Hyper-Kamiokande

Hyper-Kamiokande experiment

ILANCE, LLR, LPNHE, OMEGA

ILANCE
International Laboratory for Astrophysics, Neutrino and Cosmology Experiments

LLR

LPNHE PARIS

OMEGA Microelectronics

SCIENCES SORBONNE UNIVERSITÉ

ÉCOLE POLYTECHNIQUE

cnrs dépasser les frontières IN2P3 Les deux infinis

IN2P3 physicists and engineers

ILANCE: M. Gonin, G. Pronost (postdoc)

LLR: A.Afiri, M. Buizza-Avanzini, O. Drapier, F. Gastaldi, M. Louzir, T. Mueller, J. Nanni, P. Paganini, B. Quilain, A. Beauchene (PhD student)

LPNHE: A. Blondel, J. Dumarchez, C. Giganti, M. Guigue, M. Martini, B. Popov, S. Russo, V. Voisin, M. Zito, W. Saenz (postdoc ANR), L. Mellet (PhD student), C. Dalmazzone (PhD student) + one more ANR postdoc starting from 2023

OMEGA: S. Callier, P. Dinaucourt, S. Conforti, F. Dulucq, L. Raux, C. de la Taille

APC: C.Volpe (theoretician)

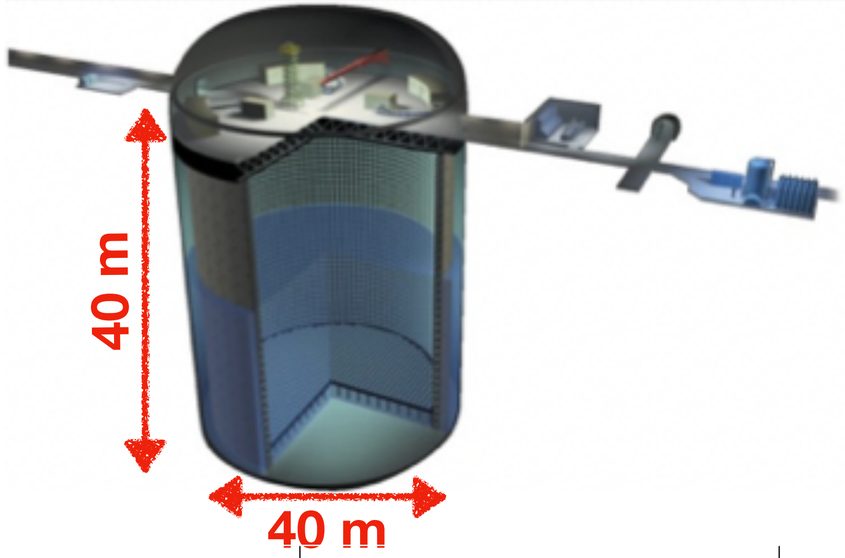
Natural continuation of our participation in the Japanese neutrino program (T2K and SK)
In close collaboration with CEA-IRFU colleagues

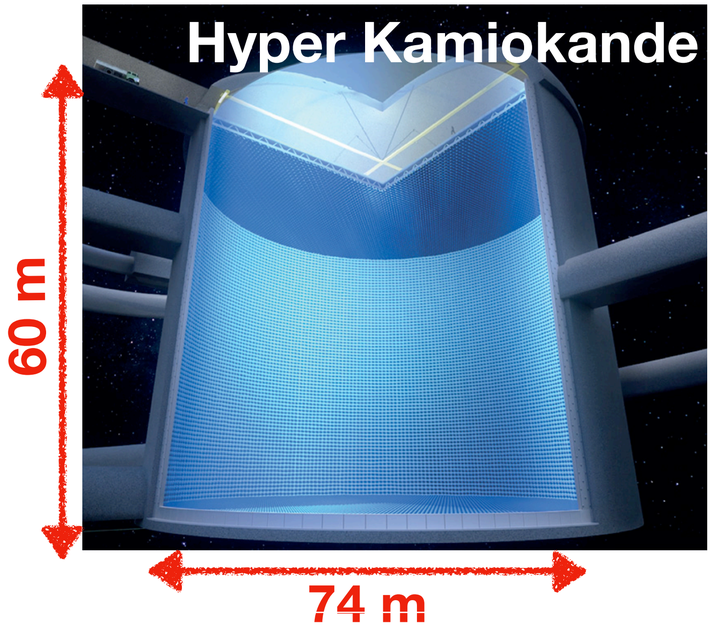
Hyper-Kamiokande in Japan

- Third generation Water Cherenkov detector in Japan
- Based on the experience from T2K and Super-Kamiokande
- 295 km and 2.5° off-axis w.r.t. existing neutrino beam ($\langle E_\nu \rangle \approx 600$ MeV) from J-PARC
- Existing near detector ND280 currently being upgraded for T2K-II
- Vast non-accelerator scientific program

Hyper-Kamiokande vs Super-Kamiokande

Super Kamiokande





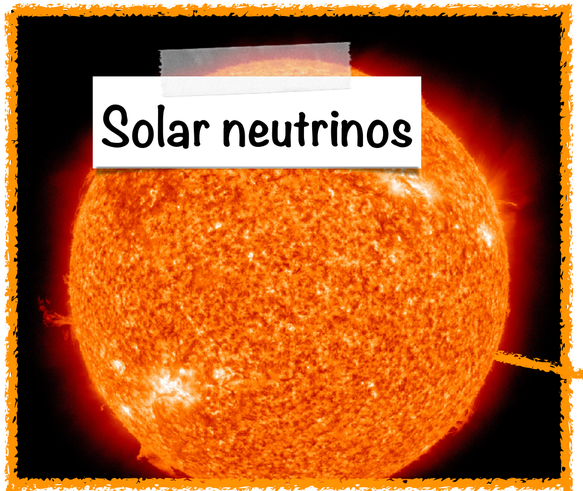
	Super Kamiokande	Hyper Kamiokande
Site	Mozumi-yama	Tochibora-yama
Number of ID 20” PMTs	11 129	>20,000
Photo-coverage	40 %	>20%
Single-photon efficiency/PMT	~12%	~24%
Dark rate/PMT	~4 kHz	~4kHz
Time resolution of 1 photon	~3 ns	~1.1 ns
Total/fiducial mass (kton)	50 / **22.5**	260 / 187

Fiducial volume x8:
→ non-beam ν physics

Beam neutrino event rate x 20:
→ beam ν physics

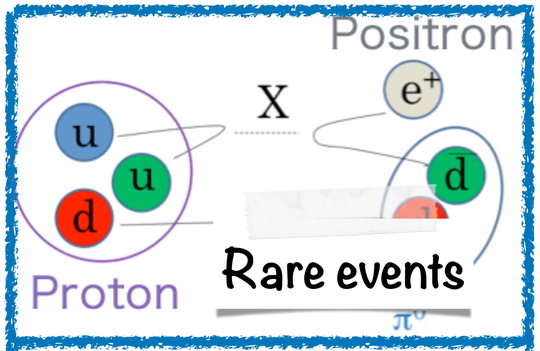
Start operations in 2027 with 240 kt.MW and an assumed runtime 10^7 s per year

Hyper-Kamiokande physics program



- MSW effect
- Non-standard interactions

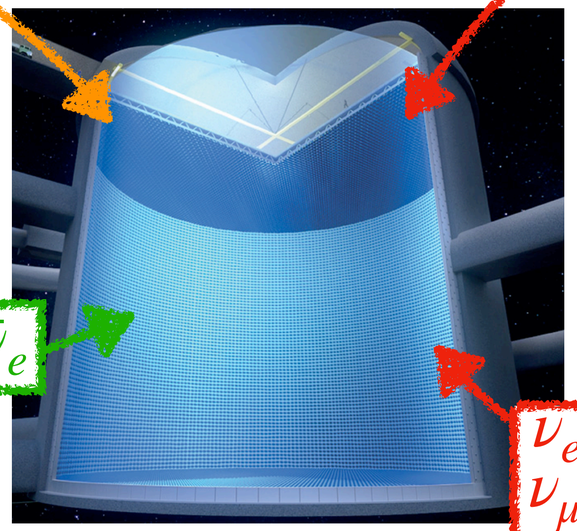
- Transient SN ν: constrain SN profile models
- Relic SN ν: constrain cosmic star formation



- Probe Grand Unified Theories via p-decay or $n - \bar{n}$ oscillation

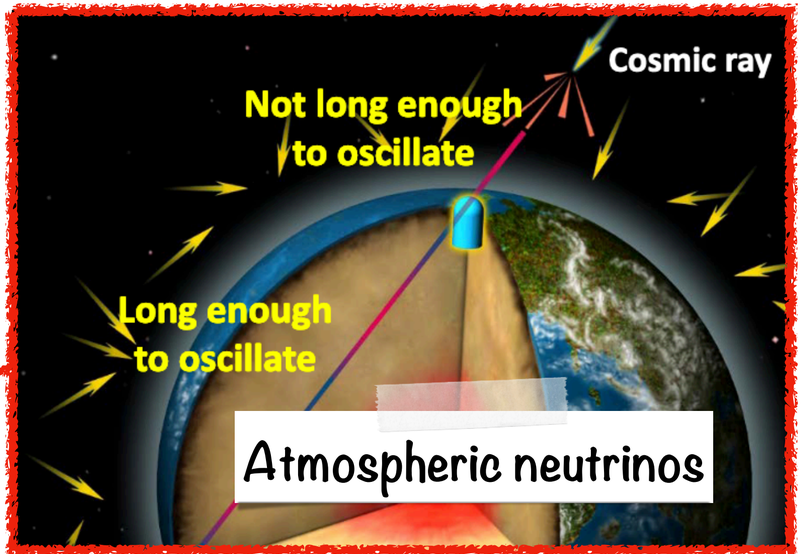
ν_e

$\bar{\nu}_e$

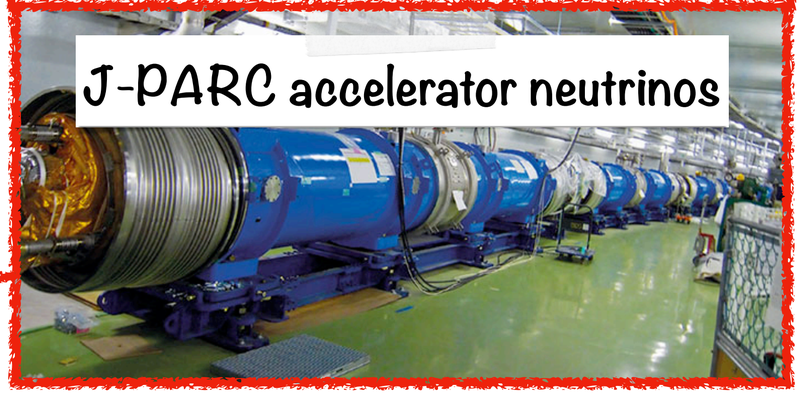


ν_e ν_e
ν_μ $\bar{\nu}_\mu$

ν_e ν_e
ν_μ $\bar{\nu}_\mu$

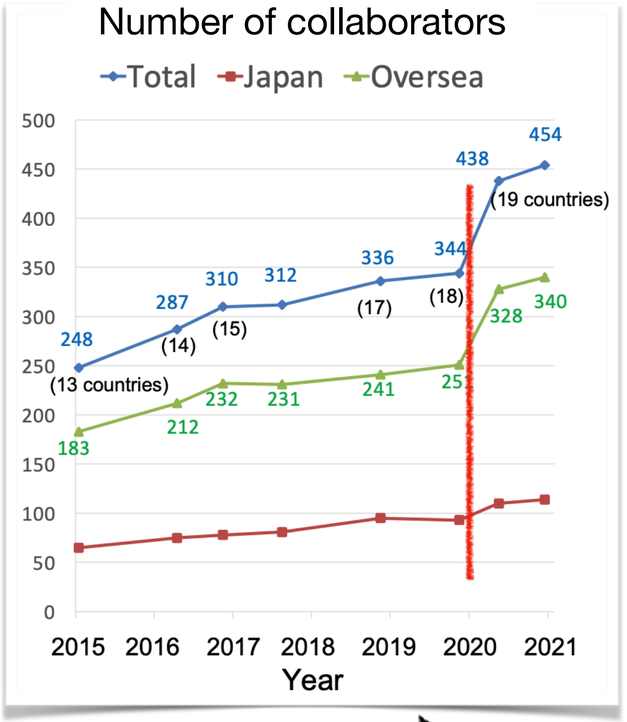


- Observe CP violation for leptons at 5σ
- Precise measurement of δ_{CP}
- High sensitivity to ν mass ordering



Experiment approval: key dates

Conclusions of 2018 SC : “Le projet n’est pas actuellement approuvé au Japon et il n’y a pas suffisamment d’informations quant à l’organisation du projet pour envisager et discuter des participations directes à HK.”



Aug. 2019: MEXT approval of HK project

Feb. 2020: HK budget approved

May 2020: Signature of MOU

May 2021: Groundbreaking ceremony

2018 | 2019 | 2020 | 2021

Oct. 2018: IN2P3 CS discussing HK

Oct. 2019: LPNHE CS approved HK

Jan. 2021: CEA CS approved HK

March 2021: LLR CS approved HK

Oct. 2021: IN2P3 CS discussing HK

Conclusions of the 2021 SC

6.3. Avis du Conseil

La dernière présentation de la contribution de l'IN2P3 à HK en session du Conseil Scientifique de l'IN2P3 est assez récente (octobre 2018). En octobre 2021, le Conseil constate une évolution positive remarquable au cours des deux dernières années :

- Le projet HK est approuvé par le gouvernement japonais en août 2019, le budget (500 M$) est voté en février 2020, et le début de la prise de données est confirmé pour 2027 ;
- Deux laboratoires de l'IN2P3 (LPNHE, LLR) et le CEA, soutenus par leurs conseils scientifiques respectifs, rejoignent le projet HK, en octobre 2019 pour le LPNHE, en janvier 2021 pour le CEA, et en mars 2021 pour le LLR.

…

Le Conseil souligne cependant qu'un engagement technique direct sur le détecteur lointain de HK est requis pour confirmer et valider le ticket d'entrée de l'IN2P3 dans HK[4], et considère que la participation centrale proposée par le LPNHE et le LLR en collaboration avec OMEGA sur le digitaliseur HKROC et sur le système de distribution d'horloge répond à cette condition dans une enveloppe budgétaire raisonnable. Le Conseil note également que les équipes de l'IN2P3 proposent une réflexion pour contribuer aux coûts d'opération à travers la participation du CC-IN2P3.

RD4HK initiated in 2022
(Benjamin's talk)

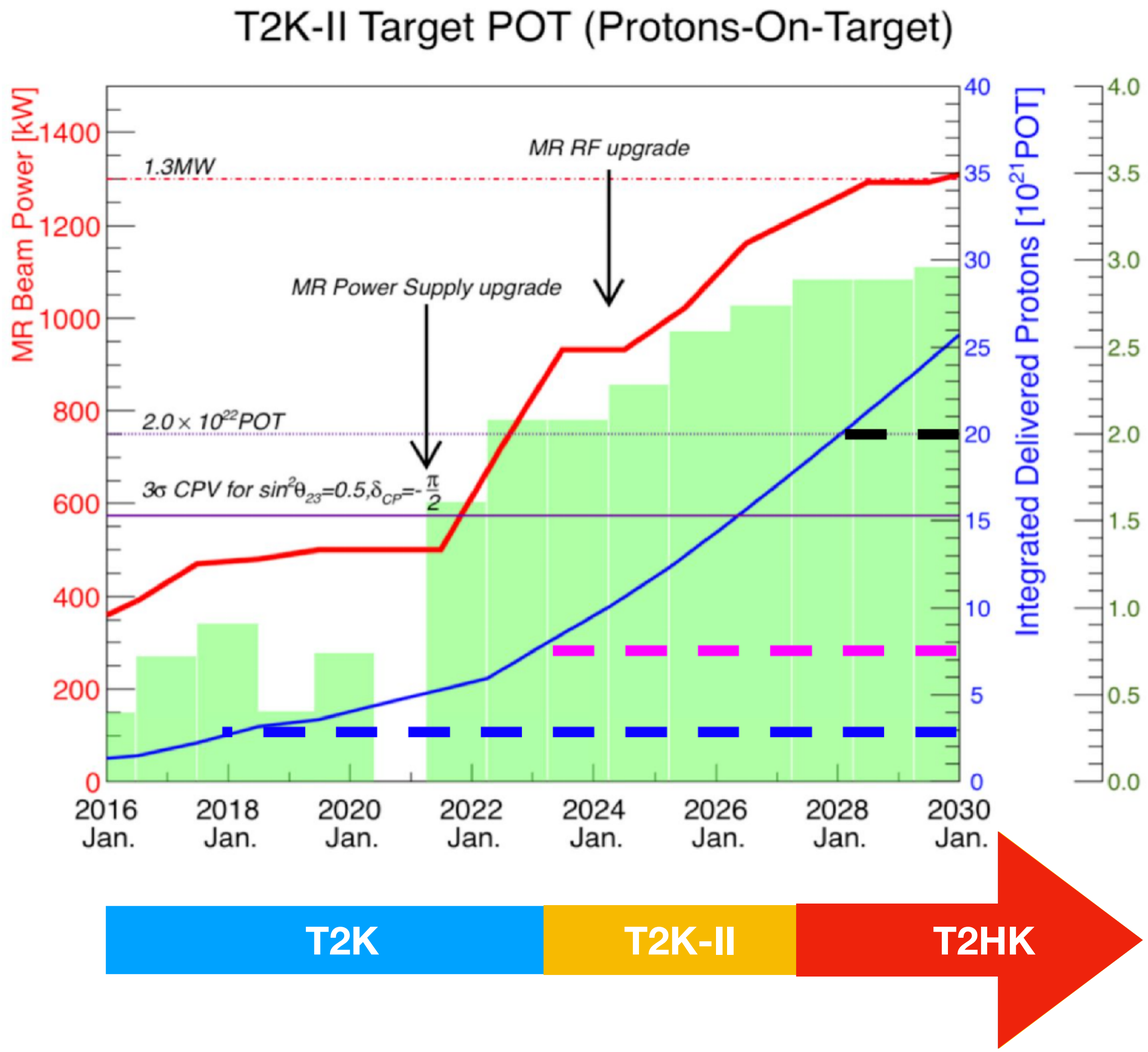
Tokai to HK: heritage from T2K

Accelerator upgrade

Power increase (500kW → 1.3 MW)

x2.7 more stats per s (wrt T2K-I)

$\nu/\bar{\nu}$ flux uncertainty < 5% thanks to NA61/SHINE hadroproduction measurements



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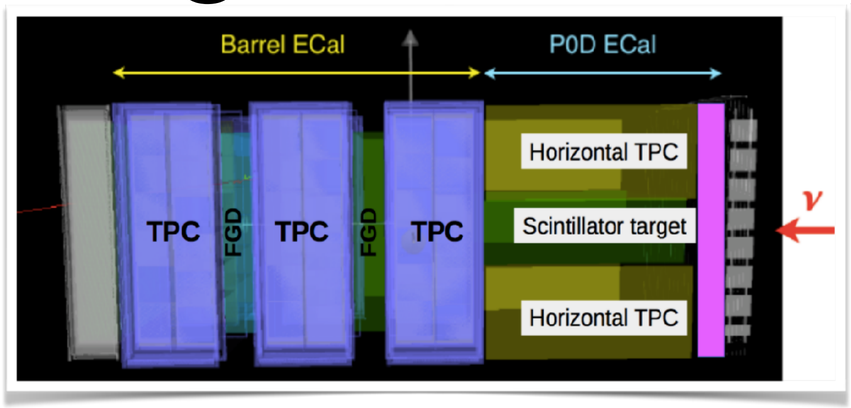
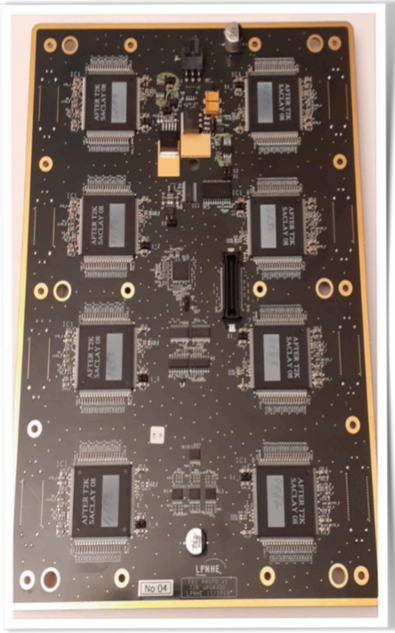
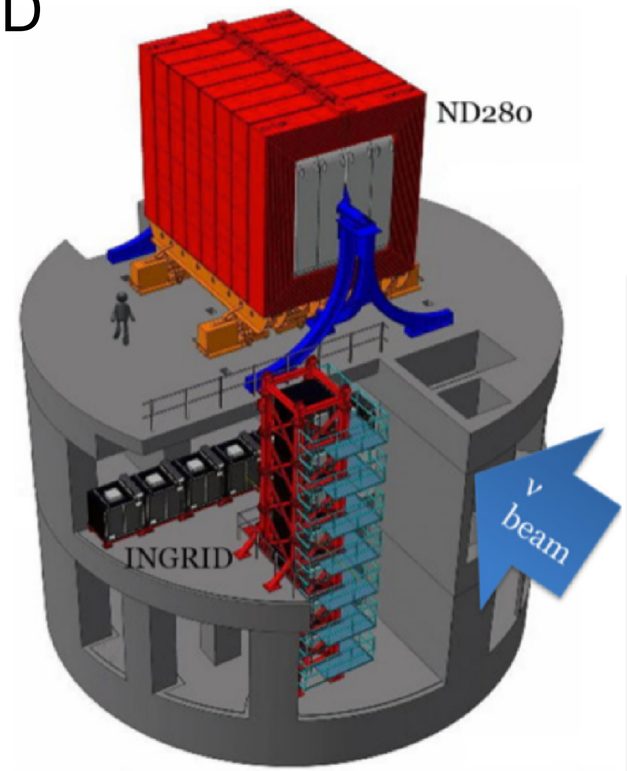
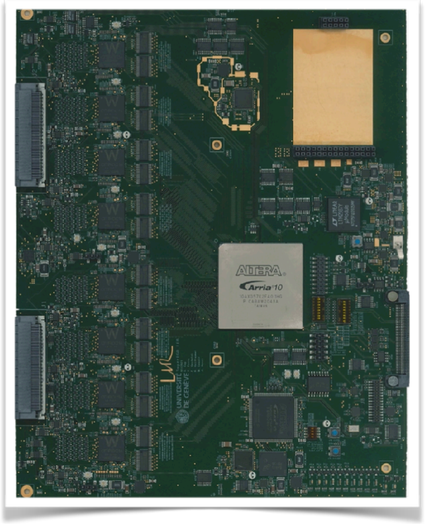
Magnetized near detector @280 m (ND280) + INGRID
- Used for T2K Oscillation Analysis for >10 years
- Being upgraded now for T2K-II
- (crucial contributions and strong support from IN2P3)
- **Systematics uncertainties under control from Day-1 of HK**





