Status of Hyper-Kamiokande

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on behalf of HK-France

GDR neutrino, 2020/11/24

Outline of the talk

1. Status of Hyper-Kamiokande project and construction.

2. Hyper-Kamiokande new sensitivity results.
→ Previous ones where shown at GDR :
https://indico.in2p3.fr/event/17355/contributions/66478/attachments/50836/65049/HyperK_20181105_StatusOfHyperKamiokande_Quilain_v2.pdf
https://indico.in2p3.fr/event/19474/contributions/75235/attachments/55611/73365/T2K_HK_GDR_Bordeaux.pdf

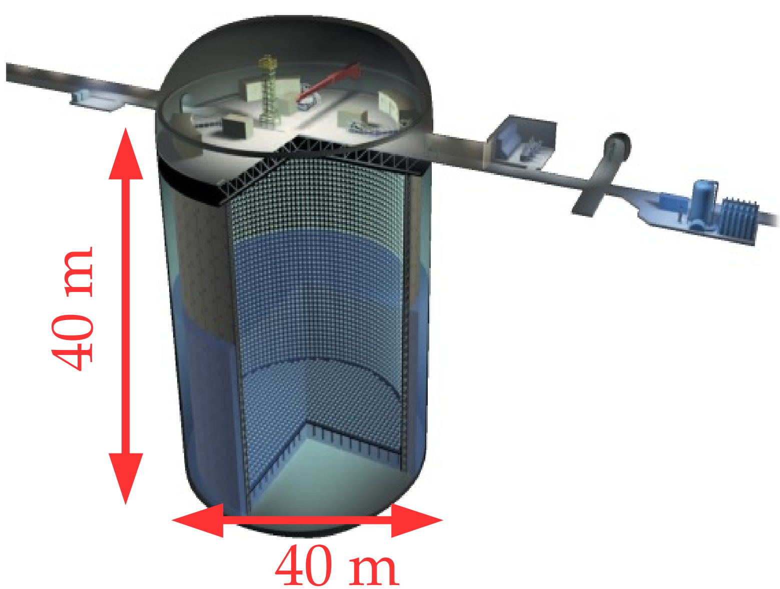
3. Focus on French hardware R&D and contributions.

I. Status of Hyper-K project and construction

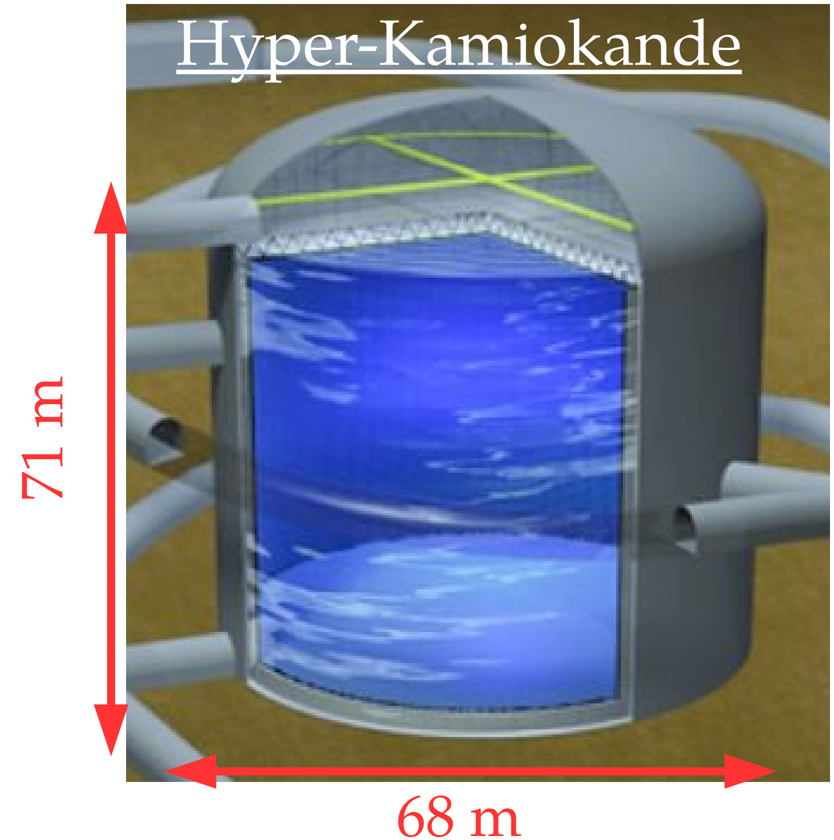
What ?

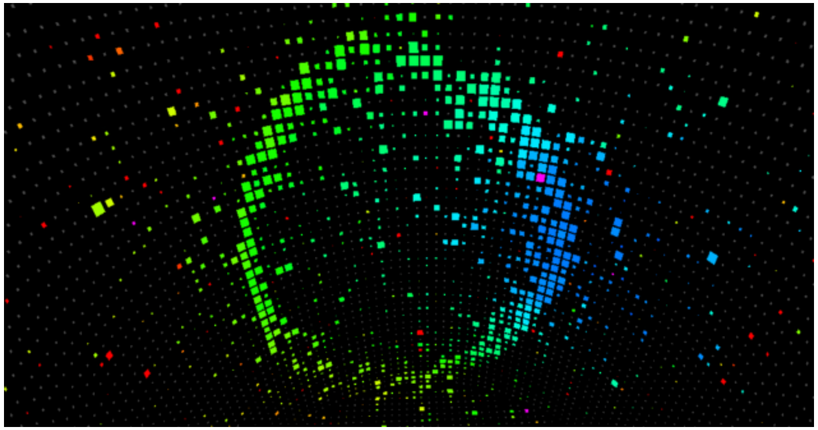
- Next generation of neutrino observatory in Japan→ construction 2020-27
  → A 260 kton water Cherenkov detector → <u>Fiducial Mass ~ 8 x SK.</u>

<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% (**×2 sensitivity**)
Mass / Fiducial Mass	50 kton / **22.5 kton**	260 kton / **187 kton**

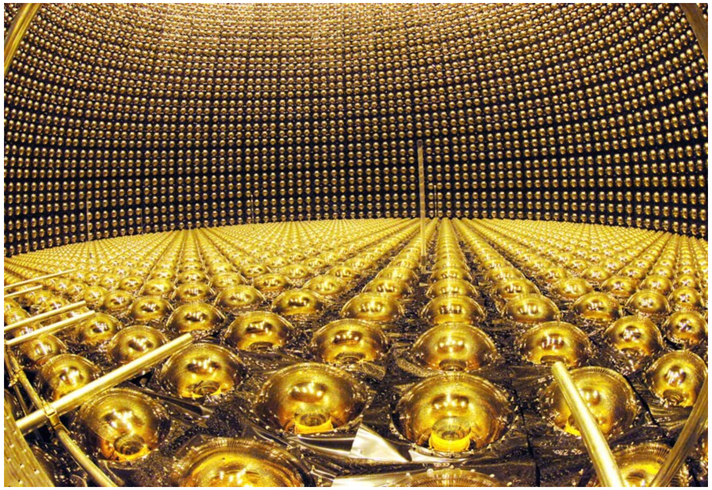
Hyper-Kamiokande final approval

- Last presentation @GDR : HK approved by MEXT (Japan Ministry of Research).

Japan will build the world's largest neutrino detector

Cabinet greenlights US$600-million Hyper-Kamiokande experiment, which scientists hope will bring revolutionary discoveries.

- 2019/12 : HK budget has been officially approved by the Japanese ministry of finance.



- 2020/02 : HK budget voted by Parliament.

→ Project officially starts !

The overall Japanese contribution will include the cavern excavation, construction of the tank (water container) and its structure, half of the photosensors for the inner detector, main part of the water system, Tier 0 offline computing, together with J-PARC accelerator upgrade and construction of a new experimental facility for the near detector complex. International contributions will include the rest of photosensors for the inner detector, sensor covers and light collectors, photosensors for the outer detector, readout electronics, data acquisition system, water system upgrade, detector calibration systems, downstream offline computing system, and the near/intermediate detector complex.

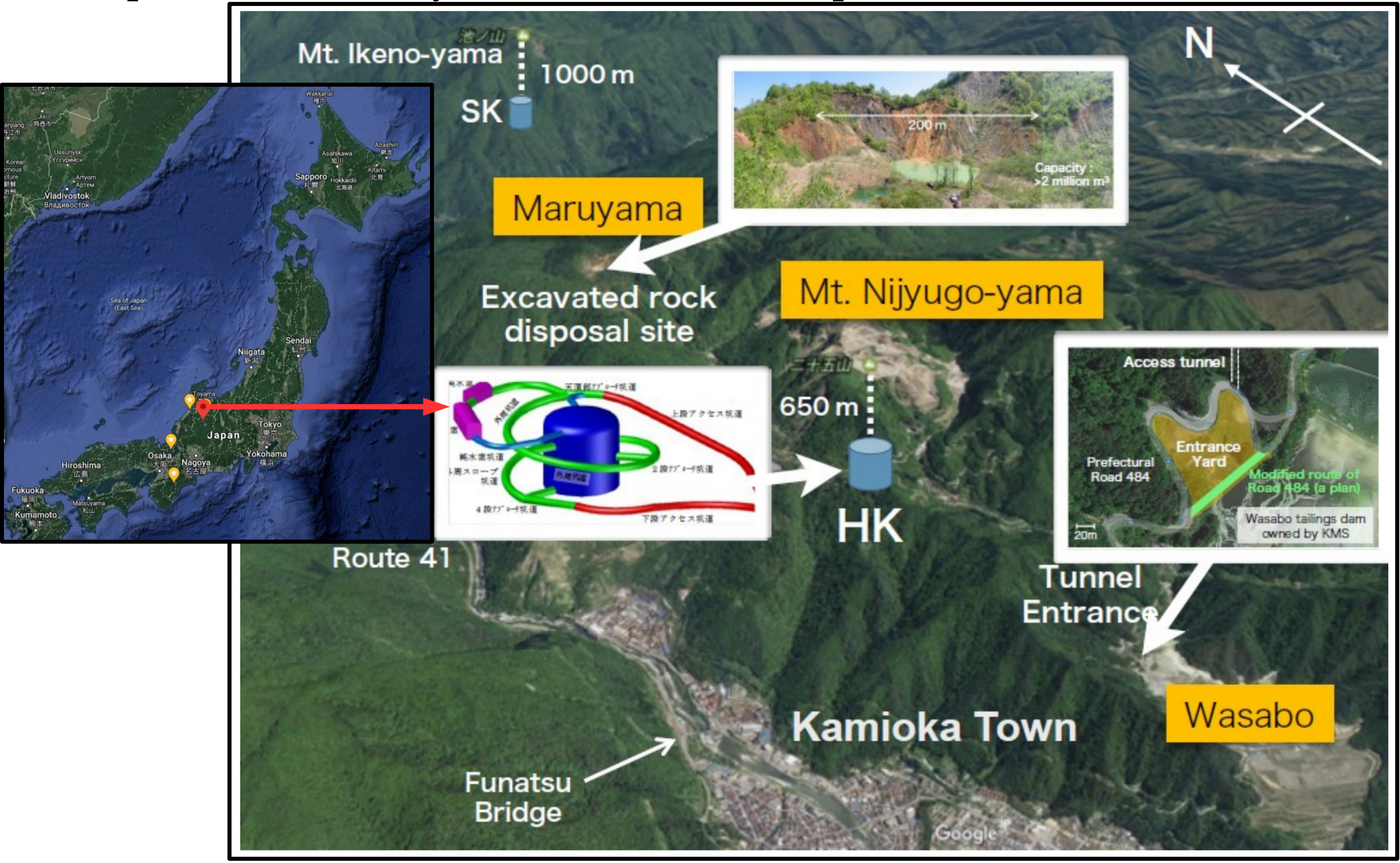
→ 25 % of the total budget from International contributions expected.

→ Lots of possibilities for contributions w/ high visibility.

- 2020/04 : Construction of HK has started !

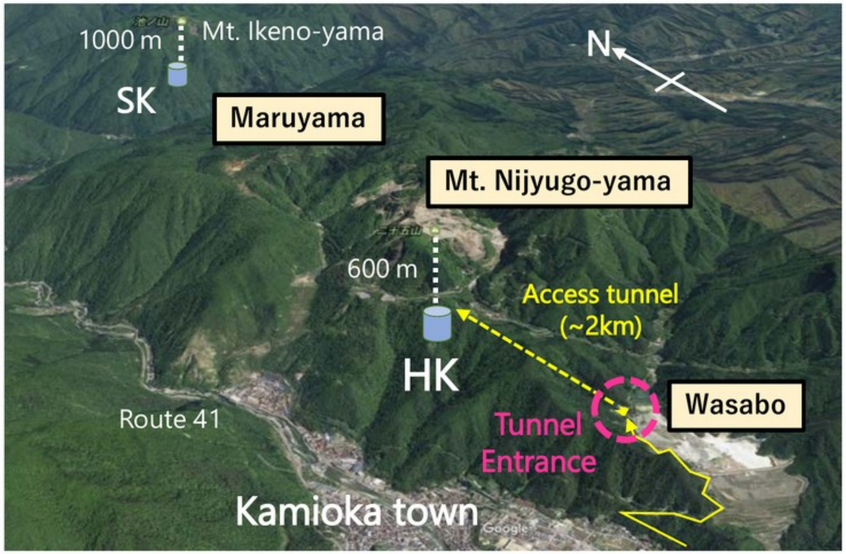
Where ?

