Hyper-Kamiokande

Precise clock generation for the Hyper-Kamiokande experiment

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LNE-SYRTE & LPNHE

Ateliers “Technologies quantiques pour les deux infinis” — July 2021

SCIENCES SORBONNE UNIVERSITÉ

Emergences@Sorbonne Université

SYRTE l'Observatoire de Paris | PSL
SYstèmes de Référence Temps-Espace

LPNHE PARIS

cnrs dépasser les frontières IN2P3 Les deux infinis

Collaboration with LNE-SYRTE

LNE: Laboratoire National de Métrologie et d'Essais
SYRTE: SYstèmes de Référence Temps-Espace
- Operating frequency standards for SI second definition (Sr + fountain)
- Generates UTC(OP) for legal time in France: here
- Strong expertise in frequency standards and UTC realization

Fruitful discussions and feedbacks from LNE-SYRTE
- Lots of the designs are based on discussions with the team
- Happy to collaborate with IN2P3 teams

→ **Useful R&D for future projects at IN2P3**

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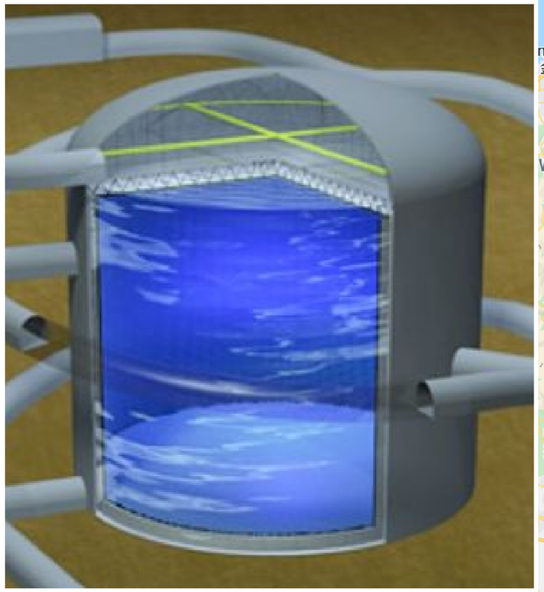
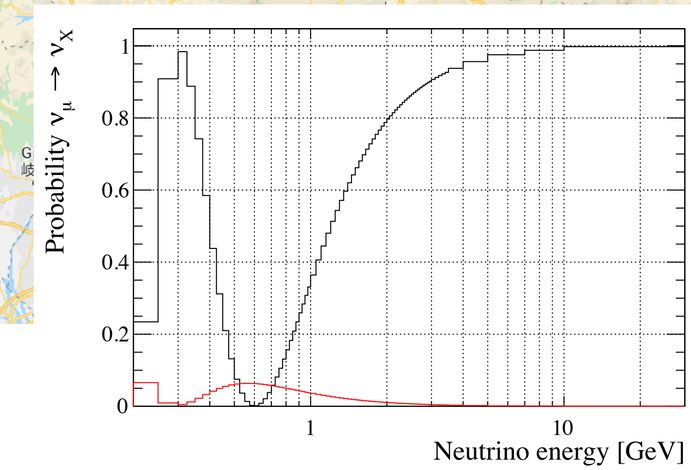
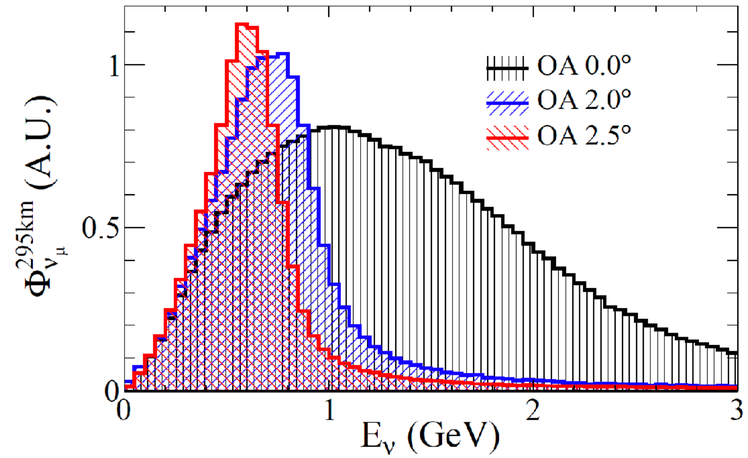
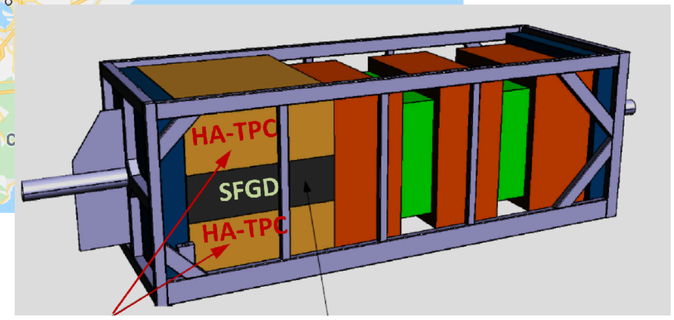
Hyper Kamiokande in a nutshell









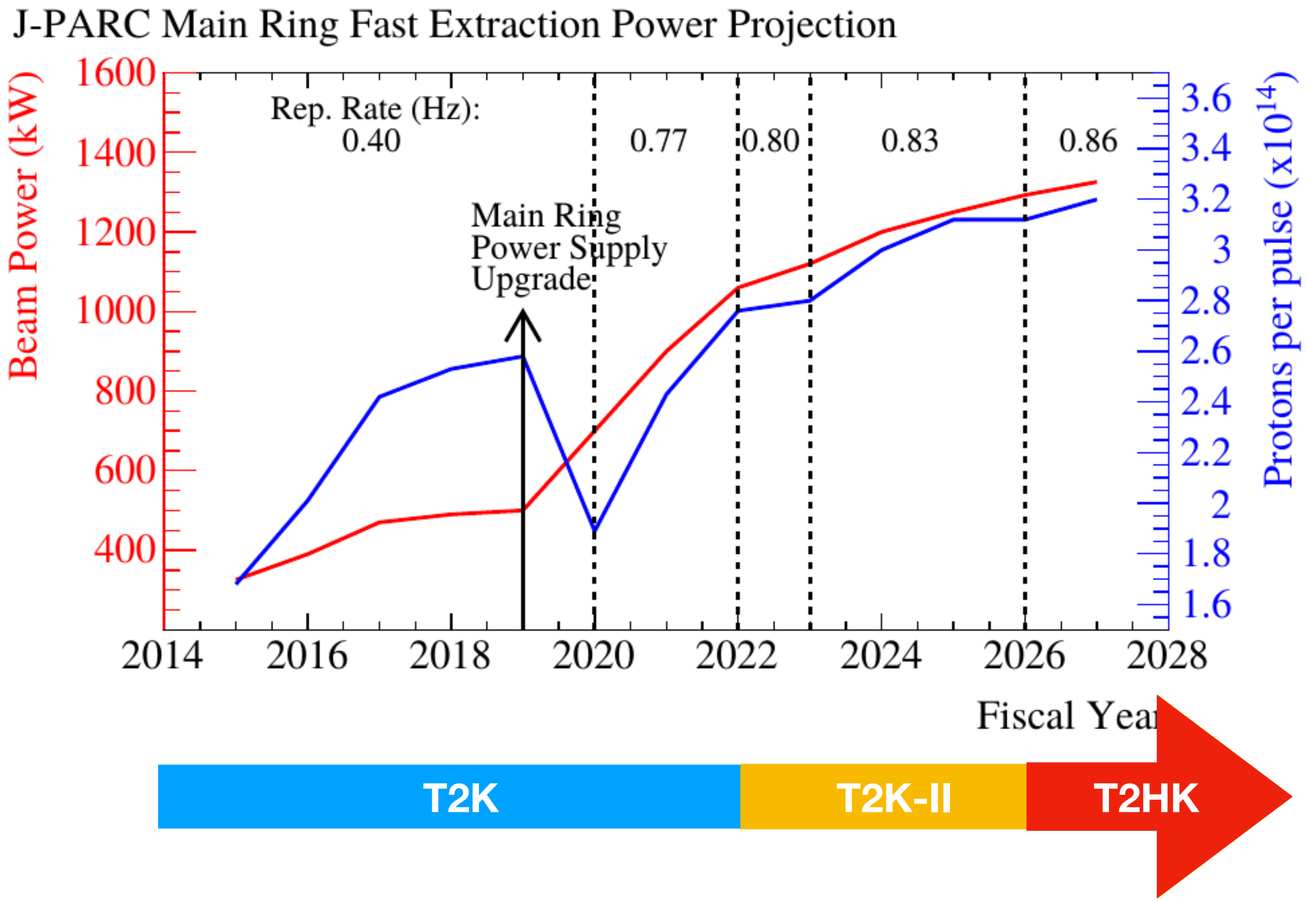
Long-baseline neutrino oscillation experiment and astroparticle observatory

Muon (anti)neutrinos off-axis beam btw Tokai and HK Water Cherenkov detector

Measurement of changes in the energy spectrum induced by neutrino oscillation

Tokai to HK: what will be new?

