International Symposium on Neutrino Frontiers'18
ICISE, Quy Nhon, VN, 16/07/2018

New results from T2K and future prospects

Anselmo Cervera Villanueva
IFIC-Valencia

On behalf of the T2K Collaboration

Flavour mixing

ν_e

ν_μ

ν_τ

weak eigenstates

$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k} \nu_{kL}$$

(arbitrary sizes)

ν_1

ν_2

ν_3

mass eigenstates

Flavour mixing

(arbitrary sizes)

ν_e, ν_μ, ν_τ

weak eigenstates

$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k} \nu_{kL}$$

ν_1, ν_2, ν_3

mass eigenstates

PMNS mixing matrix

Pontecorvo–Maki–Nakagawa–Sakata

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmospheric sector — connection between solar and atmospheric — solar sector

$c_{ij}=\cos\theta_{ij}$
$s_{ij}=\sin\theta_{ij}$

Dirac

Flavour mixing

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mass eigenstates

θ_{23} θ_{13}, δ_{CP} θ_{12}

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$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k} \nu_{kL}$$

(arbitrary sizes)

ν_1

ν_2

ν_3

mass eigenstates

Δm^2_{12}

Δm^2_{23}

$\Delta m^2_{ij} = m^2_i - m^2_j$

θ_{23} θ_{13}, δ_{CP} θ_{12}

PMNS mixing matrix

Pontecorvo–Maki–Nakagawa–Sakata

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atmospheric sector — connection between solar and atmospheric — solar sector

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Dirac

Flavour mixing

ν_e

ν_μ

ν_τ

weak eigenstates

$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k} \nu_{kL}$$

(arbitrary sizes)

ν_1 Δm^2_{12}

ν_2 Δm^2_{23}

ν_3

$\Delta m^2_{ij} = m^2_i - m^2_j$

mass eigenstates

θ_{23} | θ_{13}, δ_{CP} | θ_{12} | α_1, α_2

PMNS mixing matrix

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atmospheric sector | connection between solar and atmospheric | solar sector

$c_{ij}=\cos\theta_{ij}$

$s_{ij}=\sin\theta_{ij}$

Majorana

Dirac

Experimental strategies

T2K

θ_{23}~46º (8%), **octant ?** **θ_{13}~8.3º** (5%), **δ_{CP} ?** **θ_{12} ~33º** (4%)

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

PDG particle data group **2017**

Δm^2_{12} ~ 7.53x10^{-5} eV^2 (2.4%)
$|\Delta m^2_{23}|$ ~ 2.45x10^{-3} eV^2 (2%)
sign(Δm^2_{23}) unknown

Experimental strategies

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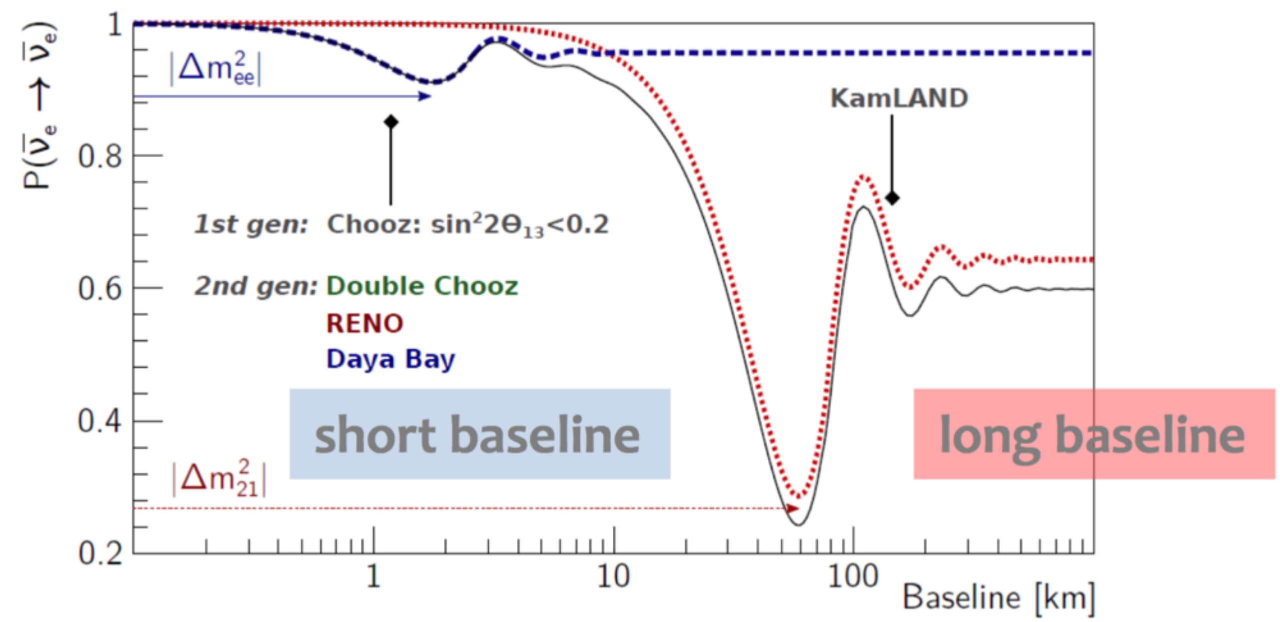
sign(Δm^2_{23}) unknown

- Independent θ_{13} measurement at reactor experiments: $\bar{\nu}_e$ dissap.

short baseline **long baseline**

$$P_{\bar{\nu}_e\to\bar{\nu}_e} = 1 - \sin^2 2\theta_{13} \sin^2(\Delta m^2_{ee}\frac{L}{4E}) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\Delta m^2_{21}\frac{L}{4E})$$

$$\sin^2(\Delta m^2_{ee}\frac{L}{4E}) \equiv \cos^2\theta_{12}\sin^2(\Delta m^2_{31}\frac{L}{4E}) + \sin^2\theta_{12}\sin^2(\Delta m^2_{32}\frac{L}{4E})$$



Experimental strategies

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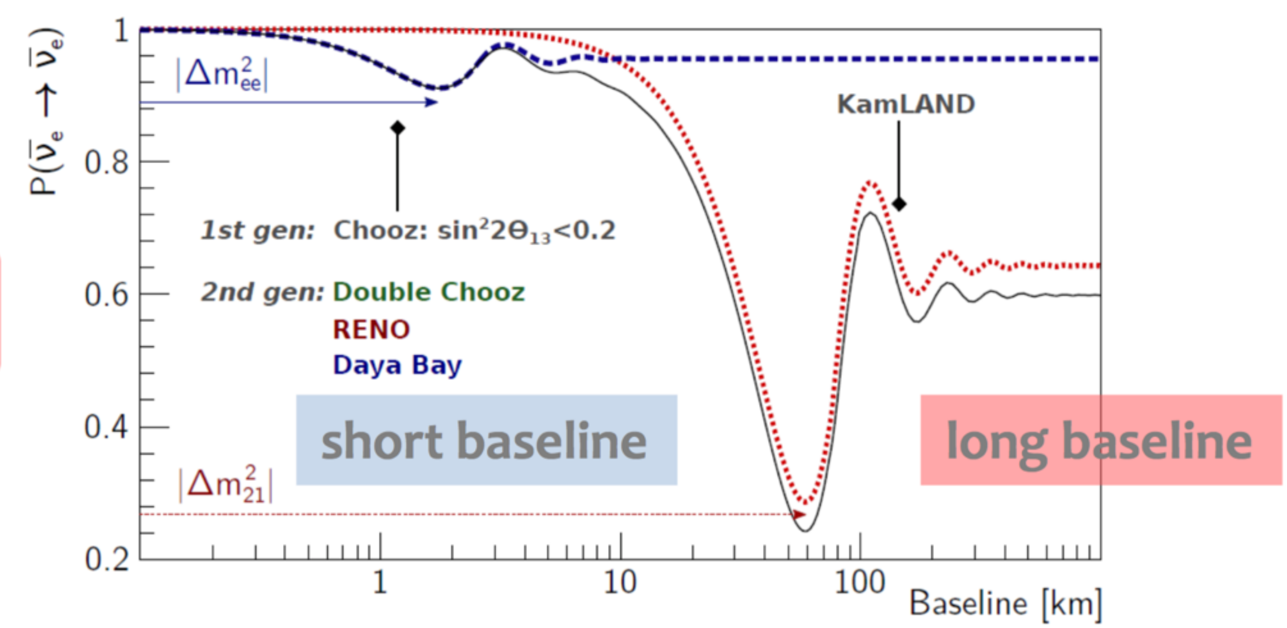


- θ_{13}-δ_{CP} measurement at LBL experiments: ν_e /$\bar{\nu}_e$ appearance

$$P(\nu_\mu \to \nu_e) \sim \sin^2 2\theta_{13} \times \sin^2\theta_{23} \times \frac{\sin^2[(1-x)\Delta]}{(1-x)^2}$$
$$-\alpha\sin\delta \times \sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23} \times \sin\Delta\frac{\sin[x\Delta]}{x}\frac{\sin[(1-x)\Delta]}{(1-x)}$$
$$+\alpha\cos\delta \times \sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23} \times \cos\Delta\frac{\sin[x\Delta]}{x}\frac{\sin[(1-x)\Delta]}{(1-x)}$$
$$+\mathcal{O}(\alpha^2)$$

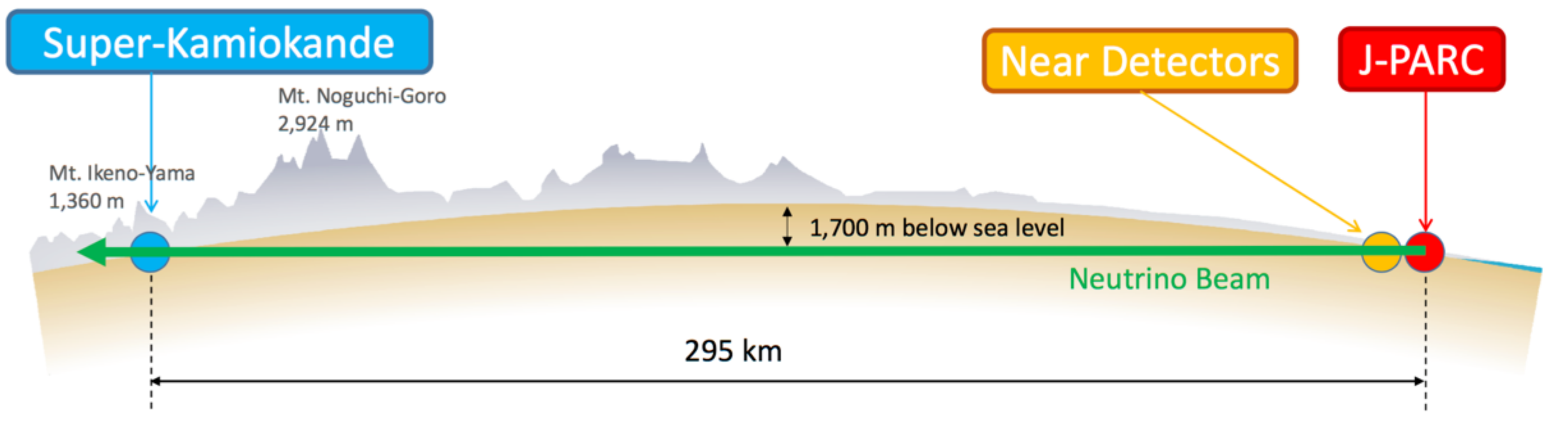
$$\alpha = \left|\frac{\Delta m^2_{21}}{\Delta m^2_{31}}\right| \sim \frac{1}{30} \qquad \Delta \equiv \frac{\Delta m^2_{31}L}{4E} \qquad x \equiv \frac{2\sqrt{2}G_F N_e E}{\Delta m^2_{31}}$$

M. Freund, Phys.Rev. D64 (2001) 053003

- $\sin^2 2\theta_{13}$ dependence of leading term
- θ_{23} dependence of leading term: "octant" dependence (θ_{23}=/>/<45°?)
- CP odd phase δ: asymmetry of probabilities $P(\nu_\mu\to\nu_e) \neq P(\bar{\nu}_\mu\to\bar{\nu}_e)$ if sin δ ≠ 0
- Matter effect through x: $\nu_e(\bar{\nu}_e)$ enhanced in normal (inverted) hierarchy

The T2K experiment

- First **off-axis** neutrino oscillation experiment, started taking data early 2010 and in 2011 published the first indication of **electron neutrino appearance** (and non-zero θ_{13}) **in a muon neutrino beam**, which was later discovered (> 5σ) in 2013



- Since 2014 most data taken in anti-neutrino mode
- Next goals:
  - Observe $\overline{\nu}_e$ appearance
  - Search for strong indication of CP violation

The T2K Collaboration (2018)

~500 members, 67 Institutes, 12 countries

Canada
TRIUMF
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
U. Winnipeg
York U.

France
CEA Saclay
LLR E. Poly.
LPNHE Paris

Germany
Aachen U.

Italy
INFN, U. Bari
INFN, U. Napoli
INFN, U. Padova
INFN, U. Roma

Japan
ICRR Kamioka
ICRR RCCN
Kavli IPMU
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Okayama U.
Osaka City U.
Tokyo Institute Tech
Tokyo Metropolitan U.
U. Tokyo
Tokyo U of Science
Yokohama National U.

Poland
IFJ PAN, Cracow
NCBJ, Warsaw
U. Silesia, Katowice
U. Warsaw
Warsaw U. T.
Wroclaw U.

Russia
INR

Spain
IFAE, Barcelona
IFIC, Valencia
U. Autonoma Madrid

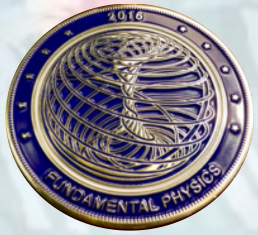
Switzerland
ETH Zurich
U. Bern
U. Geneva

United Kingdom
Imperial C. London
Lancaster U.
Oxford U.
Queen Mary U. L.
Royal Holloway U.L.
STFC/Daresbury
STFC/RAL
U. Glasgow
U. Liverpool
U. Sheffield
U. Warwick

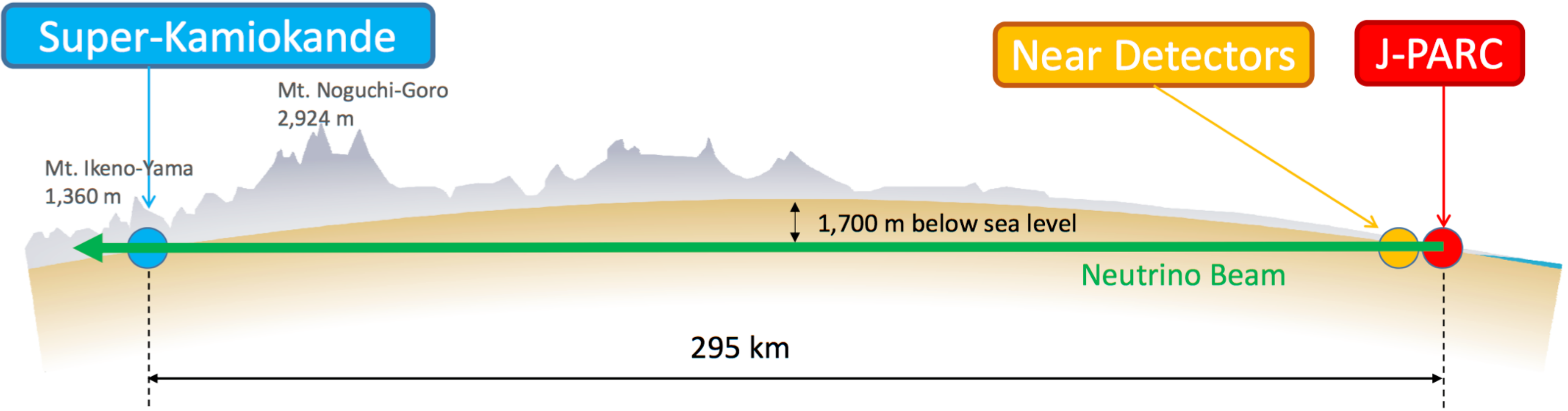
USA
Boston U.
Colorado S. U.
Duke U.
Louisiana State U.
Michigan S.U.
SLAC
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

Vietnam
IFIRSE
IOP, VAST

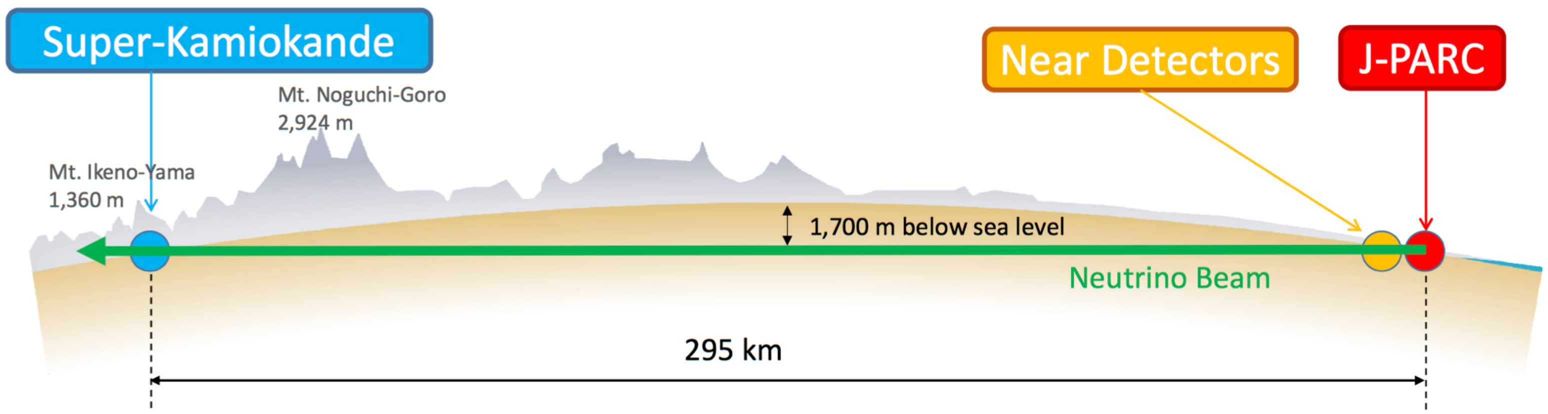
T2K Breakthrough Prize Celebration, 2016

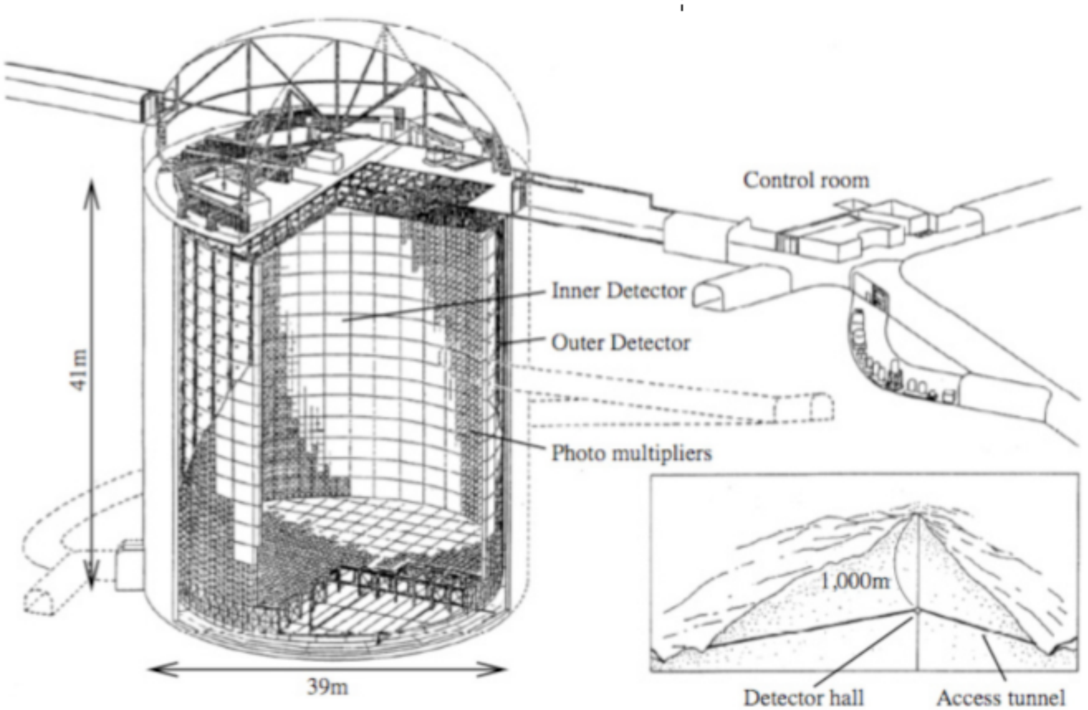


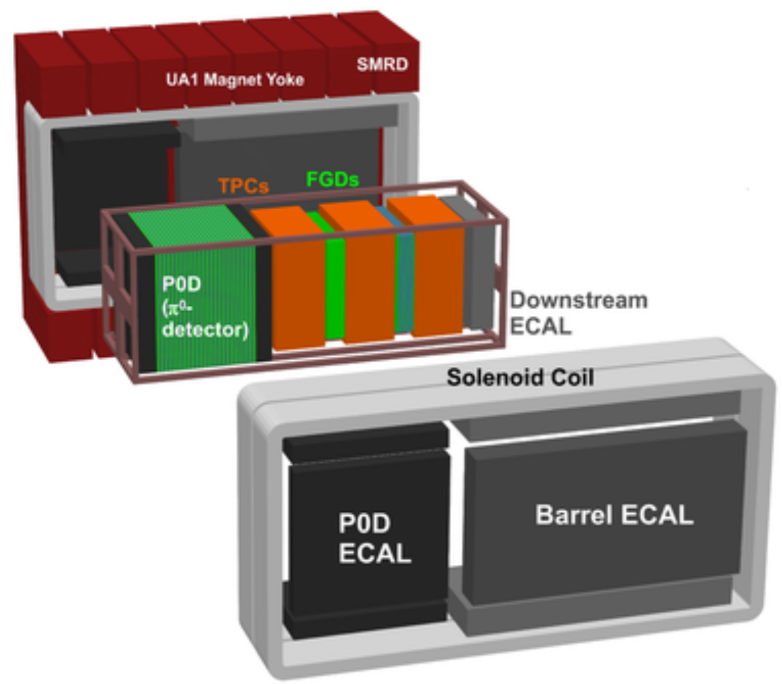

Super-Kamiokande
J-PARC
ν_μ


Super-Kamiokande
Near Detectors
J-PARC
Mt. Noguchi-Goro
2,924 m
Mt. Ikeno-Yama
1,360 m
1,700 m below sea level
Neutrino Beam
295 km