- In Japan, ~10km away from the current Super-Kamiokande detector



Location of entrance

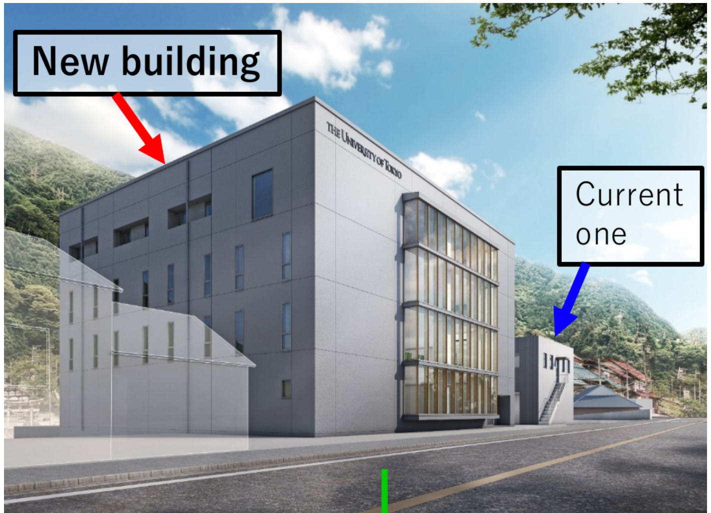
Construction of the entrance yard



Construction of entrance yard in Wasabo was completed.

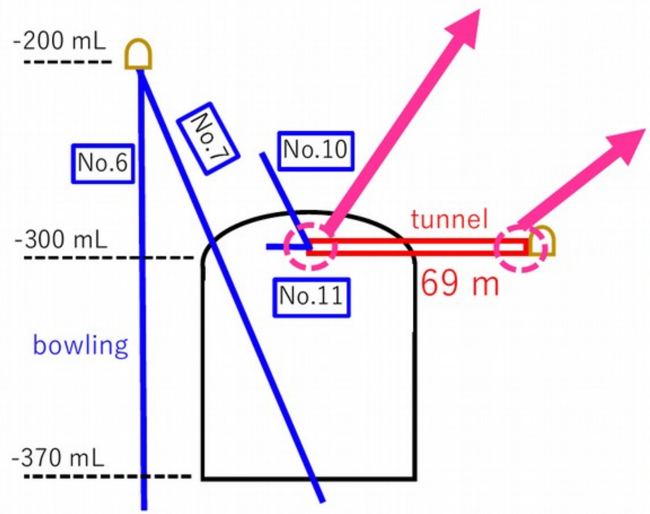
- Construction of the entrance yard and water treatment facility is finalized.

Construction of the cavern tunnel



Around center of HK tank-top

Construction of base structure is ongoing.



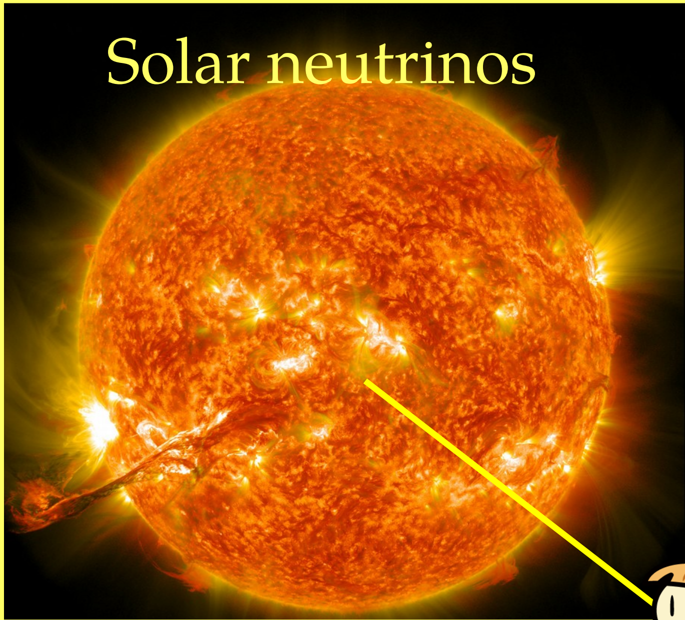
- The much larger and new research center is under construction in Mozumi.
→ Finalized next summer !

- Reached top of future HK tank !

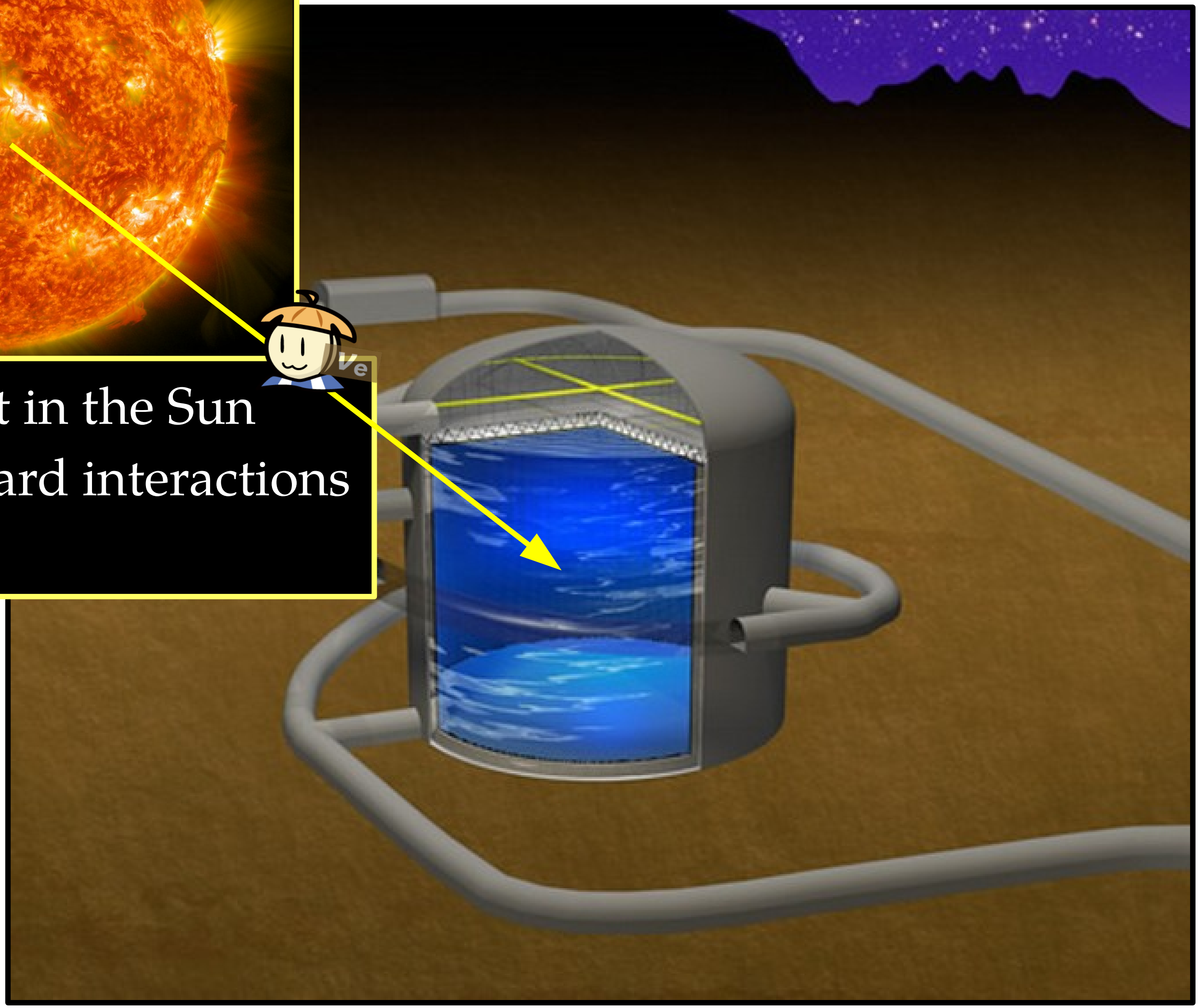
- The 11th (!) rock quality check is done
→ So far, no problem for excavation.

