be feasible, we will work on the analog part.

Also, we need to prepare new QTC for the real detector.

(We are planning to contact "Iwatsu", for possible collaboration.)

6. Recent updates of the DAQ R&D



1) Digitize all the signal (timing and charge) above ~ 1/4 p.e.
2) Read out timing and charge with the computers.
3) Define events with software and store the event data.

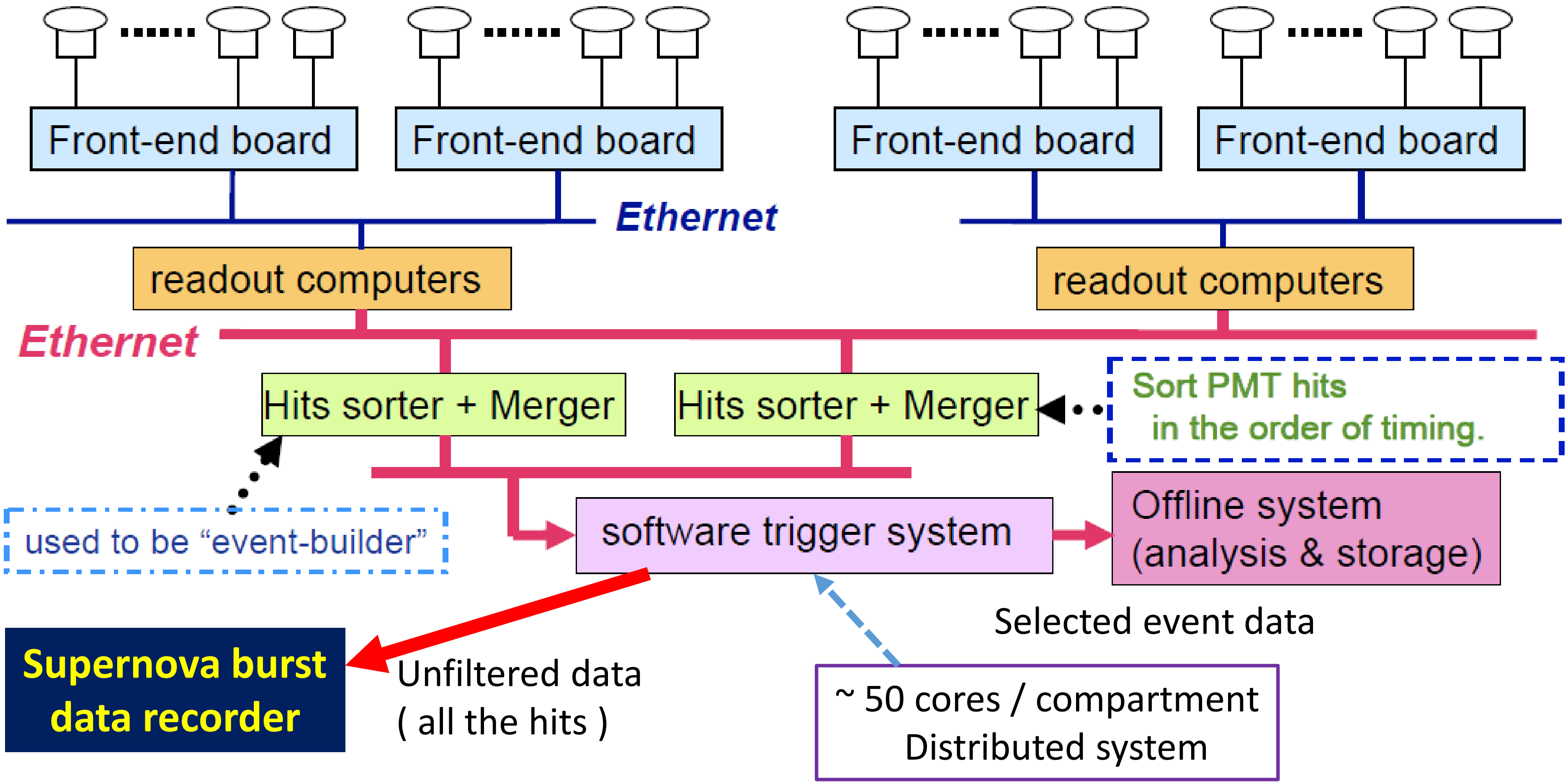
Sort the hits in the order of timing and

a) search for the timing cluster, and

b) apply reconstruction program for low E_ν

(recent work / improvements in SK)

