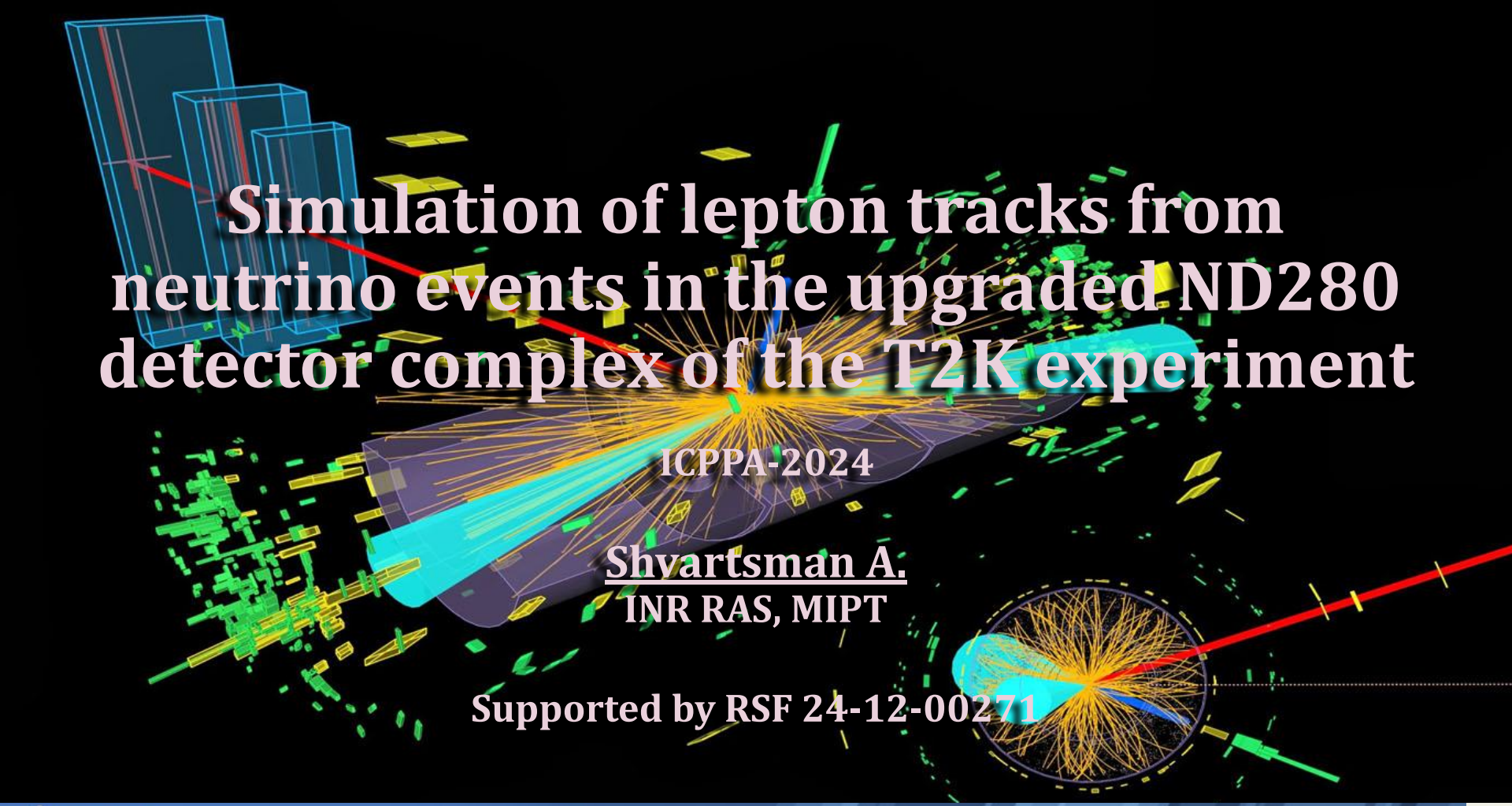


Simulation of lepton tracks from neutrino events in the upgraded ND280 detector complex of the T2K experiment

ICPPA-2024

Shvartsman A.
INR RAS, MIPT

Supported by RSF 24-12-00271

T2K experiment

Nucl. Instrum. Methods A, 659 (2011)
arXiv:1910.03887 [hep-ex]

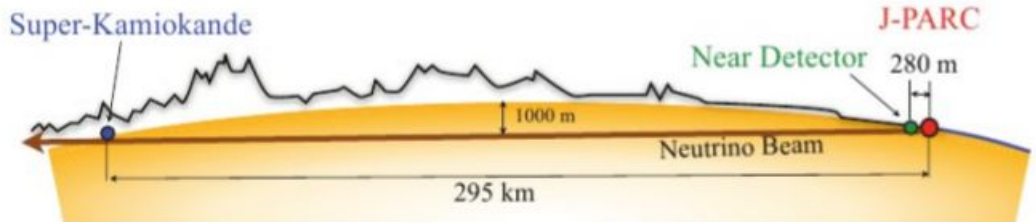
T2K (Tokai to Kamioka) is an experiment with a long baseline for searching for neutrino oscillations

