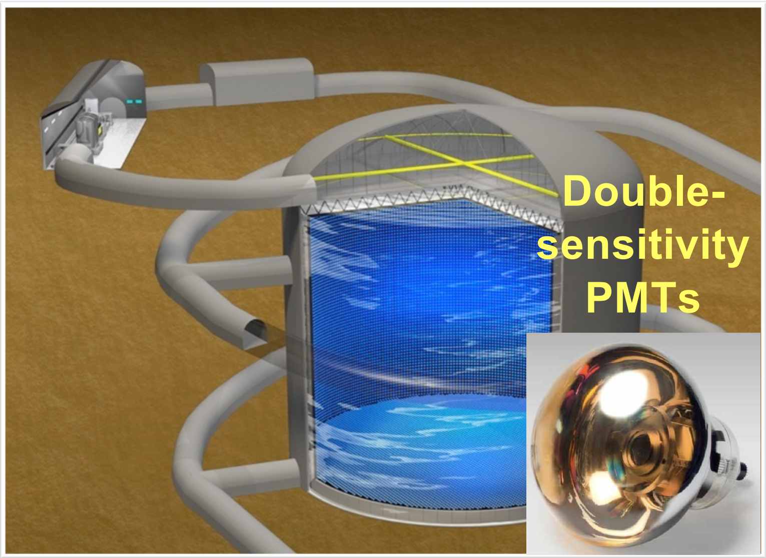
Report on the Hyper-Kamiokande experiment

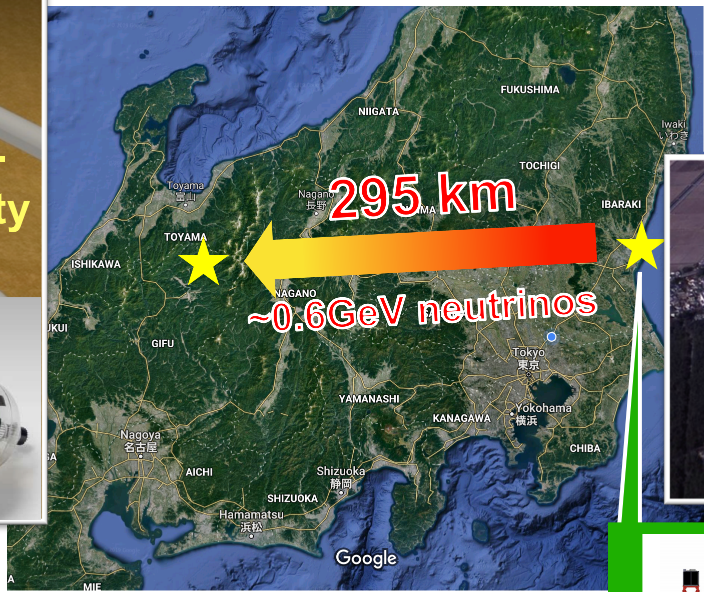
Masato SHIOZAWA
The University of Tokyo

FNAL PAC meeting
15 January, 2020

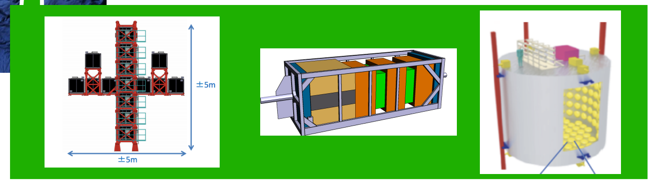
HYPER-KAMIOKANDE:



Hyper-Kamiokande
(hosted by the University of Tokyo)



High power proton beams
J-PARC
(hosted by KEK)



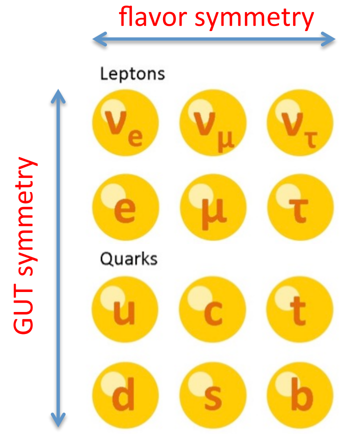
	Super-K	Hyper-K
Site (overburden)	Mozumi, 1,000m	Tochibora, 650m
Number of ID PMTs	11,129	40,000
Photo-coverage	40%	40% (x2 sensitivity)
Total / Fiducial Mass	50 / 22.5 kton	260 / 187 kton

1. Hyper-K detector to be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and to be instrumented with **double-sensitivity PMTs**.
2. J-PARC neutrino beam to be upgraded from 0.5 to 1.3 Mega Watt
3. New and upgraded near detectors to control systematic errors

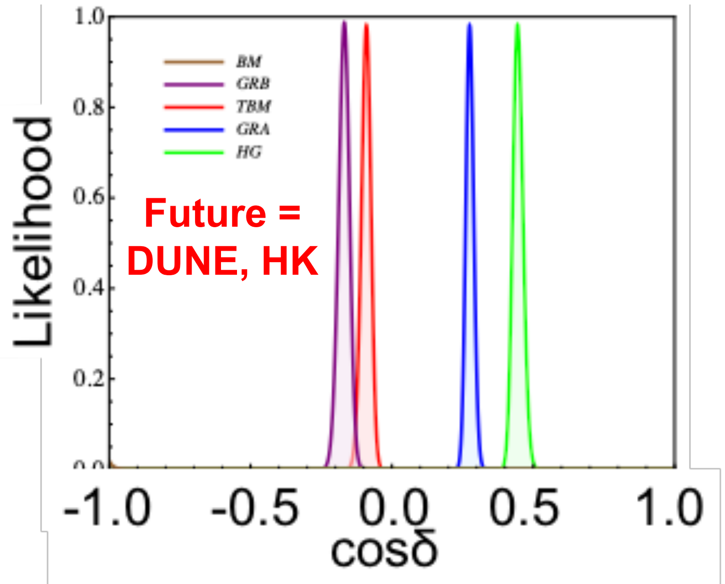
PHYSICS MOTIVATIONS:

- We want to understand an unified organizing principle for mass/mixing of “quarks & leptons.” Big question is Grand Unified Theory.
- Future higher precision data would bring further insights.

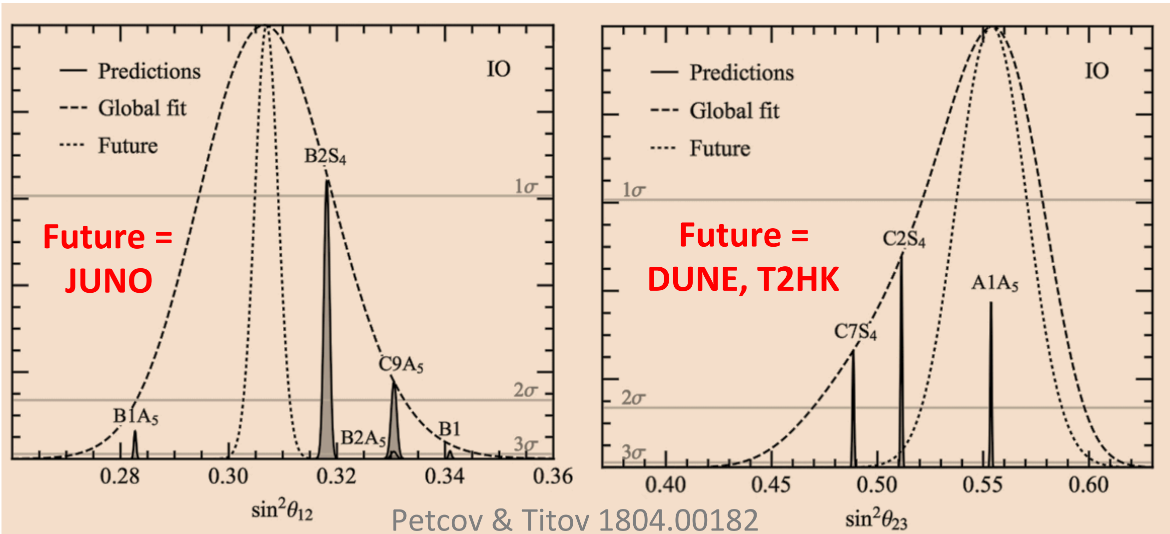
New high scale(s) with higher symmetries



