Overview of Hyper-Kamiokande project

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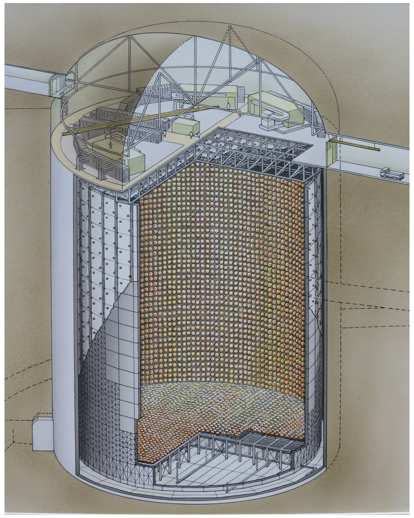
Satellite Hyper-K Workshop @ Vancouver
31 October 2018

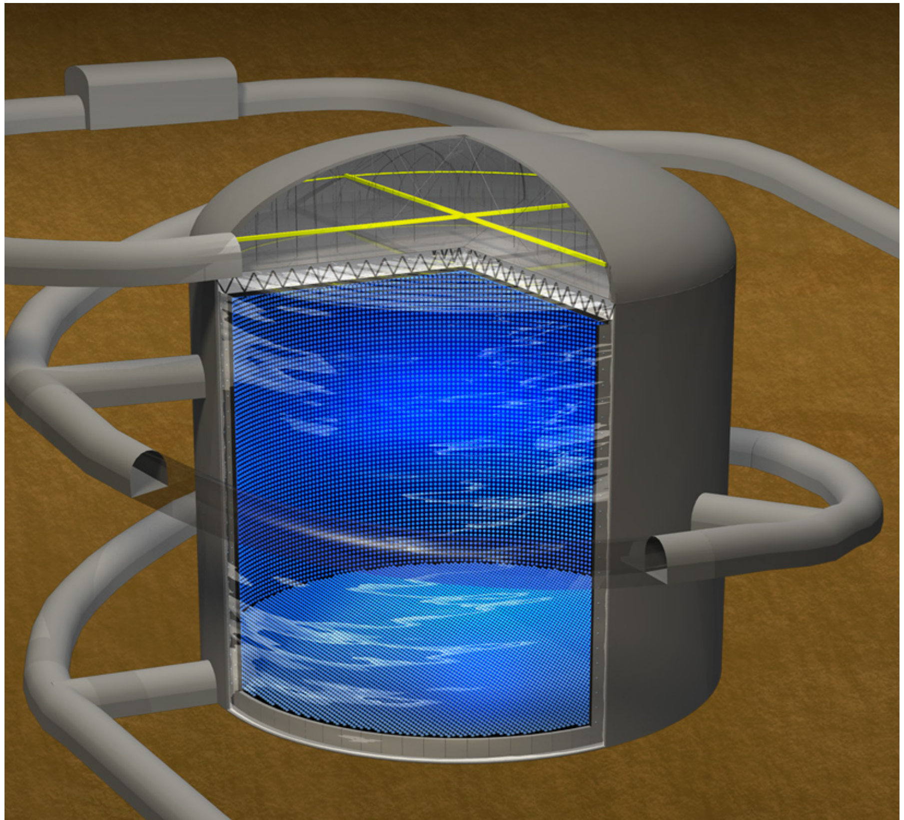
Hyper-Kamiokande

Extension of Super-K "neutrino and nucleon decay detector"
combined with MW-class world-leading ν-beam by upgraded J-PARC

✓Atmospheric ν oscillations
✓Solar ν oscillations
✓Accelerator ν in K2K/T2K



Φ41 m × H40 m
Total volume 50 kton
Fidual vol. 22 kton



"Hyper-Kamiokande Design Report", arXiv:1805.04163

Φ74 m × H60 m
Total volume 260 kton
Fiducial vol. 186 kton (~8xSuper-K)
High-sensitivity PMTs (2×Super-K)

J-PARC upgrade

Power upgrade from ~0.5 to 1.3 MW

1st priority among projects which require new funding requests in KEK Project Implementation Plan (KEK-PIP)

Project to be prioritized:
- COMET II
- J-PARC upgrade for Hyper Kamiokande
- Hadron Hall Extension
- H-line and g-2/EDM
- LHC and ATLAS
- Super Computer
- RNB

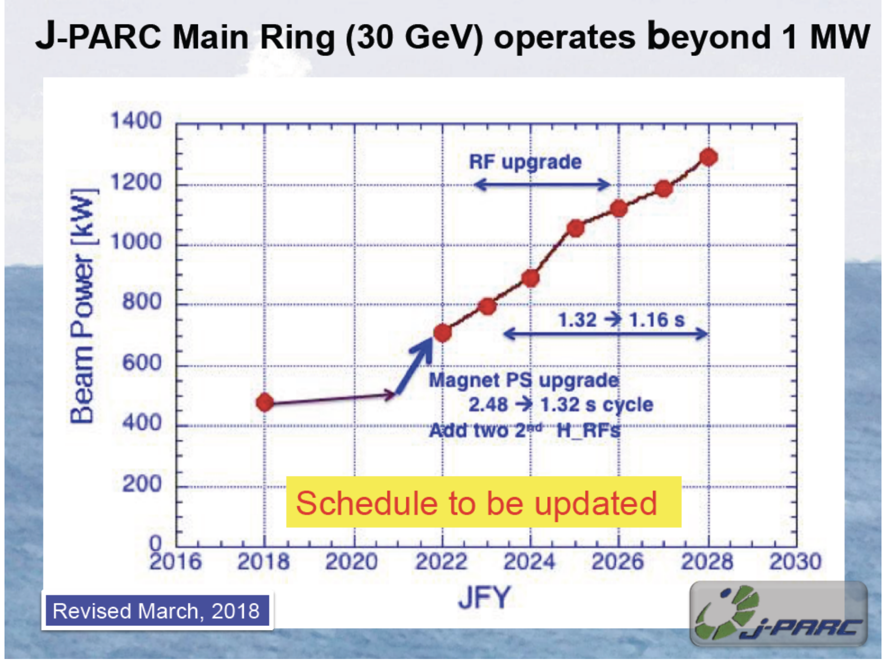
Separate prioritization
- Light Source

Beam Power (kW)	485 (Achieved)	(940)	1,300 (Goal for T2K-II)
#p/p(10^{12})	250	250	310
Rep T (s)	2.48	1.28	1.16

