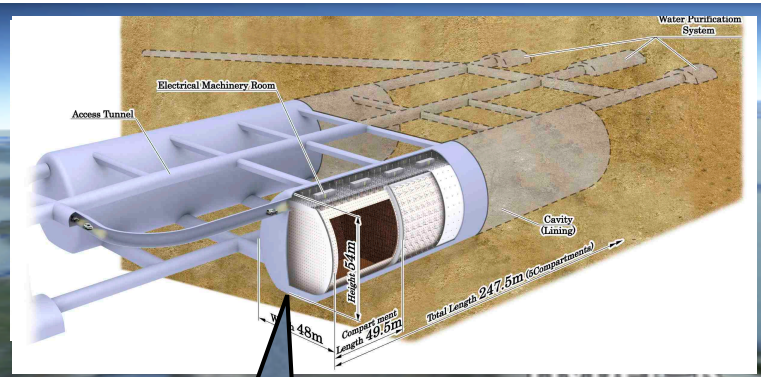
Hyper-Kamiokande project

Masato SHIOZAWA

Project-X workshop, June-16-2012

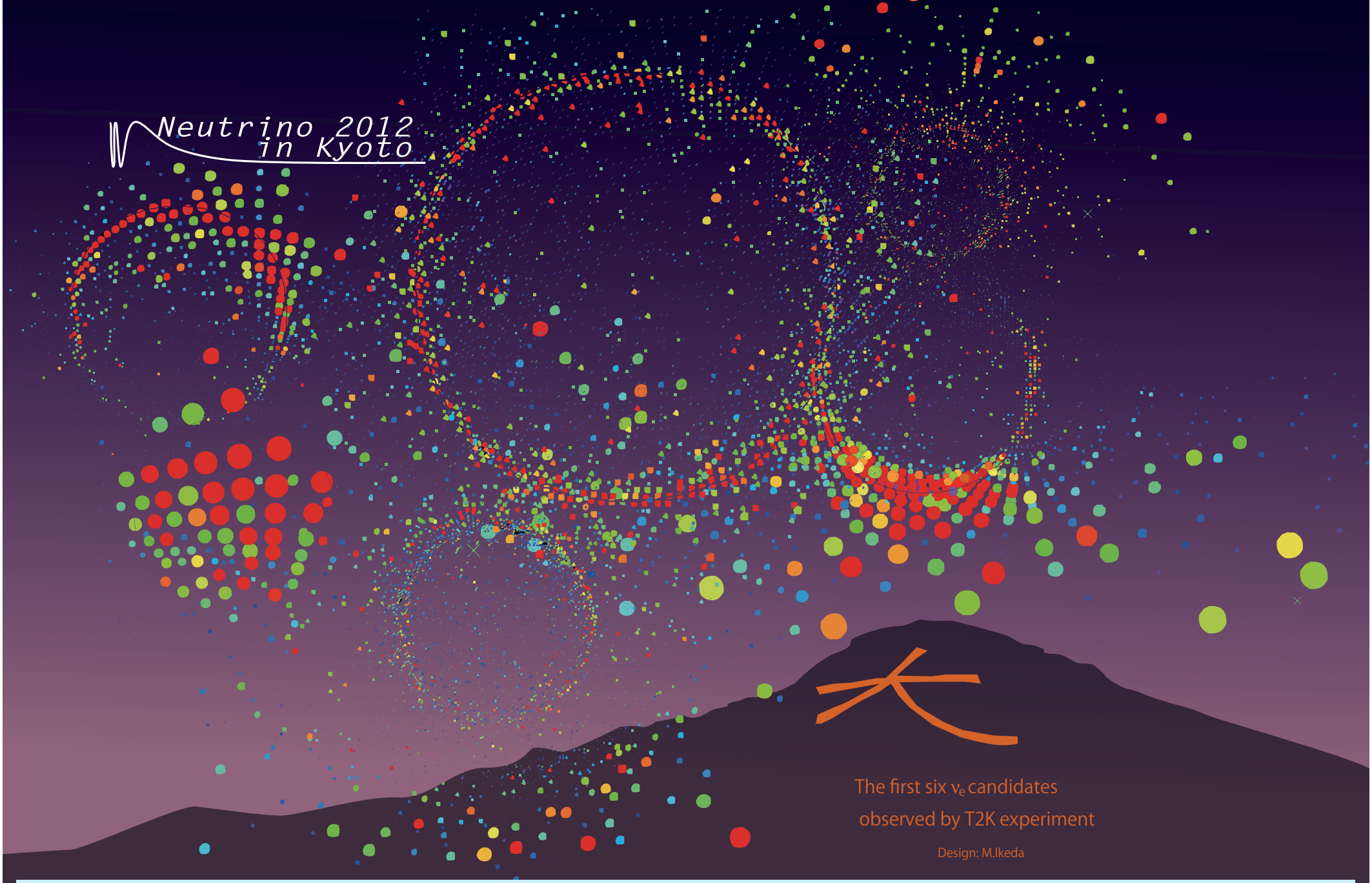


x25 Larger ν Target

Quest for CP Violation in lepton sector + Proton Decay

~0.6GeV νμ
295km

higher intensity ν by upgraded J-PARC



- T2K showed indication of $\nu_\mu \rightarrow \nu_e$ in PRL107,041801(2011)
- In Kyoto, presented the evidence of electron neutrino appearance

Introduction

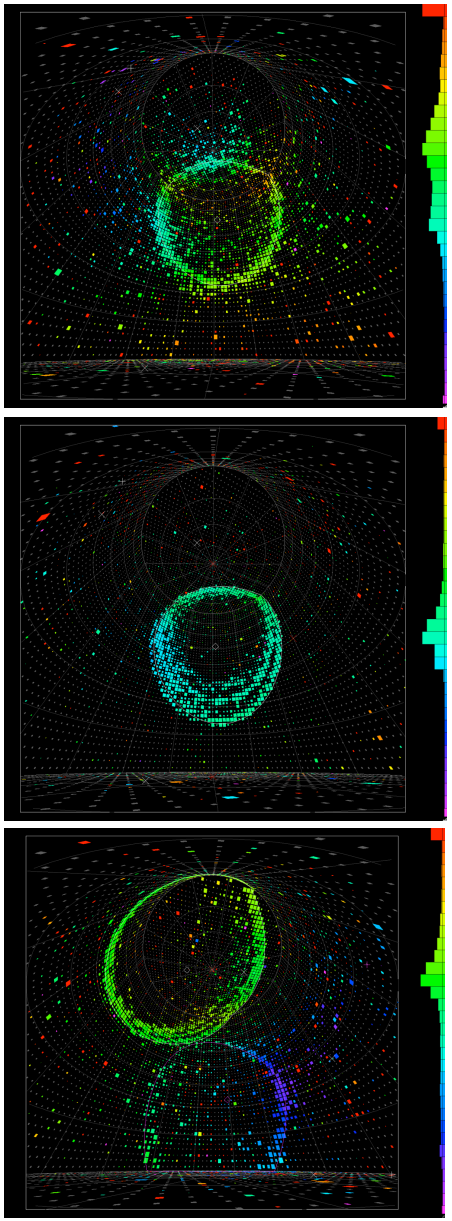
- Recent results of T2K shows evidence for $\nu_\mu \rightarrow \nu_e$ appearance
  - 10 νe candidates, p-value=0.08% (3.2σ) for zero θ_{13}
  - consistent w/ 2011 T2K result, solar+KamLAND, MINOS, Daya Bay, Reno, DoubleChooz
  - $\sin^2 2\theta_{13}$=0.089±0.010(stat.)±0.005(syst.) from DayaBay

- The existence of $\nu_\mu \rightarrow \nu_e$ phenomena opens the way to perform experiments to discover leptonic CP violation.

- Good reason to do it in Japan
  - J-PARC is expected to be upgraded to ~700kW and beyond
  - well-proven & high performance detector technique w/ the successful experiences in Super-K
  - To me, it is an economical, feasible way to explore CPV by extending JPARC-SK experimental setup.

- Rich physics topics can be covered by the extension.
  - must extend nucleon decay search capability
  - high statistics atmospheric neutrino study
  - Supernova ν
  - astrophysics is also interesting topic

Water Cherenkov technique



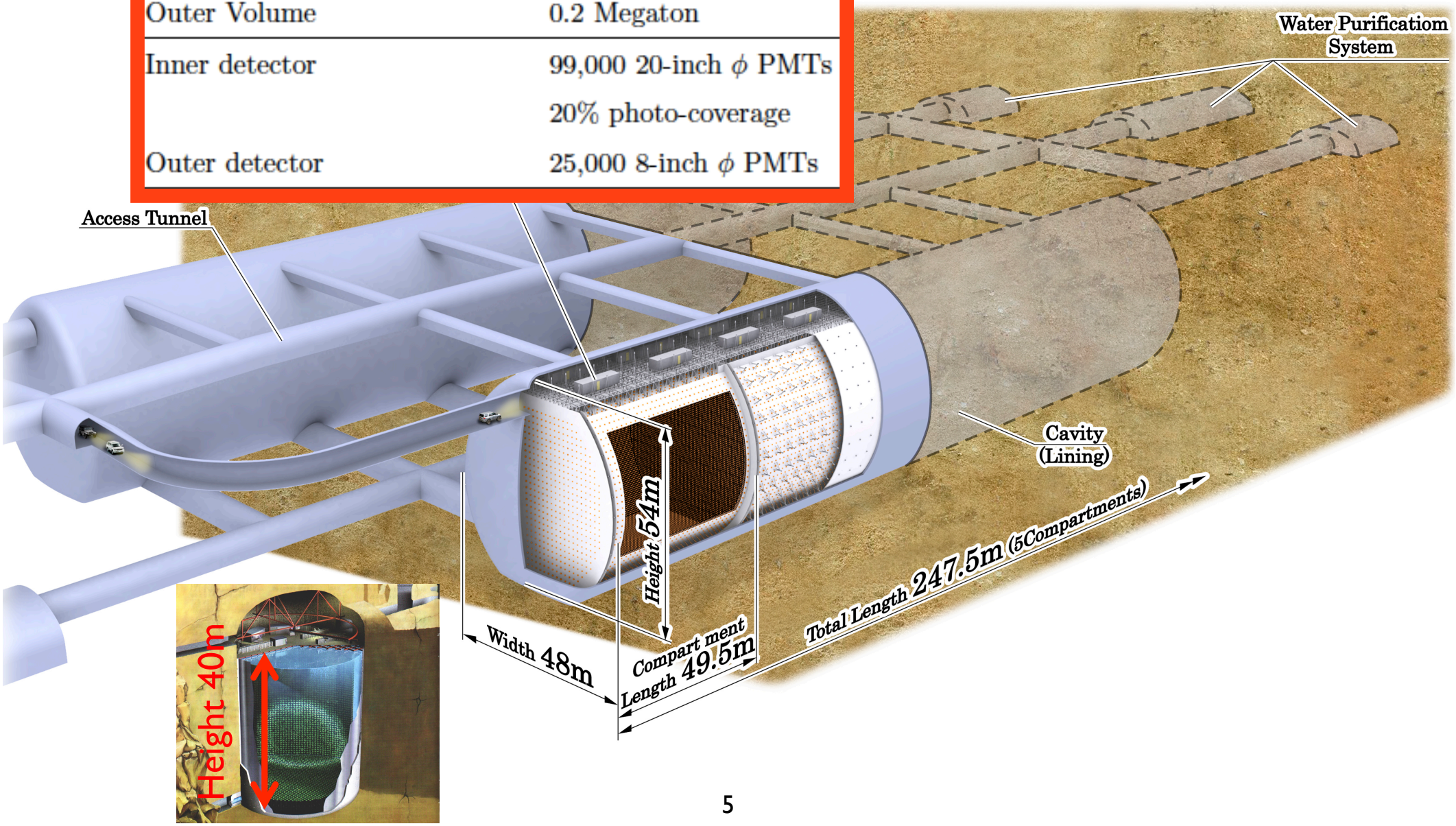
- Good imaging capability at ~1GeV
  - accelerator ν, atmospheric ν, proton decays
- Excellent particle ID capability > 99%
- Energy resolution for e and μ ~3%
- Energy threshold ~5MeV
  - muon decay electron, nuclear de-excitation γ, Supernova ν, solar ν...
- Stable operation
  - energy scale stability ~1%
  - livetime for physics analyses > 90%

- For νe appearance in T2K
  - νe signal efficiency ~60%
  - BG ν_μ+antiν_μCC<0.1%, NCπ^0<5% (0.1<E^{rec}_ν<1.25GeV)

Well-proven technology
Excellent detector performance

Schematic view of Hyper-K

Total Volume	0.99 Megaton
Inner Volume (Fiducial Volume)	0.74 (0.56) Megaton
Outer Volume	0.2 Megaton
Inner detector	99,000 20-inch ϕ PMTs
	20% photo-coverage
Outer detector	25,000 8-inch ϕ PMTs



Hyper-K WG,
arXiv:1109.3262 [hep-ex]

Letter of Intent:

The Hyper-Kamiokande Experiment

— Detector Design and Physics Potential —

K. Abe,[12,14] T. Abe,[10] H. Aihara,[10,14] Y. Fukuda,[5] Y. Hayato,[12,14] K. Huang,[4]
A. K. Ichikawa,[4] M. Ikeda,[4] K. Inoue,[8,14] H. Ishino,[7] Y. Itow,[6] T. Kajita,[13,14] J. Kameda,[12,14]
Y. Kishimoto,[12,14] M. Koga,[8,14] Y. Koshio,[12,14] K. P. Lee,[13] A. Minamino,[4] M. Miura,[12,14]
S. Moriyama,[12,14] M. Nakahata,[12,14] K. Nakamura,[2,14] T. Nakaya,[4,14] S. Nakayama,[12,14]
K. Nishijima,[9] Y. Nishimura,[12] Y. Obayashi,[12,14] K. Okumura,[13] M. Sakuda,[7] H. Sekiya,[12,14]
M. Shiozawa,[12,14,*] A. T. Suzuki,[3] Y. Suzuki,[12,14] A. Takeda,[12,14] Y. Takeuchi,[3,14]
H. K. M. Tanaka,[11] S. Tasaka,[1] T. Tomura,[12] M. R. Vagins,[14] J. Wang,[10] and M. Yokoyama[10,14]

(Hyper-Kamiokande working group)

[1] *Gifu University, Department of Physics, Gifu, Gifu 501-1193, Japan*

[2] *High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, Japan*

[3] *Kobe University, Department of Physics, Kobe, Hyogo 657-8501, Japan*

[4] *Kyoto University, Department of Physics, Kyoto, Kyoto 606-8502, Japan*

[5] *Miyagi University of Education, Department of Physics, Sendai, Miyagi 980-0845, Japan*

3262v1 [hep-ex] 15 Sep 2011

Open Meeting for the Hyper-Kamiokande project, Kashiwa city, JAPAN (Indico test) (21-23 August 2012)

https://indico.cern.ch/conferenceDisplay.py?confId=188673

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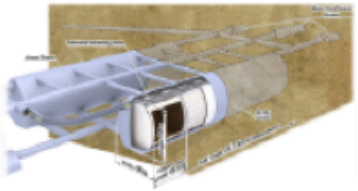
Open Meeting for the Hyper-Kamiokande project, Kashiwa city, JAPAN (Indico test)

21-23 August 2012 *Kavli IPMU (Kashiwa, Japan)*
Japan timezone

Visit http://db.ipmu.jp/seminar/?conference_id=66 for more info.

