Hyper-Kamiokande

Participation of IN2P3 physicists in Hyper-Kamiokande

ILance, LLR, LPNHE, OMEGA

ILANCE
International Laboratory for Astrophysics, Neutrino and Cosmology Experiments

LLR

LPNHE PARIS

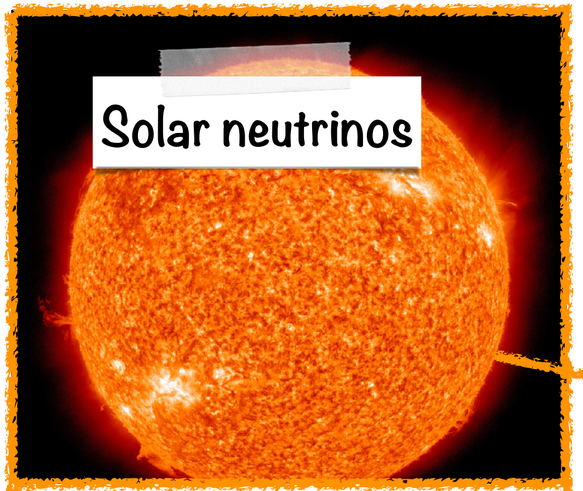
OMEGA Microelectronics

SCIENCES SORBONNE UNIVERSITÉ

ÉCOLE POLYTECHNIQUE

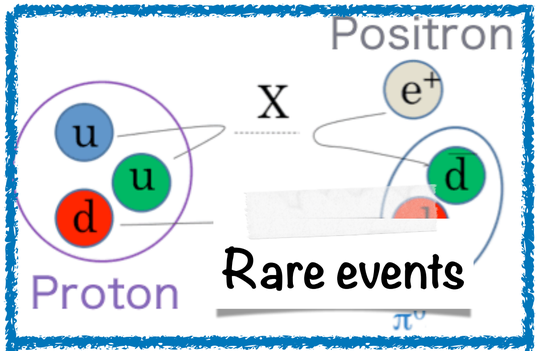
cnrs dépasser les frontières IN2P3 Les deux infinis

Hyper Kamiokande in a nutshell



- MSW effect
- Non-standard interactions

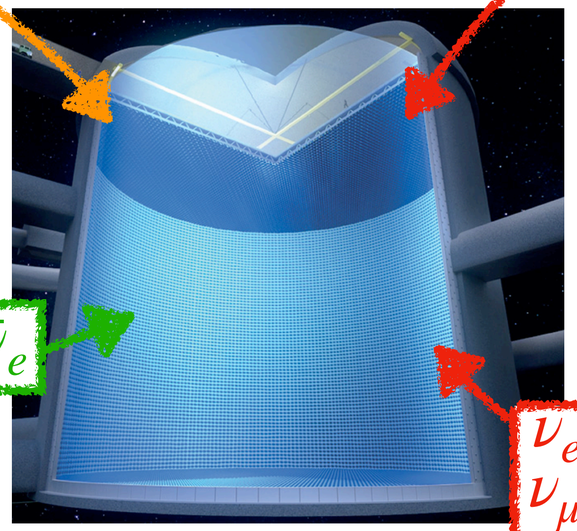
- Transient SN ν: constrain SN profile models
- Relic SN ν: constrain cosmic star formation



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

ν_e

$\bar{\nu}_e$



ν_e $\bar{\nu}_e$
ν_μ $\bar{\nu}_\mu$

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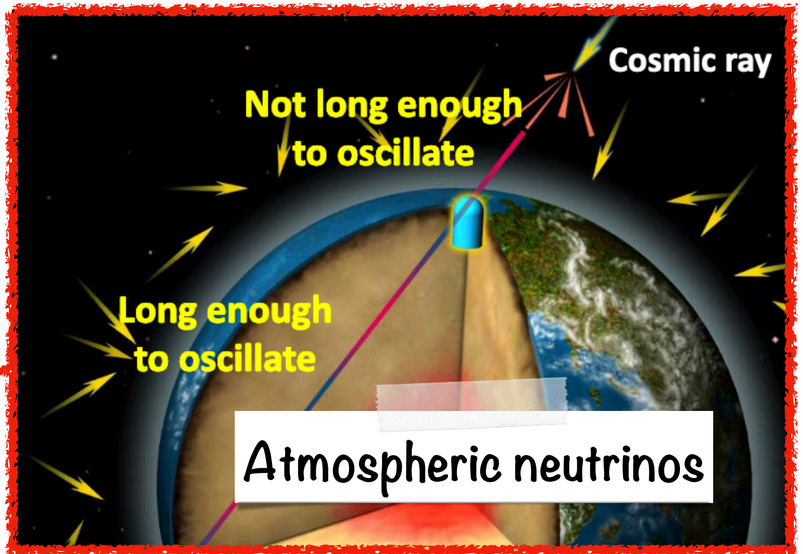
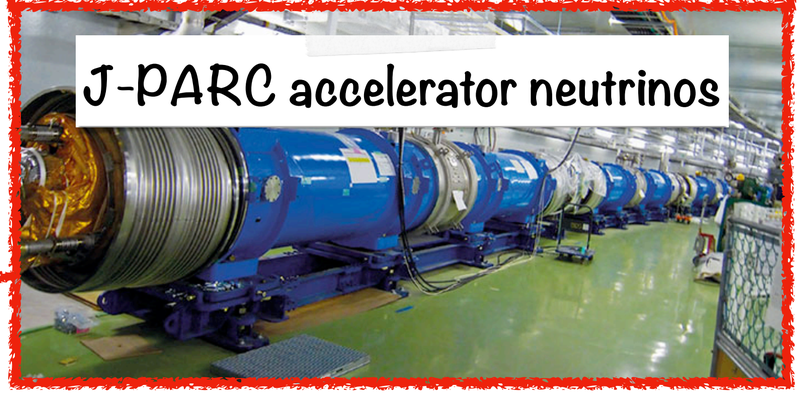


- Observe CP violation for leptons at 5σ
- Precise measurement of δ_{CP}
- High sensitivity to ν mass ordering



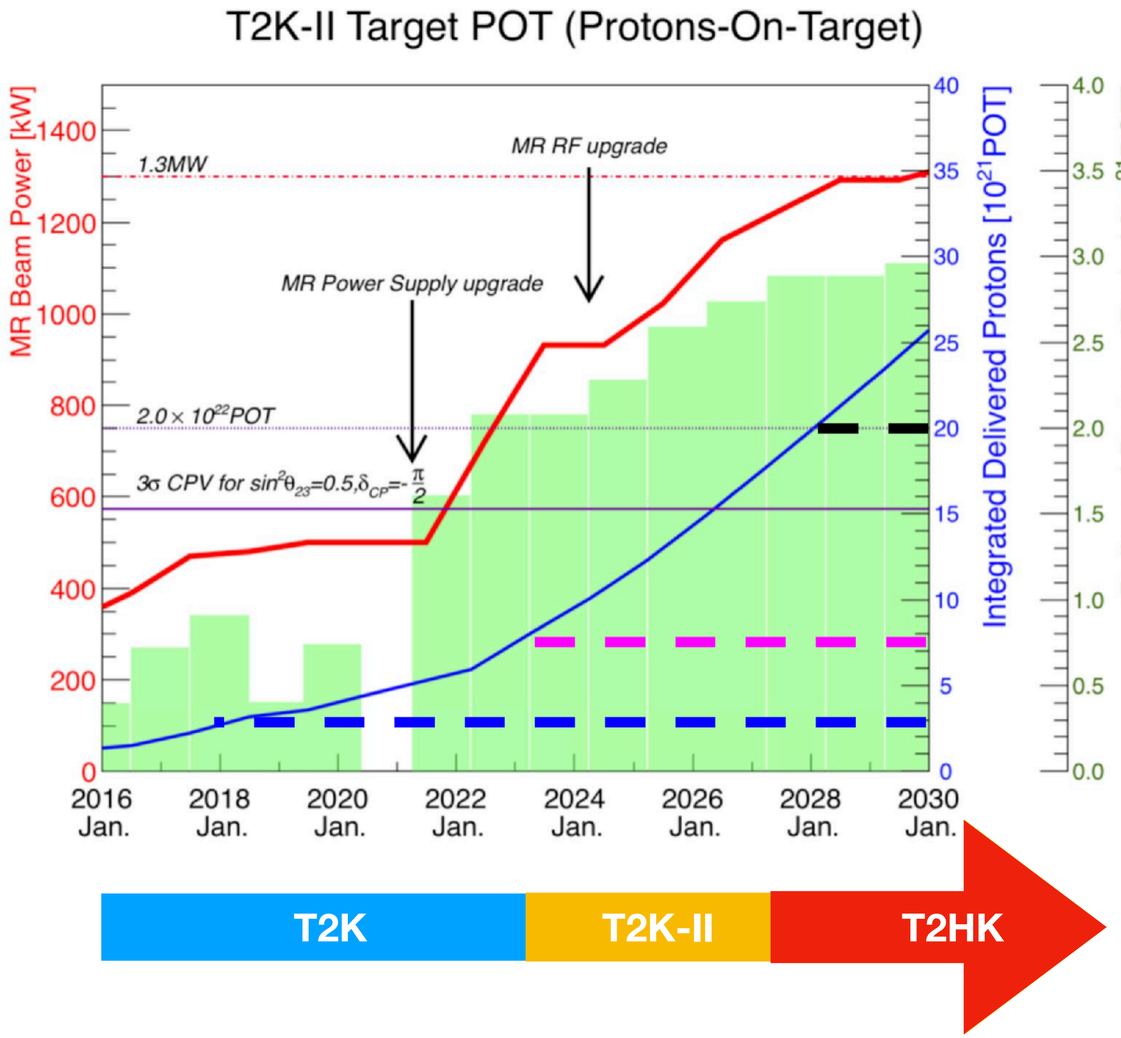
Tokai to HK: heritage from T2K

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



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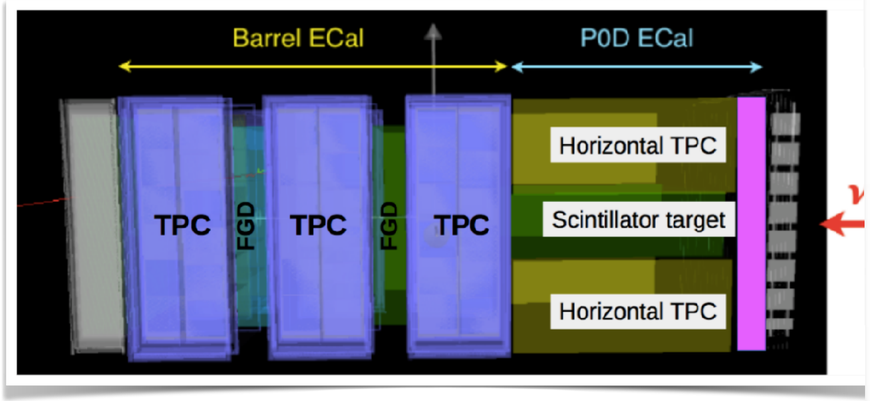
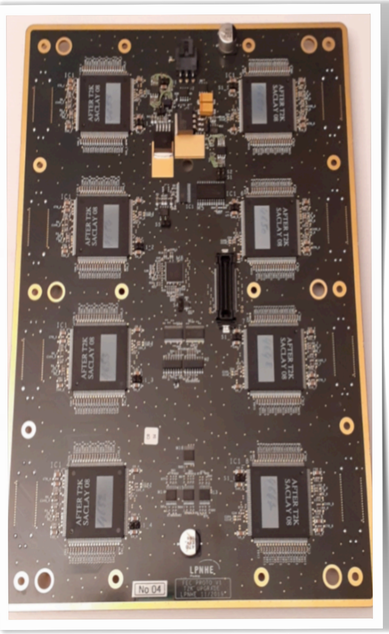
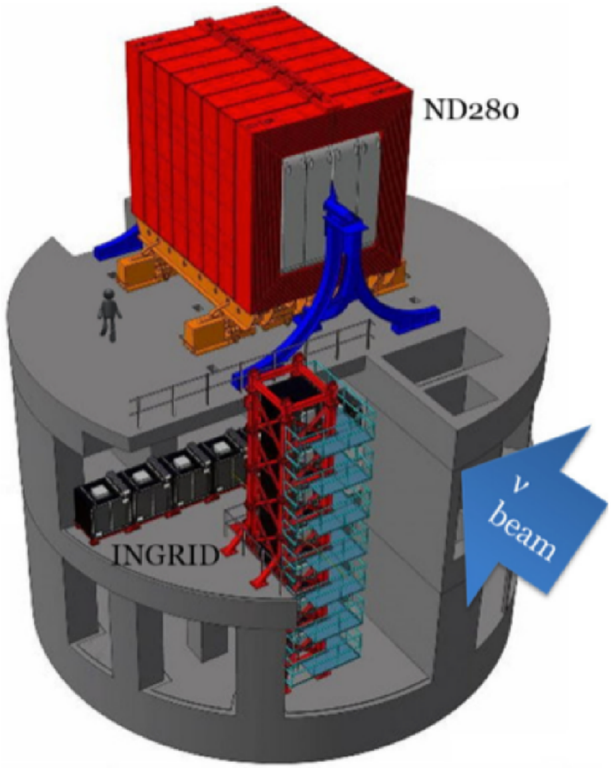
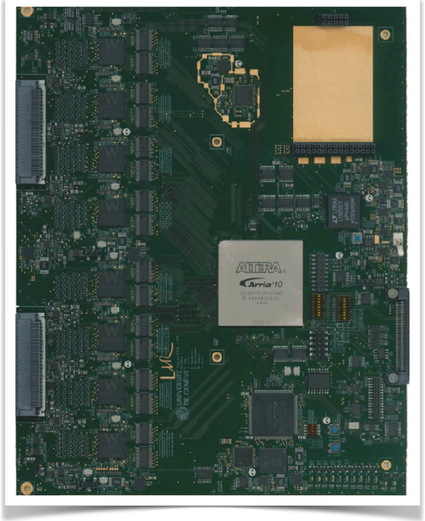
Magnetized near detector @280 m

