Recent Progress on Hyper-Kamiokande Project

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2016. 5. 13

International Symposium on
Revealing the history of the universe with underground particle and nuclear research 2016

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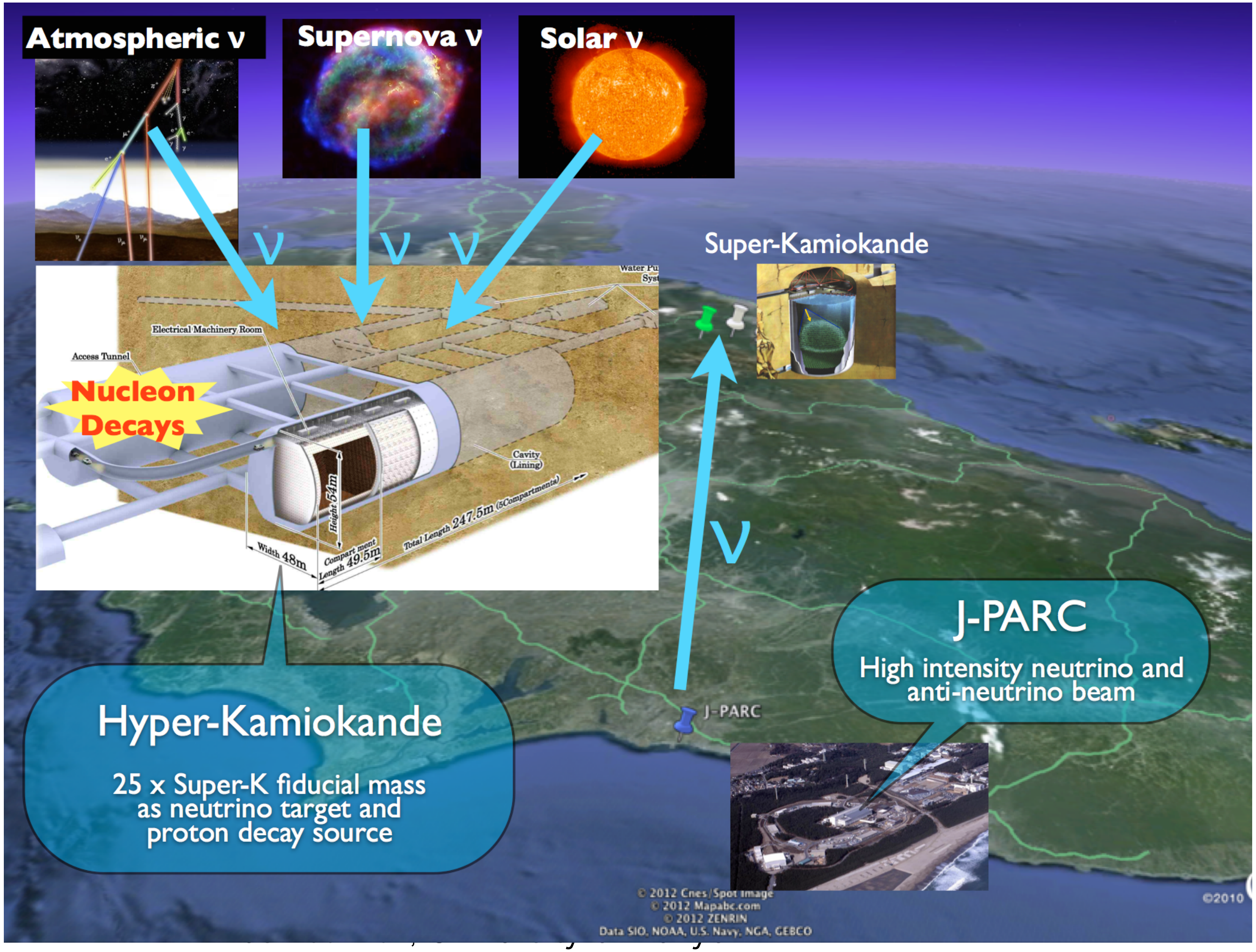
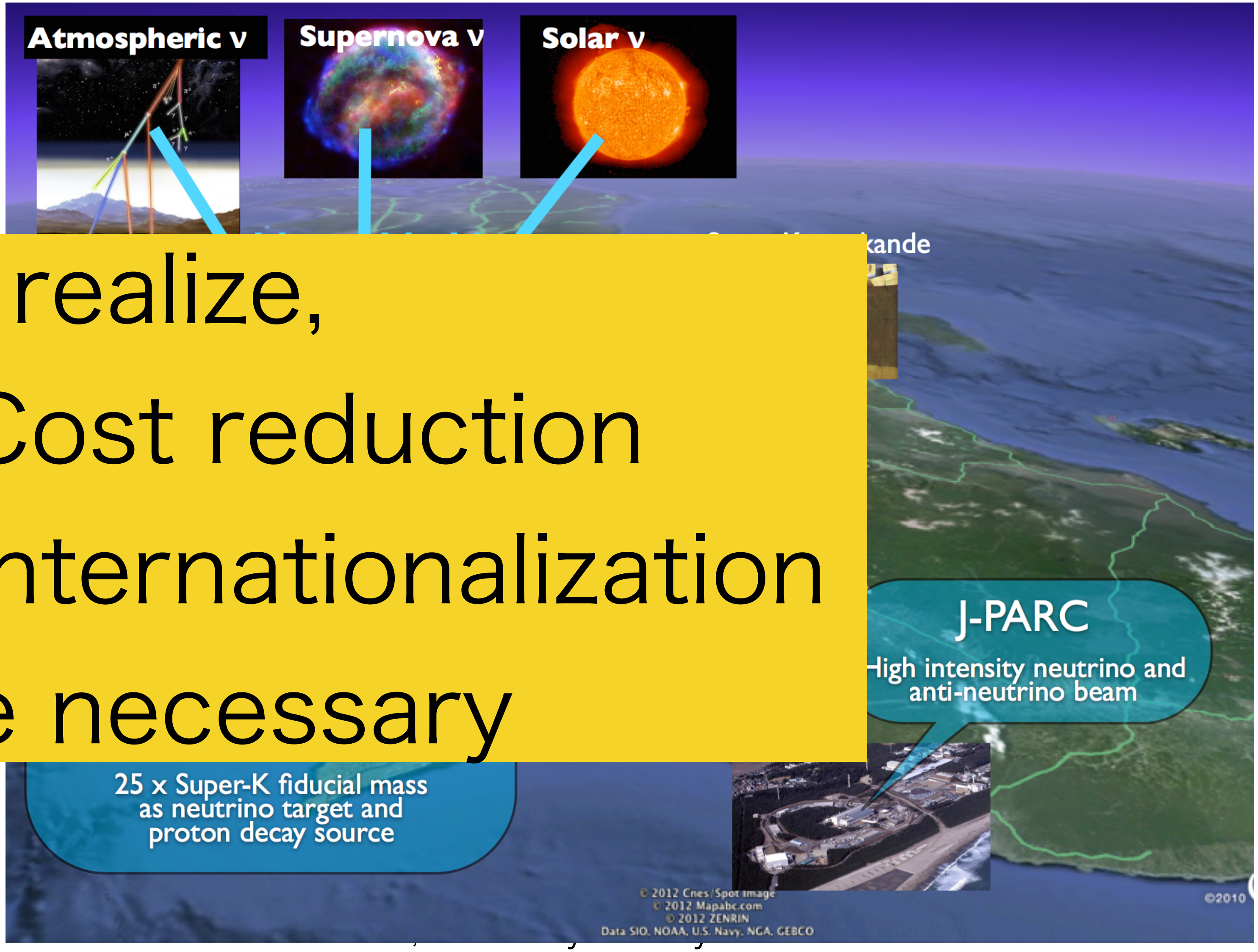
Hyper-Kamiokande

- Next generation water cherenkov detector
    - Multi-purpose detector for various physics



Hyper-Kamiokande

- Next generation water cherenkov detector
  - Multi-purpose detector for various physics

