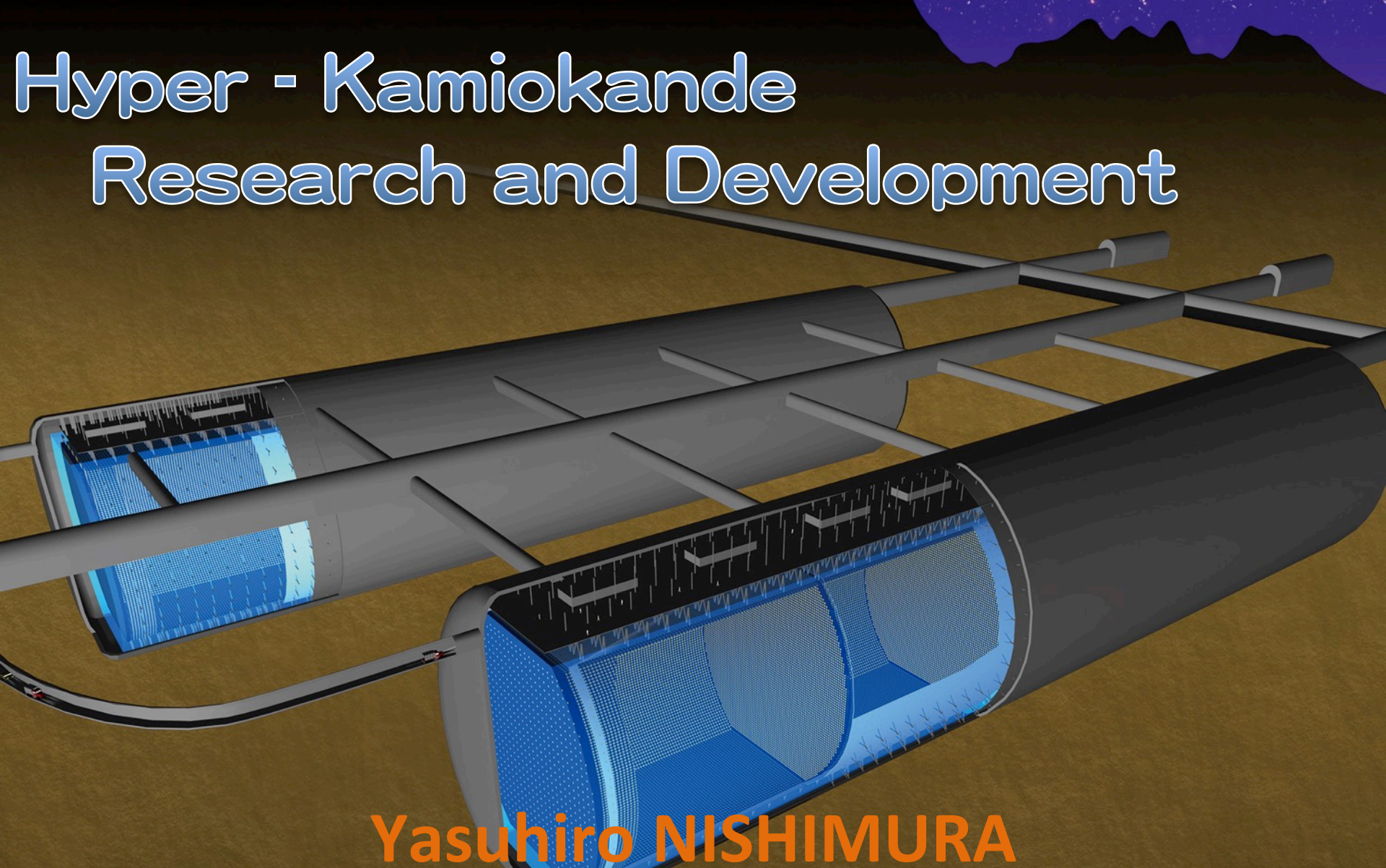
Hyper - Kamiokande Research and Development



Yasuhiro NISHIMURA

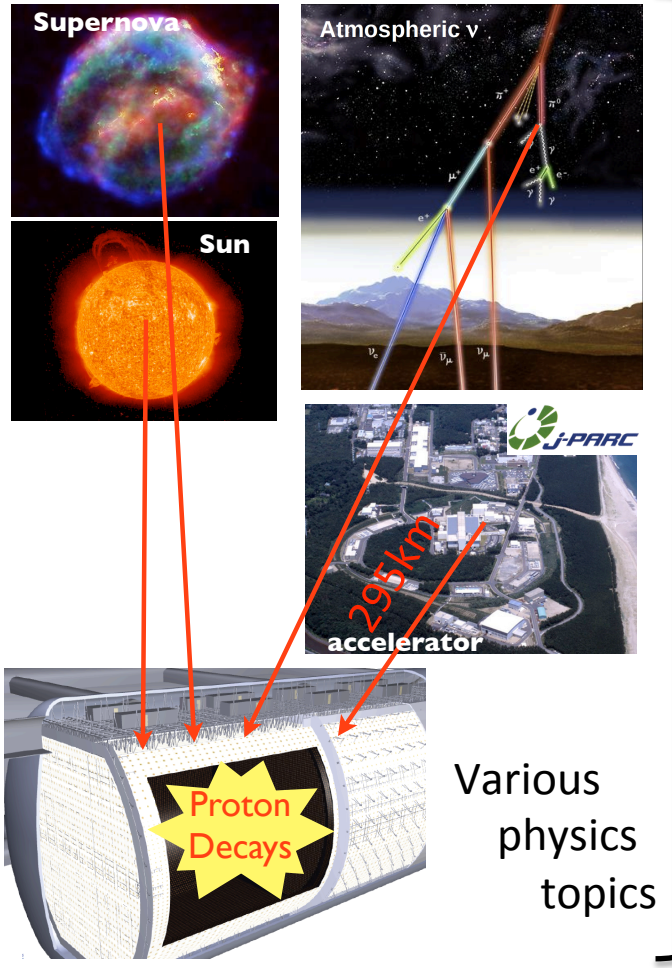
ICRR RCCN, The University of Tokyo

International Workshop for the Next Generation Nucleon Decay and Neutrino Detector (NNN15)

28/Oct/2015

Physics of Hyper-Kamiokande

- Neutrino oscillation
  - Atmospheric, solar, accelerator ν
  - ν mixing parameters
    - Leptonic CP, etc.
- Nucleon decay
- Astronomy
  - Supernova, sun, etc.
- Neutrino geophysics
- Dark matter (WIMP, …)



Details of Hyper-K physics and overall will be presented later in

29 Oct (Thu)16:45 "Hyper-K Strategy for Controlling Systematic Uncertainties" (Sam SHORT, QMUL)

30 Oct (Fri) 16:30 "Hyper-Kamiokande" (Hidekazu TANAKA, ICRR Univ-Tokyo).

Hyper-Kamiokande Project

Super-Kamiokande (since 1995)

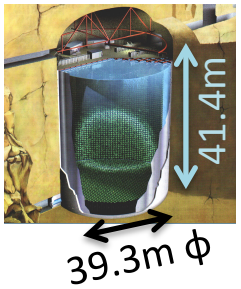
0.0225 (0.05) Mton
Fiducial (Total)

x 25(20)

Hyper-Kamiokande Large water Cherenkov detector

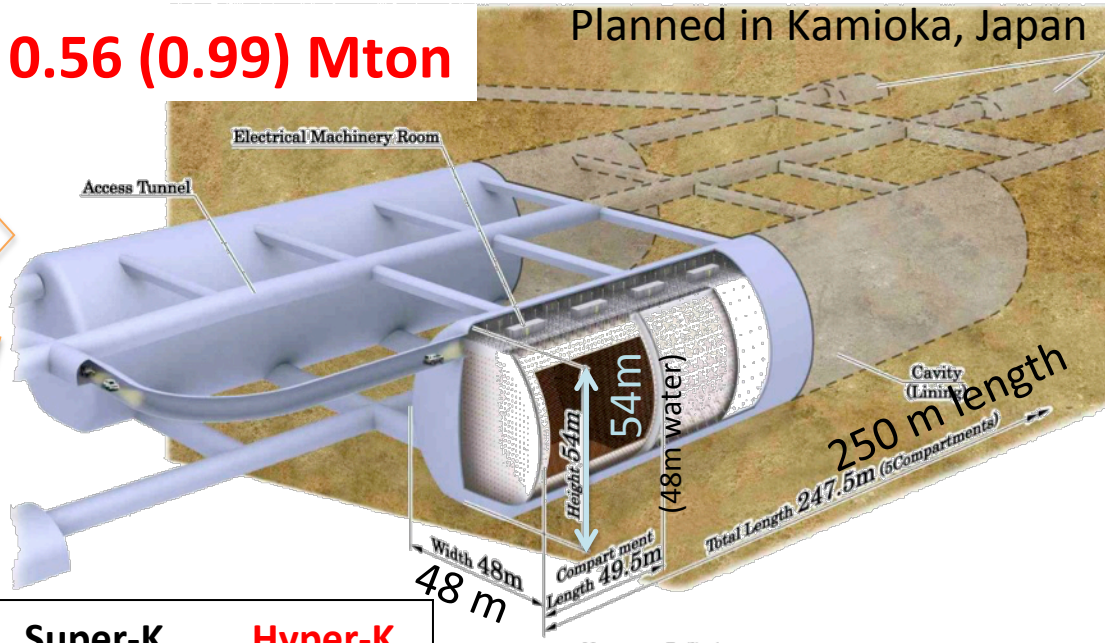
0.56 (0.99) Mton

Planned in Kamioka, Japan



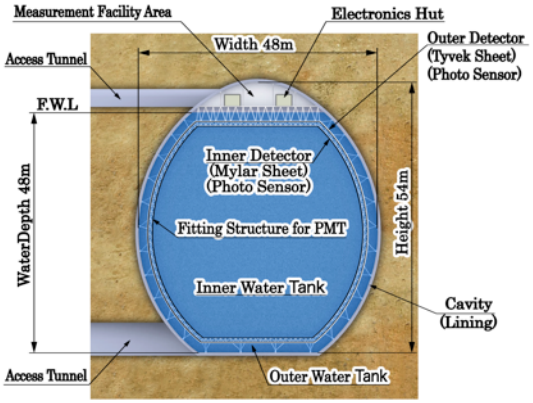
Based on established technologies

+ Improvement with new technologies



Photosensors

Photo-sensor	Super-K	Hyper-K
Inner detector (for ν detection)	11,129 (50cmΦ)	**99,000 (50cmΦ)**
Outer detector (for cosmic-ray veto)	1,885 (20cmΦ)	**25,000 (20cmΦ)**
Photo-coverage	40%	20%
Sensor efficiency (Quantum × Collection Eff.)	18% (22%×80%)	**29% (30%×95%)**



Expected in new photo-sensor R&D

R&D topics in Hyper-Kamiokande

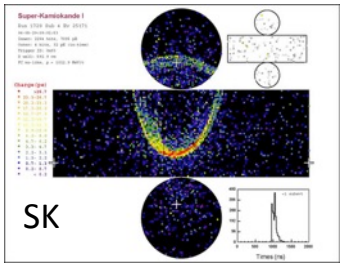
Construction : Super-K 1993 – 1996 ~25 yrs Hyper-K 2018 – 2023 (?)

