HYPER-KAMIOKANDE PROJECT

the next generation nucleon decay and neutrino experiment

2022/7/21

Snowmass meeting,

XF UF-NF Long Baseline (18Q)

Masato Shiozawa

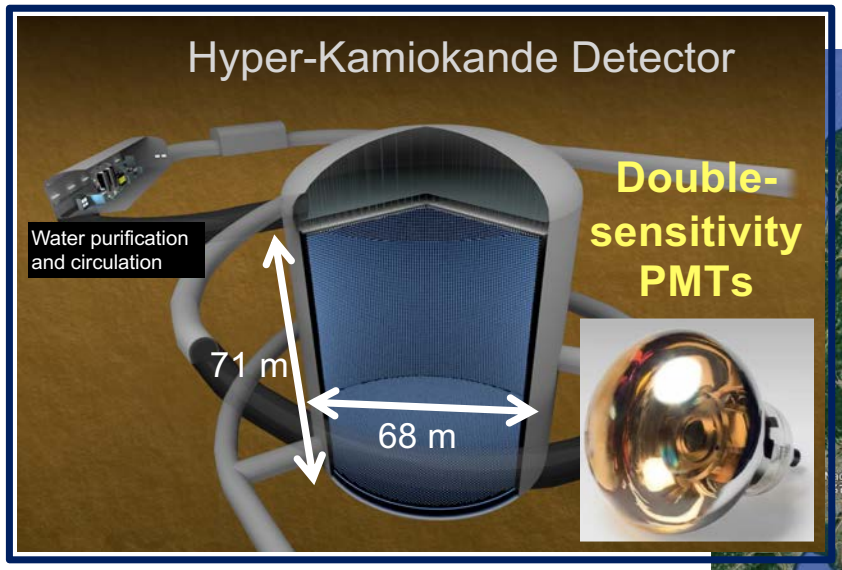
(University of Tokyo, Japanese co-spokesperson)

Hyper-K

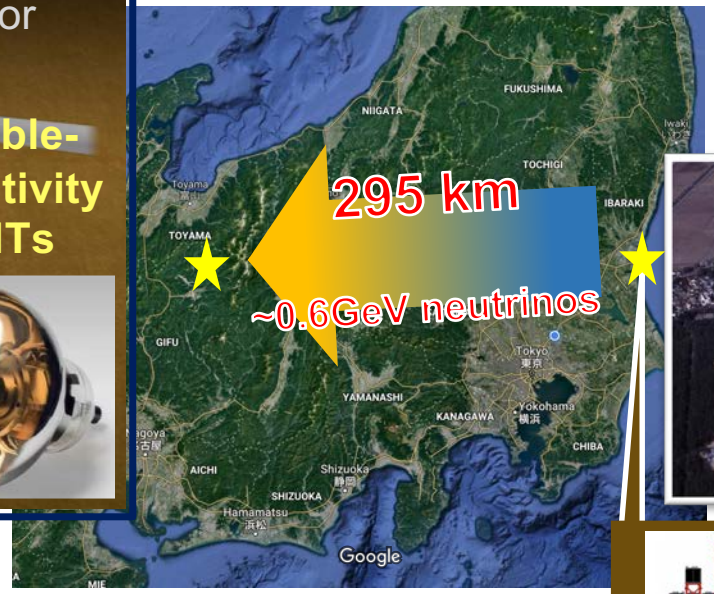
PROJECT IN A NUTSHELL:

Operation start in 2027

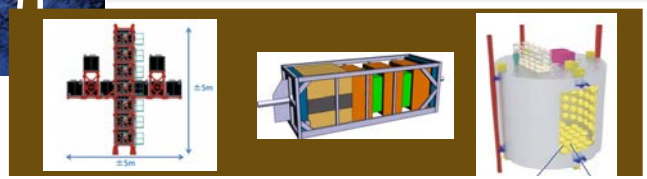
For Accelerator/Atmospheric/Solar/
Supernova neutrinos, and proton decays



Hyper-Kamiokande
(hosted by the University of Tokyo)



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



1. World-largest detector for Nucleon-decay and Neutrino experiment

to be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and to be instrumented with **double-sensitivity PMTs**

2. World most-intense neutrino beam

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

Global science by state-of-the-art technologies w/ international partners

HYPER-K COLLABORATION

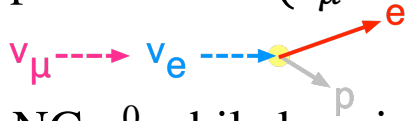
July-1, 2022
Collaboration
Meeting

- ~500 collaborators, 25% Japanese/75% non-Japanese
- ~20 countries including Japan
- UTokyo and KEK host the project