FEC for HA-TPC readout





FEB for SuperFGD readout

Tokai to HK: what will be new

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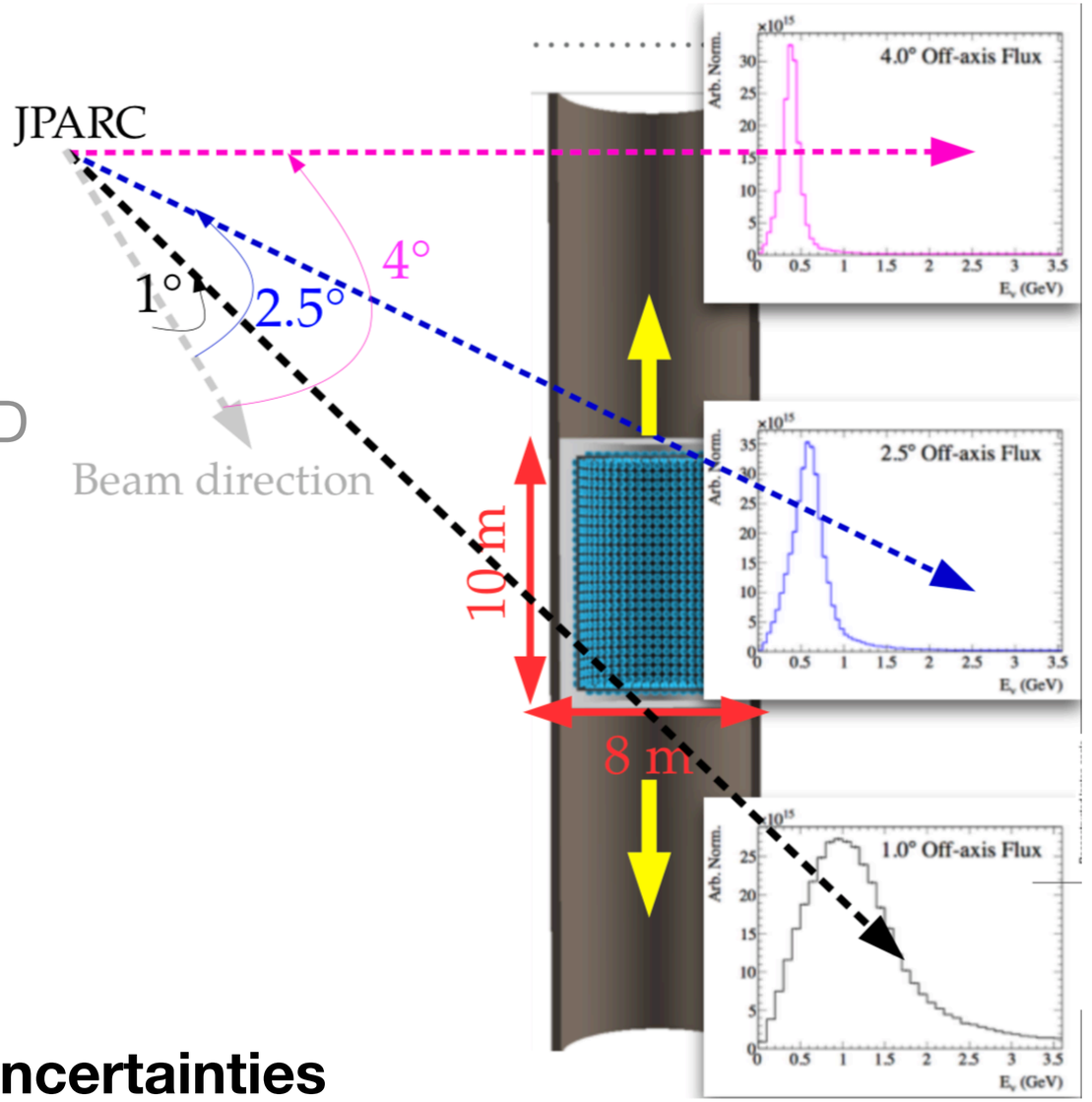
Magnetized near detector @280 m (ND280) + INGRID
- Used for T2K Oscillation Analysis for >10 years
- Being upgraded now for T2K-II
- (crucial contributions and strong support from IN2P3)
- Systematics uncertainties under control from day 1 of HK

Intermediate Water Cherenkov Detector (IWCD/E61)
- Measure ν interactions on Water
- High stats. sample of ν_e interactions

NEW

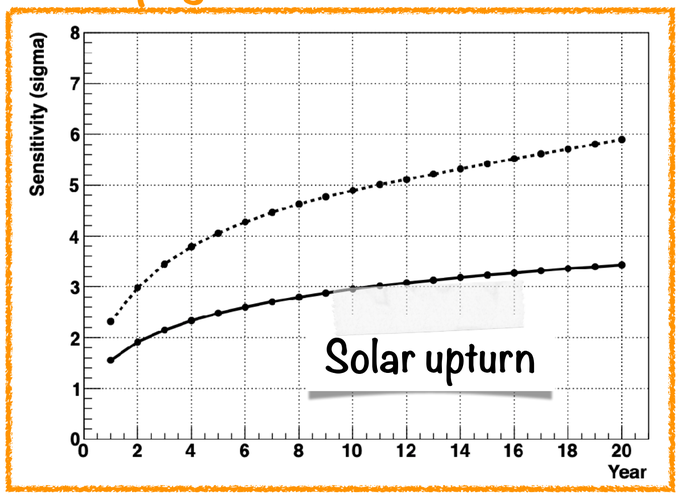
Needed to reach final HK goal for systematics uncertainties

(if IWCD is delayed, ND280 will be the only near detector on day 1 of HK)

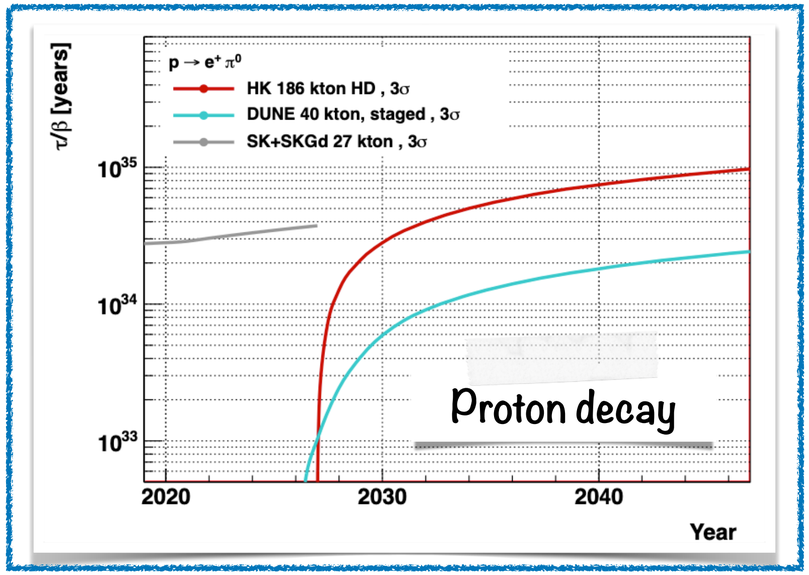


Hyper-Kamiokande Physics

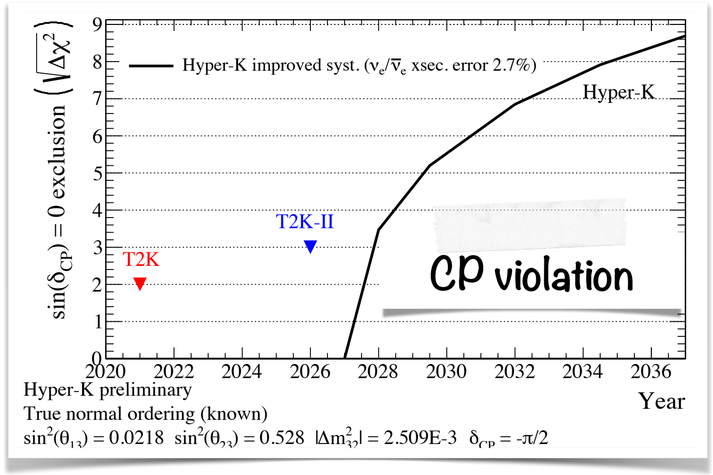
Solar physics

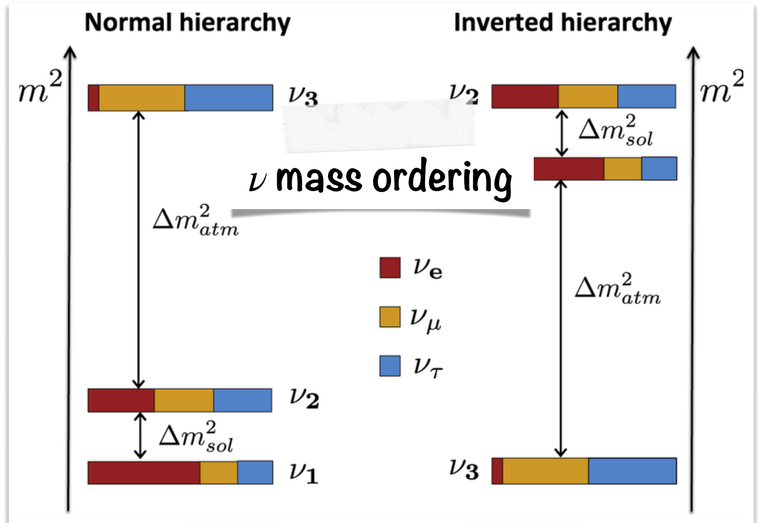


Rare events

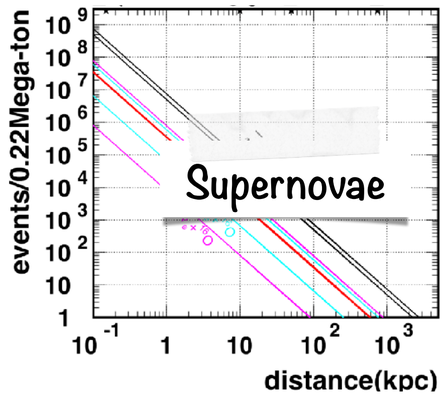


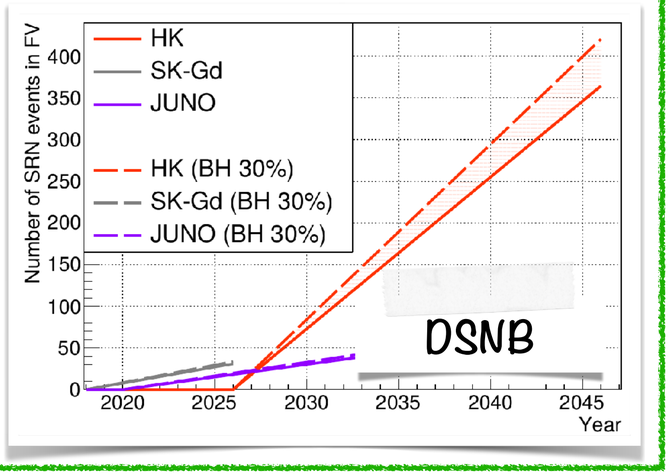
Neutrinos oscillation





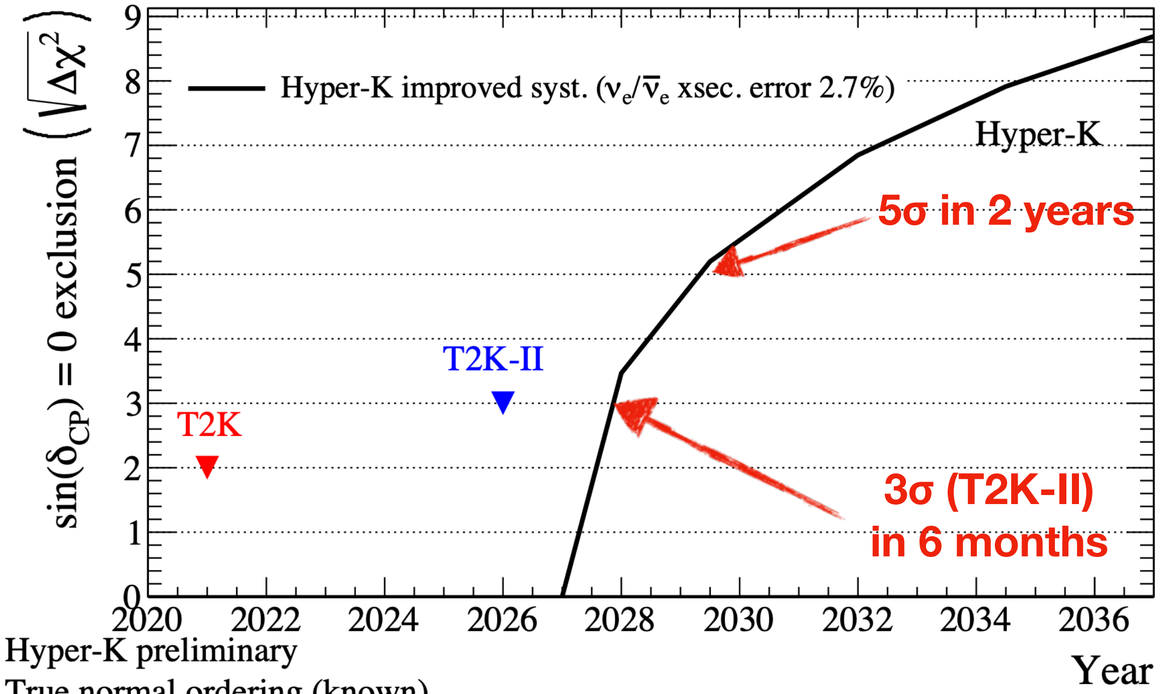
Supernovae modeling and Early Universe

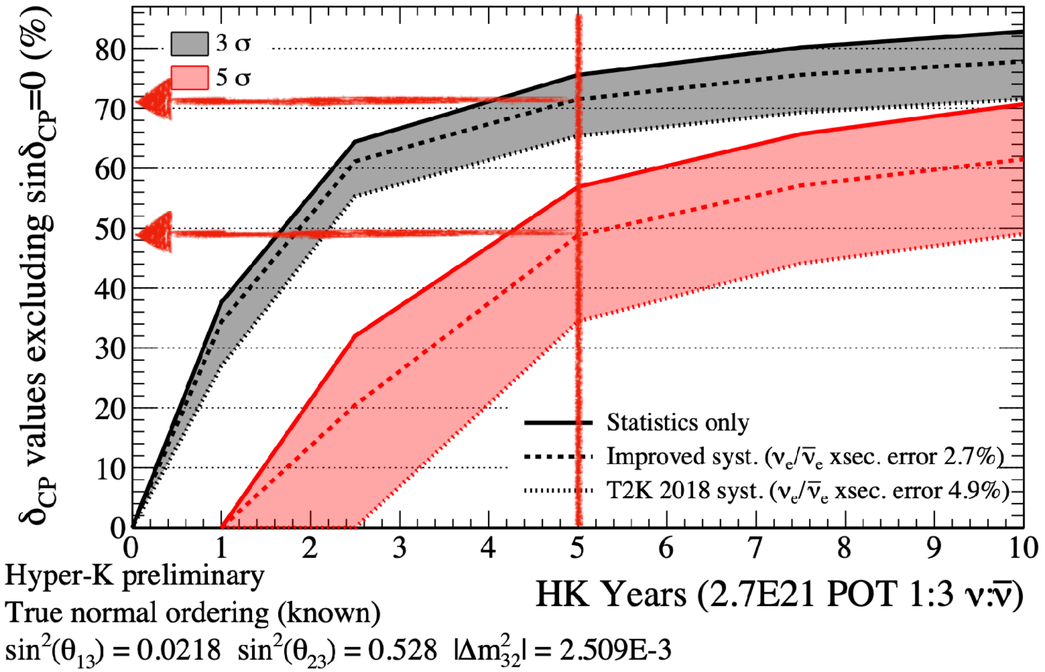




Fast CP-violation discovery

Known mass ordering





If δ_{CP}=-π/2, CP violation discovered before any other LBL-ν experiment

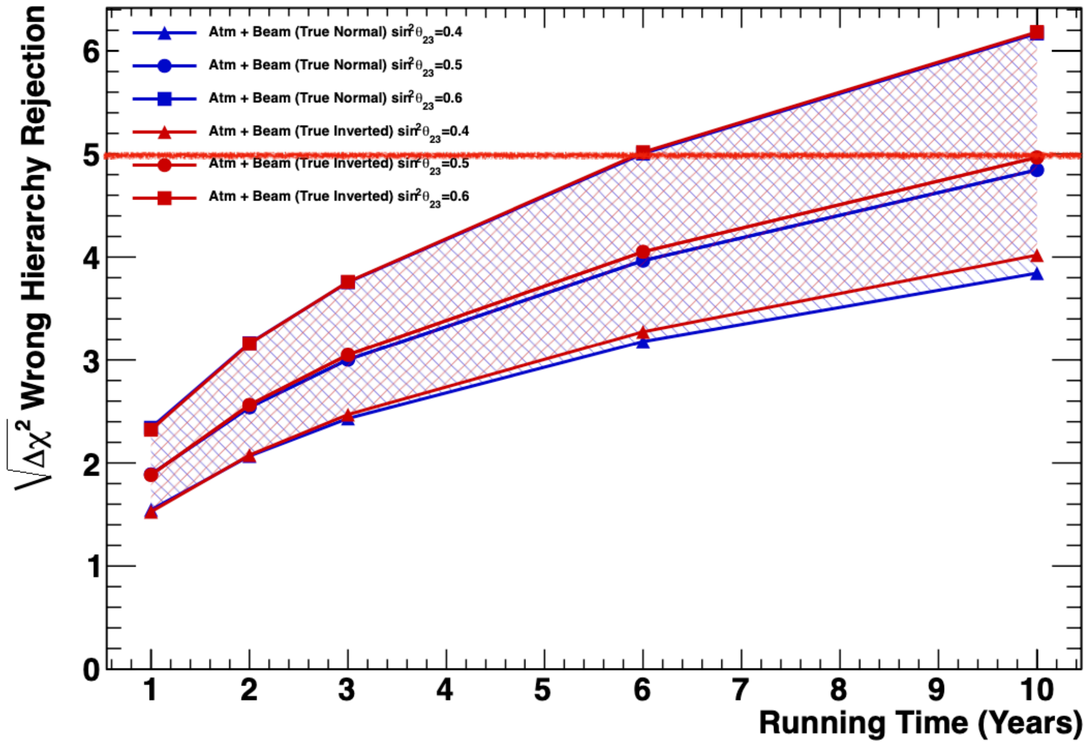
Fastest experiment to survey possible δ_{CP} values

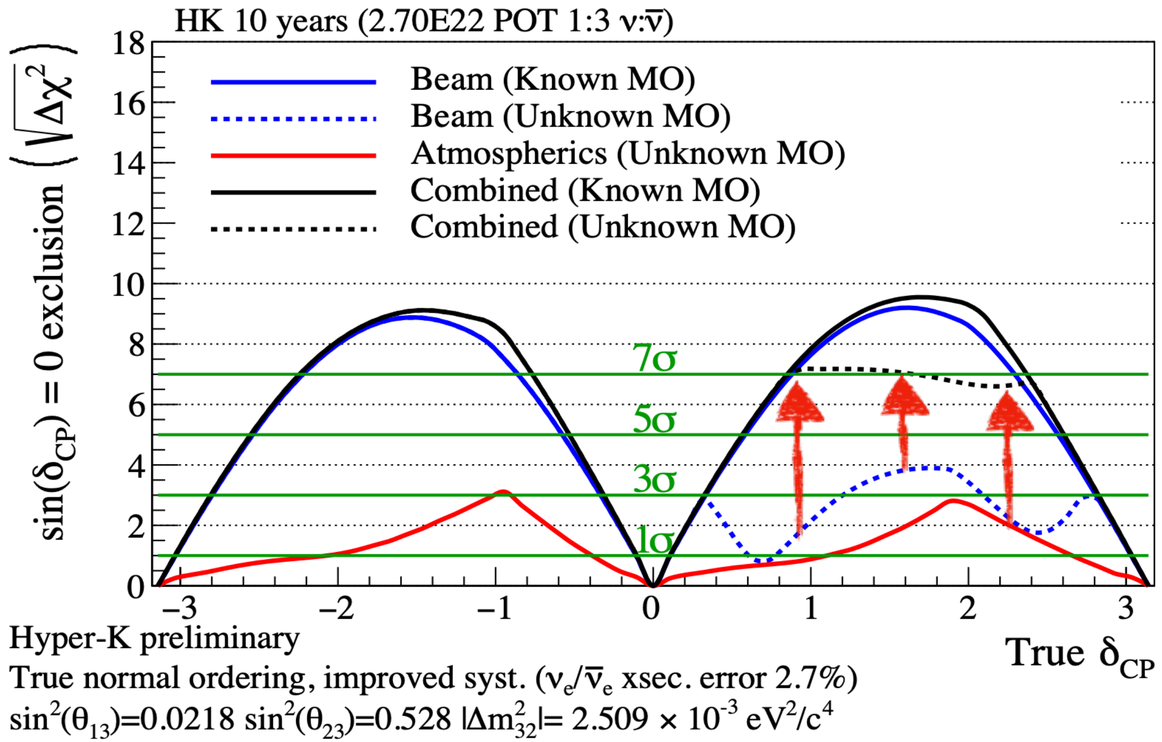
	$\delta_{CP} = -\pi/2$		All δ_{CP}	
	3σ	5σ	50 % 5σ	70 % 3σ
Hyper Kamiokande	0.5 y	2 y	5 y	5 y
DUNE (staged*)	4 y	8 y	10 y	13 y