- **Overview**
- Important Dates
- Meeting Program
- Call for Abstracts
  - View my abstracts
  - Submit a new abstract
- Contribution List
- Registration
  - Registration Form
- List of registrants
- Access
- Accomodation



Overview

We will hold the International Open Working Group Meeting for the Hyper-Kamiokande project. The Hyper-K is the flagship experiment in the next decade for neutrino oscillation and nucleon decays that we are developing.

The goal of the meeting is to discuss the detector design and necessary R&D items covering

- cavern excavation
- tank liner material and its design
- photo-sensors and their support structure
- DAQ electronics and computers
- calibration system
- water purification system
- software development, and so on.

Physics potentials of Hyper-K are also within the scope of the meeting. Workshop participants are expected to guide the discussions to achieve optimal detector design and maximum physics potentials. Participants are encouraged to submit abstracts for their talks to present their individual interests and possible future contributions to the project.

Moreover, we'd like to start discussion to form an international Hyper-K working group that could become a seed for a formal Hyper-K collaboration in future. We expect that those who are interested in joining the project will show up in this meeting.

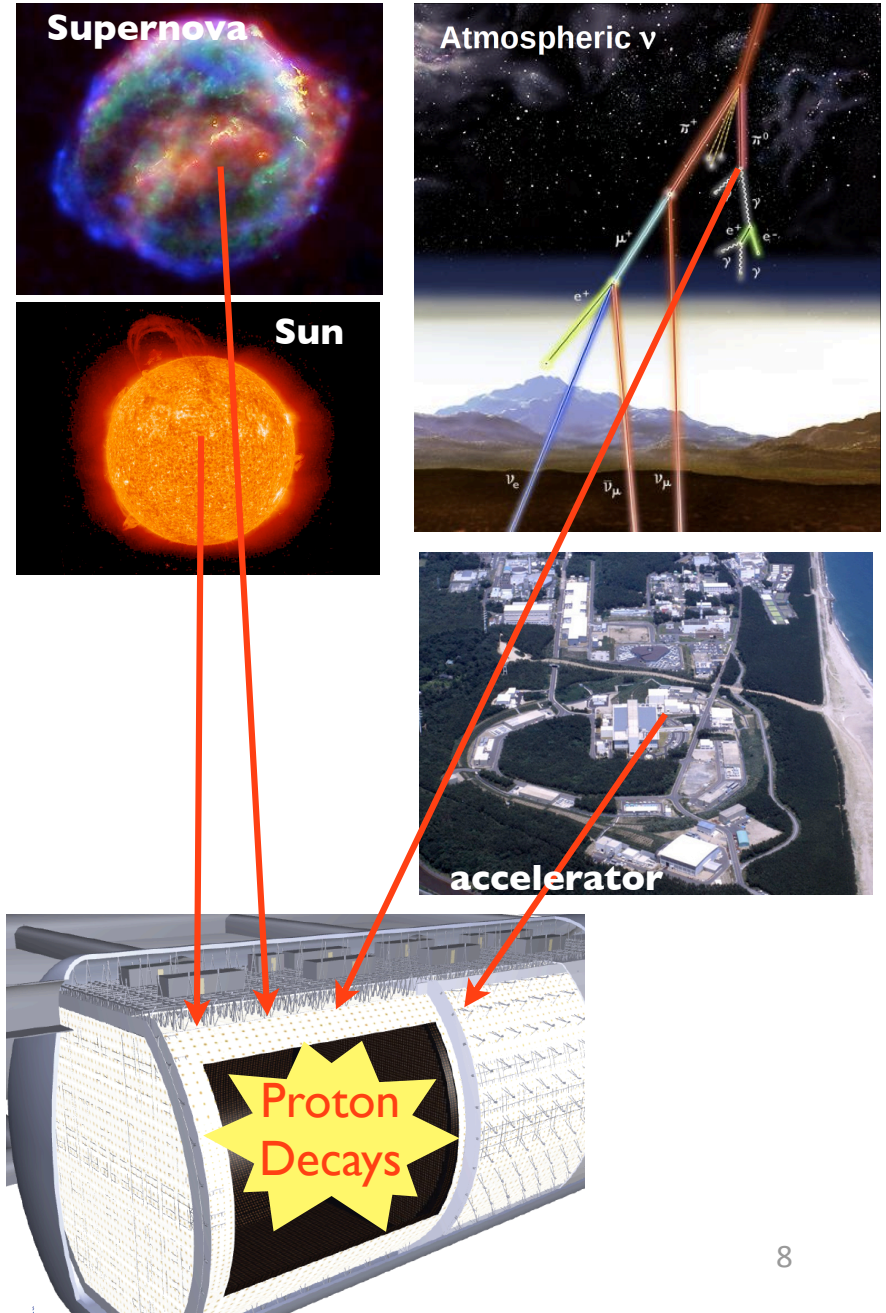
This meeting will be open for all interested scientists and community members. However, prior registration is required to participate the meeting.

We are looking forward to seeing you in Kashiwa,

Hyper-K WG,
arXiv:1109.3262 [hep-ex]

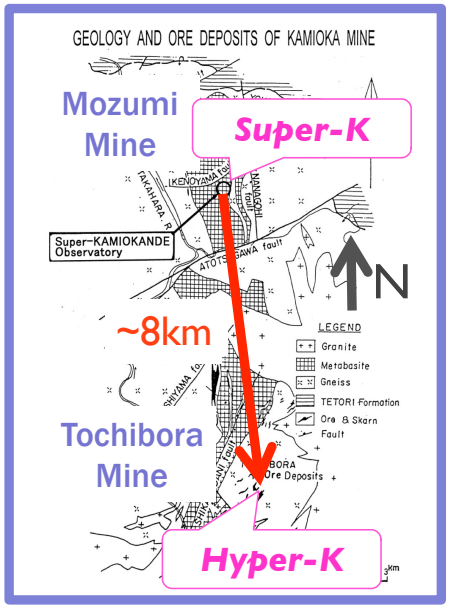
Multi-purpose detector, Hyper-K

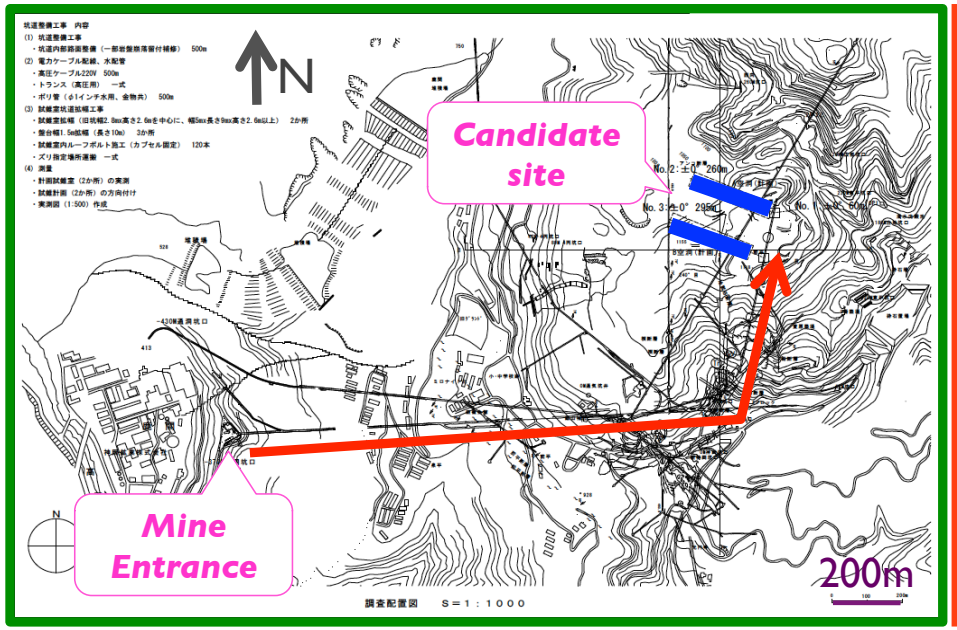
- Total (fiducial) volume is 1 (0.56) million ton
  - 25 × Super-K
- Explore full picture of neutrino oscillation parameters.
  - Discovery of leptonic CP violation (Dirac δ)
  - ν mass hierarchy determination($\Delta m^2_{32}>0$ or <0)
  - θ_{23} octant determination ($\theta_{23}<\pi/4$ or $>\pi/4$)
- Extend nucleon decay search sensitivity
  - $\tau_{proton}=10^{34}\sim10^{35}$ years
- Neutrinos from astrophysical objects
  - 200 ν's / day from Sun
    - possible time variation, ~3σ day/night asym.
  - 250,000 (50) ν's from Supernova @Galactic-center (Andromeda)
  - ~300 ν's / 10 years (>20MeV) SN relic ν
  - WIMP ν, solar flare ν, etc

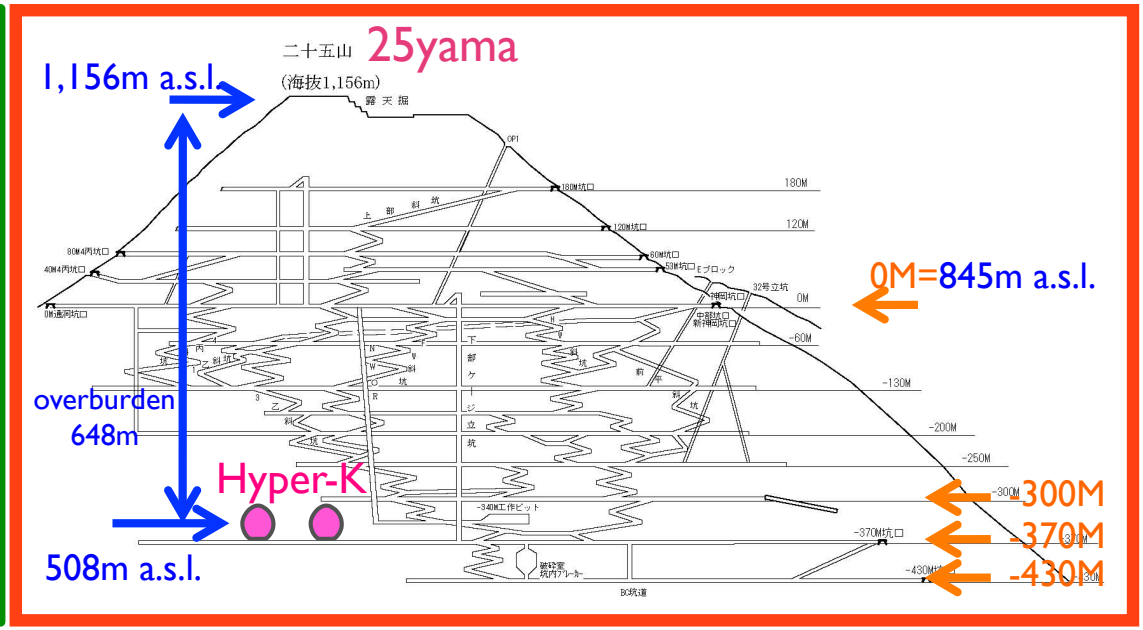


Hyper-Kamiokande candidate site

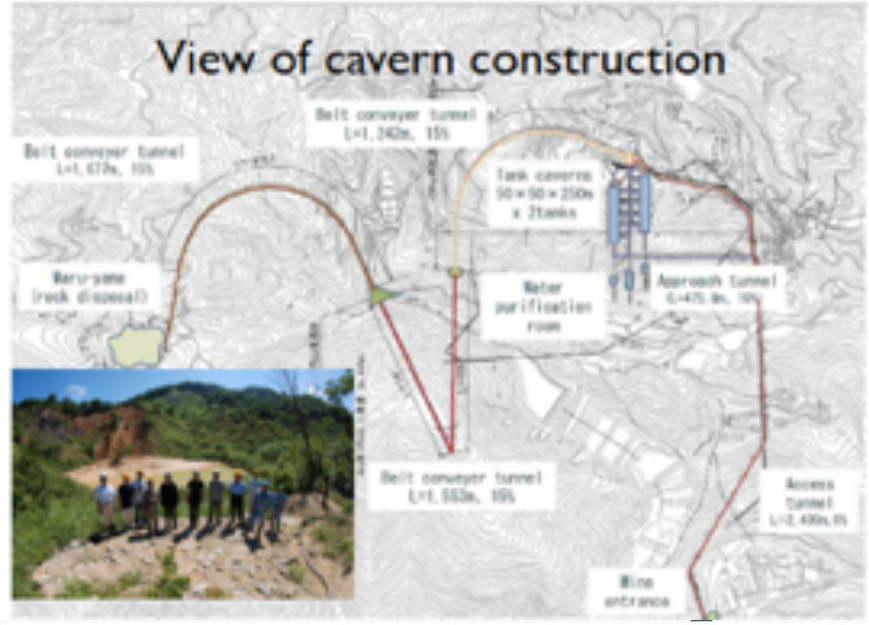
- ✦ 8km south from Super-K
  - ✦ same T2K beam off-axis angle (2.5 degree)
  - ✦ same baseline length (295km)
- ✦ 2.6km horizontal drive from entrance
- ✦ under the peak of Nijuugo-yama
  - ✦ 648m of rock or 1,750 m.w.e. overburden
- ✦ 13,000 m^3/day or 1megaton/80days natural water



