T2K ND280 Upgrade Status

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NNN23, Napoli

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Contents

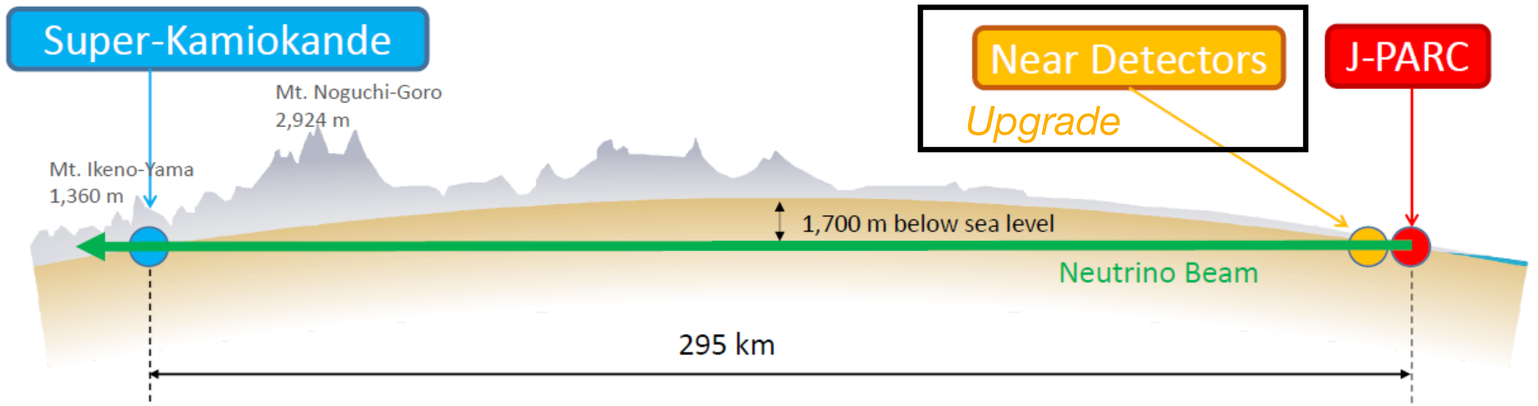
- **T2K ND280 upgrade detectors.**
- **Towards physics: neutrino event reconstruction and selection developments in T2K ND280 upgrade.**

Contents

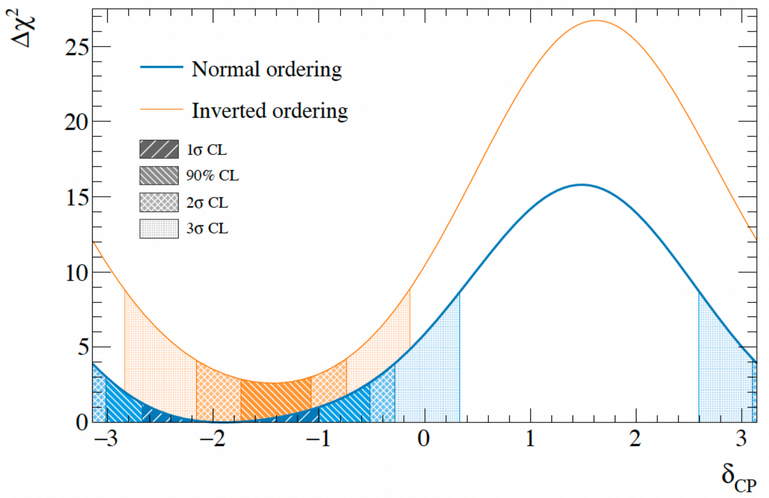
- **T2K ND280 upgrade detectors.**
- Towards physics: neutrino event reconstruction and selection developments in T2K ND280 upgrade.

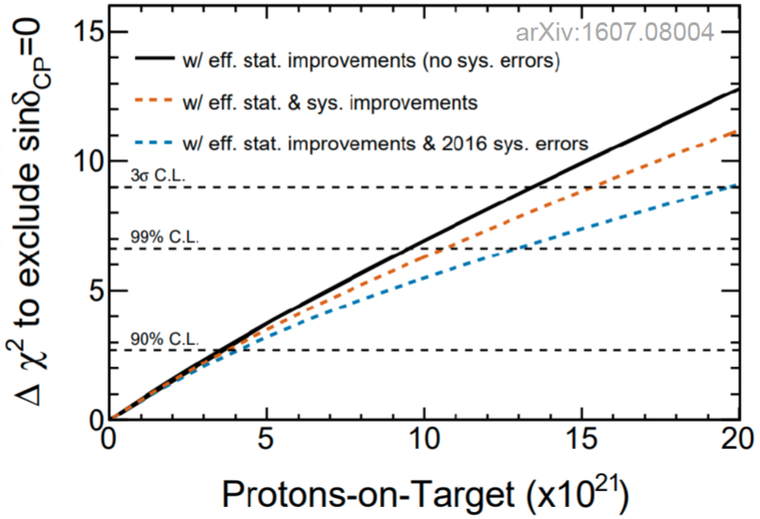
The T2K Experiment

- Tokai-to-Kamioka (T2K) is a long baseline accelerator neutrino experiment located in Japan.
- One of its major goals is to measure CP violation phase δ_{CP}, through measuring neutrino oscillation probability from ν_μ ($\bar{\nu}_\mu$) to ν_e ($\bar{\nu}_e$).
- $\sin\delta_{CP} = 0$ rejected with 90% C.L.
- Towards 3σ sensitivity, we need more protons on target (~ 1.5×10^{22}) and lower systematic uncertainties (< 4%).
- Introduce near detector upgrade to increase statistics and reduce systematic uncertainties.

