Hyper-K detector and calibration

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For
Hyper-Kamiokande Proto-collaboration

NNN16, Beijing, November 3, 2016

Outline

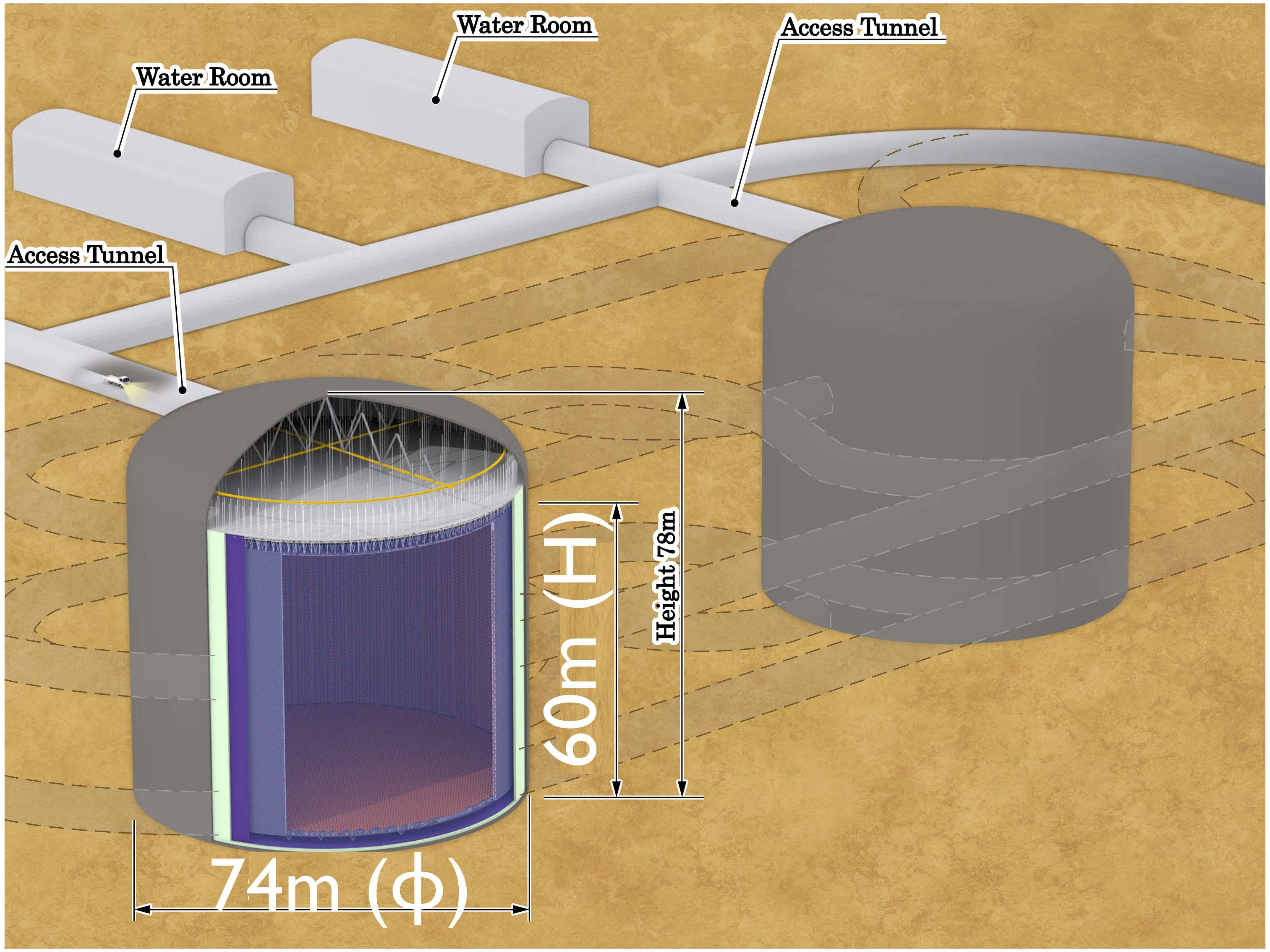
- Hyper-K detector design overview
- Hyper-K detector calibration
- Summary

Hyper-Kamiokande Design Report

https://lib-extopc.kek.jp/preprints/PDF/2016/1627/1627021.pdf

KEK Preprint 2016-21,
ICRR-Report-701-2016-1

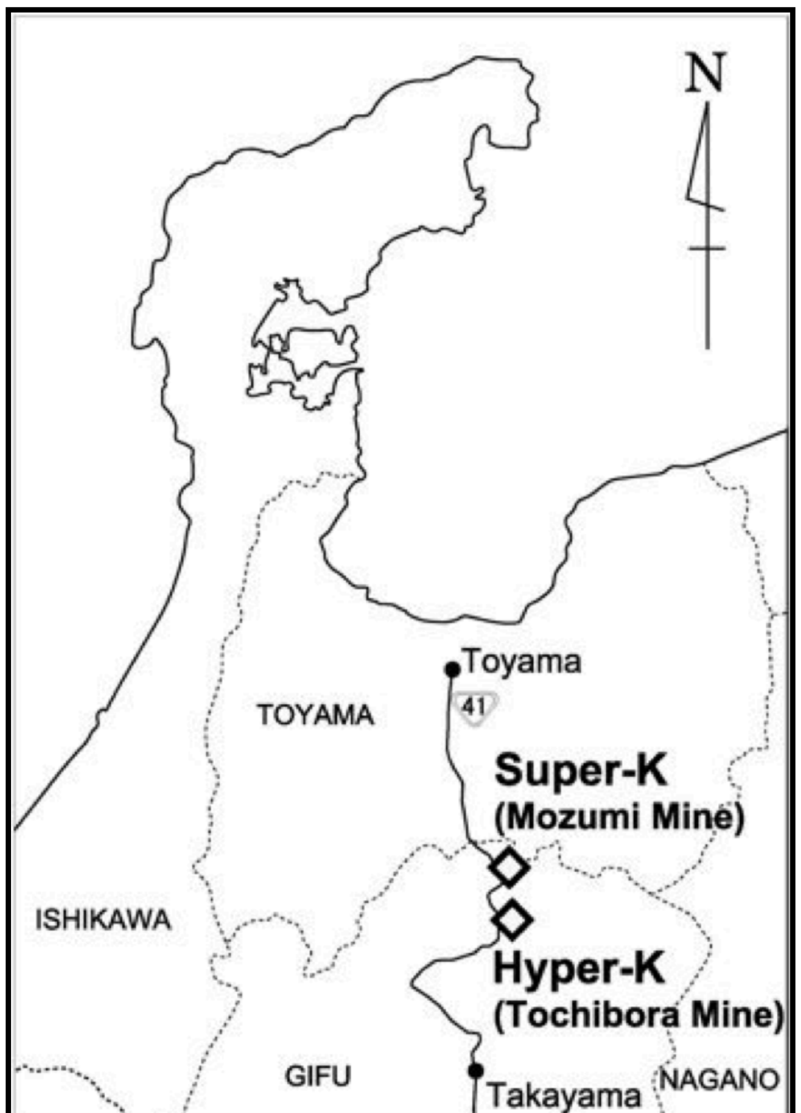
Hyper-K detector

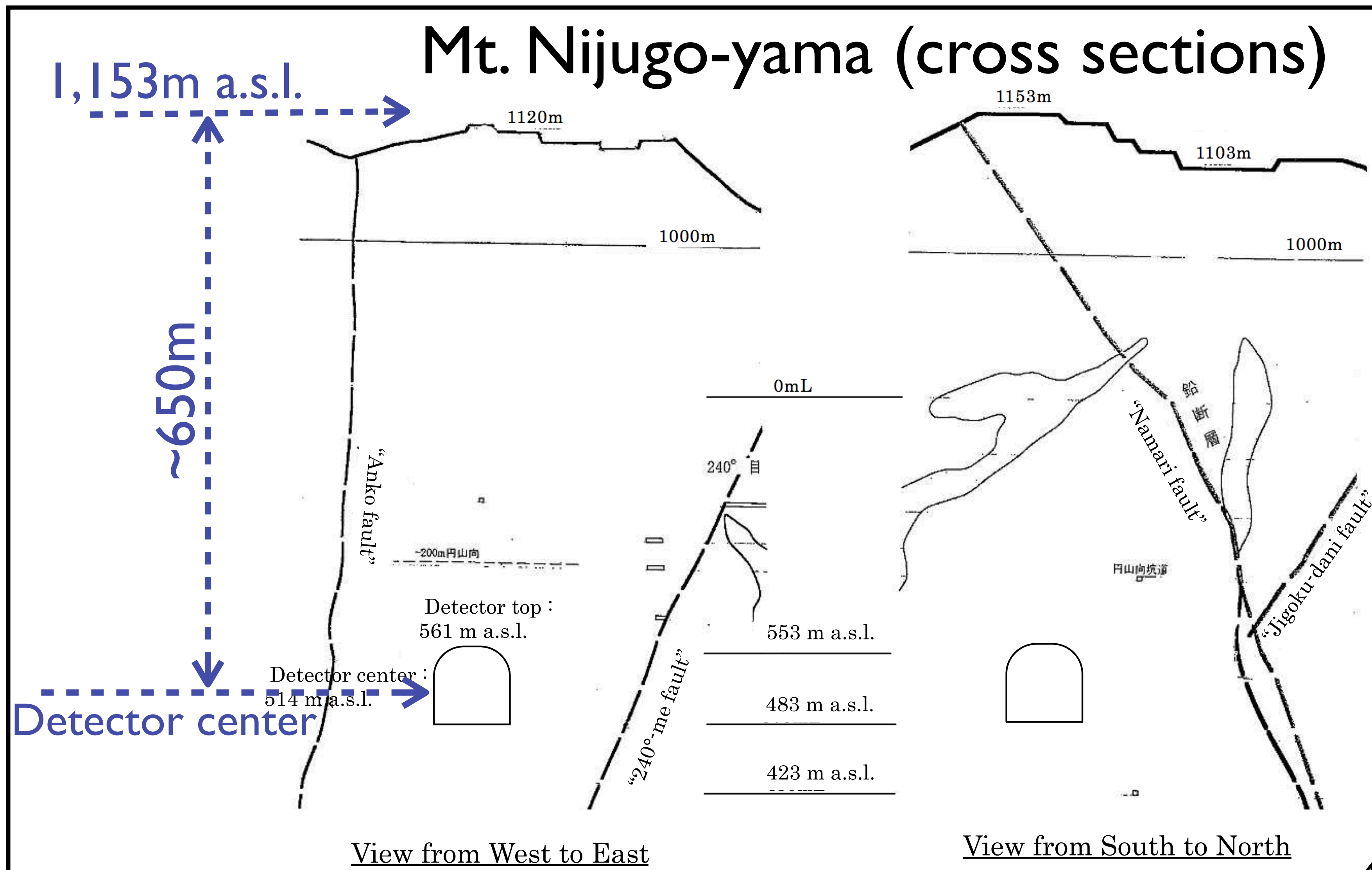


- Two cylindrical-shape detectors in stages
  - 74m diameter, 60m water-depth
- Fiducial volume: 0.37Mton
  - ~20 times larger FV than Super-K
- 40% photo-coverage (inner-detector: 80k PMTs)

Detector location

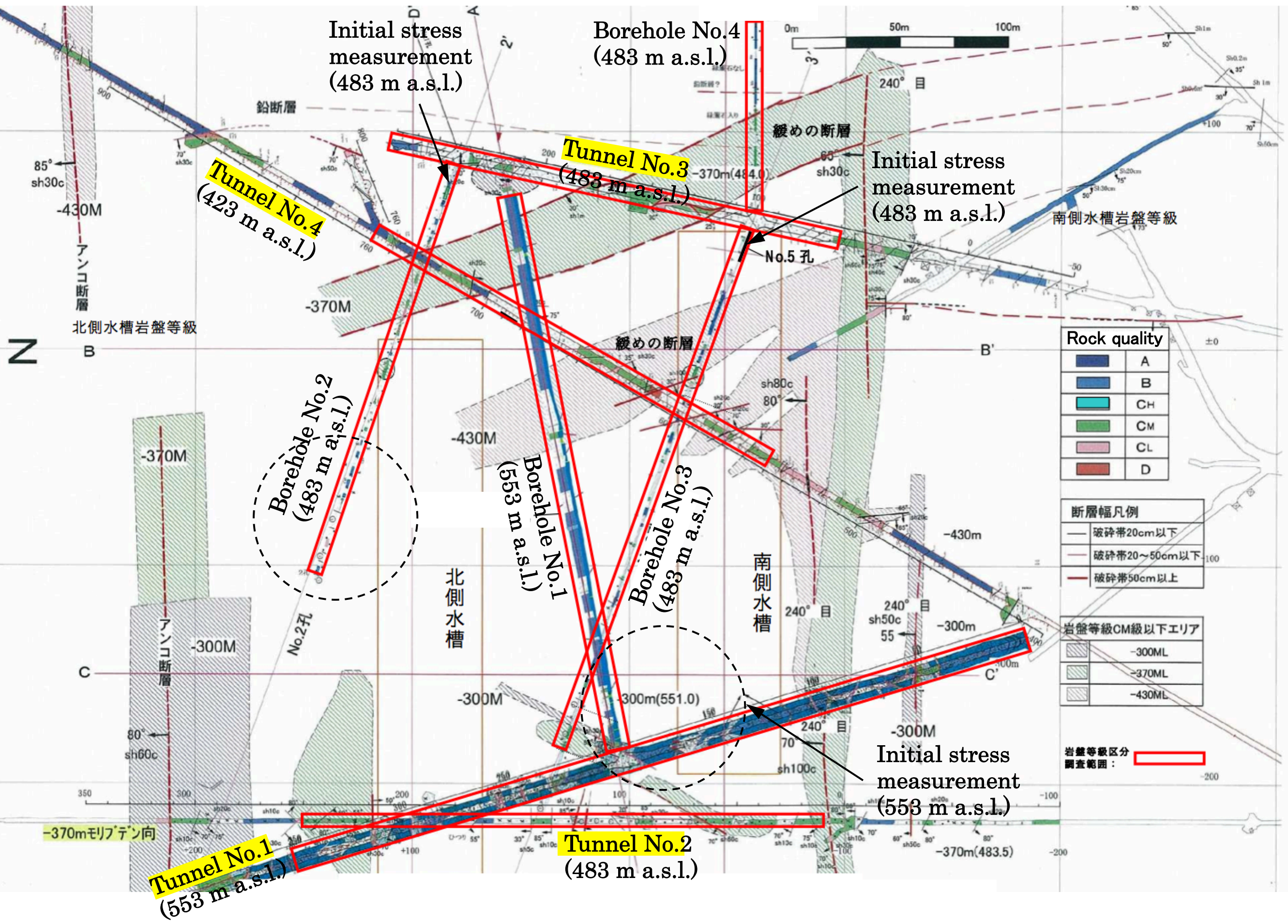
- The candidate site locates under Mt. Nijugo-yama
  - ~8km south from Super-K
  - Identical baseline (295km) and off-axis angle (2.5deg) to T2K
- Overburden ~650m (~1755 m.w.e.)