Accelerator upgrade
- Power increase (1.3 MW)
- Cycle change (1.16 sec cycle)



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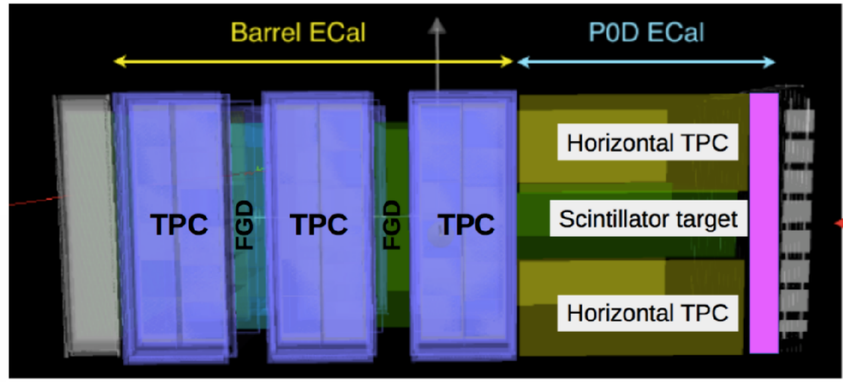
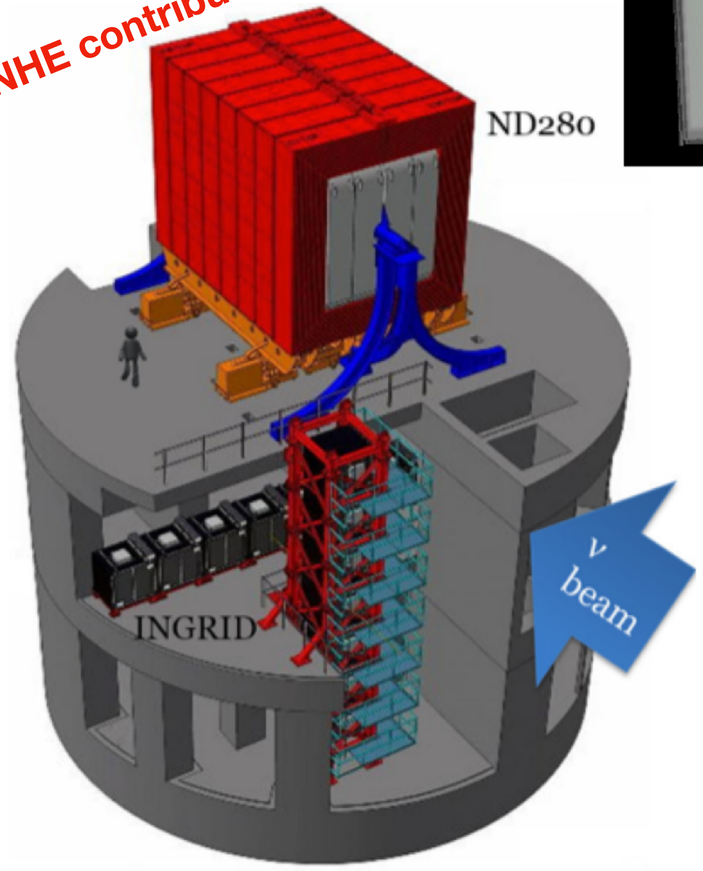
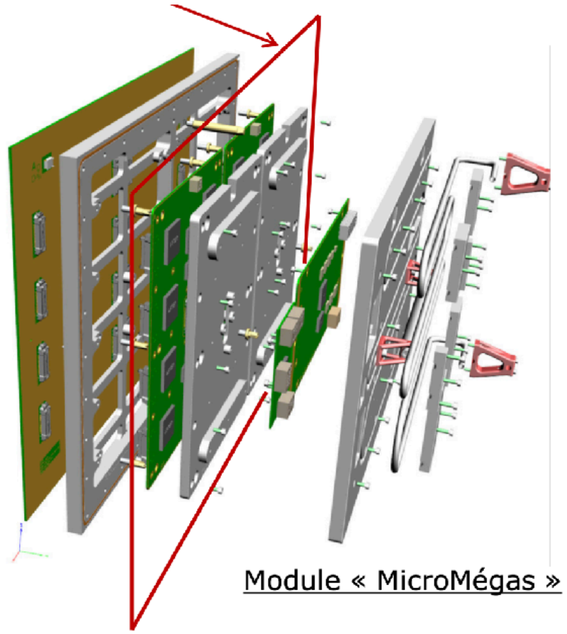
  - Reduce uncertainties 5% to 3%
  - ND280 is being upgraded now

LPNHE contributions







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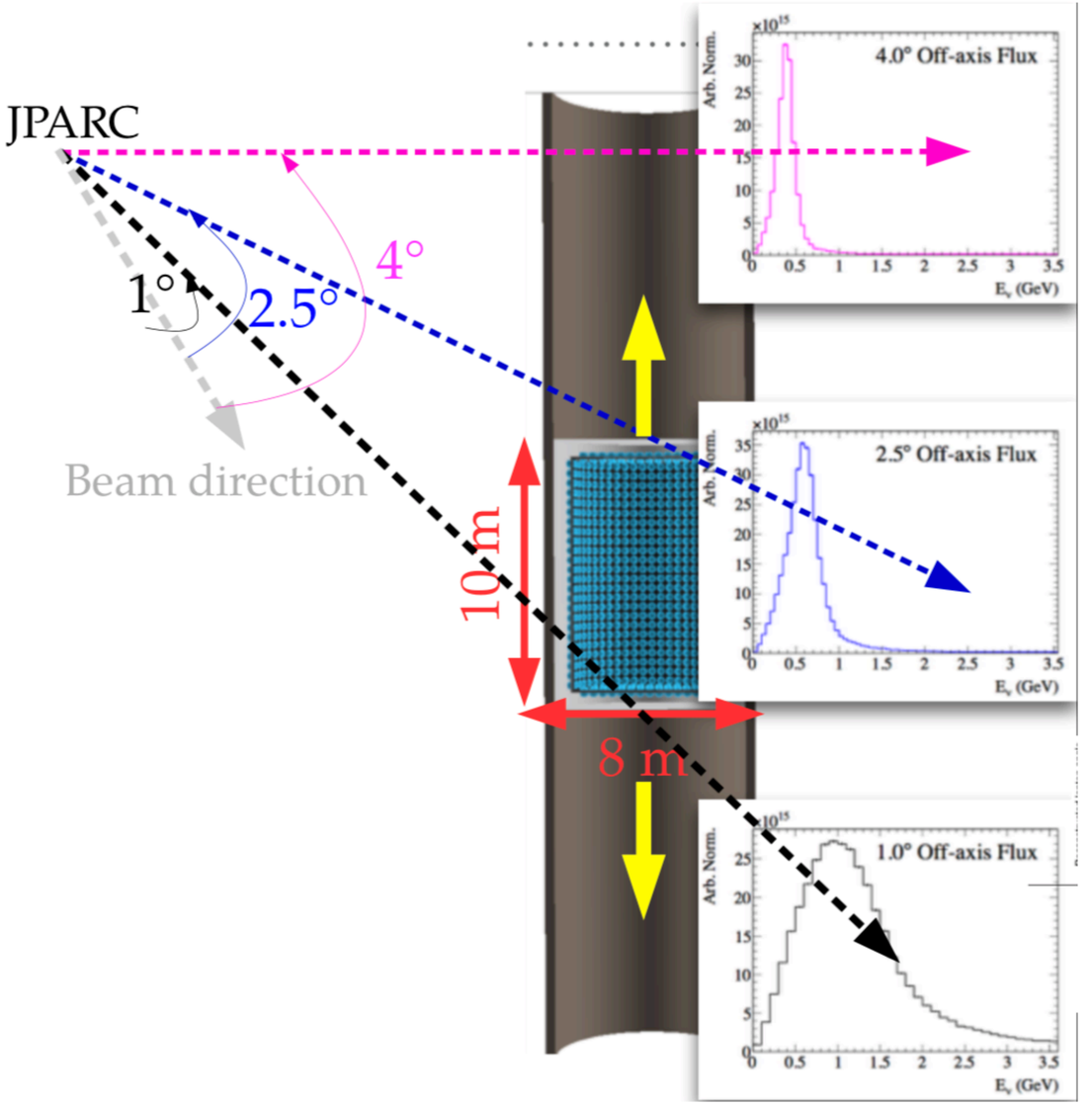
- Intermediate water Cherenkov detector (E61)
  - Constraining beam alignement
  - Better constraints on cross-section models
  - Measurement of ν_e background



