Recent Results from T2K

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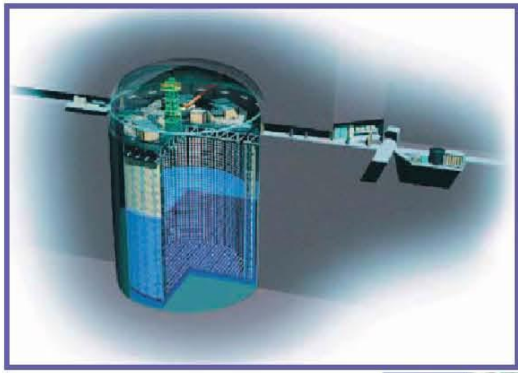
on behalf of the T2K Collaboration

ICNFP2017
Kolymbari, Crete
August 26, ‘17

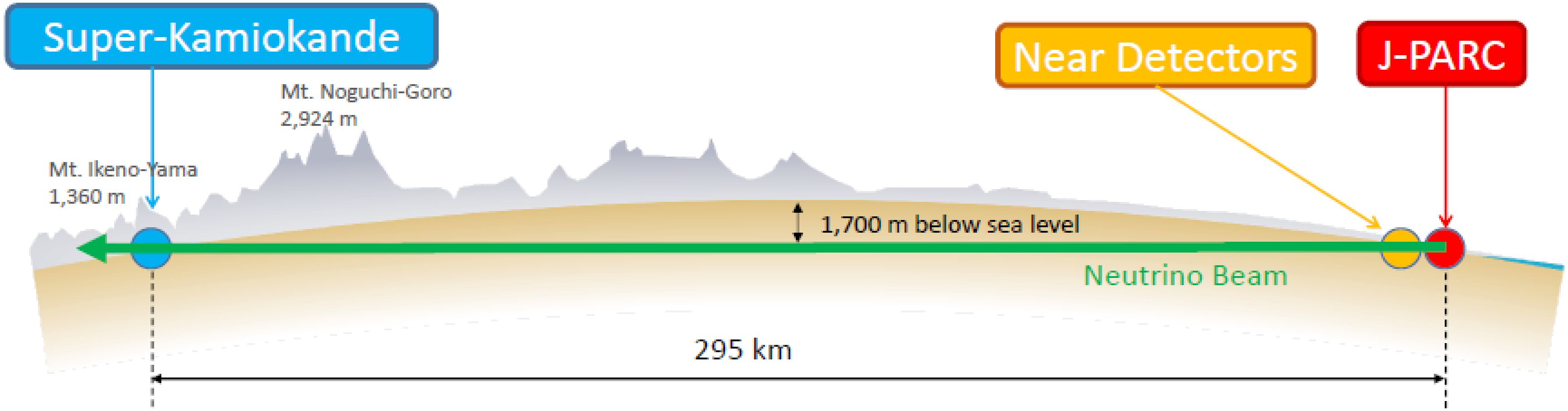
The T2K Experiment



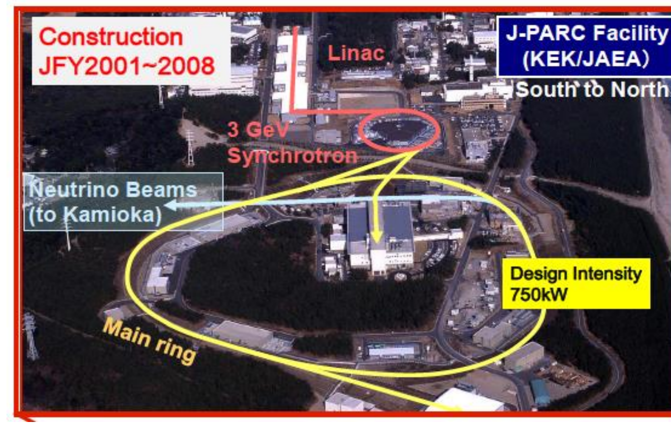
Super-Kamiokande
(ICRR, Univ. Tokyo)

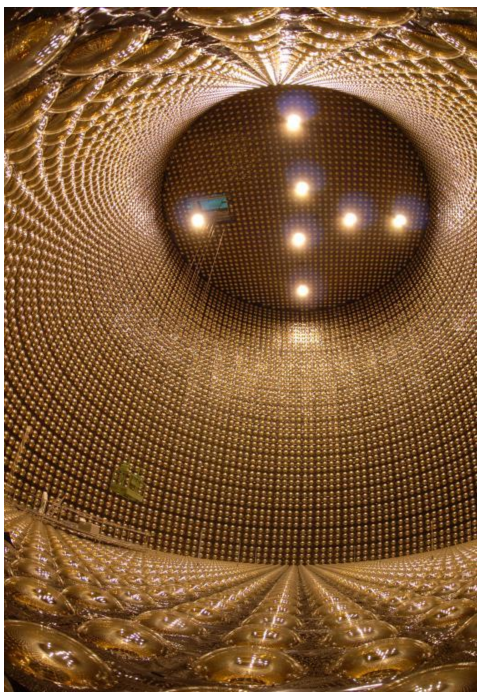
J-PARC Main Ring
(KEK-JAEA, Tokai)

