Status and commissioning of the ND280 upgrade

E. Radicioni

Jennifer2 general meeting

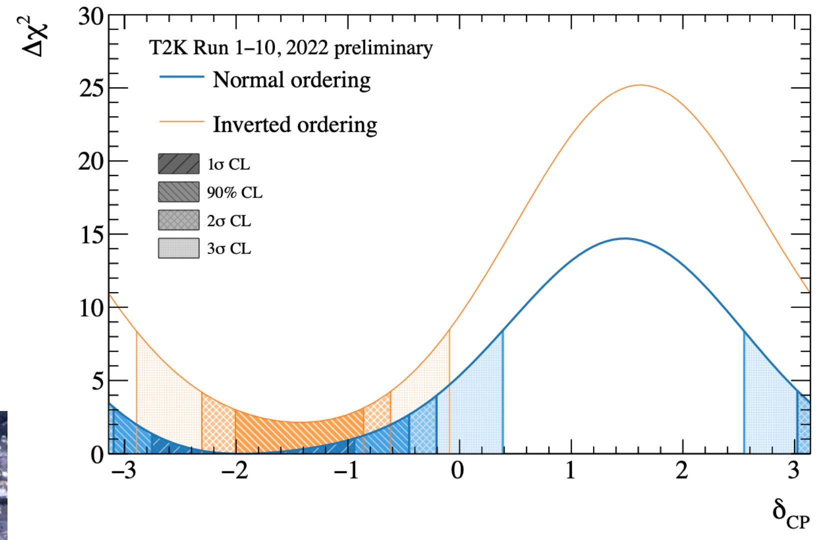
2024/06/02

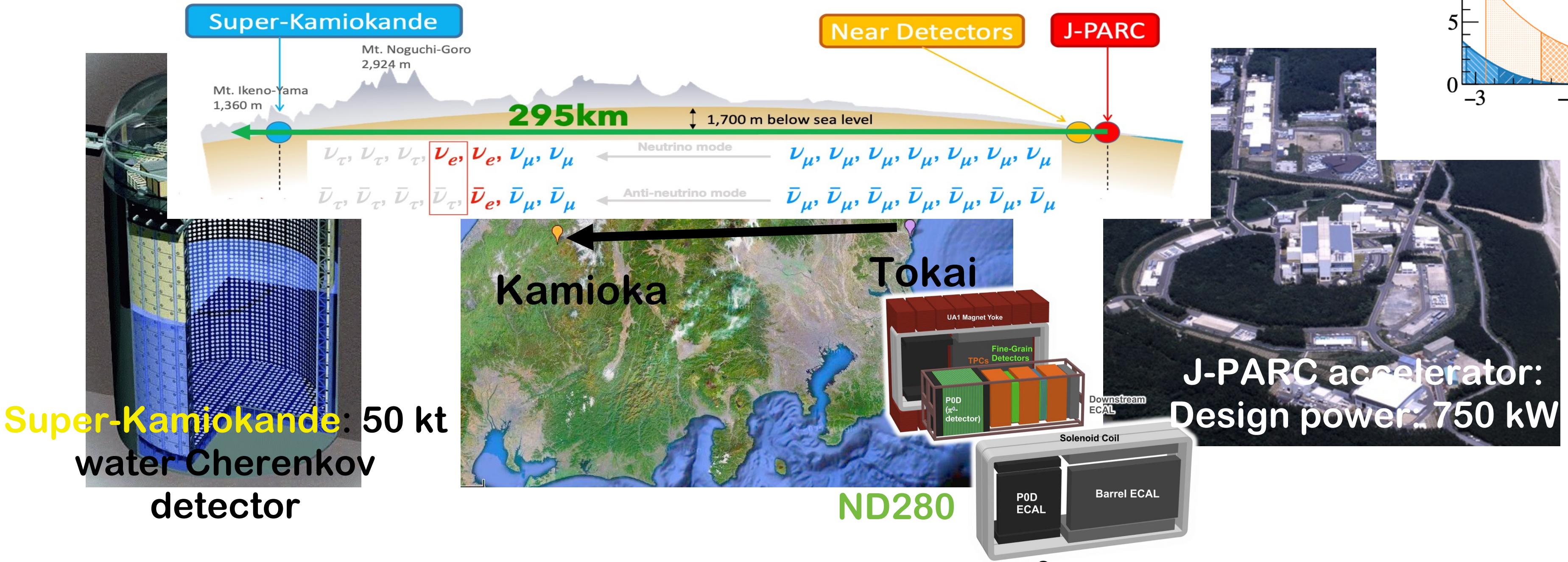
(Slides: thanks to Claudio Giganti, Ulysse Virginet, Viet Nguyen)

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 $|\Delta m^2_{32}|$

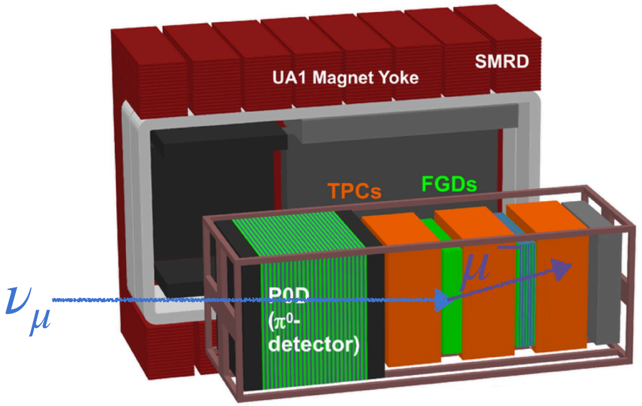
δ_{CP} ~ -π/2 → Several values of δ_{CP} excluded at more than 3σ



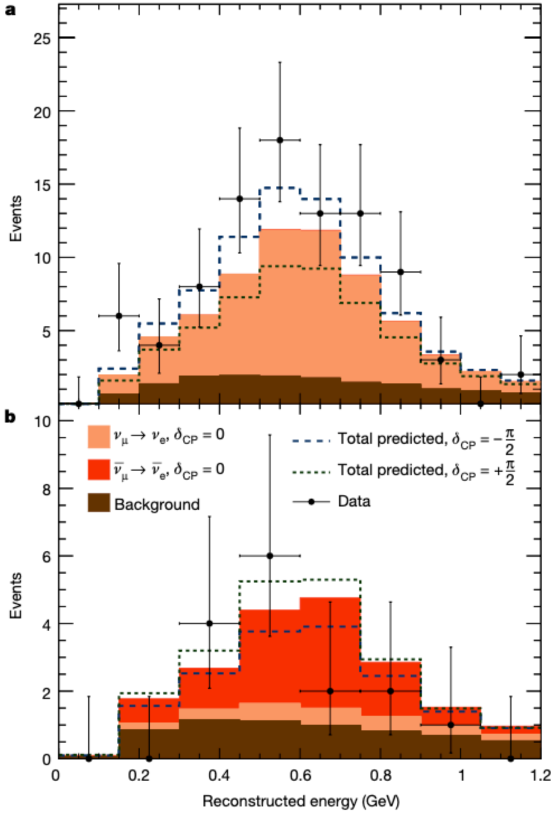


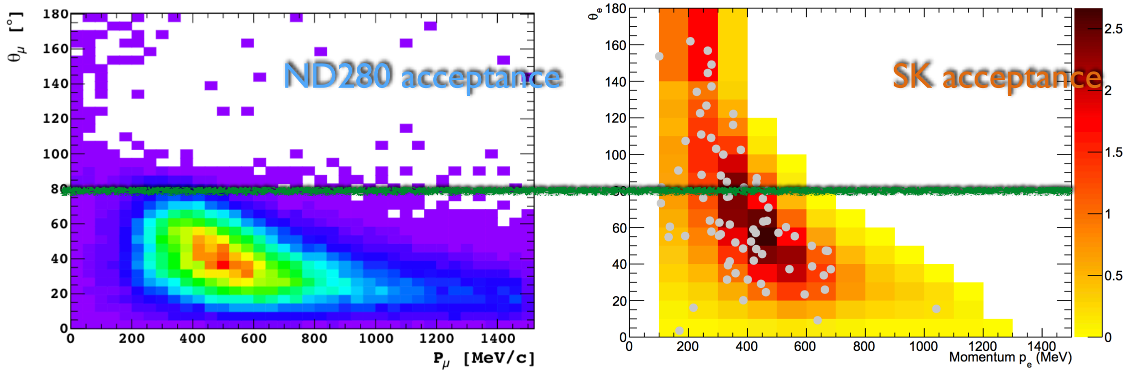
T2K (2010-2022)…

- T2K was the first to observe ν_e appearance in ν_μ beam: $\theta_{13} \neq 0$ at 7.3σ ***[PRL 112, 061802 (2014)]***
- Later, $\delta_{CP} = 0$ and $\delta_{CP} = \pi$ CP-conserving points were ruled out at ~2σ confidence level !



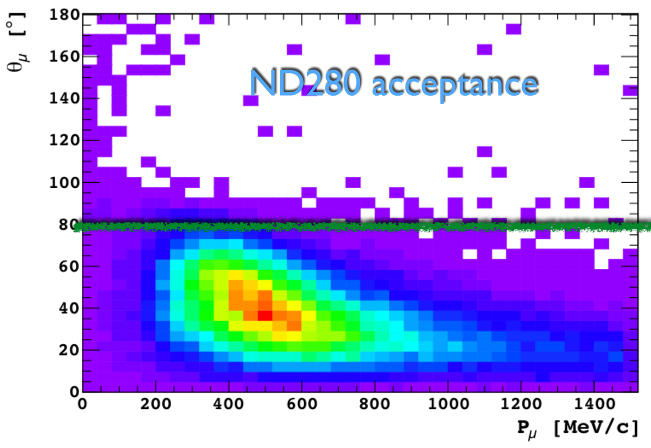
Nature volume 580, pages 339–344 (2020)

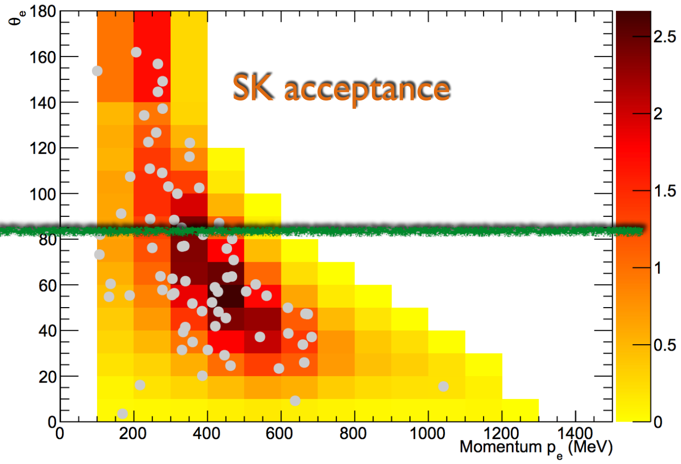


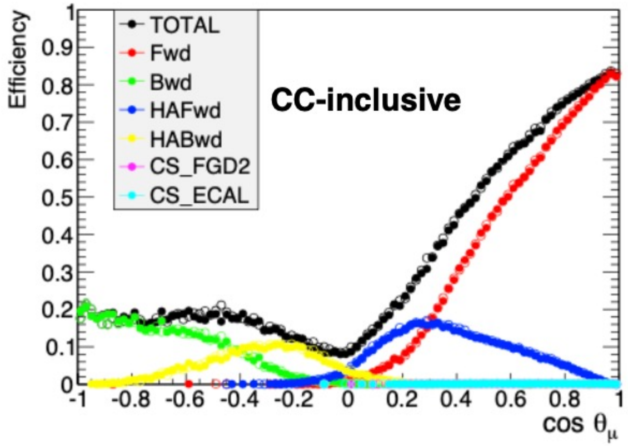


- **But** at ND280, mainly ν_μ ($\bar{\nu}_\mu$) interactions with forward-going μ^- (μ^+) are selected
- Small number of events and relatively low purity in ν_e and $\bar{\nu}_e$ selections
- High threshold to reconstruct protons in ν_μ interactions, no selection of neutrons → only muon kinematics used in T2K Oscillation Analyses