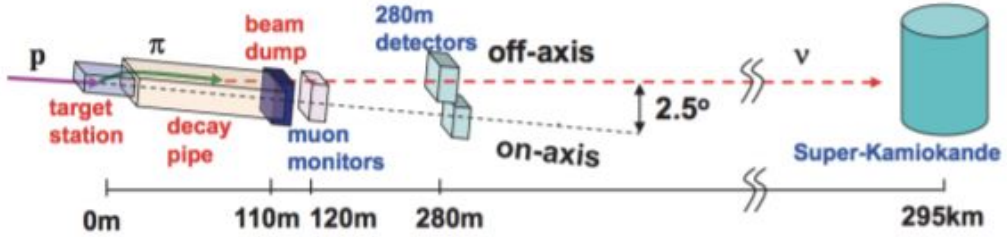
Observations: $\nu_\mu \longrightarrow \nu_e$

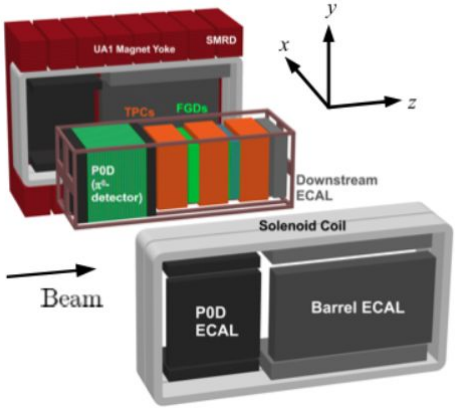
T2K conducts very precise measurements of the probability of oscillations and the difference between the masses of two types of neutrinos.

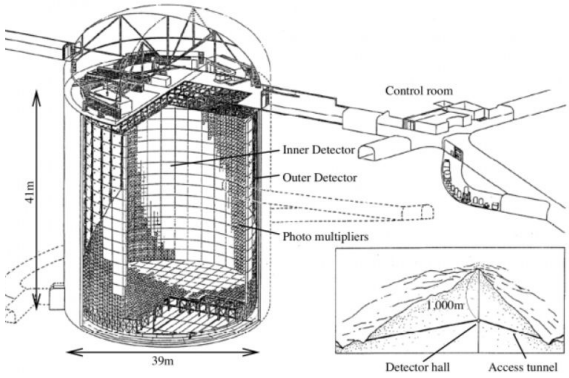
2.5° off-axis angle peaks ν_μ energy spectrum at ~600 MeV

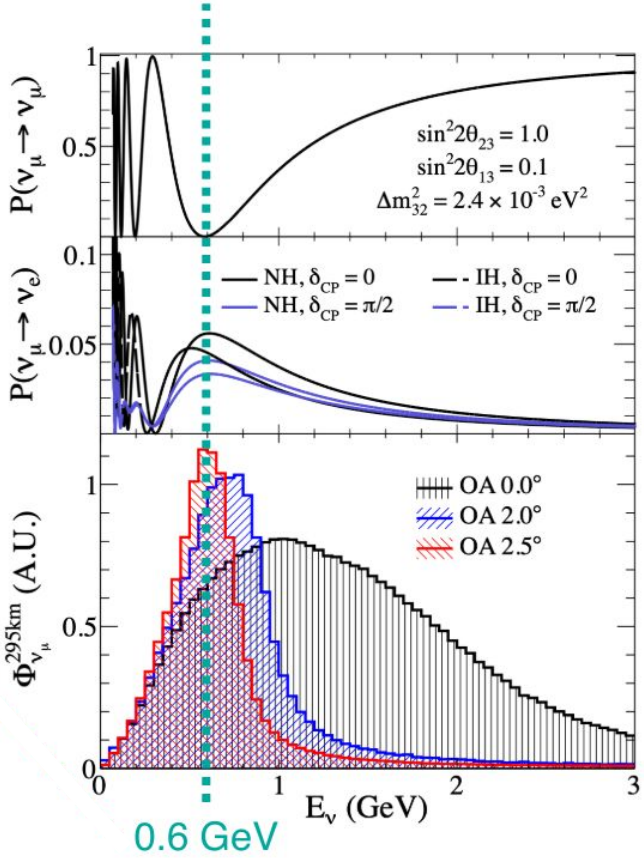
The main goal of the experiment is a search for CP-violation in neutrino oscillations.





