T2K ND280 Upgrade status

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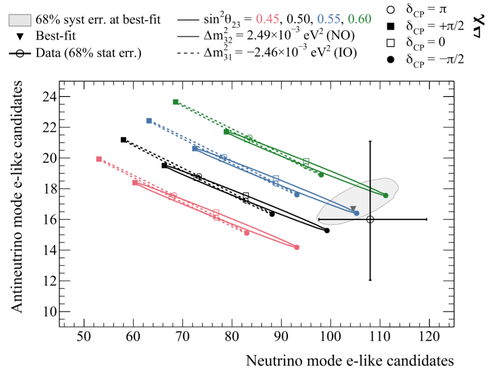
on behalf of the NP-07 groups

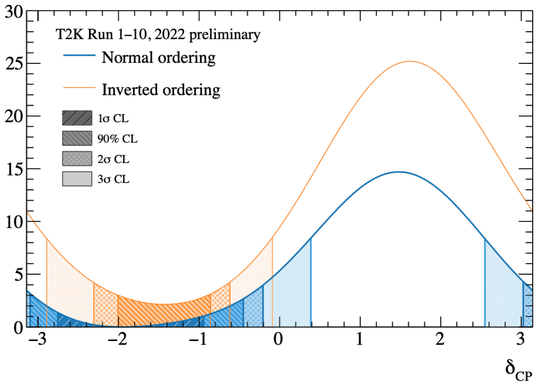
SPSC Meeting - 7 May 2024

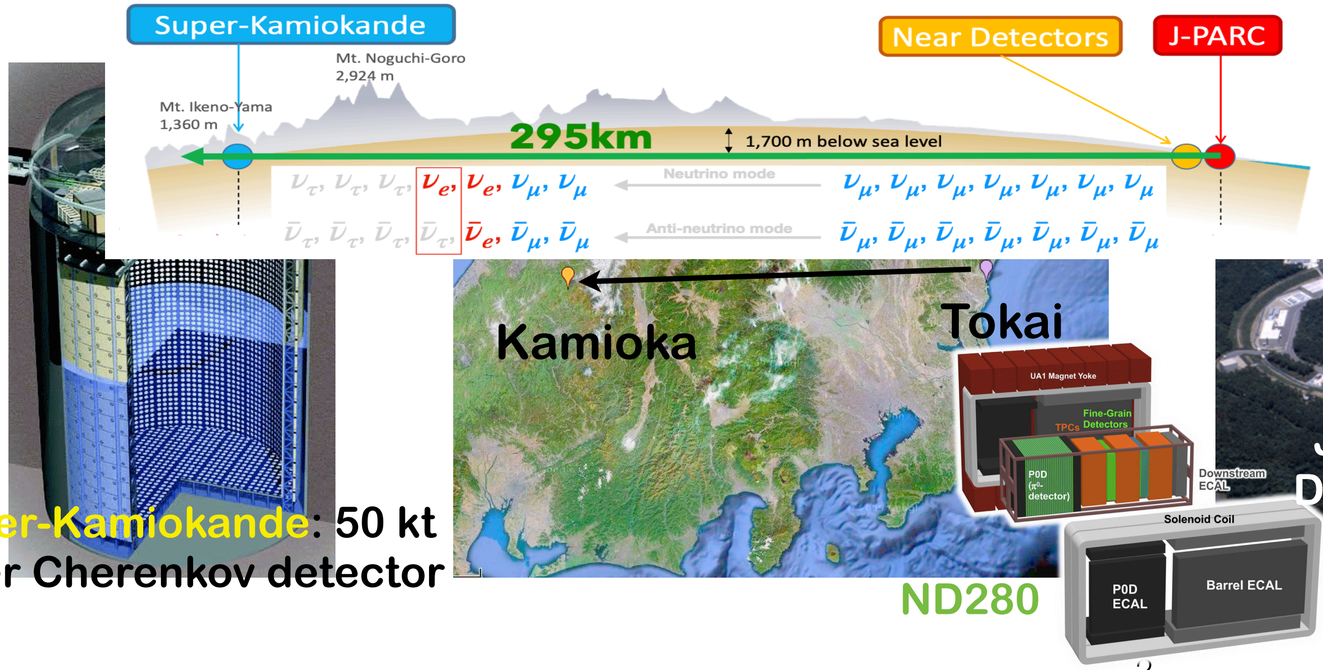
T2K experiment

- High intensity ~600 MeV ν_μ beam at J-PARC (Tokai) → ν or $\bar{\nu}$ mode by changing the horn polarity
- Neutrinos detected at the Near Detector (ND280) and at the Far Detector (Super-Kamiokande)
  - ν_e and $\bar{\nu}_e$ appearance → determine θ_{13} and δ_{CP}
  - Precise measurement of ν_μ disappearance → θ_{23} and $|\Delta m^2_{32}|$

$\delta_{CP} \sim -\pi/2$ → Several values of δ_{CP} excluded at more than 3σ

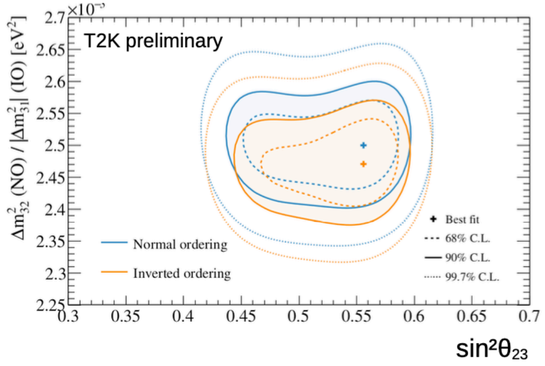






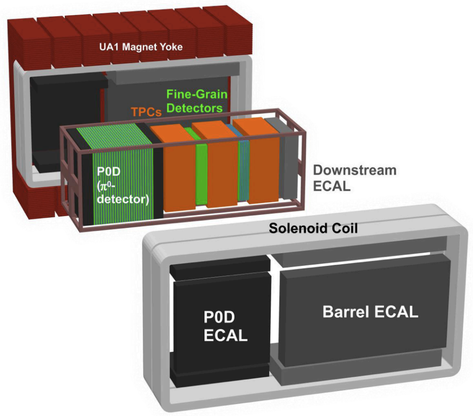
Super-Kamiokande: 50 kt water Cherenkov detector

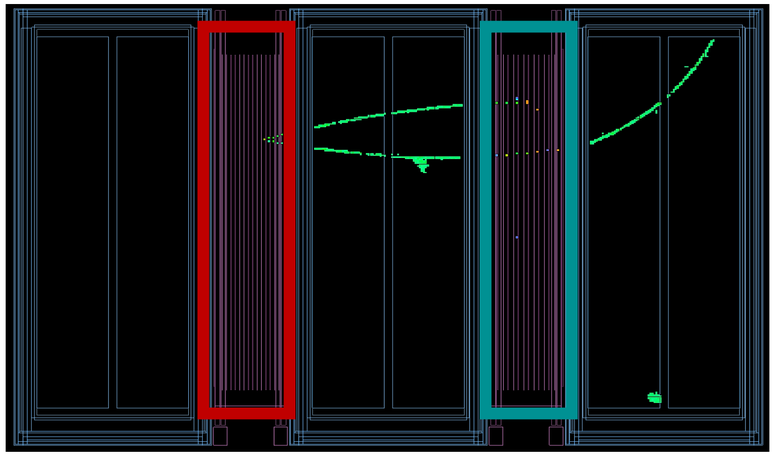
Precise measurement of Δm^2 (~2% uncertainty) $\sin^2(\theta_{23})$ compatible with maximal mixing

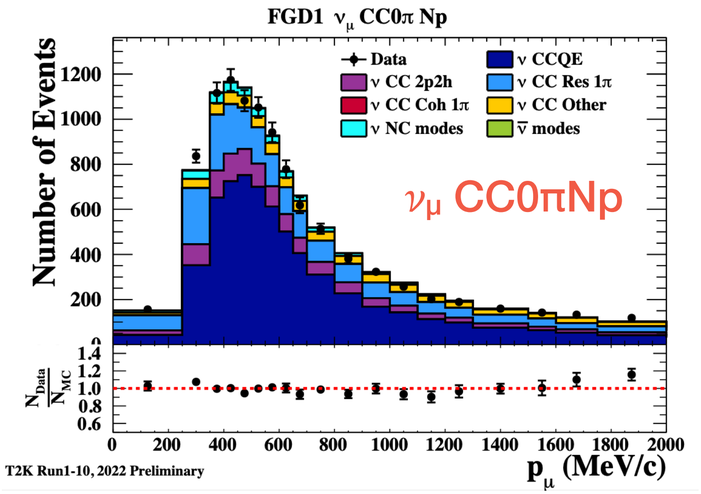


ND280 impact on T2K OA

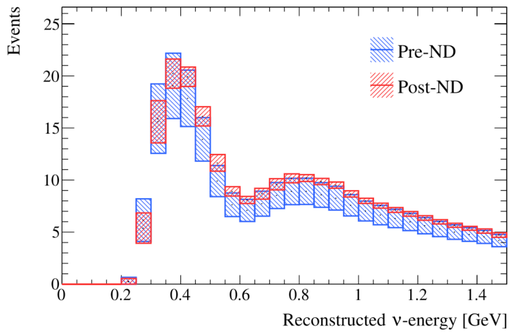
- ND280 magnetized detector
- Select interactions in FGD and measure muon kinematics in the TPCs
- Separate samples based on number of reconstructed pions (CC0π, CC1π, CCNπ), protons, photons, etc
- Factor of ~3 reduction on the uncertainty on the event rates at the Far Detector

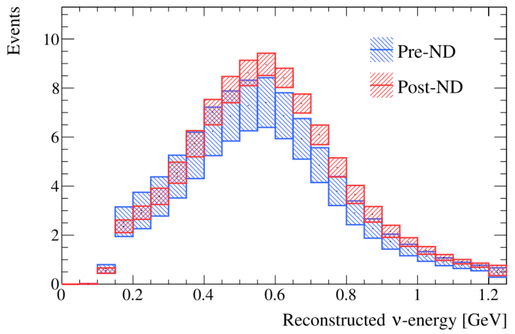


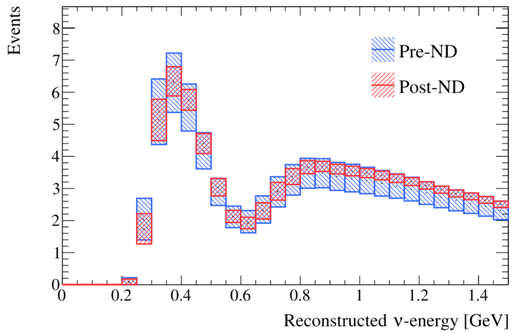




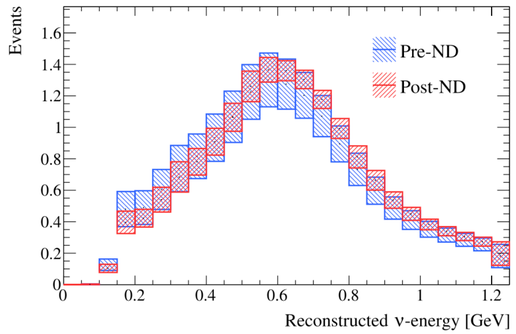
Sample	Pre-ND FIT error	Post-ND FIT error
FHC 1Rμ	11.1%	3.0%
RHC 1Rμ	11.3%	4.0%
FHC 1Re	13.0%	4.7 %
RHC 1Re	12.1%	5.9%
FHC 1Re 1d.e.	18.7%	14.3%