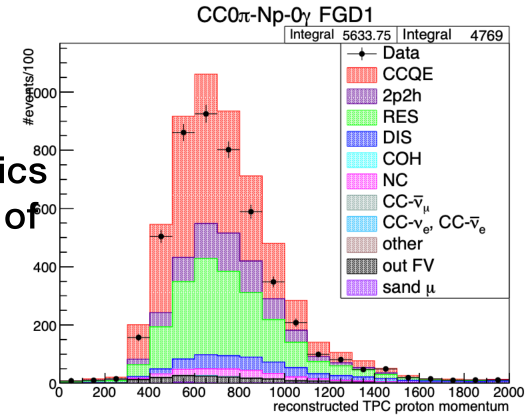
ND280 limitations



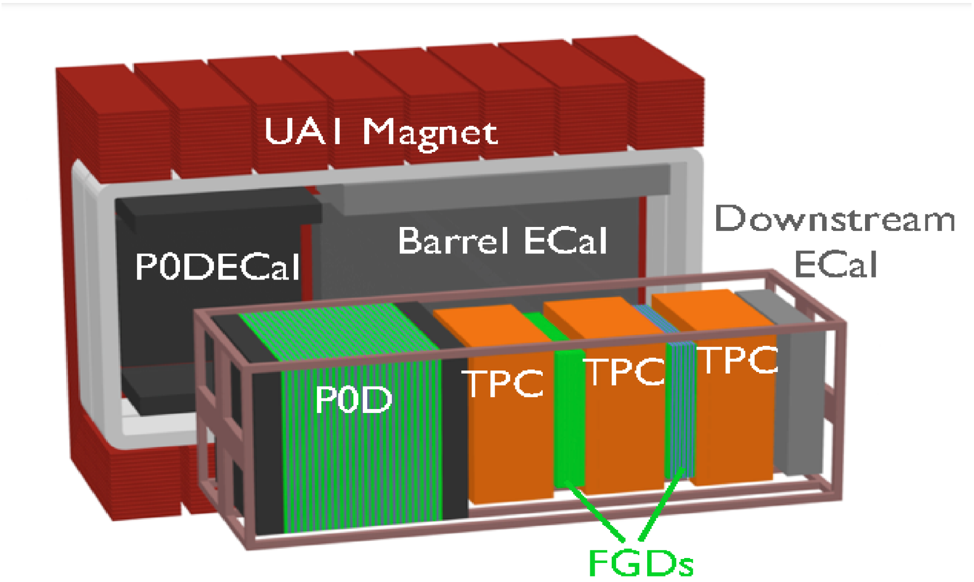


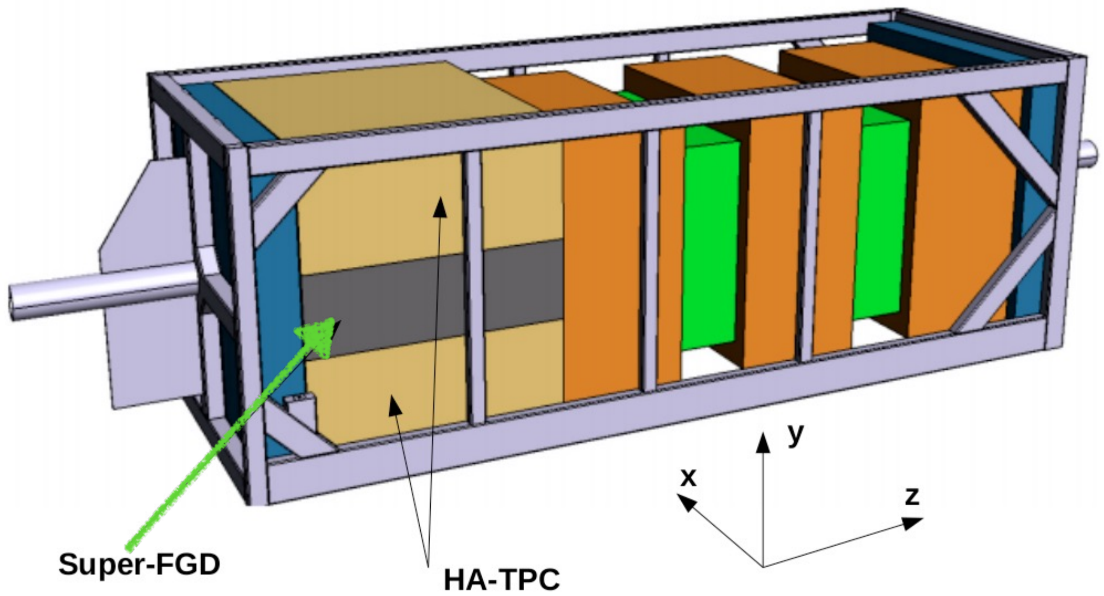


- Improve angular acceptance ν
- Better reconstruction and usage of the hadronic part of the interactions!
  - Currently samples are selected according to their topology (0π, 1π, 1p, Nπ, …) but the kinematics of the hadrons is not used in any way in the constraint on flux and x-sec systematics → plenty 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 planned to improve the efficiency to reconstruct hadronic part



UPGRADED NEAR DETECTOR ND280: CONFIGURATION

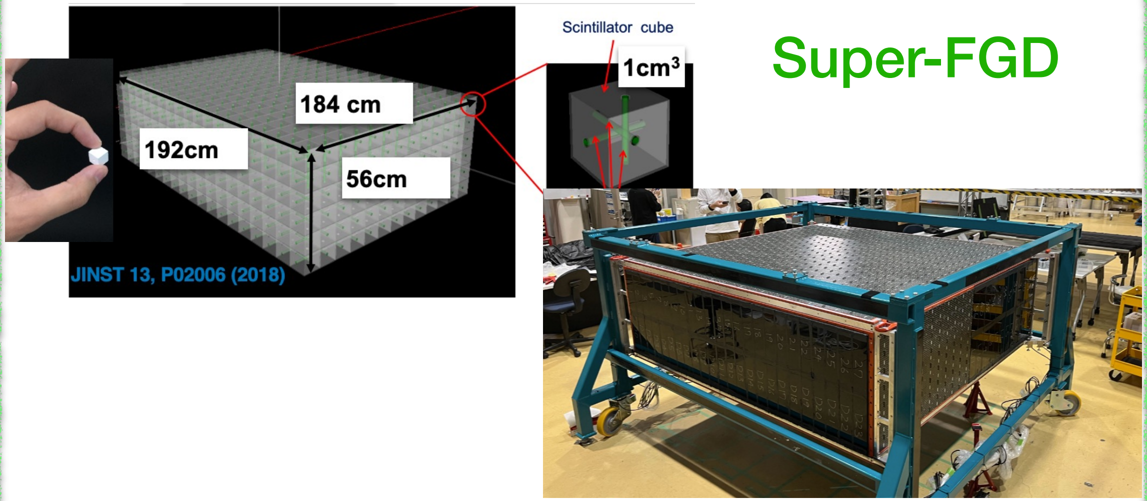




- 2 new High Angle TPC (HA-TPC)
- New Time Of Flight detector (TOF)
- Super-fine-grained detector (Super-FGD) → neutrino target (same scheme as the forward part, but covering large angles acceptance)

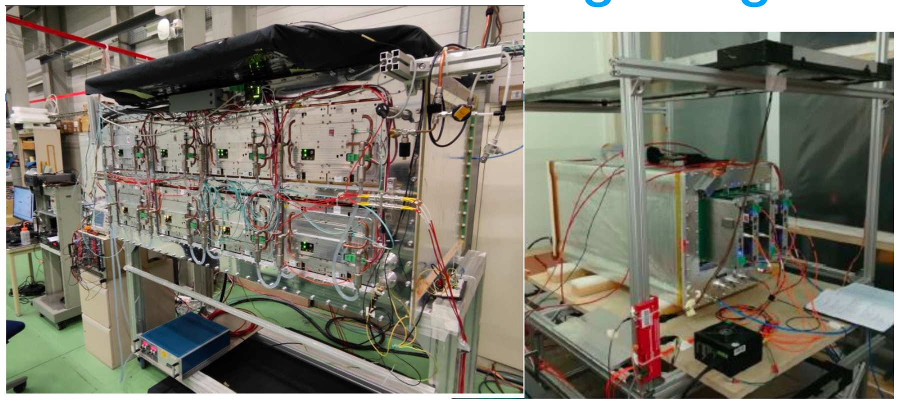
New detectors

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)

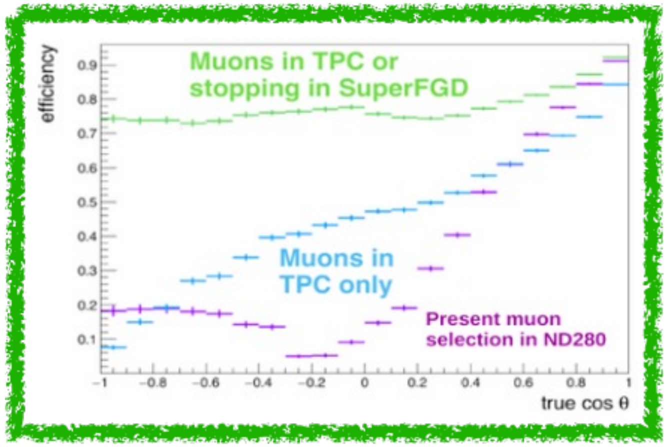
TOF

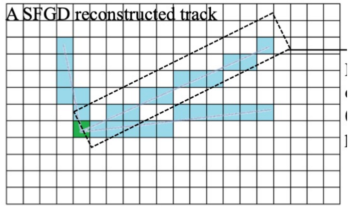
JPS Conf. Proc. 27, 011005 (2019)