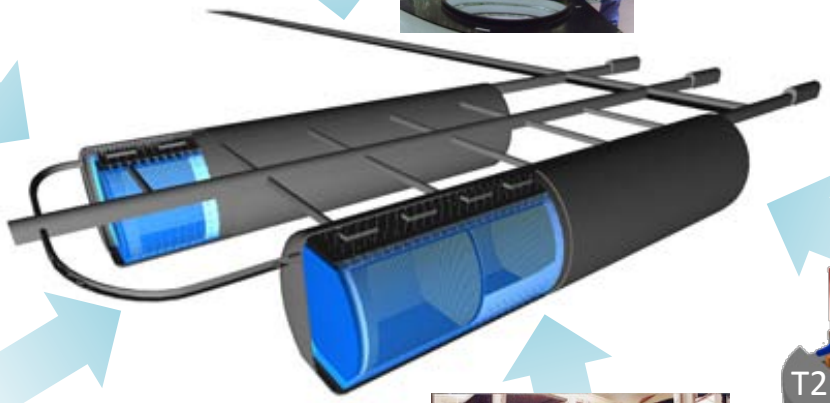
- Studying Hyper-K design based on well-established Super-K by 8 Detector R&D working groups to construct Hyper-K.

1. Cavity & Tank

3. Photo-sensor

5. Software

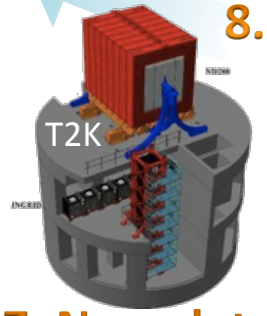




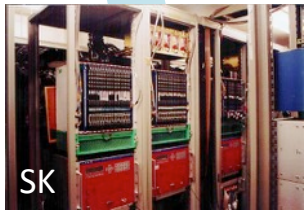
2. Water

6. Calibration

8. Beam&Accelerator



4. Electronics & DAQ



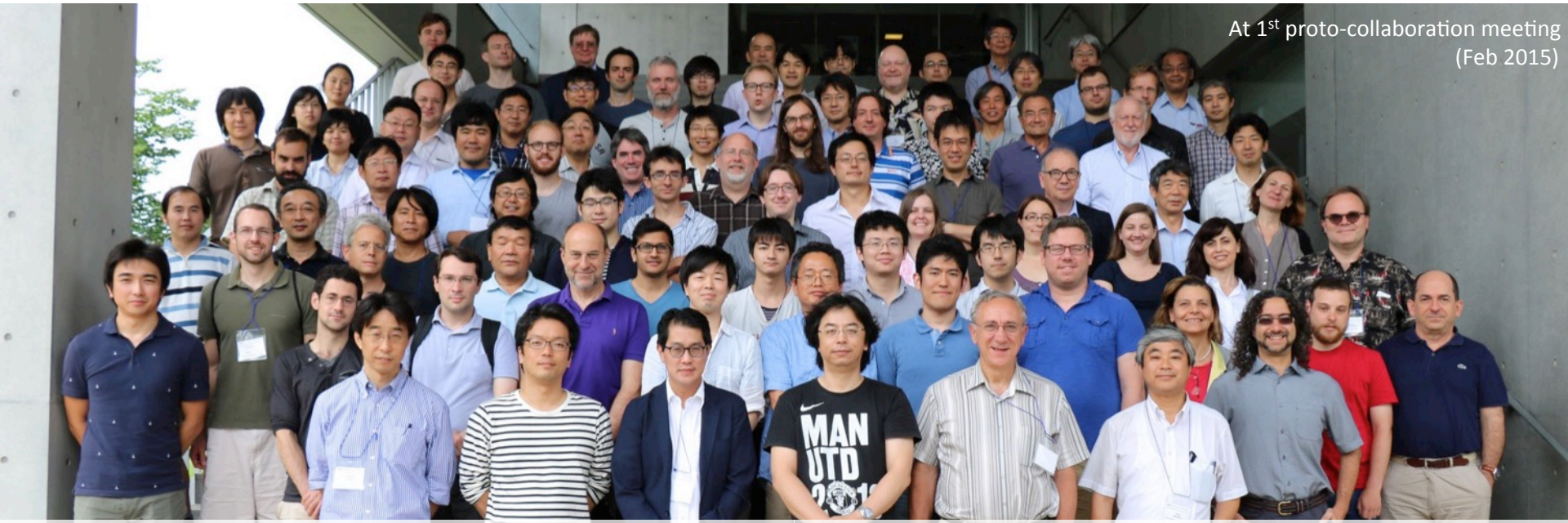
7. Near detector

and physics working groups

Various R&D groups are actively working for further improvement.

Hyper-Kamiokande Proto-Collaboration

International working group was formed since 2012, and proto-collaboration since 2015.

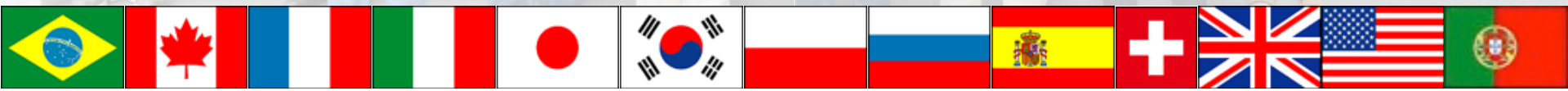


At 1st proto-collaboration meeting (Feb 2015)

Hyper-Kamiokande open meeting series
(1st) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=7
(2nd) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=10
(3rd) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=23
(4th) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=29
(5th) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=34
(6th) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=52

Hyper-Kamiokande Proto-Colaboration meeting (closed)
(1st) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=67

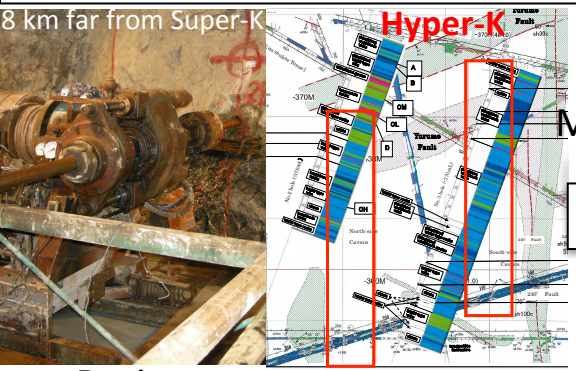
Next meeting on 1/Jan-2/Feb 2016 at Kashiwa IPMU, Japan.
(Registration is not yet opened, will open only for proto-collaborator)
(2nd) http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=79



23 countries, 261 people (Oct.2015)

Cavern and Optimization

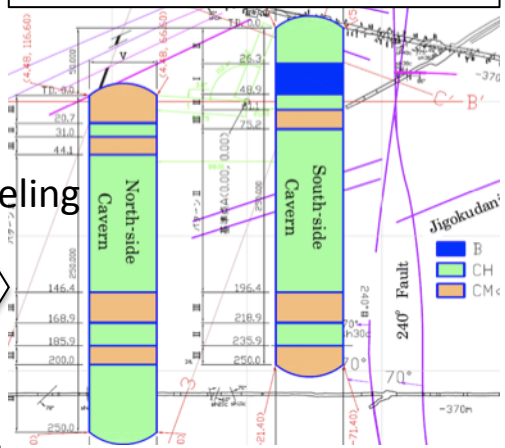
Geological survey
at Tochibora candidate site



Boring rock mass/initial stress obtained

Modeling

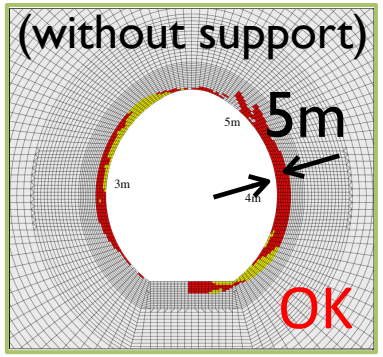
Rock classification

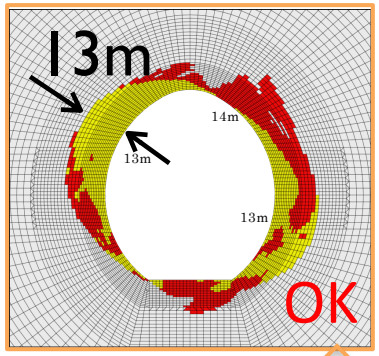


☺ B-class (4.5% volume)

☺ CH-class (71.3% volume)

😐 CM-class (24.2% volume)





Plasticity region depth by stability analysis

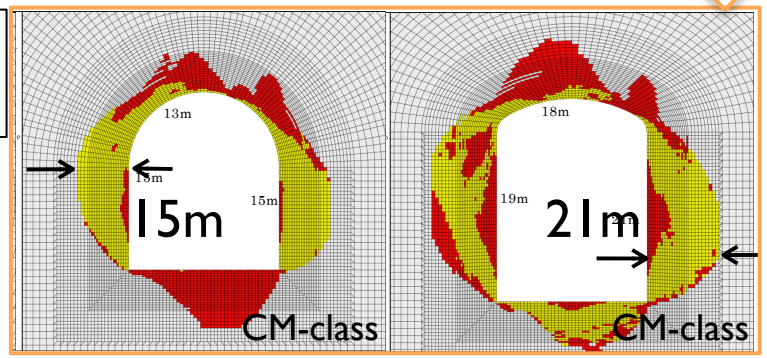
Egg-shape caverns can be constructed in all region by the existing technologies (pre-stressed anchors, etc.).

For further cost reduction, tuning of cavern and tank is ongoing by

- Possibility of SK-like tank
- Thin Outer Detector layer
- Photocoverage tuning
- Photosensor options with better performance

Wall optimization
in 250m long caverns

Egg-shape is more stable than straight walls.