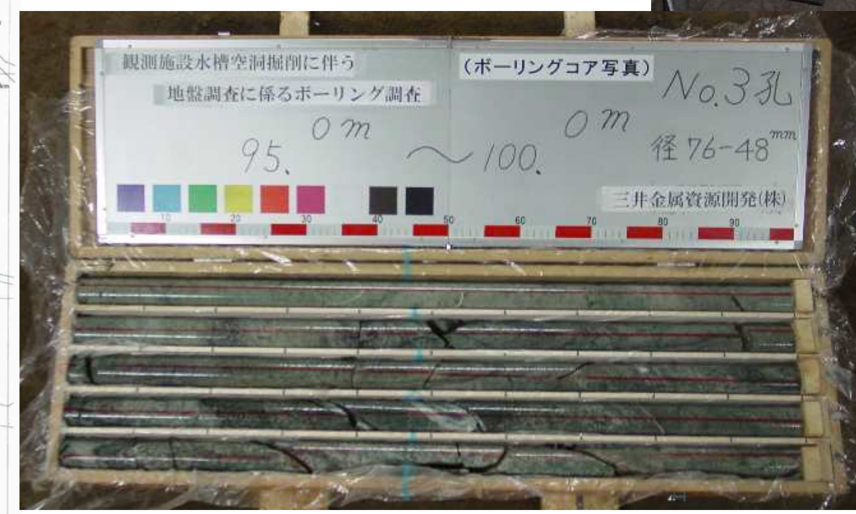


Cavern Excavation

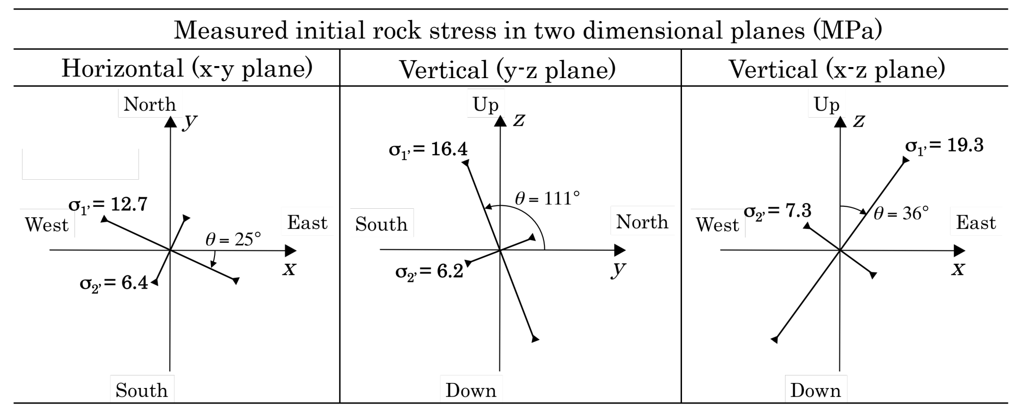
Geological condition



Rock cores



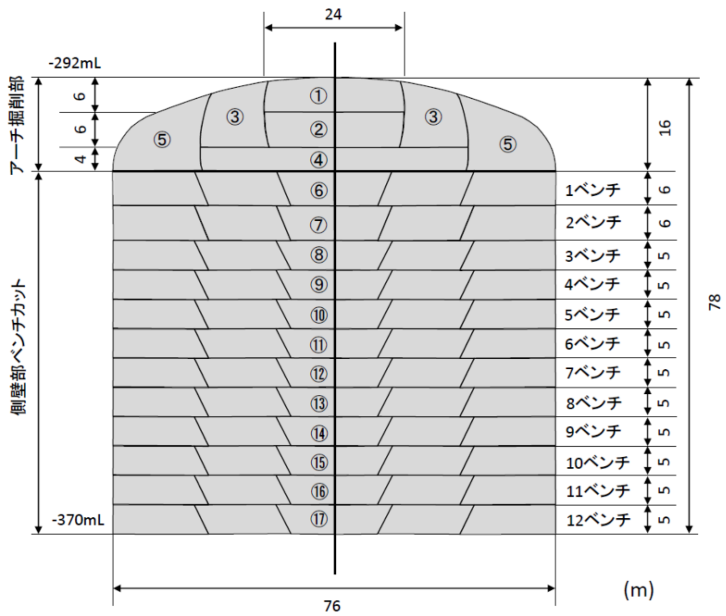
Initial rock stress



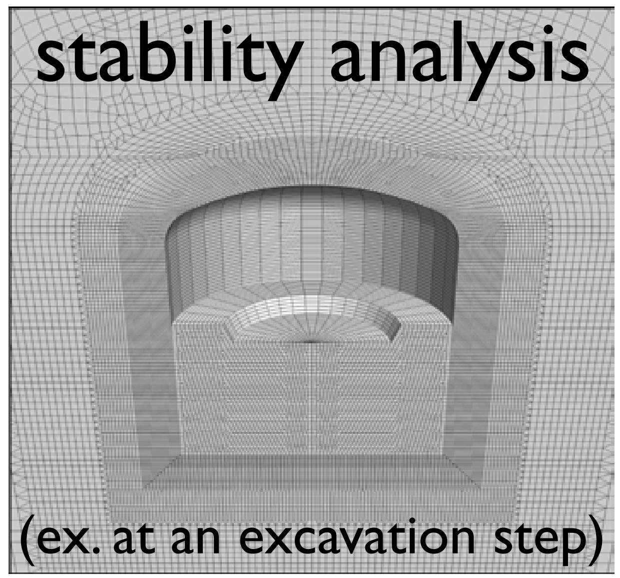
- Detailed geological surveys at the candidates site vicinity
  - Rock core sampling, initial stress of bedrock, etc
- Confirmed the bedrock condition suitable for a large cavern construction
- Examine the cavern stability based on the geological survey results

Cavern stability analysis

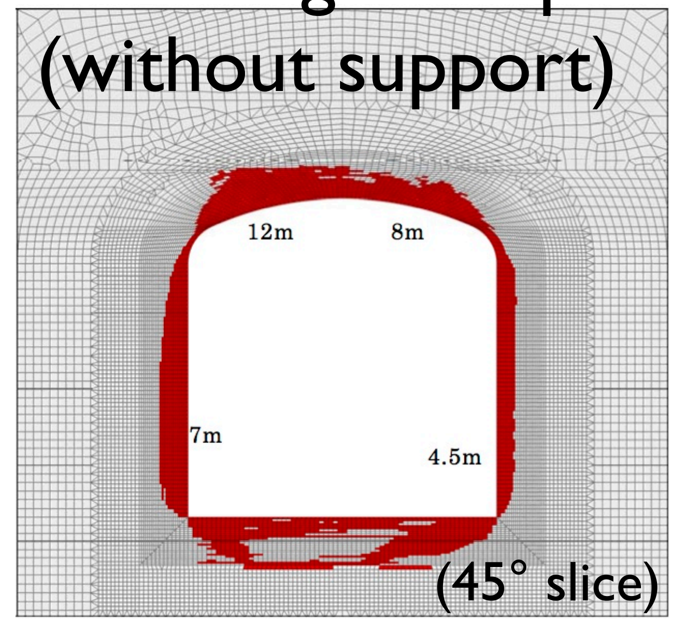
Excavation steps



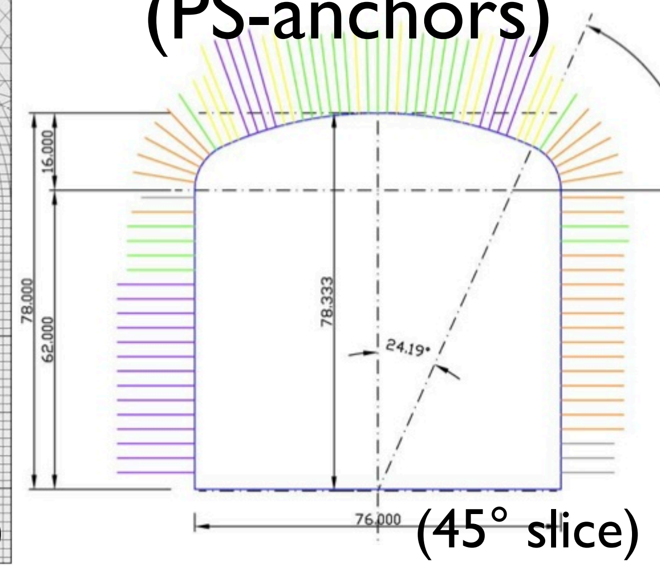
3D model for stability analysis



Plastic region depth (without support)



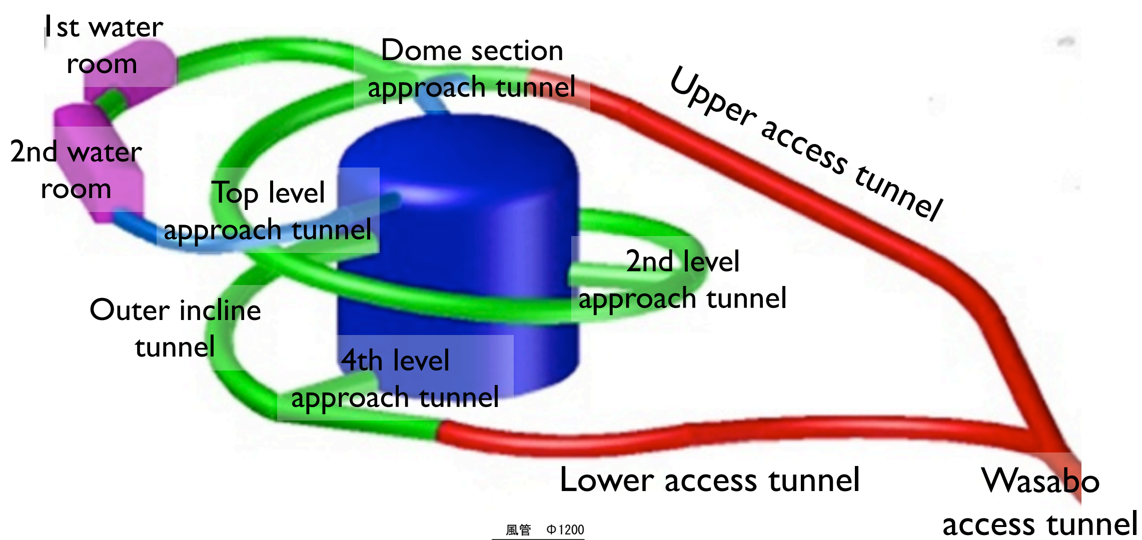
Cavern support (PS-anchors)

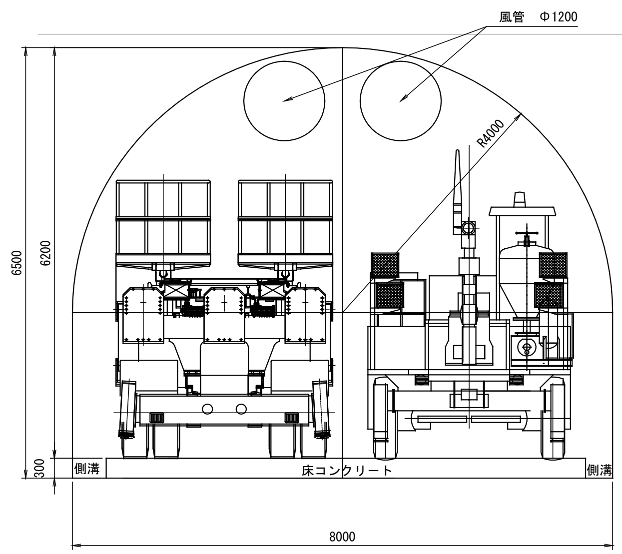


- Cavern stability analyses based on geol. survey results
  - 3D finite element analysis adopting Hoek-Brown model
    - Adopt a model to treat the elastic and inelastic behaviors of rock
  - Excavation steps taken into account in stability analysis
  - Evaluate plastic region depth and design cavern support
- Confirmed the Hyper-K cavern can be constructed with the existing technologies