6 TOF planes to reconstruct track direction

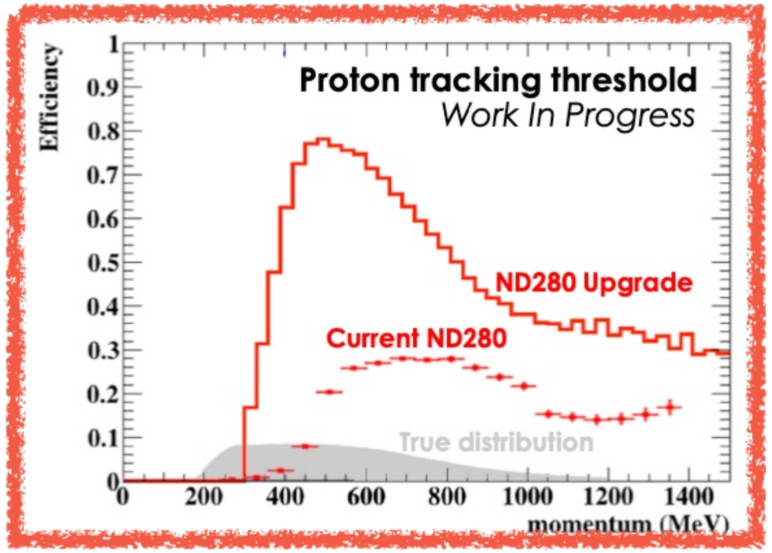
Time resolution ~150 ps

ND280 Upgrade improvements

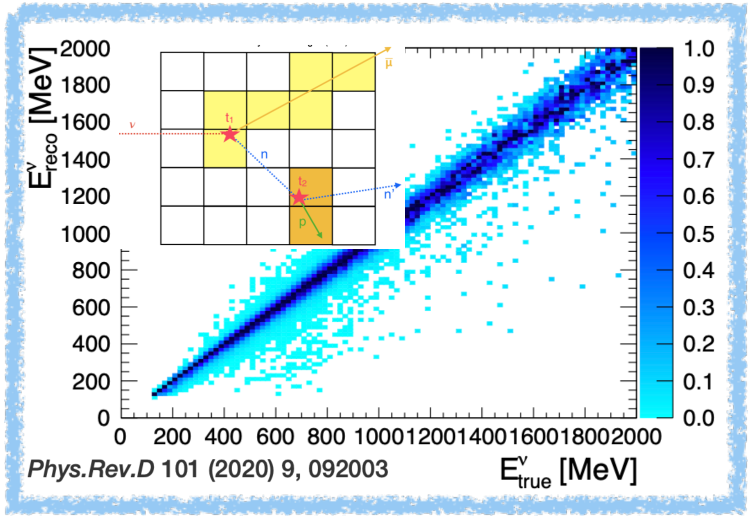




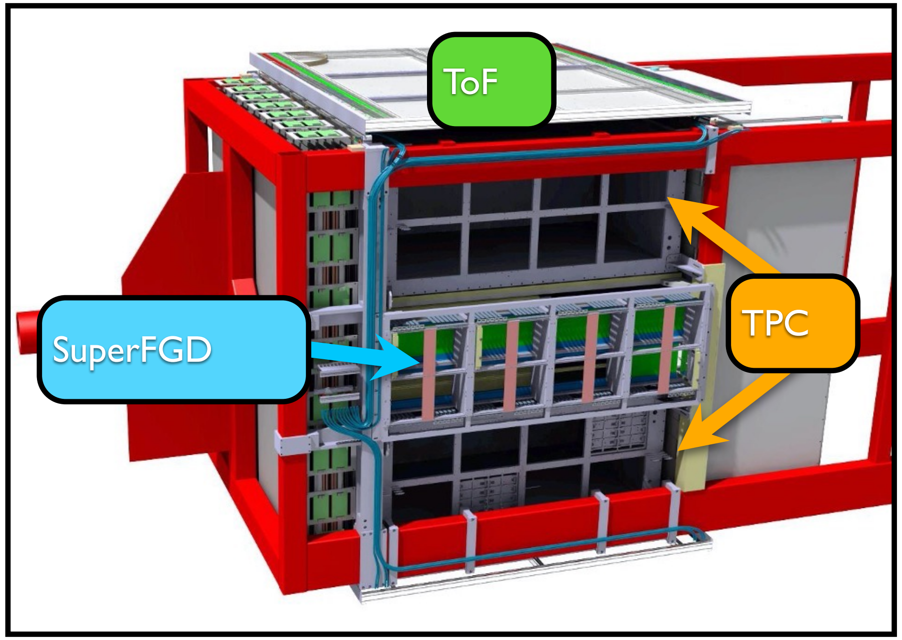
Protons → threshold down to 300 MeV/c
(>500/c MeV with current ND280)

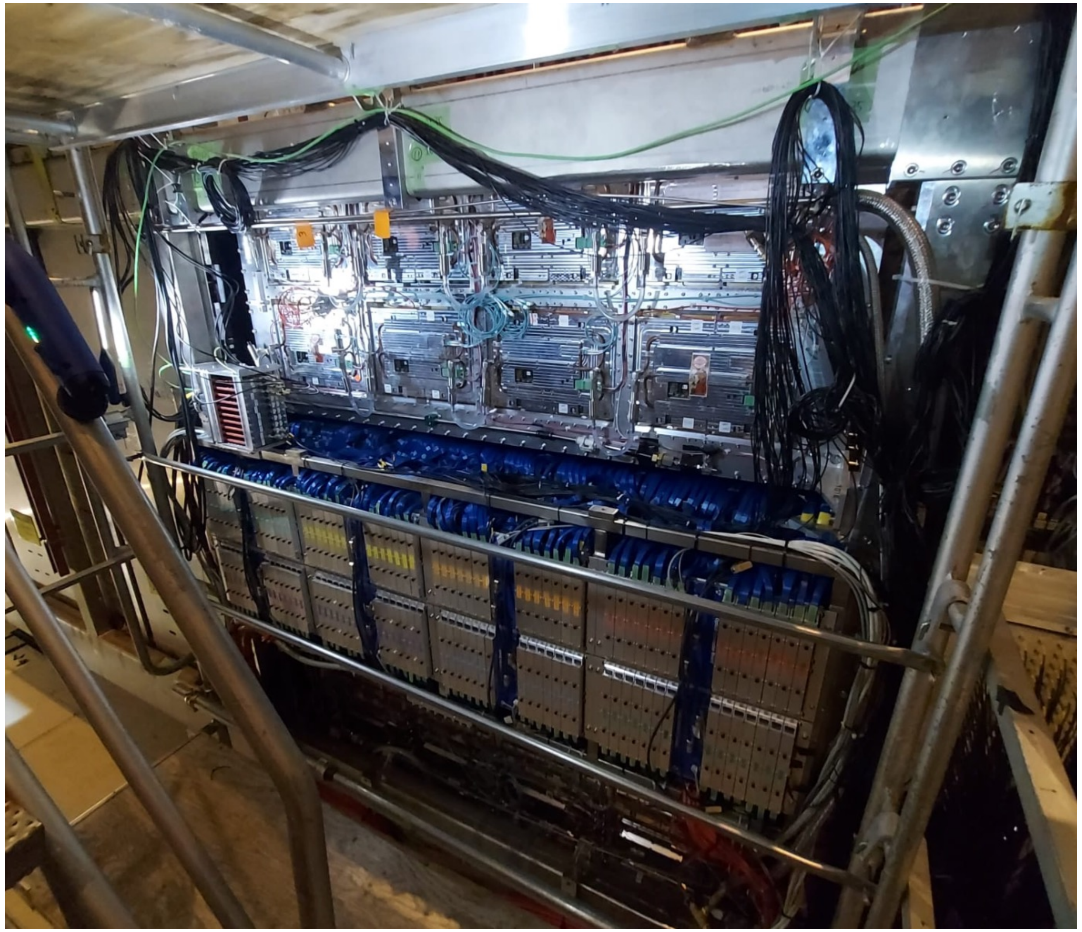


- High-Angle TPCs allow to reconstruct muons at any angle with respect to beam
- Super-FGD allow to fully reconstruct in 3D the tracks issued by ν interactions →lower threshold and excellent resolution to reconstruct protons at any angle
  - Improved PID performances thanks to the high granularity and 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

