Hyper-Kamiokande

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On behalf of the Hyper-Kamiokande Proto-Collaboration

Instrumentation2020
Novosibirsk, Russia
27 February 2020

Collaboration

Hyper-Kamiokande proto-collaboration

- International proto-collaboration was formed in 2015
- 18 countries, 73 institutes, ～350 members
- 2 host institutes: U-Tokyo/ICRR & KEK/IPNS

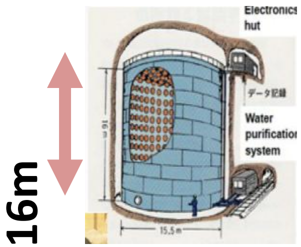
Hyper-Kamiokande

Third Generation Water Cherenkov Detector
will start data taking in 2027
- 237kton water tank (FV=187 kton ~8 x Super-K)
- 40% photo coverage with 20'' HK PMT

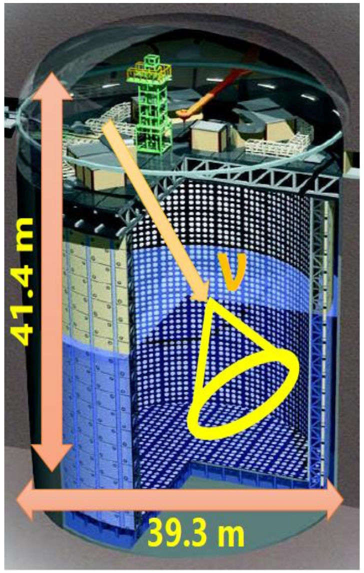
Hyper-Kamiokande
237(187 fiducial) kton
Data taking to begin in 2027

Super-Kamiokande
50(22.5) kton
Data taking since1996

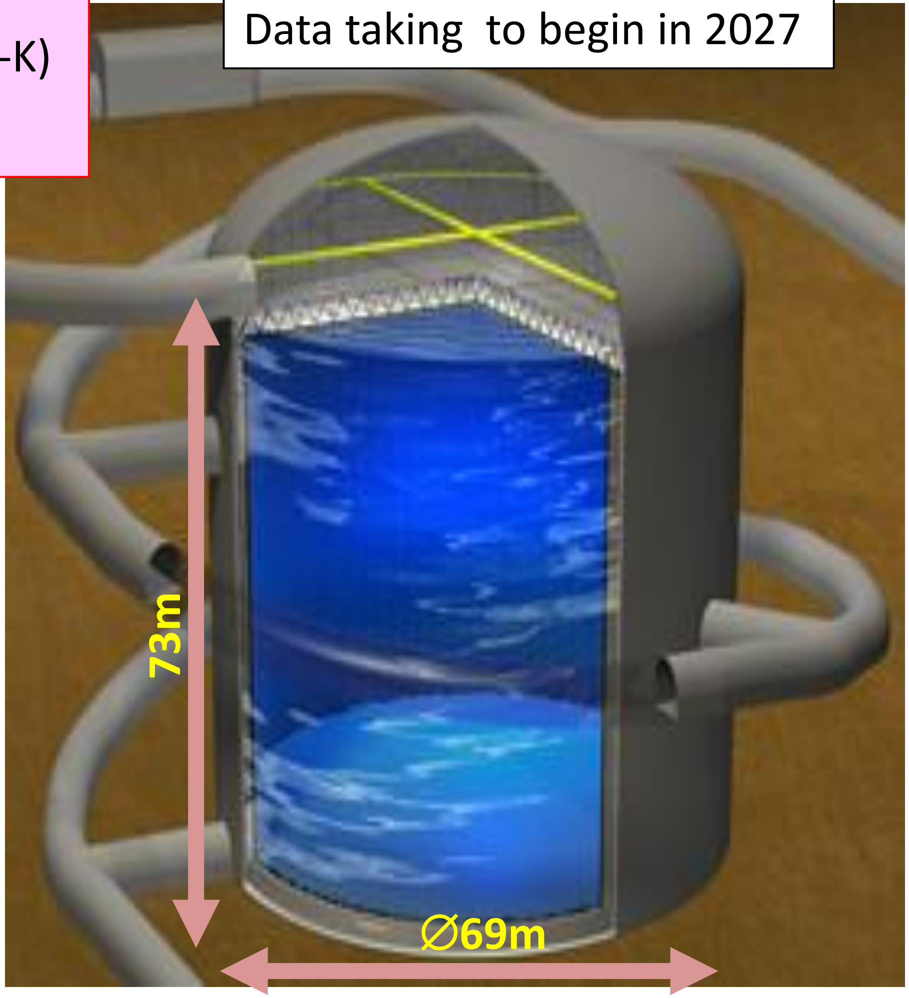
Kamiokande
4.5(0.68) kton
1983 - 1996



x30

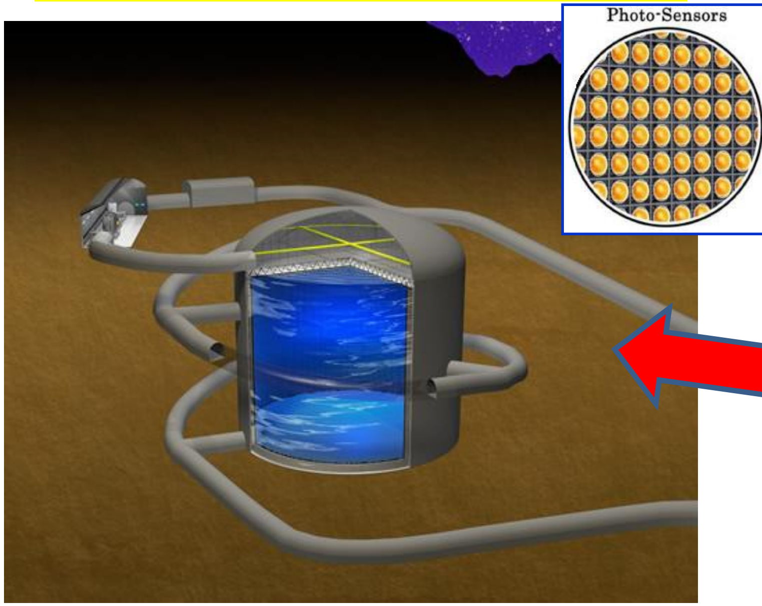


x8

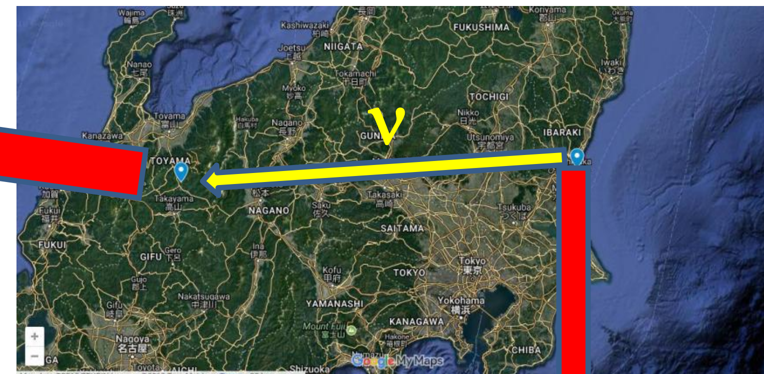


Hyper-Kamiokande Project

Hyper-Kamiokande water tank



Main goals:
- Search for CP violation
- Proton decay
- Neutrino astrophysics



Water tank
73 m(H)x69m(D)
Total volume 237 kt
Fiducial volume 187 kt ~8xSuper-K
40000 50 cm ID PMTs, coverage 40%
15000 7.5 cm OD PMT's
Photon sensitivity ~2 x Super-K

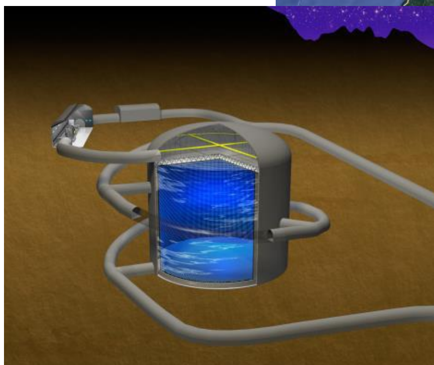
+

- J-PARC upgrade
- Near neutrino detector upgrade
- Construction of intermediate water Cherenkov detector

J-PARC

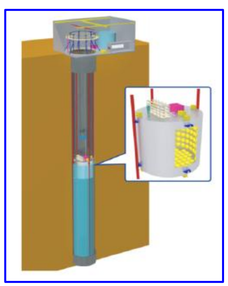
Tokai-to-Hyper-K (T2HK)

