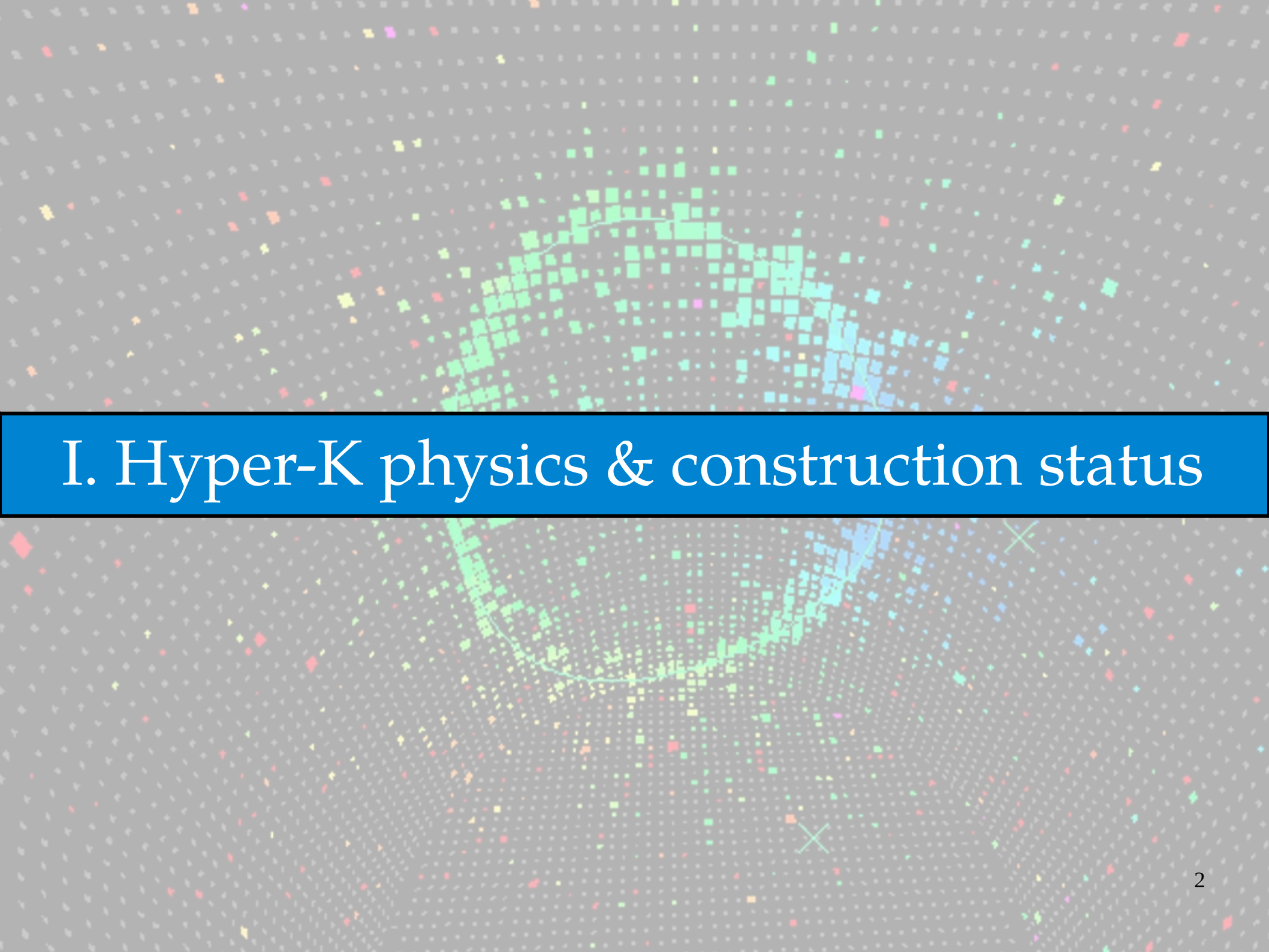
Updates about LLR contributions to Hyper-K

Benjamin Quilain representing the LLR neutrino group
& Jerome, Franck, Axel, Mark, Remi, Lorenzo, Leo, Fred, Igor

Hyper-Kamiokande

Conseil Scientifique du LLR, 2024/01/18

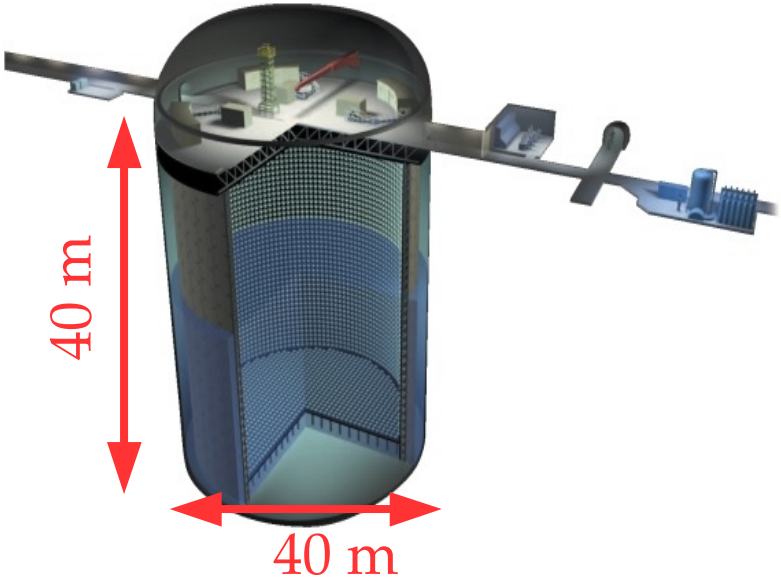


I. Hyper-K physics & construction status

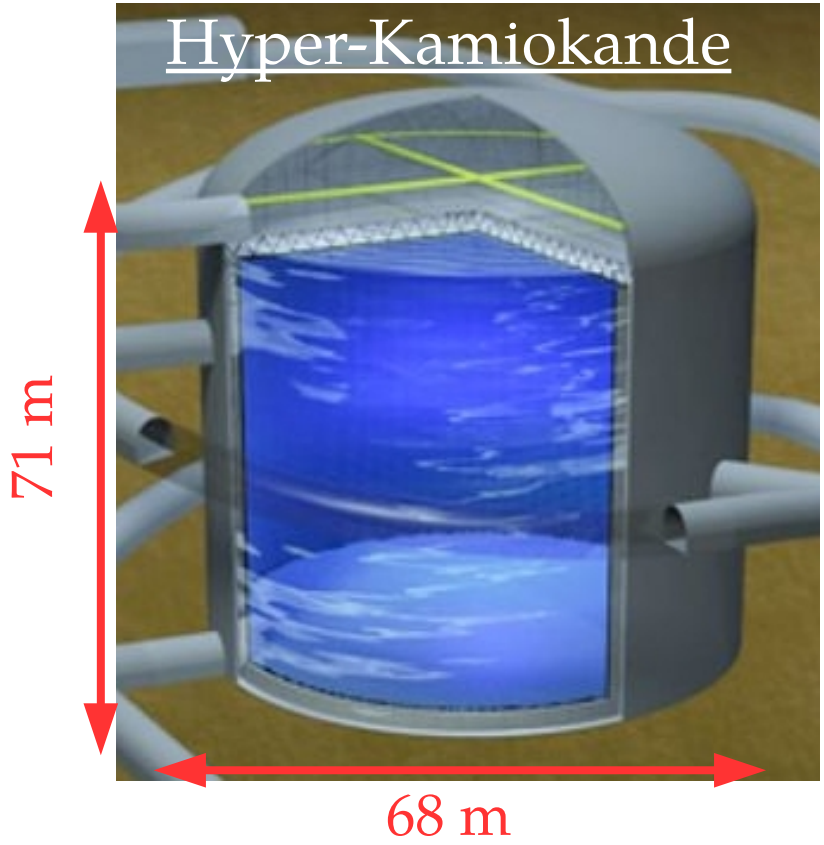
Reminder : what is Hyper-K ?

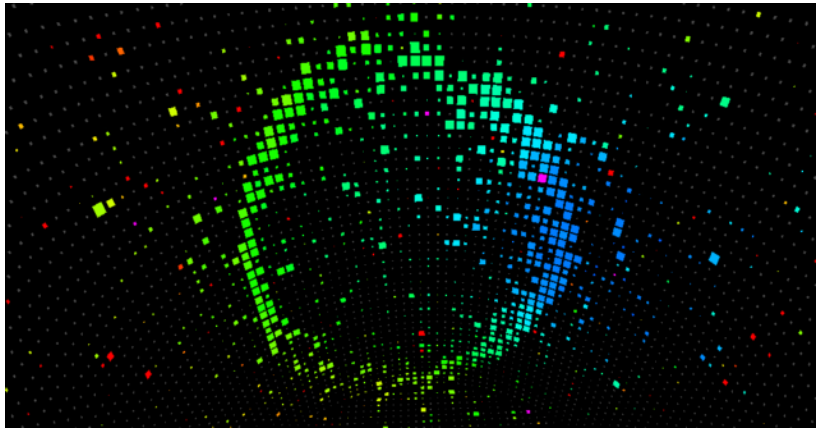
- Next generation of neutrino observatory in Japan→ construction 2020-27
  → A 260 kton water Cherenkov detector → Fiducial Mass ~ 8 x SK.

Super-Kamiokande



Hyper-Kamiokande

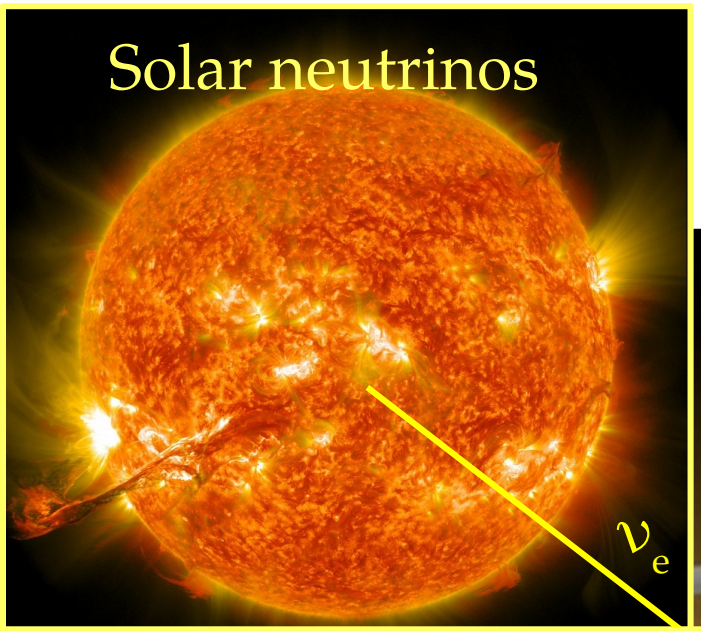




	Super-K	Hyper-K (1st tank)
Site	Mozumi	Tochibora
Number of ID PMTs	11,129	**20,000**
Photo-coverage	40%	20 %(×2 sensitivity)
Mass / Fiducial Mass	50 kton / **22.5 kton**	260 kton / **187 kton**

Physics case

Solar neutrinos

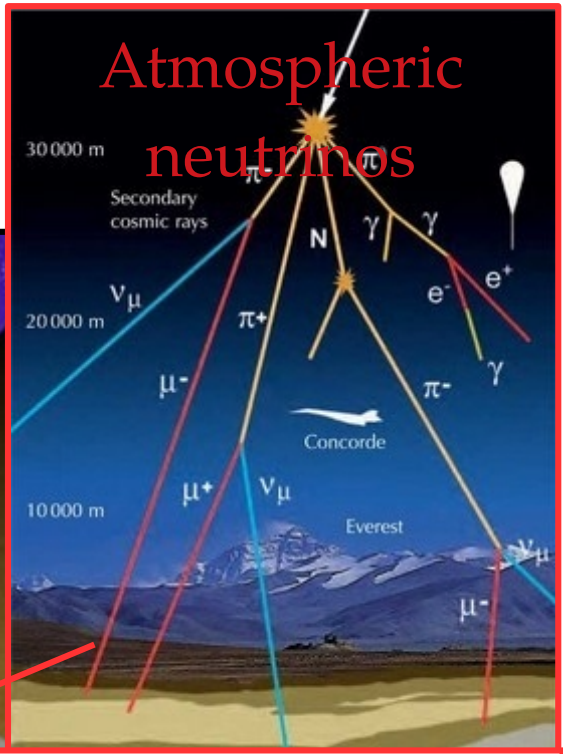


- MSW effect in the Sun
- Non-standard interactions in the Sun.

Proton decay

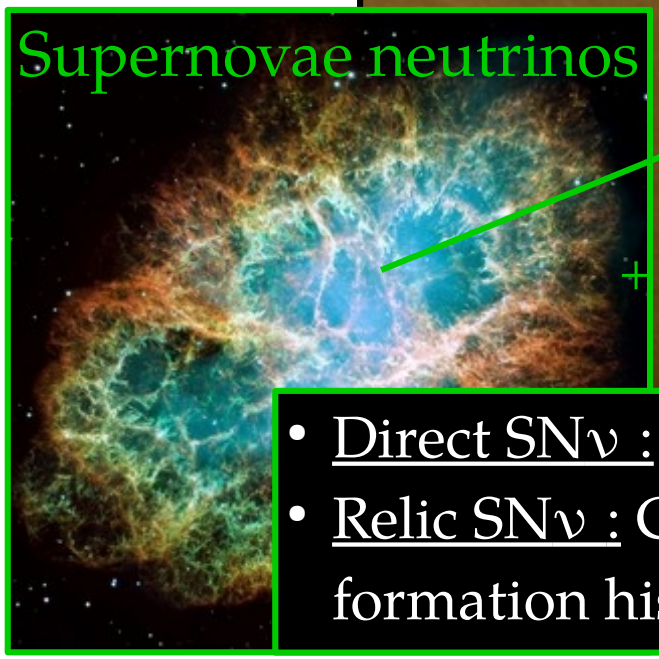
Probe Grand Unified Theories through p-decay (world best sensitivity)

Atmospheric neutrinos



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

Supernovae neutrinos

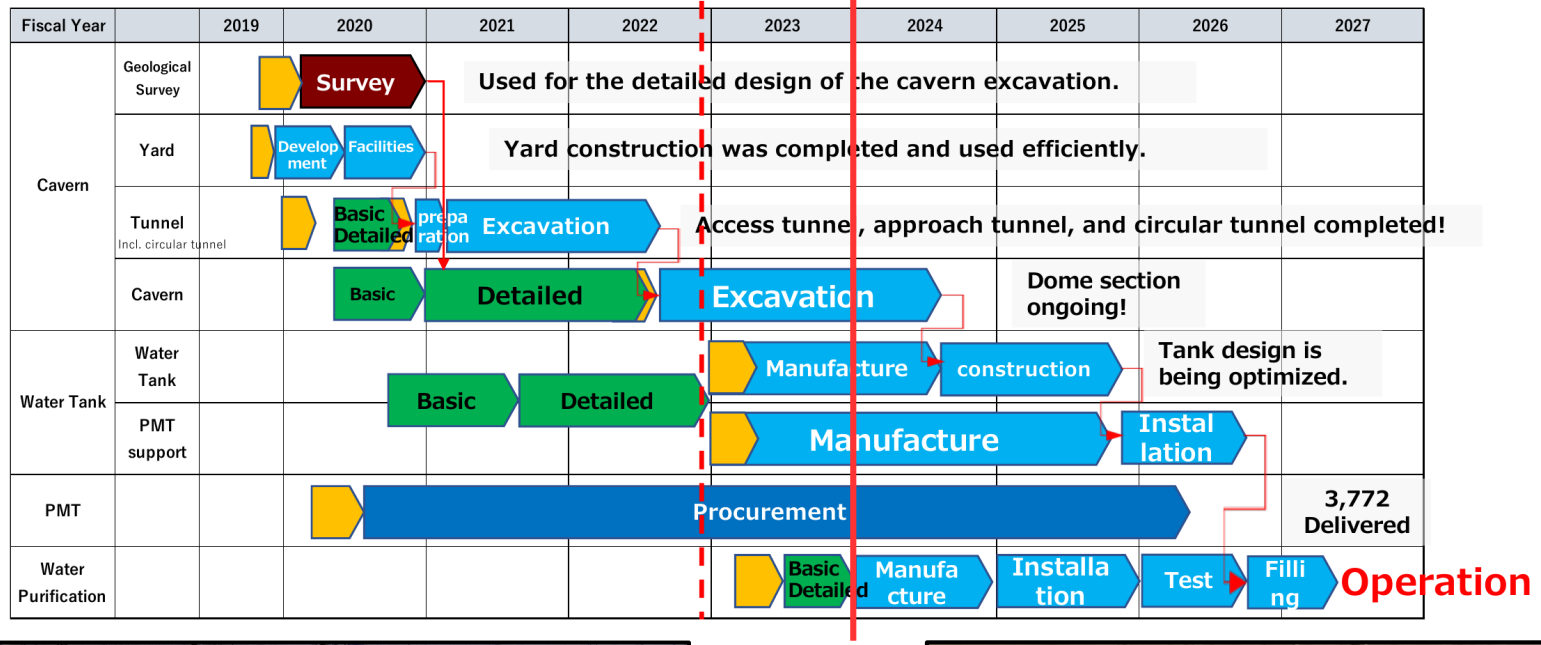


$\bar{\nu}_e$ + (ν_μ , ν_e, $\bar{\nu}_\mu$)

- Direct SNν : Constrains SN models.
- Relic SNν : Constrains cosmic star formation history

Construction schedule

We are here !



No delay in excavation or PMT prod. → Will take our first data in 2027

Our updated proposal

- Last CS : our PMT electronics digitization system, HKROC, was not selected as #1 by the HK management.

- Our updated proposal for HK :

  1. Focus on our final goal : become the leader in HK reconstruction and analysis softwares using our expertize in SK & T2K.

  2. Ensure our participation with a smaller but visible contribution :
     - Software : develop & maintain the HK data-base.
     - Hardware : develop the HK electronics test & calibration bench.

- Beyond HK : Finalize the HKROC board development as a generic digitizer for coming 15 years & publish > 1 paper.

