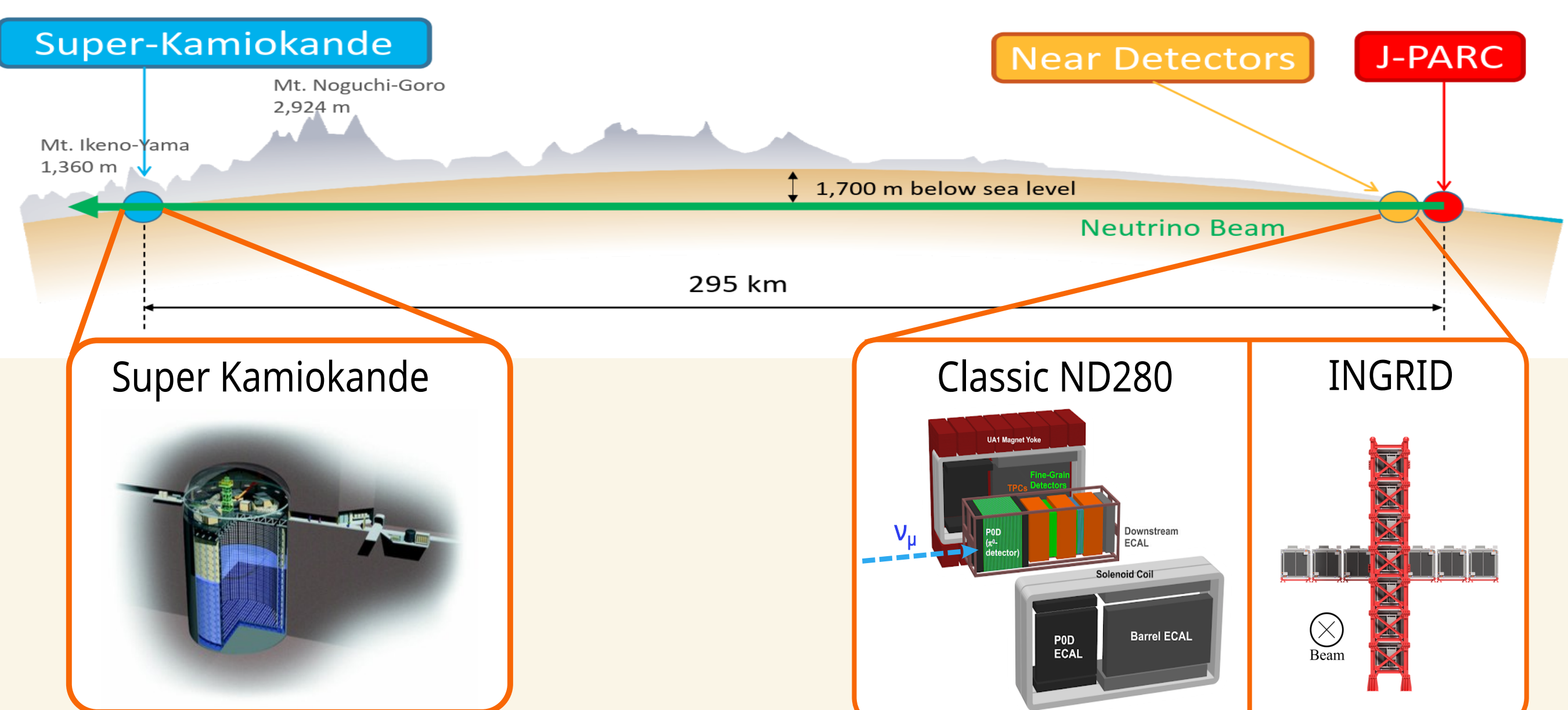


T2K Experiment and FGD Detectors

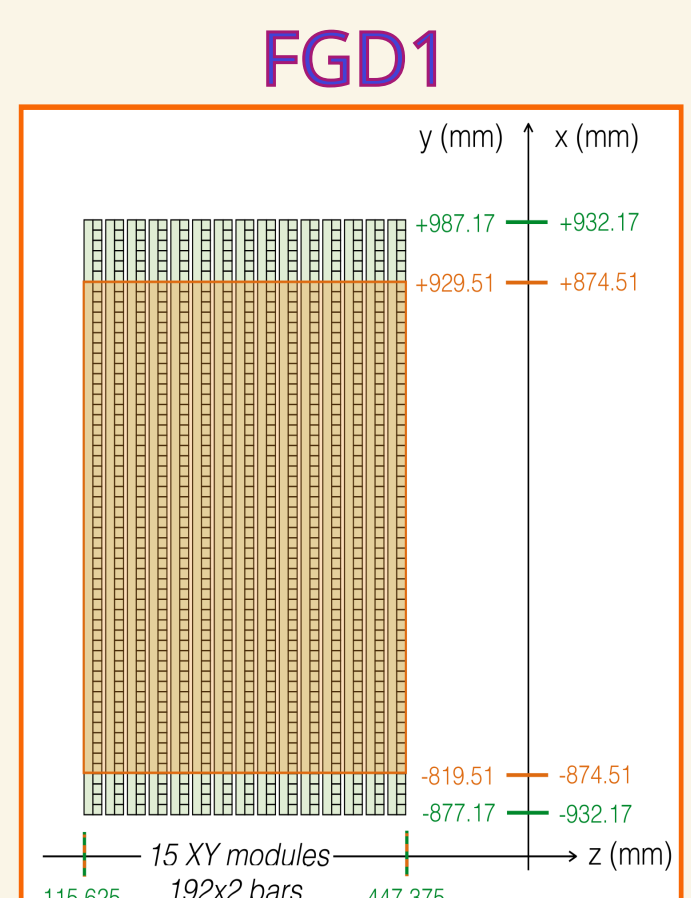
The Tokai-to-Kamioka (T2K) experiment is a state-of-the-art long-baseline neutrino experiment with the physics goal of precisely measuring the neutrino oscillation parameters.



