Electron neutrino interactions in SuperFGD

QUARKS-2024

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T2K experiment

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

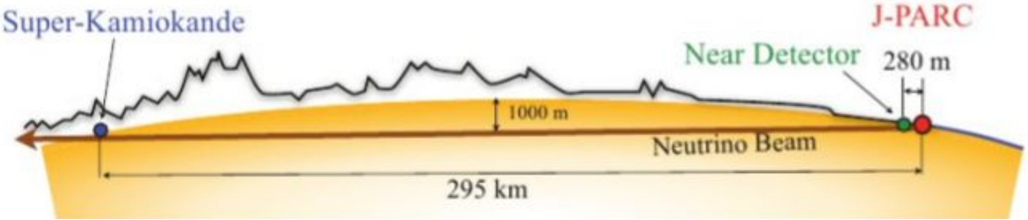
T2K (Tokai to Kamioka) is an experiment with a long baseline for searching for neutrino oscillations

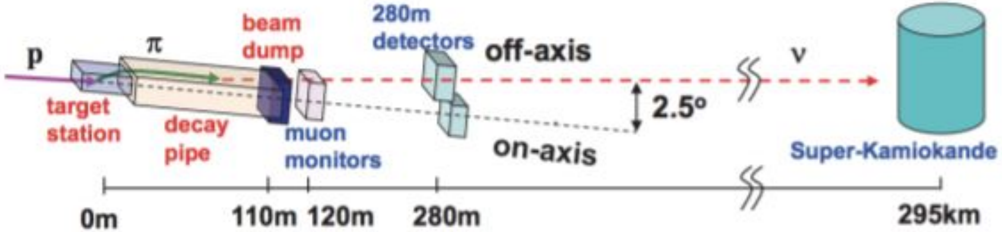
Observations: $\nu_\mu \longrightarrow \nu_e$

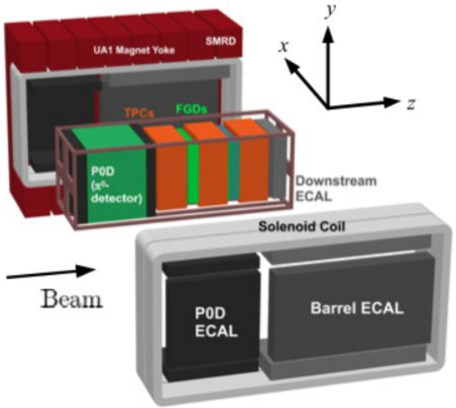
T2K conducts very precise measurements of the probability of oscillations and the difference between the masses of two types of neutrinos.

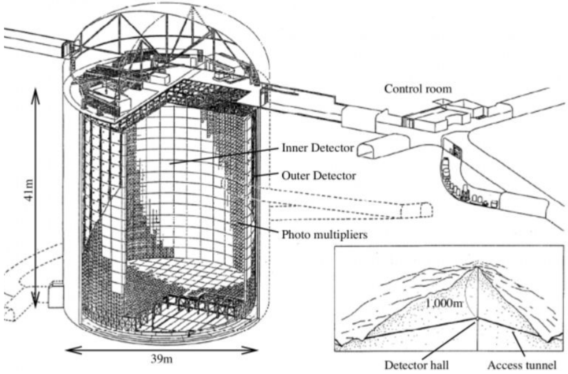
2.5° off-axis angle peaks ν_μ energy spectrum at ~600 MeV

