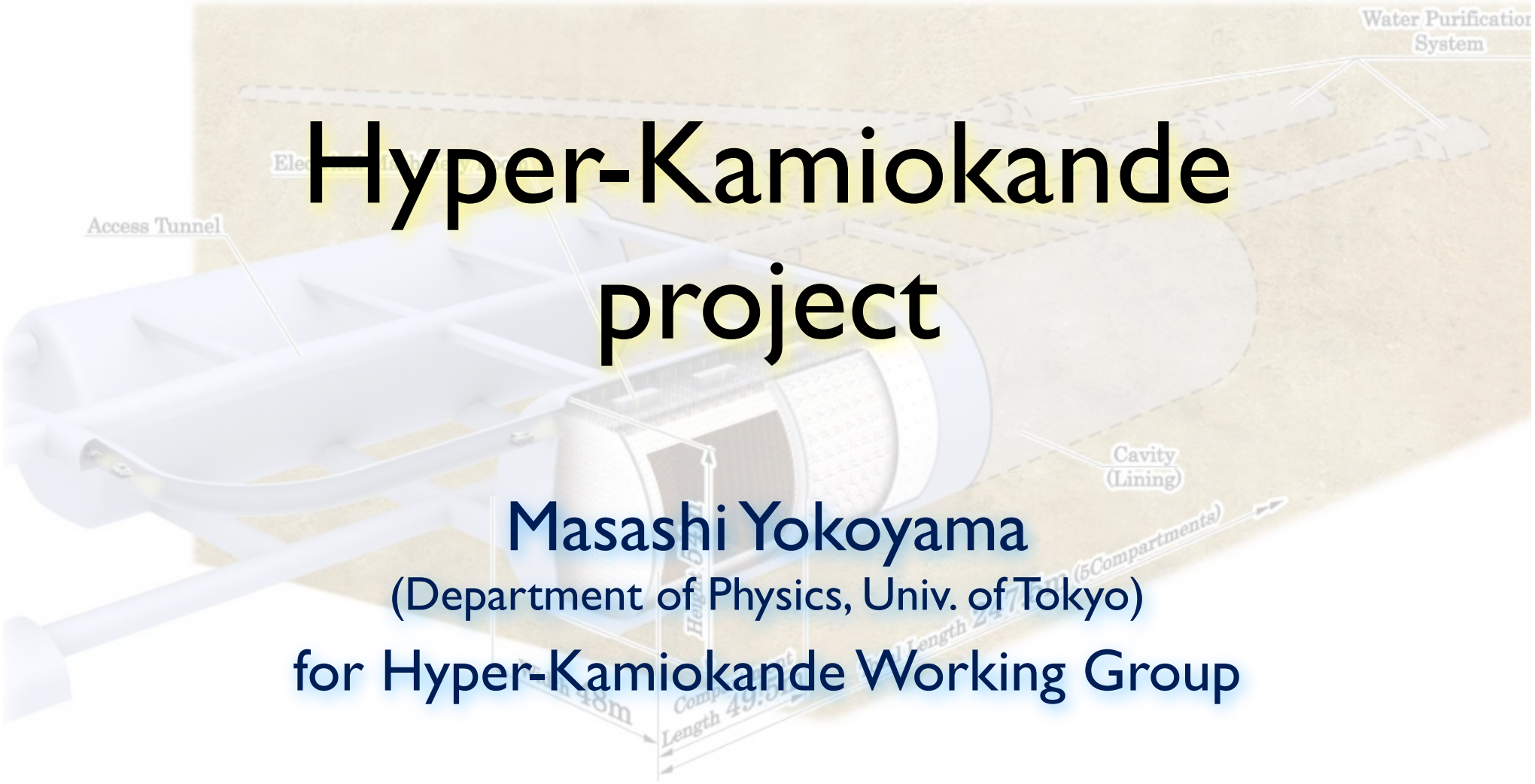
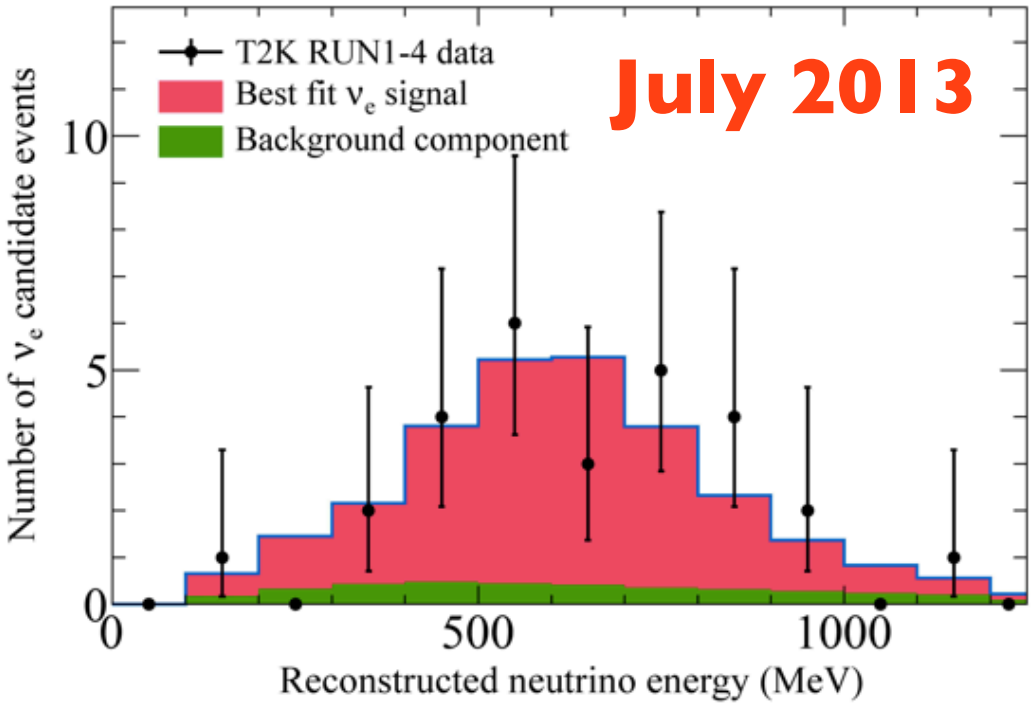


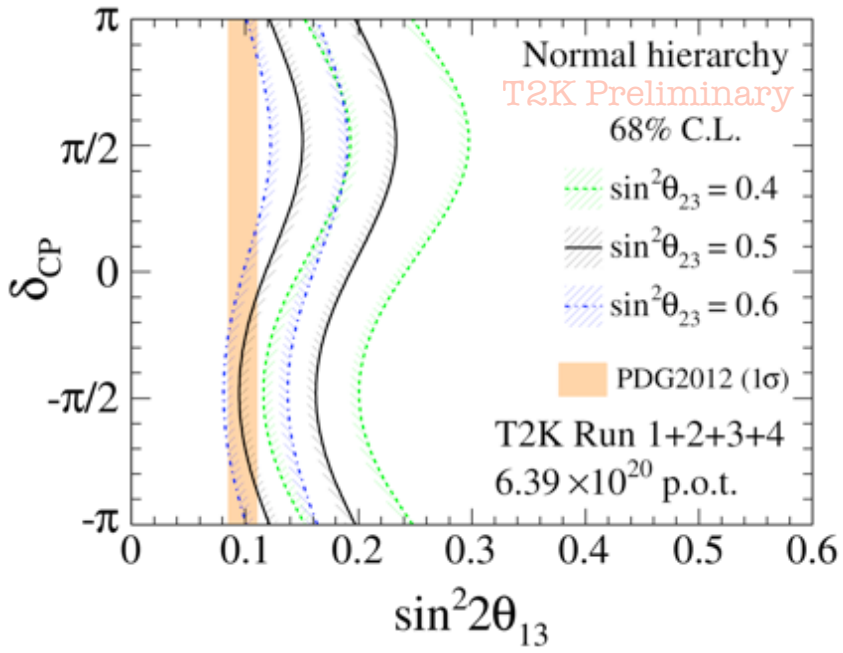
Hyper-Kamiokande project

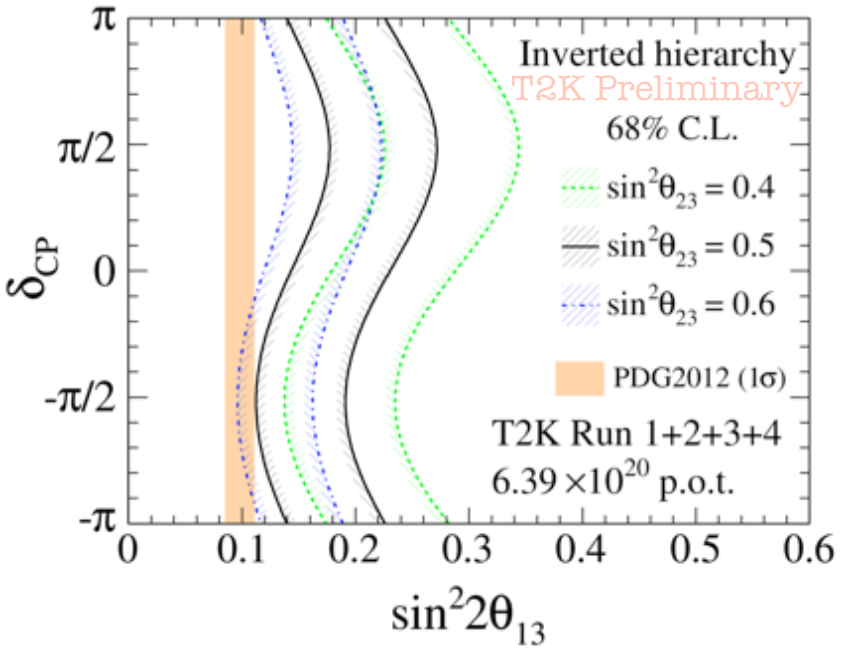
Masashi Yokoyama
(Department of Physics, Univ. of Tokyo)
for Hyper-Kamiokande Working Group

16th Lomonosov Conference on Elementary Particle physics
Moscow State University, Aug. 22-28, 2013

Observation of ν_e appearance by T2K







Opened a clear way to the next step

CP asymmetry,
Mass hierarchy,
θ_{23} octant

It's time for the next step!!