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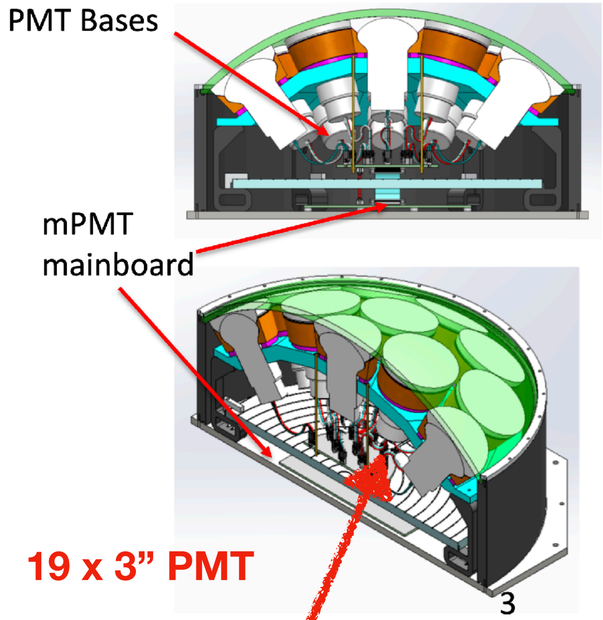
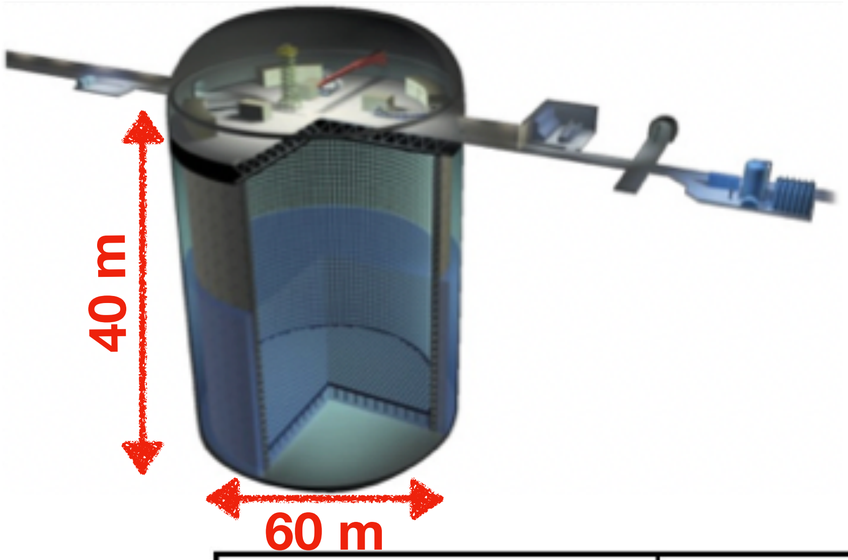
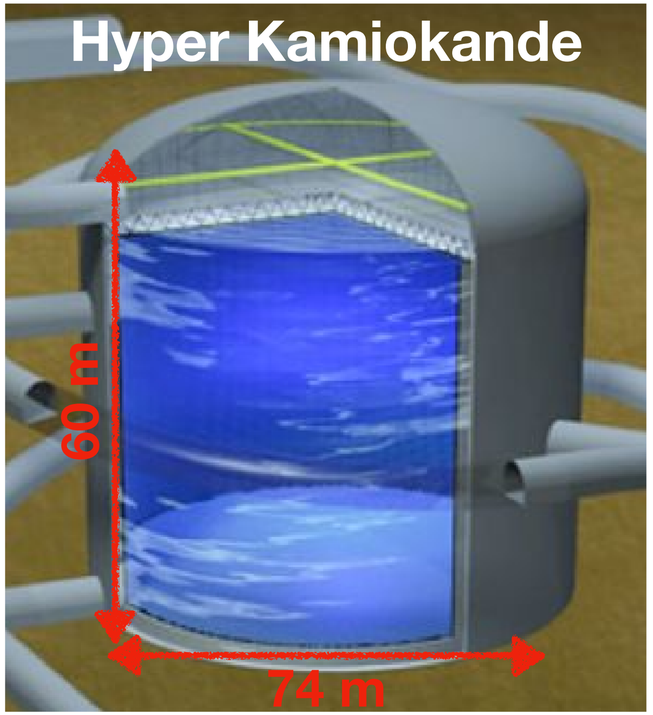
  - Measurement of ν_e background
- Use additional 5k+ mPMTs to enhance physics performance
  - Increase fiducial volume
  - Better momentum resolution, SNR
- …



Hyper Kamiokande: far detector

Super Kamiokande





	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**

Start operations in 2027

Neutrino physics with HK

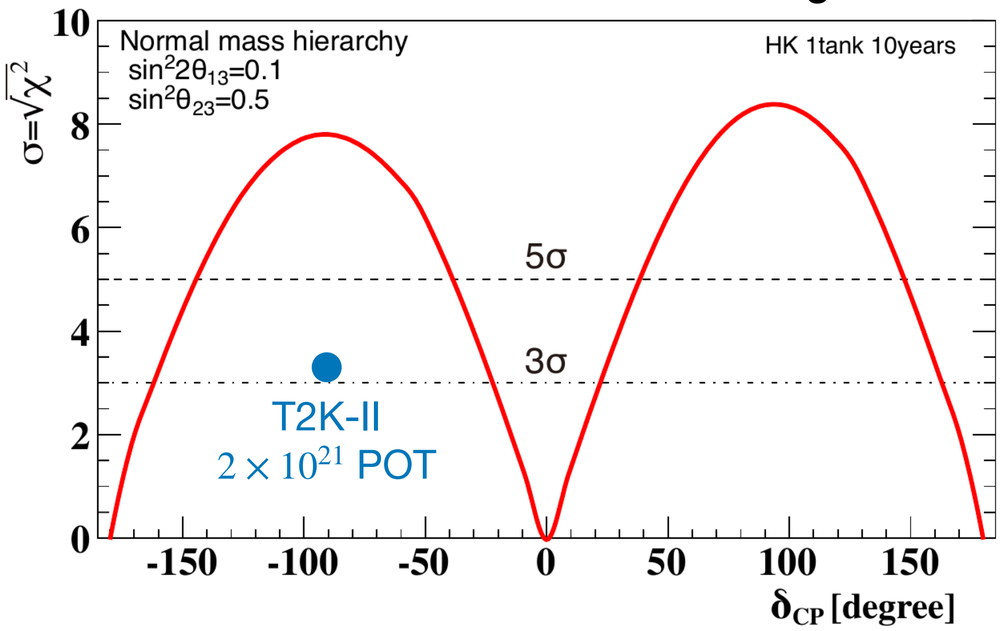
CP-violation
60%@5σ of δ_{CP} phase-space after 10 y