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

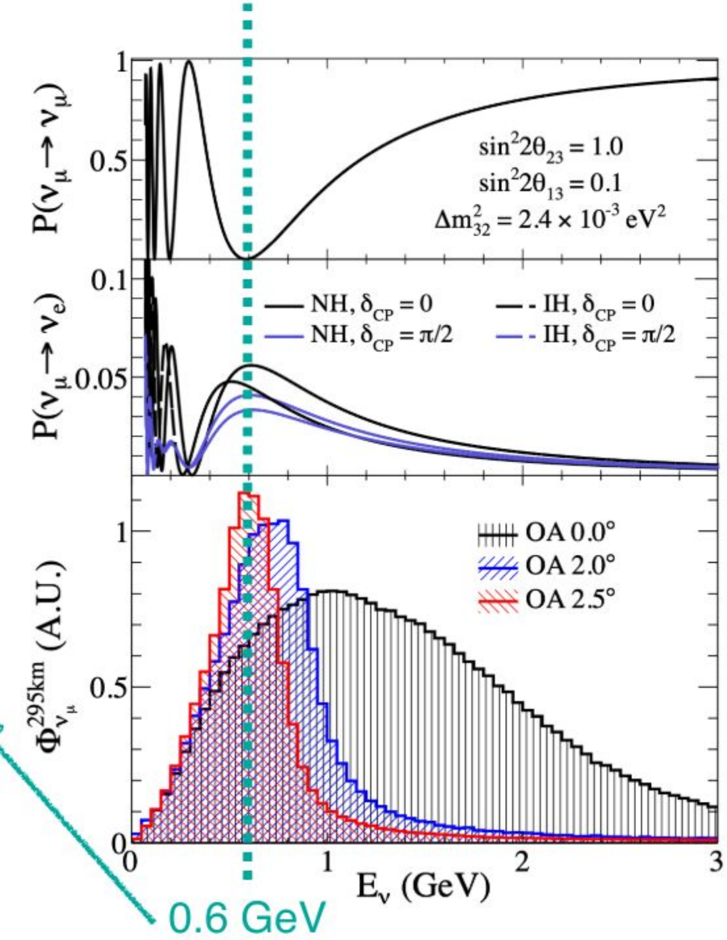


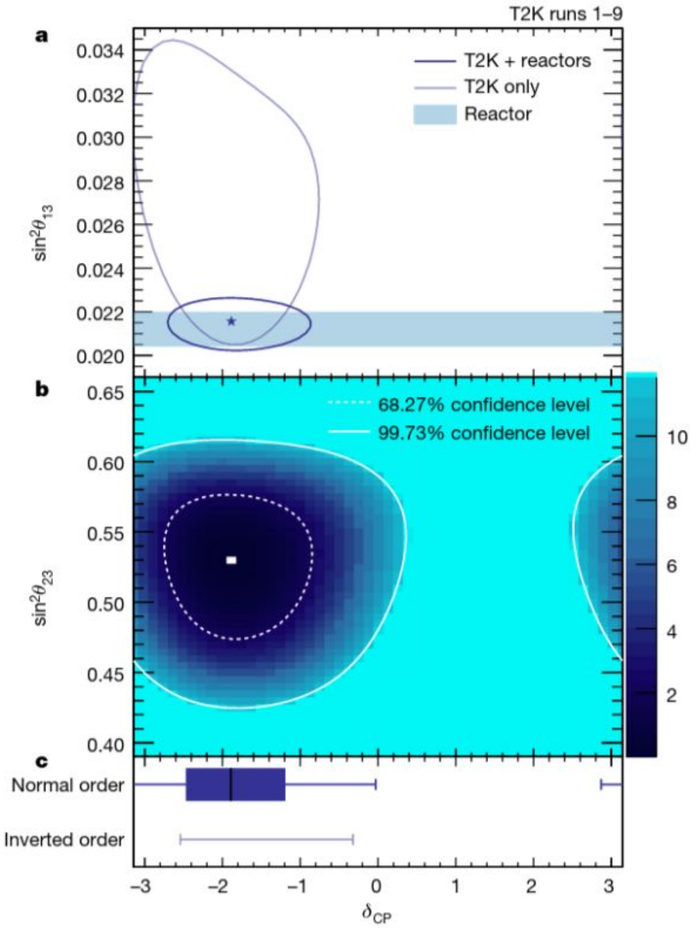






T2K experiment





Nature 580, 339-344 (2020)
arXiv:1910.03887 **[hep-ex]**

Normal order

$$\Delta m^2_{32} = (2.45 \pm 0.07) \times 10^{-3}\ \mathrm{eV}^2/c^4$$

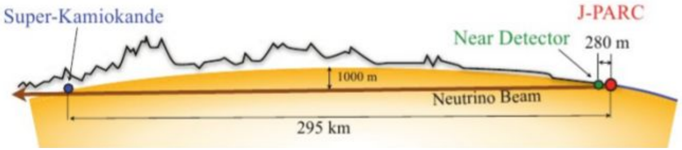
Inverted order

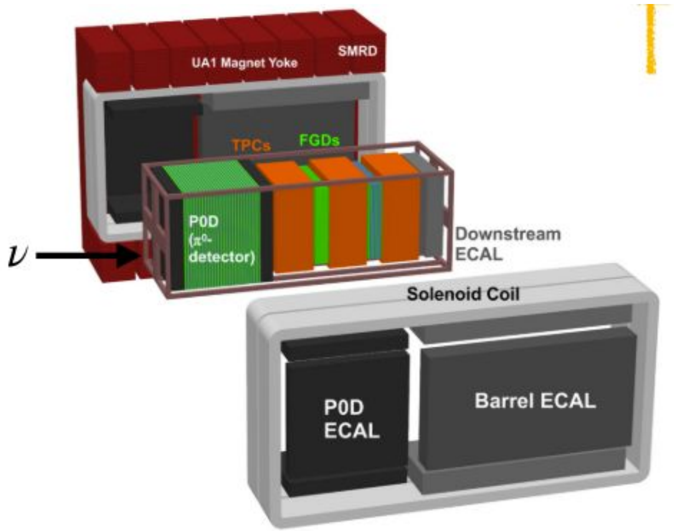
$$\Delta m^2_{13} = (2.43 \pm 0.07) \times 10^{-3}\ \mathrm{eV}^2/c^4$$

δ_{CP} normal (inverted)

$$-1.89^{+0.70}_{-0.58}\ (-1.38^{+0.48}_{-0.54})$$

CP-conserving phase is excluded with 90% confidence level



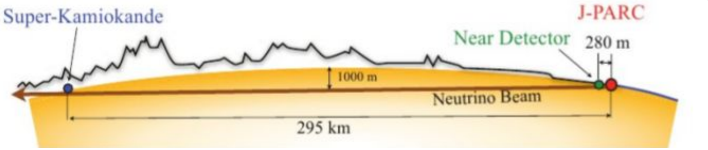


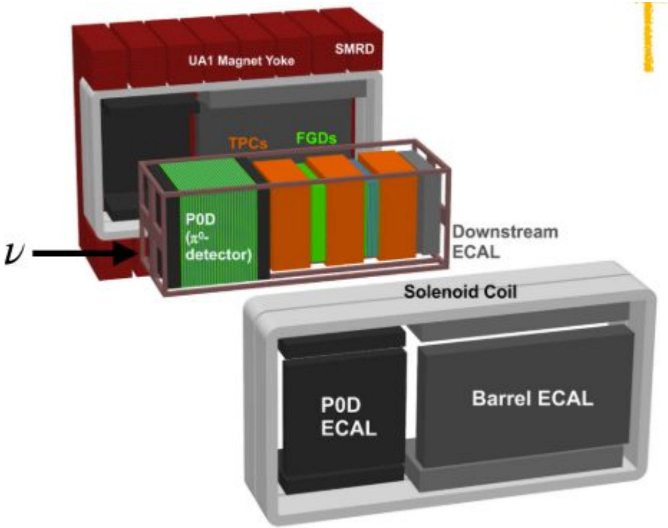
Previous configuration (2010-2022)

- 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.