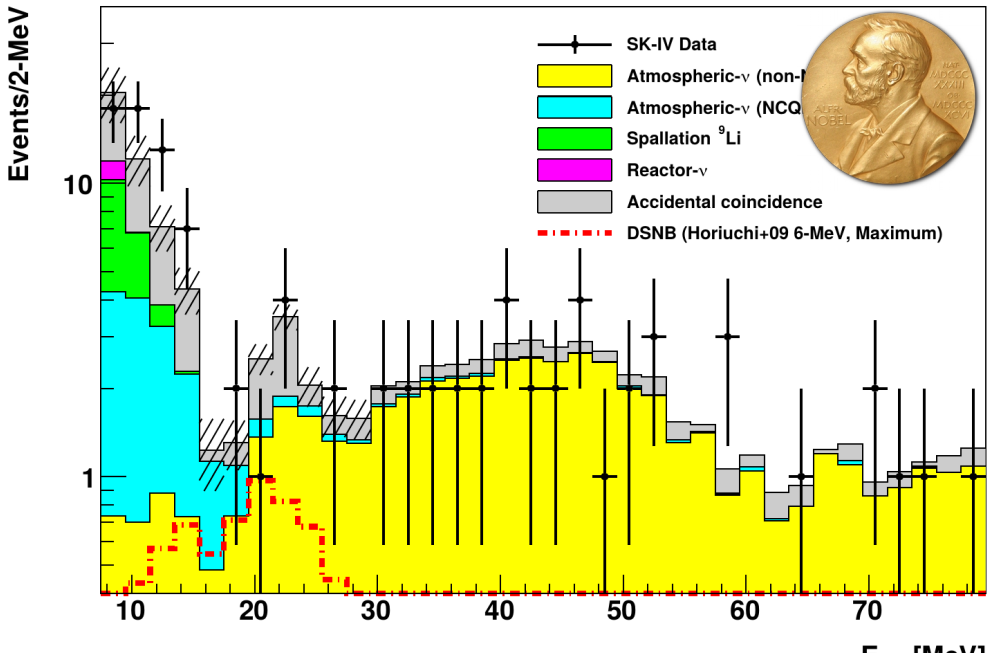
II. LLR software contributions

Physics & analyses in T2K-SK era

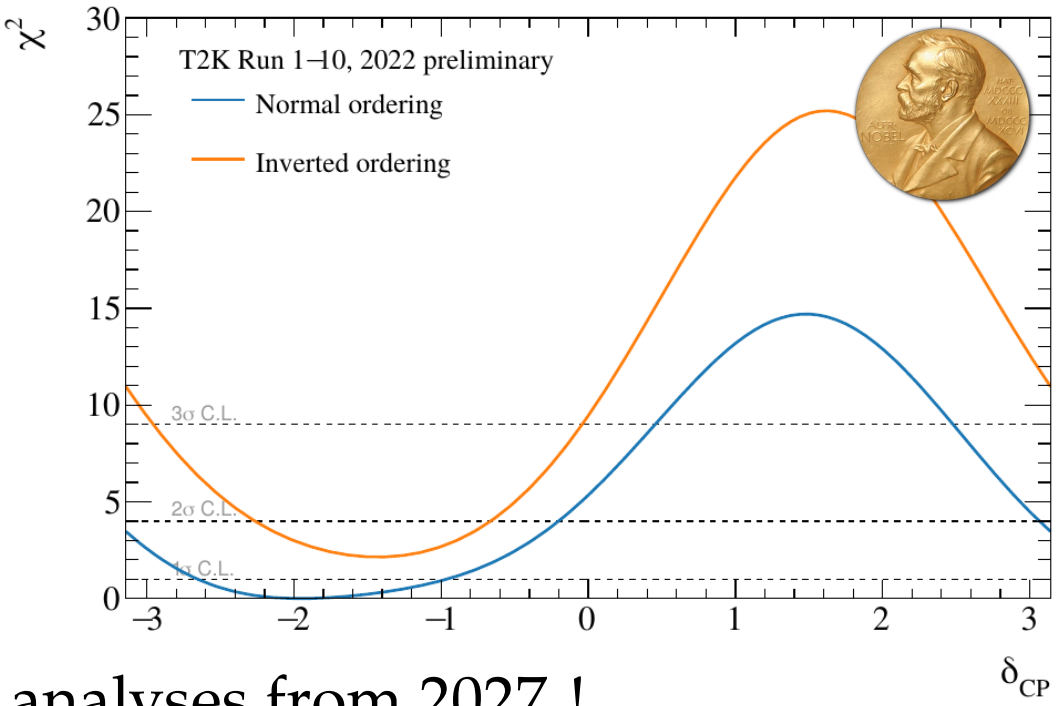
LLR have leading roles in T2K & Super-Kamiokande physics.

- T2(H)K near-detector : analyzers (Andres, Viet), conveners (Margherita-cross-section, Olivier-sFGD, Thomas-WAGASCI)
- ν oscillation analysis : ND (Lena), FD (Denis), convener (Benjamin)
- Leader of SK DSNBν analyses in 2018-2023 @LLR : main analyzers (Antoine, Andrew, Rudolph), supervisors (Thomas, Pascal, Benjamin).

DSNBν @Super-Kamiokande



CP violation @T2K

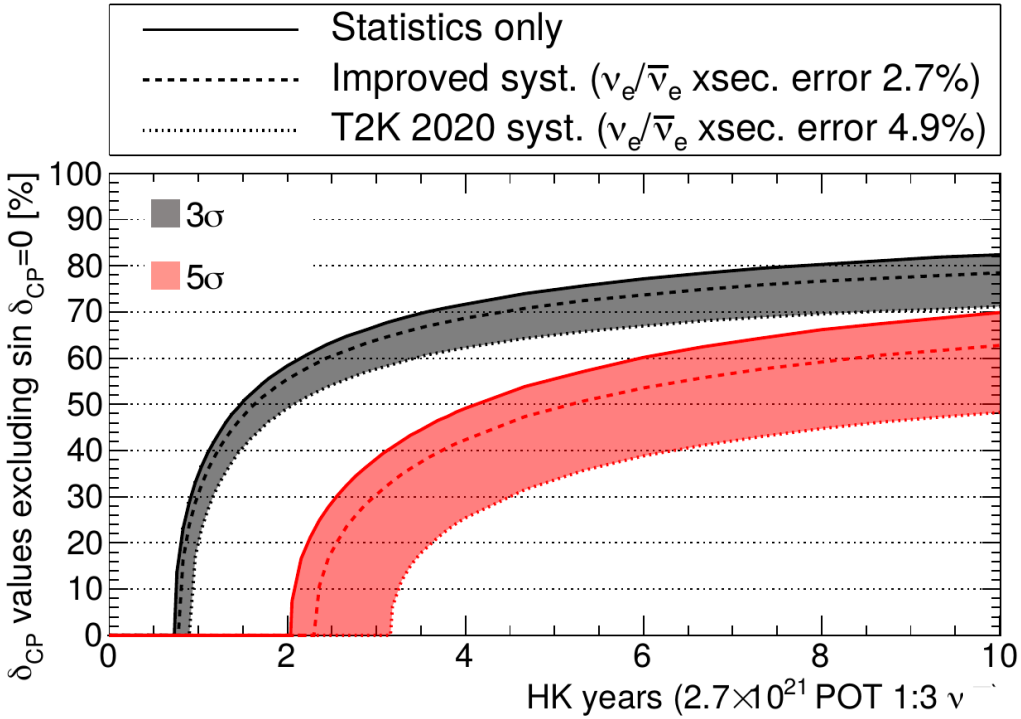


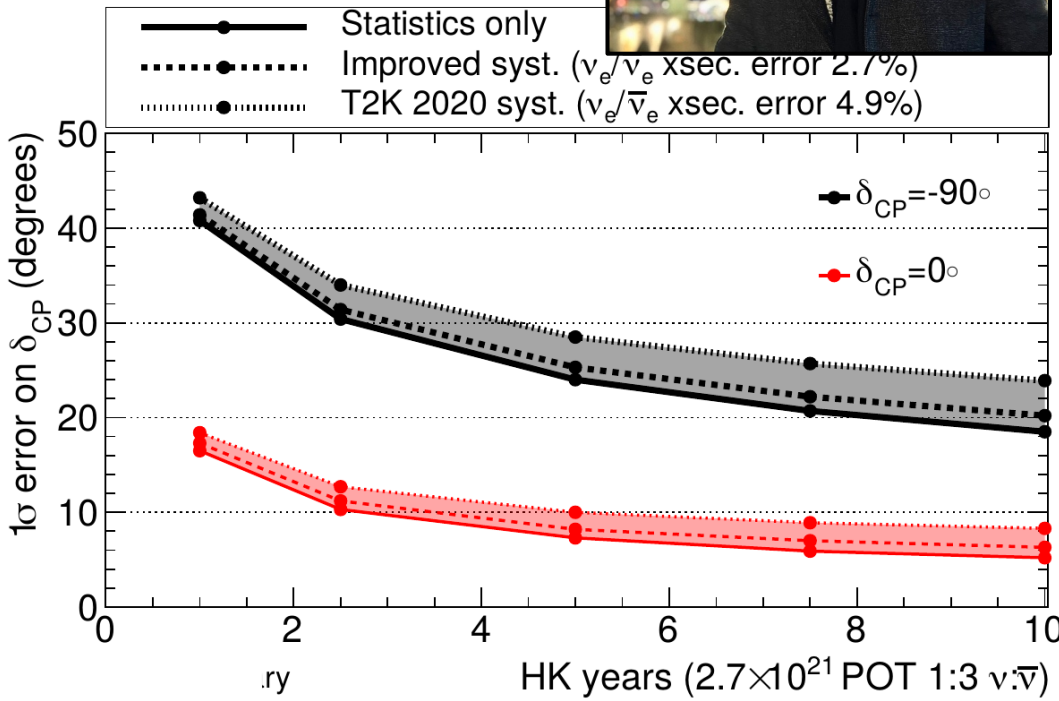
Our goal : Lead the future Hyper-K analyses from 2027 !

1. Port & update the analysis softwares on which we are experts.
2. Develop new reconstruction algorithms.

HK official sensitivity studies

- In 2023 : official HK sensitivity studies produced at LLR → Ported Japan/France oscillation analysis framework from T2K → HK (updated systematic error model etc.)



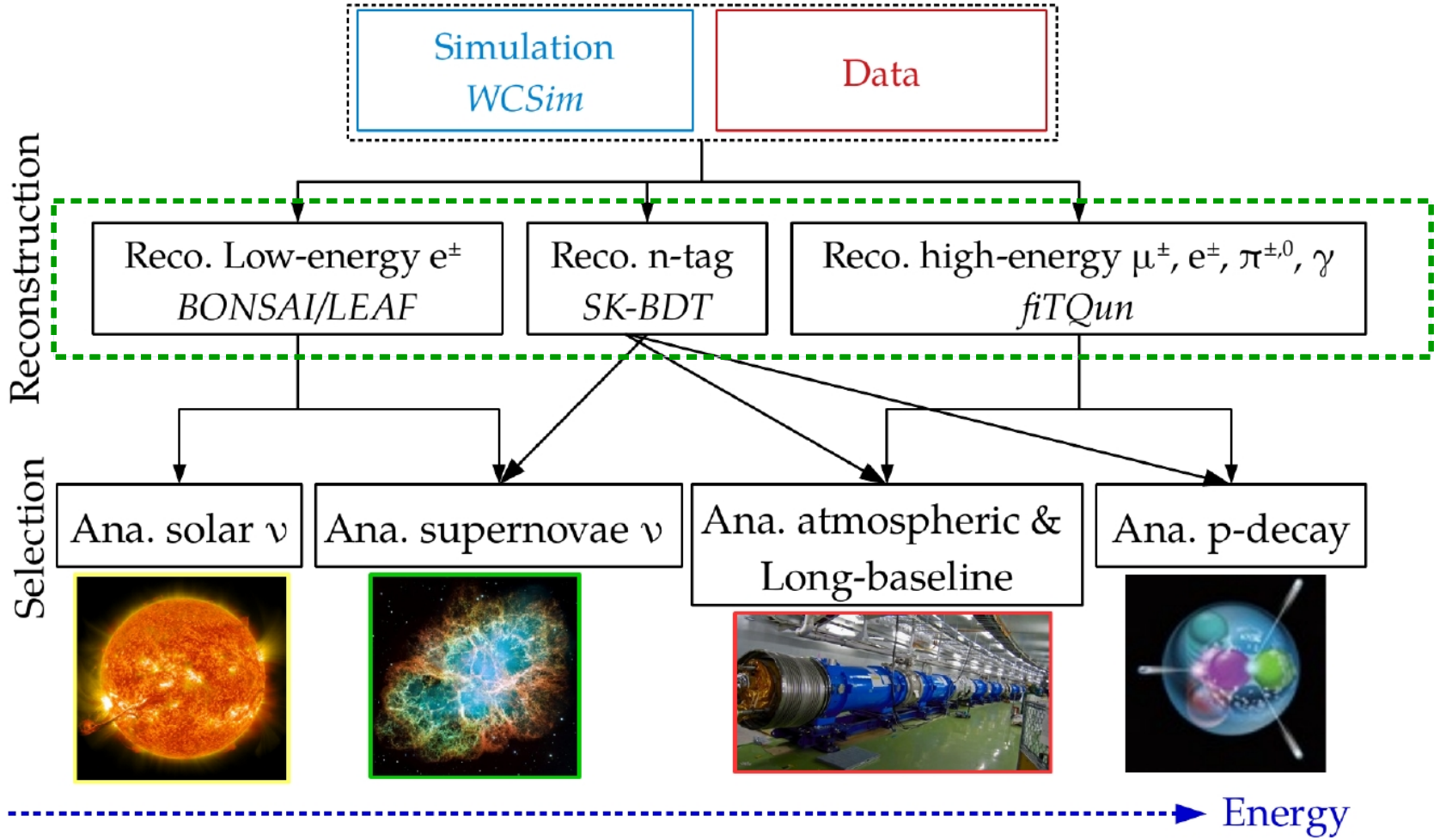


- Reminder : if CPV maximal ⇒ 5σ in 2.5 years of HK + World leading precision on δ_{CP} ⇒ Constrain flavour symmetry, leptogenesis etc.
- What's next : in 2024, we will move to a joint beam + atmospheric ν fit (1 or 2 new PhD in autumn 2024 with Pascal/Benjamin).

Towards a new reconstruction software

- Reconstruction softwares on SK ≥ 15 years-old : already starts to be outdated & **cannot be scaled to Hyper-K** !

- Since 2023 : we started to develop new algorithm using Graph Neural Networks → Apply it for low (~MeV) and high (~GeV) energy.



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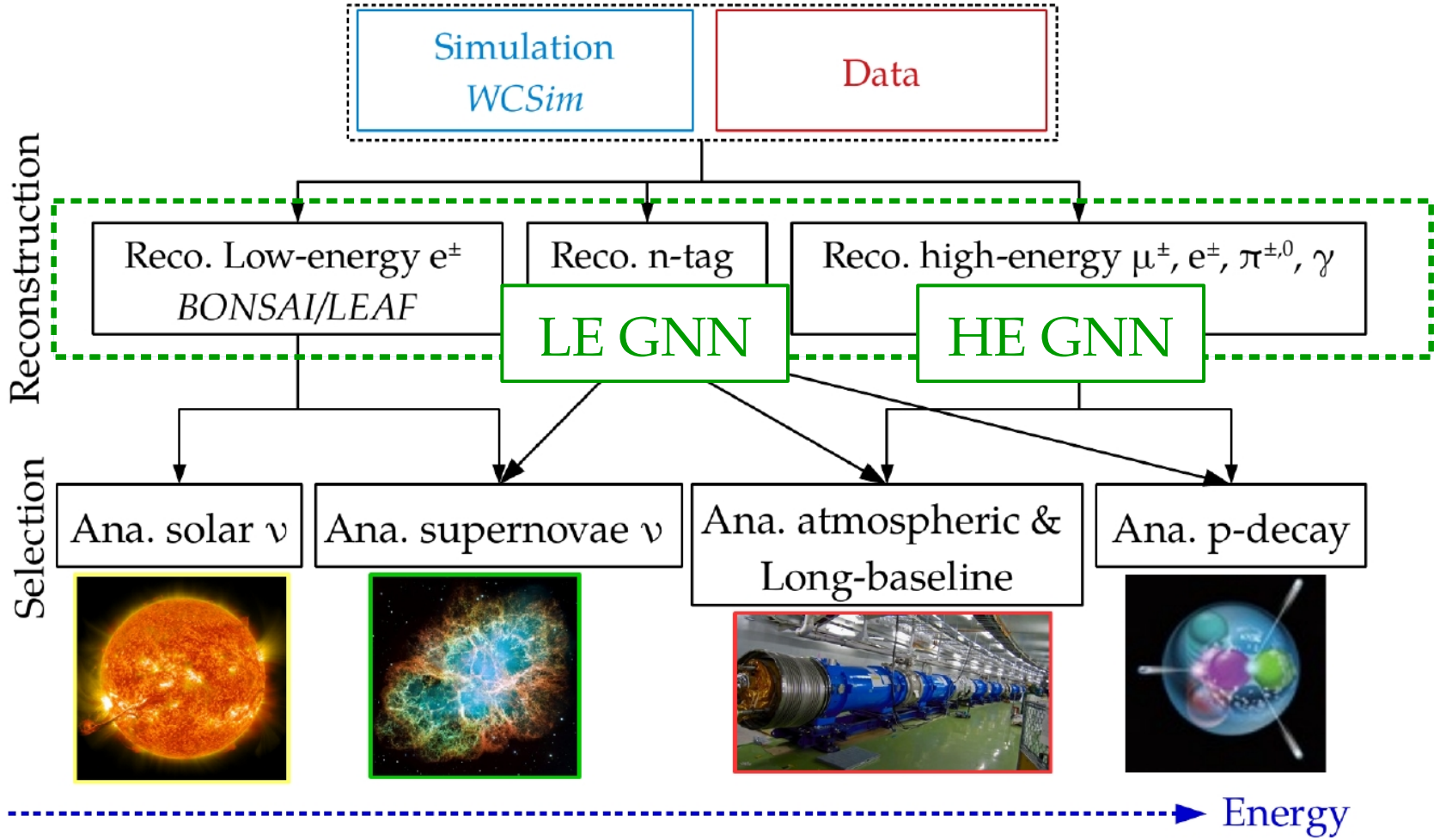
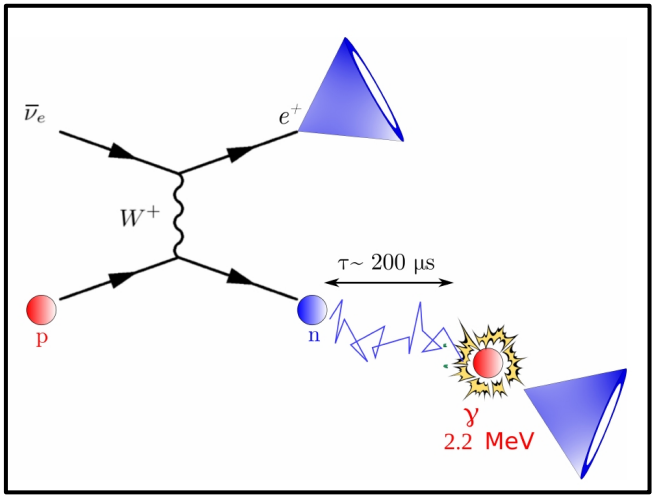
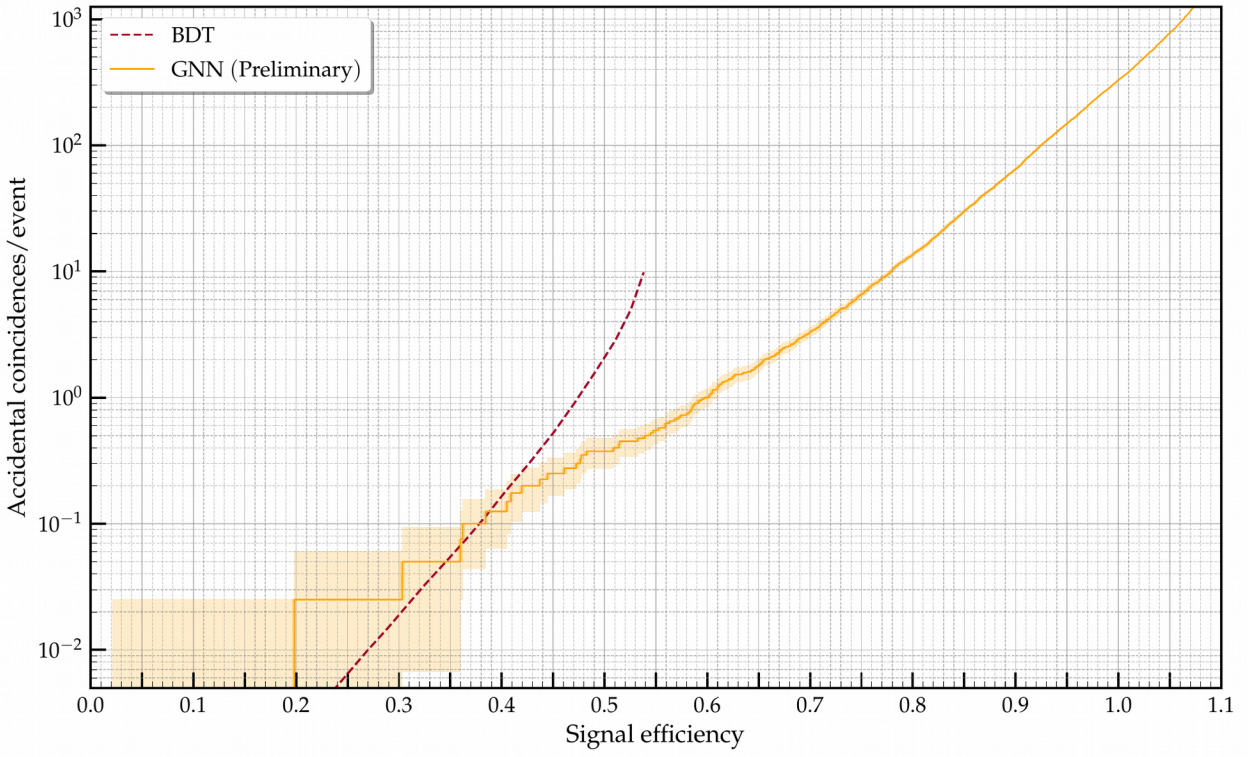


Where it started : neutron-tagging

- Tagging neutron ⇒ Key to Identify Diffuse Supernova Neutrinos.