11 countries
~500 members

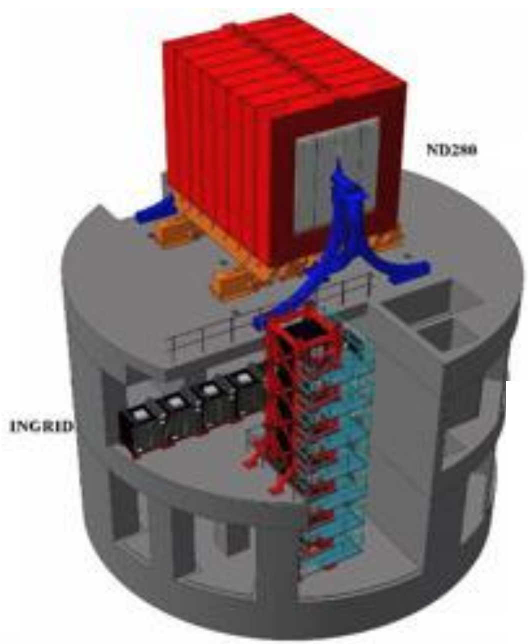


JPARC - accelerator complex



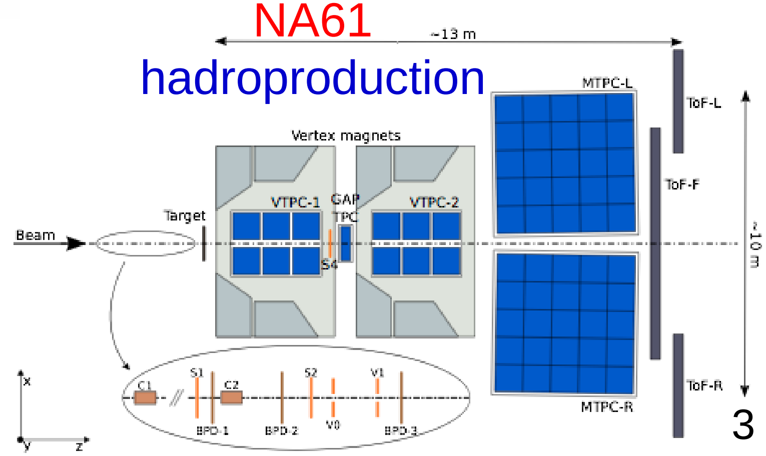


far detector
Super–Kamiokande

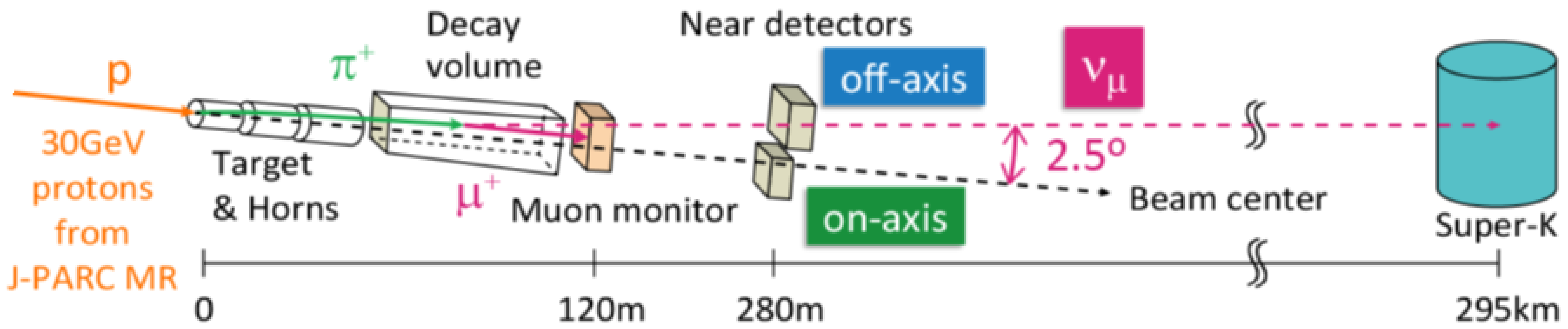


near detectors
Off-axis: ND280
On-axis: INGRID

NA61
hadroproduction



Neutrino Source at J-PARC



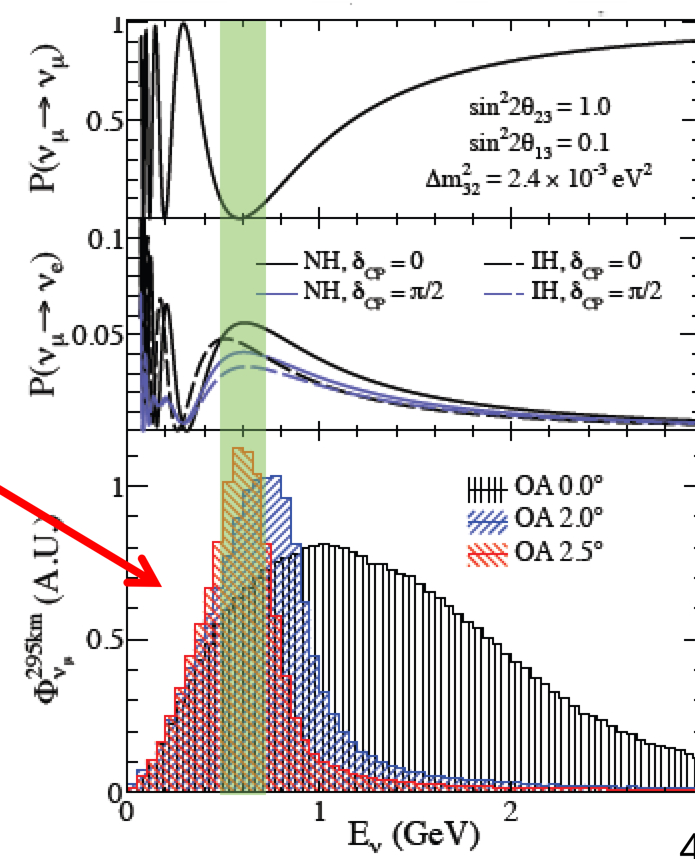
- 30 GeV protons on a 90 cm long graphite rod
- ν beam created in the decay in flight of π / K / μ

- 2.5^0 off-axis neutrino beam

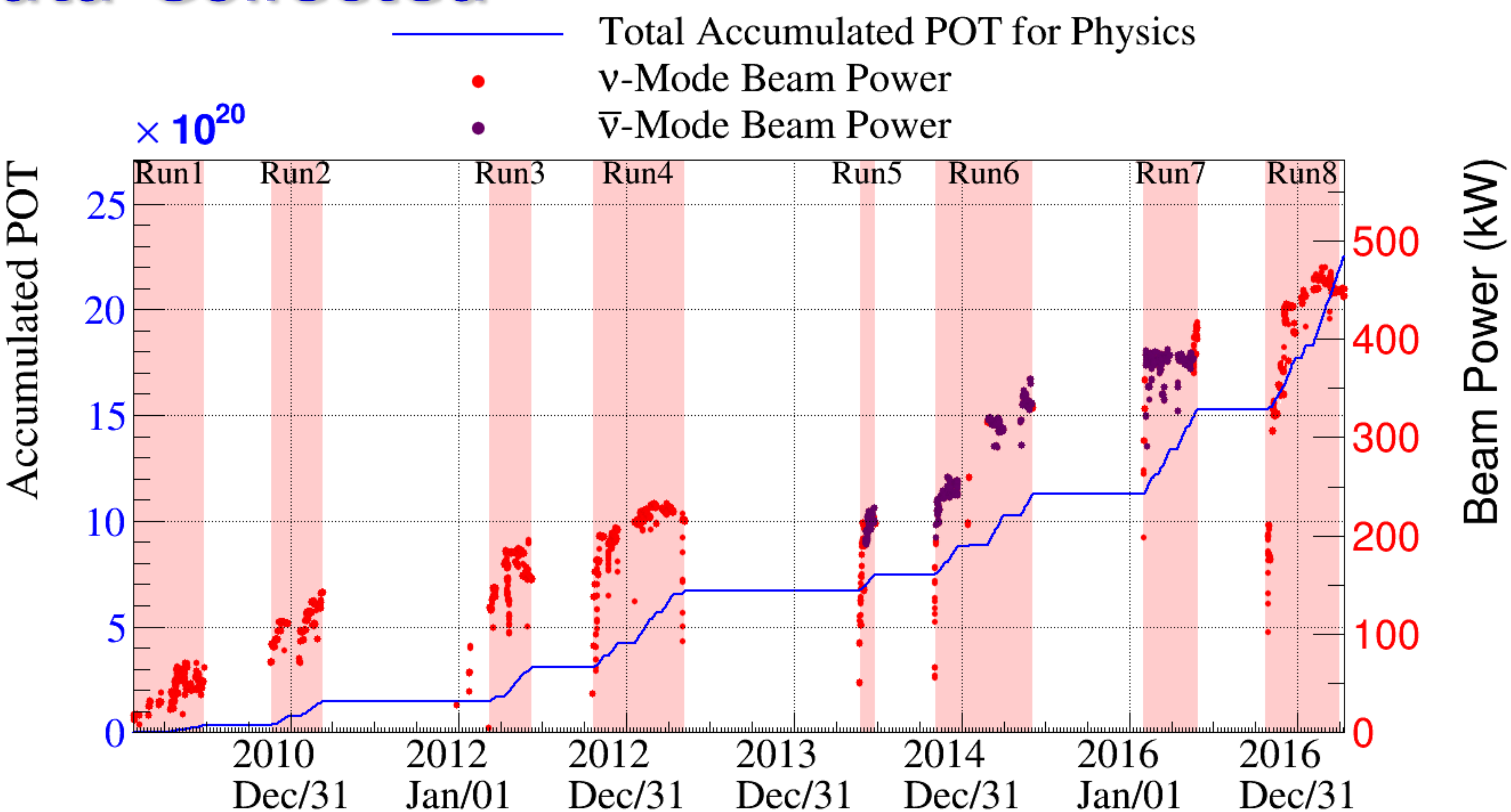
- very narrow energy spectrum
- neutrino beam energy "tuned" to oscillation maximum
- reduced high-energy tails
- E_ν almost independent of parent pion energy

- neutrino beam predictions data driven (NA61 hadro-production measurements)

- Horn focusing cancels partially the p_T dependence of the parent mesons



Data Collected



Reached beam power of 475 kW

Accumulated POT (protons on target) by April 2017

22.3×10^{20} in total

14.7×10^{20} in ν mode

7.6×10^{20} in $\bar{\nu}$ mode

3 Flavor Neutrino Mixing

Flavor eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS}\left(\vartheta_{12}, \vartheta_{23}, \vartheta_{13}, \delta_{CP}\right) \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass eigenstates

Pontecorvo-Maki-Nakagawa-Sakata Matrix (CKM matrix of lepton sector)

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{+i\delta_{CP}} & 0 & \cos\theta_{13} \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{-i\alpha/2} & 0 \\ 0 & 0 & e^{-i\beta/2} \end{pmatrix}$$

$\theta_{23} \sim 45^0$
SuperK (atm. ν)
K2K / Minos
T2K

$\theta_{13} \sim 8^0$
Daya Bay
Reno
T2K

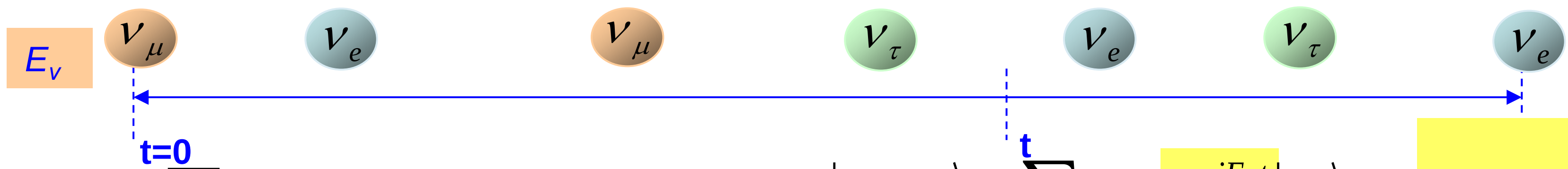
$\theta_{12} \sim 34^0$
solar ν
KamLAND

Majorana phases
neutrinoless
double-beta
decay

$$|U|_{3\sigma}^{\rm LID} = \begin{pmatrix} 0.798 \to 0.843 & 0.517 \to 0.584 & 0.137 \to 0.158 \\ 0.232 \to 0.520 & 0.445 \to 0.697 & 0.617 \to 0.789 \\ 0.249 \to 0.529 & 0.462 \to 0.708 & 0.597 \to 0.773 \end{pmatrix}$$

NuFIT 2016

Neutrino Oscillations and Time Evolution



$$|\nu_\alpha(t=0)\rangle = \sum_i U_{\alpha i}|\nu_i\rangle \quad \dashrightarrow \quad |\nu_\alpha(t)\rangle = \sum_i U_{\alpha i}\, e^{-iE_i t}|\nu_i\rangle$$

$$E_i \approx p + \frac{m_i^2}{2p}$$

$$P_{\alpha\to\beta} = \left|\langle \nu_\beta(t)|\nu_\alpha(t=0)\rangle\right|^2 = \sum_i |U_{\alpha i}\, U_{\beta i}|^2 + \sum_{i\neq j} U_{\alpha i}\, U^*_{\beta i}\, U^*_{\alpha i}\, U_{\beta i}\, e^{-i(E_i - E_j)t}$$

$$\Delta m_{ij}^2 = m_i^2 - m_j^2$$

$$P_{\mu\to e} = 4C_{13}^{\ 2} S_{13}^{\ 2} S_{23}^{\ 2} \sin^2\frac{\Delta m_{31}^2 L}{4E}\left(1+\frac{2a}{\Delta m_{31}^2}(1-2S_{13}^2)\right)$$ leading, θ_{13} driven

