Preparation of the Hyper-Kamiokande experiment

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On behalf of the LPNHE neutrino group

From T2K to Hyper-Kamiokande

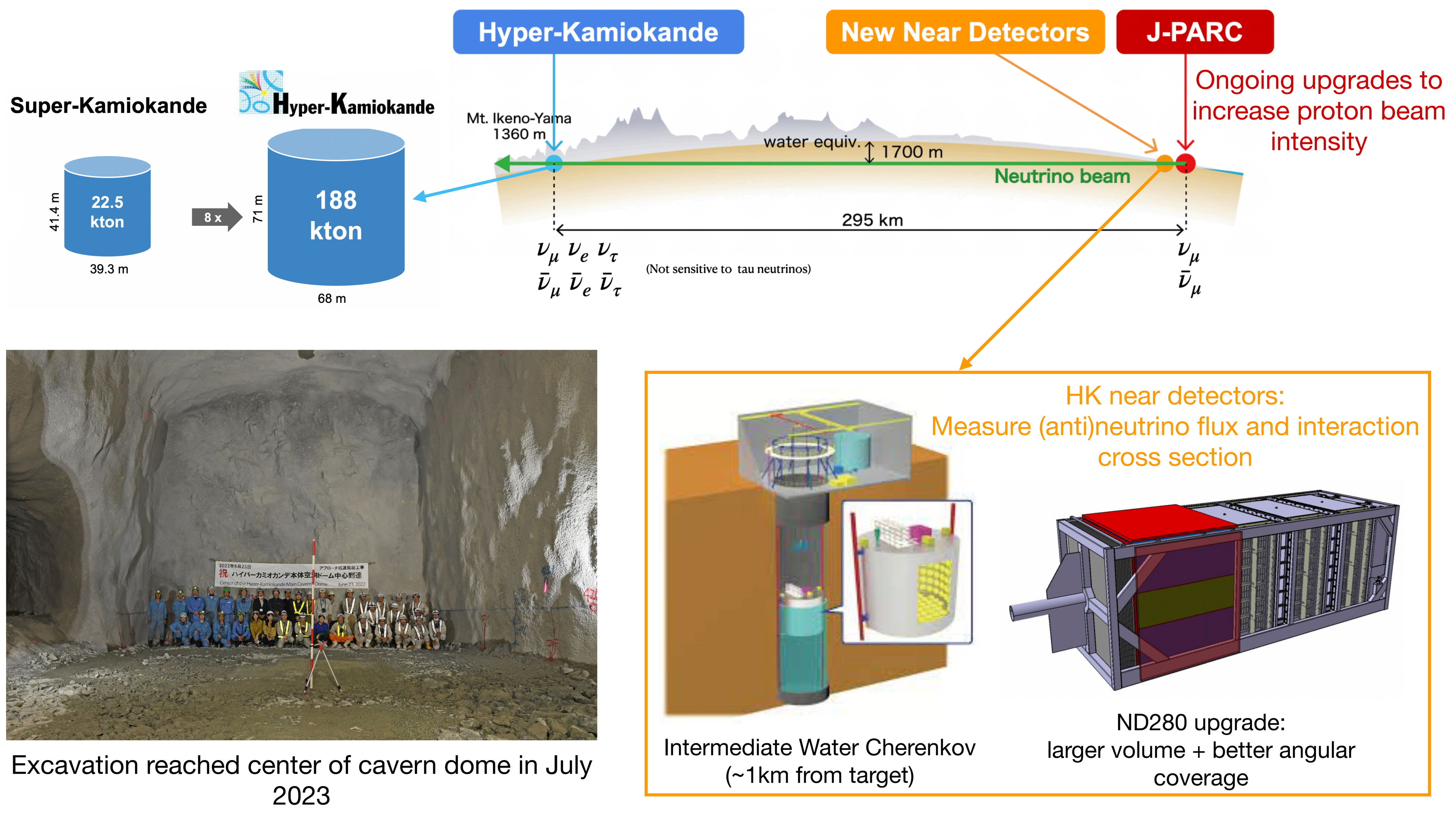


*Figure 1. The Hyper-Kamiokande [3] detector is being built in Japan and the **data-taking is planned to start in 2027**. The HK long baseline program will use the same neutrino beam as T2K but a bigger far detector with the same off-axis angle of 2.5°. The neutrino flux will be well characterized thanks to NA61/SHINE [1] hadron production measurements.*

