The Hyper-Kamiokande experiment

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for the Hyper-Kamiokande proto-collaboration

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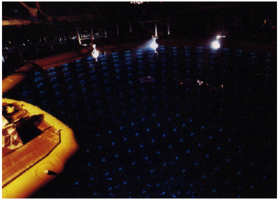
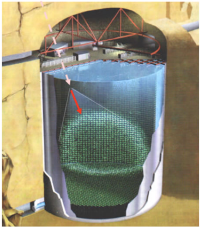
Introduction

Kamiokande (1983-1996)
3000 ton



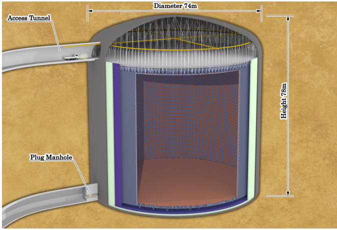
- Neutrinos from SN1987a.
- Atmospheric neutrino deficit.
- Solar neutrinos.

Super-Kamiokande (1996-)
50,000 ton



- Atmospheric neutrino oscillation.
- Solar neutrino oscillation with SNO.
- Far detector for KEK-PS (K2K) and J-PARC beam (T2K): electron neutrino appearance.
- World leading limit on proton lifetime $> 10^{34}$ years.

Hyper-Kamiokande ($\sim$2026-)
$2\times$260,000 ton



Physics programme:

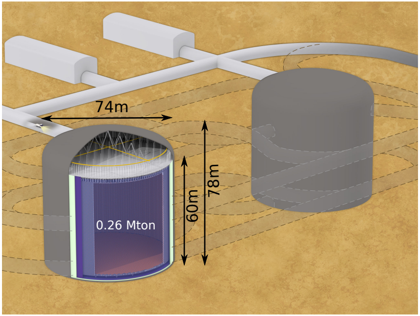
- Neutrino oscillations: Mass Hierarchy, Leptonic CP violation, θ_{23} Octant,...
- Nucleon decay: $p \rightarrow e^+\pi^0$, $p \rightarrow K^+\bar{\nu}$,...
- Neutrino astrophysics: Solar neutrinos, Supernova neutrinos, WIMP searches

The Hyper-Kamiokande Collaboration

- Proto-collaboration formed in January 2015.
- ∼300 members and growing, from 70 institutes and 12 countries.

The Hyper-Kamiokande Detector

- Two Super-K like cylindrical tanks with staging.
- 2nd tank assumed to be ready 6 years later.
- Tank dimensions:
  - 60m (high) $\times$ 74m (diameter)
  - Total Volume: 260 kton.
  - Fiducial Volume: 190 kton ($\sim$ 10$\times$ Super-K).
  - 40% PMT coverage.
  - 40,000 50cm ID PMTs, 6,700 20cm OD PMTs.



- Candidate site: $\sim$8 km south of Super-K (2.5 degree off-axis beam, L = 295km).
- Investigating option for 2nd tank in Korea.
- More details on tank and calibration: see talk H. Tanaka (Nov 3).
- Hyper-K electronics: see talk M. Ziembicki (Nov. 3)

New Photosensor Candidates

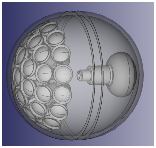
50 cm Box&Line PMT
(R12860-HQE)

- Box&Line dynode.
- Baseline Hyper-K choice.
- Double photon detection efficiency (wrt Super-K).
- Large improvements in timing and charge resolution.
- Improved glass bulb design for higher pressure tolerance.
- More details on cover design and pressure tests: talk by Y. Nishimura (Nov. 5)

50 cm Hybrid PMT
(R12850-HQE)

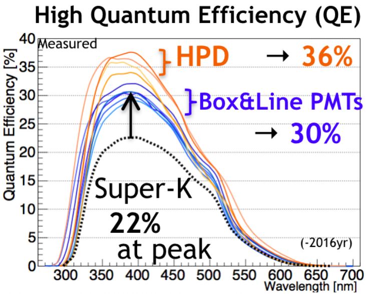
- Avalanche diode.
- Under development.
- Improved charge and timing resolutions, but limited by preamplifier.
- Fast/low-noise pre-amplifier under development.
- See poster by Y. Nishimura (Nov. 3)