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

$$+8C_{13}^{\ 2} S_{12}S_{13}S_{23}(C_{12}C_{23}\cos\delta - S_{12}S_{13}S_{23})\cos\frac{\Delta m_{32}^2 L}{4E}\sin\frac{\Delta m_{31}^2 L}{4E}\sin\frac{\Delta m_{21}^2 L}{4E}$$ CPC

$$-8C_{13}^{\ 2} C_{12}C_{23}S_{12}S_{13}S_{23}\sin\delta\sin\frac{\Delta m_{32}^2 L}{4E}\sin\frac{\Delta m_{31}^2 L}{4E}\sin\frac{\Delta m_{21}^2 L}{4E}$$ CPV

$$+4S_{12}^{\ 2} C_{13}^{\ 2}(C_{12}^{\ 2} C_{23}^{\ 2} + S_{12}^{\ 2} S_{23}^{\ 2} S_{13}^{\ 2} - 2C_{12}C_{23}S_{12}S_{23}S_{13}\cos\delta)\sin^2\frac{\Delta m_{21}^2 L}{4E}$$ solar

$$-8C_{13}^{\ 2} S_{13}^{\ 2} S_{23}^{\ 2}(1-2S_{13}^{\ 2})\frac{aL}{4E}\cos\frac{\Delta m_{32}^2 L}{4E}\sin\frac{\Delta m_{31}^2 L}{4E}$$ matter effects

6 independent parameters govern oscillation

θ_{12}, θ_{23}, θ_{13}, δ_{cp}, (Δm^2_{12}), Δm^2_{23}, Δm^2_{13}

ν_e Appearance and Oscillation Parameters

$\sin^2 2\theta_{13}$ and $\sin^2\theta_{23}$

leading terms

"octant" dependence, whether $\theta_{23} > 45^0$, $\theta_{23} = 45^0$, or $\theta_{23} < 45^0$

δ_{CP}: +- 27% effect at T2K for $\theta_{23} = 45^0$

δ_{CP} = ~–π/2: enhances $P(\nu_\mu \to \nu_e)$

suppresses $P(\bar{\nu}_\mu \to \bar{\nu}_e)$

δ_{CP} = ~+π/2: suppresses $P(\nu_\mu \to \nu_e)$

enhances $P(\bar{\nu}_\mu \to \bar{\nu}_e)$

mass hierarchy: +-10% effect at T2K

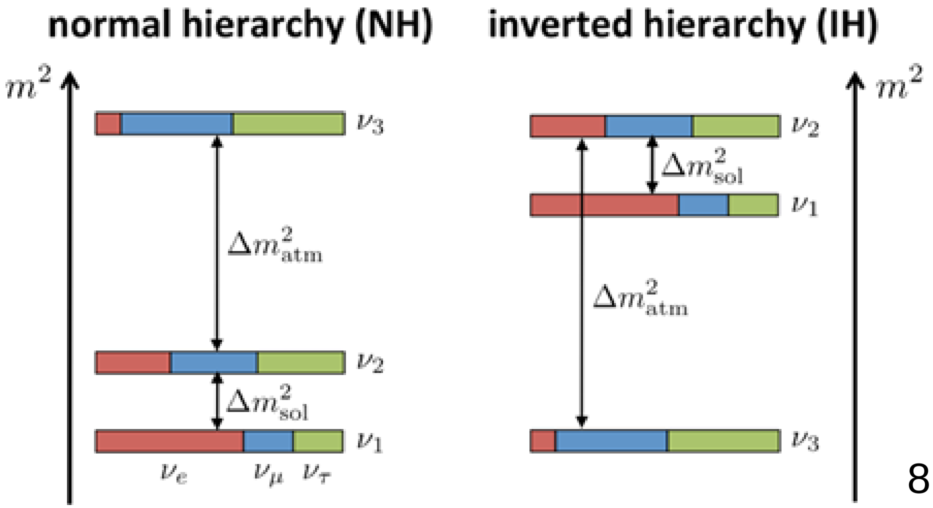
normal: enhances $P(\nu_\mu \to \nu_e)$

suppresses $P(\bar{\nu}_\mu \to \bar{\nu}_e)$

inverted: suppresses $P(\nu_\mu \to \nu_e)$

enhances $P(\bar{\nu}_\mu \to \bar{\nu}_e)$

mass ordering



Neutrino Oscillation Analysis Overview

$$N_{FD} \sim \Phi_{FD}\left(E_\nu\right)\cdot\sigma_{FD}\left(E_\nu\right)\cdot\varepsilon_{FD}\cdot P\left(\nu_\mu \rightarrow \nu_e\right)$$

Observed rate of ν_μ and ν_e constrains the oscillation probability *P*.
It depends on:

Neutrino flux prediction	Neutrino cross-section model	Far Detector selection & efficiency

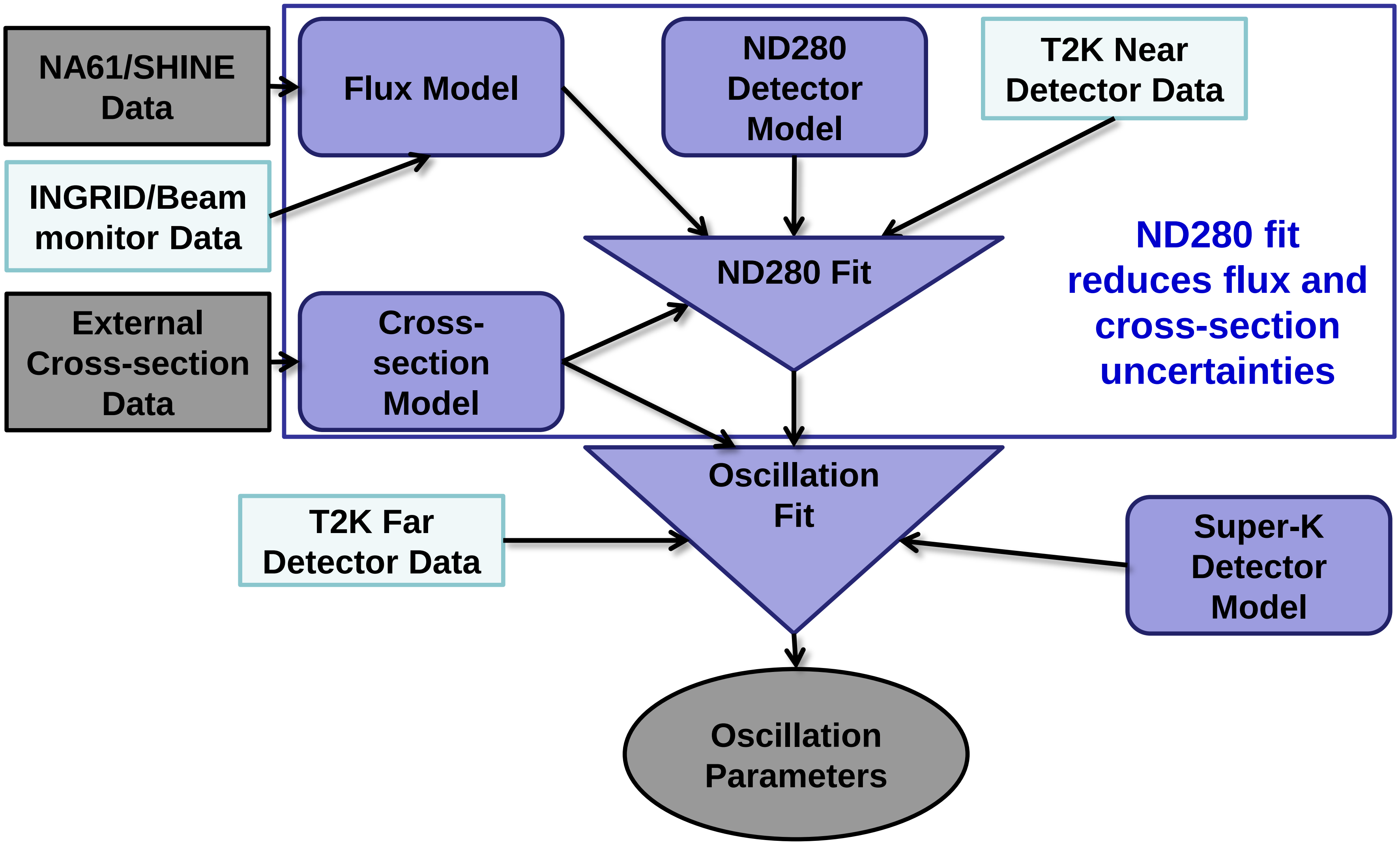
Reduce the error of the ν_μ rate with the near detector measurements.

$$N_{ND} \sim \Phi_{ND}\left(E_\nu\right)\cdot\sigma_{ND}\left(E_\nu\right)\cdot\varepsilon_{ND}$$

Neutrino flux prediction	Neutrino cross-section model	Near Detector selection & efficiency