+25%

Funding started

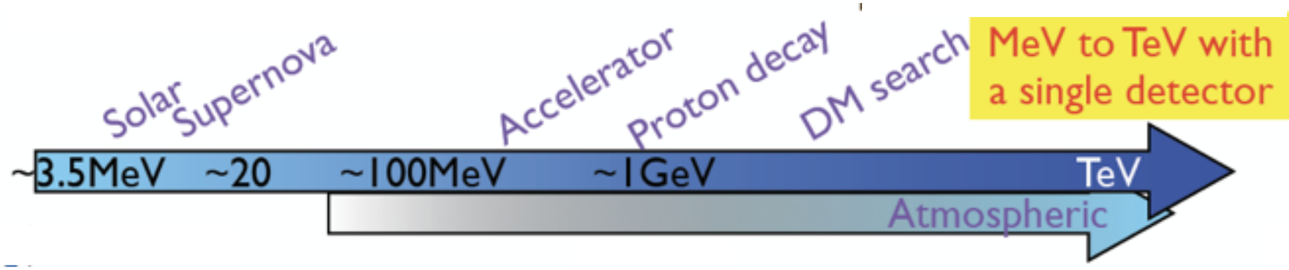
-10%



- Higher rep rate: **Funding started**
  - MR magnet power supply upgrade
  - MR RF upgrade (High grad/PS)
  - MR Fast Extraction Kicker upgrade
- Higher #p/p
  - MR RF upgrade (PS)

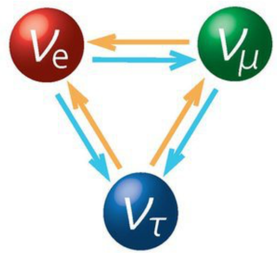
Broad/Unique Physics in Hyper-K

w/ wide energy coverage and High-mass

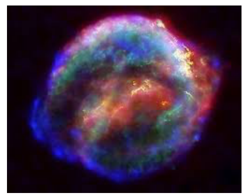


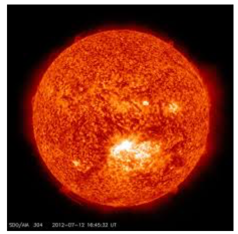
	material	Fiducial Mass
Super-K	Water	22
Hyper-K	Water	**190**
Dune	Argon	40
JUNO	Liq. Scinti	20

1. Comprehensive Neutrino Oscillation Measurements
   - θ_{12}, θ_{23}, θ_{13}, Δm^2_{21}, Δm^2_{32}, CPδ by Solar, Atm, and Accelerator ν's

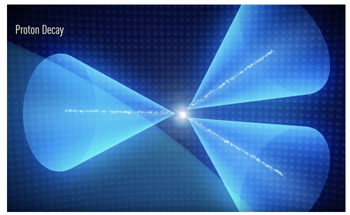


2. Neutrino astrophysics and astronomy
   - High-statistical Solar ν measurements
   - Supernova ν's from ~kpc (ν burst) w/ directional, flavor, energy info.
   - Supernova ν's from >Mpc (guaranteed SN relic ν signal)
   - Search for DM-induced ν, Extragalactic ν, and more?





3. Proton decay search with high-mass (190 kiloton)
   - One order of magnitude better discovery potential than Super-K

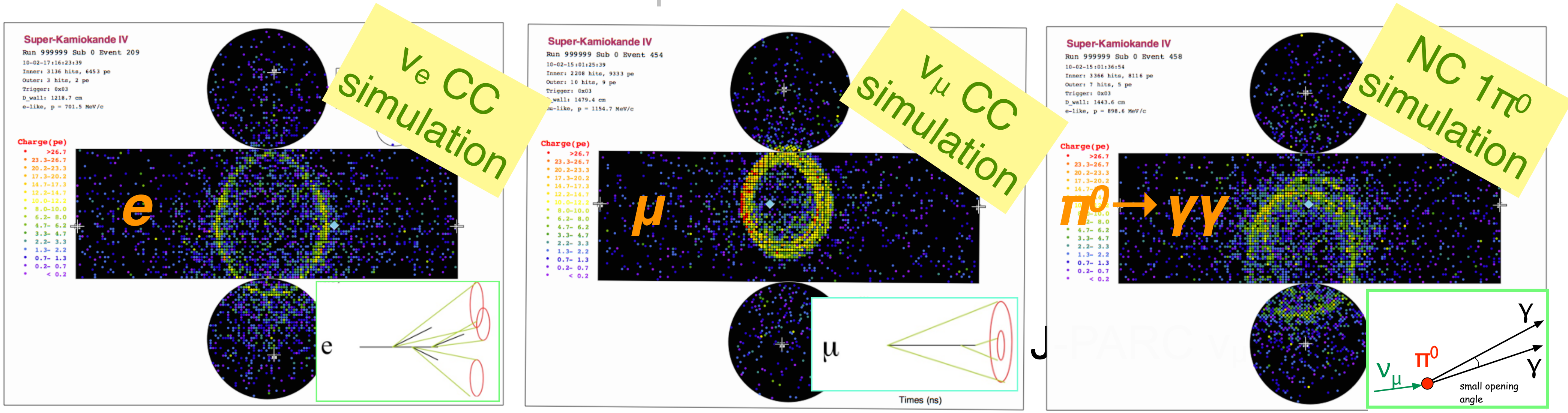


J-PARC ν_μ ($\bar{\nu}_\mu$) beam (~0.6GeV)

ν_e appearance signal = single e event

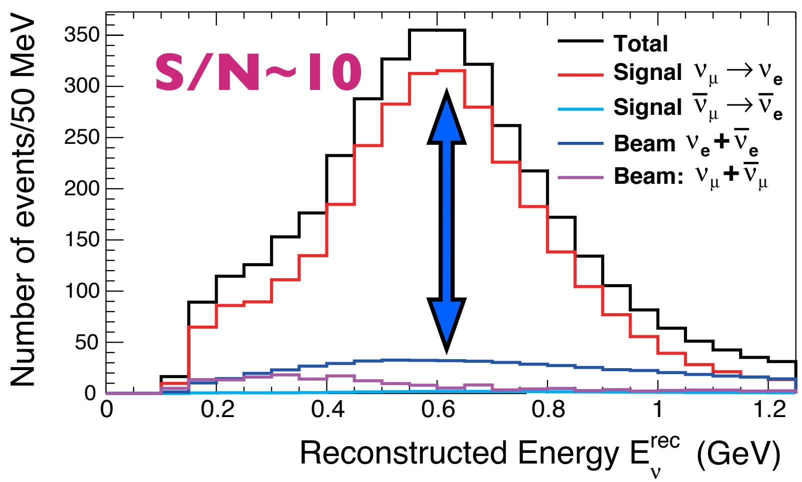
CCQE : $\nu_e + n \rightarrow e + p$

(dominant process at J-PARC beam energy)