Tunnels

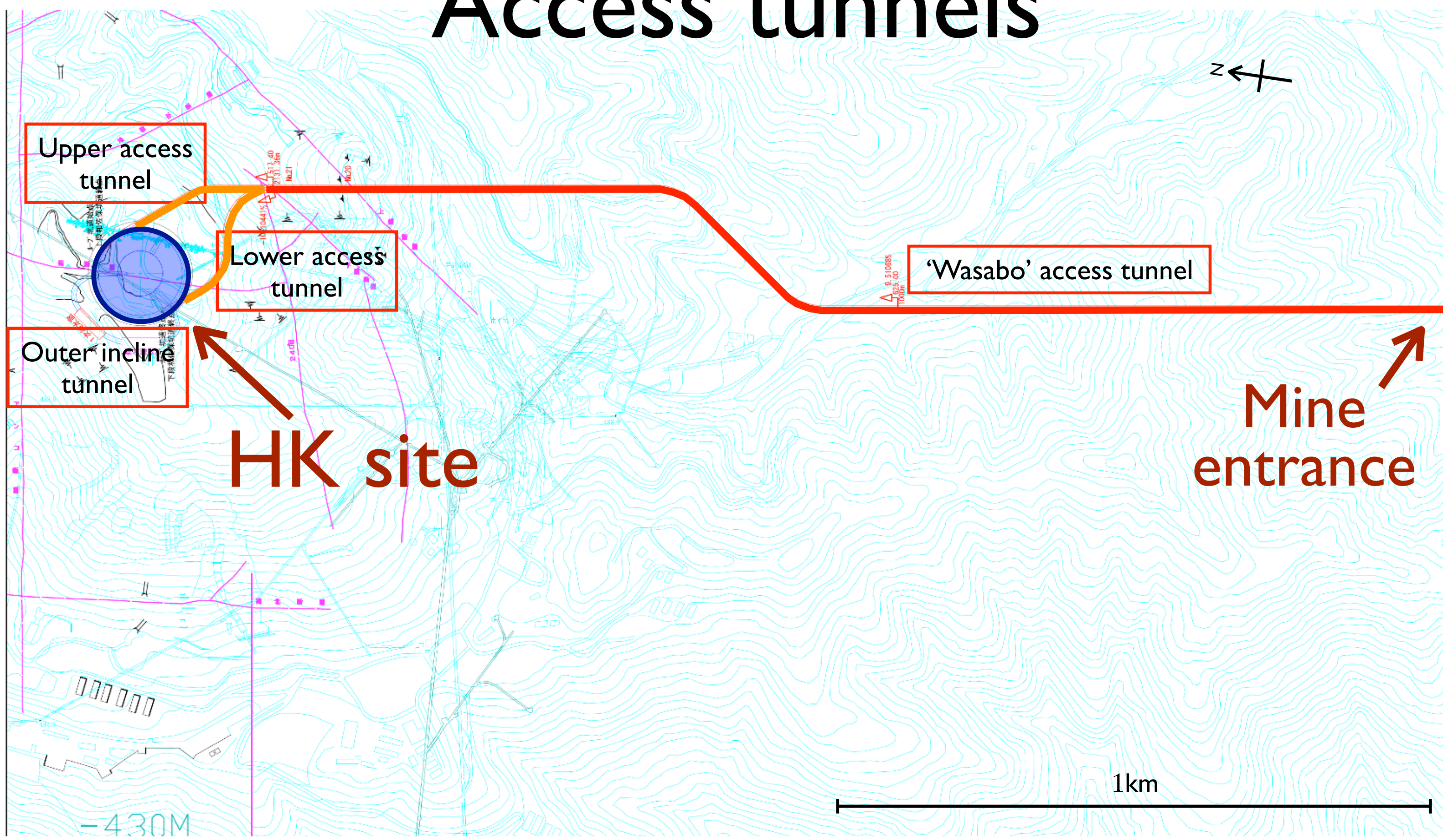
Approach tunnels





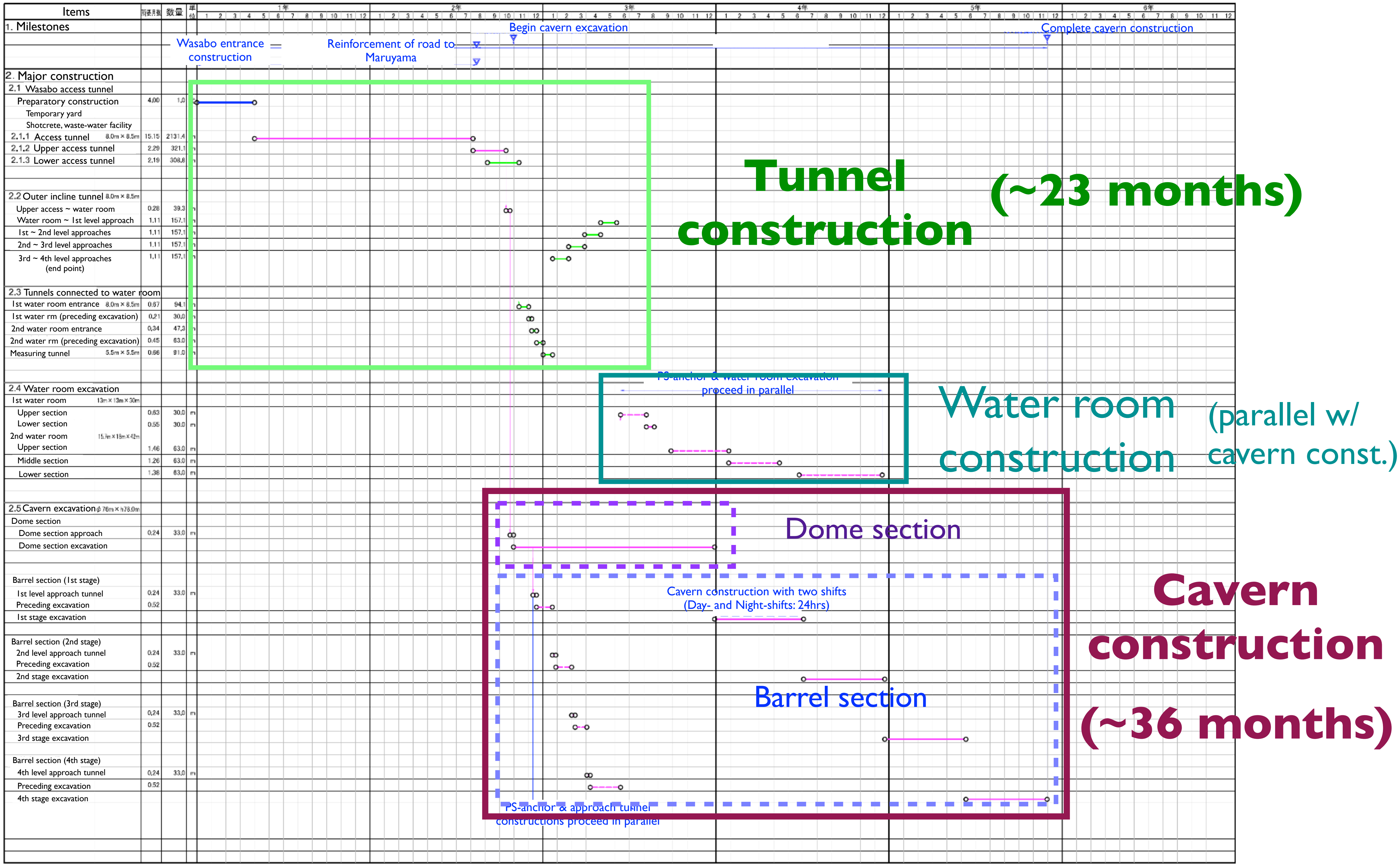
Tunnel cross section

Access tunnels



- Cavern construction begins with tunnels construction
  - Access tunnels, outer incline tunnels, approach tunnels
- Design & layout of the tunnels established
  - Include the cavities for water purification system

Cavern excavation timeline



- Tunnel construction: ~2 years
- Cavern construction: ~3 years

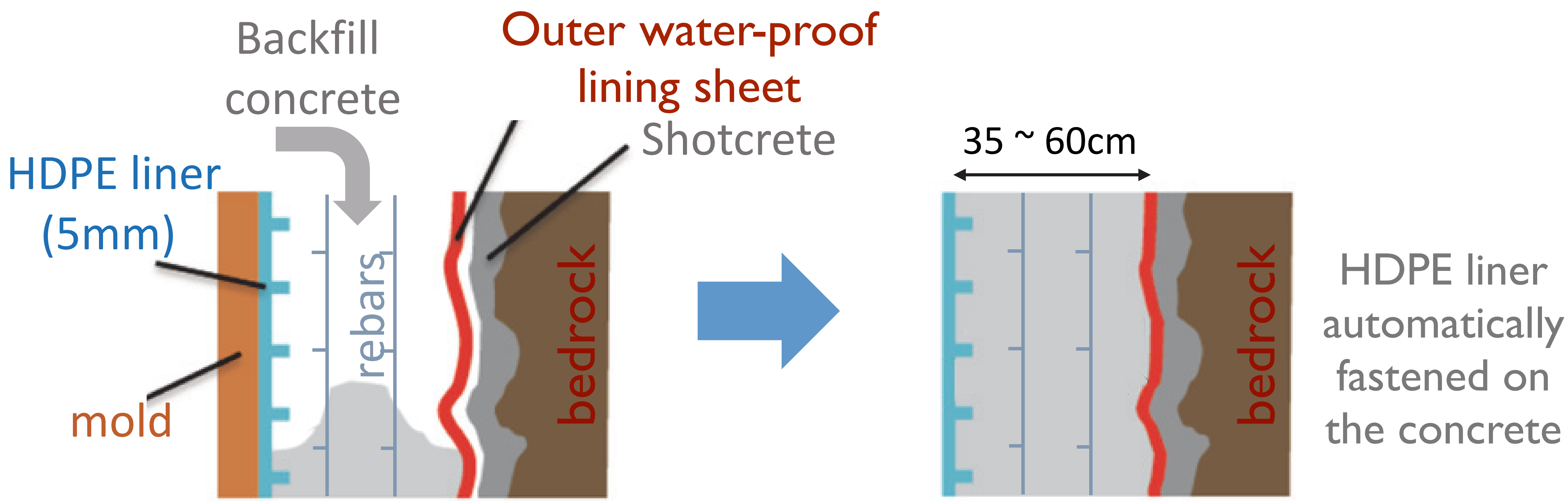
} **~5 years** in total

Tank Construction

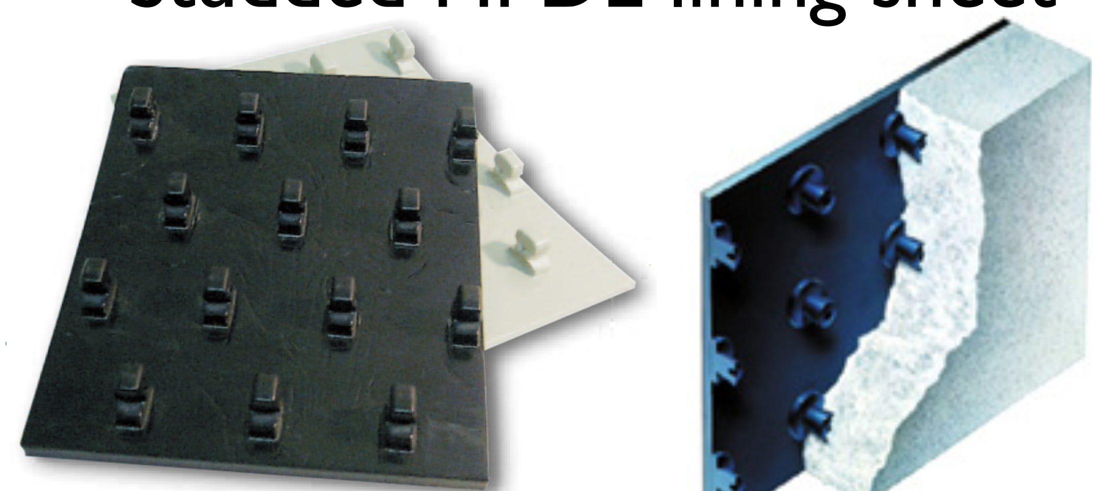
Water containment system, photosensor support

Water containment system

- Water containment system consists of three layers of lining system:
  - Outer water-proof sheet, Concrete lining, High Density Polyethylene (HDPE) lining

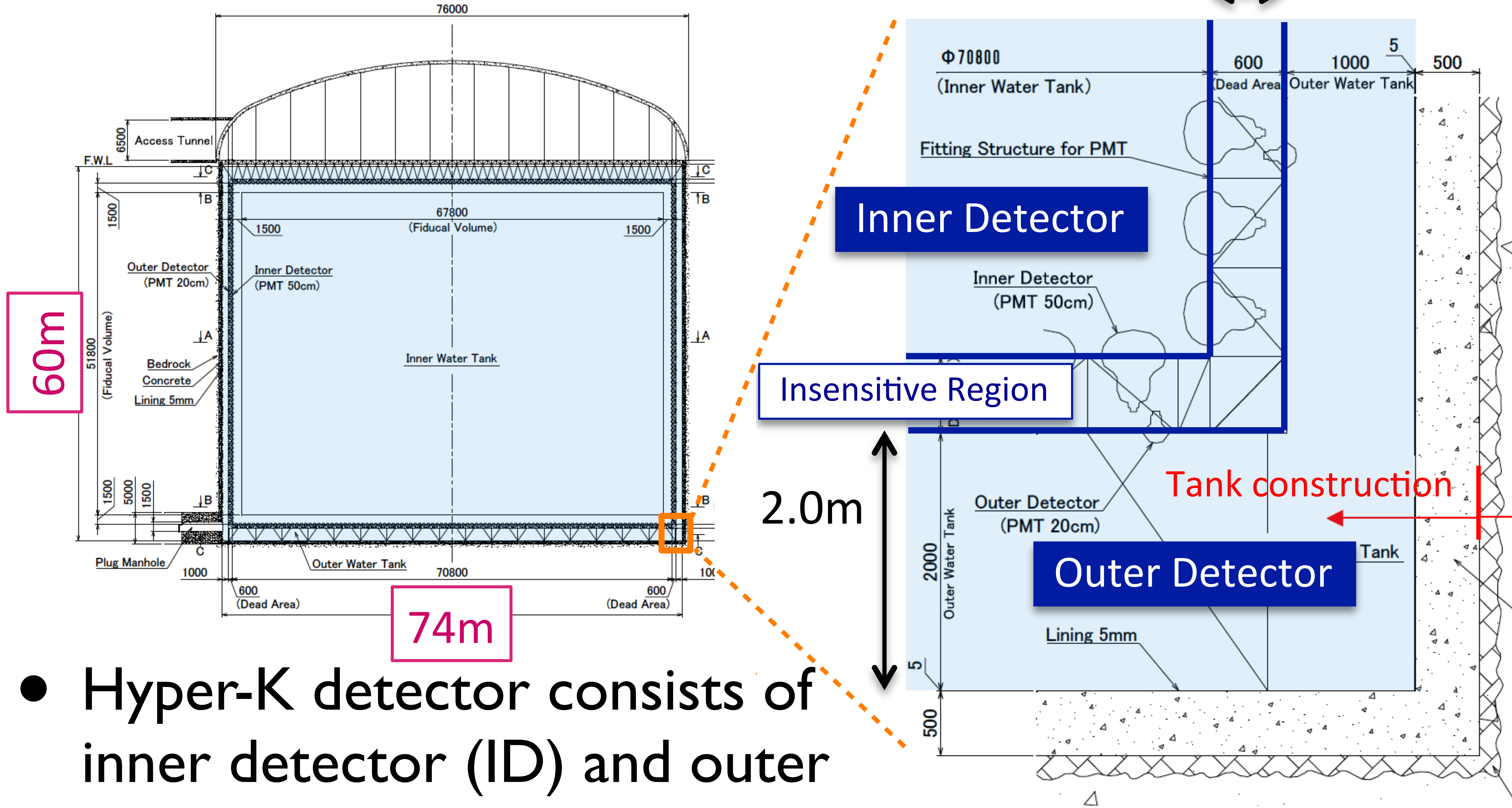


Studded HPDE lining sheet



Three layers of liners are constructed simultaneously
→ Minimize the const. time

Hyper-K detector



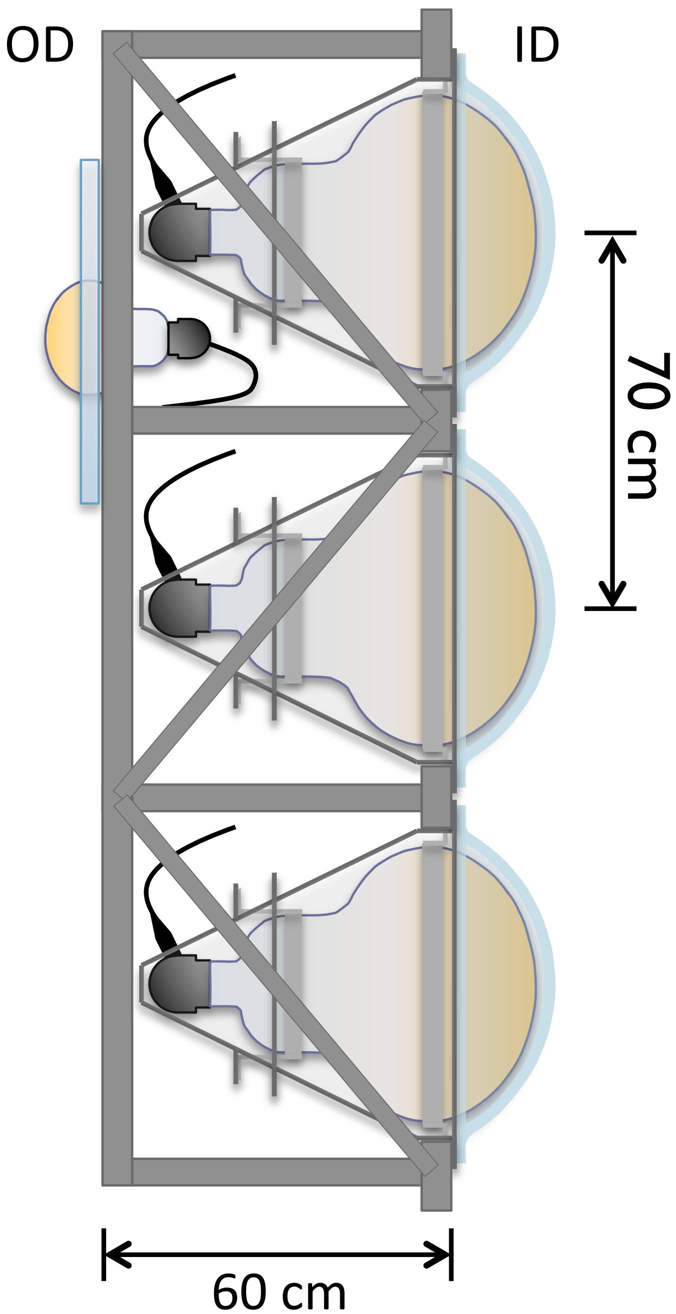
- Hyper-K detector consists of inner detector (ID) and outer detector (OD)
  - and ‘insensitive region’ in between
  - ID & OD are optically separated

