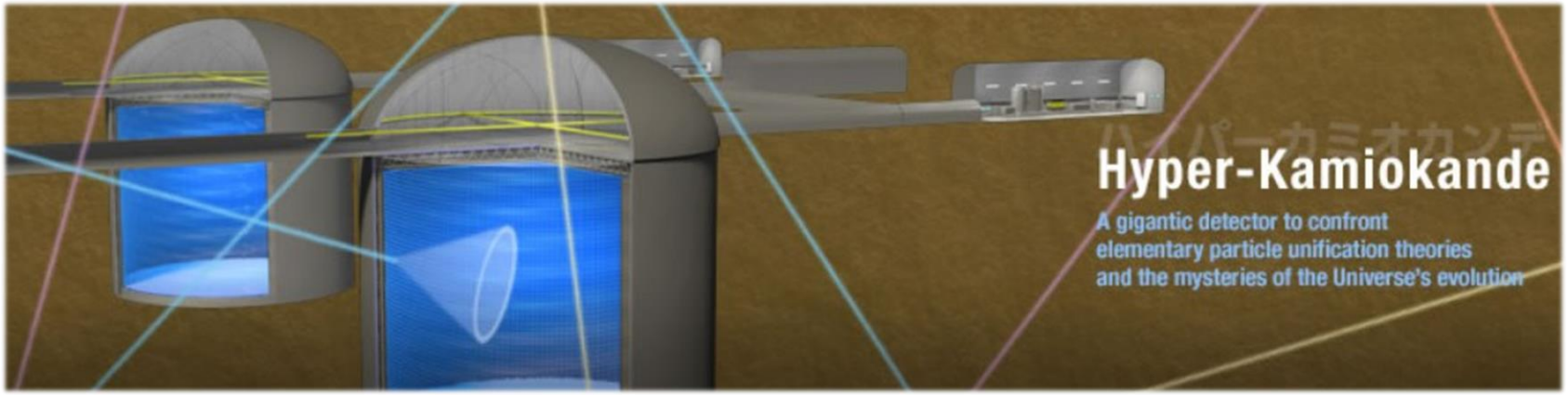
Neutrino Oscillation Physics Sensitivity of Hyper-Kamiokande



ICHEP – Chicago 2016

Michel Gonin - On behalf of the @HyperKamiokande collaboration

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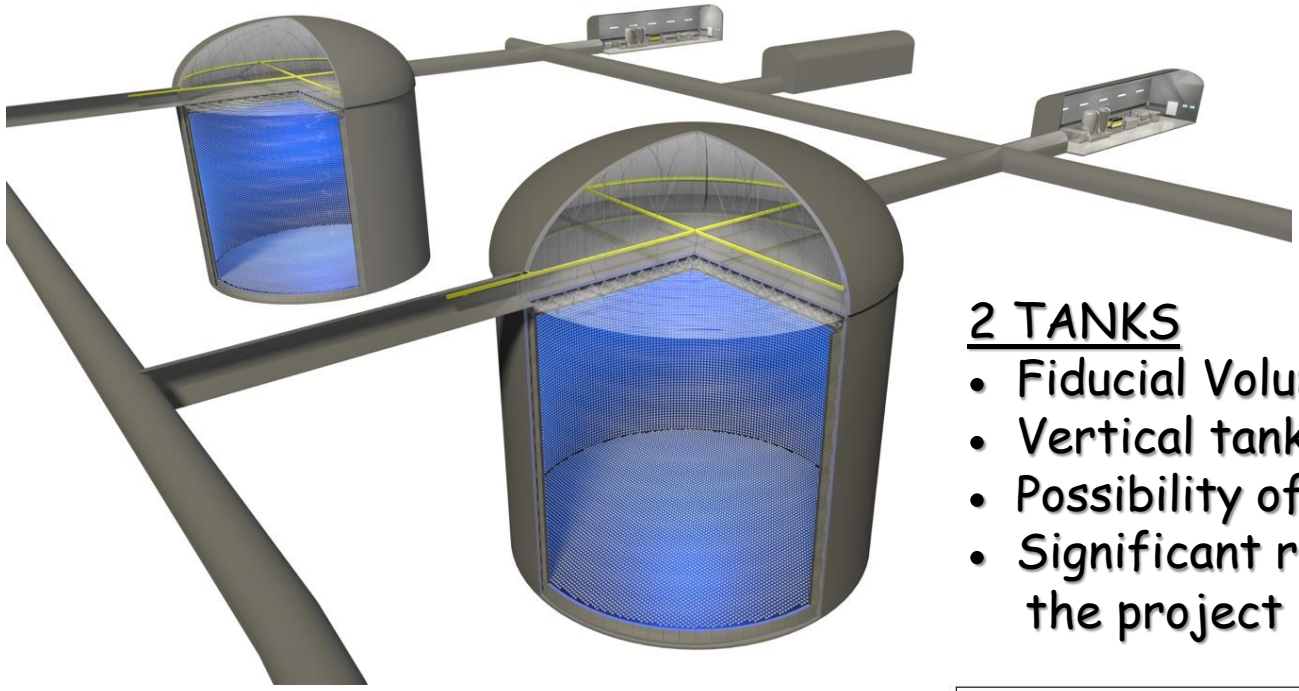
Hyper Kamiokande
@HyperKamiokande

HK Proto Collaboration was formed on January 2015

Symposium at Kashiwanoha

- MOU between Tokyo Univ – ICRR and KEK – IPNS
- On going reviews by an International HK Advisory Committee
- International groups formed and developing
- New proposal submitted in March to the Science Council of Japan
- Reviewed by the KEK-PIP committee – top priority

A new design for HK submitted last February



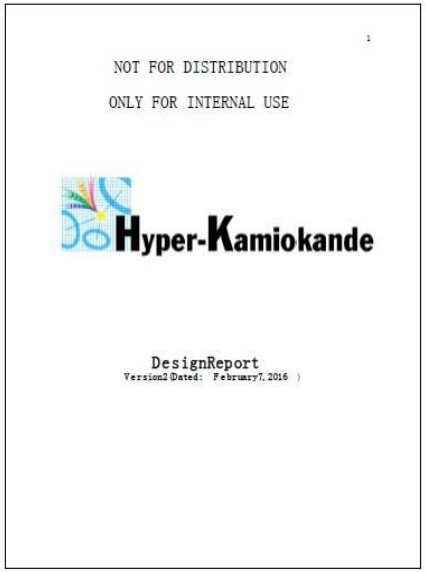
2 TANKS

- Fiducial Volume : 2/3 of original design
- Vertical tanks
- Possibility of staging
- Significant reduction for the cost of the project

EACH TANK

- 260 Kton total
- 10 x SK fiducial volume
- Very good PMT coverage (40%)
- 60 m height x 74 m diameter

