RD4HK & Hyper-Kamiokande experiment

Benjamin Quilain (LLR - CNRS/Ecole polytechnique)

on behalf of HK-France

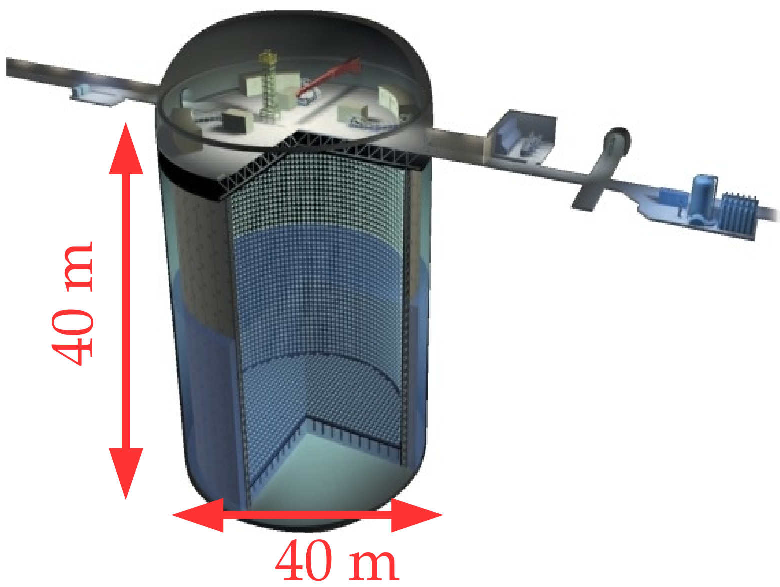
Journees R&T, 2022/10/17

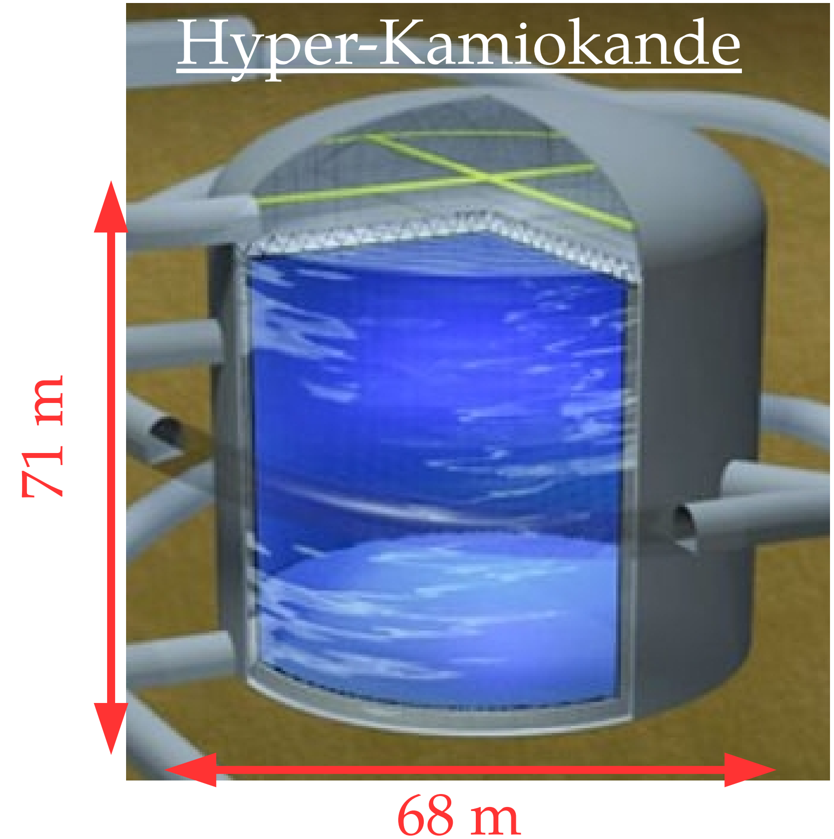
I. Introduction to Hyper-K

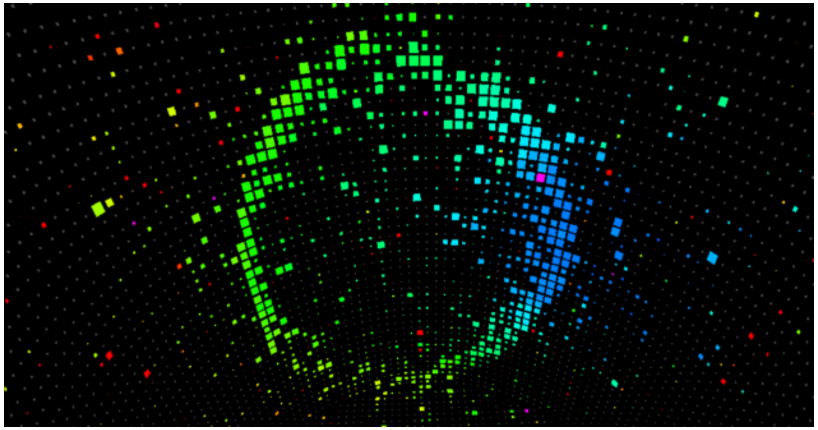
What is Hyper-K ?

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

<u>Super-Kamiokande</u>



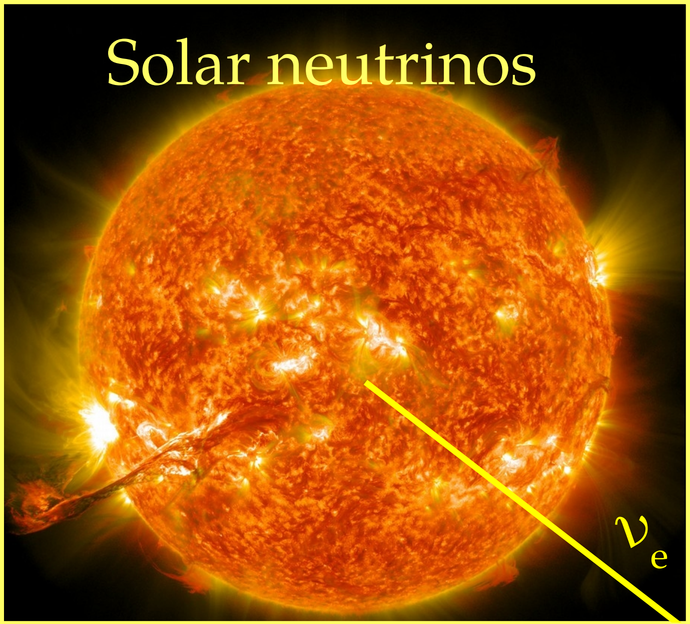




	Super-K	Hyper-K (1st tank)
Site	Mozumi	Tochibora
Number of ID PMTs	**11,129**	**>20,000**
Photo-coverage	40%	20 % (**×2 sensitivity**)
Mass / Fiducial Mass	50 kton / **22.5 kton**	260 kton / **187 kton**

Physics case

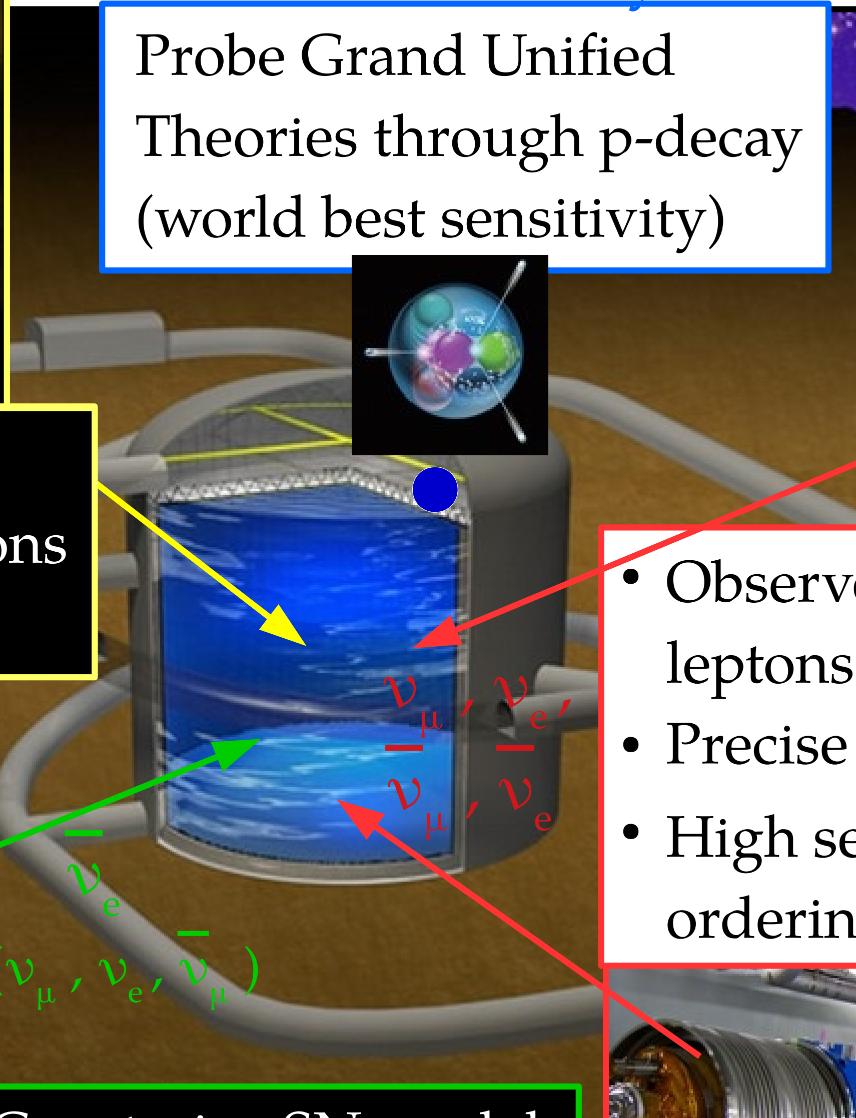
Solar neutrinos



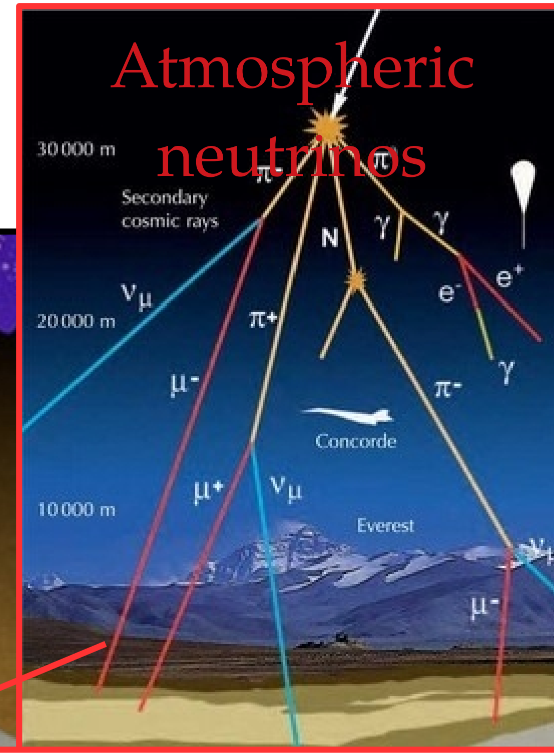
- MSW effect in the Sun
- Non-standard interactions in the Sun.

Proton decay

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

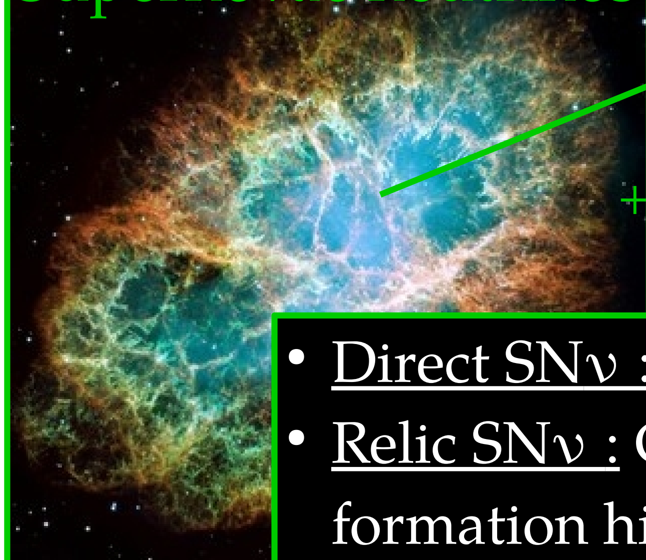


Atmospheric neutrinos

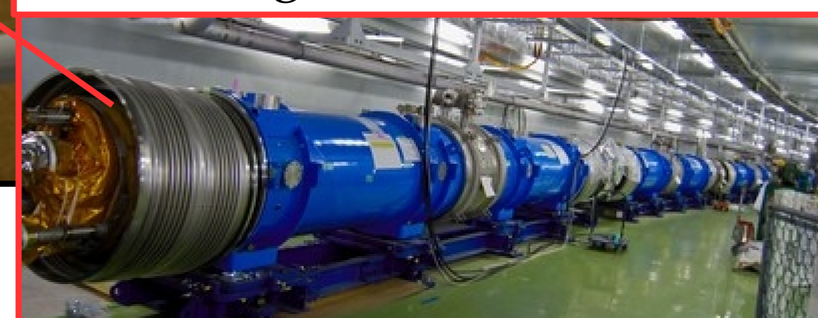


- Observe CP violation for leptons at 5σ
- Precise measurement of δ_{CP} .
- High sensitivity to ν mass ordering.

Supernovae neutrinos



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



JPARC accelerator neutrinos

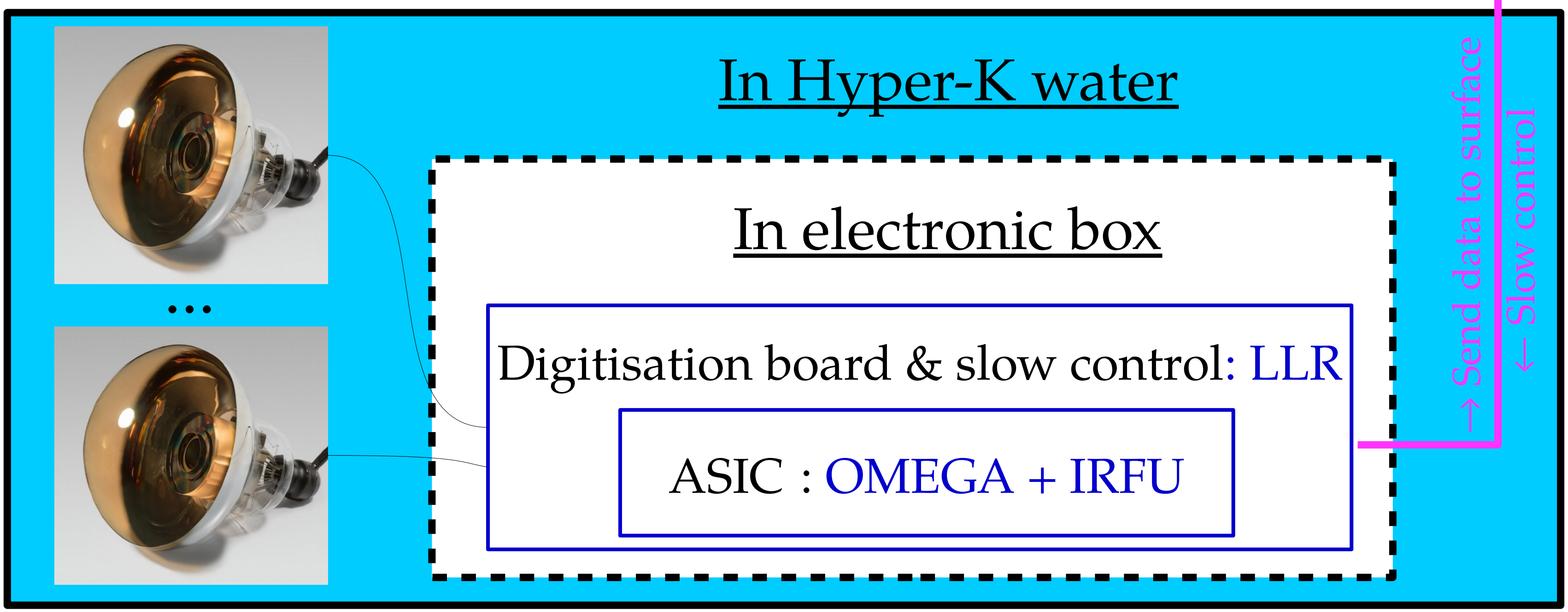
II. Scope of RD4HK & results

HK far detector electronics

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

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

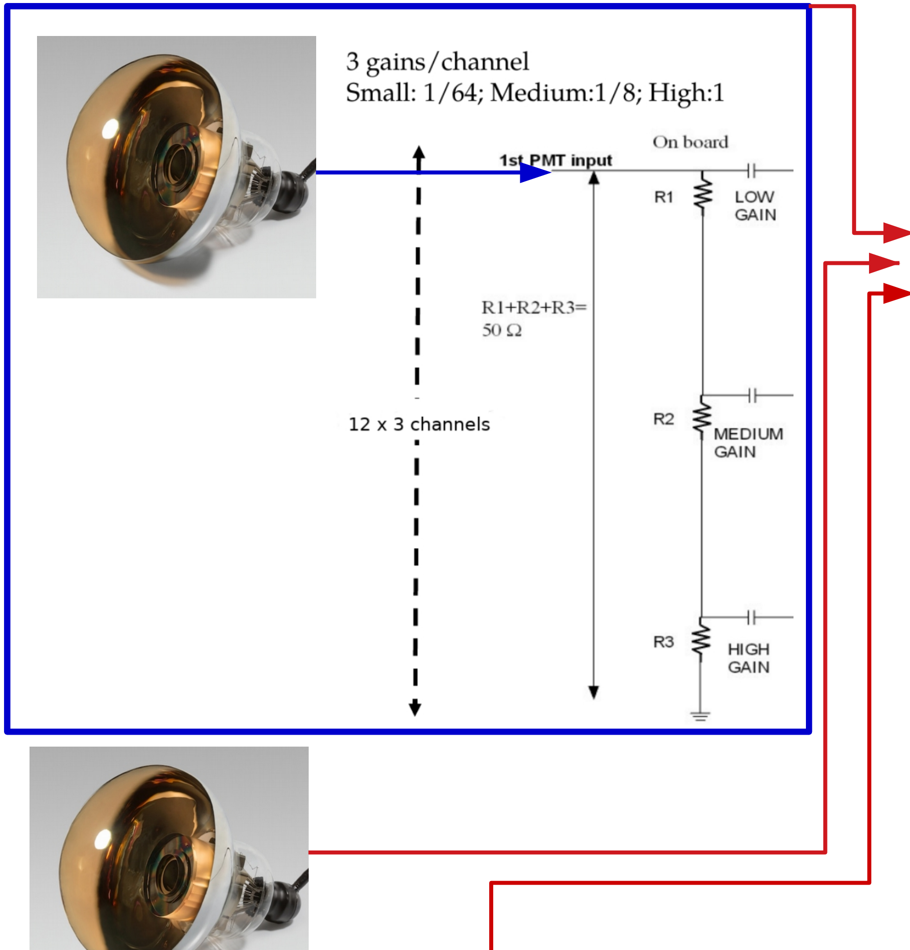
Clock generation & distribution
LPNHE + IRFU

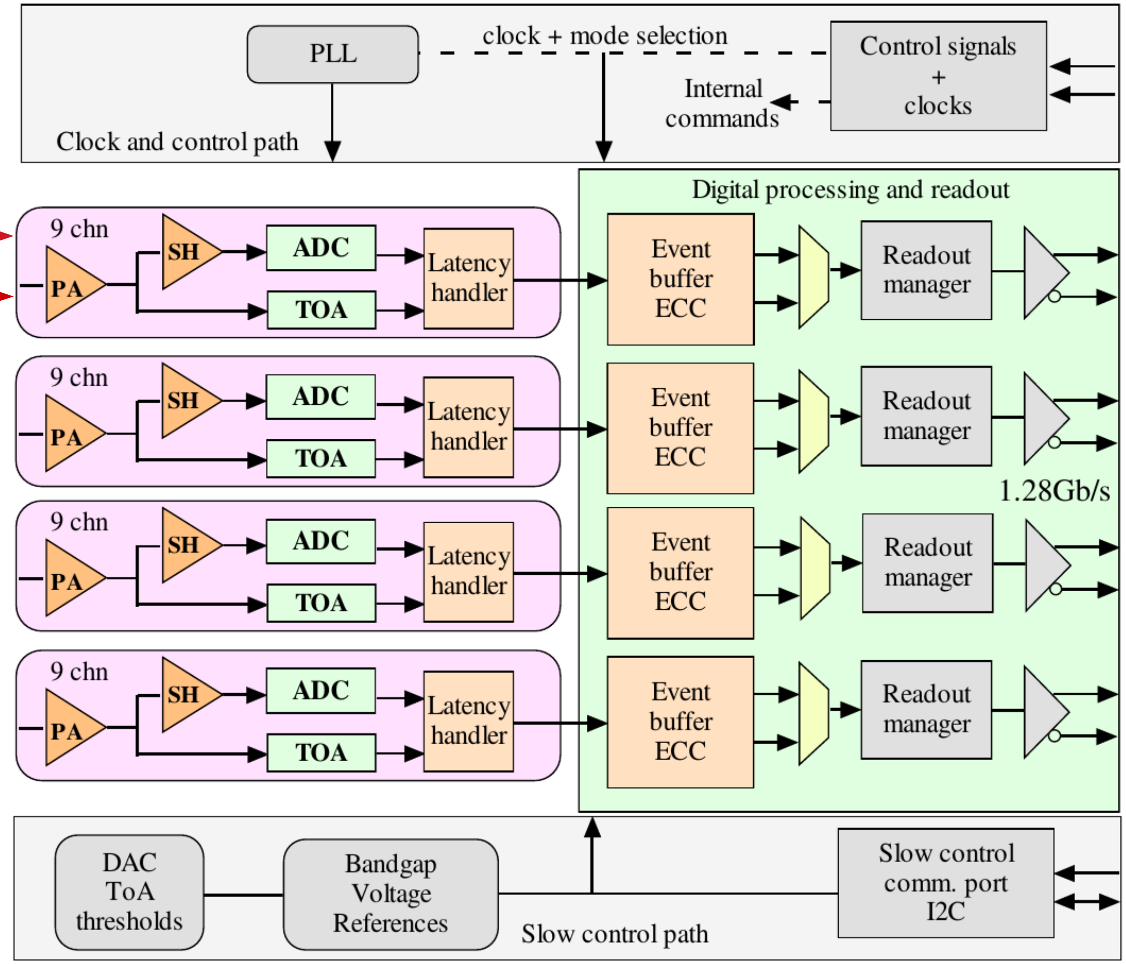


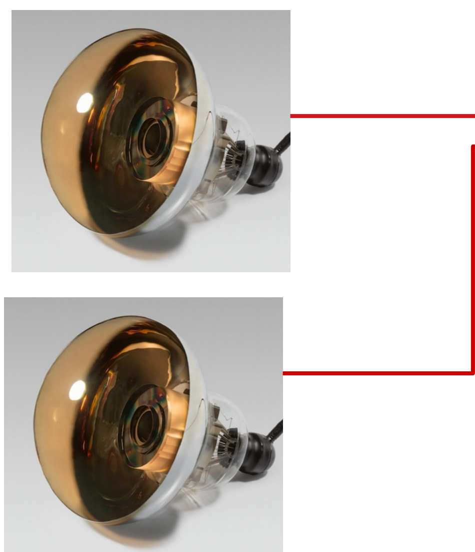
<u>France's proposal :</u> develop the whole PMT read-out digitization & synchonization systems → Absolutely central role in HK !

