

Hyper-Kamiokande

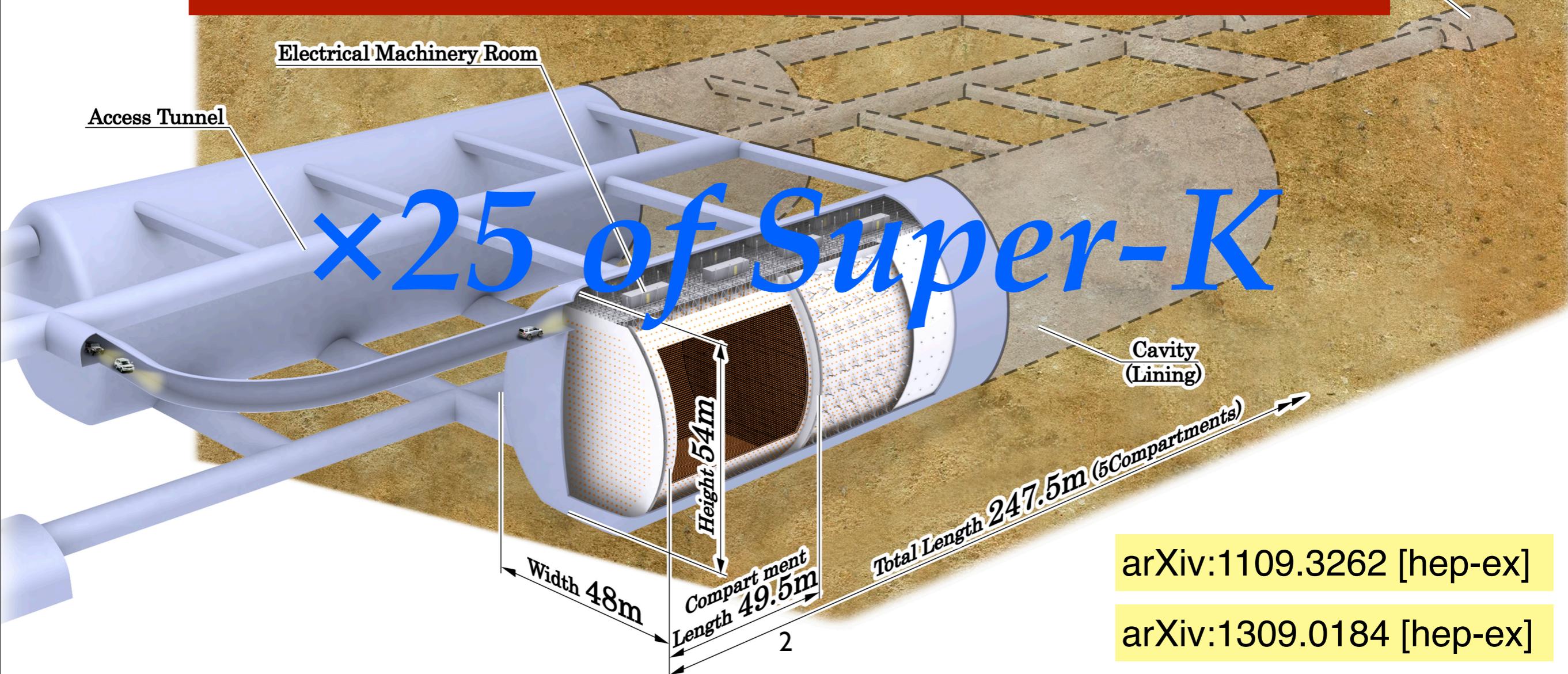
-Overview-

T. Nakaya (Kyoto)
for the Hyper-K working group

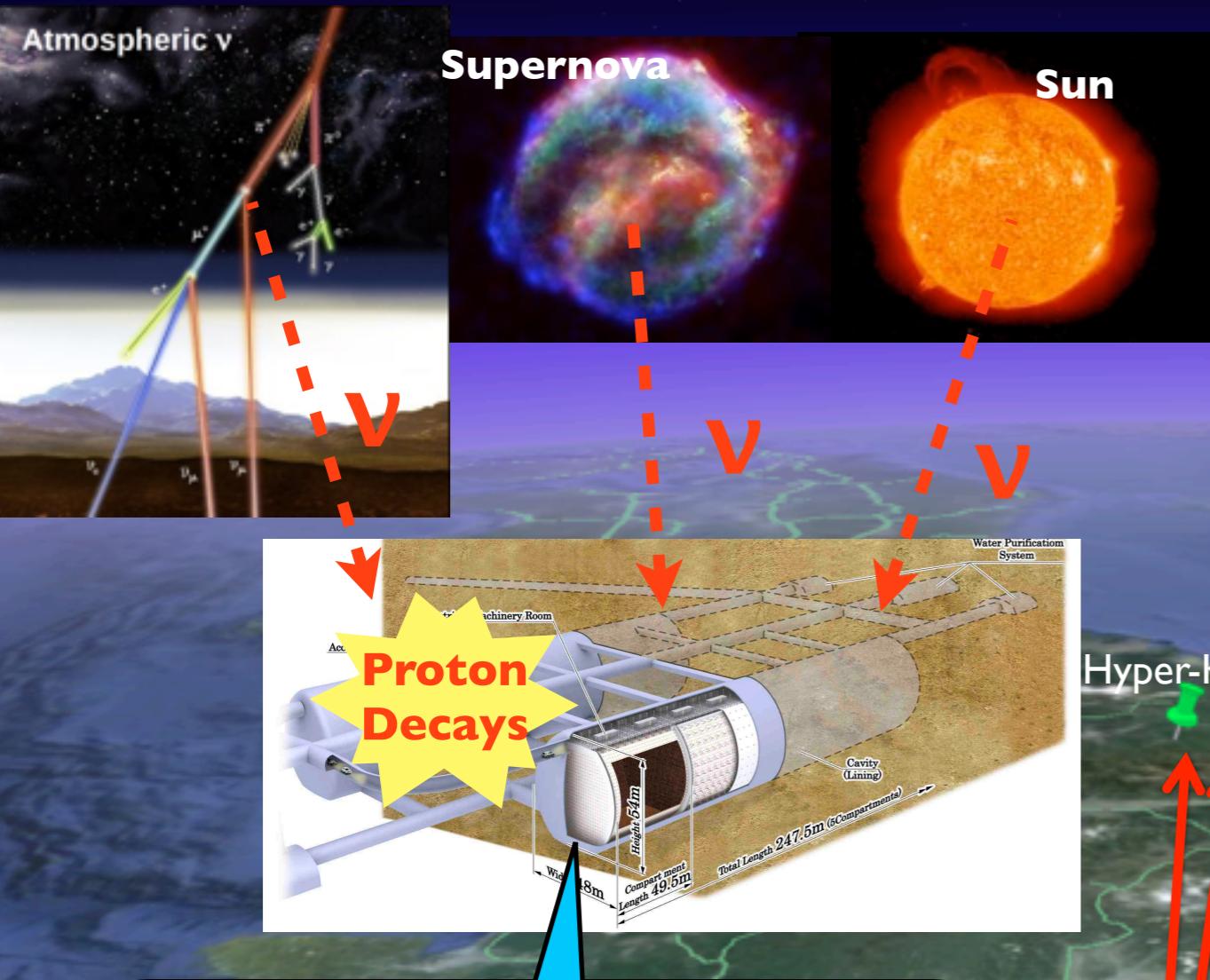
Hyper-K Overview

Total Volume	0.99 Megaton
Inner Volume	0.74 Mton
Fiducial Volume	0.56 Mton ($0.056\text{ Mton} \times 10\text{ compartments}$)
Outer Volume	0.2 Megaton
Photo-sensors	99,000 $20''\Phi$ PMTs for Inner Det. (20% photo-coverage) 25,000 $8''\Phi$ PMTs for Outer Det.

Water Purification System



x50 for ν CP
to T2K



x25 Larger ν Target
& Proton Decay Source

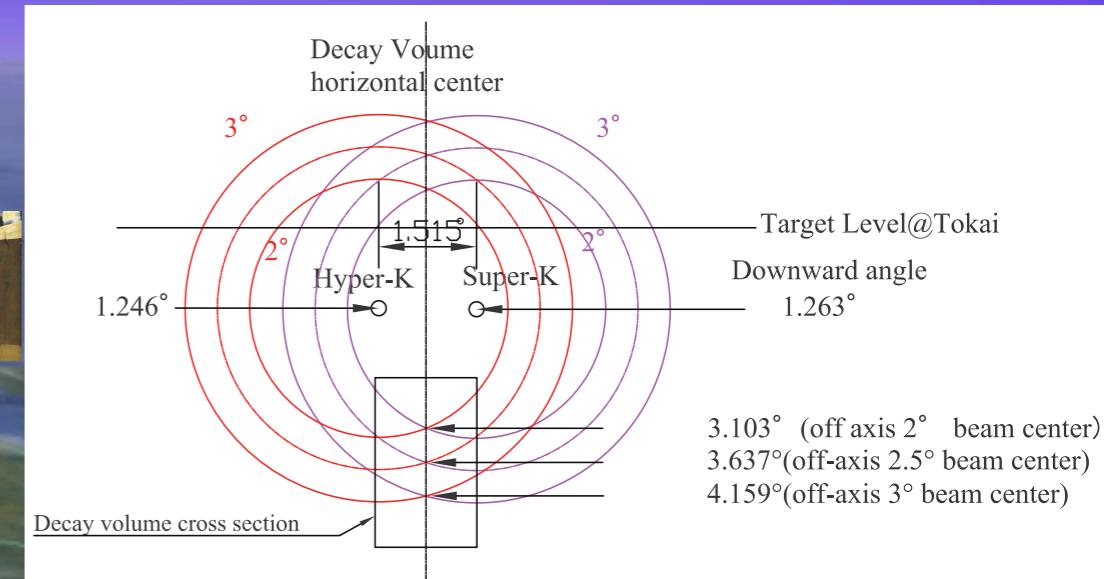


Fig. 13. Schematic directional view of Super-K and Hyper-K from the neutrino beam line target at J-PARC.

higher intensity ν by
upgraded J-PARC



x2 (year
or power)
Google

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Hyper-K Working Group

- The most updated member list is found in arXiv:1309.0184 [hep-ex]
 - 9 countries: Brazil, Canada, Japan, Korea, Russia, Spain, Switzerland, UK, and US.
 - 49 institutions and 167 physicists (Ph.D. students only counted in Japan)
- International Working groups are formed, and we have two meetings in a year.
 - Next meeting: Jan. 27-28, 2014 @ Kavli IPMU, Kashiwa, JAPAN



Hyper-K Working Group Organization

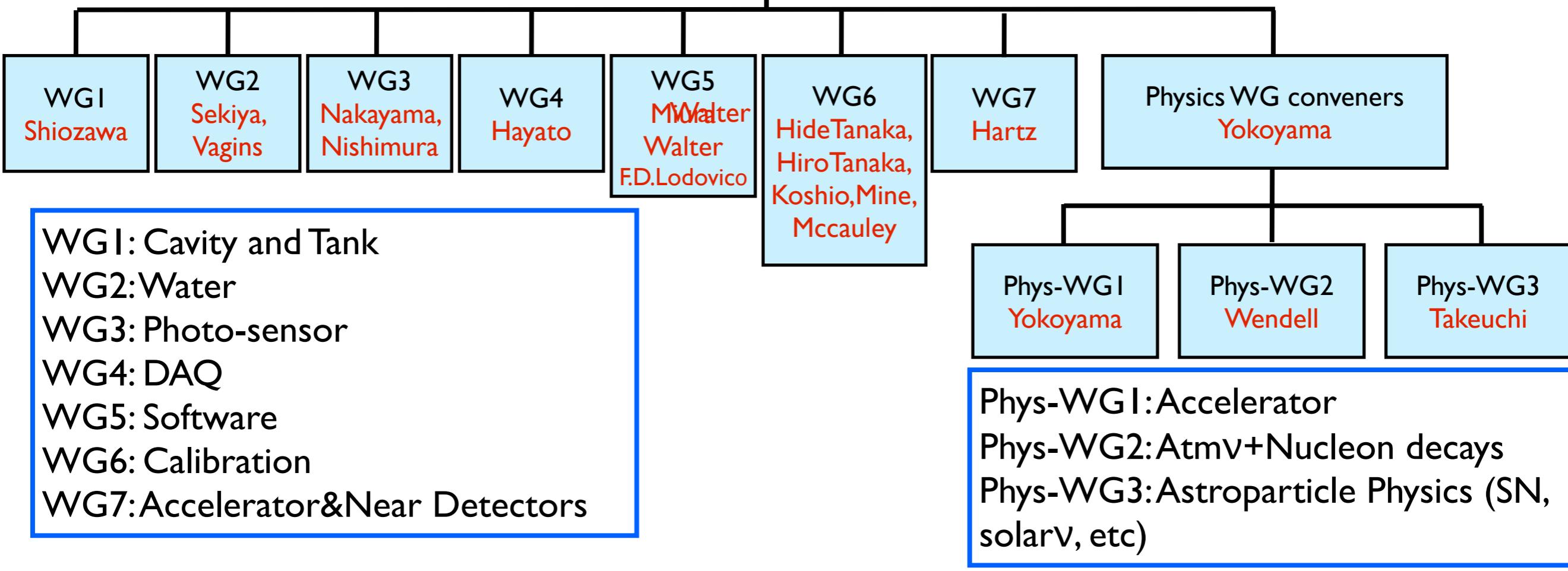
- ▶ oversee the HK group
- ▶ channel for contacting to the group
- ▶ involve non-Japanese in future

- More leading physicists are welcome from the international community.

Steering Committee
Nakaya (chair)
Aihara, Nakahata,
Shiozawa, Yokoyama
+ a few more

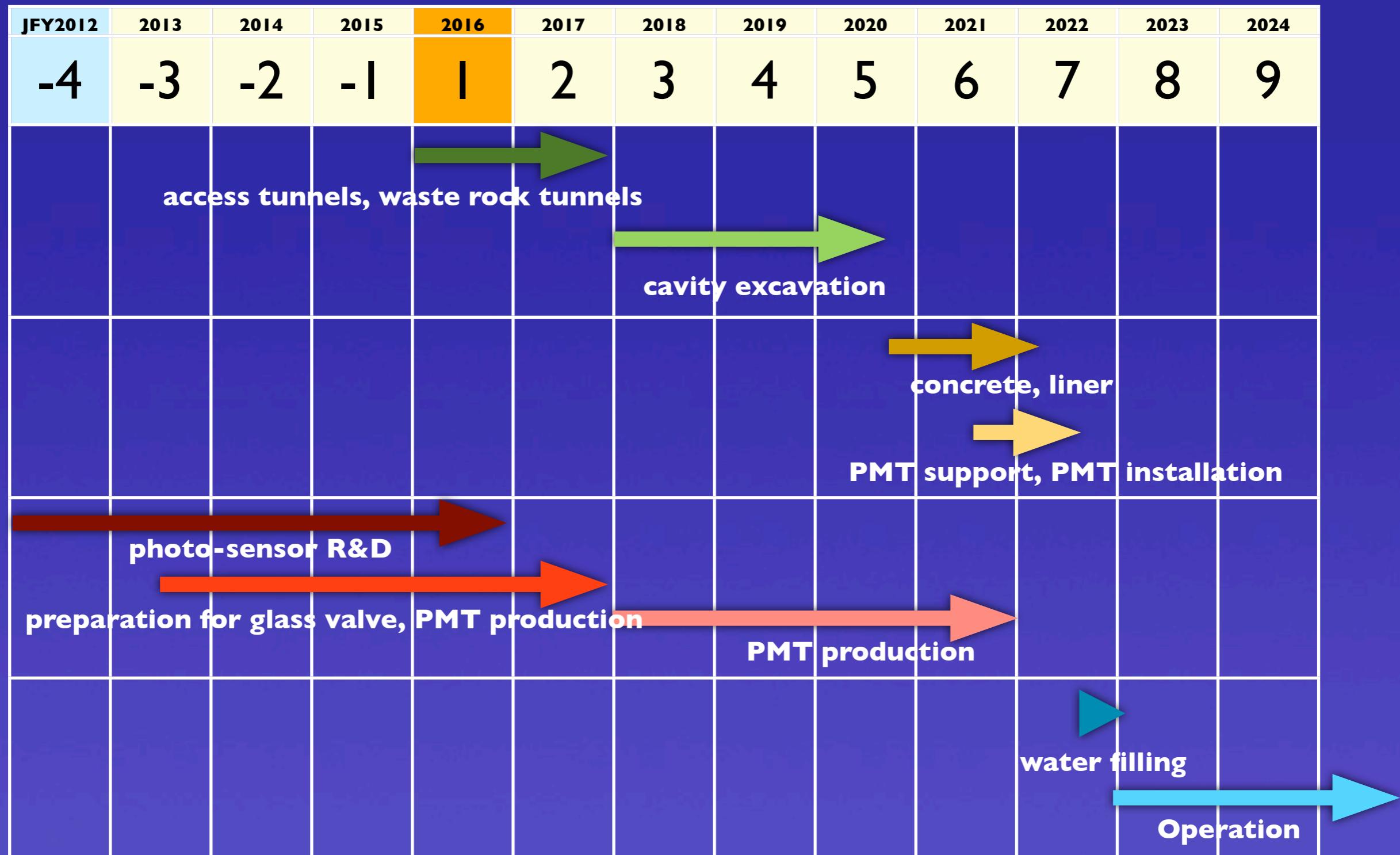
Project Leader
Shiozawa

- ▶ PL oversees the sub-WGs
- ▶ WG conveners may be composed of one Japanese plus some non-Japanese.



Target Schedule

Construction to be ready



assuming full budget being approved from JFY2016

Physics with Hyper-Kamiokande

Physics Potential

- x25 more fiducial volume than Super-K.
 - x25 more sensitive to
 - Proton Decay
 - Atmospheric neutrinos
 - Solar neutrinos
 - Supernova neutrinos
 - Cosmic neutrinos (and search for dark matters decaying to neutrinos)
 - > ~1MW narrow band (off-axis) neutrino beam from J-PARC (KEK accelerator group is eager to the more ambitious goal)
 - T2K current: 240 kW (design: 750 kW)
 - x100 more sensitive neutrino experiment than today's T2K.

Hyper-K presentation by Shiozawa-san at P5

“BIG” questions in Snowmass

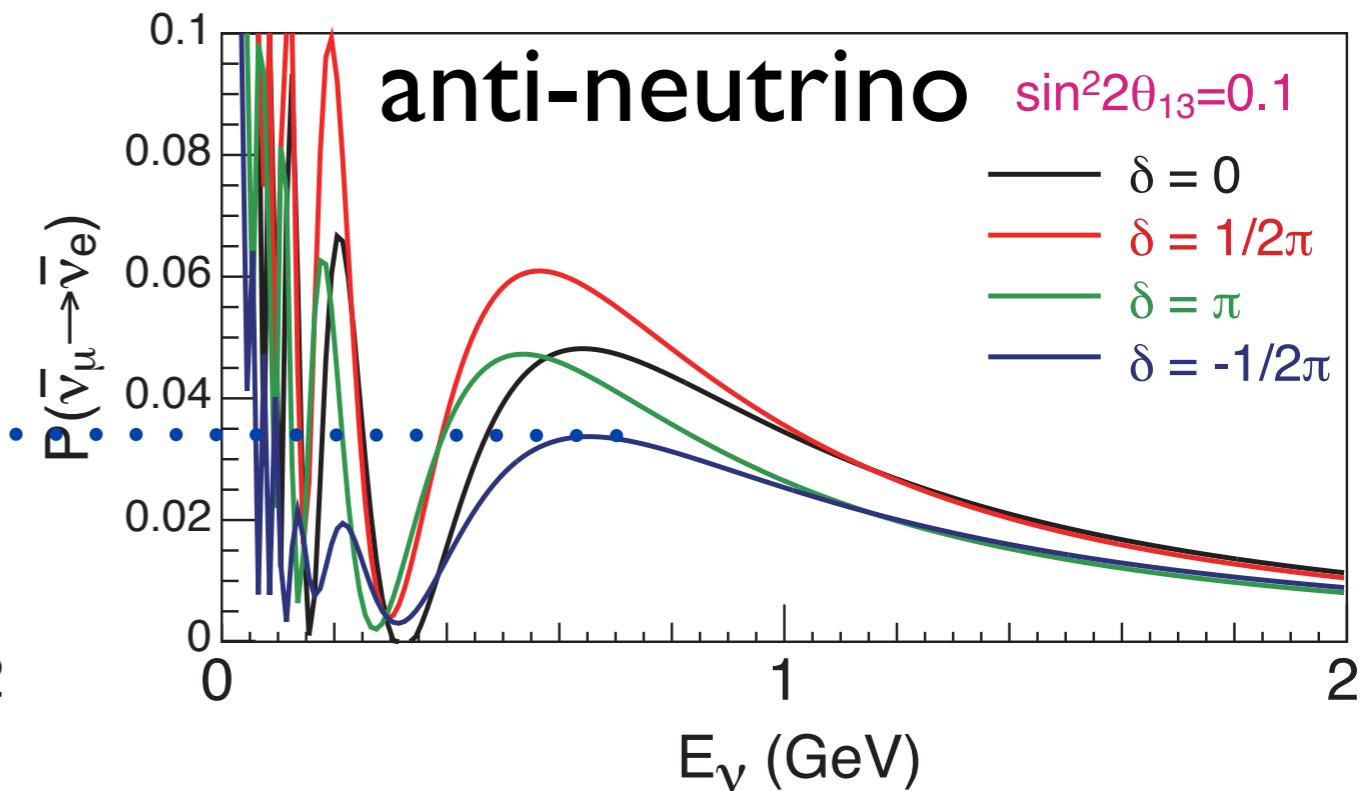
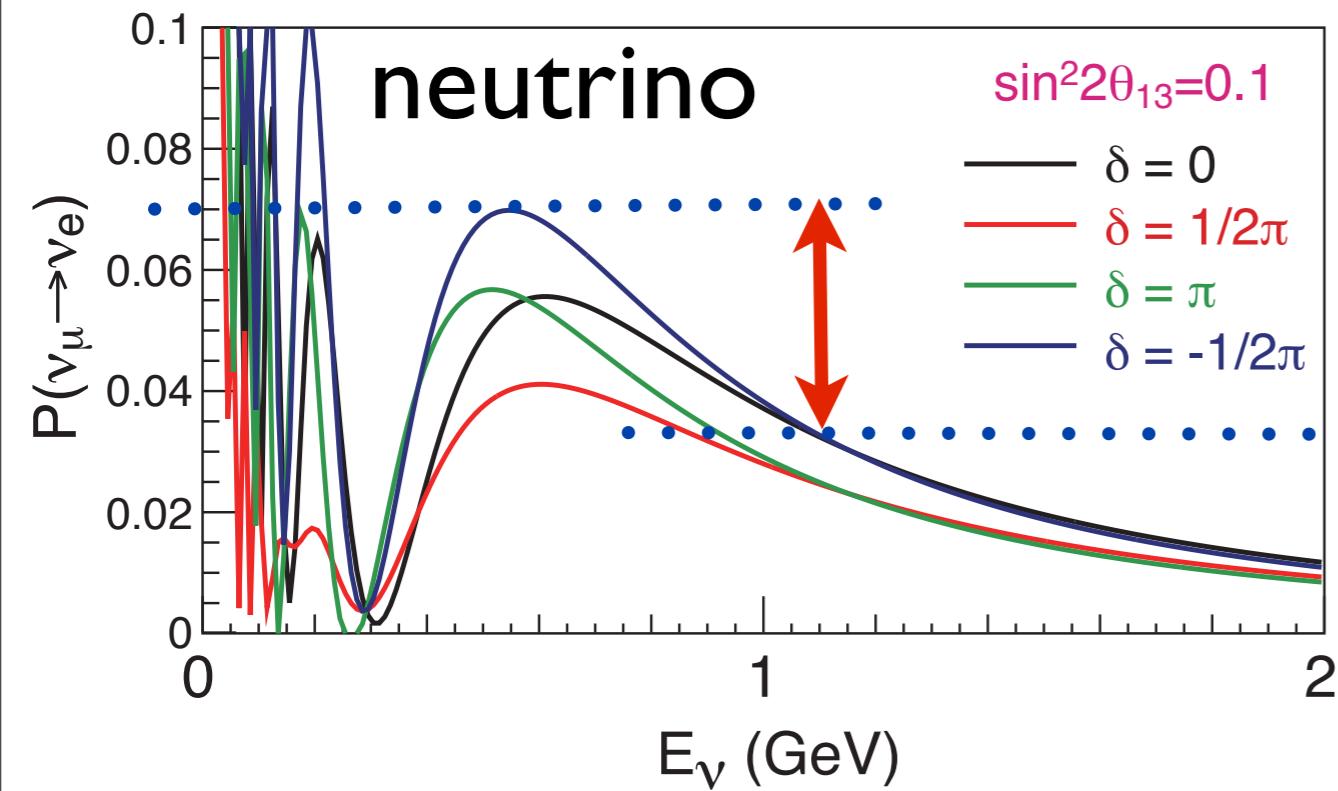
<http://www.symmetrymagazine.org/article/october-2013/the-big-questions>

- The Higgs particle is unlike any other particle we have ever encountered. Why is it different? Are there more?
- Neutrinos are very light, elusive particles that change their identity as they travel. How do they fit into our understanding of nature?
- The known particles constitute one-sixth of all the matter in the universe. The rest we call dark matter. But what is it? Can we detect these particles in our labs? Are there other undiscovered particles in nature?
- There are four known forces in nature. Are these manifestations of a single unified force? Are there unexpected new forces?
- Are there new hidden dimensions of space and time?
- Both matter and antimatter were produced in the big bang, but today our world is composed only of matter. Why?
- Why is the expansion of the universe accelerating?