1 ID-PMT/0.5m^2 (40% coverage)

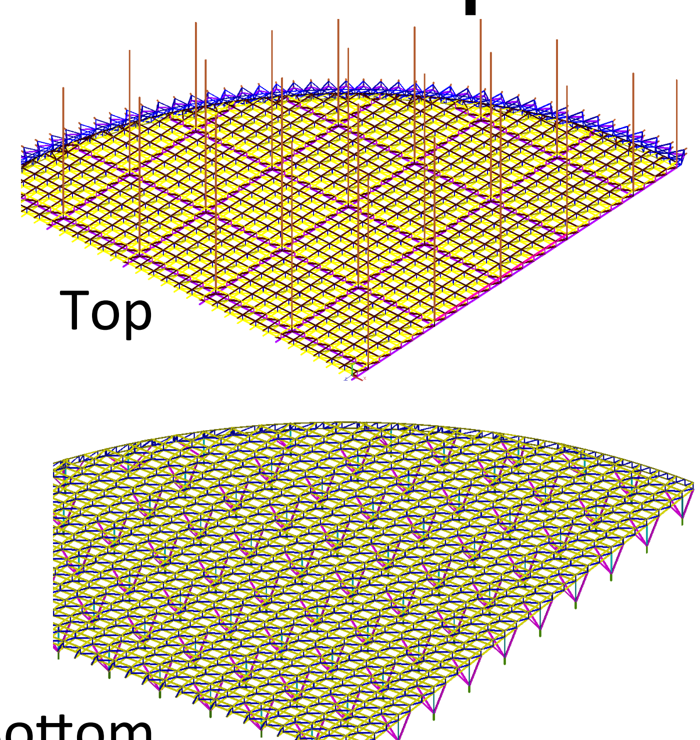
→ ~40,000 ID-PMTs/tank

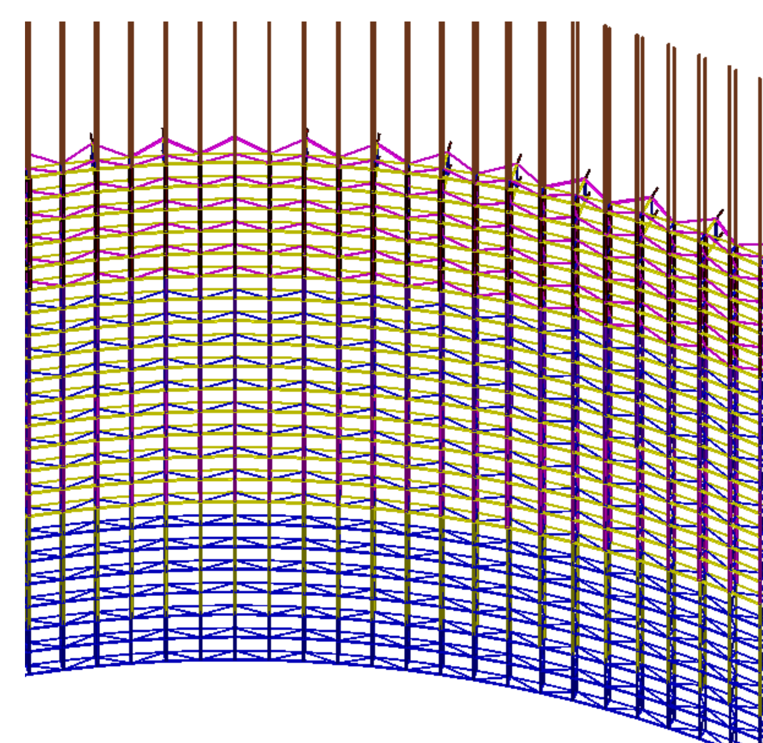
~6,700 OD-PMTs/tank

PMT support structure



- PMT support structure design adopts a truss-structure made of SUS members
- Seismic response analysis confirmed earth quake do not make damage to the detector
  - even if no water in the tank
- Construction & installation procedure similar to Super-K





Tank construction timeline

Lining construction

<u>20 months</u>

+

PMT support construction
PMT installation

<u>13 months</u>

<u>Total : 33 months</u>

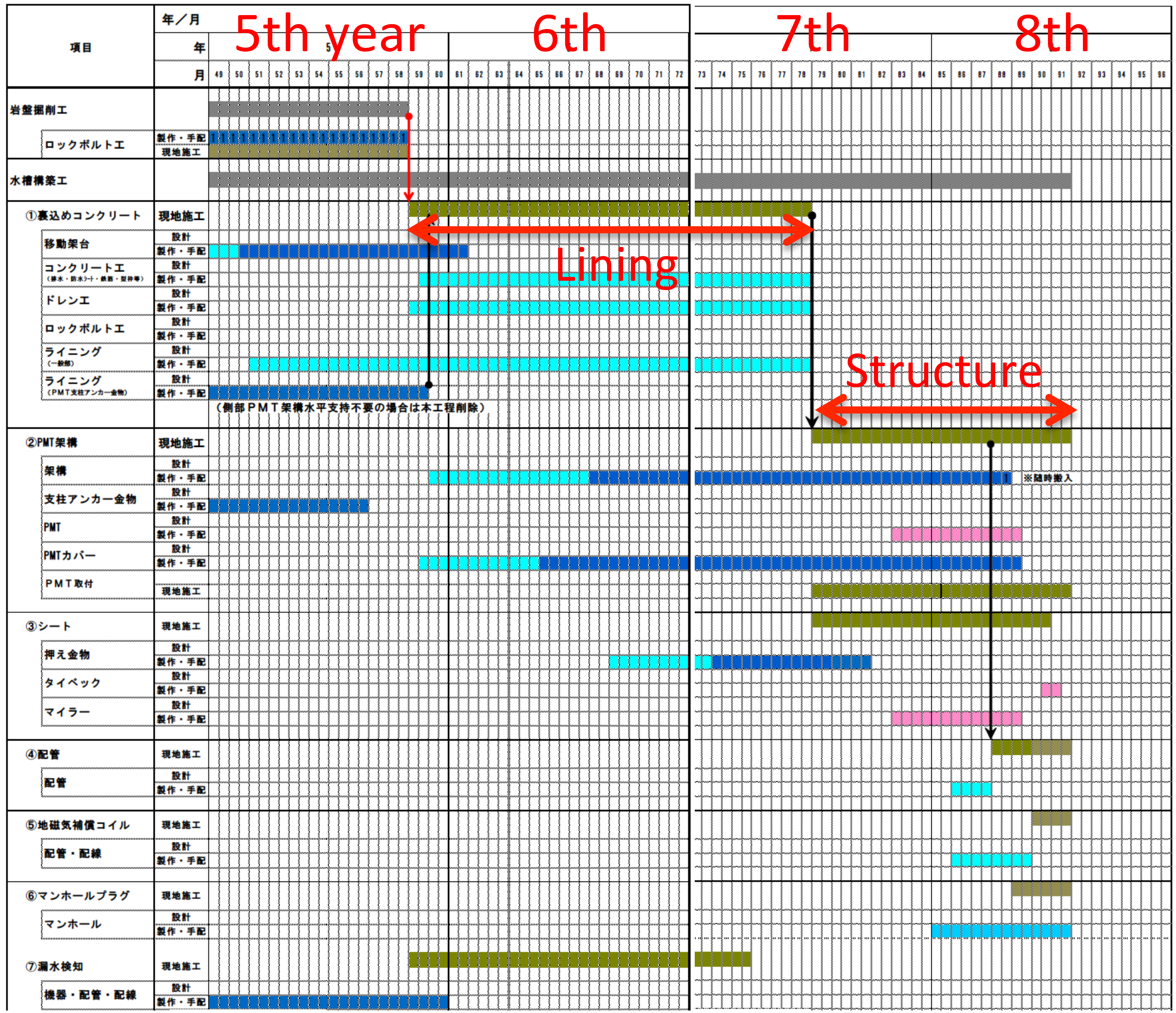
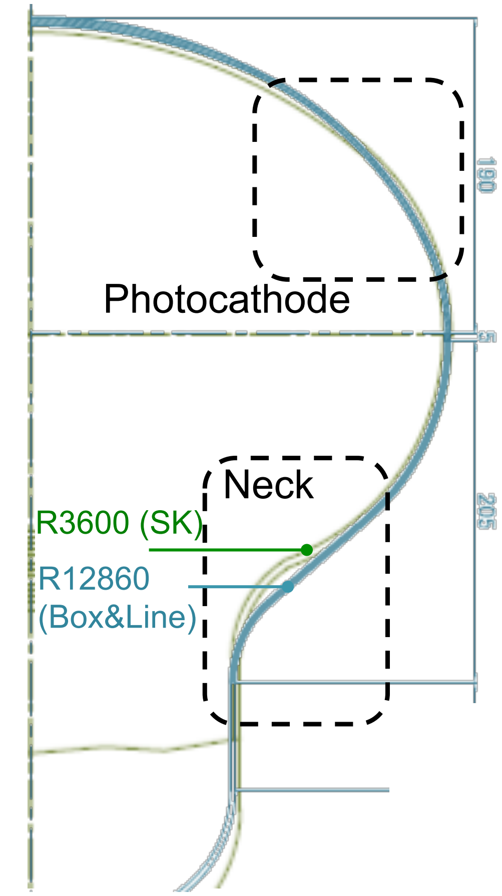


Photo-sensors

See ***Nishimura-san's talk (Nov. 5)*** *and* ***Tom F. talk (Nov. 4)*** *for details*

Photo-sensor (1)

- New 50cmϕ PMT for Hyper-K has a mechanical improvements
- Gives a higher pressure tolerance than Super-K PMTs
  - HK water depth: 60m (cf. 40m in SK)
- Confirmed no damage in new PMTs under 1.25 MPa (125m water depth)

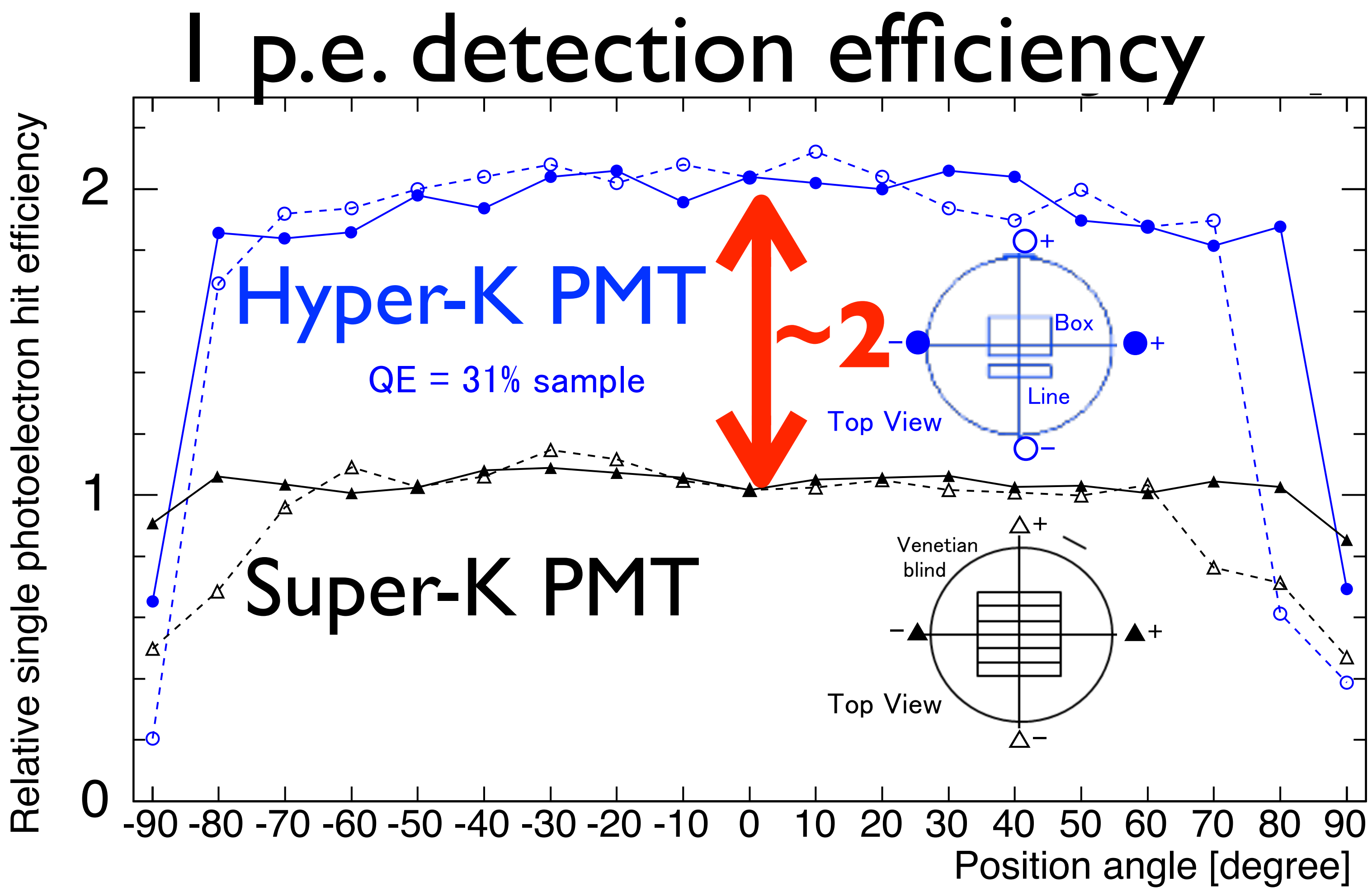


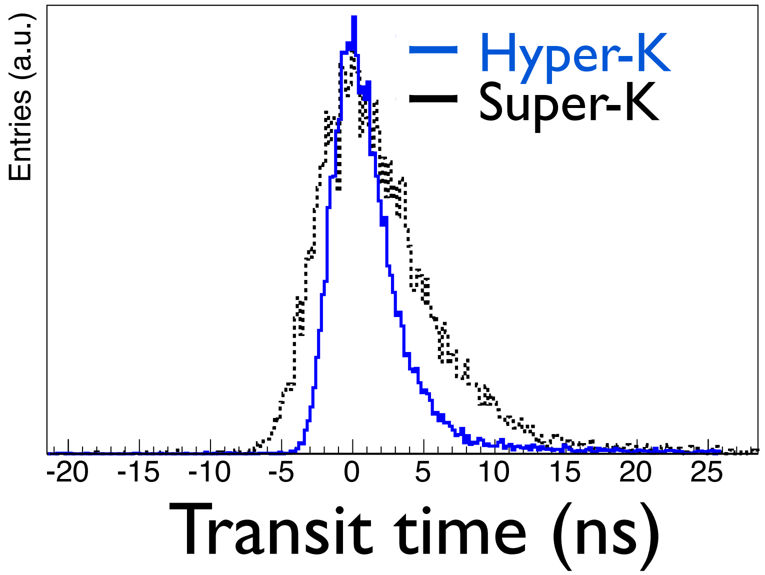
- PMT housing has also been developed to prevent PMT chain-implosion
- Confirmed the PMT housing prevents chain reaction at 80m under water

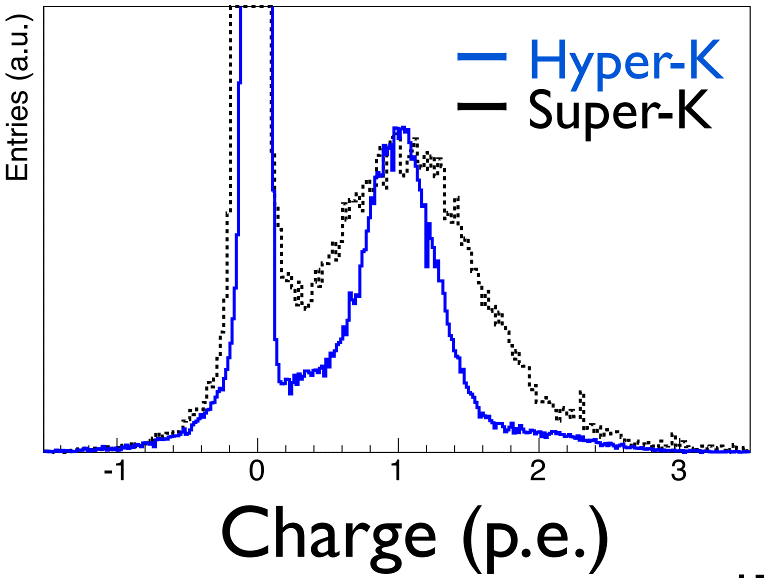
PMT housing

- New PMT works with baseline design

Photo-sensor (2)







