Status of NP-07 - T2K Near Detector Upgrade

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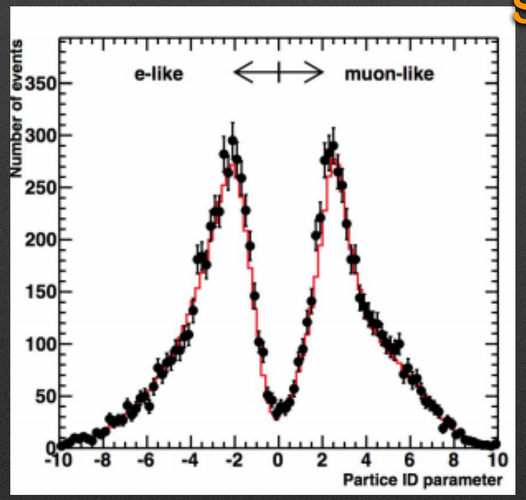
(For the NP-07 - ND280 Upgrade working group)

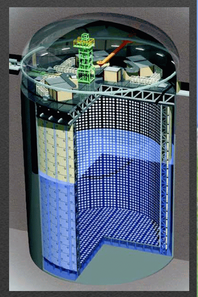
CERN SPSC meeting - 12/04/2022

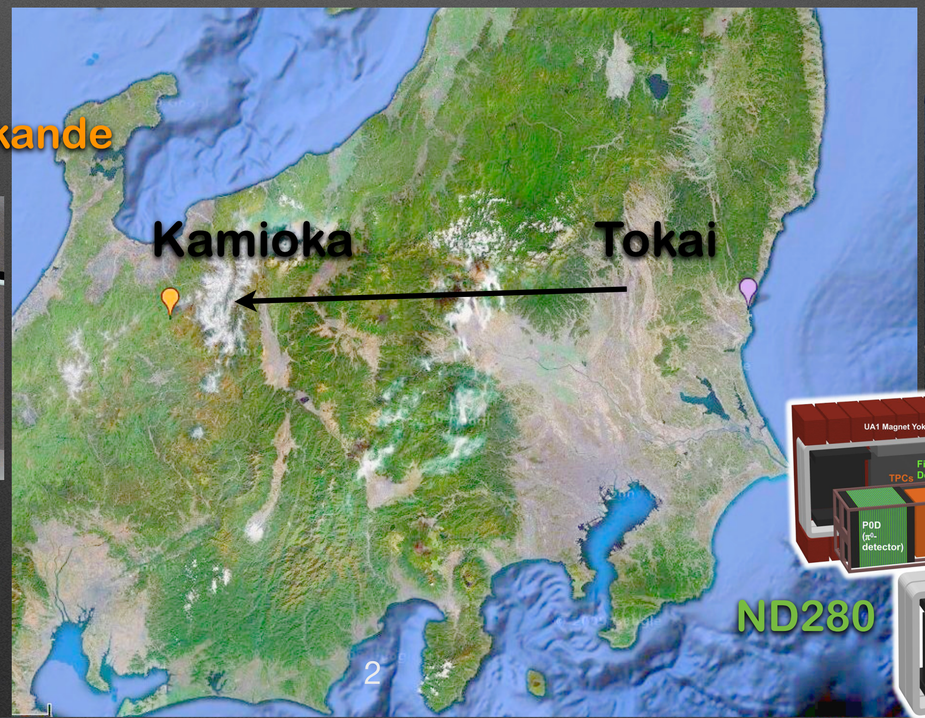
T2K - Tokai to Kamioka

- High intensity ~600 MeV ν_μ beam produced at J-PARC (Tokai, Japan)
- Neutrinos detected at the Near Detector (ND280) and at the Far Detector, Super-Kamiokande 295 km from J-PARC
- Main physics goals:
  - Observation of ν_e and $\bar{\nu}_e$ appearance → determine θ_{13} and δ_{CP}
  - Precise measurement of ν_μ and $\bar{\nu}_\mu$ disappearance → θ_{23} and Δm^2_{32}

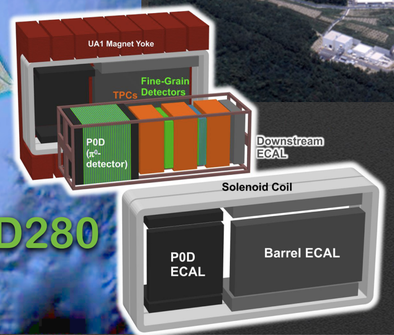


Super-Kamiokande





J-PARC accelerator:
Design power: 750 kW
(1.3 MW for HK)

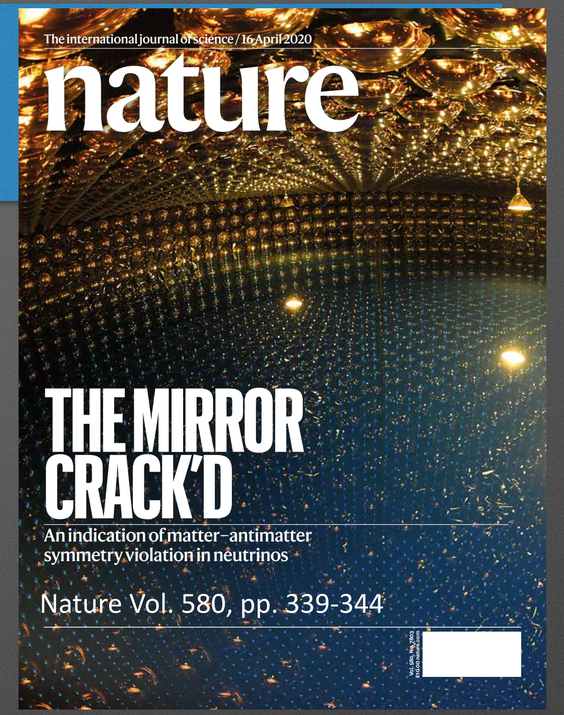


ND280

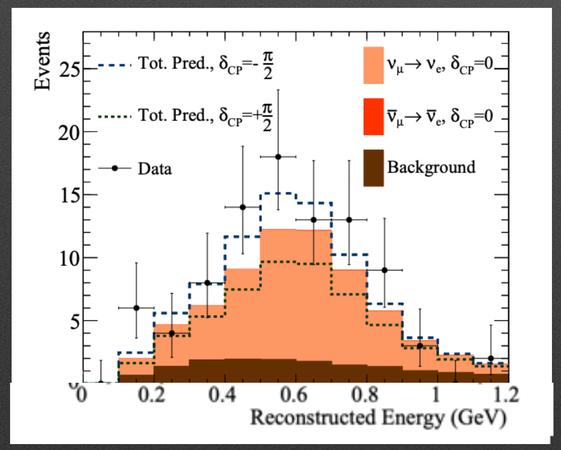
T2K results

- Constraint of the matter-antimatter symmetry violating phase in Neutrino oscillations

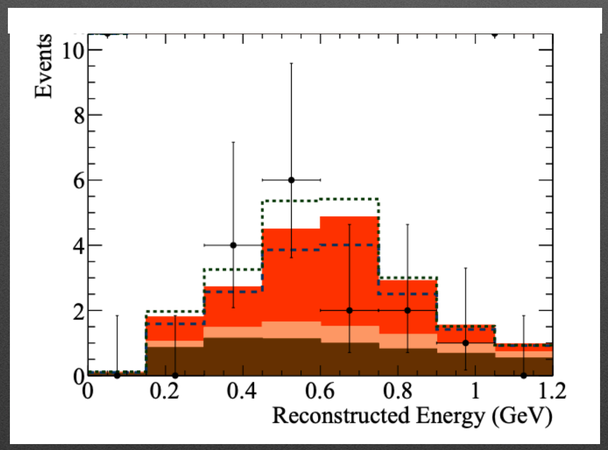
- First 3σ exclusion for 46% (65%) of the δ_{CP} values in NO (IO) using Run1-9 data