- Used for T2K Oscillation Analysis for >10 y
- Being upgraded now for T2K-II
- **Systematics uncertainties under control from Day-1 of HK**









Tokai to HK: what will be new?

Accelerator upgrade
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Magnetized near detector @280 m
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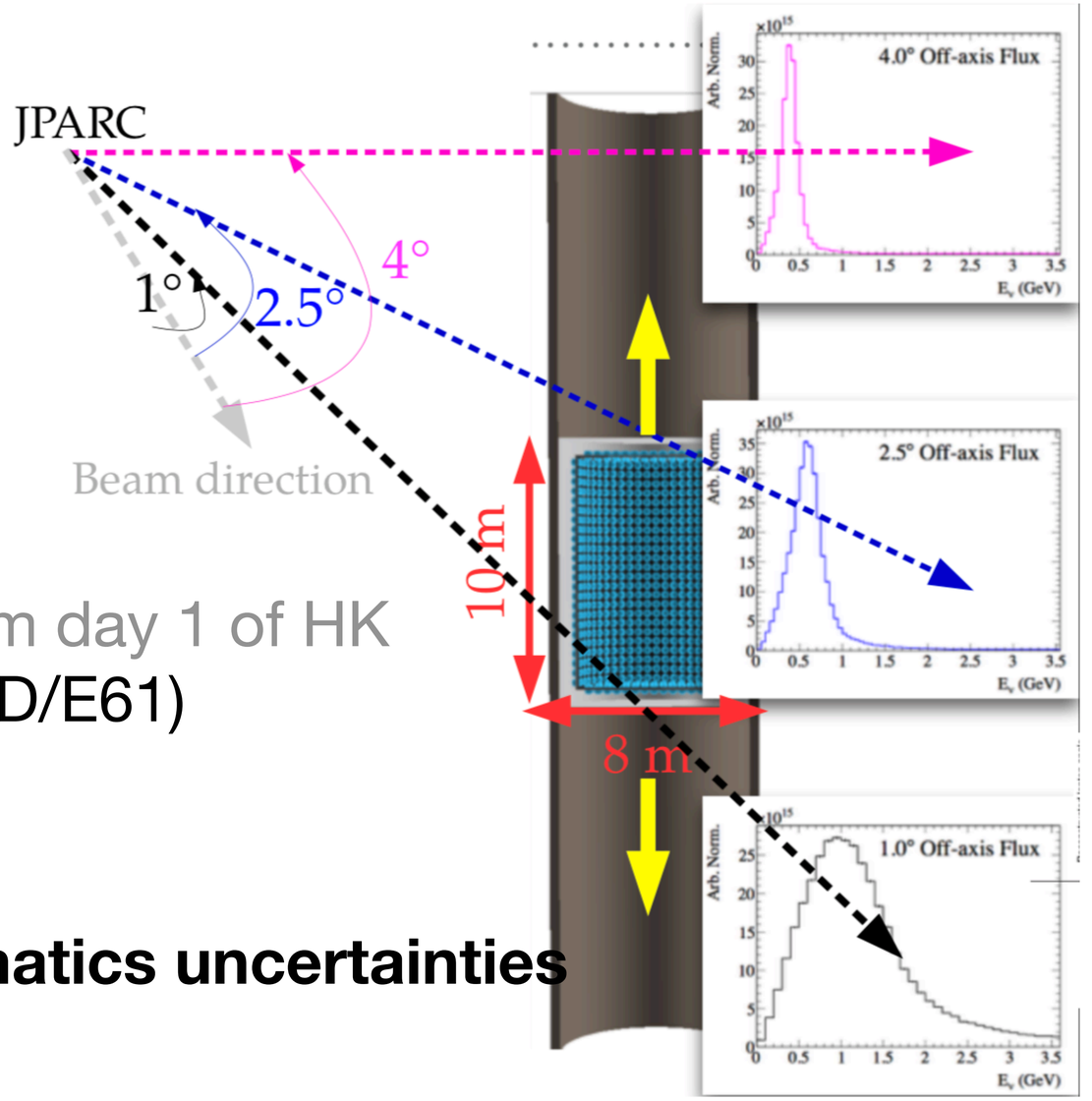
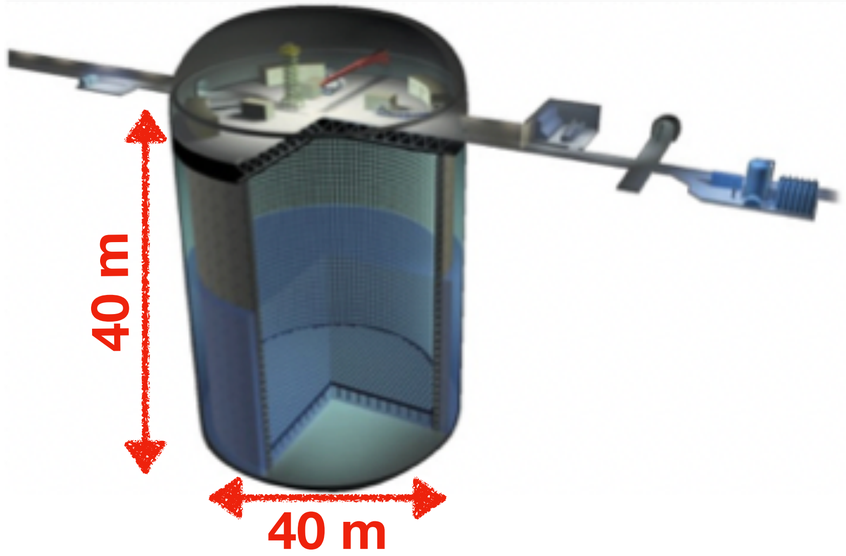
Intermediate Water Cherenkov Detector (IWCD/E61)

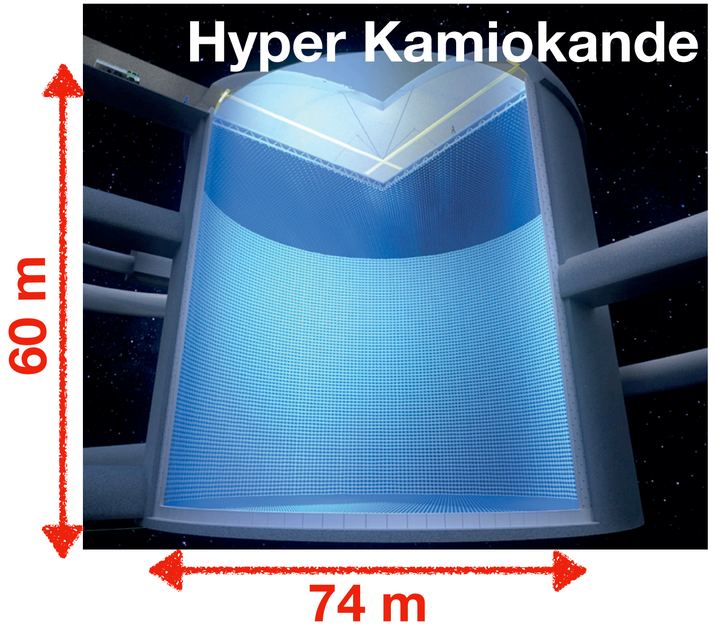
NEW
- Measure ν interactions on Water
- High stats. sample of ν_e interactions
- **Needed to reach final HK goal for systematics uncertainties**



Tokai to HK: what will be new?

Super Kamiokande





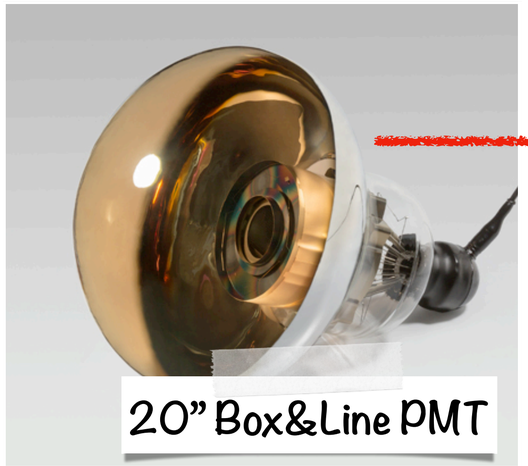
	Super Kamiokande	Hyper Kamiokande
Site	Mozumi-yama	Tochibora-yama
Number of ID 20” PMTs	11129	>20,000
Photo-coverage	40%	>20%
Single-photon efficiency/PMT	~12%	~24%
Dark rate/PMT	~4 kHz	~4kHz
Time resolution of 1 photon	~3 ns	~1.5 ns
Total/fiducial mass (kton)	50 / **22.5**	260 / **187**

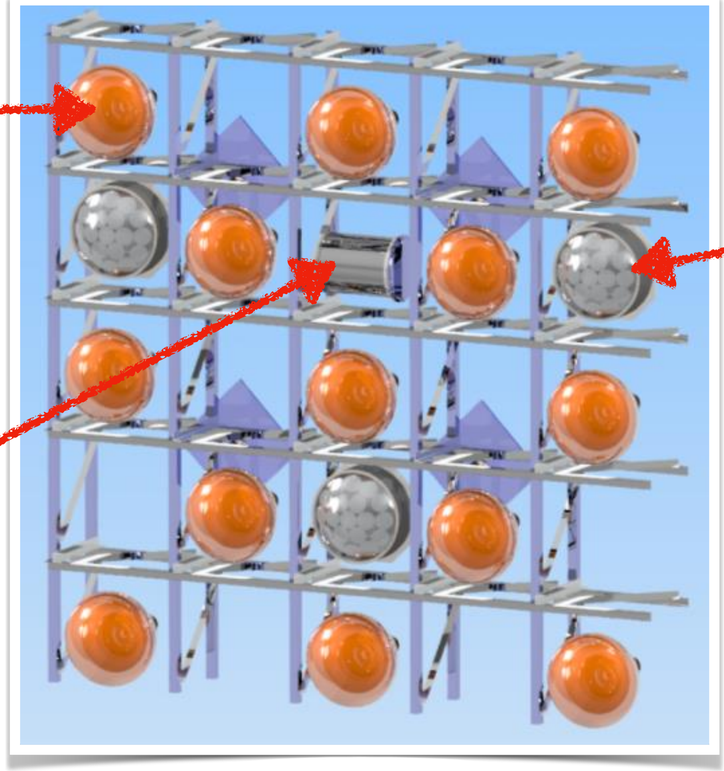
Fiducial volume x8
→ non-beam ν physics

Beam neutrino event rate x 20
→ beam ν physics

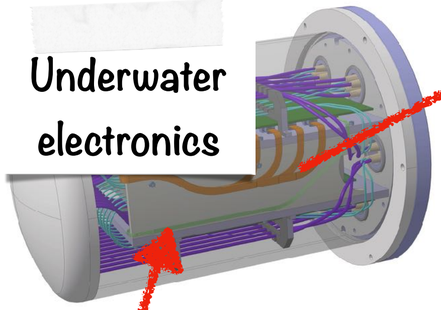
Start operations in 2027 with 240 kt.MW and an assumed runtime 10^7 s per year