* 2 modules@1.2 MW y1; 3 modules y2; 4 modules y4; @2.4 MW y7

DUNE CDR arXiv:2002.03005
IUPAP Neutrino panel report

Mass ordering sensitivity with atmospherics



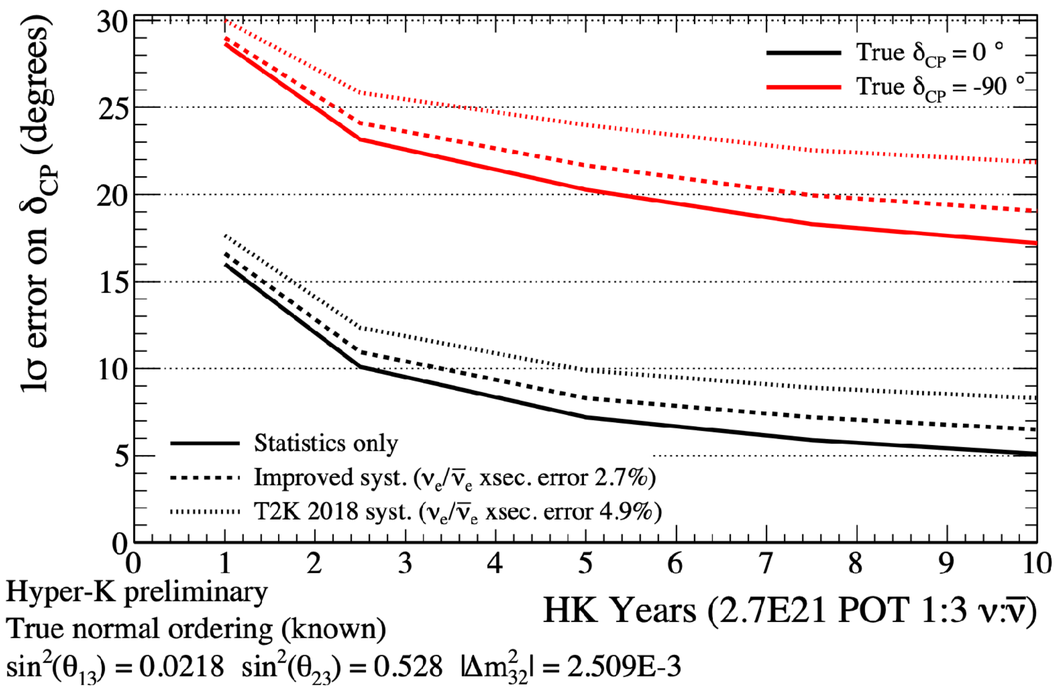


If not discovered by T2K/SK, NOvA, ORCA or JUNO before 2027, HK can determine MO after 6-10 years via atmospheric ν

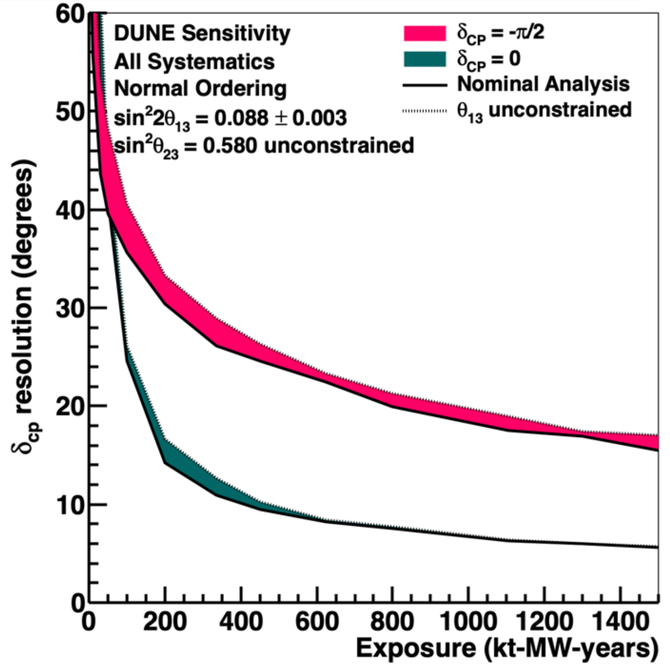
	$\sin^2\theta_{23}$	Atmospheric neutrino	Atm + Beam
Mass ordering	0.40	2.2 σ	→ 3.8 σ
	0.60	4.9 σ	→ 6.2 σ

Sensitivity to CPV is <u>little affected</u> if we add atmospheric ν
→ MO prior knowledge not really required to explore δ_{CP}

δ_{CP} measurement resolution



	$\delta_{CP} = -\pi/2$		$\delta_{CP} = 0$	
	30°	20°	15°	10°
Hyper Kamiokande	1 y	7 y	1 y	3 y
DUNE	5 y	12 y	5 y	8 y



DUNE CDR arXiv:2002.03005

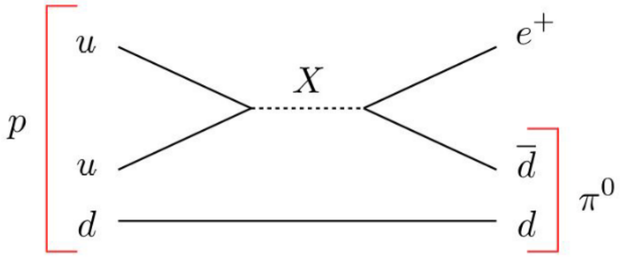
Precision = sensitivity to matter-antimatter models

→ **HK will quickly reach precision on δ_{CP} of 30°(15°) for δ_{CP} =-π/2 (0)**

For the ultimate precision on δ_{CP} it will be important to further reduce systematics uncertainties w.r.t. T2K (ND280 Upgrade + IWCD)

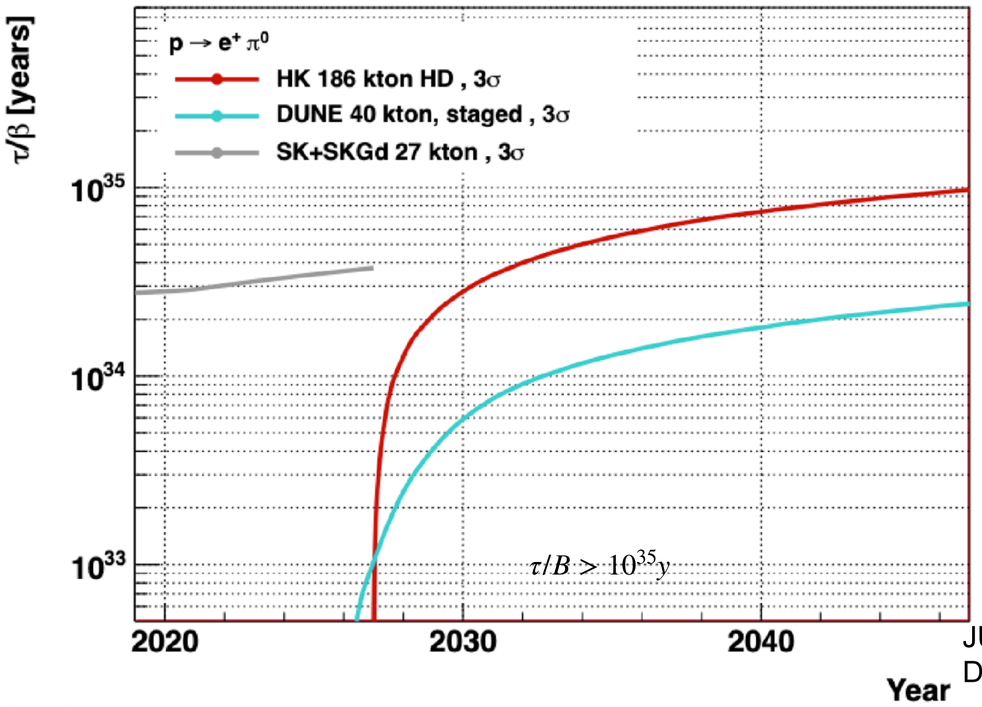
Proton decay

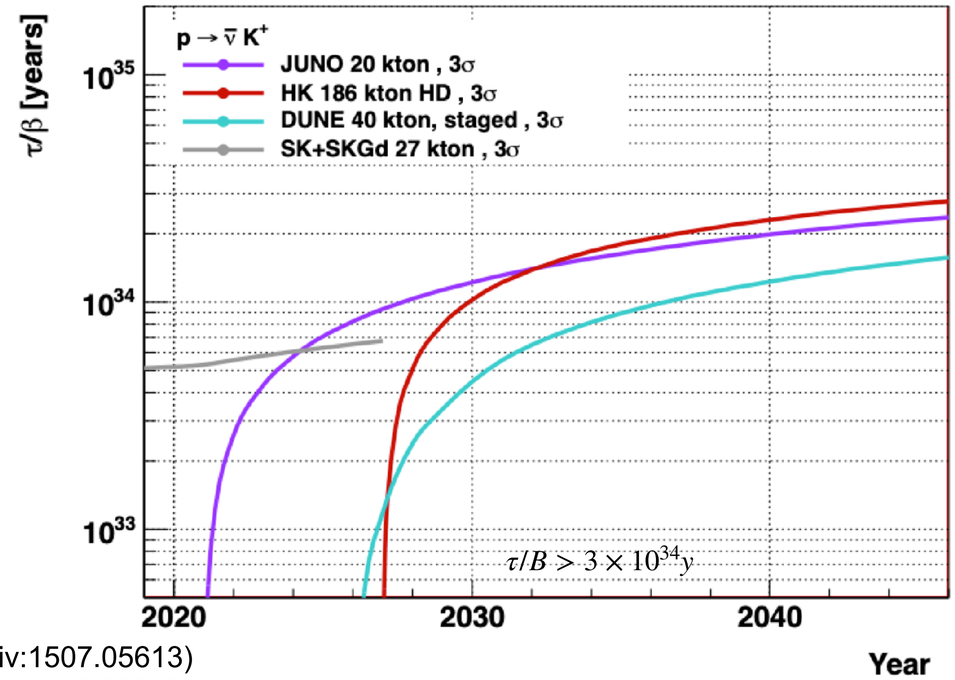
Motivated by Grand-Unification Theories
HK will have the best limit on p → $e^+\pi^0$ for <u>bound</u> protons
→ about 1 order of magnitude better than current limits



Phys. Lett. B 233 (1-2) 178-182

Thanks to its huge mass, HK will also have leading sensitivity to channels with invisible particles (p → ν K^+)
HK is sensitive to <u>free</u> proton decay





JUNO: J. Phys. G 43 (2016) 030401 (arXiv:1507.05613)
DUNE: FERMILAB-PUB-20-025-ND (arXiv:2002.03005)

Astrophysical neutrinos

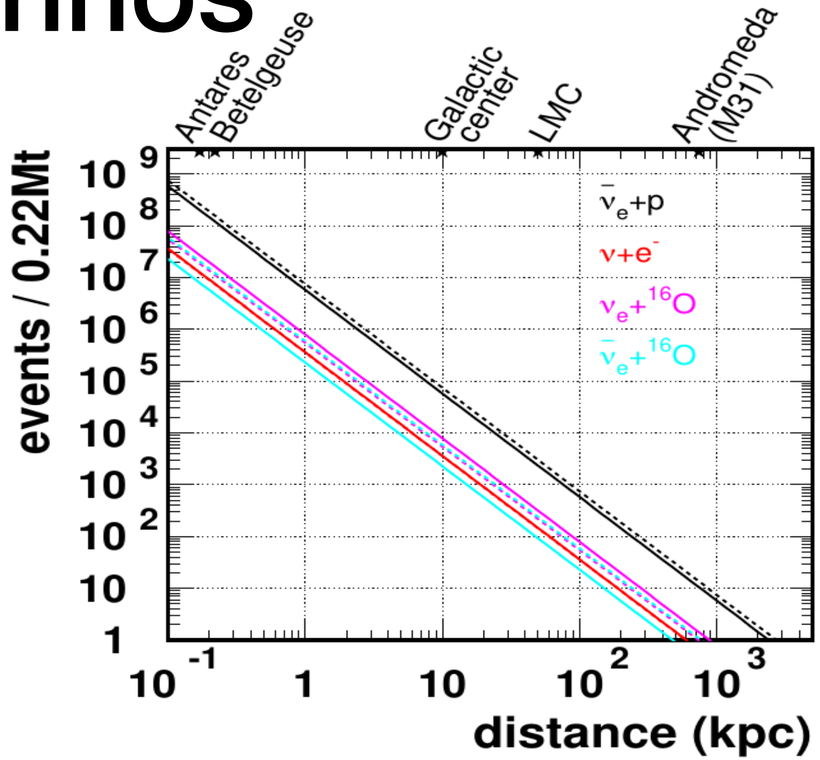
Supernova neutrinos arXiv:2101.05269

Increase by ~10 in stat sensitivity w.r.t. SK
- SN1987A type ~2500 events
- Galactic center: ~50000+ events

Direction (1°@10kpc) → triangulation

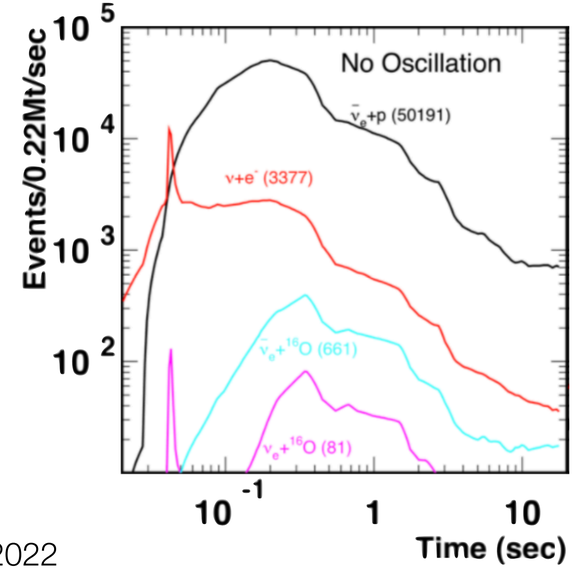
Time profile: collapse models

Since HK is sensitive to about 1 Mpc SN, detection of SN explosion expected every 10 y



Gravitational waves sources

Nearby (10 Mpc) neutron star mergers



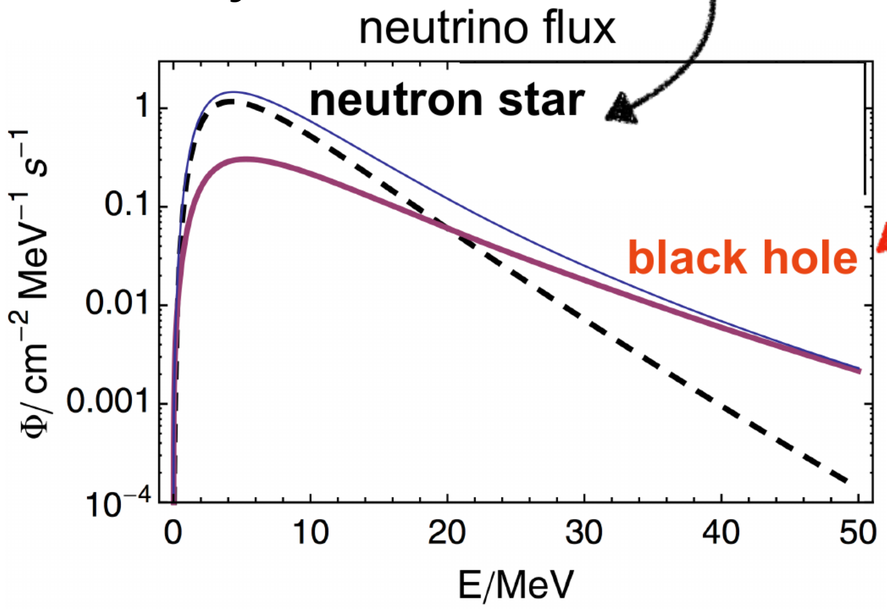
→Unique multi-messengers observatory

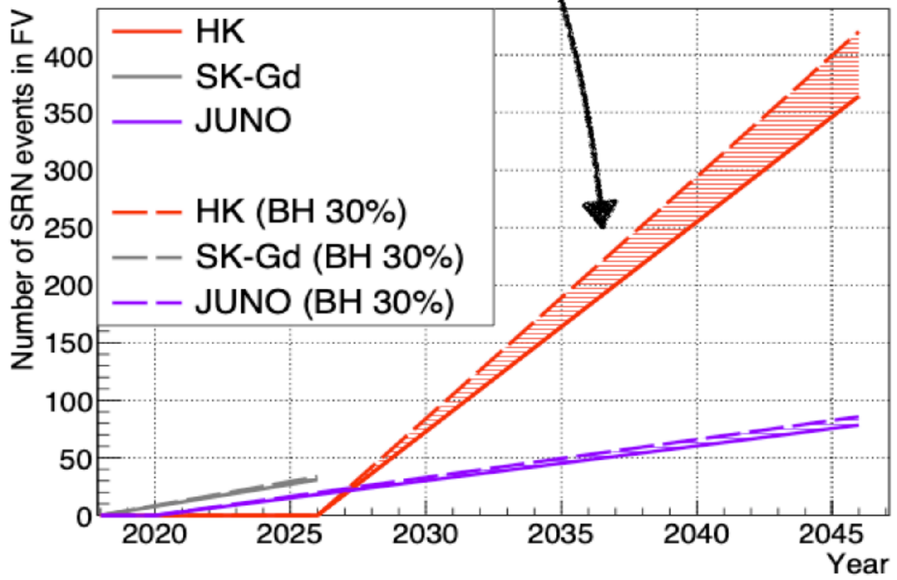
SN-relic neutrinos (DSNB) in HK

SN-relic neutrinos (SNRv) offer new constraints on cosmic star history
→ Could be first detected by SK-Gd
→ The spectrum will be <u>determined by HK</u>

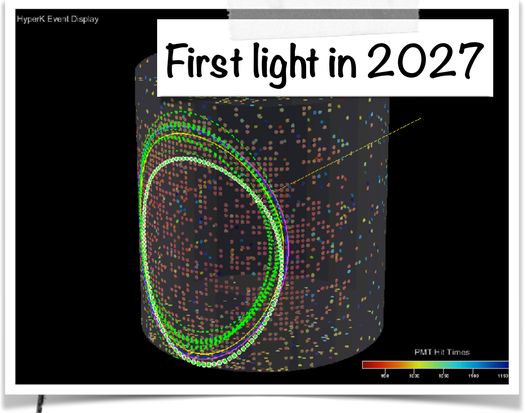
Impact of redshift: low energy ↔ probe older stars

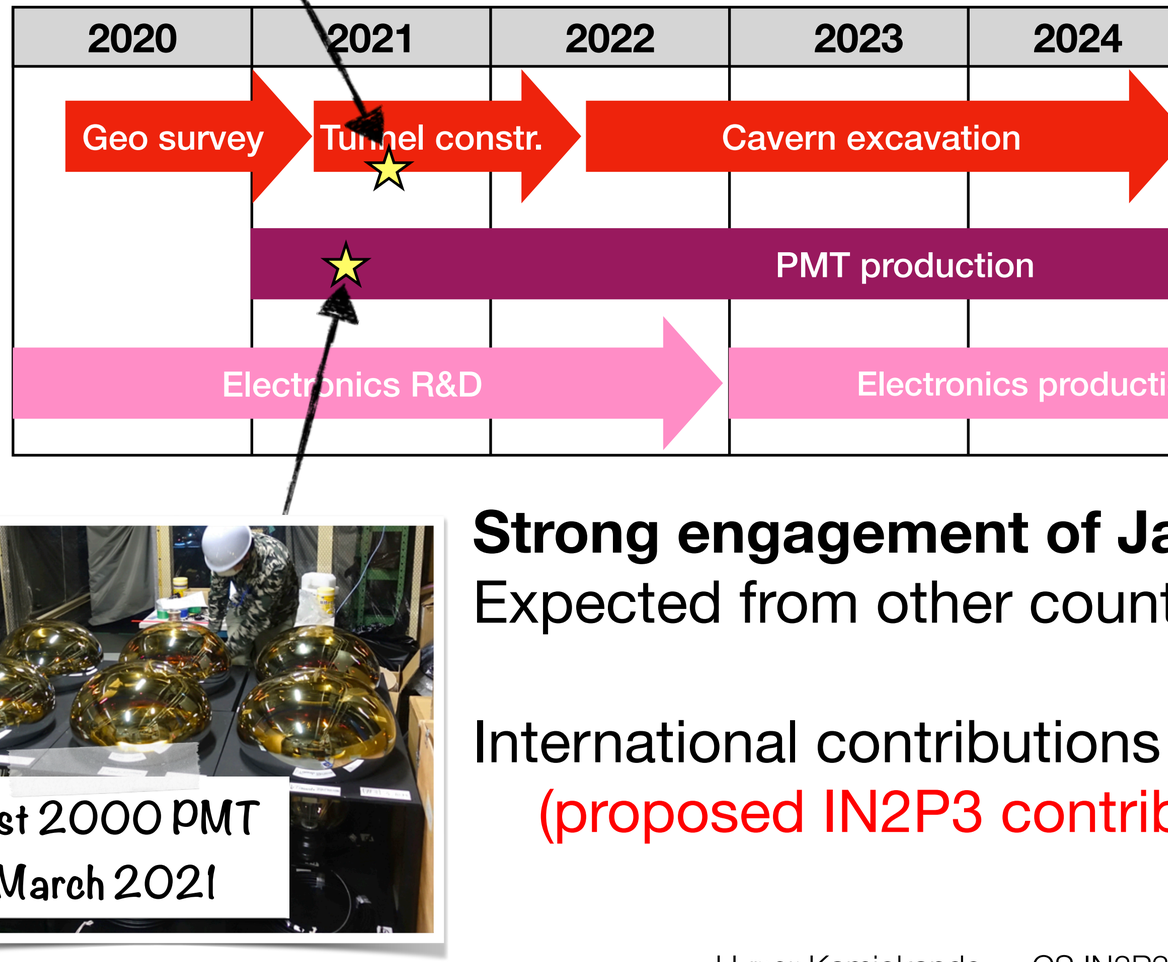
Sensitivity to neutron star vs black hole formation





HK schedule





Strong engagement of Japan: ~500 M$ for construction
Expected from other countries: ~100 M$

International contributions are nearly formalized
(proposed IN2P3 contributions presented by Benjamin)

