Neutrino, Particle and Cosmic Messenger
- Hyper-Kamiokande Experiment -

Michel Gonin (IN2P3) and Masato Shiozawa (UT)

ILANCE kick-off meeting
7 April, 2021

I L Λ N C E

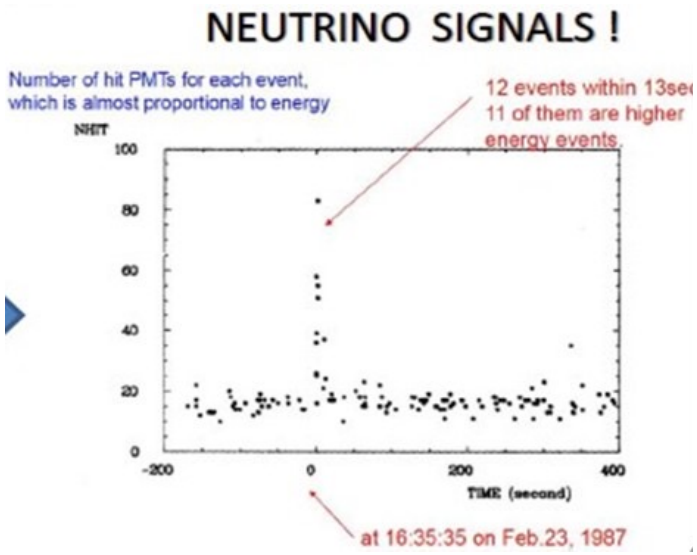
International Laboratory for **A**strophysics,
Neutrino and **C**osmology Experiments

Members of neutrino field of ILANCE
(As of April 1, 2021)

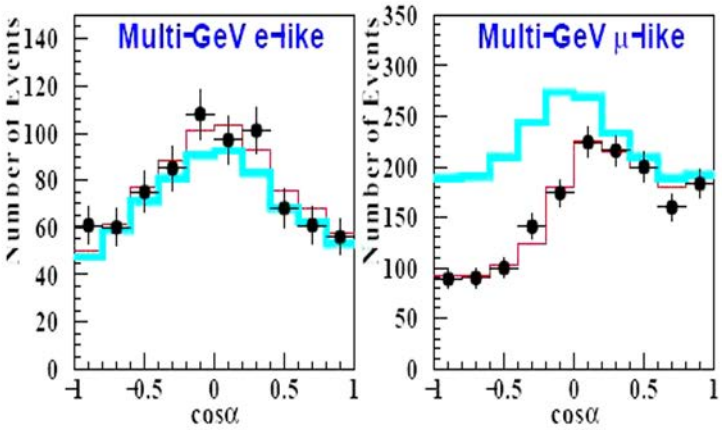
- CNRS/IN2P3
  - Michel Gonin (PI, LLR)
  - Olivier Drapier (LLR)
  - Pascal Paganini (LLR)
  - Thomas Mueller (LLR)
  - Margherita Buizza-Avanzini (LLR)
  - Benjamin Quilain (LLR)
  - Marco Zito (LPNHE)
  - Mathieu Guigue (LPNHE)
  - Boris Popov (LPNHE)
  - Claudio Giganti (LPNHE)
- UTokyo
  - Masato Shiozawa (PI, ICRR)
  - Takaaki Kajita (ICRR)
  - Masayuki Nakahata (ICRR)
  - Shigetaka Moriyama (ICRR)
  - Masashi Yokoyama (Department of Physics)
  - Kimihiro Okumura (ICRR)
  - Yoshinari Hayato (ICRR)
  - Katsuki Hiraide (ICRR)

PROLOGUE (1)

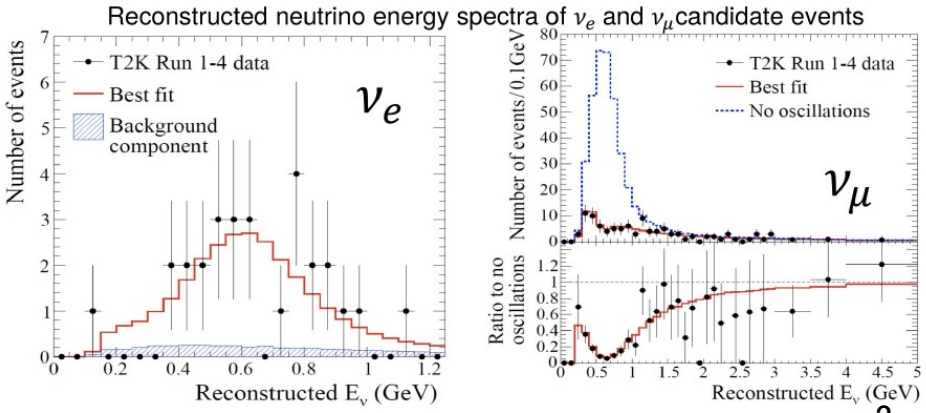
- Supernova explosion, Kamioka 1987 (Nobel Prize)



- Neutrino oscillations, Super-K 1998 (Nobel Prize)



- First flavor appearance, T2K 2013 (Breakthrough Prize, …)

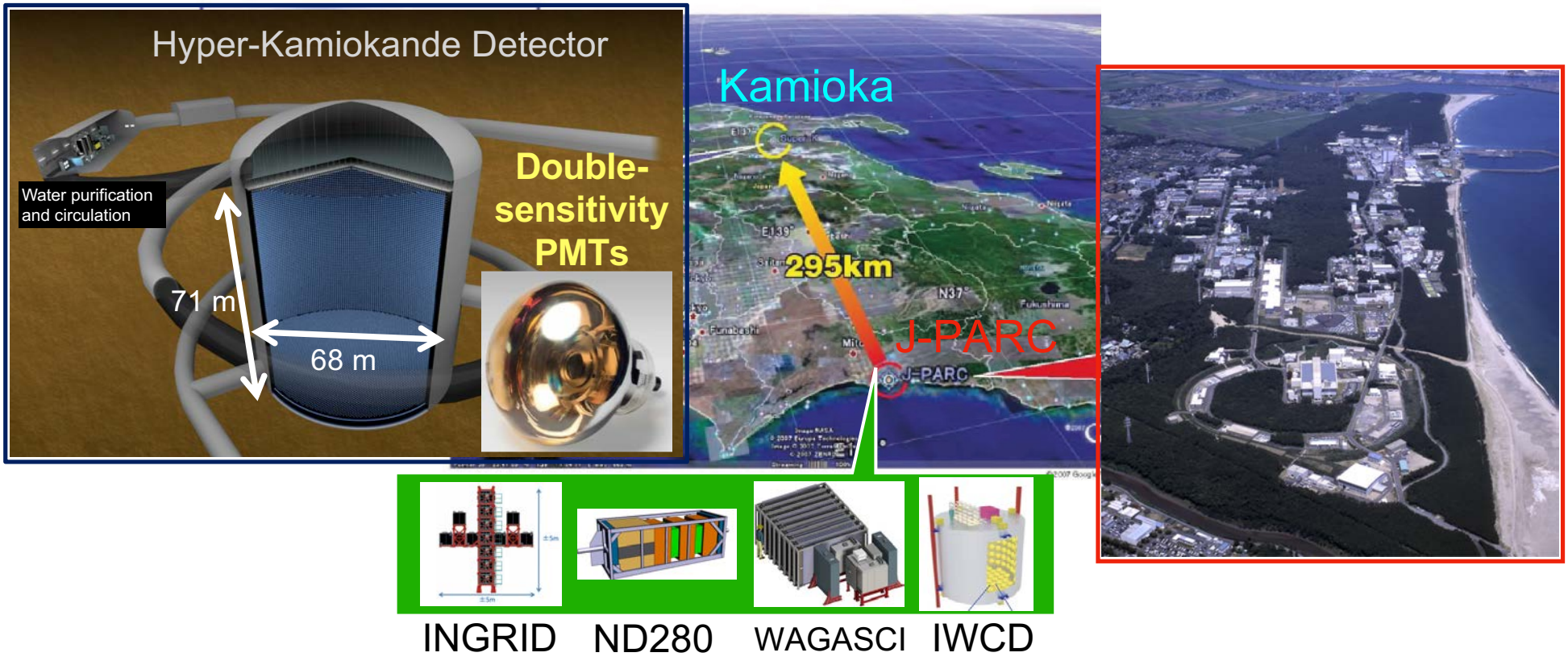


PROLOGUE (2)

- After the discovery of atmospheric neutrino oscillations in the Super-Kamiokande, the discovery of "$\nu_\mu \rightarrow \nu_e$ phenomena" in T2K opens the way to perform experiments to measure leptonic *CP* violation.