Near Detector



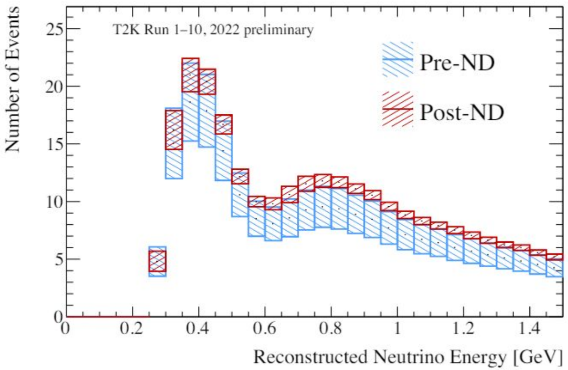


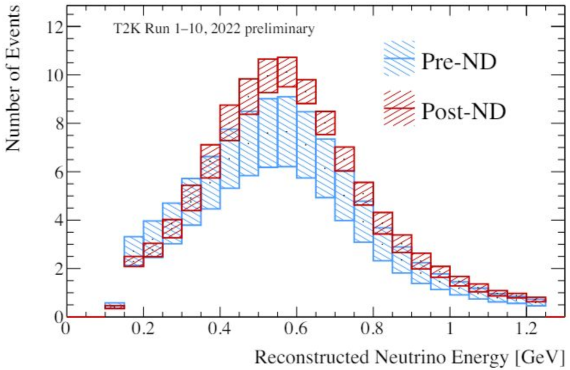
Previous configuration (2010-2022)

Systematic uncertainty is contrained by the measurements of the Near Detector

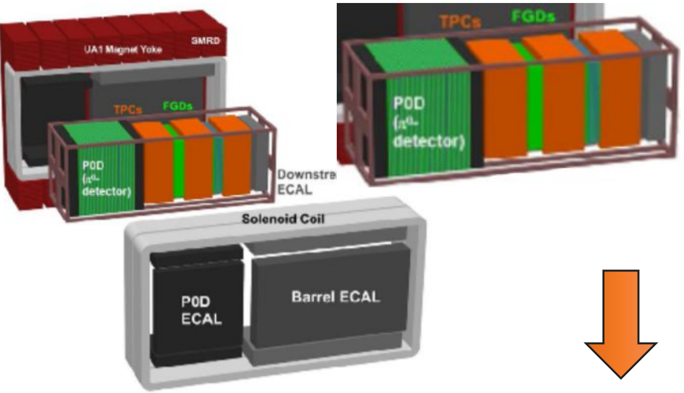
- ➔ Neutrino flux
- ➔ Neutrino spectrum
- ➔ Neutrino interaction cross sections

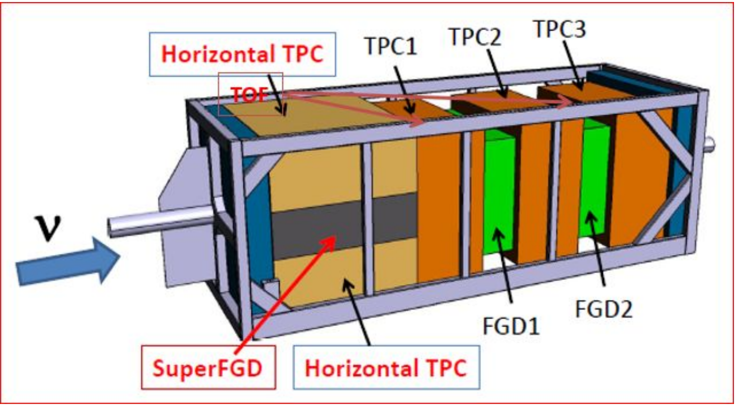
ND280 helps to reduce Super-Kamiokande systematics from 15% to ~5-6%





Upgrade of the off-axis near detector ND280





Requirements for a scintillation detector

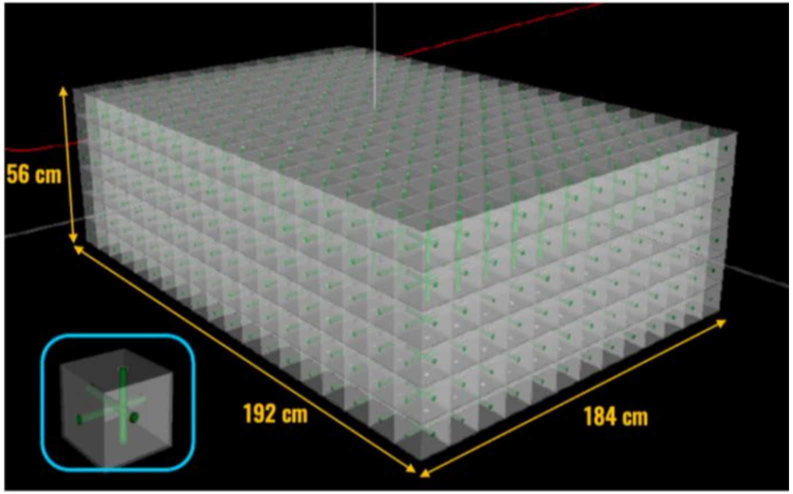
- ➔ Significant mass to ensure a large number of neutrino interactions (comparable to the mass of two FGDs).
- ➔ 4π registration of charged leptons.
- ➔ Study of electron neutrino reactions.
- ➔ Ability to reconstruct and identify short tracks of low-energy hadrons around the interaction vertex.
- ➔ Differentiation between electrons and photons.
- ➔ Registration of neutrons.