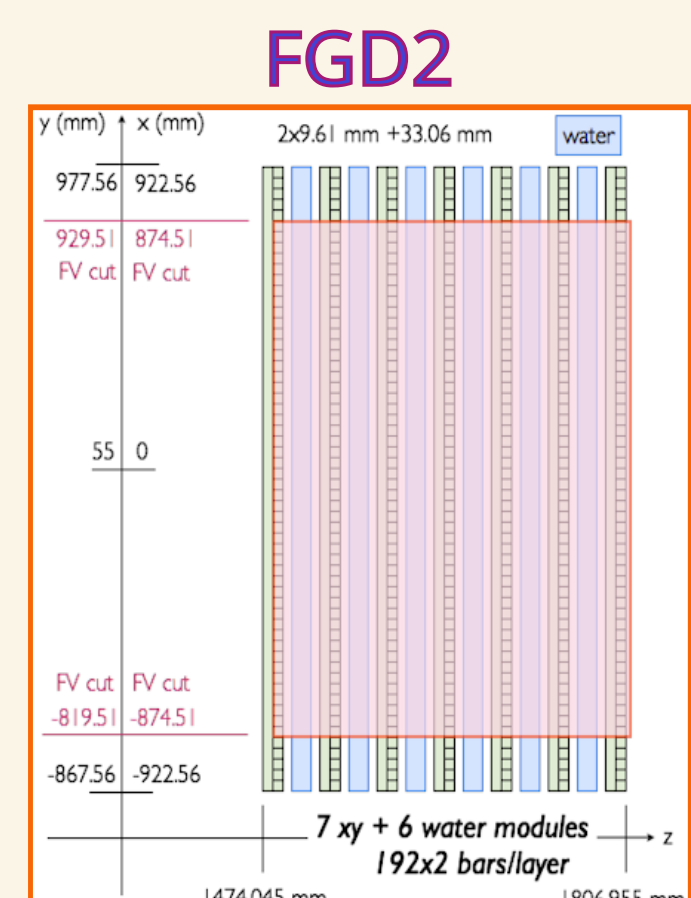
- Super K measures neutrinos after oscillations

- The off-axis detector ND280 characterizes the muon neutrino beam before oscillations.
- The on-axis detector INGRID monitors beam direction.

Target Mass for Classic ND280 : Fine Grained Detectors



- 15 active XY-scintillation modules as C targets (~86.1% Carbon by total mass).
- Scintillation light is collected with wavelength-shifting fibers.



- 7 active XY-scintillation modules and 6 passive water modules.
- The water modules provide O targets.
- ~48.6% Carbon and ~40.6% Oxygen by total mass.