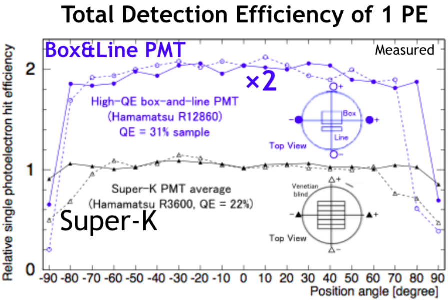
Multi-PMT module
with 8 cm PMTs

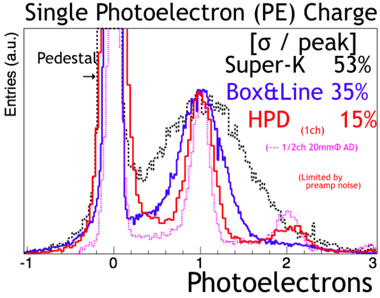


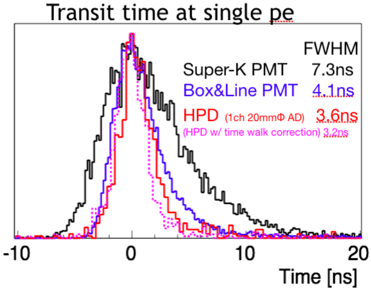
- Pressure vessel for both ID and OD photosensors.
- Finer granularity and directional information from small 8cm PMTs.
- Natural housing for in-water electronics.
- MoU with KM3NeT to exchange knowledge on technology.
- Prototypes are being developed for near and far detector.