- Current generation experiments (T2K, NOvA)
  - Can be sensitive for CPV at ~2σ level
- Next generation experiments necessary for definitive measurement
  - Neutrino experiments always statistics hungry
    → larger detectors
- Such detector will also enable rich physics program, if designed properly
  - Proton decay
  - Astrophysical neutrino observation

Hyper-Kamiokande Detector

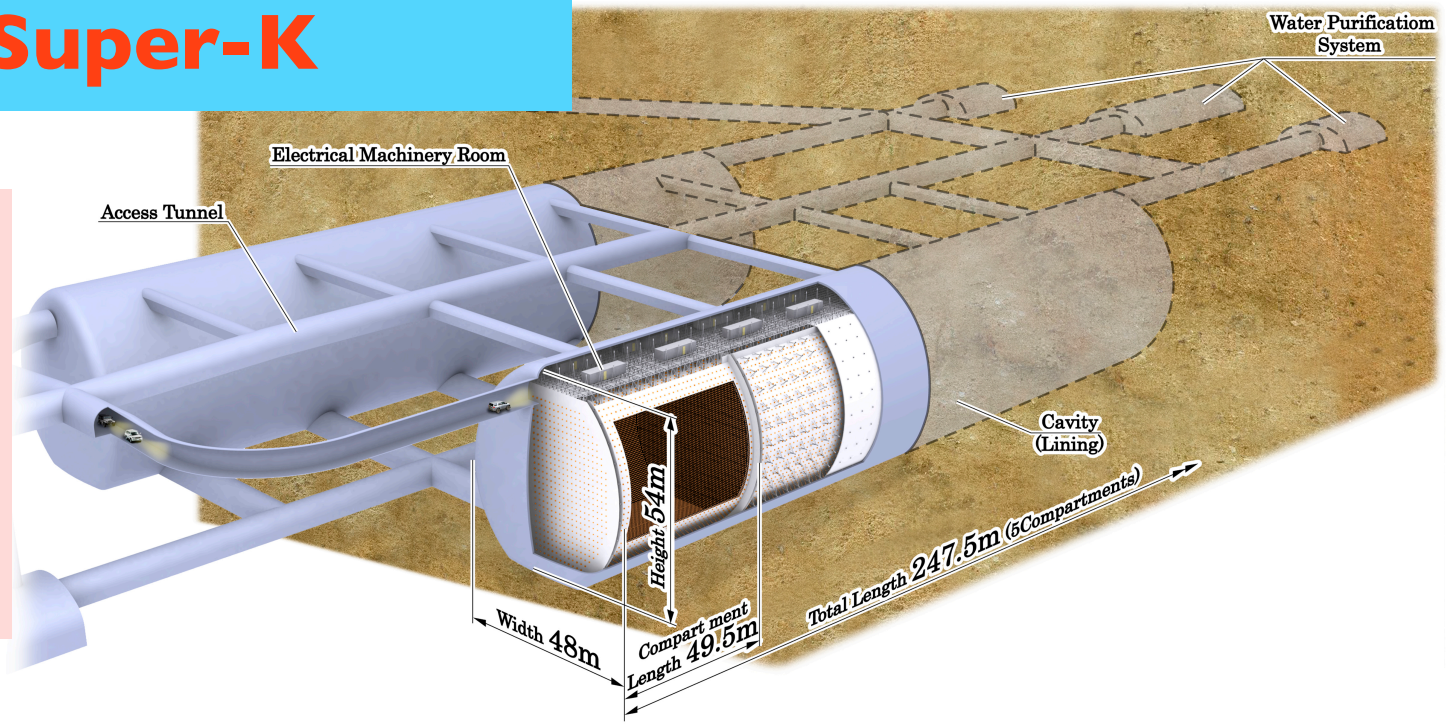
Total volume:	0.99 Mton
Inner volume:	0.74 Mton
Outer volume:	0.2 Mton
Fiducial volume:	0.56 Mton

(0.056Mton × 10 compartments)

x25 of Super-K

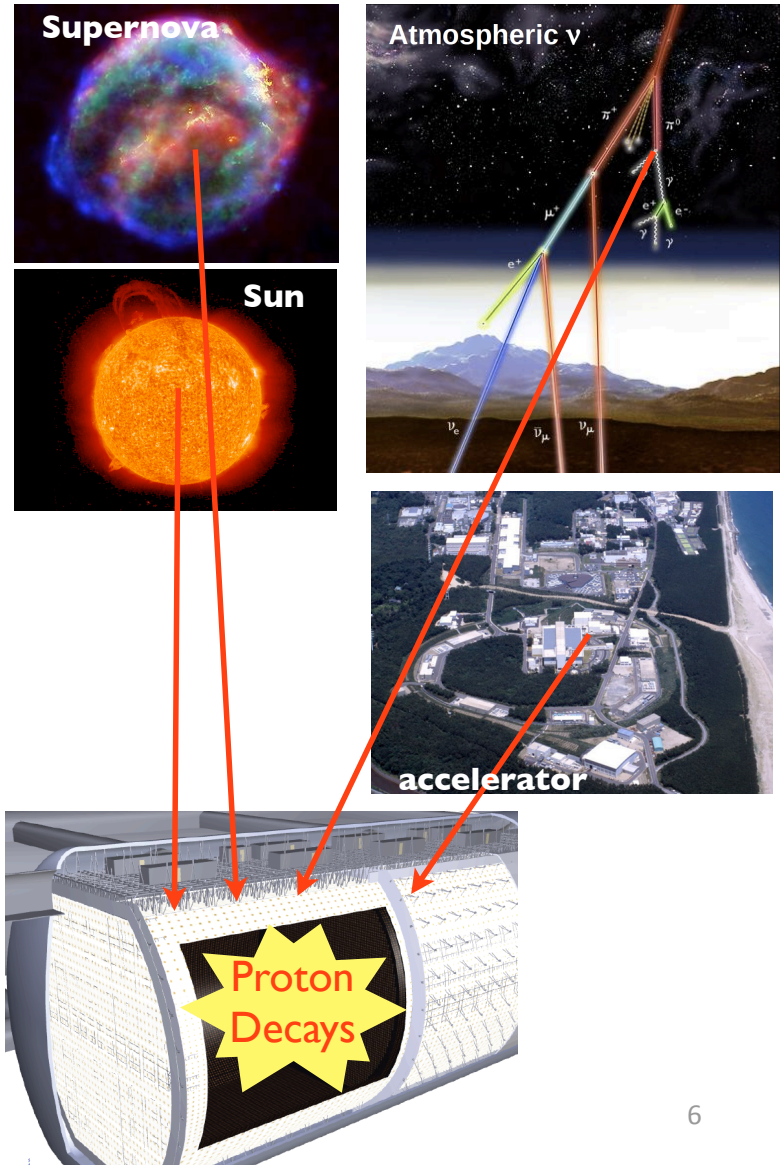
LoI by Hyper-K WG, arXiv:1109.3262 [hep-ex]

- 99,000 20" PMT for inner-det. (20% coverage)
- 25,000 8" PMT for outr-det.



Strong and broad science program

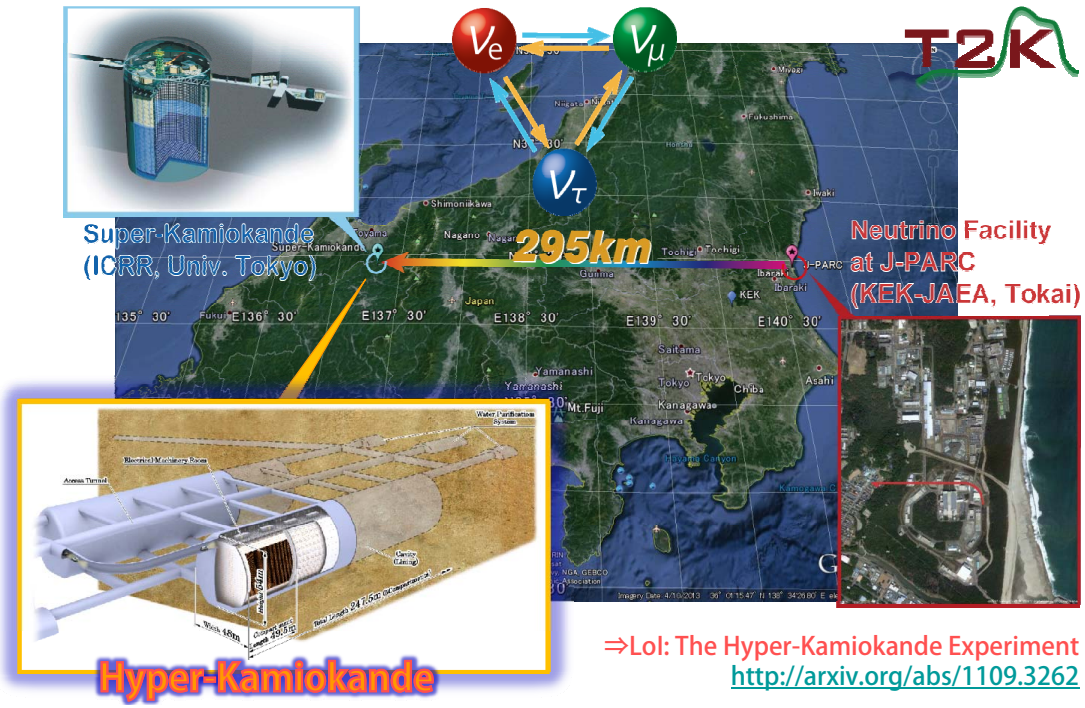
- ν oscillation
  - Accelerator ν beam
  - Atmospheric ν
  - Solar ν
- Nucleon decay
- Astrophysics
  - Supernova burst ν
  - SN relic ν
  - Monitoring of Sun
  - WIMP, GRB,
- Geophysics
- Maybe more (unexpected)



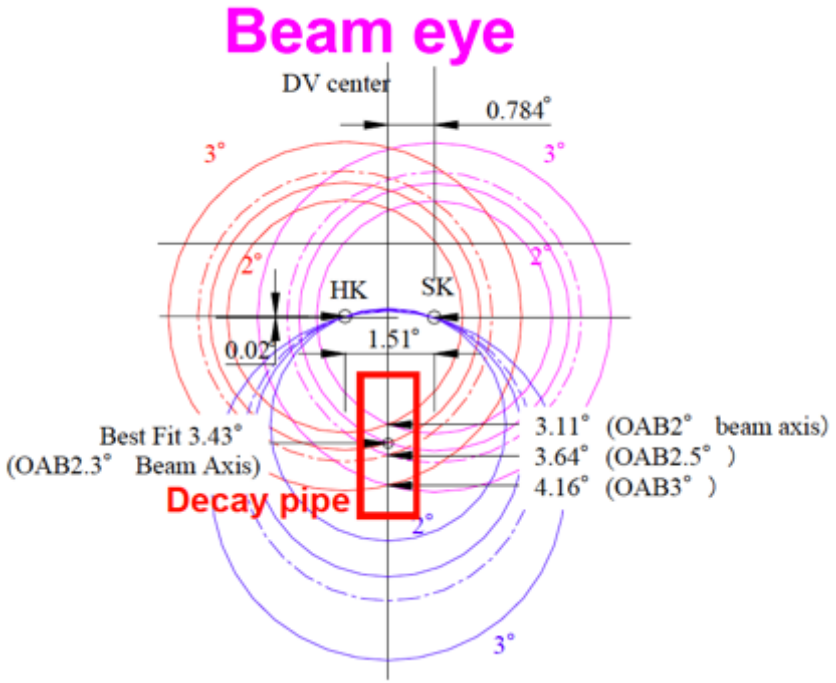
6

Accelerator ν beam

- Extension of T2K:
  - Same baseline (295km) and beam energy (~0.6GeV)
  - Off-axis beam + gigantic water Cherenkov detector
- "short" baseline → less matter effect
  - Focus on *CP* measurement (↔ LBNE/LBNO)



