HYPER-KAMIOKANDE DETECTOR

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FOR THE HYPER-KAMIOKANDE PROTO-COLLABORATION

NNN18 SATELLITE HYPER-K WORKSHOP

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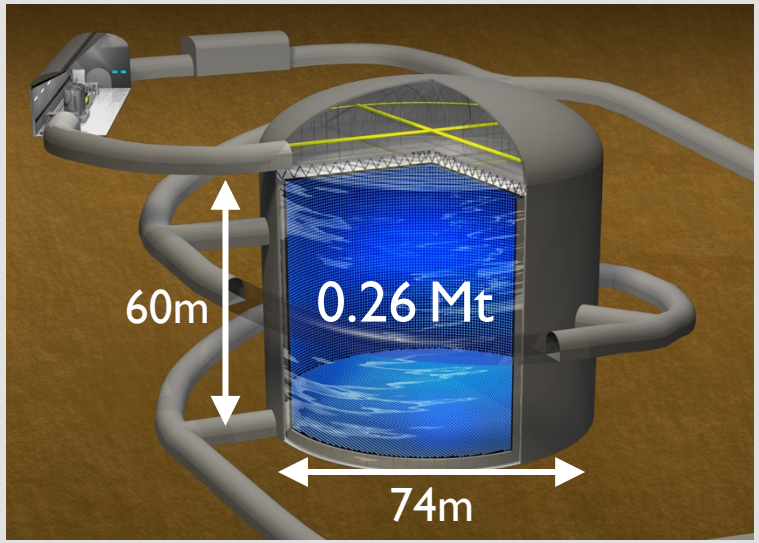
PREFACE

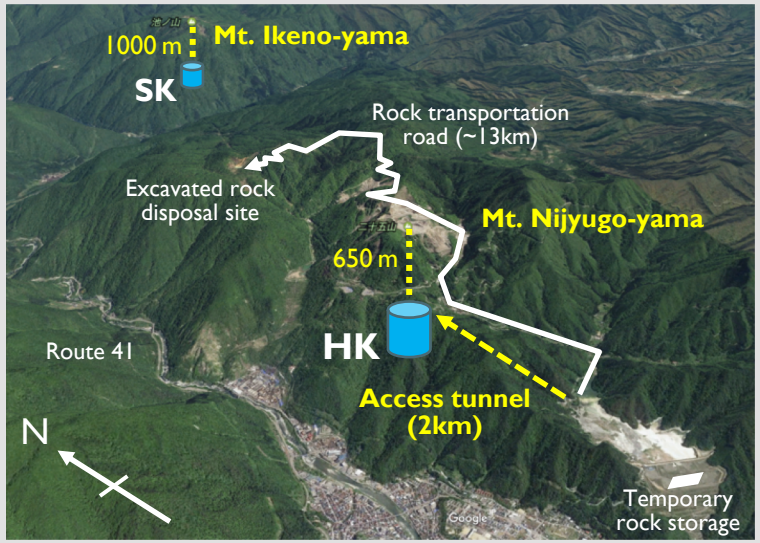
- Though being built on technology established with Kamiokande/Super-Kamiokande, Hyper-K detector will not be just an enlarged version of them
- Hyper-K offers great new challenges : Need significant contributions to overcome them with hardware breakthroughs

Contents

- Overview of the Hyper-K detector
- [Challenges] Photosensors
- [Challenges] Inner detector isolation (for Radon reduction / for Gadolinium loading)
- [Challenges] Electronics
- [Challenges] Calibration
- Conclusion

HYPER-K DETECTOR AND SITE





- 187 kton fiducial mass : ~8 x SK's
- Inner volume viewed by 40,000 of 20″ PMTs providing 40% photocathode coverage (reference design)
- Covers a wide energy range : a few MeV ~ TeV

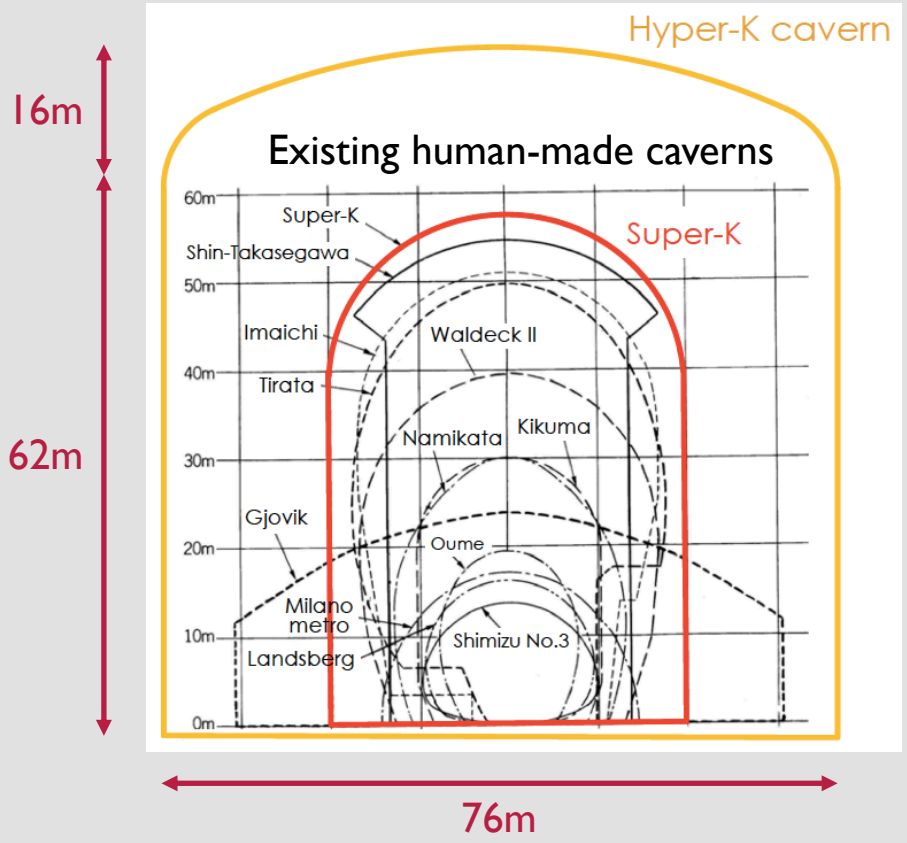
- 8 km south of the SK site
- 650m rock (1750m.w.e.) overburden
  - x5 cosmic-ray muon flux of that at SK
- 2km tunnel to be excavated for the access to the underground HK site

CAVERN

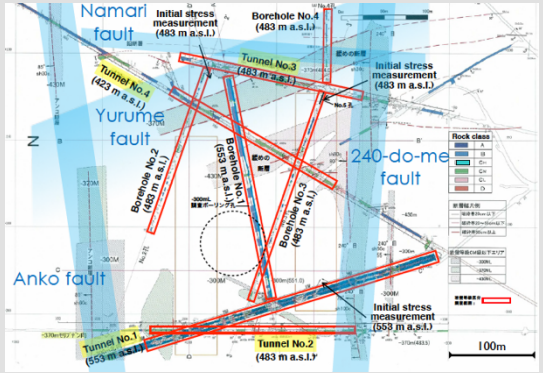
Japanese responsibility

The cavern for the Hyper-K water tank will have the world largest span

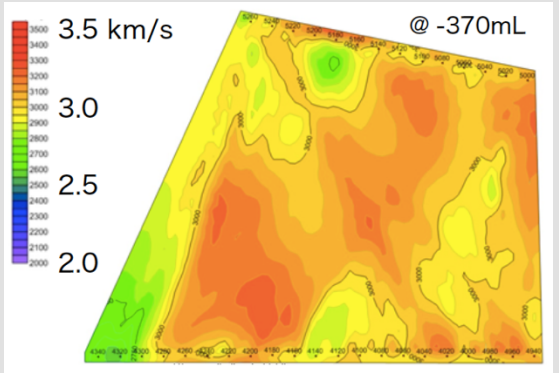
(among all human-made caverns)



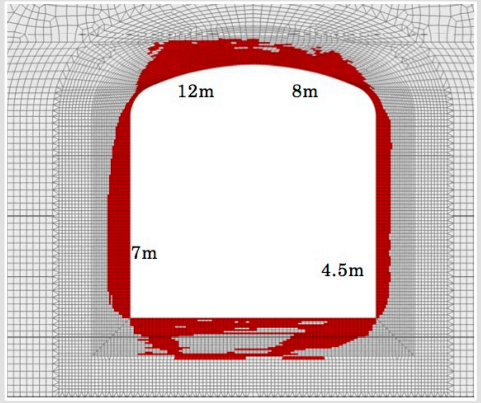
Geological information obtained by tunnel and boring surveys



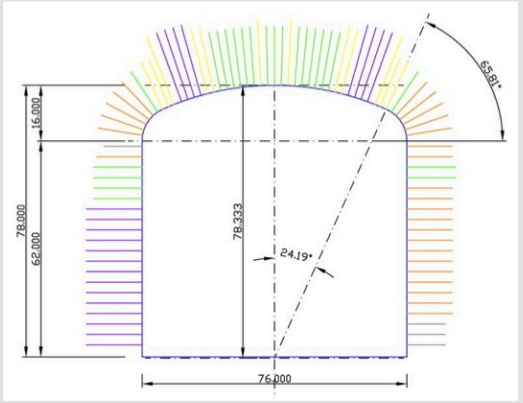
Velocity distribution obtained by a seismic prospecting