Construction is on schedule

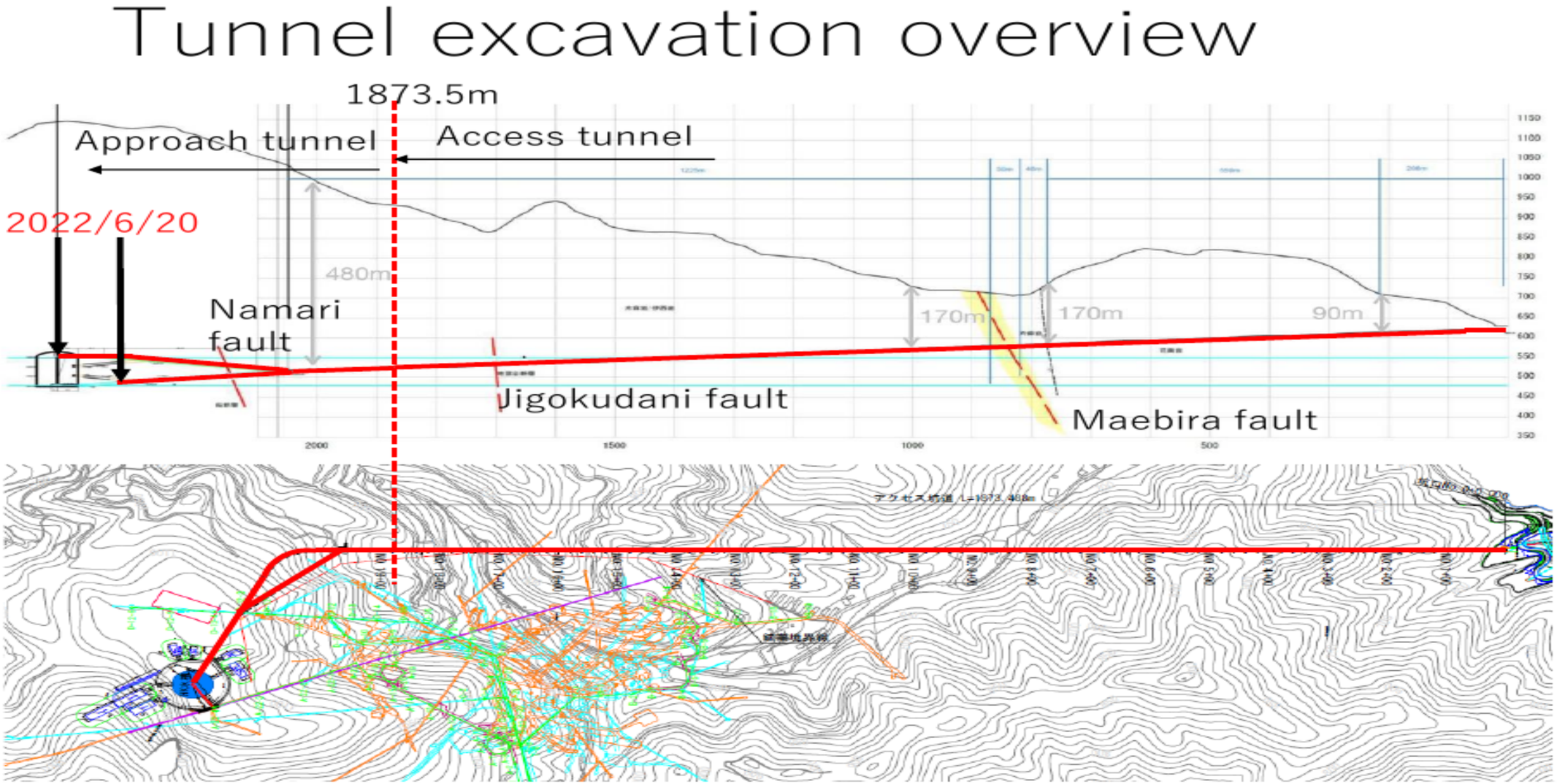
Survey completed ✓

Excavation on-going

New main building ✓

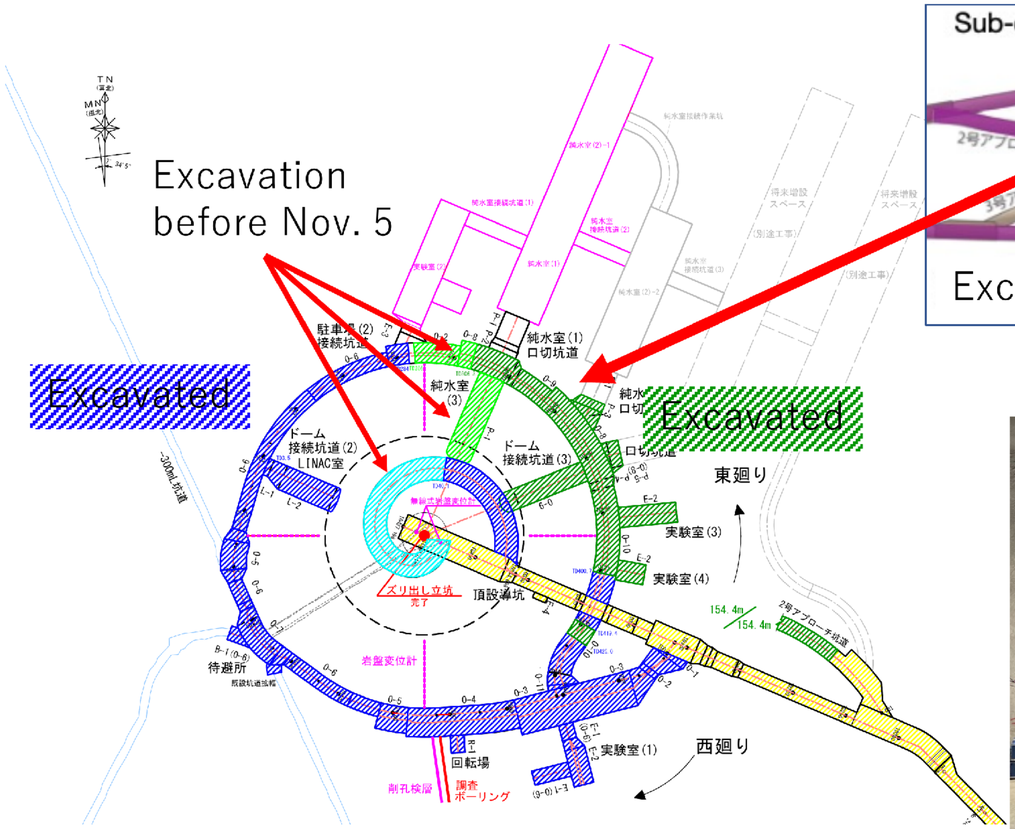
Everything on track! ✓

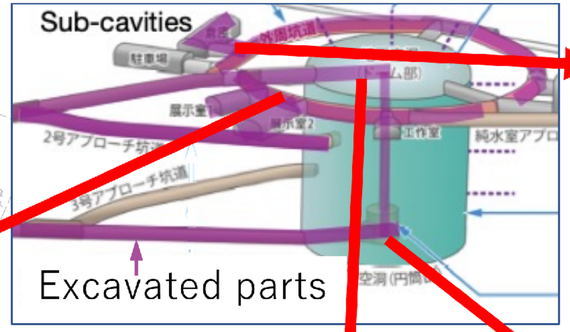
Recent progress: access tunnel excavation



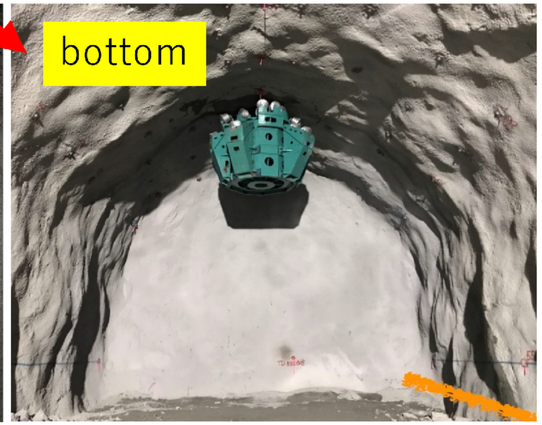
The dome center was reached on 24th of June 2022!

Recent progress: cavern excavation





Vertical shaft excavation completed (~60 m length)

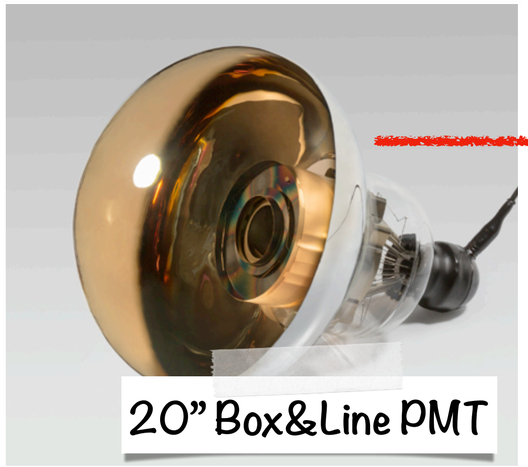


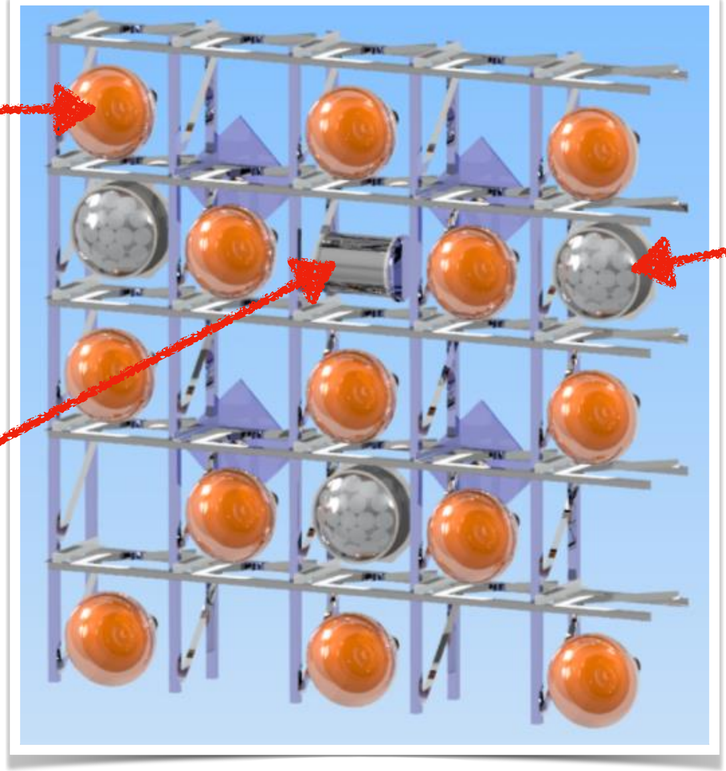
- The excavation work is on schedule. In Oct., a spiral tunnel towards the top of the dome is excavated.
- Ready for excavating the top of the dome in Nov.

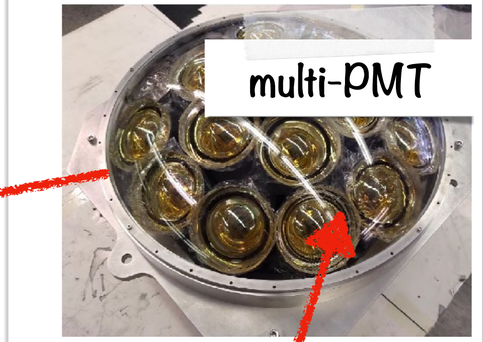
9

Vertical shaft excavation completed on schedule!

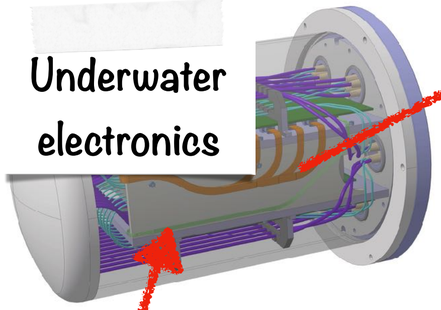
20” PMTs, mPMTs and readout

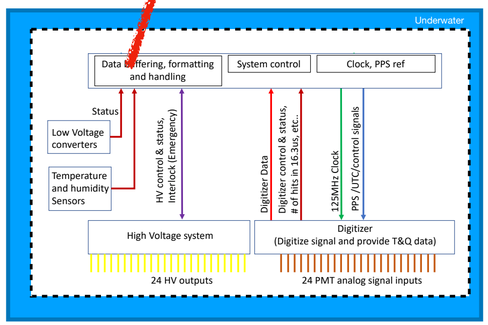






19 x 3” PMT





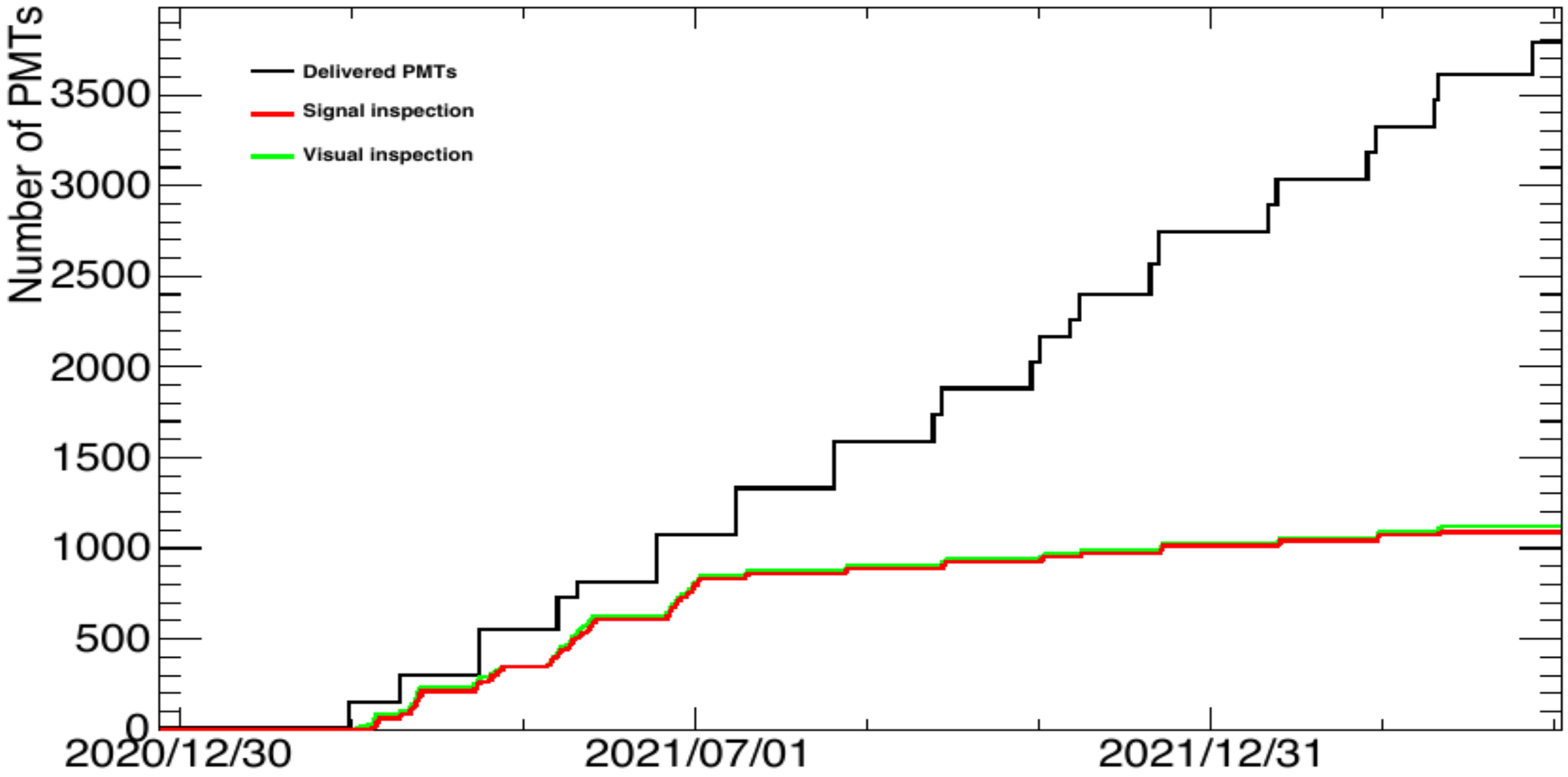
Inner detector composed of

- 20k+ 20” PMTs (Hamamatsu R12860)
- ~1k mPMTs (19 3” R12199-02 PMTs)

NEW → <u>Better signal-to-noise ratio, directionality, timing</u>

Size of detector requires an in-water electronics

Recent progress: 20” PMT production



> 3700 20” PMTs already produced (at the beginning the signal and visual inspection was done for almost all PMTs).
Since July 2021 the inspection rate is 10%.

Intermediate conclusions

Hyper-Kamiokande has a vast and rich physics program including:

Precision study of ν oscillations (fast CP-violation discovery, δ_{CP} measurement, etc)

Rare events observatory (e.g. proton decay)

Multi-messenger astrophysics

→ **Impressive and quick discovery potential!**

Construction started and on schedule → Operation will start in 2027

Natural continuation of our involvement in Japanese ν program (T2K/T2K-II and SK)

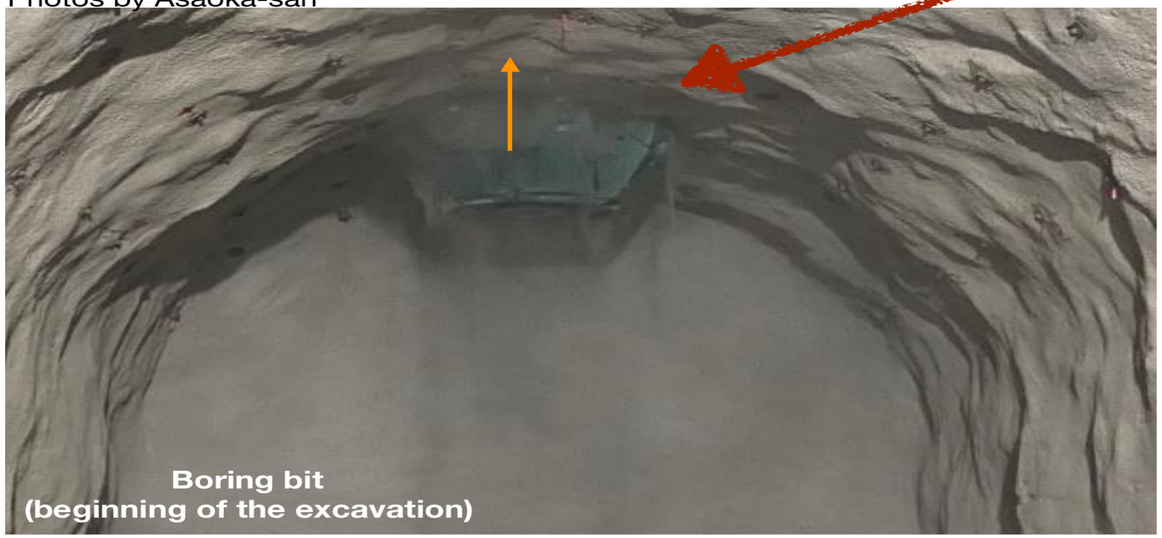
Upgraded ND280 will be used as the HK near detector starting from day 1

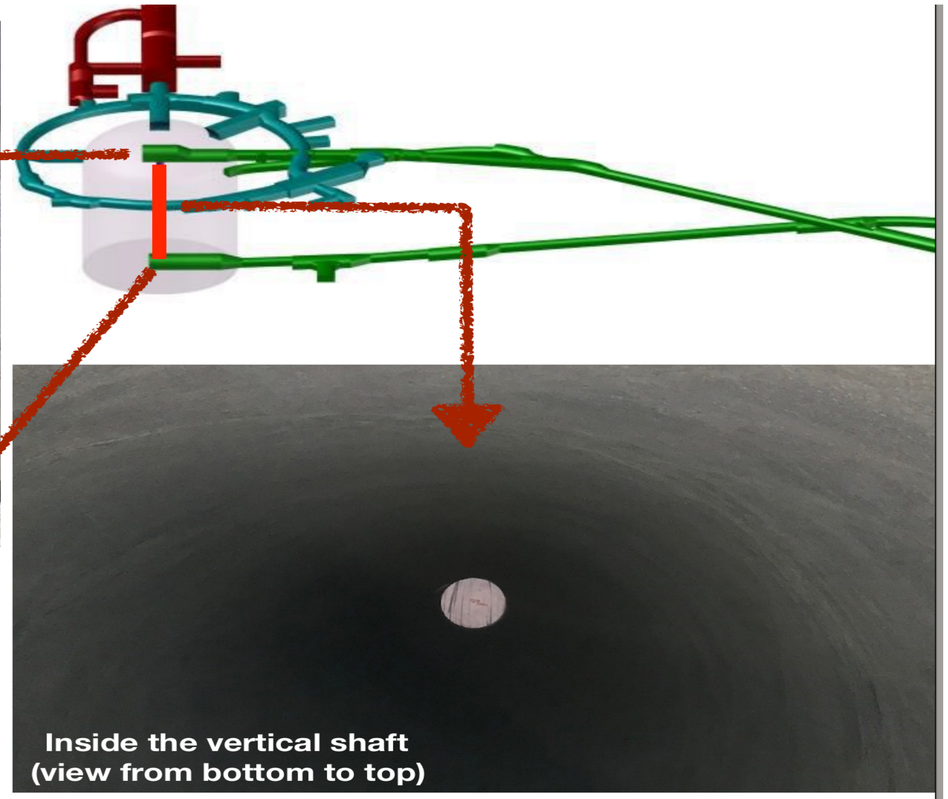
Unique program of world-leading measurements and discoveries up to ~2040