The HKROC digitizer

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



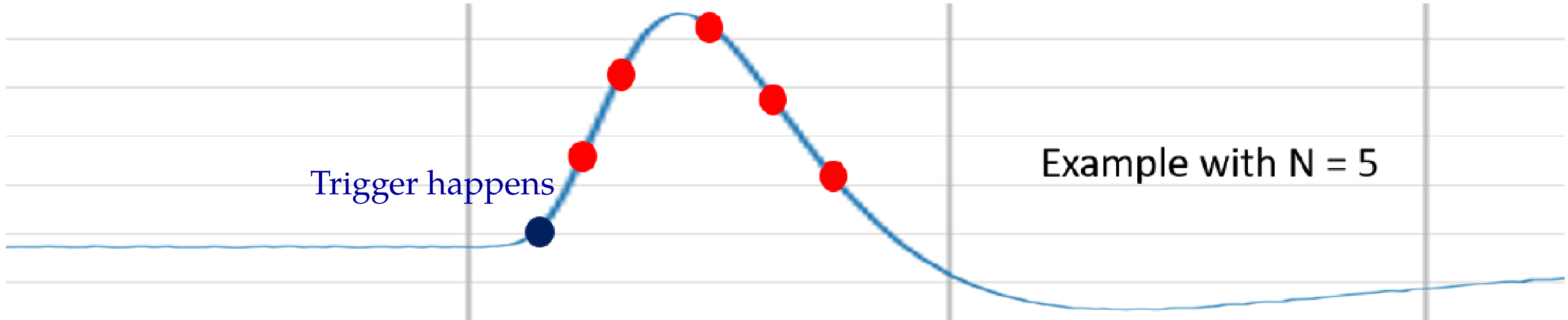




- TSMC CMOS 130nm etching.
- Dynamic range from 0 – 2500 pC : 3 gains / channel.
- 4 readout / ASIC @1.28 Gb/s : 1 readout ↔ 3 PMTs.
- <u>If 1 PMT trigger :</u> read all 3 PMTs of 1 readout.

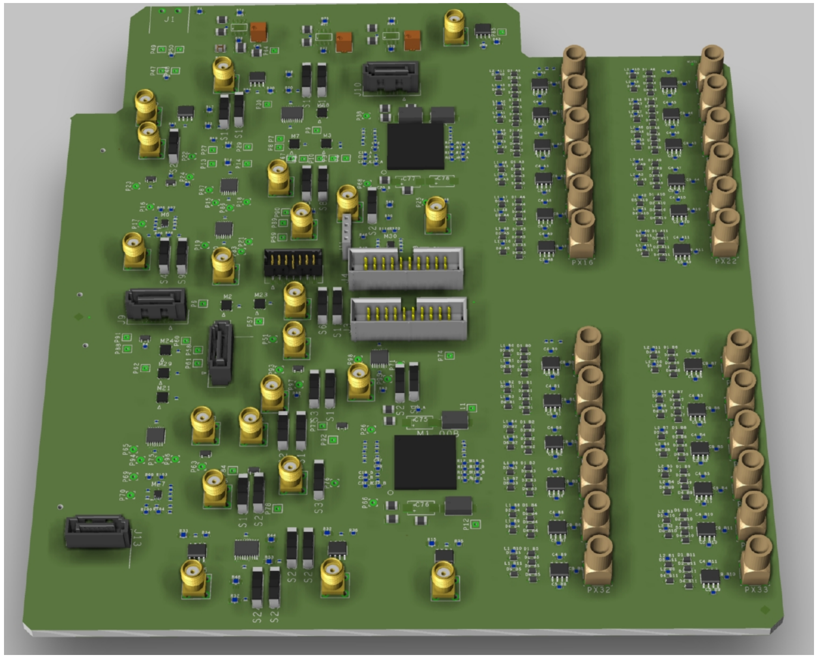
Overview of the HKROC digitizer

- HKROC is a waveform-like digitiser @40 MHz→ 1 point every 25 ns.
  → Charge digitized by N = 1 → 7 points (chosen by slow-control).

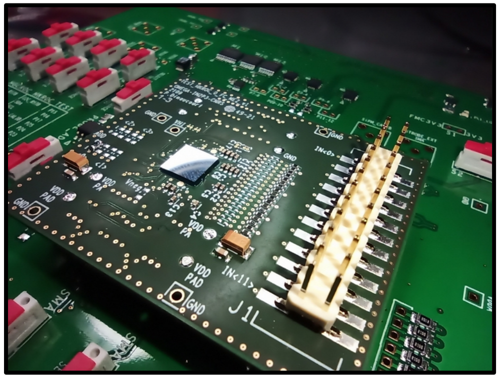


- HKROC digitizer : 24 PMT channels readout by 2 HKROC ASIC.

HKROC prototype v1



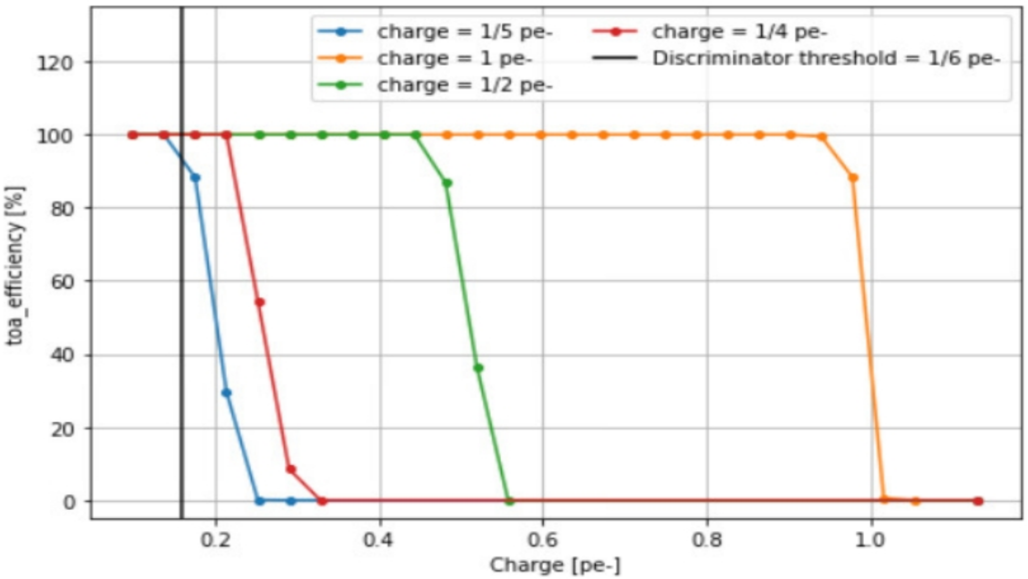
- Started R&D in summer 2020 : Make a chip in 2 years → Challenging schedule :
  1. Receive chip in Dec. 2021.
  2. Provide tested chip by end of June 2022.

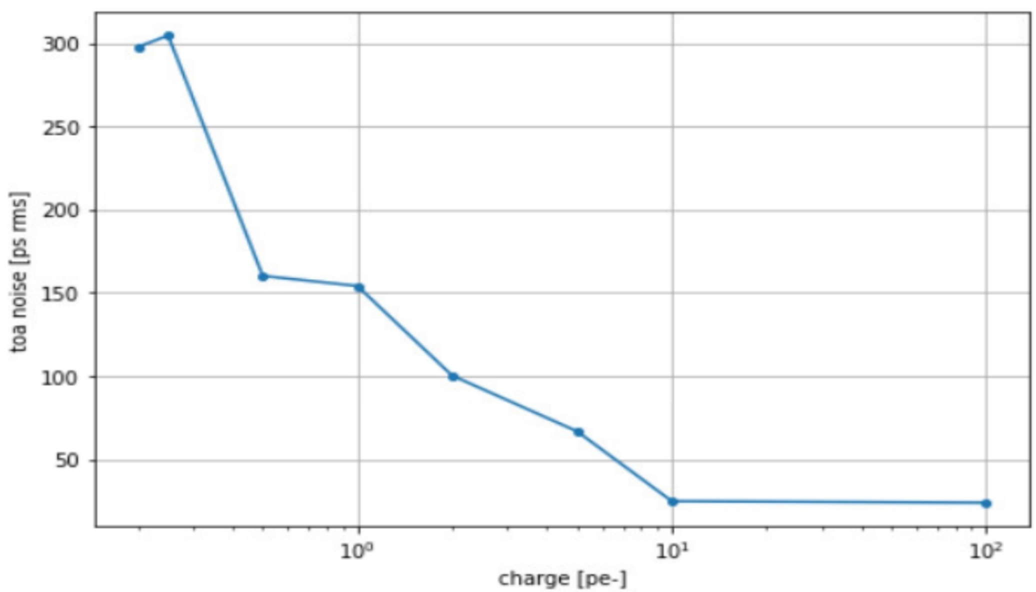


- No delay in 2 years :
  → Chip came back in Jan. 2022 (pandemic).
  → Worked hard to finalize tests for June.

HKROC digitizer - trigger & timing results

- HKROC-digitizer v1 received & completely tested in few months.





- <u>Set threshold at 1/6 p.e.</u>

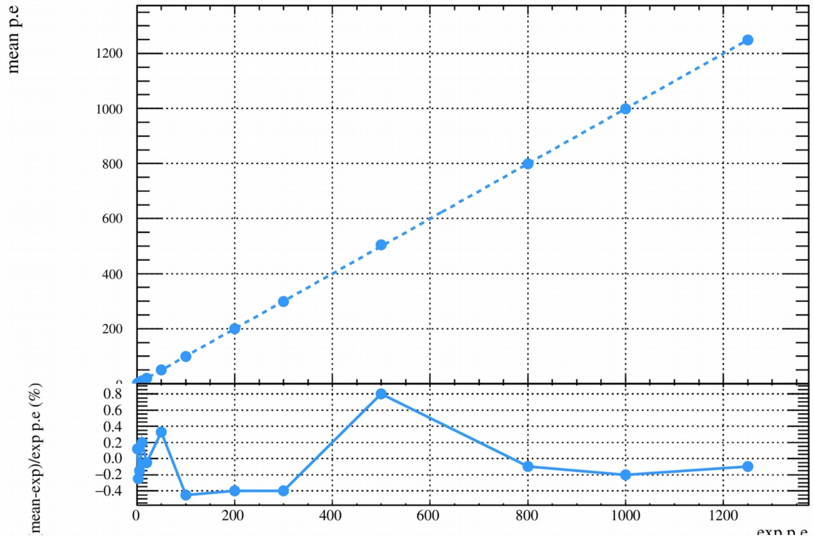
- <u>Hit efficiency :</u>
  90 % for 1/5 p.e events
  ~100 % if ≥ 1/4 p.e

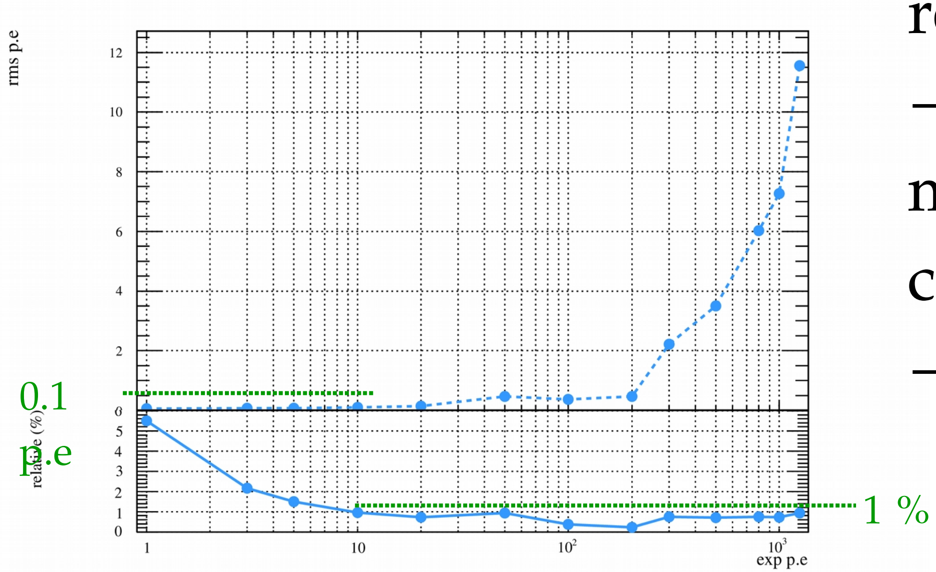
- <u>Very low noise :</u> < 1 Hz.

- <u>TDC resolution :</u>
  150 ps @1 p.e [300 ps required]
  ≤ 30 ps @ 10 p.e [200 ps required]

→ Excellent agreement with HK requirements.

HKROC digitizer - Charge results





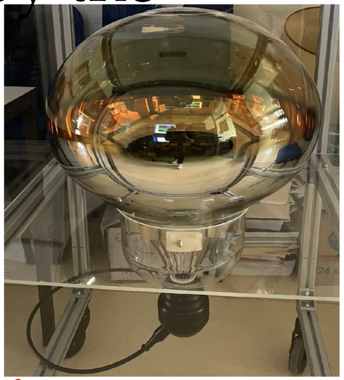
- Charge linearity < ±1% [1 to 1250 p.e.]

- Charge resolution :
  < 0.1 p.e @≤ 10 p.e, < 1 % otherwise.

→ All characteristics fulfill HK requirements & confirmed w/ PMT.

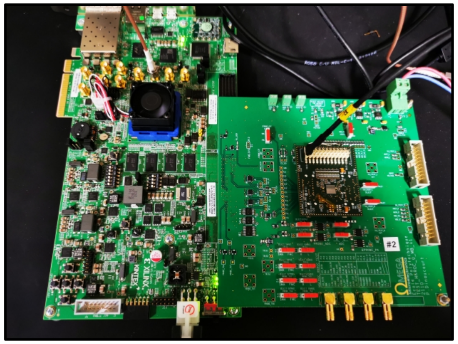
→ Large improvements w/ HKROC much beyond requirements by the collaboration

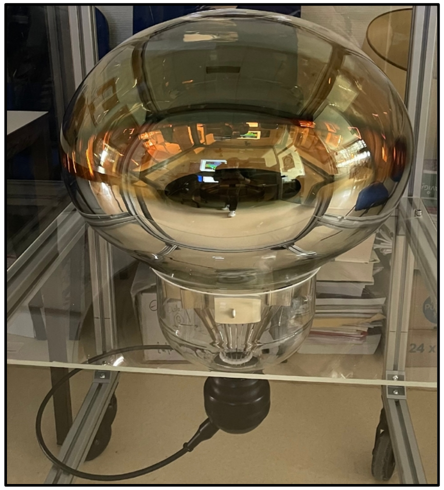
→ Ex: dead-time ↓ **from 1 µs → 30 ns**.



- HKROC project has been **on-time & is a huge technical achievement** that has only been possible thanks to the great collaboration between the IRFU, OMEGA & LLR + financial support from X & IN2P3.

Summary of the digitizer measurements



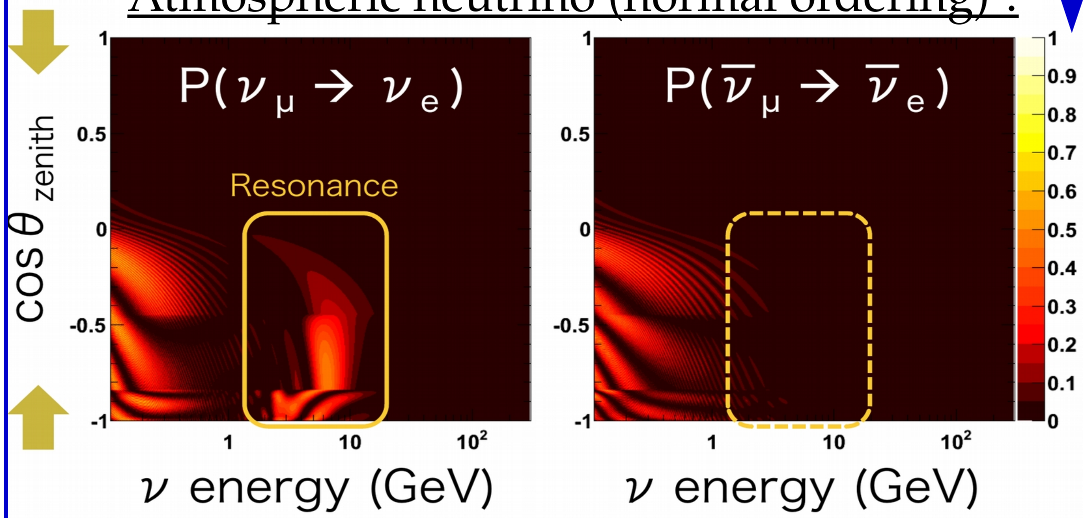


Item measured	Performances
Trigger efficiency at 1/6 p.e.	$> 90\%$ for 1/5 p.e signals 100% for $\geq 1/4$ p.e signals
Trigger noise at 1/6 p.e.	< 1 Hz (No trigger observed in 10 s)
TDC resolution	150 ps at 1 p.e, 70 ps at 5 p.e, 25 ps > 10 p.e Validated with PMT
Charge linearity	$< 0.5\%$ in high & medium gain channels $< 1\%$ in low gain channel up to 1250 p.e Validated with PMT
Charge resolution	< 0.1 p.e for signals up to 10 p.e $< 1\%$ for signal $40 - 300$ p.e and > 750 p.e $< 2.4\%$ for all other cases. Will be improved by reducing the unnecessary voltage division. Validated with PMT
Dead-time & pile-up	≤ 30 ns for two signals of same amplitude ≤ 30 ns for a prompt ≤ 5 p.e and secondary of 1 p.e < 1 μs for a prompt signal ≤ 850 p.e and secondary 1 p.e
Maximal hit-rate w/ 100% eff.	415 kHz in normal mode 950 kHz in SN-mode Potential extension beyond to be studied.
Cross-talk	Hit probability in neighbouring channel of a 1250 p.e signal is $< 0.1\%$ *Note that cross-talk found at ASIC level, but cut* *by FPGA. Identified and will be removed in ASIC v2.*
Maximal hit-rate w/ 100% eff.	415 kHz in normal mode 950 kHz in SN-mode Potential extension beyond to be studied.
Temperature dependency[2]	time resolution $\Delta T = 1$ ps/°C gain variation $\Delta Q = 0.05\%$/°C (no correction)
Resistance to HV	Unprotected ASIC received 10^8 5V injection without any impact on performances

HKROC digitizer - Impact on physics

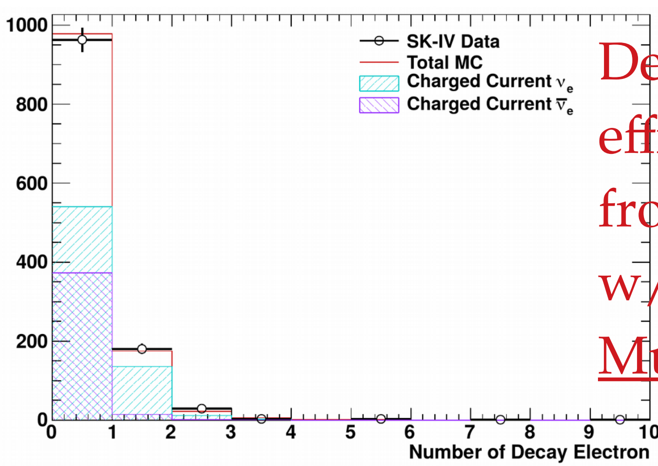
- Large impact on physics : ν mass ordering & Supernova ν.

Atmospheric neutrino (normal ordering) :

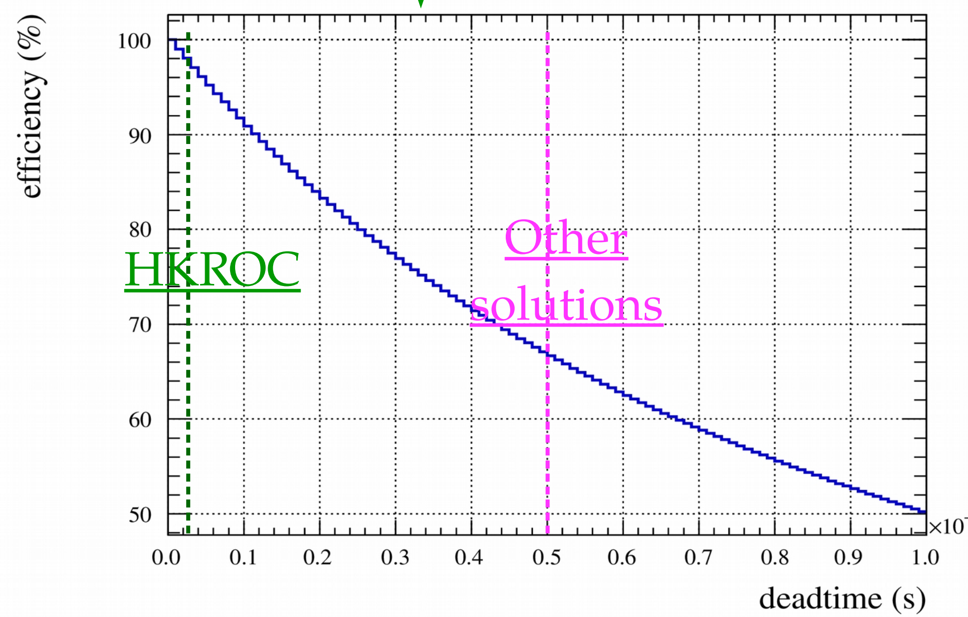


- Normal hierarchy : ↑ $\nu_\mu \to \nu_e$.
- Inverted hierarchy : ↑ $\bar{\nu}_\mu \to \bar{\nu}_e$.

→ Decay-e are central to separate ν_e / $\bar{\nu}_e$.