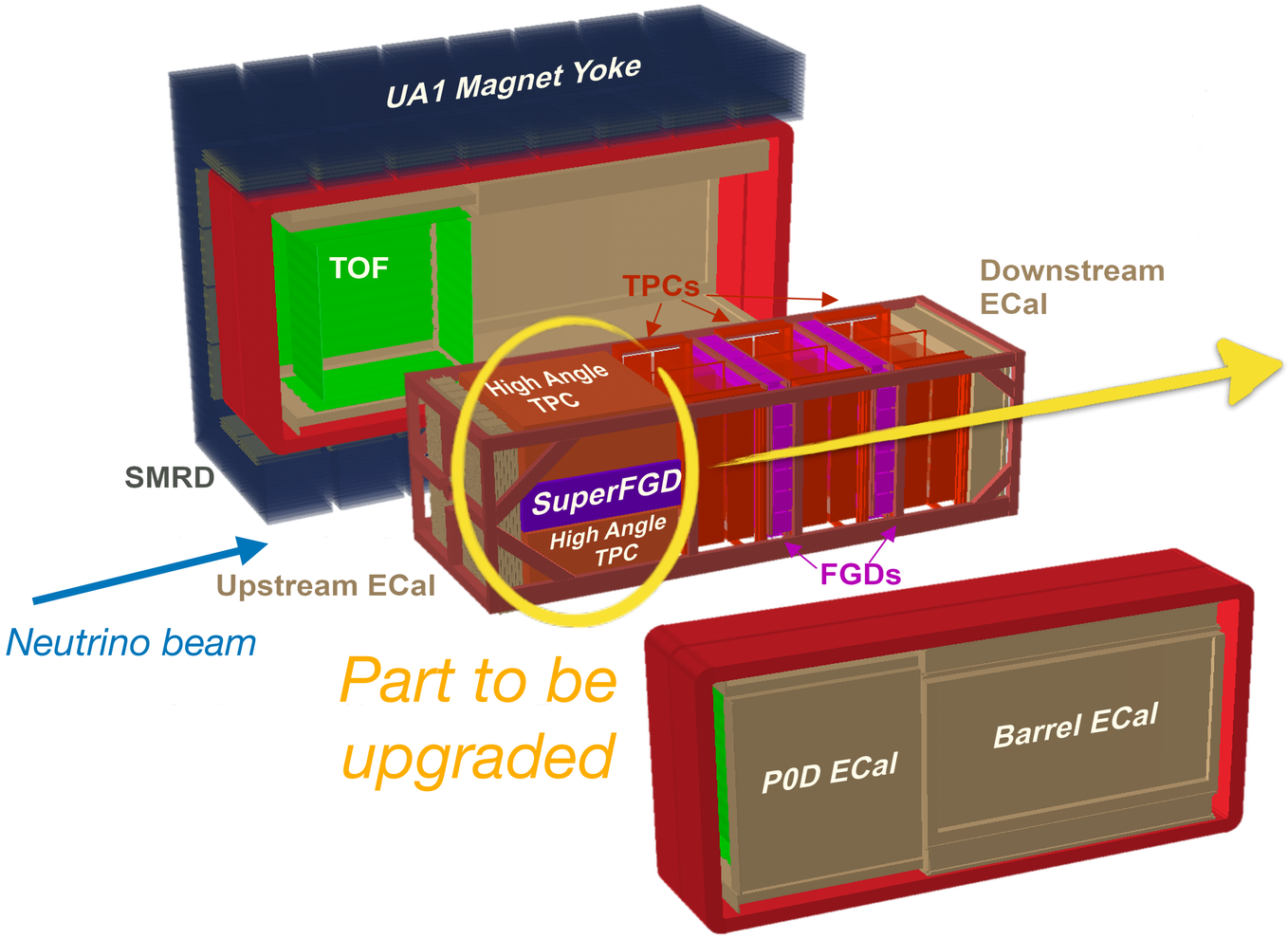


arXiv: 2303.03222

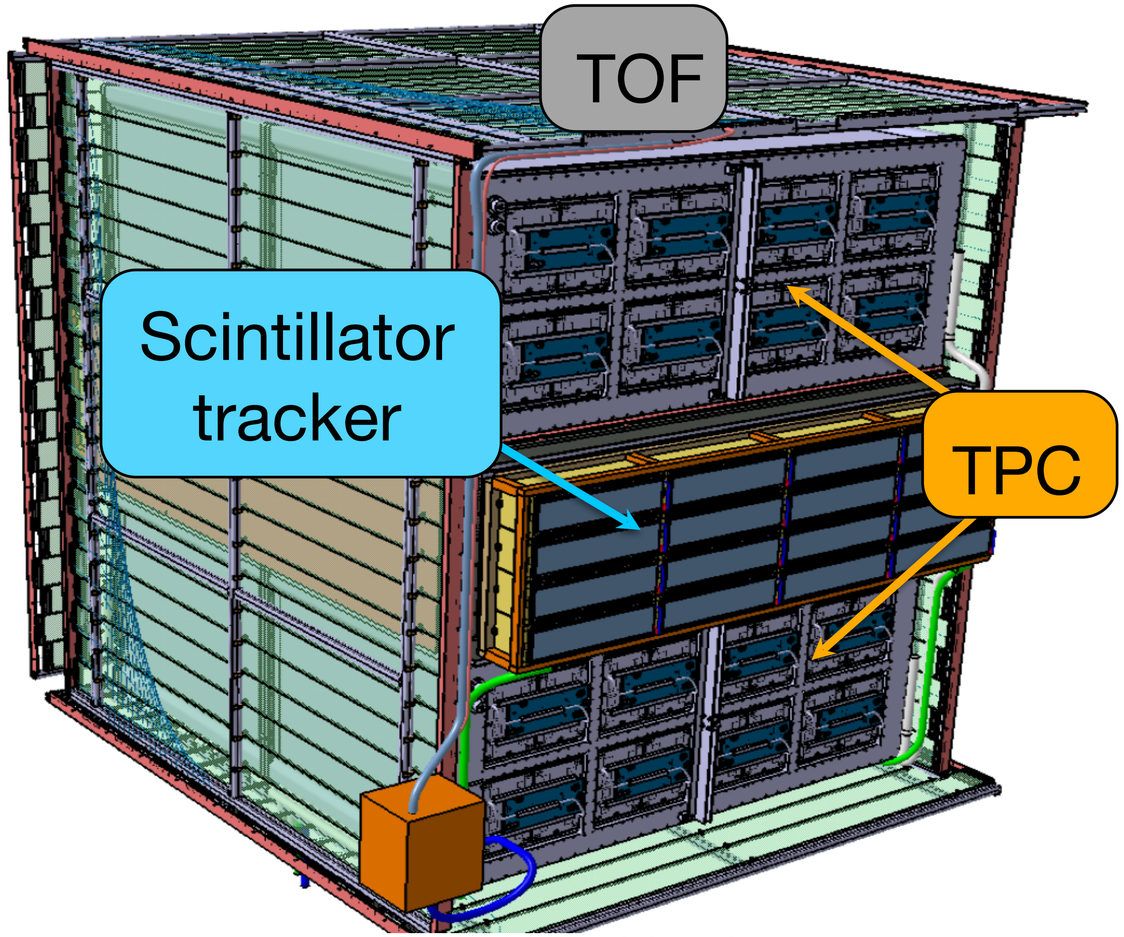




ND280 Upgrade Overview



Sketch of ND280 detector (decomposed)



arXiv:1901.03750

CERN-SPSC-2018-001 / SPSC-P-357

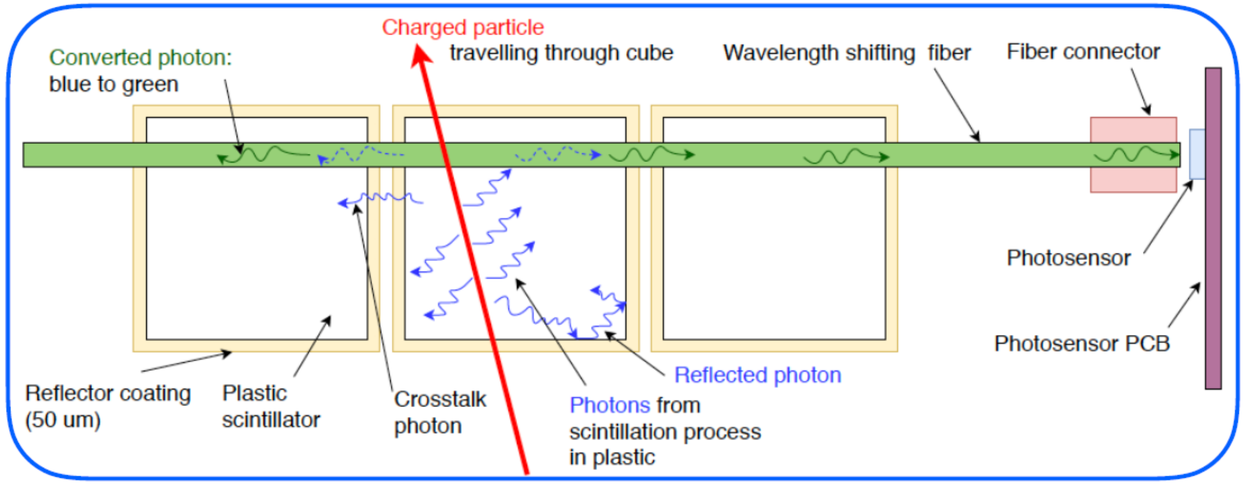
Super Fine-Grained Detector (Super-FGD)

- Super-FGD has ~ 2 million scintillator cubes ($1cm^3$) made of polystyrene. Target mass is ~ 2.1 tons.
- It is the main place where neutrino interactions happen.
- Advantages compared with current FGD detector:

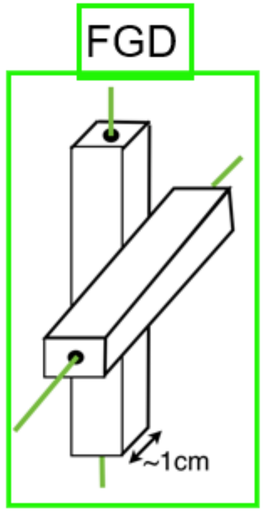
① Three readout views provide 4π solid angle acceptance.

② 3D fine granularity allows to detect short protons.

③ ~ ns time resolution enables to reconstruct neutron kinematics.

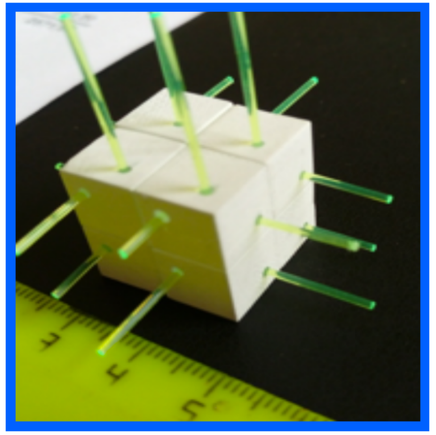


Scintillator bar



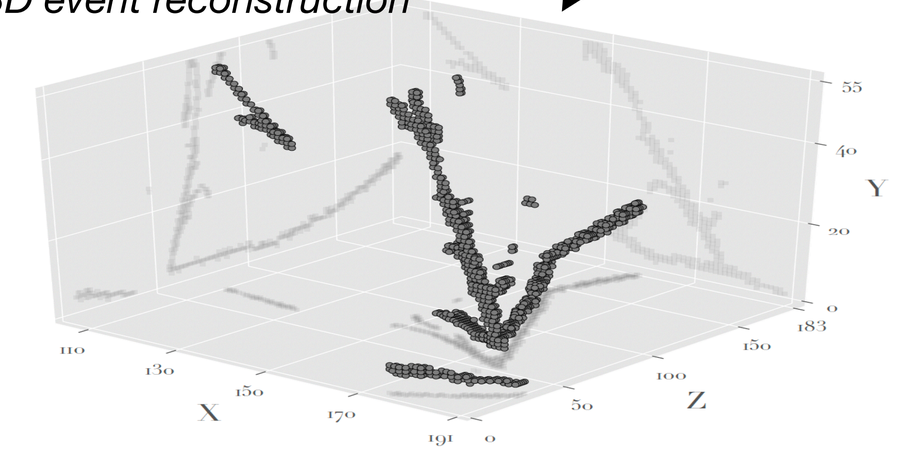
Upgrade

SFGD cube



2018 *JINST* **13** P02006
NIM A936 (2019) 136-138

3D event reconstruction

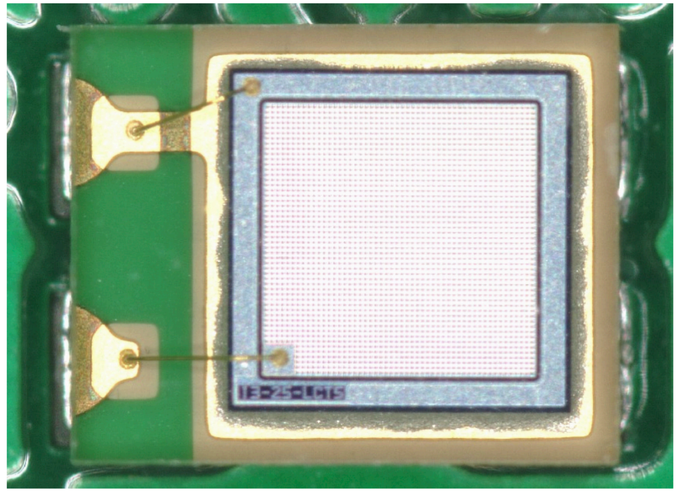


Super-FGD Hardware

- Super-FGD box panel made of foam sandwiched by carbon / glass fiber skins.
  - *Low radiation length and ~ 120k holes for WLS fibers to exit the dark box.*
- Light signal transmitted by WLS fibers and received by MPPC S13360-1325PE (~ 2700 pixels) whose surface is mounted on a PCB (8*8 MPPCs).
  - *The high dynamic range improves stopping proton and vertex activity measurement.*
- FE electronics mainly composed of CITIROC ASIC that digitizes MPPC analogue signal.
  - *Measure not only the signal peak with both low gain for stopping protons and high gain for MIPs, but also the charge from time-over-threshold.*
  - *FPGA has sampling rate ~ 400 MHz.*