Backup slides

Recent progress: cavern excavation

Photos by Asaoka-san

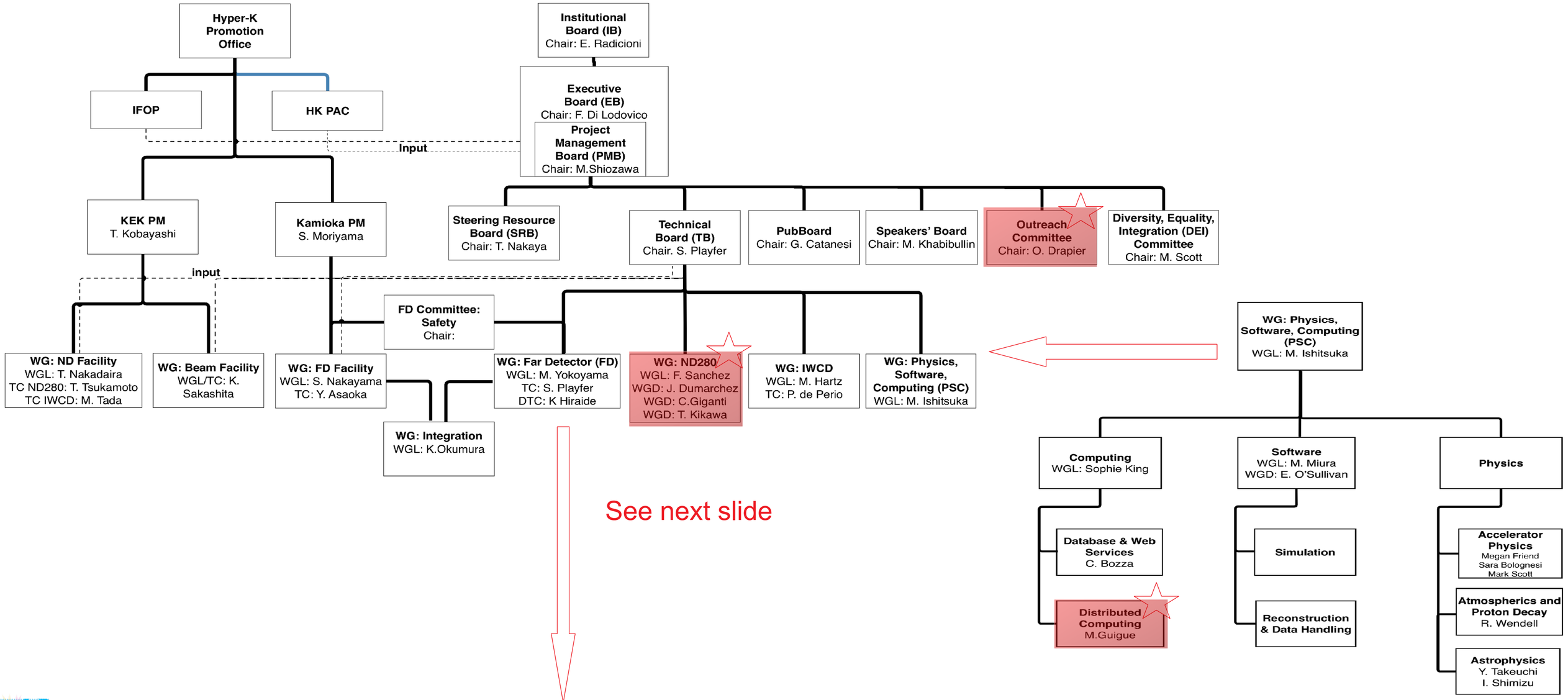




- The excavation of the vertical shaft completed on schedule
  - Vertical shaft: Φ3.4m, 63m-long
- Collect geological data with borehole camera
  - No obvious geological defective throughout the vertical shaft
- No heavy metal content in the excavated rock

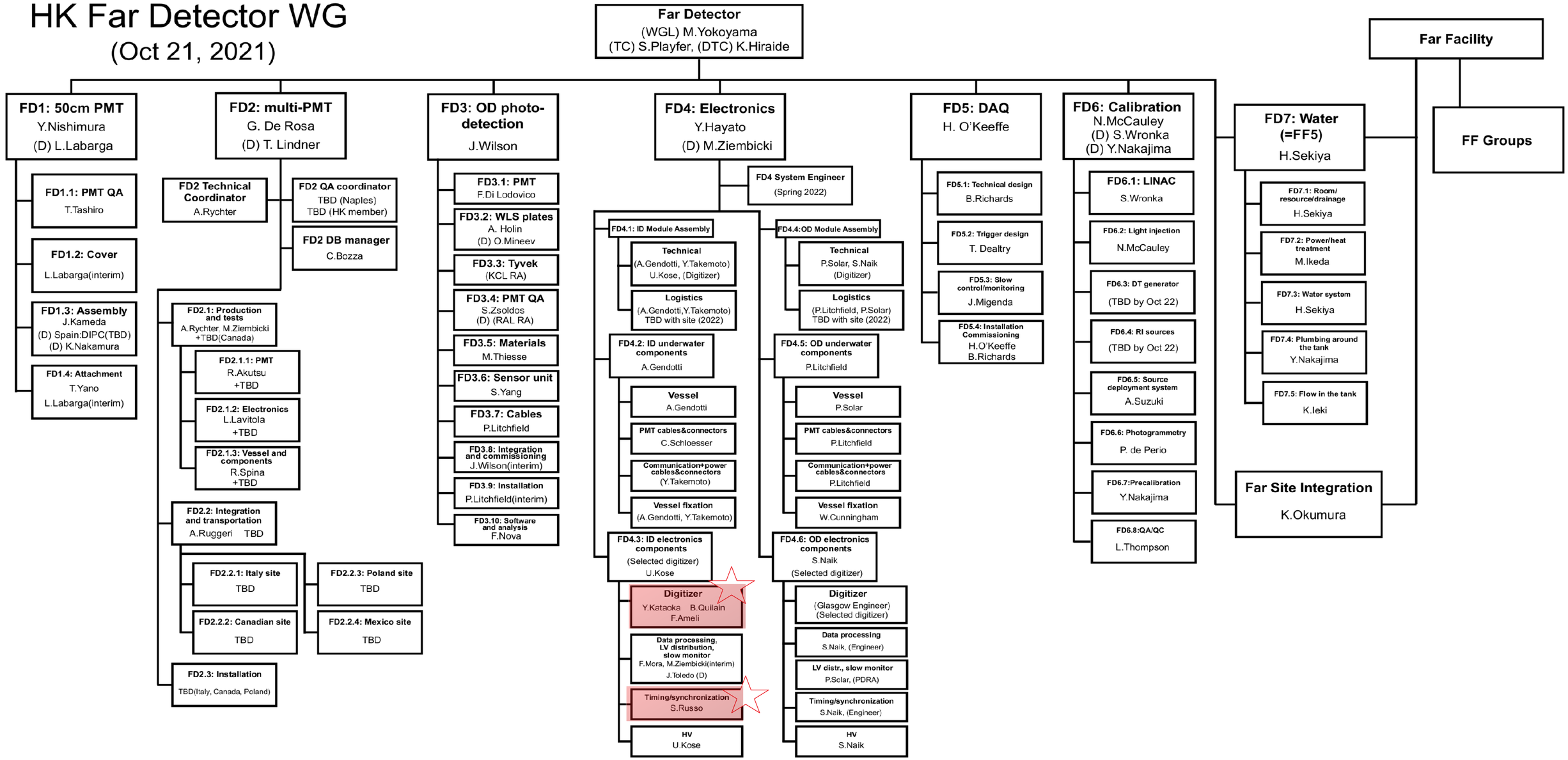
Vertical shaft excavation completed on schedule!

HK organizational chart



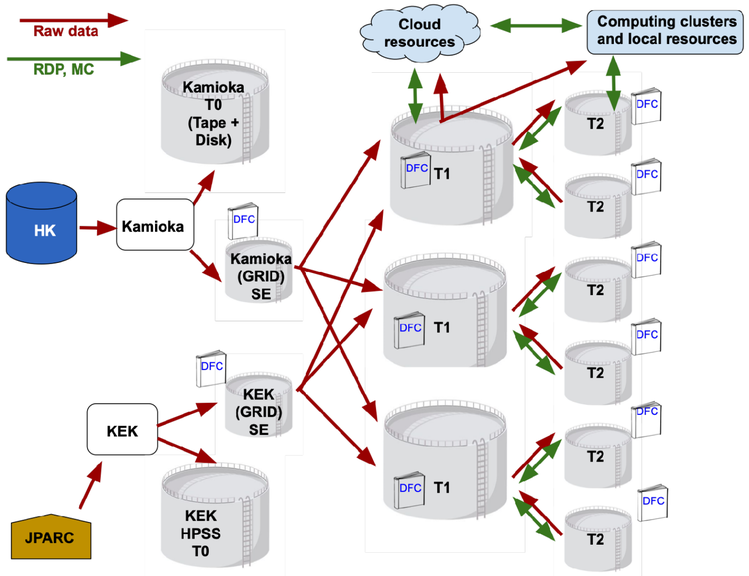
See next slide

Far detector Working Groups



IN2P3-CEA technical contributions to HK

- **<u>ND280 Upgrade and maintenance</u>**
  - Super-FGD electronics
  - High-Angle TPCs electronics & readout
- **<u>Construction of HK far detector</u>**
  - Front-end electronics & timing system
- **<u>International computing effort</u>**
  - CC-IN2P3 as T1 for HK



SWOT

Strengths:

- Well-known exceptional Water Cherenkov technology
- Use of existing neutrino beam and near detector complex built for T2K, thus saving large amount of money for the long-baseline program and reducing systematics uncertainties from the first day of the experiment.
- Construction budget for Hyper-Kamiokande have been allocated by Japanese government in 2019 with a budget profile that will allow to start the experiment in 2027.
- Leading roles of French groups and acquired expertise in the ongoing T2K experiment

Opportunities:

- Fast measurement of CP violation, before any other experiments.
- Huge target mass, making HK the most sensitive observatory for rare events in the MeV–GeV energy region.
- IN2P3 groups can build on their long standing expertise in the T2K experiment to propose strong contributions in Hyper-Kamiokande. There are still many possibilities to contribute, e.g. electronics of the outer detector, further ND280-upgrade, IWCD.
- Deployment of a similar timing system for the near and intermediate detectors without any additional R&D.

Weaknesses:

- Small groups at LLR and LPNHE. Mitigated by the large overlap in terms of physics case, technologies and tools between T2K, SK and HK.
- Hyper-Kamiokande is an IN2P3 R&D project since 2022, but not yet an IN2P3 master project, undermining our visibility within the collaboration.

Risks:

- Approval by CS-IN2P3 and allocation of IN2P3 funding is needed to capitalize on the R&D on the digitizer to make a strong contribution to the HK detector in addition to the timing system and computing.
- Since the HKROC digitizer was not selected as the primary option for the HK inner detector, there is still an uncertainty about the outcomes of this contribution.

Financial resources

Item	Cost (M)	Partially covered with external fundings	Funding approval	Construction period	Requested fundings (M)
ND280 Upgrade	6	T2K Collaboration	2019	2019 – 2022	0.6 (obtained)
Far detector timing	0.6	ANR - INFN - CEA	2022	2023 – 2026	0.4
Communication cables	2	European countries	2022	2023 – 2026	0.2-0.4
Chip and Front-end	2.5	CEA - INFN	2022	2023 – 2026	1-2.5
Computing (CC-IN2P3)	3.8	CEA	2021	2021 – 2037	3.8
	Note that costs for computing are spread over a much longer period of time (15 years).				
Total	14.9	-	-	-	∼6-7.7

External and internal investments:
- 70k€ for R&D towards HK (Sorbonne Université)
- 400k€ (X) + 90k€ (IN2P3) for R&D on HKROC
- 300k€ (ANR) + 150 k€ (IN2P3) for R&D on time generation and clock distribution

Significant efforts to acquire externals fundings before asking for IN2P3 investments

Conclusions and outlook

Hyper-Kamiokande has a vast and rich physics program including:
- Precision study of ν oscillations (fast CP-violation discovery, δ_{CP} measurement, etc…)
- Rare events observatory (e.g. proton decay)
- Multi-messenger astrophysics

→ **Impressive and quick discovery potential!**

Construction started and on schedule → Operation will start in 2027

Natural continuation of our involvement in Japanese ν program (T2K/T2K-II and SK)
- Upgraded ND280 will be used as the HK near detector starting from day 1
- **Unique program of world-leading measurements and discoveries** up to ~2040

Identified contributions on electronics (RD4HK during 2022) and computing
Used funding from external sources (Sorbonne University, Ecole Polytechnique, ANR)
Technological decisions taken in September 2022

→ **approval by CS-IN2P3 & recognition of HK as IN2P3 master project are needed for full-scale participation in the HK experiment**

Time Distribution costs estimations

Second stage distribution	Total number of PMTs	PMT per FE	Total number of FE (Time distribution nodes)	Number of nodes per distributor	Number of distributors	Distributor cost per unit	**Total distributor's cost**
Outer detector	13 300	72	185	16	12	3 000	36 000
Inner detector	20 000	24	833	16	53	3 000	159 000
MultiPMT	2 000	12	167	16	11	3 000	**33 000**

Total distributor's cost	**228 000**
Atomic Clock cost	54 000
GNSS recevier	13 000
Antenna + cable	4 000
Clock multiplication board	2 000
Total clock ref cost	**73 000**
Redundant system	**73 000**
Grand total clock reference	**146 000**
Slow Control switch	2 000
Total cost	**376 000**
Contigency	20%
Gran total	**451 200**

Time generation estimated cost: 145 k€ (LPNHE)
Time distribution (first and second stages) estimated cost: 250 k€ (LPNHE +CEA)
Time distribution endpoint cost: 80 k€ (INFN)

Total = ~480 Keuros

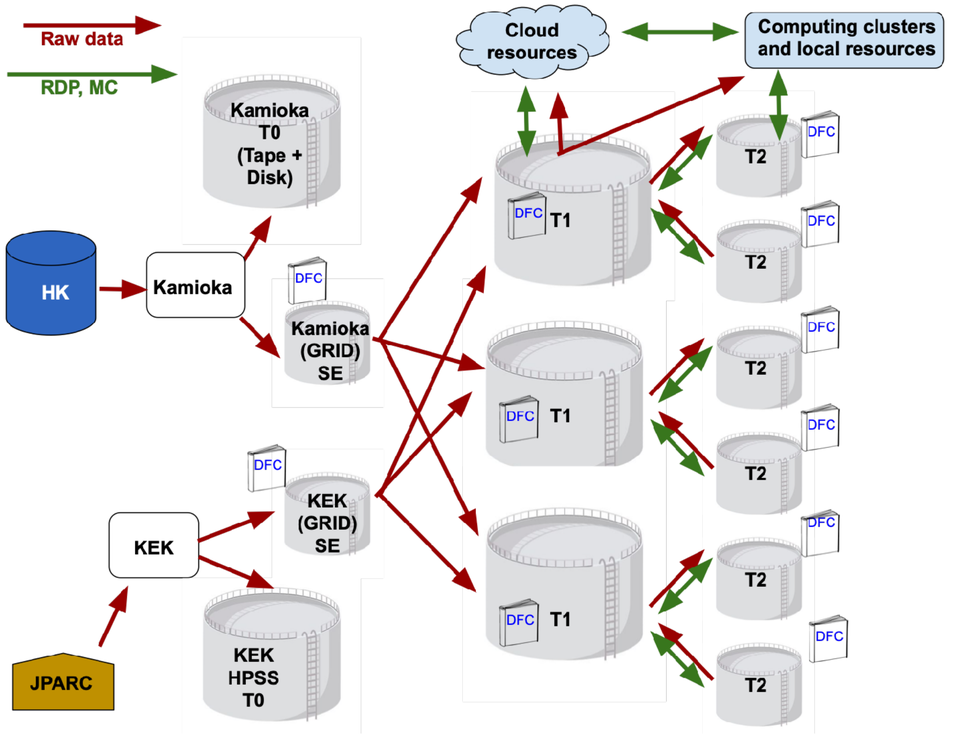
Computing efforts in Hyper Kamiokande

Tier model similar to CERN's
Resources and data management using DIRAC
Software containerized and shared via CVMFS

JENNIFER 2
EU grant n.822070

System similar in other IN2P3 exp. (Belle-II, CTA, LSST…)
obvious synergies

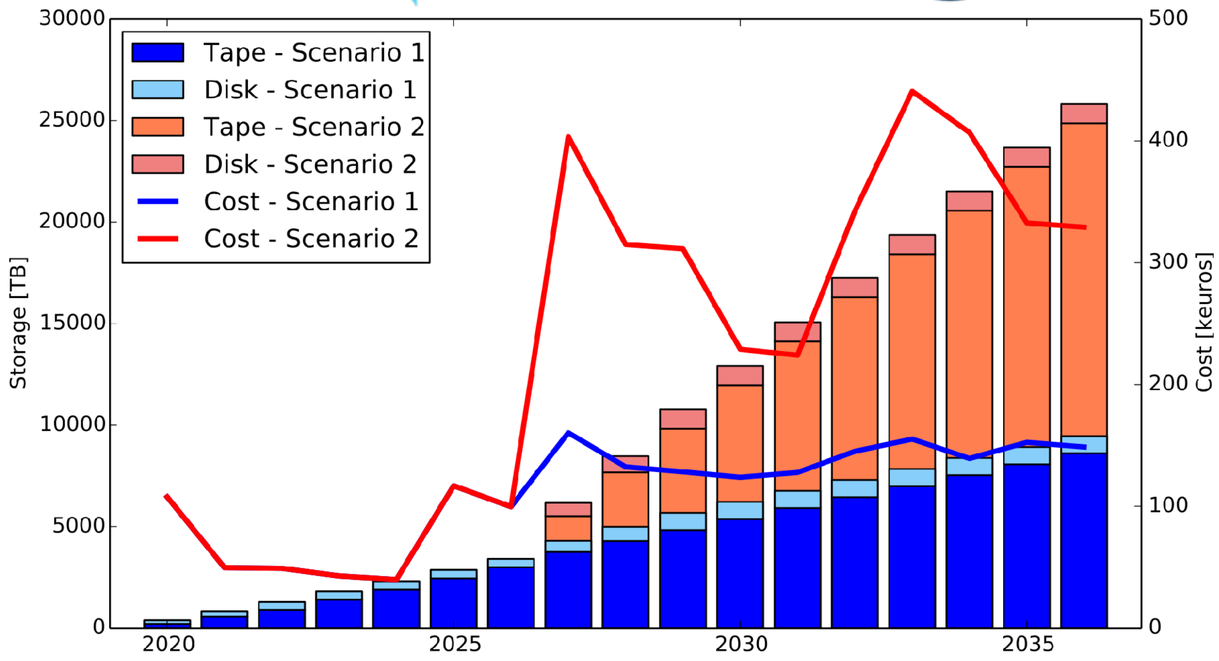
First 10 years of operations:
~~25 PB (data + MC — mostly Far Detector)~~
880 MCPU.hours
~~(minimal with one copy of each file)~~



Proposed Contribution: CC-IN2P3 as T1 site

CC-IN2P3 Tier1 for LHC (WLCG)
 infrastructure, expertise available
Low-rate data stored on tapes
Disk and CPU for productions
Database management

Two proposed scenarii:
1. ND280 data storage
2. Near and Far detectors data storage

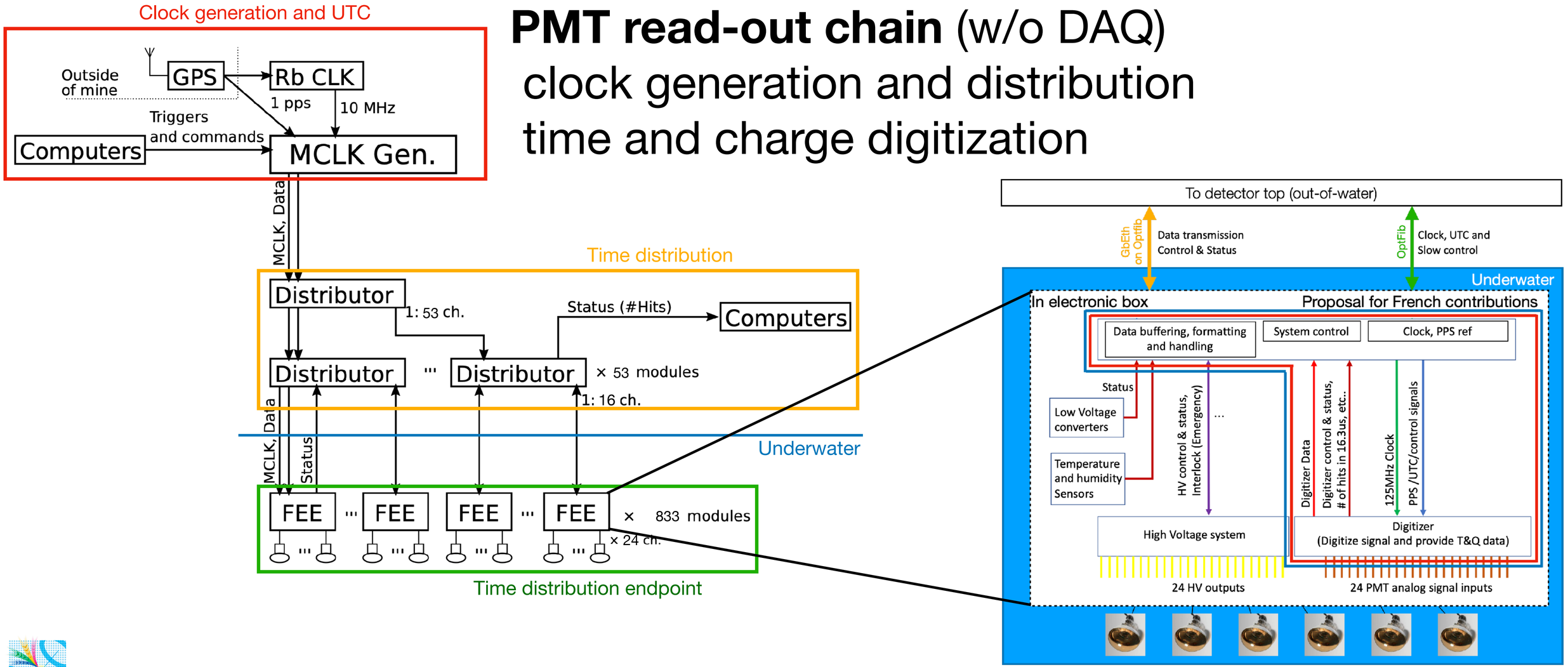


<u>First step:</u> CC-IN2P3 as T1 site for T2K
 integration of CC as grid site into GridPP
 disk allocation and data transfer

First production for HK at CC-IN2P3 completed

Contribution to HK Far Detector electronics

France would **develop and produce the whole PMT read-out chain** (w/o DAQ)
- clock generation and distribution
- time and charge digitization



HKROC: new chip and readout

HK requirements fulfilled

Chip and readout board for PMT inspired by HGCROC chip

1. Large dynamic range: 3 gains / ch.→ up to 2500 pC
2. Excellent charge & time resolution: (<200 ps)
3. TSMC CMOS 130nm etching
4. Reduced dead-time (<50 ns): SAR ADC sampling waveform at 40 MHz

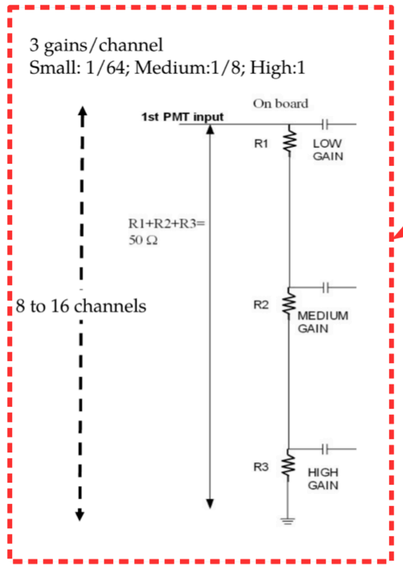
R&D funded by X (400 k€)

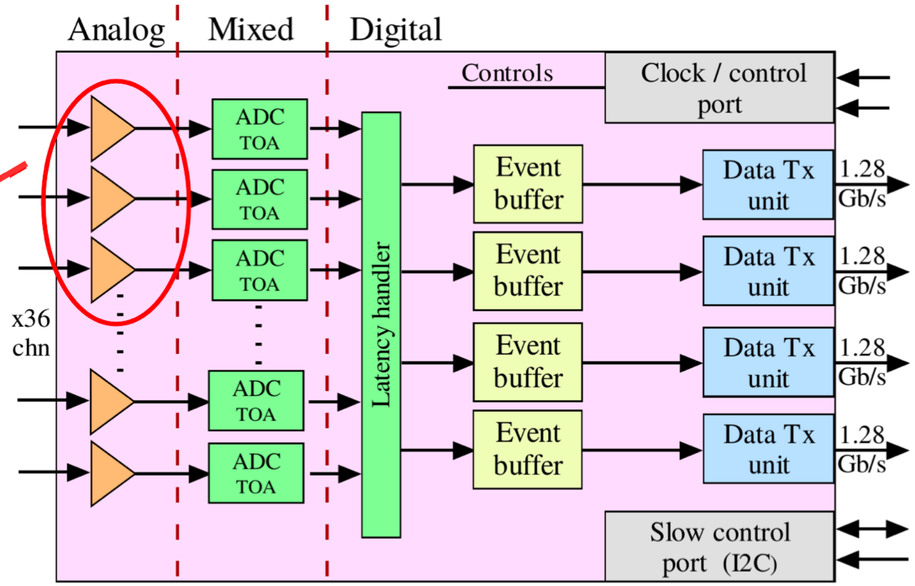
HKROC delivered in Nov 2021

First tests in December 2021

Synergy OMEGA/LLR/IRFU

Use in future WC detectors!