6. Recent updates of the DAQ R&D



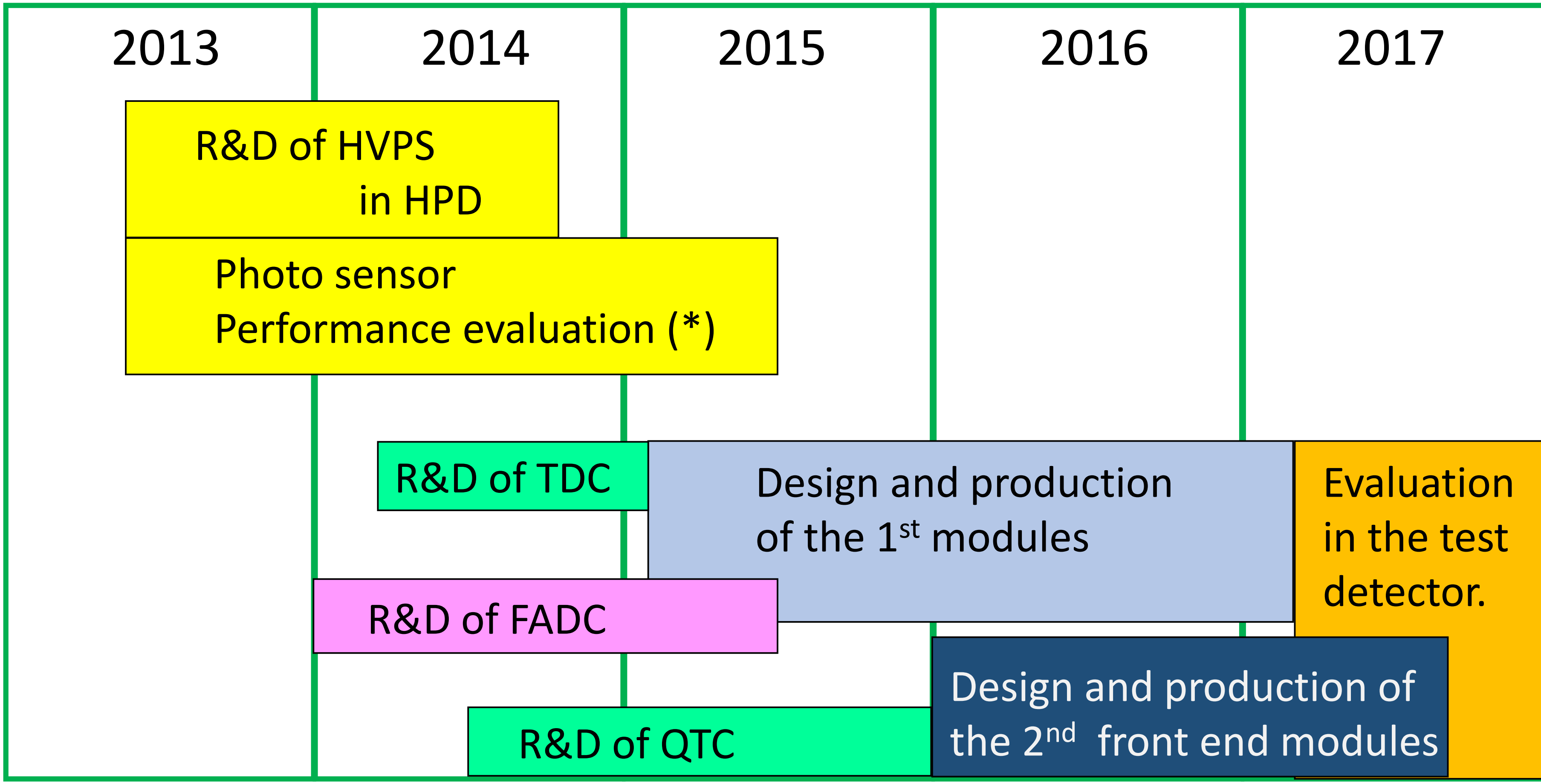
Record all the hit data before and after the supernova for ~ 60 sec.

Transfer all the data to single computer and keep them in the main memory for ~ 60 seconds.
Once supernova burst candidate is identified, dump the data to the disk.

This also implemented in SK and now under the test.

6. Recent updates of the DAQ R&D

Rough timeline of the DAQ system R&D

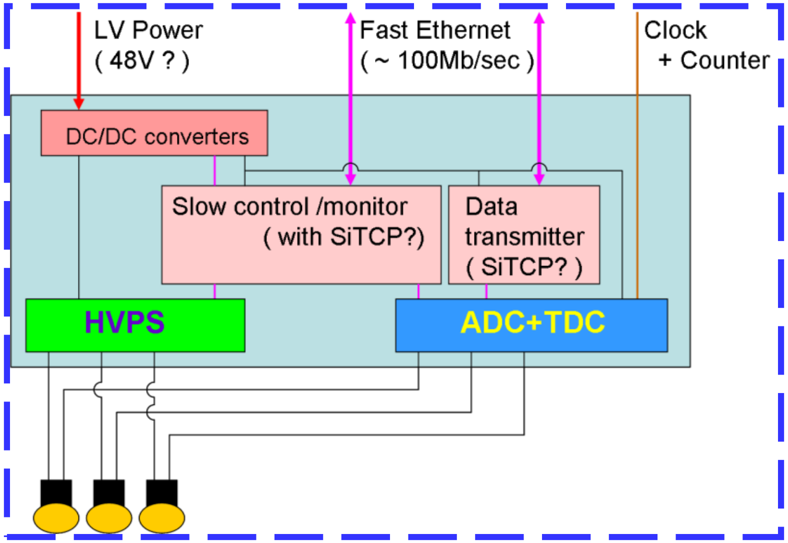


*) Currently, we are testing the new photo sensors in the EGADS detector in collaboration of the EGADS group.

Fin.

Front end electronics + High voltage system

水中用 Front end module の 開発事項



- ケーブルの導入方法
  水中用コネクタ
- 耐圧防水ケース
  防爆対策も必要か？
- 熱設計
  ケースを通して水中に
  放熱するしかない
- データおよびタイミング信号を光ファイバーで集約するか?
  耐(水)圧のネットワークケーブルは高いらしい
- こわれにくい HVモジュールの選定(開発？)
- HV制御、電圧モニターの開発
- HVPS と ADC部のノイズシールド
- ADC/TDC の開発

などなど

☆ Hybrid PMT で HV や ADC/TDC を PMT に内蔵する場合、
LV供給とデータ集約を行うモジュール

Neutrino physics of LBL J-PARC & HK ~ Determination of CP δ

- Expected # of events for $\sin^2 2\theta_{13} = 0.1$, $\delta = 0$ and NH

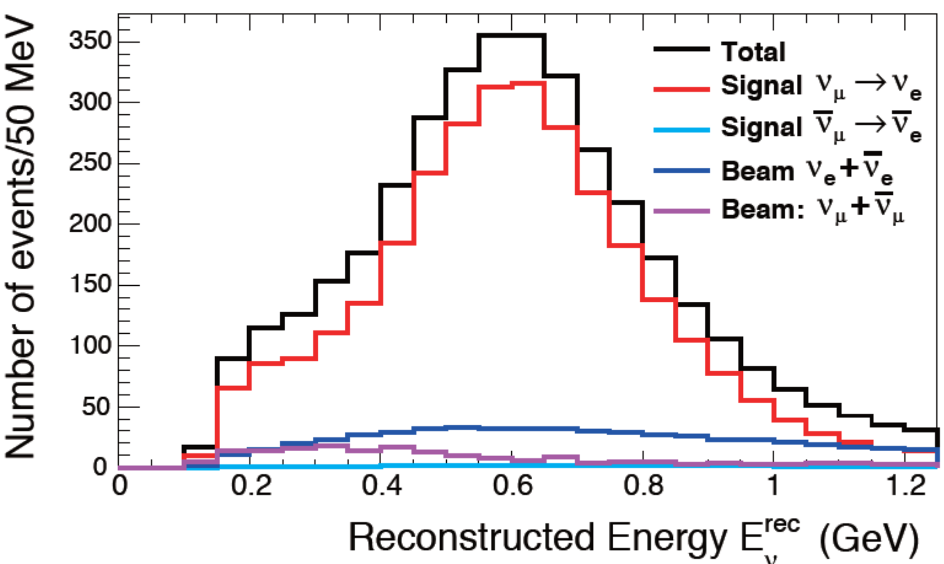
(7.5 x 10^7 MW·sec)