LONG-BASELINE MEASURMENT WITH J-PARC NEUTRINO BEAM

Experimental setup

- 2.5° off-axis beam peaked at 0.6 GeV (oscillation maximum at 295km)
- Measures CP violation by precision comparison of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
- Select single-ring electron-like events

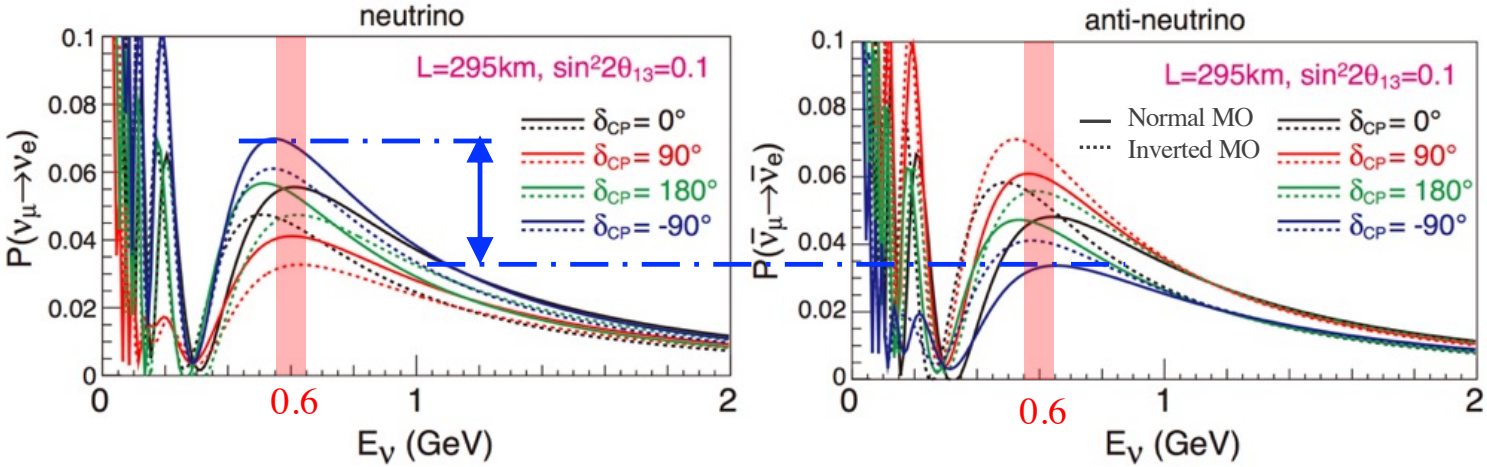


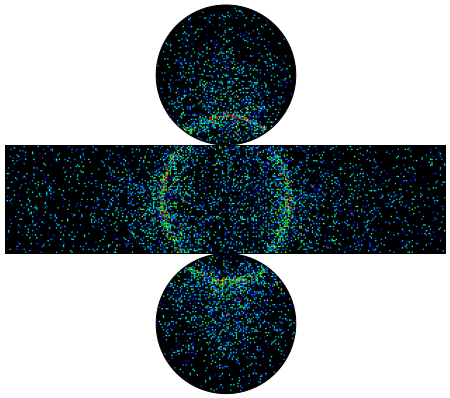
CCQE : $\nu_e + n \rightarrow e + p$

(dominant process at J-PARC beam energy)

→High rejection of >99.9% ν_μCC, 99% NC π^0 while keeping 60% ν_e signal efficiency

→Clean appearance measument with S/N~10 for neutrino beam





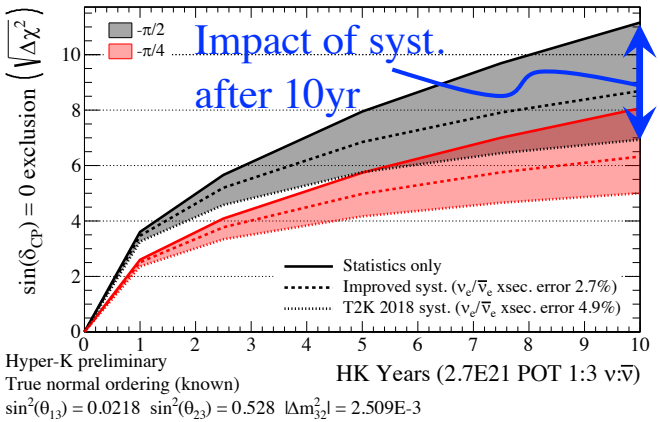
- A few % statistical uncertainties after 10 years operation with >1000 ν_e and $\bar{\nu}_e$ signals
- Projected sensitivity based on T2K systematics uncertainties + improvements for HK