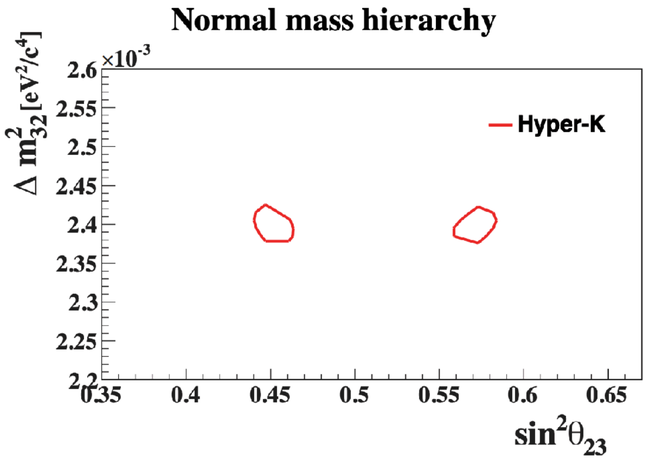
Atmospheric parameters
Resolution of $\sin^2\theta_{23}$
0.6% precision on Δm^2_{32}

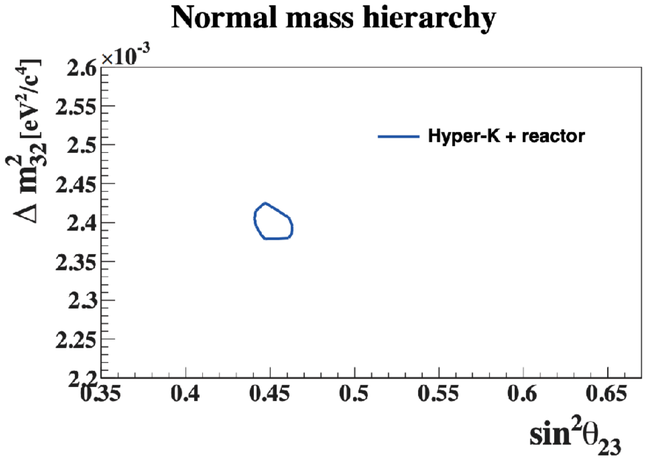
Mass hierarchy: 5σ after 10 years

Neutrino cross-sections
Sterile neutrinos w/ ND and ID
…

Assuming 1.3 MW







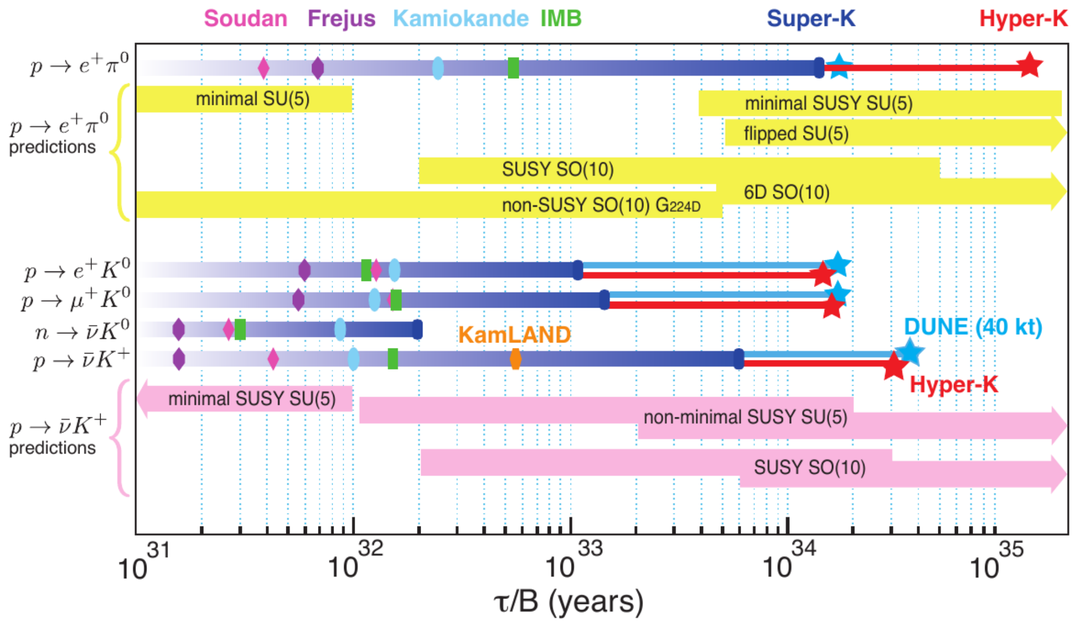
Rare events physics with HK

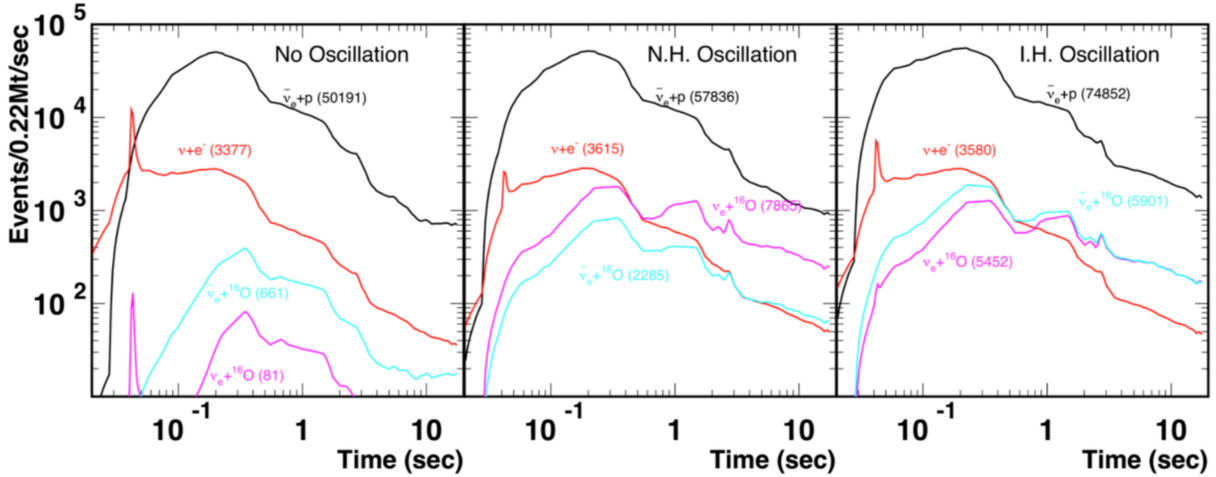
Proton decay
Sensitivity to GUT predictions
x10 on “golden channel” $p \rightarrow e^+\pi^0$

Supernova neutrinos arXiv:2101.05269
Increase by 200 in stats sensitivity
SN1987A type ~2500 events
Galactic center: ~50000+ events
Direction → triangulation (1°@10kpc)
Time profile: collapse models