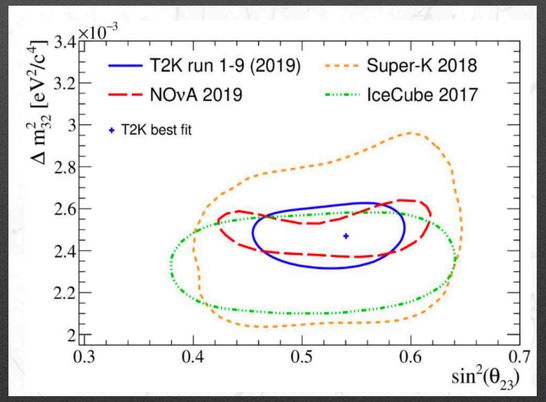


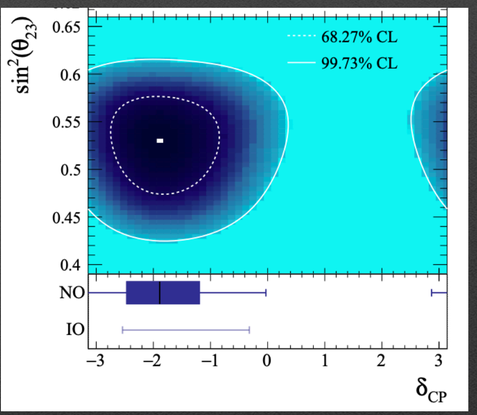
ν-mode



$\bar{\nu}$-mode



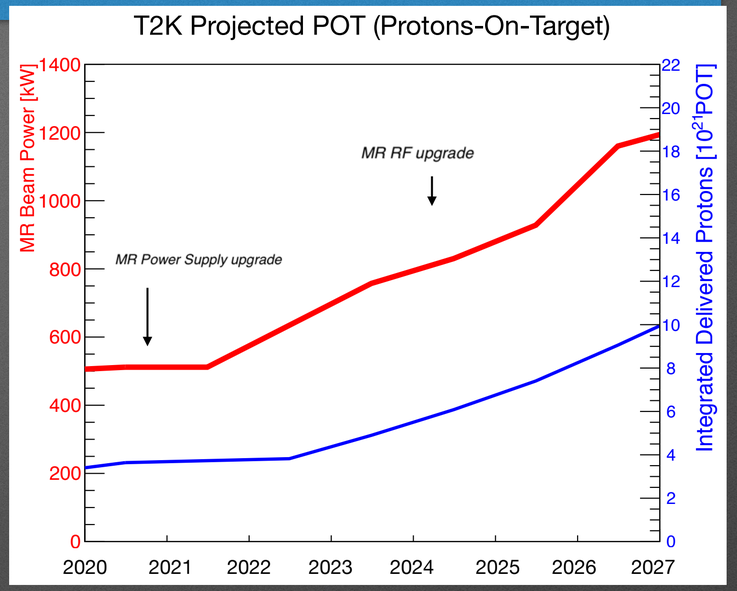


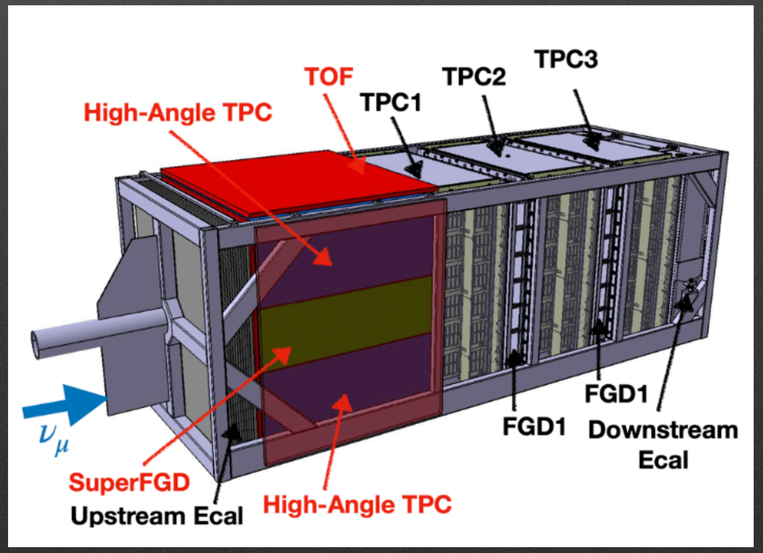


	ν-mode	$\bar{\nu}$-mode
Observed	**90**	**15**
Exp ($\delta_{CP}=-\pi/2$)	81.7	17.2
Exp ($\delta_{CP}=0$)	68.4	19.6

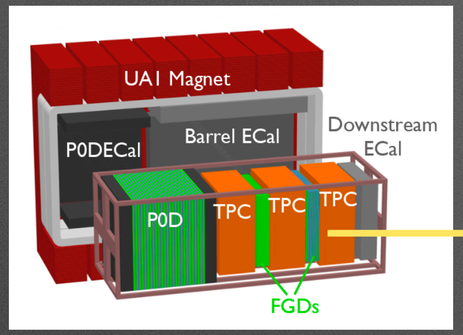
Future of T2K (T2K-II)

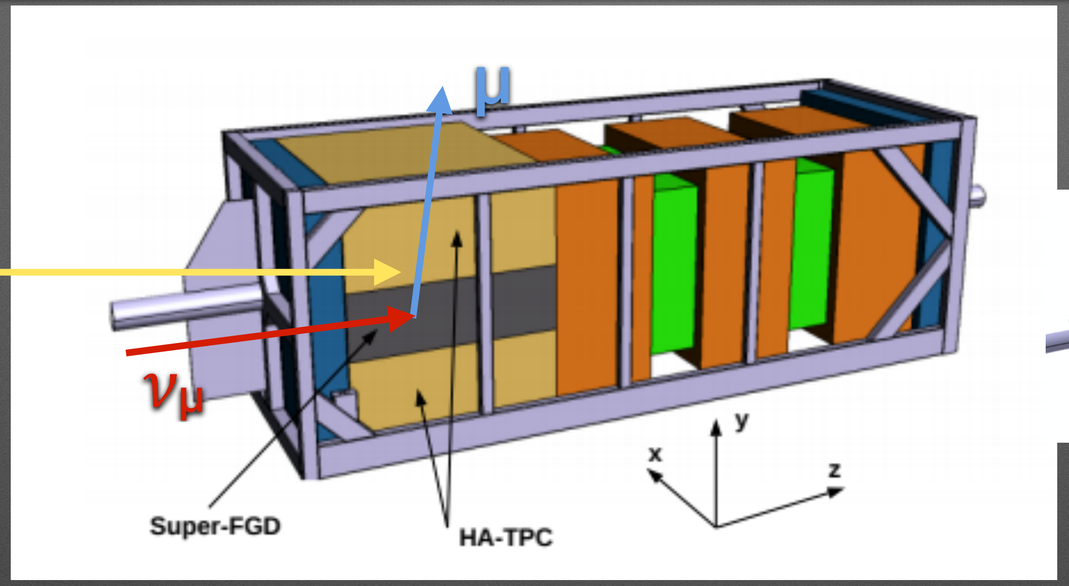
- **T2K-II**: extension of T2K running time in the period 2022 - 2027
  - 2027: Beginning of Hyper-Kamiokande
- Collect >10x10^{21} POT → 3σ sensitivity to CPV if δ_{CP}=-π/2
- T2K-II consists in two hardware projects:
  - **Beamline upgrade** → double repetition rate and increase power from 500 kW to 1.3 MW
  - **Off-axis Near Detector upgrade** → reduce systematics uncertainties to cope with additional statistics
  - After the upgrades we will collect 4 months of data per year until the beginning of HK
  - ND280 (and the upgrade) are also expected to be one of the NDs for Hyper-Kamiokande



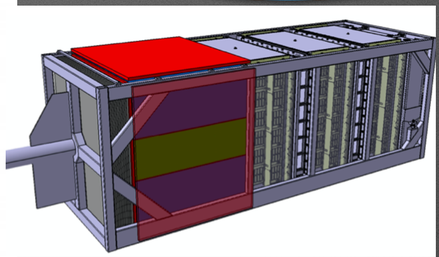


ND280 Upgrade





NP-07 at CERN NP



- One horizontal highly segmented target (Super-FGD) formed by 2 millions 1cm^3 cubes → Improve reconstruction of hadronic part of the interaction and of low momentum particles
- Two new High Angle TPCs → Improve reconstruction of high angle particles
- 6 Time Of Flight planes → Reduce backgrounds entering from outside the Super-FGD

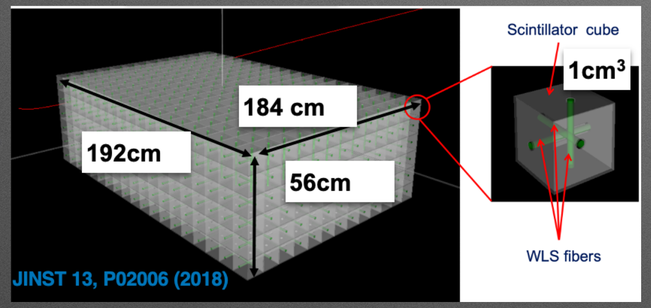
Participating institutes

- Europe: 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
- US: Louisiana State University, University of Colorado, University of Pennsylvania, University of Pittsburgh, Stony Brook University, University of Rochester

