icise
QUY NHON VIETNAM

東京大学
THE UNIVERSITY OF TOKYO

The University of Tokyo
Hongo, Bunkyo-ku, Tokyo 113-8654, Japan

September 12th, 2018

Concerning the Start of Hyper-Kamiokande

Seed funding towards the construction of the next-generation water Cherenkov detector Hyper-Kamiokande has been allocated by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) within its budget request for the 2019 fiscal year. Seed fundings in the past projects usually lead to full funding in the following year, as it was the case for the Super-Kamiokande project.

The University of Tokyo pledges to ensure construction of the Hyper-Kamiokande detector commences as scheduled in April 2020. The University of Tokyo has made this decision in recognition of both the project's importance and value both nationally and internationally.

The neutrino research that lead to Nobel prizes for Special University Professor Emeritus Koshiba and Distinguished University Professor Kajita has entered a new era. The international community has demonstrated the need for Hyper-Kamiokande. The considerable expertise and achievements of the University of Tokyo and Japan, and unique and invaluable contributions from national and international collaborators will ensure the project will make significant contributions to the intellectual progress of the world.

Makoto Gonokami

Makoto Gonokami
President, The University of Tokyo

CP Violation Tokai-to-HyperK (T2HK)

Ankur Nath

Pursuing Ph.D. (PHP17004)

Tezpur University, Assam

India

Contents

Please Note

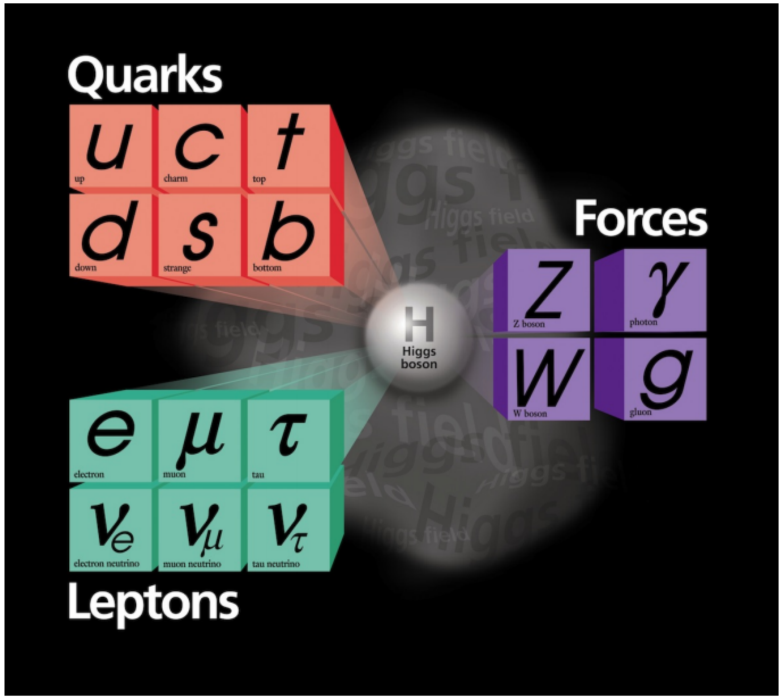
- A few figures have been taken from VsoN-2018 lectures and Super-Kamiokande website for illustrative purposes
- Ask me anything, i'll make an attempt to answer.

  Or else, I shall note down and get back to you.

Standard Model and Neutrino

Neutrinos :

- Very light (neutrino mass ~10^{-6} electron mass)
- spin – 1/2, electrically neutral, leptons.
- Most abundant fermion in the Universe 336 cosmic neutrinos/cm^3
- In the Standard Model, neutrinos are massless.
- Non-zero neutrino mass is evident from the observation of **neutrino oscillations.**



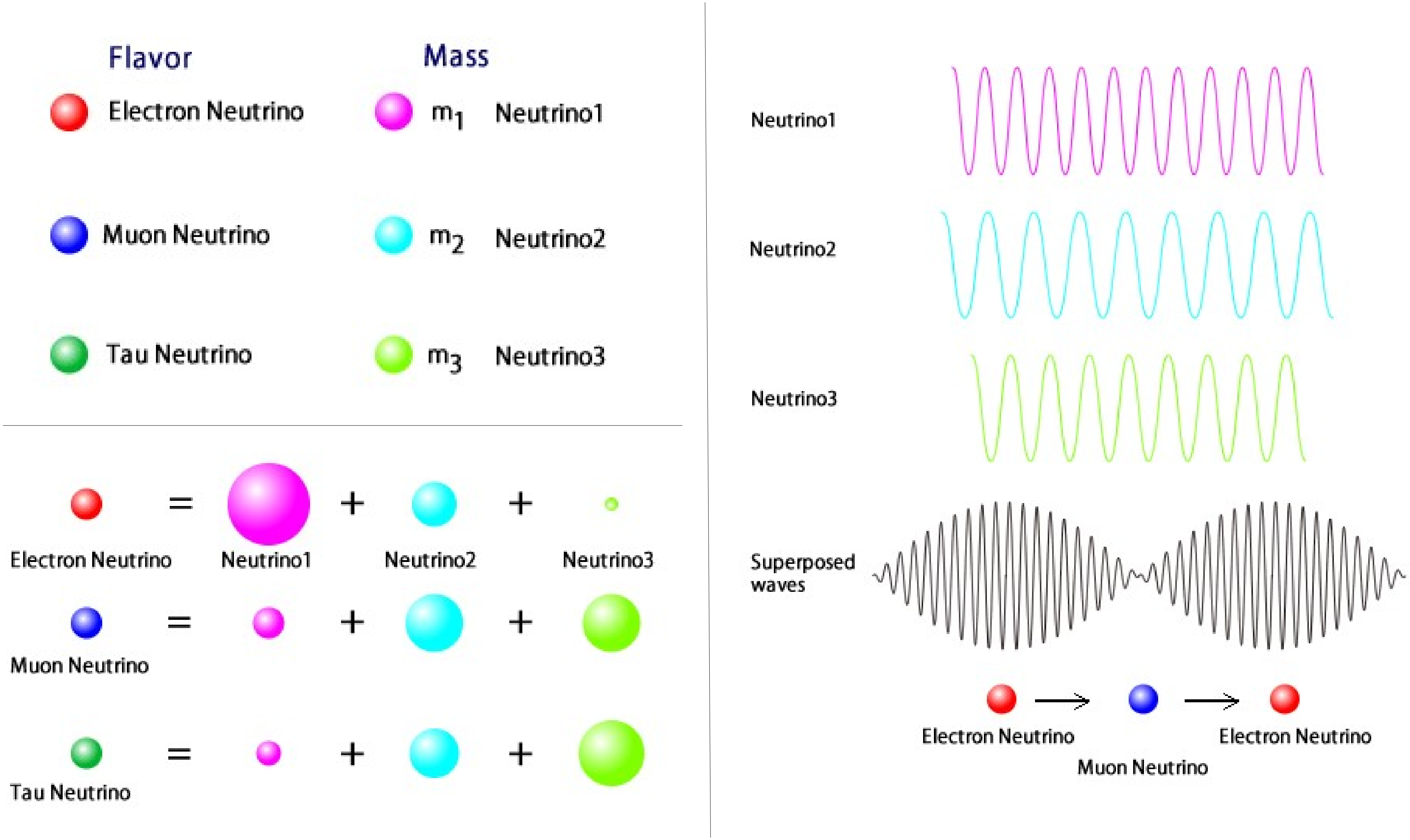
Neutrino mass → Beyond Standard Model Physics.

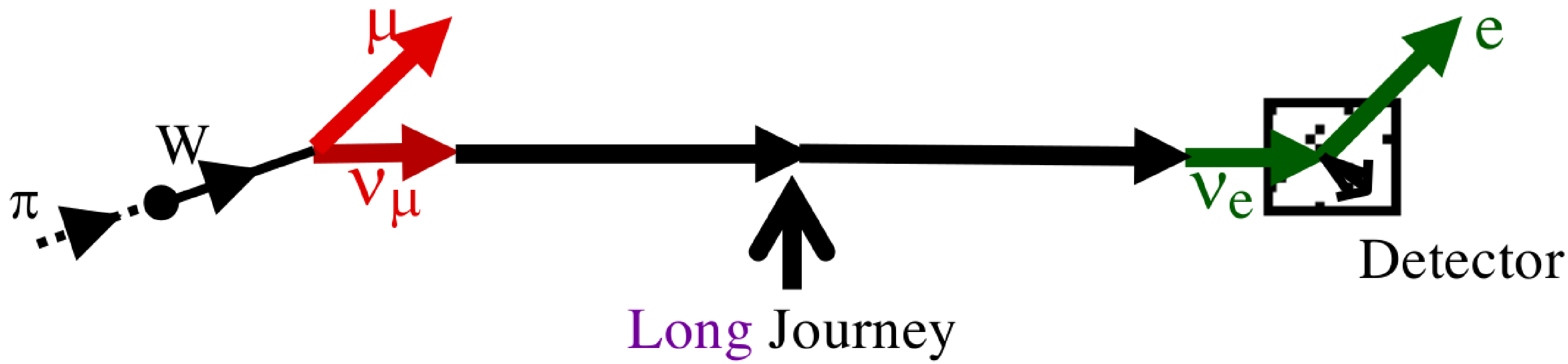
The 2015 Nobel Prize in Physics went to **Takaaki Kajita** and **Art McDonald** for the experiments that proved this.

Super-Kamiokande, Japan

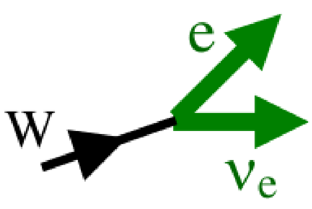
Sudbury Neutrino Observatory, Canada

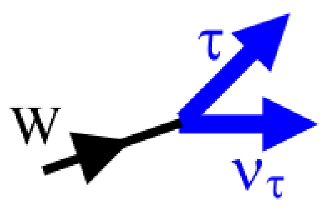
A sketch of Neutrino Oscillation





- *charged leptons:* ***e , μ , τ***
- *flavors of neutrinos:* $\boldsymbol{\nu_e}$, $\boldsymbol{\nu_\mu}$, $\boldsymbol{\nu_\tau}$
- ***We define the neutrinos of specific flavor,*** $\boldsymbol{\nu_e}$, $\boldsymbol{\nu_\mu}$ ***and*** $\boldsymbol{\nu_\tau}$ ***by W boson decays***





Neutrino Oscillation

- The unitary transformation relating the flavour to the mass eigenstates is the **leptonic mixing matrix (PMNS)**, given by:

$$|\nu_\alpha >= \sum_{k=1}^{3} U_{\alpha k}|\nu_k >$$

such that-

$$U_{\alpha k} = U^{3\nu}_{PMNS} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix}$$

$$= \begin{bmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{13}s_{23}c_{12}e^{i\delta} & c_{23}c_{12} - s_{13}s_{23}s_{12}e^{i\delta} & c_{13}s_{23} \\ s_{23}s_{12} - s_{13}c_{23}c_{12}e^{i\delta} & -s_{23}c_{12} - s_{13}c_{23}s_{12}e^{i\delta} & c_{13}c_{23} \end{bmatrix}$$

where $c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$, $\alpha = e, \mu, \tau$ and $i, j, k = 1, 2, 3$

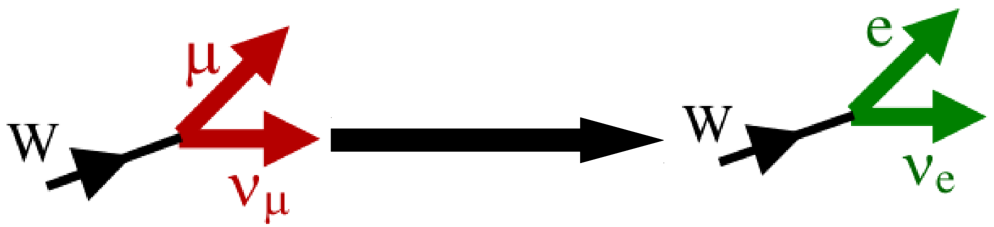
The oscillation probability of neutrinos (anti-neutrinos) in vacuum is:

$$P\left(\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\beta\right) =$$

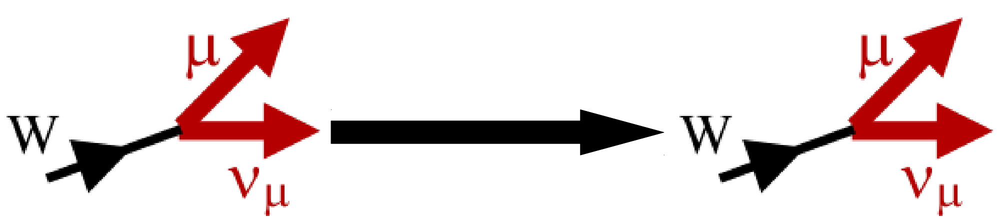
$$= \delta_{\alpha\beta} - 4\sum_{i>j} \mathrm{Re}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin^2\left(\Delta m^2_{ij} \frac{L}{4E}\right)$$

$$\underset{(-)}{+} 2\sum_{i>j} \mathrm{Im}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin\left(\Delta m^2_{ij} \frac{L}{2E}\right)$$

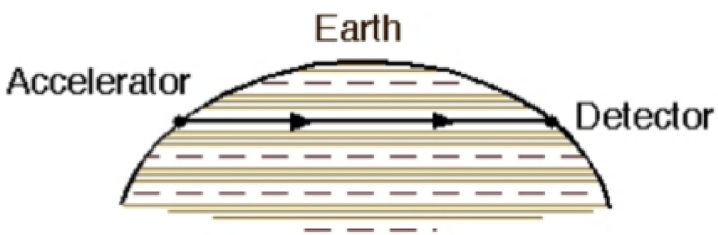
Transition/Appearance Probability :



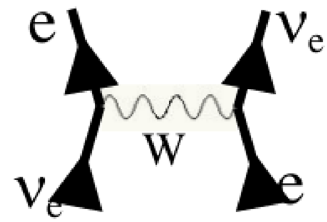
Survival/Disappearance Probability :



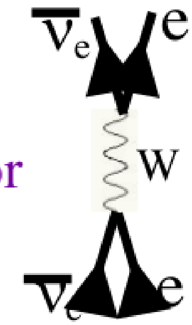
Neutrino Oscillation (matter)



involves



or



Coherent forward scattering via this W-exchange interaction leads to an extra interaction potential energy —

$$V_W = \begin{cases} +\sqrt{2}G_F N_e, & \nu_e \\ -\sqrt{2}G_F N_e, & \overline{\nu}_e \end{cases}$$

Fermi constant → G_F; Electron density → N_e

CP Asymmetry

CP transformation

$$\nu_\alpha \overset{\text{CP}}{\longleftrightarrow} \bar{\nu}_\alpha$$

Appearance case

$$\nu_\alpha \to \nu_\beta \overset{\text{CP}}{\longleftrightarrow} \bar{\nu}_\alpha \to \bar{\nu}_\beta$$

Disappearance case

$$P_{\nu_\alpha \to \nu_\alpha} = P_{\bar{\nu}_\alpha \to \bar{\nu}_\alpha}$$

CP Asymmetry : $A^{\text{CP}}_{\alpha\beta} = P_{\nu_\alpha \to \nu_\beta} - P_{\bar{\nu}_\alpha \to \bar{\nu}_\beta}$

$$A^{\text{CP}}_{\alpha\beta}(L, E) = 4 \sum_{k>j} \Im\mathfrak{m}\left[U^*_{\alpha k}\, U_{\beta k}\, U_{\alpha j}\, U^*_{\beta j}\right] \sin\left(\frac{\Delta m^2_{kj} L}{2E}\right)$$

Oscillation Probabiility in matter

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \cdot \sin^2\Delta_{31} \\
+8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta_{CP} - s_{12} s_{13} s_{23}) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21} \\
-8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta_{CP} \cdot \sin\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21} \\
+4s_{12}^2 c_{13}^2 (c_{12}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta_{CP}) \cdot \sin^2\Delta_{21} \\
-8c_{13}^2 s_{13}^2 s_{23}^2 \cdot \frac{aL}{4E_\nu}(1 - 2s_{13}^2) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \\
+8c_{13}^2 s_{13}^2 s_{23}^2 \frac{a}{\Delta m_{31}^2}(1 - 2s_{13}^2) \cdot \sin^2\Delta_{31},
\end{aligned}
$$

$\Delta_{ij} = \Delta m^2_{ij}\, L/4E_\nu$

Matter Term, $a = 2\sqrt{2} G_F n_e E_\nu = 7.56\times10^{-5}[\mathrm{eV}^2]\times\rho[\mathrm{g/cm}^3]\times E_\nu[\mathrm{GeV}]$

The corresponding probability for a anti-($\nu_\mu \to \nu_e$) transition is obtained by:
replacing **$\delta_{CP} \to -\delta_{CP}$** and **$a \to -a$**

Oscillation Probabiility in matter

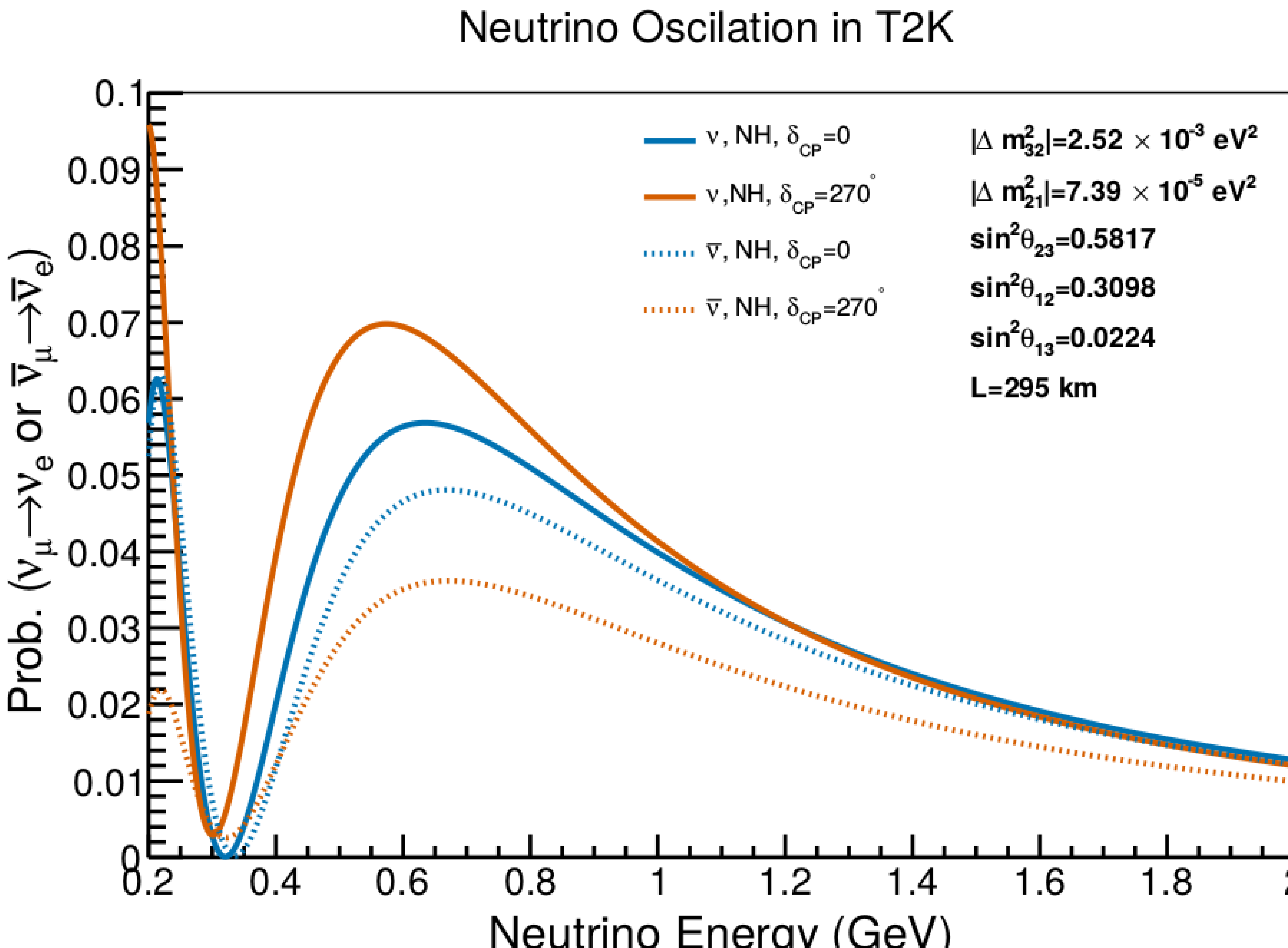
$$P(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \cdot \sin^2 \Delta_{31}$$
$$+8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta_{CP} - s_{12} s_{13} s_{23}) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21}$$
$$-8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta_{CP} \cdot \sin\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21}$$
$$+4s_{12}^2 c_{13}^2 (c_{12}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta_{CP}) \cdot \sin^2 \Delta_{21}$$
$$-8c_{13}^2 s_{13}^2 s_{23}^2 \cdot \frac{aL}{4E_\nu}(1 - 2s_{13}^2) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31}$$
$$+8c_{13}^2 s_{13}^2 s_{23}^2 \frac{a}{\Delta m_{31}^2}(1 - 2s_{13}^2) \cdot \sin^2 \Delta_{31},$$