II. Updated HK sensitivities

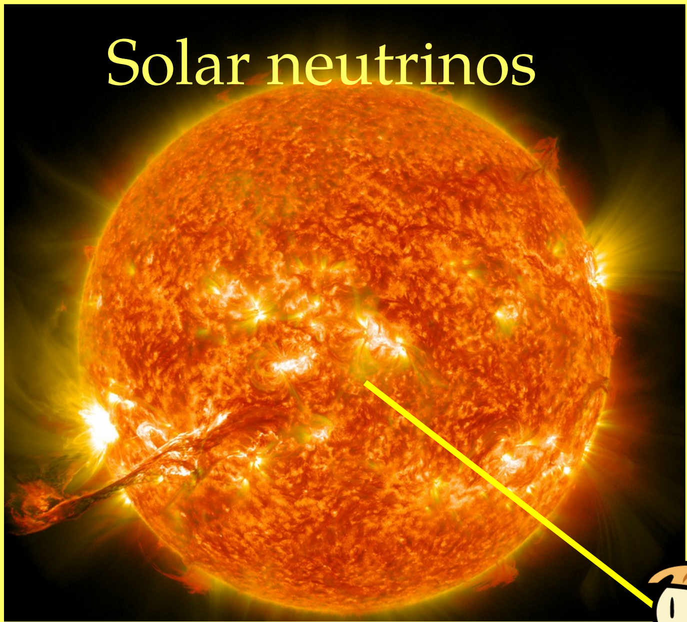
Physics case



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



Physics case



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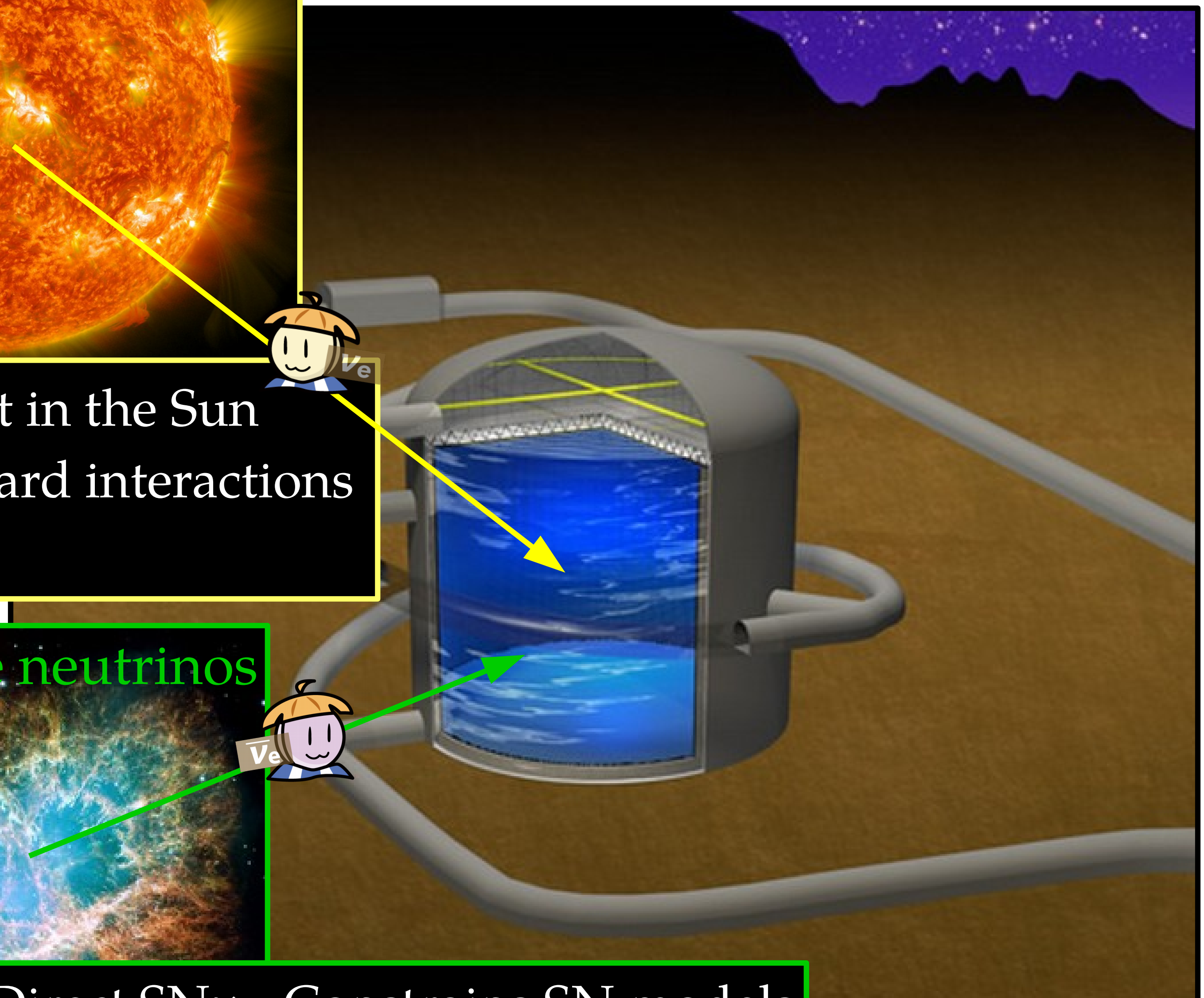
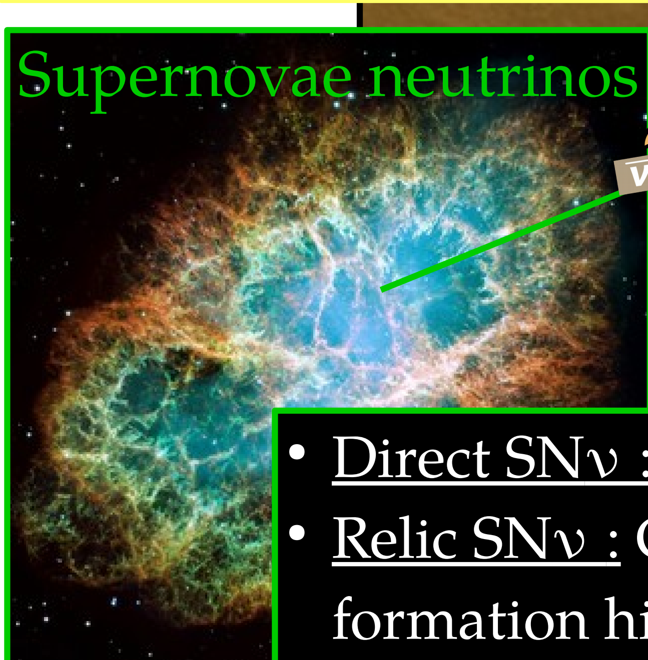
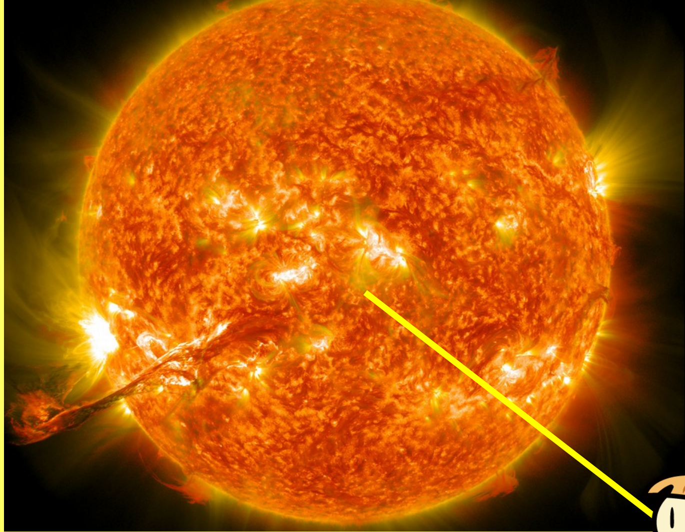




- <u>Direct SNν :</u> Constrains SN models.
- <u>Relic SNν :</u> Constrains cosmic star formation history

Physics case

Solar neutrinos



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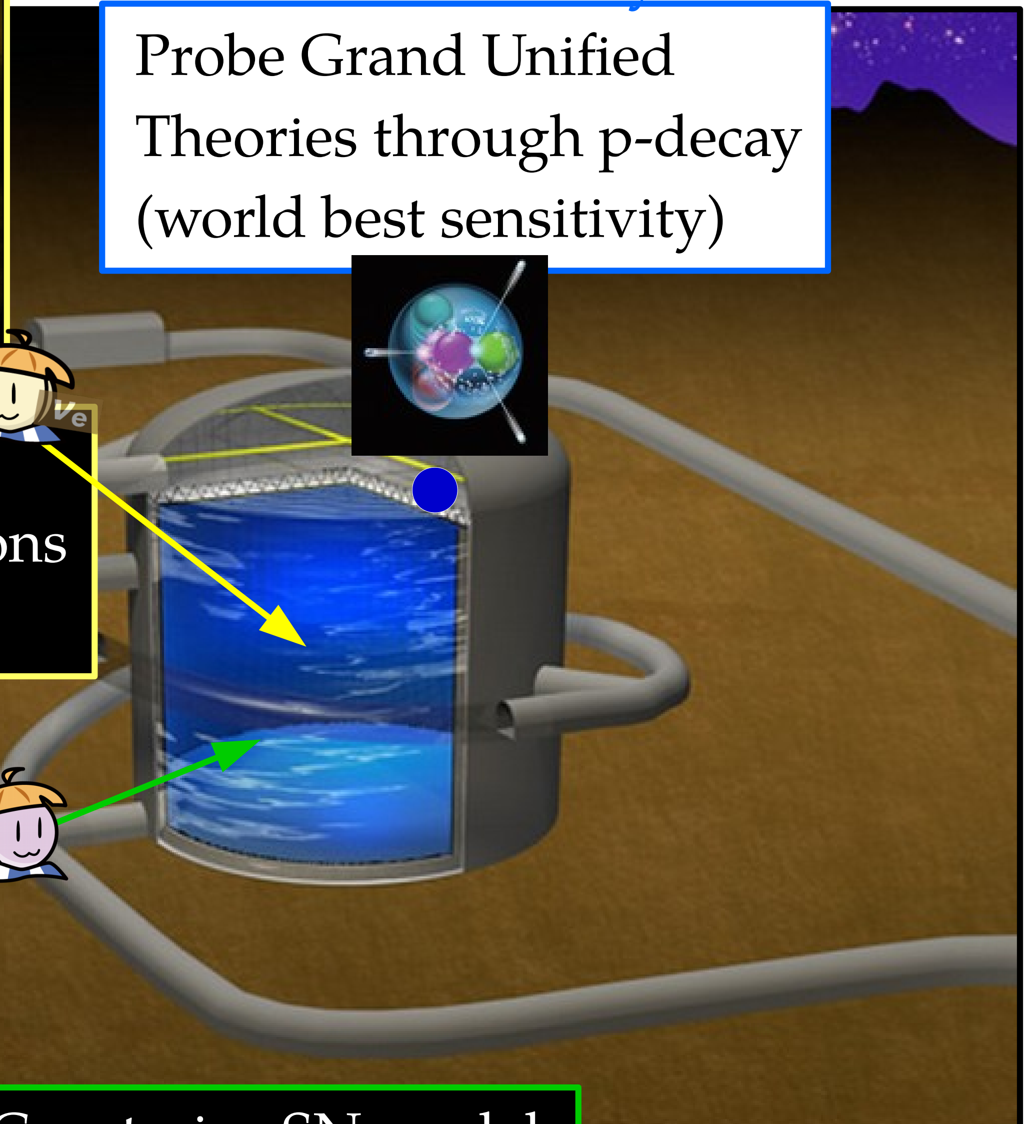
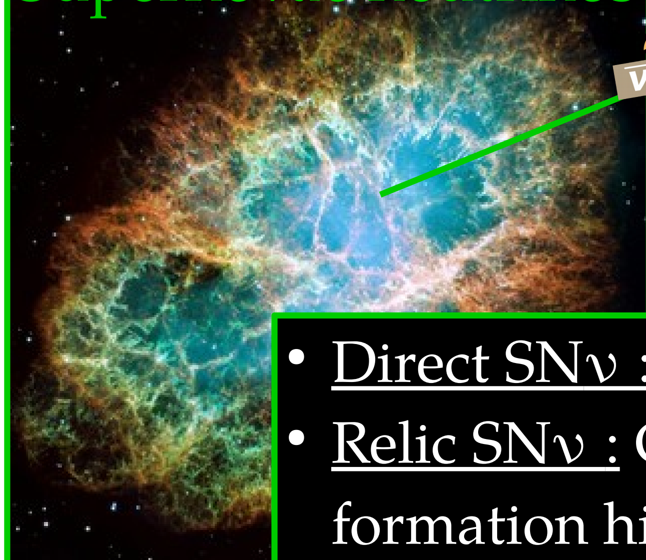
Proton decay

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



Supernovae neutrinos



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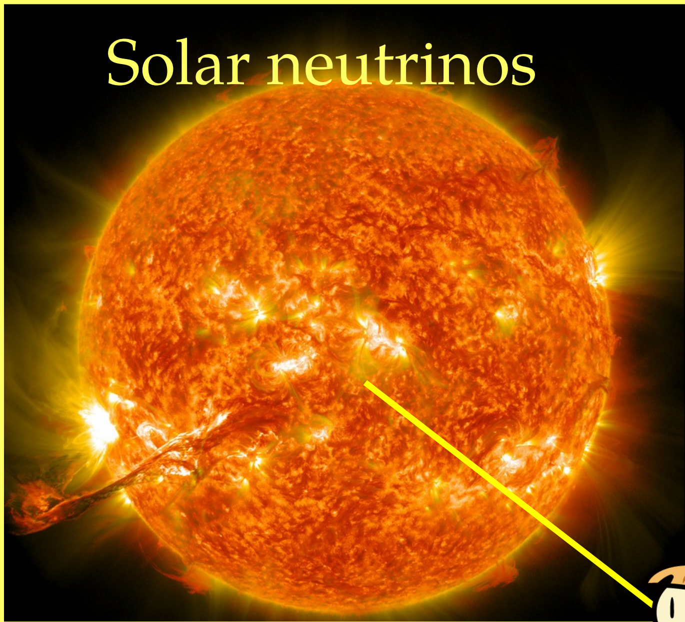
Physics case