Sensitivity goals are maintained for HK oscillations physics

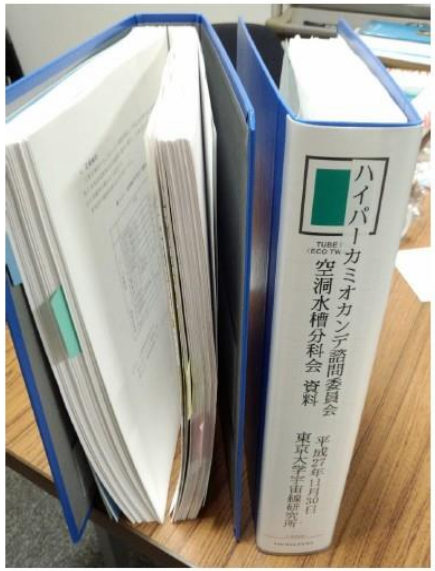

NOT FOR DISTRIBUTION

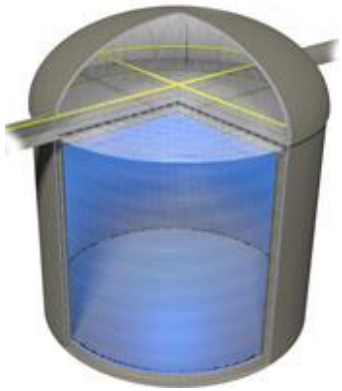
ONLY FOR INTERNAL USE

Hyper-Kamiokande

DesignReport

Version2 (Dated: February7, 2016)





The Hyper-Kamiokande project for Oscillation Physics

Hyper Kamiokande
@HyperKamiokande

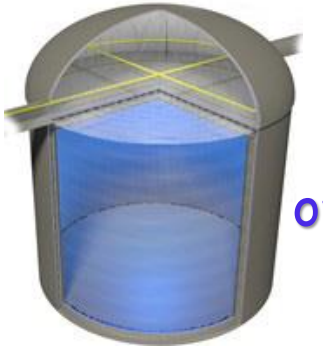
Very large physics program CPV, precision measurement for mixing parameters and mass hierarchy, in addition to proton decay (world leading researches) and astrophysics neutrinos

The experiment "T2HK" will be an off-axis long baseline experiment
L = 295 km @ 2.5 degrees (similar to T2K)

- Well known state-of-the-art water Cherenkov technique
- Reasonable and predictable total cost
- Reasonable timescale for approval and construction
- Will greatly benefit from SK and T2K expertise and momenta
- Approved and foreseen upgrades of the JPARC muon-neutrino beam

T2K Latest results

T2K data prefers maximal θ_{23} mixing, CPV of $-\pi/2$ and normal hirearchy



Precise measurement of electron-neutrino appearance will be performed in T2HK

H.A. Tanaka et al. , Neutrino2016

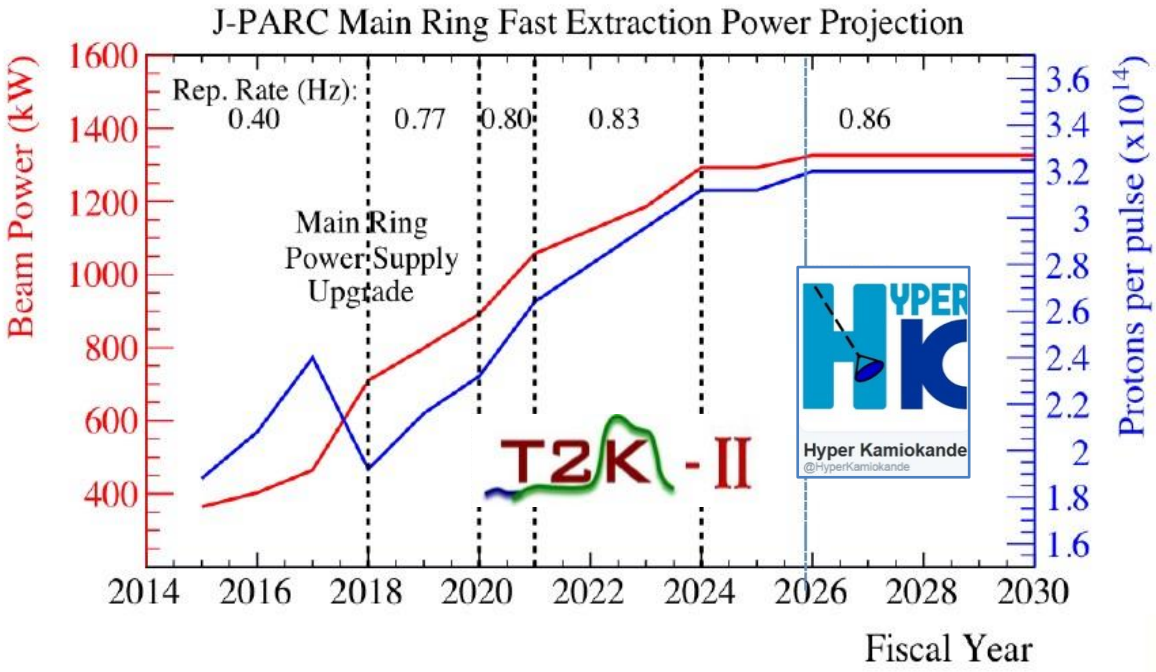
observed vs. expected number of ν_e and $\bar{\nu}_e$ candidates

		EXPECTED (NH, $\sin^2\Theta_{23}$=0.528)			
	OBS.	$\delta_{CP}=-\pi/2$	$\delta_{CP}=0$	$\delta_{CP}=+\pi/2$	$\delta_{CP}=\pi$
ν_e	32	27.0	22.7	18.5	22.7
$\bar{\nu}_e$	4	6.0	6.9	7.7	6.8

- Toy MC run to assess probability of outcome given a set of "true" parameters
- Below: fraction where δ_{CP} =0 excluded at 90% or 2 σ CL for NH, δ_{CP} = -π/2, 0

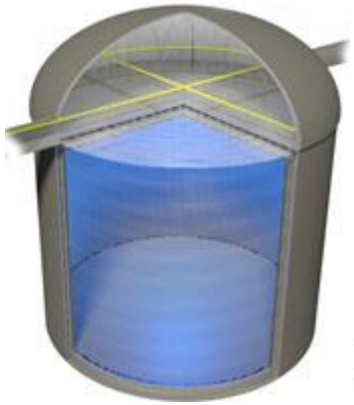
	TRUE PARAMETERS	
	$\delta_{CP}=-\pi/2$, NH	$\delta_{CP}=0$, NH
90%	0.187	0.102
2 σ	0.089	0.047

Continuous beam upgrade @ J-PARC



"J-PARC upgrade for HK is the highest priority"

KEK - PIP



Hyper-Kamiokande systematic errors

Estimations and simulations will be based on *T2K and SK studies with real data*

ν-mode ν_e candidates T2K

Source of uncertainty	$\delta N_{SK}/N_{SK}$
SKDet+FSI+SI	3.48%
SKDet only	2.28%
FSI+SI only	2.63%
Flux	3.67%
2p-2h (corr)	3.90%
2p-2h bar (corr)	0.05%
NC other (uncorr)	0.15%
NC 1gamma (uncorr)	1.47%
XSec nue/numu (uncorr)	2.61%
XSec Tot (corr)	4.26%
XSec Tot	5.21%
Flux+XSec (ND280 constrained)	2.90%
Flux+XSec (All)	4.17%
Flux+XSec+SKDet+FSI+SI	5.45%
Flux+XSec+SKDet+FSI+SI (pre-fit)	12.1%
Oscillations	4.20%
All	6.91%
All (pre-fit)	12.6%