E. Lisi



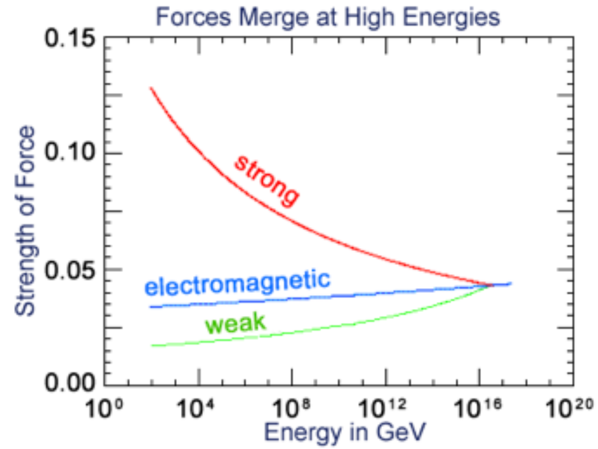
Petcov 1504.02402v1



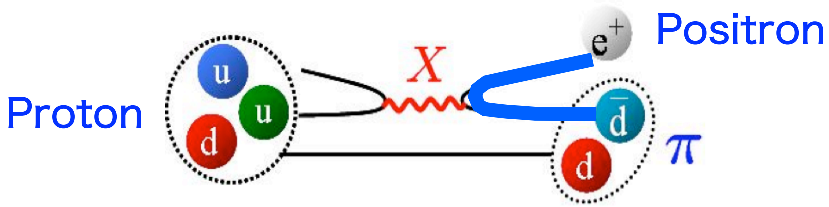
Petcov & Titov 1804.00182

PHYSICS MOTIVATIONS(2):

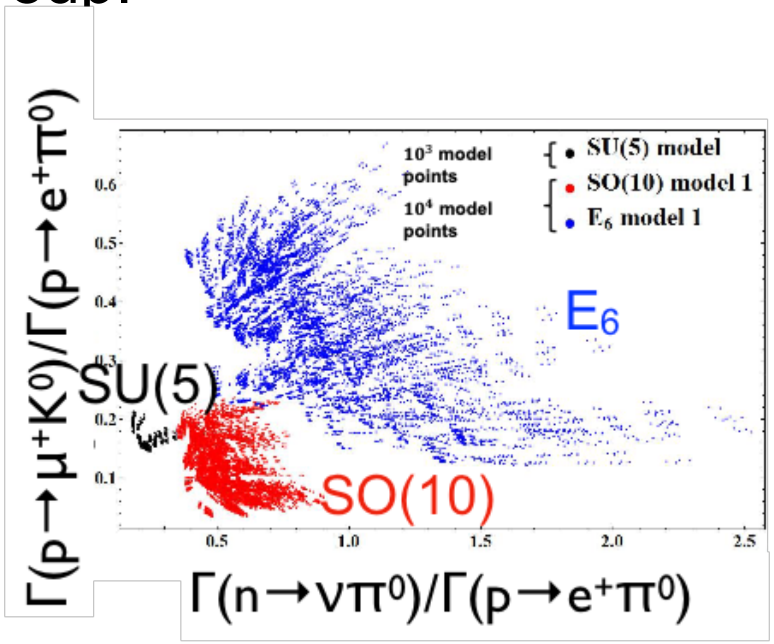
- Proton decay observation would prove the Grand Unification of elementally particles.
- Future measurements would reveal details of unification picture, e.g. unification scale and gauge group.



$$p \rightarrow e^+ \pi^0$$



$$\Gamma(p \rightarrow e^+\pi^0) \sim \frac{g^4 m_p^5}{M_X^4}$$

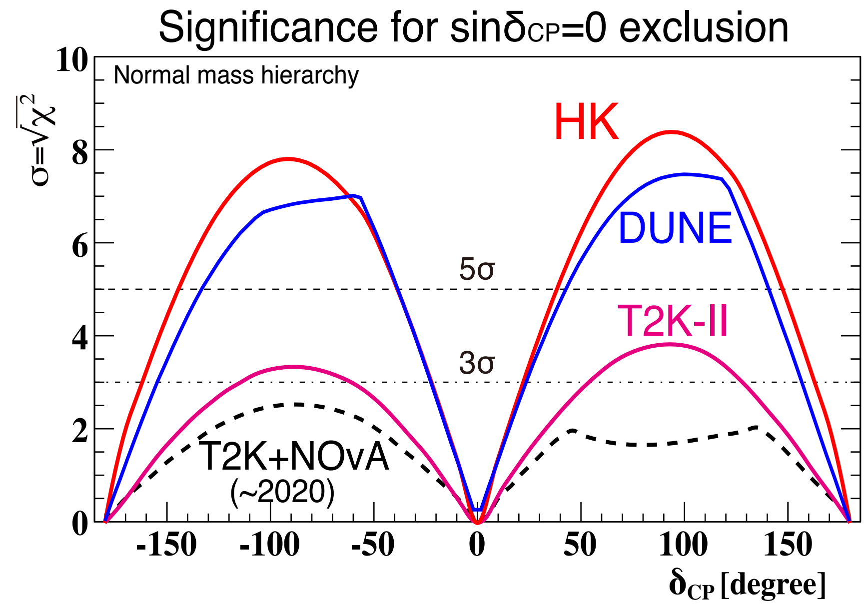


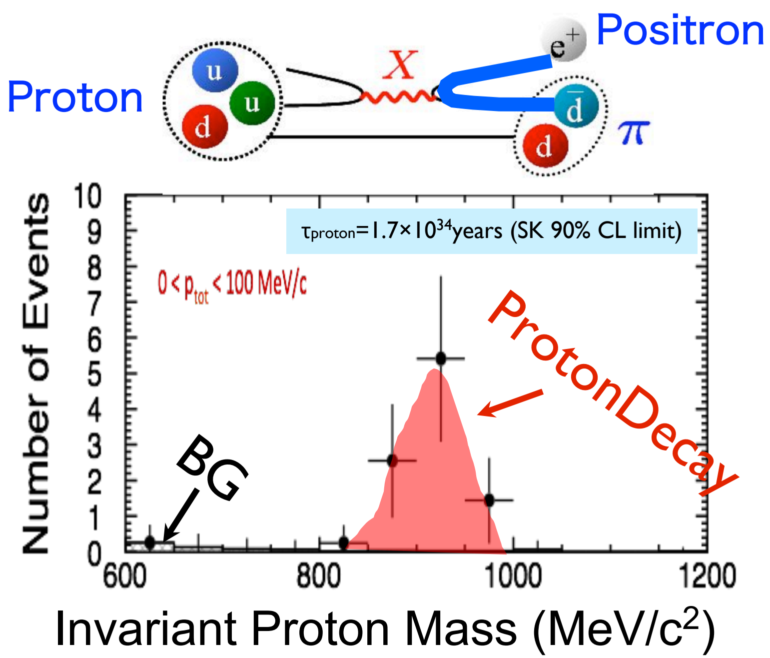
SCIENTIFIC GOALS:

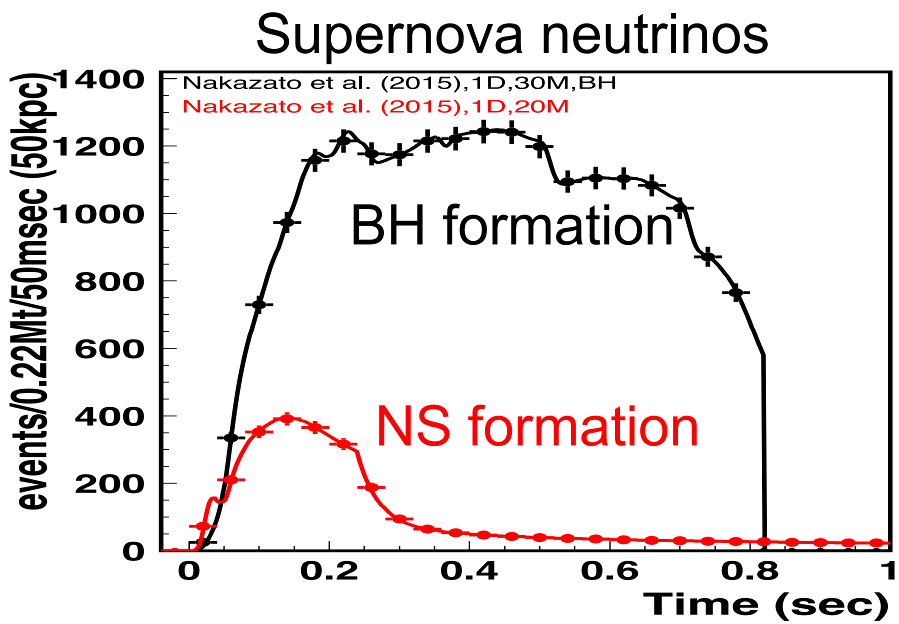
- By sending neutrino and anti-neutrino beams from J-PARC to Hyper-Kamiokande, the difference, if any, between the oscillation nature of those two (CP violation) can be measured.
- Prove the grand unification of three forces by discovering the proton decays.
- Precision measurements of neutrino oscillation phenomena through the observation of solar and atmospheric neutrinos.
- Reveal the mechanism of the supernova explosion by observing large number of neutrinos emitted from them.
- Reveal the history of supernova explosions by observing remnant of neutrinos from supernova explosions that occurred during the history of the evolution of the Universe.
- Others

DISCOVERY POTENTIAL:

- CP violation discovery and measurement, mass hierarchy determination, and so on.
- Neutrino astronomy
- Proton decay discovery







FUNDING STATUS:

- On December 13 2019, the Japanese Cabinet has proposed the supplementary budget for FY2019 which includes the construction of Hyper-K.

