The T2K Near Detector Upgrade

IRN neutrino meeting - Karlsruher Institut für Technologie

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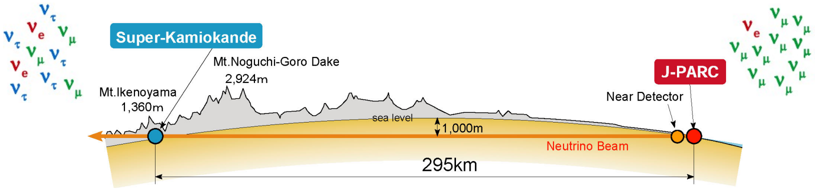
for the ND280 Upgrade Group

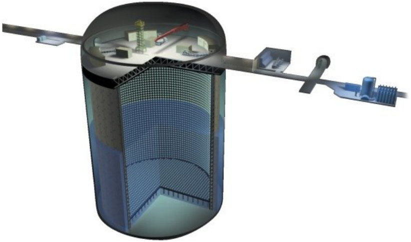
CEA-Saclay/DRF-IRFU-DPhP

2023/11/28

Tokai-to-Kamioka: T2K long-baseline experiment

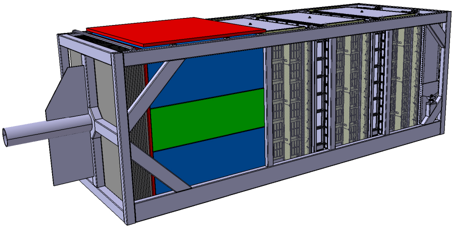


- Far detector: Water-Cherenkov Super-Kamiokande



- Upgrade planned to T2HK
  SK to be replaced by HK

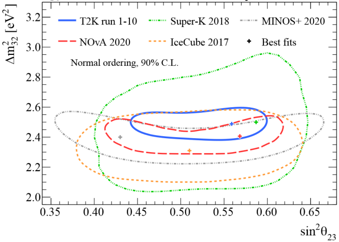
- Near detector suite: INGRID and ND280

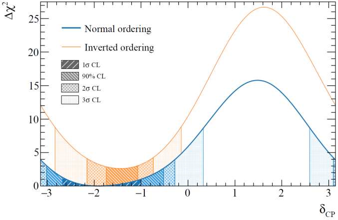


- Upgrade of ND280 ongoing
  P0D ⇒ sFGD/HA-TPCs/ToF

Current T2K results

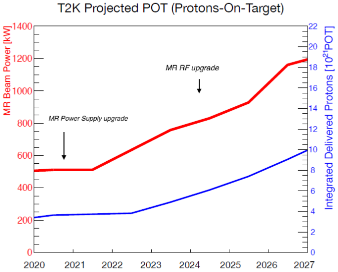
Eur. Phys. J. C 83, 782 (2023)





Nature 580, 339–344 (2020)

- **Indication** of CP-violating value of δ_{CP} around $-\dfrac{\pi}{2}$
- More statistics needed: **beam upgrade**
  Proton beam power above 1 MW
- Improved systematic uncertainty: **ND280 upgrade**