- **High background rejection**
  - >99.9% ν_μCC, 99% NC π^0 rejection
  - keeping 60% ν_e signal efficiency
- **Unique CPV measurement**
  - High statistical, clean (S/N~10)
  - Simple Eν reconstruction by charged lepton kinematics (for CCQE)
  - Quasi-monochromatic beam w/ peak at 1st oscillation maximum (~0.6GeV)
  - Less matter effect (fake CPV effect)

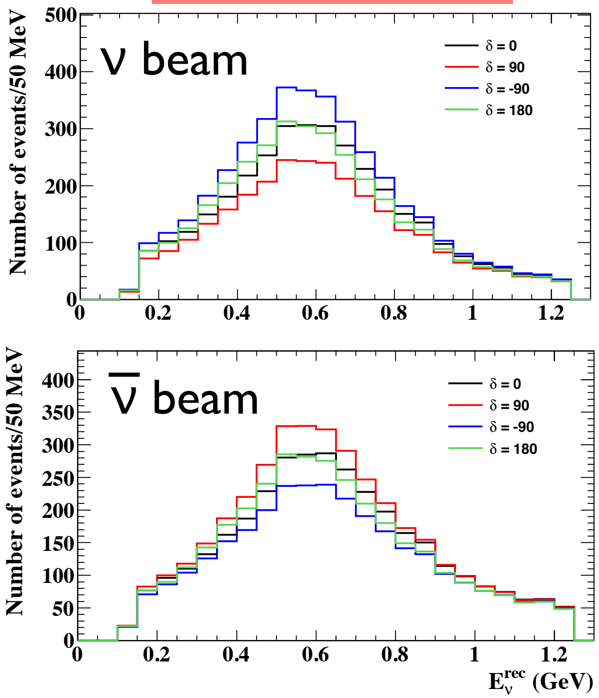
Appearance ν mode



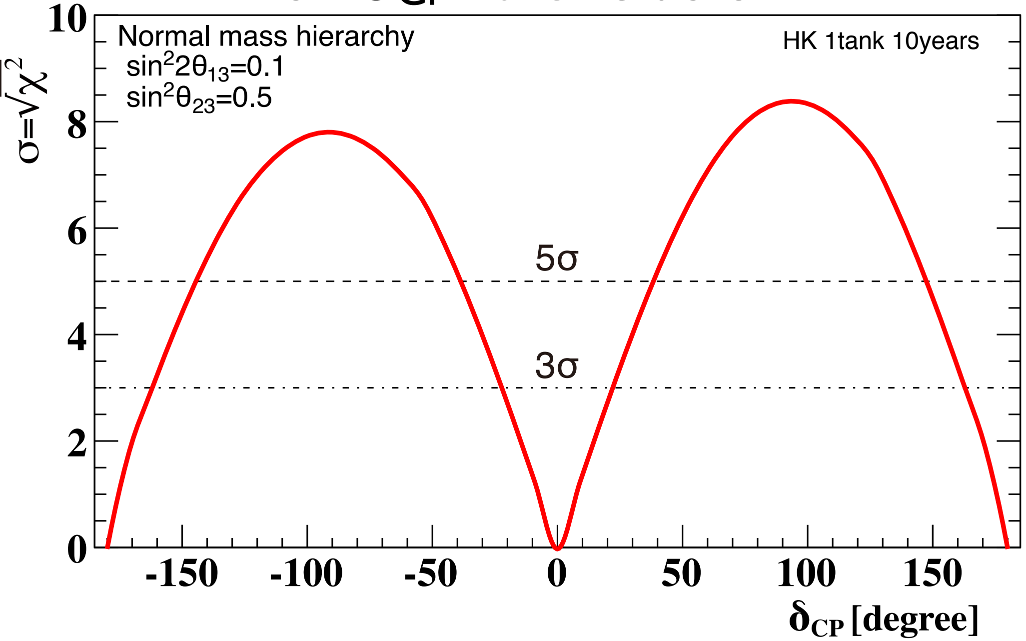
CPV sensitivity

10 years (13MW×10^7s)

ν_e appearance



sinδ_{CP}=0 exclusion

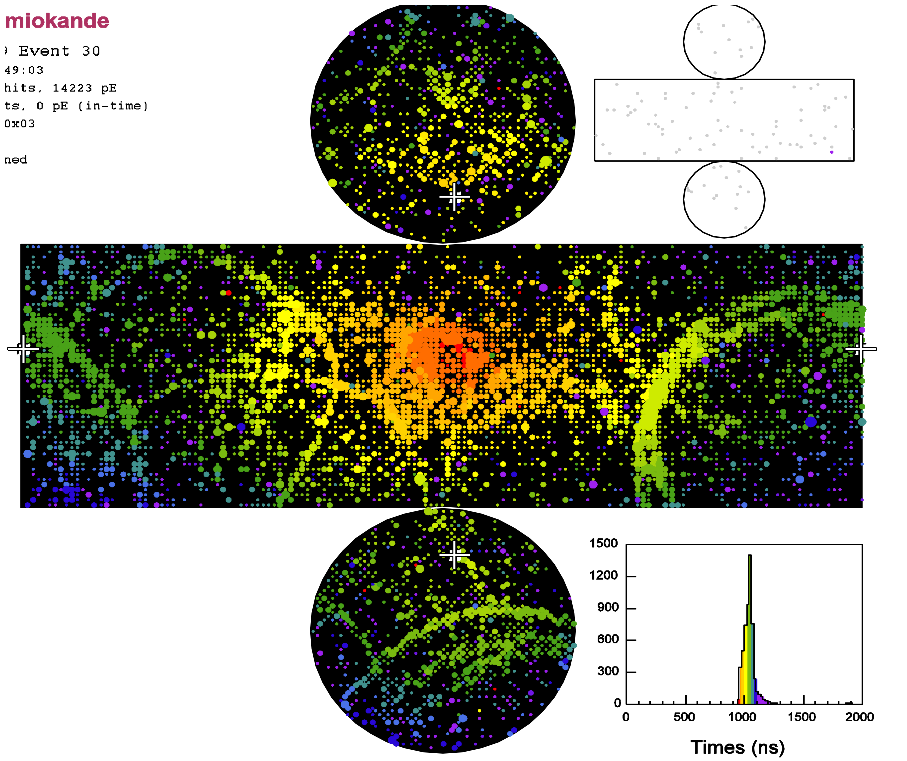


- Exclusion of sinδ_{CP}=0
  - 8σ for δ=-90° (T2K best fit)
  - 80% coverage of δ parameter space for CPV discovery w/ >3σ
- δ_{CP} precision measurement
  - 22° for δ=-90°, 7° for δ=0°