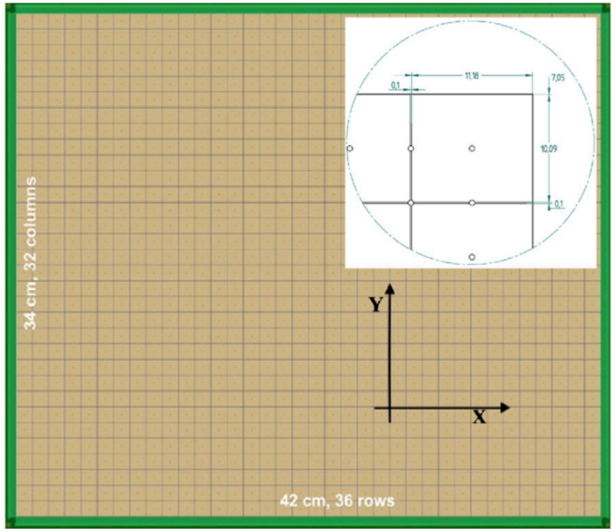


From drawings to reality

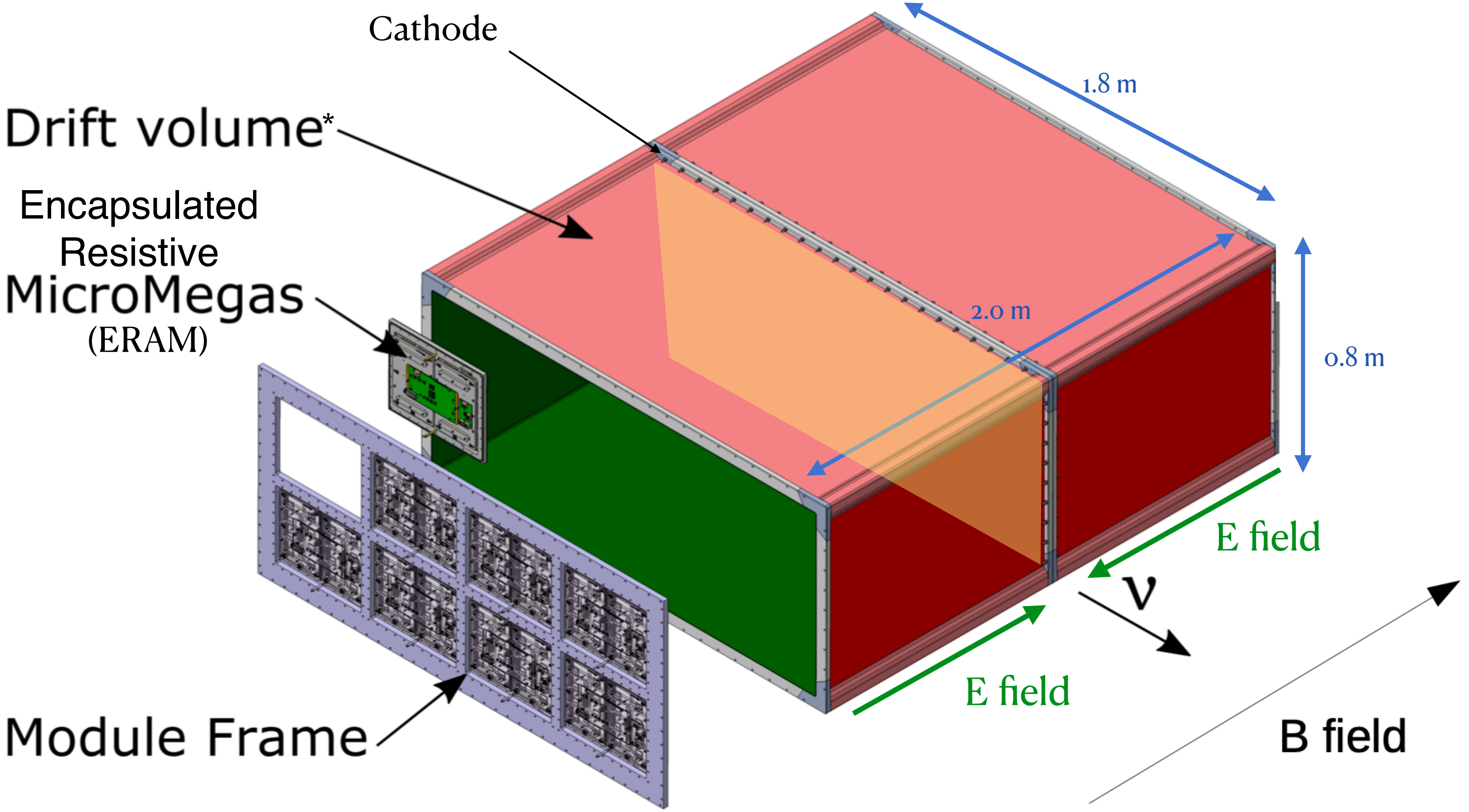




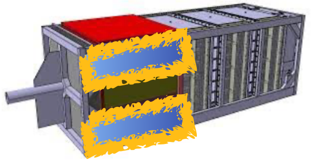
*Filled with « T2K » gas mixture:
Ar : CF_4 : iC_4H_{10} (95 : 3 : 2)

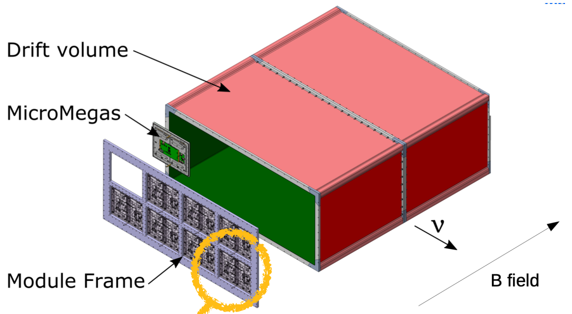


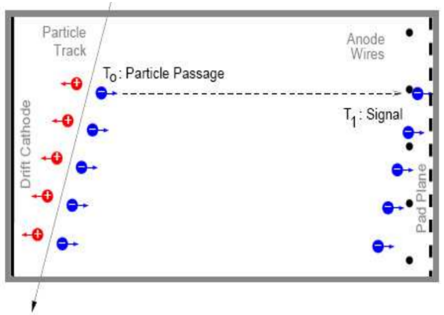
1 pad:
$x \times y = 11.2 \times 10.1 \text{ mm}^2$
36 pads in x and 32 pads in y in each ERAM



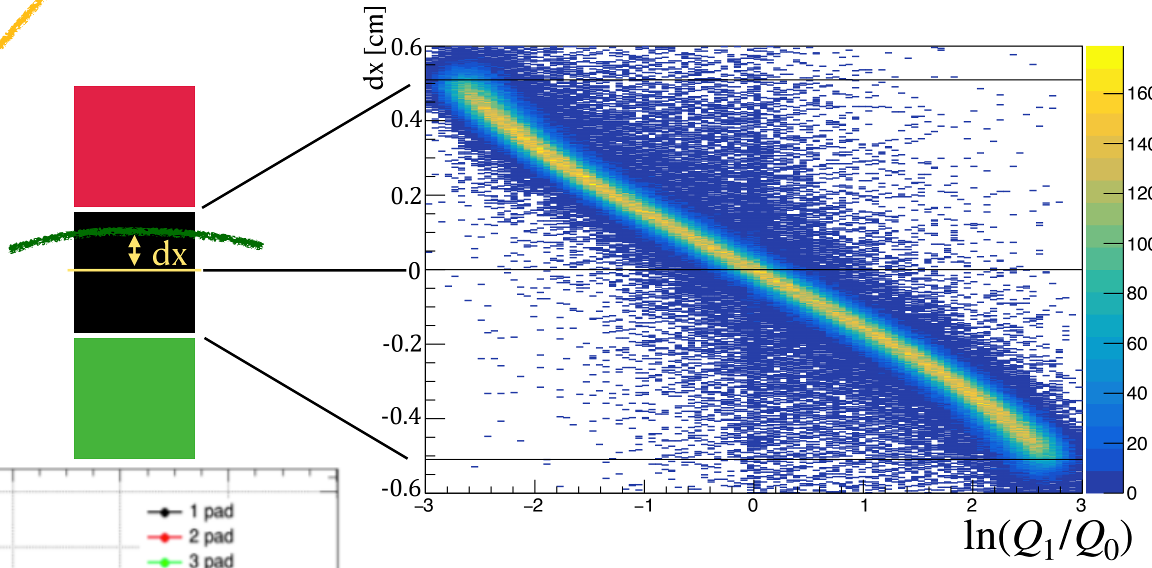
The HA-TPC principle

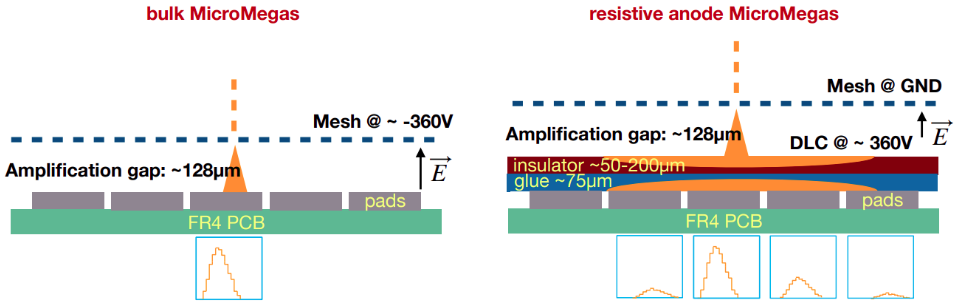


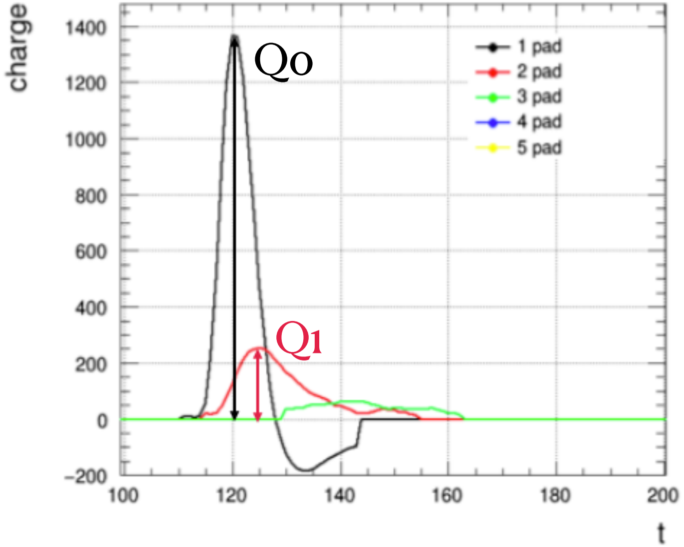


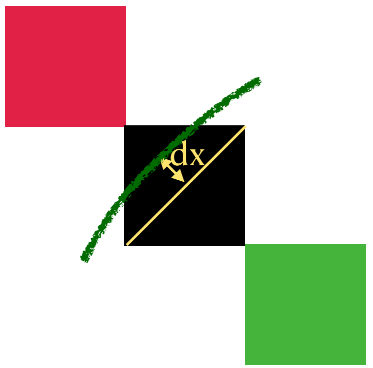


- New TPCs equipped with the **Encapsulated Resistive Anode MicroMegas (ERAM) technology**
- Contrary to the bulk MicroMegas which equip the vertical TPC, ERAM allow a charge spreading on several pads



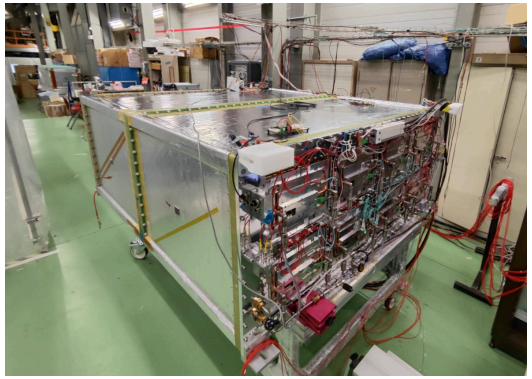






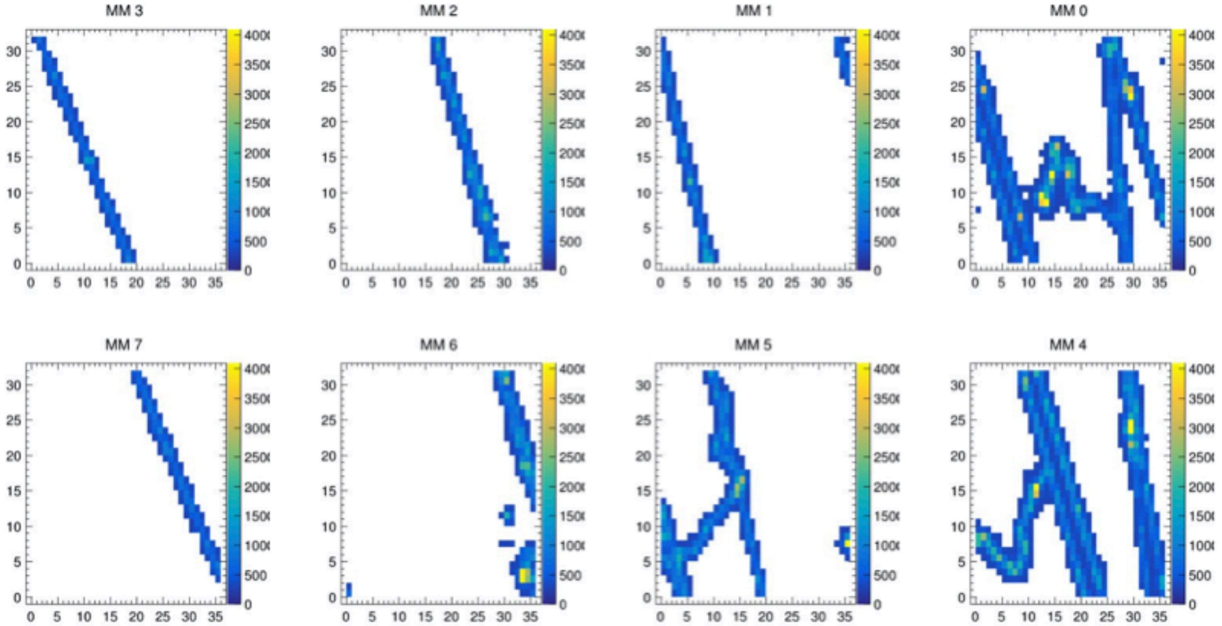
Assembled and commisionned at CERN

- Bottom* HA-TPC assembly and commisioning at CERN



- Cosmics data taken by Bottom HA-TPC at CERN previous to J-PARC shipment

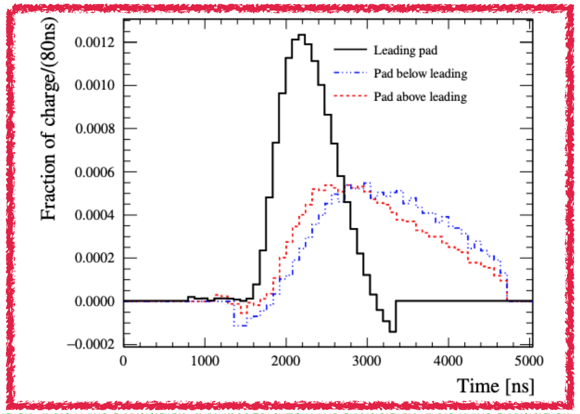
*Top HA-TPC not shown here but same process was done



