

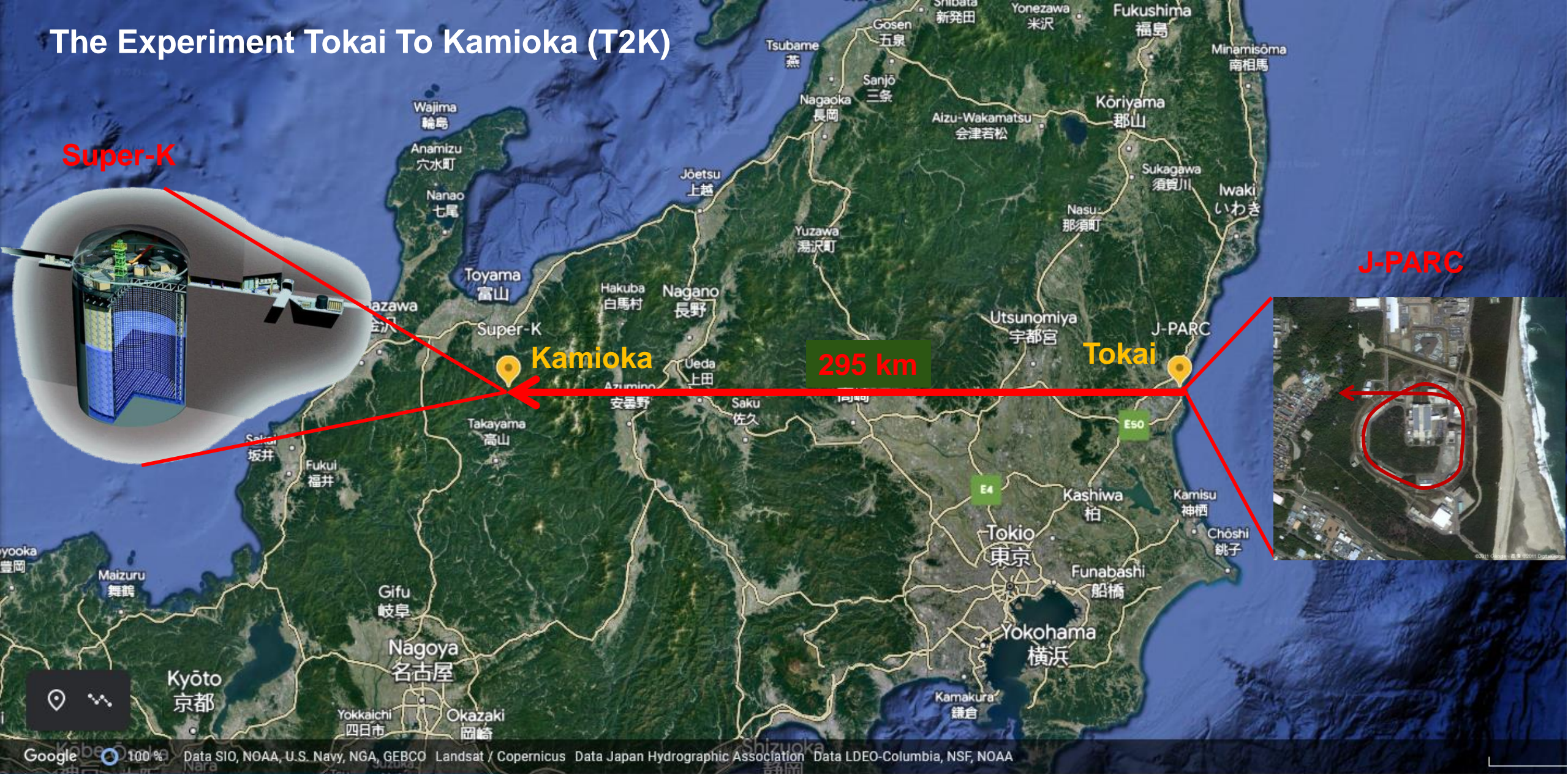


The T2K Near Detector Upgrade

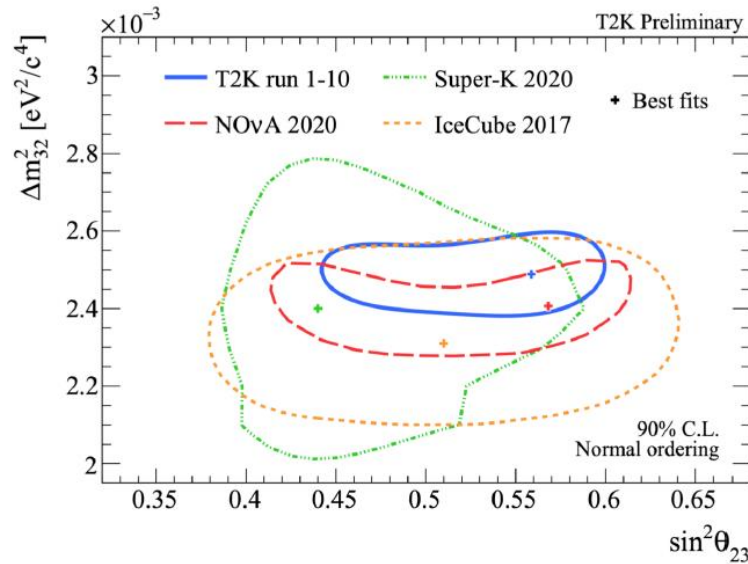
Stefan Roth
RWTH Aachen University
For the T2K Collaboration

XVIII International Conference on Topics in Astoparticle and Underground Physics (TAUP2023)
28 August 2023
Vienna, Austria

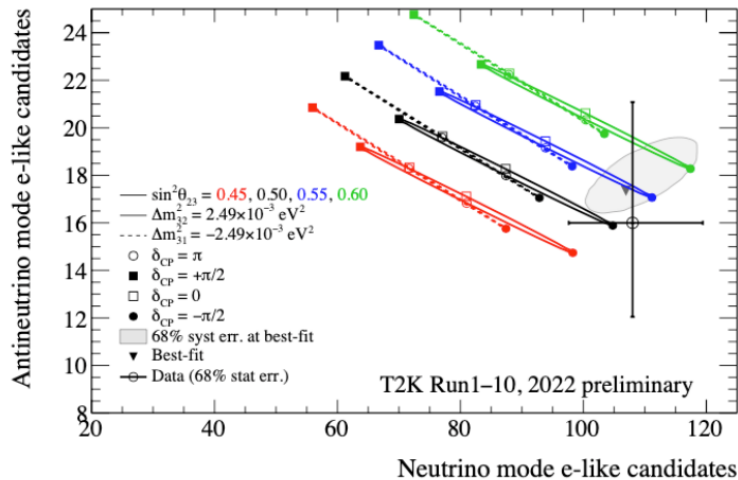
The Experiment Tokai To Kamioka (T2K)



Current Results

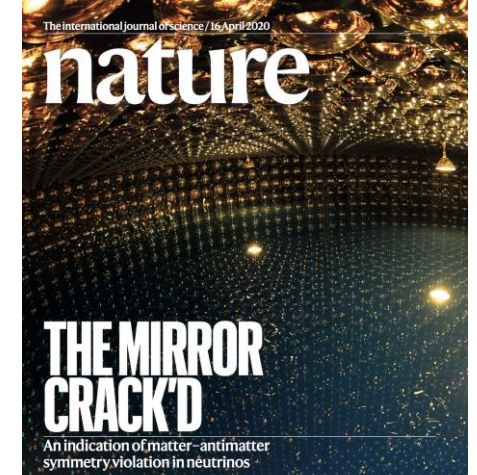


Oscillation parameters
 $\theta_{23}, \Delta m_{23}^2$
 via $\nu_\mu \rightarrow \nu_\mu$ disappearance

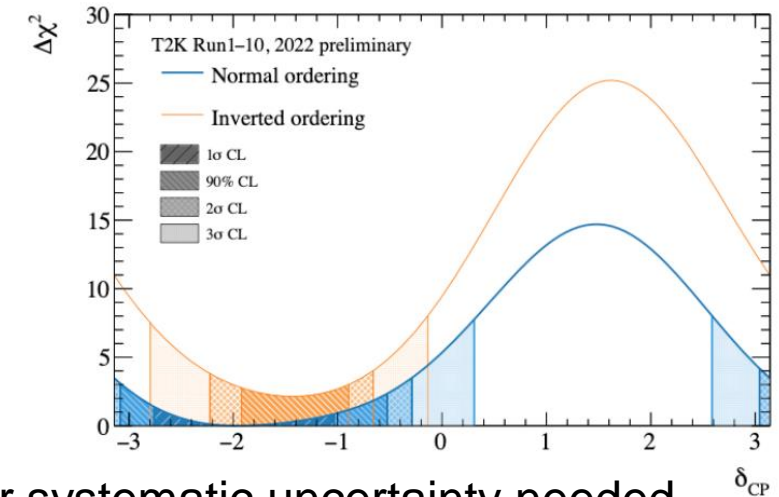


Oscillation parameters
 θ_{23}, δ_{CP}
 via $\nu_\mu \rightarrow \nu_e$ appearance