Plastic region (if no support)



Support design (PS-anchors)



It has been concluded that the HK cavern can be excavated using existing techniques

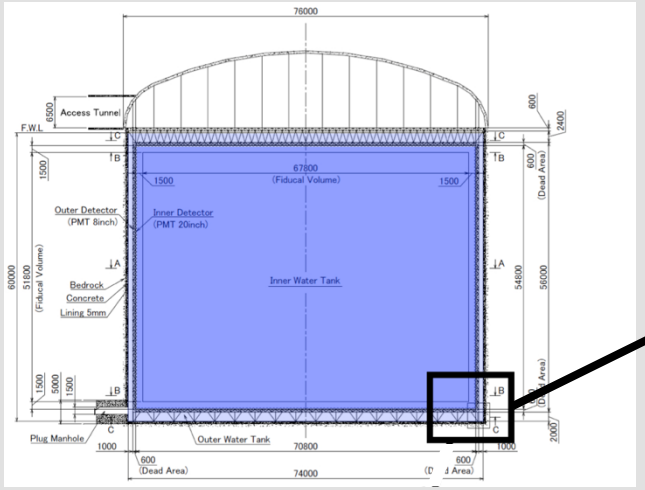
WATER TANK

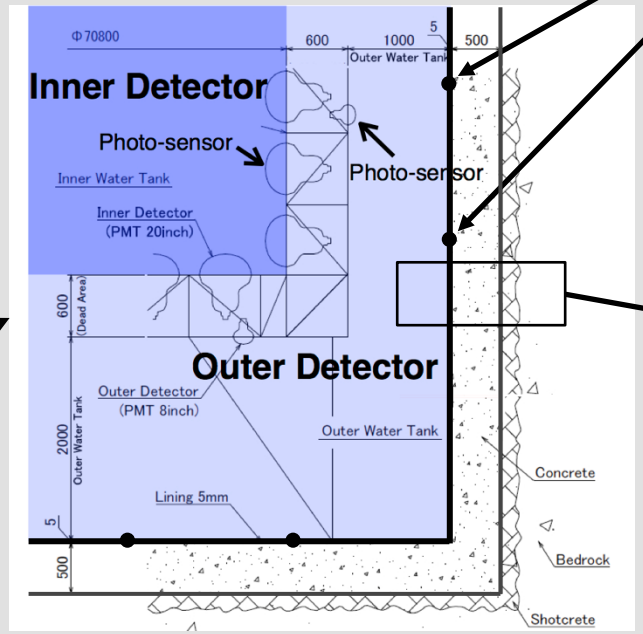
Japanese responsibility

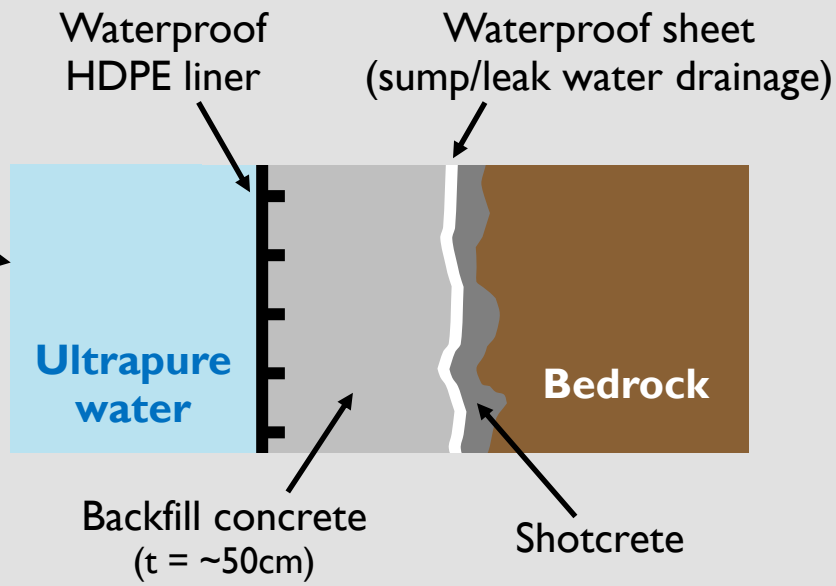
International responsibility

Geomagnetic field compensation coils

- Embedded in the concrete layer or fixed on the HDPE surface







Inner Detector (ID)

- Φ 70.8m x H 54.8m (216 kton)
- Main active volume for physics measurement

Outer Detector (OD)

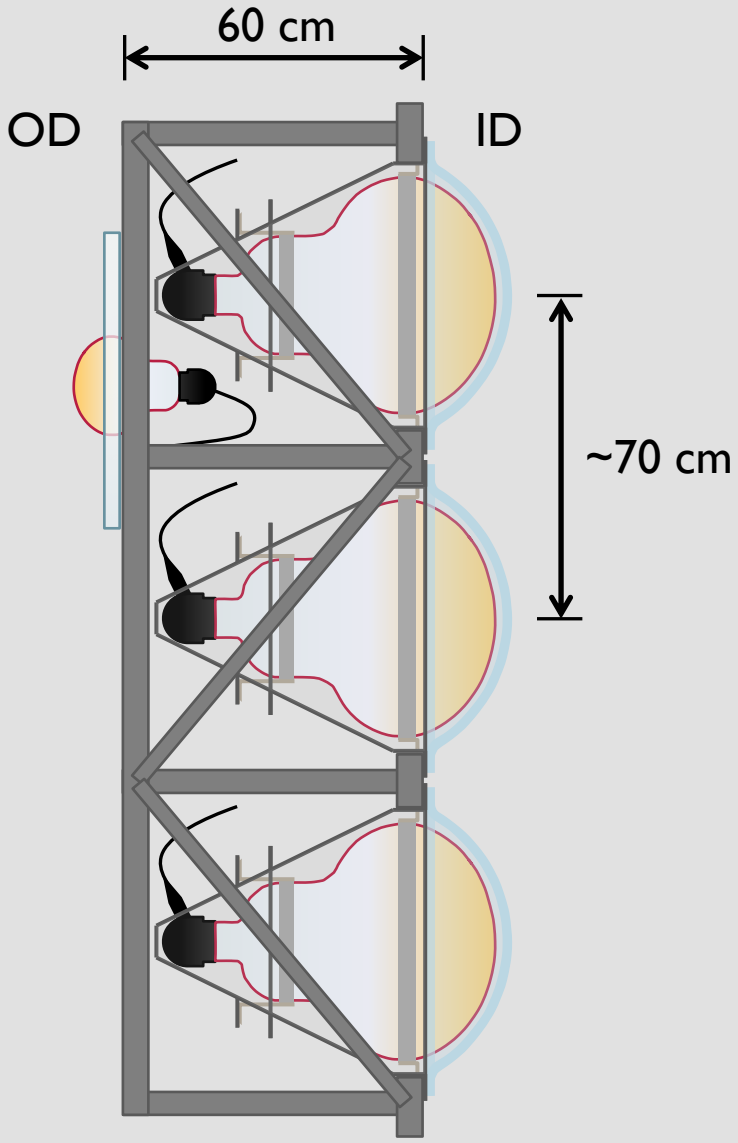
- Thickness : 1m for barrel, 2m for top/bottom
- Veto for entering particles
- Detection of particles escaping from ID

Water tank lining

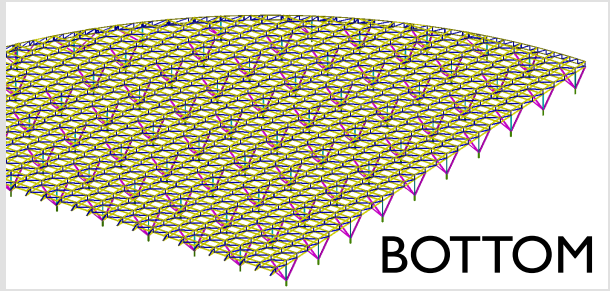
- High density polyethylene (HDPE) liner with studs, + Backfill concrete layer
- Many examples of usage : Industrial waste disposal plant, ..
- Additional waterproof sheets between bedrock-covering shotcrete and backfill concrete