Decay-e hit efficiency increased from 68 % → 98 % w/ HKROC for Multi-GeV events

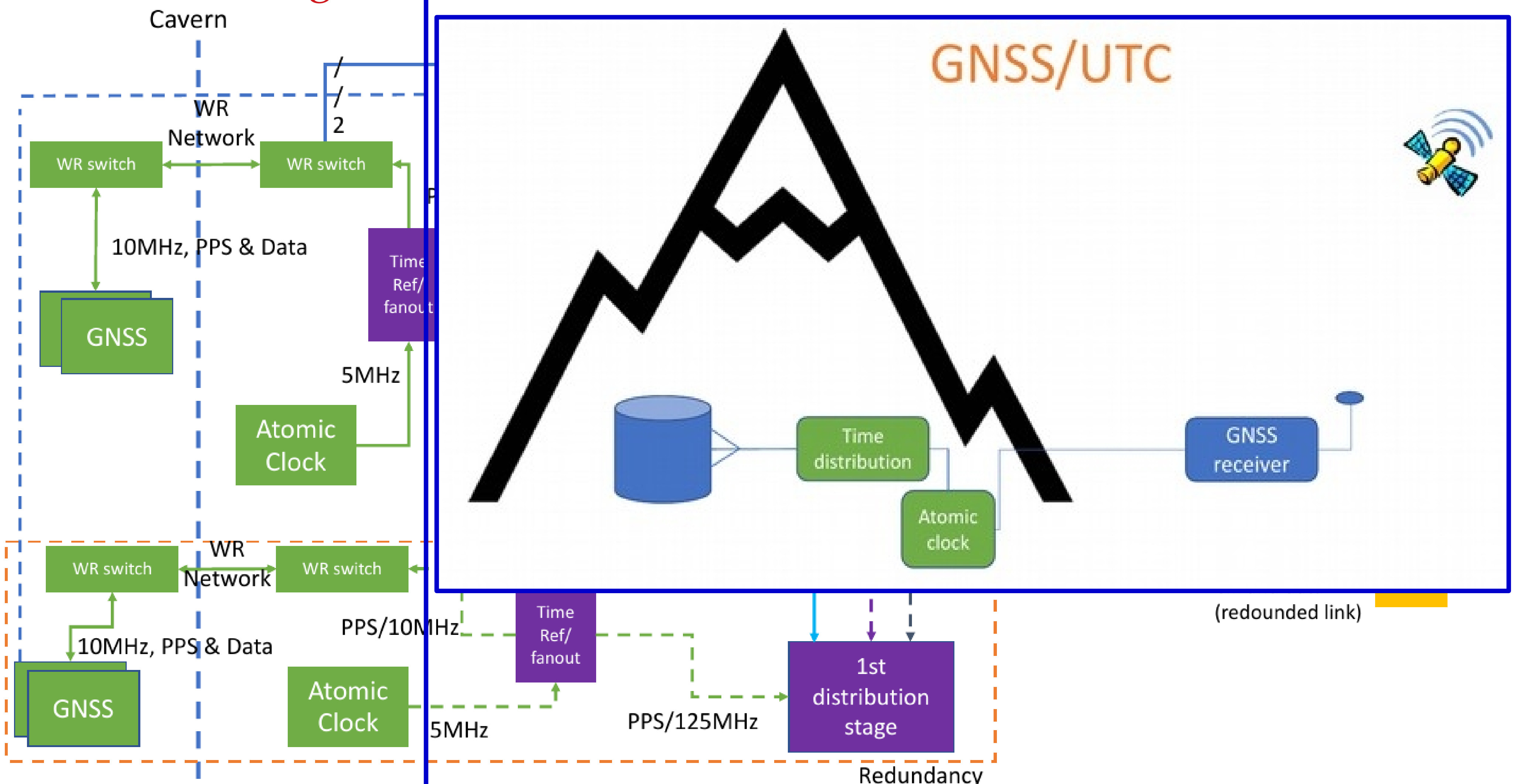


- For 1MHz [Betelgeuse] : HKROC allows to significantly increase efficiency from 67 % to 92.5 % compared to other solutions.

Overall view of the timing system

Time-generation :

- Provides local time w/ high stability to synchronize HK w/ ν beam & other multi-messenger detectors



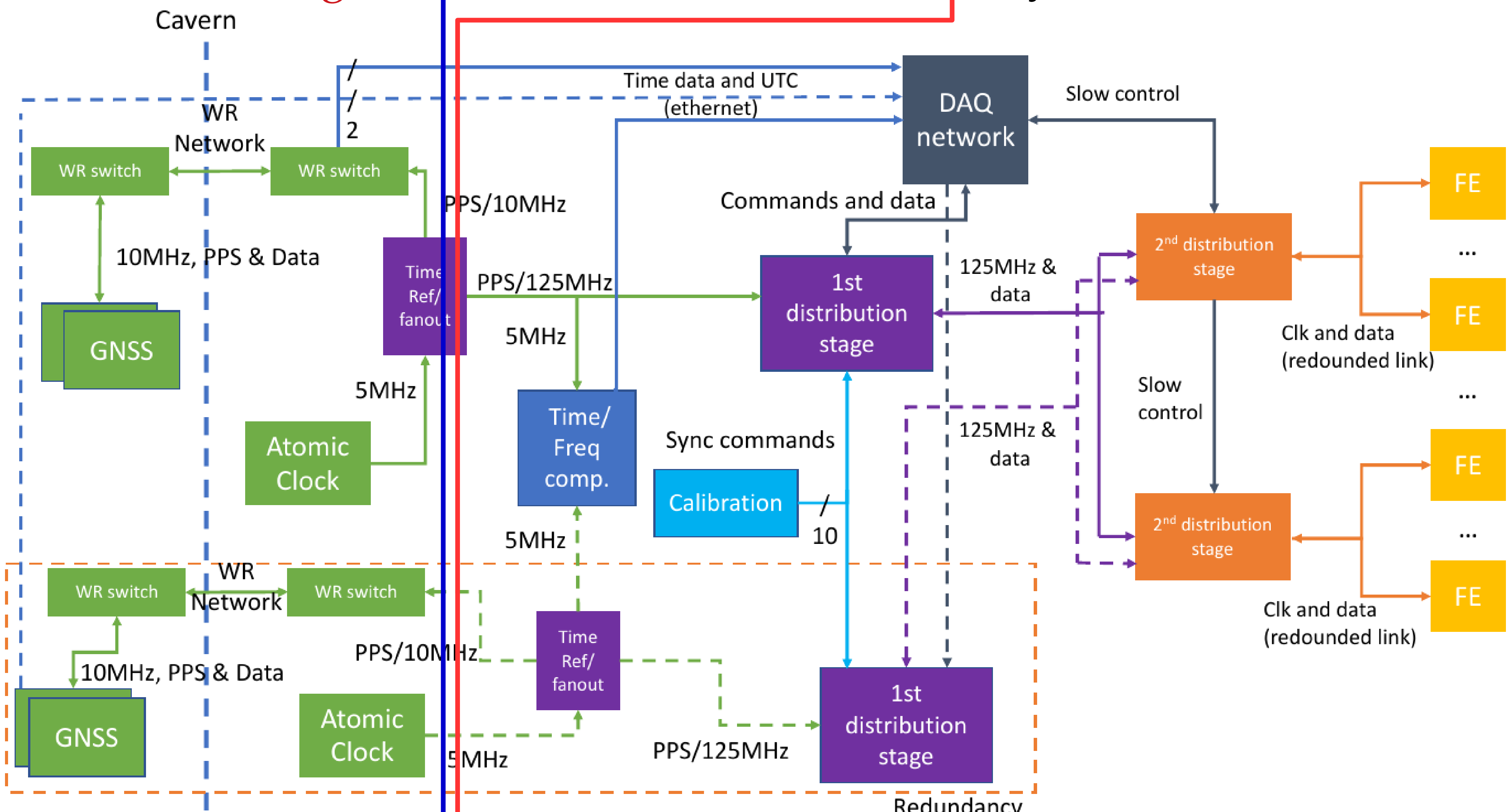
Overall view of the timing system

Time-generation :

- Provides local time w/ high stability to synchronize HK w/ ν beam & other multi-messenger detectors

Time-distribution :

- Distribute the local time to all digitizers, and synchronize them.

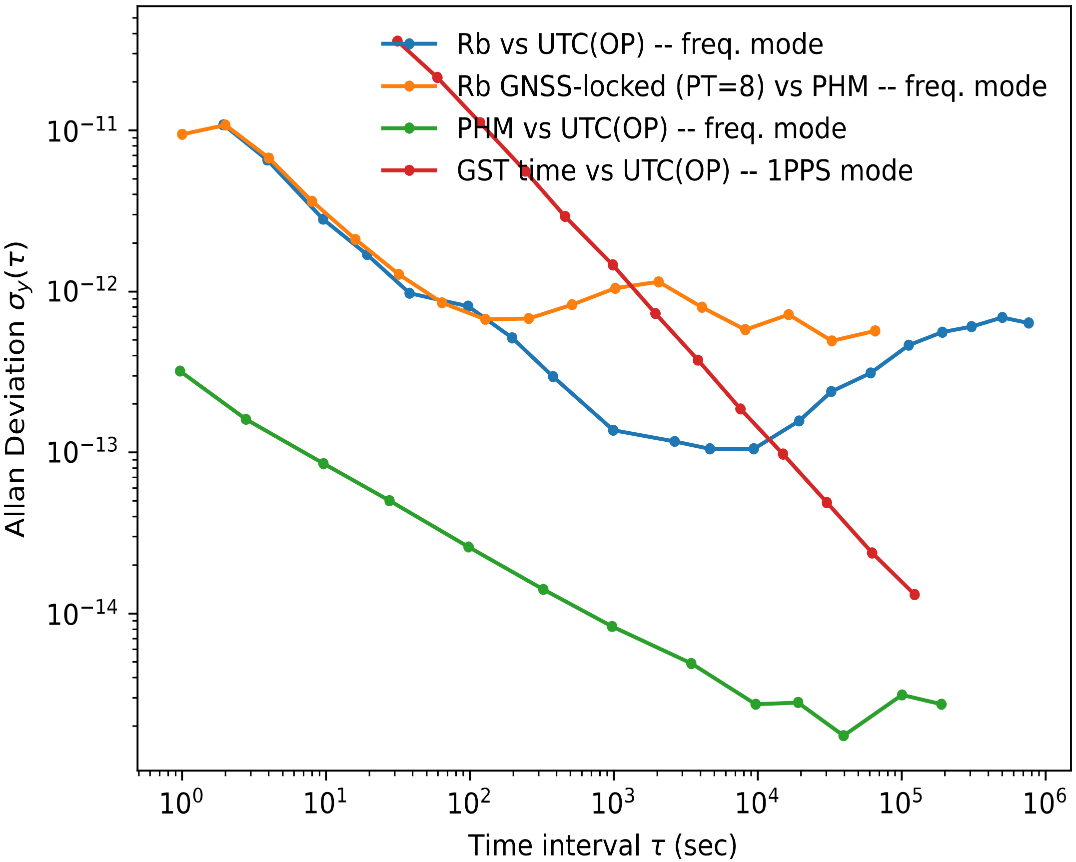


Time-generation

- Local time PPS generated by a 5 MHz Rb atomic clock.

- 2 GNSS receivers connected to same antenna to measure the difference between local PPS & UTC time → Transform local time to UTC.

- Collaboration w/ SYRTE which provide the French National time.



- Absolute time requirements for HK : ± 100 ns.
- Largely achieved w/ our system based on Rb clock. → Deviation of 10^{-12}s/day. ✔

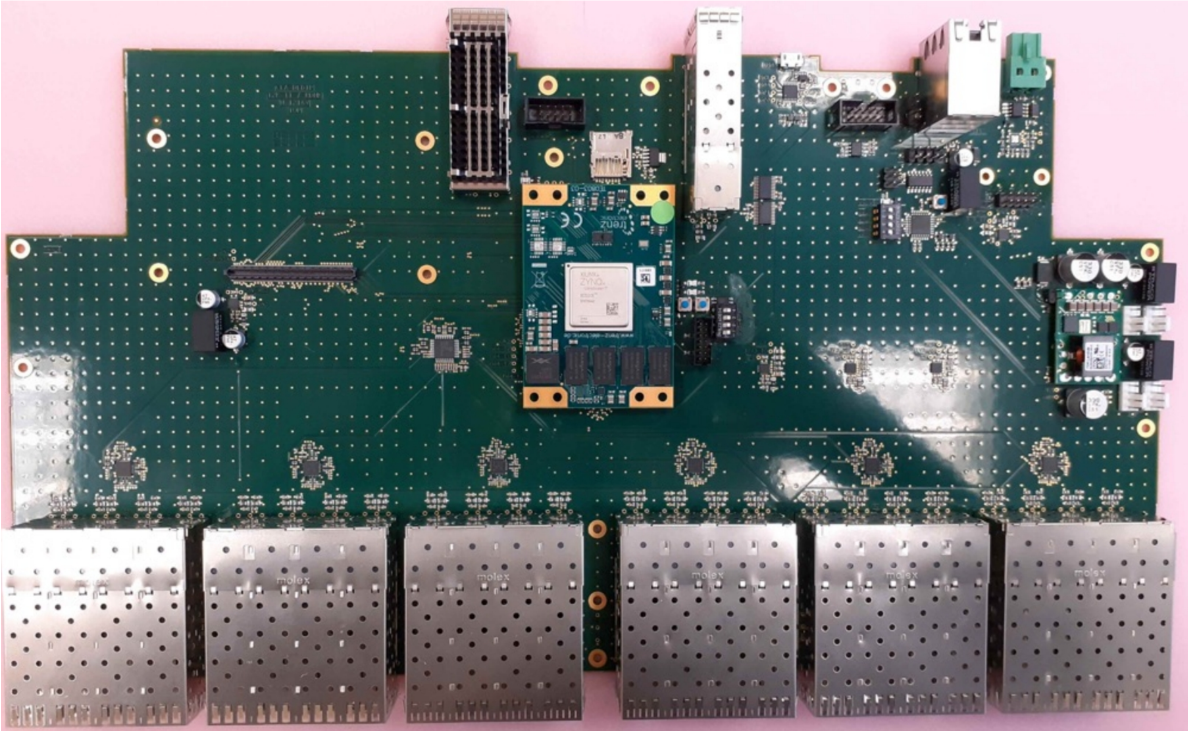
- Wish ↑ accuracy in future (ν mass measurements etc.)

→ Reach 10^{-12} s w/ corrections. ✔

First stage distribution

- First stage is on surface :
  1. Generates the 125 MHz clock for Hyper-K from the 5 MHz of the atomic clock.
  2. Broadcasts this clock and synchronize command to 2nd stage.

- CEA-IRFU has realized the 1st distribution stage very first prototype.

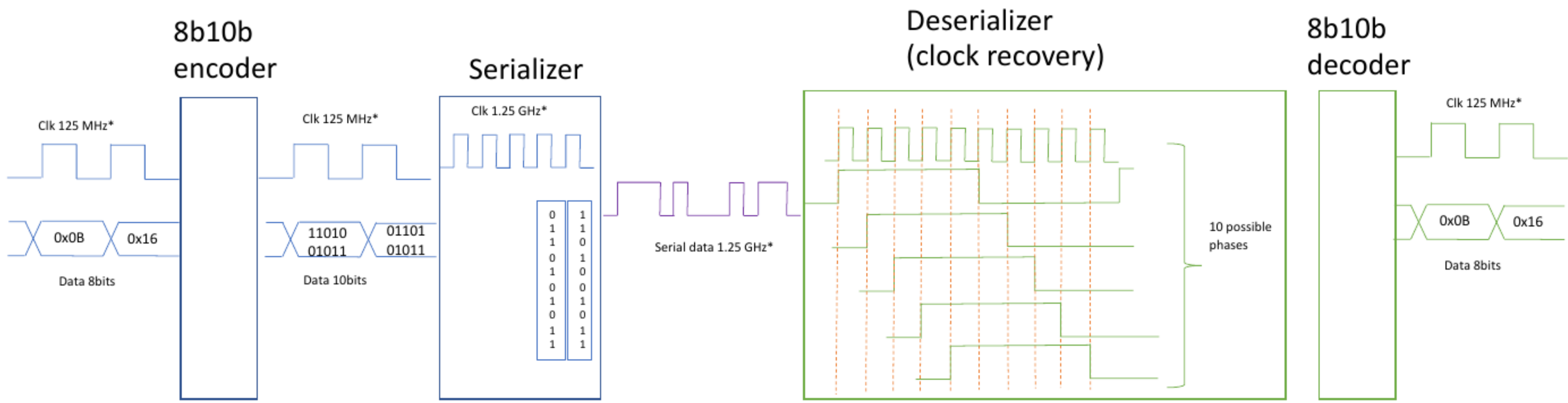


- The board has been received in April.
- Most of the tests are finalized.

Second stage distribution

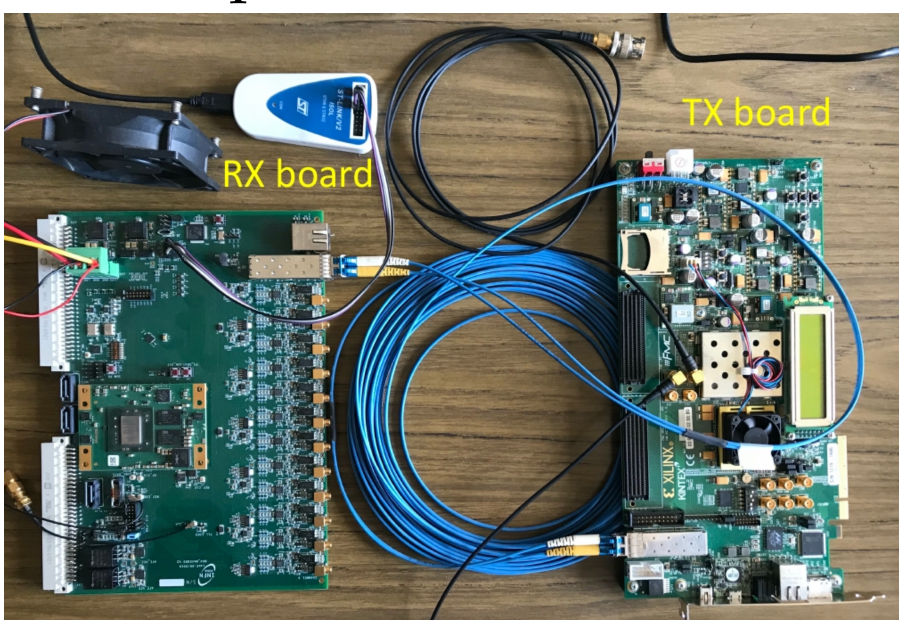
- Second stage at surface & in water vessel :

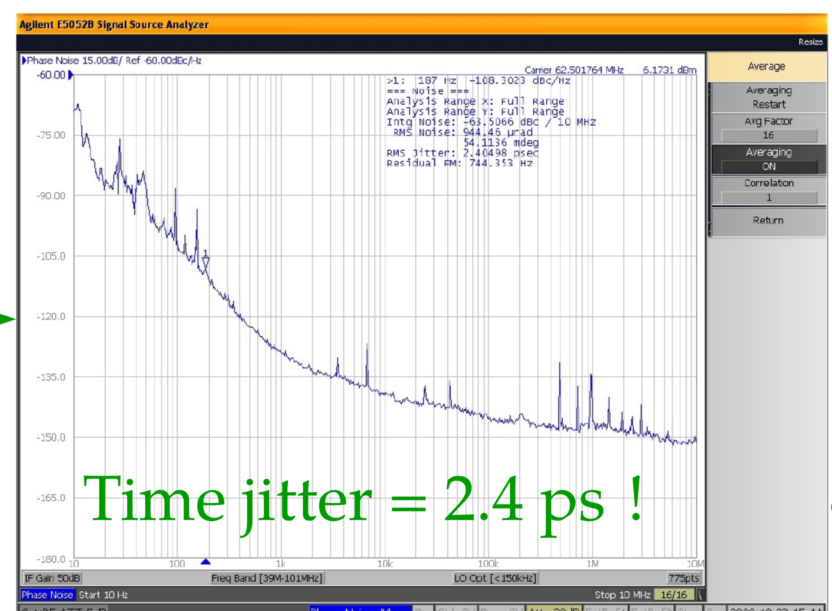
  → Encodes, sends, & decodes the clock.



*Not in scale

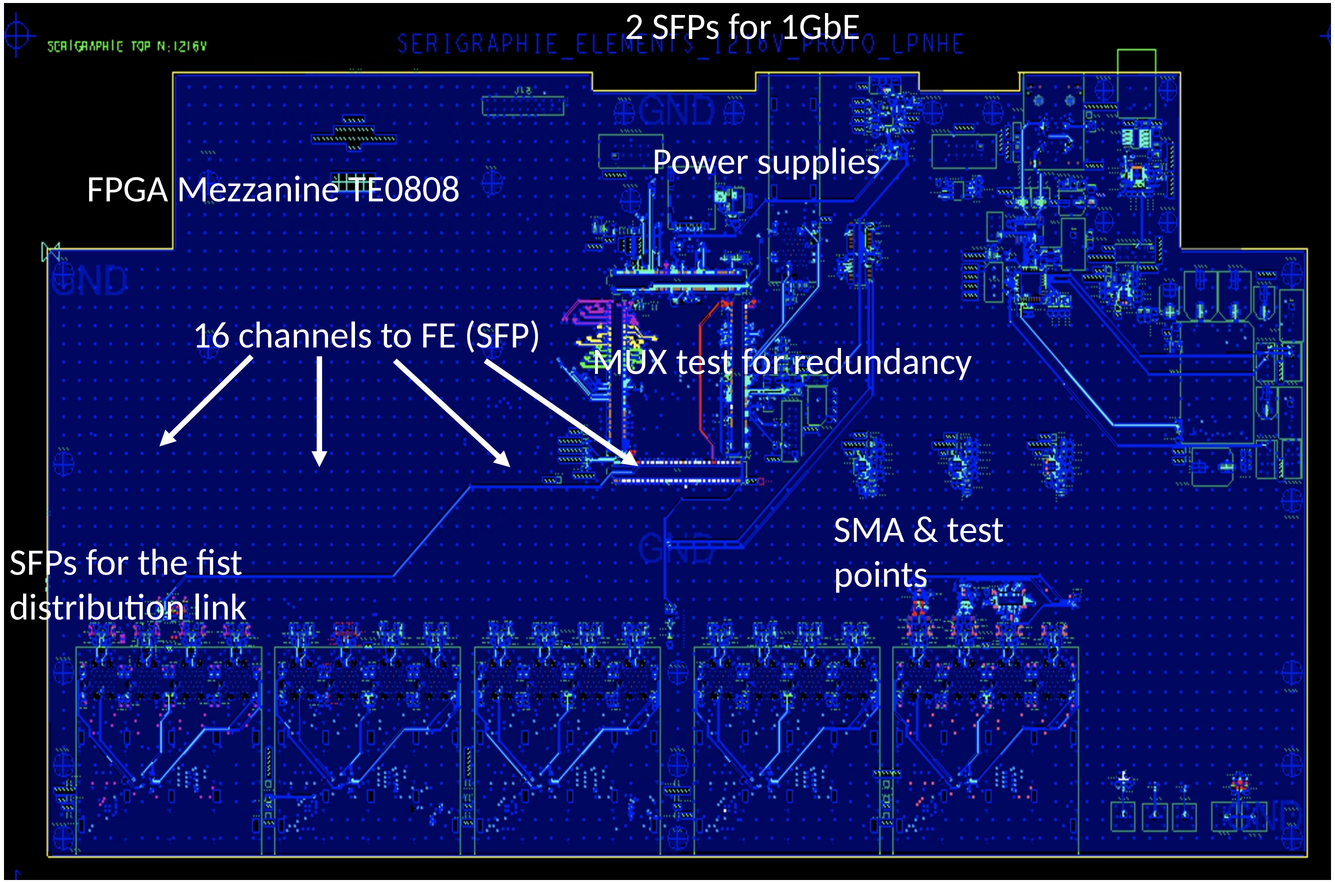
- Concept tested at LPNHE :





Second stage distribution

- <u>Second stage prototype board :</u> design finalized & send to fabrication.



- <u>Firmware :</u> under development using the same mezzanine (TE0808) and a motherboard EBV

- <u>Software :</u> Embedded under dev. Linux OS already installed and tested. Most peripherals control's sw already written.