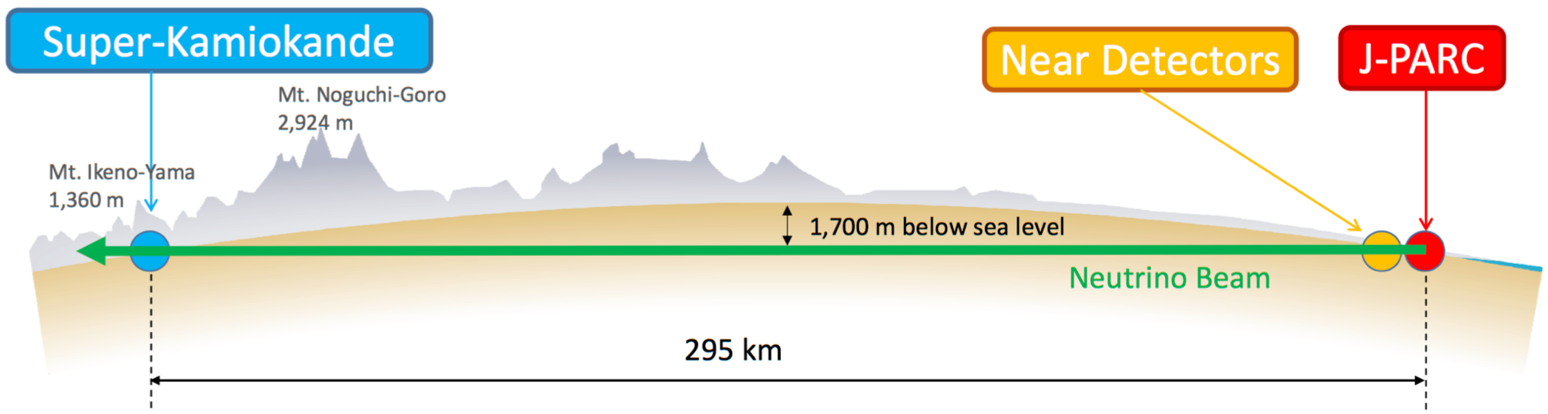
T2K detectors

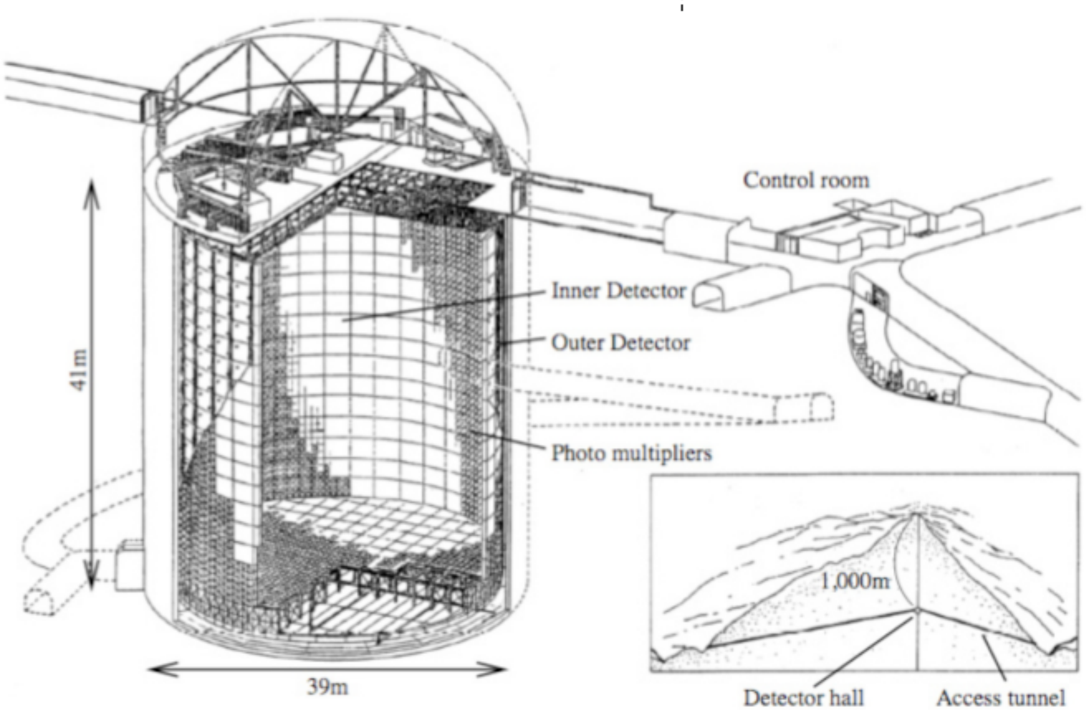


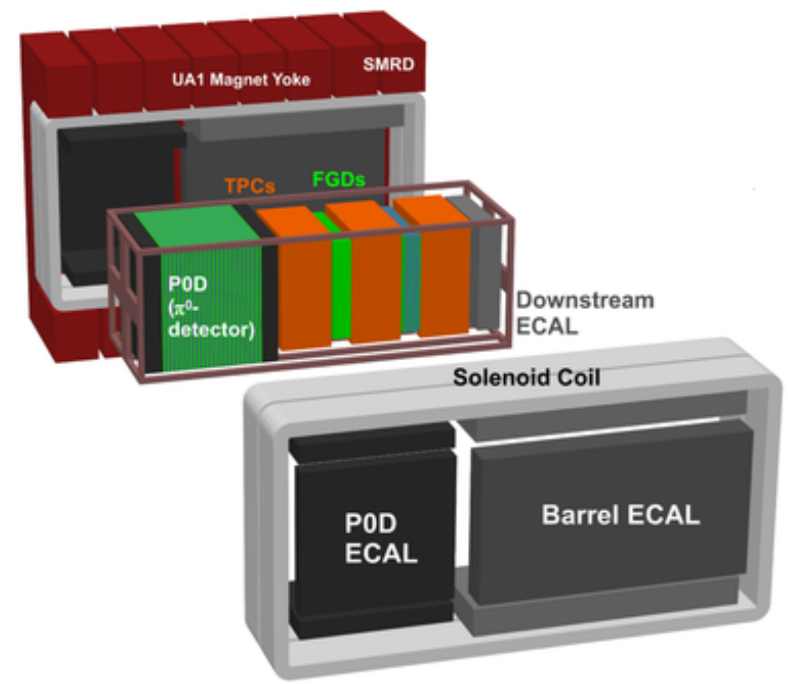


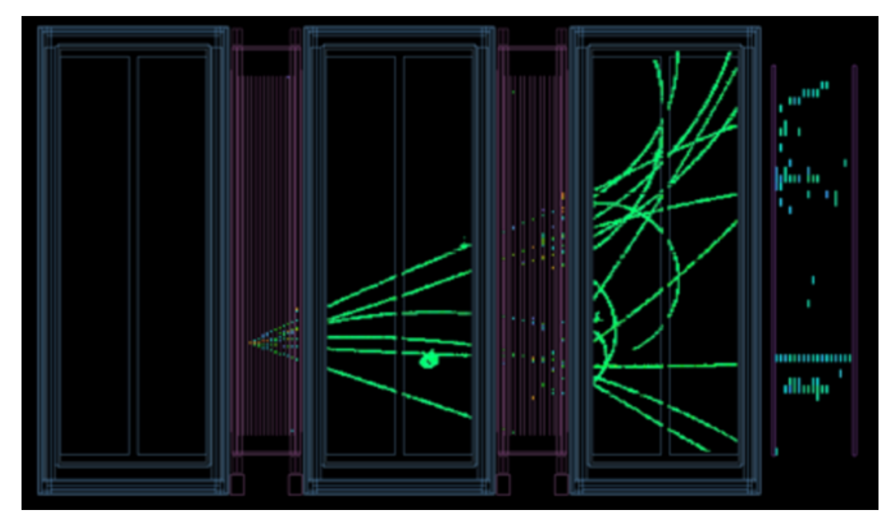


T2K detectors

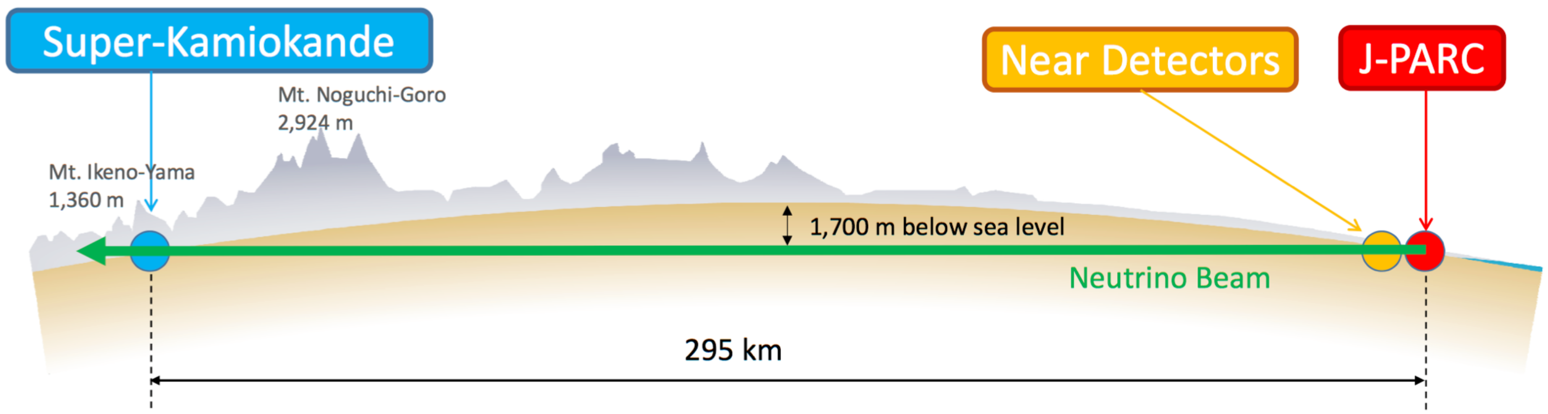


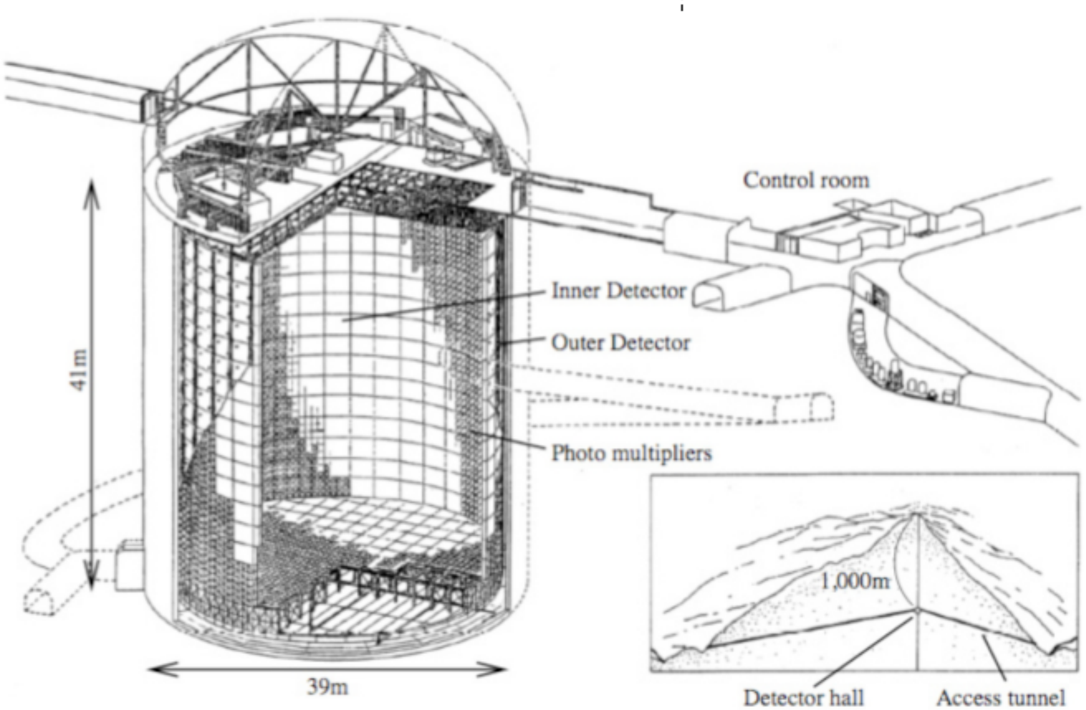


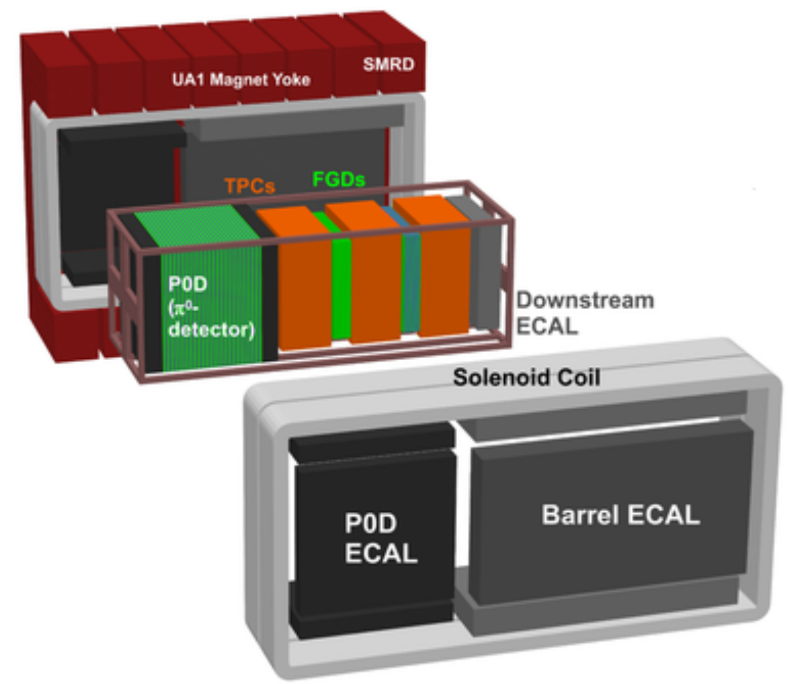


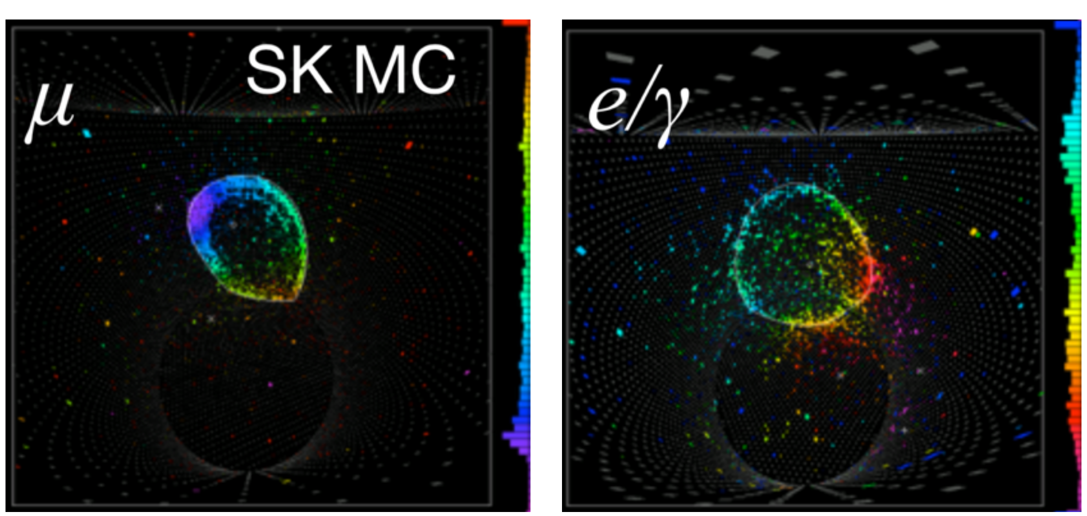


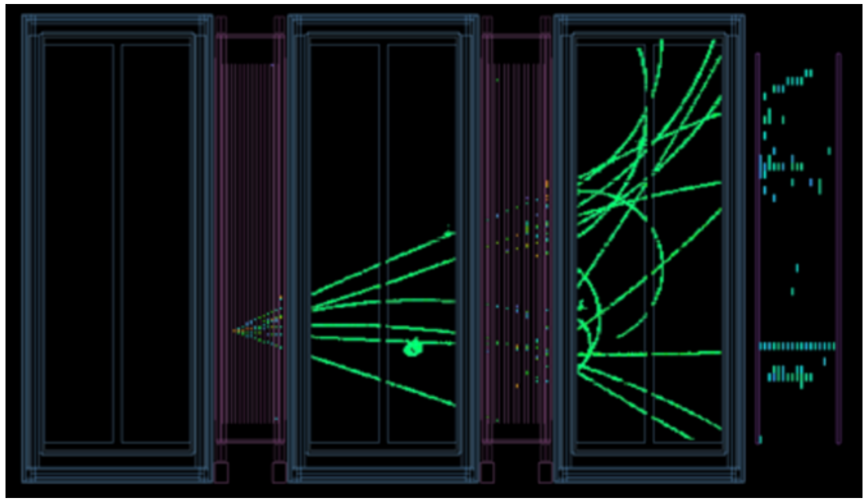
T2K detectors



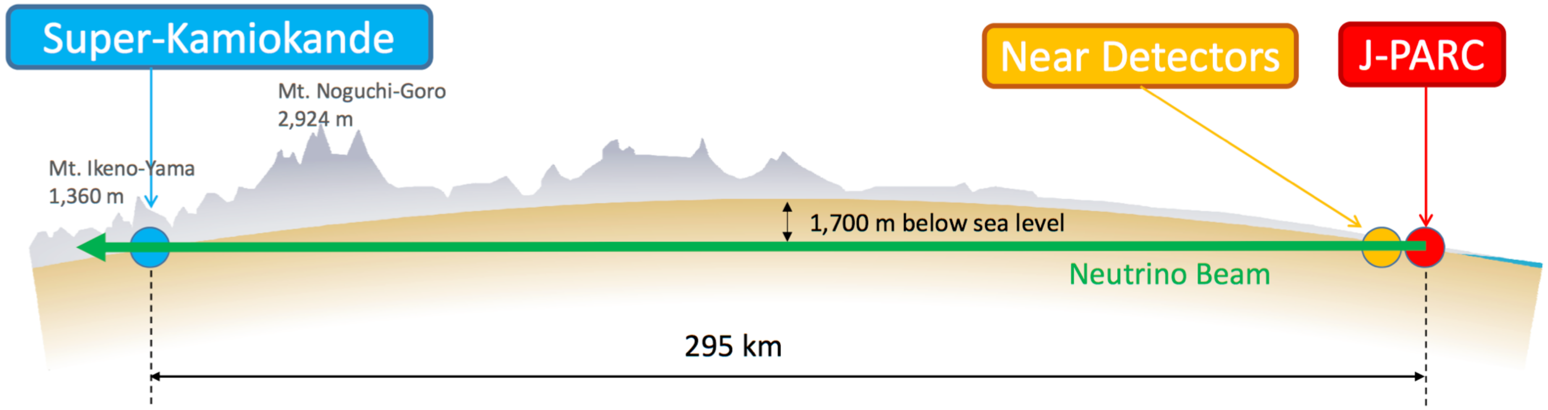








T2K oscillation analyses



- Prediction of neutrino flux at SK
- Reconstruction and selection of the SK data

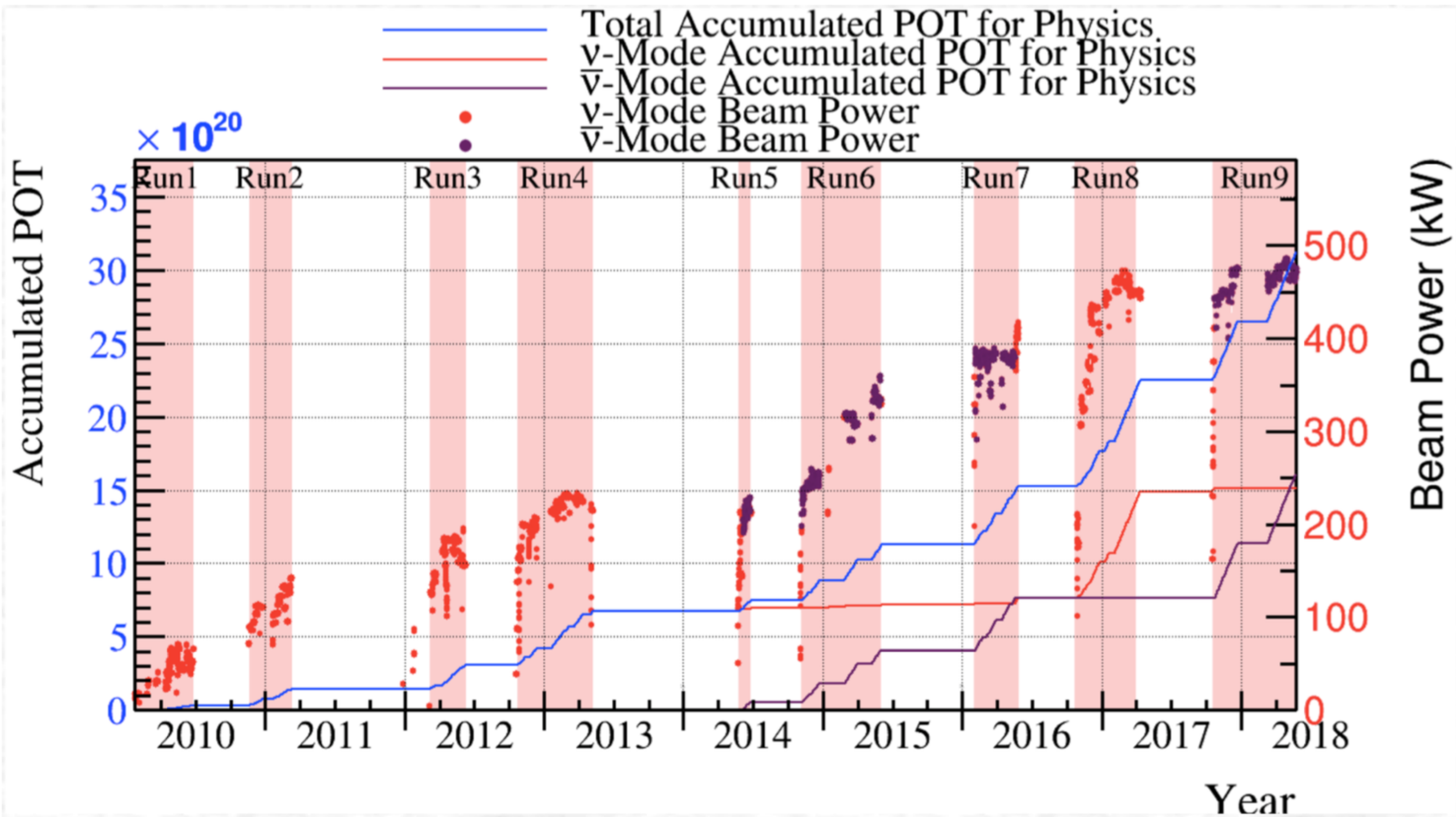
- Near detector constraint of the flux and neutrino interaction parameters

Comparison of the observed SK data to predictions

oscillation parameters

Data taking summary

- Continuous rise in power from ~225 kW (2014) to 500 kW (2018)

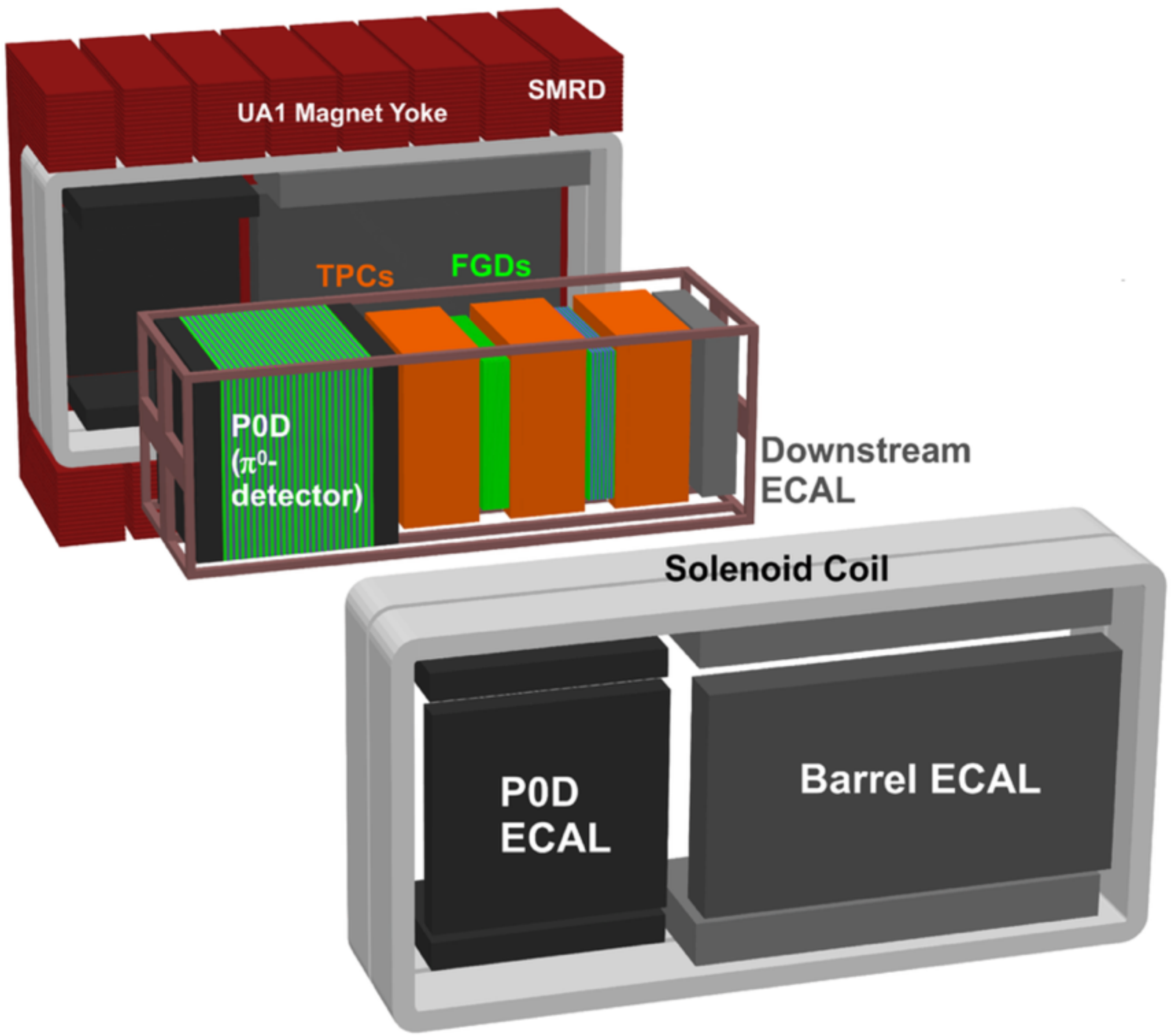


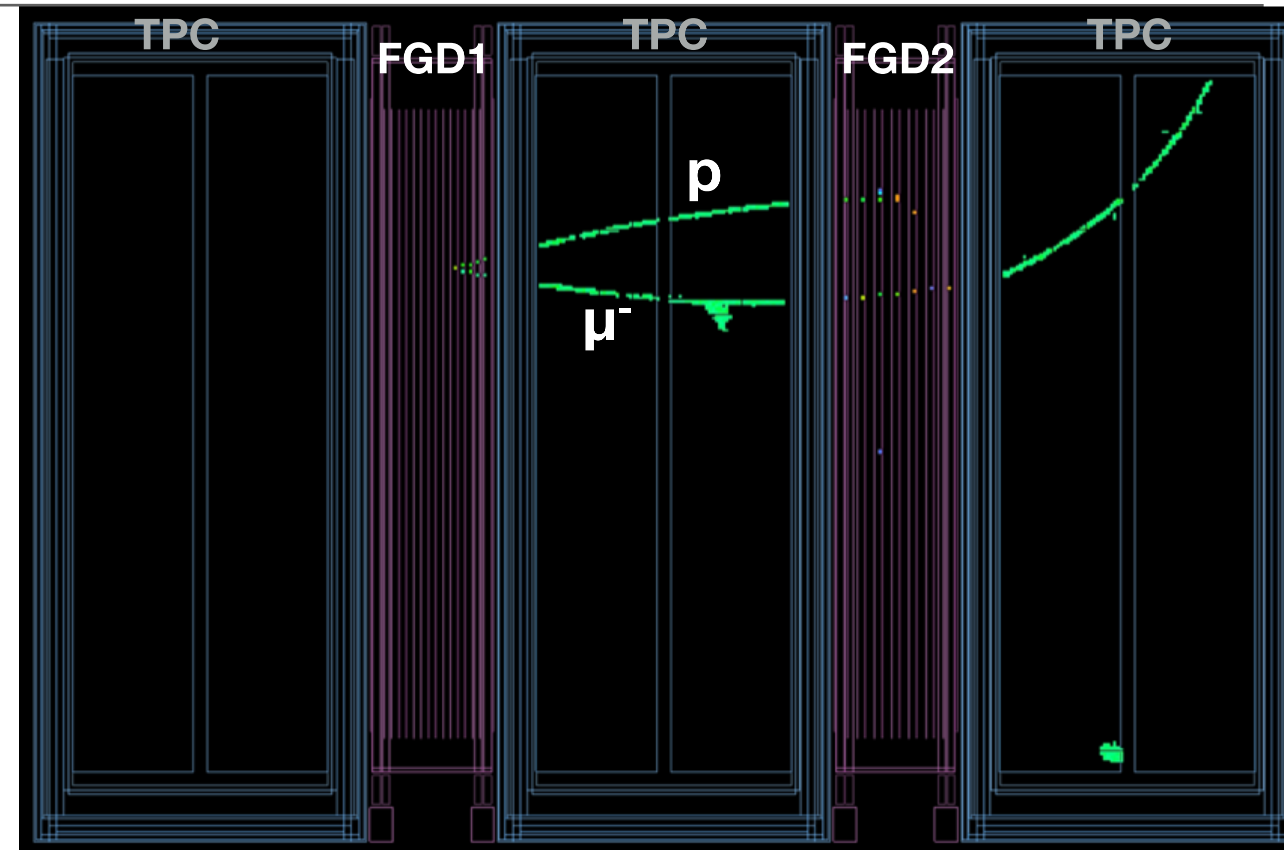
$3.16{\times}10^{21}$ POT TOTAL

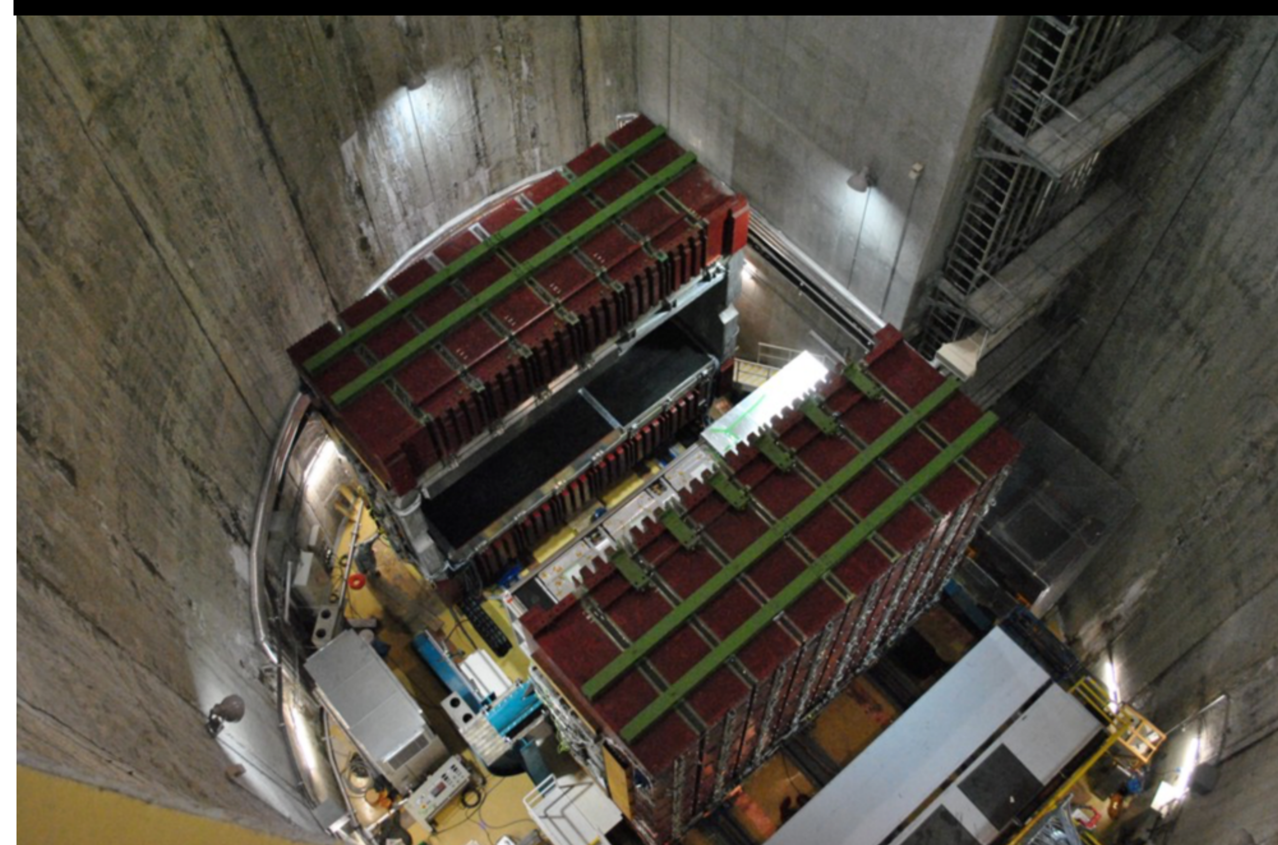
POT ≡ Protons on Target

$1.51{\times}10^{21}$ POT ν-mode (FHC)
$1.65{\times}10^{21}$ POT ν̄-mode (RHC) ⇢ $1.12{\times}10^{21}$ analysed

ND280 near detector

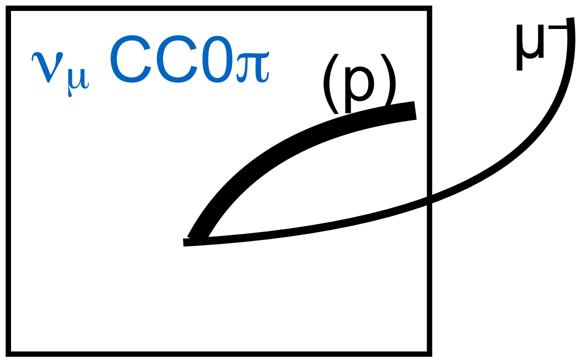


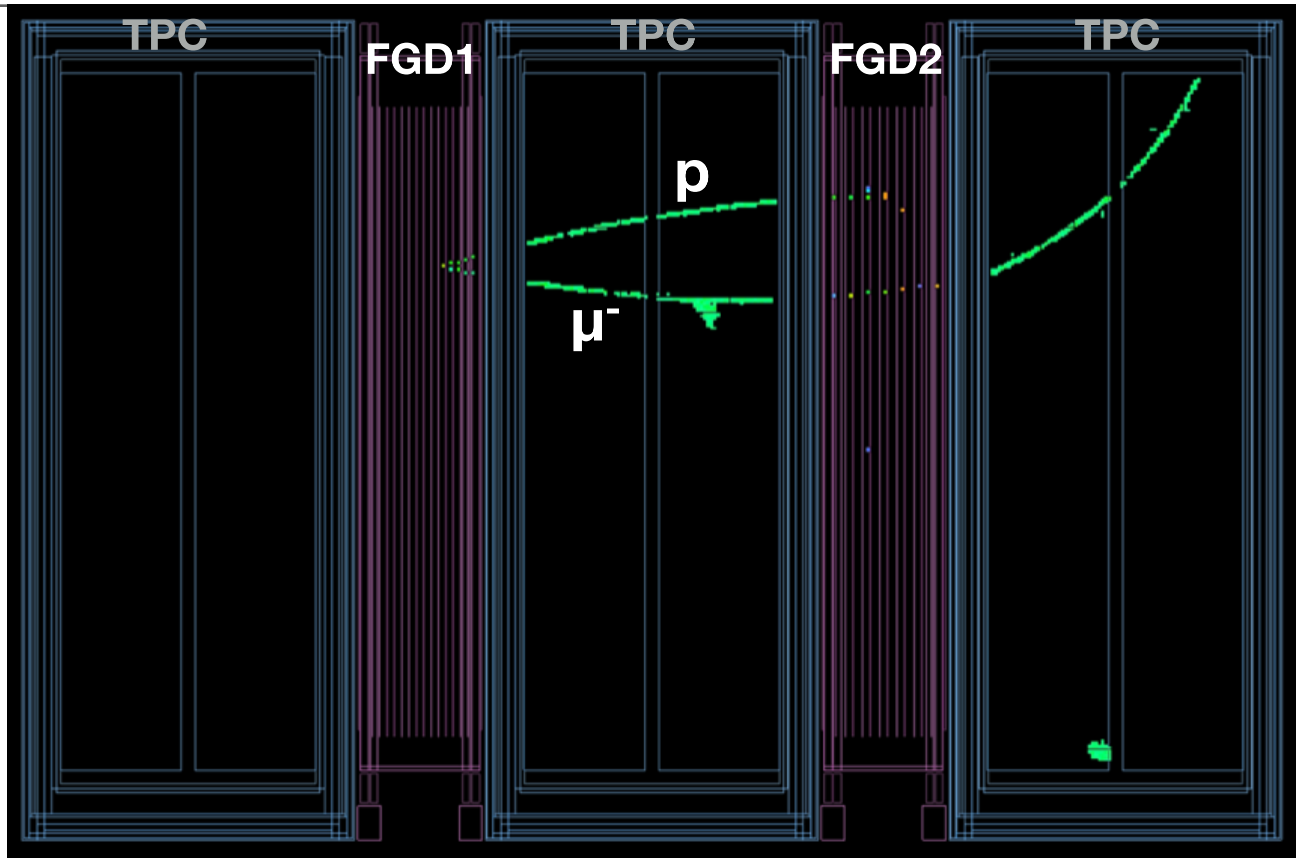




ND280 data samples

- 14 samples in total
- Distinguish between FGD1 and FGD2





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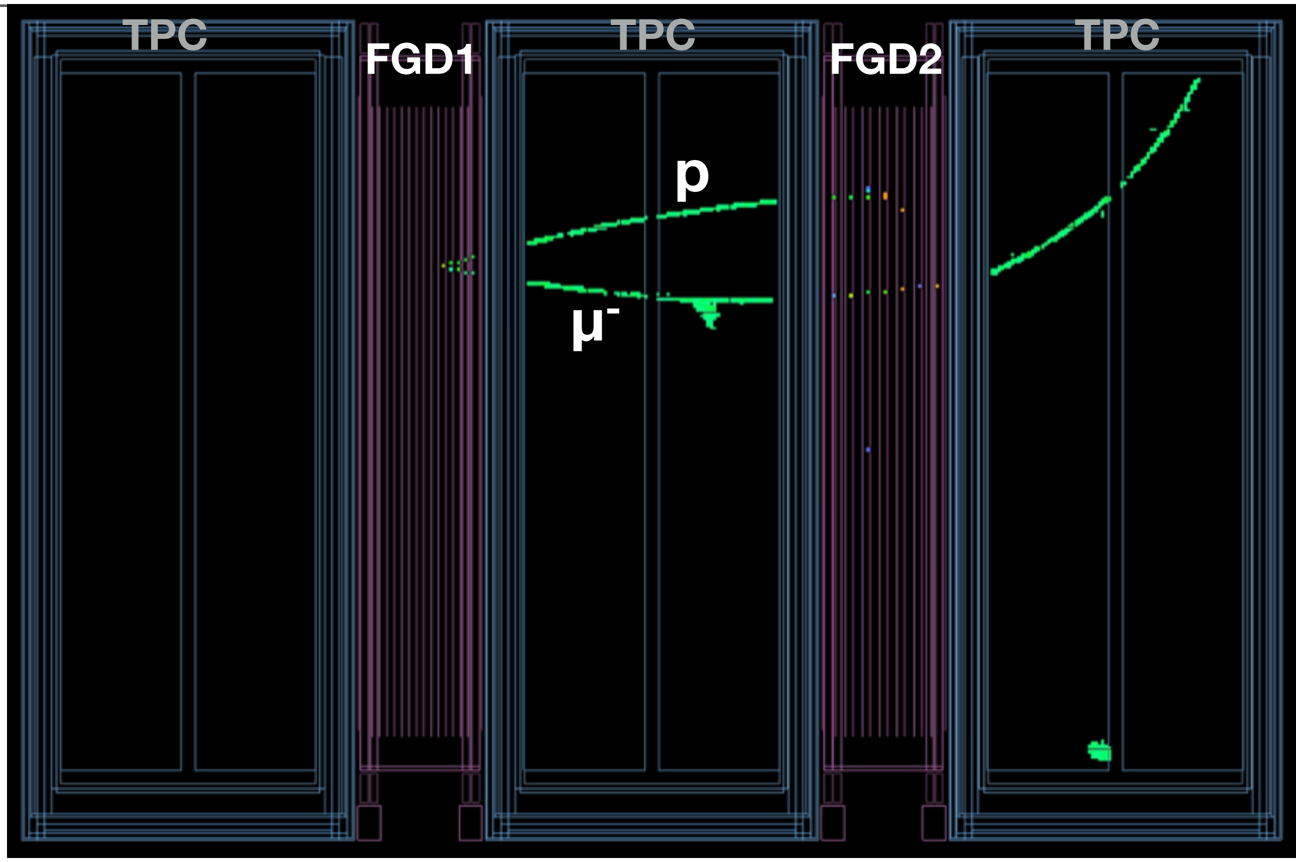
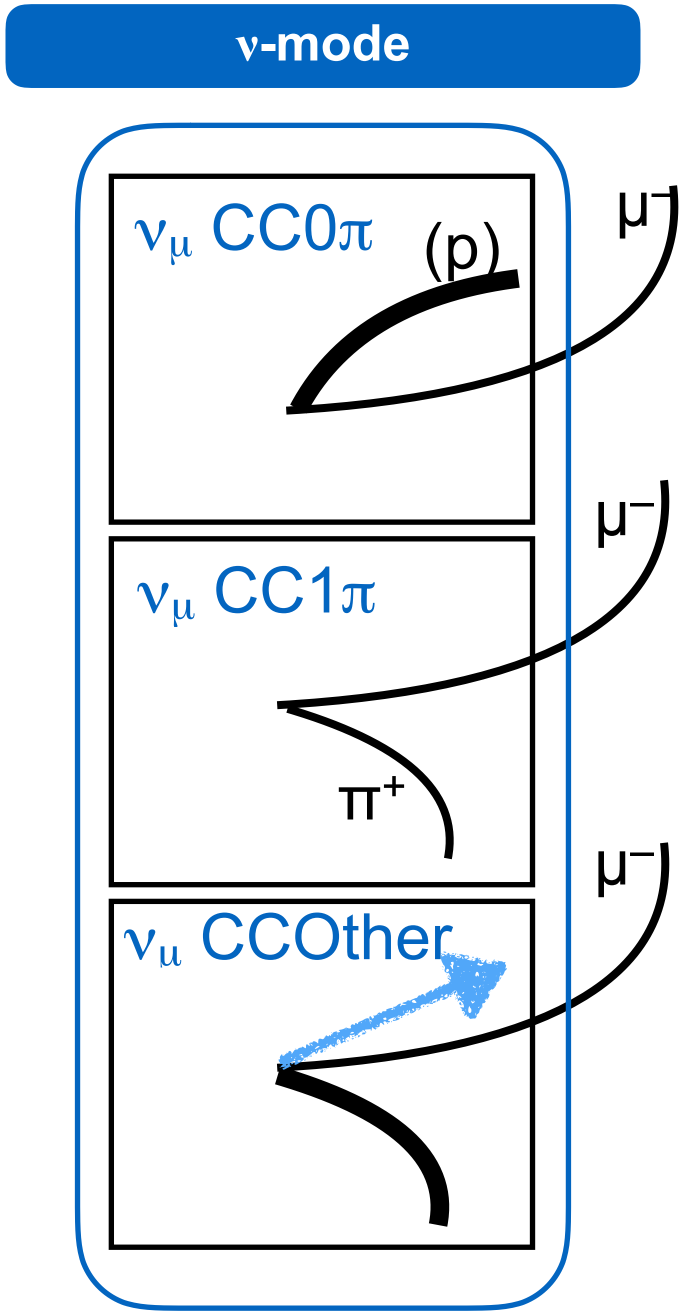
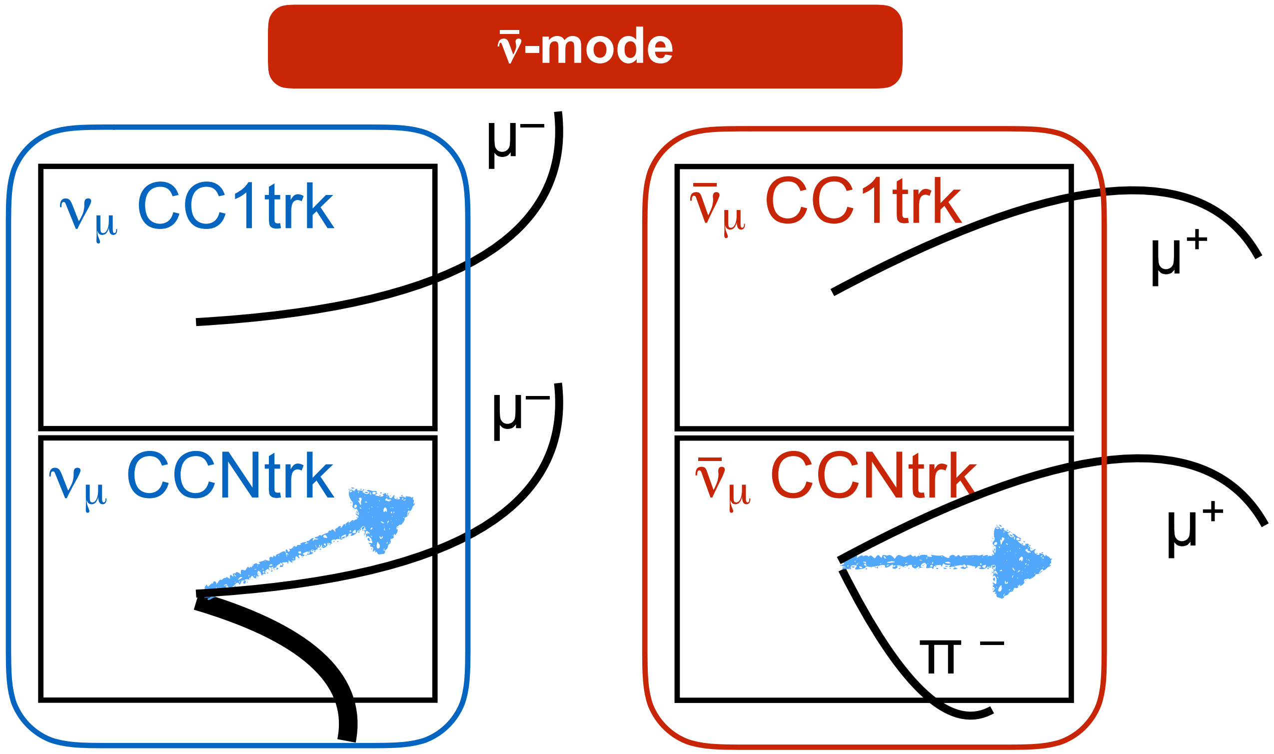