	Signal ($\nu\mu \rightarrow \nu e$ CC)	Wrong sign appearance	$\nu\mu/\bar{\nu}\mu$ CC	beam $\nu e/\bar{\nu}e$ contamination	NC
ν	3,016	28	11	523	172
$\bar{\nu}$	2,110	396	9	618	265

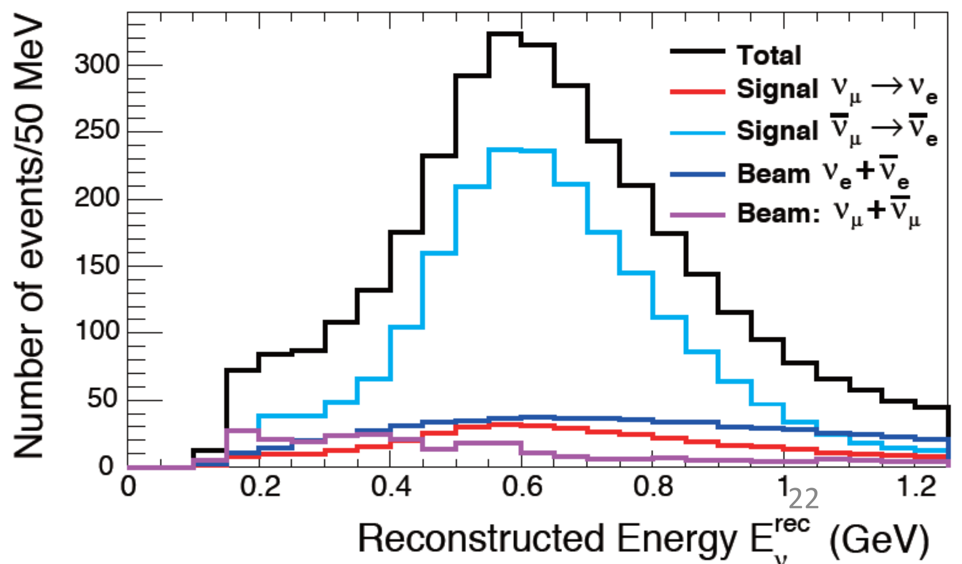
NC (π^0) is not the dominant background already.

- Reconstructed energy of neutrino for candidate events

Neutrino mode beam



Anti neutrino mode beam



Neutrino physics of LBL J-PARC & HK ~ Determination of CP δ

Systematic error Errors used in the sensitivity studies

~ Realistic estimation of the errors based on the experiences ~

	ν mode		anti-ν mode	
	νe	νμ	νe	νμ
Flux&ND	3.0	2.8	5.6	4.2
XSEC model	1.2	1.5	2.0	1.4
Far Det. +FSI	0.7	1.0	1.7	1.1
Total	3.3	3.3	6.2	4.5

(T2K 2014)	
νe	νμ
2.9	2.7
4.7	4.9
3.5	5.6
6.8	8.1

Reduction of errors in the XSEC models

New measurements of neutrino interactions

Improved theoretical modeling

Reduction of errors in the far detector + Final state interactions

Increased statistics of atmospheric ν control sample in HK

New near (intermediate) detectors with H_2O target

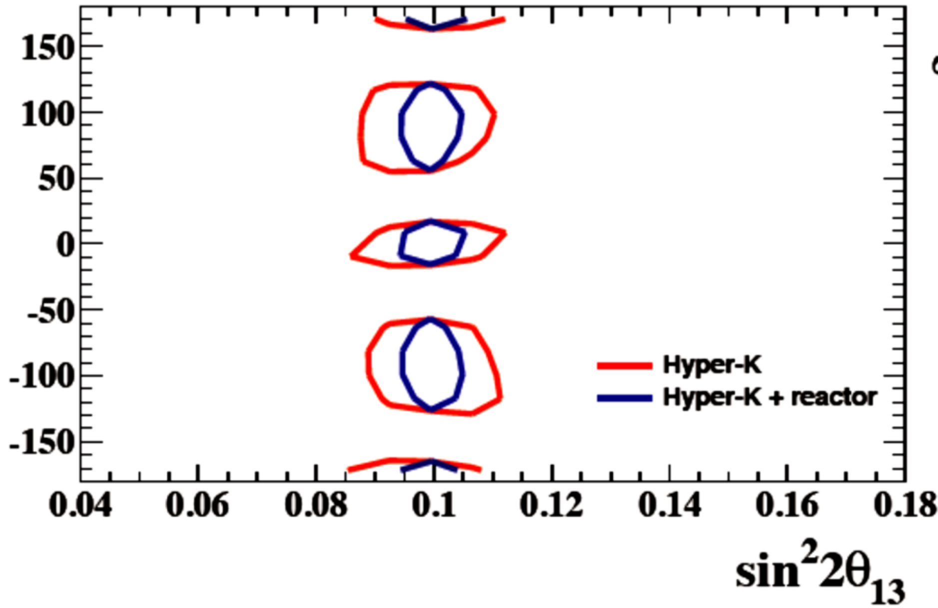
(incl. Water Cherenkov detector)

