Hyper-Kamiokande project

Outline

1. Detector construction
2. Detector system
3. J-PARC beam upgrade
4. Near detectors
5. Physics sensitivities

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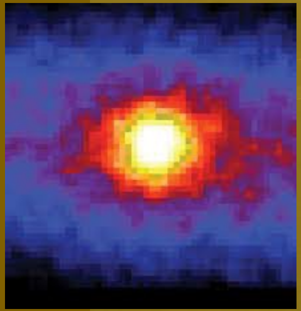
King's College London
LNS colloquium, MIT, USA, Feb 18, 2025

Hyper-Kamiokande Science

Supernova neutrinos

Solar neutrinos



Reactor neutrinos

Astrophysics

- Cosmic ray physics
- Multi-messenger astronomy

Particle Physics

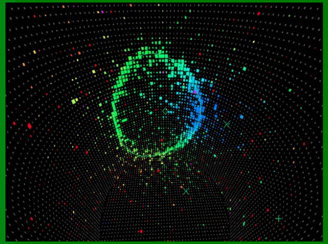
- Leptonic CP violation
- Neutrino-nucleus cross-sections

New physics

- Proton decay
- Dark sector particles
- Indirect DM search
- Unexpected!

Accelerator neutrinos

Atmospheric neutrinos



High-energy astrophysical neutrinos

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Hyper-Kamiokande

Hyper-Kamiokande project

Hyper-Kamiokande project includes 3 components

1. Hyper-Kamiokande far detector

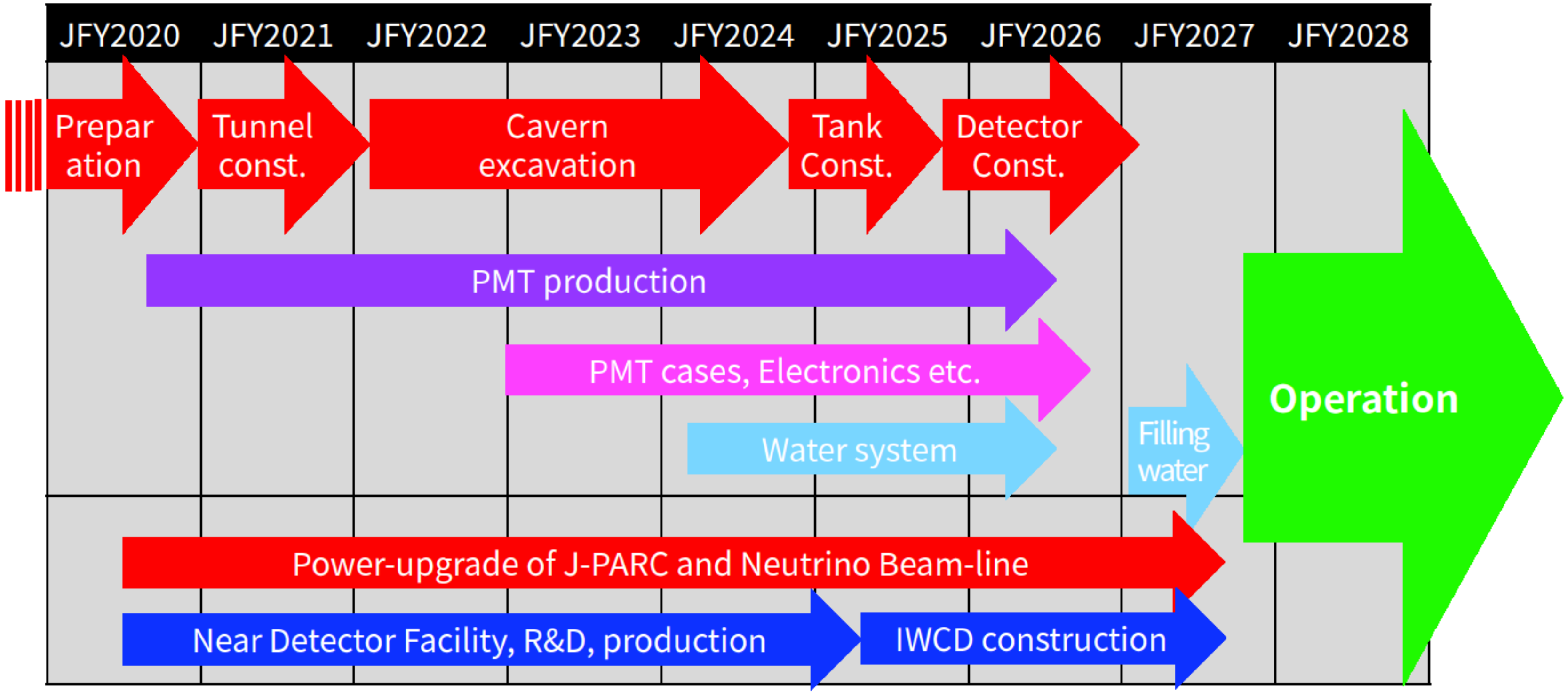
2. J-PARC beam upgrade

3. Hyper-Kamiokande near detectors: ND280-upgrade, Intermediate water Cherenkov detector (IWCD), NF280++

This talk mainly cover the status of (1)

Hyper-Kamiokande project

2027 operation start
- R&D of all stages are finishing
- Site excavation finishing
- PMT mass production continuing (delivered, QA finished > 10,000 PMT)



1. Detector construction

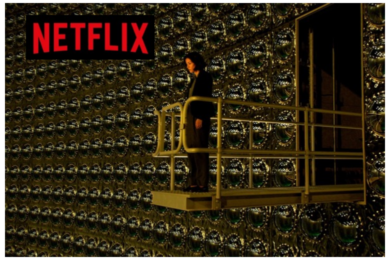
2. HyperK detector system

3. J-PARC beam upgrade

4. Near detectors

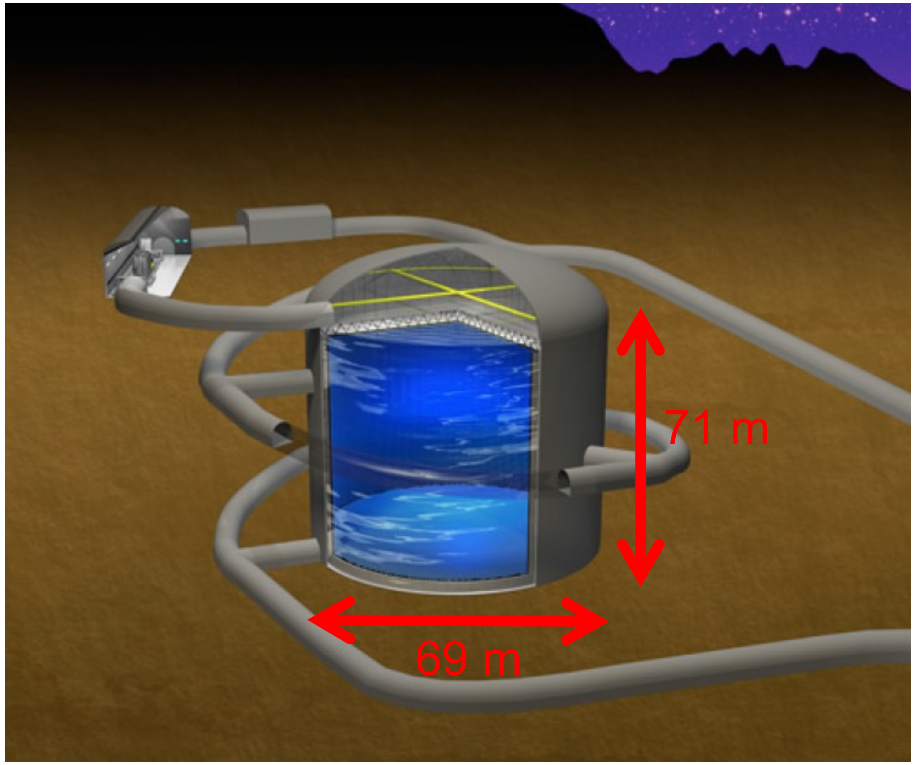
5. Hyper-Kamiokande physics

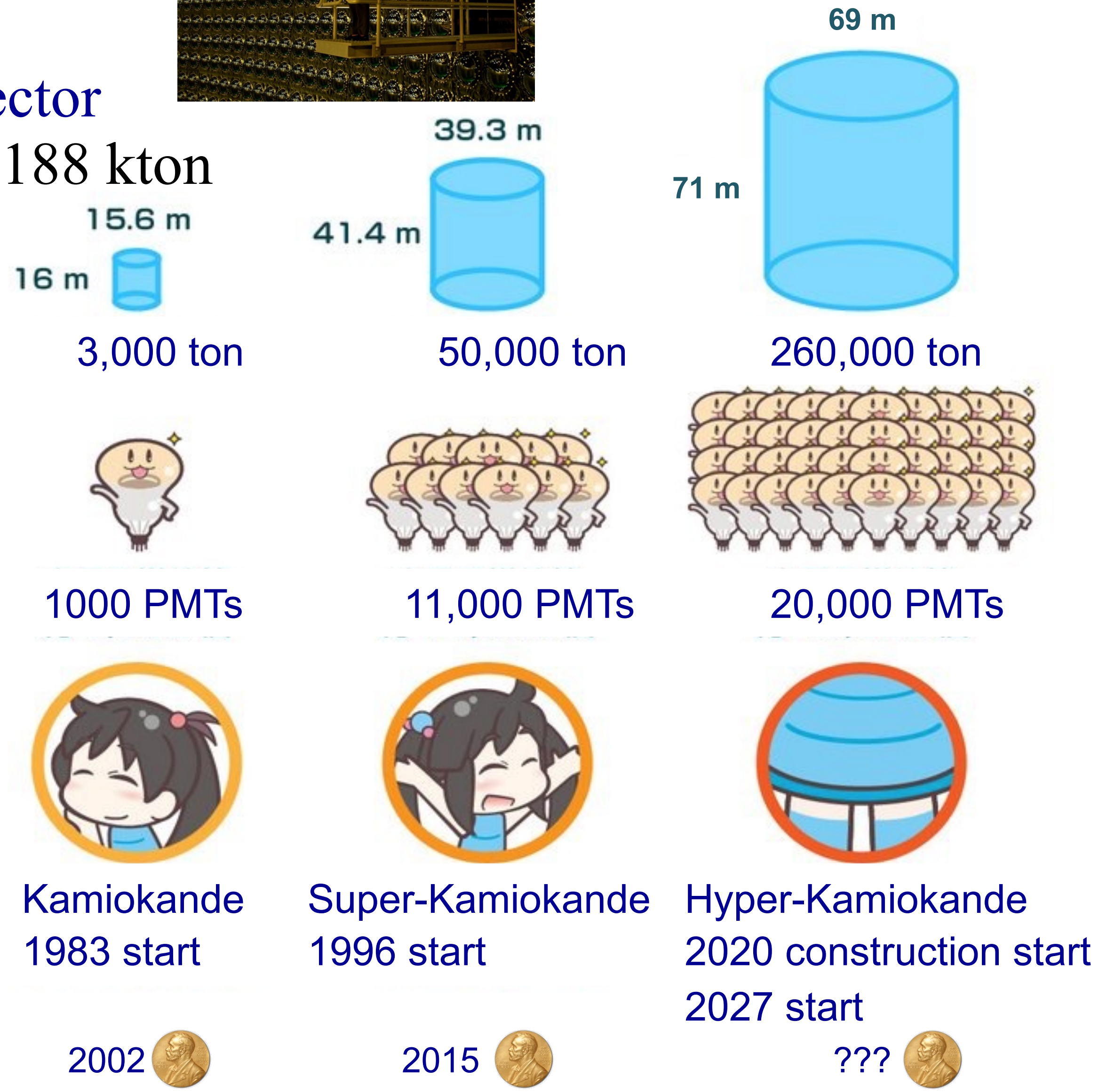
Hyper-Kamiokande detector



3[rd] generation of Kamioka water Cherenkov detector

- Detector volume ~250 kton, fiducial volume ~188 kton
- x8.4 fiducial volume of Super-K





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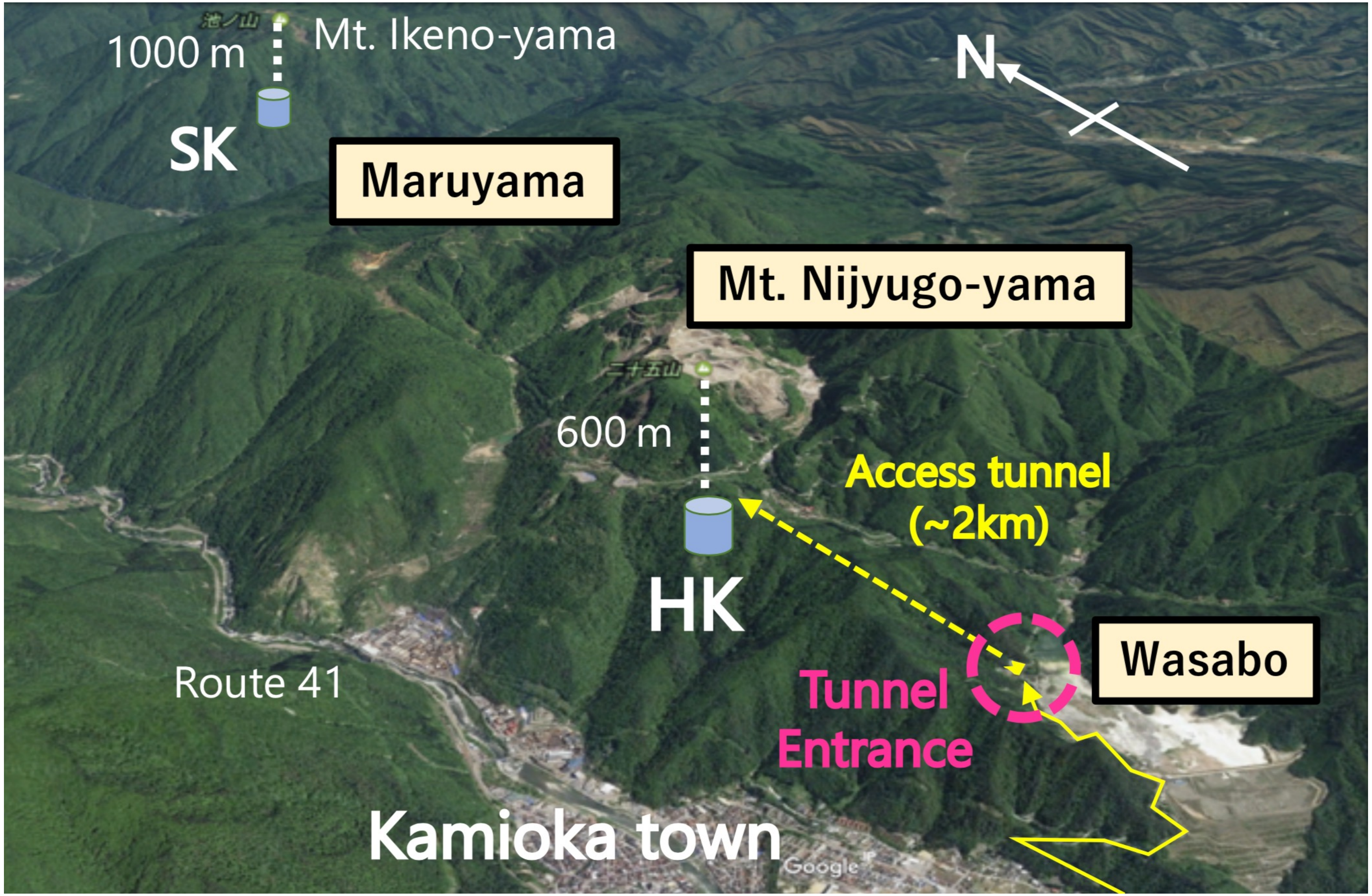
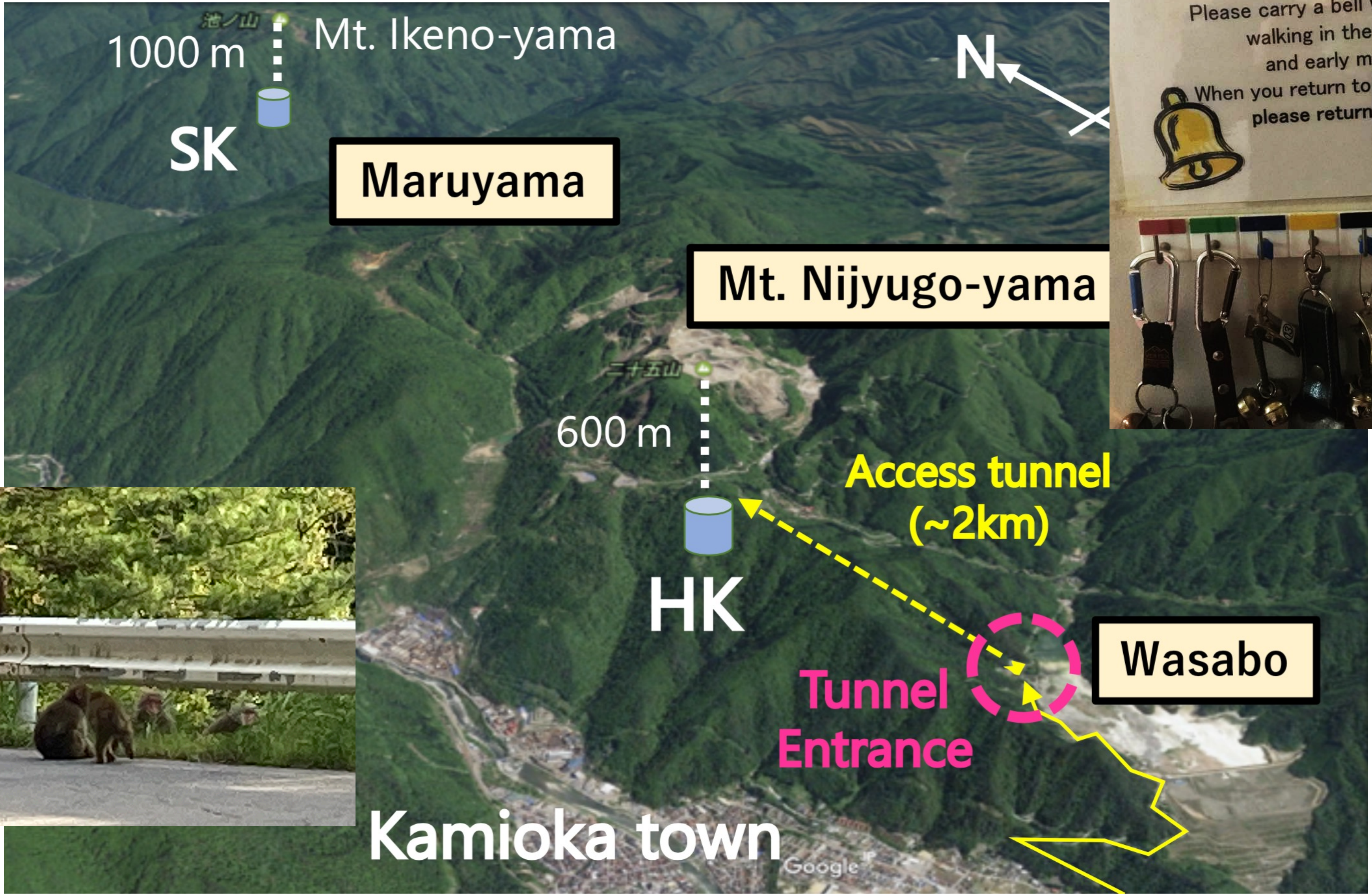
Hyper-Kamiokande

Hyper-K site



1000 m
Mt. Ikeno-yama
N
SK
Maruyama
Mt. Nijyugo-yama
600 m
Access tunnel
(~2km)
HK
Wasabo
Route 41
Tunnel
Entrance
Kamioka town
Google

Hyper-K site


1000 m
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SK
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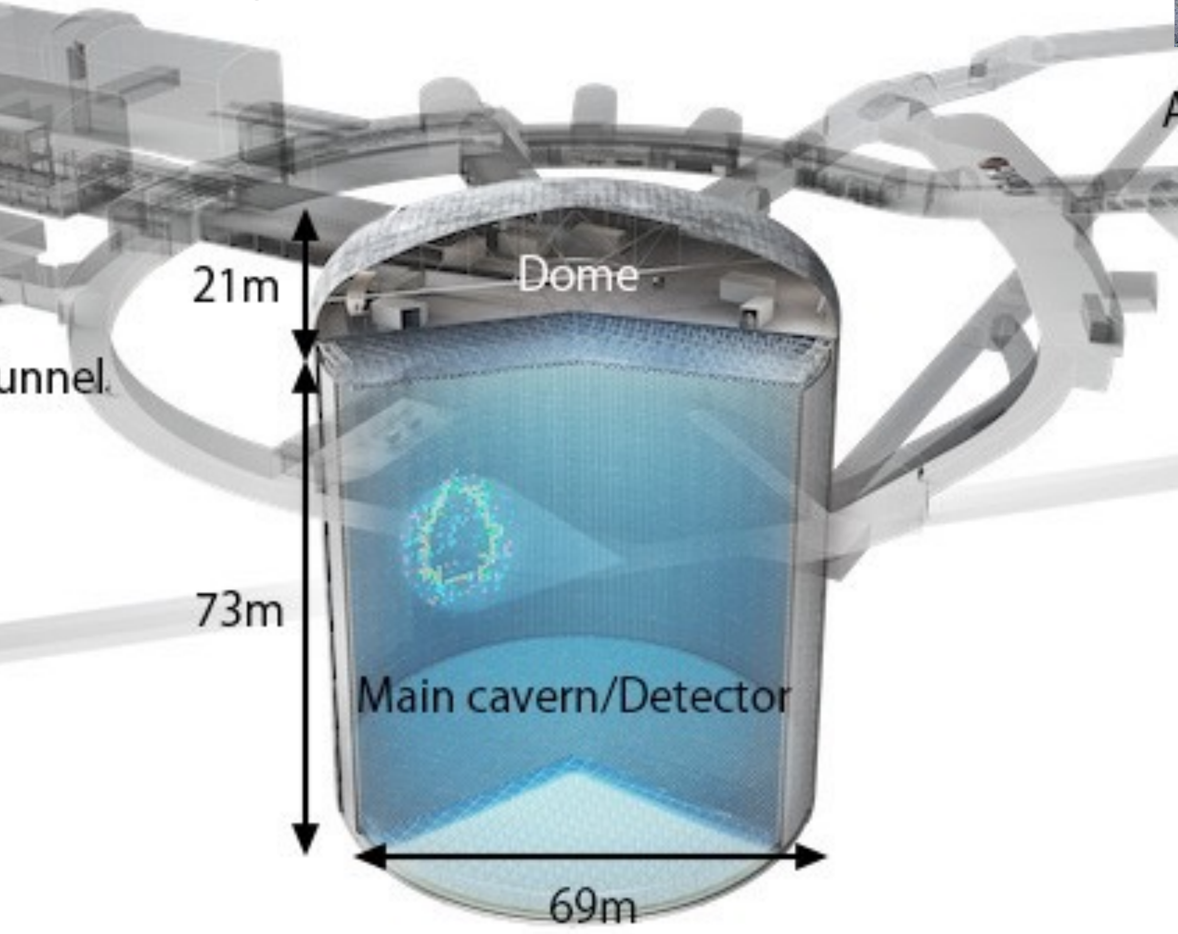
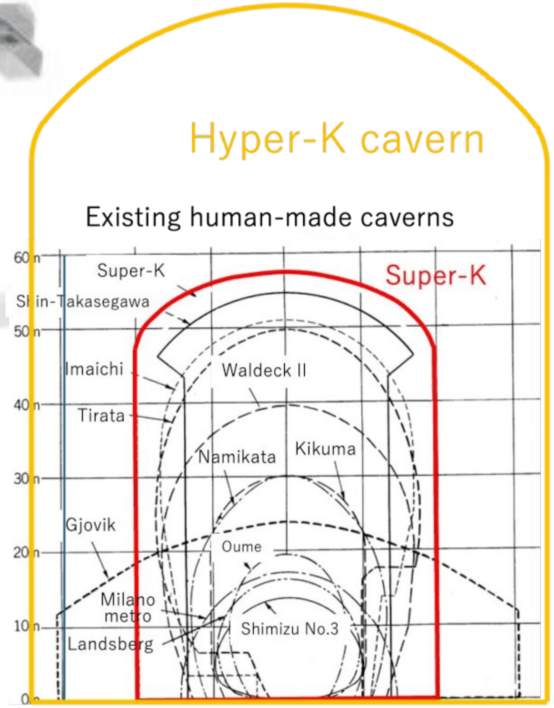
Mt. Nijyugo-yama
600 m
Access tunnel
(~2km)
HK
Wasabo
Tunnel
Entrance
Kamioka town
Google


Watch out for bears!
Please carry a bell with you when
walking in the evening
and early morning.
When you return to the dormitory,
please return the bell.