(red box) = CP-even terms (green box) = CP-odd term (blue box) = due to matter effects

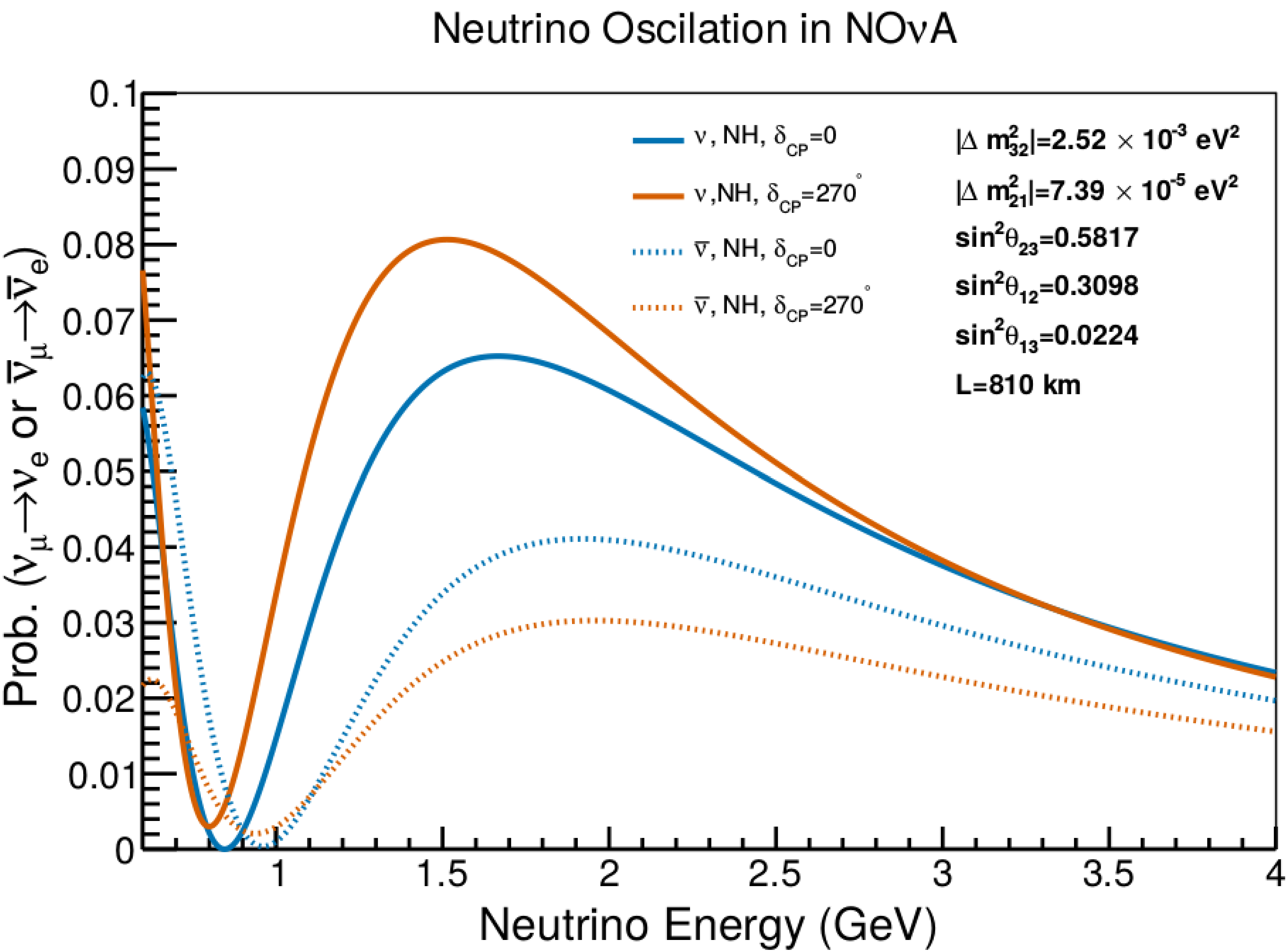
- In the leptonic mixing, CP symmetry is violated by the phase $\delta_{CP.}$
- From the above expression, δ_{CP}=0 also produces CP asymmetry due to CP-even terms. It is because the matter effect produces a fake asymmetry *(as the Earth is composed of e^-, p^+ & n, not their anti-particle)*.
- It is, therefore, important to experimentally separate the effects of the Earth matter and natural CP-violation. This will allow to get information about the dirac CP violation phase in U_{PMNS}.

We study the appearance probability, $P_{\mu e}$ for both neutrino and anti-neutrino for a few selected baselines to understand the **effect of $\boldsymbol{\delta}_{CP}$** and the **matter potential** in the behaviour of oscillation and CP-asymmetry.

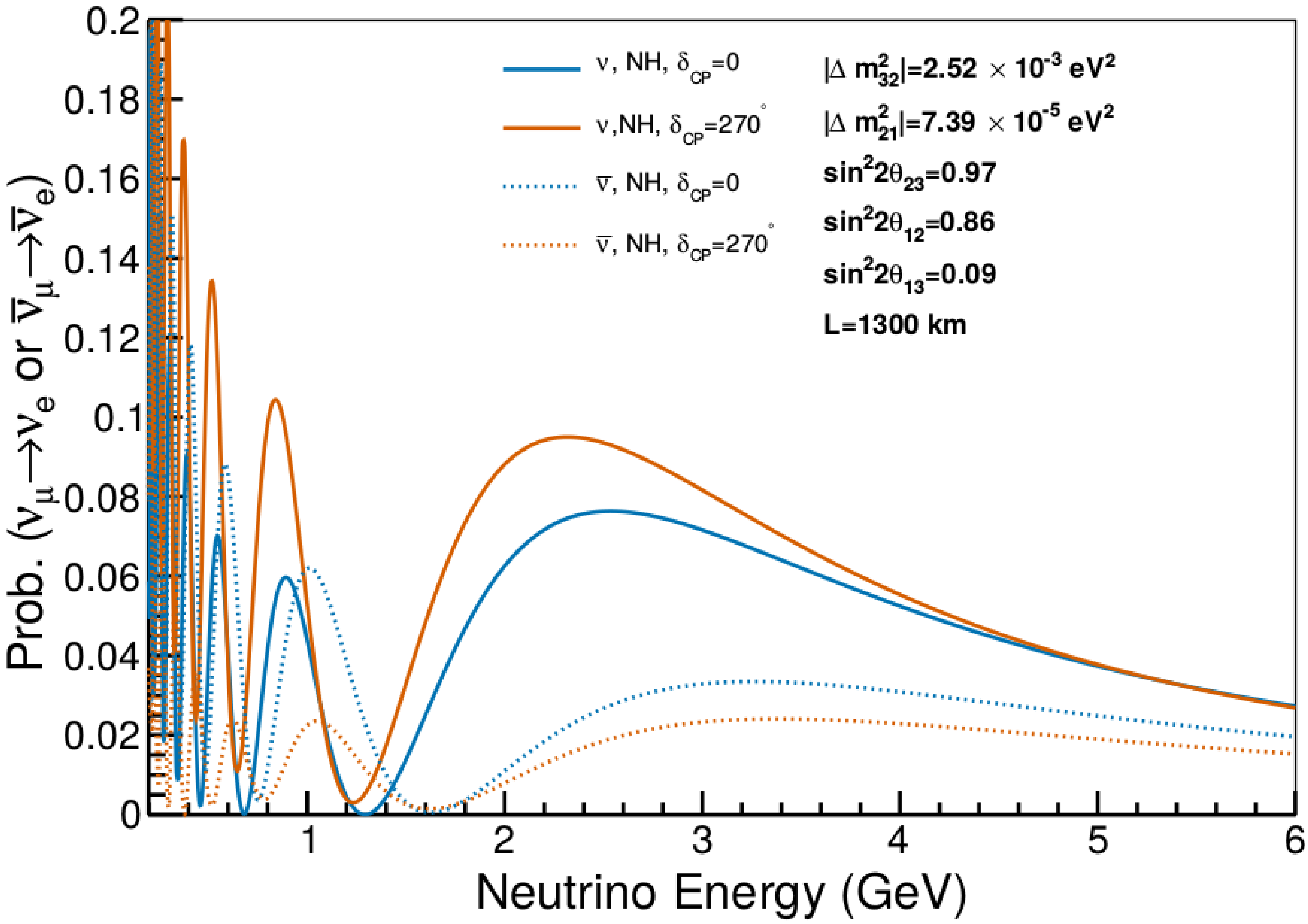
T2K (Tokai to Kamioka, Japan)



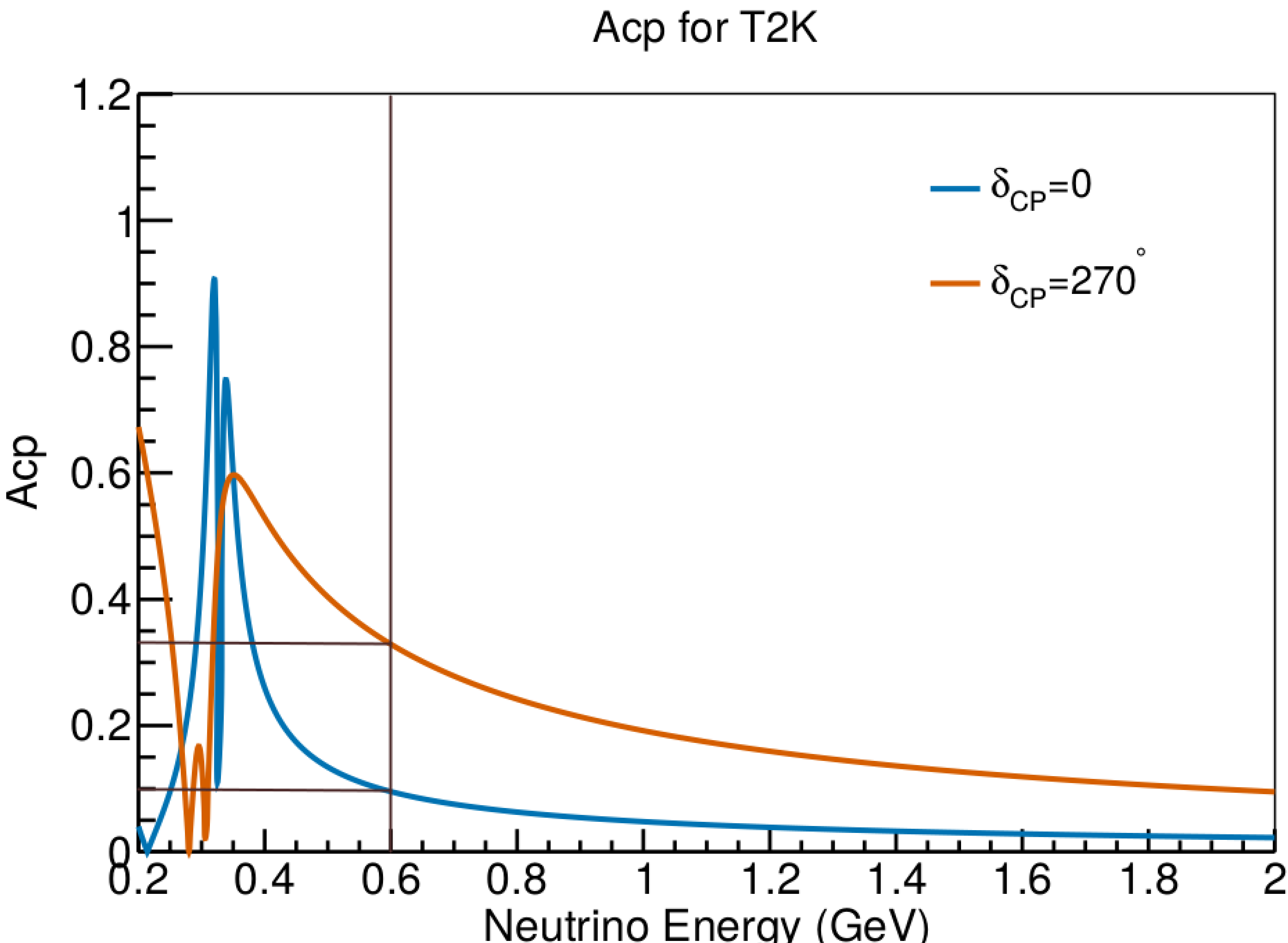
NOvA (NuMI Off-Axis Neutrino Appearance, USA)



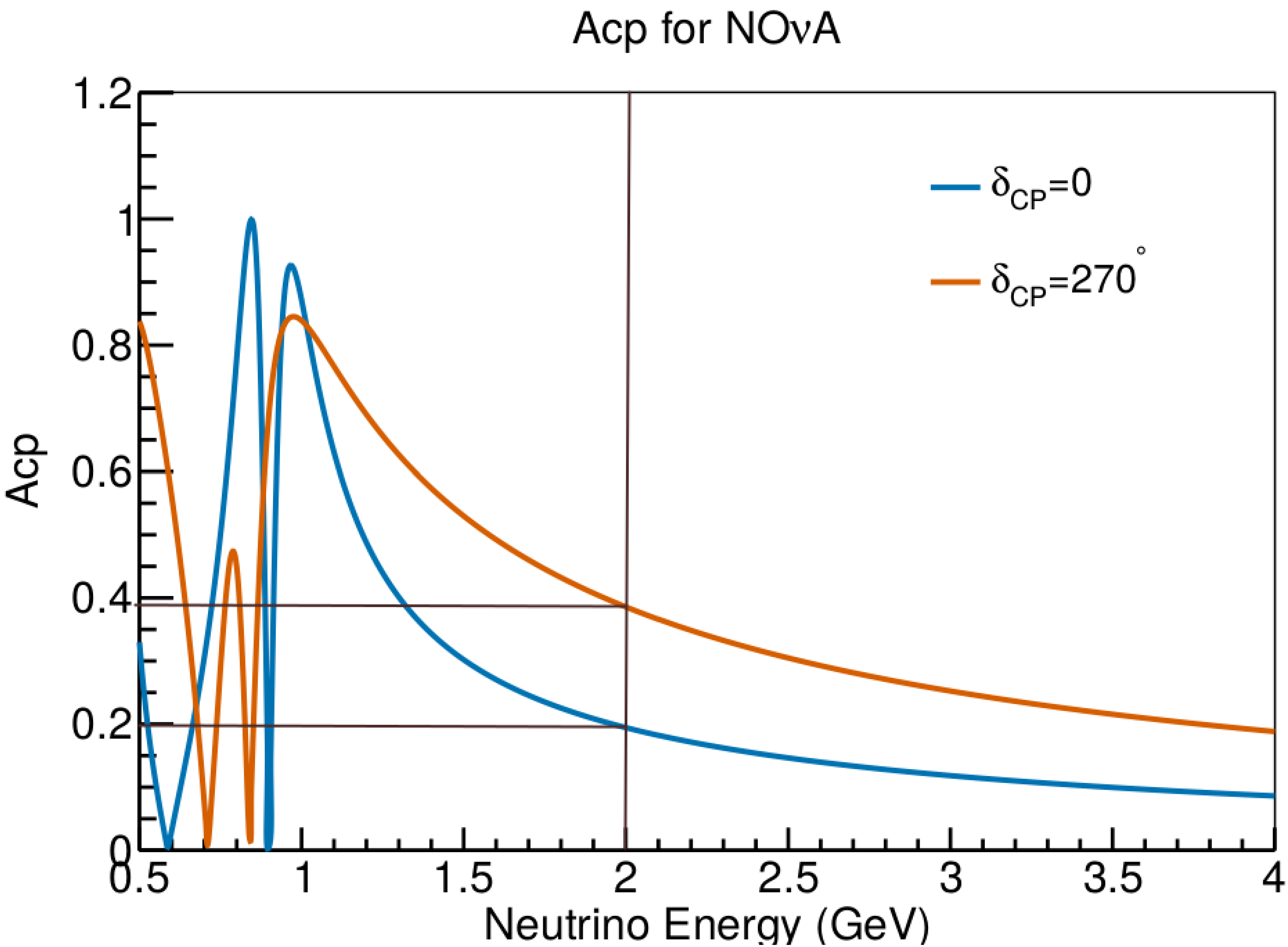
DUNE (Deep Underground Neutrino Experiment, USA)



CP Asymmetry in T2K



CP Asymmetry in NOνA



Motivation

- Due to it’s baseline, T2HK has the least matter-effect ambiguity in CP asymmetry making it the most important experiment for CPV studies.
- T2HK is the third LBL experiment of Japan.
- The Near Detector technique is well-exploited in Japan. With ND280 and INGRID, systematic uncertainities can be highly reduced.
- Due to the very high volume of FD and upgraded beam power, T2HK will have higher events collection i.e. richer statistics.

Objective

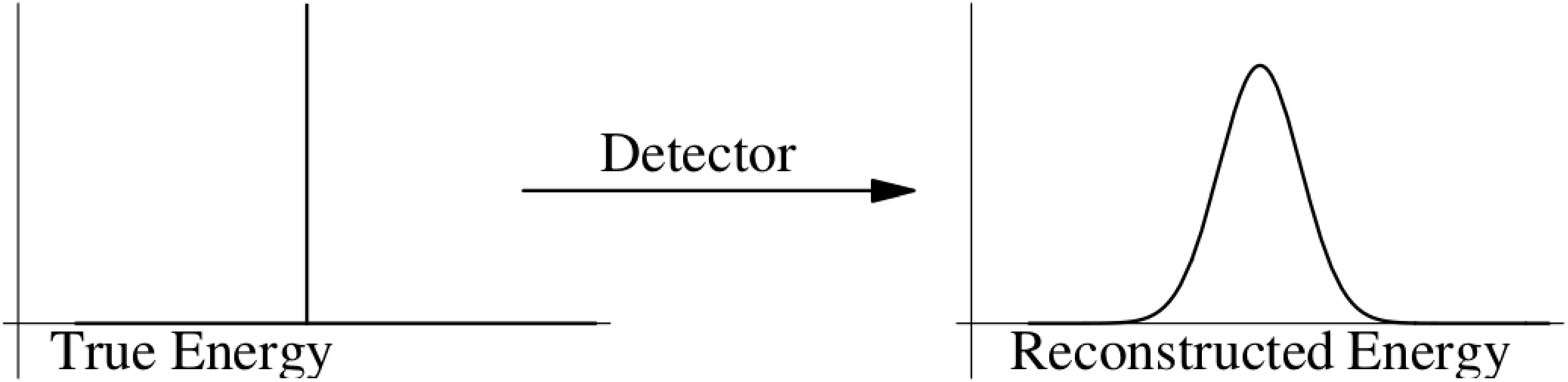
CPV sensitivity study in the frameworks of :

i. 3+0,

ii. 3+1 and

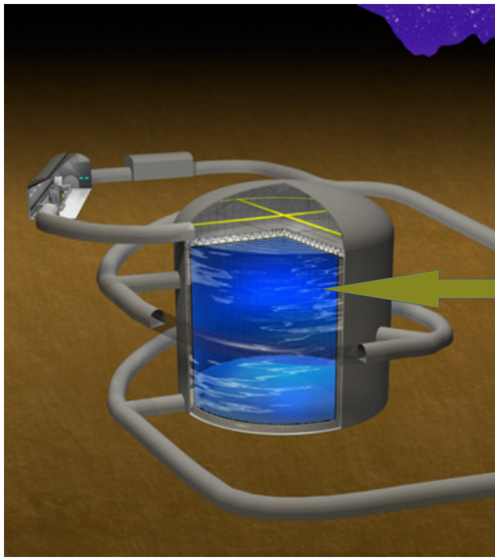
iii. Non-Standard Interaction (NSI)

