

# FJPPL NU-09 project

## Characterization of the upgraded J-PARC neutrino beam for T2K-II and HK experiments

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# Goals (1)

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The main goal of this joint France-Japan project is to **improve our knowledge on the upgraded (anti)neutrino beam** produced at J-PARC for T2K-II and HyperKamiokande (HK) experiments.

The important upgrade of the J-PARC neutrino beamline was finalized in 2023. Operation with a horn current set at **320kA** (instead of 250kA used previously) was performed at the end of 2023. The record beam power of **760kW** has been reached!

# Goals (2)

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Dedicated hadron production data collected with a **replica** of the **T2K target** using a significantly upgraded **NA61/SHINE** spectrometer at the CERN SPS are being used to improve our knowledge about the obtained (anti)neutrino flux.

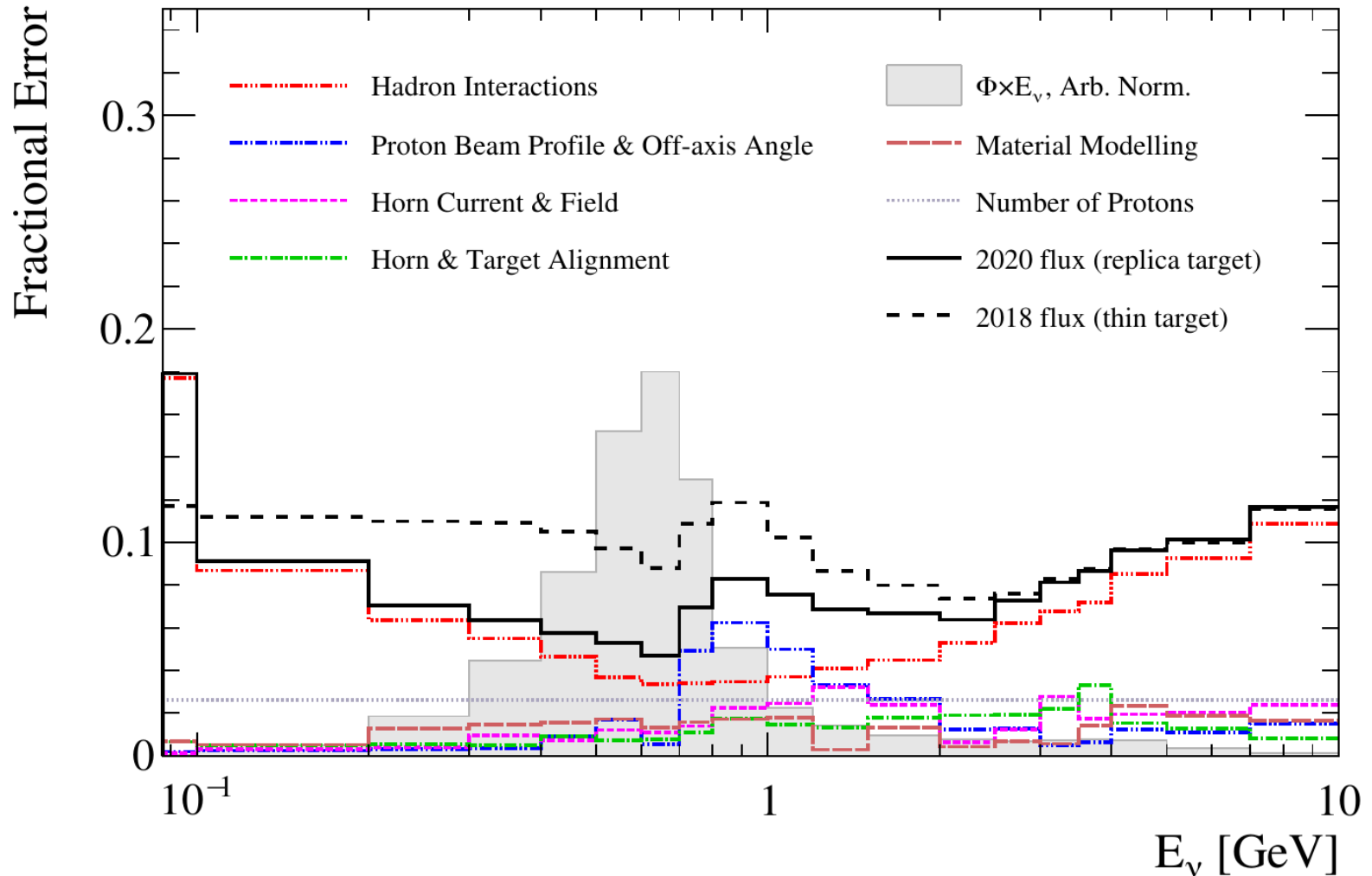
The measurements of hadron yields from the surface of the T2K target are crucial for detailed characterization of the J-PARC neutrino beam and already allowed to achieve unprecedented precision on flux uncertainties.