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta_{CP}}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{i\delta_{CP}} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Parameters constrained by T2K and HK LBL program: δ_{CP}, $\sin^2\theta_{13}$, $\sin^2 2\theta_{23}$ and Δm^2_{32}

Figure 2. Parametrization of the neutrino mixing matrix

Simultaneously measured in the Near Detectors

Flux in detector — Interaction cross-section

Event rate measured in detector

$$N = F \times \sigma \times \epsilon$$

Detector efficiency

Figure 3. Three types of systematic parameters impact the measured event rates.

LPNHE's contributions:

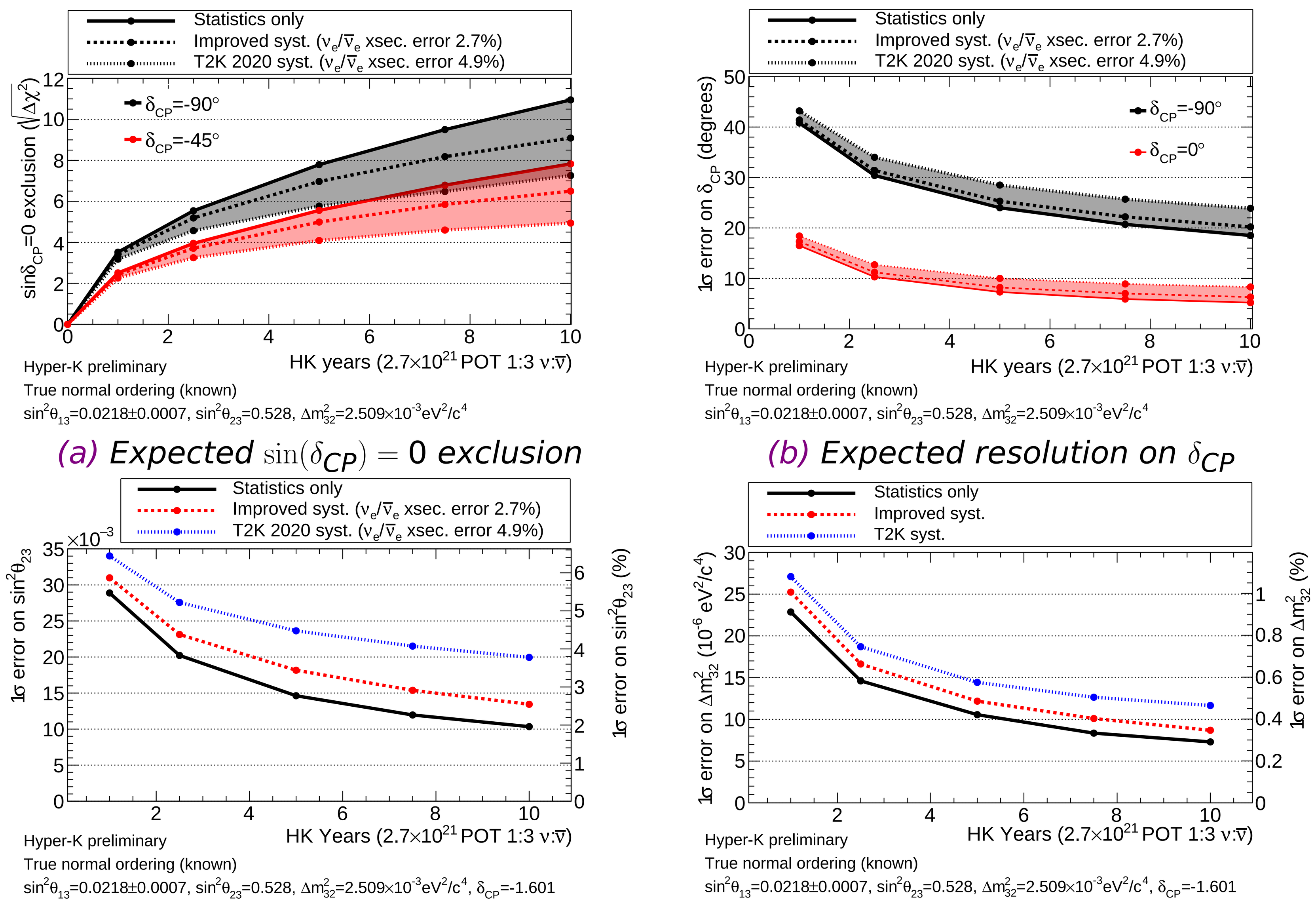
- ND280 upgrade: see Anäelle and Ulysse's poster
- Timing distribution: see Vincent Voisin's poster
- Sensitivity's studies: see below
- Participation in the WCTE project (prototype for IWCD): see below
- Work on particle reconstruction algorithms