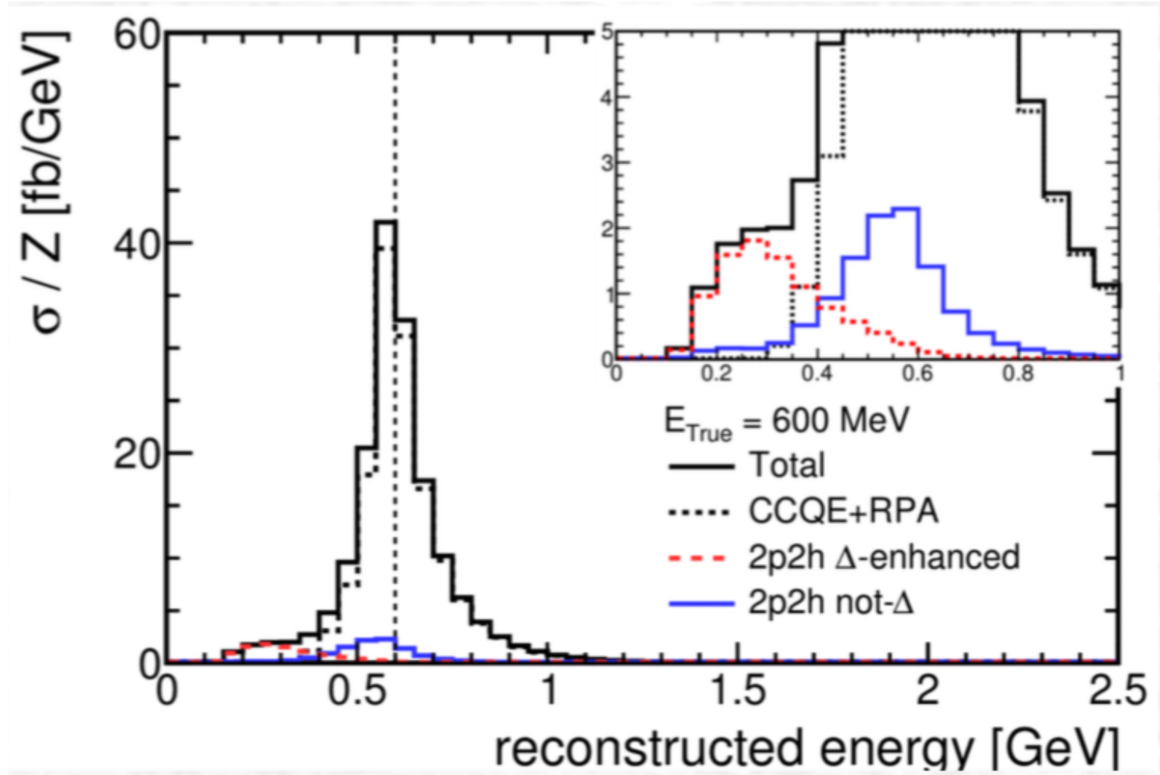


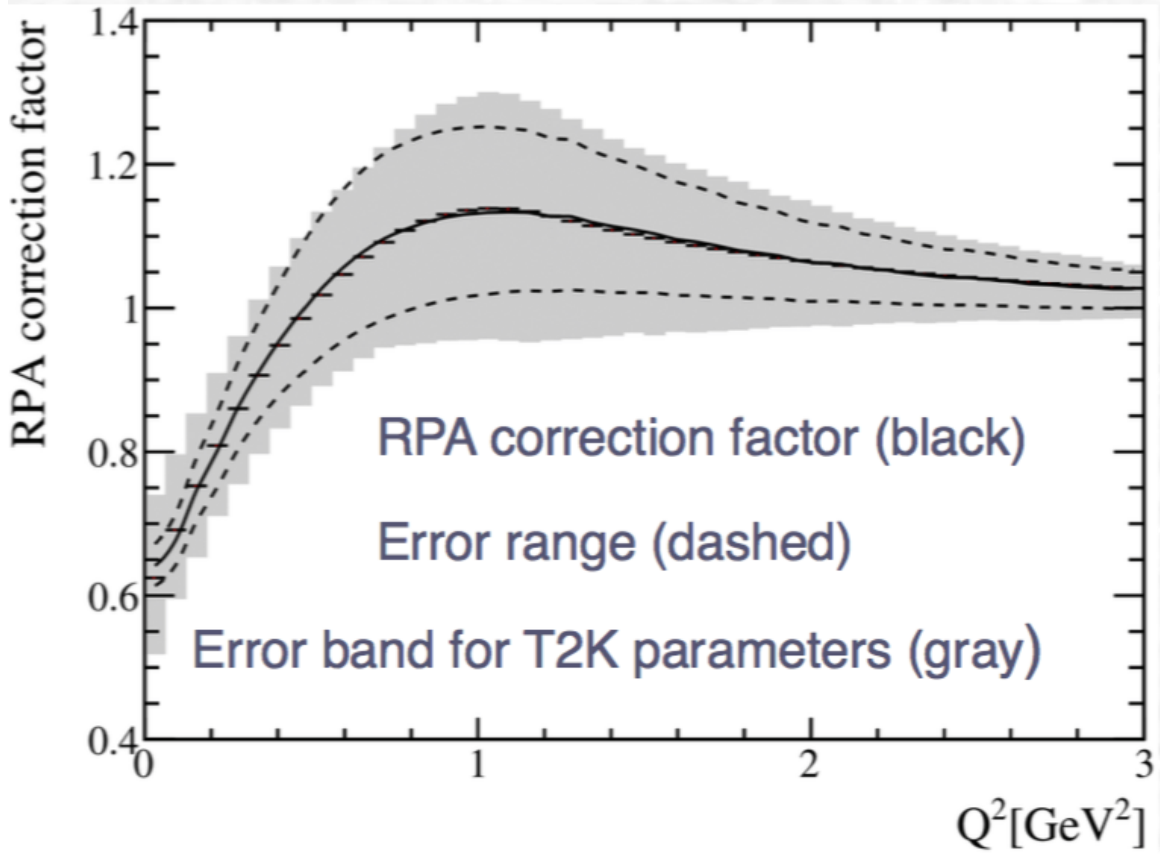


Improvements in Interaction model

Modifications of the main T2K neutrino generator (NEUT):

- **A model for multi-nucleon scattering processes** (Valencia 2p-2h model)
- **CCQE model** was improved by including the RPA correction factor
- **Pion production model** was tuned to data on hydrogen and deuterium

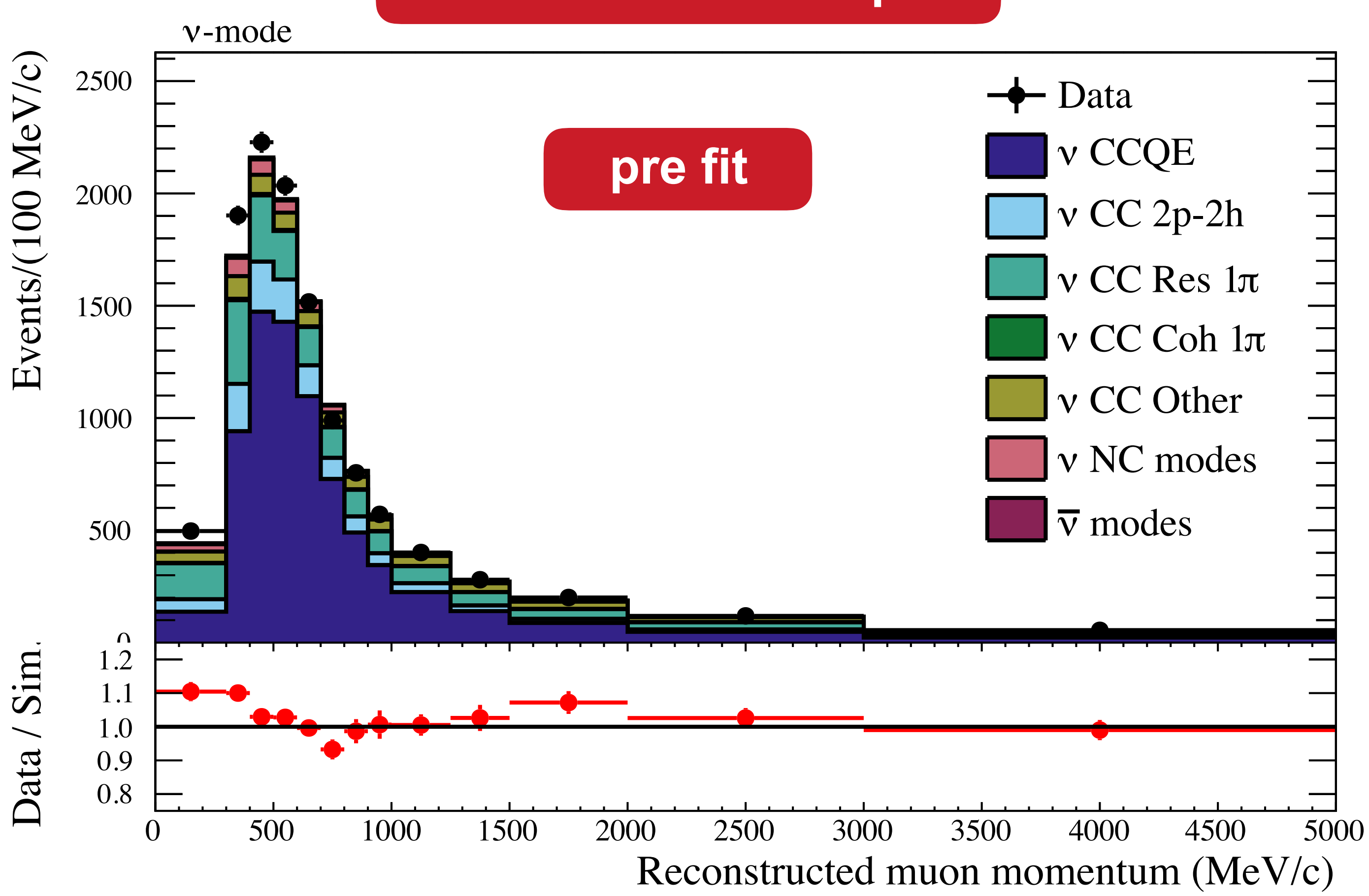




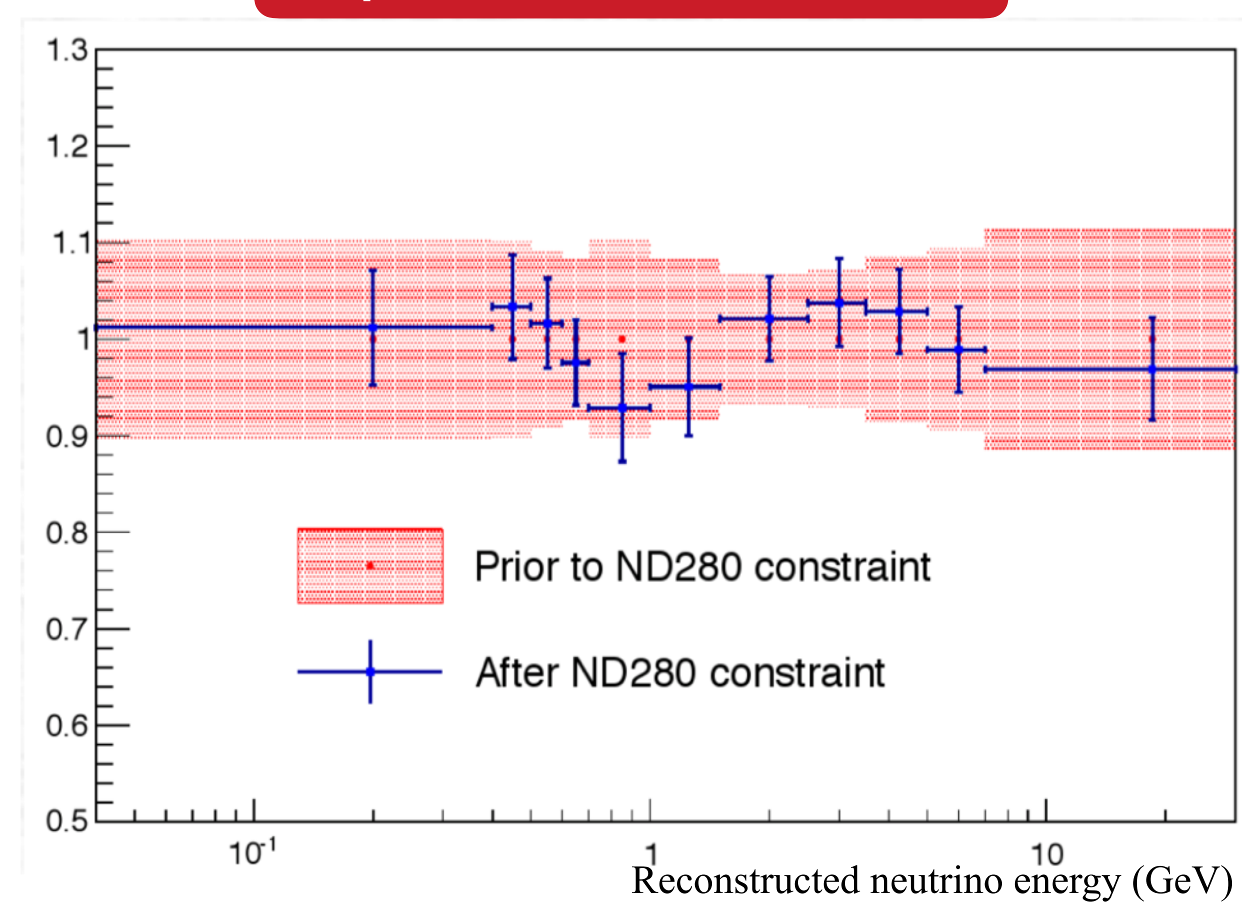
ND280 constraint

- Parametrise cross section & flux models
- Constrain by fitting ND280 data
- Result of data fit reduces flux & interaction model uncertainties at SK

ND280 CC 0π sample



Super-K neutrino-mode flux



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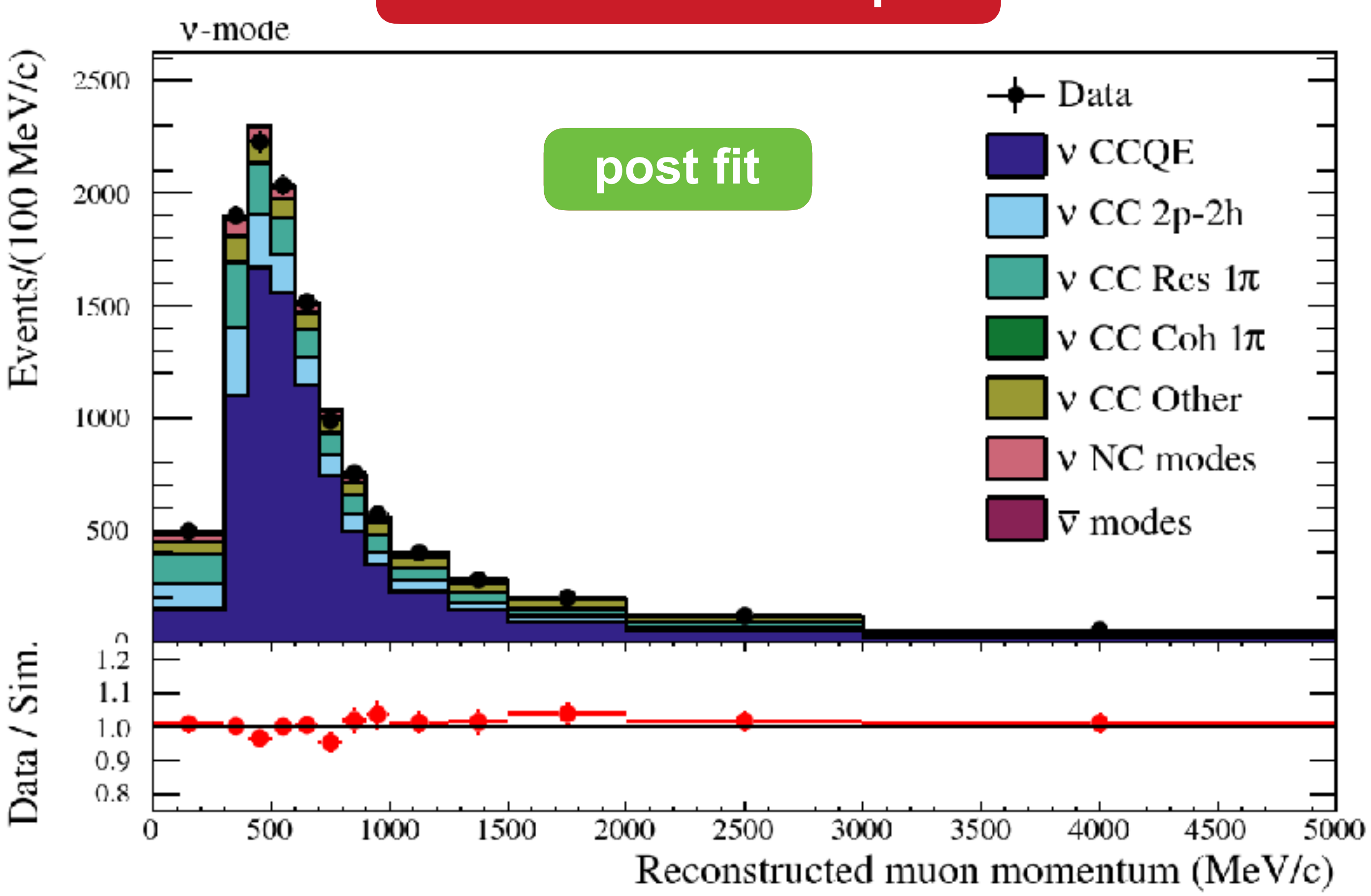

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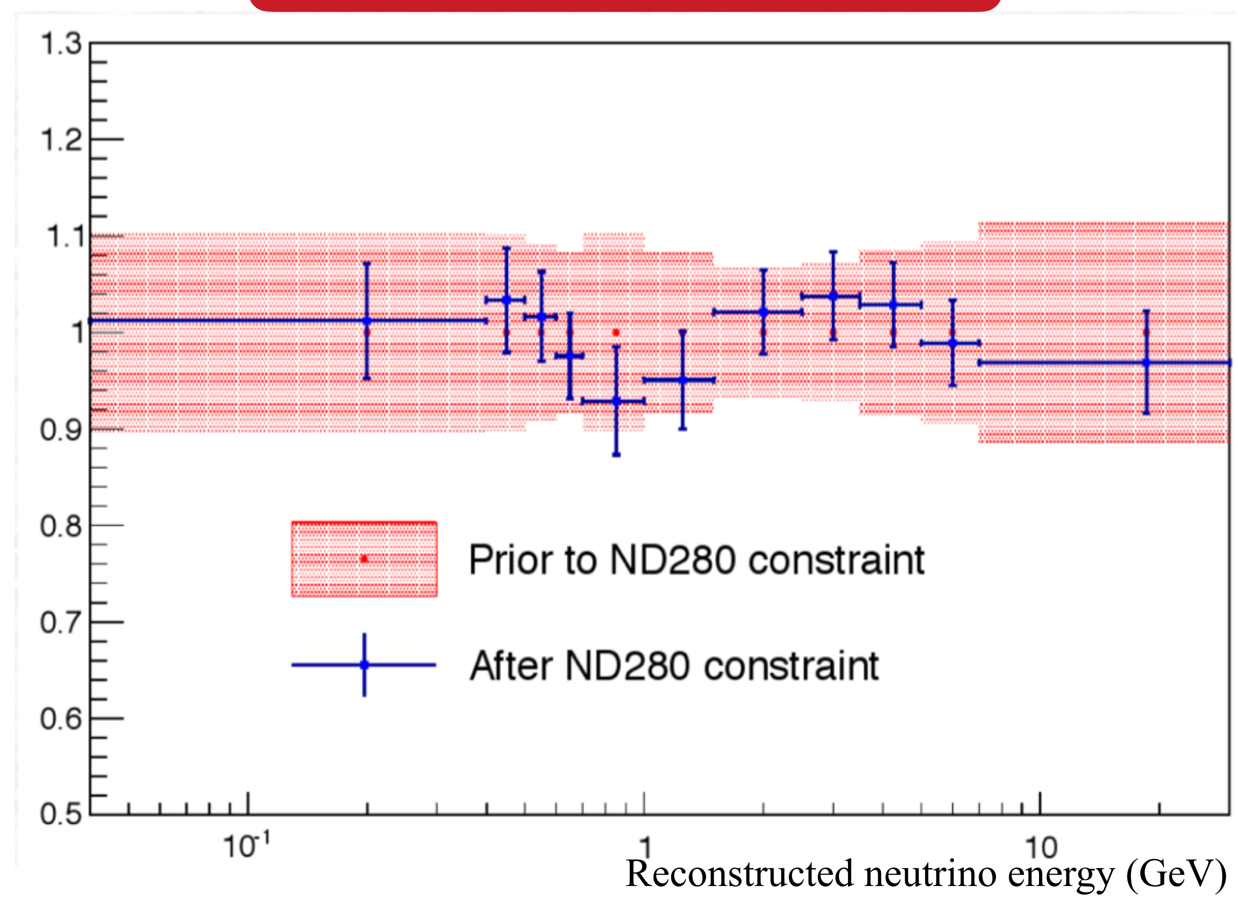
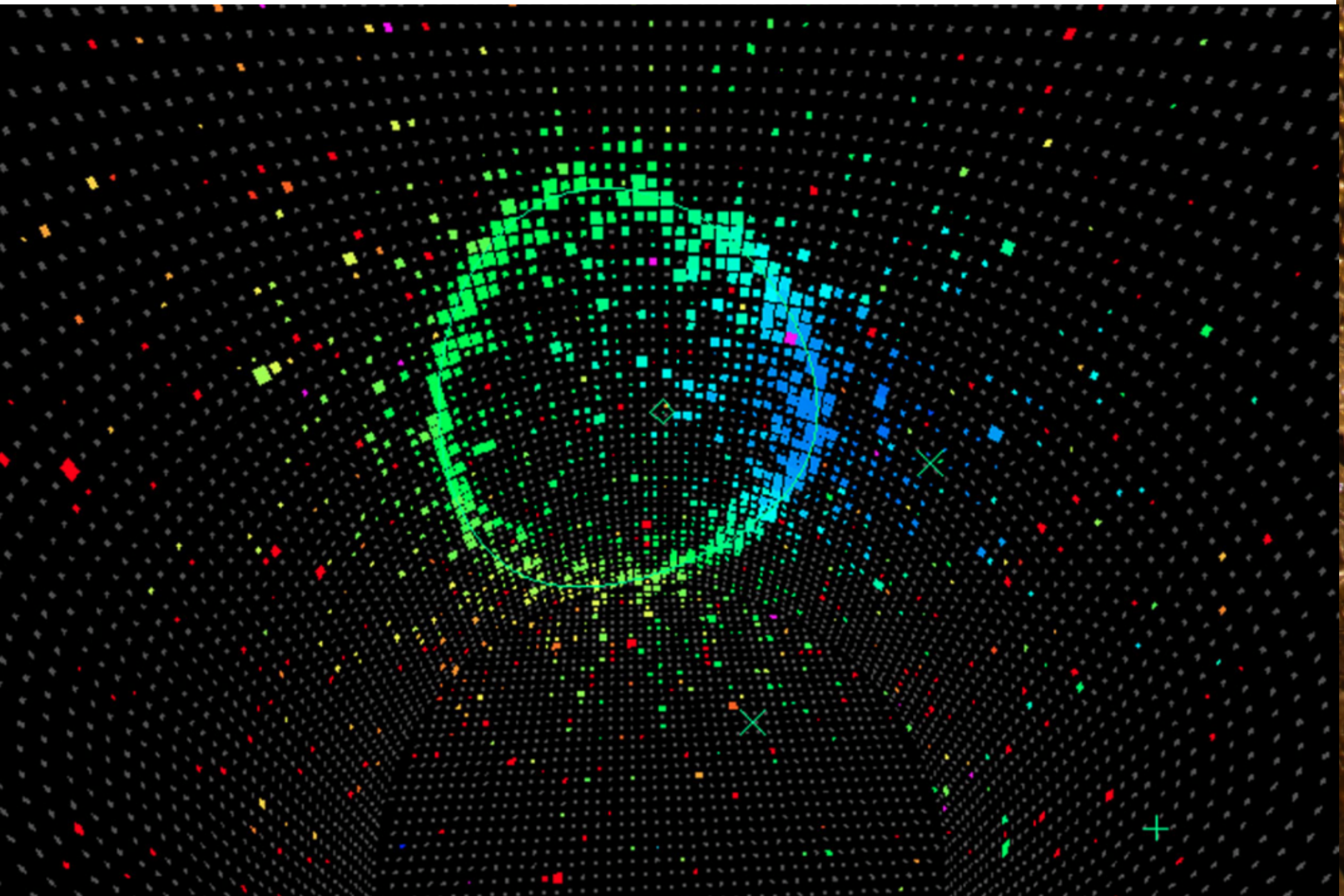
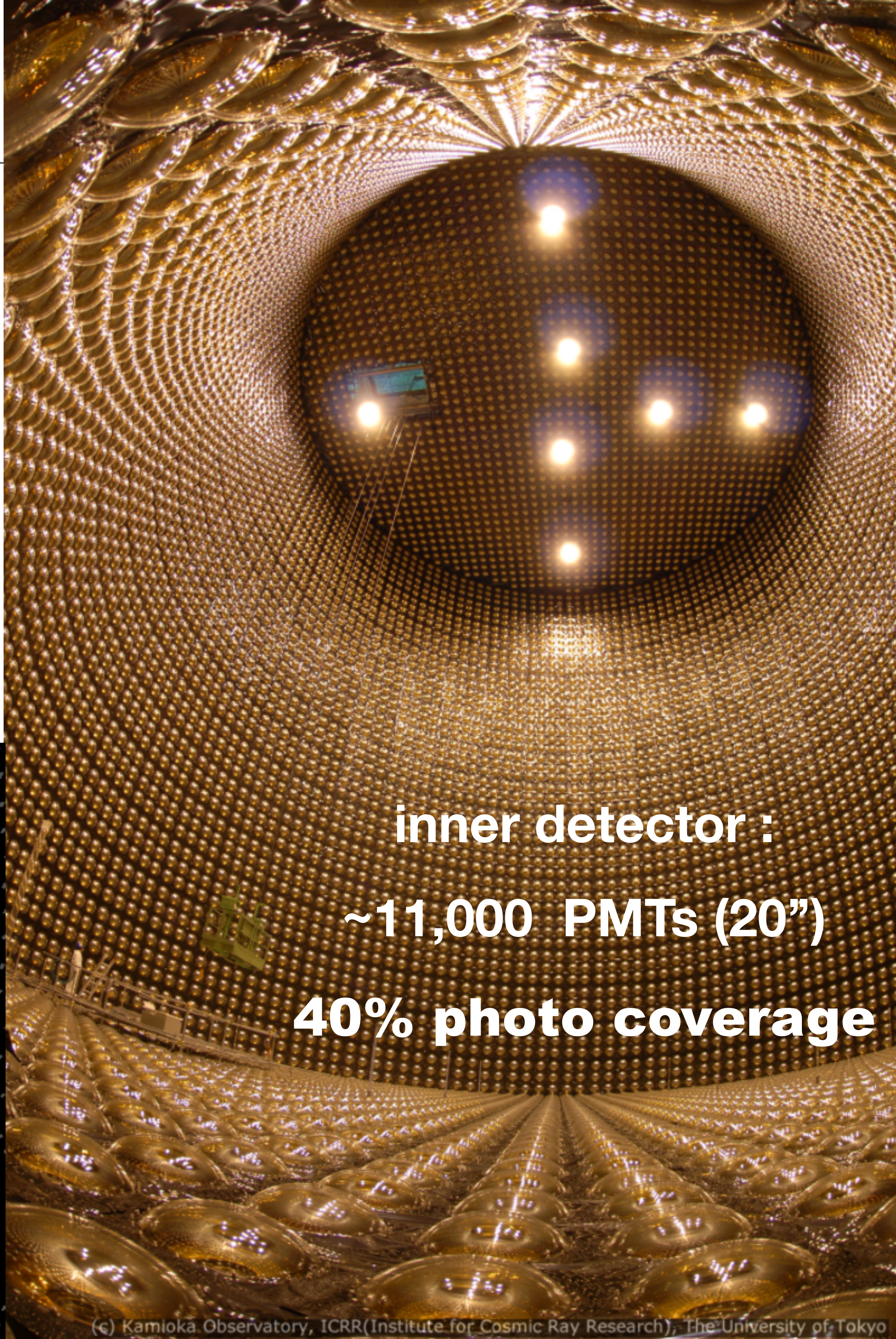


Super-Kamiokande

- Very well known performance after more than 20 years
- 50 kton water Cherenkov detector: **ultra pure water**

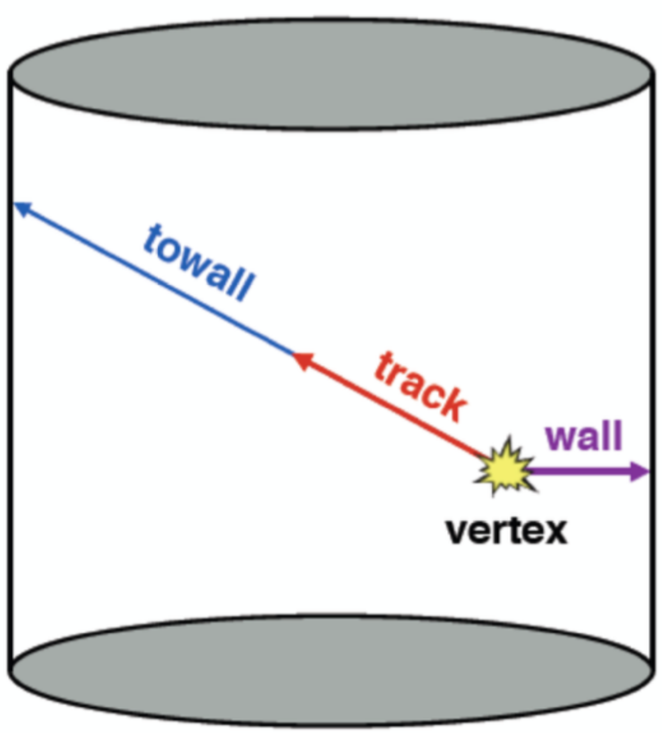


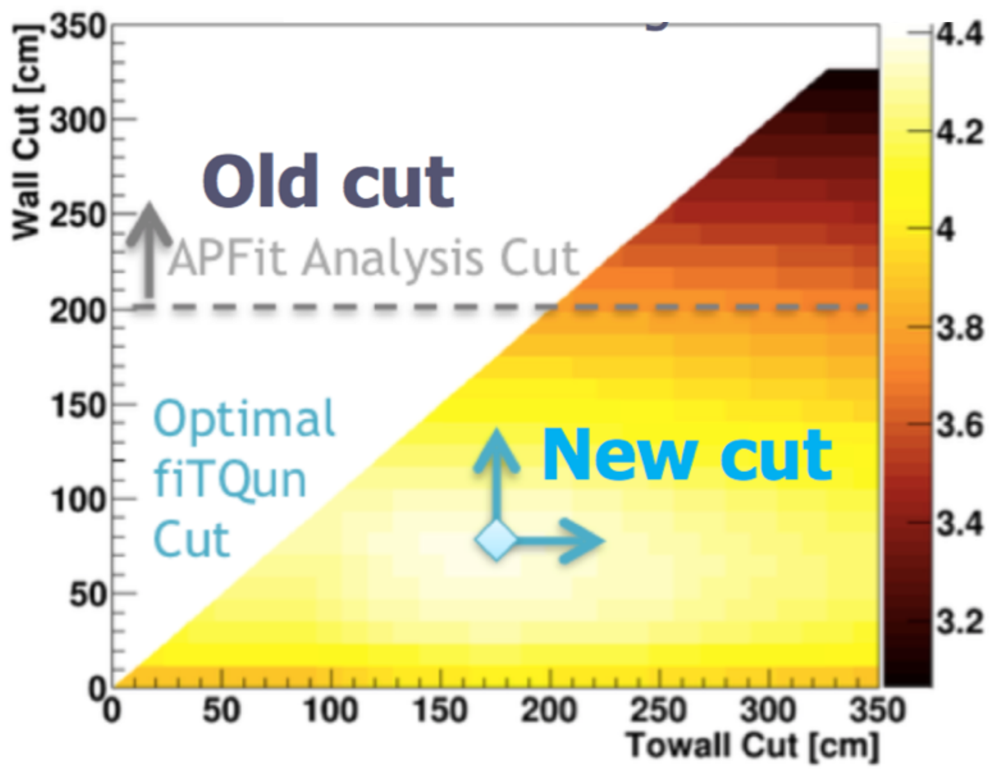


Improvements in SK

- New reconstruction algorithm: **fiTQun** (uses a charge and time likelihood) instead of previous algorithm APFit
  - New data sample **ν_eCC1π** in addition to ν_e CCQE, **add 10%** stat
  - Re-optimizing fiducial volume (FV) cut: expansion of the FV by **15-20%**

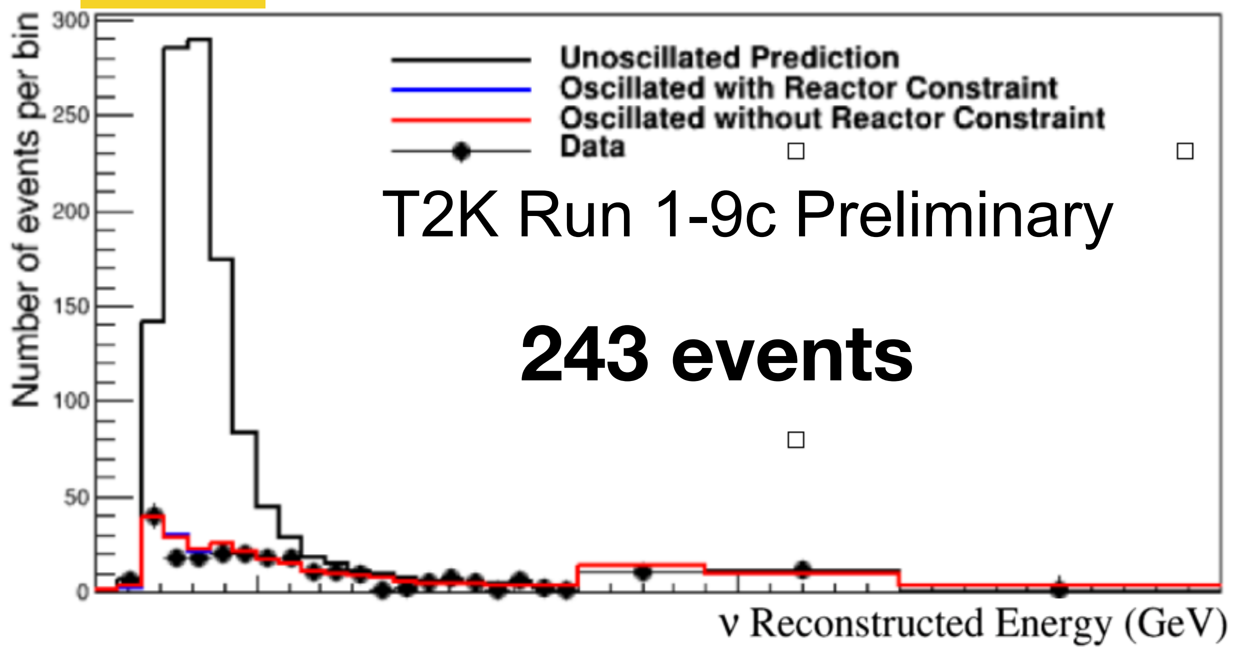
→ **~30% increase in effective statistics**