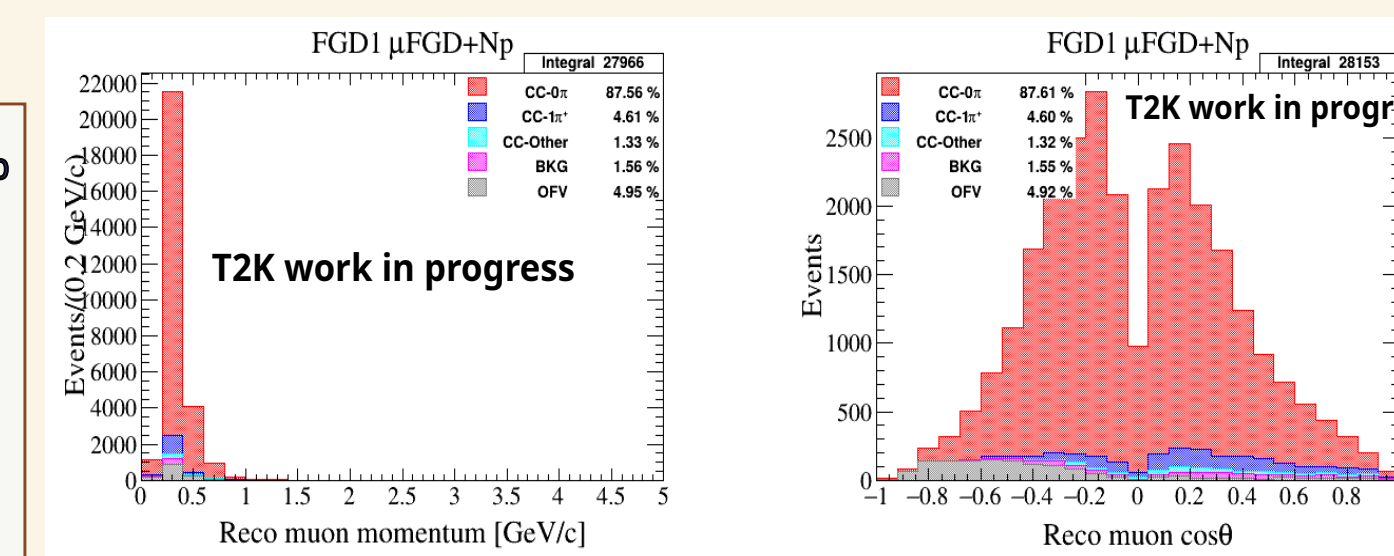
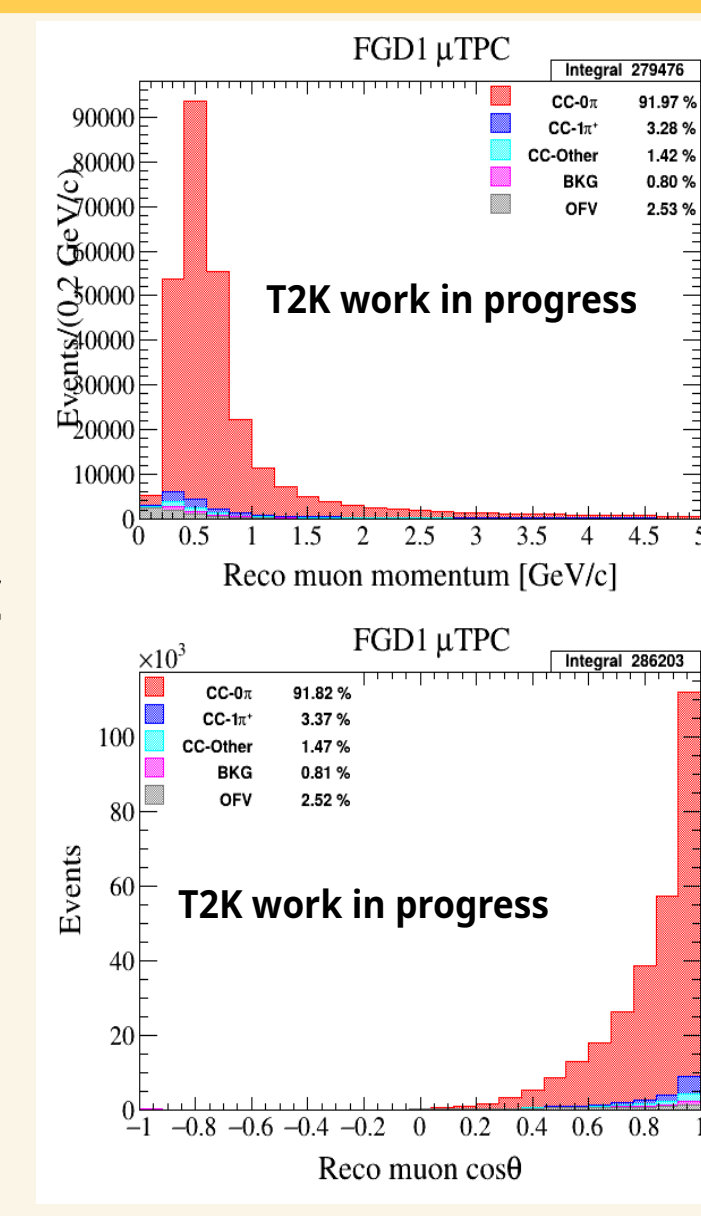