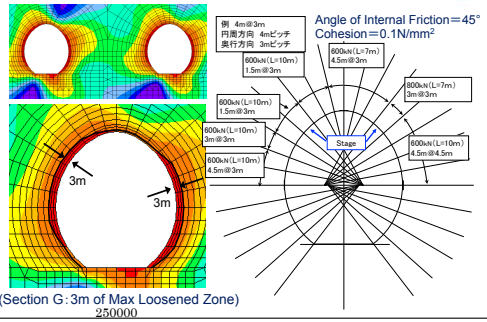


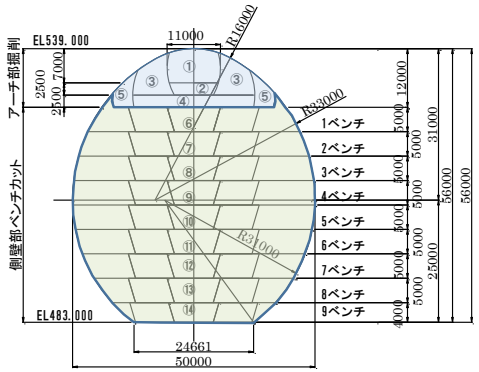


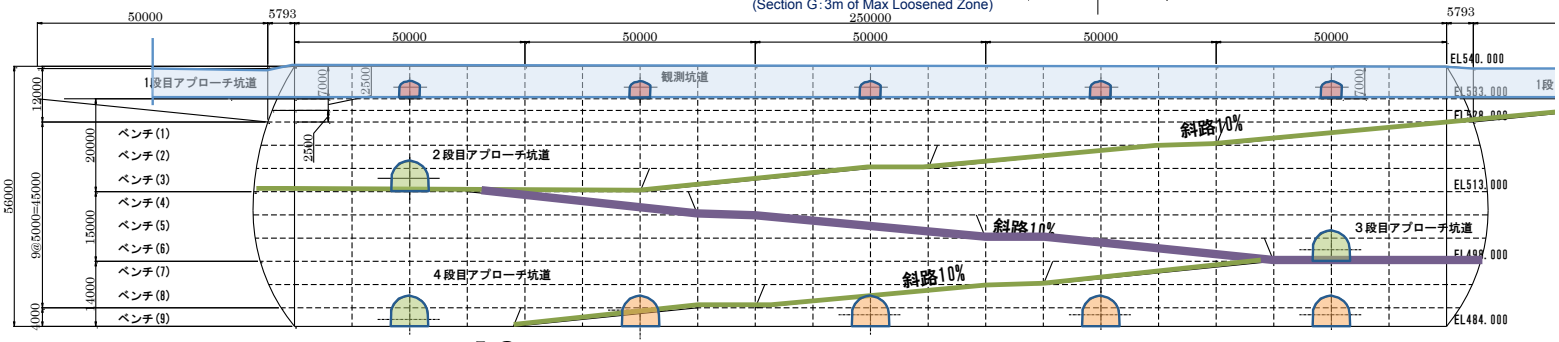
Cavern excavation



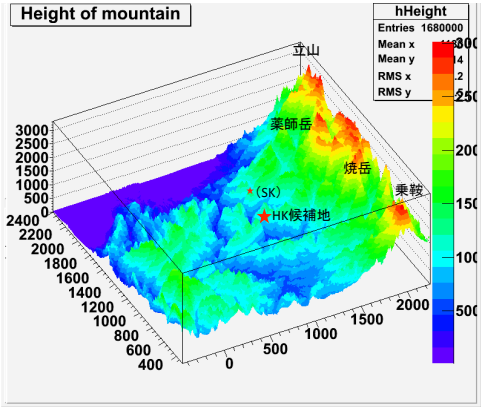
- geological survey, in-situ rock stress tests
- scheduling & costing ongoing

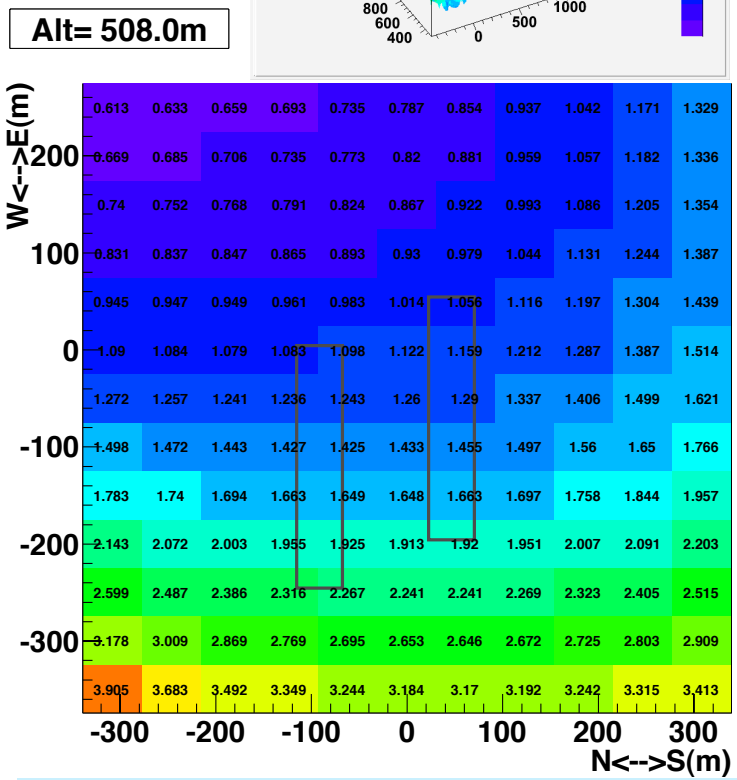






Muon rate





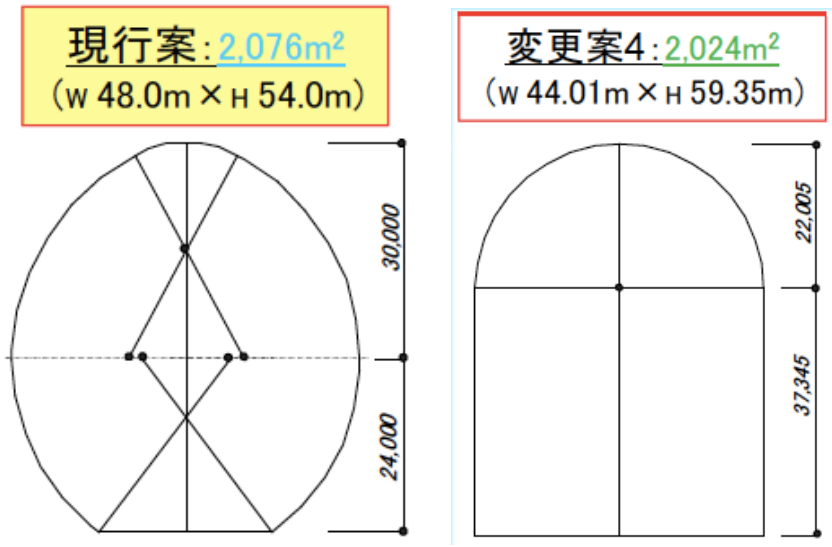
- $1.0\text{-}2.3\times10^{-6}s^{-1}cm^{-2}$ at 508m
  - about 10 times Super-K
  - $0.13\text{-}0.14\times10^{-6}s^{-1}cm^{-2}$ at SK

Effect of 10 times more CR μ

- No impact for accelerator ν
- No problem for atmospheric ν and proton decay studies
  - π^0 production by fast neutron OK.
  - K^0 BG is also negligible. (need confirmation)
  - Deadtime by muons is <1%
- Impact on solar ν: ~3σ day/night effect expected.
- Impact on SN relic ν: higher threshold to ~20MeV, 300ν/10yrs

On-going studies

- Design optimization is going on to achieve concrete proposal, lower cost, shorter construction period.
  - Vertical straight wall possible? expecting cost &period reduction for liner construction
  - Further reduction by wire support of PMTs
  - Further reduction by reducing the segmentation walls.
- Need to secure waste rock disposal. (feasibility, cost estimation)
- Water purification system design, water quality control strategy underway.



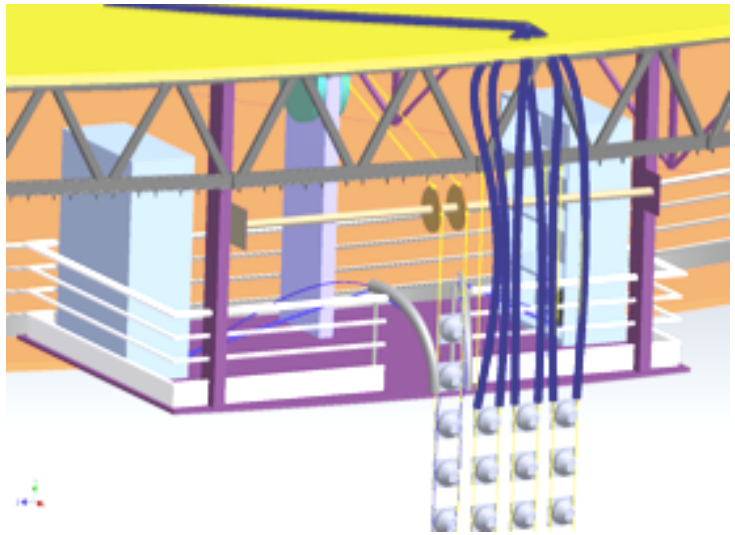
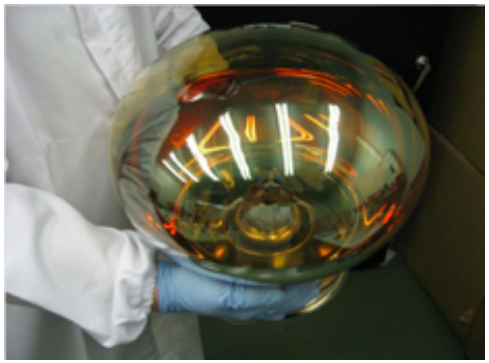
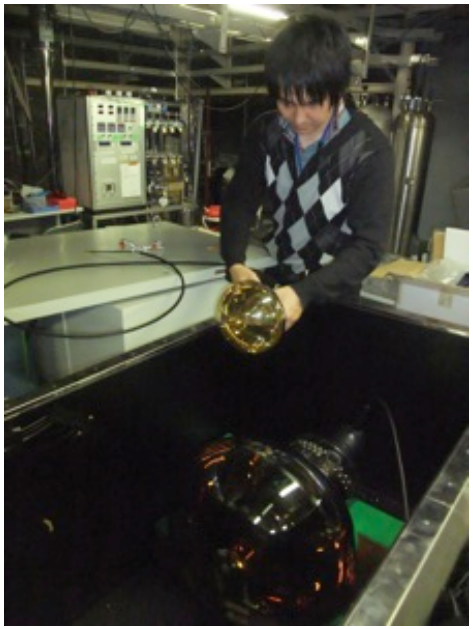


Photo-sensor

- Candidates for ID sensor
  - 20” Hybrid Photo Detector (HPD)
  - Improved 20” PMT
- Proof test of 8” HPD in water tank from this summer
- 20” HPD prototype expected in ~a year