$\bar{\nu}$-mode $\bar{\nu}_e$ candidates T2K

Source of uncertainty	$\delta N_{SK}/N_{SK}$
SKDet+FSI+SI	3.95%
SKDet only	3.11%
FSI+SI only	2.43%
Flux	3.84%
2p-2h (corr)	3.04%
2p-2h bar (corr)	2.36%
NC other (uncorr)	0.33%
NC 1gamma (uncorr)	2.95%
XSec nue/numu (uncorr)	1.46%
XSec Tot (corr)	4.46%
XSec Tot	5.55%
Flux+XSec (ND280 constrained)	3.20%
Flux+XSec	4.60%
Flux+XSec+SKDet+FSI+SI	6.28%
Flux+XSec+SKDet+FSI+SI (pre-fit)	13.5%
Oscillations	4.00%
All	7.38%
All (pre-fit)	14.1%

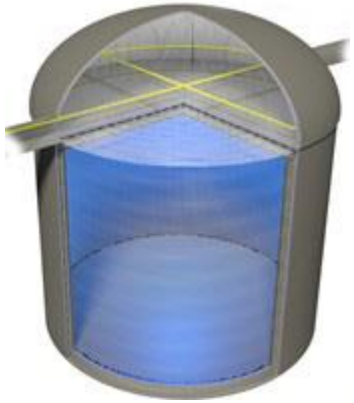
Goal

Reduction from ~ 6-7% in T2K

to ~ 3-4% in T2HK for the expected number of events.

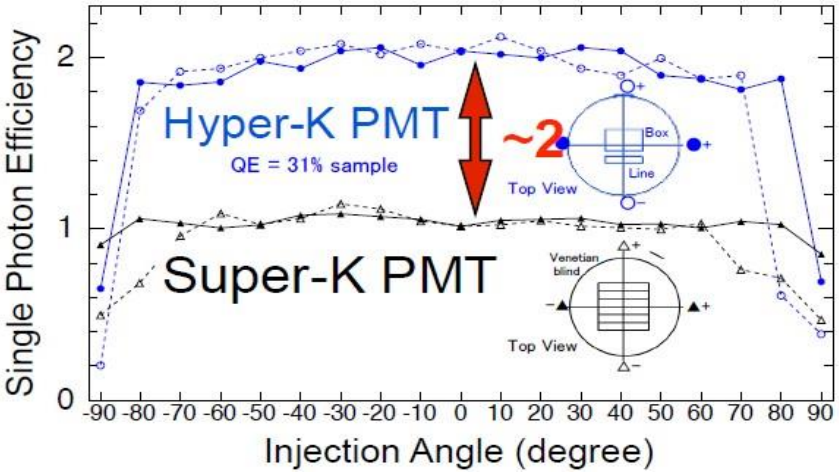
Beam flux, XSections, HK Det, New Near Detectors.

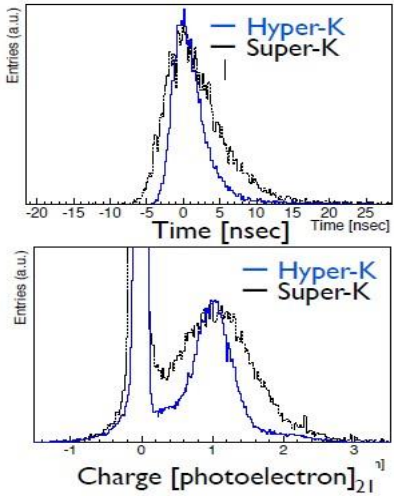
The HK Detector



50cm Ø PMT

New technologies and on going studies for PMT





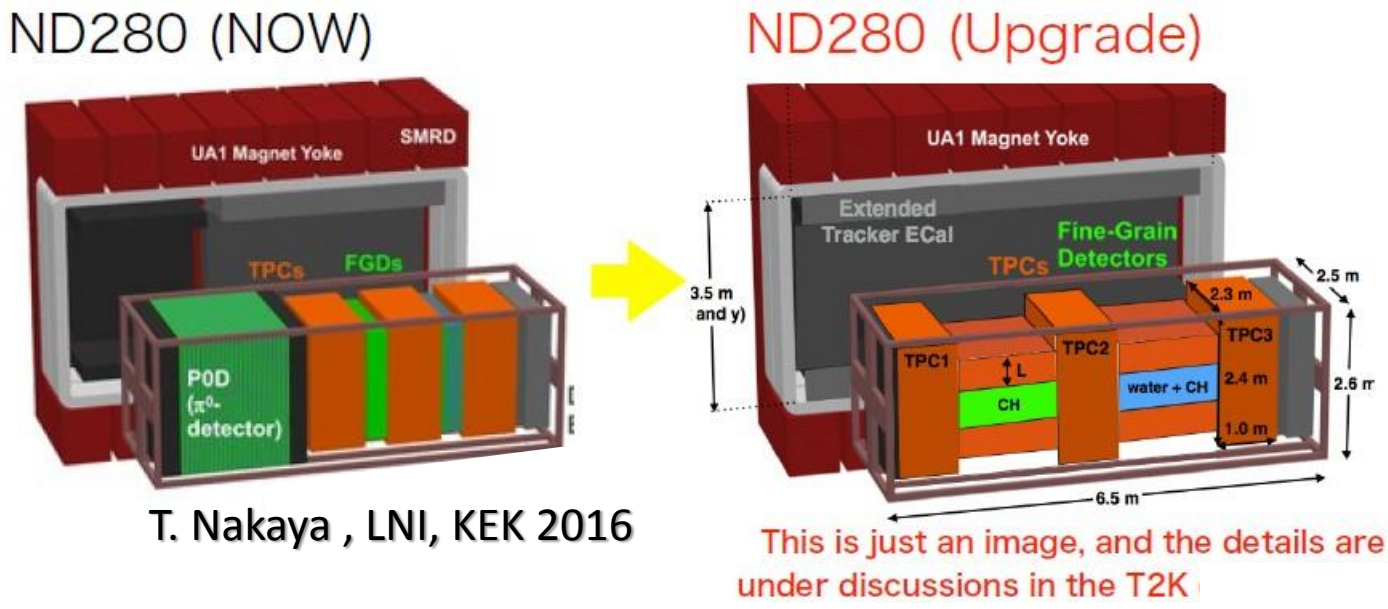
- Significant improvement of single photon efficiency
- Better time and charge resolution (x2)

Possible mixed technologies in HK for PMT

- Worldwide studies for new photo sensors detectors (JUNO, IceCube, KM3NET, …)
- Foreseen collaborative efforts of HK with other experiments

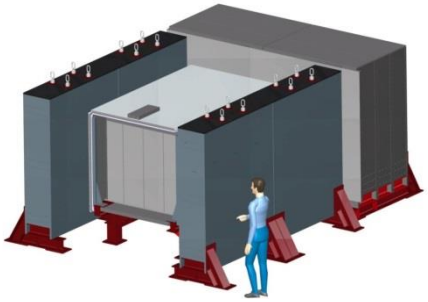
Beam flux and Xsections

The Near Detector ND280 upgrades for T2K-II and T2HK



T. Nakaya , LNI, KEK 2016

WAGASCI



- The new ND280 will continue to perform for T2HK
- Same narrow band beam centered at 600 MeV
- Cross section measurements in WATER
- Investigation of the nuclear effects (FSI,….)