- Hyper-K project has been approved by Japanese government in 2020 and attracts the worldwide researcher community.
  - Good reason to do the *CP* measurement in Japan
    - Much experiences and techniques for water Cherenkov detectors
    - Existing J-PARC to be upgraded to over Mega Watt
  - More rich physics topics can be covered by the project, e.g. proton decay searches and neutrino astrophysics.

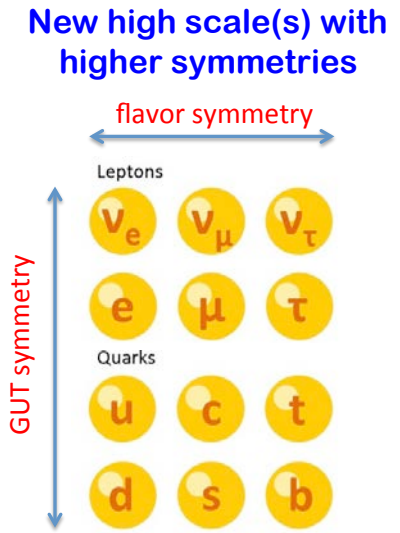
PROJECT IN A NUTSHELL:



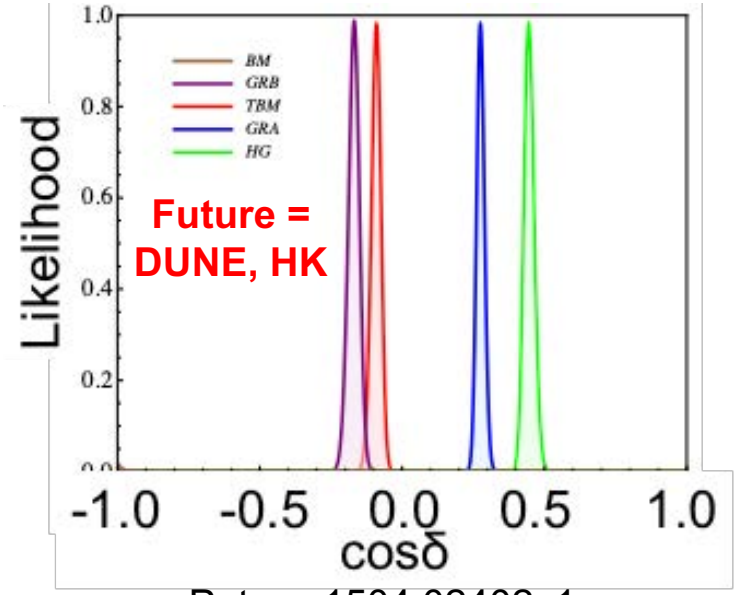
1. Hyper-K detector will be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and will be instrumented with **double-sensitivity PMTs**.
2. J-PARC neutrino beam will be **upgraded from 0.5 to 1.3 Mega Watt**
   - **x8** Natural Neutrino Rate and **x20** Accelerator Neutrino Rate
3. New and upgraded near detectors to control systematic errors

PHYSICS MOTIVATIONS

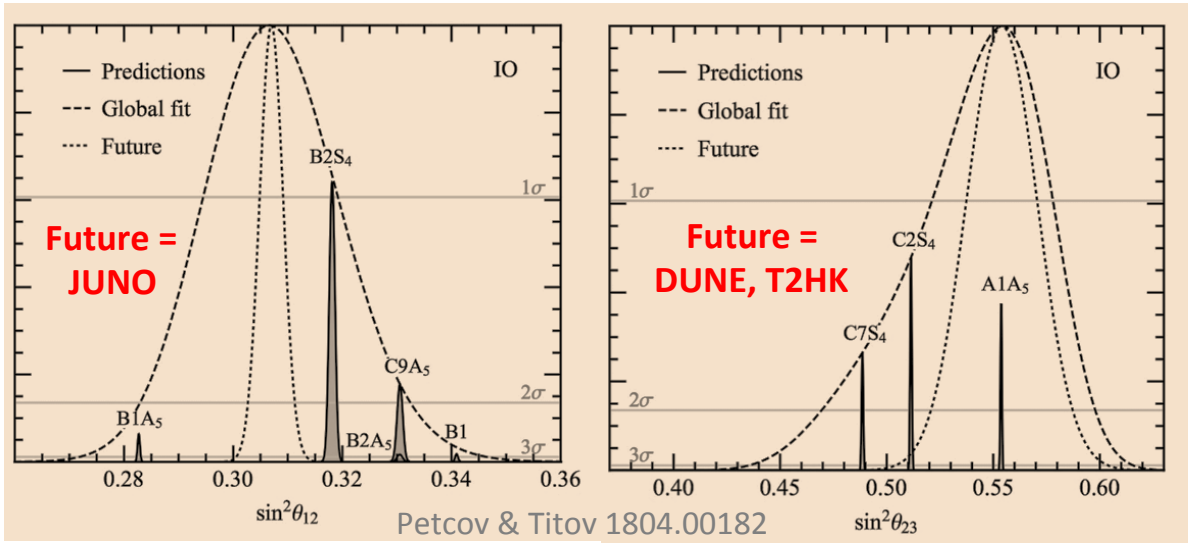
- We want to understand an organizing principle for mass/mixing of quarks & leptons in a unified way. Big question is Grand Unified Theories.
- Future higher precision data would bring further insights.



E. Lisi



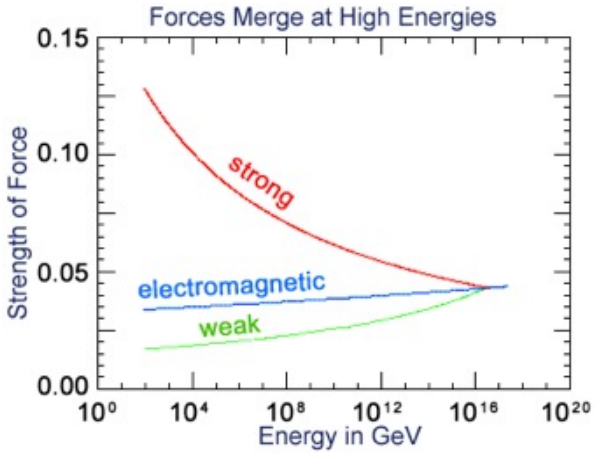
Petcov 1504.02402v1



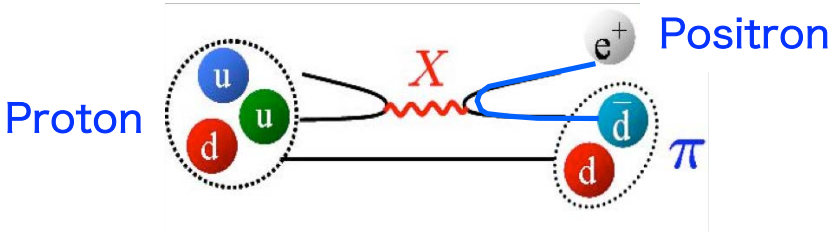
Petcov & Titov 1804.00182

PHYSICS MOTIVATIONS (2)

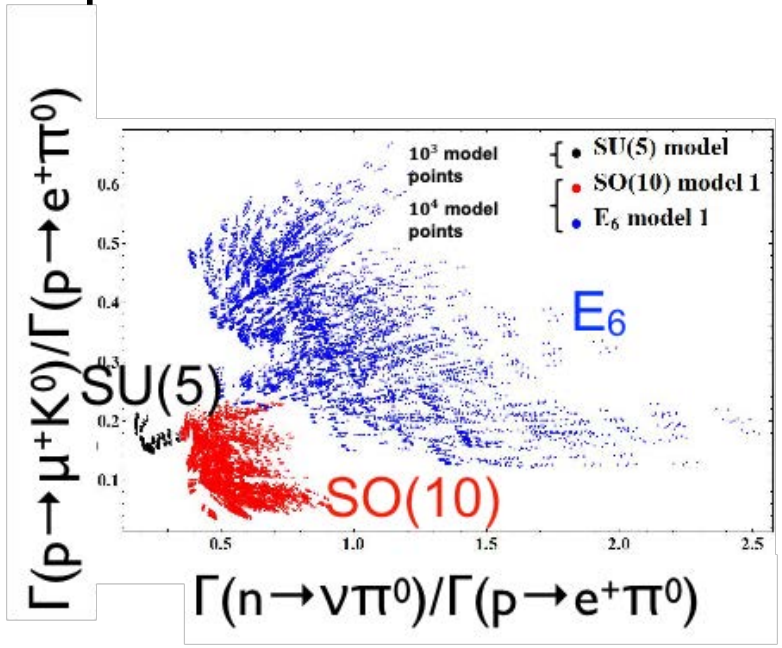
- Proton decay observation would prove the Grand Unification of elementally particles.
- Future measurements would reveal details of unification picture, e.g. unification scale and gauge group.