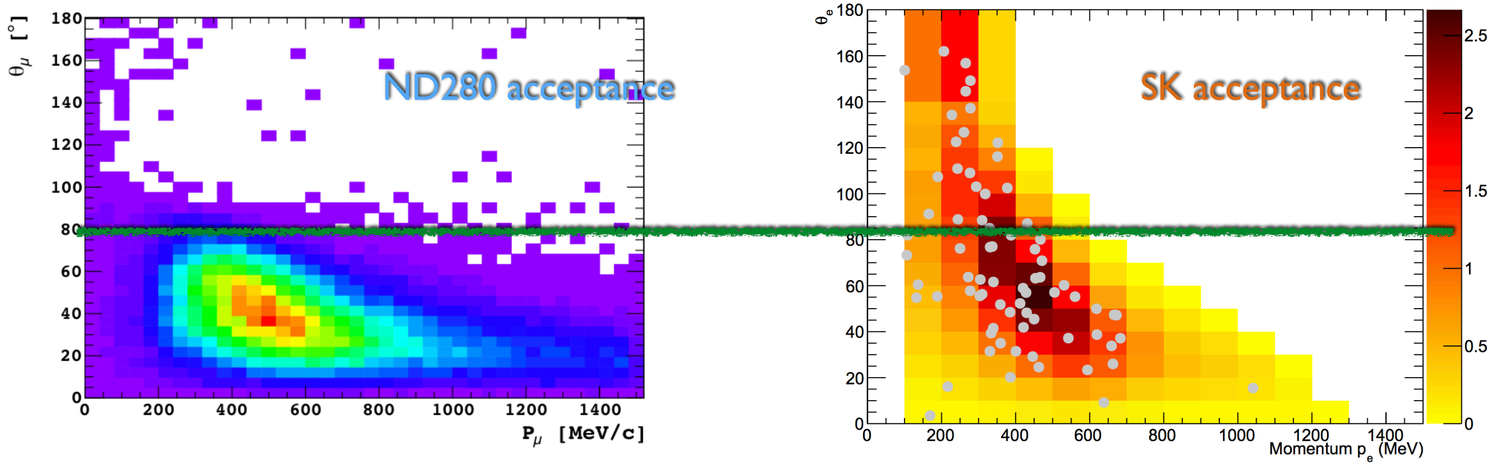


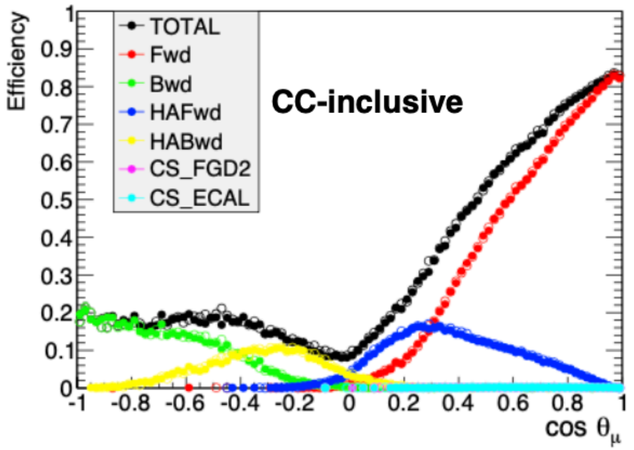
(d) $\overline{\nu}$-mode 1Rμ



(e) $\overline{\nu}$-mode 1Re

ND280 limitations





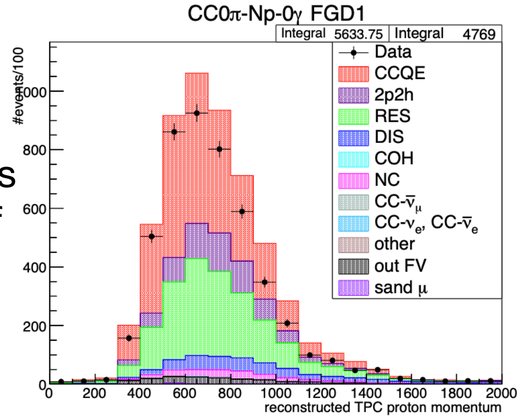
- Improve angular acceptance ν

- Better reconstruction and usage of the hadronic part of the interactions!

  - Currently samples are selected according to their topology (0π, 1π, 1p, Nπ, …) but the kinematics of the hadrons is not used in any way in the constraint on flux and x-sec systematics → plenty of additional information to be exploited

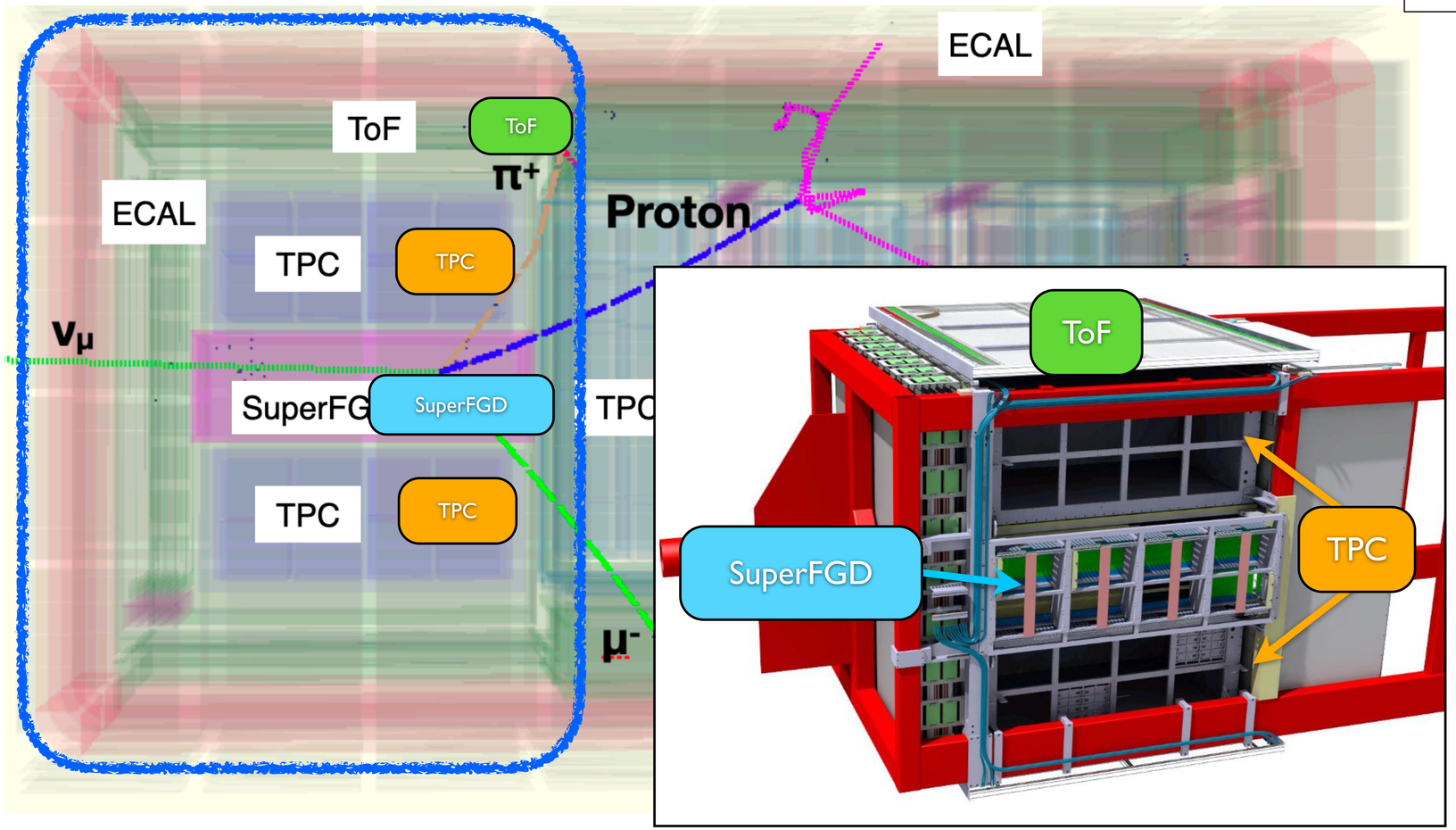
  - This is due to both, a low efficiency from ND280 to reconstruct hadrons and the difficulties in modeling the x-sec systematics for the hadronic part

    - With the upgrade we plan to improve the efficiency to reconstruct hadronic part



The Near Detector upgrade

arXiv:1901.03750



France (CEA Saclay, LLR, LPNHE), Germany (RWTH), Italy (INFN Sezioni di Bari, Napoli, Legnaro, Padova, Roma 1), Poland (IFJ Pan, NCBJ, WUT), Russia (INR and Dubna), Spain (IFAE), Switzerland (University of Geneva, ETHZ) + CERN

Japan: University of Tokyo, KEK, Kyoto University, Tokyo Metropolitan University

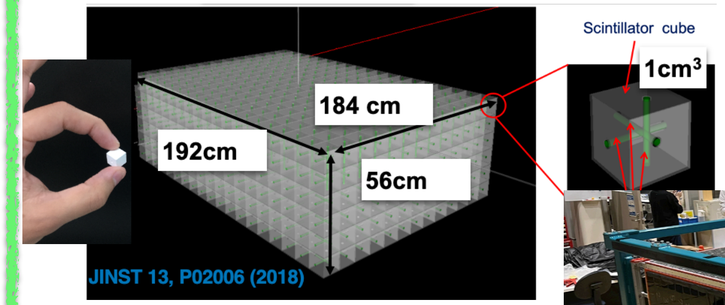
USA: Louisiana State University, University of Colorado, University of Pennsylvania, University of Pittsburgh, Stony Brook University, University of Rochester

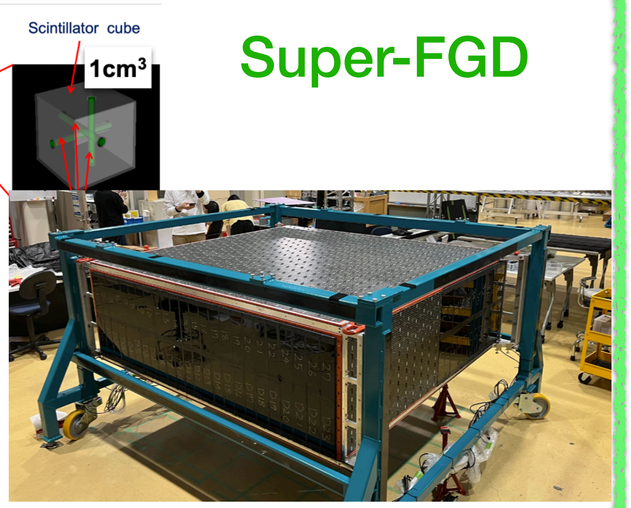
MoU signed in 2020 → NP-07

Replace part of the P0D detector (measured NC π^0 production) with a new scintillator target (SuperFGD), two TPCs and a ToF detector

New detectors

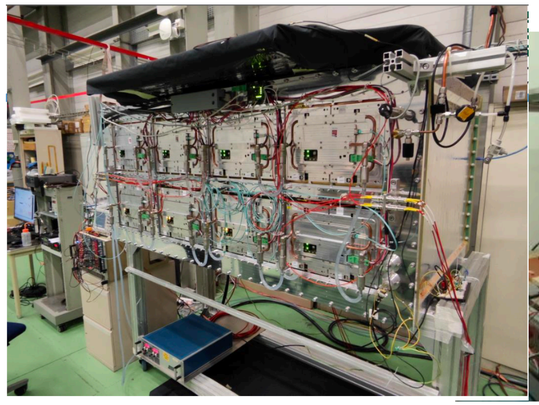
Super-FGD

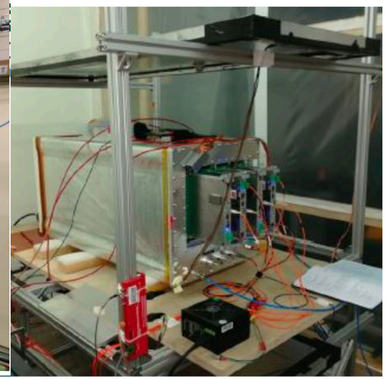




- New concept of detectors, 2×10^6 $1cm^3$ cubes
- Each cube is read by 3 WLS → 3D view