III. Incoming steps & timeline

Prospects for the HKROC digitizer

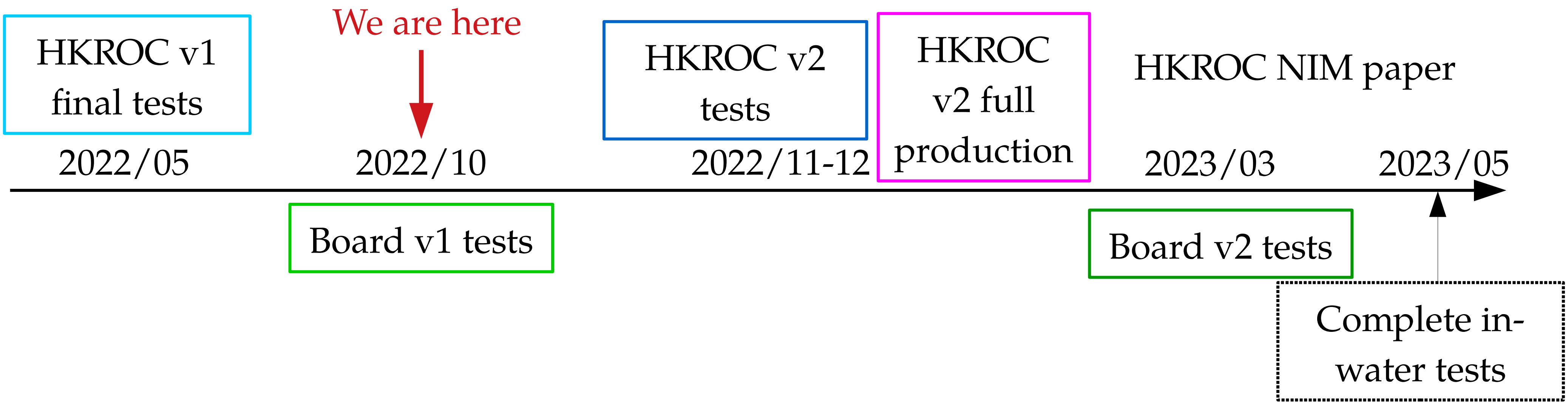
- 2 other digitizers were competing for HK : QTC (Japan), discrete (Italy).
  → Unfortunately, HKROC not chosen as primary solution for HK.

- Summary of the review:

1. All 3 solutions for HK digitization are suitable both in terms of minimal requirements & schedule.
2. The HKROC team has clearly shown the large advantages for physics.
3. The HK management **preferred an already final solution with less impact on physics compared to HKROC which will be finalized in 8 months** → **The main reason we were not selected was that we did not had a on-shelves solution ready (others had).**

- HKROC has been built to be a **waveform digitizer for any PMT-based experiment in the next 10-15 years**.
  → We will finalize the HKROC development all the way to a modular front-end board.

HKROC digitizer timeline



- We propose to keep our R&D original schedule :
  → **First complete digitizer board in spring 2023.**

- NIM paper : Being prepared for a publication at the end of spring 2023.
  → Based on HKROC v2 & prototype board v1.

- From now : starts contact with other experiment using PMTs : IceCube gen2, potential HK upgrade, Intermediate Water Cherenkov Detectors
  → If you are interested, please let me know !

Status & timeline for the clock

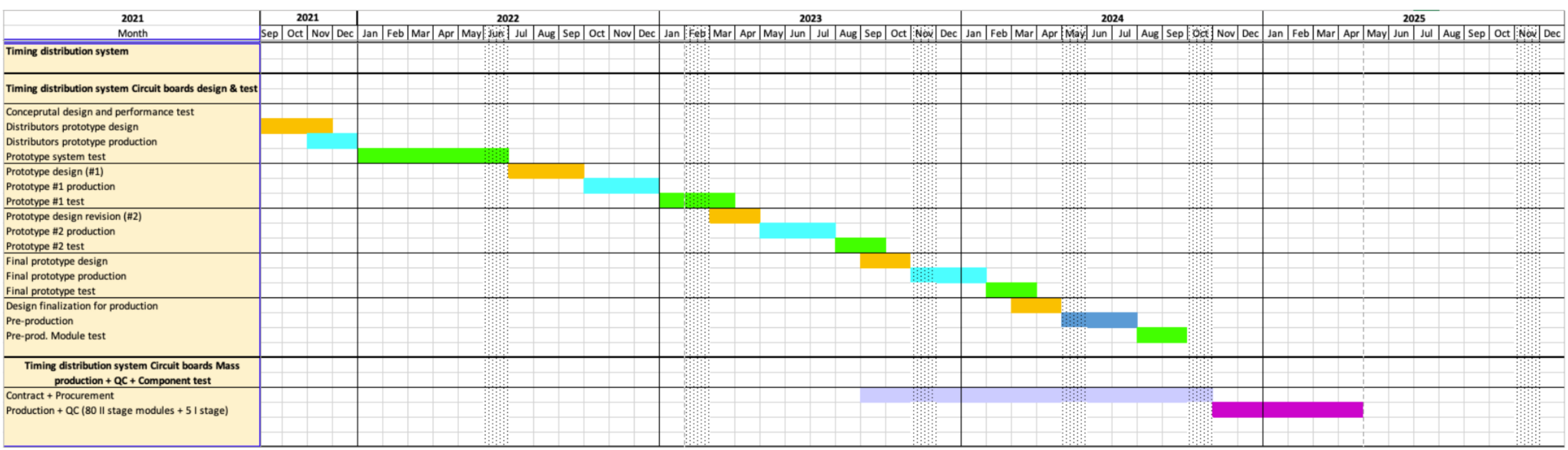
- Final time generation & distribution scheme presented and **<u>validated by the HK electronics group.</u>**
- The timing system technical **<u>note has been submitted and is under evaluation</u>** (delayed due to digitiser choice)

→ There is no alternative solution in HK !

- <u>Significant progresses on-going :</u> ahead of official schedule

→ The development is going **perfectly well & on-time !**

→ Ordering components for the final production has started.



Conclusions

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

- RD4HK only started in January 2022, but tremendous progresses have been made :

1. The HKROC ASIC has been received and completely characterized

→ Excellent agreement with expectations, though this is very 1st version.

→ Largely surpass existing CATIROC & other solutions in Hyper-K.

→ Very very small cross-talk found (0.02 %) → To be reduced by a factor of 10 in HKROC v2.

2. Clock generation & distribution system scheme has been completed :

→ Time generation system has been validated through measurements.

→ First stage distribution first prototype completely characterized.

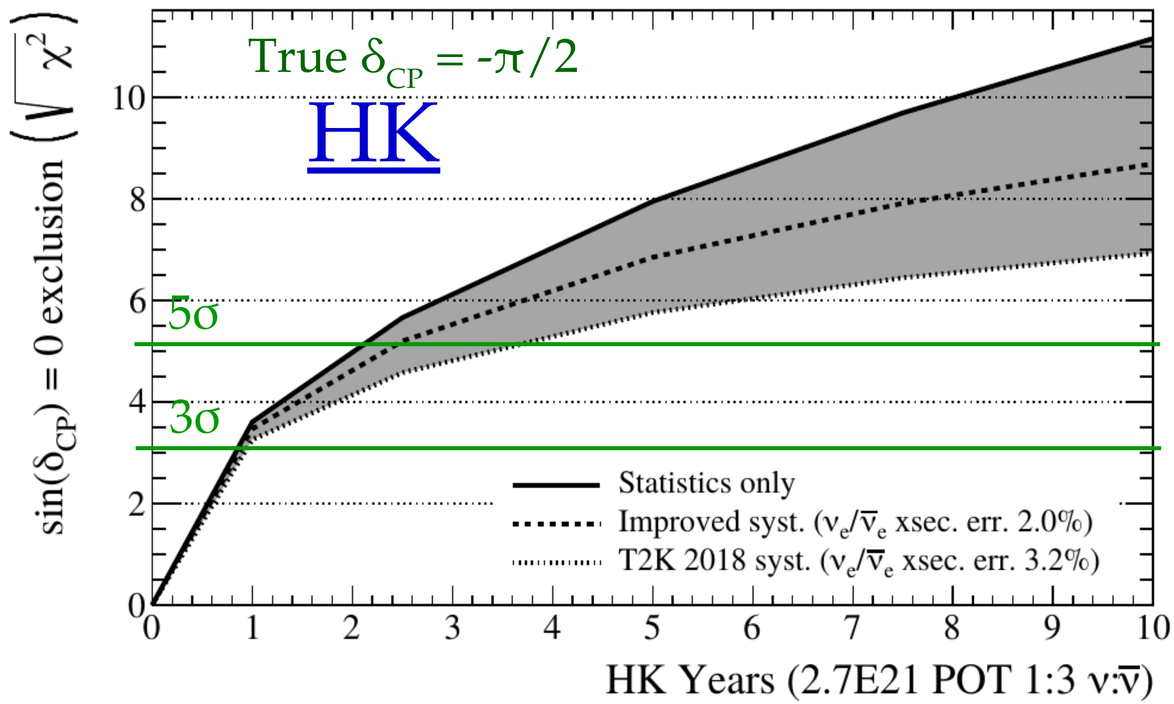
→ Second stage distribution first prototype sent to production.

- **Huge technical achievements & success in only 1 year !!**

Conclusions

- The HKROC digitizer & clock system development will continue in 2023.
  → Final production-ready digitizer for HKROC.
  → All the way to production for the timing system.

- Wish to transform this R&T project into a physics master project from beginning 2023.

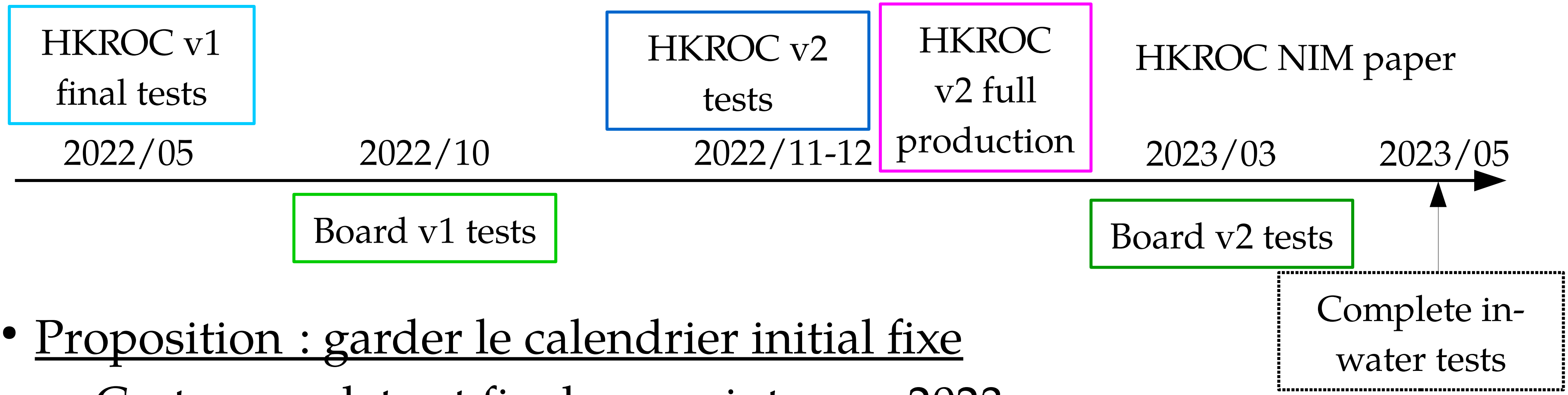


- $\delta_{CP} = -\pi/2$: 5σ after 2-4 years of data taking
  → Independent from ↓ systematic uncertainties.
  → DUNE will require 7-8 years.

Additional slides

HKROC digitizer - Impact on physics

Le groupe HKROC propose de finaliser la R&D ASIC + carte :



- Proposition : garder le calendrier initial fixe
  → Carte complete et finale au printemps 2023.
  → Demande budgetaire additionnelle : prod. de quelques cartes v2.

- Papier NIM : Preparation pour publication fin printemps 2023.
  → Base sur HKROC v2 & carte proto v1 : tests finalises en Fevrier 2023.

- Hiver 2022 : contact avec d'autres manip utilisant des PMTs (IceCube gen2…), upgrade HK eventuel, HK outer-Detector etc.

HKROC digitizer - Impact on physics

- <u>Conclusion de la revue:</u> malheureusement, **<u>HKROC n'a pas ete selectionne en premiere position par Hyper-K.</u>**

Item	HKROC	QTC	Discrete	Weight
Basic requirements	4	4,857143	4,8571429	30,00%
Comparison of technical performance beyond basic requirements	4,428571	2,428571	3	15,00%
Proposed schedule and risks	3,071429	4,714286	4,7142857	25,00%
Resources	4,857143	4,428571	4,2142857	15,00%
Reliability	4,142857	4,214286	4,1428571	15,00%
TOTAL	**3,982143**	**4,296429**	**4,3392857**	

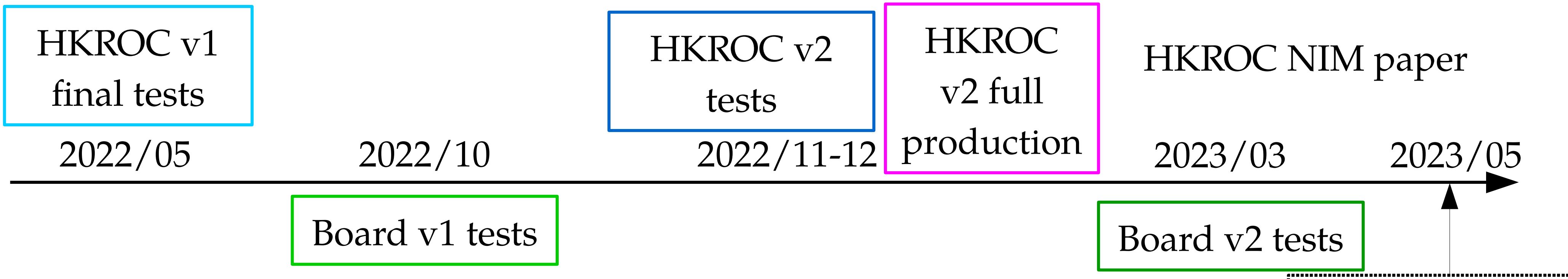
- <u>En resume :</u>

1. Les 3 solutions ont ete retenue comme parfaitement viable pour HK.
2. Le cross-talk de l'ASIC a impacte les « basic requirements & schedule. »
3. L'equipe HKROC a su demontre ses larges avantages sur la physique.
4. Le management a clairement <u>prefere une solution déjà finale moins ambitieuse a une solution optimale mais qui sera finale dans 8 mois</u>.

→ Nous avons **decide de proposer un projet alternatif permettant de maintenir ne visibilite forte pour l'IN2P3 et l'IRFU** : plusieurs options sont en cours d'evaluation/negociation.

HKROC digitizer - Impact on physics

<u>Le groupe HKROC propose de finaliser la R&D ASIC + carte :</u>



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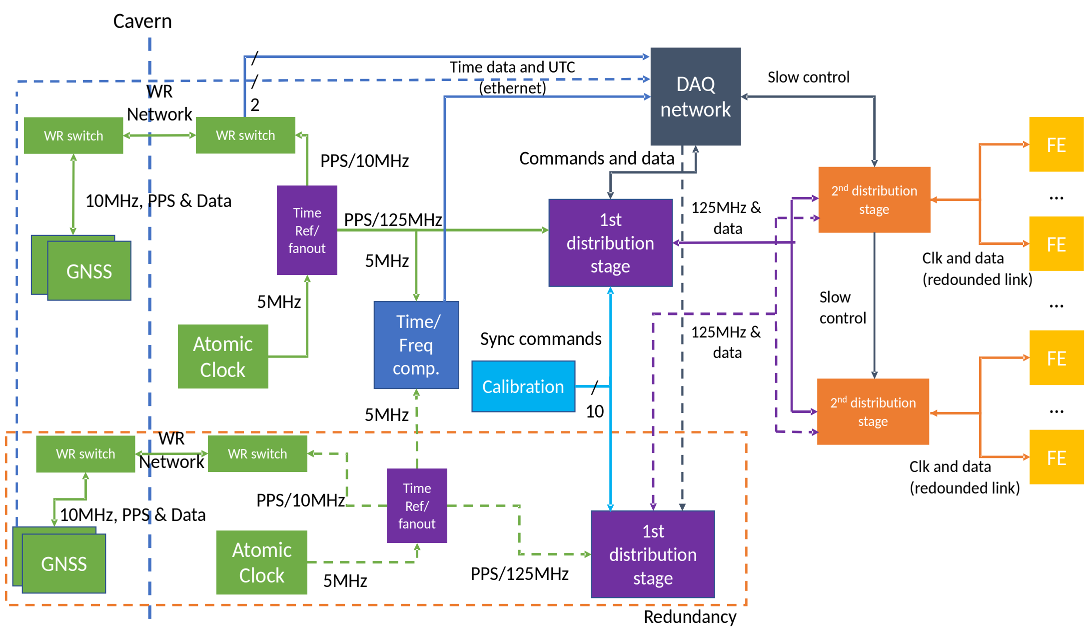
- <u>Hiver 2022 :</u> contact avec d'autres manip utilisant des PMTs (IceCube gen2…), upgrade HK eventuel, HK outer-Detector etc.

Faits marquants 2022 - Electronique

- Final time distribution scheme presented and validated by the HK electronics group.
- The time distribution subsystem technical **<u>note has been submited and is under evaluation</u>** (delayed due to digitiser choice)

→ It should be highlighted that there is no alternative solution in HK !



- <u>Significant progresses on-going :</u> ahead of official schedule

→ **The development is going perfectly well & on-time !**

- Ordering components for the final production via PUMA procedure : Anticipation on the 2024 spending

Rappels de l’organisation RD4HK

Responsable national : B. Quilain

HKROC	Digitiseur	Generation horloge	Distribution horloge
F. Dulucq (OMEGA)	J. Nanni (LLR)	M. Guigue (LPNHE)	S. Russo (LPNHE)

OMEGA

S. Callier (IR)
S. Conforti (IR)
C. De la Taille (IR)
P. Dinaucourt (AI)
F. Dulucq (IR)
A. Mghazli (IR/CDD)
L. Raux (IR)
→ 1.3 FTE / an IR

LLR

A. Afiri (IR/CDD)
L. Bernardi (IR)
F. Gastaldi (IR)
J. Nanni (IR)
→ 1.2 FTE / an IR
A. Beauchene (PhD)
M. Buizza-Avanzini (CR)
O. Drapier (DR)
T. Mueller (CR)
P. Paganini (DR)
B. Quilain (CR)
→ 1.8 FTE / an phys.

LPNHE

E. Pierre (IR)
S. Russo (IR)
V. Voisin (IR)
→ 1.3 FTE / an IR
M. Guigue (MdC)
C. Giganti (CR)
L. Meller (PhD)
B. Popov (DR)
M. Zito (DR)
→ 1.2 FTE / an phys.

ILANCE

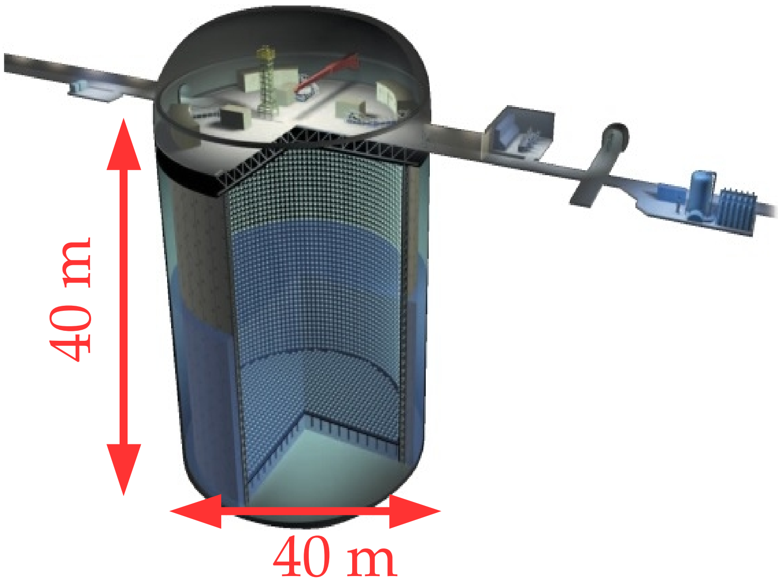
M. Gonin (DR)
G. Pronost (Posdoc)
→ 1.2 FTE / an phys.

FTE moyens calcules sur 4 ans (01/2022-12/2025)

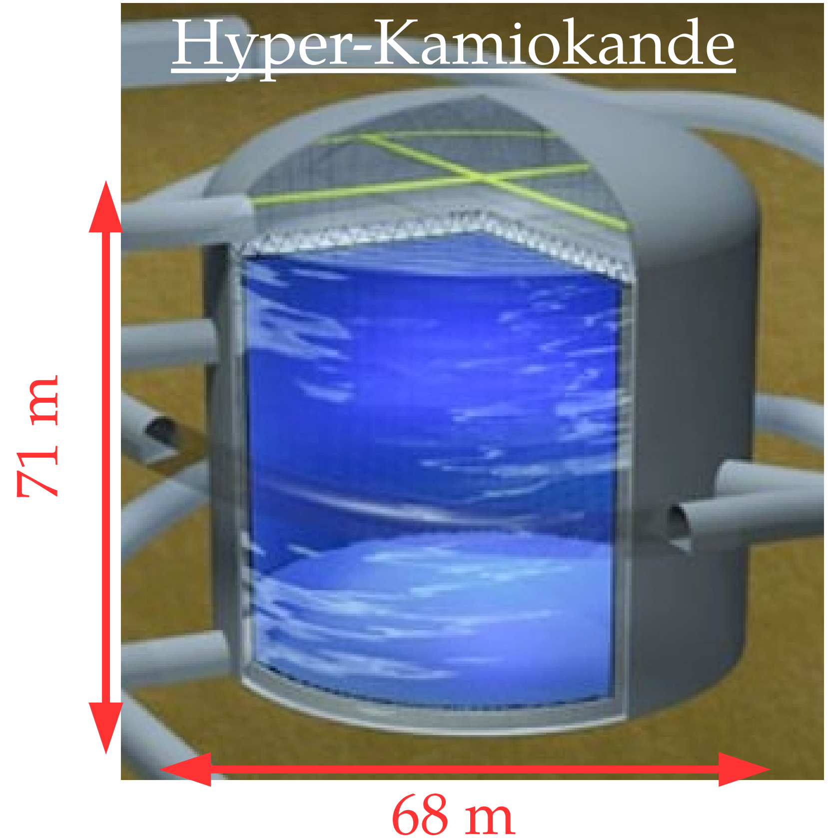
Reminder : what is Hyper-K ?