- We have currently started its construction phase. Experiment will start in 2027.

→ We would like to work together with international partners and contribute to the world-wide effort to strong particle physics and astronomy program.

Nature 16 December 2019

Road sign for HK power distribution

FUNDING STATUS (DETAILS):

Supplementary budget for FY2019 and General budget for FY2020

(Proposed by Japanese cabinet)

○ Supplementary budget for FY2019 3.5 BJPY (coming from later year's schedule)

* HK detector 3.129 BJPY
* J-PARC upgrade 0.371 BJPY

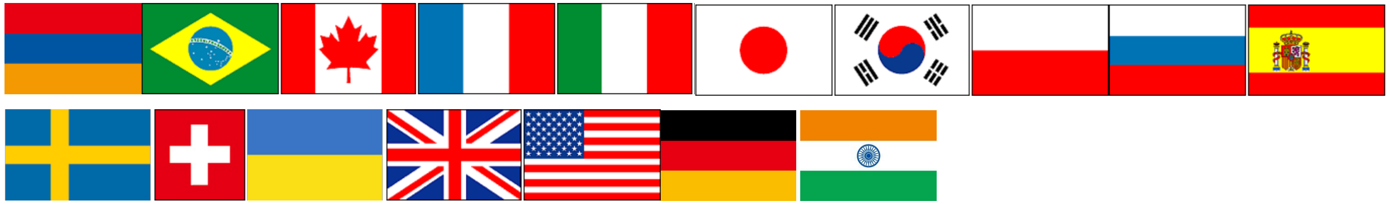
○ General budget for FY2020 0.3 BJPY (requested 1.81 BJPY)

* HK detector 0.3 BJPY

[Overall Plan]

1.HK detector about 64.9 BJPY (Japan's share: 50.2 BJPY) [until FY2026]
2.J-PARC upgrade about 7.3 BJPY (Japan's share: 4.3 BJPY) [until FY2026]
* Japan's share includes 20 BJPY by the implementing institute.

ORGANIZATION:

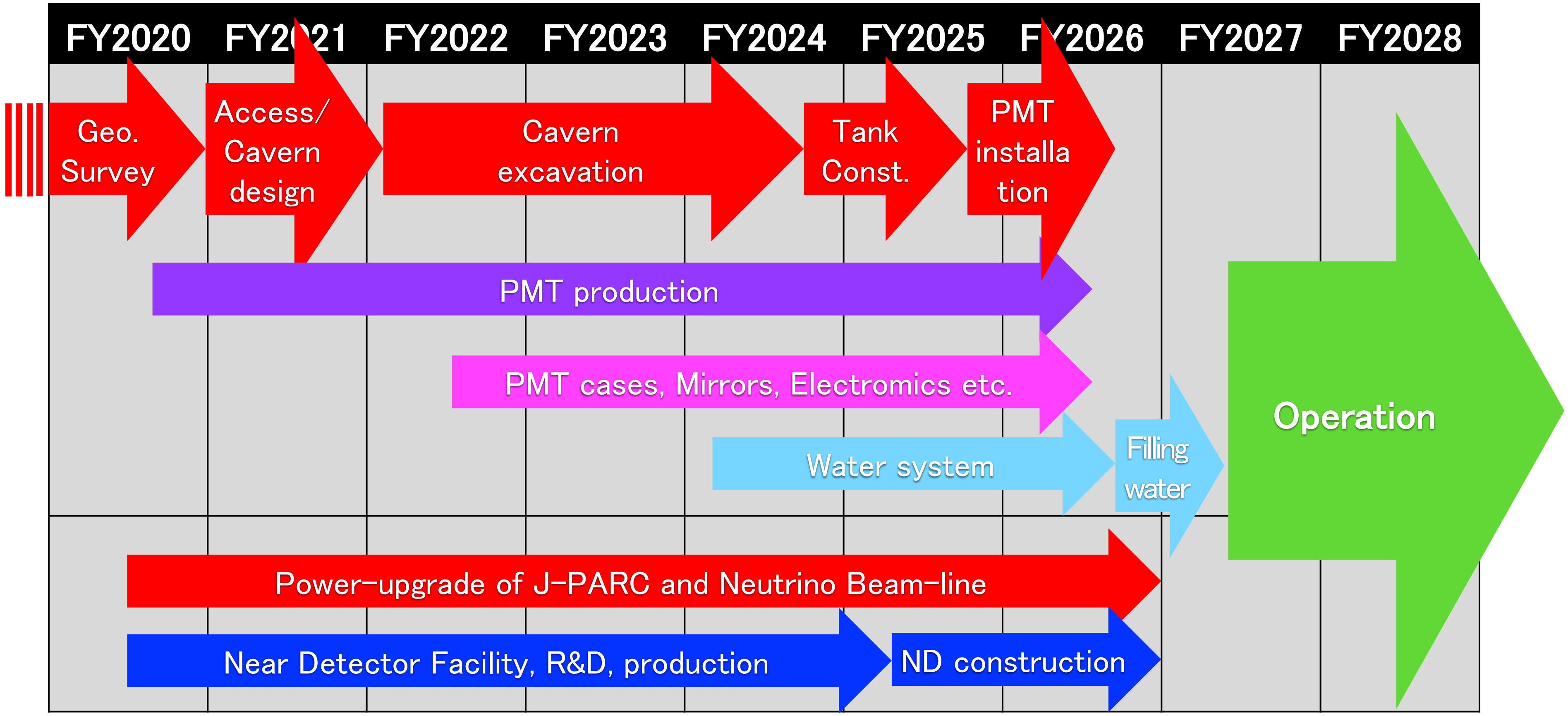


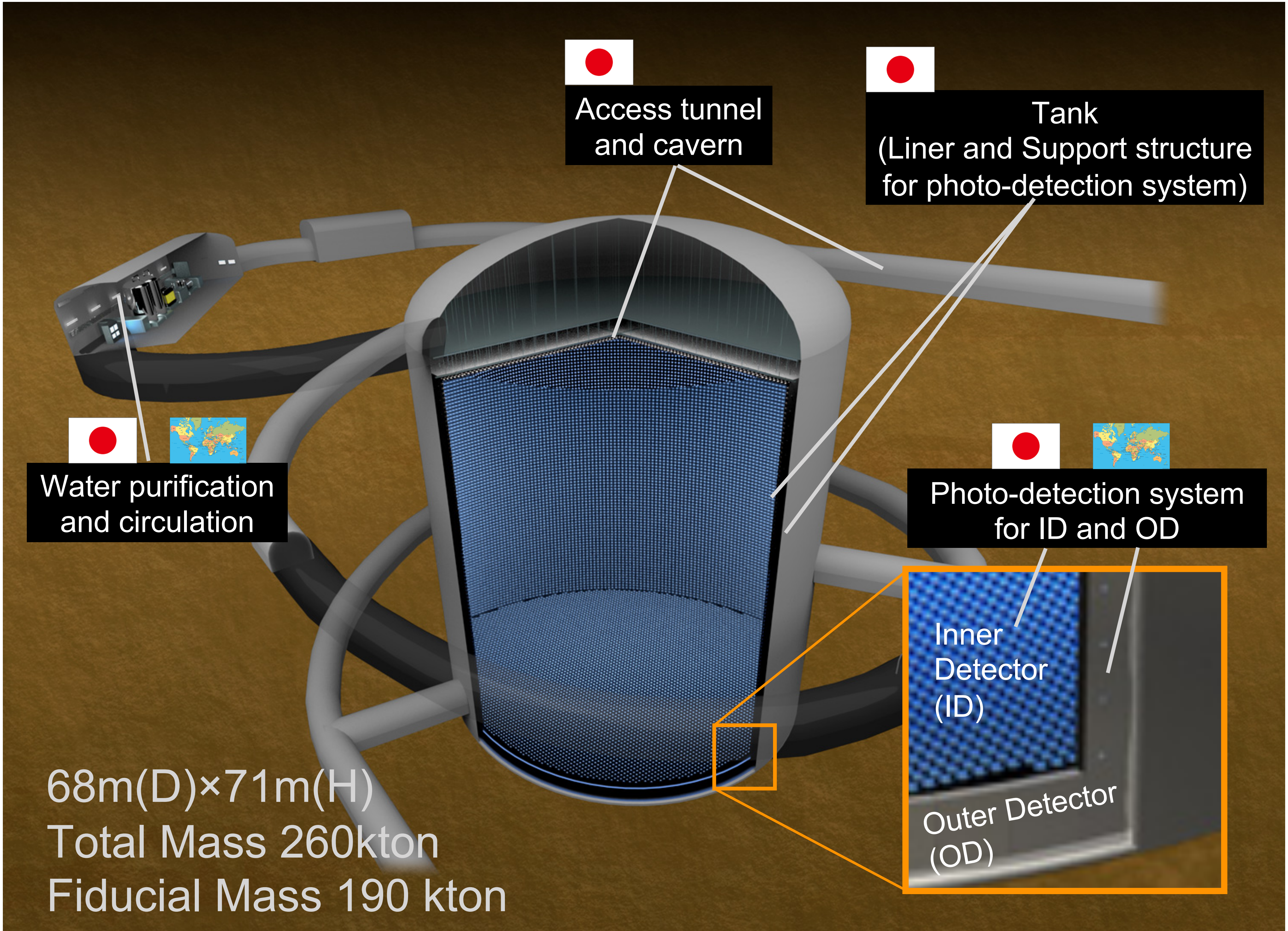
Hyper-K meeting@Kashiwa, September 2019

- 2 host institutes; Univ. of Tokyo and KEK
- Proto-collaboration; 340 members from 17 countries
- Both organizations are in transition to construction phase

SCHEDULE:

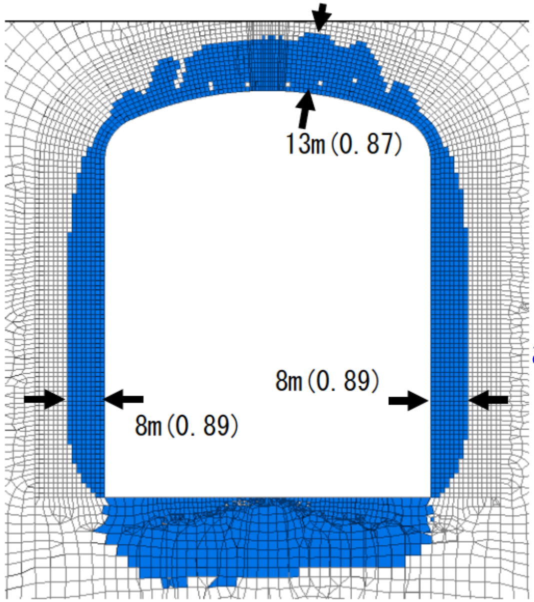
- We are here; January 2020.
- Aiming at operation start in 2027.




Access tunnel and cavern
Tank (Liner and Support structure for photo-detection system)
Water purification and circulation
Photo-detection system for ID and OD
Inner Detector (ID)
Outer Detector (OD)
68m(D)×71m(H)
Total Mass 260kton
Fiducial Mass 190 kton

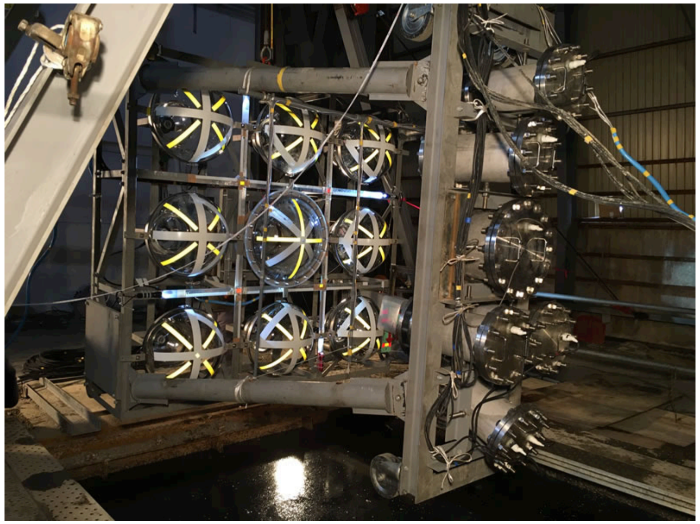
READY TO START CONSTRUCTION:

- Large cavern excavation is found to be feasible with various geological survey data, discussions with the engineering experts etc.



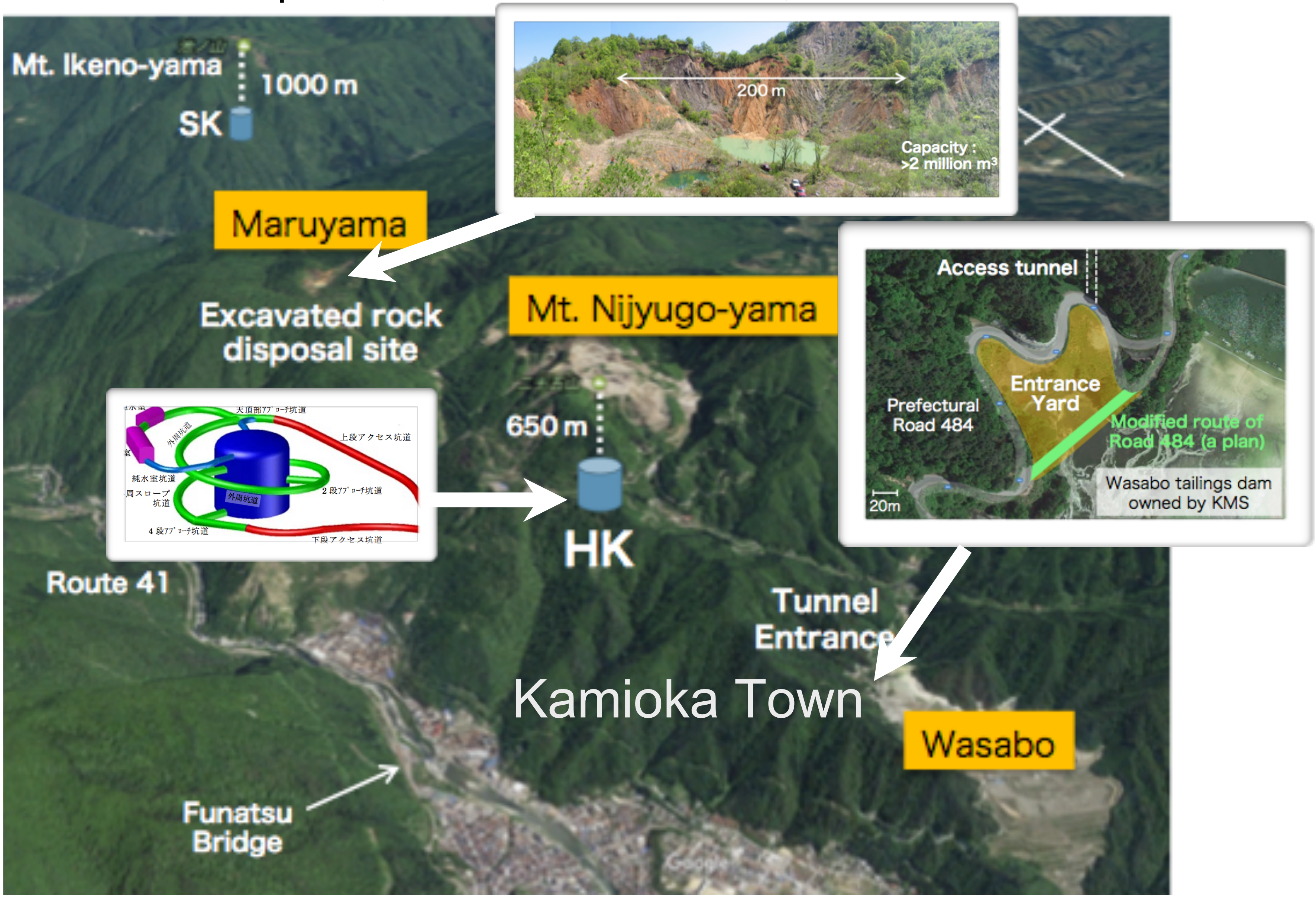
Thickness of the plastic region (blue part) can be affordable by existing support technology.