Super-FGD installation in ND280 basket

MPPC S13360-1325PE

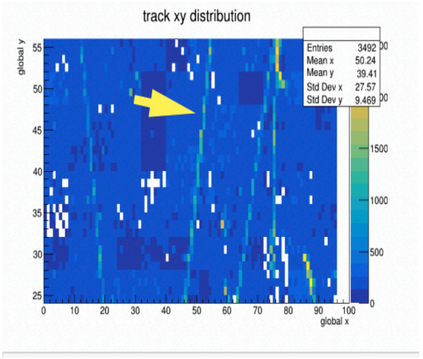


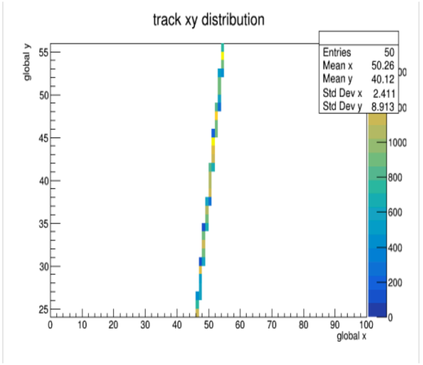
Super-FGD Test and Installation

- Prototype beam tests have been done at CERN (charged particle beam, *JINST 15 P12003 (2020)*) and LANL (neutron beam, *arXiv: 2207.02685*).
- Installation on site is ongoing:
  - *Super-FGD has been just installed in ND280 basket.*
  - *All electronic components produced. Some being tested and ~ half have been installed.*
  - *Already collected some cosmic events on surface.*

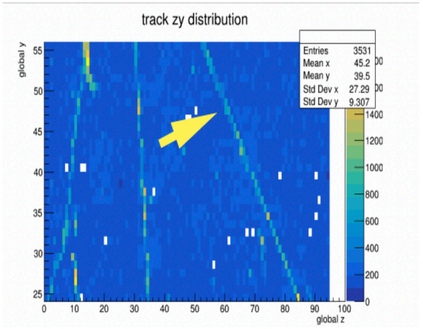
A cosmic event with final electronics

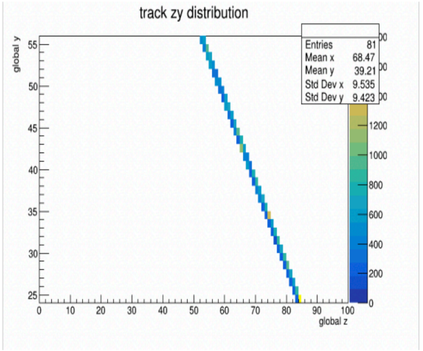
x-y plane (crate 1)



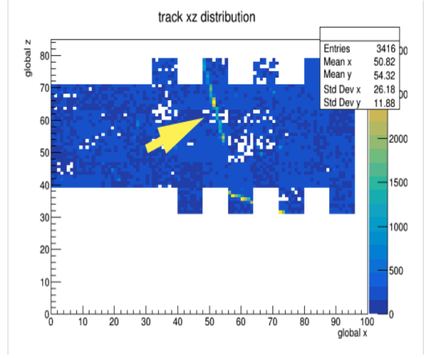


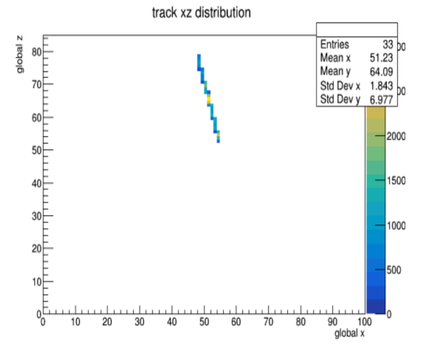
z-y plane (crate 5)



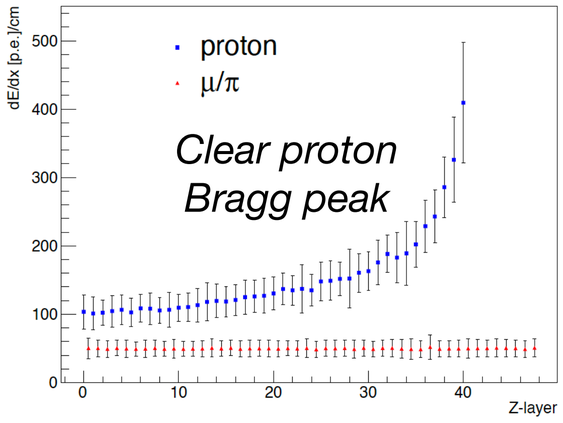


x-z plane (crate 2)

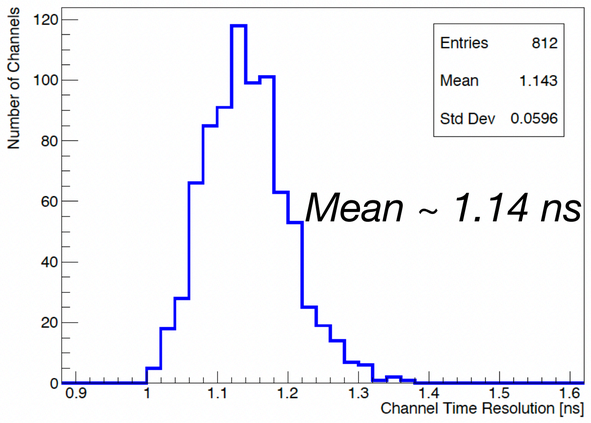




Local dE/dx measurement

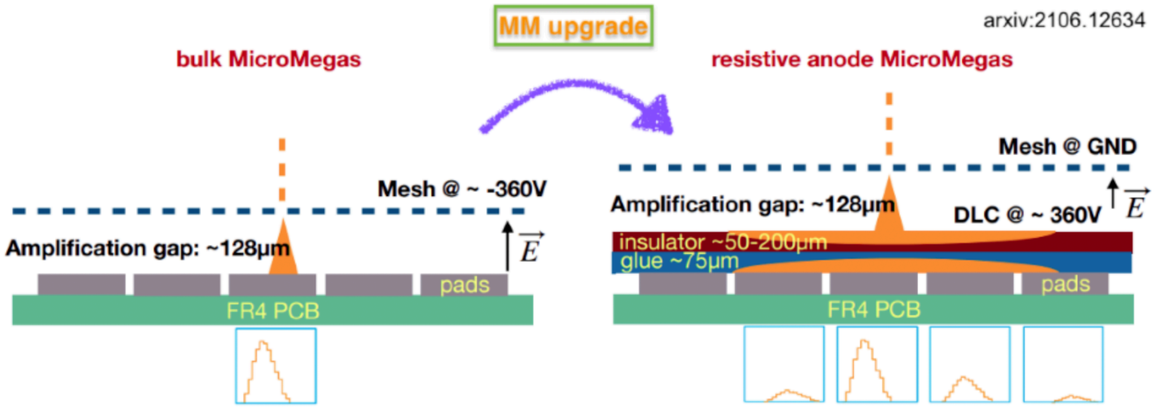


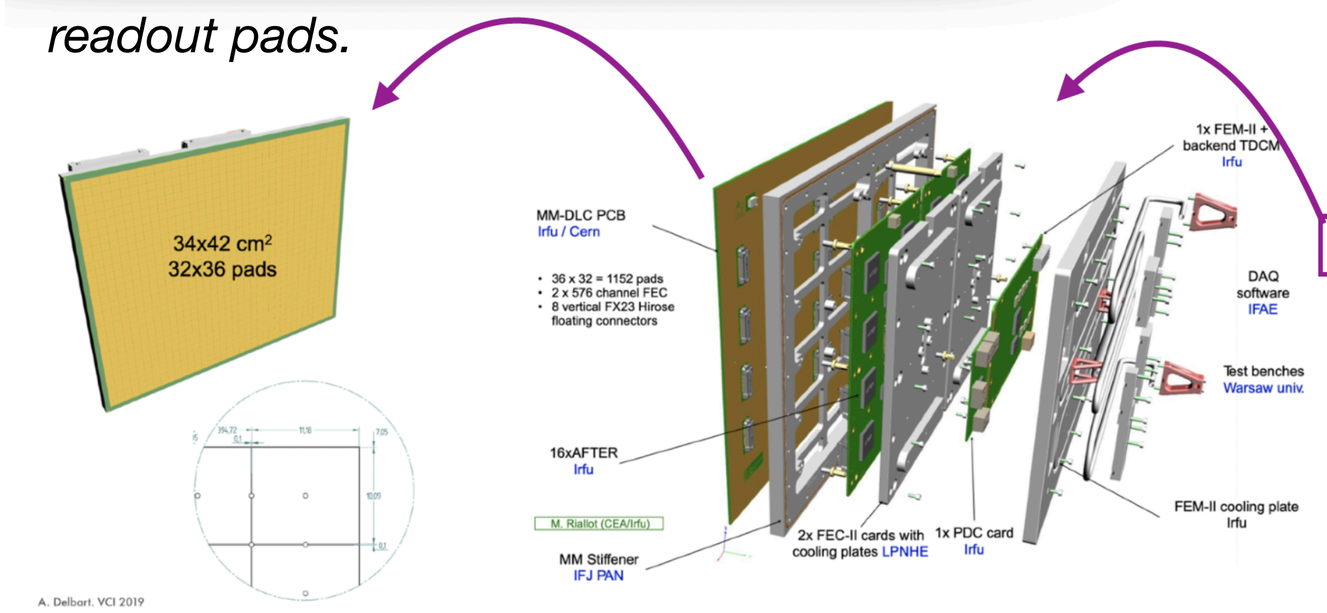
Time resolution measurement

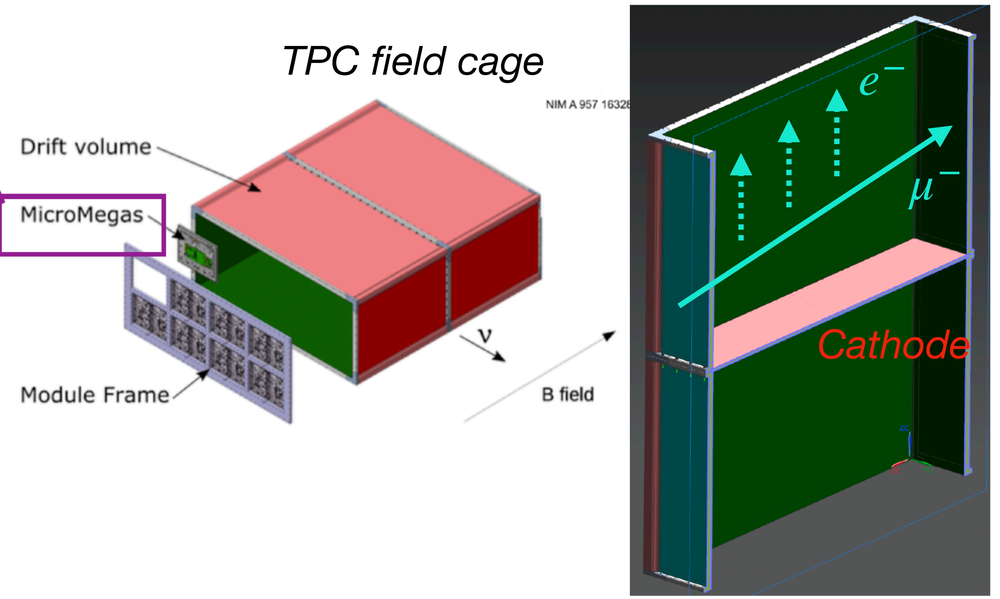


High-Angle Time Projection Chamber (HA-TPC)