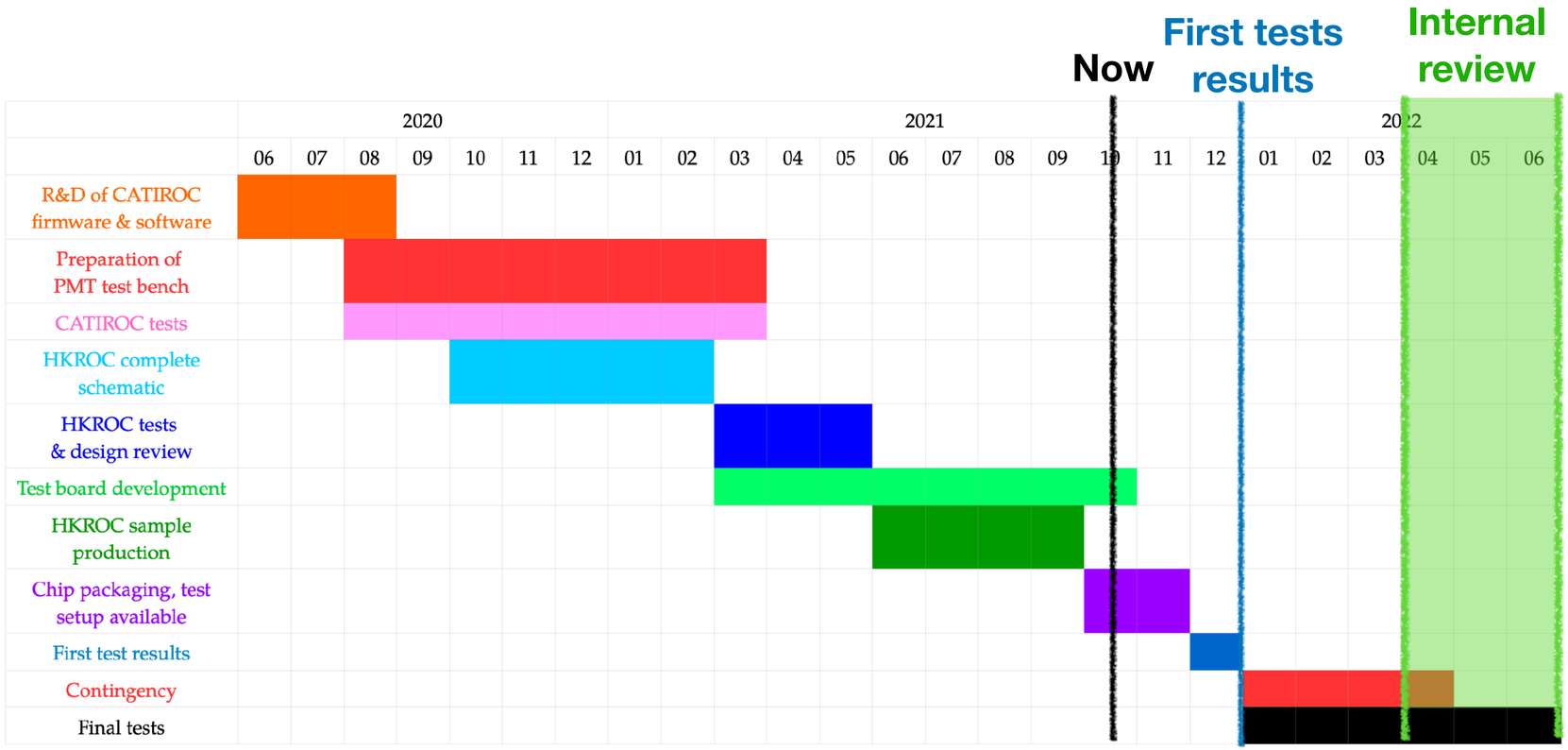


Competitors and time constraints

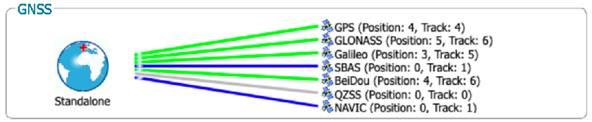
Two other competitors : Japan QTC (SK chip) & Italian discrete solution
HK internal review Apr-June 2022 selection of digitizer solution

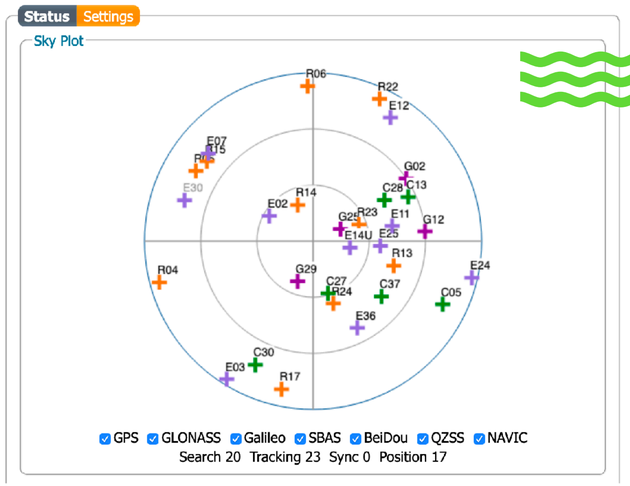
Selection criteria:

- Performances
- Group expertise
- **Official engagement on fundings in June 2022**

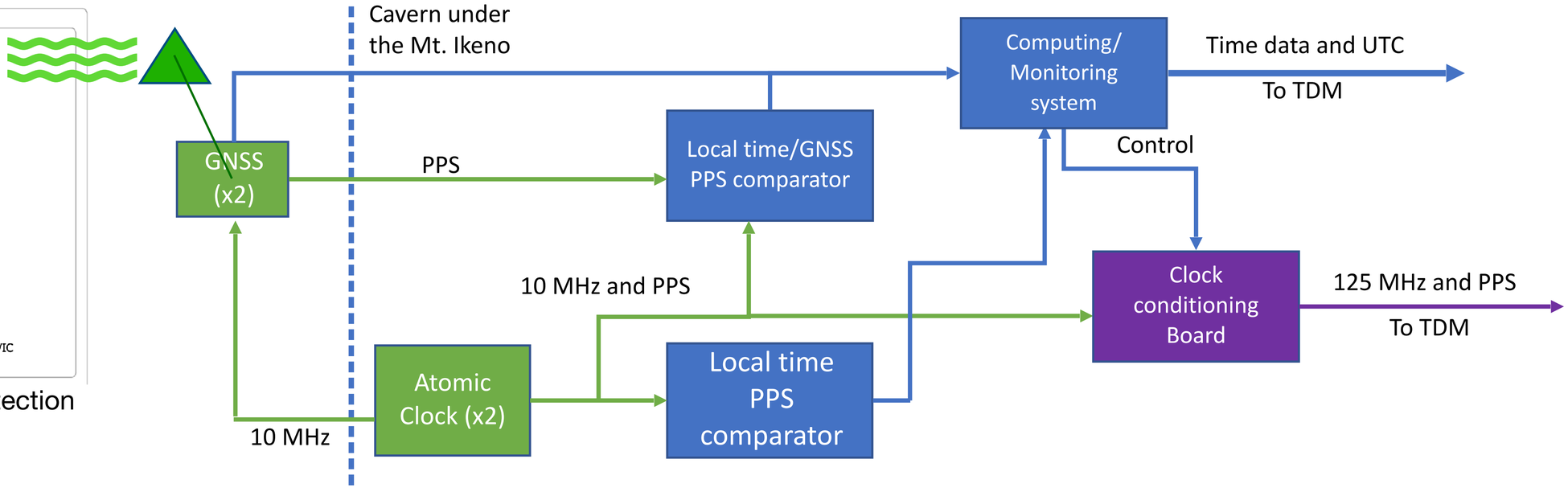


Time Generation & UTC





Septentrio PolaRx5 satellites detection



Creation of reliable Universal Time for global synchronization and stable 125 MHz frequency for front-end digitizers

Strong collaboration between LPNHE and SYRTE (Observatoire de Paris)

Calibration of clocks and GNSS antennas

Creation of a dedicated lab to study clocks and GNSS at LPNHE

Long-term studies and comparison using atomic clocks, antennas and PPS-SYRTE

R&D program supported by SU Emergence and ANR “Bertha”

Clock distribution

Strong collaboration between LPNHE/INFN/IRFU

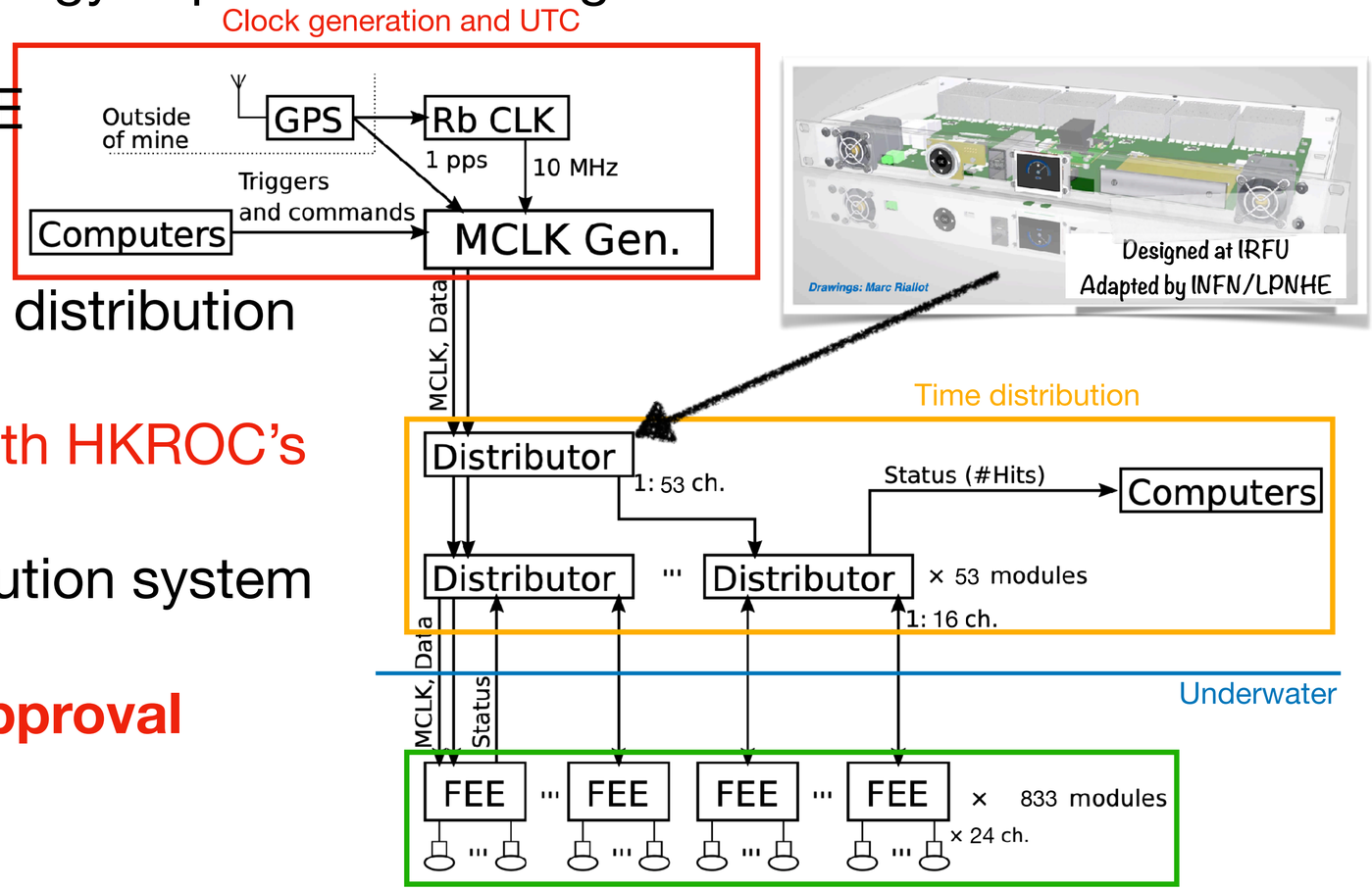
Baseline proposal of time distributor modules (TDM) was finalized

- Clock and Data Recovery (CDR) technology implemented using ser-des
- “Tree-like” structure
- Board design shared btw CEA & LPNHE
- Main distributor (53 ports)
- Second distributors (16 ports)
- Slow control and asynchronous signals distribution

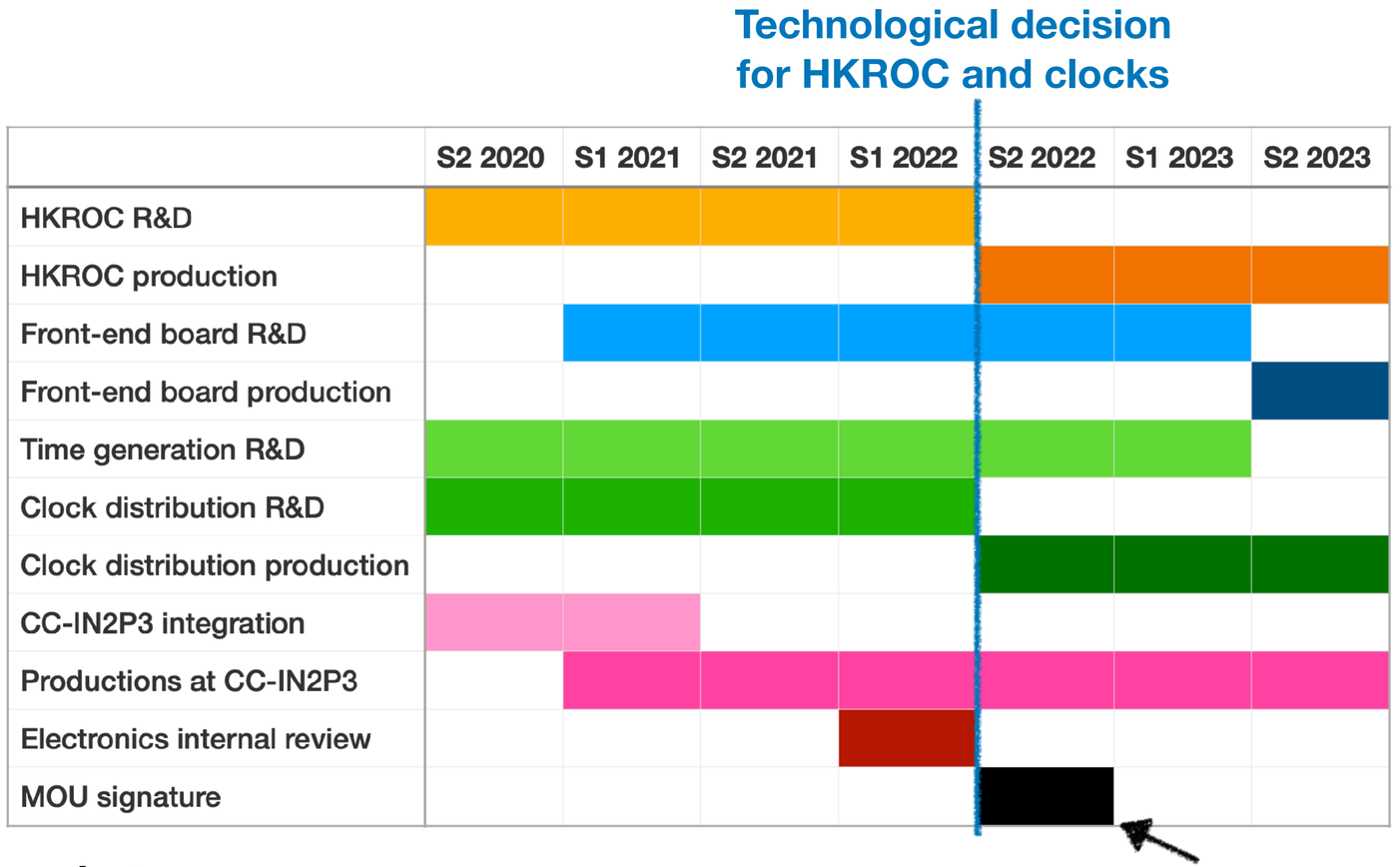
FE board development in collaboration with HKROC’s

Other competitor: SK-based clock distribution system selection of the solution in June 2022

Official engagement on fundings for approval



Upcoming milestones



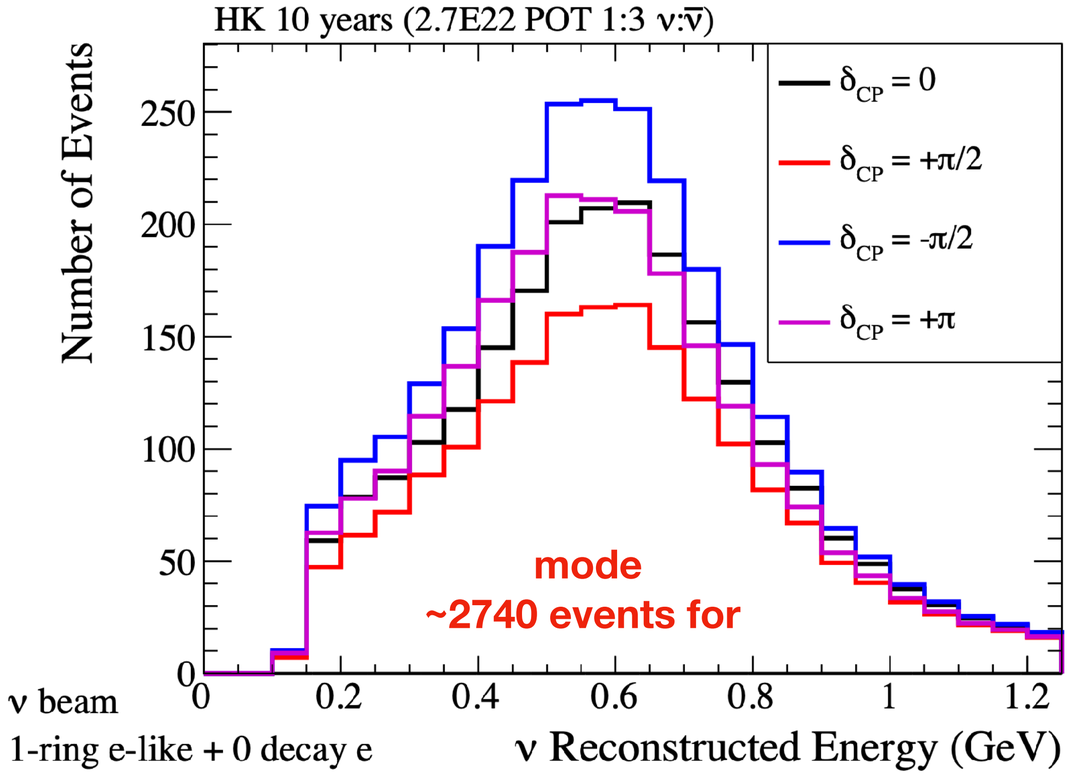
R&D almost complete

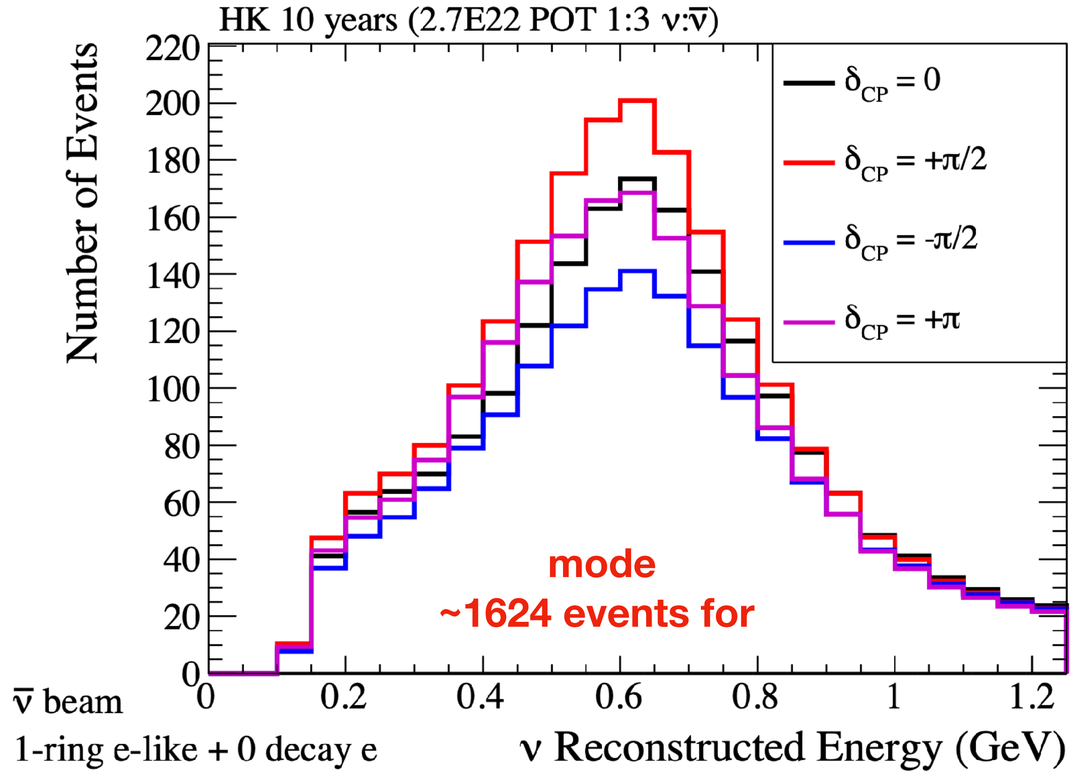
HK internal review beginning of 2022 **technological decision June 2022**