New Photosensors: performance

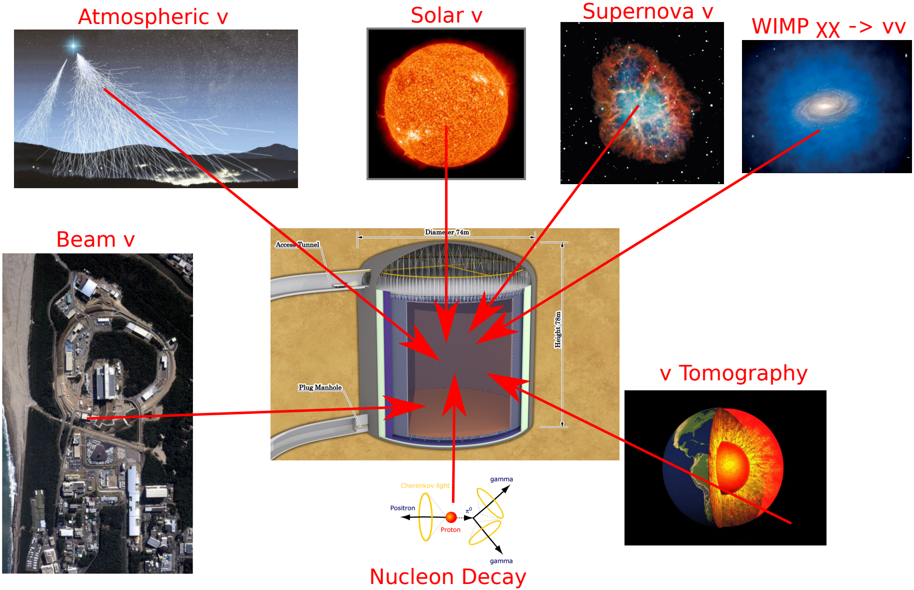




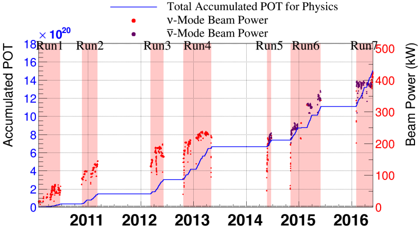


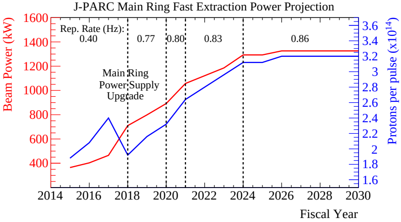


Hyper-K Physics: Overview



Improving the neutrino beam at J-PARC



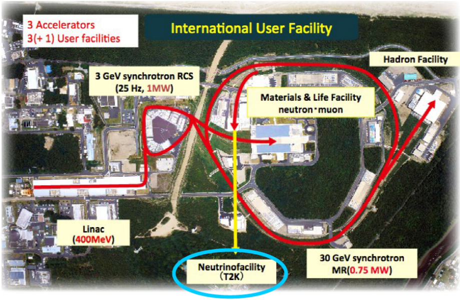


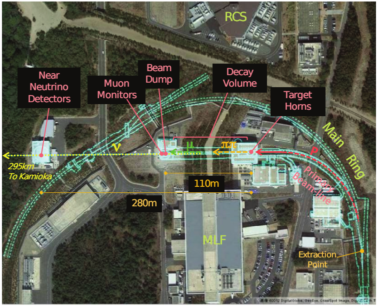
Current situation:

- 1.5×10^{21} POT, equally in ν and $\bar{\nu}$ mode.
- $\sim$**425kW** beam power.
- 2.2×10^{14} protons-per-pulse.
- Repetition cycle: 2.48 seconds.
- Main Ring power supply upgrade approved to reduce repetition cycle to 1.3 seconds $\Rightarrow$ factor of two in beam power ($\sim$750 kW).

Goal: Upgrades to beam to reach $\sim$1.3 MW by $\sim$2026.

Improving the neutrino beam at J-PARC





Upgrades proposed to reach 1.3MW and beyond:

- Upgrades to Main Ring magnets, RF cavities, injection and extraction devices.
- 3.2×10^{14} protons-per-pulse.
- Further reduction of repetition cycle to 1.16 seconds.
- Stable running for 5 months each year.
- Upgrade power supplies for T2K horns by 2019 to run at design current of 320kA (wrt 250kA).
  $\Rightarrow$ 10% higher neutrino flux.
  $\Rightarrow$ reduction of wrong-sign neutrino contamination by 5-10%.

KEK Project Implementation Plan (KEK-PIP) put first priority to "J-PARC upgrade for Hyper-Kamiokande".

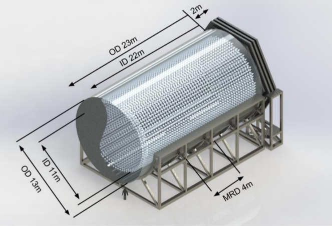
Intermediate Near Detector

- 1 kton scale Cherenkov detector: contain muons up to $\sim$GeV or more with 100 ton fiducial volume.
- 1-2km baseline: avoid significant pile-up.
- Same (water) target and 4π acceptance as far detector.
- Large fraction of active mass.
- Direction measurement of intrinsic ν_e and NC backgrounds.
- Good e/μ and e/π^0 separation.
- But, no direct detection of below Cherenkov threshold particles and no charge identification.

Two proposed designs: TITUS and νPRISM

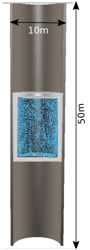
TITUS:

- 2.5° off-axis in same direction as Tochibora (Hyper-K proposed location) at 1.8km.
- Gd loading for neutron detection.
- Magnetized muon range detector.
- Long geometry for high momentum muon containment.
- See: arXiv 1606.08114 [physics.ins-det] and 7th Open Hyper-K meeting.



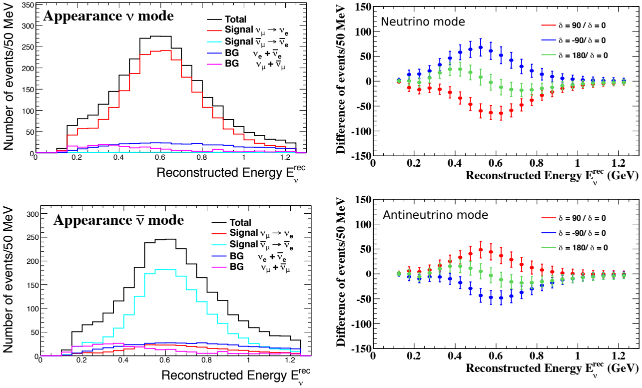
NuPRISM

- Tall detector covering 1.0°-4.0° off-axis angles for studying energy dependence of neutrino interactions.
- Located at 1-1.2km baseline.
- See: arXiv 1412.3086 [physics.ins-det] and 7th Open Hyper-K meeting.