Cavern excavation

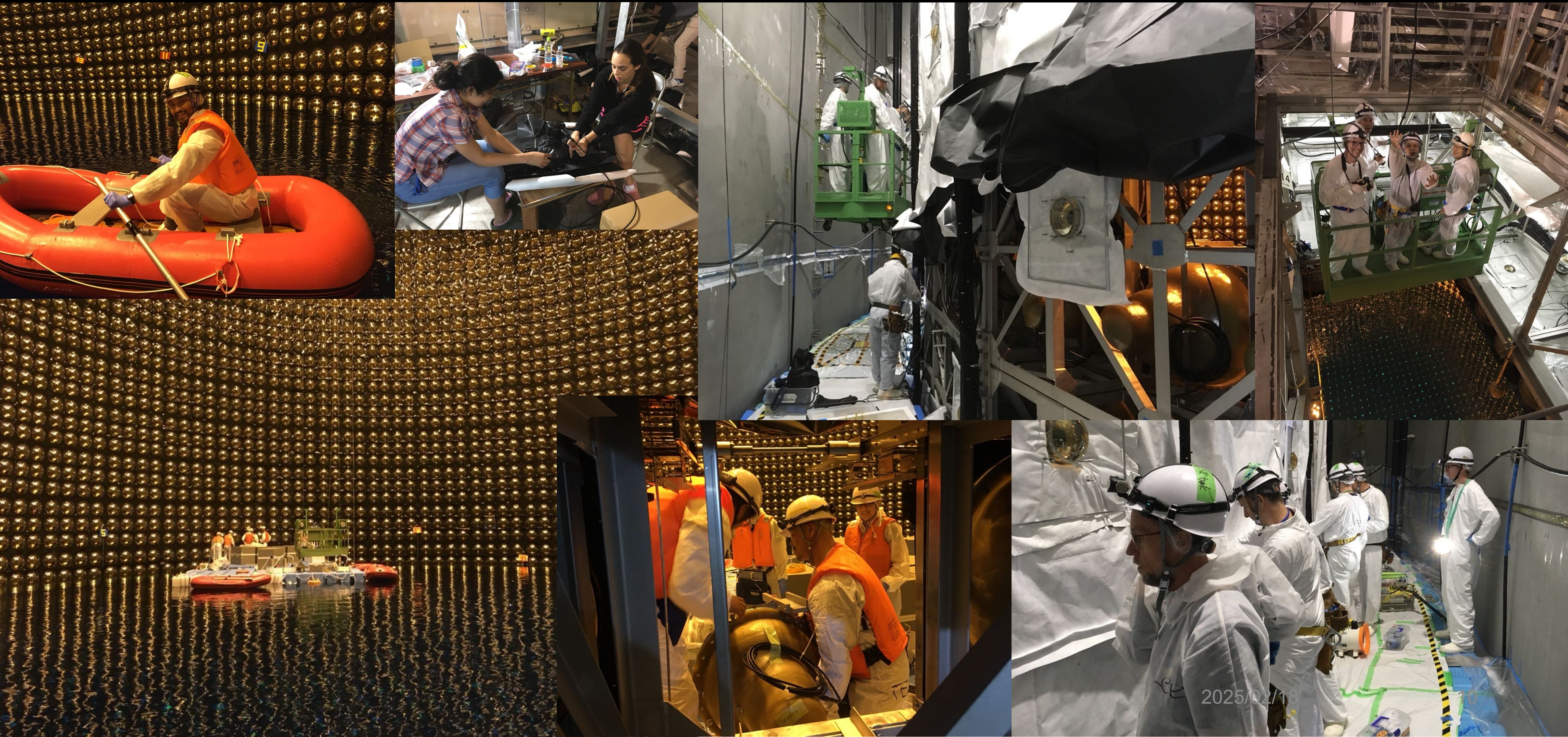
Horizontal access to the detector by car
- Tunnels: completed
- Cavern excavation: finishing soon





The largest man-made cavern in the world

Super-Kamiokande detector refurbishment 2018



1. Detector construction

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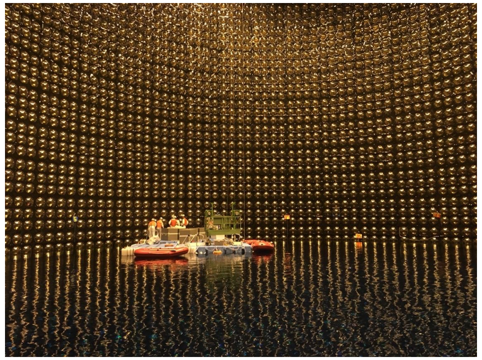
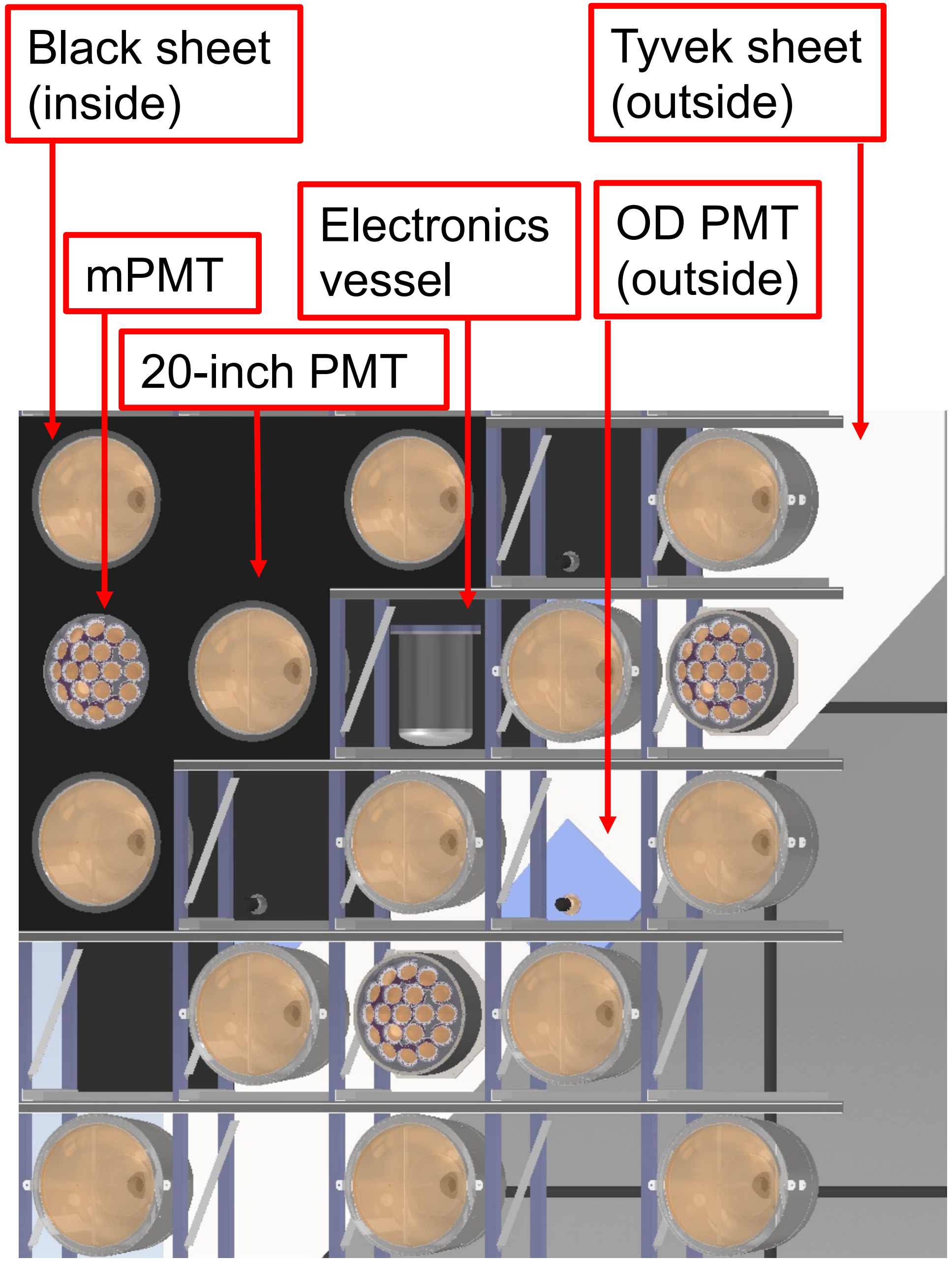
Hyper-K detector system

Inner detector (ID) 20-inch PMTs, mPMTs, outer detector (OD) PMTs, electronics vessel, Tyvek and black sheets are all mounted on stainless streel frame

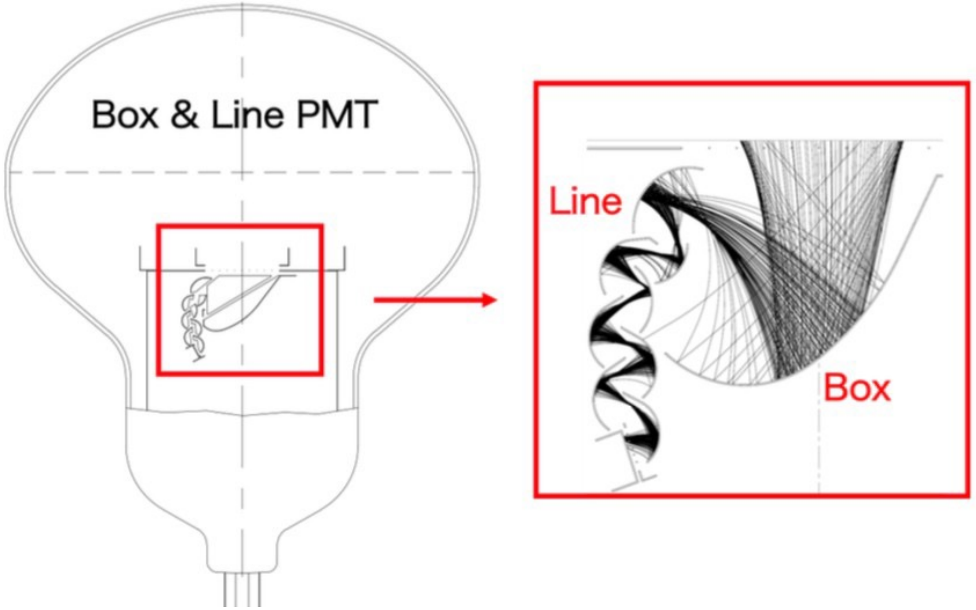
Each slot is 70cm x 70cm, and roughly 300 x 90 slots are available on barrel (70% filled)
- ~20,000 ID PMTs
- >800 ID mPMTs
- >3,000 OD PMTs



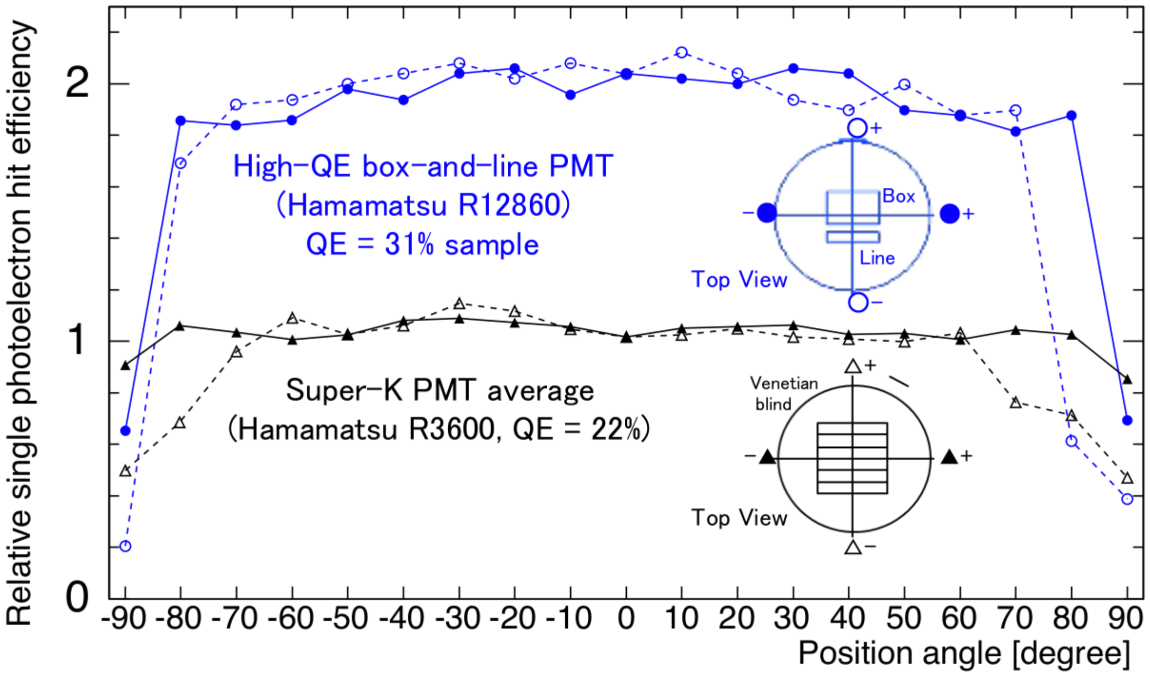


Hyper-K ID 20-inch PMTs

R12860, new generation 50cm PMT
- 50% higher quantum efficiency (30%)
- x2 better charge resolution (30%)
- x2 better timing resolution (1.5ns)
- Stay on the same dark rate (4kHz)
- Performance tested in Super-K



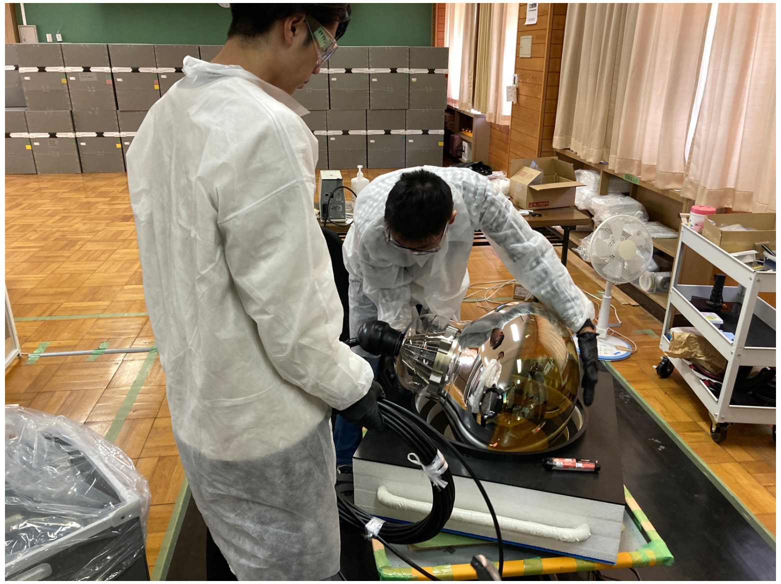
134 Hyper-K 20-inch PMTs are installed (2018 refurbishment)



Hyper-K ID 20-inch PMTs

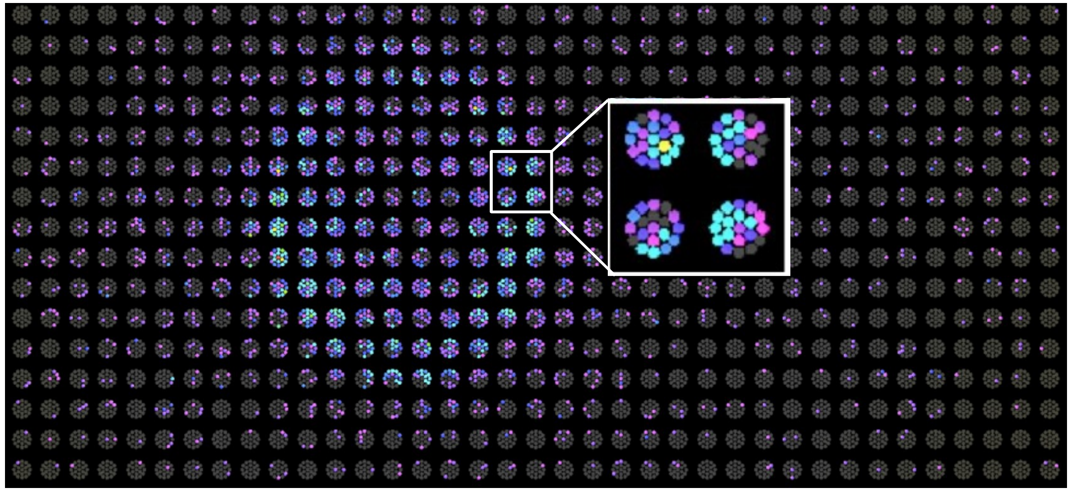
20-inch PMT mass production

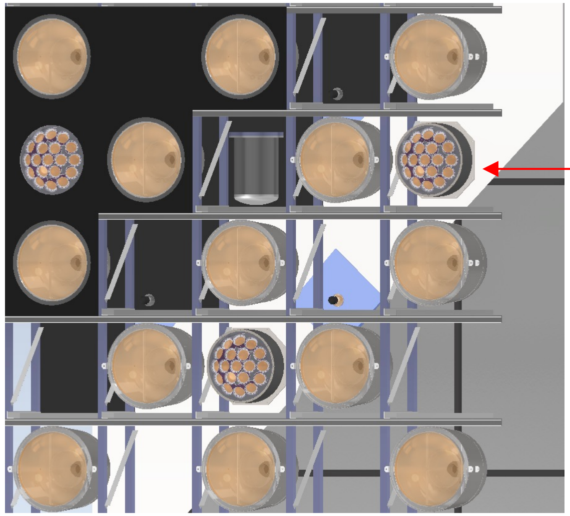
- >10,000 PMTs are delivered
- QA, Signal check + visual check
- Long term stabilities for several PMTs
- QA shifts taken by collaborators

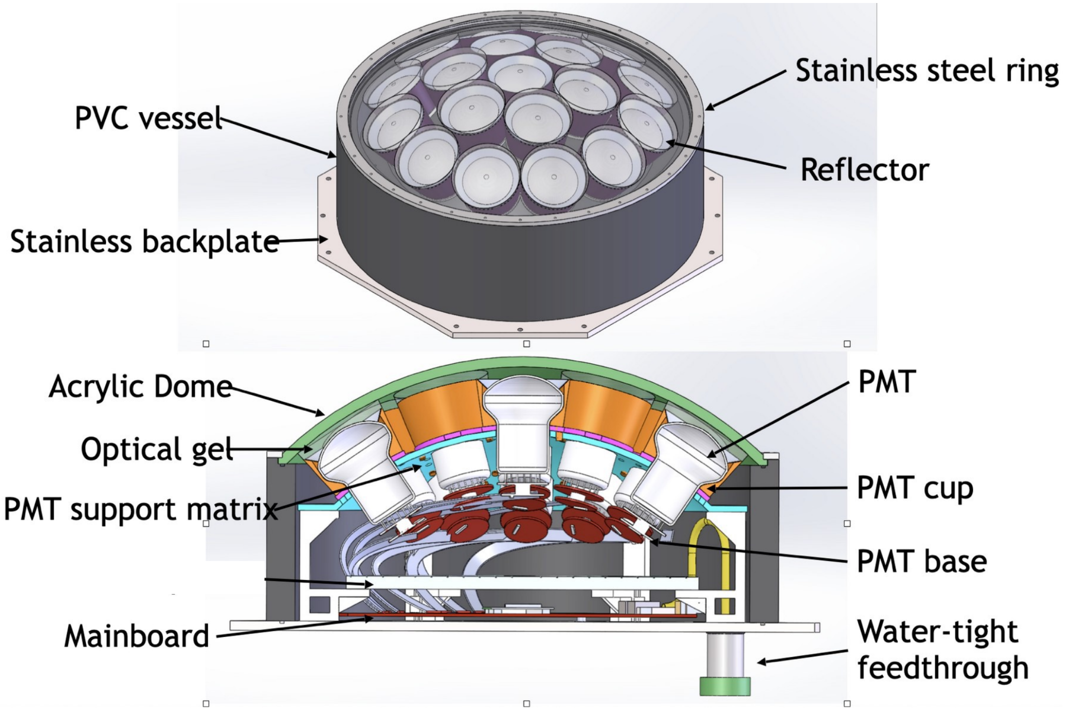


Hyper-K ID mPMTs

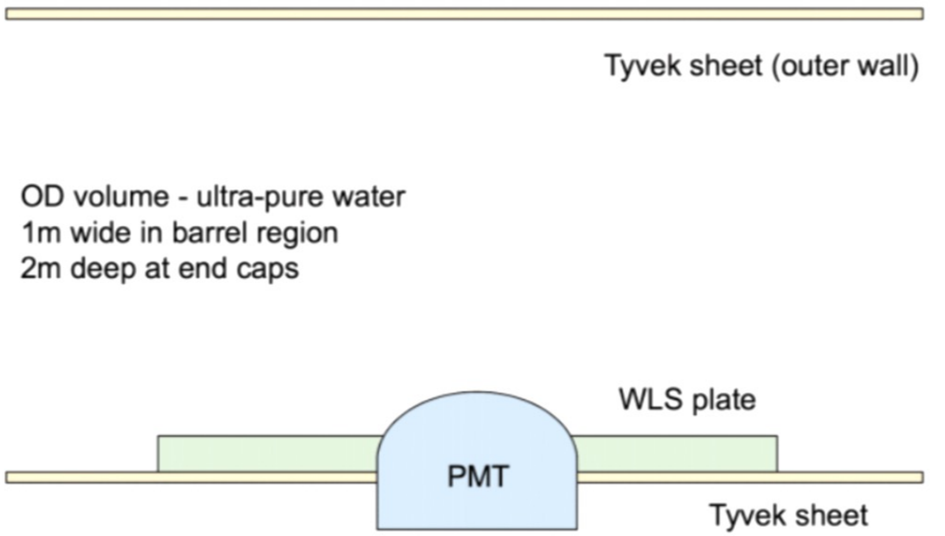
KM3NeT-based concept
- 19 3-inch PMTs, lower noise
- half photo-cathode coverage of 20-inch PMT
- High-granularity, photon direction information







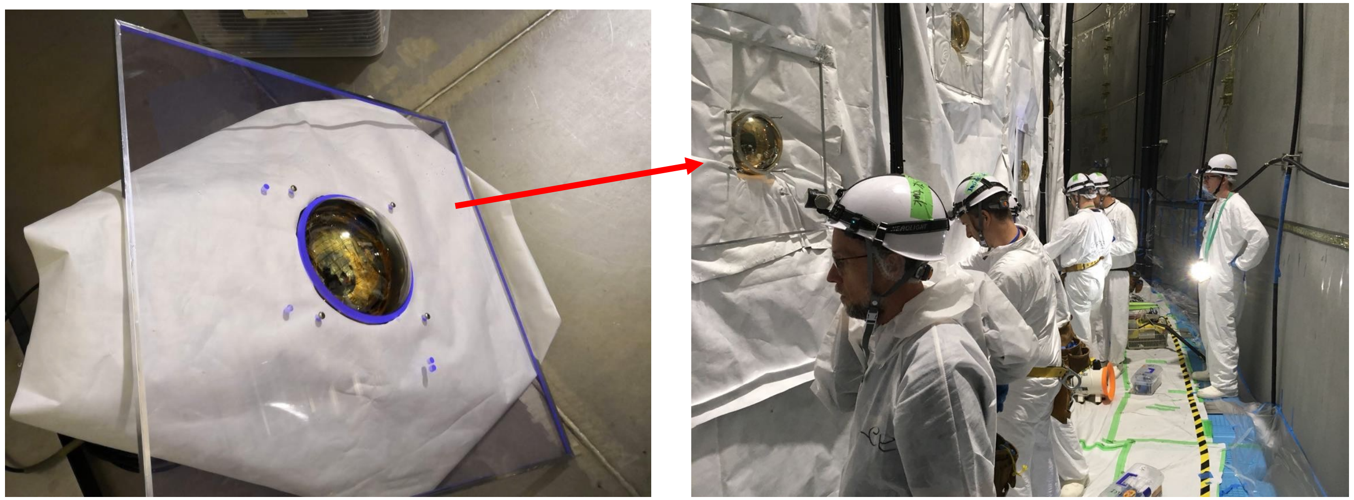
Hyper-K outer detector system



Hyper-K OD system
- 3-inch PMT
- WLS plate
- Tyvek sheet

Cosmic ray rate 2Hz (SuperK) → ~45Hz (HyperK)
- Bigger than SuperK (50 kton → 260 kton)
- Shallower overburden than SuperK (1000 m → 600 m)
- Narrower barrel OD region (2 m → 1 m)

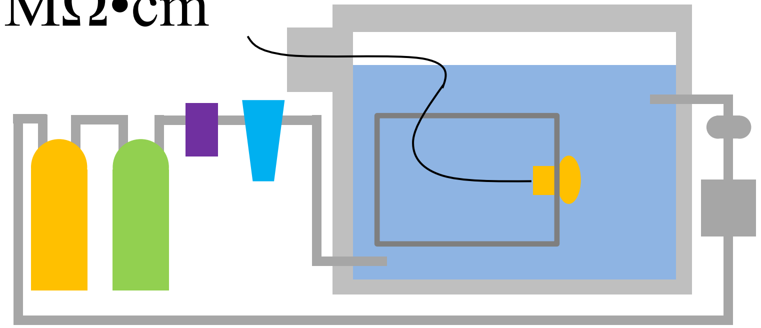
Baseline design
- >3000 units
- 3-inch PMTs + 30cm x 30cm WLS plate
- Tyvek reflector sheets

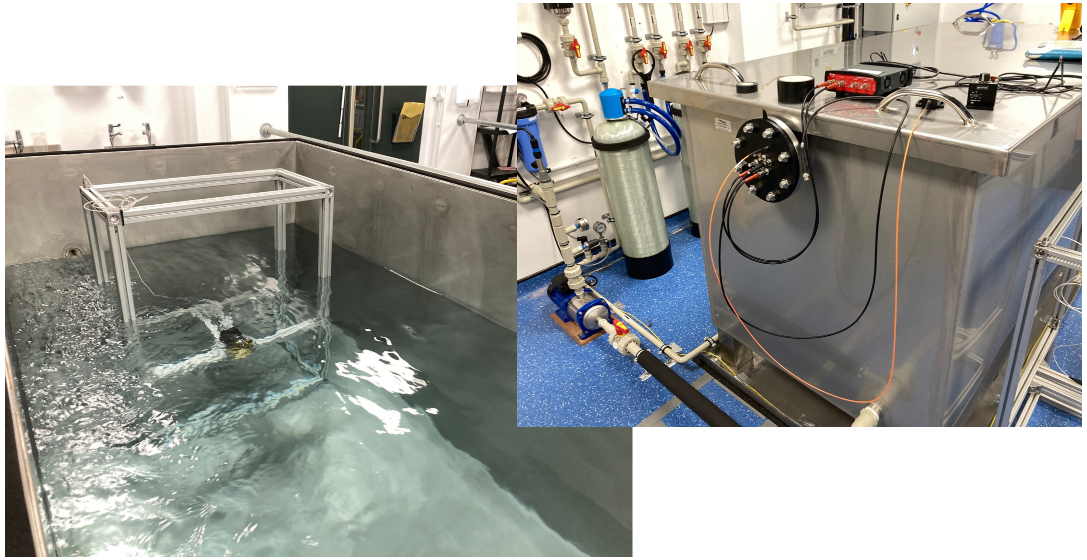


Hyper-K OD system tests at King's College London

King's ultrapure water system

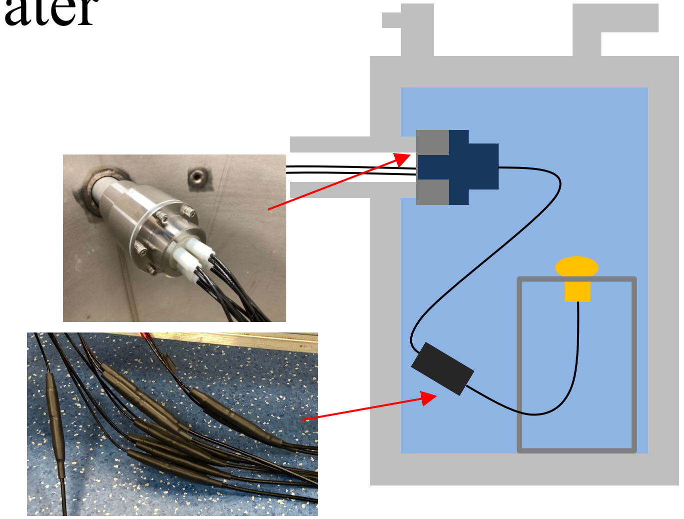
- 2000 L ultrapure system
- Purity, 16(out)-18(in) MΩ•cm