- New 50cm PMTs were developed which has double photon-efficiency of that of Super-K. Protection cover has been tested and confirmed under 80m depth water.



SITE OVERVIEW:

- 8km south of Super-K, 295km from J-PARC, 650m rock overburden



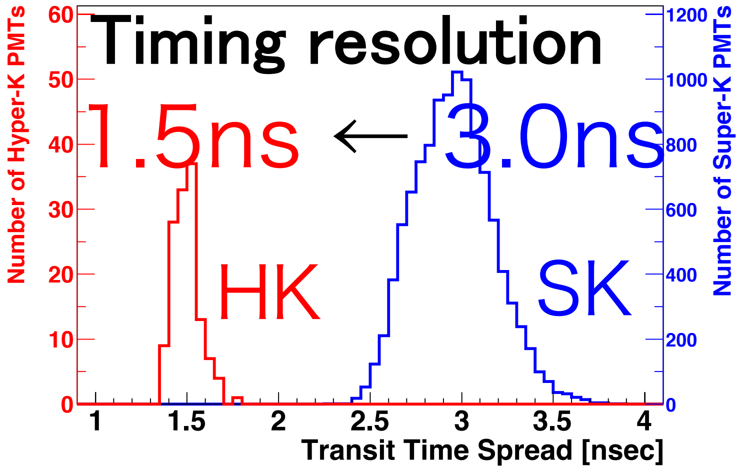
CONSTRUCTION 2020:

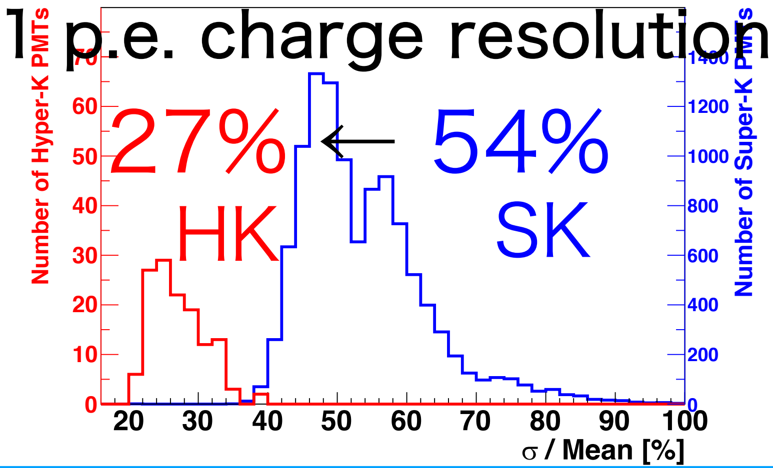
- Geological survey for detailed cavern design
  - 1 year for borehole coring, in-situ rock stress, in-situ rock property meas. etc.
- Access tunnel
  - Detailed designing
- Entrance yard
  - Yard leveling, power distribution, water supply, waste water treatment facility

HK-PMT IN SK:

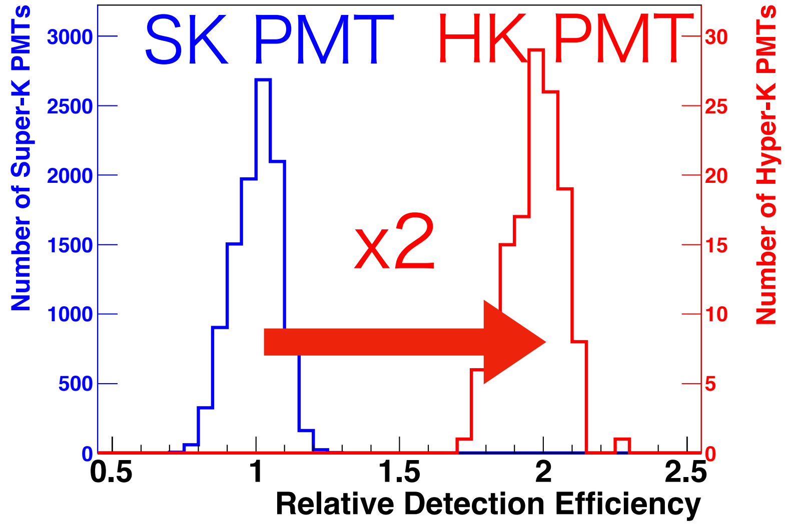
New 50cmφ PMT

- 136 HK-PMTs in Super-K in 2018
- Direct comparison w/ SK-PMTs
- long-term test will be performed in real WC detector

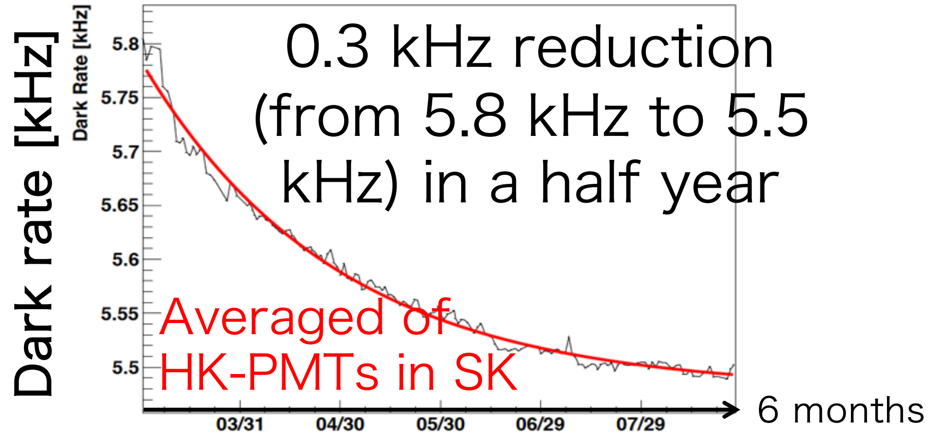




1 p.e. efficiency



- Long-term dark rate monitoring



- R&D to further reduce dark rate with the target of 4 kHz

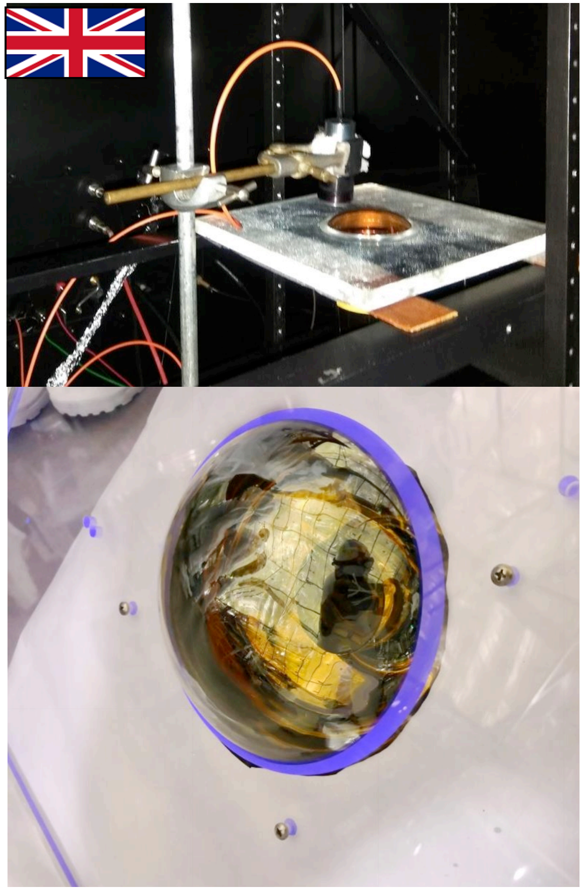
INTERNATIONAL CONTRIBUTION:

- Ongoing discussions to decide international contributions.