Solar neutrinos



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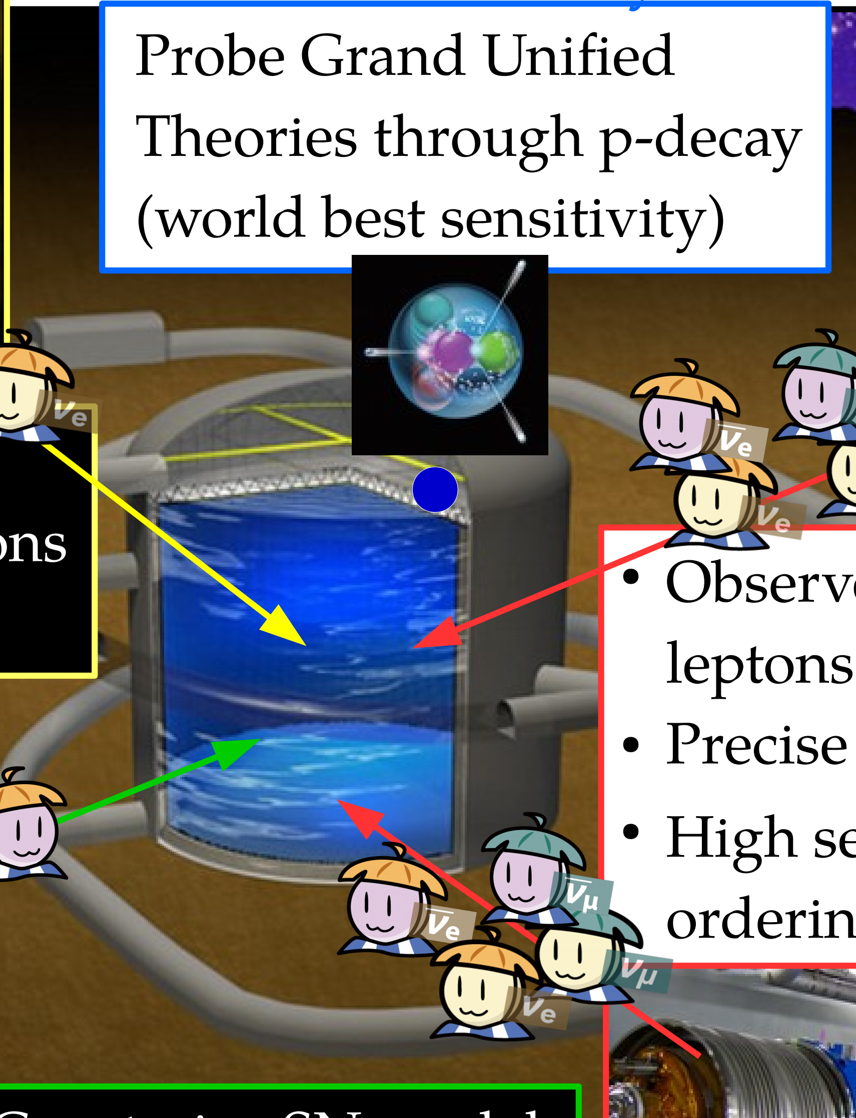
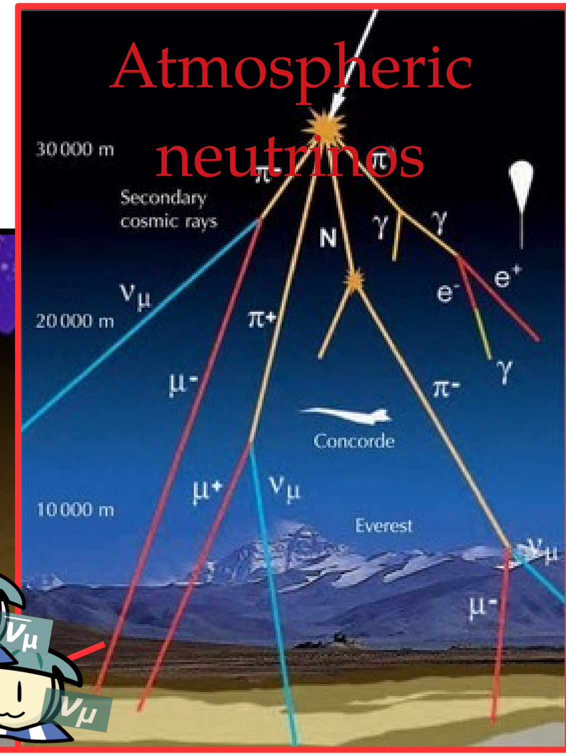
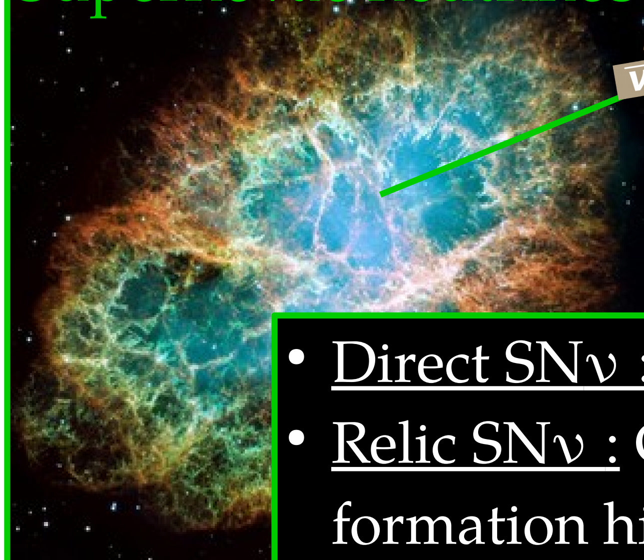


Atmospheric neutrinos



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

Supernovae neutrinos



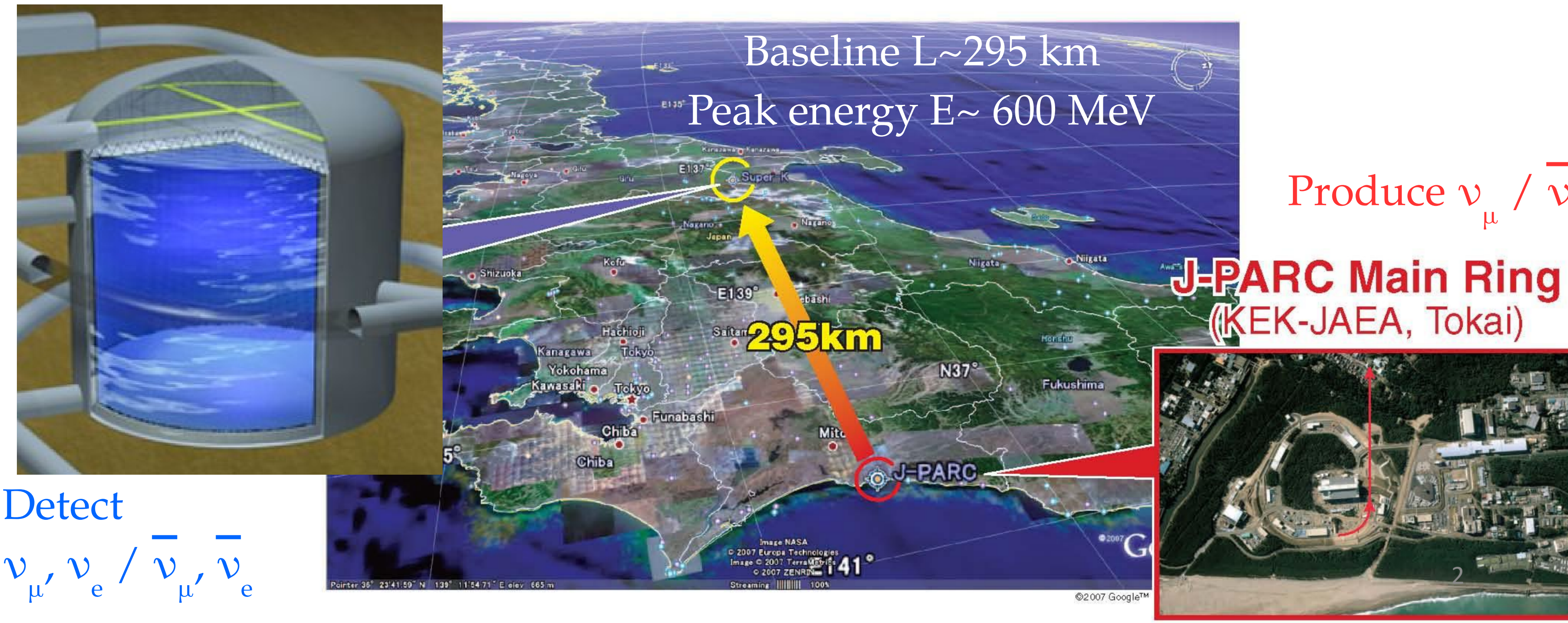
- Direct SNν : Constrains SN models.
- Relic SNν : Constrains cosmic star formation history

JPARC accelerator neutrinos

Focus on CP violation

- CP violation search essentially based on accelerator ν : T2HK

Hyper-Kamiokande



Produce ν_μ / $\bar{\nu}_\mu$

Detect
ν_μ, ν_e / $\bar{\nu}_\mu$, $\bar{\nu}_e$

- ν_e appearance in a ν_μ beam and ν_μ disappearance & $\bar{\nu}$ equivalents.
- Detector technologies, calibration, analyses well-proven by T2K&SK.
- <u>⟹ Quick start ! Which relies on 2 milestones :</u>
  1. ↓ time to accumulate statistics → Beam upgrade (already shown at GDR)
  - 2. ↓ systematic uncertainties → Constrains ν_μ&ν_e flux before oscillation

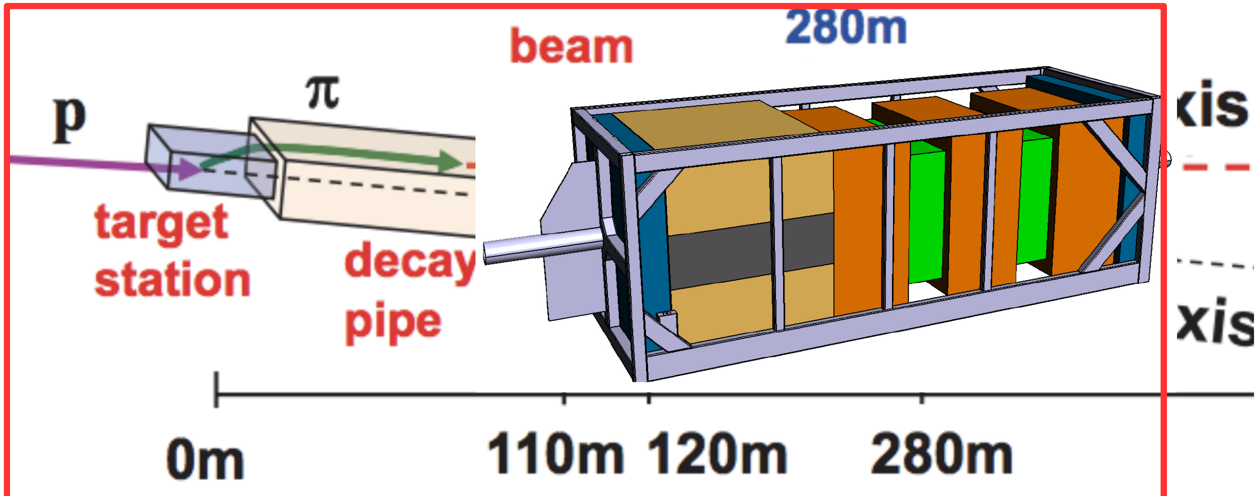
Updated systematic uncertainties

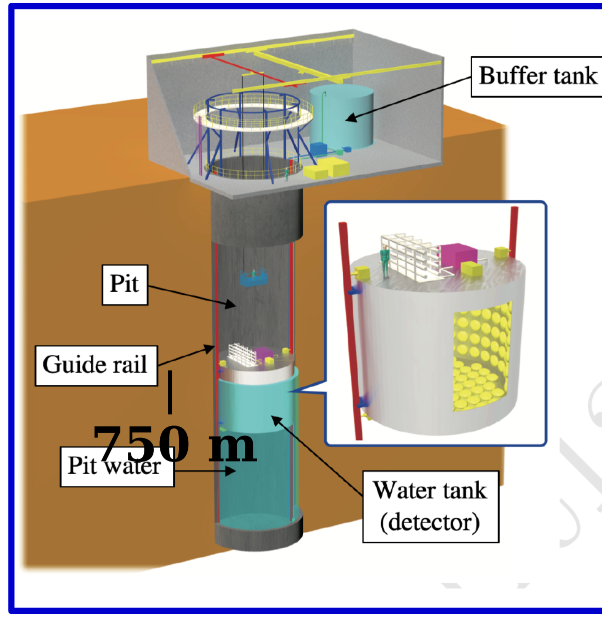
- Up-to-date flux & cross-section models : Updated to T2K 2018 model…

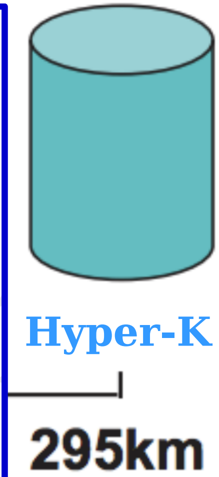
… which will be improved by the new Near Detector (T2K-II and HK).

Upgraded ND280
→ 2022 & possibly 2030

New Intermediate Water Cherenkov Detector







- Higher mass → ↑ statistics.
- High angle tracking.
- Finer granularity & ↓ E-threshold.

→ ↑ CC0π, CC1π, CCNπ separation.

→ ↑ measurements of 2p2h & FSI effects on sample migration.

→ Assumes ND280 upgrade improves only ν_μ measurements

Sample	QE	non-QE CC0π	CC1π CCOther	$\bar{\nu}$
Improvement	2.5 x √N	3 x √N	3 x √N	2 x √N

N = New data / data taken so far w/ T2K

Updated systematic uncertainties

Assumes IWCD upgrade ↑ only ν_e measurements.

$\nu_e/\bar{\nu}_e$ cross-section error is crucial.

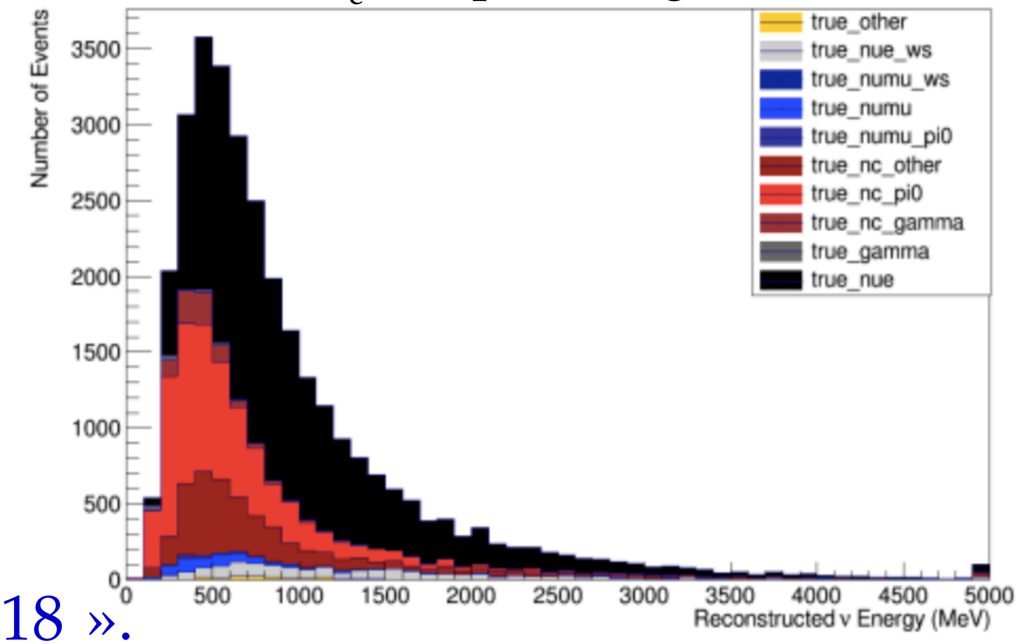
- IWCD : ↓ from 3.2% (T2K) to 2%.