High-Angle TPCs



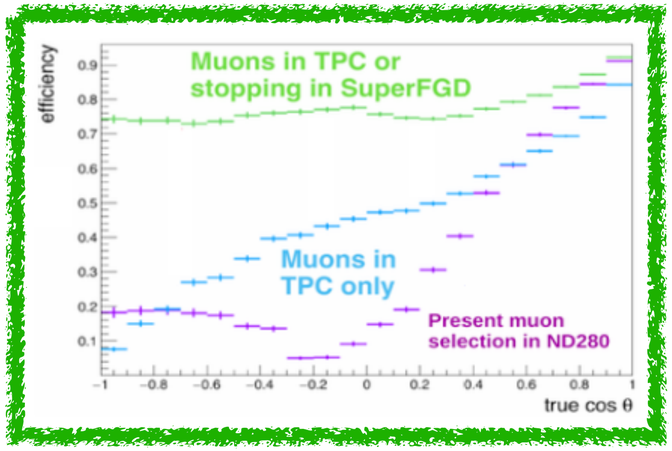


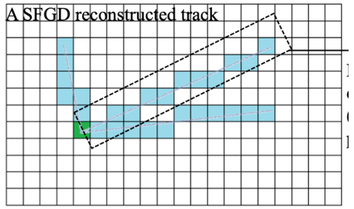
- New TPCs instrumented with Encapsulated Resistive Anode MicroMegas (ERAM)

TOF

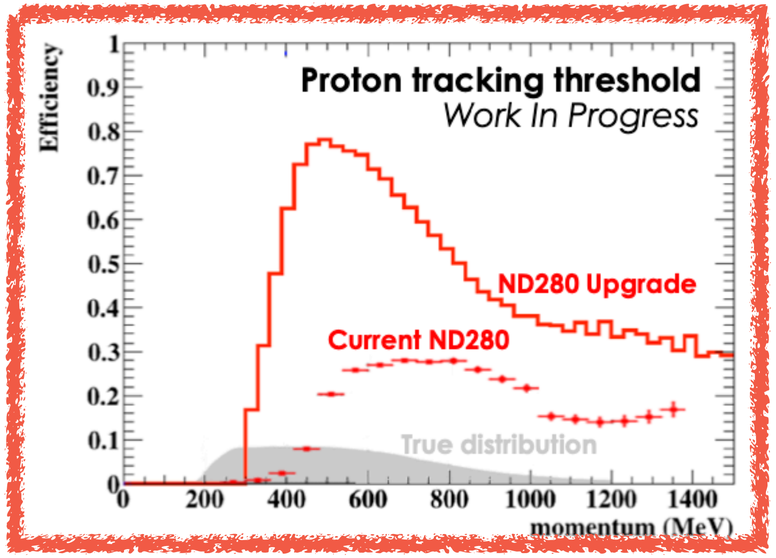
6 TOF planes to reconstruct track direction
Time resolution ~150 ps

ND280 Upgrade improvements

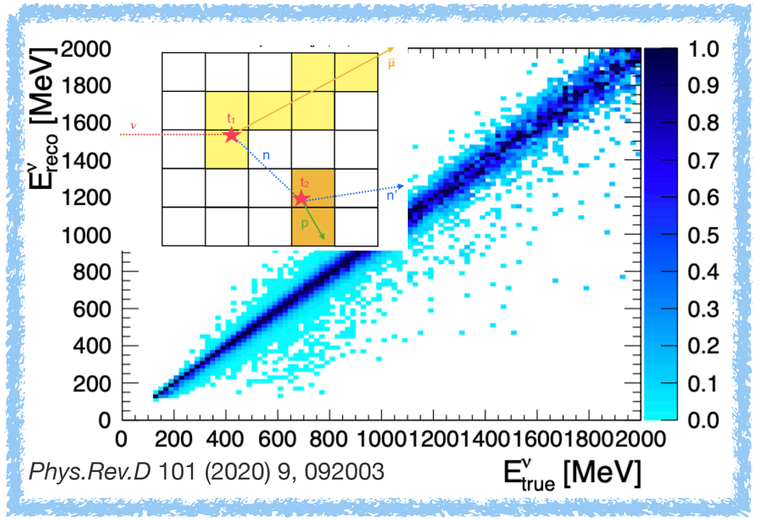




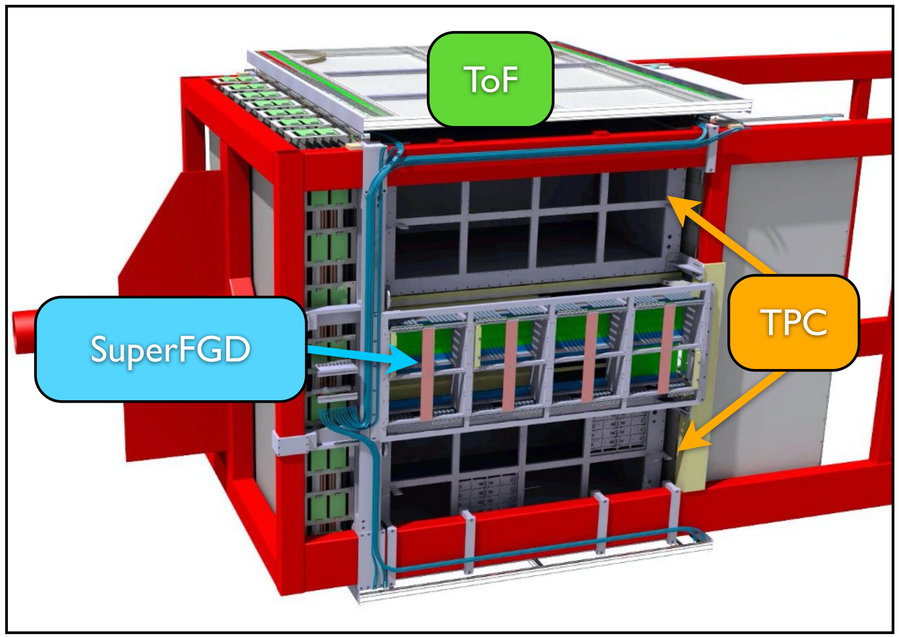
Protons → threshold down to 300 MeV/c
(>500/c MeV with current ND280)

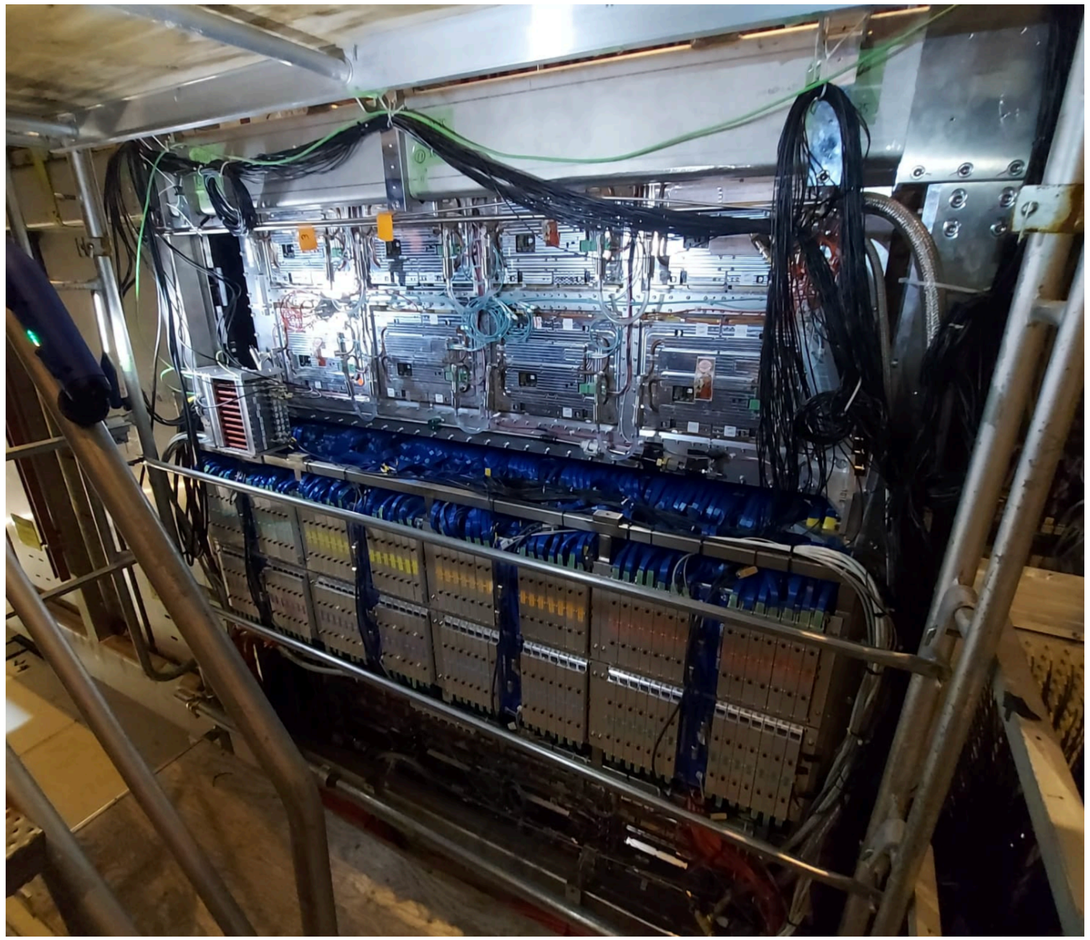


- High-Angle TPCs allow to reconstruct muons at any angle with respect to beam
- Super-FGD allow to fully reconstruct in 3D the tracks issued by ν interactions →lower threshold and excellent resolution to reconstruct protons at any angle
  - Improved PID performances thanks to the high granularity and light yield
- Neutrons will also be reconstructed by using time of flight between vertex of $\bar{\nu}$ interaction and the neutron re-interaction in the detector



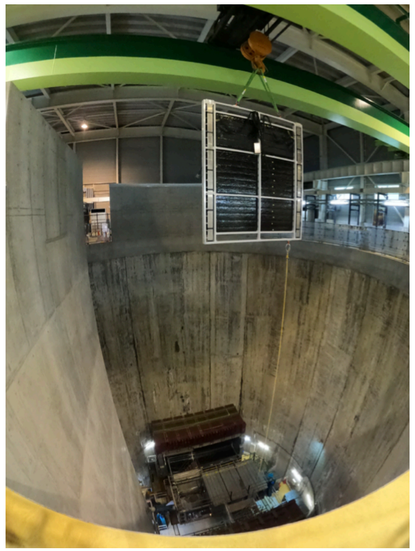
From drawings to reality

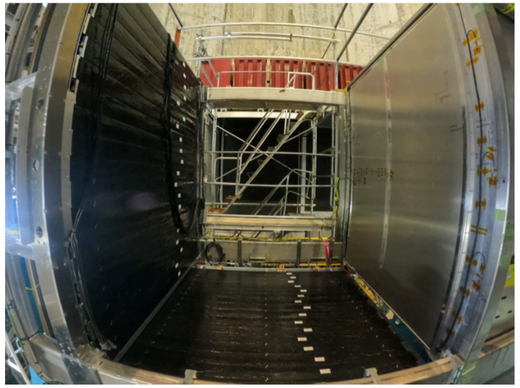




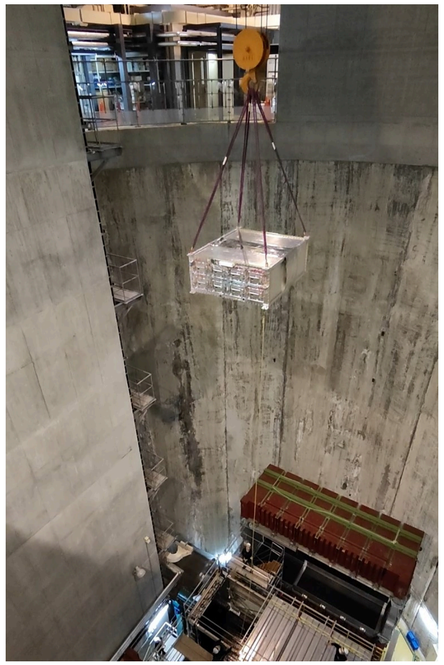
Installation at J-PARC

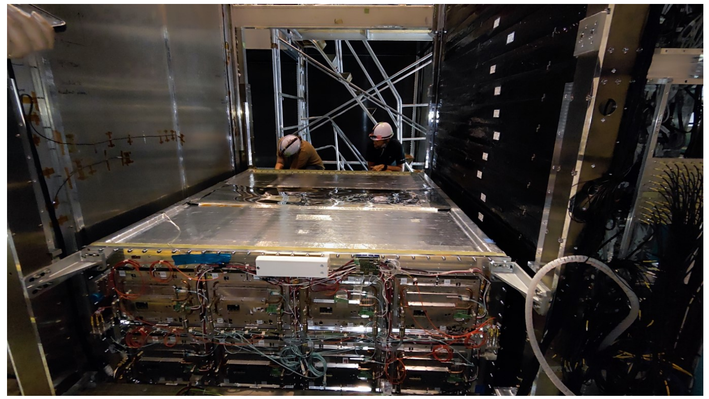
TOF installation (July 2023)