- Goal is to identify charged particles leaving Super-FGD, especially those going upwards.
- TPC is filled with argon gas ($Ar : CF_4 : iC_4H_{10} = 95 : 3 : 2$).
- Replace old bulk Micromegas readout module with new resistive Micromegas module (ERAM).
  - *Spread charge over multiple pads.*
  - *Improve spatial resolution and reduce number of readout pads.*







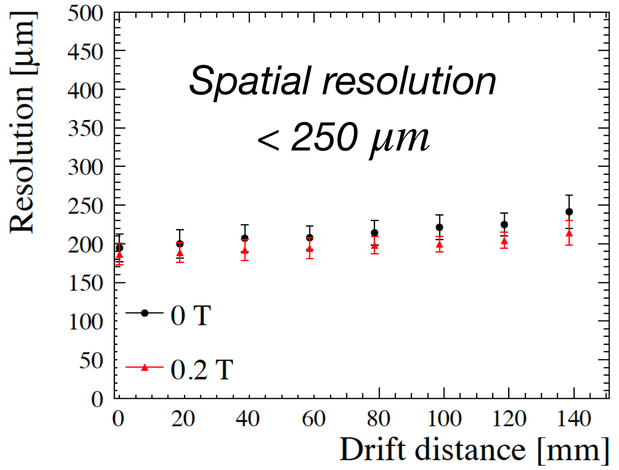
HA-TPC Test and Installation

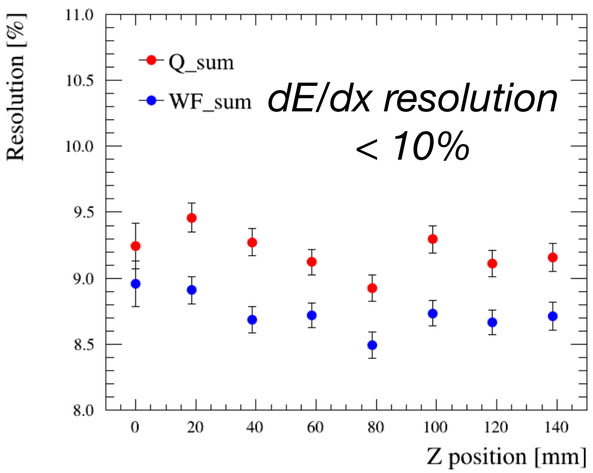
- Prototype beam tests have been done at CERN (*Nucl. Inst. and Methods, A 957 (2020) 163286*) and DESY (*arXiv: 2106.12634*).
- Installation on site is ongoing:

① Bottom HA-TPC has been already installed in ND280 basket.

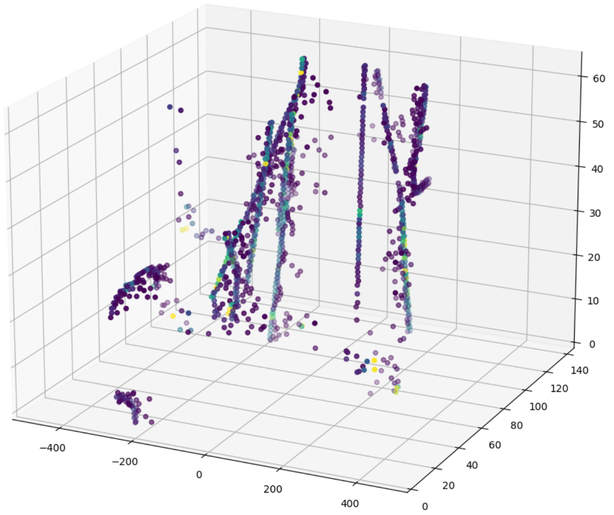
② Top HA-TPC will be installed next year.

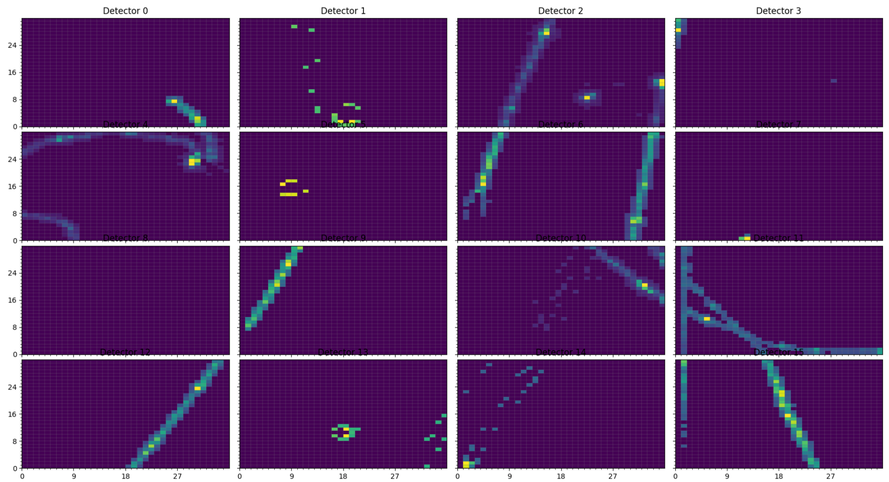
Performance satisfies ND280 upgrade requirement



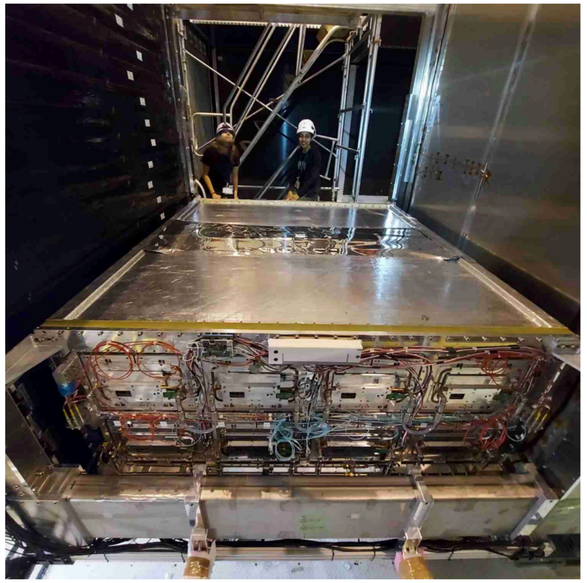


Real cosmic event collected in ND280 basket



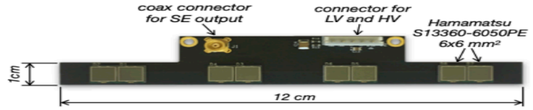


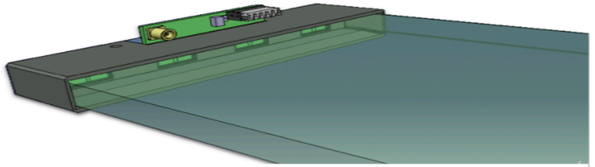
Installation in ND280 basket

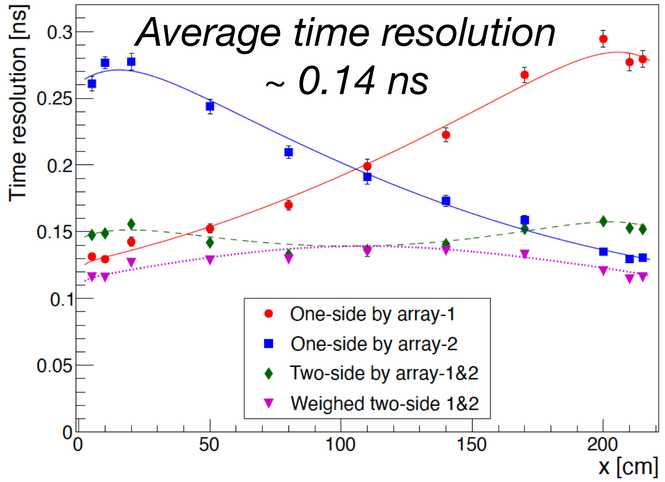


Time-of-Flight Detector (TOF)

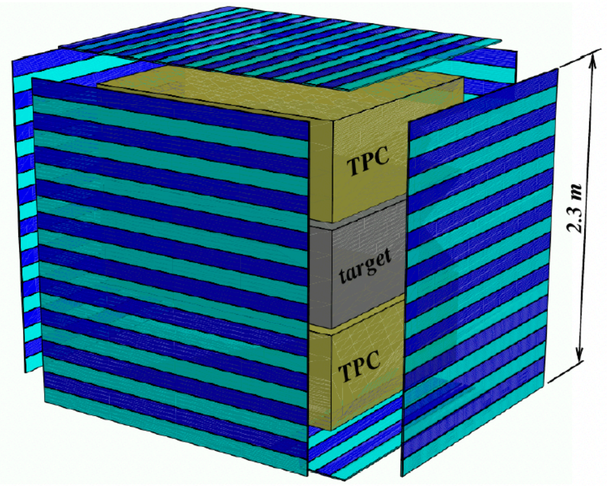
- 6 TOF planes cover 2 HA-TPCs and Super-FGD. Each plane consists of 20 scintillator bars, readout with 16 MPPCs at both ends of each bar.
- Goal is to measure direction of charged particles and provide veto to reduce background.
- Cosmic muon test has been done at CERN (*JINST 17 P01016 (2022)*).
- Installation on site is ongoing. Two planes have been already installed in ND280 basket. The rest will wait after top HA-TPC.