→ « Improved systematics »

- Might be ambitious, so also used scenario w/ various improvements :

→ No $\nu_e/\bar{\nu}_e$ improvement ↔ « T2K 2018 ».

ν_e sample using IWCD

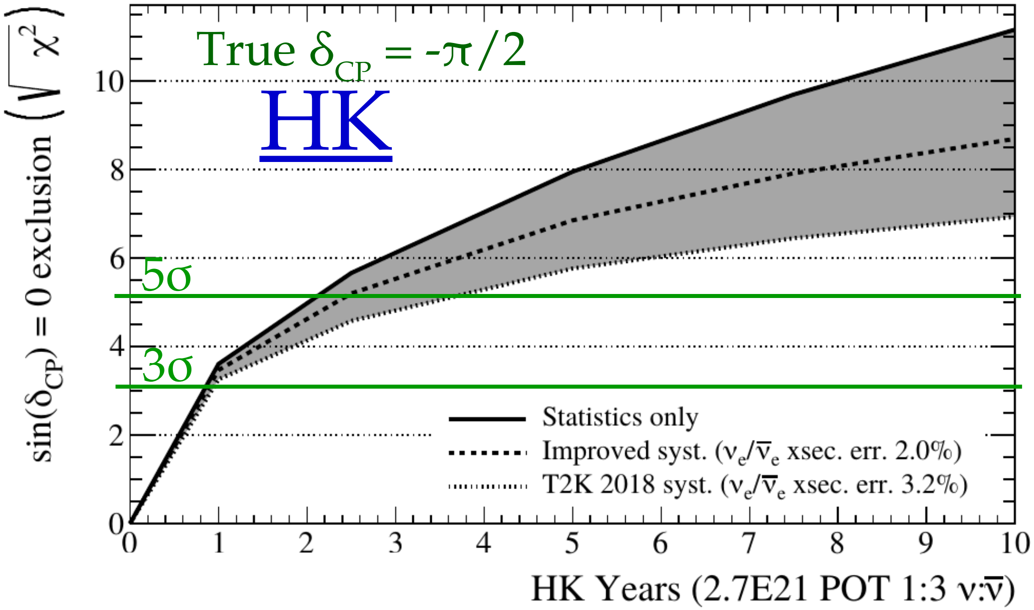


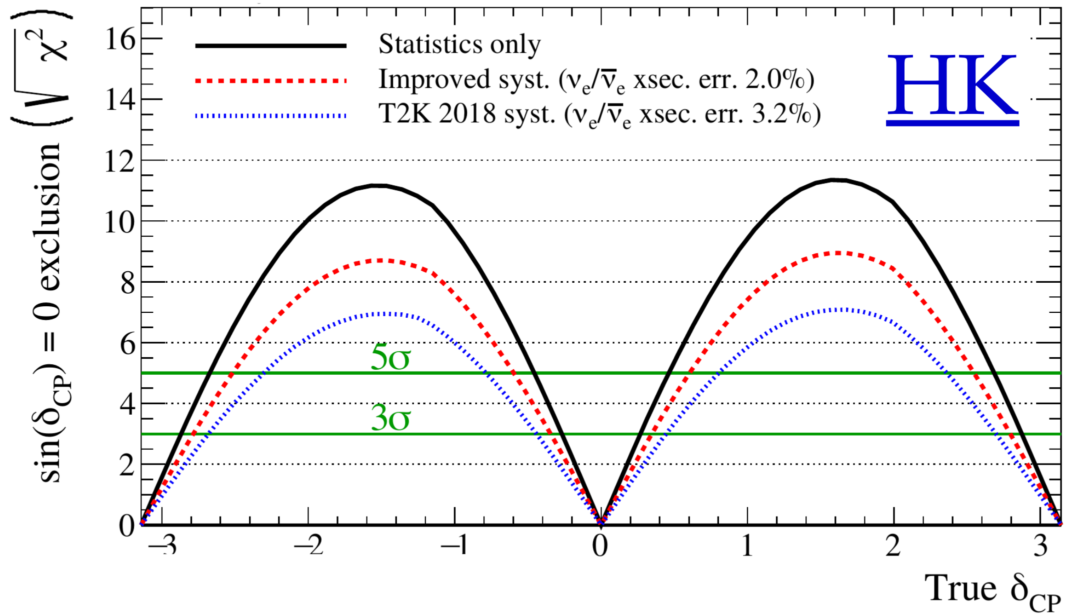
	1-Ring ν_μ-Like		1-Ring ν_e-Like			
Error source	ν-Mode	$\bar{\nu}$-Mode	ν-Mode CCQE-like	$\bar{\nu}$-Mode CCQE-like	ν-Mode CC1π-like	ν-Mode/$\bar{\nu}$-Mode CCQE-like
Cross section	0.92%	0.77%	3.43%	2.62%	3.43%	3.72%
Flux	0.85%	0.80%	0.87%	0.83%	0.89%	0.51%
Flux + xsec	0.82%	0.72%	3.44%	2.62%	3.51%	3.76%
Detector+FSI	1.69%	1.59%	1.54%	1.72%	5.22%	0.95%
All syst	1.88%	1.74%	3.75%	3.12%	6.24%	3.88%

- ↓ uncertainties on ν_e at HK from 7-9 % (T2K 2018) to 3-4 % (HK).

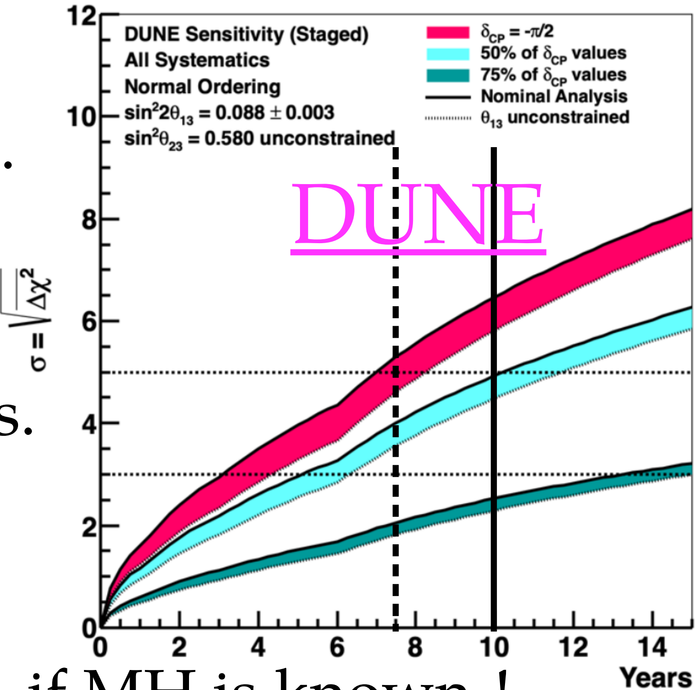
Sensitivity to CP violation

- 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.

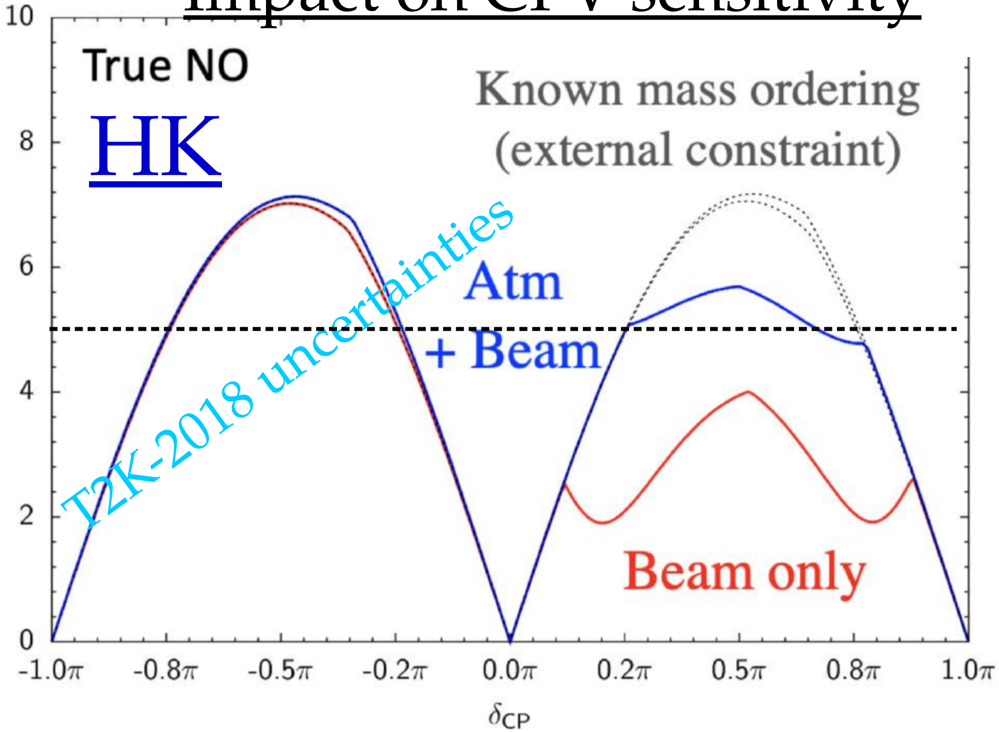


- HK 10 years : 5σ sensitivity on 60% of δ_{CP} values.
  → DUNE : 5σ sensitivity on 50%

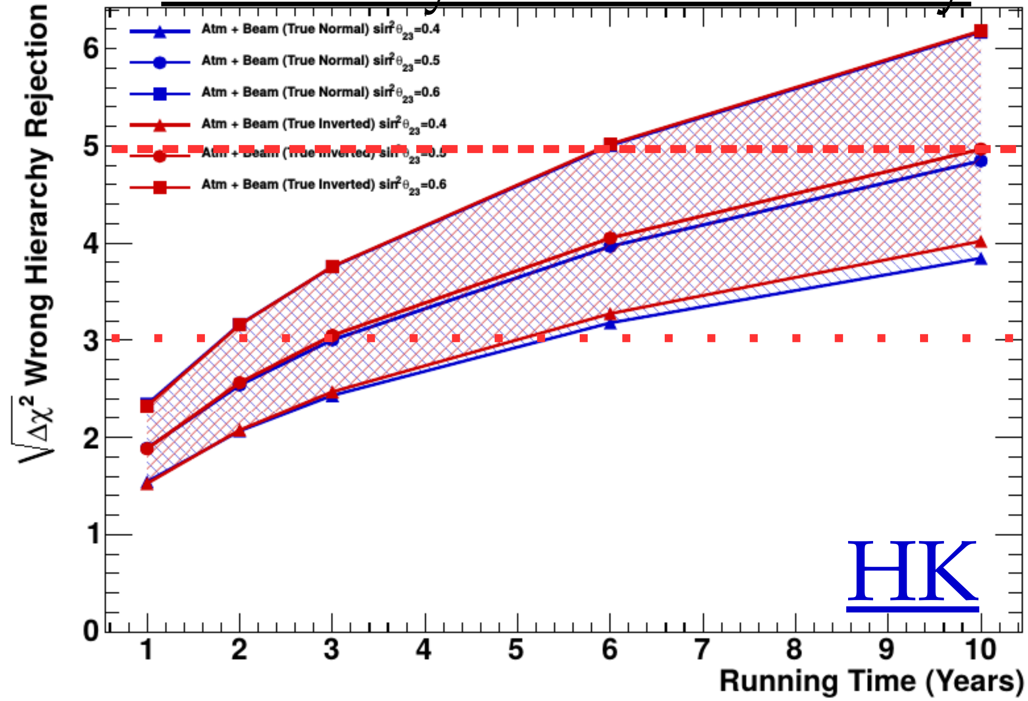
- HK has world-best sensitivity to CP violation … if MH is known !