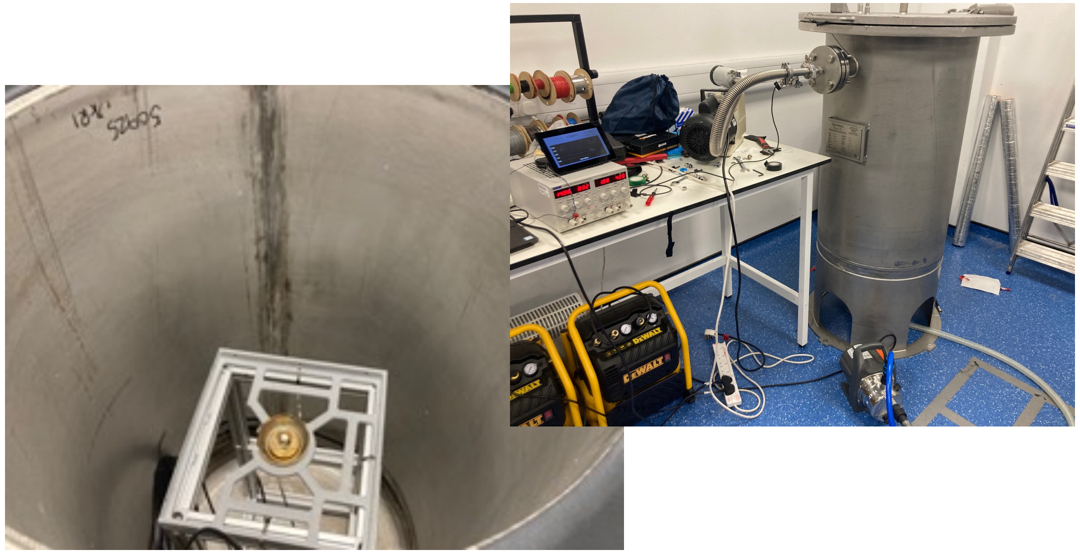




King's pressure vessel

- 300 L tank up to 10 bar
- Pressurize with air or water





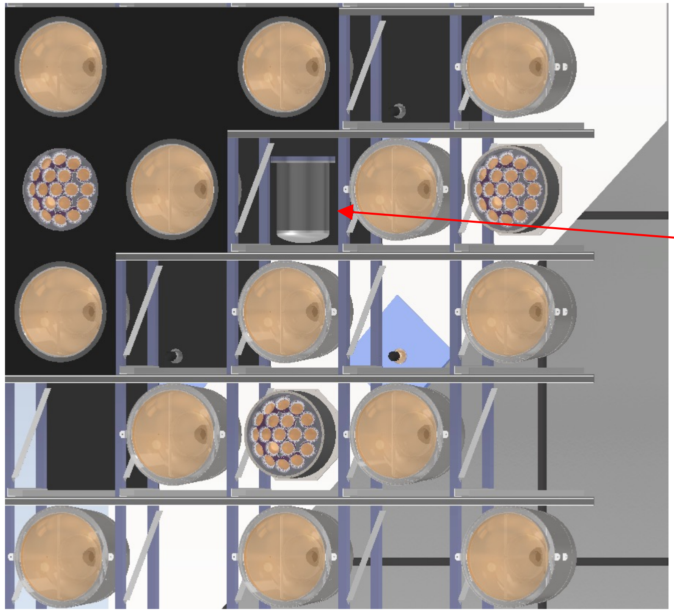
Ageing test
Tyvek reflectivity test
Component pressure test
etc

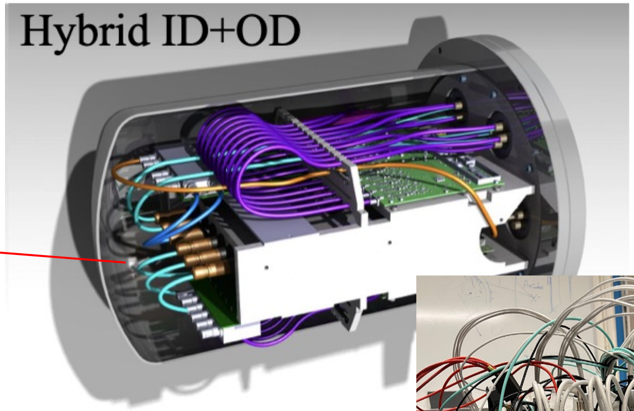
Hyper-Kamiokande

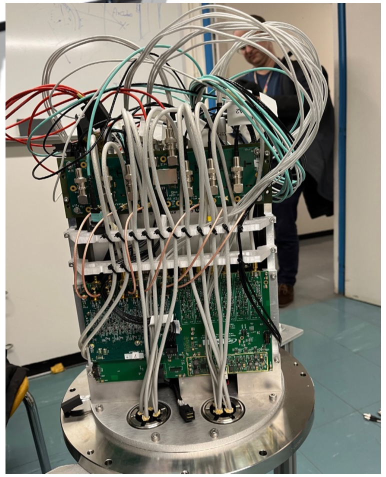
Hyper-K underwater electronics

Underwater electronics

- Digitizers, HV power supply etc in electronics vessel
- Underwater cable connection, feedthroughs (~8 bar)
- 2 main test sites: Kamioka and CERN

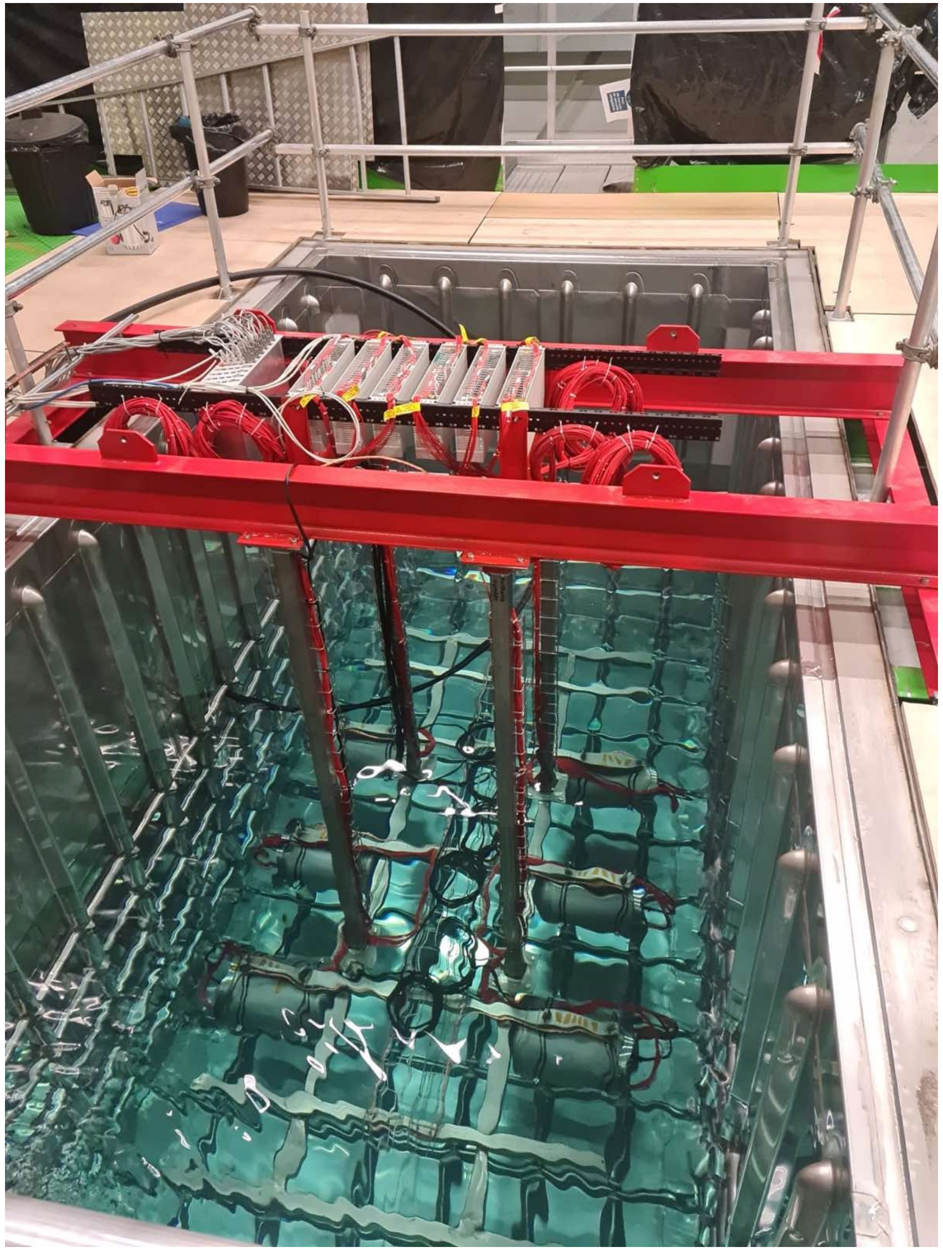






CERN electronics prototype

CERN electronics vessel underwater test

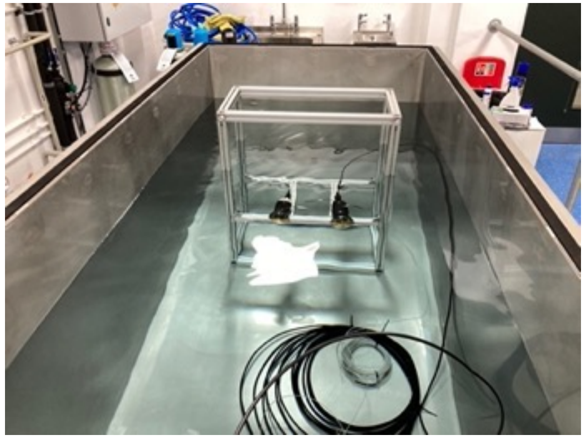


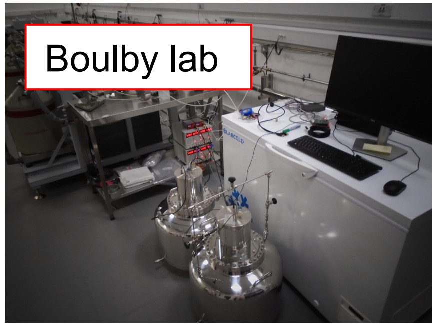
Hyper-K material screening

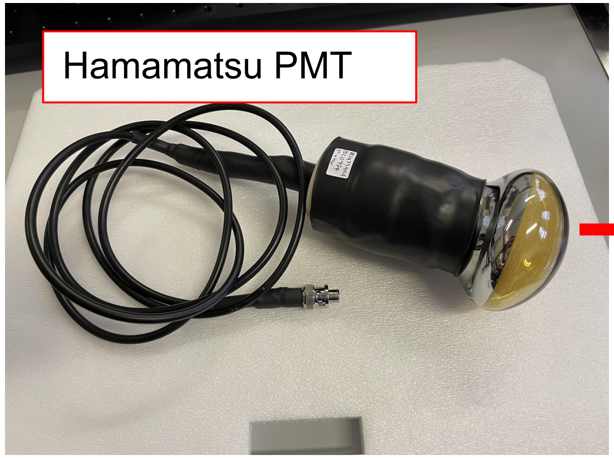
Soak tests
- UV transparency scaled to HyperK volume

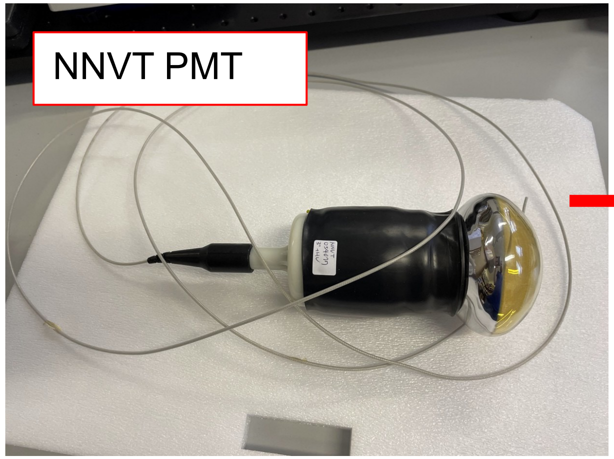
Radioactivity screening tests
- Boulby Underground Lab

Aging test
- Ultrapure water system









Hyper-K integration

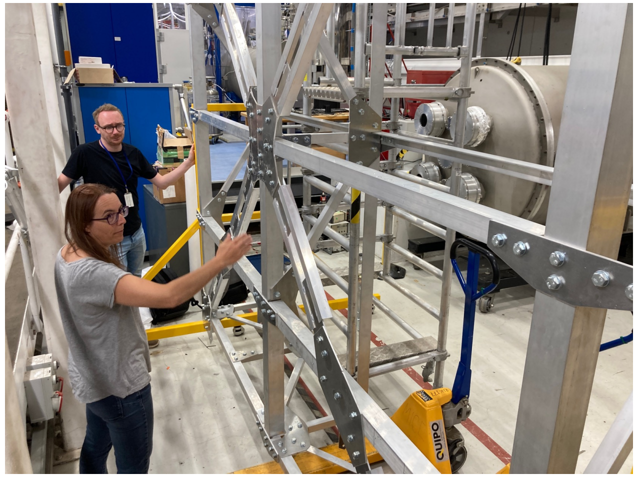
All working group installation practice

- Raised many (minor) issues
- Second installation practice soon

OD installation

- OD PMT unit
- Tyvek installation (very time consuming)

HyperK installation practice frame
(ICRR, Japan)



UK installation practice frame
(Rutherford Appleton Lab, UK)

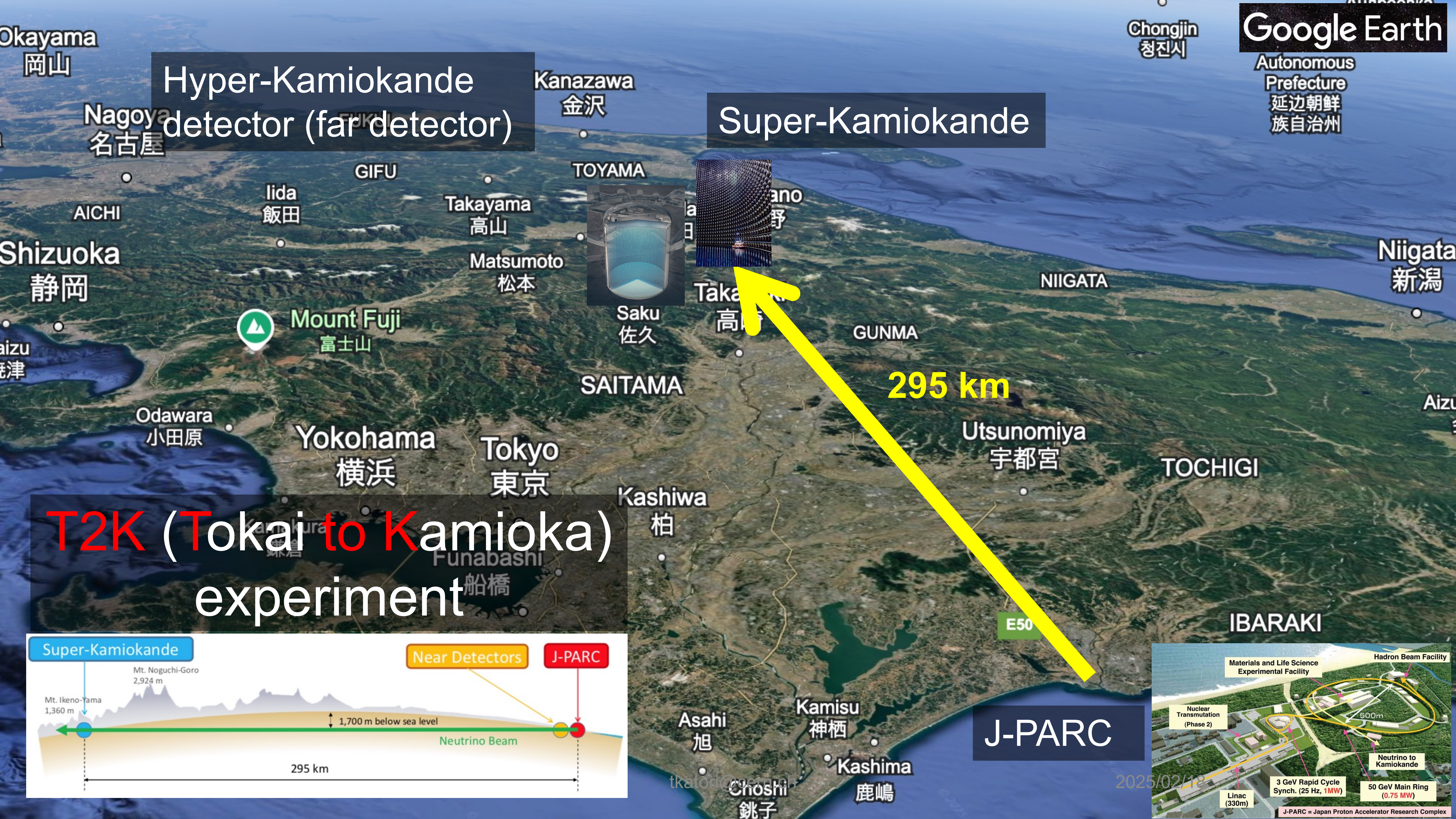
1. Detector construction

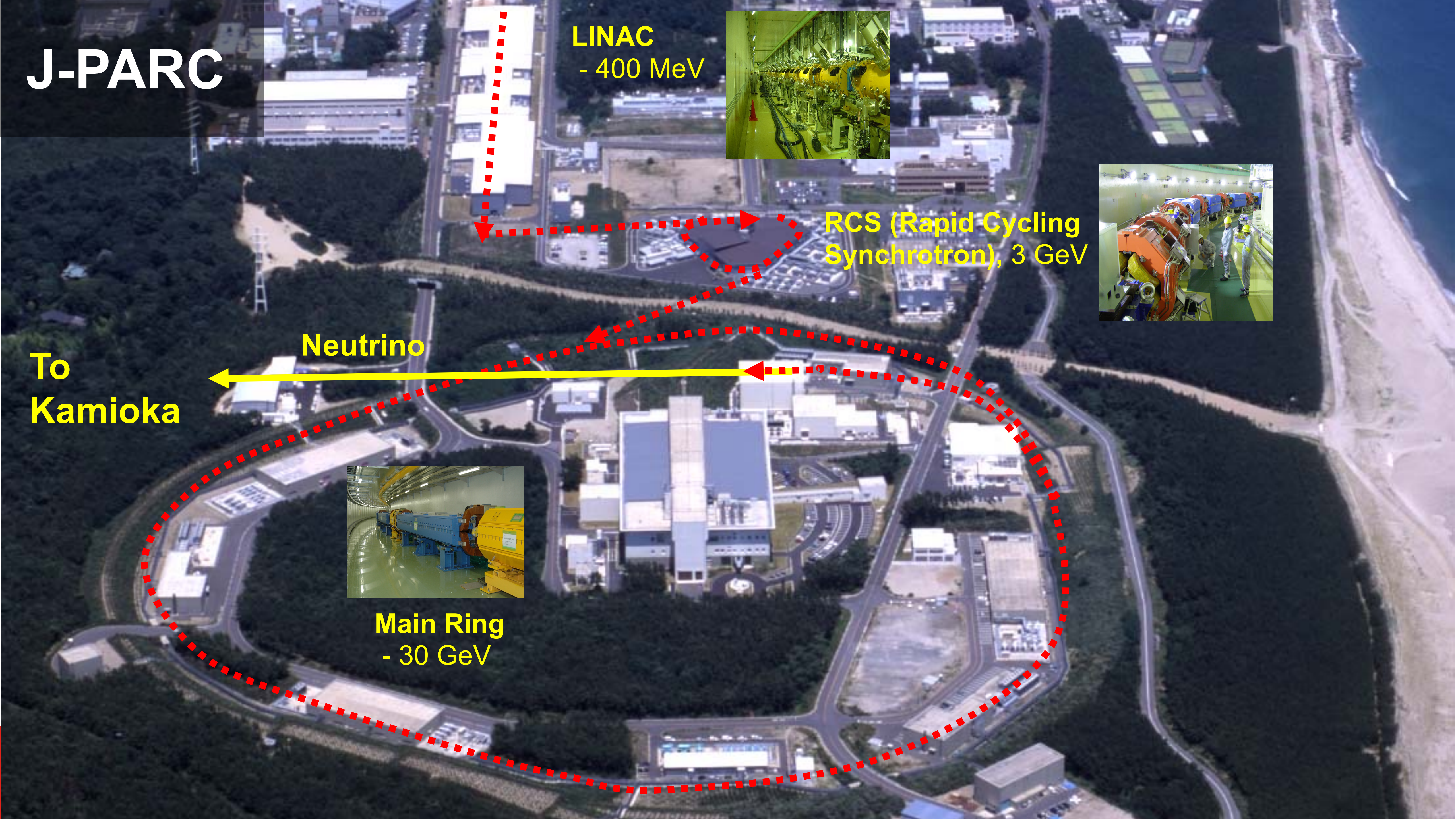
2. HyperK detector system

3. J-PARC beam upgrade

4. Near detectors

5. Hyper-Kamiokande physics


Hyper-Kamiokande detector (far detector)
Super-Kamiokande
295 km
T2K (Tokai to Kamioka) experiment
J-PARC
Google Earth
Okayama
岡山
Nagoya
名古屋
Kanazawa
金沢
GIFU
TOYAMA
Iida
飯田
AICHI
Takayama
高山
Matsumoto
松本
Shizuoka
静岡
Mount Fuji
富士山
Saku
佐久
SAITAMA
GUNMA
NIIGATA
Niigata
新潟
Chongjin
청진시
Autonomous Prefecture
延边朝鲜族自治州
Odawara
小田原
Yokohama
横浜
Tokyo
東京
Kashiwa
柏
Funabashi
船橋
Utsunomiya
宇都宮
TOCHIGI
IBARAKI
E50
Asahi
旭
Kamisu
神栖
Kashima
鹿嶋
Choshi
銚子
Super-Kamiokande
Near Detectors
J-PARC
Mt. Noguchi-Goro
2,924 m
Mt. Ikeno-Yama
1,360 m
1,700 m below sea level
Neutrino Beam
295 km
Materials and Life Science Experimental Facility
Hadron Beam Facility
Nuclear Transmutation (Phase 2)
500m
Neutrino to Kamiokande
3 GeV Rapid Cycle Synch. (25 Hz, 1MW)
50 GeV Main Ring (0.75 MW)
Linac (330m)
J-PARC = Japan Proton Accelerator Research Complex
tkatori@cern.ch
2025/02/18


J-PARC
LINAC
- 400 MeV
RCS (Rapid Cycling
Synchrotron), 3 GeV
Neutrino
To
Kamioka
Main Ring
- 30 GeV

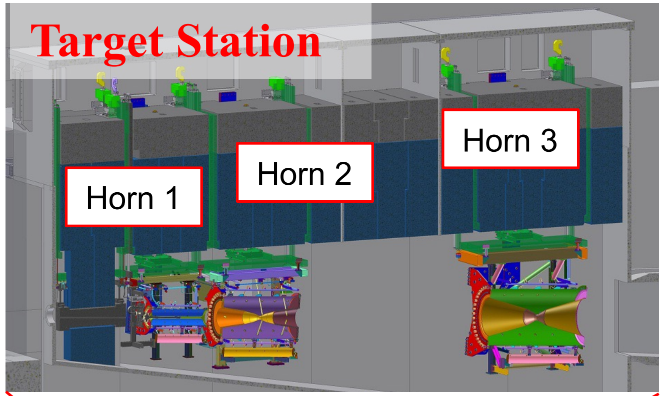
T2K, PRD87(2013)012001, NIMA789(2015)57, NA61/SHINE, EPJC76(2016)84

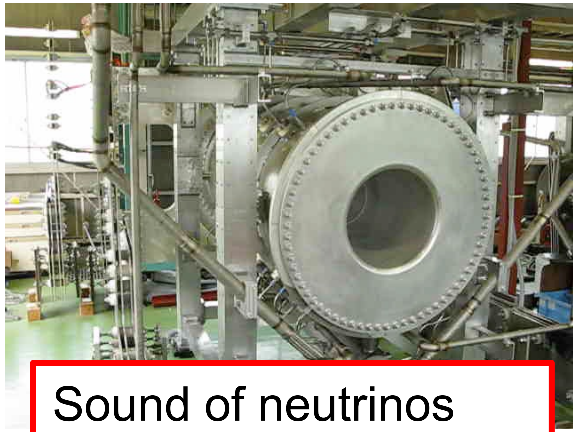
J-PARC Neutrino beamline

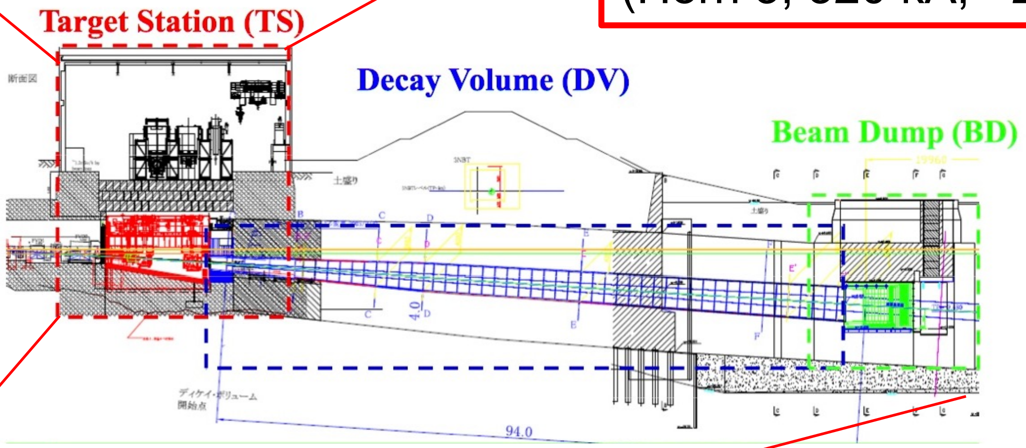
Primary beamline (protons)
- 30 GeV protons are extracted from MR

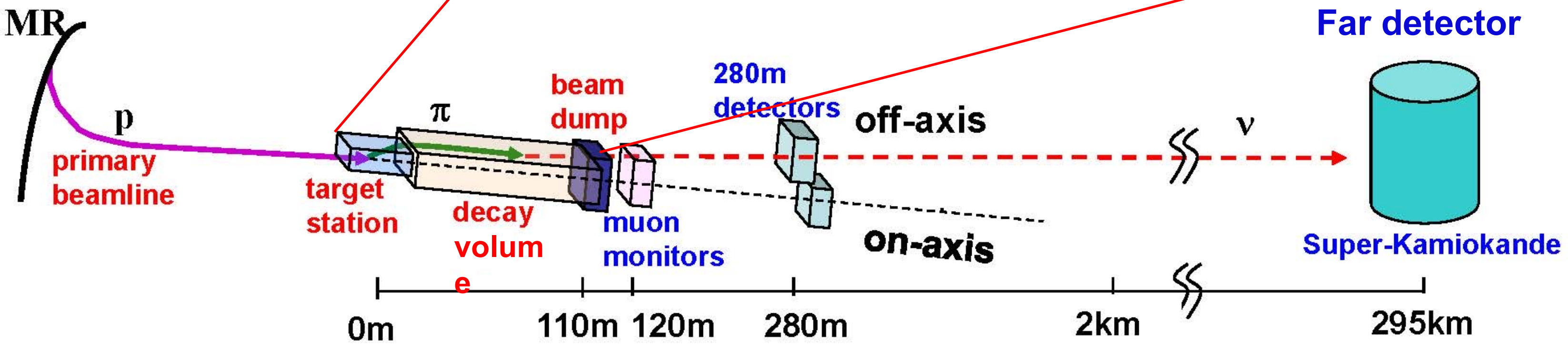
Secondary beamline (mesons)
- 3 magnetic horns |(flux x15)
- Hadron production tuned to NA61/SHINE data