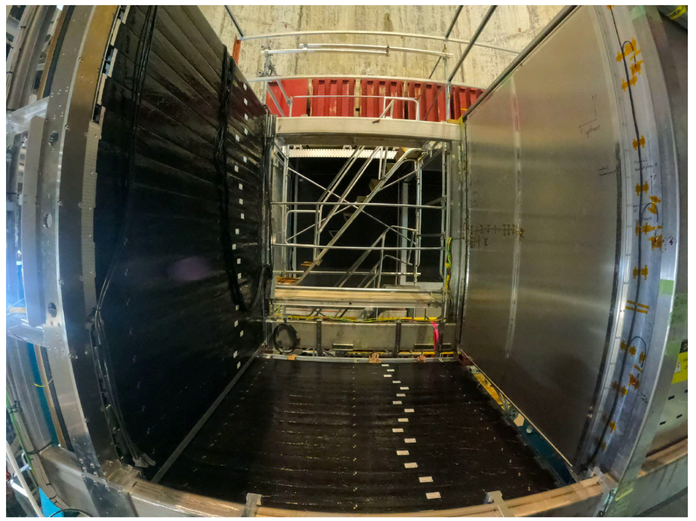




All 6 planes have been shipped to J-PARC



Installation in ND280 basket



Contents

- T2K ND280 upgrade detectors.
- **Towards physics: neutrino event reconstruction and selection developments in T2K ND280 upgrade.**

ND280 Upgrade Physics Overview

Phys. Rev. D 105, 032010 (2022)

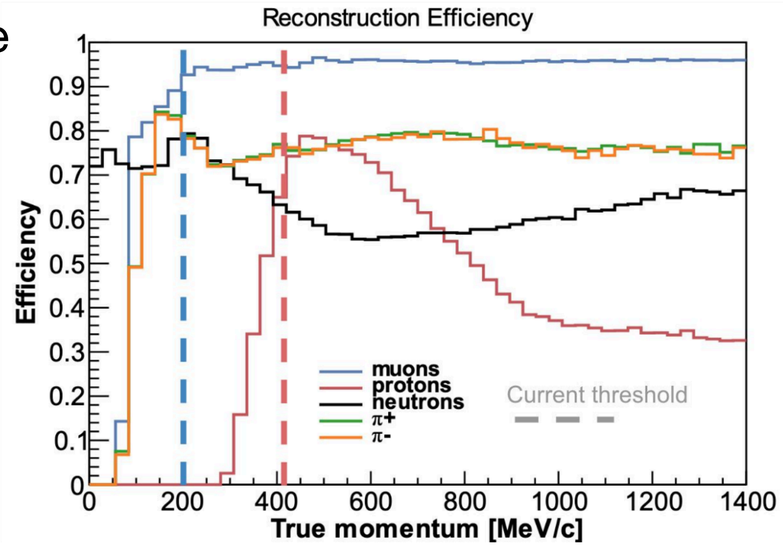
- With finer 3D granularity of Super-FGD, we are able to:

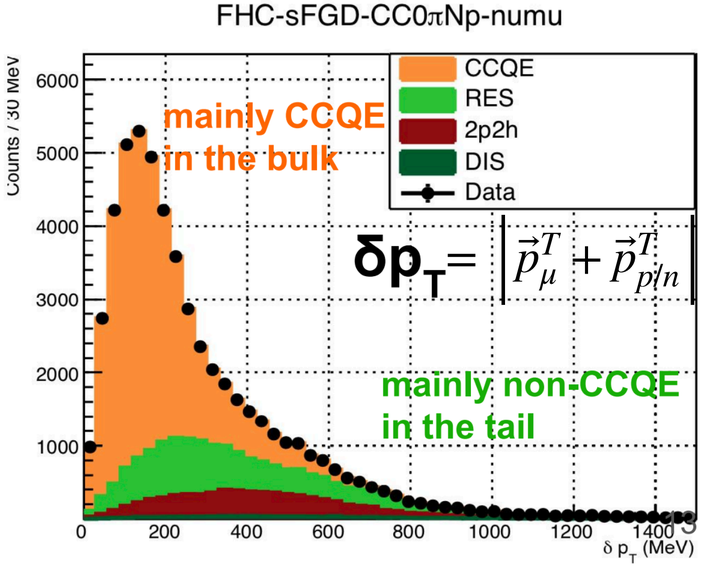
① Lower down proton reconstruction threshold and tag neutron.

② More precisely measure variables related to

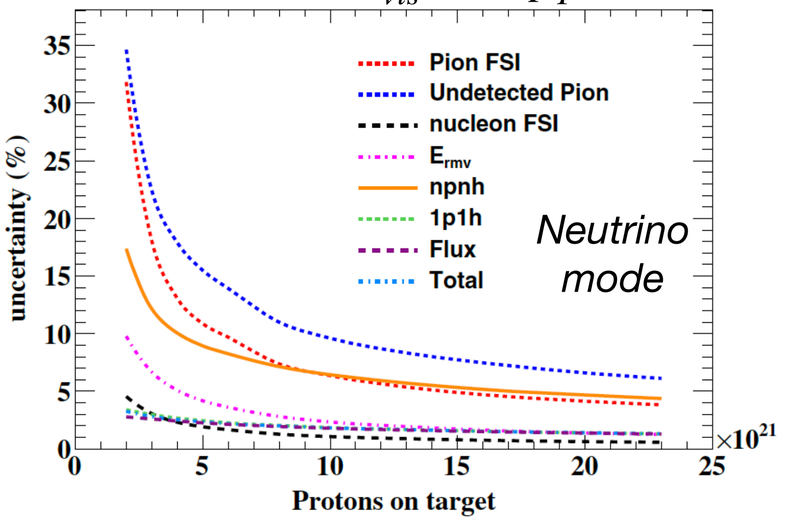
  - visible energy $E_{vis} = E_{\mu} + T_{p/n}$.
  - transverse momentum imbalance (TKI) (e.g. δp_T).

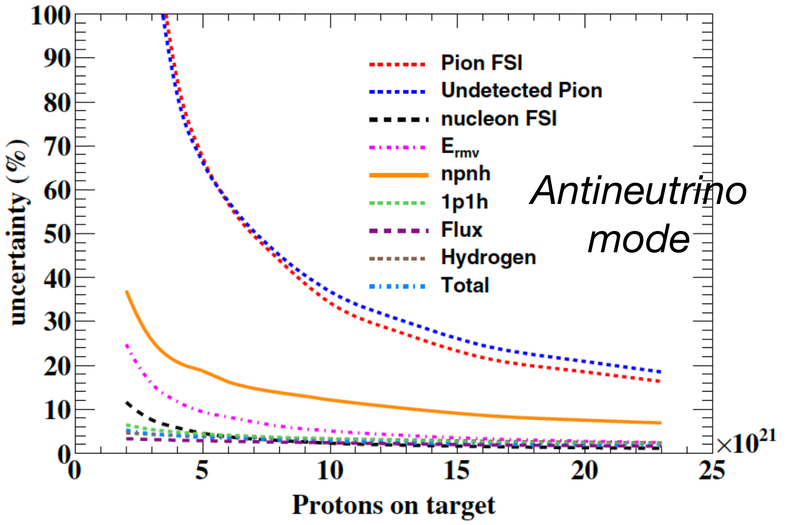
- Goal is to better constrain neutrino interaction uncertainties.
- Need good neutrino event reconstruction and selection performances.





ν_μ ($\bar{\nu}_\mu$) CC0π sample fitted in E_{vis} and δp_T



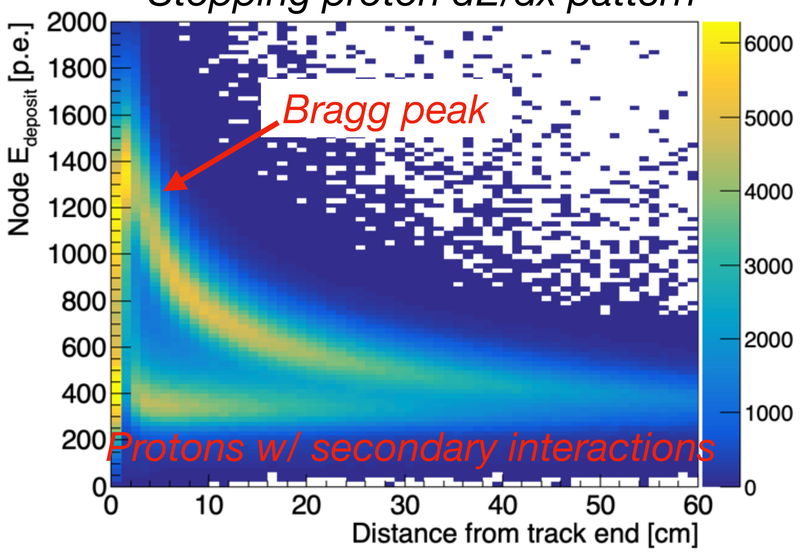


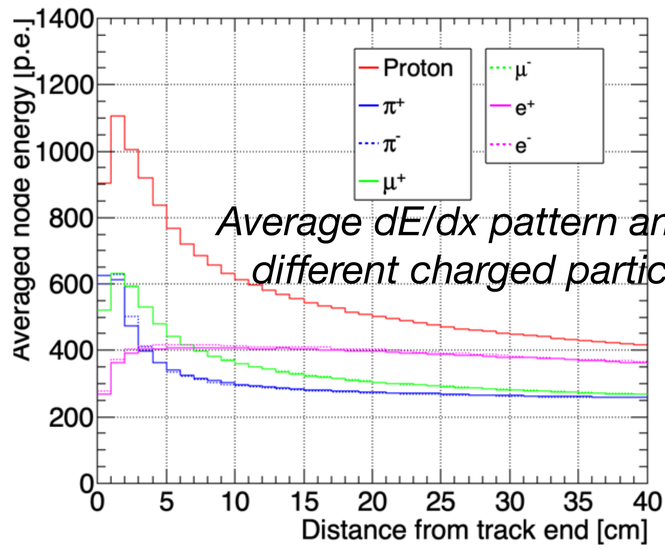
Neutrino Event Reconstruction (MC Study)

Proton Reconstruction

- In T2K ND280 neutrino energy range, most produced protons in Super-FGD will just stop before escape.
- The proton track is reconstructed with pattern recognition algorithm (DBSCAN + MST).
- The particle identification and momentum measurement are performed with local dE/dx analysis method, combined with machine learning technique (*boosted decision tree, BDT*).
- MC uses single particle simulation (PGUN).