Tested in various campaigns

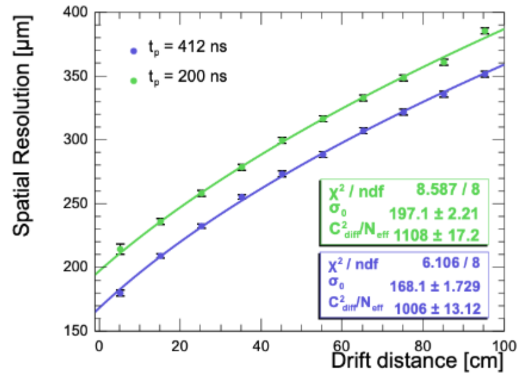
- CERN 2018 test beam (μ, π, e @ 2 GeV/c)
  [*Nucl.Instrum.Meth.A 957 (2020) 163286*]

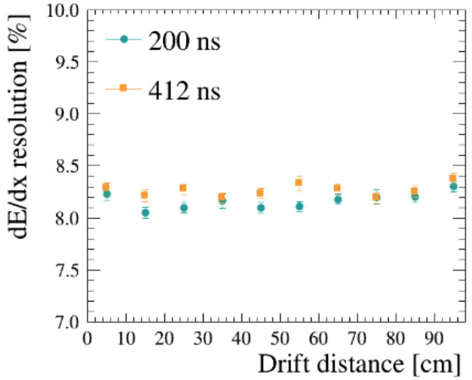
  Test of first prototype of resistive MicroMegas



- DESY 2019 and 2021 test beams (e @ 4 GeV/c)
  [*Nucl.Instrum.Meth.A 1025 (2022) 166109*]
  [*Nucl.Instrum.Meth.A 1052 (2023) 168248*]

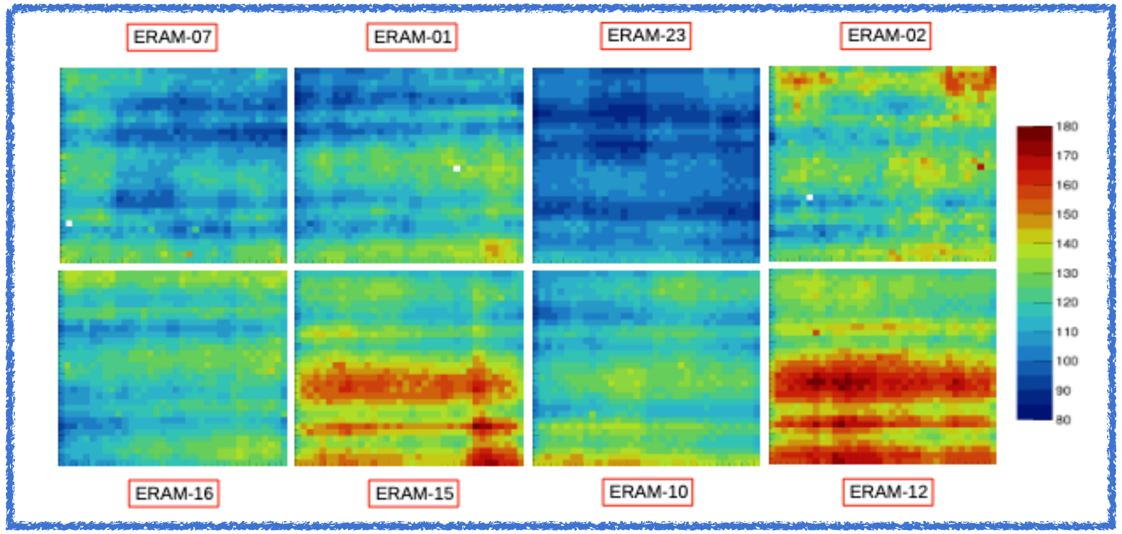
  Spatial and dE/dx resolutions measurement





- CERN 2022 X-Ray test bench (280 MBq ^{55}Fe source)
  [*Nucl.Instrum.Meth.A 1056 (2023) 168534*]

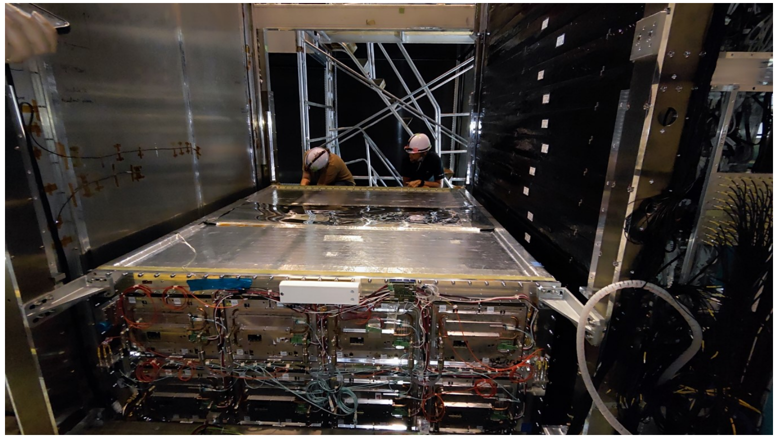
  Characterization of charge spreading and gain of the ERAMs



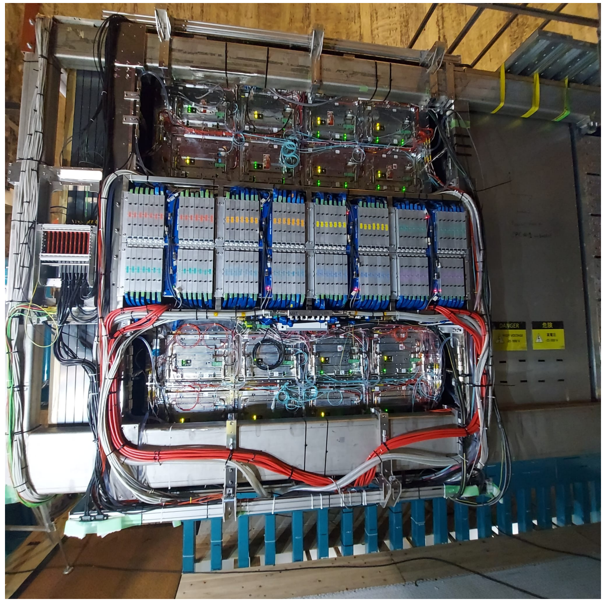
Then installed in J-PARC!

Bottom HA-TPC arrived at J-PARC (August 2023)

Top HA-TPC arrived in J-PARC (April 2024)



Bottom HA-TPC installed in the pit (September 2023)

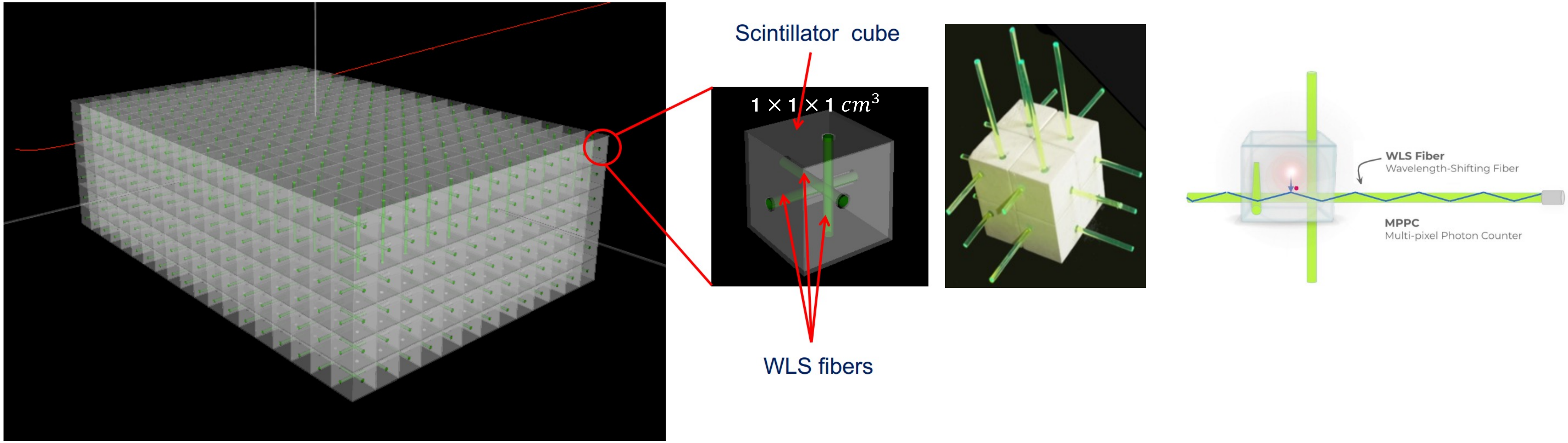


Full upgrade installed in the pit 🎉 (May 2024)

SCIENCES SORBONNE UNIVERSITÉ

LPNHE PARIS

SUPER FGD DETECTOR



- Super-FGD: 182 × 192 × 56 scintillator cubes (2 million) with 3D readout => 2 tons of fully active target

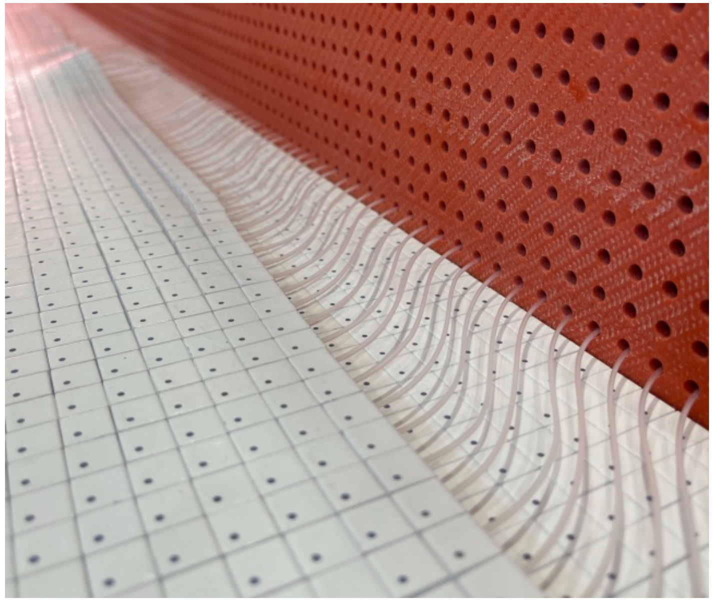
- Wavelength shifting (WLS) fibers are used to collect light from scintillator cubes. (70 km of WLS fiber in total)
- One end of the fibers is connected to a Multi-Pixel Photon Counter (MPPC) the other end is mirrored. => around 60.000 channels.