Hyper-K

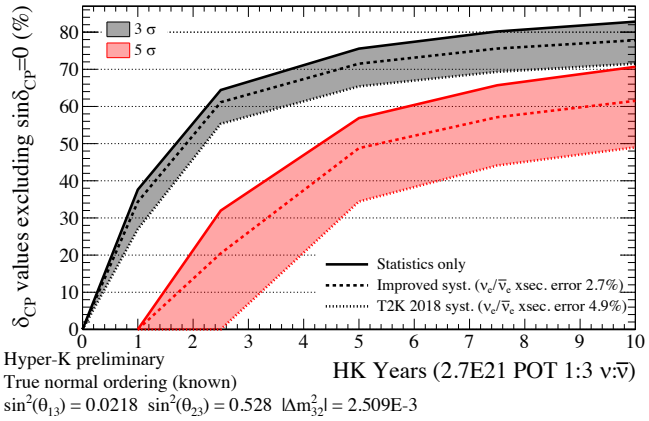
PRECISION MEASUREMENT OF NEUTRINO OSCILLATIONS

1.3MW, 10 years

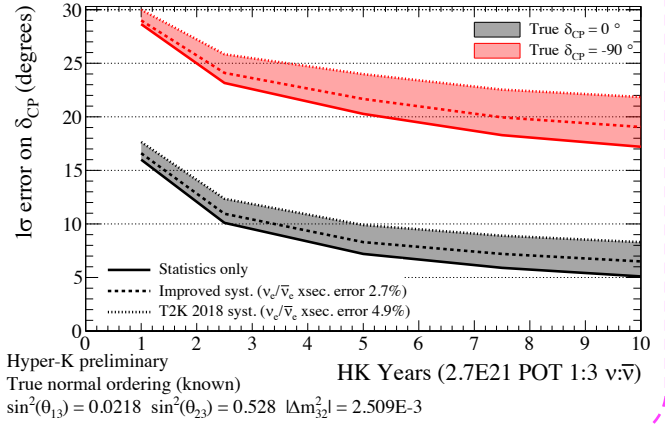
δ_{CP} Projected sensitivity to CPV



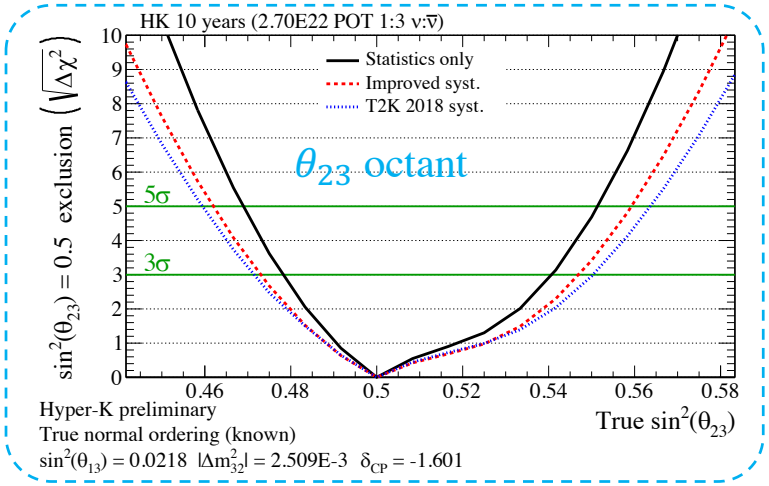
Fraction of δ_{CP} to exclude $\sin\delta_{CP} = 0$



Precision of δ_{CP} measurement



- Good opportunity to make discovery of CP violation at >5 σ
- Measurement of δ_{CP}
  - ~20° for $\delta_{cp} = -90°$ / ~7° for $\delta_{cp} = 0°$
- Reduction of systematic uncertainty has sizable impact
  - Upgrade of ND280 + 1kton scale water Cherenkov (IWCD)
  - Aim to suppress detector error below 1%