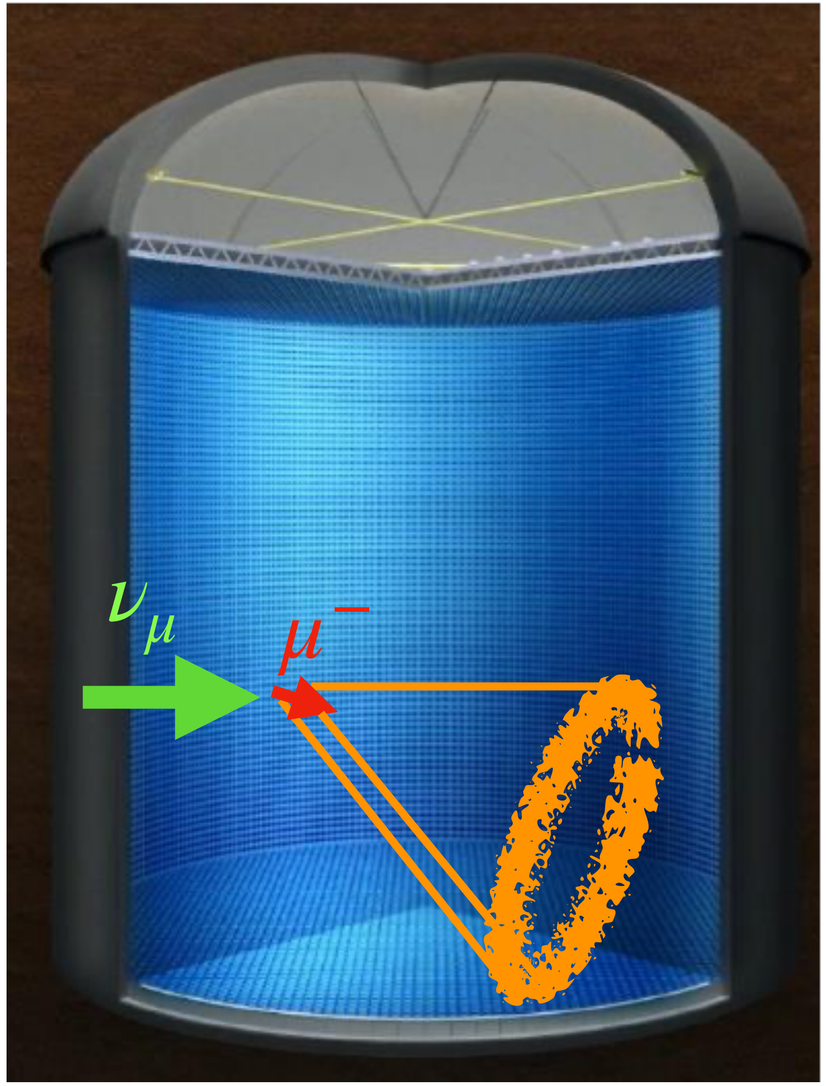
Gravitational waves sources
Nearby (10Mpc) neutron star mergers

→Multi-messengers observations





HK Electronics and Synchronization System



Events are reconstructed from Cherenkov ring by means of PMTs. Precise time determination of the light arrivals on PMT is essential.

→ **time "jitter" cause reconstruction issues**

The total number of PMTs is up to 50.000 read with more than 2.000 Front-End board.

Hyper-K is expected to be operated for >20 yrs.

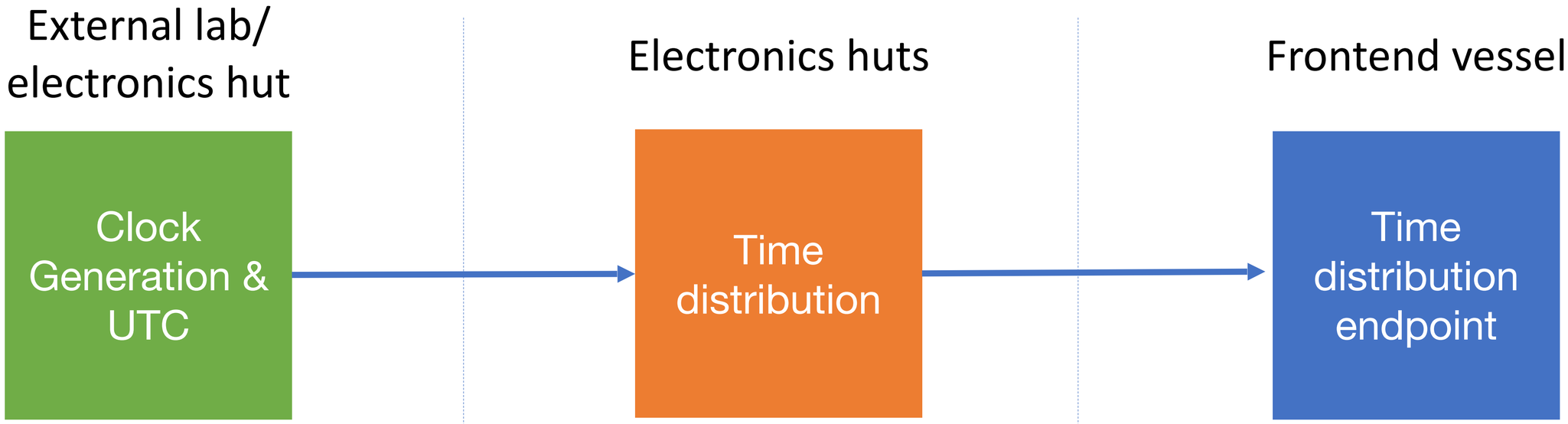
→**long term stability and durability are essential**

Multi-messengers physics and correlation with other astro-detectors requires time tagging

→ **need of a system synchronized with UTC(k)**

Time Synchronization Experimental Constraints	
Total Jitter	$\leq$ 100 ps *
Board to Board skew	fixed over any reset and power cycle
Accuracy to UTC	$\leq$ 50 ns *