Oscillation Analysis Strategy

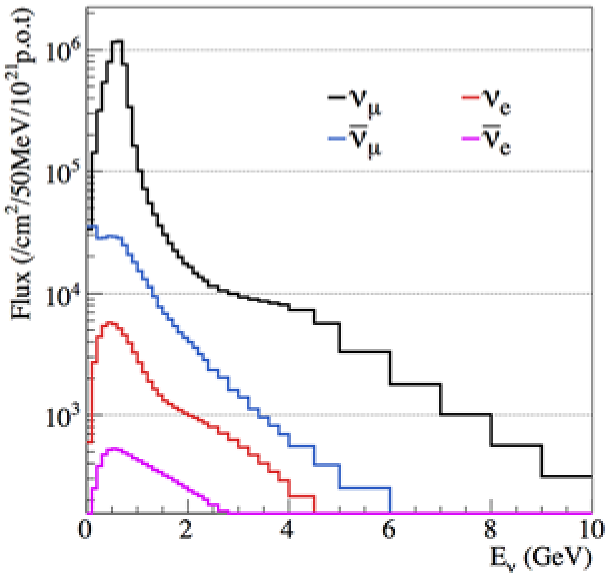
data driven



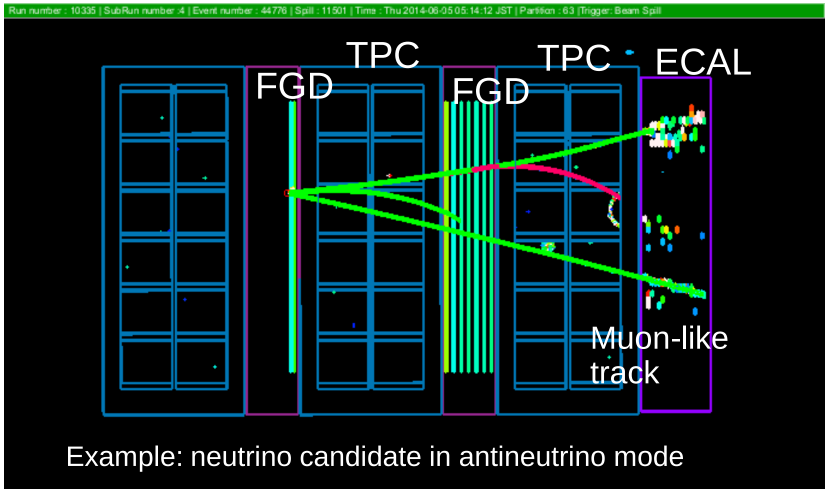
In the latest analyses, the ν_μ, $\bar{\nu}_\mu$, ν_e, and $\bar{\nu}_e$ samples are fit simultaneously to maximize the sensitivity to the oscillation parameters

Sources of Systematic Uncertainties

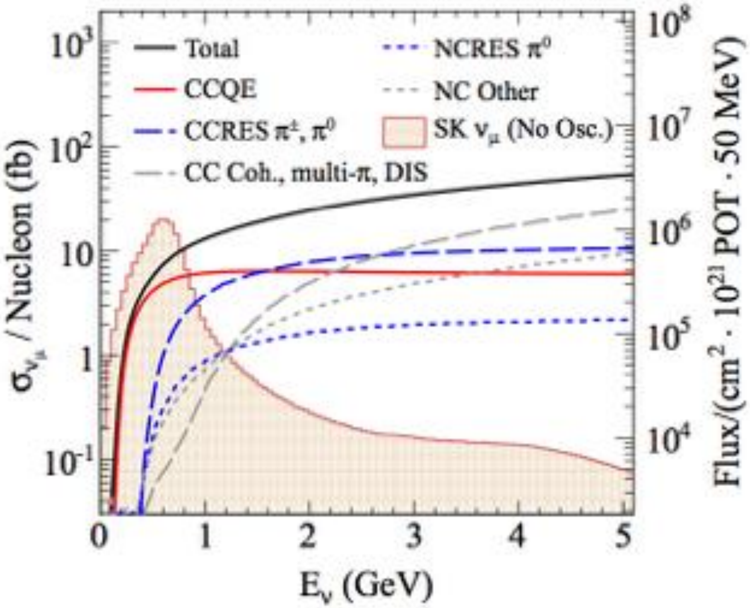
Neutrino flux



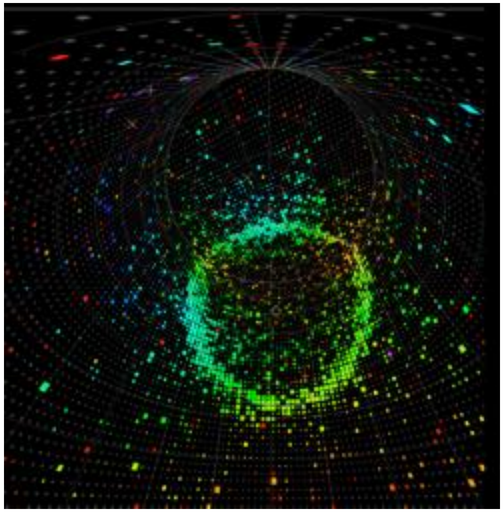
Near Detector response



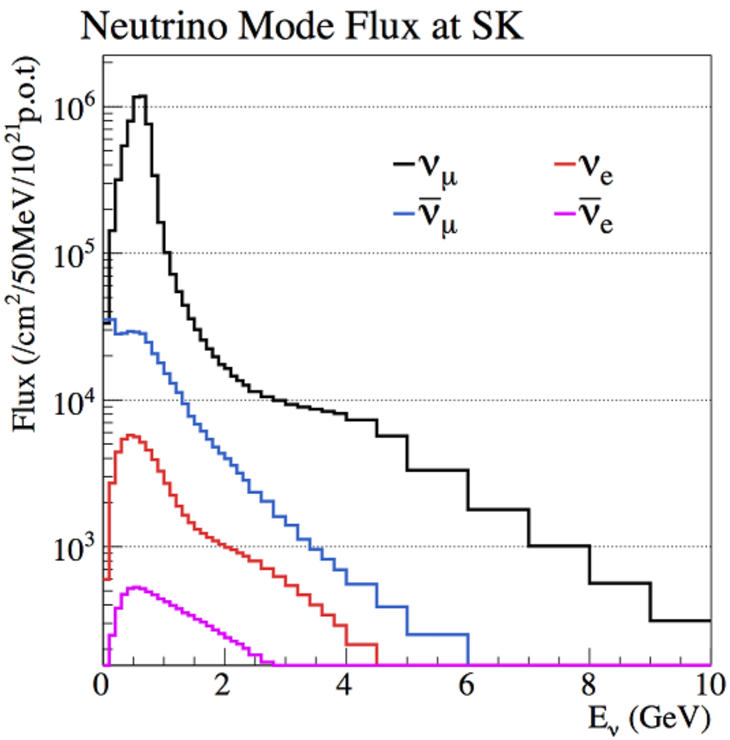
Neutrino interactions

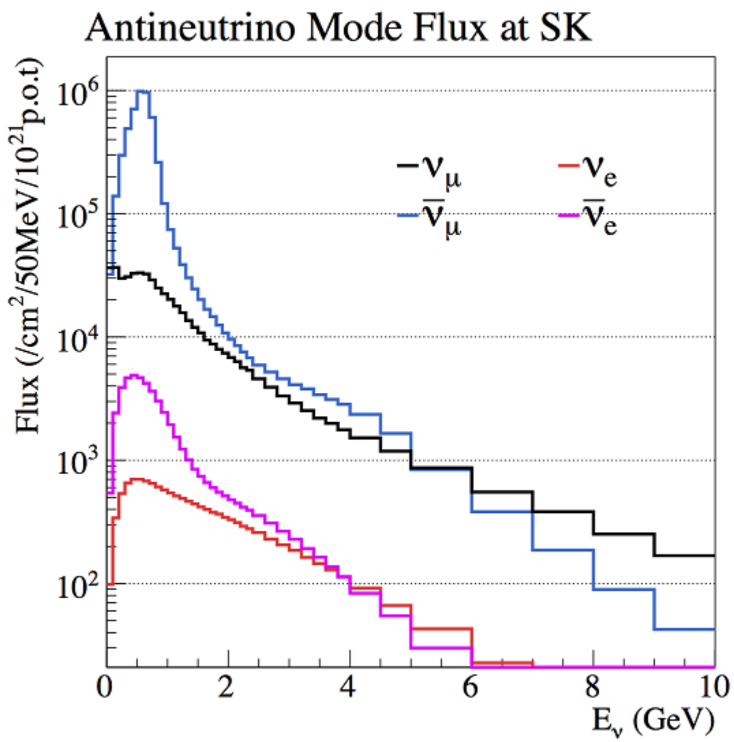


Far Detector response



Neutrino and Antineutrino Flux at SK





Mostly but not only pions are produced in the target

Other ν parents – K as well as μ produce a background flux coming from:

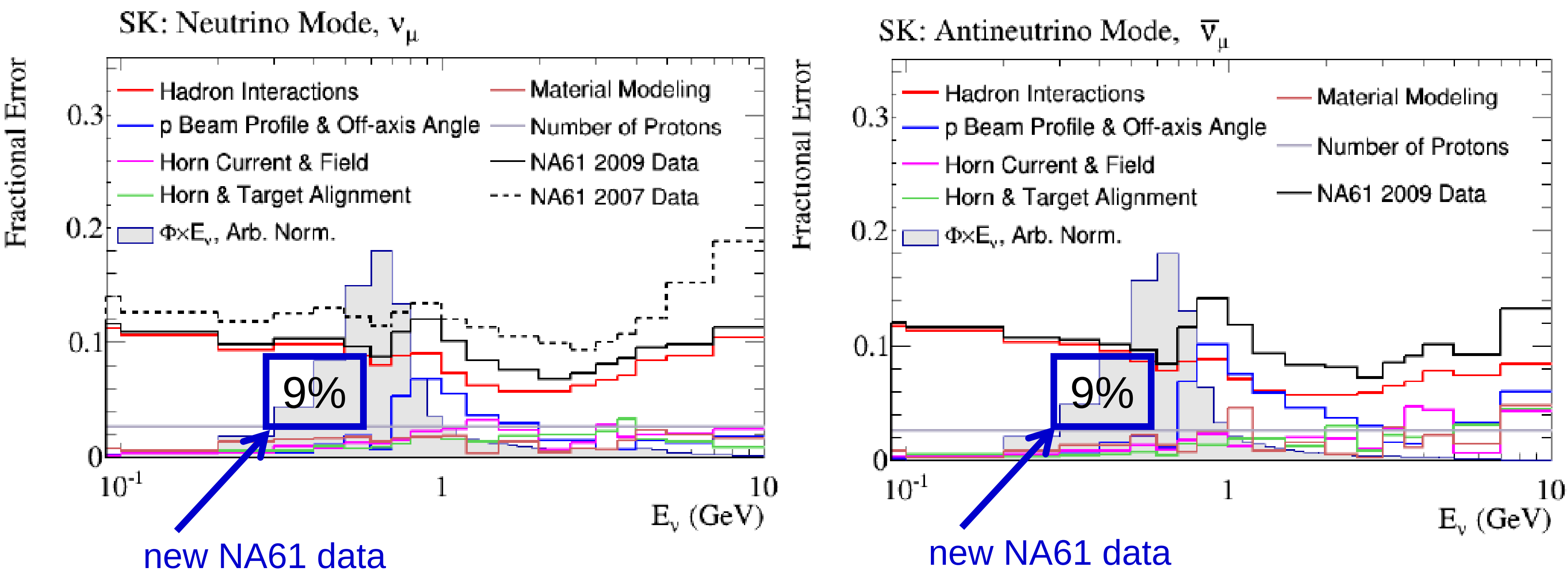
- intrinsic ν_e component around 0.5% near the peak energy
  it is an important background for the appearance analysis
- "wrong sign neutrinos" in antineutrino mode
  increase in event rate due to lower $\overline{\nu}$ cross-section

Absolute Neutrino Flux Uncertainties

Beamline related uncertainties
proton beam profile
off-axis angle
horn current and field

Hadron interaction model uncertainties
NA61 uncertainties
re-interactions
secondary hadron production

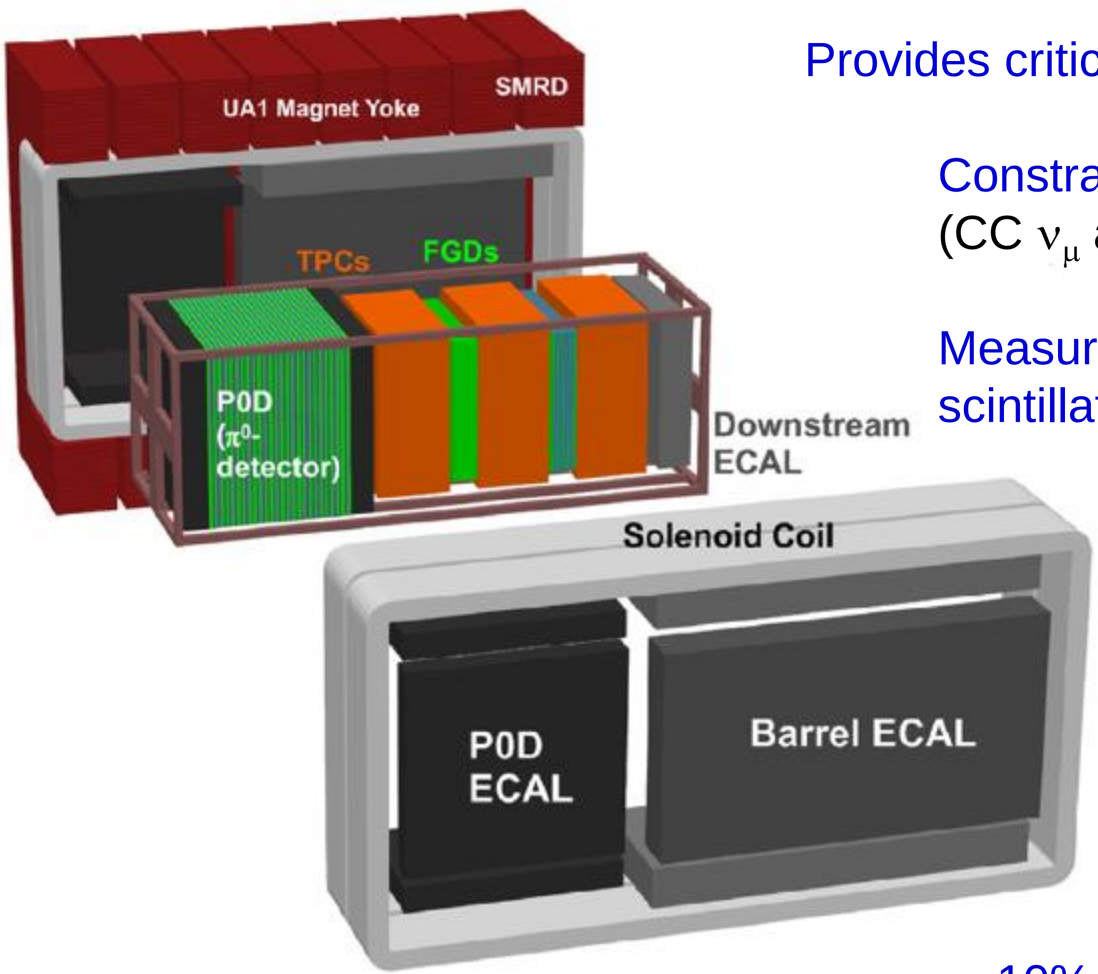
At T2K peak energy, flux uncertainty has decreased to 9%
(before ND280 fit constraint)



Dominant flux uncertainties stem from hadron interactions

Replica target data from NA61/SHINE is being incorporated in the T2K flux prediction
→ reduce systematics further (< 5% ?)

The ND280 Near Detector



Excellent performance
Operated since 2010

Provides critical input for oscillation measurements

Constrains neutrino flux before oscillations
(CC ν_μ and $\bar{\nu}_\mu$ data)

Measures neutrino interactions on scintillator (CH) and water targets

0.2 T magnetic field

Plastic scintillator detectors (tracking, calorimetry)

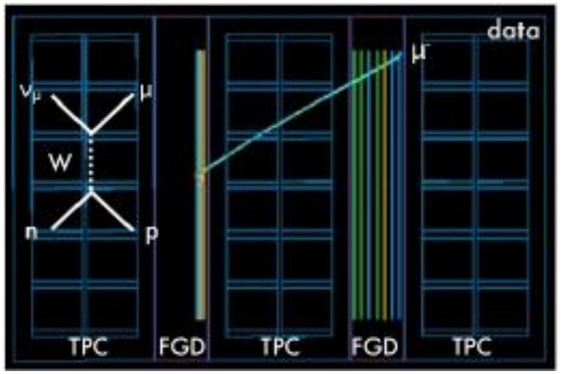
Time Projection Chambers better than 10% dE/dx resolution

10% momentum resolution at 1 GeV/c

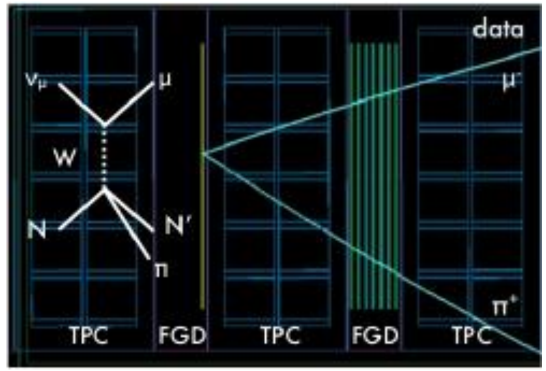
Gallery of Events in ND280 (FGD1)

