Hyper-Kamiokande Detector

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for Hyper-Kamiokande Working Group

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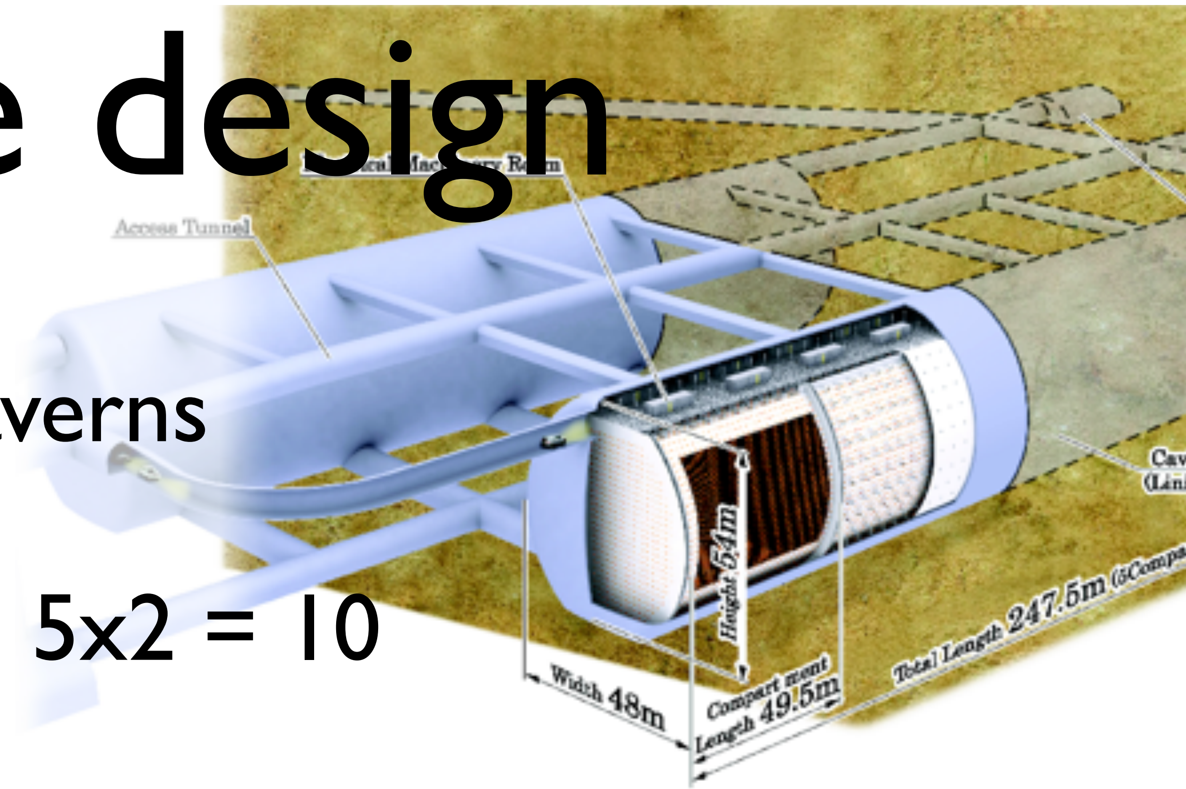
Outline

- Hyper-Kamiokande detector baseline design
  - Cavern construction
  - Tank construction
    - Lining, photo-sensor support, etc

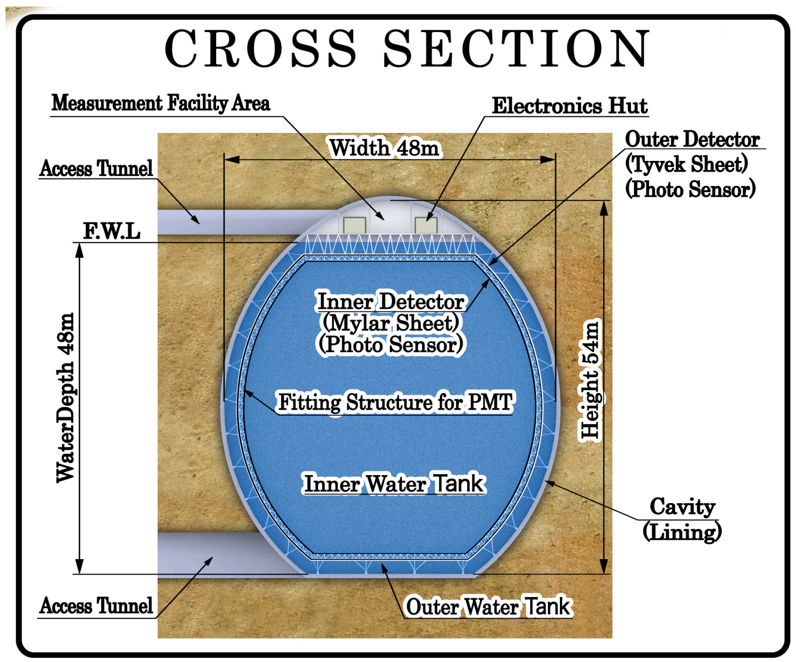
- R&Ds for Hyper-Kamiokande

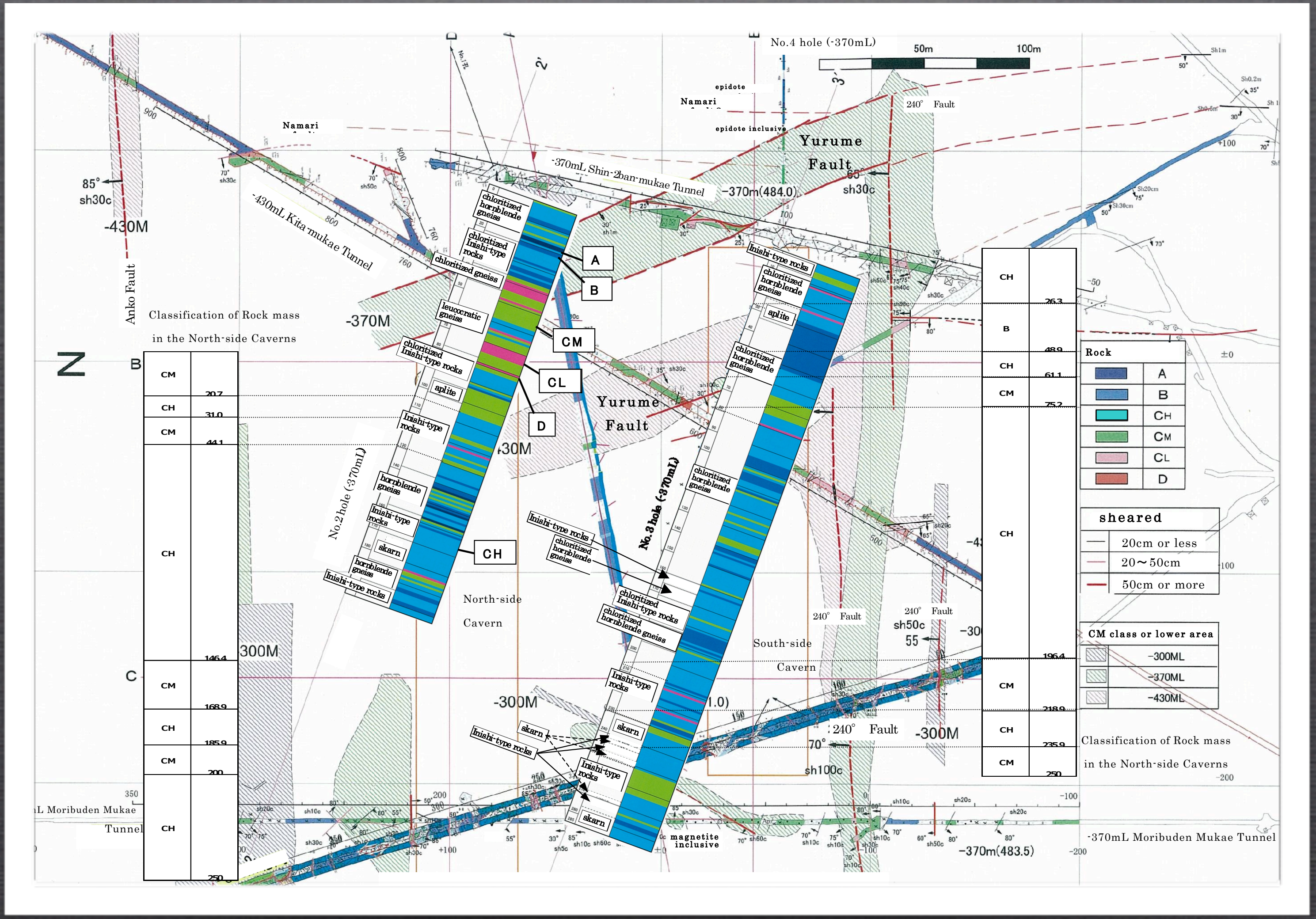
- Summary

Key parameters of the baseline design



- Cavern size:
  48m(W) x 54m(H) x 250m(L) x 2 caverns
- Cavern shape: oval shape (egg shape)
- Optically separated compartments: 5x2 = 10
- Water Volume:
  - Total: 0.496x2=0.992 Megaton
  - ID volume: 0.74 Mton
  - Fiducial Volume: 0.056x10 = 0.56 Mton (25 x Super-K)
  - Depth of tank water: 48m
- Number of photo-sensors:
  - ID: ~99,000 20" photo-sensors (20% photo-coverage)
  - OD: ~25,000 8" photo-sensors (same coverage as SK)

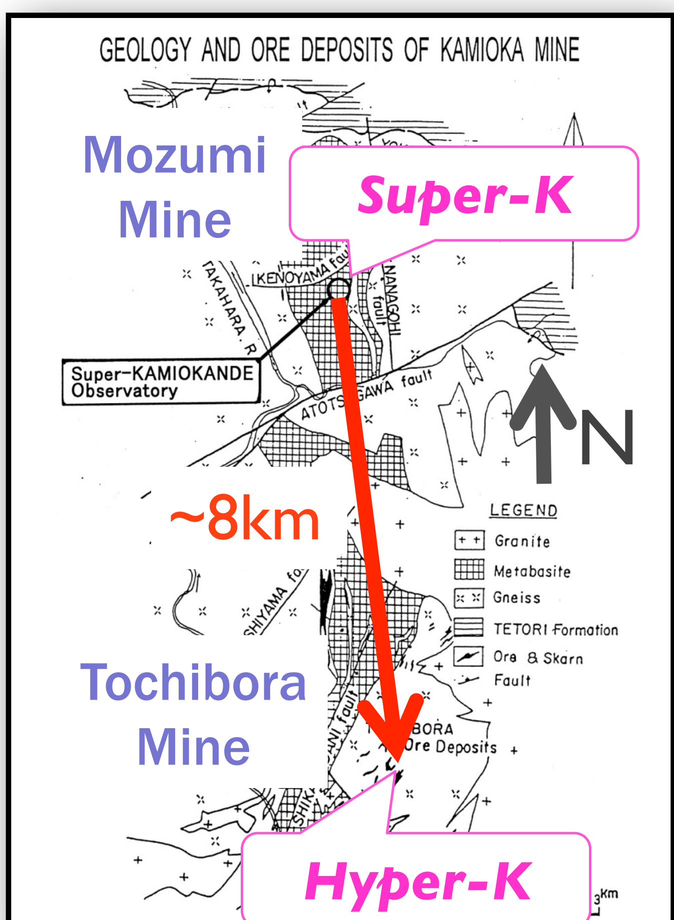


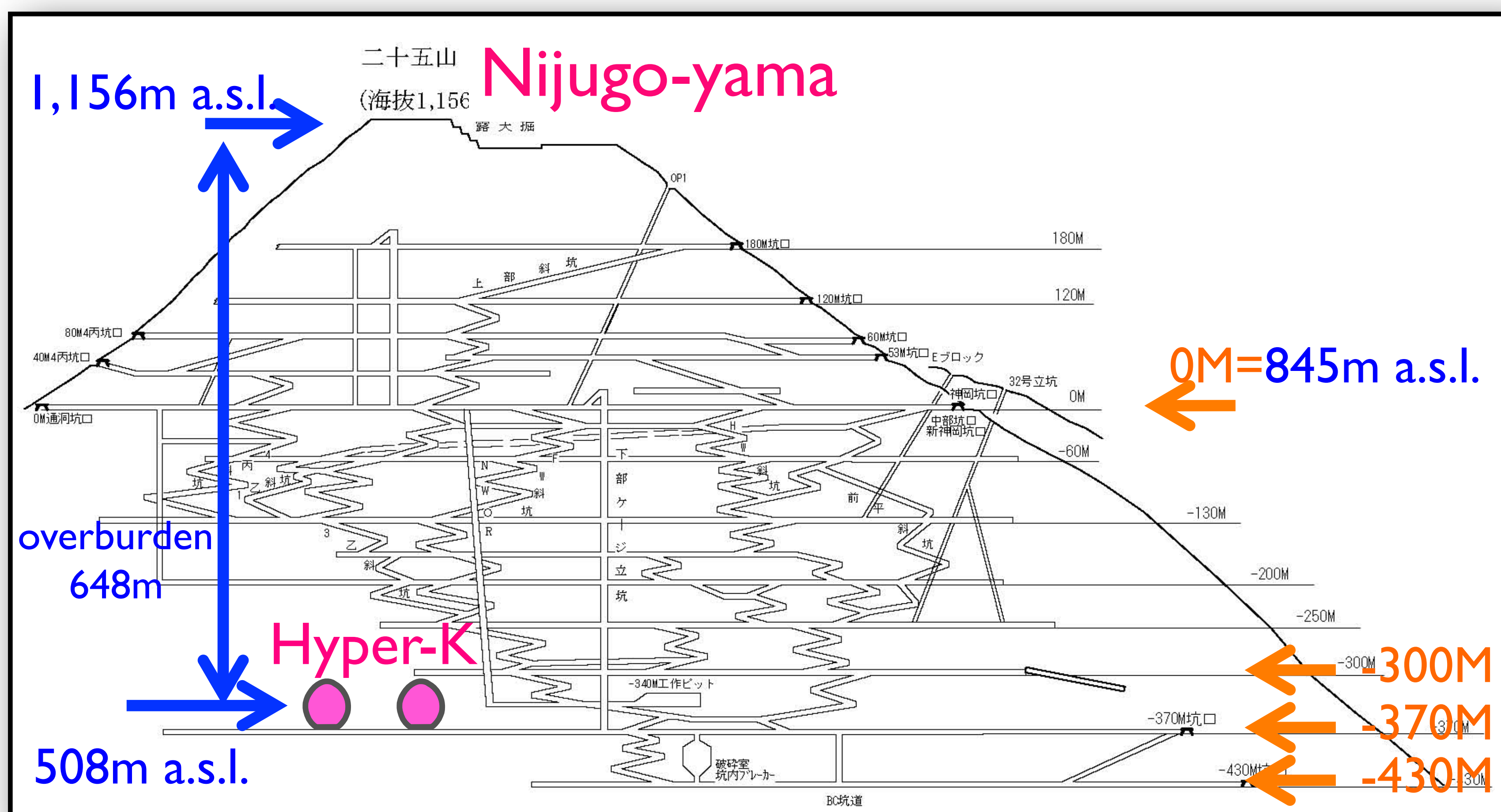


Cavern Construction

Detector location/site

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



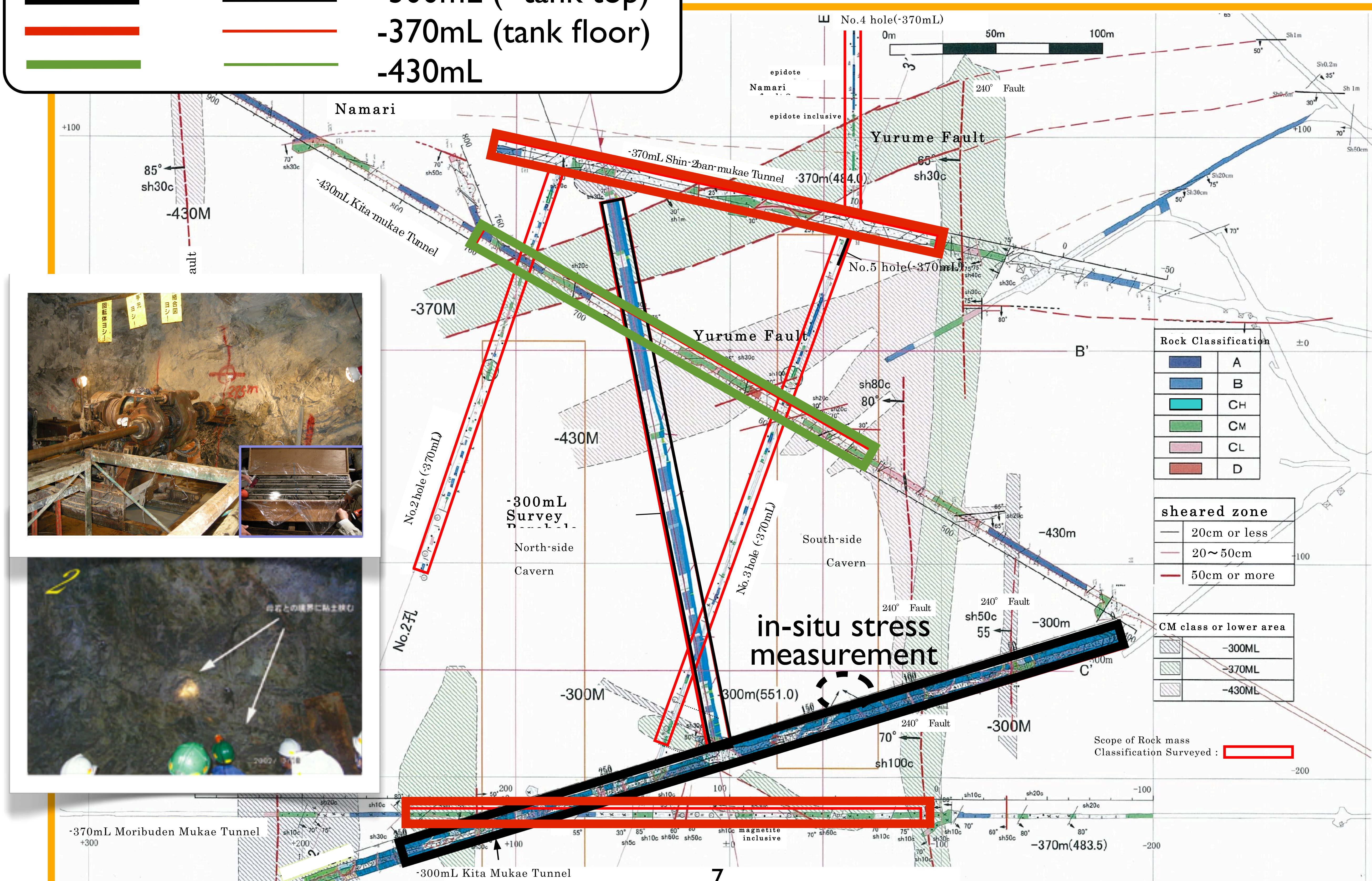


Geological survey at Tochibora-site

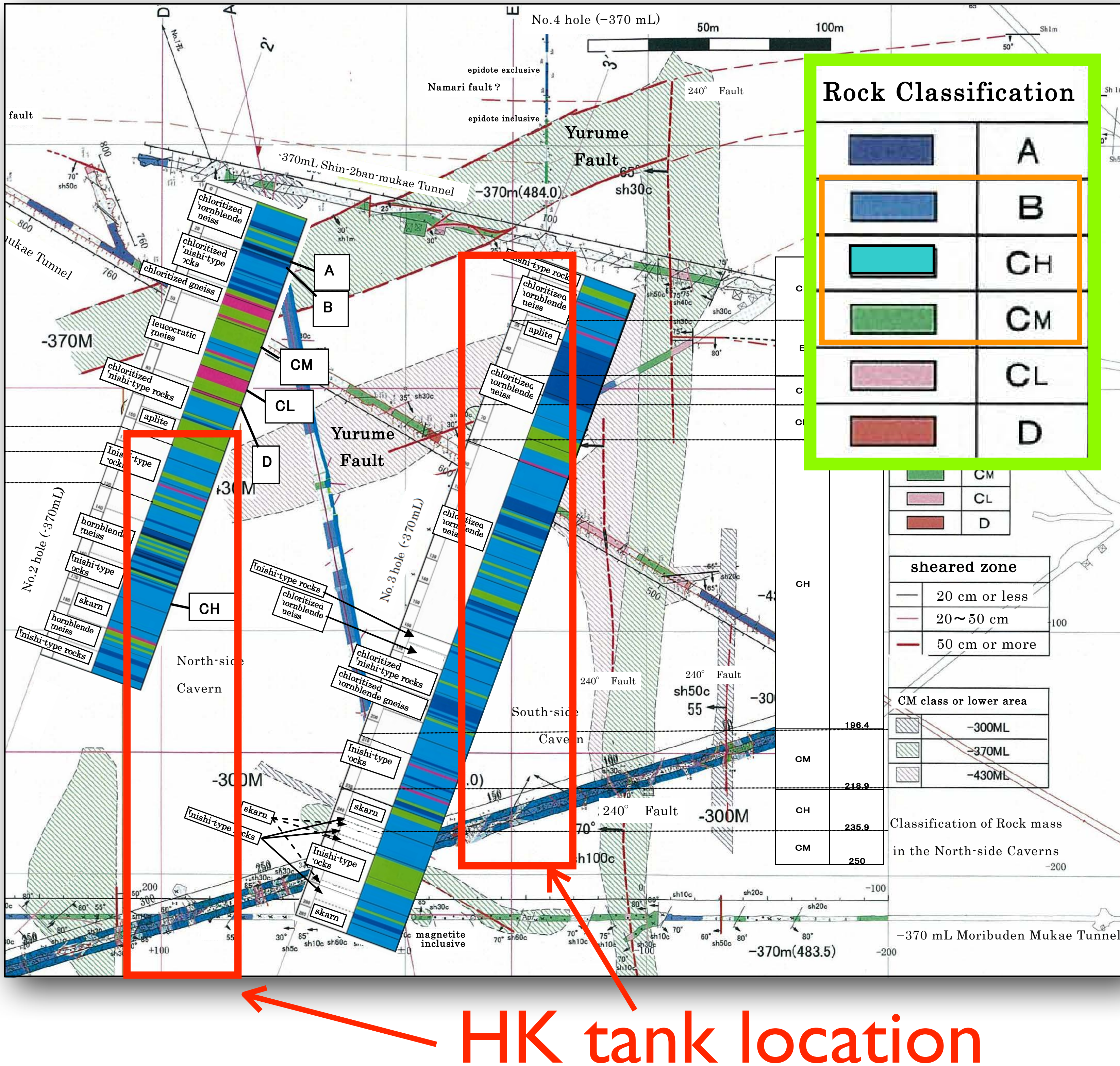
- The candidate site vicinity had been used for mining, and historically many surveys have been done in wide area and at several levels/depths.
    - ex. mapping the location of faults
- There are many existing tunnels and shafts at the around candidate site.
- The rock mass characterization has been done by mapping the existing tunnels and geological logging of rock core samples.