- Neutron-tagging : starting point of our GNN.
  → Simple event topology : 2.2 MeV event
  ⇒ Identify ~20 simulatenous γ from bgkd.





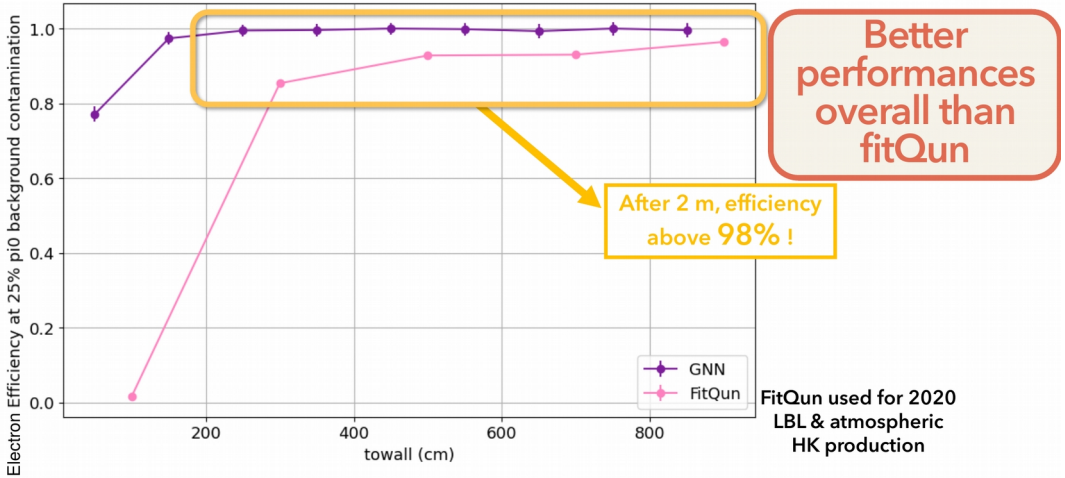
- N-tag already largely improved compared to official SK algorithm !

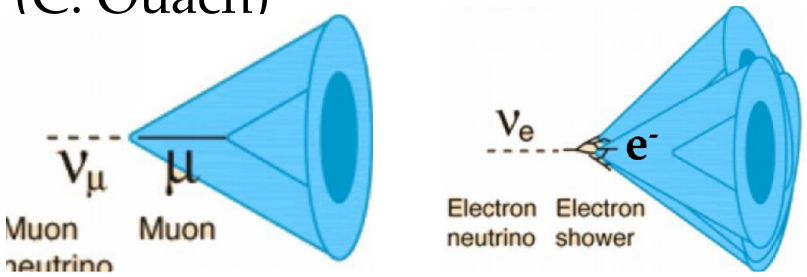
At high-energy

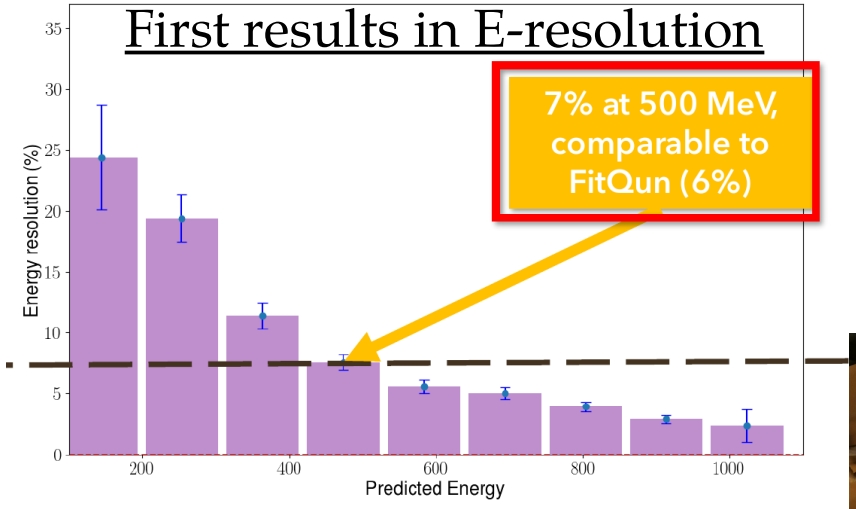
- High-energy event has calorimetric & tracking info → More complex.

→ Since 2023 : Adapted the GNN for high-energy (C. Ouach)

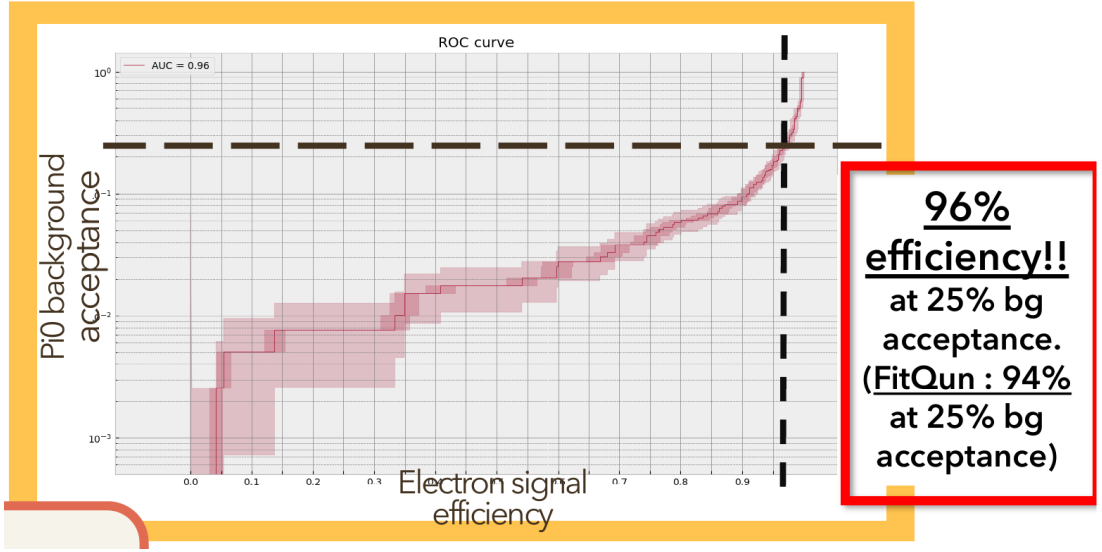
Easy mode : Separation e / μ





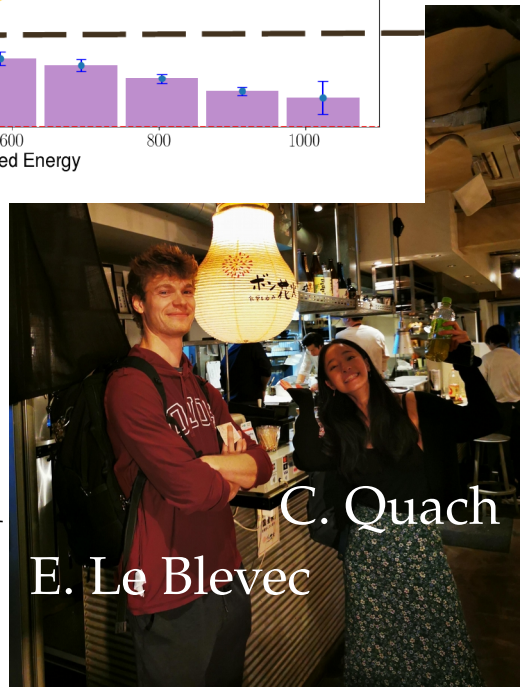


Hard mode : Separation e / π^0



- Already surpass fiTQun (official soft. SK/HK since 10 years)

→ Also supported by E. Le Blevec (LLR/ILANCE)



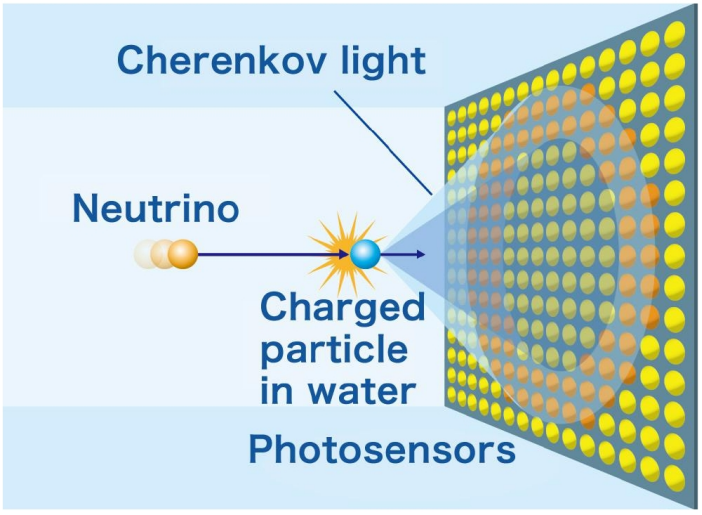
Testing these algorithms : SK & WCTE

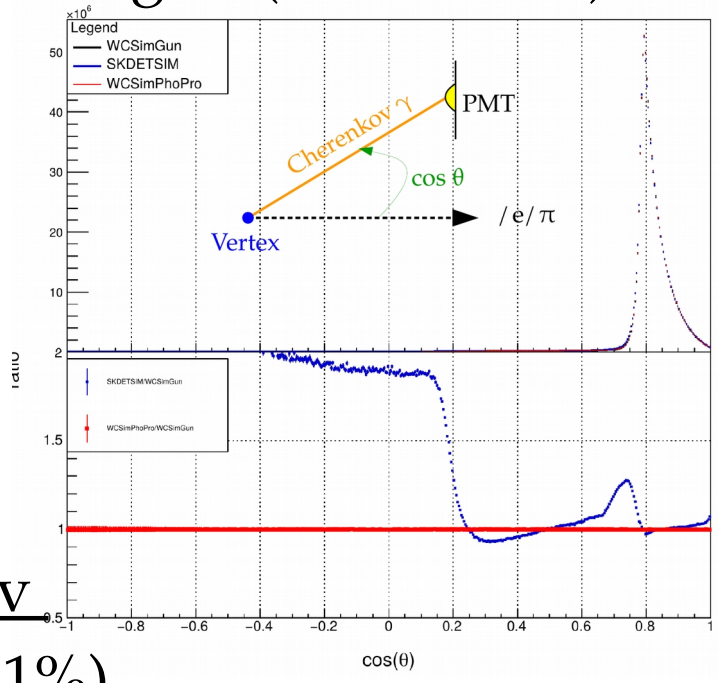
- 2023 : developed algorithms starting to open tremendous possibilities…
  → That are (almost) proportional to their dependency to training model.
  → No way to use them from day-1 of HK w/o years of prior testing.
- 2024 : continue/boost the development & train them on data.

Where to test them → Complementary data set :

set #1 : SK data → Real neutrino data & in-situ events (C. Quach)

set #2 : WCTE data → Well controlled particle & energies (A. Ershova).

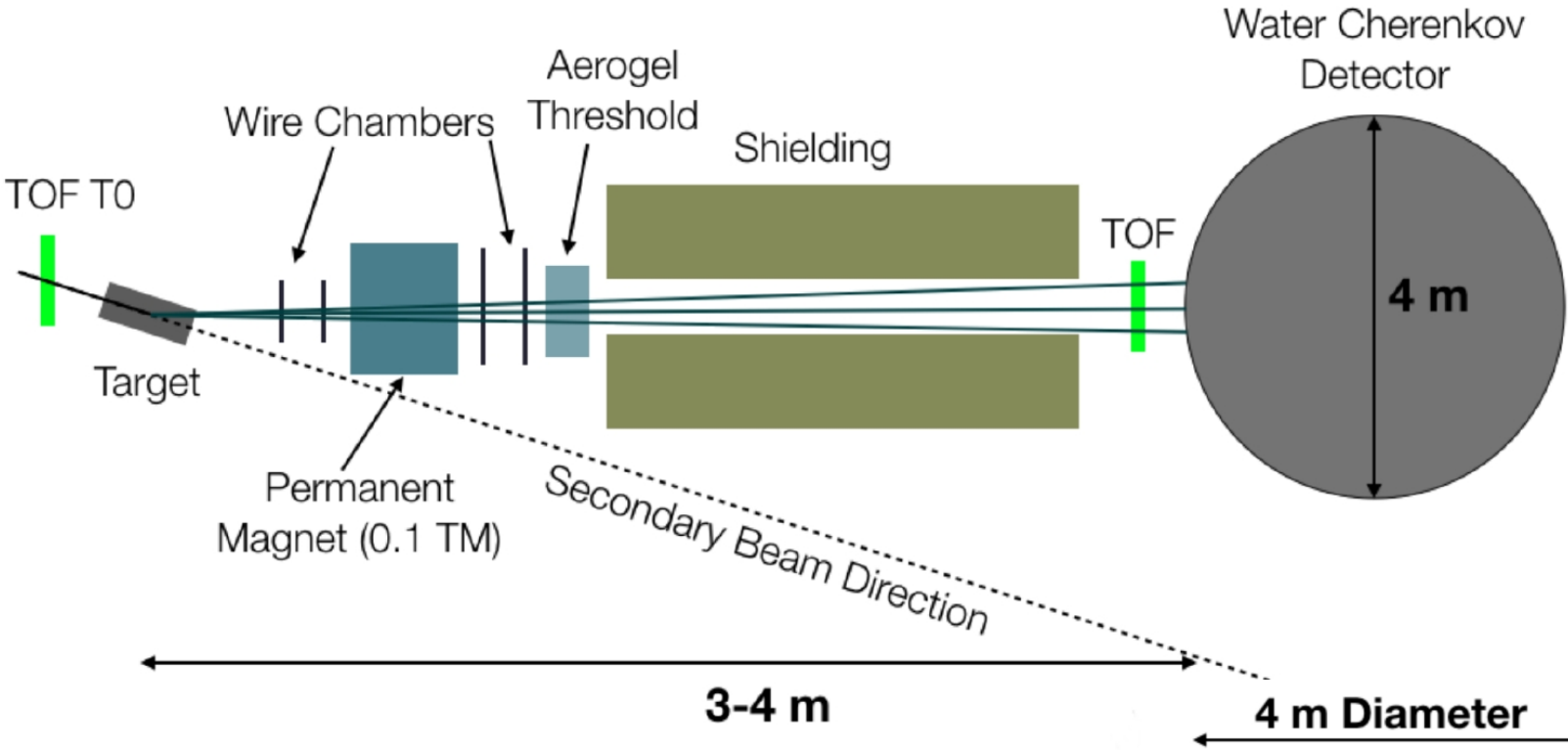




- Cherenkov profile not well-known ~ Cherenkov threshold → Not acceptable in HK era (syst. ≤ 1%)

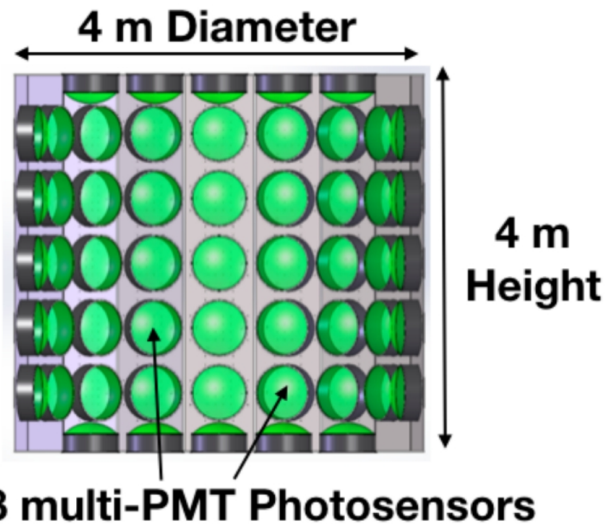
What is the WCTE ?

- WCTE : The Water Cherenkov Test Experiment
  → A 40ton water Cherenkov detector in a beamline.



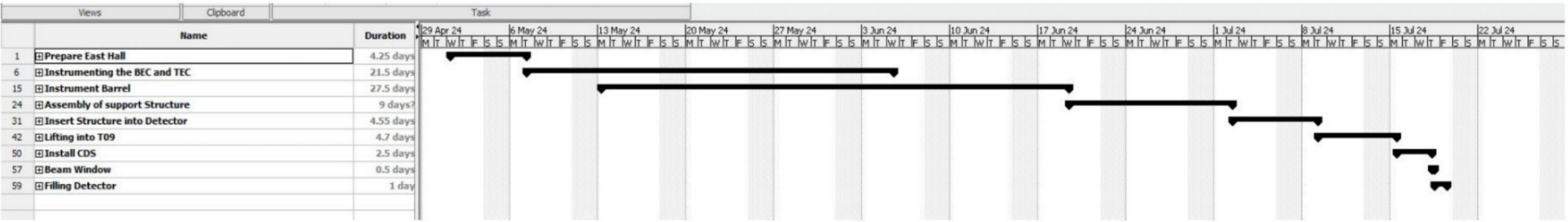
- Which particles : π, e, μ, from 200 to 1000 MeV/c.
  → Very same as expected in the T2HK final state !

- Where : in the T9 beamline at CERN

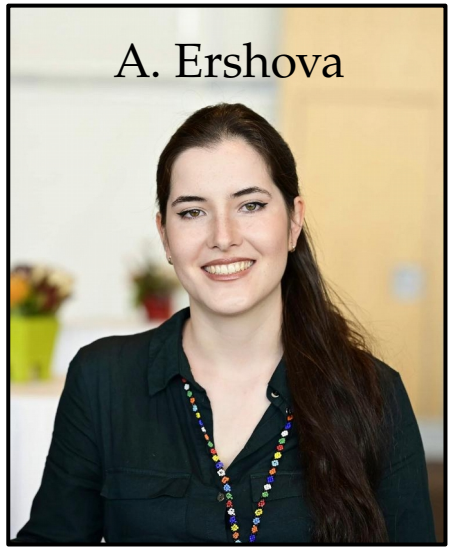


New WCTE schedule

- WCTE construction & data taking in 2024 :



- May → July 2024 : Assembly @CERN
- August-October 28th : commissioning & data-taking.



- Our group activity&contribution :
  - Adapt our GNN to WCTE → High-energy particle reconstruction → A. Ershova.
  - WCTE will also be Gd-loaded → Adapt our n-tag reconstruction ⇒ Will retro-actively impact our SK analysis also.
  - A financial contribution (15k) is expected to enter the collaboration → Simplest way to have direct access to data.