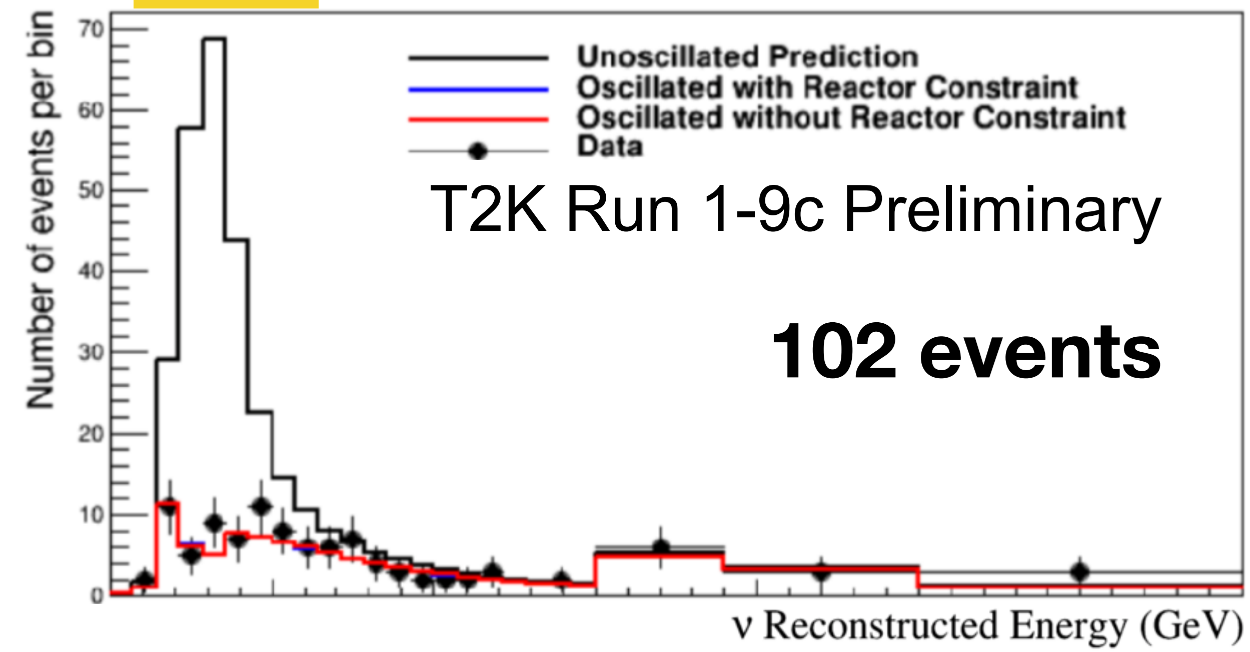


five SK neutrino samples

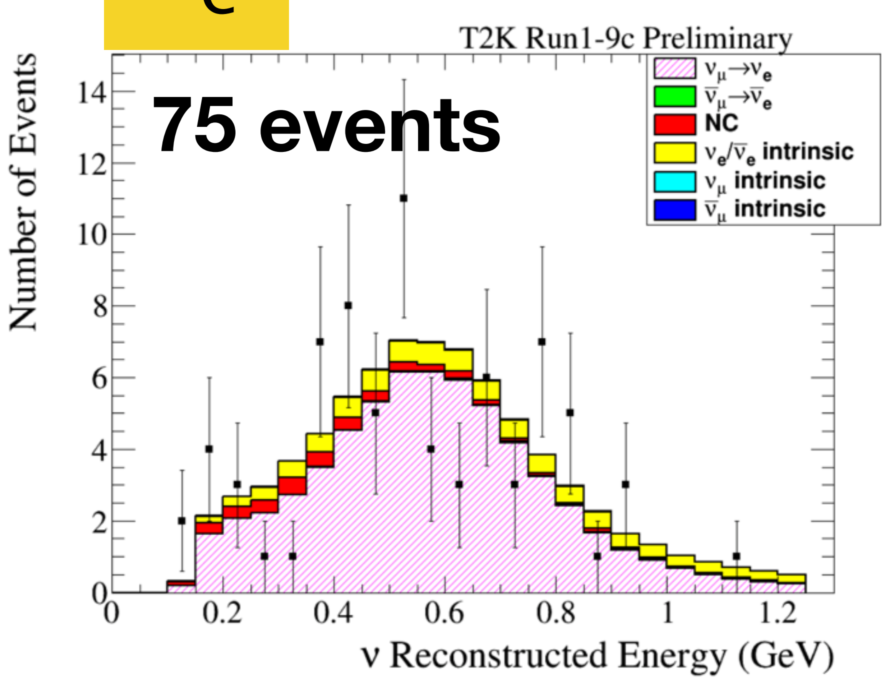
ν_μ



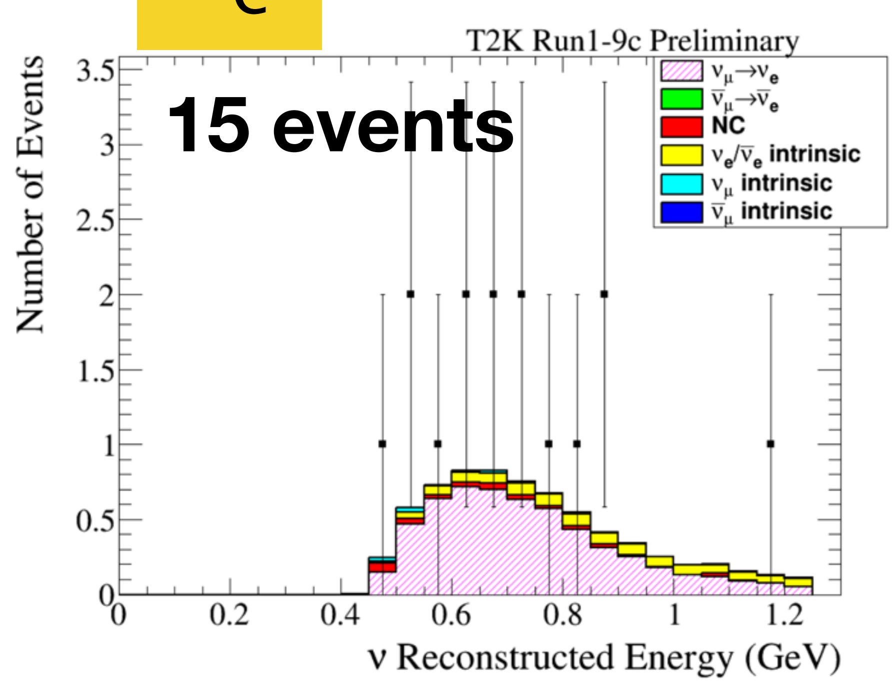
$\bar{\nu}_\mu$



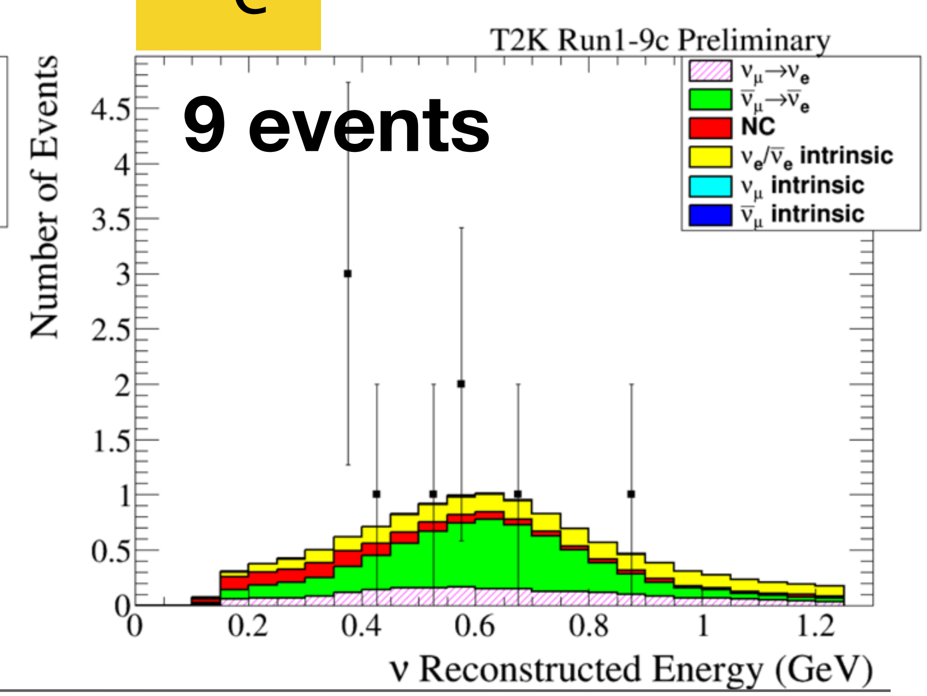
ν_e 0 decay-e



ν_e 1 decay-e



$\bar{\nu}_e$ 0 decay-e



Oscillation analyses: rates

- Compare observed rates at SK to predictions under oscillation hypothesis, tuned with observed ND rates

	SK SAMPLE	PREDICTED				OBSERVED
		$\delta_{CP}=-\pi/2$	$\delta_{CP}=0$	$\delta_{CP}=+\pi/2$	$\delta_{CP}=\pi$	
ν_μ	FHC 1Rμ	268,5	268,2	268,5	268,9	243
$\bar{\nu}_\mu$	RHC 1Rμ	95,5	95,3	95,5	95,8	102
ν_e	FHC 1Re 0 decay-e	73,8	61,6	50,0	62,2	75
	FHC 1Re 1 decay-e	6,9	6,0	4,9	5,8	15
$\bar{\nu}_e$	RHC 1Re 0 decay-e	11,8	13,4	14,9	13,2	9

- SK event rates are in line with expectations based on oscillation model
  - Of note: 15 events observed in CC1π ν_e sample, with prediction of 6.9 maximum
    - p-value for up/down fluctuation in 1 of 5 samples is: ~5% (1% with single sample).

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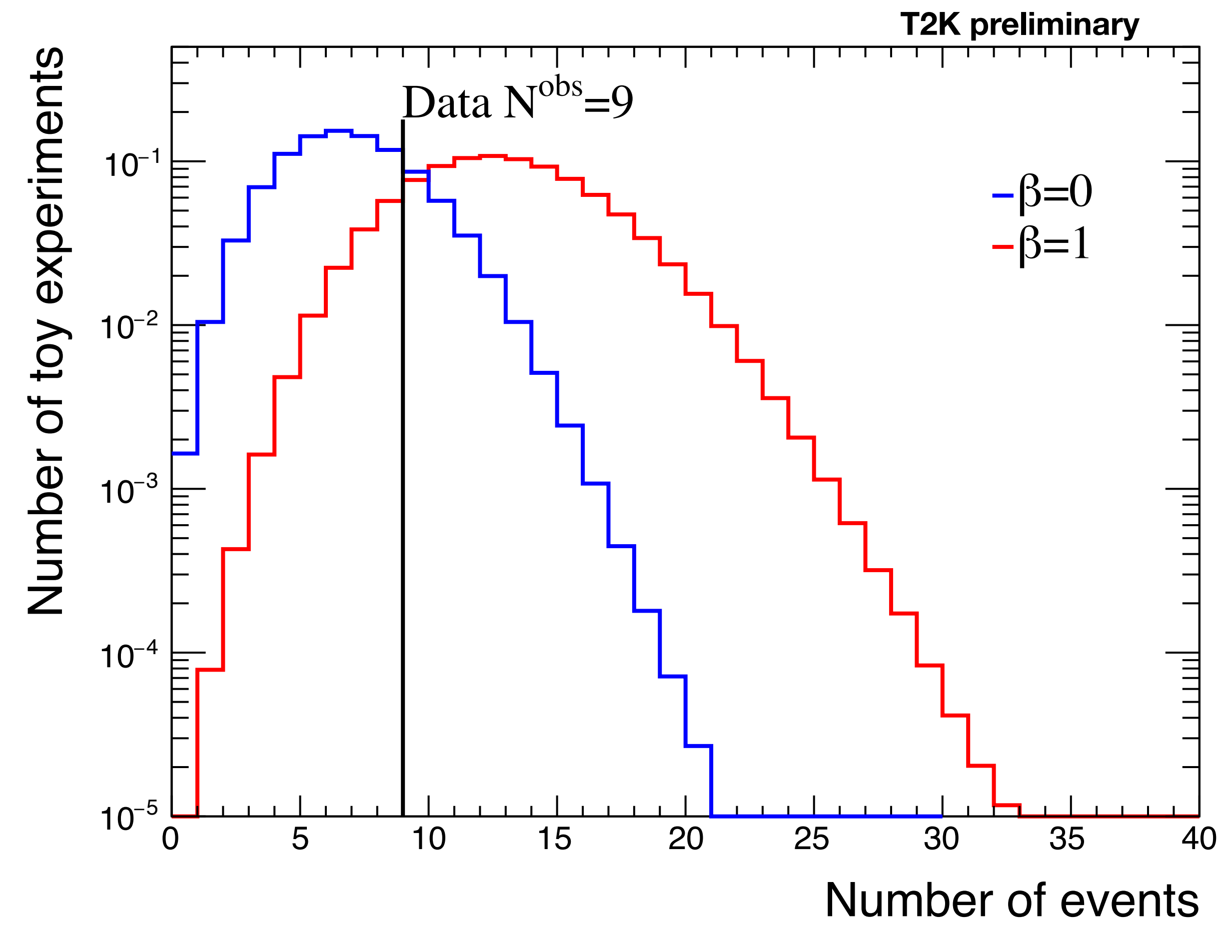
$\bar{\nu}_e$ appearance

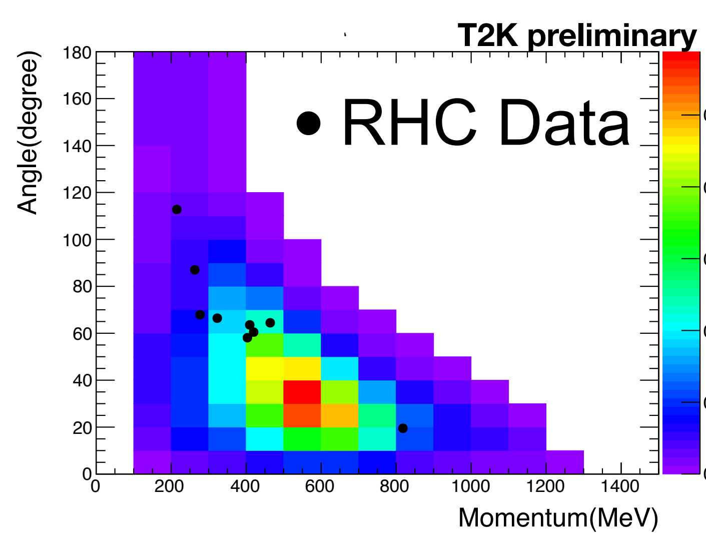
- Compare consistency with PMNS $\bar{\nu}$e appearance (β = 1) and no $\bar{\nu}$e appearance (β = 0). For rate only:
  - if β = 0 expect 6.5 events
  - if β = 1 expect 11.8 events
  - p-value very similar for both



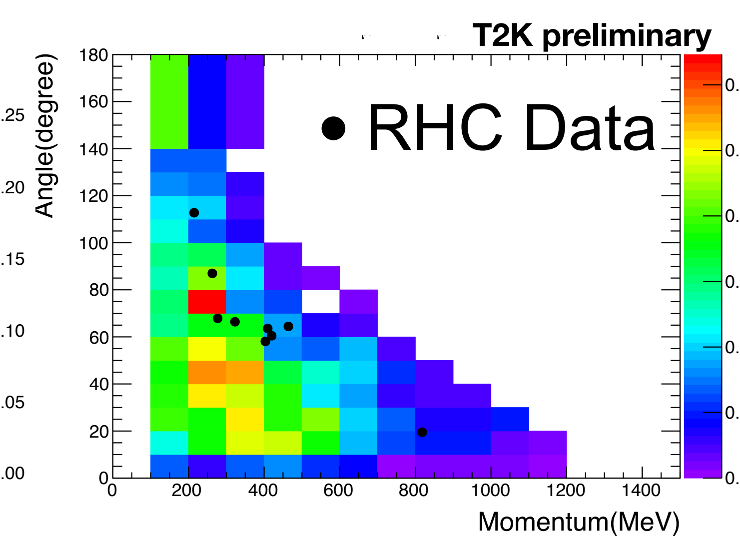
- Use rate+shape analyses:
  - The data shapes look more consistent with background spectra than $\bar{\nu}$e signal spectrum
  - **No strong statistical conclusion yet**

β	HYPOTHESIS	P-VALUE
β=0	NO app.	p=0.233
β=1	PMNS app.	p=0.0867

Shape of $\bar{\nu}_e$ signal



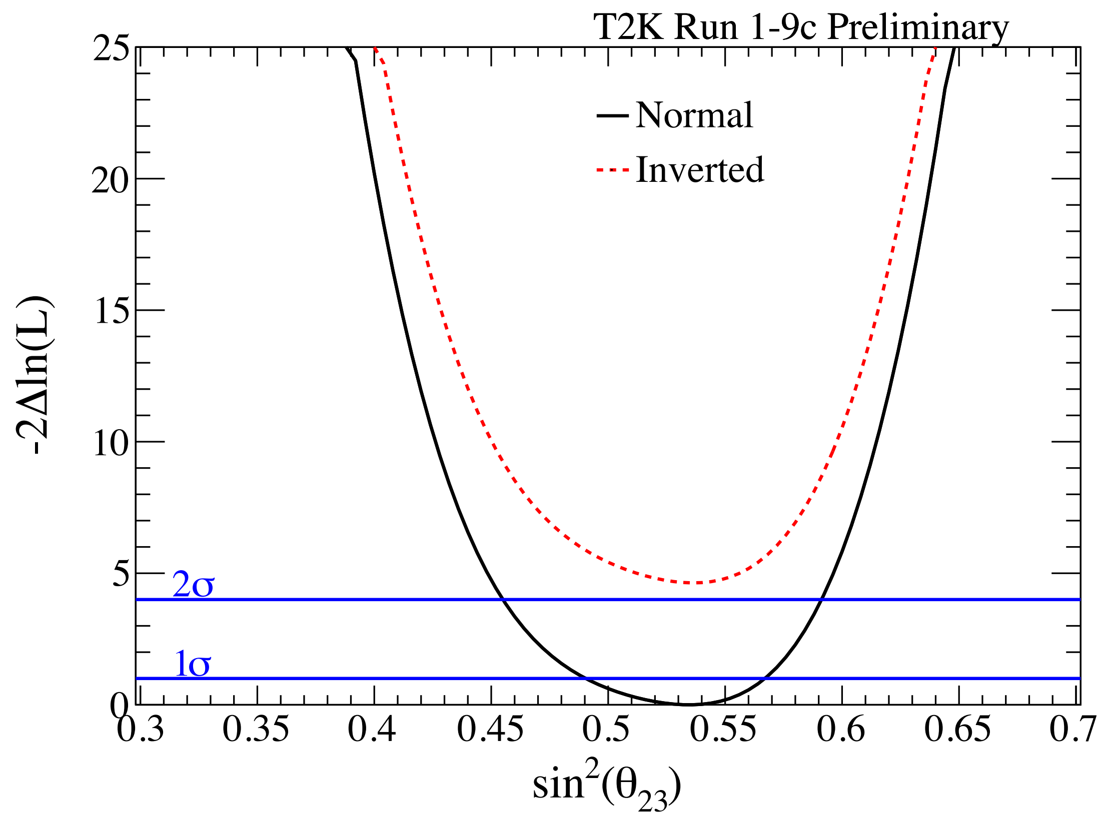
Shape of mis-ID BGs

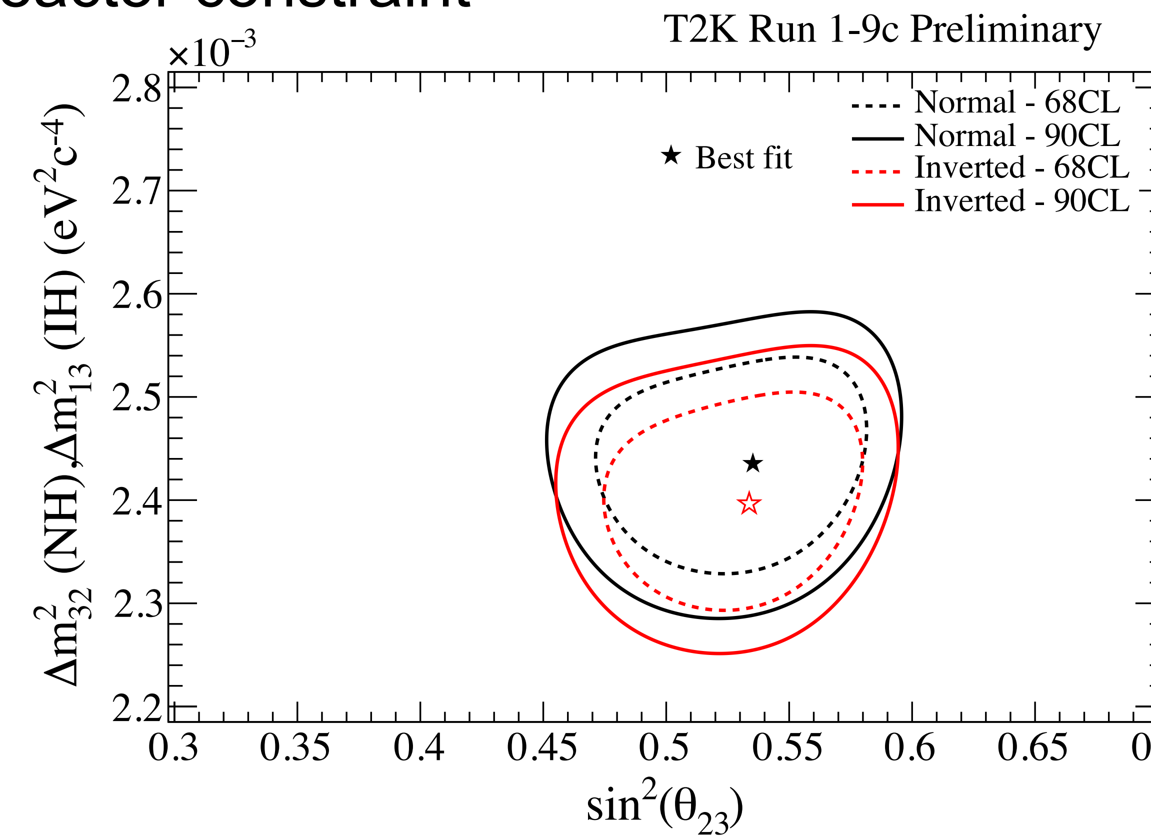


Atmospheric sector: θ_{23}, $\Delta m^2_{32(1)}$

$\nu_\mu/\bar{\nu}_\mu$ disappearance

Data fit with reactor constraint





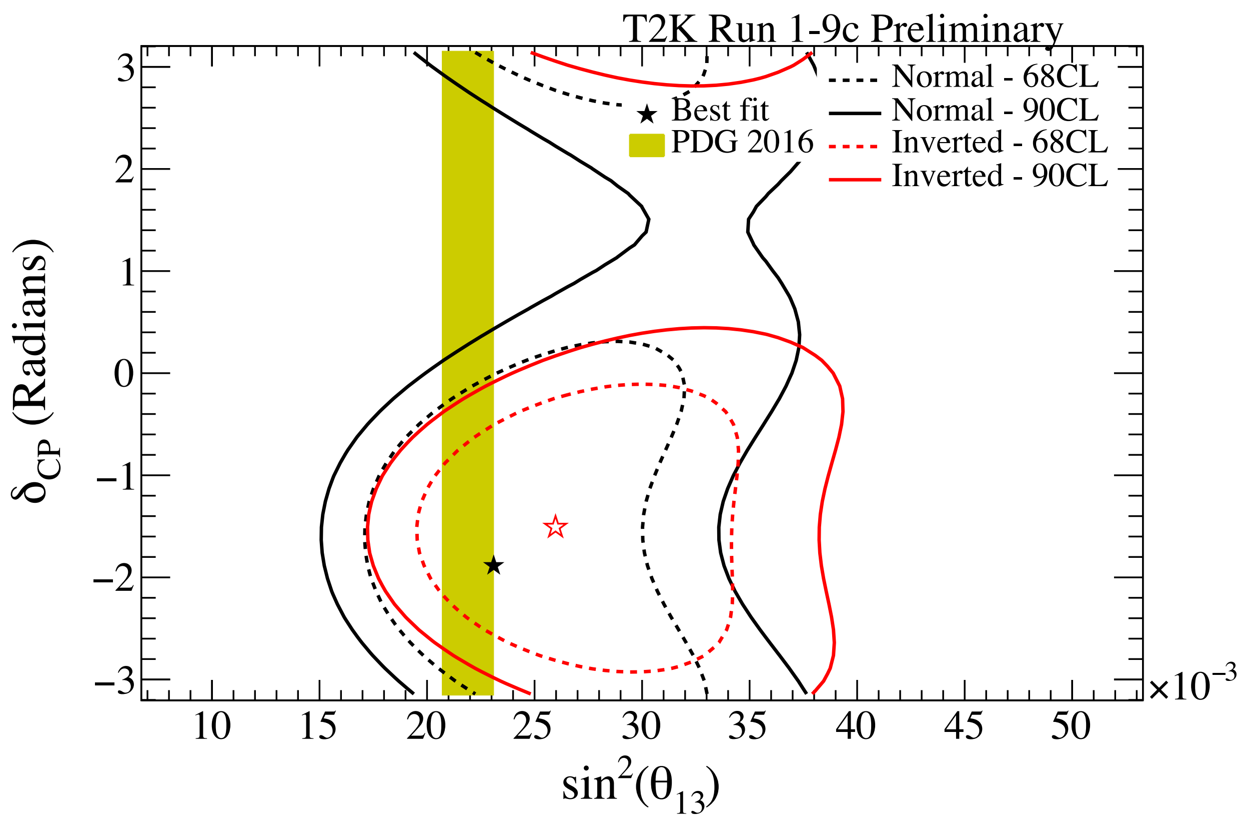
	NH	IH
$\sin^2\theta_{23}$	$0.536^{+0.031}_{-0.046}$	$0.536^{+0.031}_{-0.041}$
$\lvert\Delta m_{23}^2\rvert$	2.434 ± 0.064	$2.410^{+0.062}_{-0.063}$

x 10^{-3} eV^2

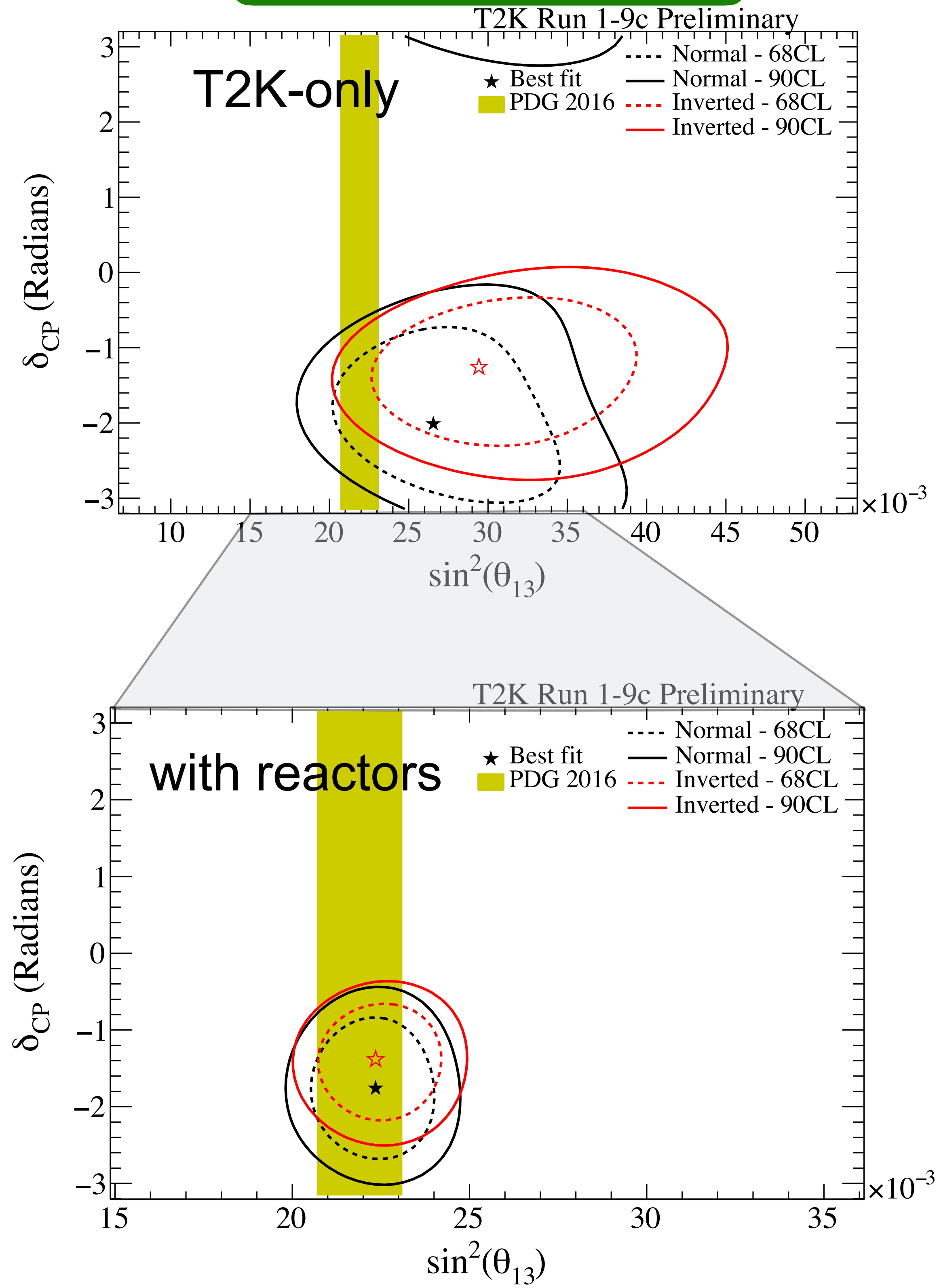
δ_{CP} vs. $\sin^2\theta_{13}$

$\nu_e/\bar{\nu}_e$ appearance

SENSITIVITY



DATA FIT

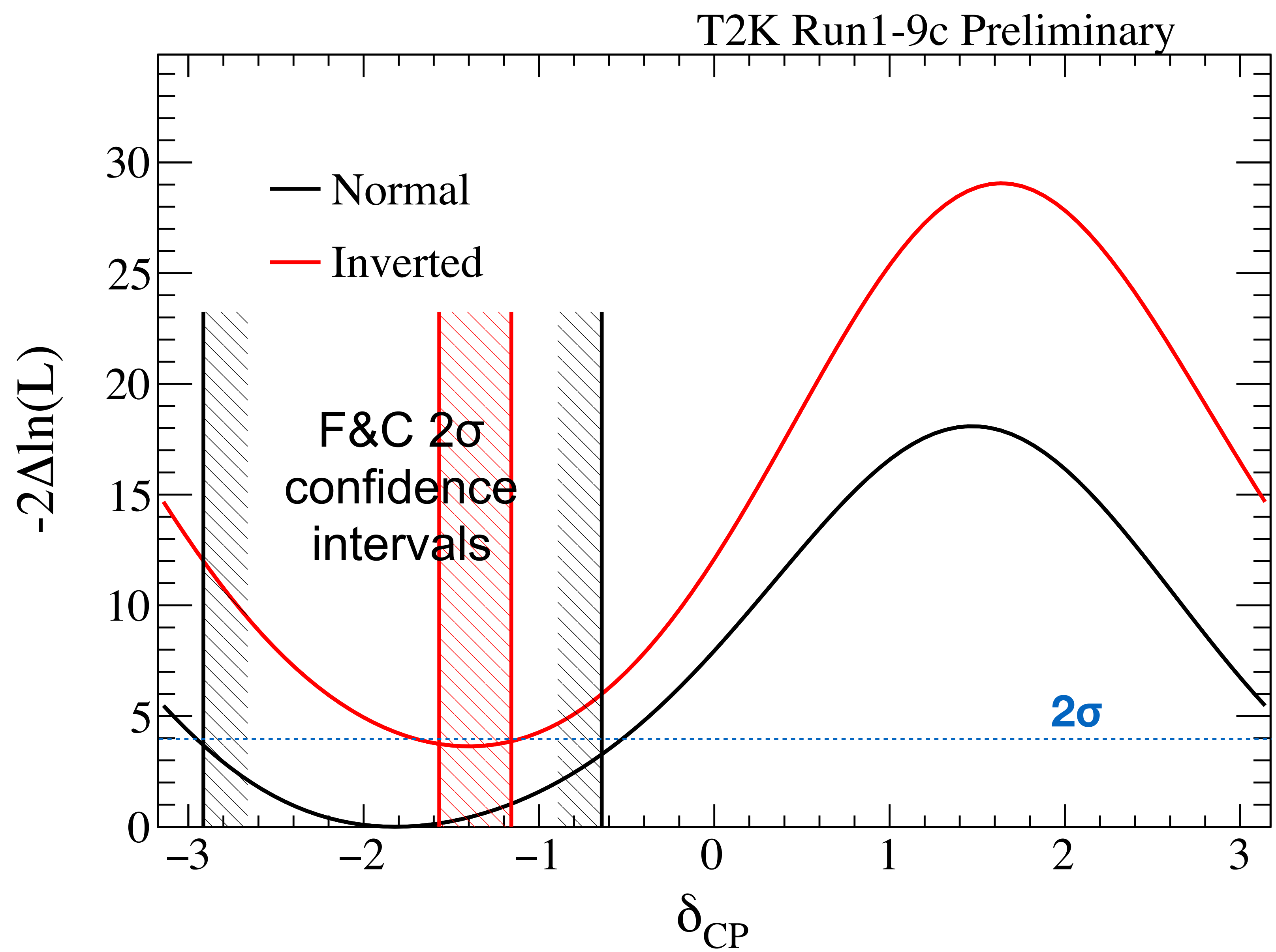


- sensitivity assumptions:
  - $\sin^2\theta_{13}$= 0.0219 (2016 PDG)
  - $\sin^2\theta_{23}$ = 0.528
  - NH, δ_{CP} = -1.601
- **Data fit stronger than sensitivity**

δ_{CP} 1D contour

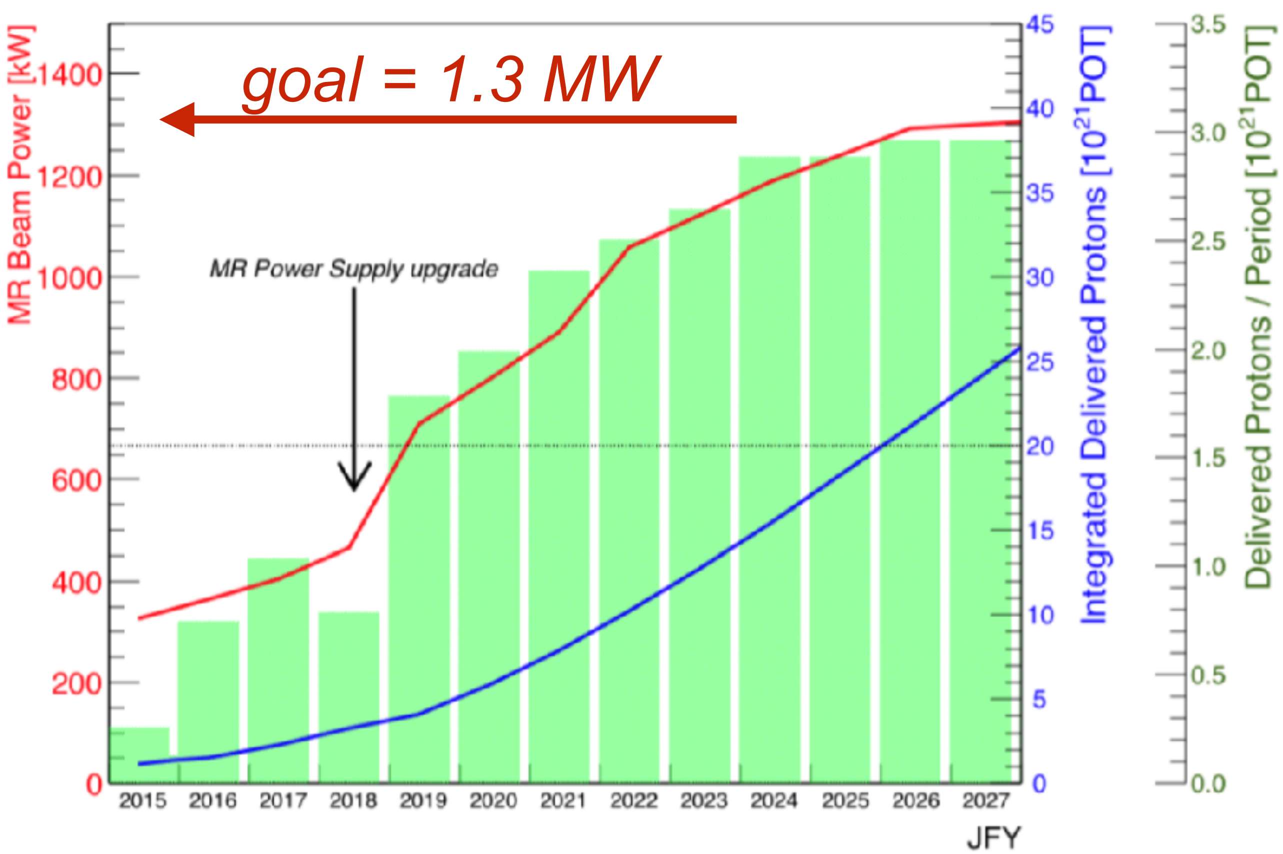
- CP conserving values (δ_{CP}=0 & δ_{CP}=π) outside of **2σ region** for both hierarchies.