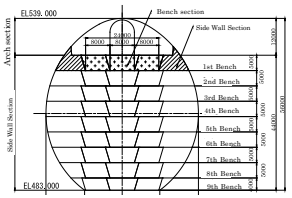
➔ *Find the best tank design soon with optimized.*

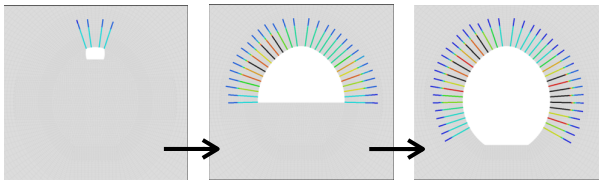
Base Idea of Tank Construction

(Case study of long egg-shape tanks)

Excavation step

Stability analysis
by each excavation step

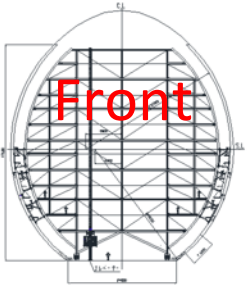


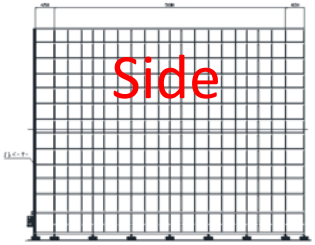


←Pre-Stressed anchor,
as well as shotcrete,
rock-bolt, ..

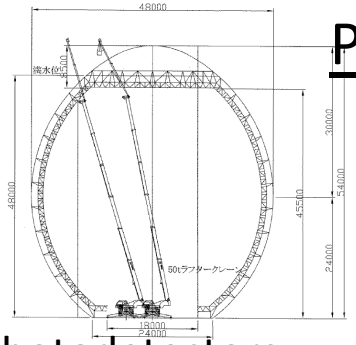
Support frame construction

Movable scaffold between compartments





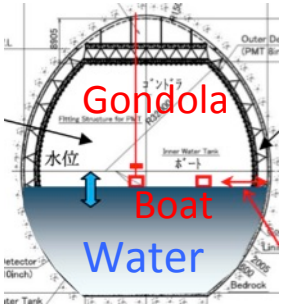
Construction of
support frame
by crane



To install photodetectors
by each segmentation.

By 5 segmentations / 1 tank

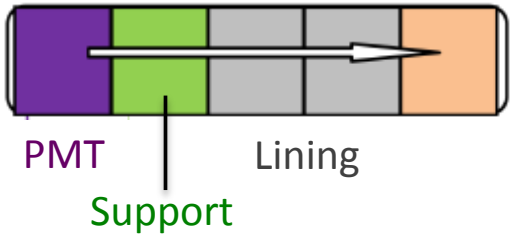
Photodetector maintenance



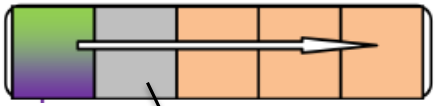
By floating boat,
with changing
water level.

Ordering of installation

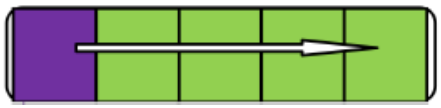
Fast and safe scenario



For 23 months in this case



Difficult



Slow
by 1 tank

Construction procedure
is also considered
to estimate cost and period
to optimize the tank design.
(Long egg-shape tanks have
difficulty in construction
compared with SK-like tank.)

50cmΦ Photosenor Candidates

By Hamamatsu Photonics K.K.

- 2 types of new 50 cm Φ photodetectors are developed.

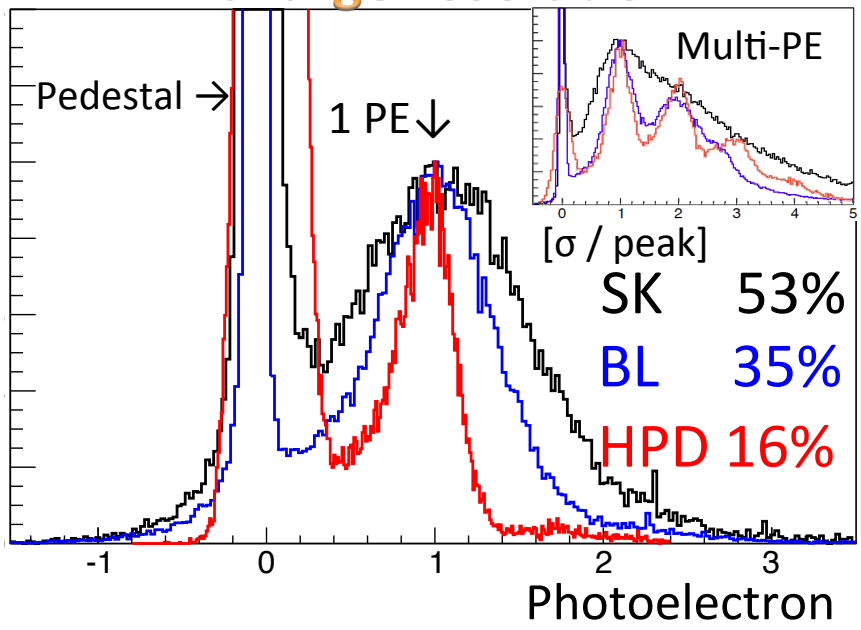
Model	R3600 (Established)	R12860	R12850 † still in R&D
Amplification	Venetian blind dynode	Box and line dynode	20mmΦ Avalanche diode
Q.E.	~22% (or ~30% in HQE)	~30%	~30%
C.E. Φ46 (Φ50)	67% (61%)	95% (85%)†	93% (76%) w/ 5ch AD†
T.T.S. (FWHM)	5.5 ns	2.7 ns	0.75ns (w/o Preamp.)
Bias voltage	2 kV bias	2 kV bias	8 kV bias + AD bias (<1kV)
Proof test	2 yrs for HQE (19yrs in SK)	1 yrs now from Sep.2014	> 0.5 yrs expected

C.E. = Collection efficiency of 1 photoelectron, T.T.S. = Transit Time Spread, by calculation

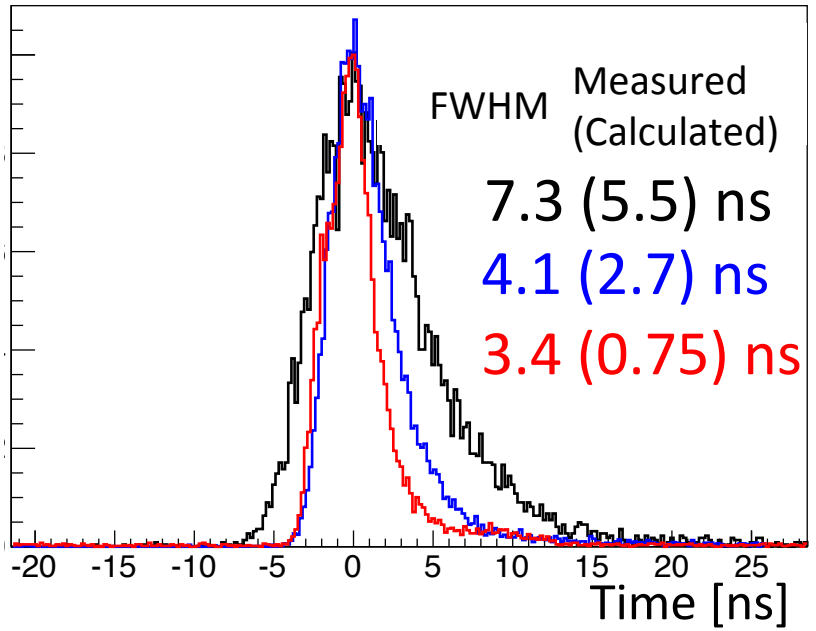
1 PE Detection in 50cmΦ Photodetector

Results shown in NNN14

Charge resolution



Time resolution



	Charge σ / peak	Time σ (left)	Time FWHM
Super-K PMT	**53%**	**2.1 ns**	**7.3 ns**
Box&Line PMT	**35%**	**1.1 ns**	**4.1 ns**
HPD (w/5mmΦ AD†)	**16%**	**1.4 ns**	**3.4 ns**
(20cmΦ HPD)	(12%)	(1.1 ns)	(3.3 ns)

More details will be reported by D.Fukuda in poster presentation.

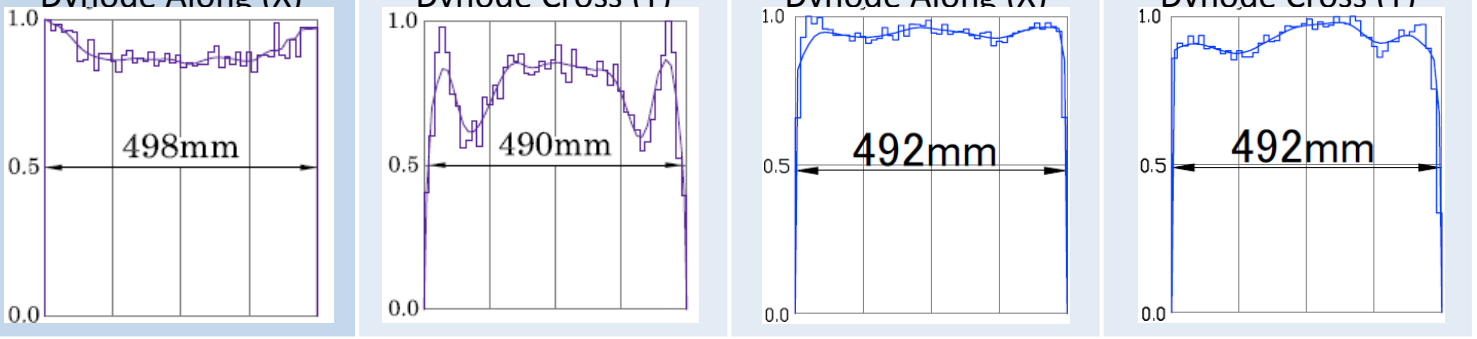
† 20mmΦ Avalanche Diode in final design with full efficiency

w/ preamplifier (intrinsic resolution is better, less than 1ns)

Single p.e. charge and time resolutions are better for both new photodetectors.