Nature 580 (2020) 7803, 339

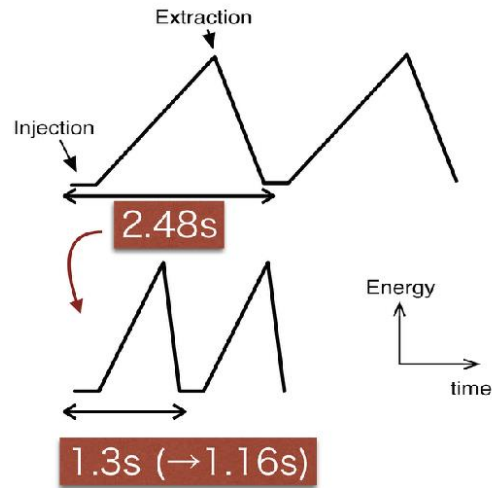


Indication of
 CP violating value of
 δ_{CP} around $-\pi/2$



More statistics and smaller systematic uncertainty needed
 → Project of Near Detector Upgrade

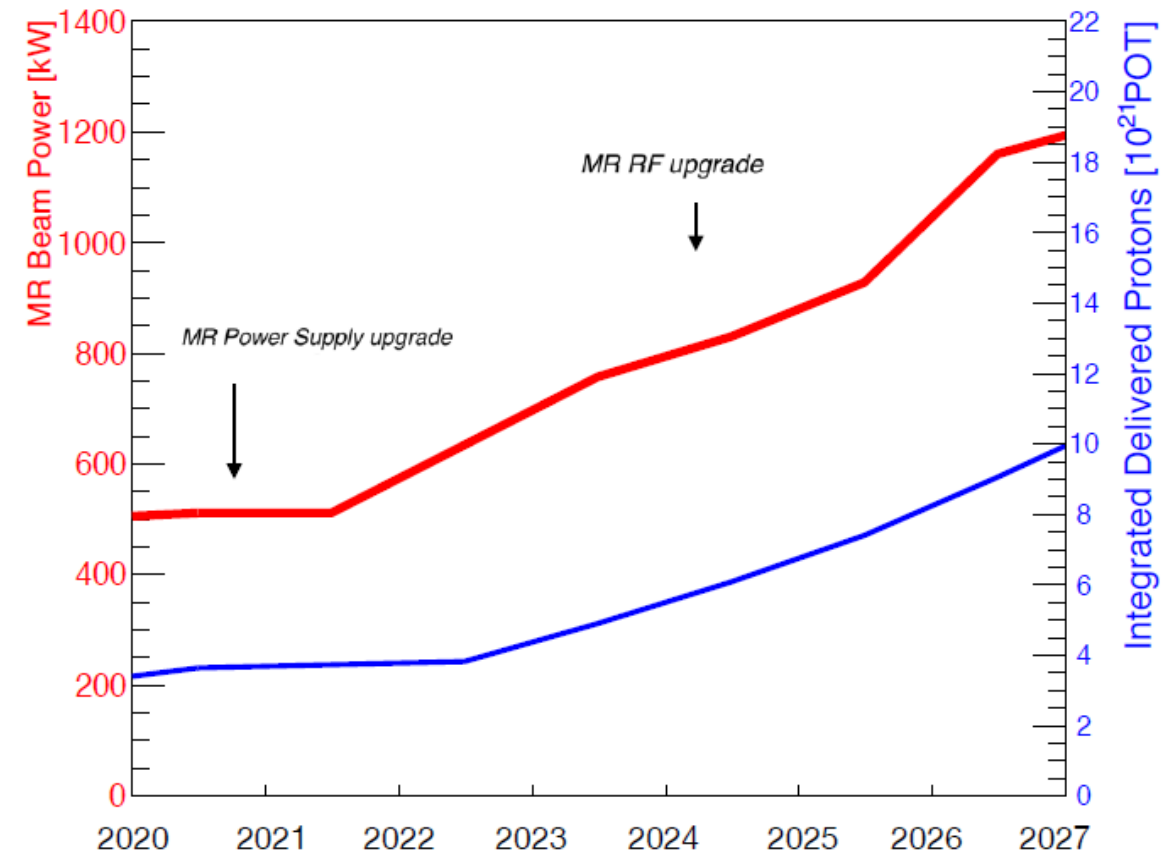
Beam Upgrade



- Increase of proton beam power above 1 MW by upgrade of main ring PS and RF
- Increase of horn current

→ More statistics needs improved systematic uncertainty

T2K Projected POT (Protons-On-Target)

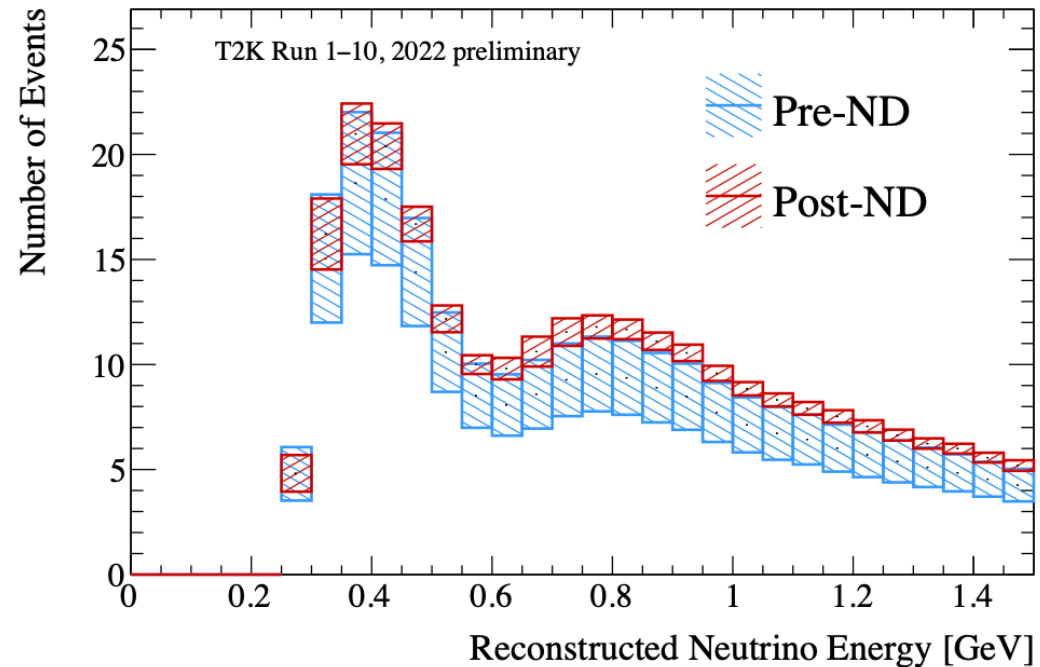


Near Detector

Systematic uncertainty is constrained by the measurements of the Near Detector

- Neutrino flux
- Neutrino spectrum
- Neutrino interaction cross sections

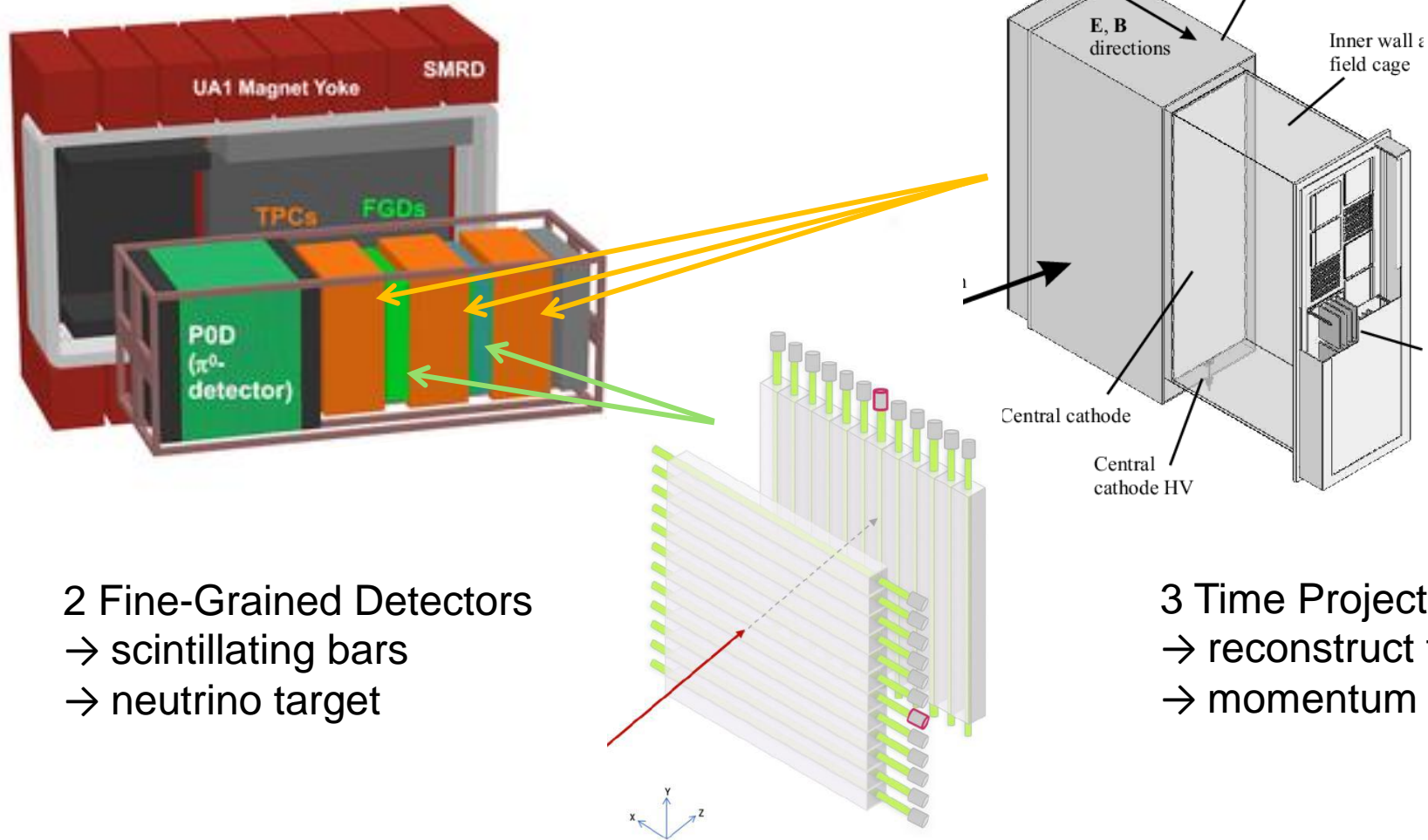
Systematic uncertainty of predicted neutrino spectrum at Super-K