LLR contribution : the HK data-base

- We aim to make CC-IN2P3 a Tier-1 for HK
  → Contain a computing & data-base aspect.

The HK data-base

HK calibration data	HK members personal info.	HK internal documents
→ Obtained with our test bench. → Crucial for reco. software training		(Technical notes, plots, presentation etc.)

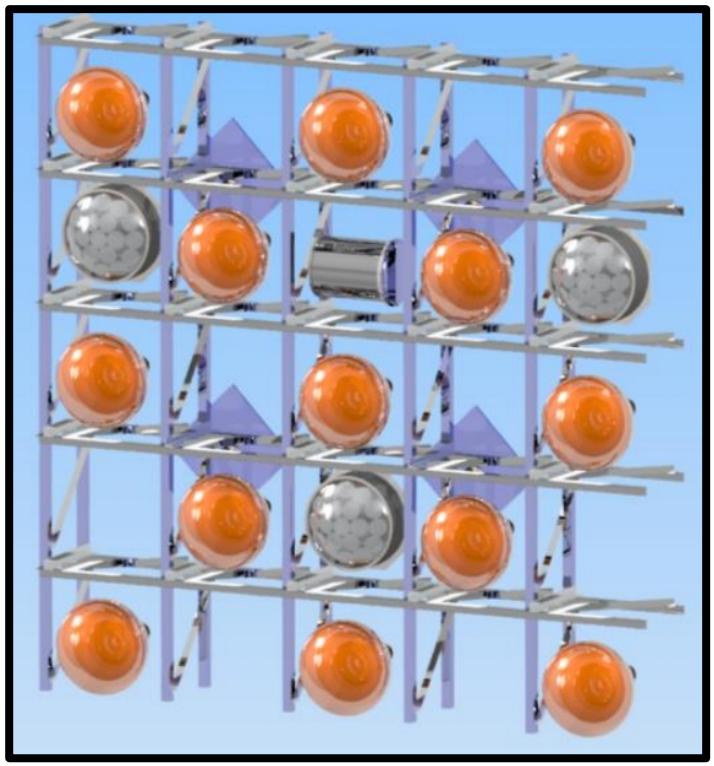
- Pros :
  - Visible contribution from the whole collaboration.
  - Relative synergy with our software & test bench activities.

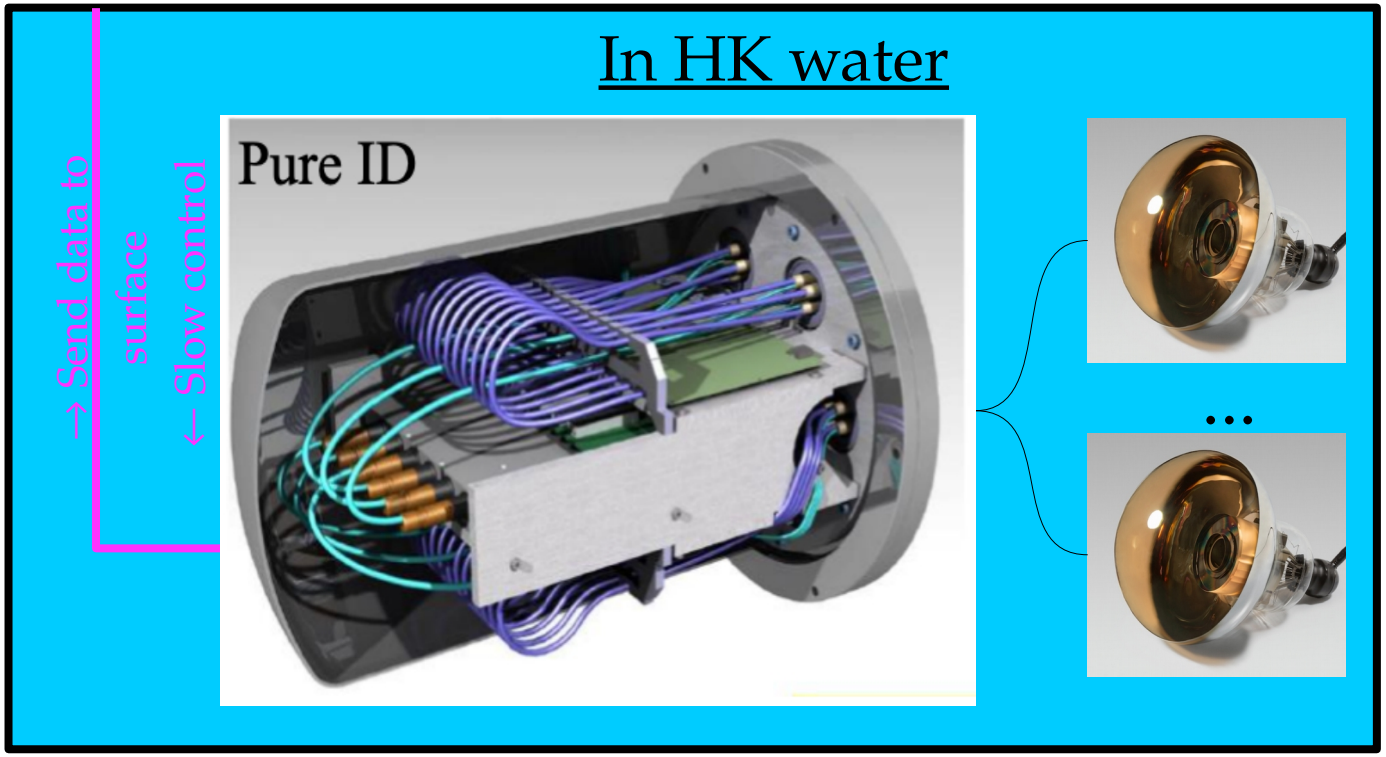
- Who :
  - Coordination & CC-IN2P3 requests : Thomas.
  - Software development : In discussion with Frederic and Igor.

III. LLR hardware contributions

The HKROC electronics assembly

- 20k PMTs of HK → Read-our under water in 1000 electronics boxes
  → Fixed between ID & OD structure.





- Electronic boxes : assembled, tested & calibrated @CERN.
  → We propose to take responsibility of the test&calibration benches.
  → Full R&D of the test bench.
  → During the tests, we will be on-call experts & shift-organisers.
  → No responsibility in assembly.

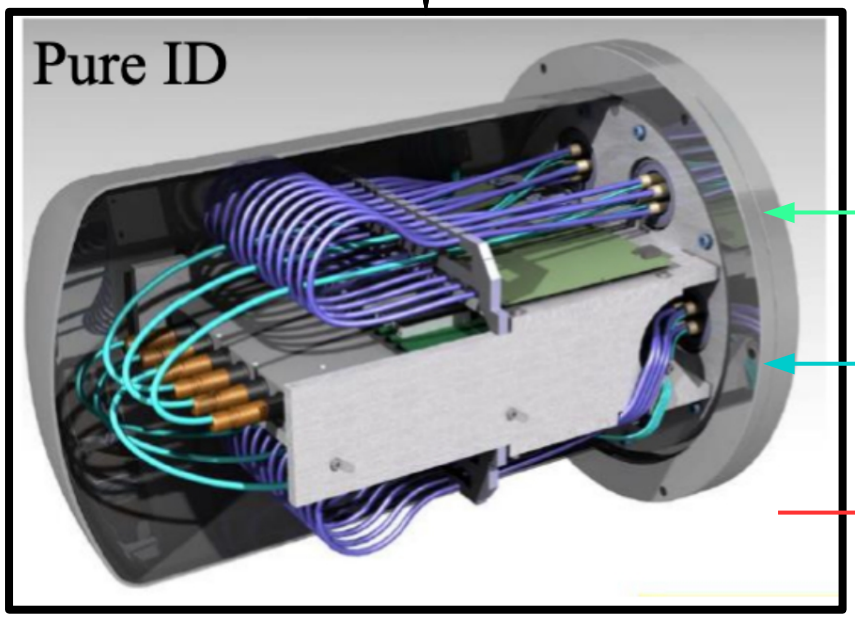
Test bench schematics

Wavefunction Generator

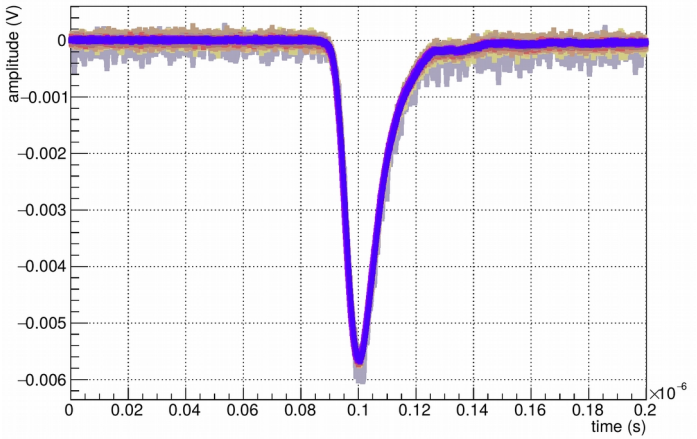
Korean distributor

Korean distributor

24/32 channels output



Generate a PMT -like waveform



PC

Time generation

External Power Supply

Data

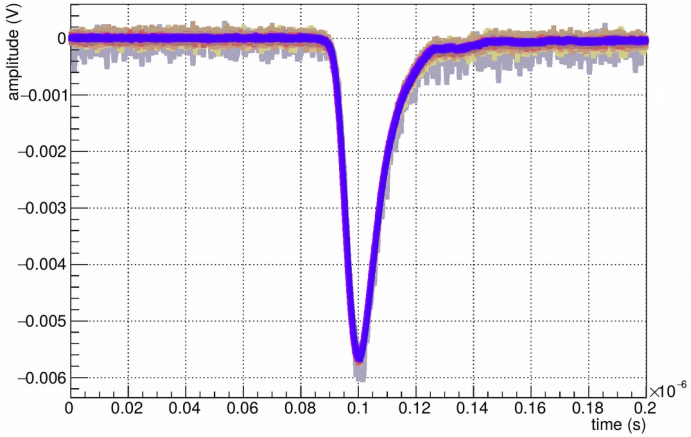
Official HK DAQ (UK)

Test bench schematics

Global DAQ layer

Wavefunction Generator

Generate a PMT -like waveform



Korean distributor

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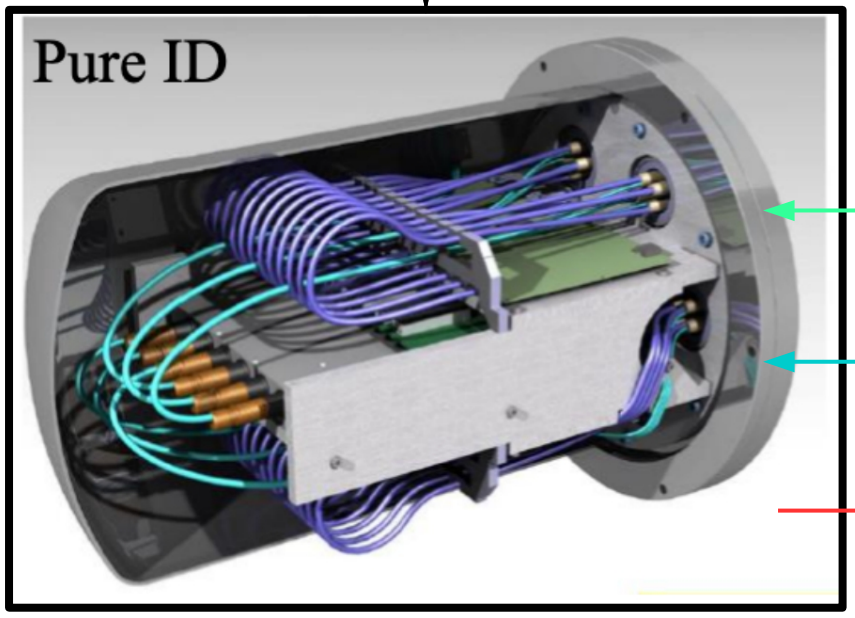


PC

Time generation

External Power Supply

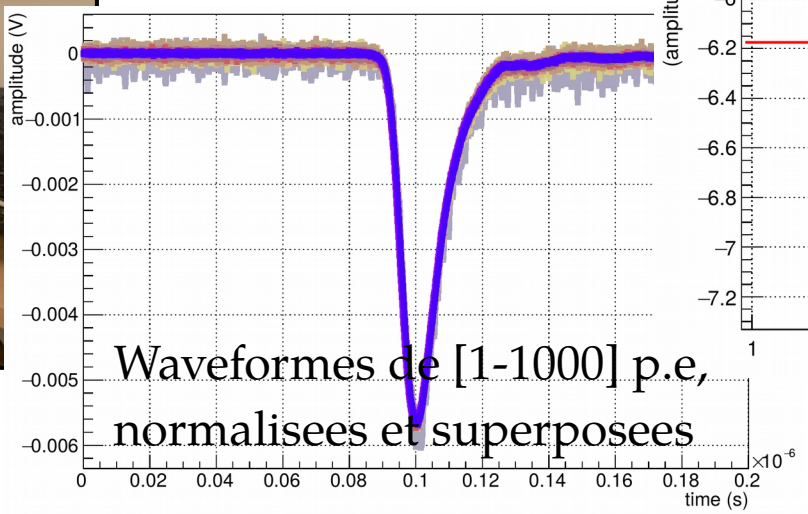
Data

Official HK DAQ (UK)

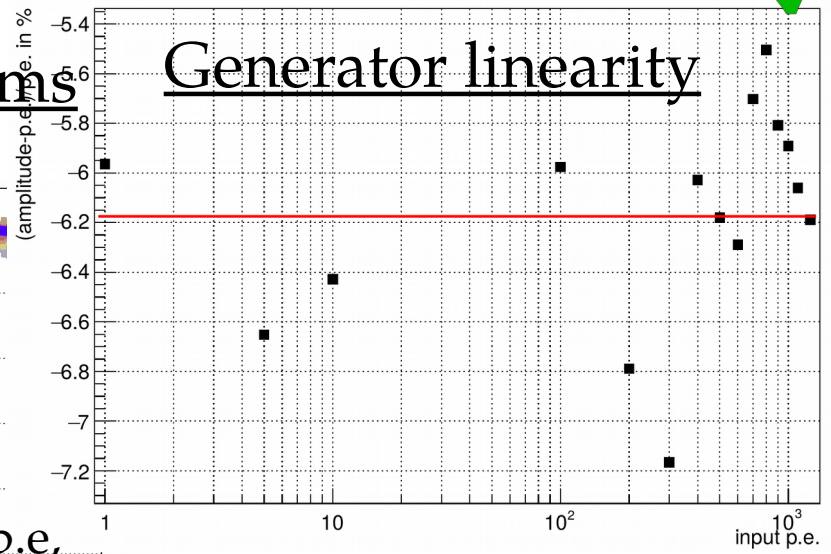
Test bench development

- Test bench development has started (P. Paganini & R. Rogly).
- Group focused on primary constraint (time&cost):
  - Price : Identifying a generator following stringent HK requirements. ✓

Generator waveforms

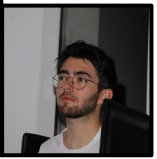


Generator linearity ✓

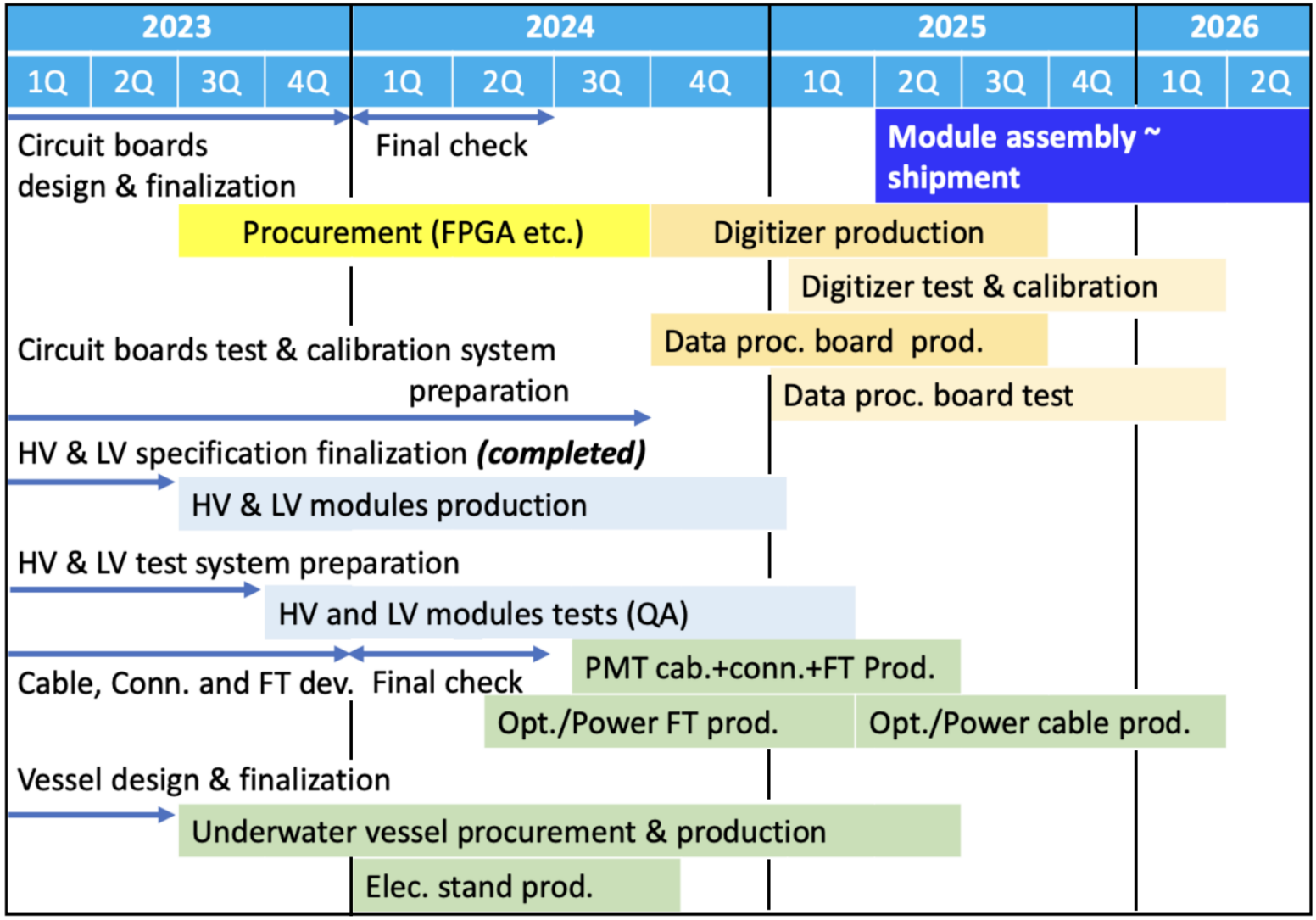


	Generate PMT wv	Time jitter	Charge linearity	Charge res.	Voltage range
Requirements	✓	200 ps	~ 1 %	0.1 p.e	0-7V [0-1250 p.e]
Measured performances	✓	110 ps @ 1p.e 50 ps @ 10p.e	< 1 %	6mV / 0.15mV ~ 0.025 p.e	V

- Overlay DAQ → L. Bernardi has started : can control the generator, now interfacing with HK DAQ.