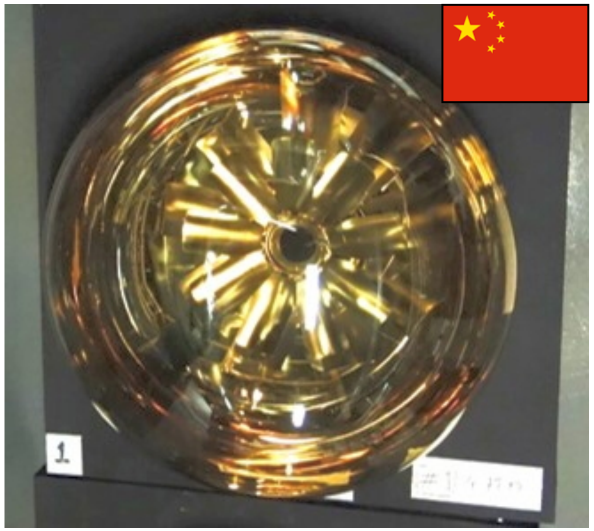
PMT cover

multi-PMT module

Outer Detector



MCP-PMT

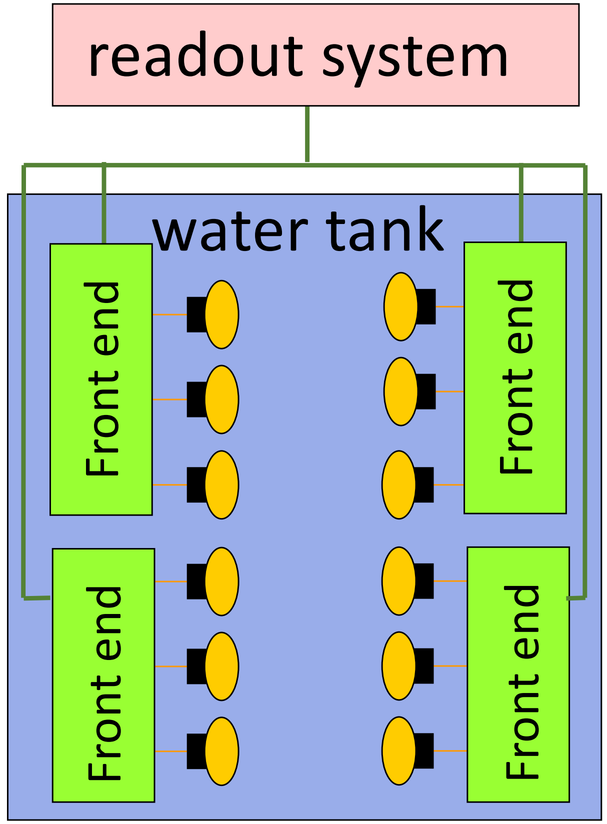


Front-end electronics system of Hyper-Kamiokande

Water-tight pressure tolerant case, feed-through and connectors.

Many technical challenges

- Mechanical design (pressure tolerance)
- Water tightness
- Low radioactive background



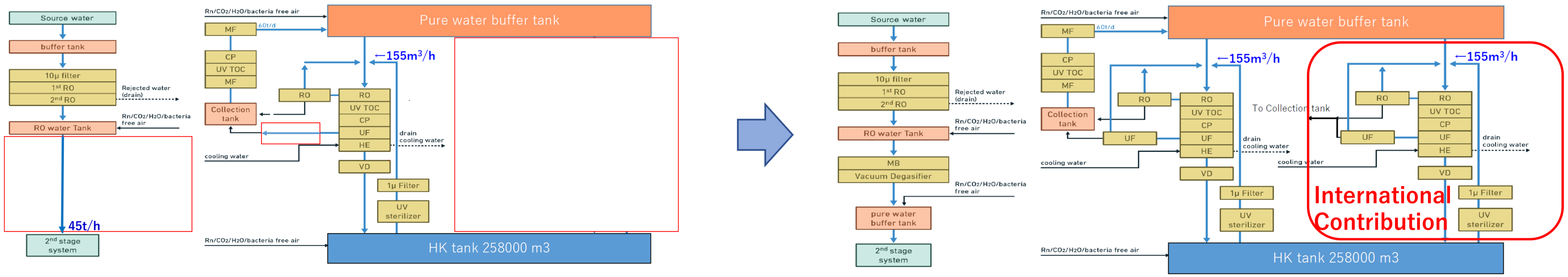
Front-end module contains

- high voltage power supply (for PMT),
- digitizers (QTC/ADC + TDC or FADC),
- system controllers,
- communication modules (optical interfaces etc.),
- timing (synchronization) system with GPS,

and all the components need to be robust and durable.

Ultrapure water system

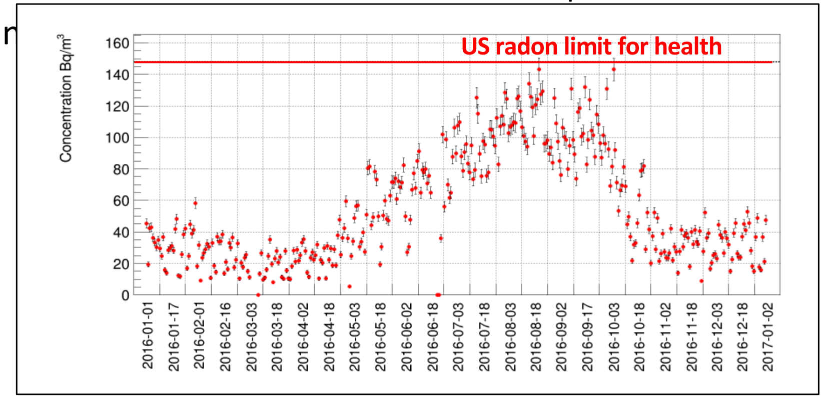
- In early stage of Super-K, 50kt of water had been processed at the rate of 30t/hour. Later the process rate was increased at the rate of 60t/hour to achieve better water quality.
- Scaling these numbers up for the 258kt of water the Hyper-K tank, for the initial stage a water circulation of at least 155t/hour is indispensable. This minimum 155t/hour will be prepared by Japan, but International contributions is anticipated to get 310t/hour flow.



Fresh air system

- The flow rate of the fresh air into the Super-K dome area is 100m^3/min. This keeps the radon level below 148Bq/m^3, the US health limit.
- A similar fresh air system will be necessary for Hyper-K, but with a larger flow rate scaled for the larger volume of the dome.
- The fresh air system for Hyper-K is expected to be built with an international contribution as it was built for Super-K.

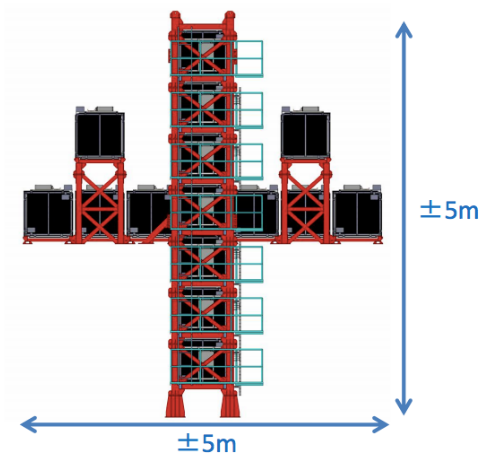
Radon concentration in Super-K dome



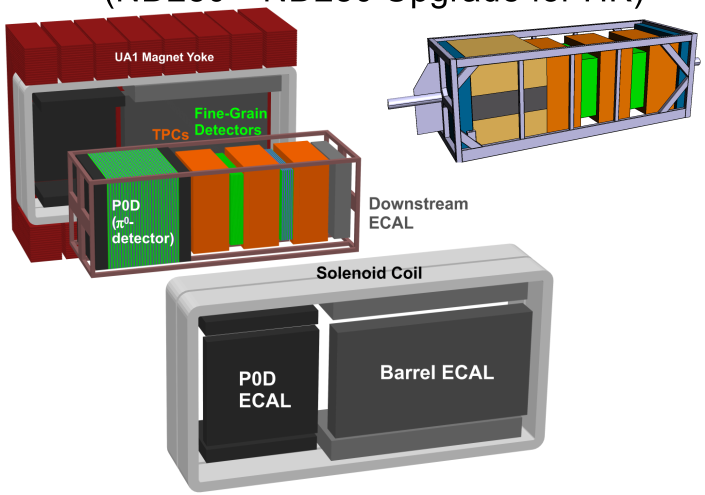
Near/Intermediate detectors

Critical components to precisely understand J-PARC beam and neutrino interactions.

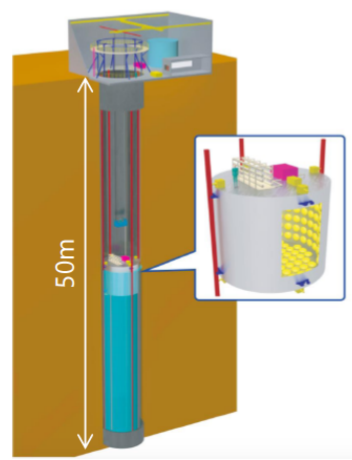
On-axis Detector
(INGRID)



Off-axis Magnetized Tracker
(ND280→ND280 Upgrade for HK)



Off-axis spanning intermediate water Cherenkov detector
IWCDの概念図



- On-axis detector: Measure beam direction and event rate
- Off-axis magnetized tracker: Measure primary (anti)neutrino interaction rates, spectrum and properties. Charge separation to measure wrong-sign background
- Intermediate WC detector: H_2O(Gd) target with off-axis angle spanning orientation

Connection to FNAL and CERN: Beam test of prototype detectors, Hadron production measurements for precision determination of J-PARC neutrino flux, etc.