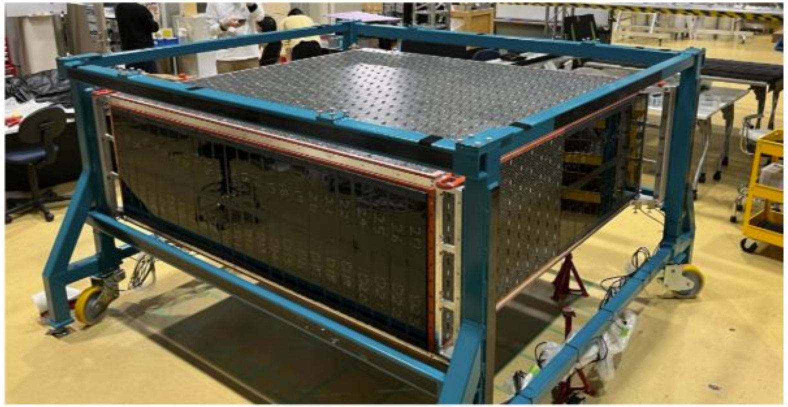
P0D is replaced with: SuperFGD, 2 High-angle TPCs, 6 TOFs

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

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.

Possible issues

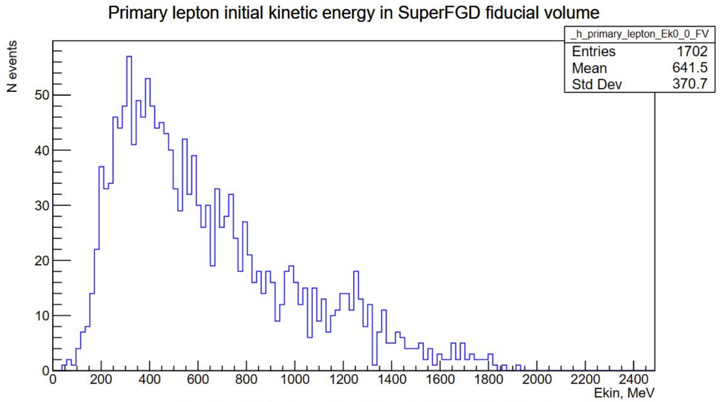
- ➢ Energy losses in the inactive material
- ➢ Difficulties with electron track reconstruction

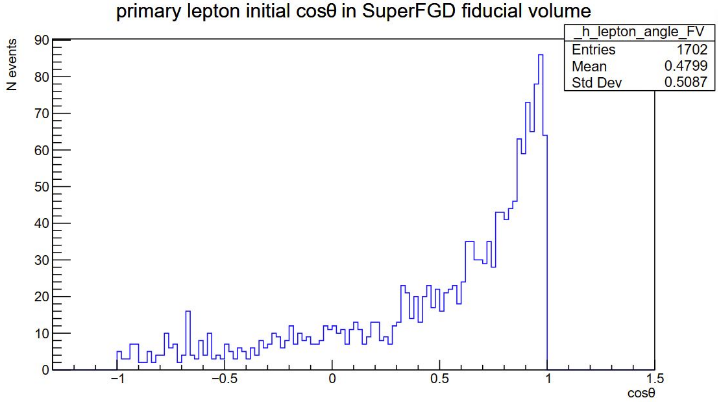
Task: investigate ability of SuperFGD to reconstruct electron neutrino events

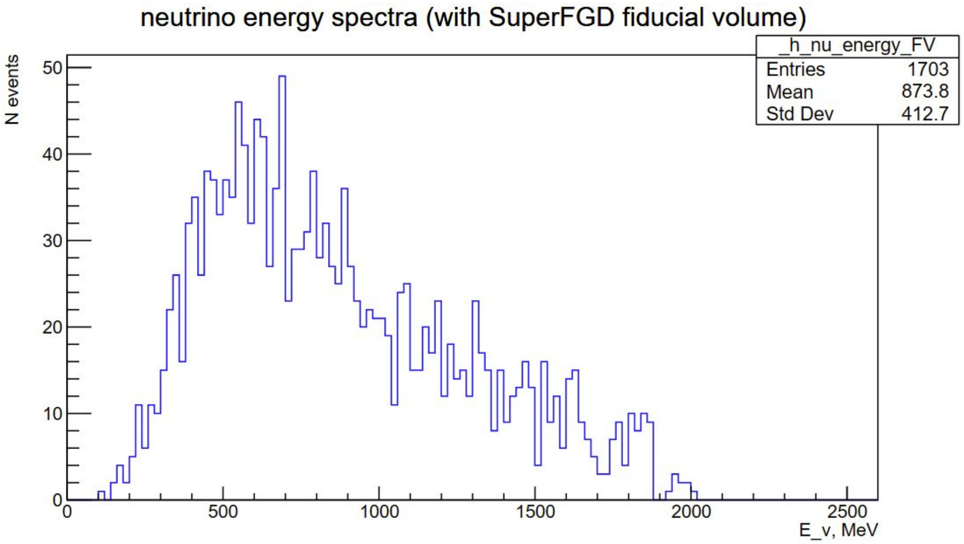
Simulation of CCQE nu_e events is done with GENIE according to the T2K neutrino flux, max energy 2 GeV