Current oscillation analyses: Systematic uncertainty reduced from ~15% to ~5%

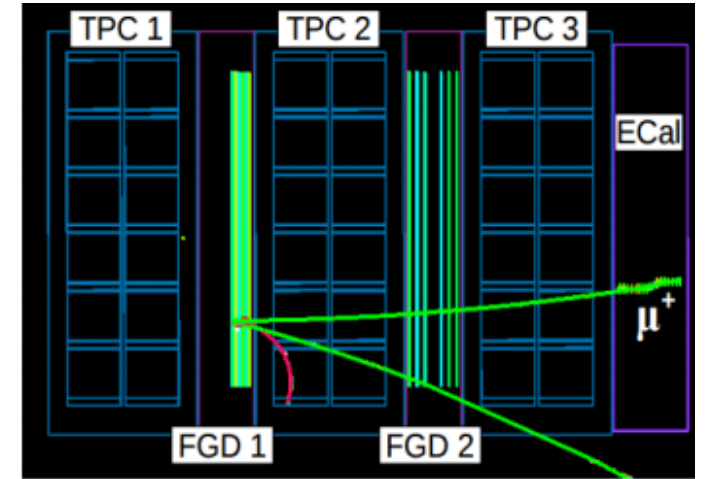
Near Detector ND280

UA1/NOMAD magnet (0.2 T field)