Hyper-K



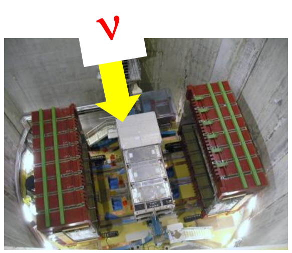
J-PARC

Intermediate Water Cherenkov detector

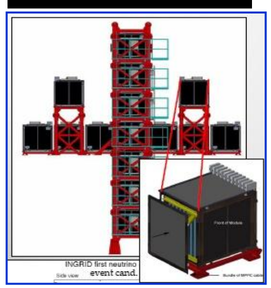


at ~1 km from target

Off-axis near neutrino detector



Neutrino monitor INGRID



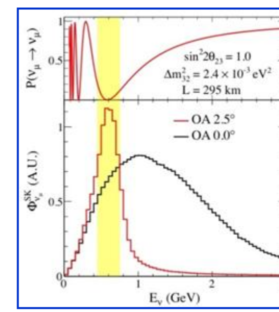
Near neutrino detector at 280 m from target

Decay tunnel

Horn

Target

Off-axis neutrino beam



Neutrino beam elements

J-PARC neutrino beam 2.5°off-axis, peak energy 600 MeV (oscillation maximum)

Physics Program

Refs:
- PTEP 2018(2018) 6, 063C01;
- arXiV:1805.04163;
- arXiv:1412.4673

Accelerator neutrinos
- search for CP violation
- precise measurement of oscillation parameters

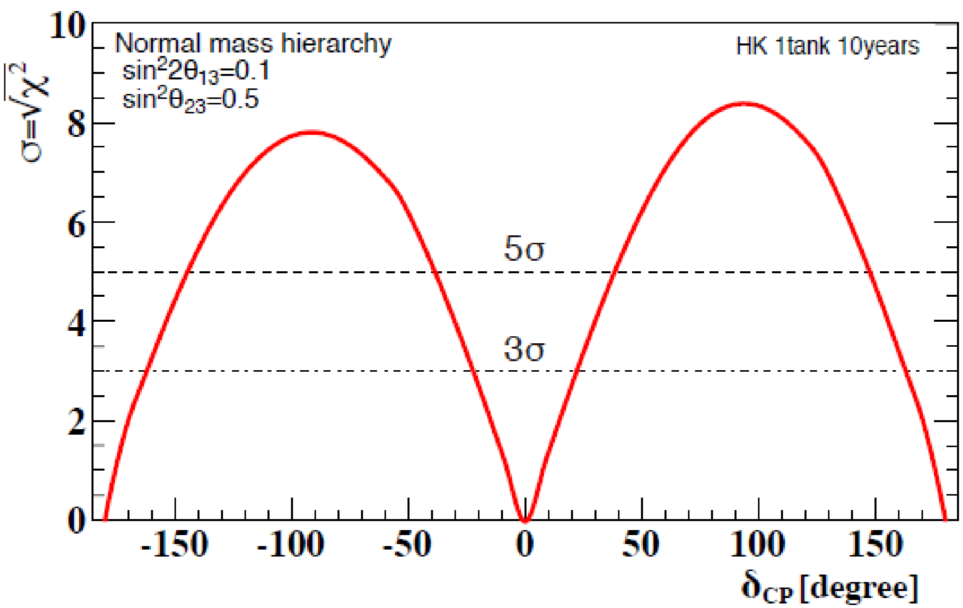
Nucleon decays

Atmospheric and solar neutrinos
- mass hierarchy
- octant

Neutrino astronomy and astrophysics

Sensitivity to CP

Integrated beam power 1.3 MW x 10^8 s
$\rightarrow$ 2.7 x 10^{22} POT with 30 GeV proton beam
$\nu : \bar{\nu} = 1:3$ $\sin^2 2\theta_{13} = 0.1$



Hyper-K: uncertainties of expected number events

$\nu_\mu \rightarrow \nu_e$	3.2%
$\nu_\mu \rightarrow \nu_\mu$	3.6%
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.9%
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	3.6%

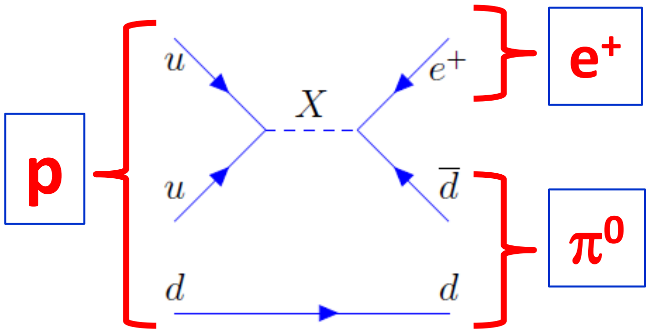
T2K systematic uncertainties 5-6 %

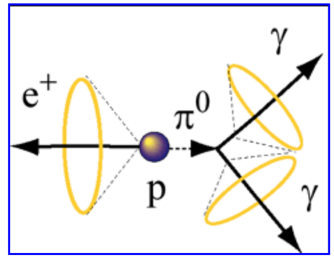
Exclusion of δ=0 at 8σ (for δ= -π/2)
5σ (3σ) significance for 57 (80)% of possible δ values

Proton Decay: $p \to \pi^0 e^+$

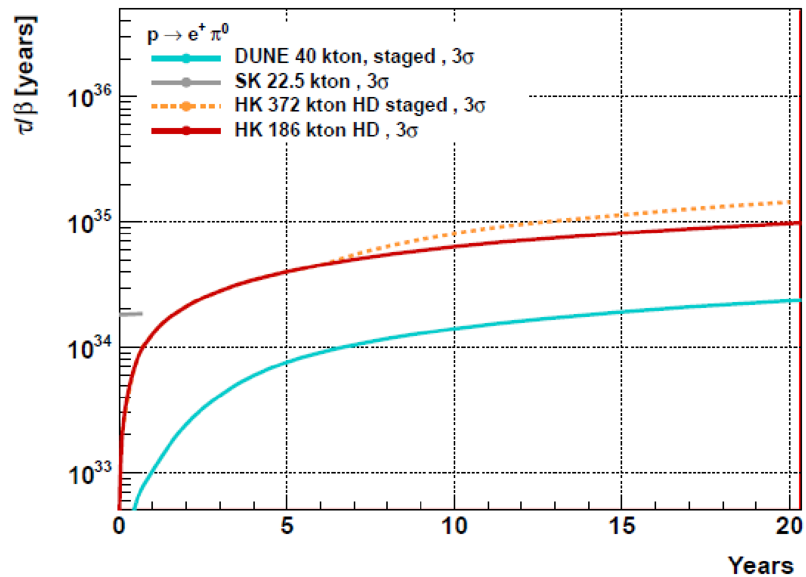
GUT predicts this process through gauge bosons

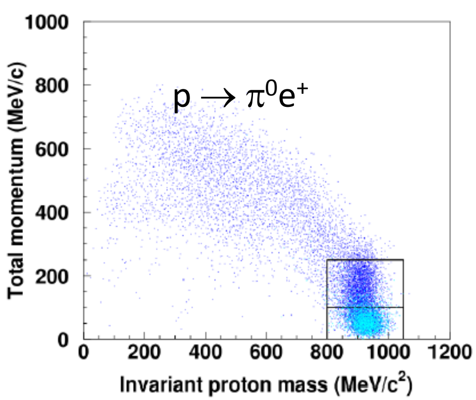
$$\Gamma(p \to e^+\pi^0) \sim \frac{1}{M_X^4} \qquad \tau_p \sim M_X^4 / m_p^5$$

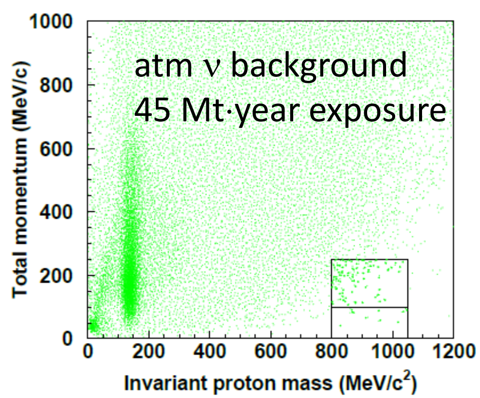




3σ discovery potential







0.06 bkg events/Mt·year in free proton bin
0.62 bkg events/Mt·year in bound proton bin