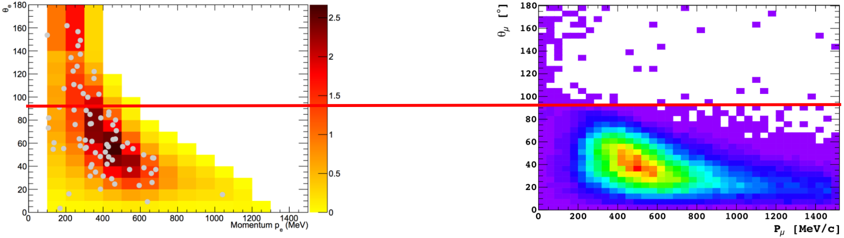


Motivation for the upgrade of ND280

arXiv:1901.03750

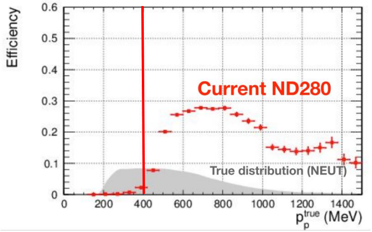
Super - Kamiokande

ND 280

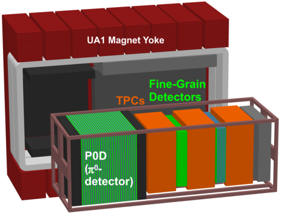


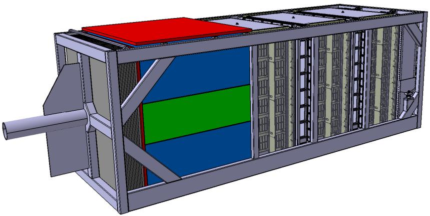
- Limited angular acceptance for final state muons at ND 280

- Limited efficiency for low energy protons



TPCs for the near detector of T2K-ND280

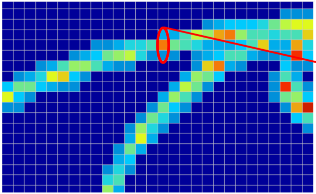


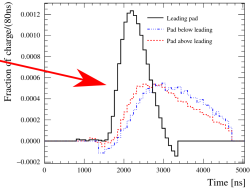


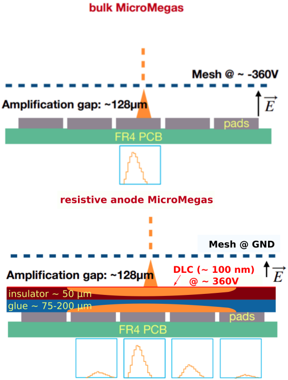
- 1998: TPC studies conducted for ILC with Micromegas R&D
- 2009: 3 vertical TPCs with 72 bulk Micromegas ($\sim$ 9 m^2)
- 2017: Encapsulated Resistive Anode bulk Micromegas (ERAM) proposed for T2K ND280-Upgrade ($\sim$ 5 m^2)
- 2023: Installation of ERAMs in ND-280

Encapsulated Resistive Anode bulk Micromegas (ERAM)

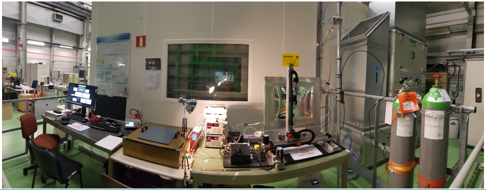
- Bulk Micromegas, with resistive Diamond-Like Carbon (spark protection)
- Charge spreading over multiple pads (ILC-TPC R&D) improves spatial resolution

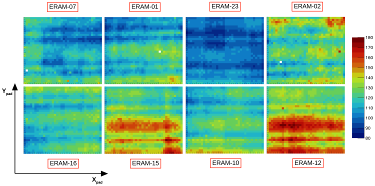






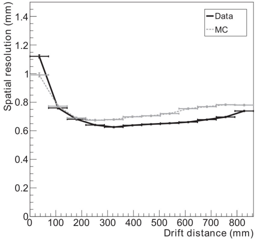
- Test bench with ^{55}Fe source to characterize all ERAMs (NIM-A.2023.168534)



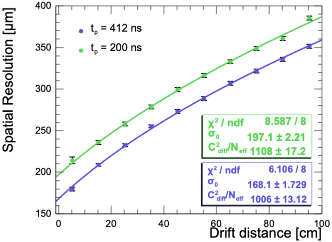


High Angle TPCs

Current ND280 TPCs

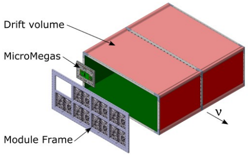


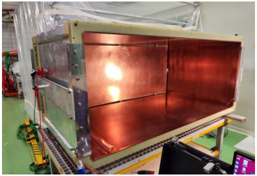
ERAM at DESY

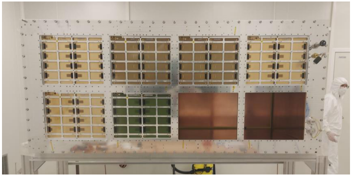


(NIM-A.2023.168248)