Beam flux and Xsections

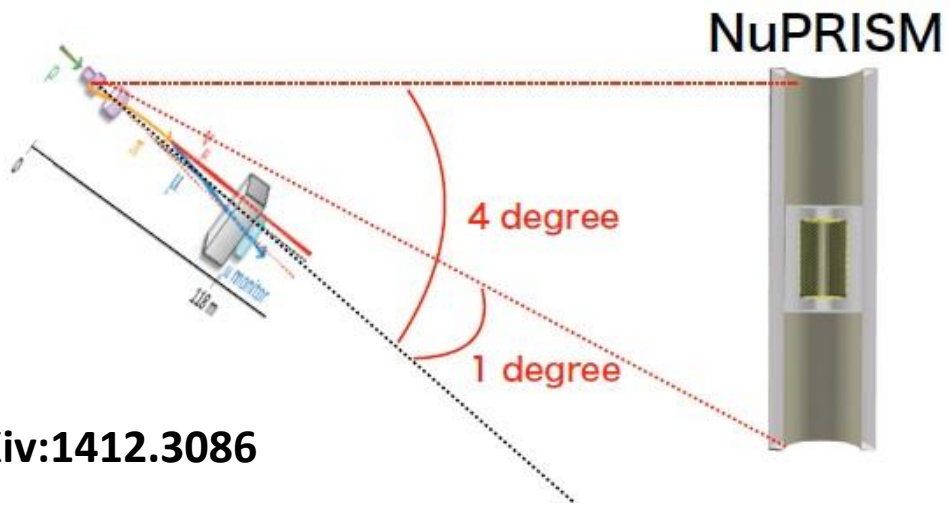
Proposals for New Intermediate Water Cherenkov detectors at 1.2 Km

- NUPRISM.

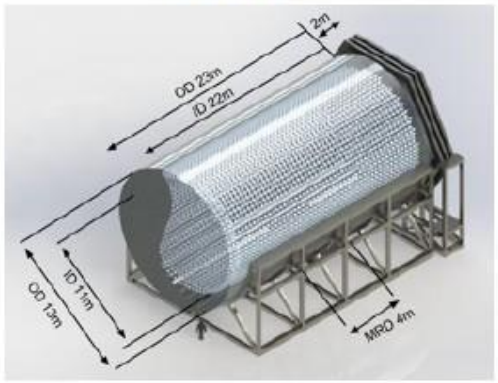
Off-axis angle spanning orientation. Some new and original approach to extrapolate neutrino events in HK.

- TITUS

Gd loading, magnetized muon range detector. Good Near/Far flux ratios for prediction in HK

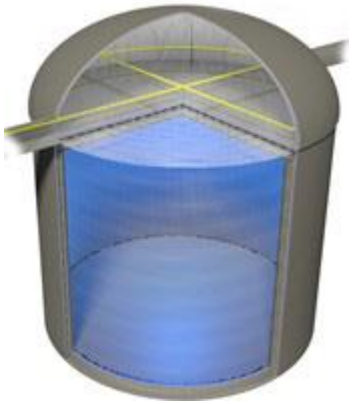


arXiv:1412.3086



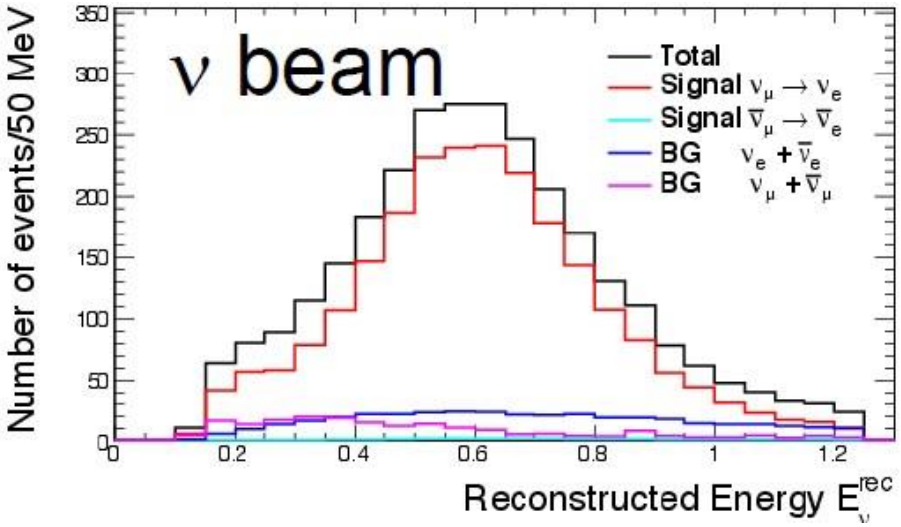
arXiv:1606.08114

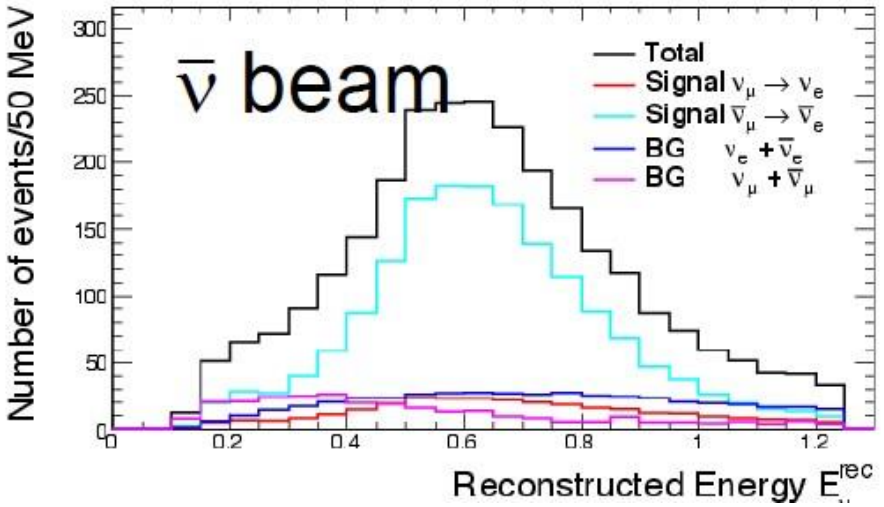
Physics performance for oscillation studies