DATA FIT with reactor constraint

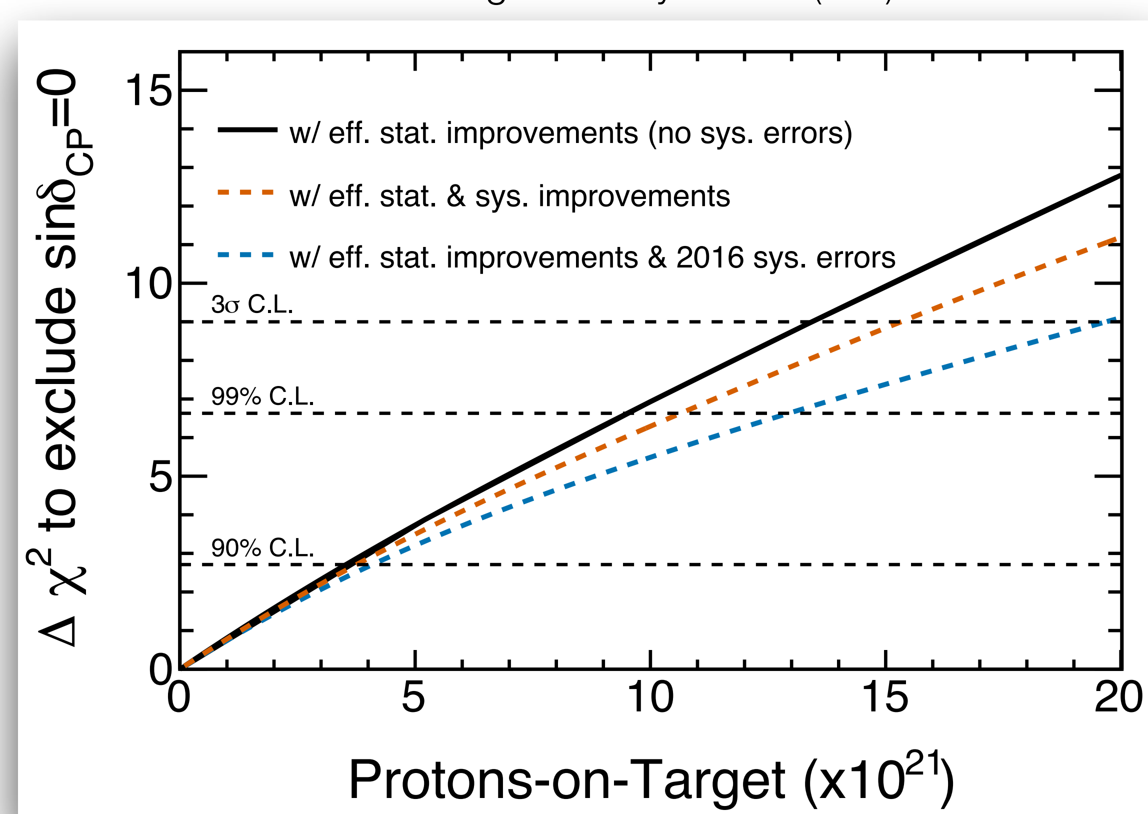


T2K phase II

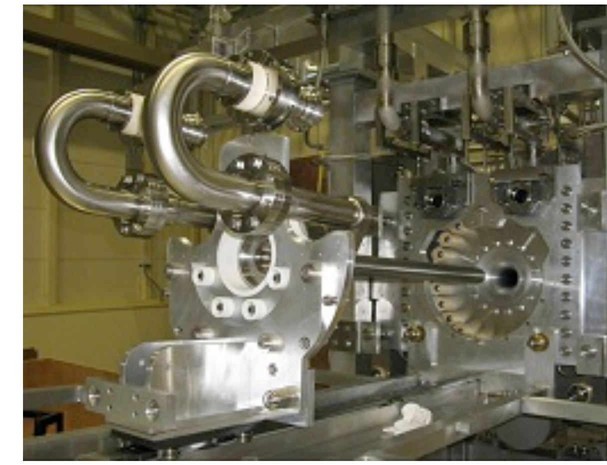
- Proposed to cover the gap between T2K/NOvA and the next generation of experiments: HK/DUNE (from 2020 to 2026)
- Same far detector (SK) + beam upgrade: collect **20x10^{21} p.o.t**.
- New improved near detector complex and reduced systematics
- **Could achieve >3σ sensitivity on CP violation**



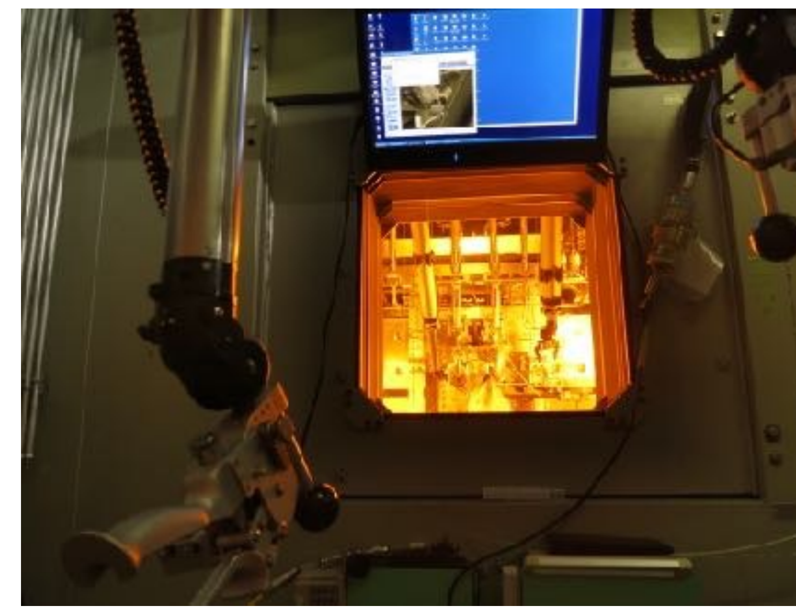
Assuming hierarchy known (???)



Neutrino beam upgrades



- Main Ring power supply upgrade approved by MEXT
  - allow faster beam rep rate (2.2→1.3 s)
  - Mitigate beam losses at higher power running conditions

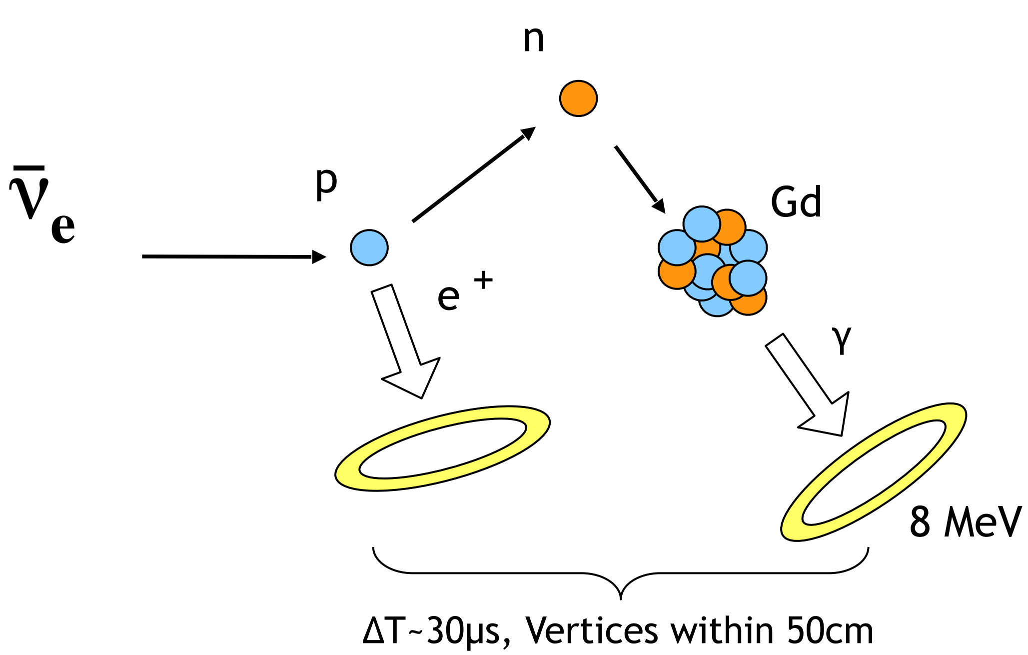


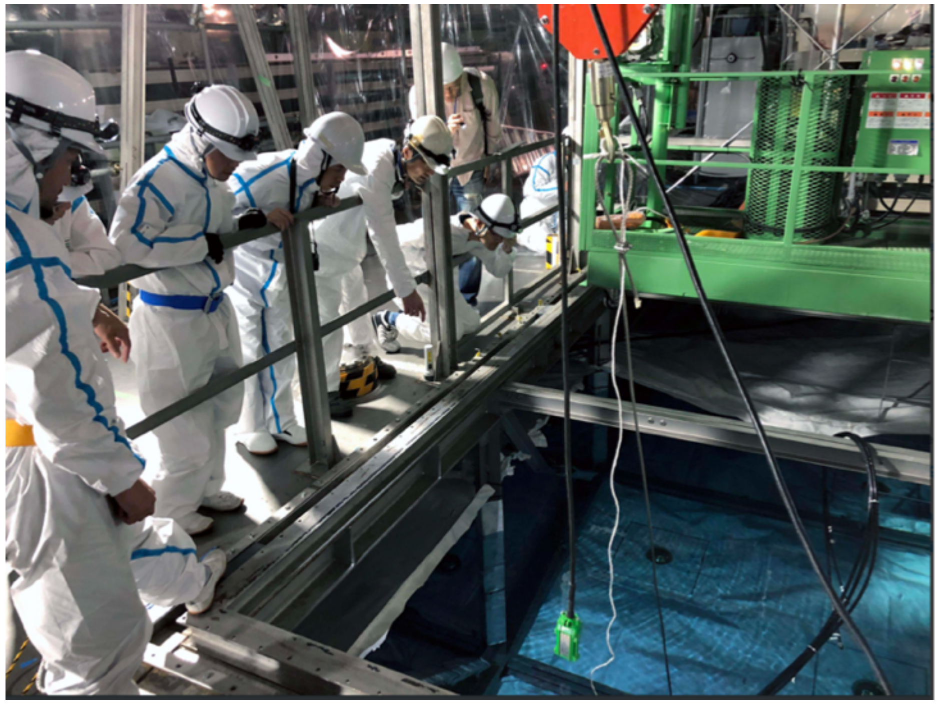
750 kW, with eventual upgrades to 1.3 MW

- Aim to complete work when MR-PS upgrade is done → **2021**
- TDR has been submitted to KEK-IPNS Director for review in June 2018

Far detector upgrade

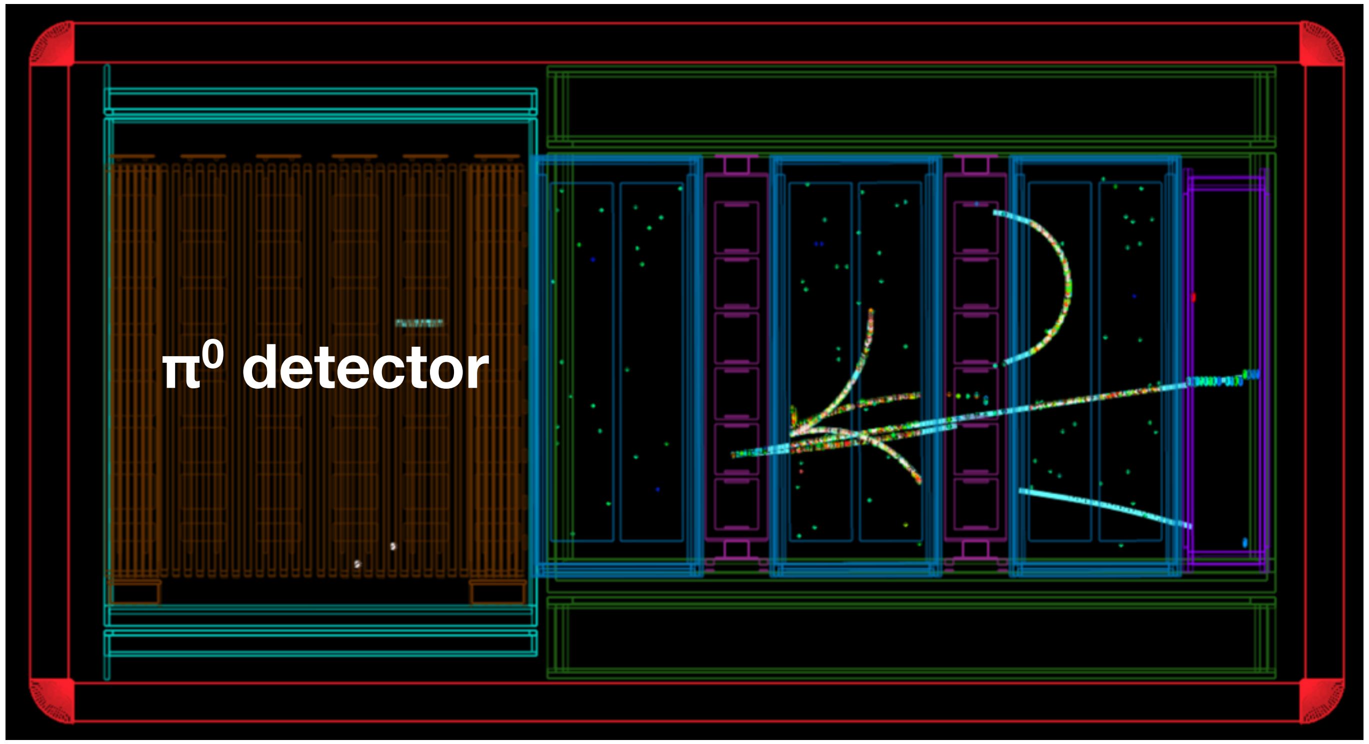
- **Additional SK data samples** under study
  - CC1π± and NCπ0, for ν/$\bar{\nu}$ modes
- **SK-Gd project**: add Gadolinium to SK water (0.01%)
  - enhance neutron detection capability
  - improves low energy antineutrino detection
  - could provide wrong-sign BG constraint in T2K $\bar{\nu}$ data





ND280 upgrade

- Reduce systematics to ~4%
- Main improvements:
  - Full polar angle acceptance
  - High efficiency for short tracks
  - TOF for particle direction



- Strong involvement from CERN
  - Submitted proposal to CERN SPSC
- TDR expected by the end of 2018
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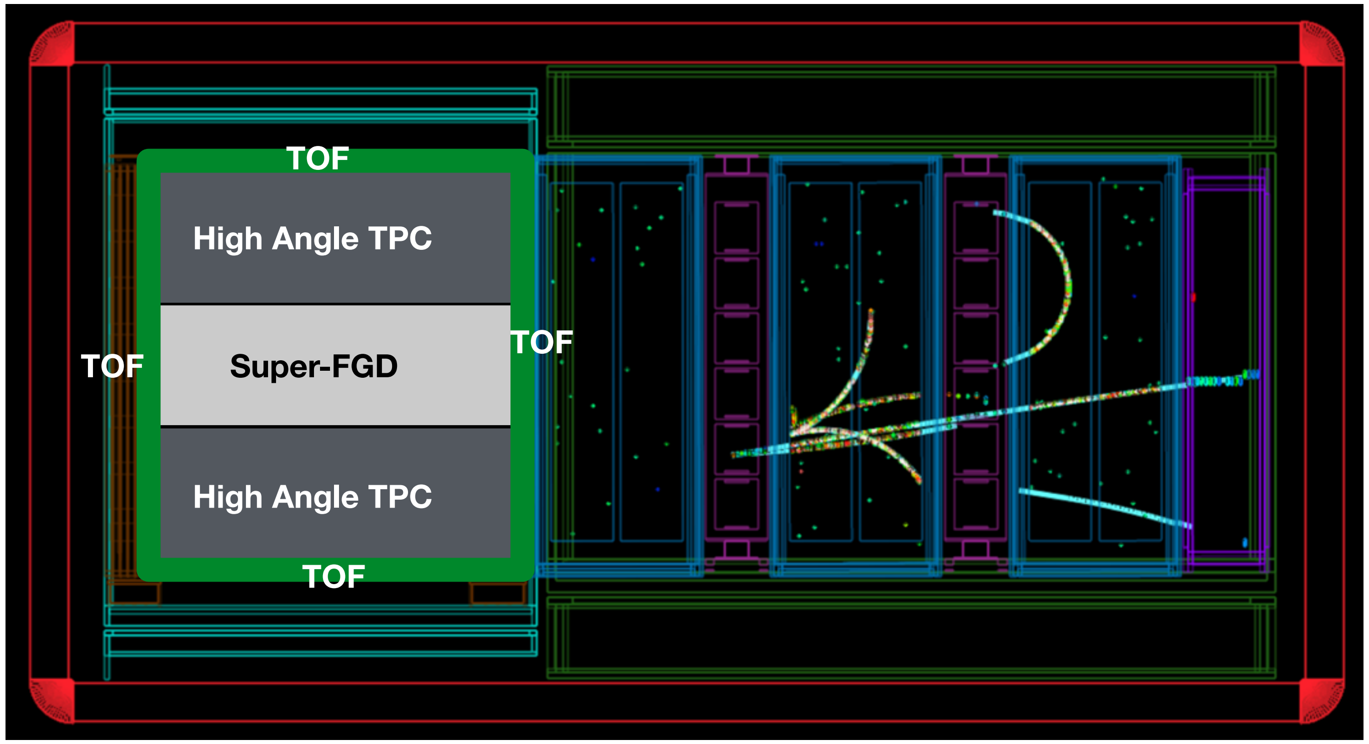

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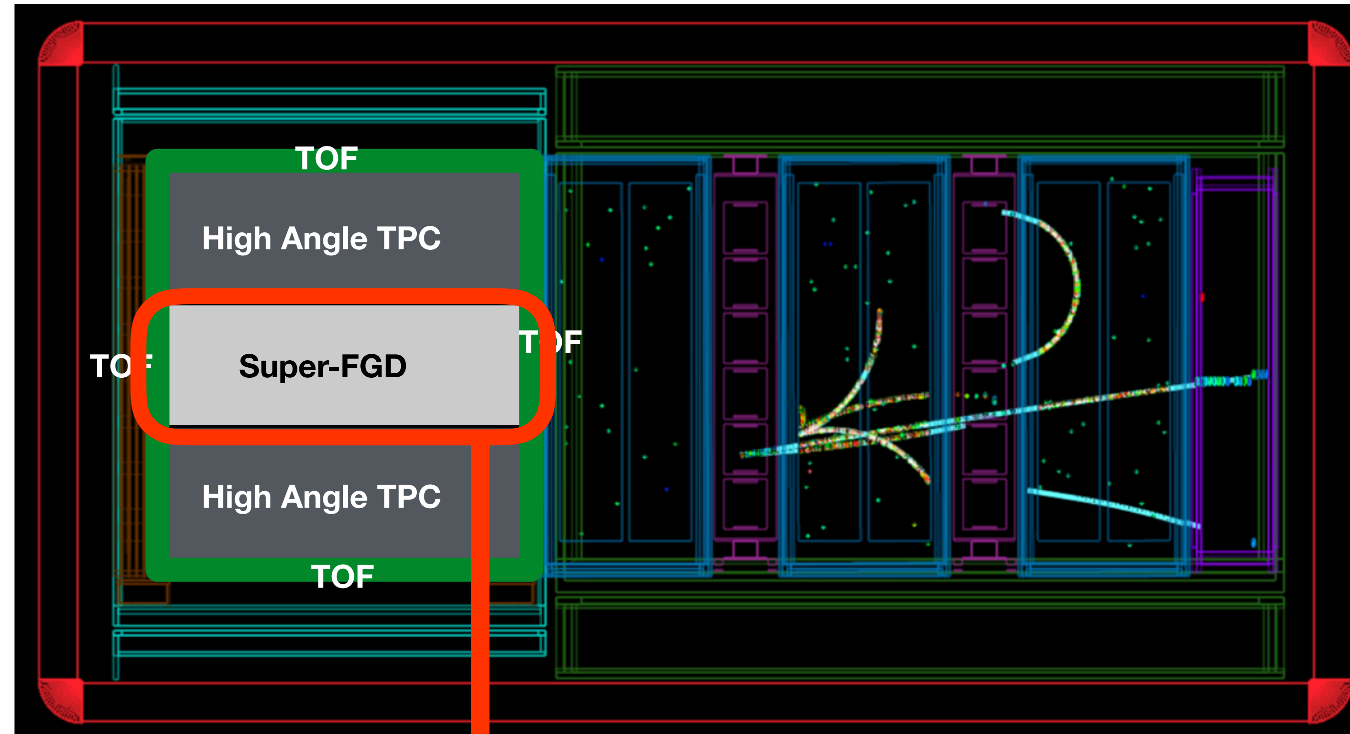
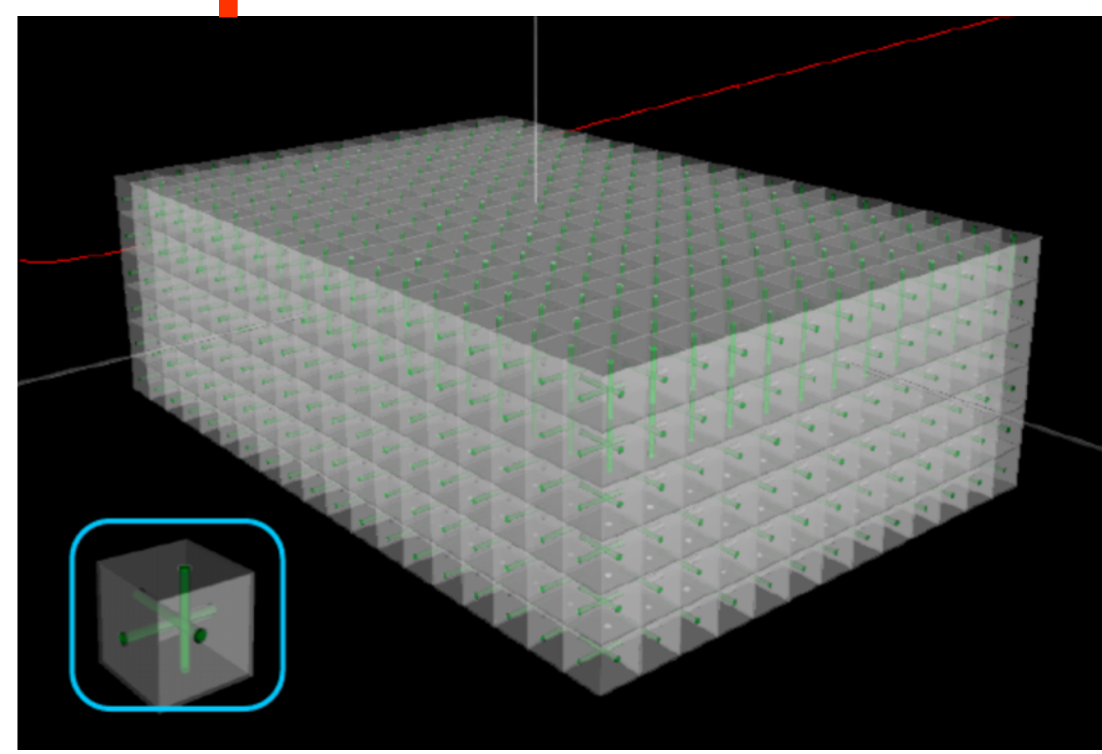




http://iopscience.iop.org/article/10.1088/1748-0221/13/02/P02006/pdf

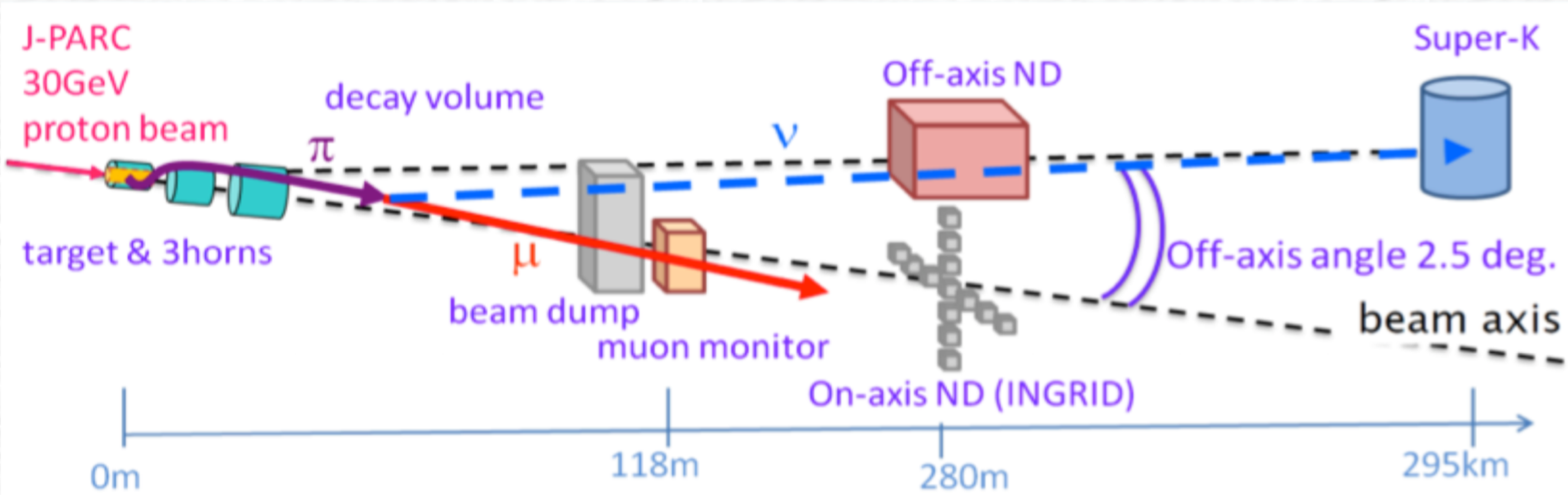
Scintillator target (Super-FGD):
over 2 million cubes

Outlook

- **T2K**, currently running at **485 KW** power, has double statistics in the last two years
- Updates to the T2K oscillation analysis:
  - Improvements to neutrino interaction model (added nuclear effects)
  - New reconstruction and event selection at Super-K: effective improvement in statistics by ~30%
- Results:
  - Continues improvements in atmospheric parameters
  - **CP conserving values excluded at 2σ for both hierarchies**
- Proposal of **T2K-II**: to collect 20×10^{21} POT in 2021-2026
  - R&D for Upgrade of the Near Detector is ongoing
  - **Potential for >3σ sensitivity on δ_{cp}**

BACKUP SLIDES

Beam production



Protons hit the **target**: graphite rod (∅26 mm × 914 mm long, 1.8 g/cm^3)

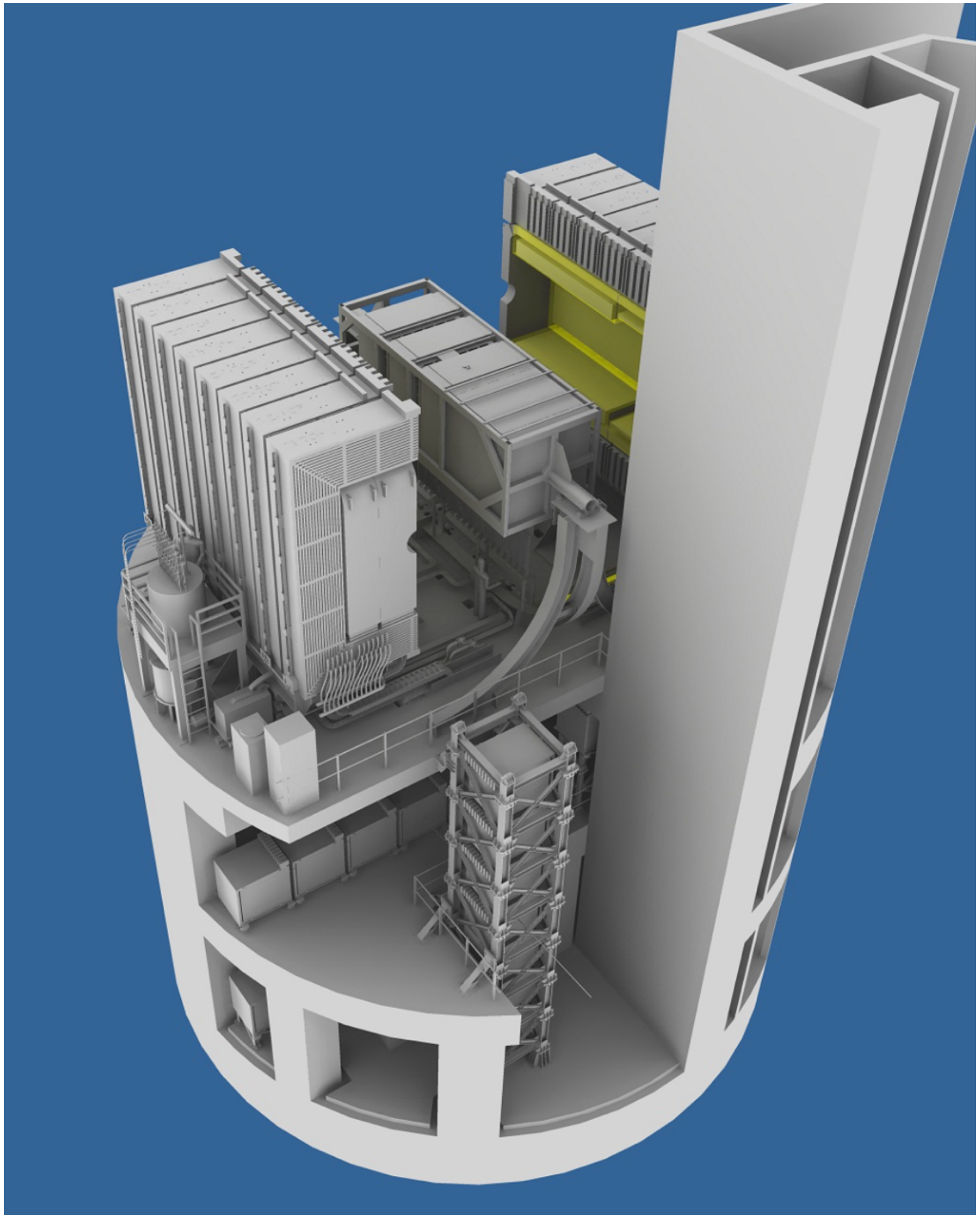
$$\mathbf{p + C \rightarrow \pi^{+/-} + X}$$

Three horns (+/−250 kA): collect and focus positive/negative pions

Decay Volume (96 m long, He ~1 atm.): $\pi^+ \rightarrow \mu^+ + \nu_\mu$; $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$;

Beam Dump: stops all the hadrons and muons with $p_\mu < 5$ GeV/c

Muon Monitors (ion. chambers and Si PIN diodes): measure the intensity and profile of the muons ($p_\mu > 5$ GeV/c) on the bunch-by-bunch basis