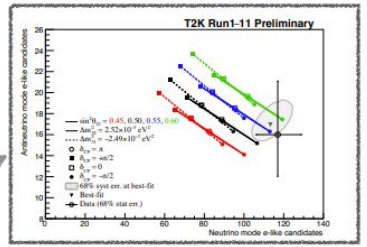




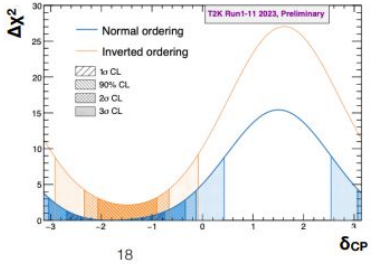


Oscillation analysis results

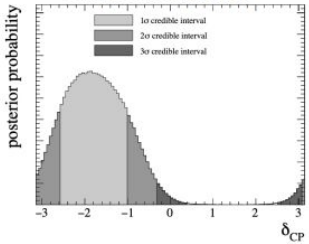
Sample	δ_{CP}=-π/2	δ_{CP}=0	δ_{CP}=π/2	δ_{CP}=π	Data
ν-mode 1Rμ	417.2	416.3	417.1	418.2	357
ν-mode MR	123.9	123.3	123.9	124.4	140
ν̄-mode 1Rμ	146.6	146.3	146.6	147.0	137
ν-mode 1Re	113.2	95.5	78.3	96.0	102
ν̄-mode 1Re+d.e.	10.0	8.8	7.2	8.4	15
ν̄-mode 1Re	17.6	20.0	22.2	19.7	16



CP-symmetry is excluded at 90% confidence level

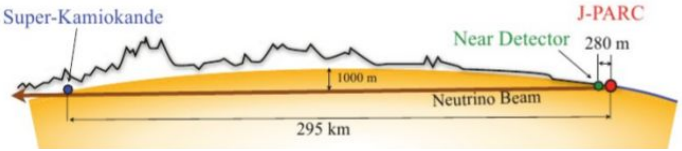


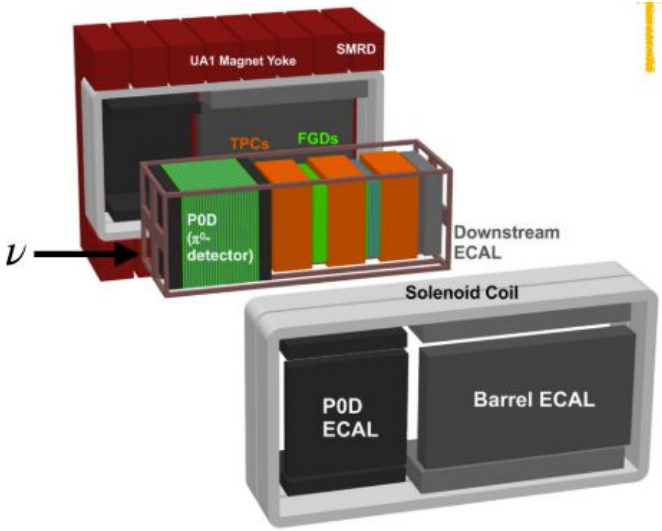
Credible intervals marginalized over both hierarchies



C. Giganti's talk at Neutrino-2024, 2024.06.17

Near Detector





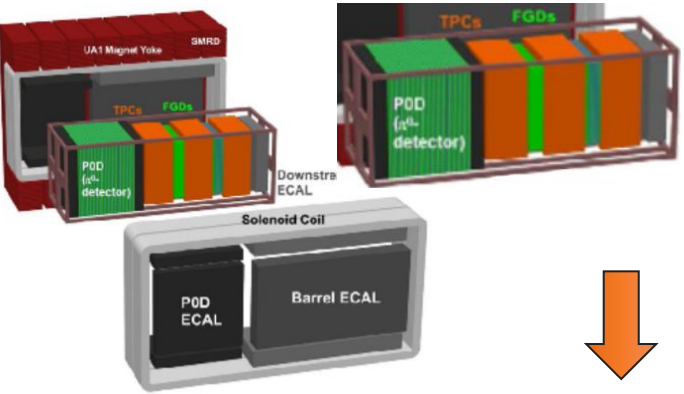
Previous configuration (2010-2022)

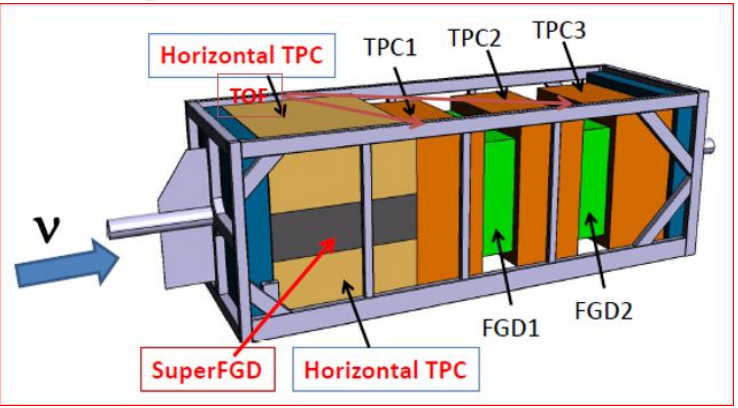
- P0D — measurement of pi0 production (pi0->g+g mimics nu interaction)
- FGDs — plastic scintillator bar planes (and water in FGD2): target for neutrino interactions
- TPCs — highly accurate reconstruction of particle's momentum: very precise tracker (+target)
- ECAL — measures energy deposit

- The tracker from TPC and FGD can register any outgoing particles.
- The large mass of the tracker (2 tons) provides a significant number of neutrino events.
- Excellent efficiency in registering tracks in the forward direction.
- The detector is model-independent.