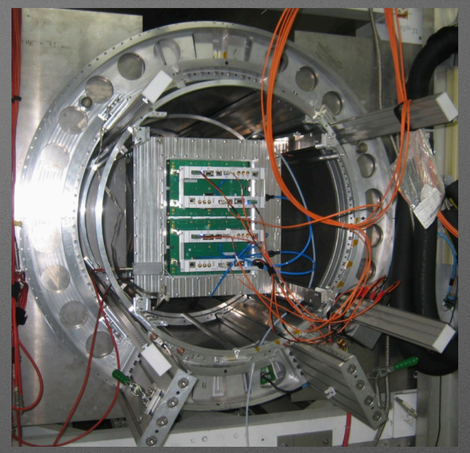
- MoU signed in 2020 between participating institutes and CERN (NP-07/ND280 Upgrade project)
- J-PARC PAC Stage-2 approval (green light for construction) granted in 2020

New detectors

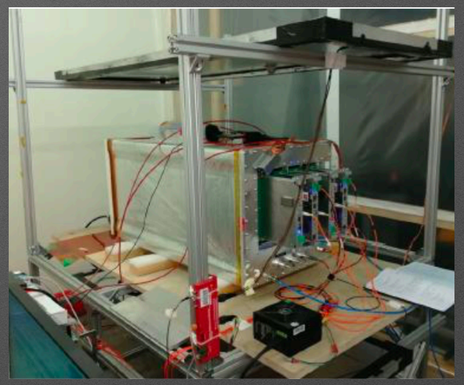
Super-FGD



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



High-Angle TPCs

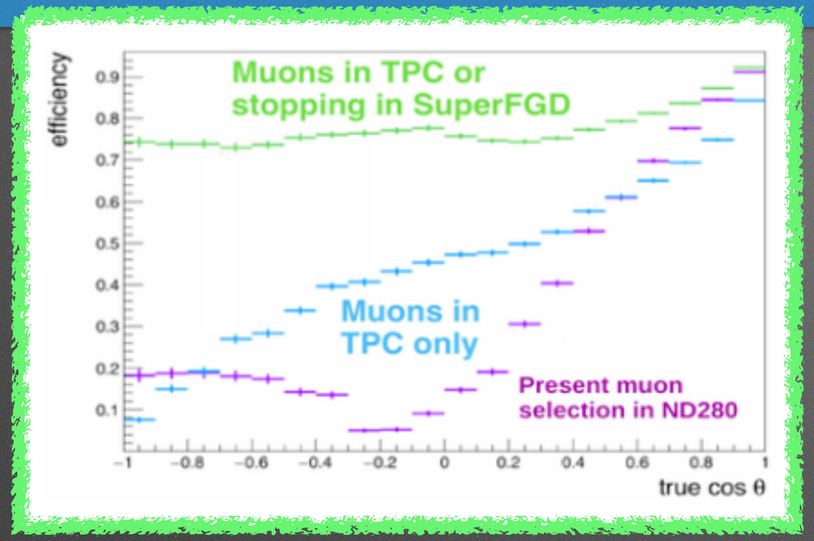


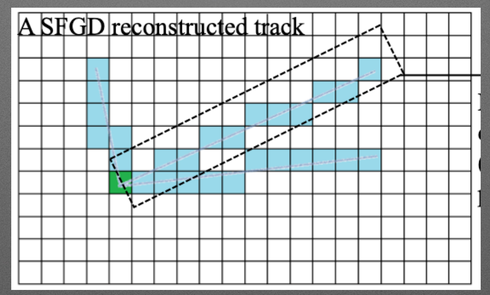
New TPCs instrumented with Encapsulated Resistive Anode MicroMegas (ERAM)

TOF

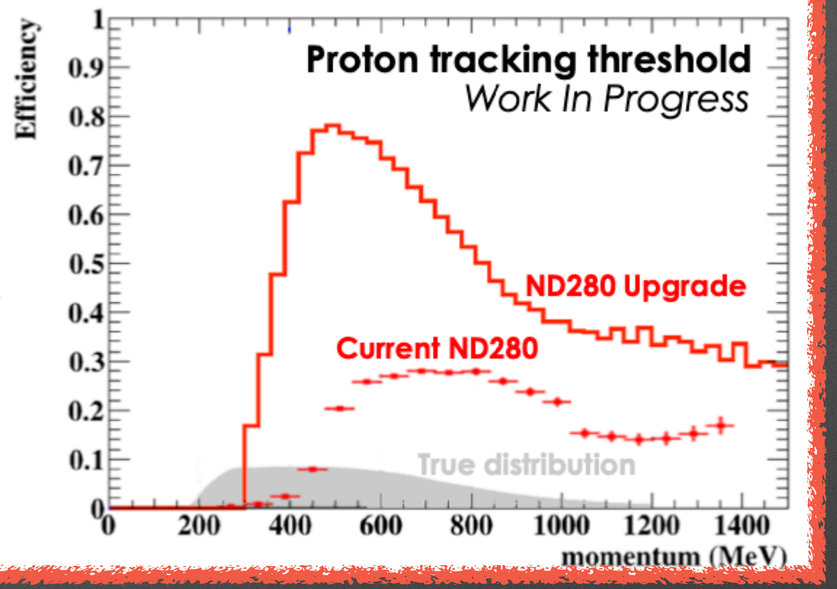
6 TOF planes to reconstruct track direction
Time resolution ~150 ps

ND280 Upgrade physics performances

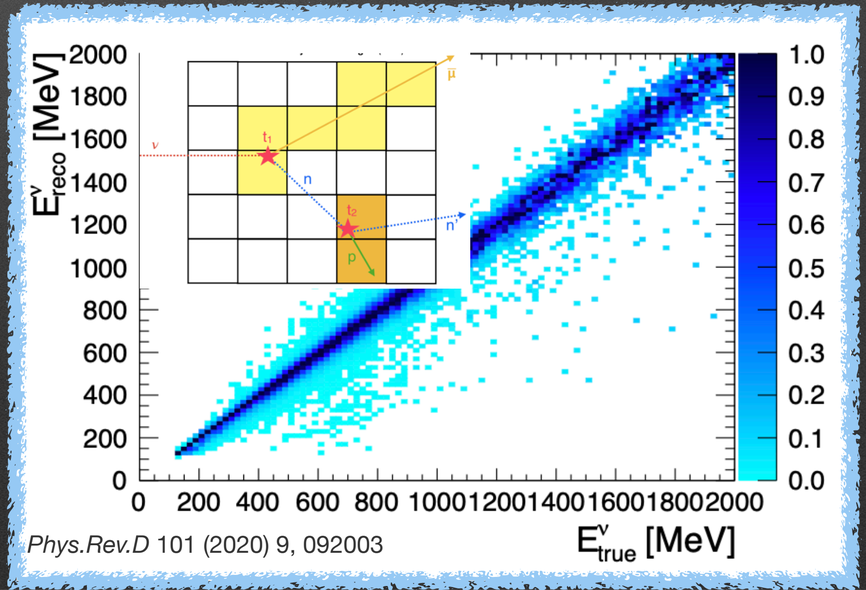




Protons → threshold down to 300 MeV/c
(>500/c MeV with current ND280)



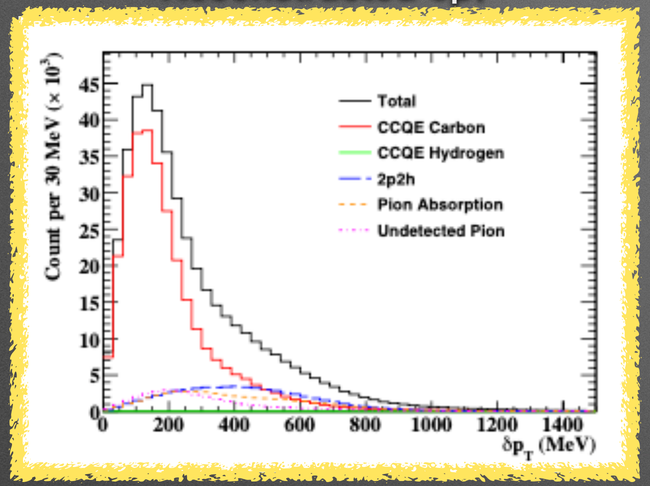
- High-Angle TPCs allow to reconstruct muons at any angle with respect to beam
- Super-FGD allow to fully reconstruct in 3D the tracks issued by ν interactions → lower threshold and excellent resolution to reconstruct protons at any angle
  - Improved PID performances thanks to the high granularity and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