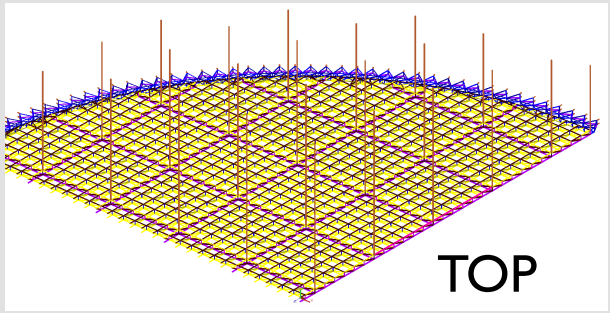
PHOTOSENSOR SUPPORT STRUCTURE

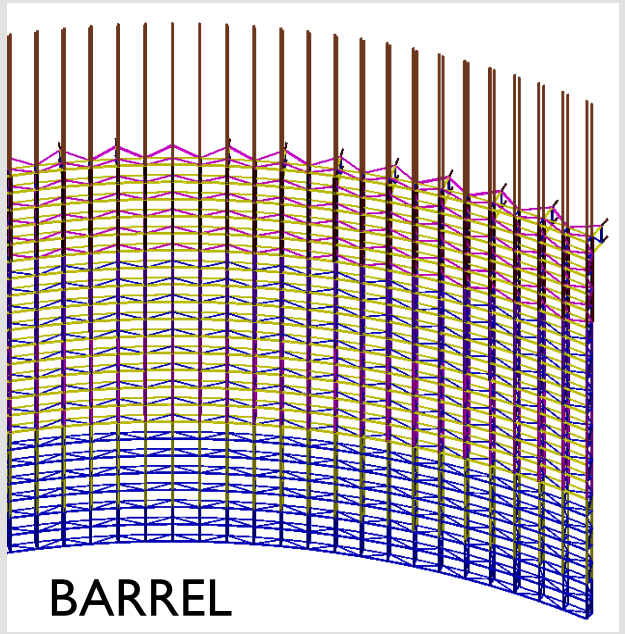
Japanese responsibility



- Truss structure made of shaped stainless steels
- Bottom structure : Set on the ground
  Top and barrel structure : Hung from the ceiling
  → Weight is an important factor for photosensor/cover choice







PHOTOSENSORS IN THE INNER DETECTOR

- Basic requirements for ID photosensors
  - Large aperture + High photodetection efficiency
  - Nano-second T resolution for single PE
  - Wide dynamic Q range (1-1000 PEs)
  - Low dark rate (< 4 kHz for 20″ PMTs)
  - Waterproof + High pressure tolerance (> 8 atm)
- ~40,000 of 70cm square cells covering the full ID area
  - 40% photosensitive area if all cells are instrumented with 20″ PMTs

Requirements	Value	Conditions
Quantum efficiency (QE)	30%	Minimum at 400nm
Collection efficiency (CE)	85%	Minimum at 400nm
Detection efficiency	26%	QE × CE
Timing resolution	5.2ns	FWHM for 1PE
Charge resolution	50%	Maximum σ/mean for 1PE
Signal window	200ns	Contains 95% of integrated charge
Dynamic range	2 photons/cm^2	Maximum flux per unit area
Gain	10^7	Typical
Afterpulse rate	5%	Maximum for 1PE
Dark count rate	2Hz/cm^2	Typical
Rate tolerance	10MHz	1PE rate for 10% change of gain
Magnetic field tolerance	100mG	Maximum for 10% change of gain
Life time	20years	Less than 10% dead PMTs
Pressure rating	0.8MPa	Minimum static load in water

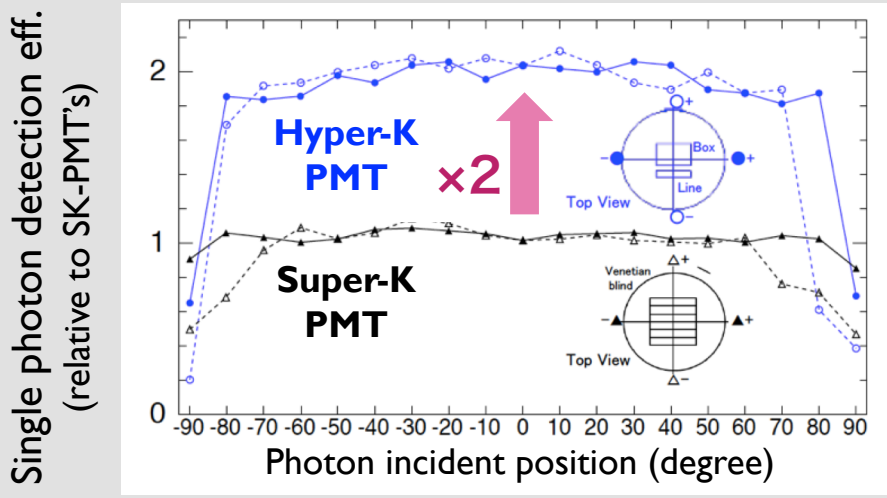
- 20% photo-coverage by instrumenting half of the cells with 20″ PMTs is **Japanese responsibility**
- The remaining half is open to any innovative photodetection system by **International responsibility** to achieve the Hyper-K baseline physics goals and further enrich the Hyper-K physics program

20″ PMTs

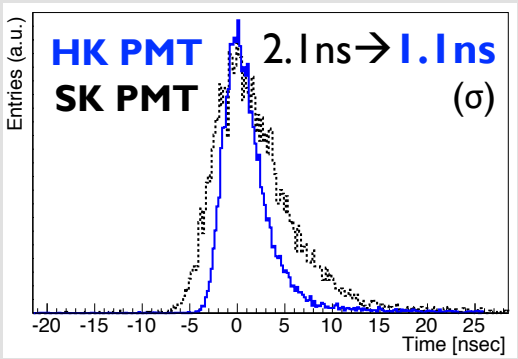
Japanese responsibility

Primary candidate : Hamamatsu R12860

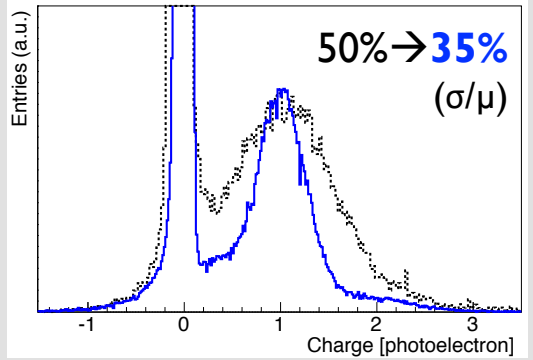
- Newly developed for Hyper-K
- High-QE photocathode + Improved dynodes
- Achieved
  - ×2 single photon detection efficiency
  - ×2 better timing resolution
  - ×2 hydrostatic pressure tolerance (than those of Super-K PMT)
- ~140 samples installed to SK in this summer



Timing (for Single PE)

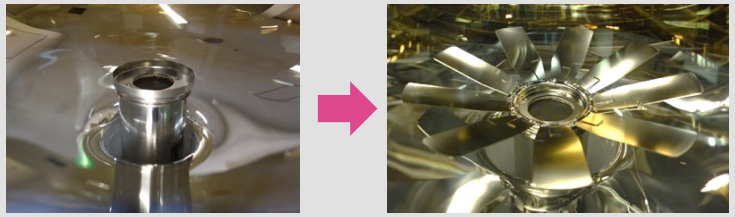


Integrated charge



Alternative candidate : MCP-PMT by NNVT (China)

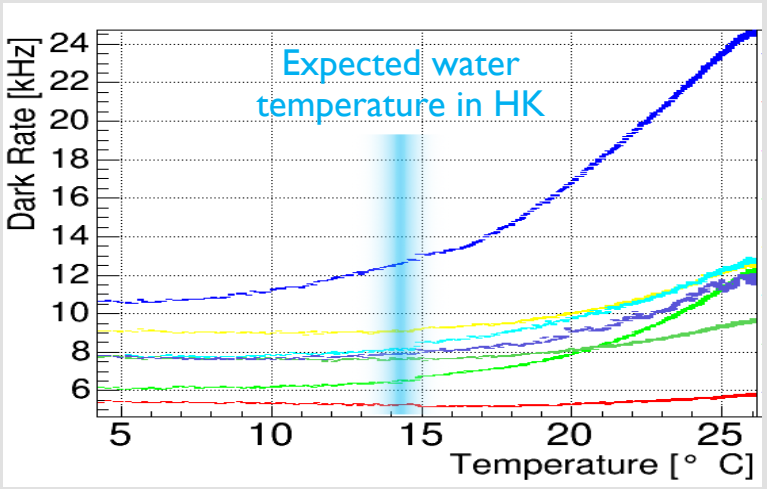
- Originally developed for JUNO
- Under some improvements for Hyper-K
- Performance now comparable to R12860



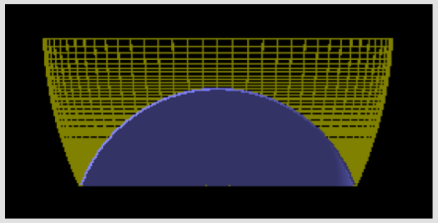
Timing resolution greatly improved by modifying the electric field

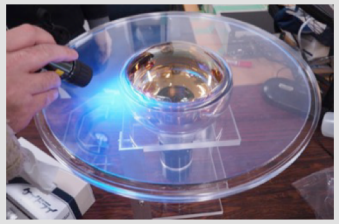
20″ PMTs : FOR FURTHER IMPROVEMENT

- Lowering the dark rate **Japanese responsibility**
  - The average dark rate of Hyper-K PMTs is roughly twice as high as Super-K PMT's
  - Not surprising since HK PMTs have much higher quantum/collection efficiencies
  - Trying to reduce further by optimizing the design, manufacturing conditions, etc.