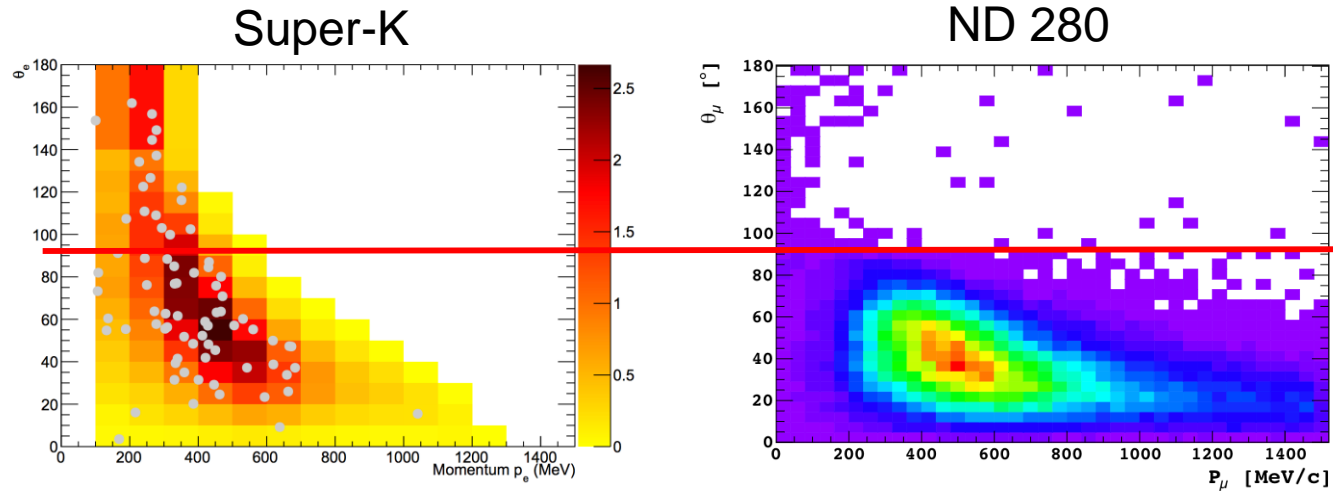


2 Fine-Grained Detectors
→ scintillating bars
→ neutrino target

3 Time Projection Chambers
→ reconstruct final state particles
→ momentum and PID

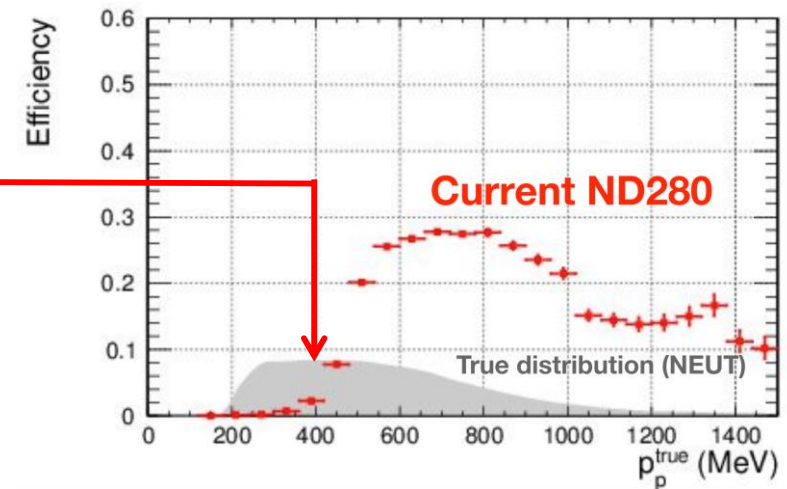


Limitations

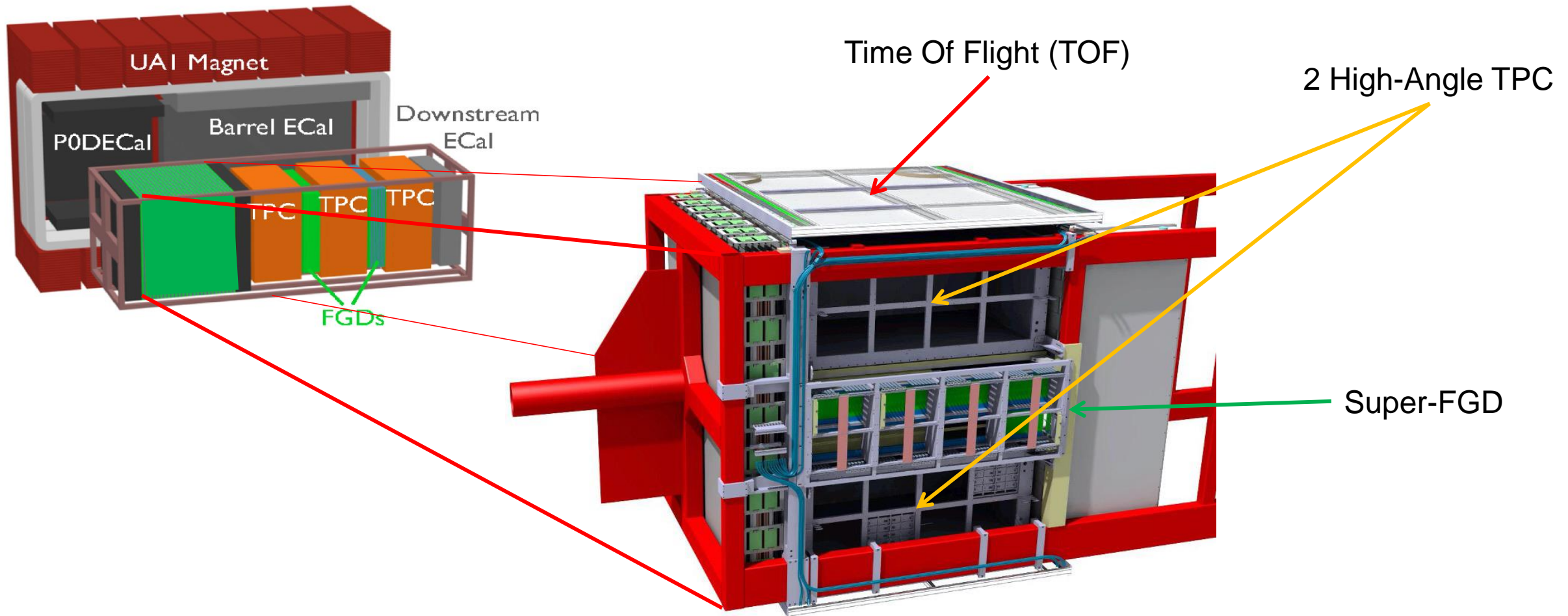


Limited angular acceptance
for final state muons at ND 280

Limited efficiency
for low energy protons



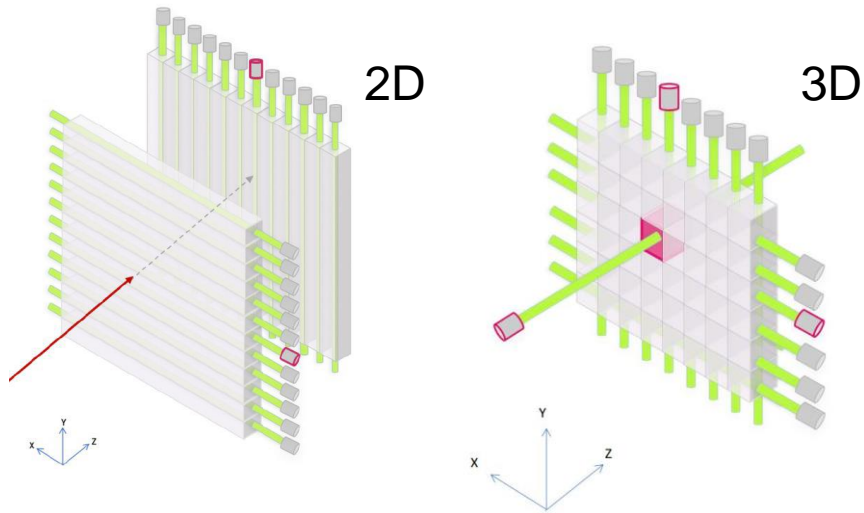
Upgrade



Technical Design Report: [arXiv:1901.03750](https://arxiv.org/abs/1901.03750)

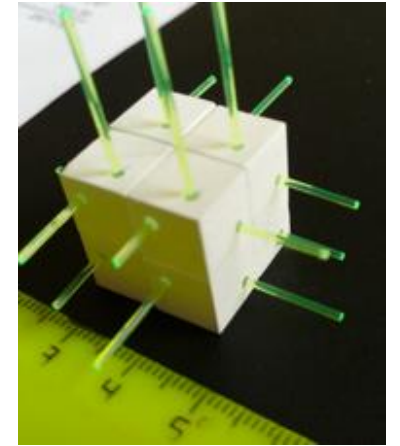
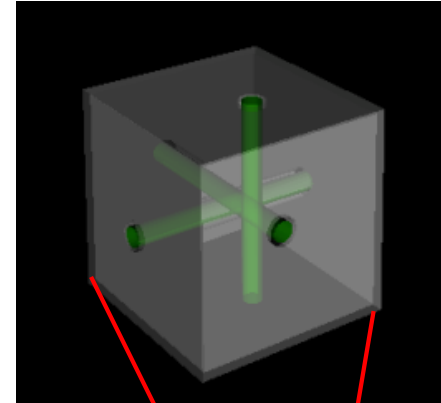
Super FGD

FGD \longrightarrow SFGD

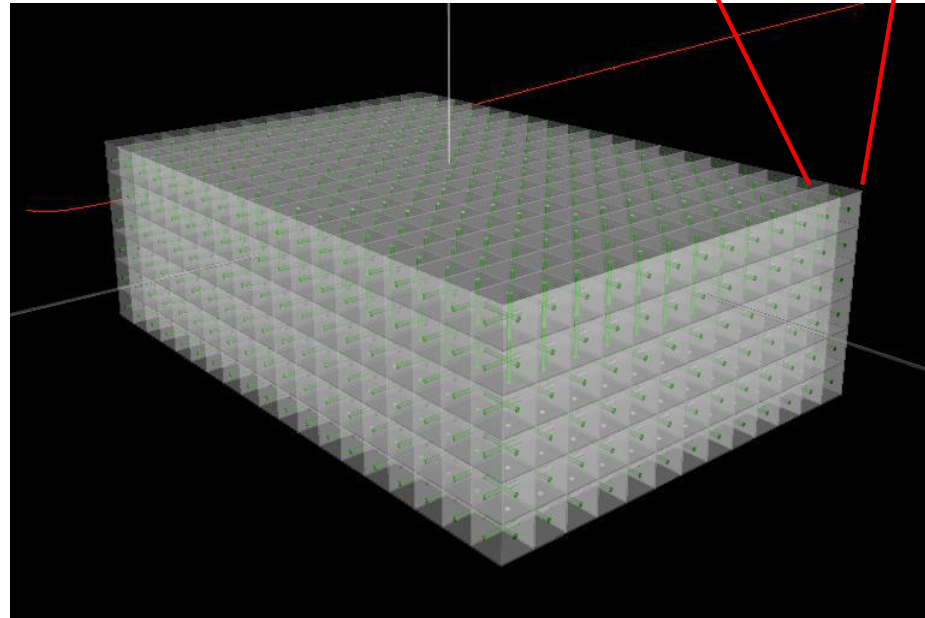


- 2×10^6 scintillator cubes with 3 holes in x, y, z direction
- Connected by WLS fibers readout with ~ 60.000 MPPC
- Active mass ~ 2 tons

$1 \times 1 \times 1 \text{ cm}^3$



$192 \times 184 \times 56 \text{ cm}^3$



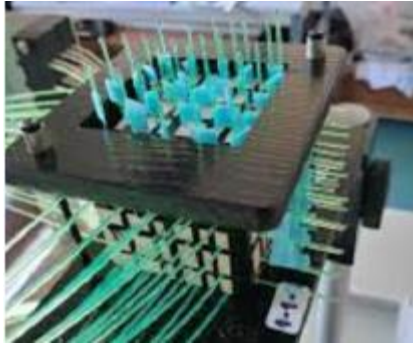
Etched surfaces for optical isolation

JINST 13 (2018) 02, P02006

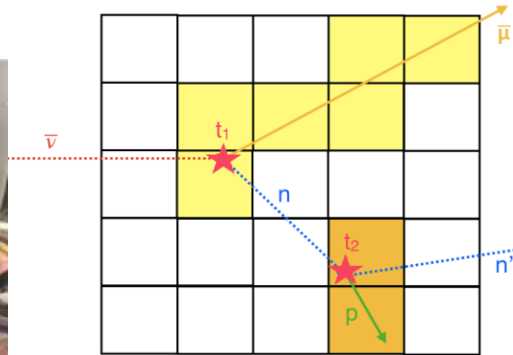
Super FGD Tests and Performance

Prototypes:

5 x 5 x 5 cubes

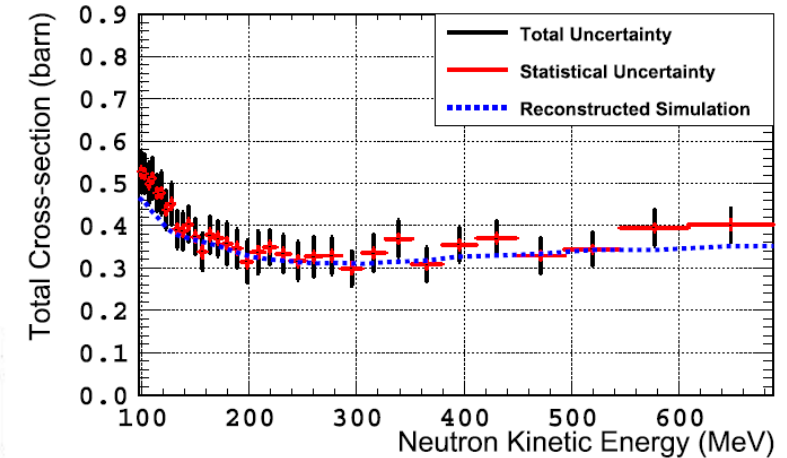


48 x 24 x 8 cubes

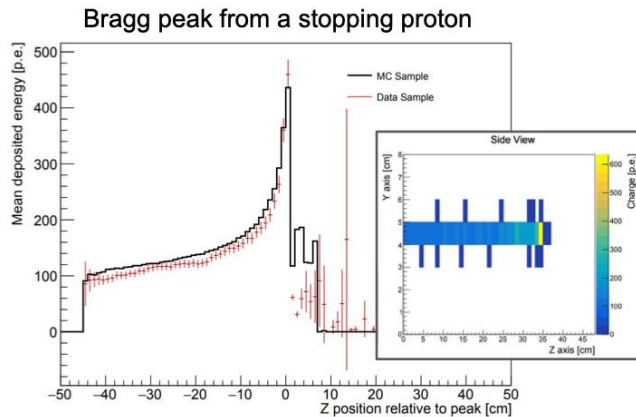


[Phys. Lett. B 840 \(2023\) 137843](#)