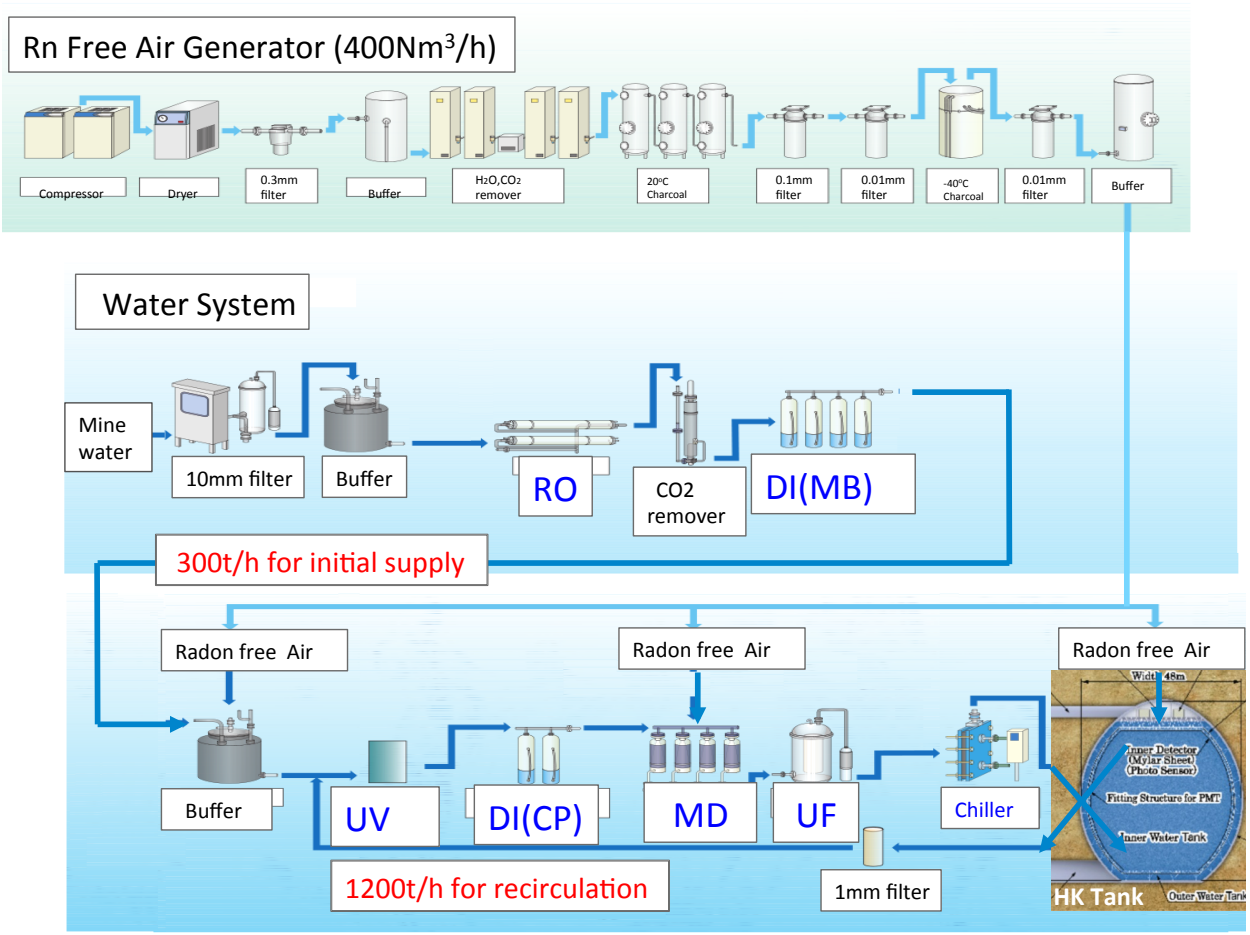




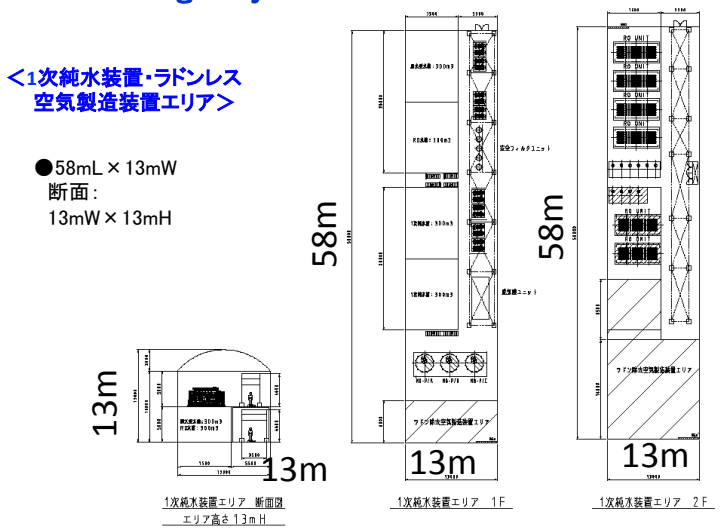
Preparation @ Kamioka

Water system

Based on Super-K system



1st stage layout

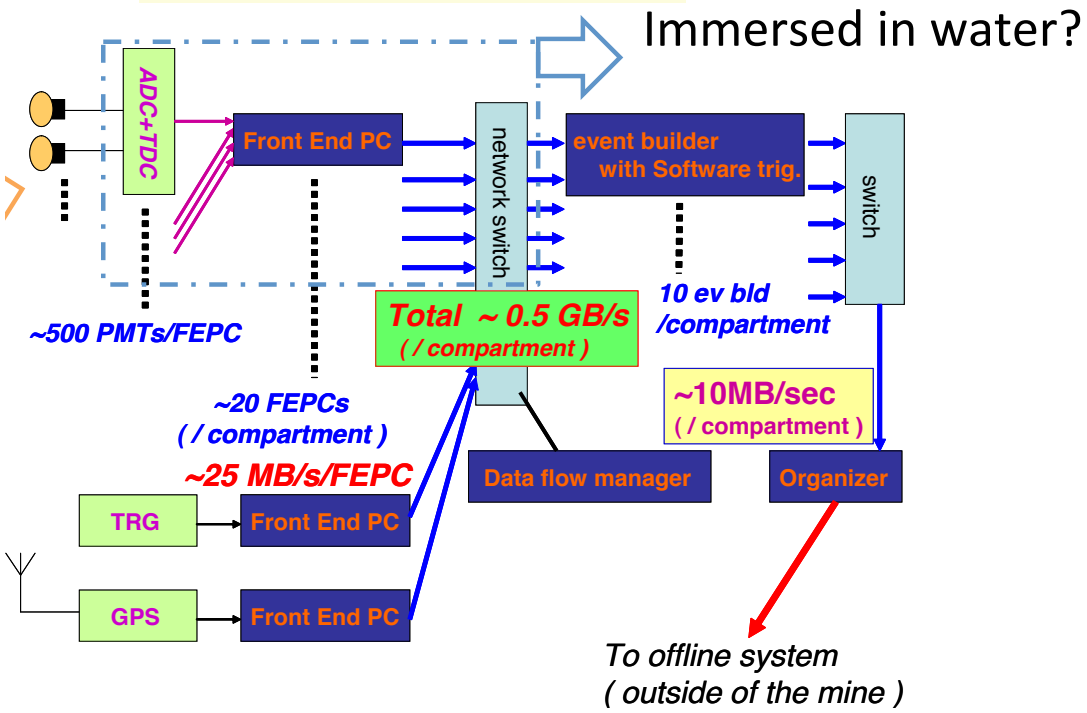


Under design with companies in Japan and US

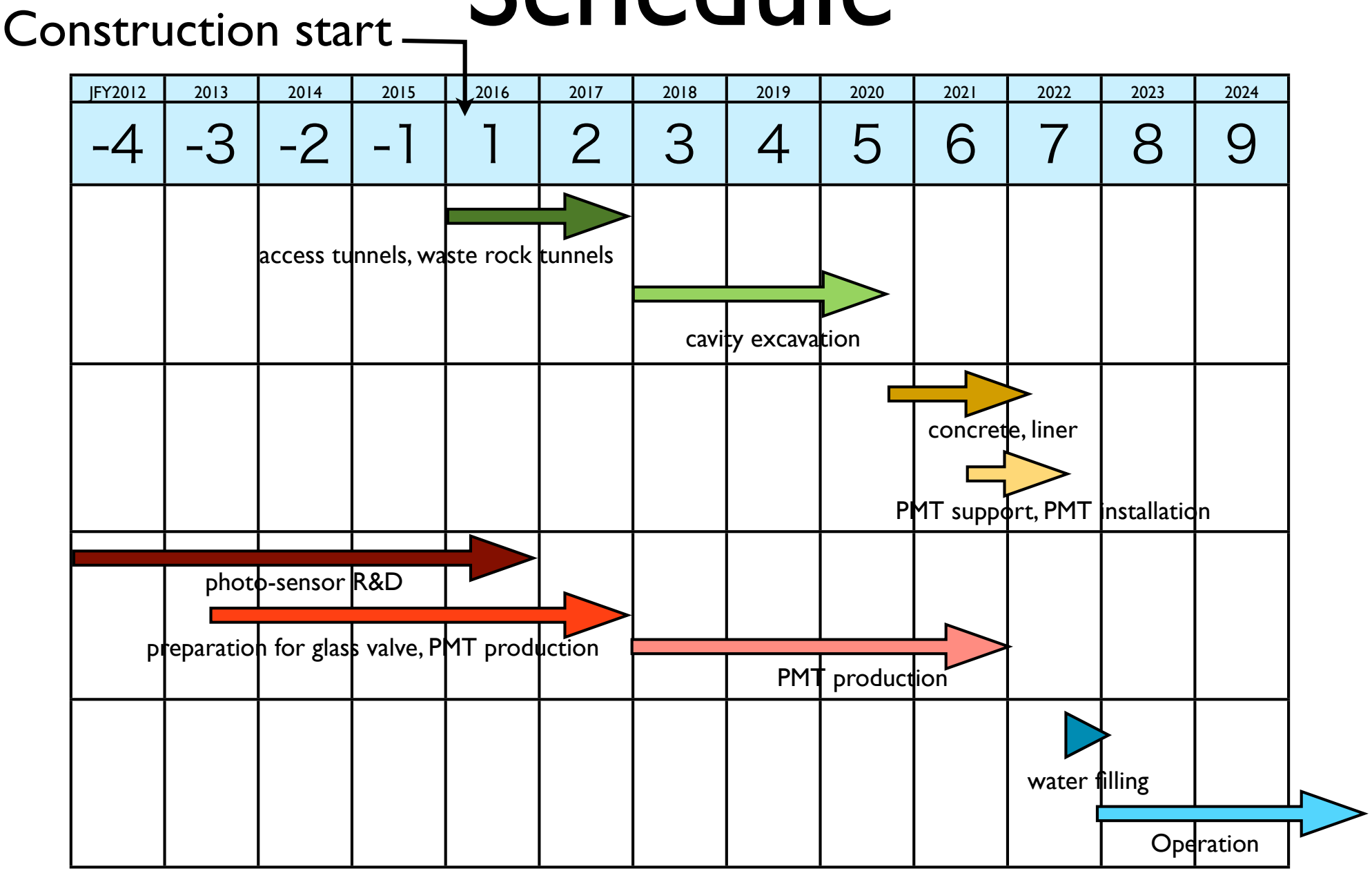
More Developments

- Electronics/DAQ
  - Requirements similar to Super-K
    - R&D of front-end in water starts
- Detector calibration
  - R&D based on Super-K experience
- Dedicated software development
  - Under discussion
- ...

Elec. schematics



Schedule



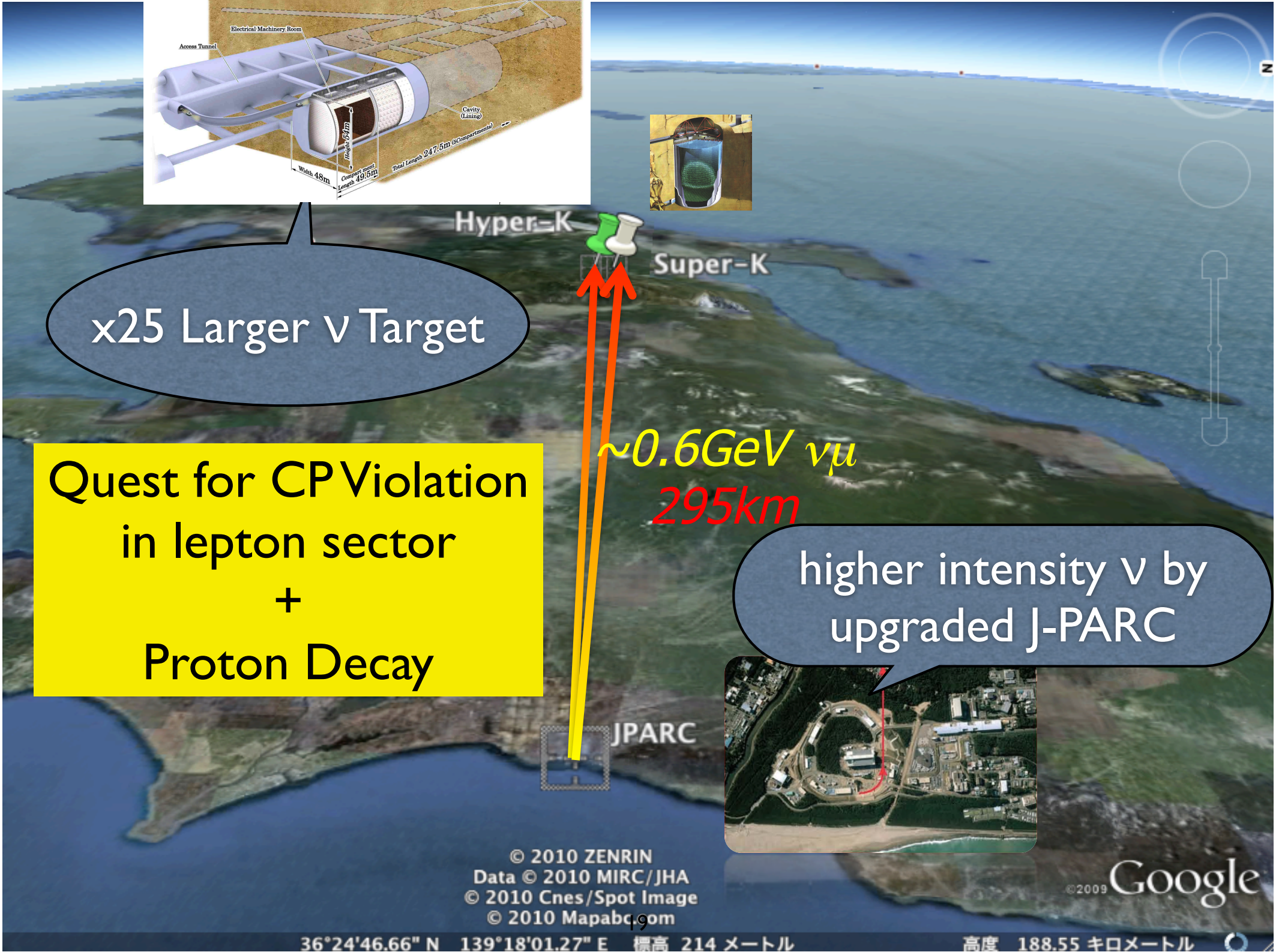
assuming budget being approved from JPY2016

Physics Potentials

ν physics targets of Hyper-K

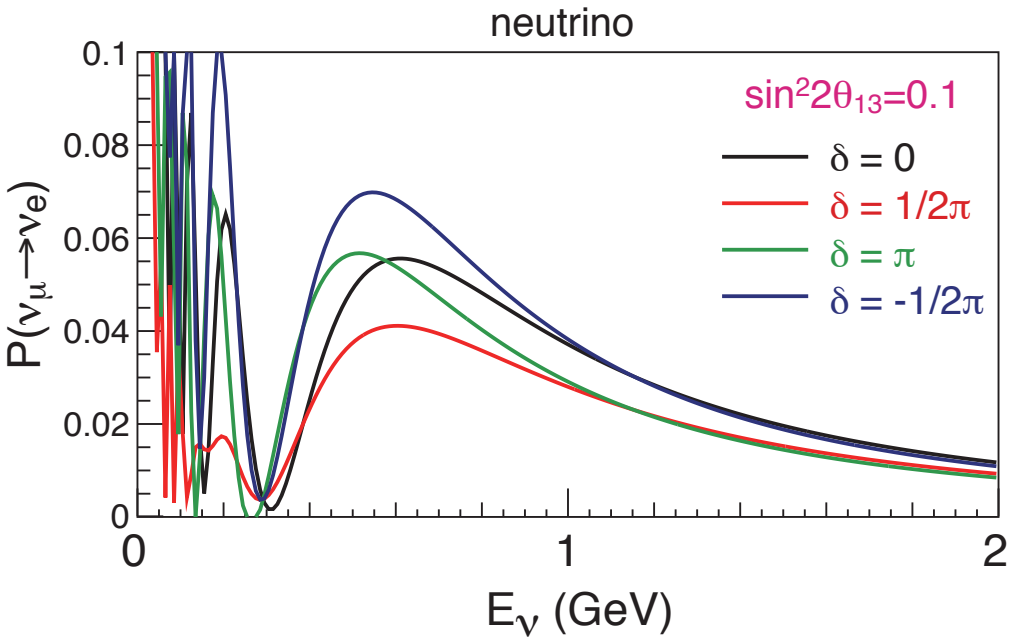
- Leptonic CP violation, Dirac phase δ
- ν mass hierarchy, $\Delta m^2_{32}>0$ or $\Delta m^2_{32}<0$
- θ_{23} octant, $\theta_{23}<\pi/4$ or $\theta_{23}>\pi/4$

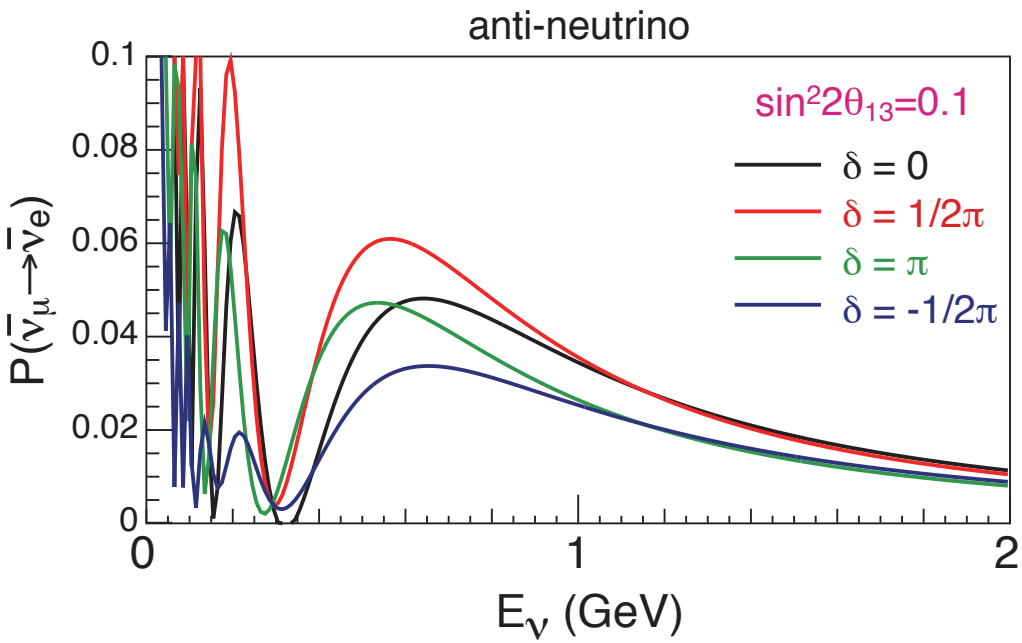
Aiming to explore full picture of neutrino oscillation parameters by using:
Accelerator ν & atmospheric ν