Combination of atmospheric + beam ν

Impact on CPV sensitivity



Sensitivity to mass hierarchy



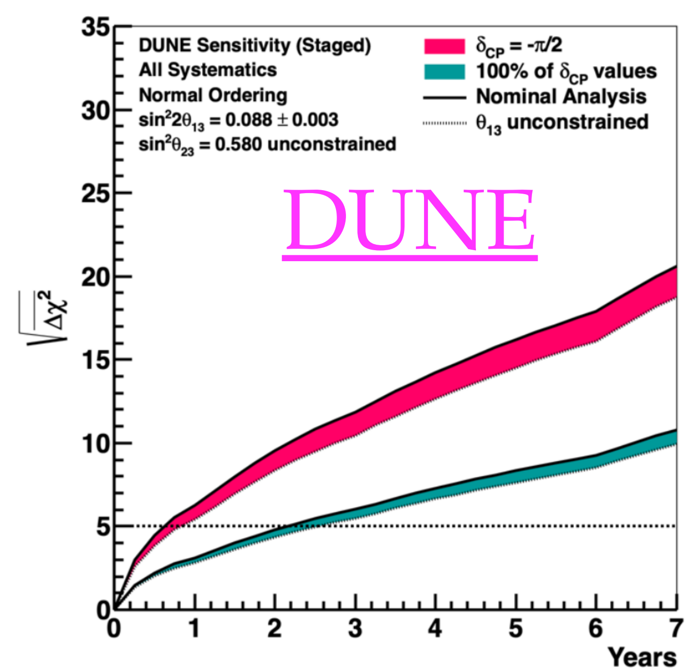
- Even if MH is not known when HK starts

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

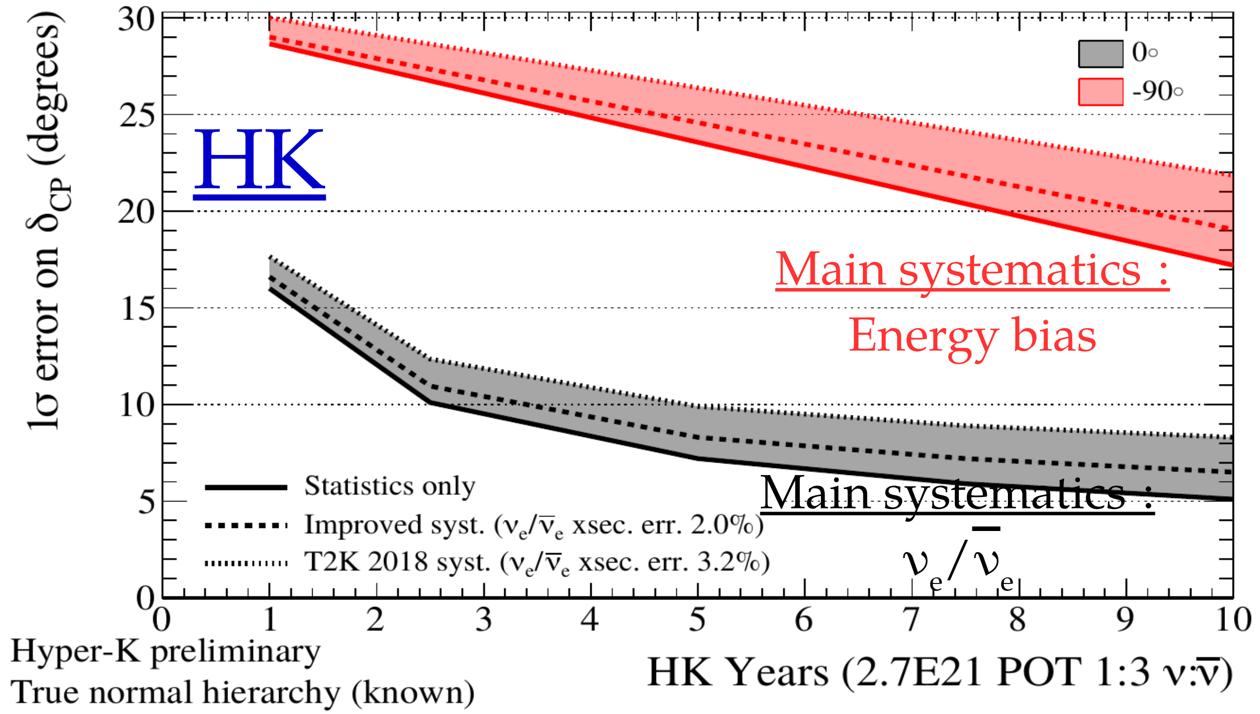
- MH would be determined by :

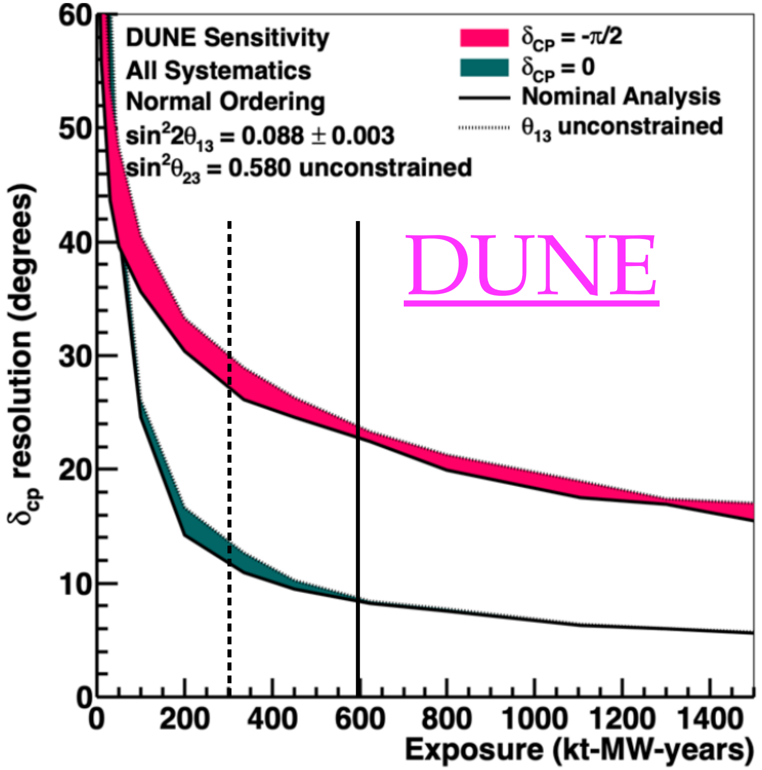
  → HK after ≥ 6-10 years via atmospheric.

  → DUNE : after 1-2 years.



Precision of δ_{CP} measurement





	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°

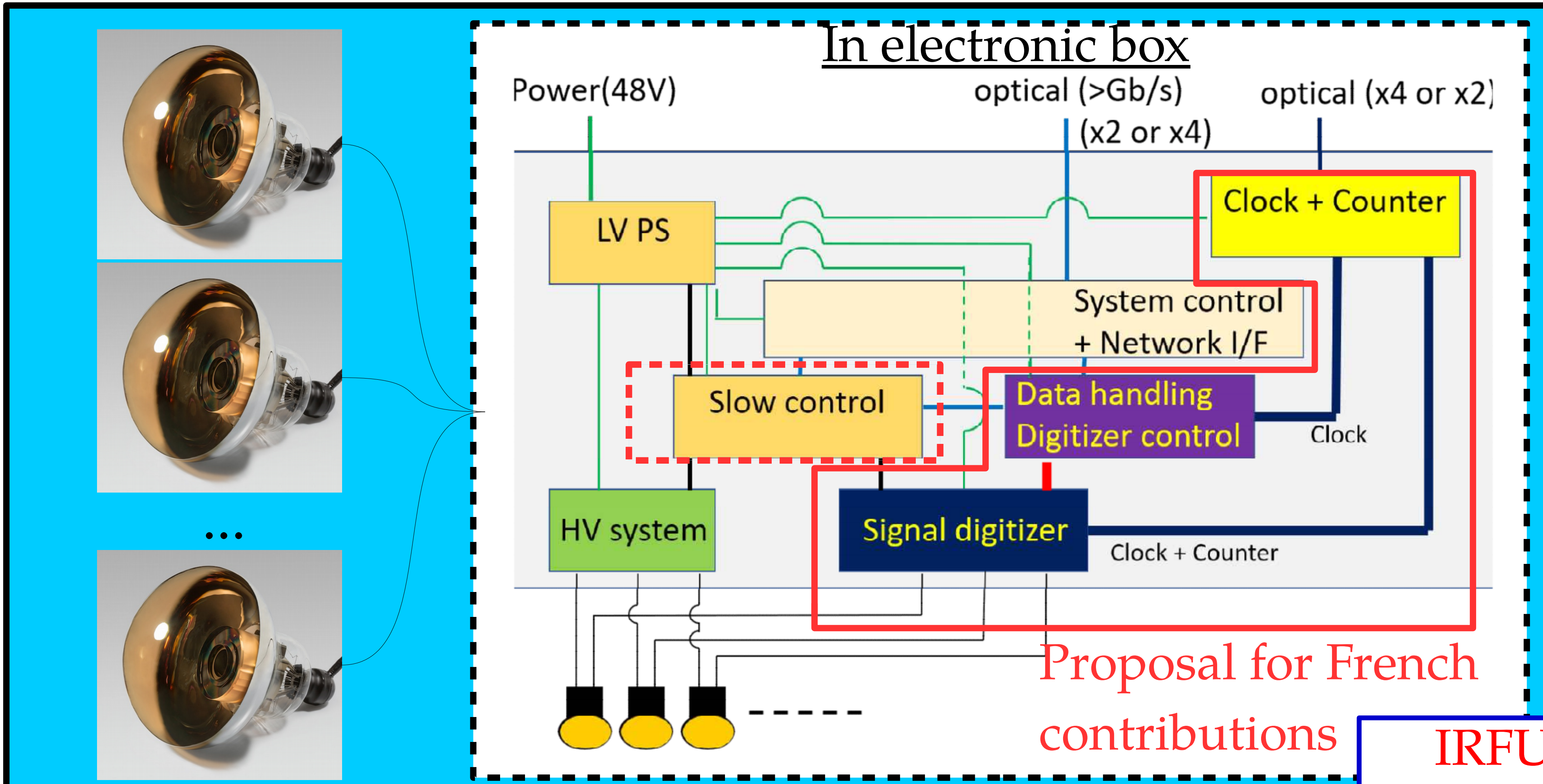
- HK sensitivity δ_{CP} highly improved with syst. error updates.

→ World-leading sensitivity together with DUNE full config.

III. Focus on French hardware R&D and contributions

HK far detector electronics

- <u>HK front end located under water (still under discussion):</u>
  → 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.*