- Light collector system : an alternative way to increase the coverage **Potential international contributions**
  - Typically cheaper than the addition of more photosensors
  - But usually limits the angular acceptance and degrades the timing performance
  - Must be compatible with PMT covers





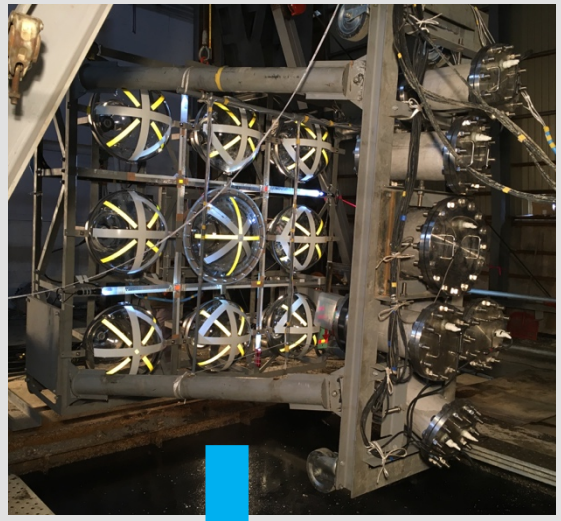
An initial study has just started.

PROTECTIVE COVERS FOR 20″ PMTs

Japanese responsibility

- Every 20″ PMT in Hyper-K to be housed in a protective cover to prevent a chain reaction of the PMT implosion
  - Cover with small holes limits the water flow into evacuated area if PMT implode → Avoid shockwave outside the cover
- Performance of prototype covers has been validated by a series of PMT implosion tests performed at 80m water depth
  - Central PMT in 3 × 3 PMT array artificially imploded

    → Confirmed that pressure pulse outside cover was very weak and no chain implosion happened



Sunk down to 80m

- Working for better design
  - Inexpensive, lightweight, …
  - Welcome new ideas/contributions

Potential international contributions

Baseline design (Stainless)

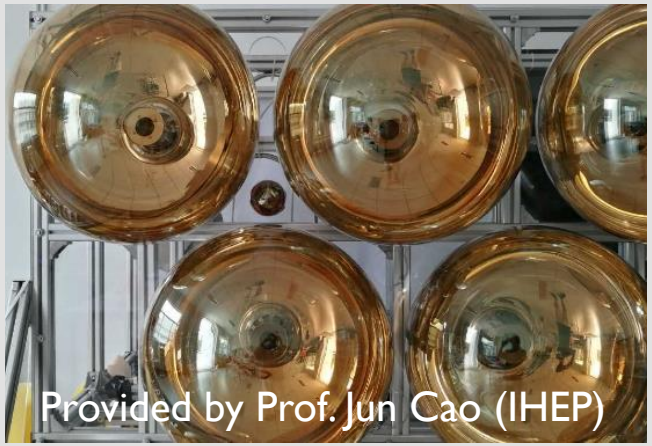
Lightweight (Resin)

Simple structure (Stainless)

HYBRID PHOTODETECTION SYSTEM

Japanese responsibility
+
International responsibility

- The baseline Hyper-K physics goals are defined assuming an ID photosensor configuration of the full (= 40,000) 20″ PMTs
- A possible alternative solution to achieve the goals and even enrich the HK physics is to combine the 20″ PMT system with an innovative and complementary photodetection system
  - A good example of such a hybrid system may be the double calorimetry system proposed in JUNO
    - Energy response of the 20″ PMT system can be calibrated by a photon-counting technology with the 3.5″ PMT system
  - By overcoming 20″ PMT's drawbacks
    - Positional/directional sensitivities → reconstruction improvements for events near the wall, etc.
    - Lower dark noise, better timing resolution → higher tagging efficiency of neutrons, etc.

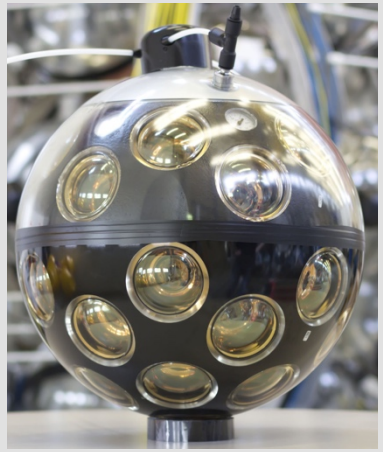

Provided by Prof. Jun Cao (IHEP)

MULTI-PMT MODULE

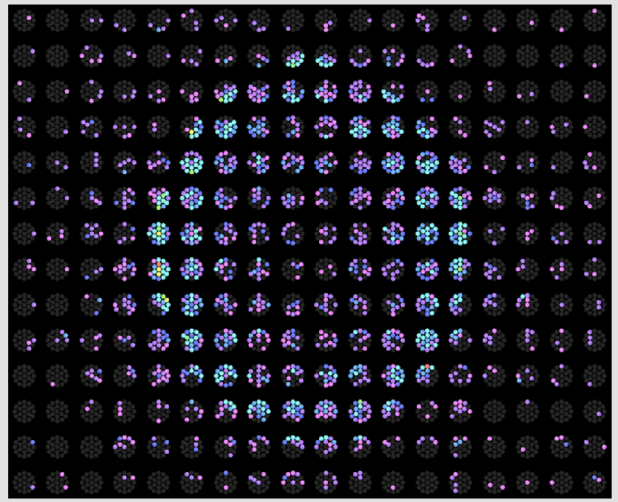
International responsibility

- A novel technology which combines a number of small 3″ PMT inside a module
- Various benefits compared to large-area PMTs
  - Finer granularity
  - Intrinsic directional sensitivity
  - Improved timing resolution
  - Less magnetic field sensitivity
  - Lower dark noises

  Expected to improve the reconstruction, particularly for events near the wall and multi-ring events
  - More vendors for 3″ PMTs → Competition
  - Pressure tolerance
- Trade off
  - Smaller photo-coverage
  - Heavier weight
  - Higher cost, longer manufacturing time



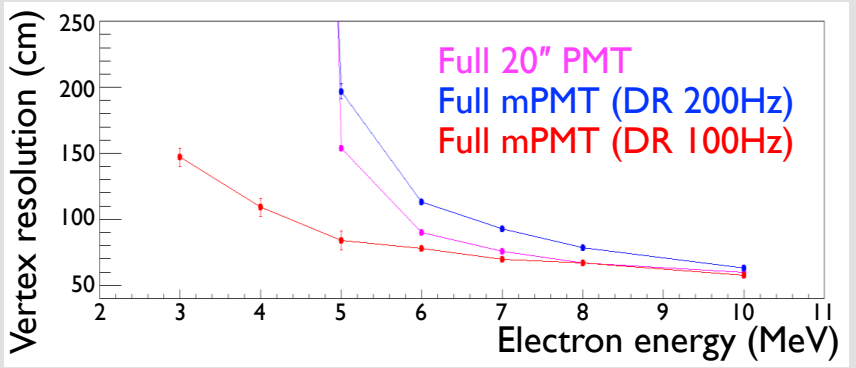
KM3NeT
Digital Optical Module



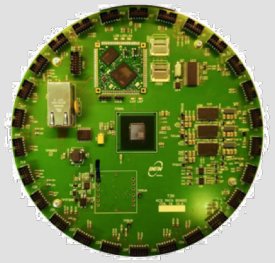
Exciting challenges to innovate the HK design and enrich HK physics!

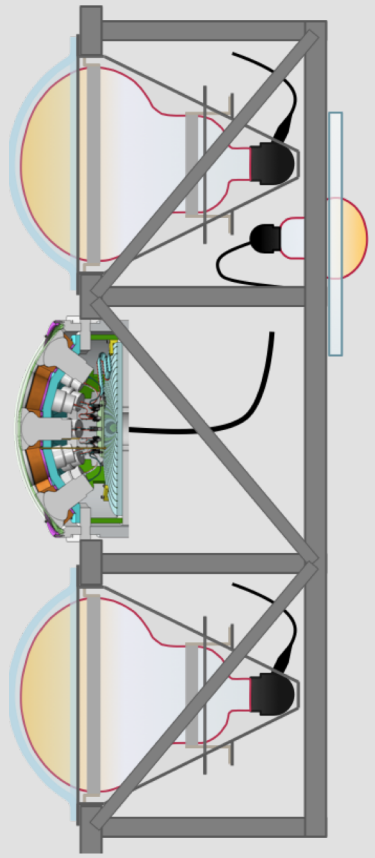
MULTI-PMT MODULE

International responsibility



- R&D studies ongoing very actively and internationally
  - Simulation studies on the reconstruction performance
    - Improvement visible in the initial full 20″ vs full mPMT comparison
    - Performance of the hybrid (20″ + mPMT) configuration to be studied
  - Characterization of 3″ PMTs (Hamamatsu, HZC, ET Enterprises)
    - Basic performances satisfactory
    - Reduction of dark rates crucial
  - Module/assembly designing
  - Acrylic vessel testing (optics, mechanics, ..)
  - Reflector design optimization for physics
  - Electronics designing
  - First prototypes under preparation
- Many many things to do