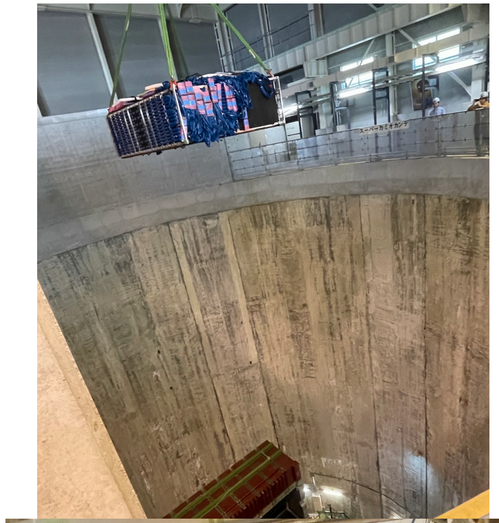


Bottom TPC installation (September 2023)

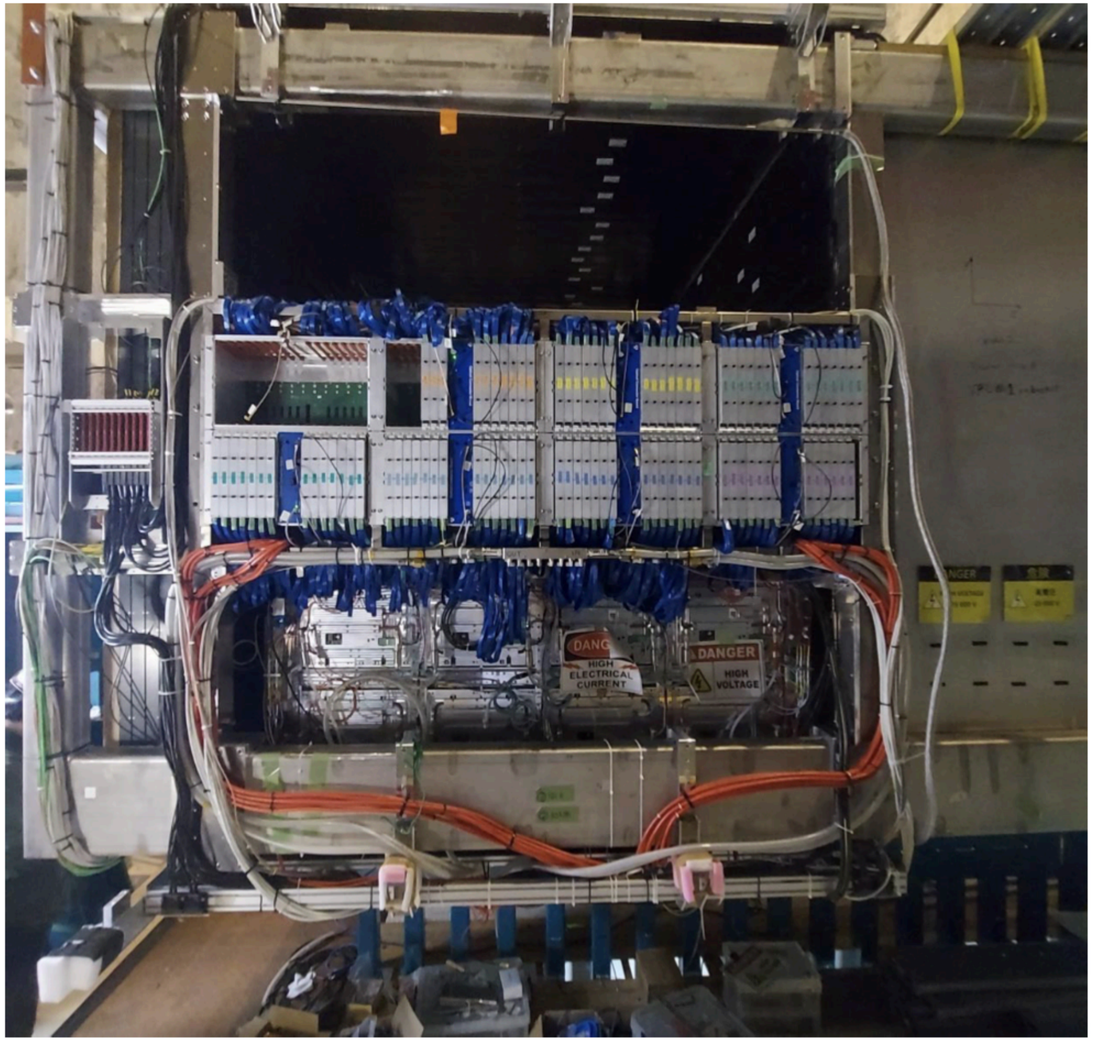


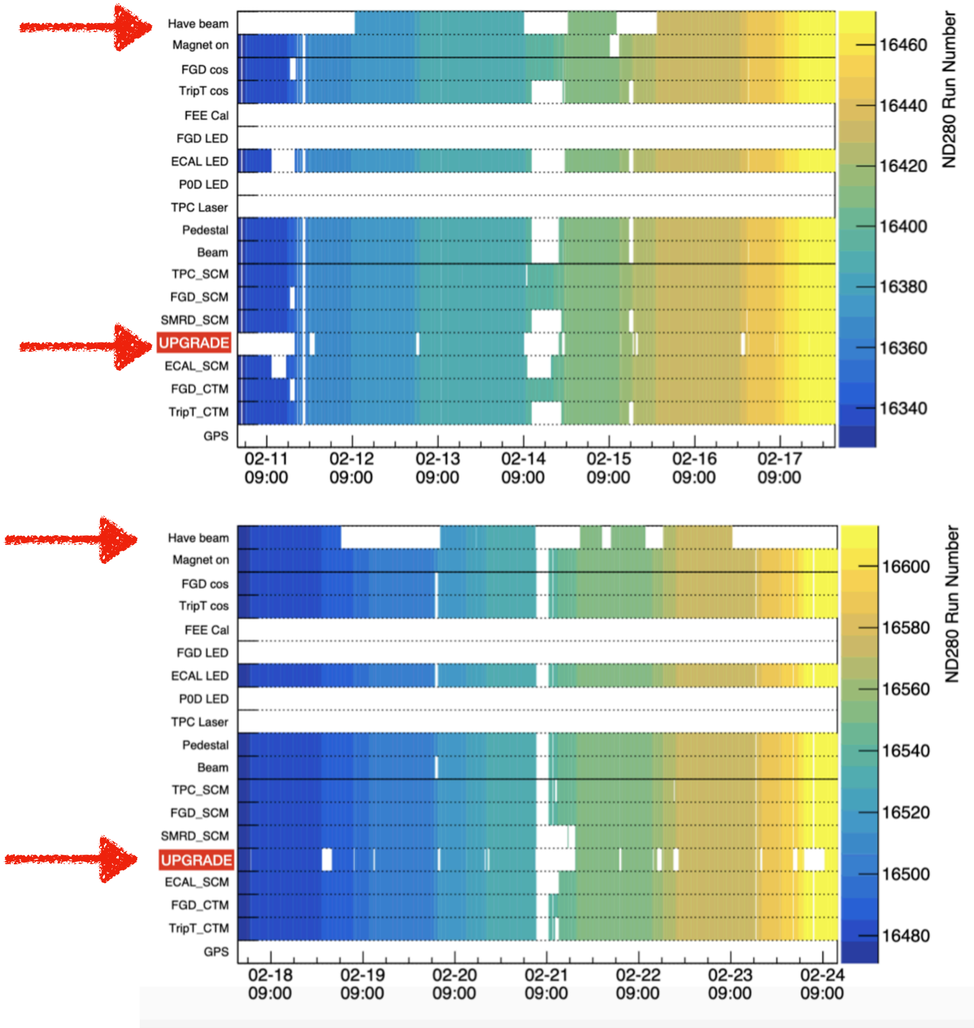


Super-FGD installation (October 2023)

