Next-Generation Water Cherenkov Detectors (1) Hyper-Kamiokande

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3 Generations of Kamioka Nucleon Decay Experiments

	Kamiokande	Super-Kamiokande	Hyper-Kamiokande
Mass	3,000 t (+1,500 t)	50,000 t	1,000,000 t
Photosensitive Coverage	20 %	40 % (SK-1)	?
Observation Started	1983	1996	?
Cost (Oku-Yen)*	5	100	400 – 500?**

* 1 Oku-Yen ≈ 1M$

** Target cost; No realistic estimate yet

Hyper-Kamiokande: A Multi Purpose Detector

- Proton decay
  - ✓ νK^+ Reach: $\tau_p(\nu K^+)/B \sim 10^{34}$ yr
  - ✓ $e^+\pi^0$ $\tau_p(e^+\pi^0)/B \sim 10^{35}$ yr
  - ✓ and other modes
- Supernova neutrino (~10^5 neutrinos for a SN at the center of the galaxy.)
- JHF-Kamioka long baseline neutrino oscillation experiment:
  - ✓ 2nd phase, CP violation
  - ✓ If the θ_{13} measurement in the 1st phase gives only an upper limit, the 2nd phase will enhance the reach.

Common topics to Hyper-K and UNO
→Next talk

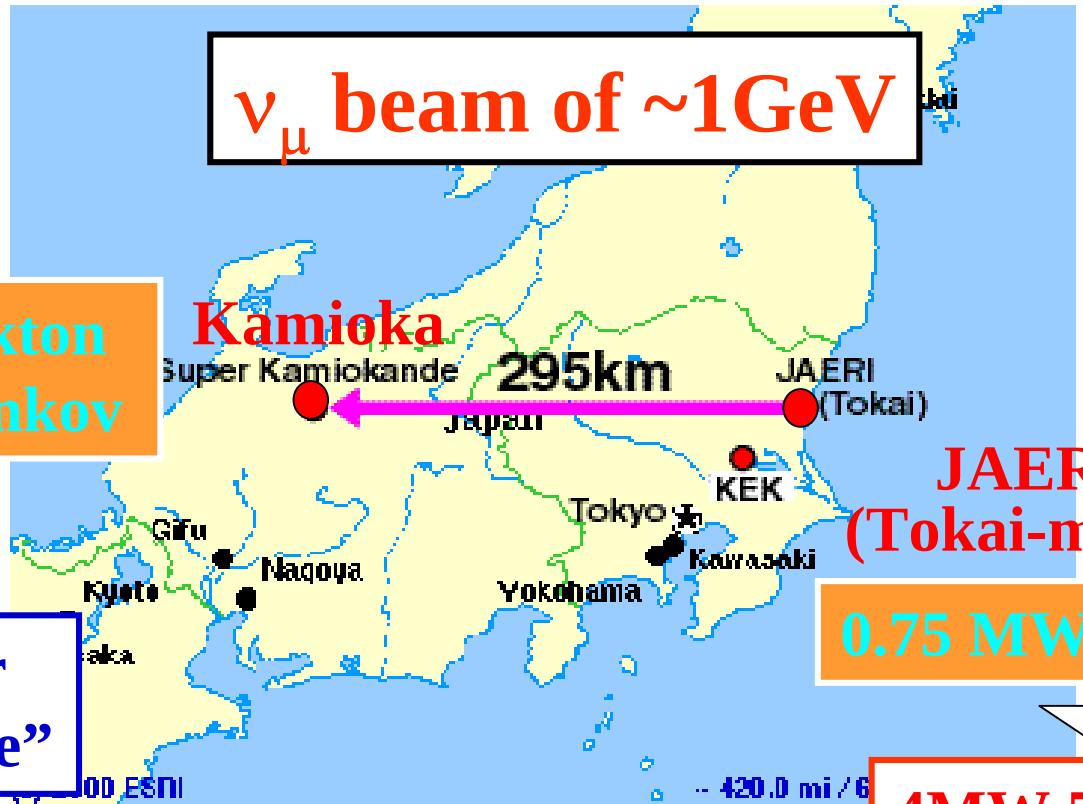
Why water Cherenkov?

■The primary reason for Super-Kamiokande to have been successful is that it is only one order of magnitude extension of the well-proven Kamiokande.

■One order of magnitude extension of well-proven Super-Kamiokande will not cause any serious difficulty both in construction and in operation.
(We now know how to avoid an accident caused by the implosion of a PMT under water pressure.)

■Water is the cheapest detector material.

Overview of the JHF-to-Kamioka Experiment



ν_μ beam of ~1GeV

Super-K: 50 kton Water Cherenkov

~Mt "Hyper Kamiokande"

JAERI (Tokai-mura)

0.75 MW 50 GeV PS

4MW 50 GeV PS

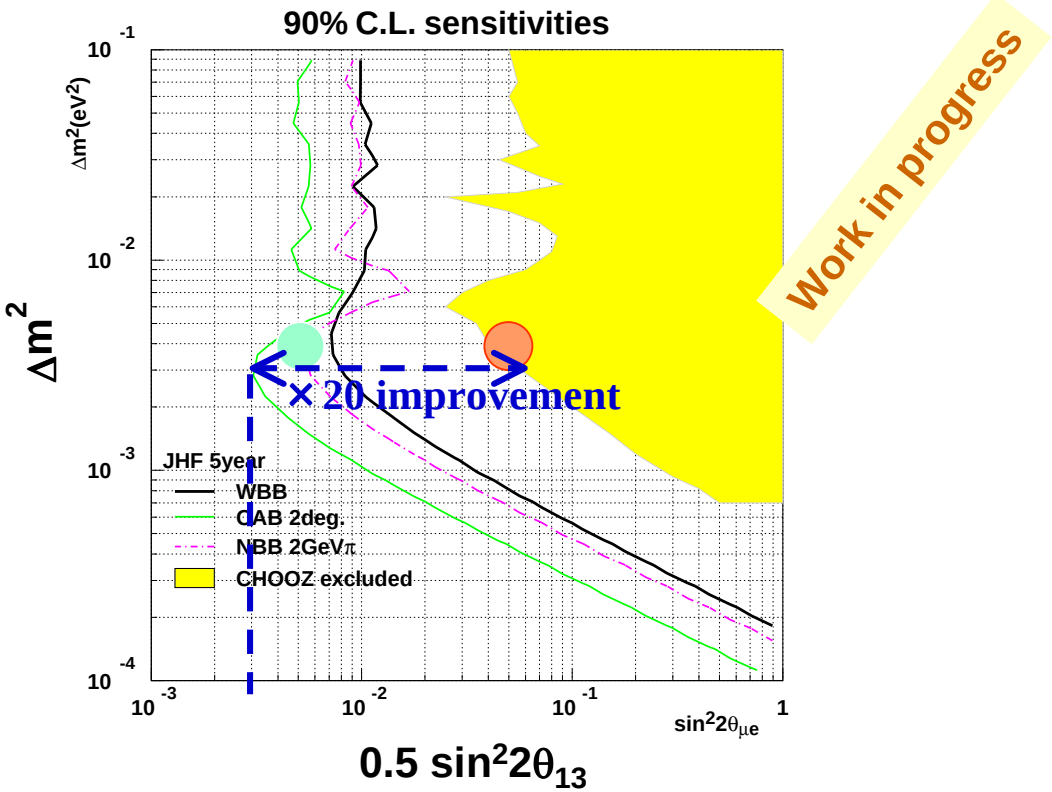
1st Phase

- $\nu\mu \rightarrow \nu x$ disappearance
- $\nu_\mu \rightarrow \nu e$ appearance
- NC measurement

2nd Phase

- CPV
- proton decay

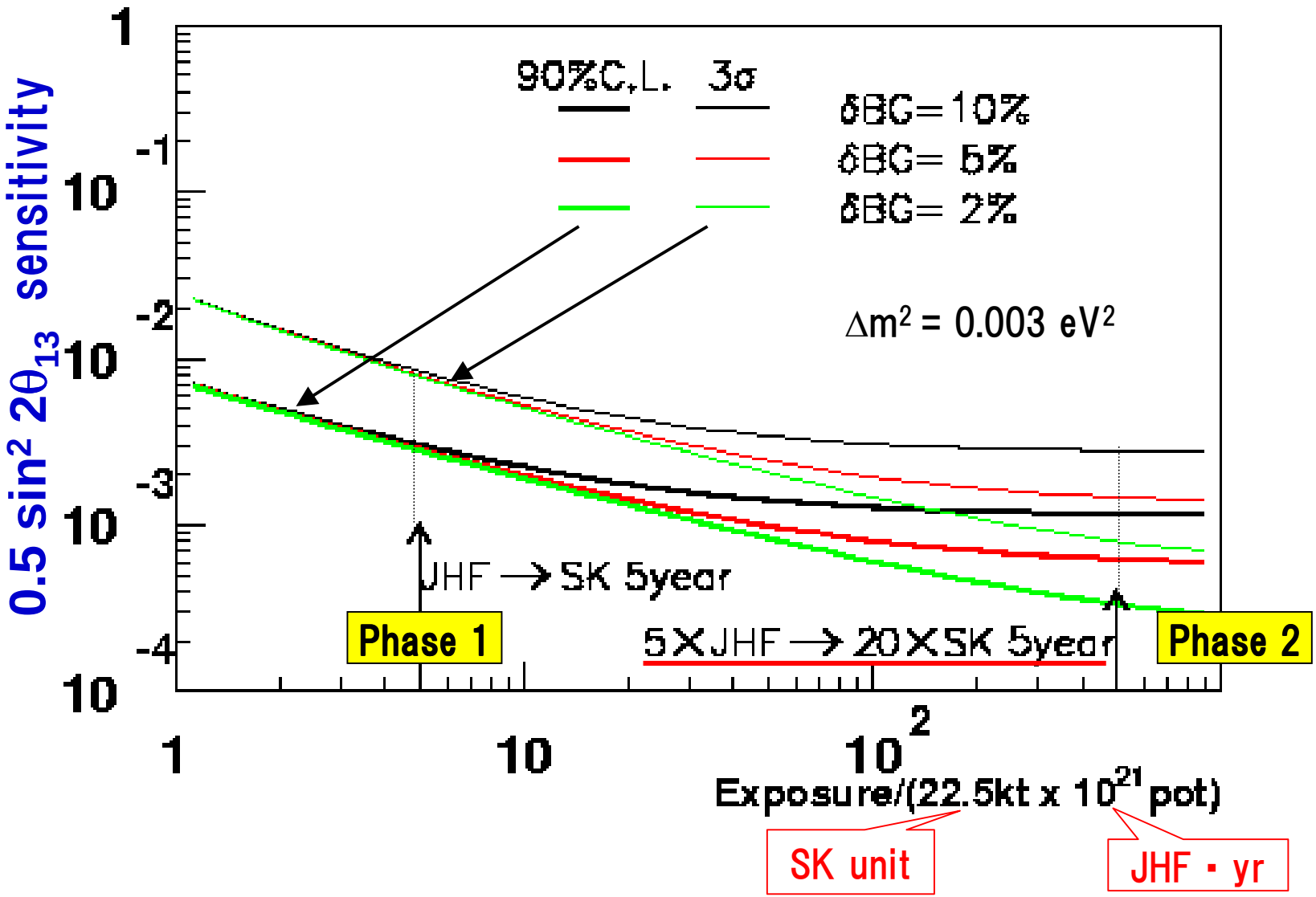
$\sin^2 2\theta_{13}$ from ν_e Appearance (JHFν 1st Phase)