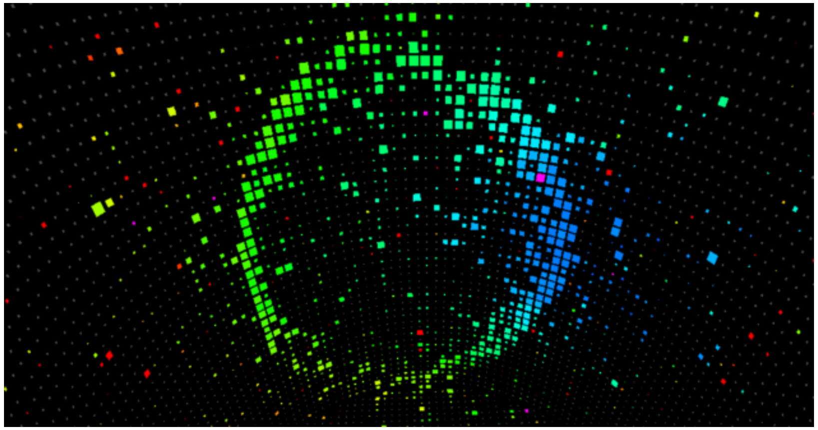
- Next generation of neutrino observatory in Japan→ construction 2020-27
  → A 260 kton water Cherenkov detector → <u>Fiducial Mass ~ 8 x SK.</u>

<u>Super-Kamiokande</u>



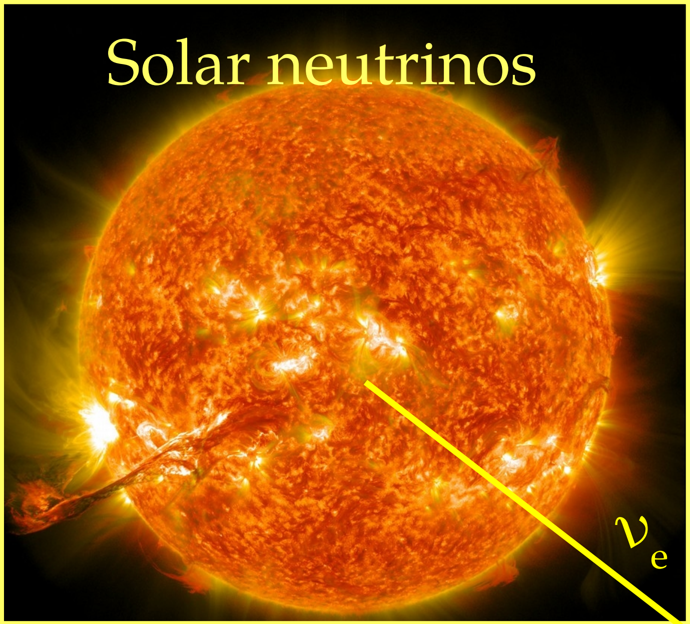
<u>Hyper-Kamiokande</u>



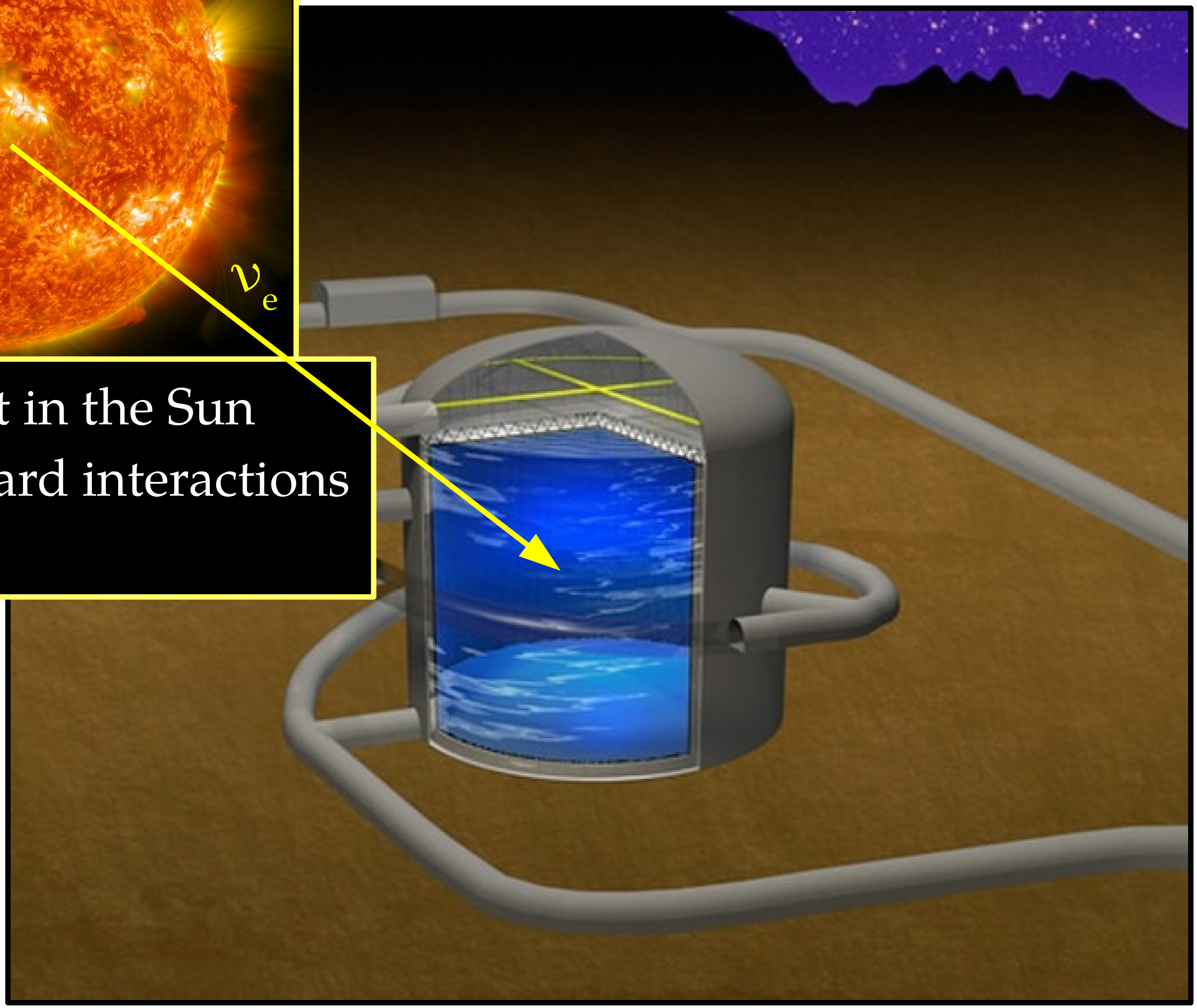


	Super-K	Hyper-K (1st tank)
Site	Mozumi	Tochibora
Number of ID PMTs	**11,129**	**40,000**
Photo-coverage	40%	40% (**x2 sensitivity**)
Mass / Fiducial Mass	50 kton / **22.5 kton**	260 kton / **187 kton**

Physics case

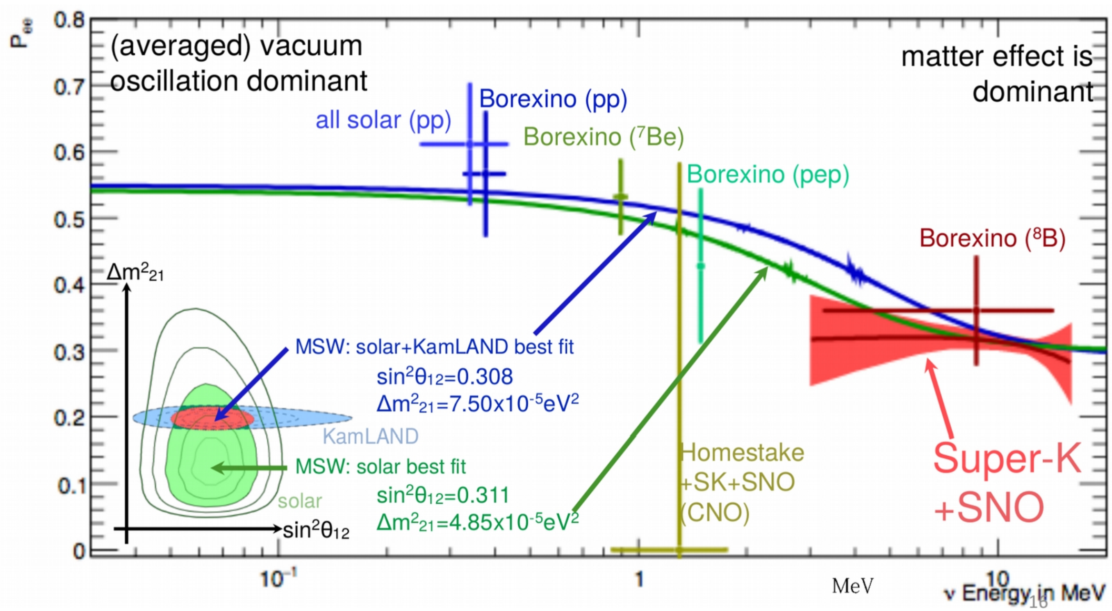


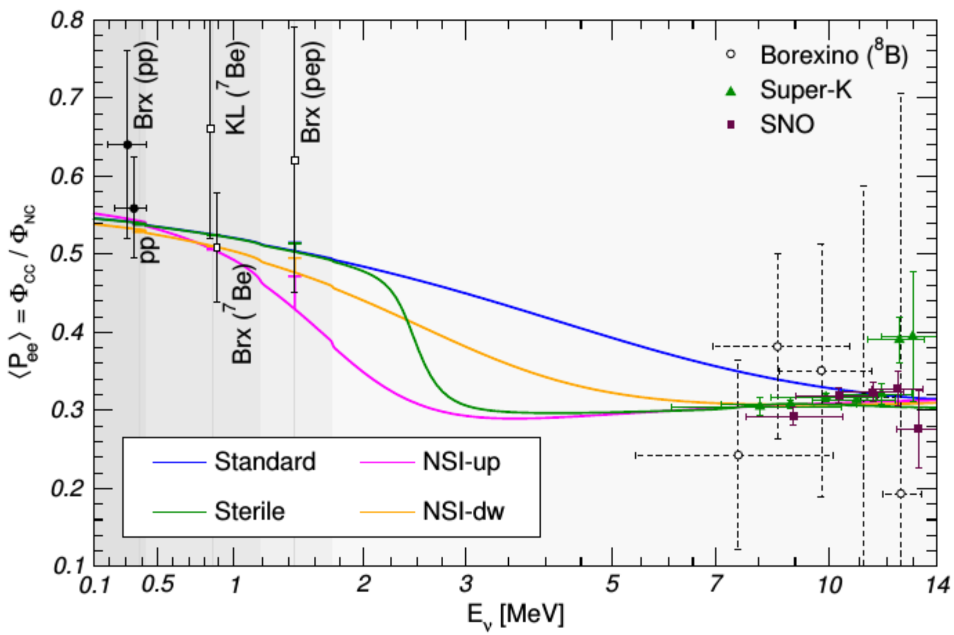
- MSW effect in the Sun
- Non-standard interactions in the Sun.



Solar neutrinos : upturn

- <u>Probe solar ν :</u> SK/SNO found a high matter effect in the Sun
  ↔ Solar upturn shifted to lower energies

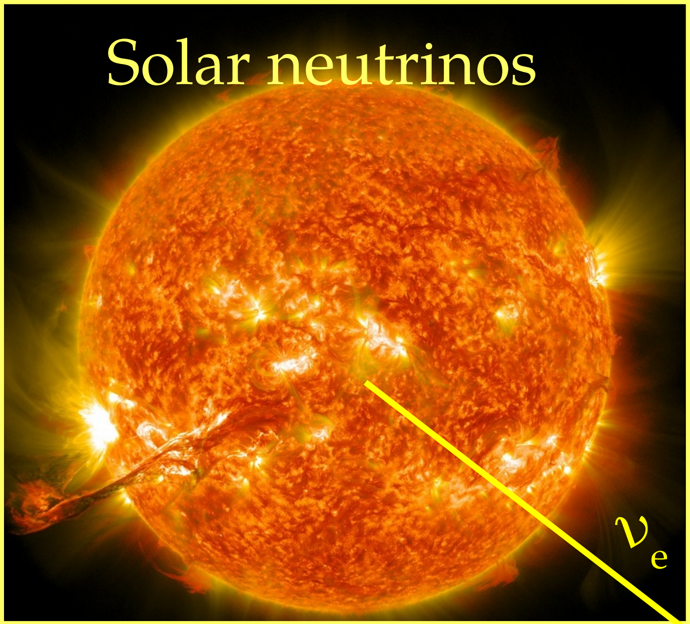




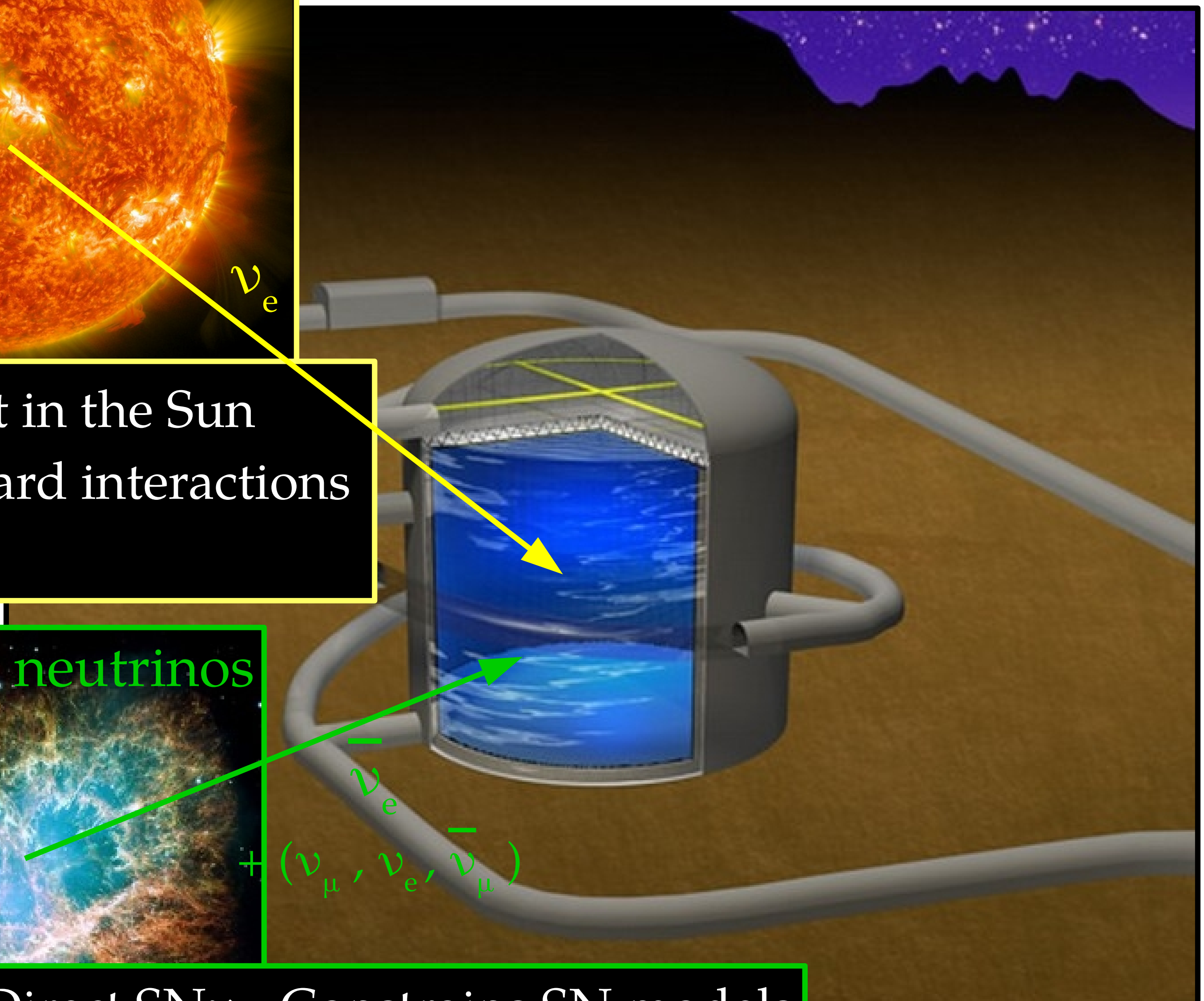
- SK deviates from standard upturn scenario > 2σ.

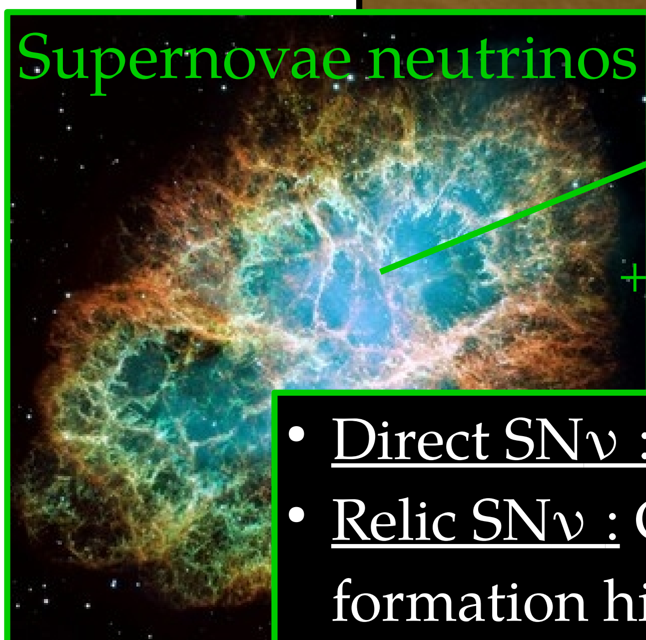
- <u>Displacement of the upturn can be explained by :</u>
  - Statistical fluctuation ?
  - Light sterile neutrino ?
  - Non Standard Interaction in the dense Sun ?

Physics case



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

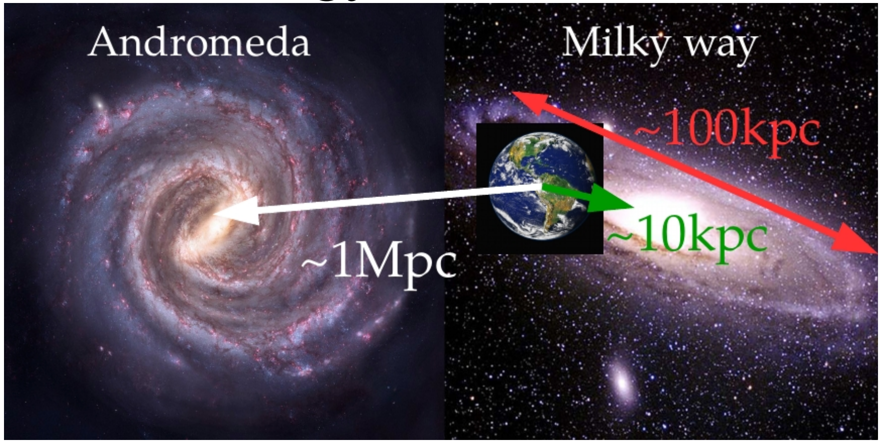




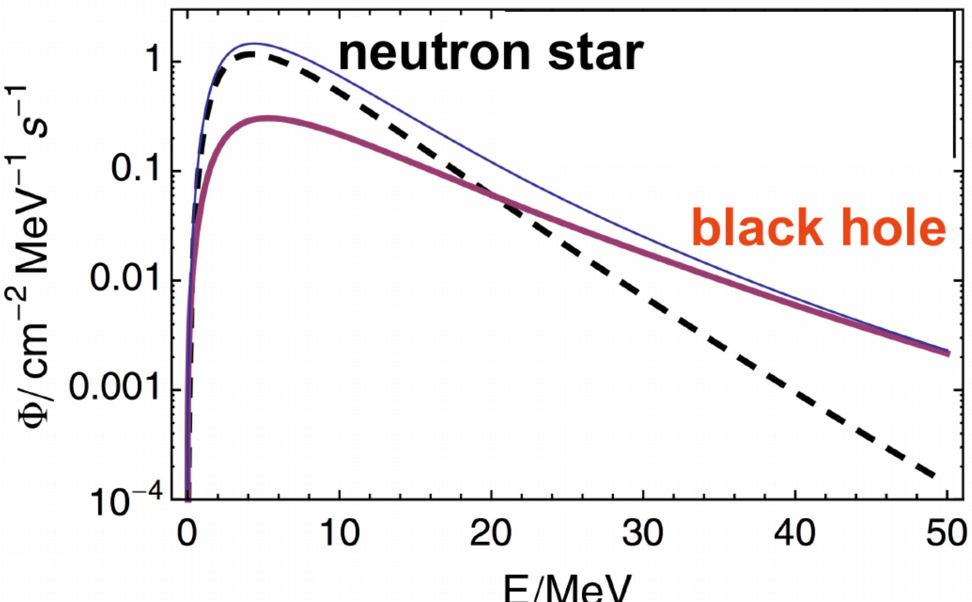
- Direct SNν : Constrains SN models.
- Relic SNν : Constrains cosmic star formation history

Supernovae neutrinos

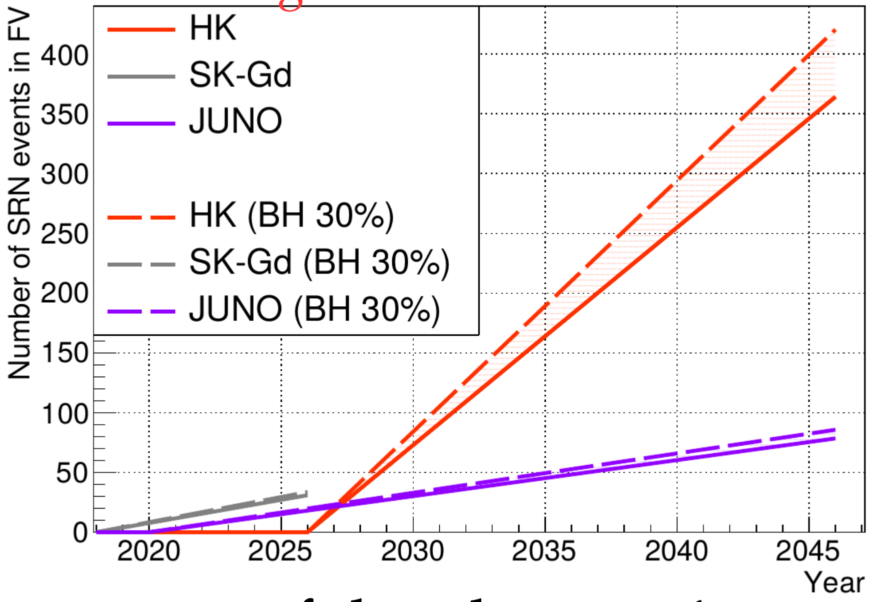
- Unique probe for supernovae ν : 99 % of SN energy → ν.
  - But direct ν detection very rare.
  - HK also sensitive to extra-galactic SNν from Andromeda !