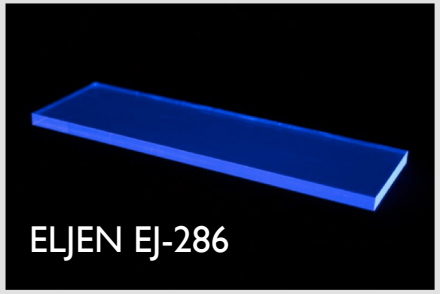


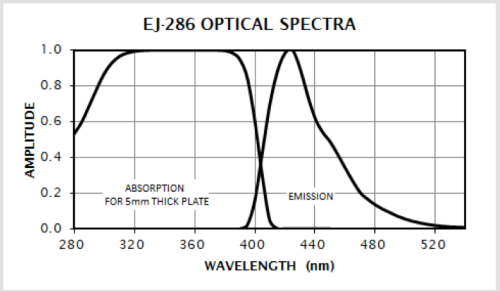


PHOTOSENSORS IN THE OUTER DETECTOR

International responsibility

- Thickness of the HK barrel OD layer (1.0m) is ~1/2 of the SK's (2.2m)
  - To minimize the excavation cost while securing the FV
  - Making the veto performance more challenging
- Primary option : 3″ PMT + Wavelength shifting (WLS) plate
  - ↔ 8″ PMT + Wavelength shifting plate @ Super-K OD
  - 3″ PMTs : Competitive suppliers, Lower cost per area
  - Smaller PMT spacing → Good for the thinner OD
  - OD design optimization is progressing
    - Total number of OD PMTs, OD layer thickness, ..
  - Testing of candidate PMTs / WLS plates also under way





- Any new idea ? PMT array along vertical strings ? (like ANTARES / KM3NeT / IceCUBE / ..)
  - Expecting an easier installation/maintenance, a reduction of the weight load to the support structure, good match to the complete hermetic ID tank, lower cost, and great expertise in the field

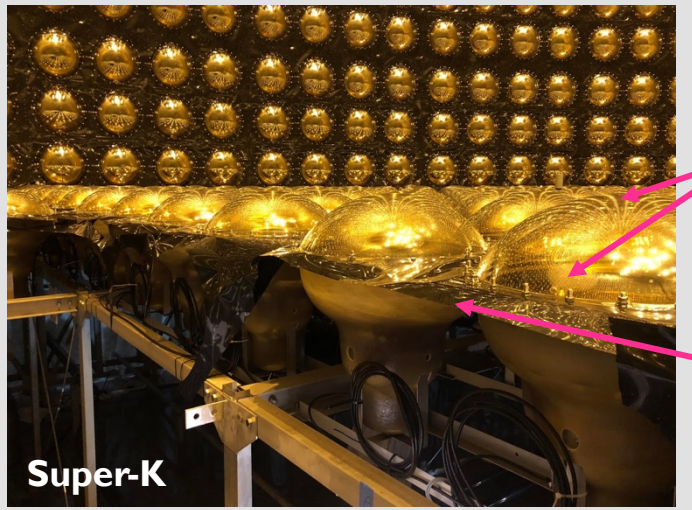
RADON REDUCTION

- ^{222}Rn in the host mine's air, water supply, and surrounding rock will be one of major background sources for low energy (< several MeV) physics at HK
- Polyethylene tank liner is more permeable than stainless steel one (used in SK) to radon emanating from the concrete and surrounding rock
- Radon measurement result at the underground HK site suggests that the SK-level ID/OD water separation might be OK

Japanese responsibility

- A tighter water sealing at the ID surface should be effective to lower the radon concentration and enhance the HK physics reach

Potential international contributions



Small holes on the PMT cover

Thin black sheets : Adjacent sheets bonded loosely by stapler

More solid black panels instead of thin black sheets ?
Can remove holes from the front PMT cover ?

GADOLINIUM LOADING

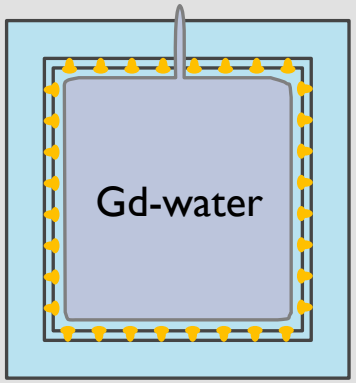
- High efficiency neutron tagging with the gadolinium-loaded water will enhance the Hyper-K capability in various physics programs
- Past/future experiences in the SK-Gd project will help us designing Hyper-K to be compatible with the Gd loading
  - Safety management, low-RI $Gd_2(SO_4)_3$ development, Gd water system development/operation, detector calibrations/operation, physics analyses, ..
  - The Super-K tank refurbishment work almost done, and have started filling the tank with pure water
  - Gd loading to the SK tank is expected to happen in autumn next year or so
  - Good opportunity for new participations in SK-Gd

Potential international contributions

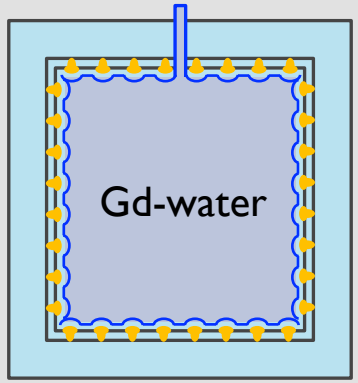
Super-K Gd water system installed in a new underground hall

GADOLINIUM LOADING

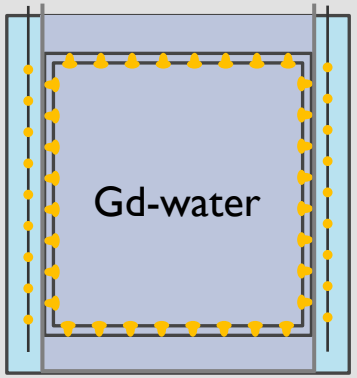
- The water tank lining is designed so that the Gd-water cannot leak outside the HK region, but ..
- A complete hermetic seal of the Gd-loaded water volume would be necessary for redundancy to prevent possible leakage
  - Not included in the funding request in Japan. Need **International contributions** to to realize it



Balloon inside the ID ?



Acrylic vessel fixed on the ID surface ?



In-tank stainless steel tank ?

Good match to string-type photo-sensor systems

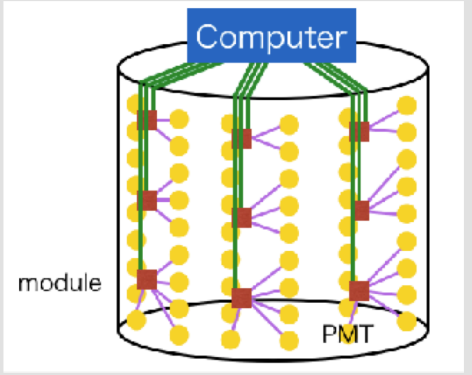
ELECTRONICS

Japanese responsibility

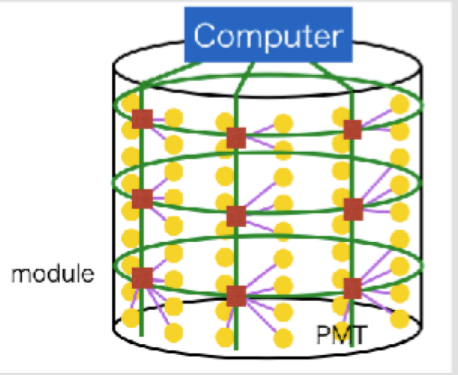
International responsibility

- Basic requirements on the signal digitizer are common to SK/HK
  - Capable to collect all the hit data even during a nearby supernova
  - All the front-end electronics have to be synchronized
- Hyper-K front-end electronics modules will be placed under water
  - Unlike the SK ones used in the dedicated on-deck "electronics huts"
  - Shorter PMT cables
    → Smaller signal degradation / Lighter weight load
  - Introduces new challenges
    - Watertight housing / connectors
    - Redundancy to component failures
  - Expertise acquired in the past/current subsea and in-ice experiments should be valuable

Item	Requirements
Trigger	self triggering for each channel
PMT impedance	50Ω
Signal reflection	<0.1%
Discriminator threshold	<0.25 p.e. (well below 1 p.e.)
Processing speed/hit (channel dead time)	<1 μs
Maximum hit rate	>1 MHz for each channel
Charge dynamic range	0.1 to 1250 p.e. (0.2 to 2500 pC)
Charge resolution	RMS~ 0.05 p.e. (below 25 p.e.)
Timing LSB	<0.5ns
Timing resolution	RMS <0.3ns at 1 p.e. RMS <0.2ns above 5 p.e.
Power consumption	<1W per channel



One-to-one model

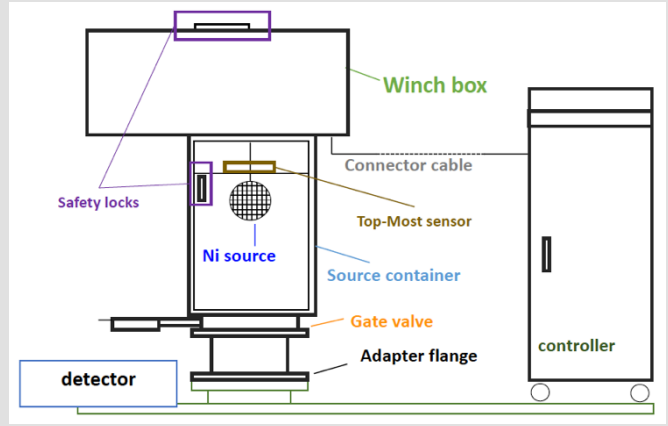


Mesh model

DETECTOR CALIBRATION SYSTEM

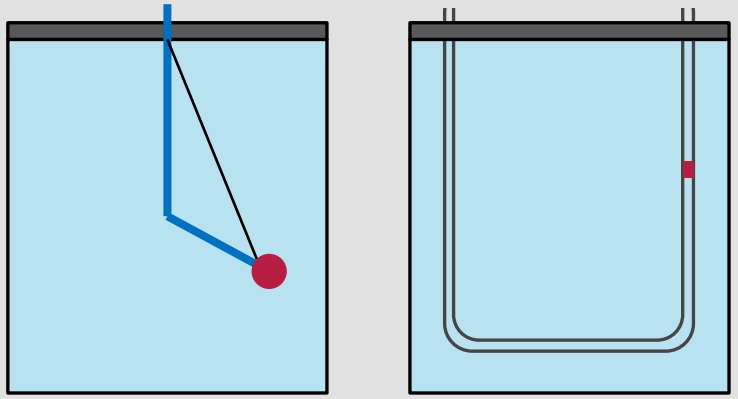
- Proposed HK calibration system is based on extensions of the SK calibrations