Assuming
- 10 years of running
- 1.3 MW for JPARC proton beam
- 1 tank then 2 tanks
- ~ 40% PMT coverage in HK
- 3-4% systematic uncertainties

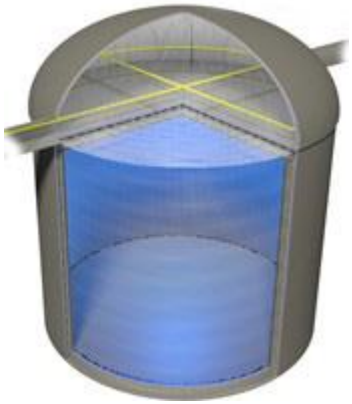
Electron-neutrino appearance





δ=0	Signal ($\nu_\mu \rightarrow \nu_e$ CC)	Wrong sign appearance	ν_μ , $\bar{\nu}_\mu$ CC	Beam ν_e, $\bar{\nu}_e$ contamination	NC
ν beam	2300	21	10	362	188
$\bar{\nu}$ beam	1656	289	6	444	274

Physics performance for oscillation studies



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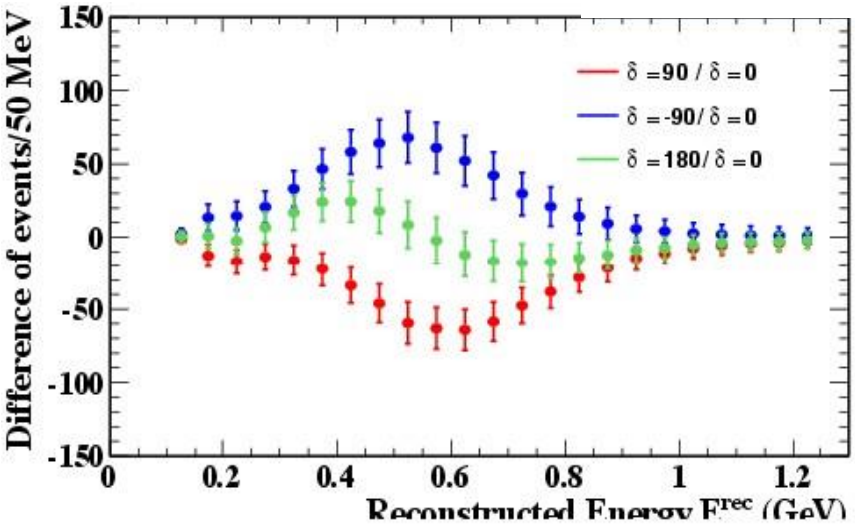
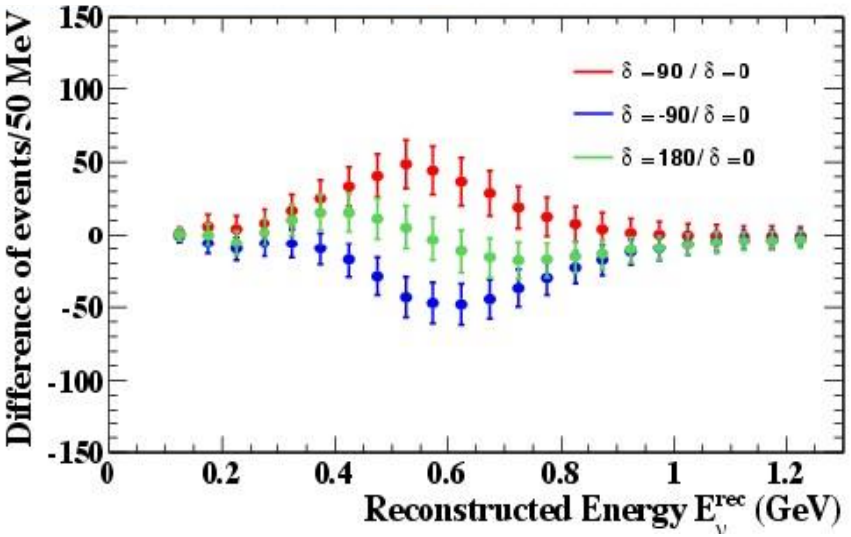
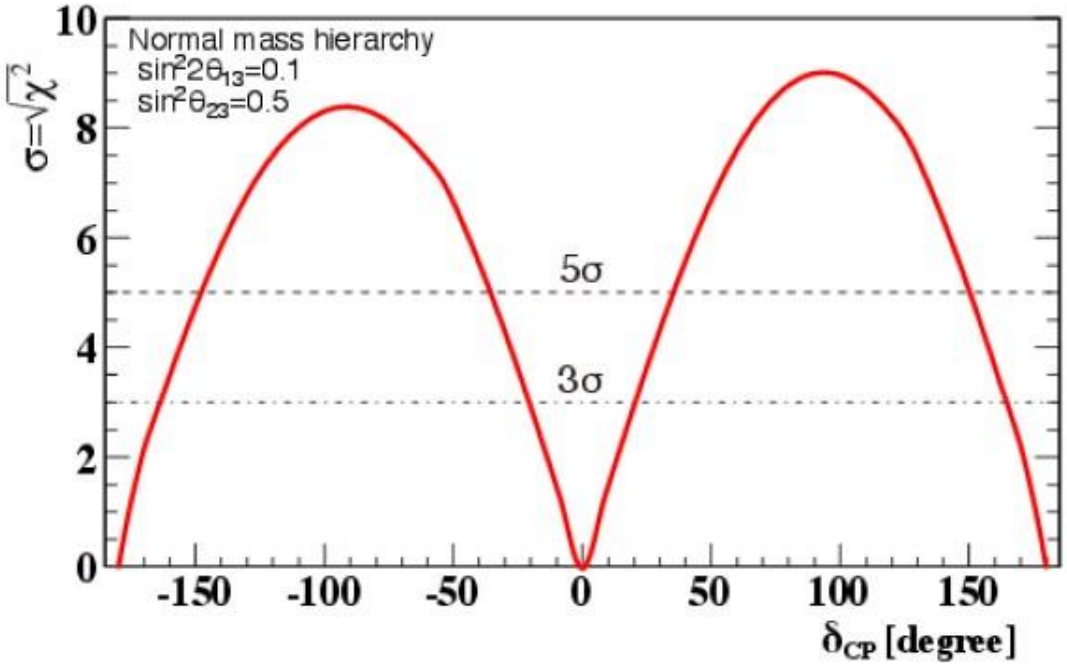
Electron-neutrino appearance