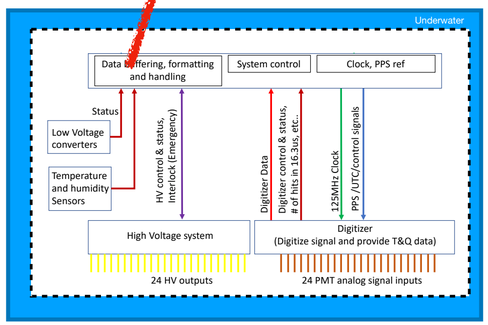
20” PMTs, mPMTs and readout





19 x 3” PMT





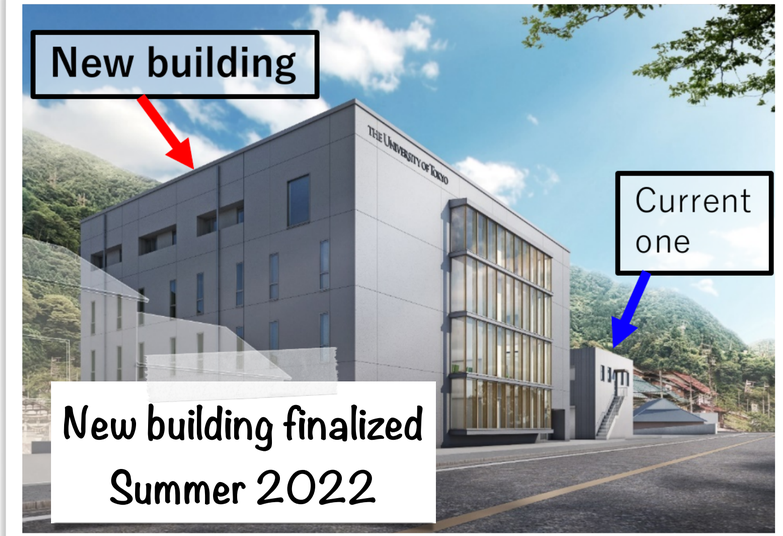
Inner detector composed of

- 20k+ 20” PMTs (Hamamatsu R12860)
- ~5k mPMTs (19 3” R12199-02 PMTs)

→ <u>Better SNR, directionality, timing</u>

NEW **Size of detector requires an in-water electronics**

Construction status



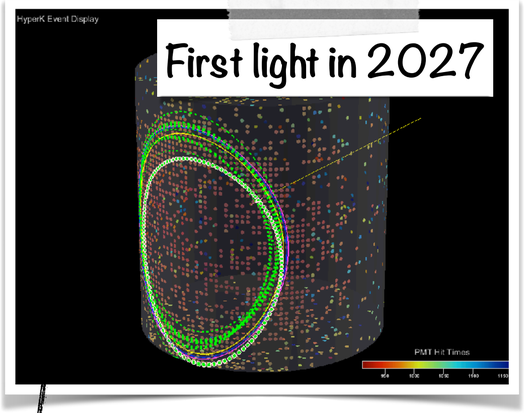
Survey completed ✓

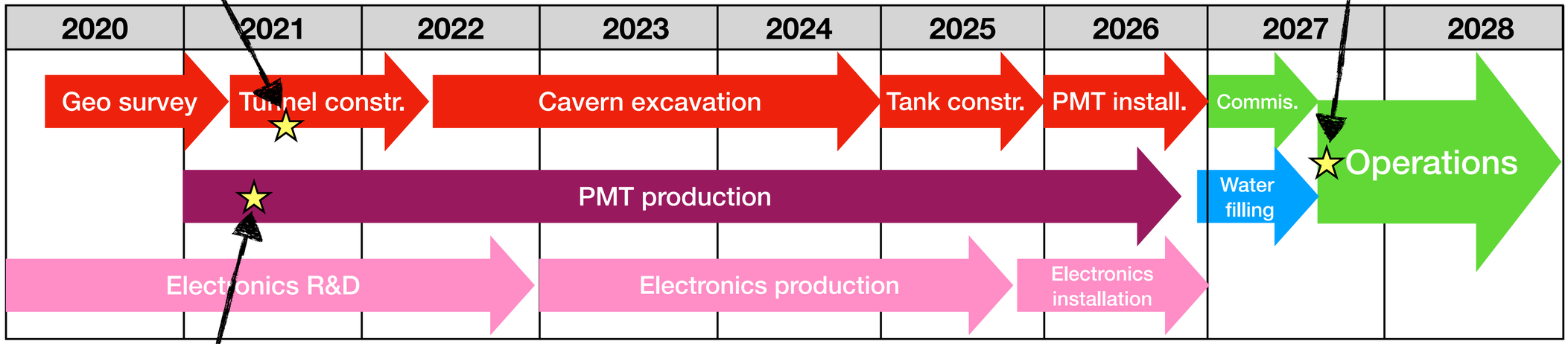
Excavation on-going

New main building

Everything on track! ✓

HK schedule





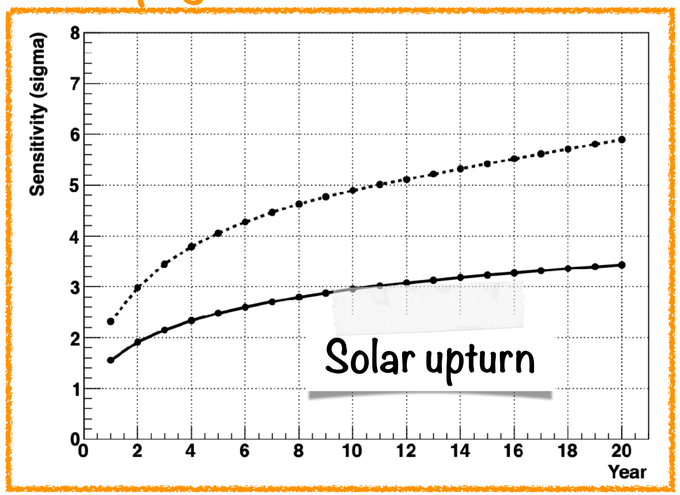
Strong engagement of Japan: ~500 M$ for construction

→Expected from other countries: ~100 M$

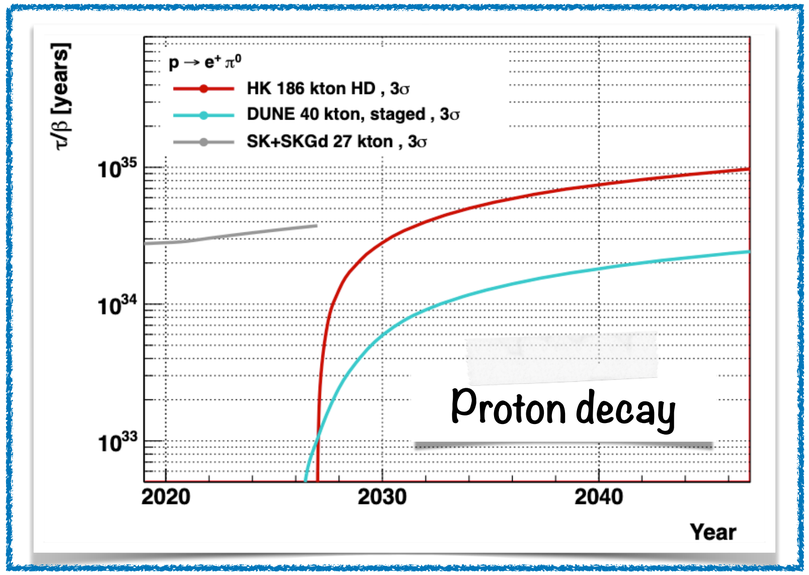
International contributions being formalized (MOU expected in 2022)

