Hyper-Kamiokande

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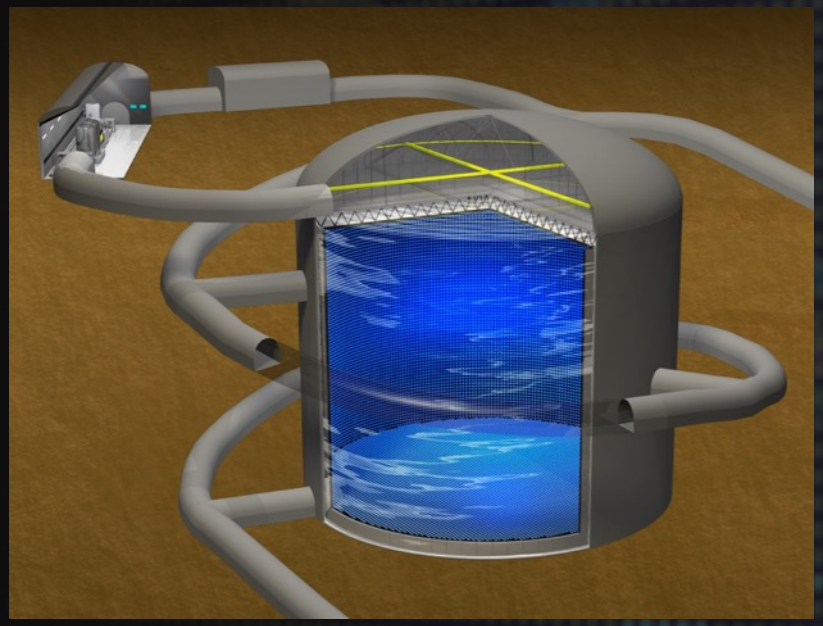
for the Hyper-Kamiokande proto-collaboration

June 20, 2017
The 26th International Workshop on Weak Interactions and Neutrinos (WIN2017)
University of California, Irvine

Hyper-Kamiokande Detector



Tank : 60 m tall × 74 m diameter

260 kton ultrapure water
186 kton fiducial mass : ~10 × SK

Innermost main volume viewed by
40,000 of new 50cm photosensors

× 2 higher photon sensitivity than SK

Aiming for quick start with a single tank

- Budget request being submitted to start construction in JFY2018
- Physics sensitivity presented in this talk is for one tank

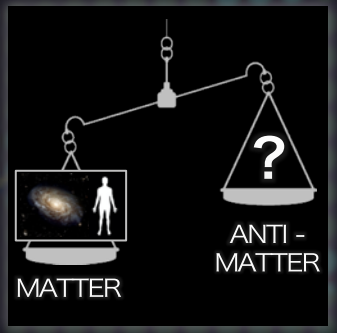
Optional second tank built afterwards is under consideration

- Time, Design, Location (Kamioka, Korea, ⋯), etc.

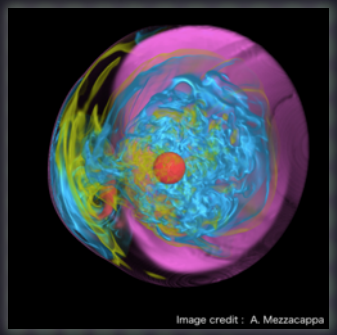
Hyper-K Physics

Rich program to explore fundamental questions

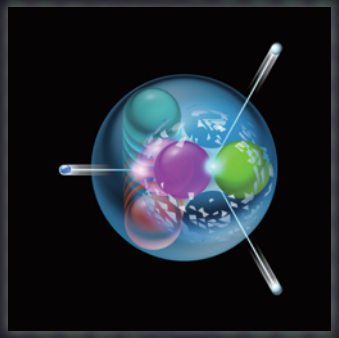
- Neutrino oscillation
  - δ_{CP} measurement
    → Mystery of our matter-made universe
  - ν mass ordering / parameter measurements
    → Origin of Generation / Underlying symmetries?



- Neutrino astrophysics
  - Supernova burst ν observation
    → Mechanism of SN explosion, NS/BH formation
  - Relic SN ν measurement (flux & spectrum)
    → History of star formation / black hole formation



- Nucleon decay
  - Great potential for "discovery"
    → Direct verification of Grand-Unification

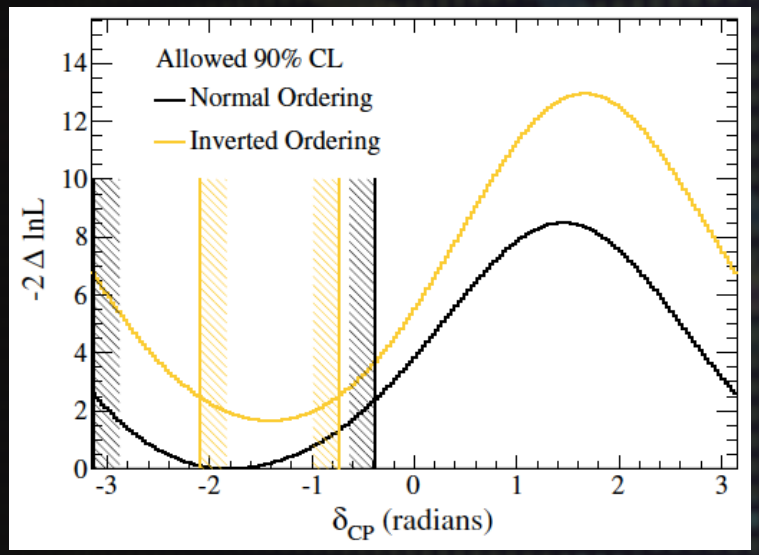


and more …

Leptonic CP Violation

Latest result from T2K

PRL 118, 151801 (2017)



- Excludes $\sin\delta_{CP} = 0$ at 90% CL
- Favors $\delta_{CP} = -90^{o}$
  - Super-K atmospheric ν data also
- It could be possible that ongoing experiments discover CPV (~3 σ)