The HKROC electronics assembly

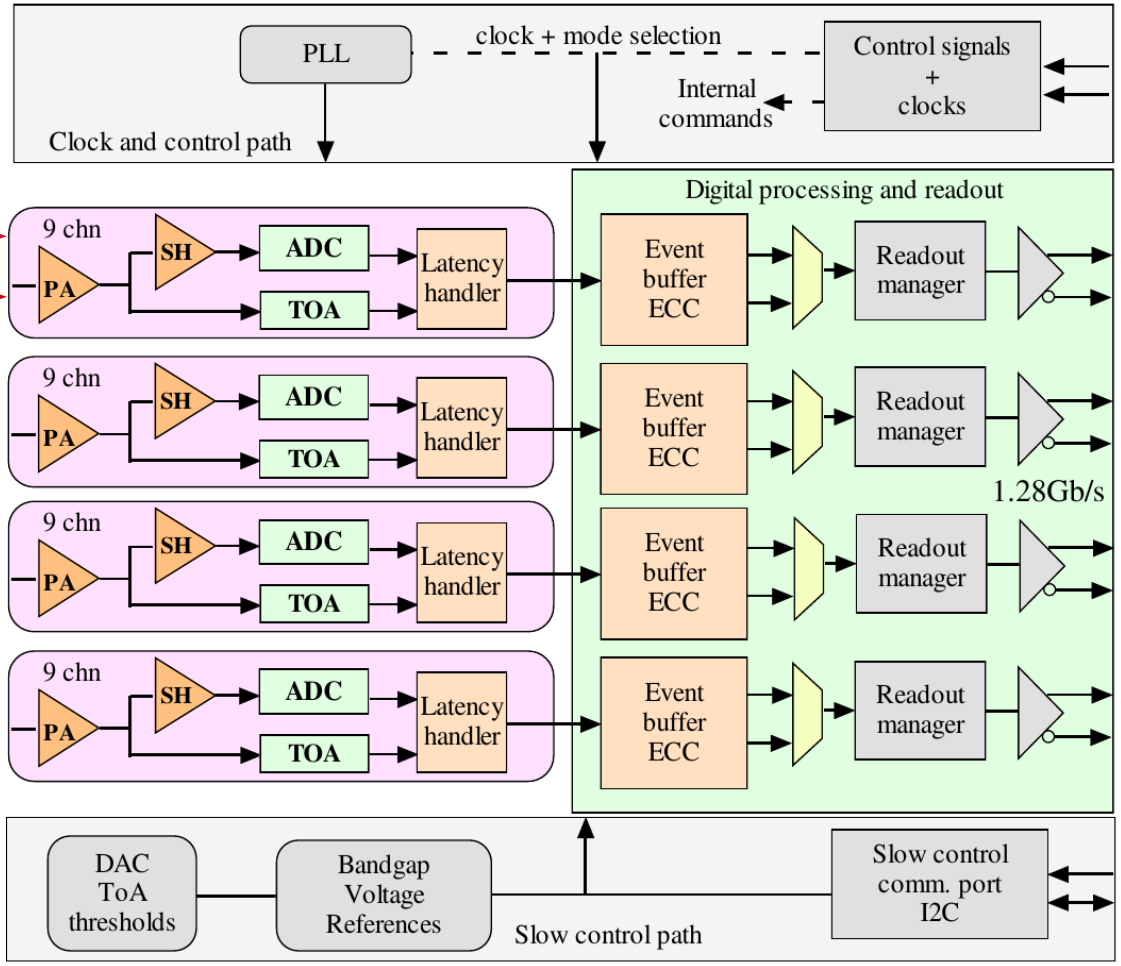


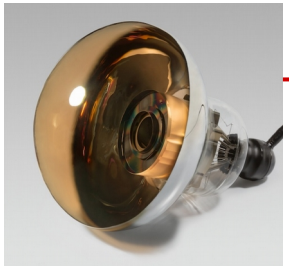
- 2024 is the year when HK production starts.
- The test bench R&D should be completely finalized in 2024.
  → Time pressure is strong.

IV. The HKROC digitizer

Reminder : the HKROC digitizer

- Based on HKROC chip : 12 PMTs ↔ 36 channels (high,medium,low gain)





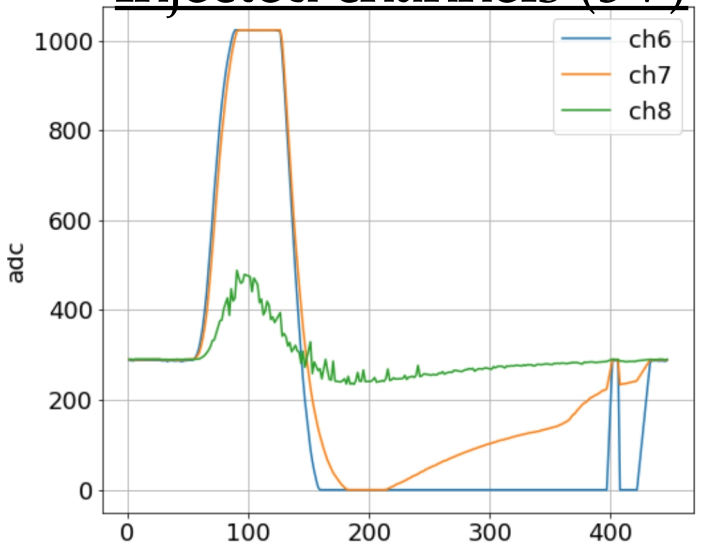
Reminder at last CS (10/2022) :

- An excellent digitizer that fulfill HK requirements.
- 2 aspects that can be improved : diffuse & close cross-talk.

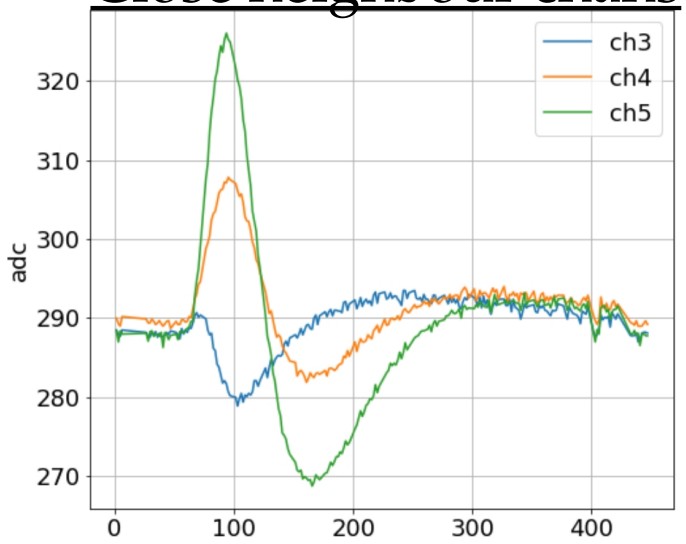
Cross-talk measurements

- Full cross-talk measurements :

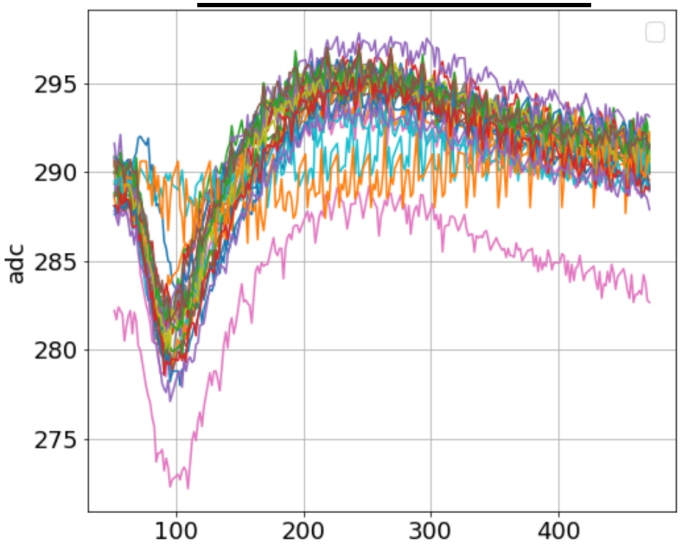
Injected channels (5V)



Close neighbour chans



All other chans



- Found 2 sources of cross-talk :

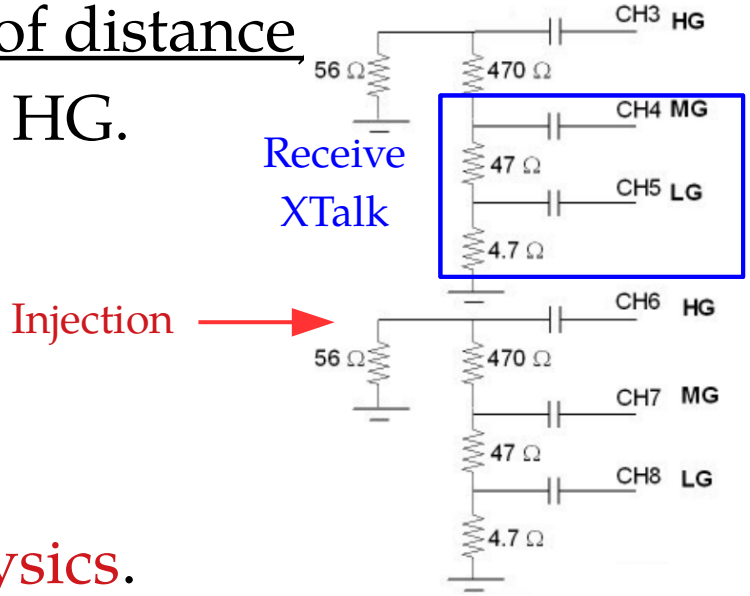
1. Close : Only on 2 neighbour (as a function of distance

→ Receive ~ 100 p.e on LG, 5 p.e on MG, 0 on HG.

2. Diffuse cross-talk :

→ Receive 0.35 p.e on all channels : close to detection threshold.

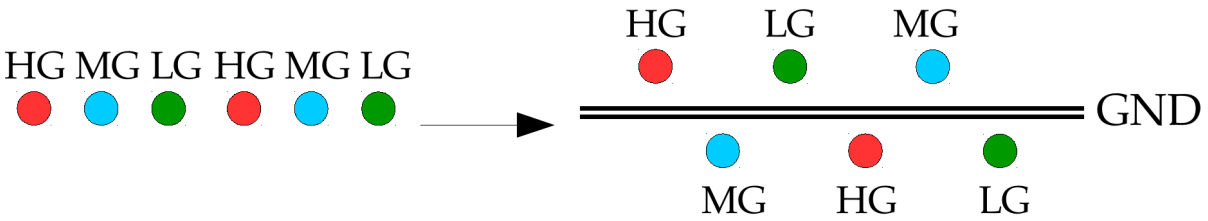
→ Smaller but much more worrysome for physics.



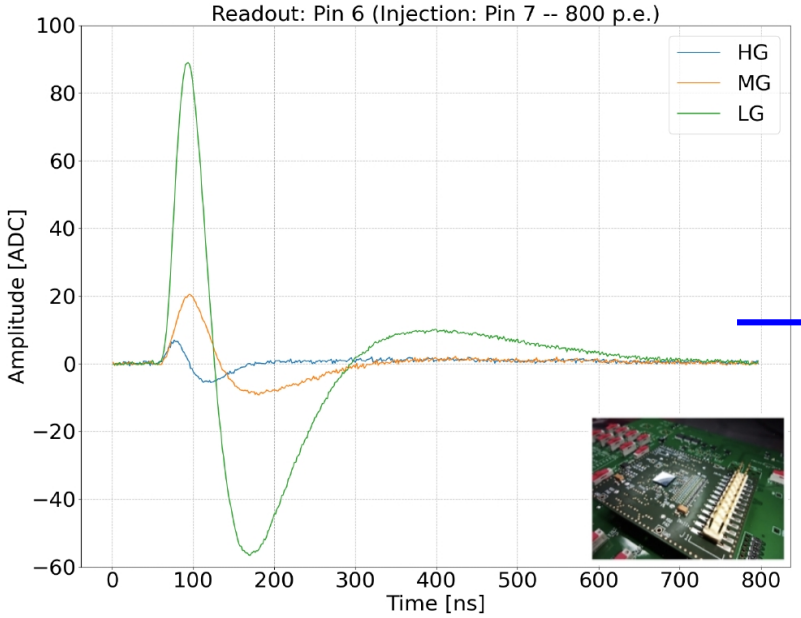
Jerome odysseus : Close Xtalk removal

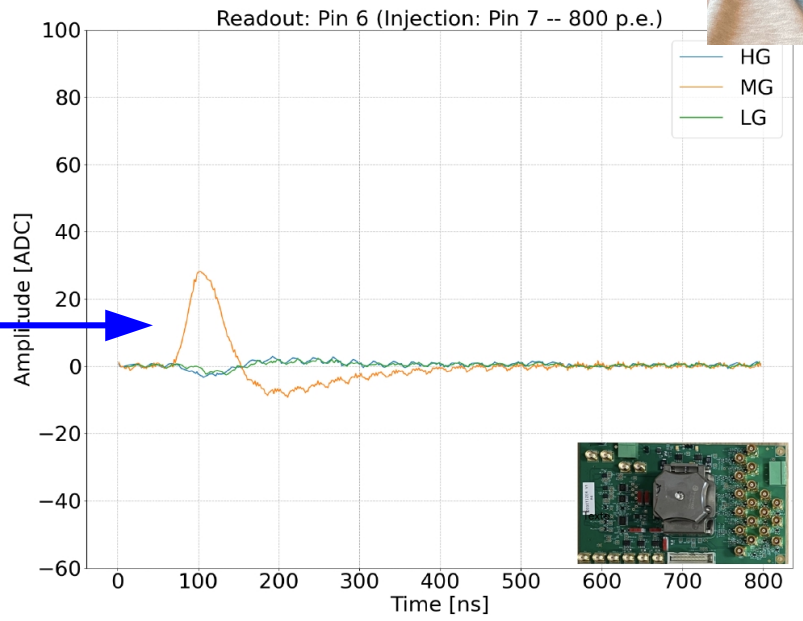
- Diagnostic : Close Xtalk comes from the proximity of channels on the board (right before the entrance to the chip).

- Solution : scatter neighbouring channels on ≠ PCB layers.
  → New intermediate board in 2023 (v1) to test our solution.



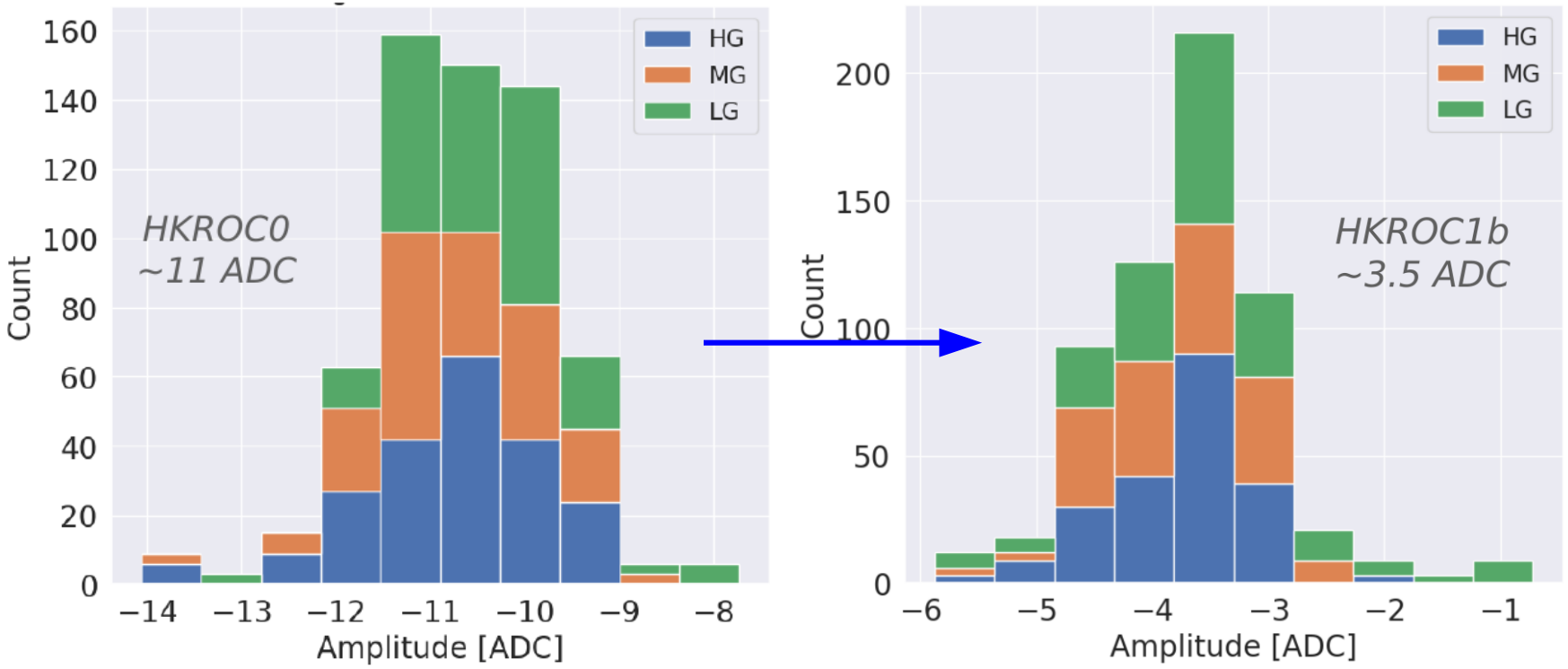
- Result : Close Xtalk completely removed from neighbouring channels.





OMEGA odysseus : Diffuse Xtalk removal

- Diagnostic : close Xtalk mostly comes from pre-amp coupling in ASIC.
- Solution : Add a C=100 nF decoupling capacitor (+other updates).
- Result : suppression by a factor 3 → 1000 p.e signal ⇒ 0.12 p.e (0.012%)
  → Does not affect trigger or reconstruction anymore.



Paper status

- Conferences : TWEPP (2022), TIPP, Kyoto conference of 2∞, IRN (2023)

- Papers : goal is to publish 2 papers
  → 1 NIM paper focused on the ASIC performances.
  → 1 paper focused on the integrated digitizer performance.

- The ASIC NIM paper close to final shape : → Released in coming month

HKROC: a modern integrated front-end ASIC to readout photomultiplier tubes for Cherenkov-based experiments

Author name[a]

[a]University of the Moon, , Earth, , ,

Abstract

The HKROC ASIC has been designed as an innovative readout of modern photomultiplier tubes. HKROC is an auto-triggered very versatile and innovative ASIC capable of reading a large number of channels while meeting very stringent requirements in terms of noise, time & charge resolution together with sustaining very high hit-rate and low-power consumption. Each HKROC channel features a low-noise preamplifier and shaper, a 10-bit successive approximation Analog-to-Digital Converter (SAR-ADC) for the charge measurement (up to 2500 pC) and a Time-to-Digital Converter (TDC) for the Time-of-Arrival (ToA) measurement with 25 ps binning. The key feature of HKROC is its "waveform digitization" capability: it dynamically opens acquisition windows for internal digitization. The waveform amplitude is sampled by N snapshots taken at 40 MHz. It enables new possibilities in terms of pulse-shape analysis and double pulse triggering with a low dead time (down to 10 ns), while preserving a very low power consumption compared to standard flash-ADC. Moreover, HKROC is equipped with an adaptive readout which allows to cope with very high rate events such as close supernovae (Betelgeuse...) for neutrino based experiment.

Keywords: keyword 1, keyword 2, keyword 3, keyword 4

1. Introduction

2. Description of the HKROC ASIC

The HKROC ASIC is designed in TSMC 130 nm technology. It is conceived as an autonomous and flexible system operating in self-trigger mode providing measurement of the arrival time and of the charge for the 36 input signals. Each channel is made of three main parts:

1. An analog front end part that allows the input signal amplification, the trigger detection and the signal shaping ;
2. A mixed part to provide the charge and time of arrival measurements ;
3. A digital part to manage all the system, the conversion and the read-out.