Effect of different

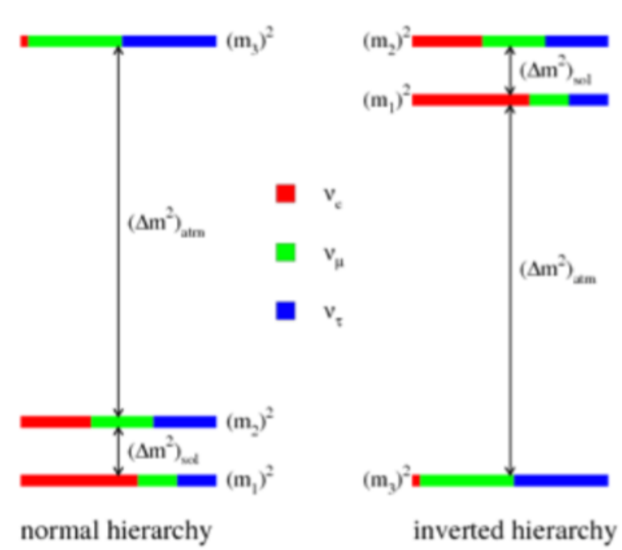
QUICK SUMMARY

- **$\sin^2\theta_{23}$, $\sin^2 2\theta_{13}$**
  - enhance/suppress both $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
- **CP violating parameter δ_{CP}** ***up to ±30% effect at T2K***
  - δ_{CP}=0,π: no CP violation: vacuum oscillation probabilities equal
  - δ_{CP} ~-π/2: enhance $\nu_\mu \rightarrow \nu_e$, suppress $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - δ_{CP} ~+π/2: suppress $\nu_\mu \rightarrow \nu_e$, enhance $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

"normal" hierarchy (NH):

- enhance $\nu_\mu \rightarrow \nu_e$
- suppresses $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

±10% effect at T2K



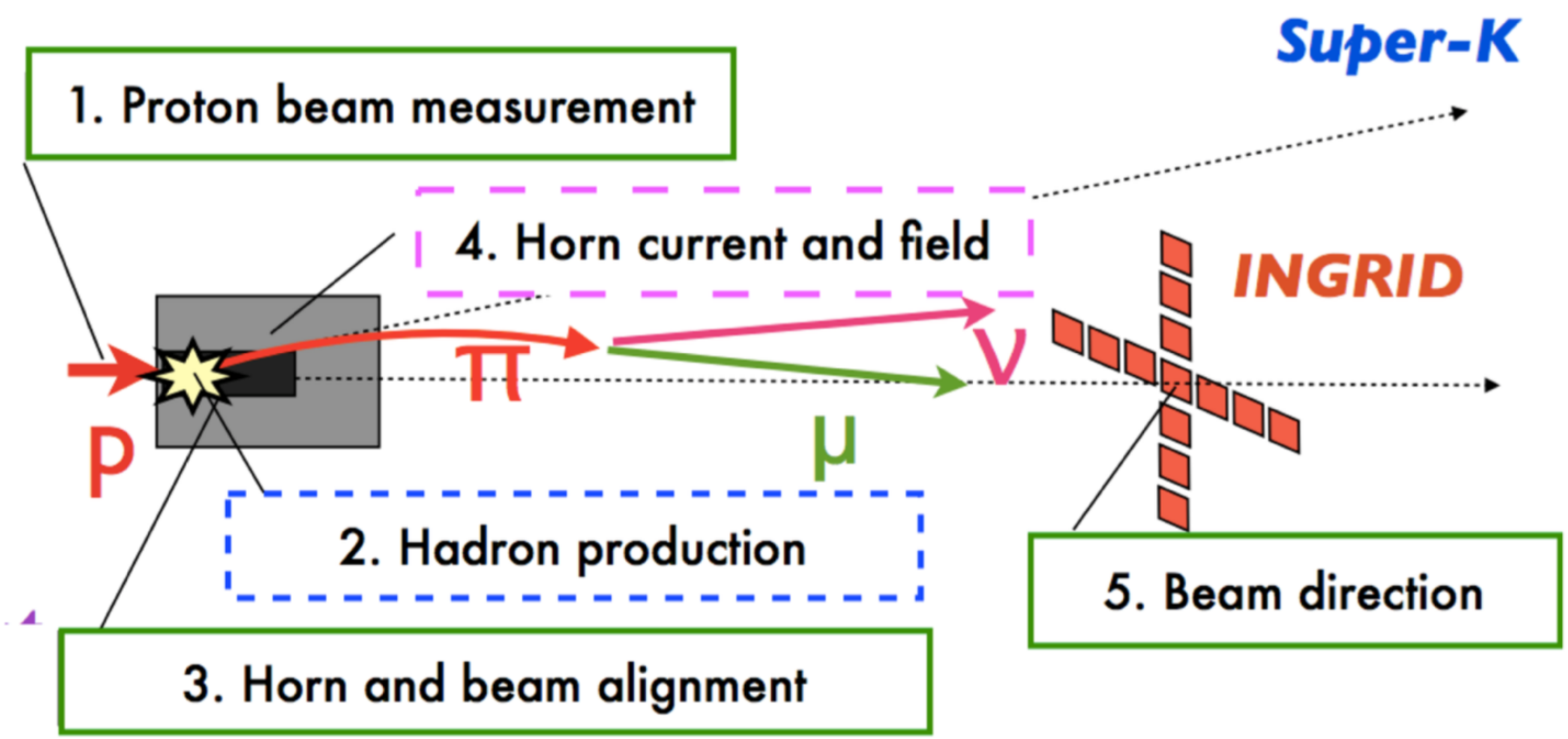
"inverted" hierarchy: (IH)

- suppress $\nu_\mu \rightarrow \nu_e$
- enhance $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

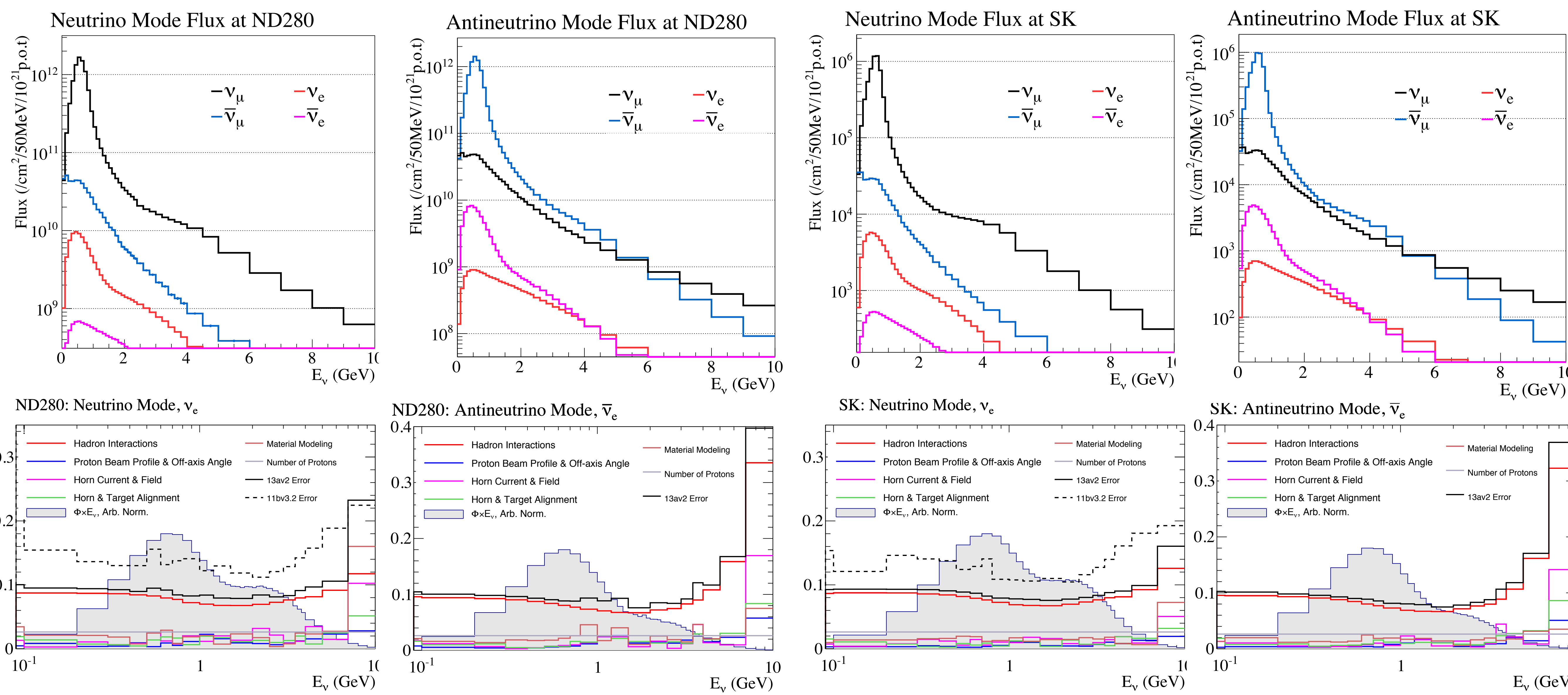
FLUX

T2K neutrino flux

- Neutrino flux calculations are based on
  - Input from the proton **beam monitors** (beam profiles and current)
  - **FLUKA2011** simulation: hadron production in the graphite target
  - this is tuned with **NA61/SHINE** *thin* (2 cm) target **data**
- **GEANT3**: propagation through magnetic horns and decay into neutrinos



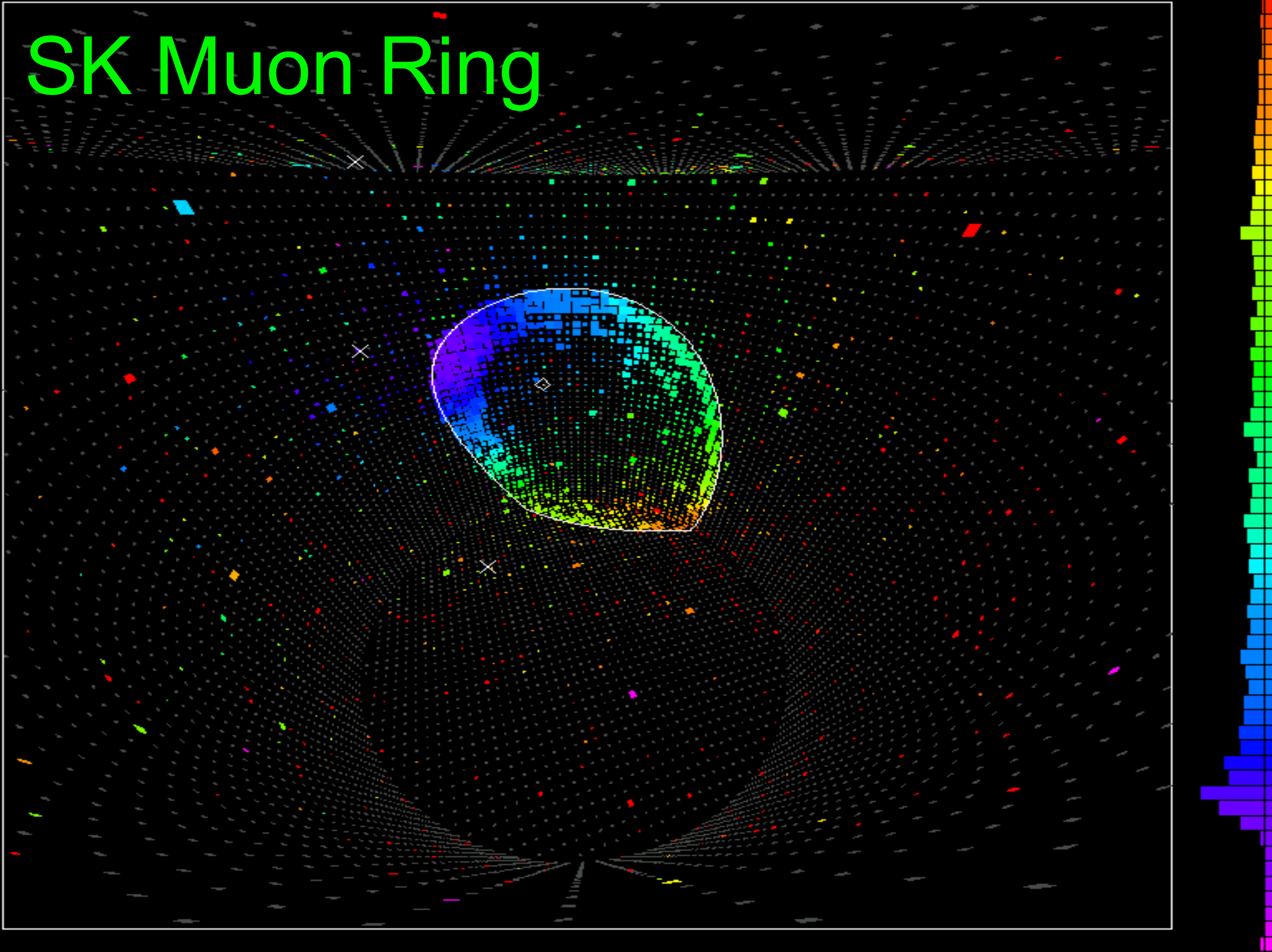
ν Fluxes & Uncertainties



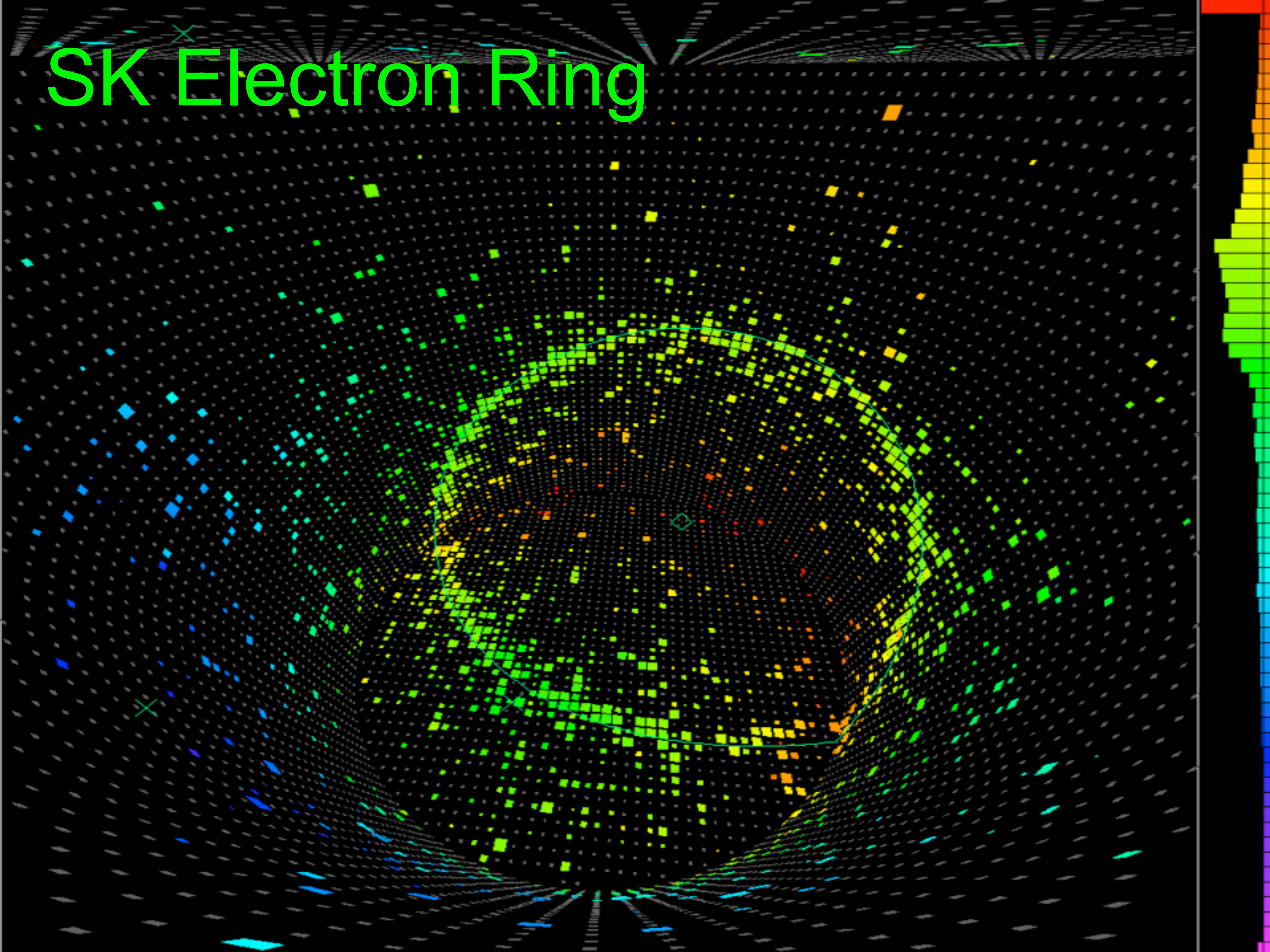
- A priori prediction of flux at Super-K has ~10% uncertainties from 0.1 to 5 GeV
  - Tuned with data from CERN NA61/SHINE
- Near and Far flux shapes are not identical, but highly correlated

SK

SK Muon Ring

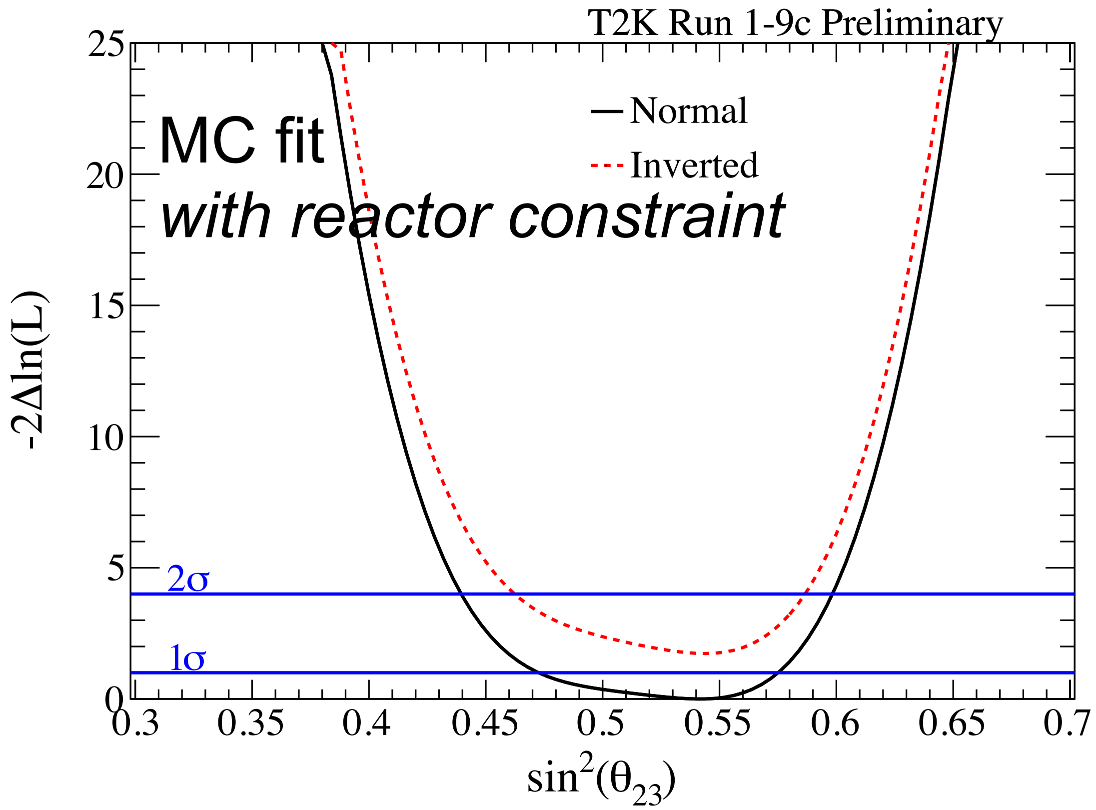


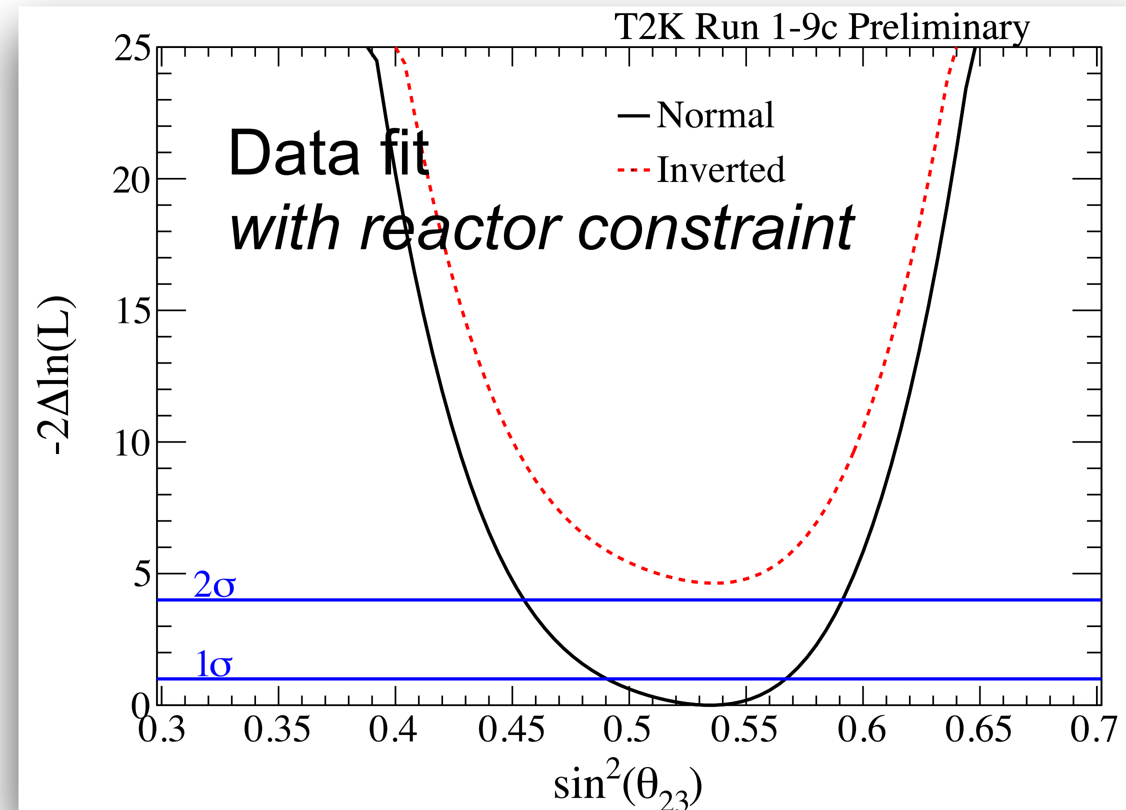
SK Electron Ring



OSCILLATION ANALYSES

Atmospheric sector: θ_{23}, $\Delta m^2_{32(1)}$





	NH	IH
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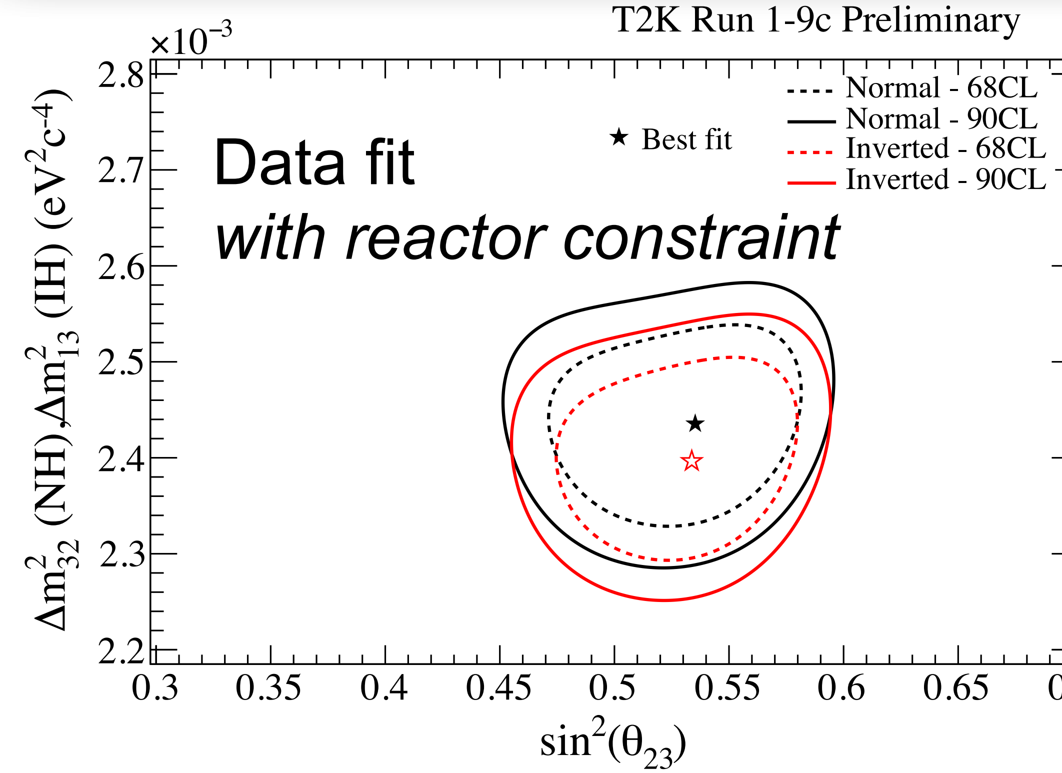


Systematic errors at SK (%)

	1-Ring **μ-like**		1-Ring **e-like**			
Error source	ν-mode	$\bar{\nu}$-mode	ν-mode	$\bar{\nu}$-mode	ν-mode $CC1\pi^+$	ν-/$\bar{\nu}$-modes
SK Detector	1.86	1.51	3.03	4.22	16.69	1.60
SK FSI + SI + PN	2.20	1.98	3.01	2.31	11.43	1.57
Flux+Cross sect. constrained	3.22	2.72	3.22	2.88	4.05	2.50
$\sigma(\nu_e)/\sigma(\bar{\nu}_e)$	0.00	0.00	2.63	1.46	2.62	3.03
$NC1\gamma$	0.00	0.00	1.08	2.59	0.33	1.49
NC Other	0.25	0.25	0.14	0.33	0.98	0.18
Total Systematic error	4.40	3.76	6.10	6.51	20.94	4.77

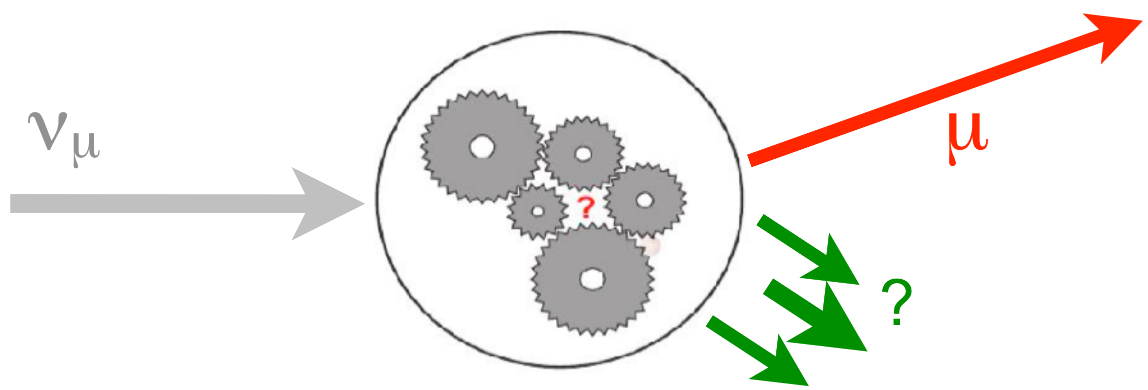
FSI = Final State Interaction
SI = Secondary interactions
PN = Photo-nuclear interactions
NC = Neutral Current

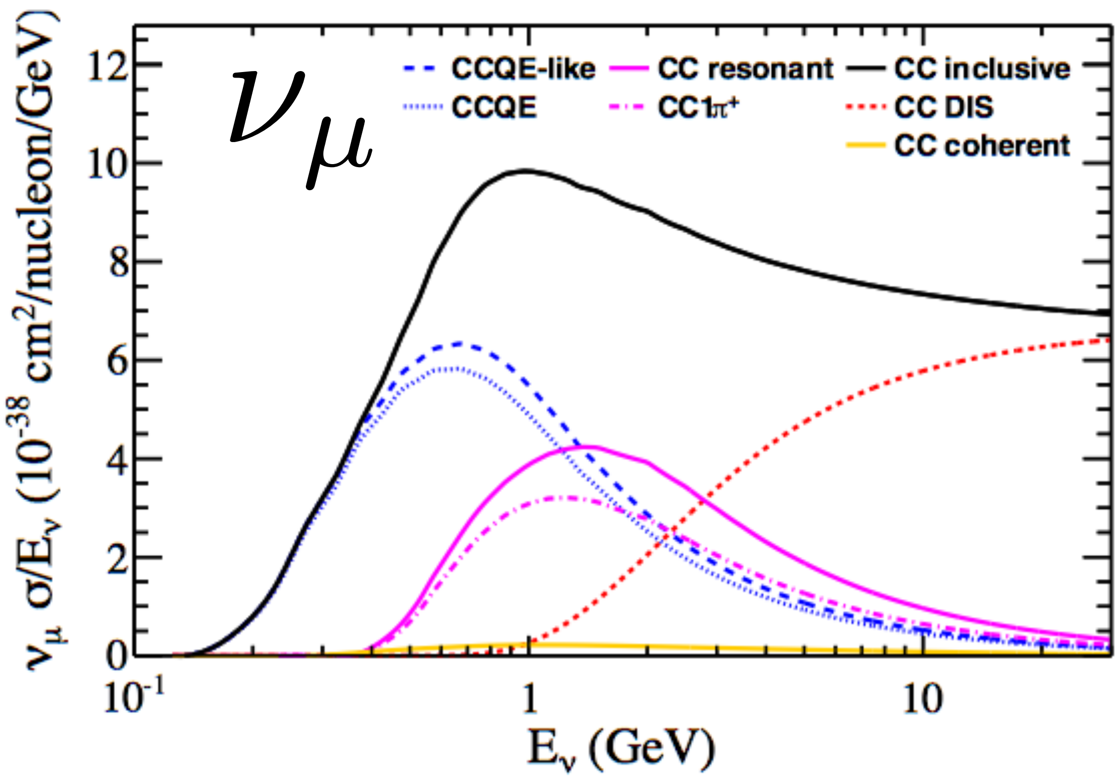
Total error is in 4-7% range
(except for ν-mode CC1π sample)

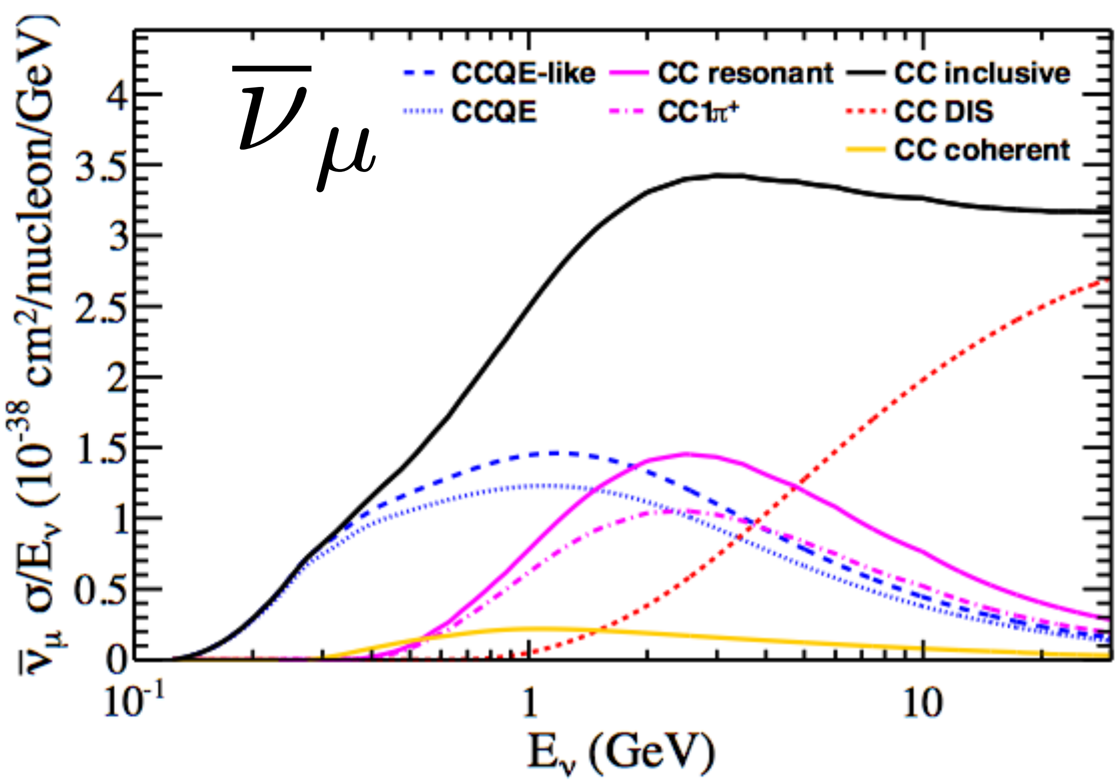
NEAR DETECTOR

Modelling ν interactions

(NEUT v5.3.3)



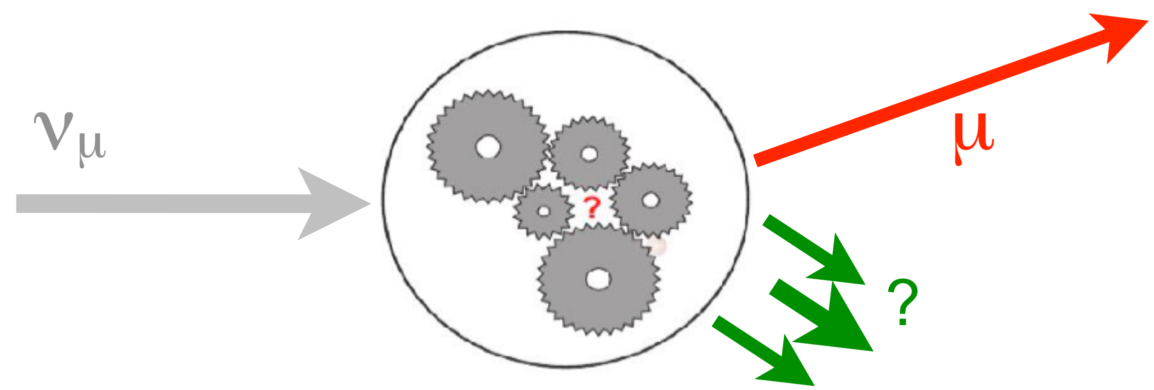




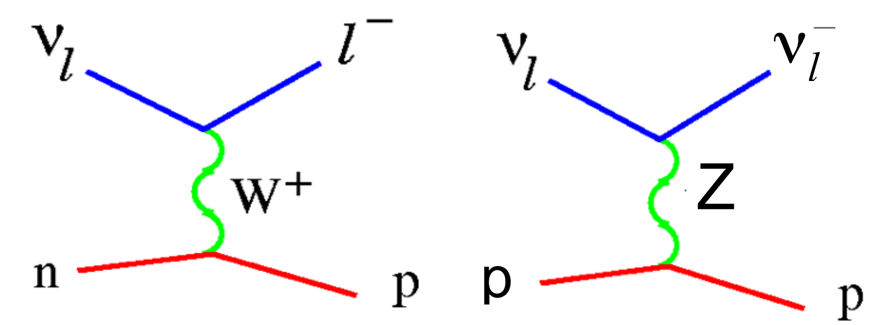
- CCQE: Llewellyn Smith, M_A^{QE}=1.0 GeV/c^2
- CC resonant π: Rein-Sehgal, M_A^{RES}=1.2 GeV/c^2
- 2p2h: Nieves model
- Nuclear model: Smith-Moniz RFG
  - Bulk effects (RPA) effects included
- Coherent pion: Rein-Sehgal
- DIS with Bodek-Yang corrections
- Neutrino and antineutrino interactions simulated
- ν_μ and ν_e simulated
  - Only differ at low energy