Neutrino & nucleon decay experiments address many “BIG” questions.

Measuring CP asymmetry w/ J-PARC v beam

$P(\nu_\mu \rightarrow \nu_e)$ appearance probability
(normal hierarchy)



- Comparison between $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
 - as large as $\sim 27\%$ from nominal (at $\theta_{23} = \pi/4$).
 - also sensitive to any CPV (such as > 3 neutrinos)

Rich Physics in 3 generation mixings

$$\begin{aligned}
 P(\nu_\mu \rightarrow \nu_e) = & 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2 \Delta_{31} \text{ Leading} \\
 & + 8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos \delta - S_{12} S_{13} S_{23}) \cdot \cos \Delta_{32} \cdot \sin \Delta_{31} \cdot \sin \Delta_{21} \\
 & - 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin \delta \cdot \sin \Delta_{32} \cdot \sin \Delta_{31} \cdot \sin \Delta_{21} \\
 & + 4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos \delta) \cdot \sin^2 \Delta_{21} \\
 & - 8C_{13}^2 S_{13}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu} (1 - 2S_{13}^2) \cdot \cos \Delta_{32} \cdot \sin \Delta_{31} \\
 & + 8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{13}^2} (1 - 2S_{13}^2) \sin^2 \Delta_{31} \quad \text{Solar}
 \end{aligned}$$

Matter effect

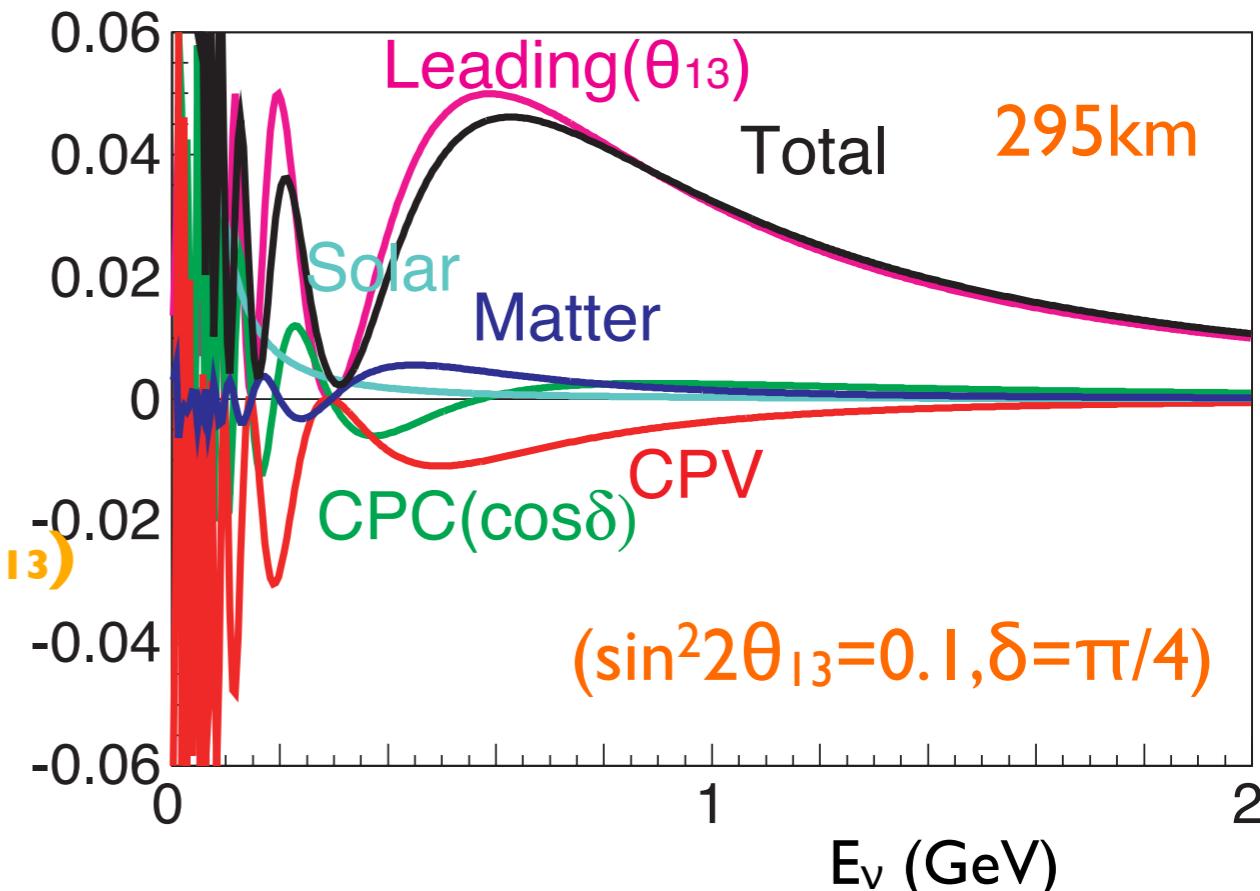
Leading

$$\sin^2 \theta_{23} \sin^2 2\theta_{13} \sin^2 \left(\frac{\Delta m_{31}^2 L}{4E} \right)$$

CPV

$$\begin{aligned}
 & \frac{\sin 2\theta_{12} \sin 2\theta_{23}}{2 \sin \theta_{13}} \left[\sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{31}^2 L}{4E} \right] \sin \frac{\Delta m_{21}^2 L}{4E} \sin \delta \\
 & \sim 0.03 \\
 & \sim \frac{\pi}{4} \frac{\Delta m_{21}^2}{\Delta m_{32}^2} \frac{\sin 2\theta_{12} \sin 2\theta_{23}}{\sin^2 \theta_{23} \sin \theta_{13}} \frac{E_{1st \max}}{E} [\text{leading}] \sin \delta \\
 & \sim 0.27 \times [\text{leading}] \times \frac{E_{1st \max}}{E} \times \sin \delta
 \end{aligned}$$

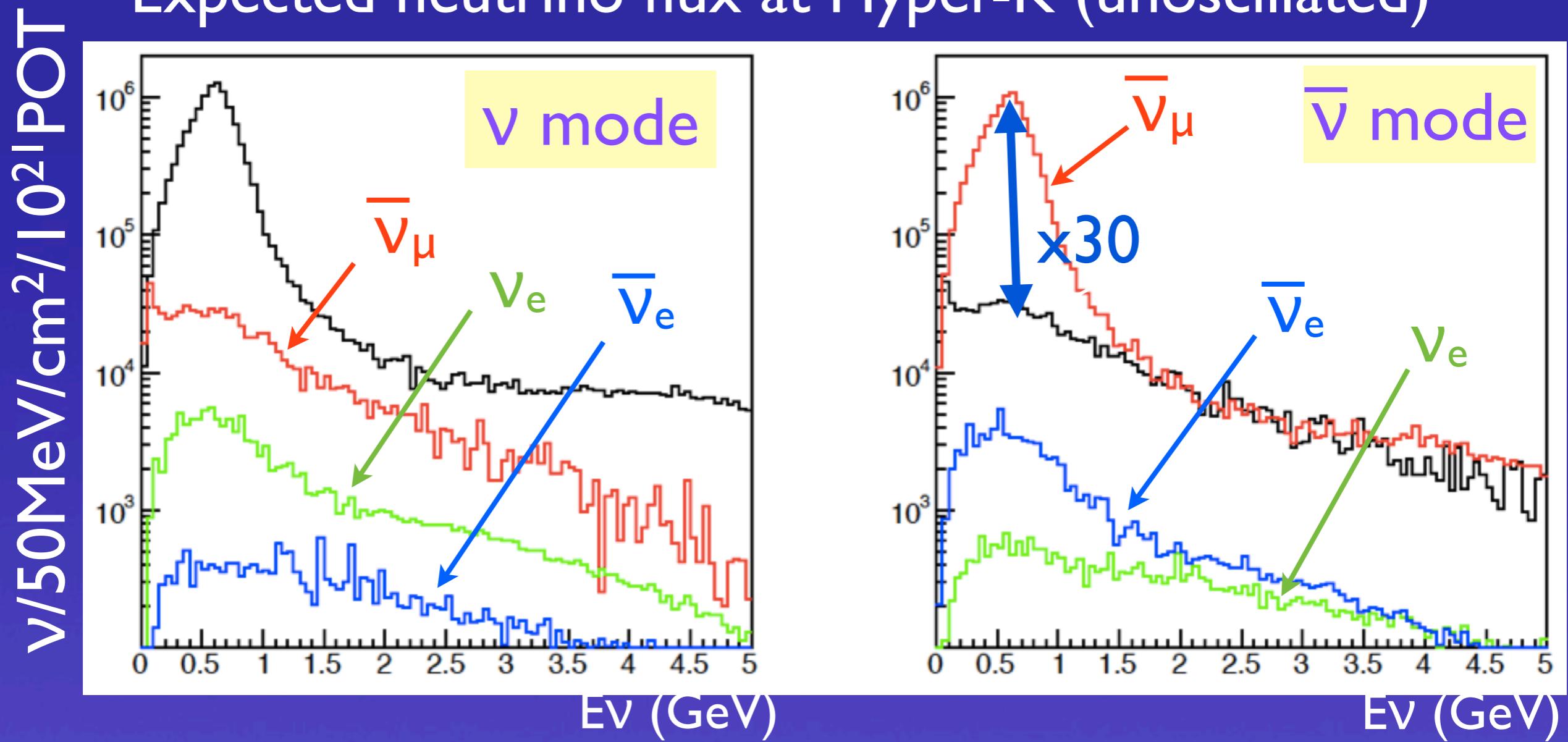
27%



- No magic for the 2nd maximum.
- Energy dependence is important.

The ν beam ($\nu:\bar{\nu}=3:7$)

Expected neutrino flux at Hyper-K (unoscillated)



2.5° off-axis beam from J-APRC

Peaked at oscillation maximum

Suppress BG from high energy component (ν_T negligible)

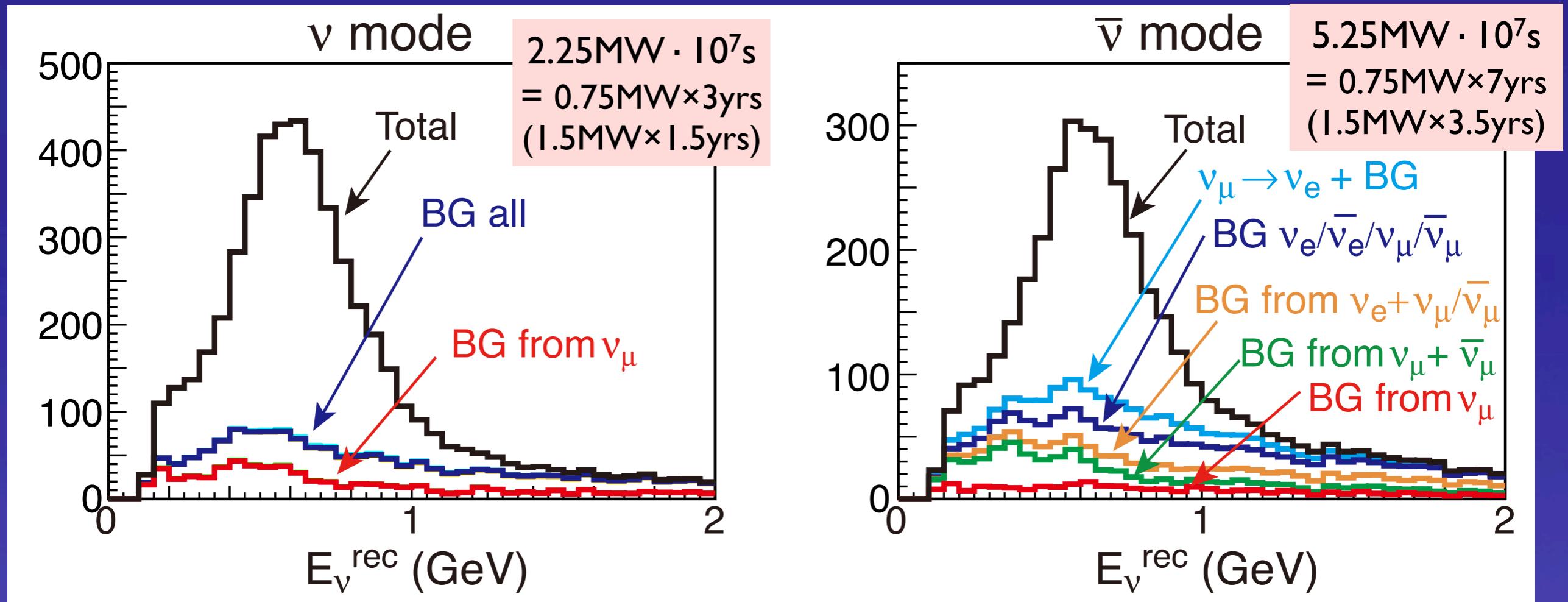
CP measurement with **Hyper-K**

- Strength of water Cherenkov detector
 - LARGE mass – statistics is always critical
 - Excellent reconstruction/PID performance especially in sub-GeV region (quasi-elastic → single ring)
- Best matched with low energy, narrow band beam
 - Off-axis beam with relatively short baseline
 - Sensitive to CPV with less matter effect
 - Complementary to other $> \sim 1000\text{km}$ baseline experiments planned w/ Lq.Ar

(natural extension of technique proved by T2K)

ν_e candidate events after selection

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



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

NC background can be further reduced by FiTQun.

LARGE $\theta_{13} \Rightarrow$ good for Hyper-K

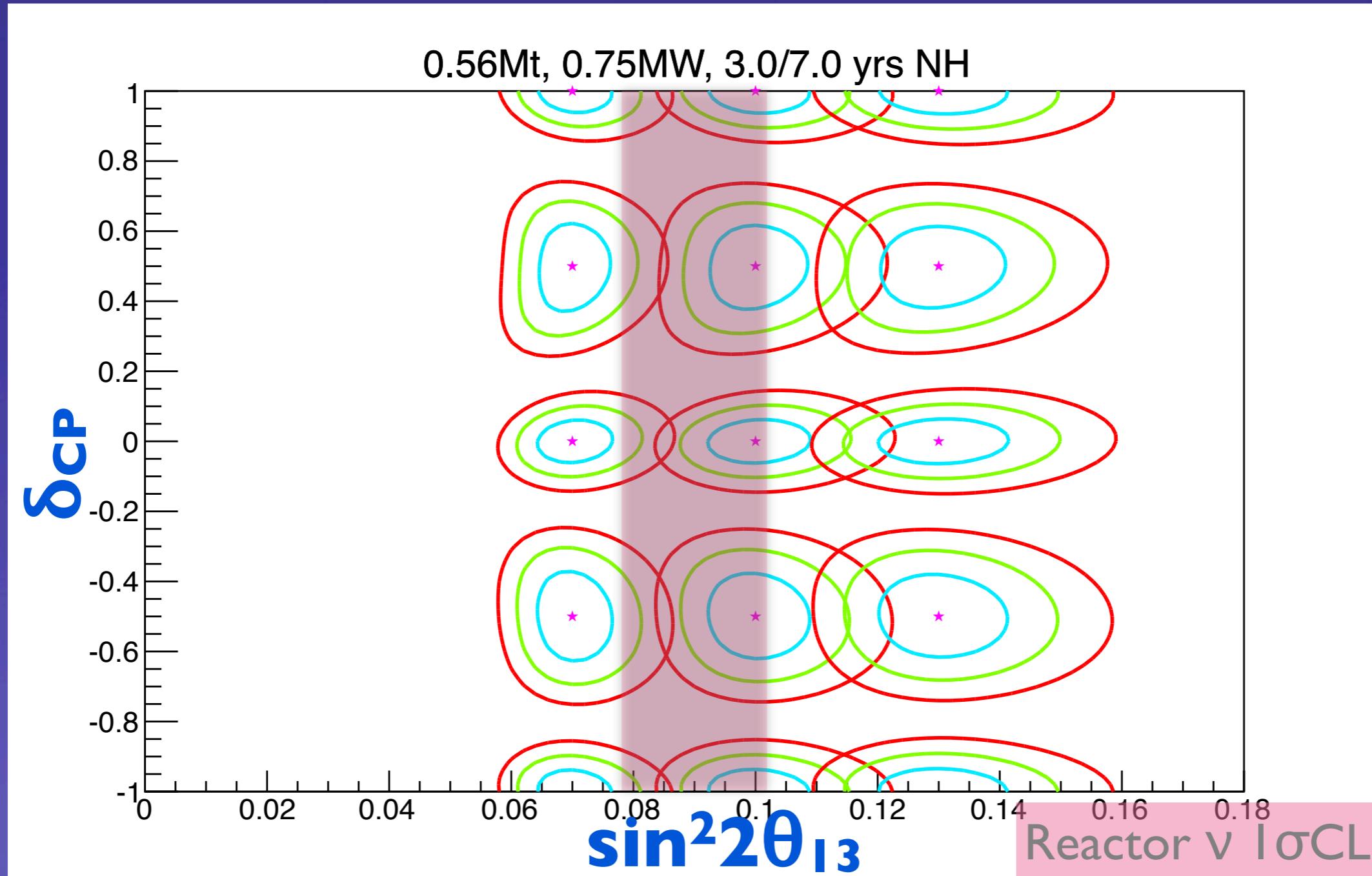
- High Signal ($\nu_\mu \rightarrow \nu_e$) and Low Background (π^0 , beam ν_e , etc..)
 - Systematic error is more reliable (under control) for the ν_e signal than BG (example, π^0)
 - Assuming 5% sys. error for both ν_e signal and background (beam ν_e and NC π^0 dominant).
- >10% larger asymmetry is expected for δ between 20 and 160 degrees (200 and 340) which corresponds to ~77% region of δ .