Upgrade of the off-axis near detector ND280

arXiv: 1901.03750

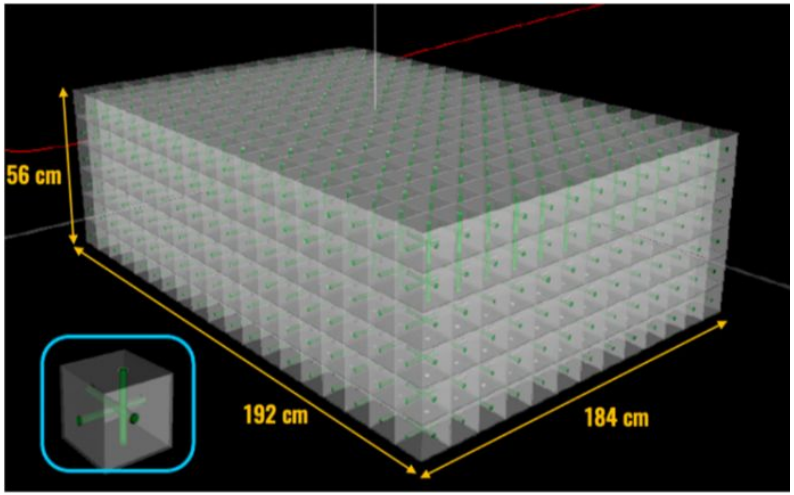


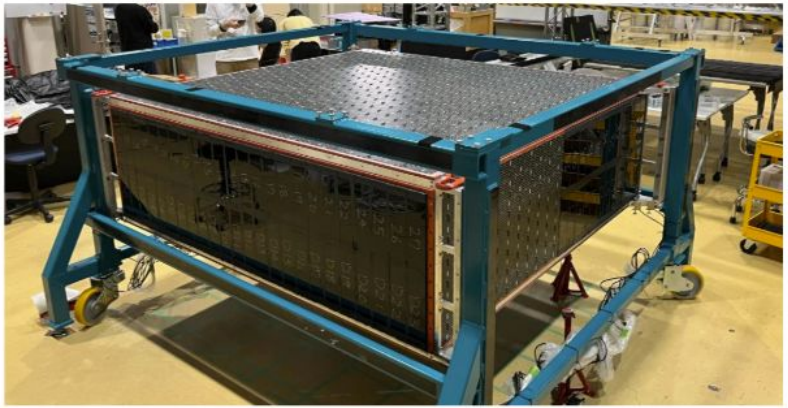


P0D is replaced with: SuperFGD, 2 High-angle TPCs, 6 TOFs

- High-Angle TPCs allow to reconstruct muons at any angle with respect to beam
- SuperFGD (Super Fine-Grained Detector) allows to fully reconstruct the tracks issued by ν interactions in 3D → lower threshold and excellent resolution to reconstruct protons at any angle
- Neutrons will also be reconstructed by using time of flight between vertex of $\bar{\nu}$ interaction and the neutron re-interaction in the detector
- PID for proton/muon and electron/photon

For a more detailed information please see A. Chvirova's talk at 22.10.2024, M. Kolupanova's poster





SuperFGD

arXiv: 2005.11048

Characteristics

- Volume 192 x 56 x 182 cm^3
- **~2 x 10^6** scintillation cubes 1 x 1 x 1 cm^3
- 3 orthogonal holes with 1.5 mm diameter each
- 3D (x,y,z) WLS readout – about **56000** readout WLS/MPPC channels
- Active weight **2 tons** (like FGD1+FGD2)