ν mode

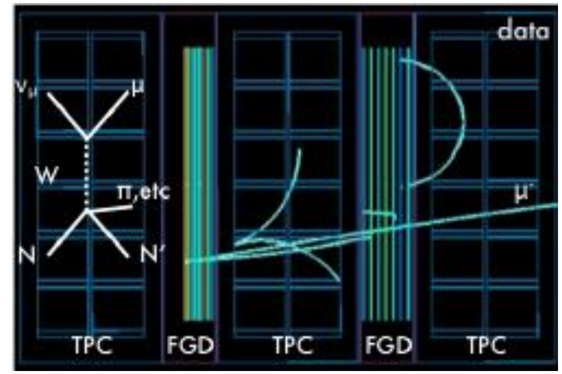
ν_μ CC0π



ν_μ CC1π^+

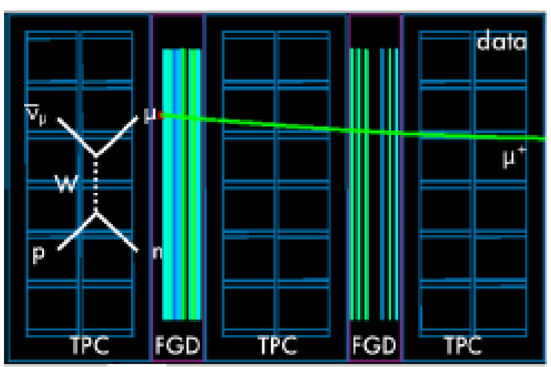


ν_μ CC other

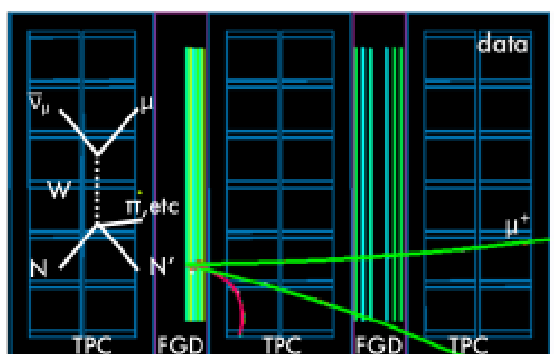


$\bar{\nu}$ mode

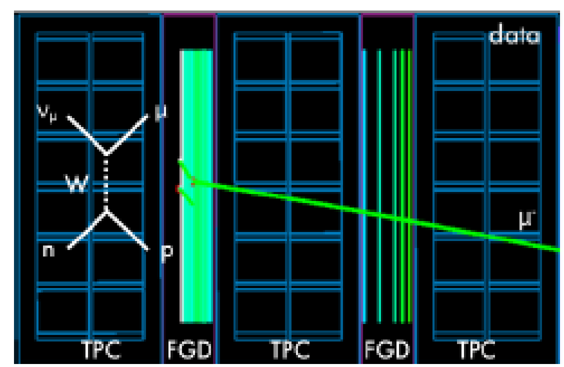
$\bar{\nu}_\mu$ CC 1-track



$\bar{\nu}_\mu$ CC N-track



ν_μ CC 1-track

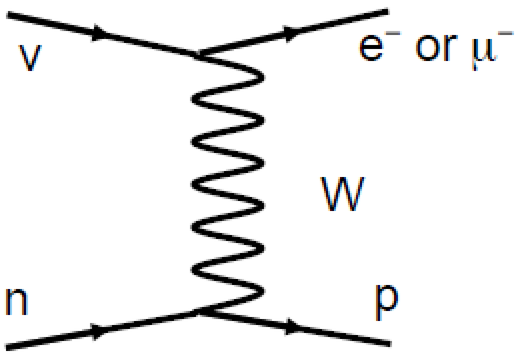


Neutrino Interactions

Oscillation probability depends on neutrino energy.

In T2K energy range, dominant process is Charged-Current Quasi-Elastic

CCQE

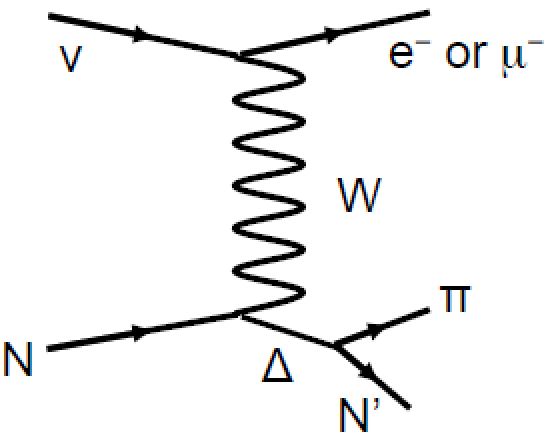


Neutrino energy from measured lepton momentum and angle

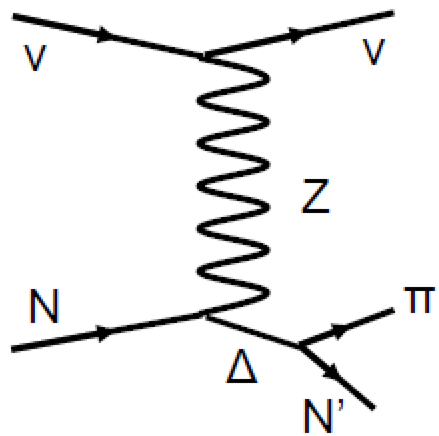
$$E_\nu^{QE} = \frac{m_p^2 - m'^2_n - m_\mu^2 + 2m'_n E_\mu}{2(m'_n - E_\mu + p_\mu \cos\theta_\mu)}$$

2-body kinematics and assumes the target nucleon is at rest

CC1π



NC1π



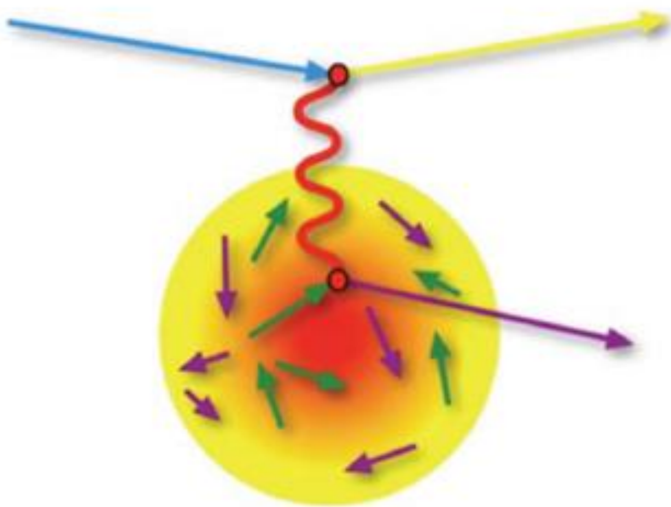
Additional significant processes:

CCQE-like multi-nucleon interaction

Charged-current single π production (CC1π) (resonant production)

Neutral-current single π production (NC1π)

Don’t Forget the Nucleus!

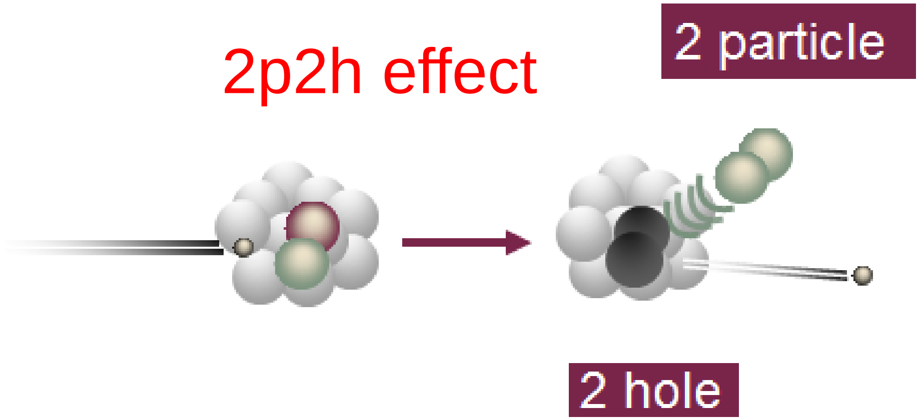


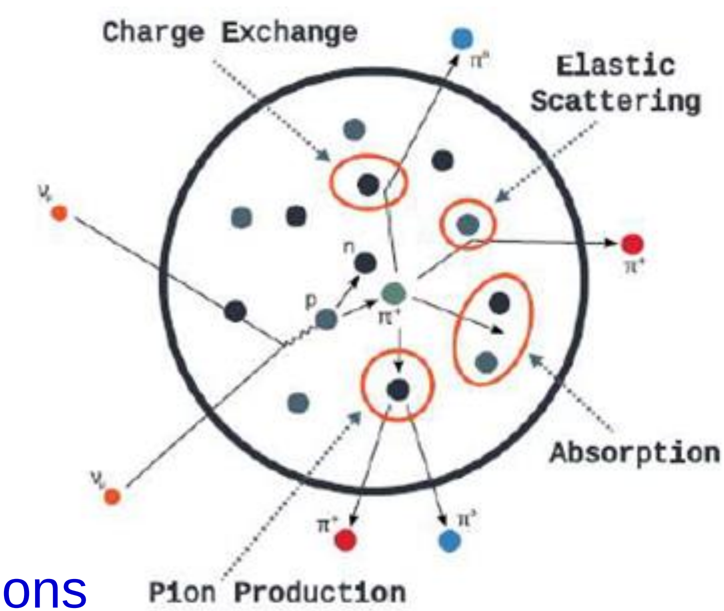
short range correlations and
medium range correlations
scatters off a pair of correlated nucleons – 2p2h effect

long range correlations – RPA effect

final state interactions
created particles have to work their way out of the nucleus

2p2h effect



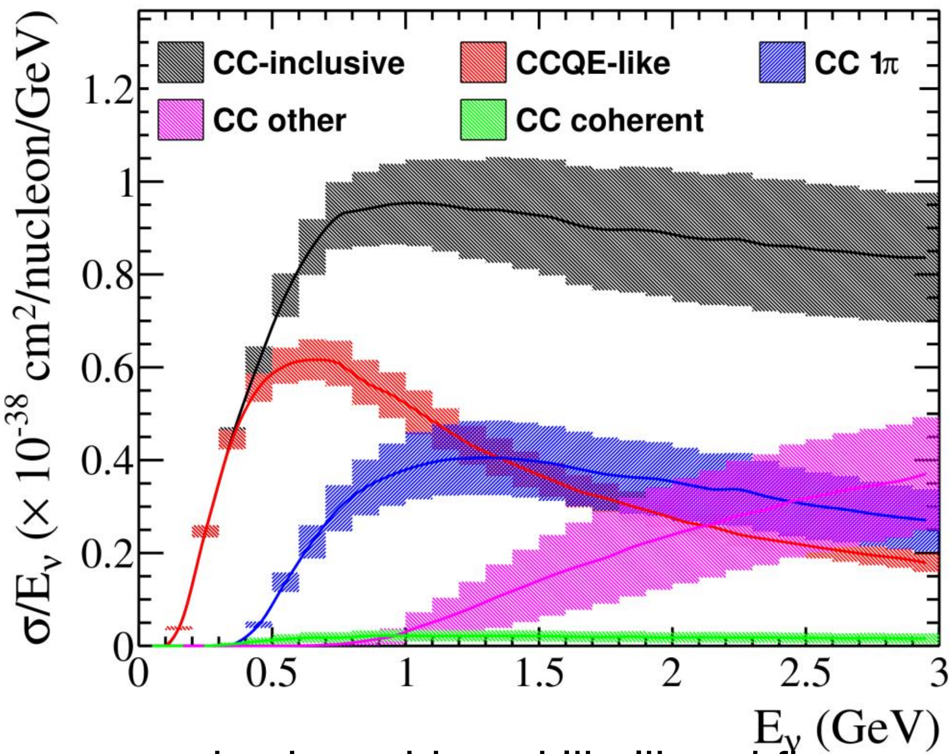


big source of uncertainties in neutrino interactions
ND280 measurements try to improve modelling of all these effects