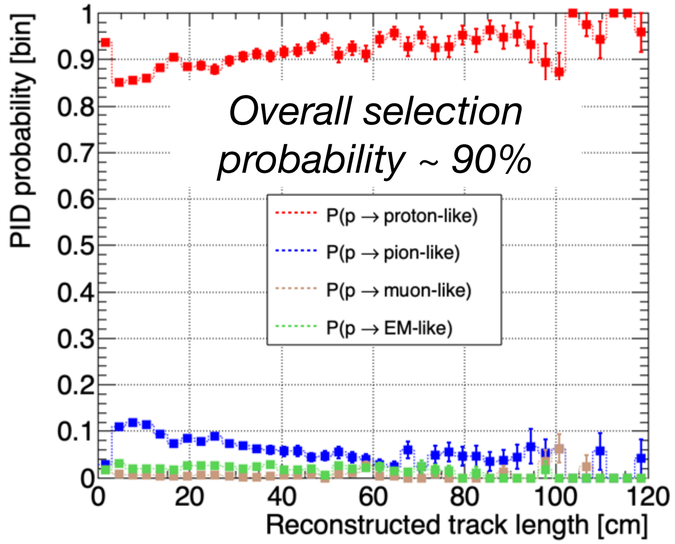
Stopping proton dE/dx pattern

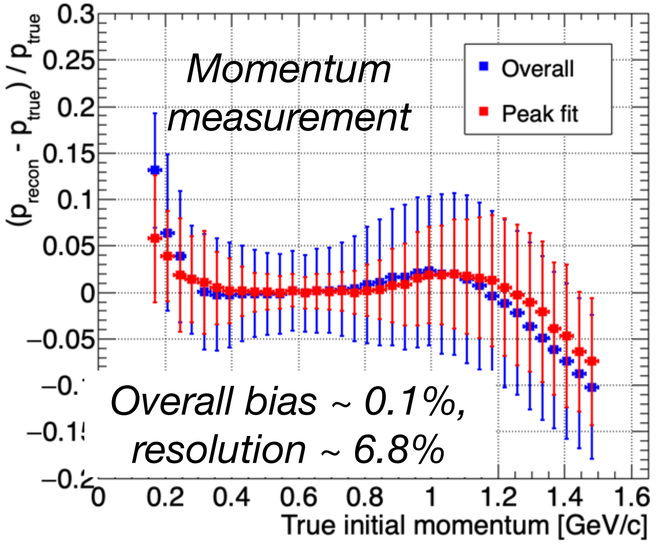




Work in progress

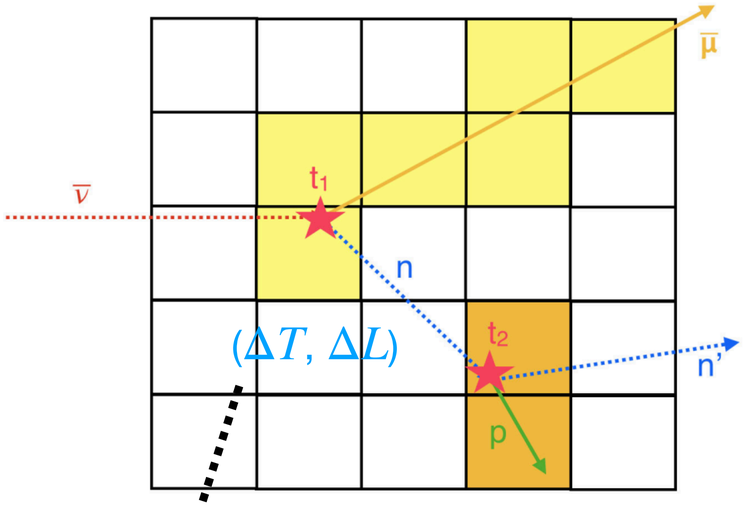
Particle identification



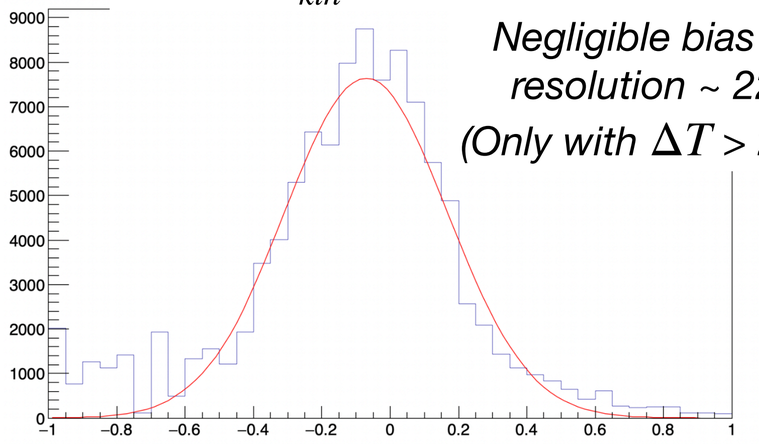


Neutron Reconstruction

- Tag neutrons which are produced in Super-FGD and interact before leaving the detector.
- Measure time-of-flight between neutrino vertex and neutron interaction point to infer neutron kinematics.

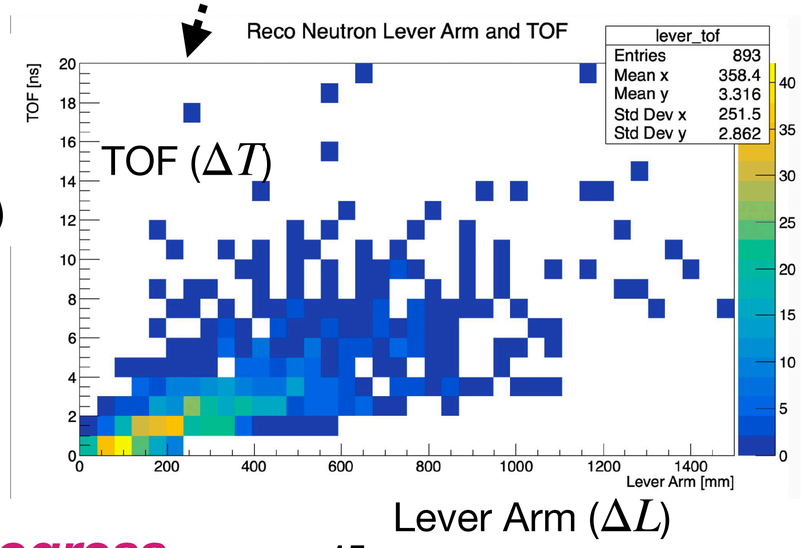


Neutron E_{kin} reconstruction



Negligible bias and resolution ~ 22%

(Only with $\Delta T > 2.5$ns)