Electrical Machinery Room
Access Tunnel
Cavity (Lining)
Height 54m
Width 48m
Compart-ment Length 49.5m
Total Length 247.5m (6Compartments)
Hyper-K
Super-K
x25 Larger ν Target
~0.6GeV νμ
295km
Quest for CP Violation
in lepton sector
+
Proton Decay
higher intensity ν by
upgraded J-PARC
JPARC
© 2010 ZENRIN
Data © 2010 MIRC/JHA
© 2010 Cnes/Spot Image
© 2010 Mapabc.com
©2009 Google
36°24'46.66" N 139°18'01.27" E 標高 214 メートル
高度 188.55 キロメートル

$\nu_\mu \rightarrow \nu_e$ probability

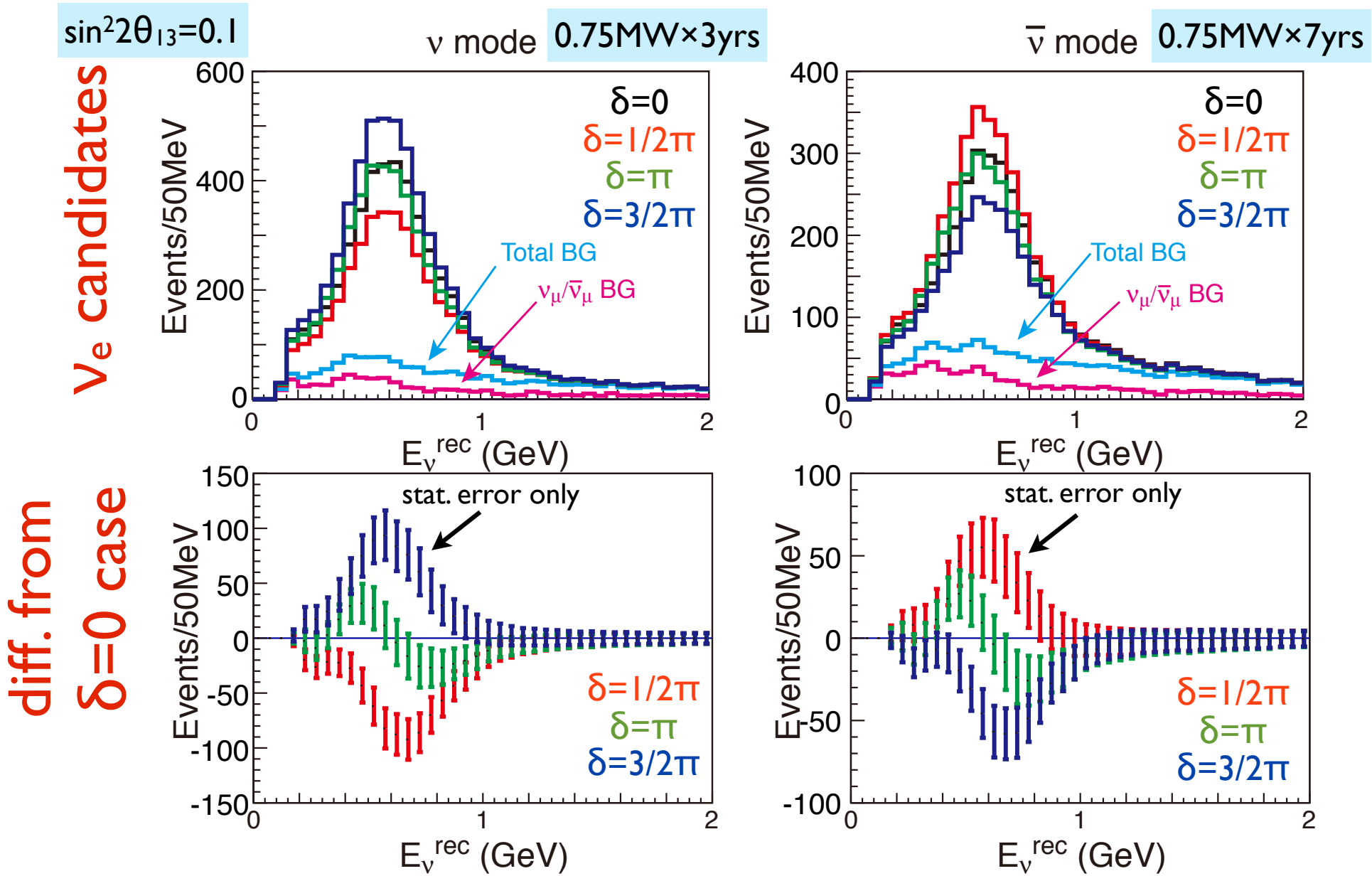
Normal hierarchy





- CPV test by comparing $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
- sensitive to exotic CPV (non MNS matrix origin)

Expected ν_e CC candidates



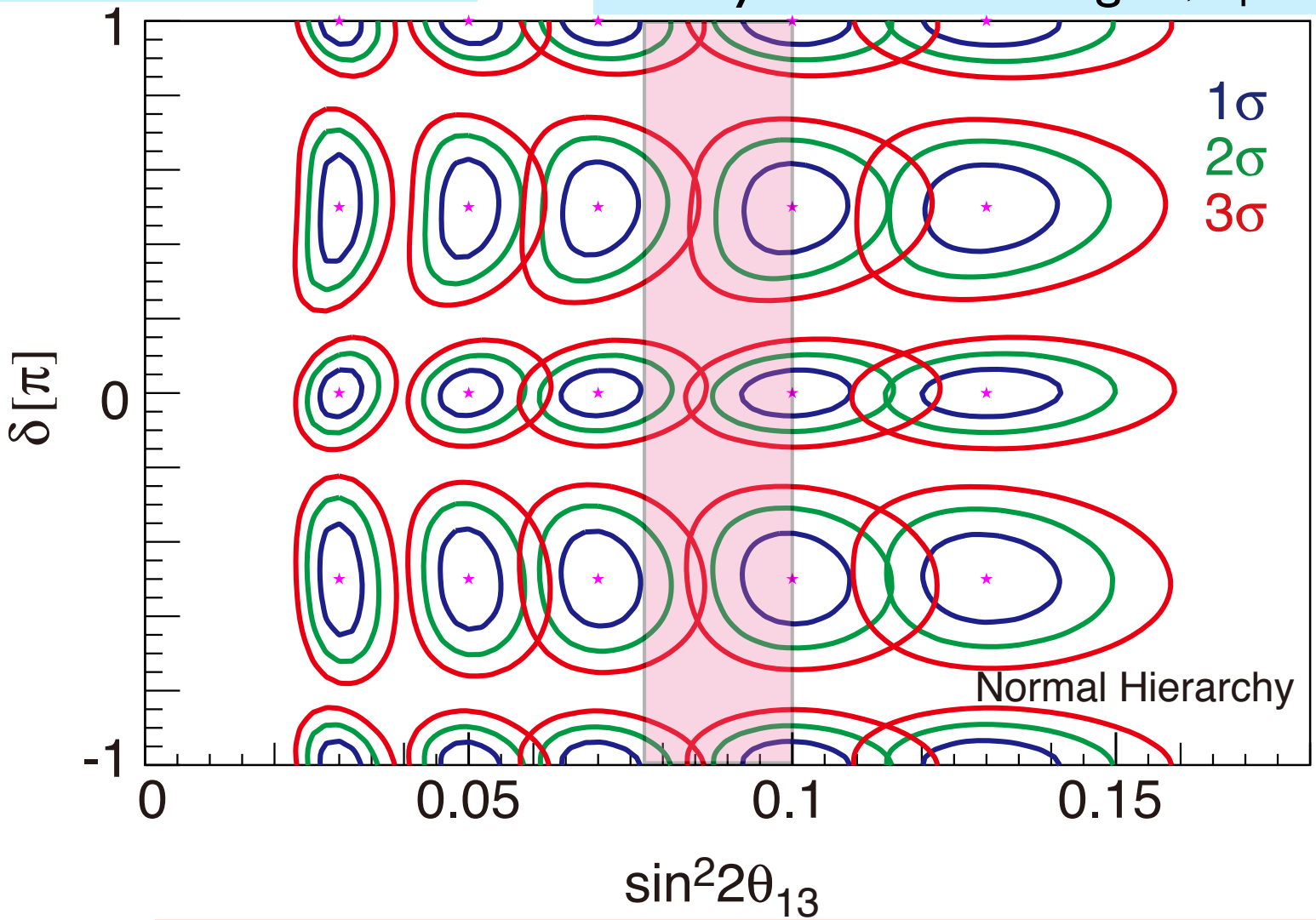
Numbers and shape for CP measurement

Contours

7.5MW・years

Normal mass hierarchy (known)

5% systematics on signal, ν_μ BG, ν_e BG, $\nu/\bar{\nu}$

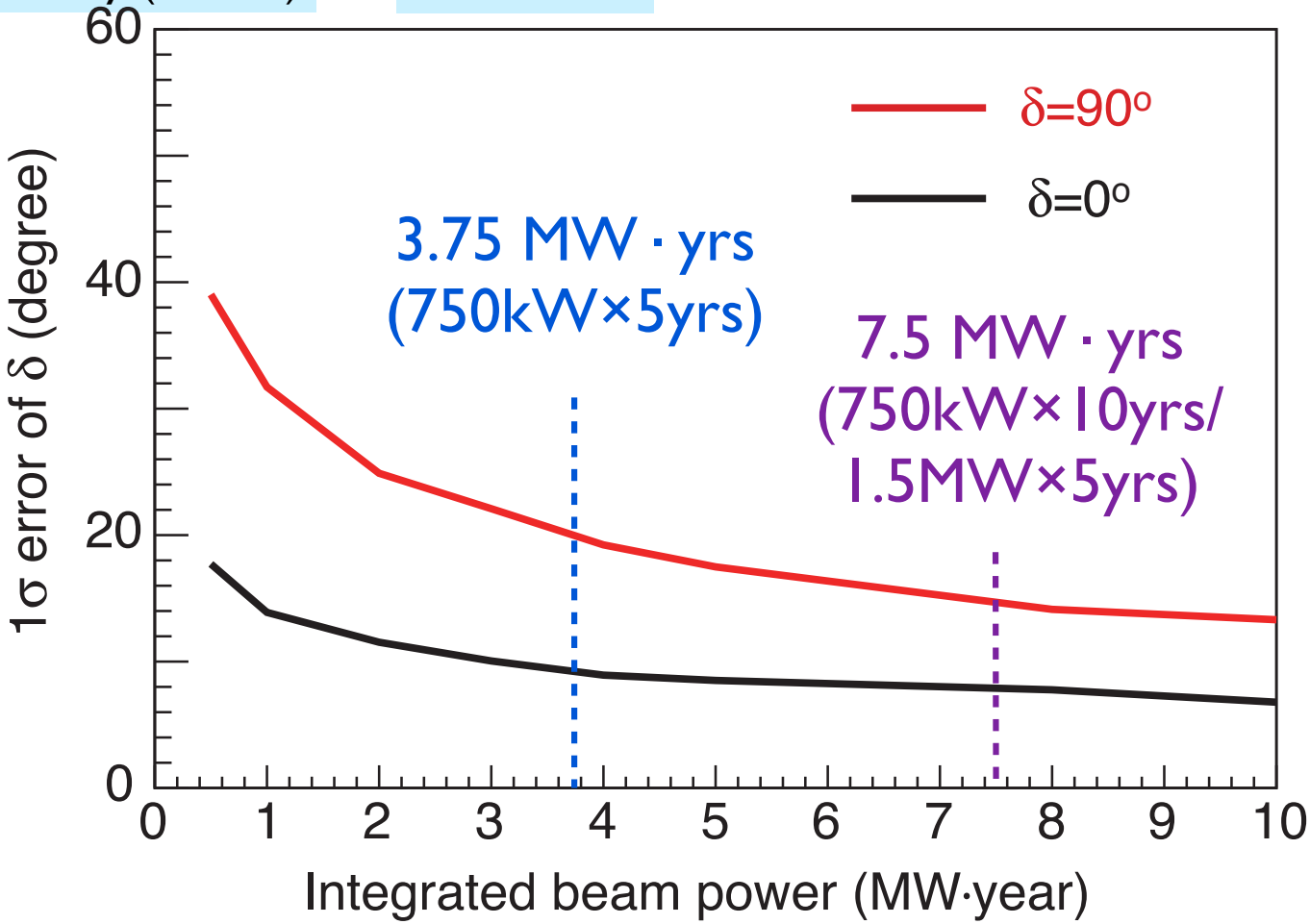


- Good sensitivity for CPV
- modest dependence on θ_{13} value

δ resolution

Normal mass hierarchy (known)