New data (**180M** triggers compared to 10M used previously) collected during the 2022 NA61/SHINE run will allow to improve this even further.

These data are currently being calibrated and analyzed by a joint team of Japanese and French physicists. A significant progress has been achieved during 2023.

# NA61/SHINE for T2K

FD: Neutrino mode,  $\nu_\mu$



# Goals (3)

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Another important task for the long-baseline neutrino experiment is the synchronization of the accelerator spill from J-PARC with neutrino interactions observed in the near (ND280) and far (SK or HK) detector.

In the framework of this project a new time synchronization system is being developed and will be installed at J-PARC by the joint French-Japanese team. An intensive R&D has already been performed at LPNHE and important tests of the selected equipment (**GNSS antenna** and **receiver**) were performed during summer 2023 at both J-PARC and HK sites.

A required scheme of the timing system with a free-running rubidium atomic clock accompanied by a set of GNSS antenna and receivers will be deployed and tested.

# GNSS antenna installation at HK



# Selected NU-09 publications

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**Development of a Clock Generation and Time Distribution System for Hyper-Kamiokande**, Lucile Mellet, Mathieu Guigue, Boris Popov, Stefano Russo, Vincent Voisin, 2023, Phys.Sci.Forum 8 (2023) 1, 72; DOI: 10.3390/psf2023008072

**Updated T2K measurements of muon neutrino and antineutrino disappearance using  $3.6 \times 10^{21}$  protons on target**, T2K Collaboration, K.Abe et al, 2023, Phys.Rev.D 108 (2023) 7, 072011; DOI: 10.1103/PhysRevD.108.072011

**Addressing the challenge of neutrino interaction uncertainties in Hyper-Kamiokande**, C.Dalmazzone (for HK collaboration), talk at the NNN'2023 conference, October 2023

**NA61/SHINE experiment for neutrino physics**, Y. Koshio (for NA61/SHINE collaboration), talk at the NuFact 2023 conference, August 2023

*The group meets regularly on the occasion of NA61/SHINE, T2K and HK collaboration meetings. We also organize dedicated Zoom meetings in order to discuss the ongoing activities and to define plans for the future. During 2023 we organized two in-person workshops devoted to the calibration of the upgraded NA61/SHINE spectrometer and analysis of the T2K replica target data. A seminar at LPNHE on the supernovae detection at HK by Koshio-san in December 2023.*

# Future plans (1)

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In 2024 we will continue our very successful joint France-Japan project with the main goal of improving our knowledge on the upgraded (anti)neutrino beam produced at J-PARC for T2K-II and HyperKamiokande (HK) experiments.

In 2024, we will **conduct extended periods of physics data taking** using upgraded beamlines and neutrino detectors. In addition to the period before summer, we also plan to operate for several months in the fall.



# Future plans (2)

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The measurements of hadron yields from the surface of **the T2K replica target performed with the upgraded NA61/SHINE spectrometer** at the CERN SPS are crucial for detailed characterization of the J-PARC neutrino beam and already allowed to achieve unprecedented precision on flux uncertainties. New data (180M triggers) collected during the 2022 are currently being calibrated and analyzed by a joint team of Japanese and French physicists.

In 2024 we plan **to finalize the calibration of the raw data** and to start the analysis efforts to study the cross-sections for the production of neutral kaons and charged kaons with high momentum, aiming to reduce neutrino flux errors in T2K.