Tertiary beamline (neutrinos)
- ~15 years of operation experience (ΔΦ~5%)









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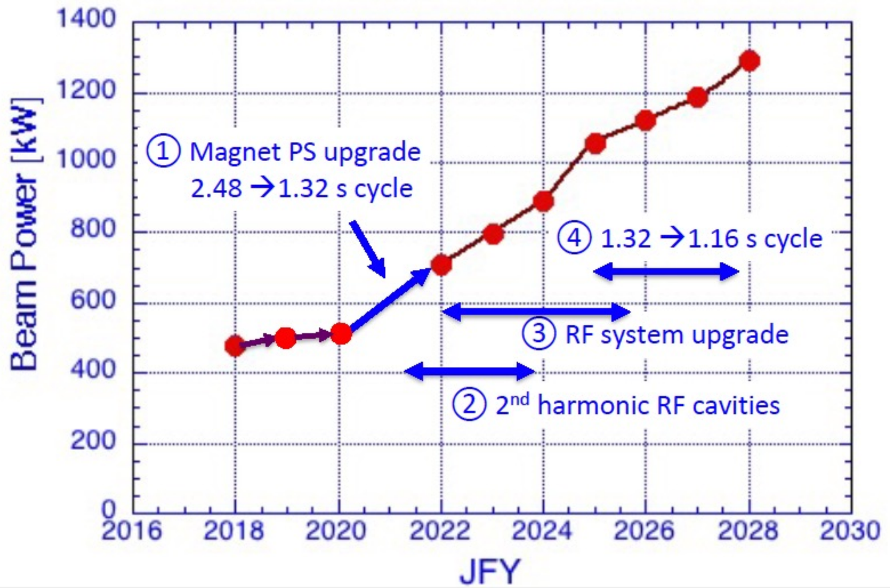
Hyper-Kamiokande

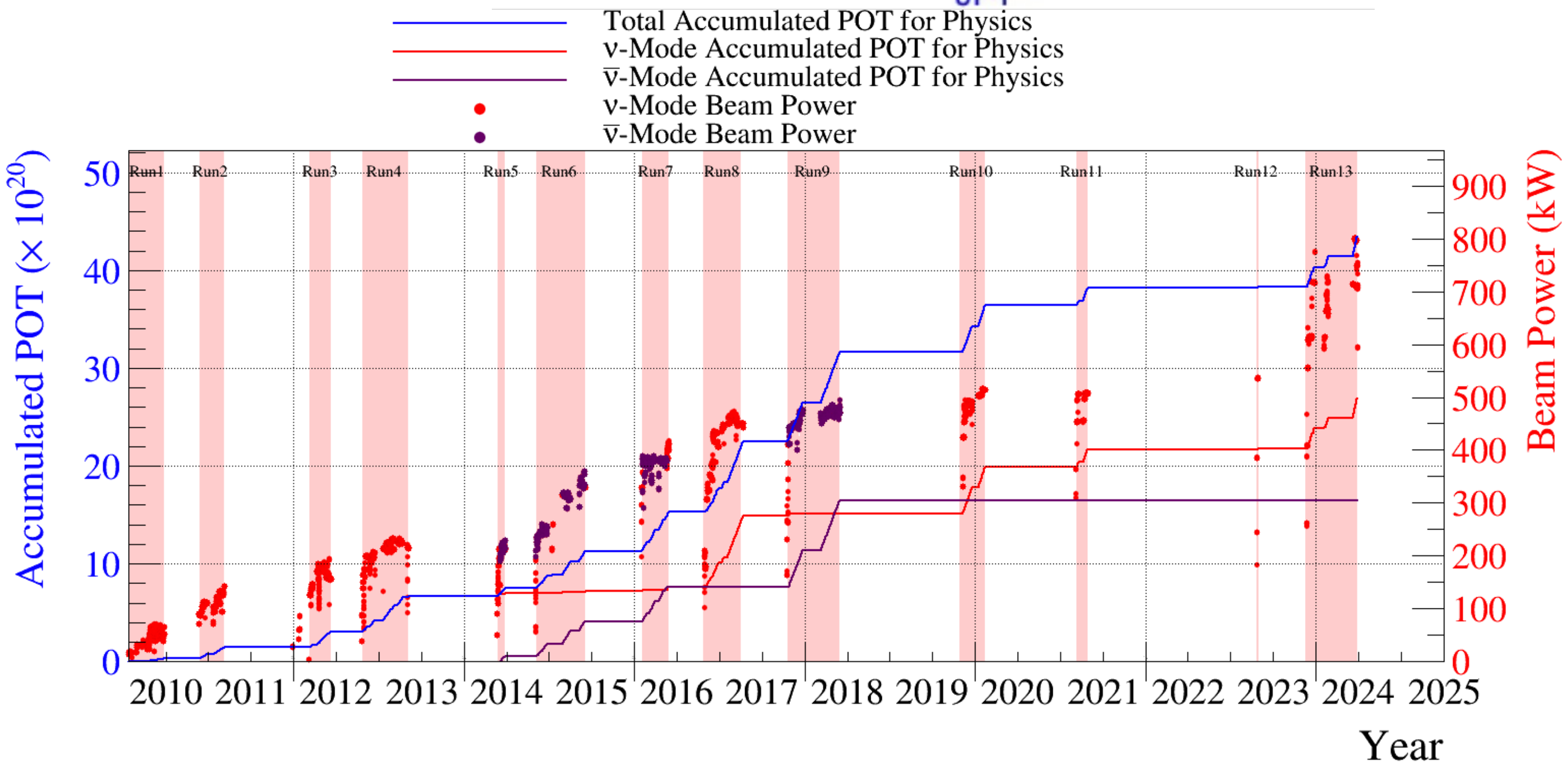
T2K, Arxiv:1908.05141

J-PARC Beam Upgrade



Key improvements

- Horn current 250kA → 320 kA (now)
- Cycle 2.48s → 1.36s (now) → 1.16s
- Proton per pulse 2.6E14ppp → 3.2E14ppp



Power: 515kW

→ 800kW (now)

→ 1.3MW (2027)

Hyper-Kamiokande

1. Detector construction

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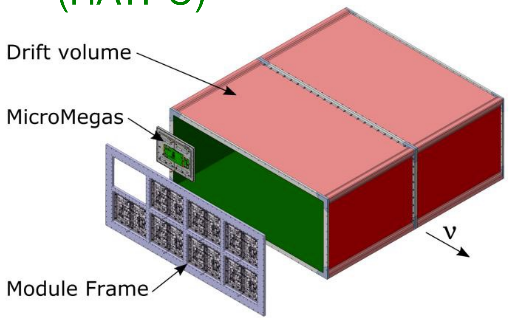
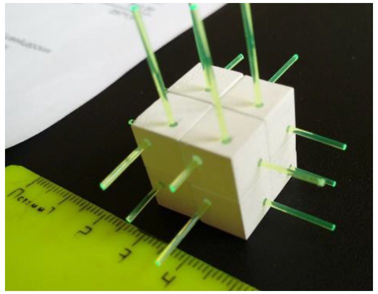
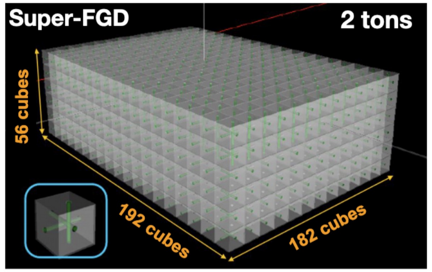
ND280 Upgrade

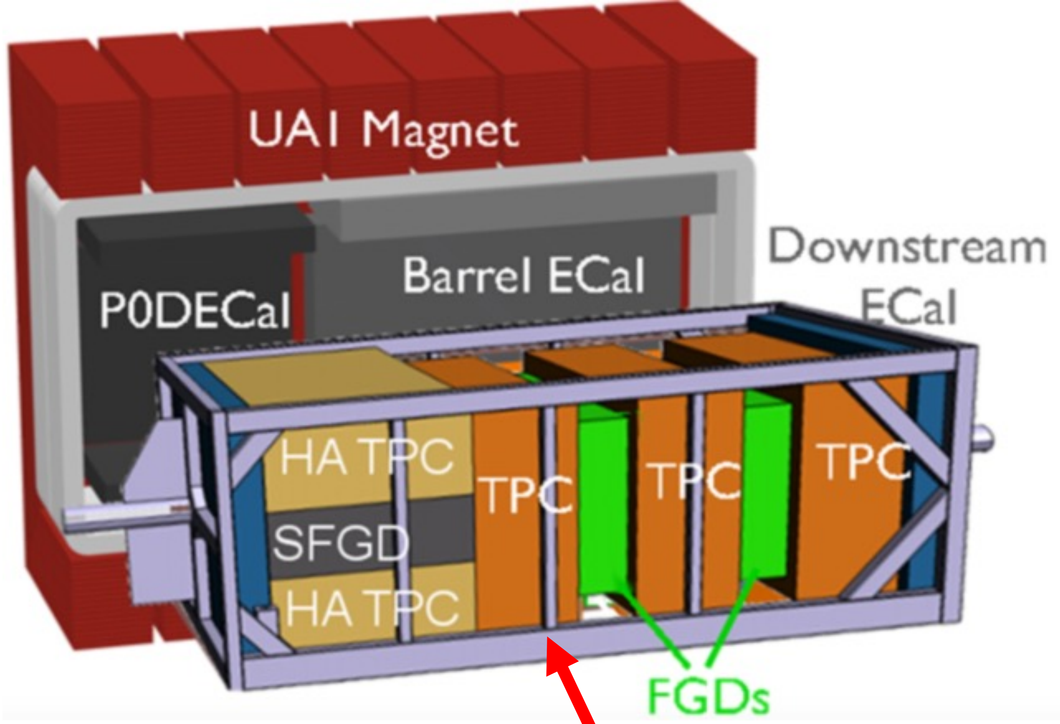
ND280 Upgrade
- Out: P0D detector
- In: High angle TPC (HATPC)
- In: SuperFGD



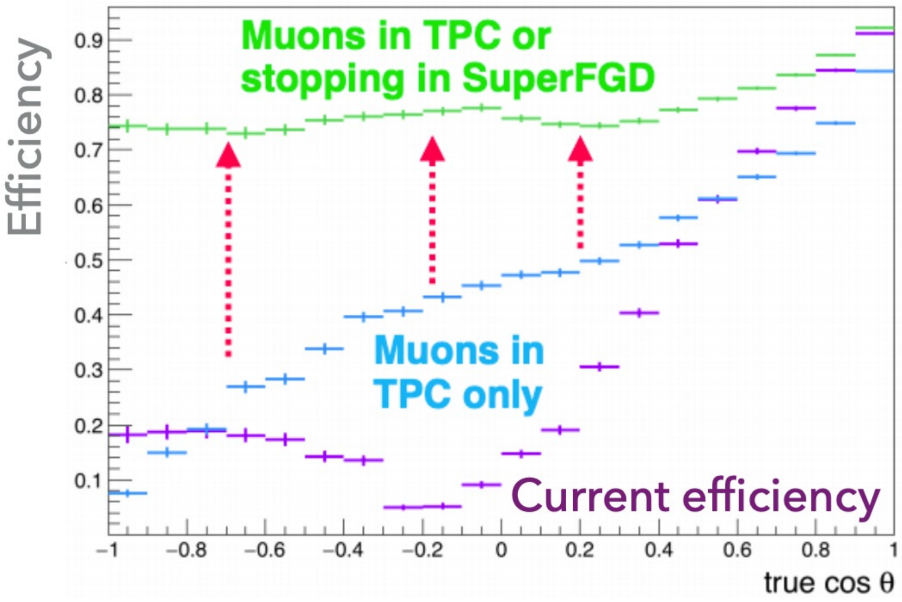


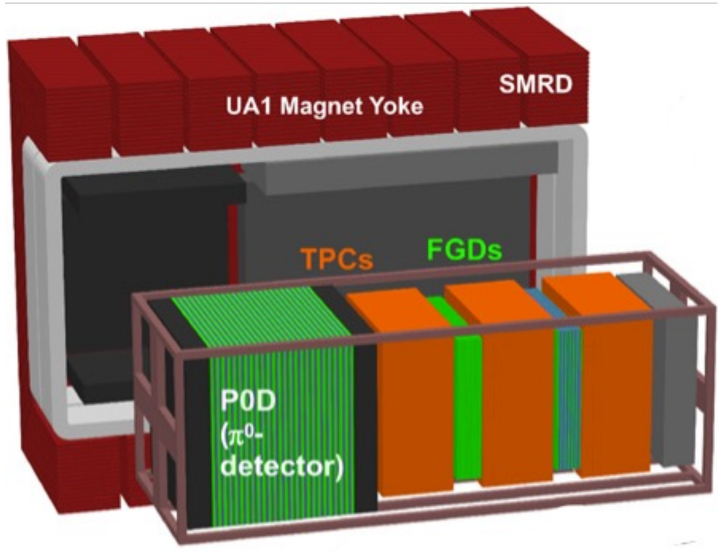
SuperFGD
(SFGD)





- Hyper-K is a 4π detector, larger acceptance of near detector is necessary
- Lower proton threshold to understand nuclear effects





Physics Letters B 840 (2023) 137843
JINST15 (2020) P12003

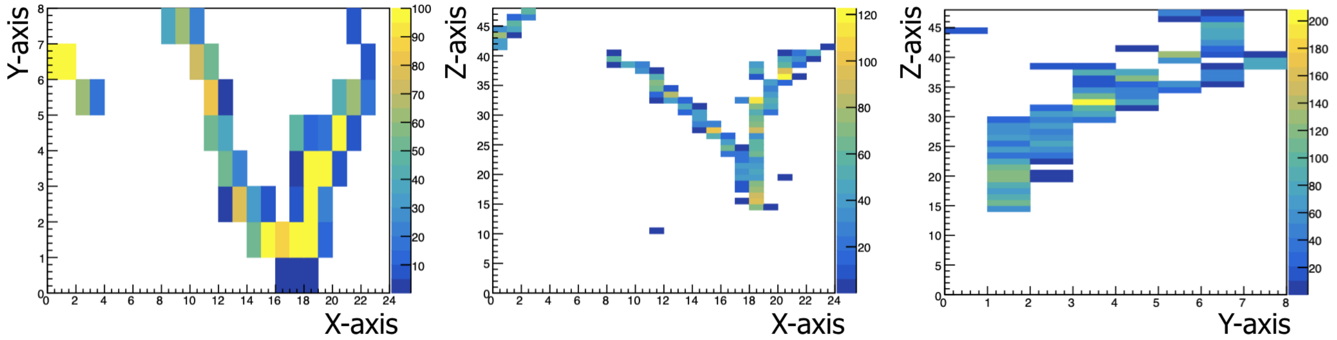
ND280 Upgrade

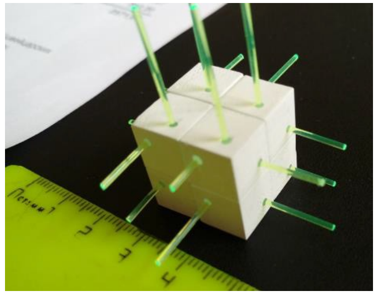
ND280 Upgrade
- Out: P0D detector
- In: High angle TPC (HATPC)
- In: SuperFGD

SuperFGD prototype beam test
- LANL neutron xs measurement
- CERN track reconstruction

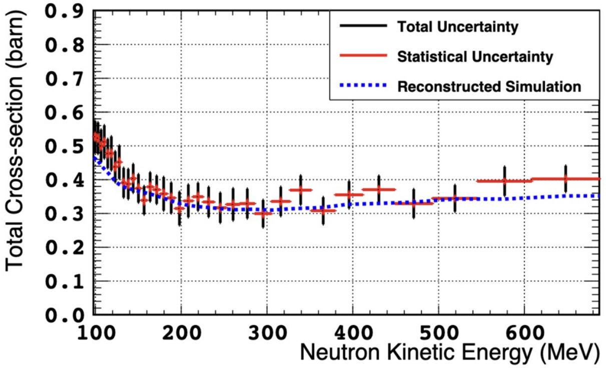
Installation
- labour-intensive assembly
- Neutrino data!

CERN beam test pair production

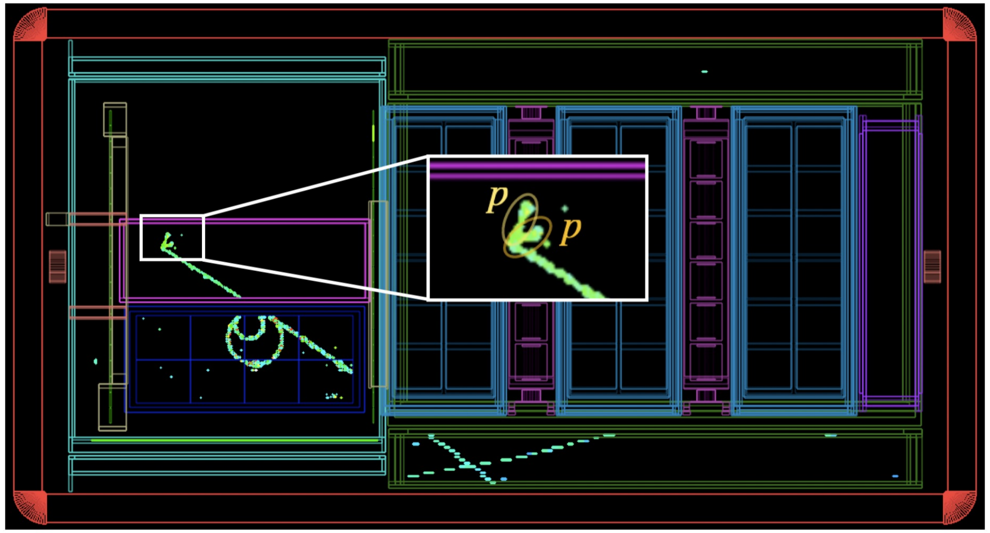




Total carbon-neutron cross-section



Neutrino even candidate



Hyper-Kamiokande

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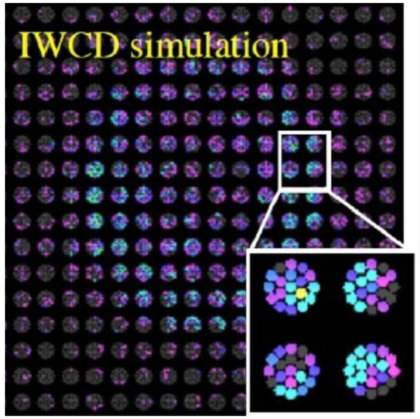
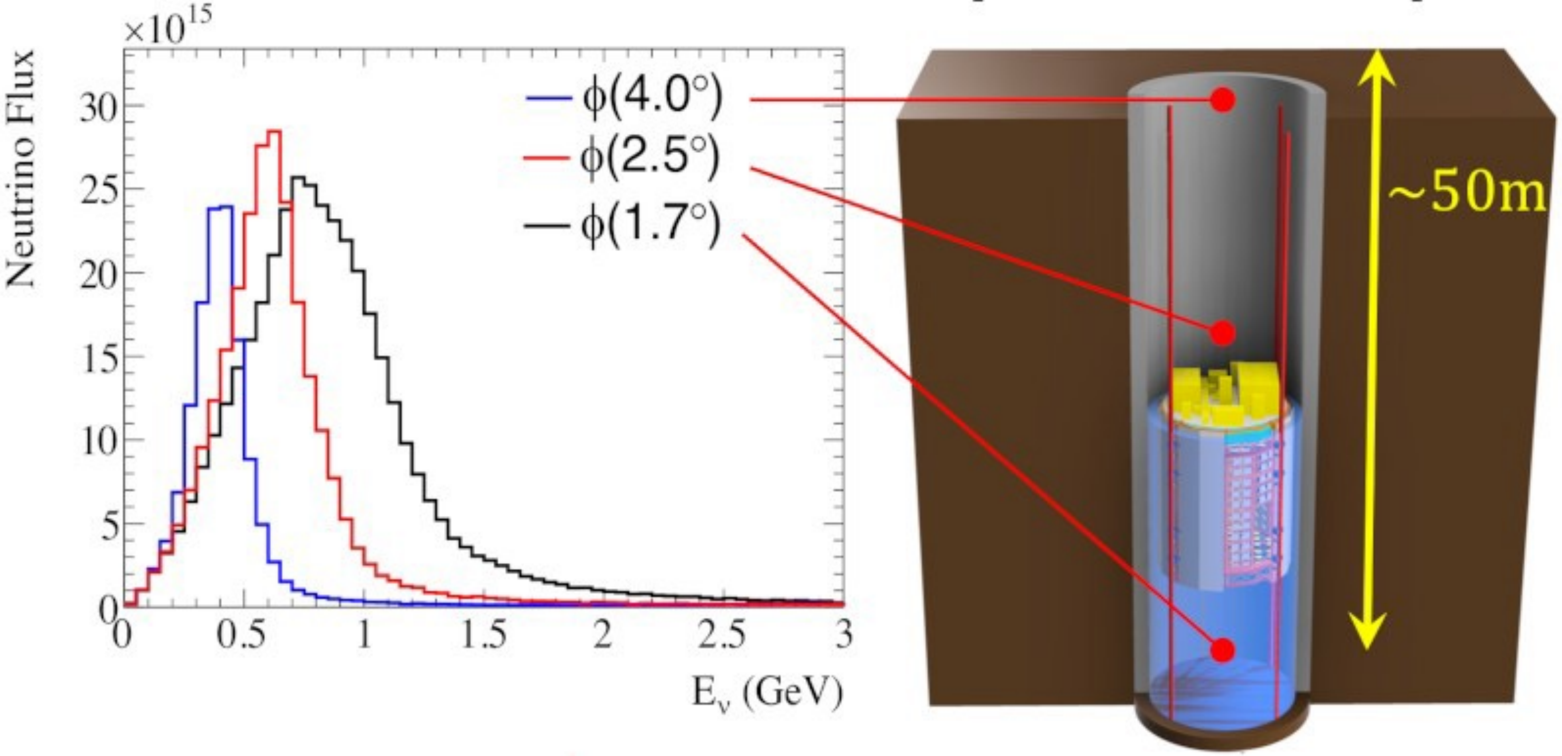
IWCD

Intermediate Water Cherenkov Detector
- nuPRISM concept, ~1km from the target
- KM3NeT-inspired mPMT unit
- Machine learning-based reconstruction