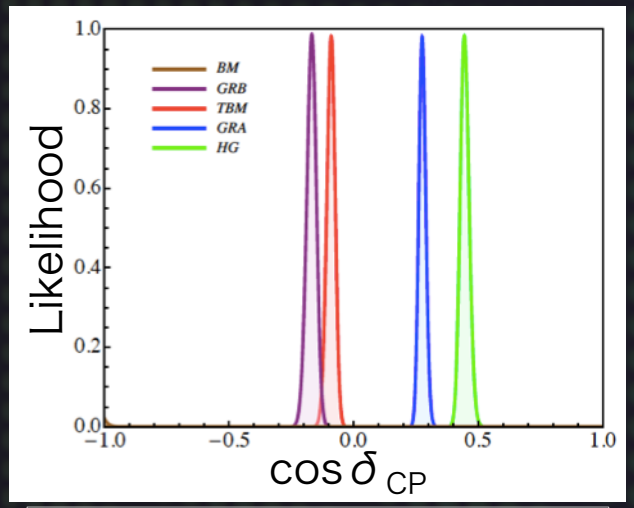
Measurement of δ_{CP} is essential

- Possibility to explain the baryon asymmetry in leptogenesis with only Dirac δ_{CP}

  $|\sin\delta_{CP}| > \sim 0.6$

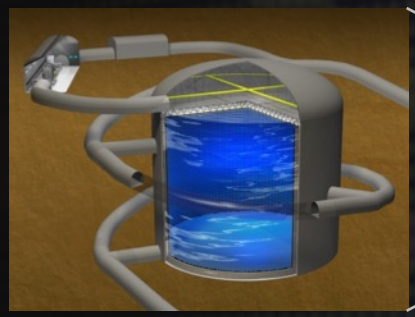
  PRD 75, 083511 (2007)
  S. Pascoli, S.T. Petkov, and A. Riotto

- Prediction of δ_{CP} by unknown symmetries



arXiv:1504.02402v1
S. T. Petcov, I. Girardi, and A. V. Titov

Hyper-K LBL Beam Neutrino Program



Hyper-K

J-PARC
Accelerator Complex

- Superb configuration to measure δ_{CP}
  - Not very long baseline → Less matter effect
- Huge statistics (~3000 appearance signals) with high S/N
- Performance well proven by ongoing experiments, SK/T2K
  - Common beamline / Same far detector technology
  - Realistic assumption of systematic uncertainties

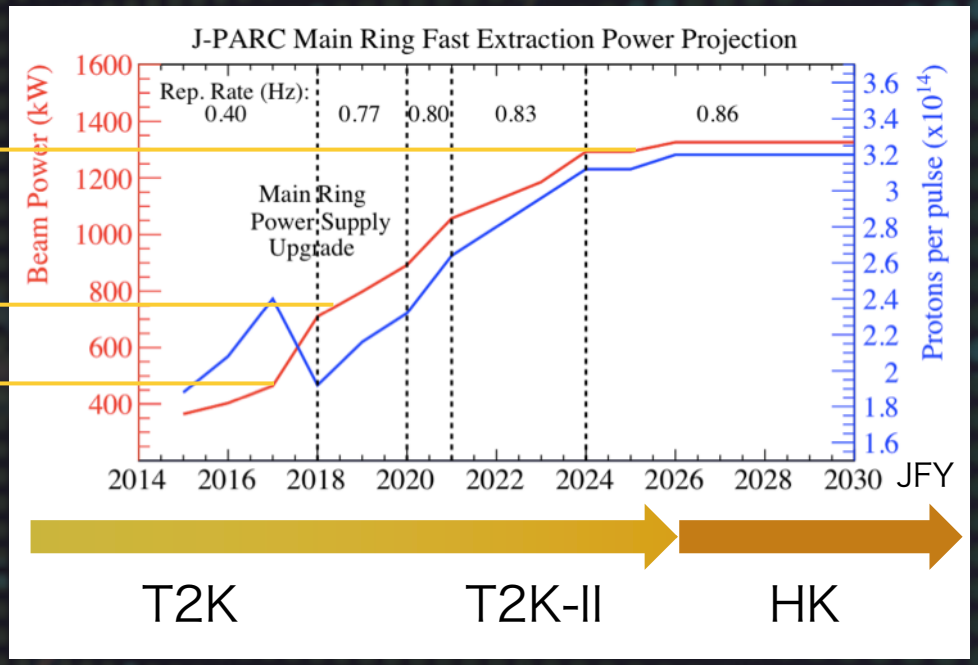
    Error on expected number of ν_e events : 5-6% (T2K) → 3-4% (HK)

J-PARC Beam Power Upgrade

1.3 MW : By 2026 for HK

750 kW : T2K design spec.

470 kW : T2K achieved



→ 750 kW 1.3 sec cycle

- New magnet power supply to increase repetition rate being funded (60M$/3yrs)

→ 1.3 MW 1.16 sec cycle

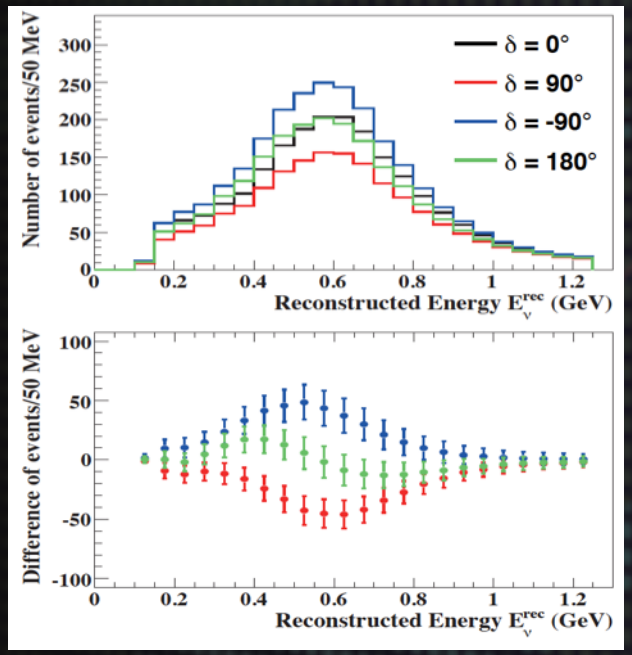
- Trial for 1MW-equivalent operation was successful
- KEK Project Implementation Plan (KEK-PIP) put first priority to "J-PARC upgrade for Hyper-K" in 2016