Neutron tagging
($n+p \to d+\gamma$, E_γ=2.2MeV)
helps to reduce background

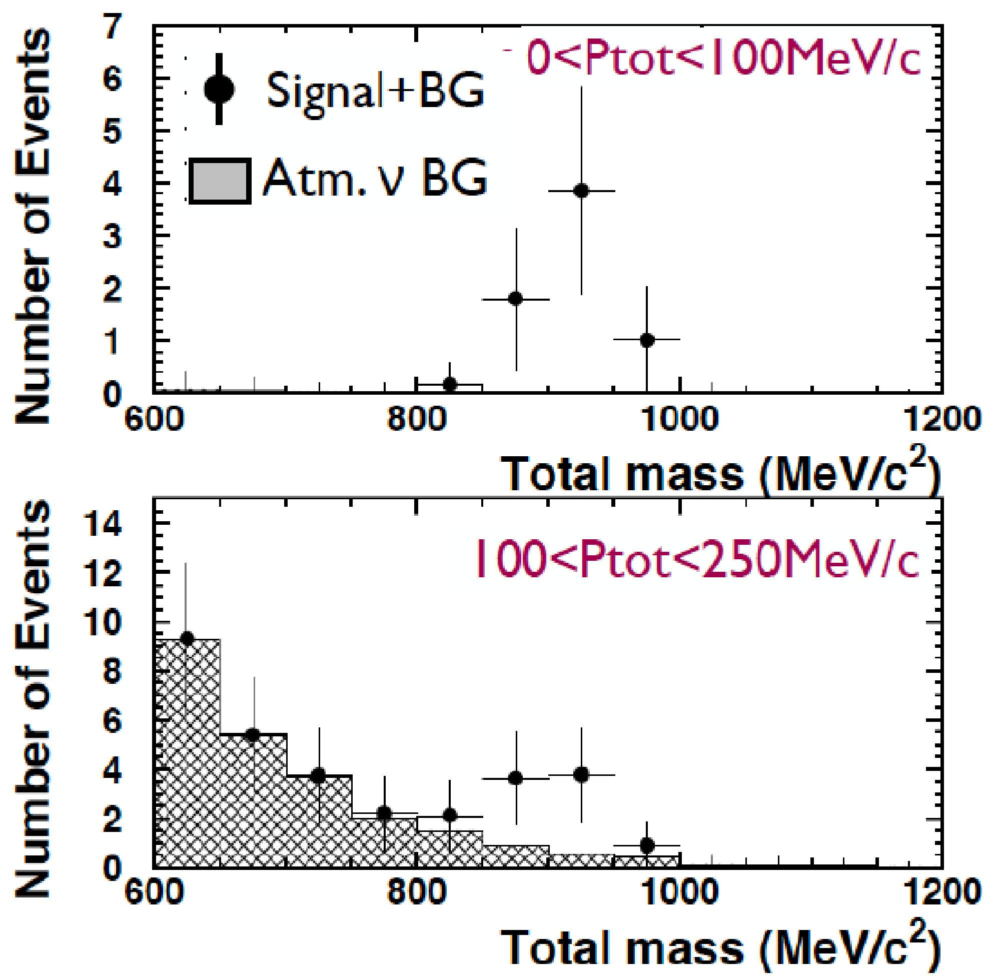
$p \to e^+\pi^0$ events

Assumed proton lifetime
$\tau_p/Br = 1.7 \times 10^{34}$ years

Free proton bin

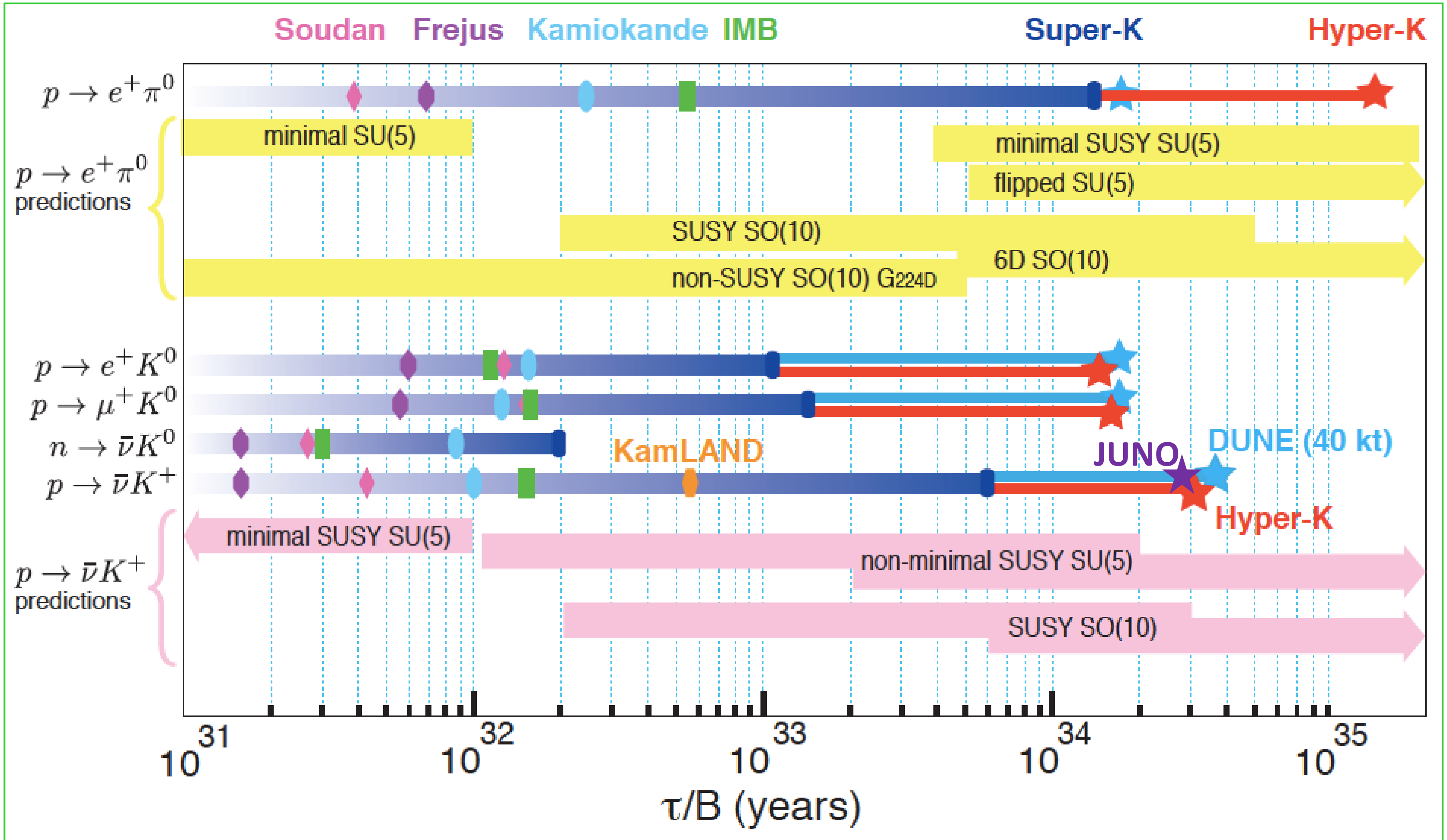
Bound proton bin

10 year exposure



Nucleon Decay sensitivities

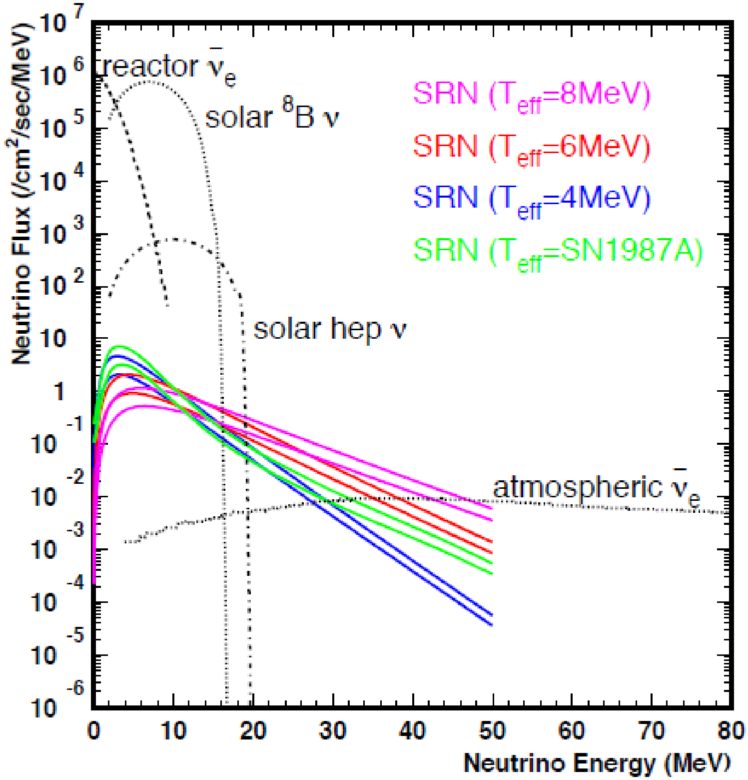
Hyper-K 3σ discovery potential

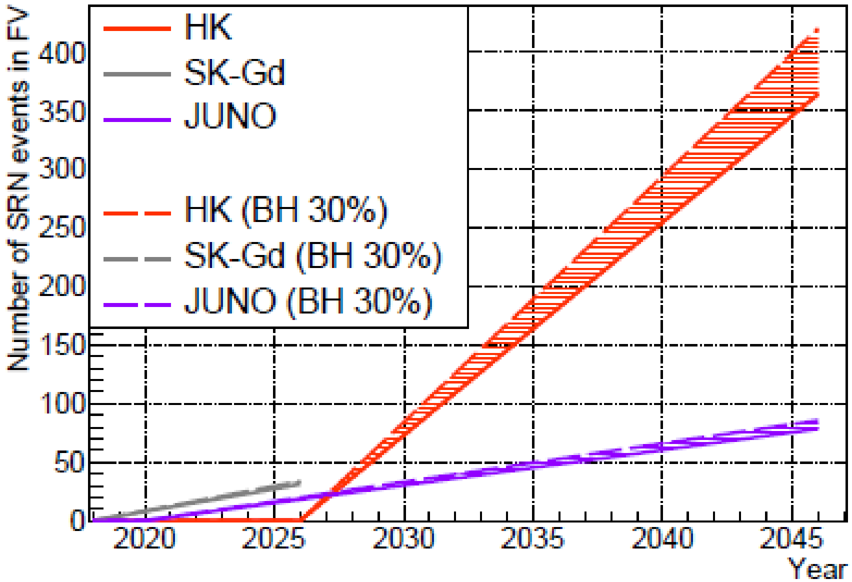


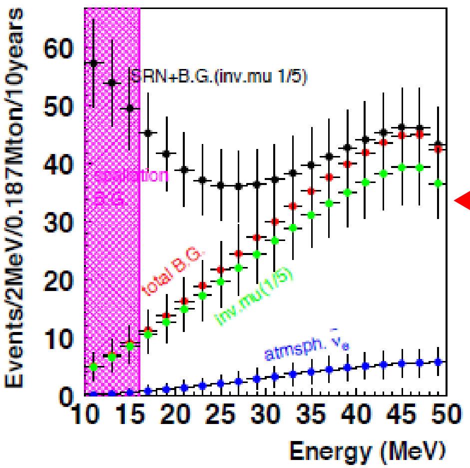
Supernova Relic Neutrino

Hyper-K will measure the SRN spectrum
$\rightarrow$ formation of black holes
$\rightarrow$ formation of stars, their metallicity