Off axis 2 deg, 5 years

$\sin^2 2\theta_{13}$	Background in Super-K					Signal	Signal + BG
	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$	total		
0.1	12.0	10.7	1.7	0.5	24.9	114.6	139.5
0.01	12.0	10.7	1.7	0.5	24.9	11.5	36.4

Sensitivity to $\sin^2 2\theta_{13}$ as a function of exposure



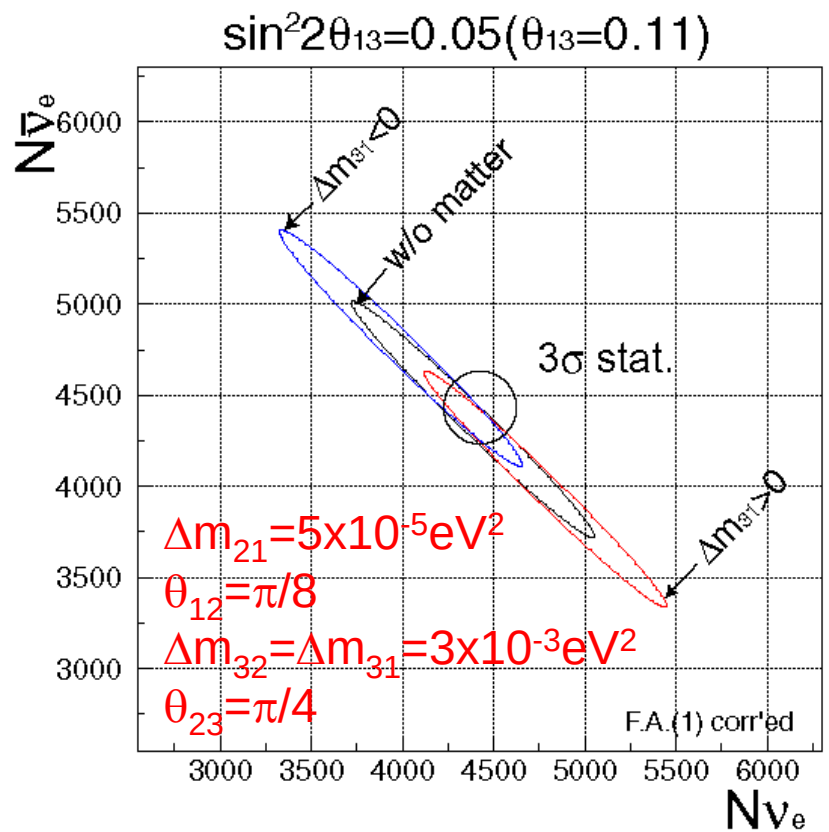
JHF-Kamioka Neutrino Project: Phase-II

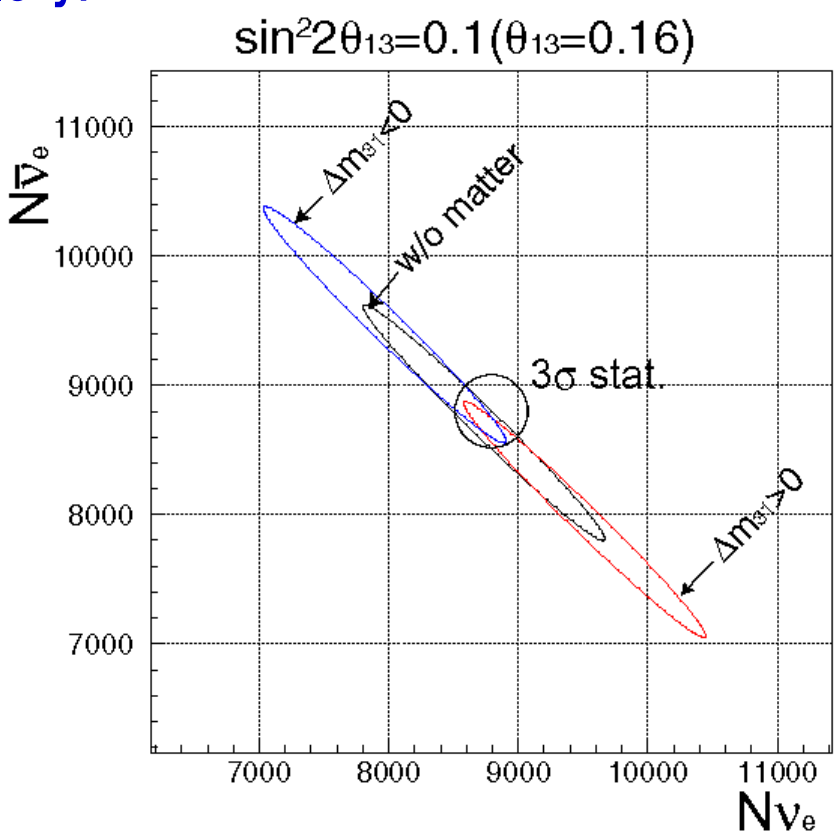
★ 0.75 → 4 MW beam power
★ Hyper-Kamiokande (1 Mt FV)

⇒ 10^6 events

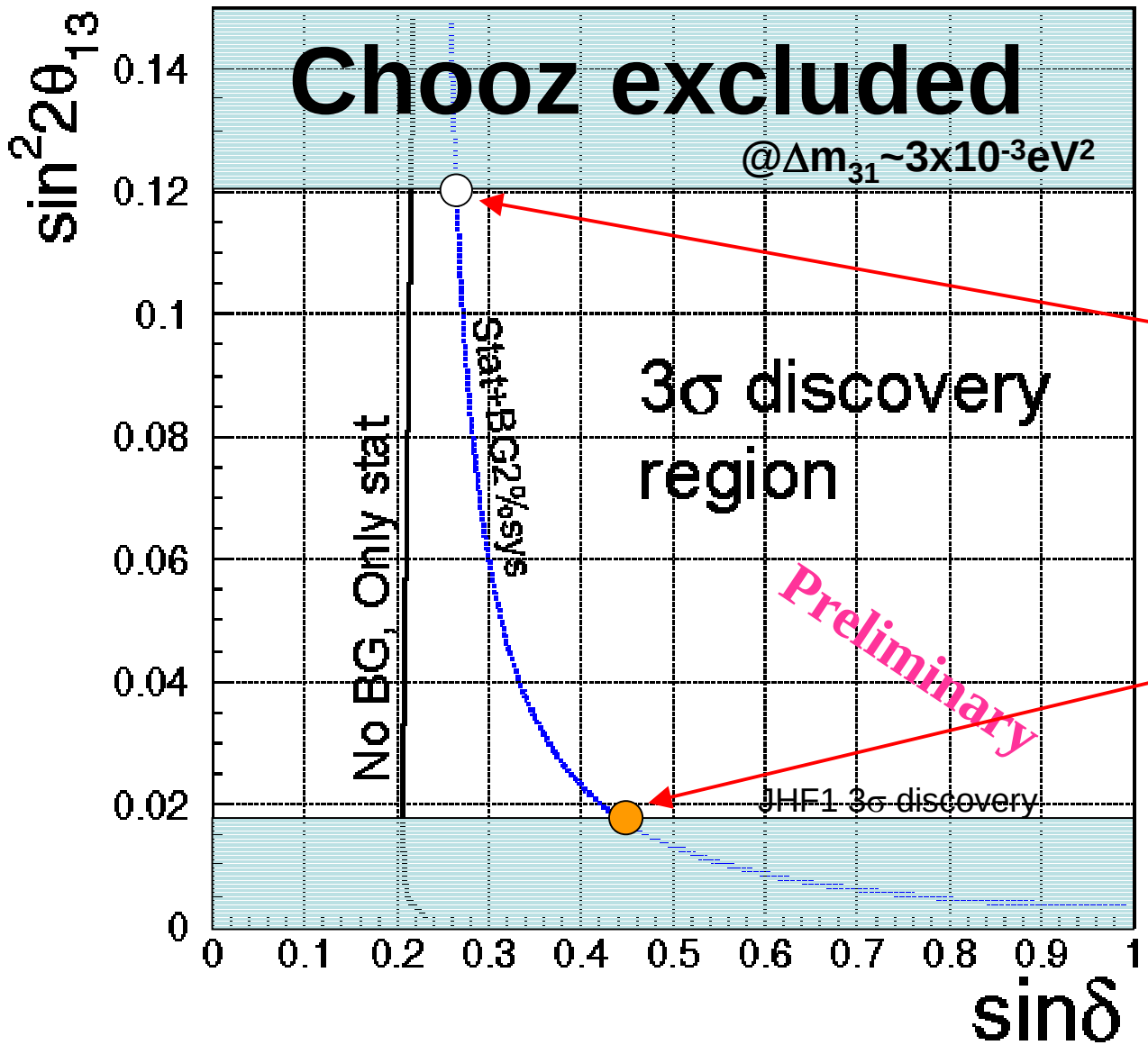
CP Violation

ν : 2 yr
$\bar{\nu}$: 6.8 yr





Sensitivity (3σ) to CPV (JHFν 2nd Phase)