SUPER FGD ASSEMBLY AT J-PARC (EARLY 2023)

The cubes were shipped from Russia to Japan by plane

The Super-FGD box which carry all the cubes

SUPER FGD ASSEMBLY AT J-PARC (EARLY 2023)

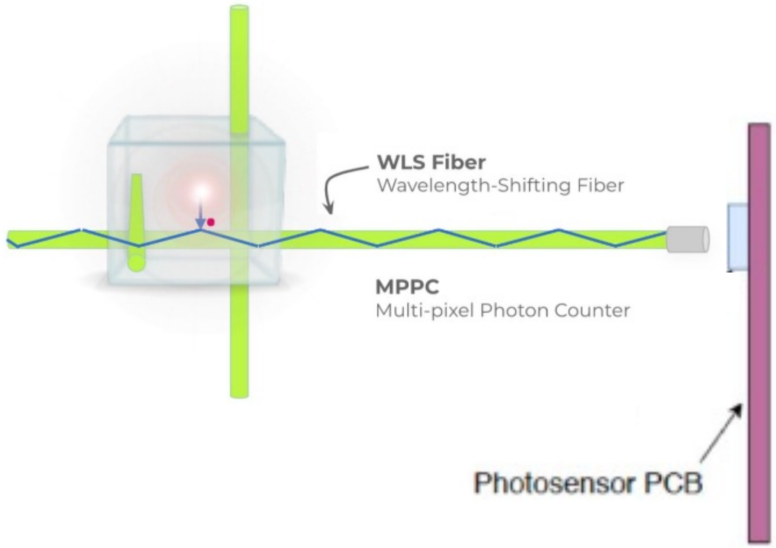


Insert the 2 million cubes in the Super-FGD box layer by layer

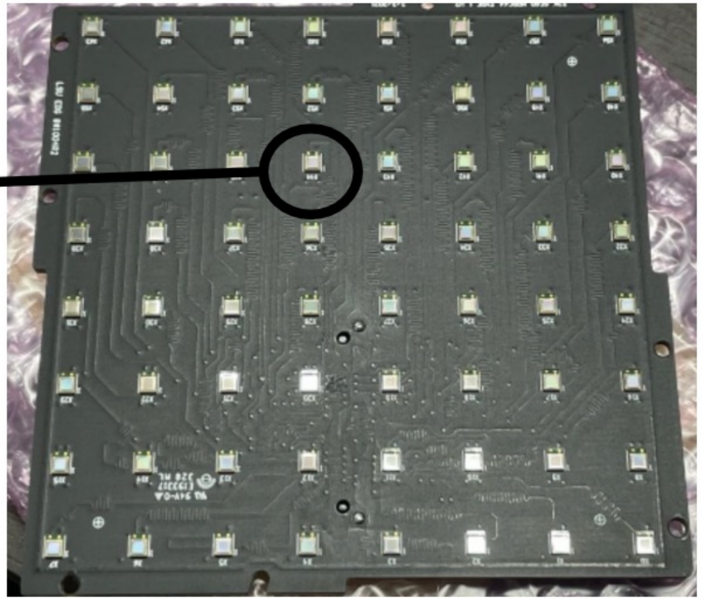
Insert the fishing lines

After closing the Super-FGD box, the fishing lines will be replaced by the wavelength shifting fibers