Expected Events in Hyper-K CPV Study

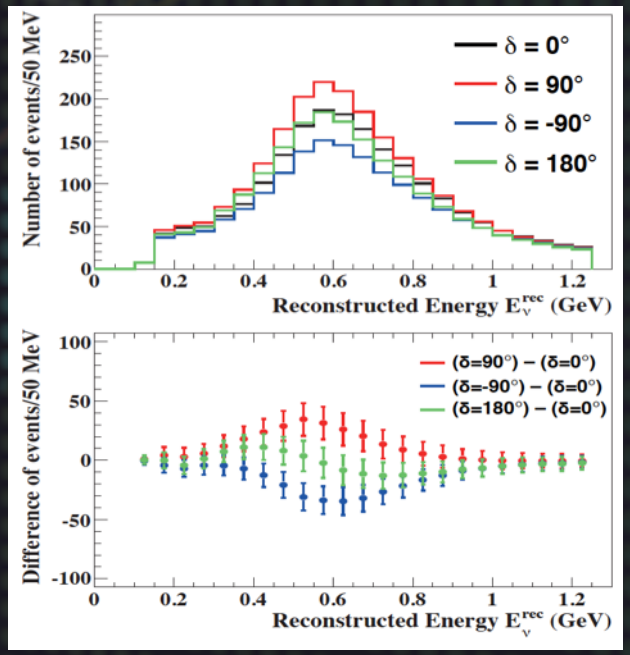
Number of signal candidate events, 1.3 MW × 10 years (10^8 sec), $\nu : \bar{\nu}$ = 1:3

for $\delta_{CP} = 0$	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 beam	1,643	15	7	259	134
$\bar{\nu}$ beam	1,183	206	4	317	196

ν beam ν_e appearance



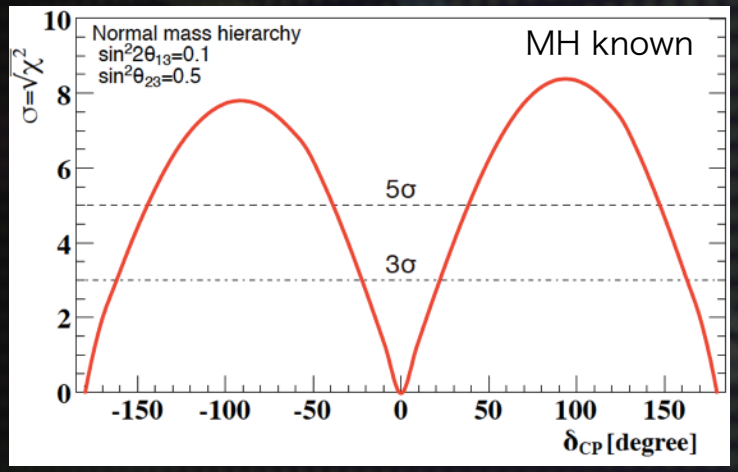
$\bar{\nu}$ beam $\bar{\nu}_e$ appearance



CPV Sensitivity

1.3 MW × 10 years (10^8 sec), $\nu : \bar{\nu}$ = 1:3

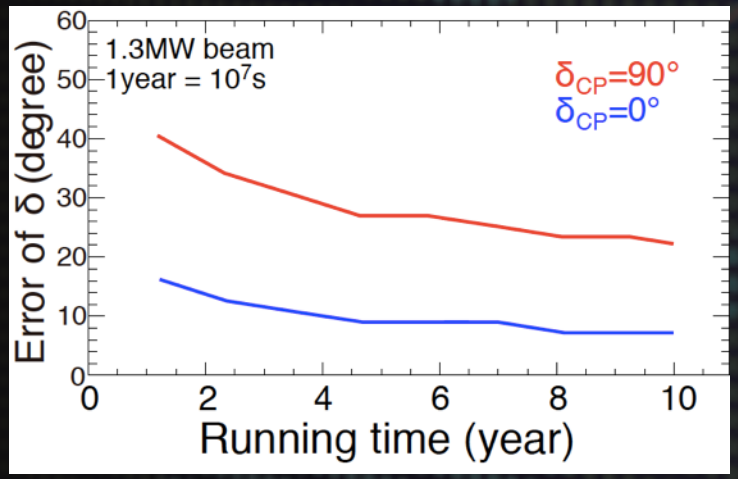
Significance for $\sin\delta_{CP} = 0$ exclusion



~8 σ exclusion if $\delta_{CP} = \pm 90^\circ$
~6 σ exclusion if $\delta_{CP} = \pm 45^\circ$