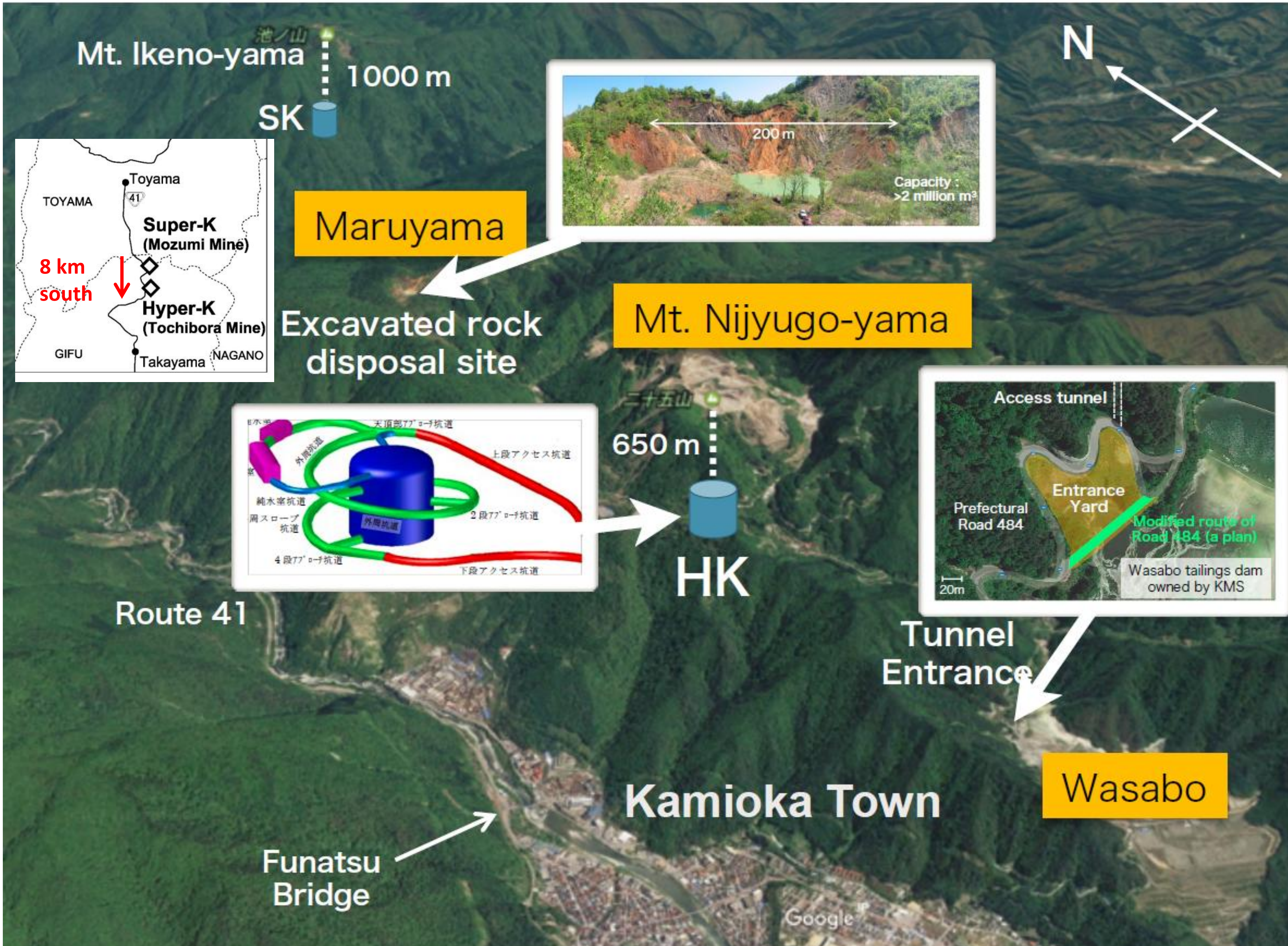
S.Horiuchi et al. PRD 79 (1990) 083013





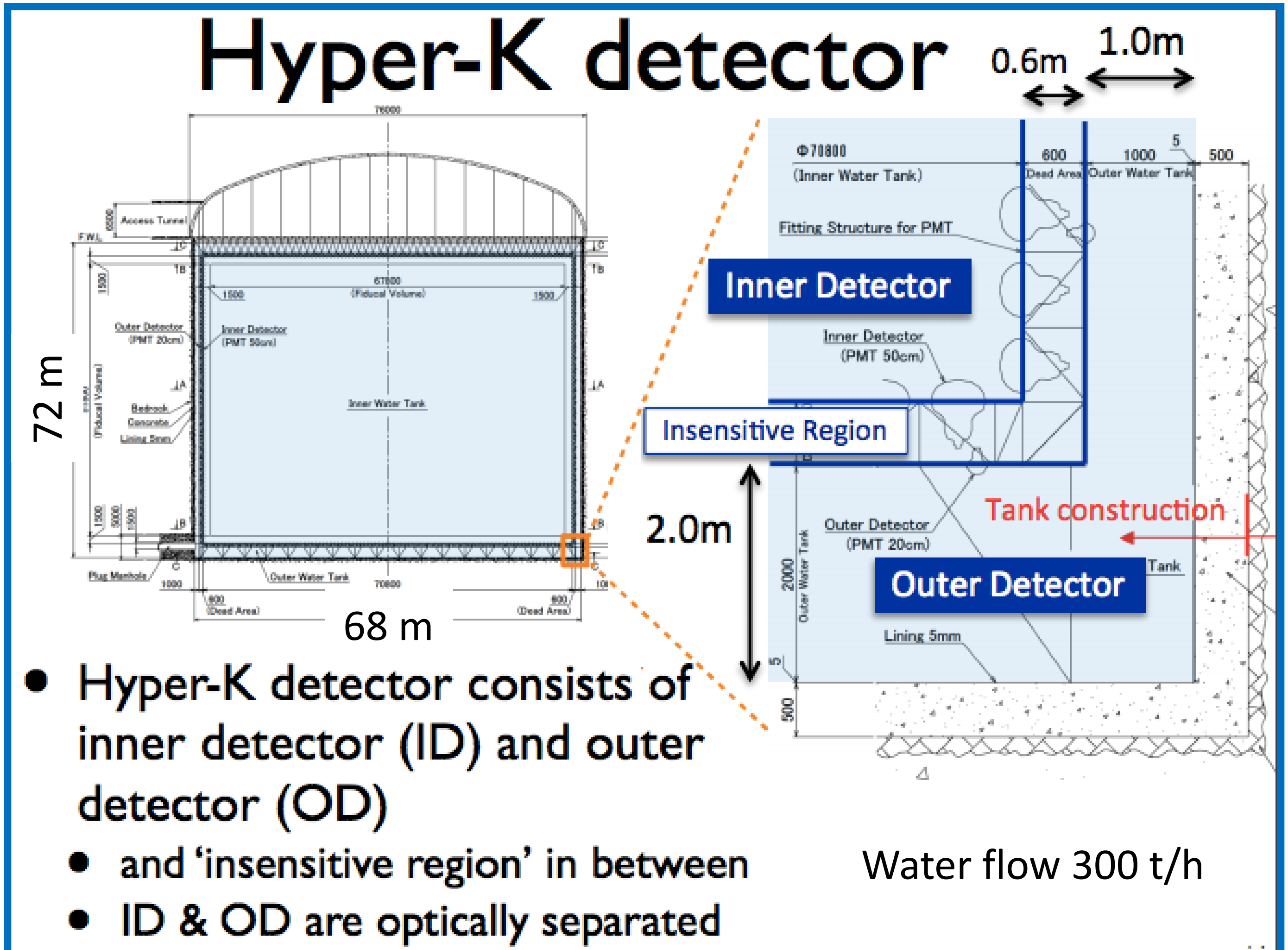


Energy spectrum of SRN
- 10 years of exposure
- neutron tagging efficiency 67%



Mt. Ikeno-yama
1000 m
SK
N
200 m
Capacity : >2 million m³
Toyama
TOYAMA
41
Super-K
(Mozumi Mine)
8 km south
Hyper-K
(Tochibora Mine)
GIFU
Takayama
NAGANO
Maruyama
Excavated rock disposal site
Mt. Nijyugo-yama
天頂部アプローチ抗道
上段アクセス抗道
外周抗道
純水室抗道
2段アプローチ抗道
4段アプローチ抗道
下段アクセス抗道
650 m
HK
Access tunnel
Entrance Yard
Prefectural Road 484
Modified route of Road 484 (a plan)
Wasabo tailings dam owned by KMS
20m
Route 41
Tunnel Entrance
Wasabo
Kamioka Town
Funatsu Bridge
Google

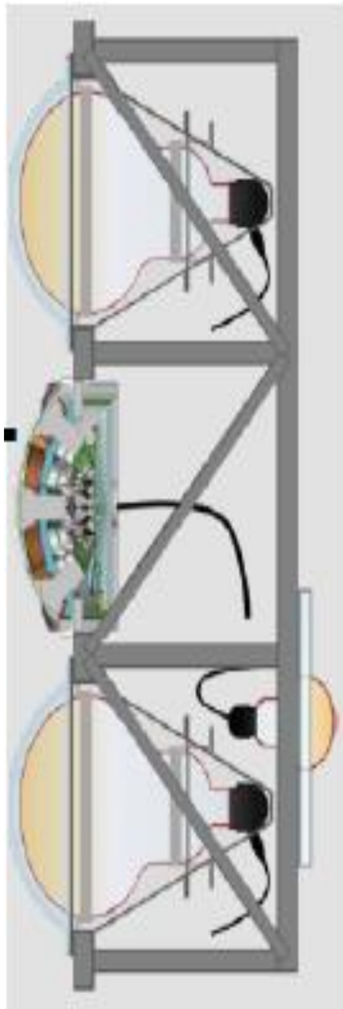
Water tank


Hyper-K detector
0.6m
1.0m
72 m
68 m
Access Tunnel
Outer Detector (PMT 20cm)
Inner Detector (PMT 50cm)
Inner Water Tank
Bedrock
Concrete
Lining 5mm
Plug Manhole
Outer Water Tank
(Dead Area)
Φ70800 (Inner Water Tank)
