FJPPL NU-09 project

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

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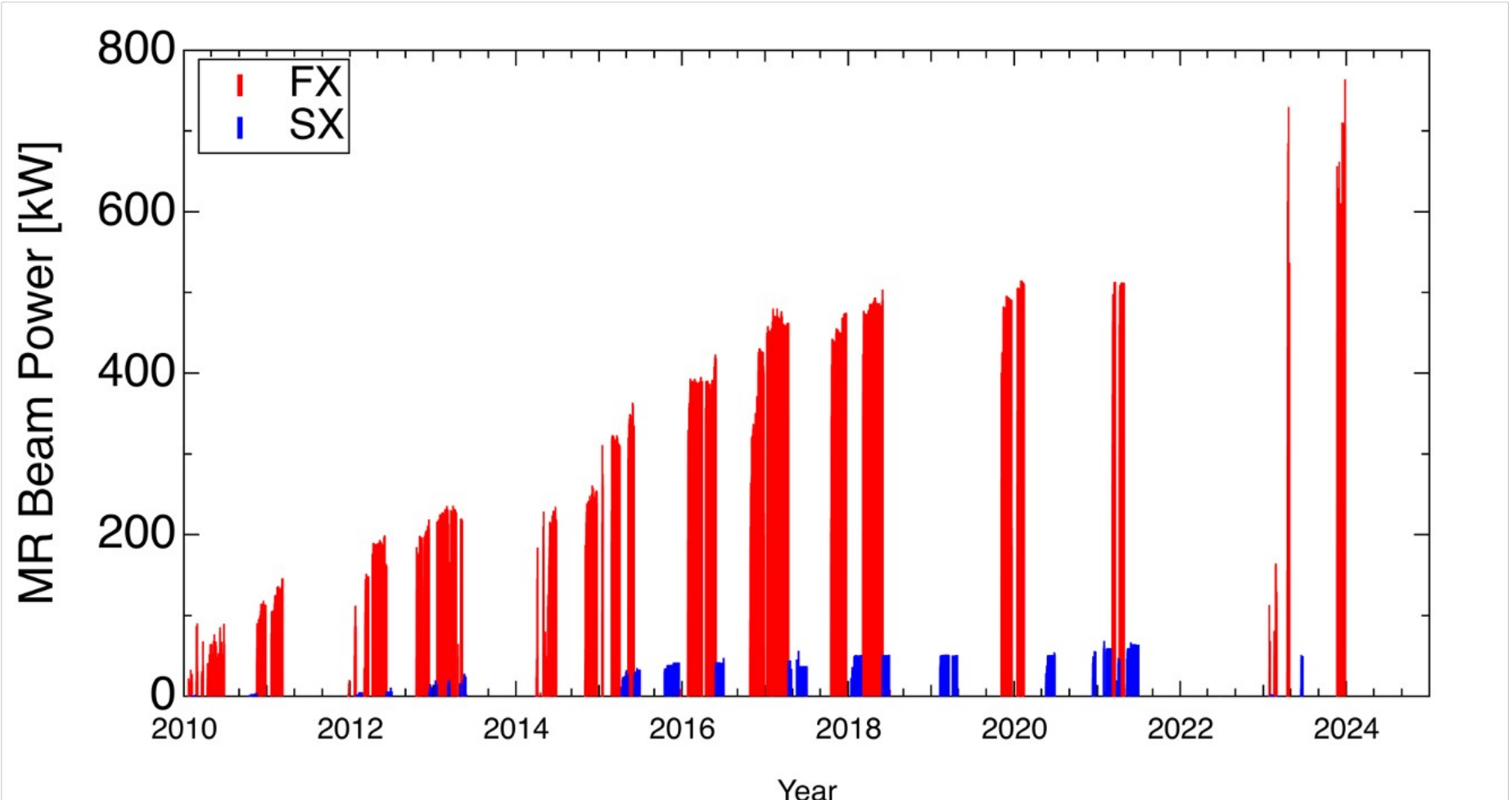
Goals (1)

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!

MR Beam Operation

- Hardware upgrade was completed for the 1.36 s operation by JFY2022.
- Beam tuning and FX operation were performed in April, Nov. and Dec. of 2023
- Beam power was gradually increased with beam tunings.
- Beam of 760 kW was successfully delivered on Dec. 25, 2023.