Overview of the geological survey

	Tunnel	Bore hole core
-300mL (~tank top)	black (thick)	black (thin)
-370mL (tank floor)	red (thick)	red (thin)
-430mL	green (thick)	green (thin)



Rock mass characterization



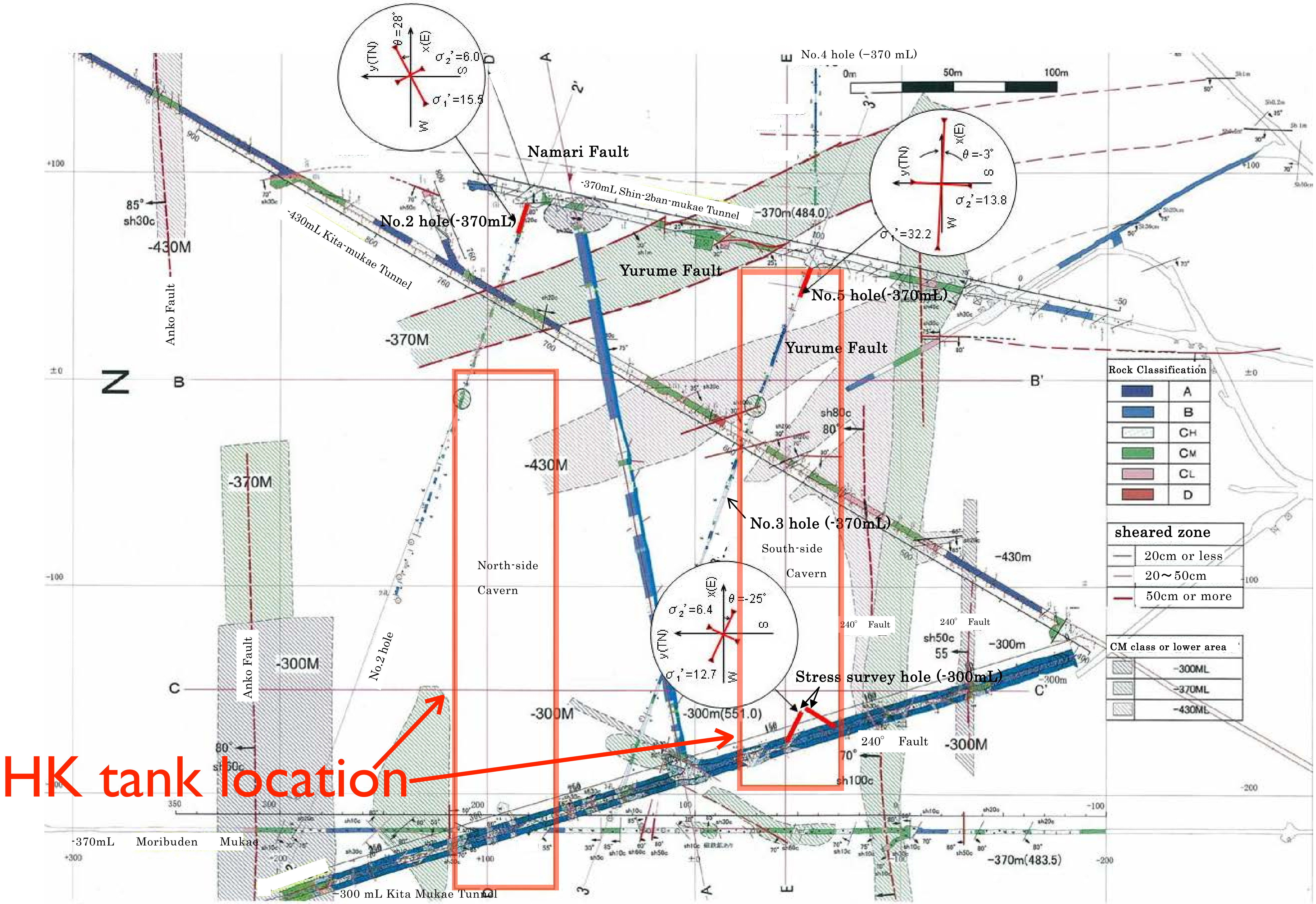
From the survey results, rock mass characteristics are classified into 6 categories: A, B, CH, CM, CL and D (defined by CRIEPI).

'A' (blue) is the highest grade rock and 'D' (red) is lowest.

Based on these results, established a model of the rock class distribution at HK tank locations.

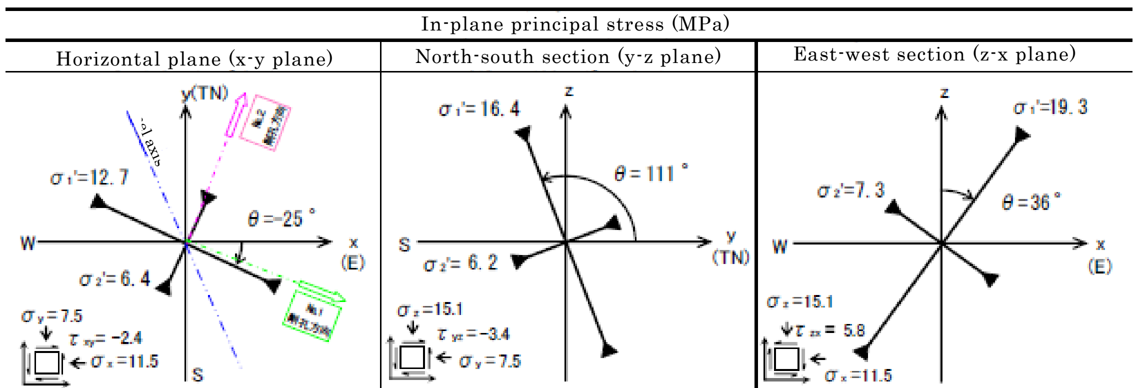
(CRIEPI: The Central Research Institute of Electric Power Industry)

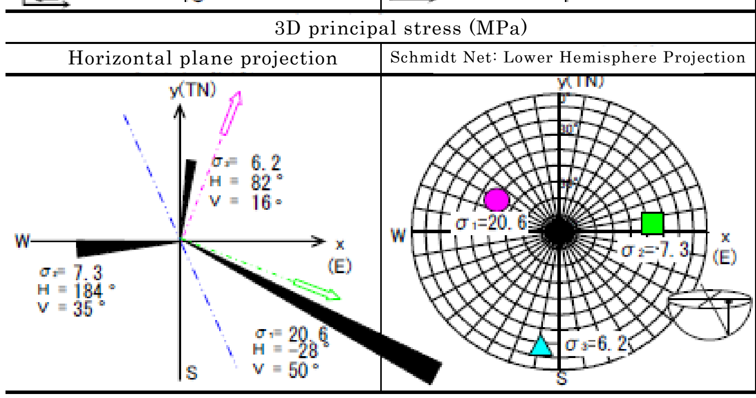
Initial stress measurements



Cavern stability analysis

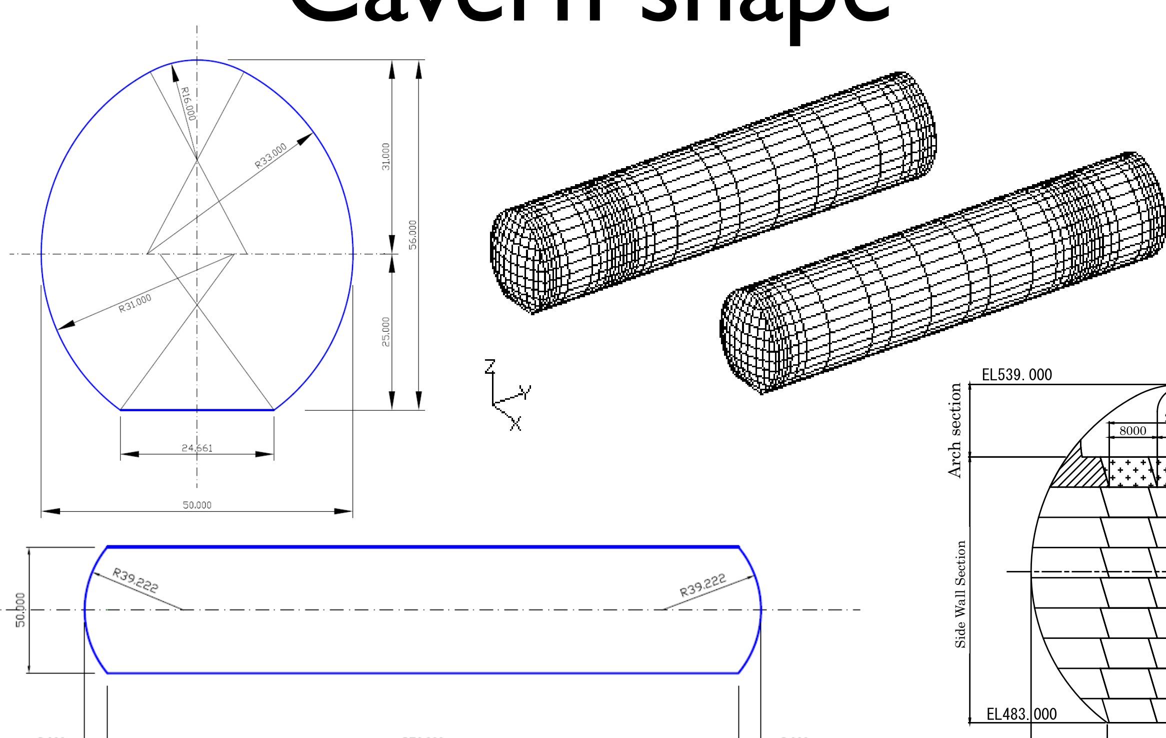
Initial stress



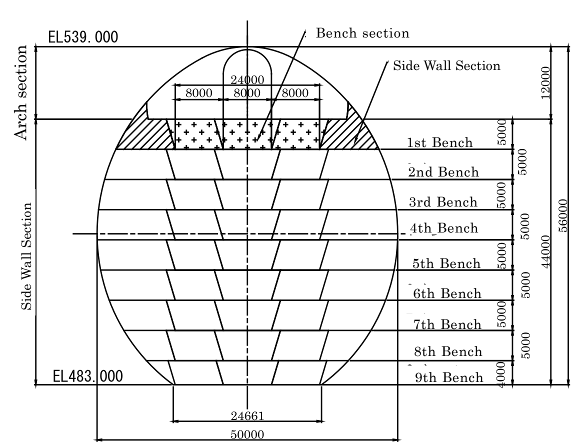


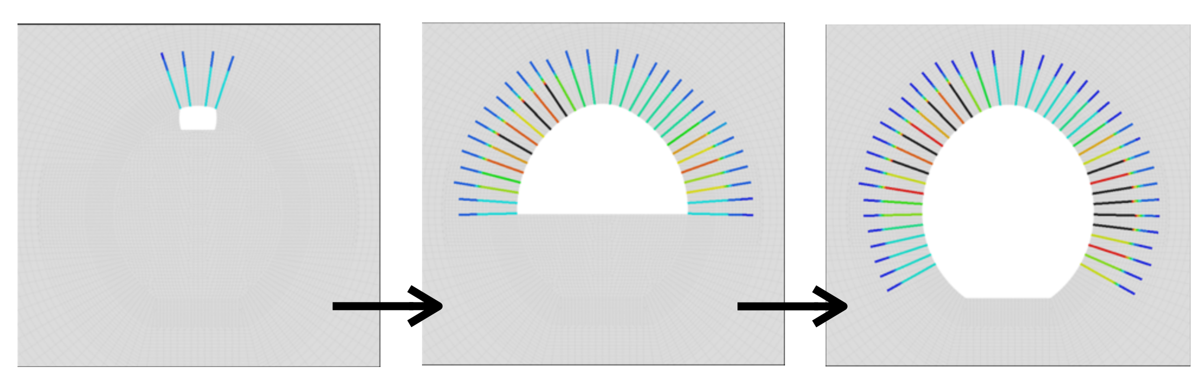
Six Stress Components (MPa)	
σ_x	11.5
σ_y	7.5
σ_z	15.1
τ_{xy}	-2.4
τ_{yz}	-3.4
τ_{zx}	5.8

Cavern shape



- Based on the survey results (rock mass characteristics and initial stresses), structural stability of caverns has been studied
  - Elasto-plastic, static analysis & adopt Hoek-Brown yield (failure) criteria
- The excavation-steps taken into account in the studies
  - Include the cavern supporting material: shotcrete, rock-bolt, and Pre-Stressed (PS) anchor



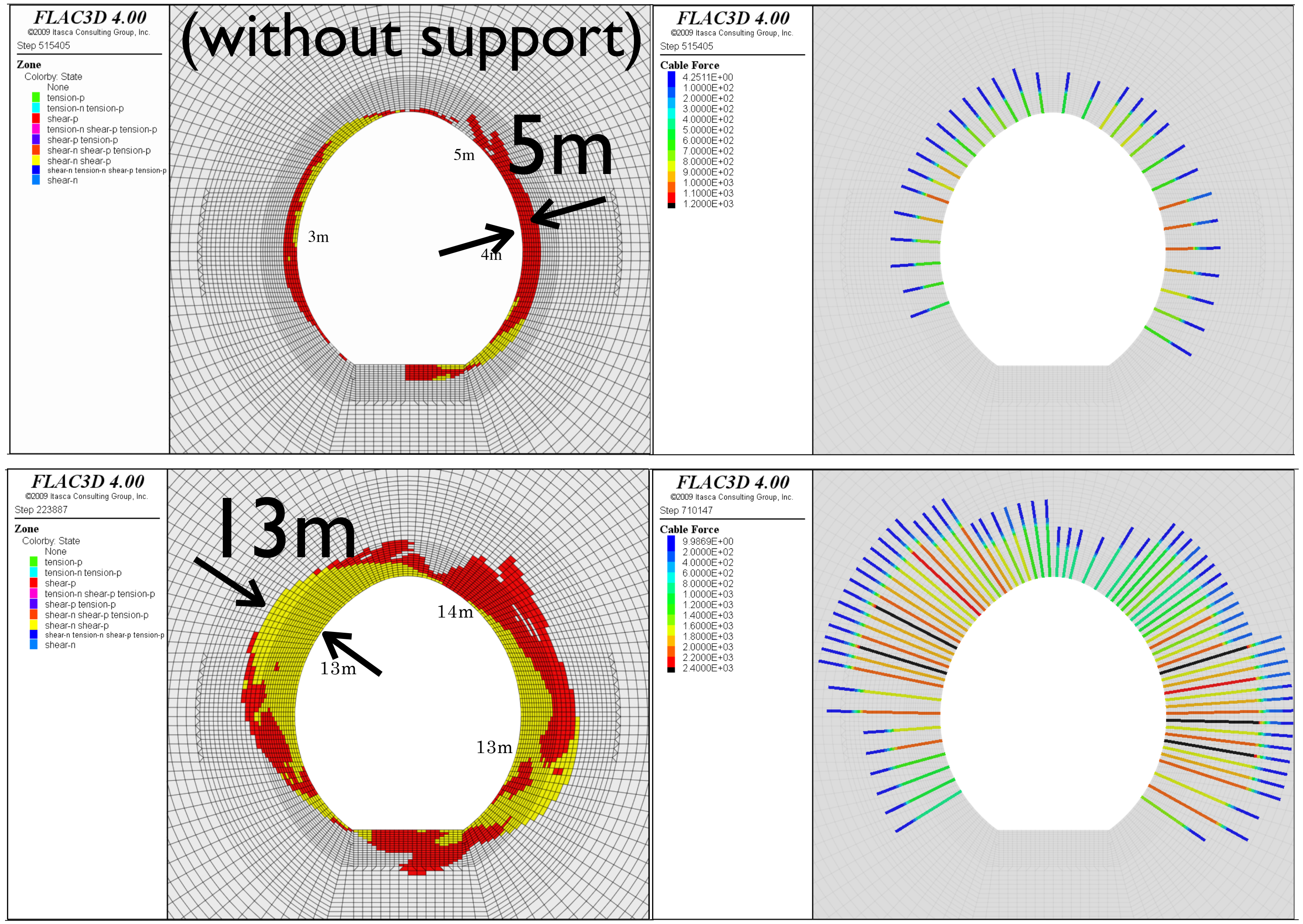


Cavern Stability

Plasticity region depth PS-anchor tension

CH-class
(>70% at HK location)

CM-class
(20~30% at HK location)



- Plasticity region ~13m at most (CM class) → affordable level
  - Proved in the existing underground facilities (ex. power plants)
- For all rock mass classes (B, CH, CM), HK caverns can be constructed by the existing excavation/support techniques.

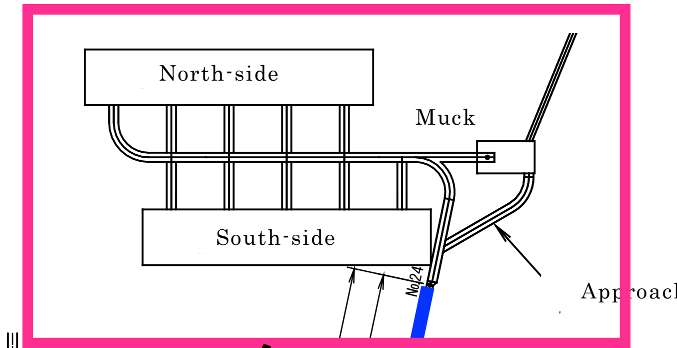
Construction procedure

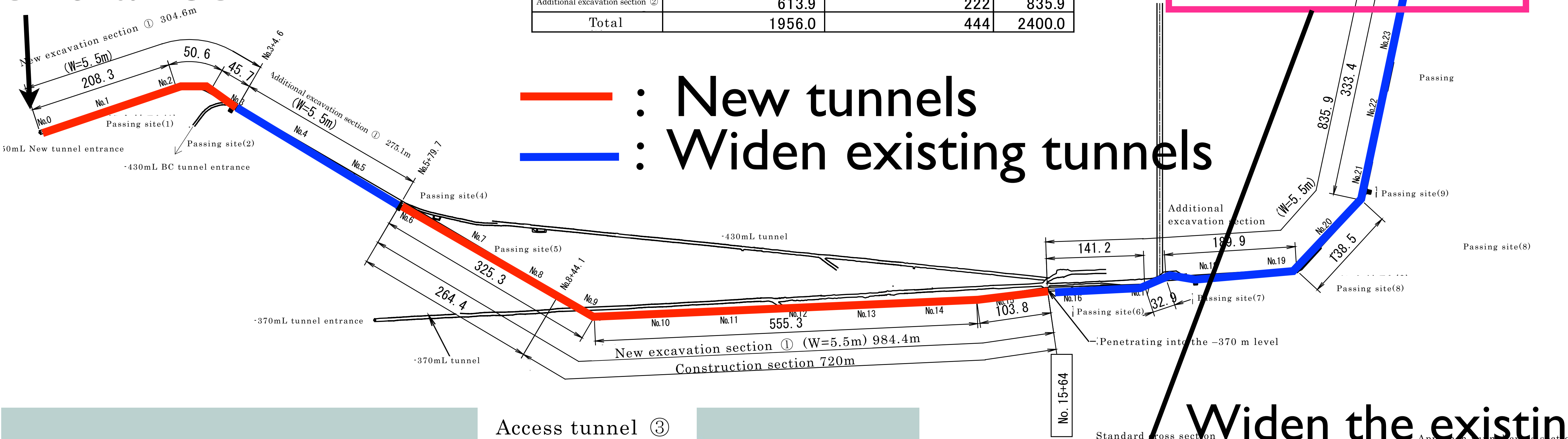
- Two major construction stages:
- Tunnel construction [~2 years]
  - Construct new tunnels, and widen the existing tunnels, arch tunnels, etc.
  - Construct the shafts/tunnels for muck (rock waste) transportation, belt conveyer tunnels, etc.
- Cavern construction [~3 years]
  - Excavate caverns and install prestressed anchors, etc
    - North and south caverns in parallel
  - Construct water purification rooms

Tunnel construction

Mine entrance

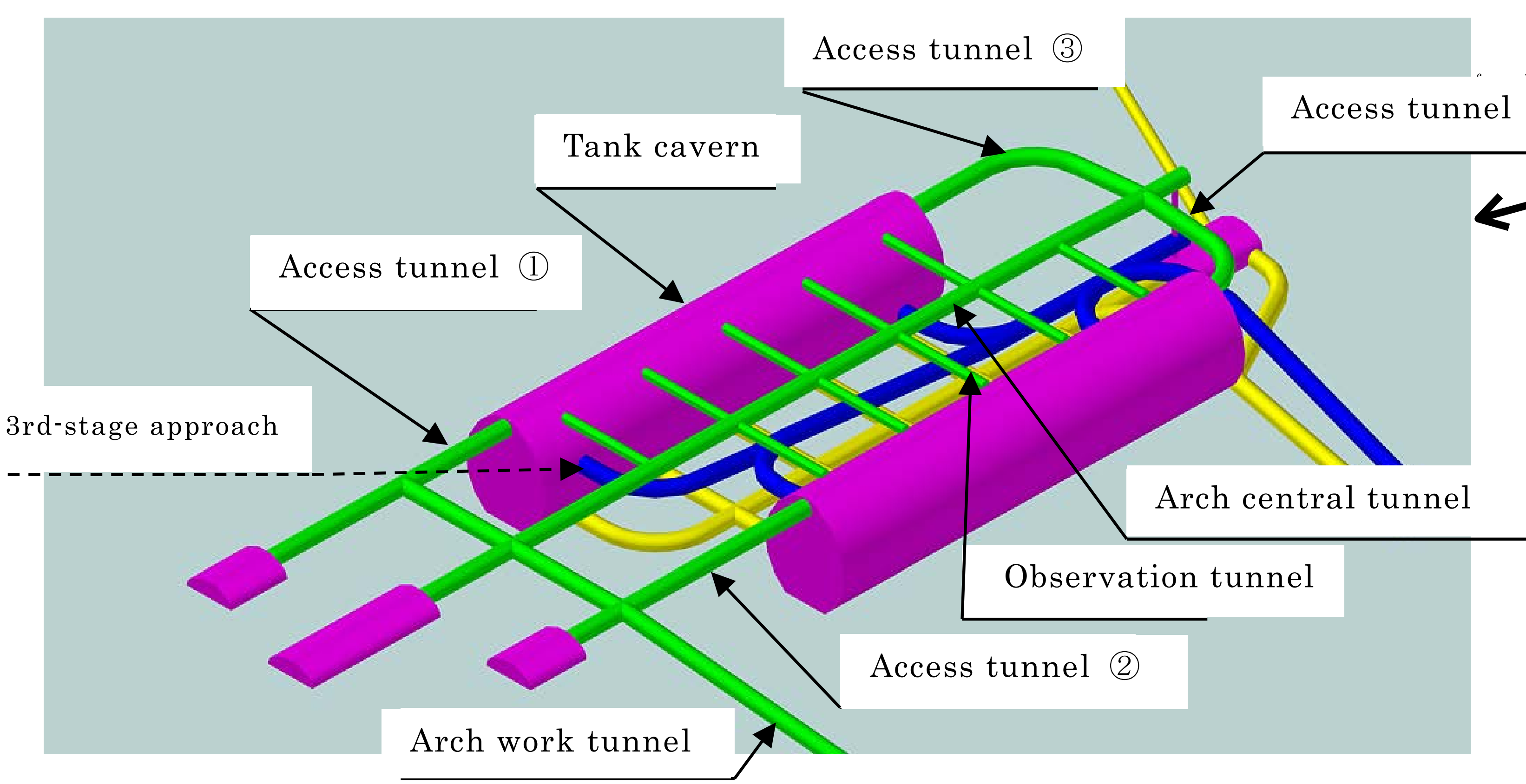
	Standard cross (W = 5.5 m, H = 5.0	Widened cross-section of (W = 7.0 m, H = 5.4	Total
New excavation section ①	252.6	52	304.6
Additional excavation section ①	191.1	84	275.1
New excavation section ②	898.4	86	984.4
Additional excavation section ②	613.9	222	835.9
Total	1956.0	444	2400.0