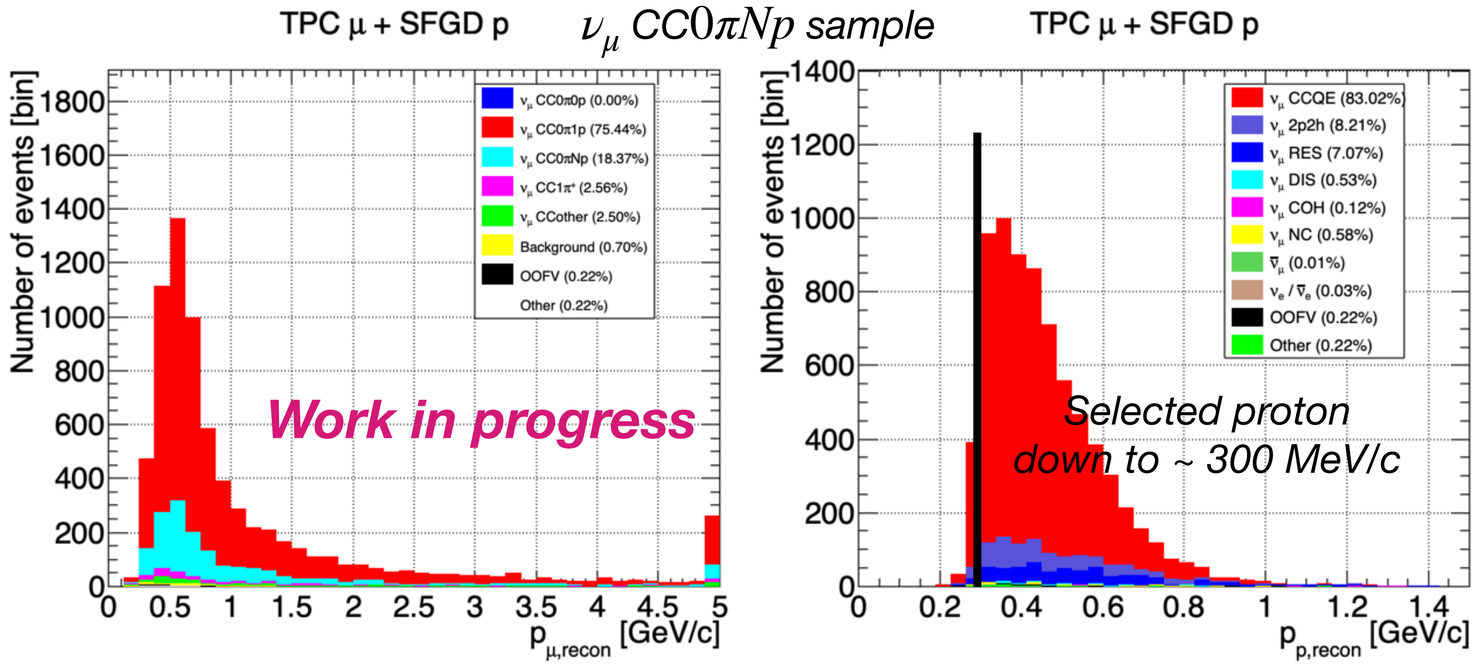
Work in progress

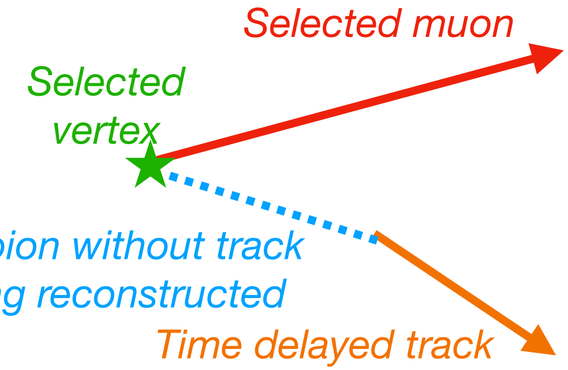
Calorimetry Reconstruction

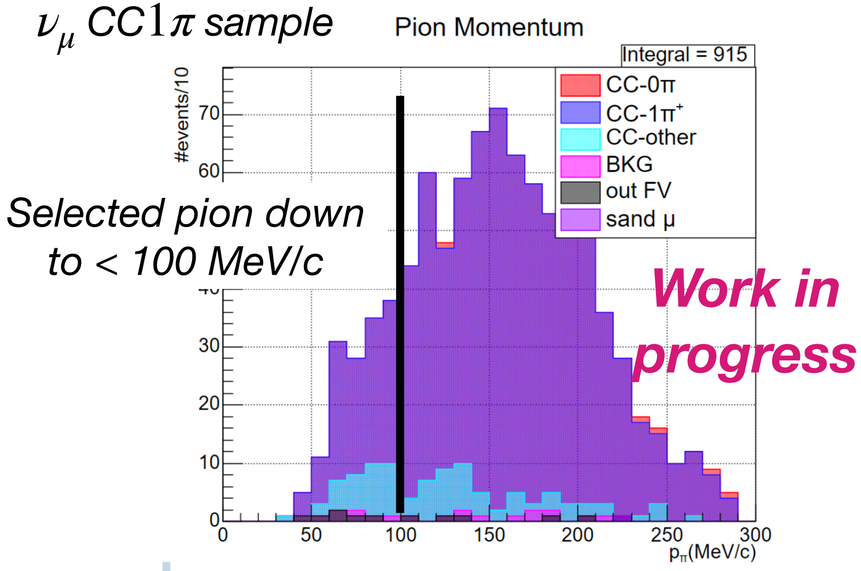
- Crucial to measure visible energy $E_{vis} = E_{\mu} + T_{p/n}$.
- Developing methods to precisely measure energy deposition by considering corrections from e.g. Birk's quenching.
- Currently achieved ~ 1.1% resolution for total energy deposition, now working on single track.

Neutrino Event Selection (MC Study)

- Based on the final state particles reconstructed in the detector, it is not possible to identify the true interaction mode, instead we use topology to separate different neutrino samples, e.g. CC0π.
- Preliminary selection on ν_μ CC$0\pi Np$ sample has been developed.
  - A good CC$0\pi Np$ purity (~ 94%) is achieved.
- Ongoing developments on $\bar{\nu}_\mu$ CC$0\pi Nn$ and other neutrino samples (e.g. ν_μ CC1π and ν_e).
- Neutrino events simulated with NEUT.







Summary

- The T2K ND280 is upgraded with one primary goal to measure $\sin\delta_{CP} = 0$ exclusion in 3σ C.L. through collecting more statistics and reducing systematic uncertainties.
- The installation of ND280 upgrade on site is ongoing. The upgrade detectors, Super-FGD, HA-TPCs and TOFs, have been tested and the performances meet the requirements.
- The developments of neutrino event reconstructions and selections in ND280 upgrade detectors are going in parallel.
- The ND280 upgrade (Super-FGD + bottom HA-TPC + 2 TOFs) is expected to take neutrino beam data from this winter.

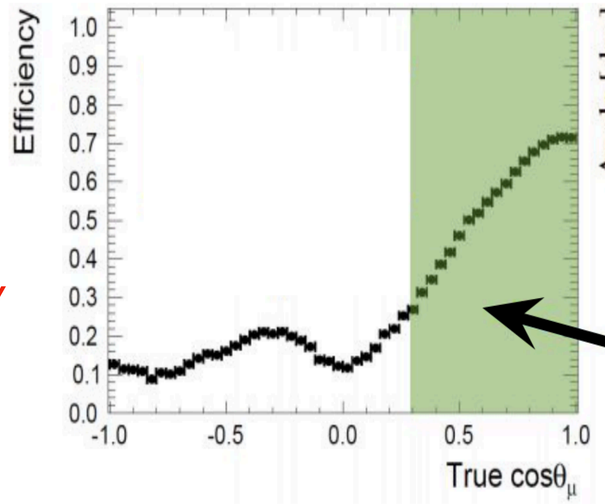
Thanks for your attention!

Backup Slides

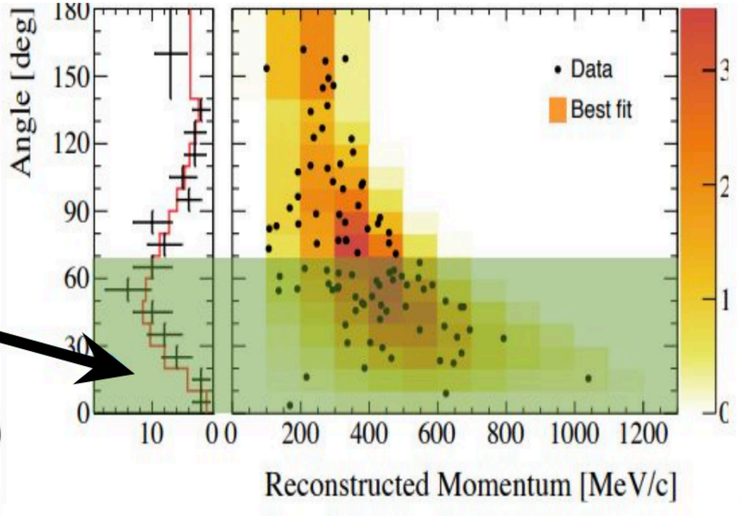
Reduce Systematic Uncertainty

- The old ND280 is more sensitive to forward going tracks, while SK has 4π coverage. → *Need upgrade to cover 4π as well.*
- CCQE neutrino energy reconstruction is biased by nuclear effects. → *Need upgrade to precisely reconstruct outgoing hadrons (proton in ν_μ and neutron in $\bar{\nu}_\mu$).*

Muon detection efficiency at ND280



ν_e candidates at Super-K



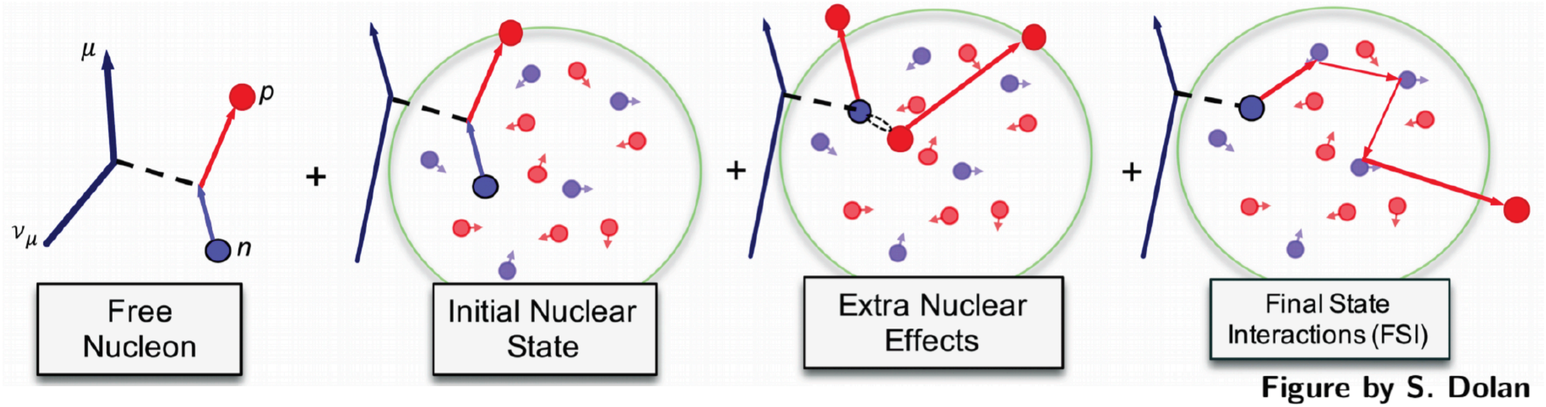
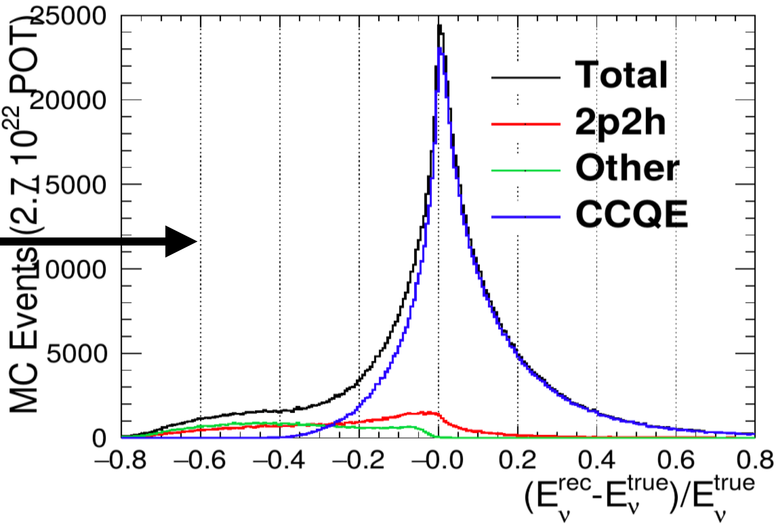
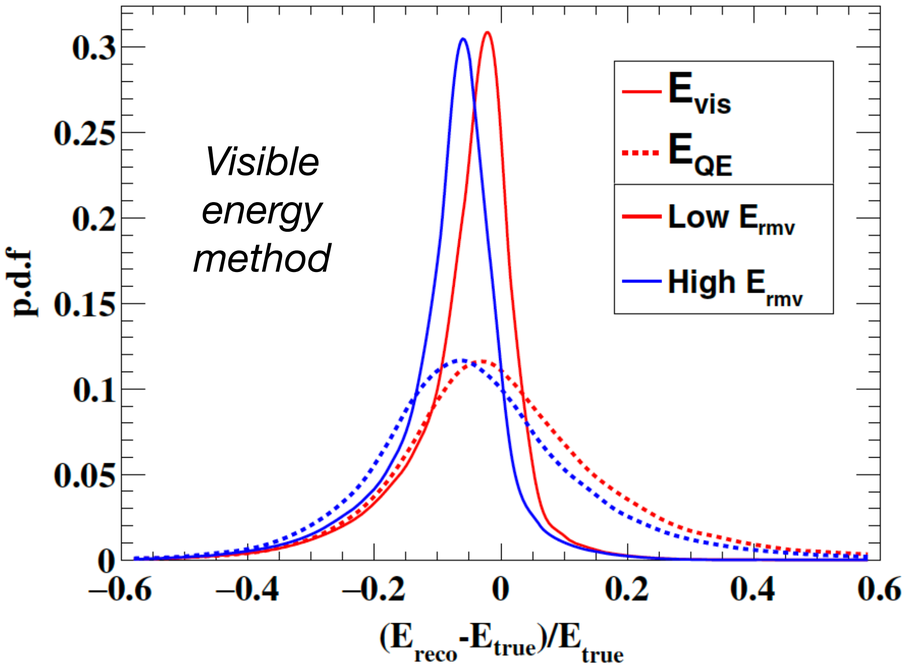