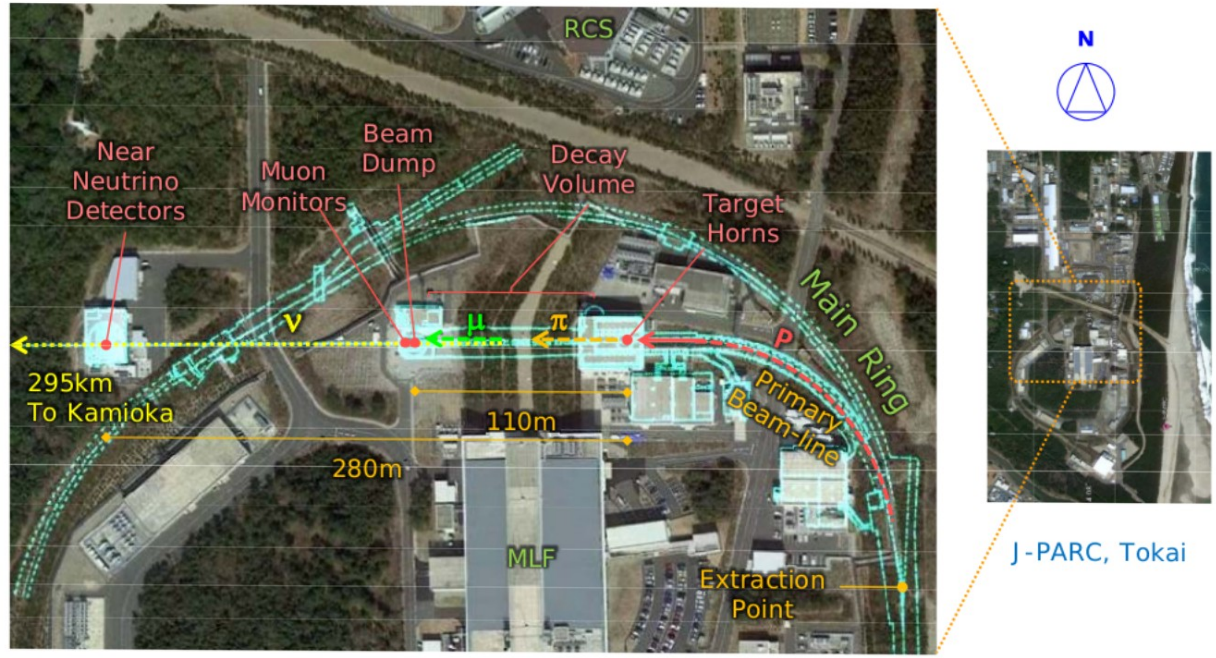
➔**Event level**


True Energy
Detector
Reconstructed Energy

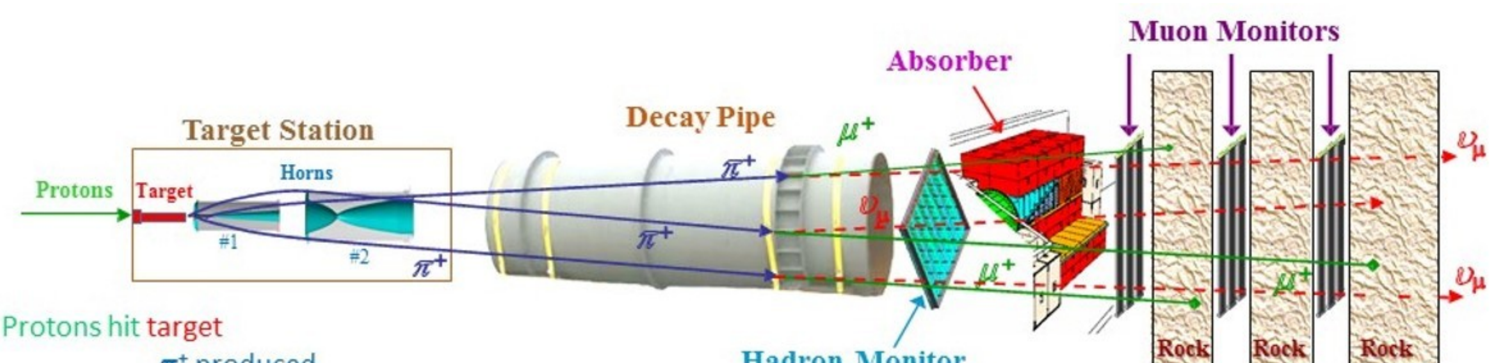
The T2HK Experiment

FD : HyperK





L=295 km



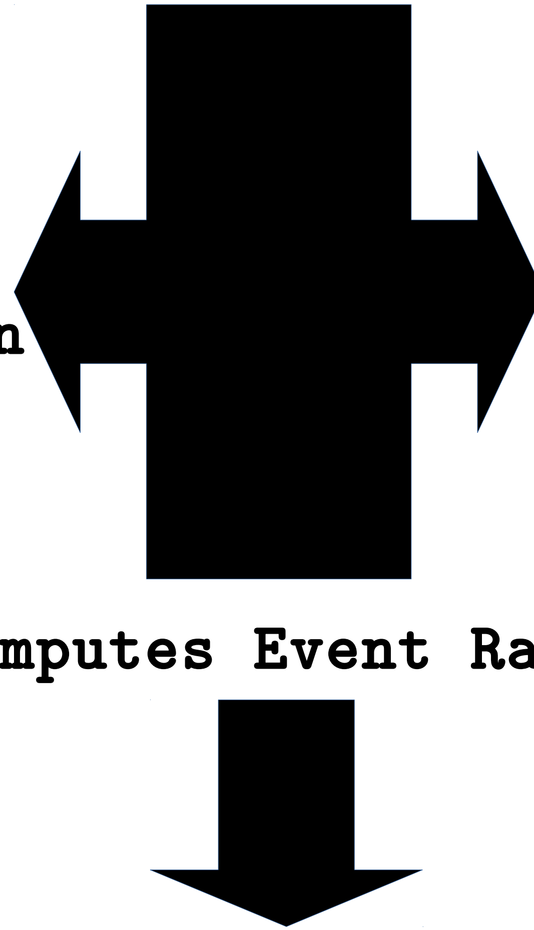
Protons hit target
π^+ produced
magnetic horn to focus π^+
π^+ decay to $\mu^+ \nu$ in long evacuated pipe
left-over hadrons shower in hadron absorber
rock shield ranges out μ^+
ν beam travels through earth to experiment

Experiment Specification

- L=295km
- Fiducial target mass : 187 kton
- Beam Source : J-PARC, Tokai
- Detector : Hyper-Kamiokande
- Energy at the 1st oscillation maxima : 0.6 GeV
- Horn Current : 320 kA
- Running time (considered) : 10 years (1:3)
- Beam Power : 1.3 MW
- Total Proton-on-Target : 2.7×10^{22}
- Year of Construction : April, 2020
- Year of Operation : ~2026

Experiment Setup in GLoBES

AEDL construction



User C-interface

Computes Event Rates

Studies Physics reach of LBNEs

Event Rates in GLoBES

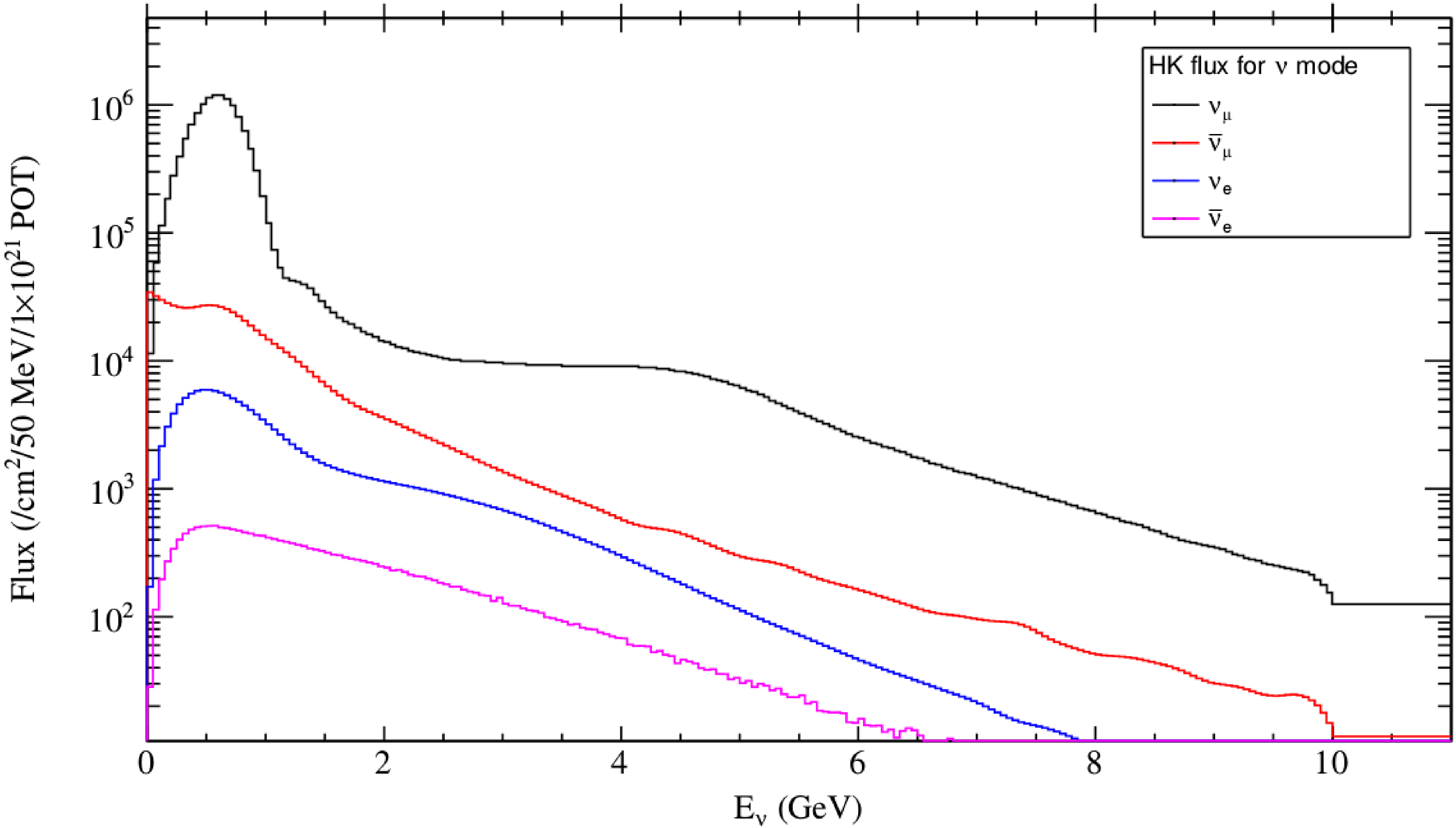
The differential event rate for each channel is given by

$$\frac{dn_\beta^{\mathrm{IT}}}{dE'} = N \int_0^\infty \int_0^\infty dE\, d\hat{E} \underbrace{\Phi_\alpha(E)}_{\text{Production}} \times \underbrace{\frac{1}{L^2} P_{(\alpha\to\beta)}(E, L, \rho; \theta_{12}, \theta_{13}, \theta_{23}, \Delta m_{31}^2, \Delta m_{21}^2, \delta_{\mathrm{CP}})}_{\text{Propagation}} \times \underbrace{\sigma_f^{\mathrm{IT}}(E) k_f^{\mathrm{IT}}(E-\hat{E})}_{\text{Interaction}} \times \underbrace{T_f(\hat{E}) V_f(\hat{E}-E')}_{\text{Detection}},$$

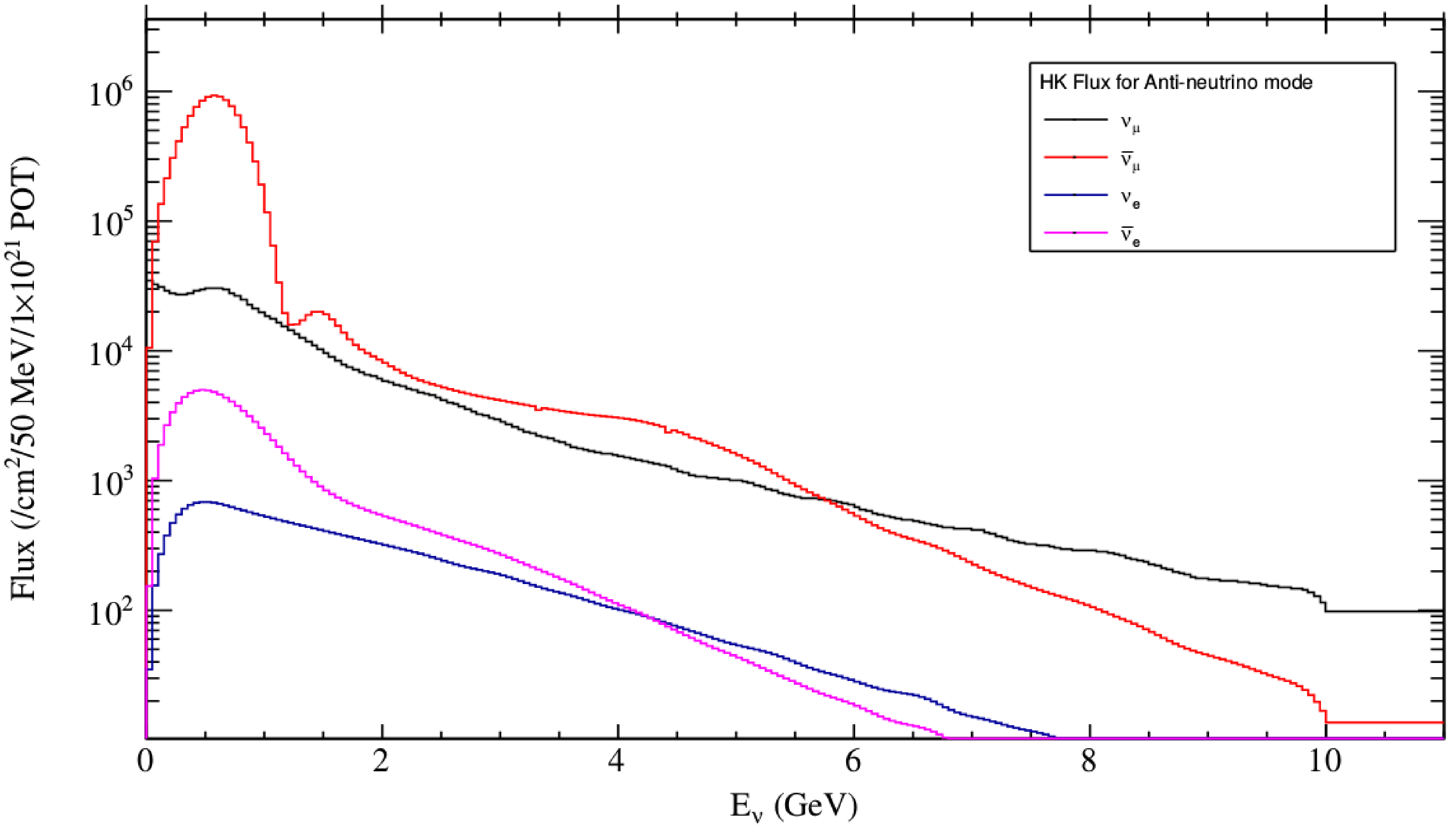
where α is the initial flavor of the neutrino, β is the final flavor, $\Phi_\alpha(E)$ is the flux of the initial flavor at the source, L is the baseline length, N is a normalization factor, and ρ is the matter density. The energies in this formula are given as follows:

- E is the incident neutrino energy, *i.e.*, the actual energy of the incoming neutrino (which is not directly accessible to the experiment)
- $\hat{E}$ is the energy of the secondary particle
- E' is the reconstructed neutrino energy, *i.e.*, the measured neutrino energy as obtained from the experiment

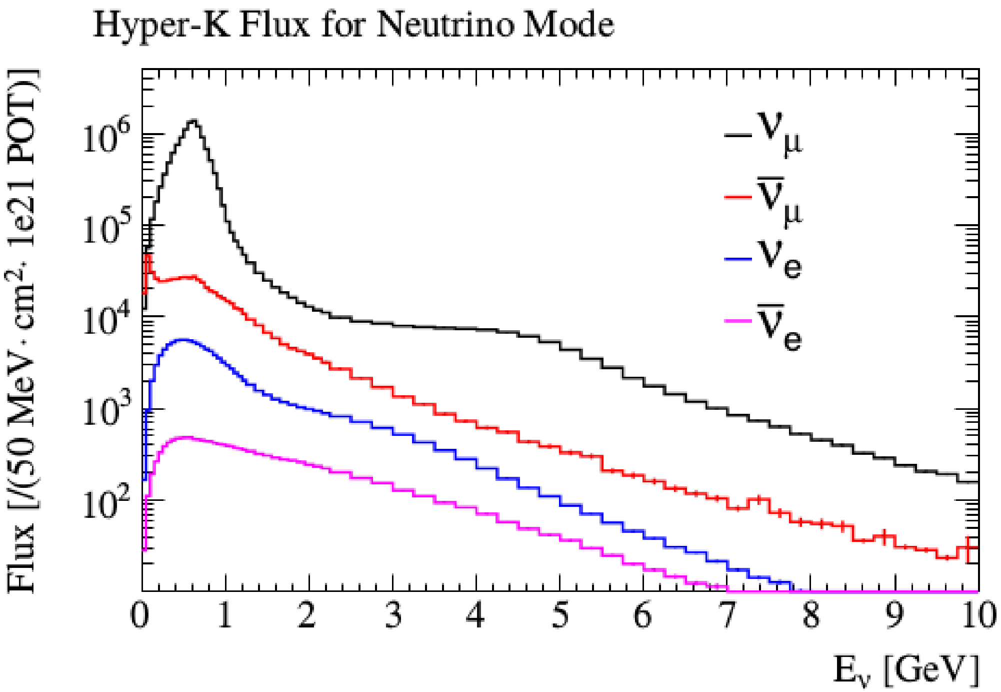
Flux : Neutrino Mode

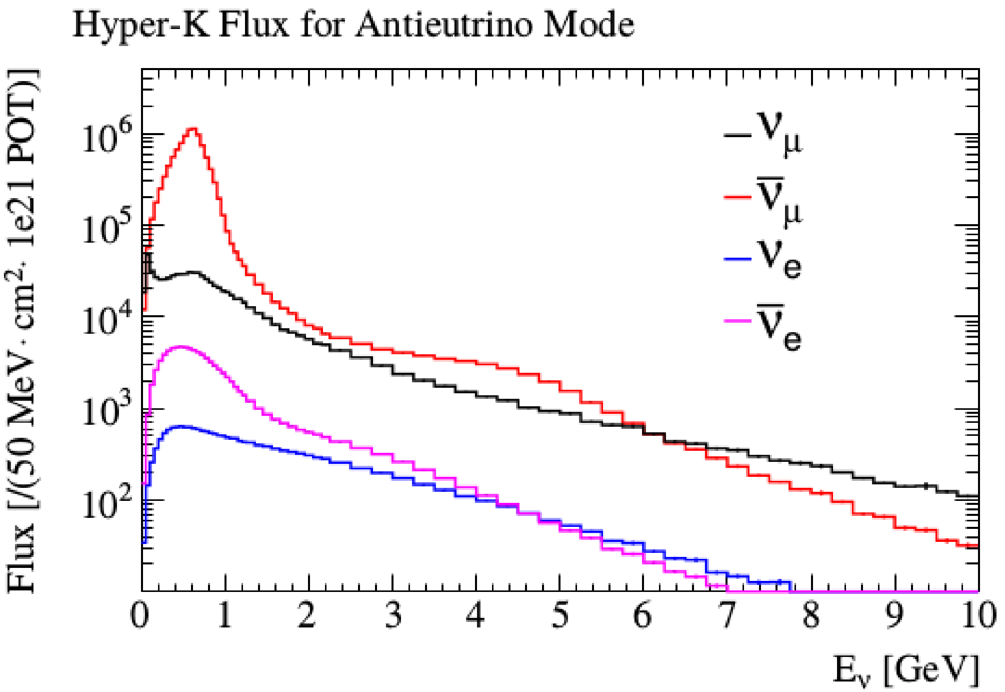


Flux : Anti-Neutrino Mode



HK Design Report, Nov 30, 2018





Normalization constant 'N'

The ***@norm variable*** is an overall normalization which defines a conversion factor from the fluxes in the file to the units in GLoBES.

the number of protons in water of 22.5kt mass

$$@\texttt{norm} = \frac{1}{5.2}\left(\frac{\text{GeV}}{\Delta E}\right)\left(\frac{\text{cm}^2}{A}\right)\left(\frac{L}{\text{km}}\right)^2\left(\frac{\tau}{m_u}\right)\times 10^{-38}\times\left(\frac{\mathcal{L}_u}{\mathcal{L}}\right)$$

Energy Bin Width — **Baseline** — **Target Mass**

L absorbs all factors in the flux file related to the integrated luminosity, and L_u is the unit chosen for it.