Process for single detector design with off-axis angle spanning coverage and Gd loading started.

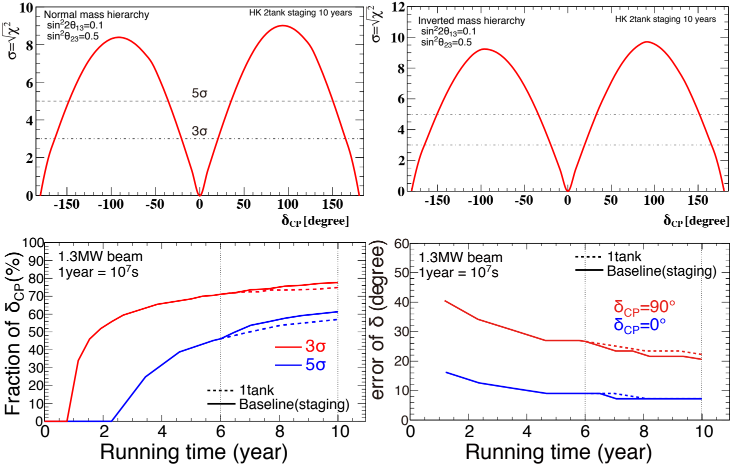
Expected Number of Events in 10 years



Ratio of neutrino/antineutrino mode running: 1:3.

	δ_{CP}	Total	Signal $\nu_\mu \to \nu_e$	Signal $\bar{\nu}_\mu \to \bar{\nu}_e$	Beam ν_e	Beam ν_μ	NC
ν mode	0	2880	**2300**	21	362	10	188
$\bar{\nu}$ mode	0	2669	289	**1656**	6	444	274

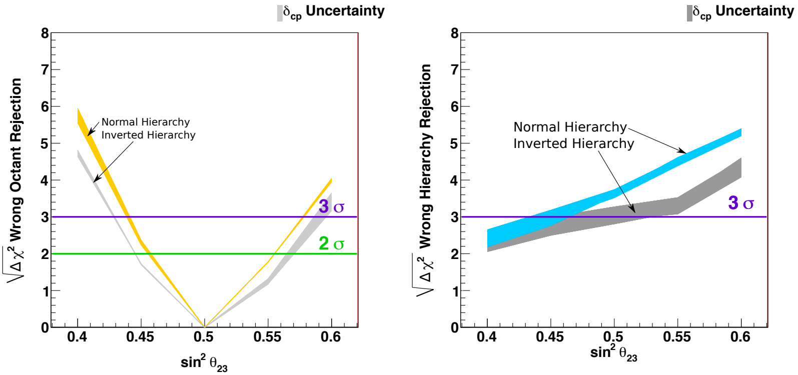
CP Sensitivity



With 1.3MW achieved during T2K-II and with known Mass Hierarchy:

- Observe CPV for >76% (57%) of δ_{CP} with $> 3(5)\sigma$ significance.
- Measure δ_{CP} up to $\sim 7^{\circ}$ precision.

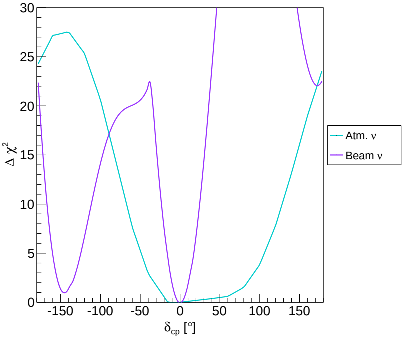
Atmospheric ν: Octant and Mass Hierarchy Sensitivity

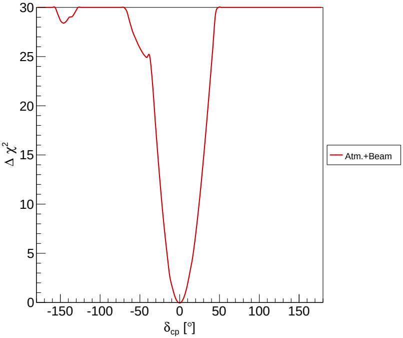


Assuming 10y exposure (2.6 Mton year):

- Octant resolution with reactor θ_{13}: wrong octant rejection for $\sin^2\theta_{23} < 0.46$ or > 0.56.
- If mass hierarchy not yet known: Hyper-K can determine mass hierarchy using its atmospheric neutrino sample at $\sqrt{(\Delta\chi^2)} > 3$ when $\sin^2\theta_{23} > 0.45$.