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)

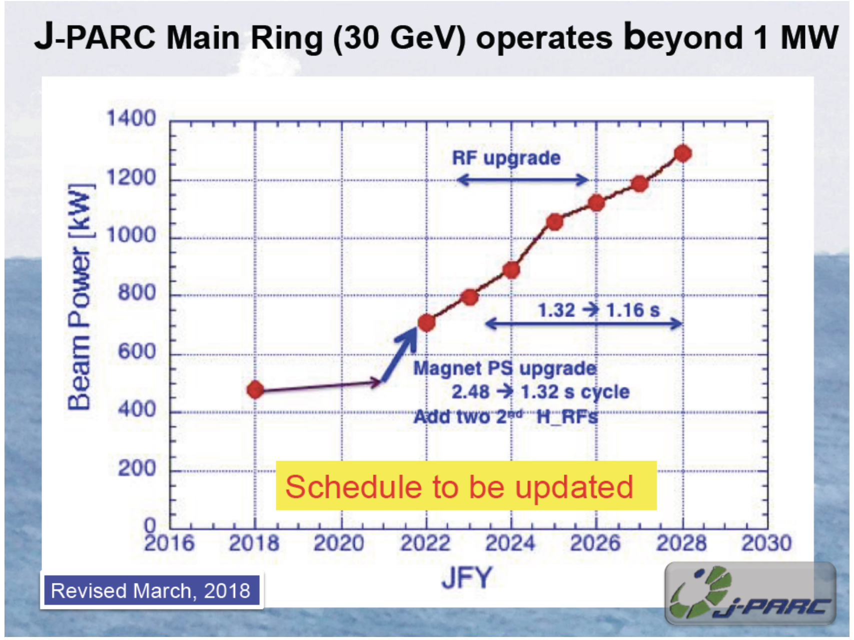
Project to be prioritized:
- COMET II
- J-PARC upgrade for Hyper Kamiokande
- Hadron Hall Extension
- H-line and g-2/EDM
- LHC and ATLAS
- Super Computer
- RNB

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% (940 → 1,300)

Funding started (2.48 → 1.28) · -10% (1.28 → 1.16)



- 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)

Long-Standing KEK-Fermilab Cooperation for Neutrino Beam

Good relationship between KEK and Fermilab experts since 1999

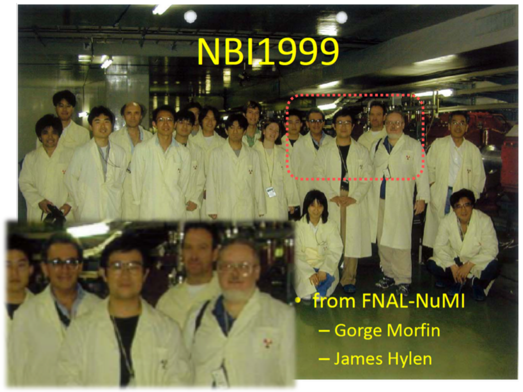
- Detailed discussions and information exchange in Neutrino Beam and Instrumentation (NBI) workshop series
  - **Many lessons learned from other facilities**

KEK/J-PARC and Fermilab share the challenges for high power neutrino beam (toward J-PARC 1.3 MW upgrade / LBNF)

- Precise and reliable beam operation
  - Reduction of beam loss / robustness of beam monitors
- Overcome high-power target facility issues
  - Handling of radioactive waste (e.g., Tritium etc.)

US-Japan Cooperative Programs in High Energy Physics

- Accelerator and beamline R&D for high power neutrino beam since 2014
  - KEK-Fermilab collaboration in accelerator and neutrino beamline development
    - Beam dynamics study for beam loss reduction
    - Beam monitor development (Gated-IPM/WSEM)
    - Laser manipulation of H- beam
    - High-power target facility issues
- LBNF-specific program launched since 2018
  - KEK-Fermilab collaboration for LBNF (next page)



Joint beam study at J-PARC MR

Joint Tune-shift measurements at Fermilab

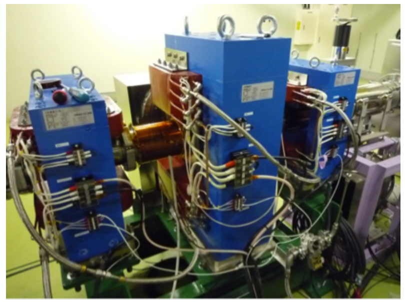


Photo of IPM

KEK-Fermilab Cooperation for LBNF

KEK Neutrino group started R&D activities for LNBF neutrino beamline since 2018

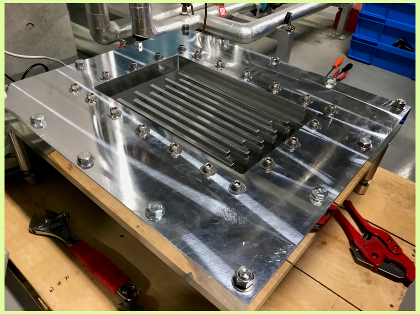
- KEK and Fermilab has common R&D items for facility upgrade/construction
- LBNF adopts similar beamline configuration to J-PARC, so KEK’s expertise can help for the design
- Fruitful discussions through remote (monthly) and face-to-face (twice/year) meetings

Cooperation items

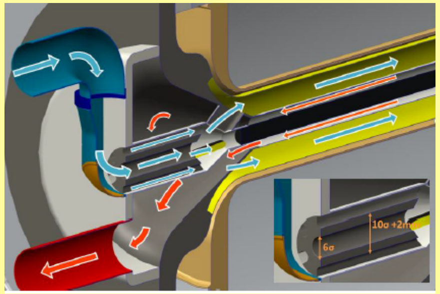
- Hermetic structure of Hatch cover of N_2 vessel
- Hermetic structure of stripline feedthrough for magnetic horns
- He circulation system for target cooling
- H_2 removal system for magnetic horn water cooling
- Muon monitor development (Electron multiplier tube: EMT)
- Tritium issues (fundamental measurements on Tritium production and release)

Hatch Cover prototype test at J-PARC

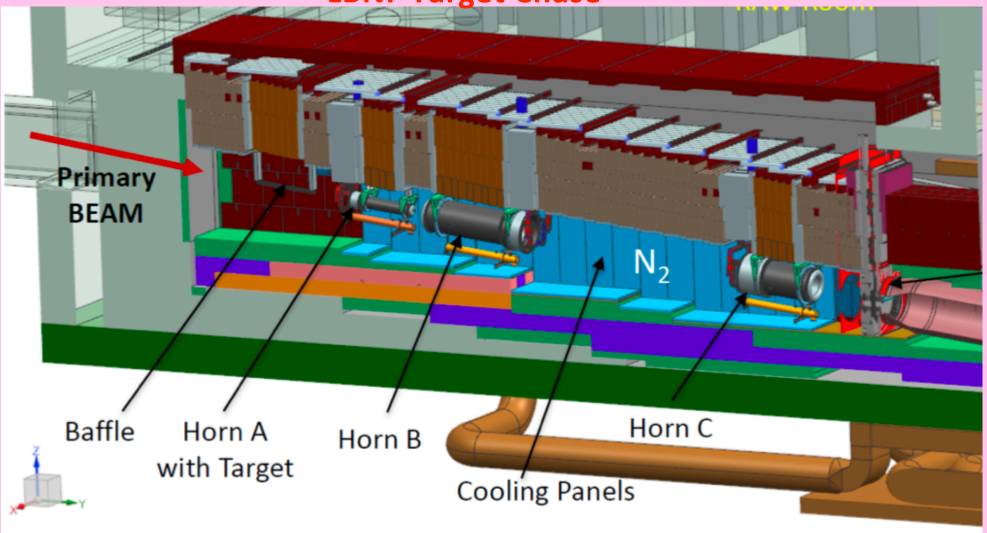
Stripline Feedthrough prototype test at J-PARC