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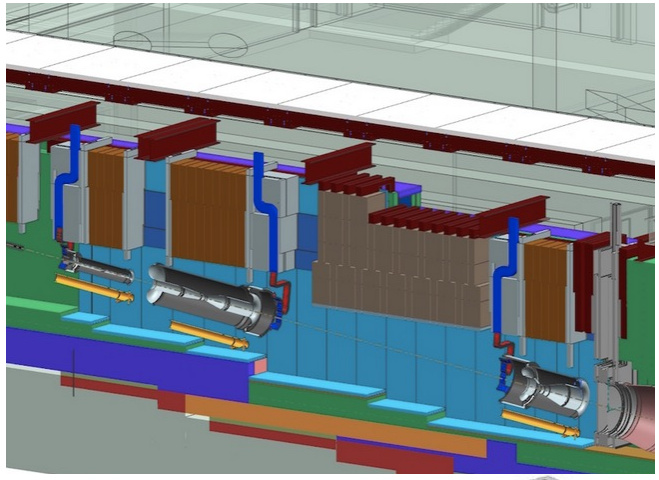
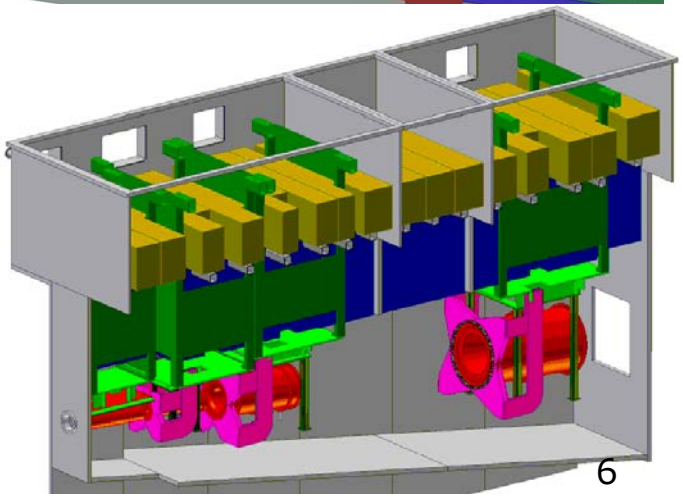
SYNERGY BTW HK AND DUNE:

- 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





HK and DUNE can work together for common challenges.

Hyper-K

COMPLEMENTARITY:

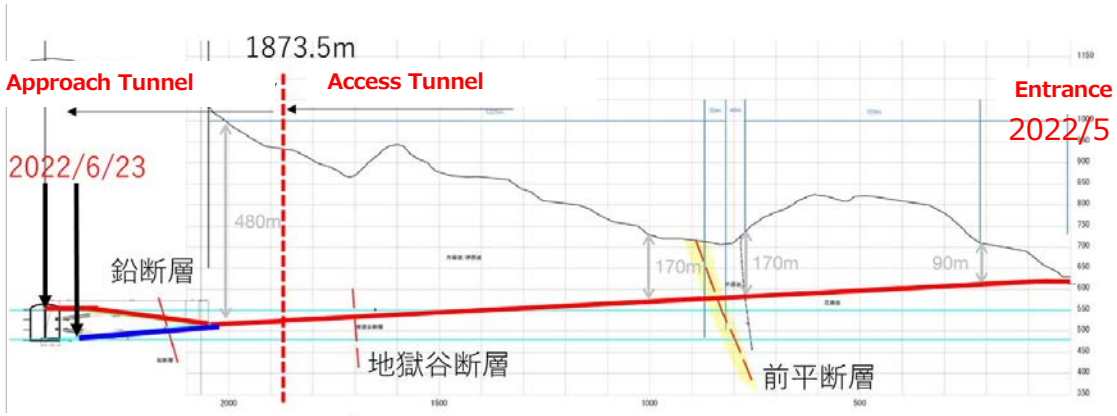
- Accelerator neutrinos
  - Different beam spectra (off axis vs WBB) lead to different systematics and physics sensitivities.
- Neutrino astronomy (solar, supernova)
  - Hyper-K: high statistics $\bar{\nu}_e$, direction of ν_e
  - DUNE: energy of ν_e
- Atmospheric neutrino oscillogram
  - Hyper-K: high statistics to test Earth's matter resonance to determine mass hierarchy
  - DUNE: fully reconstruct ν final states to get direction and energy
- Proton decays
  - Hyper-K: w/ high mass, w/ free protons, to reach 10^{35} yrs for gauge mediated $p \rightarrow e^+ + \pi^0$
  - DUNE: low BG in SUSY $p \rightarrow \nu + K^+$