Neutrino physics of LBL J-PARC & HK ~ Determination of CP δ

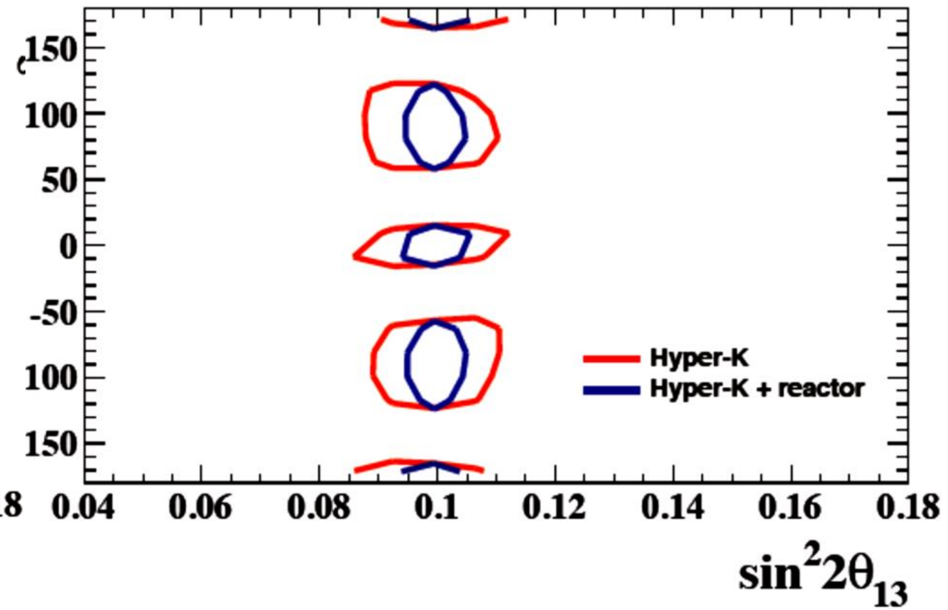
Use both # of observed events
and reconstructed energy spectra of ν and $\bar{\nu}$.

(@ 7.5 x 10^7 MW·sec , ν : $\bar{\nu}$ = 1 : 3)

Normal mass hierarchy



Inverted mass hierarchy

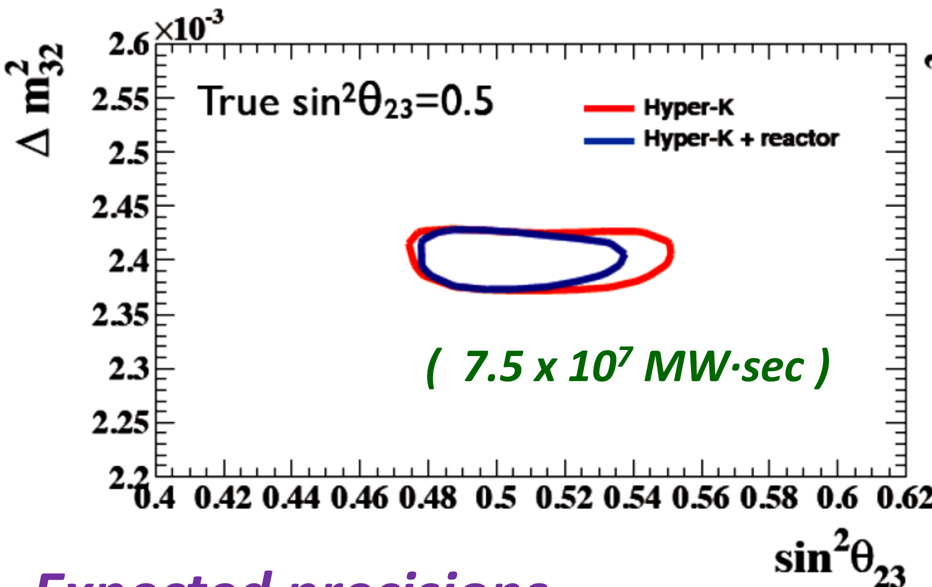


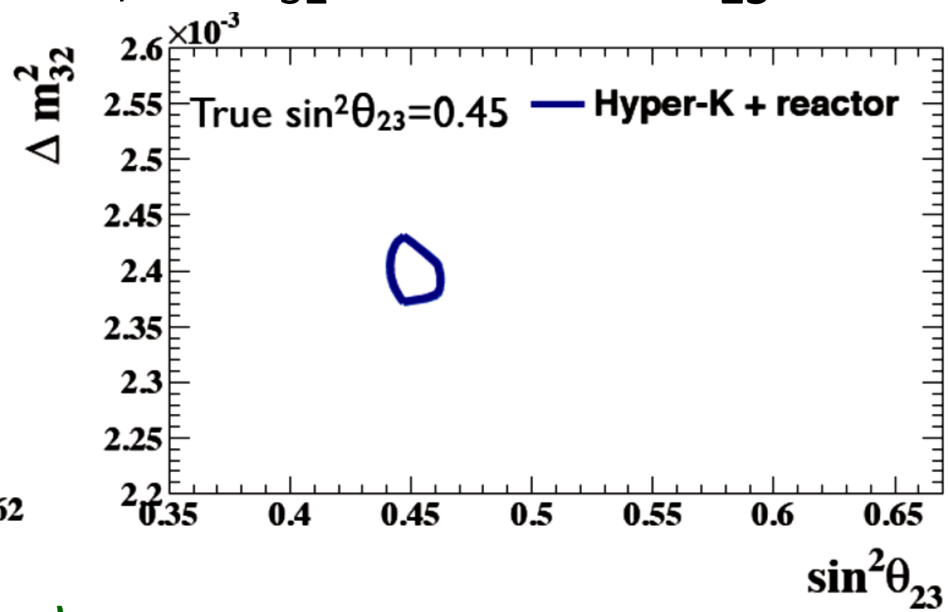
Determination power of CP δ parameter

1σ error of δ is expected to be 8° ~ 19°.