⇒LoI: The Hyper-Kamiokande Experiment
http://arxiv.org/abs/1109.3262



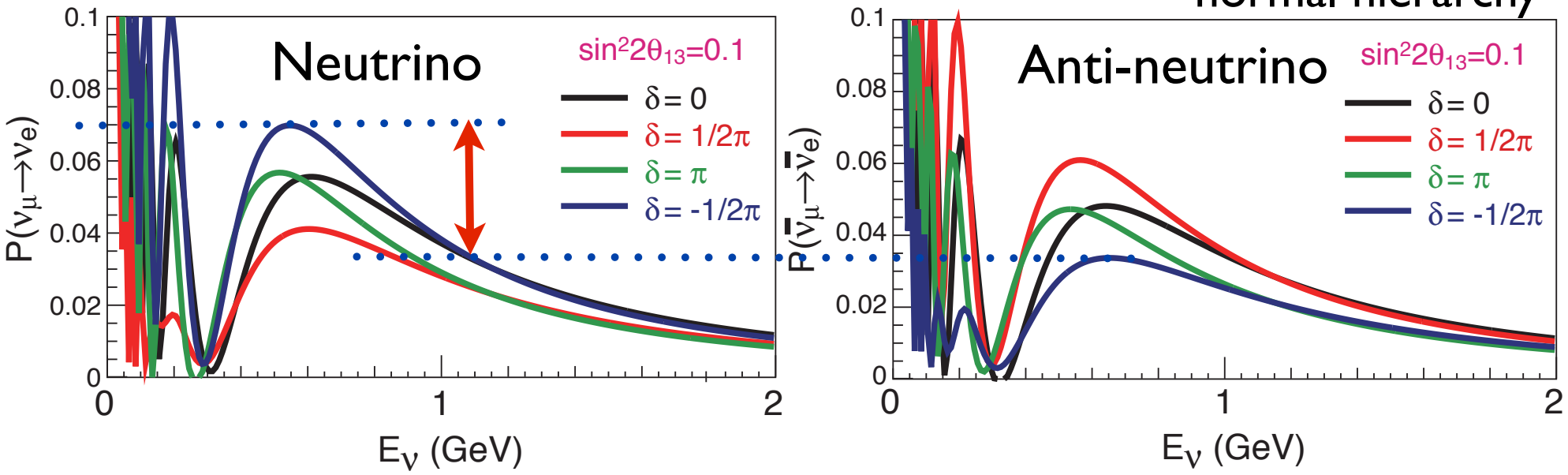
≥1MW beam from J-PARC

J-PARC ν beamline designed to be compatible with HK!

Measurement of *CP* asymmetry

$P(\nu_\mu \rightarrow \nu_e)$: ν_e appearance probability

for 295km baseline,
normal hierarchy

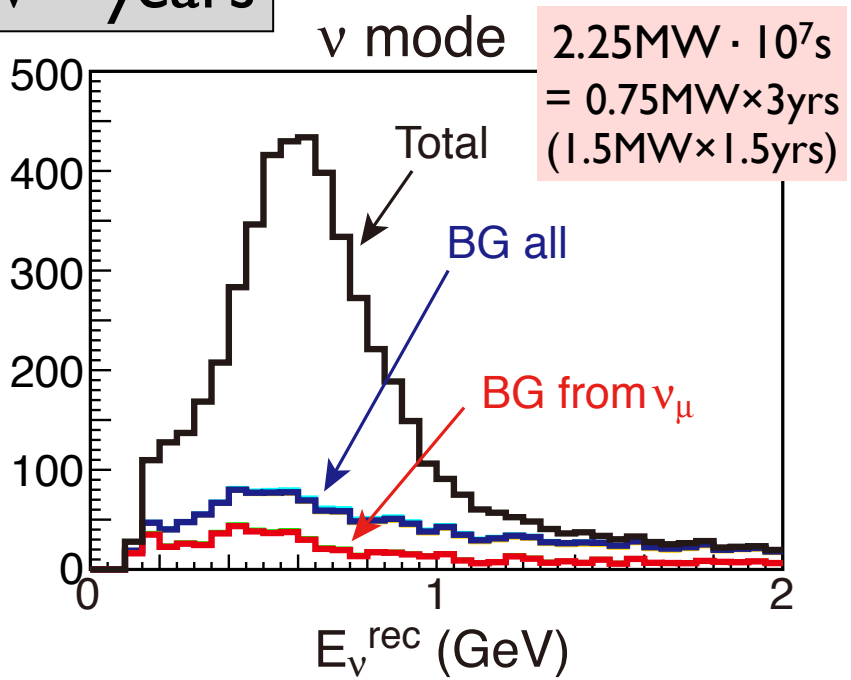


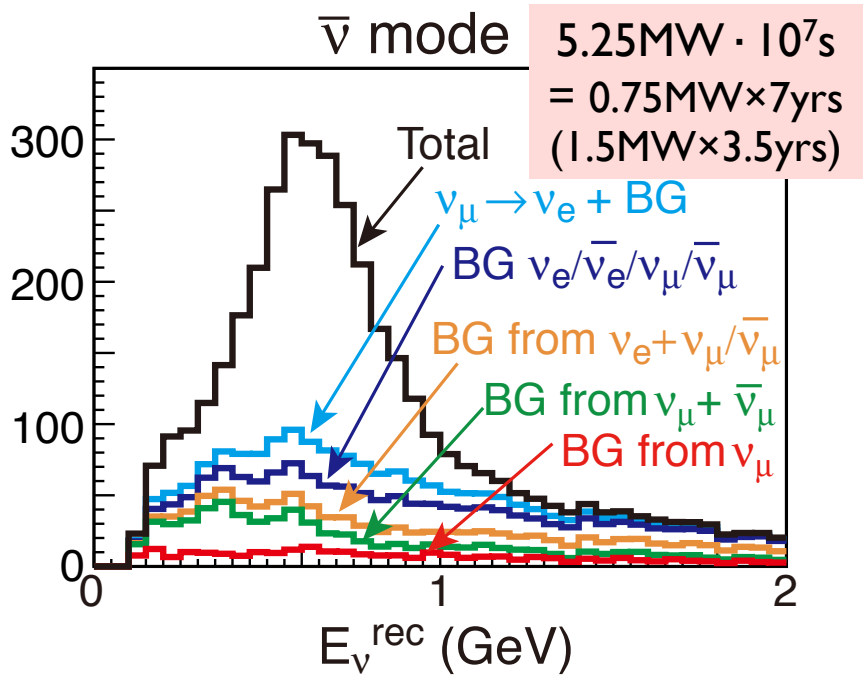
- Comparison of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
  - Max. ~±25% change from δ=0 case
  - Sensitive to exotic (non-MNS) CPV source

ν_e candidate reconstructed energy distributions

7.5MW · years

$\sin^2 2\theta_{13}=0.1, \delta=0$, normal MH



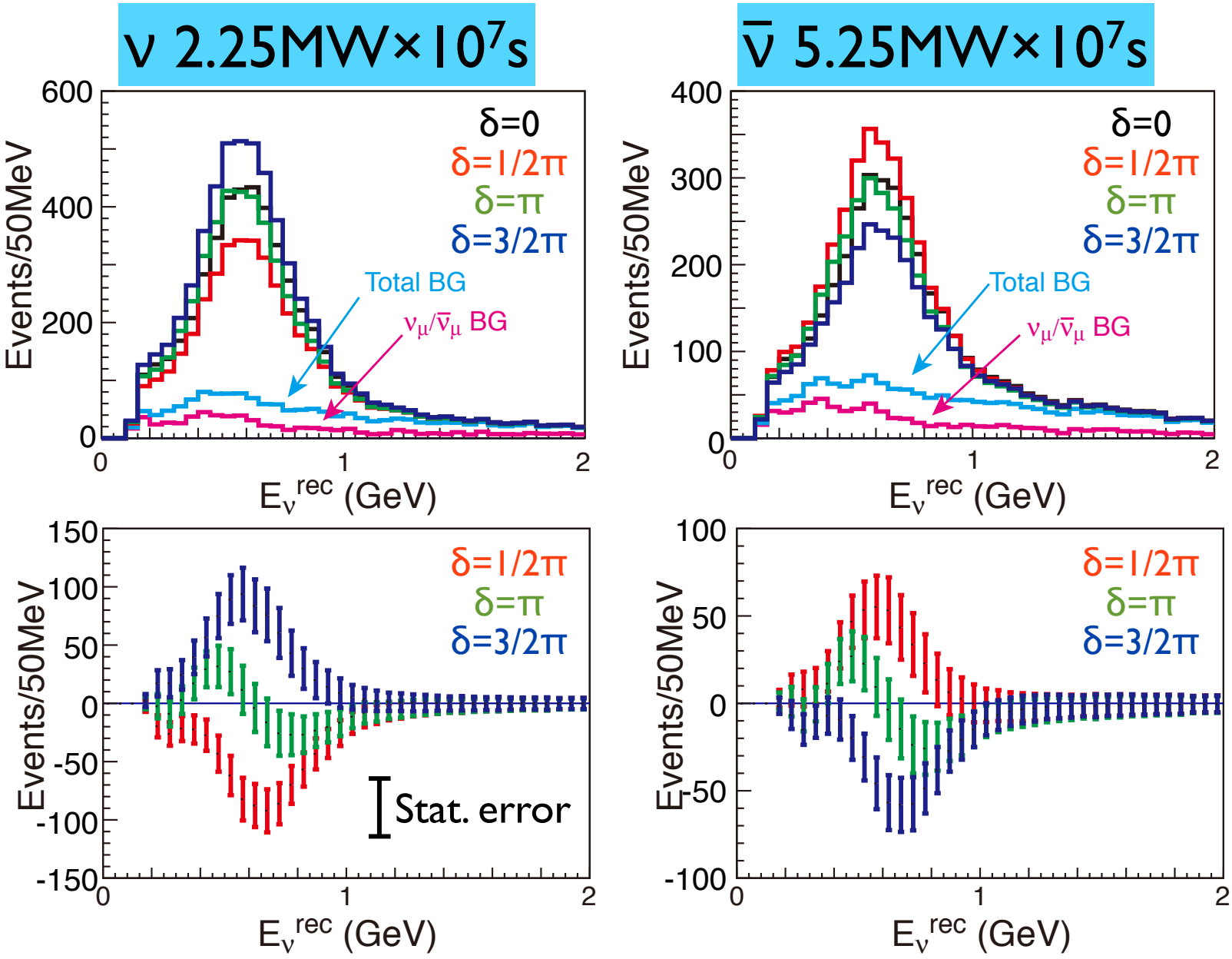


	Signal ($\nu_\mu \to \nu_e$ CC)	Wrong sign appearance	$\nu_\mu/\bar{\nu}_\mu$ CC	beam $\nu_e/\bar{\nu}_e$ contamination	NC
ν (2.25MW · 10^7s)	3,560	46	35	880	649
$\bar{\nu}$ (5.25MW · 10^7s)	1,959	380	23	878	678