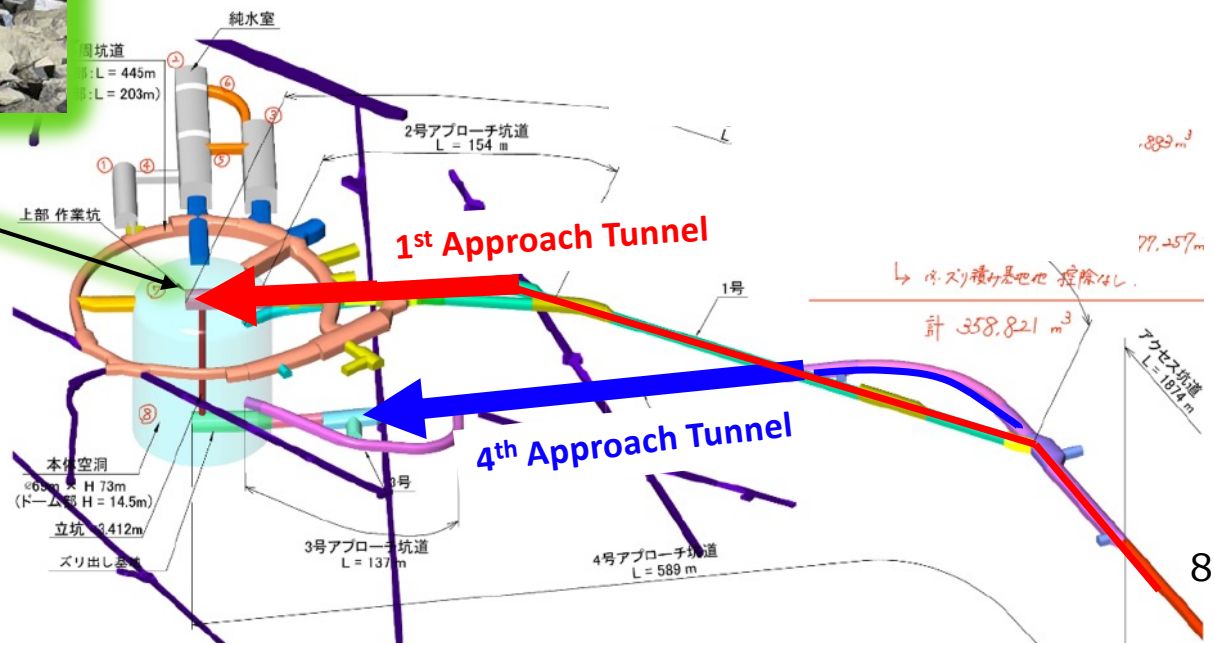
Need success of both experimenmts to get concrete results.

Hyper-K

CIVIL CONSTRUCTION

23-June,2022: The center of the main cavern dome was reached in 13 months by using high-speed drilling.





Hyper-K


Access tunnel straight section

Junction of Tunnel No. 1 and No. 4

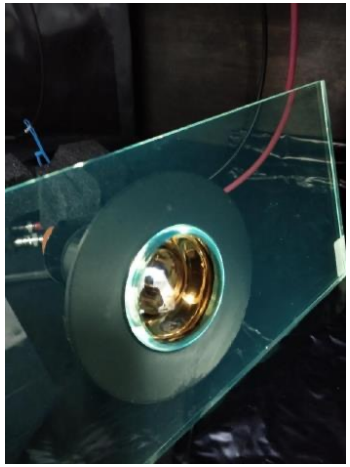

Cavern excavation (2.5 yrs) is about to begin on schedule.
Vertical shaft excavation @ center of dome

50CM PHOTO-SENSORS

- Total 3,772 PMTs (~20%) delivered by April 2022.
- Production is being suspended now to investigate their failure rate. The date of completion of delivery remains unchanged.