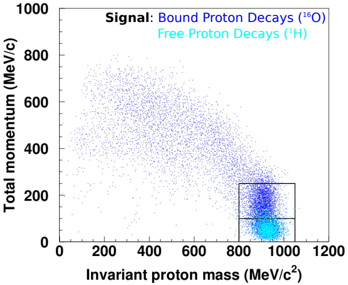
Combine Accelerator and Atmospheric Data

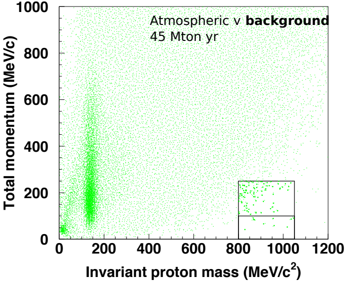




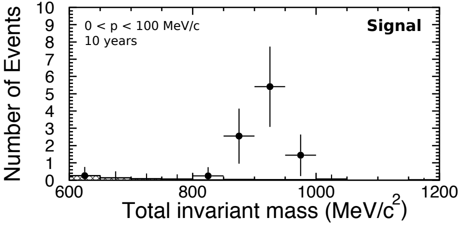
- If mass hierarchy unknown, several minima because unable to separate CP violation from matter effects.
- Combination of accelerator and atmospheric data resolves ambiguity!

Nucleon Decay at Hyper-K: p$\rightarrow$e$^+\pi^0$





- Background free due to high sensitive PMTs.
- Background rate with neutron tagging for momenta $<$ 100 MeV/c: 0.06 events/Mton yr.
- Signal efficiency: 18.7%



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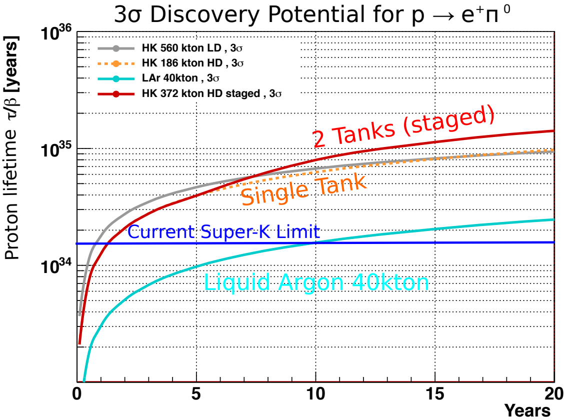
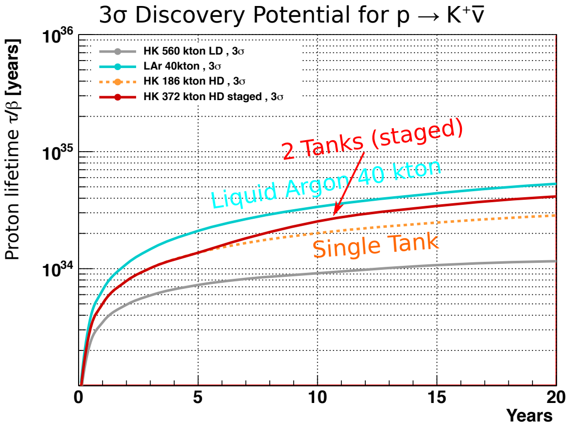


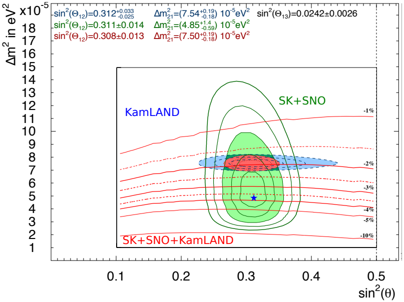
- $> 1\times10^{35}$ years: 3σ discovery with 4.0 Mtonyr.
- If proton lifetime is at current Super-K limit (1.6×10^{34}) (see talk S.Mine Nov.4), Hyper-K will observe a signal at 8.9σ in 2.7 Mton exposure.