- New 50cmϕ PMT for Hyper-K has twice better photo-detection efficiency than Super-K PMT
  - Also better timing and charge resolution
- Implemented in Hyper-K detector simulation for the sensitivity studies

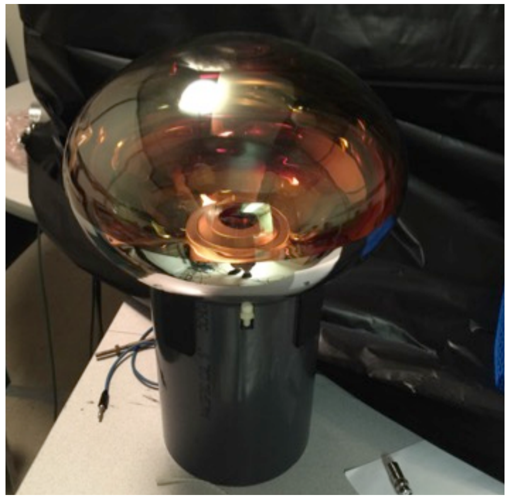
Photo-sensor (3)

- Number of photo-sensor R&D on-going in world-wide for further improvement:

- 50cmϕ Hybrid Photo-detector (HPD)
- 20~30cmϕ photo-sensors for OD / ID
- Multi-PMT
  - Being developed based on KM3NeT optical module
  - MoU with KM3NeT to exchange knowledge on Multi-PMT technology

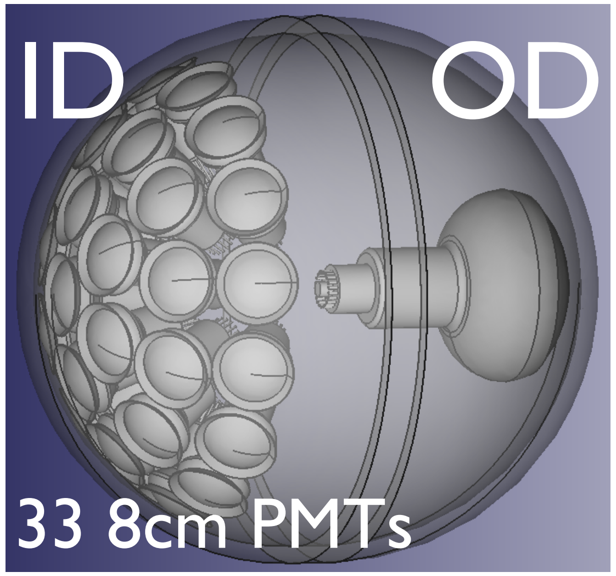
HPD

28cm (8") PMT



KM3NeT optical module

Multi-PMT



8cm (3") PMT

Water system

- Quality of HK source water is almost same as in SK
  - Source water for HK sampled at the candidate site
- Hyper-K water purification system designed based on the Super-K system

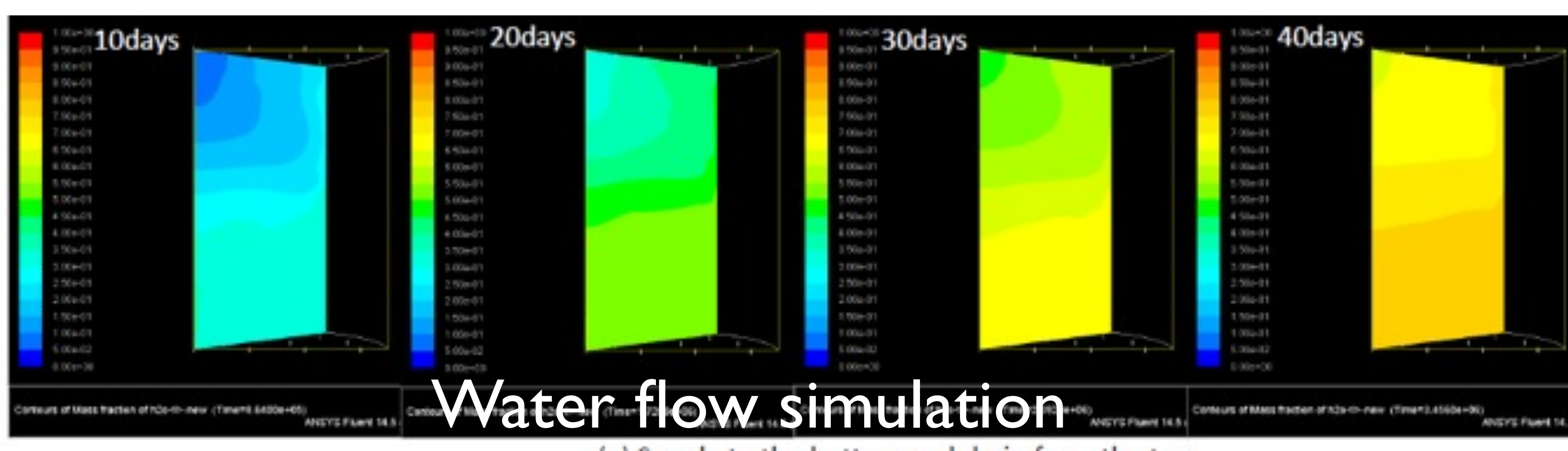
Source water quality

		Tochibora spring water as of 1 Mar. 2011	Mozumi spring water as of 16 Mar. 2011
Temperature(Typical)	°C	11	12
pH (25°C)		7.8	7.8
Conductivity	μS/cm	170	221
Turbidity	degree(Kaolin)	< 1	< 1
Acid consumption (pH 4.8)	mg $CaCO_3$/L	40.0	75.8
TOC	mg/L	< 1	< 1
Phosphate	mg/L	< 0.1	< 0.1
Nitrate	mg/L	1.0	1.6
Sulfate	mg/L	36.4	30.2
Fluoride	mg/L	0.3	0.4
Chloride	mg/L	1.6	1.8
Sodium	mg/L	4.9	6.2
Potassium	mg/L	0.5	0.5
Calcium	mg/L	25.2	32.0
Magnesium	mg/L	1.5	2.9
Ammonium	mg/L	< 0.1	< 0.1
Ionic silicon dioxide	mg/L	17.1	11.8
Iron	mg/L	< 0.01	< 0.01
Copper	mg/L	< 0.01	< 0.01
Zinc	mg/L	0.09	< 0.01
Lead	mg/L	< 0.1	< 0.1
Aluminum	mg/L	< 0.01	< 0.01
Boron	mg/L	< 0.01	0.2
Strontium	mg/L	0.18	0.52
Barium	mg/L	< 0.01	0.03

possible source water for HK

SK source water

- Water flow in the tank directly affects the water quality and the physics
- Supply water from bottom and drain from top: suppress convection and water flow become laminar (effective water replacement)

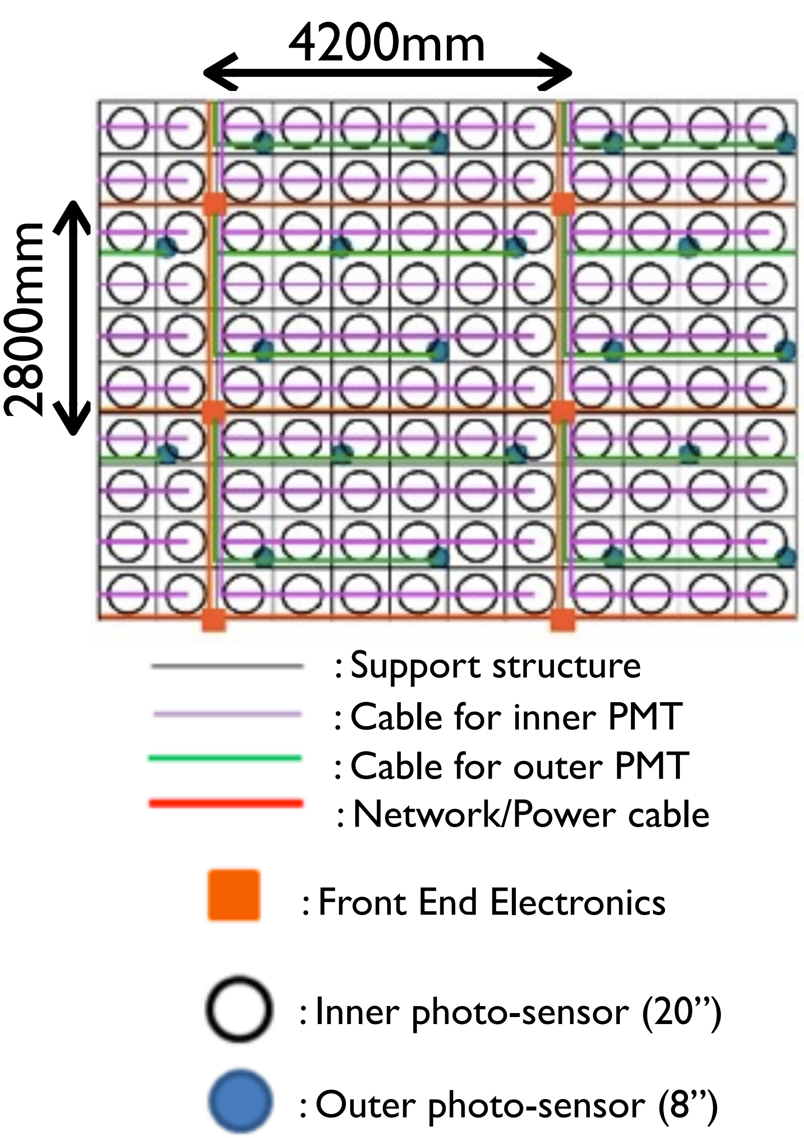


Water flow simulation

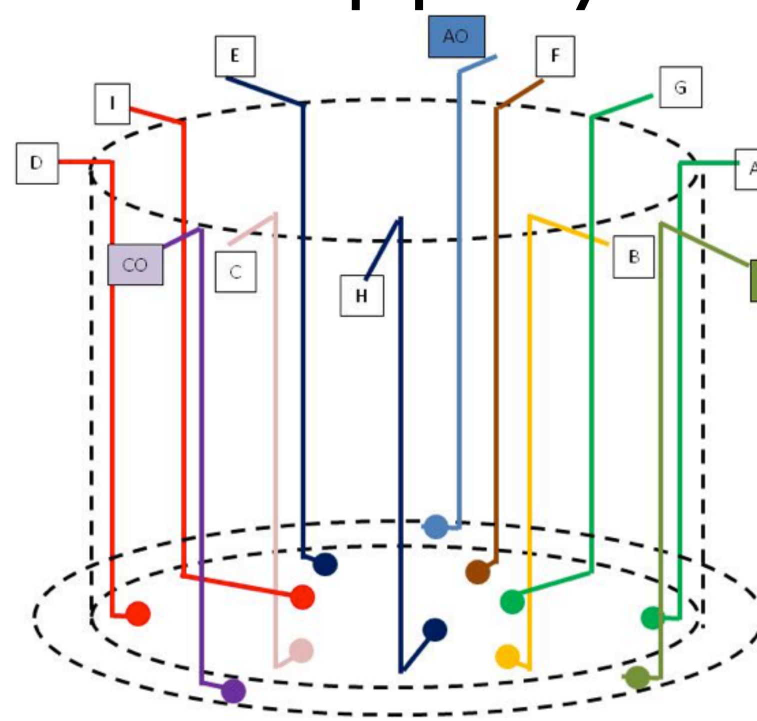
Design detector components

- All HK detector components has been designed
  - Front-end electronics, cables routing, layout of water pipes, geomagnetic field compensation coils, calibration holes, crane, ... etc.