- Vertical deployment system that can be moved between calibration ports on the deck
  - A straightforward and well-defined way for a cylindrical detector
  - Arrangement of the calibration ports not determined yet
  - A prototype auto-deployment system for HK was installed in SK and being tested



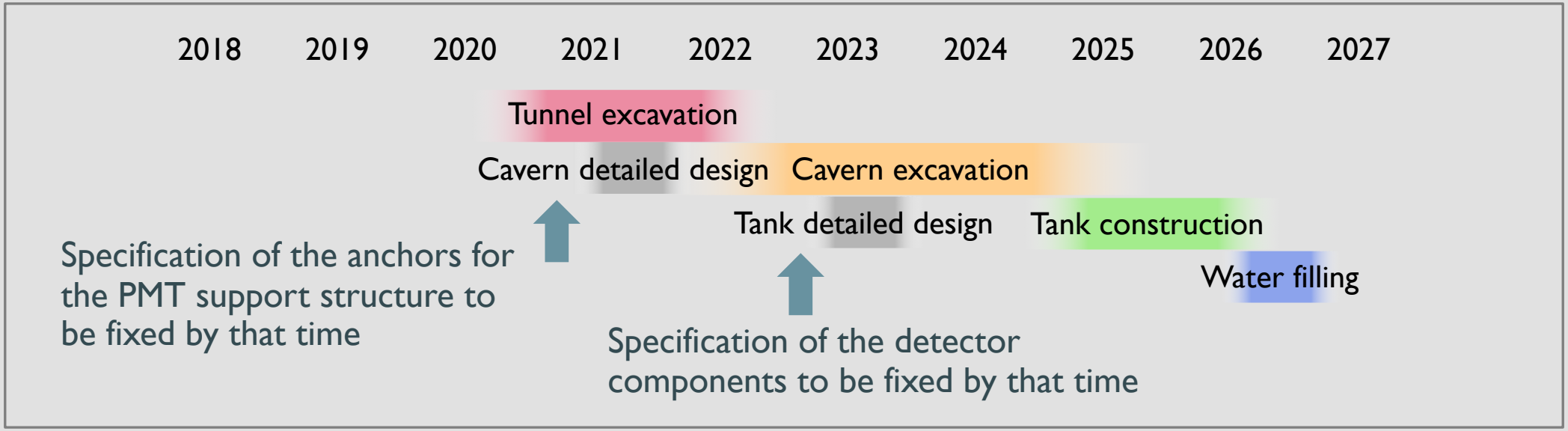
Prototype auto-deployment system

- Chance to introduce new ideas
  - 3D deployment system ?
  - Tube-guided radioactive source deployment ?
  - Better light sources (more stable intensity, better-defined energy, higher frequency, faster pulse, easier to handle, ..)

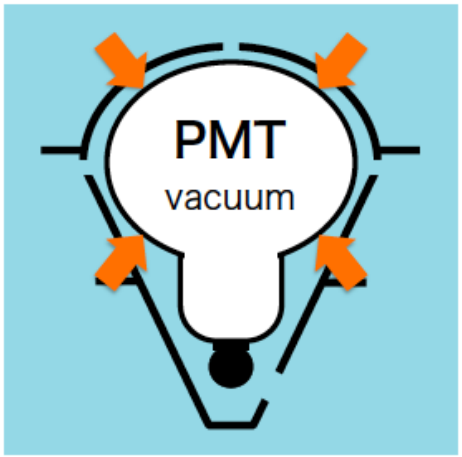


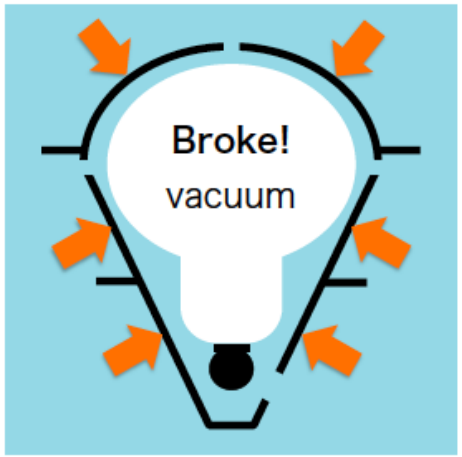
CONCLUSION

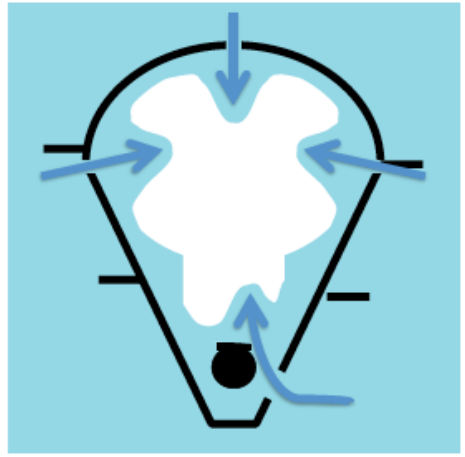
- Need significant Japanese and international contributions to achieve the HK physics goals
- Big improvements to enrich the HK physics program should be possible by potential hardware breakthroughs : Your expertise and new ideas really welcome
- The project moving forward : Nice time for new participations



SUPPLEMENT







Cover has small holes

PMT always exposed to the water pressure

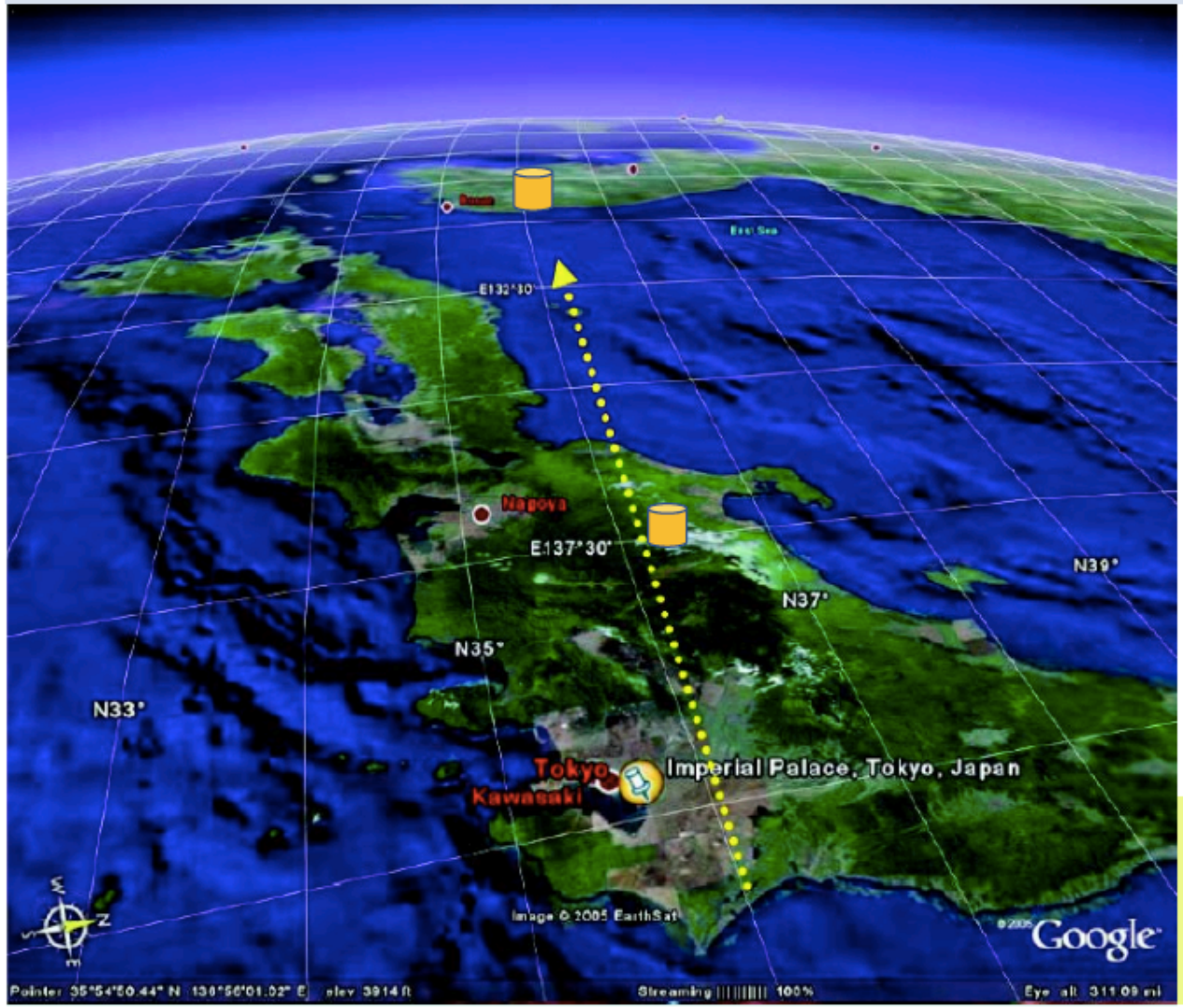
Unexpected implosion!