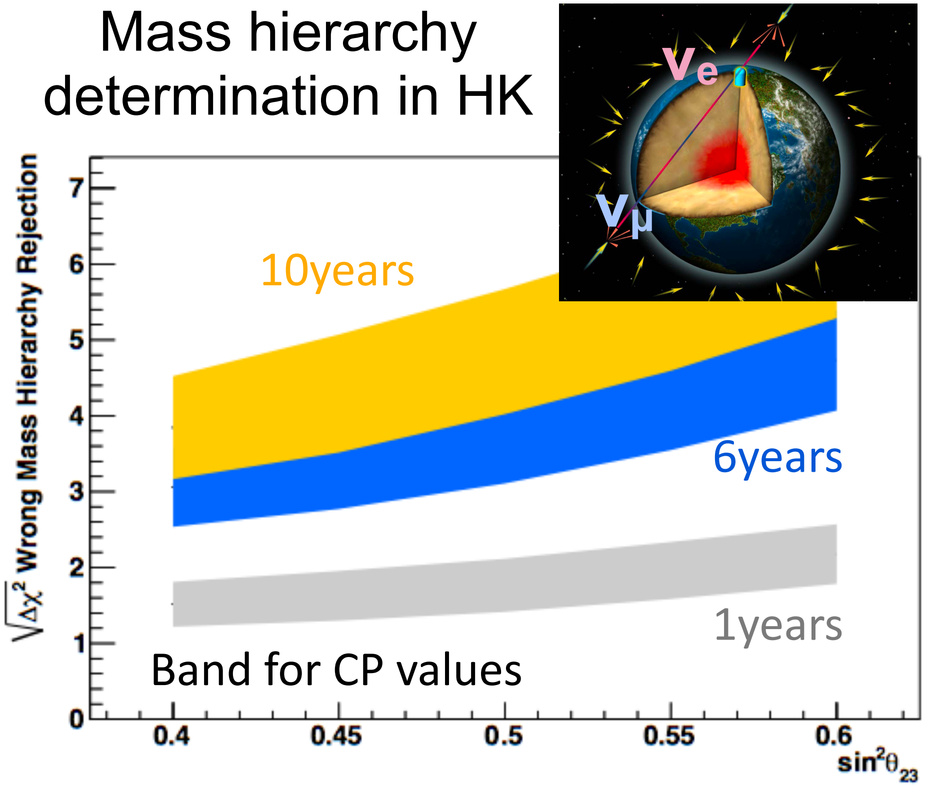
Atmospheric ν's (0.1~10³ GeV)

Oscillation studies with wide energy and baseline

Tau appearance in Super-K



Mass hierarchy determination in HK

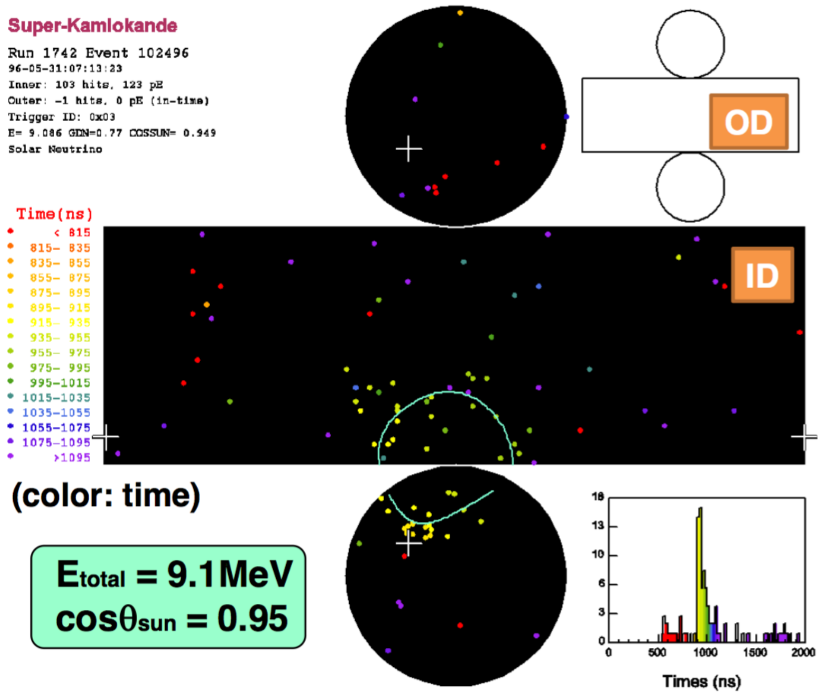


- Wide range of ν energy (0.1 GeV ~ 10³ GeV) and ν baseline (10km downward ~ 13,000km upward)
- Study of earth matter effect to determine neutrino mass hierarchy
- Unique tests of exotic properties

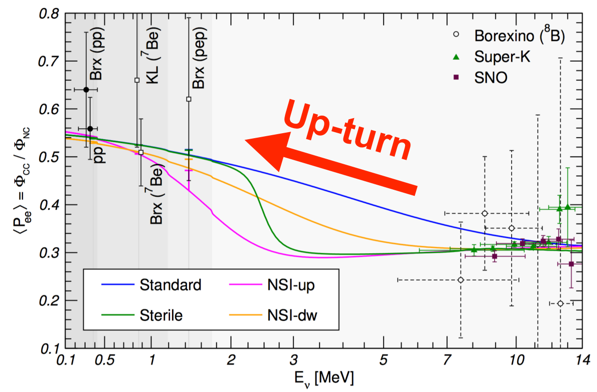
Solar neutrinos in Hyper-K

> a few MeV neutrino astronomy

Cherenkov ring image in Super-K



survival probability of electron solar neutrinos

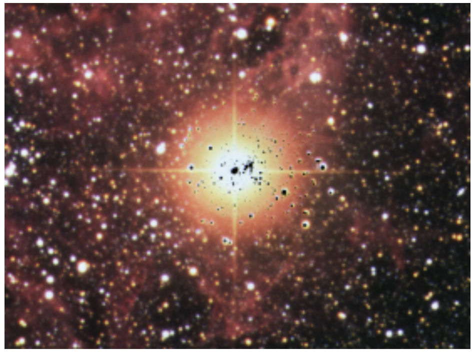


- Neutrino oscillation study
  - Precision measurements of spectrum and day/night flux asymmetry (test of standard matter effect or exotic scenario?)
- Solar physics
  - First observation of Hep ($^3He + p \rightarrow {}^4He + e^+ + \nu_e$) neutrinos

Low energy threshold, high resolution reconstruction, and low background are critical