Simulation of SuperFGD events is done with the T2K software

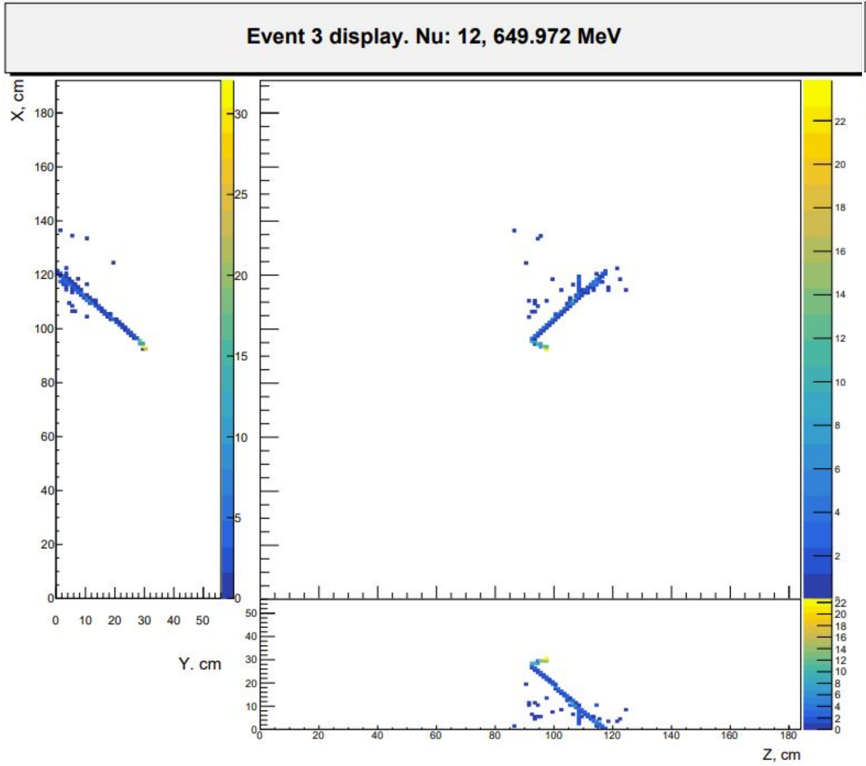
Fiducial volume of SuperFGD – volume of the detector without two layers of cubes on its edges