- SN-relic neutrino → new constraints on cosmic star history → May be first detected in SK-Gd.
  → But spectrum determined by HK : Low energy ↔ Probe older stars



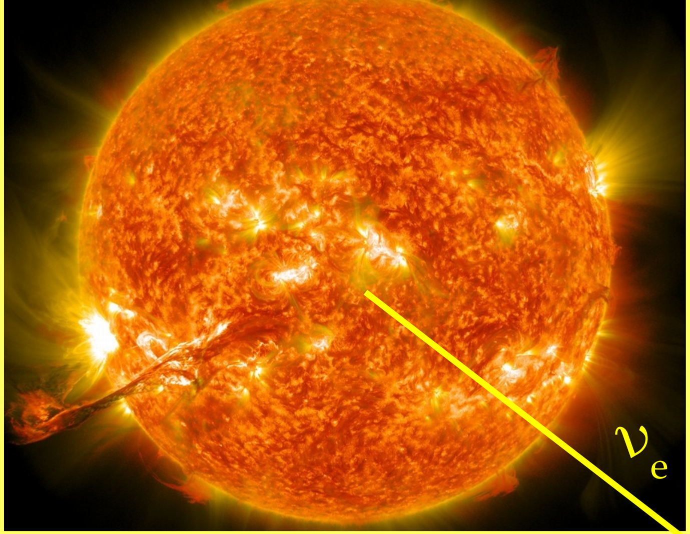
Higher redshift



- SK-Gd & then, HK are the pioneer experiments of this domain !

Physics case

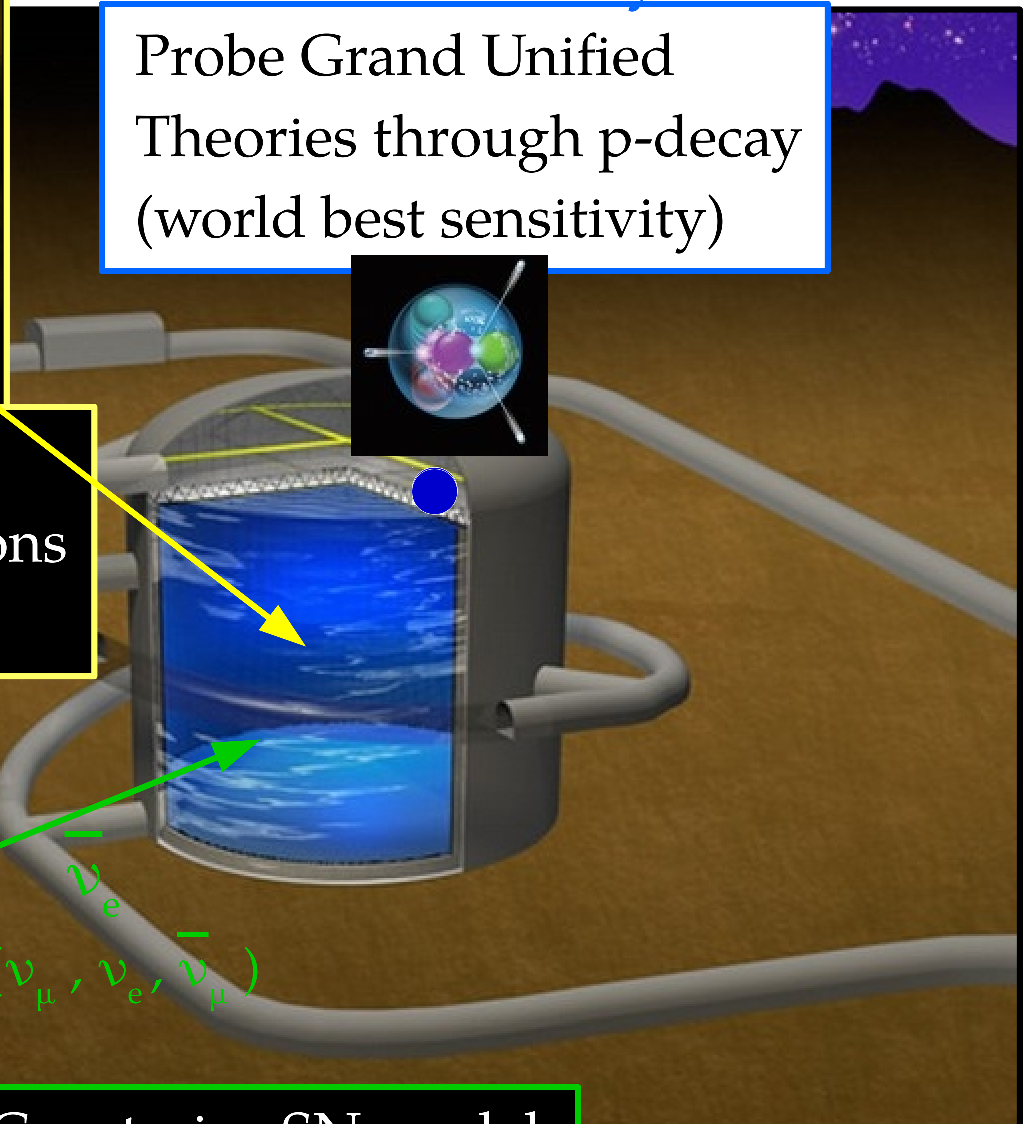
Solar neutrinos



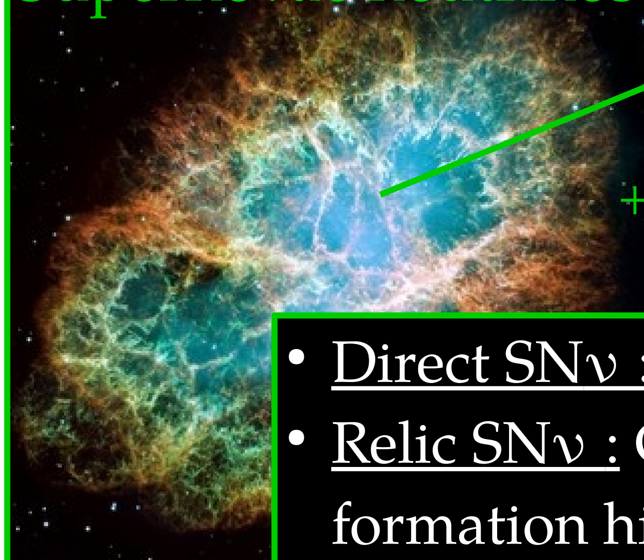
- MSW effect in the Sun
- Non-standard interactions in the Sun.

Proton decay

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



Supernovae neutrinos

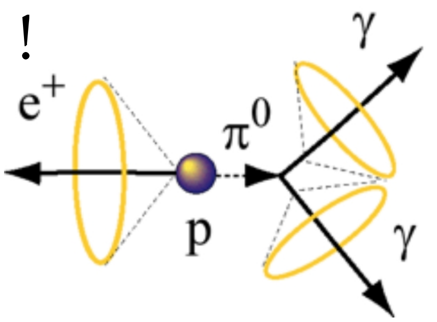


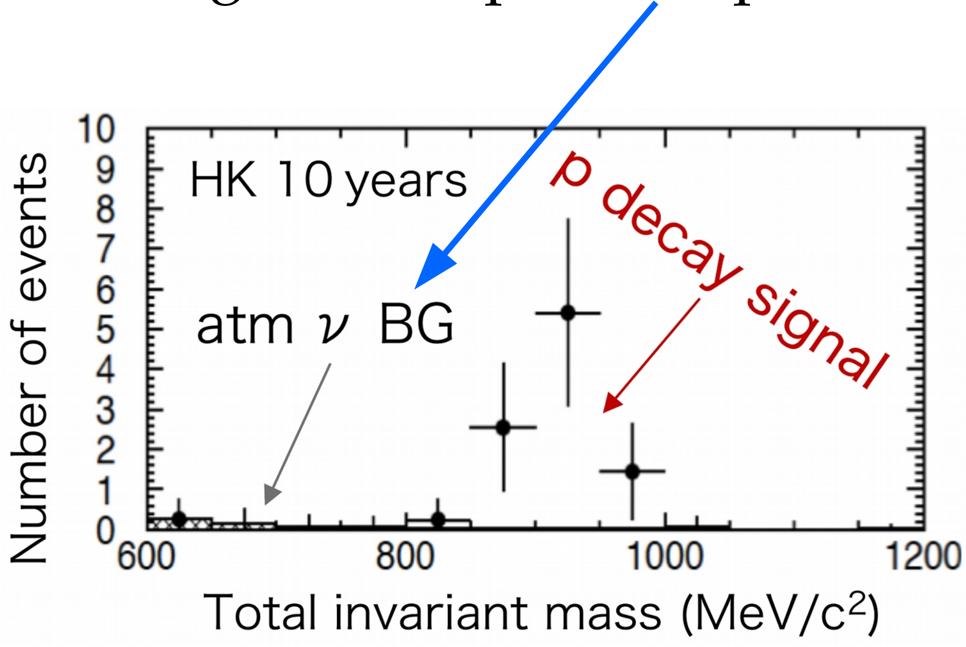
- Direct SNν : Constrains SN models.
- Relic SNν : Constrains cosmic star formation history

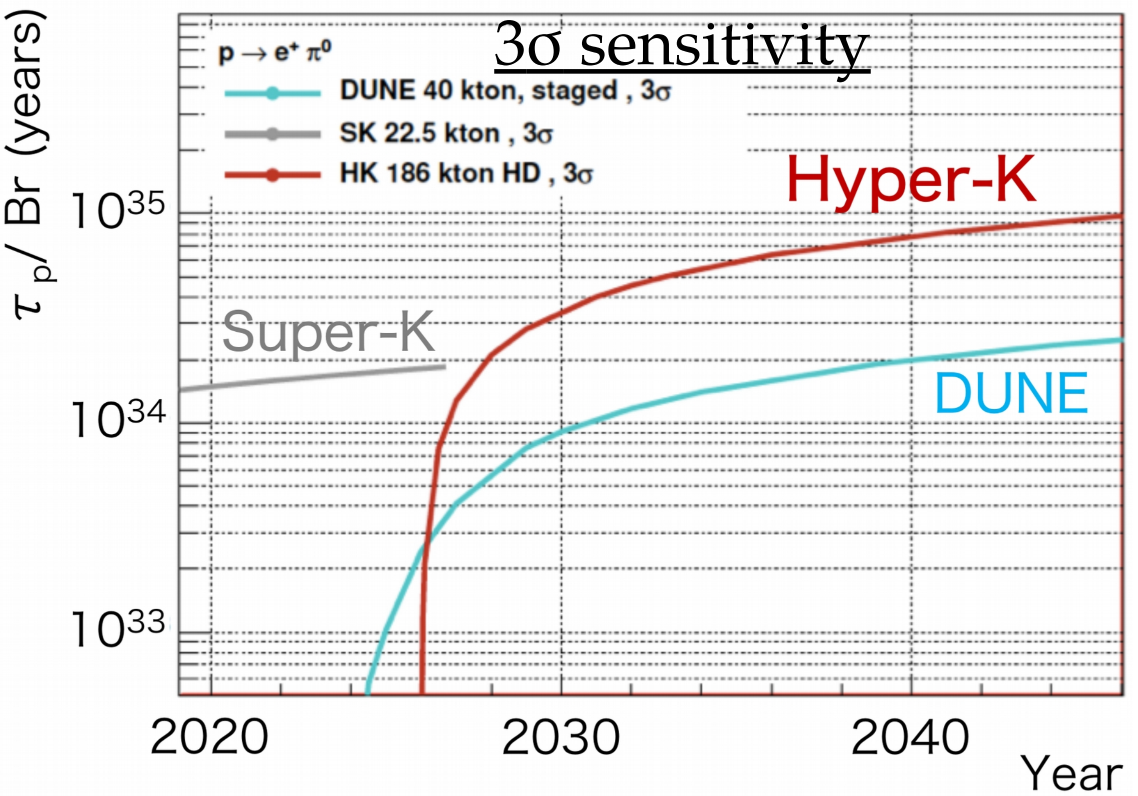
GUT and proton decay

- Probe Grand Unified Theories at a new scale through proton decay.

- <u>Golden channel :</u> $p \rightarrow e^+ + \pi^0 \rightarrow$ Almost background free !
  $\rightarrow$ Requires 2γ & reconstructed energy = Invariant M_P
  $\rightarrow$ <u>Bkg :</u> Atmospheric ν producing e.g. a π^0.



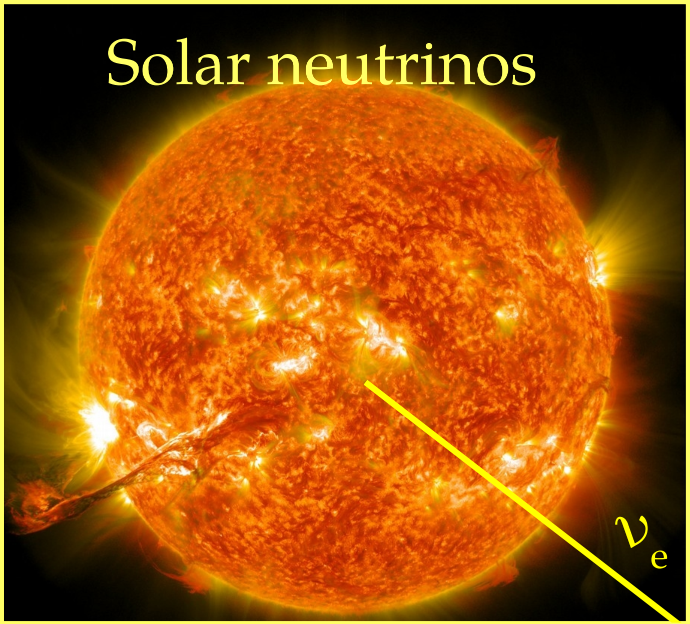




- 3σ sensitivity reach τ_P /Br = 10^{35} years → 1 order of magnitude beyond SK or DUNE

Physics case

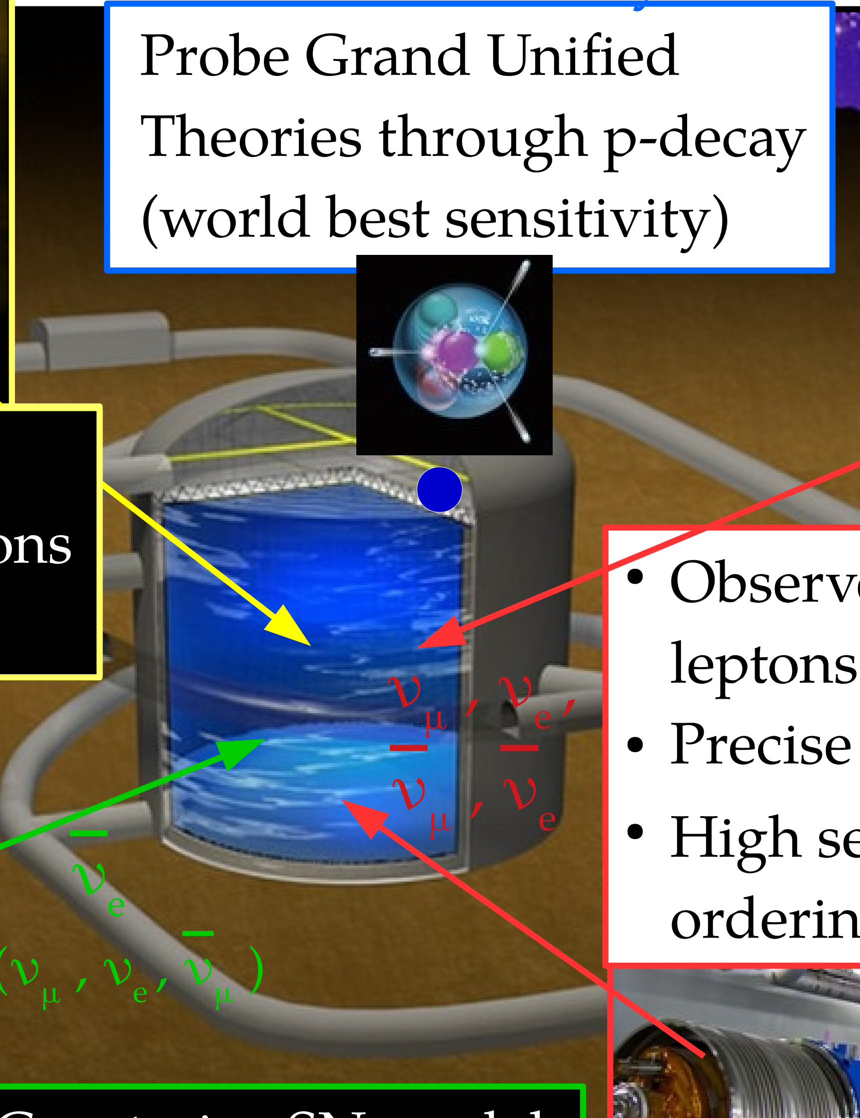
Solar neutrinos



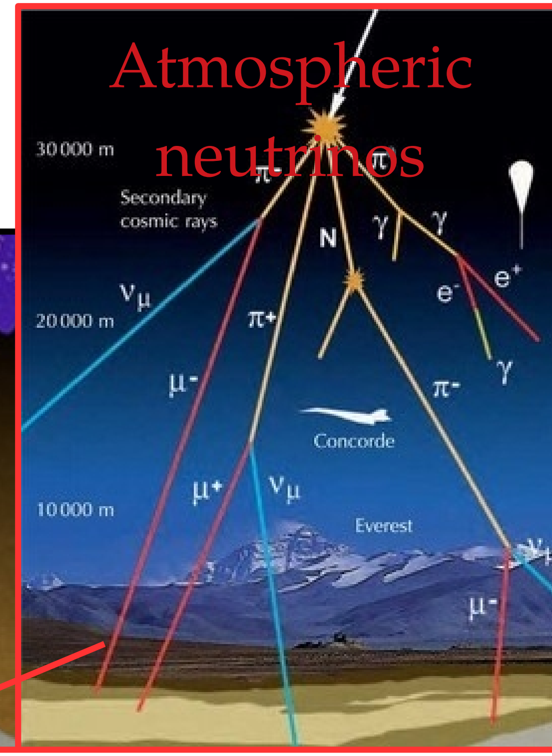
- MSW effect in the Sun
- Non-standard interactions in the Sun.

Proton decay

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

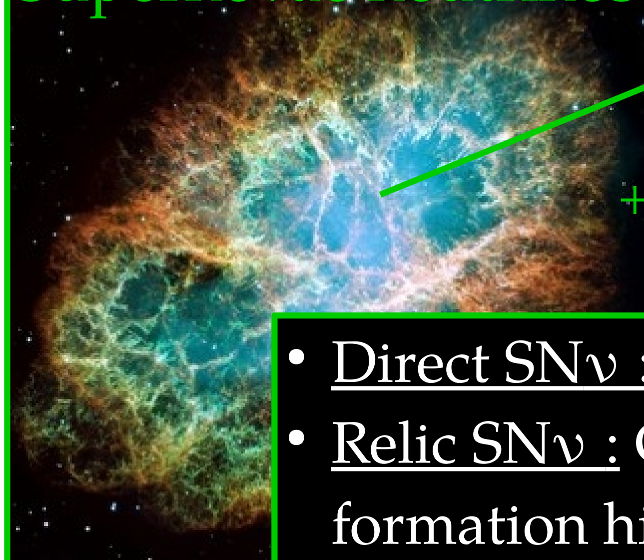


Atmospheric neutrinos

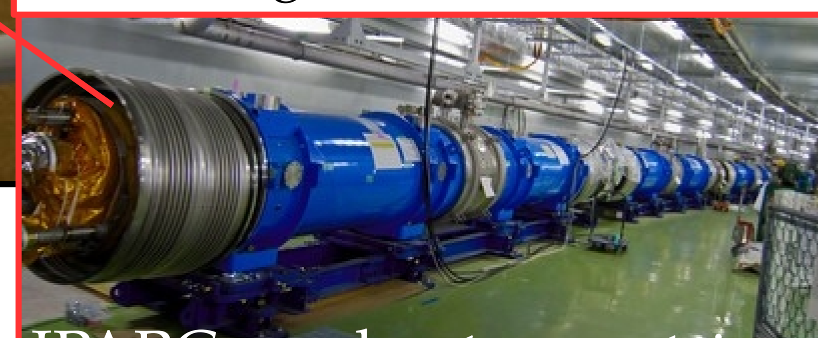


- Observe CP violation for leptons at 5σ
- Precise measurement of δ_{CP} .
- High sensitivity to ν mass ordering.

Supernovae neutrinos



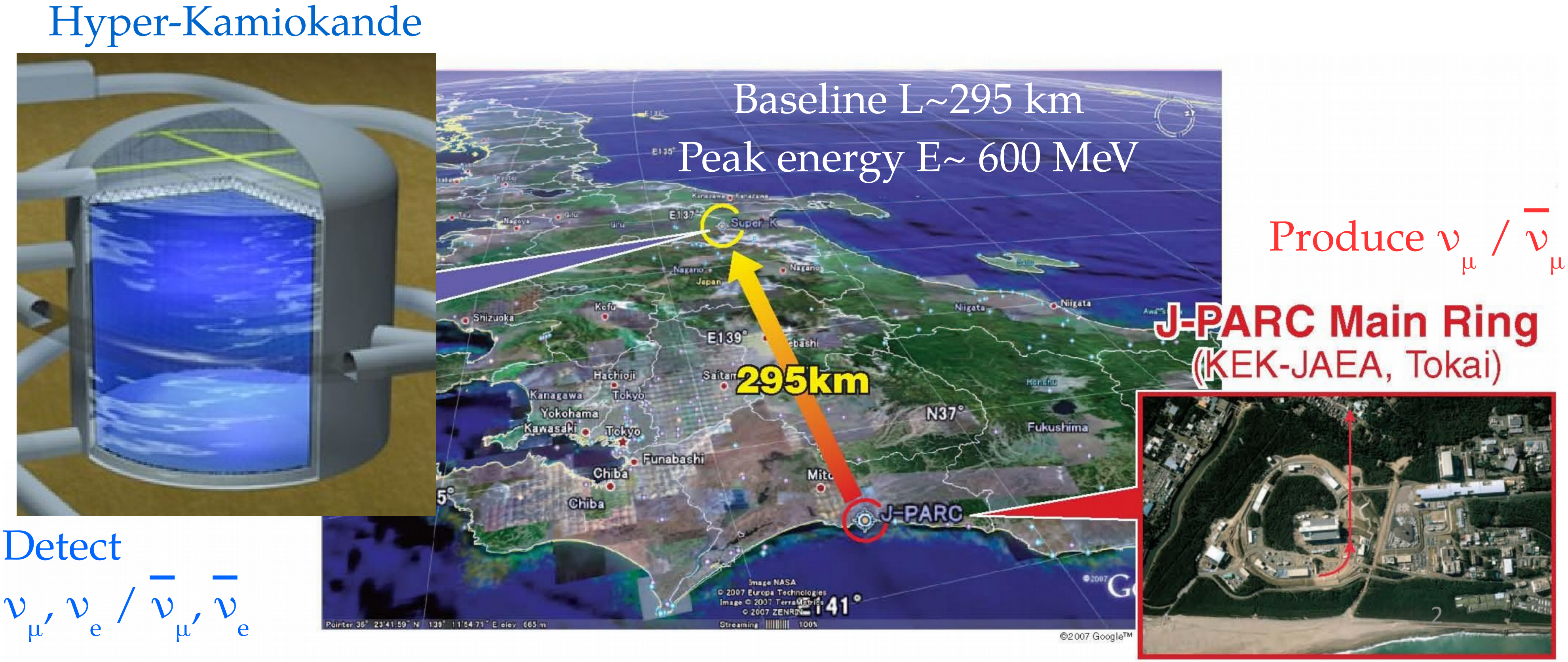
- Direct SNν : Constrains SN models.
- Relic SNν : Constrains cosmic star formation history



JPARC accelerator neutrinos

Focus on CP violation

- CP violation search essentially based on accelerator ν : T2HK



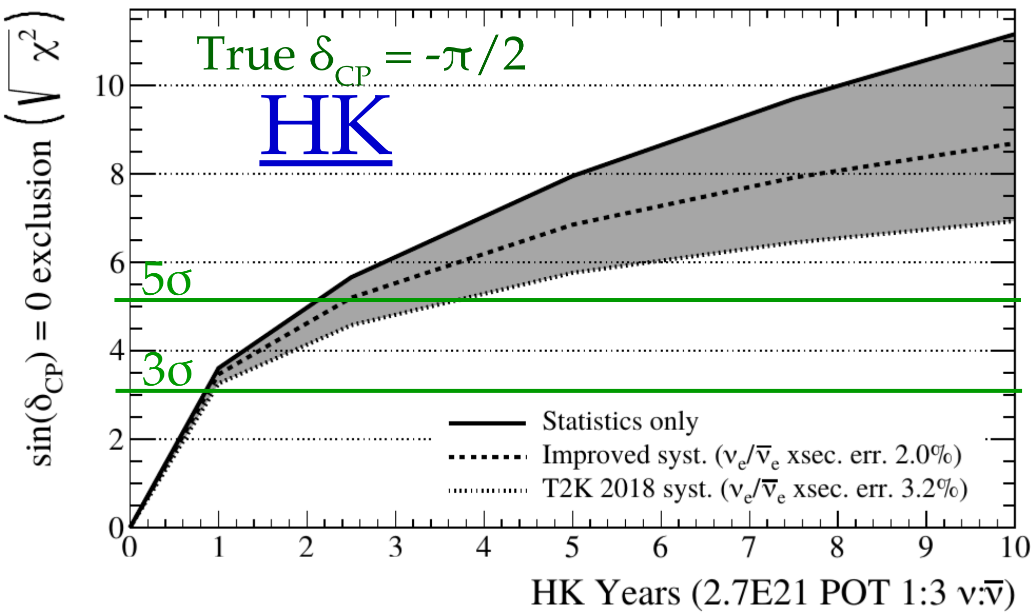
- ν_e appearance in a ν_μ beam and ν_μ disappearance & $\bar{\nu}$ equivalents.
- Detector technologies, calibration, analyses well-proven by T2K&SK.