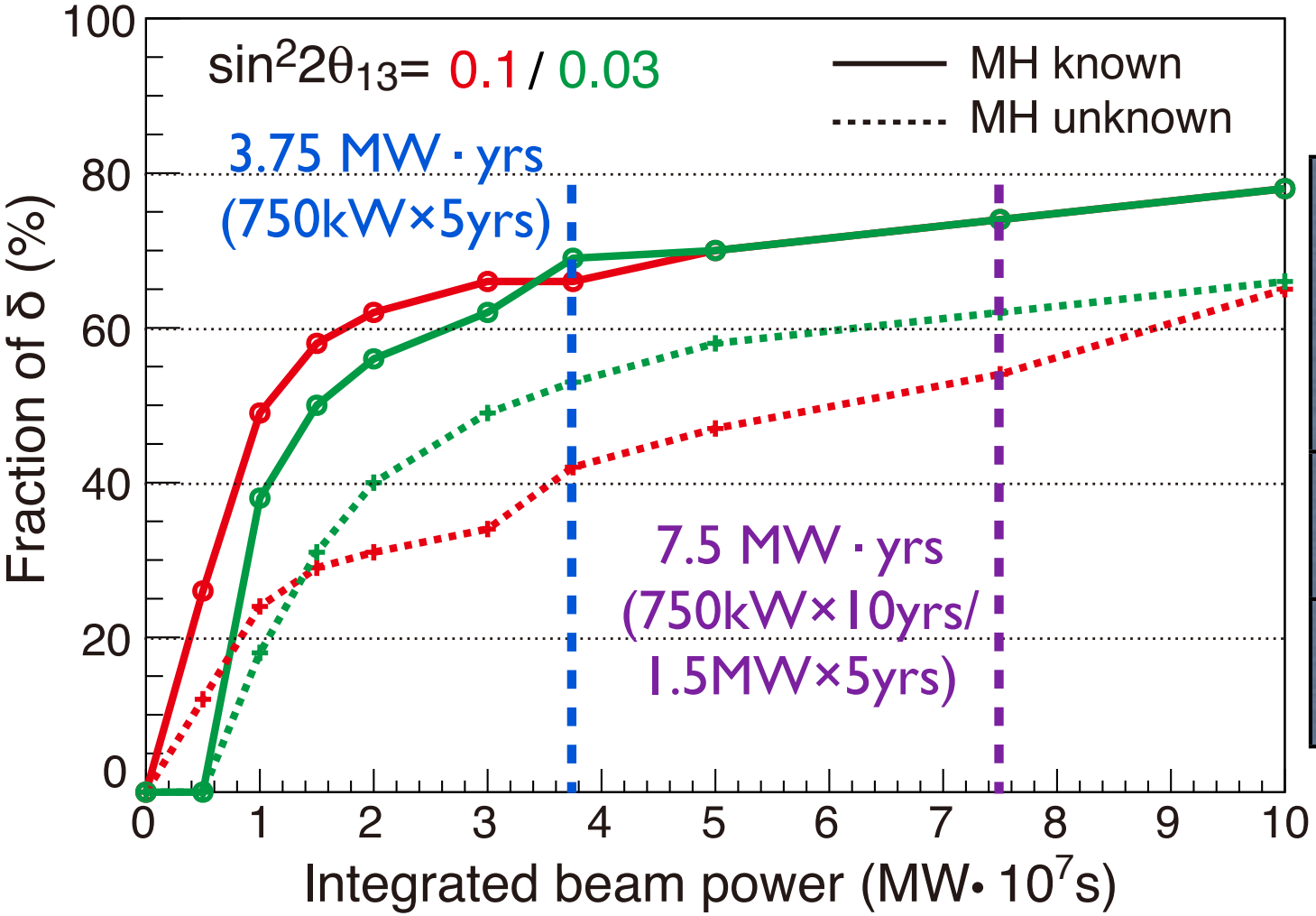
$\sin^2 2\theta_{13}=0.1$



- δ precision < 20° (δ=90°)
  < 10° (δ= 0°)
- modest dependence on θ_{13} value

Fraction of δ (%) for CPV discovery

Fraction of δ in % for which expected CPV ($\sin\delta \neq 0$) significance is >3σ

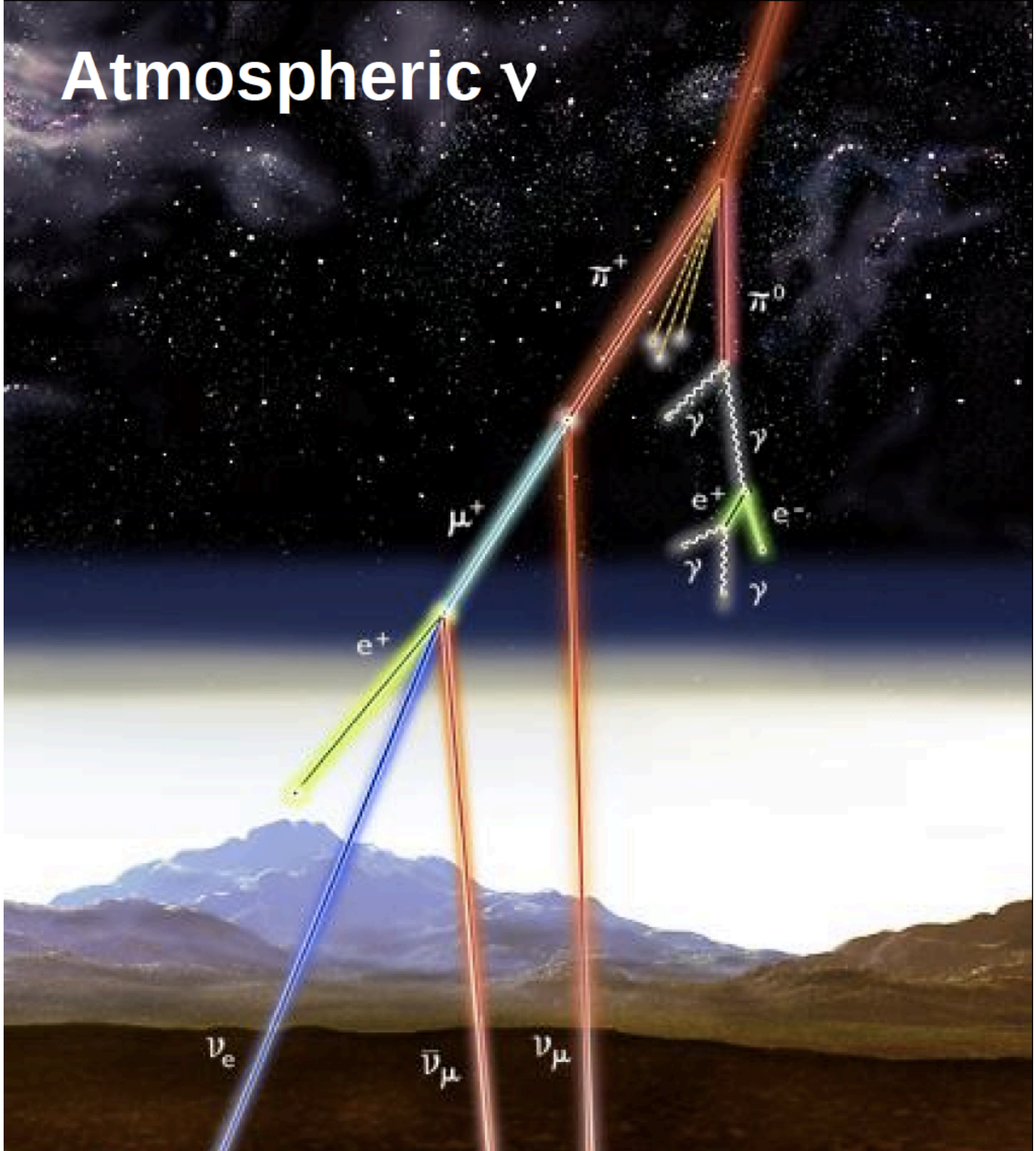


$\sin^2 2\theta_{13}$=0.1

(MW× yrs)	Mass hierarchy	
	known	unknown
3.75	69%	42%
7.5	74%	54%

- Effect of unknown mass hierarchy is limited
  - Input from atm ν and other experiments also expected for MH

Atmospheric ν



ν_e appearance in atmospheric ν

NuclPhysB669,255(2003)
NuclPhysB680,479(2004)

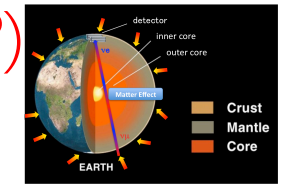
r : μ/e flux ratio (~2 at low energy)

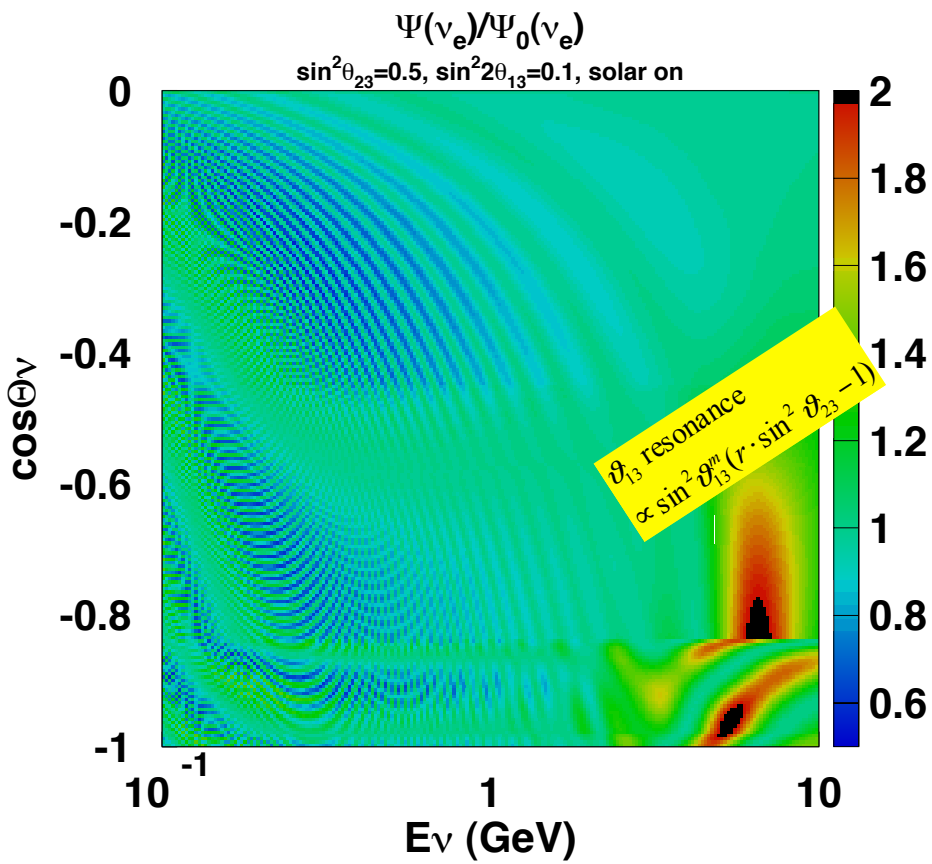
$P_2 = |A_{e\mu}|^2$: 2ν transition probability $\nu_e \rightarrow \nu_{\mu\tau}$ in matter
$R_2 = \mathrm{Re}(A^*_{ee}A_{e\mu})$
$I_2 = \mathrm{Im}(A^*_{ee}A_{e\mu})$
A_{ee} : survival amplitude of the 2ν system
$A_{e\mu}$: transition amplitude of the 2ν system

$$\frac{\Phi(\nu_e)}{\Phi_0(\nu_e)} - 1 \approx P_2(r \cdot \cos^2\theta_{23} - 1)$$ Solar term

$$-r \cdot \sin\tilde{\theta}_{13} \cdot \cos^2\tilde{\theta}_{13} \cdot \sin 2\theta_{23}(\cos\delta \cdot R_2 - \sin\delta \cdot I_2)$$ Interference term (δCP)

$$+2\sin^2\tilde{\theta}_{13}(r \cdot \sin^2\theta_{23} - 1) \quad (3)$$ θ_{13} resonance term





ν_e appearance is expected due to MSW effect in the Earth's matter
- happens in ν in the case of normal mass hierarchy
- in anti-ν in inverted mass hierarchy

Large θ_{13} value gives us a good chance to discriminate mass hierarchy.

ν_e-like and anti-ν_e-like sample

$$\nu_e + N \rightarrow e^- + X$$
$$\bar{\nu}_e + N \rightarrow e^+ + X$$

- ν_e CC produce more π^+
  - more muon decays
- More energy transfer to hadronic system
  - lower charged lepton energy
  - more pions (muon decays)

enrichment by variables

- # of rings
- # of muon decay electrons
- Lepton energy fraction
- transverse momentum

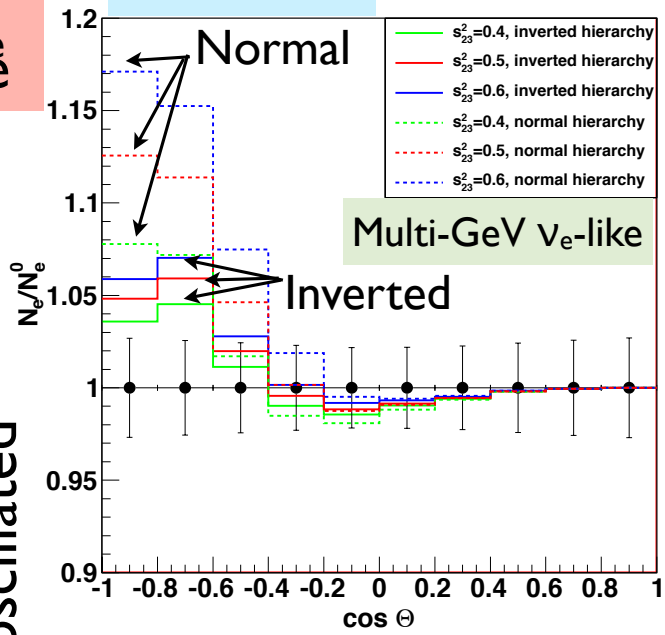
	νe CC	anti-νe CC	others	Total
νe-like	57%	11%	32.0%	100%
anti-νe-like	55%	34%	11%	100%