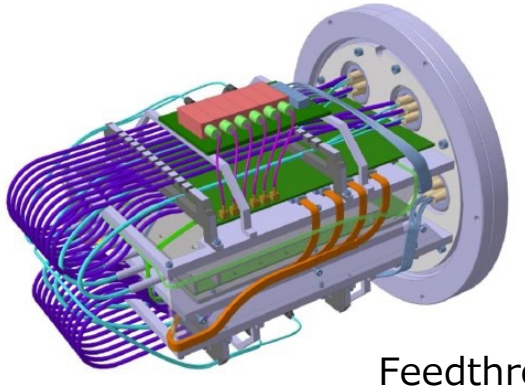
MORE DETECTOR COMPONENTS

Outer detector: PMT+WLS plate

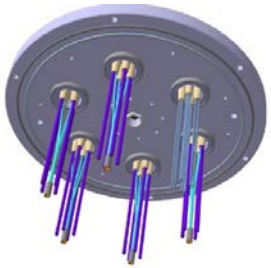


ID mockup

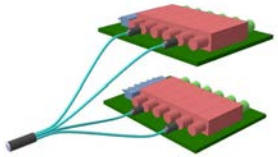
Underwater electronics:
20 x 50 cm ID PMTs + 12 x OD PMTs



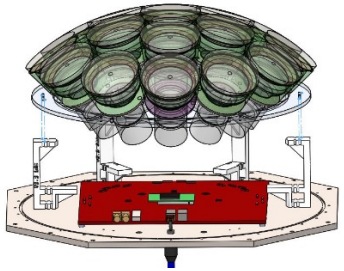
Feedthroughs for ID and OD



OD signal + HV splitter



Multi-PMT module:
(ref. KM3NeT)



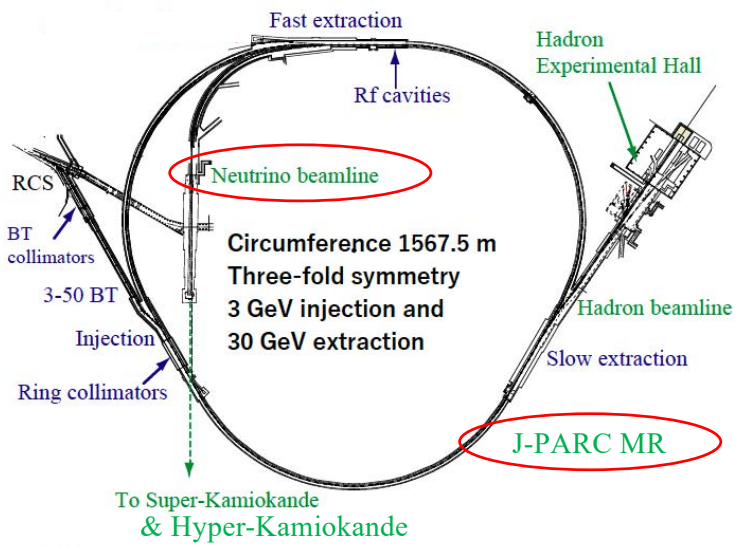
PMT cover

Hyper-K

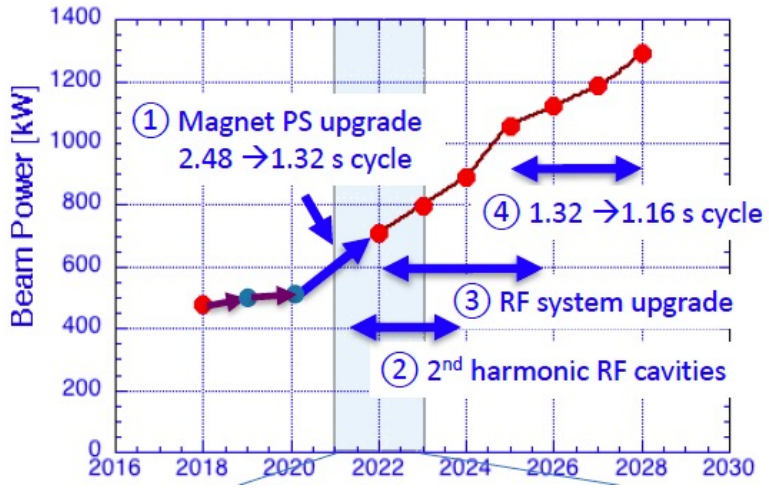
J-PARC upgrade

Beam Power upgrade from ~0.5 to 1.3 MW

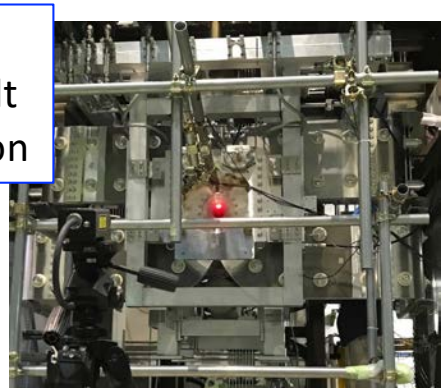
J-PARC MR & neutrino beam-line upgrade towards 1.3MW are parts of HK project.