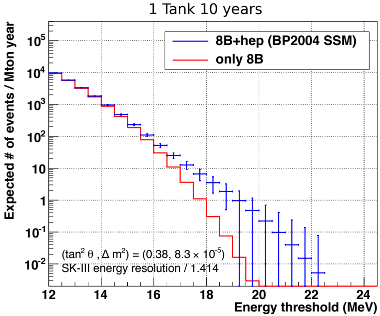
Nucleon Decay: p$\rightarrow$K$^+\bar{\nu}$



- Discovery potential higher in liquid Argon.
- If proton lifetime is at current Super-K limit (6.6×10^{33}) (see talk Mine Nov.4), Hyper-K will observe a signal at 8.6σ in 2.7 Mton exposure.

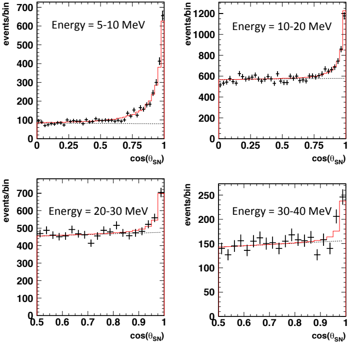
Solar Neutrinos

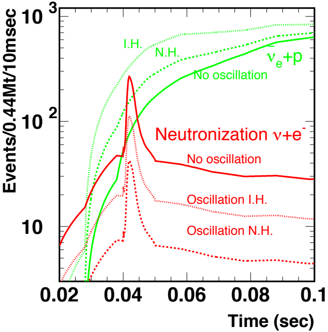




- $\sim 2\sigma$ tension between solar global analysis for ν_e and KamLAND result on reactor ν_e $\rightarrow$ Need precision measurement of day/night asymmetry (3σ indication by Super-K) and Δm^2_{21} of ν_e (not $\overline{\nu}_e$).
- Test various exotic scenarios by spectrum
- ν astronomy:
  - Time variation test with 200νs/day
  - First measurement of hepν.
  - 5.2σ discovery sensitivity to spectrum upturn (with 10 year running).
  - 6σ sensitivity to day/night asymmetry expected from KamLAND best fit.

Supernova Burst Neutrinos

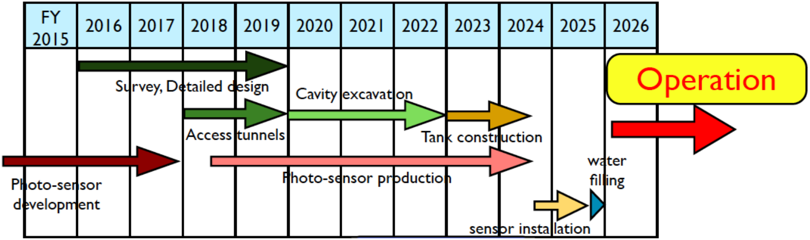




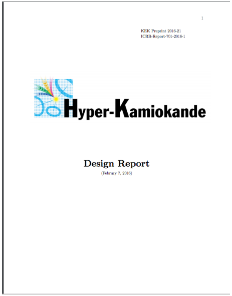
Lower energy threshold and larger volume than Super-K yield for Hyper-K:

- 100,000 - 160,000 ν_e from Supernova at 10 kpc with 2 tanks (440kton).
- Directional information from $\nu + e$ scattering.
- 12-80 νe scattering events expected in neutronization burst peak from SN at 10 kpc, depending on hierarchy or no oscillations.
- Total flux and temperature of interior of SN from detecting NC events.

Status



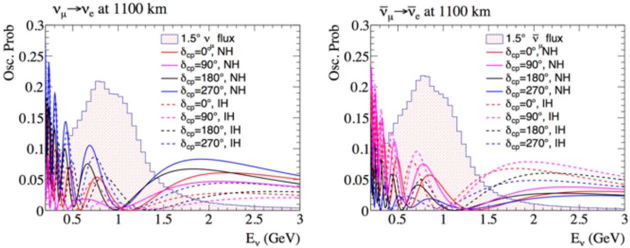
- Conceptual Design Report reviewed by Hyper-K Advisory Committee and submitted as KEK preprint (KEK Preprint 2016-21, ICRR-Report-701-2016-1).
- Hyper-K project proposal was submitted to the Science Council of Japan (SCJ). If successful, Hyper-K will be listed as one of the "Master Plan Projects" of SCJ.
- Then, Hyper-K will be reviewed by the Ministry of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) in 2017. If it is evaluated highly, it will be listed in the MEXT "Roadmap".