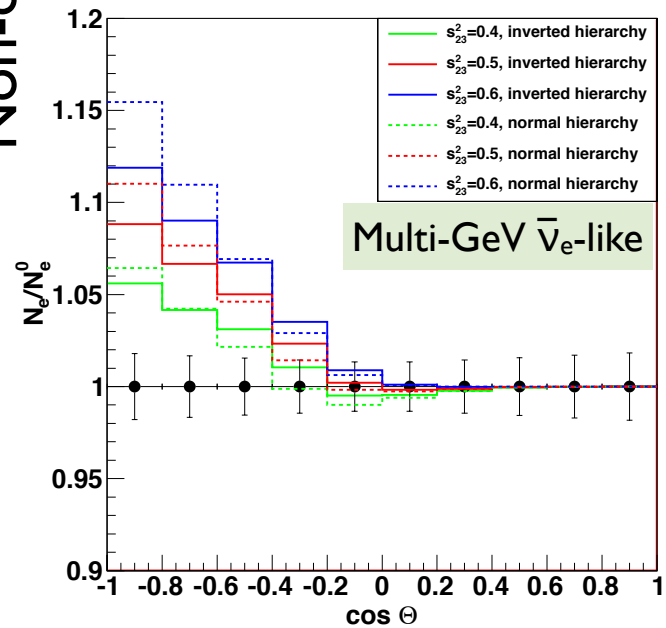
Upward ν_e appearance

$\sin^2 2\theta_{13}=0.1$

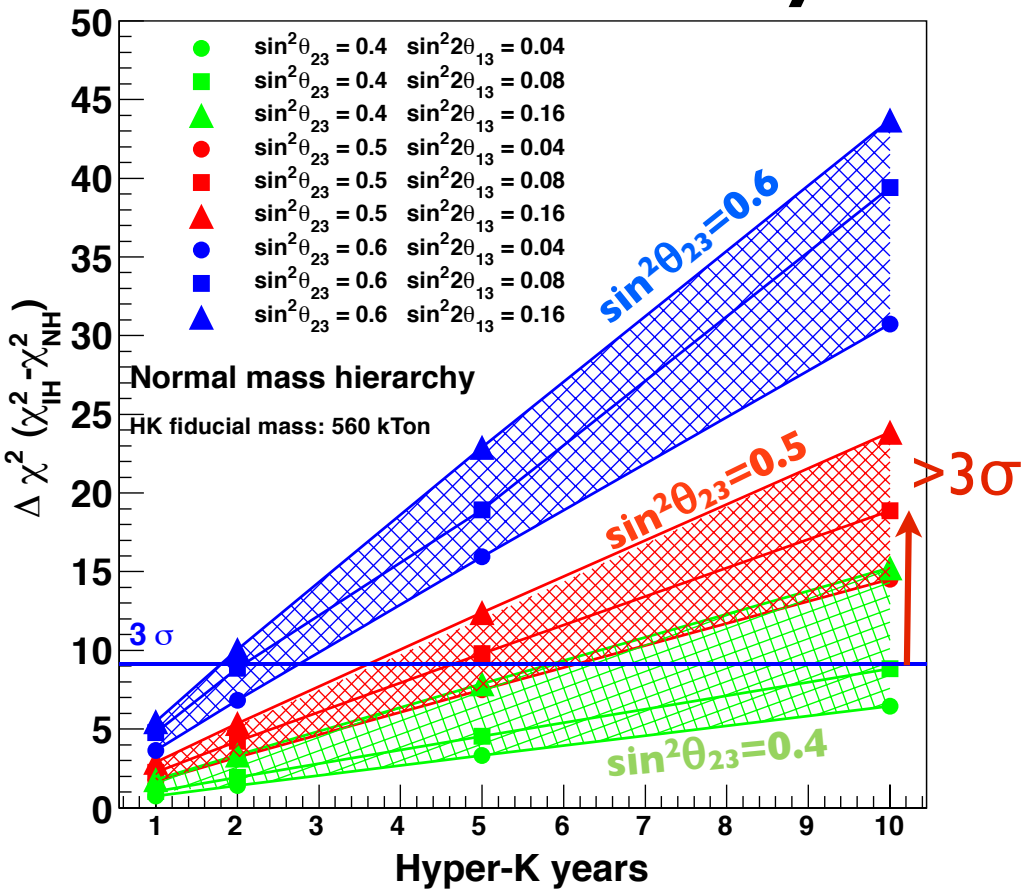
Oscillated e-like events

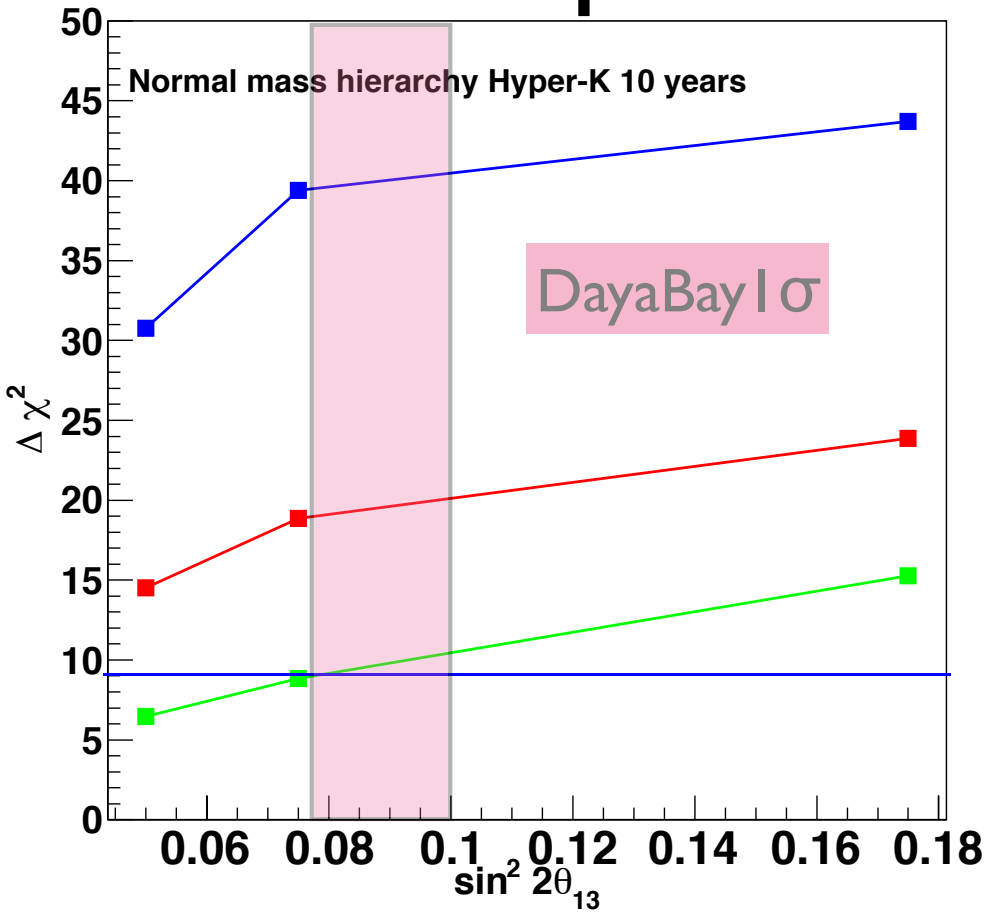
Non-oscillated





Mass hierarchy discrimination power



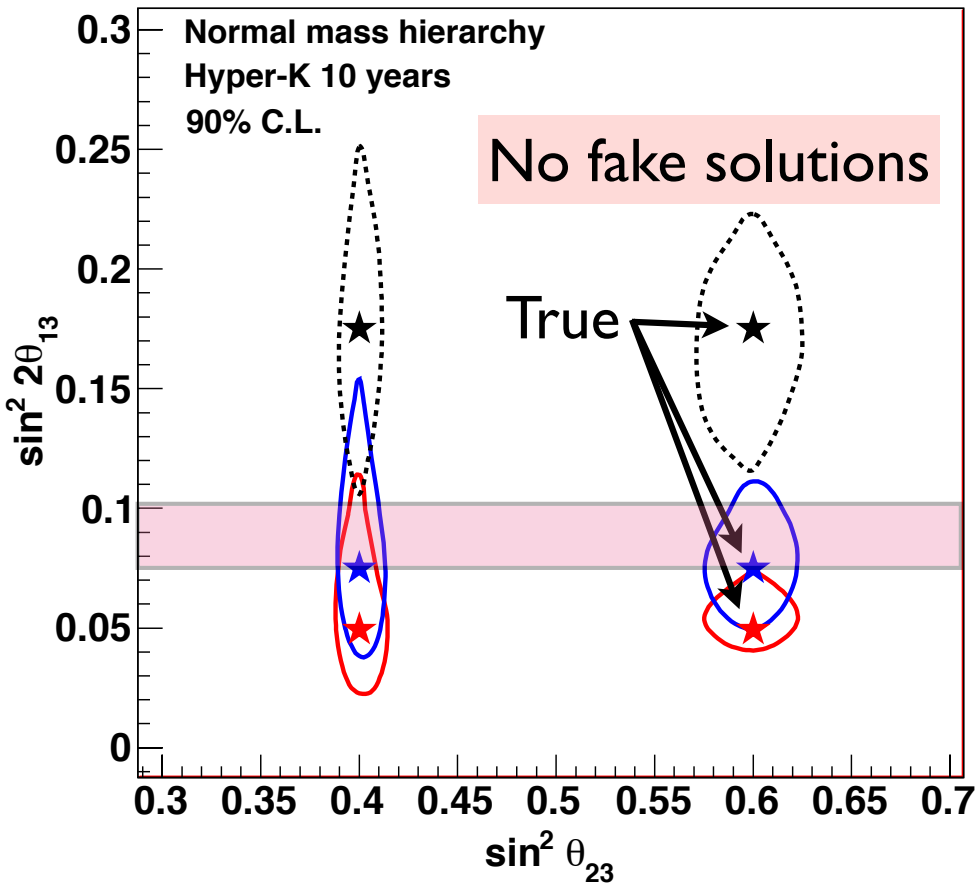


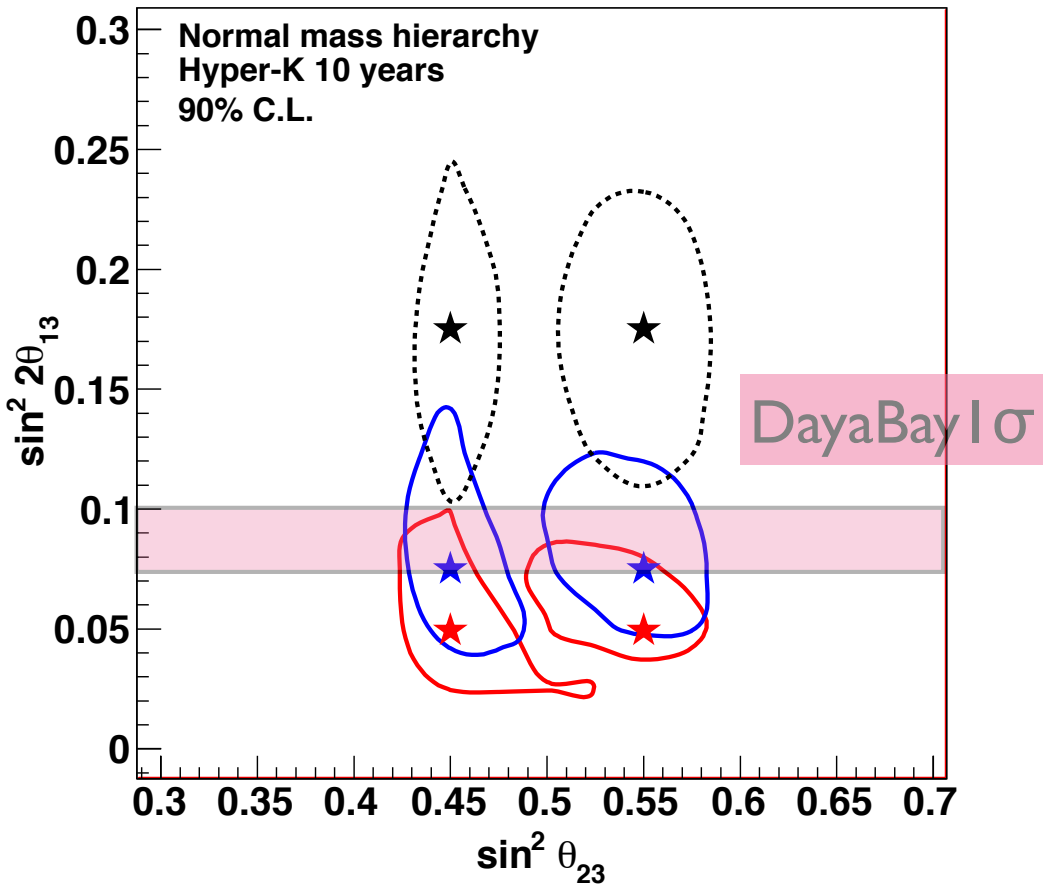
- expect to discriminate normal from inverted hierarchy w/ 3σ significance by ~5years data.
- Large θ_{13} values are encouraging.
- dependence on θ_{23}

θ_{23} octant

$\sin^2 2\theta_{23}=0.96$
↓
$\sin^2\theta_{23}=0.4$ or 0.6

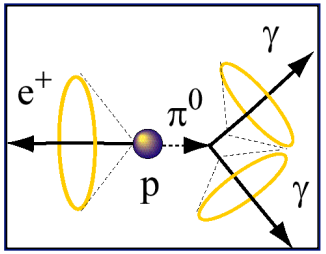
$\sin^2 2\theta_{23}=0.99$
↓
$\sin^2\theta_{23}=0.45$ or 0.55

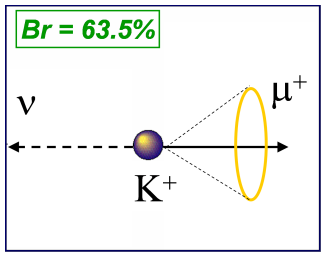


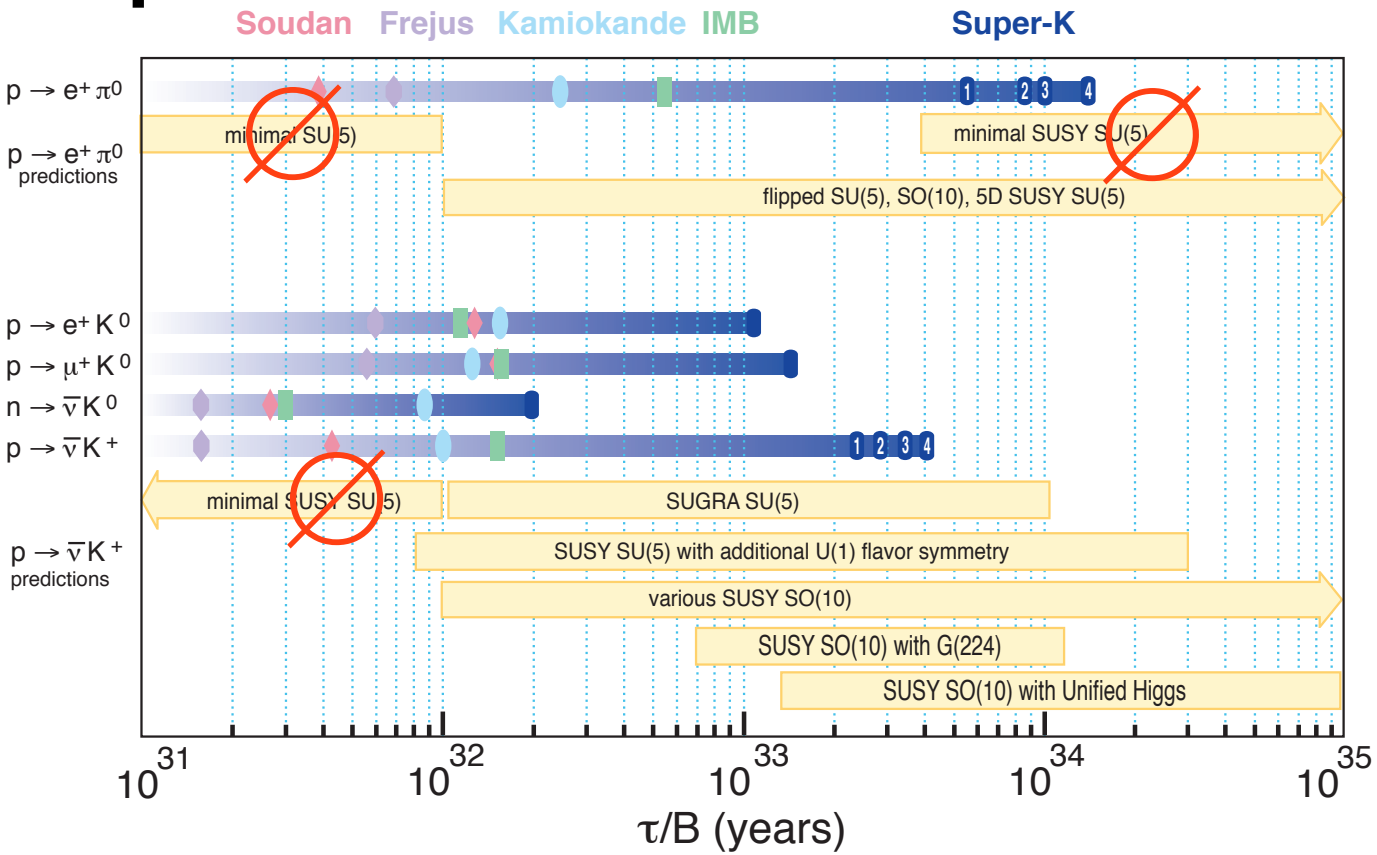


If $\sin^2 2\theta_{23}<0.99$, θ_{23} octant can be determined.