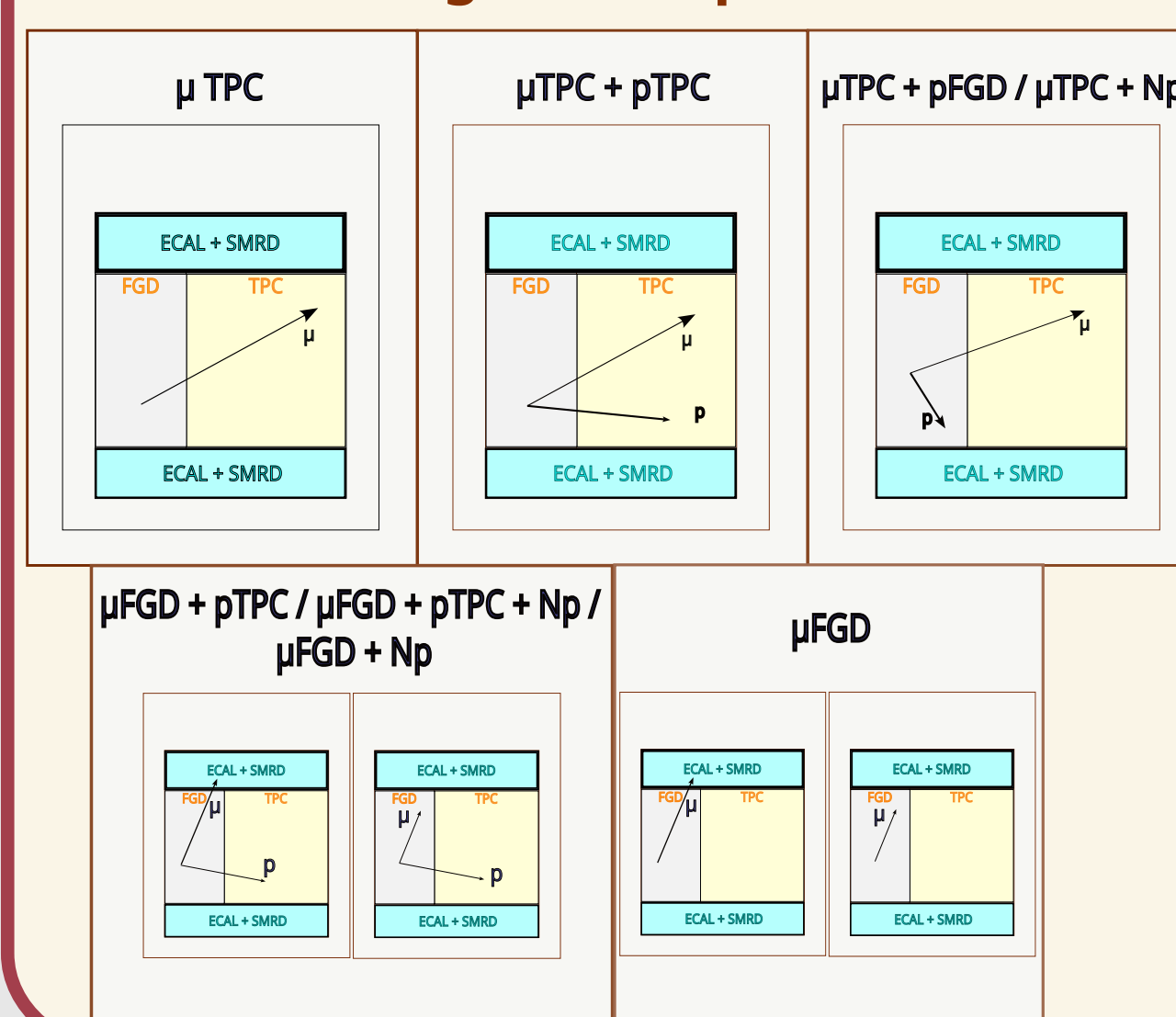
Event Selection and Samples