→ Cover pressurized, but strong enough to keep its shape

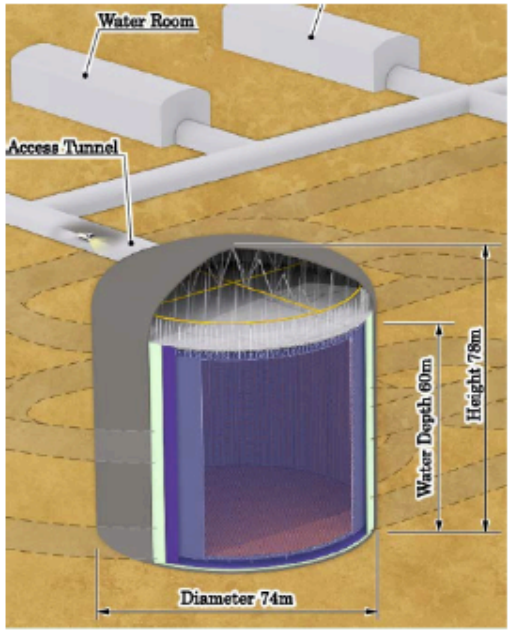
Water flows in slowly

Large pressure shock-wave doesn't arise outside the cover

Hyper-Kamiokande 2nd Detector in Korea



Hyper-Kamiokande



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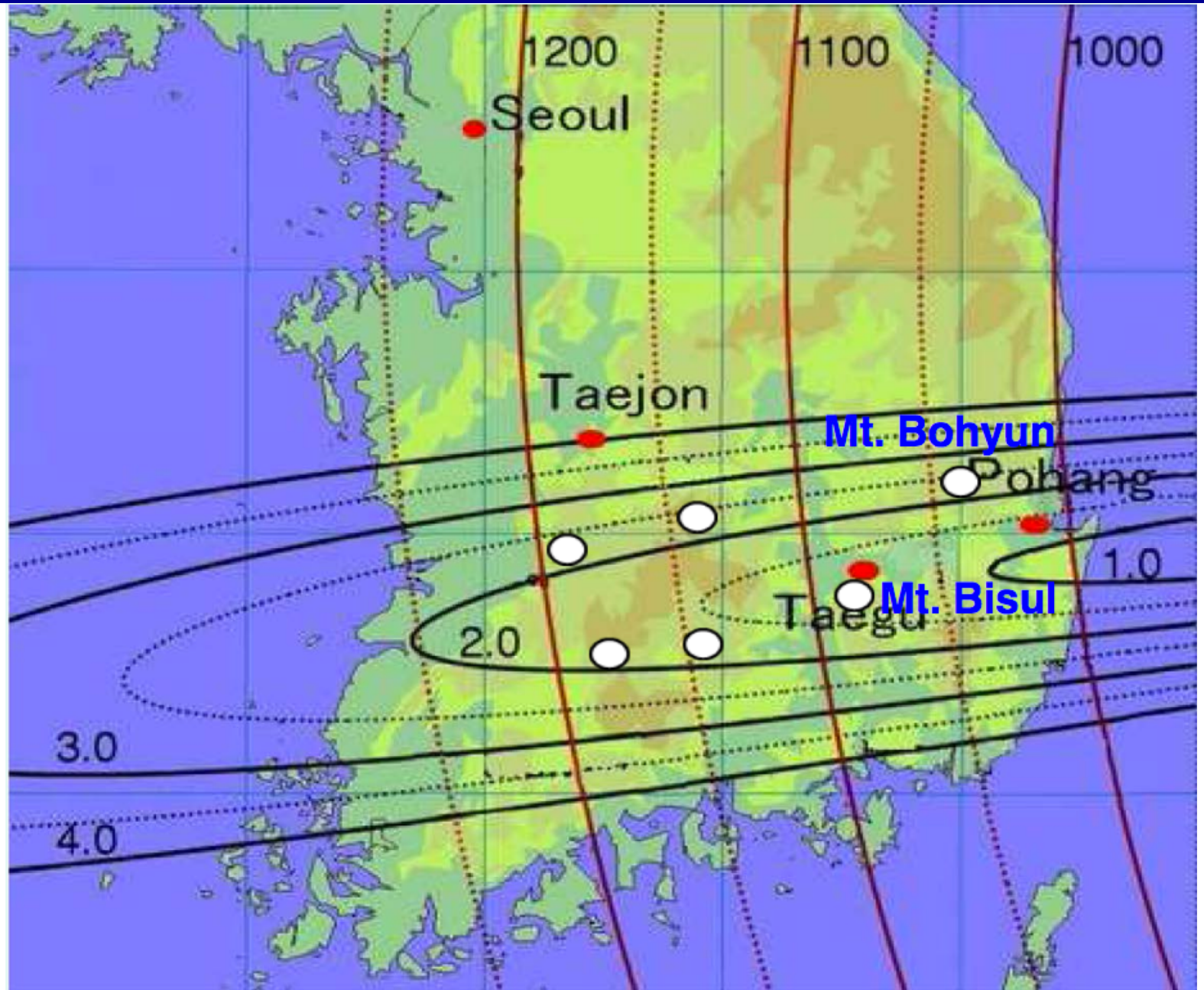
Some candidate sites in Korea

Site candidates for a 2nd osc. maximum detector in Korea

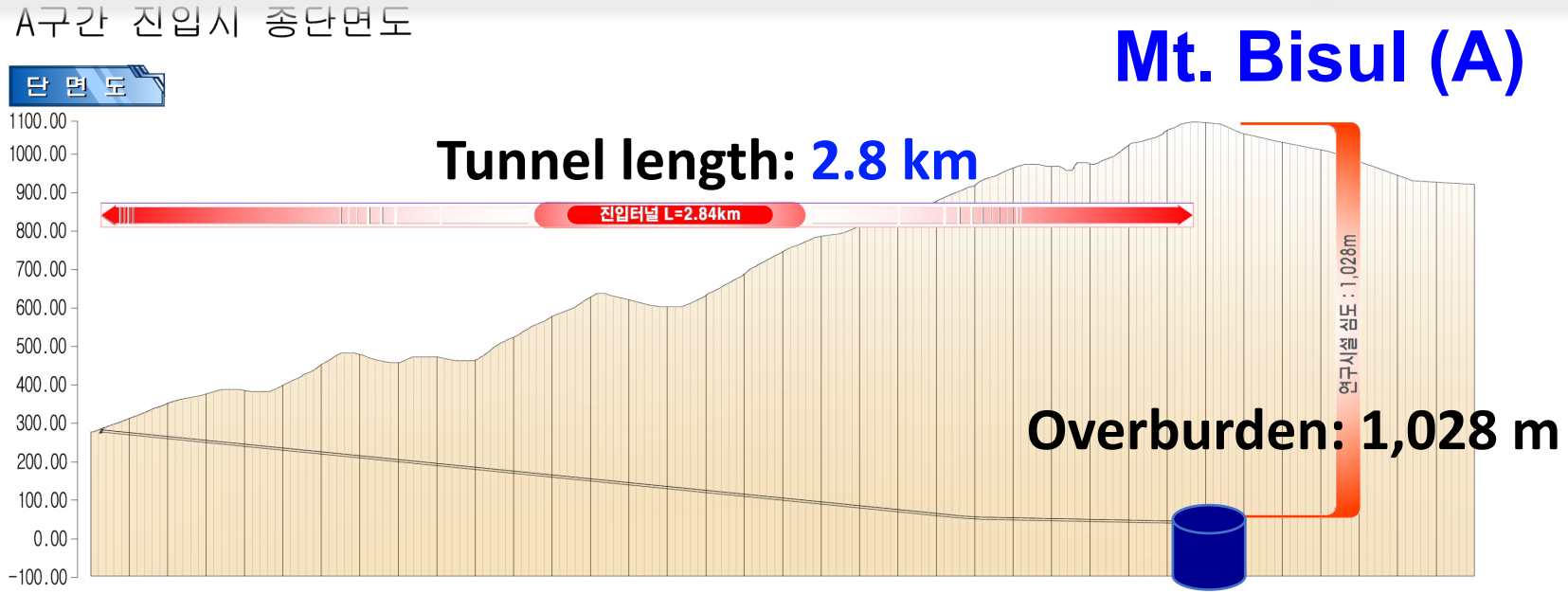
-- Baselines with 1,000~1,200 km
-- 2.0~2.5° or 1.5~2.0° off axis beam directions
-- >1,000 m high mountains with hard granite rocks

Site	OAB	Baseline [km]	Height [m]
Mt. Bisul	**~1.3°**	**1088 km**	**1084 m**
Mt. Hwangmae	~1.8°	1140 km	1113 m
Mt. Sambong	~1.9°	1180 km	1186 m
Mt. Bohyun	**~2.2°**	**1040 km**	**1126 m**
Mt. Minjuii	~2.2°	1140 km	1242 m
Mt. Unjang	~2.2°	1190 km	1125 m