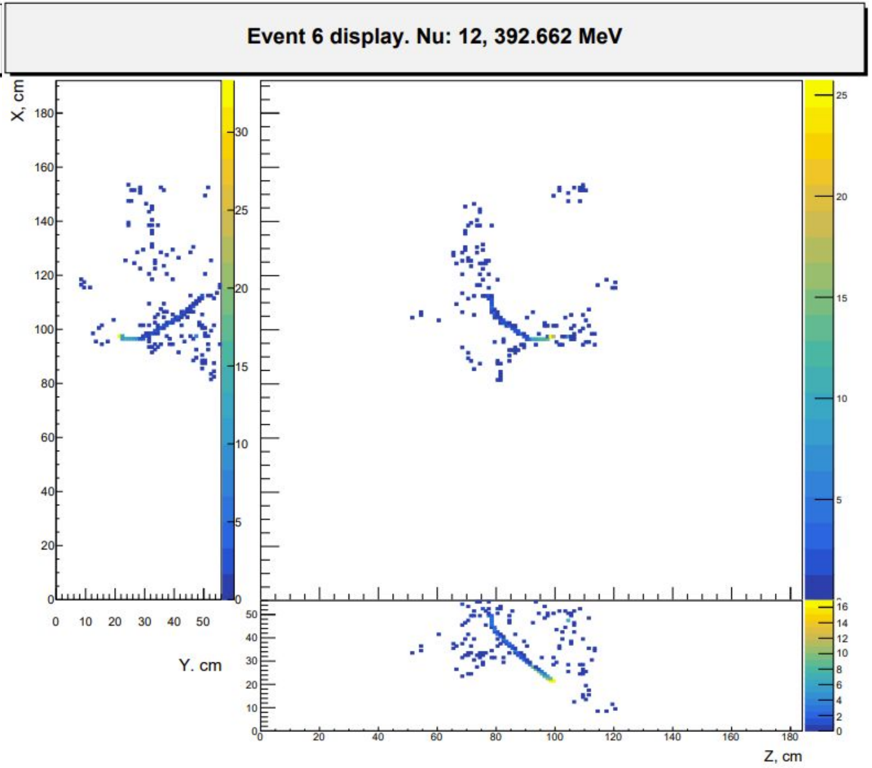






SuperFGD simulation: examples of ν_e events

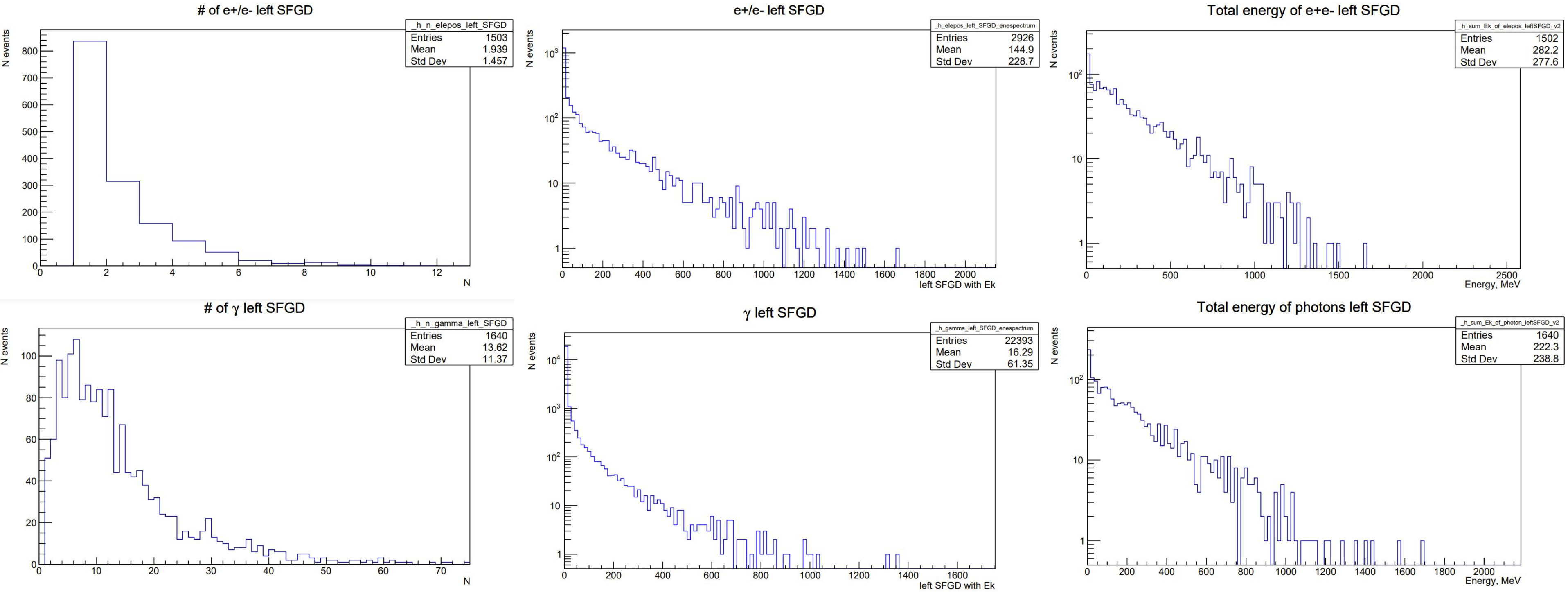




Many e+/e- and gammas from primary electron shower left SuperFGD

SuperFGD simulation:

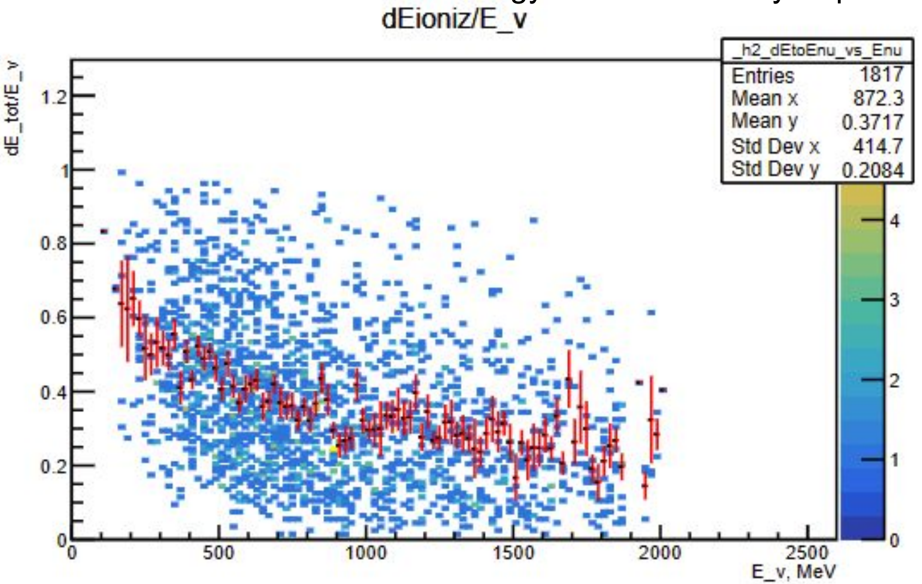
Many e+/e- and gammas from primary electron shower left SuperFGD

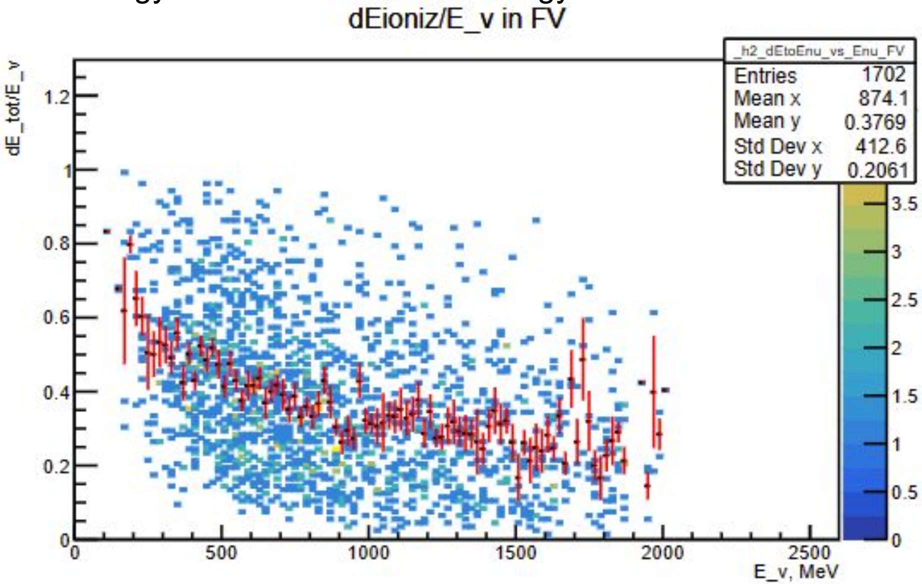


SuperFGD simulation: CCQE ν_e, <=2GeV; magnetic field 0.2 Tesla

Many e+/e- and gammas from primary electron shower left SuperFGD =>
SuperFGD collects 38.37% of total interaction energy (true simulation information)