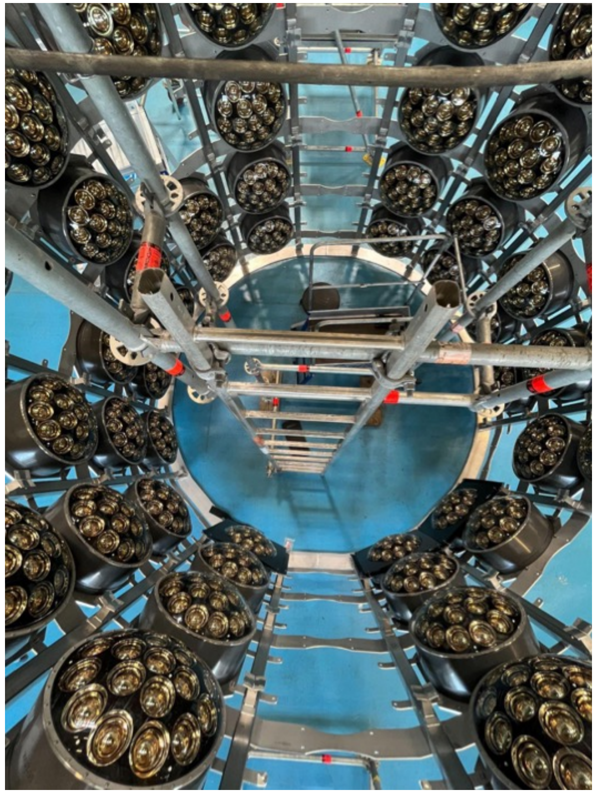


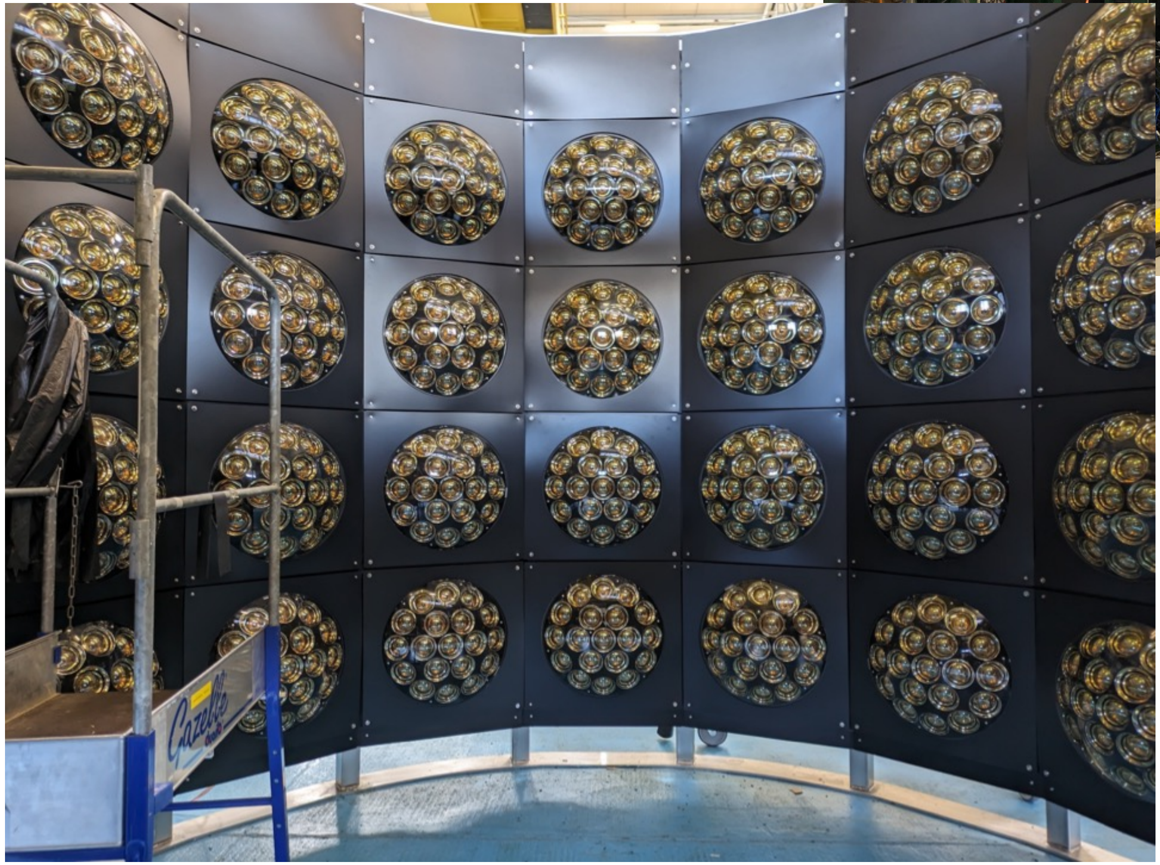


WCTE

Water Cherenkov Test Experiment

- CERN T9 beamline, 0.1-1.1 GeV/c of e, μ, π, p
- ~100 mPMTs to test performance





Hyper-Kamiokande

1. Detector construction

2. HyperK detector system

3. J-PARC beam upgrade

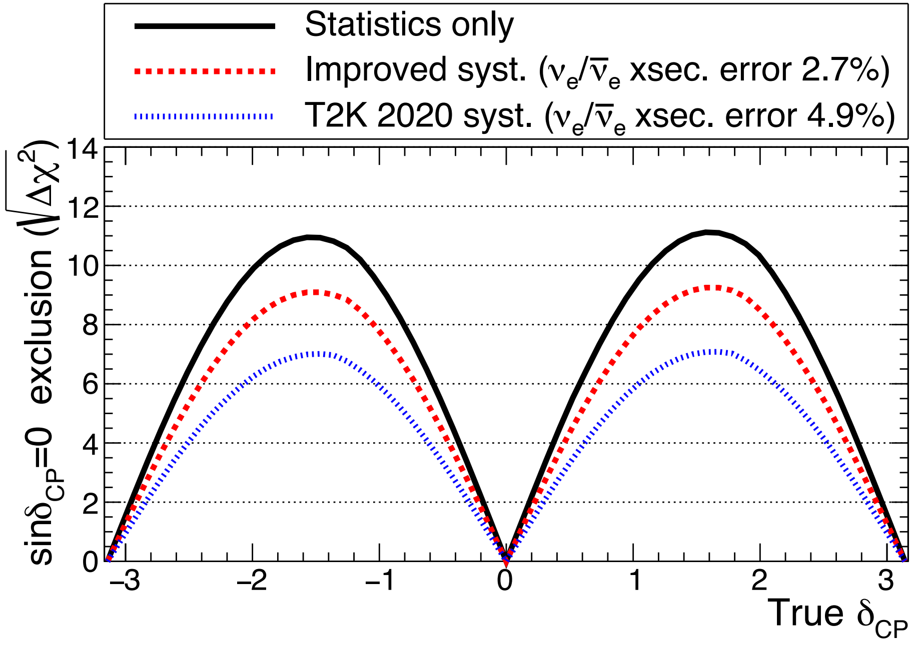
4. Near detectors

5. Hyper-Kamiokande physics

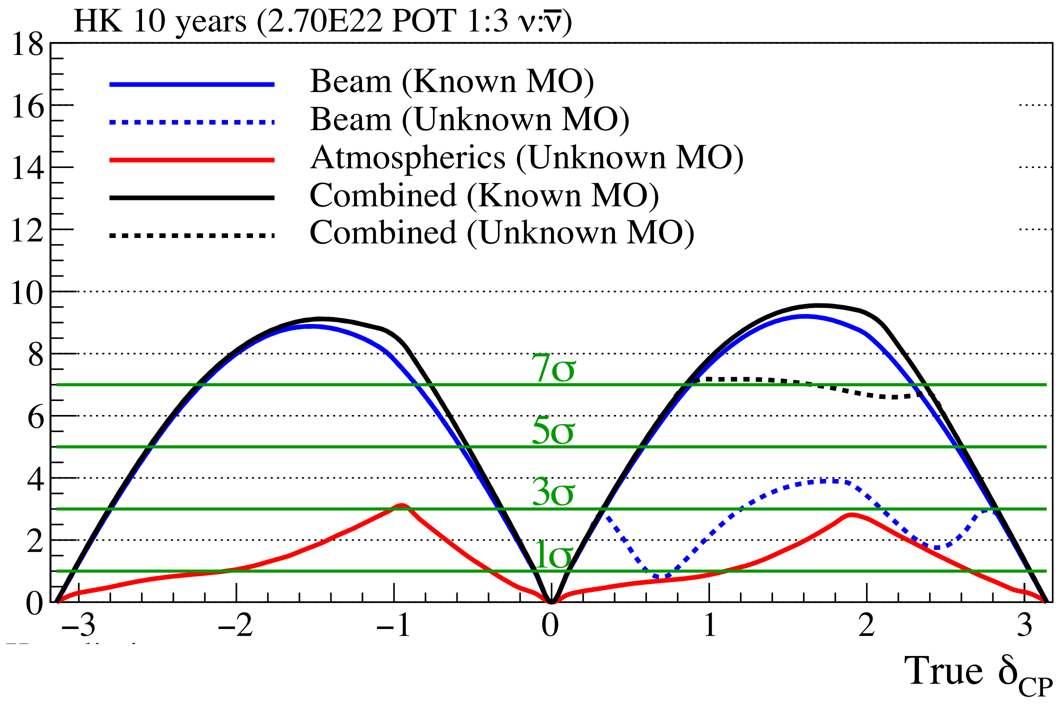
Hyper-K physics sensitivities

Neutrino oscillation physics

- x20 higher statistics of T2K, 10yrs beam data can explore 63% of δ_{CP} values
- Combining with atmospheric neutrino data can break parameter degeneracy



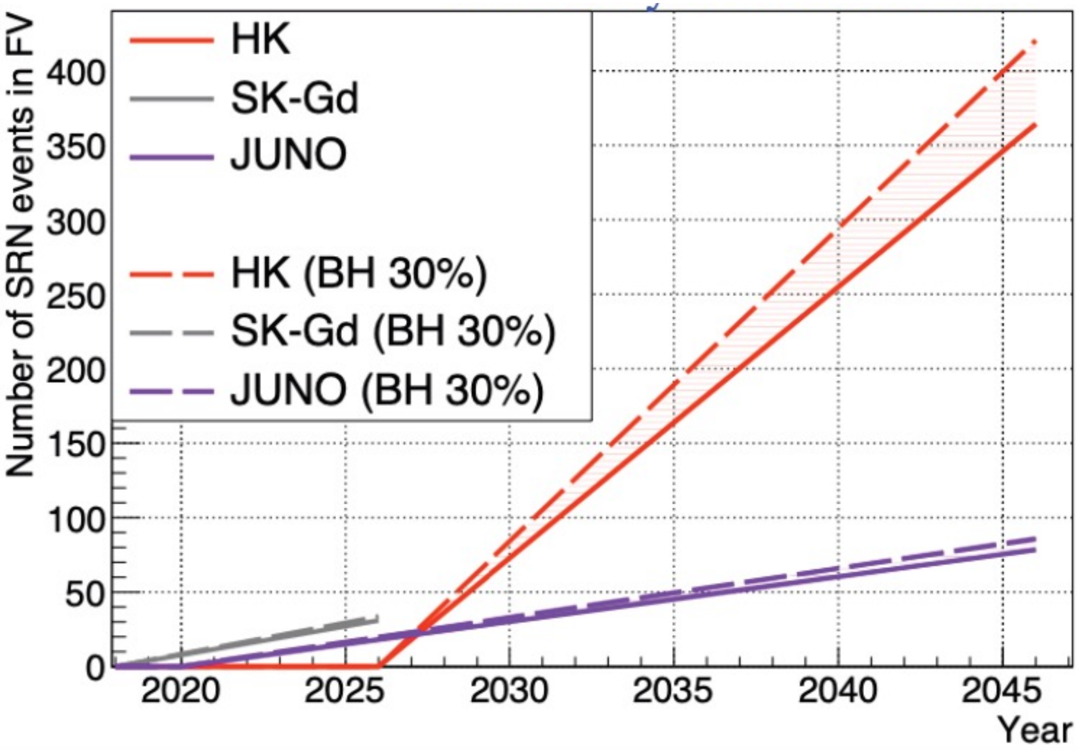
Hyper-K preliminary
True normal ordering (known), 10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)

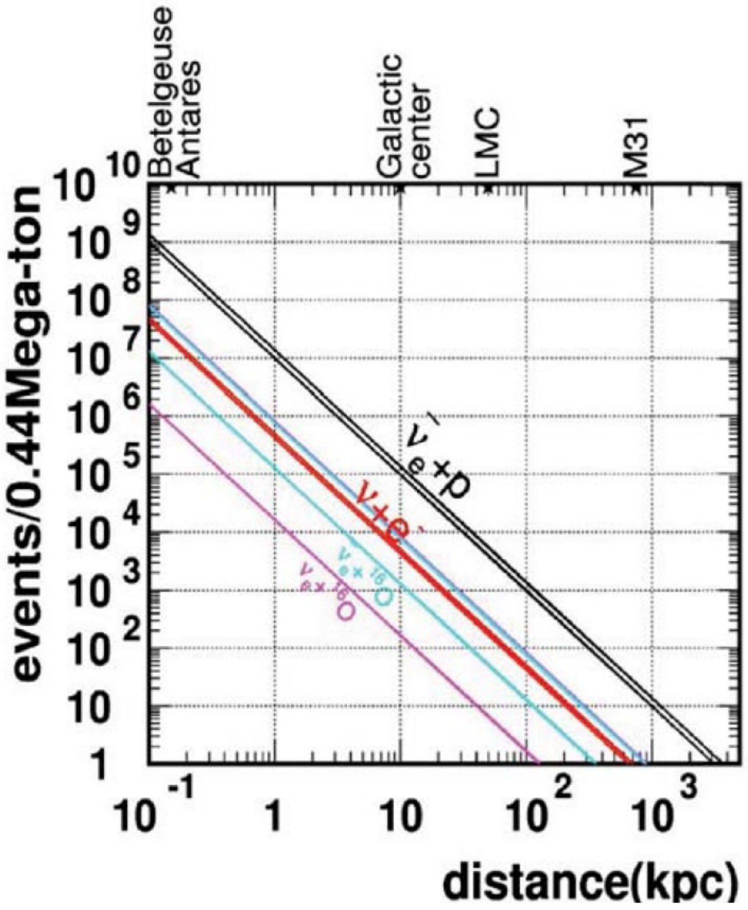


Hyper-K physics sensitivities

Supernova neutrinos

- Core collapse supernova neutrinos. ~70k at 10kpc
- Andromeda is within the range
- Diffuse supernova neutrino background ~ 4 events/yr



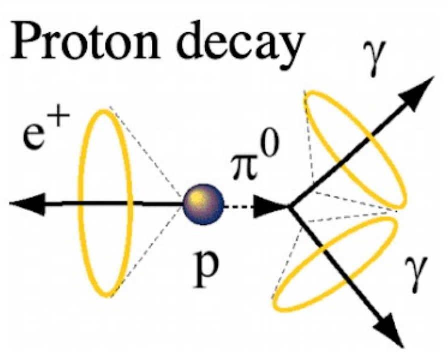


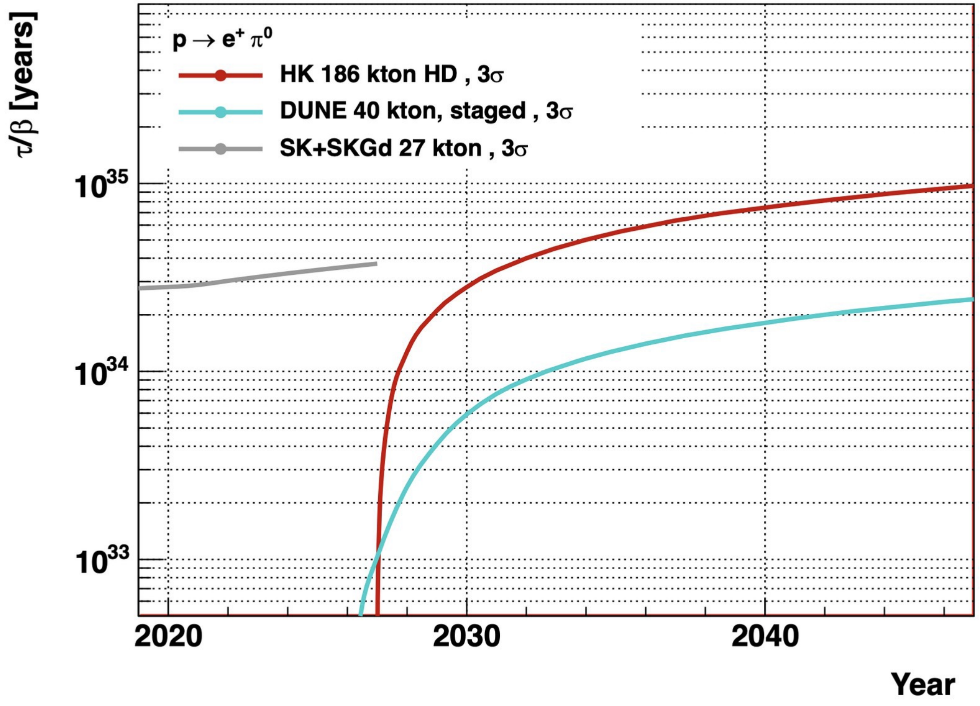
Hyper-K physics sensitivities

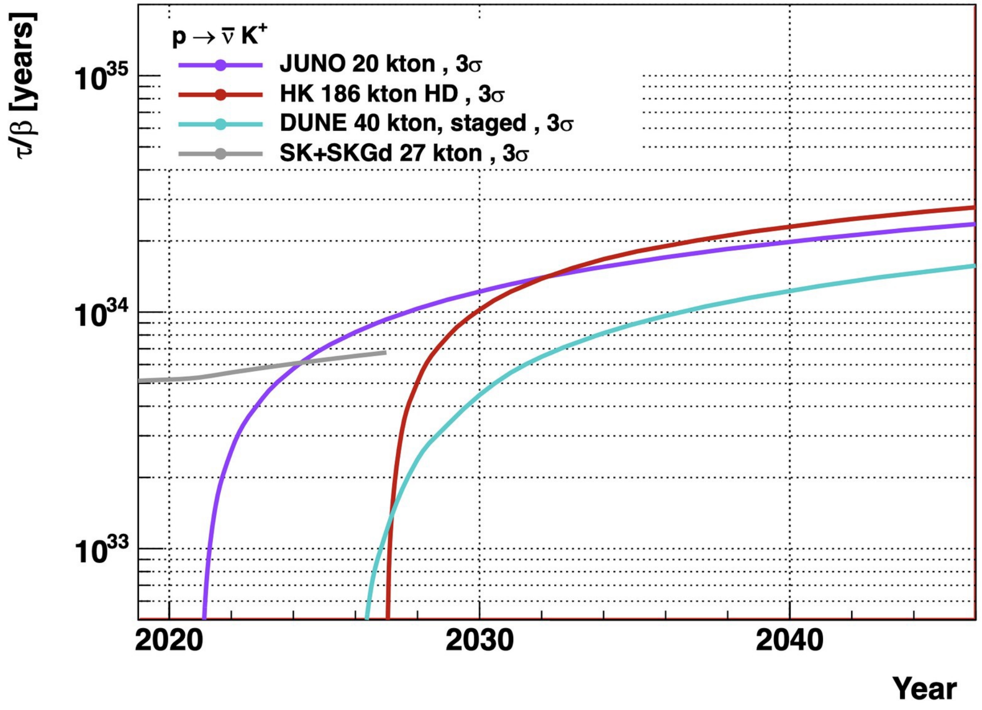
Mode	Sensitivity (90% CL) [years]	Current limit [years]
$p \to e^+\pi^0$	7.8×10^{34}	1.6×10^{34}
$p \to \bar{\nu}K^+$	3.2×10^{34}	0.7×10^{34}
$p \to \mu^+\pi^0$	7.7×10^{34}	0.77×10^{34}
$p \to e^+\eta^0$	4.3×10^{34}	1.0×10^{34}
$p \to \mu^+\eta^0$	4.9×10^{34}	0.47×10^{34}
$p \to e^+\rho^0$	0.63×10^{34}	0.07×10^{34}
$p \to \mu^+\rho^0$	0.22×10^{34}	0.06×10^{34}
$p \to e^+\omega^0$	0.86×10^{34}	0.16×10^{34}
$p \to \mu^+\omega^0$	1.3×10^{34}	0.28×10^{34}
$n \to e^+\pi^-$	2.0×10^{34}	0.53×10^{34}
$n \to \mu^+\pi^-$	1.8×10^{34}	0.35×10^{34}

Proton decay

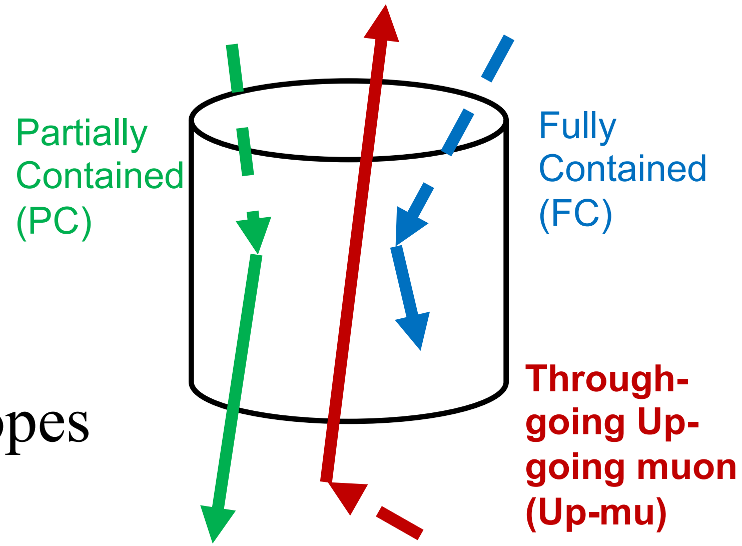
- $p \rightarrow e + \pi^o$: $\sim 6\times10^{34}$ yr (10yr)
- $p \rightarrow \bar{\nu} + K^+$: $\sim 2\times10^{34}$ yr (10yr)
- A lot more channels to explore!





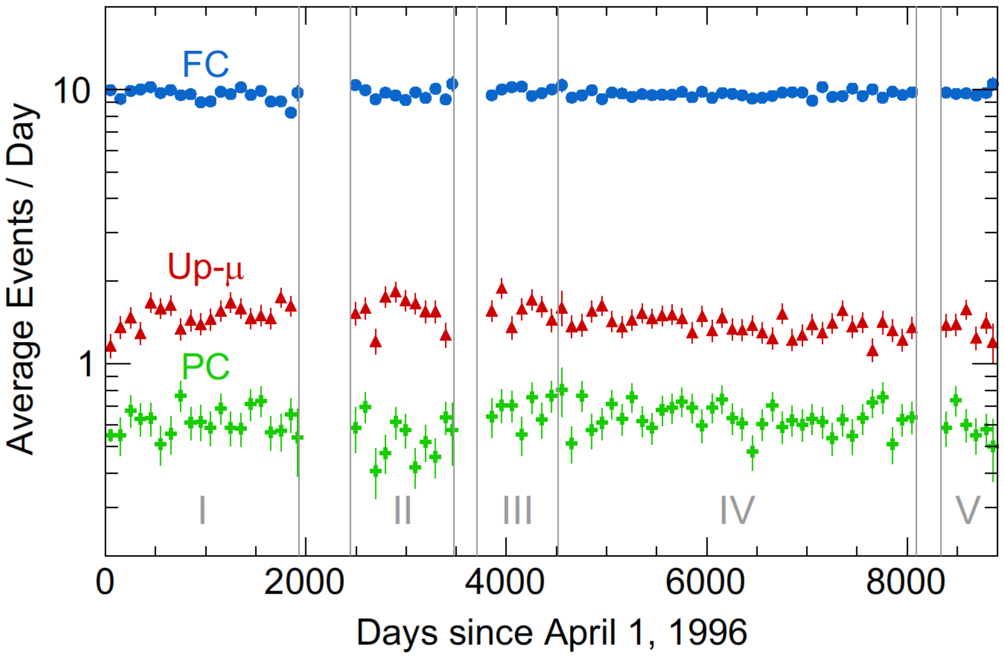


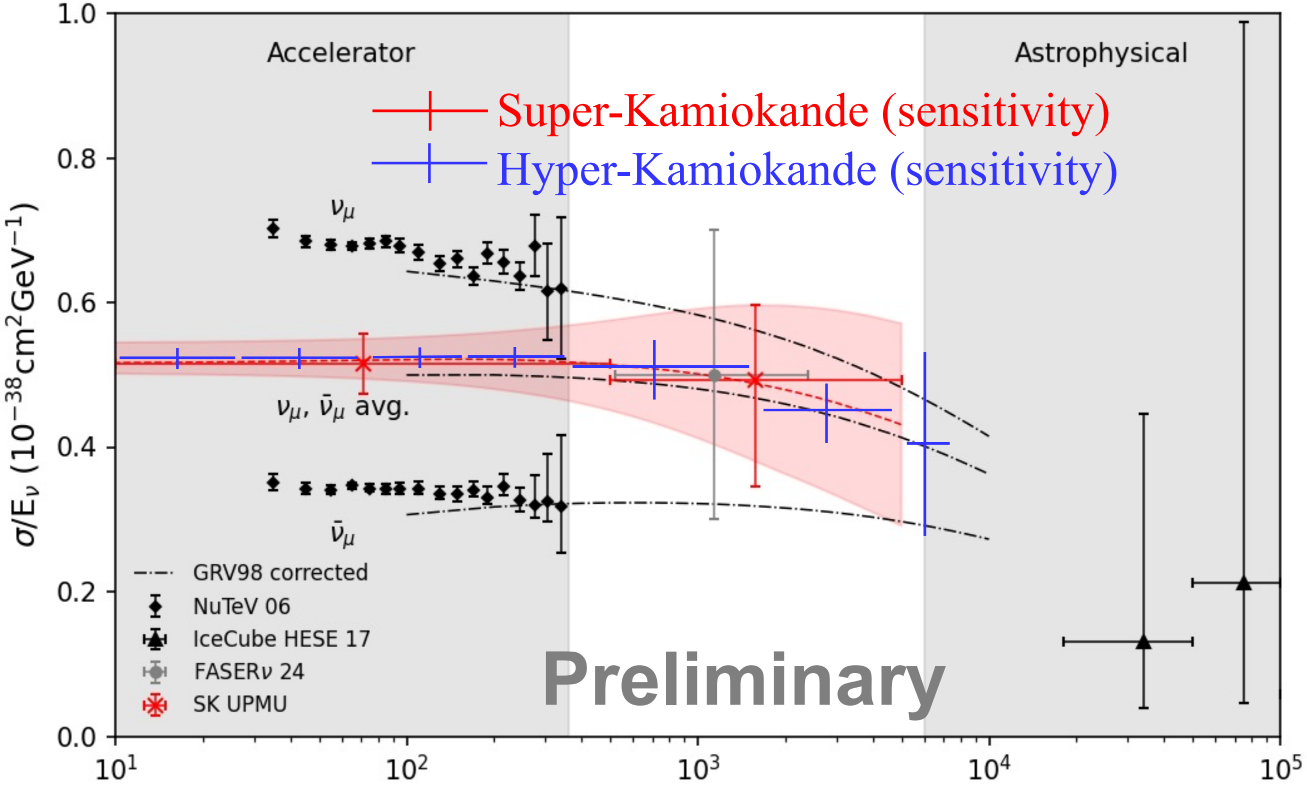
Hyper-K physics sensitivities



High-energy neutrinos

- ~1000 events/yr in TeV region
- Fill the "gap" between accelerator neutrinos and neutrino telescopes
- Prompt neutrinos, galactic plane neutrinos, TeV neutrinos, etc

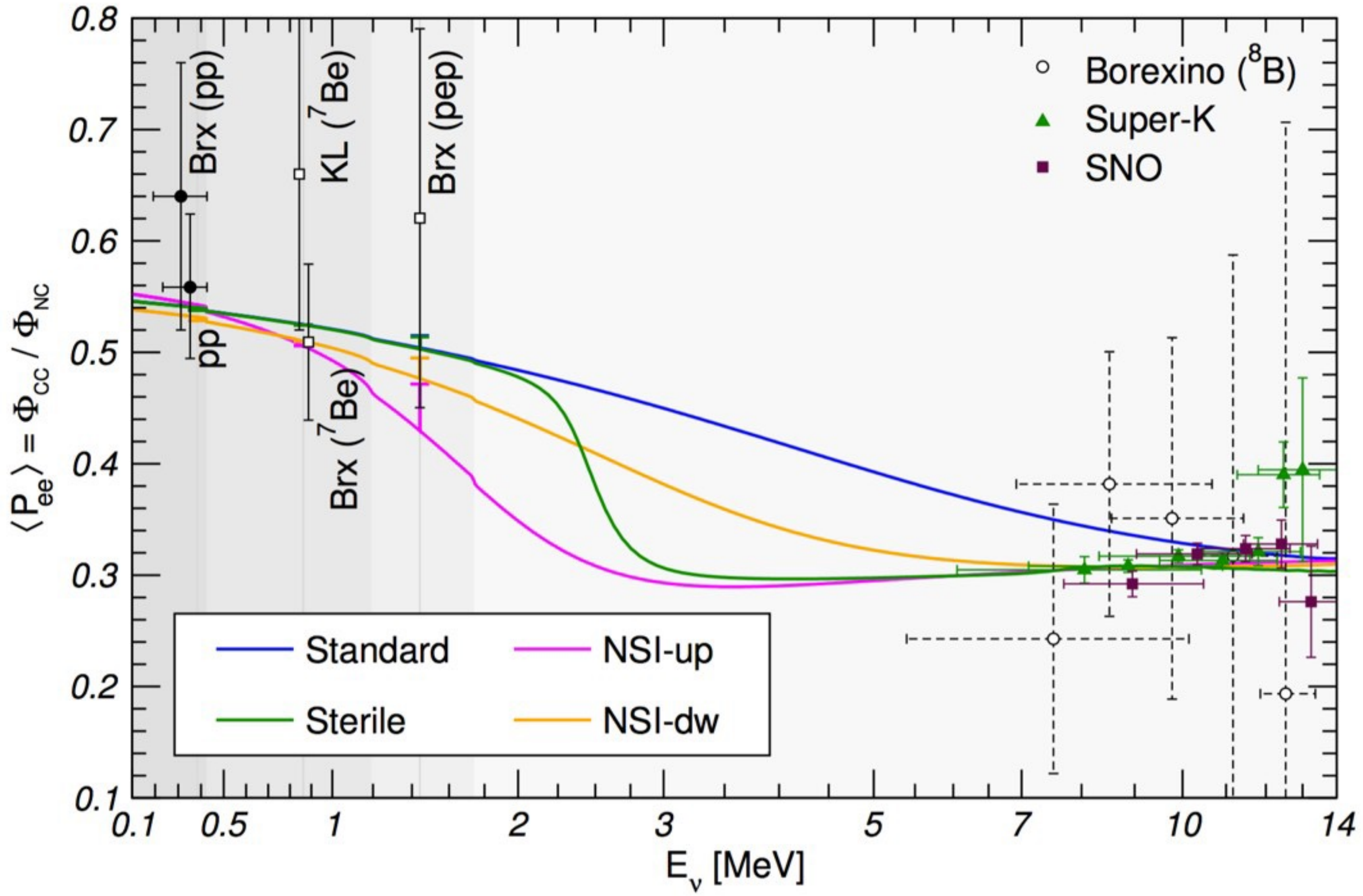




Hyper-K physics sensitivities

Solar neutrinos

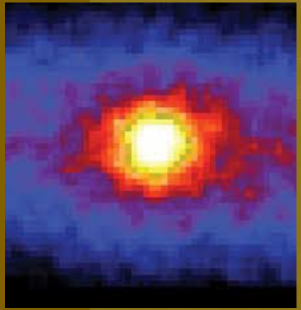
- 3σ sensitivity to upturn, final confirmation of the MSW effect



Hyper-Kamiokande Science

Supernova neutrinos

Solar neutrinos



Reactor neutrinos

Astrophysics

- Cosmic ray physics
- Multi-messenger astronomy

Particle Physics

- Leptonic CP violation
- Neutrino-nucleus

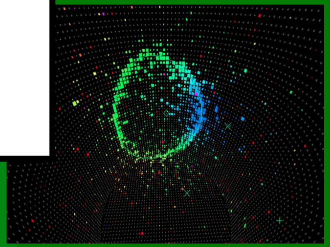
How to discover unknown unknowns???