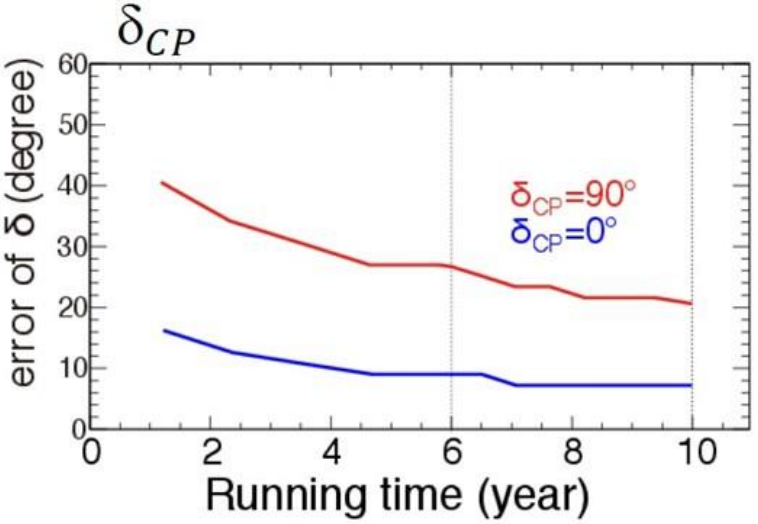


Possibility of using shape information in energy to distinguish different values for δ (CP)

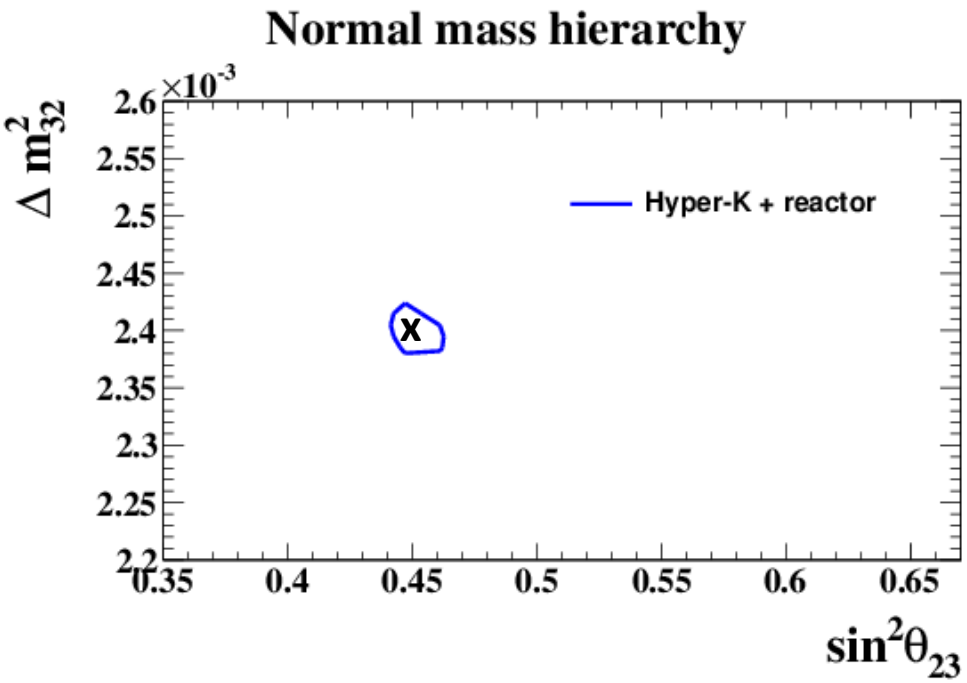
Physics performance for CPV studies

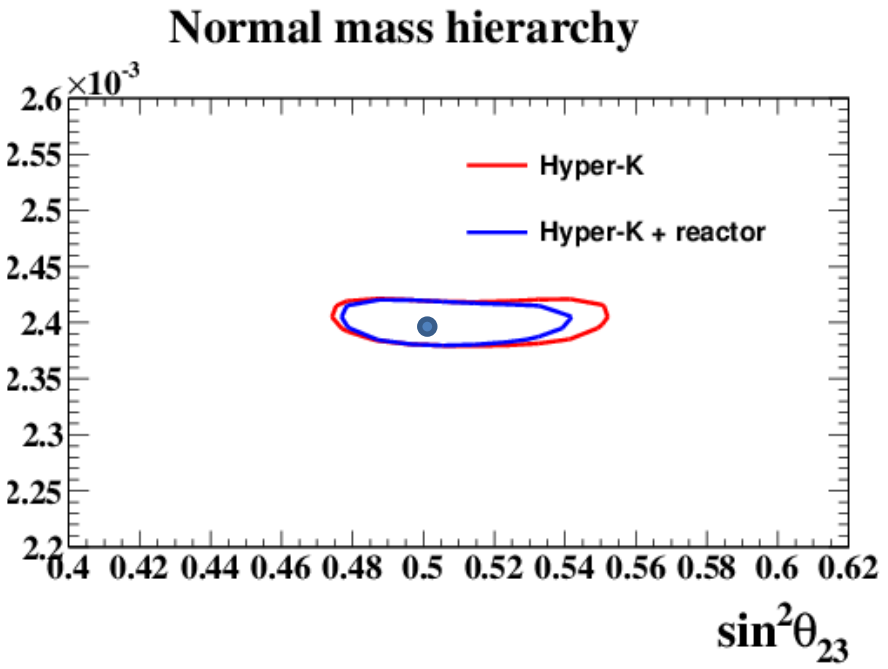


- Exclusion of $\sin\delta_{CP}=0$
  - 8σ for δ=-90°
  - 80% coverage of δ parameter space for CPV discovery w/ >3σ
- δ_{CP} precision measurement
  - 20° for δ=-90°
  - 7° for δ=0°