@norm$_{\textbf{T2HK}}$ is obtained to be **11.6770176**, then multiplied by a factor of 2.7 to achieve total POT of $2.7\text{x}10^{22}$

Configurations : Appearance and Diappearance Events

A) Event rates with no modification

B) Event Rates with @norm modified with bin correction

C) Event Rates with @norm and @effi modified with bin correction

Oscillation Parameters (Best Fit)

Θ_{12} = 0.6013 radian

Θ_{13} = 0.1609 radian

Θ_{23} = 0.7853 radian

Δm^2_{21} = 0.000076 eV^2

Δm^2_{32} = 0.0024 eV^2

***atmospheric parameters, ***solar parameters, ***reactor parameters

A. Predicted Appearance Event Rates

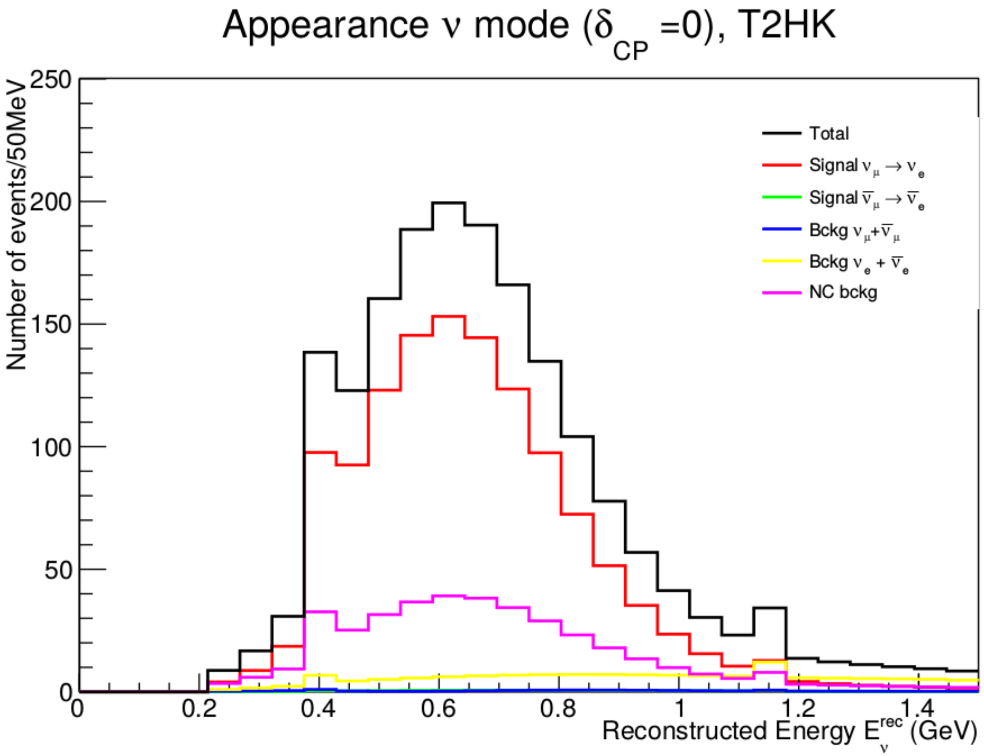
(the figures below in blue represent the event rates in the Report)

$\nu_\mu \to \nu_e$	ANTI($\nu_\mu \to \nu_e$)	ν_μCC	ANTI-ν_μCC	ν_eCC	ANTI-ν_eCC	NC	Total BG
--------- #NU_E_Appearance_QE ---------							
1248.01	10.06	11.45	0	142.03	3.47	387.7	**544.6**
1643	15	7	0	248	11	134	**415**
--------- #NU_E_BAR_Appearance_QE ---------							
104.8	**983.2**	1.2	1.8	39.3	134.8	332.05	**509.3**
206	**1183**	2	2	101	216	196	**723**

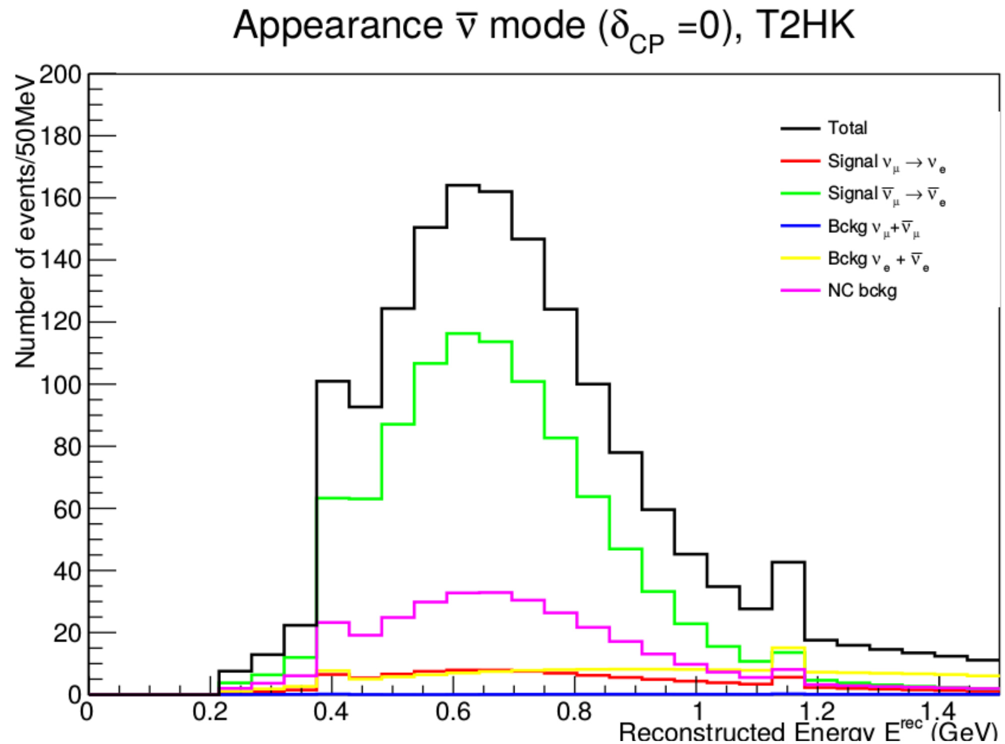
N.B. @norm used here and in subsequent sections unless mentioned otherwise are : 33.72794752 (neutrino) and 30.62794752 (anti-neutrino)

A. Predicted Disappearance Event Rates

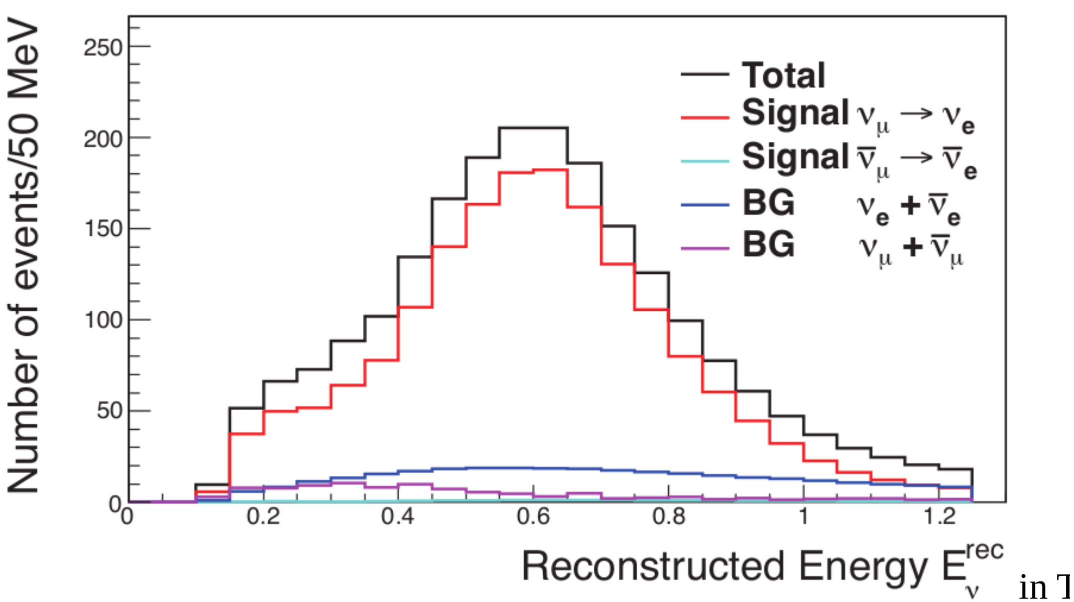
ν_μCCQE	ν_μCCnonQE	ANTI-ν_μCCQE	ν_μCCnonQE	(ν_e+ANTIν_e)CC	NC	$\nu_\mu \rightarrow \nu_e$	TotalBG
--------- #NU_MU_Disapperance_QE ---------							
6509.51	2370.7	216.5	206.2	(2.54+0.02)	2437	31.15	**5264**
6043	2981	348	194	6	480	29	**4037**
--------- #NU_MU_BAR_Disappearance_QE ---------							
1755.7	832.3	**6097**	5021.7	(0.26+1.36)	1826.3	2.8	9440
2699	2354	**6099**	1961	7	603	4	**7627**