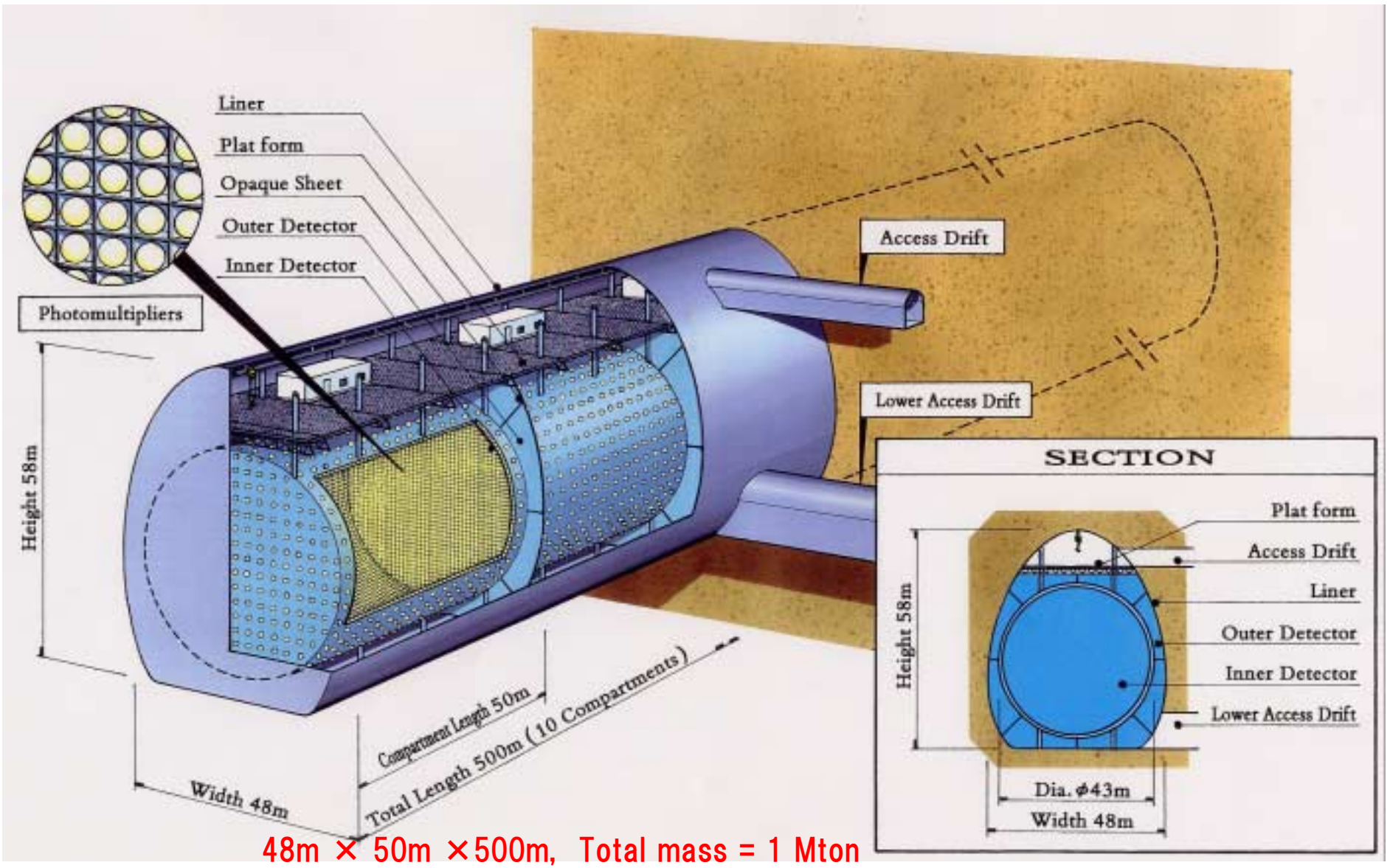
4MW, 1Mt Fid.Vol.
2yr for ν_μ
6.8yr for $\bar{\nu}_\mu$

δ>~14deg

δ>~27deg

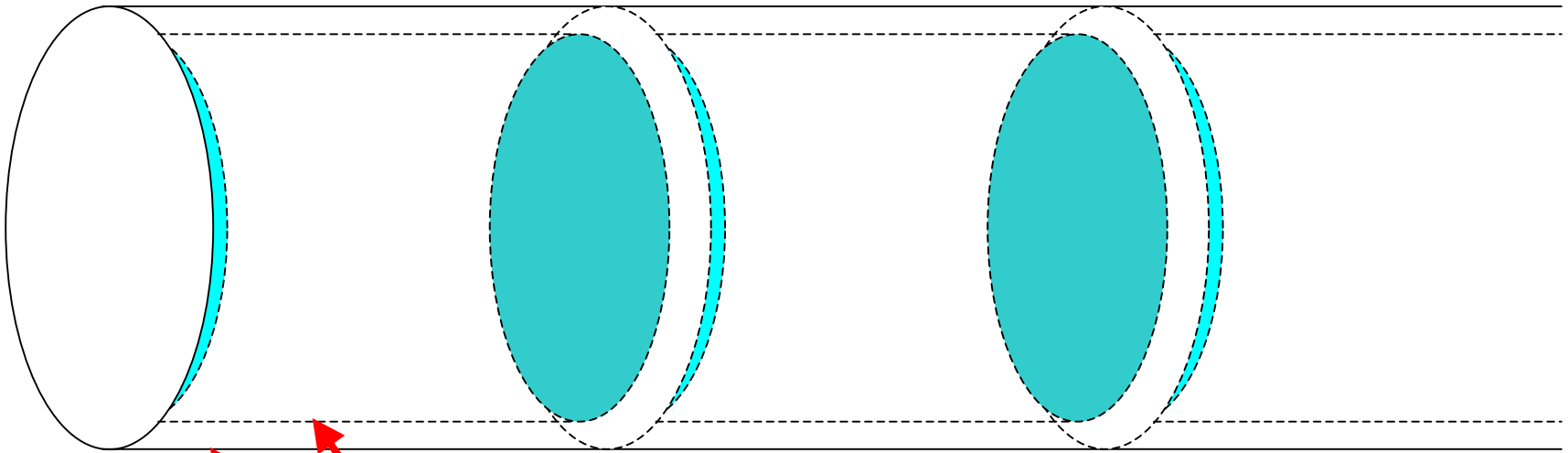
$\Delta m_{21}=5\times10^{-5}eV^2$
$\theta_{12}=\pi/8$
$\Delta m_{32}=\Delta m_{31}=3\times10^{-3}eV^2$
$\theta_{23}=\pi/4$

Conceptual Design



48m × 50m ×500m, Total mass = 1 Mton

Fiducial / Total



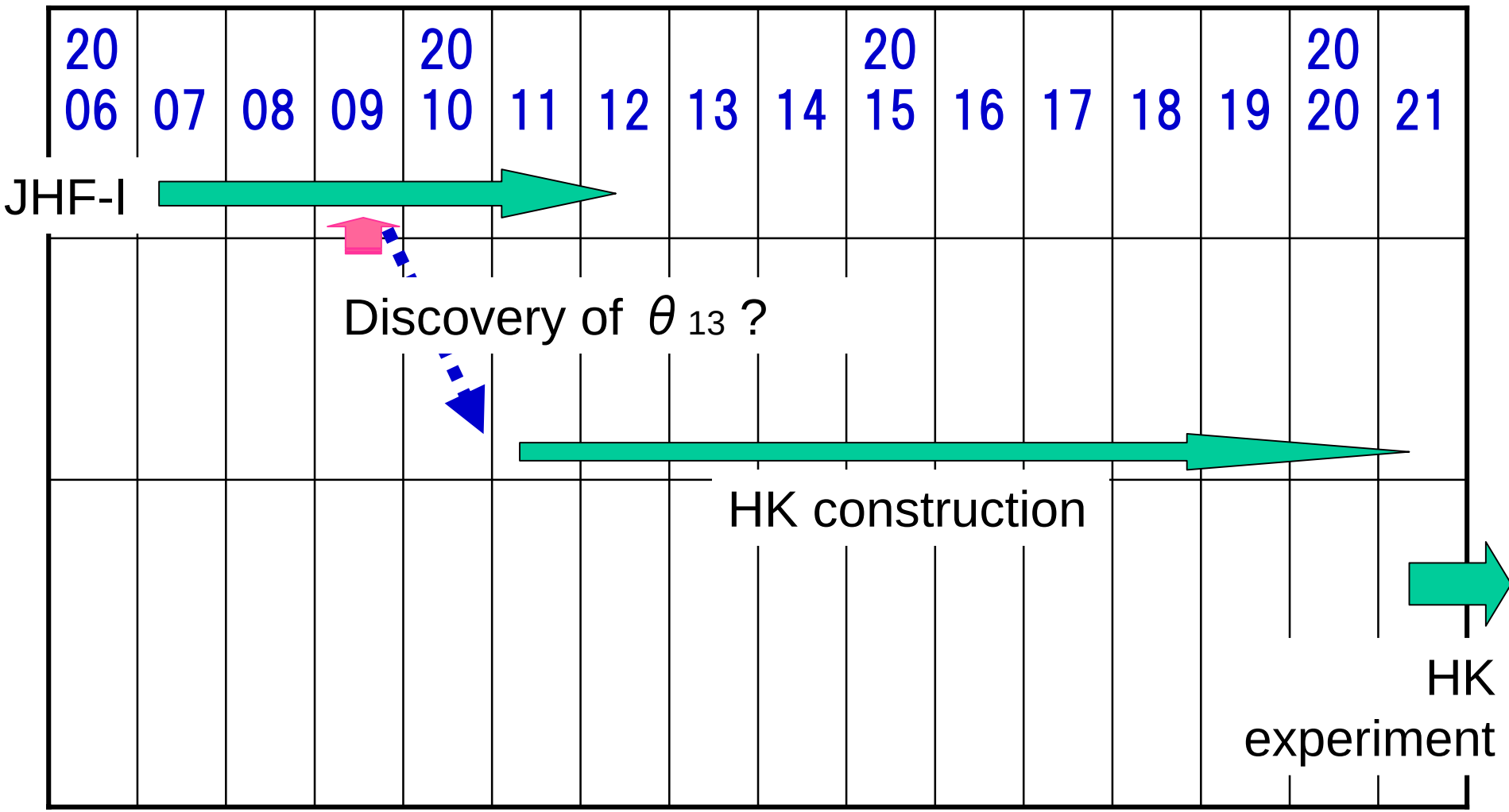
Fiducial volume: 39mϕ ×45m ×10 sections
= 0.54 Mton