• Signal signature for CCQE-like events is:

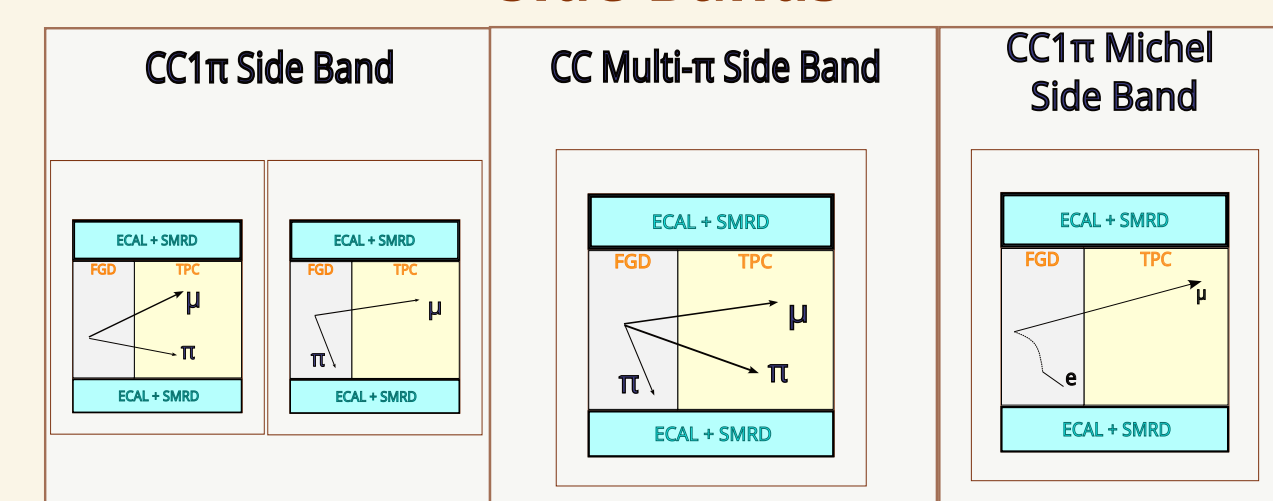
- One muon track
- Zero or more proton tracks
- No other identified tracks

- Signal events are divided into 5 samples to accommodate response, reconstruction, and systematic differences between sub-detectors
- Signal selection is inverted to obtain side bands rich in background events.
- Dominant background contribution is from events producing one or more pions which may get mis-reconstructed as protons.