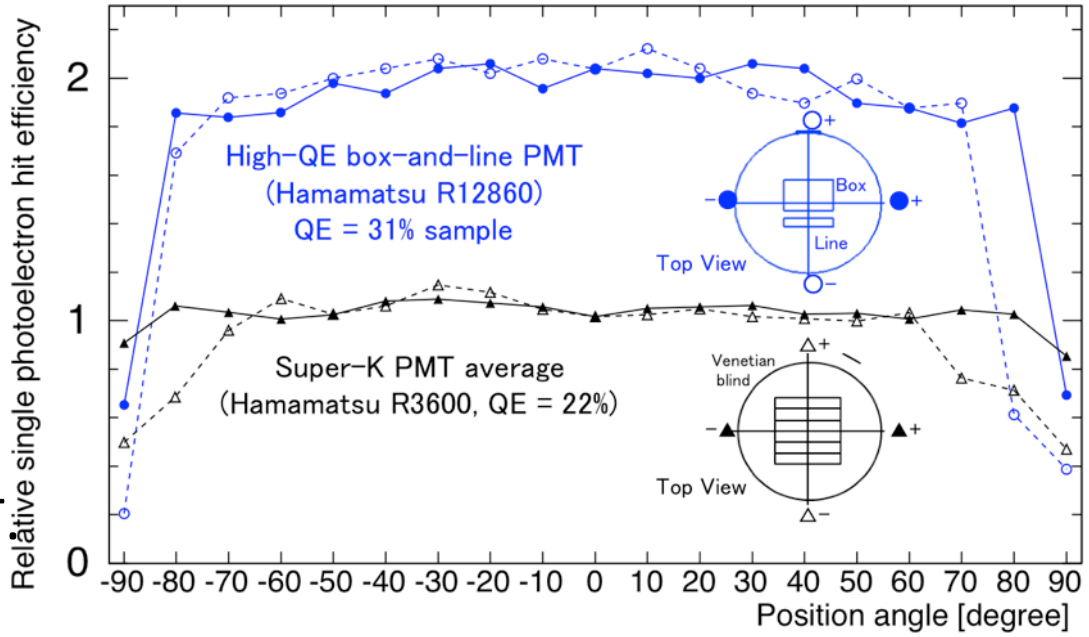
Detection Efficiency

Simulation (Hamamatsu)	R3600 SK PMT		HQE Box&Line PMT	
Gain × CE uniformity	Dynode Along (X)	Dynode Cross (Y)	Dynode Along (X)	Dynode Cross (Y)

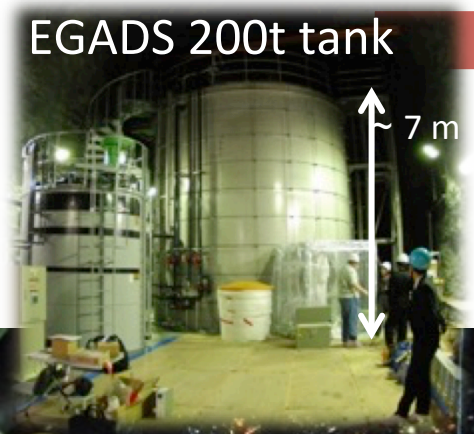


Total detection efficiency was measured at single photoelectron.

Detection efficiency is doubled in HQE Box&Line PMT compared with Super-K PMT



Test in Water Cherenkov Detector



2013 | 2014 | 2015 | 2016

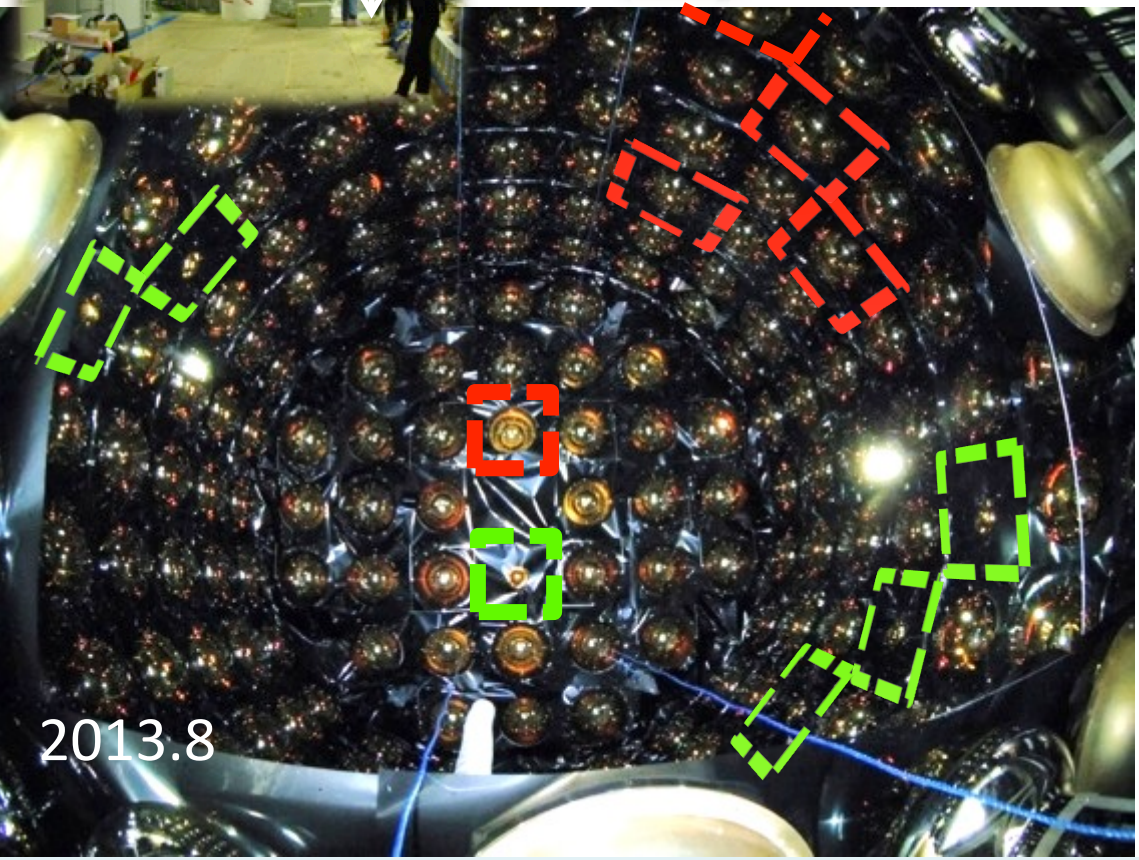
+ 5 HQE Super-K PMT

+ 8 HPD (20cmΦ)

+ 2 HPD (replaced)

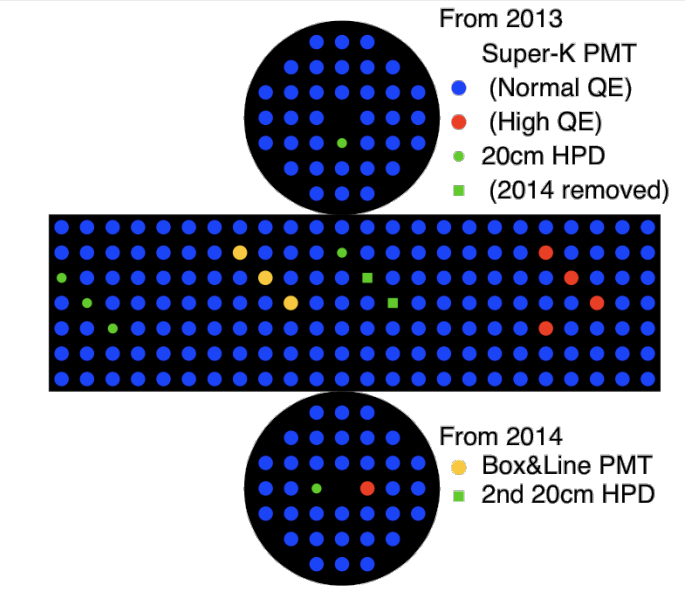
+ 3 HQE Box&Line PMT (50cm Φ)

(+ 50cm HQE HPD)