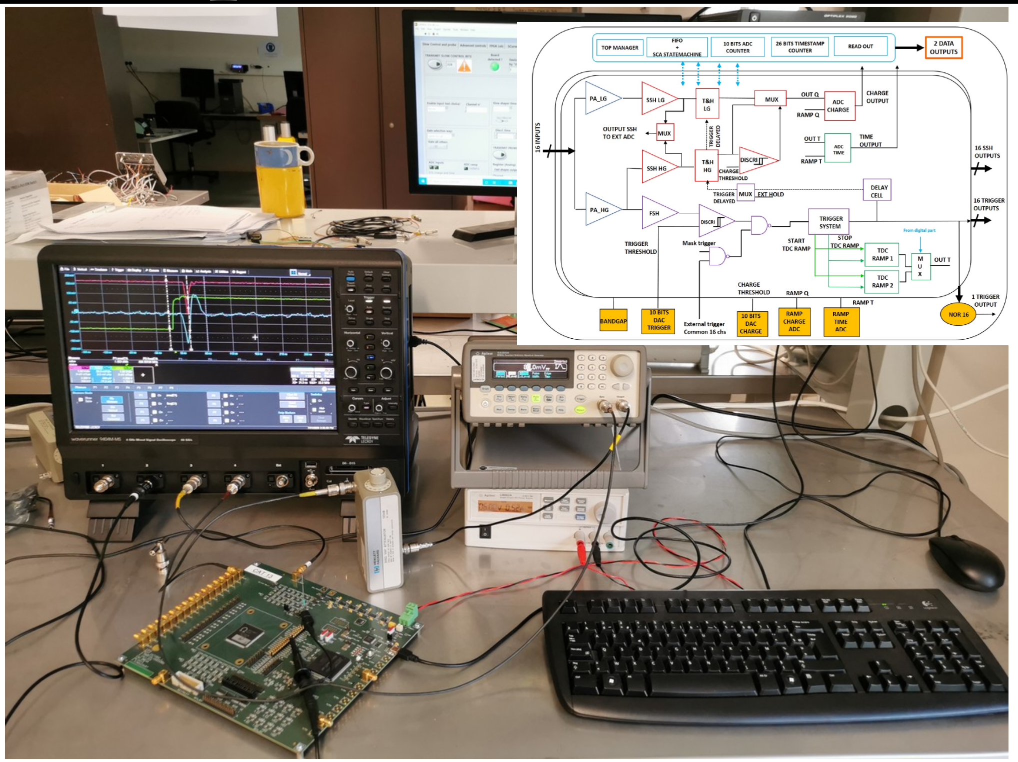
IRFU
LLR
LPNHE
OMEGA

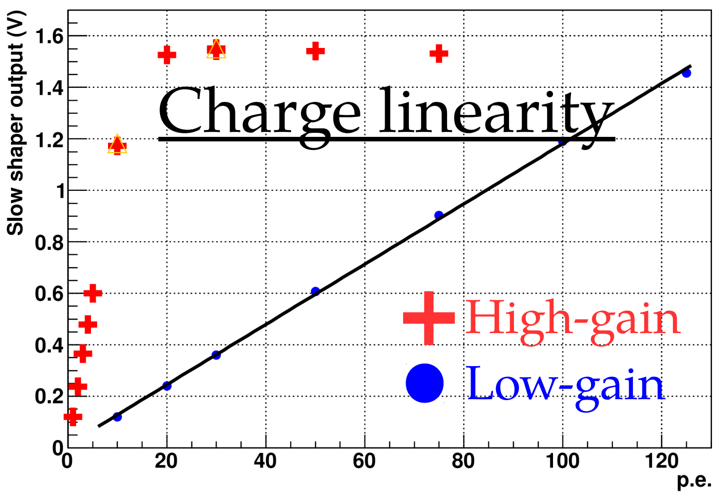
Front-end development

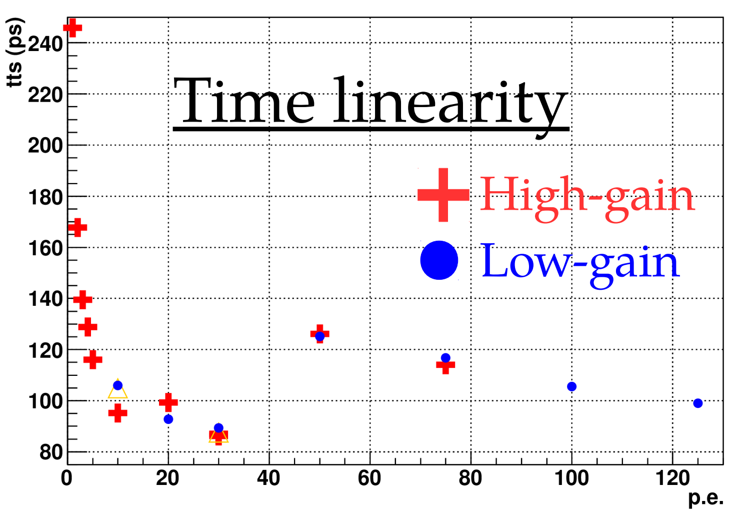
- Propose a new Front-end for HK

→ 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 .

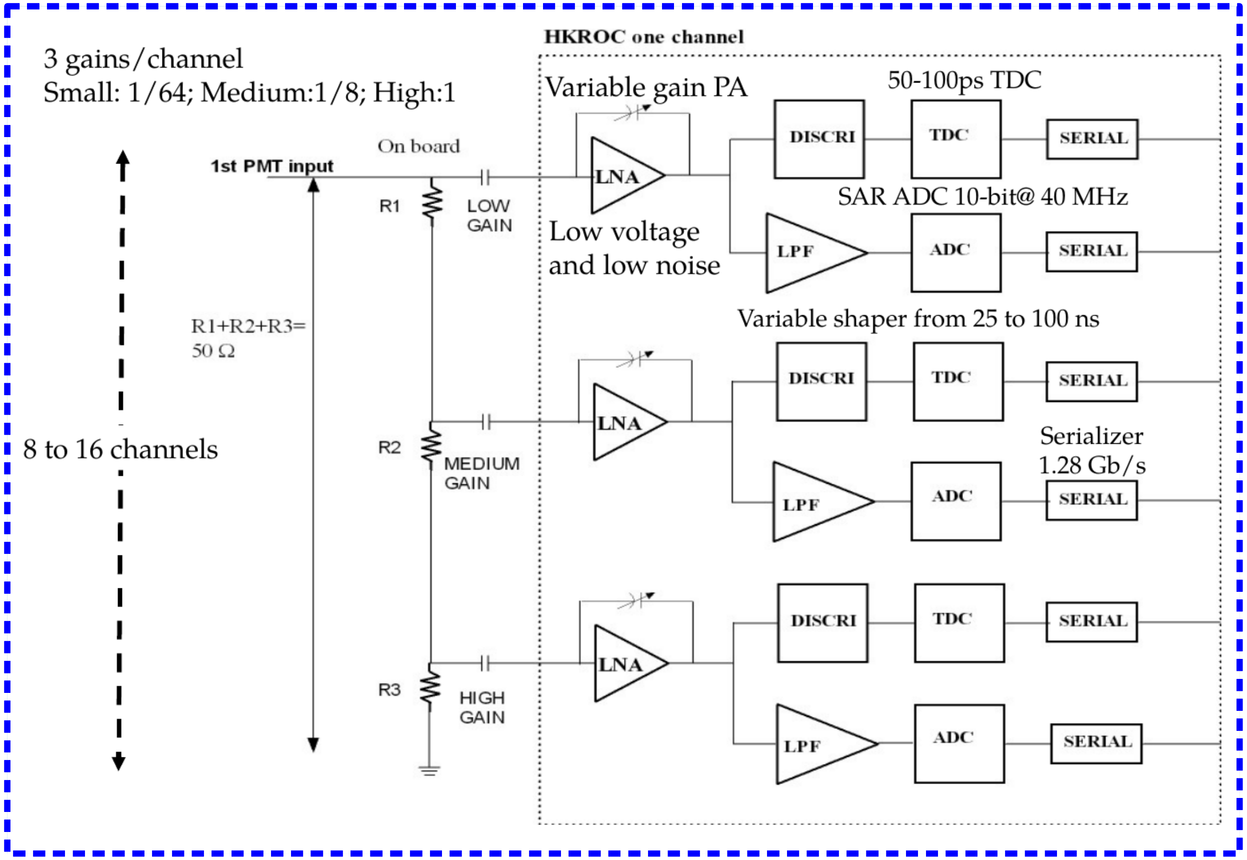
New HKROC chip

→ 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)

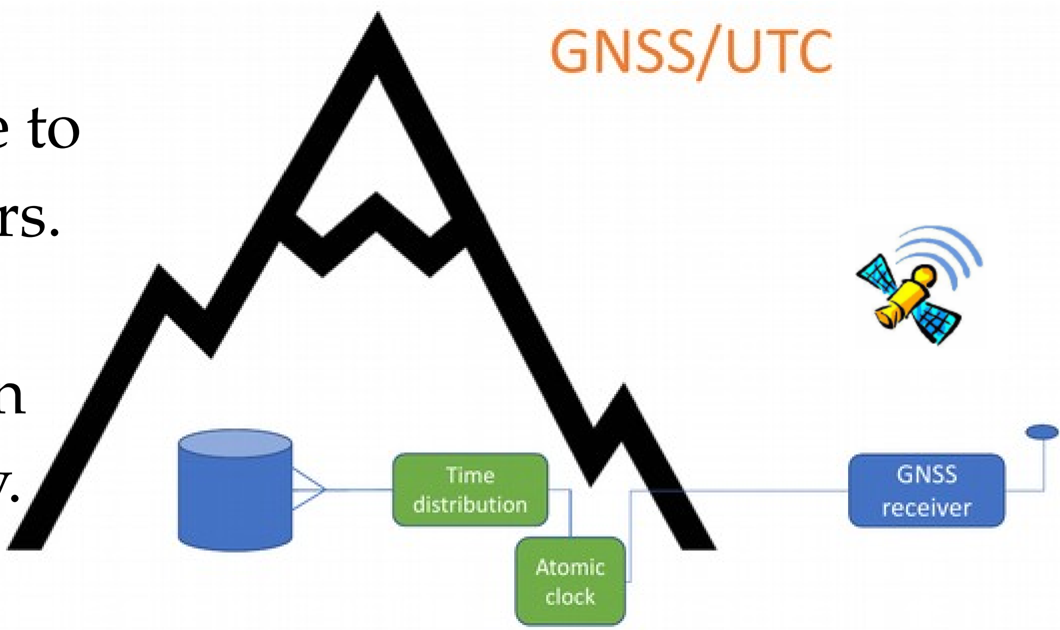
Similar to CMS HGCROC.

→ Simulations available & first production in spring 2021.

The GNSS and clock distribution system

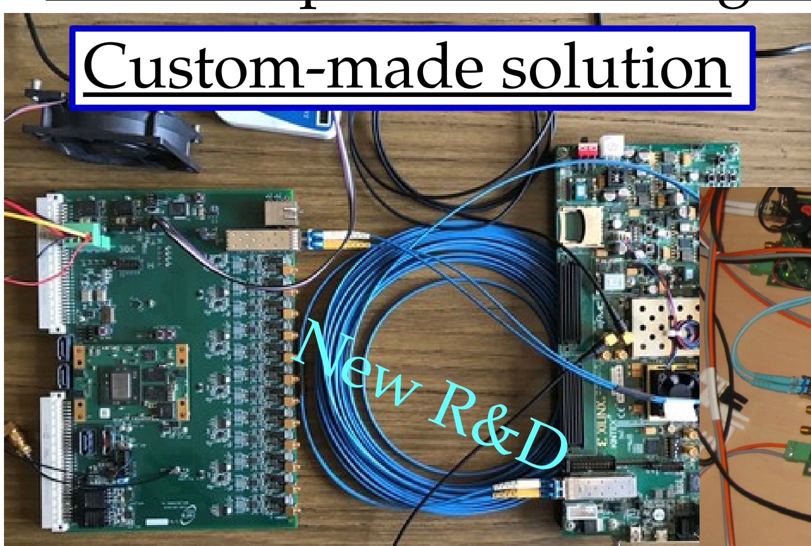
- France is working both on :

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

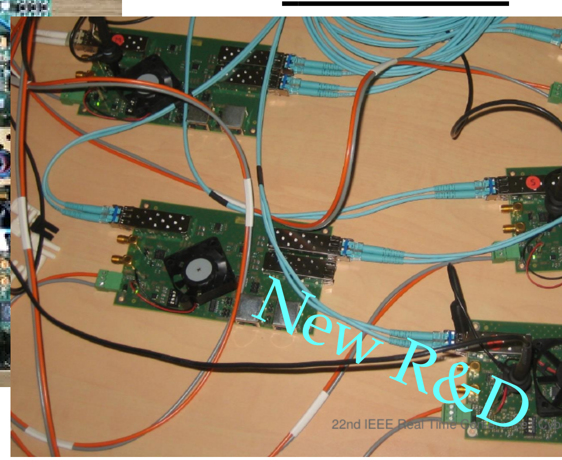


- Several options are being studied for clock distributions :