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



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

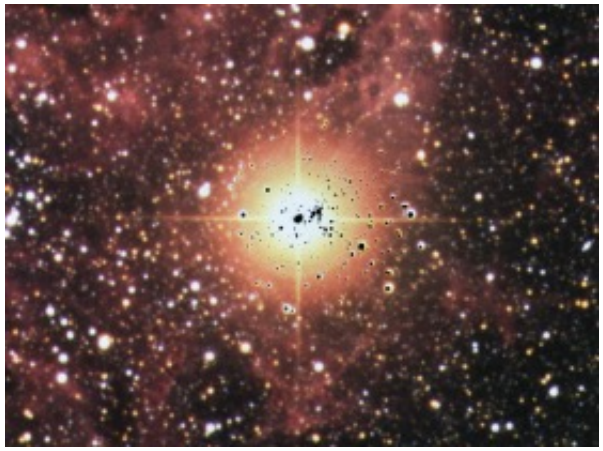


PHYSICS MOTIVATIONS (3)

Neutrino is a probe to see the interior of stars

- Supernova explosion
  - We are made from heavy chemical elements (Carbon etc) which were produced in stars and released by Supernova
  - Neutrino telescope will explore the detailed mechanism of core collapse, explosion evolution, cooling of porto-neutron star
  - Moment of when a new black hole is born
- Neutrino physics
  - Test of neutrino properties in high density
- Early alert for astronomers
  - Neutrino arrives a day before light

Kamiokande observed 13 neutrinos from SN1987

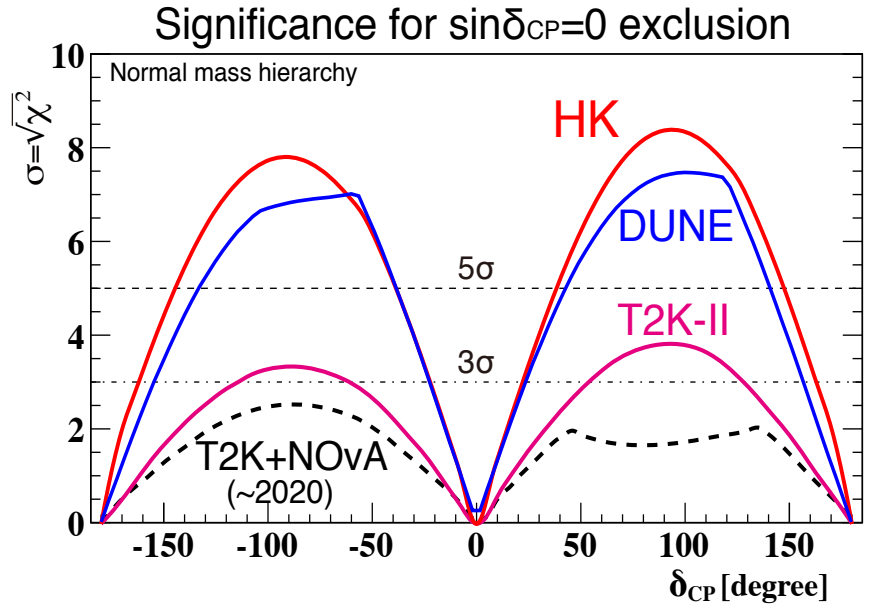


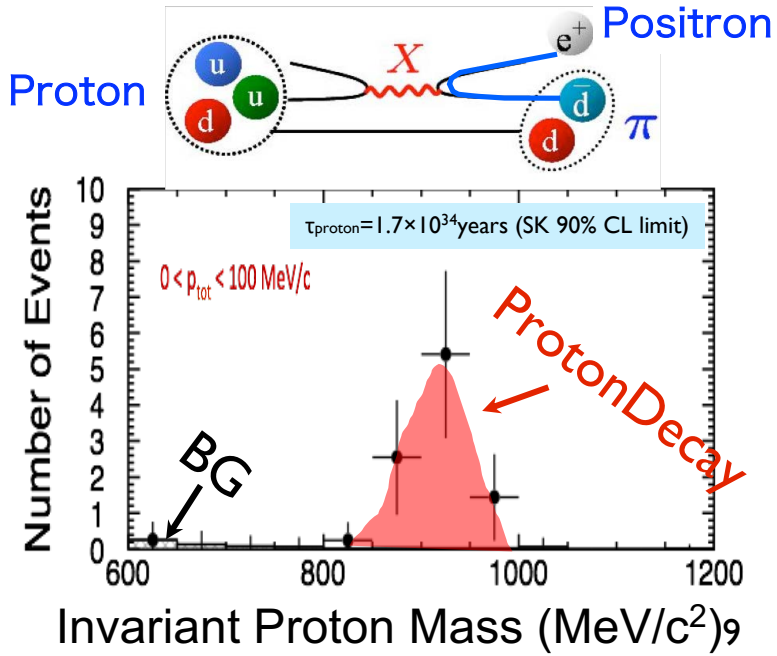
Hyper-Kamiokande

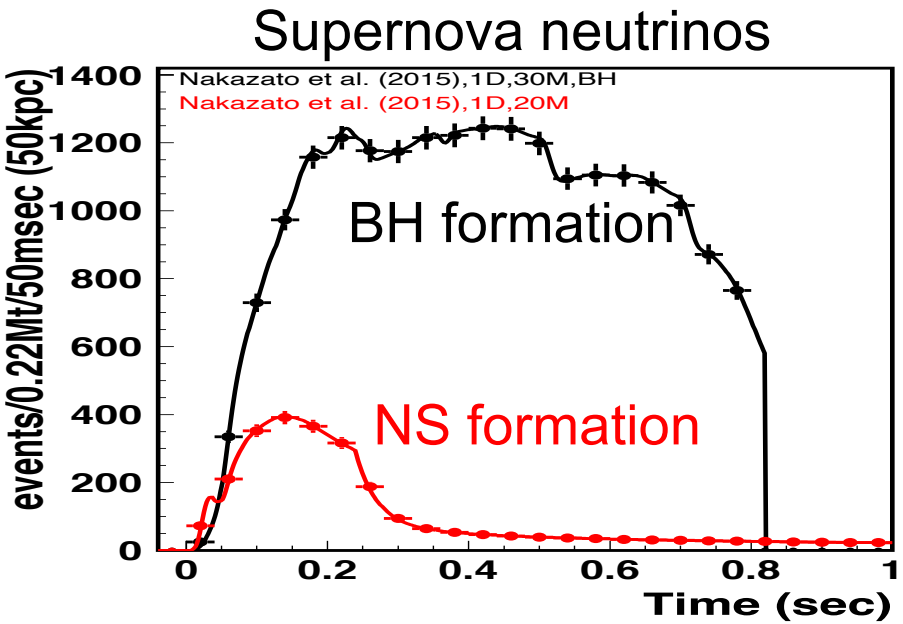
- 54,000-90,000 for our galaxy
- 10 for Andromeda

MANY DISCOVERY CHANCES:

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

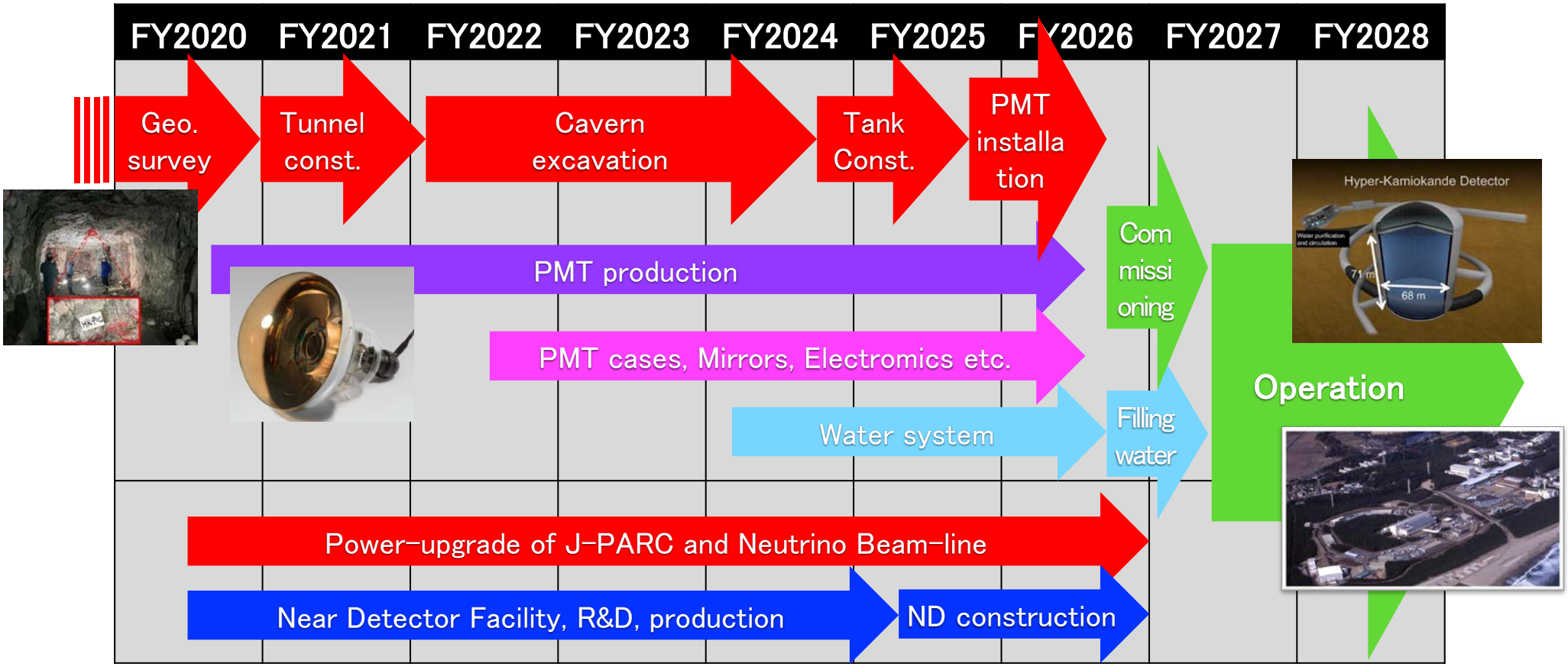






HYPER-K SCHEDULE:

- 7 years construction from year 2020;
  5 years excavation + subsequent 2 years detector construction.
- Data taking from 2027.

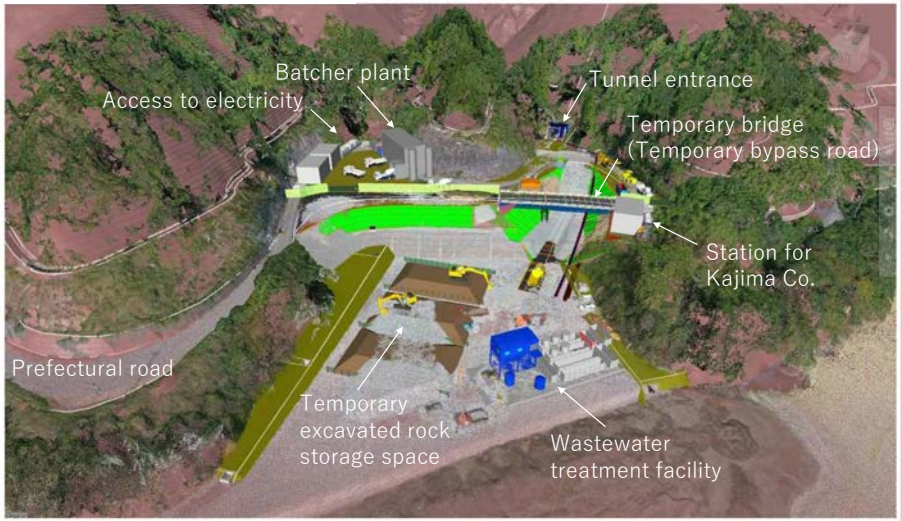


GOOD PROGRESS IN FY2020

Current Status and Conceptual Drawing of Entrance Yard

Overall plan of the entrance yard

Jan 28, 2021, Kajima Corporation.

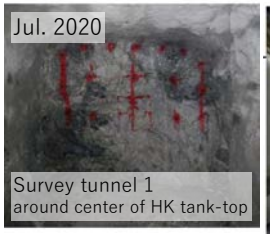


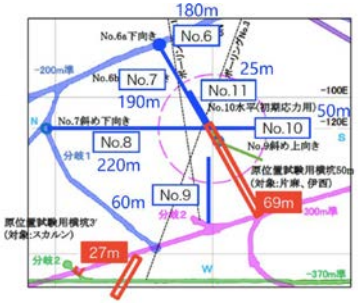
[Nakahata@Feb.-24](#)

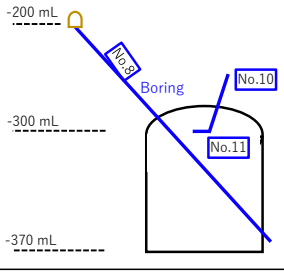
HKPAC Meeting

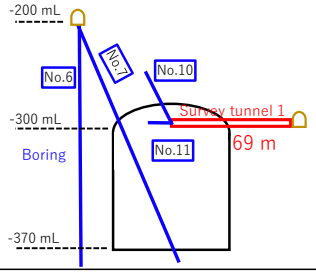
Geological survey

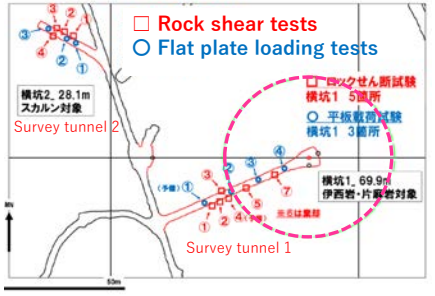
All on-site tests have been completed. Results are being compiled.











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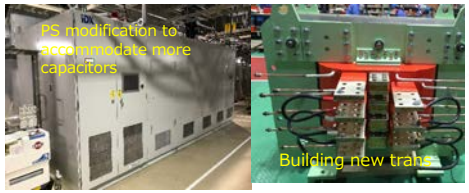
GOOD PROGRESS IN FY2020 (2):

Status of neutrino beamline upgrade

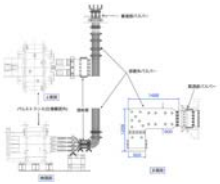
- Building and preparing upgraded components to be installed during long shutdown (2021.7~2022.5)

- **Upgrade of primary beam line**

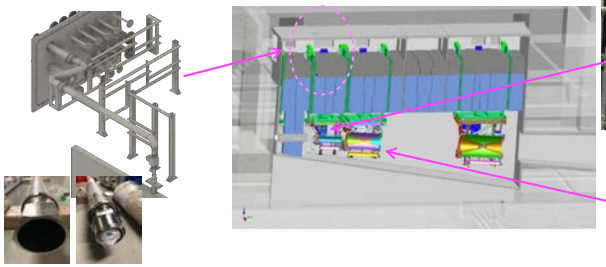
- **Horn system upgrade for higher rep.**



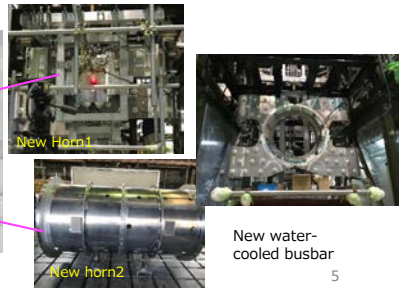
New busbar



- **Upgrade of target system**
  - New heat exchanger, vacuum insulated pie



- **Cooling upgrade of horns**



New water-cooled busbar

5

Status of neutrino beamline upgrade (Cont.)

- Increase capacity of dilution of radioactive water

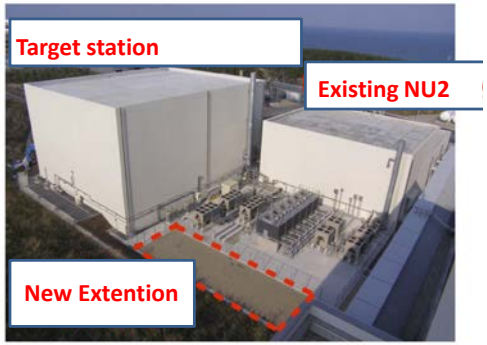
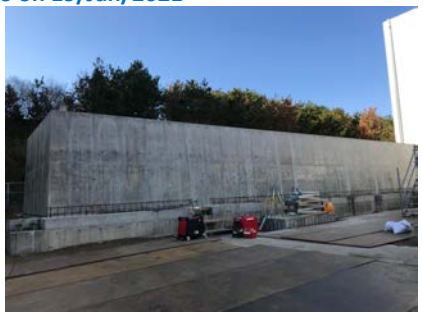
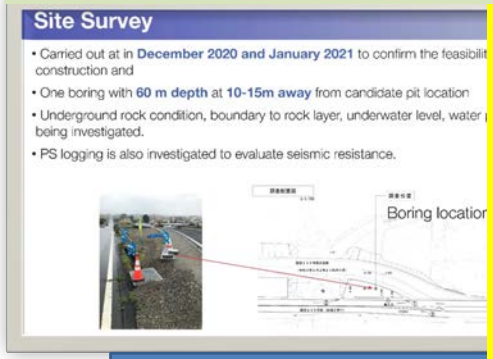


Photo on 19/Jan/2021



Site Survey for IWCD

M. Harz's slide
https://kds.kek.jp/event/36722/contributions/183037/attachments/140000/171742/iwcd_report_hkpac_20210203.pdf



- Following the HK-PAC advice, survey of 750m candidate site was performed in Dec/Jan. (details were already reported on 15/Feb.)
- Design work of the facility is planned in FY2021.
- Discussion with the local government has started.
- In parallel, de-bunched beam option is studied by a task force by the accelerator group.