600
1000
500
Dead Area
Outer Water Tank
Fitting Structure for PMT
Inner Detector
Inner Detector (PMT 50cm)
Insensitive Region
2.0m
Tank construction
Outer Detector (PMT 20cm)
Tank
Outer Detector
Lining 5mm
Hyper-K detector consists of inner detector (ID) and outer detector (OD)
and 'insensitive region' in between
ID & OD are optically separated
Water flow 300 t/h

PMT configuration

Inner Detector

B&L PMT



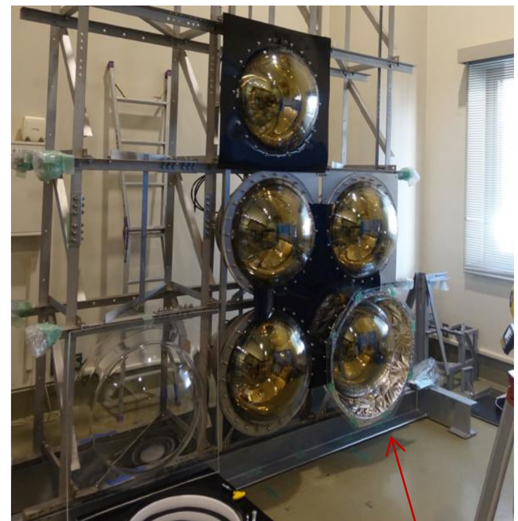
multiPMT

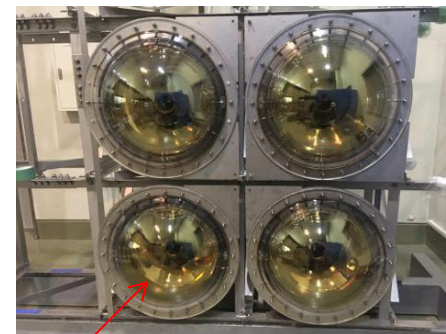
B&L PMT

Outer Detector

OD PMT

PMT mockup frame

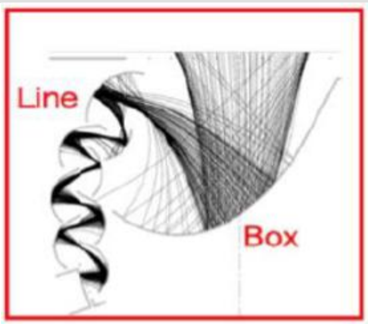




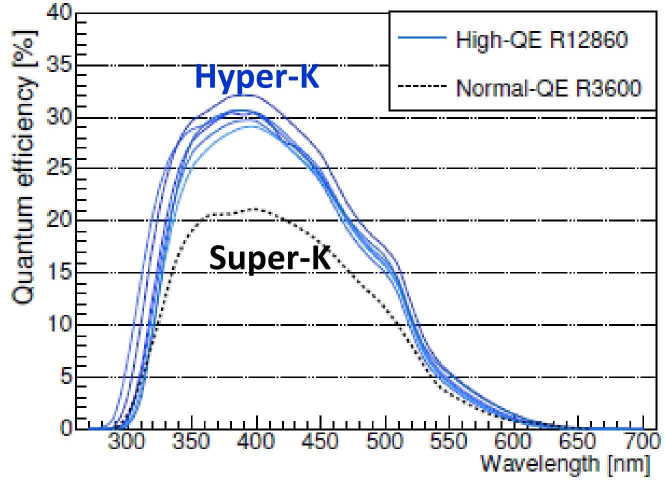
B&L PMTs

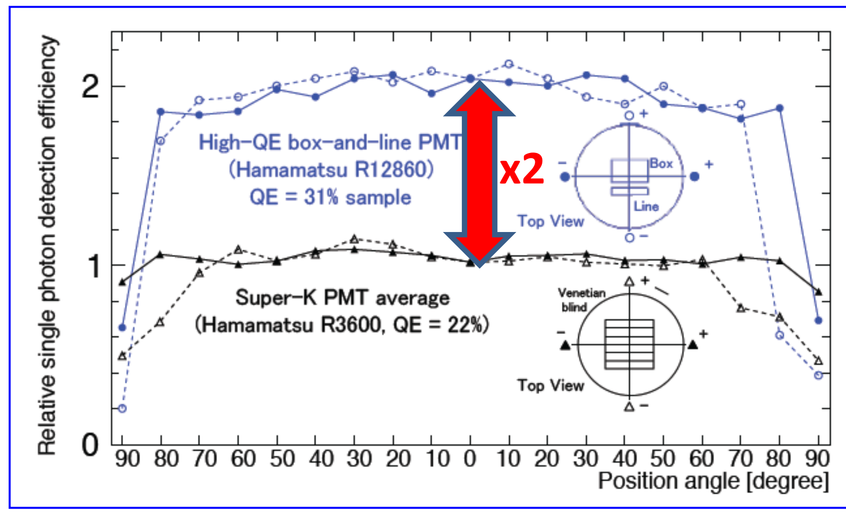
Photosensors: B&L PMT

Baseline choice for Inner Detector:
Hamamatsu R12860-HQE
Box&Line 50 cm PMT



40000 PMTs
40% photocoverage





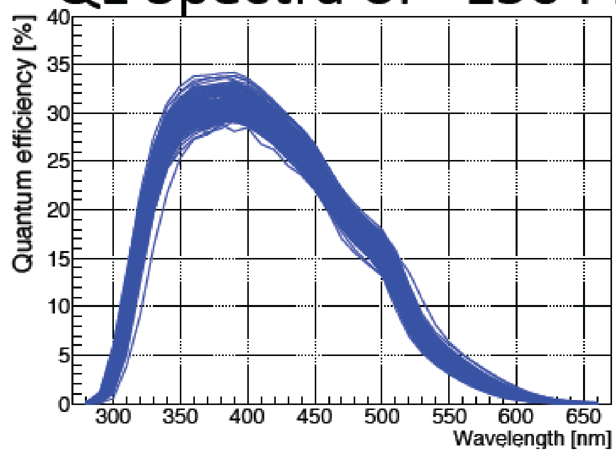
1 p.e. → time resolution 1.1. ns,
→ charge resolution 35%