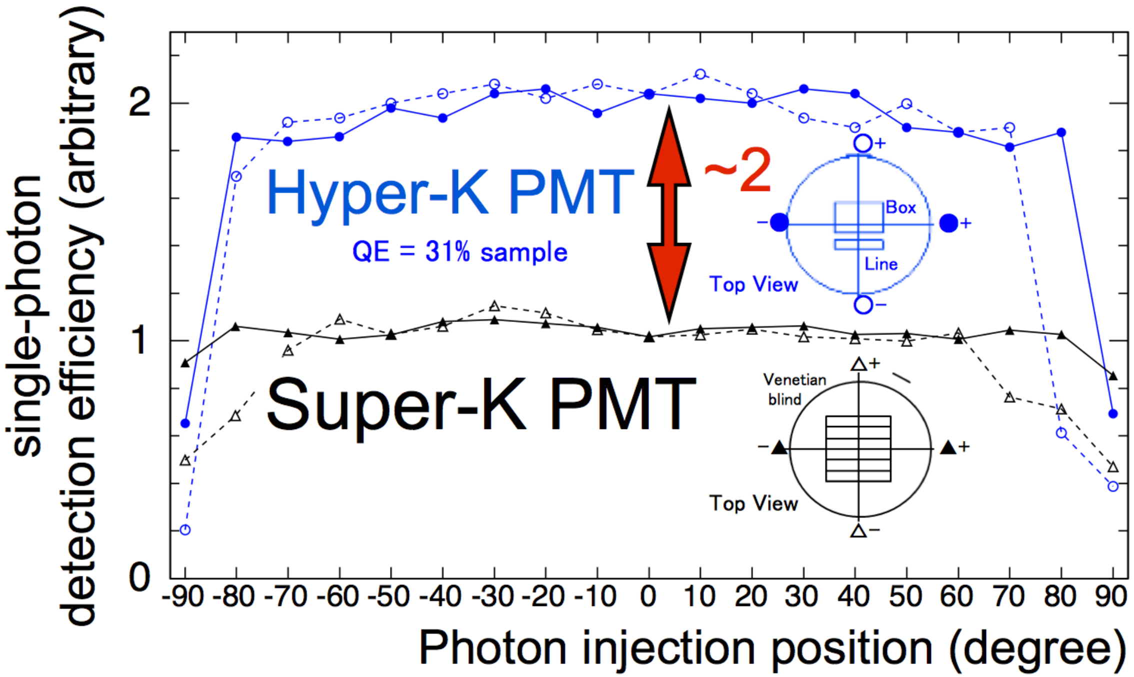


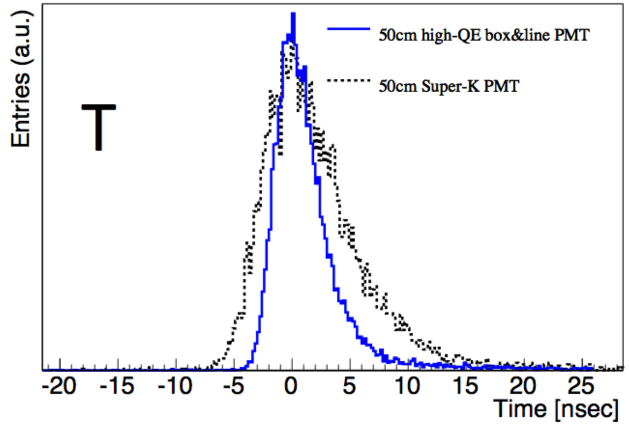
To realize,

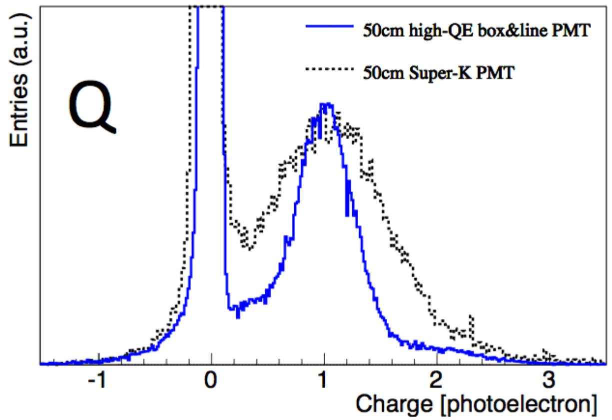
- Cost reduction
- Internationalization

are necessary

New Photo-Sensor

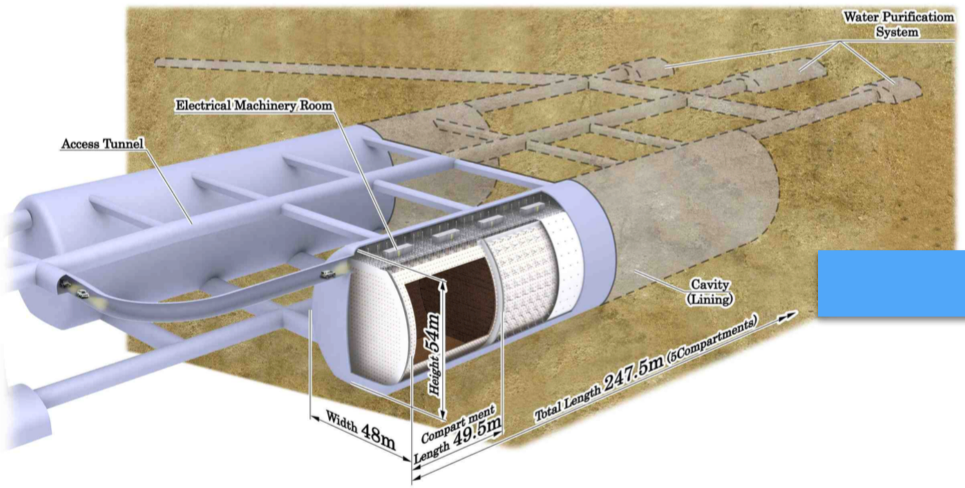


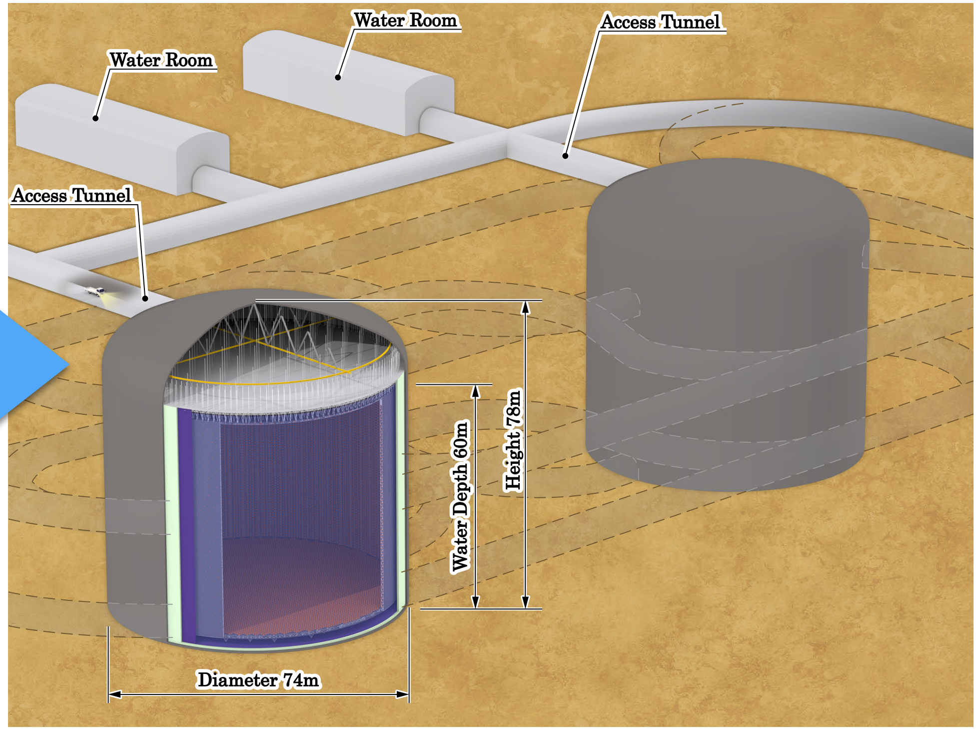




- New 20-inch photo-sensors: higher performance
  - Single-photon efficiency: x2
  - 1 p.e. timing resolution: 2ns → 1ns
  - 1 p.e. charge resolution: 53% → 35%
- Large impact on detector performance/physics sensitivity

Design Optimization





- SK-like cylindrical vertical tank: Φ74m x H60m
  - Total volume: 260kton/tank, Fiducial volume: 190kton/tank
- Photo-coverage = 40% → 40k ID PMTs/6.7k OD PMT
- 2 tanks with staging (1 tank at day1)
  - In this talk, assume 2nd tank operation starts from 7th year after 1st tank operation.