Total Inner detector volume: 43mϕ ×49m
×10 sections = 0.72 Mton

Total detector volume: 1 Mton

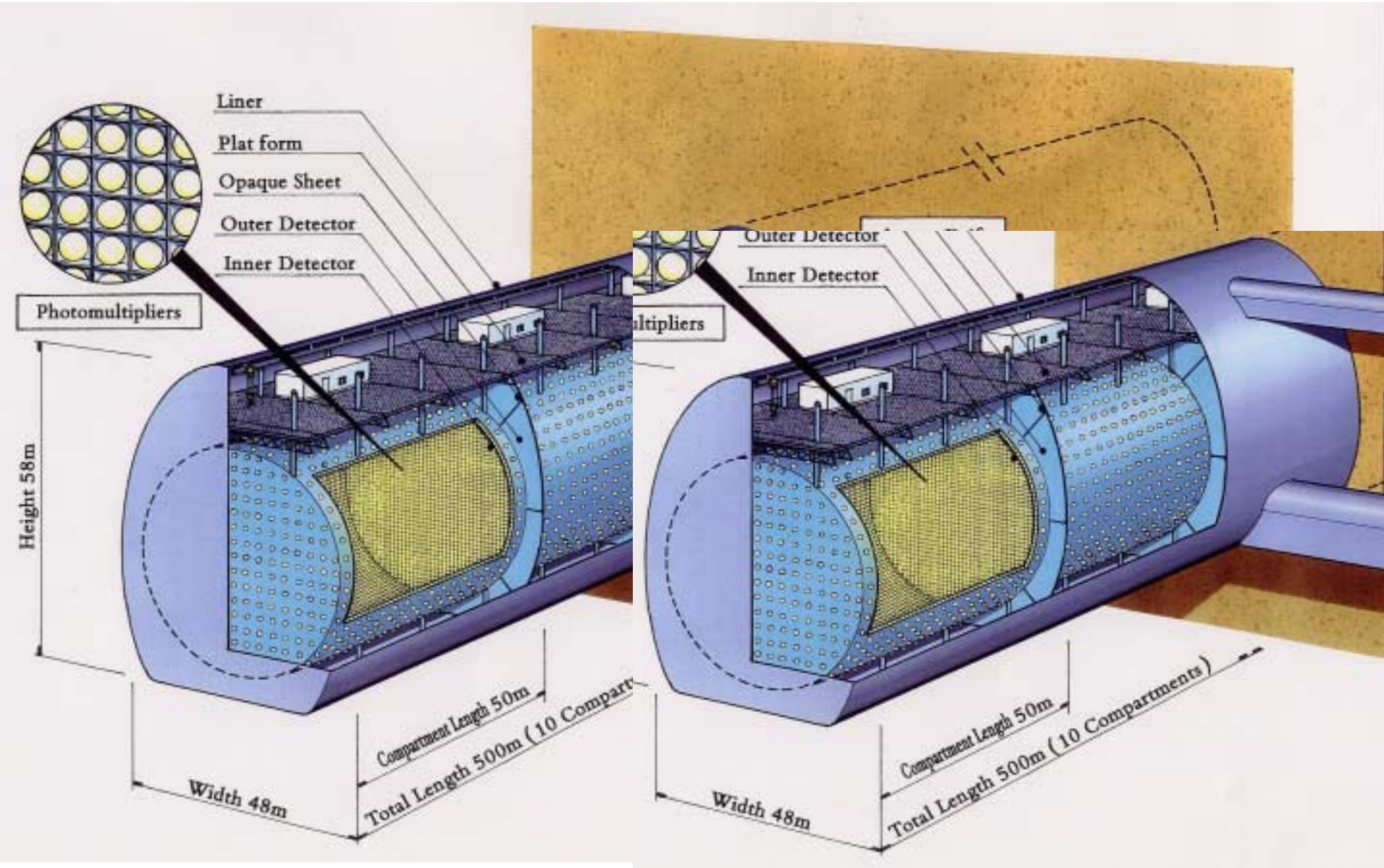
Total number of PMTs: 200,000 (if 2/m^2)

Wished Construction Plan



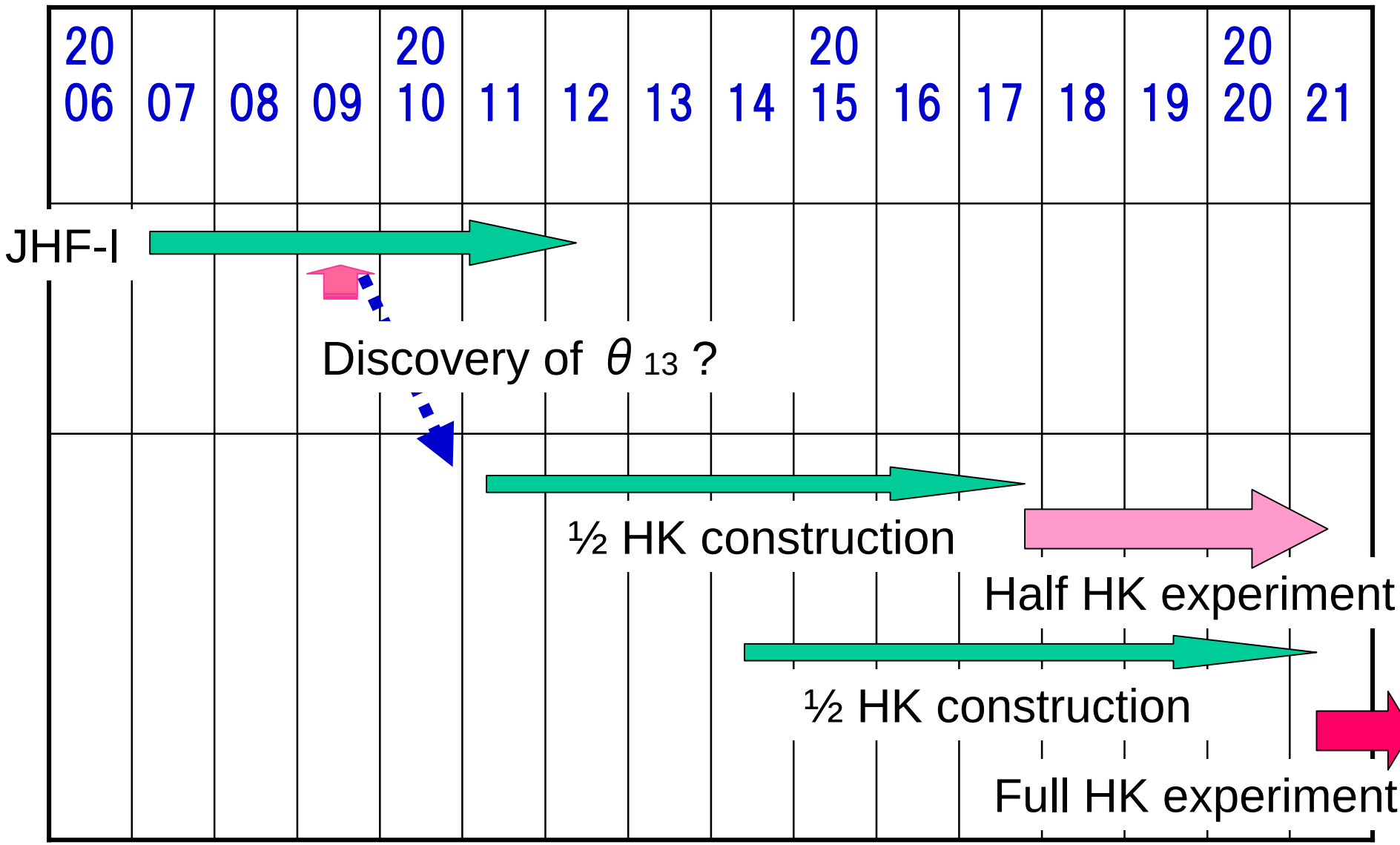
Any other way to start Hyper-K earlier?

2 Detector Hyper-Kamiokande ?



2 detectors × 48m × 50m × 250m, Total mass = 1 Mton

Wished Construction Plan (2 Detector Hyper-K)