➔ Focused on newly installed High-QE Box&Line PMT

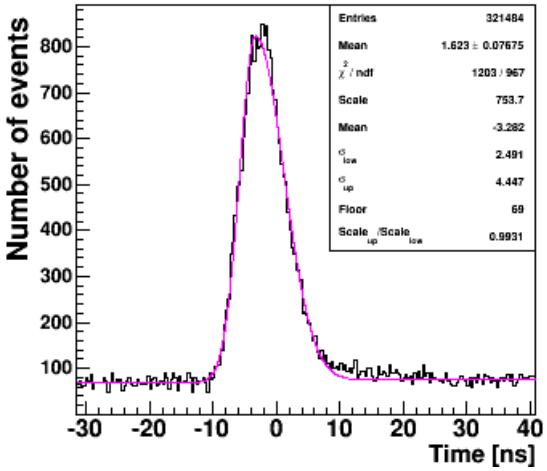
In total, 240 photodetectors



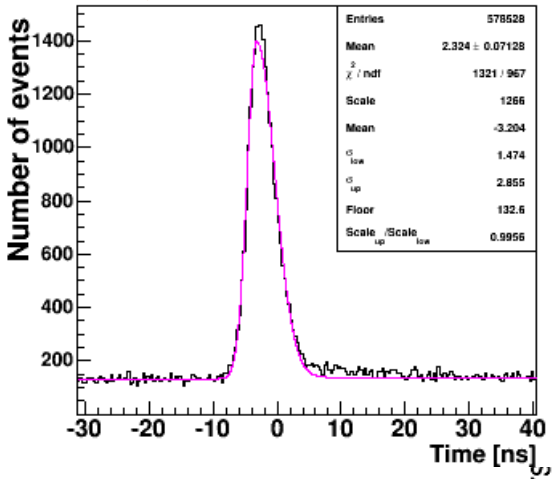
Single PE Time in Water

Transit Time Distribution

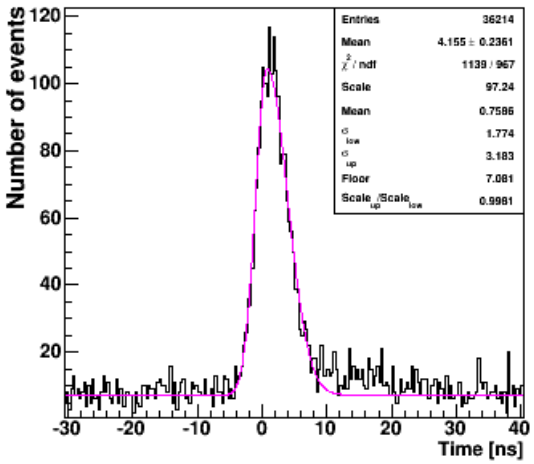
HQE SK PMT



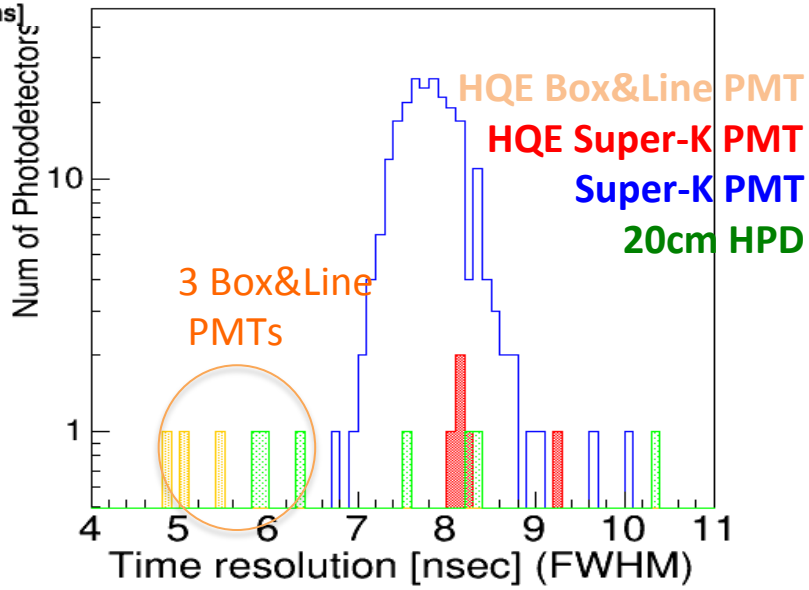
HQE Box&Line PMT



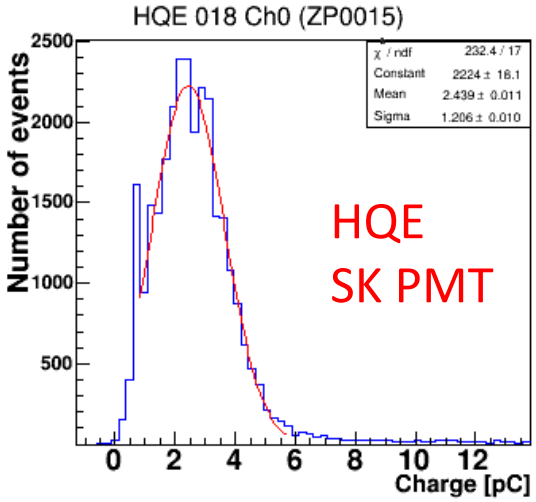
20cm HPD

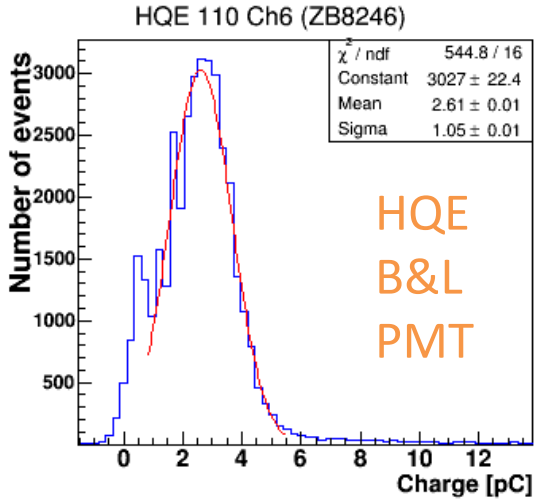


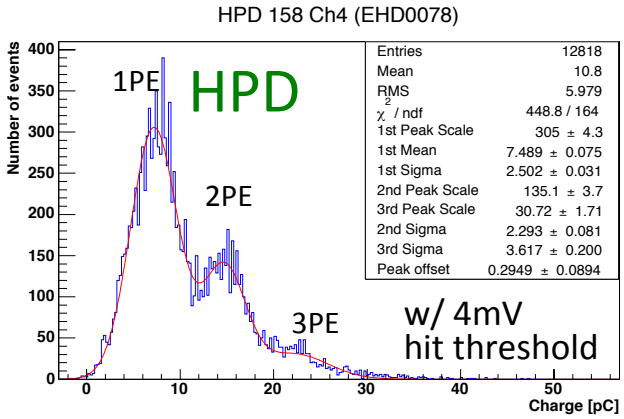
Time resolution at 1 p.e.



Single PE Charge in Water

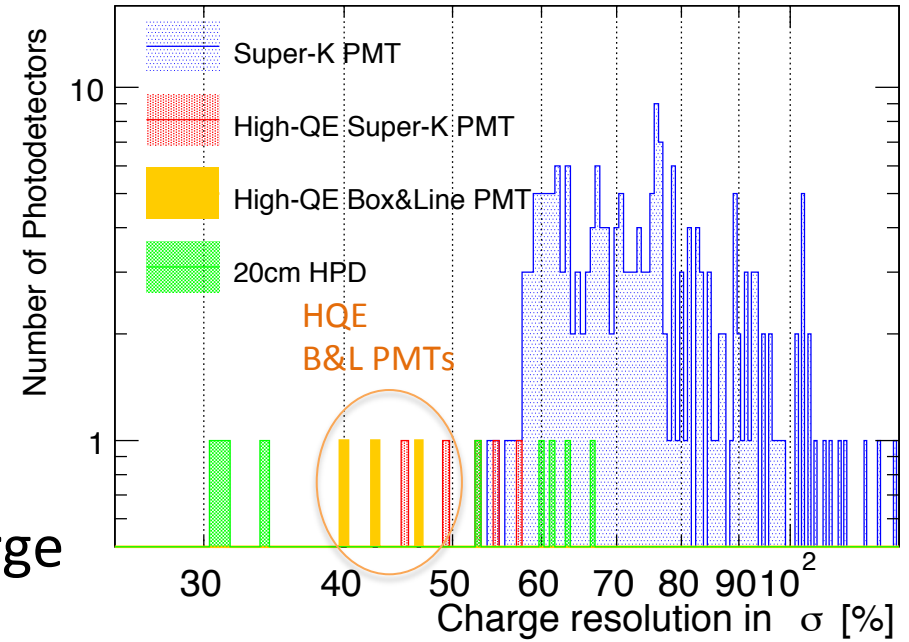






Charge resolution at 1 p.e.

(Low resolution of HPD/PMT is due to low gain set)



High-QE Box&Line PMTs clearly showed better time and charge resolutions in water.

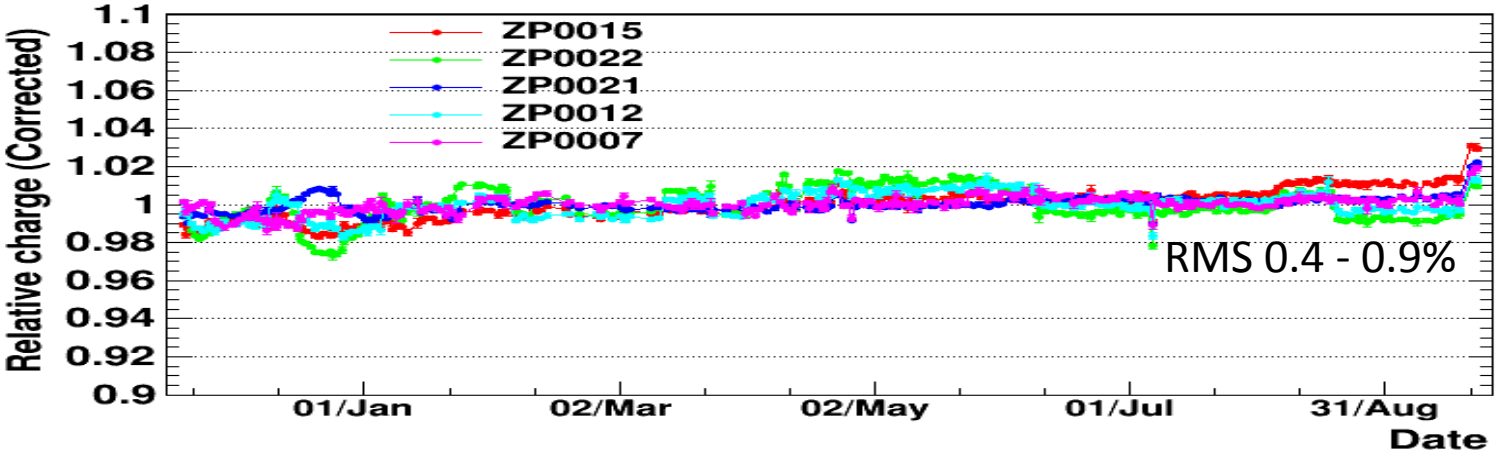
High-QE PMT Gain Stability

Monitoring 1 Hz pulse light from Xe light source around a few tens PEs.

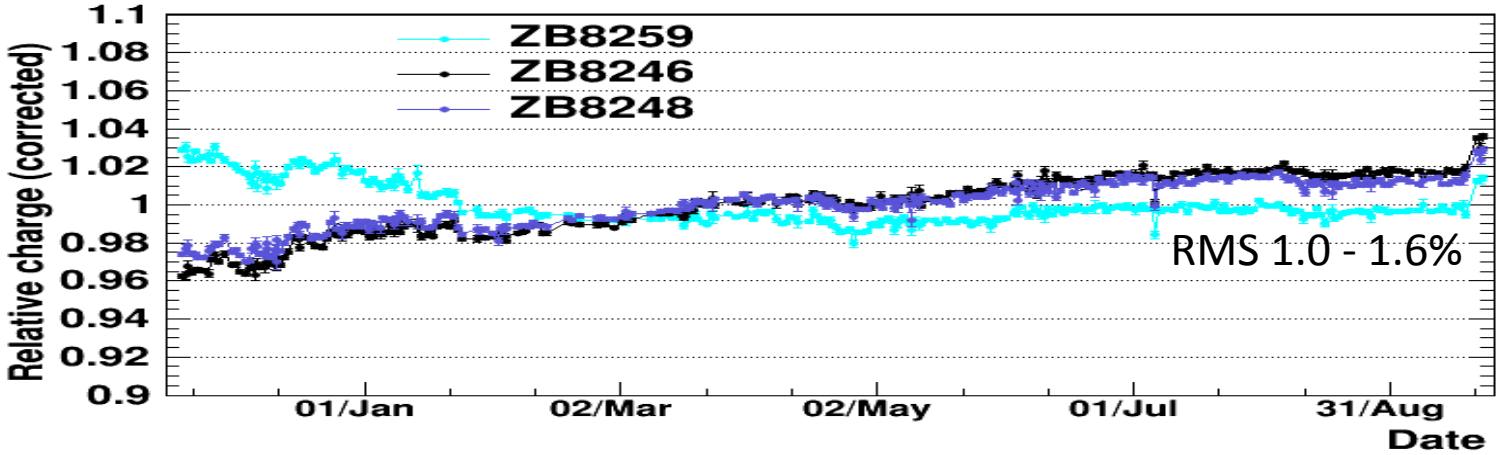
Relative peaks transition referring average of Super-K PMT peaks