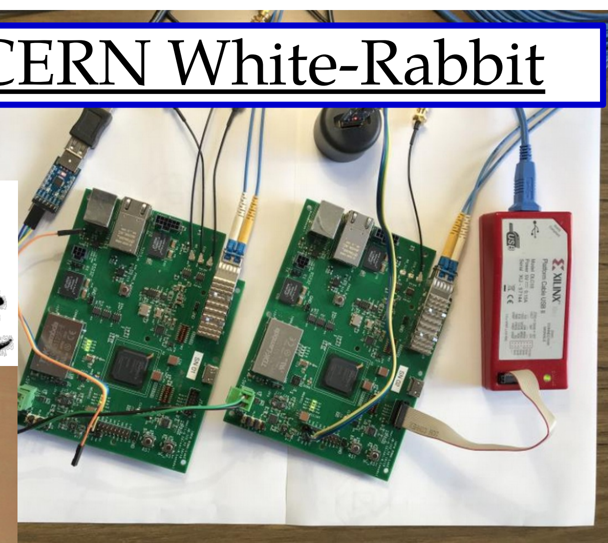
Custom-made solution



Clock-centric scheme



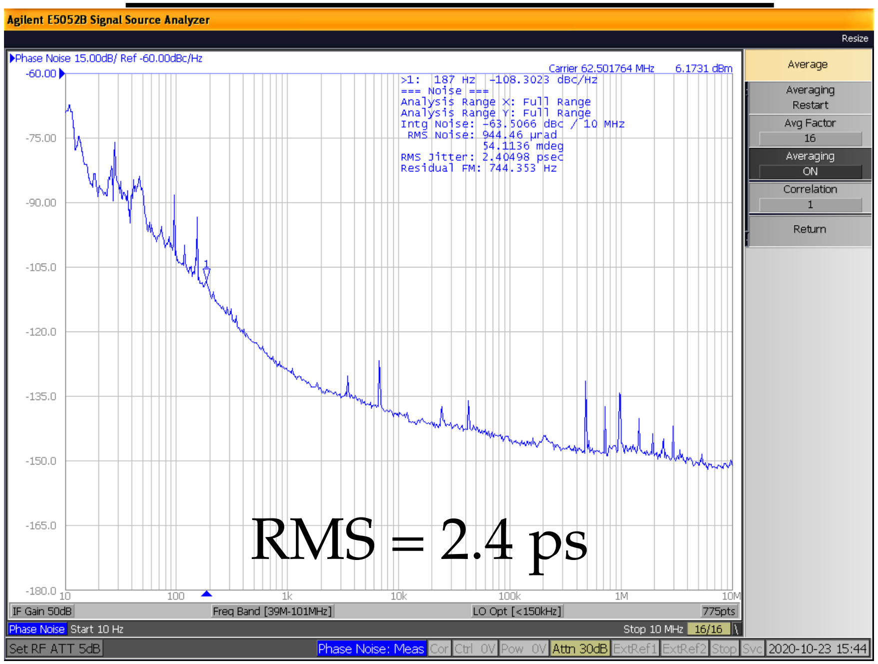
CERN White-Rabbit



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

The GPS and clock distribution system

Custom-made solution



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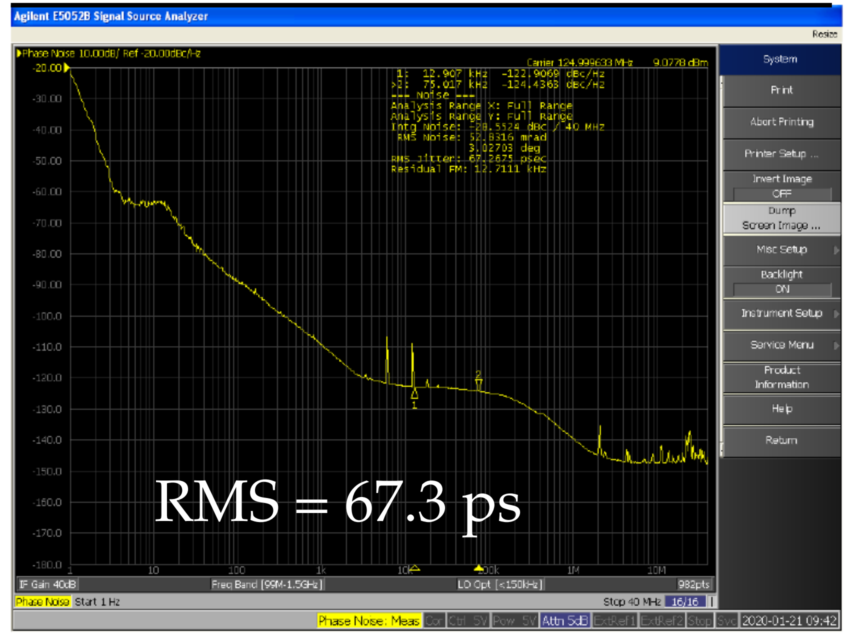
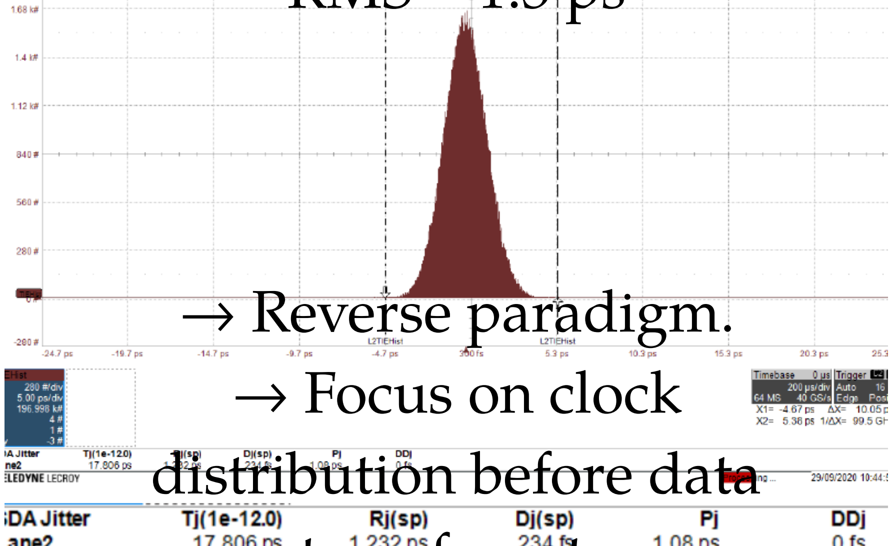


Clock-centric scheme

RMS = 1.3 ps



→ Reverse paradigm.

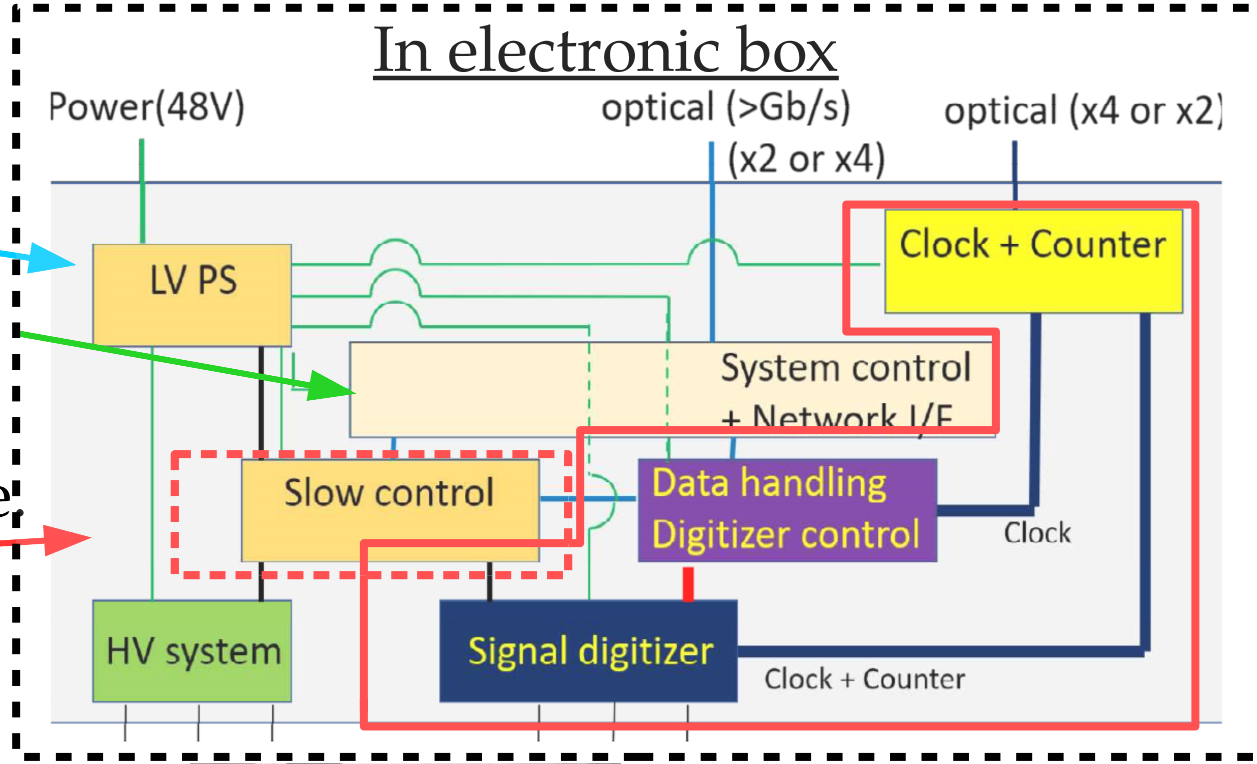
→ Focus on clock distribution before data transfer rate

Very preliminary. Far from final results

	Requirements	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.

Many other contributions available



1. Low Voltage Power Supply for board.

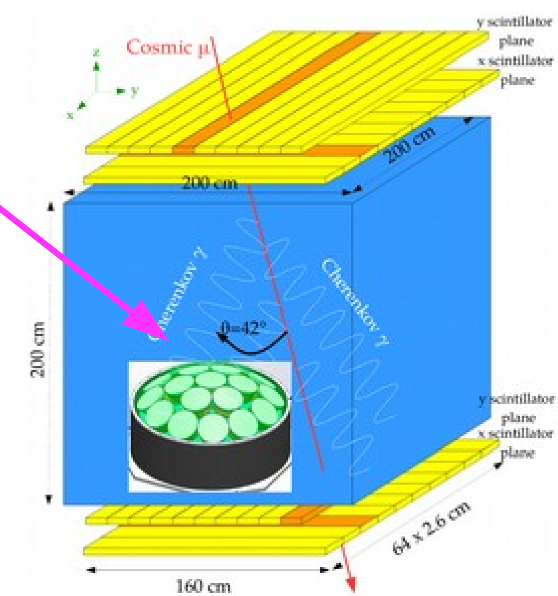
2. System control & network.

3. Slow control infrastructure.

4. Boxes to contain electronics in water.

5. Multi-PMTs to ↑ HK physics.
→ In far & near detectors !

MEMPHYNO @APC



Lots of places to have a central role in HK

→ New contributors are highly welcome !

→ Electronics, mechanical or photosensors !

Conclusions

- <u>HK will have a world-leading program, from low to high energy.</u>
  → Only covered CP violation today (see previous GDR).

- <u>Japanese budget contribution is fully approved → Project started !</u>

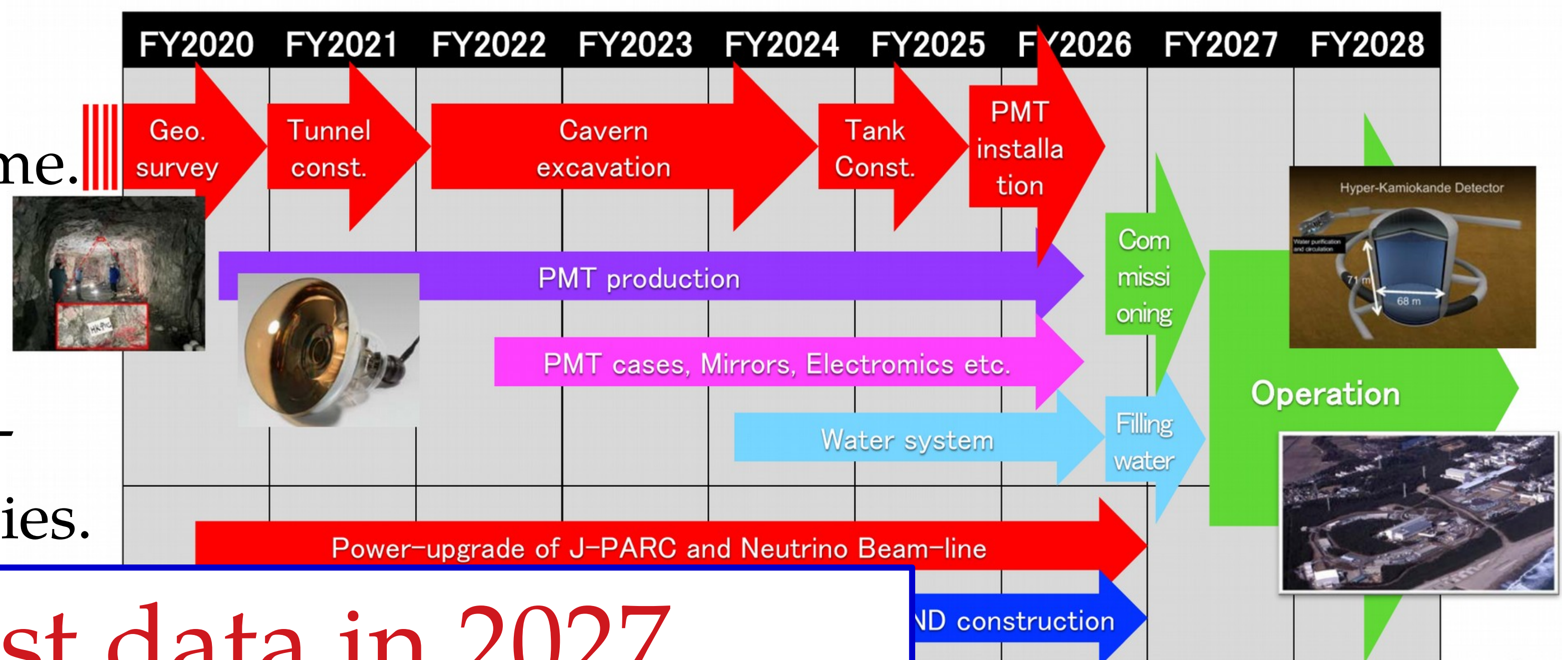
→ Large international contributions are being built : <u>good time to join</u>.

→ French labs coordinated to have a central & synergetic contributions in the Far Detector electronics : R&D started.

→ Many contributions are open and new collaborators highly welcome.

- HK construction started and on-time.

- Very little risk of delay due to well-known technologies.



→ First data in 2027.

- In France : IRFU (CEA), LLR (IN2P3-Ecole polyechnique), LPNHE (IN2P3-Sorbonne Universite) and OMEGA (IN2P3-Ecole polytechnique)