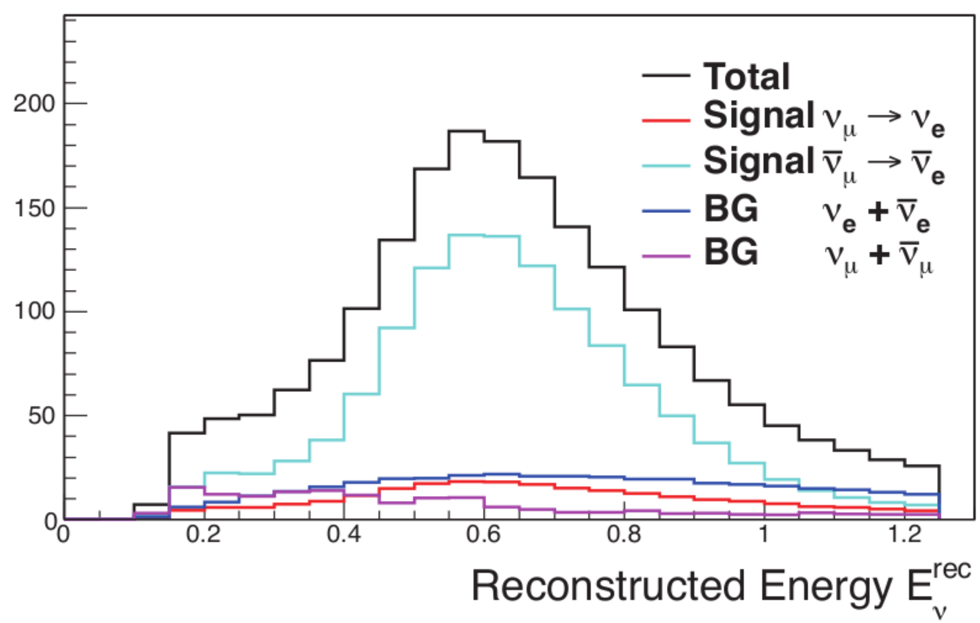


Appearance ν mode

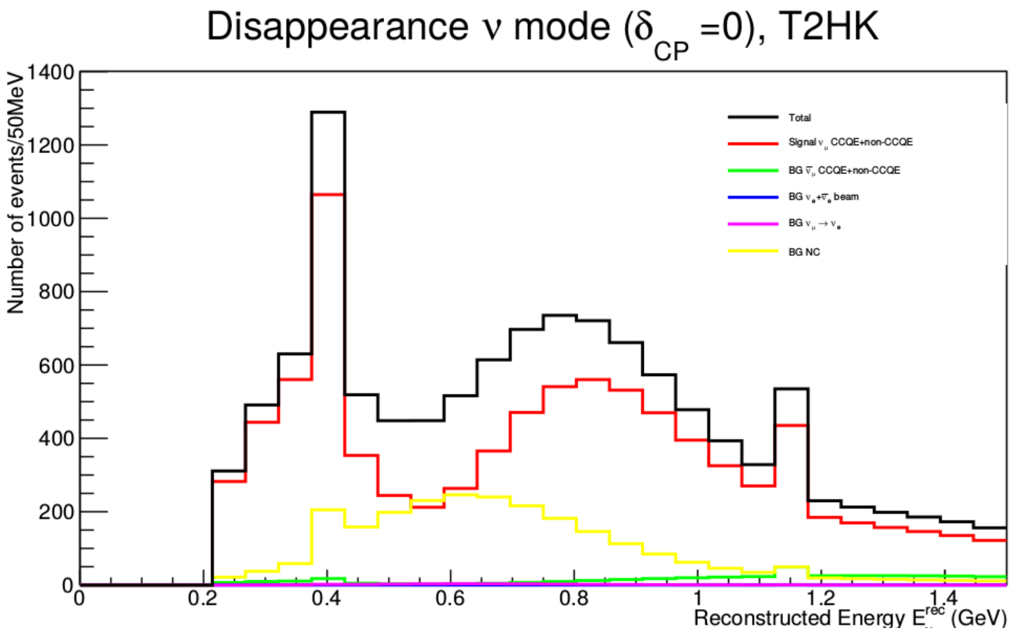


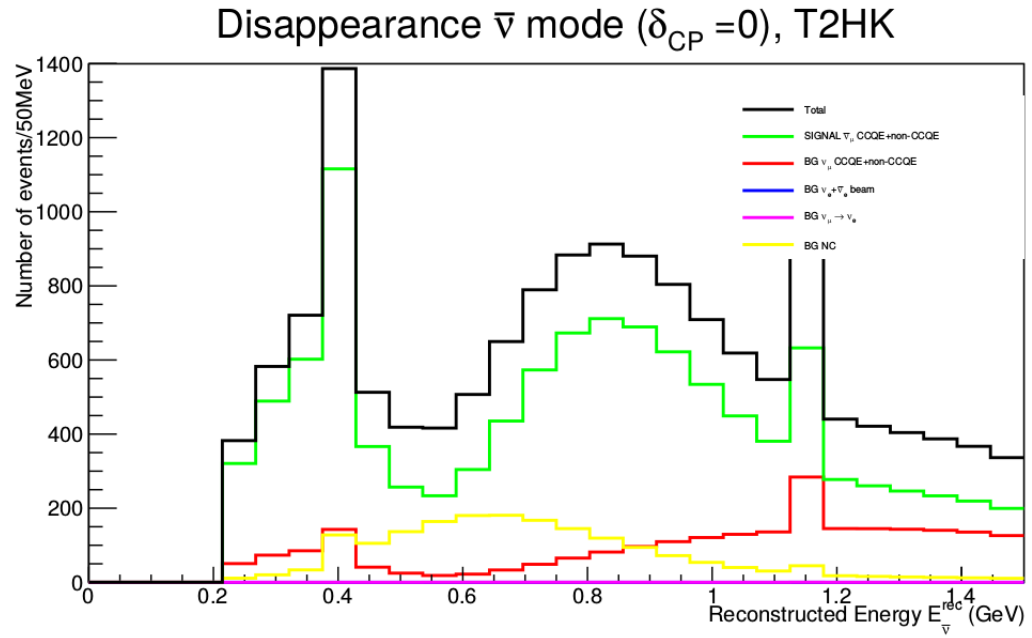
Appearance $\bar{\nu}$ mode



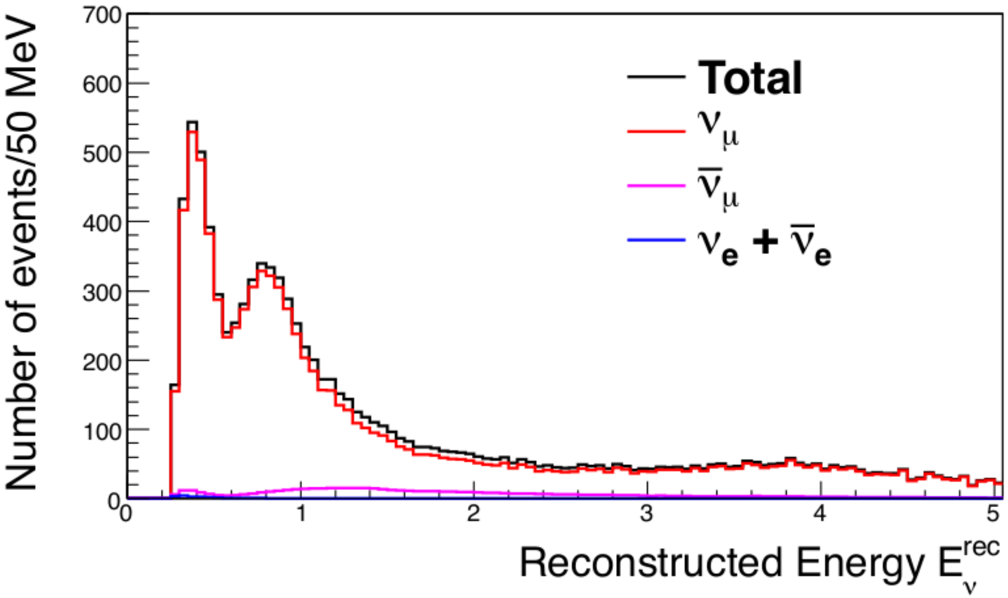


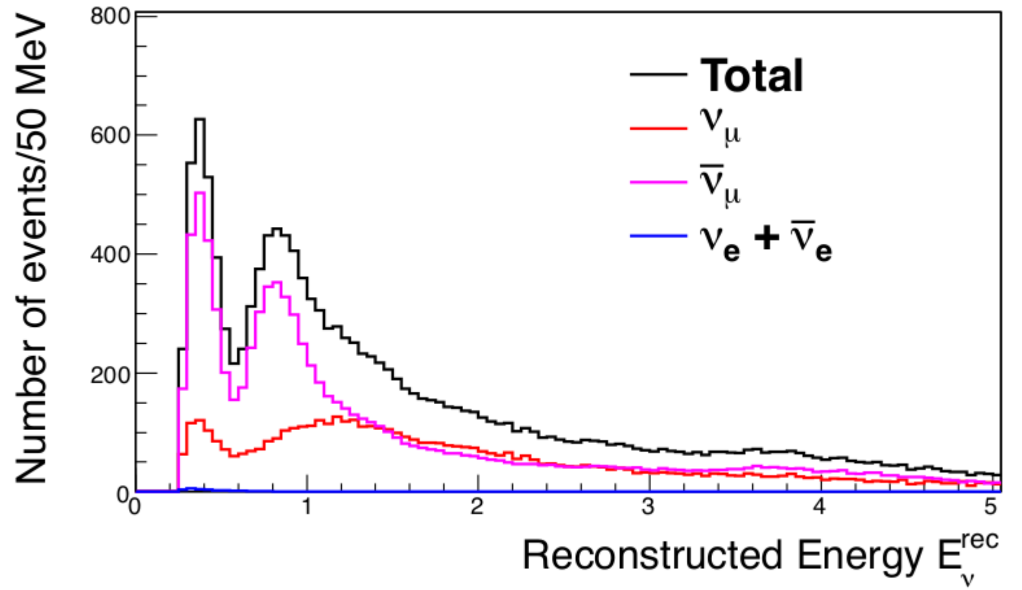
Top : *Our work*, **Bottom :** *Report*





Disappearance ν mode **Disappearance $\bar{\nu}$ mode**

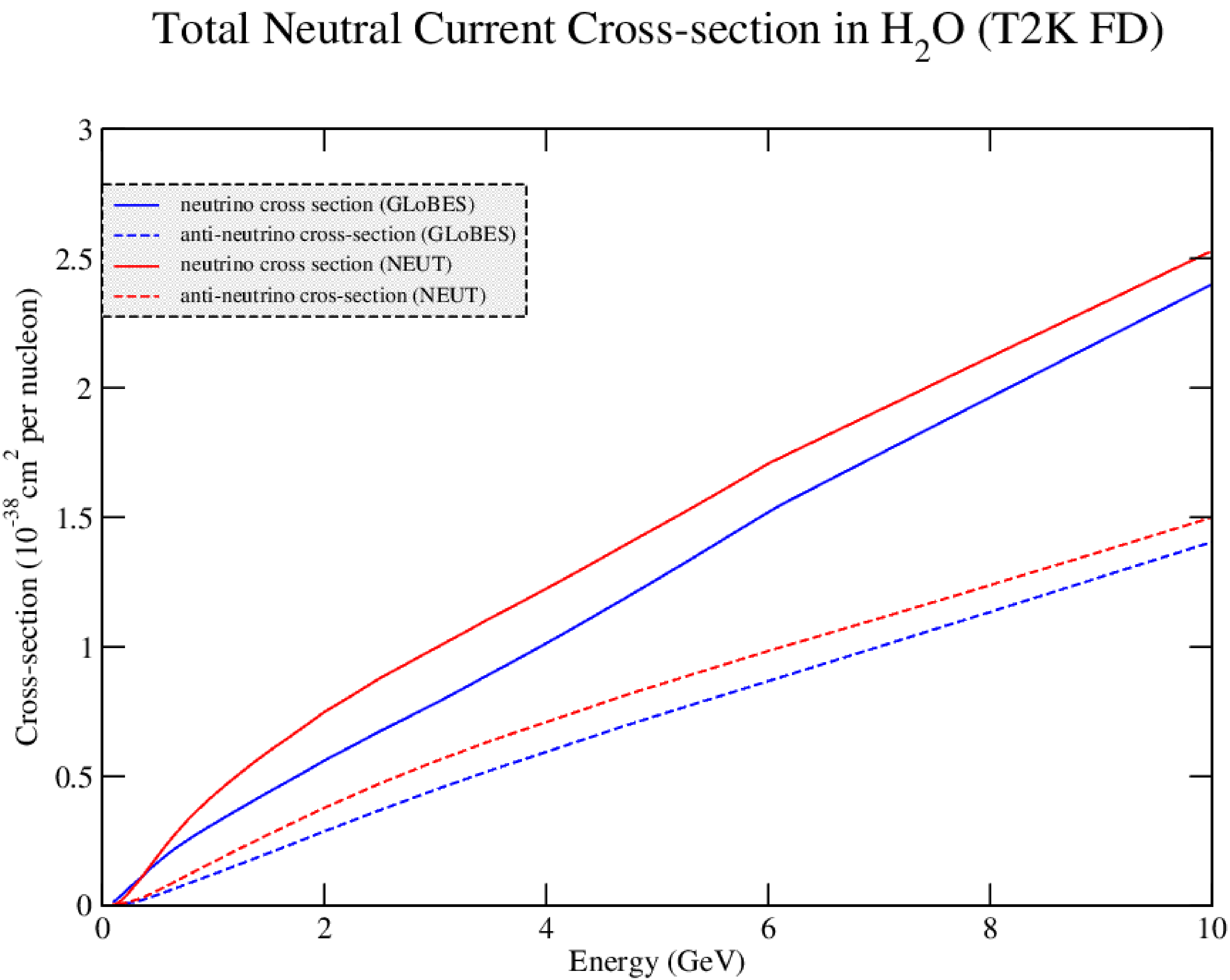




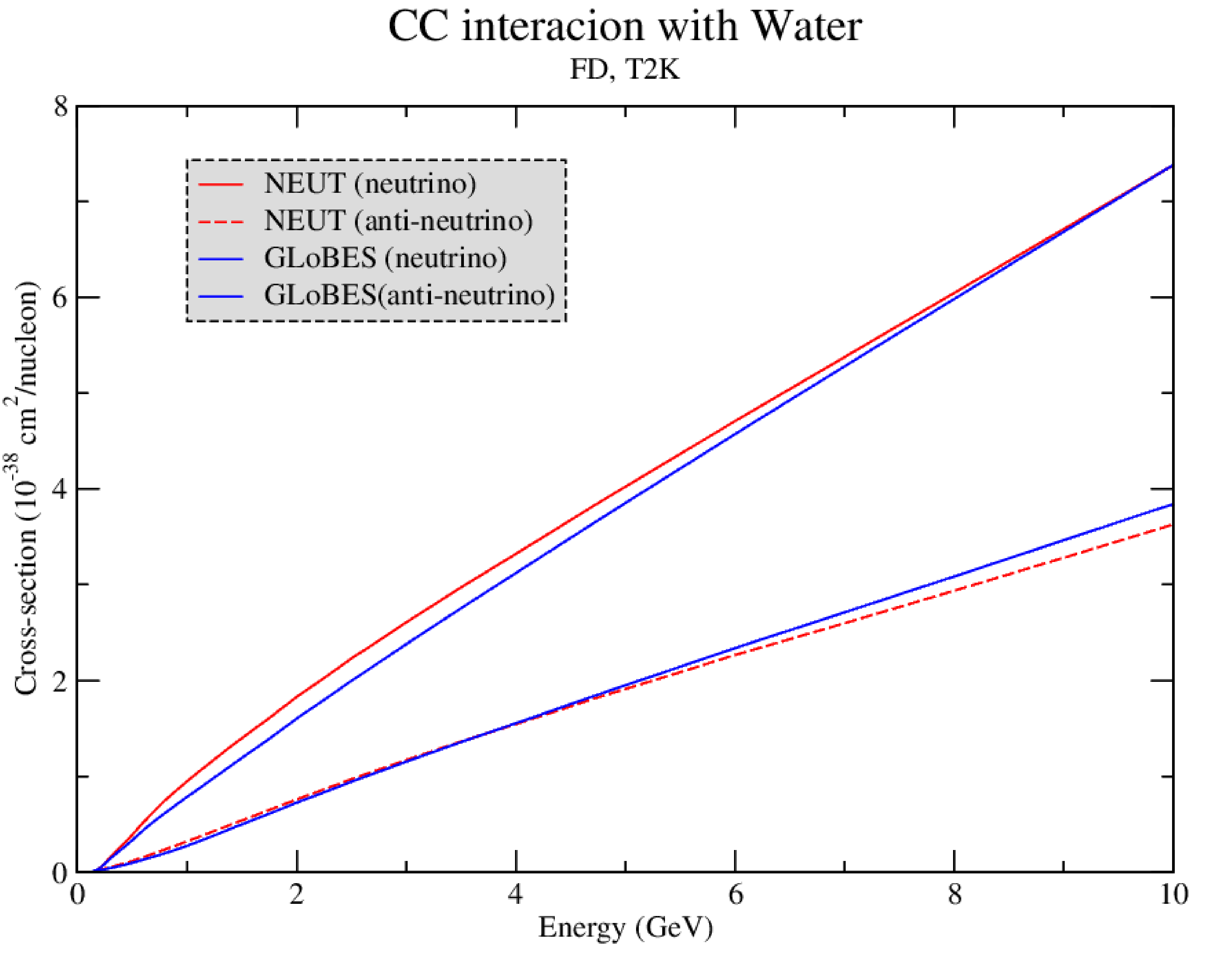
Top : *Our work*, **Bottom :** *Report*

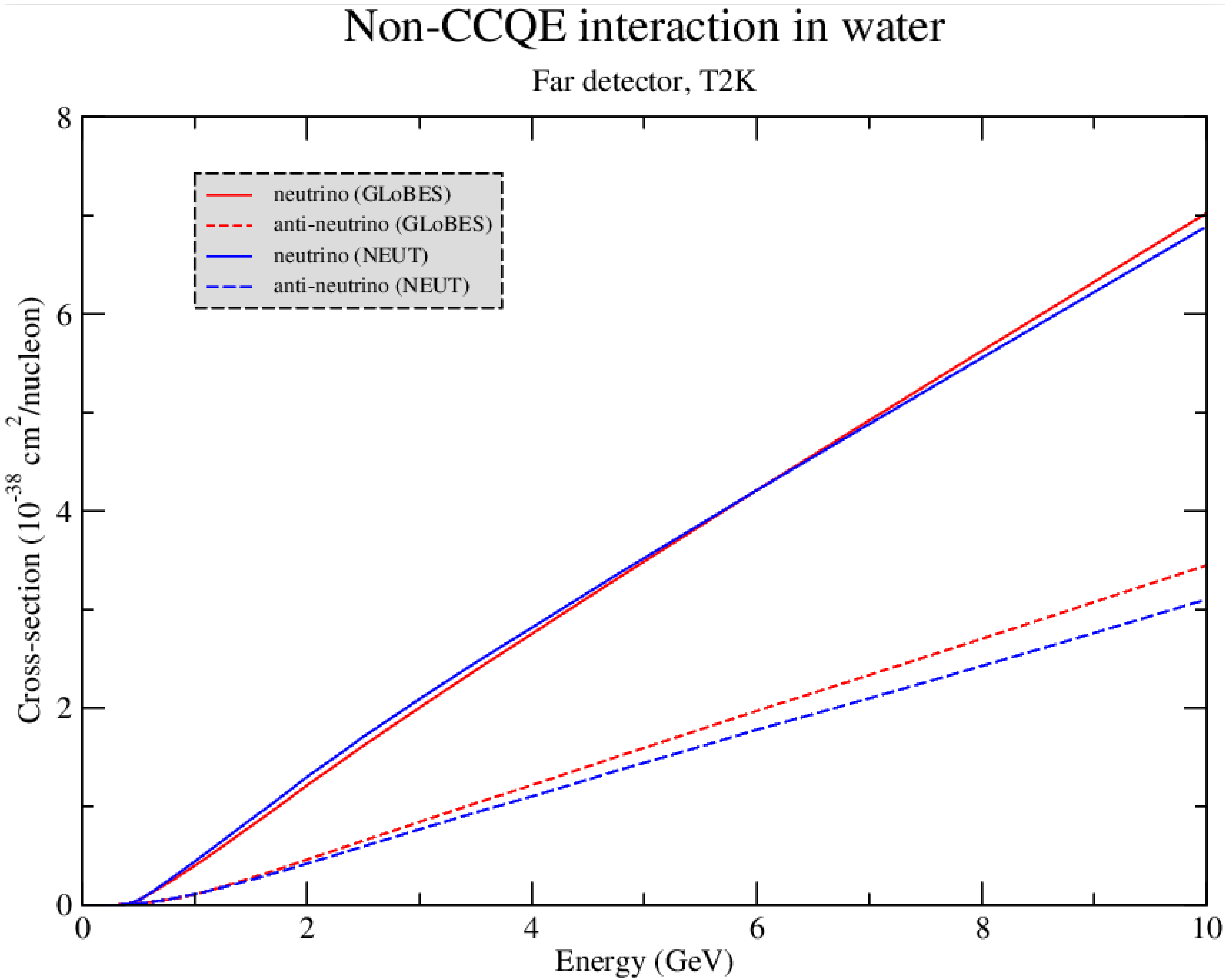
DISCUSSION

- Poor Event rates specially over-estimated for NC
- Bump seen certain energies
- Energy binning is incorrect
- Disappearance channel doesn't cover energy range as in the report
- Incorrect cross-sections considered for CC-nonQE interaction
- We tackle Appearance & Disappearance Events 1-by-1

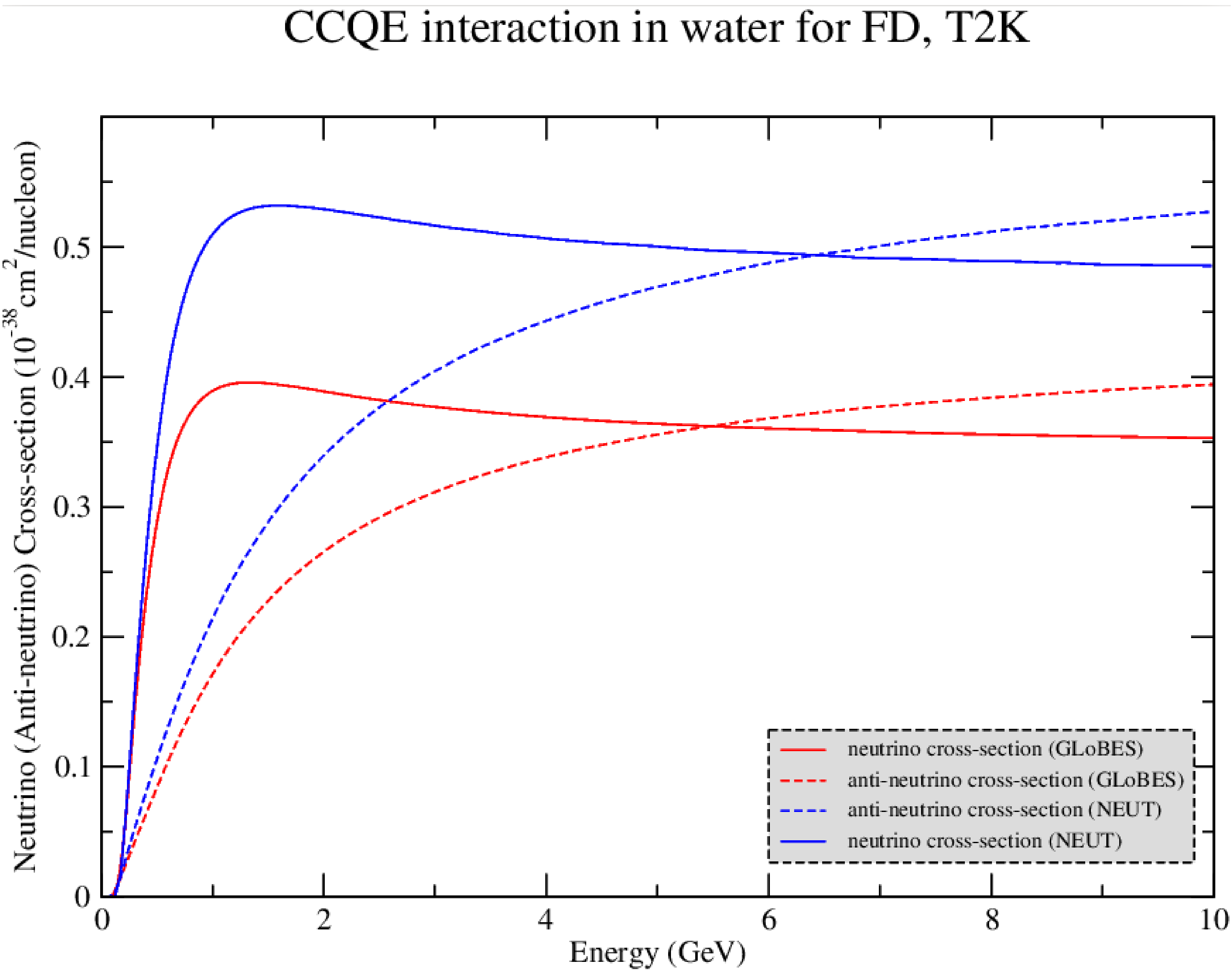


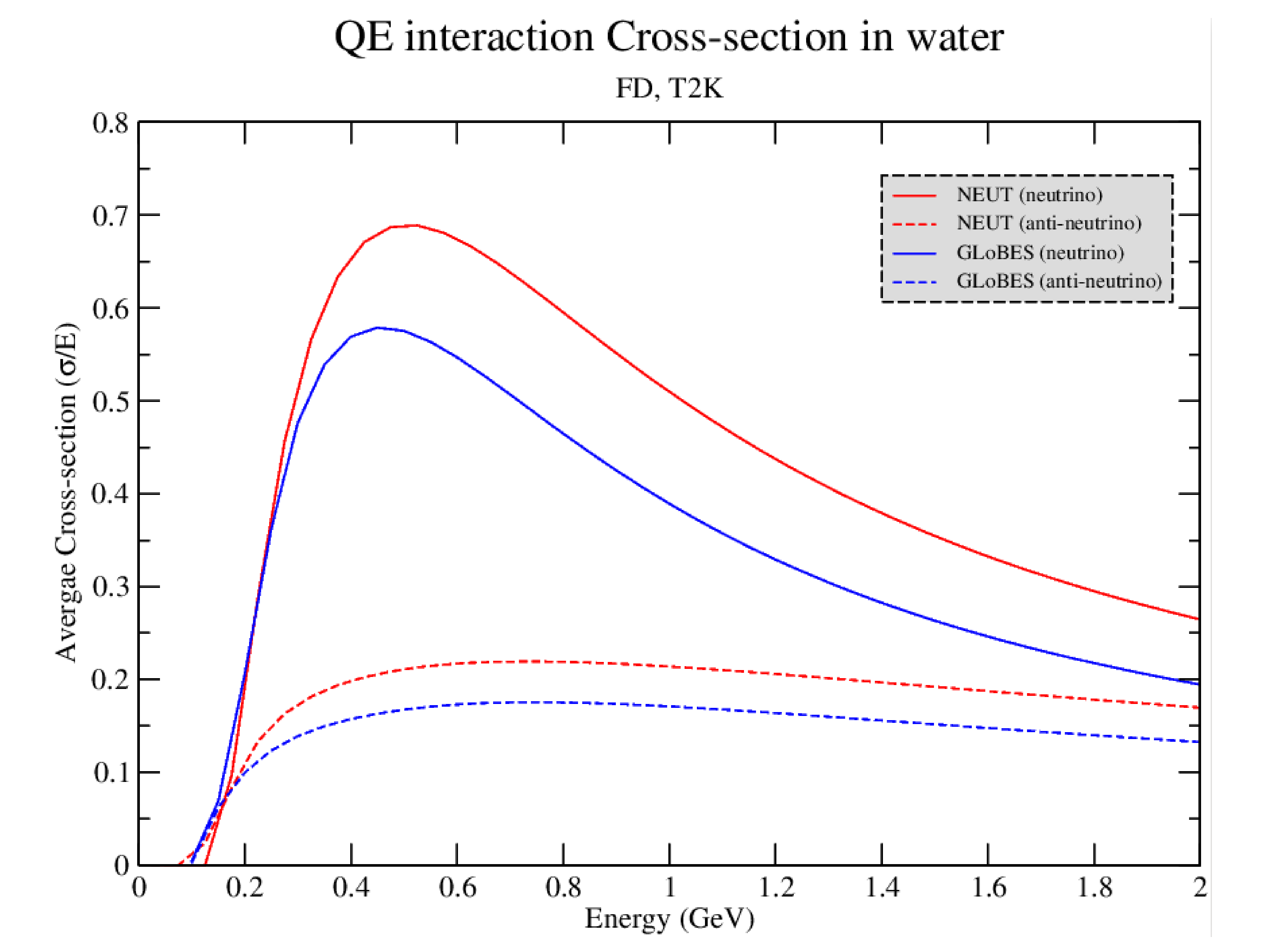
Total Neutral Current Cross-section in H_2O (T2K FD)
neutrino cross section (GLoBES)
anti-neutrino cross-section (GLoBES)
neutrino cross section (NEUT)
anti-neutrino cros-section (NEUT)
Cross-section (10^{-38} cm^2 per nucleon)
Energy (GeV)
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10


CC interacion with Water
FD, T2K
NEUT (neutrino)
NEUT (anti-neutrino)
GLoBES (neutrino)
GLoBES(anti-neutrino)
Cross-section (10^-38 cm^2/nucleon)
Energy (GeV)
0
2
4
6
8
10



Non-CCQE interaction in water
Far detector, T2K
neutrino (GLoBES)
anti-neutrino (GLoBES)
neutrino (NEUT)
anti-neutrino (NEUT)
Cross-section (10^{-38} cm^2/nucleon)
Energy (GeV)
0
2
4
6
8
10

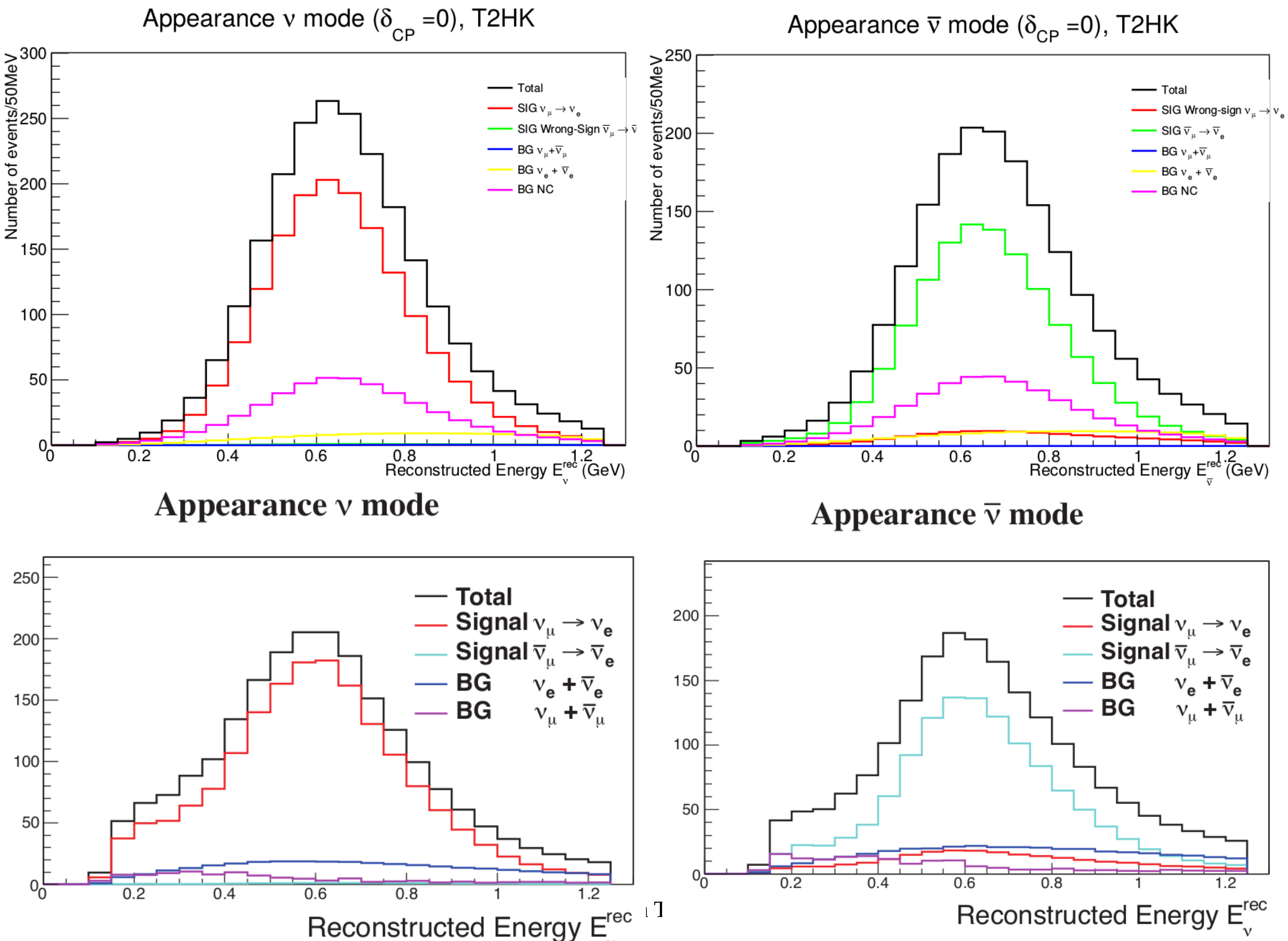

CCQE interaction in water for FD, T2K
Neutrino (Anti-neutrino) Cross-section (10^{-38} cm^2/nucleon)
Energy (GeV)
0
0.1
0.2
0.3
0.4
0.5
0
2
4
6
8
10
neutrino cross-section (GLoBES)
anti-neutrino cross-section (GLoBES)
anti-neutrino cross-section (NEUT)
neutrino cross-section (NEUT)


QE interaction Cross-section in water
FD, T2K
Avergae Cross-section (σ/E)
Energy (GeV)
NEUT (neutrino)
NEUT (anti-neutrino)
GLoBES (neutrino)
GLoBES (anti-neutrino)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

- Appearance Events: Configuration B & C

B. Appearance Event Rates

		Computed		Report	
		neutrino	Anti-neutrino	neutrino	Anti-neutrino
SIGNAL & BACKGROUNDS	nue_app_QE	**1640.99**	124.4	**1643**	206
	nuebar_app_QE	11.9077	**1183.22**	15	**1183**
	numu_disappCC	3.61872	0.301009	7	2
	numubar_disapp_CC	0	0.380824	0	2
	nue_CC	136.415	29.0485	248	101
	nuebar_CC	2.57189	118.569	11	216
	NC	490.447	428.219	134	196
Total BG events :		**645**	**692**	**415**	**723**