2.1. Analog part

2.1.1. Overview

The analog front-end, schematized in Fig. 1, can be split in three main paths:

1. The Preamplifier (PA) – orange part in Fig. 1 – provides the first amplification of the PMT signal with the best noise performances. The PA has a variable feedback capacitor (Cf on 4 bits) to tune the gain and a variable feedback resistors (Rf on 4 bits) to shape the output signal which is sent into the shaper path. A second capacitor (Ccomp on 2 bits) in the PA feedback allows to ensure the PA stability. These three variable parameters are common for the 36 channels and sulmmarized in Tab. 1. The preamplifier provides two outputs: an output connected to the TOA discriminator for the time of arrival measurements and a second output, through a buffer, connected to the shaper path to allow charge measurement.
2. The slow shaper path (blue part in Fig. 1) is a 3rd-order RC shaper with variable gain and peaking time which parmeters are displayed in Tab. 2. The typical peaking time set is around 30 ns (min 25 ns and max 40 ns). The purpose of this slow path is to shape the PA output signal in order to allow the charge measurement, to optimize the signal-to-noise ratio and use the full available dynamic range (1 V). It is made by a first RC shaper with variable shaping (RC on 4 bits) and gain (on 4 bits) followed by two RC2 shapers in parallel (RC1 and RC2 both on 2 bits). The first provides an Inverted signal with variable shaping time and the second provides a Non-Inverted signal with variable shaping time and gain (on 2 bits). An output buffer is implemented to drive the ADC. The two Non-Inverted and

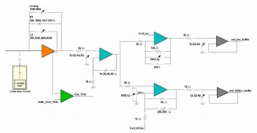


Figure 1: Analog front-end part of the HKROC ASIC.

slow shaper outputs between the pile-up (Fig. 12) and the single (Fig. 11) event waveforms are relatively small in the case of a trigger difference of dt = 30 ns. However, using this slight difference together with the two event trigger time, we will show in next sections that the joint fit allows to reconstruct the charge accurately even in case of close pile-up events separated by 30 ns.

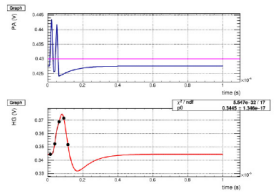


Figure 12: Waveform obtained in simulation from two 1 p.e events which triggers are separated by dt = 30 ns. The top plot shows the Preamplifier output as a function of time, while the bottom plot shows the slow shaper output, which is closed to the digitized waveform. The digitized points used for the digital filtering are shown in black.

Finally the waveform digitization could also be exploited for any residual cross-talk corrections. Similarly to what has been shown above, a joint fit could be performed considering the main signal waveform and the cross-talk waveform induced by nearby channels.

4. Characterization measurements

To quantify the performance of the HKROC digitizer in terms of time and charge reconstruction, we use a waveform digitizer, model AFG31252 from Tektronix.

In the tests detailed in the subsequent sections, the BGA-packaged HKROC ASIC is placed in a socket, that is mounted on an acquisition board. This board is connected to a "Xilinx Kintex UltraScale FPGA KCU" test board, which handles the communication with the ASIC, provides the differential clocks (320MHz) from the distributed 125MHz clock, and allows to send slow control parameters and read out the digital data coming out of the chip. The acquisition board gives access to various ASIC probes or pins to monitor the analog and digital processing, as well as the input channels to inject the signal from the waveform digitizer. [Should rather talk in terms of pC, instead of p.e. ? Carry out the tests with triangles or PMT waveforms ?] The overall apparatus is shown in Figure [?].

4.1. Trigger threshold, efficiency and noise evaluation

The trigger threshold of the ASIC is set by means of a global and coarse 10b-DAC (toa_vref), common to all channels, as well as a local and fine 6b-DAC trimming (trim_toa) to reduce the channel-to-channel dispersion. Both parameters are tunable by slow control, and as such by the KCU board, and the overall threshold is given by: ToA_threshold = toa_vref <9:0> − trim_toa <5:0>.

In order to set the trigger threshold as low and as accurately as possible, low amplitude signals are injected from the waveform generator, spanning charges from 0.2 to 0.5 p.e. For each charge, one sends 500 signals and records the number of triggered events as a function of the threshold. Given the low signal amplitudes, only the HG channels are considered.

For all channels and all measurements, the toa_vref value has been fixed to 175, and one varies only the values of trim_toa to (finely) scan over threshold values. For these measurements, the generator has been synchronized with the digitizer clock, using the trigger pin on the KCU board. Plotting the S-curves for each channel, i.e. the number of triggered events as a function of trim_toa (again toa_vref is fixed), one finds the (closest) trim_toa value corresponding to 50% trigger efficiency, whose associated threshold value is to coincide with the injected charge value (under the reasonable assumption of symmetric gaussian fluctuations of the analog signal coming from electronic noise).

Fig. [?] summarizes the results of these measurements for the HG channel n°[?]. The S-curves are reported as functions of the threshold values in p.e. [pC instead ?], stemming from the linear extrapolation of the afore-detailed conversion procedure from trim_toa to threshold (see Fig. [?]). In particular, with a threshold set as low as 1/6 p.e., one still retrieves a high trigger efficiency for signals as low as 1/5 p.e. (> 90 %). This comes from the very low noise level of the chip. Extracting it from a fit of the S-curve with a complementary error function, it is indeed found to be < 1/22 p.e. for all HG channels.

4.2. Timing reconstruction performances

4.3. Charge reconstruction performances

We should use here rescaled PMT waveform, with simple fit (3 (?or 4?) points, uniform weight single signal, timewalk corrections)

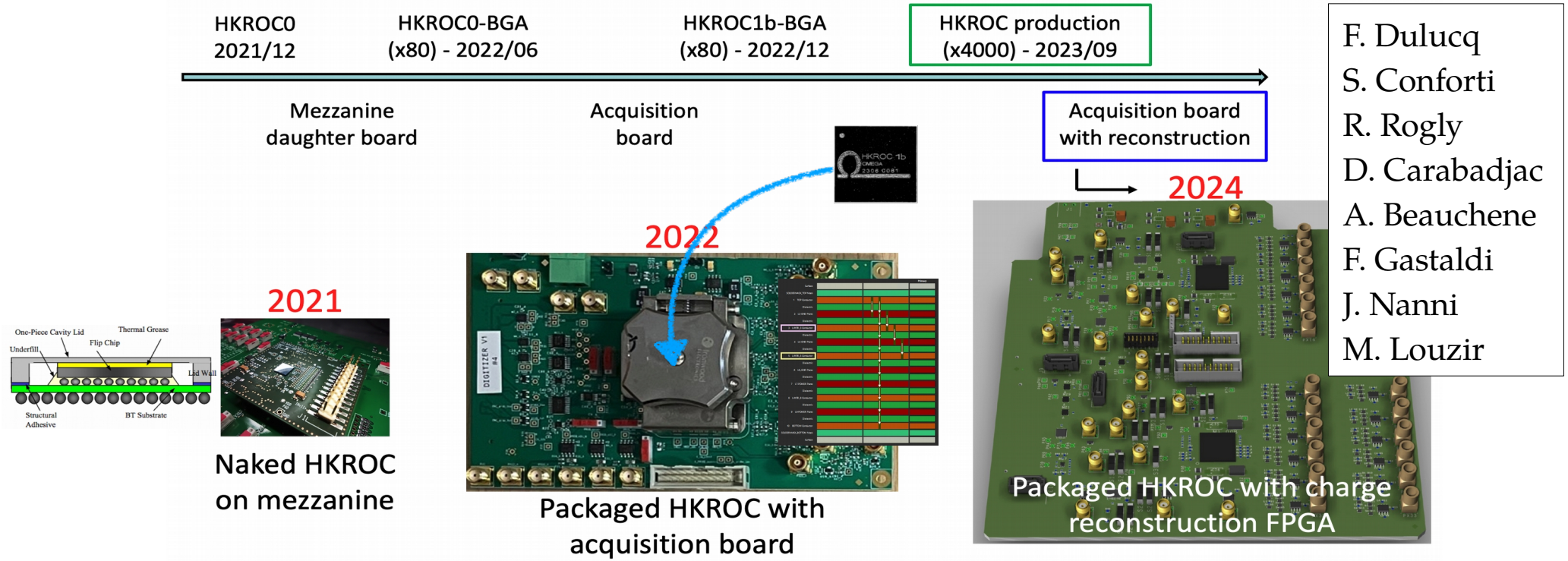
In the following, the performances for are charge reconstruction are evaluated by using the function generator Tektronix 31000, coupled to an attenuator to minimize the impact of noise in the input signal at the entrance of the digitizer. The resolution and linearity performances are first evaluated with a single injected signal channel-by-channel with fixed waveform corresponding to a PMT signal (see Fig. 13) and rescaled in amplitude to cover the whole dynamic range from 1 to 800 p.e. Figure 14 shows the reconstructed charge, its linearity and resolution. For such results, one reference waveform is used for each set of channels (2.5 p.e. for HG, 50 p.e. for MG and 300 p.e. for LG).

Figure 13: Input waveform representing a typical PMT signal.

We systematically tested the linearity and resolution for all the channels in one chip and the results are shown in Fig. 15.

Thanks to / mainly supported by D. Carabadjac & R. Rogly

HKROC in 2024



F. Dulucq
S. Conforti
R. Rogly
D. Carabadjac
A. Beauchene
F. Gastaldi
J. Nanni
M. Louzir

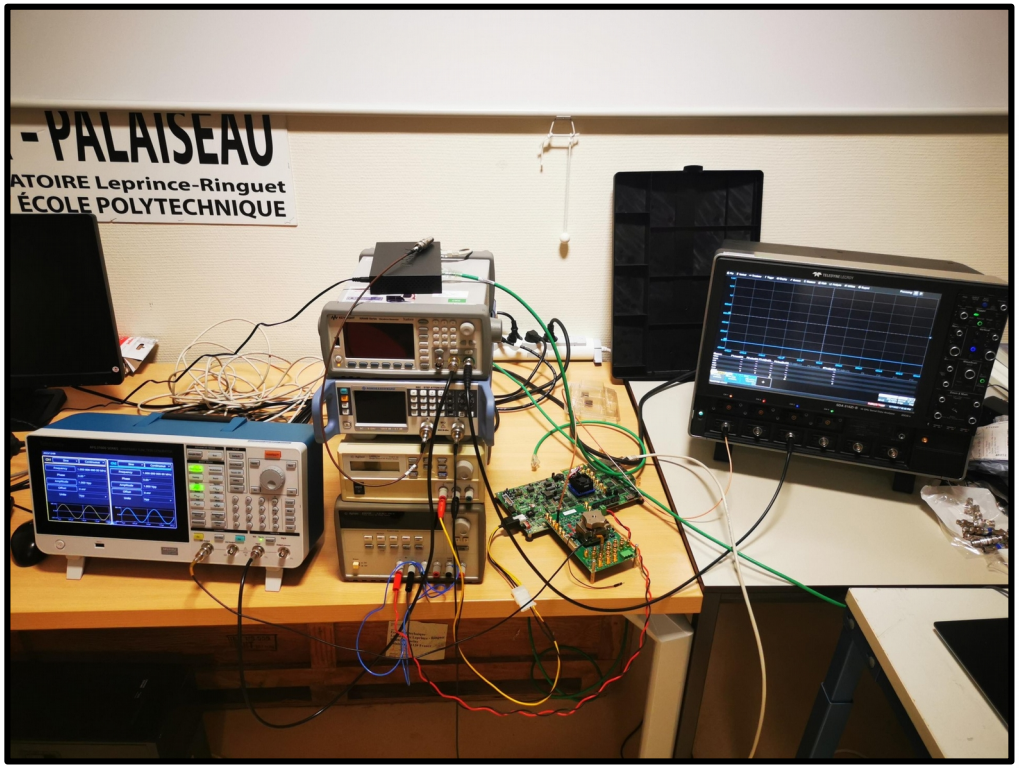
- March 2024 : receive the full production of HKROC ASICv2.

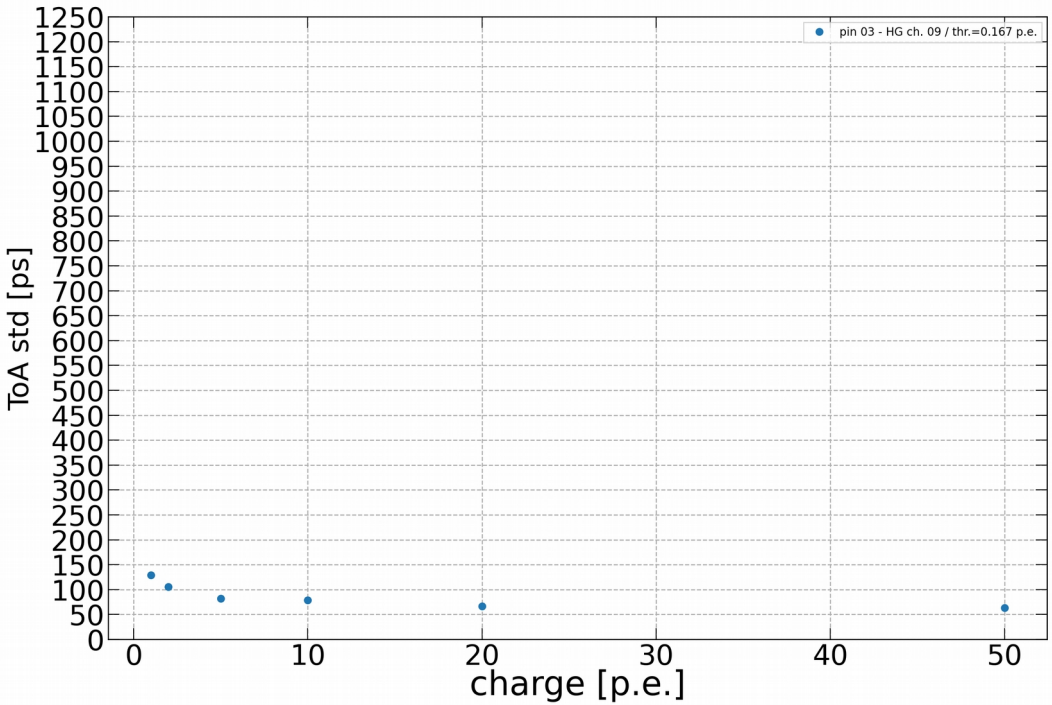
- May 2024 : receive the final digitizer board v2 (Designed by Jerome, Franck, layout by Marc
  → Why v2 : v1 works with a commercial KCU for power & FPGA ⇒ v2 is the stand-along version of v1
  → … and use this chance to extend our Xtalk removal to all channels.
- End of tests & paper submission in autumn 2024 : Finished in 2024/12

Electronics test bench… using HKROC !

- The waveform generator for test bench has very stringent constraints…

- … after many issues w/ oscilloscopes : HKROC is now used to qualify our generators :) → Better noise & time jitter than our oscillos…





Conclusions

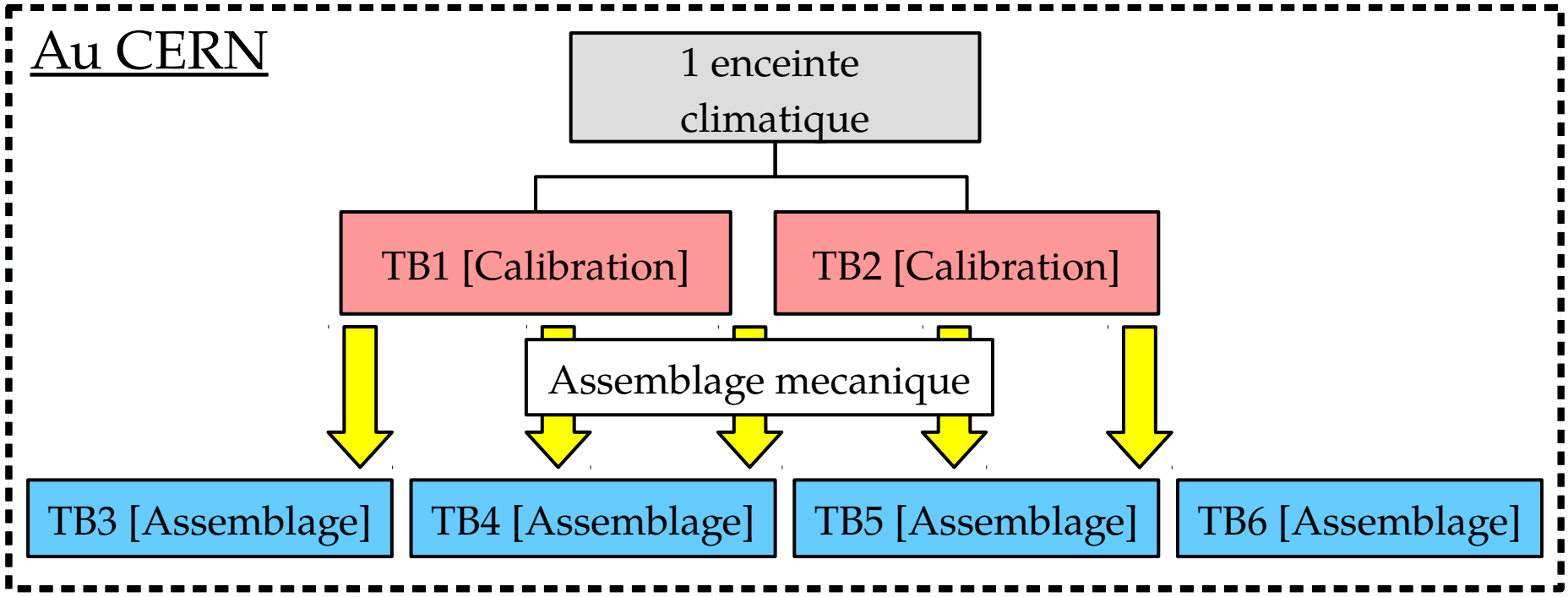
- Hyper-K will be the world-leading experiment in many aspects of neutrino physics for the coming 20 years.

- HKROC solution not selected ⇒ the group quickly reacted proposing :
  1. Lead in HK reconstruction and analysis softwares.
  2. Ensure our participation with a smaller but visible contribution :
  Software : develop & maintain the HK data-base.
  Hardware : develop the HK electronics test & calibration bench.
  3. Finalize HKROC as a versatile digitizer for coming 15 years.

- Though this is not an ideal synergy, thanks to the efforts of the whole lab (Franck, Jerome, Lorenzo, Fred, Igor & neutrino youngsters)
  → 2023 has been an excellent year and our dream is now on track :)
  → Let's push hard in 2024 to finalize the test bench & boost our software developments using exciting SK & WCTE data.
  → To our lab : Thank you to for your unwavering support after digitiser decision.