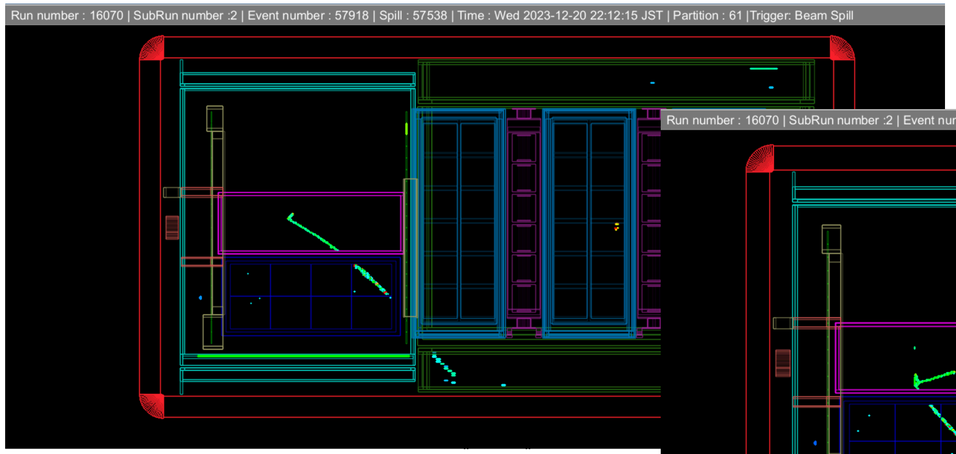


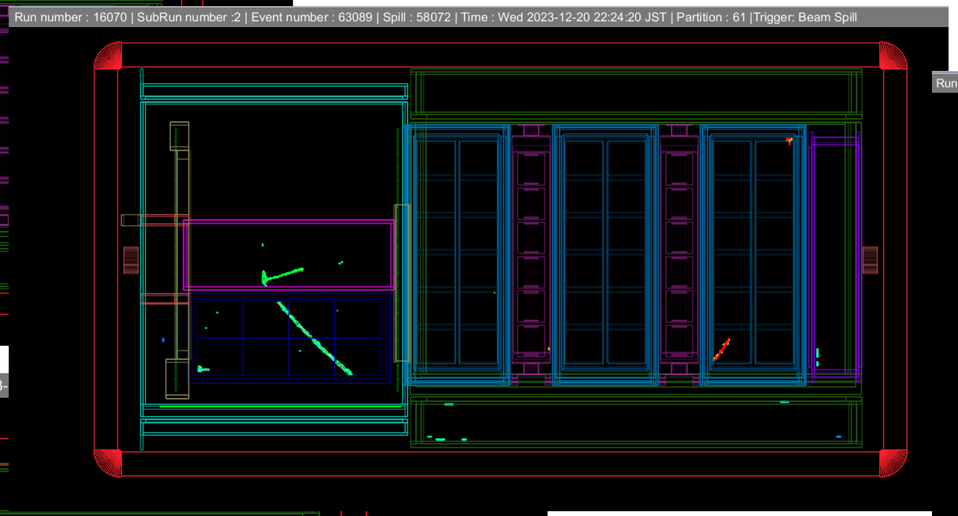
Detectors installed and taking data

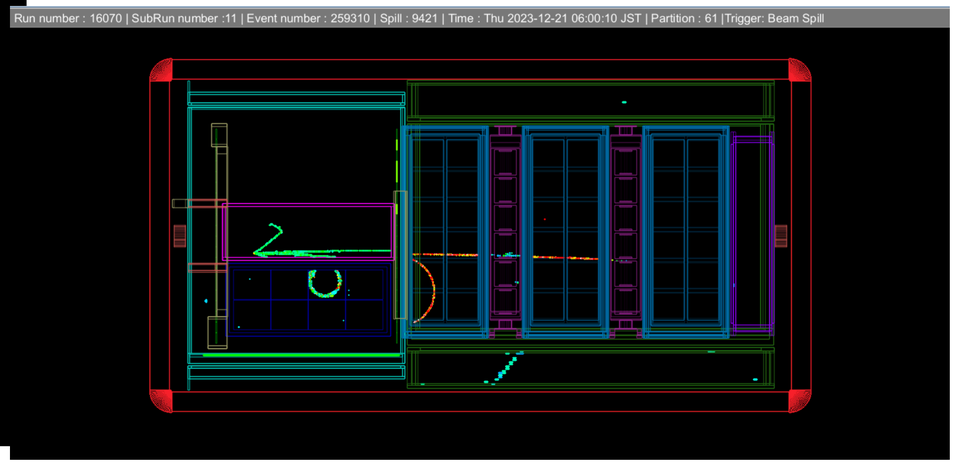


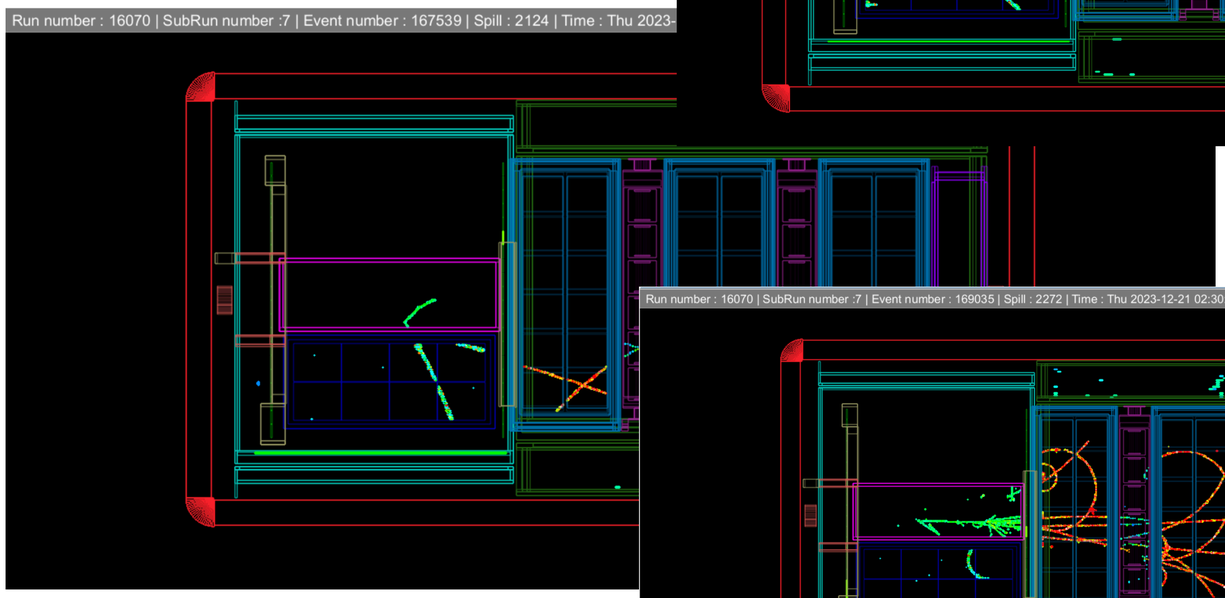


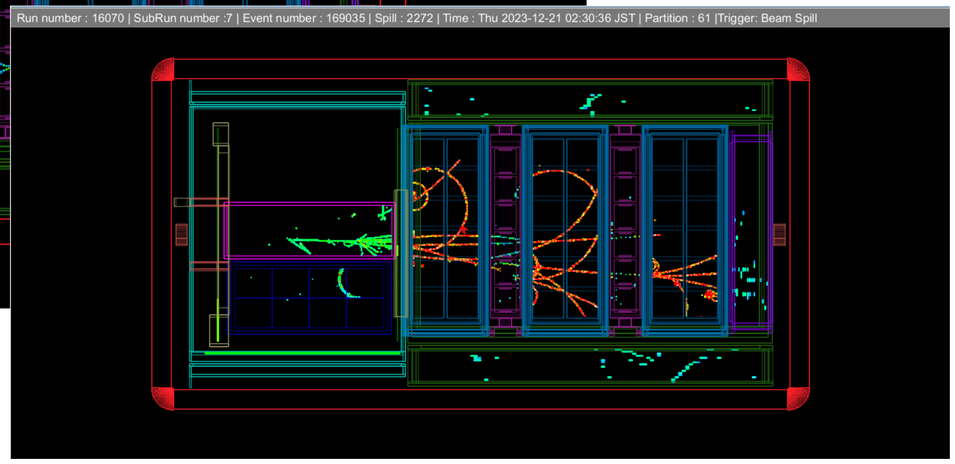
First neutrino interactions (Dec 2023)

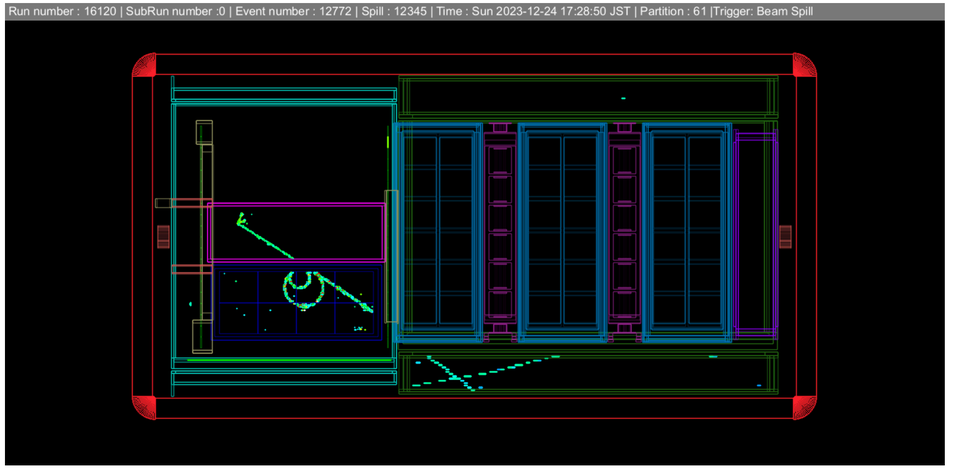




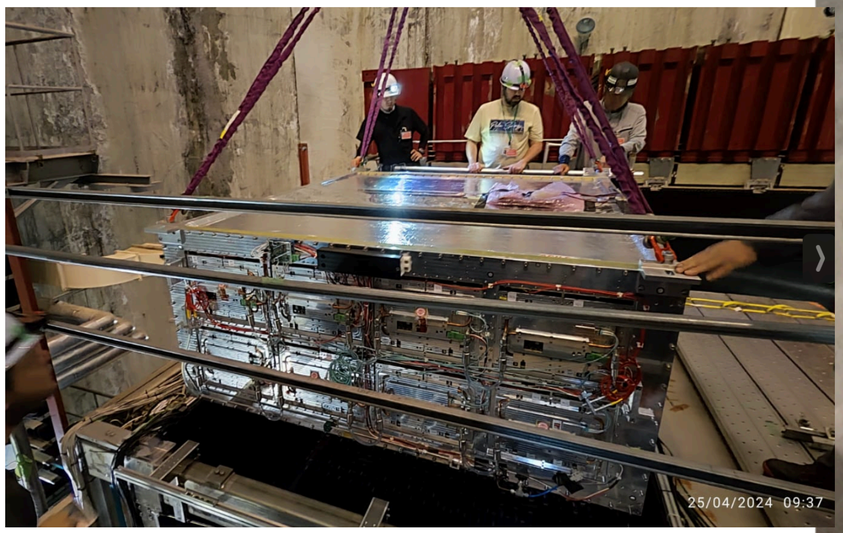


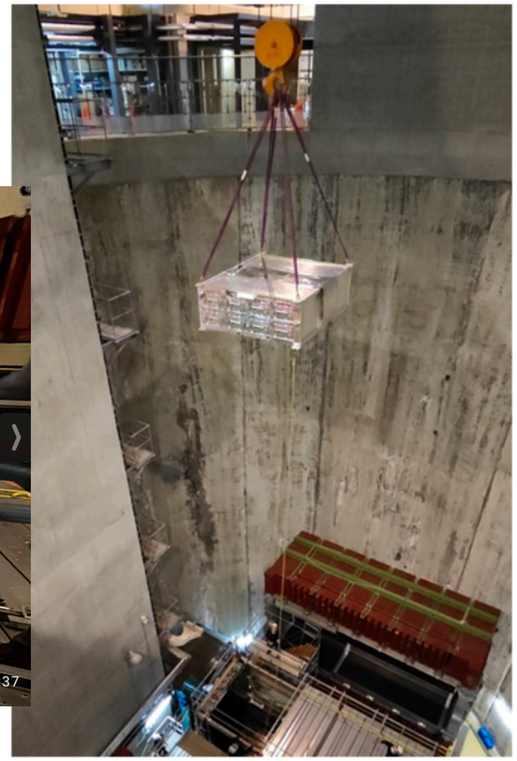






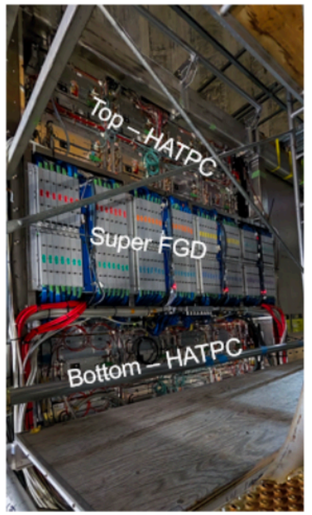
Top HATPC installed (April 2024)



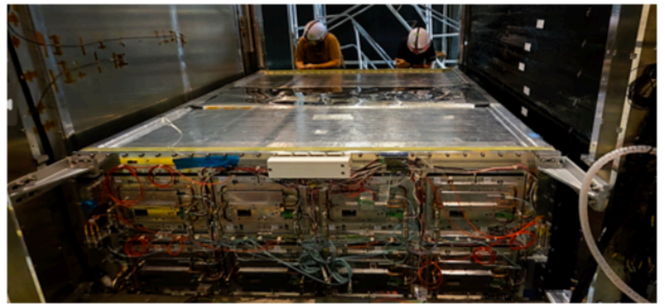


Lowering bottom HATPC
2023.9.8

Top – HATPC in ND280



Bottom – HATPC in ND280

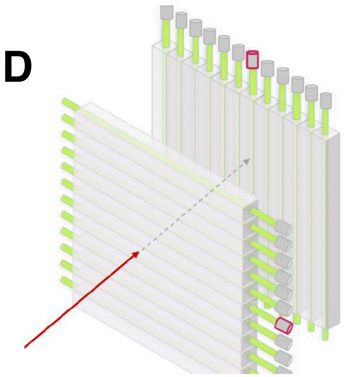


ND280 after lowering of top HATPC
2024.4.25

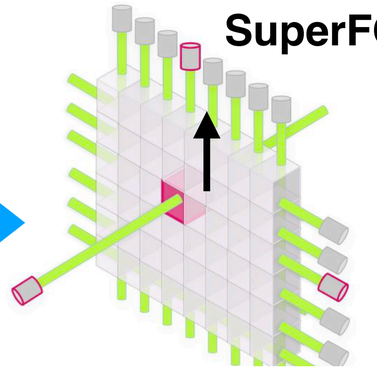
- Stay tuned for beam data with full ND280 upgrade installed in June !