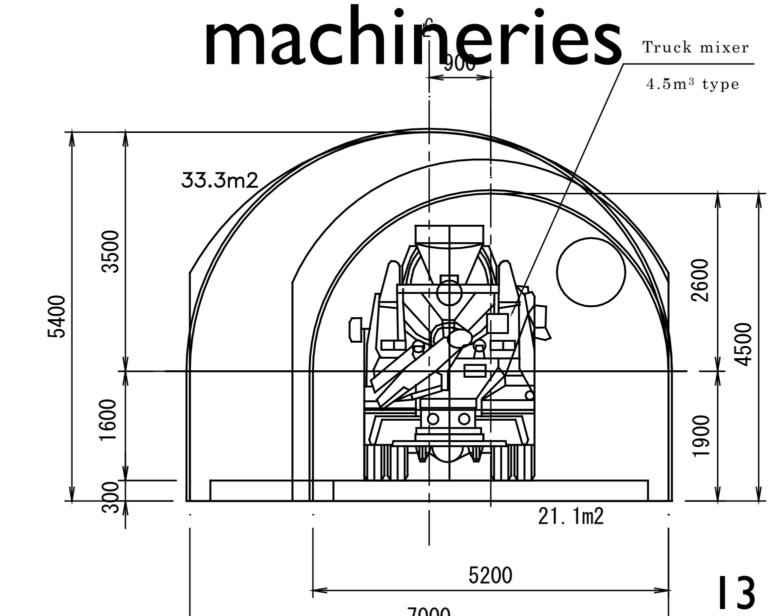


— : New tunnels

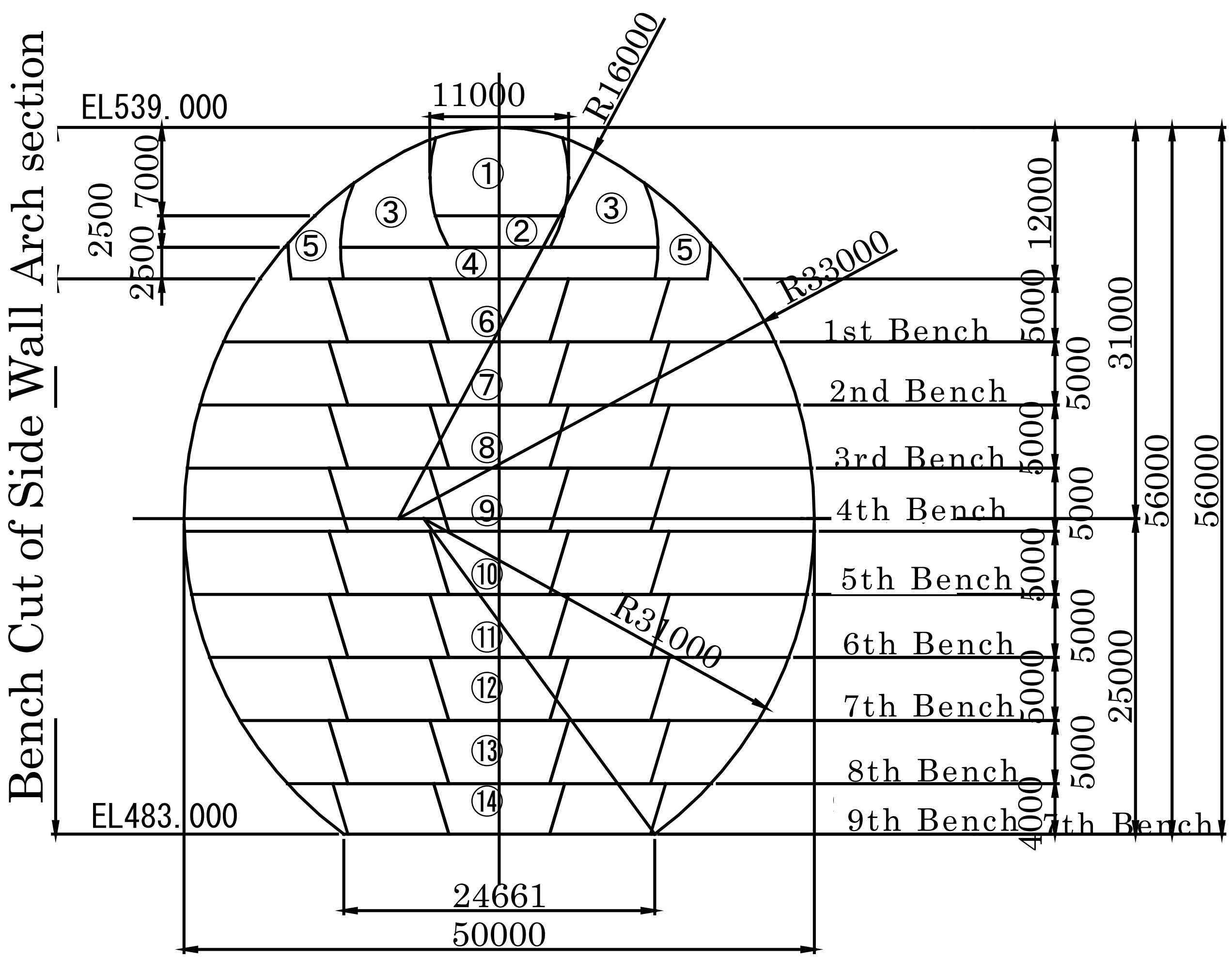
— : Widen existing tunnels



Widen the existing tunnels for heavy machineries

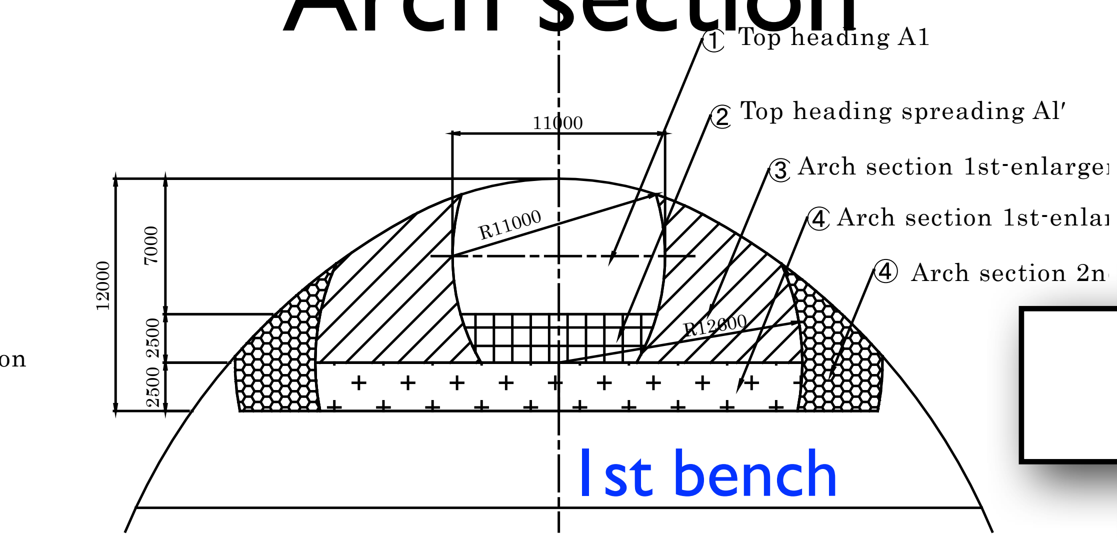


Cavern construction

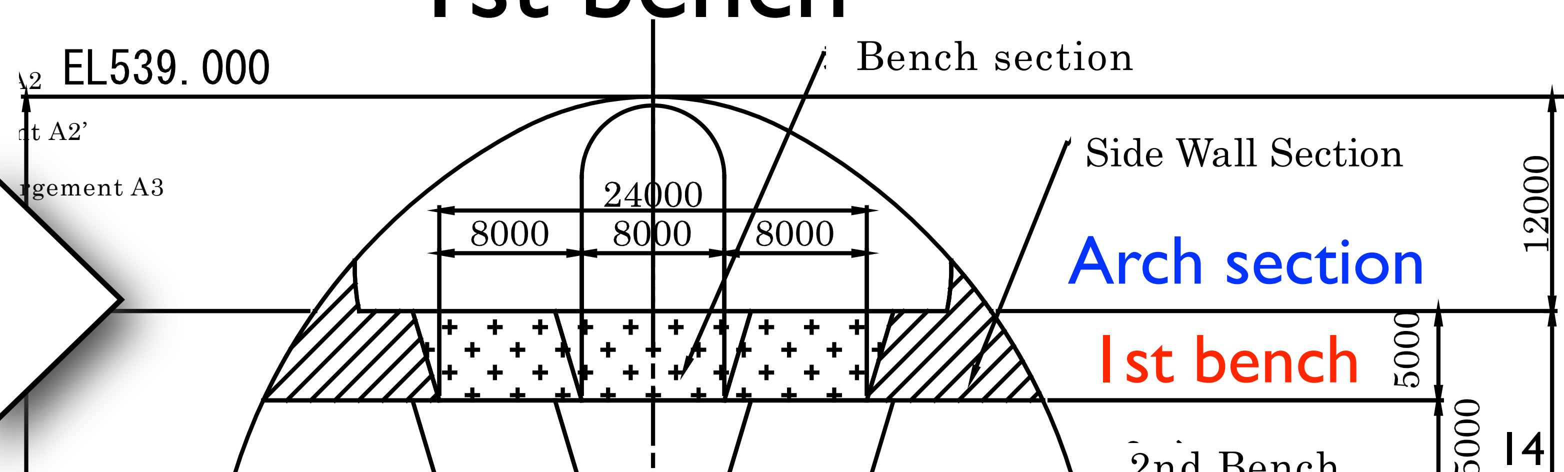


- Cavern construction goes from top to bottom step-by-step:
  - Arch section (top-most portion of the cavern)
  - 1st~9th benches
    - Each bench: ~5m height
- Install shotcrete, rock-bolt, PS-anchors at each step

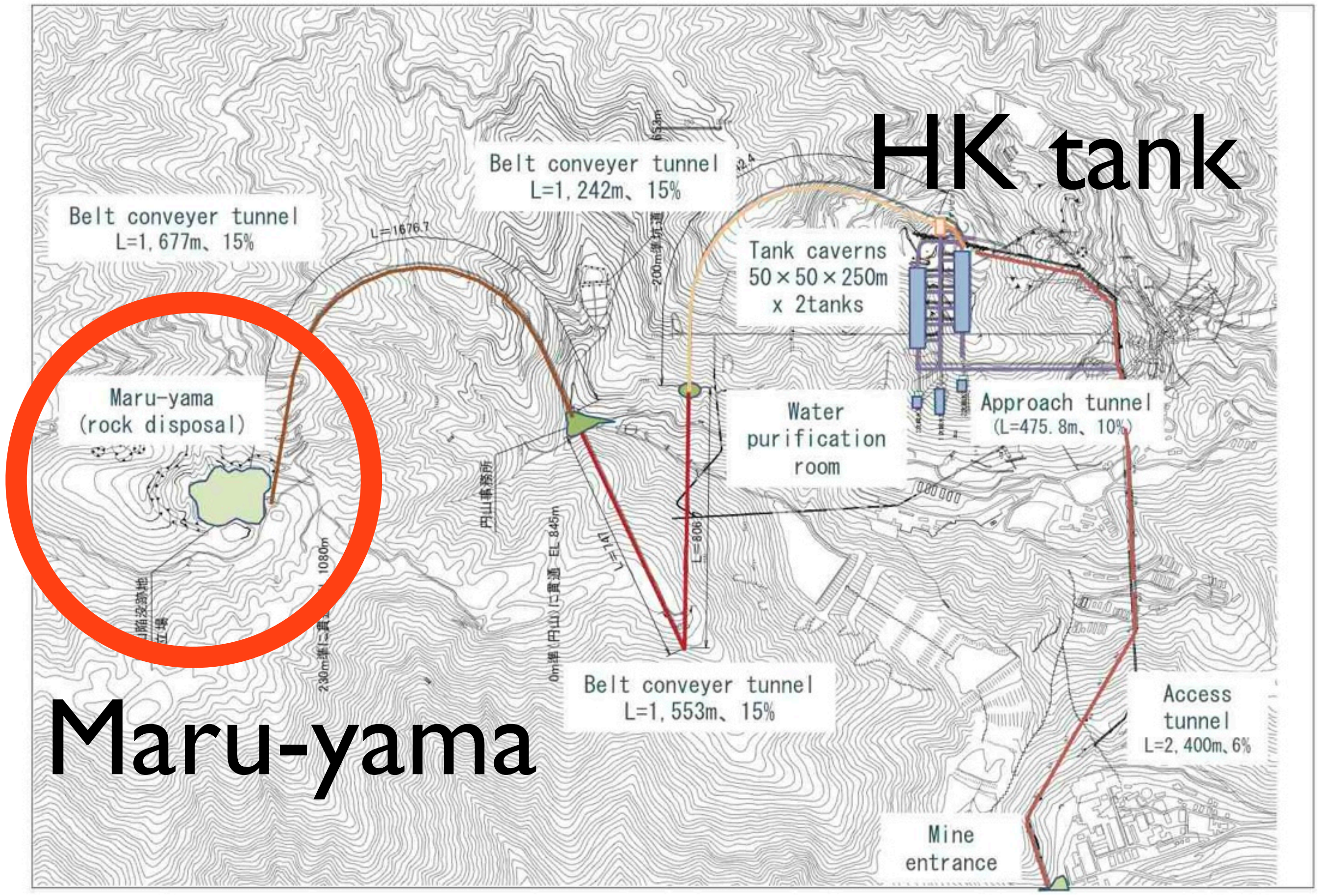
Arch section

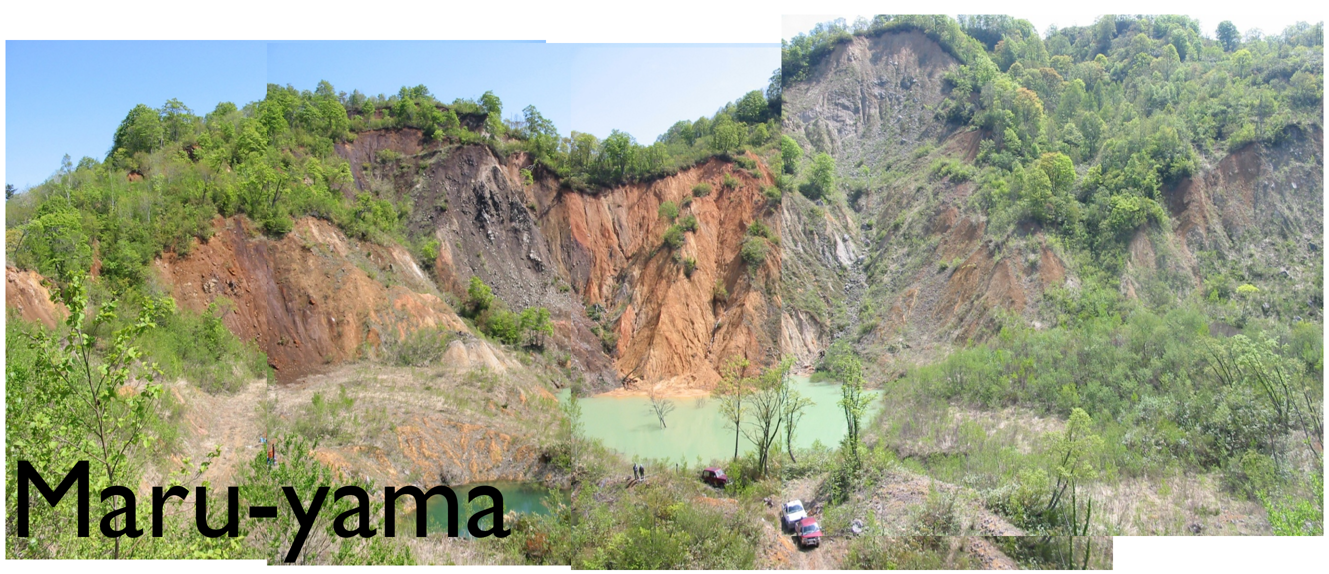


1st bench



Muck disposal

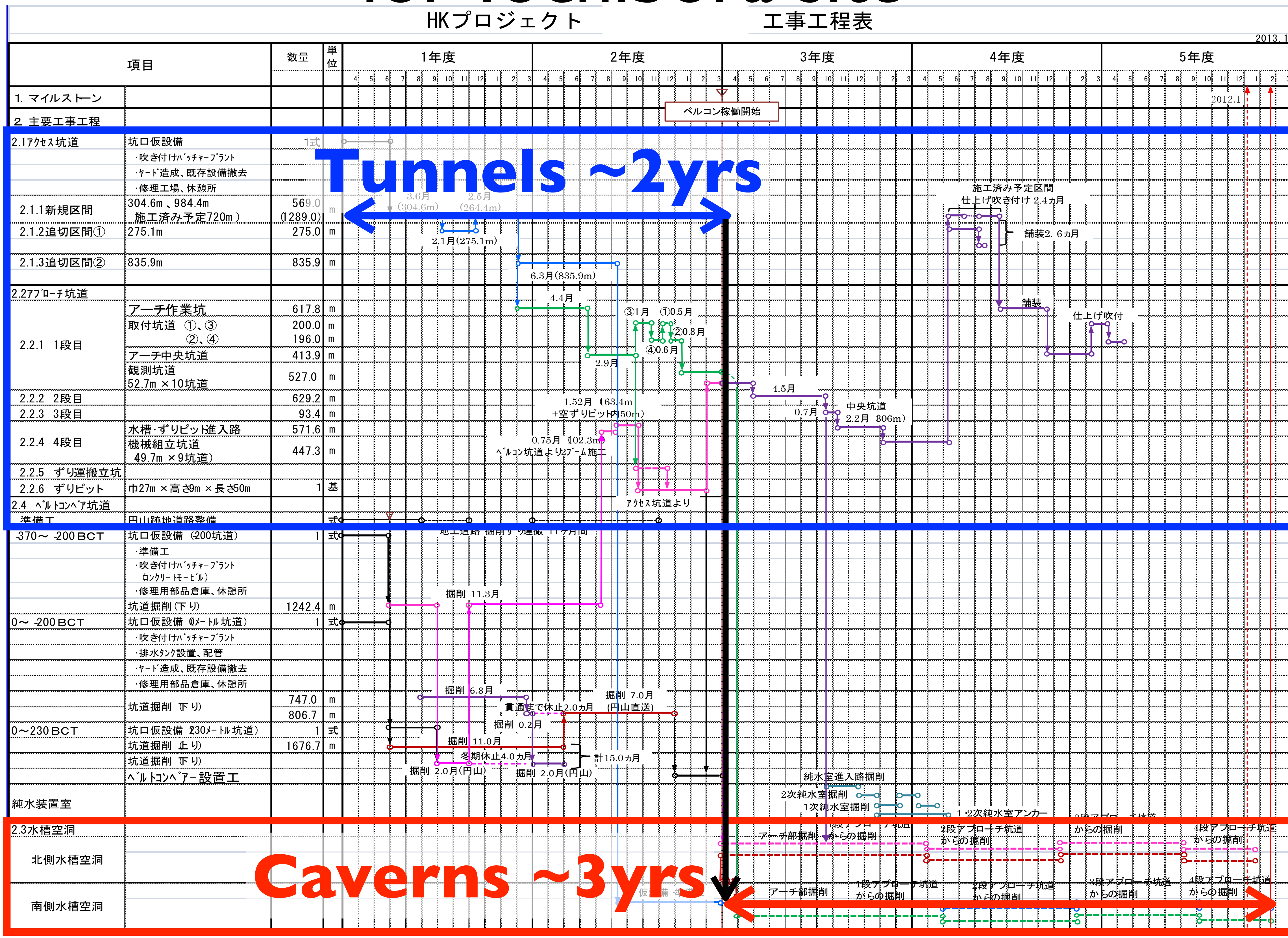




- Muck (rock waste) transported to Maru-yama using belt-conveyor
  - ~5 km long path from HK site (Tochibora)
  - Maximum excavation volume: 4,000 m^3 / day
- Need detailed survey/study on bedrock condition of Maru-yama

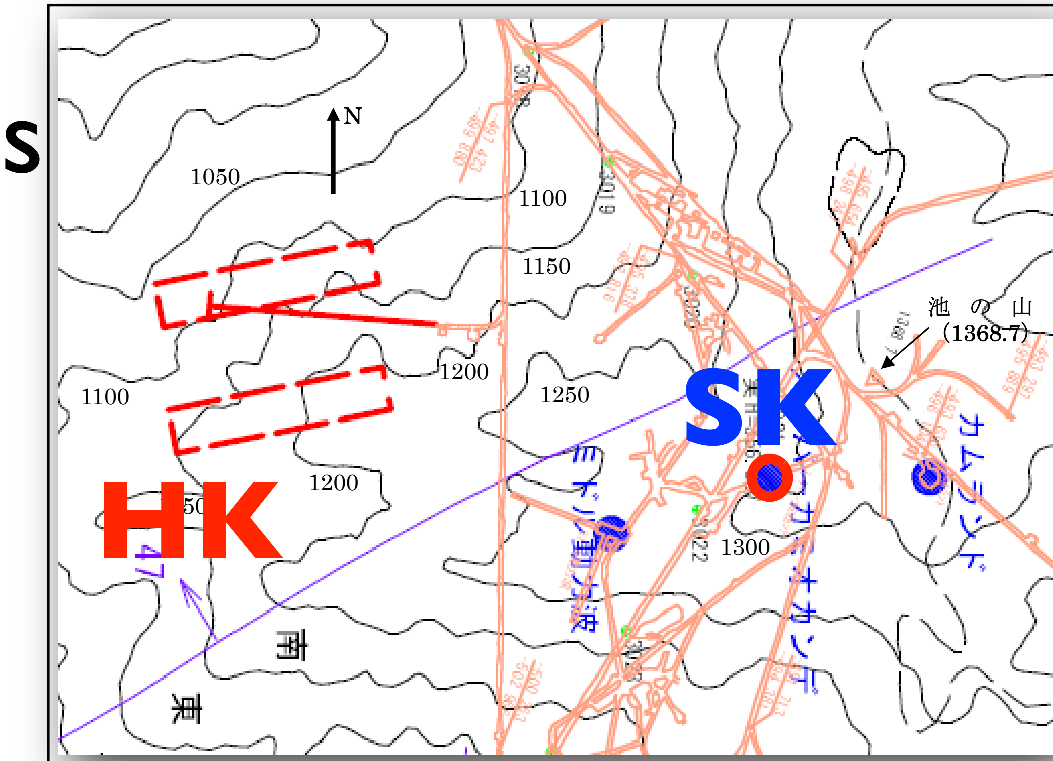
Construction schedule

for Tochibora site

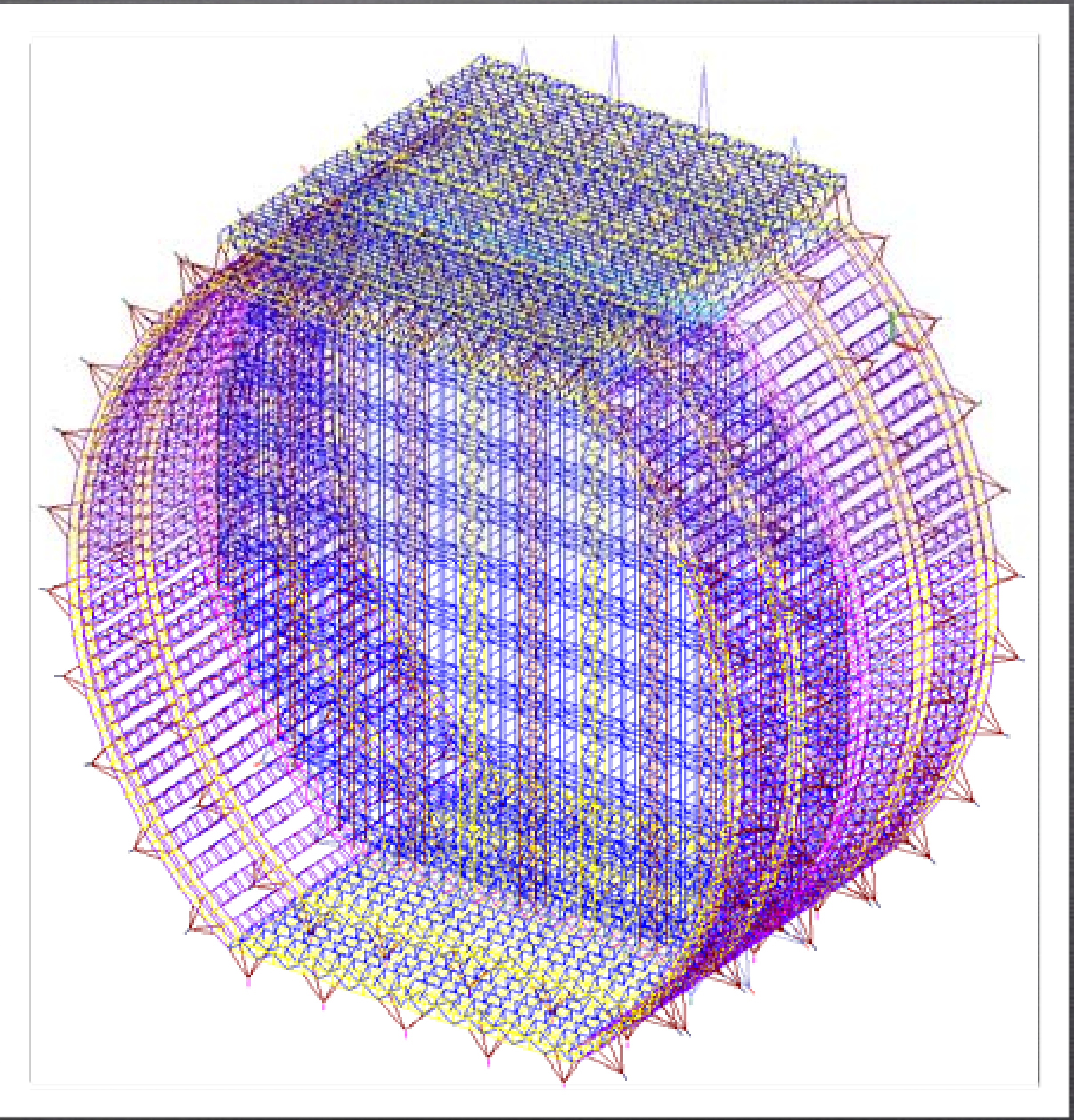


Other candidate site

- Mozumi-site would be a second choice, where potentially provides more overburden
  - >700m (cf. Tochibora-site: ~650m)
    - Preferable for low energy physics
  - Under Mt. Ikenoyama (near SK)
  - No geological survey in the past