Neutrino physics of LBL J-PARC & HK

~ Measurements of $|\Delta m^2_{32}|$ and $\sin^2 2\theta_{23}$





Expected precisions *(7.5 x 10^7 MW·sec)*

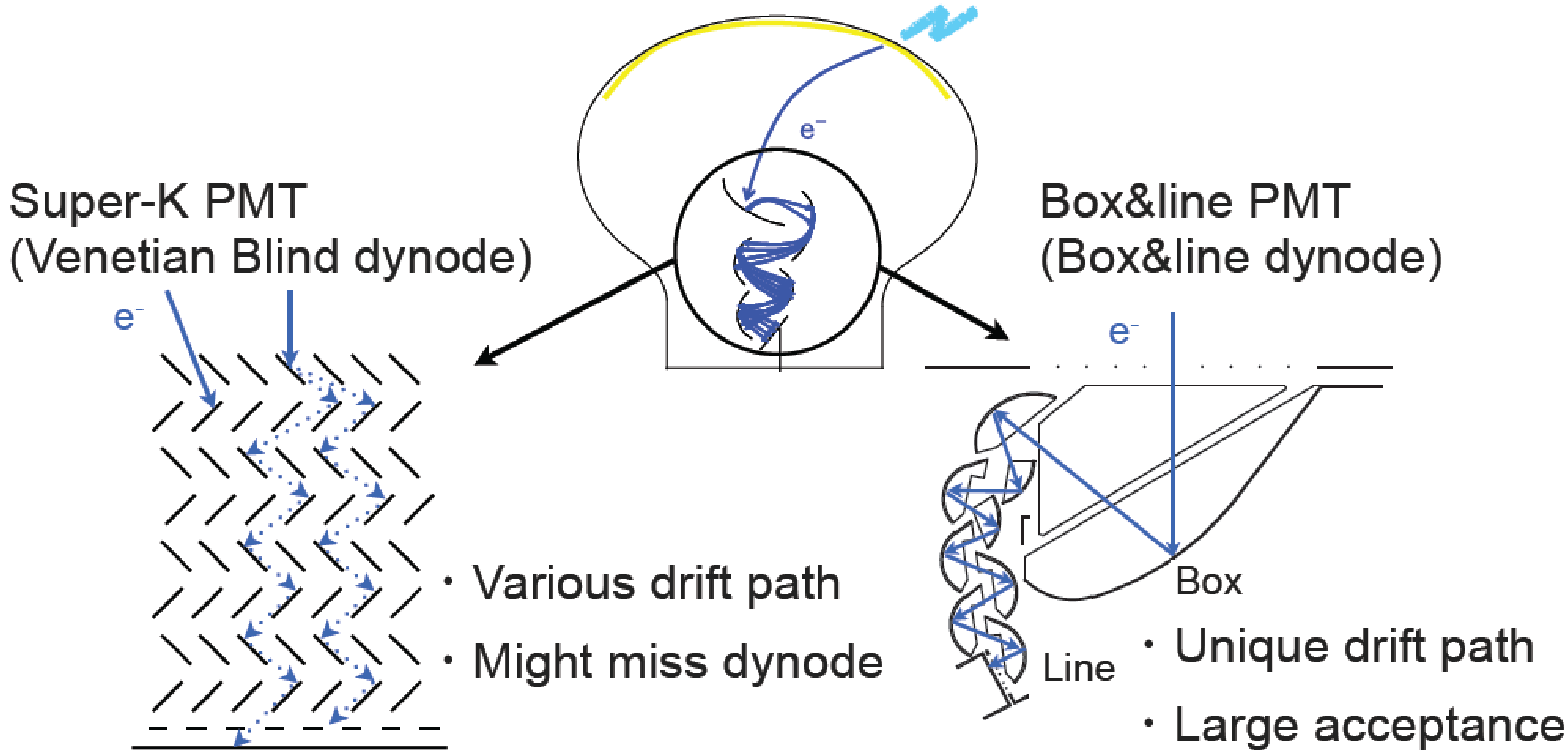
True Δm^2_{32} = 2.5 x 10^{-3} eV^2 $\pm 0.015 \times 10^{-3}\ \mathrm{eV}^2$ (0.6%)

True $\sin^2\theta_{23}$ =
- 0.55 ± 0.009 (1.6%)
- 0.50 (Full mixing) ± 0.015 (3%)
- 0.45 ± 0.006 (1.3%)

(T2K 2014 results Δm^2_{32} $= 2.51 \pm 0.10 \times 10^{-3}\ \mathrm{eV}^2$
$\sin^2\theta_{23}$ $= 0.514 \pm 0.055$)

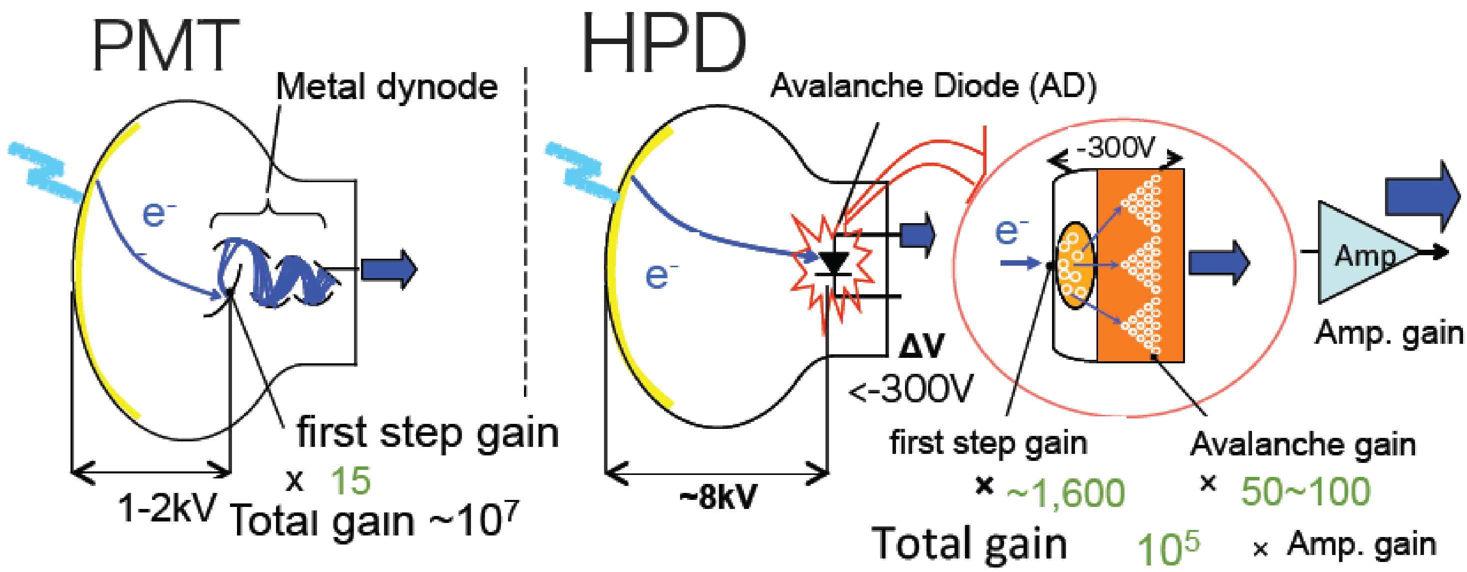
Large improvements & good chance to identify non-maximal mixing.