Full System Block System

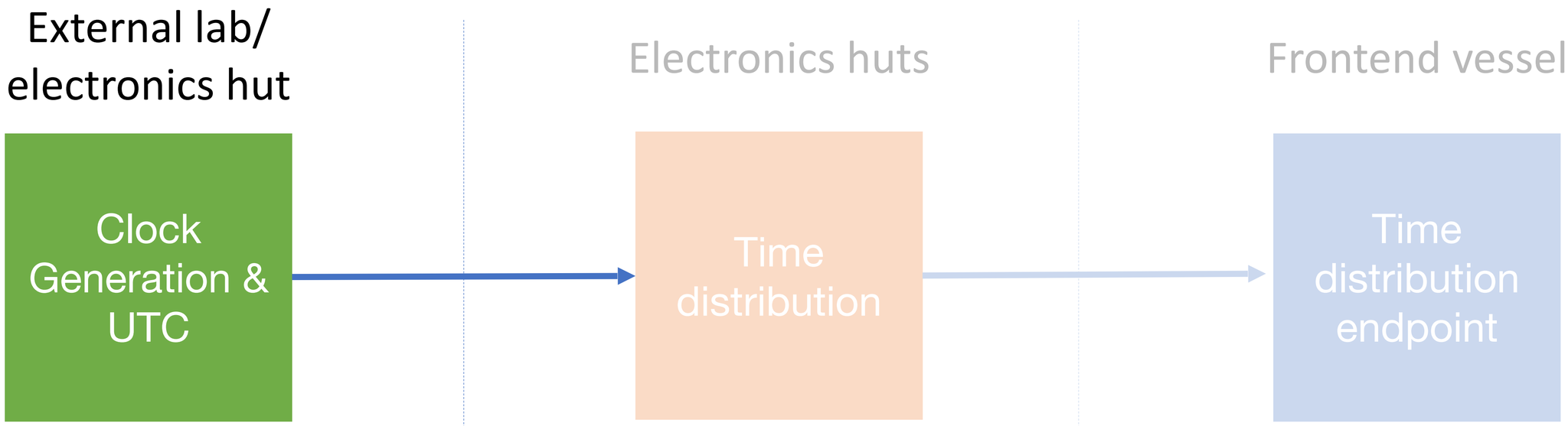


- GNSS
- Atomic clock
- Time quality measure
- High speed clock generation

- Time Distribution Board (TDM)
- DAQ connection infrastructure

- Clock recovery module
- Slow control manager
- FPGA firmware update module

Full System Block System



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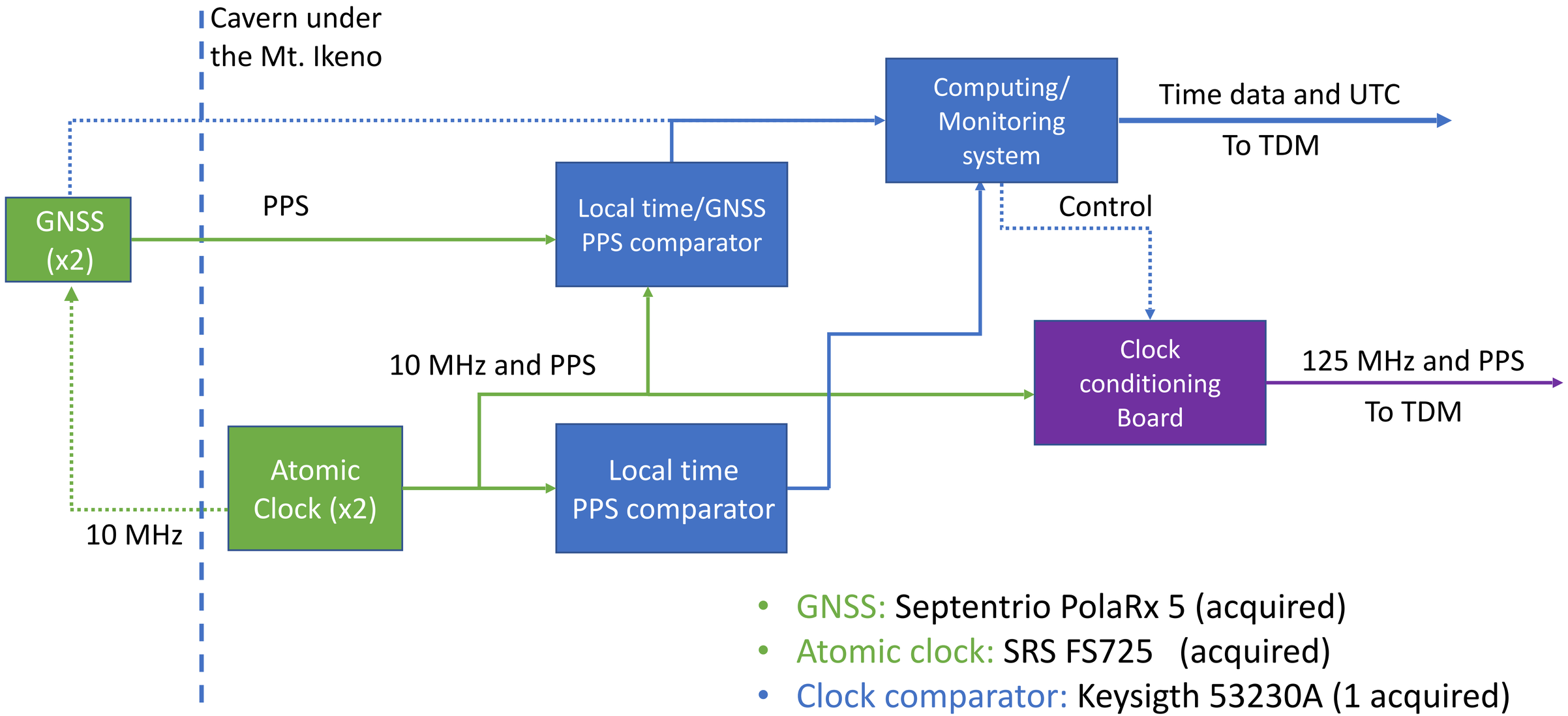
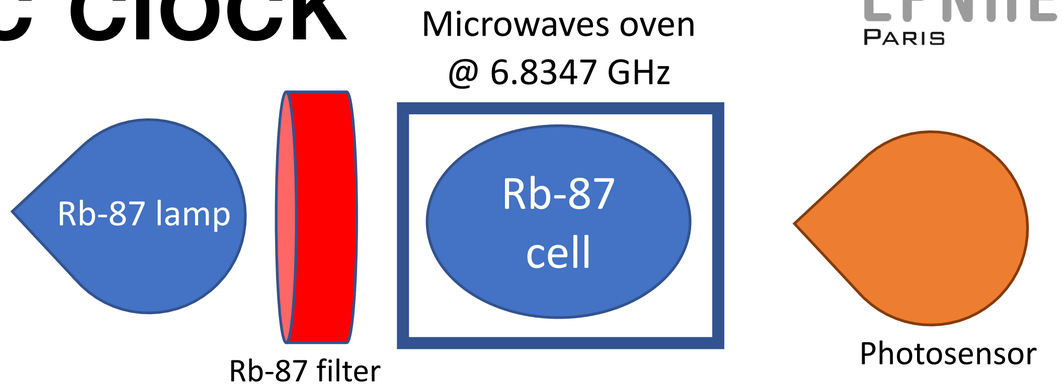
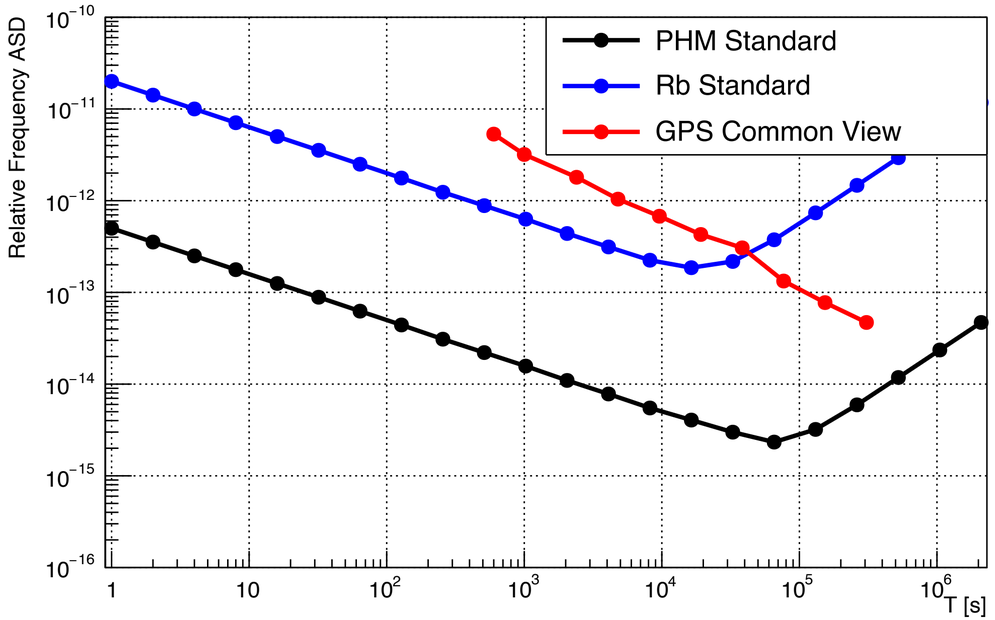
Clock Generation & UTC



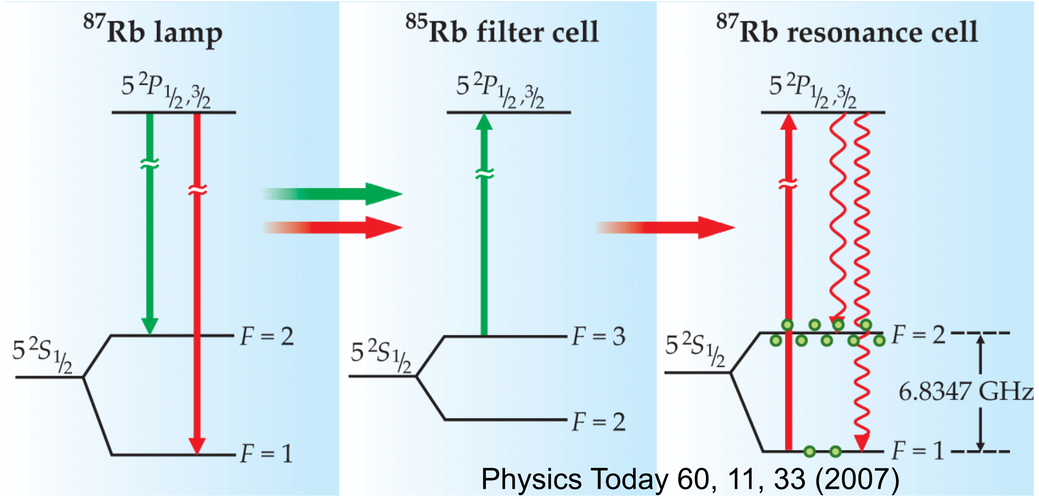
- GNSS: Septentrio PolaRx 5 (acquired)
- Atomic clock: SRS FS725 (acquired)
- Clock comparator: Keysigth 53230A (1 acquired)
- Clock conditioning board: custom (under review)