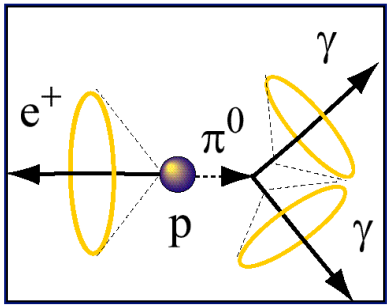
Experimental Limits







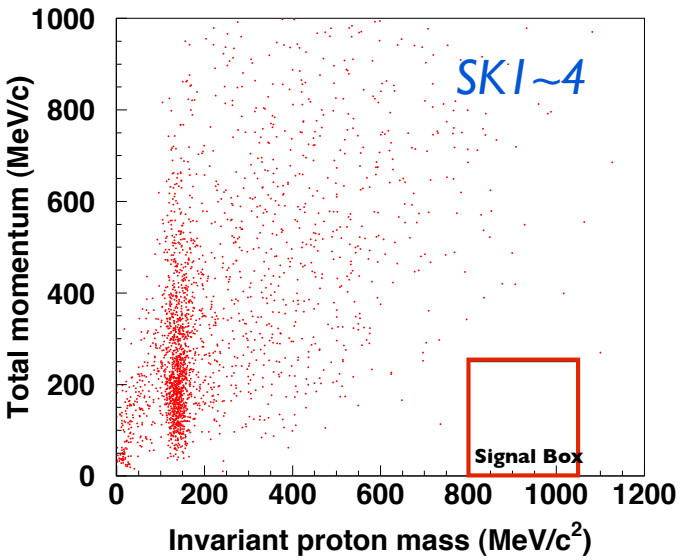
- Super-K gives most stringent limits for many decay modes.
  - $\tau(p \to e^+\pi^0) > 1.3\times10^{34}$years (90%C.L. by 220kton・yrs data)
  - $\tau(p \to \nu K^+) > 4.0\times10^{33}$years (90%C.L. by 220kton・yrs)
- No signal evidence has been found ⟹ giving constraints on models (GUTs)
  - Constraints on SUSY models (ex: R-parity conservation)
  - Exclude minimal *SU(5)* and minimal SUSY *SU(5) models*.

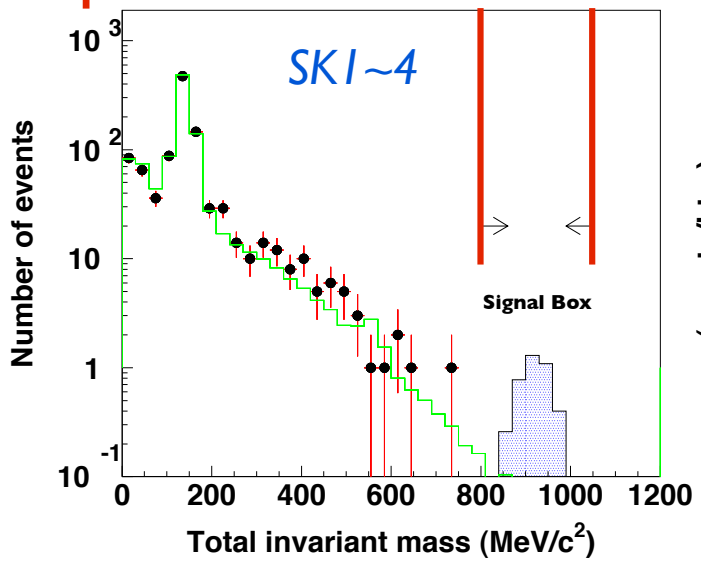


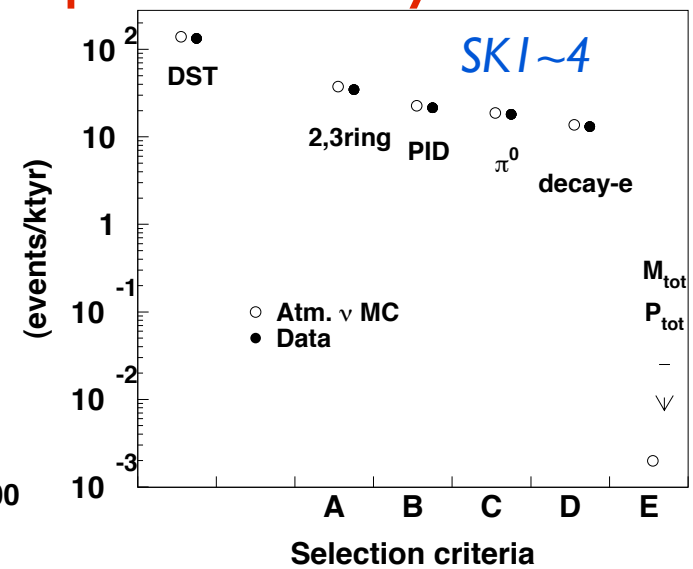
$p \rightarrow e^+ + \pi^0$ searches

Super-K cut
- 2 or 3 Cherenkov rings
- All rings are showering
- $85 < M_{\pi 0} < 185 MeV/c^2$ (3-ring)
- No decay electron
- $800 < M_{proton} < 1050$ MeV/c^2
  $P_{total} < 250$ MeV/c

Super-K data are well reproduced by BG MC.

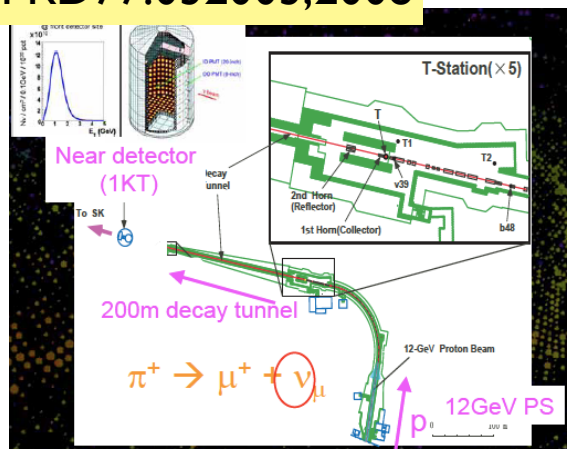






- detection efficiency = 45%
- atmospheric ν BG = 2.1±0.3(stat.)±0.8(syst.) (Mton×years)$^{-1}$
- $\tau_{proton}/Br > 1.3 \times 10^{34}$ years @ 90%CL

PRD77:032003,2008

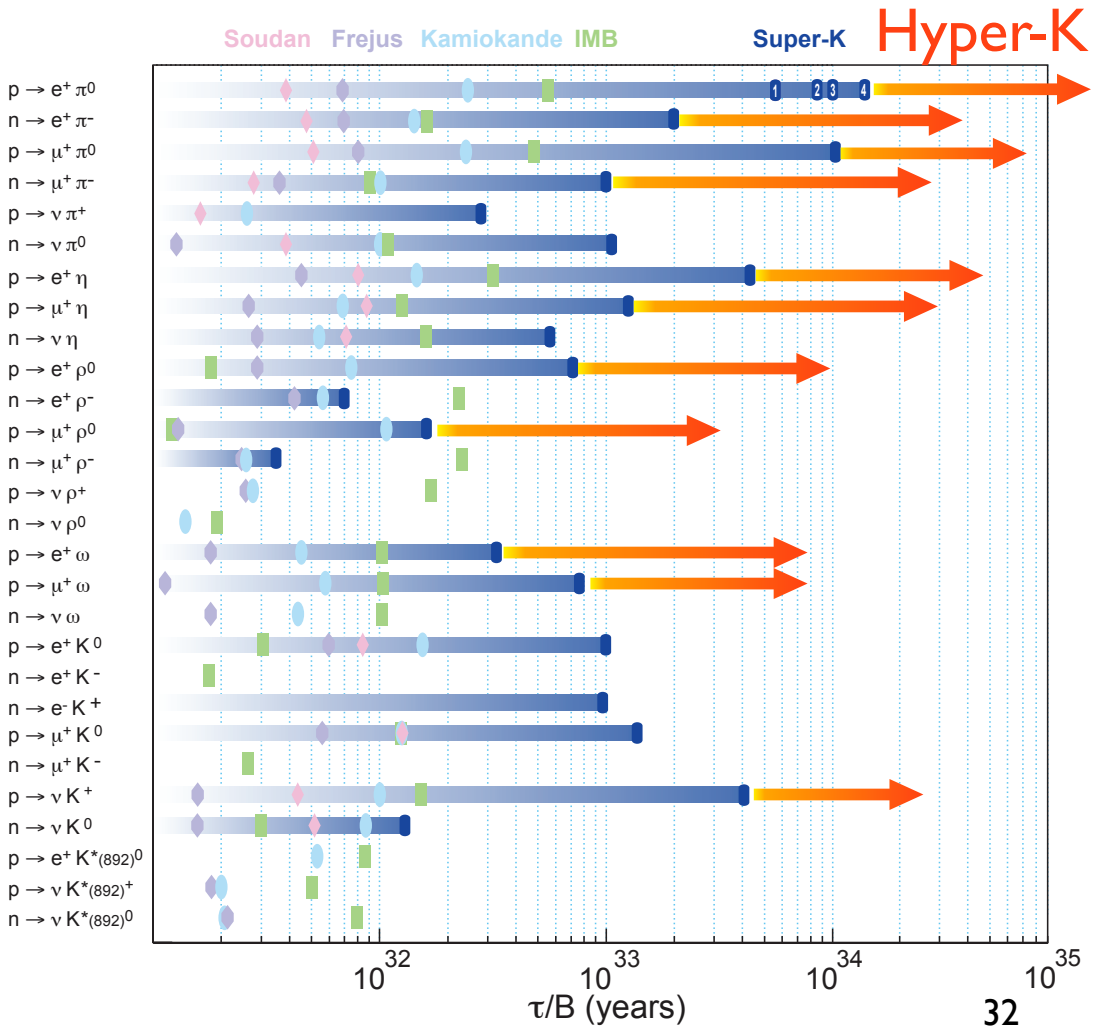


- BG measurement by accelerator ν (K2K)
  - BG=1.63+0.42/-0.33(stat.)+0.45/-0.51(syst.) (Mt×yrs)$^{-1}$ (Eν<3GeV)
  - Consistent w/ simulation 1.8±0.3(stat.)

Quality of next generation search is guaranteed.

Search for nucleon decays

- many models predicts branching ratio of $p \to e^+\eta$, $e^+\rho$, $e^+\omega$ are 10~20%
- Flipped SU(5) (Ellis) predicts $Br(p \to e^+\pi^0) \sim Br(p \to \mu^+\pi^0)$
- (B-L) violated mode, e.g. $|\Delta B|=2$.

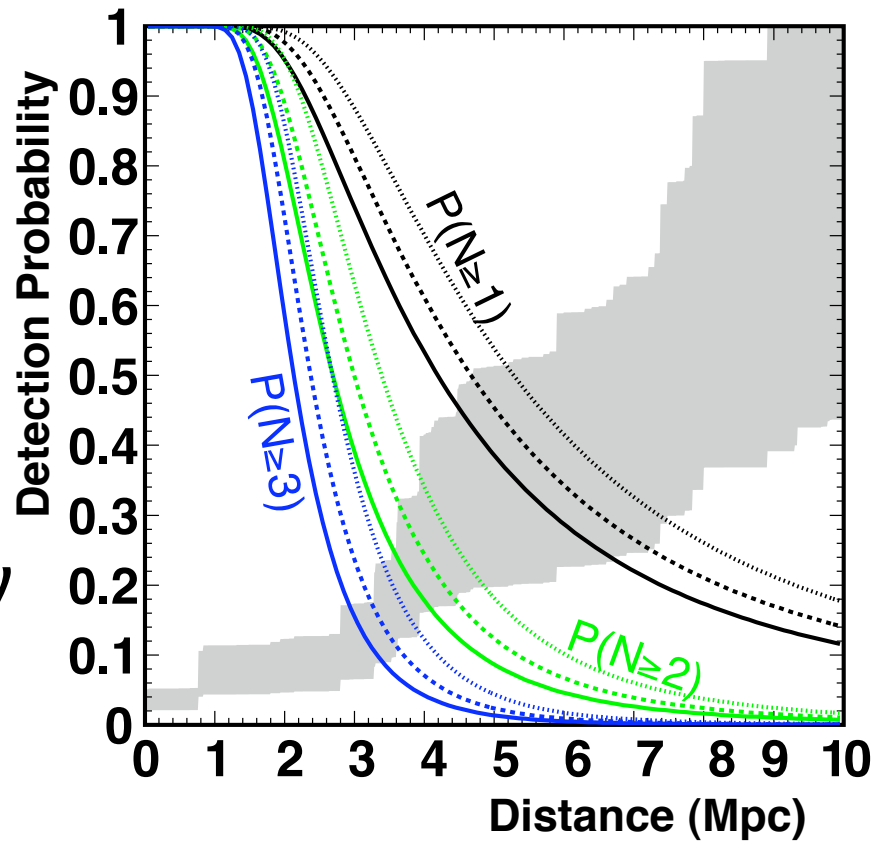


Hyper-K sensitivities

- $p \to e^+ + \pi^0$
  - $\tau_{proton}/Br > 1.3 \times 10^{35}$ years @90%CL
  - 5.6Mton×years (10 Hyper-K years)
- $p,n \to (e^+,\mu^+)+(\pi,\rho,\omega,\eta)$
  - $O(10^{34\sim35})$years
- *SUSY favored* $p \to \nu + K^+$
  - 2.5×10^{34} years
- K^0 modes, $\nu\pi^0$, $\nu\pi^+$ possible
- Other various decay modes.
  - (B-L) violated modes
  - radiative decays $p \to e^+\gamma$, $\mu^+\gamma$
  - neutron-antineutron振動 ($|\Delta B|=2$)
  - di-nucleon decays ($|\Delta B|=2$)
    - $pp \to XX$..., $nn \to XX$...

Other topics

- ν burst from Supernova
  - up to distance of ~Mpc
- relic SN ν (with Gd?)
- precise measurement of solar ν
- ν from WIMP, GRB, solar flare..
- Geophysics (ν tomography of Earth)



Hyper-K WG,
arXiv:1109.3262 [hep-ex]

Summary

- Hyper-Kamiokande will cover rich physics topics.
  - discovery reach for leptonic CP violation.
  - good chance to discriminate hierarchy and θ_{23} octant.
  - ~10 times better sensitivity for nucleon decays.
  - various astrophysical objects.

- We made the baseline design
- Design optimization & development works (PMT etc) are going on
- We are starting forming an international organization

supplements