Neutron detection via proton recoil
Neutron energy from time-of-flight

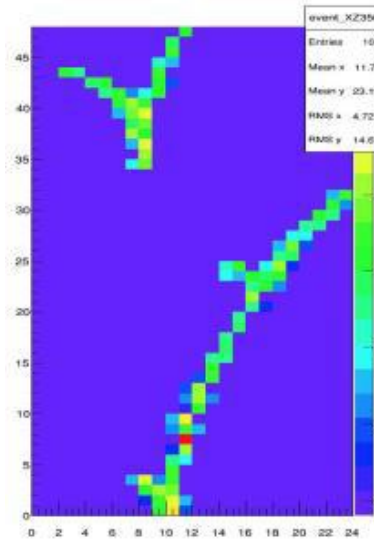
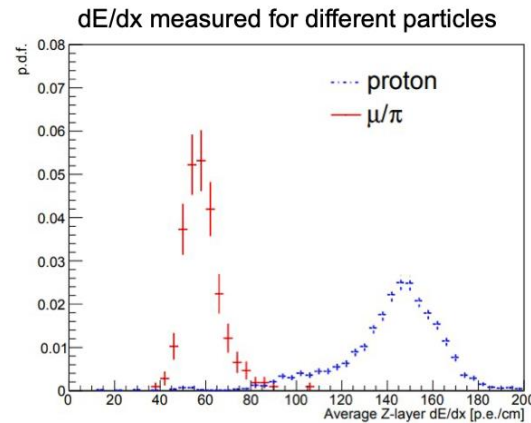


Tracking capability and
electron/photon separation

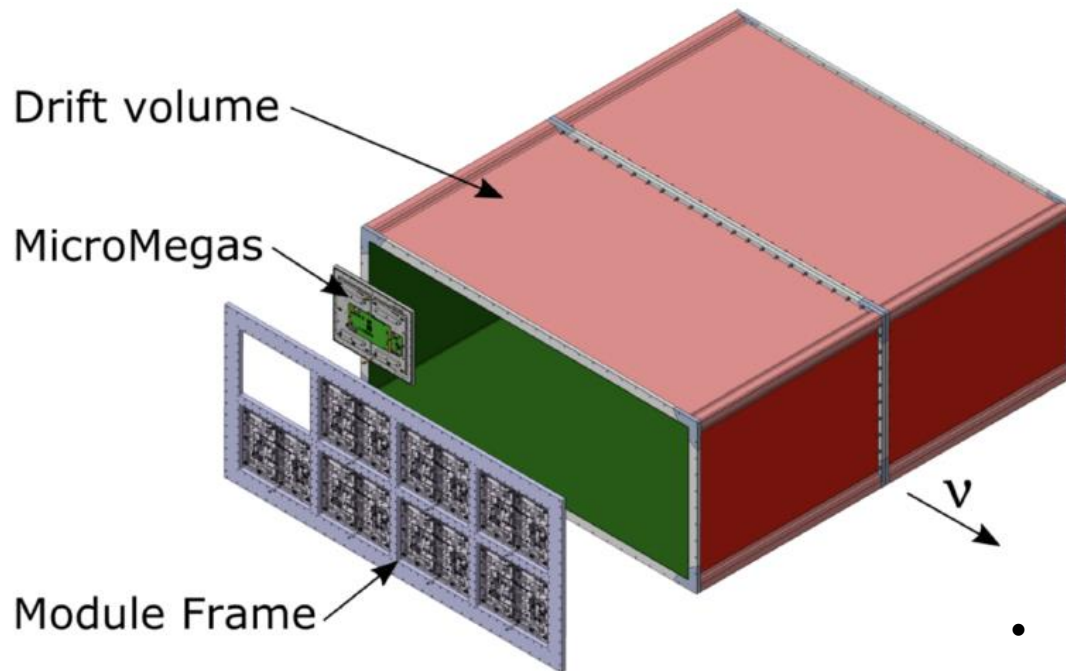


dE/dx measurement and PID

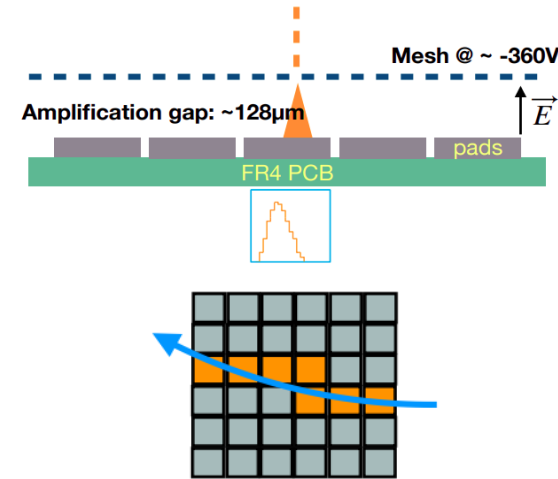
[JINST 15 P12003](#)



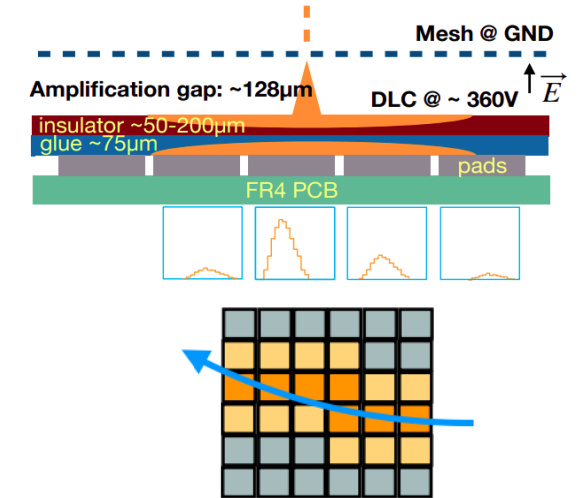
High-Angle TPC



Existing vertical TPCs:
Bulk MicroMegas

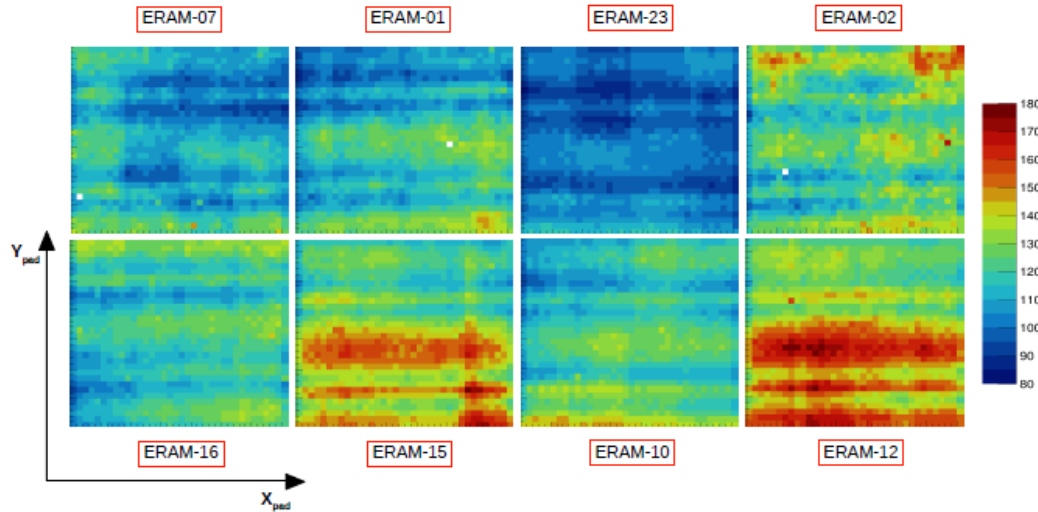


New horizontal TPCs:
Resistive Anode MicroMegas



- Ecapsulated Resistive Anode Micromegas (ERAM)
- Charge spread over several pads improves spatial resolution
- Spreading depends on RC value between adjacent pads
- Increased protection against sparks
- T2K first full-scale experiment to use this technology

High Angle TPC Tests and Performance

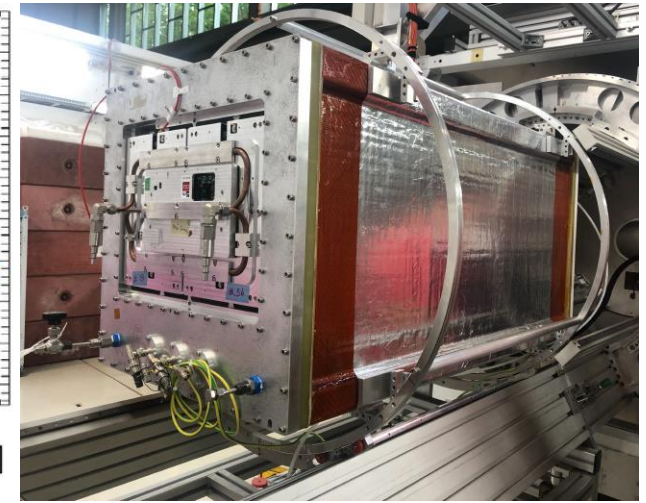
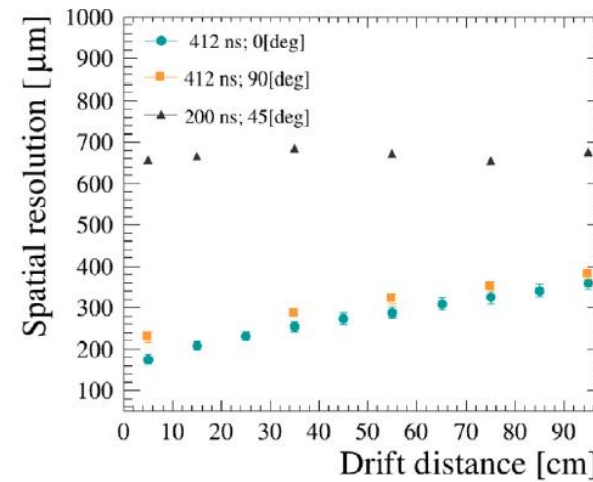
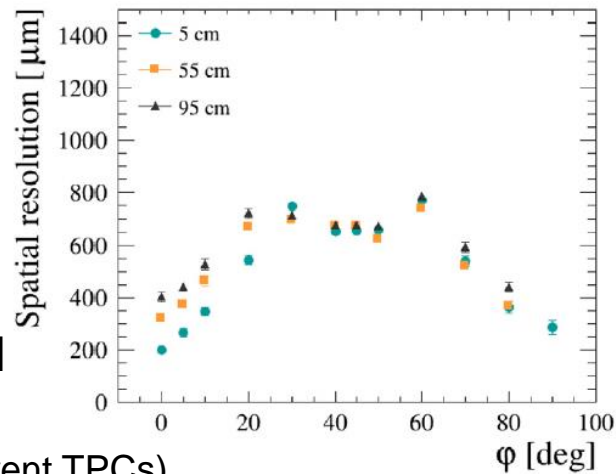