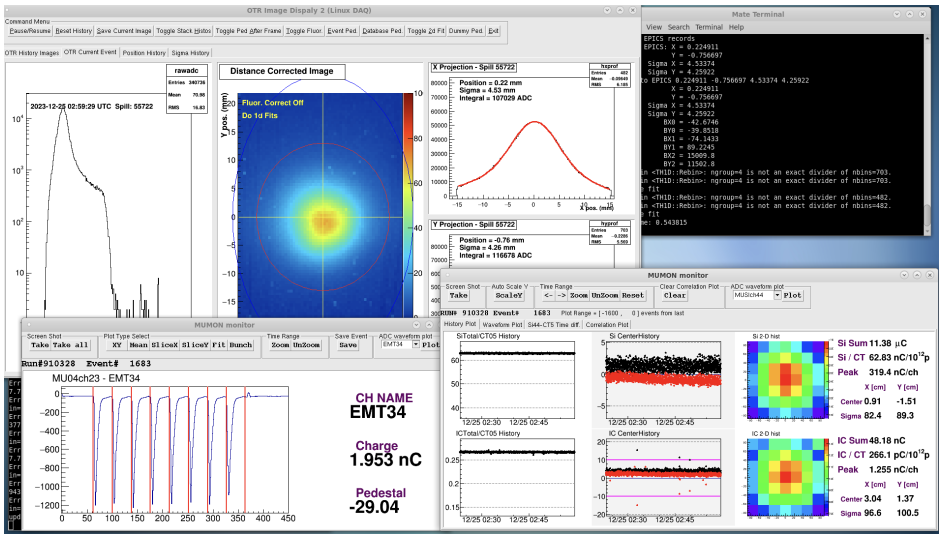
Neutrino beam operation after 2021-2022 accelerator/beamline upgrade

- Various beam commissioning items conducted (e.g. alignment check with beam)
- Successfully achieved 710kW stable operation with 320kA of horn current
- Also, 760kW continuous operation on 2023/Dec/25
- Plan another month of operation before summer 2024 after repairing the He compressor

x ~1.5 more neutrinos/second compared to before the upgrade !!

(beam power & horn)

Still in progress toward 1.3MW

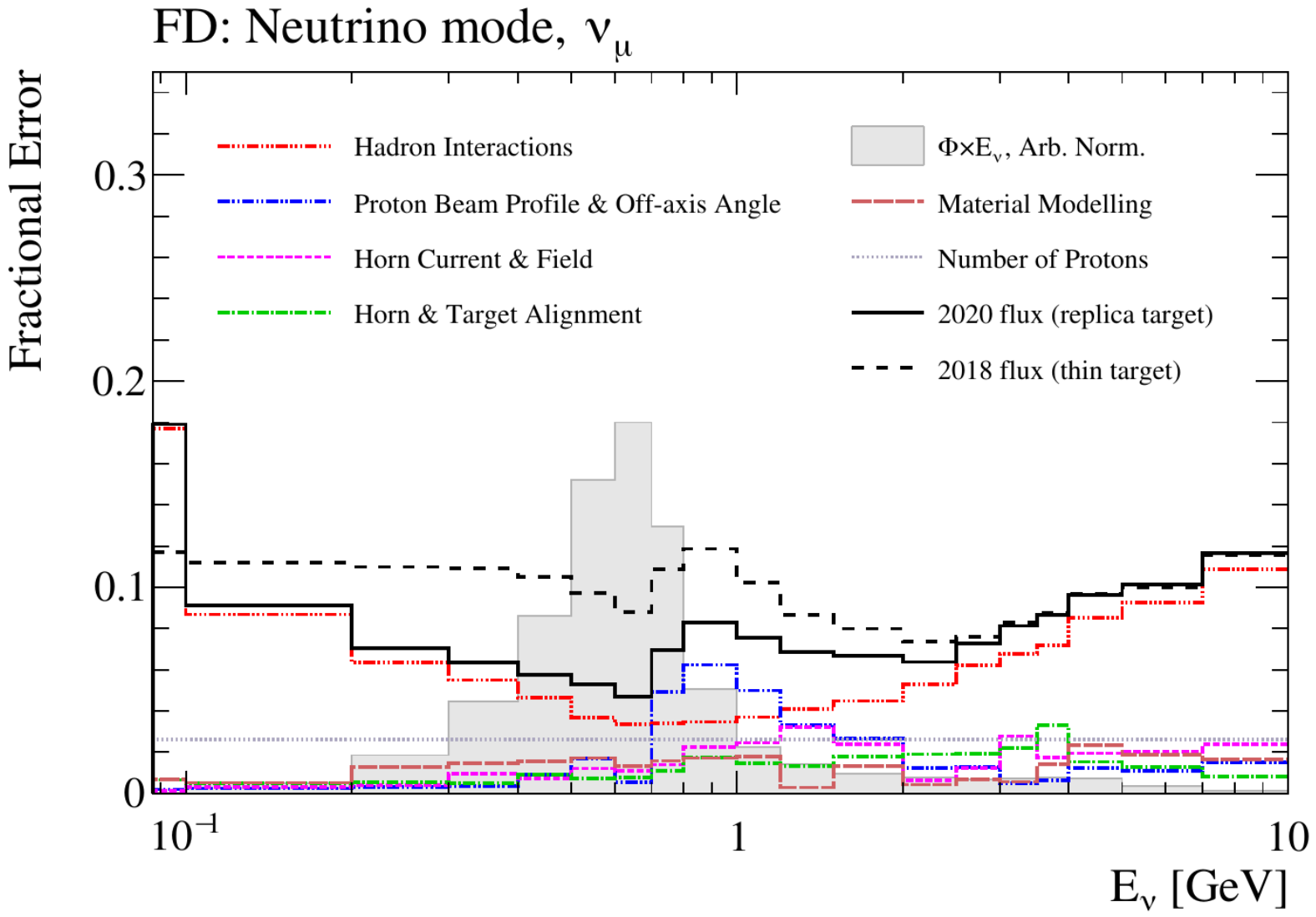


Goals (2)

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.