# Future plans (3)

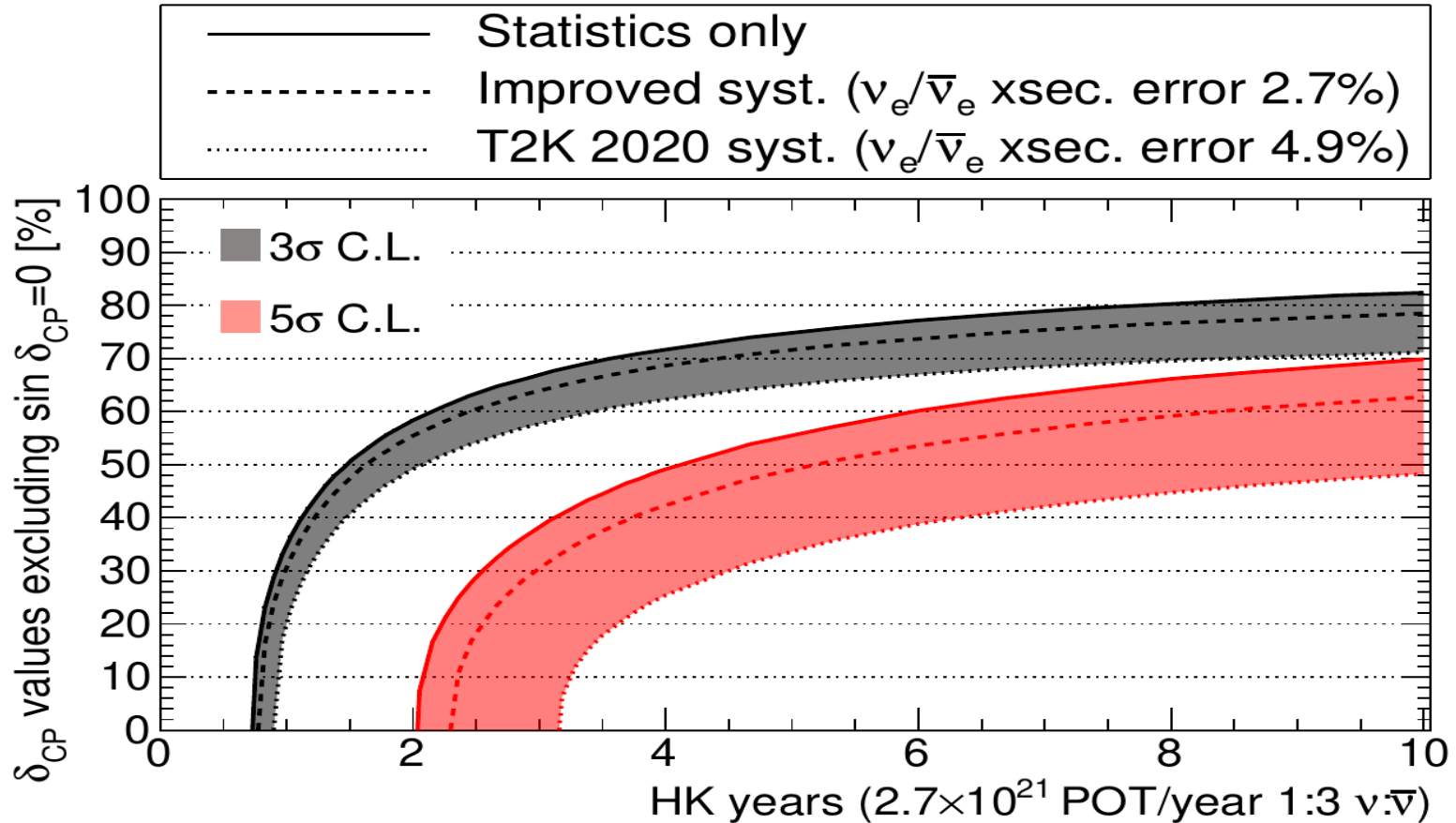
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In 2024 we also plan **to finalize the design of the new time synchronization system** being developed for the J-PARC neutrino beam by the joint French-Japanese team.

Some additional **stability tests** would have to be performed on the J-PARC site. A free-running rubidium atomic clock accompanied by a set of GNSS antenna and receivers will be installed at J-PARC, characterized and maintained.

In 2024 we also plan to prepare a **publication** devoted to the results of the new **HyperKamiokande sensitivity studies**.