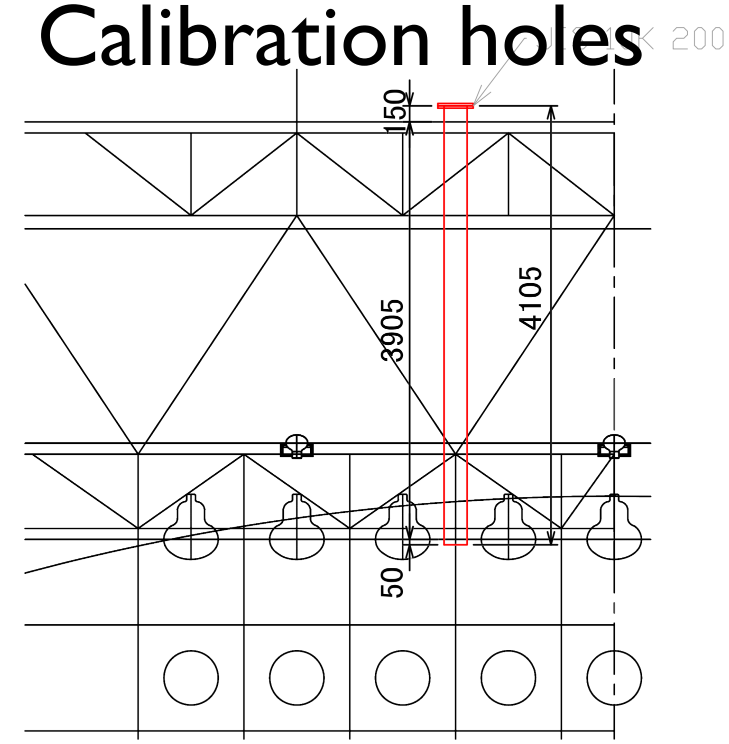
Electronics & cable layout



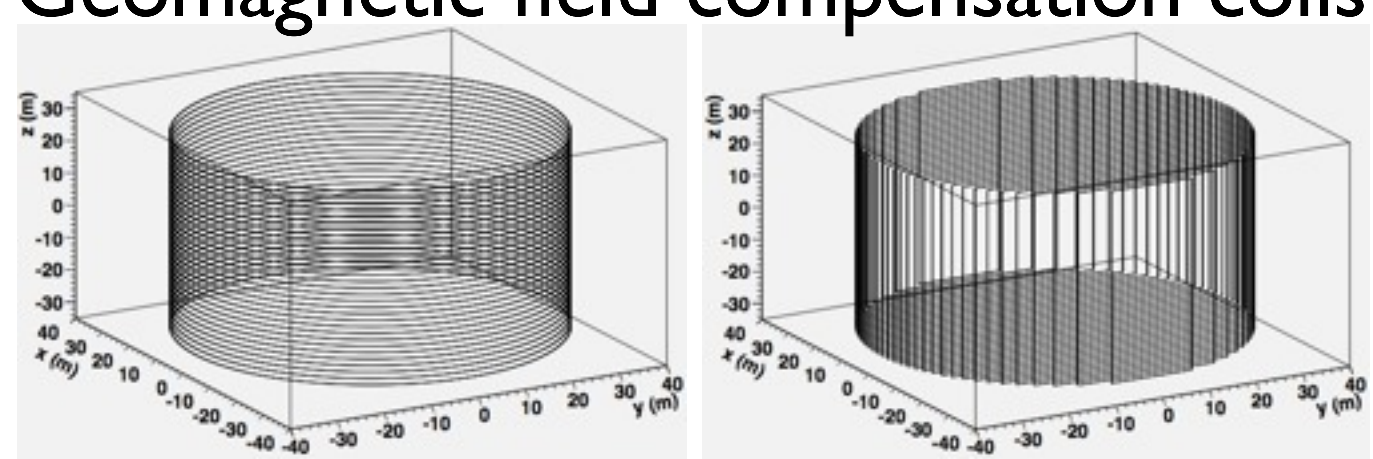
Water pipe layout



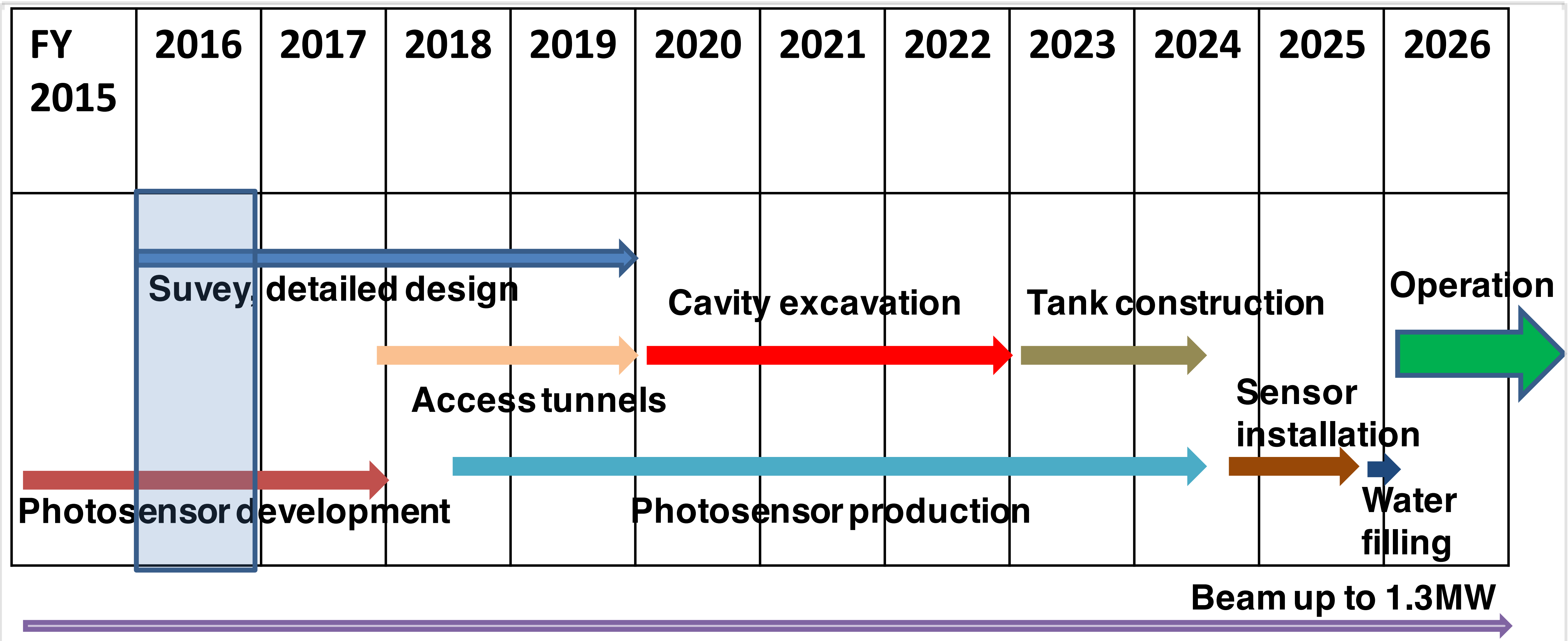
Calibration holes



Geomagnetic field compensation coils



Hyper-K construction timeline



- The 1st detector construction in 2018~2025
  - Now: Further detailed geological survey and photosensor development on-going
  - Cavern excavation: ~5 years
  - Tank (liner, photosensors) construction: ~3 years
  - Water filling: 0.5 years

Detector calibration

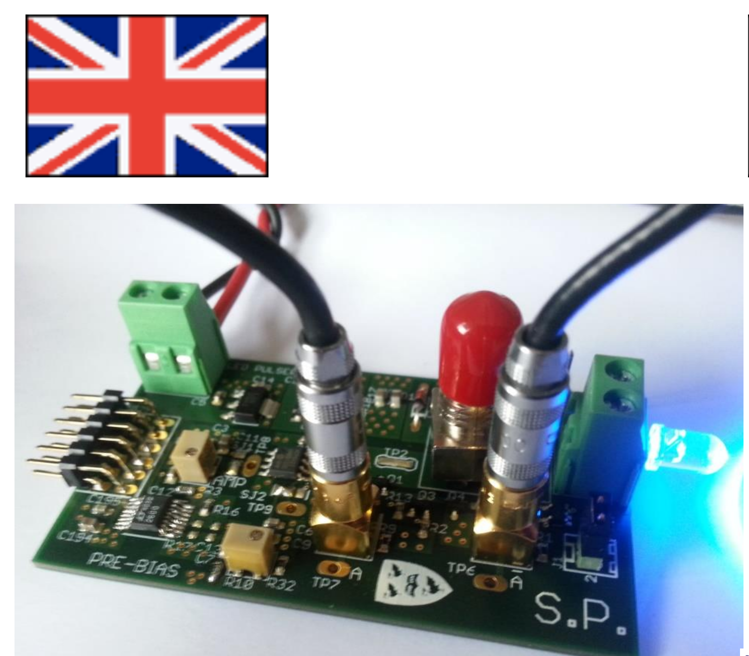
HK detector calibrations

- Hyper-Kamiokande detector calibrations designed based on Super-K calibrations
  - Feasible techniques/methods for large water Č detector
  - SK calibration paper: NIM A 737 (2014) 253-272
- Several R&D projects are in progress to develop more sophisticated calibration systems and sources for Hyper-K

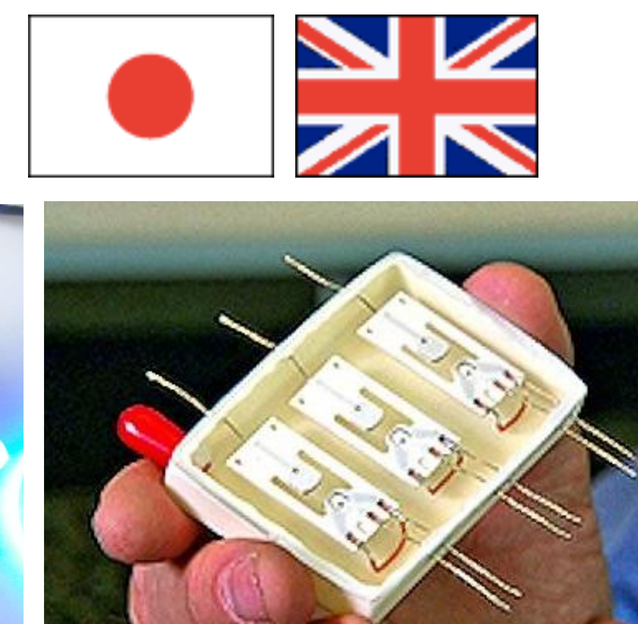
Photosensor Test Facility

Automated calibration system

Integrated light injection system



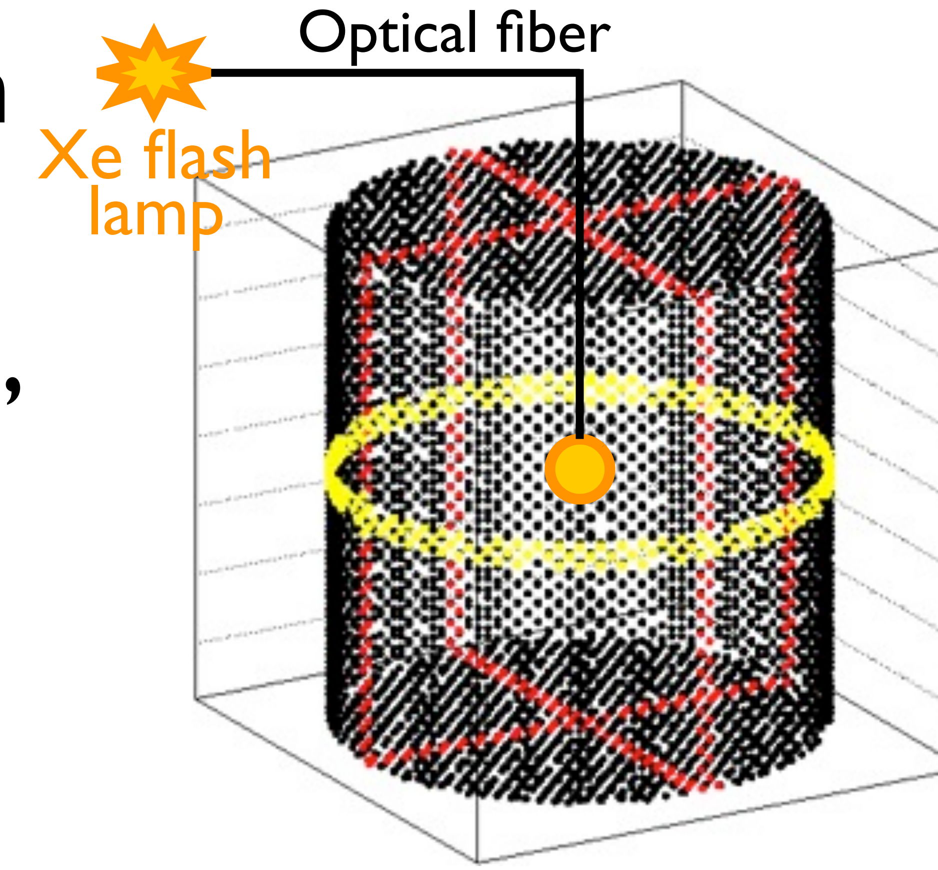
Compact neutron generator



IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 40, NO. 9, SEPTEMBER 2012

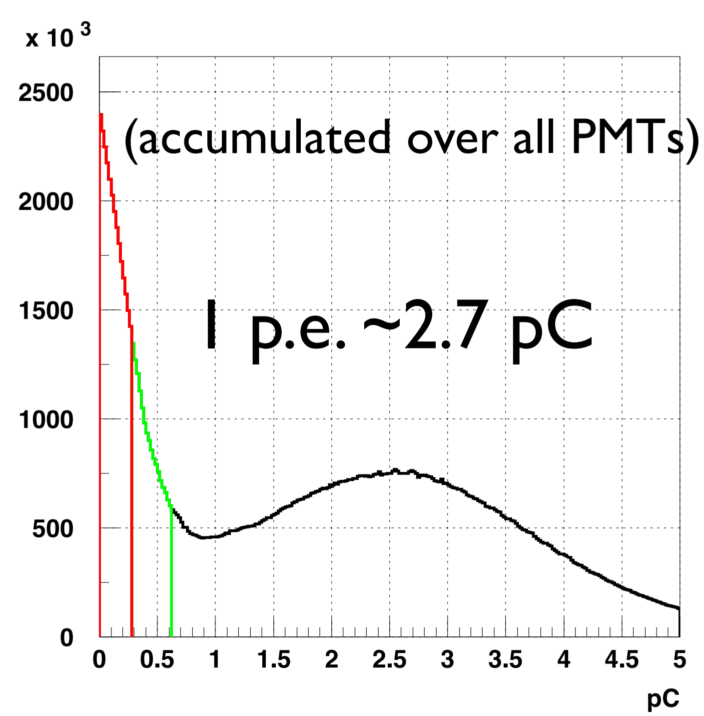
Gain calibration

- ~5% of all PMTs are tuned/calibrated to have same gain before installation (pre-calibration)
- Nominal PMTs are calibrated in-situ, after installed, by referencing to the pre-calibrated PMTs (~1% level)
  - Deploy a light source in the detector
- PMT gain stability monitored during the detector operation

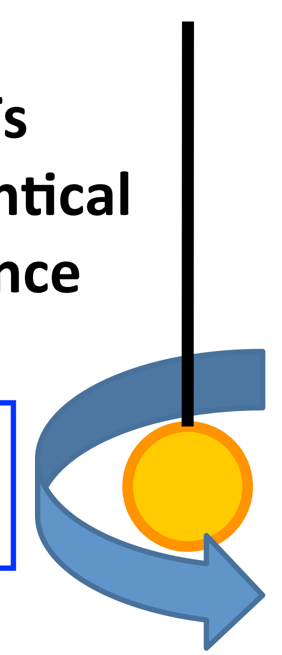


- Pre-calibrated PMTs
- Nominal PMTs
- A group of PMTs which have identical optical acceptance

1 p.e. distribution (Super-K)

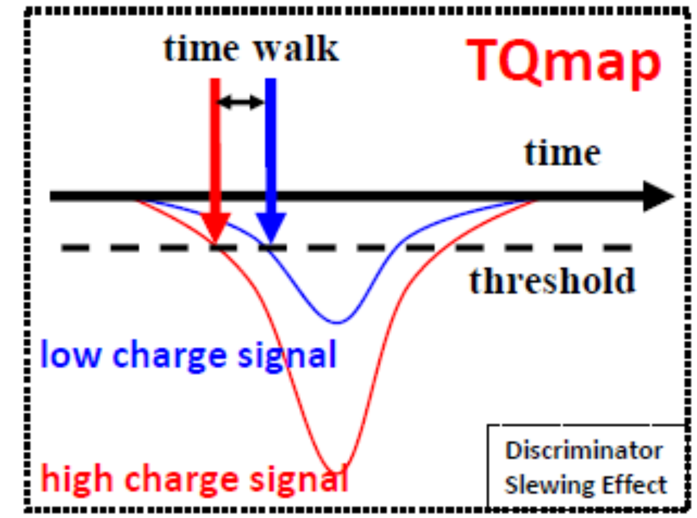


Good uniformity (±2%)



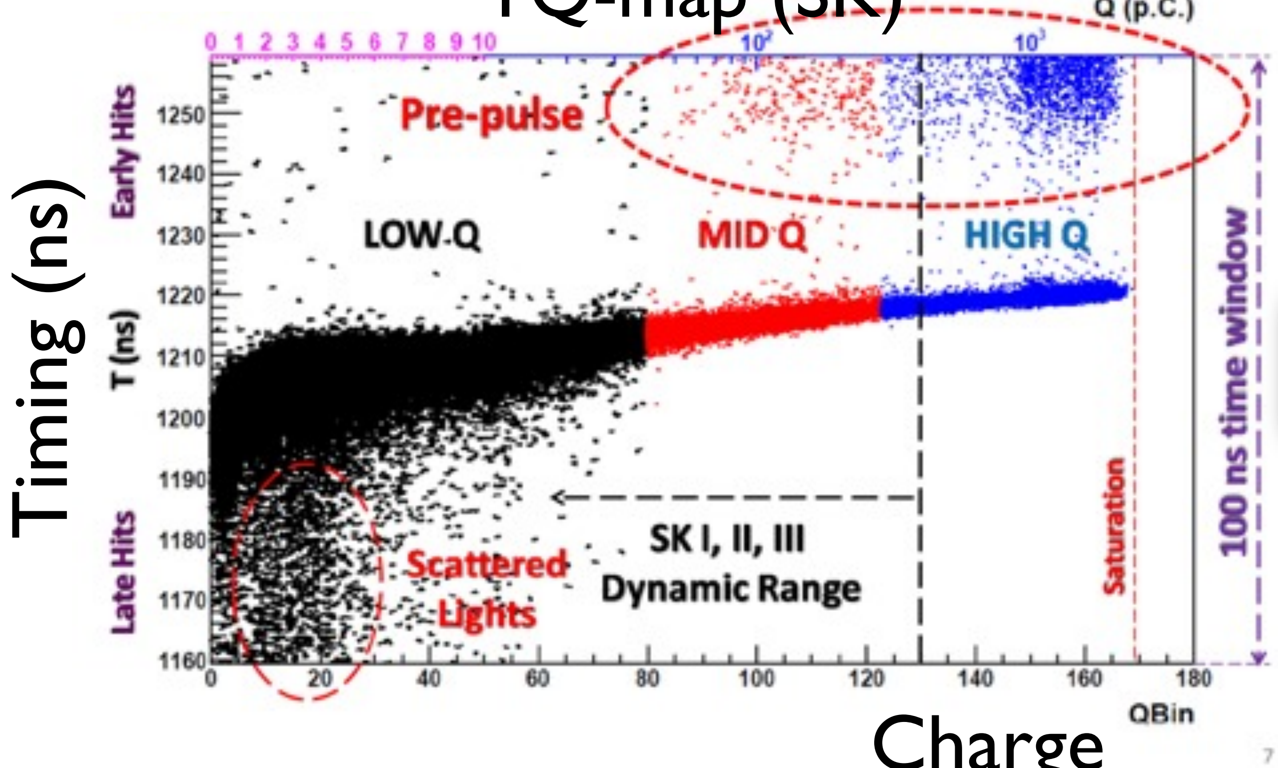
Timing calibration

- “TQ-map” (Time-Charge map)
  - Calibration to have uniform timing response for all PMTs
    - Time offset: transit-time, cable length
    - Time-walk: discriminator slewing effect