[Tokushuku@Feb.-24](#)
HKPAC Meeting

HYPER-K COLLABORATION:

19 countries, 93 institutes, ~440 people as of November 2020, still growing

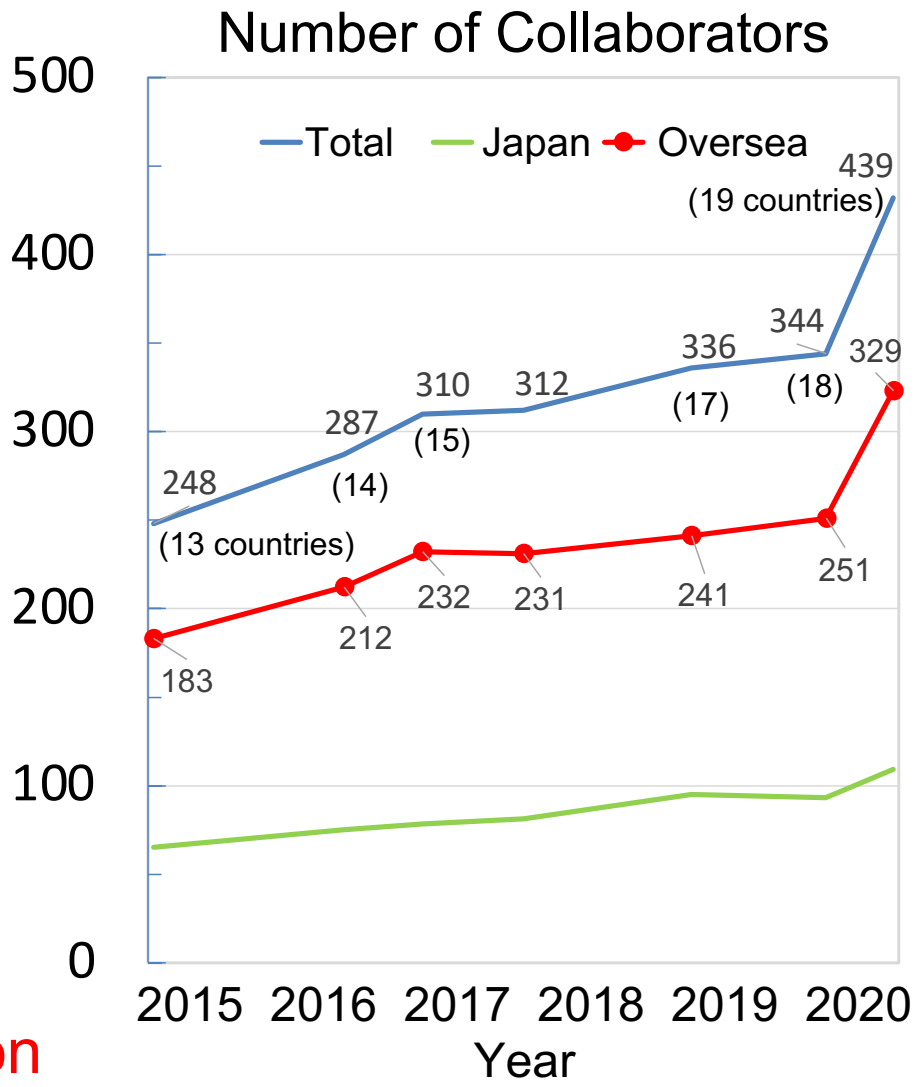
Collaborating Institutes

Europe	249 members
Armenia	3
Czech	3
France	24
Germany	1
Italy	53
Poland	37
Russia	21
Spain	26
Sweden	5
Switzerland	5
Ukraine	3
UK	68

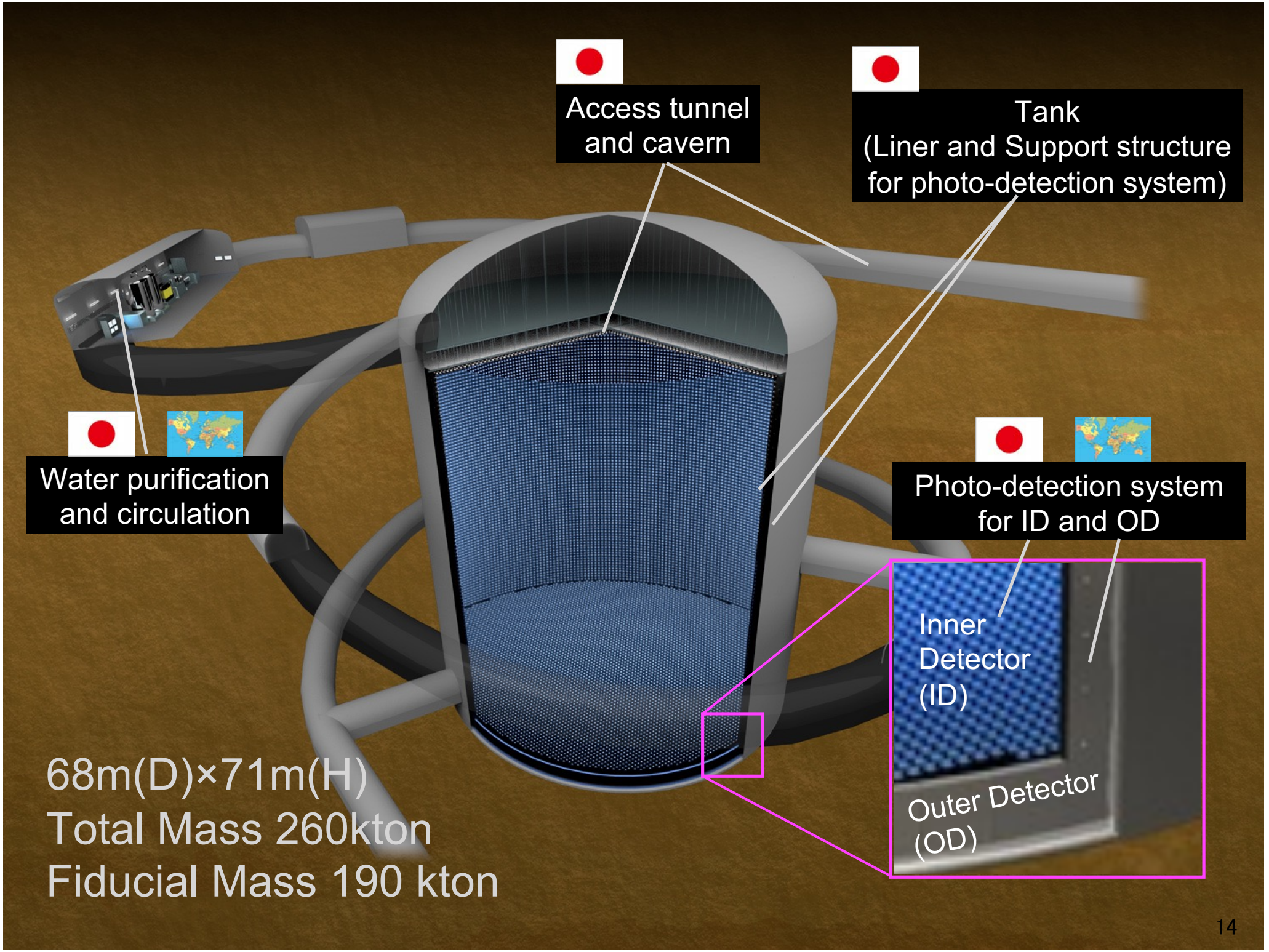
Asia	138 members
India	10
Korea	18
Japan	110

Americas	52 members
Brazil	3
Canada	28
Mexico	12
USA	9

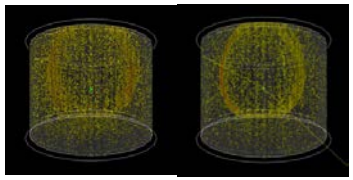
Major participation from France



*jump in 2020 is due to approval

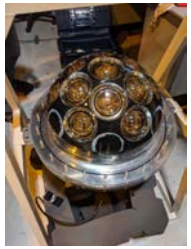

Access tunnel and cavern
Tank (Liner and Support structure for photo-detection system)
Water purification and circulation
Photo-detection system for ID and OD
Inner Detector (ID)
Outer Detector (OD)
68m(D)×71m(H)
Total Mass 260kton
Fiducial Mass 190 kton

HYPER-K DETECTOR:



Neutrino interactions

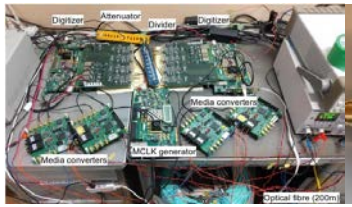
Water system:
1st stage system
2nd stage system for 155 + 155 m^3/hour



Photosensors

Photosensors:
PMT
Cover
Light Collection
Coils…

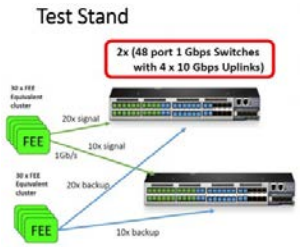
Half of ID PMTs



Electronics

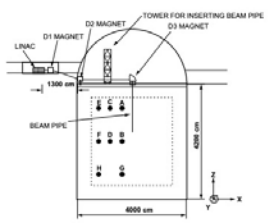
Electronics:
Digitizer
Boards
High Voltage Supply
Network
Waterproof'd box, connectors, cabling…

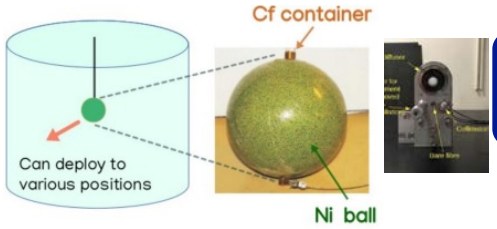
Part of ID Electronics



Data Acquisition and triggering

DAQ & Triggering:
Readout
Event builder
Software Triggers





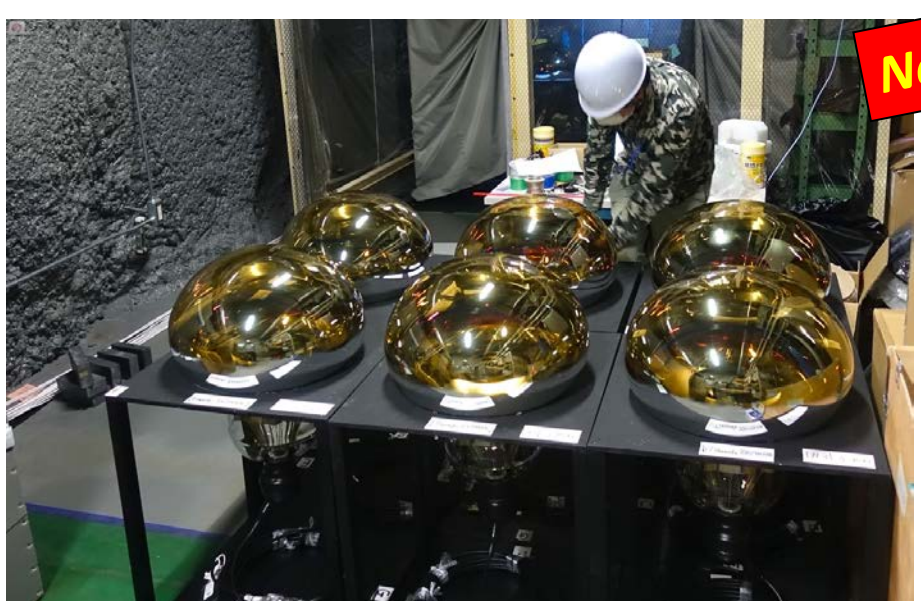
Calibration

Calibration:
Electron LINAC
Deployment system
Other RI sources, light sources et

50 CM PMTS

PMTs for the Inner Detector

	Super-K	Hyper-K
Number of PMTs	11,129 50cm PMTs	20,000 50cm PMTs (JPN) (+ additional PDs (Oversea))
Photo-sensitive Coverage	40 %	20 % (1/2 x Super-K)
Single photon efficiency /PMT	~12%	~24% (2 x Super-K)
Dark Rate /PMT	~4 kHz (Typical)	4 kHz (Average)
Timing resolution of 1 photon	~3 nsec	~1.5 nsec



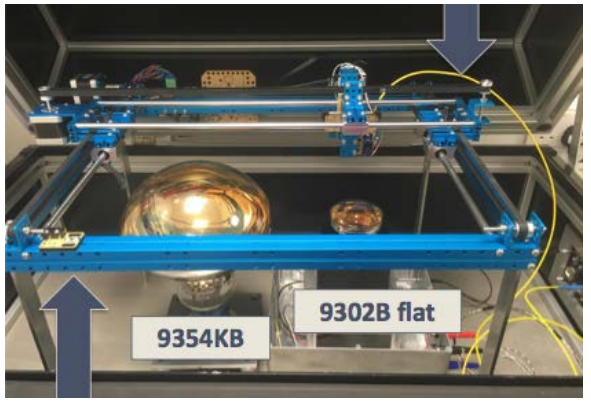
2020/12 First six PMTs delivered to Kamioka

- Production has started on time for the 50cm PMTs with Box&Line dynode.
  - 300 PMTs by March, 20,000 PMTs in total by year 2026.

International Cooperation

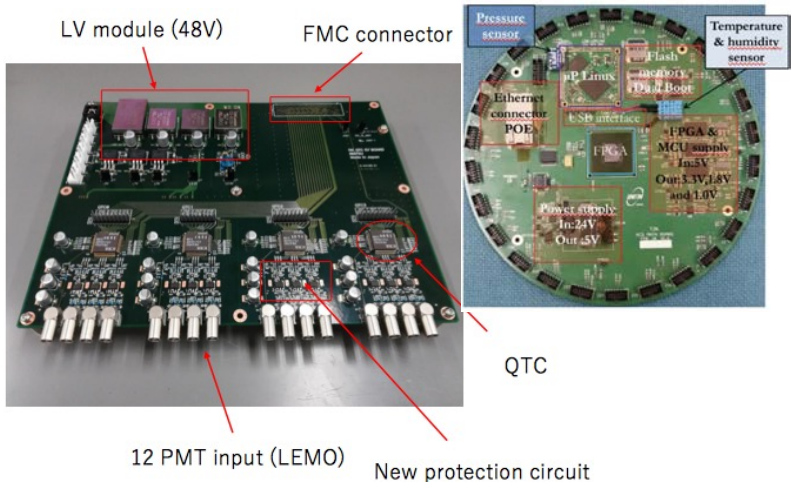
Multi-PMT module

OuterDetector

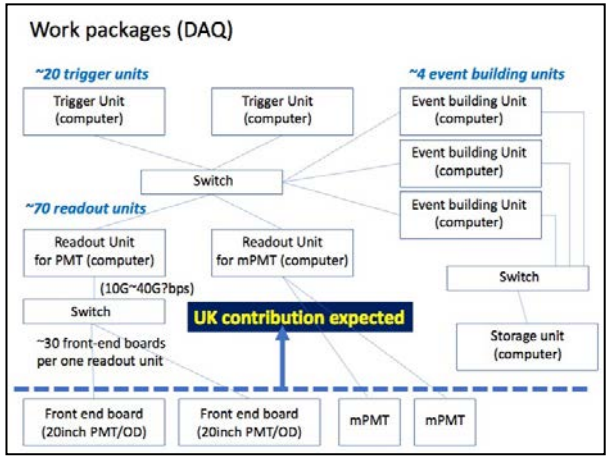


PMT cover

Electronics



DAQ



+ More

IN2P3 Contributions to T2K, T2K-II and Super-K

- Design and production of the **INGRID detector** which measures both the flux of the neutrino beam produced at JPARC and the off-axis angle before oscillation (LLR)

- Participated in the construction and implementation of the magnet and **the TPC time projection chamber** (MircoMegas) of the ND280 detector for essential off-axis measurements in the direction of the far detector (LPNHE)

- Design and development of the reading electronics and mechanics of **WAGASCI** to study nuclear effects in neutrino - matter interactions (LLR)

- Participation in the ancillary experiment **NA611** / SHINE at CERN to measure the production rates of charged particles from a proton beam on a graphite target, necessary for T2K simulations (LPNHE)

- Participation in analyzes and publications of cross section measurements and oscillation parameters (LLR & LPNHE)

- Contributions to major **renovation work on the Super-K tank** and calibration campaigns for its light detectors (LLR)