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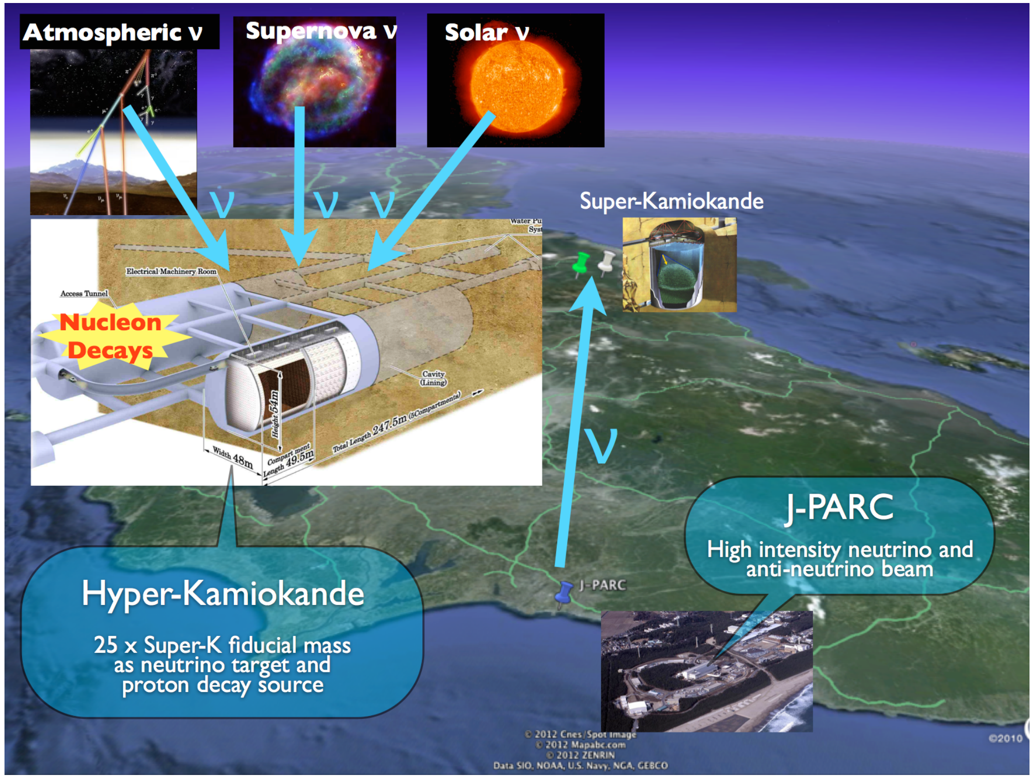
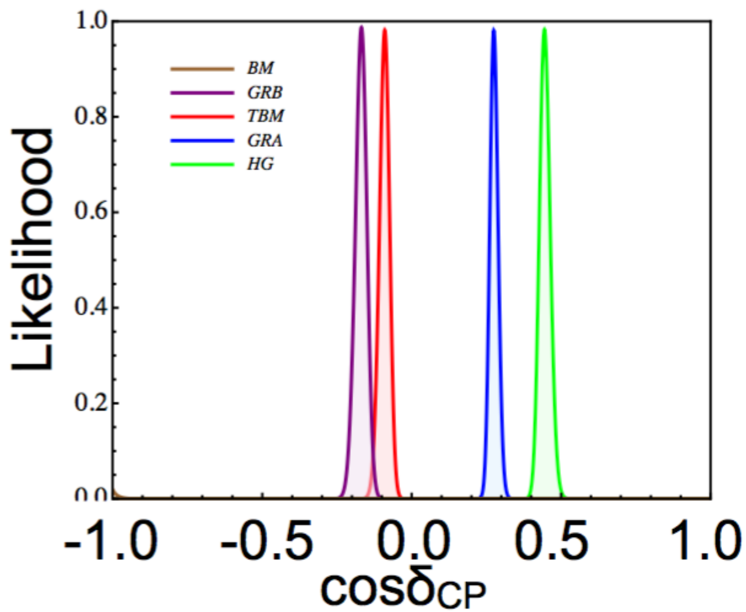
Physics at Hyper-K

- **Rich physics topics!**
  - Neutrino oscillation (acc. ν, atom. ν, solar ν)
    - CP violation
    - Mass hierarchy
    - θ_{23} = 45°?, < 45°?, > 45°?
    - Day/night asym. in solar ν
  - Proton decay → test of GUT
    - $p \rightarrow e^{+}\pi^{0}$ (SK 90% limit = 1.7×10^{34} y)
  - Supernova ν
    - Supernova burst ν
    - Supernova relic ν

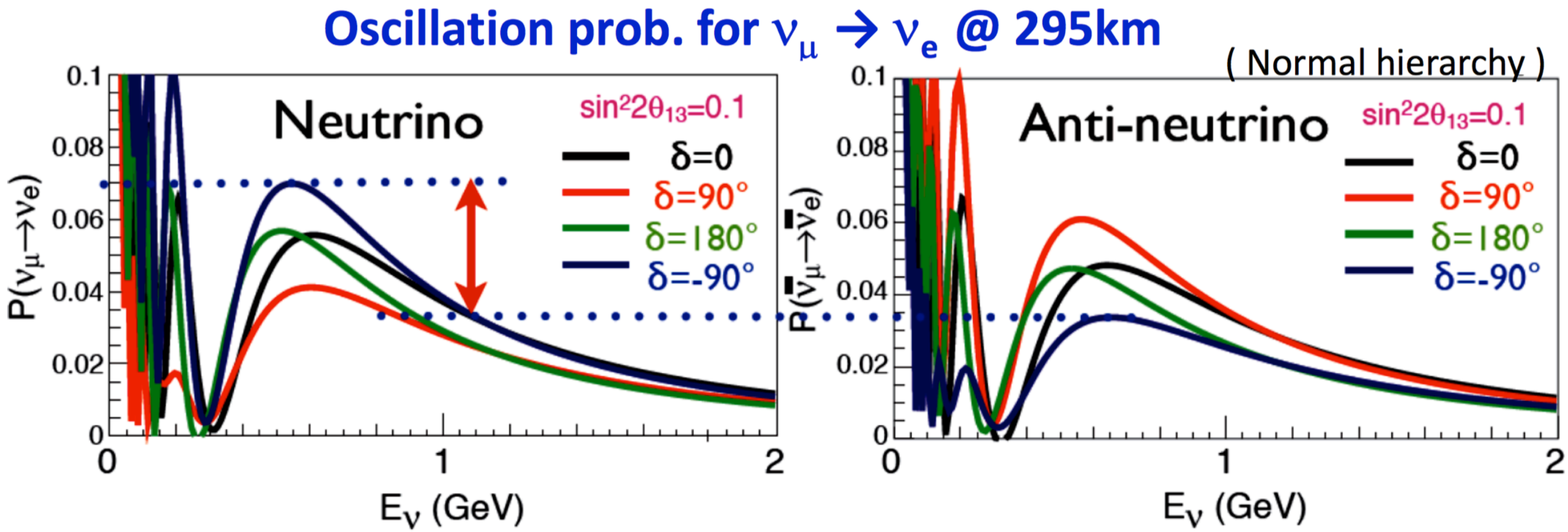


Why ν CPV is important?

- Leptonic (ν) CPV search is very important
  - The only known CPV source = CKM phase
  - Need other CPV source to explain the matter-antimatter asymmetry in the universe.
- Leptogenesis scenario only with Dirac CP phase
  - S. Pascoli et al., PRD 75, 083511 (2007) PDG review 2014
    - $|\sin\delta_{CP}|$>~0.6
- Flavor symmetry prediction on δ_{CP}
  - e.g. Petrov 1504.02402v1
- Precise measurement is also important!