R FGD DETECTOR READOUT



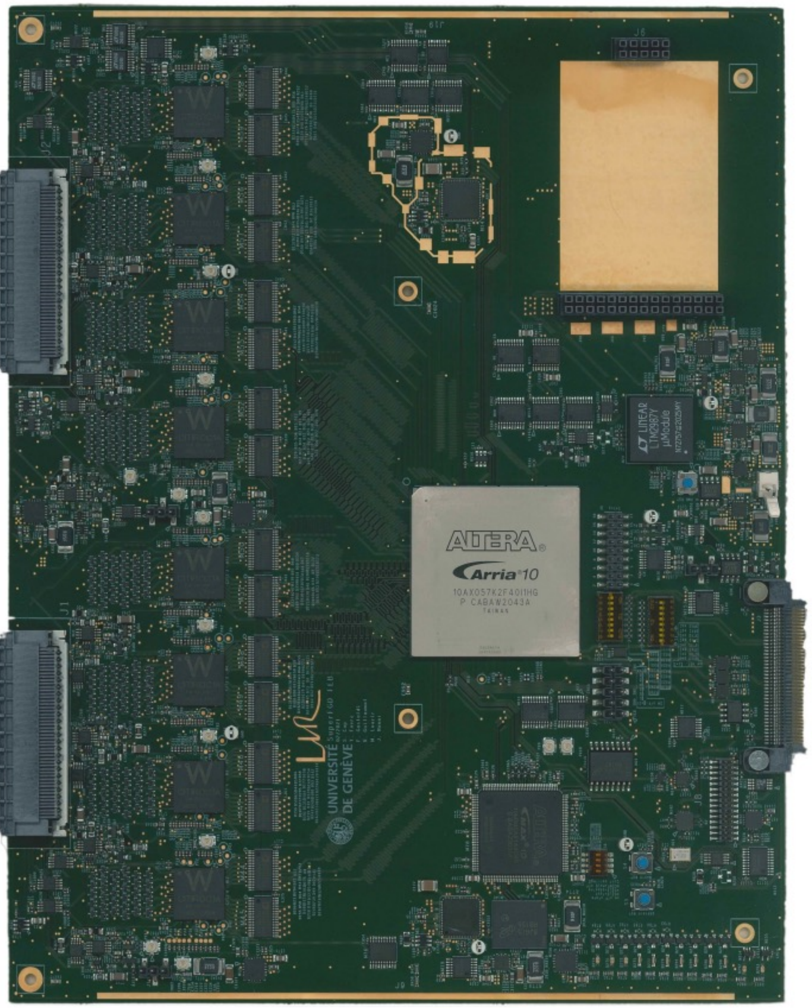
64 MPPCs



64 channels

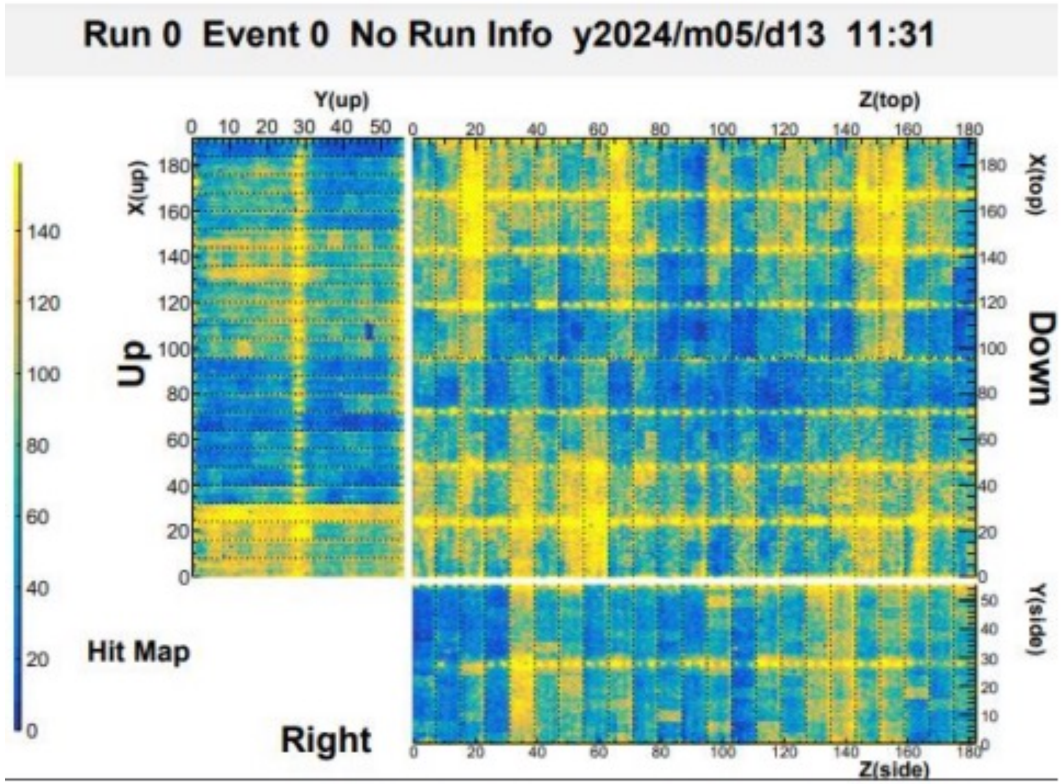
X4 MPPC => 1 FEB

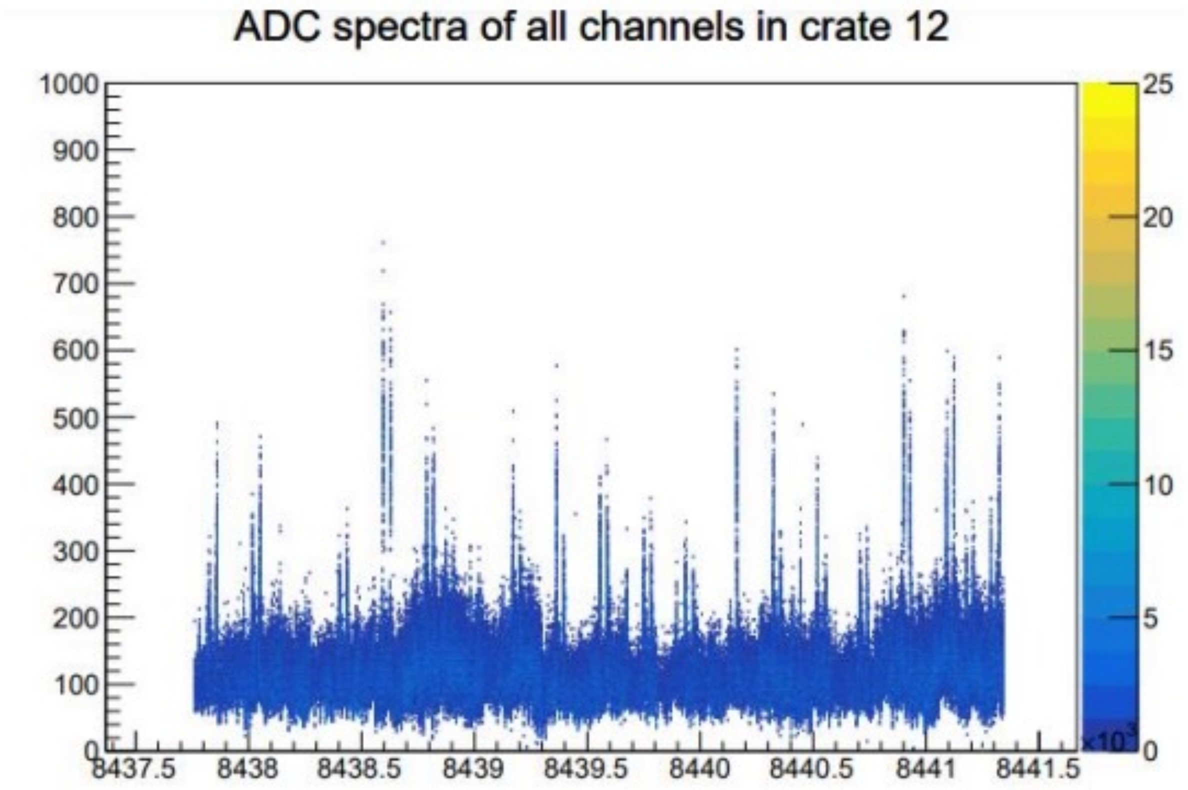
Front-End Board (FEB)



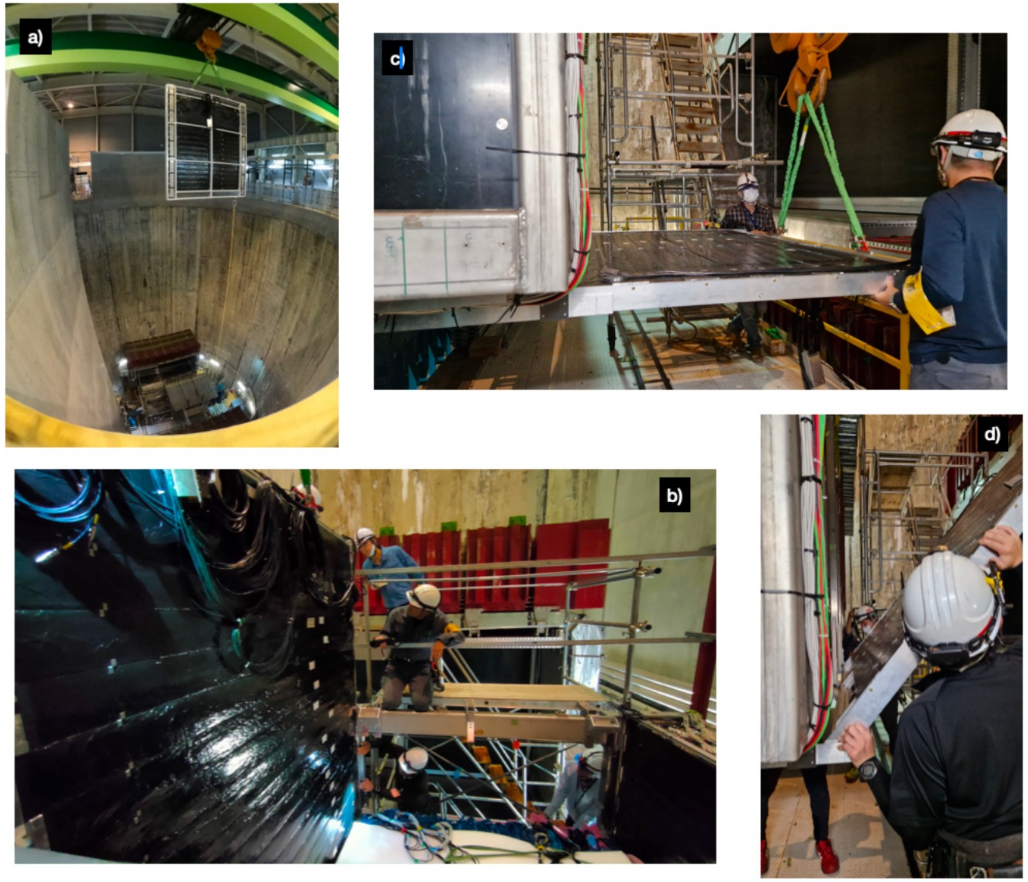
256 channels

Full hit map of SuperFGD is available. Super FGD is ready for the next beam run

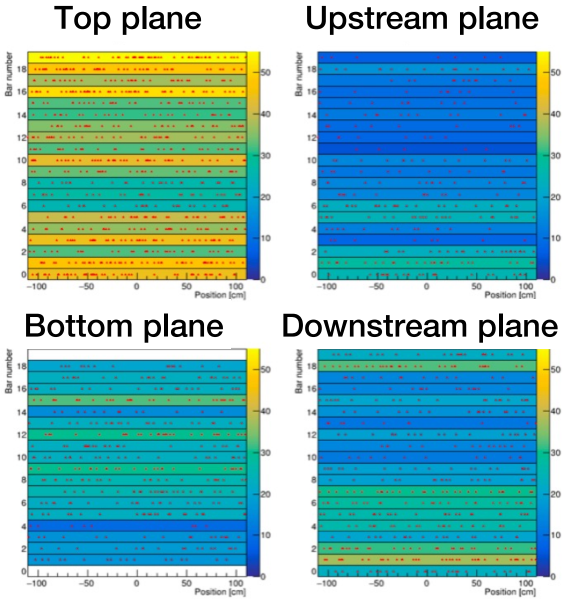


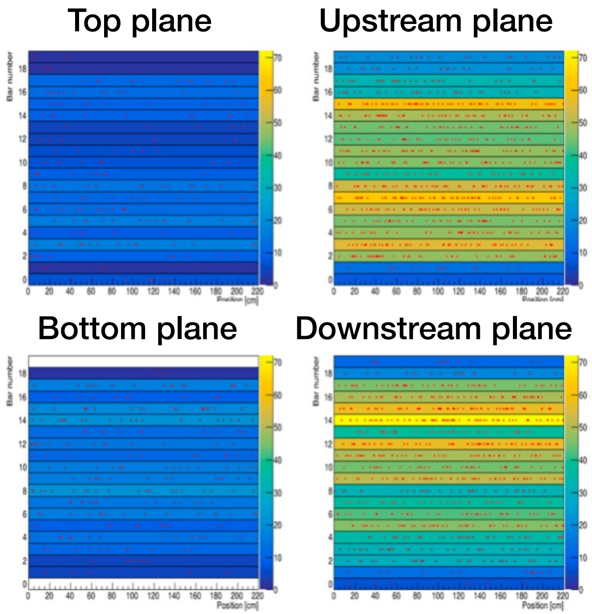


Time-Of-Flight



- 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

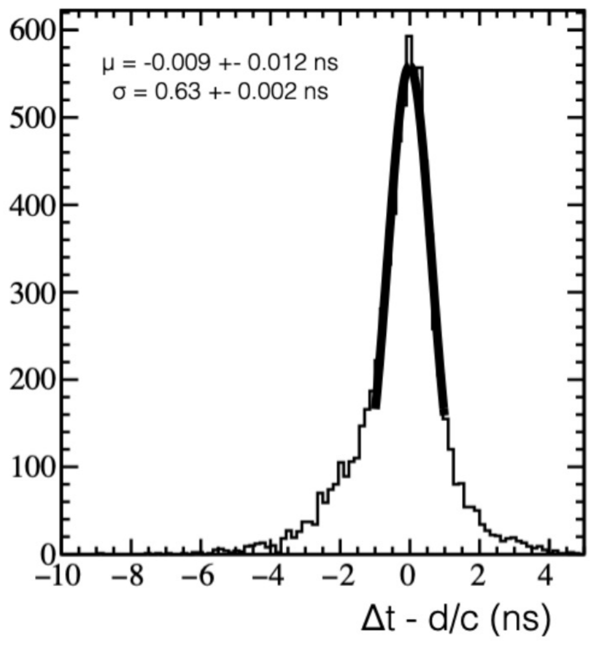


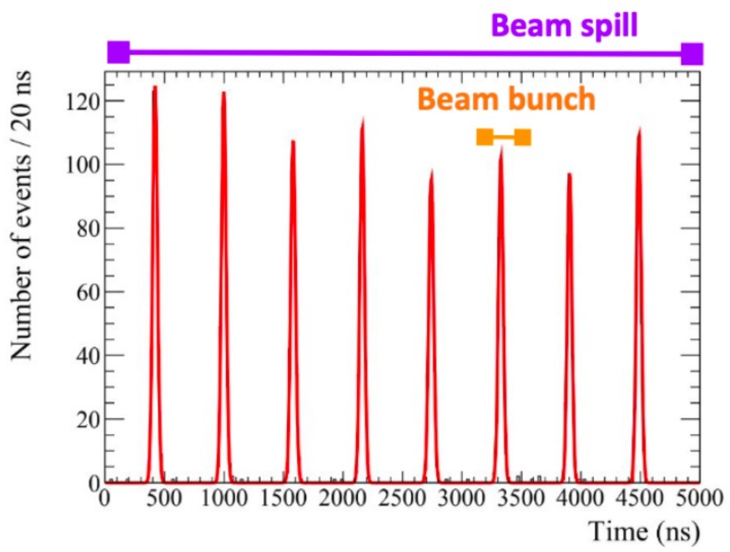


TOF performances

- 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



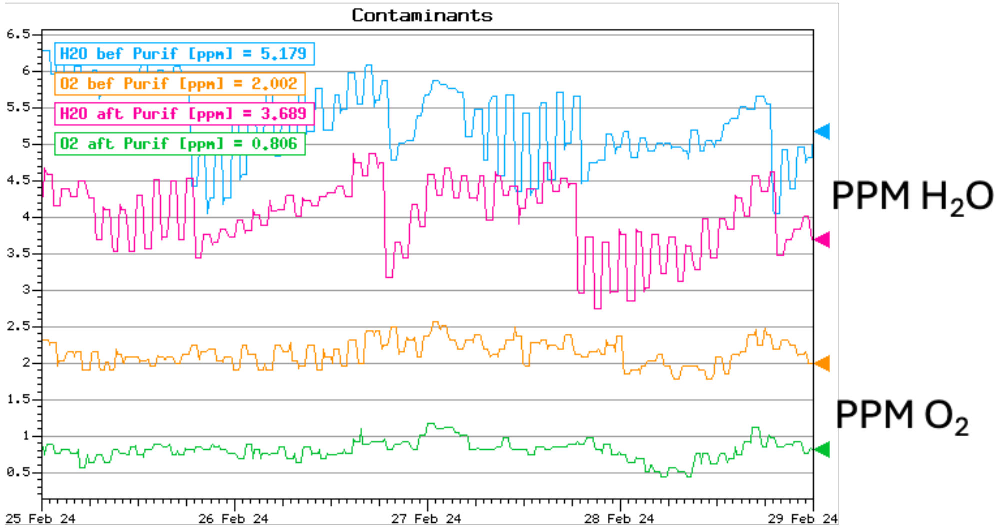


Gas system – the first to arrive (April 2023)