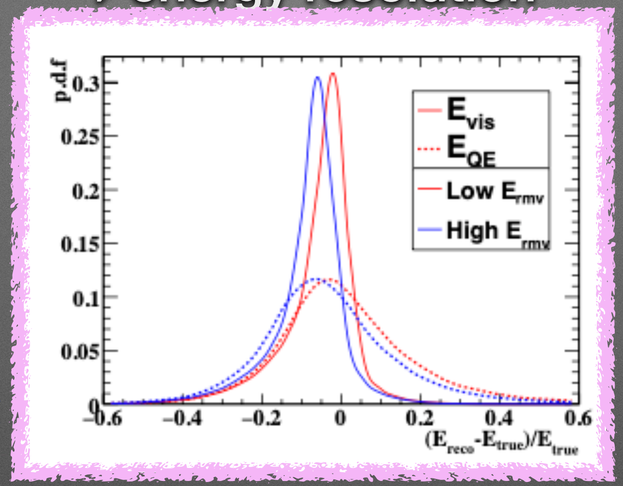
Phys.Rev.D 101 (2020) 9, 092003

Exploiting hadronic informations

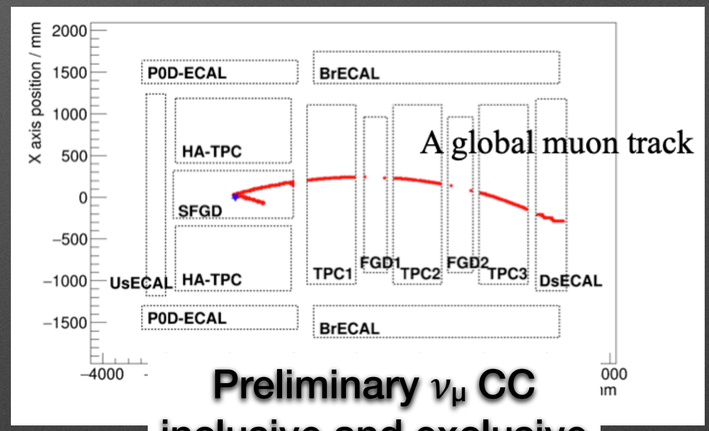
Reconstructed δp_T



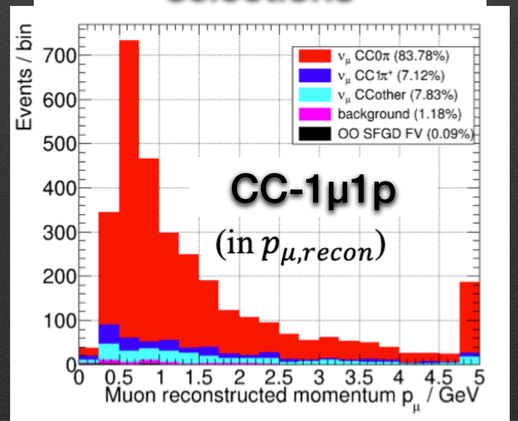
ν energy resolution



Papers:
S. Dolan, V. Nguyen, et al Upgrade sensitivity, Phys.Rev.D 105 (2022) 3, 032010
A. Ershova et al, FSI with ICNL and NuWRO, arXiv:2202.10402



Preliminary ν_μ CC inclusive and exclusive selections



- Analyses done so far by ND280 mostly exploited the μ kinematics
- Reconstruct muons and protons (neutron) emitted in ν ($\bar{\nu}$) QE interactions
  - Reconstruct variables in the transverse plane sensitive to nuclear effects such as the missing transverse momentum → $\delta p_T = |p_T^\mu - p_T^{p(n)}|$
  - $E_{vis} = E_\mu + T_{p(n)}$ → where T is the kinetic energy
    - Evis better estimator of the neutrino energy than QE formula
- Simulation of the sFGD is implemented in nd280 software including an optical simulation of the cube responses, PID and momentum reconstruction
- Global reconstruction between sFGD+TPC1 has also been implemented to develop first ν_μ CC inclusive and exclusive analyses

Super-FGD

- All the cubes have been produced and assembled in x-y layers at INR
- Also the assembly platform has been produced at JINR
- Paperwork for shipment to Japan has started → we do not see showstopper for now
  - Expect to receive the cubes in Japan in Summer 2022
- Fibers, MPPC and calibration system are also being prepared in Japan and in the US
- Assembly will start at J-PARC as soon as the mechanics box is received and we estimate it will take ~4 months

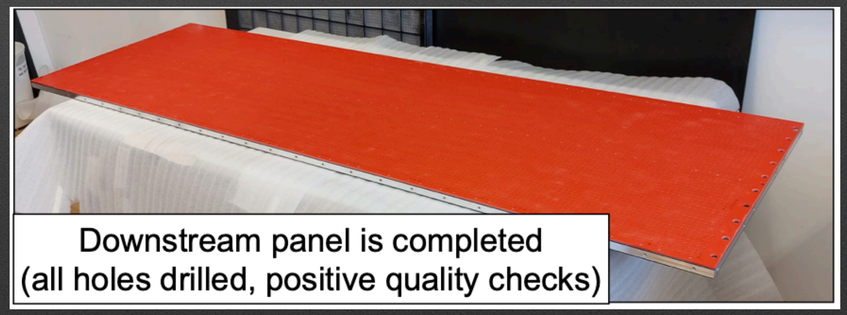
Super-FGD mechanics box

- This is one of the main elements on the critical path
- Production readiness review successfully passed in August 2021
- Procurement done in August 2021
- Suffered delays for the delivery of the fiberglass plates from NEXUS → first plate was delivered in February 2022
- 6 plates have to be drilled and it is not possible to drill them in parallel → ~4 months for the production of the plates → all plates expected at CERN in August
- Box mounting and load tests at CERN and then shipment to J-PARC (October 2022)

Production steps:

1. Fiberglass (from NEXUS) and Carbon fiber - foam sandwich (Composite Design)
2. Gluing fiberglass to Carbon fiber sandwich

Good news: first 2 panels (DS and right) has been successfully completed → production steps well in place

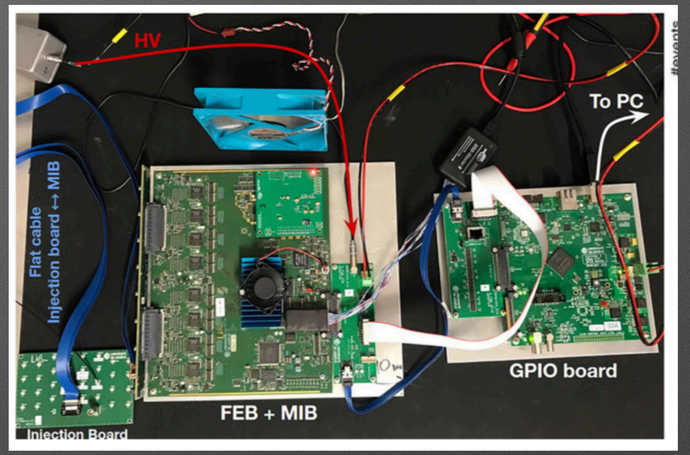


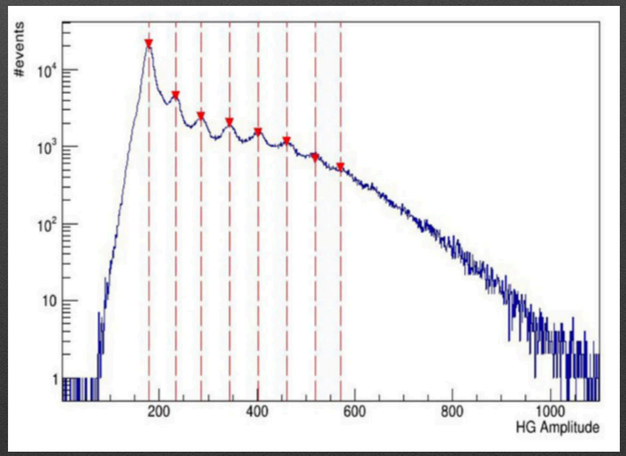
Downstream panel is completed
(all holes drilled, positive quality checks)