Candidate Sites



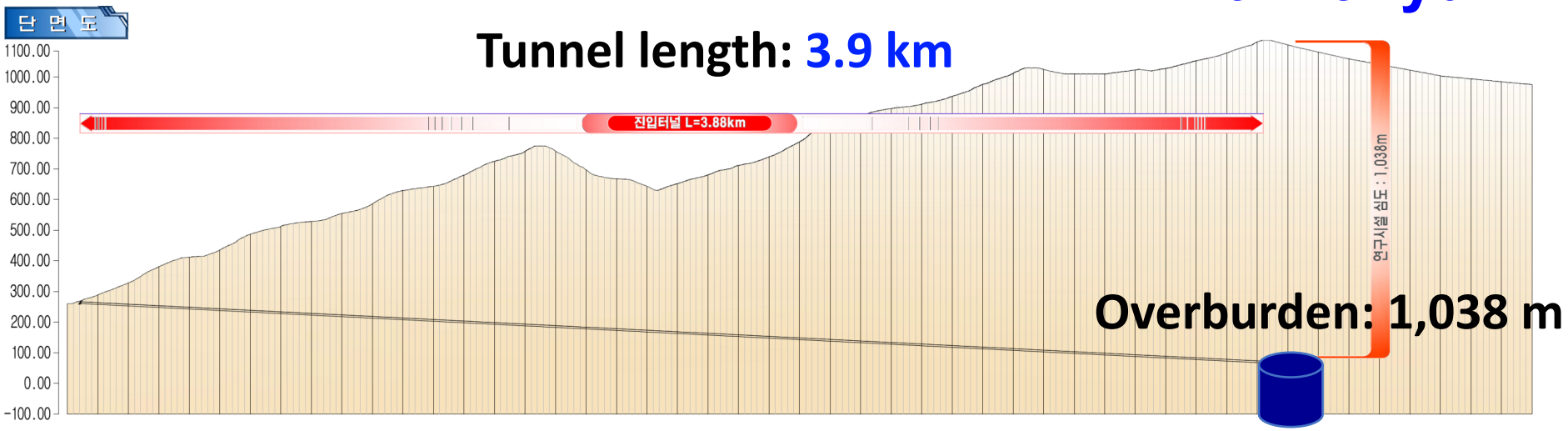
Tunnels at Mt. Bisul & Bohyun



Mt. Bisul (A)

Tunnel length: 2.8 km

Overburden: 1,028 m

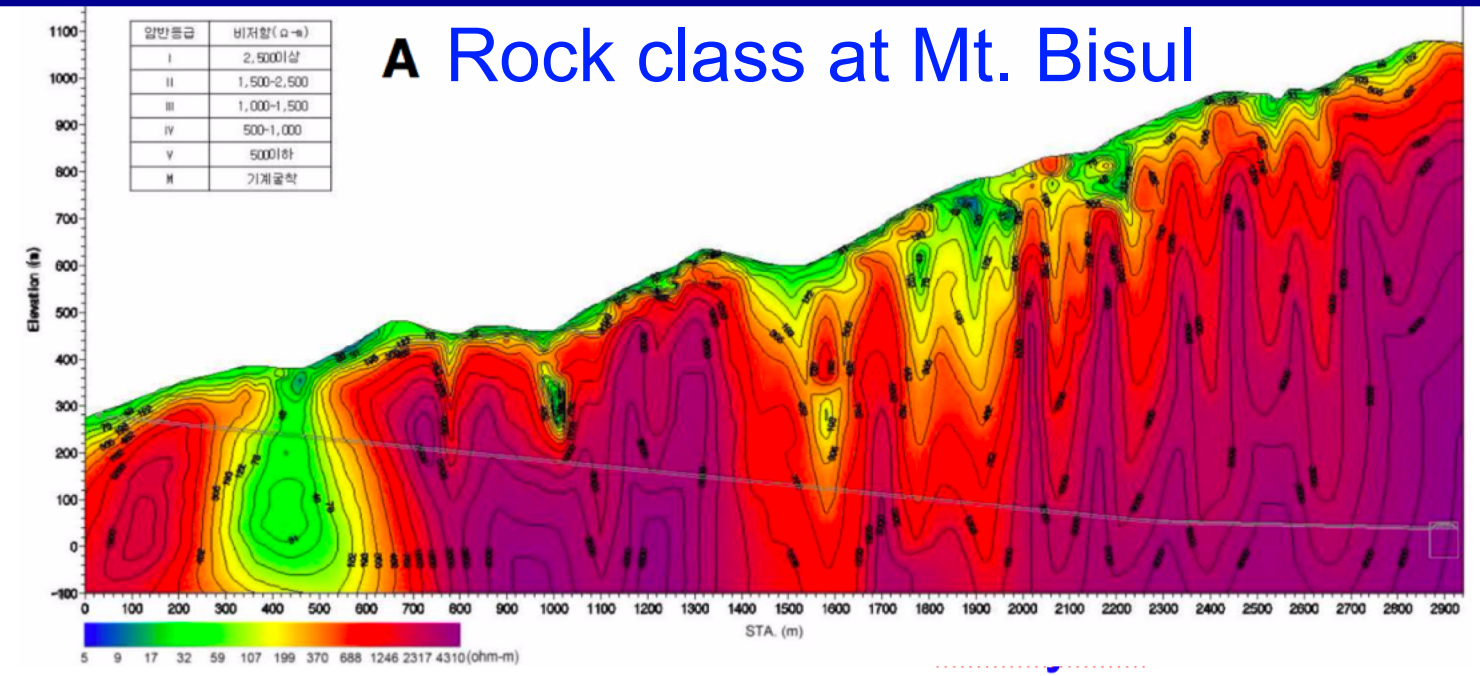


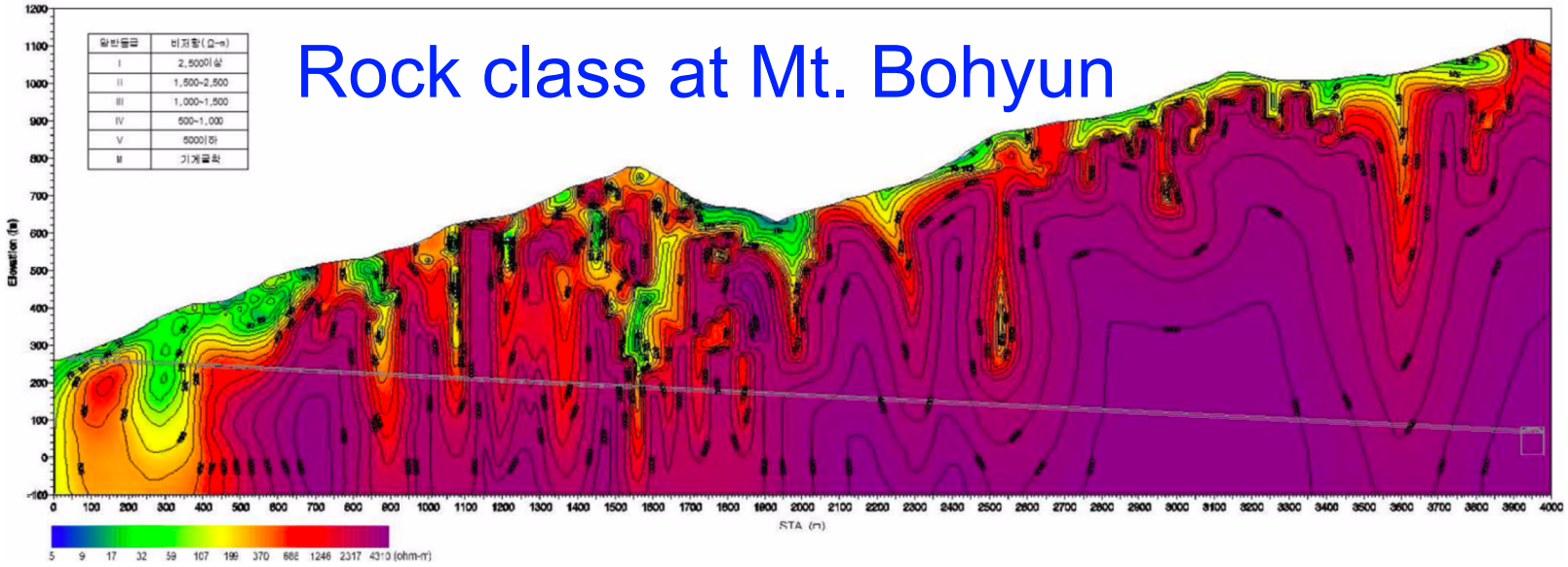
Mt. Bohyun

Tunnel length: 3.9 km

Overburden: 1,038 m

Site Survey


A Rock class at Mt. Bisul
암반등급 | 비저항(Ω-m)
I | 2,5000이상
II | 1,500~2,500
III | 1,000~1,500
IV | 500~1,000
V | 5000이하
M | 기계굴착
Elevation (m)
STA. (m)
5 9 17 32 59 107 199 370 688 1246 2317 4310(ohm-m)


Rock class at Mt. Bohyun
암반등급 | 비저항(Ω-m)
I | 2,5000이상
II | 1,500~2,500
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