Box&Line PMT



- Unique drift path → Better timing and 1PE resolution
- Large acceptance → Better collection efficiency

Hybrid Photo-Detector



HPD

Advantage

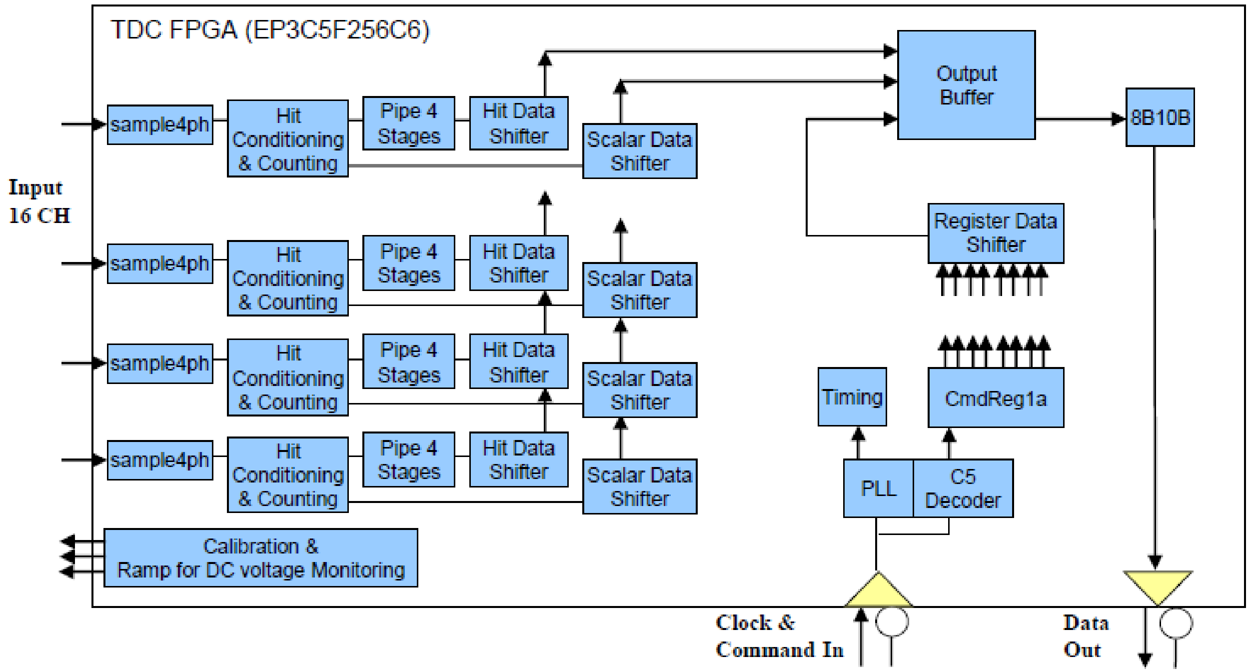
- Simple structure → Low cost production possibility
- Short drift length → Fast timing response
- High first step gain → High single photoelectron resolution

Challenge

- Difficulty in handling 8kV
- No experience to use in a water Cherenkov detector