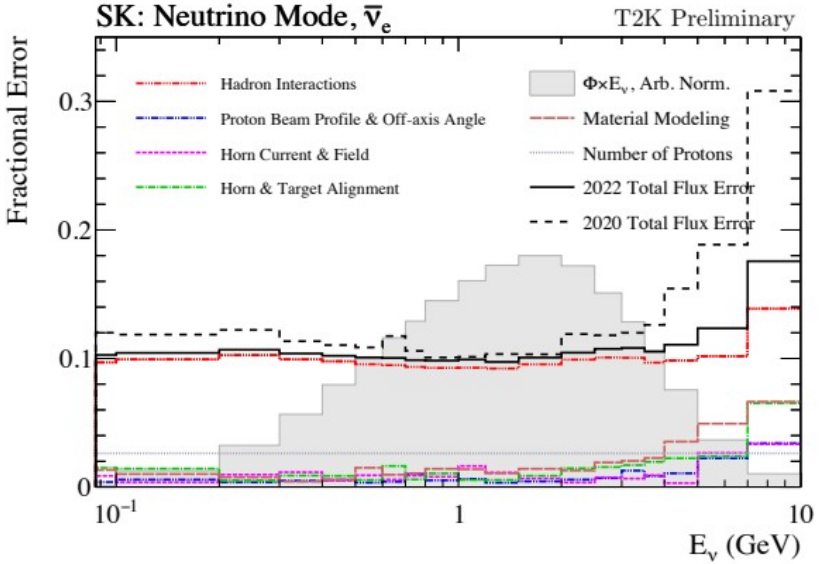
These data are currently being calibrated and analyzed by a joint team of Japanese and French physicists. A significant progress has been achieved during 2023.

NA61/SHINE for T2K



Physics motivation for K_L^0

- Wrong-sign ν_e flux uncertainty is ~ 10 % with thin target tuning for K_L^0 production.
- T2K2022 recorded over 150M events, which is over 10 times larger than the last run. K_S^0 measurement can be done with such a high statistics dataset. Flux estimation will be improved with K_S^0 measurement.

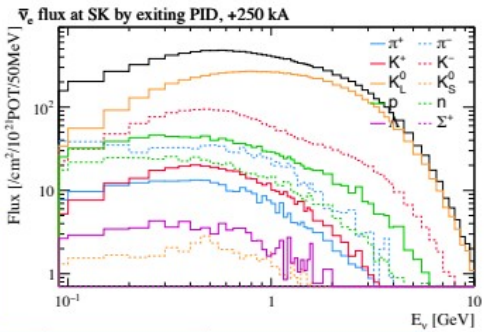


Motivation of further replica target measurement (2)

Reducing wrong-sign ν_e flux error

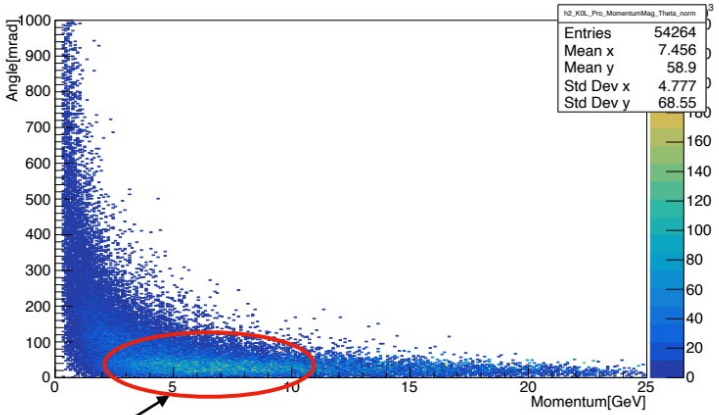
- Major contribution on wrong-sign ν_e flux from K_L
- No replica target tuning for K_L due to no K_S production yield results (currently, only thin-target)

Plan to perform K_S results from replica target data with high statistics (2021 data)