MOU signature in 2022

HK LBL- oscillations measurements

Data taking plan: **1.3 MW** 6 cycles/year 10 years ( )

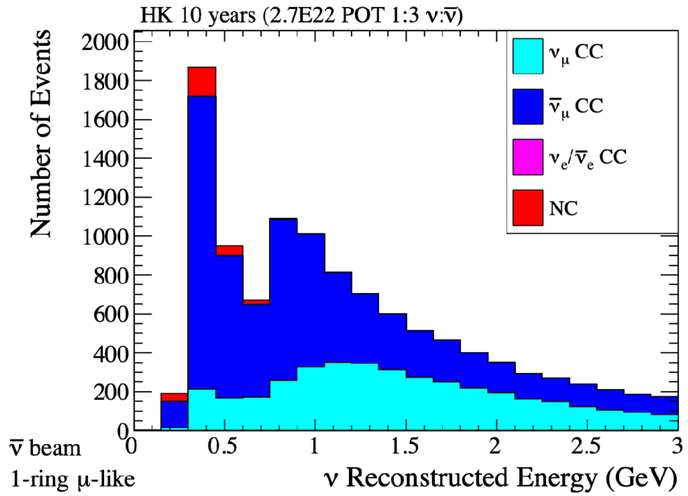


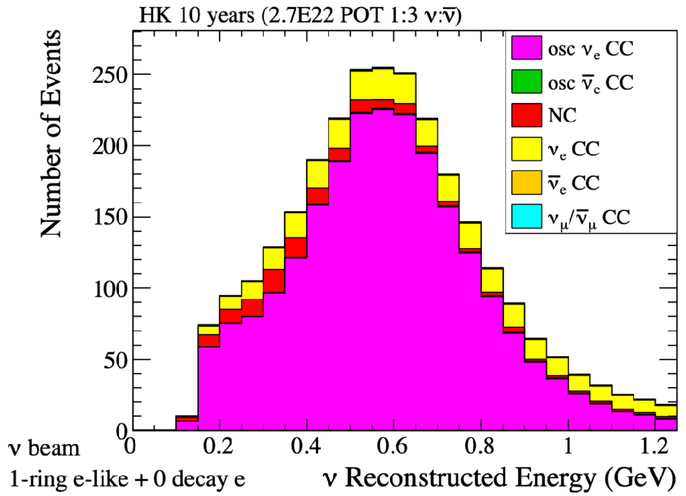


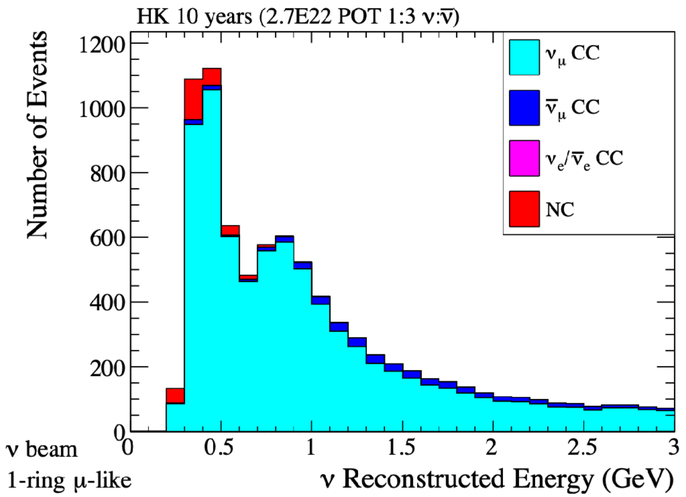
Appearance measurements: increased by 2 orders of magnitude (75:15 for T2K-I Nature)

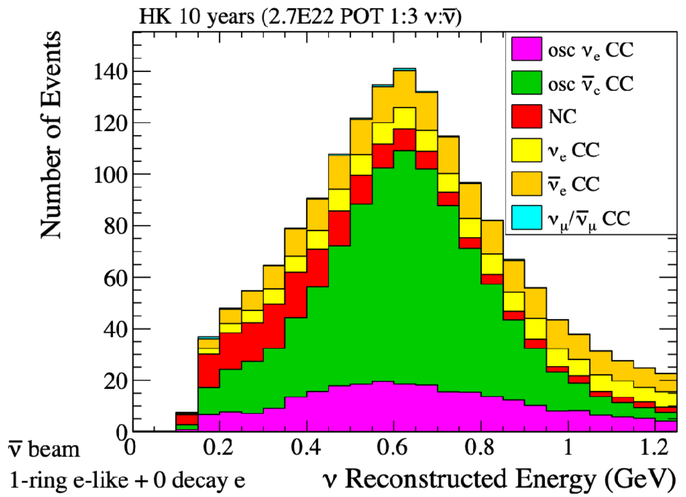
Higher statistics measurements of the oscillation parameters

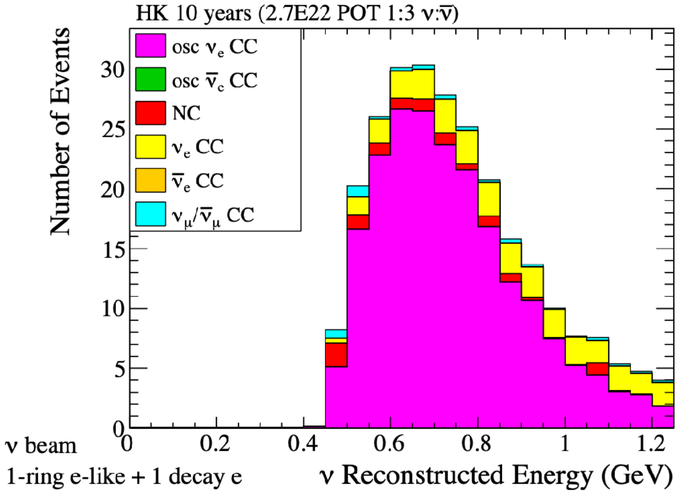
HK OA samples



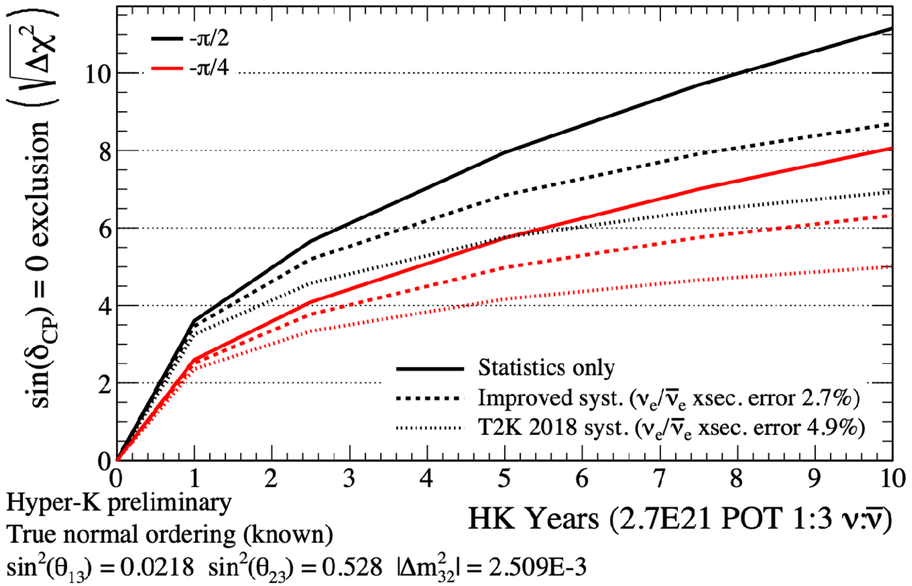


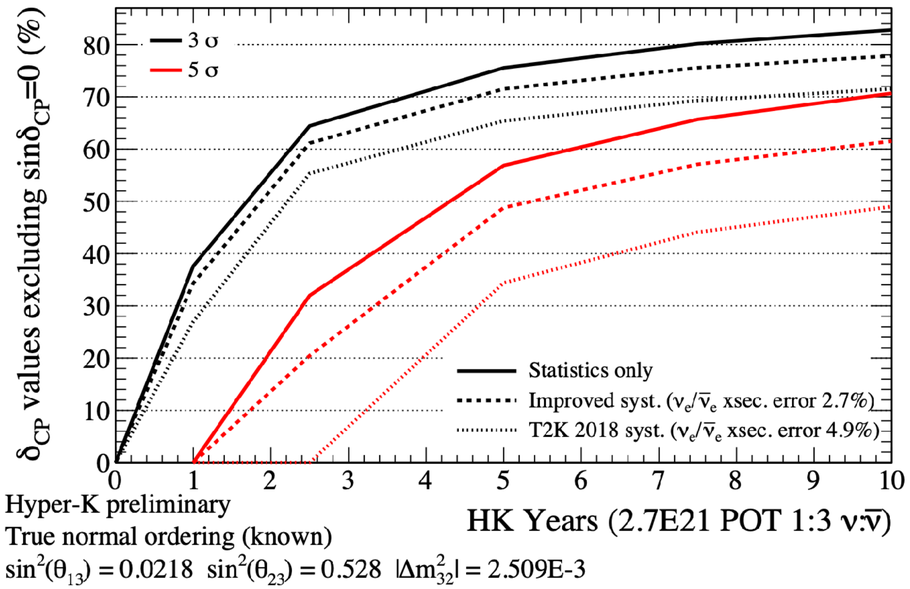






sensitivity



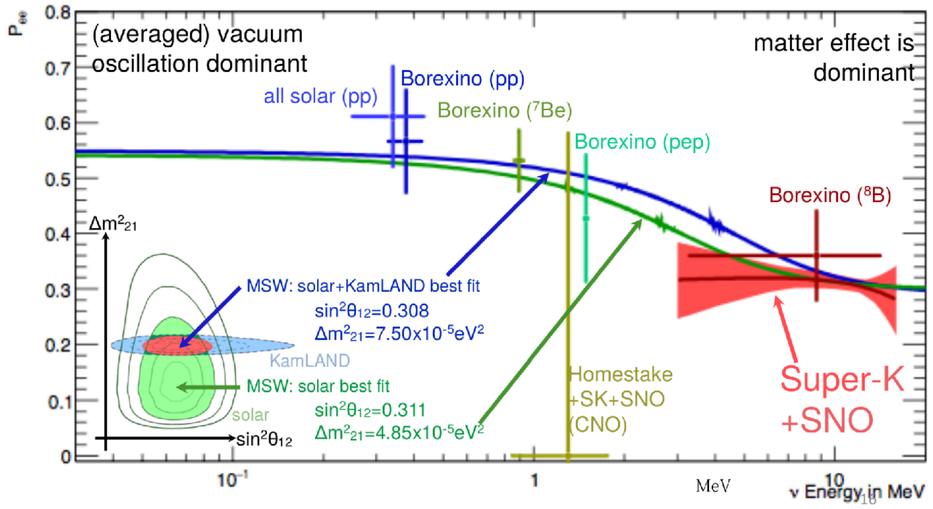


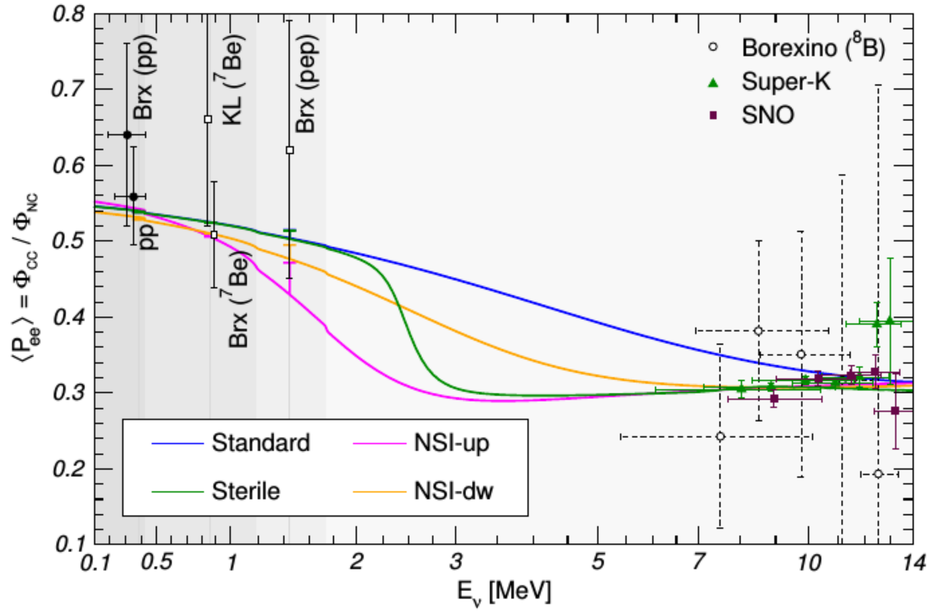
Solar neutrinos: upturn

Matter effect in the Sun dominant at high energy
 transition in probability around a few MeV
Displacement towards lower energy could be explained by

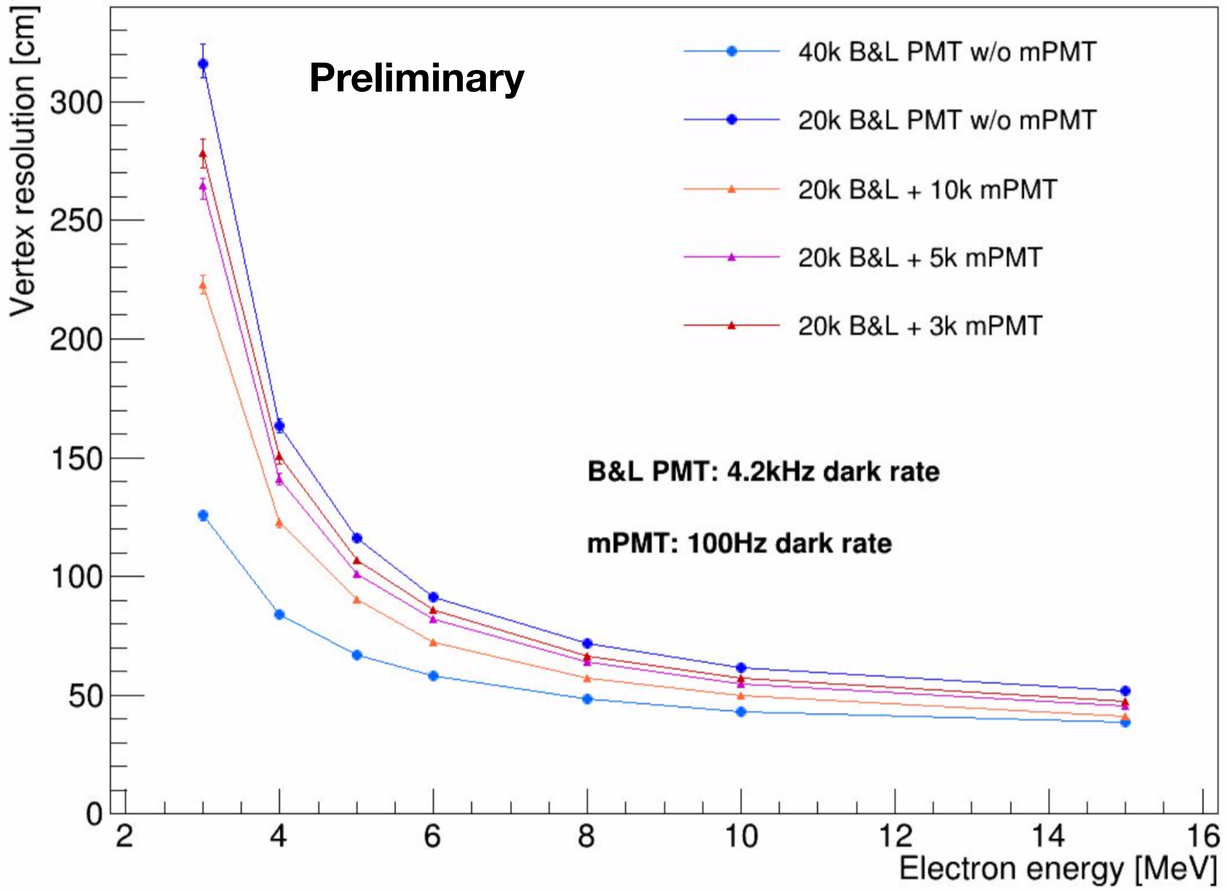
- Statistical fluctuation ?
- Light sterile neutrino ?
- Non Standard Interaction in the dense Sun ?

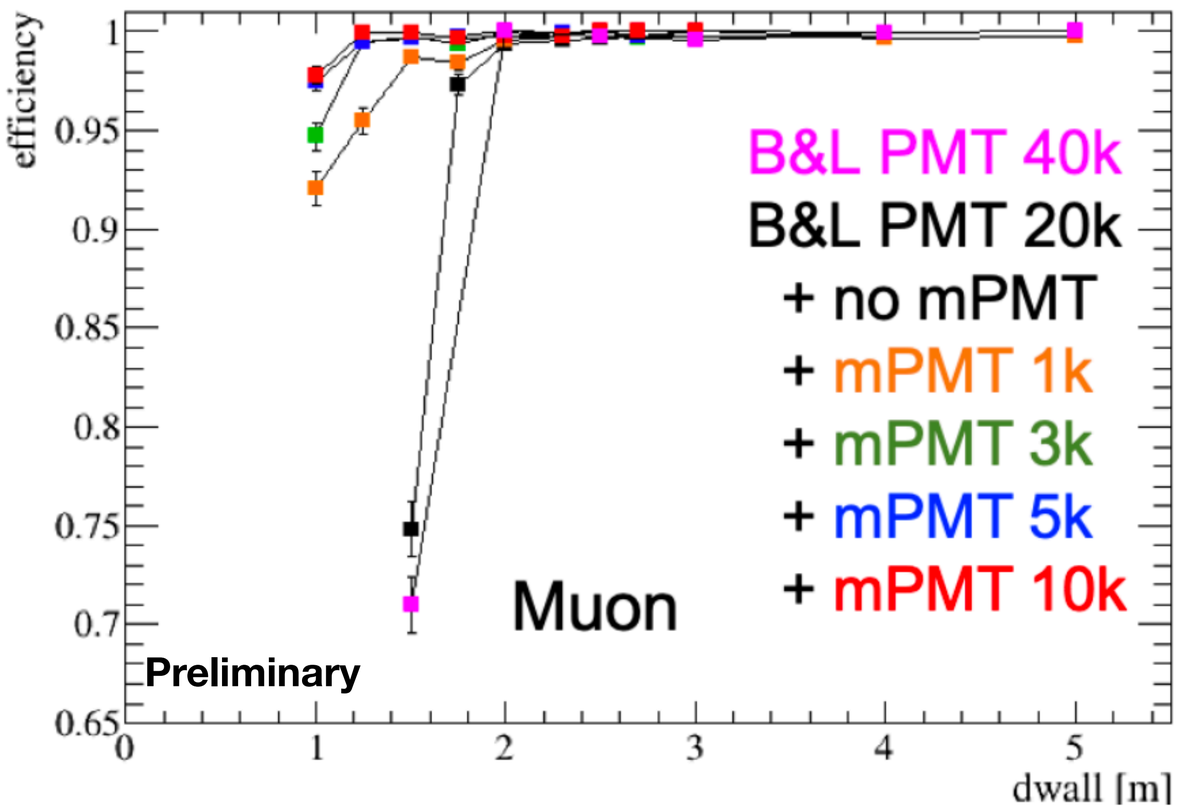
Measurement accessible using mPMTs (lower energy threshold)





mPMT impact on physics



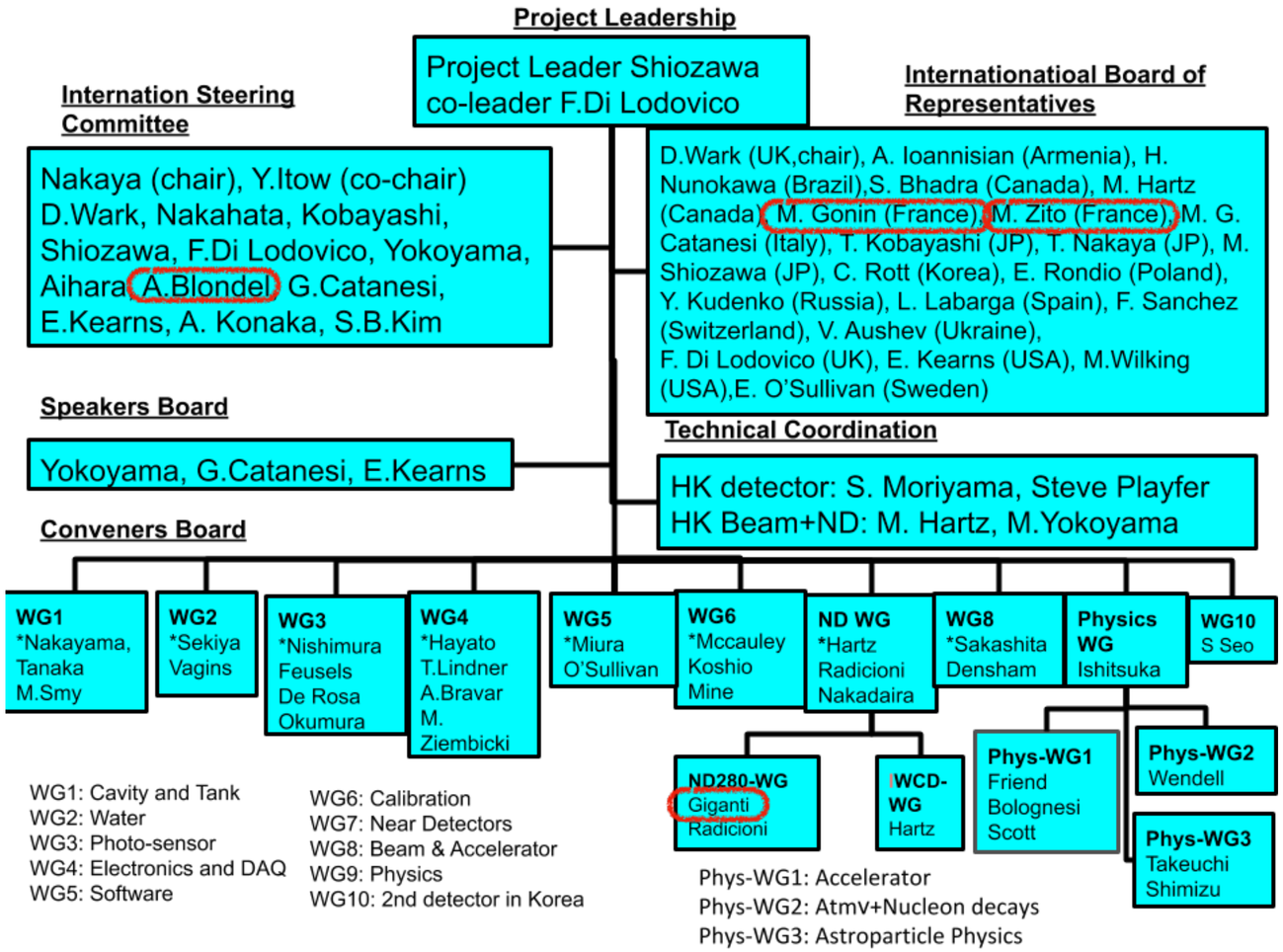


Vertex resolution improved w/ mPMT for dWall ≤ 8m → FV expansion
mPMT allows to explore < 5 MeV region.