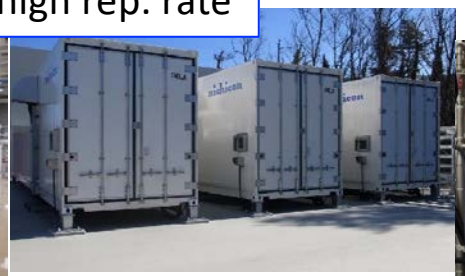
- J-PARC-MR:
  - MR magnet power supply upgrade
    ← Commissioning has been started in 2022.
  - MR RF upgrade
  - MR Fast Extraction Kicker upgrade, …
- Neutrino beam-line:
  - Upgrade of target, horn (250kA→320kA), beam monitors, …
  - Facility upgrade (cooling, radiation protection, …)



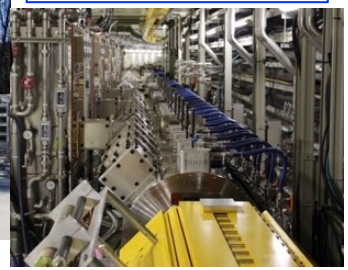
Upgraded horns for neutrino beamline built with US-JP collaboration



New main magnet PS for high rep. rate



MR-RF cavities

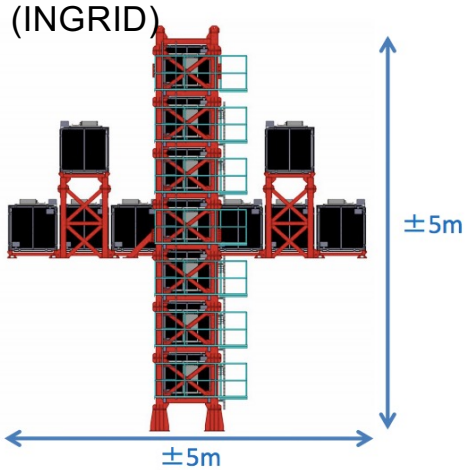


Near/Intermediate detectors

Critical components to precisely understand J-PARC beam and neutrino interactions for lepton CPV search.

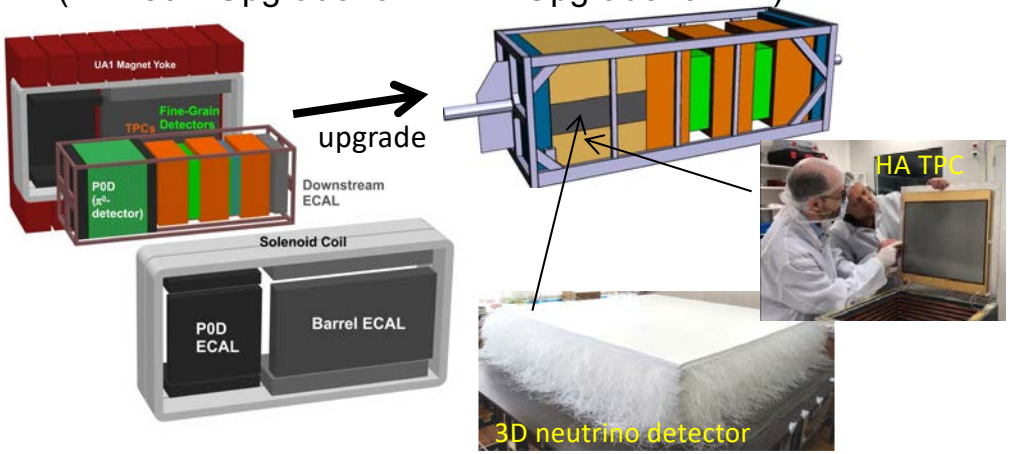
On-axis Detector

(INGRID)



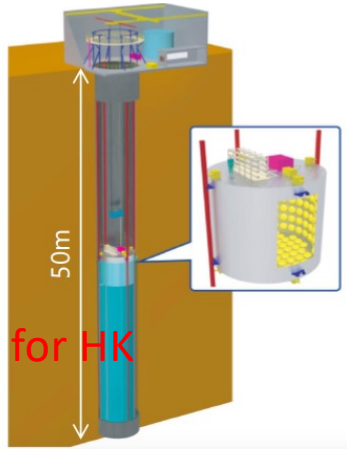
Off-axis Magnetized Tracker

(ND280→Upgrade for T2K →Upgrade for HK)



Off-axis spanning intermediate water Cherenkov detector

(IWCD)



New for HK

- 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

→ Upgrade by T2K experiment and Intensive discussion for further upgrade in HK-era is on-going.