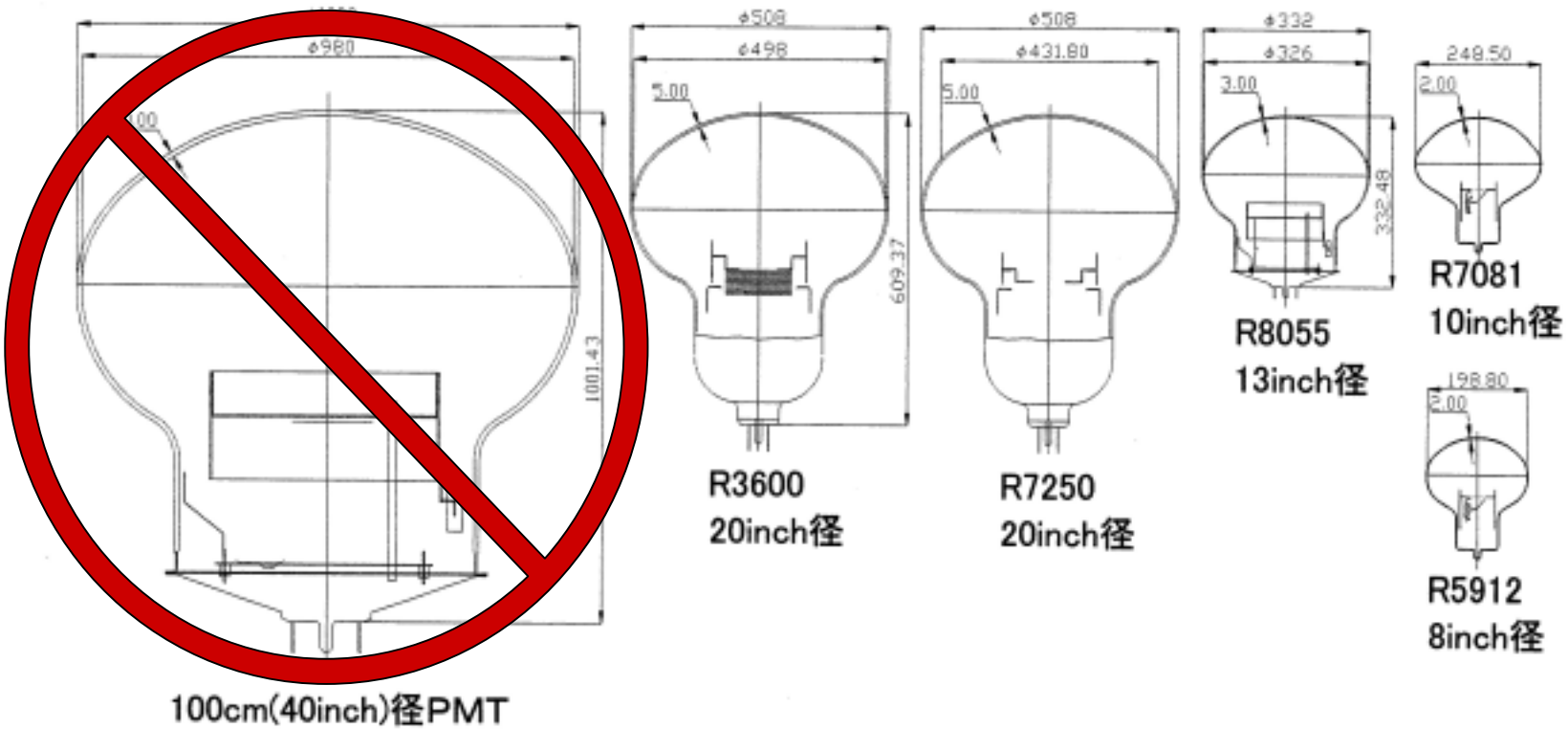


R&D Items

- Site selection
- Cavity design and assessment
  - Rock stress analysis
  - Cost analysis, optimization
- Detector tank design and study of construction method
- Simulation studies for
  - Proton decay
    - ✓ $K^+\nu$
    - ✓ e^+p^0
  - Long baseline neutrino oscillation experiment
- Development of new photo-detectors
  - PMT?
    - ✓ ~~Larger size?~~ ⇐ Initially some R&D, but no more after the SK accident
    - ✓ High QE? ⇐ Not very successful
    - ✓ Flat & thin? ⇐ Not very active
    - ✓ .....
  - Hybrid Photo-detector? ⇐ Present focus
  - Other technique? ⇐ Not active

How to improve S/N
Optimize photocathode coverage

Plan to Develop 40-inch PMT Was Given up due to the SK Accident



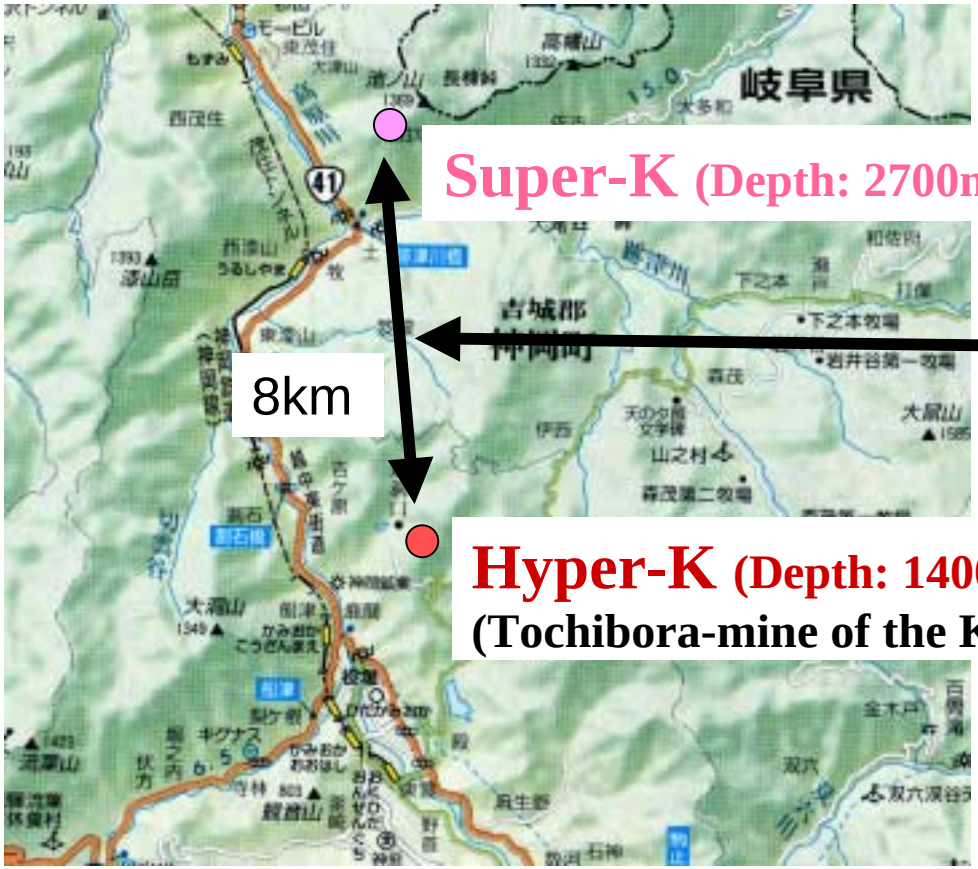
大口径PMT　R3600 vs 超大径PMT

品名	有効面	Dynode構造	段数	TTS(FWHM) (nsec)	Rise (nsec)	Fall (nsec)	P/V比
R3600(20")	φ500mm	ベネチアン	11	6	10	33	1.7
100cm(40inch)径PMT	φ980mm	Line	10	予想値 6.97	予想値 15.8	予想値 36	予想値2.5以上

浜松ホトニクス（株）

2001/1/25

Candidate Site



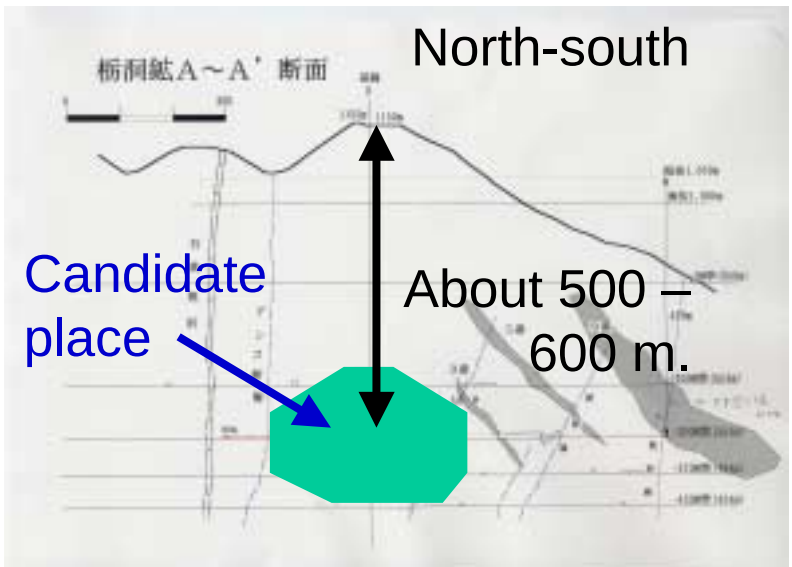
Super-K (Depth: 2700mwe)

295km

JHF

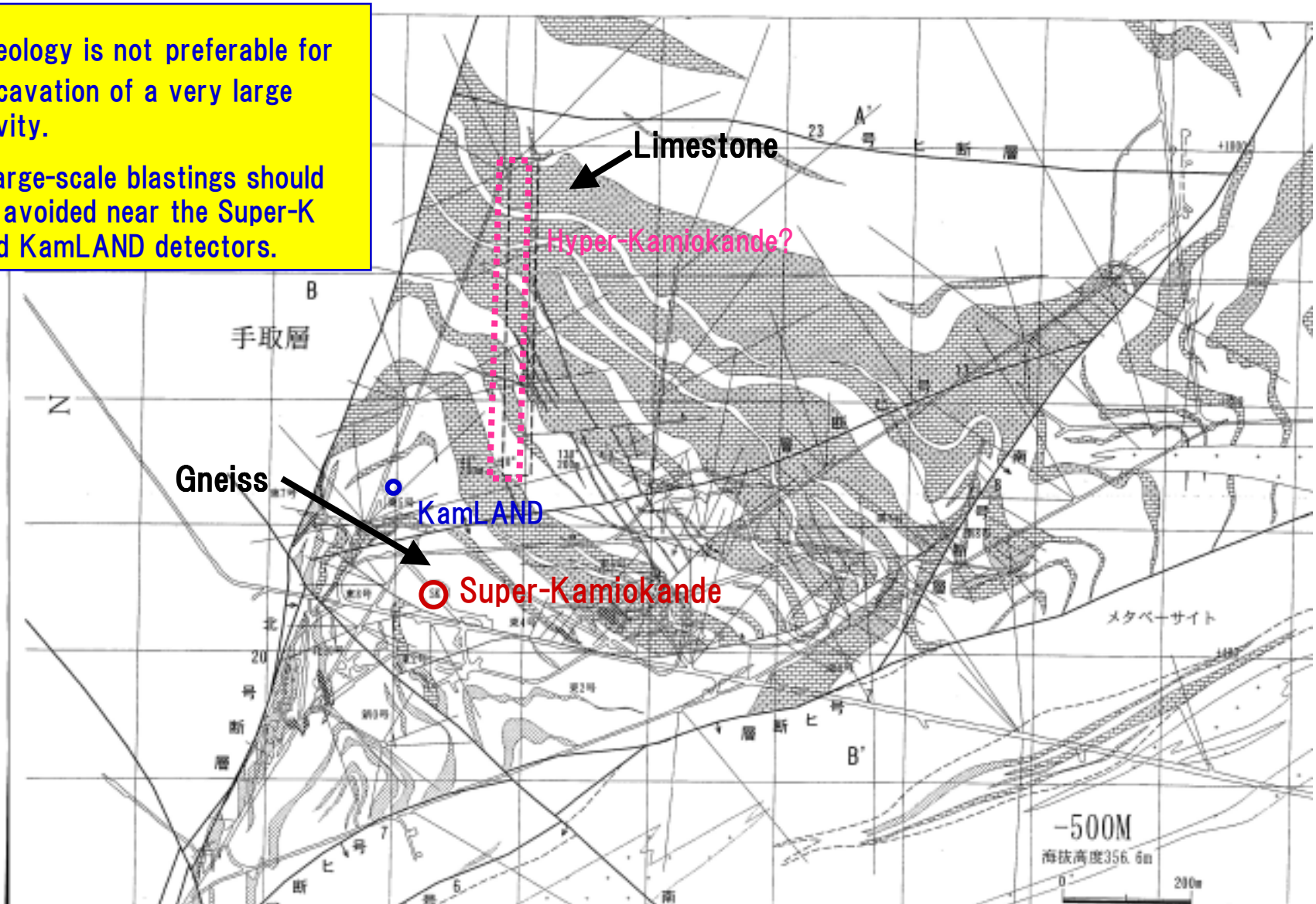
Hyper-K (Depth: 1400 – 1900mwe, not decided yet)