Sensitivity studies for Hyper-Kamiokande

New sensitivity studies were performed in France (LPNHE+LLR) using the latest published T2K results [2].

T2K 2020 (Imp.) syst.	ν-mode e-like	ν-mode μ-like	$\bar{\nu}$-mode e-like	$\bar{\nu}$-mode μ-like
ND constrained				
Flux+cross section	3.6% (1.8%)	2.1% (0.9%)	4.3% (1.6%)	3.4% (0.9%)
Not ND constrained				
Cross section	3.0% (1.6%)	0.5% (0.4%)	3.7% (1.4%)	2.6% (0.4%)
Detector	3.1% (1.1%)	2.1% (0.8%)	3.9% (1.5%)	1.9% (0.7%)
All	4.7% (2.1%)	3.0% (1.2%)	5.9% (2.2%)	4.0% (1.1%)

Table 1. 1σ uncertainty on the expected number of events in HK with the T2K 2020 or Improved error model. The Improved error model was built by shrinking the individual systematic uncertainties from T2K 2020 systematic error model to take into account the expected effects of the upgrades and the statistics increase.



(a) Expected $\sin(\delta_{CP}) = 0$ exclusion

(b) Expected resolution on δ_{CP}

(c) Expected resolution on $\sin^2\theta_{23}$