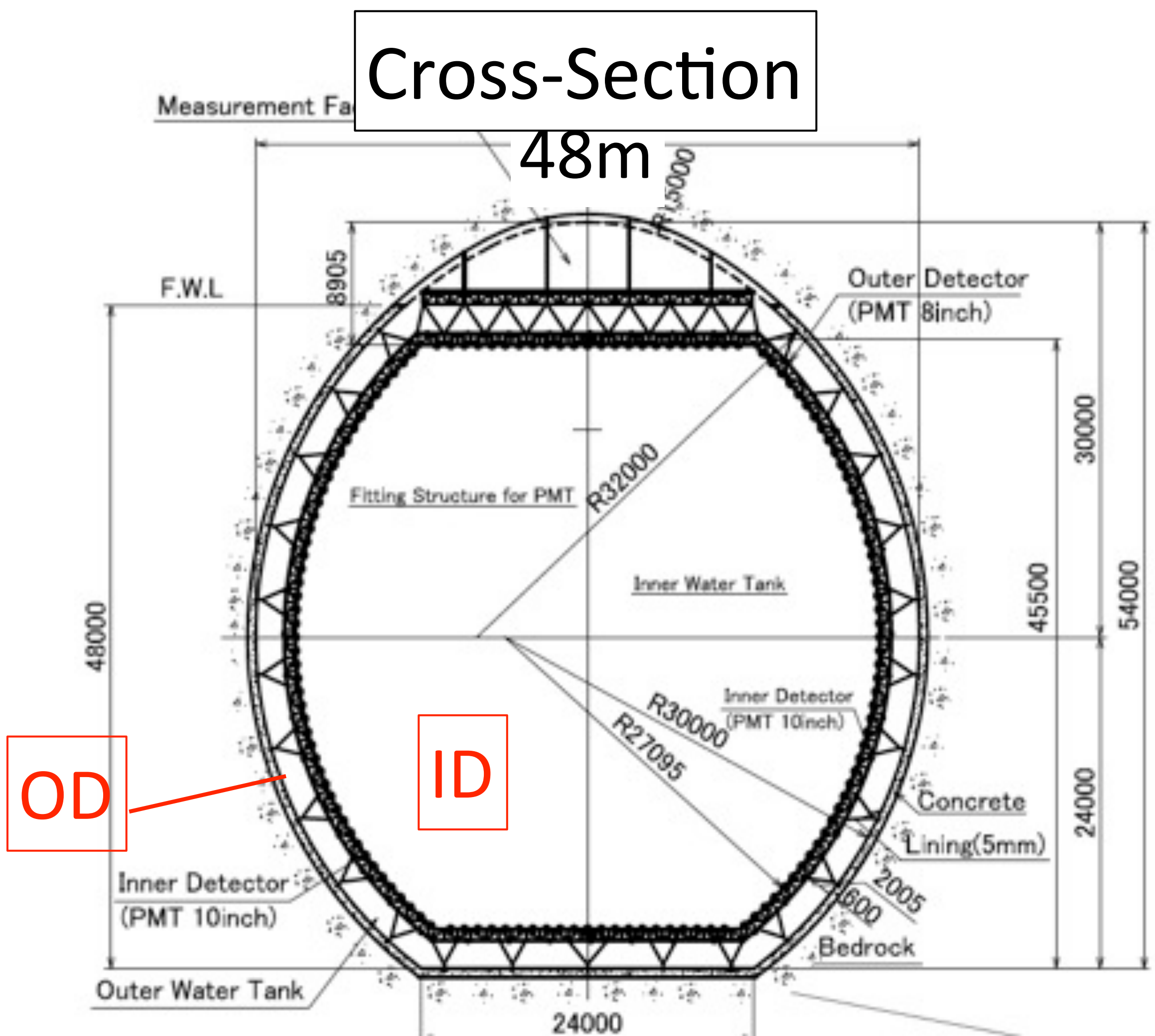
- Geological surveys carried out in the late 2013
  - 250m long rock sampling (for rock characterization)
  - ~14m (in total) rock samplings (for rock strength)
- Based on the survey results, the cavern stability analyses in progress
  - HK construction cost and schedule will follow
- Decision by HK physics sensitivity & cost/schedule

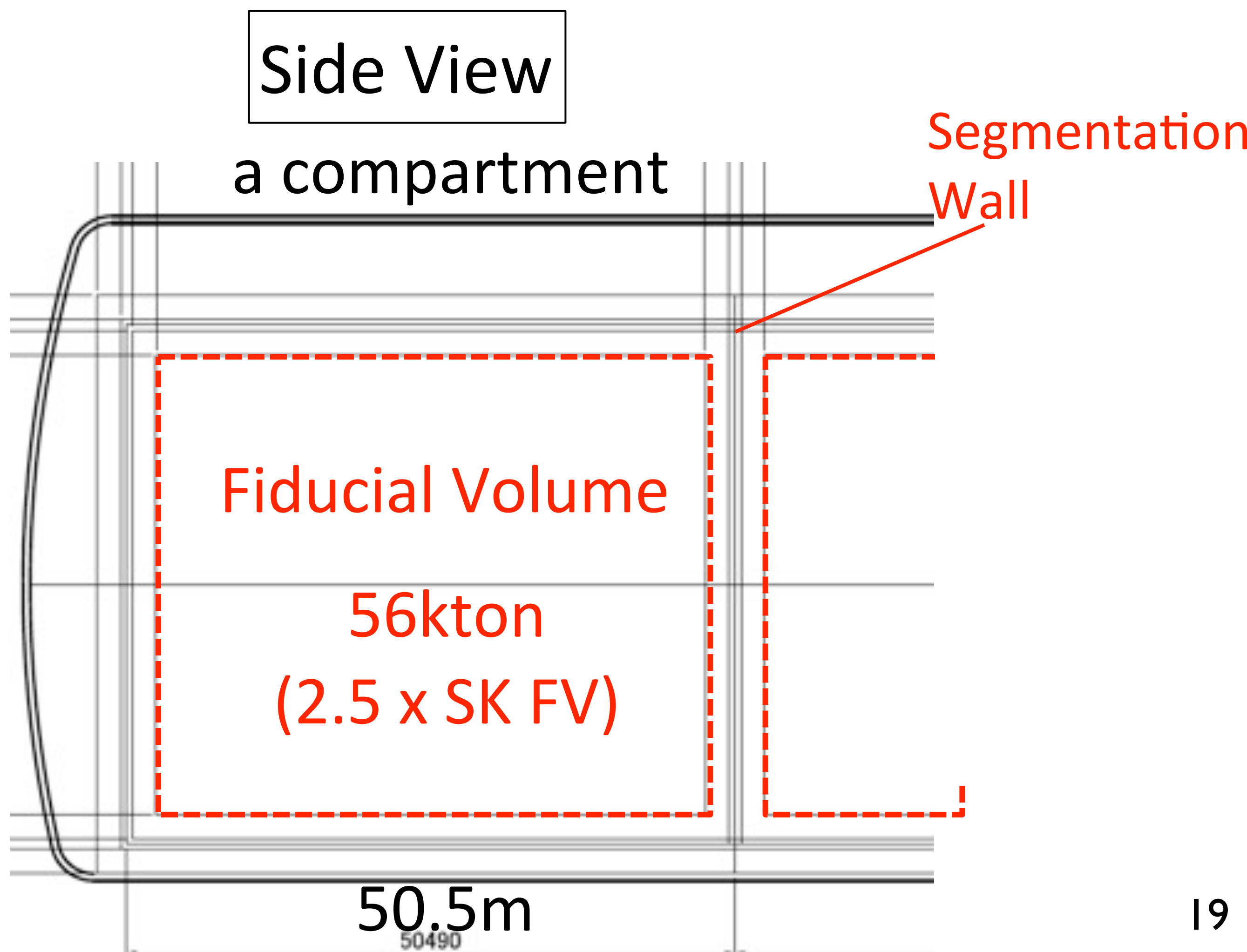


Liner and Photo-sensor Support

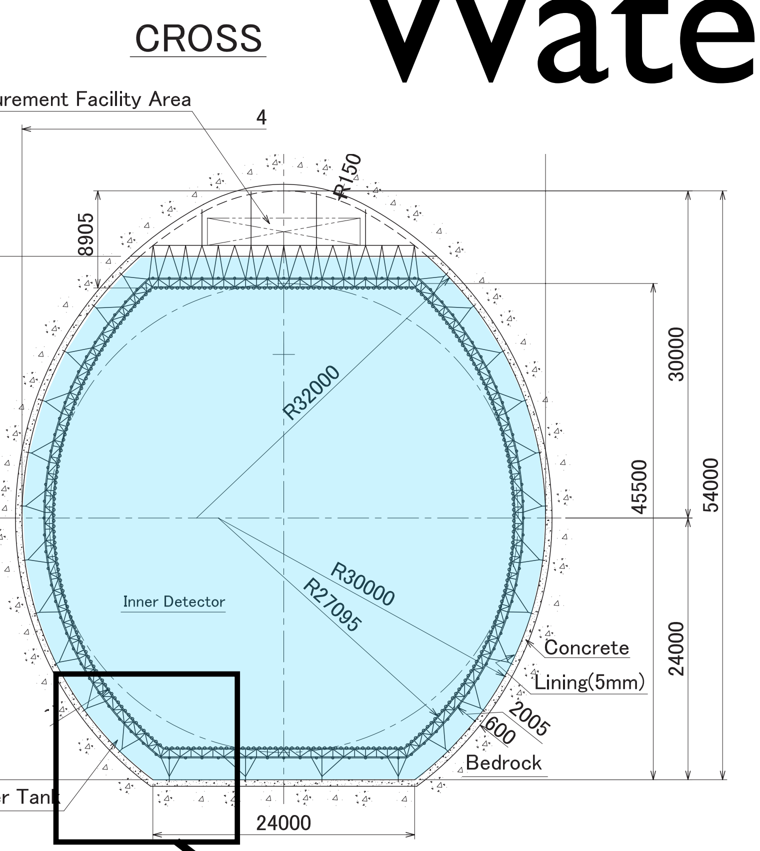
HK detector

- Hyper-K detector consists of 10 compartments which are optically separated
- One compartment consists of Inner Detector (ID) and Outer Detector (OD), like SK
  - ID uses 20" photo-sensors, ~20% photo-coverage
  - OD uses 8" photo-sensors, ~1% photo-coverage

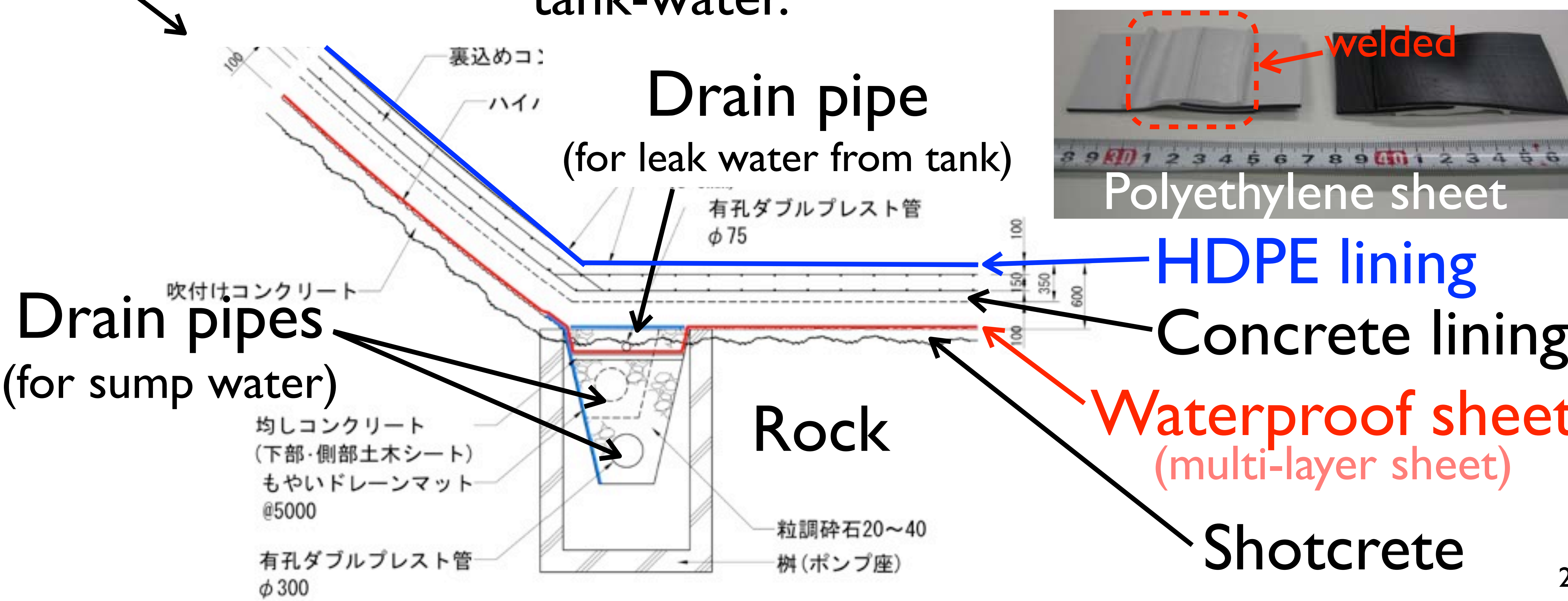




Water containment system

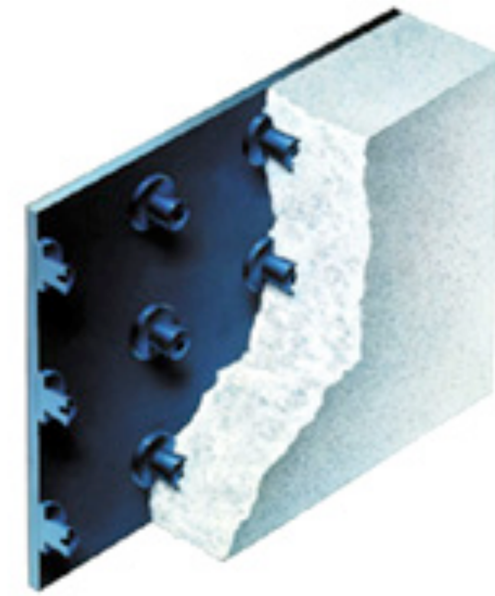


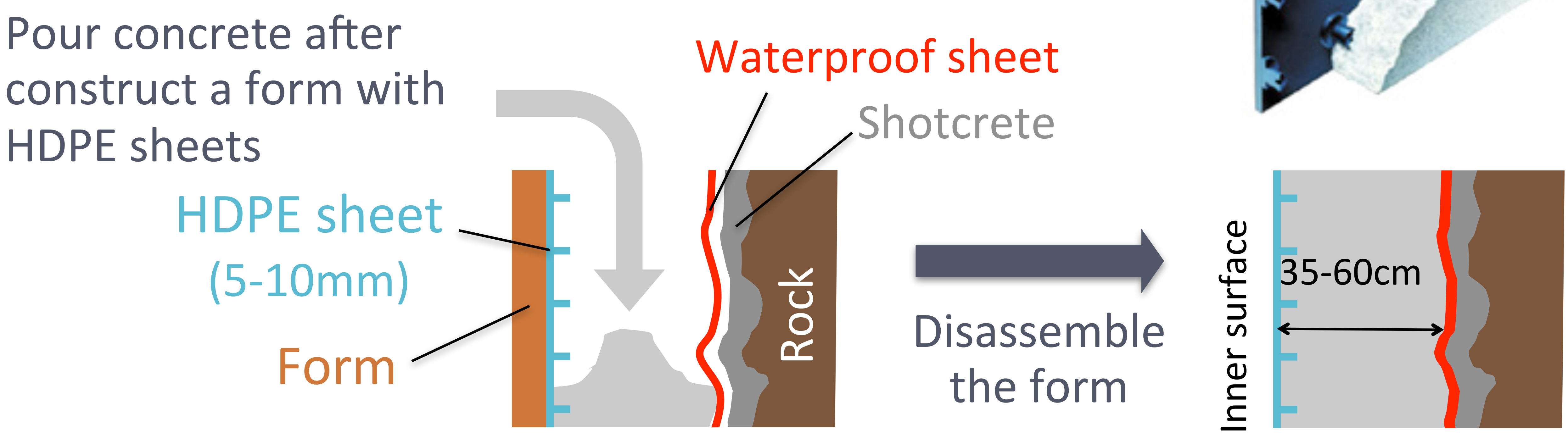
- Tank lining consists of concrete (35~60cm) and Polyethylene (5~10mm) linings
- Plus, additional lining with a waterproof sheet
  - To prevent mixing sump-water and tank-water
- Drain lines are separated for sump-water and tank-water.

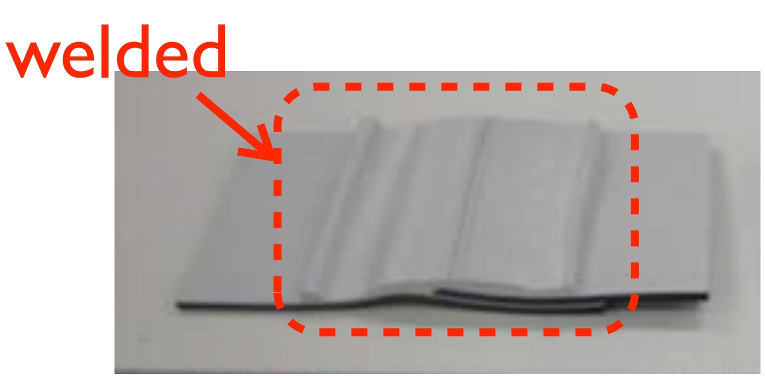


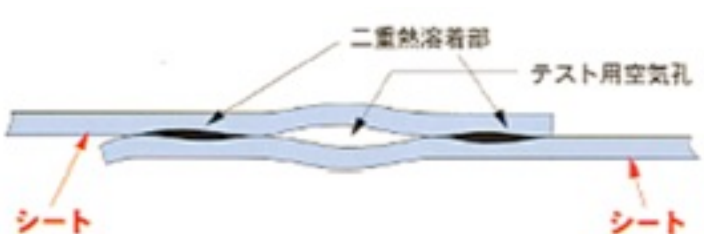
Water containment system

Polyethylene (HDPE) lining sheet has a number of studs protruding from one side, that fasten the lining sheet on the concrete.