# HK sensitivity study



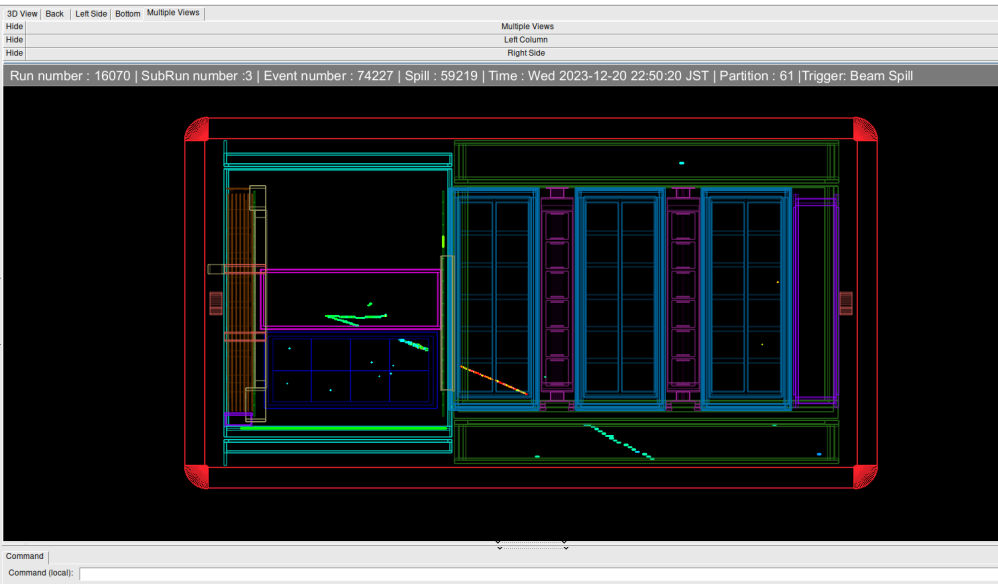
Hyper-K preliminary

True normal ordering (known)

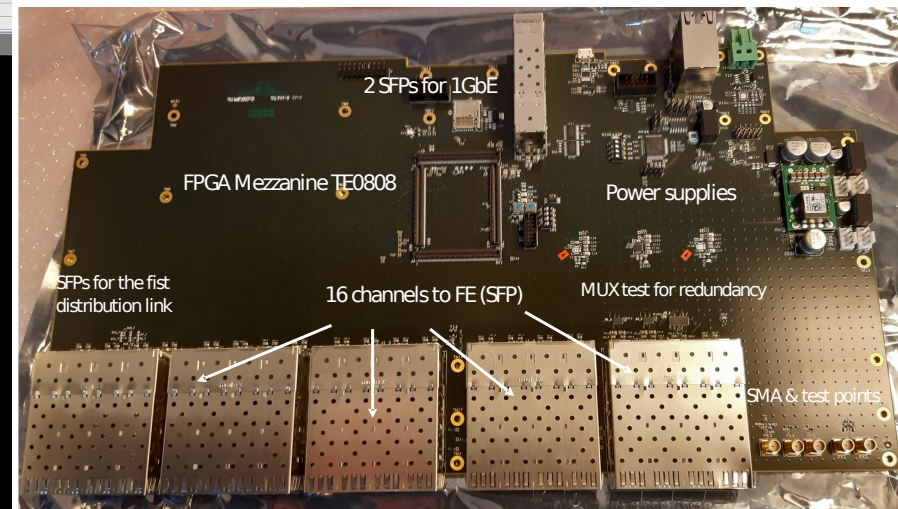
$$\sin^2 \theta_{13} = 0.0218 \pm 0.0007, \quad \sin^2 \theta_{23} = 0.528, \quad \Delta m_{32}^2 = 2.509 \times 10^{-3} \text{eV}^2/c^4$$

# Ongoing efforts

Neutrino interaction in the upgraded near detector of the T2K experiment (December, 2023 run)



Prototype of a timing distribution board for the HK experiment



# Conclusions

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**NU-09 is an ongoing project with well defined and ambitious scientific goals**

**Nice working environment within the joint team**

**New results expected in 2024**

*Thank you for your support!*