Observe CPV for 60% of δ_{CP} with >5 σ significance

Error of δ_{CP} vs Running time

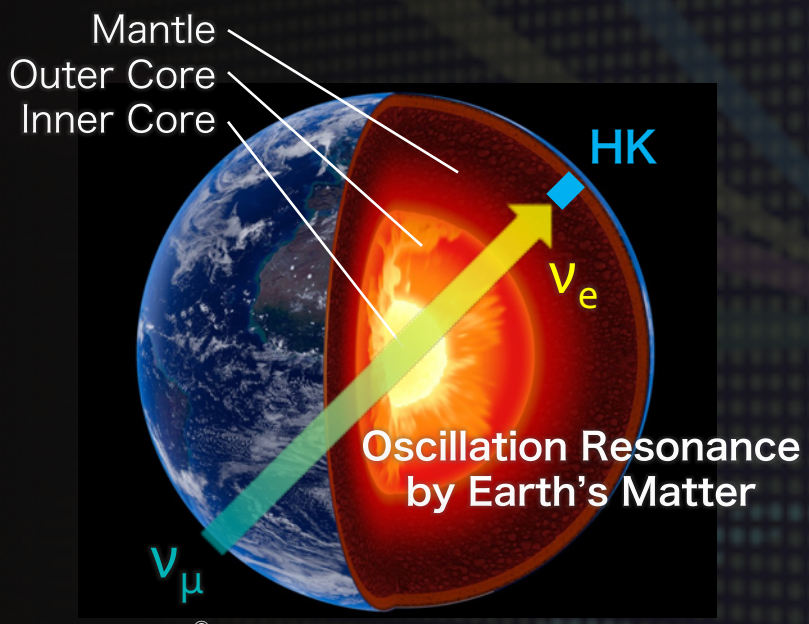


δ_{CP} measurement precision

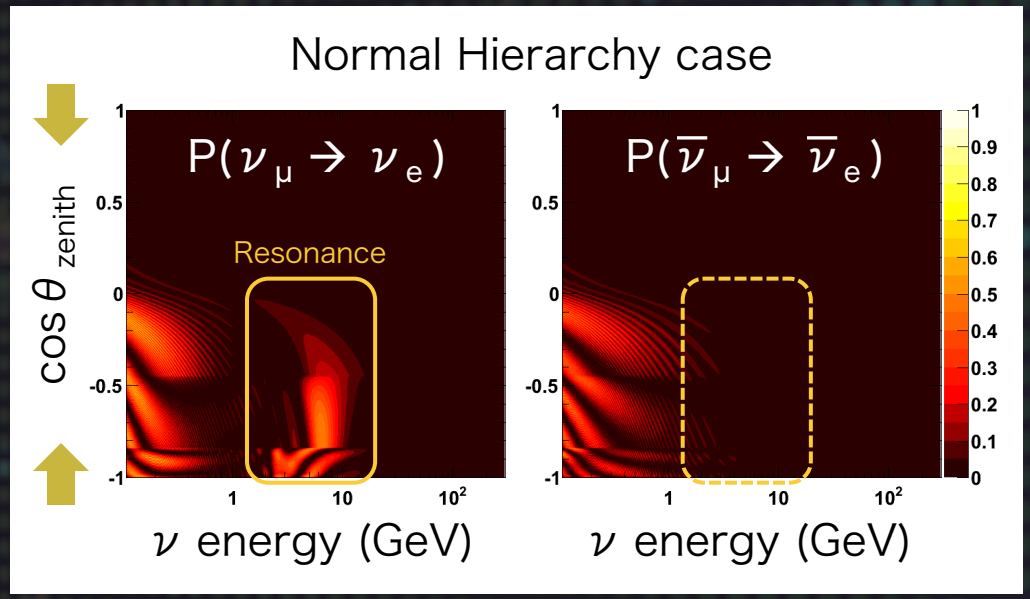
22° for $\delta_{CP} = \pm 90^\circ$
7° for $\delta_{CP} = 0^\circ/180^\circ$

Mass Hierarchy Determination in HK

With Atmospheric ν + Beam ν



© Johan Swanepoel / Shutterstock.com



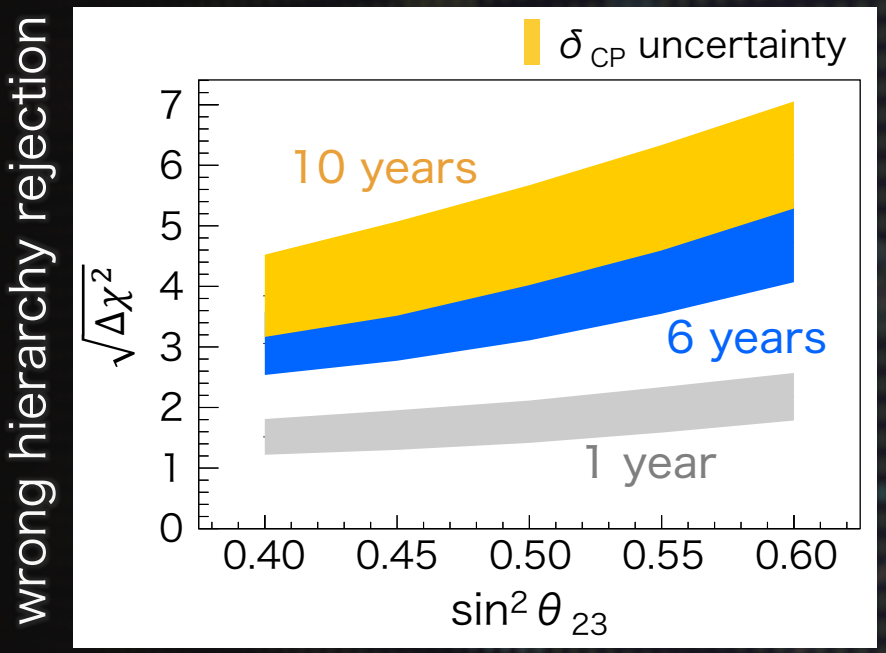
MSW resonance in upward-going multi-GeV ν_e sample

In normal hierarchy case, the resonance appears only for ν_e
In inverted hierarchy case, the resonance appears only for $\bar{\nu}_e$

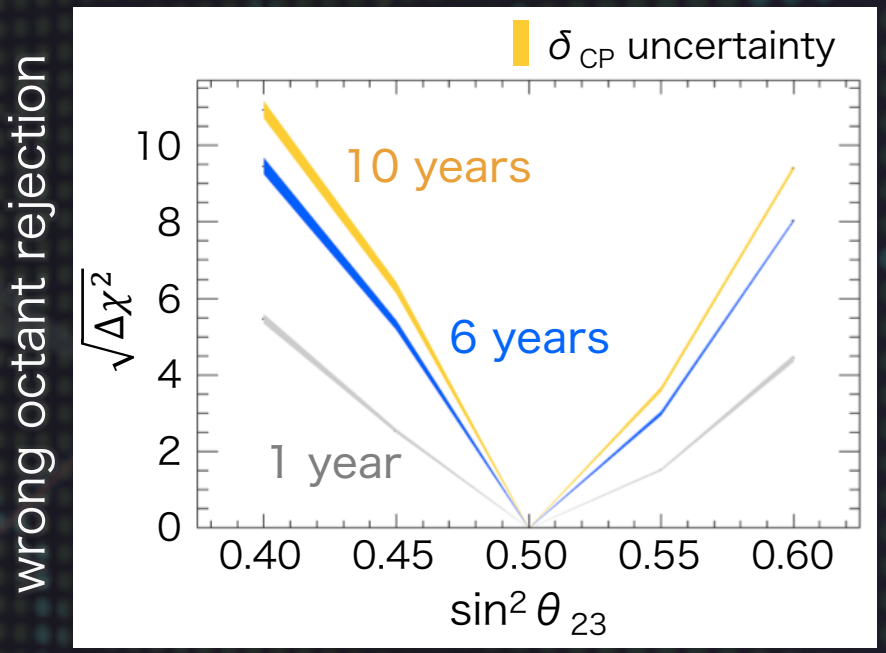
→ Atmospheric ν is sensitive to mass hierarchy