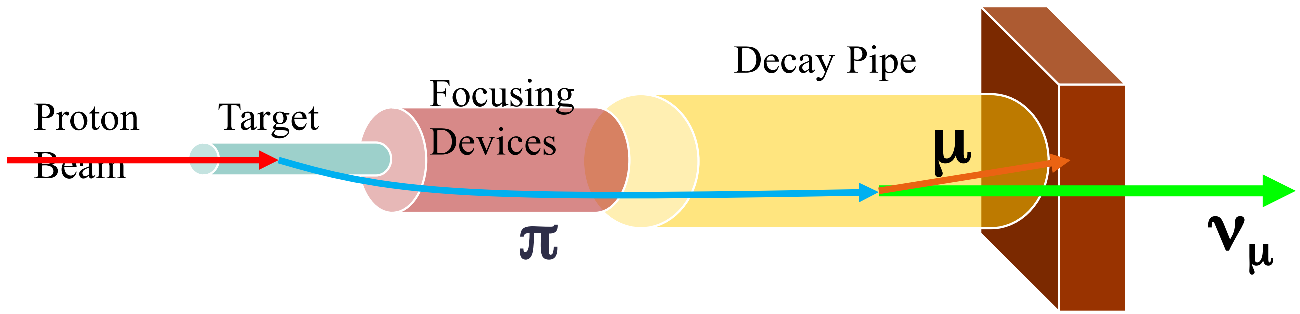
Measurement of CP Asymmetry with ν Beam

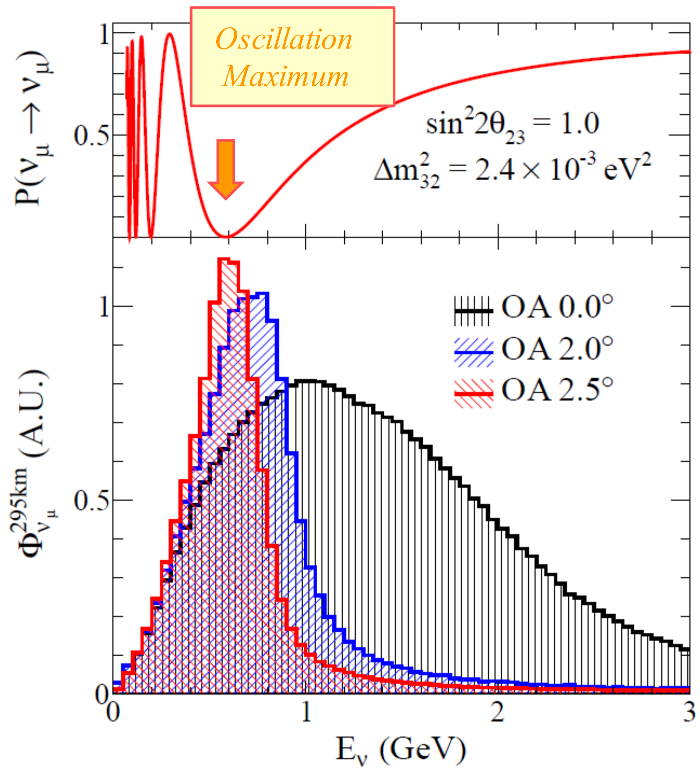


- Comparison of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
  - Max. ~±25% difference from $\delta=0$ case
  - Sensitive to exotic (non-MNS) CPV source

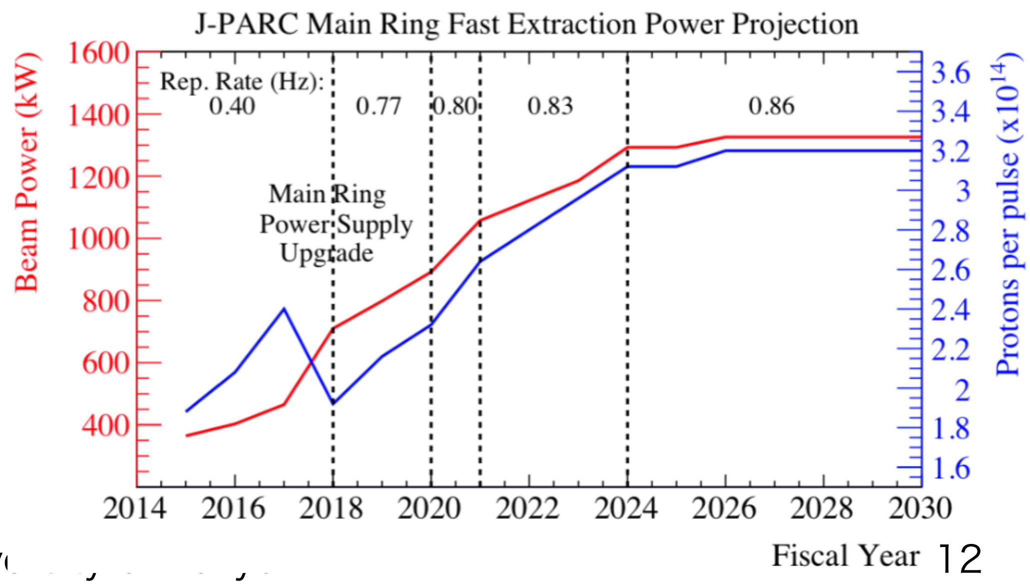
J-PARC Neutrino Beam

Conventional neutrino beam from pion decay



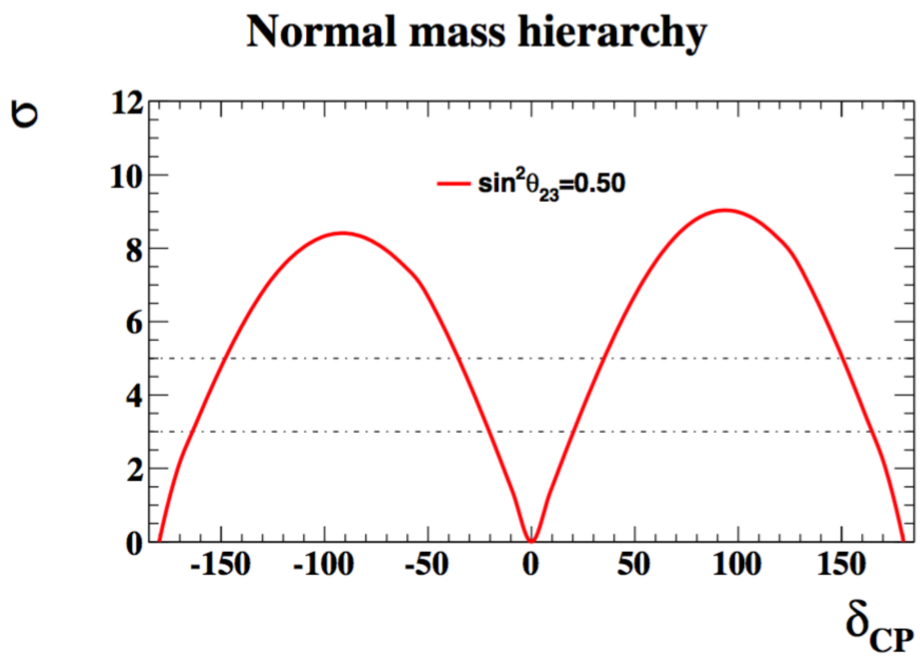


- High intensity beam
  - 30 GeV, 750 kW proton beam (2×10^{14}ppp, 1.3s cycle)
- Off-axis beam (2~2.5°)
  - 99% ν_μ purity
  - Low energy narrow-band beam ~ 0.6 GeV
    - peak at 1st osc. max. with L=300km.
- Future beam power upgrade
  - Aim to achieve **1.3 MW** by 2026
    - 3.2×10^{14}ppp, 1.16s cycle
  - Great impact on HK LBL measurements

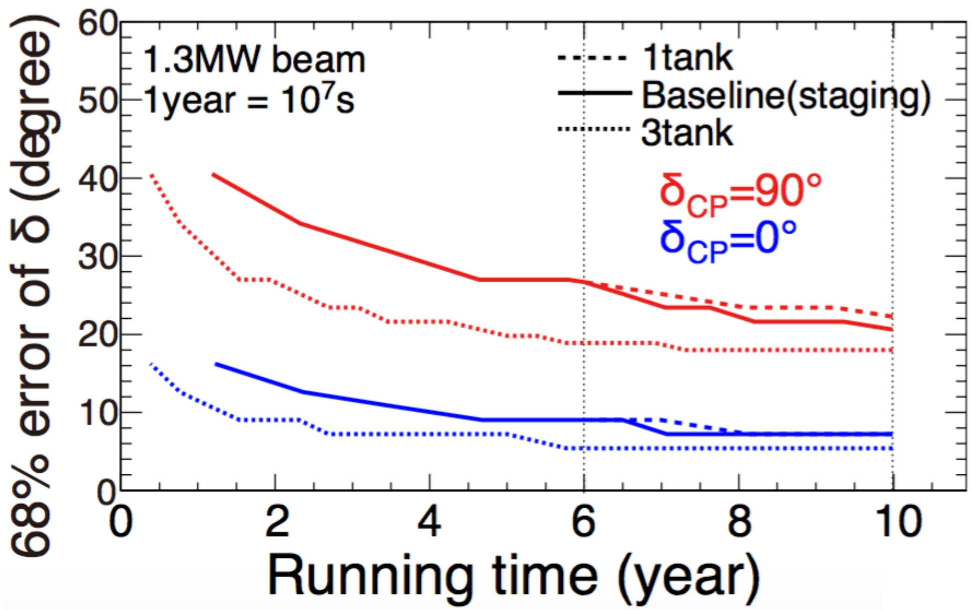


CPV Sensitivity

- Exclusion of sin δ_{CP}=0
  - >8σ (6σ) for δ=-90°(-45°)
  - ~80% coverage of δ parameter space with >3σ
- δ_{CP} measurement precision
  - 7~21° precision