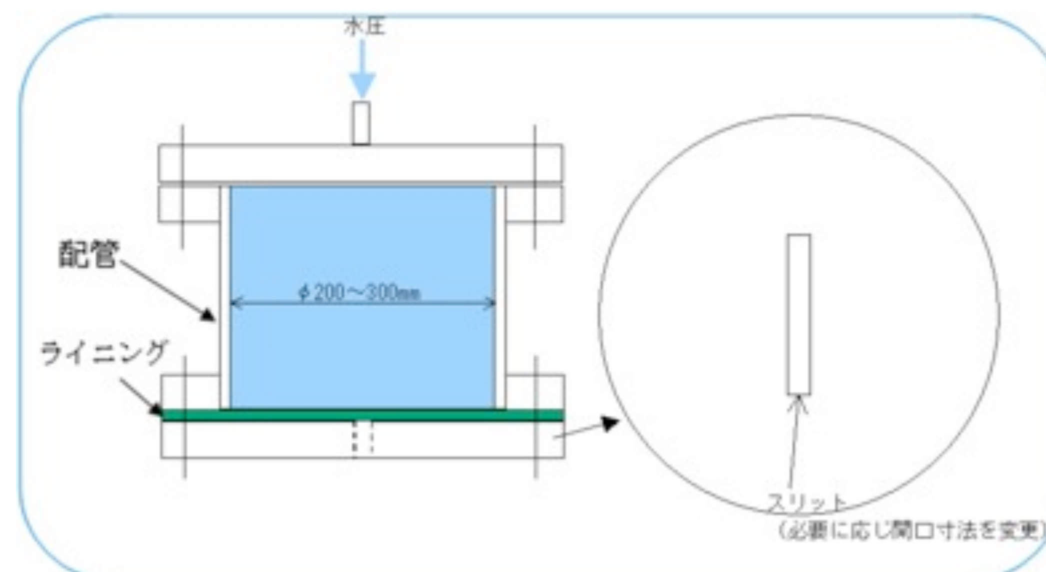




- Enable to construct HDPE lining and concrete lining simultaneously
- HDPE sheets are welded together
- Holes on the lining sheet can be identified by pinhole test / spark testing

Lining sheet testing

- Material compatibility testing
  - Soak in ultra-pure water & 1% gadolinium sulfate solution
- Tensile & creep testings
  - Tested the base material and welded part
- Pressure testings
  - Including ‘pin hole’ testing
  - Apply pressure up to 8kgf/cm^2
  - Tested also the penetrating structure (used for anchors for the photo-sensor support)
- ➜ Confirmed HDPE lining satisfactory to HK



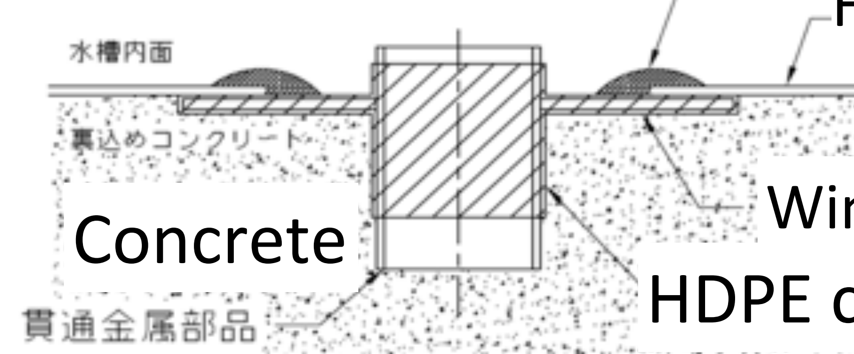
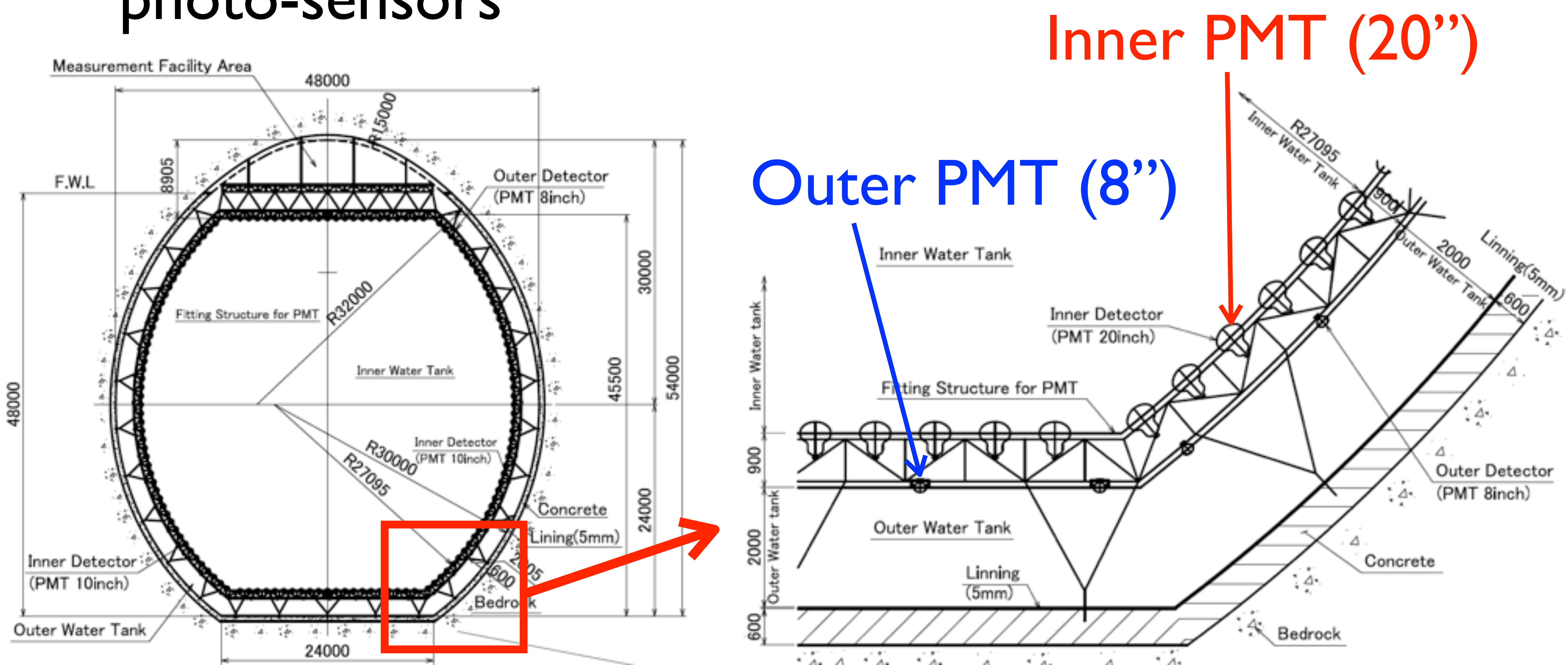


Photo-sensor support

- Number of photo-sensors
  - Inner Detector: ~99,000 of 20” (20% photo-coverage)
  - Outer Detector: ~25,000 of 8” (identical coverage to SK)
- Stainless-steel (SUS304) supporting structure holds photo-sensors

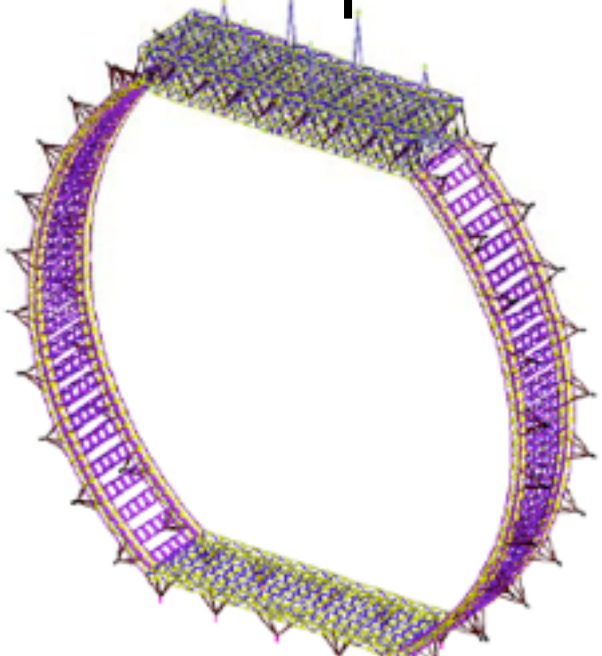


Supporting structure

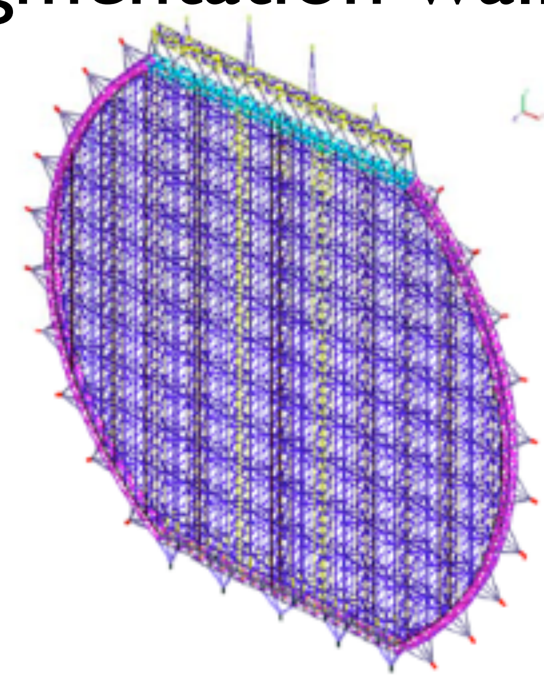
- Structure designed by taking the material/equipments loads into account:
  - Photo-sensors and its housing,
  - Front-end electronics,
  - Power/signal/network cables,
  - Water pipes,
  - Calibration system,
  - etc, etc

ID PMT + housing	27.8kg/PMT
OD PMT	1.7kg/PMT
PMT cable (10m)	2kg/PMT
HUB	5kg/HUB
Network cable (10m)	2kg/HUB
Load on the roof	100kg/m^2
Cables on the roof	0.15kg/m^2
Water system pipes	1.4kg/m (65A PVC)
Calibration holes	200A SUS

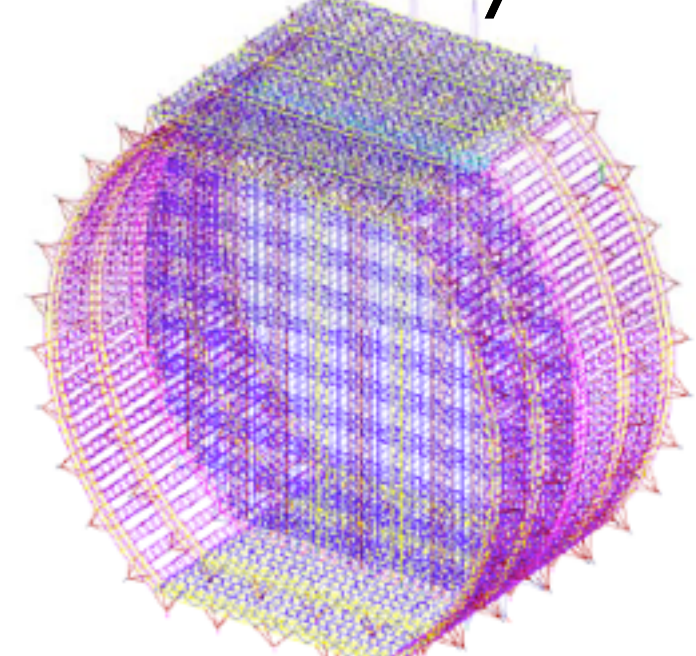
Barrel part



Segmentation wall



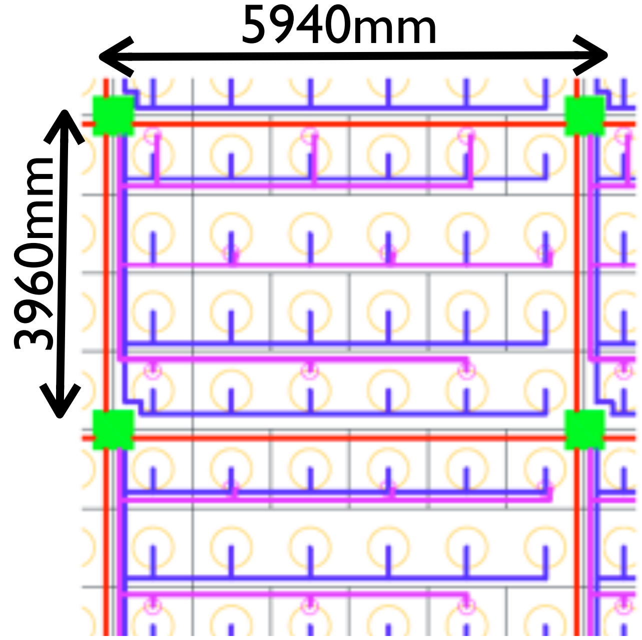
Assembly



Other designing work

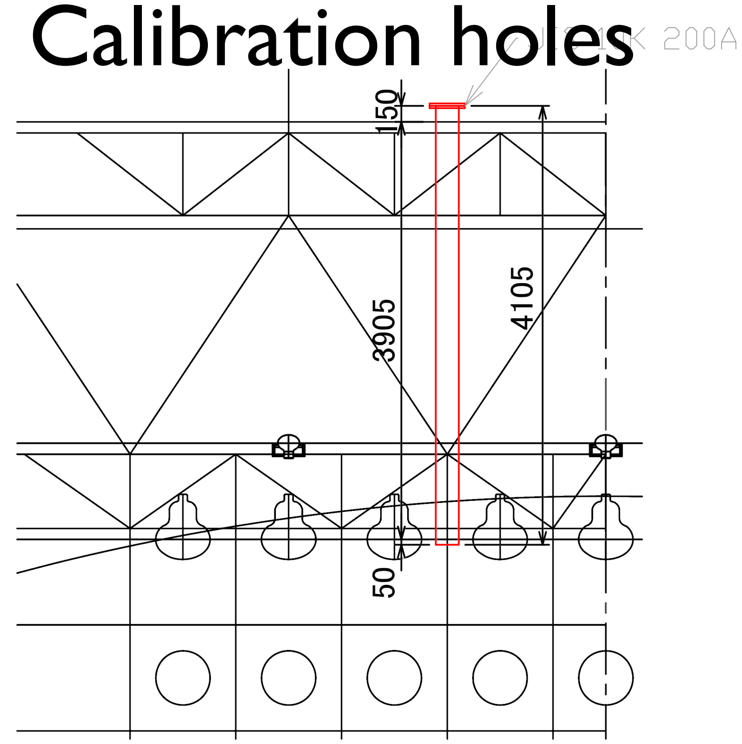
- Major part of HK tank has been designed.
  - Include layout of water pipes, front-end electronics, cables, calibration holes, plug manholes, ... etc.

Electronics & cable layout

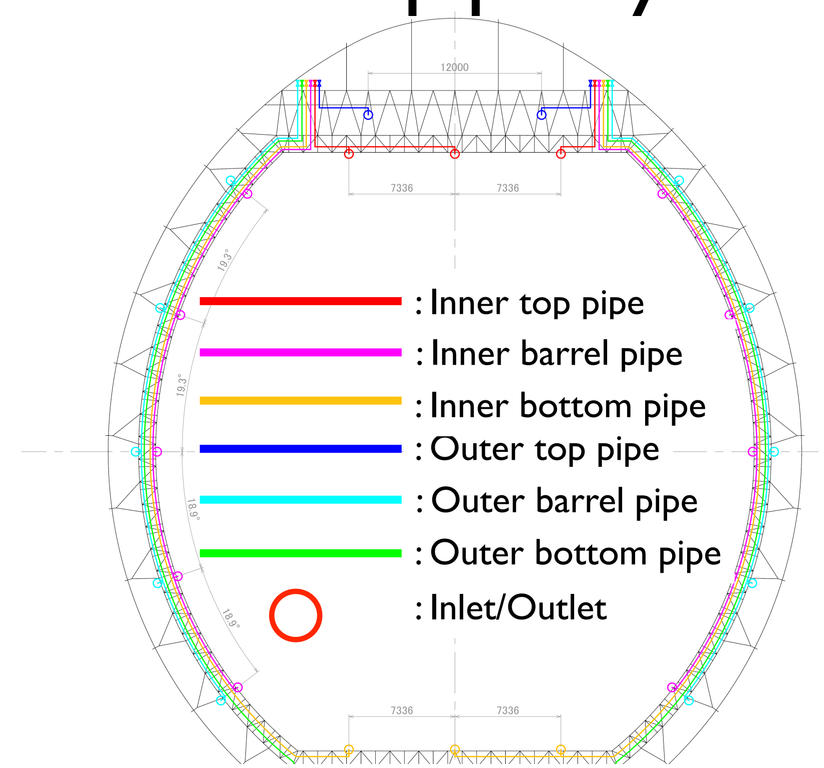


: Support structure
: Cable for inner PMT
: Cable for outer PMT
: Network/Power cable
: Hub / Front End Electronics
: Inner photo-sensor (20")
: Outer photo-sensor (8")

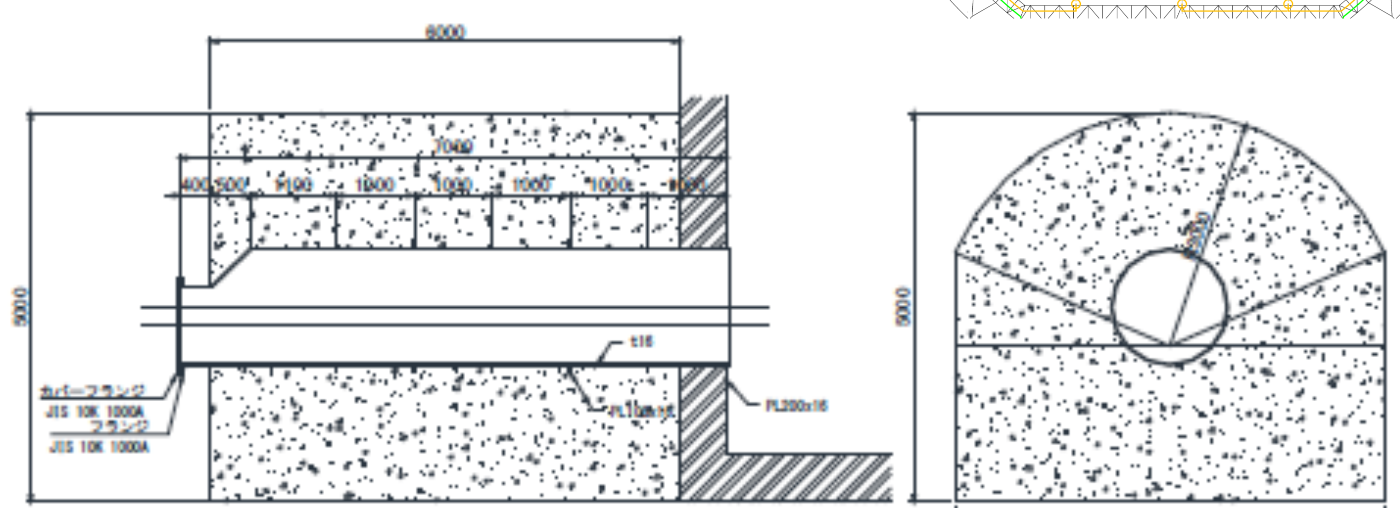
Calibration holes



Water pipe layout



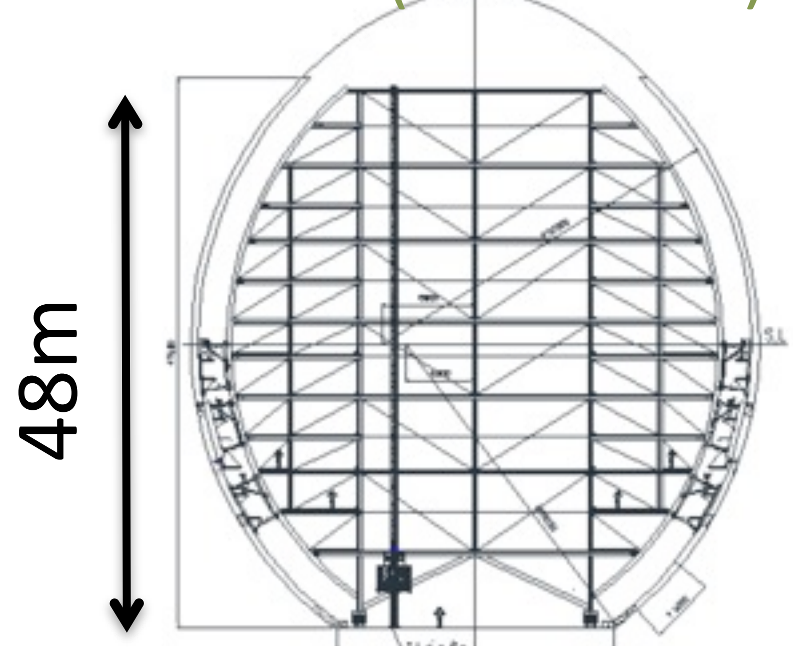
Plug manhole



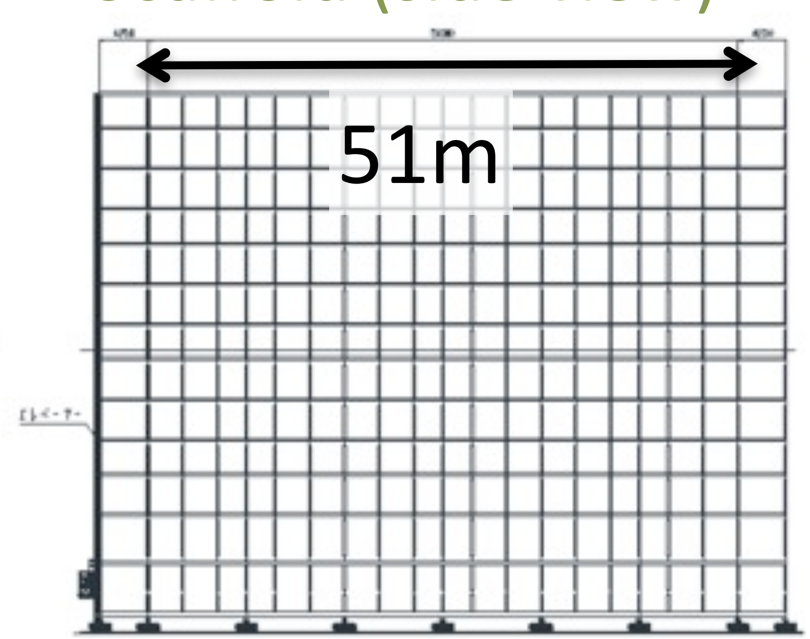
Lining and support construction

- Use a "movable" scaffolding to construct the lining (concrete lining, HDPE lining, etc)
  - Size of the scaffolding is about a compartment (50m)
- Move the scaffolding to the next compartment after the lining finished in a compartment
- Support structure construction begins in the compartment where the lining finished
  - Use 'long-arm' cranes

Scaffold (front view)



Scaffold (side view)