Atmospheric + Beam ν : Sensitivity

Neutrino Mass Hierarchy



θ_{23} Octant



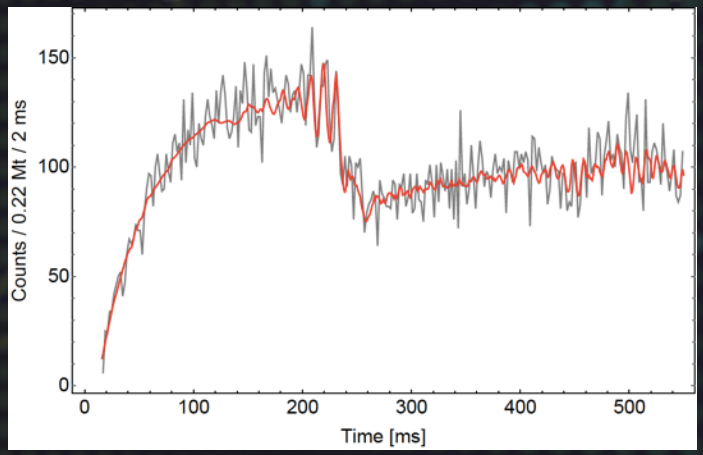
- Complementary information from atm. and beam ν
  - Sensitivity enhanced by combining both data
- Mass hierarchy / θ_{23} octant determination within several years for the nearly entire parameter space

Neutrino Astrophysics in Hyper-K

Supernova ν burst

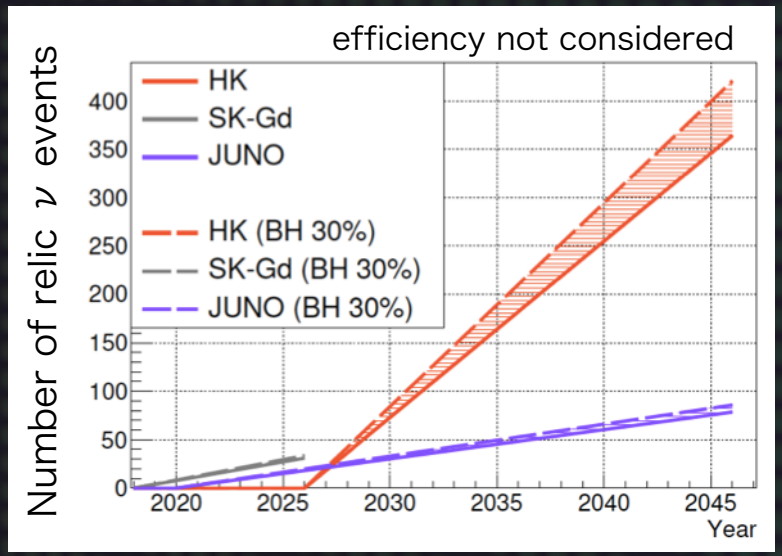
- Sensitive to even SNe in Andromeda
- 50-80k events / SN @10 kpc
- Time and energy profile with high stat.
  - → Dynamics of SN central engine, Explosion mechanism, NS/BH formation
- 1° pointing for SN @10 kpc
  - → Multi-messenger study (w/ GW, Optical, ⋯)

SASI
Standing Accretion Shock Instability



Supernova Relic ν

- Expect SK-Gd to discover first
- Hyper-K will measure the spectrum
  - → History of star/BH formation

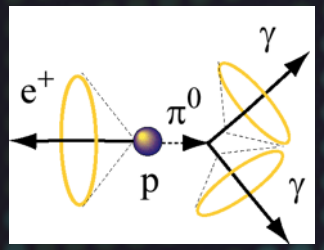


and more

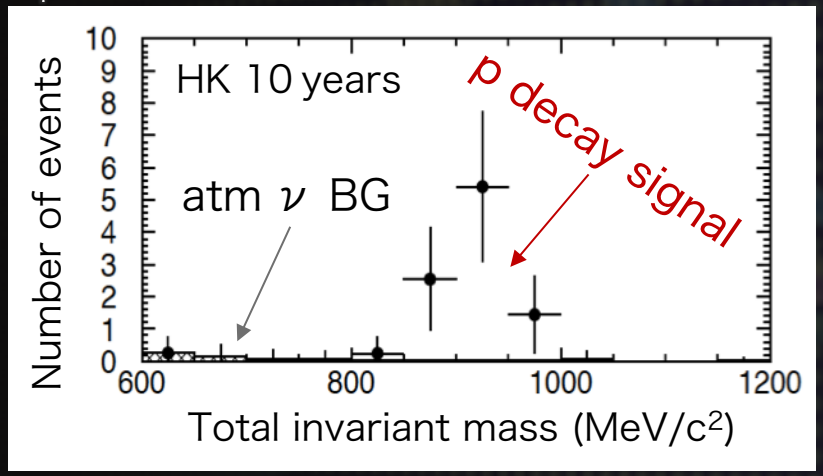
- Solar ν (day/night, upturn), WIMP ν, ⋯