Photosensors:B&L

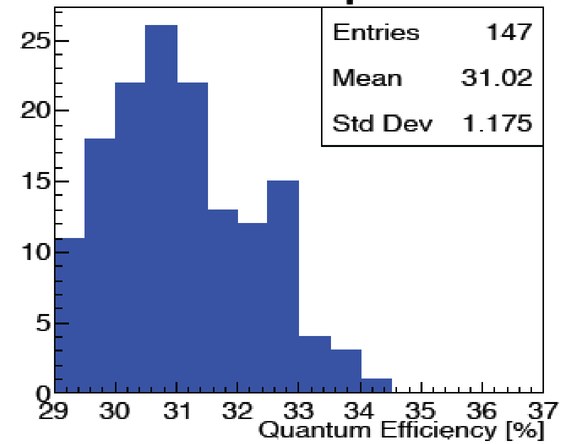
Y.Nishimura, talk at NEPTUNE2018

150 Box&Line 50 cm PMTs were manufactured
- all PMTs were tested at high pressure water ≤0.95 Mpa
- no damage was found

QE Spectra of ~150 PMTs

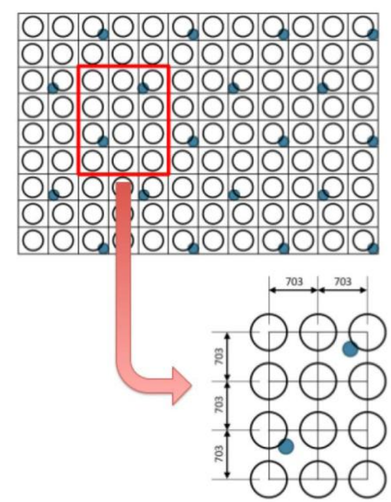


QE at peak



OD PMTs

Hamamatsu R5912-HQE
B&L 20 cm PMT



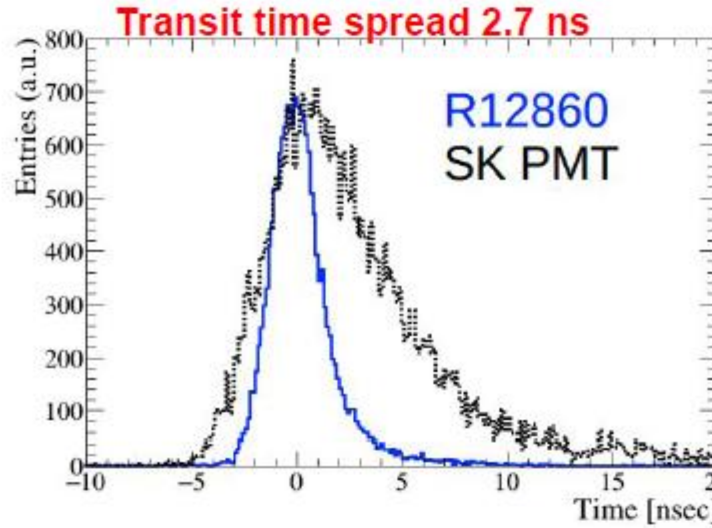
PMTs 3'' or 8'' + WLS plates

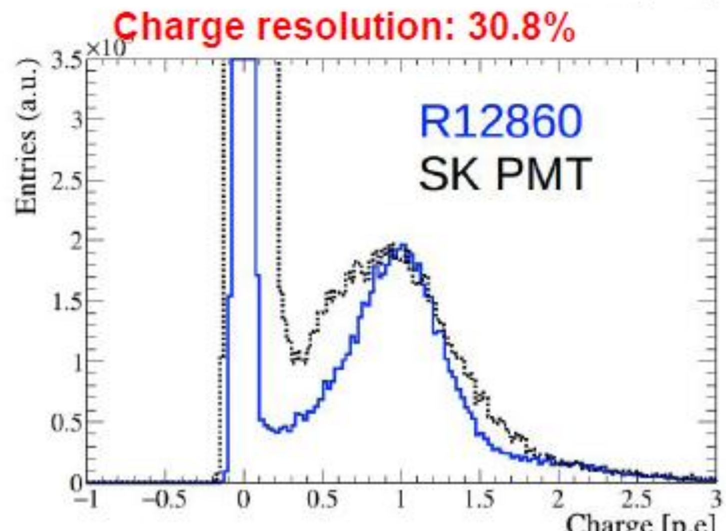
OD water thickness
1m barrel, 2 m top and bottom

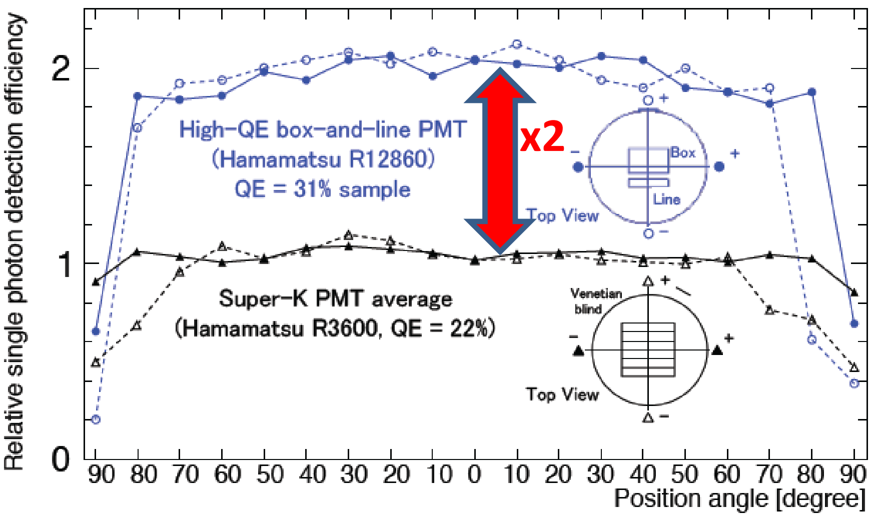
PMTs: SuperK and HyperK

Hamamatsu R12860 20''
high QE box-and-line PMT

- QE= 30%
- 2 x photon detection efficiency of Super-K R3600
- Dark rate 4 - 6 kHz



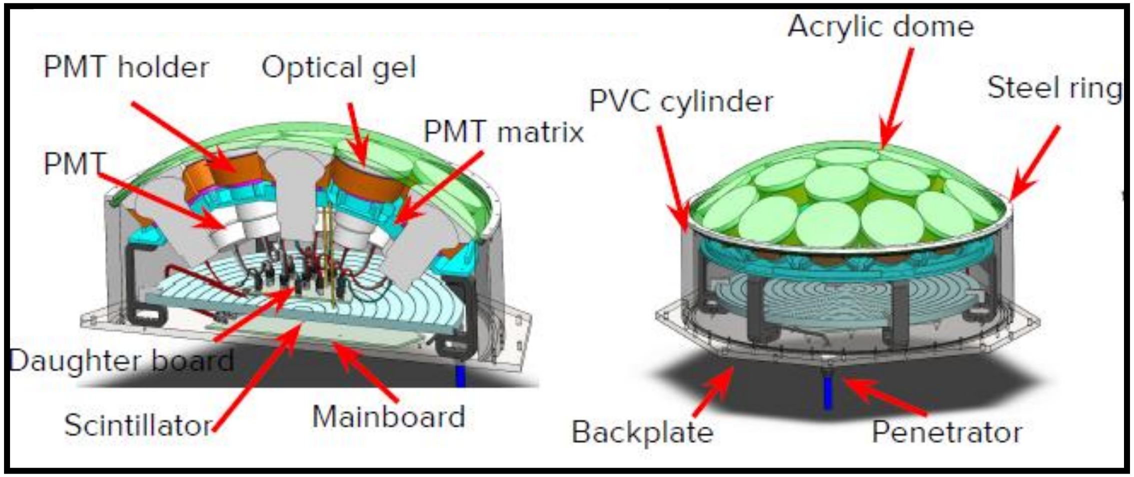




Photosensors: multiPMT

International contribution (5000 mPMTs for Hyper-K)

- Based on KM3NeT design (optimized for water tank)
- First prototype built at TRIUMF
- 19 Hamamatsu R14374 3’’ PMTs in optical module
- Less photo-coverage but improved vertex resolution
- Improved timing resolution



Optical module

Module concept from KM3NeT

arXiv:1405.0839

Collection efficiency	about 45%
Dark rate	100-200 Hz/PMT
TTS	1.3 ns for 1 p.e.