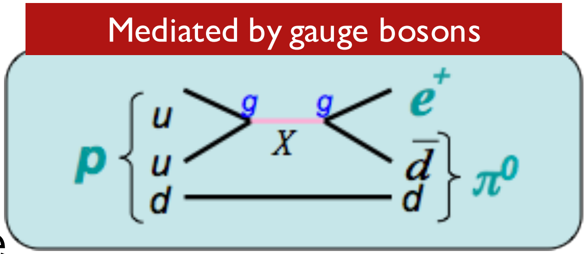


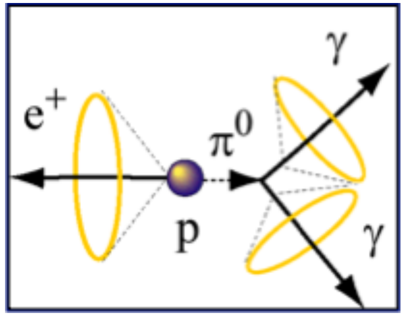
		sinδ=0 exclusion		68% error	
		>3σ	>5σ	δ=0°	δ=90°
Old	7.5MWy	76%	58%	7.5°	19°
2tank (staging)	13MWy	78%	62%	7.2°	21°



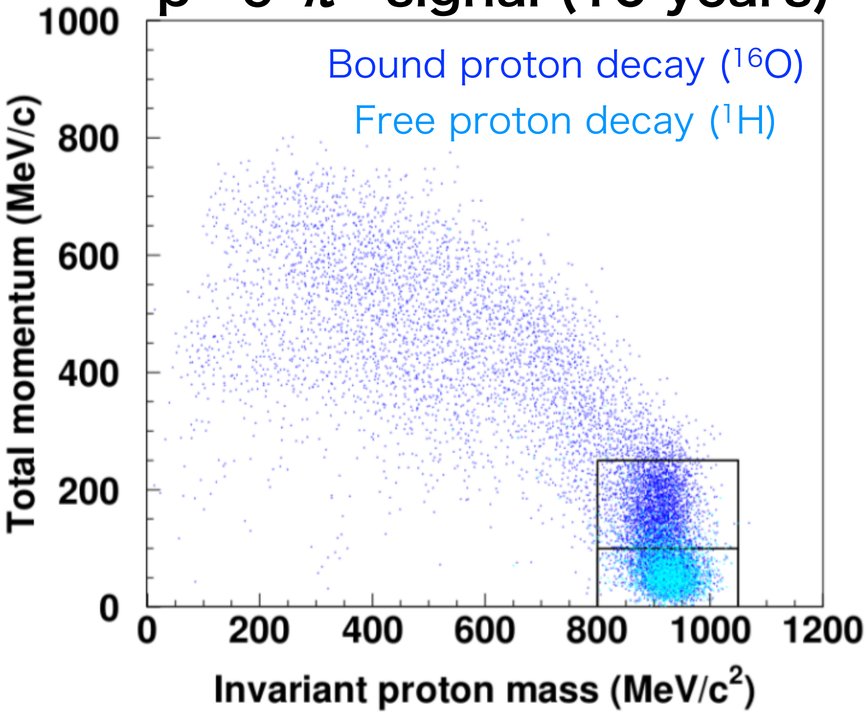
Search for Proton Decay

- **Proton decay = direct observation of GUT**
- $p \to e^+ \pi^0$: leading decay mode in many models
  - Water cherenkov detector has advantages for this mode
    - All decay products are visible.
    - Good PID and efficiency @ 1GeV
    - Free proton in hydrogen atom ↔ bound proton in ^{16}O

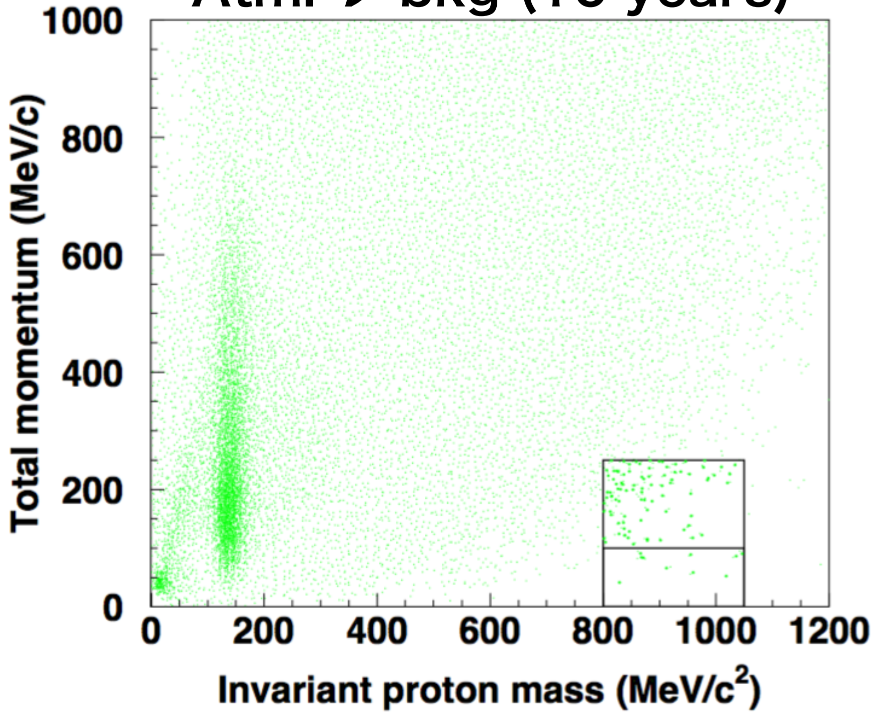




$p \to e^+ \pi^0$ signal (10 years)

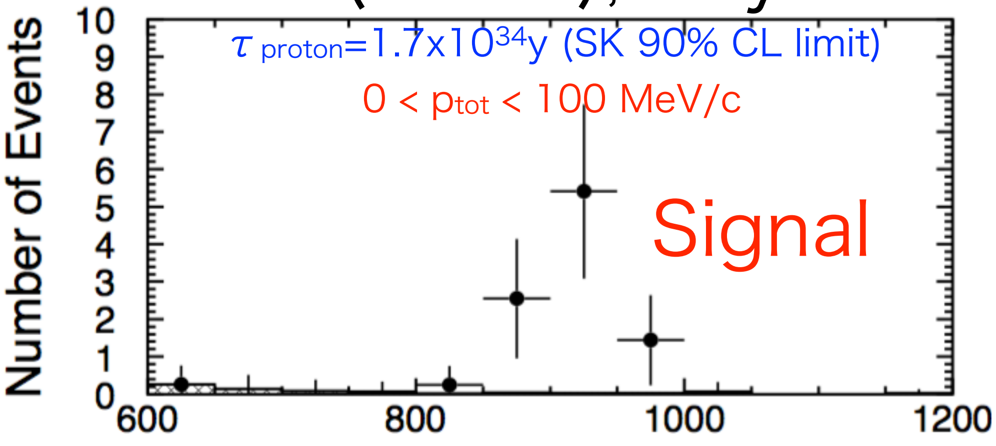


Atm. ν bkg (10 years)

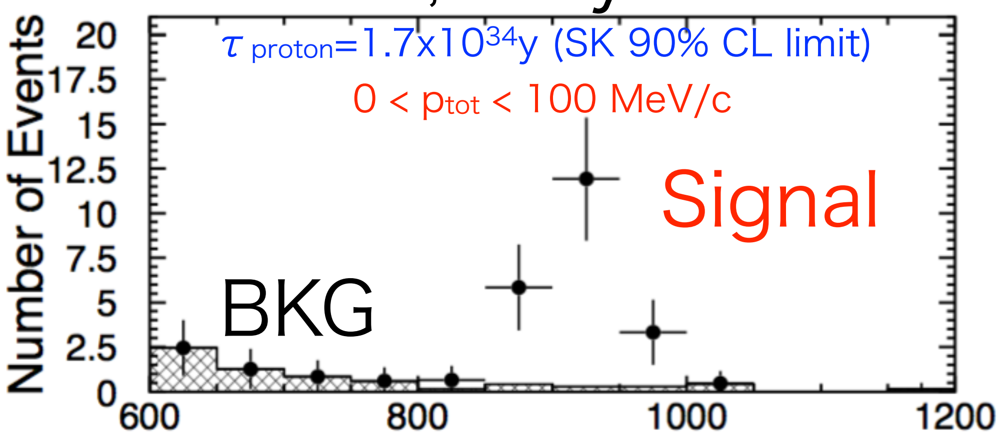


S/N improvement for Proton Decay

New (2tank), 10years



Old, 10 years



- BKG reduced to ~1/5 thanks to higher photo-coverage (40%)
- No reduction in signal eff.