Design of the FPGA-based TDC for the g-2 experiment in FNAL

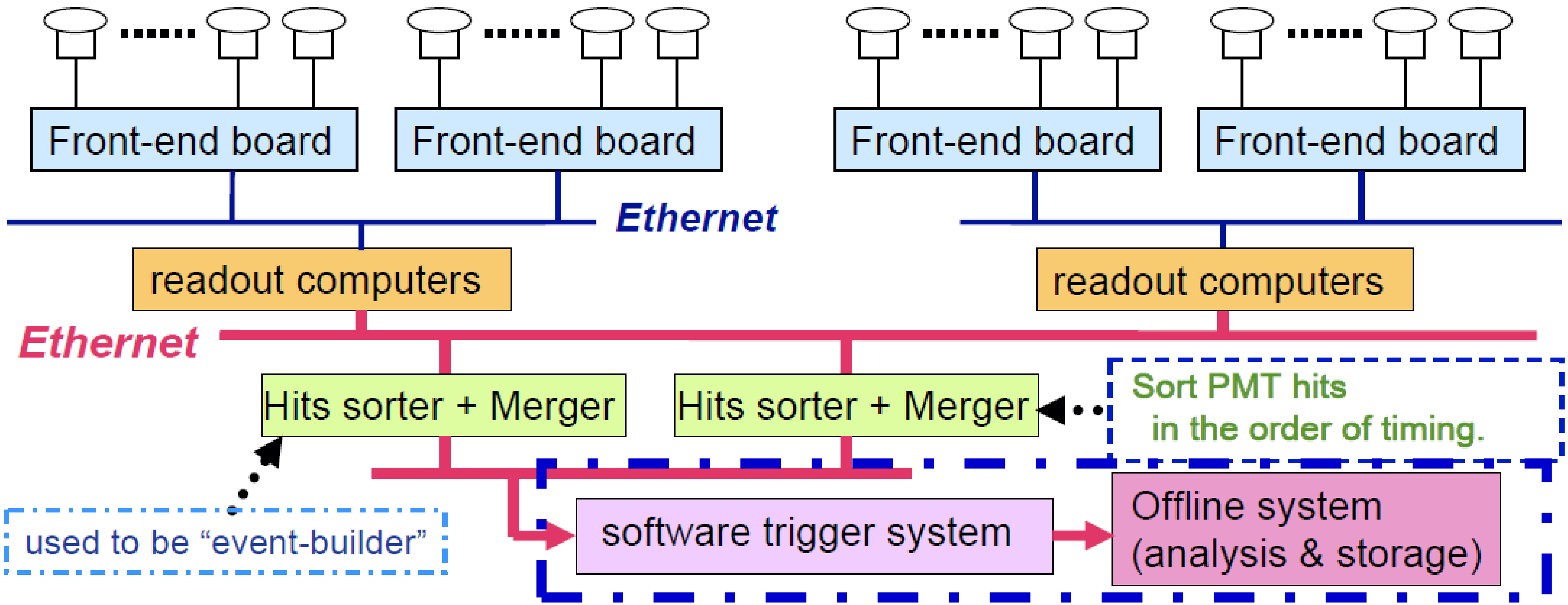
Block Diagram



- A 16-channel TDC fits in EP3C5F256C6 with ~50% silicon resource usage.
- Input clock at 10 MHz is multiplied to 200 MHz and two phases of 400 MHz for internal operation.
- Both positive and negative input transitions are digitized with precision LSB 625 ps. (=1/(4*400 MHz))
- Each channel is equipped with a 32-bit scalar which keeps hit count across long period of time.
- For each 10 ms spill, up to 2016 TDC hit data, scalar data, internal register data and an ID header are packed into 2048 32-bit words and are output using 8B10B protocol at 25 Mb/s.
- Bursts of up to 4 very rapid hits can be captured. Rapid multiple hits can also be eliminated in the hit conditioning block based on users' setting.
- Only two LVDS pairs, Clock & Command In and Data Out are needed from readout controller to serve the FPGA.
- Calibration hits generation and DC voltage monitoring features are provided.

Data rate after the software trigger

~ real-time data processing ~



Assumption 10 compartments (N = 10)

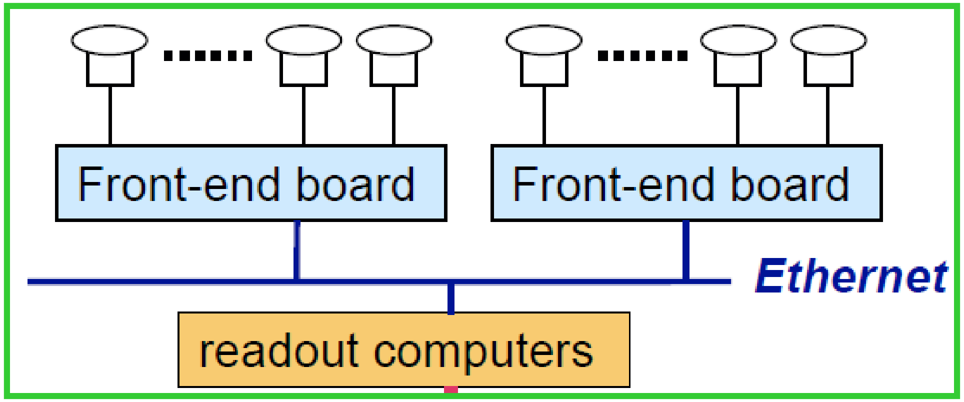
10 kHz dark, 10 k sensors / compartment

μ rate = **25 Hz** (muon rate * area ~ 12 times larger)

~ 8 MB/sec/compartment after software trigger.

~ 45 % from SLE & 35% from μ

Possible front-end electronics module connections

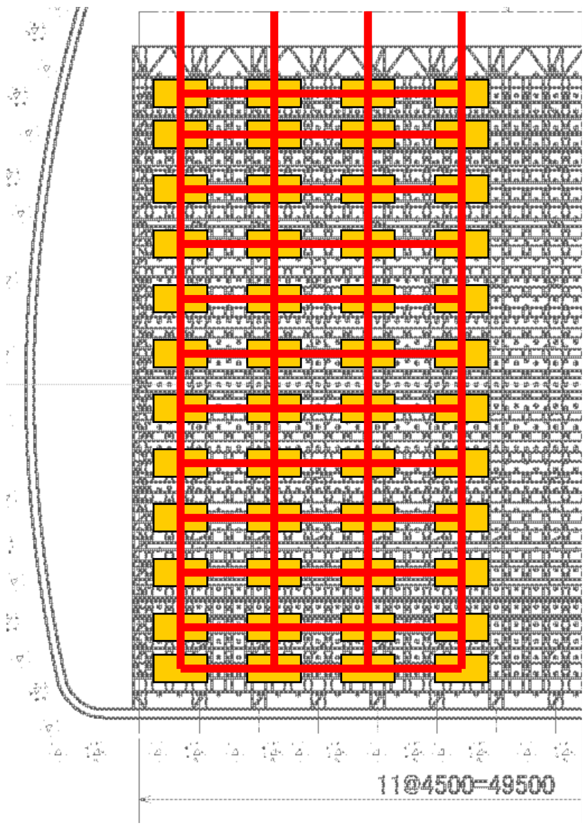


~ Design of the data flow

1) Assuming 1Gb Ethernet

- Reliability
- Power consumption

HK detector Side view



2) Connect neighboring boards

- Reduce # of the cables to the top
- Reduce total amount of cables
- Eliminate single point failure

Usually, data collected by a module are transferred to the upper module (vertically)