see also talk by Miura

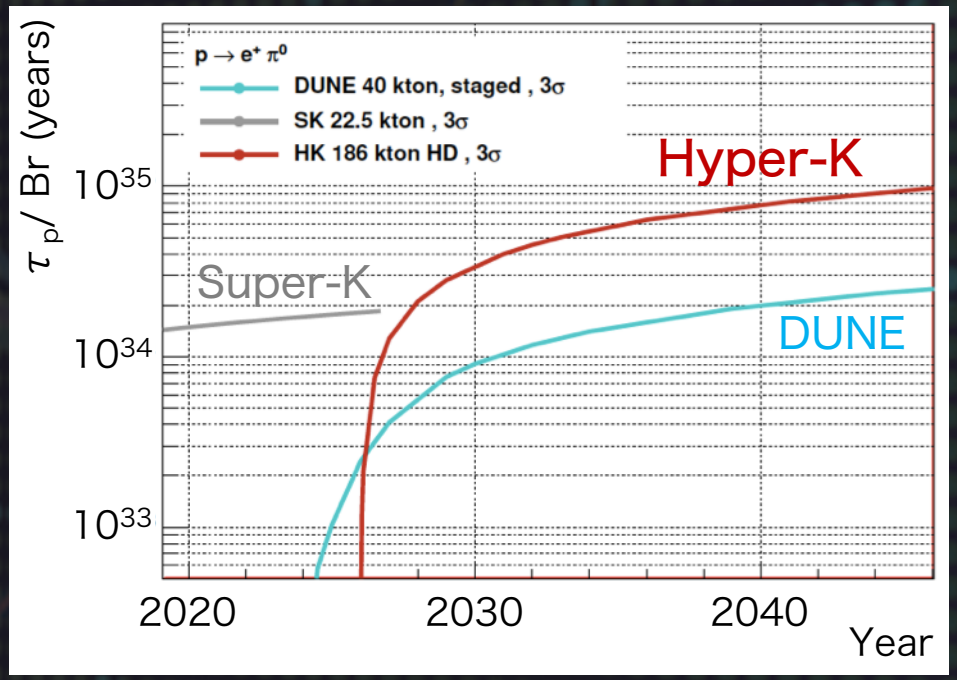
$p \rightarrow e^+ \pi^0$ Search in Hyper-K



τ_p/Br = 1.7 × 10^{34} yrs (SK 90%CL limit)



3σ discovery sensitivity



BG FREE measurement

- 0.06 BG events/Mton·year
- High efficiency neutron veto by doubled photon sensitivity
  - Most atm ν BG has neutrons
  - Tag 2.2 MeV γ from np→dγ

Great potential for discovery

3σ discovery sensitivity reaching

τ_p/Br = 10^{35} years!

see also talk by Miura

$p \rightarrow \bar{\nu} K^+$ Search in Hyper-K

K^+ identified by decay products

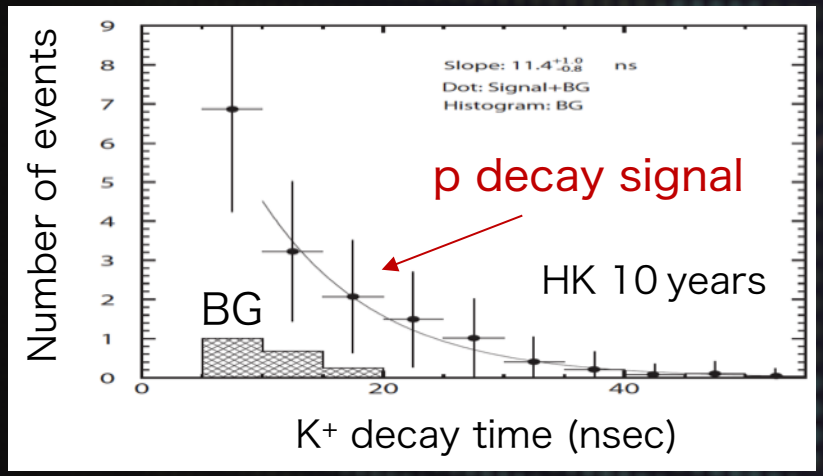
$K^+ \rightarrow \mu^+ \nu$ (Br : 64 %)

- 236 MeV/c μ^+, decay electron
- de-excitation γ from $^{15}O^*$ (6 MeV)

$K^+ \rightarrow \pi^+ \pi^0$ (Br : 21 %)

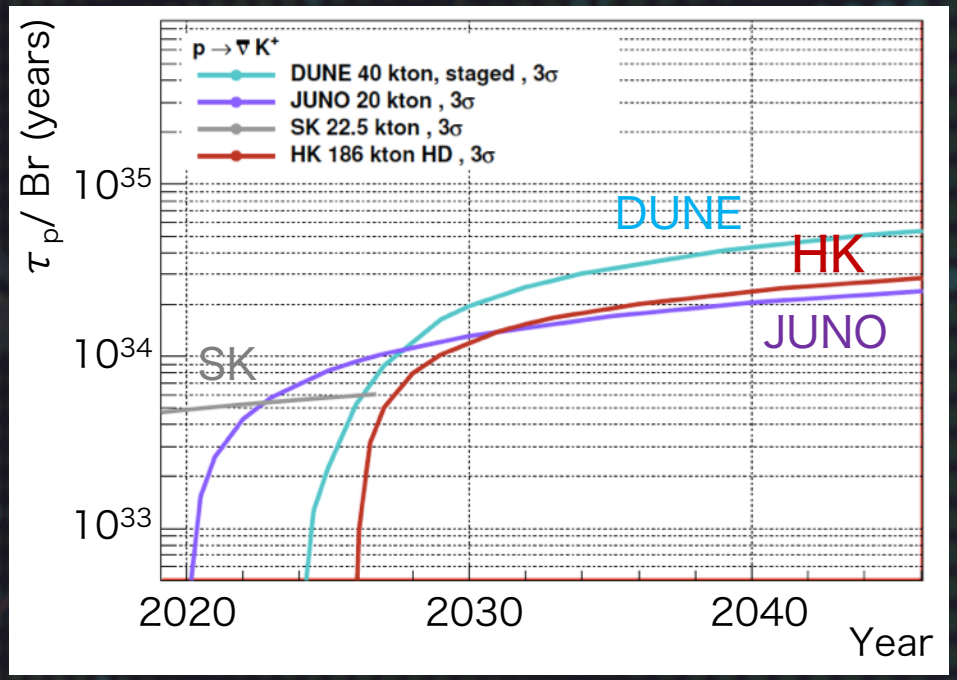
- 205 MeV/c $\pi^0 + \pi^+$ back-to-back

Improved eff. by new photosensors (×2 photon sensitivity & timing res.)