Production of top and bottom plates ongoing

Super-FGD electronics

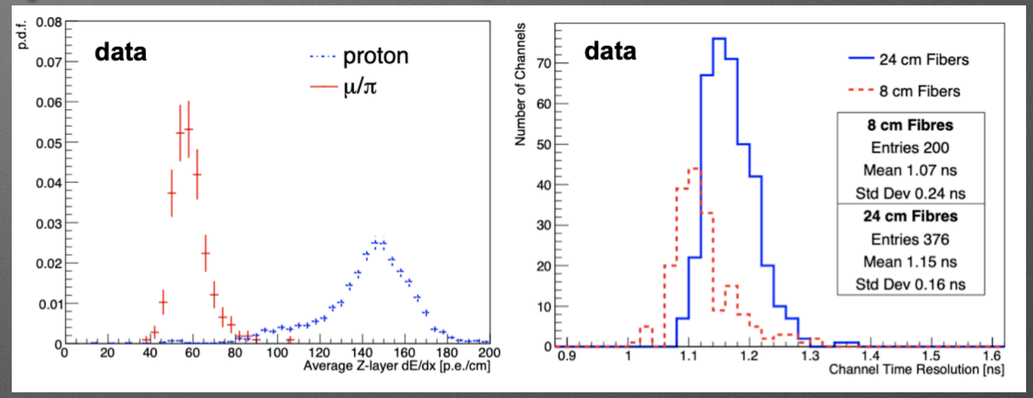
- 5 Front-End-Board prototypes have been delivered and tested → fully functional
- Further tests to evaluate full performances before mass production are on-going
- Due to shortage of electronics components we expect to receive the FPGA from INTEL by September 2022 and start the mass production immediately after that
  - All the remaining components needed for the FEB have been acquired
  - All FEB will be delivered to J-PARC in January 2023
- Optical Concentrator Board: prototypes have been received and firmware is in development
- Master clock board: design ongoing and specification document being prepared



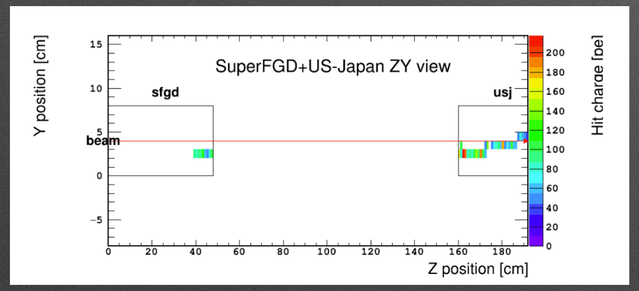


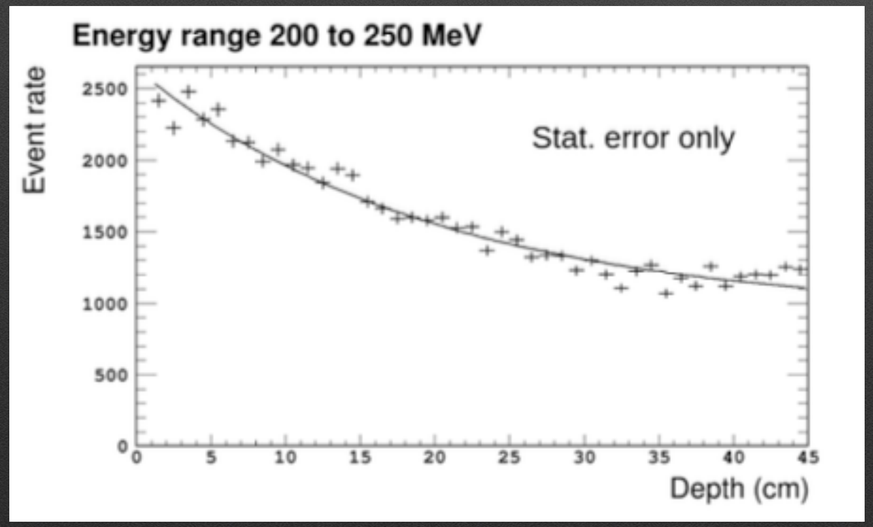
Super-FGD test beams

published Dec. 2020, 2020 JINST 15 P12003



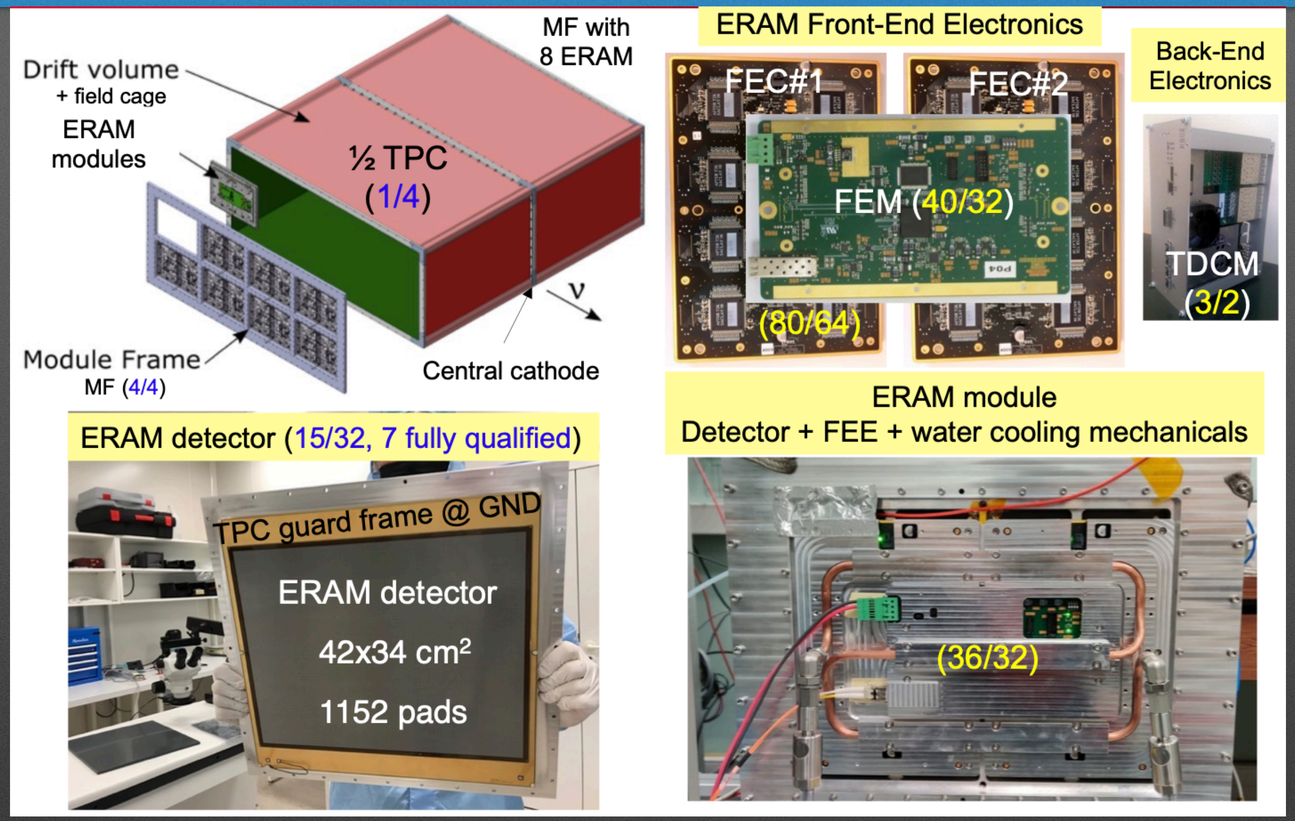
- Test beam at CERN with charged particles





- Neutron test beam at Los Alamos (LANL)
- Exposed 2 sFGD prototypes to a neutron beam with energy from 0 to 800 MeV
- Measurement of the neutron-scintillator cross-section as a function of neutron energy
- Publication expected in few months