New physics

- Proton decay
- Dark sector particles
- Indirect DM search
- Unexpected!

Accelerator neutrinos

Atmospheric eutrinos



High-energy astrophysical neutrinos

King's College London | Hyper-Kamiokande

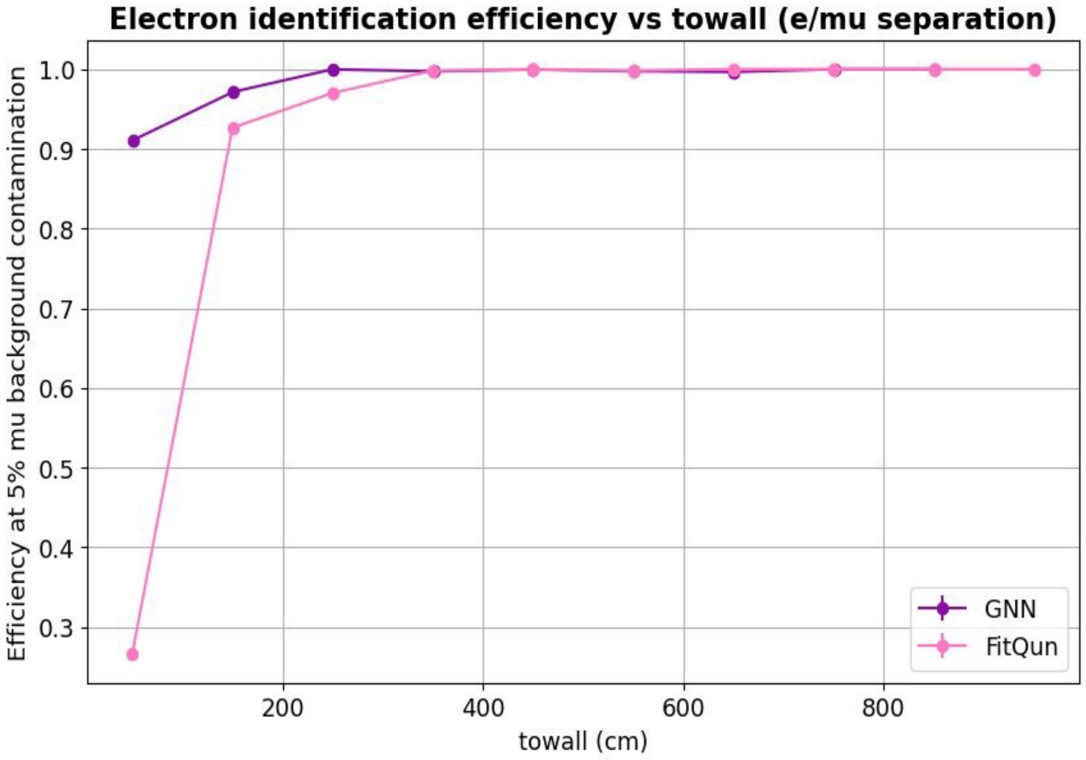
Path forward to unknown unknowns 1 - Machine Learning

WatChMaL
- International working group to develop Machine learning for water Cherenkov detector

fiTQun (SuperK/T2K)
- Likelihood based reconstruction
(LSND → MiniBooNE → SuperK)
- ~1 event/min (CPU)

Machine learning
- CNN is x100 (CPU) or x10000 (GPU) faster
- 2-d (CNN) → 3-d (GNN)
- Better reconstruction resolution
- Better background rejection

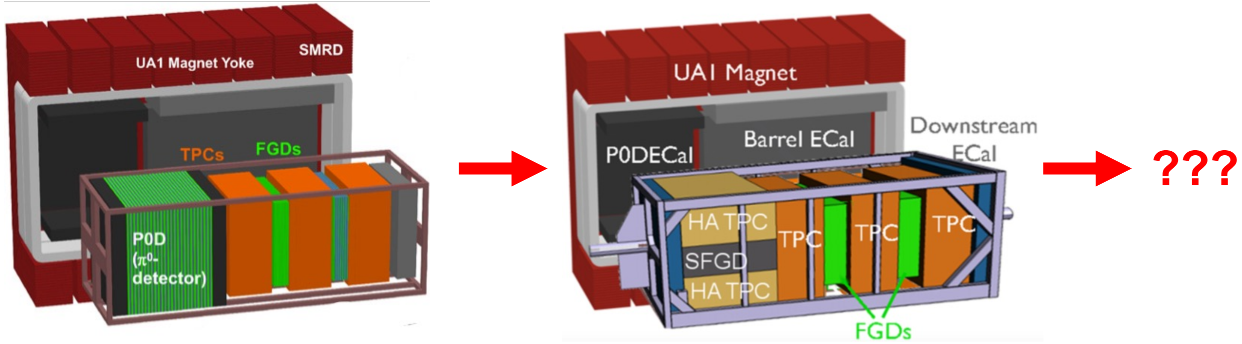
Electron PID efficiency with 95% muon rejection



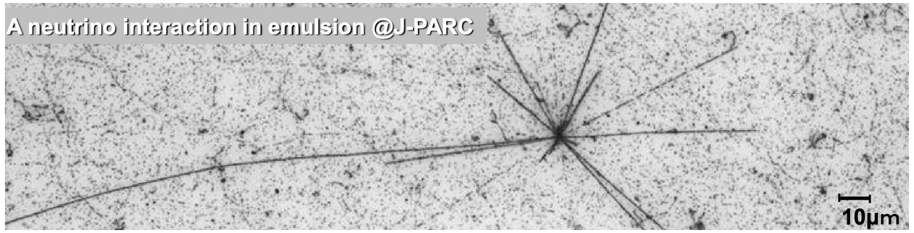
NINJA, PRD106 (2022) 032016
Zhao et al, JINS19(2024)P07014

Path forward to unknown unknowns 2 – New new near detector

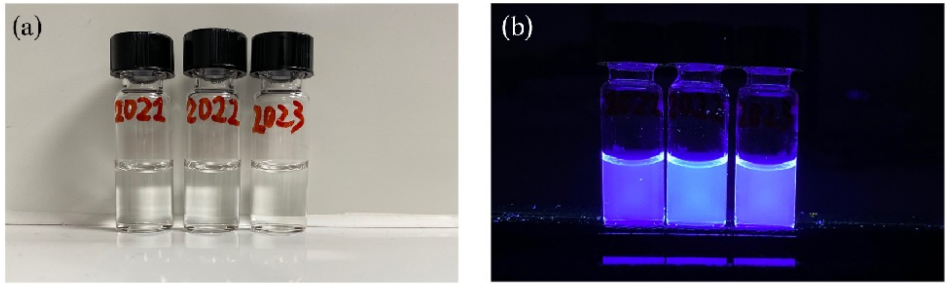
ND280++
- T2K near detector ~17yrs old (2027)

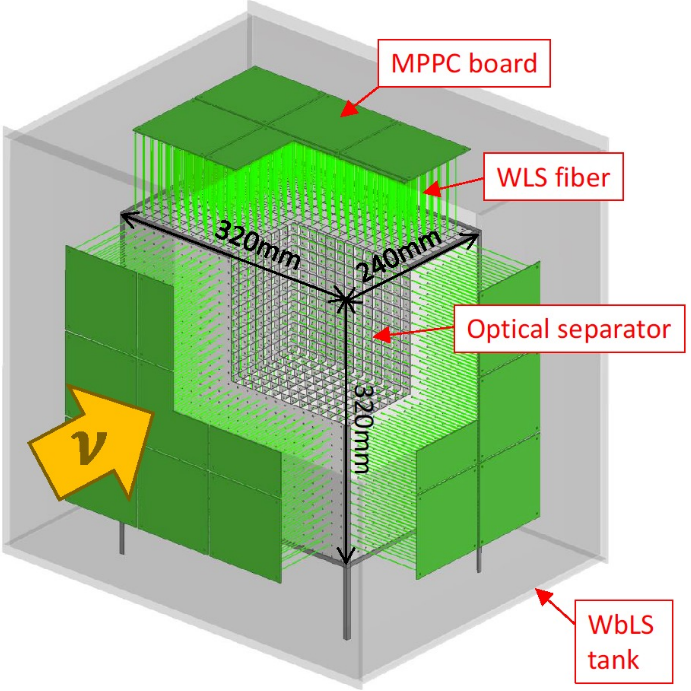


Emulsion-based detector
- High spatial resolution (0.3 um resolution)
- NINJA collaboration



Water-based liquid scintillator
- 3-d fiber reading
- Various R&D initiated
  - Nanocrystal-based liquid scintillator

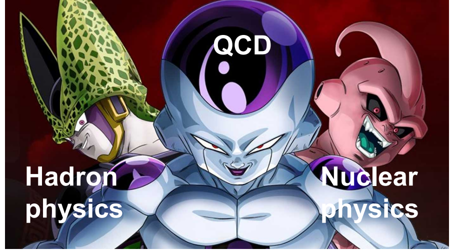




Path forward to unknown unknowns 3 – Strong interaction

CLAS, Nature566(2019)354, Lovato, Carlson, Gandolfi, Rocco, Schiavilla,PRX10(2020)031068, Gysbers, Hagen, Holt et al, Nature Phys. 15(2019)428
Meyer, Walker-Loud, Wilkinson, Annu.Rev.Nucl.Part.Sci.72(2022)205, PNDNE, PRD109(2024)014503, PACS, PRD109(2024)094505

Recent progresses in QCD, nuclear physics, and hadron physics offer answers to many mysteries in particle physics



Argonne NATIONAL LABORATORY

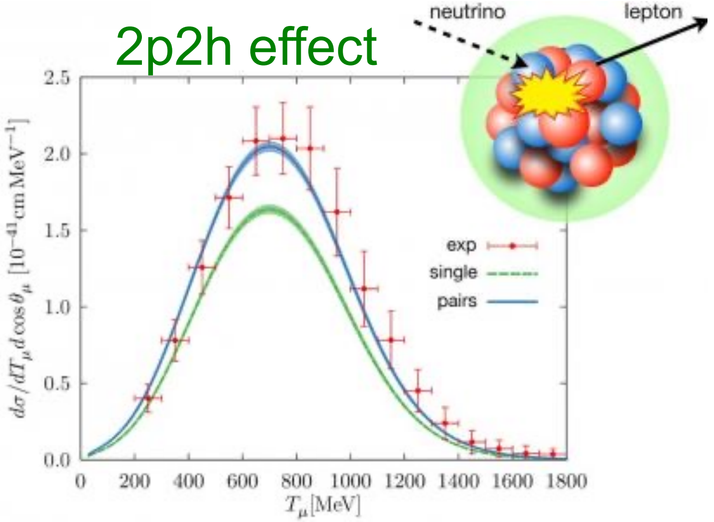
PRESS RELEASE | ARGONNE NATIONAL LABORATORY

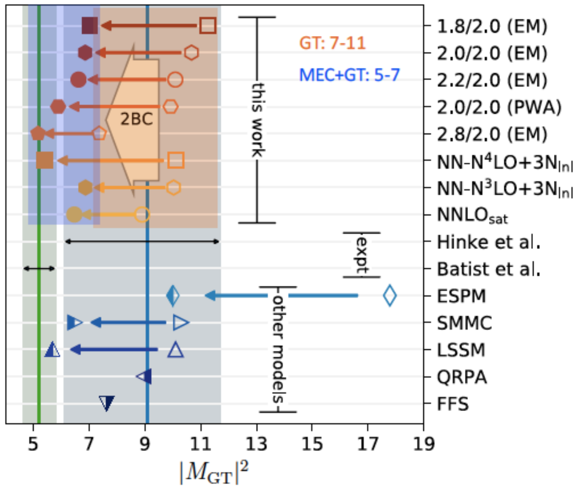
Understanding ghost particle interactions

BY JOSEPH E. HARMON | SEPTEMBER 28, 2020

Team constructs accurate nuclear physics model of neutrino-nuclei interactions.

2p2h effect

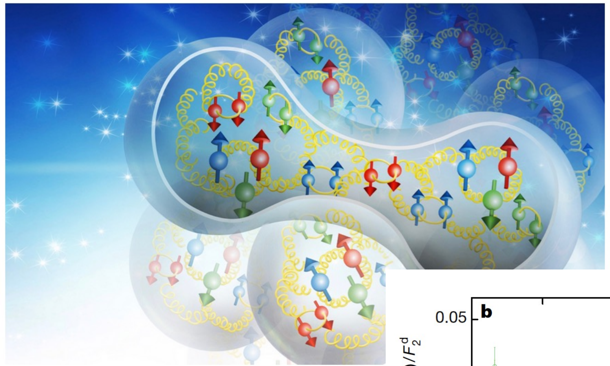


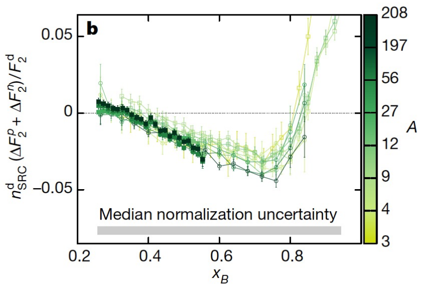


CORRELATED NUCLEONS MAY SOLVE 35-YEAR-OLD MYSTERY

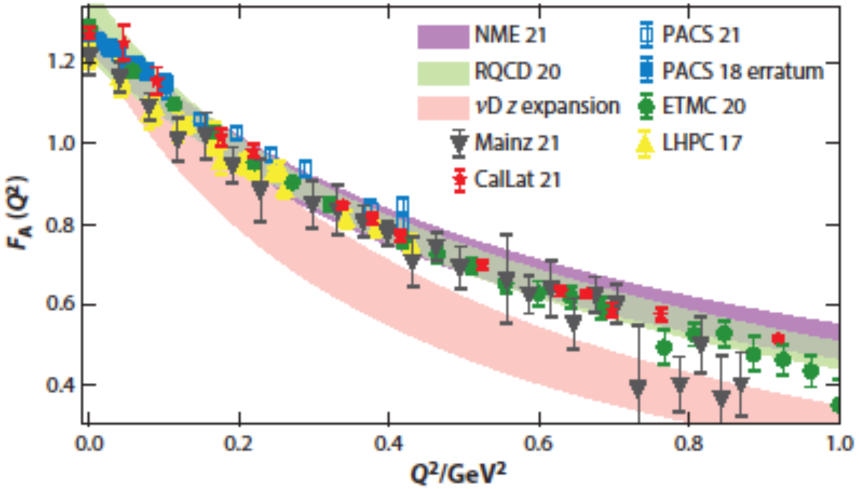
Jefferson Lab

EMC effect





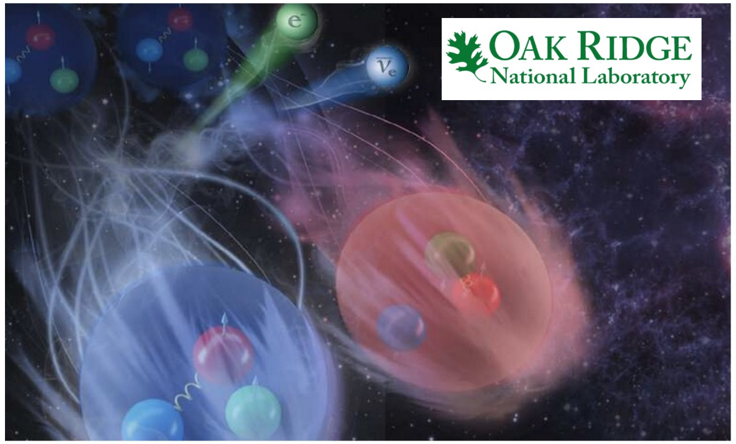
Axial form factor anomaly



Physicists solve a beta-decay puzzle with advanced nuclear models

by Oak Ridge National Laboratory

g_A quenching



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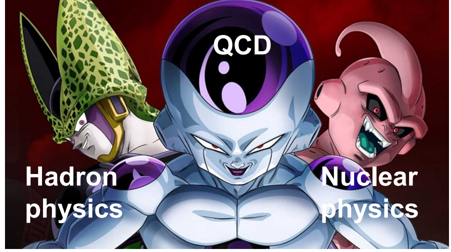
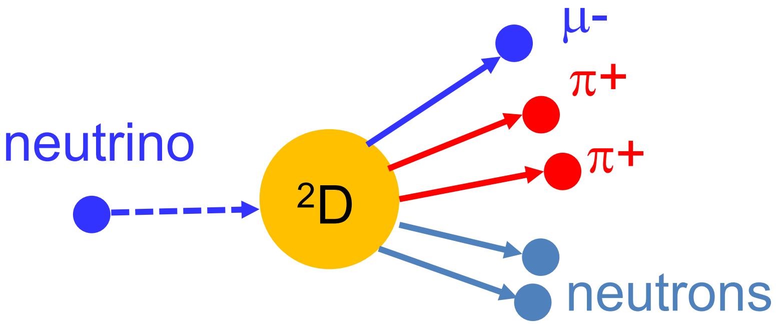
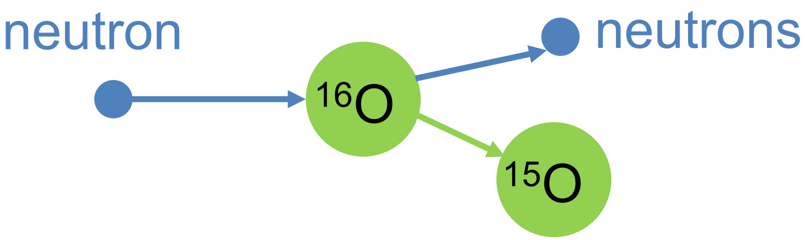
Hyper-Kamiokande

Nakamura Kamano, Hayato, Hirai, Horiuchi, Kumano, Murata, Saito, Sakuda, Sato Rep.Prog.Phys.80(2017)056301
https://tendl.web.psi.ch/tendl_2015/tendl2015.html

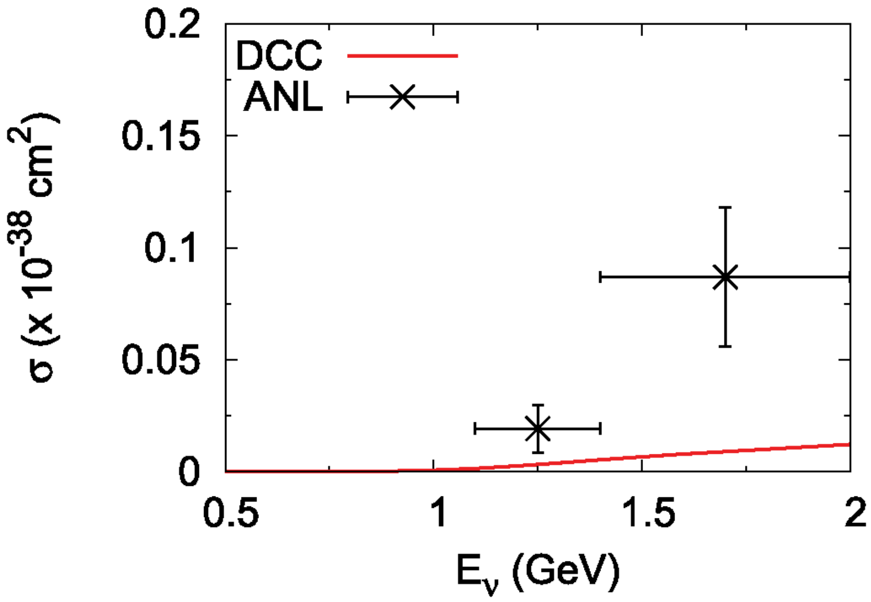
Next generation neutrino detectors use hadron information to maximize their potential (pion, neutron multiplicity, etc)



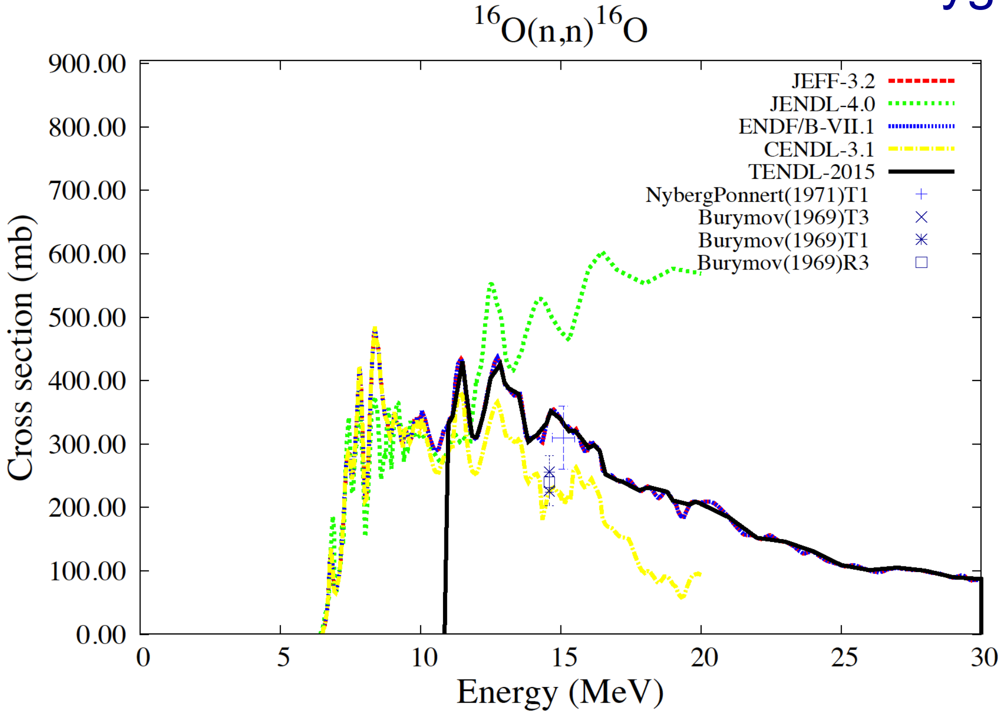




Neutrino induced 2-pion production



Neutron total inelastic cross section on oxygen

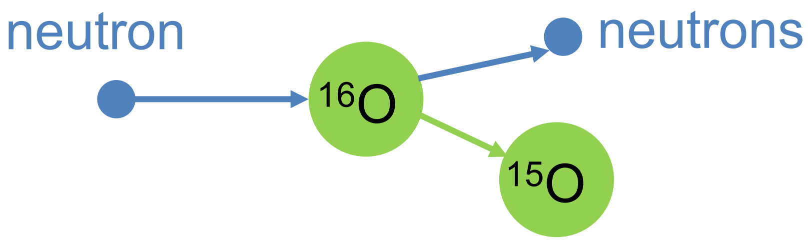


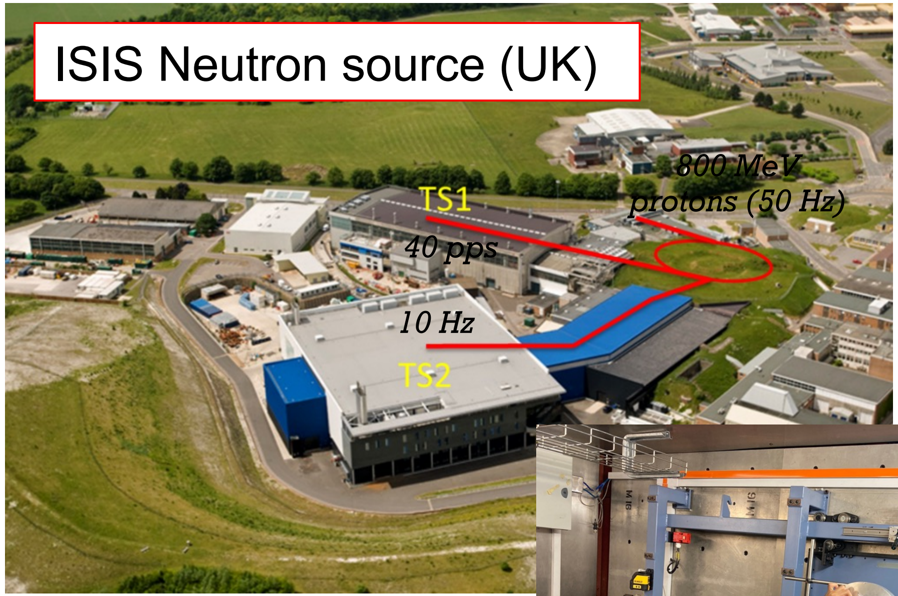
Hyper-Kamiokande

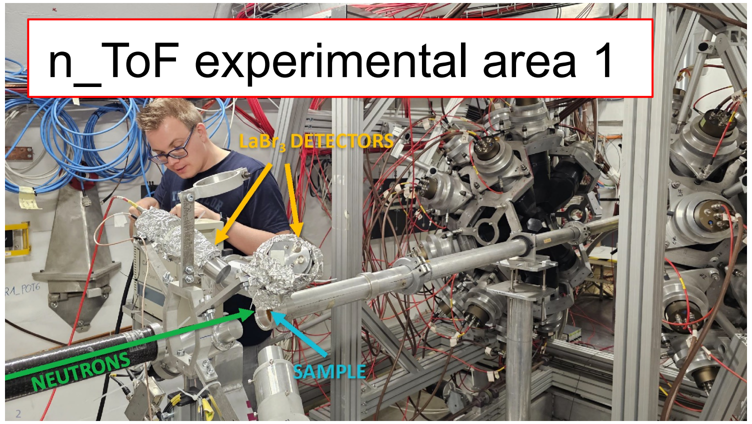
Fast neutron-water cross-section measurements

ISIS neutron source at Rutherford Appleton Laboratory (UK)

- ChipIr, up to several hundreds MeV
- Beam data taken (2023)







n_ToF at CERN

- BeO target
- Up to ~100 MeV
- Data taking (2025)

Conclusions

HyperK construction is on the right track

Growing collaborations (~600 people, ~100 institutions, ~22 countries)

There is no "red carpet", the project takes risks and challenges, but we try to solve one by one

There are many guaranteed physics results, but HyperK also have many exciting opportunities to look for "unknown unknowns"

Thank you for your attention!
Join us!