(Tochibora-mine of the Kamioka mining company)

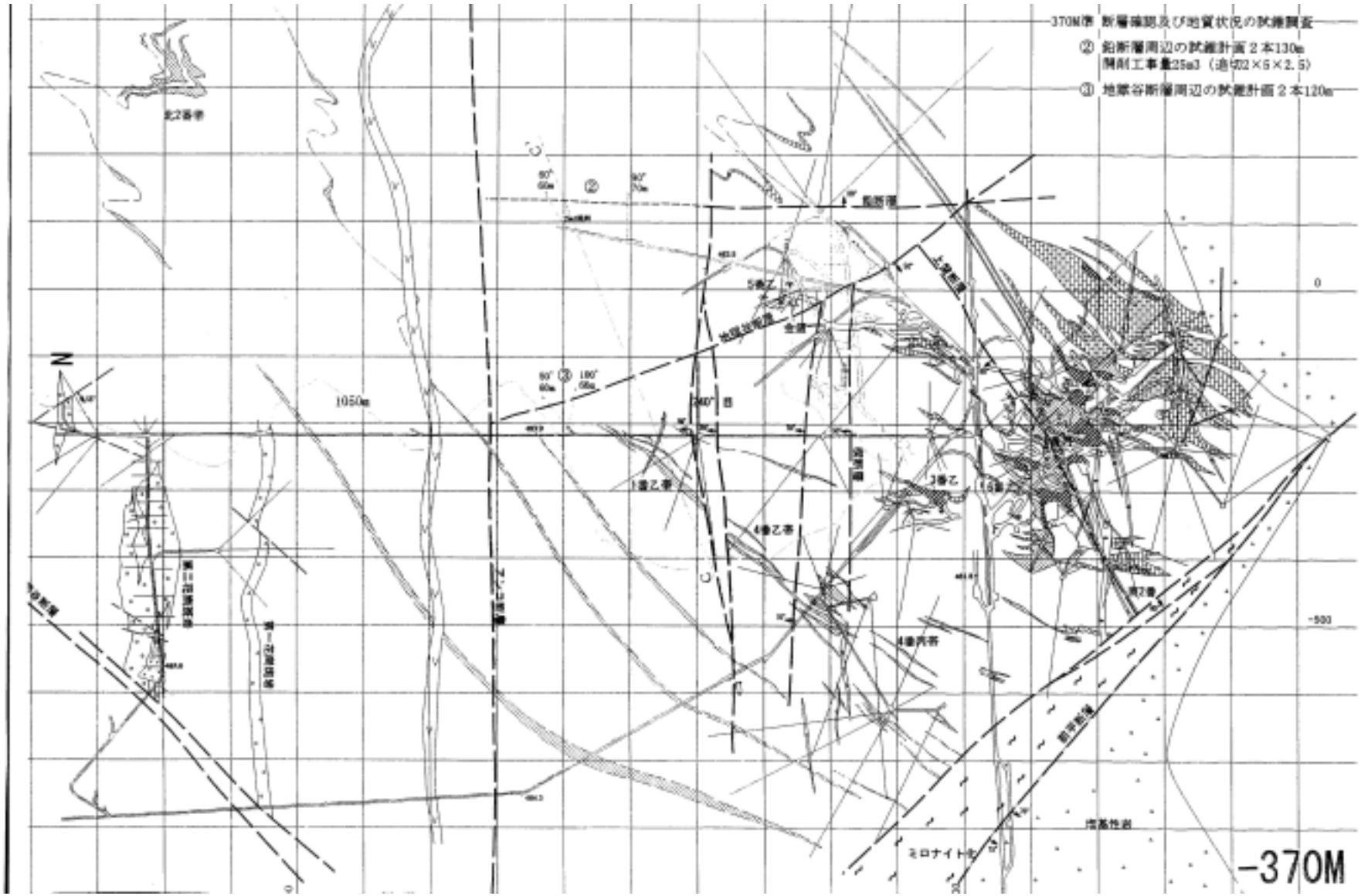


Mozumi Mine

- Geology is not preferable for excavation of a very large cavity.
- Large-scale blastings should be avoided near the Super-K and KamLAND detectors.