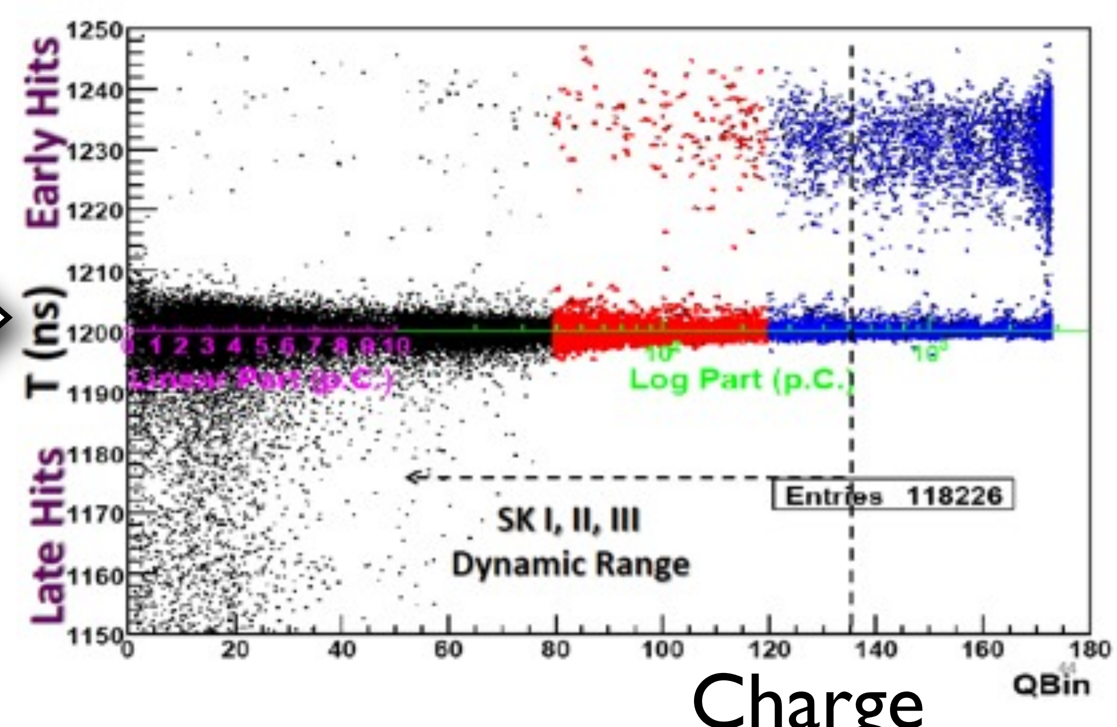


- Employ a fast-pulsed light source (a few 100ps FWHM), scan over entire dynamic range: ~1p.e. to ~1000 p.e.
  - Also timing stability monitored during the operation

TQ-map (SK)



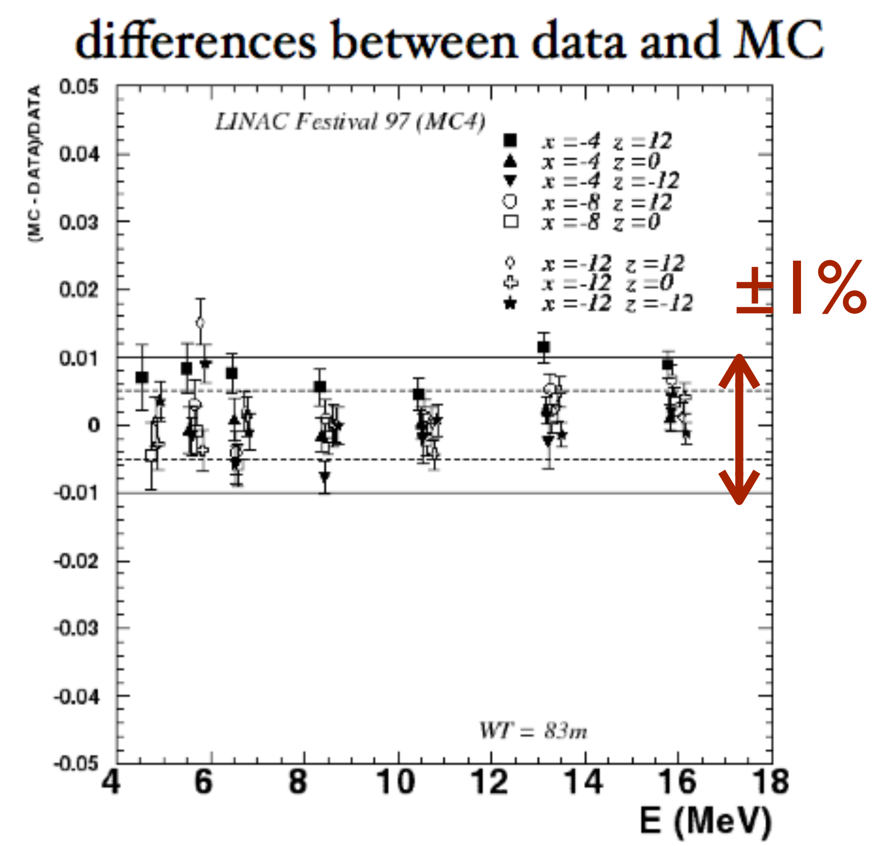
After TQ-map correction (SK)

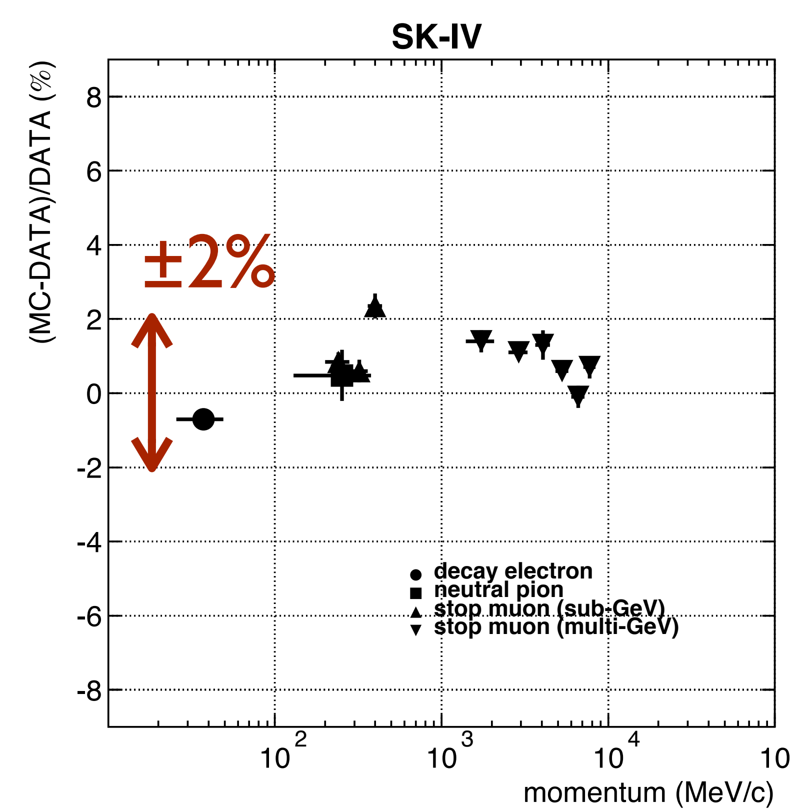


Absolute energy scale calib.

- Energy calibrations use an electron LINAC and natural sources covering a few MeV to several GeV
  - e-LINAC: monochromatic energy single-electron beam
    - ~5 MeV to ~16 MeV
    - Solar ν, Supernova ν, ...
  - Natural sources (Michel-e, atm-ν induced π^0, cosmic-μ)
    - ~40 MeV/c to several GeV/c
    - Beam-ν, atm-ν, proton-decay, ...
- Energy scale error in Super-K: <1% (solar ν), ~2-3% (beam, atm ν)
  - E-scale errors include time variation
  - Energy scale calibrated with DT, Ni-Cf, natural sources during the operation

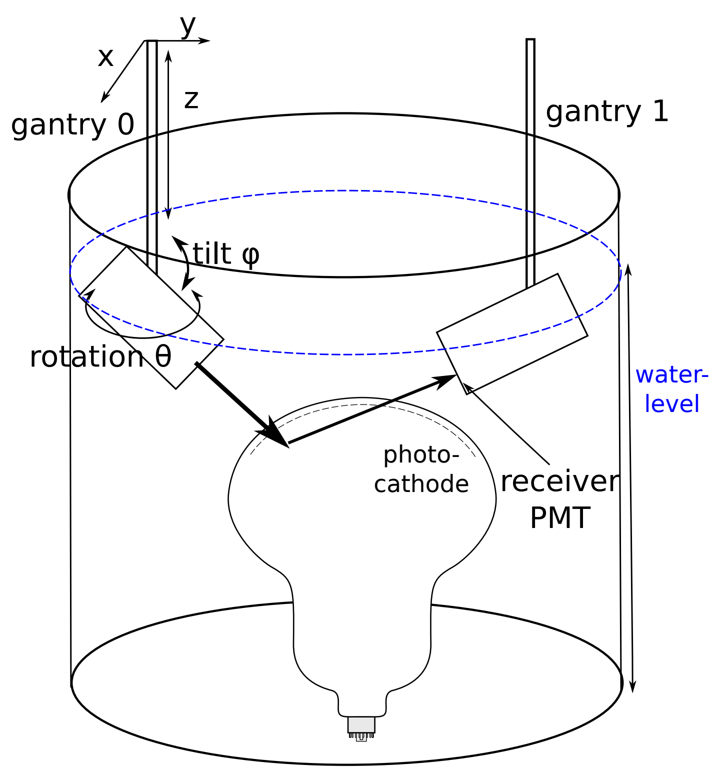
Data/MC difference (SK)





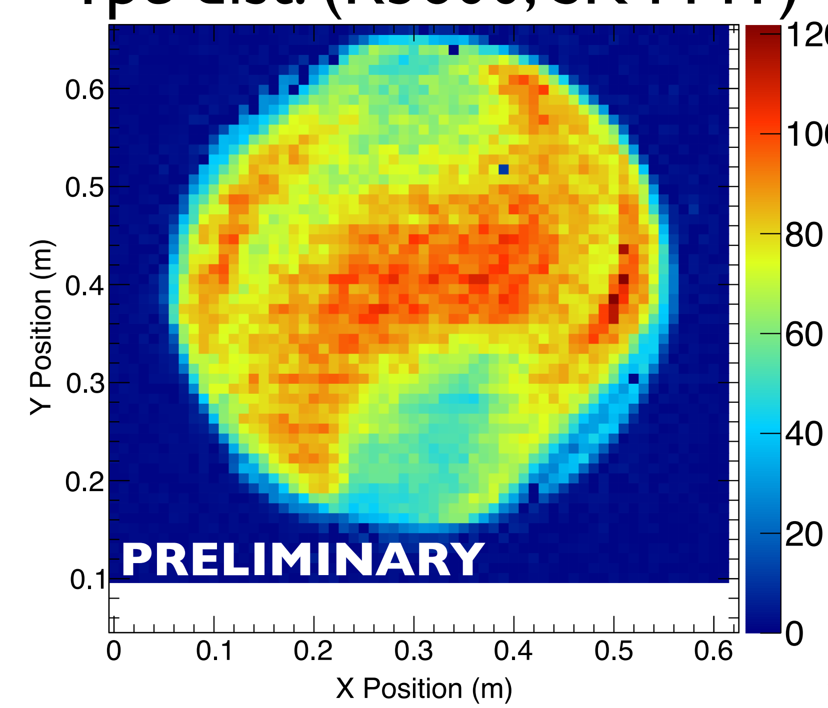
PMT test facility

- PMT characterization with PTF at TRIUMF
- Study response of large area photo-sensors to light (in water) across:
  - wavelength (330~550nm)
  - location on and incident angle to PMT surface
  - include optical property of PMT housing (ex. acrylic)
- Provide parameterized model of PMT response and reflection for the detector simulation



Measurement in ultra-pure water

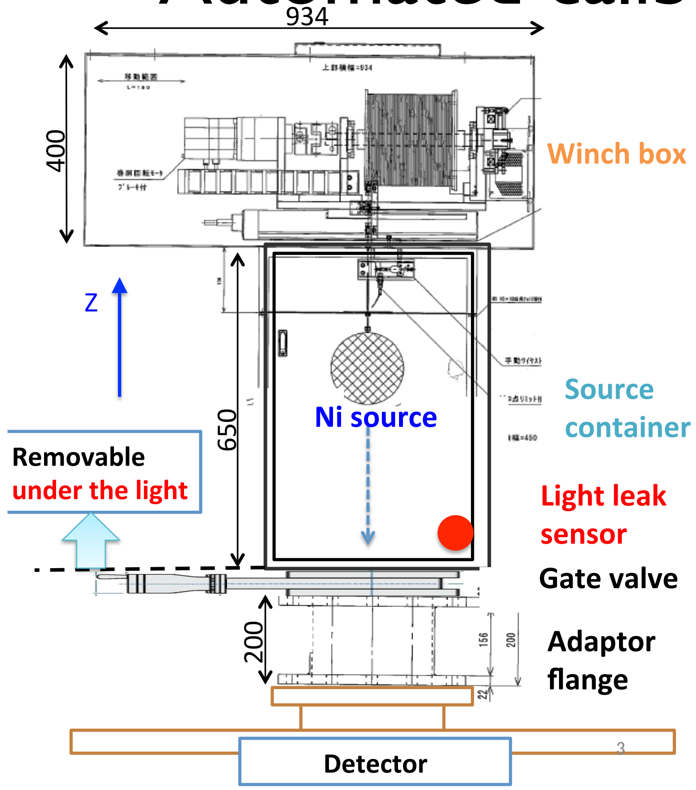
1pe dist. (R3600, SK PMT)