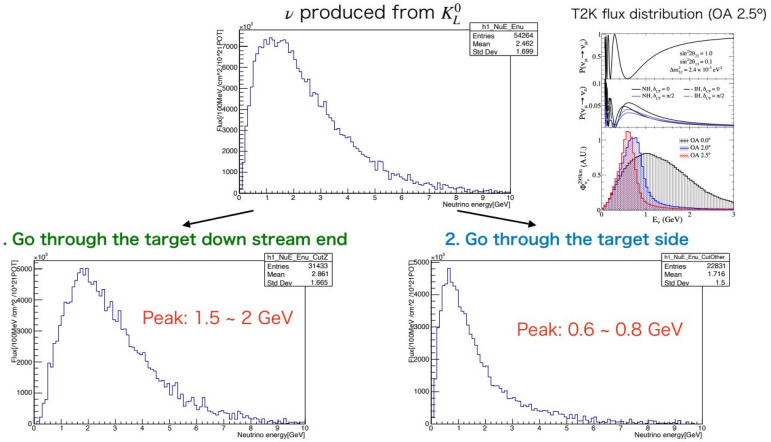
Beam	Target	Year	Stat (10^6)	Outgoing PID	Usage at T2K
protons at 31 GeV/c	Thin (2cm)	2007	0.7	$\pi^\pm$, $K^\pm$, K^0_S, Λ	past
		2009	5.4	$\pi^\pm$, $K^\pm$, p, K^0_S, Λ	in use
	T2K replica (90cm)	2007	0.2	$\pi^\pm$	
		2009	2.8	$\pi^\pm$	next T2K results
		2010	10.	$\pi^\pm$, $K^\pm$, p	in development

Check K^0_s phase space with T2K beam simulation



There is a peak. It seems this distribution has 2 components.

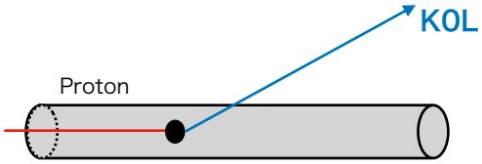
Neutrino flux distribution

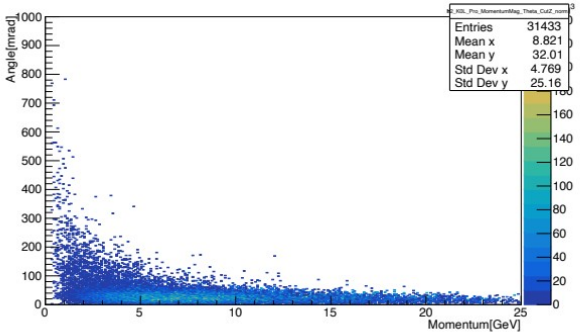


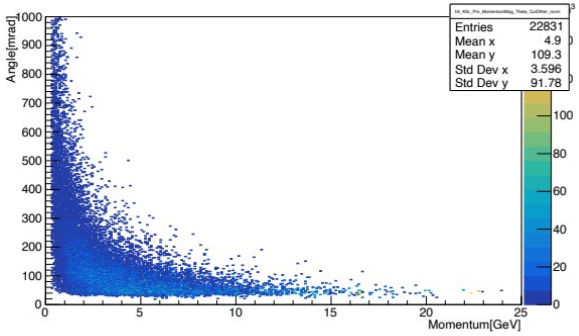
The flux peak of T2K is ~ 600 MeV.
More neutrinos less than 1 GeV are classified as group 2.
Both group are should be considered for the NA61 analysis.

1. Go through the target down stream end

2. Go through the target side





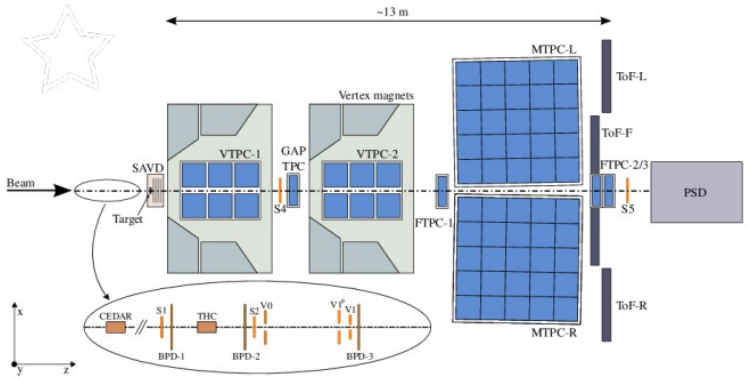


The distribution was clearly classified by the different positions they passed through on the target surface.

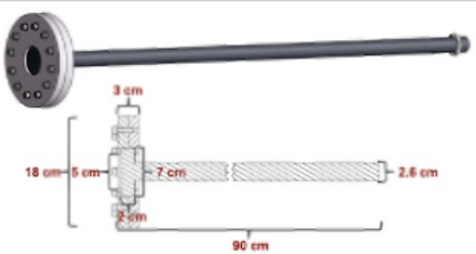
→ (z,p,theta) binning of K^0_s production measurements is under consideration for NA61/SHINE data analysis