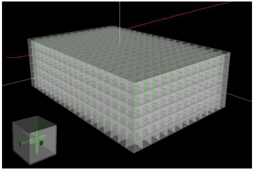
- Particle identification through dE/dx:
  Energy resolution: $\sim$ 10 % (PID: 45 % larger dE/dx for e^- than μ/π)
- Technology tested on test beams at DESY (NIM-A.2023.168248) and CERN

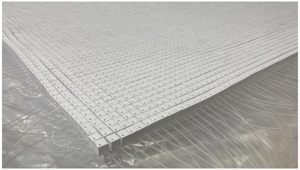




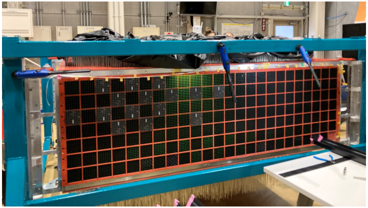


Super Fine Grained Detector





- 2×10^6 scintillator cubes
  1cm×1cm×1cm with 3 holes (x, y, z)
- WLS fibers readout with ∼ 60.000 MPPC
- Etched surfaces for optical insulation
- Active mass ∼ 2 tons



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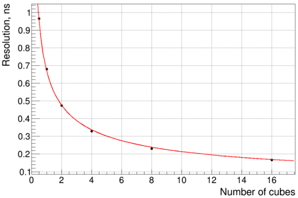
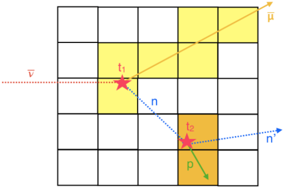
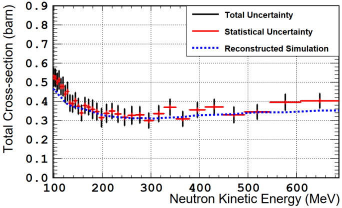
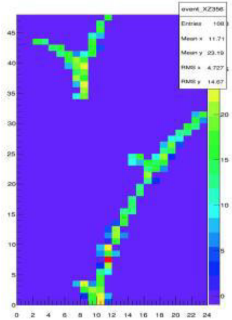






JINST 18 (2023) 01, P01012

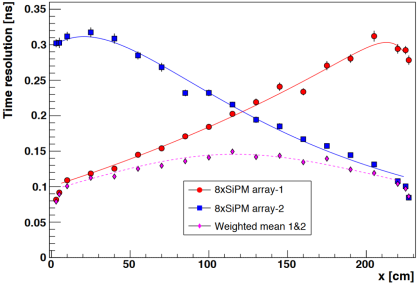
Phys. Let. B 2023 137843



- Several prototypes in lab and on beams (charged particles and neutrons)
- Time resolution measured on beam at 0.97 ns for a single channel
- Neutron detection via proton recoil and neutron energy from time-of-flight
- Tracking capability and e^-/photon separation

Time of Flight detector

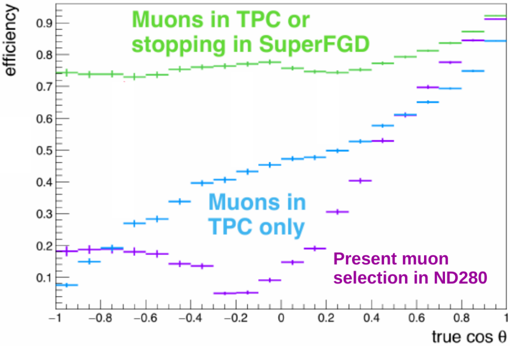
- Precise timing of final state particles
- Together with SFGD timing separate ingoing from outgoing particles
- Particle identification using timing
- Cosmic trigger for the calibration of inner detectors
- 150 ps timing resolution reached during commissioning at CERN



JPS Conf. Proc. 27, 011005 (2019)