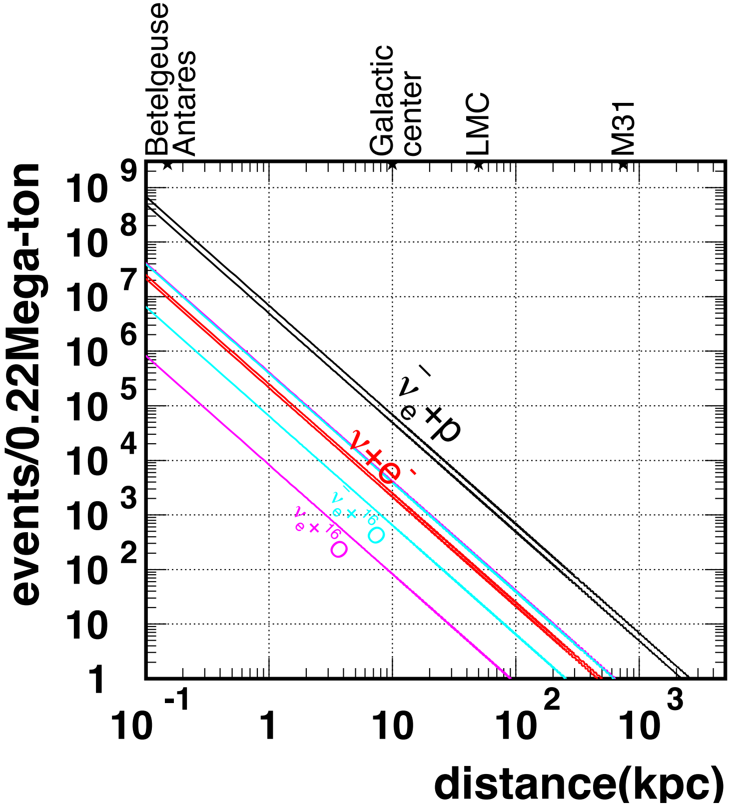
Supernova neutrinos in Hyper-K

First multi-messenger event: neutrinos and light from SN1987



Neutrino energy spectra, flavor, time, and direction will provide rich information & opportunities for:

- Supernova physics
  - Mechanism of core collapse, explosion evolution, cooling of porto-neutron star
  - Nucleosynthesis of heavy nuclei
  - Black hole formation
- Neutrino physics
  - Mass hierarchy, absolute mass, etc
- Early alert for astronomers



galactic supernova at 10 kpc

54,000-90,000 events in total

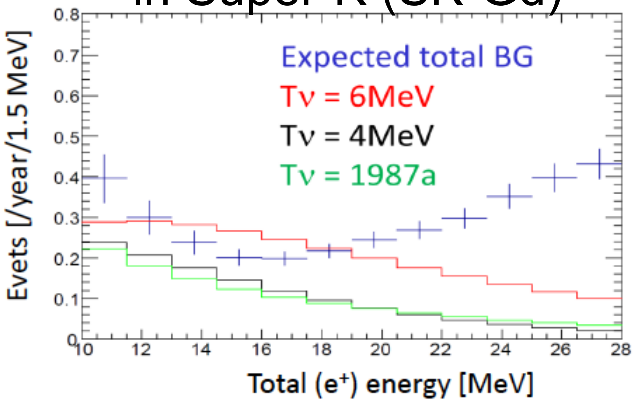
high statistics

Reach to Andromeda

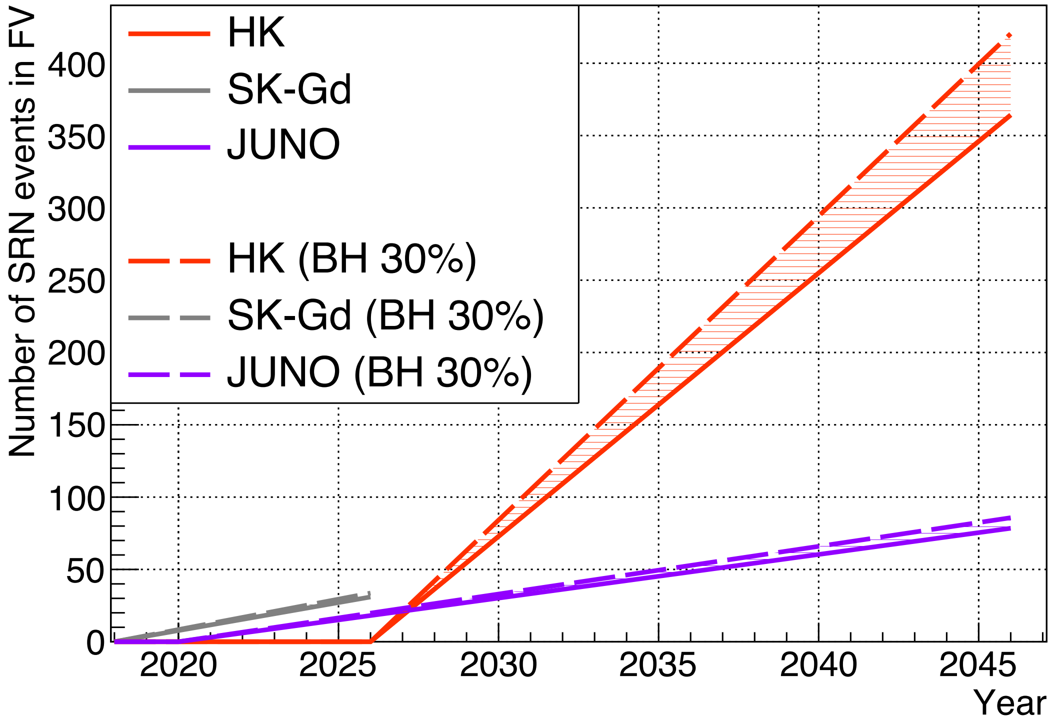
Diffuse supernova neutrino background

- DSNB from all the SN explosions in the Universe → guaranteed steady source of SN neutrinos
- Include Information about:
  - history of SN, averaged SN neutrinos, fraction of black hole formation

Expected DSNB spectrum in Super-K (SK-Gd)



Number of DSNB in Hyper-K
(efficiency is not taken into account)