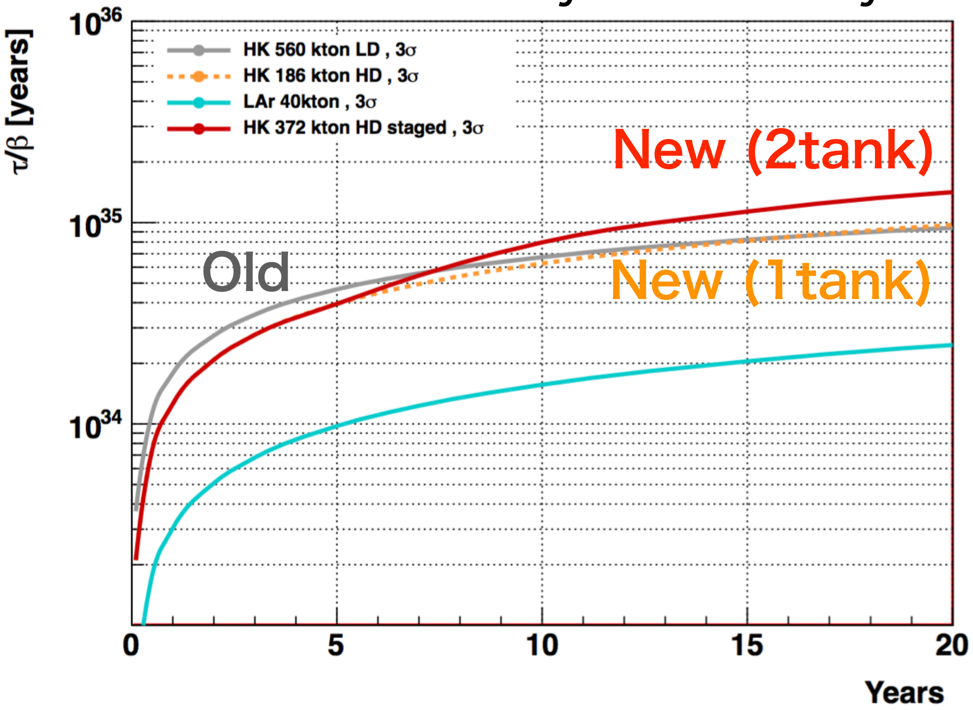
	p_{tot}<100MeV/c		100<p_{tot}<250MeV/c	
	Sig. ε(%)	Bkg (/Mtyr)	Sig. ε(%)	Bkg (/Mtyr)
Old	18.8	0.27	20.4	2.17
New	18.7	0.06	19.4	0.62

~9σ discovery potential !

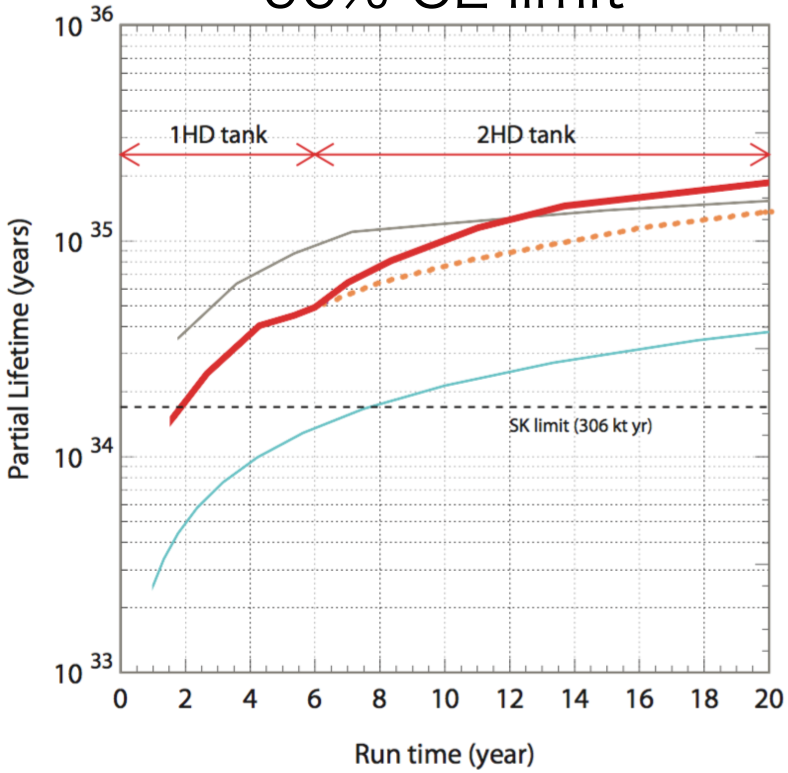
(in case of τ_{proton} = 1.7x10^{34} years: SK 90% CL limit)

Proton Decay Sensitivity

3σ discovery sensitivity



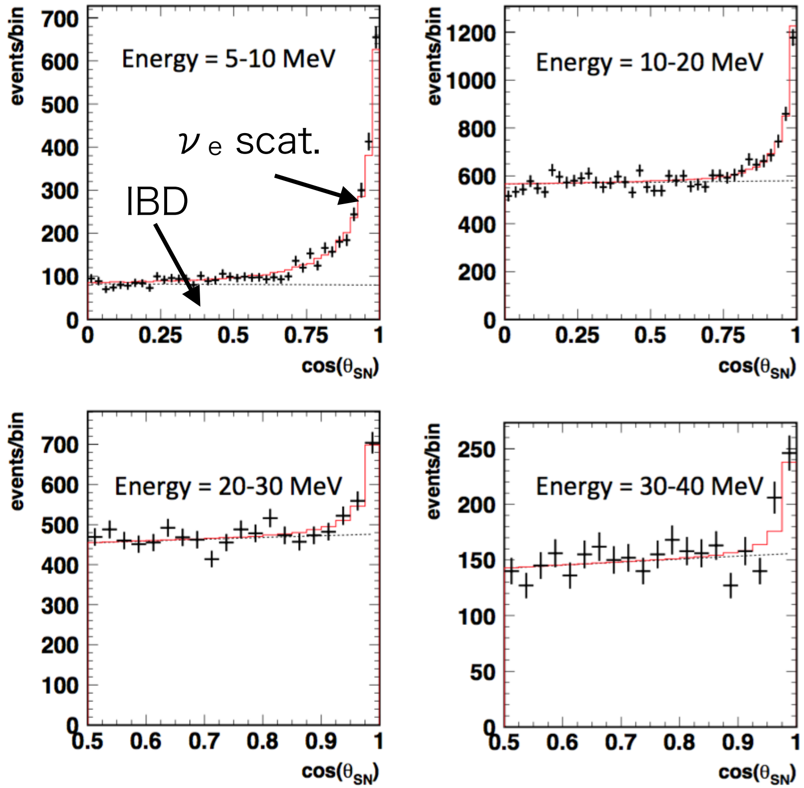
90% CL limit

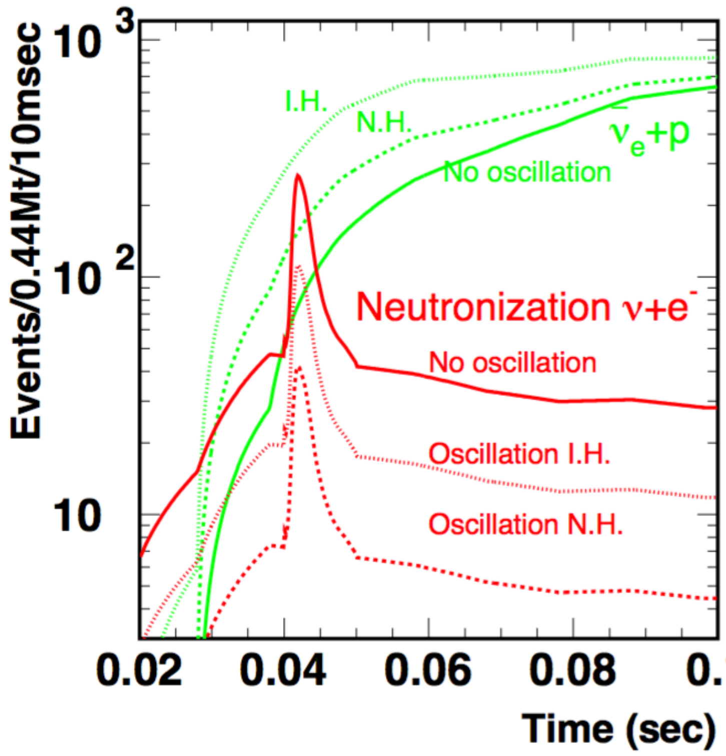


- 3σ discovery can be achieved within 15 years if lifetime=1×10^{35} years
- Higher photo-coverage (40%) gives better sensitivity even with smaller fiducial volume.
  - 3σ discovery sensitivity: New(1tank) ~ old
  - 90% CL limit: New(2tank) ~ old