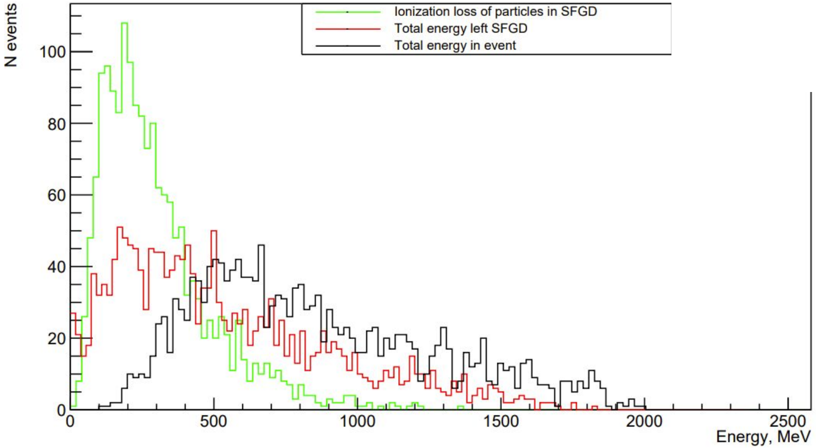
Relation of energy loss collected by SuperFGD to total energy in event wrt neutrino energy

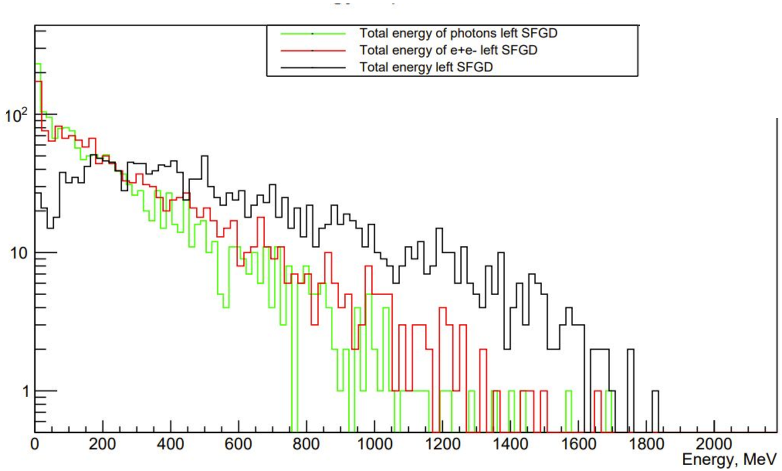




SuperFGD simulation:

Many e+/e- and gammas from primary electron shower left SuperFGD =>

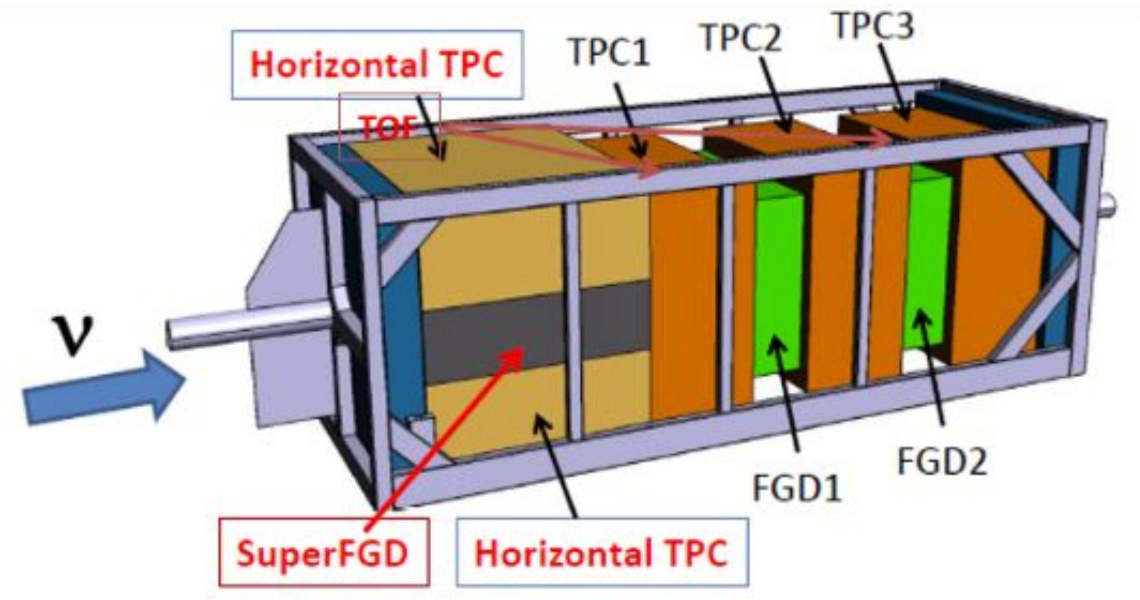




SuperFGD collects 38.37% of total interaction energy (true simulation information)
61.63% carried out by particles left SuperFGD e+/e- (52.5%), photons (41%), protons (6.5%)