Signal Samples



Side Bands



Systematic Uncertainties

Systematic uncertainties are a significant contribution to the total uncertainty in cross section measurements. These arise from detector effects, flux predictions, cross-section models etc.

Detector Systematic Uncertainty:

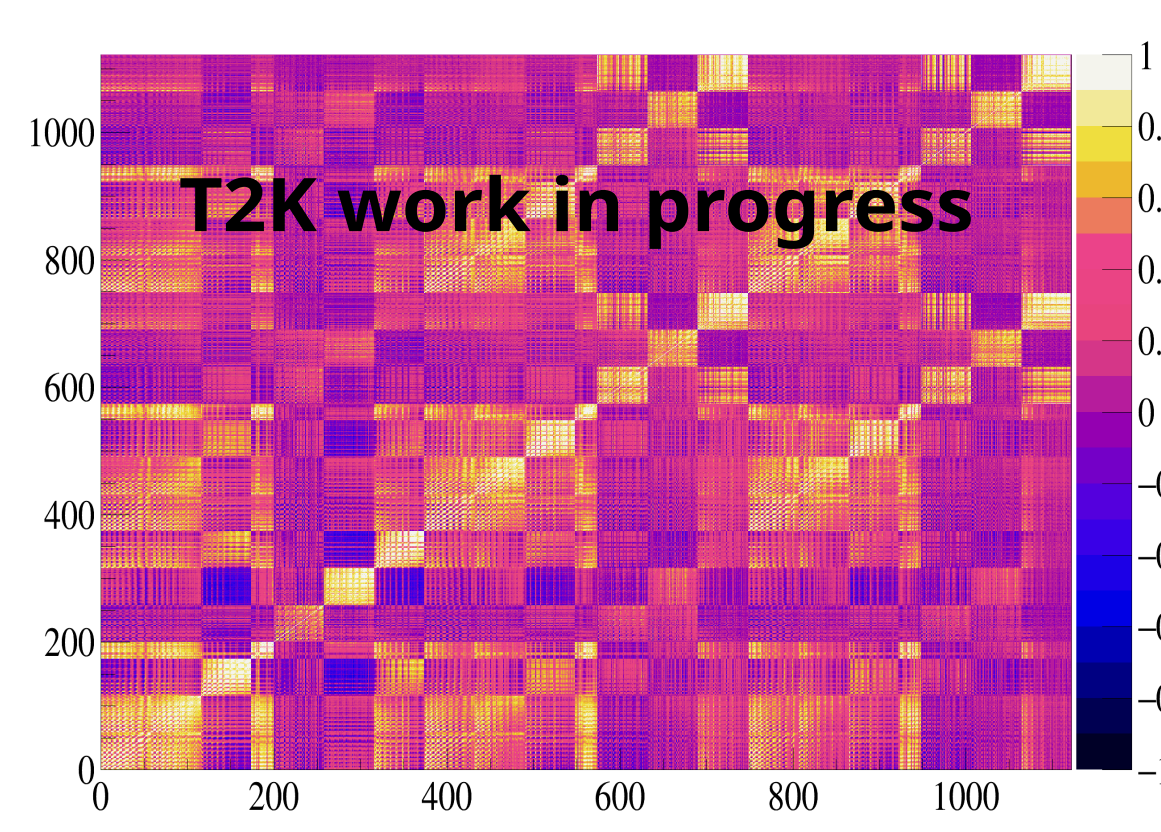
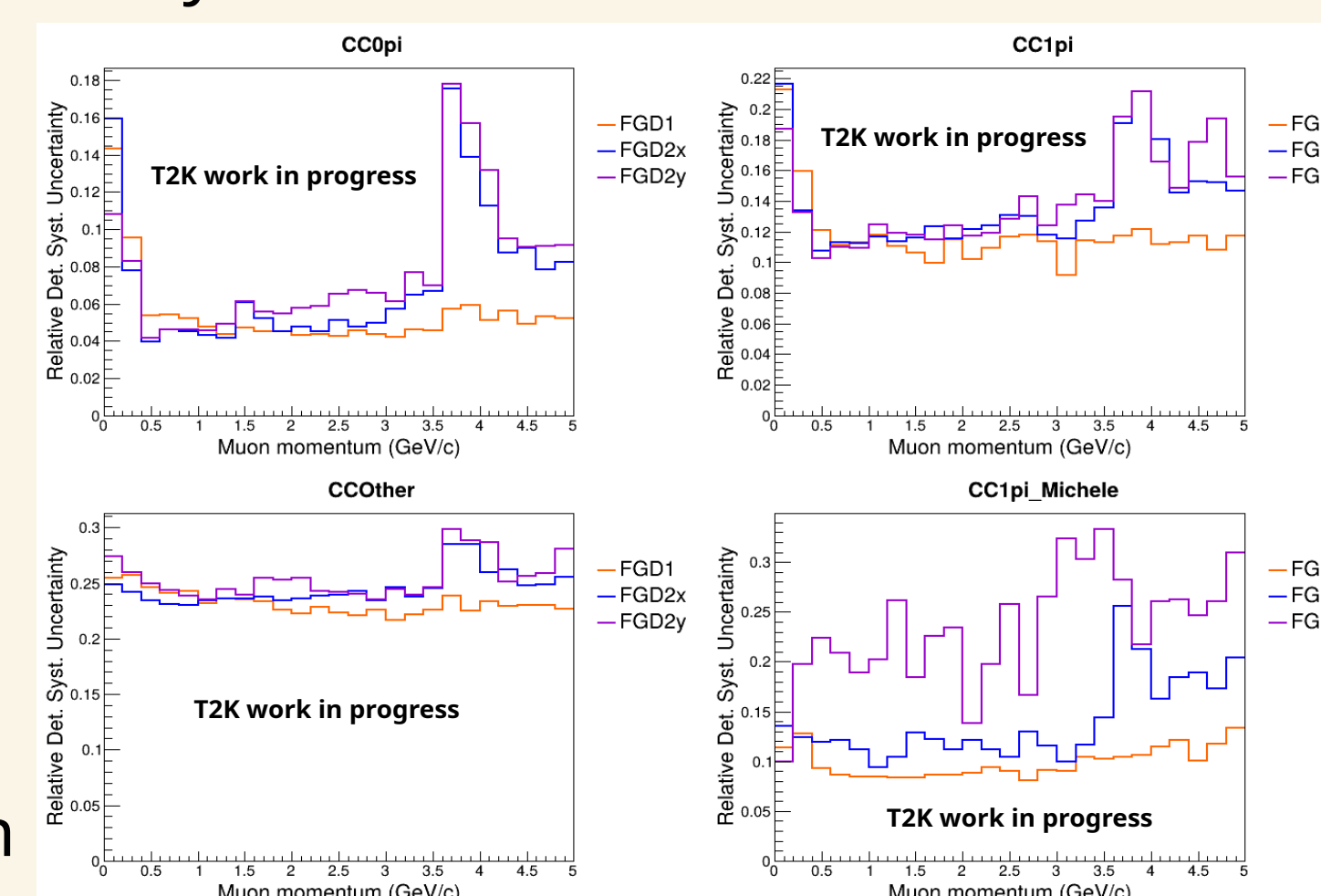
This is due to imperfections in modeling the detector response in ND280. The dead material in the detector, modeling of the magnetic field, electronic response, etc., contribute to the imperfections. There are two types and they are evaluated differently;