※Further BG suppression expected with reconstruction improvement

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

Difference from δ=0 νe candidates



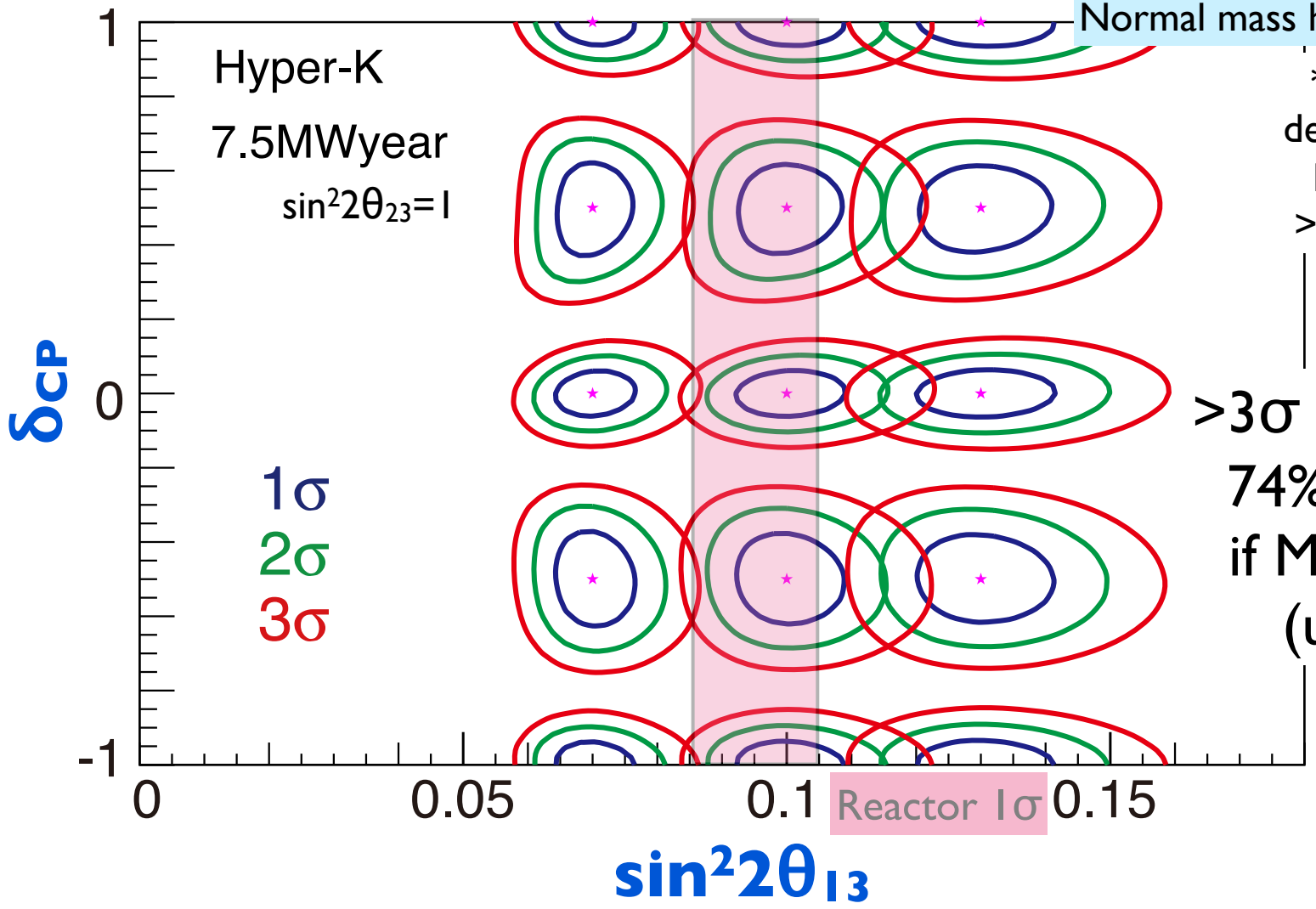
Sensitive to all values of δ with numbers + shape

Expected sensitivity to CP asymmetry

7.5MW・years

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

Normal mass hierarchy (known*)

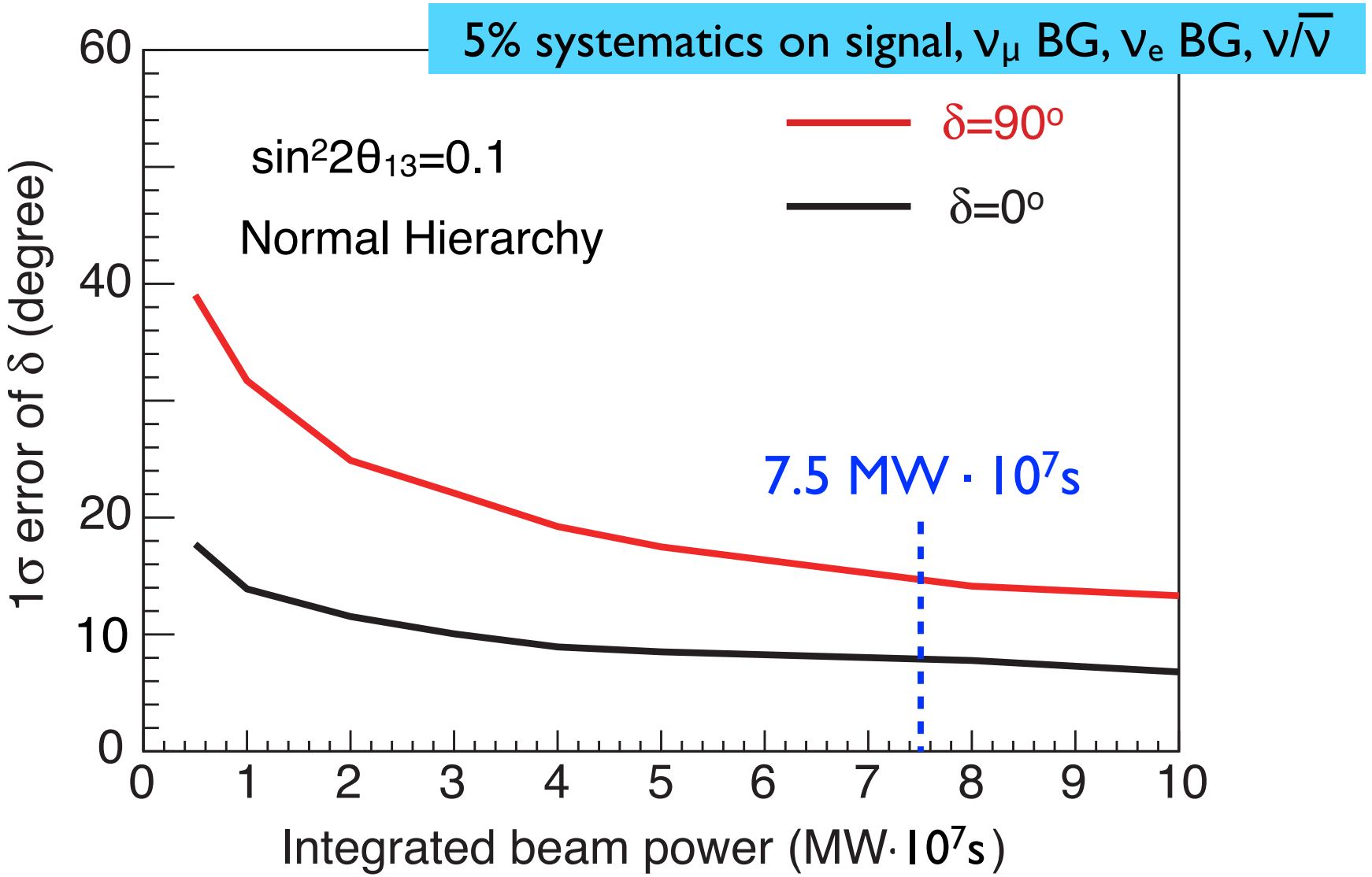


*Mass hierarchy determination with Hyper-K atm. ν: >3σ in 5-10 years

>3σ discovery for 74% (55%) of δ if MH is known (unknown)

Excellent sensitivity for currently allowed values

Expected uncertainty of δ (1σ)



<20° (δ=90°), <10° (δ=0°)

Atmospheric neutrinos

ν_e appearance prob. in 3 flavor oscillation / no oscillation

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

r:μ/e flux ratio
P_2: νe→νx prob. in matter
$R_2=\mathrm{Re}(A^*_{ee}A_{e\mu})$, $I_2=\mathrm{Im}(A^*_{ee}A_{e\mu})$

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

Matter Interference, δ

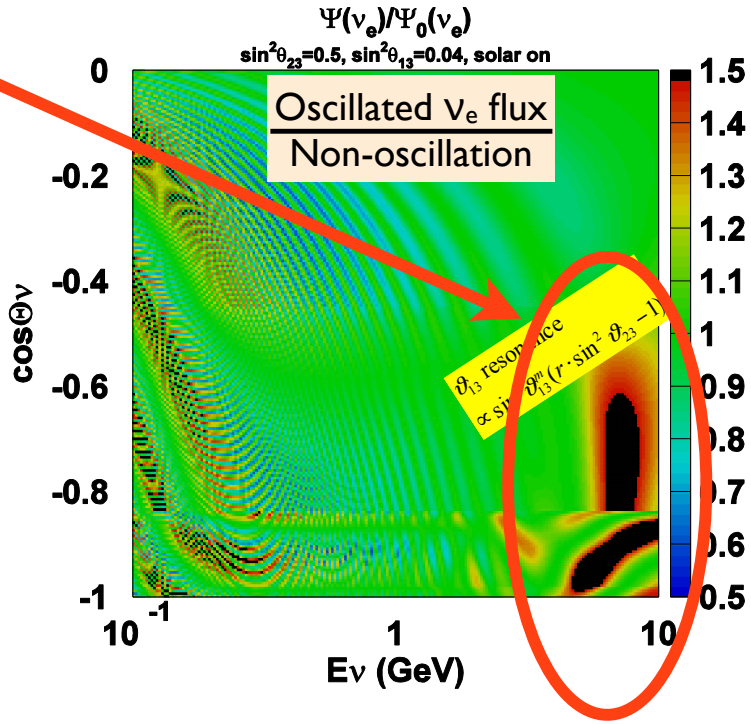
$$+2\sin^2\tilde{\theta}_{13} \cdot (r \cdot \sin^2\theta_{23} - 1)$$