Hyper-Kamiokande Physics

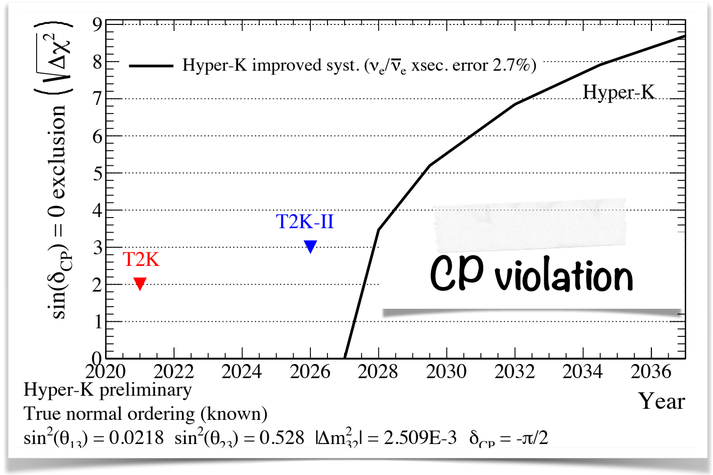
Solar physics

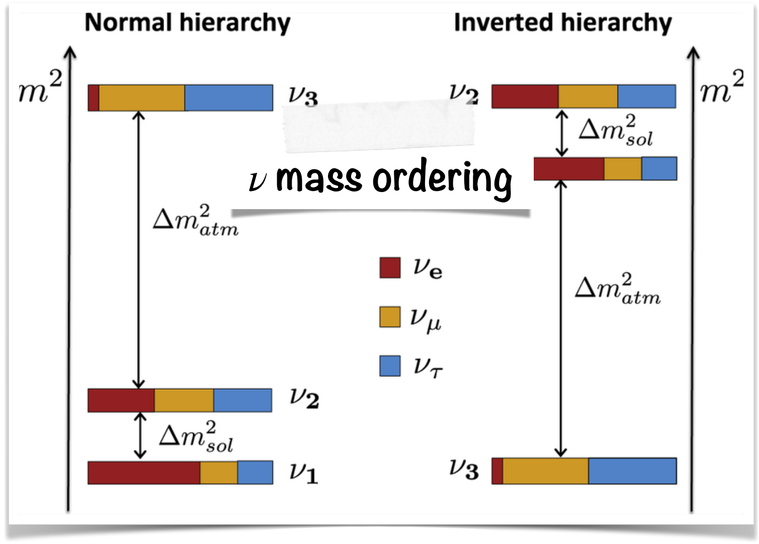


Rare events

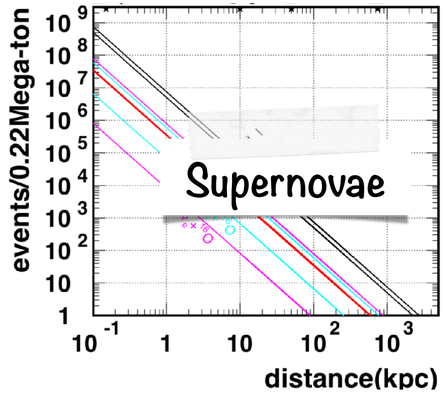


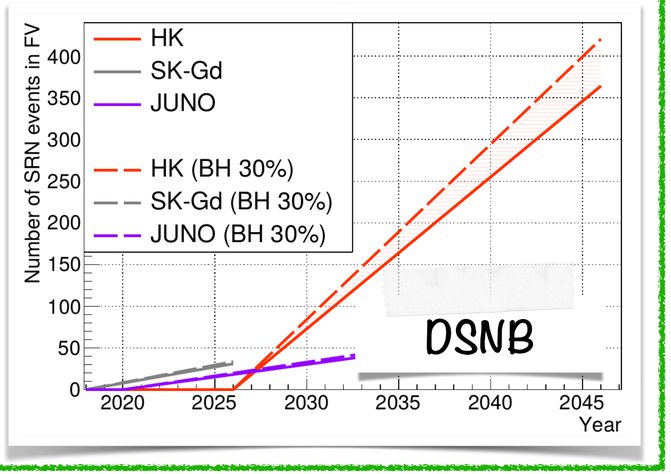
Neutrinos oscillation





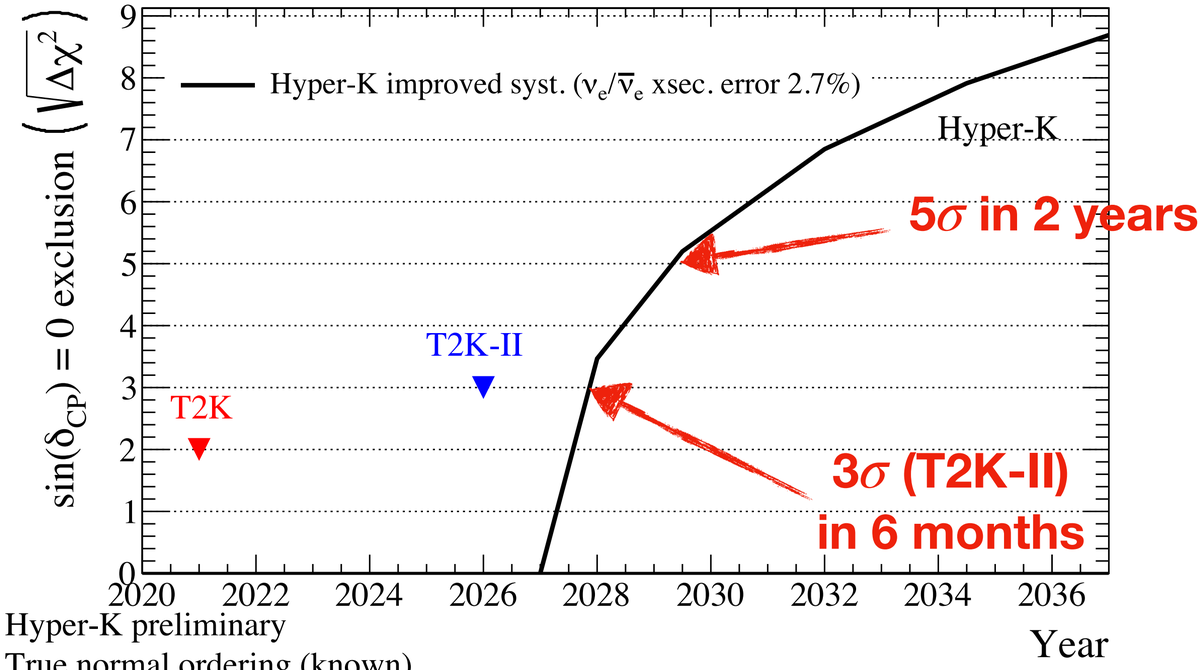
Supernovae modeling and Early Universe

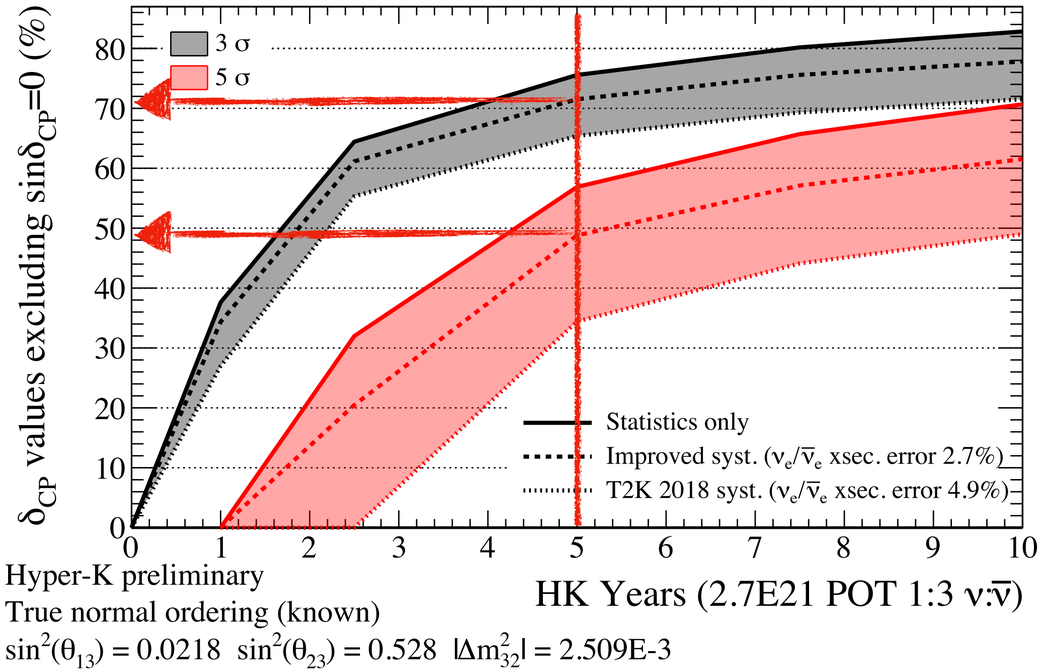




Fast CP-violation discovery

Known mass ordering (KM3NET)





→If $\delta_{CP} = -\pi/2$, CP violation discovered before any other LBL-ν experiment

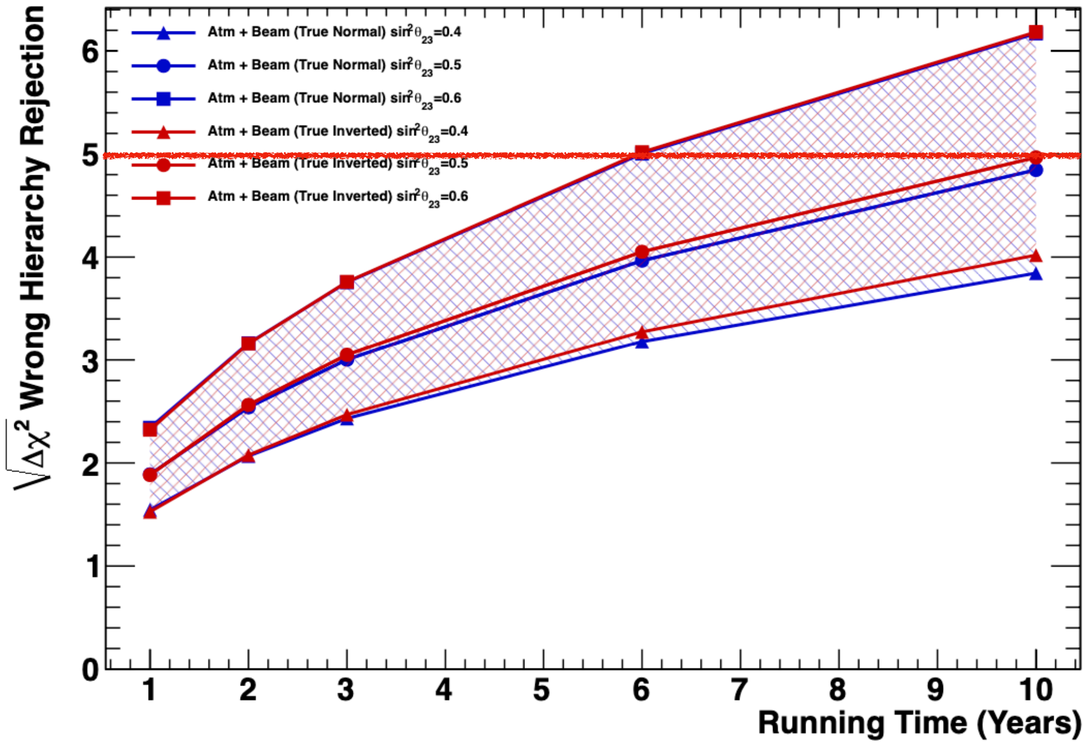
→Fastest experiment to survey possible δ_{CP} values

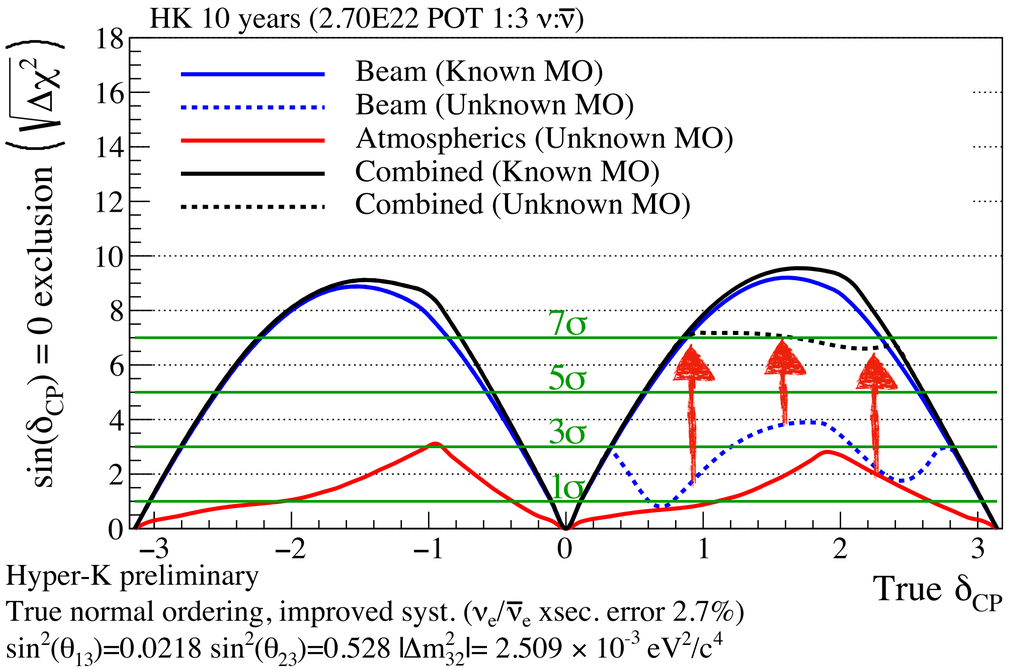
	$\delta_{CP} = -\pi/2$		All δ_{CP}	
	3σ	5σ	50% 5σ	70% 3σ
Hyper Kamiokande	0.5 y	2 y	5 y	5 y
DUNE (staged*)	4 y	8 y	10 y	13 y