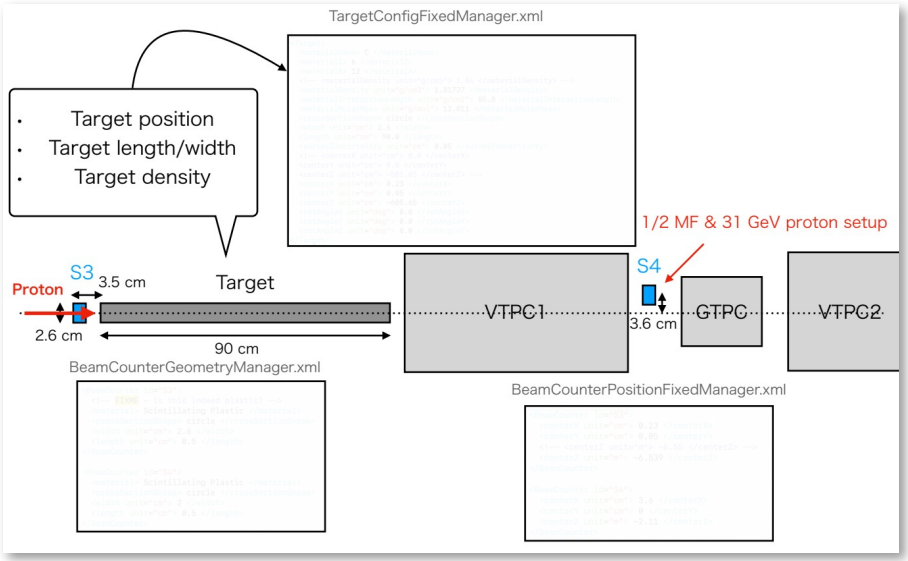
NA61/SHINE data analysis

- T2K replica target run was done in 2022 summer
  - > 150M events collected (more than 10 times larger statistics compared to the previous run)
- Calibration of this data set is in progress
- Preparation for data analysis (as well as MC production) is ongoing



<T2K replica target>





Goals (3)

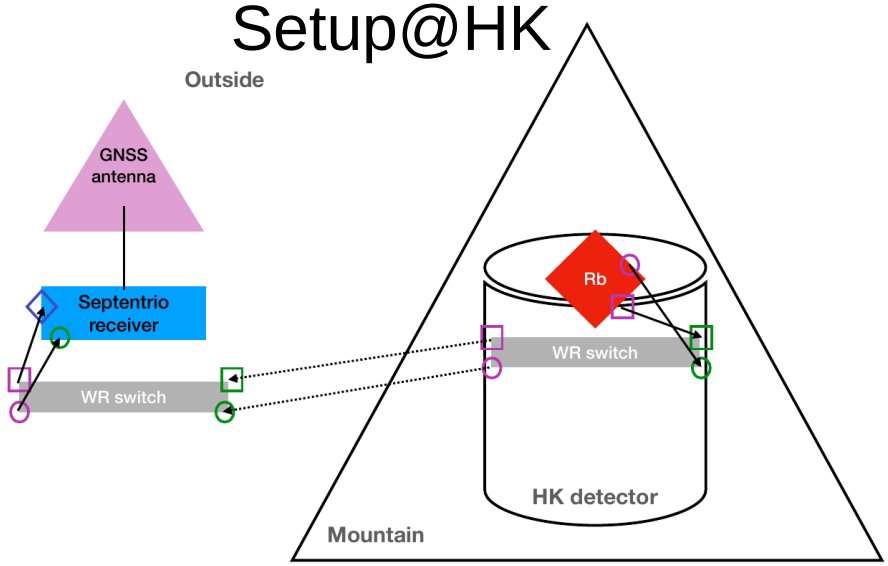
Another important task for the long-baseline neutrino experiment is the synchronization of the accelerator spill from J-PARC with neutrino interactions observed in the near (ND280) and far (SK or HK) detector.

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.

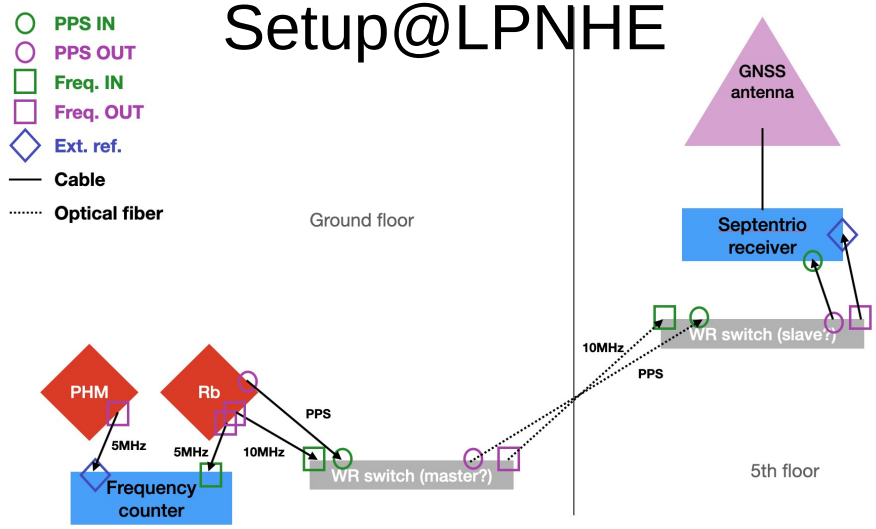
A required scheme of the timing system with a free-running rubidium atomic clock accompanied by a set of GNSS antenna and receivers will be deployed and tested.