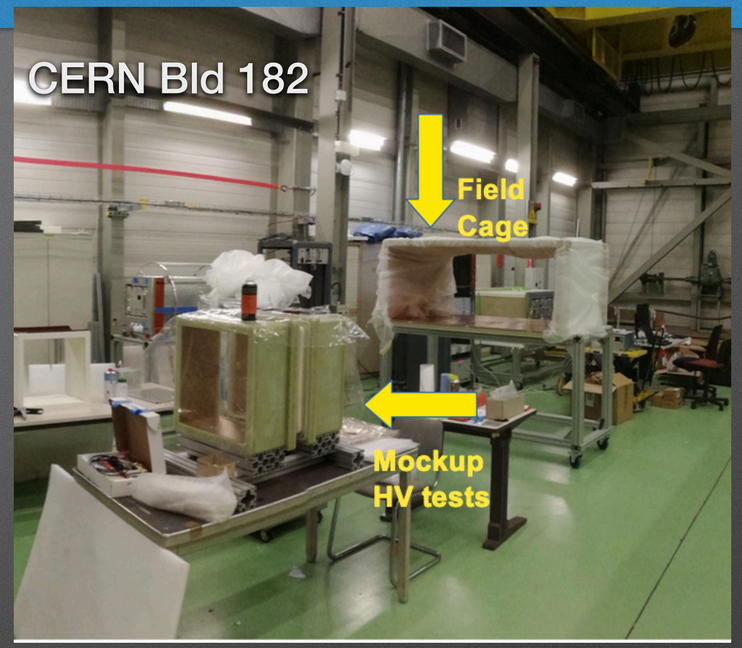
HA-TPC Production status



- All electronics and mechanics for ERAM modules have been produced
- 15 of 32 ERAM modules have been produced (8 fully qualified)
- 1 of 4 Field Cage has been produced and is being tested at CERN

First TPC Field Cage

- Delivered at CERN on February 28th
  - Originally expected in November but delays due to COVID, finding a milling company and a problem with resin leak
    - All these issues should not affect the production of the next field cages
    - Original assumption of 2 months for production and delivery to CERN is confirmed



Mechanics → OK

- Planarity of inner surfaces within tolerances ~ 100μm/m
- Parallelism and orthogonality of inner faces being analyzed ~ OK
- Planarity of flanges surfaces being analyzed ~ OK
- Parallelism of flanges wrt strips to be measured (W14)

Electrical tests → OK

Field Cage – Electrical

- Strip continuity (Field and Mirror) → OK
- R ~ 1.5Ω
- C to shielding ~ nF

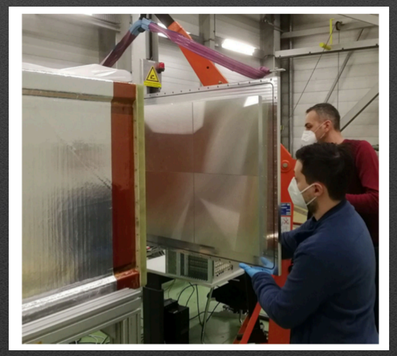
- Strip insulation (Field-Mirror) → OK
- $R_{F\text{-}M}$ ~ 100GΩ @ 300V
- only 2 F-M shorts found (200 pairs)
- → localized with V drop method → cured

- 800 x R=5.1MΩ (0.1% precision) soldered
- (A.Gambalonga – INFN LNL)

- Resistors tested @ x3 nominal divider current → OK
- (L.Lavitola – INFN NA)

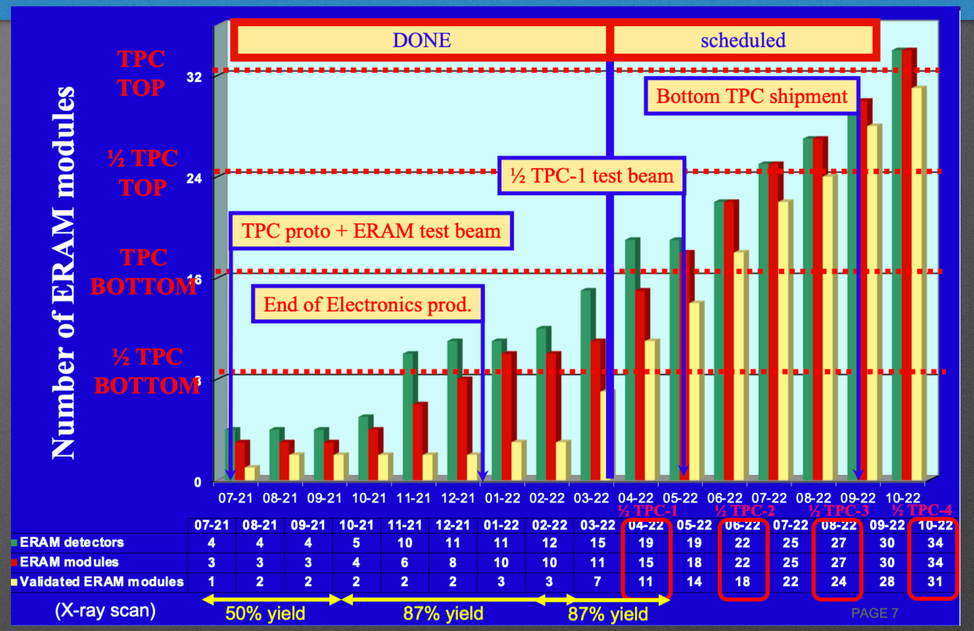
→ preliminary result for
R from F to F strip (R||R + R||R) within 2 10^{-3}

Preparation for gas leak
→ to be done this week

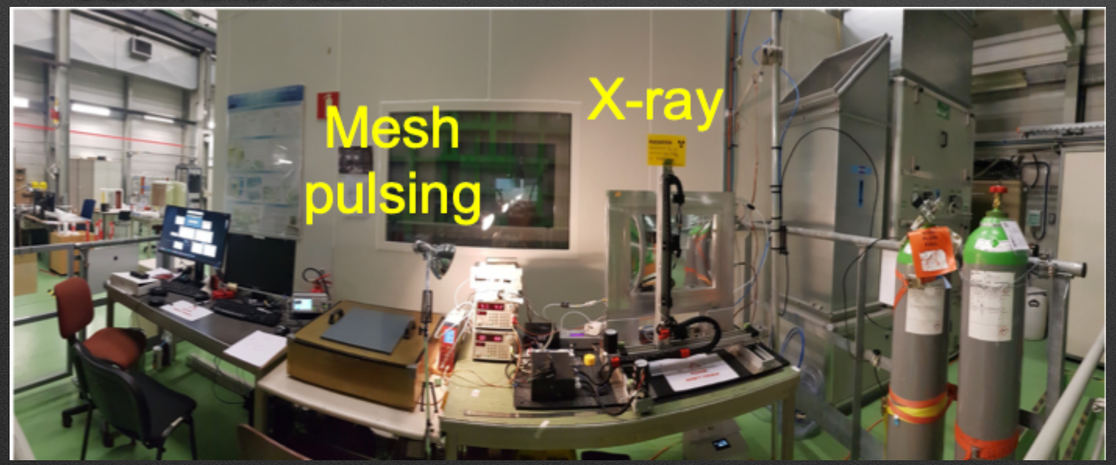


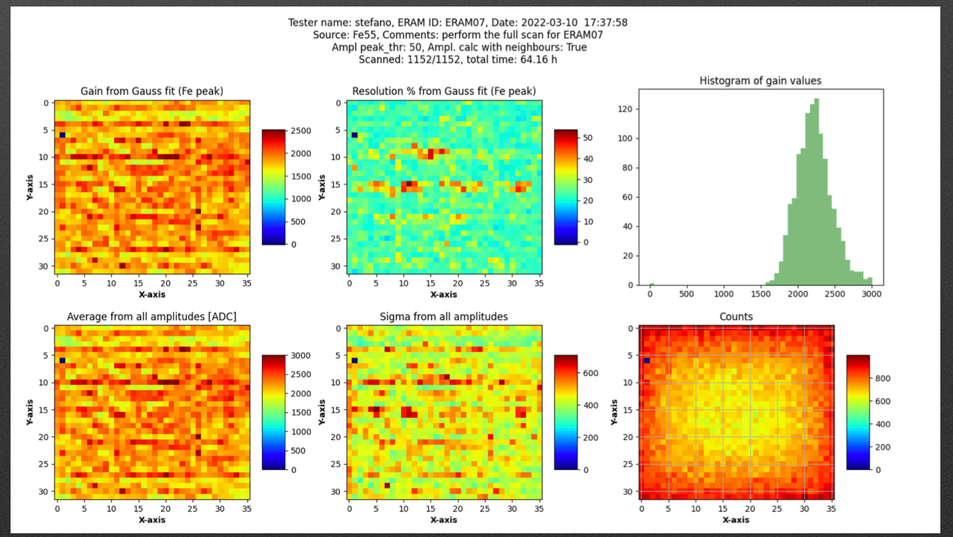
ERAM detectors

- Produced at CERN ~ 1 per week
- Qualified (~1 week)
  - Glued on the stiffener
  - Tested in an X-ray test bench using 55Fe source
- Ready to be installed on the TPC