Weight Systematics

- Changes the probability of an event to occur.
- Propagated by reweighting events.
eg: Charge ID, TPC tracking efficiency, etc.

Variation Systematics

- Changes the mean value of an observable and migrates events across analysis bins.
- Propagated by smearing observables before applying the selection.
eg: Mom. resolution, Mom. scaling Magnetic field distortions, etc.



Cross Section

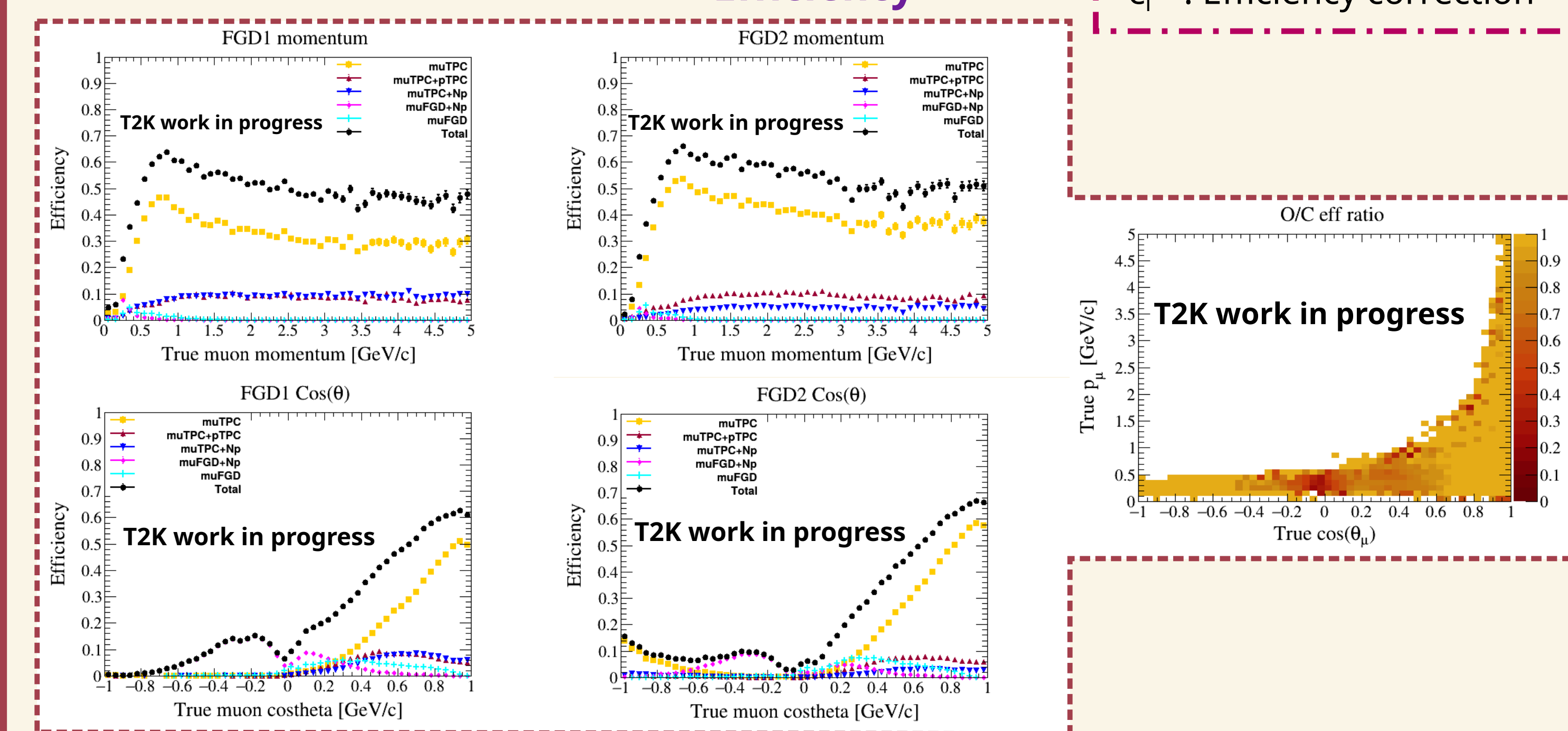
The cross section is measured as a function of final state particle's kinematics to reduce dependence on interaction models.

The 2D differential cross section in muon momentum and cosine angle is

$$\frac{d\sigma_i^\alpha}{dp_\mu^i d(\cos\theta_\mu^i)} = \frac{N_i^{signal} \alpha}{\epsilon_i^\alpha \Phi N_t^\alpha \Delta p_\mu^i \Delta(\cos\theta_\mu^i)}$$

Efficiency

α : C or O index
 Φ : Integrated Flux
 $N_i^{signal-\alpha}$: inferred signal event rate
 N_t^α : # target nucleons
 ϵ_i^α : Efficiency correction



Each analysis bin gets a template parameter and these are used to reweight MC signal event rates in true phase space to modify the 2D muon kinematics after event selection.

The template parameters are obtained from a binned likelihood fit of the reconstructed 2D muon kinematic spectrum from MC after selection to the observed spectrum in data.

The systematic parameters are included as nuisance parameters in the fit and the backgrounds are constrained by simultaneously fitting the side bands.