Physics performance for oscillation parameter measurements





$\sin^2\theta_{23} = 0.50$, $\Delta(\sin^2\theta_{23}) \sim 0.015$ ●

$\sin^2\theta_{23} = 0.45$, $\Delta(\sin^2\theta_{23}) \sim 0.006$ x

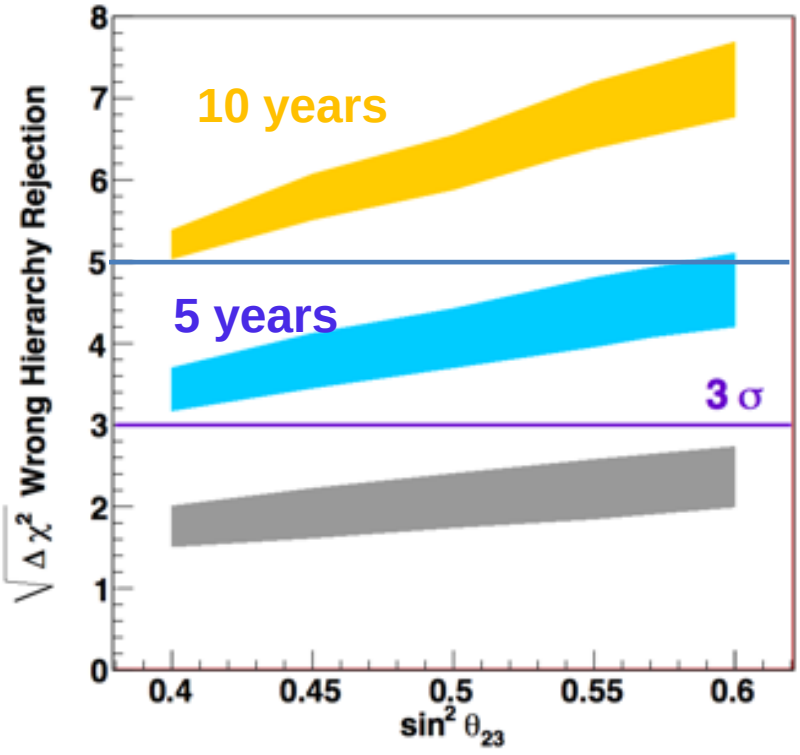
T2K

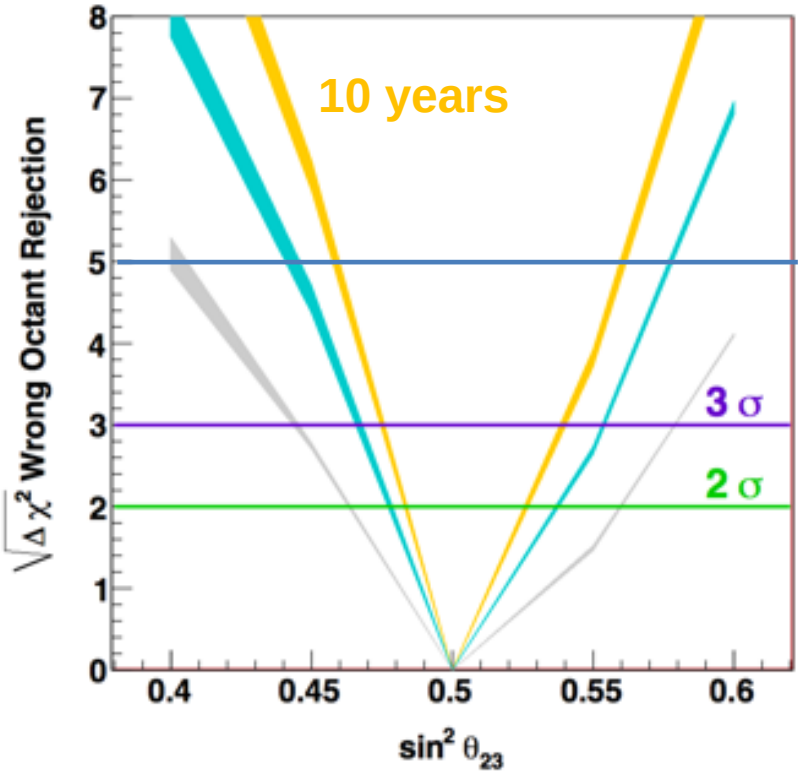
$\sin^2\theta_{23}$	$0.532^{+0.044}_{-0.060}$

Physics performance for oscillation parameter measurements

JPARC Beam + Atmospheric neutrinos

Normal Hierarchy

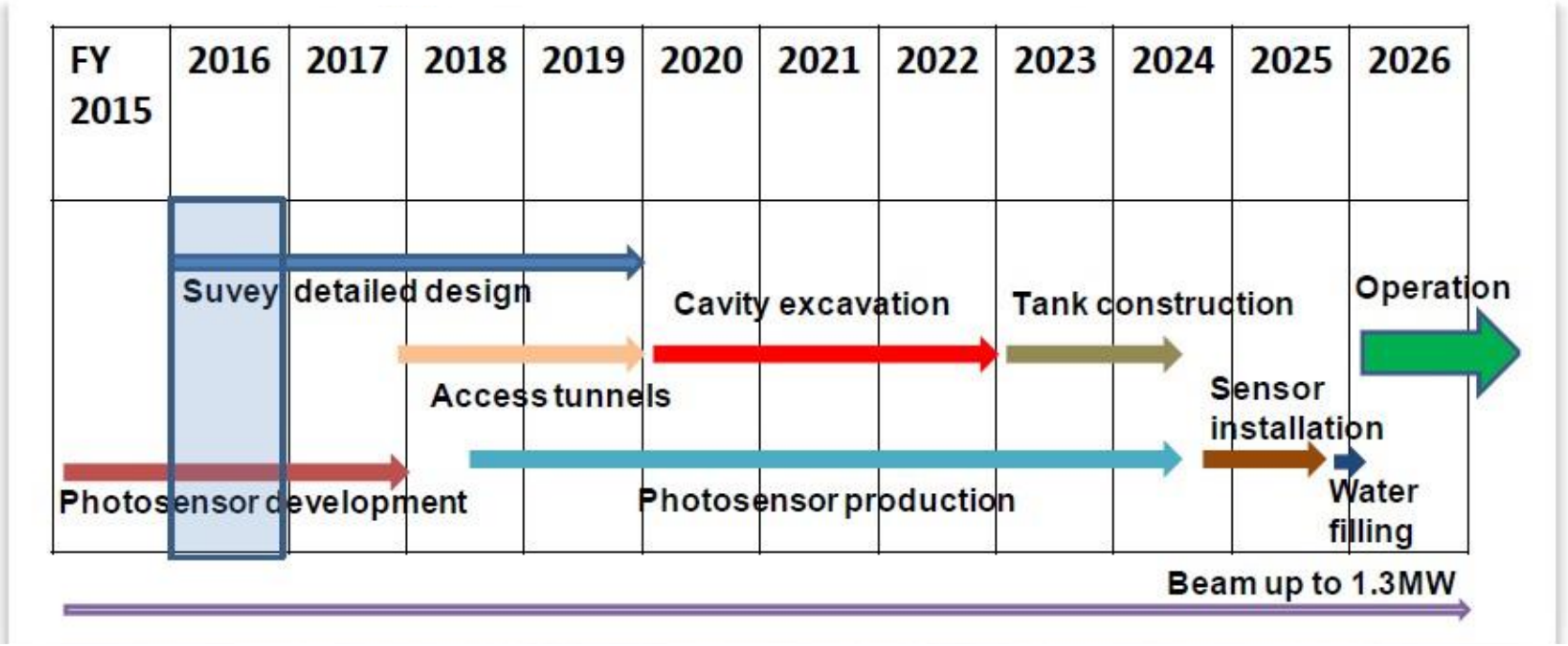




M.H. determination ~ 5σ.