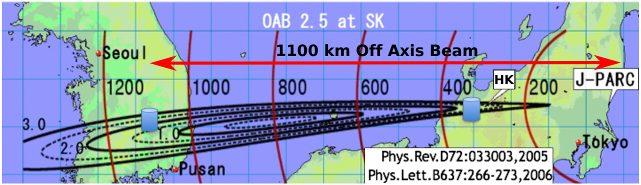

KEK Preprint 2016-21
ICRR-Report-701-2016-1

Hyper-Kamiokande

Design Report

2nd Tank in Korea?





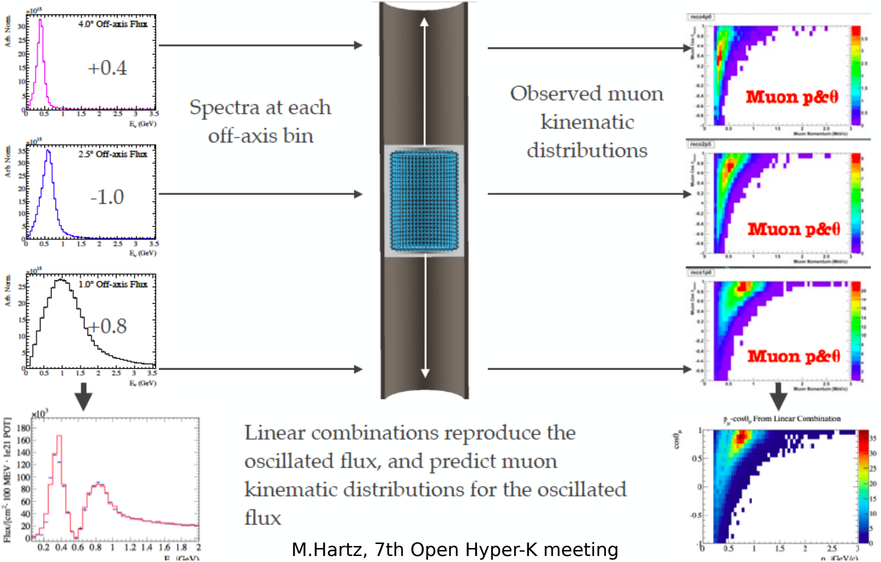
- Investigating to put 2nd in Korea: improve CP and mass hierarchy sensitivity!
- White paper in preparation!
- 1st T2HKK International Workshop: Nov. 21-22, Seoul National University, Korea.

Conclusion

- Hyper-Kamiokande is a natural continuation of successful Super-K, and has great potential to discover new physics.
- Successful development of high efficiency 50cm PMT enabled the HK detector design update, reducing cost significantly without degrading physics sensitivities.
- The neutrino oscillation experiment between J-PARC and Hyper-K will have a very high sensitivity to the CP violation and the other measurements.
- Atmospheric neutrinos will help the oscillation studies.
- Solar neutrino measurements will be very interesting in order to resolve the small tension between solar and KamLAND allowed parameter region.
- Hyper-K has great potential to discover proton decay and probe GUT theories.
- New HK members are very welcome!