Modelling ν interactions

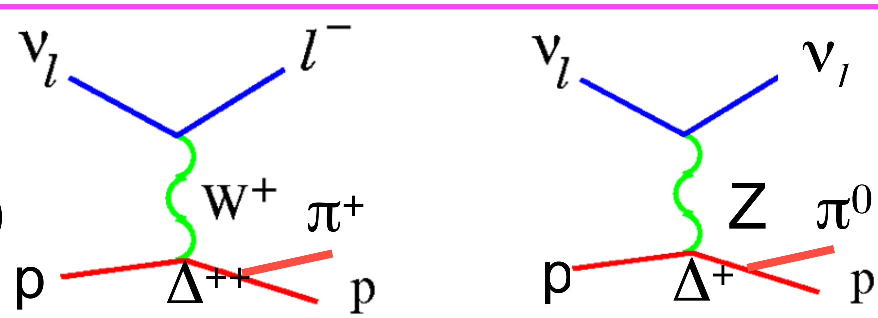
(NEUT v5.3.3)



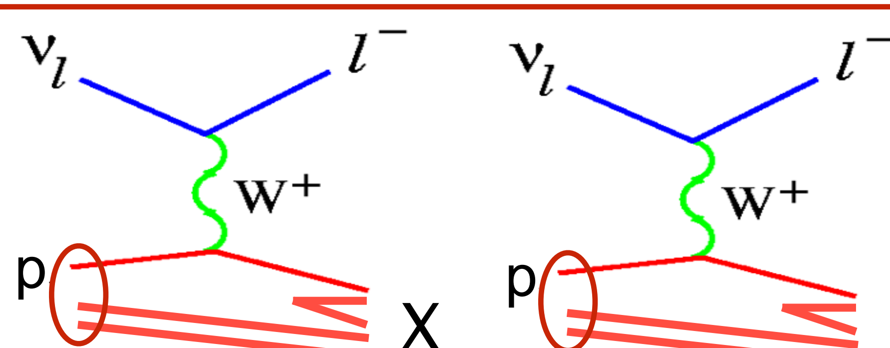
CC / NC
quasi-elastic
(QE)
39% / 18%

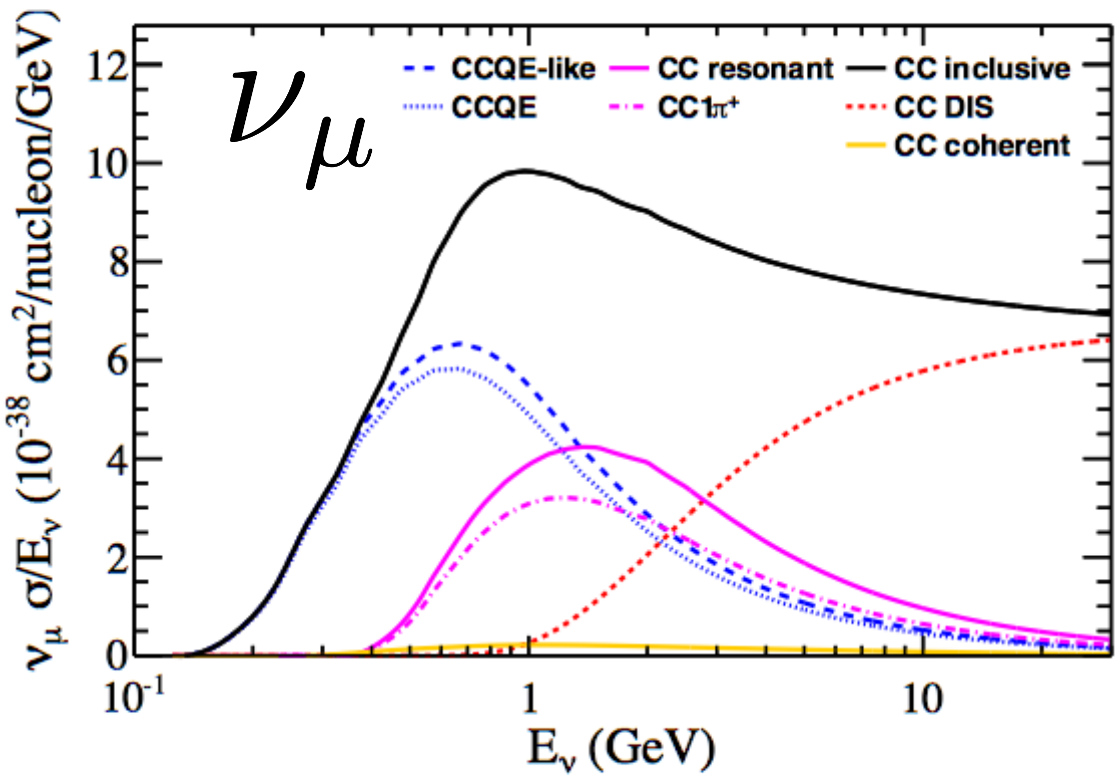


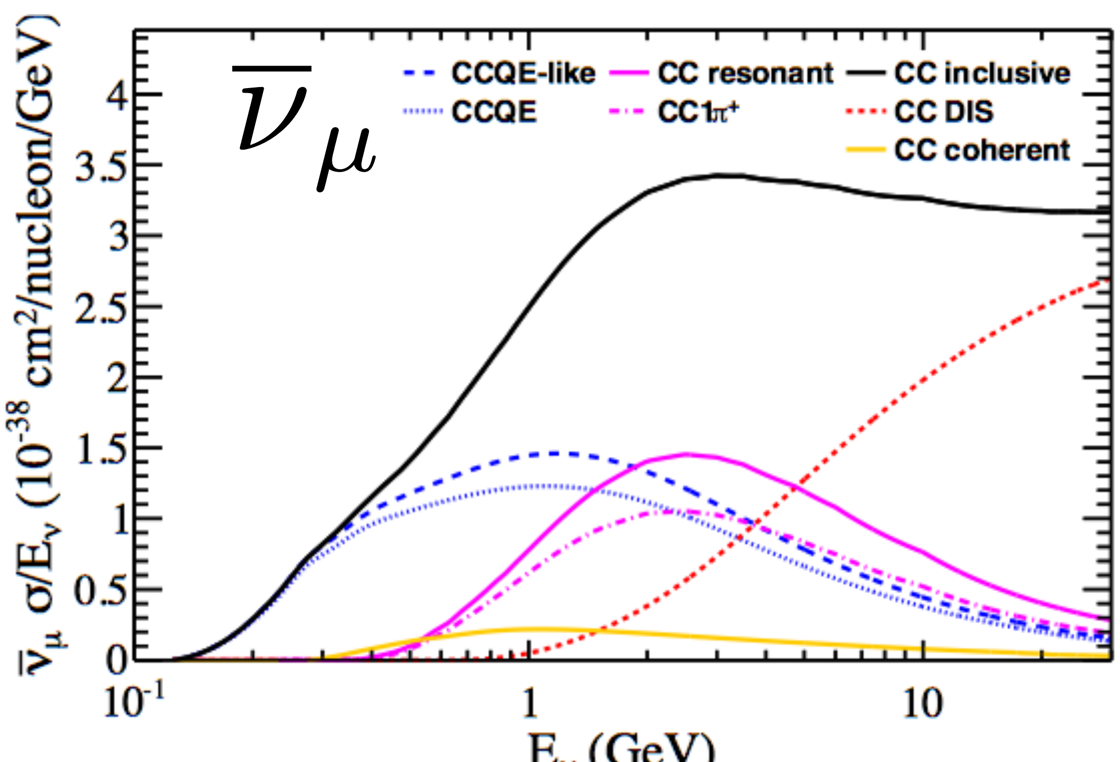
CC / NC
resonance
production (1π)
25% / 11%



CC / NC
DIS
5% / 2%



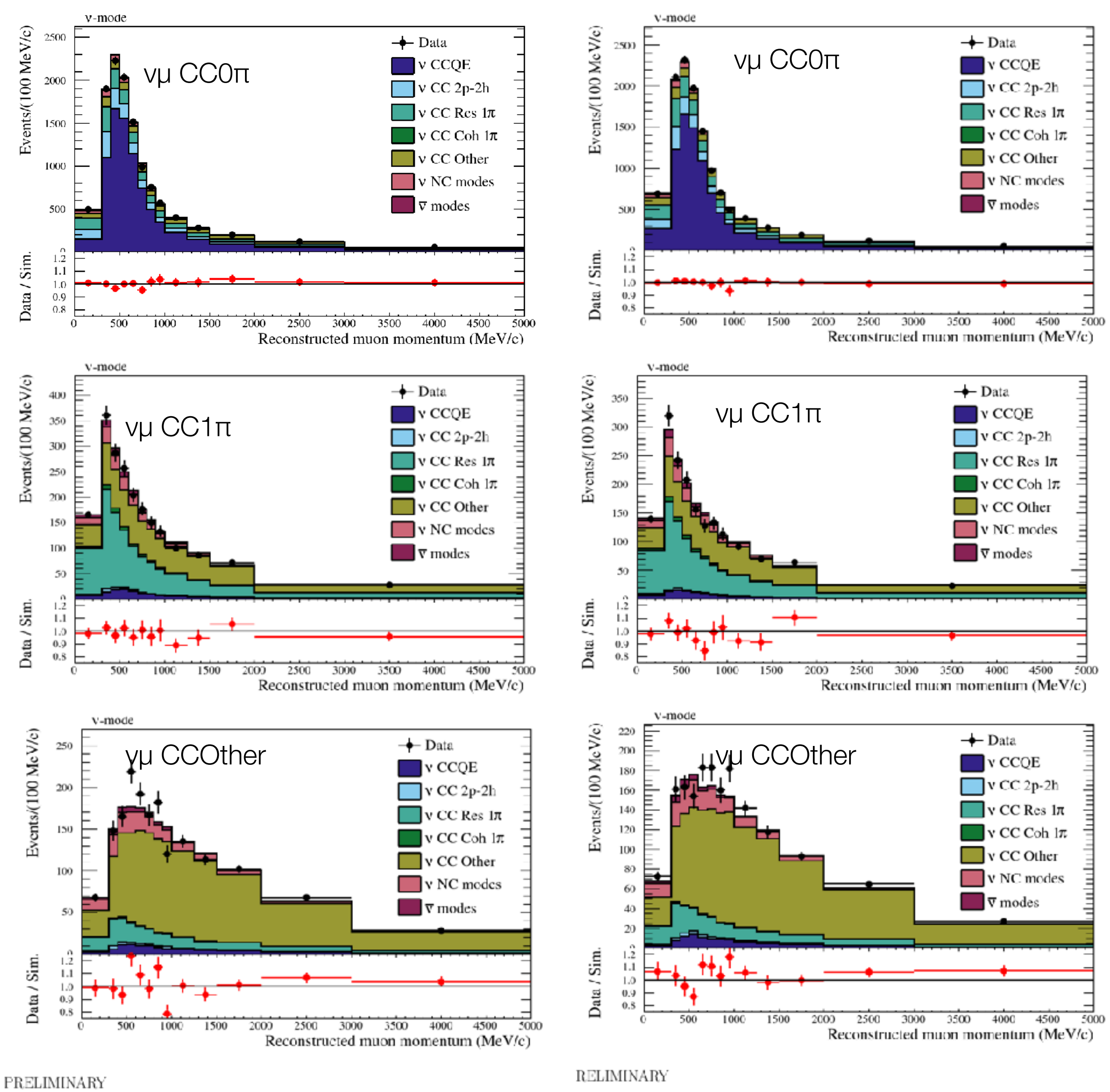




ND280 data for OA

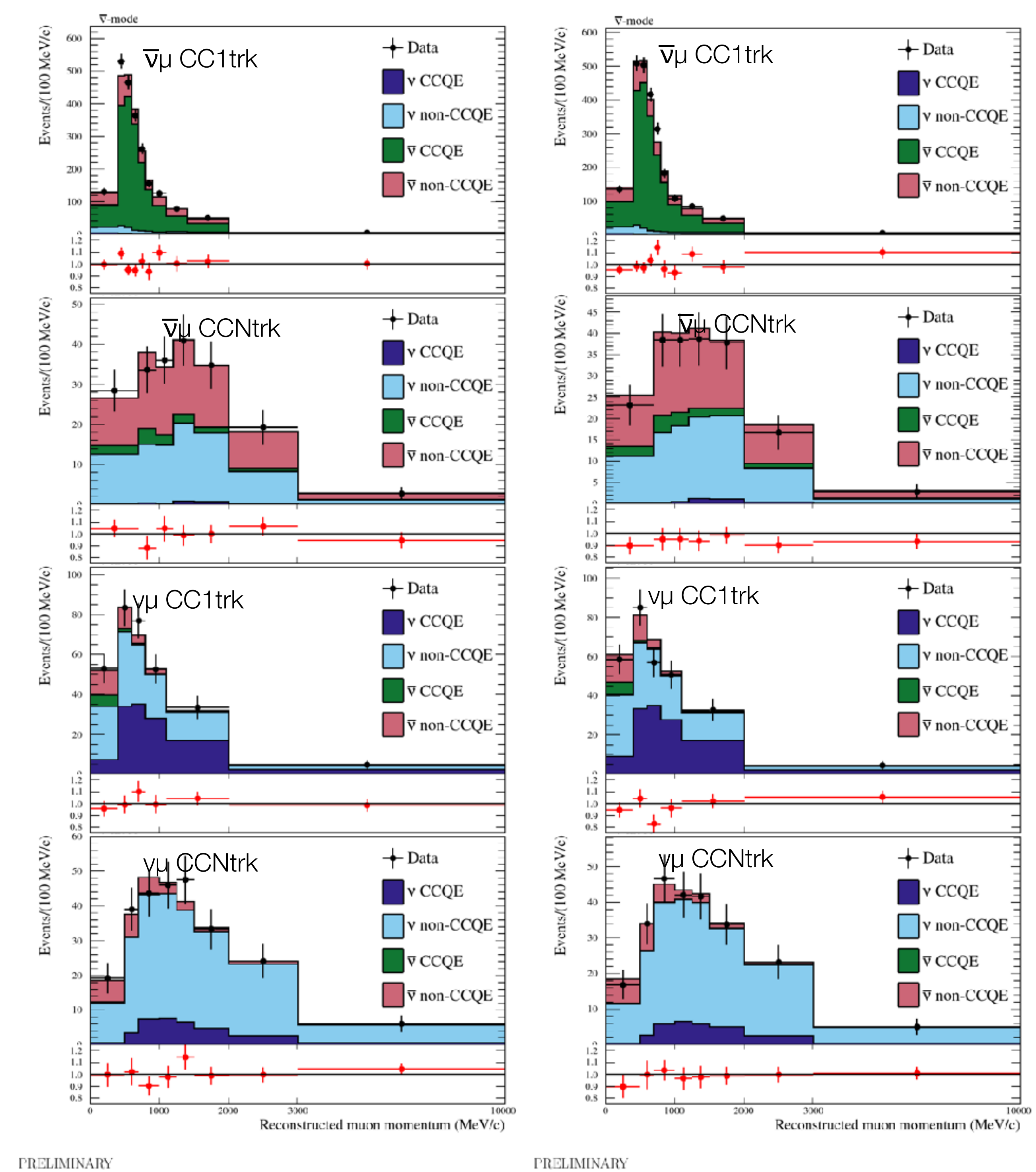
ν-mode

ν̄-mode



FGD1
(carbon)

FGD2
(carbon & oxygen)

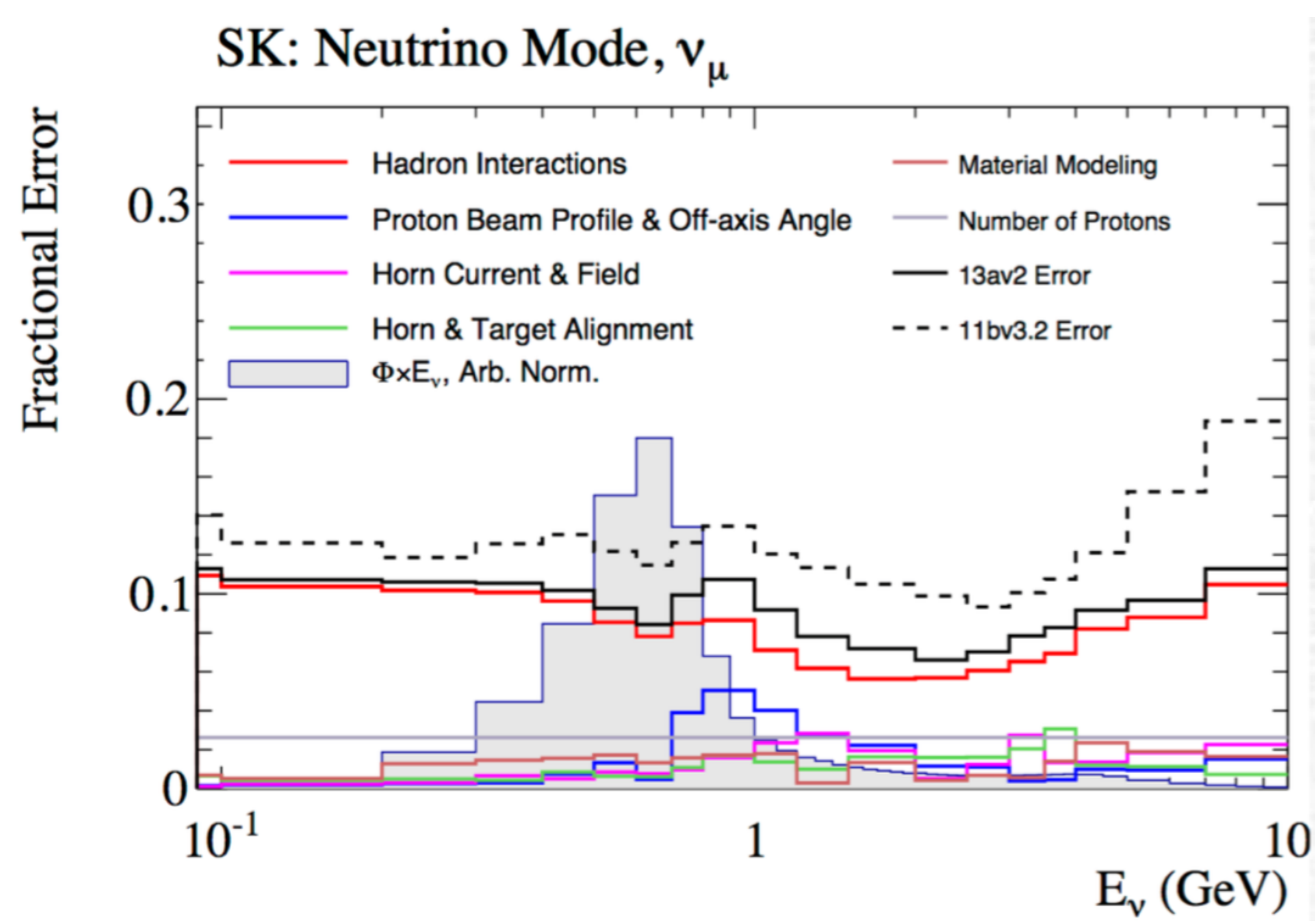


FGD1
(carbon)

FGD2
(carbon & oxygen)

Flux uncertainties

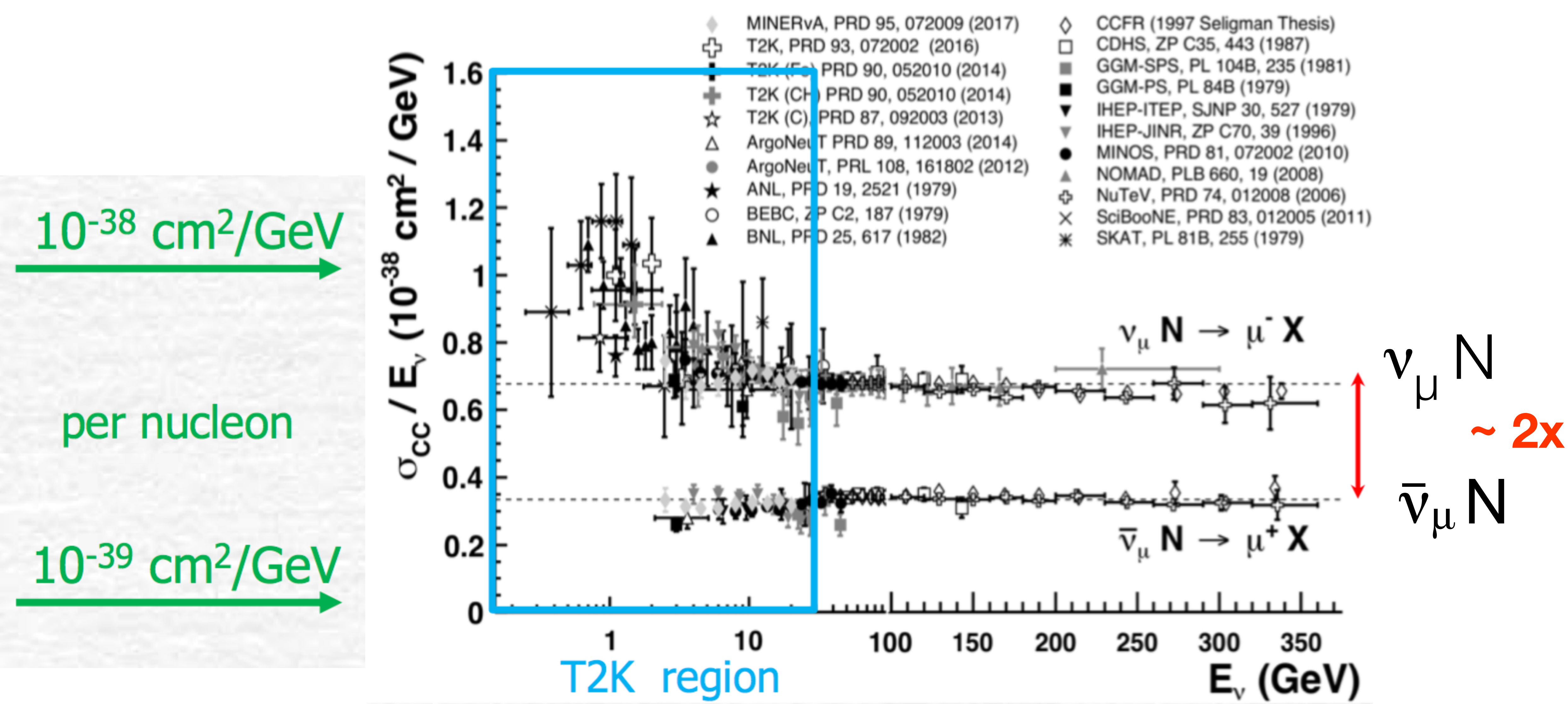
- Flux prediction uncertainty is **8-12%**
- Uncertainties on **hadronic interaction** modelling are largest
- **NA61/SHINE** data taken with **replica T2K target** is being incorporated for future analyses -> reduce flux uncertainty



Anti-neutrino interactions

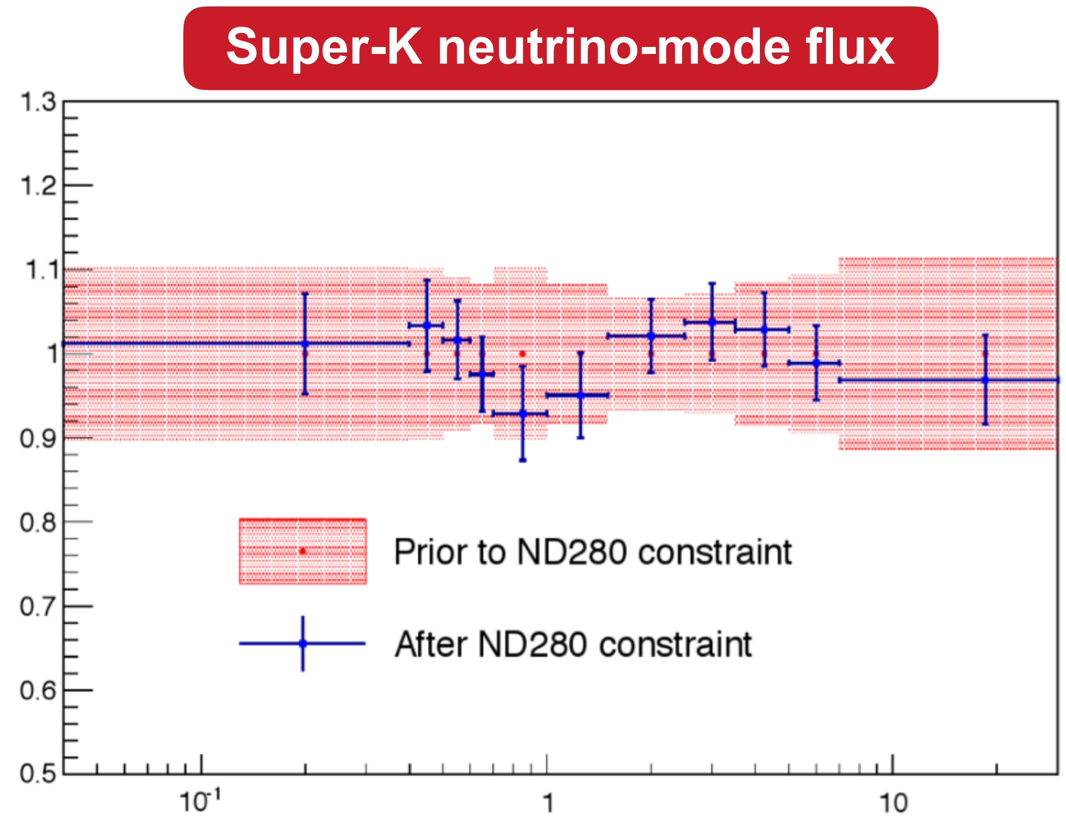
Charged-current (CC) *inclusive* $\nu_\mu/\bar{\nu}_\mu$ cross sections

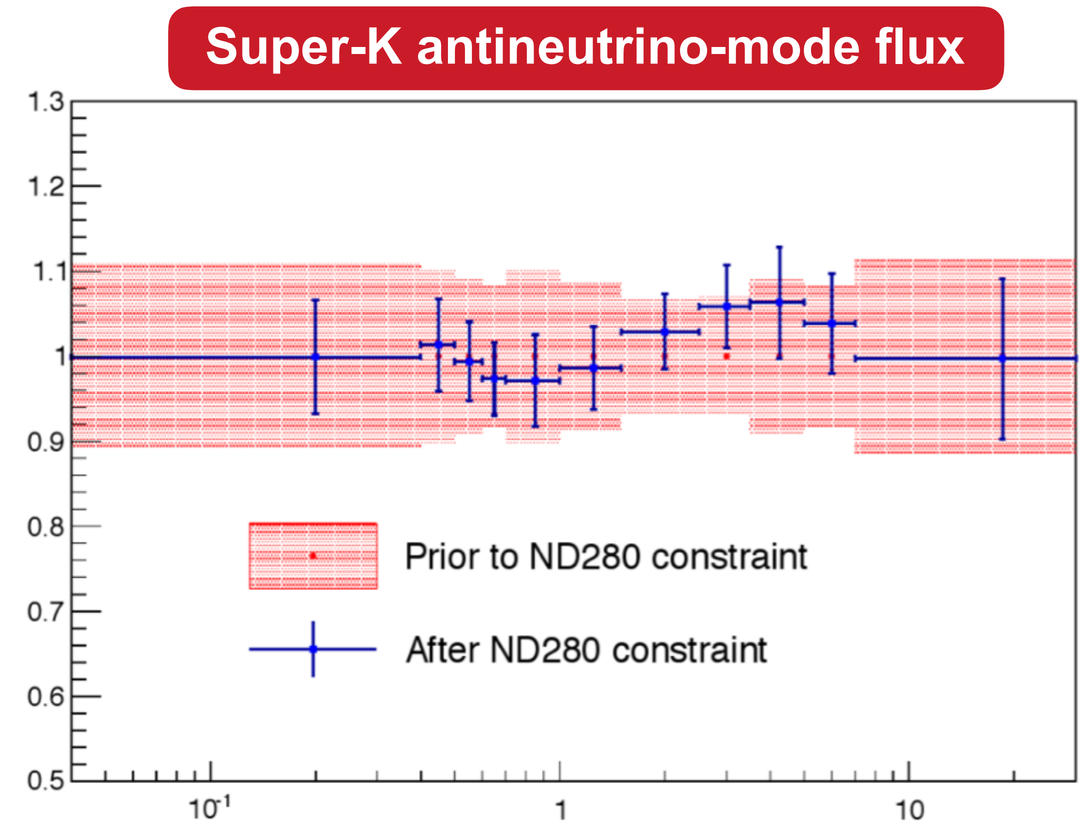
C. Patrignani et al. (**PDG**), Chin. Phys. C, **40**, 100001 (**2016**) and 2017 update:



Fitted flux parameters

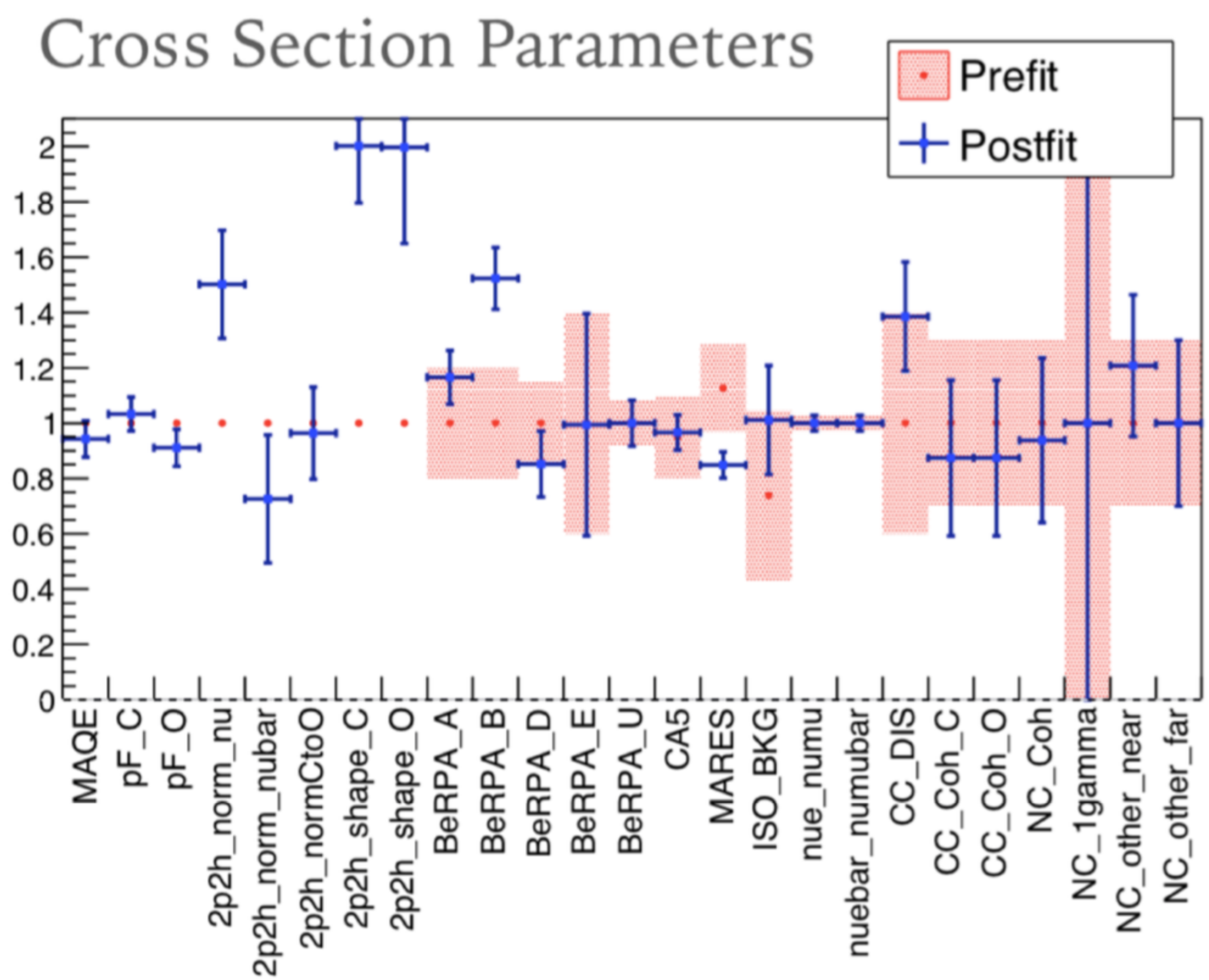
- Fitted flux parameters are near their nominal values
  - Post/Pre-fit ≃1
- Most of the fitted flux parameters are within 1σ prior uncertainty





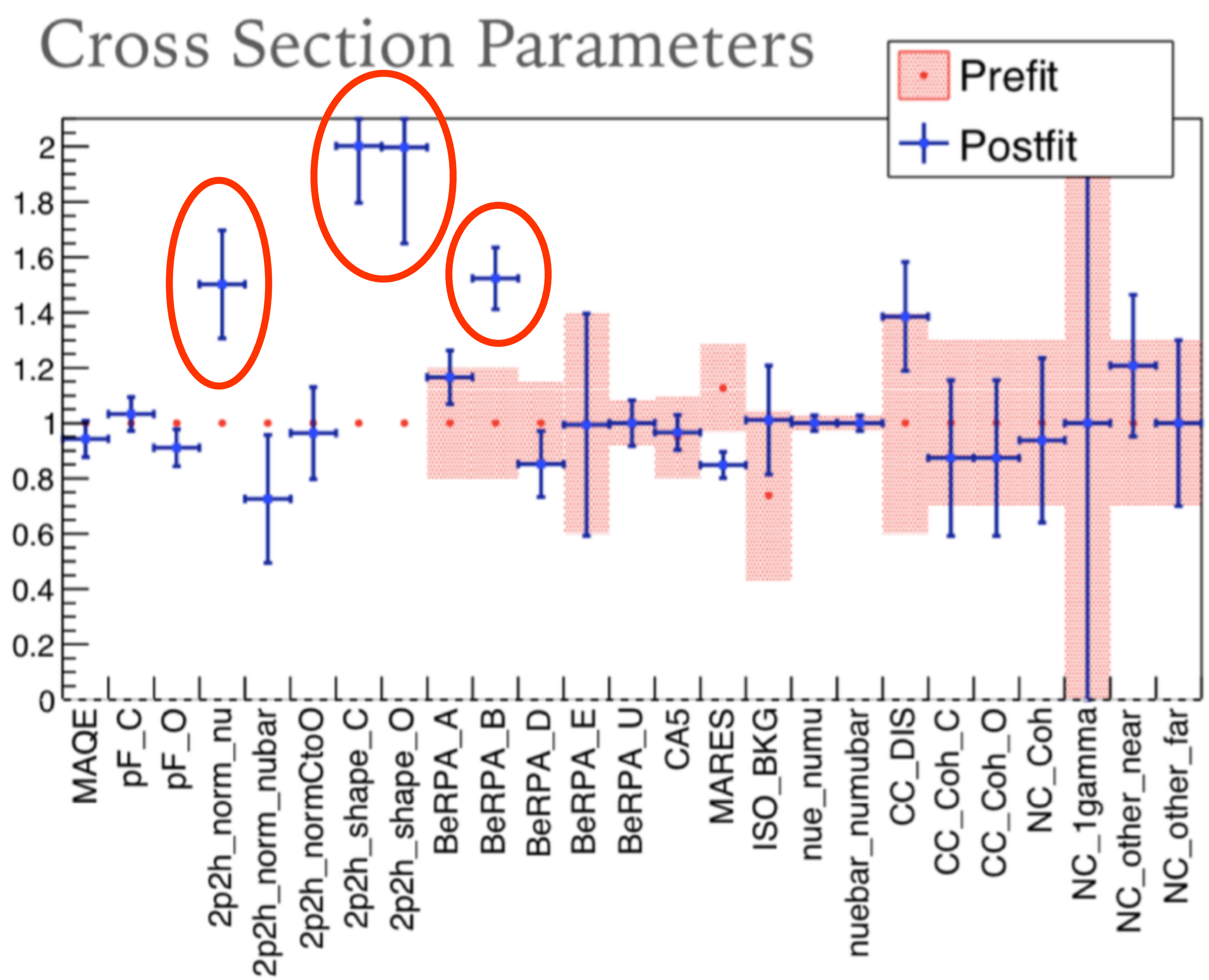
Fitted interaction model param

The cross-section parameters include normalizations and Fermi momenta for C and O, parameters of nuclear effects (2p-2h, RPA), etc.