(d) Expected resolution on Δm^2_{32}

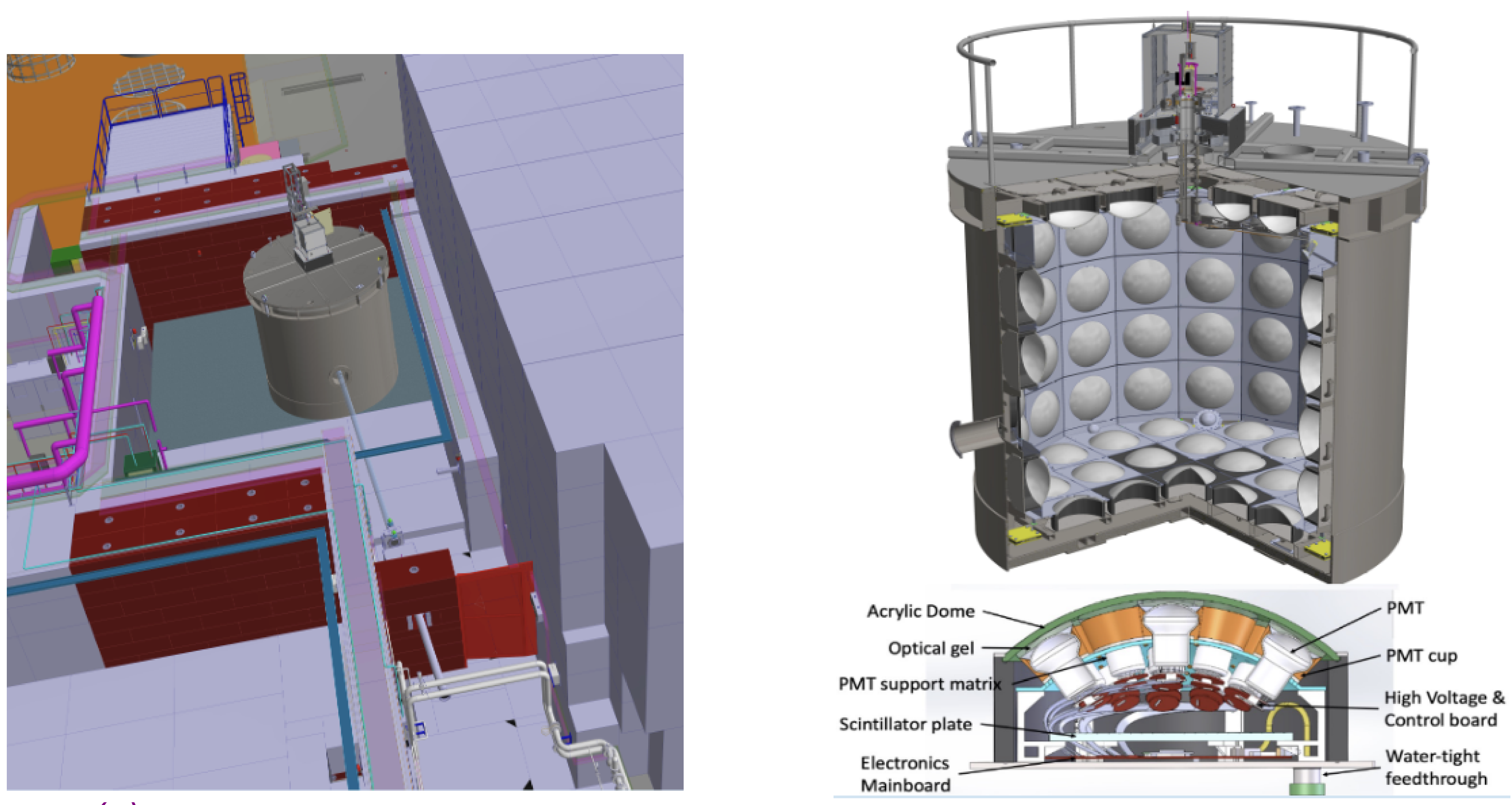
Figure 4. Prediction of HK sensitivity to oscillation parameters: impact of the statistics and the systematic uncertainties.

HK could exclude $\sin\delta_{CP} = 0$ (CP symmetry) with a few years of data ($\approx$ 2 years for $\delta_{CP} = -90°$) only if the systematic uncertainties are reduced compared to T2K! After 10 years, δ_{CP} could be measured with a less than 20° precision and the resolution would reach a few percent and less than a percent for $\sin^2\theta_{23}$ and Δm^2_{32} respectively.

The WCTE project

The discovery potential of Hyper-Kamiokande is limited by the systematic uncertainties from detector calibration and neutrino cross sections, requiring new developments. The main purpose of WCTE (*Water Cherenkov Test Experiment* at CERN) is to prove the new technologies being developed for the next-generation water-Cherenkov experiments, in particular:

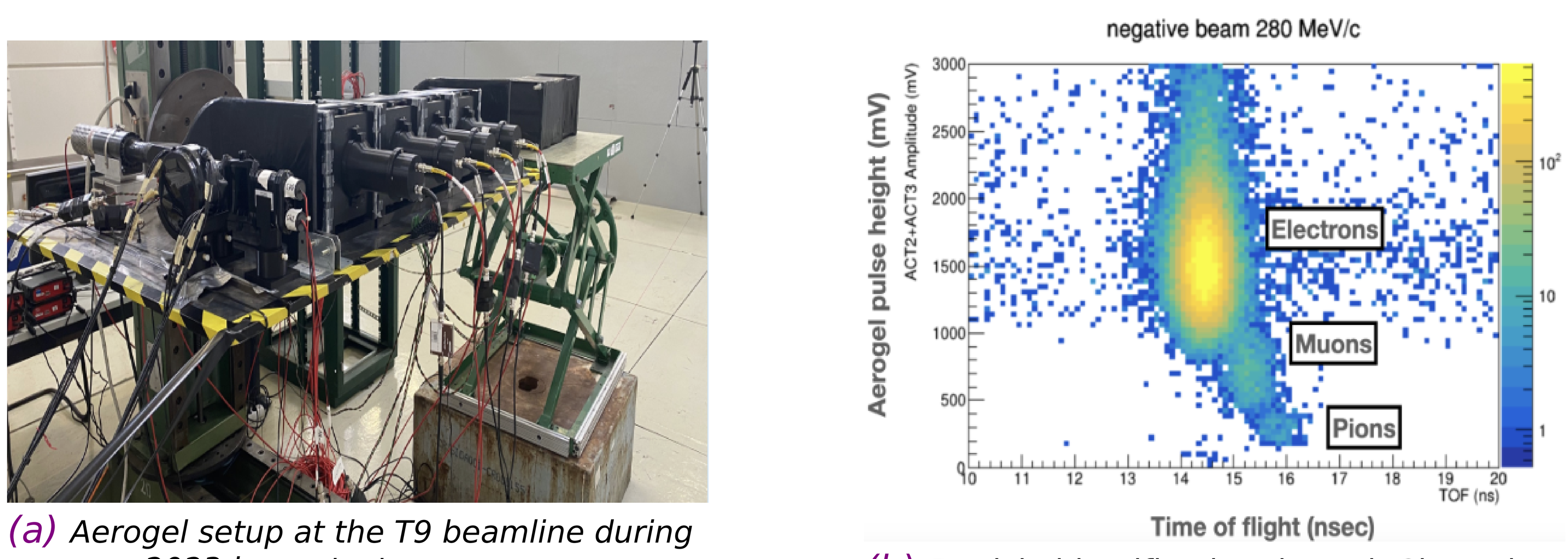
- to develop calibration methods to control uncertainties in event reconstruction and energy scale to the 1% level,
- to understand the reconstruction of pions in water-Cherenkov detectors, including the effects of their interactions with nuclei,
- to measure the production of secondary neutrons created by particle interactions with nuclei



(a) WCTE at the T9 area at CERN.

(b) Cross-section view of the WCTE vessel (top) and a multi-PMT module (bottom).

Figure 5. Schematic view of the WCTE experiment. It will consist of a tank of 3.8 m diameter and 3.5 m height, leading to a 40 ton tank filled with ultra pure water and instrumented with 102 multi-PMT modules with 19 PMTs each. In a second phase, gadolinium (Gd) will be loaded to enhance neutron tagging.



(a) Aerogel setup at the T9 beamline during summer 2023 beam test.

(b) Particle identification through Cherenkov light at the aerogels.

*Figure 6. WCTE will be placed at the T9 area at CERN providing particle samples of known charge and momentum. In order to have full control on the primary interacting particles, an extra setup for particle identification has been tested during this summer (2023) with **LPNHE** contribution.*

References

[1] N. Abgrall et al. *NA61/SHINE facility at the CERN SPS: beams and detector system*. 2014. DOI: 10.1088/1748-0221/9/06/P06005. arXiv: 1401.4699 [physics.ins-det].

[2] The T2K Collaboration. *Measurements of neutrino oscillation parameters from the T2K experiment using 3.6×10^{21} protons on target*. 2023. arXiv: 2303.03222 [hep-ex].

[3] Hyper-Kamiokande Proto-Collaboration. *Hyper-Kamiokande Design Report*. 2018. arXiv: 1805.04163 [physics.ins-det].

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