Improvements thanks to the upgrade

- High muon detection efficiency for all angles
- Proton reconstruction:
  Lower threshold
  Improved energy resolution
- PID for proton/muon and electron/photon
- Fully reconstruct final state event kinematics especially by detecting the neutrons



CERN-SPSC-2020-008 / SPSC-SR-267

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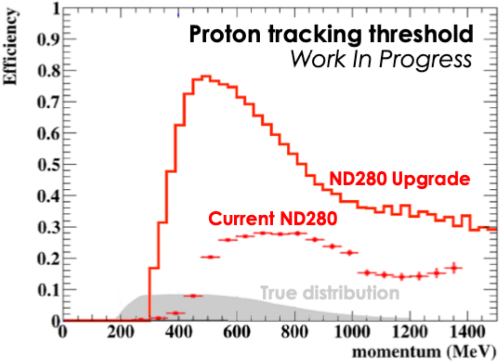

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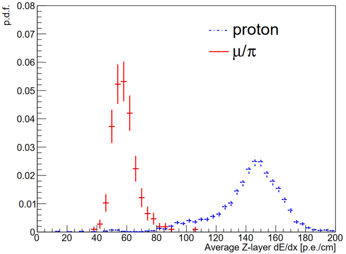
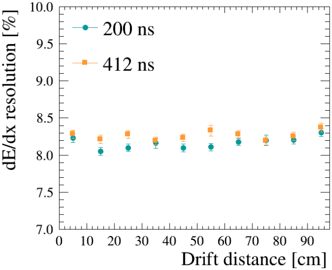
SuperFGD (JINST **15** (2020) no.12, P12003)



HA-TPC (NIM-A.2023.168248)



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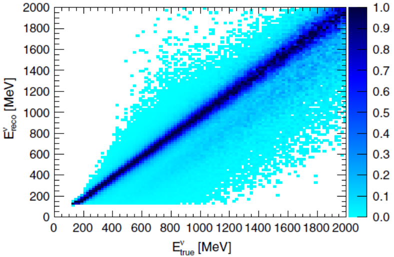
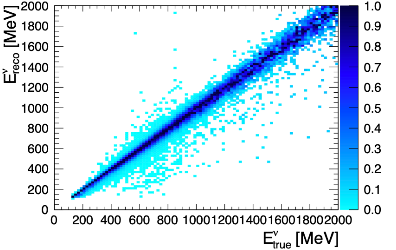
Reconstructed vs true neutrino energy

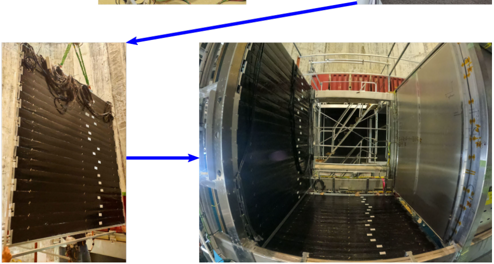


δpT and lever-arm cuts applied



PRD 101, 092003

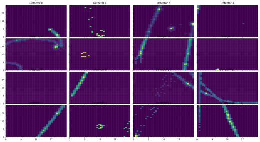
Installation of the ToF in the basket

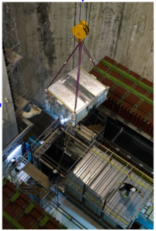


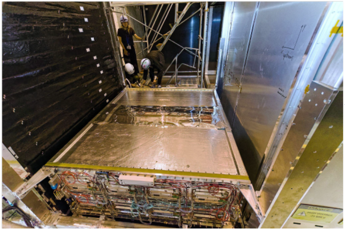
- ToF tested at CERN NP
- 8th June 2023: Shipment to JPARC
- 27th June 2023: Start commissioning on surface
- 5th July 2023: Upstream and Bottom ToF in basket
- 13th October 2023: Downstream and Top ToF in basket

Installation of the bottom HA-TPC in the basket

- 25th August 2023: delivery at JPARC
- 7th September 2023: Transport to pit building
- 8th September 2023: HA-TPC installed in basket
- 11th October 2023: First tracks using ToF trigger