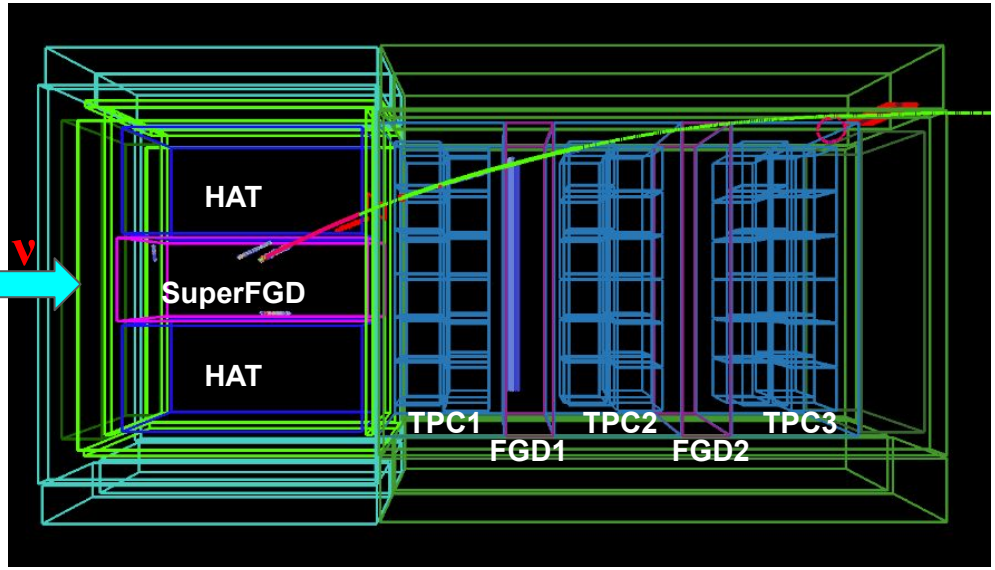
Advantages

- A sufficiently large mass (2 tons) provides a significant number of neutrino events.
- It has good sensitivity to charged particles at large angles.
- It can reconstruct and identify short tracks of low-energy hadrons around the interaction vertex.
- It measures charged particles tracks in all 3 projections.

For a more detailed information please see A. Chvirova's talk at 23.10.2024, M. Kolupanova's poster

Simulation of lepton tracks like in neutrino events

upgraded ND280 complex



goal of this work is to measure track matching efficiency between SuperFGD and Tracker subdetector system

- events from T2K flux, FHC (muon neutrino mode)
- mu- events with energies in range 100 MeV - 1 GeV
- mu- events with energies in range 1 GeV - 5 GeV

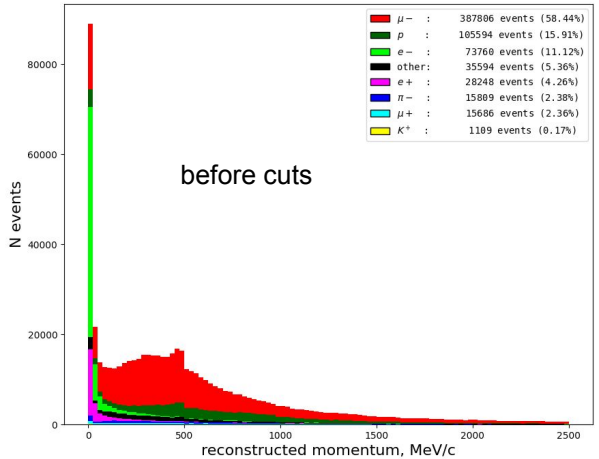
High-angle TPCs (HAT) are not included in the analysis

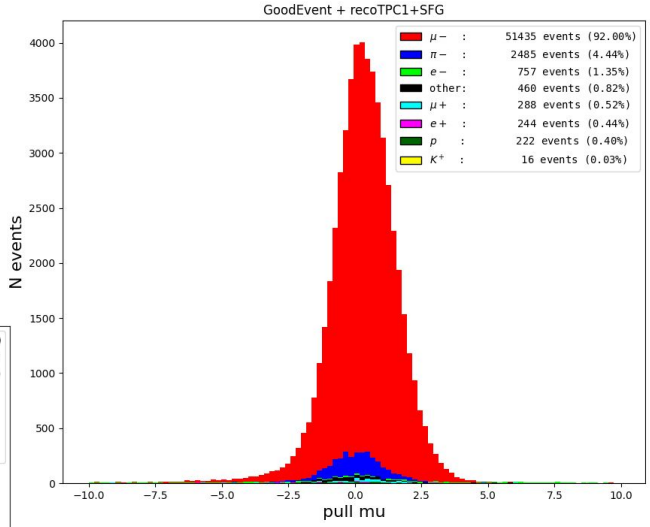
Selection of muons

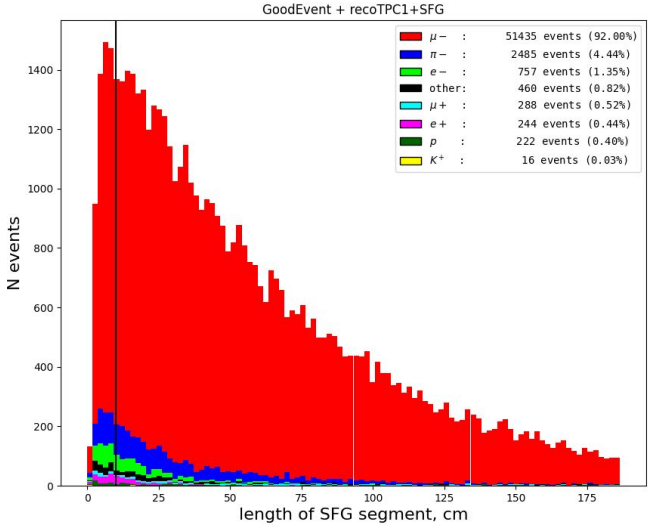
Preliminary

Cuts applied to select muons

- event quality
- track has SuperFGD and TPC1 segments
- SuperFGD segment length > 10cm
- TPC1 segment nodes > 19
- muon pull < 2.5