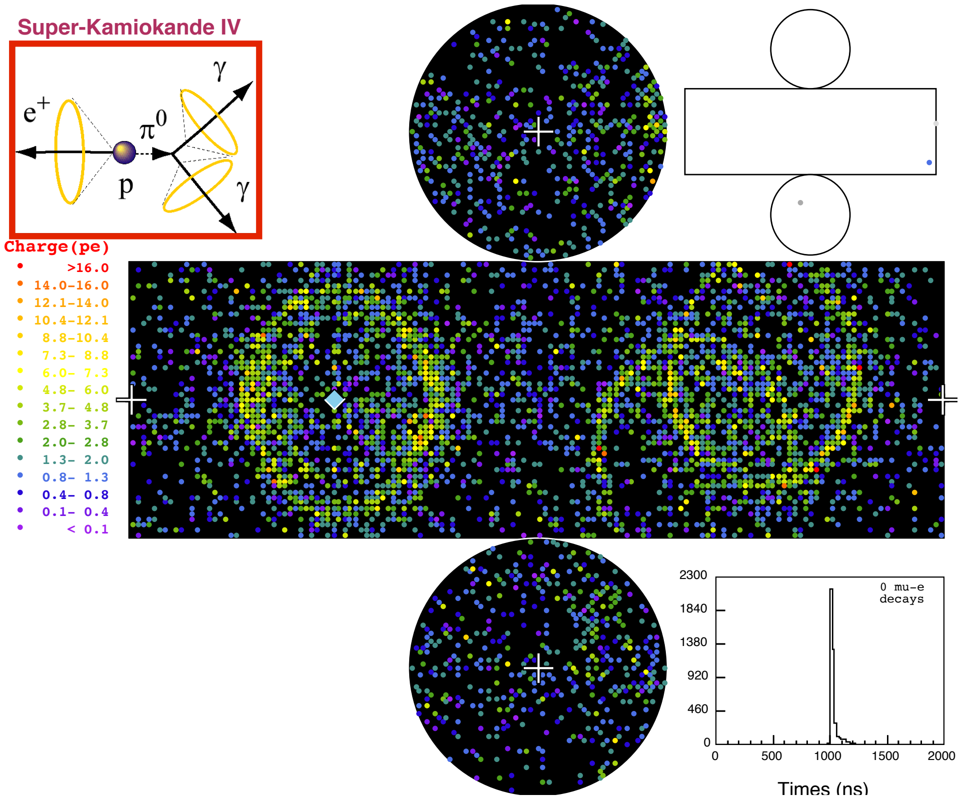


- Good chance for precise flux and energy spectrum measurement
- Main experimental issue is backgrounds (spallation isotopes by CRμ, atmospheric ν etc)

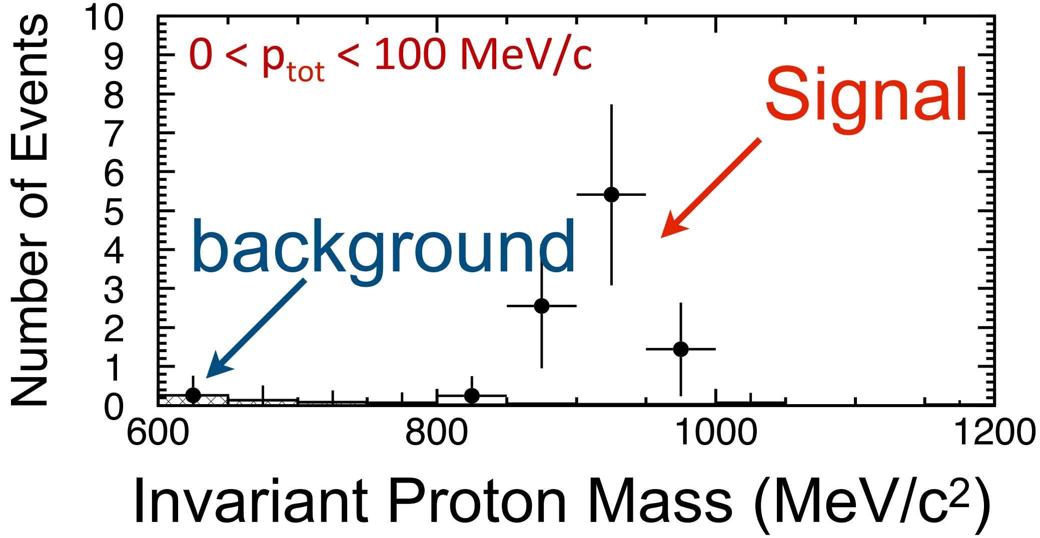
Proton decay searches

World-leading searches from Super-K to Hyper-K

Cherenkov ring image in Super-K



Hyper-K 10 years operation assuming $\tau_{proton}=1.7\times10^{34}$years (SK limit)



3σ reach to 10^{35} yrs

Neutron tagging is a key to further reduce the atmospheric neutrino backgrounds associated with neutrons.

Status in Japan

- In the end of Aug. 2018, MEXT has decided to request the budget to Ministry of Finance for "funding for feasibility study."
- In the Japanese system, "funding for feasibility study" implies "seed funding". For example;
  - ✓Super-Kamiokande received the "funding for feasibility study" in 1990, and the construction budget was approved in 1991.
  - ✓Other examples include: Subaru telescope (8m telescope at Hawaii), ALMA telescope in Chili (for 2 years), and TMT (30 meter telescope in Hawaii).
- Then, the President of the Univ. of Tokyo, in recognition of both the project's importance and value both nationally and internationally, pledged to ensure construction of the Hyper-Kamiokande detector commences as scheduled in April 2020.

Hyper-K excavation will begin in 2020!

(will begin observation in ~2027)

International Hyper-K proto-collaboration

Hyper-K meeting@Kashiwa, September 2018

15 countries, 76 institutes, ~300 people

Proto-collaboration Structure

as of 2018/9/13

Project leader

Project Leader Shiozawa
co-leader F.Di Lodovico

International Steering Committee

Nakaya (chair), Y.Itow (co-chair)
D.Wark, Nakahata, Kobayashi, Shiozawa,
F.Di Lodovico, Yokoyama, Aihara, A.Blondel,
G.Catanesi, E.Kearns, A. Konaka, S.B.Kim

International Board of Representative

D.Wark (UK, chair), A. Ioannisian (Armenia), H. Nunokawa (Brazil),
S. Bhadra (Canada), M. Hartz (Canada), M. Gonin (France),
M. Zito (France), M. G. Catanesi (Italy), T. Kobayashi (JP), T. Nakaya (JP),
M. Shiozawa (JP), C. Rott (Korea), E. Rondio (Poland), Y. Kudenko (Russia),
L. Labarga (Spain), F. Sanchez (Switzerland), V. Aushev (Ukraine),
F. Di Lodovico (UK), E. Kearns (USA), M. Wilking (USA),
E. O'Sullivan (Sweden)

Speakers Board

Yokoyama, G.Catanesi, E.Kearns

Technical Coordinators

HK detector: S. Moriyama, Steve Playfer
HK Beam+ND: M. Hartz, M. Yokoyama

Conveners Board *WG leaders

WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8	Physics WG	WG10
*Nakayama, Tanaka, M.Smy	*Sekiya, Vagins	*Nishimura, Feusels, De Rosa	*Hayato, T.Lindner, A.Bravar	*Miura, O'Sullivan	*Mccauley, Koshio, Mine	*Hartz, J.R.Wilson	*Fujii, Densham	*Ishitsuka	*Seon-Hee Seo