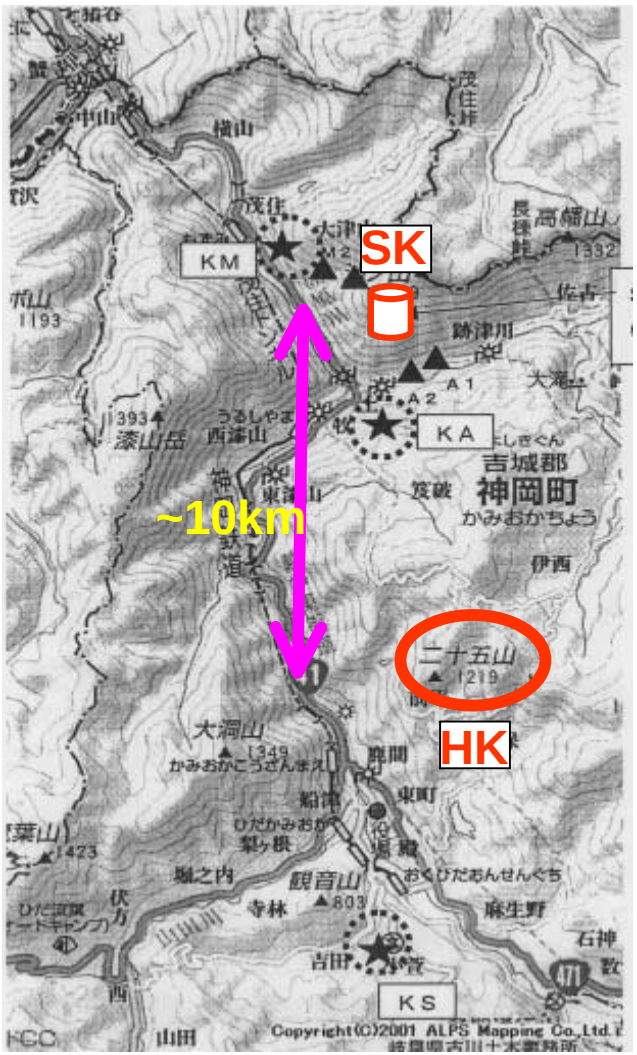


Tochibora Mine

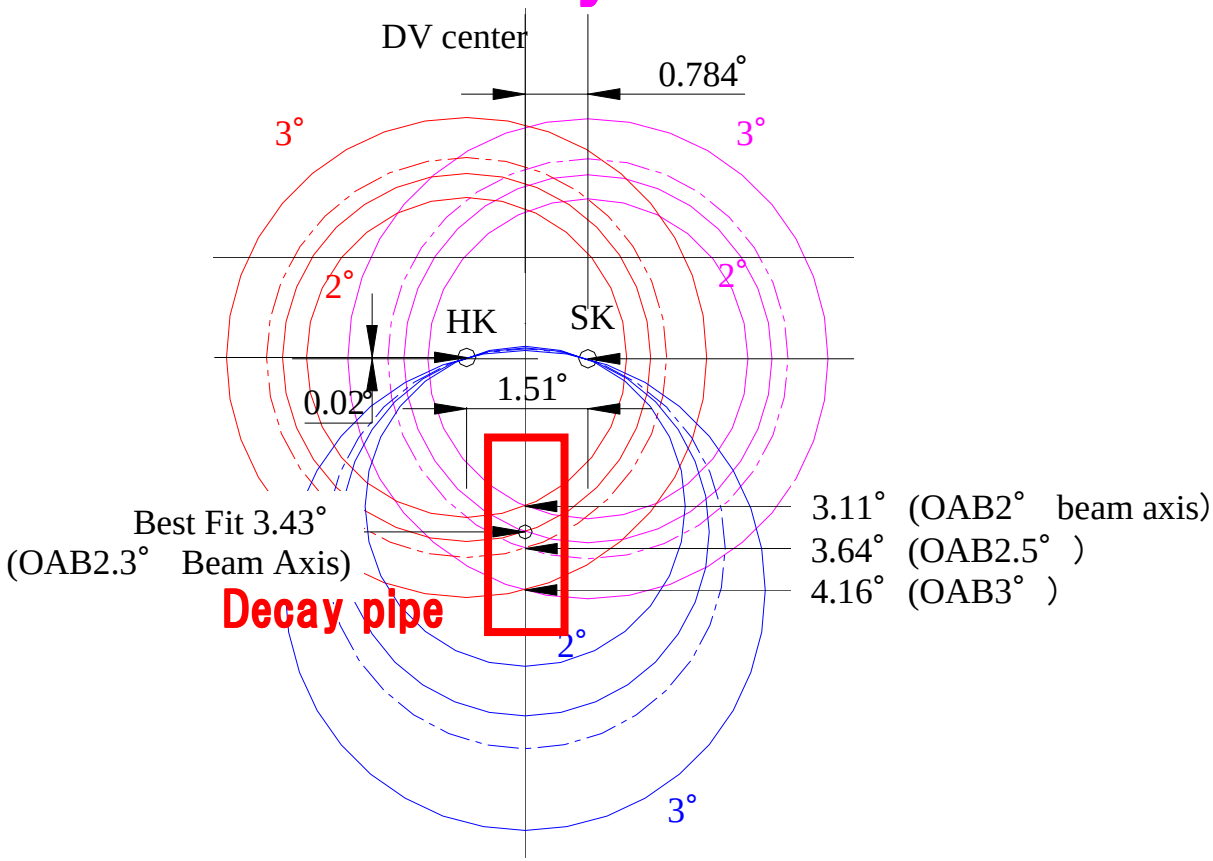


Decay Pipe Common for SK/HK

Possible site for Hyper-K



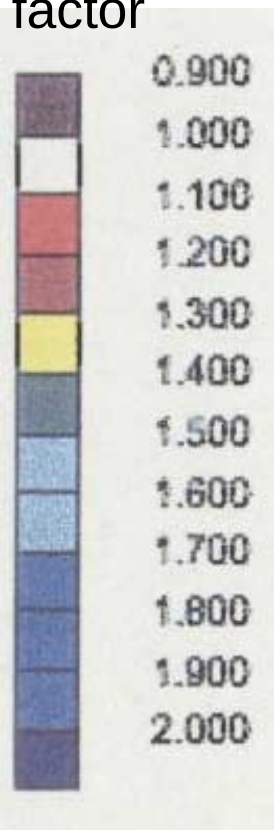
Beam eye

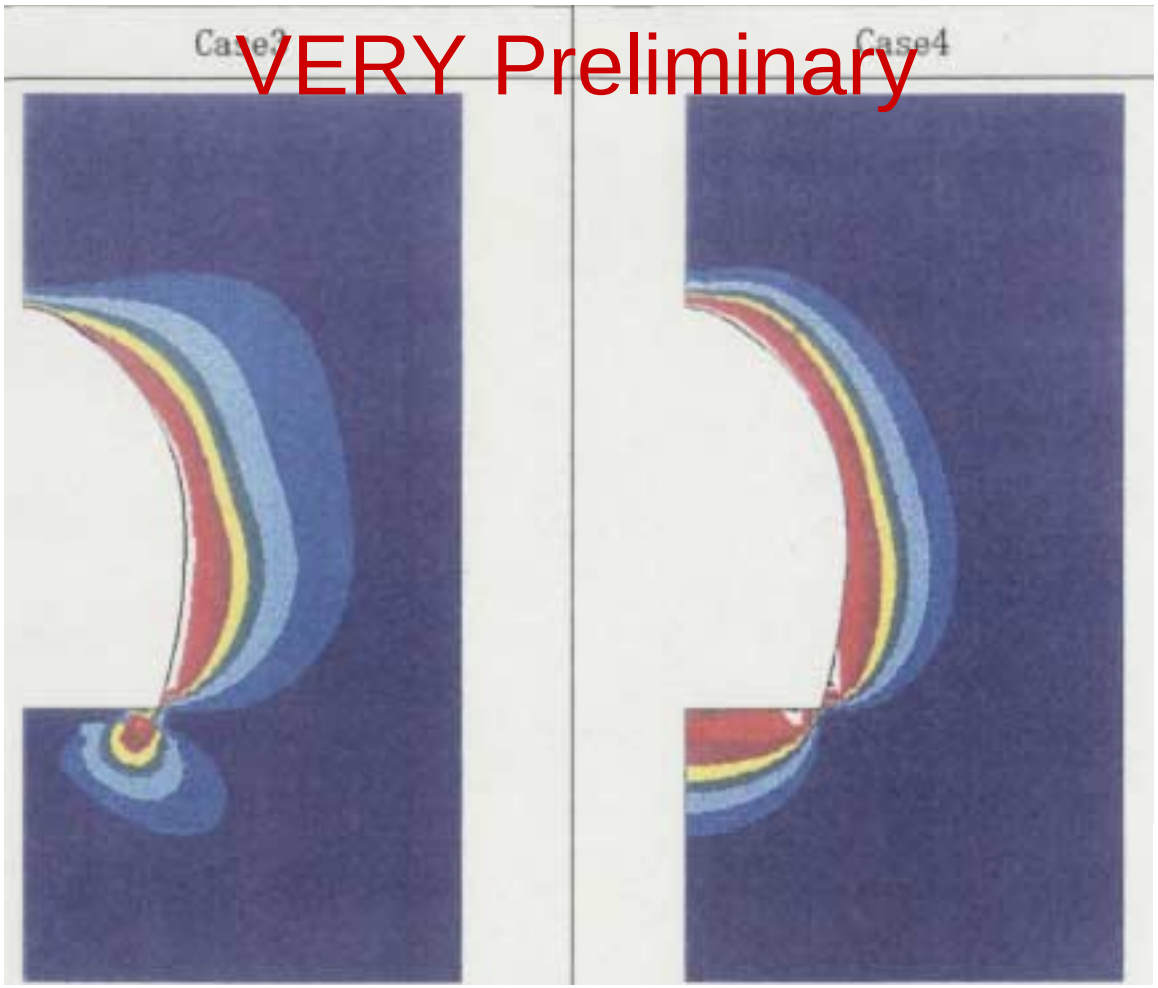


must cover p/π beam axis -(3～4) deg
corresponding to $\Delta m^2=(2.2\sim3.2)\times10^{-3}\ eV^2$

Finite Element Analysis of the Hyper-K Cavity Using the Onsite Rock Condition

Safety factor





VERY Preliminary

$$\frac{presure\,(horizontal)}{presure\,(vertical)}$$ = 0.45 = 1.0

Experts say:

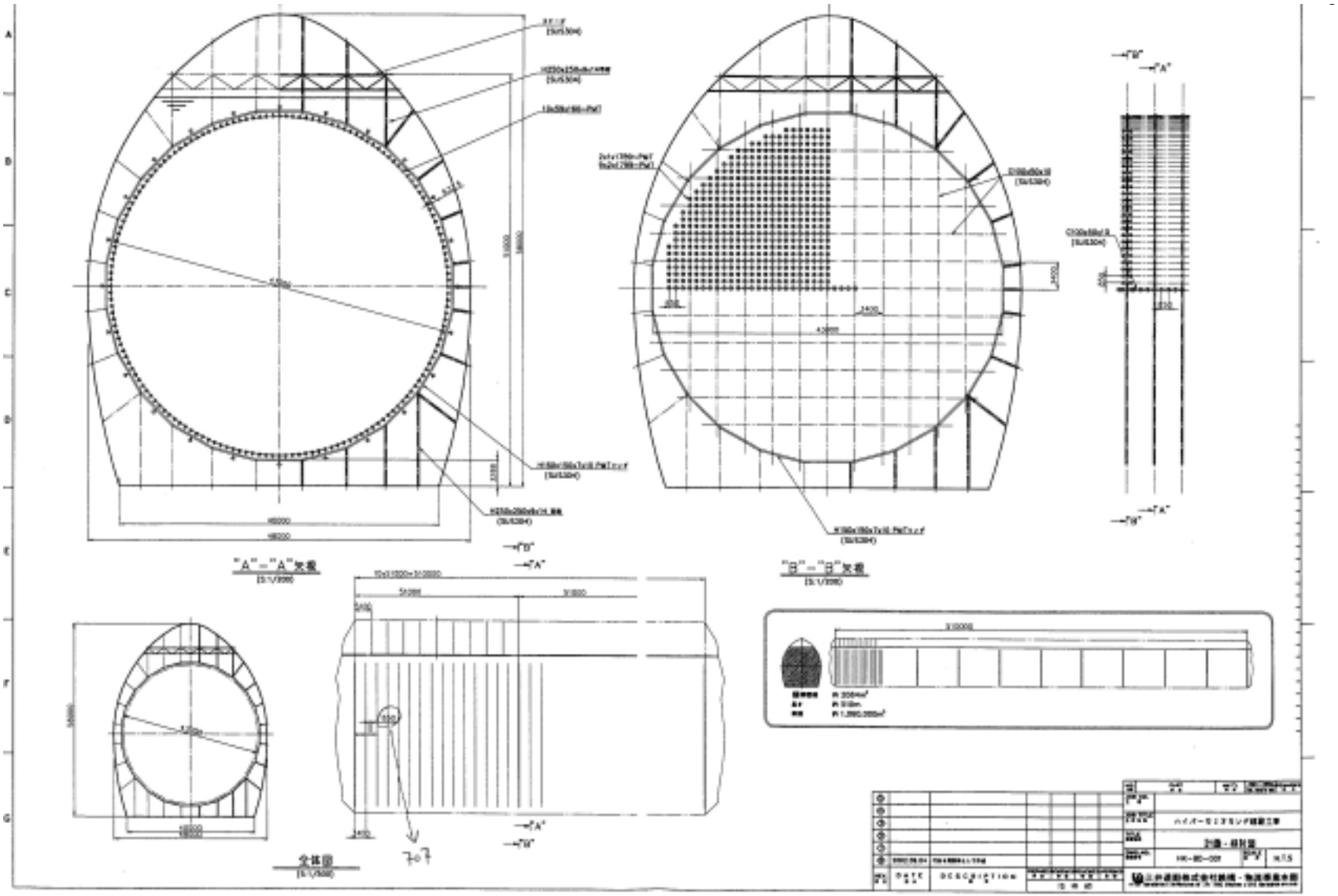
Regions with the safety factor < 1.3 need supports (rock bolt or wire)

The depth of the region with safety factor < 1.3 is similar to that in Super-K.