* 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



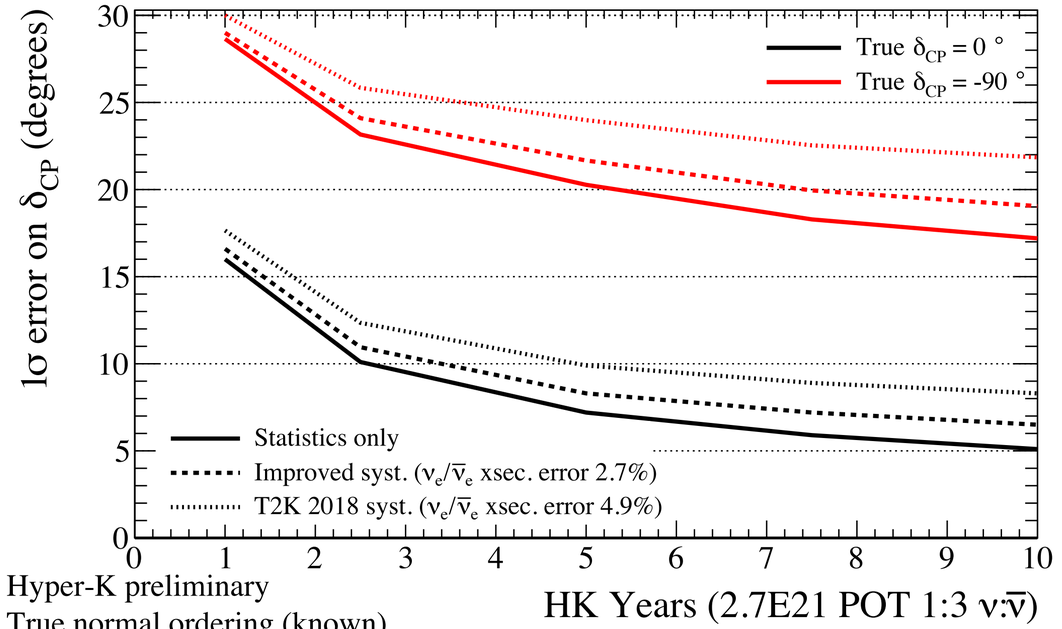


If not discovered by T2K/SK, Nova, Orca or Juno before 2027, HK can determine MO after 6-10 years via atmospheric ν

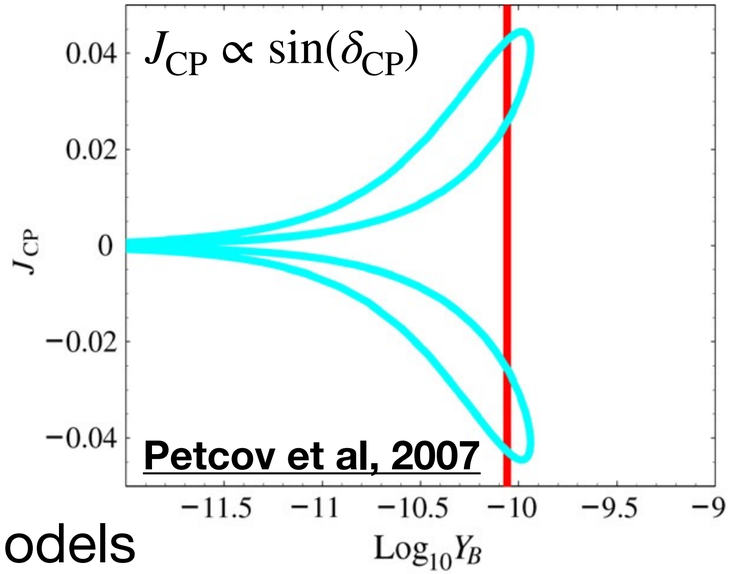
	$\sin^2\theta_{23}$	Atmospheric neutrino	Atm + Beam
Mass ordering	0.40	2.2 σ	→ 3.8 σ
	0.60	4.9 σ	→ 6.2 σ

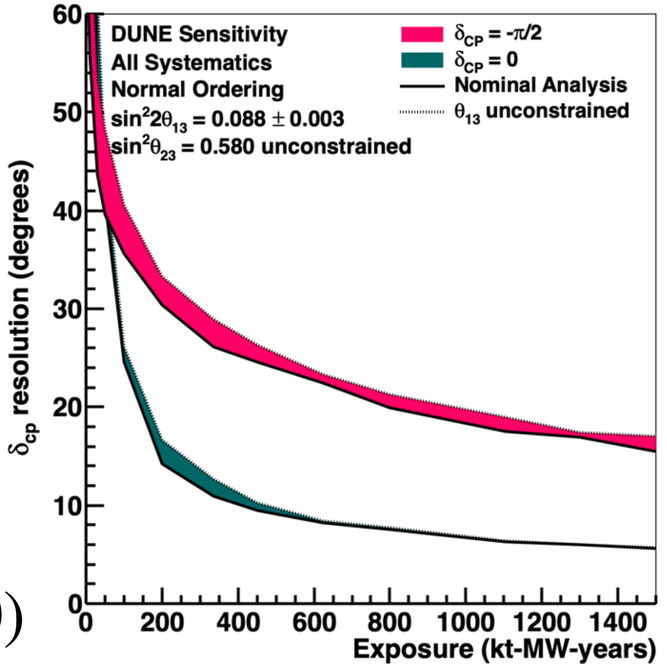
Sensitivity to CPV is <u>little affected</u> if we add atmospheric ν
→MO prior knowledge not really required to explore δ_{CP}

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 $\delta_{CP} = -\pi/2$ (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

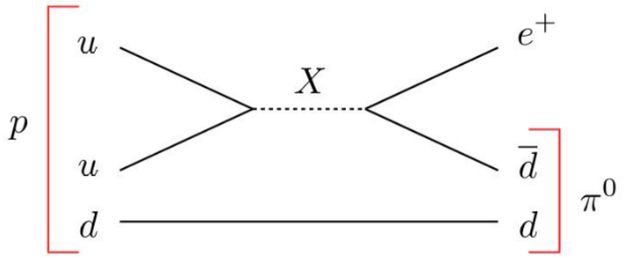
HK will have the best limit on $p \to e^+ + \pi^0$ for <u>bound</u> protons

→ about 1 order of magnitude better than current limits

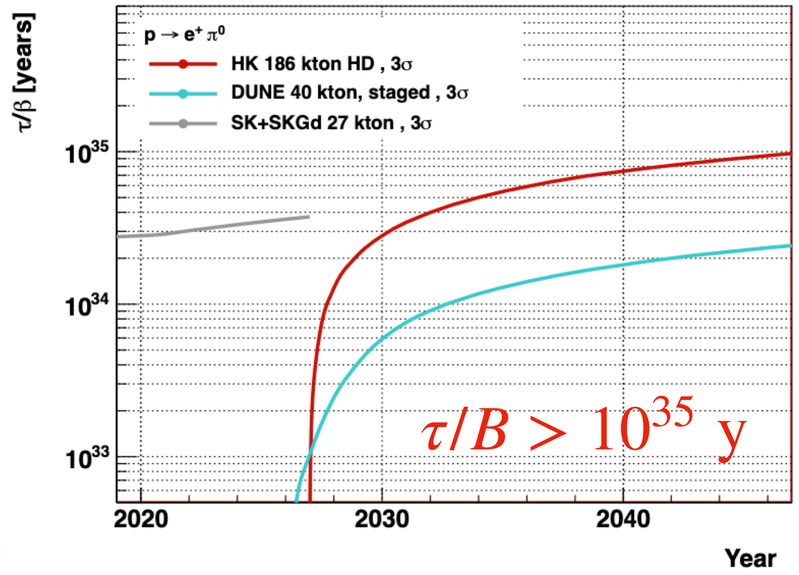
→ typical constraint $m_X \gtrsim 5 \times 10^{15}\ \mathrm{GeV}/c^2$

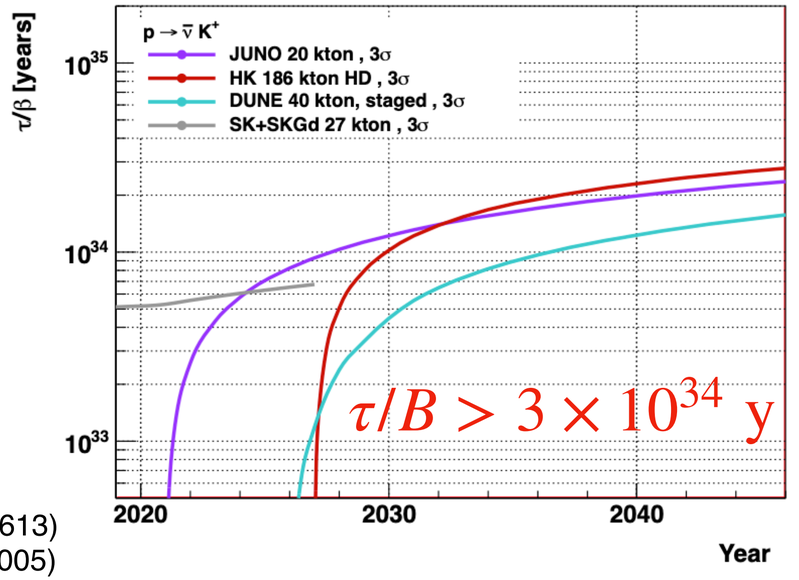
Thanks to its huge mass, HK will also have leading sensitivity to channels with invisible particles ($p \to \bar{\nu} K^+$)

HK is sensitive to <u>free</u> proton decay



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





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 stats sensitivity wrt. SK

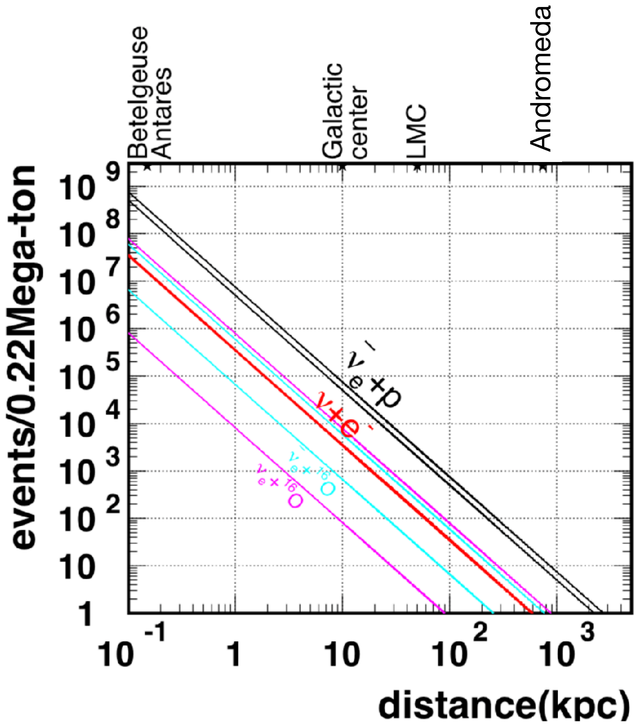
SN1987A type ~2500 events

Galactic center: ~50000+ events

Direction (1°@10kpc) → triangulation

Time profile: collapse models

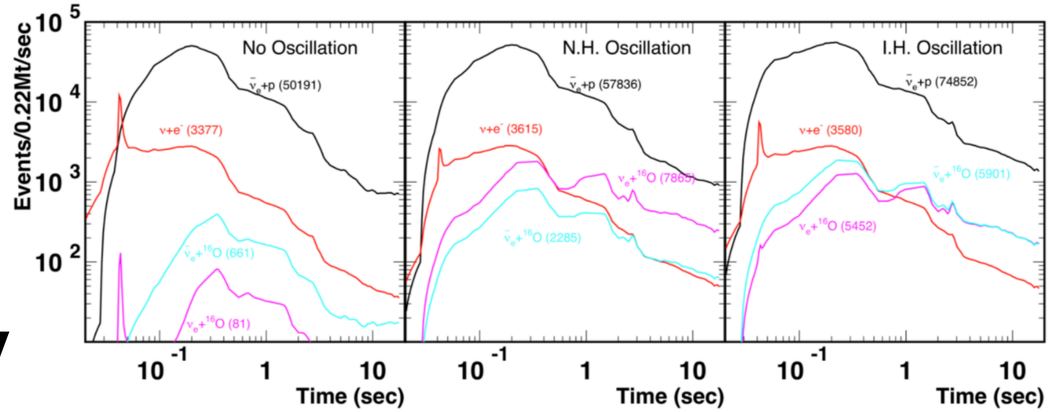
→ SN ν detected every 3 years in HK!