Physics WG sub-groups:

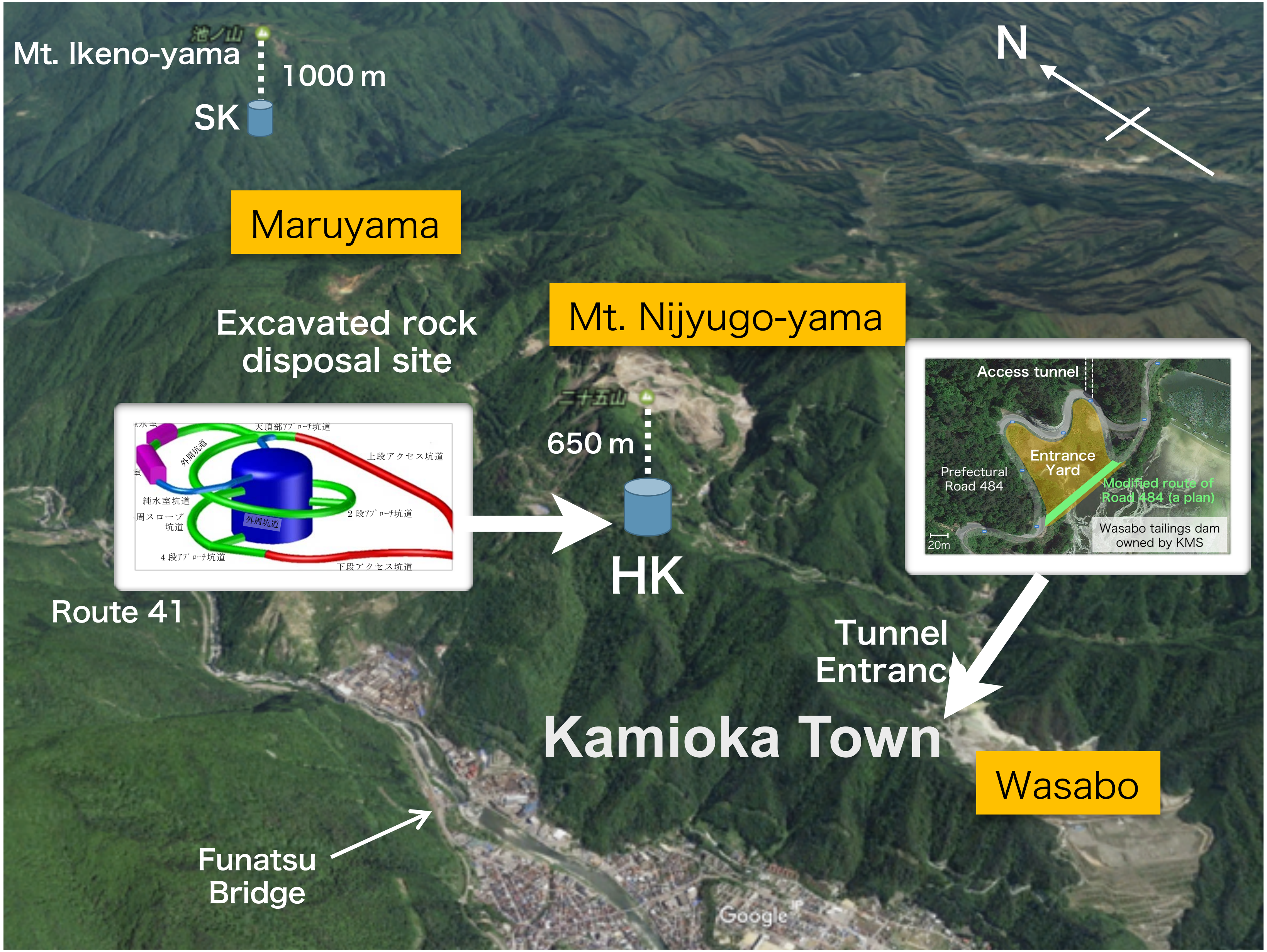
Phys-WG1	Phys-WG2	Phys-WG3
Friend	Wendell	Takeuchi, Shimizu

WG1: Cavity and Tank
WG2: Water
WG3: Photo-sensor
WG4: Electronics and DAQ
WG5: Software
WG6: Calibration
WG7: Near Detectors
WG8: Beam & Accelerator
WG9: Physics
WG10: 2nd detector in Korea

Phys-WG1: Accelerator
Phys-WG2: Atmν+Nucleon decays
Phys-WG3: Astroparticle Physics

Detector Location

- 8km south of Super-K
- 295km from J-PARC and 2.5 deg. off-axis beam (same as Super-K)
- 650m rock overburden

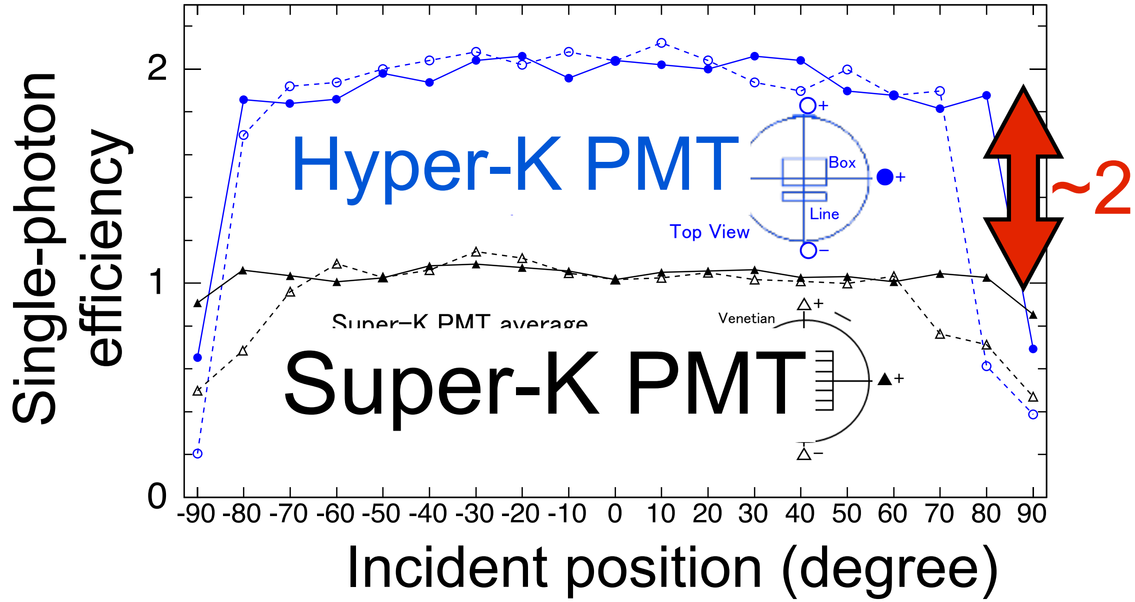


Key element: Photo-detection system

φ50cm

- sensitivity:
  2 x SK
- Time resolution:
  1/2 x SK
- Pressure:
  2 x SK

~140 new PMTs have been installed in Super-K this summer



- Ongoing R&D of B&L-dynode PMT includes
  - dark rate reduction, cover development
  - long-term performance evaluation in Super-K
  - new collaboration is welcome
- Budget request for 20,000 PMTs in Japan
  - corresponds to a half of Super-K photo-coverage (40%). HK physics sensitivities are estimated by 40% coverage.