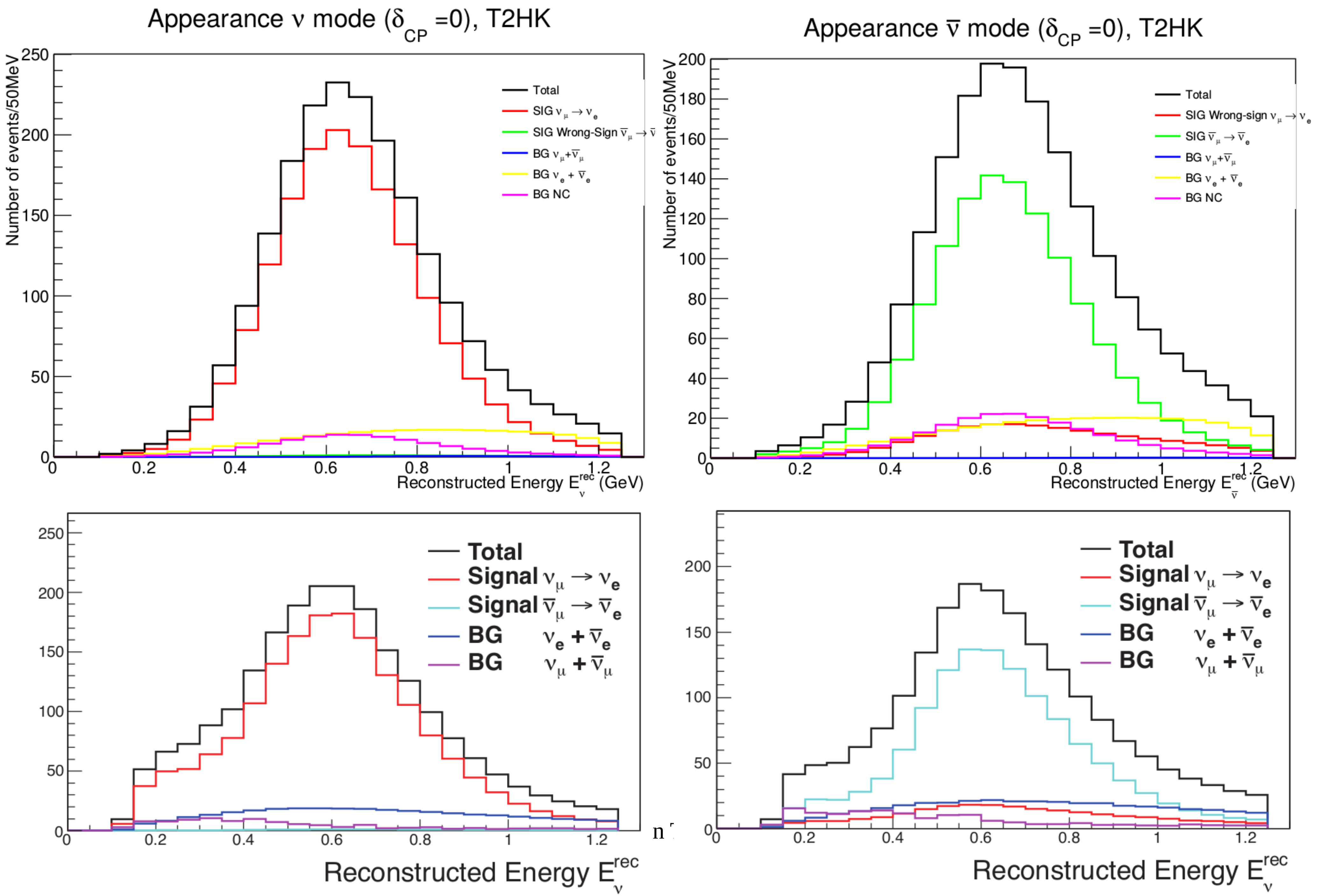
Configuration B. Top : *Our work*, **Bottom :** *Report*

C. Appearance Event Rates

		Computed		Report	
		neutrino	Anti-neutrino	neutrino	Anti-neutrino
SIGNAL & BACKGROUNDS	nue_app_QE	**1640.99**	205.074	**1643**	206
	nuebar_app_QE	13.67	**1181.34**	15	**1183**
	numu_disappCC	6.04327	1.20404	7	2
	numubar_disapp_CC	0	1.5233	0	2
	nue_CC	247.773	99.1952	248	101
	nuebar_CC	10.2059	214.81	11	216
	NC	131.72	214.109	134	196
Total BG events :		**406**	**723**	**415**	**723**

Figure: Reconstructed neutrino energy distribution of the ν_e candidate events.

(**Configuration C** : **Top :** *Our work*, **Bottom :** *Report*)

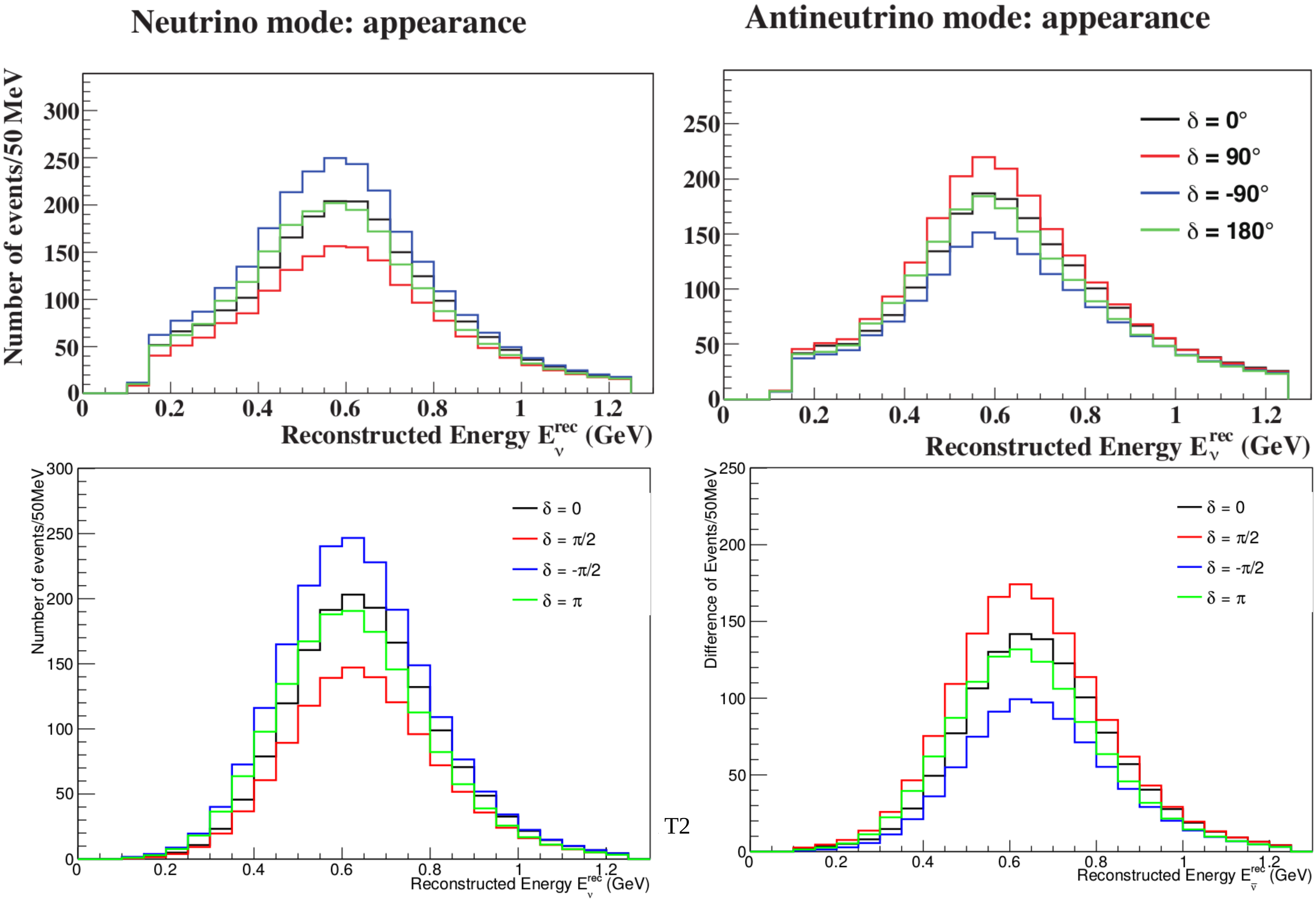


Discussion

- Energy binning of 50MeV in creating the histogram have resulted in removal of unususl ‘bumps’ at certain energies.
- The update in cross-section files and tuning of Background efficiencies helped in achieving a more relevant event spectrum.
- We fix Configuration-C for appearance channel for both neutrino and anti-neutrino for further studies.
- The normalization constant considered are **33.72794752 (neutrino) and 30.62794752 (anti-neutrino).**
- We now study the appearance event rates and difference of events for varied δ_{CP}

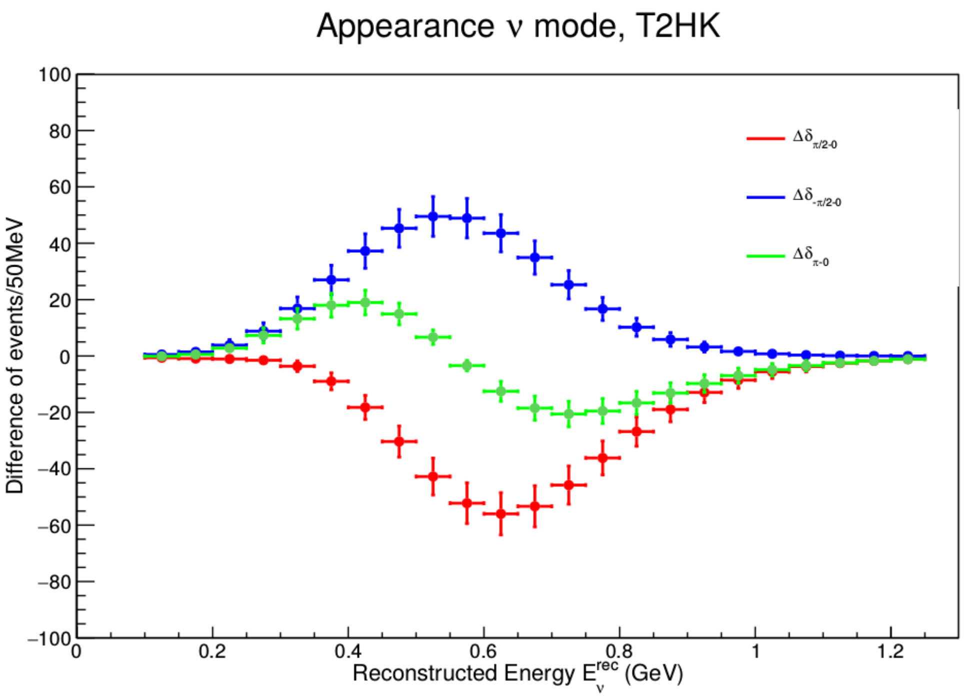
Figure : Reconstructed neutrino energy distribution for several values of δ_{CP}.

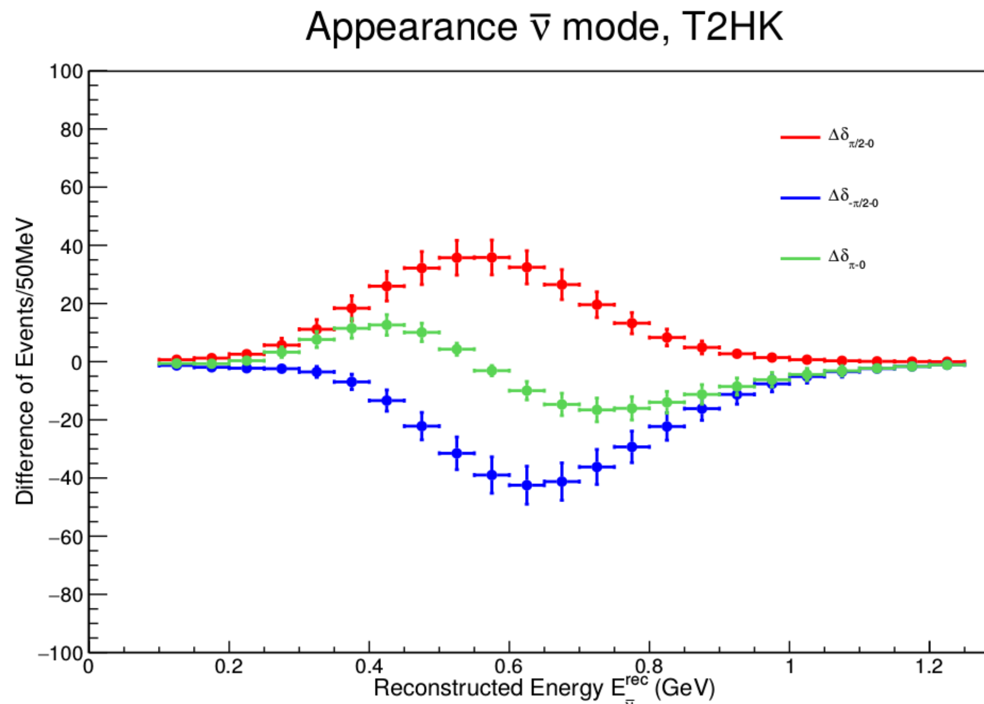
*(**Top** : Report, **Bottom** : Our work)*

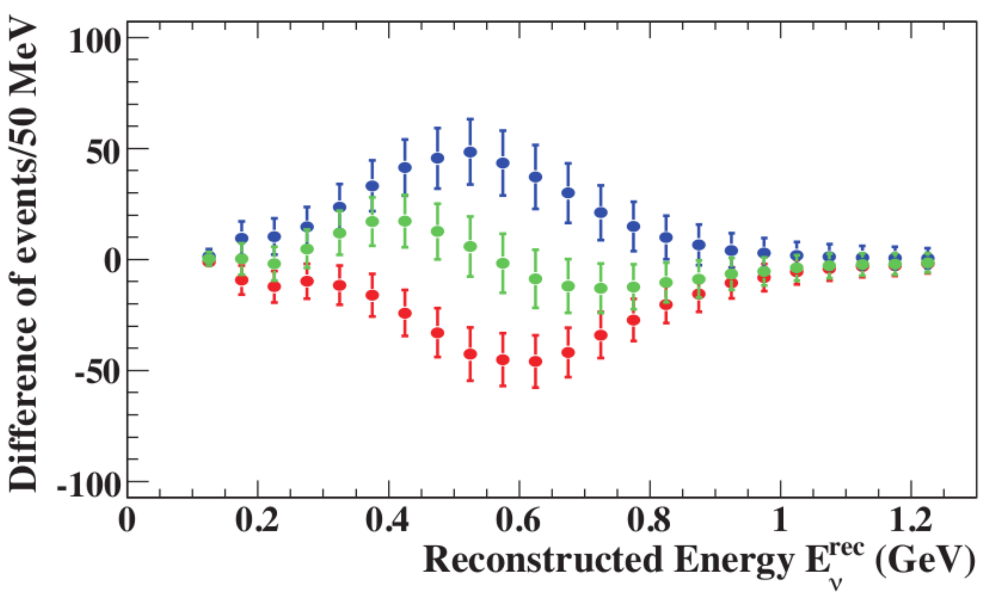


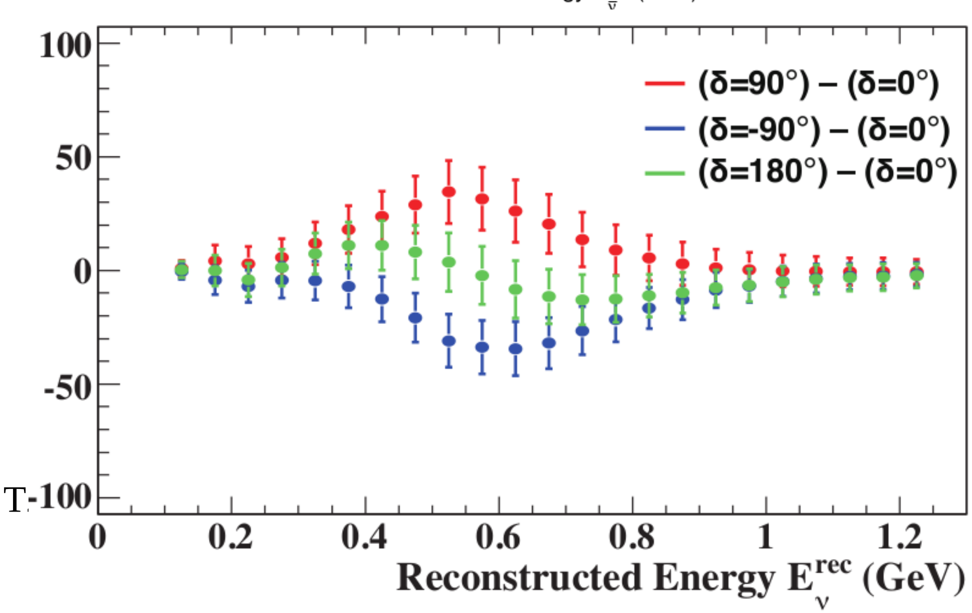
Difference of events

(Top: Our Work, Bottom: Report)