Improved Neutrino Interaction Model

Most recent NEUT generator tuned to external data (MiniBooNE and MINERνA)
- several improvements introduced in 2017 analysis
- interactions in ND280 H_20 target included

decomposition of ν-N cross-section



Improved CCQE description:
- nuclear effects (Fermi Gas Model)
- nuclear correlations (MEC – 2p2h)
- long range correlations (RPA)
- final state interactions (FSI)

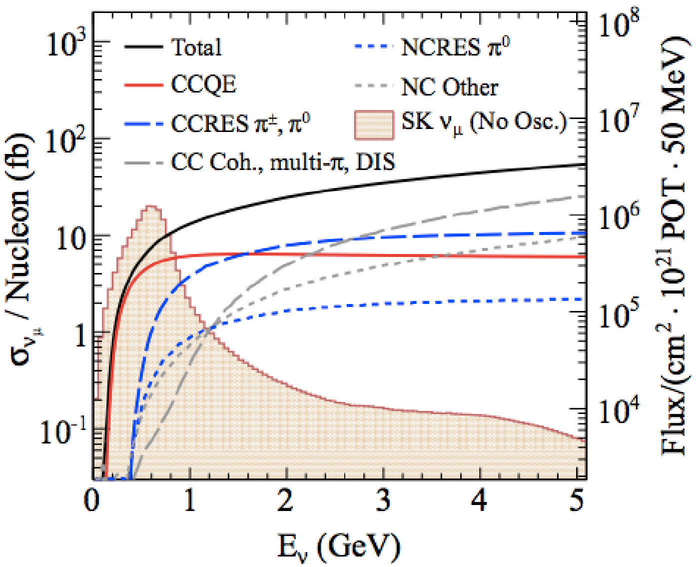
Improved resonant pion production model with tuning to H and D data

Tensions with some data sets remain. Cross-section model uncertainties come from underlying model parameters and normalization.

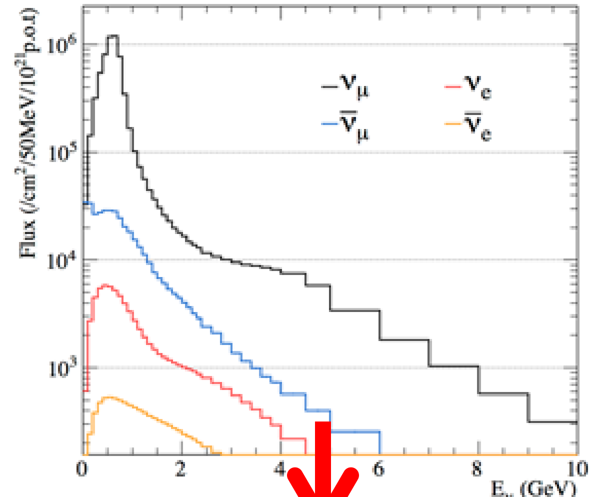
Expected number of events at the far detector tuned using a binned likelihood fit to the ND280 data (in bins of p_μ and θ_μ) taking into account
- variations in the flux model parameters
- cross-section model parameters
- ND280 detector uncertainties

ND280 Constraints for Far Detector

ν–N Interaction Model

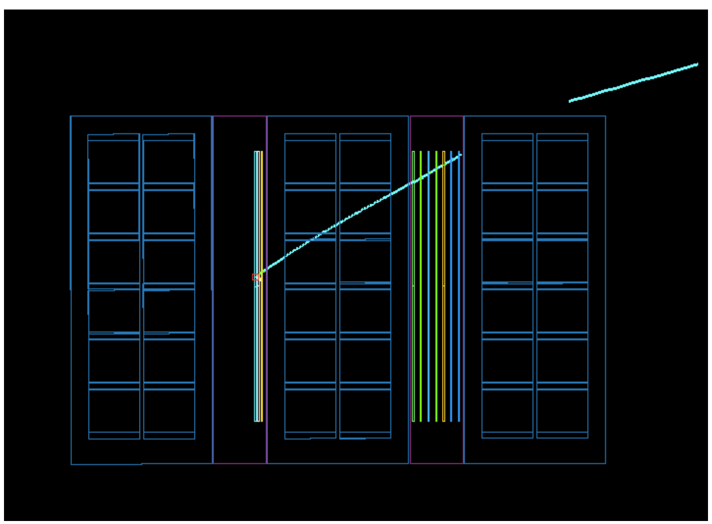


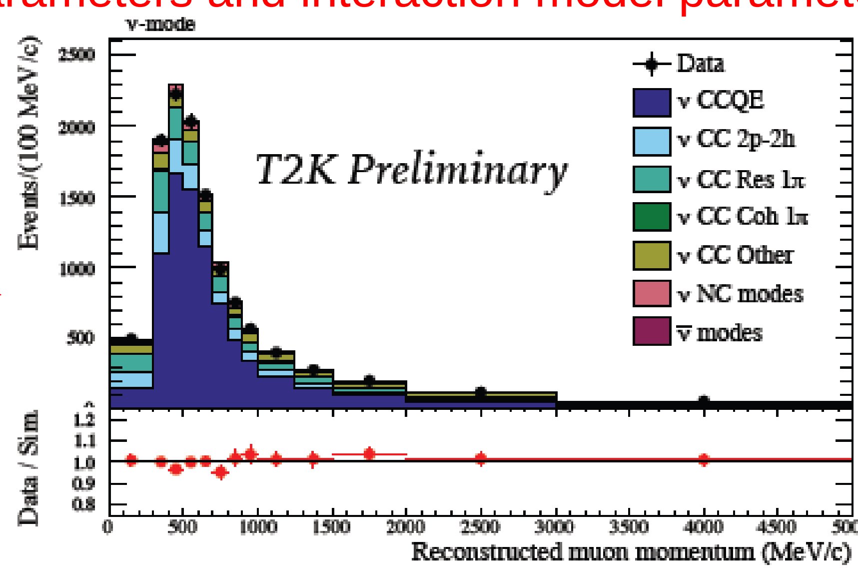
Flux Model



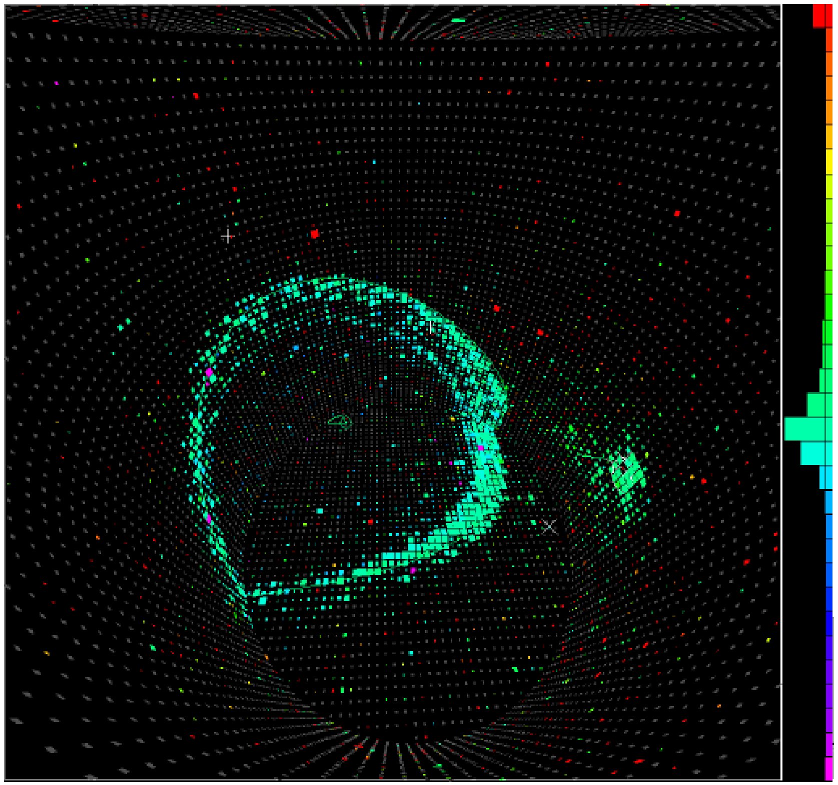
Fit to ND280 data constrains neutrino flux parameters and interaction model parameters