7.5MW · years

Contours

Normal mass hierarchy (known)

5% systematics on signal, ν_μ BG, ν_e BG, ν/ν

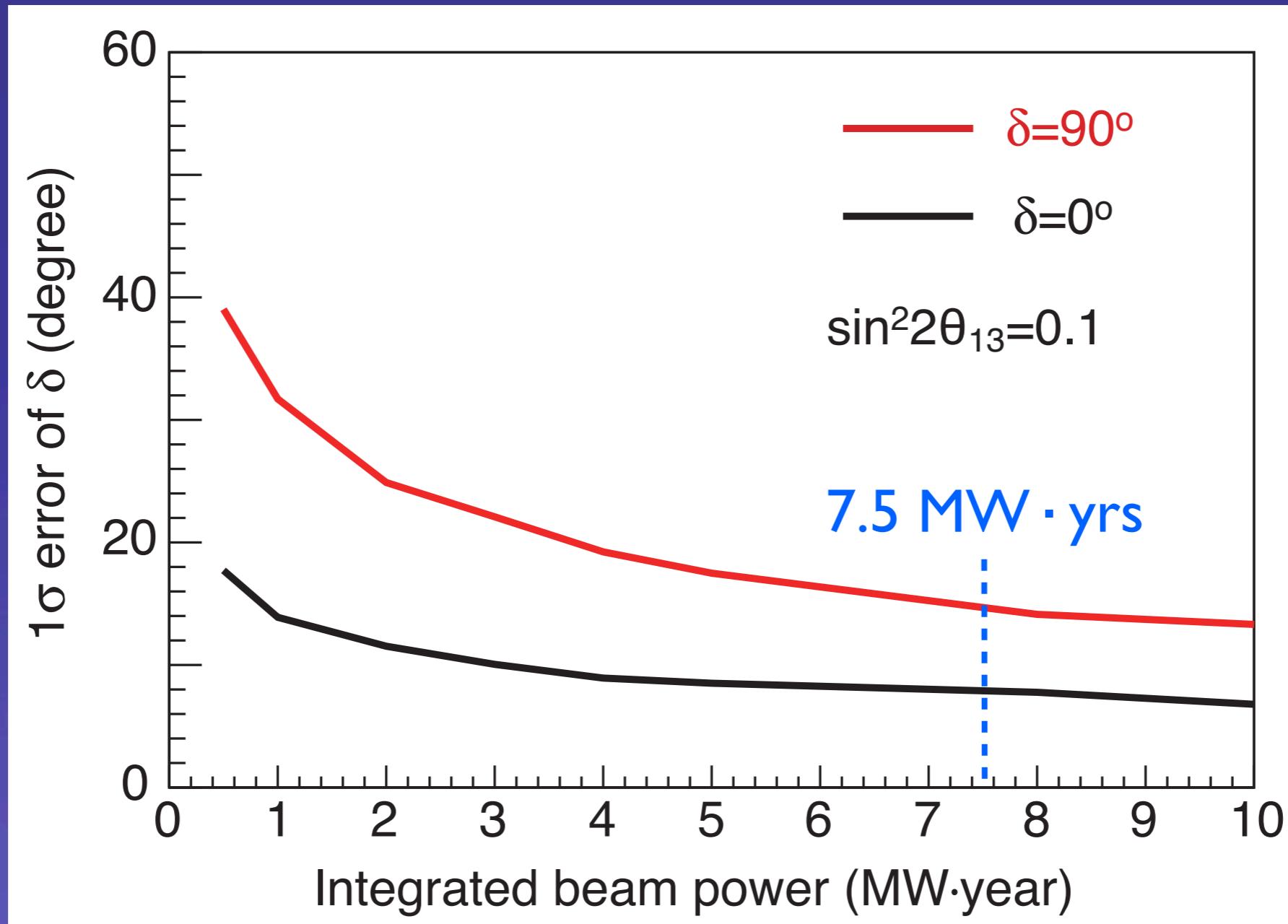


- Good sensitivity for CPV
- can be distinguish between $\delta=0$ and $\delta=\pi$

δ resolution

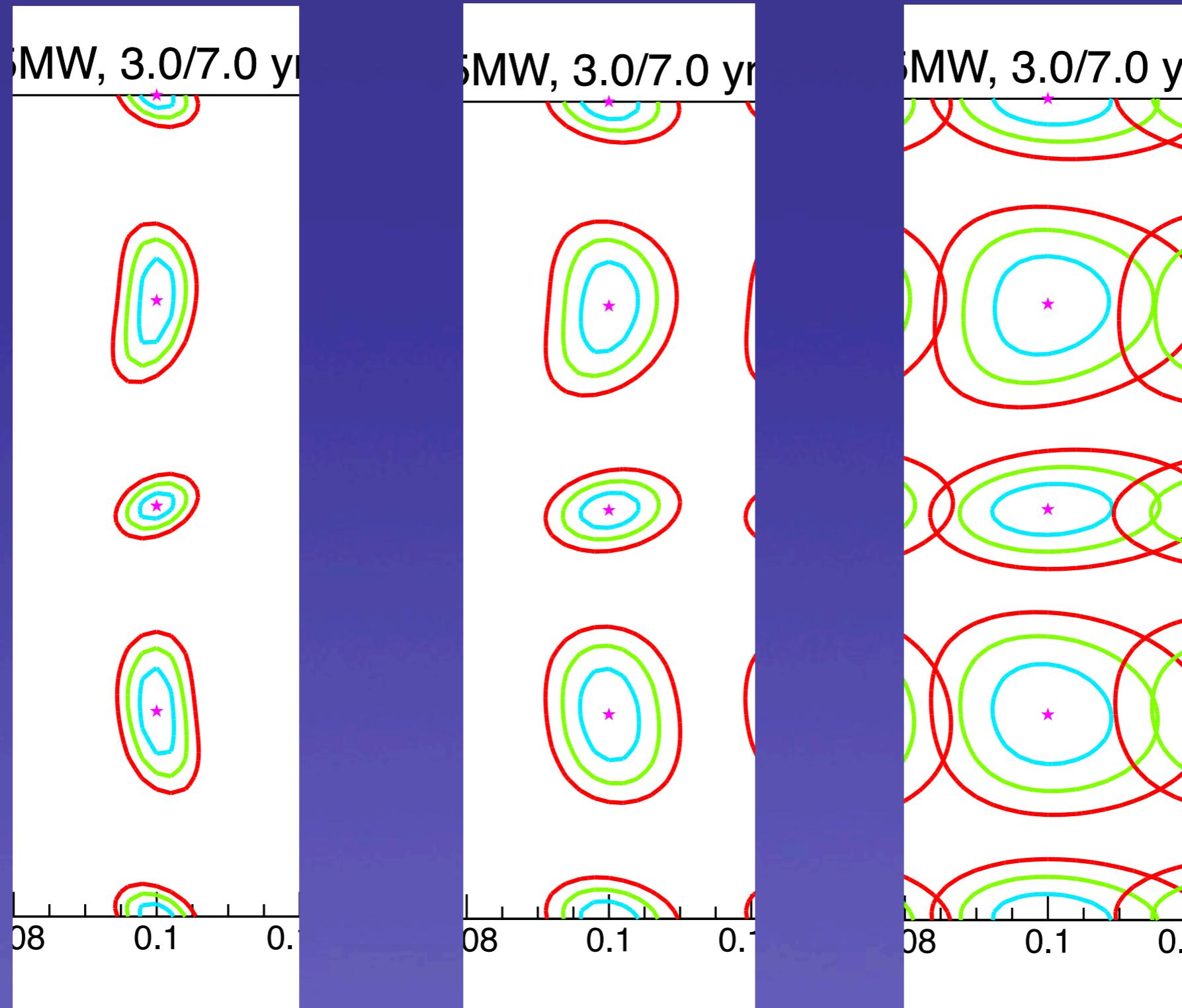
Normal mass hierarchy (known)

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



- δ precision $< 20^\circ$ ($\delta = 90^\circ$)
 $< 10^\circ$ ($\delta = 0^\circ$)
- modest dependence on θ_{13}

Effect of systematic errors



0%

2%
18

5%

Complementarity with atmospheric neutrinos

NuclPhysB669,255(2003)

NuclPhysB680,479(2004)

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

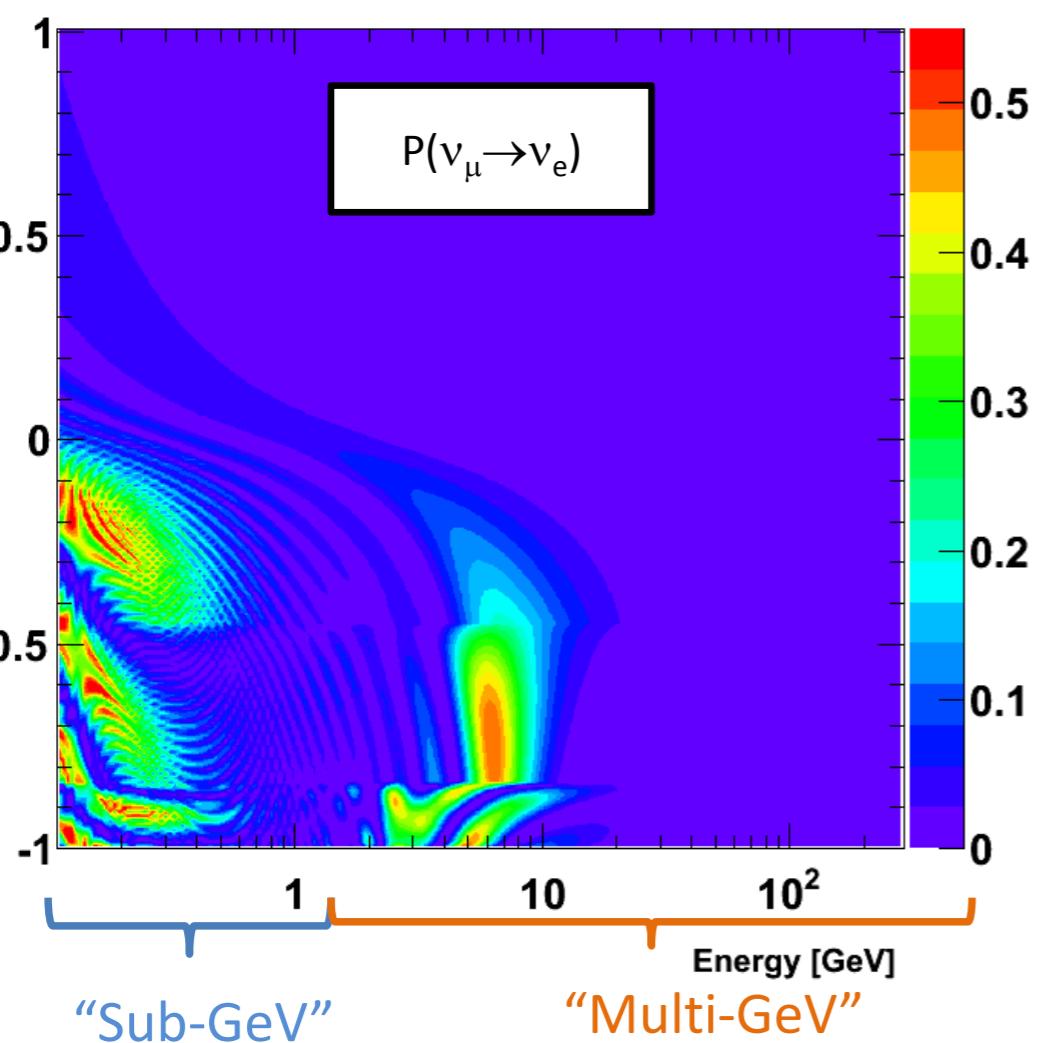
$$-r \cdot \sin \tilde{\theta}_{13} \cdot \cos^2 \tilde{\theta}_{13} \cdot \sin 2\theta_{23} (\cos \delta \cdot R_2 - \sin \delta \cdot I_2)$$

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

θ_{13} resonance term

Interference term (δCP)

(3)



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

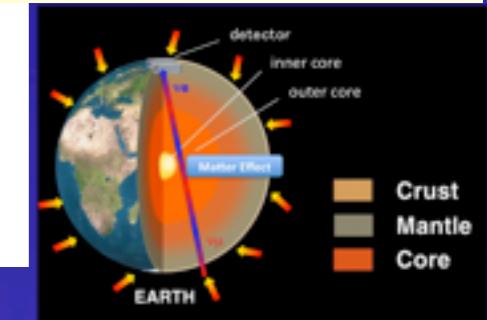
$P_2 = |A_{e\mu}|^2 : 2\nu$ transition probability $\nu_e \rightarrow \nu_{\mu\tau}$ in matter

$R_2 = \text{Re}(A_{ee}^* A_{e\mu})$

$I_2 = \text{Im}(A_{ee}^* A_{e\mu})$

A_{ee} : survival amplitude of the 2ν system

$A_{e\mu}$: transition amplitude of the 2ν system

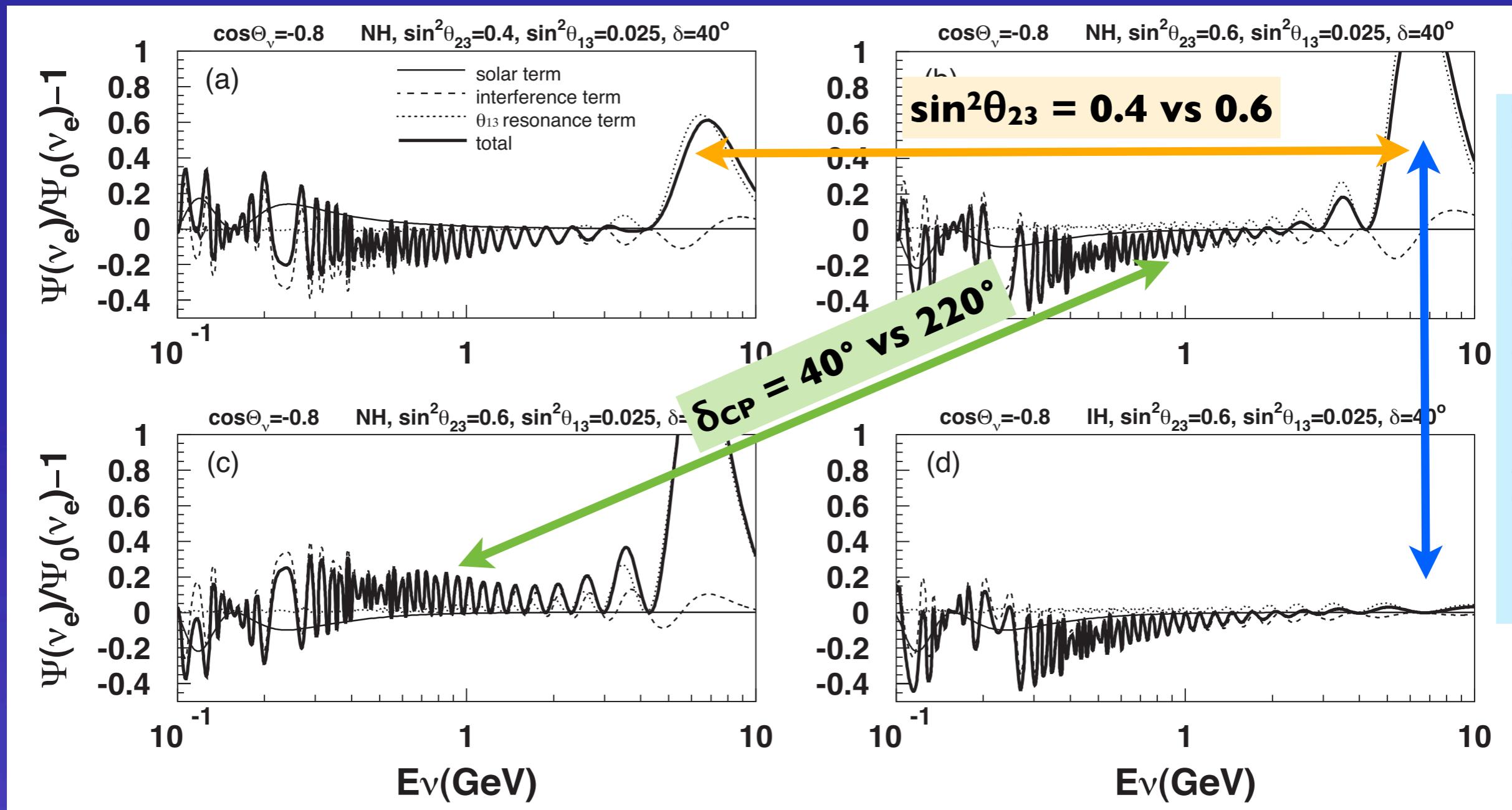


ν_e appearance (and ν_μ distortion) is expected due to MSW effect in the Earth's matter

- happens in ν in the case of normal mass hierarchy
- in anti- ν in inverted mass hierarchy

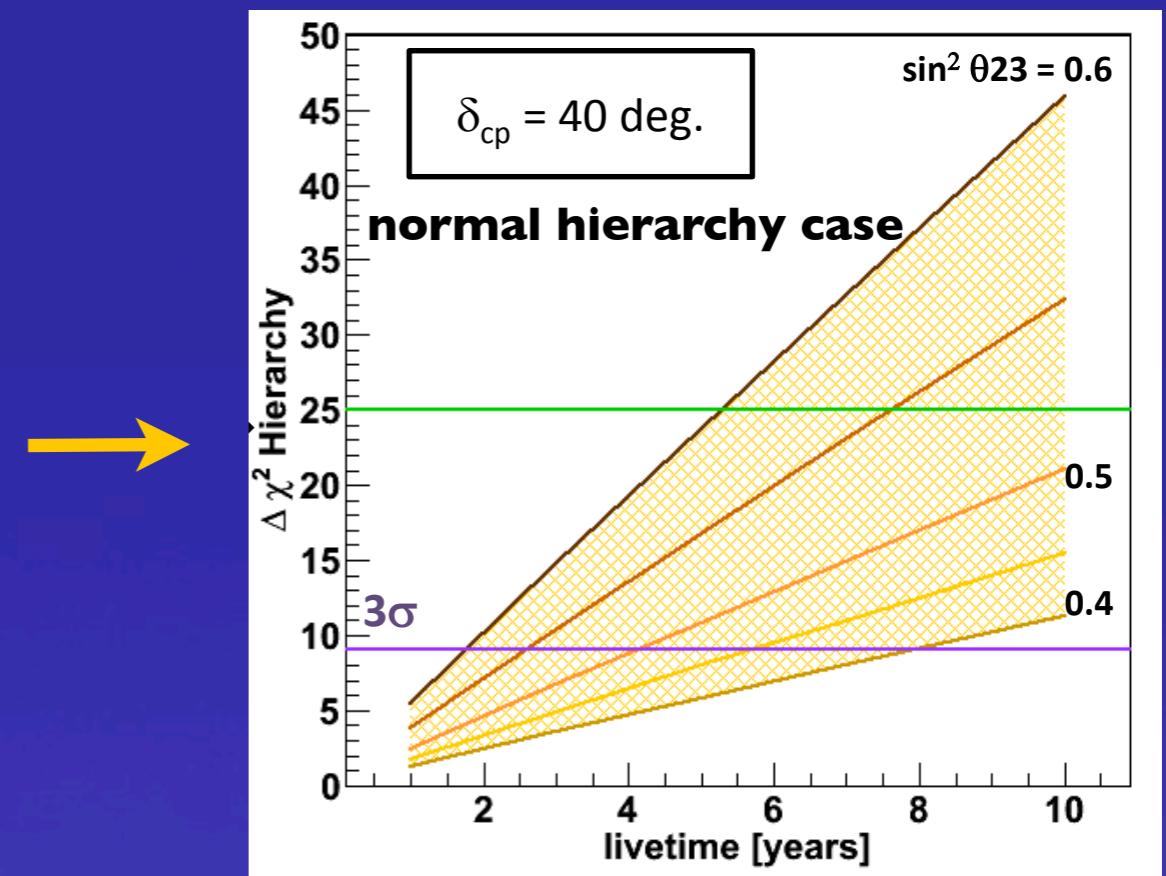
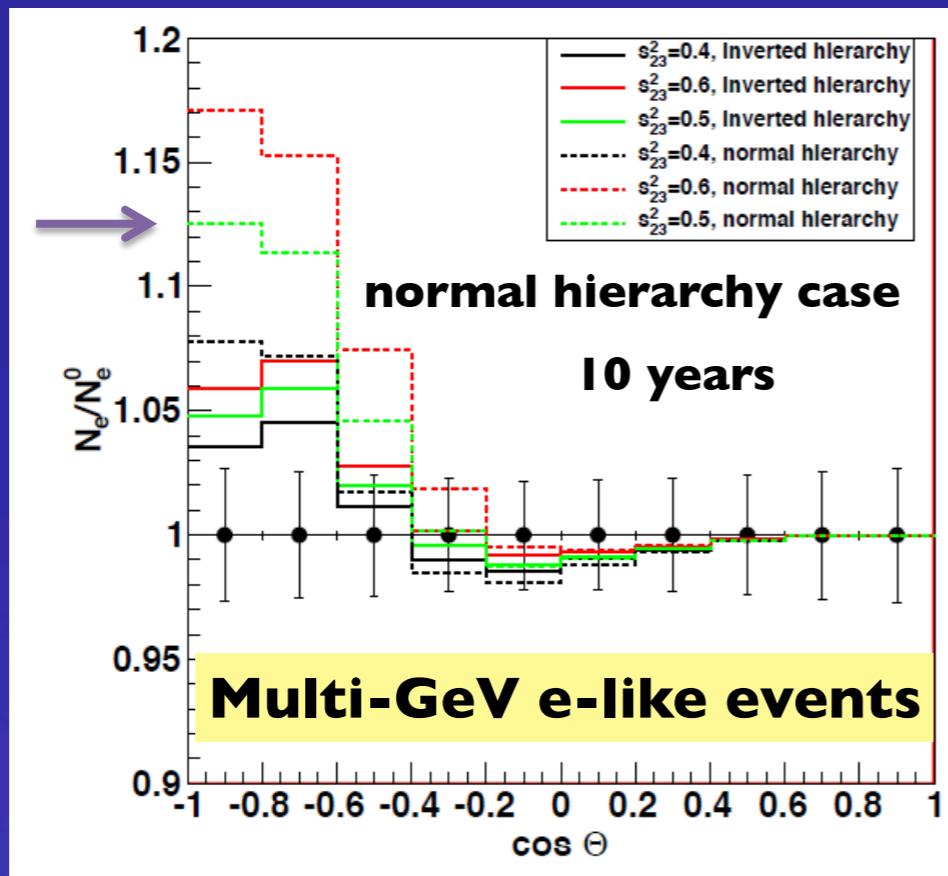
Large θ_{13} value gives us a good chance to discriminate mass hierarchy.

mass hierarchy: NH vs IH

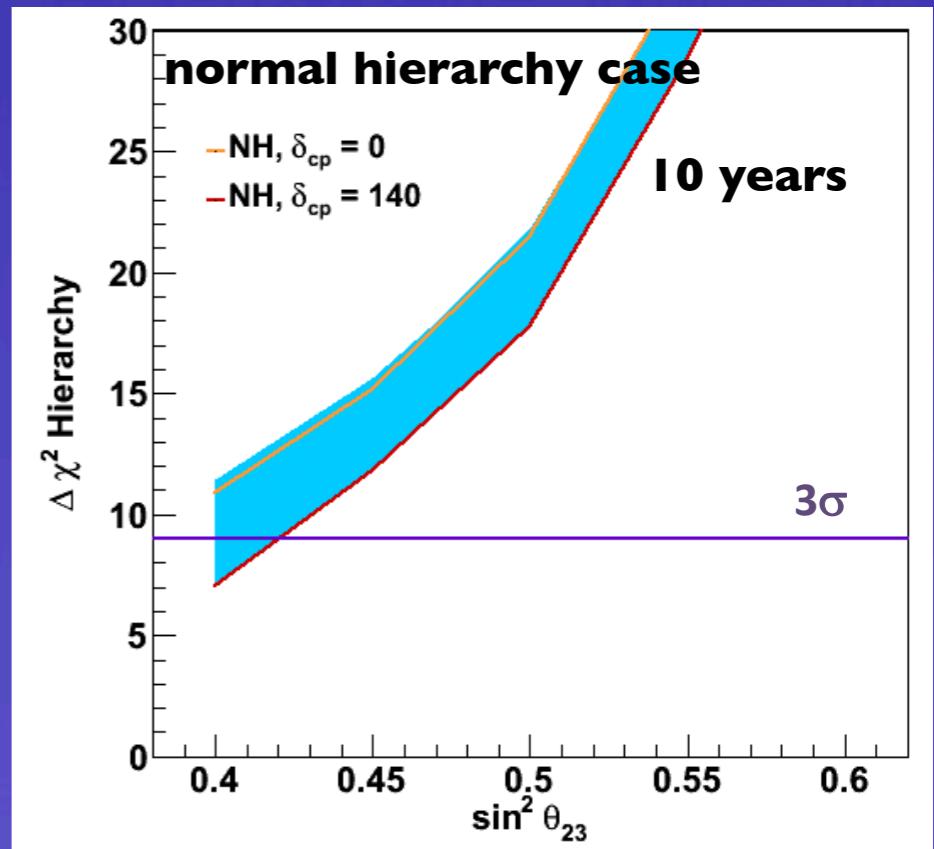


- Through matter effect (MSW), we study
 - Mass hierarchy → Asymmetry between neutrinos and antineutrinos.
 - Octant of θ_{23} → Magnitude of resonance effect
 - δ_{CP} (and θ_{13}) → Interference effects in \sim GeV energy region
- Appearance (and $\nu_\mu \rightarrow \nu_\mu$ disappearance) interplay