GNSS measurements at LPNHE

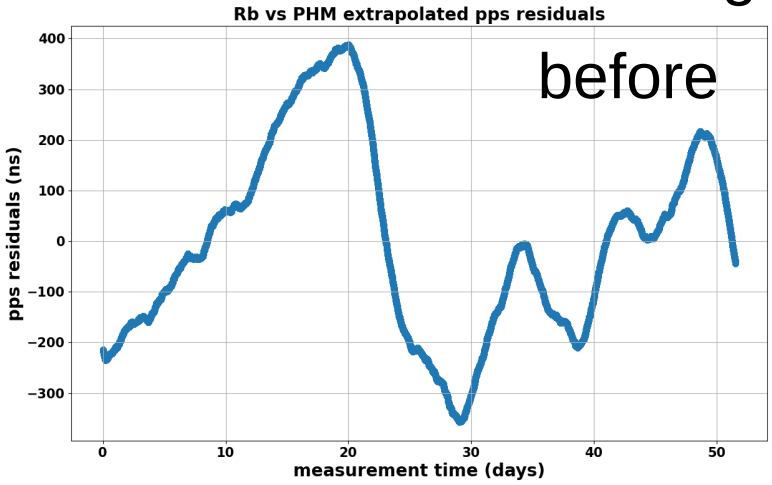
Setup@HK

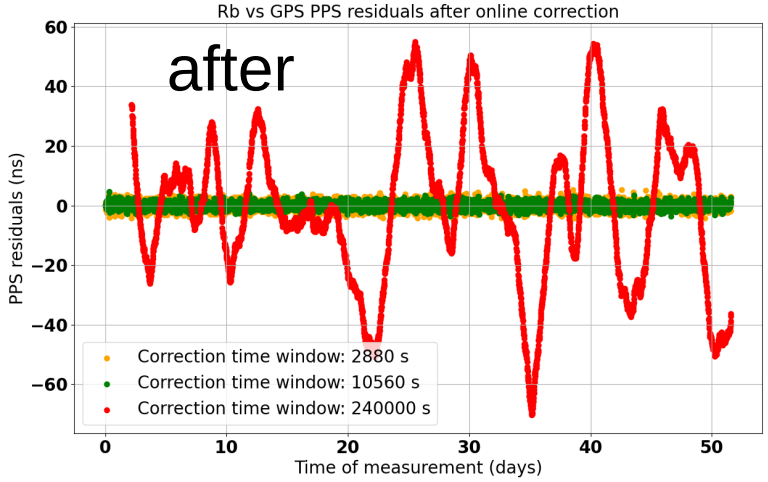


Setup@LPNHE



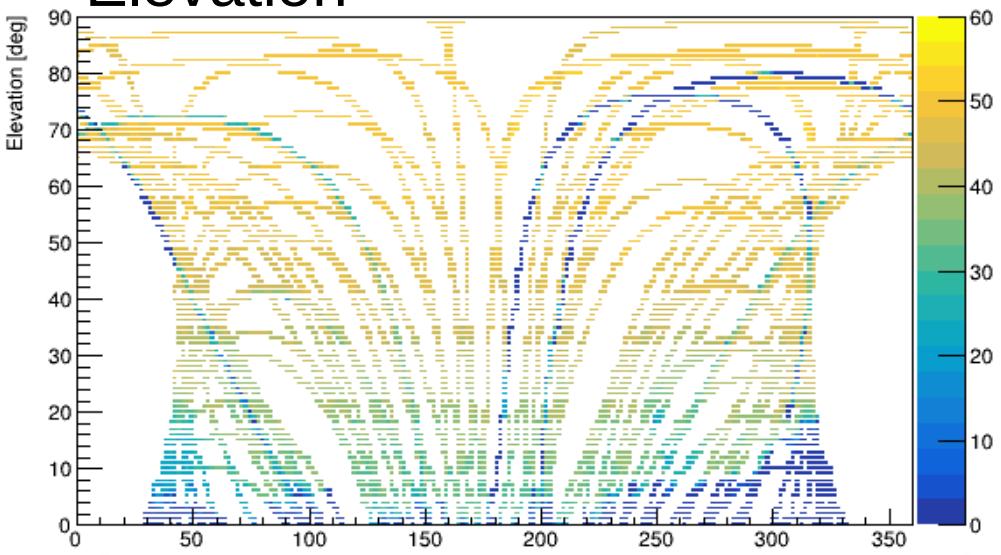
Timing correction algorithm



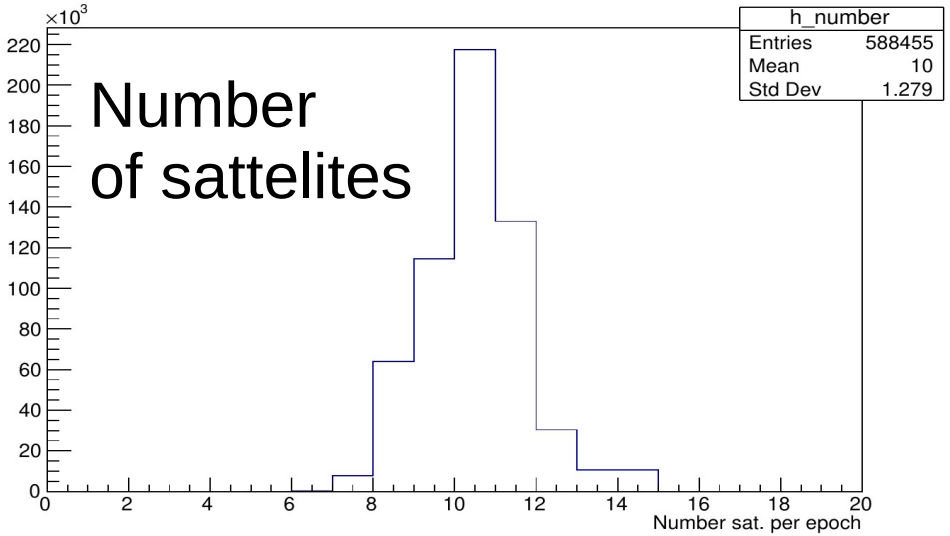


GNSS measurements at J-PARC

Elevation



Number of sattelites



GNSS antenna installation at HK