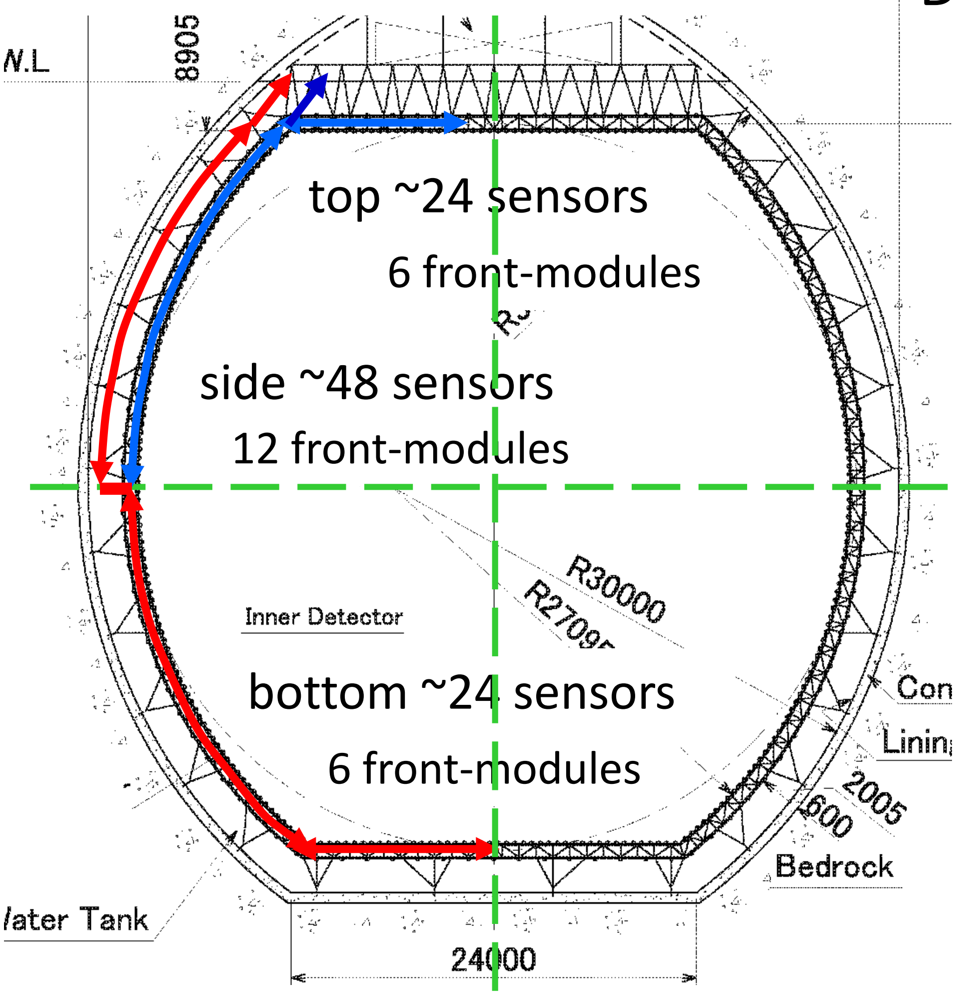
If a module failed, transfer data to the other module instead of the failed module (horizontally).

Need to design the total amount of data < 1Gb/s

Possible front-end electronics module connections

Amount of data from a module ~ 200 x [dark rate] Bytes/sec
(assuming 24 ch / board)

Possible configuration
for 10 kHz dark rate



Dark rate

1) 5kHz

Data rate ~ 1 MB/sec/board
Connect 18 boards / cable
1 cable from each side

~ 120 cables from the tank

2) 10kHz

Data rate ~ 2 MB/sec/board
Connect 9 boards / cable
2 cables from each side

~ 240 cables from the tank

of channels per 1 front-end board

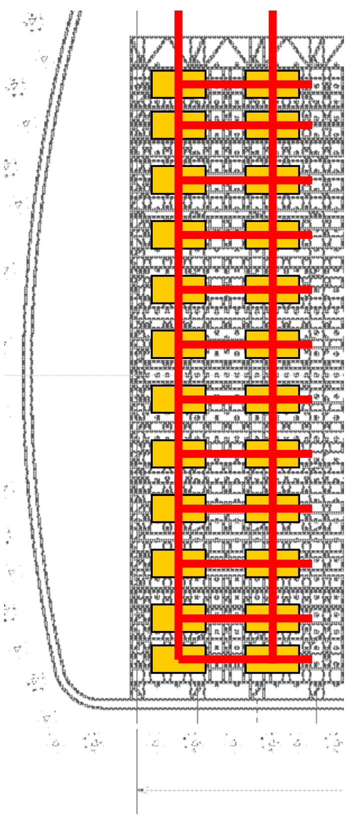
of channels per board

High density module will be cost effective.

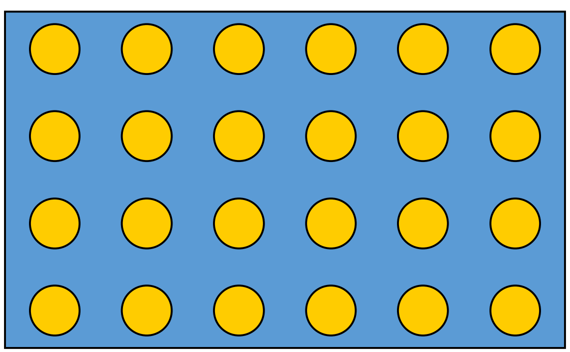
Limitations
- Data size per module will be increased
- Larger "dead region" in case of failure

→ One idea to minimize the effect

HK detector
Side view

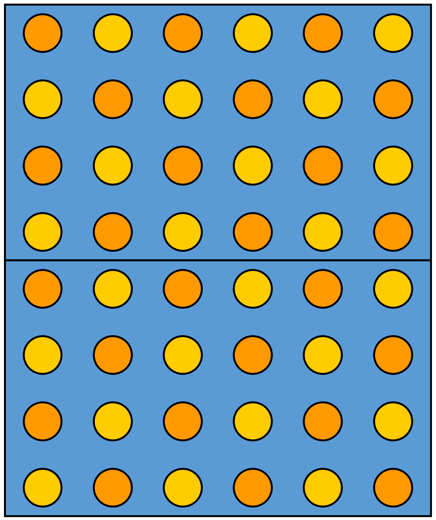


Simple configuration
(like SK)



All sensors in a block
are connected to
one font-end board

Possible alternative



Connect neighboring sensors
to different front-end boards

Hyper-K Working Group Organization

Steering Committee
Nakaya (chair)
Aihara, Nakahata, Shiozawa, Yokoyama
+ a few more

- oversee the HK group
- channel for contacting to the group
- involve non-Japanese in future

International board of representative (IBR)
a few members from each country

- represent each countries
- budget request in each countries

Project Leader
Shiozawa

- PL oversees the sub-WGs
- WG conveners may be composed of one Japanese plus some non-Japanese.

WG1
Shiozawa

WG2
Sekiya, Vagins

WG3
Nakayama, Nishimura

WG4
Hayato

WG5
Miura
Walter
F.D.Lodovico

WG6
Hide Tanaka, Hiro Tanaka, Koshio, Mine, Mccauley

WG7
Hartz

Physics WG conveners
Yokoyama

Phys-WG1
Yokoyama

Phys-WG2
Wendell

Phys-WG3
Takeuchi

WG1: Cavity and Tank
WG2: Water
WG3: Photo-sensor
WG4: DAQ
WG5: Software
WG6: Calibration
WG7: Beam & Near Detectors

Phys-WG1: Accelerator
Phys-WG2: Atmν+Nucleon decays
Phys-WG3: Astroparticle Physics (SN, solarν, etc)