Supernova Burst Neutrinos

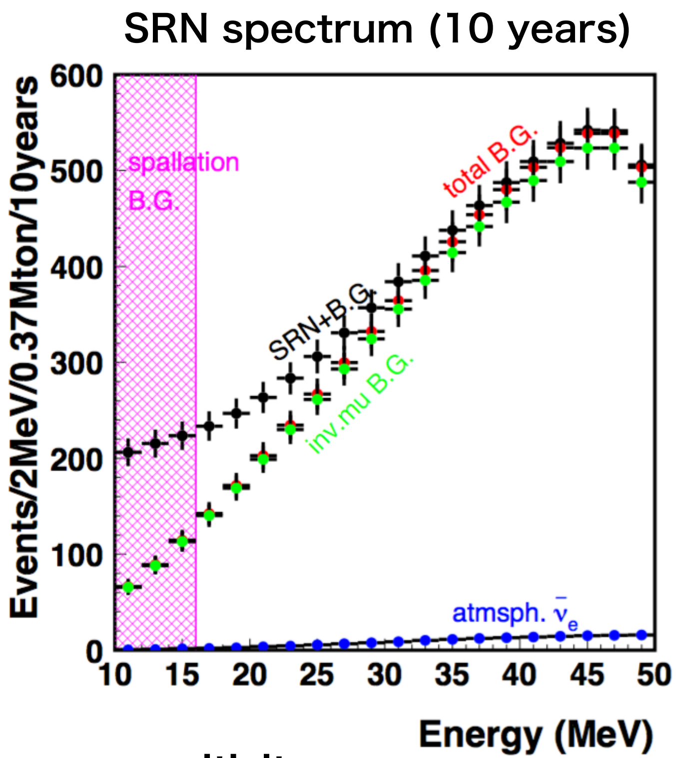
- 100k~160k ν events from SN at 10kpc → very rich info.
  - Inverse beta decay ($\bar{\nu}_e + p \rightarrow n + e^+$): 98k~136k evt. → isotopic
  - $\nu_e + e^-$ scattering: 4k~5k evt. → directional information
  - ν_e from neutronization: 12~80 evt. → SN explosion mechanism
  - Property of neutrino: absolute mass, mass hierarchy

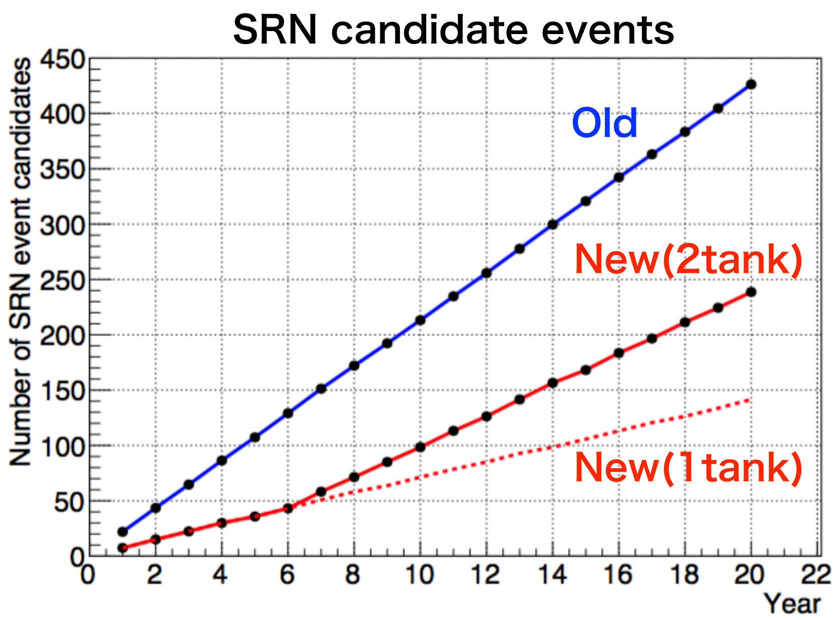


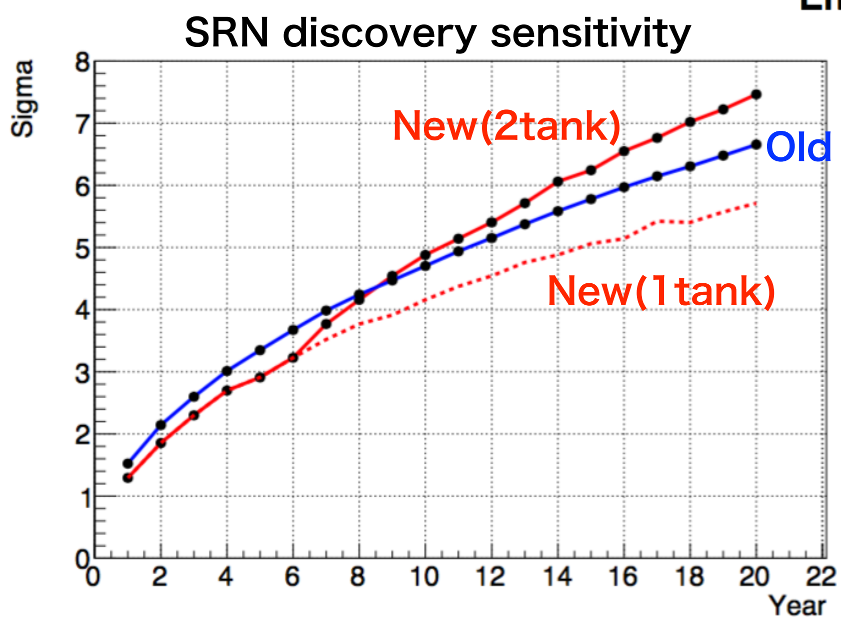


Search for Supernova Relic Neutrinos

- $O(10^{17})$ SNs occurred in the past universe
- Expected flux: 0.3~1.5 evt/cm^2/s (>17.5MeV)
- Background: spallation, atm. ν
- Higher photo-coverage helps to increase neutron-tagging efficiency
- 4.8σ discovery sensitivity expected after 10 years







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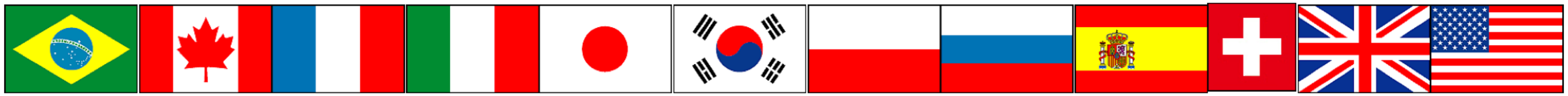
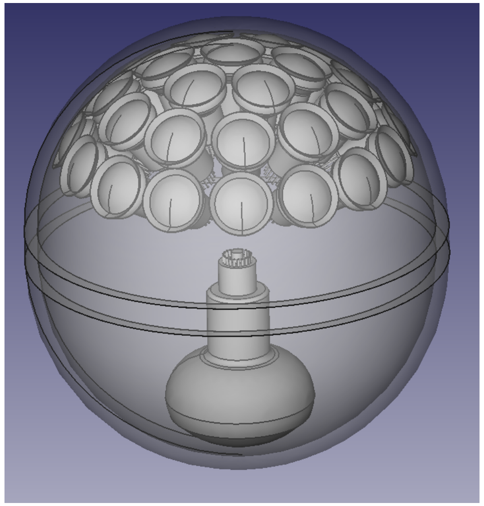
HK Proto-Collaboration

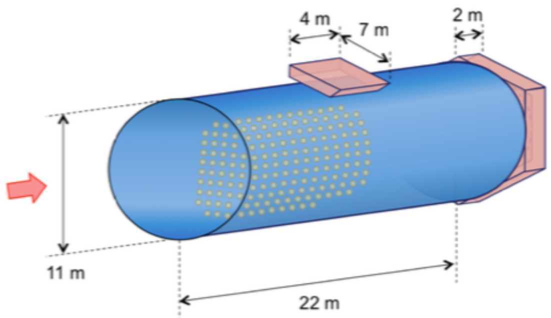
- HK proto-collaboration formed (2015. Jan.)
  - ~250 members from 13 countries
- MoU for cooperation in HK project between ICRR/U-Tokyo and IPNS/KEK (2015. Jan.)