$\nu_\mu \rightarrow \nu_e$ appearance resonance in earth's core
either ν or $\bar{\nu}$ depending on mass hierarchy

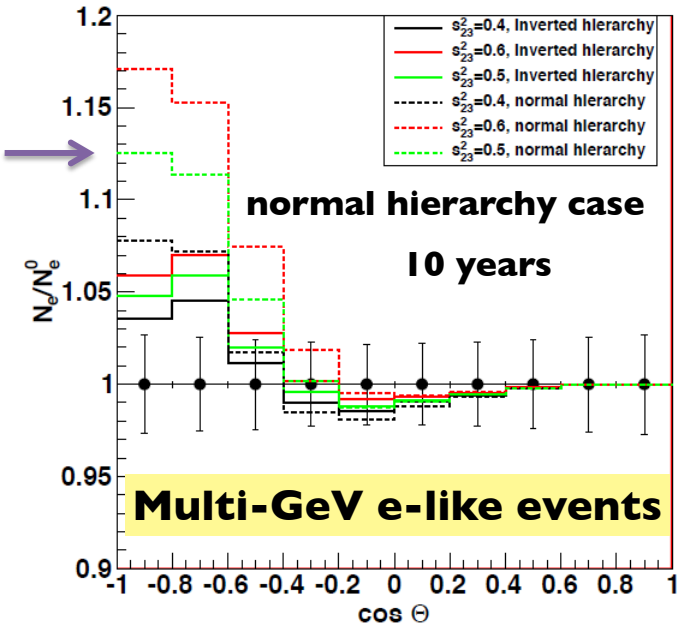
Sensitive to

- Mass hierarchy
- θ_{23} octant
- CP asymmetry

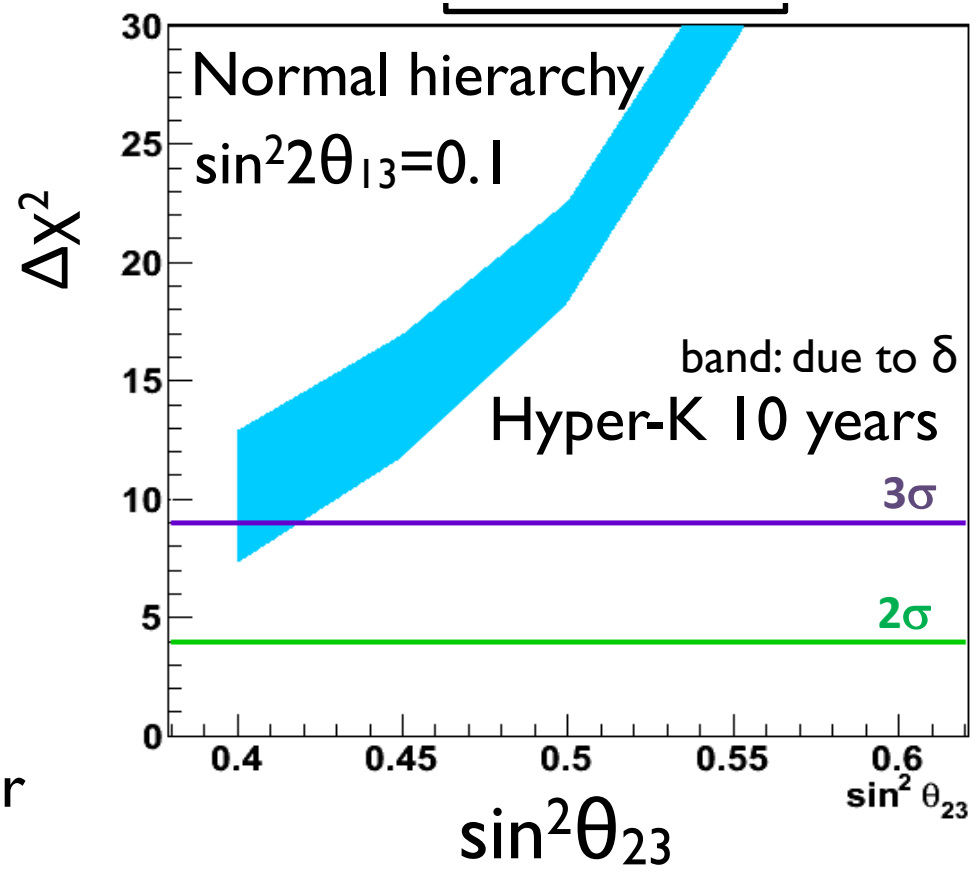
larger θ_{13} gives better sensitivity



Mass hierarchy determination with atmospheric neutrinos

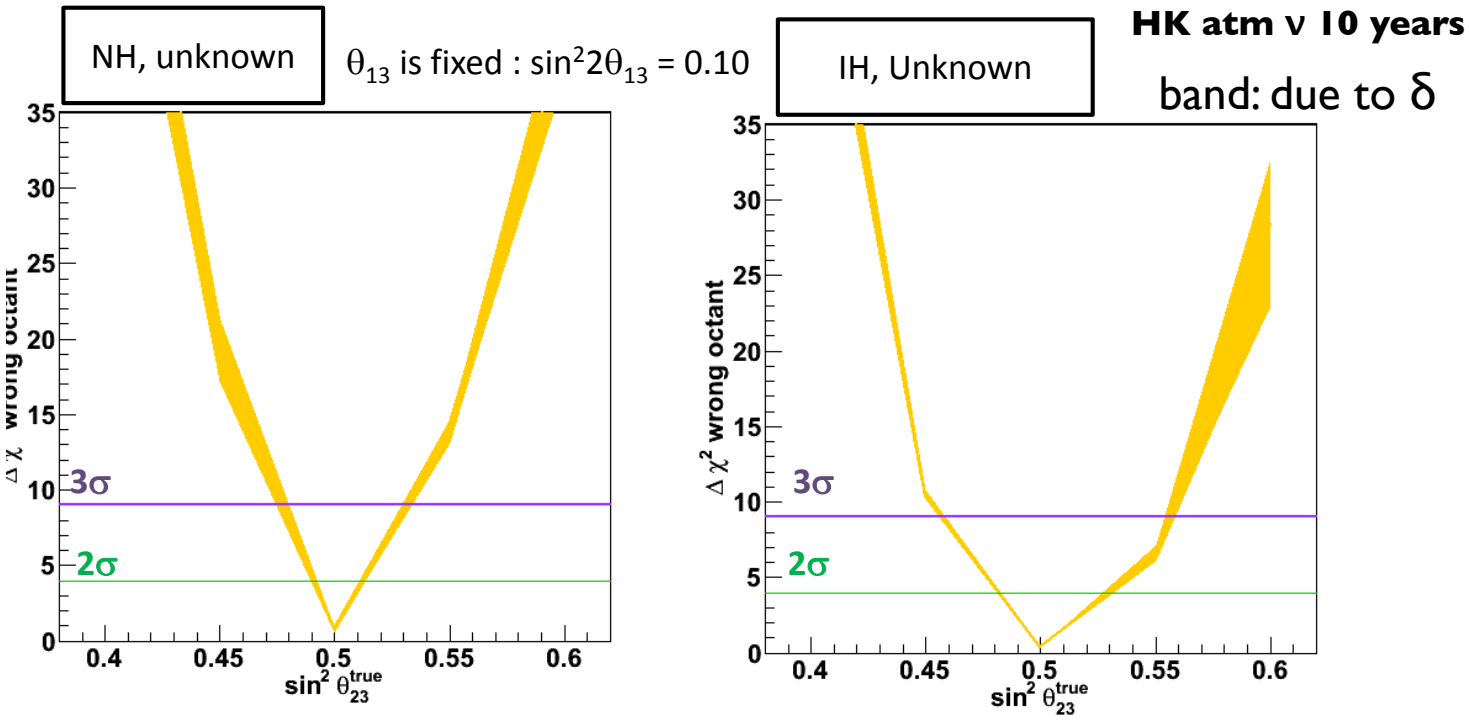


MSW effect in Earth's core
→ resonance effect on either
ν or anti-ν



3σ determination with <10 year observation
(better sensitivity depending on the value of θ_{23})

θ_{23} octant determination

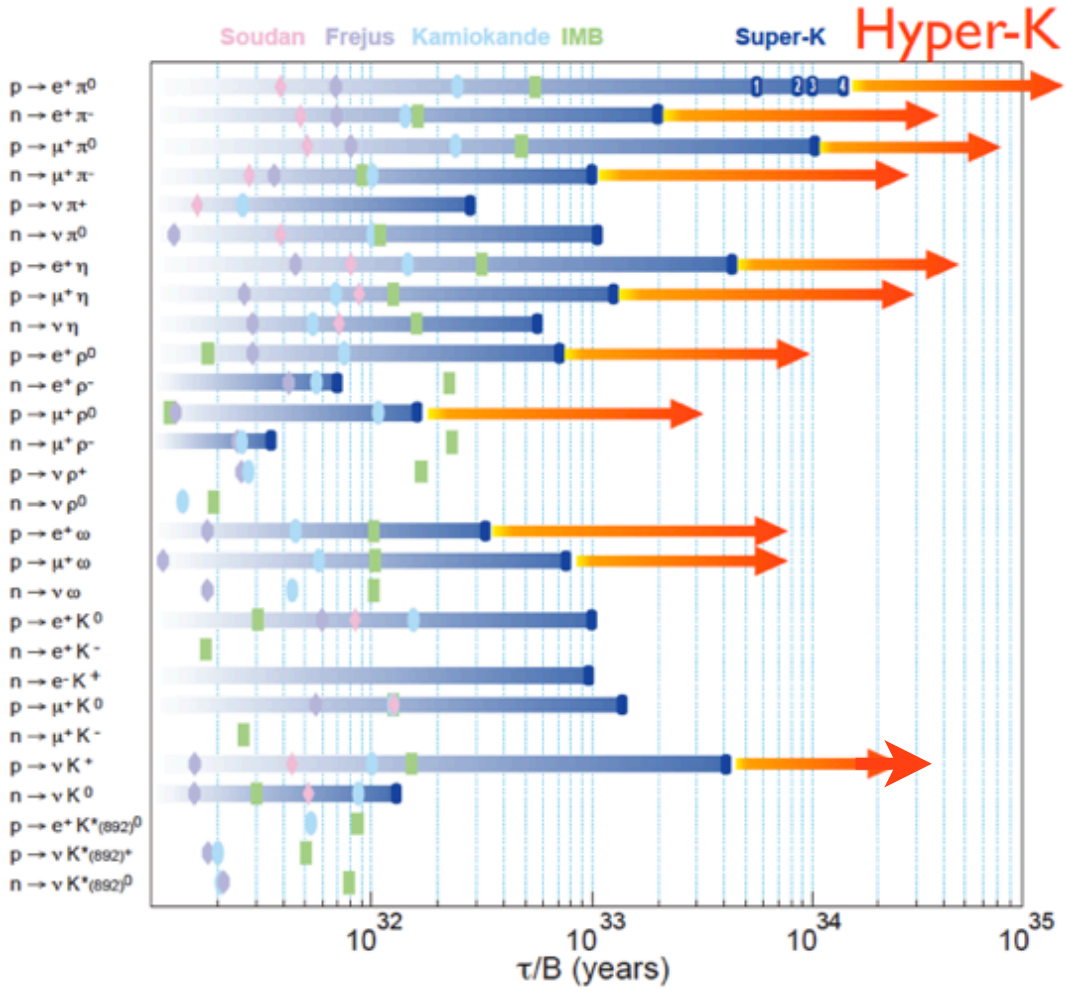


>3σ discrimination
for $\sin^2\theta_{23}<0.47(0.45)$ or $\sin^2\theta_{23}>0.53(0.0.56)$
for normal (inverted) MH