For 10 months

Five High-QE Super-K PMTs



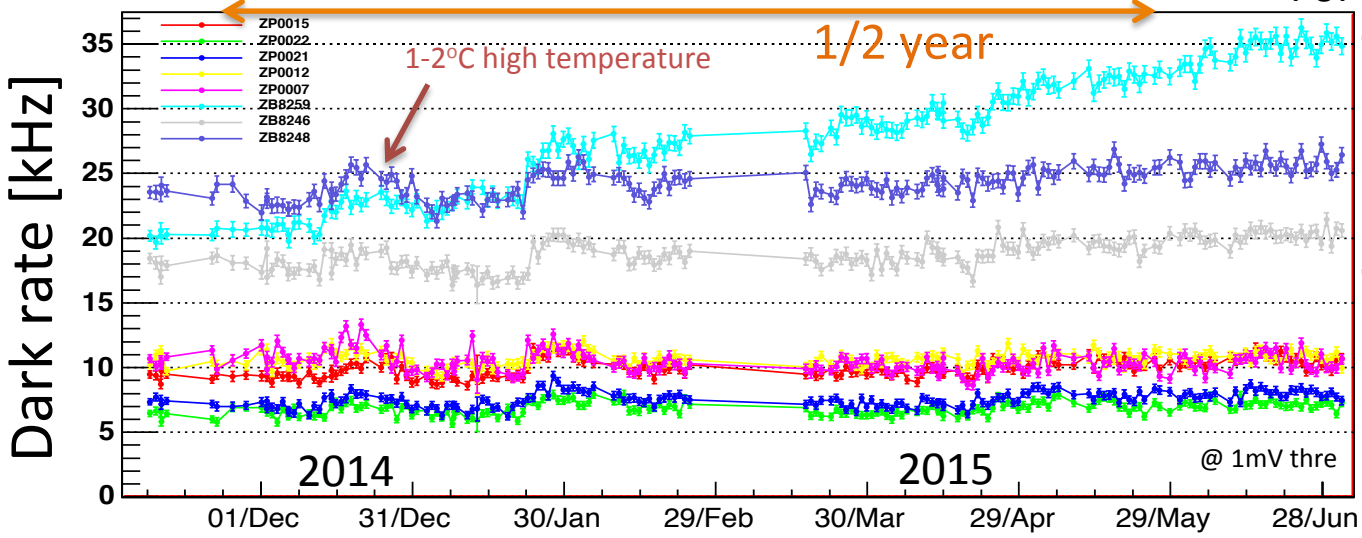
Three High-QE Box&Line PMTs



Similar gradual change was also seen in Super-K, but it's no problem by correcting it with the monitor.

High-QE PMT Dark Rate

Dark rate stability of High-QE PMTs in water tank



For recent 8 months

HQE Box&Line PMTs

1 PMT getting high rate.

NOTE : Recent version got half reduction similar to HQE Super-K PMT's

HQE Super-K PMT

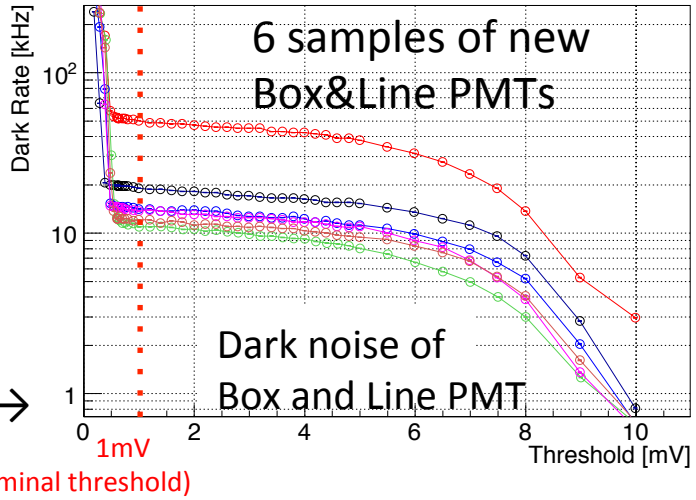
Almost stable ~8.4kHz

- Dark rate was reduced from those in water tank, as well as after pulses, in latest version of HQE Box&Line PMT.
  - Now comparable level with HQE SK PMT

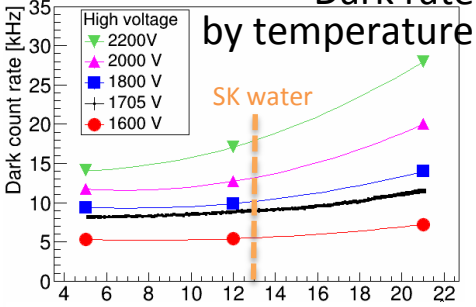
(See poster by D.Fukuda)

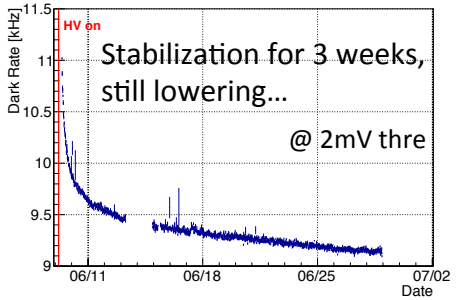
Measured in room (~25℃) → before stabilization

Dark rate as a function of thresholds



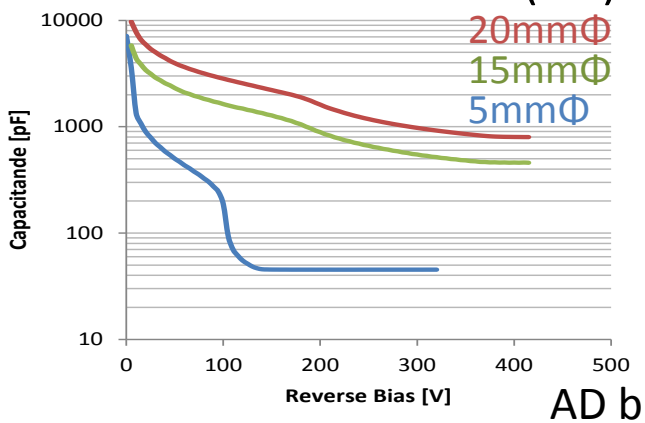
Dark rate by temperature



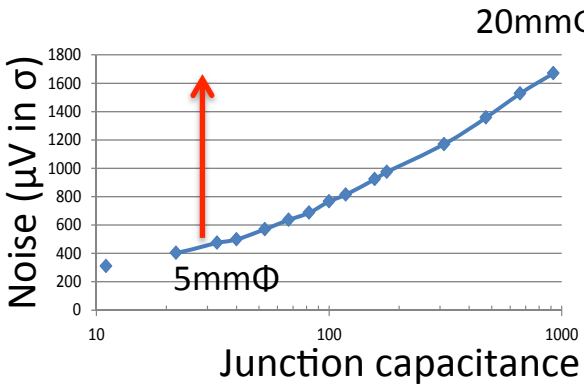


50cm HPD Electronics R&D

Junction capacitance of avalanche diode (AD)



Noise level by capacitance

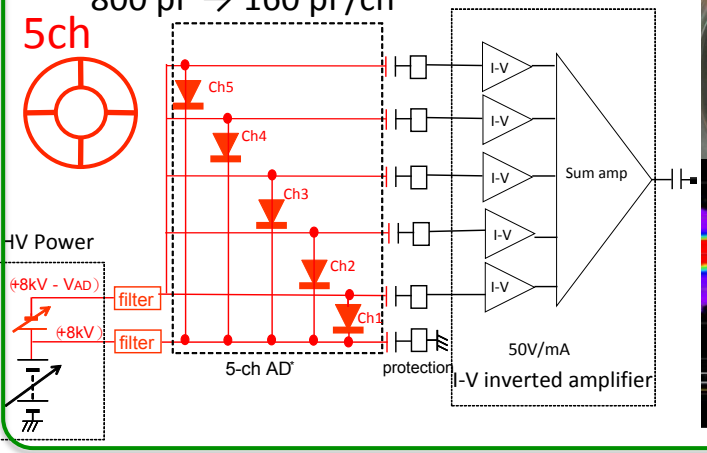


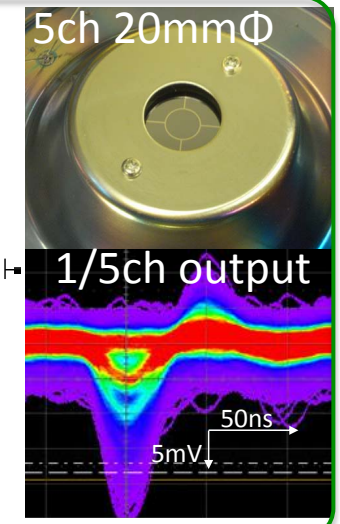
5mm Φ was used in 20 cm HPD and initial 50 cm HPD evaluation.
20mmΦ is required for 50cm HPD.
→ Amplifier design becomes difficult in 50cm HPD.

Two solutions were tried to suppress noise.