Additional slides

Electronics test bench



- Meme banc test pour calibration et assemblage

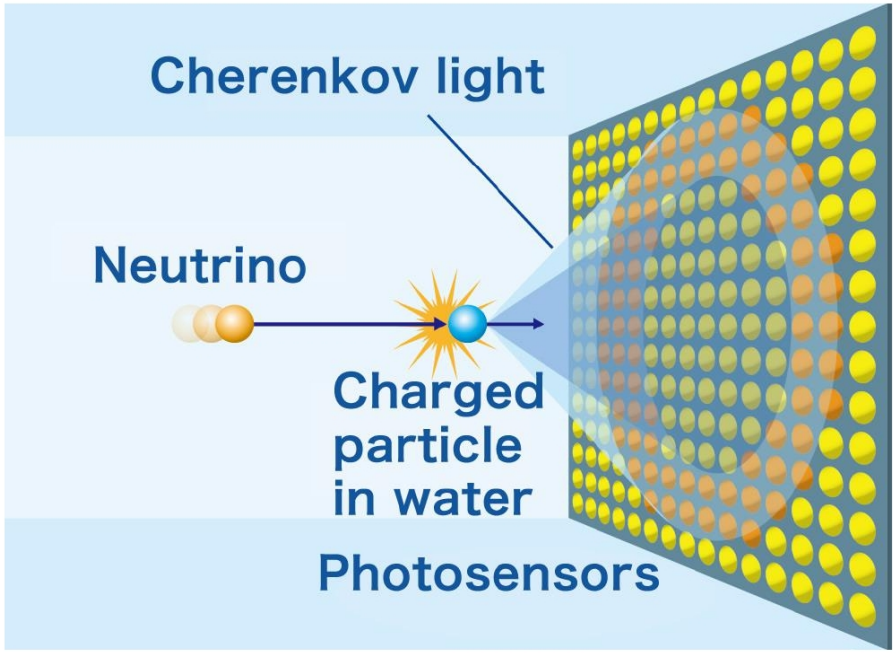
  → Sauf enceinte climatique : louee au CERN ou Antenne CEA.

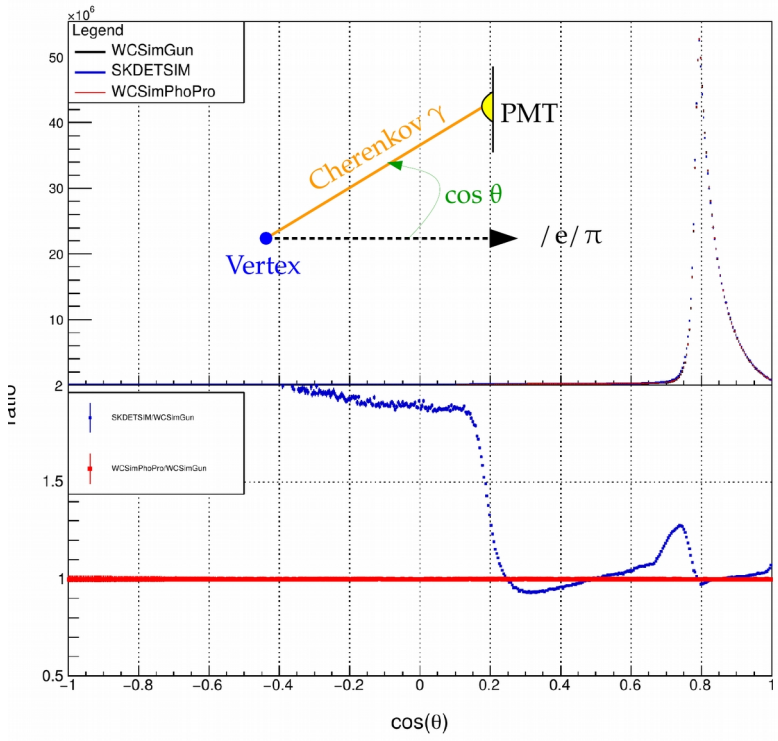
- 10 bancs tests au total :
  - 2+4 banc tests @ CERN + 2 spares.
  - 1 banc test au LLR pour le developpement/debug en phase test.
  - 1 banc test a Kamioka.

Motivations

- <u>WCTE is a cornerstone in controlling our systematic error for HK (< 1%)</u>
  → Allow calibration of the detector response at high energy with well-controlled particles (e, μ, π) of well-known energies.

- <u>An example of physics list uncertainties :</u>





Analysis strategy

- Goal : Constrain SK & HK physics with a test beam.

- Requirement : measure Cherenkov profiles @WCTE with an accuracy < 2-5 % uncertainties (order of magnitude of SK detector systematics).

- Methodology :

  1. A calibration system designed to constrain systematics < 1 %.
  → Developped by TRIUMF for IWCD. Tested on WCTE.

  2. Improved algorithms that minimize the systematic uncertainties.
  → Test the current SK algorithm on WCTE & improve it w/ data.
  → Compare it with our improved algorithm under development for HK&SK based on Graph Neural Network.
  → Demonstrate with real data the large improvements from our algorithms & extract physics for SK/HK
  → Use it in SK/T2K oscillation analysis.

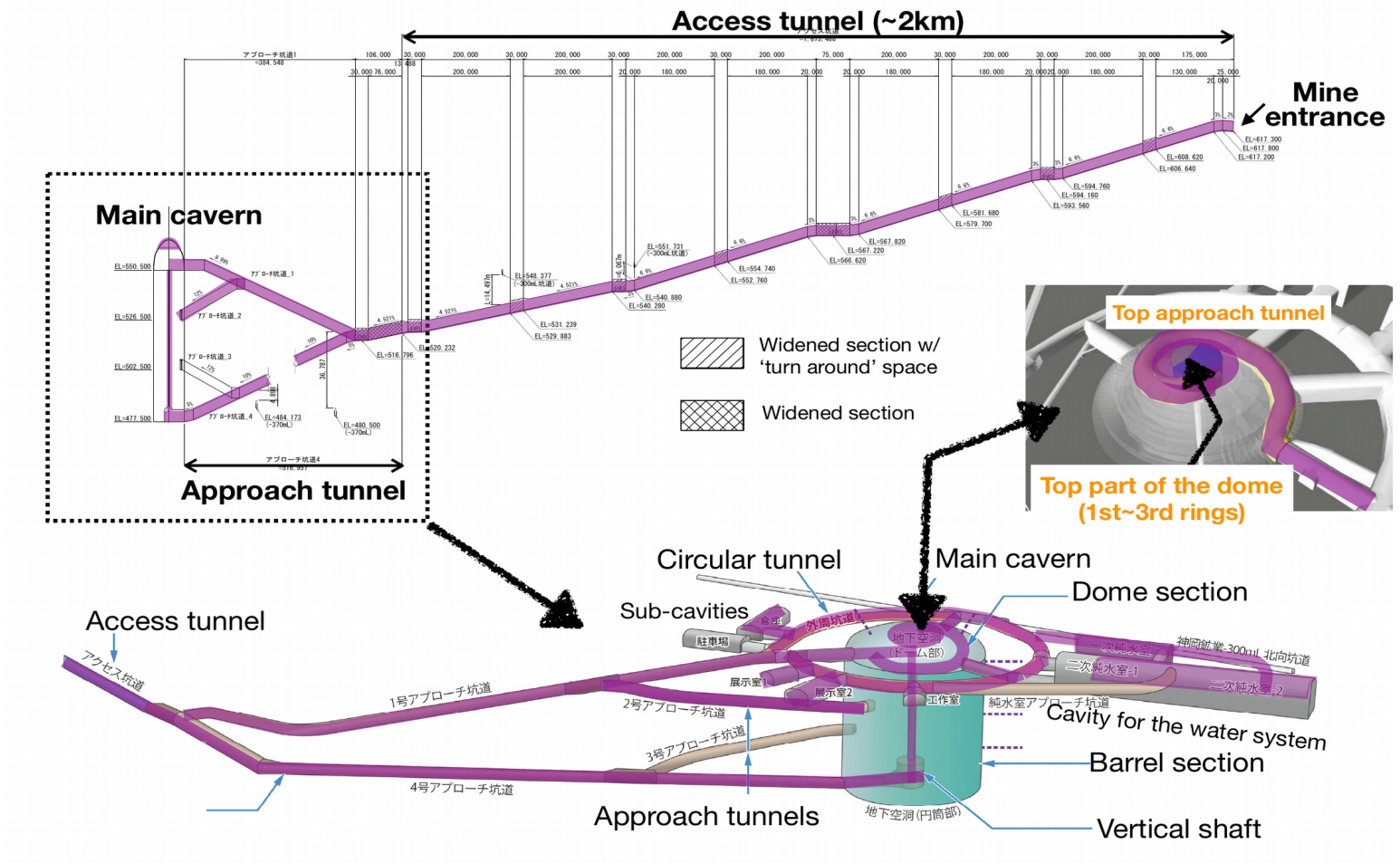
Our group focus

Excavation in 2023

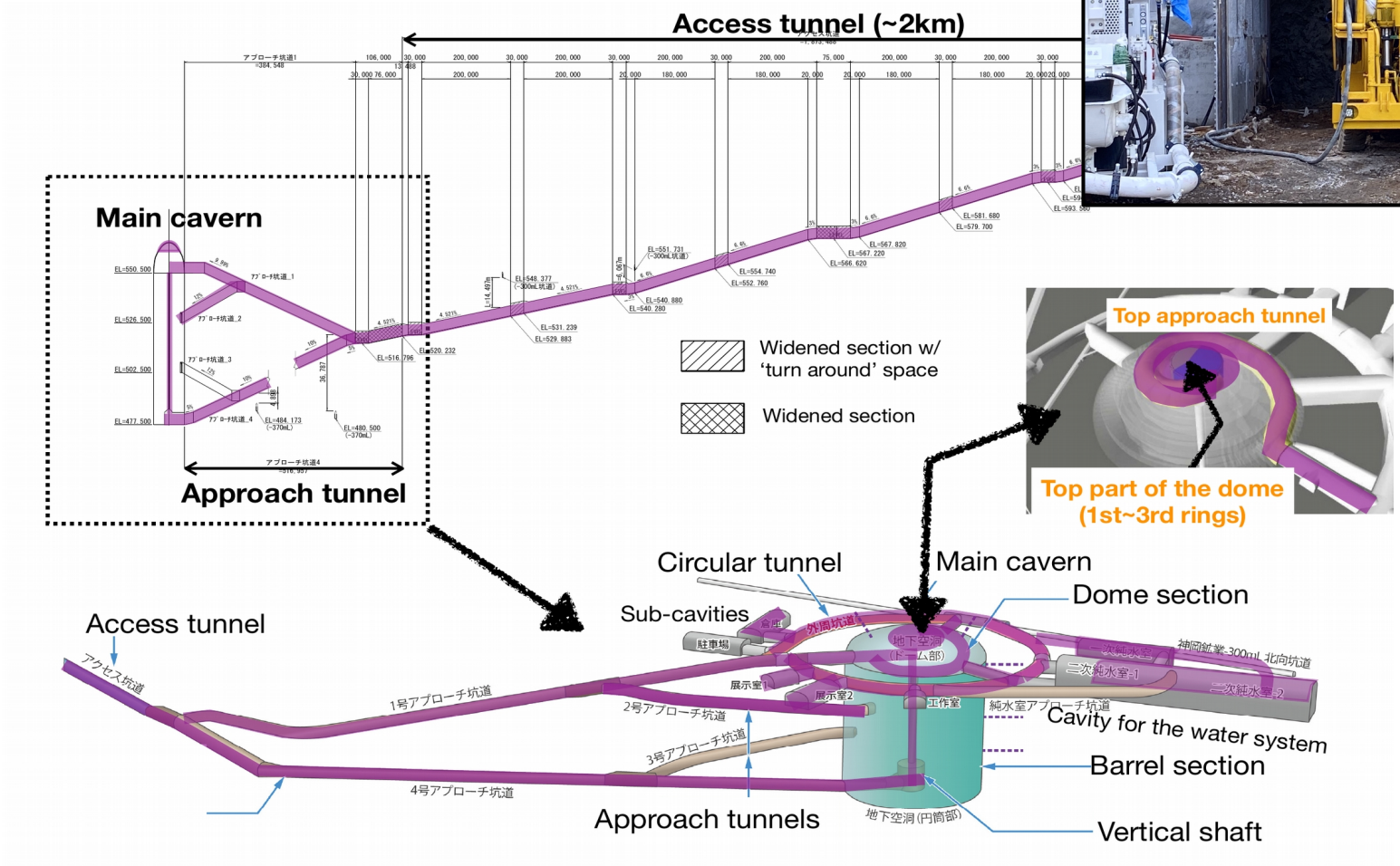
Dome section

Water filering system

Excavation : reminder of 2022



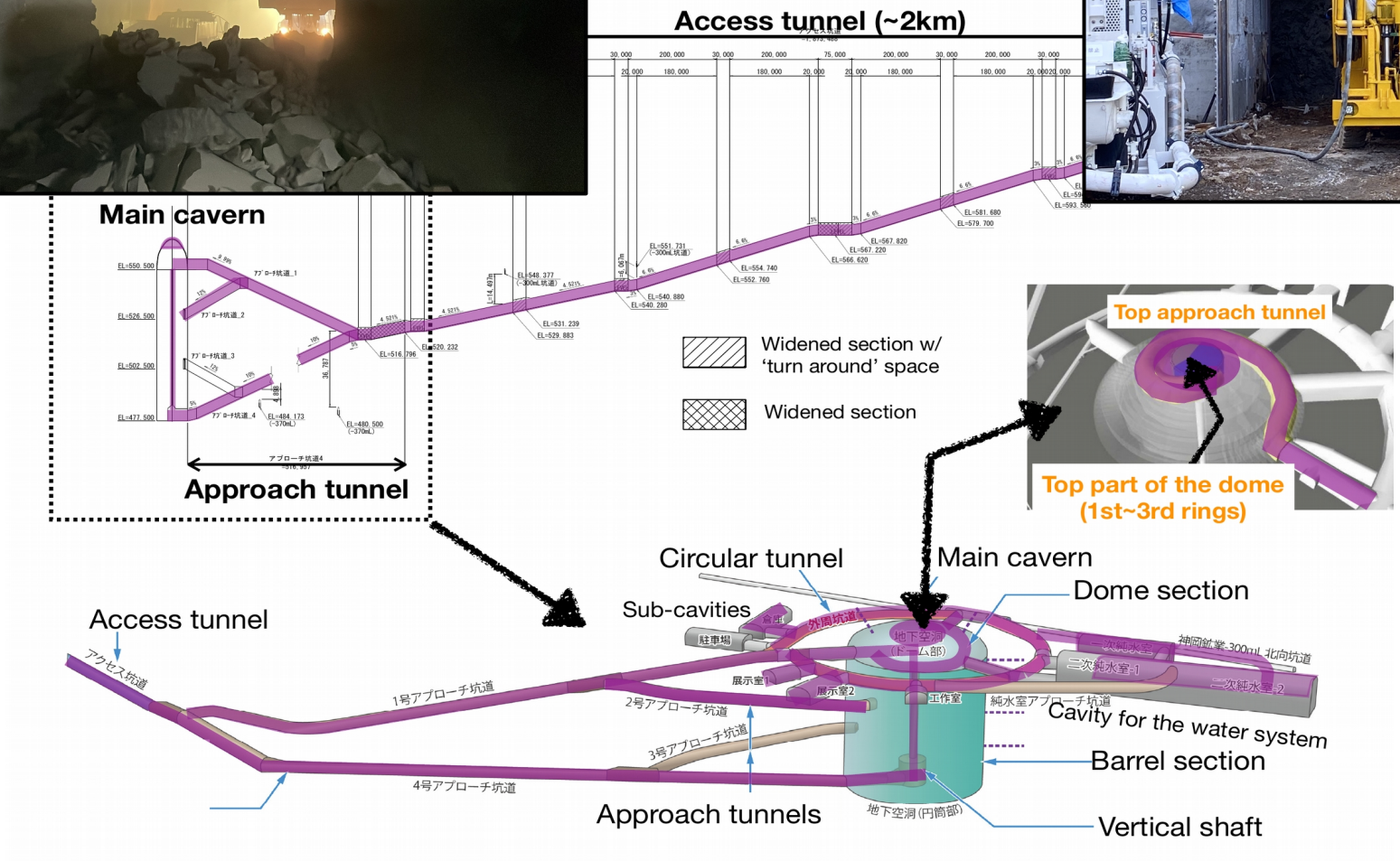
Excavation : reminder



Reaching the dome !

: reminder

Digging Mine Entrance

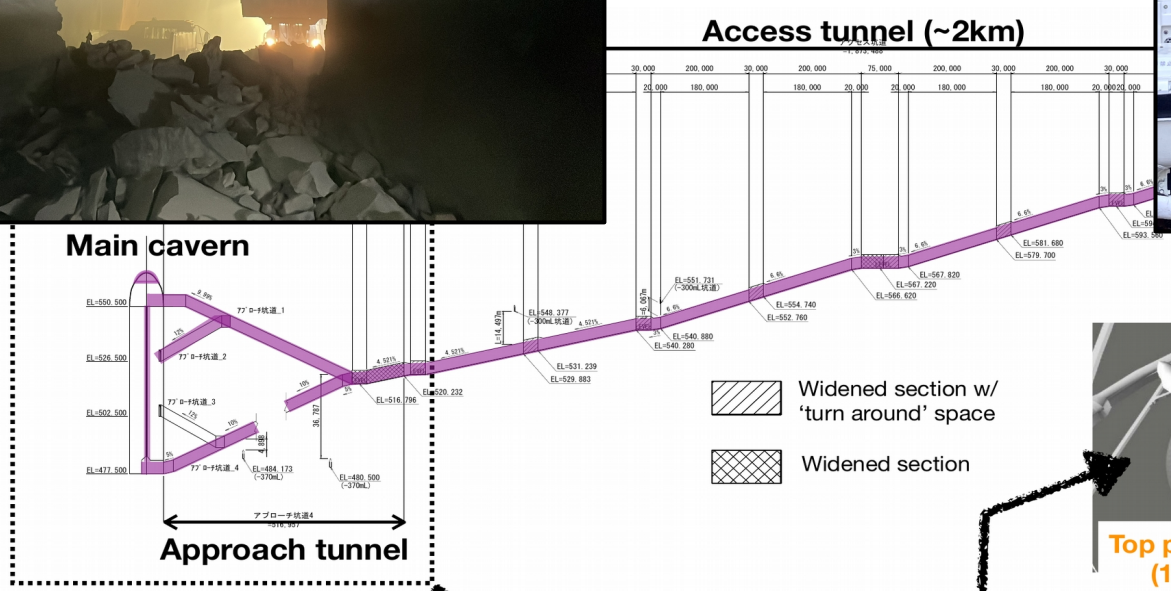


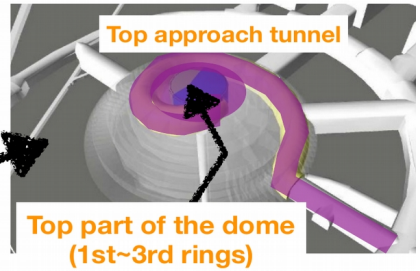
- Excavation : access tunnel (25/02/22) ✓

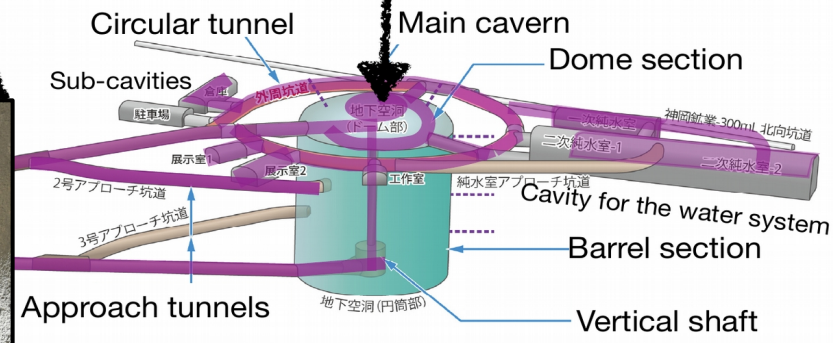
Reaching the dome !