Complementary measurements to accelerator ν
Combined analysis of acc + atm ν will enhance capability

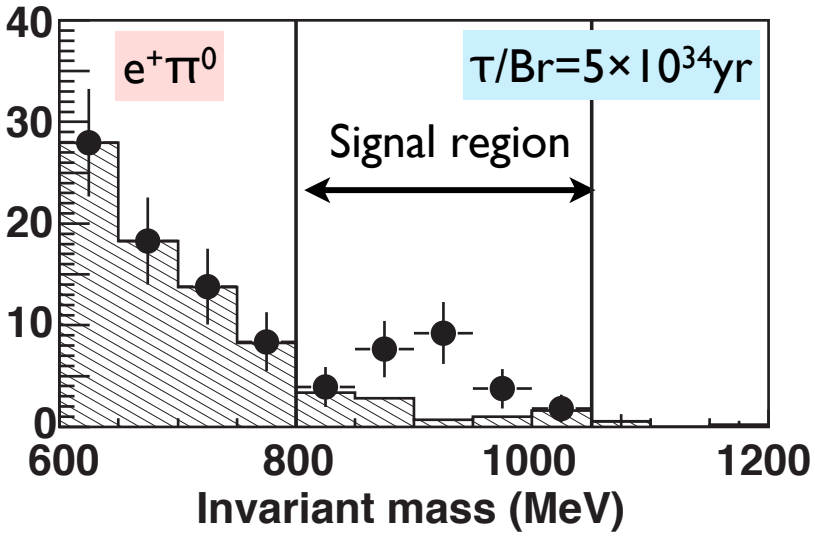
Proton decay sensitivity

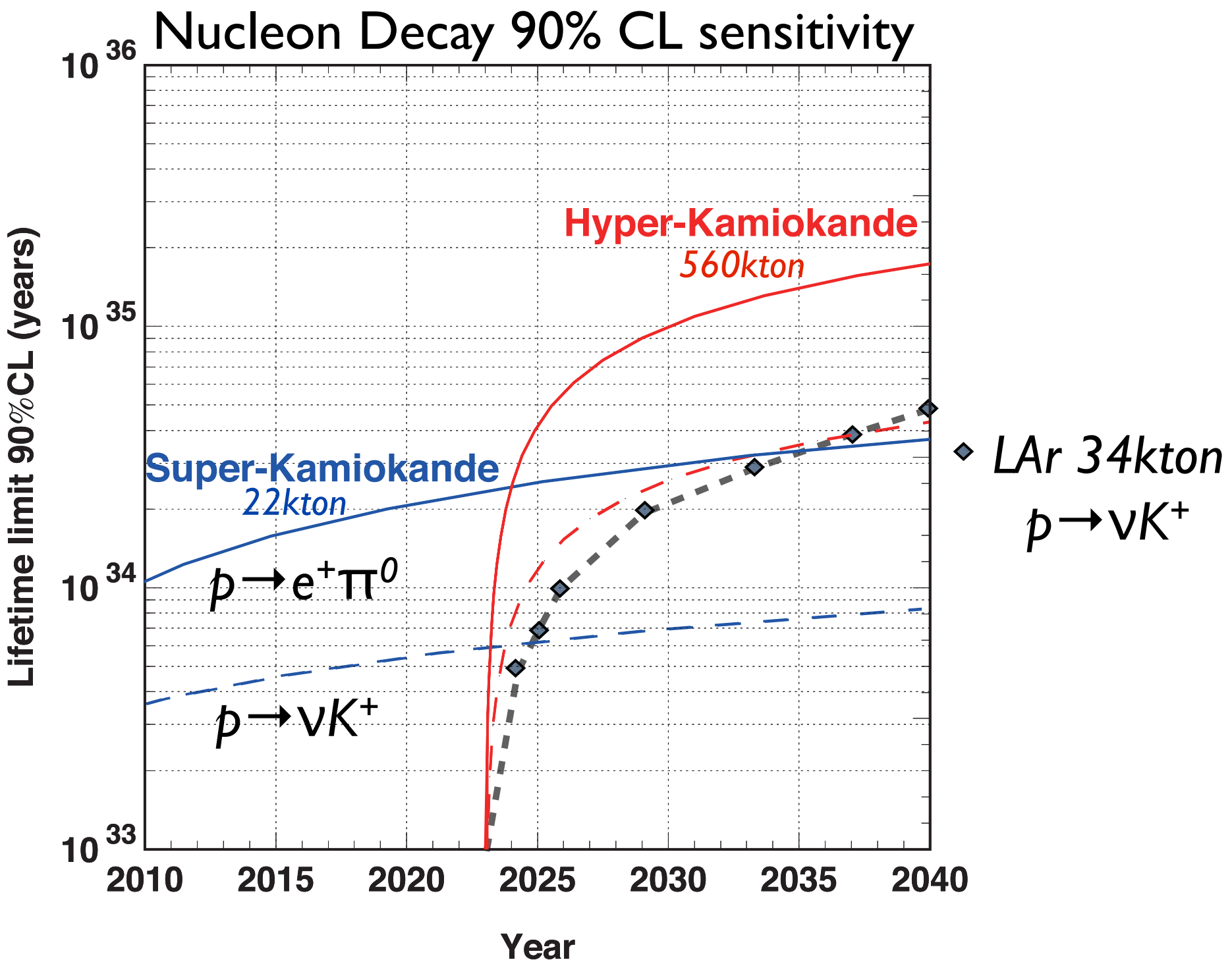
~10 times better sensitivity than current Super-K limits!



- $p \to e^+\pi^0$:
  - 1.3×10^{35}yrs (90%CL)
  - 5.7×10^{34}yrs (3σ)
- $p \to \bar{\nu}K^+$:
  - 3.2×10^{34}yrs (90%CL)
  - 1.2×10^{34}yrs (3σ)

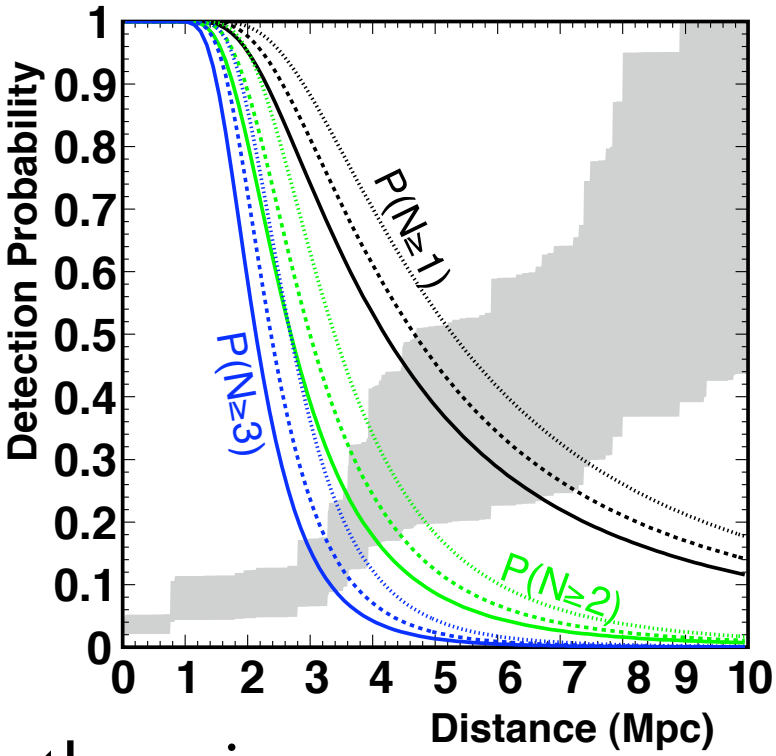
>3σ possible for lifetime above current SK limits




Nucleon Decay 90% CL sensitivity
Lifetime limit 90%CL (years)
10 36
10 35
10 34
10 33
2010
2015
2020
2025
2030
2035
2040
Year
Hyper-Kamiokande
560kton
Super-Kamiokande
22kton
p → e+π0
p → νK+
LAr 34kton
p → νK+

Neutrino astrophysics

- **Supernova burst neutrino**
  - >50% efficiency with >3 multiplicity for <2Mpc SN (~1/10yrs expected)
  - Huge statistics if SN in our Galaxy
    - ~250k events @ 10kpc

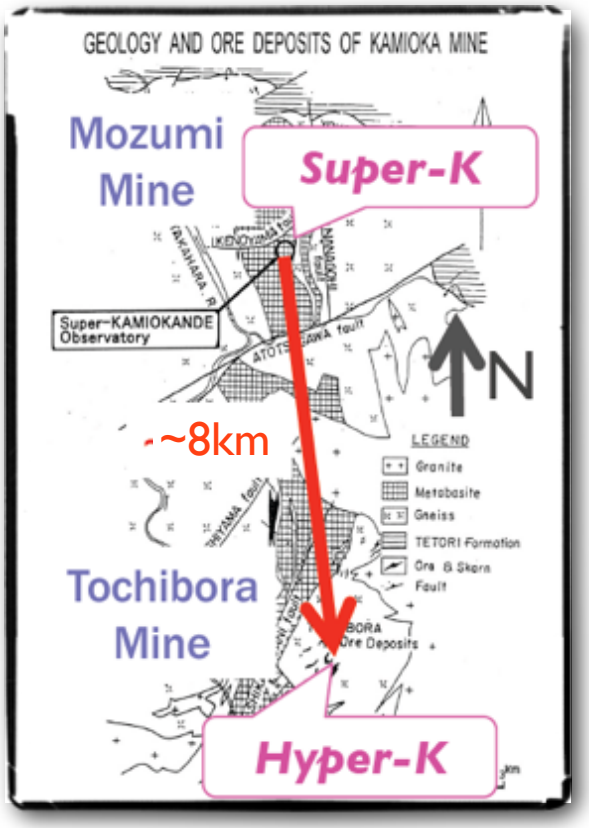


- **Supernova relic neutrino**
  - History of heavy element synthesis in the universe
- Precision measurements of solar neutrino
  - Spectrum upturn, day/night asymmetry
- Indirect WIMP Search