PMT R&D

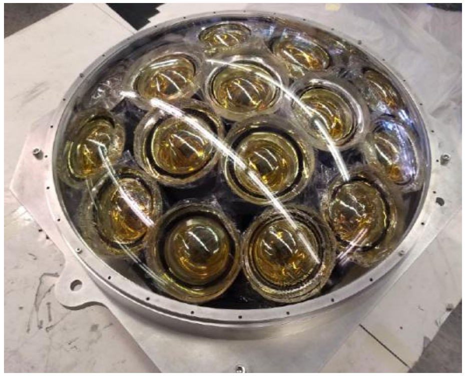
Different type of PMTs under study

MultiPMT (19 x 3'' PMT)
Fine granularity
Timing resolution ~1.3 ns
Low dark rate ≤ 2.0 kHz
Better vertex resolution, PID

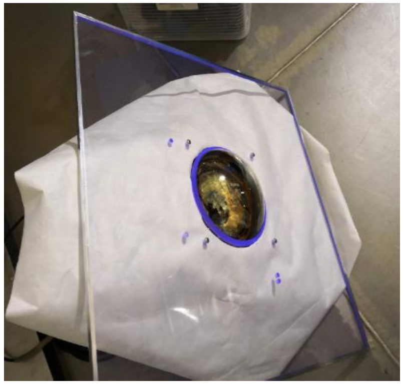
MCP PMT (20'' PMT)
Produced NNVT for JUNO
R&D for Hyper-K
TTS 4.3 ns
Dark rate ≥10 kHz

OD PMT (8/3''PMT)
with WLS plate
for OD

mPMT



MCP-PMT



PMT
acryl cover

thickness of cover 15 mm
thickness of stainless steel 3 mm
test in water, depth 60 and 80 m → OK

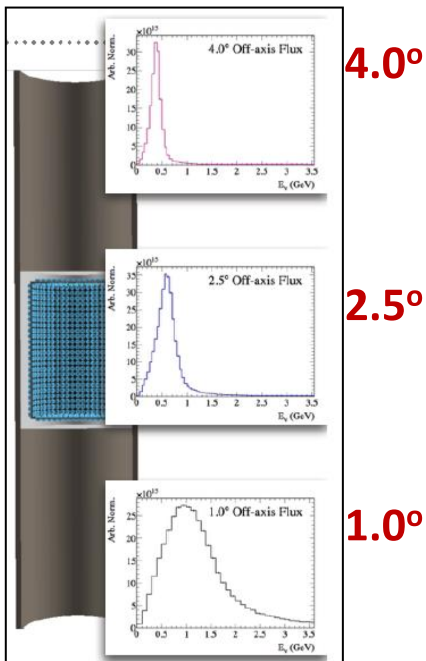
Intermediate Water Detector

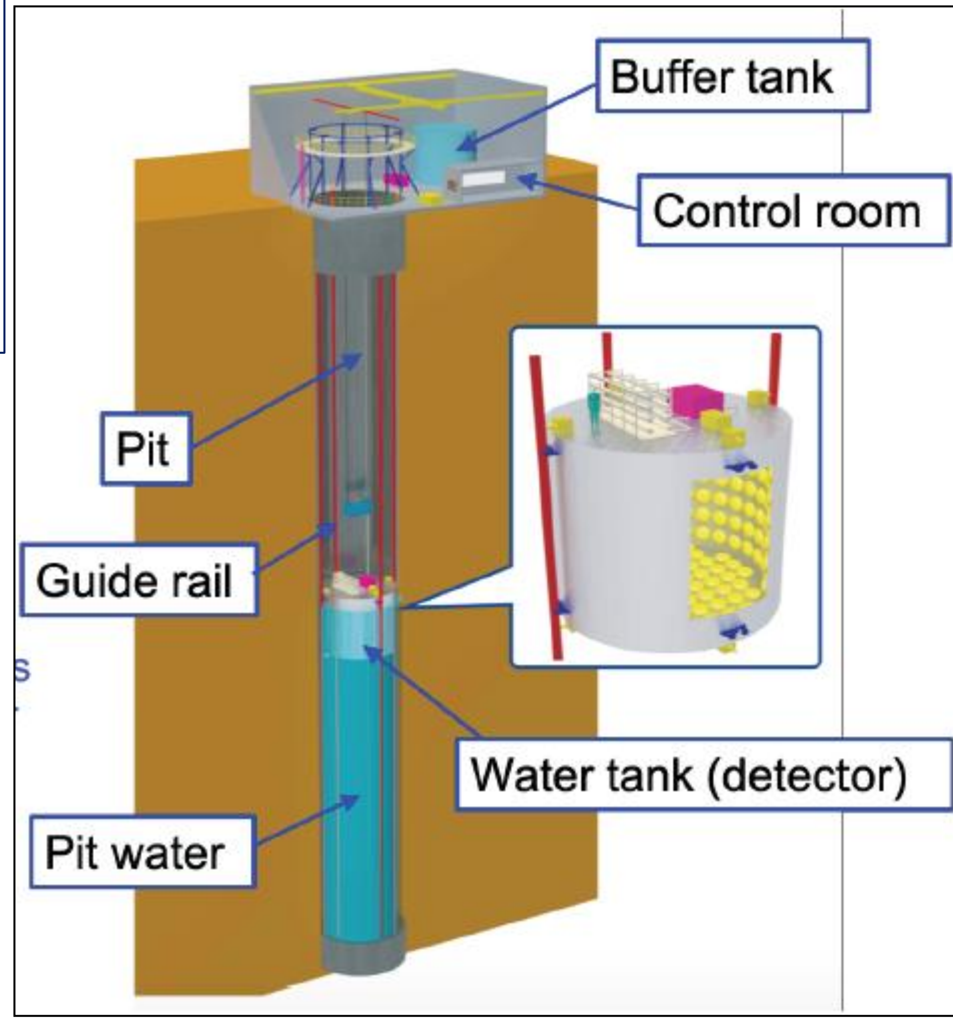
arXiv: 1606.08114; 1412.3086

to be constructed by 2026

Location: 1-2 km from target
Shaft: 50-100 m deep
Tank: diameter 10 m, height 8 m
moves up and down in pit water
Of-axis angle: 1 - 4 deg
Photosensors: 480 mPMTs

Measurements of neutrino cross sections in the neutrino energy range 0.4 - 1.0 GeV





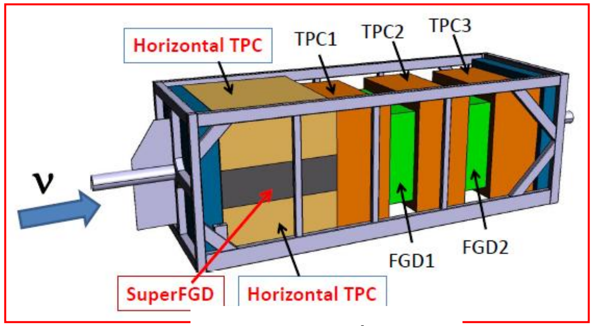
ND280 upgrade

arXiv:1901.03750

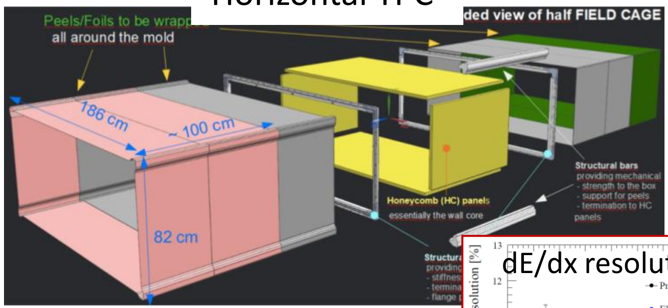
See talks: S.Fedotov
C.Jesus-Valls

New upstream tracker:
Two Horizontal TPC
One 3D fine-grained scintillator target SuperFGD
TOF system around new tracker

- 4π acceptance for muons
- Measurements of protons with p ≥300 MeV/c
- Detection of neutrons
- Reduction of systematics to 3-4%

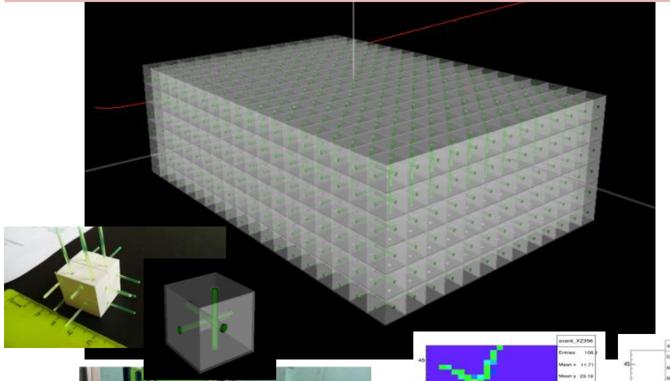


Horizontal TPC

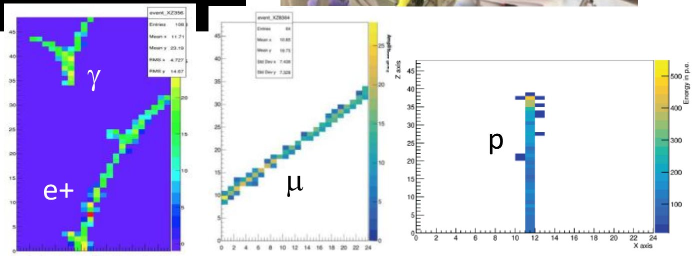


JINST 13 (2018) no.02, P02006

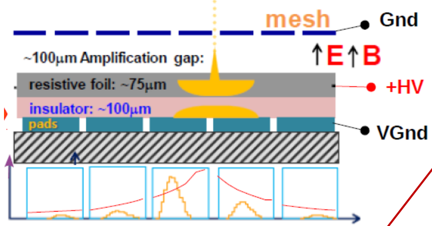
SuperFGD: 2x10^6 scintillator cubes with WLS readout