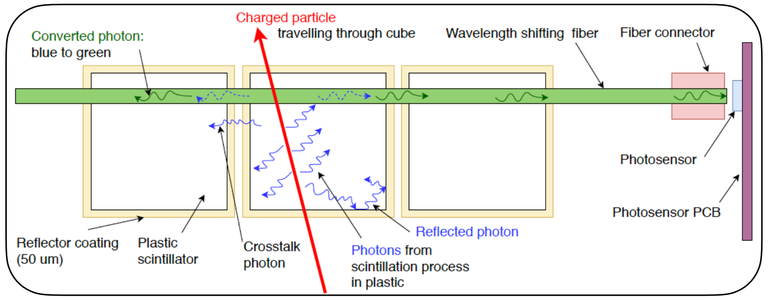
Super-FGD

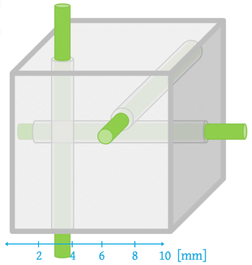
FGD



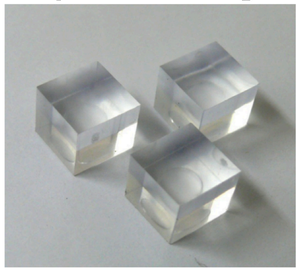
SuperFGD



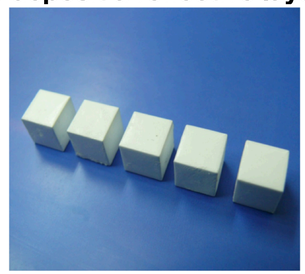




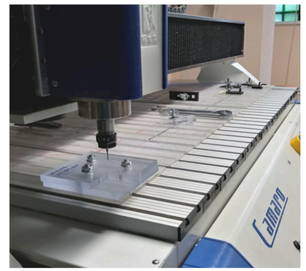
Produce cubes by injection molding

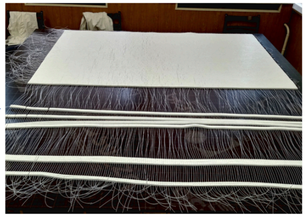


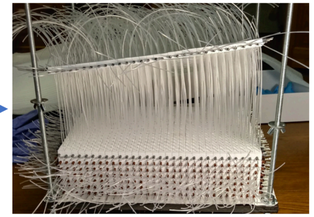
Etched in a chemical to deposit a reflective layer



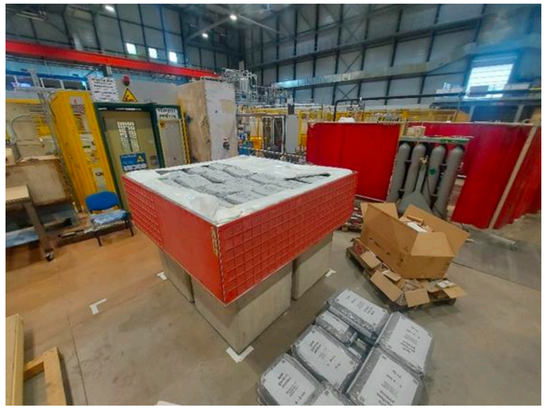
3 orthogonal holes are drilled

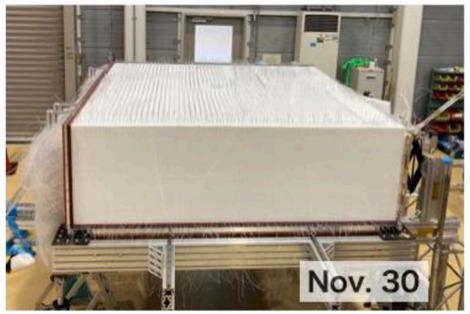




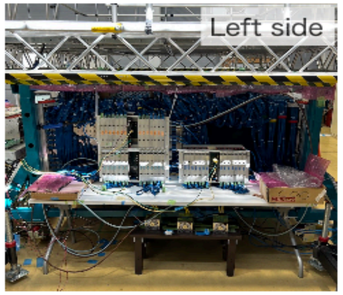


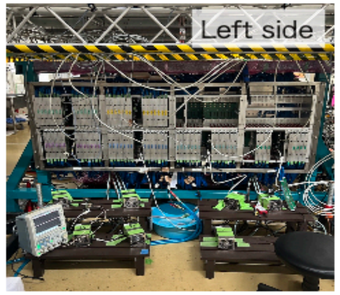
sFGD box procured and tested at CERN → shipped to J-PARC for cubes assembly in 2022

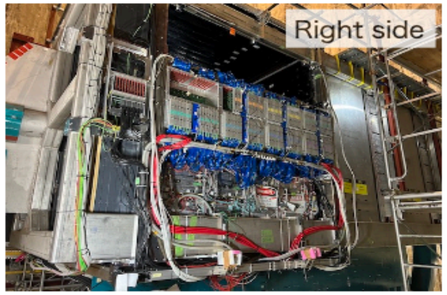




sFGD activities at J-PARC (2023/2024)







On surface vertical slice test from May

On-surface commissioning (~20% FEBs)

On-surface commissioning (~50% FEBs)

Detector installation in mid-October (~80% FEBs)

Installation of remaining electronics in March (100% FEBs)

Beam time

Beam time

This report

Beam time (plan)

Apr. 2023

July 2023

Oct. 2023

Jan. 2024

Apr. 2024

Jul. 2024

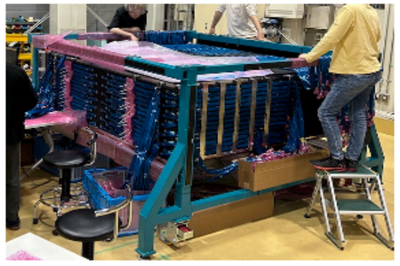
Detector assembly completed

Delivery of 42 FEBs in end-July, 2023

Delivery of 78 FEBs in mid-September, 2023

Delivery of 54 FEBs in mid-October, 2023

Delivery of 50 FEBs in mid-March, 2024

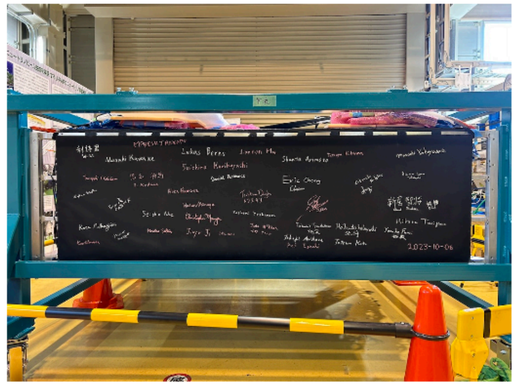


sFGD activities at J-PARC (2023/2024)

(i) Dismounting the front-end electronics and frames

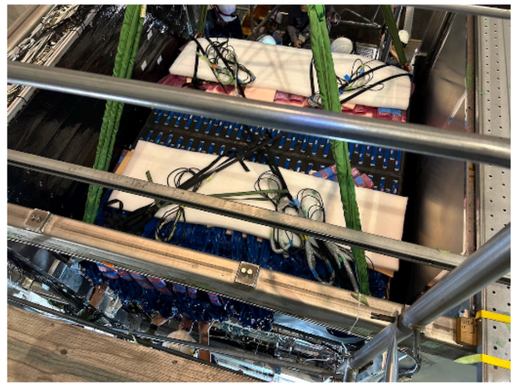
(ii) Transferring the detector from the assembly building

(iii) Last moment before installation into the pit

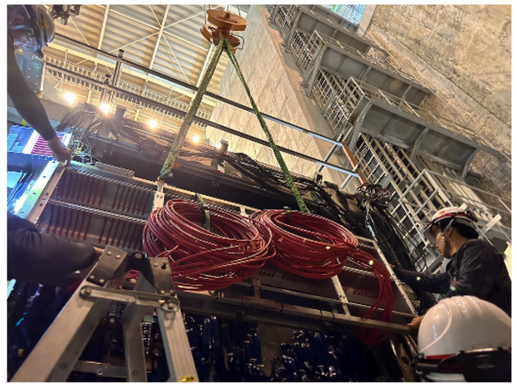


(iv) Installing the detector into the pit by a crane

(v) Fixing the detector to the basket at 4 corners

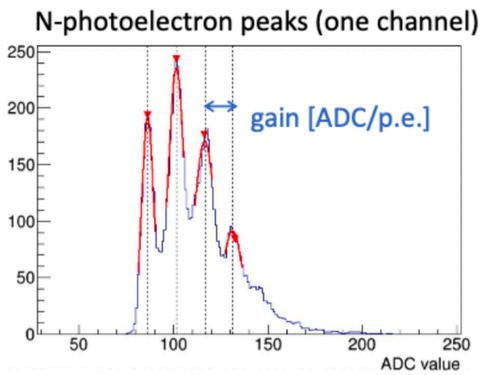


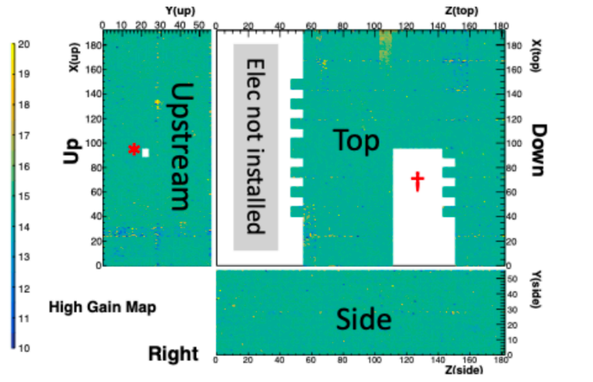
(vi) Fixing the electronics frames to two sides of the basket

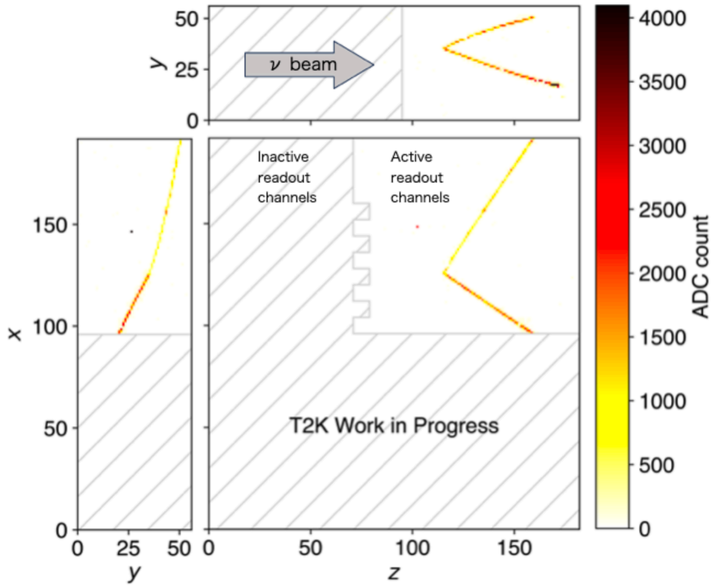


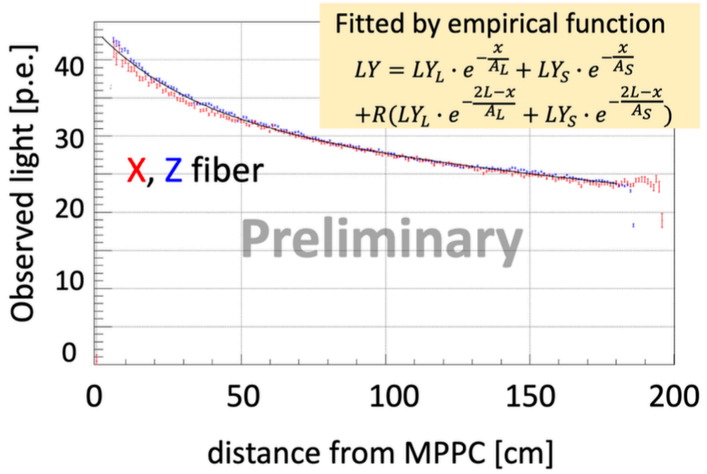
Super-FGD performances

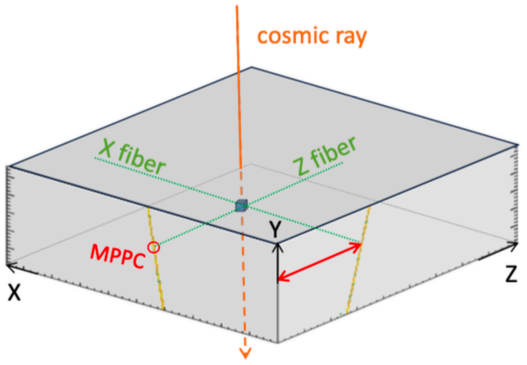
- Gain calibration of each channel with LED
- Light yield measured with cosmics of 40-25 p.e./MIP/fiber depending on distance from MPPC