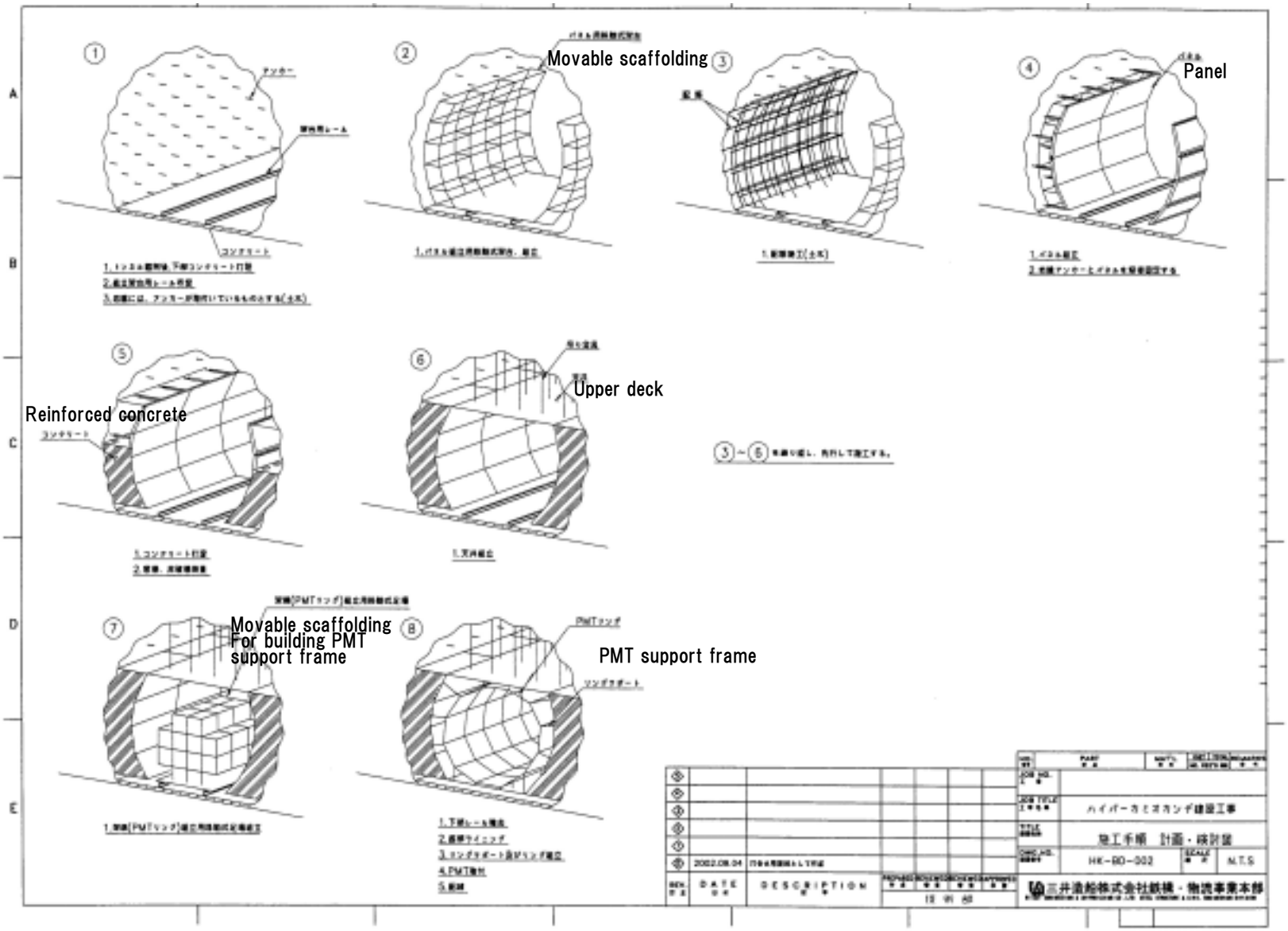
It seems possible to excavate the Hyper-K cavity.

Need more detailed studies.

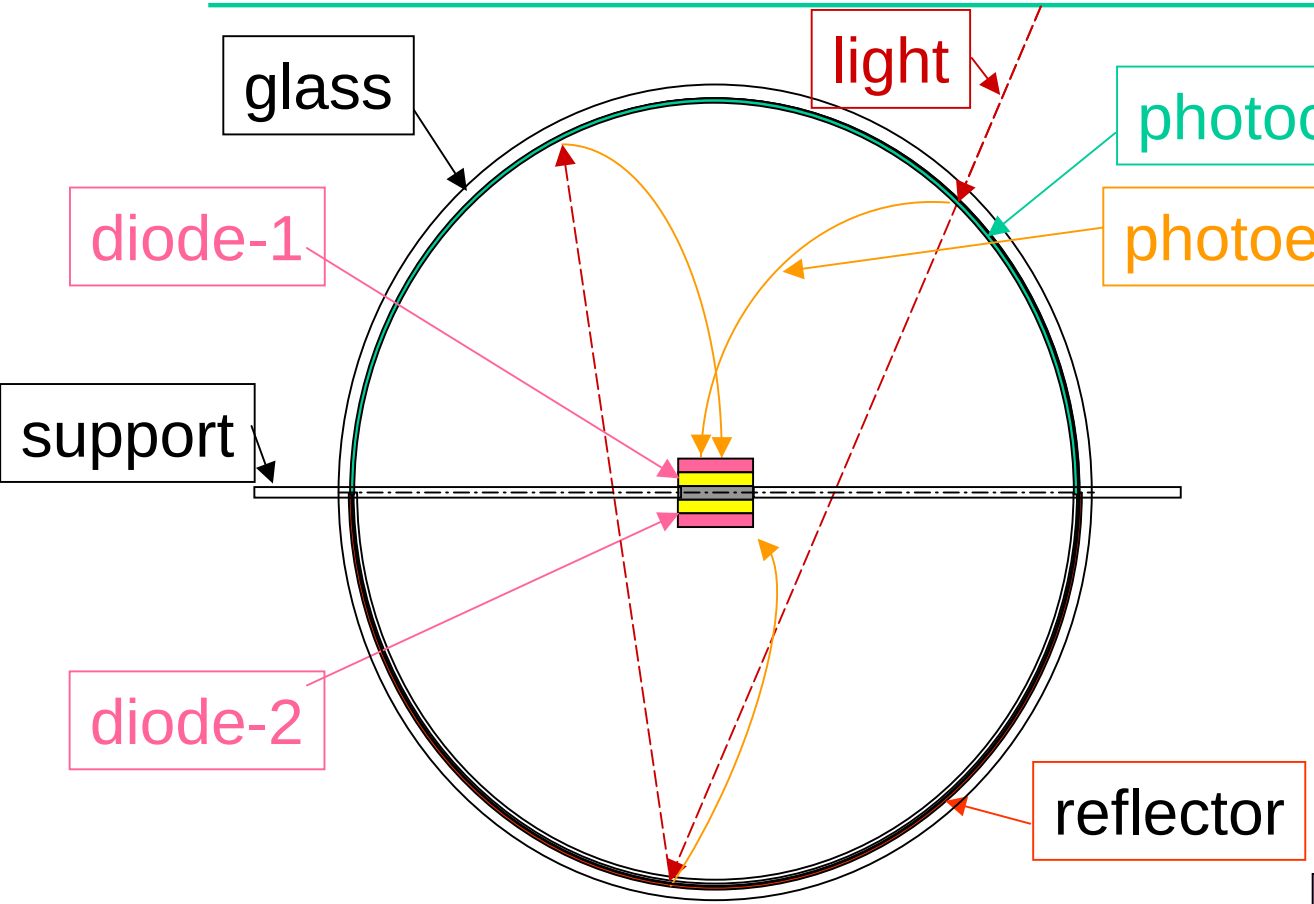
Design of PMT Support Structure



Construction Plan for the Water Tank and PMT Support Frame



Development of Large Spherical Hybrid Photo Detectors (HPD)

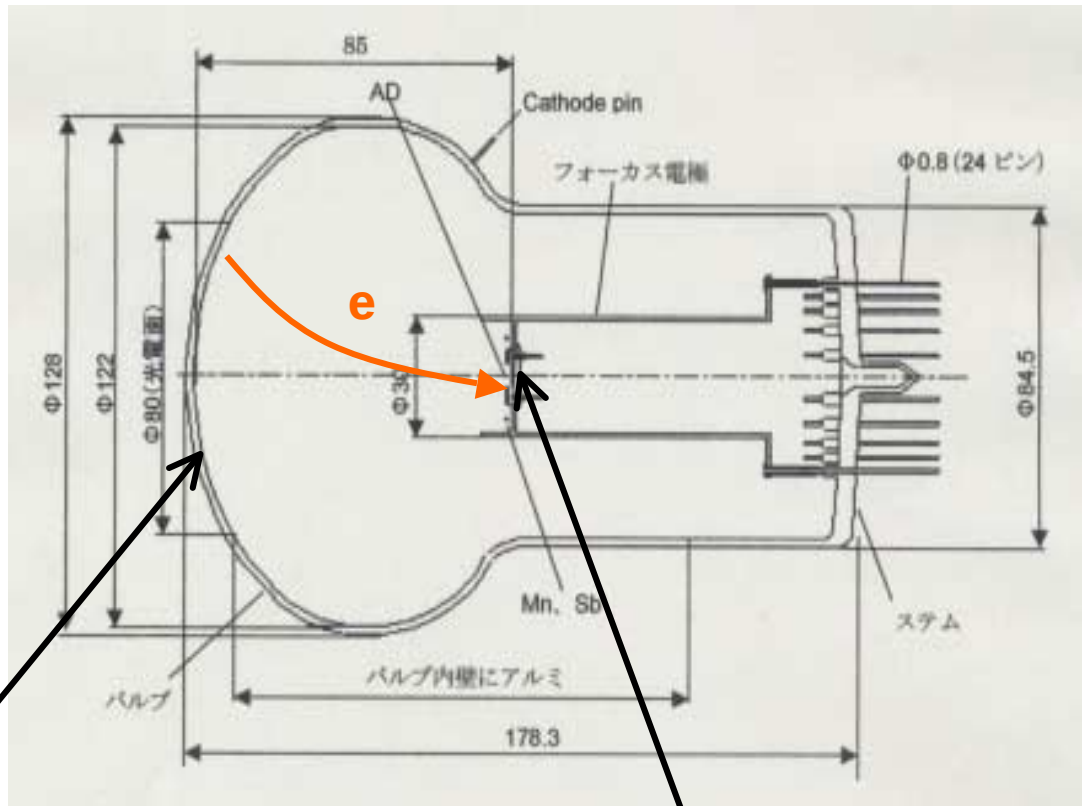


- high efficiency
- simple structure → low cost
  → high production rate
- pressure resistant (no chain-reaction of explosion)

- 5-inch HPD prototype tested.
- 13-inch HPD prototype to be developed.
- Design of a 20-inch spherical HPD.

5-inch HPD Prototype Tested

electron bombarded gain 1000 ×avalanche gain 50 = 50,000



photocathode −8kV

Avalanche diode 3mmϕ, bias150V

Characteristics of 5-inch HPD Prototype (1)

size	5inch	
Effective area	80mm ϕ	Due to non-spherical glass bulb and small(3mm) APD
QE@400nm	24(%)	
Rise time	3.2ns @-8kV	~10ns@Super-K
Fall time	5.2ns @-8kV	~16ns@Super-K
Dark rate	24000Hz 8500Hz 380Hz	First measurement(~3000Hz@Super-K) paint a conductor of electricity (outside of photo-sensitive area) paint wholly a conductor
Avalanche gain	50	Bias 150V
HV value	-8kV -16kV	
Bombarded gain	1000 3000	300/kV at >-8kV
Total gain	$5x10^4$ $1.5x10^5$	10^7@Super-K
P/V	---- 20.5	~2@Super-K

Hyper-K R&D: Summary

- Site: Tochibora mine is seriously considered as a candidate site.
- Cavity excavation: FEA in progress. Geological survey to be done; boring, *in situ* measurement of initial stress, rock sample taken from the candidate site for mechanical tests, etc.
- Water tank and PMT support: Conceptual design started.
- Spherical HPD: 5-inch prototype tested, larger HPD to be developed.
- Further physics simulation: to be done.