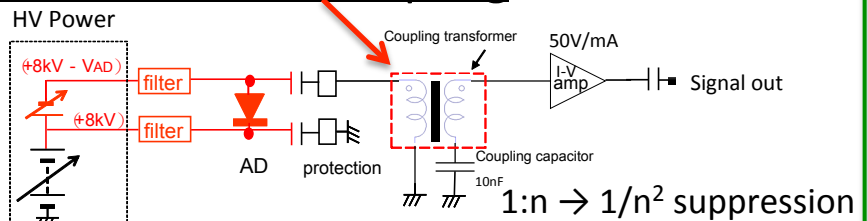
A. 5 segmented area

800 pF → 160 pF/ch

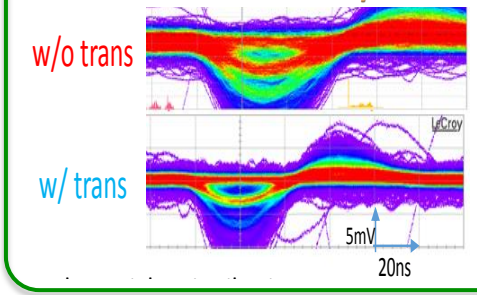




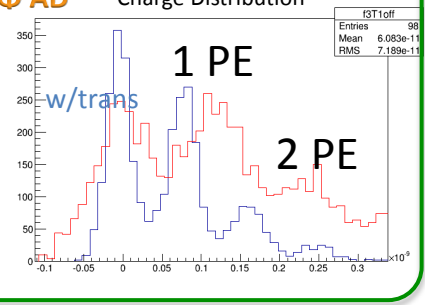
B. transformer coupling



Demonstration at 11kV w/ 15mmΦ AD



Charge Distribution

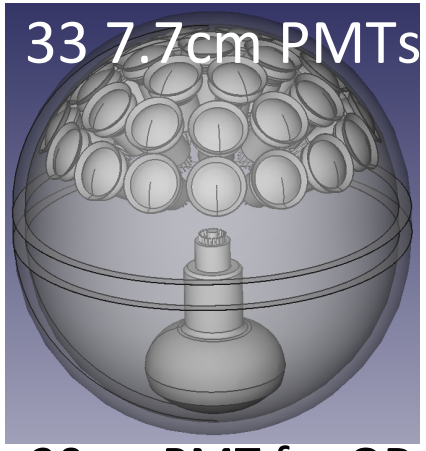


Waterproof HPD with finalizing design of preamplifier with combining two will be ready by the end of 2015.

Other Alternative PD Candidates

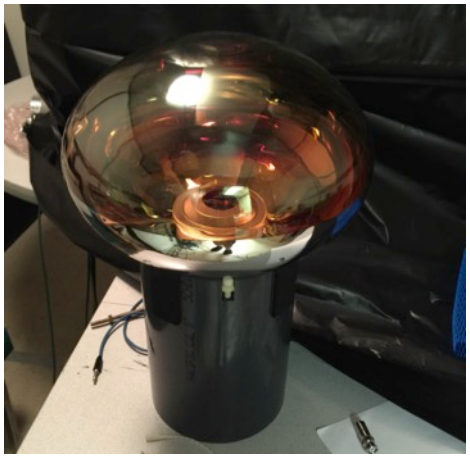
- Multi-channel optical module
  - Explore possibility of cost reduction, better high-pressure resistance, directional sensitivity, …
  - Implemented in simulation to study HK performance

Based on KM3NET optical module

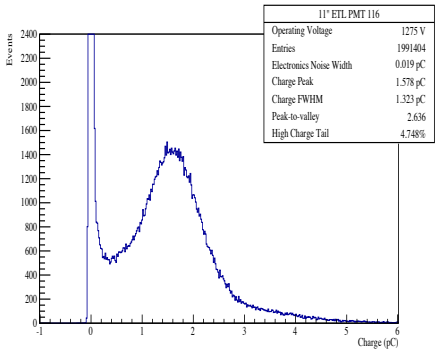


20cm PMT for OD

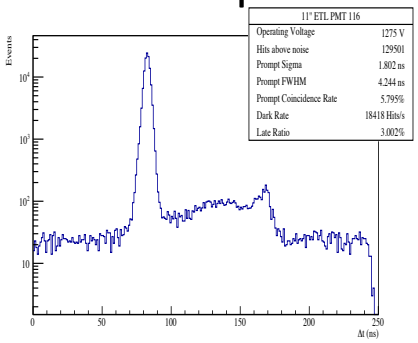
- New HQE 11” PMTs from ET Enterprises
  - Competition with Hamamatsu small PMTs (8-12 inches)



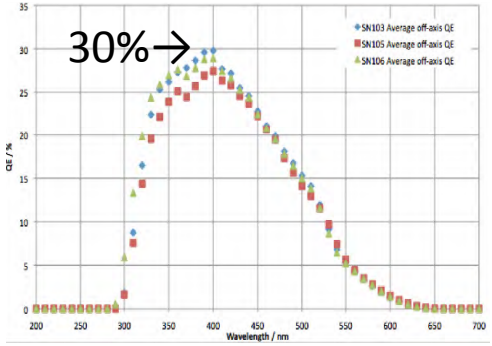
1PE charge



1PE time peak and late pulse

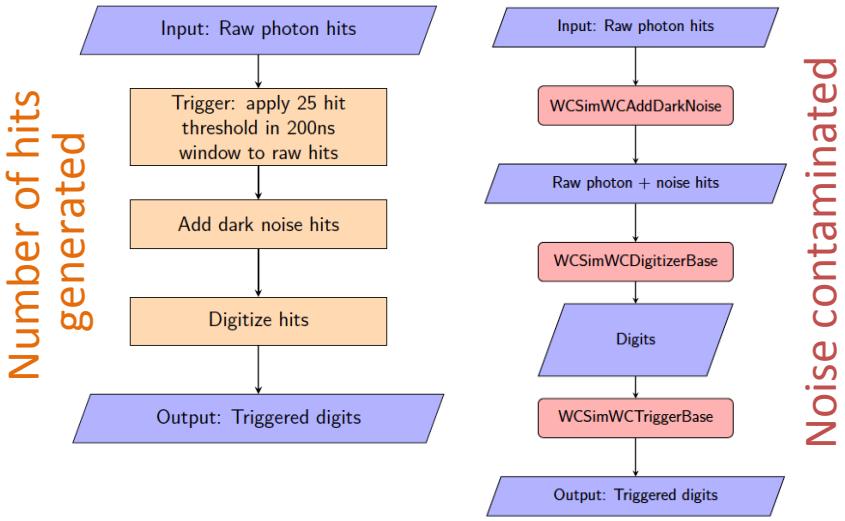


High-QE spectra



Simulation

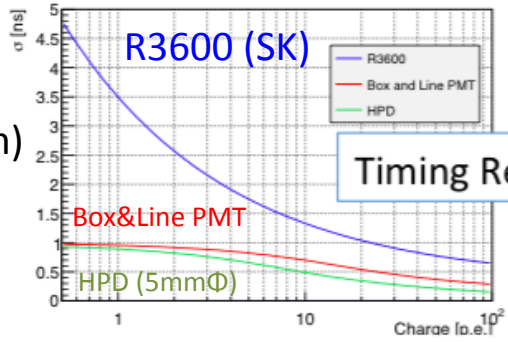
- Hyper-K with WCSim
  (The Water Cherenkov Simulator, GEANT4 base)
  - https://github.com/WCSim
  - Parameters imported from SK simulator (SKDetSim)
  - Trigger / Digitizer simulator is under study.

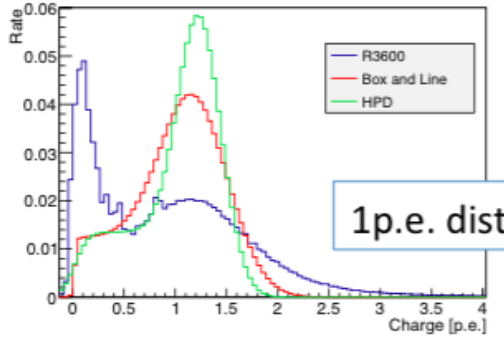


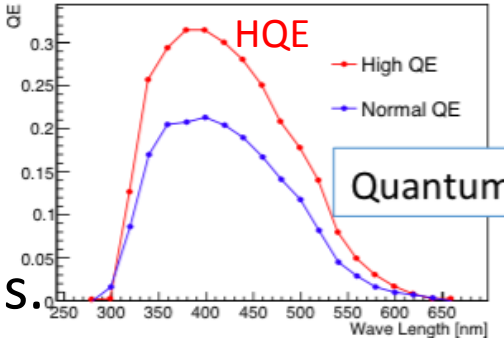
- Fitter
  - fiTQun tuned for HK geometries
  - Bonsai-fit for low energy

HK tank optimization is ongoing with the tools.

New photodetector performance implemented

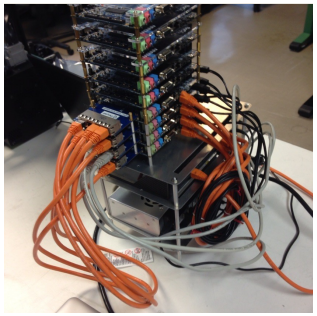


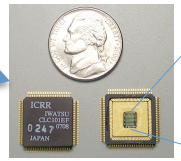


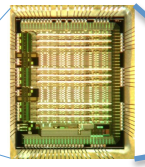


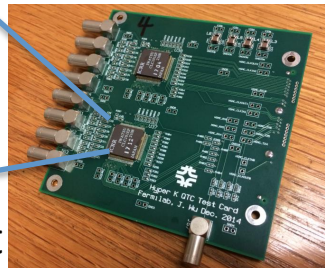
Electronics & DAQ

- Digitization
  - sub-ns FADC + shaper
    - optimization of shaper and digitizer with SPICE and MATLAB in simulation
    - hardware test with 4 different shaping time
  - QTC by Iwatsu and ICRR
    + FGPA based TDC by Fermilab
    + Ethernet readout (100M or 1G)/s
- Communication
  - SiTCP (Ethernet)
  - RapidIO
    - 4 RapidIO cores in FPGA on each board
    - each of 4 links at 550Mb/s



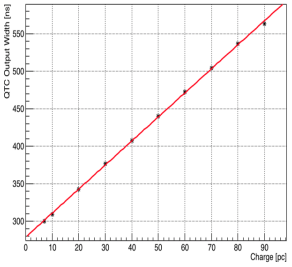




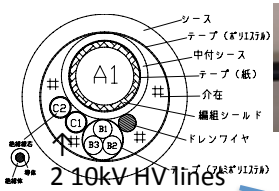


Prototype circuit for test

QTC I/O correlation



- Cable and connector in water
  - Between photodetectors and waterproof electronics
  - Connector mock-up for use in 100m water depth

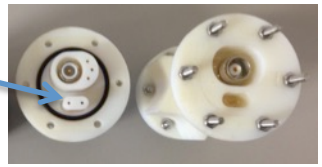


2 10kV HV lines

for HPD with 8kV lines

Testing to fix design supplied with 8-10 kV

Cable complex available (1 signal, 3 power, 2 HV)



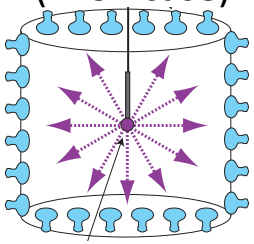
→ Soak test for 3 months was done

  - Material to be used in pure/Gd water was selected.