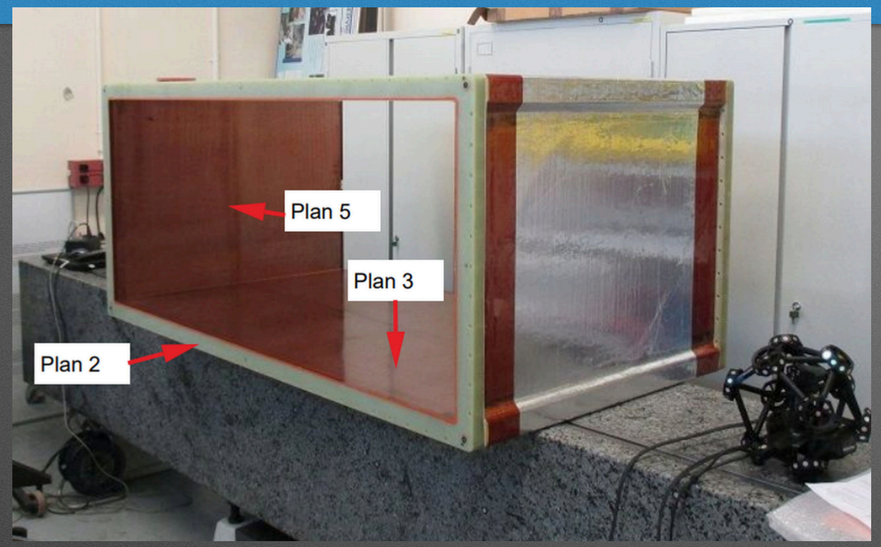


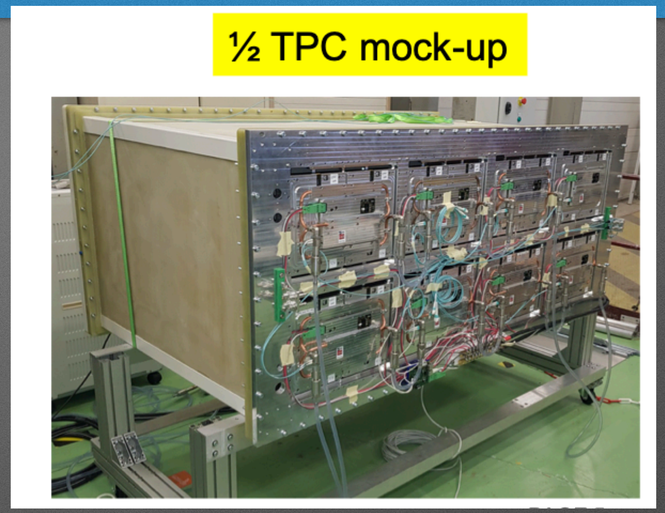
CERN Bld 182





Next CERN test beams

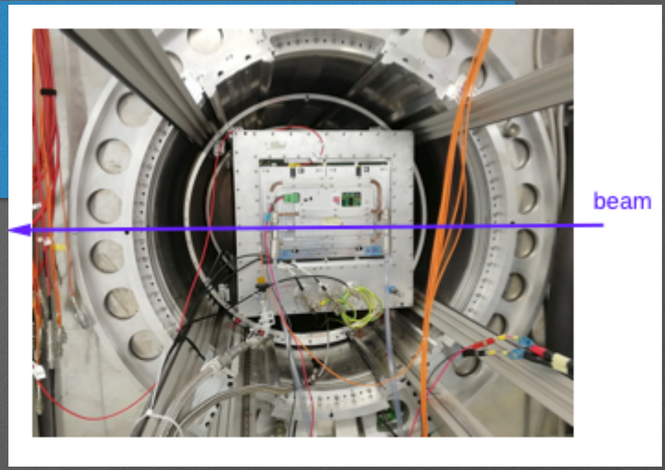


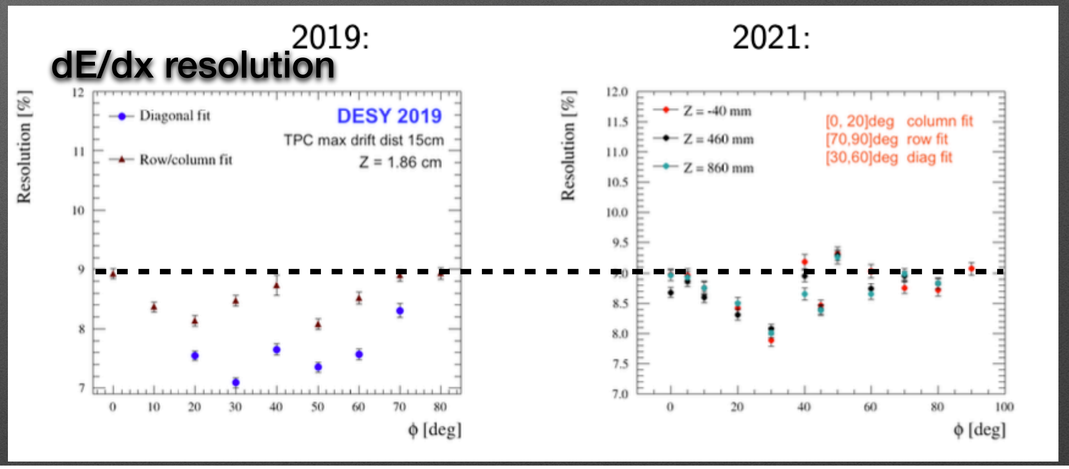


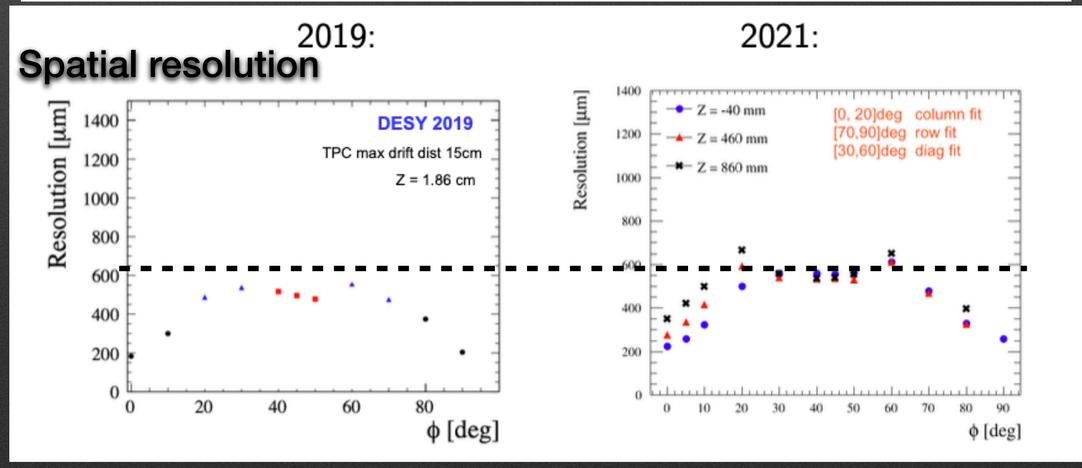
- Installation of 8 ERAM detectors and FE electronics on the TPC by the end of April
- Expect to have full TPC equipped at CERN by end of July → shipment to Japan in Fall 2022
- Second TPC will be fully equipped at CERN by end of 2022 → shipment to Japan in February 2023
- Test beam at CERN PS T9 on May 11th - 25th
  - Depending on the results and on the NP07 overall schedule we might benefit of another test beam later in 2022 or 2023
    - Eventually coupled with Super-FGD prototypes and/or TOF

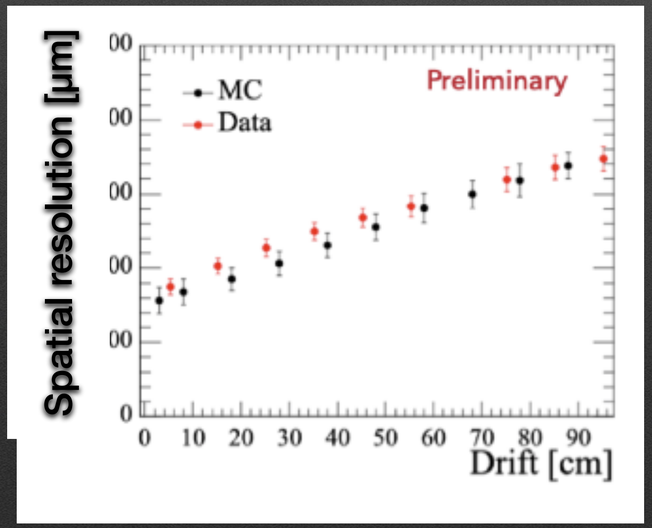
TPC Test Beam at DESY

- 2019 Test beam data have been published in Nucl.Instrum.Meth.A 1025 (2022)
- 2021 data are being analyzed
- Good performances from both test beams, good agreement with simulation
  - dE/dx resolution < 9%
  - Spatial resolution < 600 μm for all drift and angles