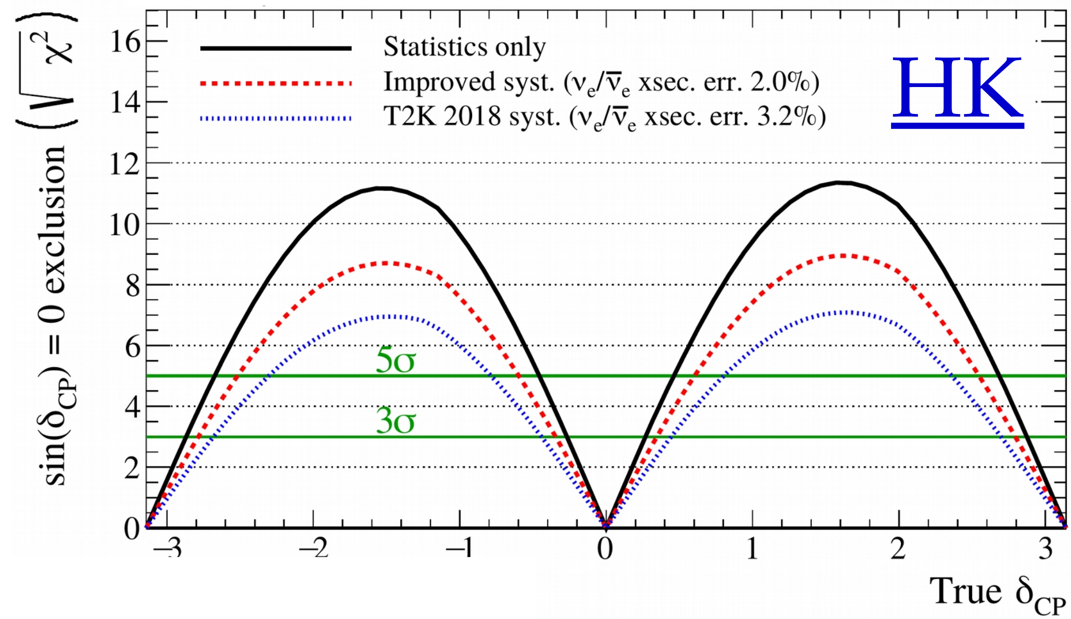
$\Longrightarrow$ Quick start ! Which relies on 2 milestones :

1. $\downarrow$ time to accumulate statistics $\rightarrow$ Beam upgrade.
2. $\downarrow$ systematic uncertainties $\rightarrow$ Constrains ν_μ&ν_e flux before oscillation

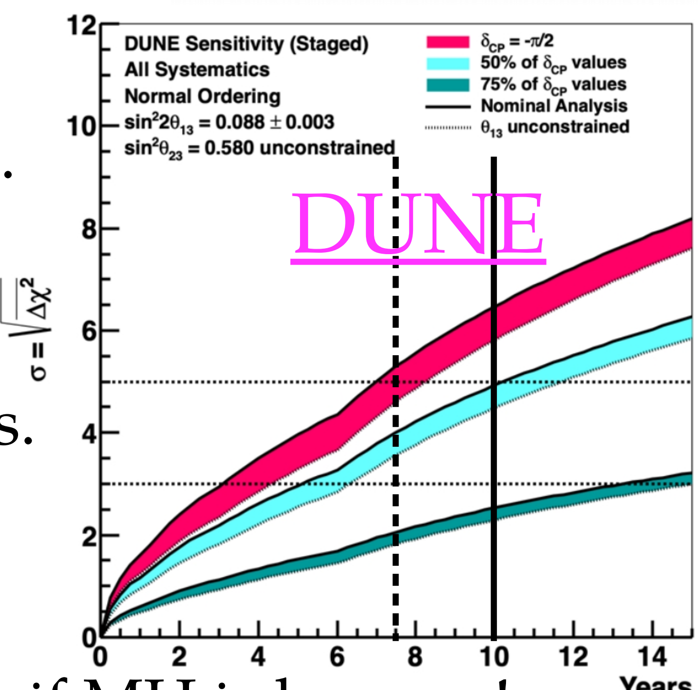
Sensitivity to CP violation

- Assuming a run $\nu:\bar{\nu}$ = 1:3 @1.3MW (can be adjusted).





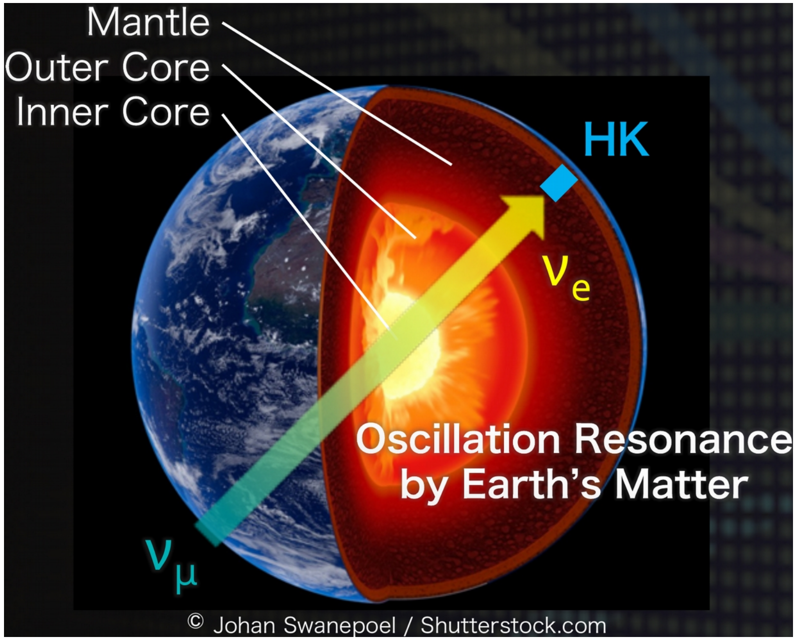
- $\delta_{CP} = -\pi/2$: 5σ after 2-4 years of data taking
  - → Independent from ↓ systematic uncertainties.
  - → DUNE will require 7-8 years.

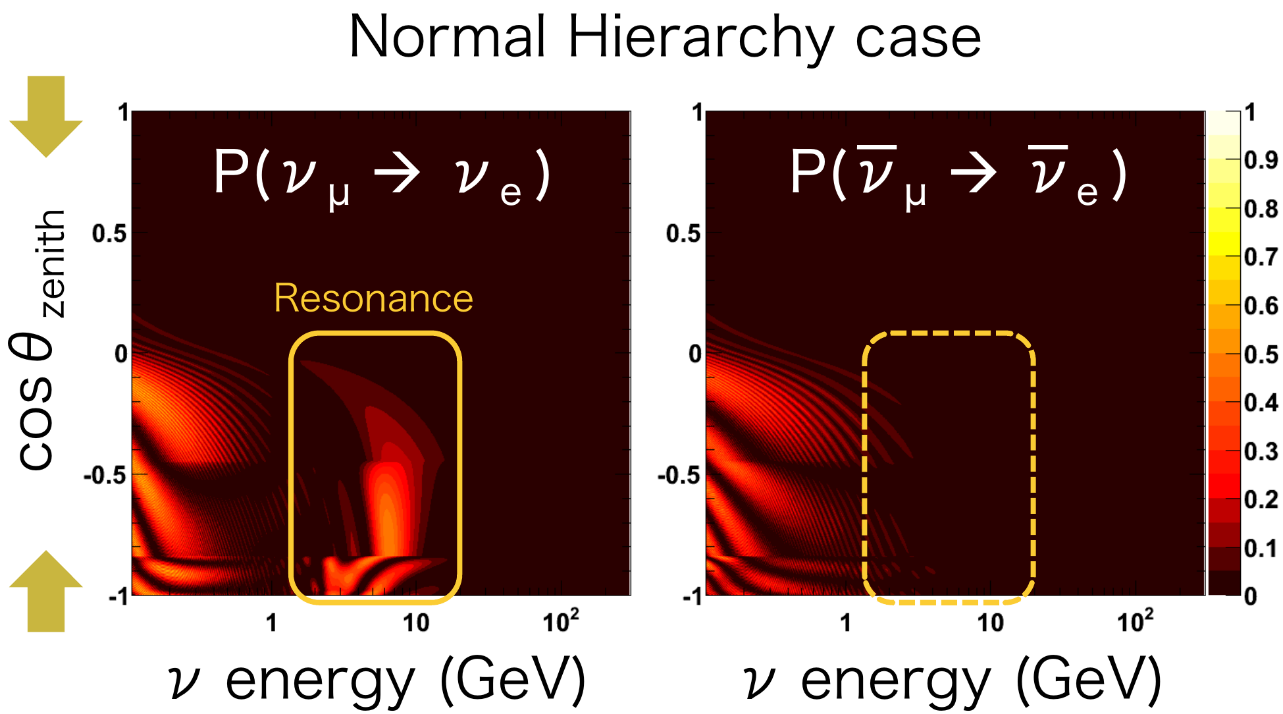


- HK 10 years : 5σ sensitivity on 60% of δ_{CP} values.
  - → DUNE : 5σ sensitivity on 40%
- HK has world-best sensitivity to CP violation … if MH is known !

Atmospheric neutrinos

- Mass-hierarchy can be accessd through matter effects
  $\rightarrow$ The longer the baseline, the higher the effects





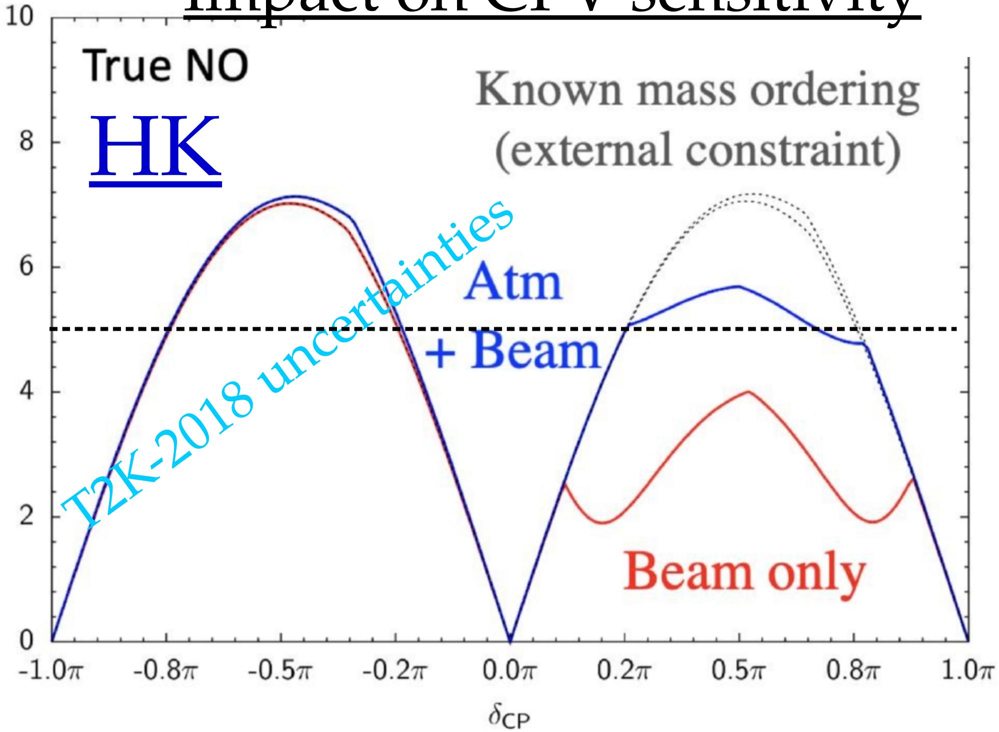
- Mass hierarchy determined with upward-going multi-GeV ν_e sample :

atm. baseline ≤ 13000 km ≫ 295 km accelerator baseline

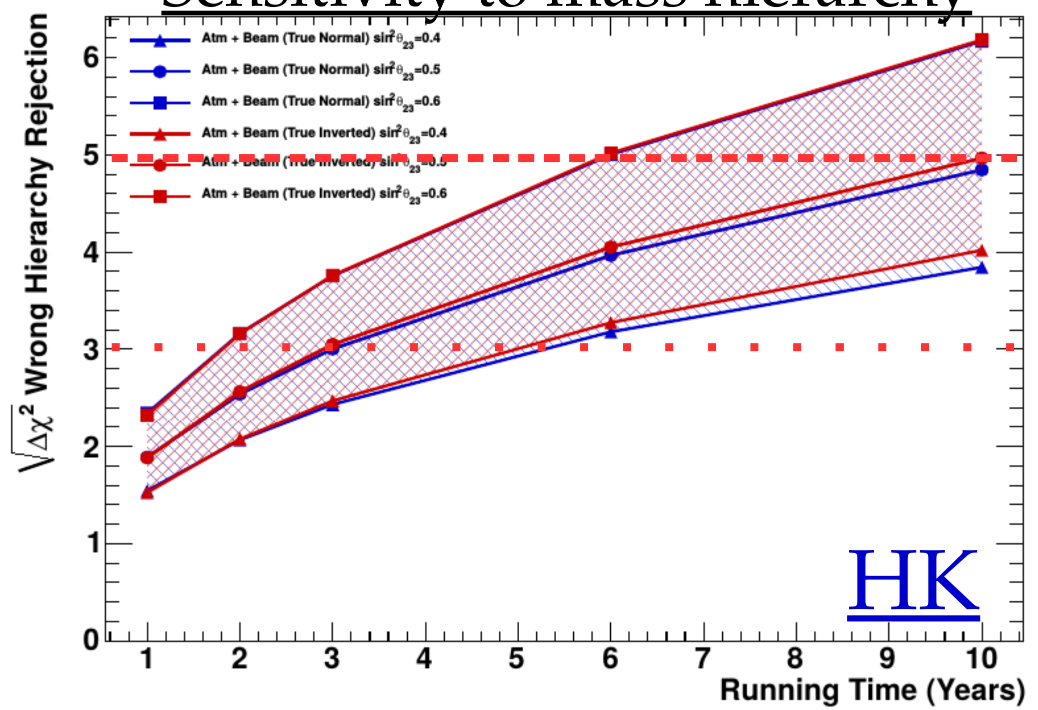
  - Normal hierarchy : enhancement of $\nu_\mu \rightarrow \nu_e$.
  - Inverted hierarchy : enhancement of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$.

Combination of atmospheric + beam ν

Impact on CPV sensitivity



Sensitivity to mass hierarchy



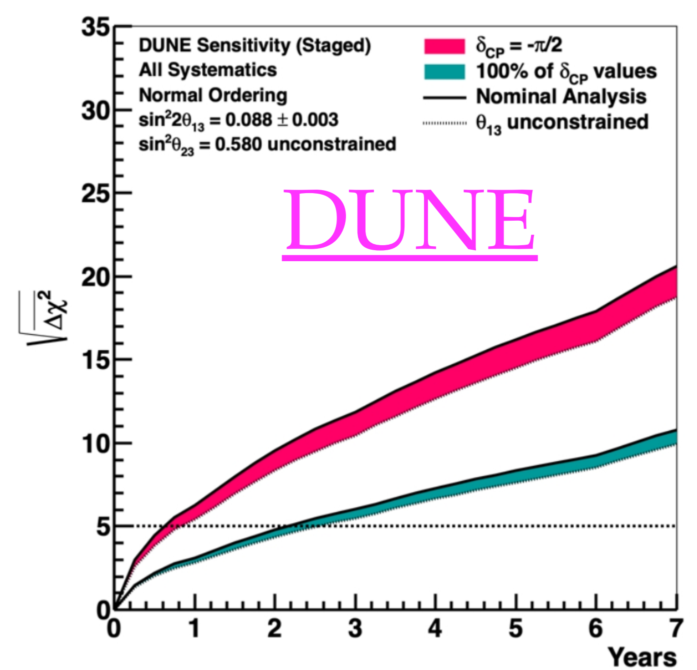
- Even if MH is not known when HK starts

→ Sensitivity to CPV is little affected if we add atmospheric ν.

- MH would be determined by :

  → HK after ≥ 6-10 years via atmospheric.

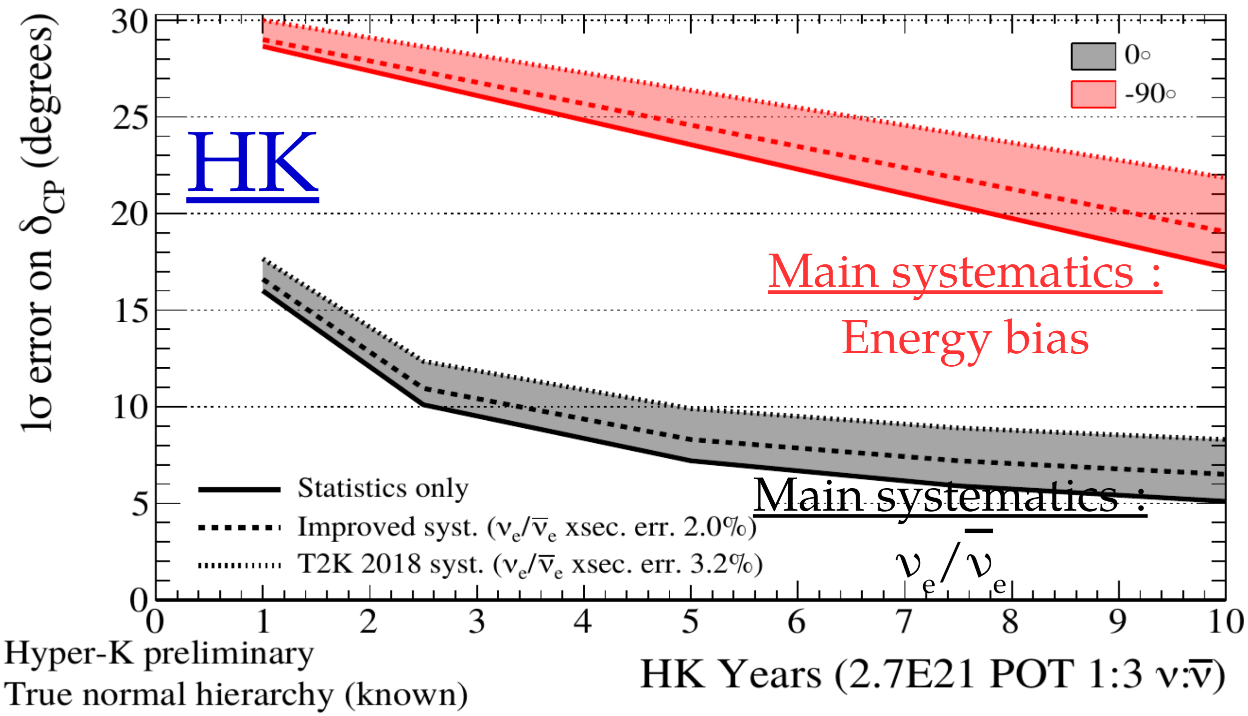
  → DUNE : after 1-2 years.

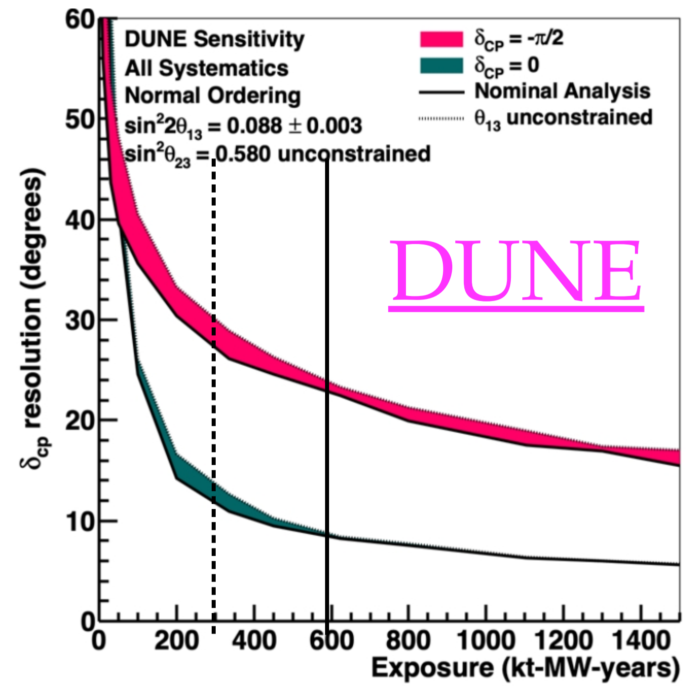


Precision of δ_{CP} measurement

- After CPV is determined, accurate measurement of δ_{CP} will be crucial

  → Maximal CPV, leptogenesis, symetries of lepton's generations ...