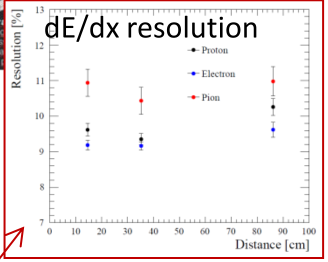
Beam tests of SuperFGD prototype at CERN

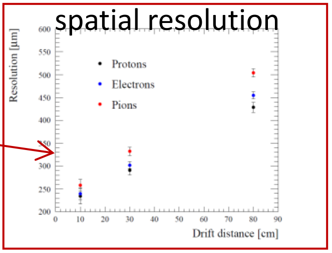


Resistive Micromegas



Beam test at CERN

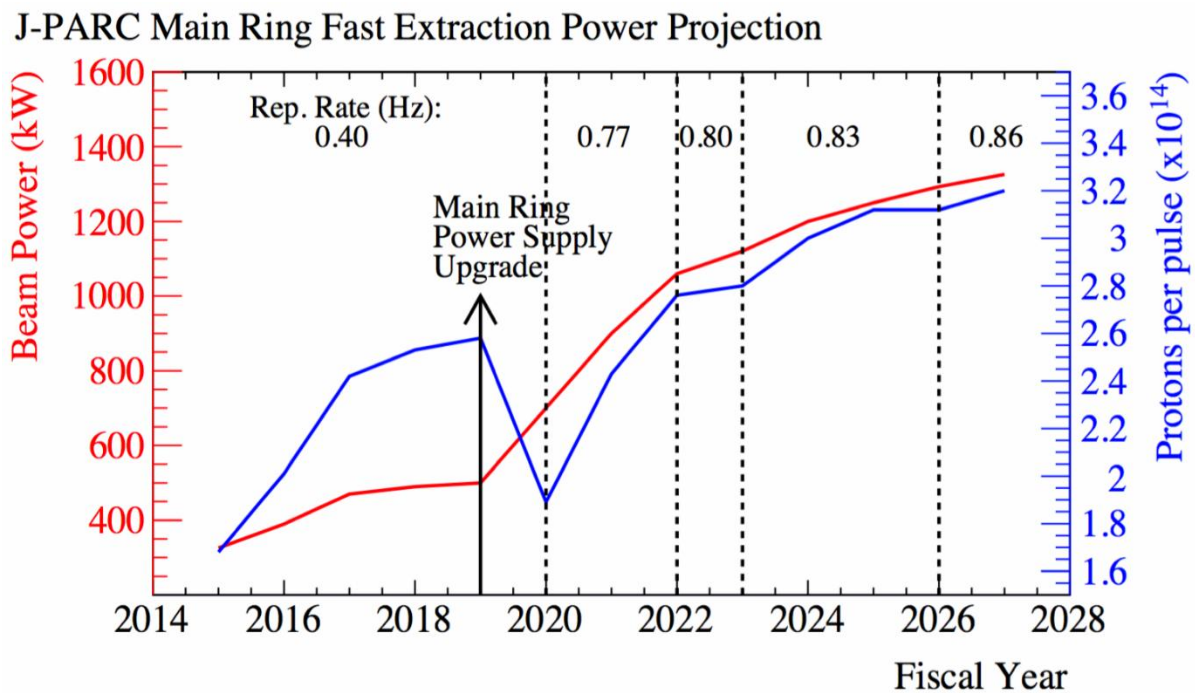




J-PARC upgrade

515 kW achieved in February 2020

1.3MW will be available for Hyper-Kamiokande



J-PARC 30 GeV main ring

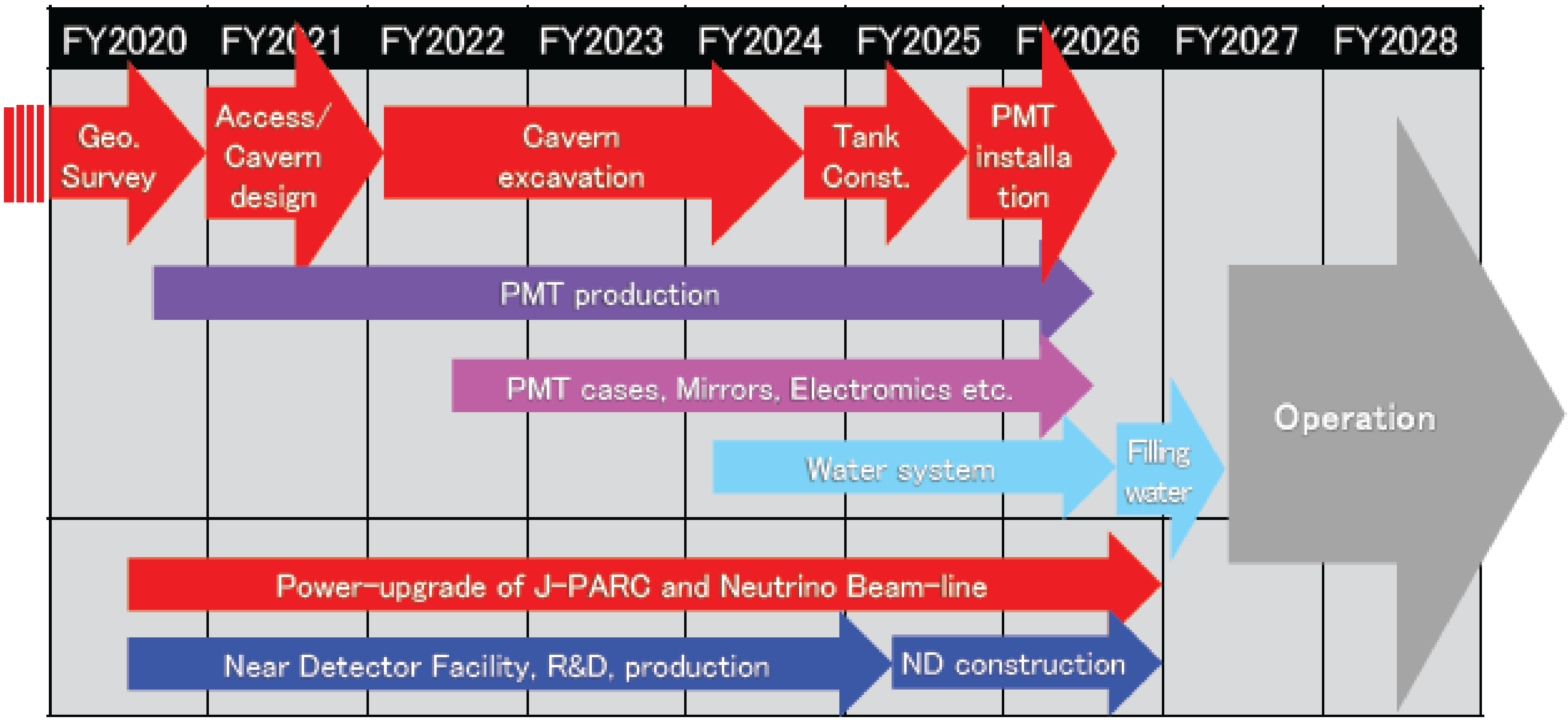
→ 750 kW (cycle 1.3 s) - 2022

→ 1.3 MW (cycle 1.16 s) - 2026

→ 3.2 x 10^{14} protons per pulse

Narrow-band neutrino beam, peak energy 600 MeV

Hyper-K timeline



Very tight schedule

Summary

Hyper-Kamiokande , the major next generation neutrino/nucleon-decay experiment , approved in January 2020

Very broad physics program:

- **search for CP violation in neutrino oscillations**
- **proton decay**
- **rich program with atmospheric and solar neutrinos**
- **supernova neutrinos**
- **+ other interesting physics**

Hyper-Kamiokande experiment:

- **8 times larger than Super-K water Cherenkov detector**
- **1.3 MW beam, intermediate water Cherenkov, upgraded T2K near detector**
- **construction starts in 2020**
- **will be built using Super-K and T2K experience**
- **start data taking in 2027**

We are at the beginning of an interesting journey!

New collaborators are very welcome!