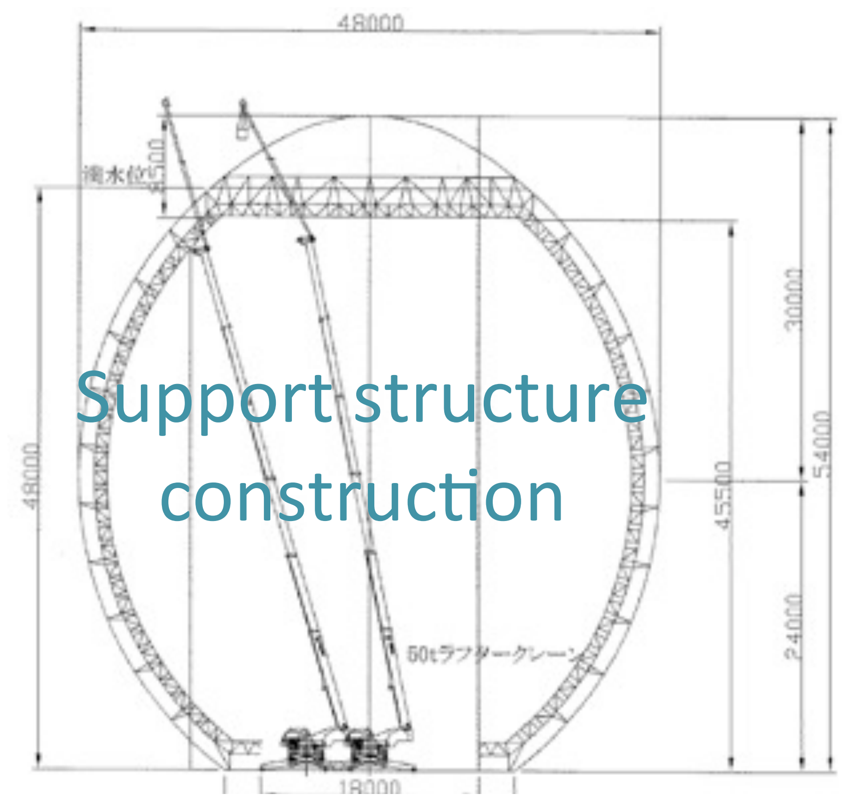
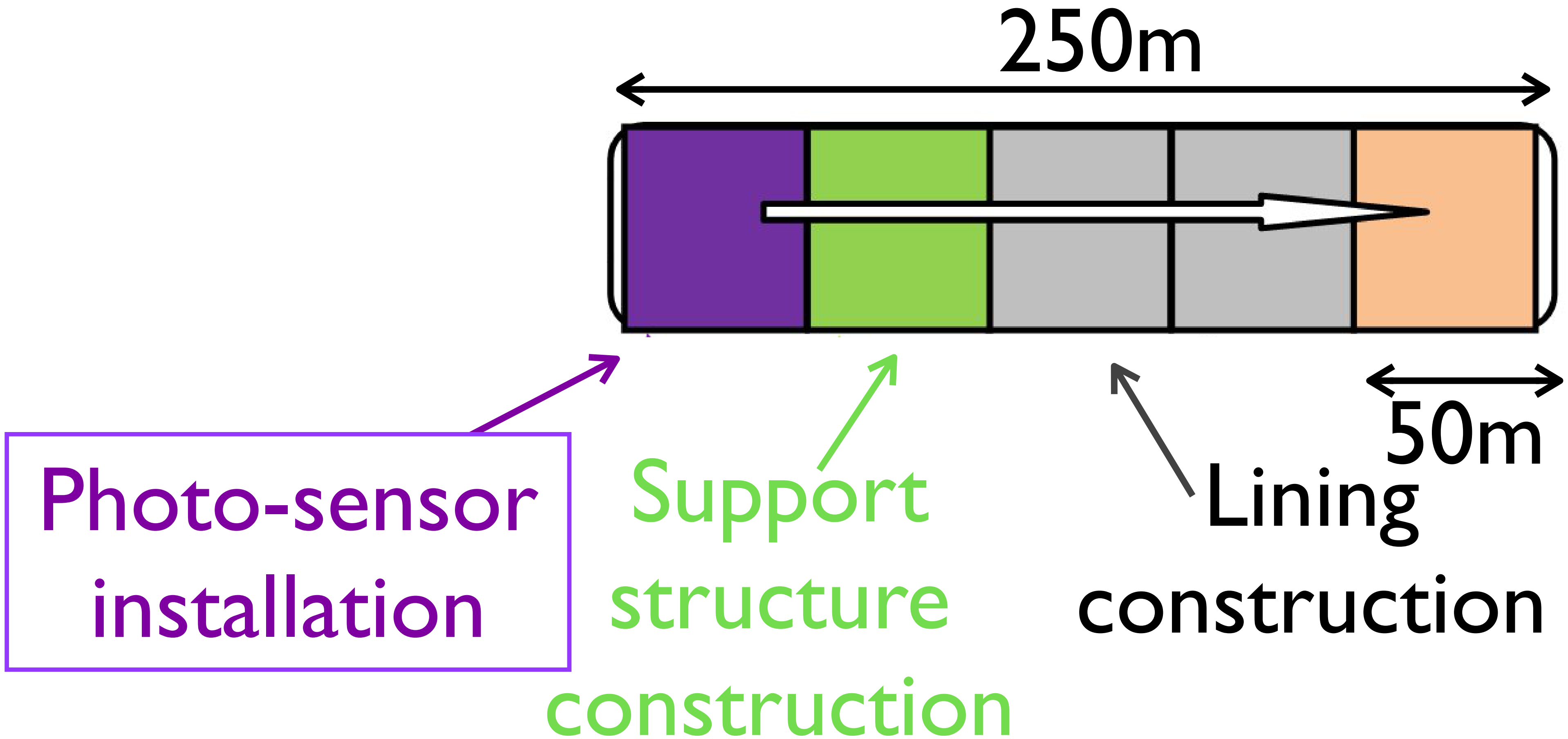
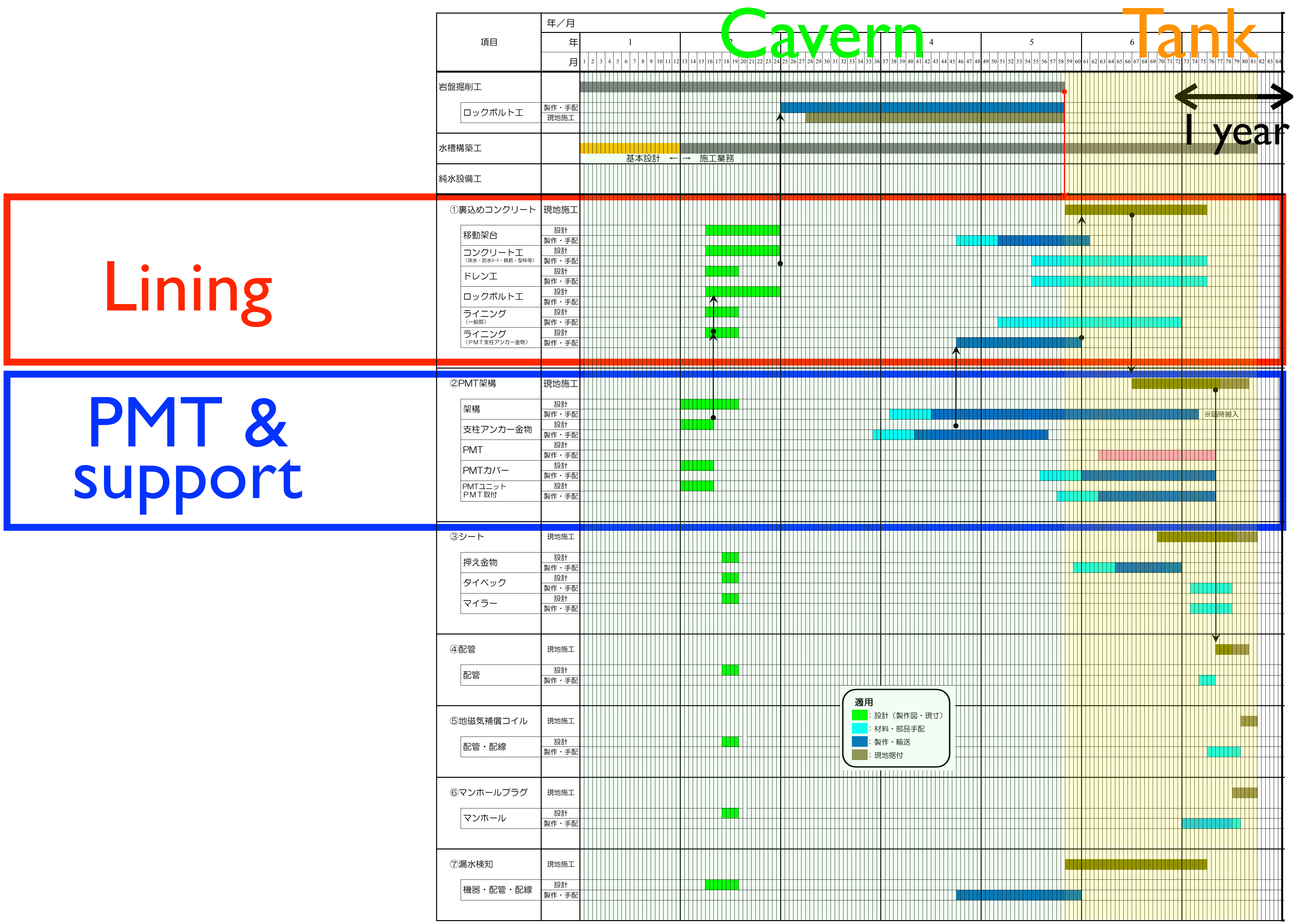


Photo-sensor installation

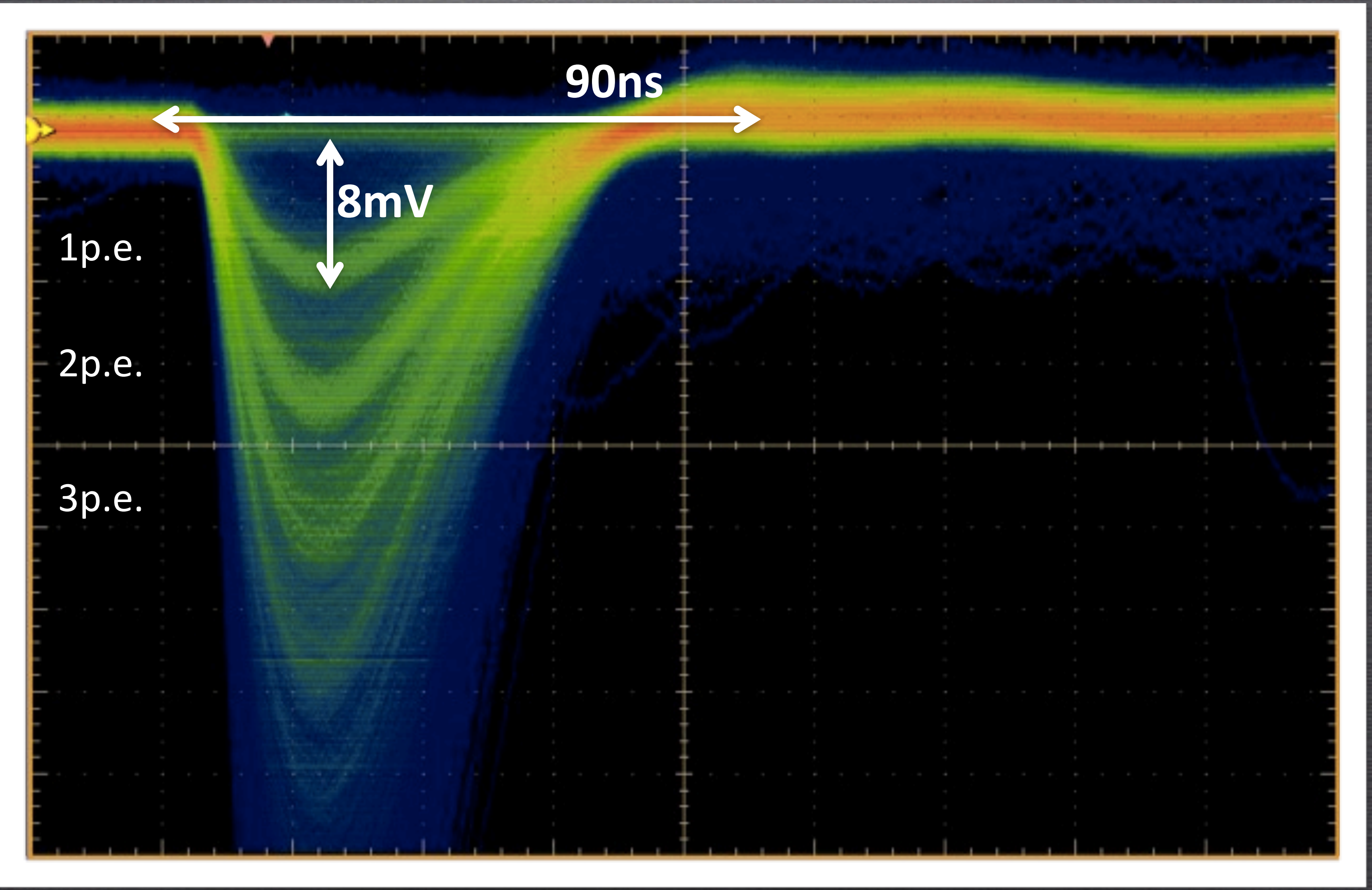


- Baseline: Install photo-sensors in a compartment where lining and support structure constructed
  - (Lining → Support structure → Photo-sensor)
- Possible options (but impact to safety and cost)
  - Install photo-sensors in parallel w/ support construction
  - Install photo-sensors during the water filling

Tank construction schedule



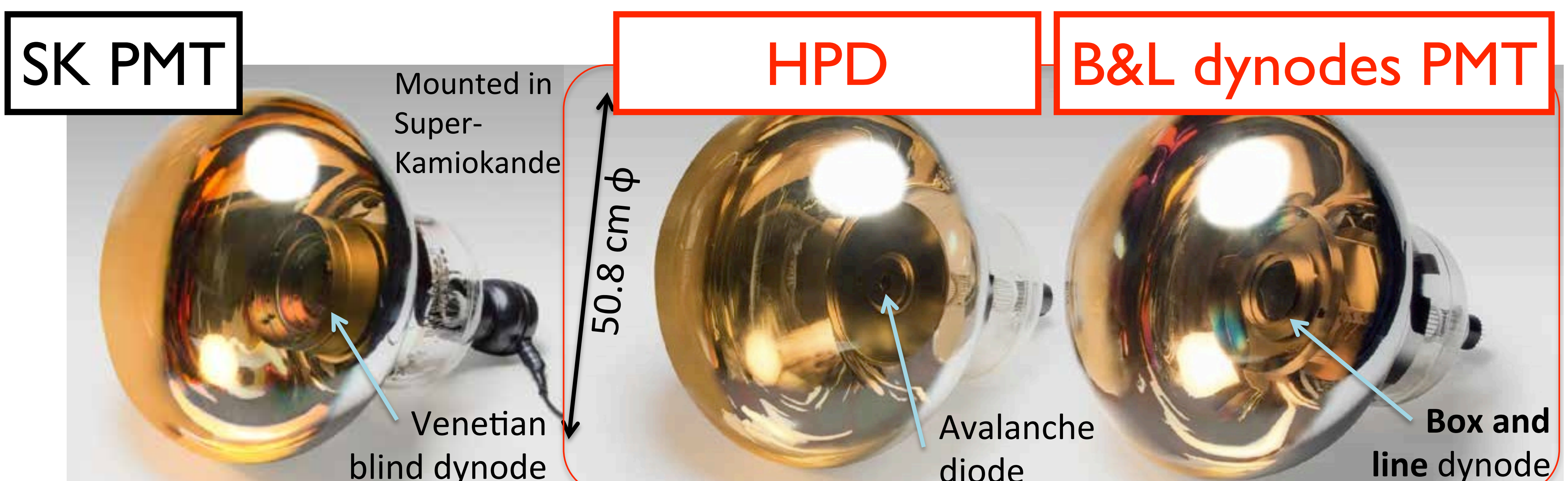
- Tank construction: ~2 years
  - Lining: 1+ years, PMT installation: ~1 year
  - Two tanks construction in parallel.



New Photo-sensor R&D

Photo-sensor candidates

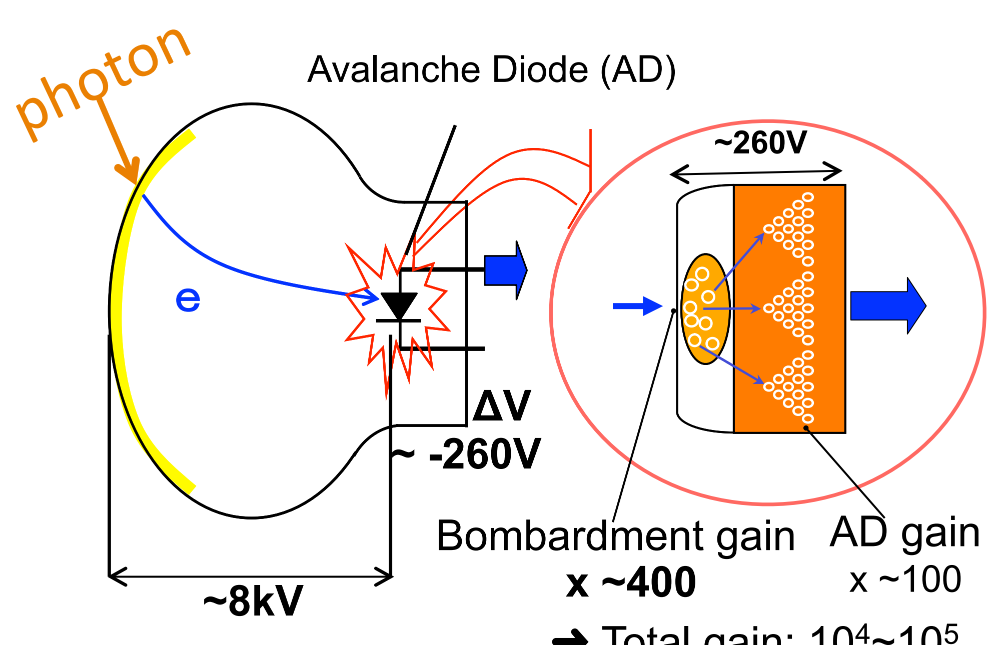
- The baseline design uses 20" PMTs (SK type PMT)
- Photo-sensors w/ better performance beneficial for Hyper-K physics and cost
- New photo-sensors R&D are in progress
  - **Hybrid Photo-detector (HPD)**
  - **Box and Line dynodes PMT**
  - **High Quantum Efficiency (HQE) tube**
    - Applicable for all photo-sensor candidates



Model R3600 (Used for ~30 yrs) R12850 (Under development) R12860 (Under development)

Hybrid Photo-detector

- Hybrid Photo-detector (HPD) is a new type of photo-sensor with an avalanche diode, replacing metal dynode.
- HPDs have a better performances than standard PMTs:
  - Timing resolution: shorter e-multiplication process
  - Collection efficiency: higher operating voltage (~10kV)
  - Lower cost: mechanically simple
- 8” HPDs prototypes are bing tested (see later slides)



5mmφ AD

	8”HPD	20”HPD	20”PMT
HV	~8kV	~8kV	~2kV
Gain	10^4-10^5	10^4-10^5	~10^7
TTS(ns)	0.6	0.8(*)	5.5
C.E.	~97%	~95%(*)	~80%
AD dia.	5mm	20mm	-

(*) expectation from field calculation.
preliminary value

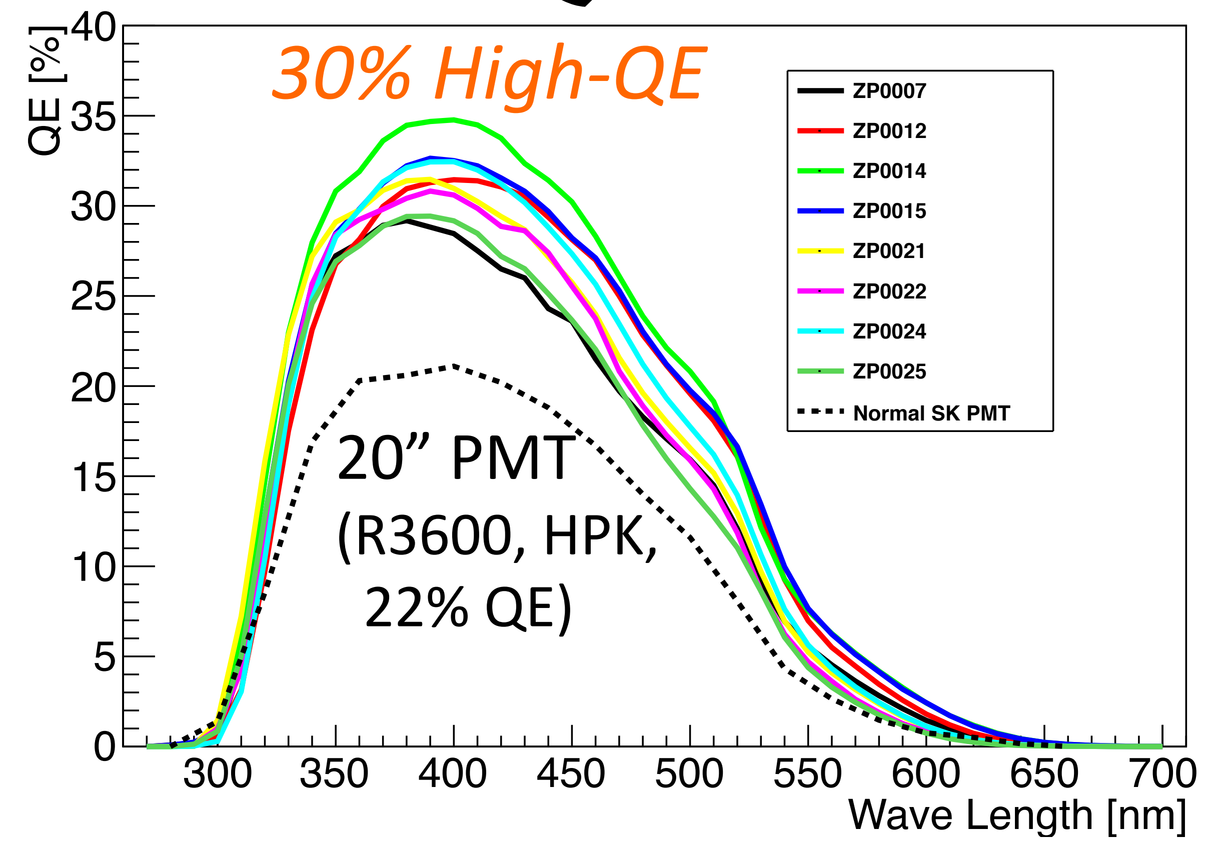
High QE photo-sensor

- HQE cathode applicable for all photo-sensors candidates (SK type PMT, box&line dynode PMT, HPD)
  - Photo-cathode technology identical for all sensors

- HQE technique has been developed by HPK, and achieved QE ~30%
  - cf. SK type PMT: ~22%

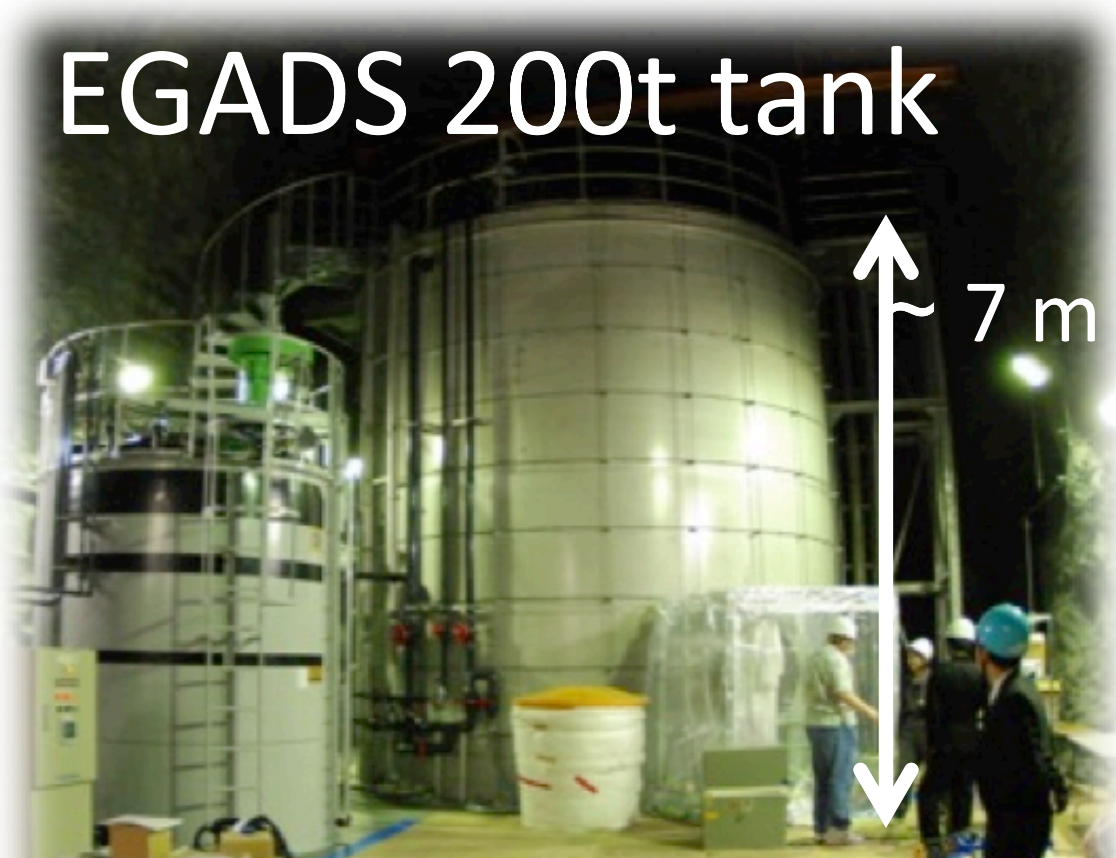
- 20" HQE PMT prototypes are being tested (see later slides)