Selected NU-09 publications

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 3.6x10 ^{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)

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)

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.

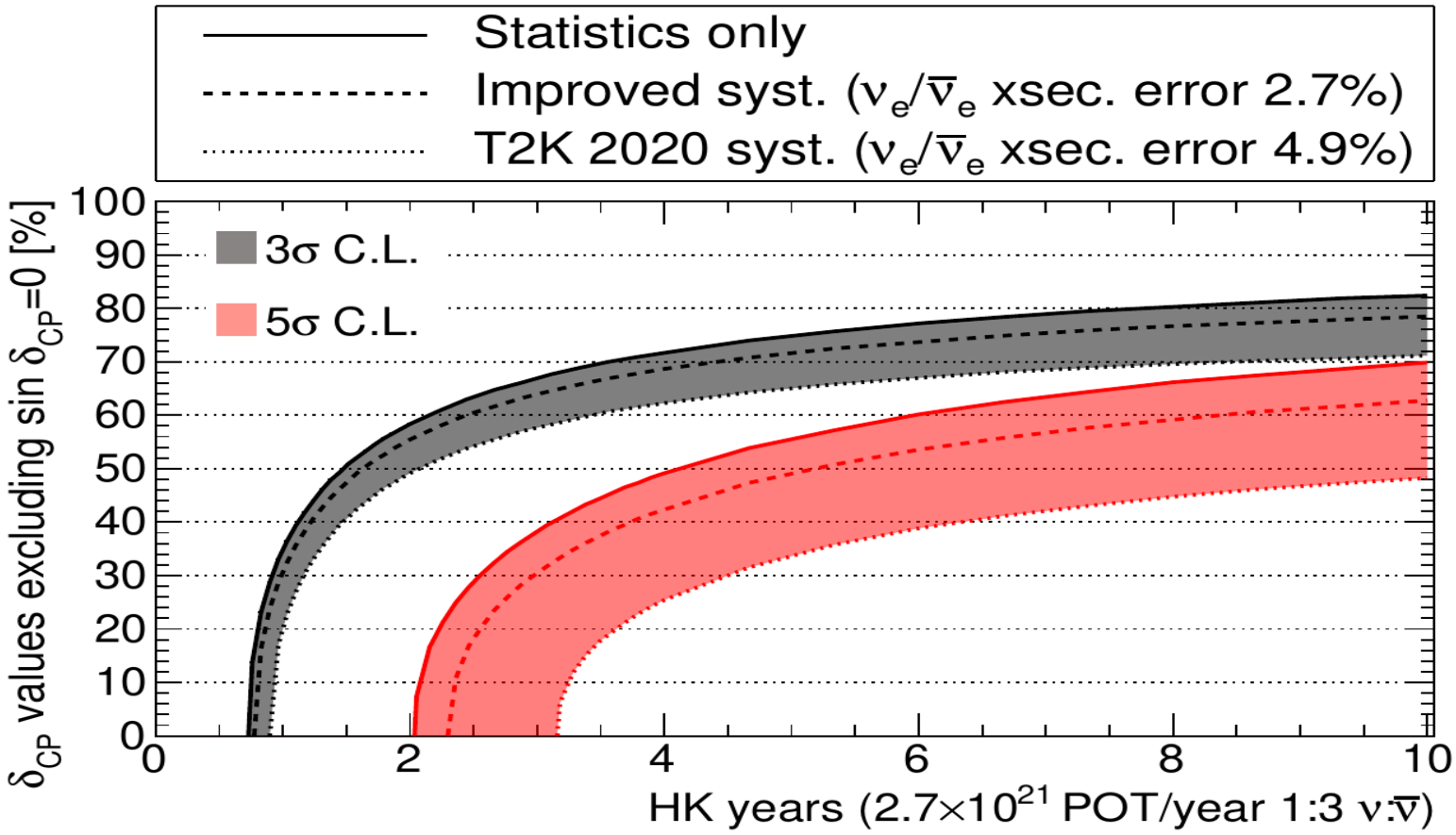
Future plans (3)