τ_p/Br = 6.6 × 10^{33} yrs (SK 90%CL limit)

3 σ discovery sensitivity



3 σ discovery sensitivity reaching τ_p/Br = 3 × 10^{34} years

Competitive/complementary to other experiments seeing K^+ directory

Project Status in Japan

- Strong commitment from the host laboratories
  - ICRR Future Project Committee has concluded that Hyper-K should be the laboratory's next main project
  - KEK Project Implementation Plan has put first priority to J-PARC upgrade for Hyper-K
- Strong support from communities
  - CRC (cosmic ray) / JAHEP (high energy) endorse Hyper-K as the main future project
  - Science Council of Japan has selected HK as one of top priority large-scale research projects (Master Plan 2017)
- MEXT (funding agency) will soon release "Roadmap 2017" on promotion of large research projects

International Collaboration

Queen Mary University of London, July 2016

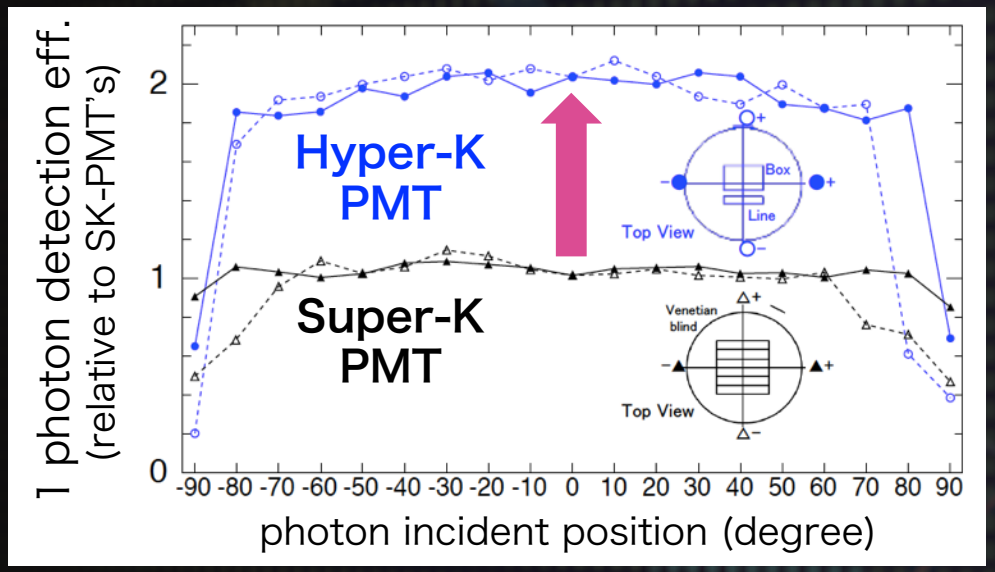
Hyper-K proto-collaboration formed in January 2015

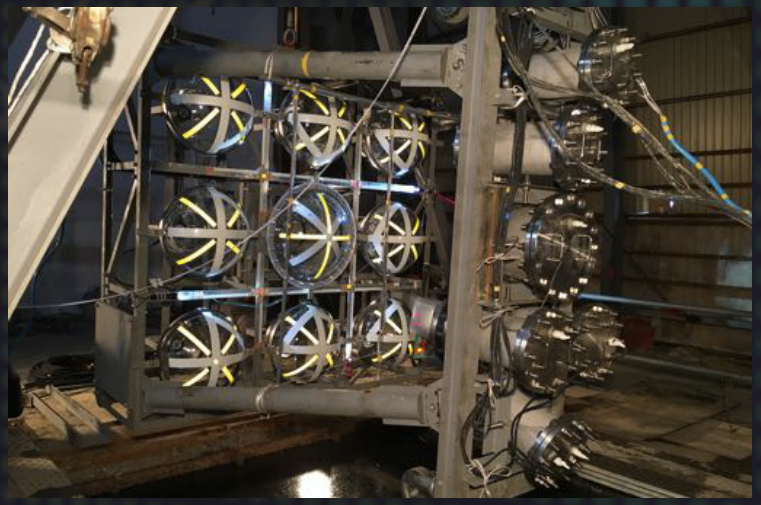
- 300 members from 15 countries (as of April 2017)
- 70% from oversea countries
- Collaboration meetings held semiannually

International contributions defined

- From oversea : half (all) of the inner (outer) photodetection systems, DAQ system, geomagnetic compensation system, calibration system, and near/intermediate detectors
- Various R&Ds progressing internationally

New Photosensor and Cover





Cover test @ Kamisunagawa Town

New 50 cm PMT completed

- ×2 single photon detection efficiency
- ×2 timing resolution
- ×2 hydrostatic pressure tolerance

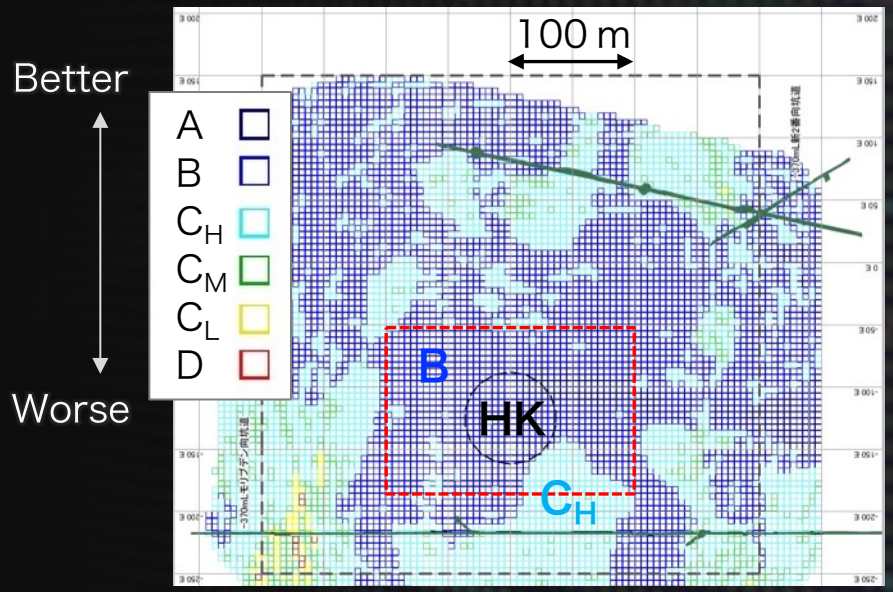
(than those of Super-K PMT)