Backup

Reference

Overview

"Hyper-Kamiokande", Shigetaka Moriyama (Neutrino 2024)
https://agenda.infn.it/event/37867/timetable/#20240616
"Hyper-Kamiokande Status", Christophe Bronner (NuFact 2024)
https://indico.cern.ch/event/949705/contributions/4555521/

PMT

"PMT development for Hyper-Kamiokande", Christophe Bronner (NuFact2021)
https://indico.cern.ch/event/855372/contributions/4366117/
"Multi-PMT photodetector system for the Hyper-K experiment", Gianfranca De Rosa (ICHEP2020)
https://indico.cern.ch/event/868940/contributions/3814071/

Beam

"Upgrade of J-PARC magnetic horn system towards 1.3 MW beam", T. Sekiguchi (NuFact2024)
https://indico.fnal.gov/event/63406/contributions/297564/
"NA61/SHINE measurements for neutrino experiments", Laura Fields (NuFact2024)
https://indico.fnal.gov/event/63406/contributions/297872/

Electronics

"The Hyper-Kamiokande Experiment Status and Prospect", Umut Kose (Tau2023)
https://indico.cern.ch/event/1303630/contributions/5620874/

Near detector

"A new near neutrino detector SuperFGD for the T2K experiment", Tristan Doyle (NuFact2024)
https://indico.fnal.gov/event/63406/contributions/297834/

Machine learning

"Enhancing Event Reconstruction with Machine Learning for Water Cherenkov Detectors of Hyper-K", Nick Prouse (ICHEP2024)
https://indico.cern.ch/event/1291157/contributions/5892379/

Hyper-Kamiokande Science

Supernova neutrinos
- Core-collapse SN neutrinos
- Diffuse SN neutrino backgrounds
- High-energy SN neutrinos

Solar neutrinos
- MSW upturn
- Solar atmospheric neutrinos

Others
- Nucleon decay

Accelerator-based neutrinos
- Leptonic CP violation
- Neutrino-nucleus cross-sections
- Dark sector particle search

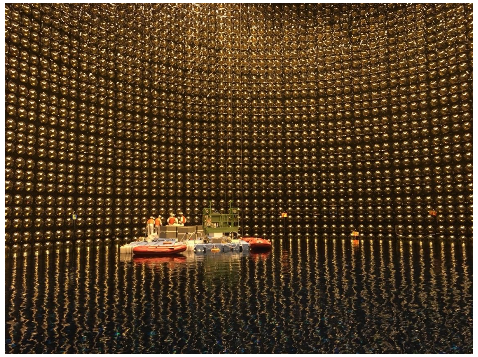
Atmospheric neutrinos
- Neutrino mass ordering
- Tau neutrino physics
- Prompt neutrinos
- TeV neutrinos

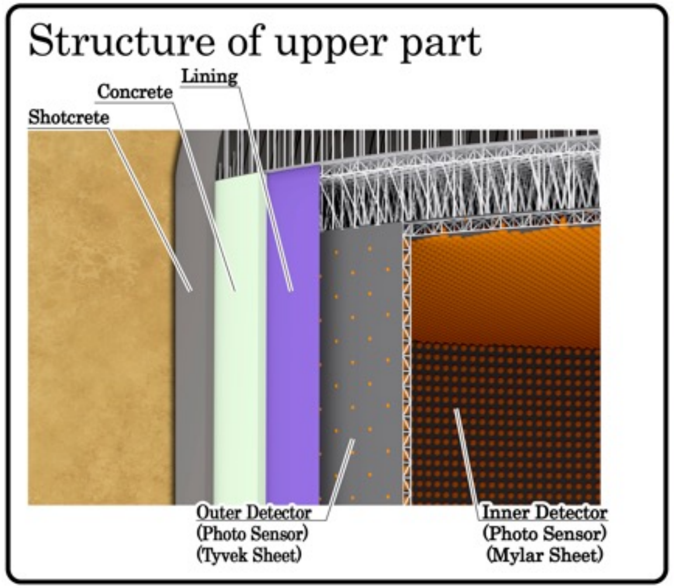
High-energy astrophysical neutrinos
- Galactic plane neutrinos
- Indirect DM search

Hyper-K tank structure

Tank wall is protected by multiple layers

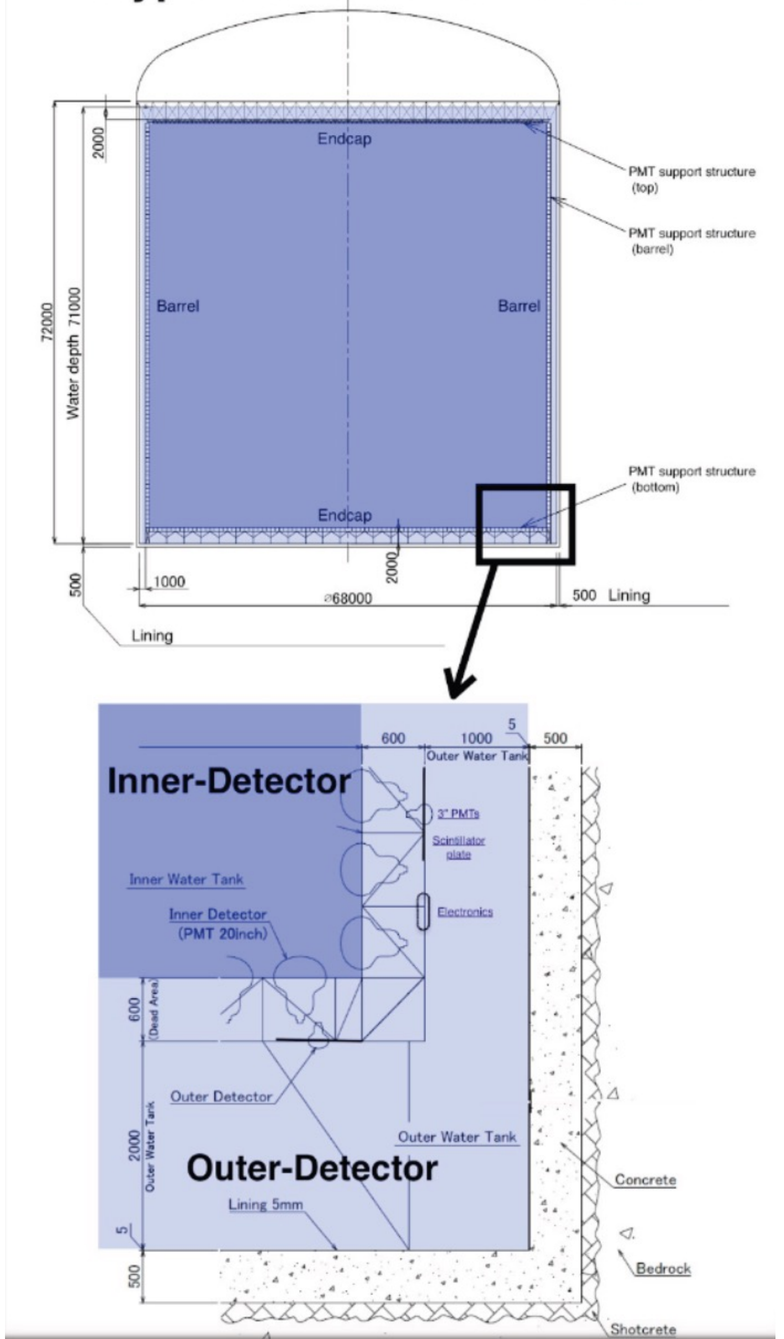
Inner detector (ID) and outer detector (OD) are optically separated by Tyvek and black sheets





Super-Kamiokande ID and OD region

Cross section of Hyper-Kamiokande detector



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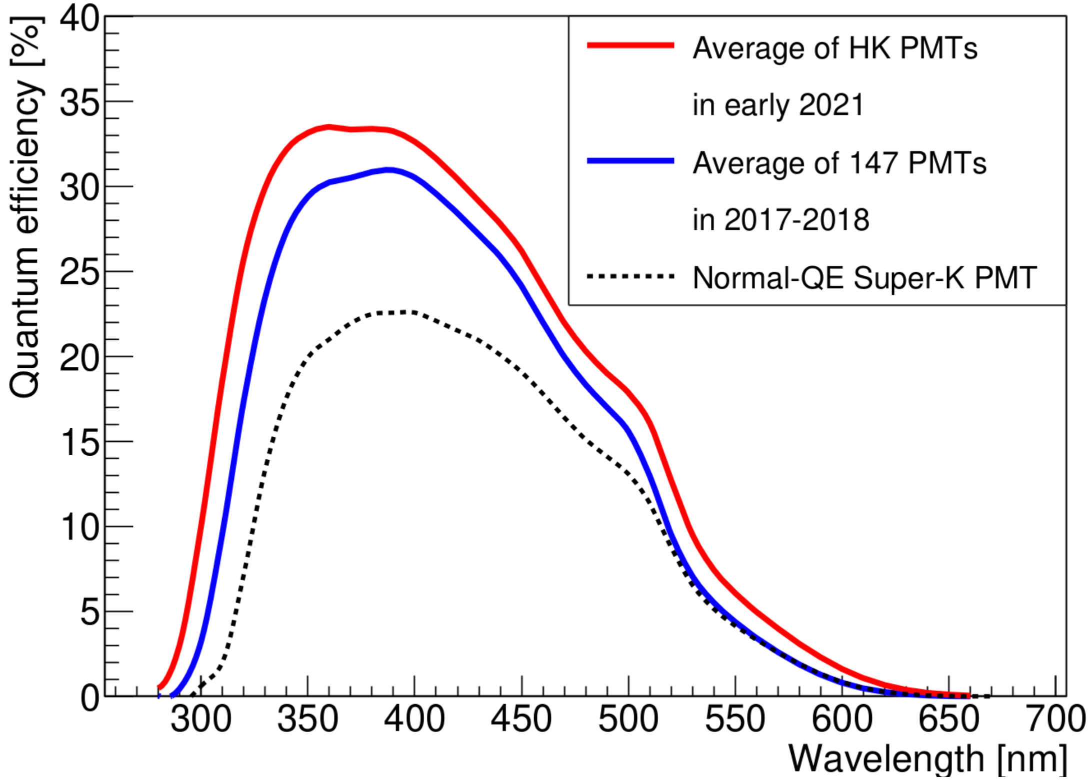
Hyper-Kamiokande

Hyper-K ID 20-inch PMTs

Radio-isotopes in glass window are the major sources of dark current (scintillation)
- After meticulous researches, people found the origin of them
- R12860 finally achieved the 4kHz target goal!
- QE is further improved for short wavelength region

Radio isotopes in glass (Bq/kg)

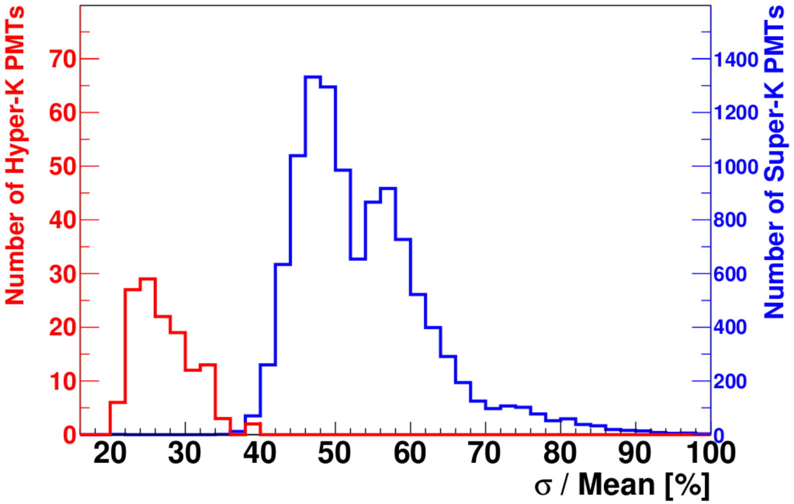
	Super-K (R3600)	R12860 (before)	R12860 (after)	R12860 (2021)
U	5.5	5.4	2.9	2.5
Th	1.8	1.8	0.95	0.7
^{40}K	18.2	1.6	2.0	1.0



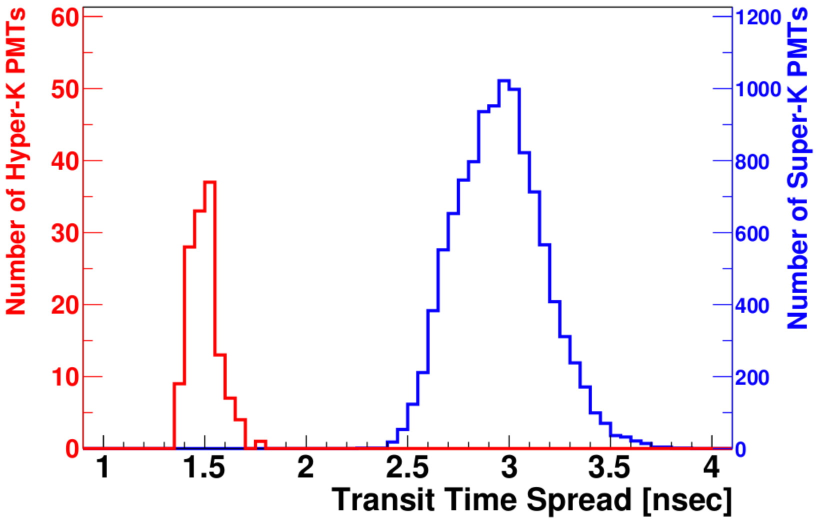
Hyper-K ID 20-inch PMTs

134 of HyperK 20-inch PMTs were installed in SuperK (2018). Performance was confirmed in the ultra-pure water environment

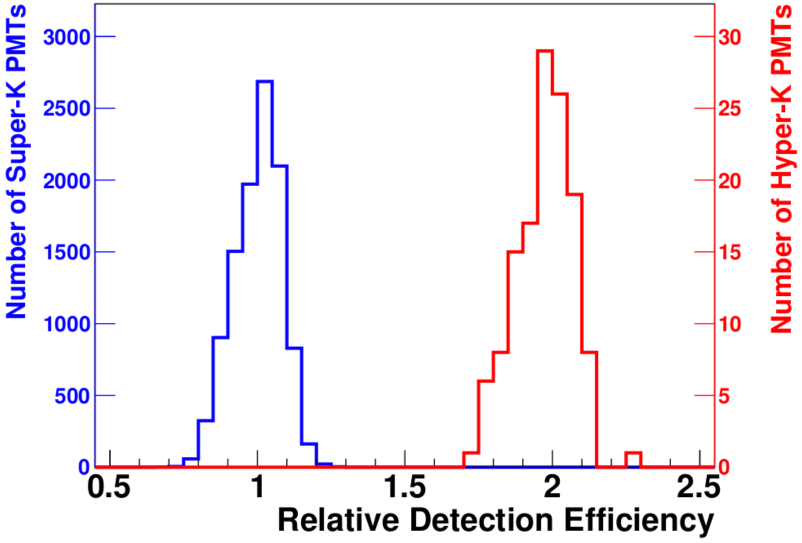
Charge resolution



Time resolution

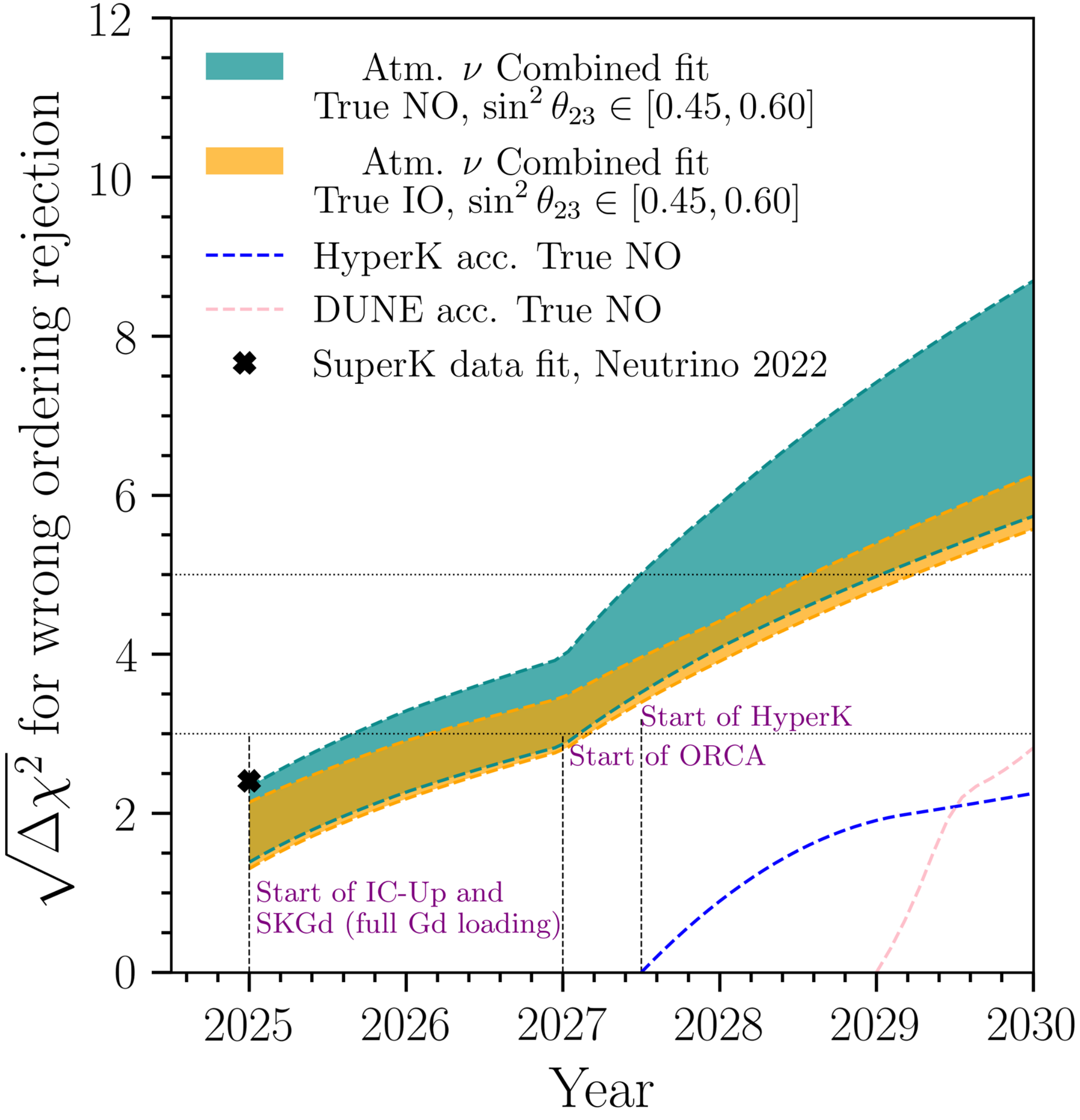


Detection efficiency



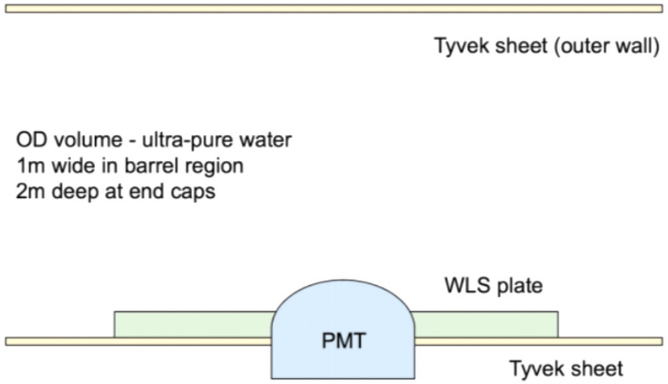
Global mass hierarchy sensitivities

Hyper-K with IceCube-Upgrade and/or KM3NeT-ORCA and/or JUNO can reach 5-sigma neutrino mass hierarchy discovery before 2030

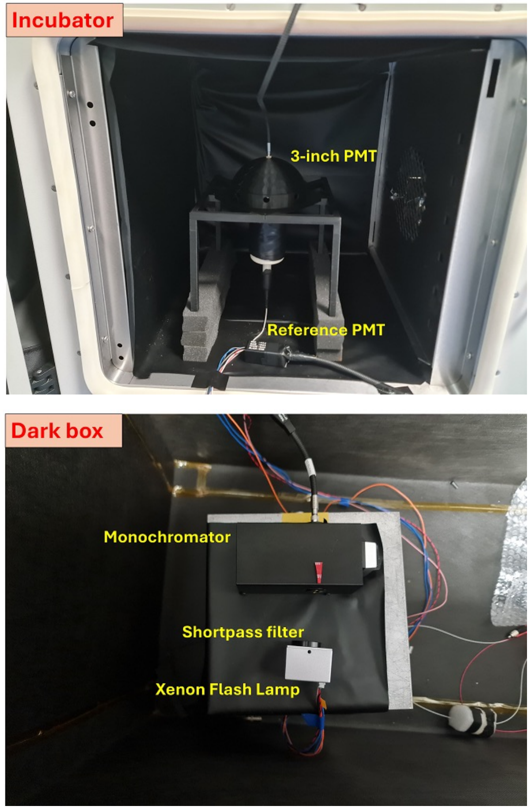


Hyper-K outer detector system

Hyper-K OD system
- 3-inch PMT
- WLS plate
- Tyvek sheet

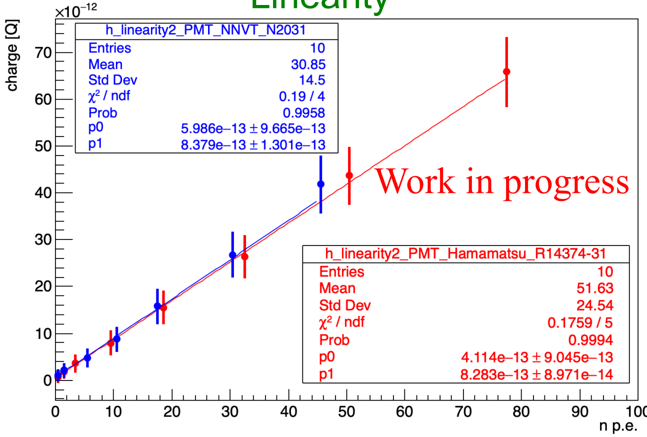


Rutherford Appleton Lab

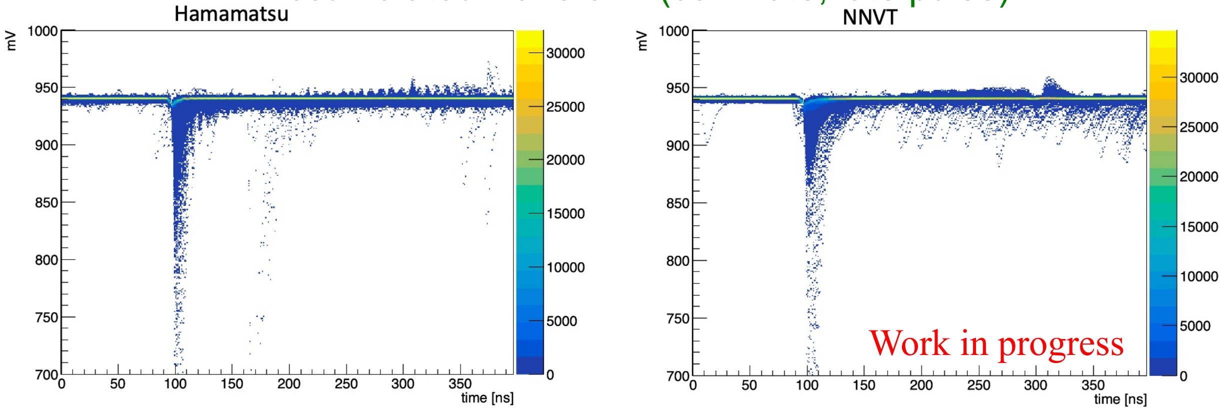


Hamamatsu vs NNVT
- 3-inch positive HV PMTs (1 cable operation)
- reasonable noise, after pulse, linearity, QE efficiency, gain
- low failure rate is the key (base, waterproof, cable, connector)

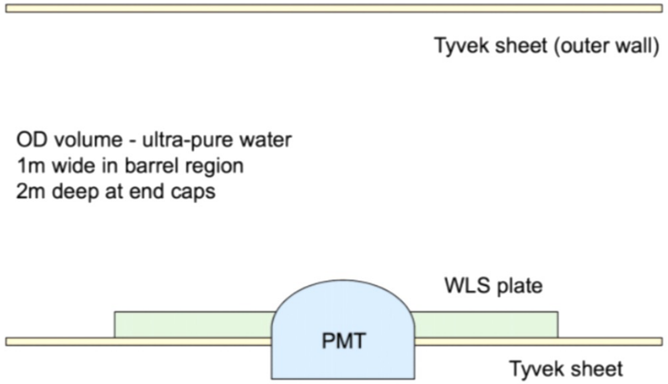
Linearity

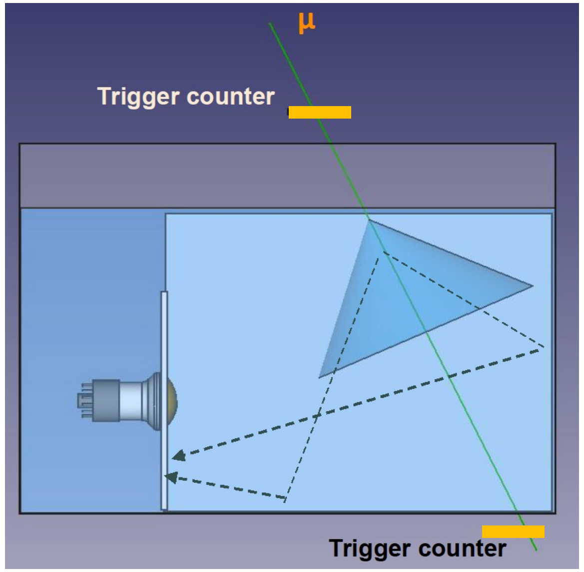


Accumulated waveform (dark rate, late pulse)