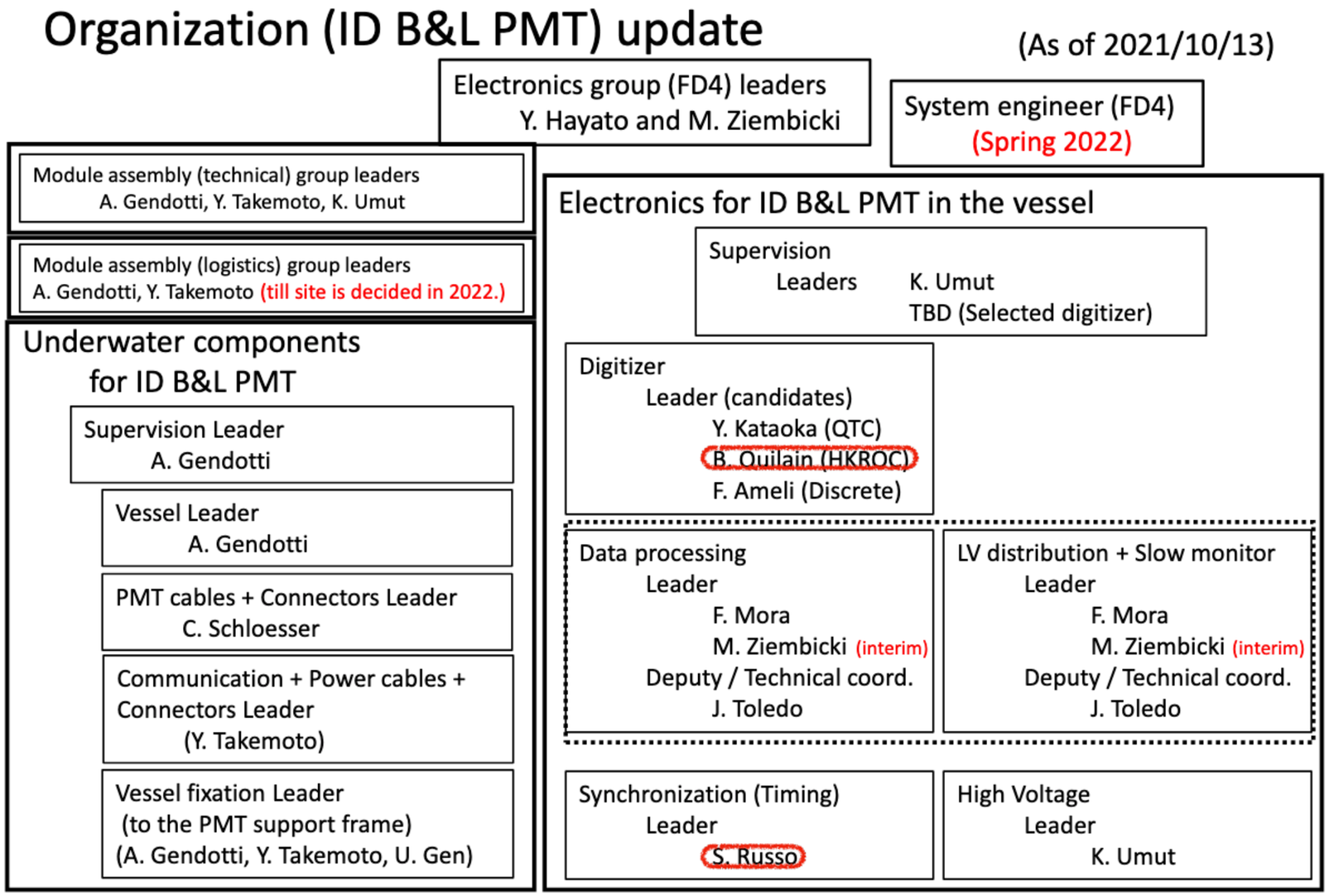
Digitizer costs

1.9 M€ for ID to be shared btw IN2P3 and CEA
0.7 M€ for OD to be shared btw IN2P3, CEA and UK

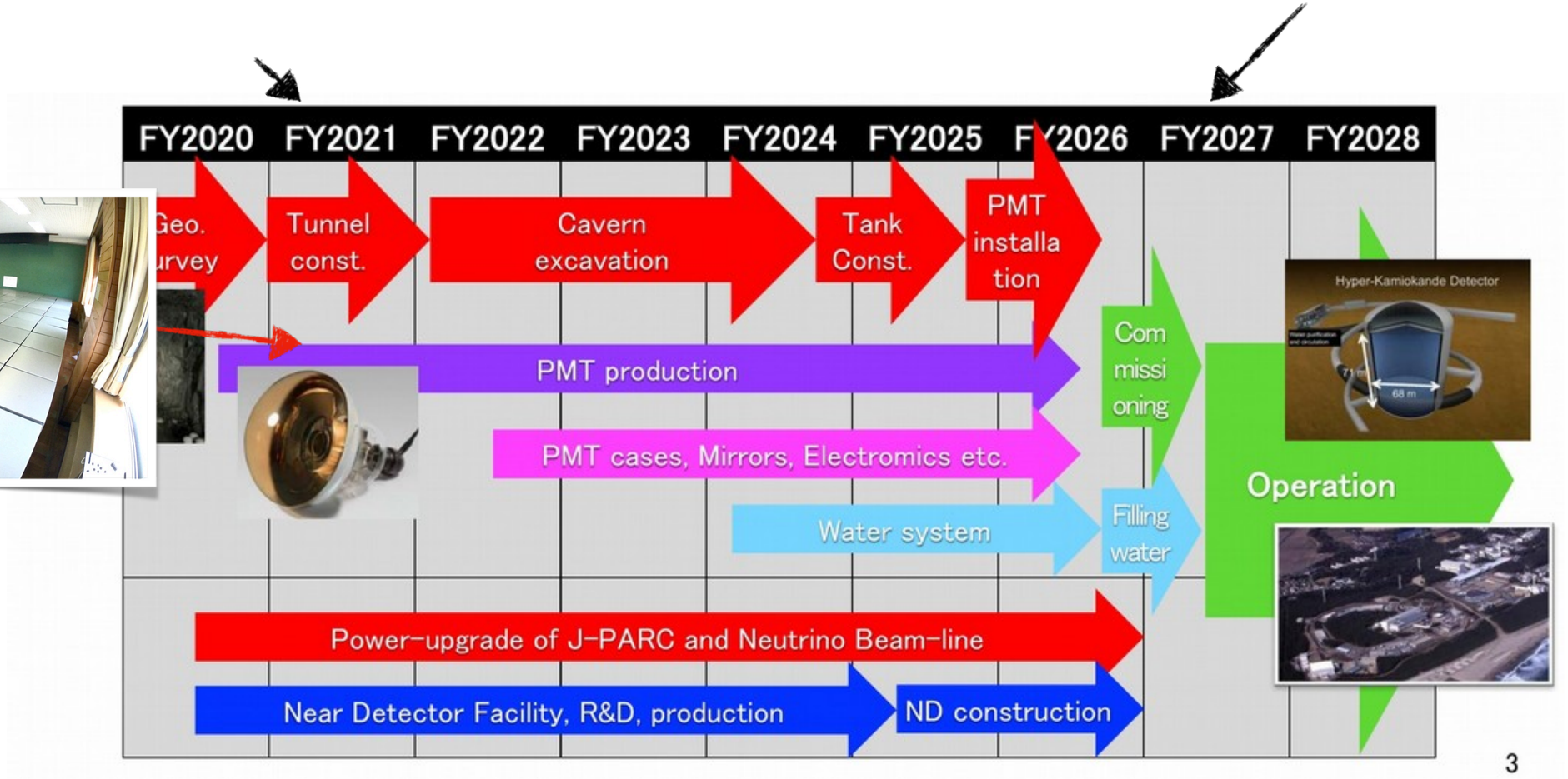
Collaboration Organigram



Electronics organization for ID B&L



Hyper-Kamiokande schedule

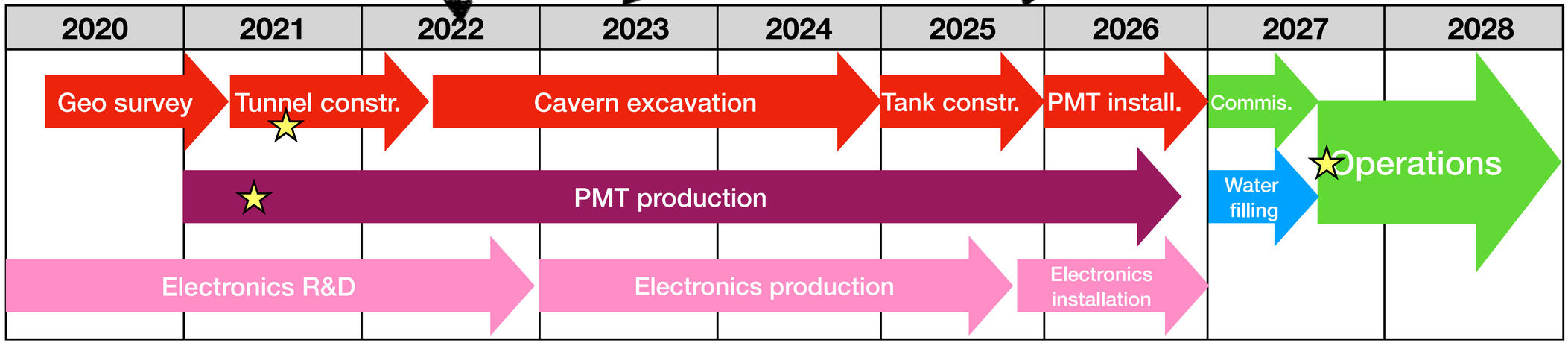


HK schedule

April-July 2022: Internal review

Mid 2023: HKROC and time distrib. production

Start electronics installation



Tunnel construction

Computing timeline

Computing resources timeline

Hyper-Kamiokande

2021 * Update **computing predictions/forecast**

2021 → 2023 * **Work with countries/institutes** that will contribute computing resources
→ Intent to contribute, application procedures, allocations
→ Acquire small scale resources for integrating/testing/using

2023 * Confirmed/**secured resources** to cover **MC validation and final prod (2024-2027)**

2024 → 2025 * **Computing forecasts** for data era recomputed based on validation samples and updated information from DAQ group.

* Work with countries/institutions to use new predictions to make **computing applications** for the **data taking phase** of HK

2025 * Confirmed/**secured resource** allocation for the first 5+ years of data taking with plans in place to expand throughout HK lifetime

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* Computing predictions will be revised every couple of years

* Addition of new resources, and development of integrating different types of new resources can be on-going. But the largest computing resources, which cover the bulk of our needs, will follow above timeline.

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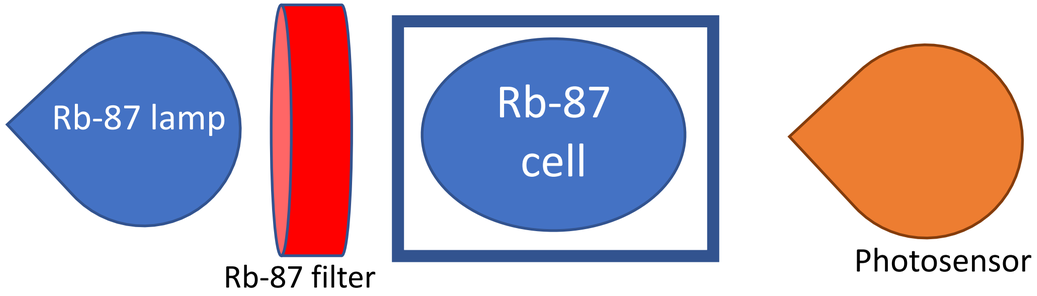
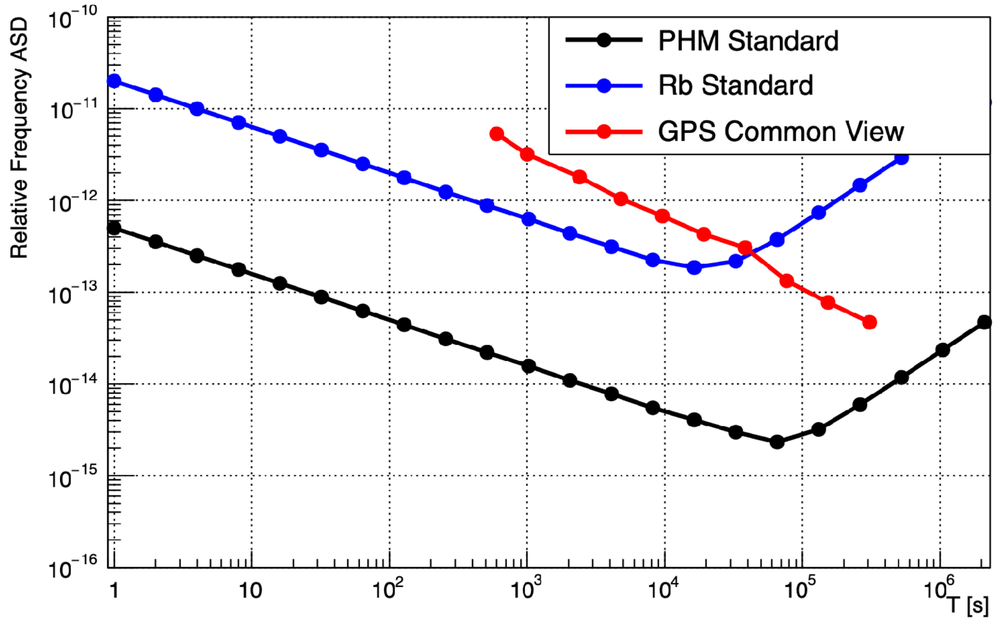
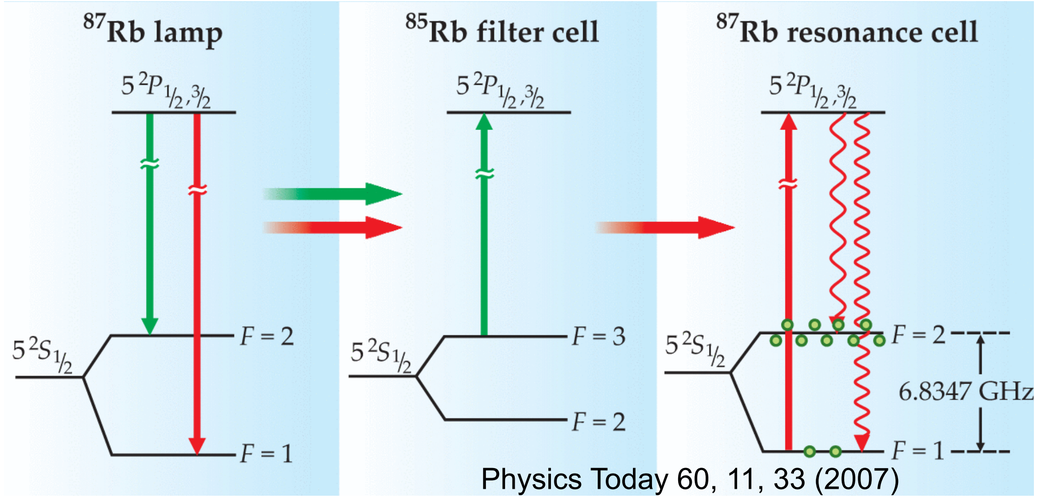
Rb atomic clock





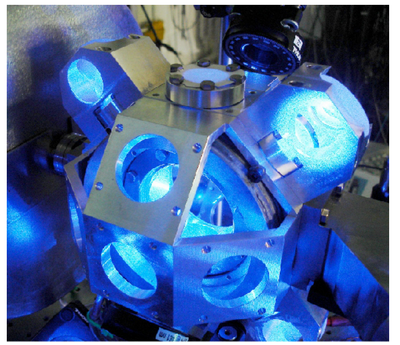


Physics Today 60, 11, 33 (2007)

Allan standard deviation: paper

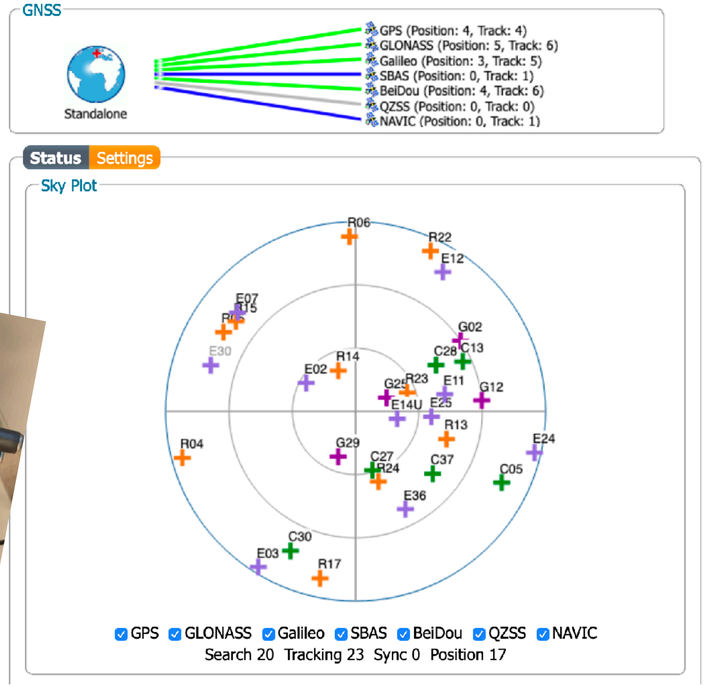
Comparison with time reference at SYRTE **performances studies**

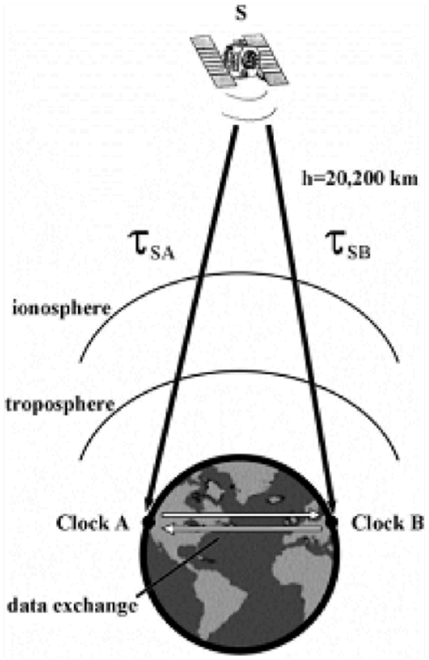
Test using more stable clocks e.g. Passive Hydrogen Maser (PHM1008)


Strontium optical atomic

GNSS antenna and receiver

Receive signals from various satellites e.g. Galileo
Produce 1 PPS using received signals
Synchronization with UTC (after calibration & correction)





Tests at Jussieu and SYRTE

Dedicated tests and performances at SYRTE
  Clock and GNSS calibration

Creation of a dedicated lab to study clocks and GNSS at LPNHE
  Room for long-term tests (5th floor, Tower 13)
Time transfer (White Rabbit) between Syrte-Obs.Paris and Jussieu
  PPS with UTC(OP) available in lab soon
Installation of GNSS antenna on the Jussieu roof (Tower 13)
  Long-term studies and comparison using
  atomic clocks and PPS-Syrte

First implementation of GNSS signals corrections
Build prototypes for HK

R&D towards HK and other IN2P3 projects