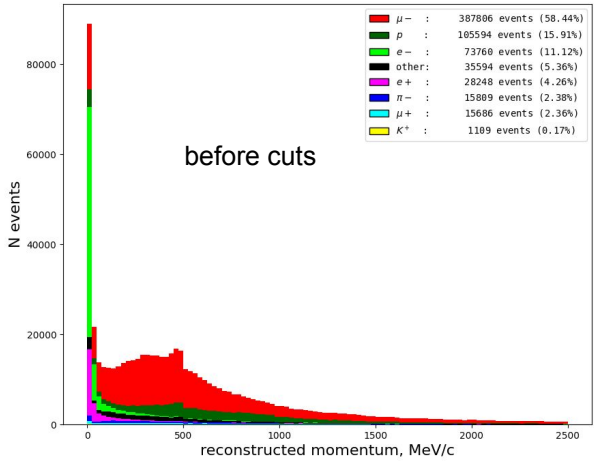


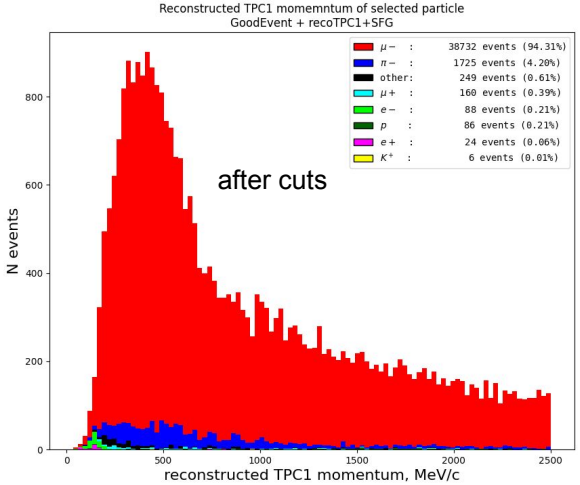
SuperFGD-TPC1 track matching for selected muons

Preliminary

Cuts applied to select muons

- event quality
- track has SuperFGD and TPC1 segments
- SuperFGD segment length > 10cm
- TPC1 segment nodes > 19
- muon pull < 2.5





Matched
True track: SuperFGD+TPC1 segments
Reco track: SuperFGD+TPC1 segments

Unmatched
True track: SuperFGD+TPC1 segments
Reco track: no TPC1 / no SuperFGD segment

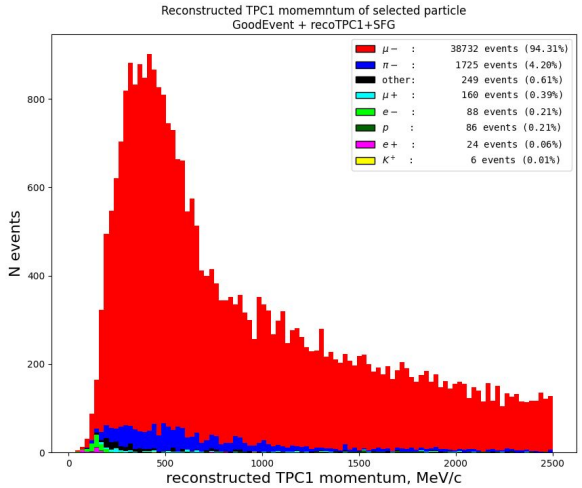
$$\text{Matching efficiency} = \frac{\text{Matched tracks}}{\text{Matched} + \text{Unmatched tracks}}$$

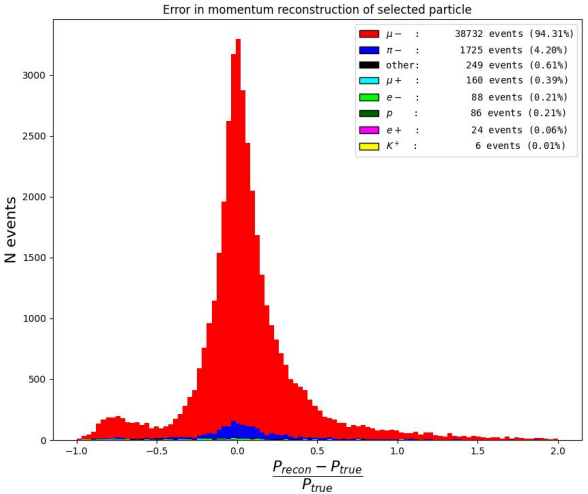
Muons selected with purity 94.3%

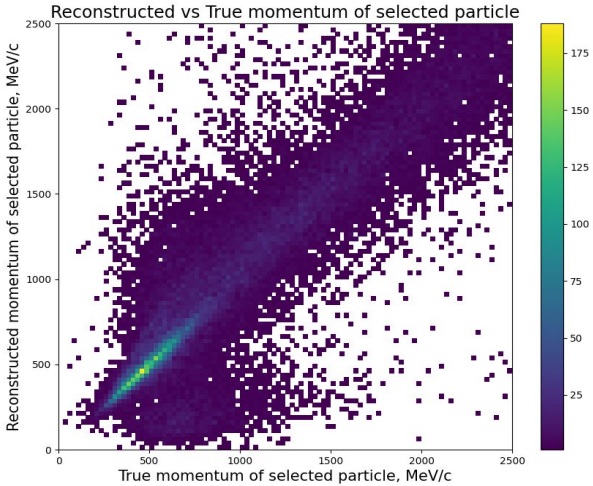
Matching efficiency = 94.4%
For tracks with P > *500 MeV/c*:
Matching efficiency = 99.6%