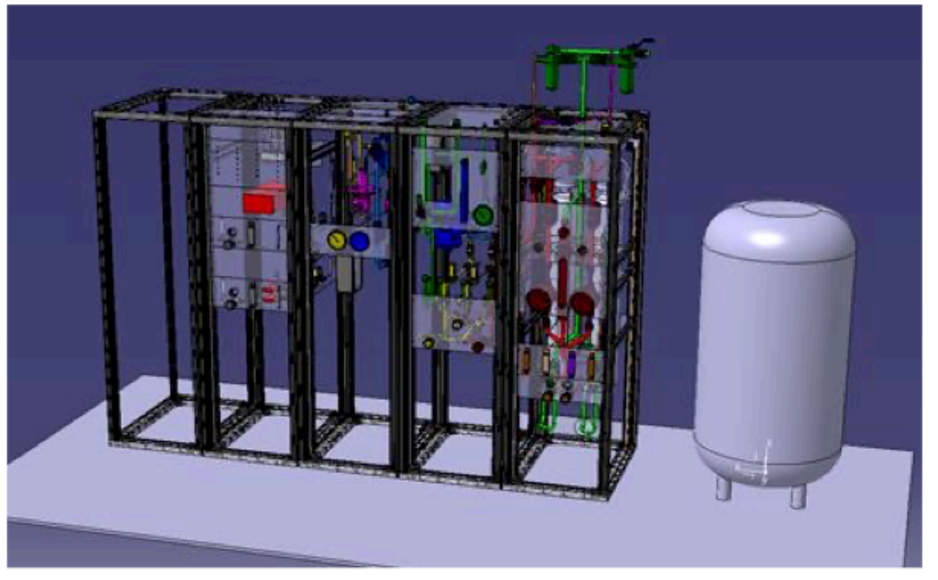




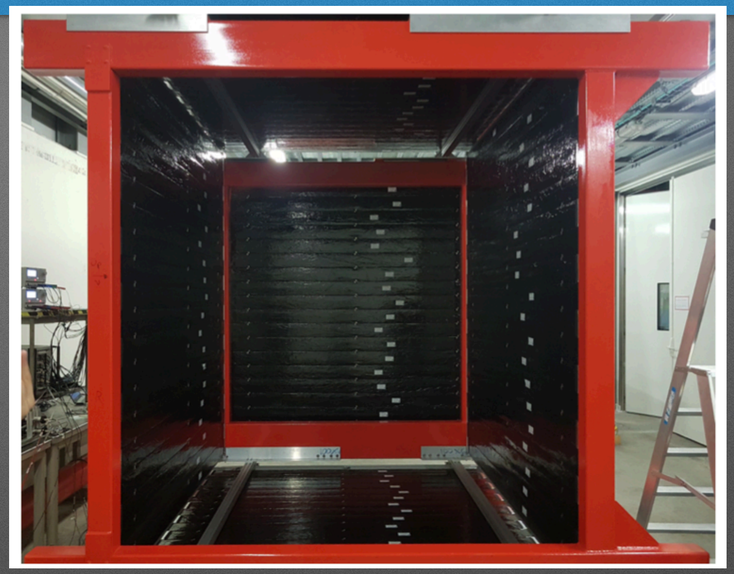


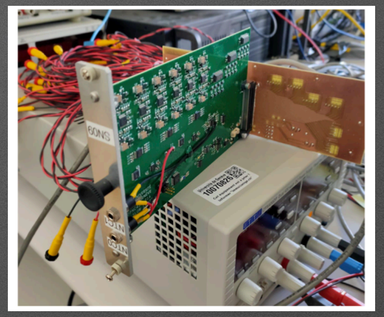
Gas System

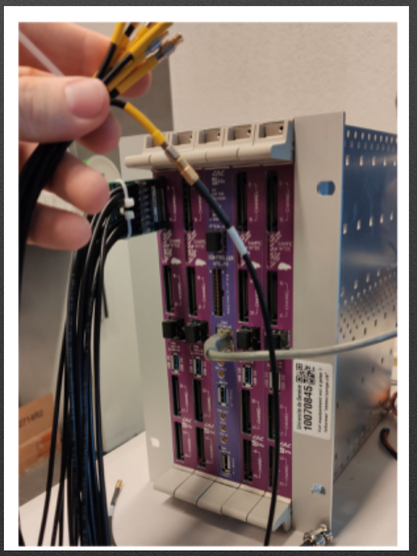
- New Gas system designed and assembled at CERN
  - Use Ar:CF_4:iC_4H_{10} (95:3:2)
  - Will replace existing gas system at J-PARC (used for new and old TPCs)
- All modules have been produced and commissioned at CERN
- Ready for shipment at J-PARC to be done together with the first TPC



TOF planes



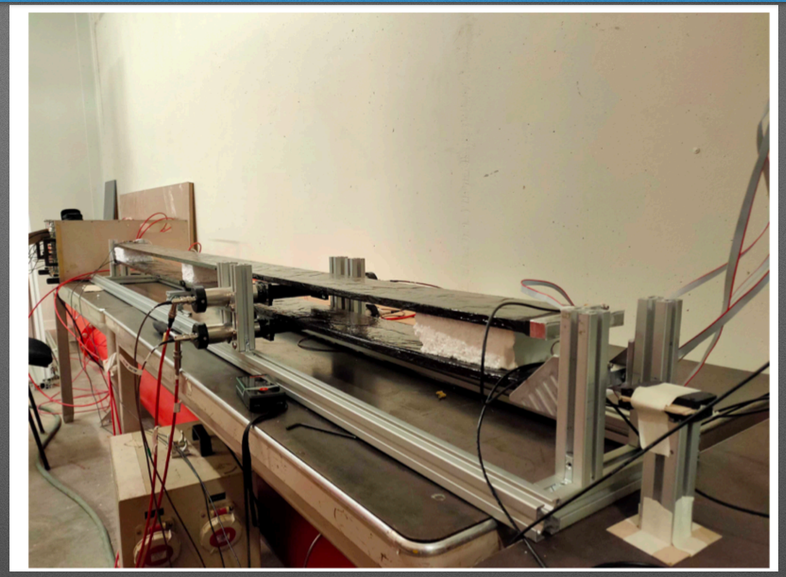


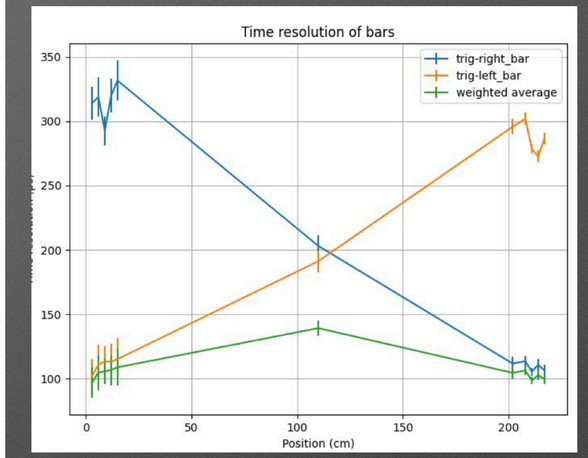


- TOF paper: JINST 17 (2022) P01016
- The 6 TOF planes have been assembled and installed in the baby Basket at CERN
- DAQ and Slow control being tested
- Working on the procedures for the shipment to Japan

TOF performances and plans

- TOF performances established with an analysis of a single bar
  - Compute time resolution → better than 150 ps





- Installation at J-PARC in two phases
  - The DS TOF plane will be the first upgrade detector to be installed
  - The remaining 5 planes will be the last, after HA-TPCs and sFGD → installation time depends on the other subdetectors

Summary

- We are working hard for the installation of the ND upgrade at J-PARC
- Installation of the first TOF plane and the first HA-TPC are planned for October 2022
- Super-FGD will be ready to be installed in the basket in mid-March 2023
  - The schedule assumes that the box, the cubes and the assembly platform will be in Japan by October 2022
    - 4 months needed for assembly of cubes in the box, installation of fibers, MPPCs, and functional tests with the electronics
- Top TPC will be at J-PARC in March 2023 ready to be installed in the basket as soon as sFGD is installed
- Remaining TOF modules and full commissioning of the upgrade will follow
- Aim to start taking data before Summer 2023