International Contribution

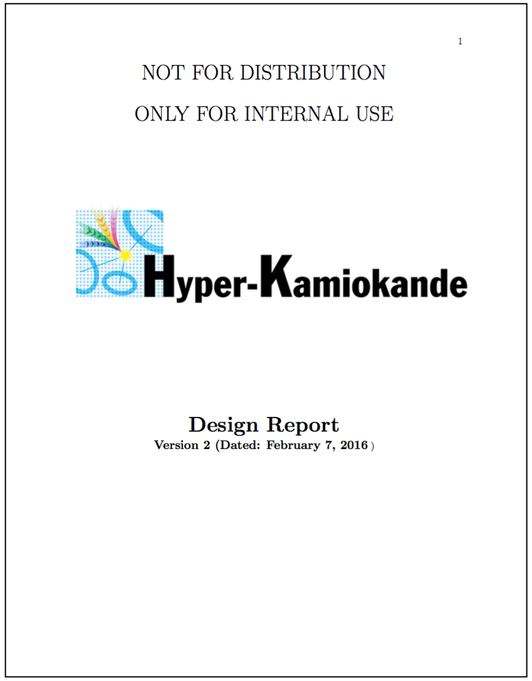
- Japanese contribution
  - Cavern, tank, half of photo-sensors
- Foreign contribution
  - Half of photo-sensors
    - Multi-PMT module (for ID/OD)
    - Texas 11” PMT by ETL (for OD)
  - Electronics, DAQ, and so on.
  - Near detectors
    - Upgrade in near detector @ 280m
    - Intermediate detector @ 1~2km





HK Design Review

- HK Design Report
  - Physics, detector, cost, organization, etc. (in English)
  - Cavern and tank design (in Japanese)
- Hyper-Kamiokande Advisory Committee
  - Formed under directors of IPNS/KEK and ICRR/U-Tokyo
  - Main committee → review the HK Design Report
    - HKAC report will be submitted to the directors soon
  - Sub-committee → review cavern and tank construction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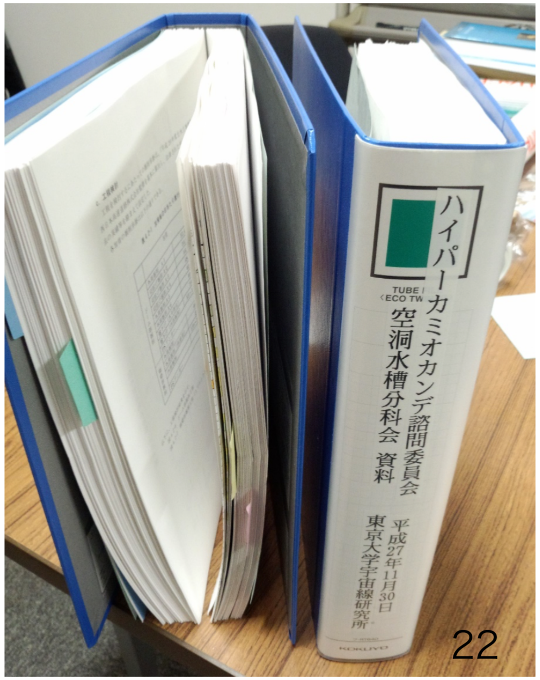
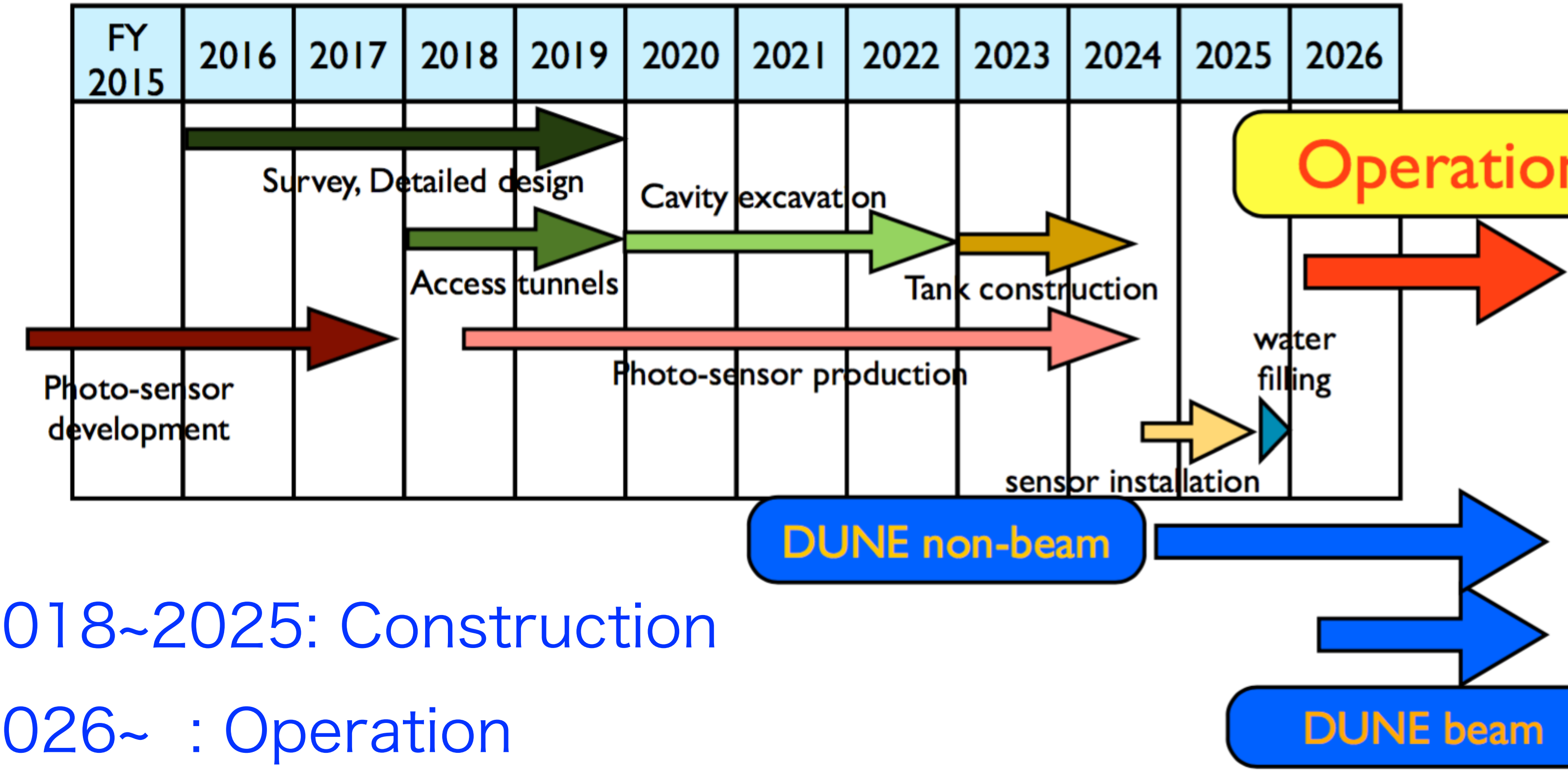
Hyper-Kamiokande

Design Report
Version 2 (Dated: February 7, 2016)



Timeline (1st Tank)



- 2018~2025: Construction
- 2026~ : Operation
  - CPV study
  - Atm･Solar･Supernova ν study, Proton decay searches
- Timely budget allocation is very important for international competition!!

Summary

- Hyper-Kamiokande
  - Next generation water cherenkov neutrino & nucleon decay detector.
- Design optimization
  - Vertical cylindrical shape (Φ74m x H60m) → 26kton/tank
  - 2 tanks with stating (to start as early as possible)
- Many physics topics can be studied.
  - Discovery of CPV → Precise measurement
  - Search for Proton decay
  - Detection of astrophysical neutrinos (Solar ν, SN, SRN)
- Recent progress
  - Porto-Collaboration, Design report, Review committee, submission to SCJ.
- We are aiming to realize HK project and to start operation from 2026.