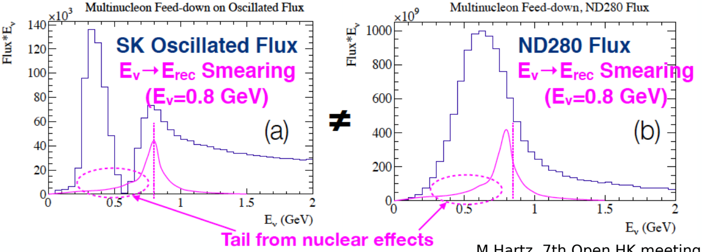
Backup

νPRISM technique



M.Hartz, 7th Open Hyper-K meeting

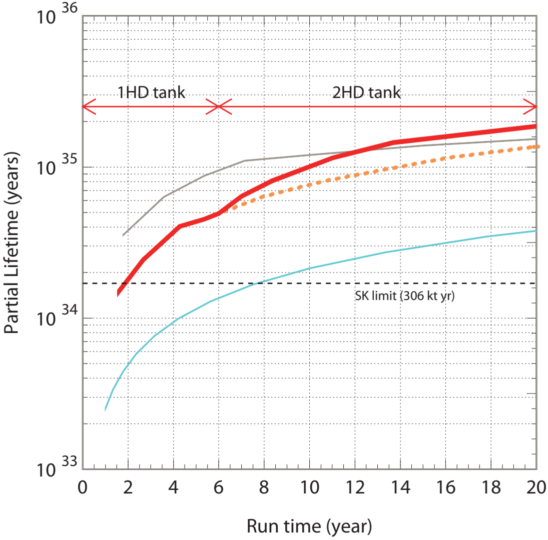
νPRISM: motivation



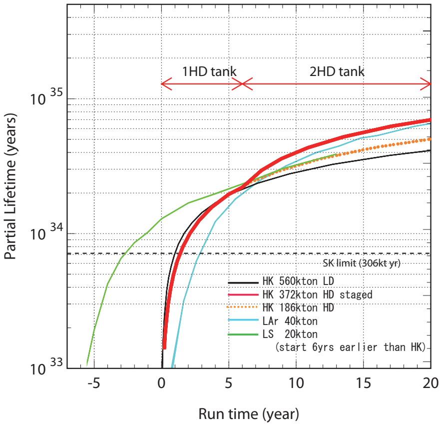
M.Hartz, 7th Open HK meeting

- Primary feature of νPRISM is to address the fact that near and far detectors have different spectra (due to oscillations).
- Not well understood nuclear effects which bias energy reconstruction from simple CCQE assumption, have a small effect in near detector (right) can have a large effect in far detector.
- νPRISM addresses this by reconstructing the neutrino energy spectrum using linear combinations of off-axis measurements, and hence reproducing the oscillated far detector flux.

Nucleon Decay



Nucleon Decay



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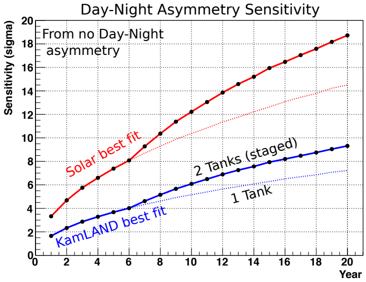
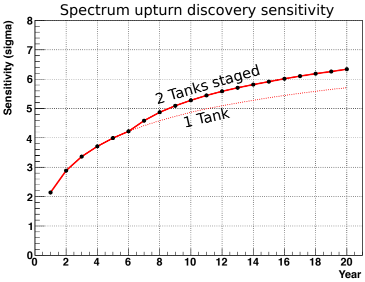
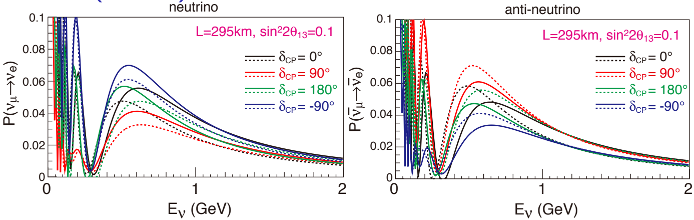
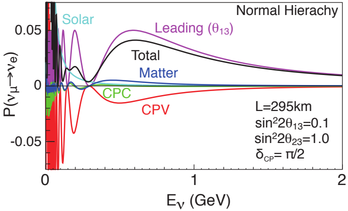




CP violation (CPV) with ν vs $\bar{\nu}$





- CPV needs non-zero mixing angles.
- CPV can be probed through difference between neutrino and anti-neutrino appearance:

$$P(\nu_\mu \to \nu_e) - P(\overline{\nu}_\mu \to \overline{\nu}_e) = -16 s_{12} c_{12} s_{23} c_{23} s_{13} c_{13}^2 \sin\delta_{CP} \sin\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right) \sin\left(\frac{\Delta m_{32}^2 L}{4E_\nu}\right) \sin\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right)$$

- At L = 295 km, $E_\nu \approx$0.6 GeV: effect of CP violation up to 28% while matter effect only 7%.