: reminder

Digging Mine Entrance





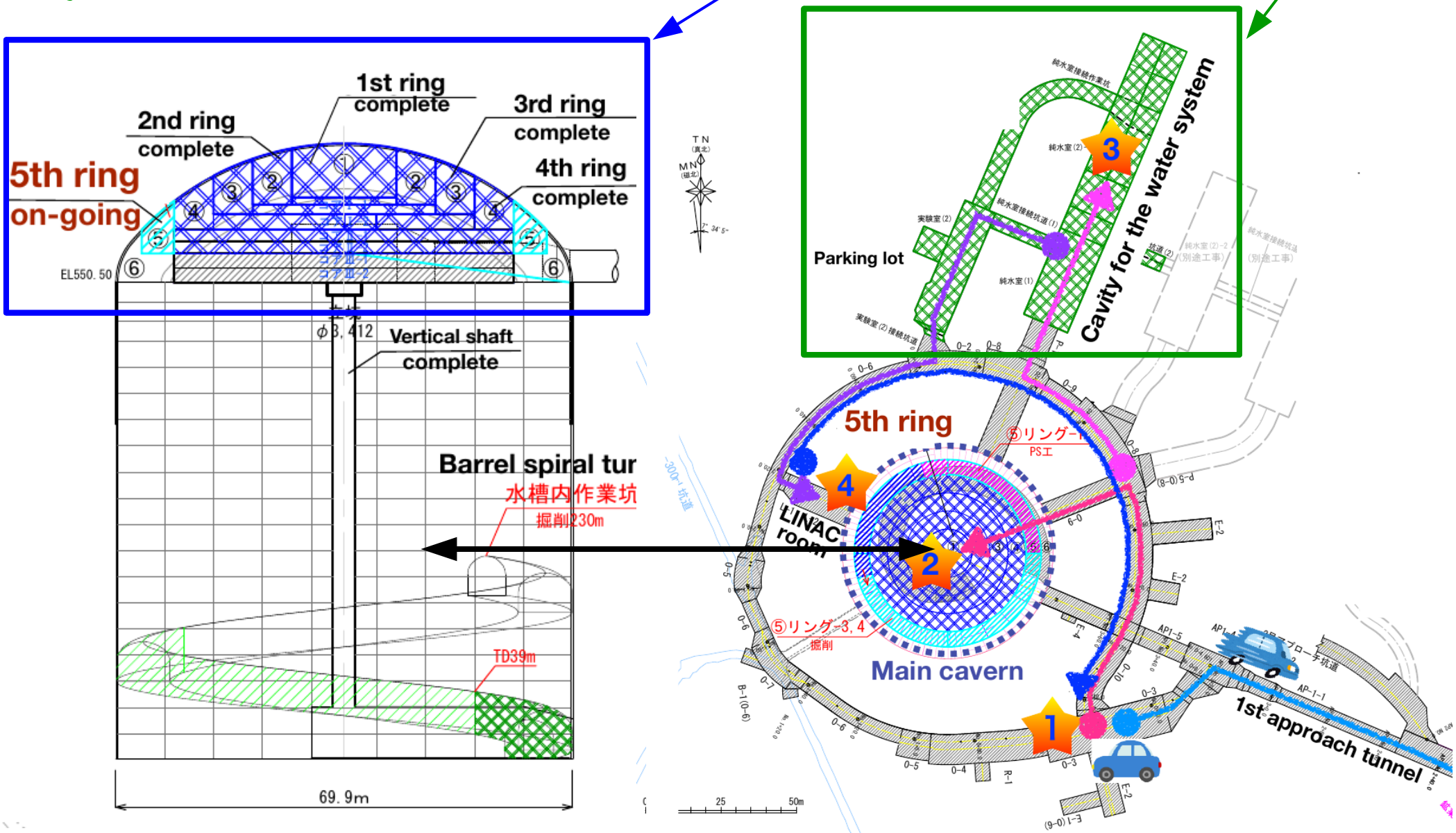


On the top of HK !

- Excavation : access tunnel (25/02/22) ✓
- Excavation : approach & circular tunnels. ✓
  → No delay in excavation.

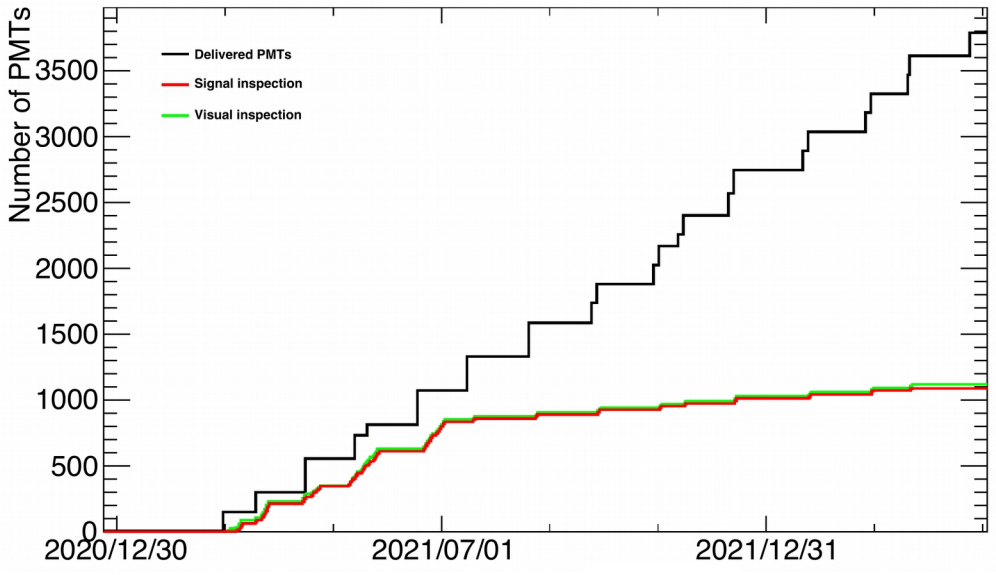
Excavation in 2023

- In 2023 : excavation focused on the **main dome** & the **water filtering system cavern**.

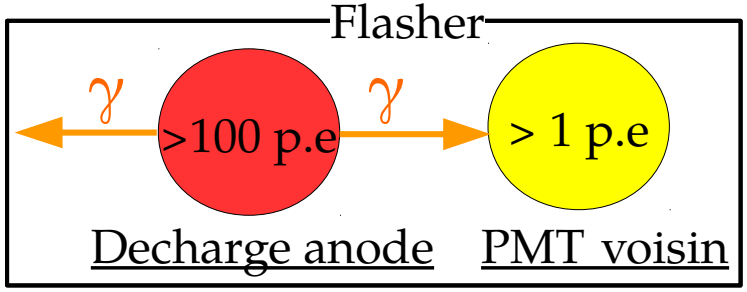


PMT production in 2023

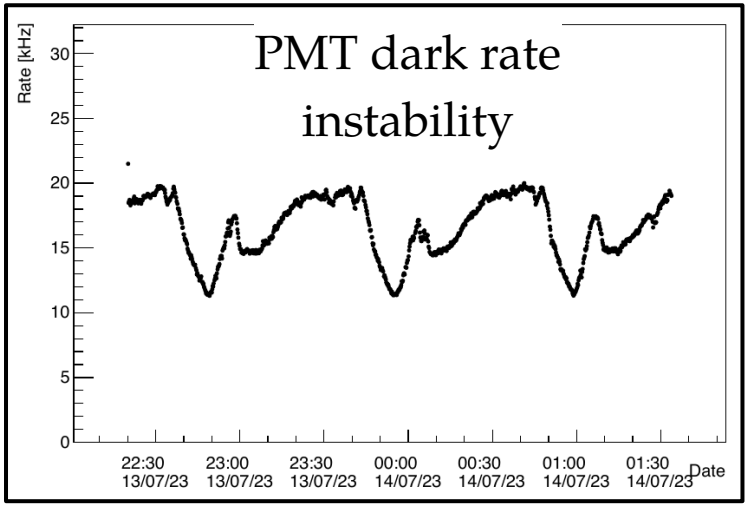
- 2020 → Mai 2022 : 3772 PMTs recus
  - Hamatsu teste basiquement les
  - PMTs avant expedition.
  - HK teste un echantillon de 10 % a Kamioka de facon + poussee.



- Mais… nous avons observes :
  - taux de flashers > au contrat.
  - taux de PMT defectueux > au contrat.
  - ≠ entre mesures a Kamioka&Hamamatsu.



	Initial failure rate	Flasher failure rate
Contract	< 1 % (in 10 yr)	< 5 % (in 1 yr)
Hamamatsu	10 %	-
HK	19 %	4 %



PMT production in 2023

- 2 problemes majeurs :
  - Les mesures a Hamamatsu sont - poussees qu'a HK (tres courte duree, aucune mesure flashers…)
    → Ne peut exclure les PMTs defectueux correspondant.
  - Nombre de bulles de verres limite avant 2027
    → Maintenir ce taux ⇒ < 20,500 PMTs dans HK (valeur contrat).

- Production interrompue en Mai 2022, avec 2 objectifs :
  - Developper un contrôle qualite plus poussee a Hamamatsu & Kamioka + harmoniser les ≠ de protocole entre les sites.
  - Developper de nouveaux PMTs avec un taux d'instabilite/flasher plus faible.

- La livraison des PMTs a Kamioka devait recommencer au plus tard en Avril 2023 pour n'occasionner aucun retard de HK.

PMT production in 2023

1. Mesures + longues (6 jours) a Kamioka et Hamamatsu.
2. Mesure a + haut voltage 200V ⇒ ↑ detection de PMTs defectueux en 6j.
3. Mise en place d'un critere flasher. Mesure uniquement a Kamioka.
4. Echantillonage ??
4. Mesure systematique de TOUS les PMTs a Hamamatsu ET Kamioka.

- <u>Pour cela :</u> creation de 2 salles x 100 PMTs + 1 salle x 16 PMT

→ Excellent accord des mesures a Hamamatsu et Kamioka. Le taux d'acceptance des PMTs passe seulement a 71 %.

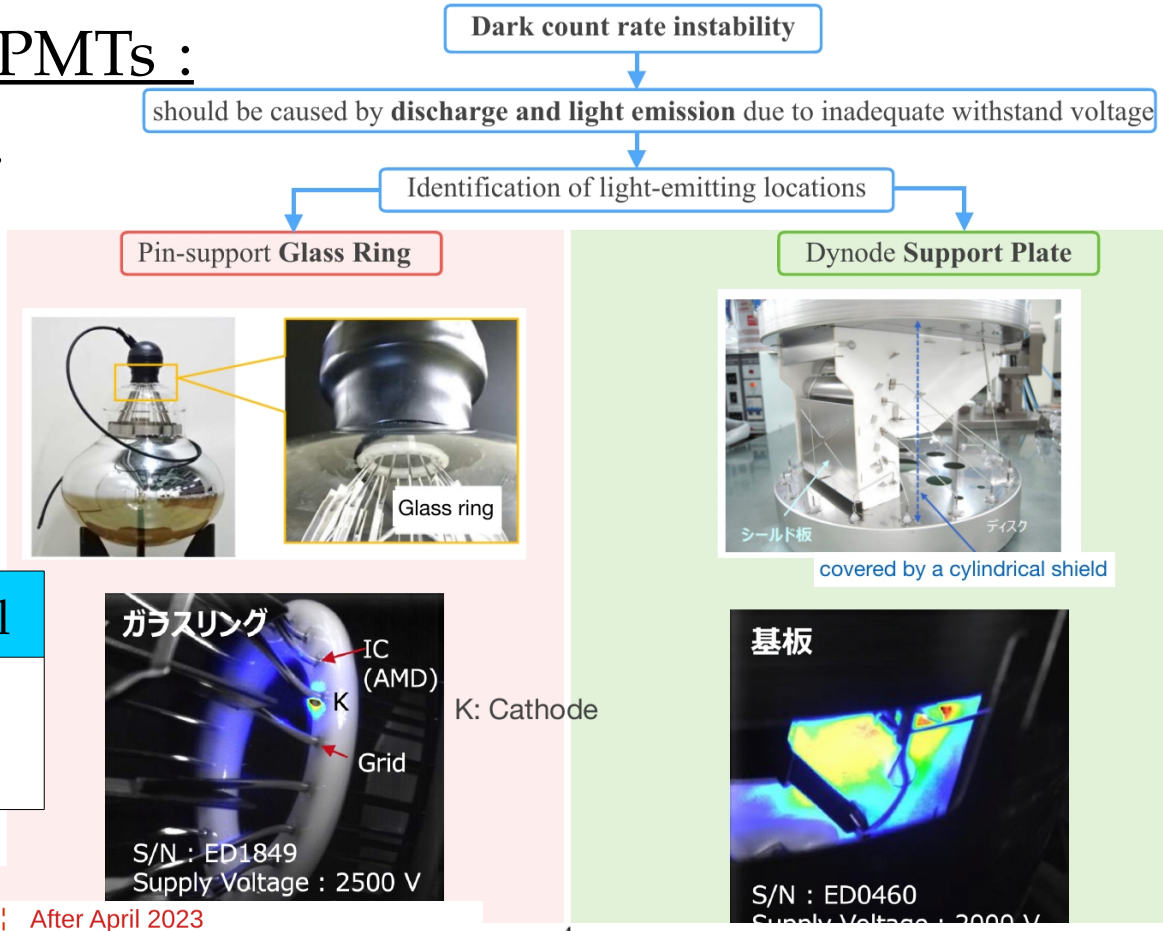
PMT production in 2023

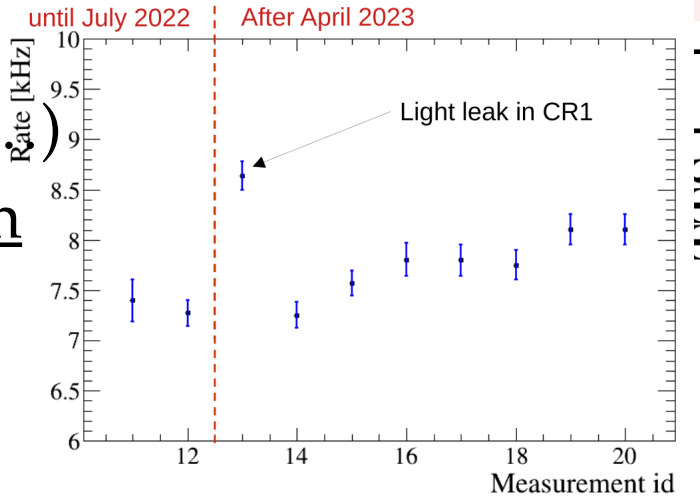
- Developpement de nouveaux PMTs :
  → 10 modifications apportees.
  ↓ decharges dans les supports en contact avec anodes.

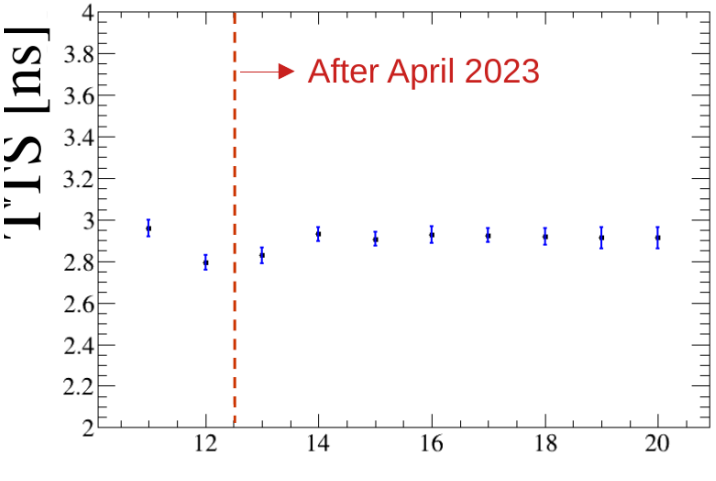
- 1er tests complets : 01/2023

	Old model	New model
Selection rate	71 %	95 %

→ Excellente ↓ des flashers et instabilite + pas de ≠ autres charac. (DR, TTS..)
→ Reprise de la livraison 04/2023 : aucun retard pour construction HK.



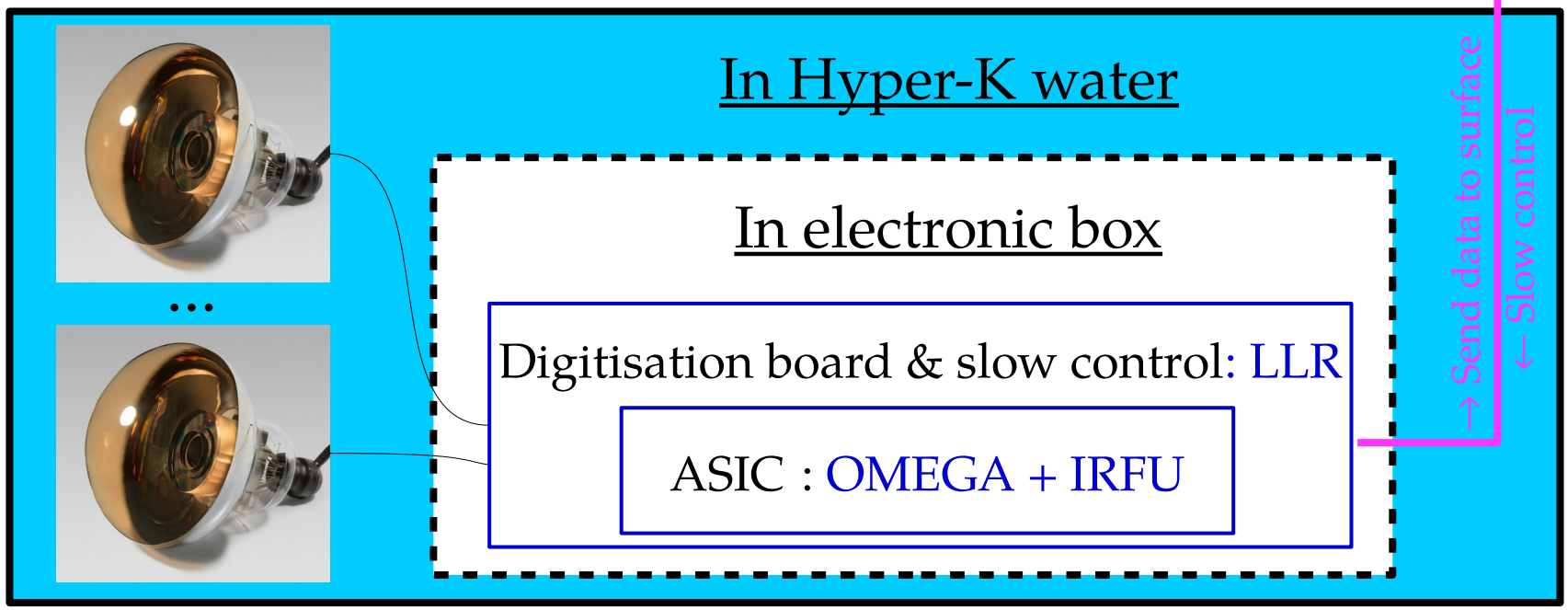




HK far detector electronics

- The whole HK physic signal will rely on 20k PMTs of 50 cm.

- PMT signal to be readout by electronics under water :
  → 24 channels/PMTs read in one stainless steel box under water.



LLR proposal : develop the whole PMT Q & T digitization system
→ Absolutely central role in HK ! … but not accepted

The IN2P3 teams computing proposal

- Make CC-IN2P3 a **Tier-1** site to host all HK data & HK data-base

- Pros :

  1. Having all data in France offers an **unparalleled visibility**.
  2. Full synergy with our goal to **lead the analyses in both low and high energy sectors.**
  3. No other country has announced the capacity of a full Tier 1 so far.
  4. CC-IN2P3 is already Tier-1 for T2K INGRID & ND280 data & Host the Hyper-K data base since 2022

  → Smooth transition & preparation until 2027.