Mass Hierarchy Sensitivity

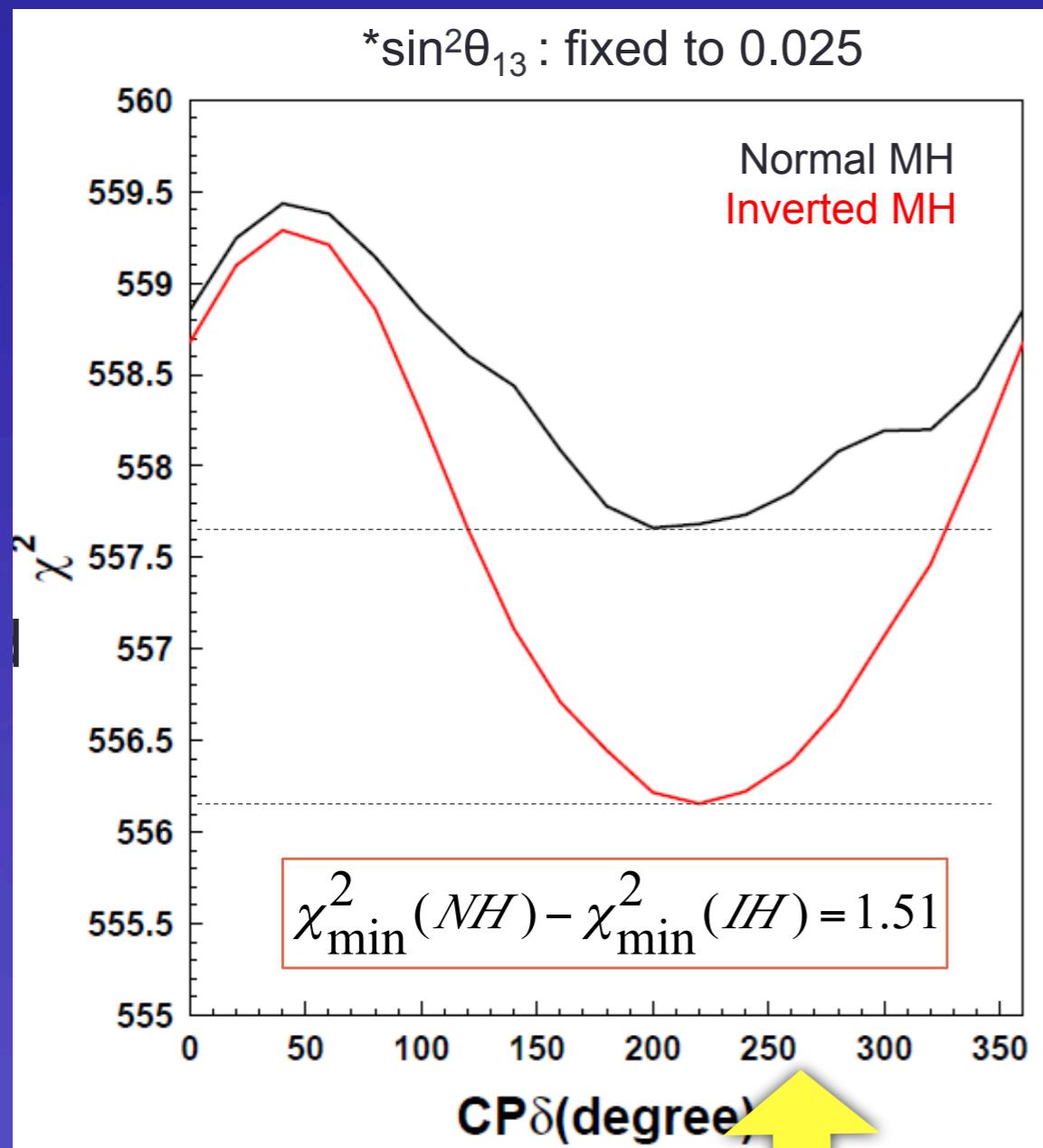


- Sensitivity depends on θ_{23} , δ and mass hierarchy (a little).
- 3σ mass hierarchy determination for $\sin^2 \theta_{23} > 0.42$ (0.43) in the case of normal (inverted) hierarchy.

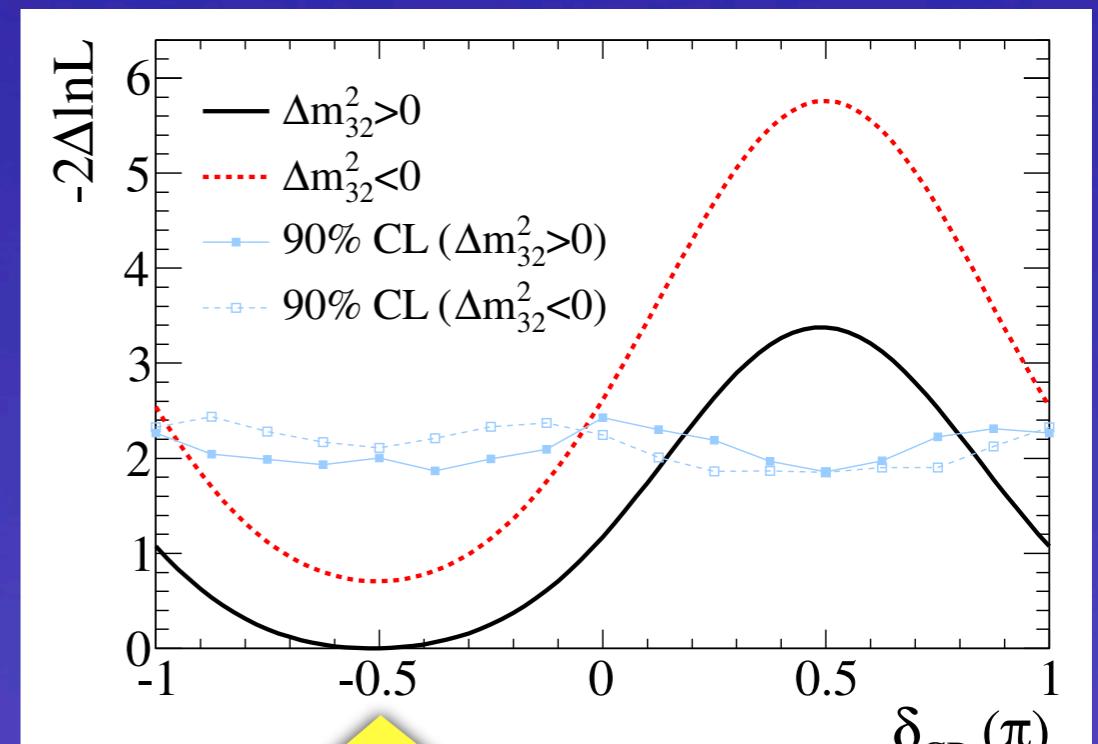


Recent Super-K result and the new T2K result

Super-K atm. v
by Jen Raaf@NNN13



T2K
arXiv:1311.4750 [hep-ex]



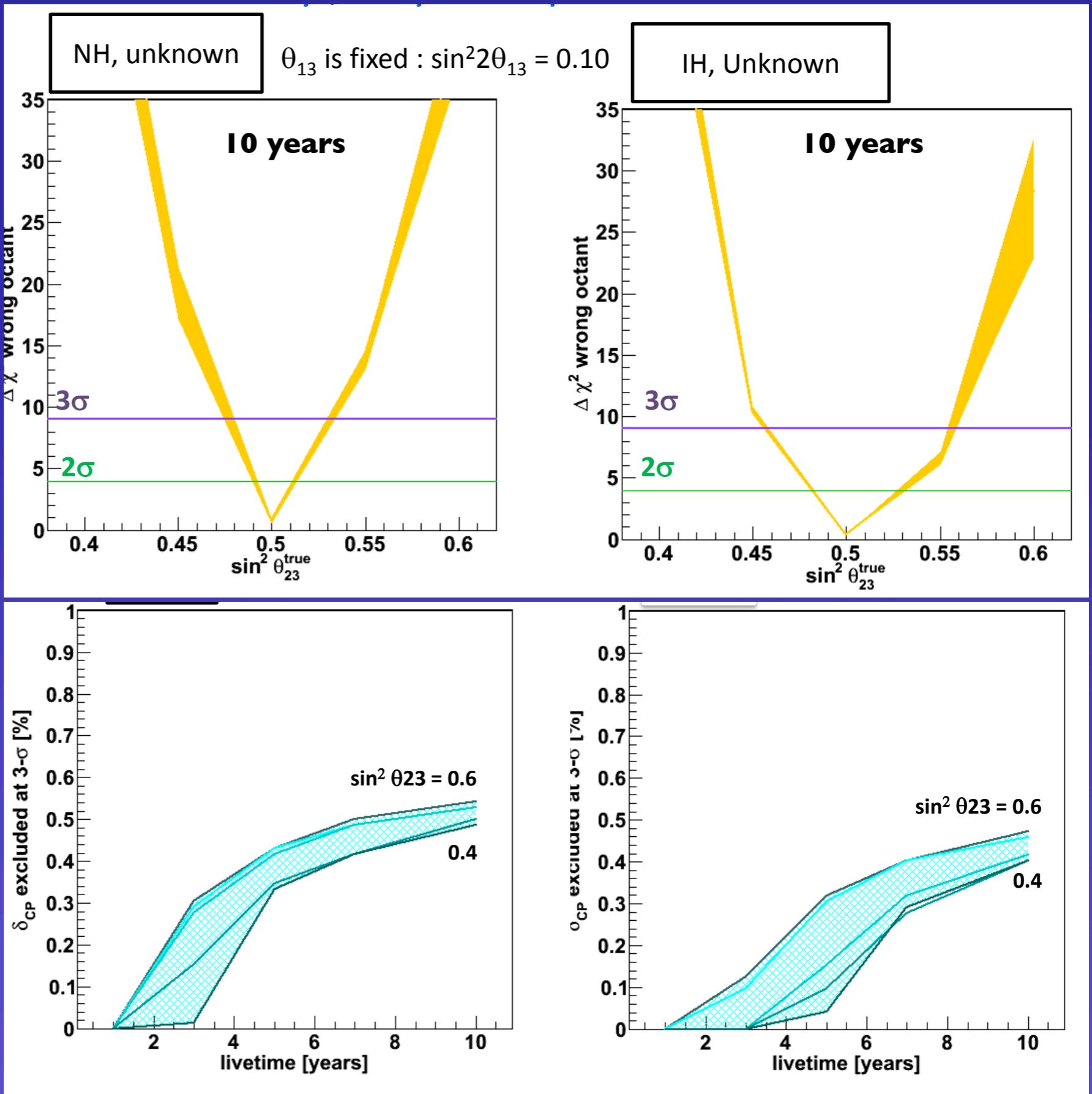
$\delta = -\pi/2$
still weak evidence, but ...

Sensitivity for θ_{23} octant and CPV

θ_{23} octant sensitivity

- (band depends on δ)

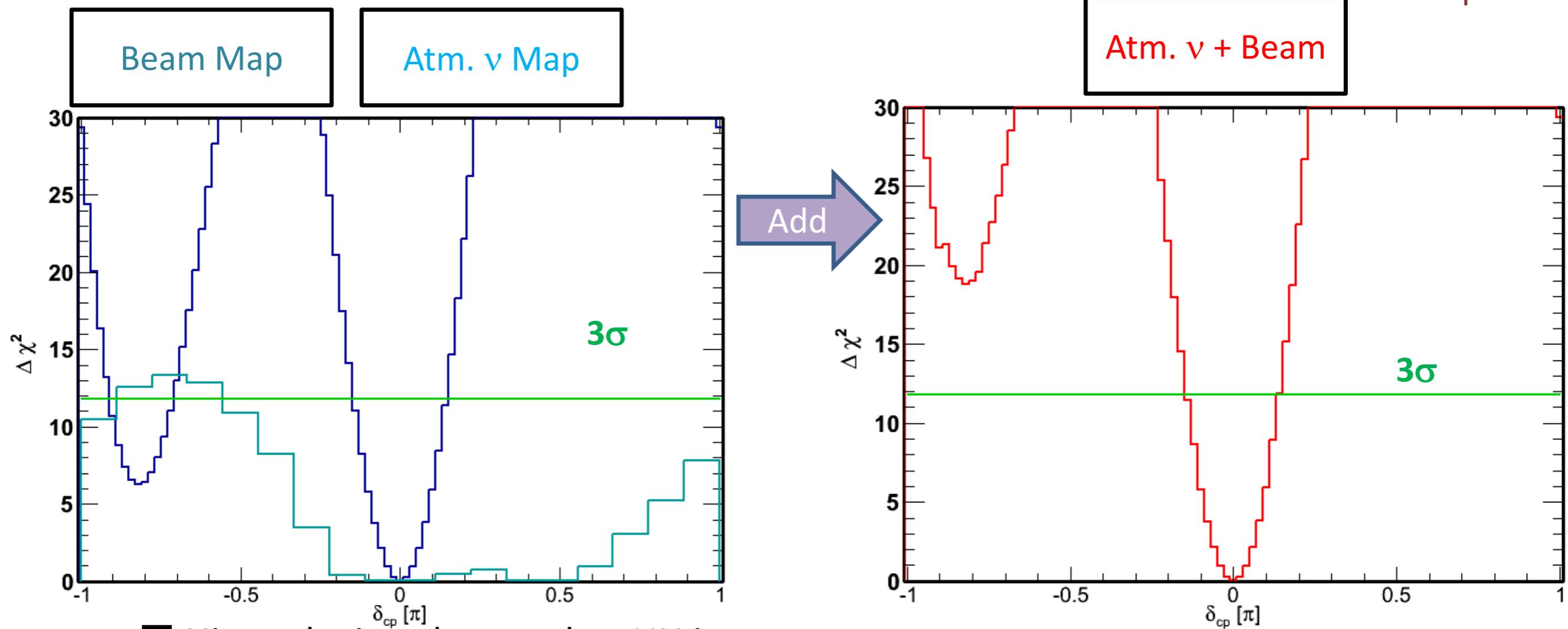
Fraction of δ_{CP} excluded (3 σ)



Combination of Beam and Atmospheric Neutrinos

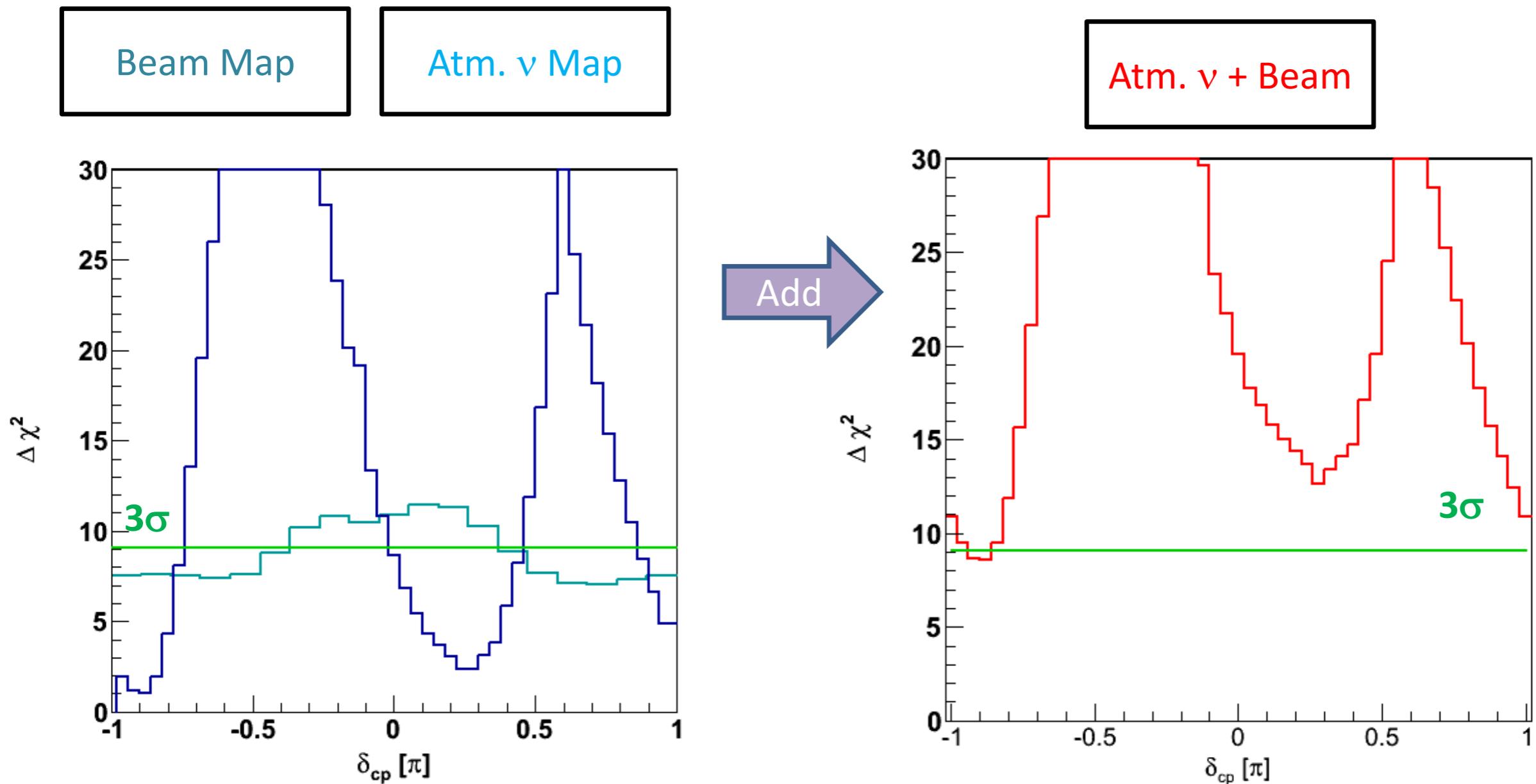
**Resolve mass hierarchy and the regeneracy
w/ $>3\sigma$!**

Combination of Beam and Atmospheric Neutrinos : Allowed δ_{cp}



- Hierarchy is unknown, but NH is true
- True $\delta_{cp} = 0.0$
- True $\sin^2 2\theta_{13} = 0.10$
- Maximal mixing , $\sin^2 2\theta_{23} = 1.0$
- Degenerate solution exists at 3σ in the beam only case - just add the χ^2 maps
- In the real world, something more sophisticated is in order

Hierarchy sensitivity : Combination of Beam and Atm. Neutrinos



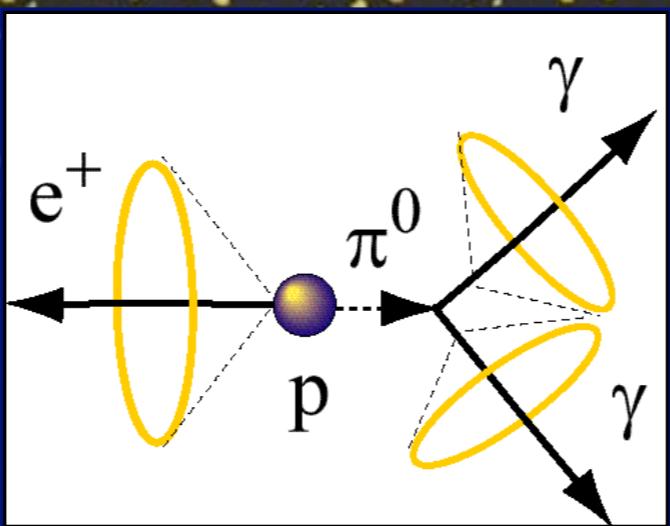
- Hierarchy is unknown, but the NH is true
 - True $\sin^2 2\theta_{13} = 0.10$
 - Using $\sin^2 \theta_{23} = 0.4$
 - Even under a conservative assumption its possible to achieve $\sim 3\sigma$ discrimination or all values of δ_{cp} if the true hierarchy is normal
- $\delta_{CP}=40$ degree