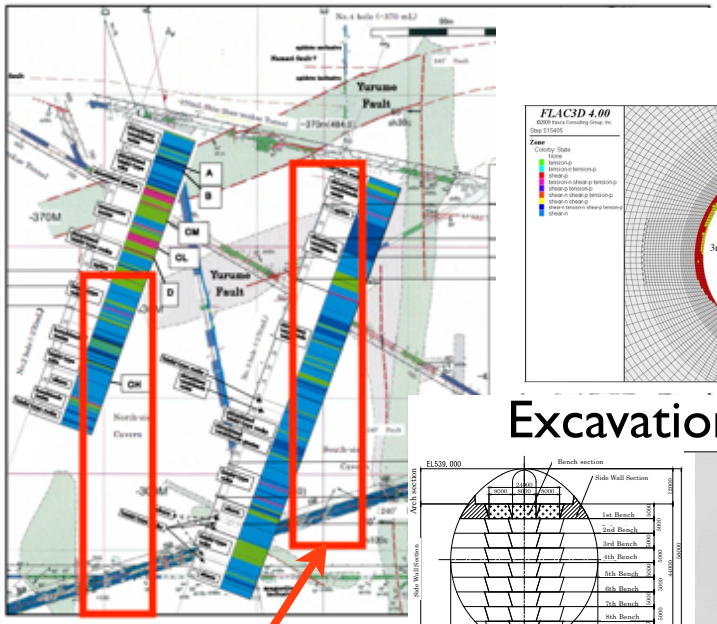
Status of project

Site and Cavern

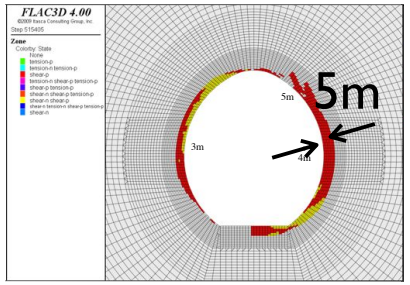
Candidate site:
~8km south of SK

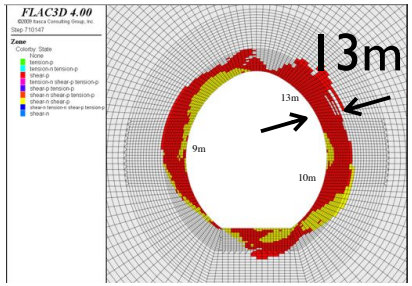


Rock mass characterization

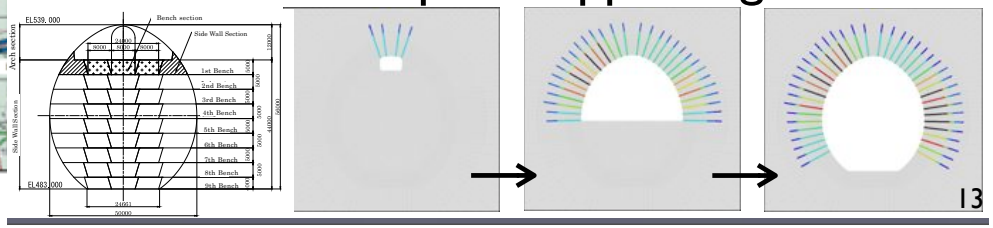


Cavern stability





Excavation steps & supporting method

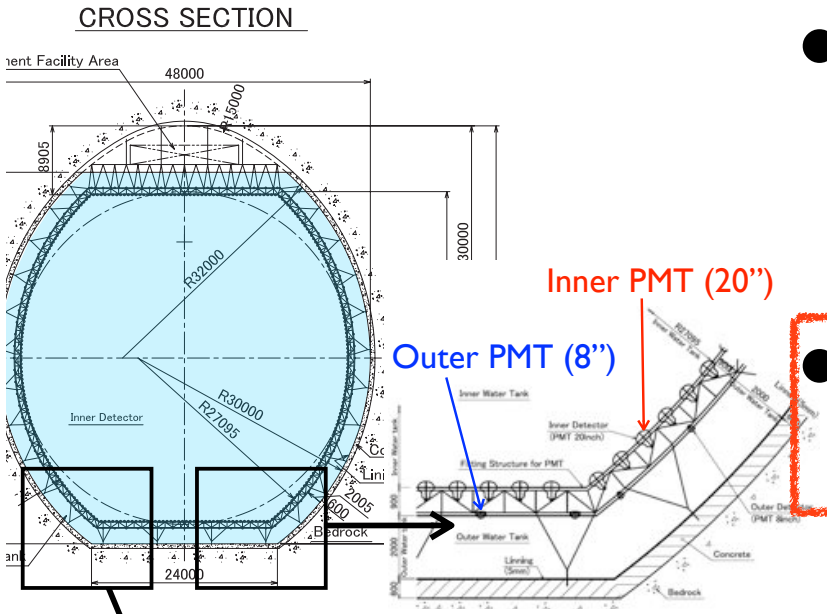


HK tank location

Cavity design studied based on the in-situ measurements of rock quality and stress

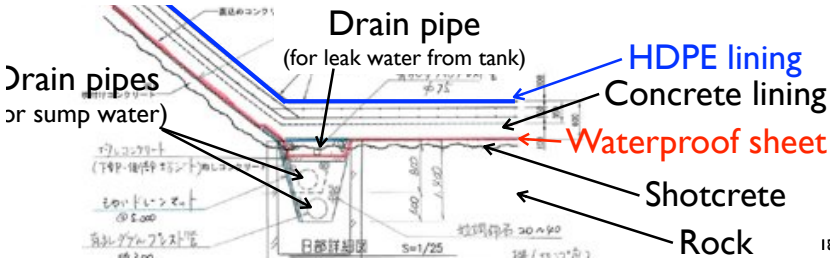
HK caverns can be constructed with existing technology.

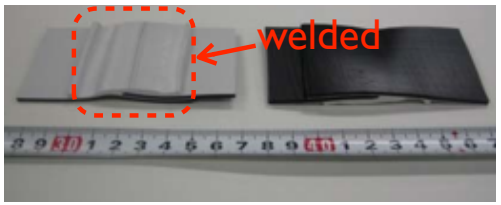
Tank and sensor support



- Baseline designs of the water containment system and photo-sensor support are ready
- Build a prototype detector (1kt)
  - Funding request approved