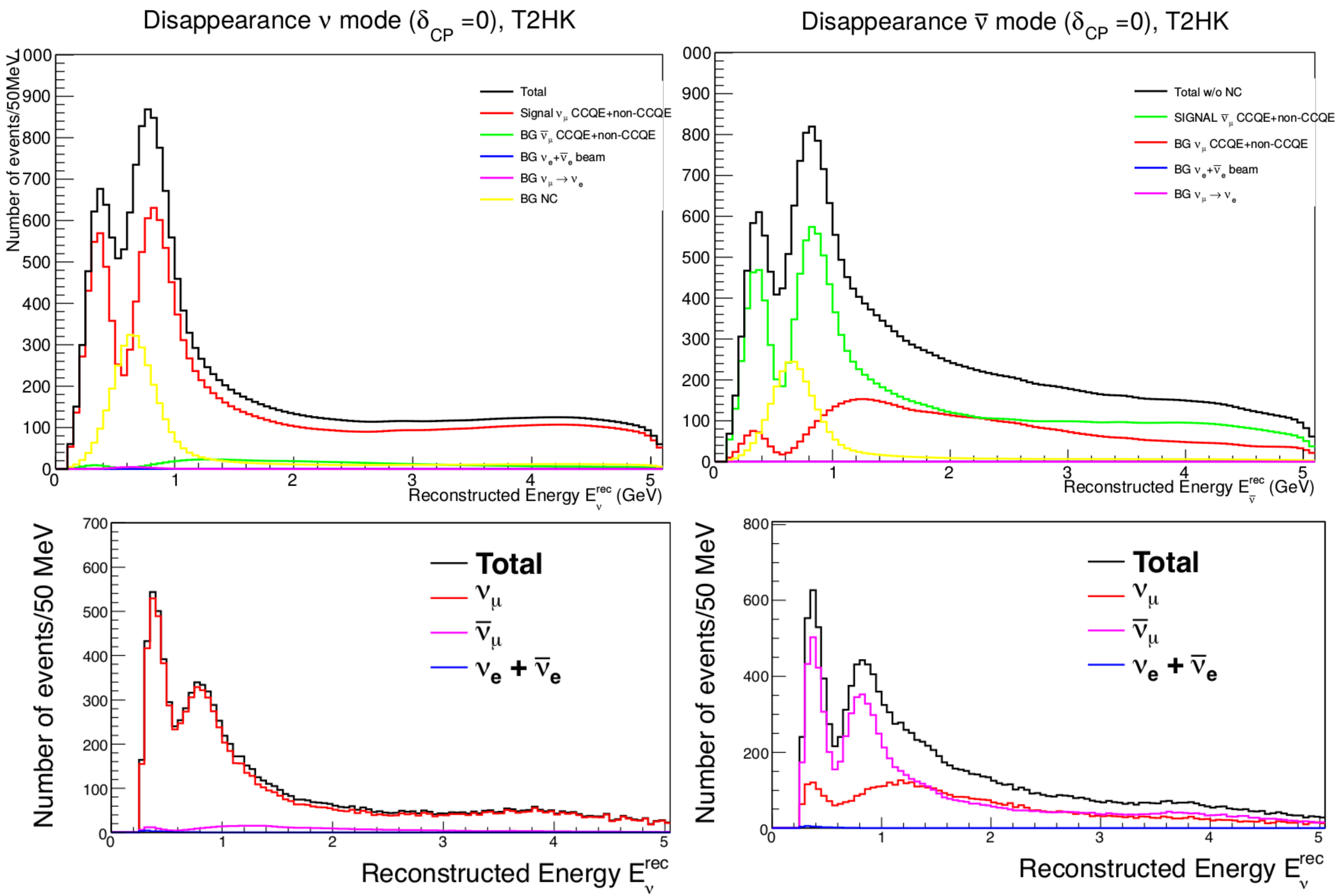




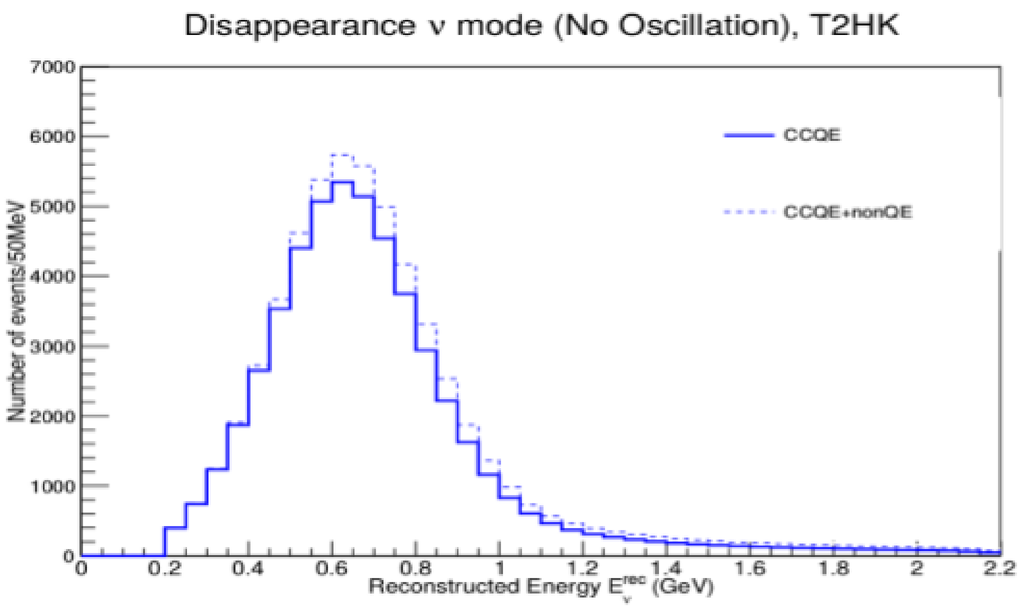


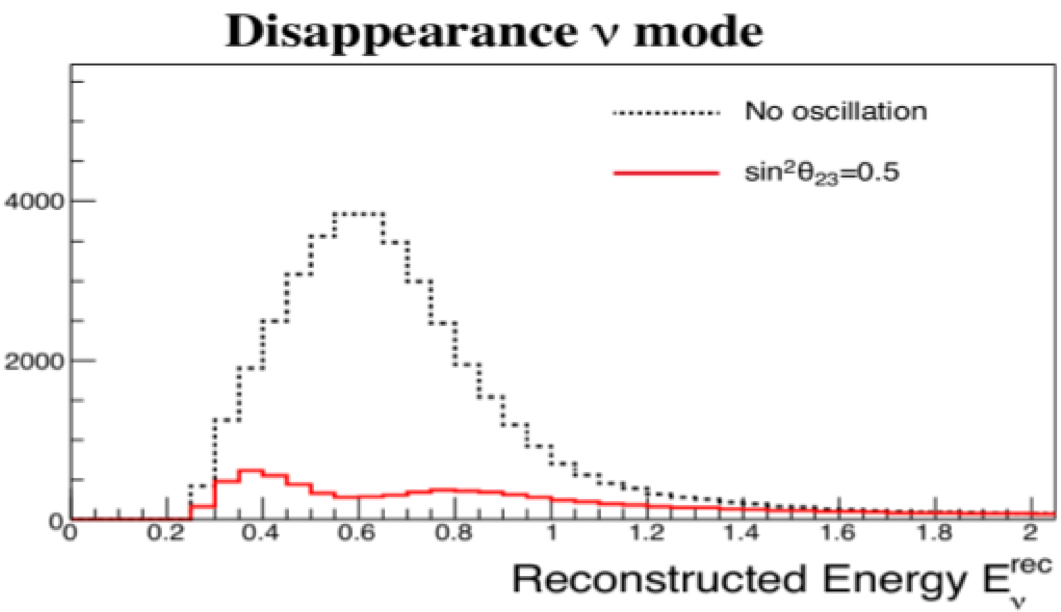
- Disappearance Events: Configuration B

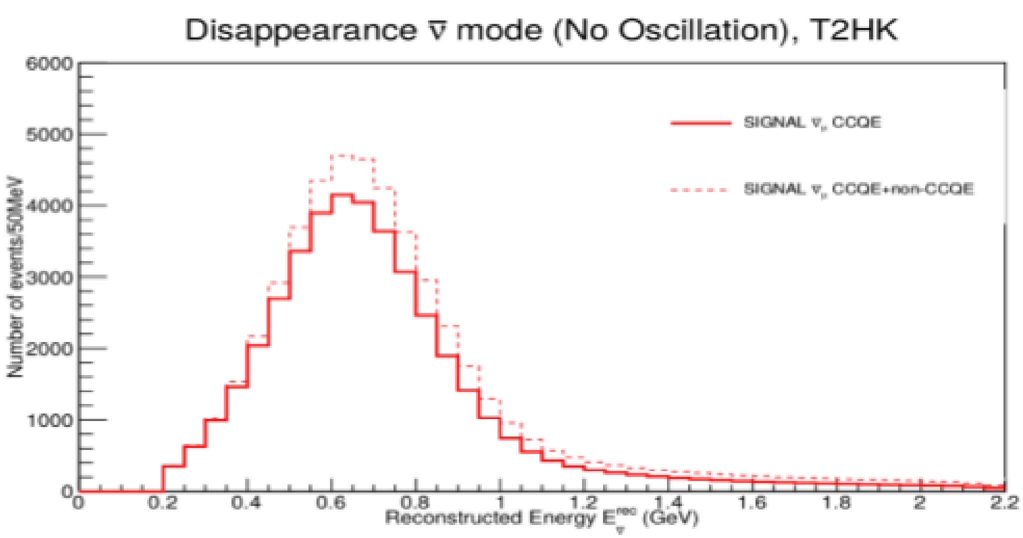
Configuration B **Top :** Our Work, **Bottom :** Report

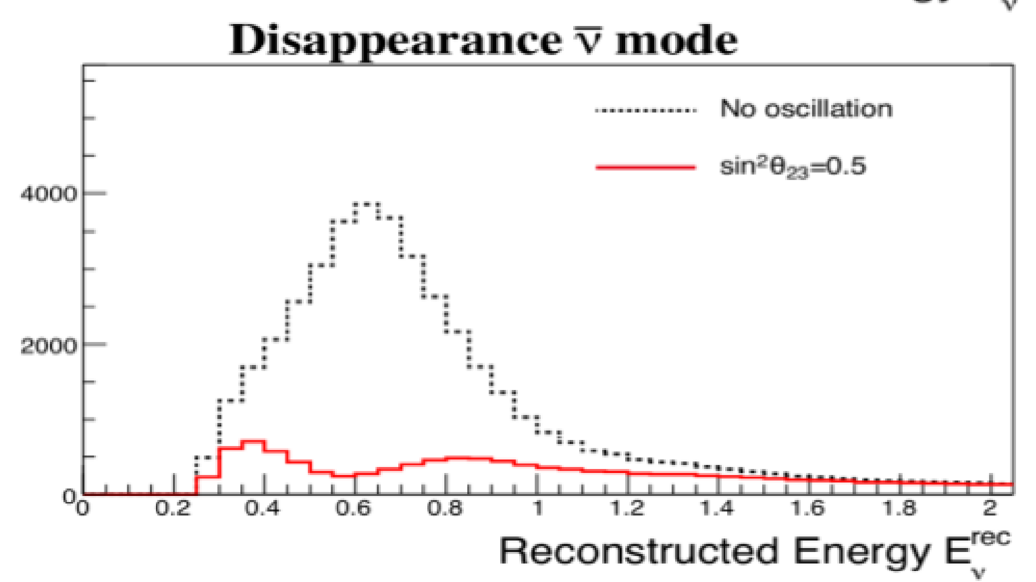


No Oscillation Mode : Configuration B









Configuration C : Making signal and BG detecting efficiencies compatible with GLoBES

TABLE XV: Event reduction for the ν_μ CC selection at the far detector. The numbers of expected MC events divided into four categories are shown after each selection criterion is applied. The MC expectation is based upon three-neutrino oscillations for $\sin^2 2\theta_{23} = 1.0$, $\Delta m^2_{32} = 2.4 \times 10^{-3}\,\mathrm{eV}^2/c^4$ and normal mass hierarchy (parameters chosen without reference to the T2K data).

(1) There is only one reconstructed Cherenkov ring

(2) The ring is μ-like

(3) The reconstructed momentum, p_μ, is greater than 200 MeV/c

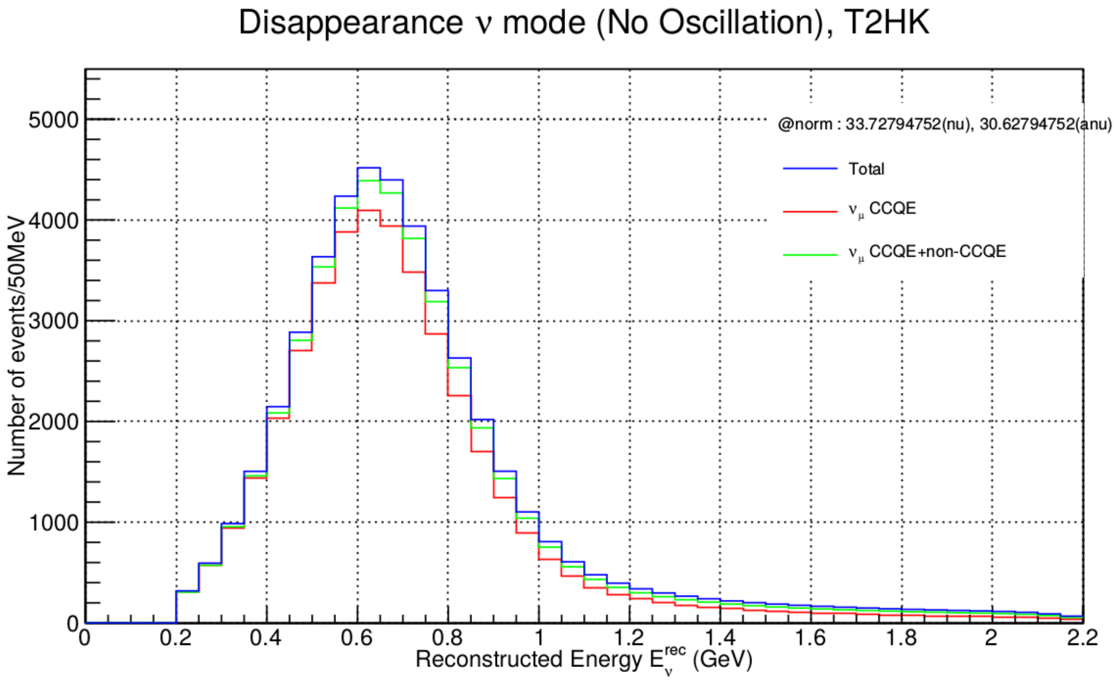
(4) There are less than two reconstructed Michel electrons

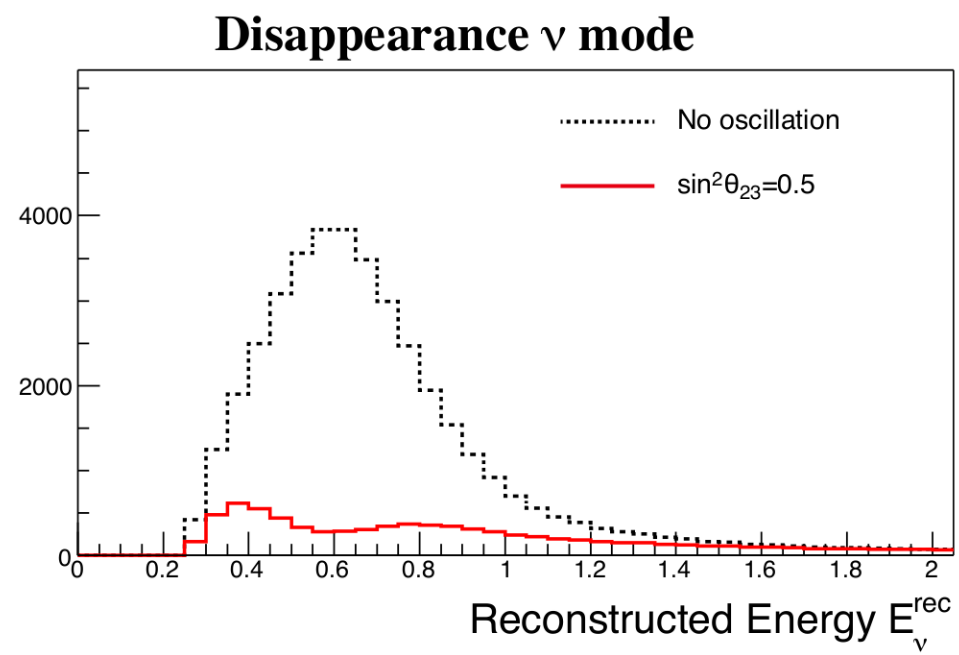
	MC total	$\nu_\mu + \overline{\nu}_\mu$ CCQE	$\nu_\mu + \overline{\nu}_\mu$ CC nonQE	$\nu_e + \overline{\nu}_e$ CC	$\nu + \bar{\nu}$ NC
interactions in FV	656.83	111.71	213.96	43.05	288.11
FCFV	372.35	85.55	162.20	41.58	83.02
(1) single ring	198.44	80.57	61.87	32.54	23.46
(2) muon-like	144.28	79.01	57.80	0.35	7.11
(3) $p_\mu > 200\,\mathrm{MeV}/c$	143.99	78.84	57.77	0.35	7.04
(4) $N_{\mathrm{Michel-e}} \leq 1$	125.85	77.93	40.78	0.35	6.78

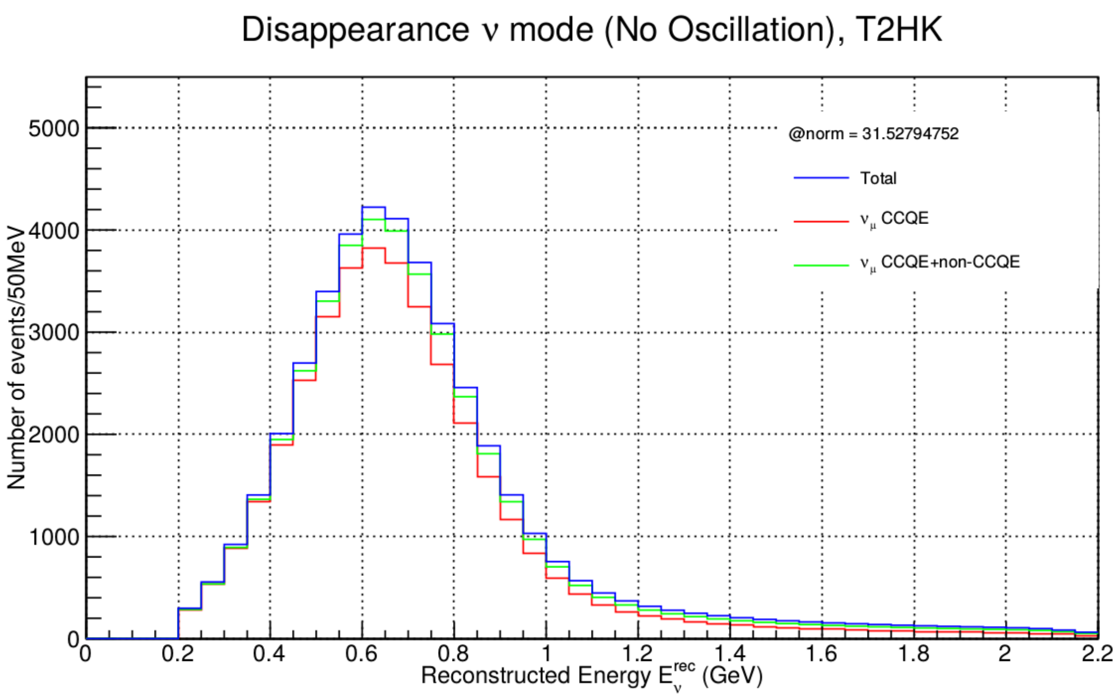
Table : Signal and Background Efficiencies for GloBES *(Disappearance)*

SIG/BG	Mode	Report (%)	MC FV	MC FCFV	X=FCFV/FV	GloBES effi (RepxX)
ν_μ CCQE	Neutrino	91	111.71	85.55	0.7658222182	69.6898218602
	Anti-neutrino	88	111.71	85.55	0.7658222182	67.3923552054
ν_μ CC non-QE	Neutrino	20.7	213.96	162.2	0.7580856235	15.6923724061
	Anti-neutrino	20.1	213.96	162.2	0.7580856235	15.237521032
Anti-ν_μ CCQE	Neutrino	95.6	111.71	85.55	0.7658222182	73.2126040641
	Anti-neutrino	95.4	111.71	85.55	0.7658222182	73.0594396204
Anti-ν_μ CCnon-QE	Neutrino	53.5	213.96	162.2	0.7580856235	40.5575808562
	Anti-neutrino	54.8	213.96	162.2	0.7580856235	41.5430921668
(ν_e + anti-ν_e)	Neutrino	0.5	43.05	41.58	0.9658536585	0.4829268293
	Anti-neutrino	0.4	43.05	41.58	0.9658536585	0.3863414634
NC	Neutrino	8.8	288.11	83.02	0.2881538301	2.5357537052
	Anti-neutrino	8.8	288.11	83.02	0.2881538301	2.5357537052
$\nu_\mu \rightarrow \nu_e$	Neutrino	1.1	1	1	1	1.1
	Anti-neutrino	0.7	1	1	1	0.7

ν_e	nu	0.438126			0.9658536585	0.4231656
	anu	0.08823			0.9658536585	0.0852172683
anti-ν_e	nu	0.061873			0.9658536585	0.0597602634
	anu	0.31177			0.9658536585	0.3011241951