2012.8.22

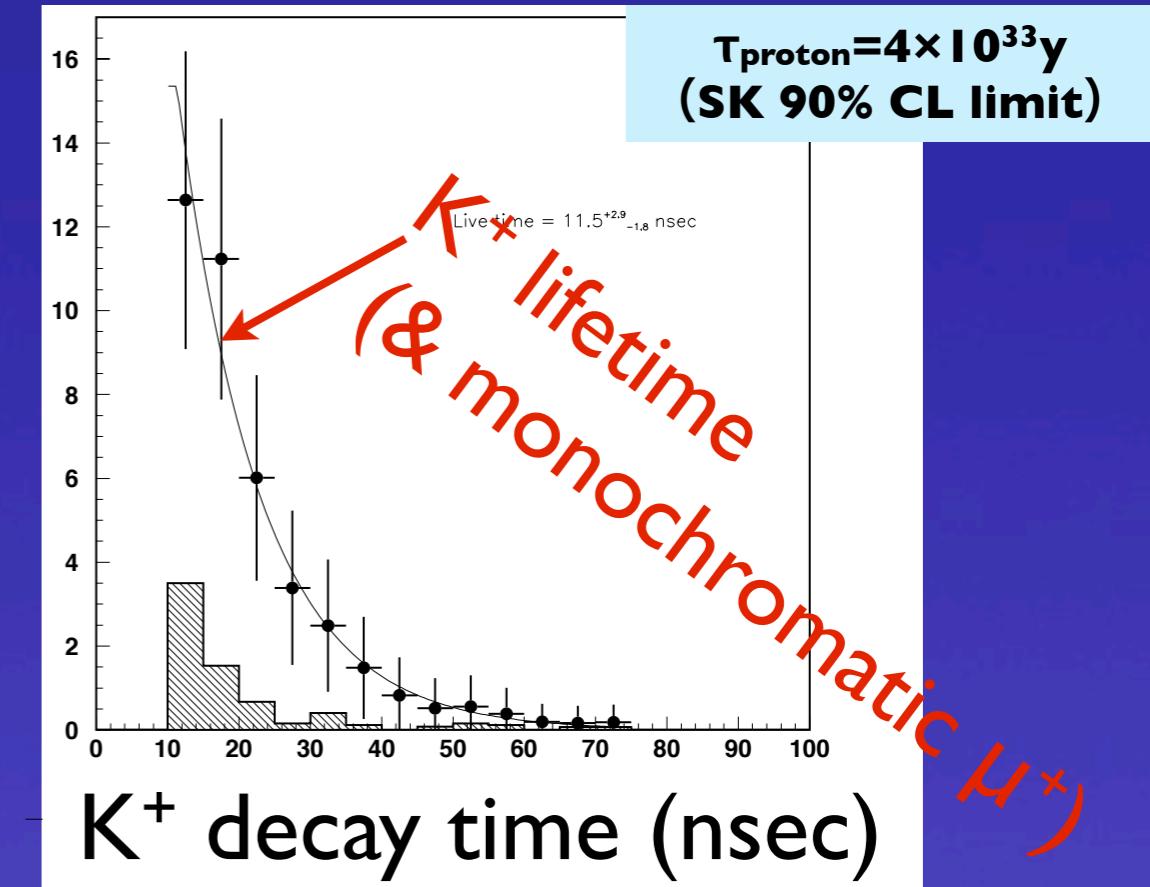
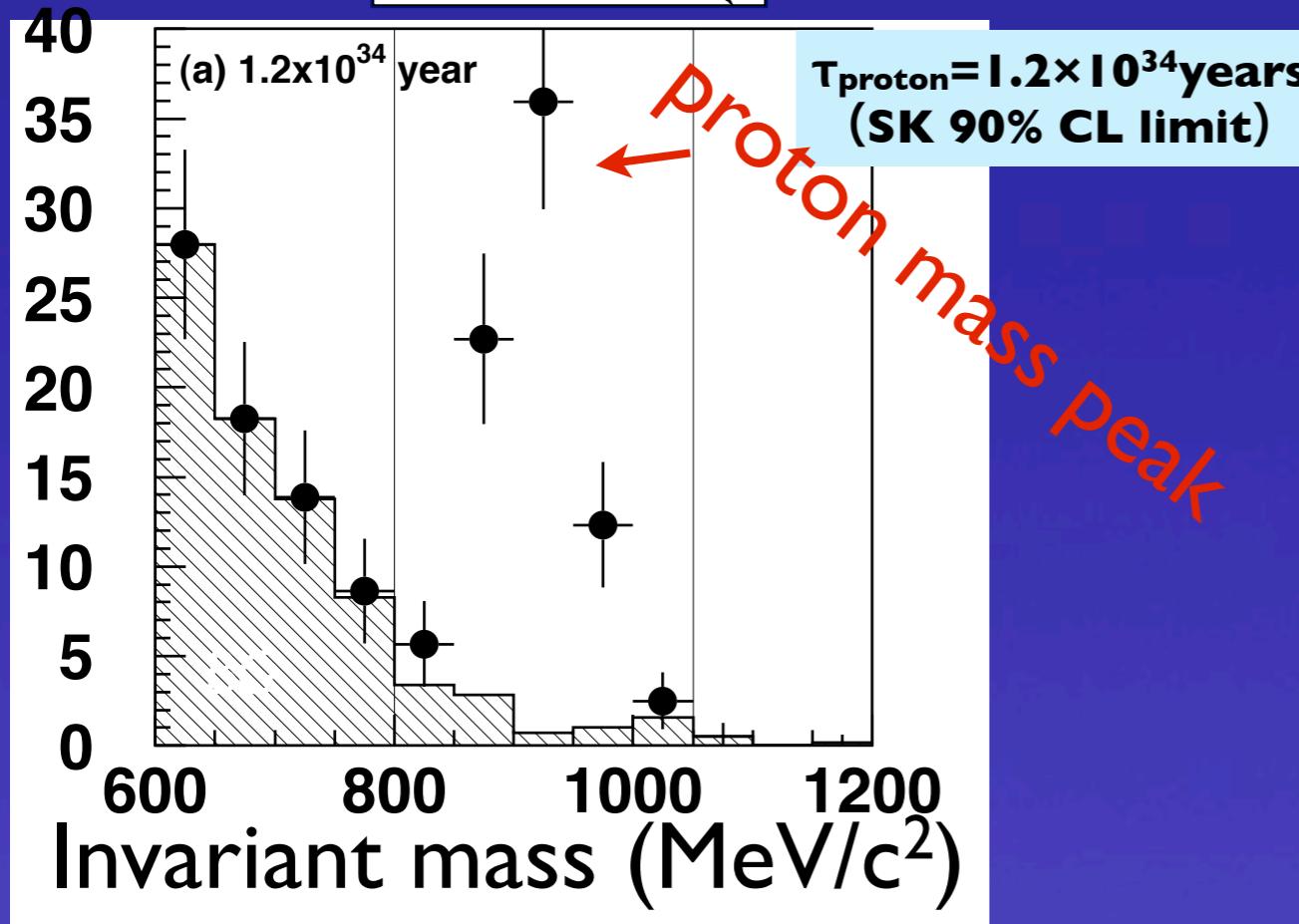
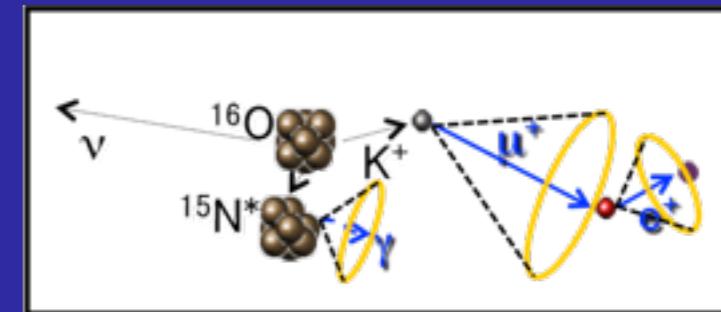
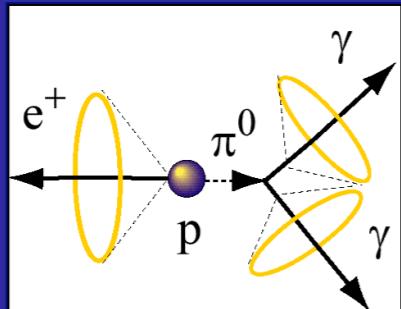
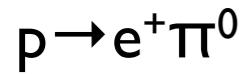
Roger Wendell

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Nucleon Decays



GUT tests by Nucleon Decay Searches



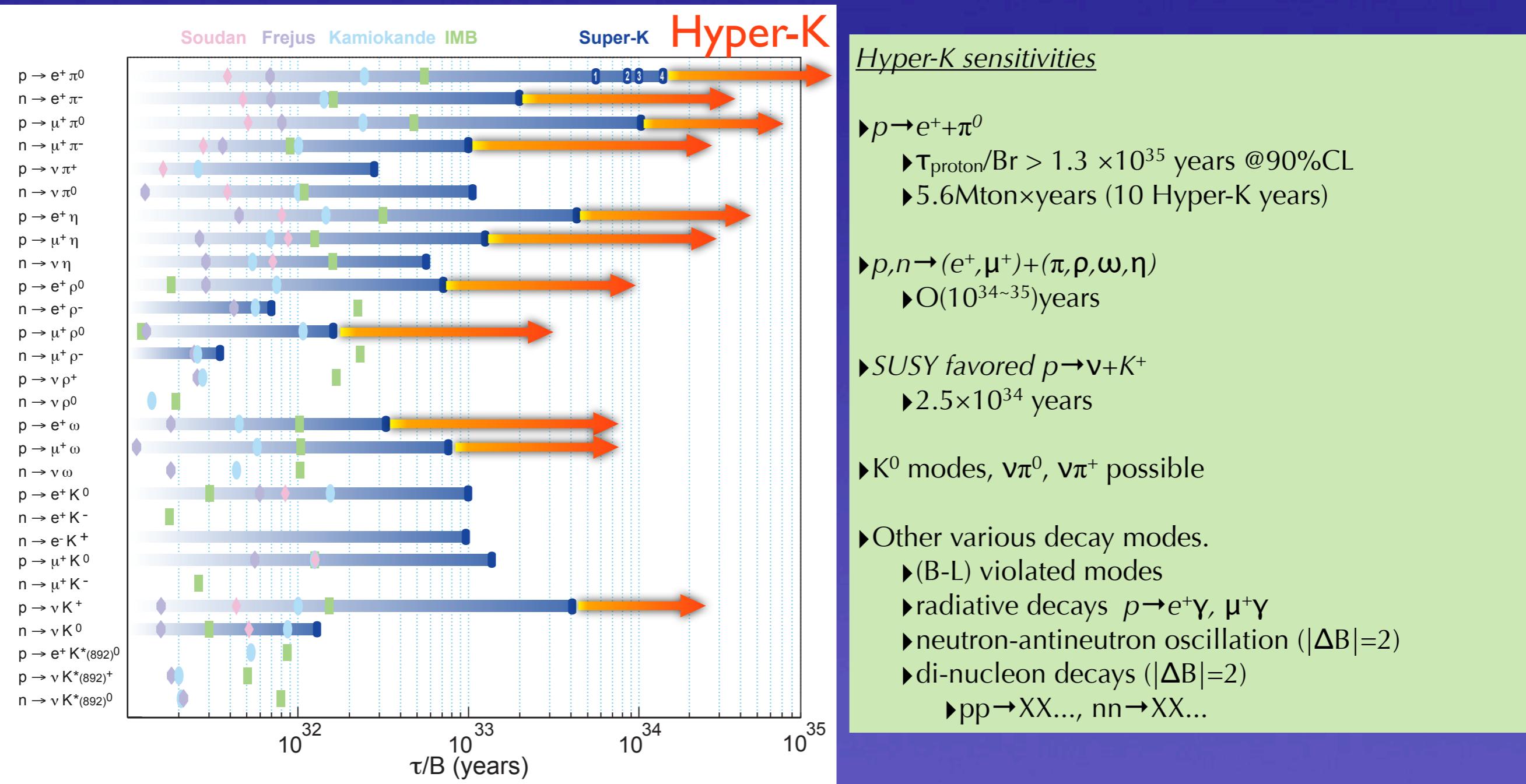
- Discovery reach (3σ)
- $\tau(p \rightarrow e^+ \pi^0) \sim 5.4 \times 10^{34} \text{ years}$ (HK 10 yrs)
- Limit (90%CL)
- $\tau(p \rightarrow e^+ \pi^0) > 1.3 \times 10^{35} \text{ years}$ (HK 10 yrs)

- Discovery reach (3σ)
- $\tau(p \rightarrow \nu K^+) \sim 1.2 \times 10^{34} \text{ years}$ (HK 10 yrs)
- Limit (90%CL)
- $\tau(p \rightarrow \nu K^+) > 3.2 \times 10^{34} \text{ years}$ (HK 10 yrs)

Good discovery potential, 90% CL sensitivity of $10^{34} \sim 10^{35}$ yrs

Search for nucleon decays

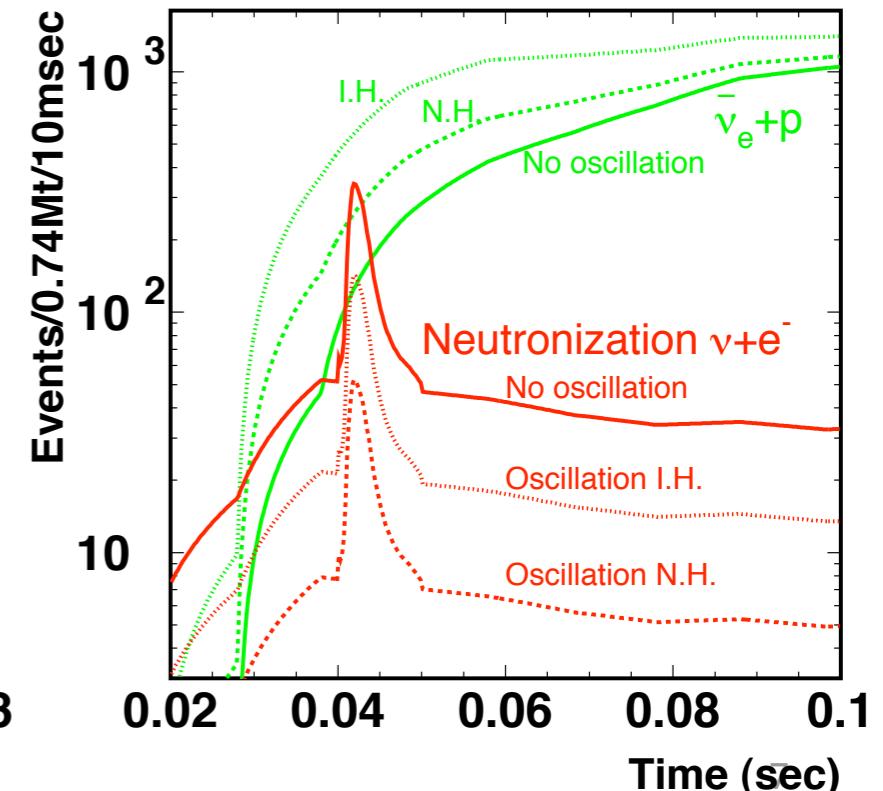
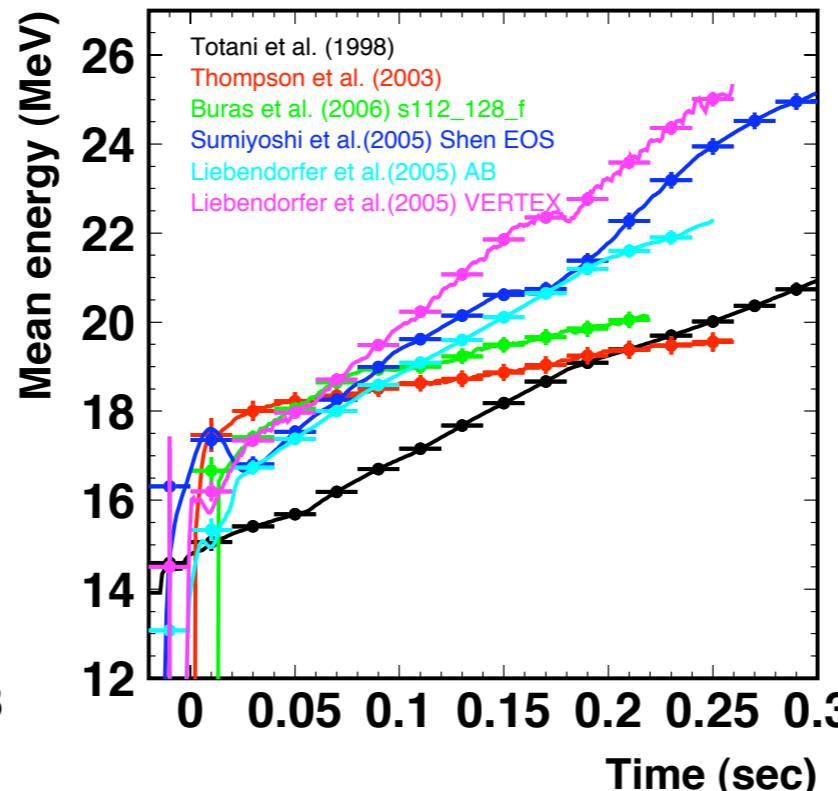
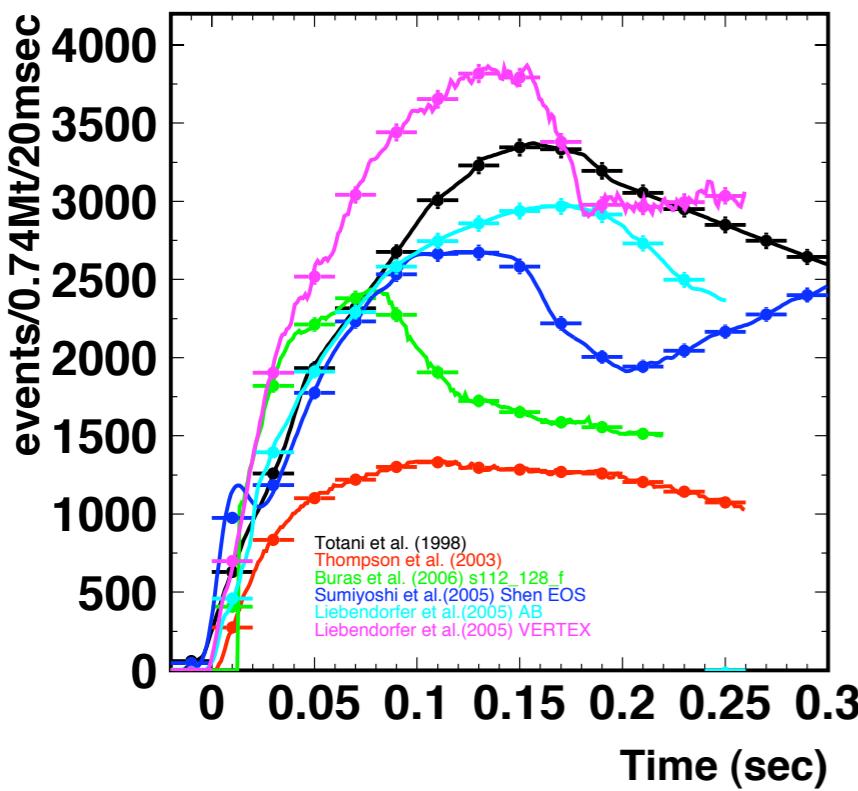
- 10 times better sensitivity than Super-K.
- only realistic plan to go beyond 10^{35} years for $p \rightarrow e^+ + \pi^0$
- $>3\sigma$ discovery is possible for lifetime beyond Super-K limits.



Cosmic Neutrinos

ν burst @ Milky way (10kpc)

- High statistical observation by 200,000 ν events
 - Time variation of (ν luminosity, temperature, flavor)
 - Explore core collapse and cooling mechanism (model)
 - exp'd νe from neutronization is 20(NH) or 56(IH) in 10msec duration \rightarrow precise moment when a neutron star is born.
 - Precise time determination \sim 1ms \rightarrow combined study w/ optical and gravitational wave observation
 - Absolute ν mass (ν 's TOF) \rightarrow 0.3~1.3eV/c²
 - Energy spectrum transition by ν mass hierarchy

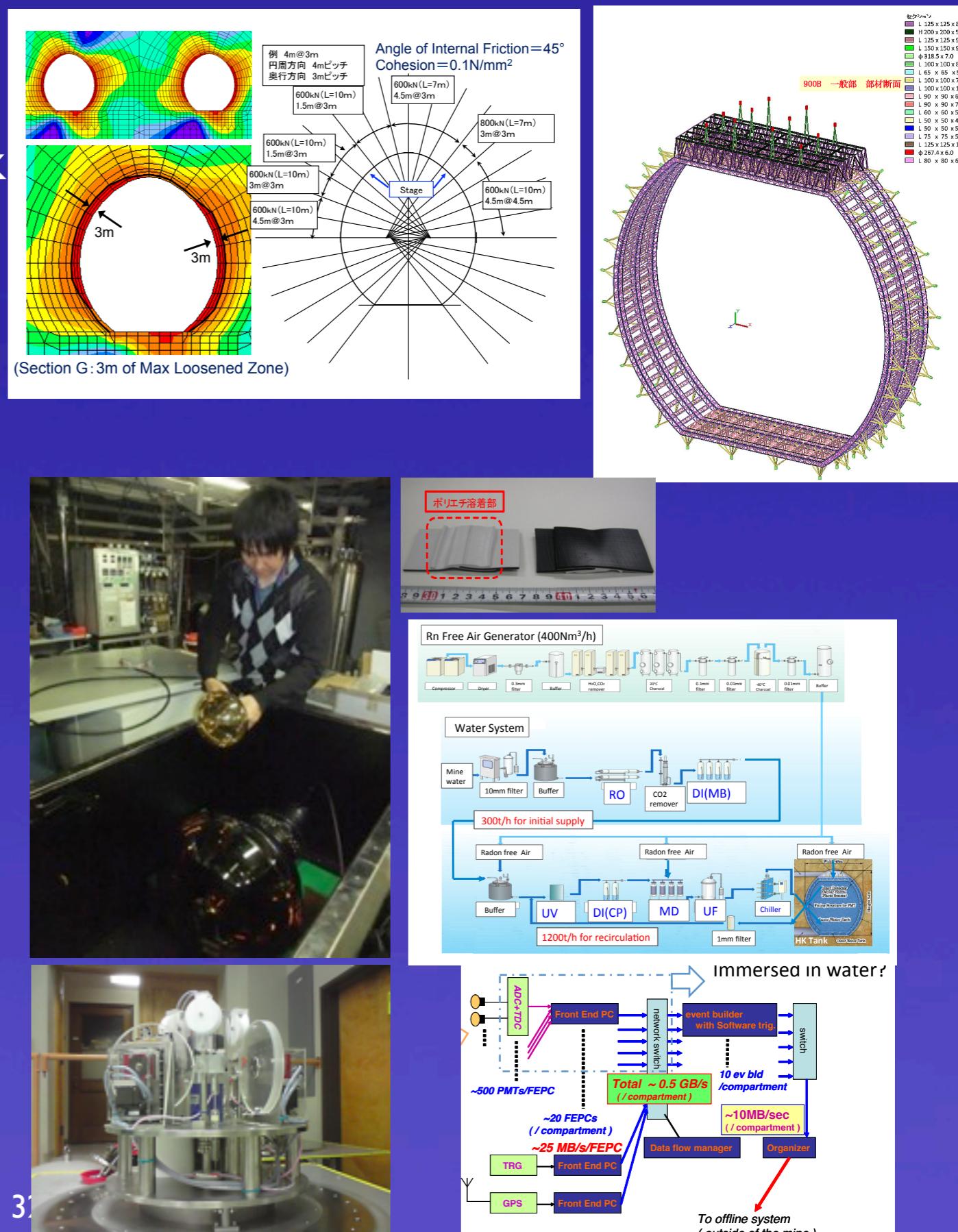


Status of R&D

- We should advance R&D more and complete many R&D subjects on schedule.
 - (Personal opinions)
 - It is necessary for the full budget approval with reliable cost estimates.
 - [Japanese] Scientists in other fields recognize/understand/support neutrino physics in Japan. We have to convince them for Hyper-K with many global activities.