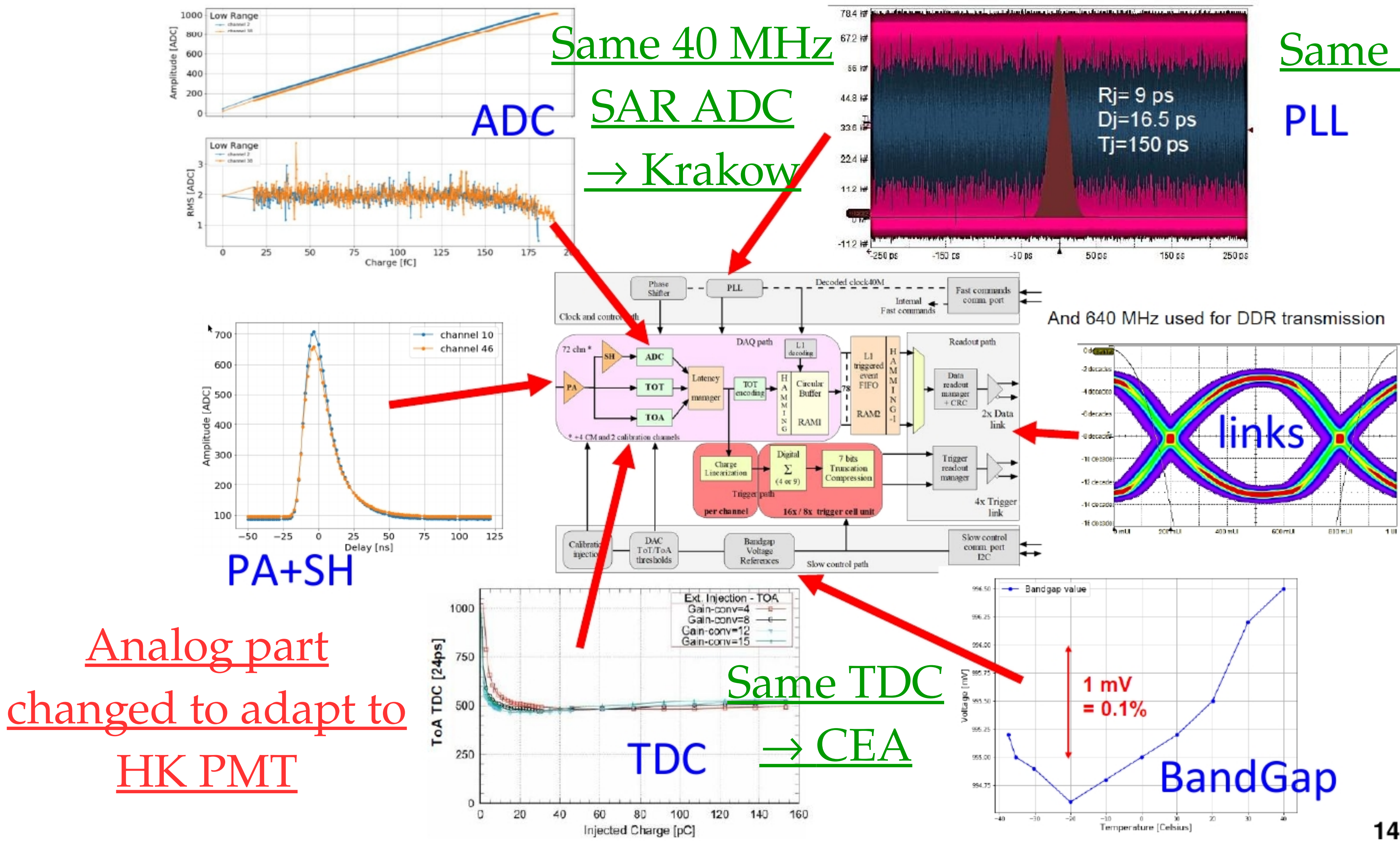


	5 years [HK & DUNE]	10 years [HK & DUNE]
CP conserved $\delta_{CP} = 0$	8° & 13°	6° & 9°
$\delta_{CP} = -\pi/2$	25° & 29°	19° & 24°

- HK will be the leading experiment for CPV & δ_{CP} measurements in the next 20 years.

Origins of the HKROC : the CMS HGCROC

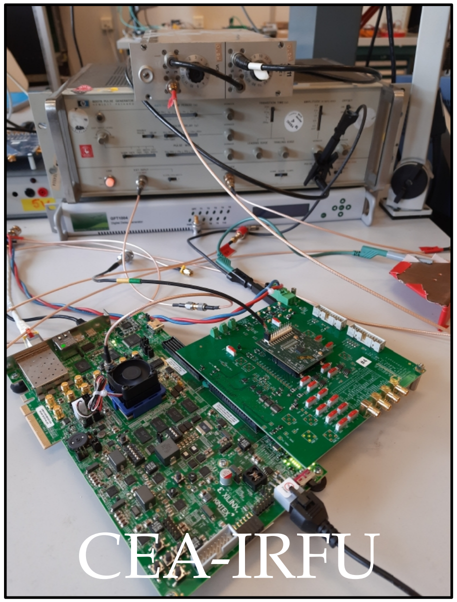
- HKROC based on HGCROC : chip developed for CMS-HGCalorimeter
  → Rely on many years of expertize & tests.

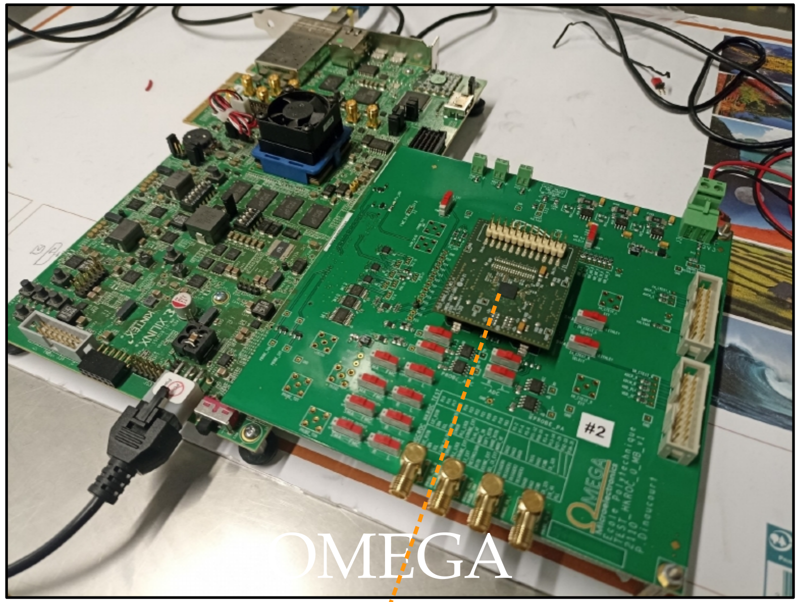


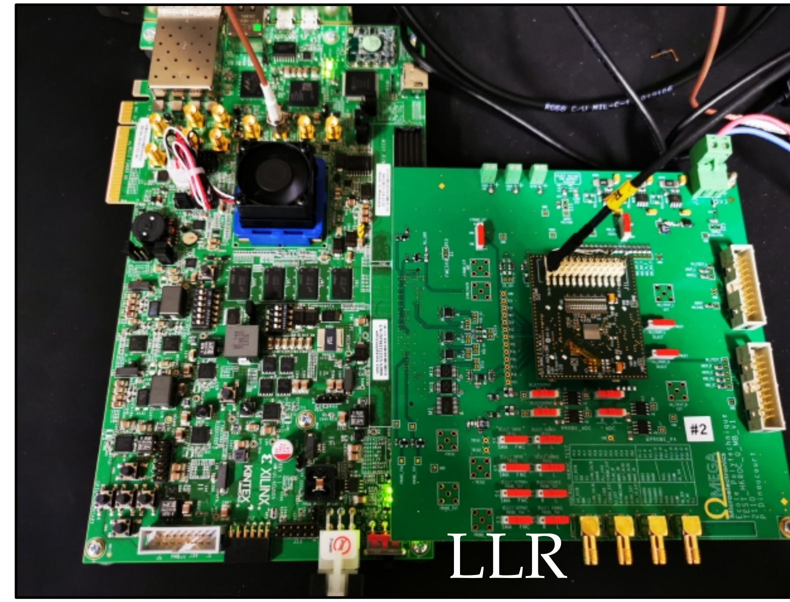
- Same experts have developed the HKROC (OMEGA, CEA, LLR).
  → Great synergy between our projects !

Performances of the HKROC digitizer

- Measurements @3 test bench/labs in parallel : CEA, OMEGA, LLR.
  → High redundancy to ↓ risk of mistakes.
  → Ready for the pre-production & production tests, also @3 labs.



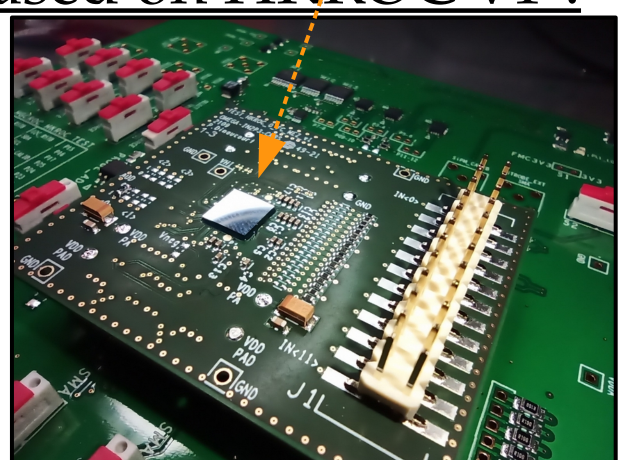


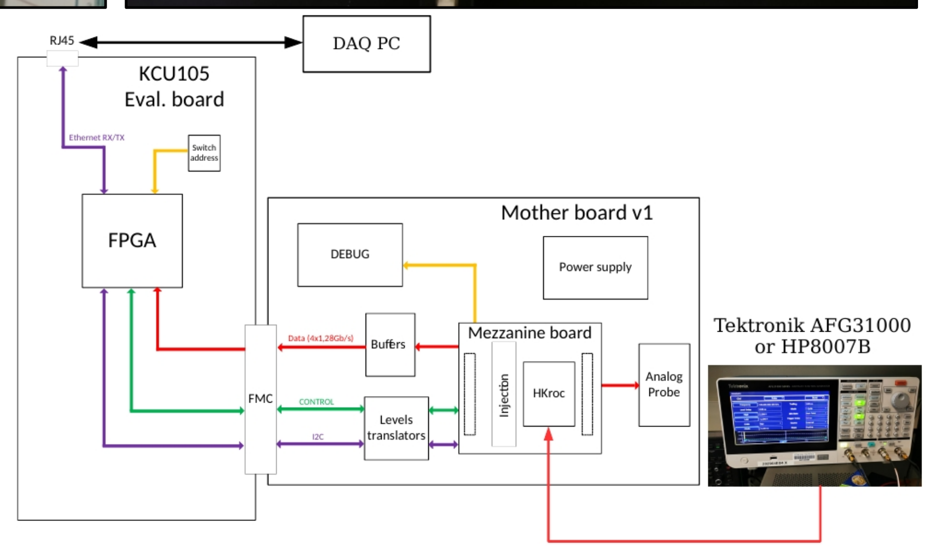


- Measurements based on HKROC v1 :

→ Back fom prod. on 01/28.

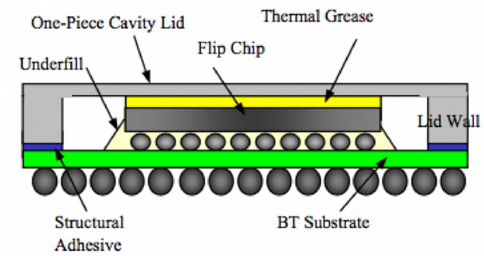
→ Chip size : 5 mm x 5 mm [Ultra-compact]



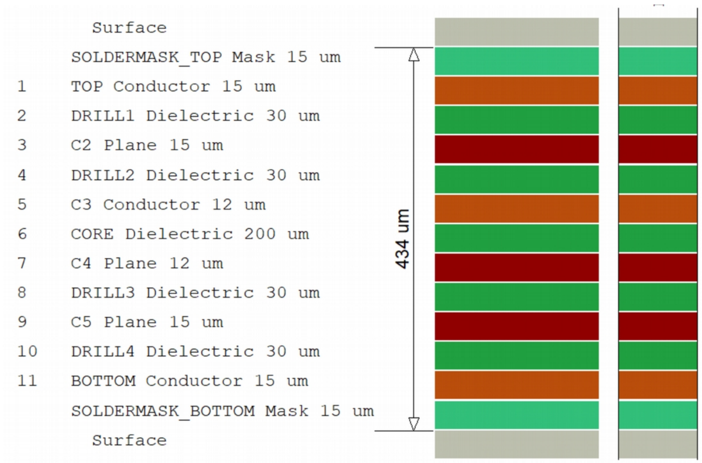


HKROC digitizer planning : ASIC

- <u>Current version v1 :</u> mounted on board w/ flip-chip.



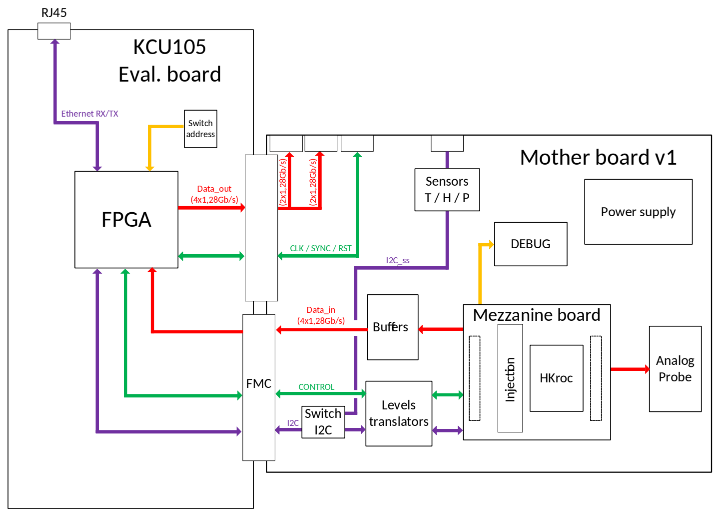
- <u>BGA-package for final board :</u> ordered & in prod.
  → To be received in September.

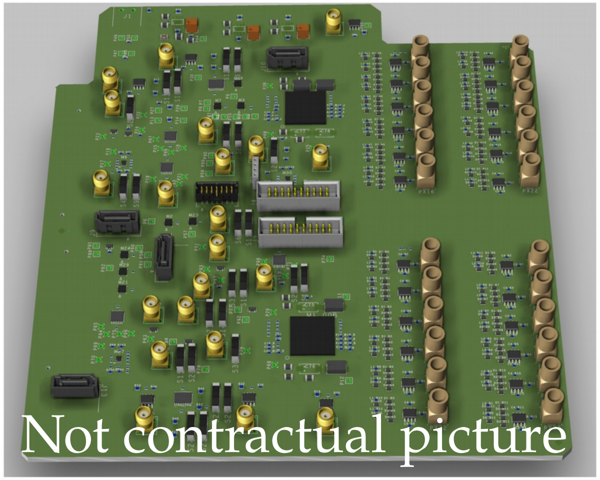


- <u>Version v2 :</u> A TSMC run for OMEGA already scheduled in Dec. 2022.
  → Will use it to fine tune HKROC for HK.
  → Completely remove cross-talk.
  → <u>Likely to submit 2 versions :</u>
  - <u>v2-A :</u> minimal change wrt v1 for safety.
  - <u>v2-B :</u> more aggressive changes to ↑ hit-rate largely beyond our requirements.

HKROC digitizer planning : Board

- Prototype v1 : Same as final prototype board except for the FPGA & Interface with PC left on the KCU105.



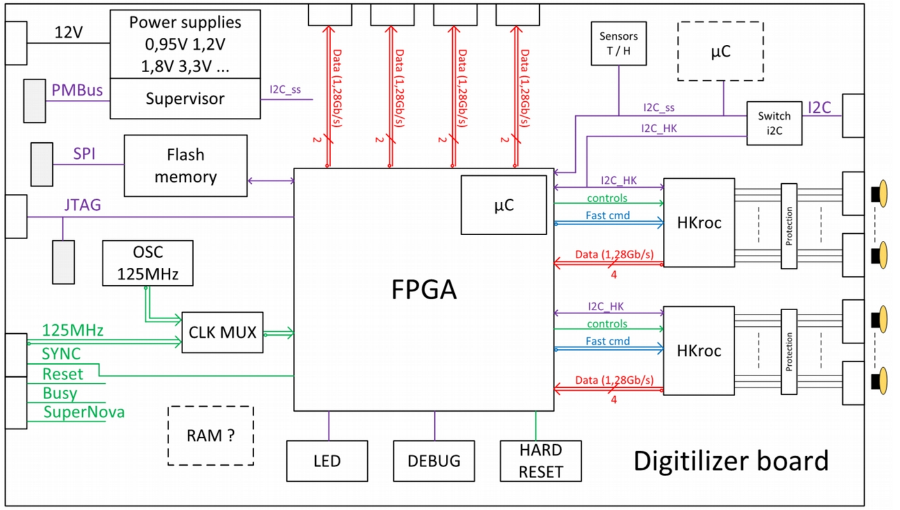


- Test whole circuit from analog to digitized points.
- Test the 2 HKROCs.
- Tests communication with DPB (Curro & al.)

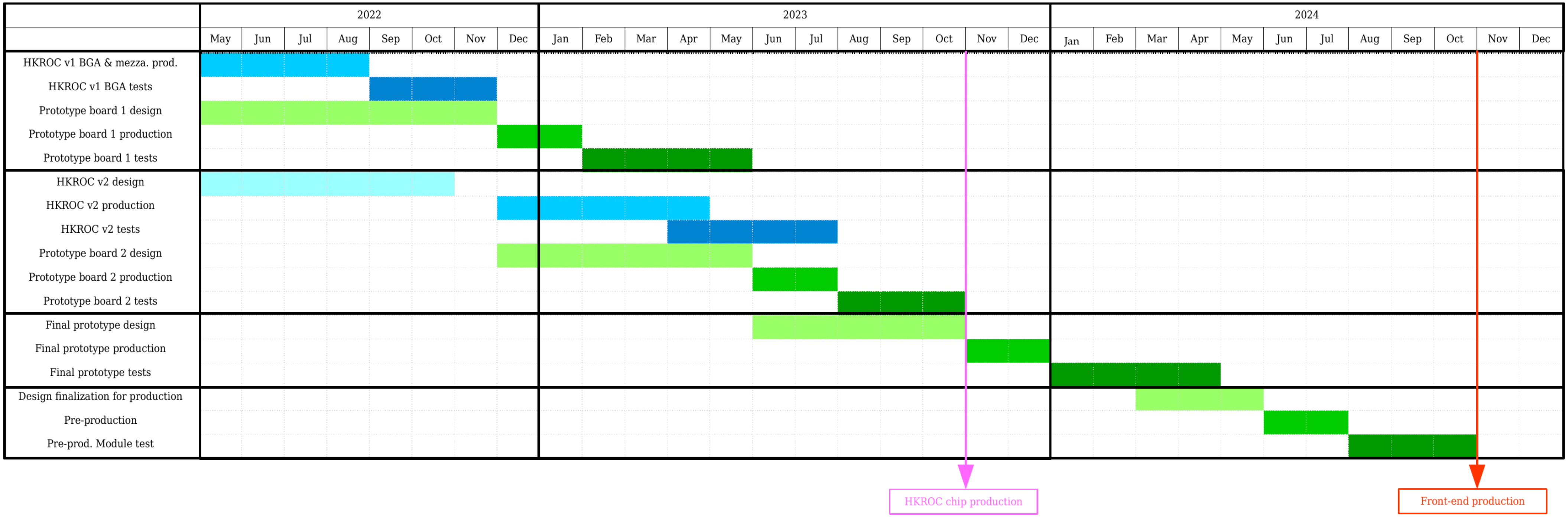
→ Schematics well-advanced (based on current mother board).

→ 1 HKROC-board in 2022/09, 2 HKROC board in 2023/01.

- Prototype v2 : The final prototype board.
  → To be received in summer 2023.



Updated schedule towards production



- <u>ASIC production could be done in advance :</u> from end of 2023.
  → Have **<u>3 operating ROBOT</u>** to test them at CEA, LLR & OMEGA (used for CMS to test 200,000 HGCROC chips).

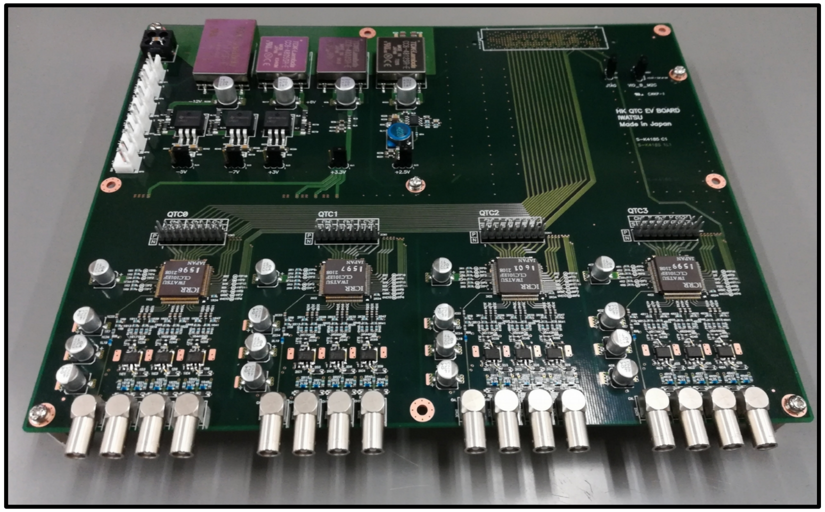
- <u>Board production :</u> from Q4 2024 to mid-2025.

- We are completely on-time !

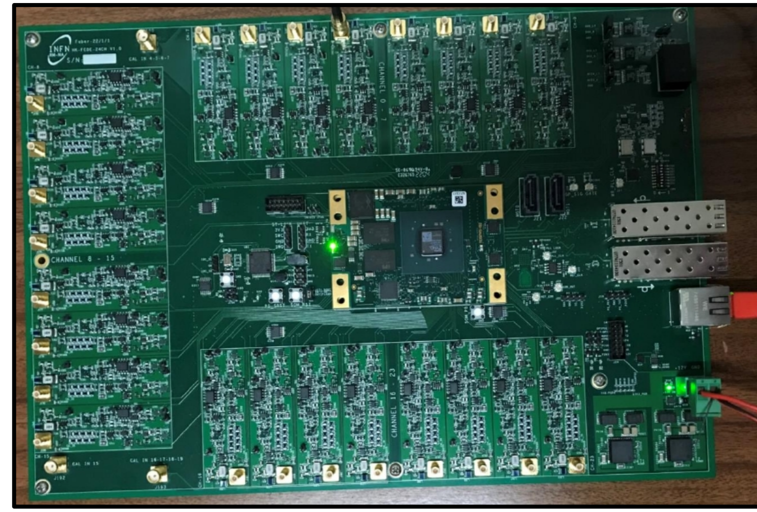
The Hyper-K candidate digitizers

- <u>3 digitizers considered :</u> all high-specs but explore ≠ digitization method

<u>QTC digitizer (Japan)</u>



<u>Discrete digitizer (Italy)</u>



	QTC	Discrete	HKROC
Charge digitizer	ASIC (QTC)	Commercial ADC	ASIC (HKROC)
Digitization method	Charge integration	Charge integration	Waveform digitizer
TDC	On FPGA	Same as QTC	HKROC internal TDC

- All 3 solutions will likely match the specs.
- Internal review will finish next week.
- Collaboration review has started

→ Decision by end of July.