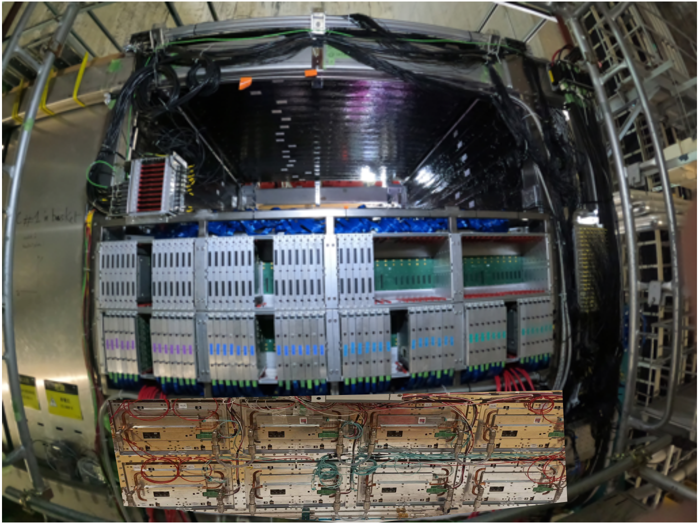
Installation of the SuperFGD in the basket

- July 2023:
  start commissioning on surface
- 11th October 2023:
  Transport to pit building
- 12th October 2023:
  Transport inside pit
- 12th October 2023:
  SFGD installed in basket

Conclusions

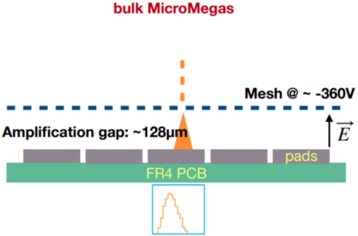
- ND280 detector upgrade is almost complete
- Commissioning ongoing and first beam data by December
- Systematic uncertainties reduction $\Rightarrow$ improve oscillation parameters and search for CP violation
- Improved performance: muon angle coverage, proton efficiency
- New measurements available: neutron detection
- Studies ongoing on new capabilities of near detector $\Rightarrow$ understand nuclear effects in neutrino interactions
- Upgrade detectors products of technological innovation (e.g. resistive Micromegas, design of the SFGD, etc.) and will be re-used (ToF in timing detector for SHiP at CERN)

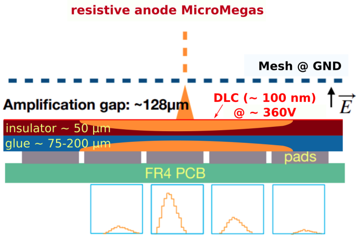
Thank you for your attention!



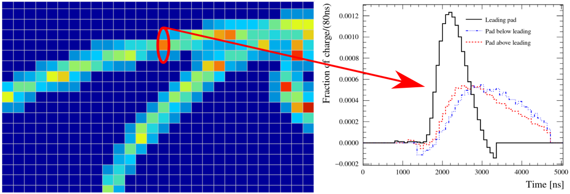
Encapsulated Resistive Anode bulk Micromegas (ERAM)

- Bulk Micromegas, mature and mastered technology
- New resistive Diamond-Like Carbon provides spark protection
- Charge spreading over multiple pads (ILC-TPC R&D) improves spatial resolution with cost-effective pad size

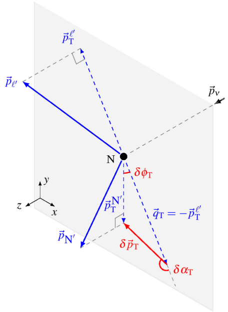




$$\sigma_r = \sqrt{\frac{2t}{RC}} \quad \begin{cases} t \approx \text{shaping time (few 100 ns)} \\ RC_{[ns/mm^2]} = \dfrac{180\, R_{[M\Omega/\blacksquare]}}{\frac{d_{[\mu m]}}{175}} \end{cases}$$



Cuts on δp_t and lever arm for neutrons



PRD 101, 092003