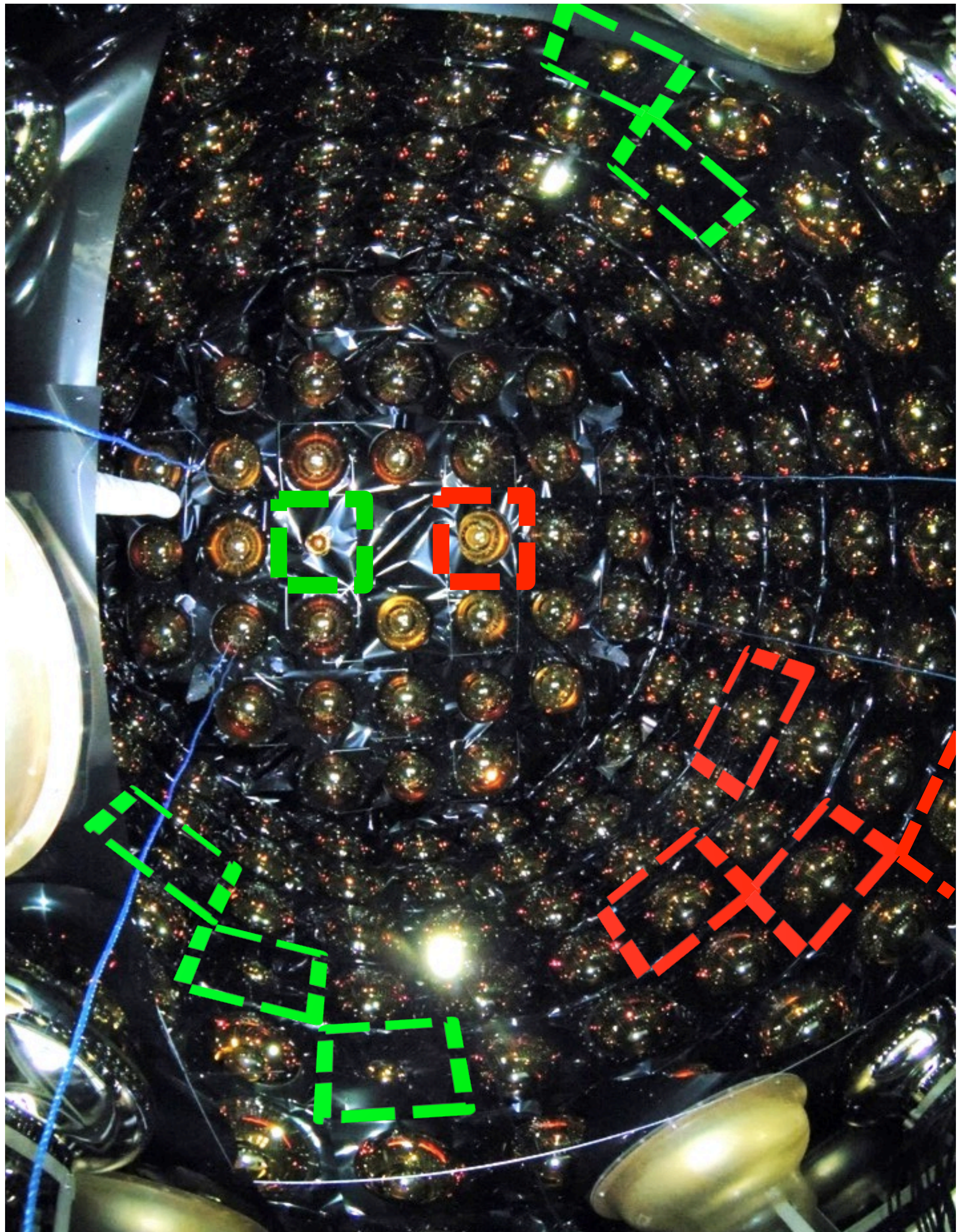
20" HQE PMTs



Testing in 200t Č detector

- New photo-sensors being tested in 200t water Cherenkov detector (EGADS detector)
  - **5 High QE PMTs (20”)**
  - **8 HPDs (8”)**
  - and 227 SK type PMTs (20”)
- Preliminary testing results (next slides)

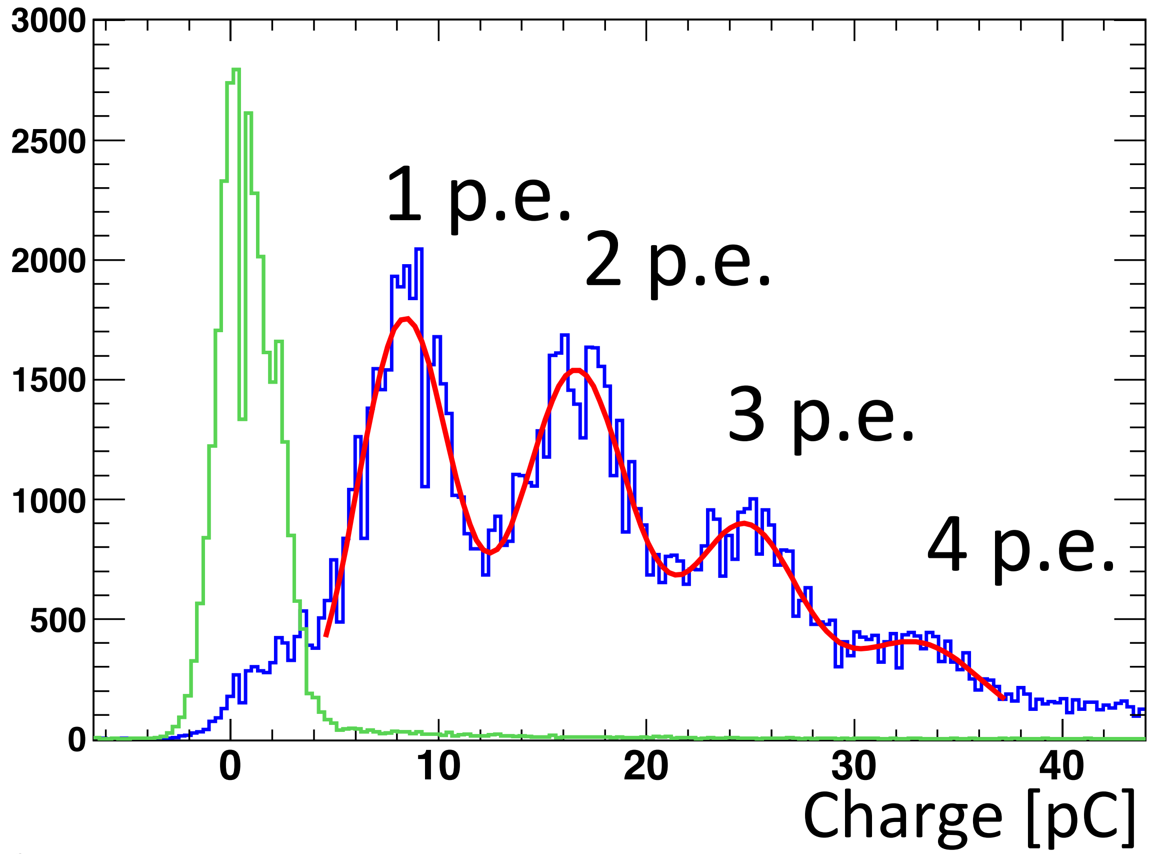




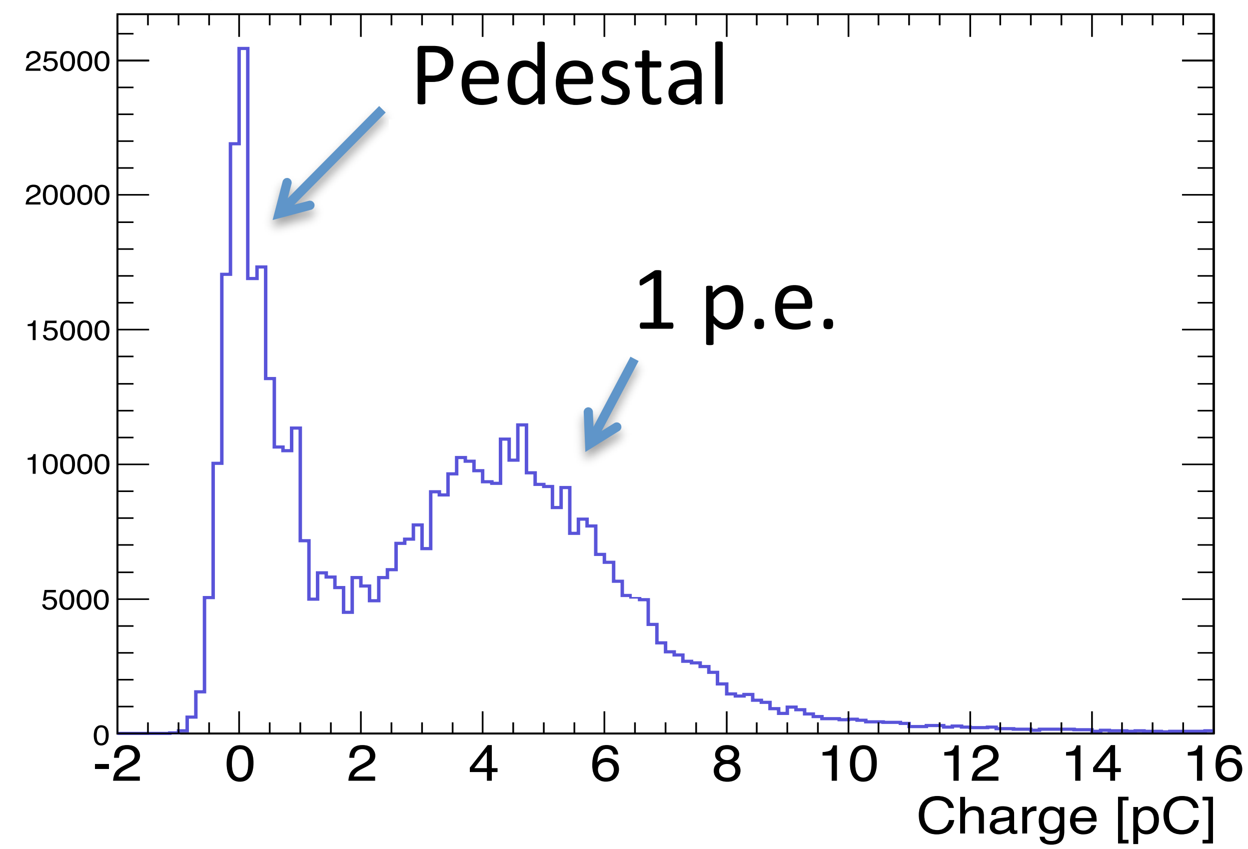
Photon counting

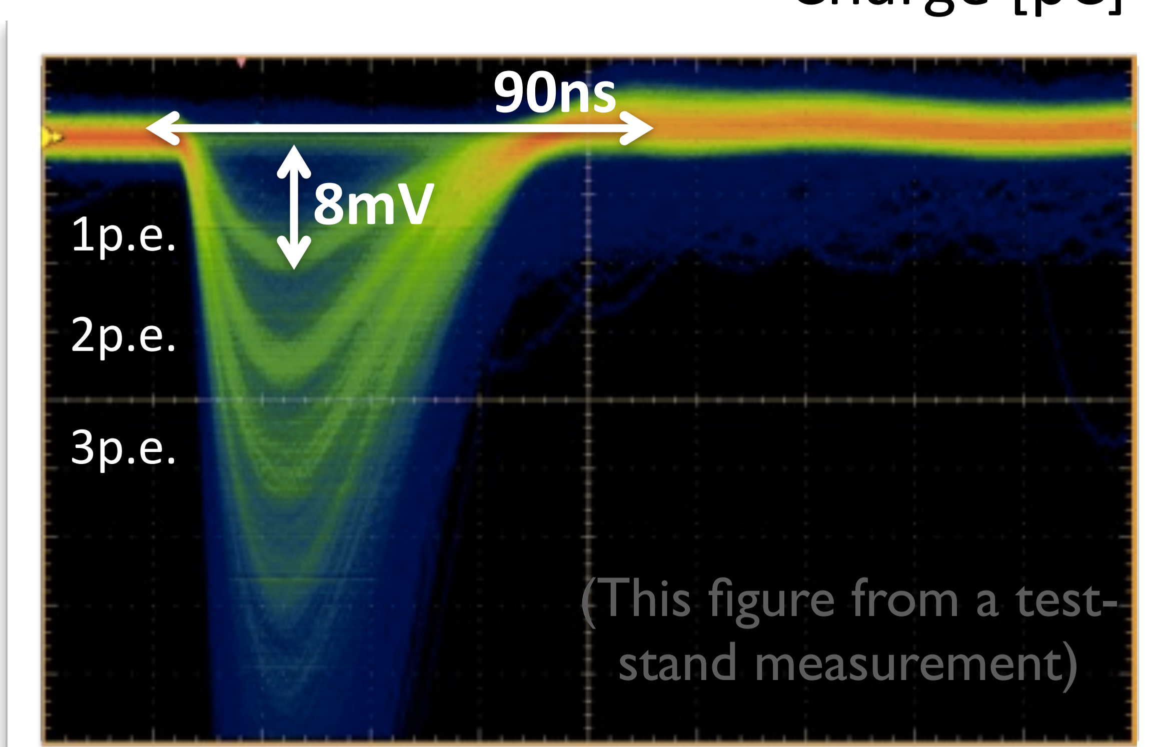
Measured in 200t water Č detector

8-inch HPD



High-QE PMT



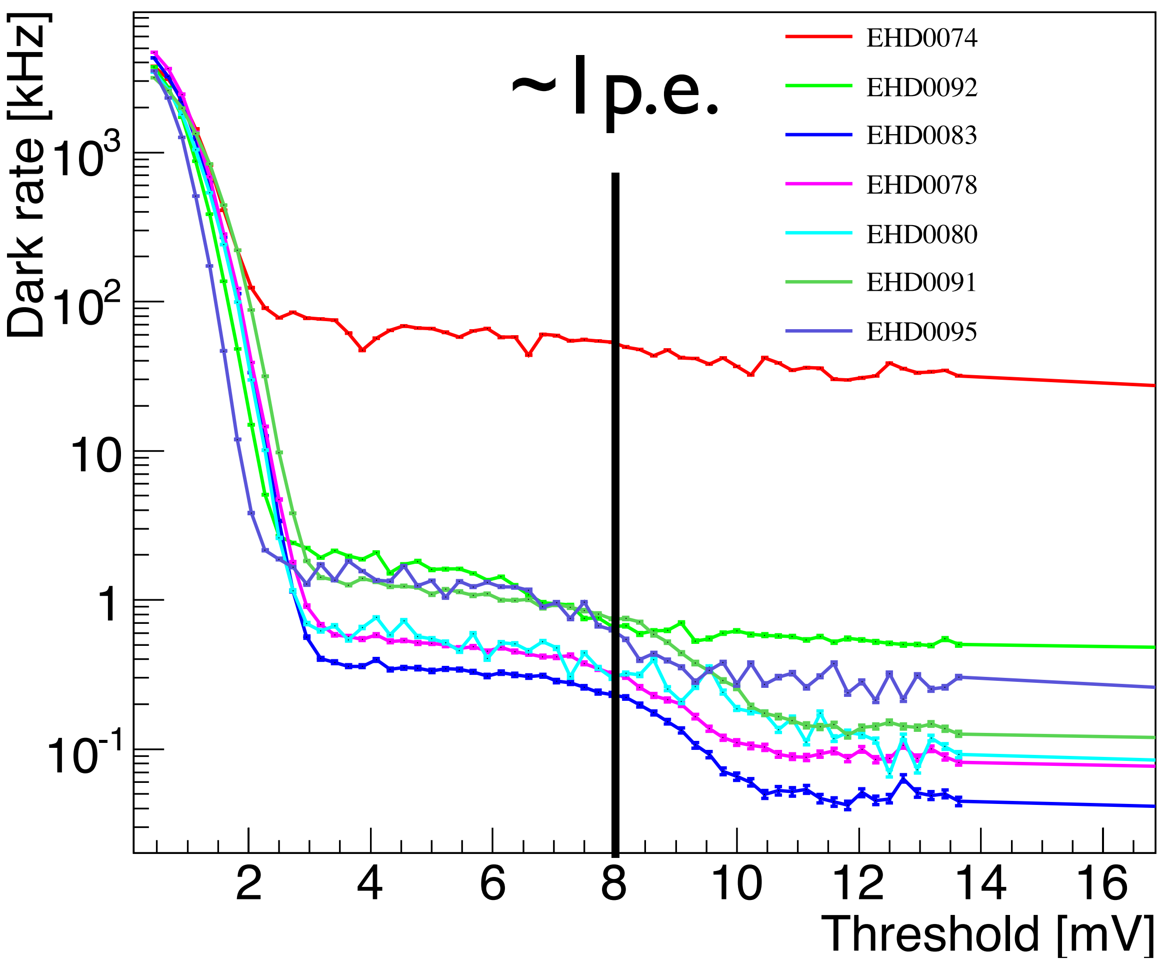


- HPDs and HQE PMTs show clear 1p.e. peak
- HPD
  - Clear multi-p.e. peaks; good photon counting capability
  - High peak/valley ratio

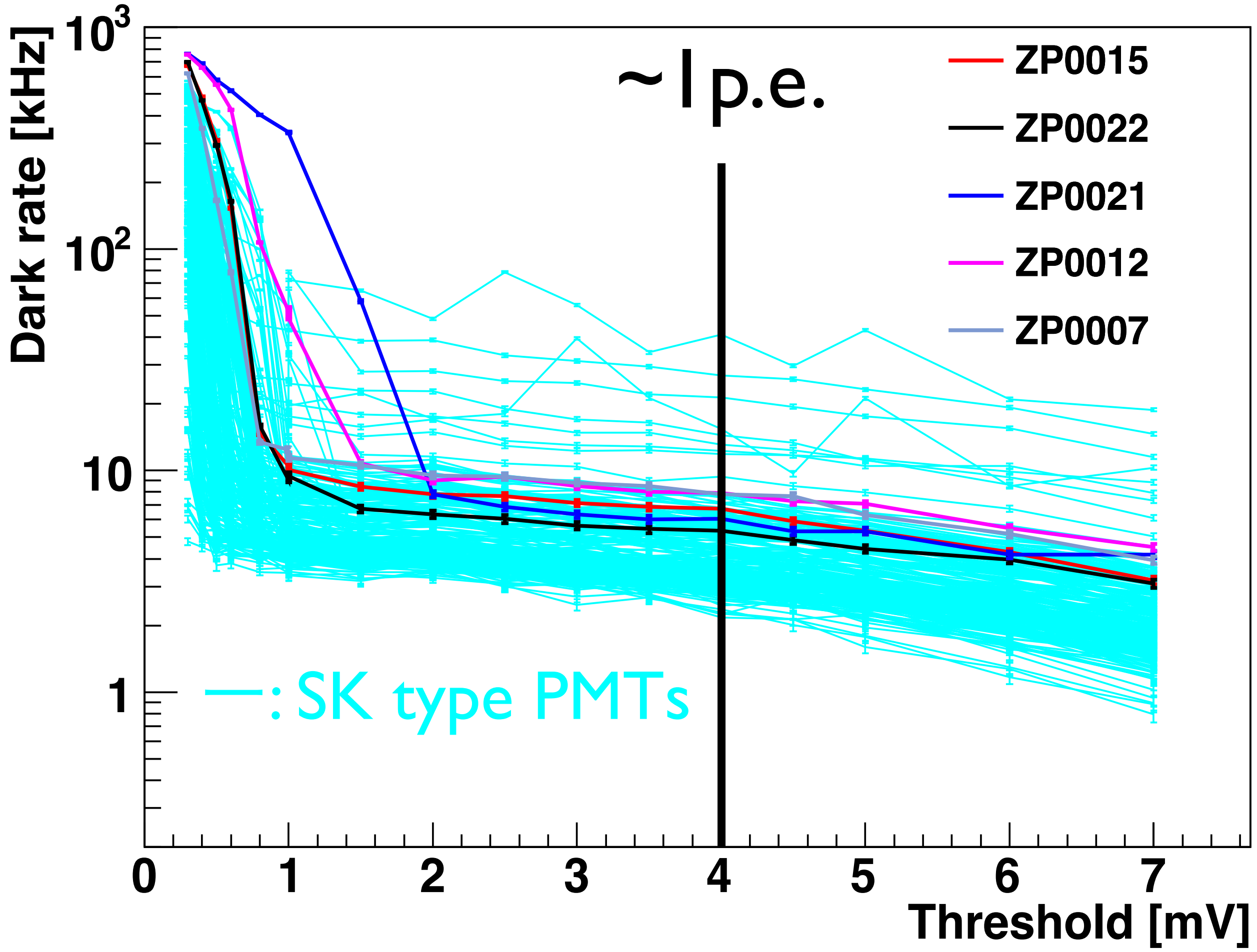
Dark rates

Measured in 200t water Č detector

8-inch HPDs



20-inch high-QE PMTs

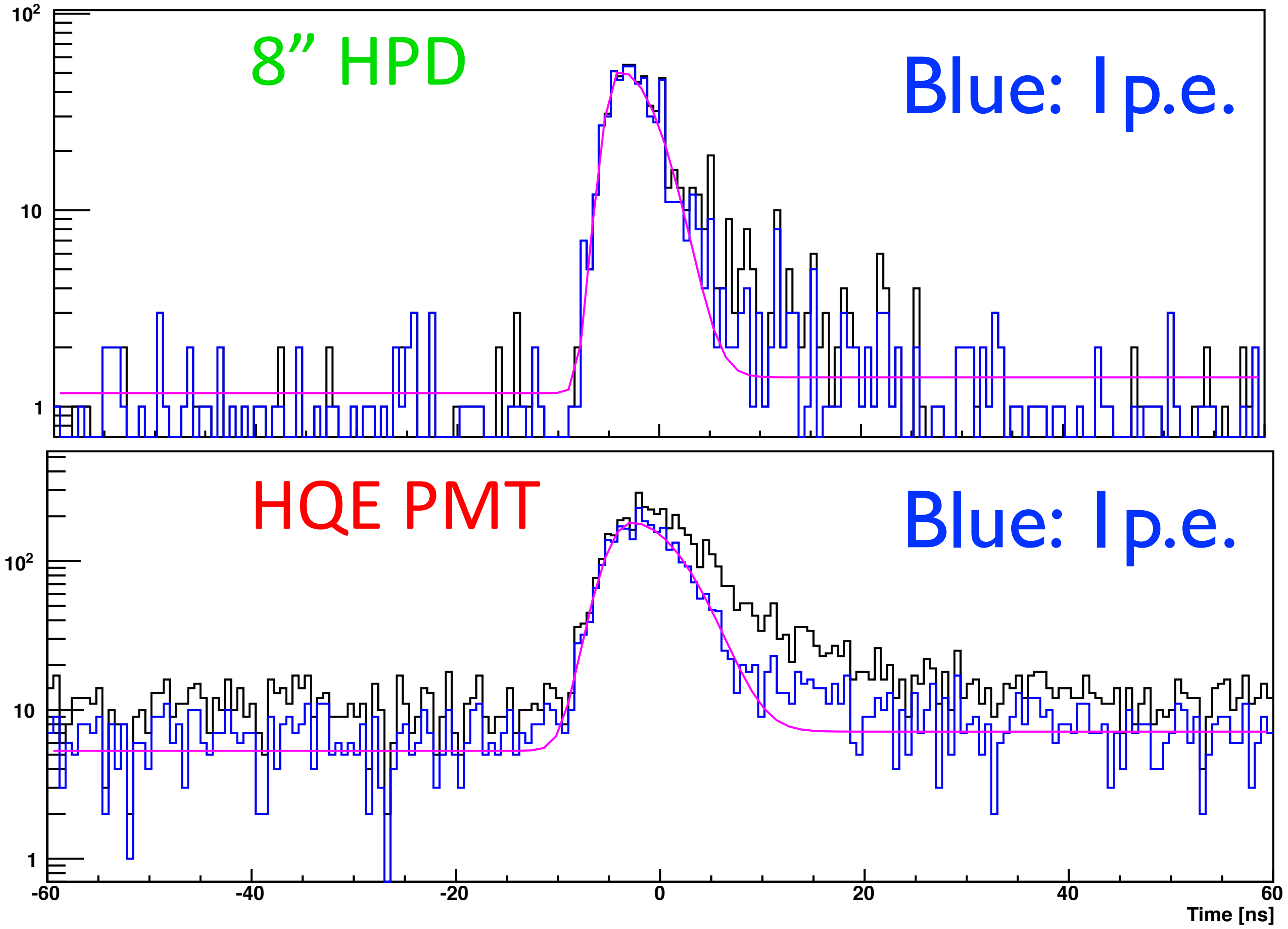


- HPDs and HQE PMTs dark rates at 1p.e.:1~8kHz
  → Similar level to SK type PMTs

Transit Time Spread

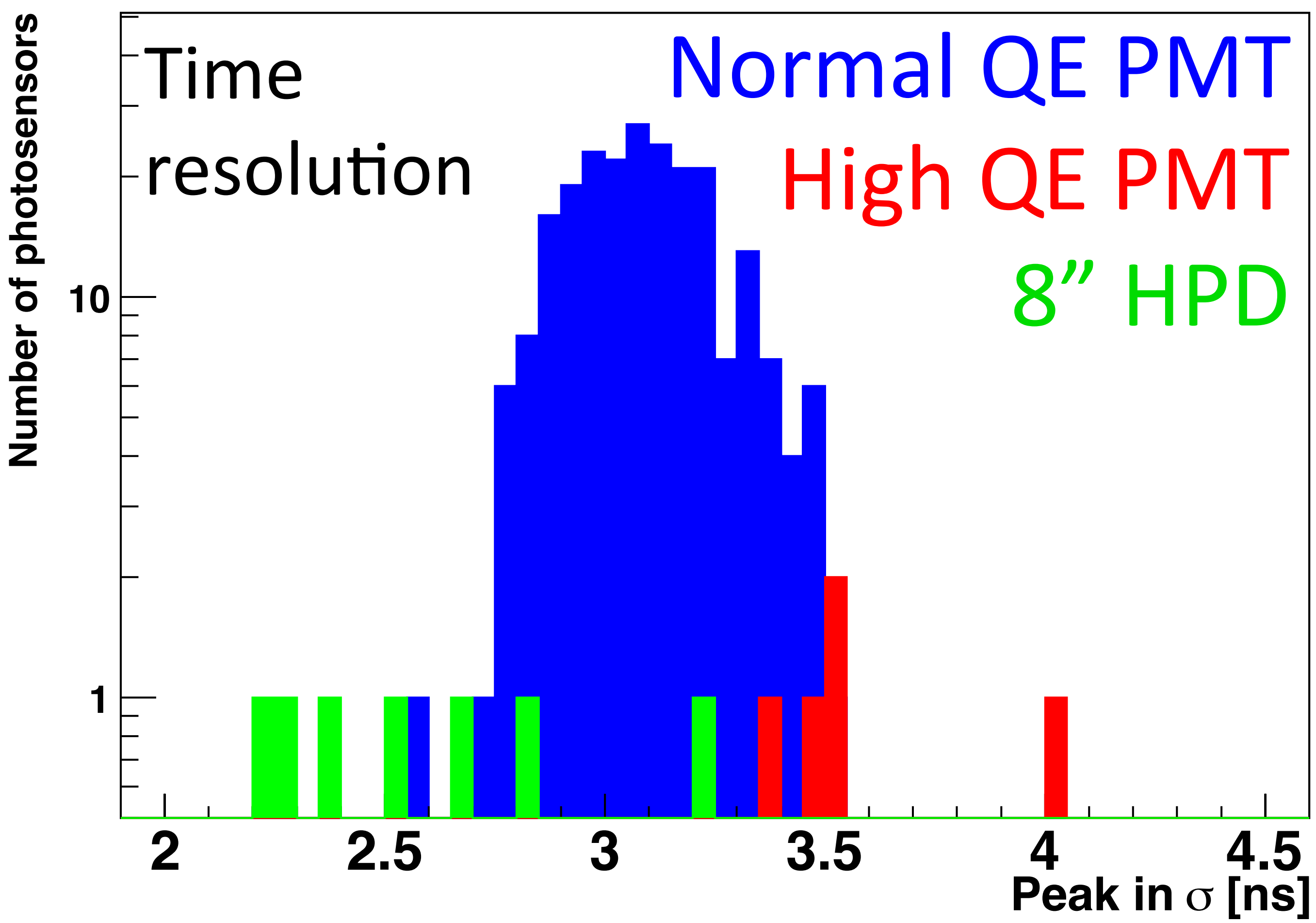
Measured in 200t water Č detector

Transit time



(Time-walk effect is not corrected)