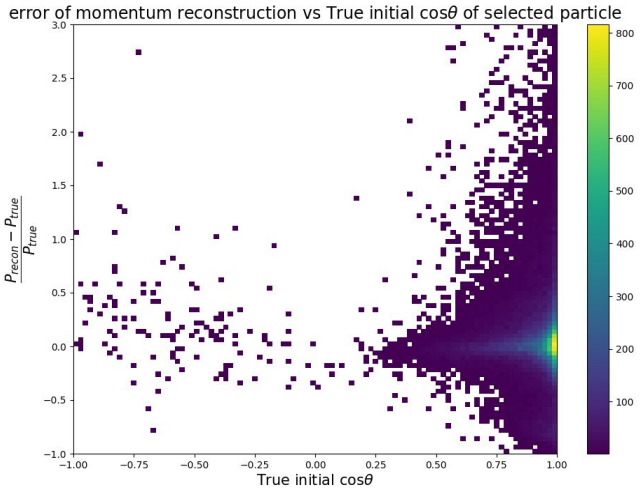
Muons momentum reconstruction resolution

Preliminary









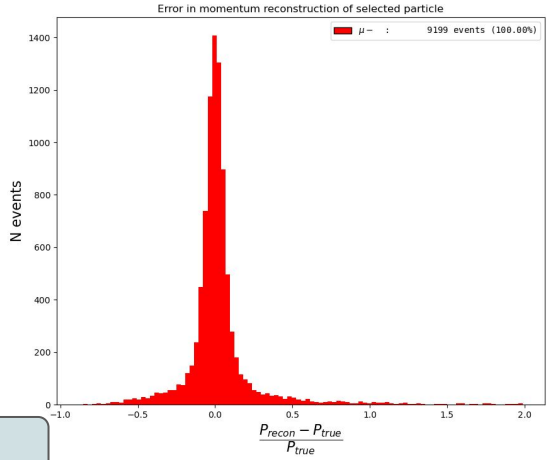
error in momentum reconstruction $\frac{P_{recon} - P_{true}}{P_{true}}$