Gravitational waves sources

Nearby (10Mpc) neutron star mergers

→Unique multi-messengers observatory



DSNB discovery by HK

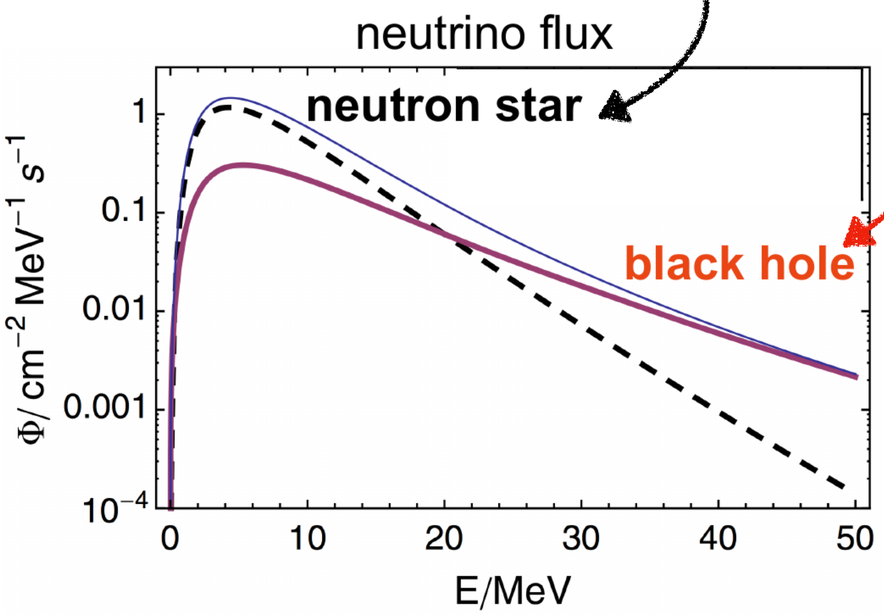
SN-relic neutrino (SNRv) offer new constraints on cosmic star history

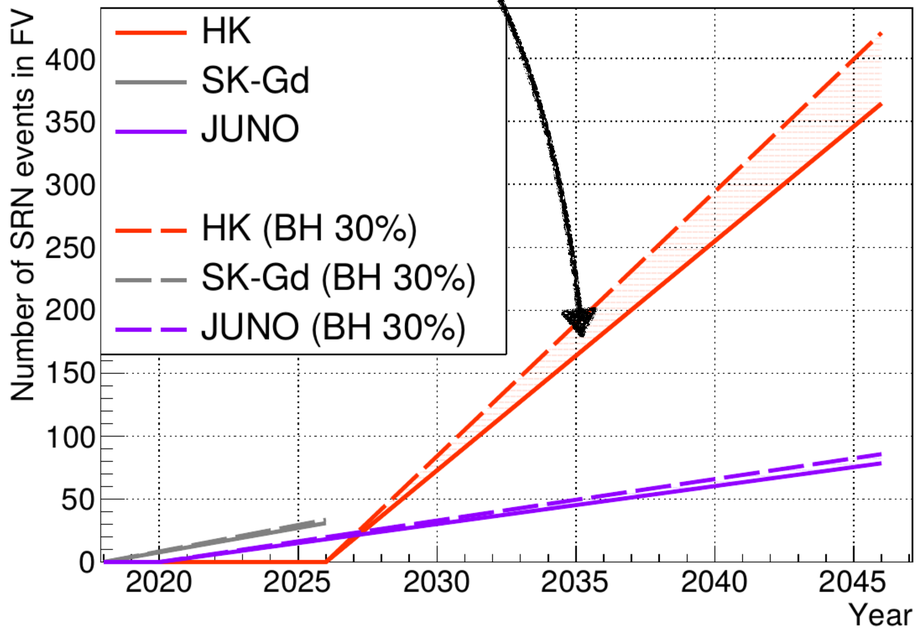
→Could be first detected by SK-Gd

→The spectrum will be determined by HK

Impact of redshift: low energy ↔ probe older stars

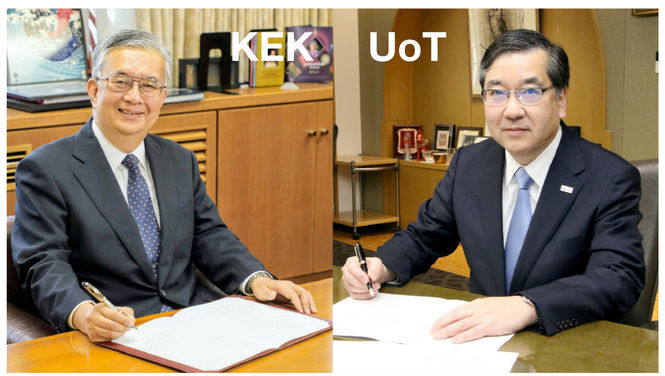
Sensitivity to neutron star vs black hole formation

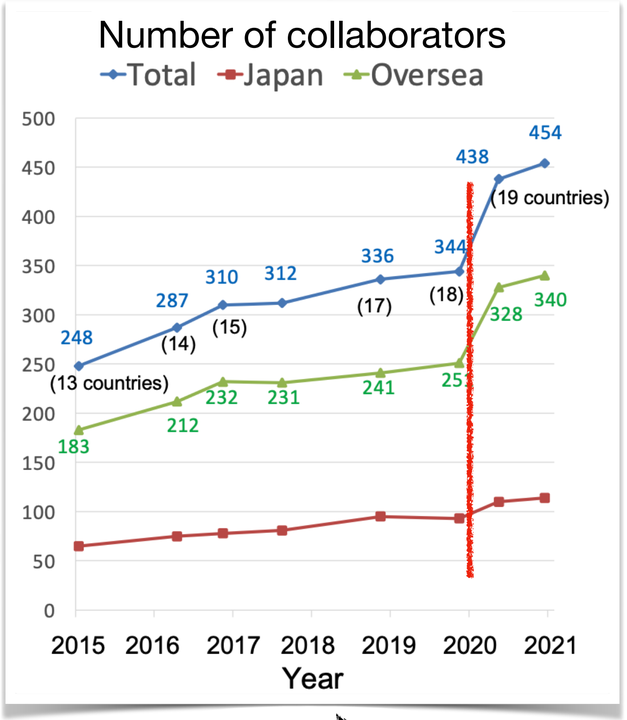




~~Project~~ Experiment approval: key dates

Conclusion of previous CS: “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

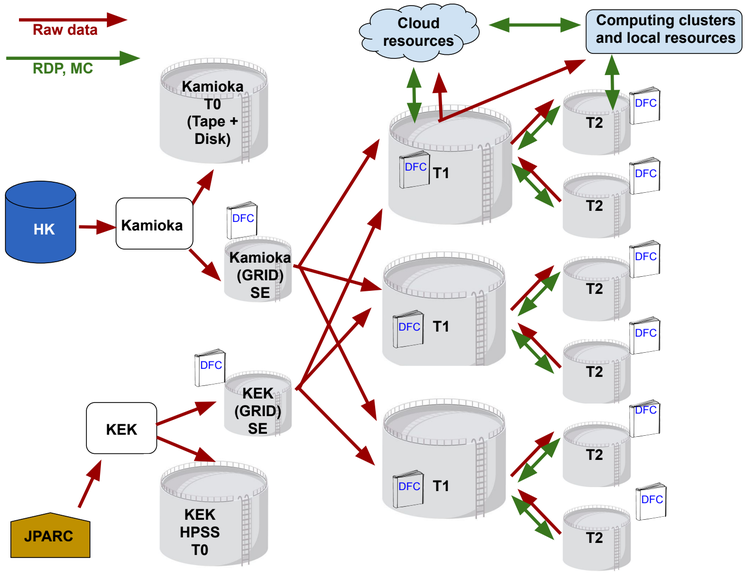
Jan. 2021: CEA CS approved HK

March 2021: LLR CS approved HK

Oct. 2021: IN2P3 CS discussing HK

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
- **<u>International computing effort</u>**
  - CC-IN2P3 as T1 for HK



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…)

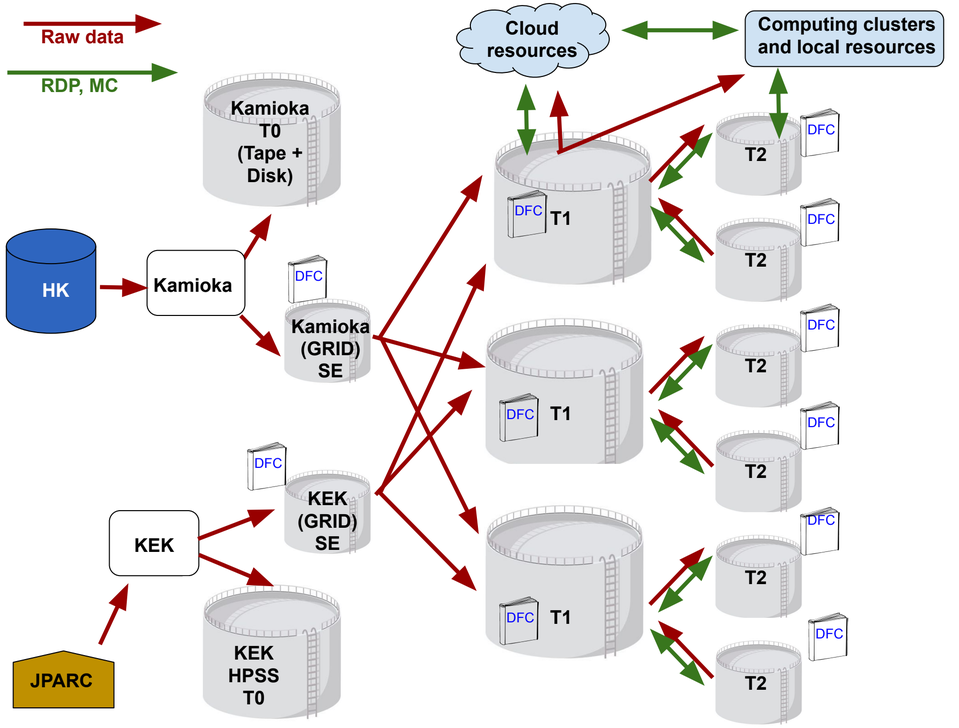
→obvious synergies

First 10 years of operations:

→25 PB (data + MC — mostly Far Detector)

→880 MCPU.hours

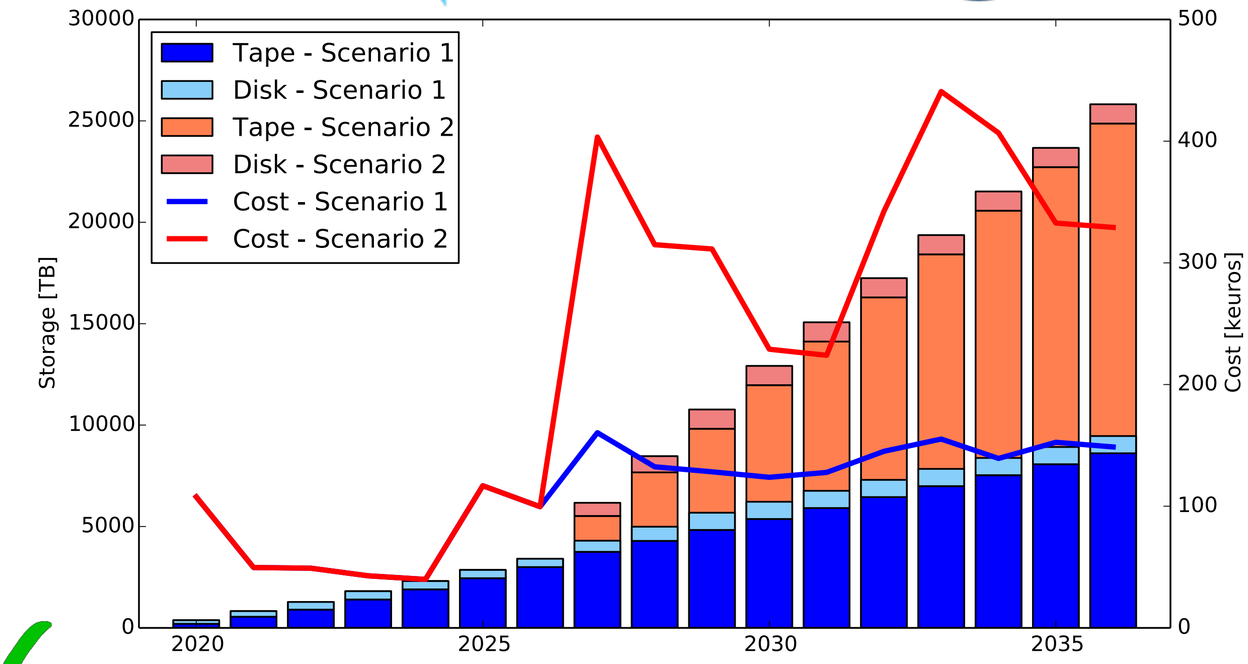
(minimal with one copy of each file)