Good performance for octant determination

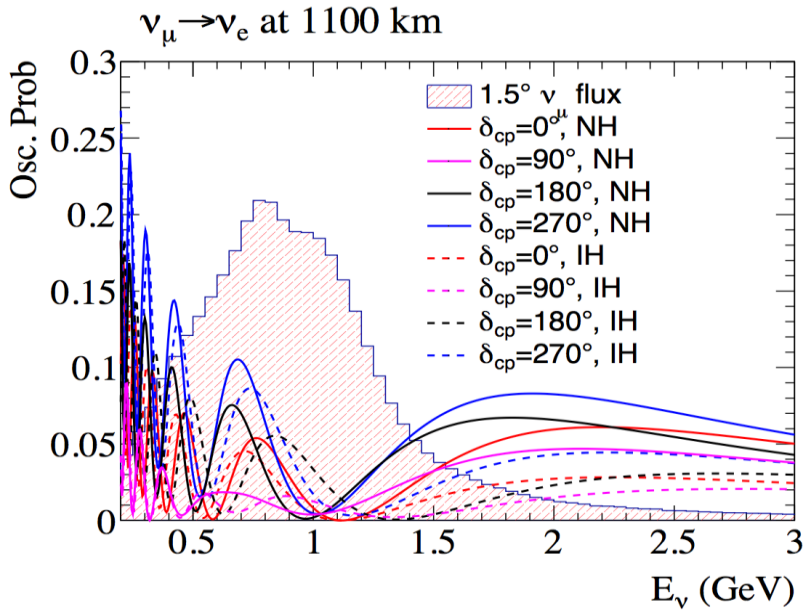
HK and T2HK Schedule

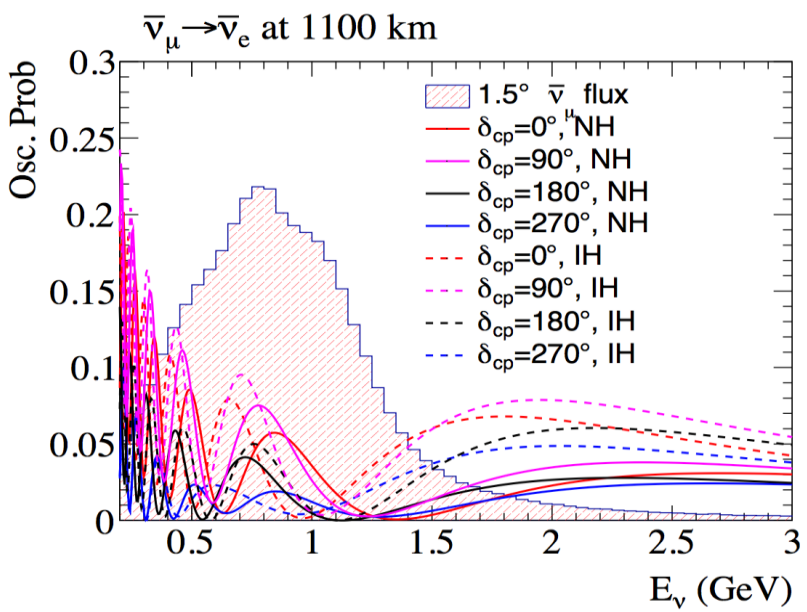


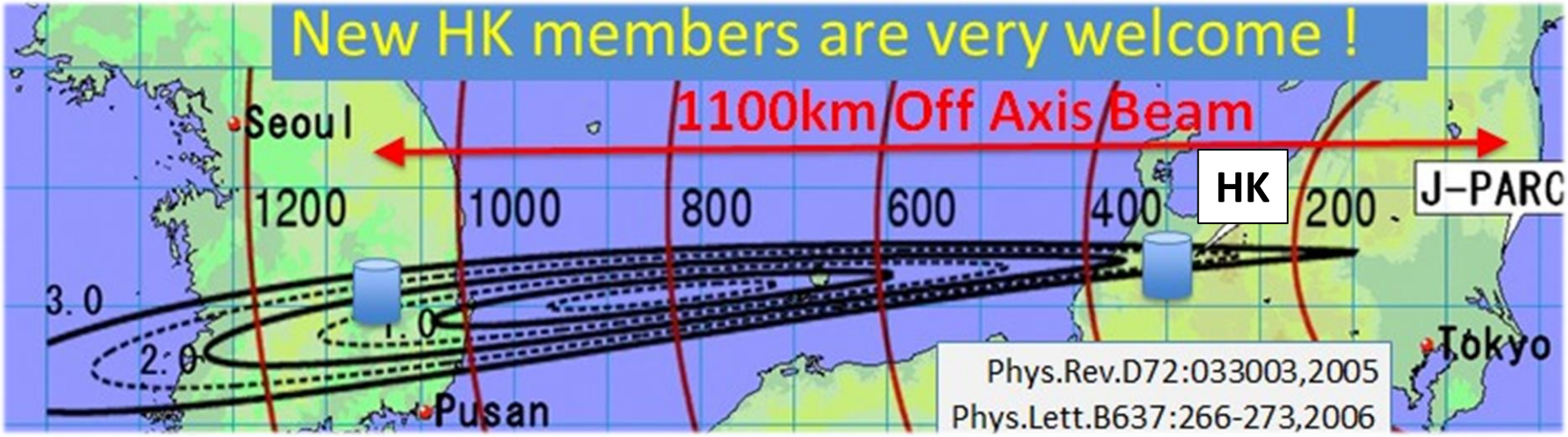
- The 2nd tank starts operation 7 years after the first one
- Schedule for ND280 upgrades and Intermediate Detectors approval and construction not included
- Based on HK proposal approved before end of 2017

Korean option for the second tank ?

Just started to study sensitivity and the physics case








A unique and amazing scientific journey
HYPER HK
Hyper Kamiokande
@HyperKamiokande
T2K - II
T2K
SUPER SK Gad
SUPER SK
K

ICHEP talks

Labarga HK
Nishimura HK
Gonin HK

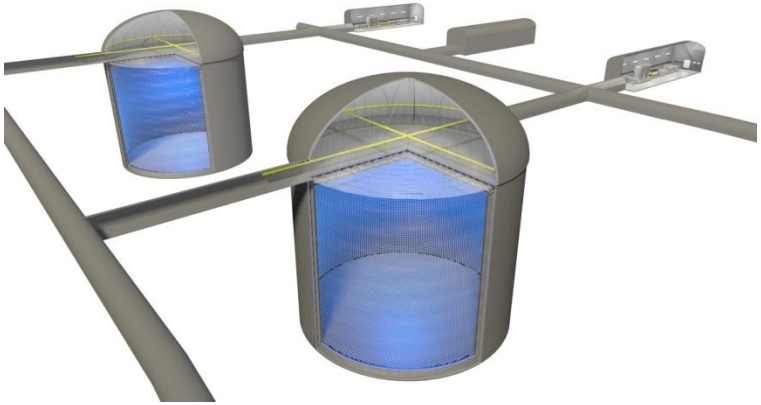
Iwamoto T2K
McCauley T2K

Chen SK
Li SK
Nakano SK

+ Many posters

Summary

- Great potential for large CP violation discovery in the lepton sector
- Precision improved significantly for mixing parameter measurements. First test of the unitarity of the PMNS matrix ?



JPARC muon-neutrino off axis beam	δ_{CP} precision (0°,90°)	7°-21°
	CPV coverage (3/5σ)	78%/62%
	$\sin^2\theta_{23}$ error (for 0.5)	±0.015
JPARC neutrino beam + Atmospheric neutrinos	MH determination ($\sin^2\theta_{23}$=0.40)	>5.3σ
	Octant ($\sin^2\theta_{23}$=0.45)	5.8σ

- New optimized tank design. Staging approach.
- New proposal submitted last March to the Science Council of Japan
- Upgrades of the ND280 detectors for T2K-II. Proposal for new I.D
- HK is based on existing technologies for neutrino detection but with the use of new generation of photo sensors