[arXiv:2303.04481](https://arxiv.org/abs/2303.04481)

MicroMegas Modules:
Calibration on X-ray test bench
using Fe-55 source

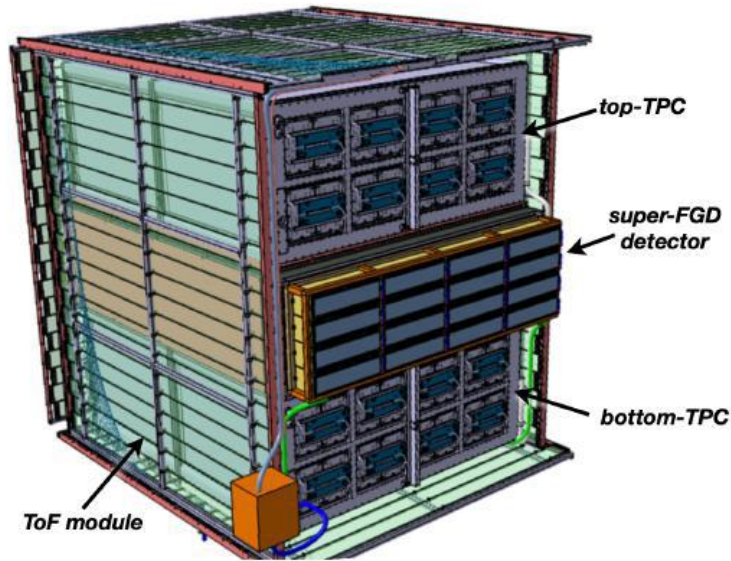
Prototype TPC:
Several Testbeams
at DESY and CERN

For horizontal tracks
improvement of spatial
resolution to **200 μm**
(compared to **600 μm** of current TPCs)

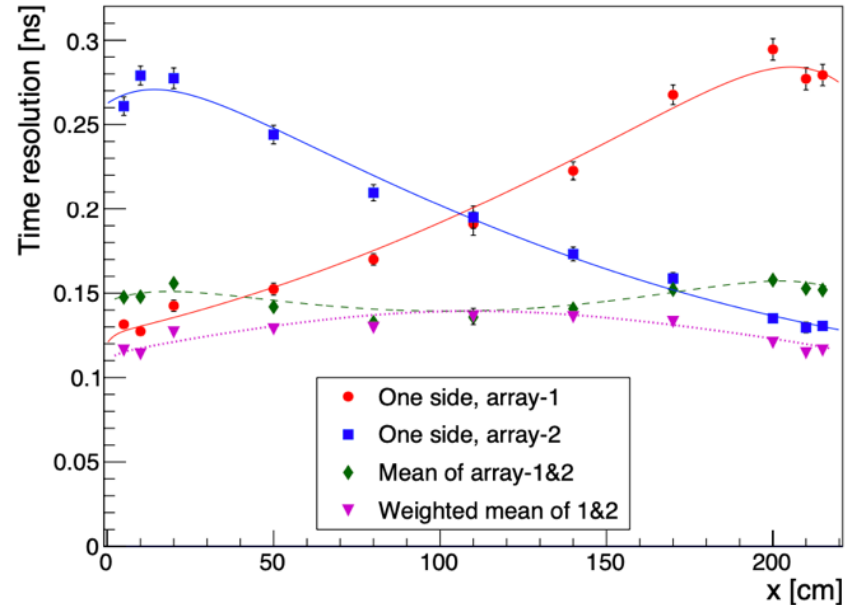


[NIM A 1025 \(2022\) 166109](#)
[NIM A 1052 \(2023\) 168248](#)

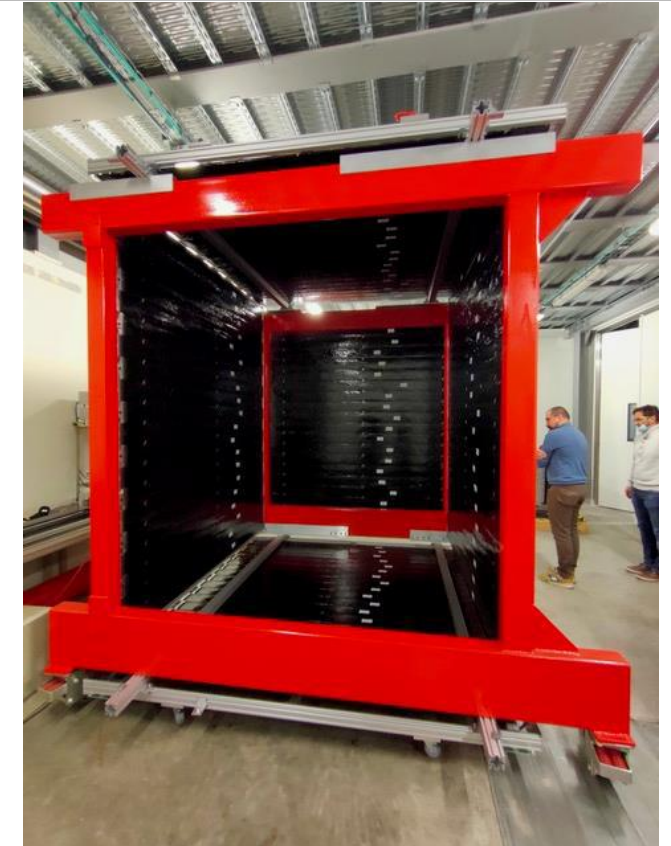
Time Of Flight (TOF) Test and Performance



150 ps timing resolution reached during commissioning at CERN



- Precise timing of final state particles
- Together with SFGD timing separate ingoing from outgoing particles
- Particle identification using timing
- Cosmic trigger for the calibration of inner detectors

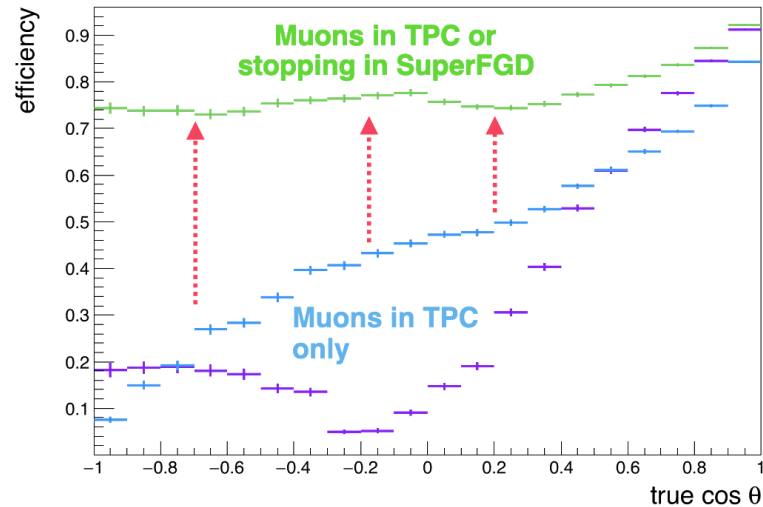


$2.3 \times 0.12 \text{ m}^2$ plastic scintillator bars read out with SiPM arrays