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

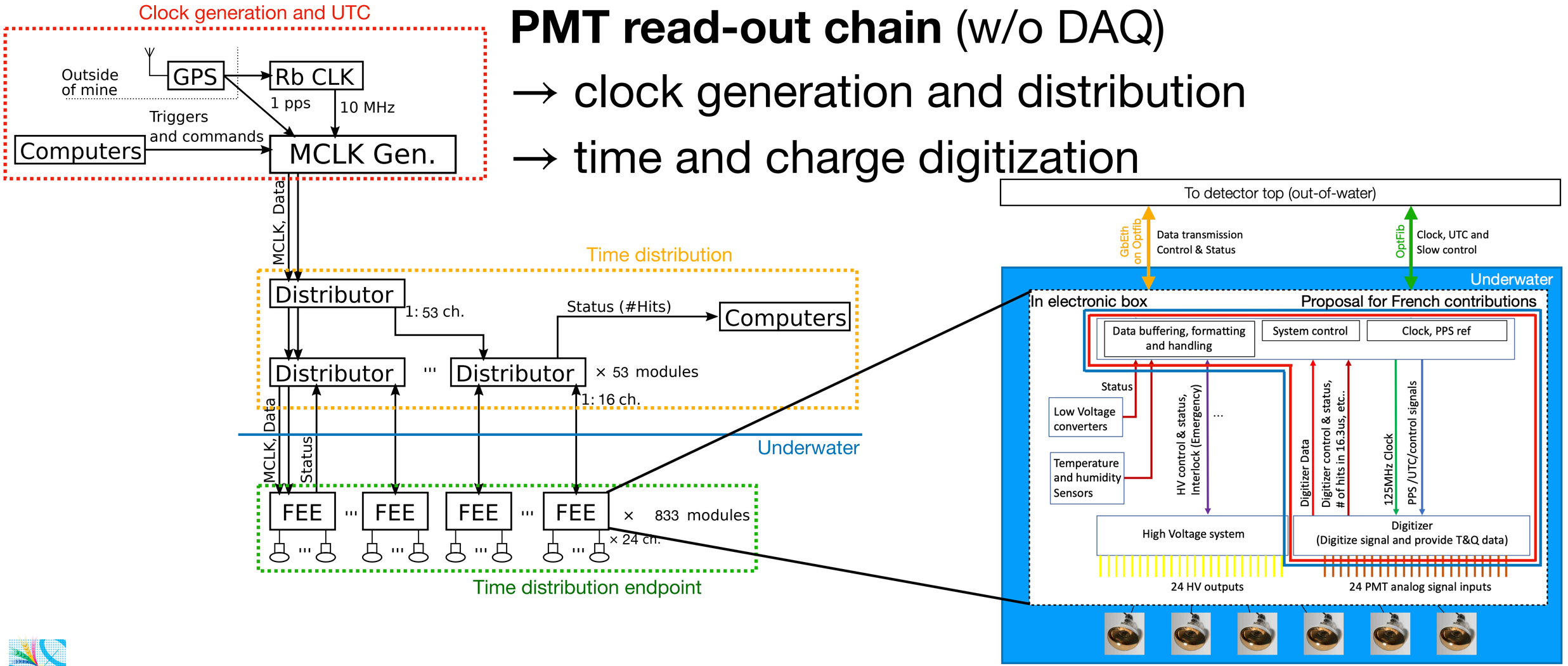
First production for HK at CC-IN2P3 completed

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 ✓

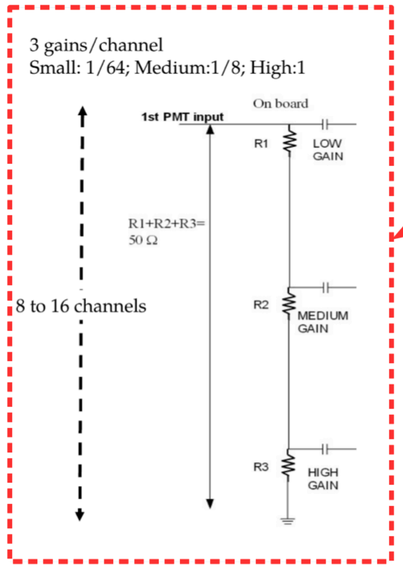
R&D funded by X (400 k€)

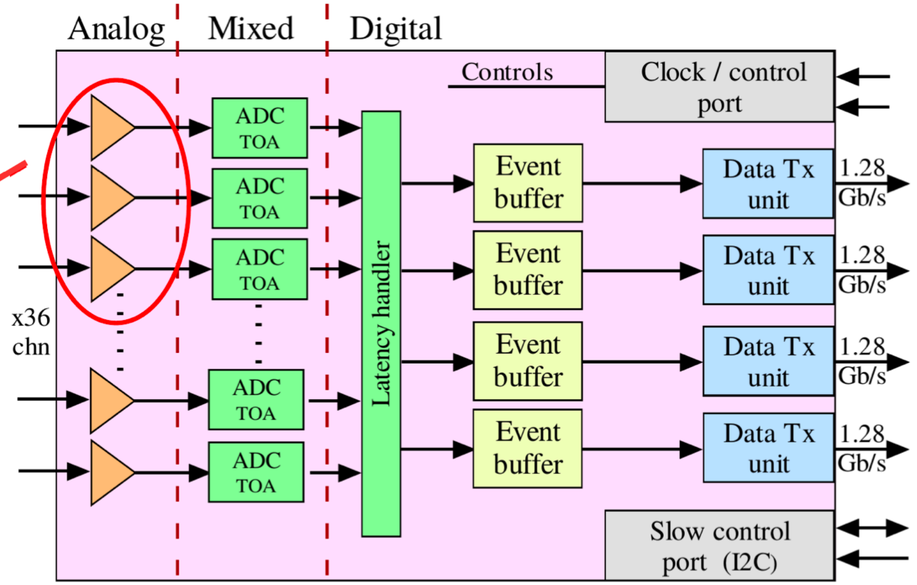
HKROC delivered in Nov 2021

First tests in December 2021

→ Synergy OMEGA/LLR/IRFU

→ Use in future WC detectors!





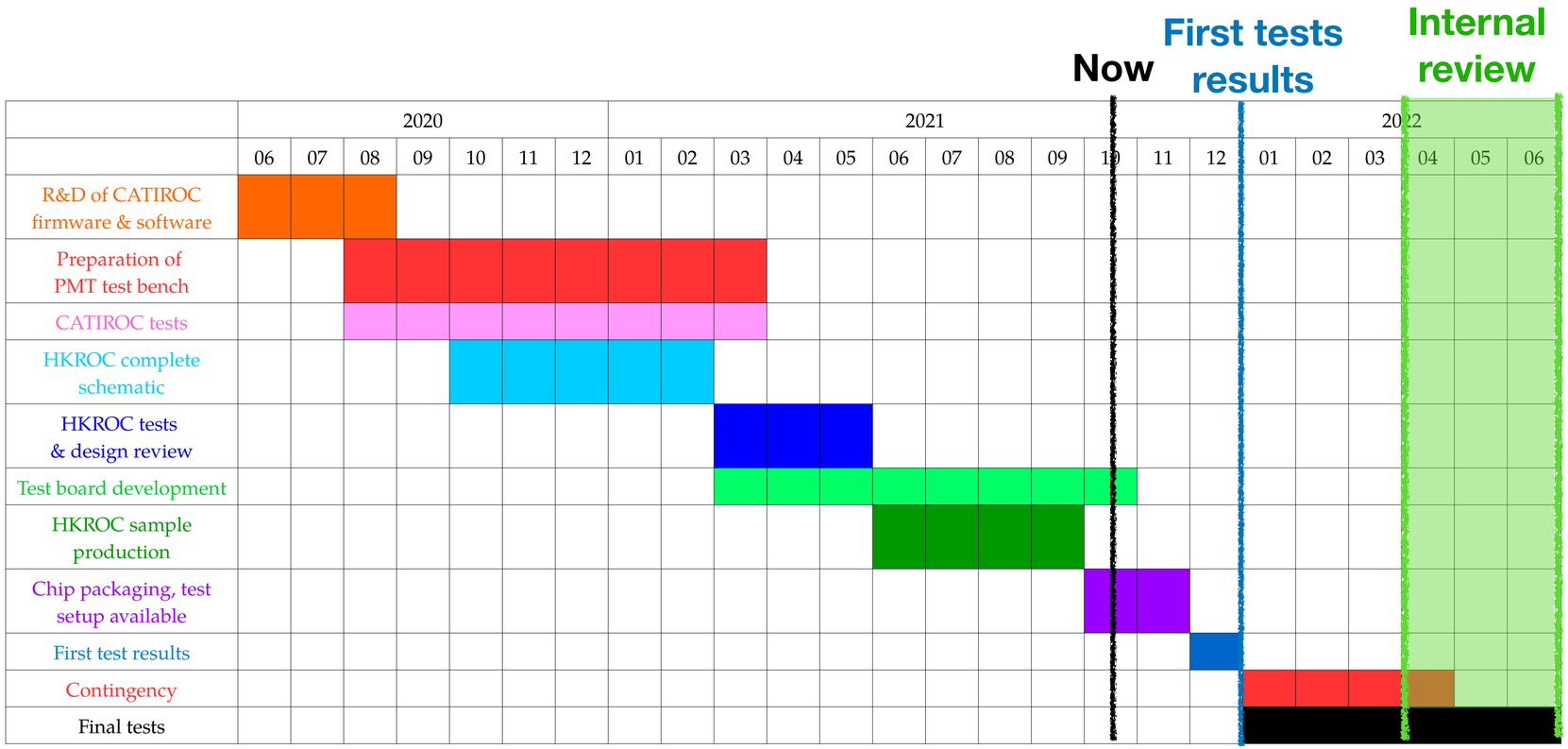
Competitors and time constraints

Two other competitors : Japan QTC (SK chip) & Italian discrete solution

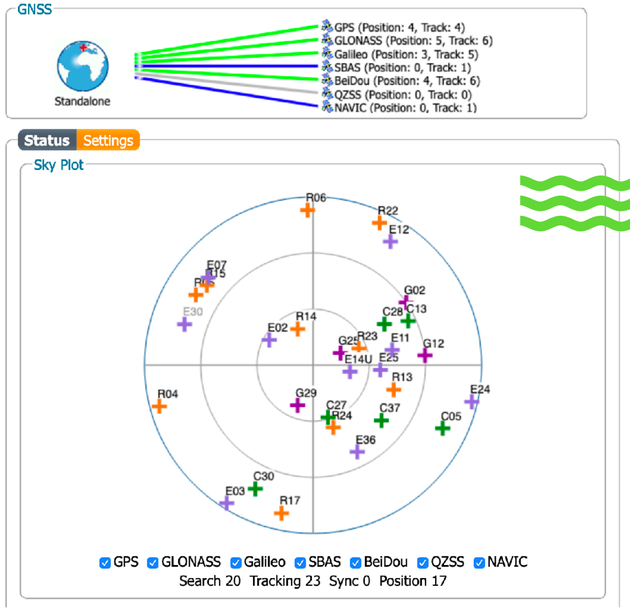
HK internal review Apr-June 2022 → selection of digitizer solution

Selection criteria:

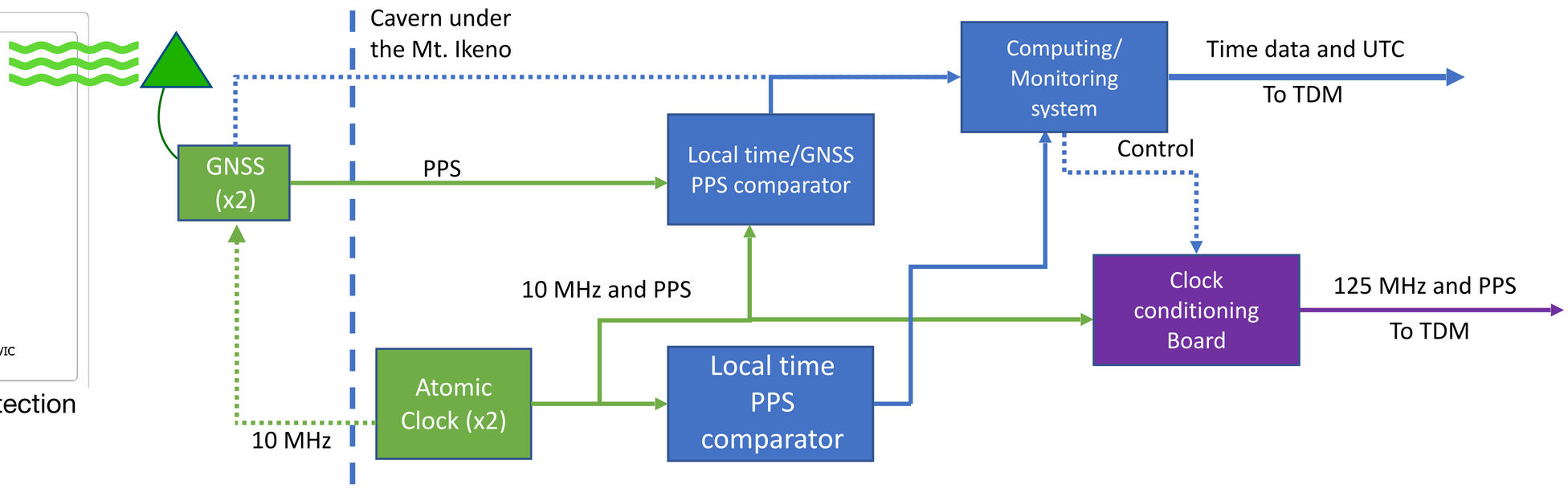
- Performances
- Group expertise
- **Official engagement on fundings in June 2022**



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

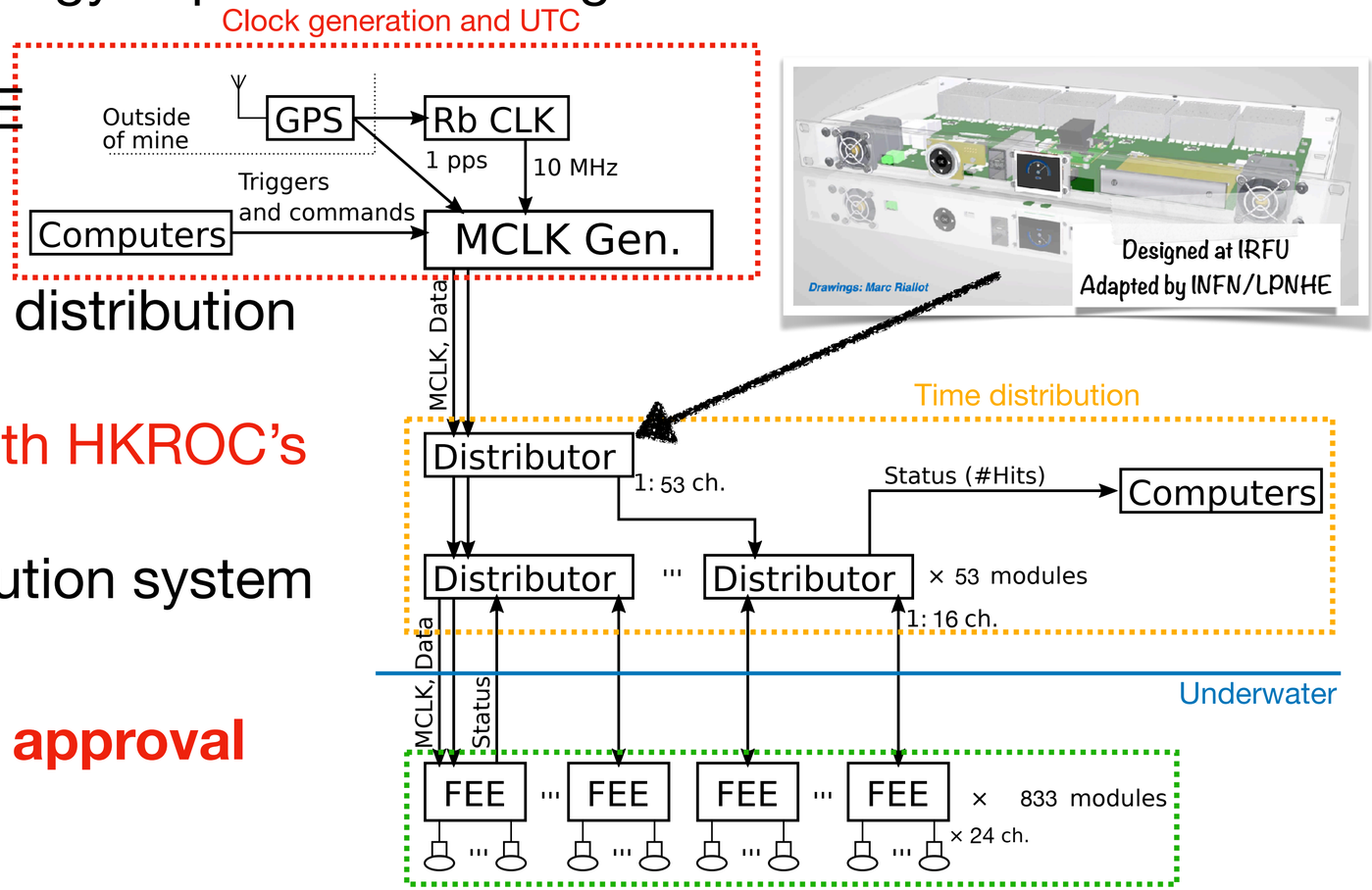
- Clock and Data Recovery (CDR) technology implemented using ser-des
- “Tree-like” structure
- Board design shared btw CEA & LPNHE
- Main distributor (53 ports)
- Second distributors (16 ports)
- Slow control and asynchronous signals distribution

FE board development in collaboration with HKROC’s

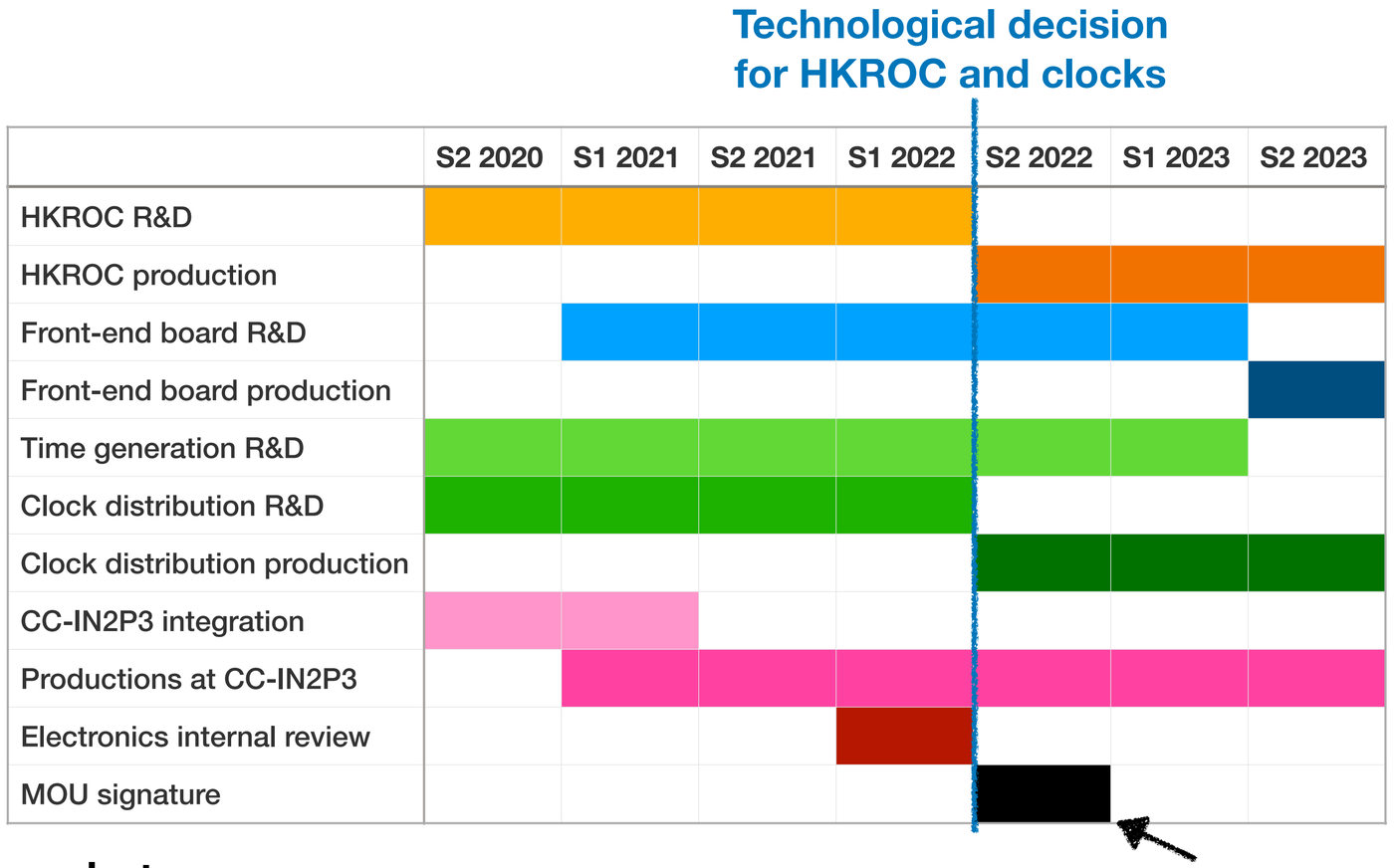
Other competitor: SK-based clock distribution system

→ 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

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.

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.
- So far no other IN2P3 groups decided to join the Hyper-Kamiokande experiment.
- Hyper-Kamiokande not an IN2P3 project, undermining our visibility within the collaboration.

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 region.
- IN2P3 groups can build on their long standing expertise in the T2K experiment to propose strong contributions in Hyper-Kamiokande. The possibility of using chips developed by OMEGA for the Hyper-Kamiokande far detector is particularly attractive from this point of view.

Risks:

- Dates for the approval by CS-IN2P3 and fundings of our proposed contributions to the HK electronics before collaboration review in Summer 2022. **Missing the Summer 2022 deadline would compromise the French contributions to the Hyper-Kamiokande far detector.**
- If the solutions not selected or not funded, no other planned French contributions to the far detector construction, putting our participation to Hyper-Kamiokande in jeopardy.

Conclusions and outlook

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

- ν oscillations (fast CP-violation discovery, δ_{CP} precision…)
- Rare events observatory e.g. proton decay
- Multi-messenger astrophysics (transient and diffuse SN detection)

→ **High and quick discovery potential!**

Construction started → Operations will start in 2027

Continuation of T2K and T2K-II

- Upgraded ND280 will be HK near detector
- Seamless program of world-leading measurements and discoveries from 2010 to 2040

Almost done: R&D phase for the proposed contributions on electronics and computing
Used fundings from external sources (SU, Ecole Polytechnique, ANR)
Technological decisions taken in Summer 2022

→ **approval by CS-IN2P3 & recognition of HK as IN2P3 project needed to strengthen our proposed contributions to HK**