Still open to innovative ideas and in-kind contributions to additional and/or alternative photo-detection system

Inner-Det.

MCP-PMT

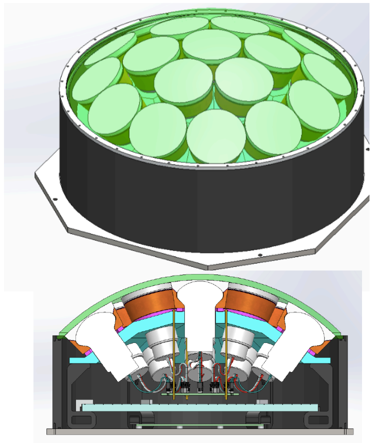
Ongoing R&D to improve timing, reduce dark rate, water-proofing, cover etc

φ50cm

Inner-Det.

Multi-PMT module

Many R&D are needed on module/assembly, acrylic vessel, electronics, simulation&reconstruction etc



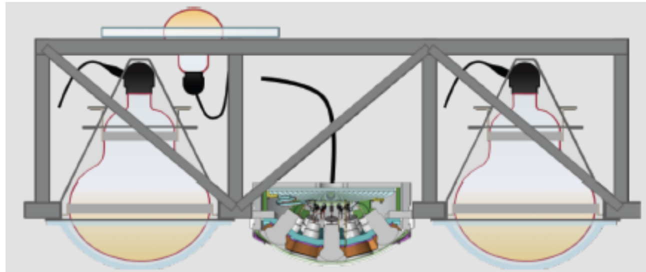
φ50cm

Outer-Det.

Outer-detector system

Open for photo-sensor type, density, light-concentrator, deployment method

Potential design of OD PMT w/ wavelength shifter plate



Potential combination of 50cm PMTs and multi-PMT modules

- MCP-PMT R&D aiming for better detector performance
- Studying potential combination w/ multi-PMT modules to improve light yield, granularity, timing resolution, and charge dynamic range
- Also need outer-detector system, still open for photo-sensor design
- Need front-end electronics, trigger, and DAQ system

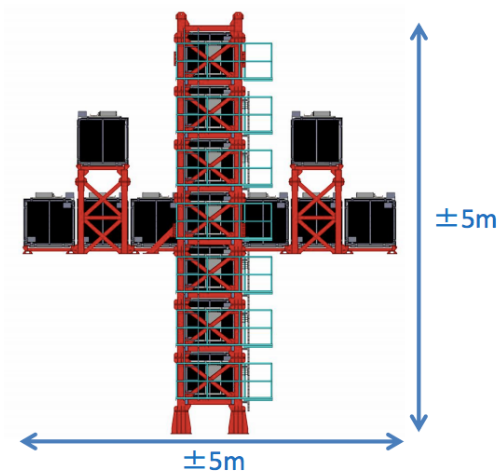
New collaboration are needed.

Baseline design for Near/Intermediate detectors

Reduction of systematic uncertainties is critical for the long baseline experiment.
Near/Intermediate detectors to be realized by international partners.

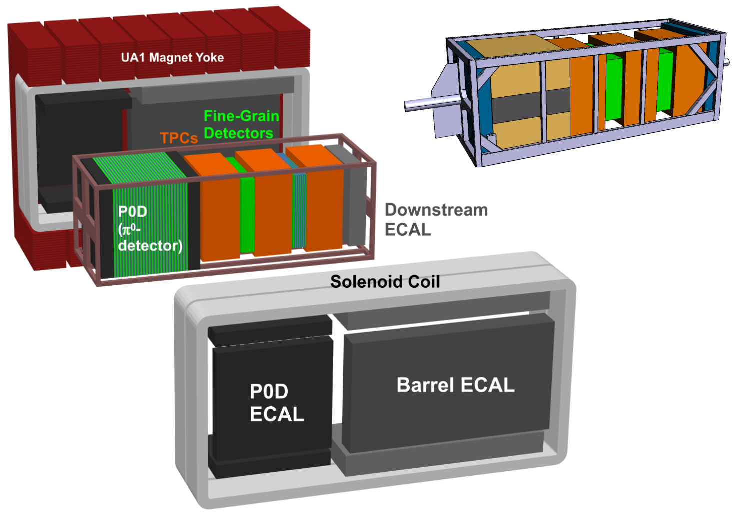
On-axis Detector

(INGRID)



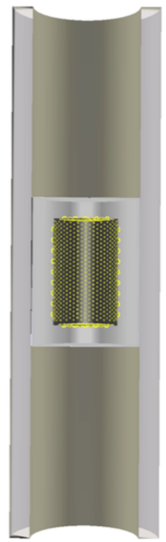
Off-axis Magnetized Tracker

(ND280→ND280 Upgrade→??)



Off-axis spanning intermediate water Cherenkov detector

(IWCD)



- On-axis detector: Measure beam direction and event rate
- Off-axis magnetized tracker: Measure neutrino flux and neutrino spectrum, and interactions. Charge separation to measure wrong-sign background
- Intermediate WC detector: H_2O target with off-axis angle spanning orientation, Gd loading

Summary

- **Hyper-K is the world largest detector for a few MeV to TeV neutrinos**
  - Long baseline, Atmospheric, Solar, Supernova neutrinos
  - Nucleon decays, dark matter searches, and other exotics

- **Potential technical breakthroughs to go beyond Super-K**
  - Photo-detection system for better light yield, timing, dynamic range, granularity
  - Neutron tagging w/ and w/o Gd
  - New algorithm for event reconstruction and background rejections possible?
  - Improve systematic uncertainties of flux, cross section, detector response

- **Time to make critical decisions and build up the collaboration**

- **There are also opportunities of Japan-based intermediate programs**
  - Commissioning, calibration, and analysis of upgraded Super-K with Gadolinium
  - Long baseline experiment by SK-Gd and the upgraded J-PARC