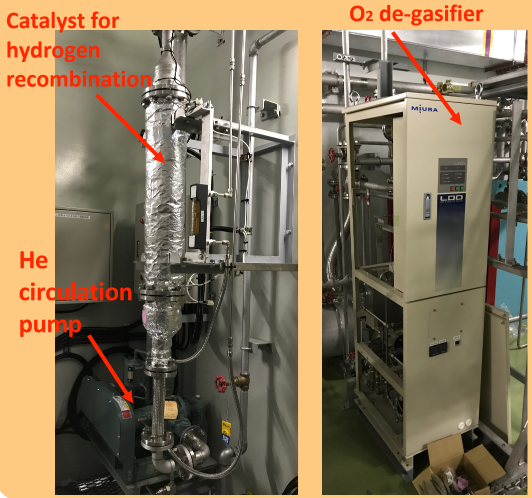
He circulation for target cooling



LBNF Target Chase

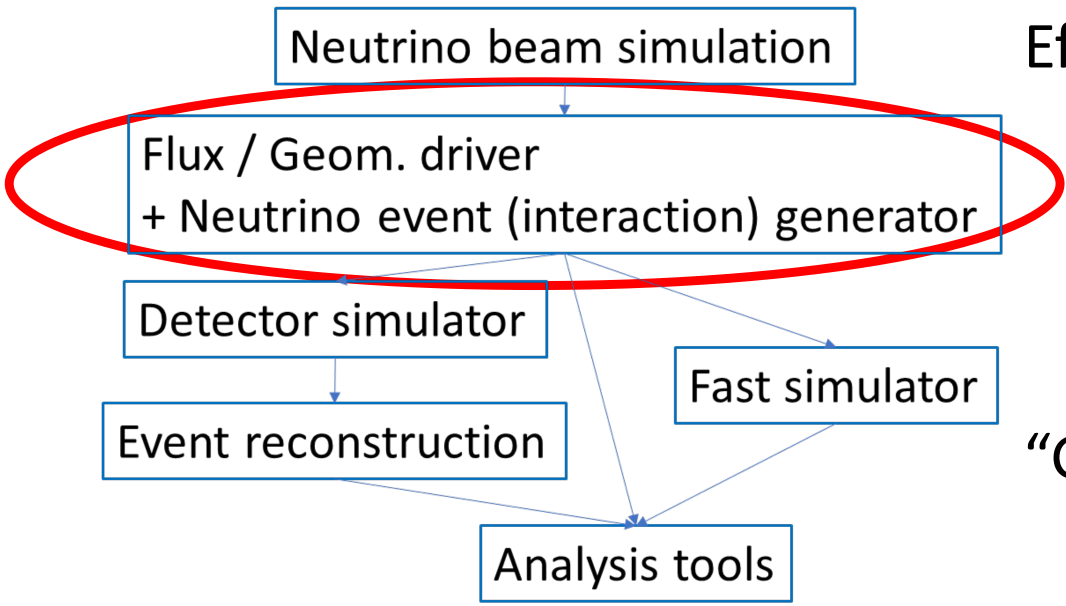


H_2 removal system



Standards for the neutrino event generators

Experiments has been bound one (or a few) “generator(s)”
but high demands to use “different” generators these days.



Efforts to define standards like
API
flux/geometry drivers,
output data formats
has been started.
“Generator tools workshop” held
at FNAL from Jan. 8 to 10th.

Flux+Geometry driver **(Generator independent software package)**
Handle various neutrino beam flux inputs and detectors

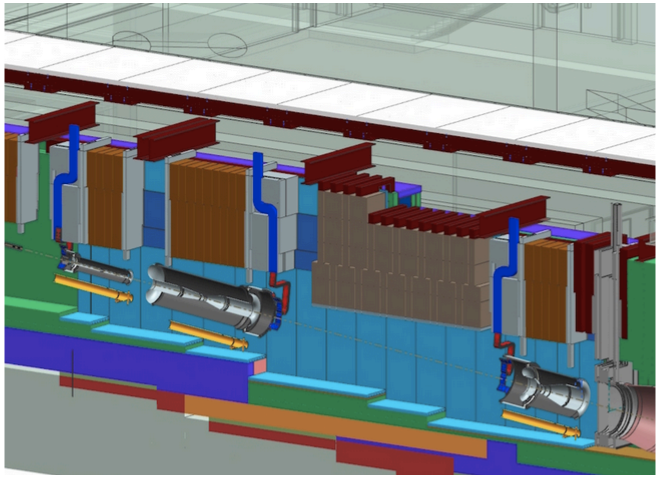
Standard API

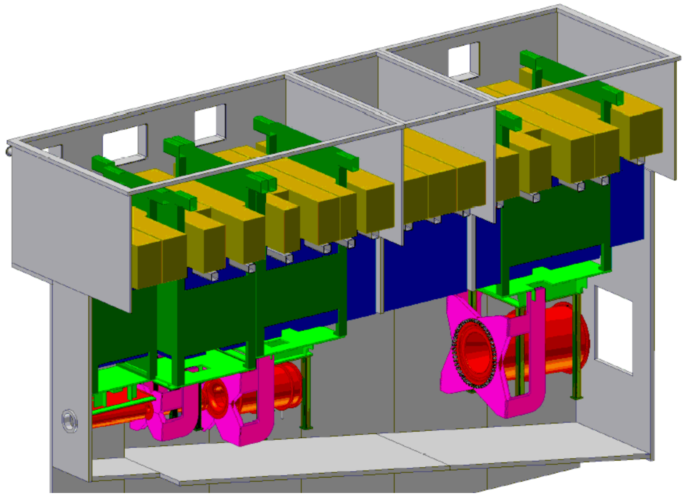
Common data format

Neutrino event generator → Generated vector

SYNERGY BTW HK AND DUNE:

- Common scientific goals
  - promoting neutrino oscillation science
    - essential for the two programs to work together
- High intensity proton accelerator and beamline
  - beam dynamics, suppression of beam loss
  - beam window, target and horn
    - on-going collaboration under US-Japan program
- Additional measurements and Analysis
  - Neutrino cross section measurements
  - Hadron production experiments for neutrino flux
    - NA61(CERN) and EMPHATIC(Fermilab)
  - Collaboration in analysis
    - T2K-NOvA supported under US-Japan program



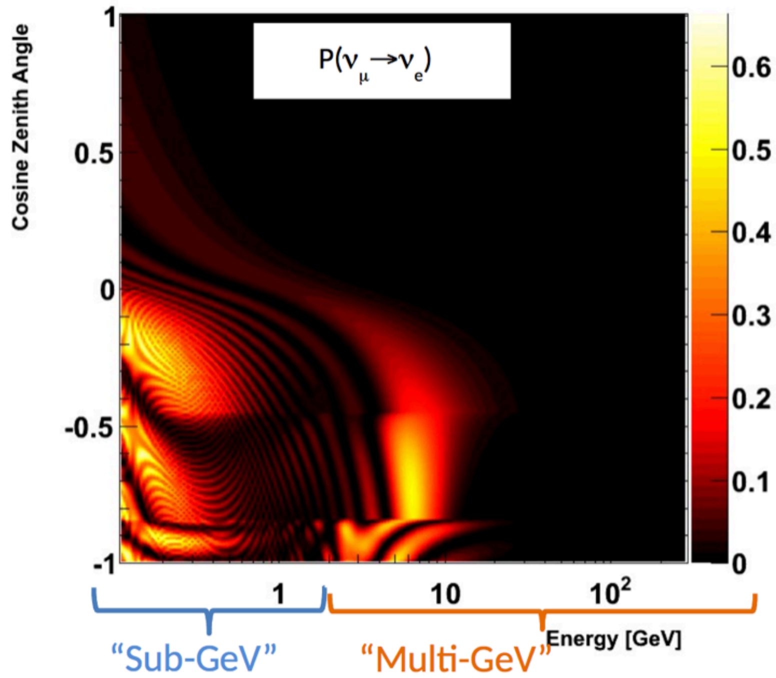


COMPLEMENTARITY:

- Accelerator neutrinos
  - Different beam spectra (off axis vs WBB) lead to different systematics and physics sensitivities.
  - Hyper-K: larger fiducial, harder for hadrons
    - kinematic energy reconstruction with leptons
  - DUNE: detects all final state particles
    - calorimetric energy reconstruction

- Neutrino astronomy (solar, supernova)
  - Hyper-K: high statistics $\bar{\nu}_e$, direction of ν_e
  - DUNE: deep low BG site, energy of ν_e

- Atmospheric neutrino oscillogram
  - Hyper-K: neutron to tag $\bar{\nu}_e$ (e^+ provides direction and energy)
  - DUNE: fully reconstruct ν_e final states to get direction and energy



SUMMARY:

- Hyper-K has started its construction phase. Experiment will start in 2027.
- Synergy and Complementarity between Hyper-K and DUNE.
- We would like to work together with international partners and contribute to the world-wide effort to make a strong particle physics and astronomy program.