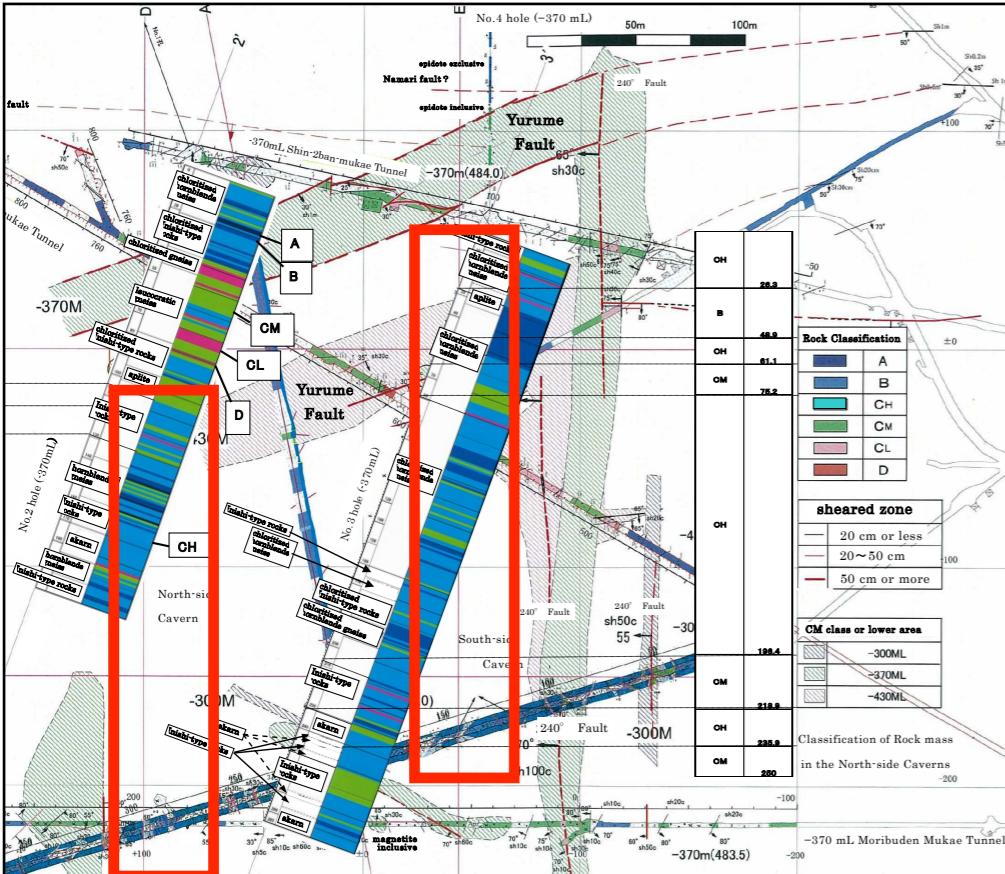
Development works

- Detector design optimization
 - tank shape, segmentation wall, tank liner, PMT support structure
- Water purification system, water quality control
- DAQ electronics (under water?)
- Calibration source deployment system
 - automated, 3D control
- Software development
 - Detector geometry optimization, enhance physics capabilities
- Physics potential studies
 - requirements for near detectors

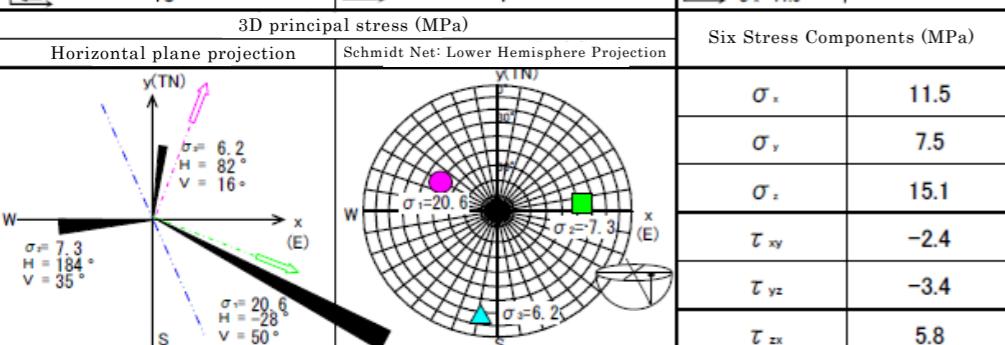
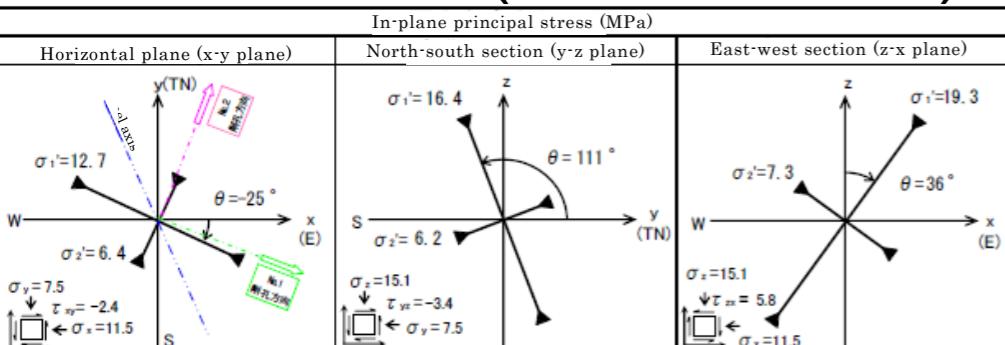


Geological survey & Cavern stability

Rock mass characterization



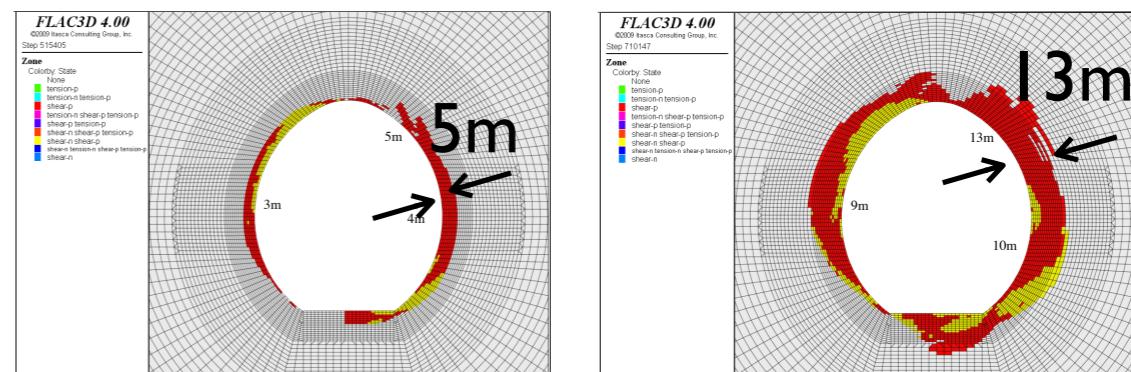
Initial stress (in-situ meas.)



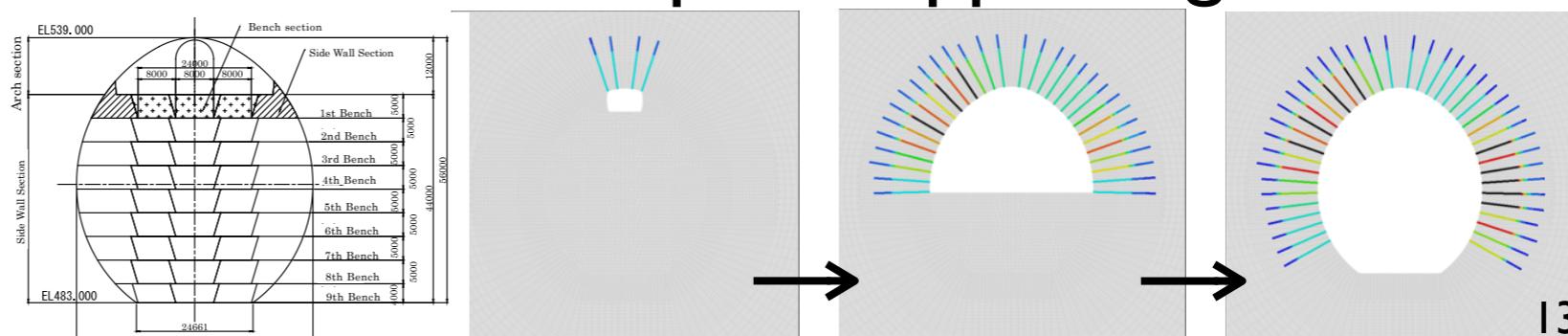
- Detailed geological surveys at the candidates site vicinity
- Cavern stability and its supporting method has been studied
- Confirmed that the HK cavern can be constructed with the existing techniques

Survey in the Mozumi (Super-K) area is on-going.

Cavern stability

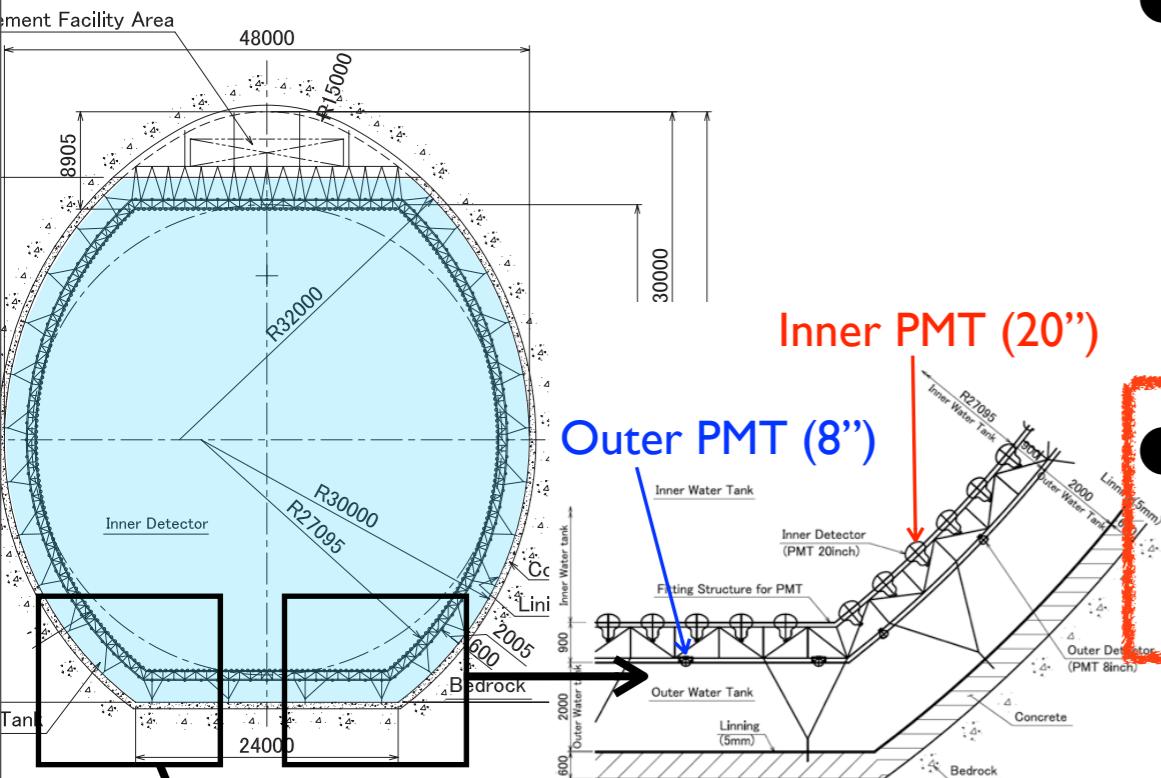


Excavation steps & supporting method



Tank and photo-sensor support

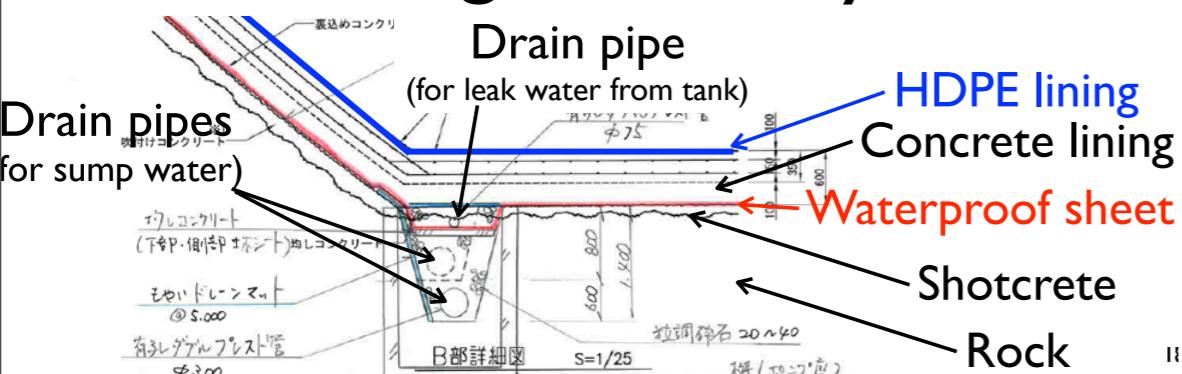
CROSS SECTION



- Baseline designs of the water containment system and photo-sensor support are ready

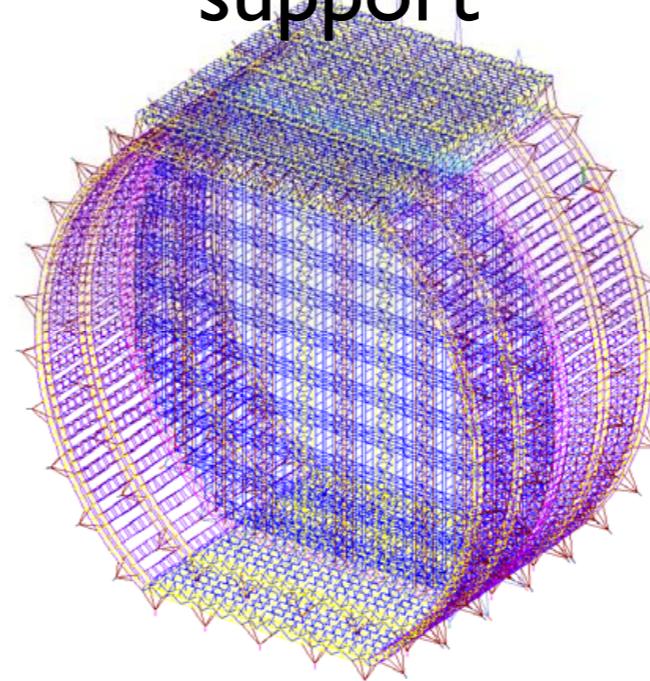
- Build a prototype detector (1 kt)
- Funding request approved