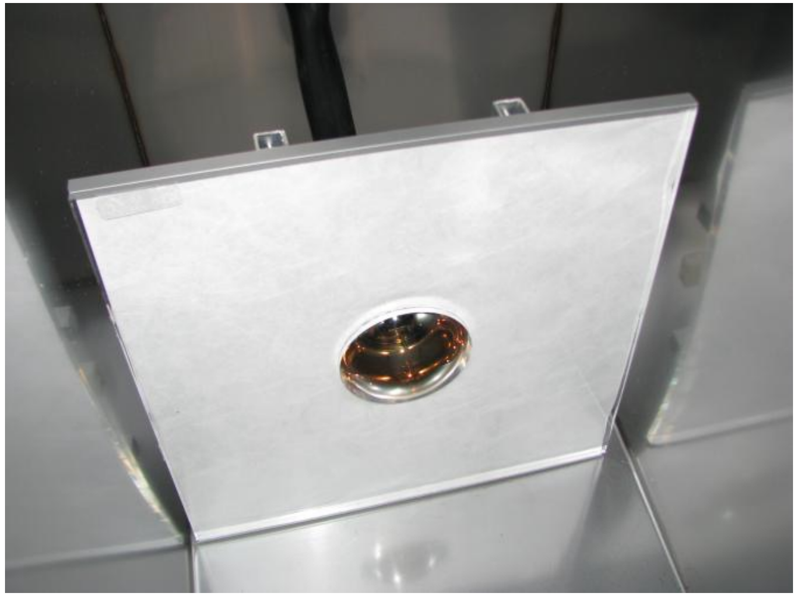
Hyper-K outer detector system

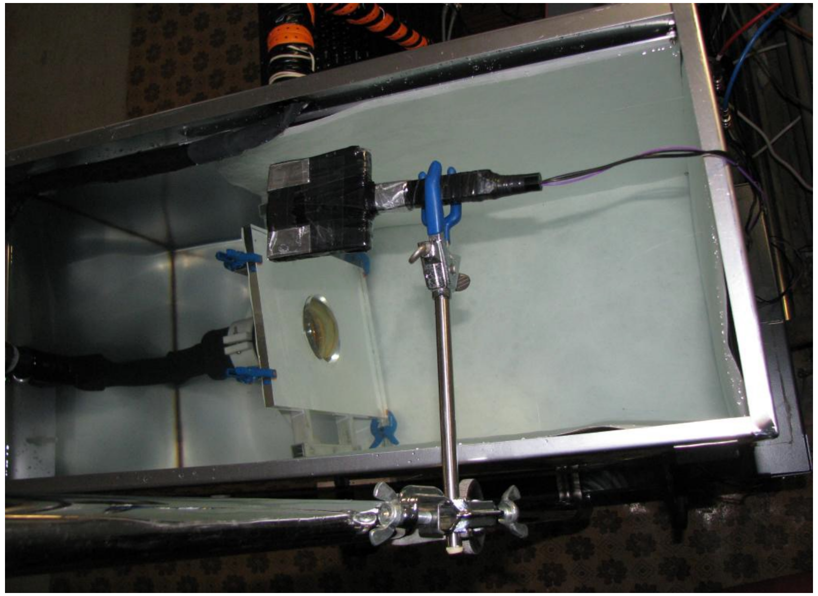




Hyper-K OD system
- 3-inch PMT
- WLS plate
- Tyvek sheet

Wave length shifting plate
-WLS plate performance is tested with cosmic rays

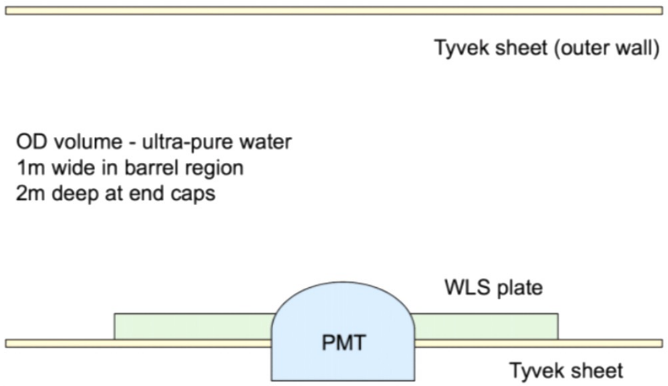




INR (Russia)

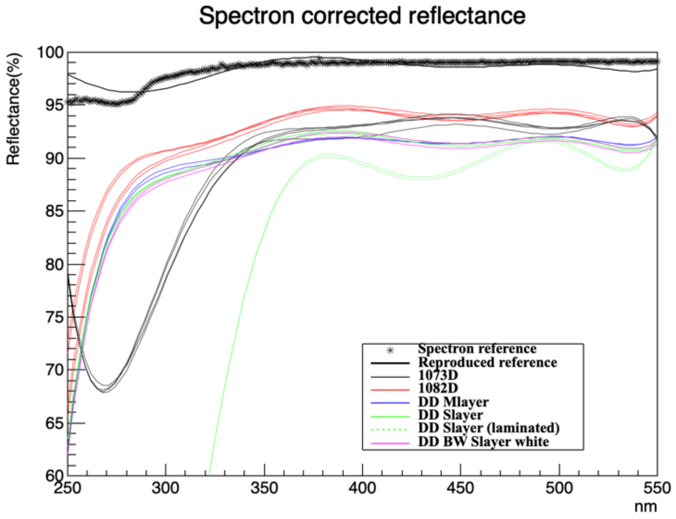
Hyper-K outer detector system

Hyper-K OD system
- 3-inch PMT
- WLS plate
- Tyvek sheet



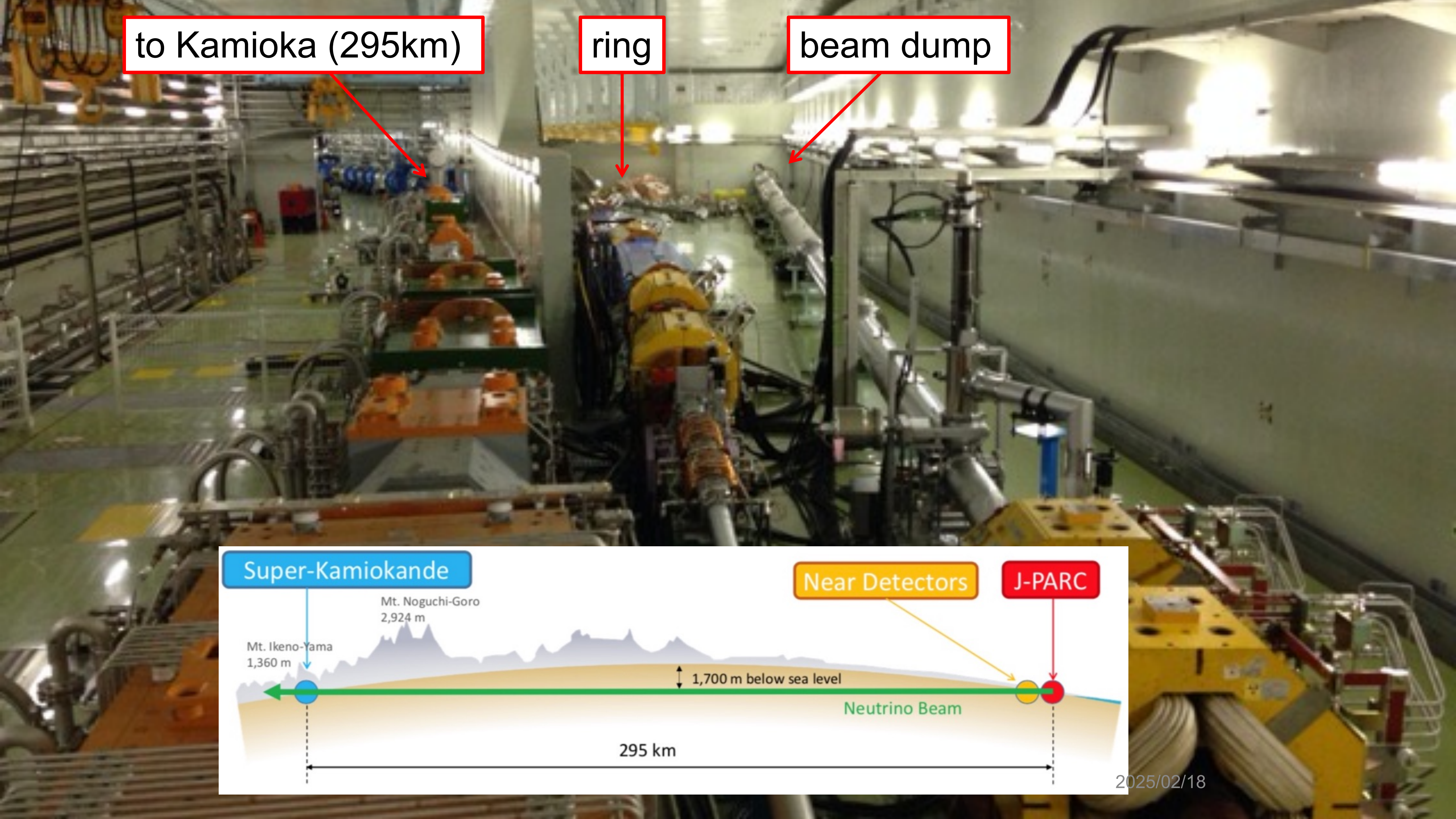
Super-K 2018 refurbishment

Requirement: >90% reflectivity
- UK installation frame for designing and practicing Tyvek installation



UK Hyper-K installation practice frame (Rutherford Appleton Lab)

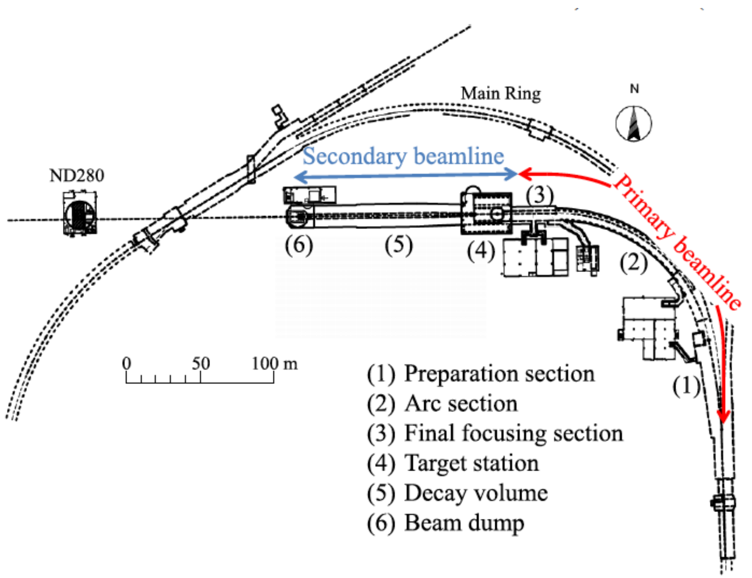
KING'S College LONDON Hyper-Kamiokande

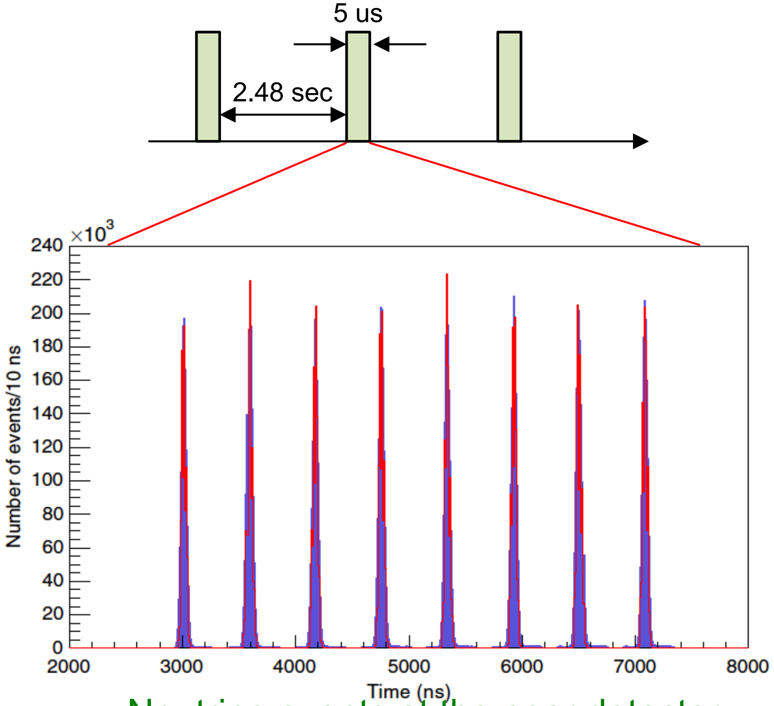

to Kamioka (295km)
ring
beam dump
Super-Kamiokande
Mt. Noguchi-Goro
2,924 m
Mt. Ikeno-Yama
1,360 m
1,700 m below sea level
Near Detectors
J-PARC
Neutrino Beam
295 km

Neutrino beamline

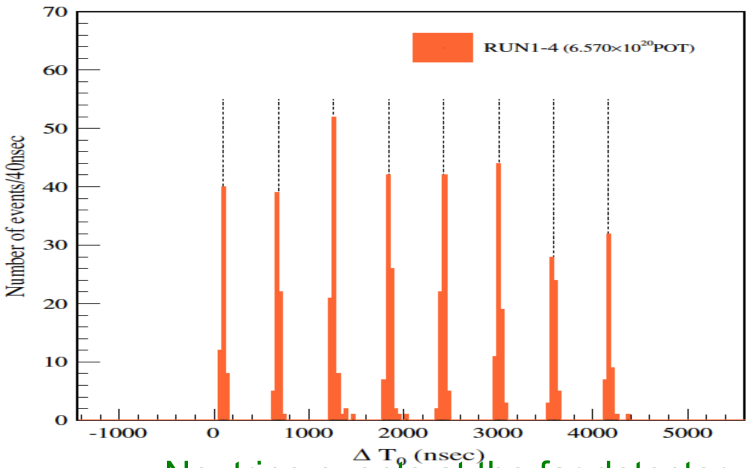
Primary beamline

- 30 GeV protons are extracted from MR
- 1 pulse = 8 bunches
- 1 bunch ~2.6E14 ppp (protons per pulse)





Neutrino events at the near detector



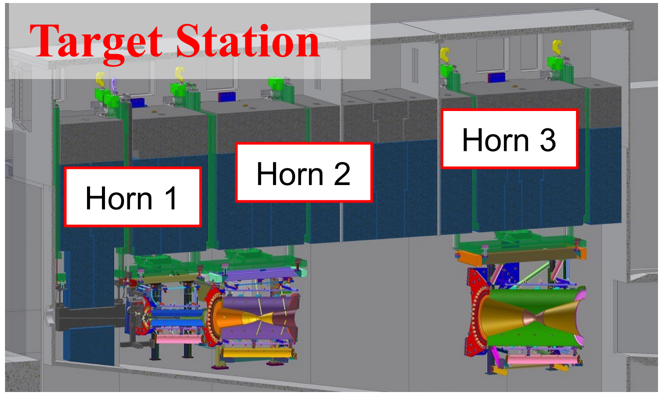
Neutrino events at the far detector

T2K, PRD87(2013)012001, NIMA789(2015)57

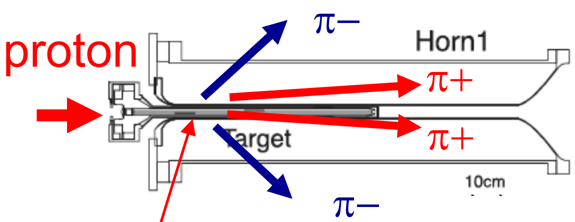
Neutrino beamline

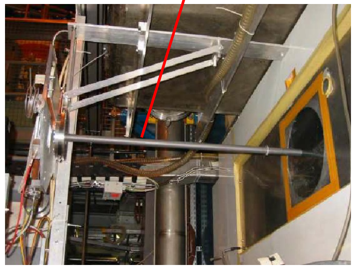
Secondary beamline

- 3 magnetic horns (flux ~x15), decay volume, beam dump
- Neutrino mode: focus π+, defocus π−
- Antineutrino mode: focus π−, defocus π+

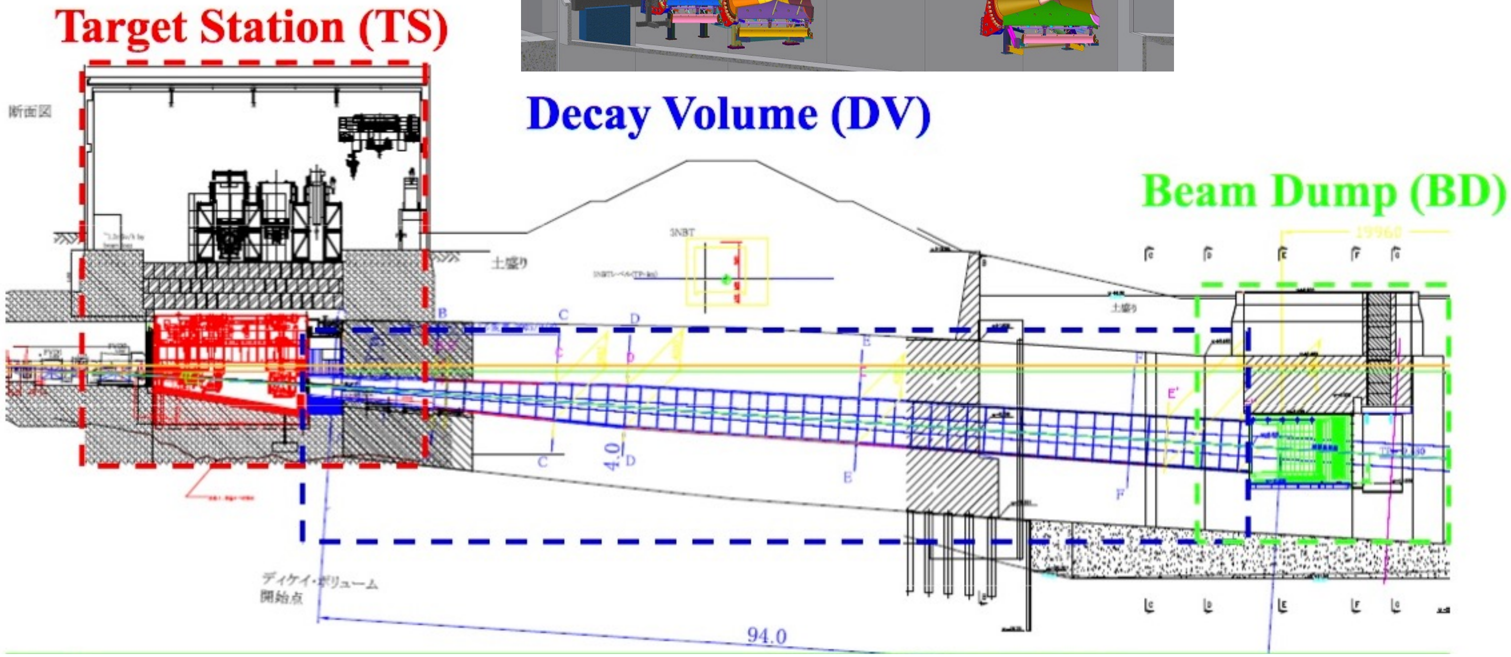


Horn 1 and graphite target





graphite target

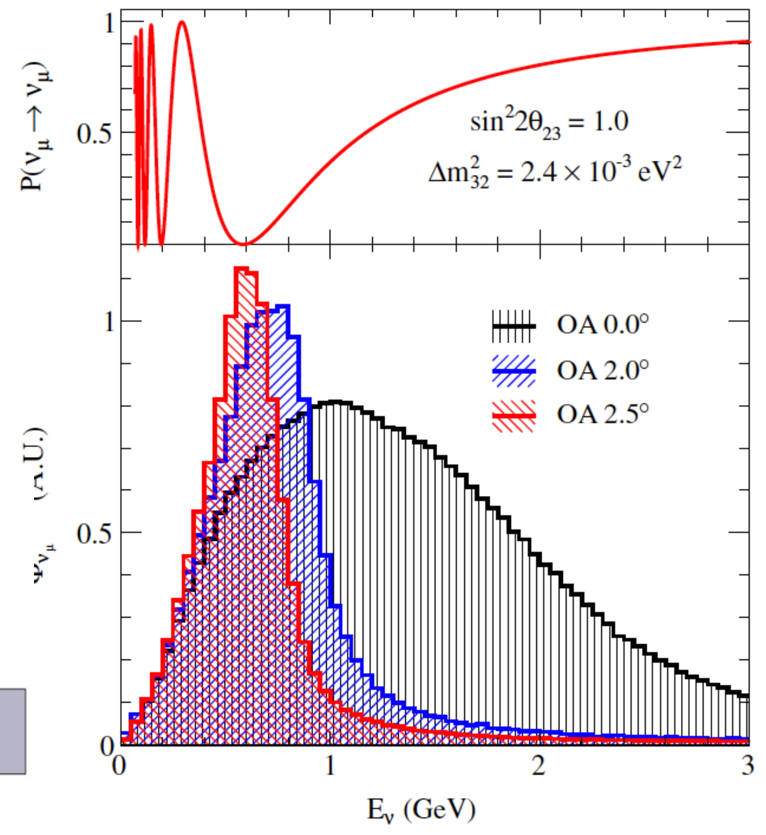


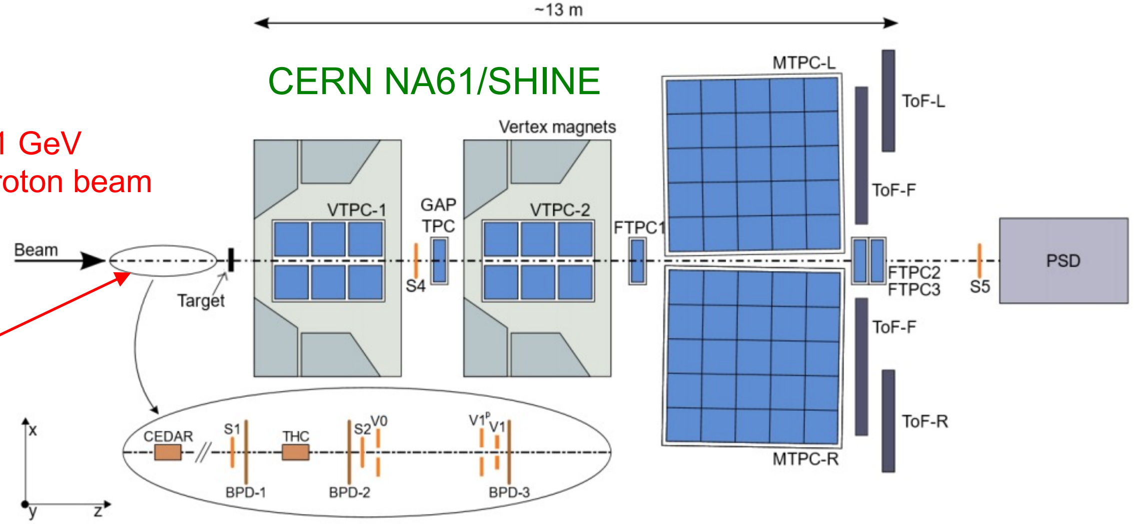
T2K, PRD87(2013)012001, NA61/SHINE, EPJC76(2016)84

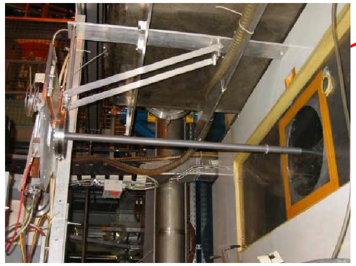
Neutrino beamline

J-PARC neutrino beam

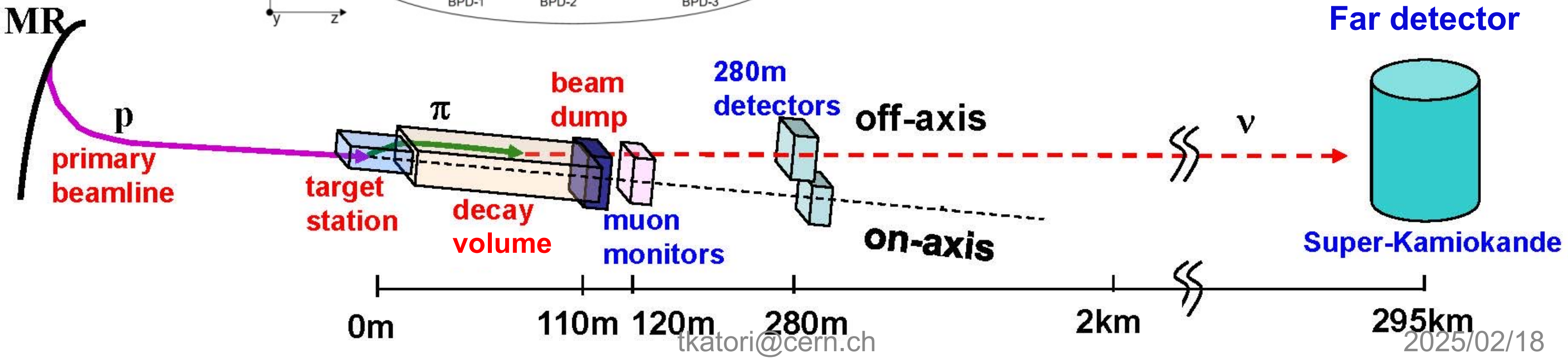
- 2.5° off-axis to make ~0.6 GeV narrow band beam
- Hadron production simulation based on NA61/SHINE data
- flux peak ~5% error







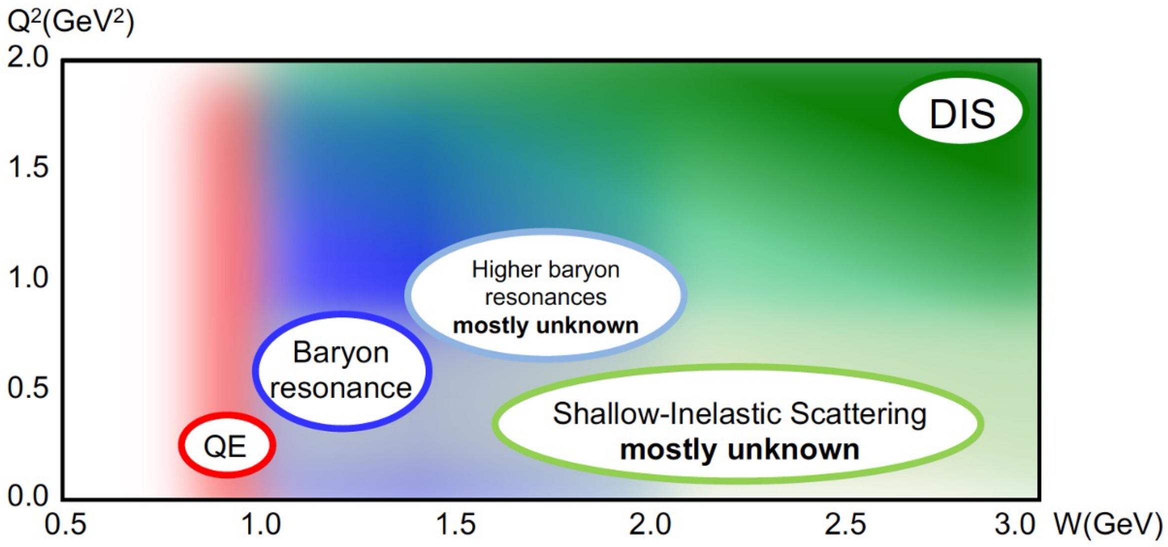
graphite target

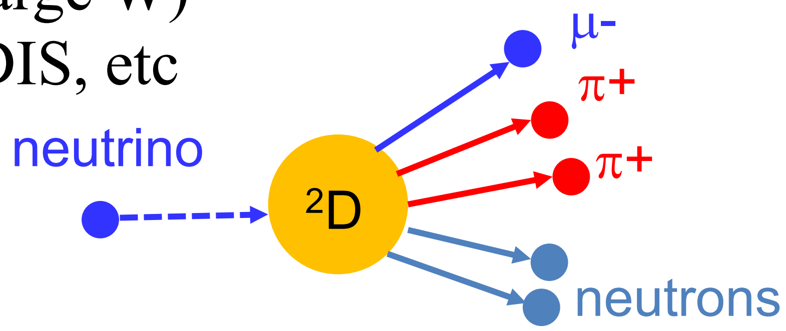


Path forward to unknown unknowns 3 – Strong interaction

Next generation neutrino experiments are systematically limited

- Current focus of oscillation experiment, around 1 GeV (T2K, NOvA)
- Next generation experiments, around 3 GeV (DUNE, ORCA, IceCube-Upgrade)
- Significant fraction of shallow-inelastic scattering (low Q^2, large W)
- Higher resonance, quark-hadron duality, nuclear dependent DIS, etc





Neutrino induced 2-pion production