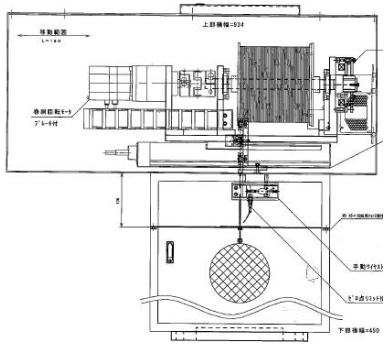
Calibration R&D

- First prototype of calibration sources deployment
  - Automated,
    for multiple sources,
    without opening tank
  - Prototype for test

(In SK case)

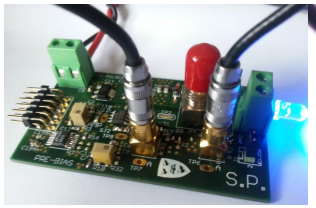


Various sources



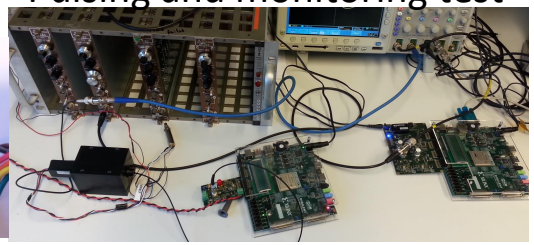
- Embedded optical calibration system
  - Fro multi-purpose
    optical and photo
    detector calibration
  - With many injection points
  - Test with LED, laser diode and pulser ongoing

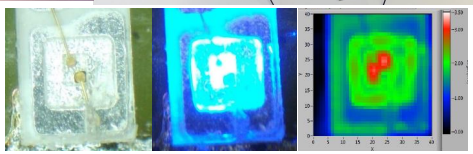
LED



Laser Diode

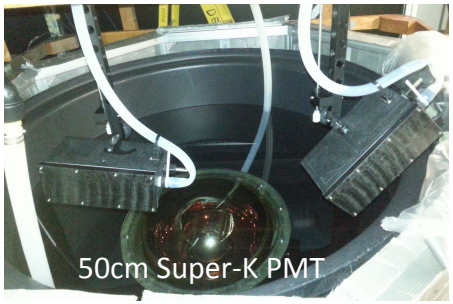
Pulsing and monitoring test

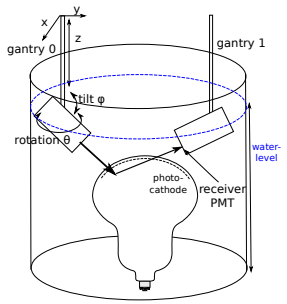




Measured
uniformity
of SMD LED

- Photosensor test facility at TRIUMF
  - Better understanding of response
  - For simulation, reconstruction, …





Near detector concepts at J-PARC site

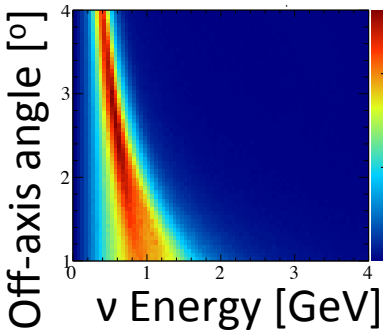
Water Cherenkov detector plans as near detector in ν long baseline experiment
in addition to existing T2K near detector complex

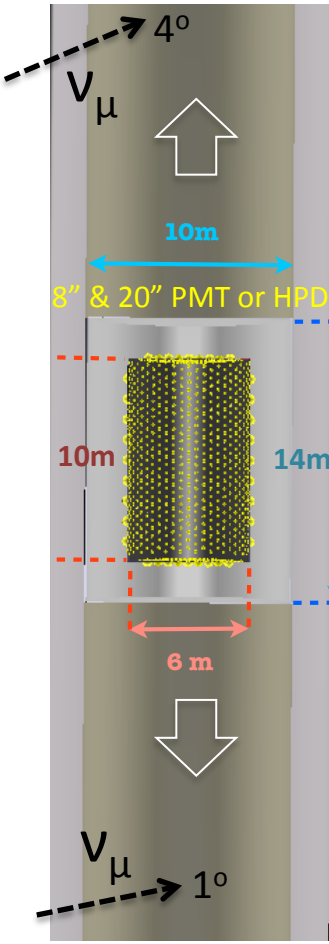
vPRISM

(Neutrino precision reaction independent spectrum measurement)

Multiple beam off-axis angles
with elevating water Cherenkov detector
for narrow energy band selection.

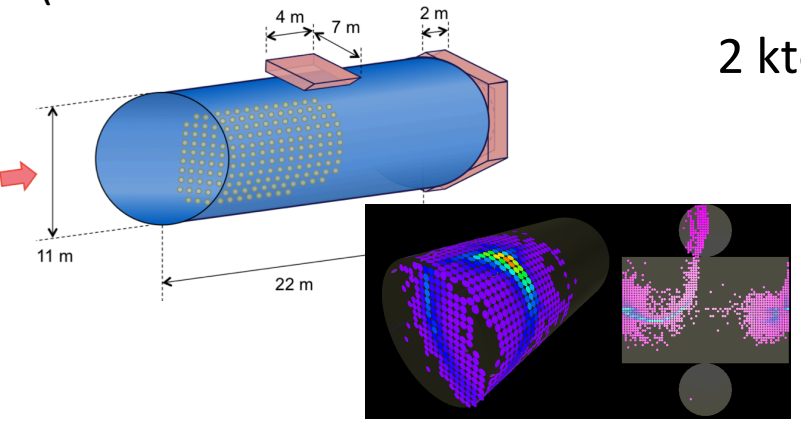
Details in nuPRISM talk tomorrow by Michael WILKING





TITUS

(Tokai Intermediate Tank for Unoscillated Spectrum)

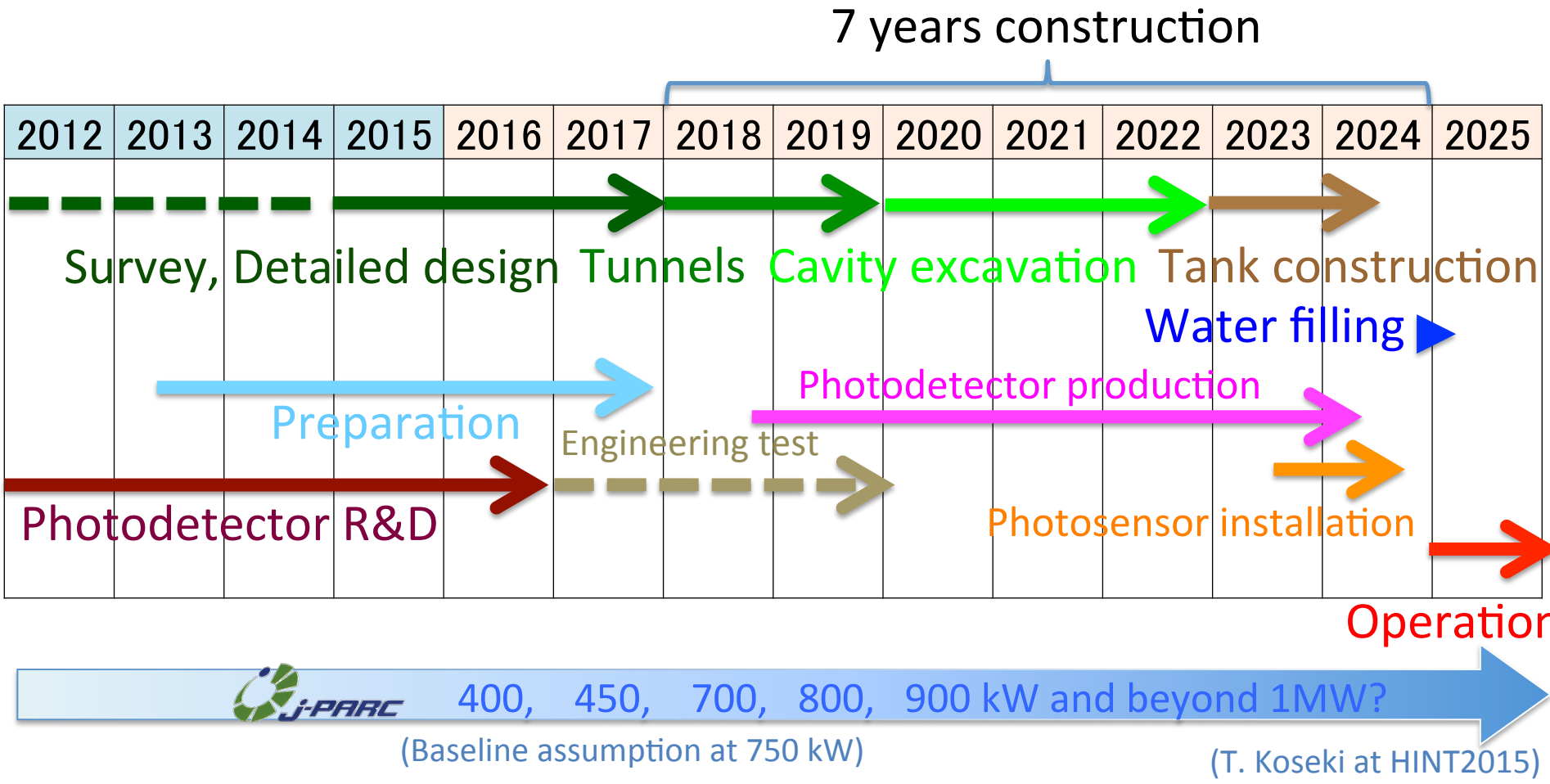


2 kton Gd-doped (for anti-ν separation)
water Cherenkov detector
+ muon range detector
using PMT/LAPPDs (or HPDs)
Same angular coverage as HK

- These Design, simulation and survey are going on.

Hyper-K Notional Timeline

(Assuming budget approval, not determined yet)



Summary

- Hyper-K working group is actively studying the design.
  - On many R&D items, with ~260 researchers
- Promising detector and physics results
  - Based on established technologies by Super-K
  - With much improvement such as photosensors
  - For next after ν oscillation discovery and supernova observation
- On 31/Jan – 2/Feb 2016,
  2nd Hyper-Kamiokande Proto-Collaboration Meeting