Lining & drain system

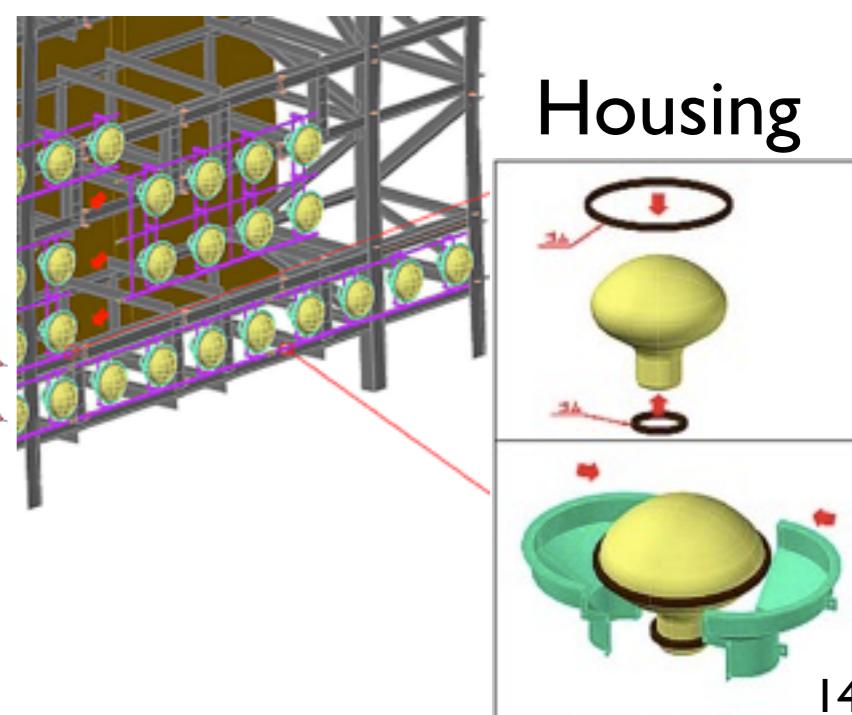


Polyethylene sheet

Photo-sensor support

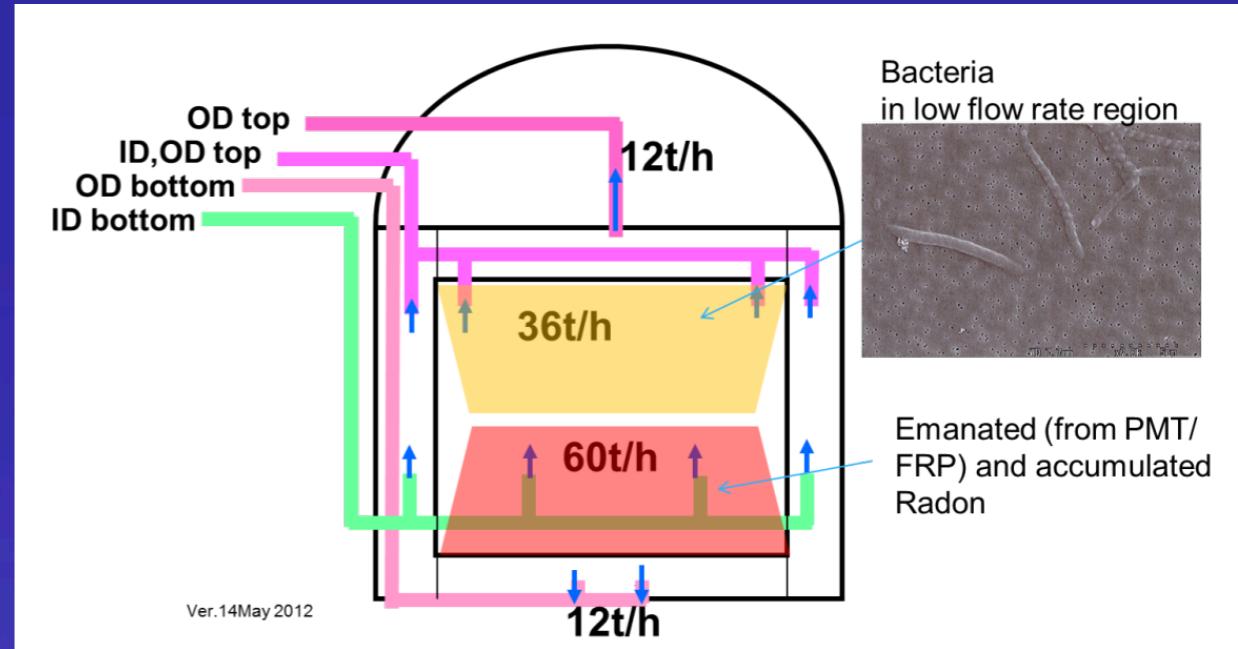


Mounting Photo-sensor

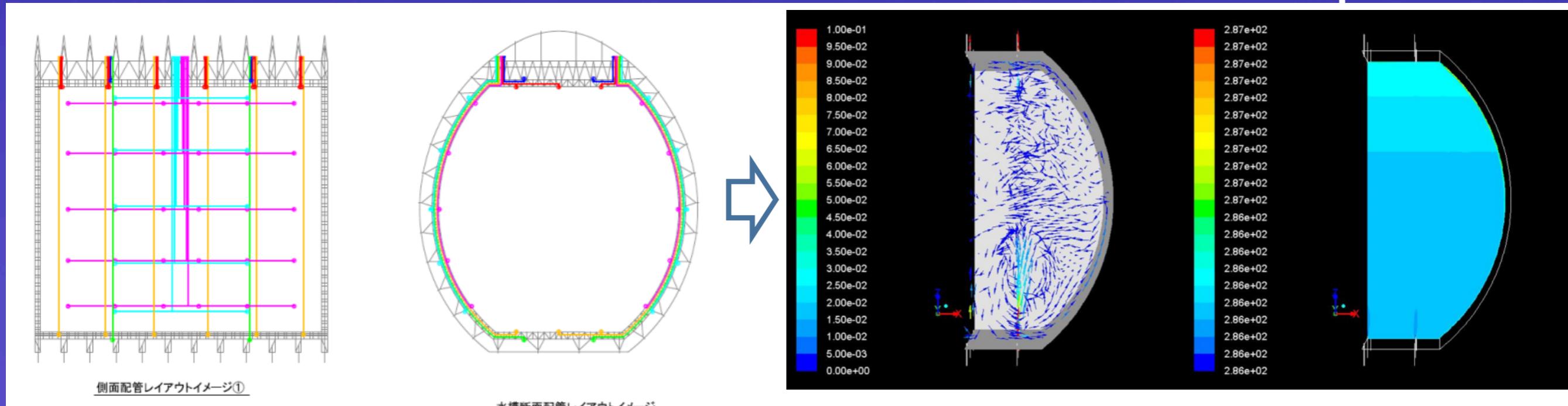


Water Quality Control and Purification system

Water Simulation is under development

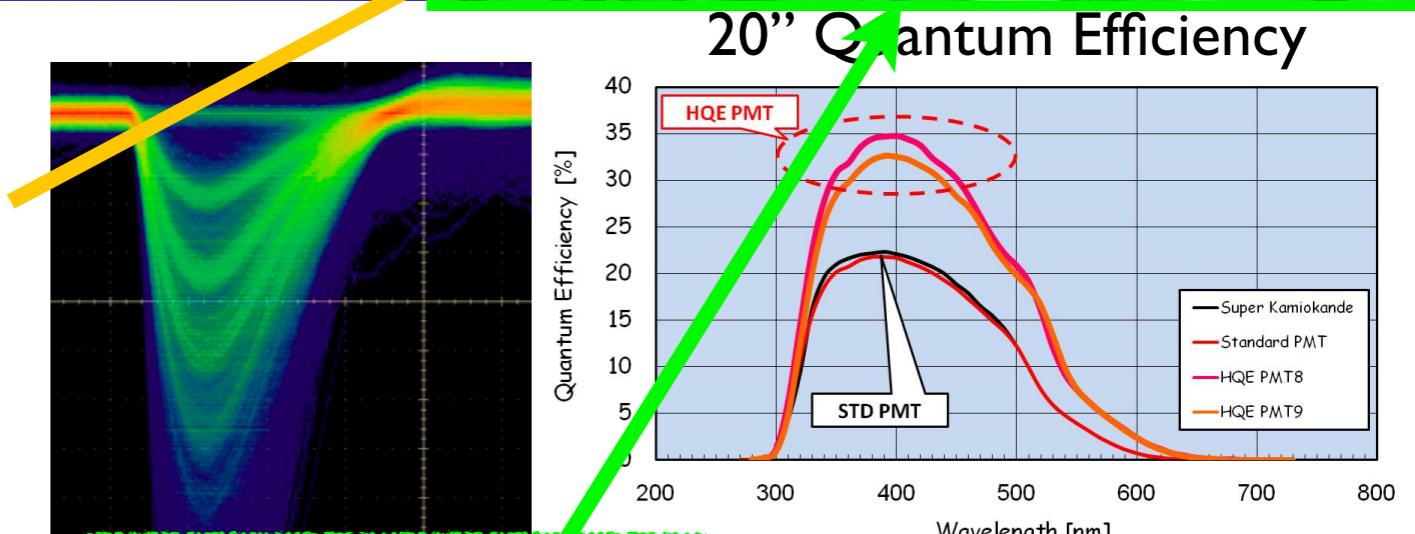
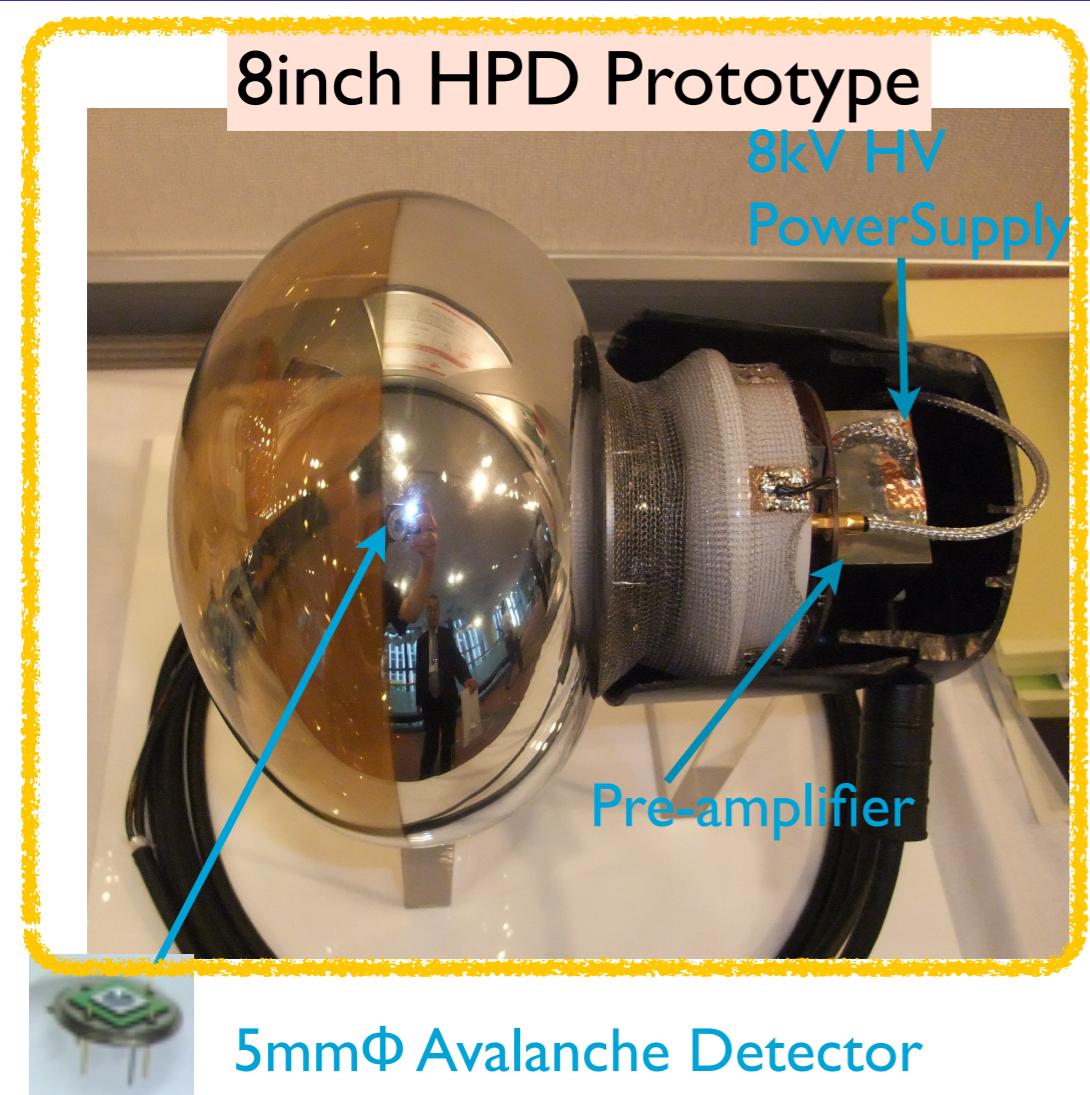


water flow temparature



New PhotoSensor Development

- High QE 20' PMT (baseline)
- High QE 20' HPD (desired option)
- Installing the new sensors (8' HPD and 20' High-QE PMT) in EGADS 200 ton tank for a long term test as a Water Cherenkov Detector

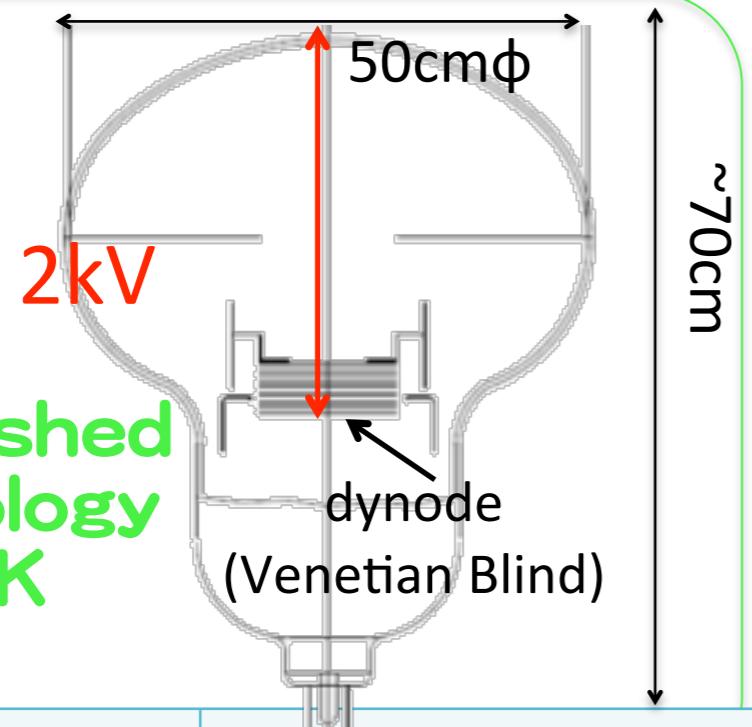


young physicists

Candidate of HK photo-sensor (50cm ϕ)

PMT R3600

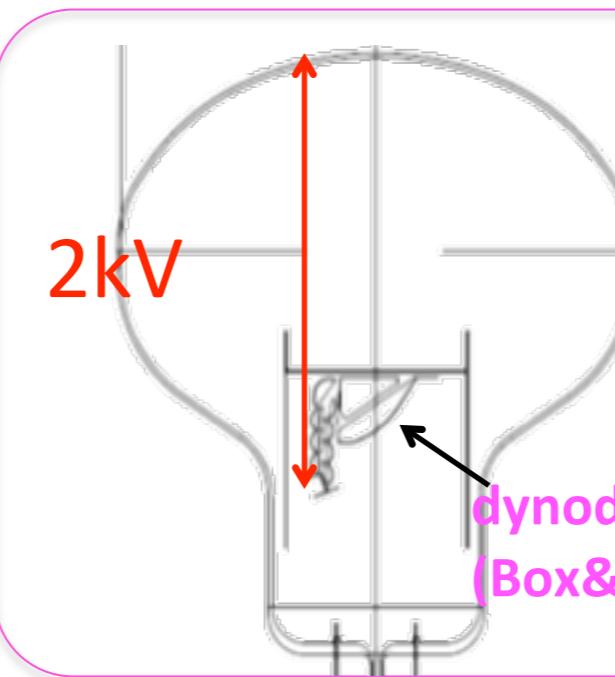
(Hamamatsu Photonics K.K.)



Established technology in SK

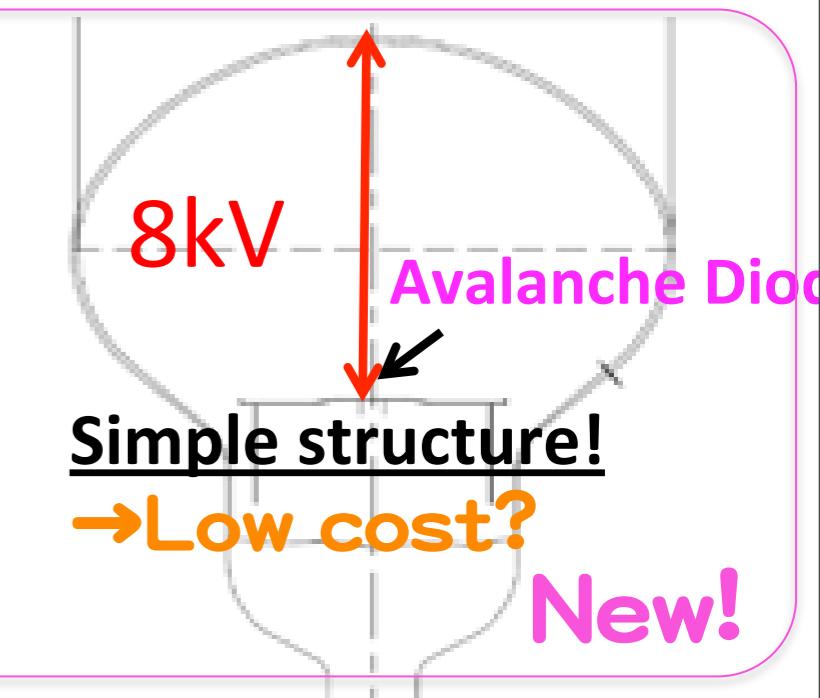
PMT R12860

(Hamamatsu Photonics K.K.)



HPD R12850

(Hamamatsu Photonics K.K.)



Simple structure!
→ **Low cost?**

New!

Gain	10^7	10^7	$10^{4\sim 10^5}$
T.T.S.(FWHM)	~5.5ns	~2.7ns	~0.75ns
C.E.	80%	93%	95%
P/V @1p.e.	1.4	>2.5	>3

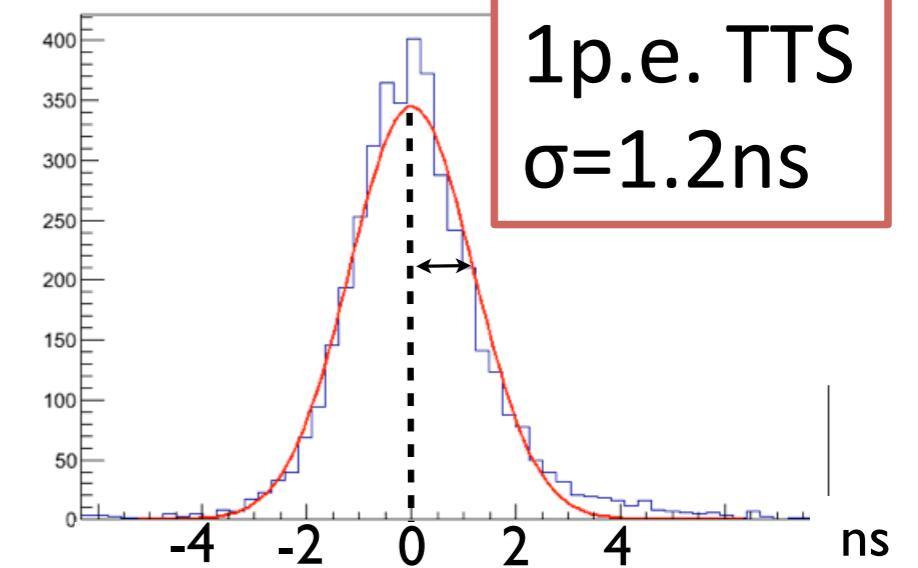
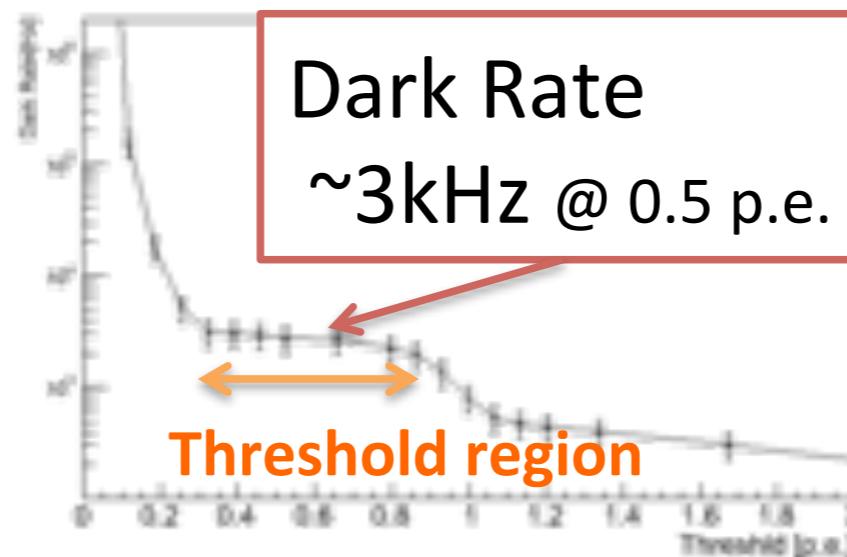
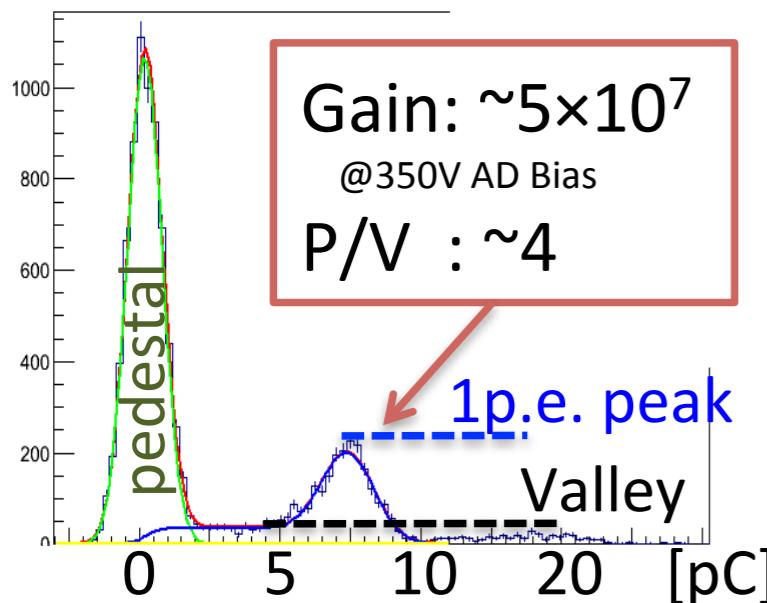
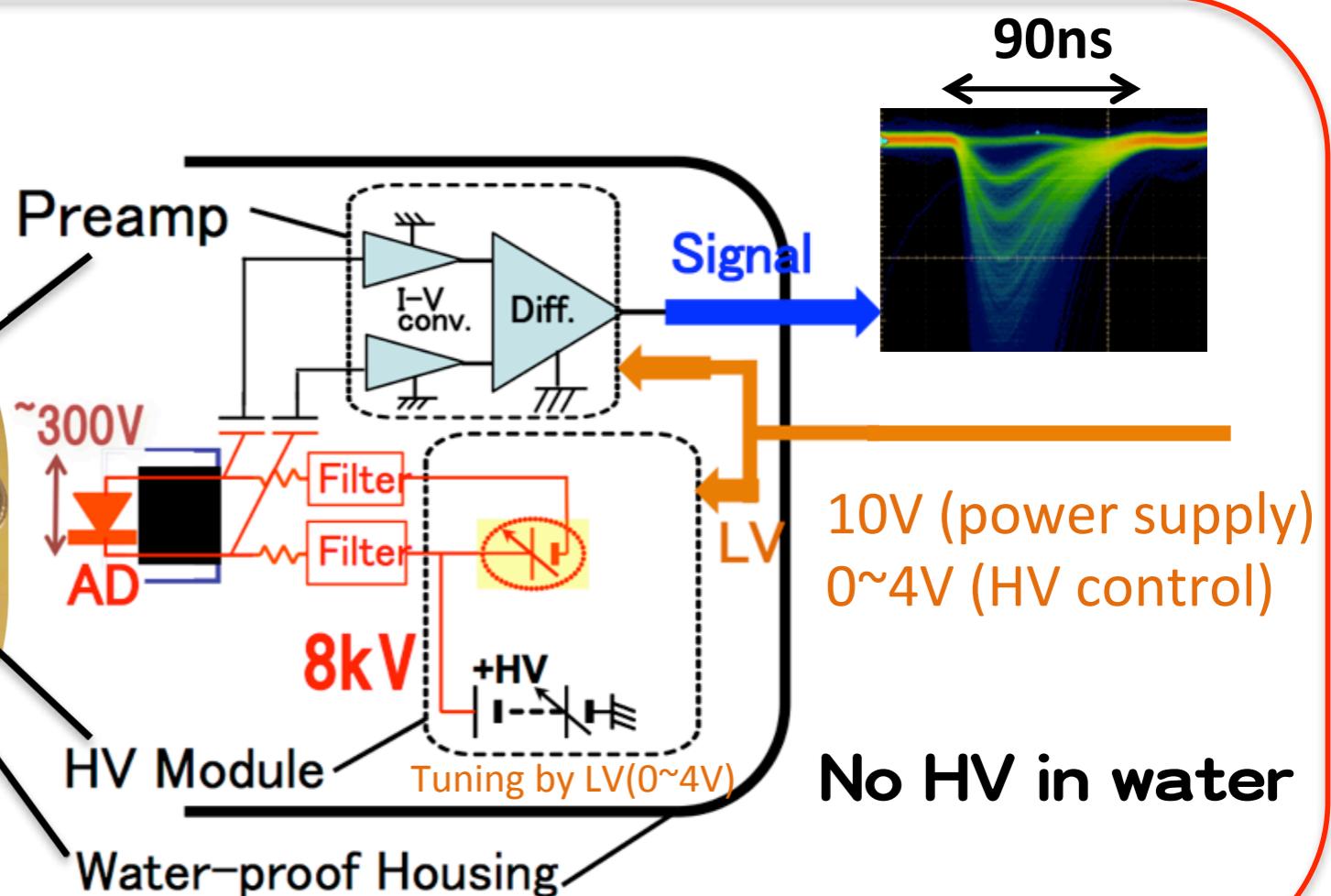
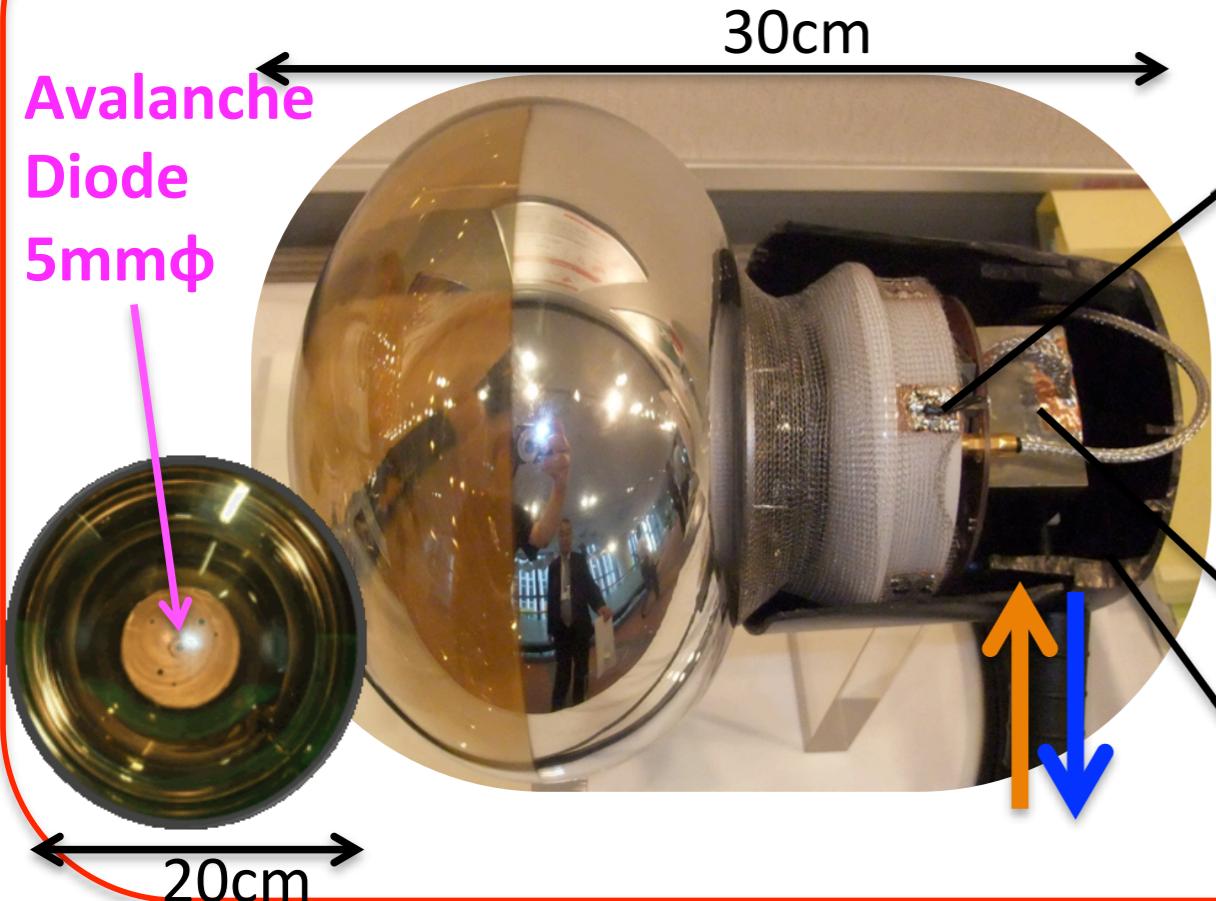
New! High QE (HQE) option for all photo-sensors! (22% → 30%)