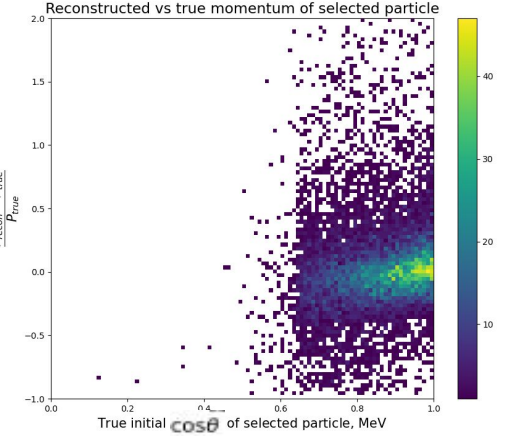
mean 0.023, standard deviation 0.28

Muons momentum reconstruction resolution

Muons with momentum < 1 GeV

Standard deviation in momentum reconstruction error: 0.085

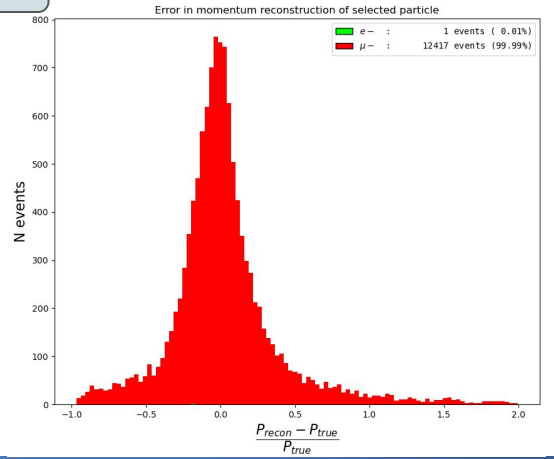


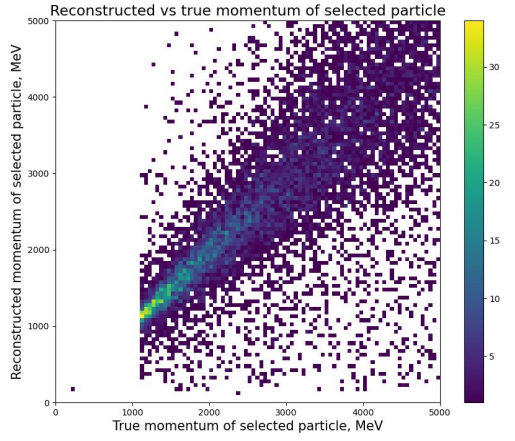


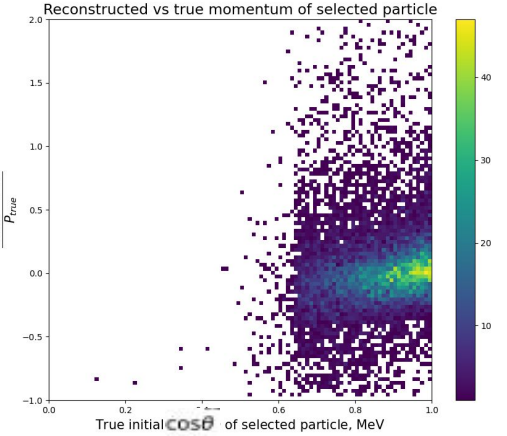
Preliminary

Muons with momentum > 1 GeV

standard deviation in momentum reconstruction error: 0.127







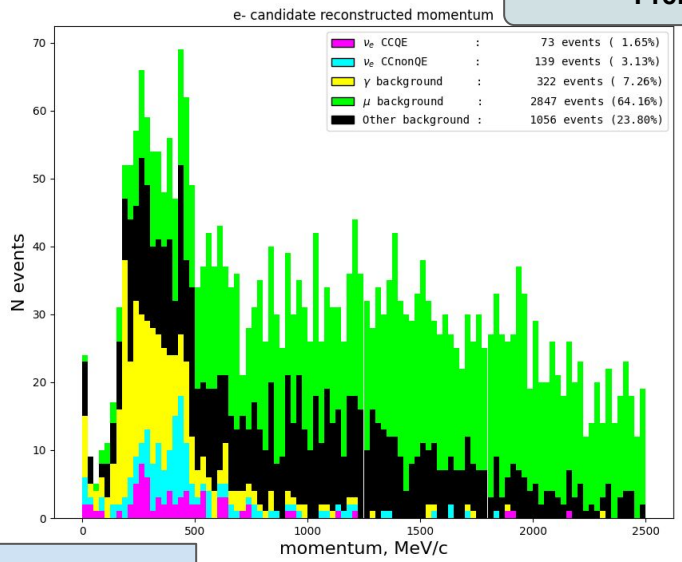
Selection of electrons and SuperFGD-TPC1 track matching

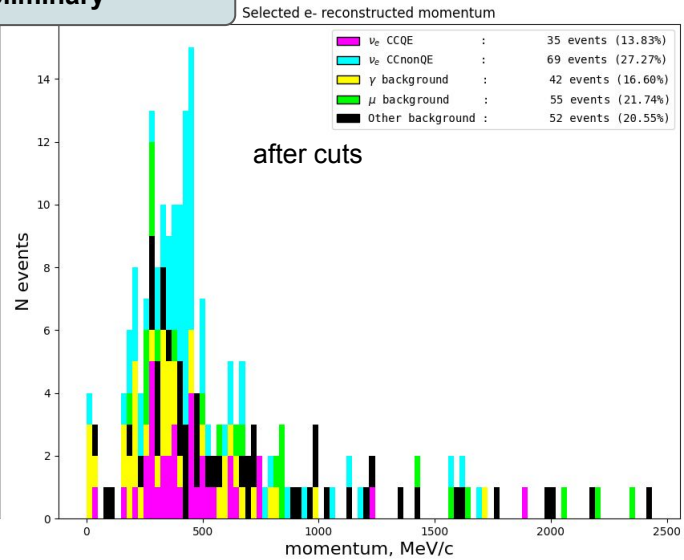
The T2K beam is a muon beam, and mixture of electron neutrinos is about 1%

Cuts applied to select electrons

- event quality
- track has SuperFGD and TPC1 segments
- vertex into SuperFGD
- Cone quality
- Electron PID (BDT-based)
- electron/gamma separation
- TPC1 PID

Preliminary





Matched
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Reco track: SuperFGD+TPC1 segments

Unmatched
True track: SuperFGD+TPC1 segments
Reco track: no TPC1 / no SuperFGD segment

$$\text{Matching efficiency} = \frac{\text{Matched tracks}}{\text{Matched} + \text{Unmatched tracks}}$$

Electrons selected with purity 30.43%
Matching efficiency = 82.1%

Conclusions

- Simulation of muon events in the upgraded ND280 is performed
- Selected muons from neutrino interactions which started in SuperFGD and left to Tracker detector system with purity 94.3%
- SuperFGD-TPC1 track matching efficiency is obtained. For selected muon tracks it is 94.4%, and 99.6% if considering only tracks with momentum higher than 500 MeV/c
- For selected muon track with SuperFGD and TPC1 segment mean error in reconstructed momentum is 0.023 with standard deviation 0.28
- Selected electrons from neutrino interactions which started in SuperFGD and left to Tracker detector system with purity 30.43%. SuperFGD-TPC1 track matching efficiency is 82.1%. Low number of events selected – muon neutrino beam


Thank you for attention!