Fitted interaction model param

The cross-section parameters include normalizations and Fermi momenta for C and O, parameters of nuclear effects (2p-2h, RPA), etc.



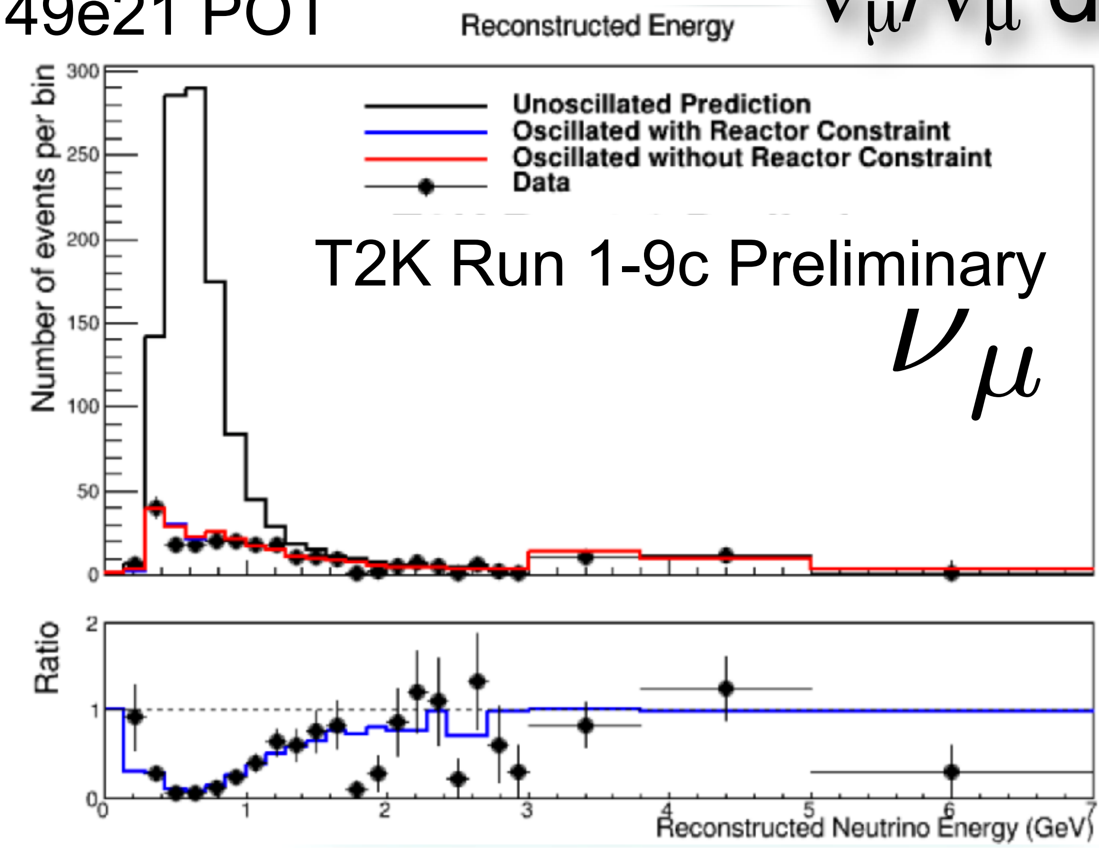
The fit enhanced some of cross-section parameters (related to 2p-2h and RPA)

SK DATA

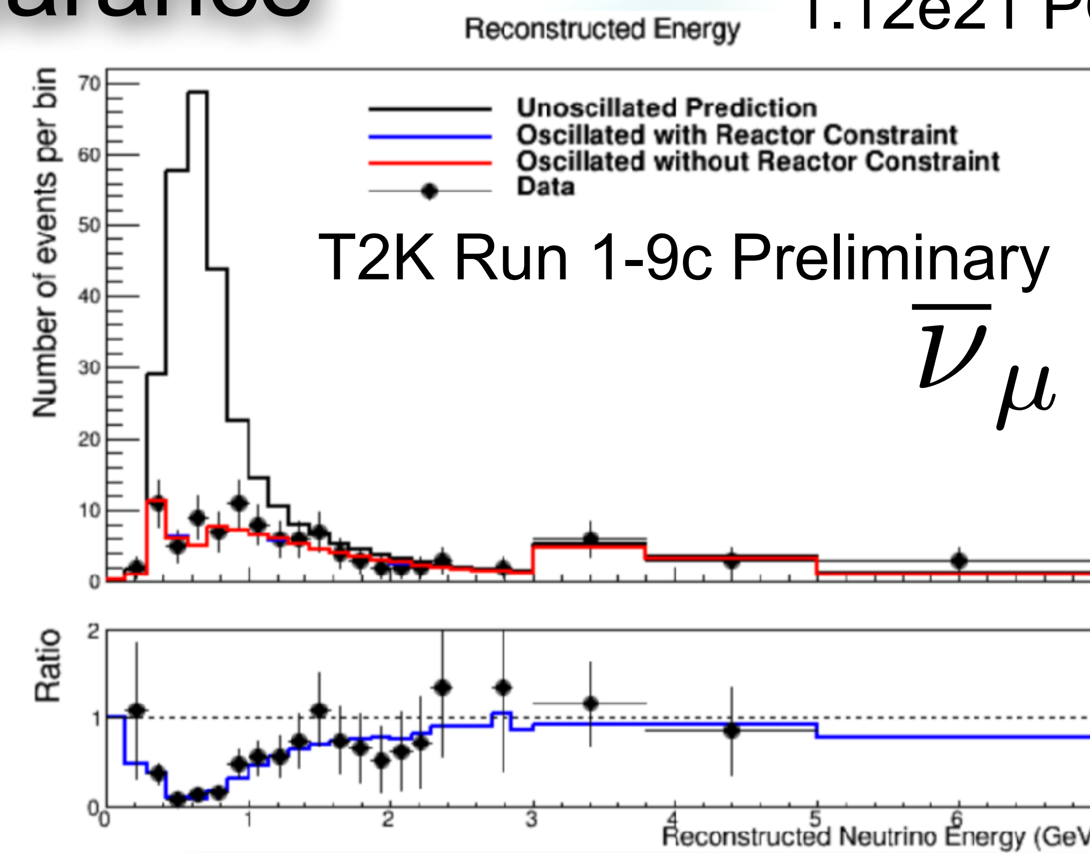
SK data for OA

$\nu_\mu/\bar{\nu}_\mu$ disappearance

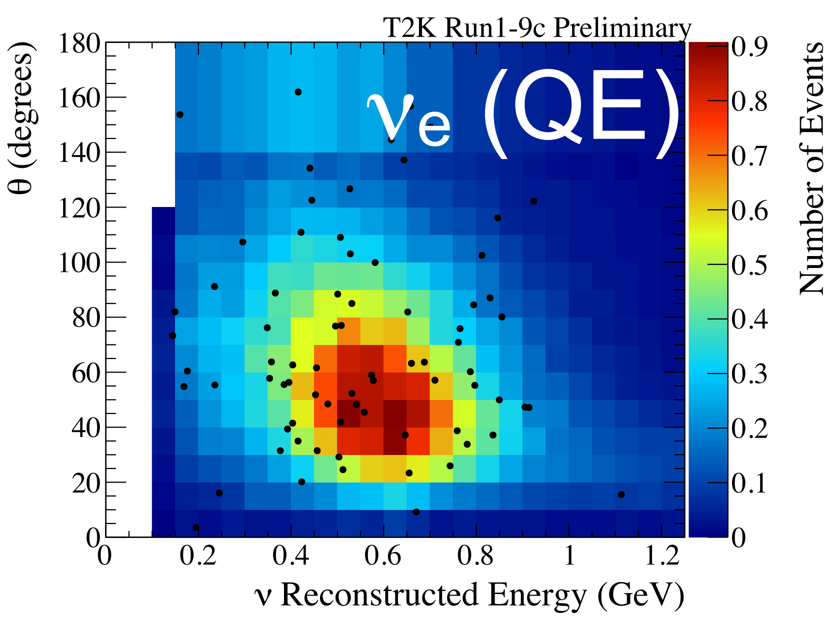
1.49e21 POT

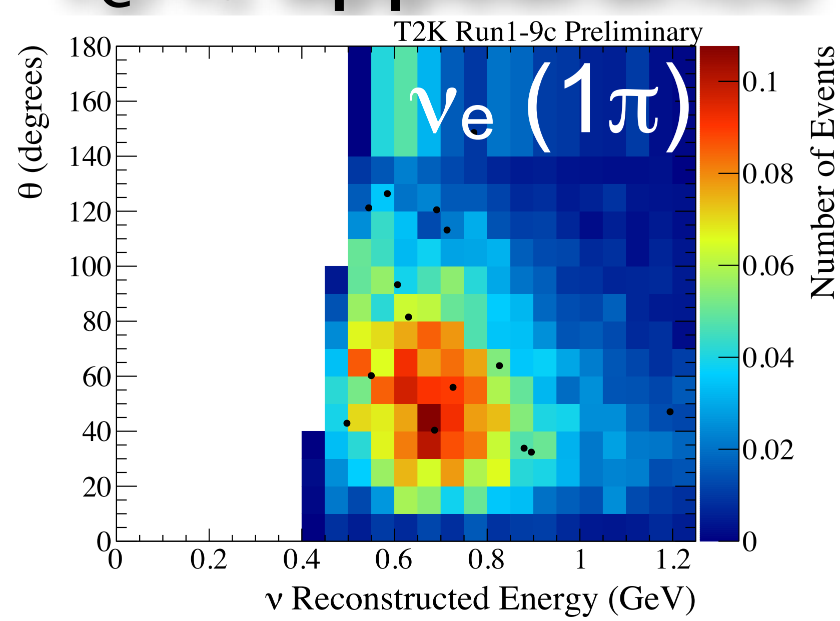


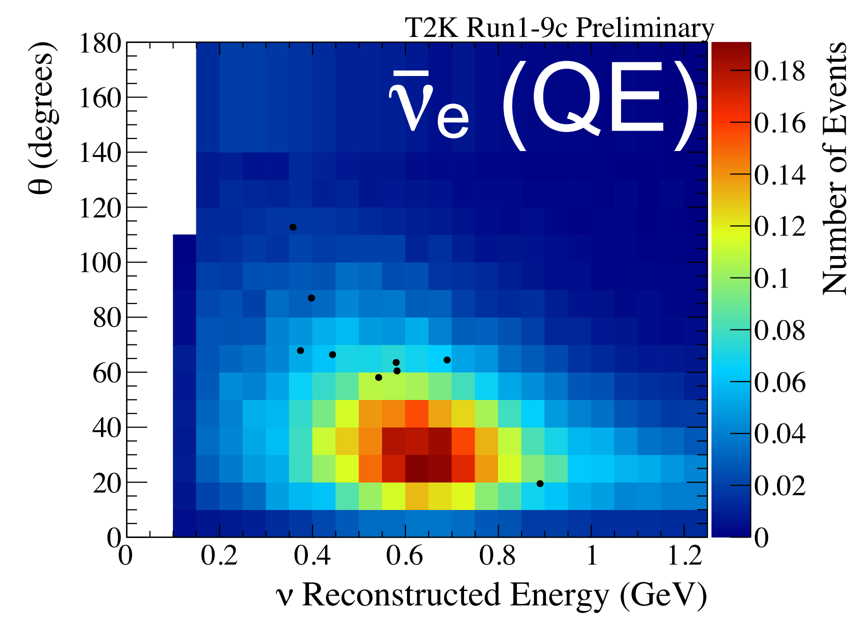
1.12e21 POT



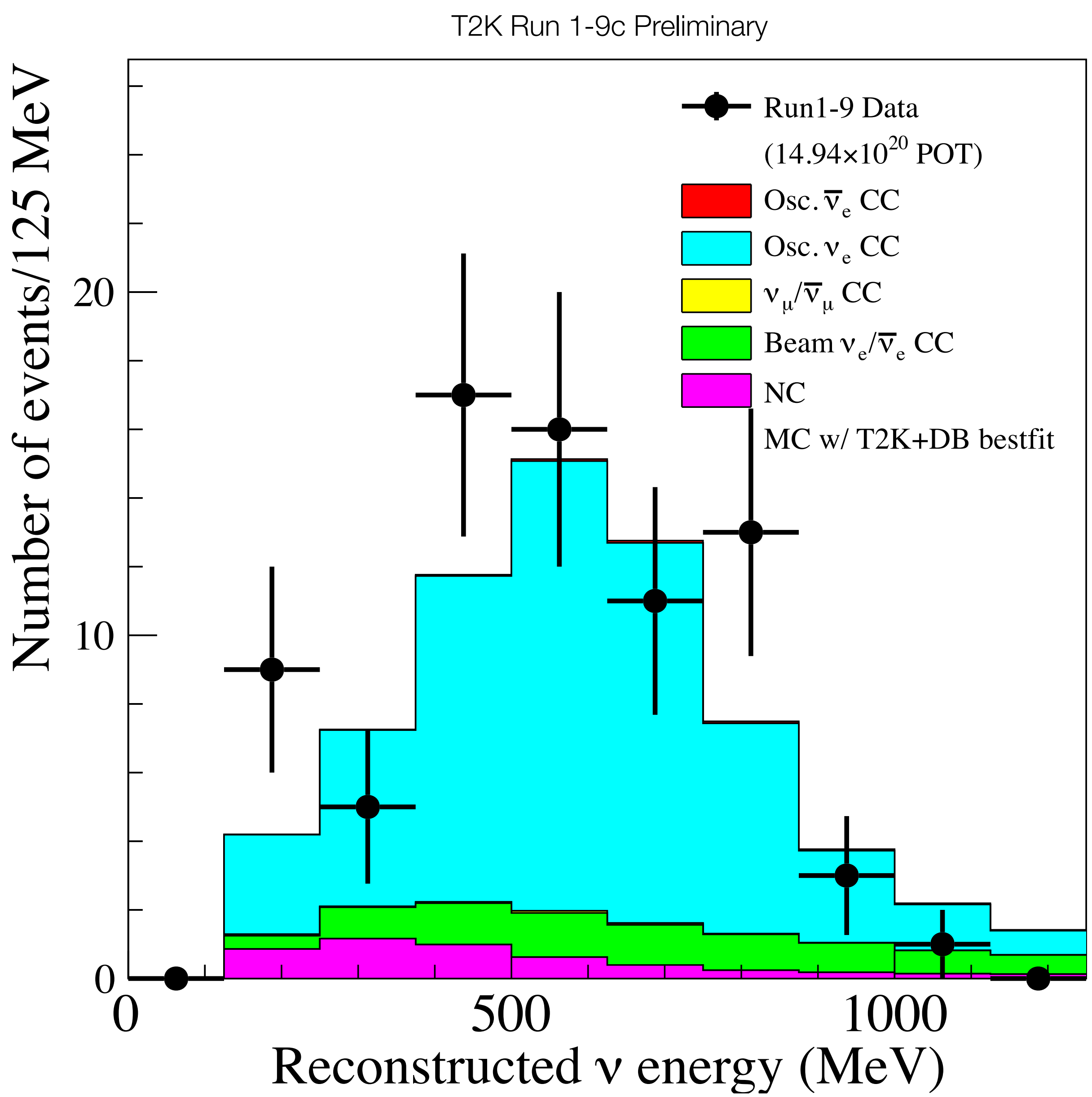
$\nu_e/\bar{\nu}_e$ appearance

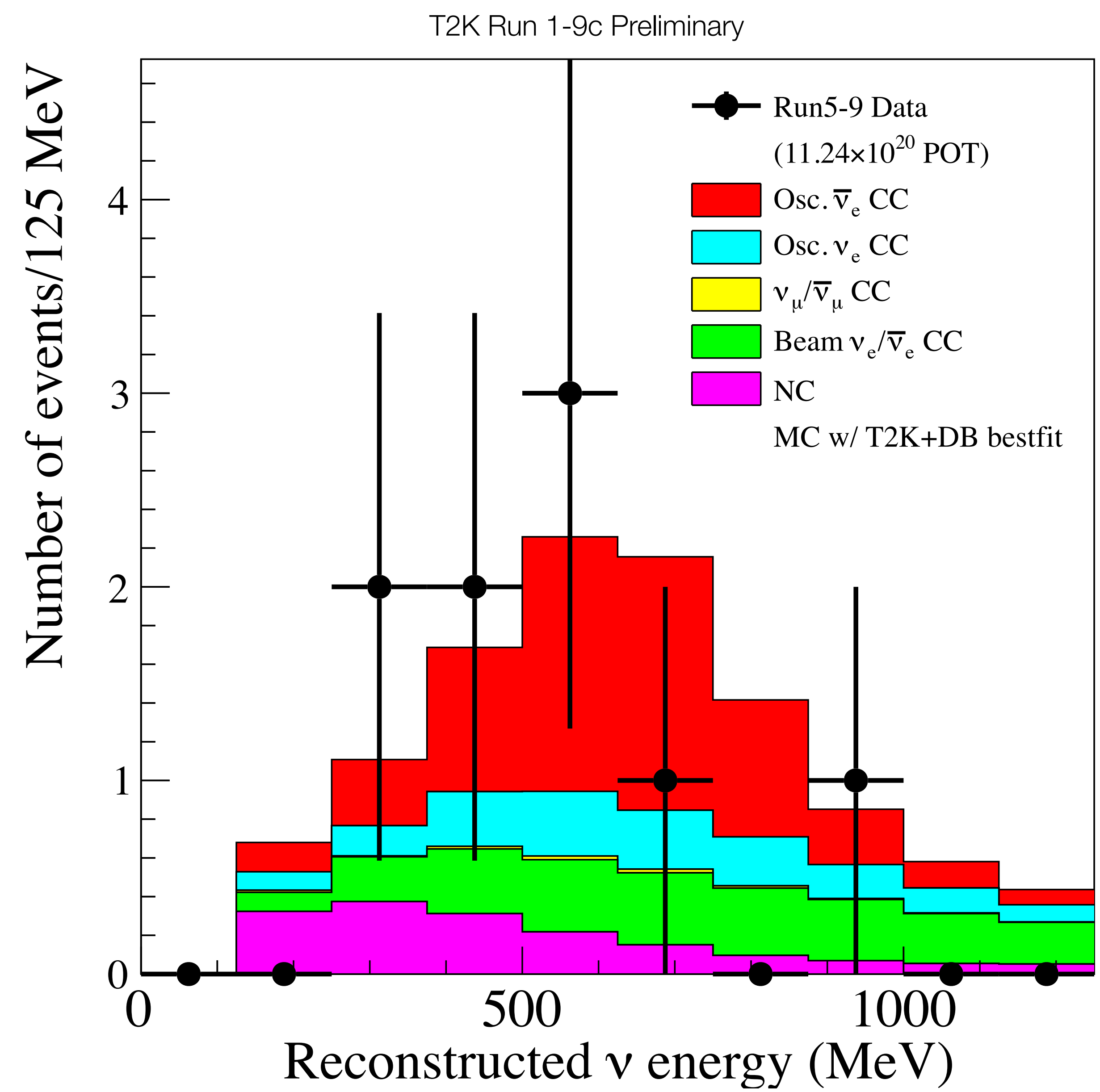






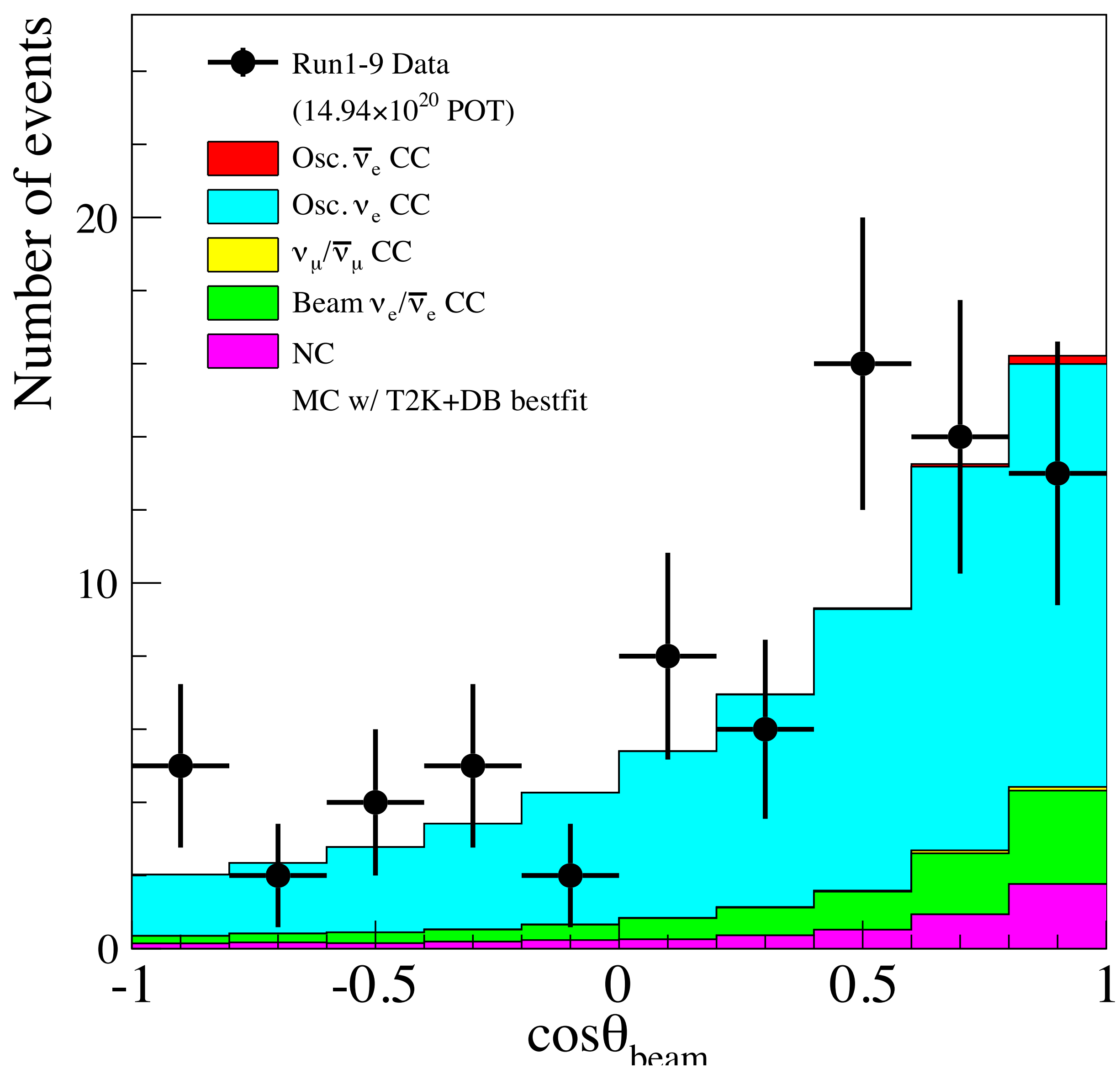
SK e-like events



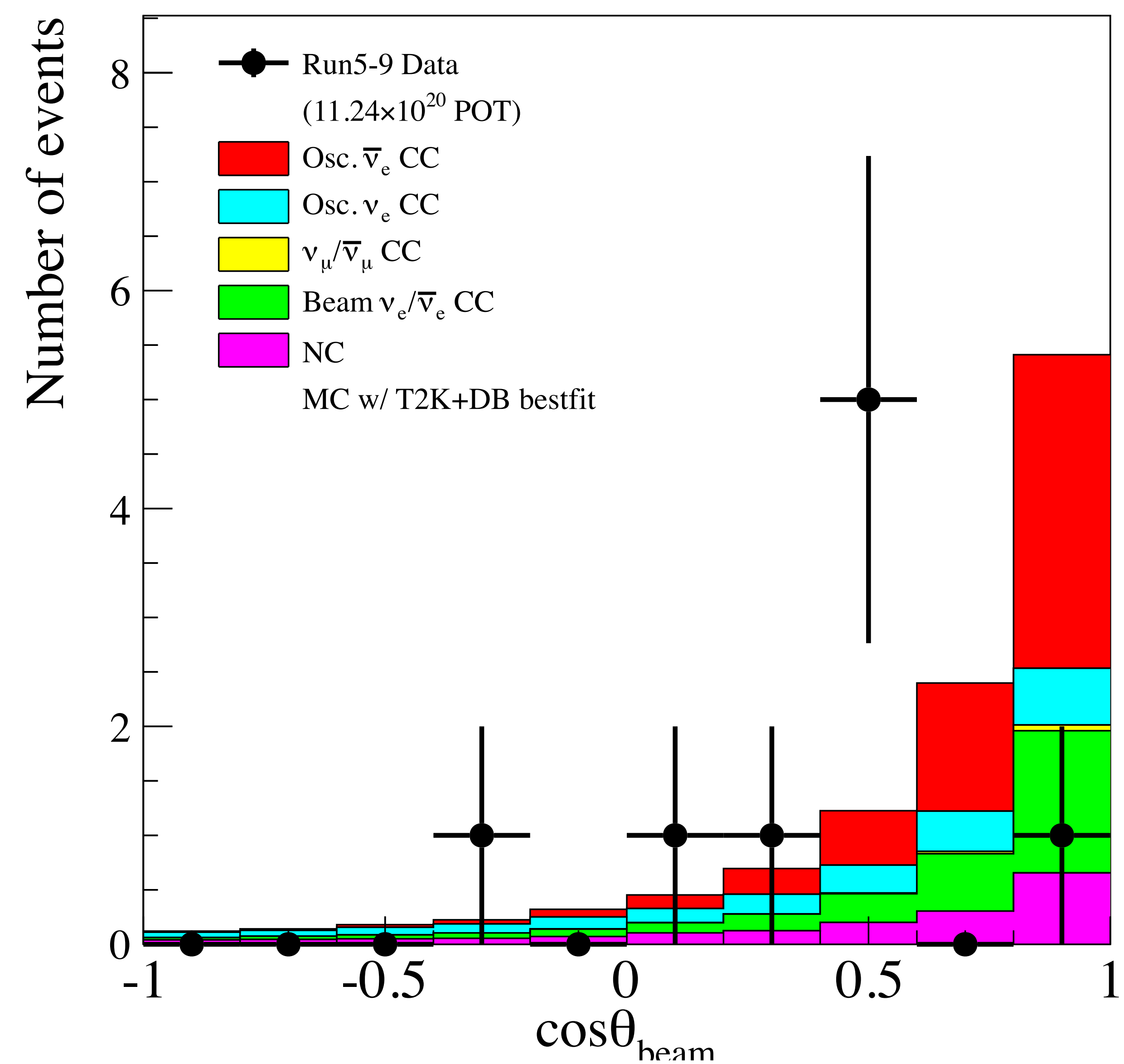


SK e-like events

T2K Run 1-9c Preliminary

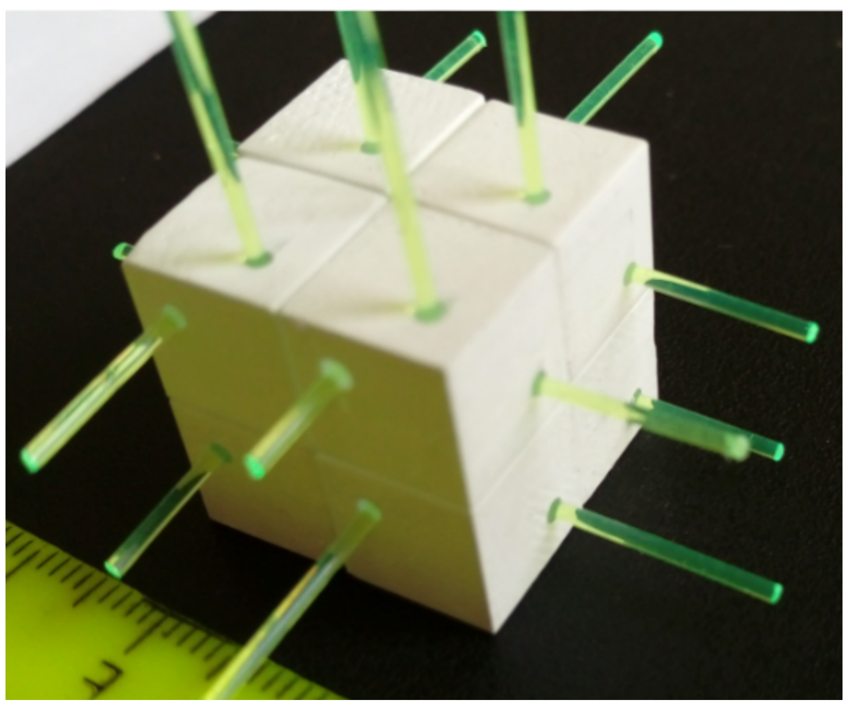


T2K Run 1-9c Preliminary

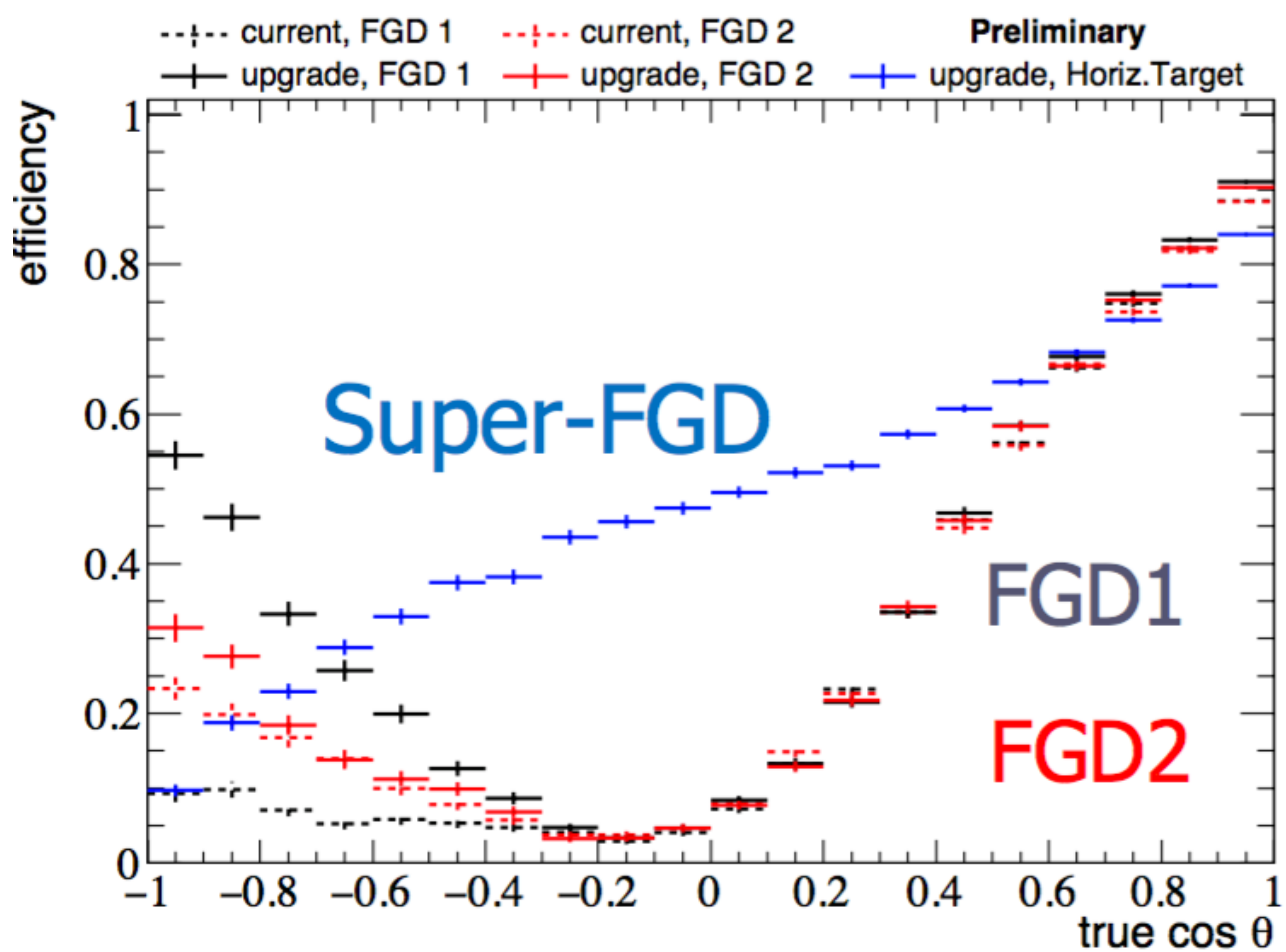


T2K PHASE-II

Super-FGD



1 cm^3 cubes
3 fibers per cube



T2K COLLABORATION