→ **Expectation of better performance!**

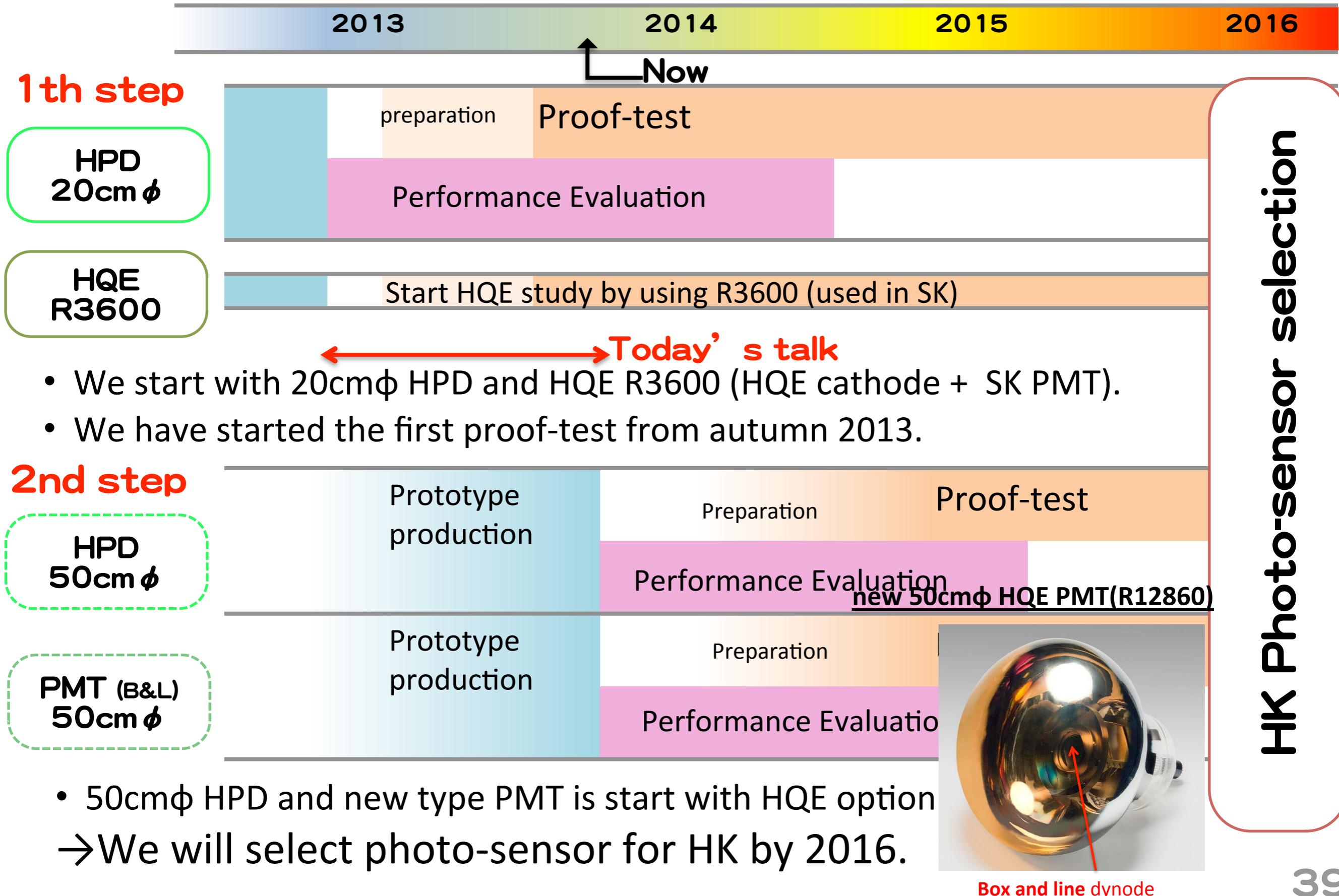
- New technology must be verified. → **Proof-test**
- Expected better performance must be confirmed → **Performance evaluation**

The prototype of 20cm ϕ HPD

Prototype of 20cm ϕ HPD



Overview of development



Need more contributions to

- Electronics R&D and proto-type building
 - working in the water with reasonable cost
- DAQ R&D and proto-type building
- Software development
- Automated Calibration technique
- Verify all the system with **a proto-type detector.**
 - also consider the **neutrino beam exposure** in the T2K neutrino beam line
- These are the important inputs to the next stage document.
 - LOI (2011) → **DONE**
 - CDR (2013-2014)
 - **J-PARC PAC Proposal for T2HK (by May 2014)**
 - TDR

Status of the Hyper-K project

- NOTE :
 - In Japan, we do not have the US system of CD1, CD2,
 - The government official approval is very serious. CD3 in US?
 - The project must be construed with the fixed term within the allocated budget w/o contingency.
 - Community consensus is very important and necessary.
 - Bottom Up approach (not top-down like US)
 - R&D budget (including a proto-type detector) for Hyper-K is approved in 2013.

Hyper-K status in Japan

- Recommendation by **HEP community**

- http://www.jahep.org/office/doc/201202_hecsubc_report.pdf
- Recommendations for two large-scale projects
 - Linear Collider
 - **Large-scale Neutrino & Nucleon decay Detector**

- **KEK roadmap includes Hyper-K**

- <http://kds.kek.jp/getFile.py/access?sessionId=1&resId=0&materialId=0&confId=11728>
- **Cosmic Ray community endorses Hyper-K as a next large-scale project**
- **The master plan for large scale projects in Science Council of Japan**
- A proposal of large neutrino/nucleon-decay detector is submitted with Hyper-K. J-PARC neutrino beam operation w $\sim >1\text{MW}$ and a near detector complex are also packaged. We expect the result soon.
- (Ref.) the master plan in 2010, Hyper-K was described in page 20
 - <http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-21-t90-e2.pdf>

- <http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-21-t90-e2.pdf>

Recommendation

Japanese Master Plan of Large Research Projects

— A Table of 43 Selected Projects —



17 March 2010

Science Council of Japan

Committee for Scientific Community

Subcommittee for Large Research Projects

A Nucleon Decay and
Neutrino Oscillation
Experiments with
Large Advanced
Detectors

C
:
C
2

b)
This project builds up on the
legacy of Super Kamiokande
with a large number of
international institutions.

A high priority will be
considered by both particle
and cosmic ray physics
communities if the on-going
long baseline neutrino (J-
PARC to Kamioka T2K)
experiment obtains the
expected results.

A	Nucleon Decay and Neutrino Oscillation Experiments with Large Advanced Detectors	Construction : 2010-75. Operation: 2/year.	Construction : 2014 to 2020. Operation: 2021 to 2035.	Advance neutrino physics/astronomy and search for nucleon decays using a large water Cherenkov detector that is approximately 20 times larger in volume than Super Kamiokande and/or a large liquid argon detector.	It would discover the particle- antiparticle asymmetry (CP asymmetry) in the lepton sector by shooting a muon neutrino beam from J-PARC to the advanced large neutrino detector. It will also probe the grand unified theories by searching for nucleon decays.	b) This project builds up on the legacy of Super Kamiokande with a large number of international institutions.	A high priority will be considered by both particle and cosmic ray physics communities if the on-going long baseline neutrino (J- PARC to Kamioka T2K) experiment obtains the expected results.
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page 20

Japan HEP community

- http://www.jahep.org/office/doc/201202_hecsubc_report.pdf

Recommendations

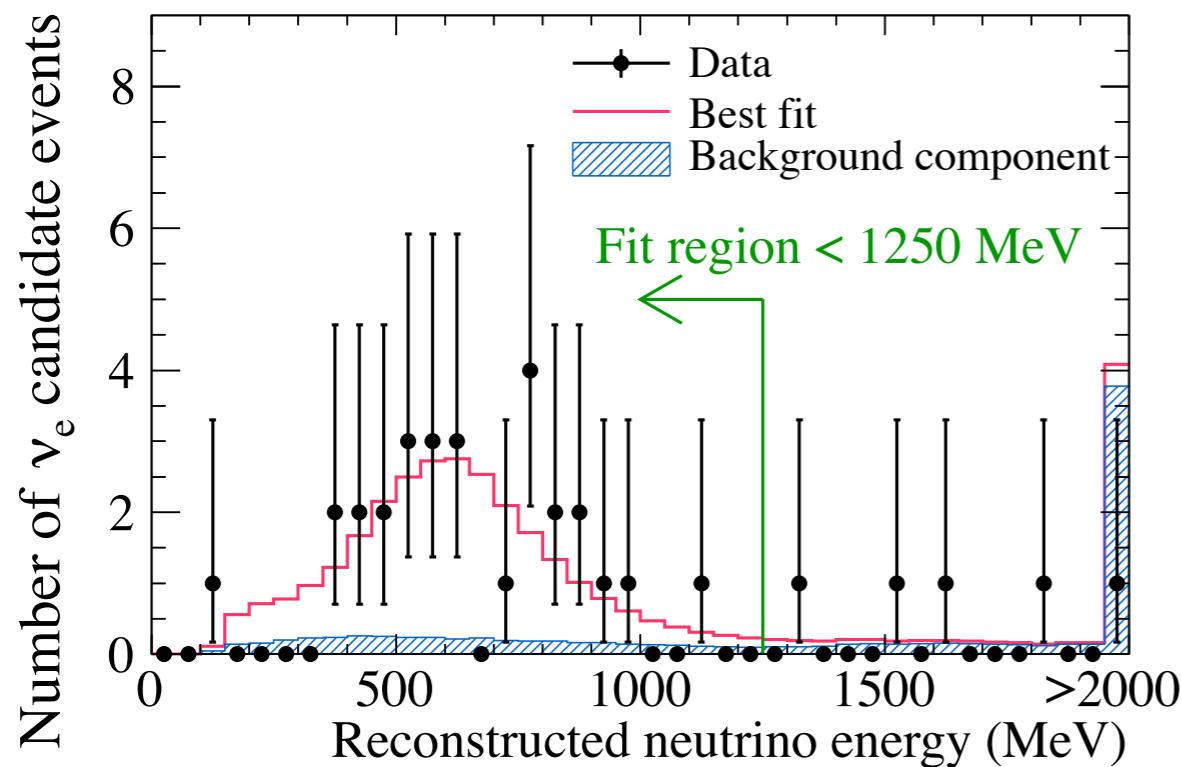
The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- **Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider.** In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.
- **Should the neutrino mixing angle θ_{13} be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations.** This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.

accepted by PRL

Observation of Electron Neutrino Appearance in a Muon Neutrino Beam

K. Abe,⁴⁶ J. Adam,³² H. Aihara,^{45,23} T. Akiri,⁹ C. Andreopoulos,⁴⁴ S. Aoki,²⁴ A. Ariga,² T. Ariga,² S. Assylbekov,⁸ D. Autiero,²⁹ M. Barbi,³⁹ G.J. Barker,⁵⁴ G. Barr,³⁵ M. Bass,⁸ M. Batkiewicz,¹³ F. Bay,¹¹ S.W. Bentham,²⁶ V. Berardi,¹⁸ B.E. Berger,⁸ S. Berkman,⁴ I. Bertram,²⁶ S. Bhadra,⁵⁸ F.d.M. Blaszczyk,²⁸ A. Blondel,¹² C. Bojochko,⁵ S. Bordoni,¹⁵ S.B. Boyd,⁵⁴ D. Brailsford,¹⁷ A. Bravar,¹² C. Bronner,²⁵ N. Buchanan,⁸ R.G. Calland,²⁷ J. Caravaca Rodriguez,¹⁵ S.L. Cartwright,⁴² R. Castillo,¹⁵ M.G. Catanesi,¹⁸ A. Cervera,¹⁶ D. Cherdack,⁸ G. Christodoulou,²⁷



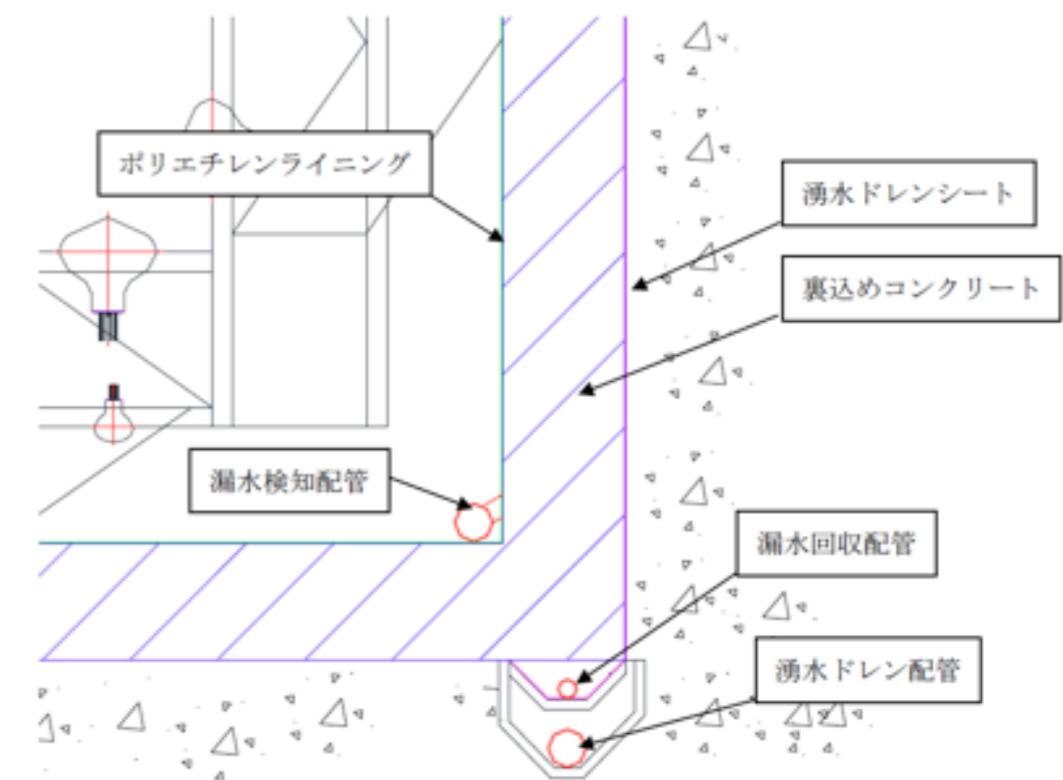
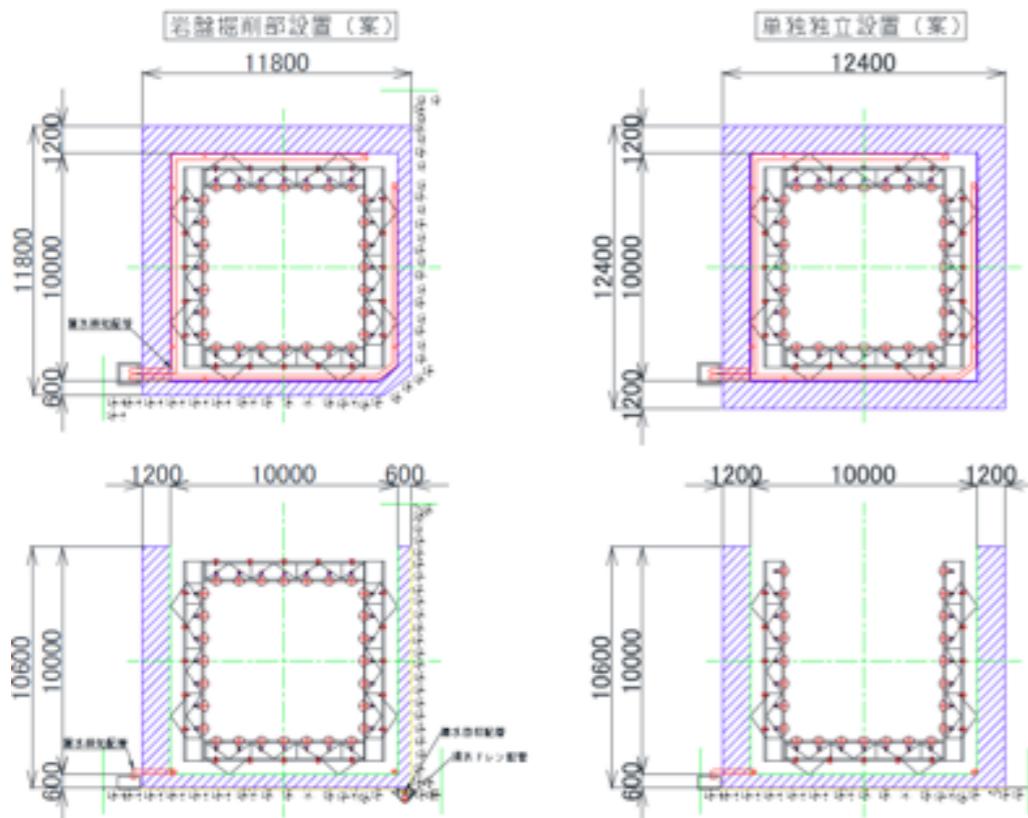
The condition is satisfied.
The νe appearance channel
is firmly observed.

FIG. 4. The E_ν^{rec} distribution for ν_e candidate events with the MC prediction at the best fit of $\sin^2 2\theta_{13} = 0.144$ (normal hierarchy) by the alternative binned E_ν^{rec} analysis.

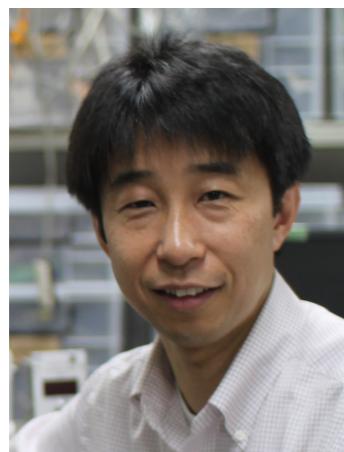
Approved budget for the Hyper-K prototype w/ several R&D subjects

Grant-in-Aid → \$1.7M/5 year

- Prototypical Detector
 - ~1kton ($10 \times 10 \times 10 \text{m}^3$)
 - Feasibility test of
 - Liners
 - Leak water collection (drain), detection
 - photo-sensor support structure
 - DAQ system
 - Calibration system
 - Including development of Water system, Photo-sensor, Electronics, Calibration system, Software ...



Science and Engineering



Title of Project : Unification and Development of the Neutrino Science Frontier

Tsuyoshi Nakaya (Kyoto University, Graduate School of Science, Professor)

【Content of the Research Project】

This project will advance experiments to study the properties of neutrinos, observe neutrinos in nature, develop new technologies for particle physics experiments, and promote theoretical studies in neutrino field. We have the following research projects. (a) Measurement of neutrino oscillation using a neutrino beam from the J-PARC accelerator to the Super-Kamiokande detector (Fig. 1). (b) Measurement of neutrino oscillation by observation of reactor neutrinos and further application of the techniques to reactor monitoring technology. (c) Observation of atmospheric neutrinos. R&D of the next generation nucleon-decay and neutrino detector “Hyper-Kamiokande” is promoted.

(d) Investigation of deep space by observation of ultra-high-energy cosmic neutrinos. We will

【Term of Project】

FY2013-2017

【Budget Allocation】 1,116,100 Thousand Yen

**Budget: \$11.2 M
Term: 2013-2017**

Main items:

- T2K/J-PARC (~\$1.8M)
- Reactor ν (~\$2.1M)
- Hyper-K (~\$1.7M)
- Ice-Cube (~\$1.4M)
- other basic ν R&D

NOTE:

Neutrino-less double β decay experiments (KamLAND-Zen) is not included because it is already supported by another Grant-i-Aud

Global Status

- US status
 - Under discussion in P5.
- Canada status
 - Proposal to Canadian Foundation for Innovation under preparation
 - Green light from TRIUMF to proceed
 - Final proposal some time in June 2014
- EU situation
 - We hear the status at this meeting.
 - In UK, Statement-of-Interest (SoI) to STFC for Hyper-K is approved. Full proposal is under preparation to be submitted in 2014.

US participation history

- There is long and successful US-Japan partnership
 - Merged IMB and Kamiokande forces on Super-K and we also collaborated on K2K and T2K
 - US contributions to SK, K2K and T2K:
 - outer detector
 - calibration
 - electronics
 - low energy trigger system
 - radon free air system
 - T2K near detector and horns
 - K2K near detectors and water system
 - successful collaboration in KamLAND
- Major US participation and leadership in the Hyper-K are welcome and indispensable

Snowmass whitepaper “Hyper-Kamiokande Physics Opportunities” (arXiv:1309.0184)

- 167 authors from 49 institutes, 9 countries
- 59 authors from 14 institutes in Japan
- 43 authors from 13 institutes in US

- * Boston University (USA): E. Kearns, J.L. Stone
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University of Winnipeg (Canada): B. Jamieson
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York University (Canada): S. Bhadra

* interests from US

Cost Estimate

Total	800M USD*	
Cavern	300M USD	
Tank & structure	200M USD	
Photo-sensors	200M USD	High QE HPD
Near Detector	30M USD	@Tokai

*The cost of rock disposal and water purification system to be added in the future

- Contribution from each country is under discussion in the Hyper-K WG
- Proportional sharing in an international project is ideal.
- The target for international contribution is 30% to 50% of the cost.

Possible foreign contributions

A conceptual design exists.

We are open to ideas toward a full design.

- Cavity and structure (500M USD)
 - contribution of innovative design and materials welcome
e.g. LBNEWC liner & PMT mounting
- Photosensors (200M USD)
 - open to manufacturers other than Hamamatsu.
Competition helps reduce cost.
 - Innovative ideas like MPC PMT welcome.
- Electronics, Calibration
 - This is an area where foreign contributions are expected.
- Other systems of modest scope
 - outer detector
 - water system
 - near detector
- Accelerator (J-PARC) and beamline intensity upgrade.
 - history of accelerator lab collaboration.

Summary

- Hyper-Kamiokande project has strong physics cases with the J-PARC neutrino beam
 - Exploring neutrino mass, mixing and CP violation
 - Aiming to establish the unification of forces.
 - More understanding the history of Universe.
- Major European participation and leadership in Hyper-Kamiokande are indispensable for the success of the project.
 - The Hyper-K group is seeking more contributions (and more man powers) to complete R&D and Technical Design on time w/ a proto-type detector construction.