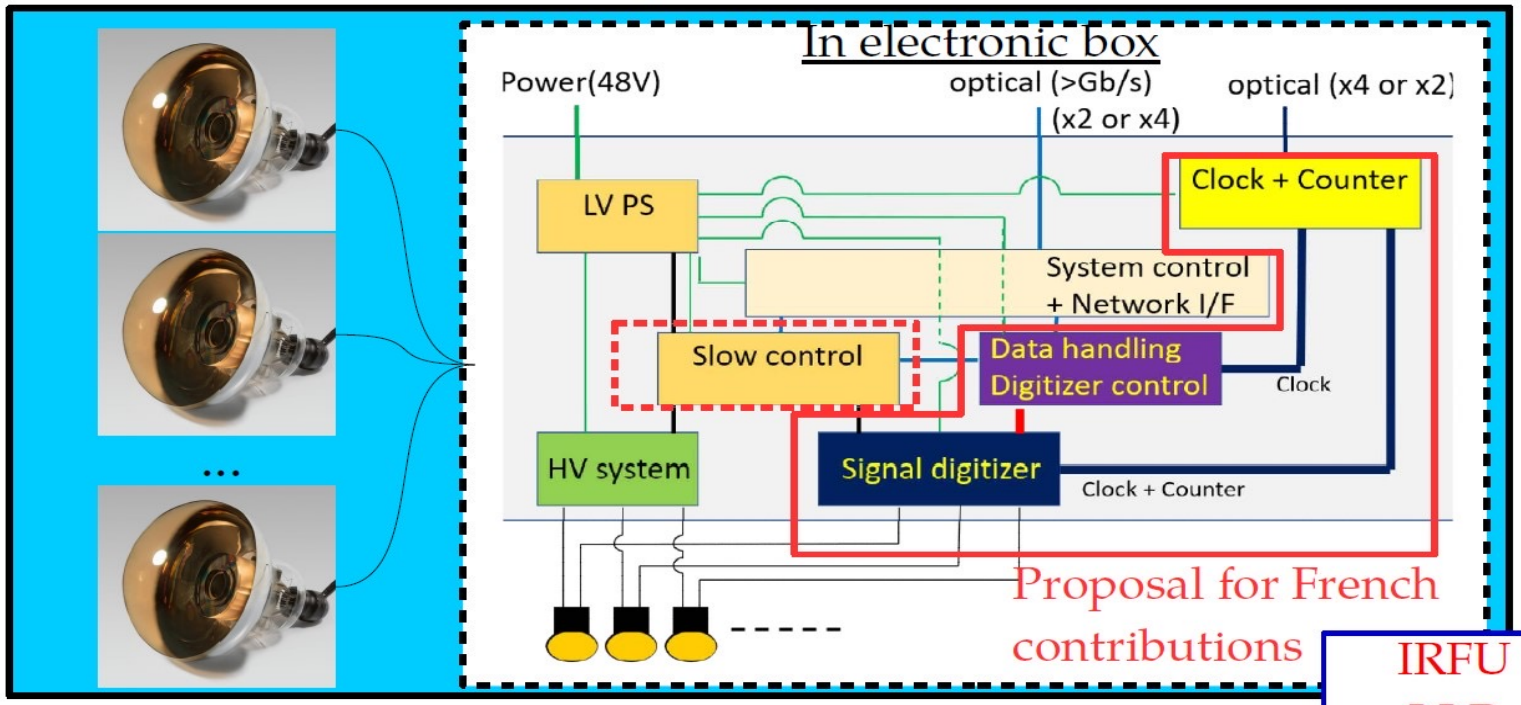
- Participation in **T2K II upgrades.** Contributions to the design and production of the electronics of the near detectors (LLR & LPNHE)

HYPER-K IN2P3 & CEA LABORATORIES

HK far detector electronics

- HK front end located under water (still under discussion):

  → 24 channels/PMTs read per box. Each box is attached structure.



- France would develop the whole PMT read-out (w/o DAQ)

→ Central role into HK !

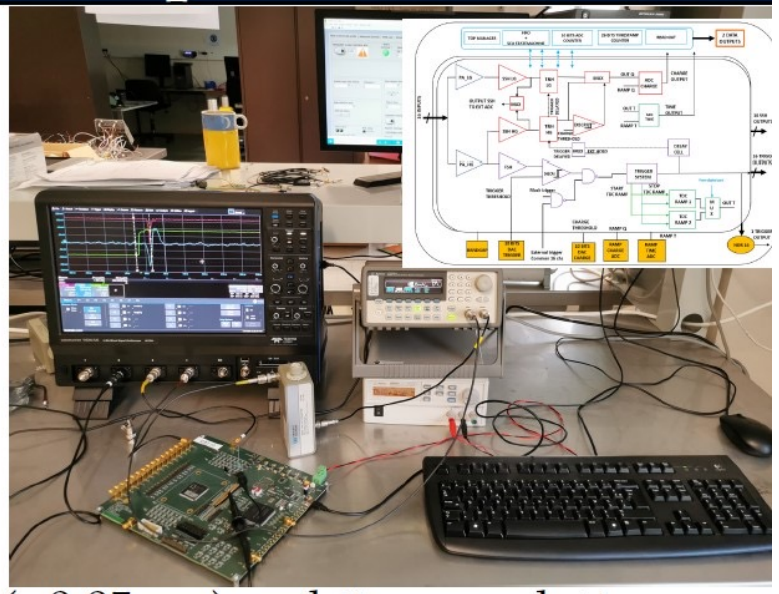
- *Reminder : France has already central contributions in ND280-upgrade*

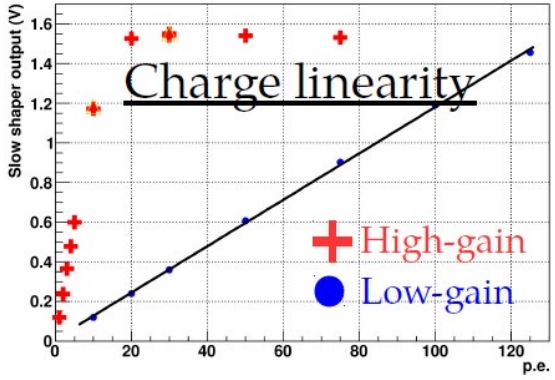
HYPER-K LLR & OMEGA IN2P3 LABORATORIES

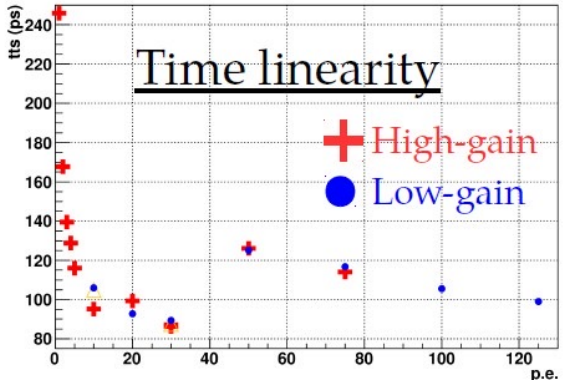
Front-end development

- Propose a new Front-end for HK
  → Start from existing Ω CATIROC.

- Installed test bench at LLR in July.







- Charge (<0.05 p.e) and time resolution (<300ps) comply w/ HK requirements.

- Major issues :

1. Chip deadtime : 3µs → 9µs
2. Charge dynamic range smaller by factor 5 : developed for 3'' PMTs operating at 10^6 gain → HK PMT will likely operate at gain = 10^7 .

HYPER-K LLR & OMEGA IN2P3 LABORATORIES

New HKROC chip

→ Develop a brand-new chip to meet HK requirements…

… but also to also operate other future WC detectors in next 10 years !

1. Large dynamic range : 3 gains / ch.→ up to 2500 pC (CATIROC 300 pC)

2. Excellent charge resolution.

3. New etching technic :

AMS 350 nm (CATIROC)

will be outdated in 1-3 years

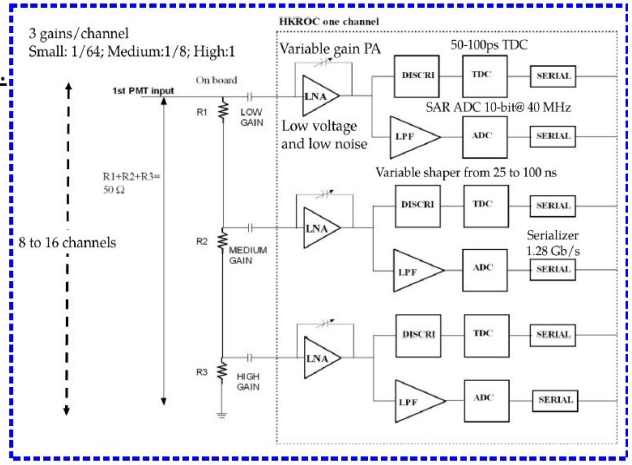
→ TSMC CMOS 130 nm

4. No deadtime :

a. SAR ADC sampling waveform at 40 MHz.

b. Readout up to 1 GHz (possible in CMOS)

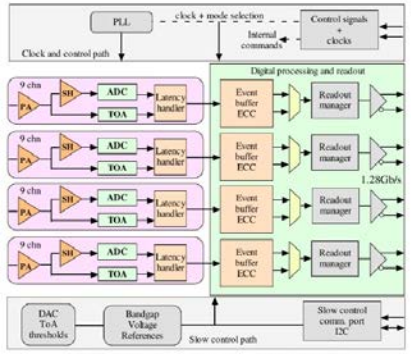
→ Simulations & results are available.