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**.

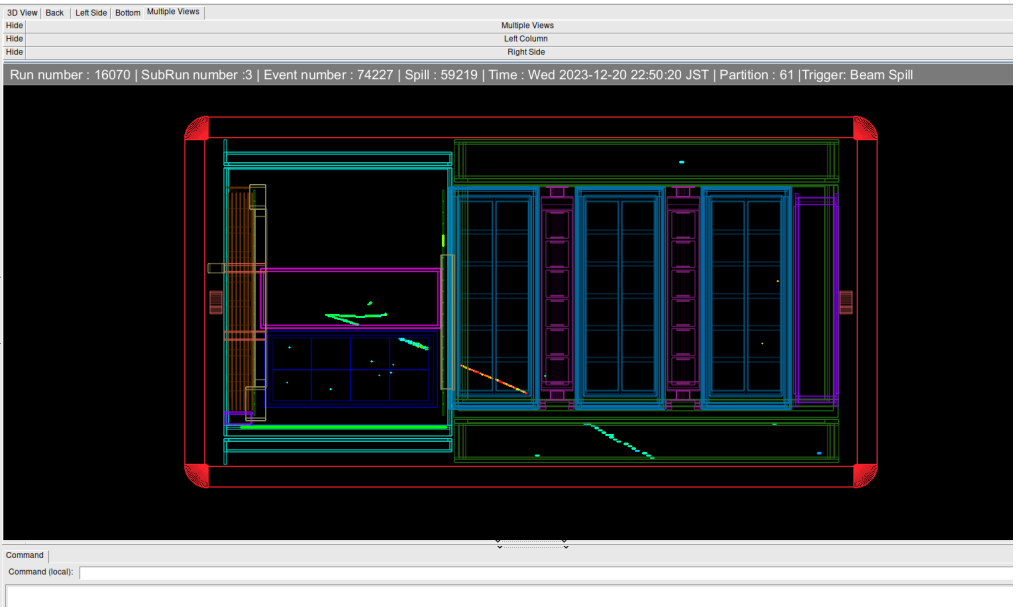
HK sensitivity study



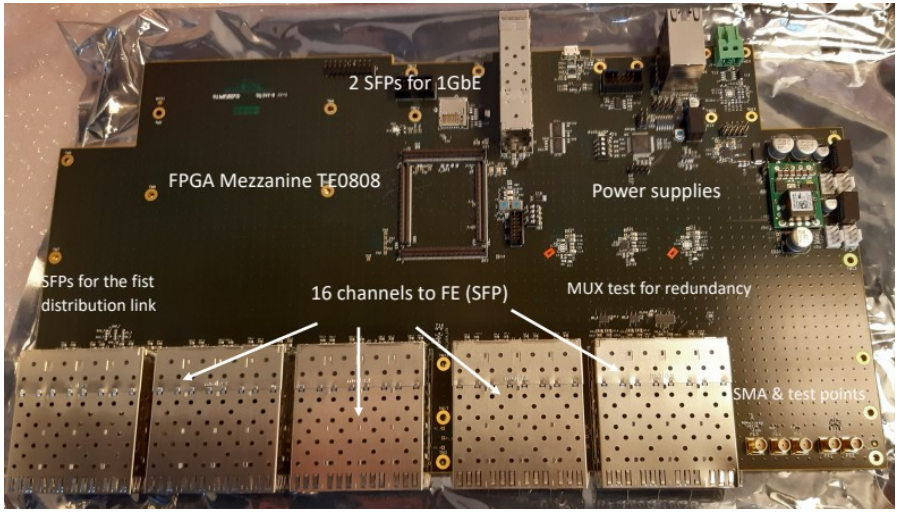
Hyper-K preliminary
True normal ordering (known)
$\sin^2\theta_{13}=0.0218\pm0.0007$, $\sin^2\theta_{23}=0.528$, $\Delta m^2_{32}=2.509\times10^{-3}eV^2/c^4$

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

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

Nice working invironment within the joint team

New results expected in 2024

Thank you for your support!