Improvements

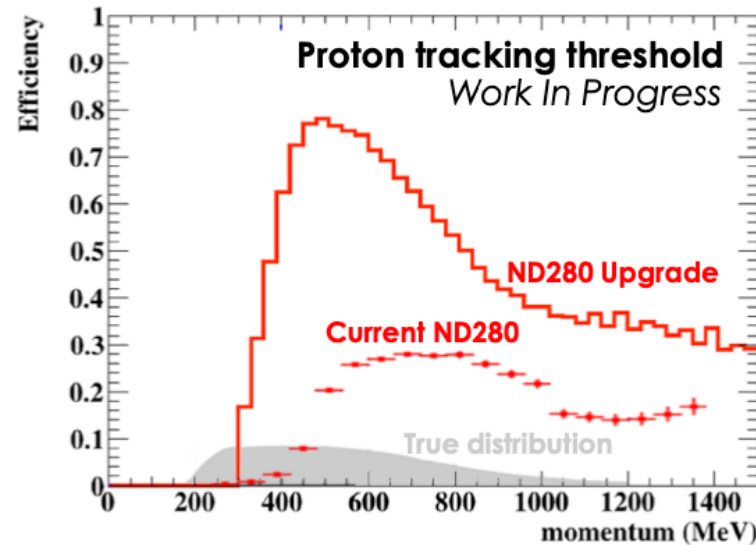
High-Angle TPCs

- high muon detection efficiency for all angles with respect to beam

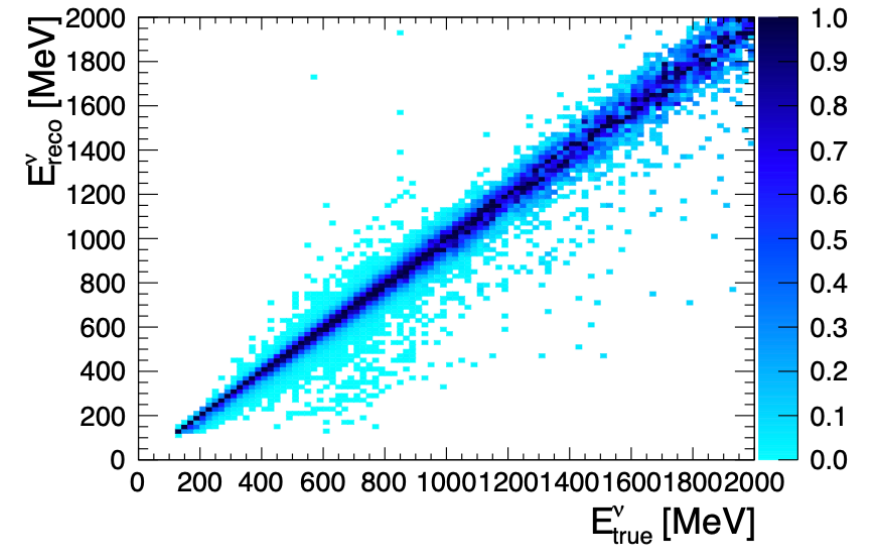


Super-FGD

- reconstruct protons at lower threshold and improved energy resolution
- PID for proton/muon and electron/photon



- fully reconstruct final state event kinematics
- especially by detecting the neutrons



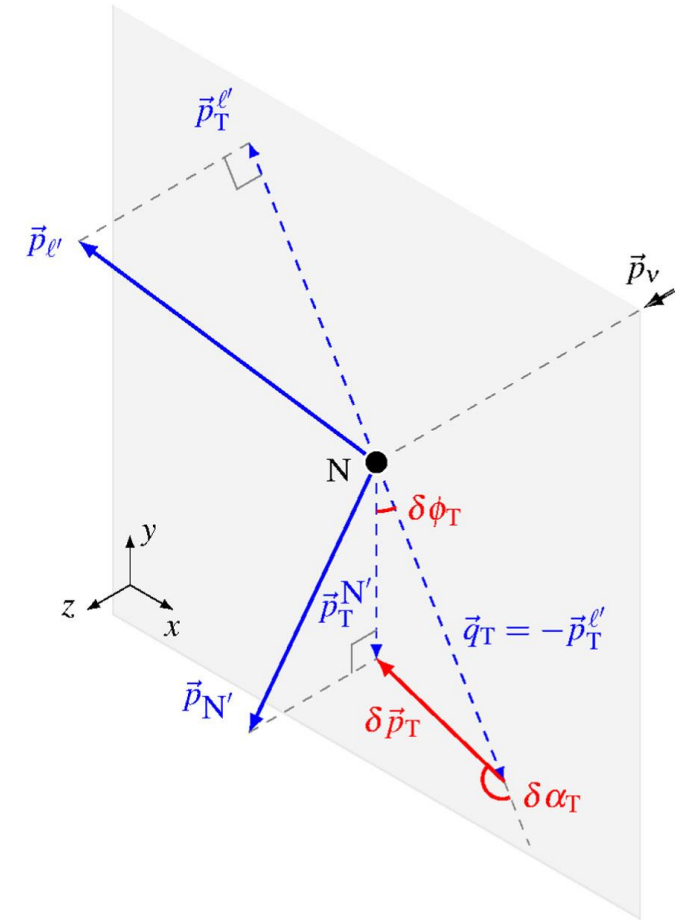
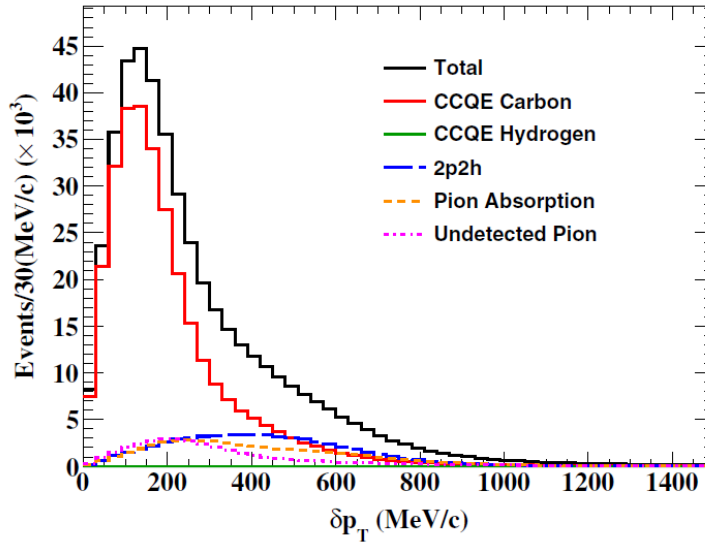
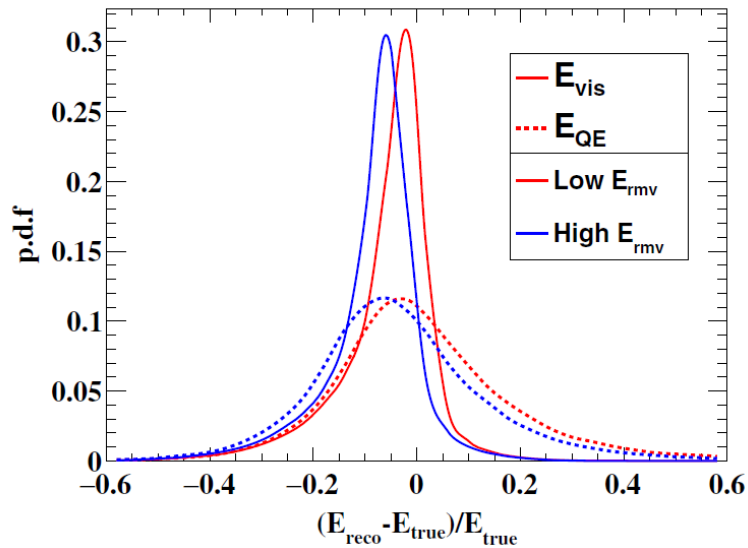
[Phys. Rev. D 101 \(2020\) 9, 092003](#)

New Capabilities

Detection and measurement of final state nucleon (proton/neutron)
→ new studies of the neutrino nucleus interaction possible

$$E_{QE} = \frac{m_p^2 - m_\mu^2 - (m_n - E_B)^2 + 2E_\mu(m_n - E_B)}{2(m_n - E_B - E_\mu + p_\mu^z)}$$