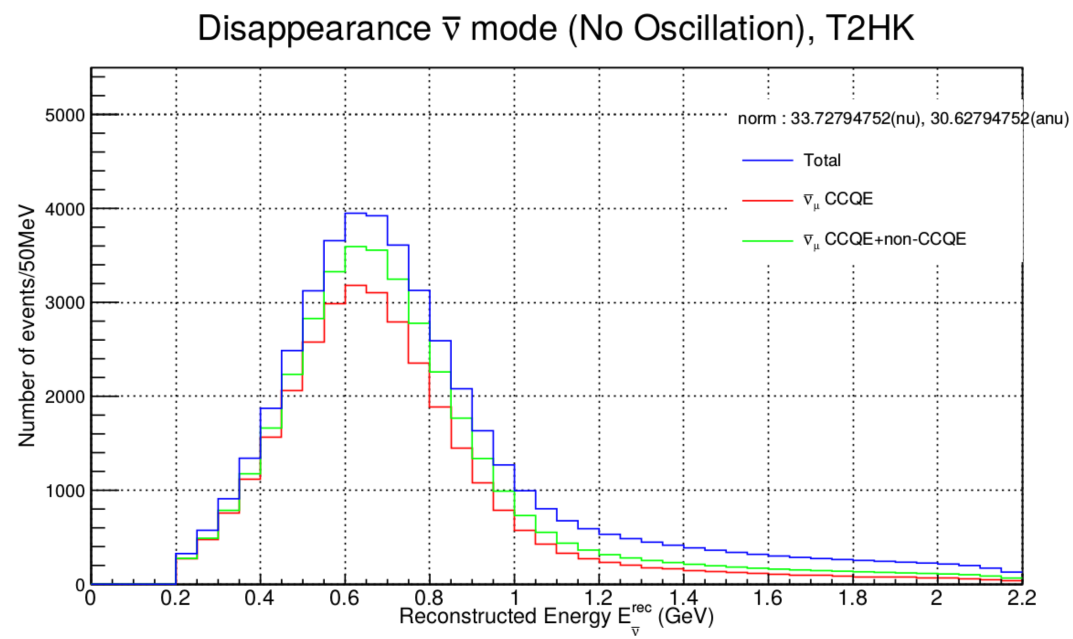


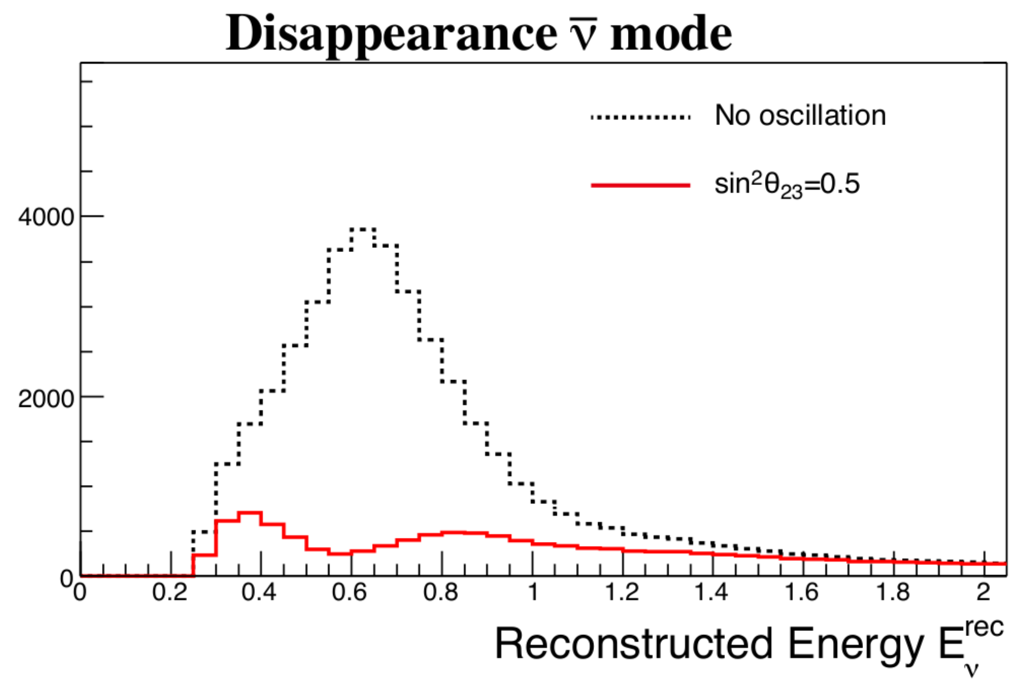


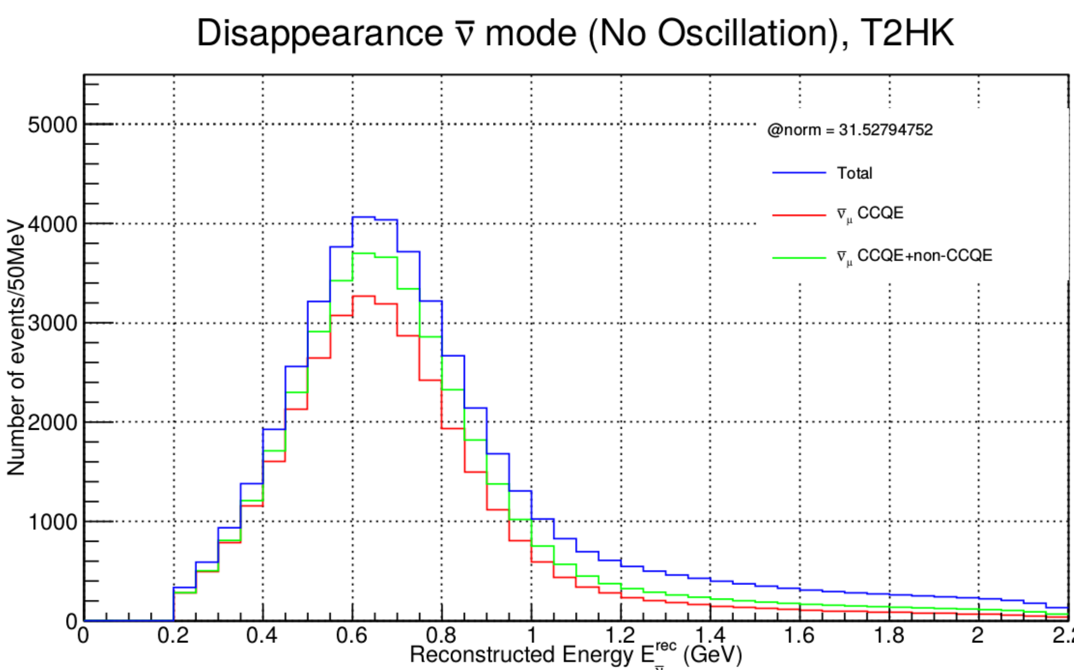


Left:
Top: @norm = 33.72794752(nu)
30.62794752 (anti-nu)
Bottom: @norm=31.52794752

Right: Report





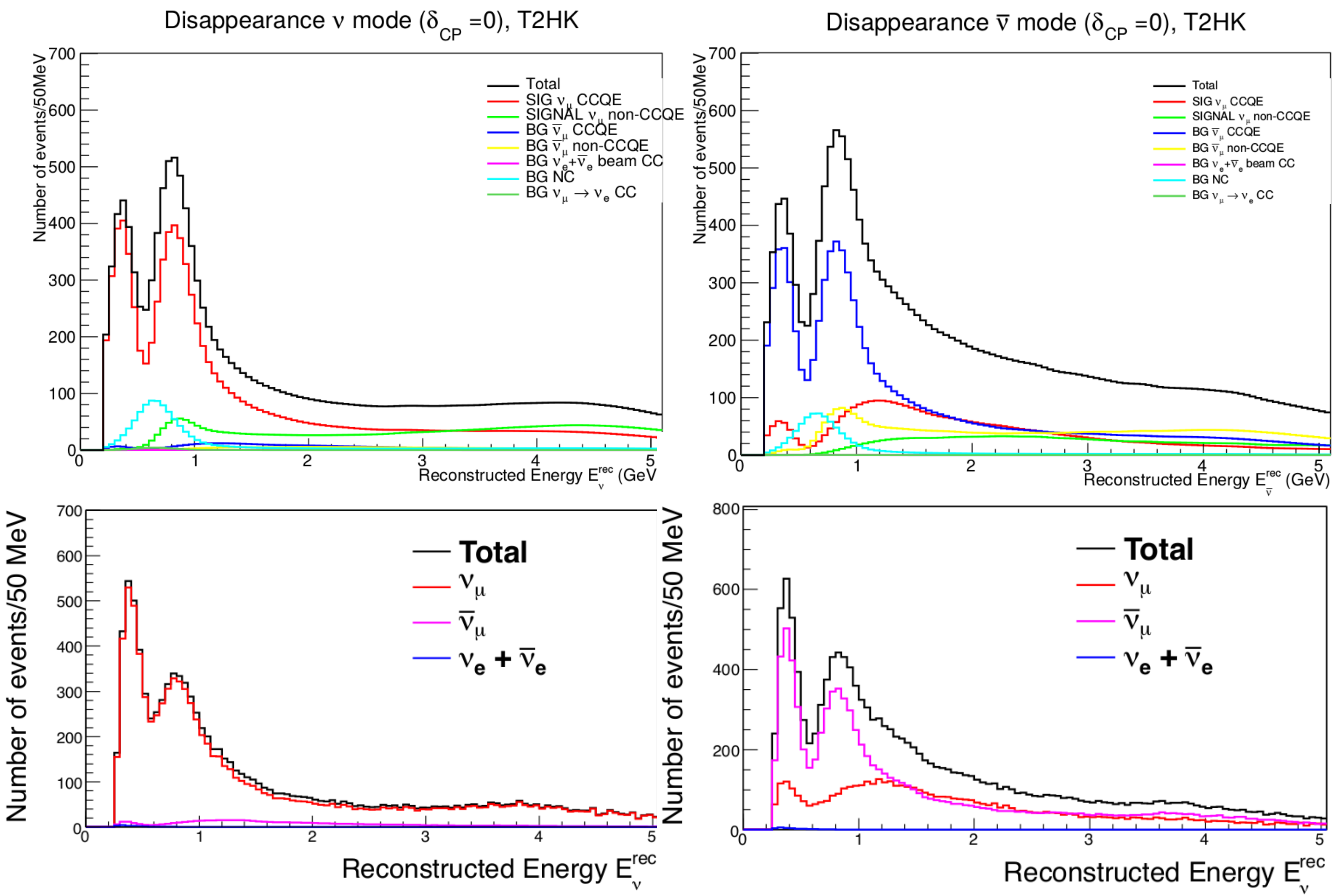


Left:
Top: @norm = 33.72794752(nu)
30.62794752 (anti-nu)
Bottom: @norm=31.52794752

Right: Report

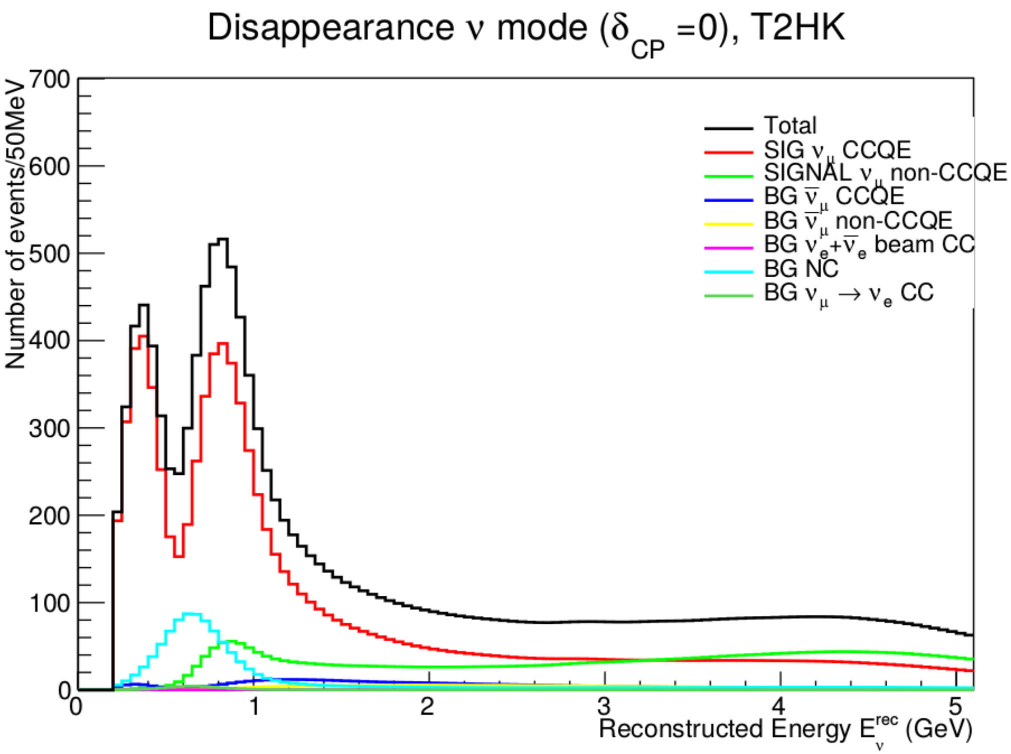
Configuration C : corrected @effi, @norm=31.52794752 and ERES=(0,0.0,0.85)

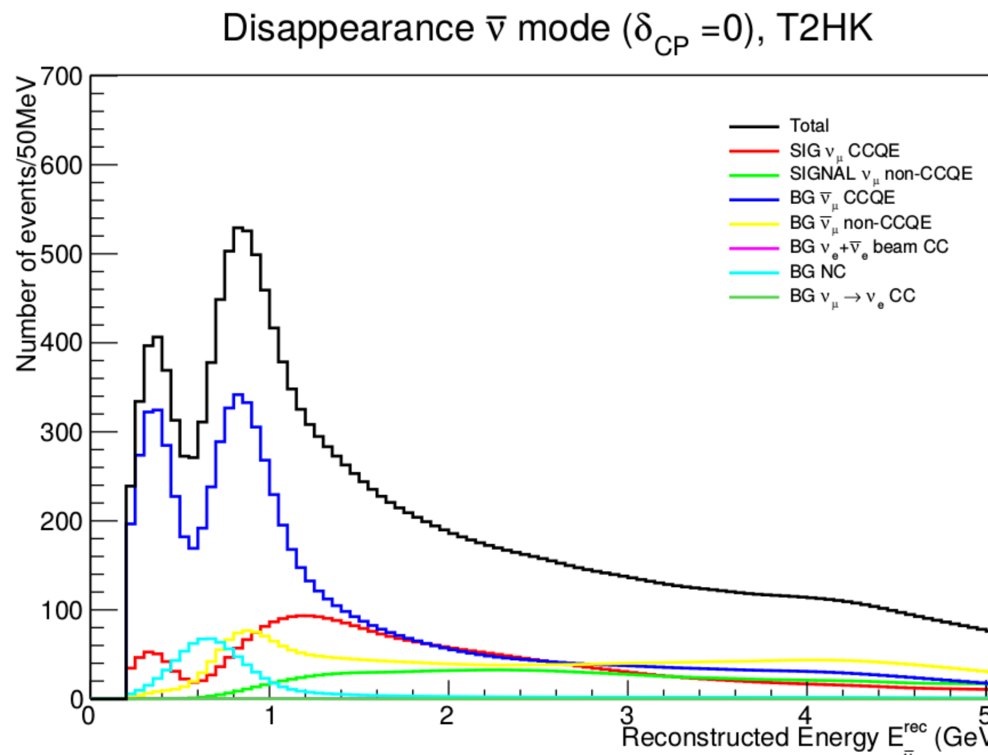
Top : Our Work, **Bottom :** Report

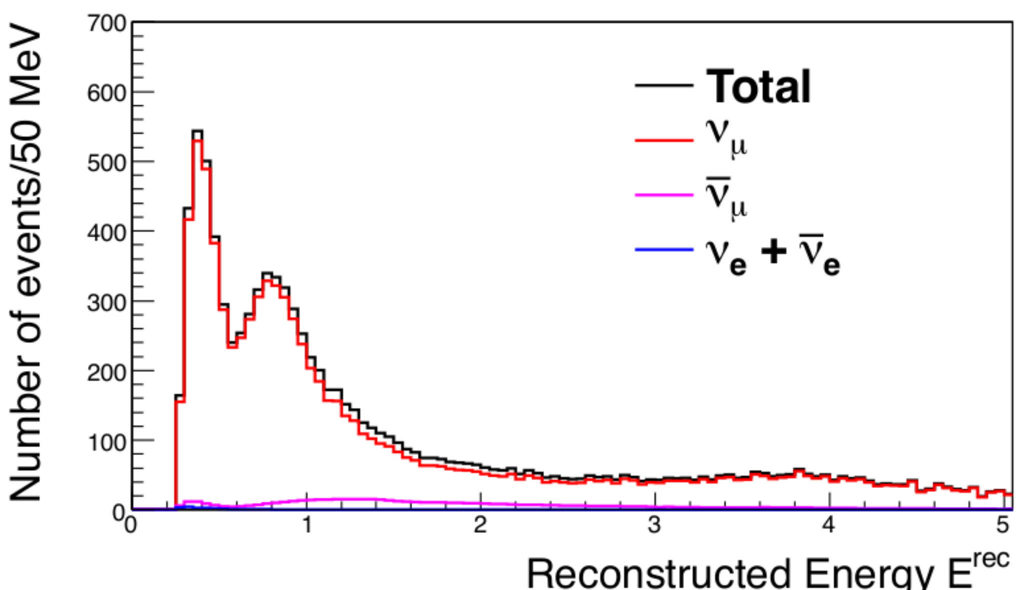


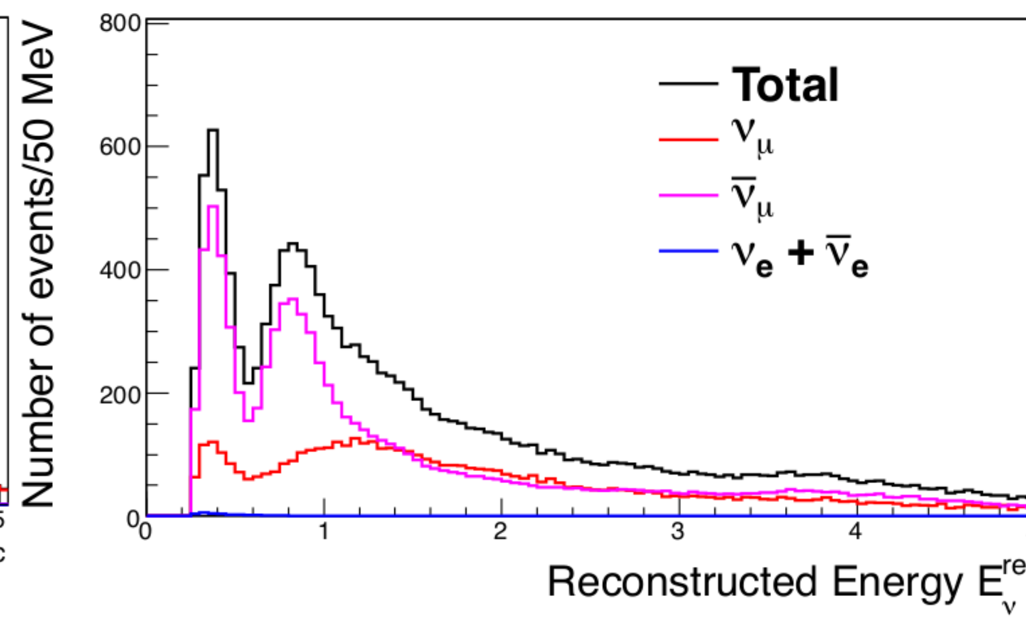
EVENT RATES

Configuration D : corrected @effi, @norm=31.52794752 and ERES=(0,0.03,0.85)









Discussion

- We're basically trying to match the event spectrum of appearance and disappearance channels as per the report, using GloBES.
- **Appearance rates:**
  - Three parameter configurations are considered
    - A) Calculated @norm = 31.52794752 and SIG/BG as in report with GloBES cross-section data.
    - B) Binning correction and @norm (33.72794752 (neutrino) and 30.62794752 (anti-neutrino)) tuned to obtain equivalent signal rates with NEUT cross-section data.
    - C) Correct bin of 50MeV, modified @norm and tuned BG efficiecies to obtain equivalent total event rates
- We also perform event rate calculation for different δ_{CP} and measure the difference of events.
- **Disappearance rates:**
  - Three parameter configurations are considered
    - A) Calculated @norm = 31.52794752 and SIG/BG as in report with GloBES cross-section data.
    - B) Binning correction and @norm (33.72794752 (neutrino) and 30.62794752 (anti-neutrino)) tuned to obtain equivalent signal rates with NEUT cross-section data.
    - C) corrected SIG/BG efficiencies, @norm=31.52794752 and ERES=(0,0.0,0.85)
    - D) corrected SIG/BG efficiencies, @norm=31.52794752 and ERES=(0,0.03,0.85)

References

- Global analysis of three-flavour neutrino oscillations: *synergies and tensions in the determination of θ_{23}, δ_{CP}, and the mass ordering, Esteban, I., Gonzalez-Garcia, M.C., Hernandez-Cabezudo, A. et al.* ***J. High Energ. Phys. (2019): 106.*** *https://doi.org/10.1007/JHEP01(2019)106*

- *Hyper-Kamiokande Design Report, Abe, K. et al.* ***arXiv:1805.04163*** *[physics.ins-det]*

- *Measurements of neutrino oscillation in appearance and disappearance channels by the T2K experiment with 6.6E20 protons on target, Abe, K.* ***Phys. Rev. D 91, 072010 (2015)***

- *CP Violation and Matter Effect in Long Baseline Neutrino Oscillation Experiments, Jiro Arafune, Masafumi Koike and Joe Sato,* ***Phys. Rev. D56 : 3093-3099****,* ***1997****; Erratum-ibid.D60:119905,1999*

- *Simulation of long baseline neutrino oscillation experiments with GloBES, P. Huber, M. Lindner and W. Winter,* ***Comput. Phys. Commun. 167 (2005) 195****, arXiv:hep-ph/0407333*

- *New features in the simulation of neutrino oscillation experiments with GLoBES 3.0, P. Huber, J. Kopp, M. Lindner, M. Rolinec, and W. Winter,* ***Comput. Phys. Commun. 177 (2007) 432****, arXiv:hep-ph/0701187*

To be continued...

- **Study sensitivity of T2HK in determination of the unsolved parameters:**
  - δ_{CP}
  - CP violation
  - Mass Hierarchy
  - Θ_{23}

- **Impact of sterile neutrino and Non-standard Interaction on the sensitivity of the LBNE**

Acknowledgement

- I would like to thank Dr. Jean Tran Thanh Van and Dr. Tran Thanh Son for providing me an opportunity to work at International Centre of Interdisciplinary Science and Education (ICISE) and IFIRSE, Vietnam.
- I thank Dr. Ngouniba Ki Francis, my Ph.D. supervisor and Dr. Nilakshi Das, Head, Department of Physics of Tezpur Univeristy, Assam, India for their permission in this carrying out this ambituous visit.
- I'm delighted to express my obligation to Dr. Cao Van Son (KEK, Japan) for his guidance with the project.
- I'm thankful Dr. Nguyen Thi Hong Van (IOP, Hanoi) and Mr. Tran Van Ngoc of the Neutrino Physics group of IFIRSE for their necessary help in the progress of the work till now.
- I also thank Dr. Le Duc Ninh and Dr. Dao Thi Nhung of Theoretical Physics Group of IFIRSE for their presence around and interesting interactions at times.
- I, specially, thank Ms. Phan To Quyen for her friendship & delicious cooking and Mr. Phan Anh Vu for his company discussing random topics of interest.
- I immensely thank the administrative and security staff of ICISE for their kindness and generosity which made my stay comfortable and memorable.
- I would like share my love for the people and climate of Quy Hoa and the sea beside.

My Next Plan

i. Board the train to Hanoi tomorrow.

ii. Board a flight to India on 11/10/2019.

iii. Attend Preparatory School on Theoretical High Energy Physics in Tezpur University, Assam.

   – *It's an exclusive training conducted every year selecting 40 Ph.D. students nationally.*
   – *Tight schedule from 14th Oct-9th Nov, 2019 (**morning** : lectures, **afternoon**: tutorials)*

iv. Continue working on the T2HK CPV project.

v. Will miss the next bi-weekly meeting but continue discussion on the work.

Aim to complete the work by Oct end/Nov start and begin paperwork.

??? ***ANY*** ???

questions . . . .

suggestions ....

feedbacks … .

proposals ....

----- Thank You -----

Saved for Later