SuperFGD simulation: if particle leaves SFGD

Split by 6 sides to which particles can fly:
- Top/Bottom – HATPC+ECAL
- Forward — Tracker (TPC+FGD)
- Left/Right/Backward — can not detect



ν_e

Top (HATPC)	:	27.9%
Forward (Tracker)	:	27.46%
Bottom (HATPC)	:	26.83%
Right	:	7.779%
Left	:	7.606%
Backward	:	2.43%

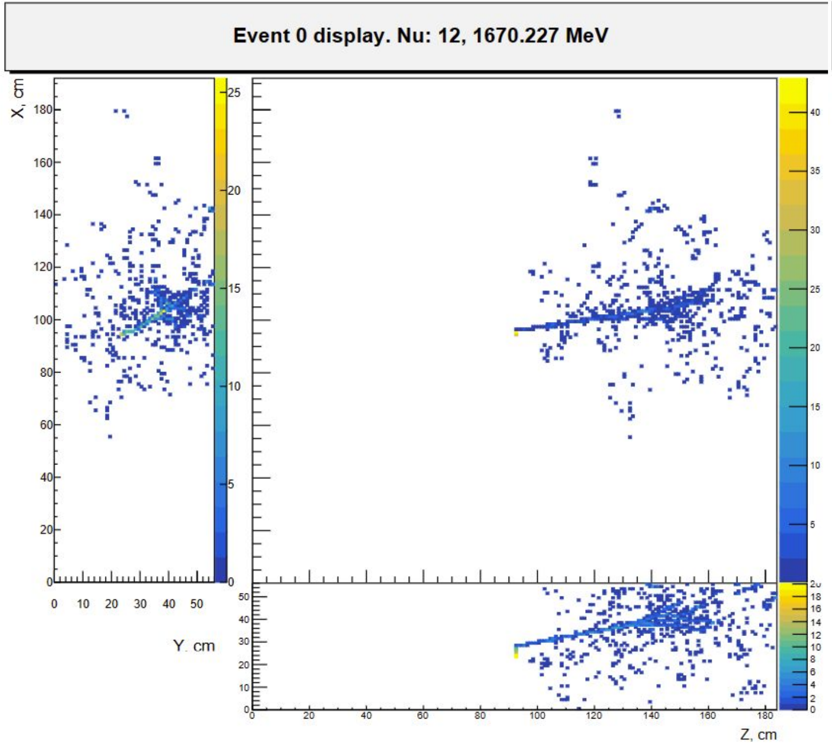
Top+Bottom+Forward: 82.19%
Left+Right+Backward: 17.81%

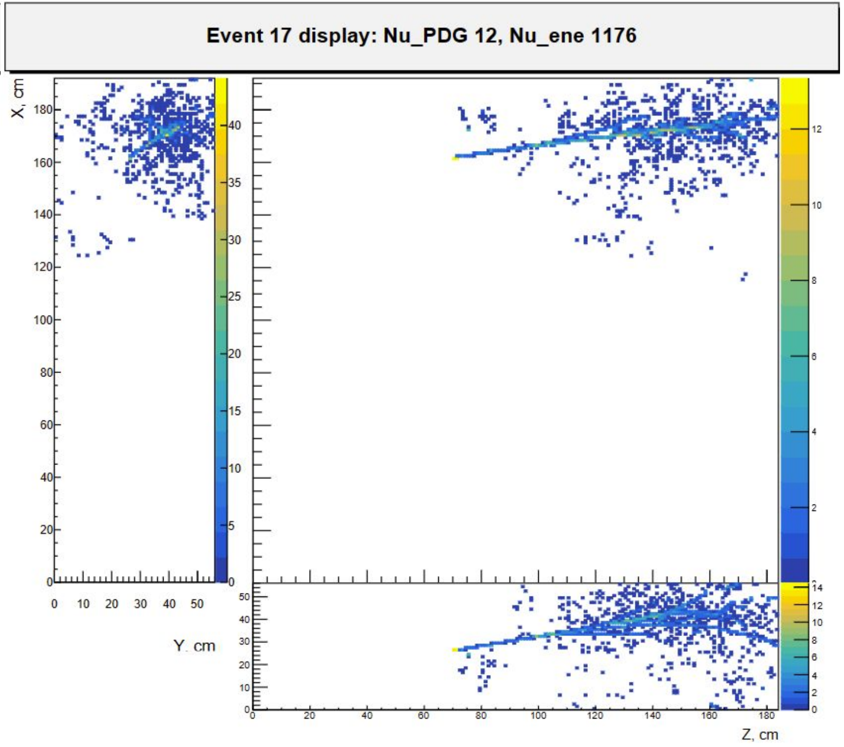
Conclusions

- ✔ **Monte-Carlo simulations of CCQE neutrino interactions in SFGD show that detector is capable to register** 38% **of deposited energy for NUE.**
- ✔ **62% of energy left SuperFGD with e+/e-/photons/protons (mainly e+/e- 52.5%, photons 41%)**
- ✔ **Particles that left SuperFGD can be detected by HATPC + ECAL (Top and Bottom detector sides), and by Tracker – FGD+TPC (Forward direction), in total about** 82% **of all energy carried out by these particles.**

Thank you for attention!

SuperFGD simulation: examples of ν_e events





500-600 MeV

Many e+/e- and gammas from primary electron shower left SuperFGD