Rb atomic clock





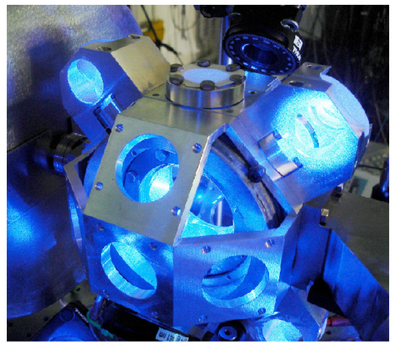
Allan standard deviation: paper



Physics Today 60, 11, 33 (2007)

Comparison with time reference at SYRTE → **performances studies**

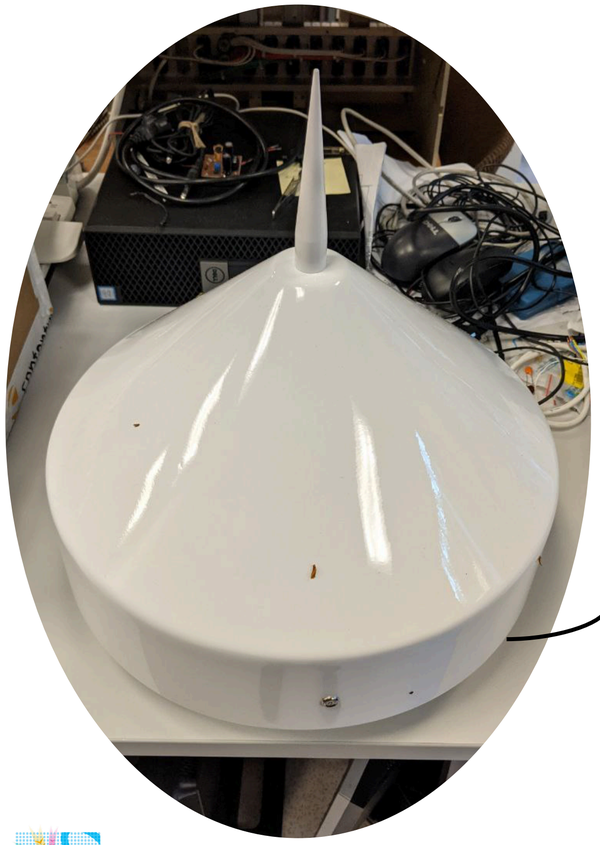
Test using more stable clocks e.g. Passive Hydrogen Maser (PHM1008)

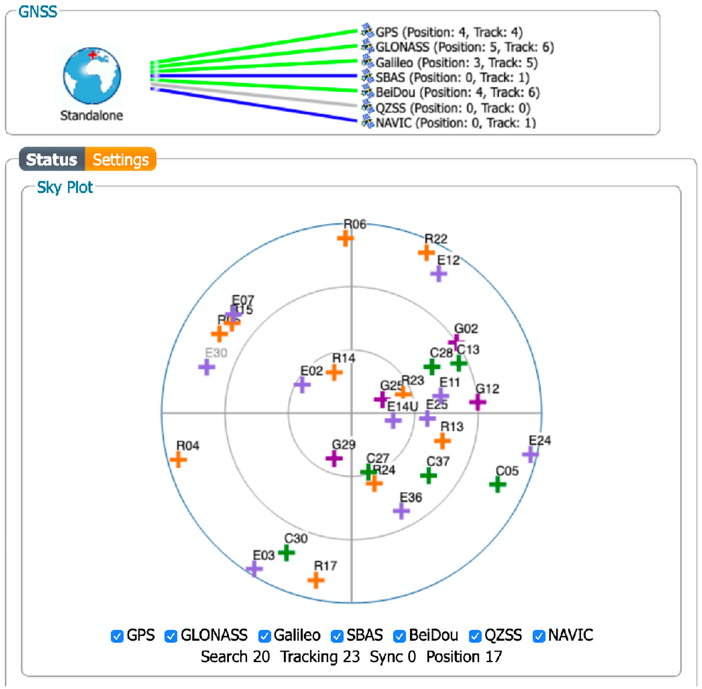


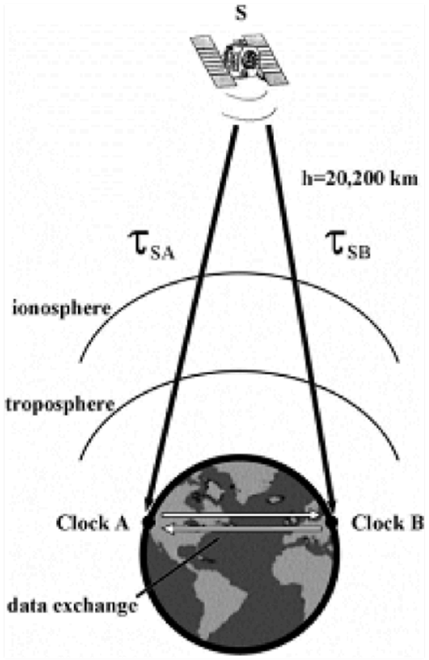
Strontium optical atomic clock @SYRTE

GNSS antenna and receiver

Receive signals from various satellites e.g. Galileo
Produce 1 PPS using received signals
Synchronization with UTC (after calibration & correction)







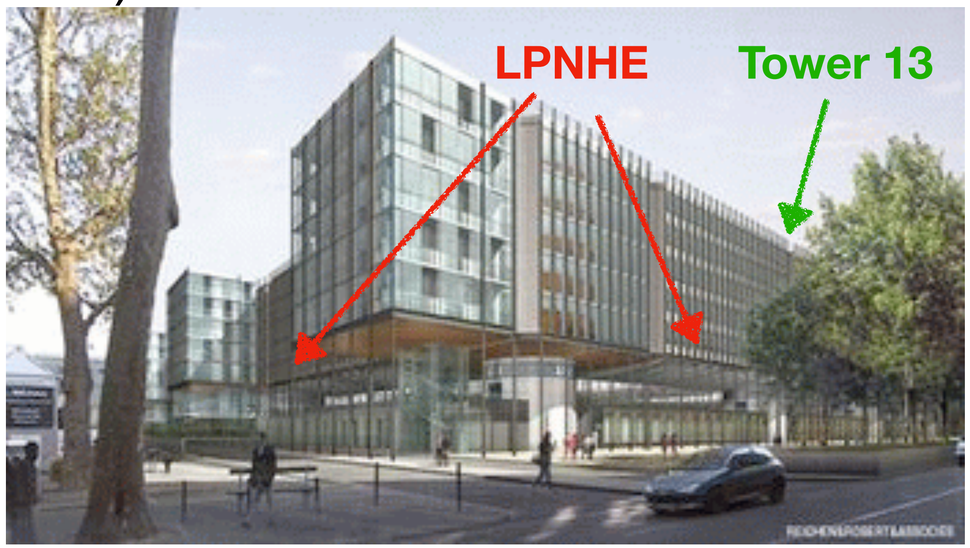
Tests at Jussieu and SYRTE

Dedicated tests and performances at SYRTE
  Clock and GNSS calibration planned over the summer

Creation of a dedicated lab to study clocks and GNSS at LPNHE
  Room for long-term tests (5th floor, Tower 13)
Time transfer (White Rabbit) between Syrte-Obs.Paris and Jussieu
  PPS with UTC(OP) available in lab soon
Installation of GNSS antenna on the Jussieu roof (Tower 13)
  Long-term studies and comparison using
  atomic clocks and PPS-Syrte