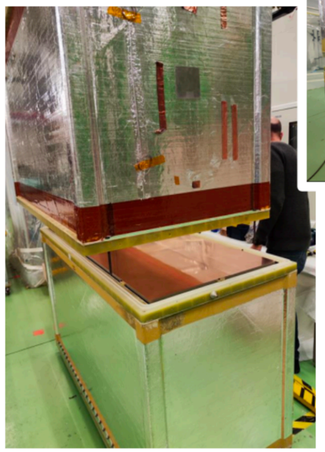


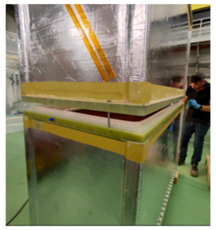


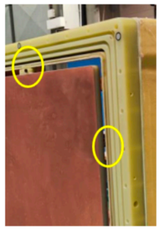


HA-TPC

- At the time of the last SPSC meeting only one working Field Cage (out of 4) had been delivered at CERN
  - Past delays due to the need to understand and fix an electrical issue encountered with the first field cage (FC-0)
- Intense year at bdg 182 for the assembly of the two chambers

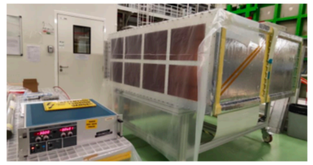

Vertical assembly of two field cages and central cathode to form a HATPC


Cathode assembly

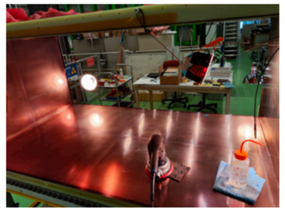

Cathode assembly


Connection of last strips to cathode and to high voltage feedtrough


High Voltage feedtrough external connection

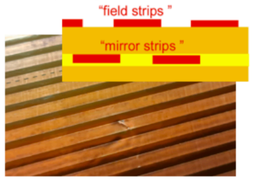

High voltage tests after assembly

Inner cage surfaces polishing

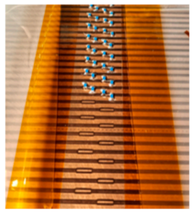


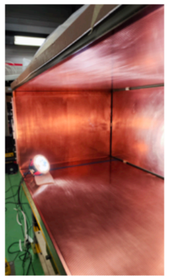

Checking grooves for o-ring and for charge labyrinth on cathode flanges

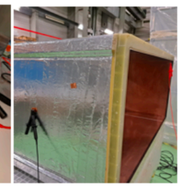
Looking for defects on strips and strip-strip short-circuits and repairing them

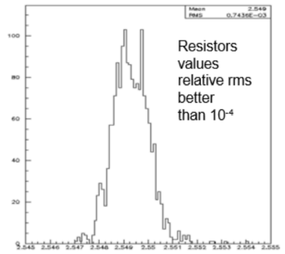


Soldering voltage divider resistors

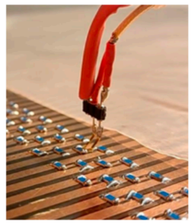




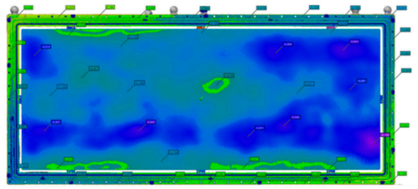

Measuring strip-strip and strip-shield insulation at high voltage



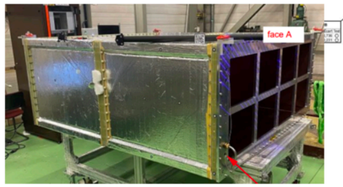
Measuring single resistors

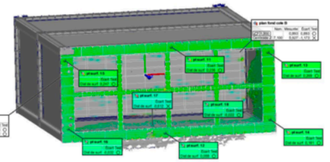


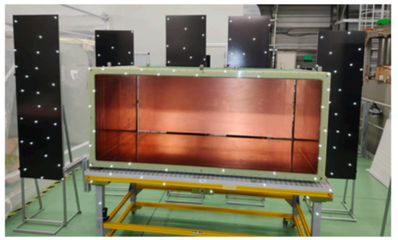
Huge thanks to the CERN metrology service for their invaluable help!

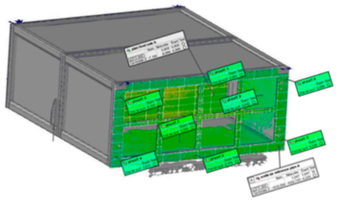


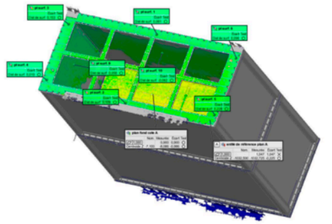
Metrology at CERN Top–HATPC (2024, single whole TPC 3D metrology)





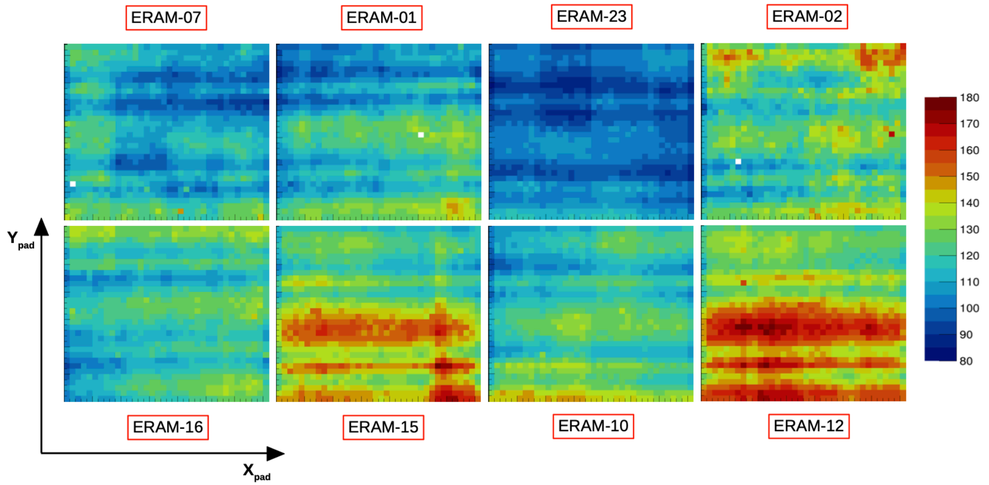

Metrology at CERN Bottom–HATPC (2023) (Two separate cages and cathode)

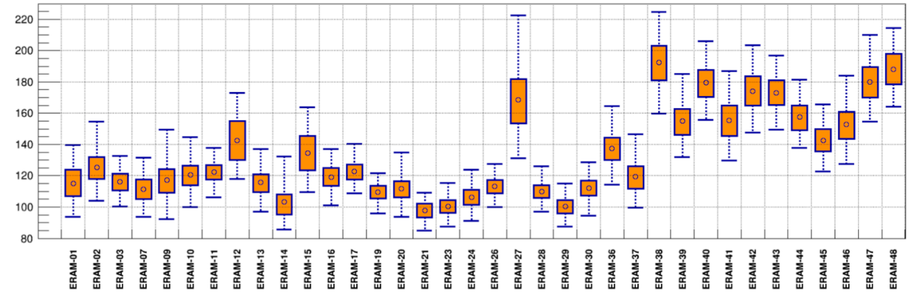


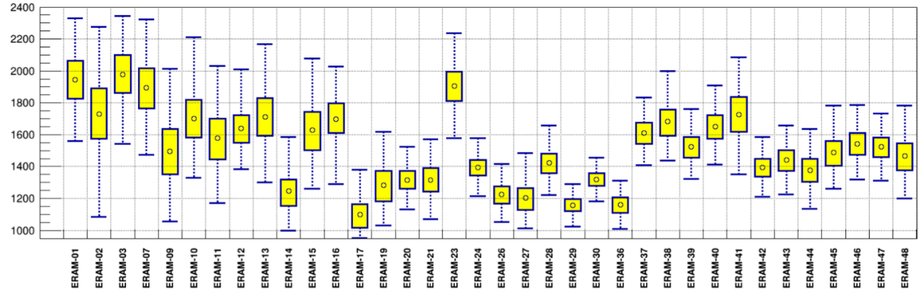


Resistive Micromegas (ERAM)

10.1016/
j.nima.2023.168534



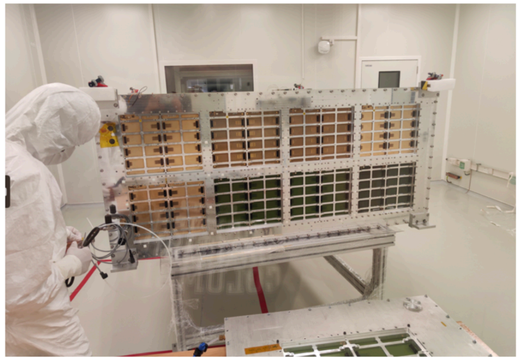




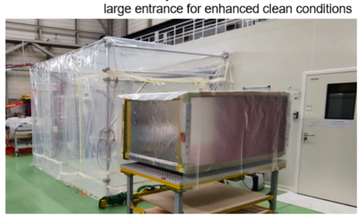
- All ERAMs produced at CERN (MPGD lab) and characterised with a test bench at CERN → great expertise of MPGD laboratory and many thanks for the very effective collaboration with IRFU for successful production and detailed characterization

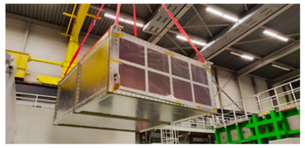
- ERAM assembly on the HATPC in the clean room at bdg. 182 and cosmic tests at CERN

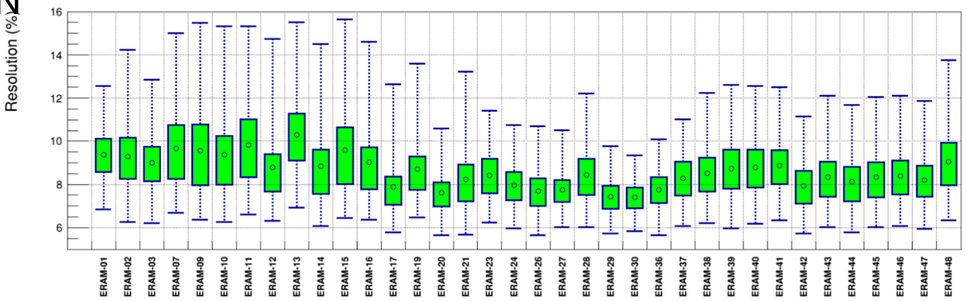
ERAM assembly (and storage) in Clean Room



Grey tent area in front of Clean Room
large entrance for enhanced clean conditions