Conclusions

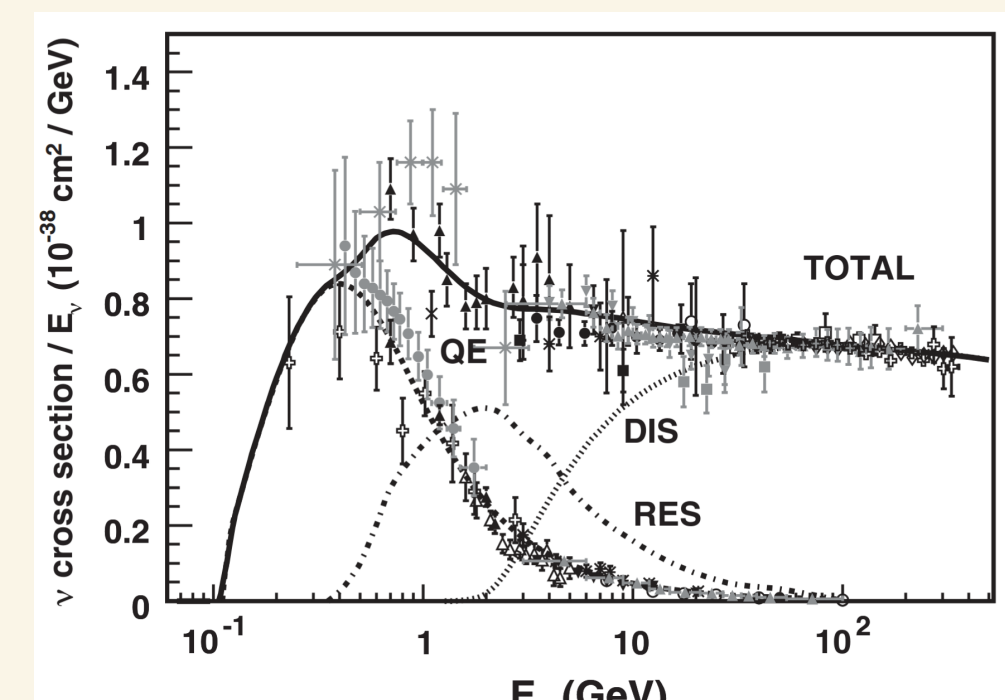
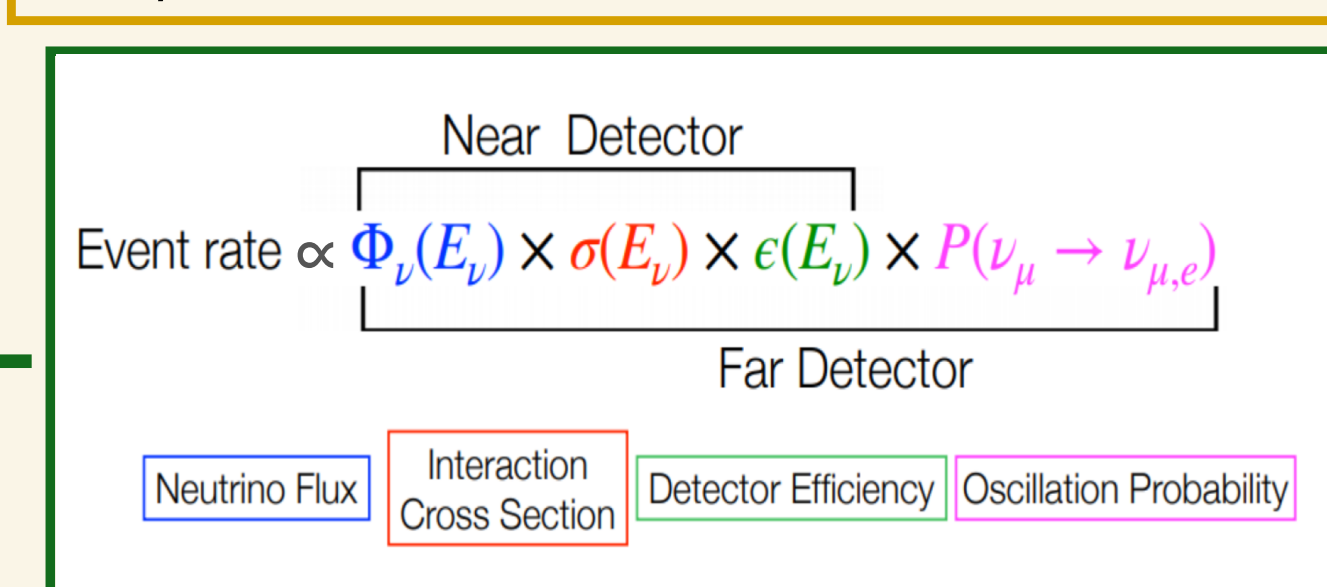
- This measurement uses the full neutrino-mode data set collected during phase-I of T2K with the classic ND280 detector configuration (total POT 1.15×10^{21}), doubling the statistics compared to the previous measurement.
- Measuring the oxygen cross section is especially important because many neutrino experiments use water targets but only a few can perform this measurement.
- The latest and improved reconstruction and selection framework is used for this measurement.
- Modified side bands are used to constrain various backgrounds:
 - CC1 π and CC Multi- π side bands improved to constrain pions stopping in the FGDs.
 - An additional side band with Michel electron signature.

References

- [1] **Detector Images** : T2K Collab. <https://t2k-experiment.org/t2k/>
 [2] **FGD cross section view** : *Phys. Rev. D*,95:012010 (2017), *Phys. Rev. D*,98:012004 (2018)
 [3] **ν_μ Interaction channels** : *Rev. Mod. Phys.* 84, 1307 (2012)

Why ν_μ CC0 π Cross Section on C & O??

Event rates are a convolution of flux, cross section and detector effects



- T2K's neutrino beam peaks around 600 MeV.
- Below ~1 GeV the dominant interaction channel is charged Current Quasi Elastic (CCQE).
- In terms of final state particles, we look for CCQE-like events that produce a single lepton and any number of nucleons with zero mesons.

~3% of the total uncertainty in the best fit oscillation parameter values comes from flux and cross section

T2K uses a predominantly carbon-target near detector and a water-target far detector