New PMT cover to prevent chain implosion also developed, and its performance confirmed by a test at 80 m underwater

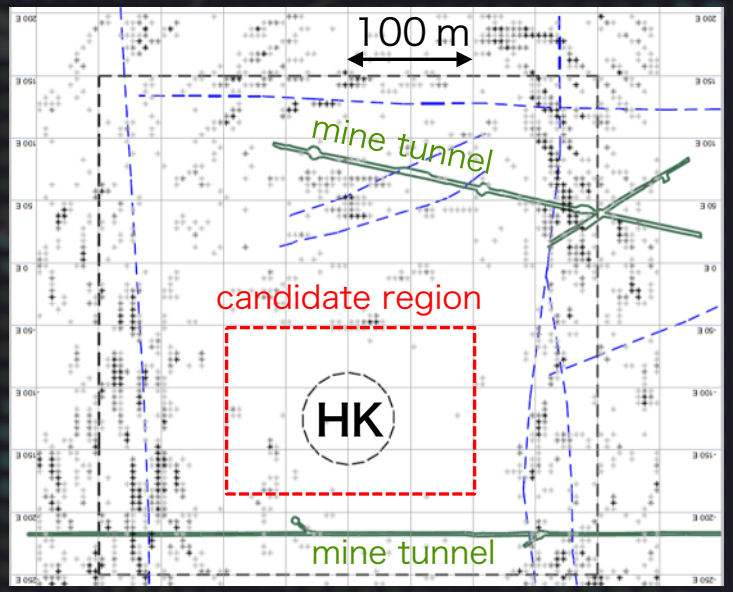
Geological Information

- Boring survey and tunnel inspection done previously
- Further survey using seismic wave completed
  - 837 shaking points / 111 receiving points set in mine tunnels located at 5 different levels → 3D tomography

Rock grade (color)

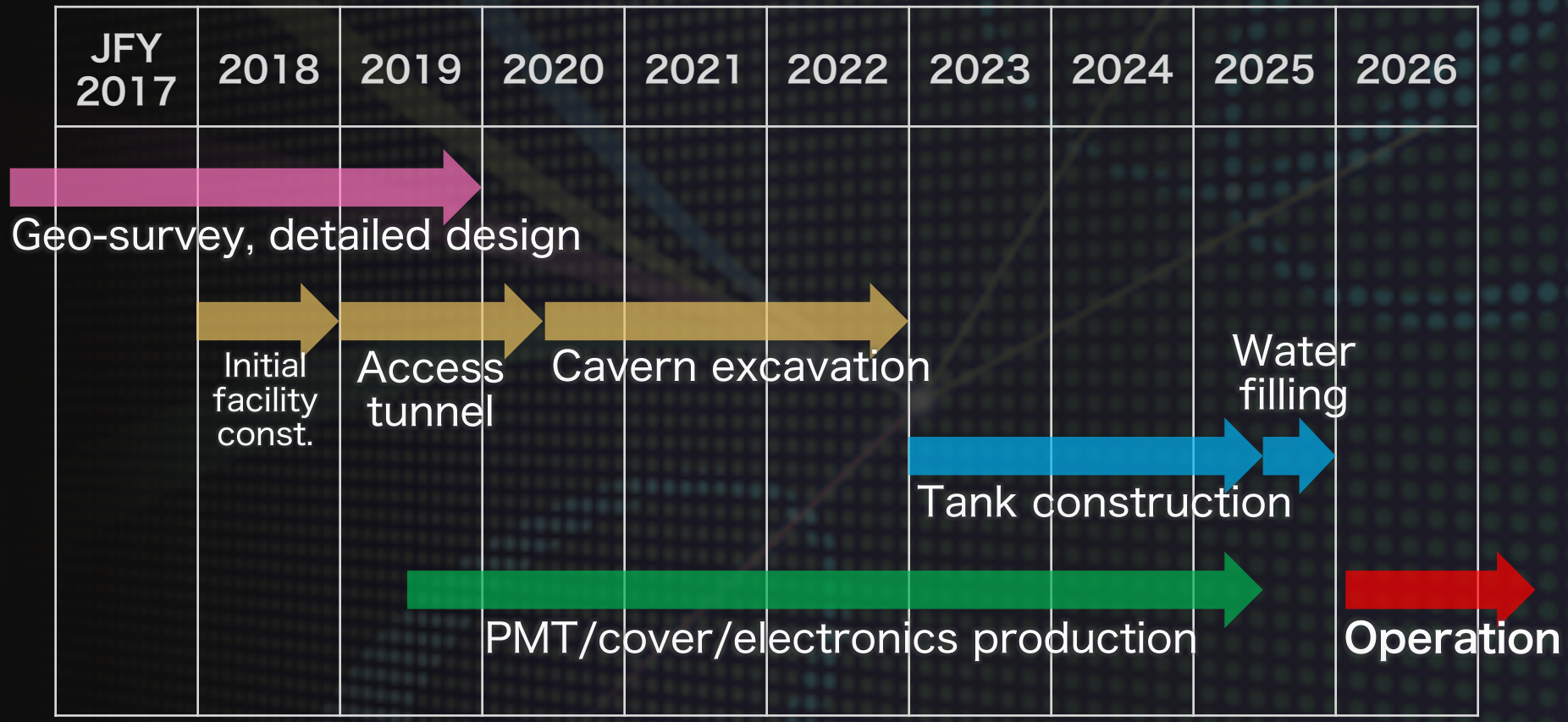


Fracture zones (grayscale dots)



Confirmed that the rock condition is good enough.
Pinned down the candidate tank potion.

Construction Timeline



Budget request being submitted to start construction in JFY2018
Aiming to start observation in 2026

Summary

- Hyper-K has rich program to explore fundamental questions
  - Fast and robust approach to leptonic CPV
  - Great discovery potential / measurement capability : proton decay, SN ν burst profile, SN relic ν spectrum, $\cdots$
  - Fully utilizes technique established in past/present experiments
  - Physics sensitivity enhanced with “×2 better” photosensors
- Project being accelerated towards early realization
  - Strong support from communities and host laboratories
  - Submitting budget request to start construction in 2018
- International collaboration open for new groups