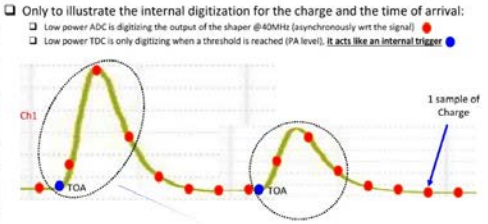


Similar to CMS HGCROC.

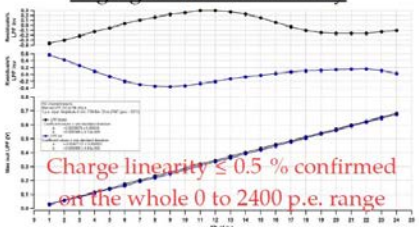
4

HKROC principle, performances & schedule





High-gain channel linearity



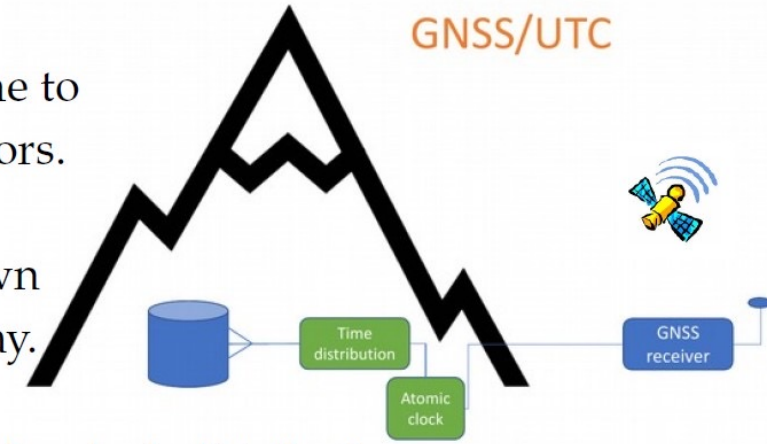
	2020	2021	2022	2023	2024	2025
Chip R&D						
Chip production						
Chip durability tests						
Chip production quality control						
Front-end board R&D						
Front-end board production						
Chip + Board durability test						
Chip + Board production control						

HYPER-K LPNHE IN2P3 LABORATORY

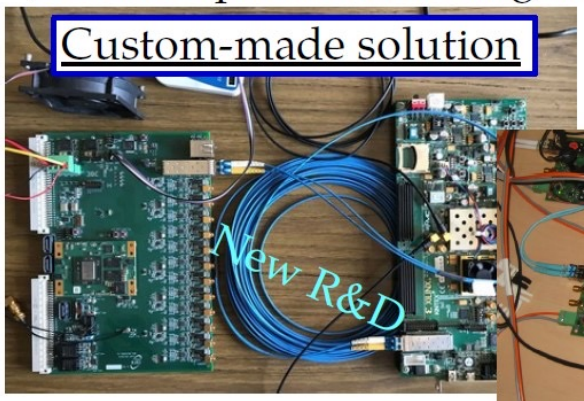
The GNSS and clock distribution system

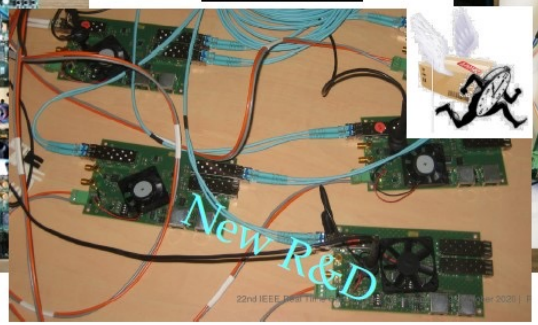
- France is working both on :

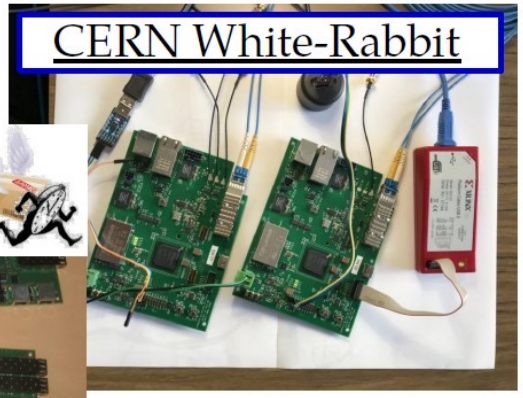
1. GNSS system : Provides local time to synchronize w beam / other detectors.
→ Is being developed with SYRTE.
2. Full clock distribution chain (down to PMT Front-End) → Focus of today.



- Several options are being studied for clock distributions :







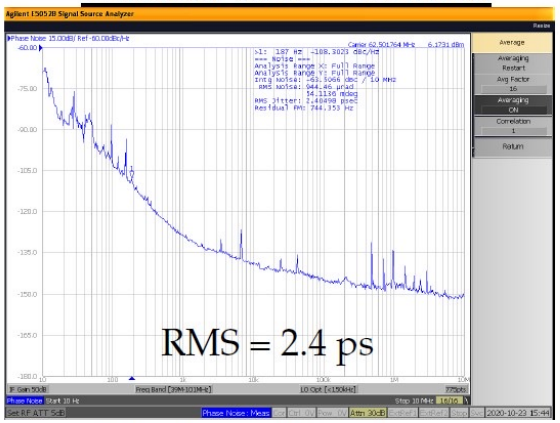
6

- Room for lots of R&Ds and completely new ideas !

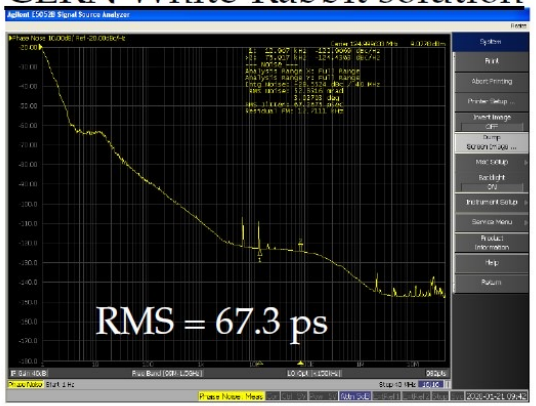
HYPER-K LPNHE IN2P3 LABORATORY

The GPS and clock distribution system

Custom-made solution

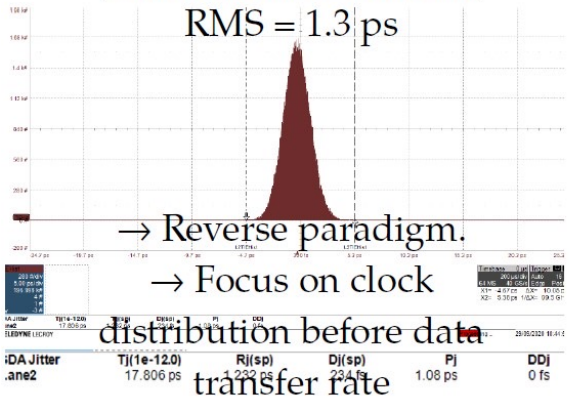


CERN White-Rabbit solution



Very preliminary. Far from final results

Clock-centric scheme



→ Reverse paradigm.

→ Focus on clock distribution before data transfer rate

	Require-ments	Custom	Clock-centric	White-Rabbit
Jitter at FE	< 100 ps	2.4 ps	1.3 ps	67.3 ps
Data Xchange rate	> 100 Mbps	1 Gpbs	> 500 Mpbs	1 Gpbs

- All solutions match HK requirements.
- R&D in parallel by France.
- Choice done by collaboration.

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HYPER-K IN2P3 Software & Computing

	Hyper-Kamiokande			T2K		
Year	CPU M HS06 CPU.h	Tape space (TB)	Disk space (TB)	CPU M HS06 CPU.h	Tape space (TB)	Disk space (TB)
2020	1	100	10	20	100	170
2021	1	100	10	20	450	270
2022	1	100	10	20	800	370
2023	1	100	10	20	1300	400
2024	1	100	10	20	1800	400
2025	1	100	10	20	2350	400
2026	1	100	10	20	2900	400
2027	25	3750	550	Merged with HK		
2028	25	4290	700			
2029	25	4830	850			
2030	25	5370	850			
2031	25	5910	850			
2032	25	6450	850			
2033	25	6990	850			
2034	25	7530	850			
2035	25	8070	850			
2036	25	8610	850			

SUMMARY

- We are in an exciting time because the large neutrino detector Hyper-K is planned to start near future. It is also a good proton decay detector!

- Good opportunity to extend the France-Japan scientific collaboration in Super-K/T2K.

- France and Japan will play the central roles in the detector construction.