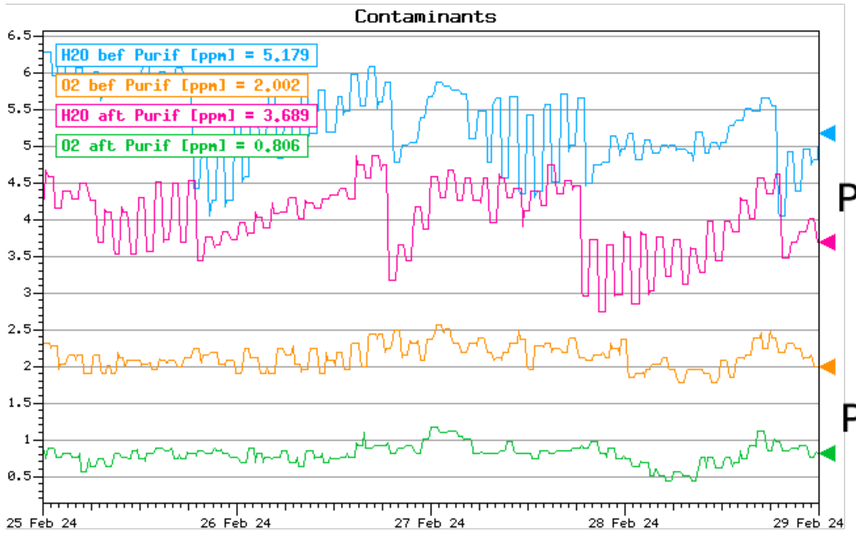




Gain and RC measured for each pad in a dedicated test bench at CERN

Gas system → provided by CERN

- Disconnection, removal of old gas racks, preparation for installation
- Delivery of new system: end of April 2023
- New racks in position and main connections done: beginning of May. Start leak checking
- May 29: installation of power lines in the mixing room & SS. Start swithcing on the various modules
- New cable trays and lying of long pipes to LP buffer: June 12. Start test and leak-check the recirculation
- First milestone Mid-July 2023: Ar standby mode re-established



•System installed by CERN group in collaboration with INFN
•Continued local operations by INFN with remote support by CERN

- Full start-up with HA-TPC-bottom + 3 V-TPCs by mid-November
- Running until end of 2023
- Second commissioning run in February 2024, achieving record gas purity (< 1ppm O2 in gas distributed to TPCs)
- Gas consumption (and rejection in the atmosphere) reduced to 1/3 w.r.t. the past system, still subject to further optimization

HA-TPC performances

25th August: Delivery at JPARC

6-7th September: Installation

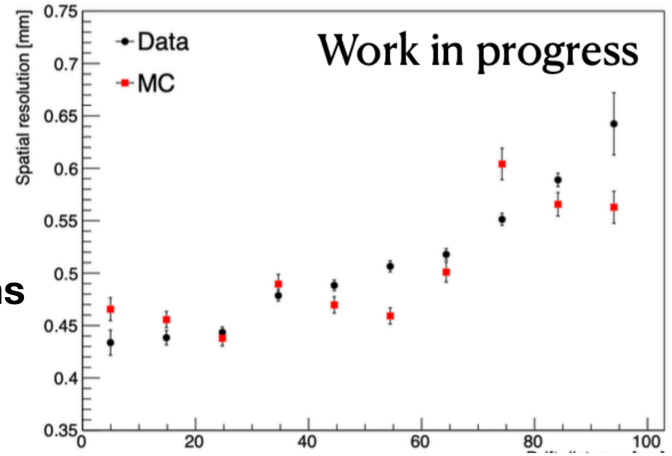
Top TPC: delivery April 7th → Installation April 25th

So quick thanks to the full characterisation of the HATPCs done at CERN and for the flawless organisation of the shipment from CERN to Japan!

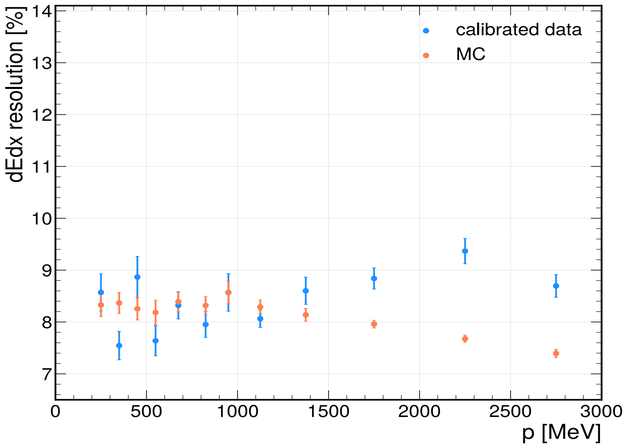
We acknowledge the CERN Import-Export service for their assistance concerning the transport and the customs related documentation

Cosmics at J-PARC
Good agreement between data and simulation

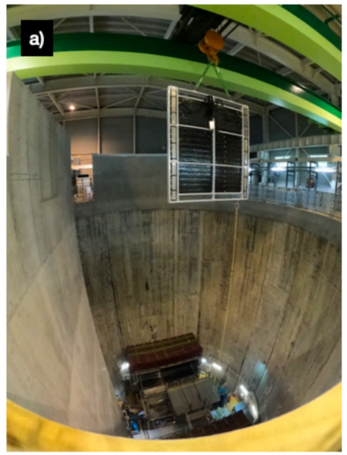
Spatial resolution ~500 µm with muons

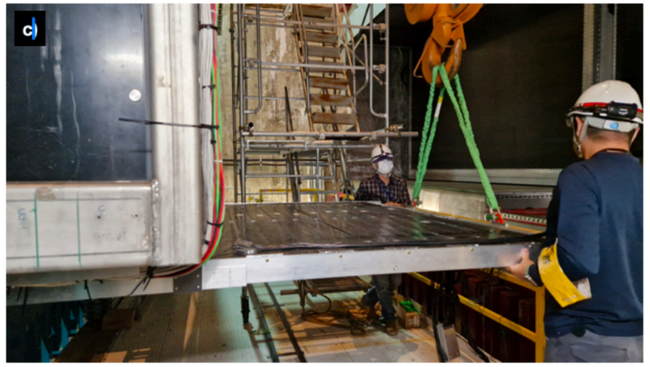


dE/dx resolution better than 10%

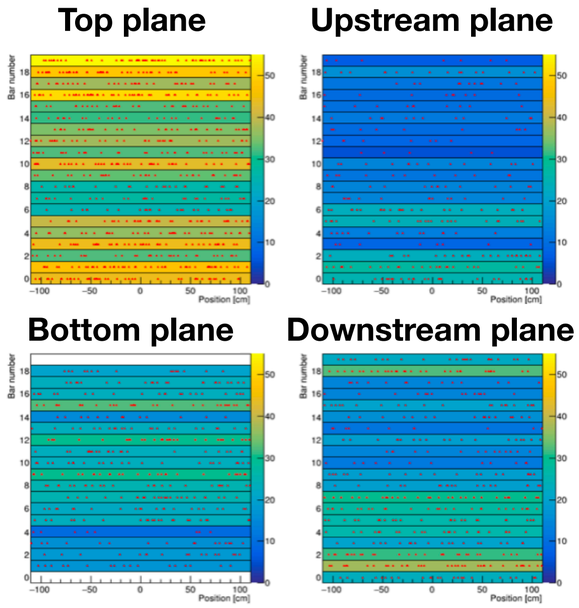


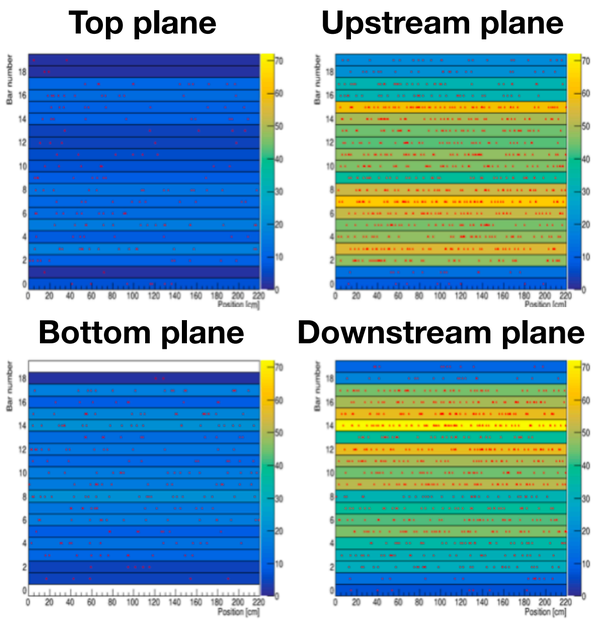
Time-Of-Flight





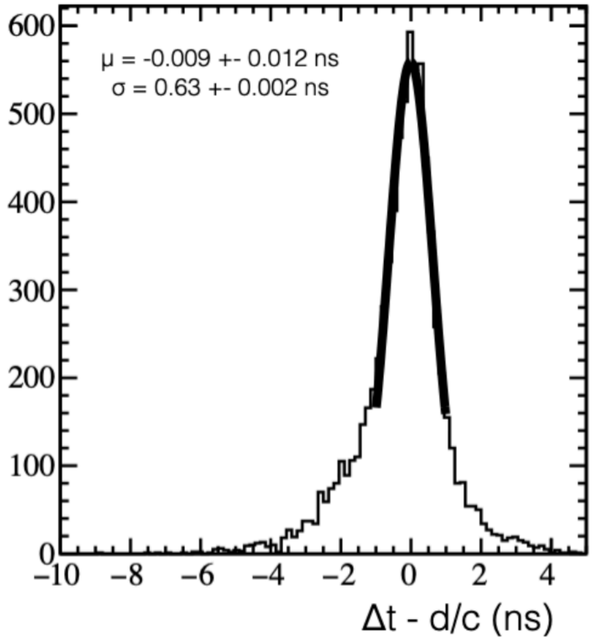
- All 6 TOF modules assembled at CERN and shipped to J-PARC in 2023
- 4 TOF modules installed during Summer 2023 and taking data during December 2023 run
- 2 more TOF modules will be installed on May 13th → possible now after top HATPC installation

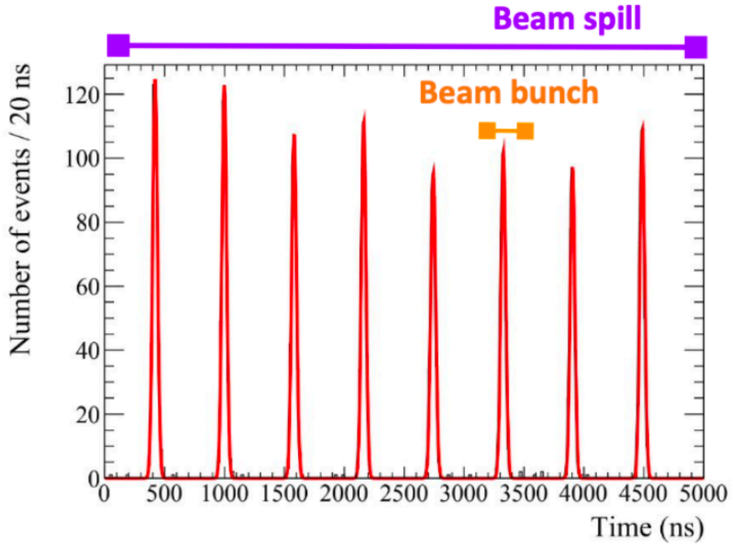




TOF performances

- Raw data time resolution of 0.63 ns for two modules → 0.45 ns for one module
- 8 bunch structure of the J-PARC neutrino beam clearly visible in the TOF





Conclusions

- Very busy and successful year for NP-07!
- All the ND280 upgrade detectors have been installed at J-PARC
- First neutrino interactions observed in December 2023!
- First run with full upgrade in June 2024!
- We also foresee a test beam at CERN PS in Spring 2025 with the refurbished HATPC FC#0
  → we would need access to clean rooms and space at bdg. 182 until then
- Many thanks to CERN for the invaluable help with the successful completion of the ND280 upgrade!

Neutrino platform for support at bdg 182
CERN metrology service for measurements of HATPC
CERN logistics service for the HATPC shipment,
CERN polymer lab and the Magnetic Measurement Section for their support in field cage insulation checks, countermeasures against the HV insulation issues, and for helping us repairing first field cage
Rui de Oliveira and the MPGD lab for ERAM production
Roberto Guida and the CERN technical department for the TPCs gas system