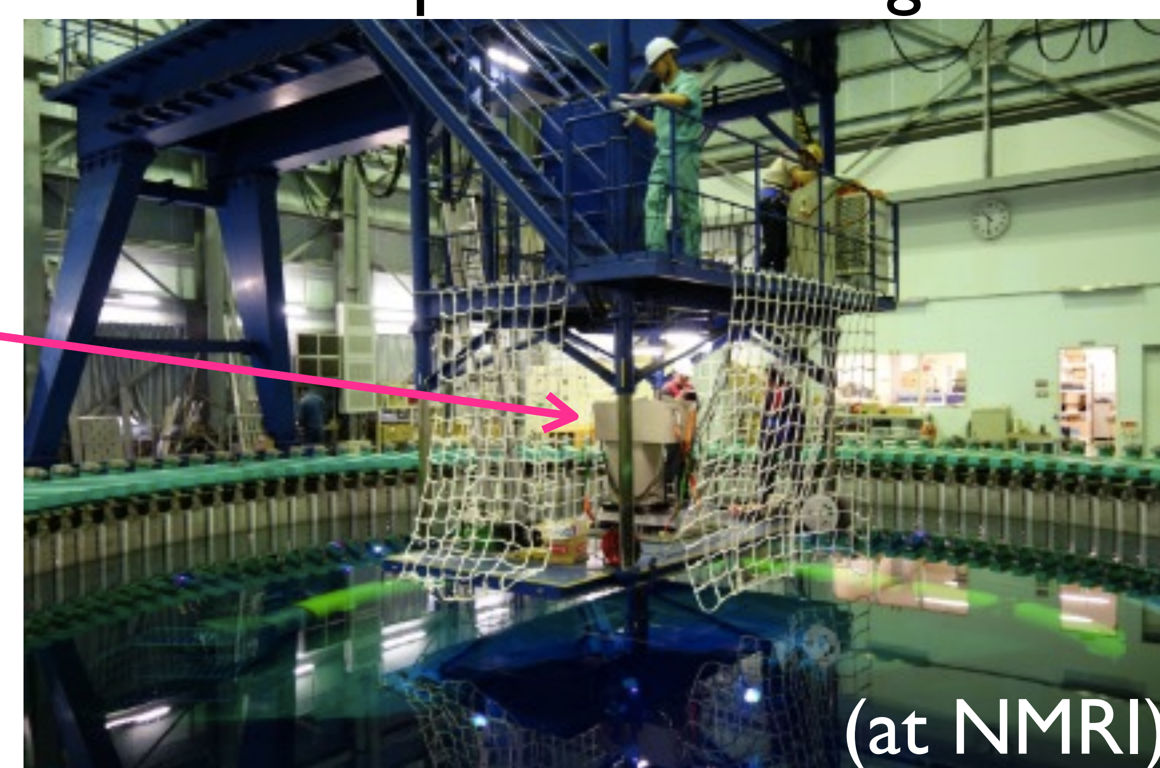
Automated calib. system

- Automated calibration source deployment system
  - Deploy Ni+Cf (γ) source, light sources in the detector
  - Provide less dead-time, less manpower to calibrate multiple detectors
- A prototype of the system built and tested in water (at National Maritime Research Institute; NMRI)
- Plan to install the system in Super-K (next FY)

Automated calib system prototype

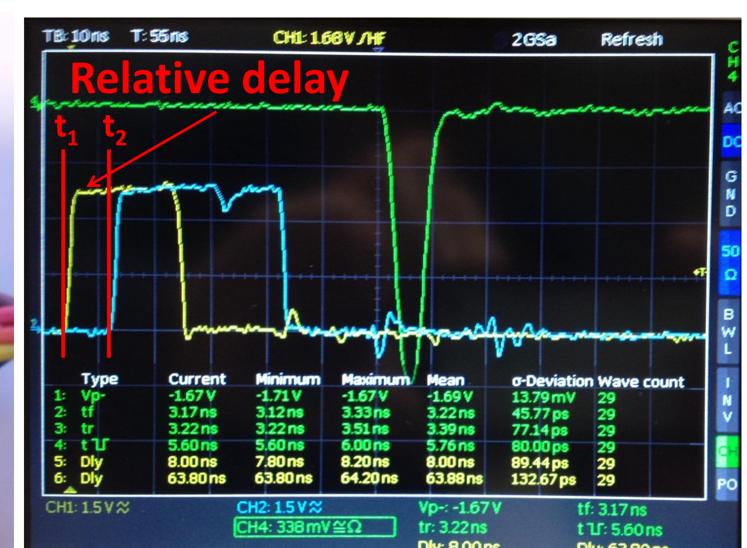


Mechanical operation testing in water



Light sources

- Light sources are important for photosensor calib
  - Gain, timing calibration & detector stability monitoring
    - SK employs laser (N_2, LD), Xe lamp
- LED is a candidate for HK light calib source
  - Compact, cheap, and stable
  - Used in many experiments; established technology
- Develop a fast-pulsed LED light source
  - Based on SNO/SNO+ LED calibration system
- A prototype module being available and plan to test in Super-K (next FY)



Summary

- Hyper-K baseline design established
  - Cavern excavation, water containment system, PMT support, water system, etc.
  - Design Report available as KEK and ICRR preprints:
    - KEK Preprint 2016-21, ICRR-Report-701-2016-1
  - Further improvement and optimization studies for the detector design
- Hyper-K detector calibration
  - Calibration will be critical to meet the physics goals
  - Adopt the calibration method established by SK
    - SK calibration paper: NIM A 737 (2014) 253-272
  - For improvement beyond Super-K, a wide varied R&D program on-going
- Plenty of scope for people to get involved!
- Open for new collaborators

Ni+Cf source

[Super-K]

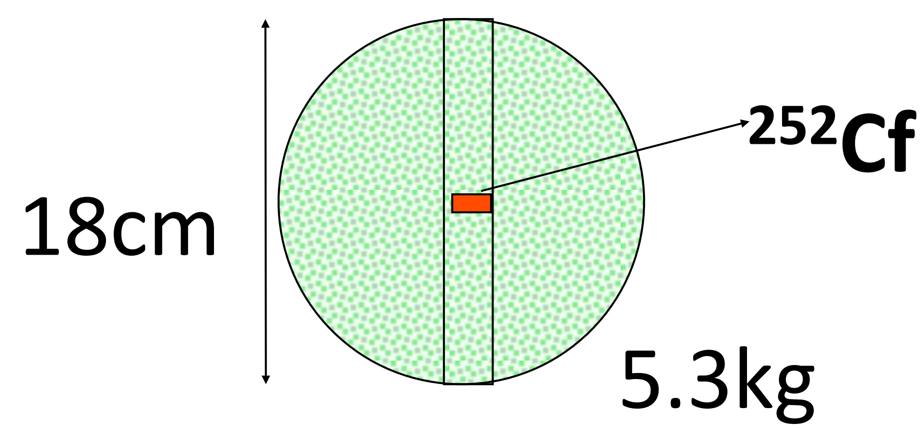
- Gamma ray source

$$^{58}Ni(n,\gamma)^{59}Ni$$

- 7, 8, and 9MeV γ
- 20-70hits/event

Reaction	natural abundance of Nickel (%)	capture cross section (barns)	γ energy (MeV)
$^{58}Ni(n,\gamma)^{59}Ni^*$	67.88	4.4	9.000
$^{60}Ni(n,\gamma)^{61}Ni^*$	26.23	2.6	7.820
$^{62}Ni(n,\gamma)^{63}Ni^*$	3.66	15	6.838
$^{64}Ni(n,\gamma)^{65}Ni^*$	1.08	1.52	6.098

Polyethylene pellet mixed with NiO powder bonded by Araldite epoxy resin.



Neutron generators

- Neutron source is a good for low energy calibration:

  $^{16}O + n \rightarrow {}^{16}N$ (decay 4.3 MeV e^- + 6.1 MeV γ)

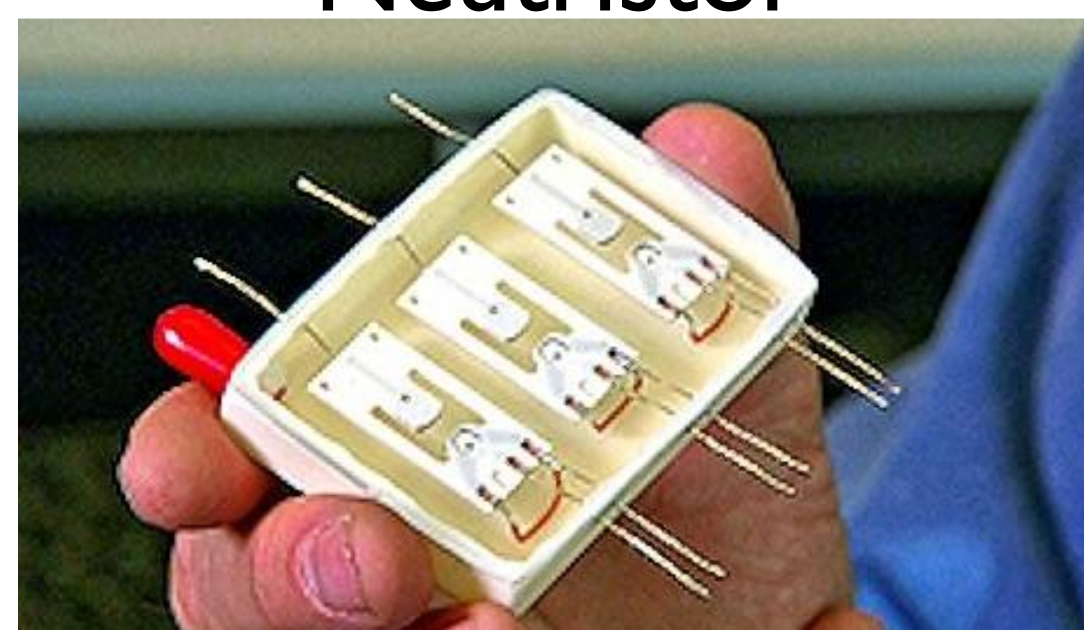
  and calib for neutron tagging

- DT generator employed in SK
  - not mobile, and expensive

- Compact neutron generator will be very useful for HK calib
- R&D of a neutron generator, called "Neutristor"
  - compact and inexpensive

SK DT generator

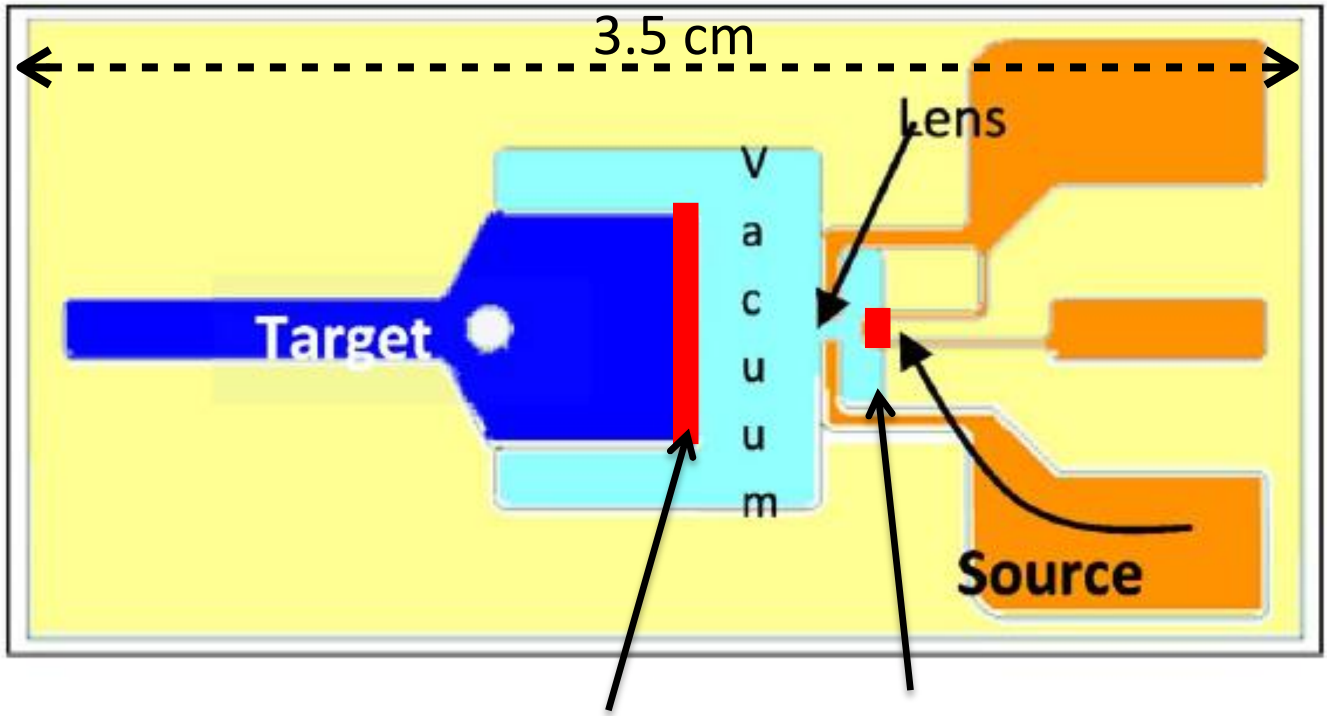
Neutristor



(IEEE Transactions on Plasma Science Vol.40 No.90, Sep 2012)

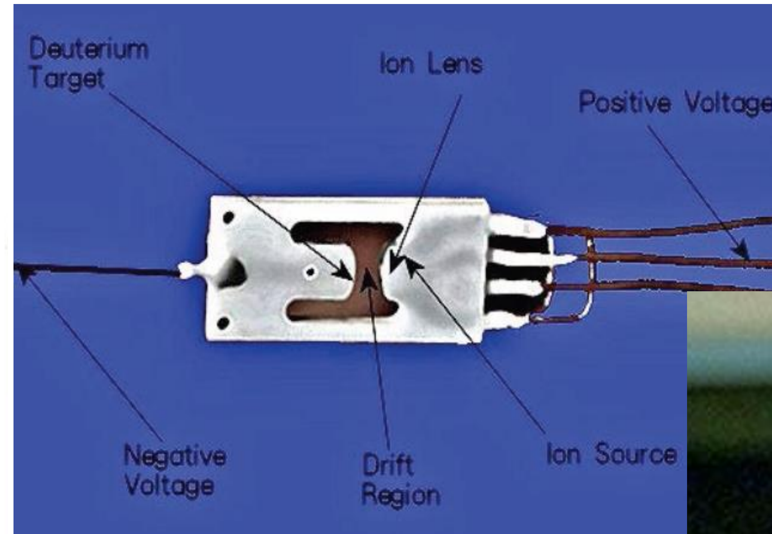
Compact neutron generator

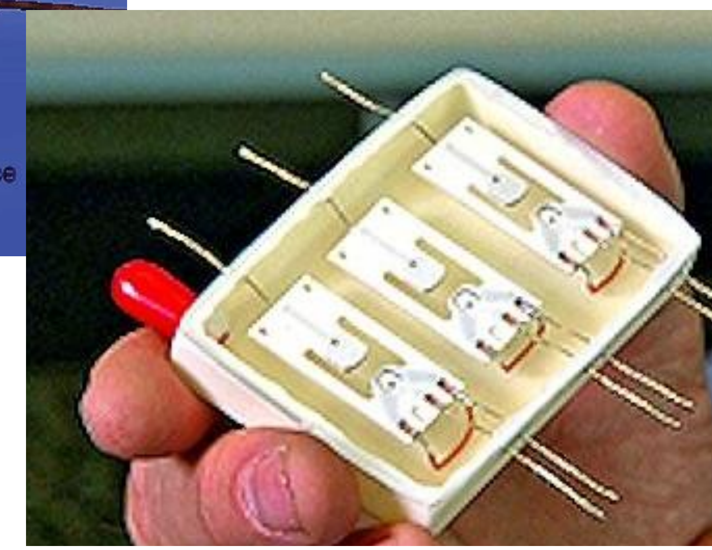
(IEEE Transactions on Plasma Science Vol.40 No.90, Sep 2012)



Target Film:
Ti • ^{3}H (2μm)

Source Film:
Ti • ^{2}H





- Deuterium and Tritium thin films are deposited onto the ion source and target element (red pieces in the left figure)
- Apply O(300)V at the source gap causes breakdown and the formation of an ionizing it at the same time
- An accelerating voltage O(15)kV across the target is used to accelerate $^{2}H^{+}$ ions onto the target film to induce D-T fusion
- An electrostatic lens is used to focus the ion flow to the target

OD calibration

- Deploy identical light source to ID
  - SK relative timing offset: T(ID)-T(OD)~5ns
  - Calibrated with light source (laser)