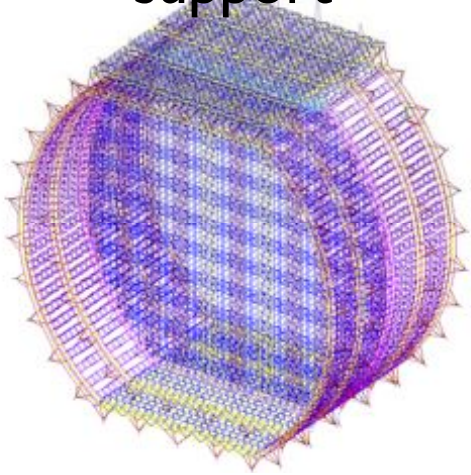
Lining & drain system



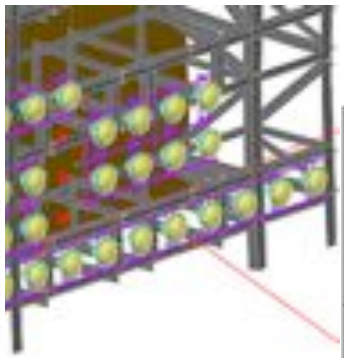


Polyethylene sheet

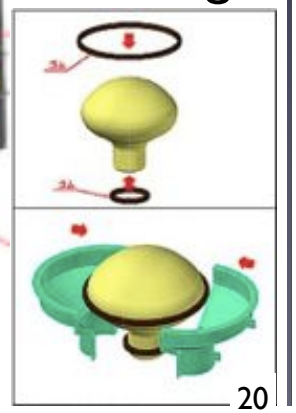
Photo-sensor support



Mounting Photo-sensor

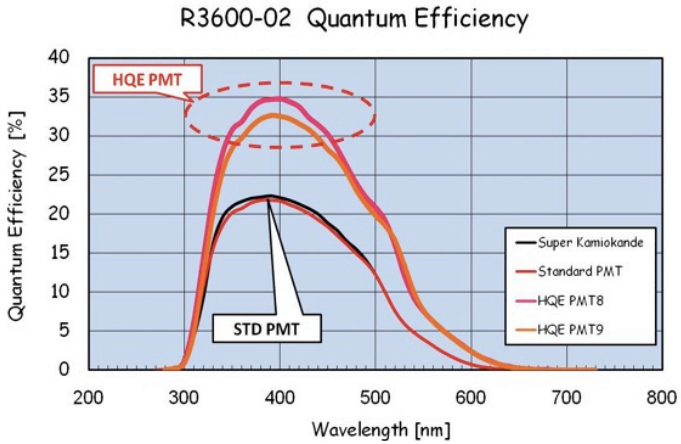


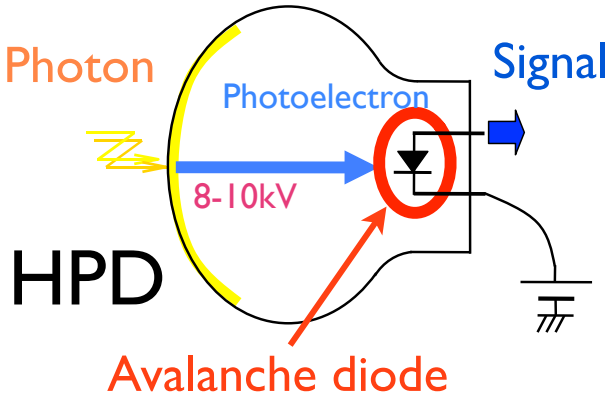
Housing

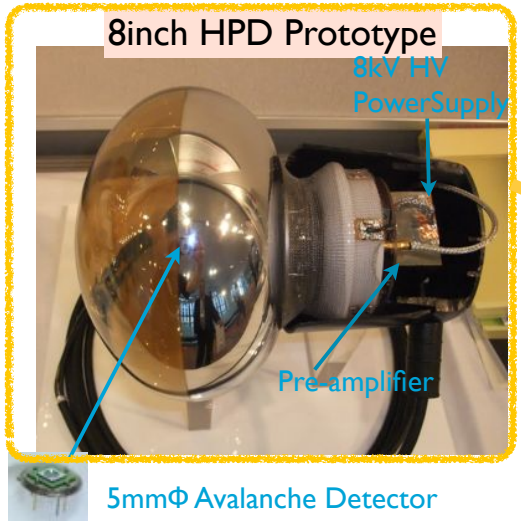


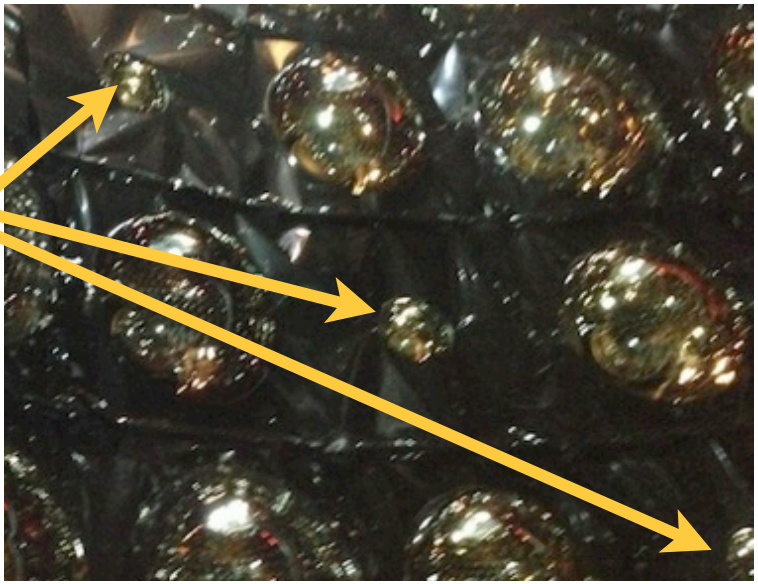
R&D of new photo sensor

- High QE 20” PMT (baseline)
- High QE 20” HPD (desired option)
  - 8” HPD prototype under evaluation
  - Long term test in 200ton water tank tank (EGADS) from this summer
- 20” HPD prototype expected in a few month









Much area for more contribution

- R&D ongoing in many areas
  - Readout electronics
  - DAQ system
  - Software development
  - Calibration system
  - Water system

  → Verification with a prototype (~1kton) detector
  (funded: JFY2013-2017)
  - Will be summarized in documents
    - LoI (2011: DONE)
    - CDR (2013-2014: next step)
    - TDR

International open Hyper-K meetings

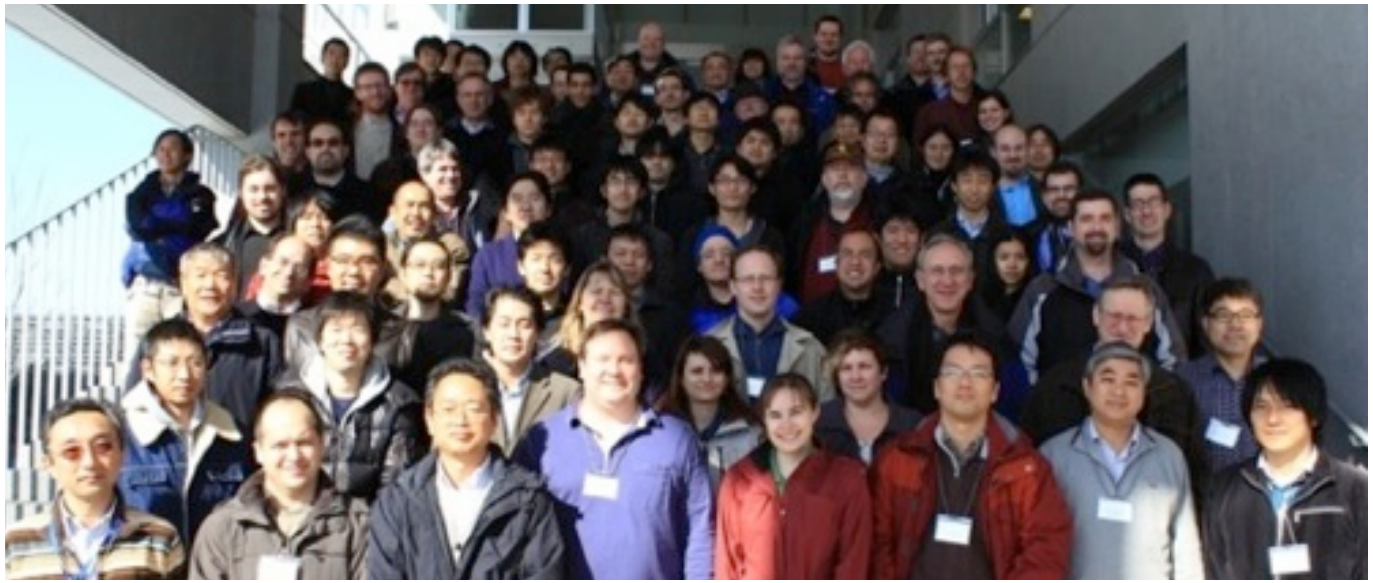
Hyper-K is completely open to the international community.

International WG was formed and actively working.

Current members are from
Japan, Canada, Korea, Spain, Switzerland, Russia, UK, US

Three meetings so far.
Aug. 2012, Jan. 2013, Jun. 2013

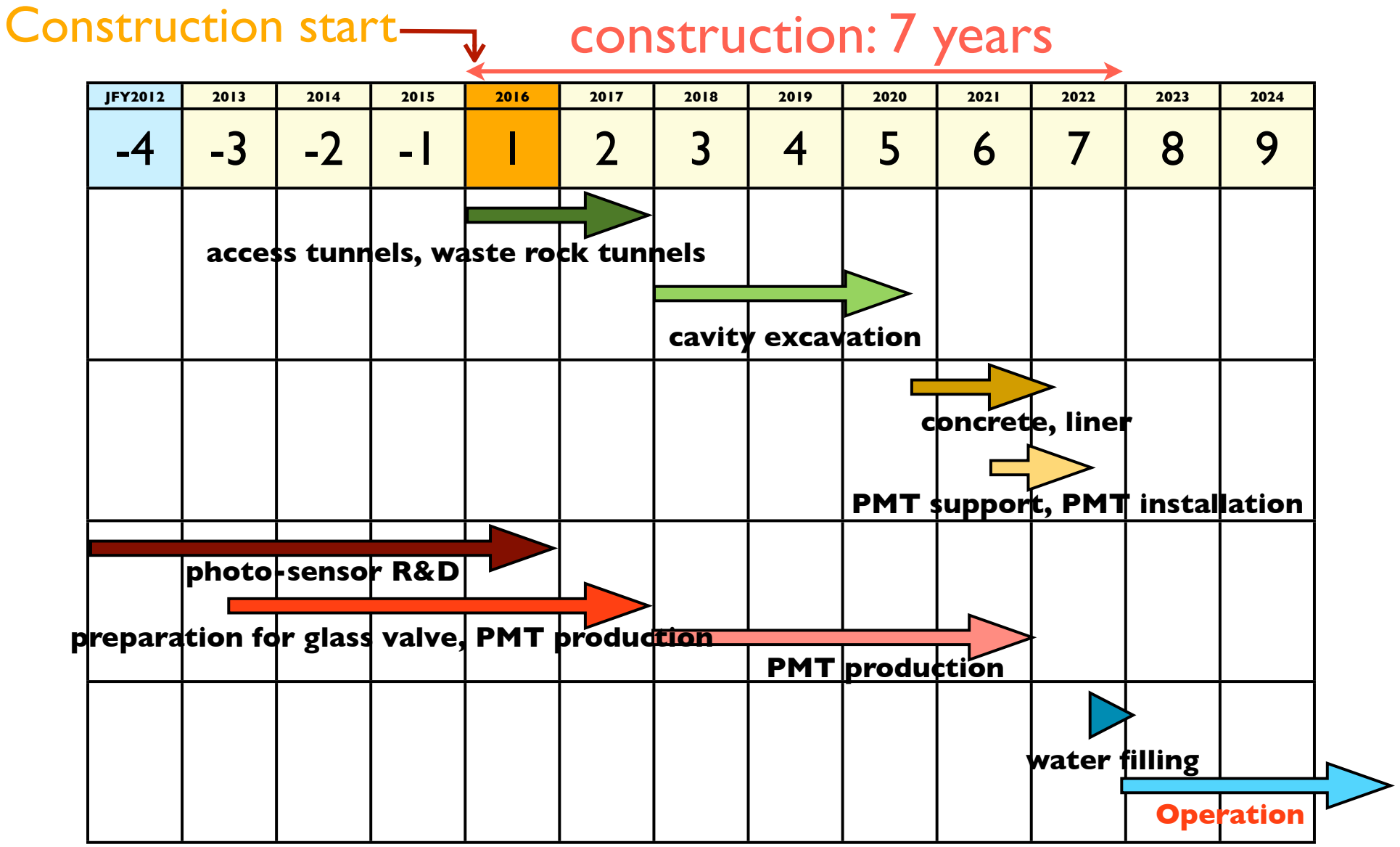
http://indico.ipmu.jp/indico/conferenceDisplay.py?&confId=23



Next meeting: Jan. 27-28, 2014 @Kavli IPMU, Kashiwa, Japan

Open to anyone interested in HK!

Target Schedule



assuming **budget being approved from JFY2016**

Summary

- Hyper-Kamiokande will provide excellent opportunity for wide range of physics topics
  - Neutrino mixing and CP violation
  - Nucleon decays
  - Neutrino astronomy
- Feasible baseline design exists. Further optimization, R&D, prototyping are ongoing.
- International WG is actively working.
- You are welcome to join!

NNN13 workshop

Nov.11-13, 2013

http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=17

Registration is open!!

wpi World Premier International Research Center Initiative

東京大学 THE UNIVERSITY OF TOKYO

TODIAS 東京大学国際高等研究所 TODAI INSTITUTES FOR ADVANCED STUDY

THE KAVLI FOUNDATION

Backup

Hyper-K in Japanese roadmap

- One of two large-scale future projects recommended by HEP future projects committee.
- Next version of KEK roadmap includes Hyper-K
- Cosmic ray physics community also endorses Hyper-K as the next large-scale project
- In 2013-14, the Japanese *Master Plan* for large scale projects (for all fields of science) is being updated by Science Council of Japan.
  - Hyper-K is one of proposed projects.
  - The *Master Plan* is expected to be an important input to the Japanese government.