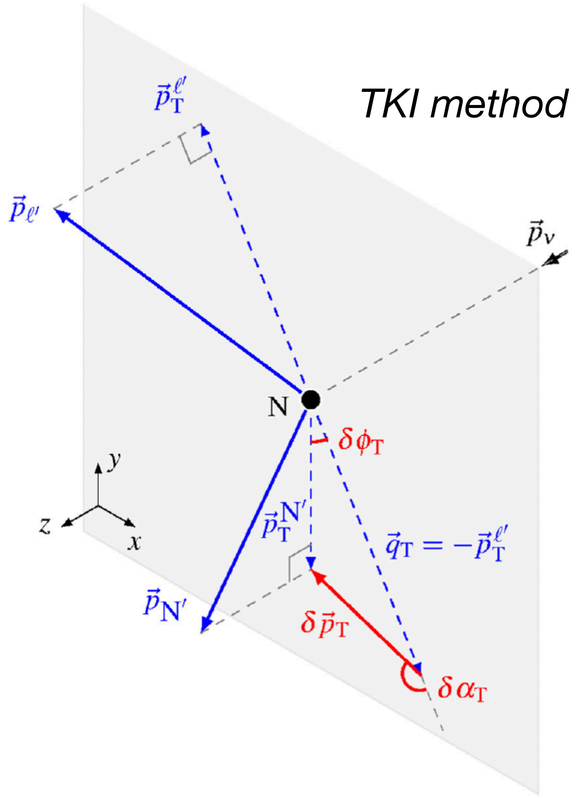
Figure by S. Dolan



Supplementary Plots (Physics)

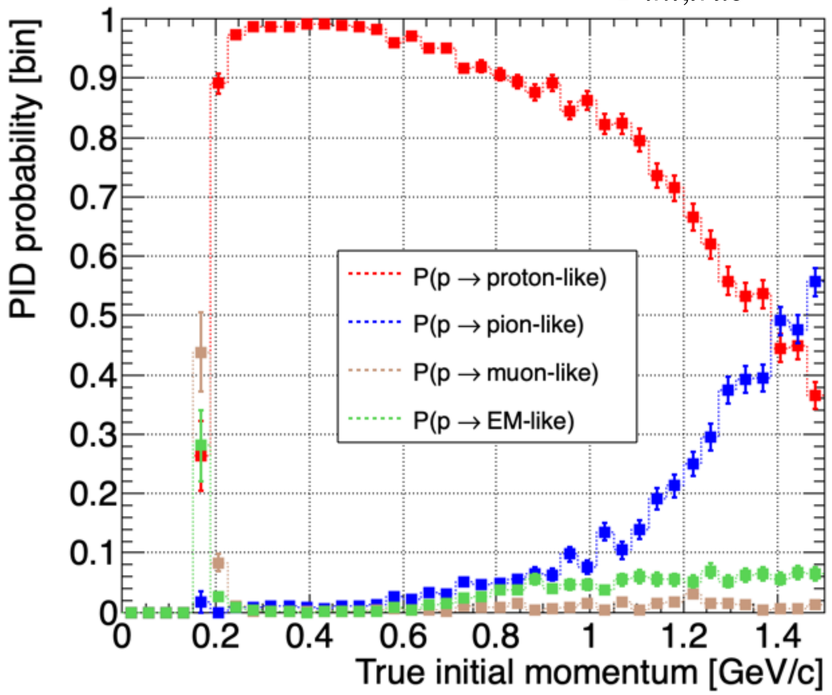
$$E_{vis} = E_{\mu} + T_{p/n}$$

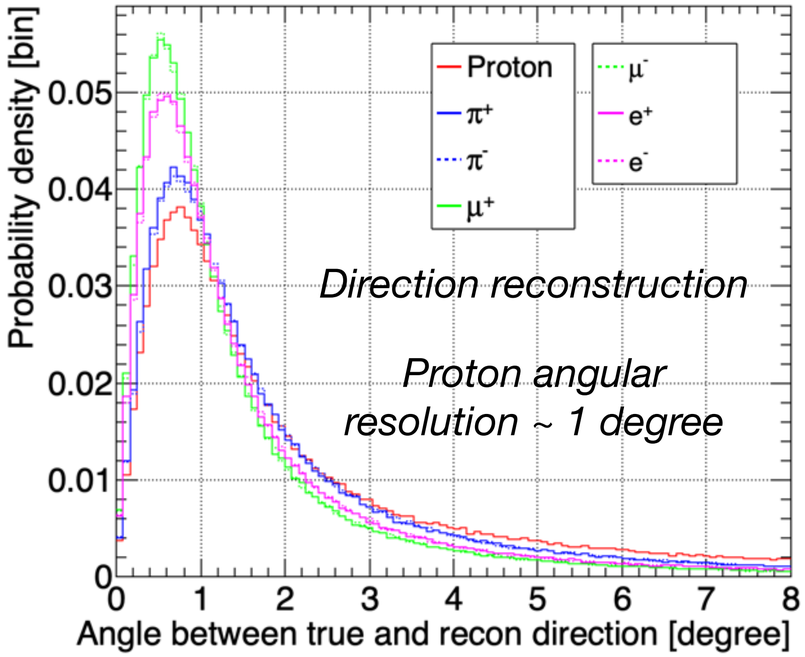




Supplementary Plots (Proton Recon)

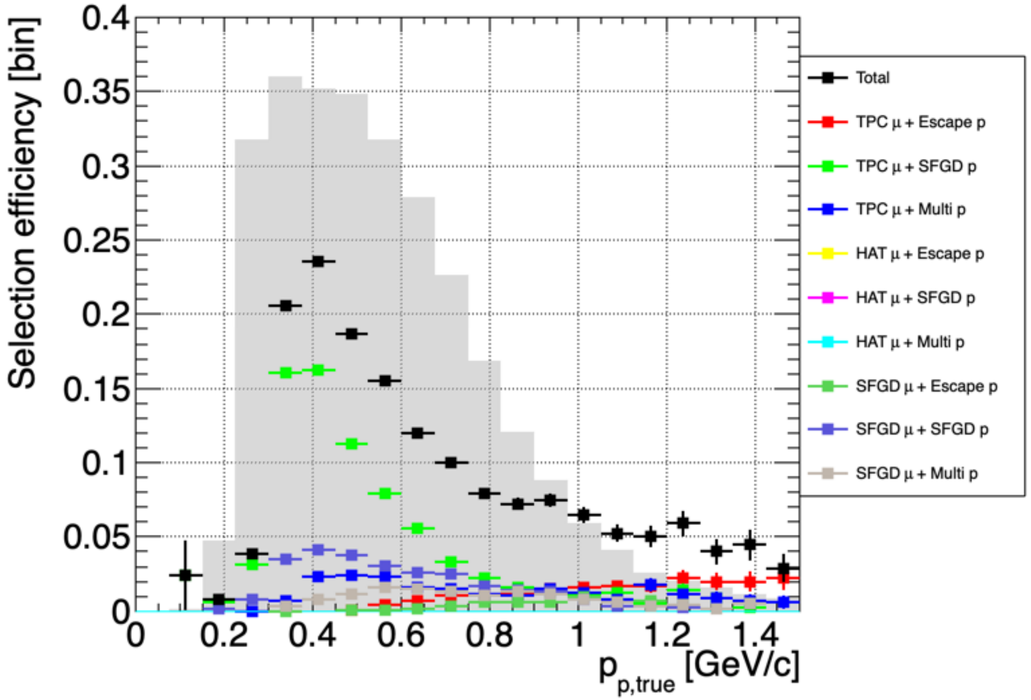
Proton PID probability vs. $p_{ini,true}$





Supplementary Plots (Selection)

Overall selection efficiency
(Denominator = all ν_μ CC0πNp in SFGD FV)



Overall selection efficiency
(Denominator = TPC μ + SFGD p sub-sample)