- 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

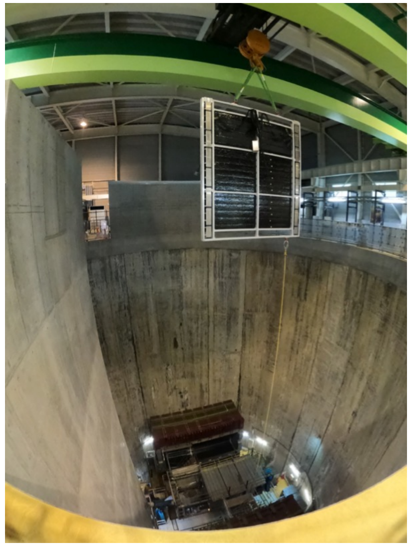
•Continued local operations by INFN with remote support by CERN

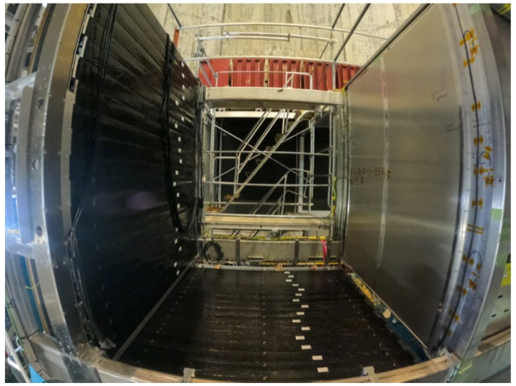


- Full start-up with HA-TPC-bottom + 3 V-TPCs by mid-November
- Running until end of 2023
- Second commissioning run in February 2024, achieving record gas purity (< 1ppm O2 in gas distributed to TPCs)
- Gas consumption (and rejection in the atmosphere) reduced to 1/3 w.r.t. the past system, still subject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

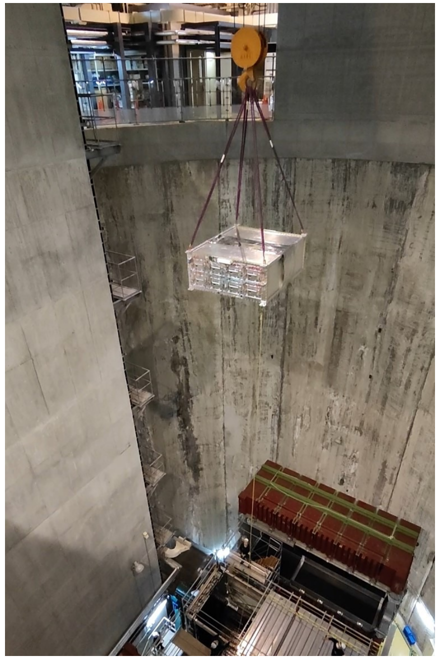
Installation at J-PARC

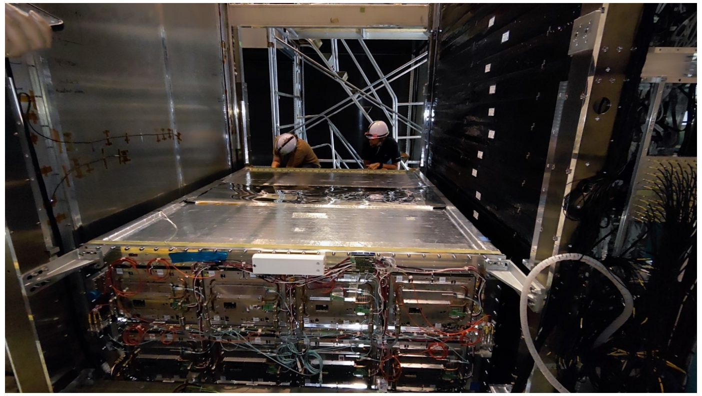
TOF installation (July 2023)



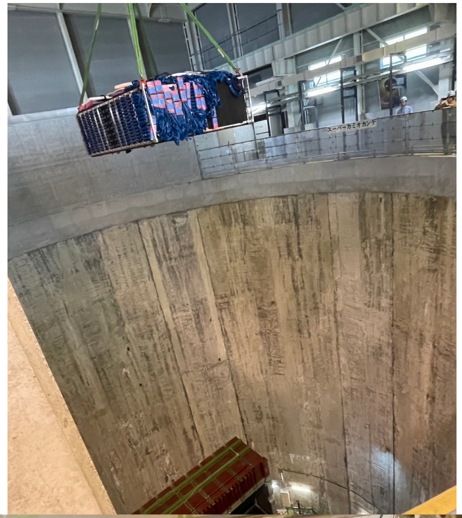


Bottom TPC
installation (September 2023)

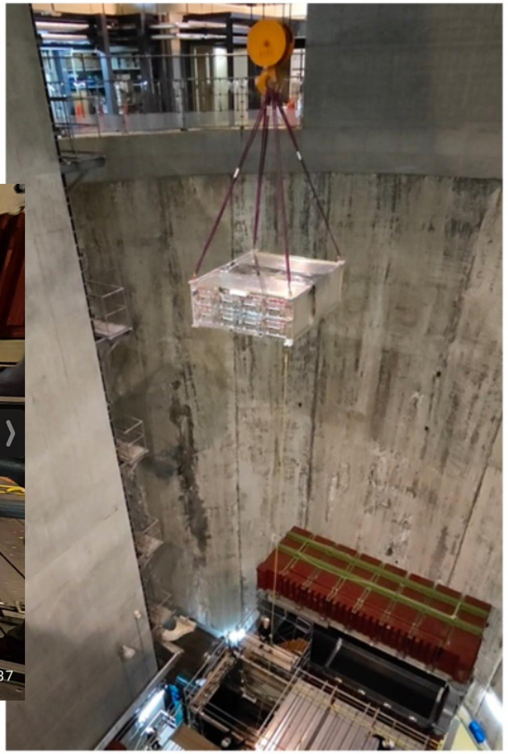




Super-FGD
installation (October 2023)

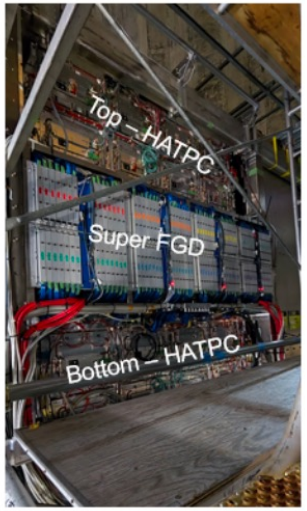


Top HATPC installed (April 2024)

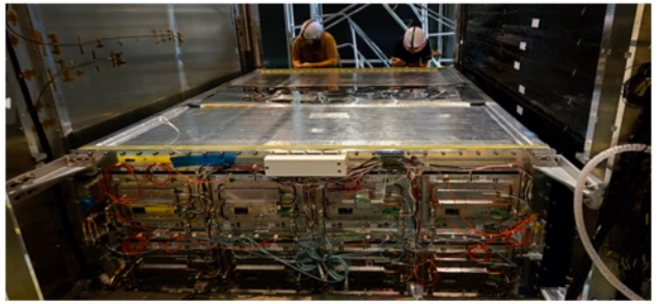


Lowering bottom HATPC
2023.9.8

Top – HATPC in ND280



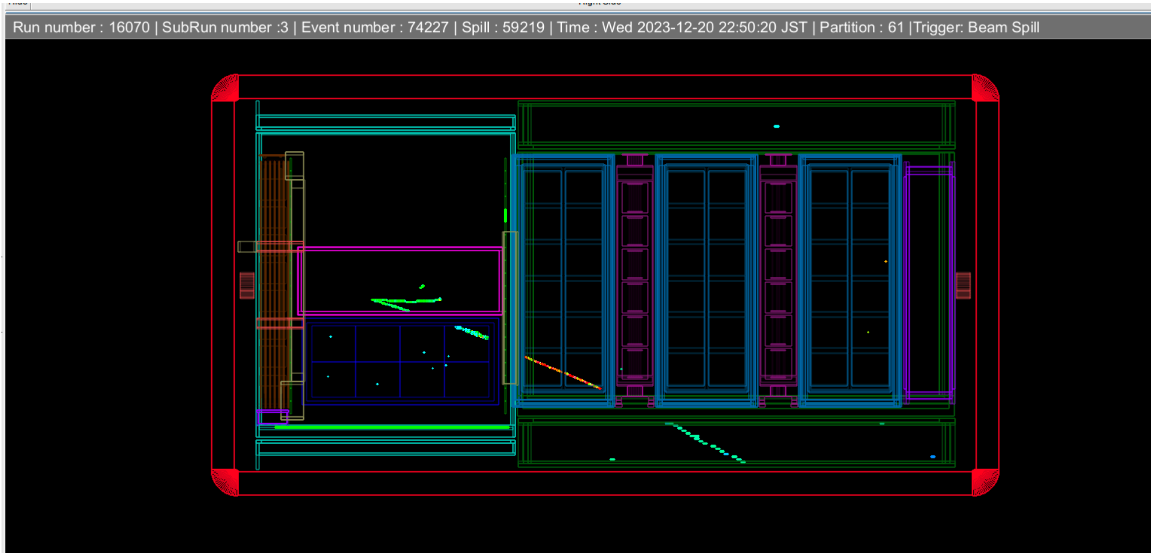
Bottom – HATPC in ND280



ND280 after lowering of top HATPC
2024.4.25

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

Passed an important milestone at the end of 2023: upgrade partially operational (missing 1 TPC) and record beam power



First neutrino events from un upgraded beam and detected with an upgraded detector!!!

WP2 secondments

Institution	WP2 done (months)	WP2 planned	WP2 % done
INFN	35,2	49,0	71,9%
IFJ-PAN	2,3	7,0	32,4%
LAL-CNRS	7,7	10,0	77,3%
CEA	7,9	17,0	46,5%
IFAE	12,0	12,0	100,0%
UNIGE	11,0	18,0	60,9%
NCBJ	12,4	17,0	72,7%
KCL (Qmul)	2,9	3,0	97,8%
UKRI	0,7	6,0	12,2%
Total	92,1	139,0	66,3%

Conclusions

- What at the beginning of Jennifer-2 was mostly on paper is now a fully installed new set of detectors
- Much work has to be done in the future to fully optimize, commission, understand and exploit the new hardware
- The support made possible by Jennifer-2 is KEY to the success of the projects under the umbrella of WP2
- → more on T2K analysis status and deliverables/milestones in the second part of the WP2 session (afternoon)