- Intermediate WC detector: H_2O target with off-axis angle spanning orientation.

→ Detector site investigation and conceptual facility design is on-going.

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

Hyper-K

MORE FOREIGN CONTRIBUTIONS

- Water system
  - Pure water system adding up to 155 ton/hour (~10M USD)
  - Gadolinium dope and its circulation system
- Photosensors
  - adding up to 20,000 50cm PMTs (~50M USD). Open to manufacturers other than Hamamatsu.
- Calibration
  - In-kind and intellectual contributions welcome to achieve better detector systematics than Super-K, e.g. energy uncertainty of <0.5%
- Low-energy triggering
  - Intelligent trigger to extend the lower energy end of solar neutrinos
- Intermediate Water Cherenkov Detector
  - Looking for movable tank mechanism, tank itself, water system, and outer detector (6M USD)
- Accelerator (J-PARC) and beamline intensity upgrade
  - history of accelerator lab collaboration

Hyper-K

US PARTICIPATION HISTORY

- There is long and successful US-Japan partnership
  - Merged IMB and Kamiokande forces on Super-K and we also collaborated on K2K and T2K. US participation in SK and T2K is continuing.
  - US contributions to SK, K2K and T2K:
    - outer detector
    - calibration
    - electronics
    - low energy trigger system
    - radon free air system
    - T2K near detector and horns
    - K2K near detectors and water system
  - Successful collaboration in KamLAND

- US participation and leadership in the Hyper-K are welcome

Hyper-K

Snowmass LOI "The Hyper-Kamiokande Experiment" (arXiv:2009.00794)

J. Bian*, F. Di Lodovico, S. Horiuchi*, J. G. Learned*, C. Mariani*, J. Maricic*, J. Pedro Ochoa Ricoux*, C. Rott*, M. Shiozawa, M. B. Smy*, H. W. Sobel*, R. B. Vogelaar* (on behalf of the Hyper-Kamiokande Collaboration)

* interests from US

Snowmass White Paper "Hyper-Kamiokande Experiment" (arXiv:2203.02029)

Hyper-Kamiokande Collaboration: K. Abe, P. Adrich, H. Aihara, R. Akutsu, I. Alekseev, A. Ali, F. Ameli, L.H.V. Anthony, A. Araya, Y. Asaoka, V. Aushev, I. Bandac, M. Barbi, G. Barr, M. Batkiewicz-Kwasniak, M. Bellato, V. Berardi, L. Bernard, E. Bernardini, L. Berns, S. Bhadra, J. Bian, A. Blanchet, A. Blondel, A. Boiano, S. Bolognesi, L. Bonavera, S. Borjabad, T. Boschi, D. Bose, S .B. Boyd, C. Bozza, A. Bravar, C. Bronner, A. Bubak, A. Buchowicz, M. Buizza Avanzini, F. S. Cafagna, N. F. Calabria, J. M. Calvo-Mozota, S. Cao, M. G. Catanesi, S. Chakraborty, J. H. Choi, S. Choubey, M. Cicerchia, J. Coleman, G. Collazuol, S. Cuen-Rochin, M. Danilov, E. De la Fuente, P. de Perio, G. De Rosa, T. Dealtry, C. J. Densham, A. Dergacheva, N. Deshmukh, M. M. Devi, F. Di Lodovico, P. Di Meo, I. Di Palma, T. A. Doyle, E. Drakopoulou, O. Drapier, J. Dumarchez, L. Eklund, S. El Hedri, J. Ellis, S. Emery, A. Esmaili, S. Fedotov, J. Feng, E. Fernández-Martinez, P. Ferrario, B. Ferrazzi, A. Finch, C. Finley, G. Fiorillo, M. Fitton, M. Friend, Y. Fujii, Y. Fukuda, G. Galinski, J. Gao, C. Garde, A. Garfagnini, S. Garode, L. Gialanella, C. Giganti, J. J. Gomez-Cadenas, M. Gonin, J. González-Nuevo, A. Gorin, R. Gornea, F. Gramegna, M. Grassi, G. Grella, M. Guigue, D. R. Hadley et al. (290 additional authors not shown)

Hyper-K

SUMMARY:

- Hyper-K has started its construction and is on schedule. 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.

Hyper-K