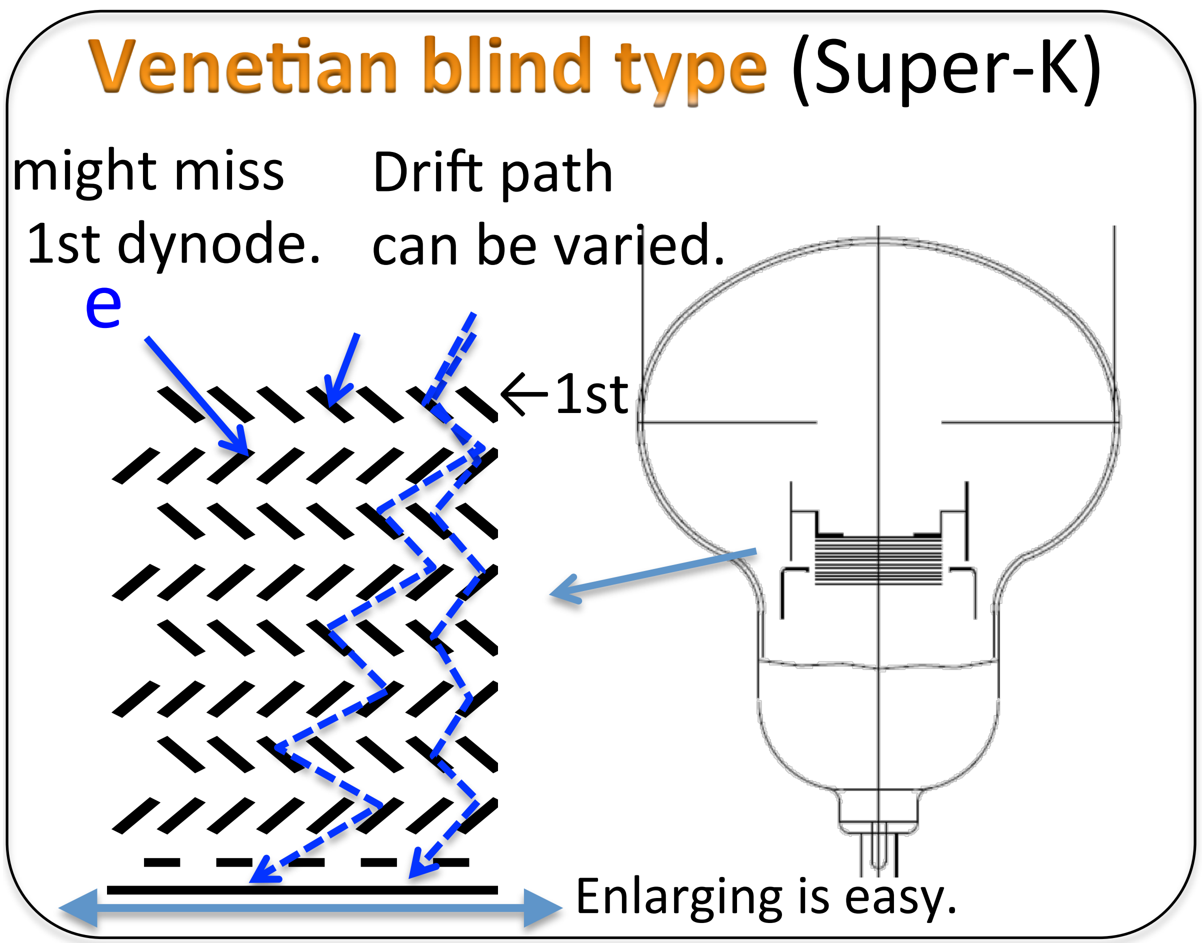
TTS

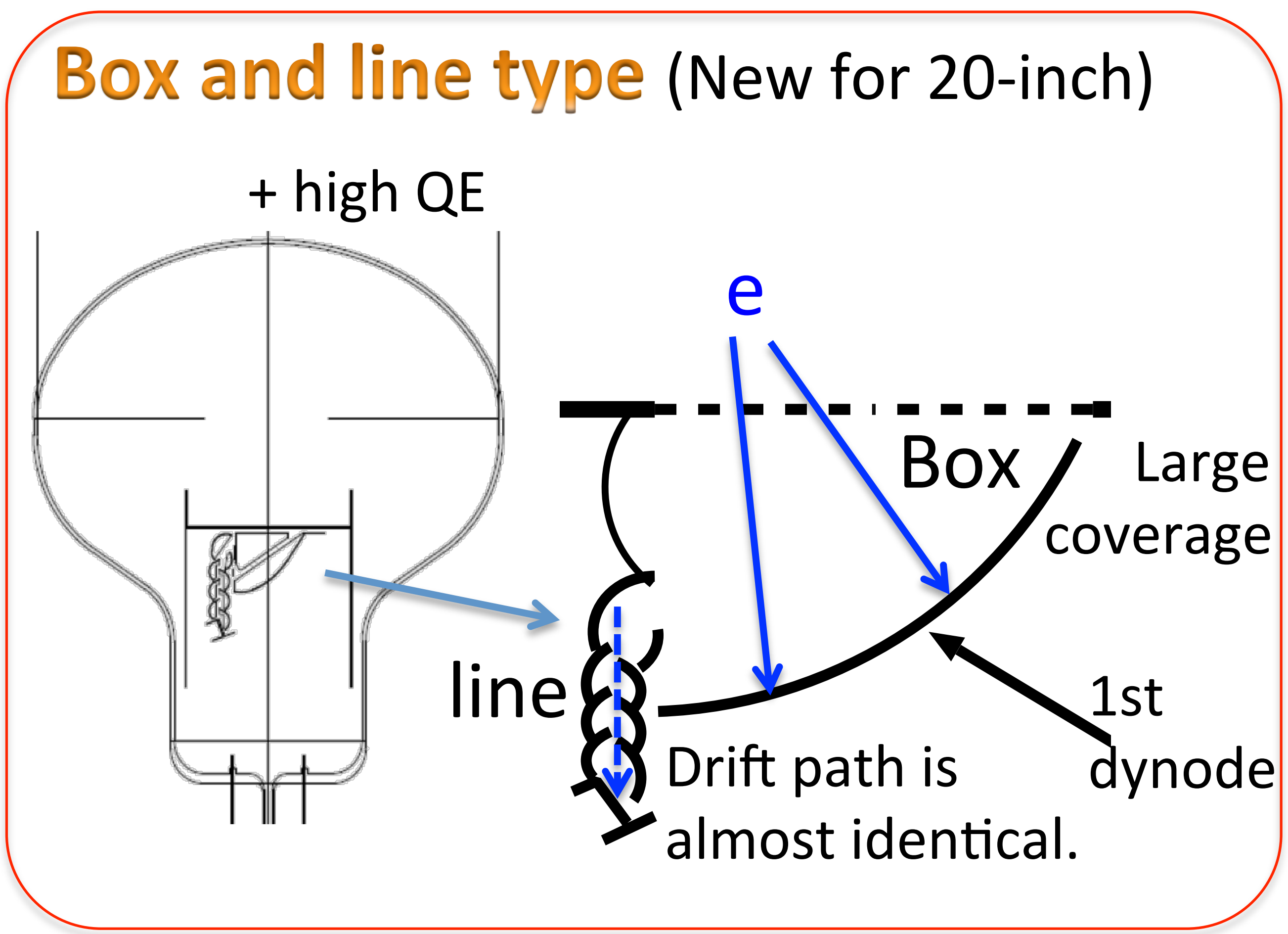


- HPDs show better TTS than SK style/HQE PMTs
  - Pre-amplifier impacts to TTS (can be improved)

Box & Line dynodes PMT

- Higher photo-electron collection efficiency (93%)
  - Larger acceptance of 1st dynode
- Fast time response (TTS: 2.7ns)
  - Electron multiplication path almost identical
- 20" Box & Line PMT prototype just delivered to Kamioka and start the testing





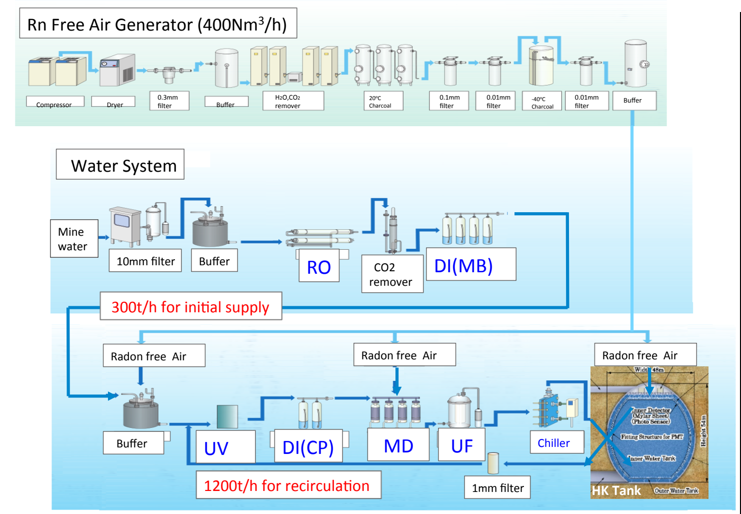
Sensor R&D status & plan

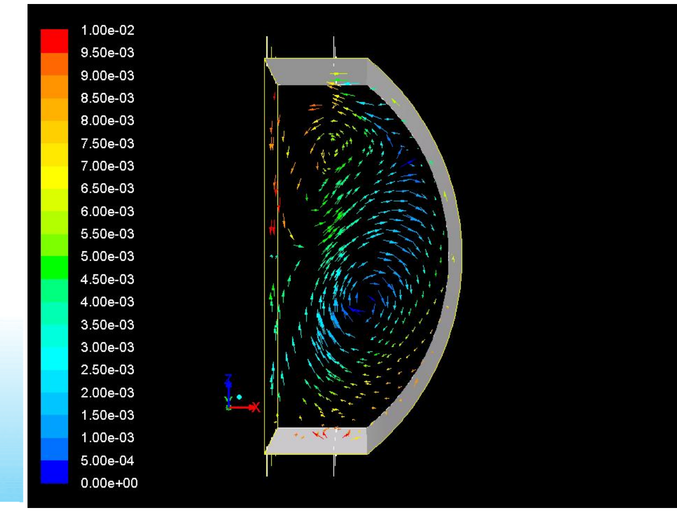
- 8" HPDs and 20" HQE PMTs prototypes being tested in 200t water Č detector (previous slides)
  - Direct comparison with SK type PMTs
  - Long term operation experience: stability and lifetime of the devices
- The first prototype of 20" HPDs and 20" Box & Line dynodes PMTs just delivered
  - with HQE photo-cathode
  - Will evaluate the performance & identify possible problems and feedback to the final design
- Plan to install 20" HPD and B&L PMT in 200t water Cherenkov detector after the Lab testing

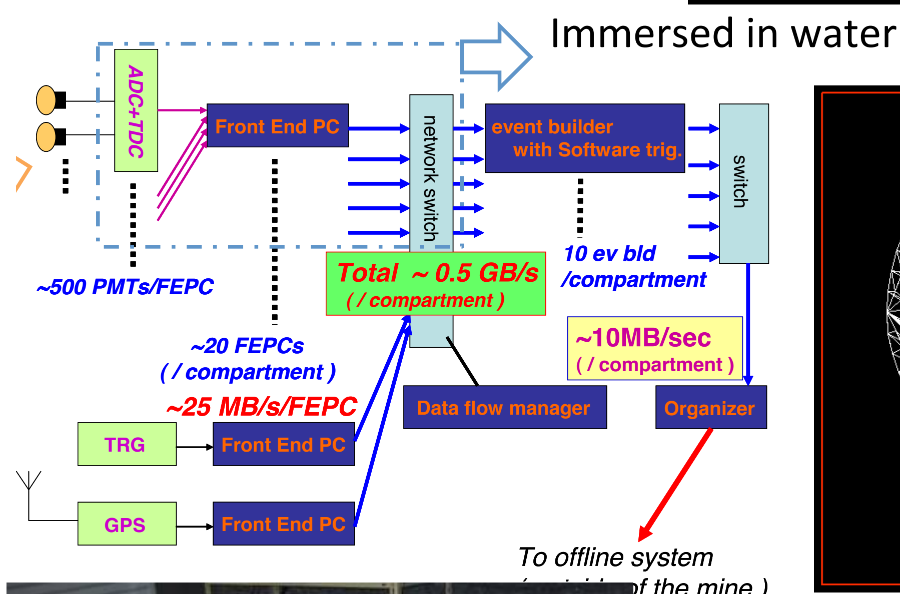
Other R&Ds

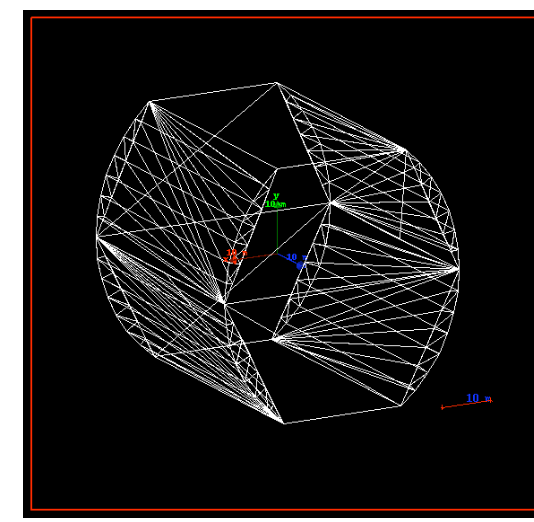
- Photosensor housing
  - ex. implosion test
- Water system
- Readout electronics
- Calibration system
- Software development
- Physics potential
- Design of near detector(s)
- …

- Progress within international working group

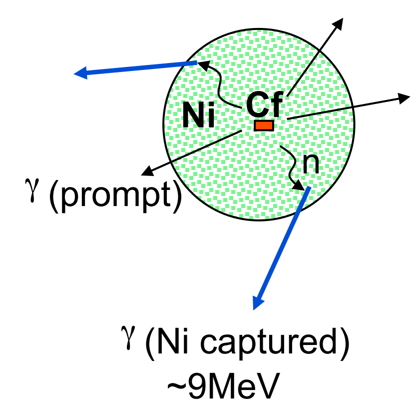








SK Nickel source



Summary

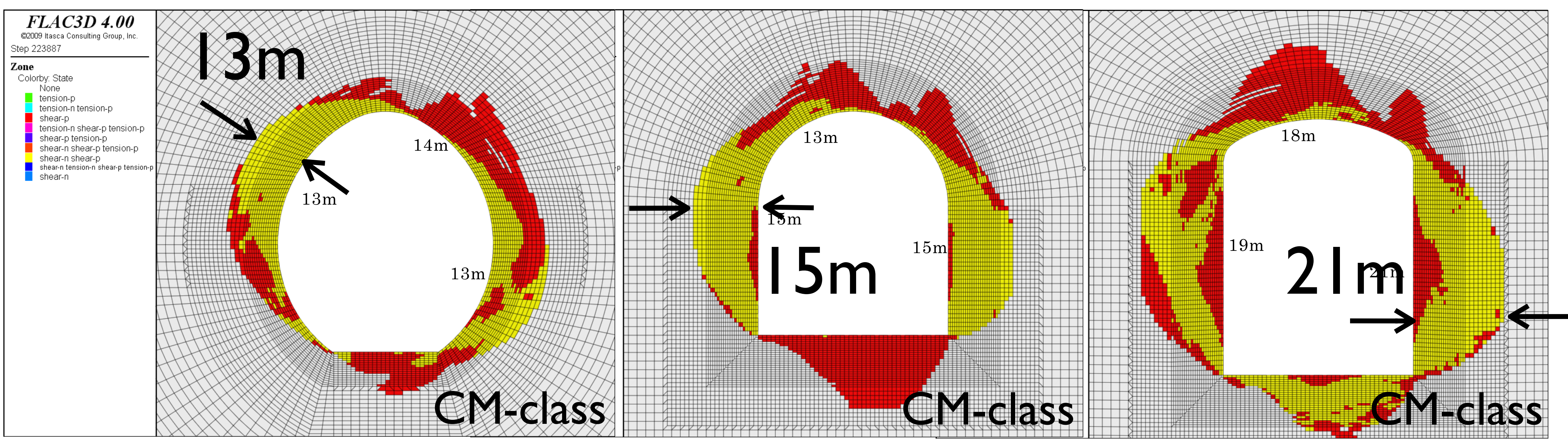
- Hyper-K detector baseline design is ready
  - Detector construction cost and schedule evaluated
  - Technical design documents available shortly
- Design optimization and further cost reduction being investigated
- Several R&Ds and prototype testings are progressing in international working groups
  - Photo-sensors, software, water system, electronics, calibration, etc.
- For further details, see slides at HK meetings:
  - http://indico.ipmu.jp/indico/conferenceDisplay.py?ovw=True&confId=29 (4th HK Open Meeting)
  - cf. next (5th) Hyper-K Open Meeting: July 19~21

Supplements

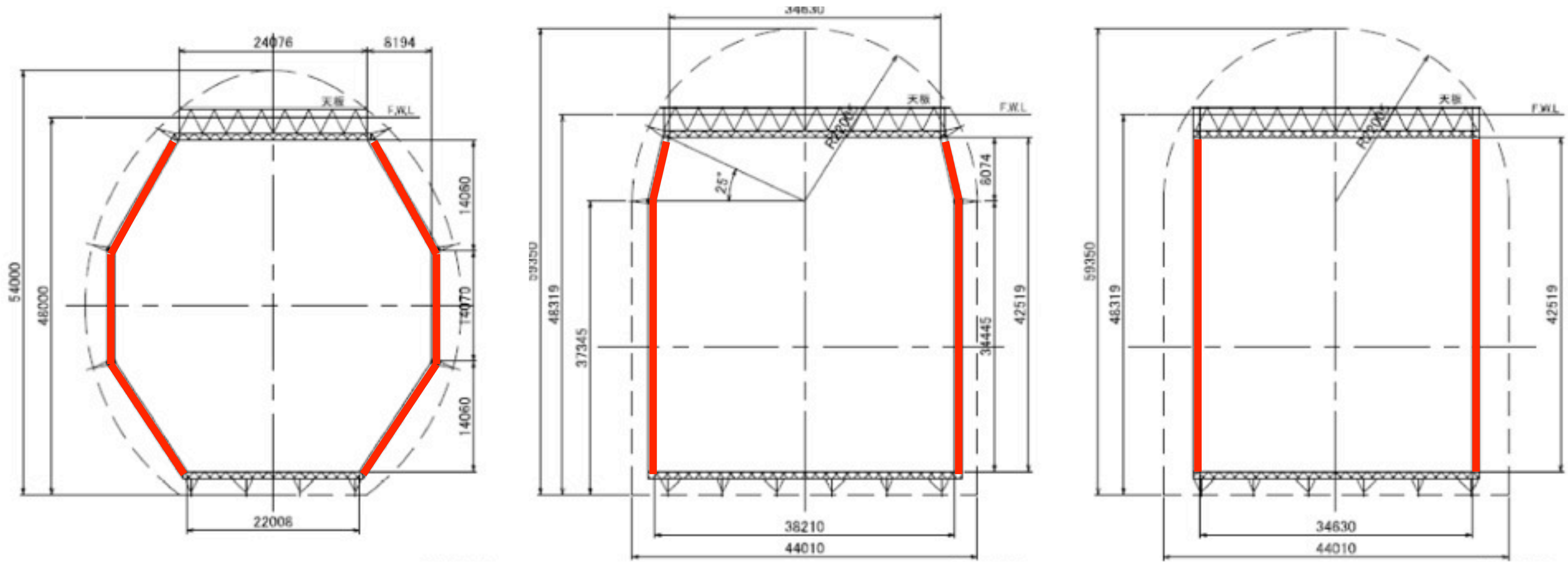
Cavern shape

- Analyzed cavern stability for other cavern shapes
- Depth of plasticity region:
  - Oval shape (Baseline): ~14m
  - Straight wall (A): ~15m
  - Straight wall (B): ~21m
- For CM-class or worser rock mass, the depth of plasticity region for straight wall is beyond the manageable level with existing techniques.

Oval shape (Baseline) Straight wall (A) Straight wall (B)



Wire support options



- PMT supporting by wires has also been studied
  - →Found the construction cost is comparable (even higher)
    - Wire termination requires special works and parts
    - Devices to give initial tensions and additional tensions when a wire stretches afterwards


"Mozumi-site"
West Mozumi
Ikeno-yama
~5.5km
Maruyama (disposal place)
2.5km
Nijugo-yama
"Tochibora-site"
1km
茂住西〜円山　約5.5km
二十五山〜円山　約2.5km
Mt Yokodake
Lake Arimine
Mt Obora
Yamabuki Pass
Inotani
Map
Traffic