$$E_{vis} = E_\mu + T_N$$

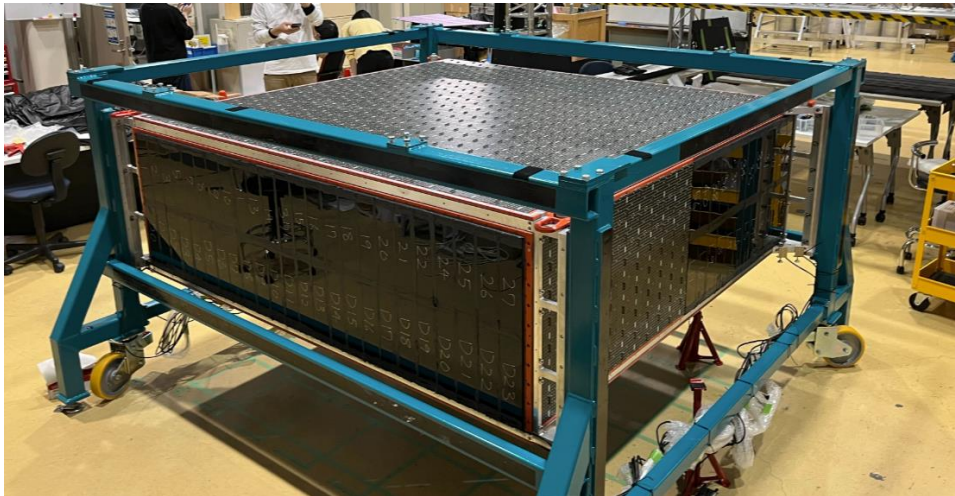


Phys. Rev. D 105, 032010

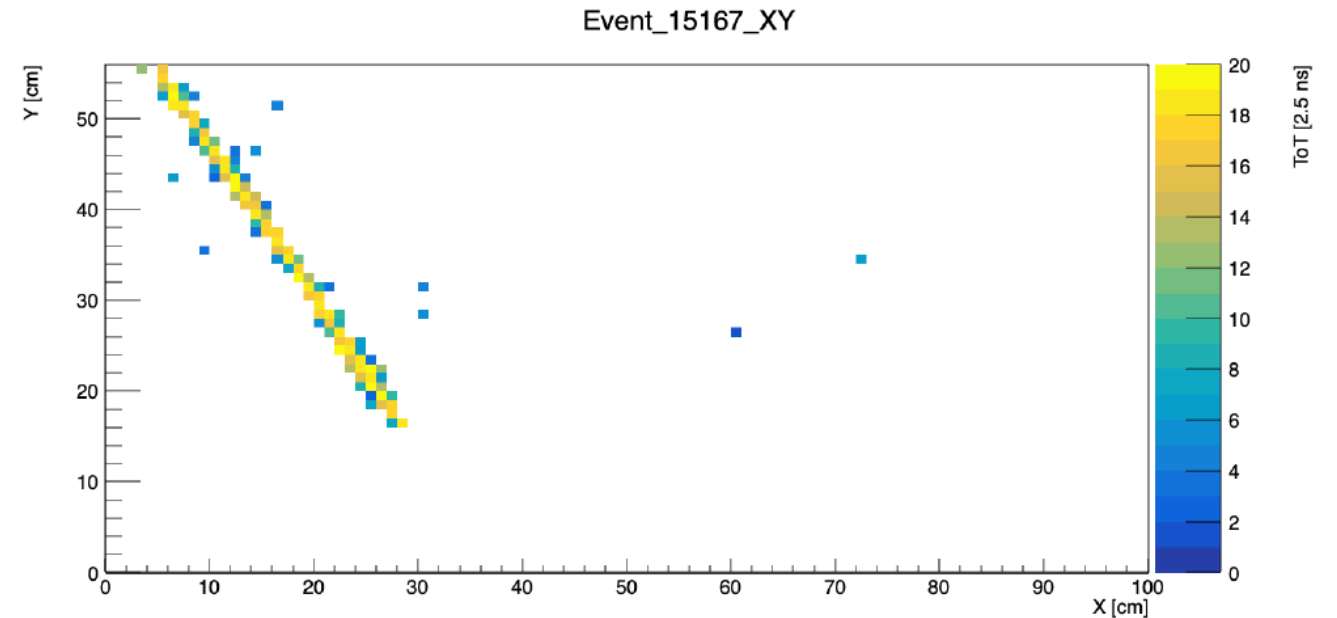
Conclusions

- T2K near detector upgrade is near to completion
→ Installation, commissioning and first data in 2023
- Reduction of systematic uncertainties
→ Improve oscillation parameters and search for CP violation
- Not only improved performance (muon angle coverage, proton efficiency)
→ Also completely new measurements possible (neutron detection)
- Studies ongoing on new capabilities of near detector
→ Understand nuclear effects in neutrino interactions

Super FGD Assembly Status

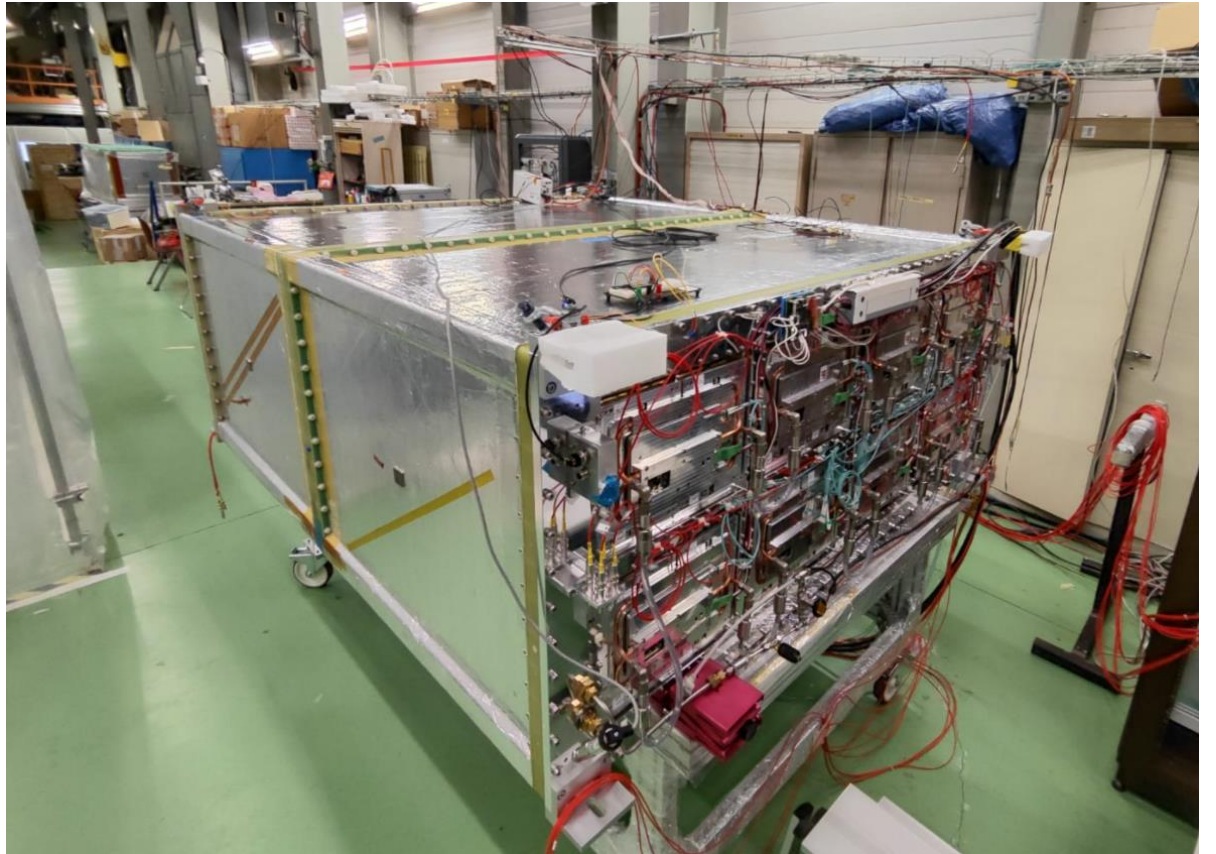
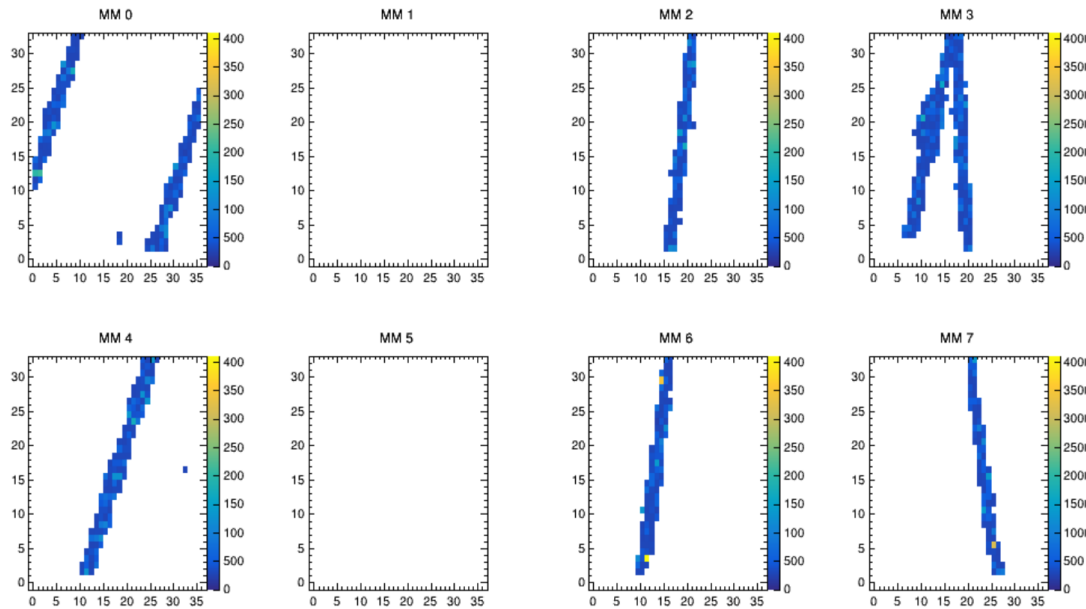


- SFGD is currently assembled at J-PARC
- Read-out electronics is currently installed
- Cosmics tracks have been observed with 10.000 channels
- Installation into the near detector in September
- Goal: Ready for first neutrino interactions in November



High Angle TPC Assembly Status

- Bottom TPC assembled at CERN in June
- Cosmic tests in July
- Shipment of first HATPC to Japan in August
- Installation of first HATPC in September
- First beam in November
- Installation of top HATPC scheduled for March 2024



Time Of Flight Assembly Status



- TOF is currently installed into near detector
- First cosmic events recorded