First implementation of GNSS signals corrections
Build prototypes for HK

→ **R&D towards HK and other IN2P3 projects**



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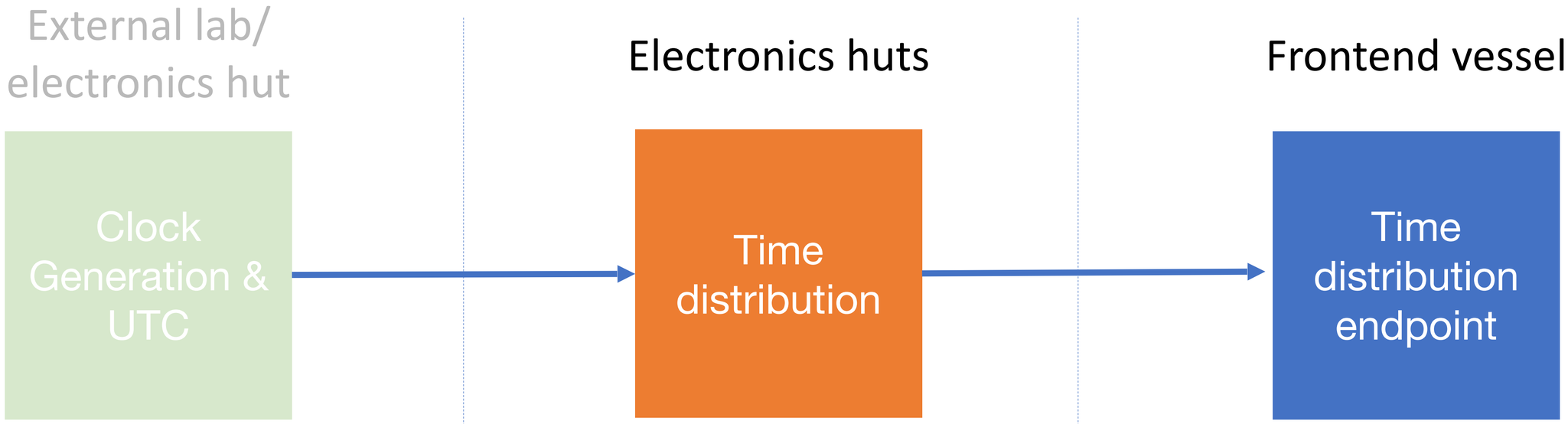

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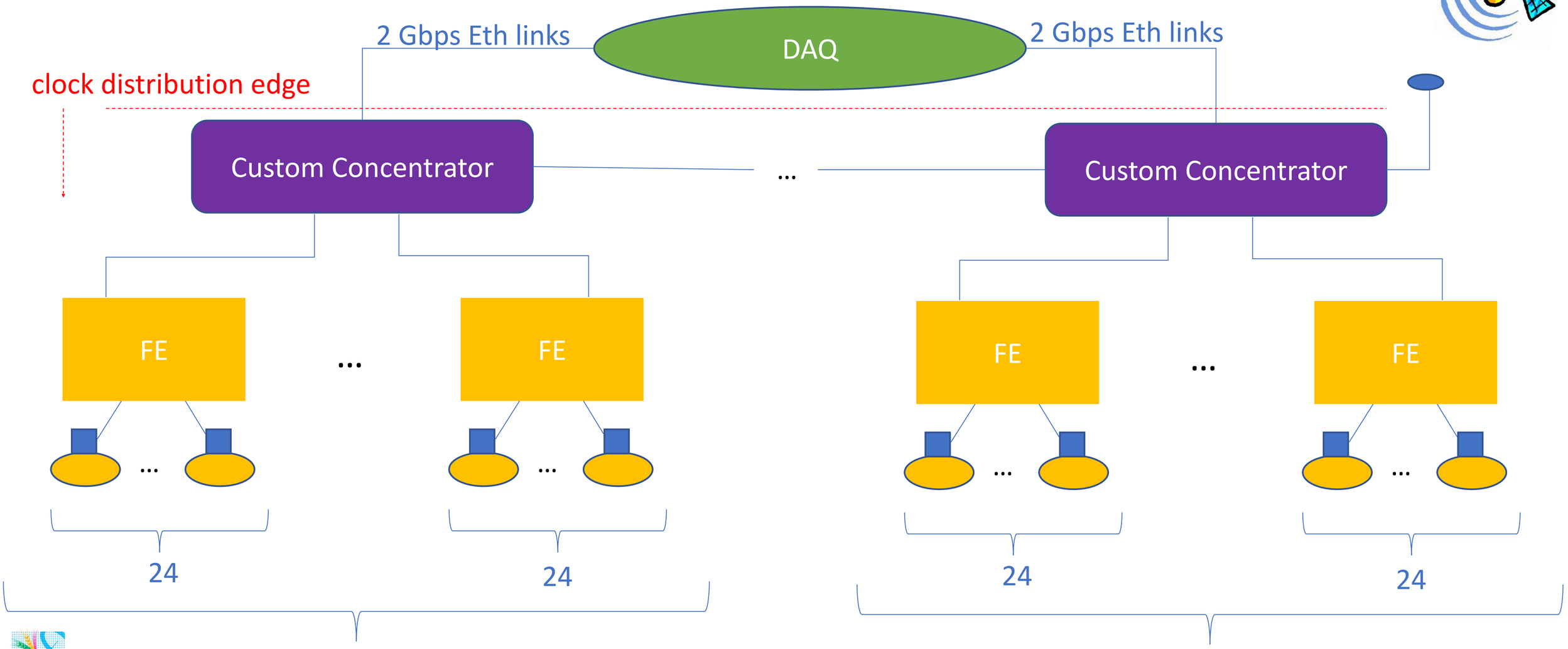
Custom Solution: A possible architecture

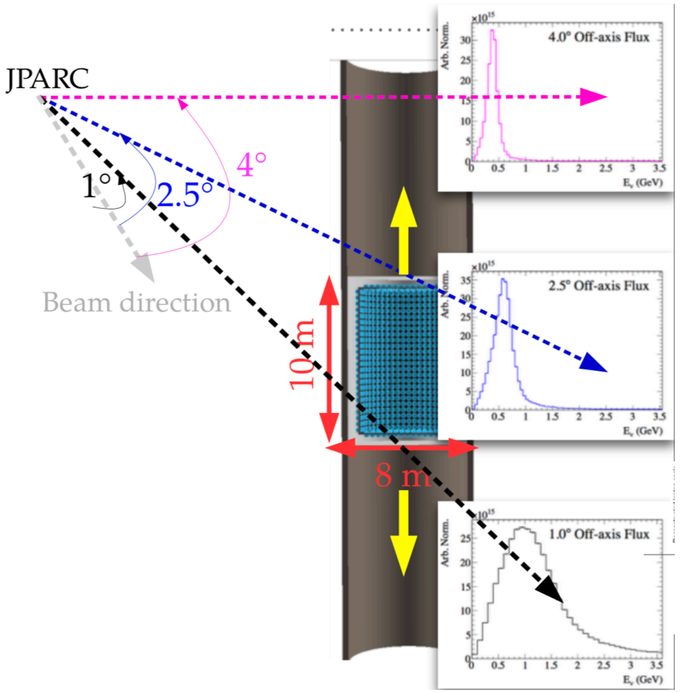


WCTE and IWCD

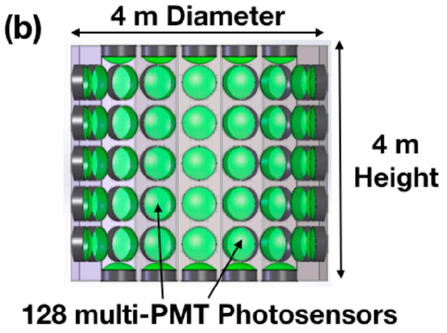
New Intermediate Water Cherenkov detector (IWCD)
- Time synchronization with J-PARC
- Clock distribution to ~1000 mPMTs (~few TDMs)

Need to test the design on a scaled-down version
- Water Cherenkov Test Experiment (WCTE)@CERN
- ~128 mPMTs → 1 TDM is needed
- Use prototypes developed during R&D on the setup

WCTE starts operations in 2023



IWCD detector



WCTE detector

Conclusions and perspectives

R&D on UTC generation and clock synchronization
  Useful discussions and feedbacks initiated with SYRTE

Development of UTC generation prototype for HK
Implementation of GNSS satellites signals corrections
  Try to reach below 10 ns accuracy
Long-term know-how at LPNHE

Ongoing and future IN2P3 projects could profit from this R&D work on HK, in particular in view of multi-messenger observations

Knowledge and technology transfer beneficial to IN2P3