ND280 Data

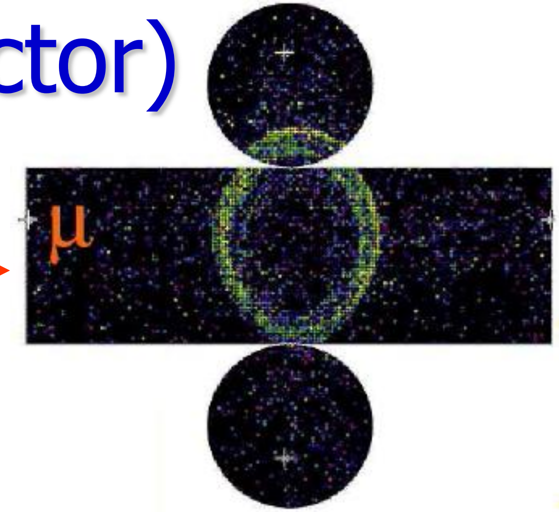


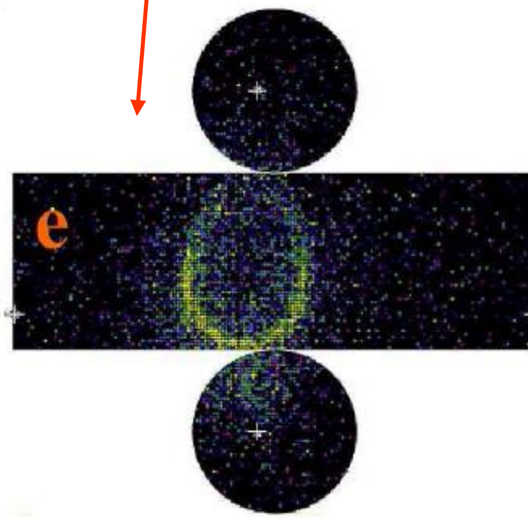


T2K Typical Events (Far Detector)

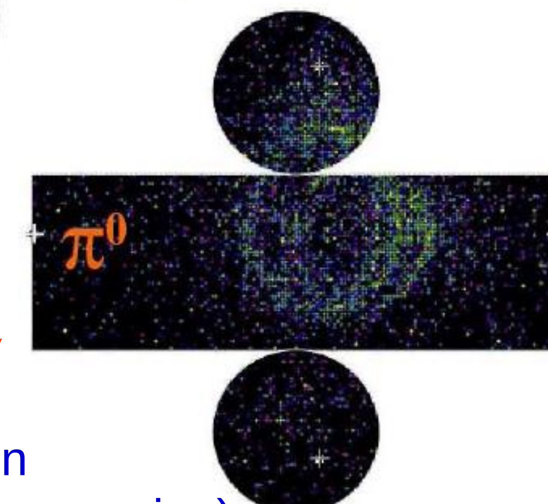


good $\mu - e$ separation





simulated event display (FD response)



background for ν_e appearance:

- intrinsic ν_e component in initial beam
- merged π^0 rings from NC interactions

good π^0 rejection
(2 rings from γ conversion)

New Far Detector Reconstruction Algorithm

Previous T2K analyses have used the event reconstruction algorithm APFit

2017 event reconstruction at Super-K updated to use the fiTQun algorithm

- fiTQun uses a charge and time likelihood for a given ring(s) hypotheses
- Maximizes likelihood for each event
- fiTQun previously used in T2K analyses for the rejection of π^0 from electron neutrino candidates

Five samples are selected

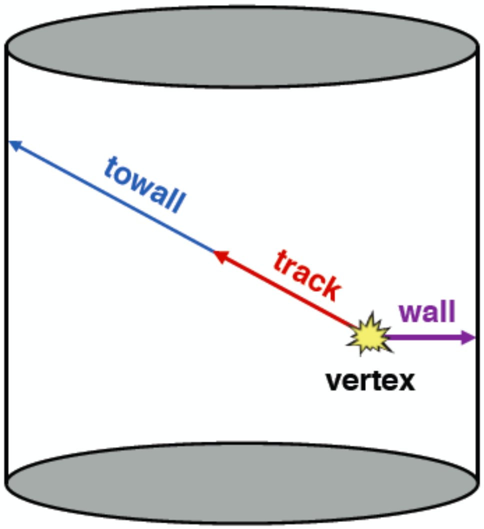
Neutrino-mode (forward horn current FHC)

- (CCQE) 1 Muon-like Ring, ≤1 decay electron
- (CCQE) 1 Electron-like Ring, 0 decay electrons
- (CC1π) 1 Electron-like Ring, 1 decay electron

Antineutrino-mode (reverse horn current RHC)

- (CCQE) 1 Muon-like Ring, ≤1 decay electron
- (CCQE) 1 Electron-like Ring, 0 decay electrons

Increasing the Far Detector Fiducial Volume



Previous APFit based fiducial volume

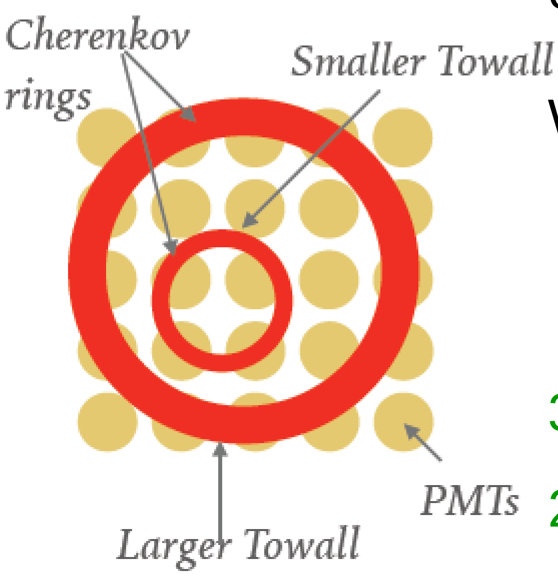
reconstructed vertex > 2 m from the detector wall

New fiTQun, the fiducial volume cut is re-optimized

distance of vertex from wall (Wall)

distance to the wall along the particle trajectory (Towall)

Optimize cuts accounting for statistical and systematic errors



With new fiTQun reconstruction and CC1π e-like sample

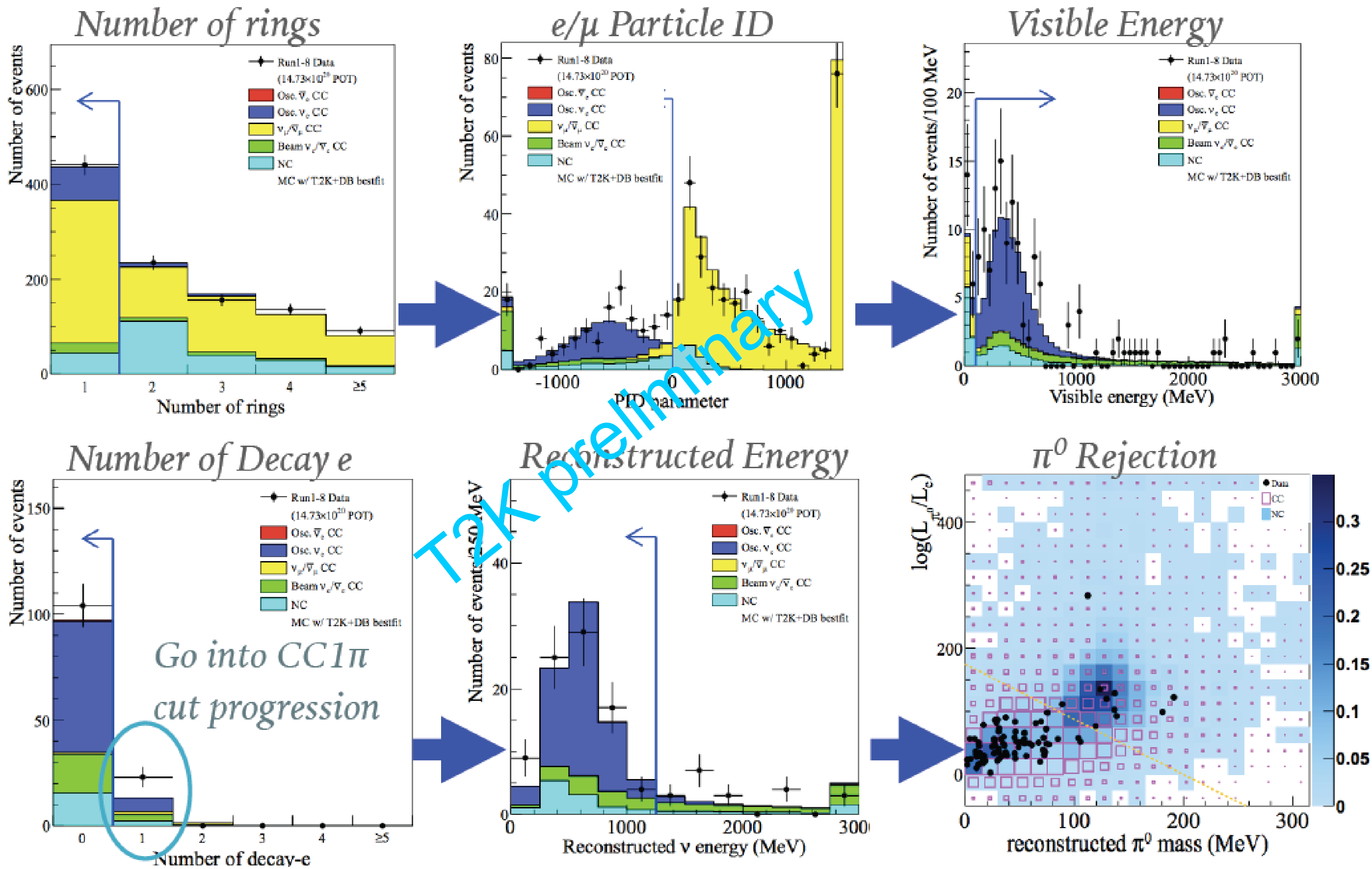
significant statistical improvement for same beam exposure

reduction of NCπ and CCπ backgrounds

30% increase for neutrino mode e-like selection

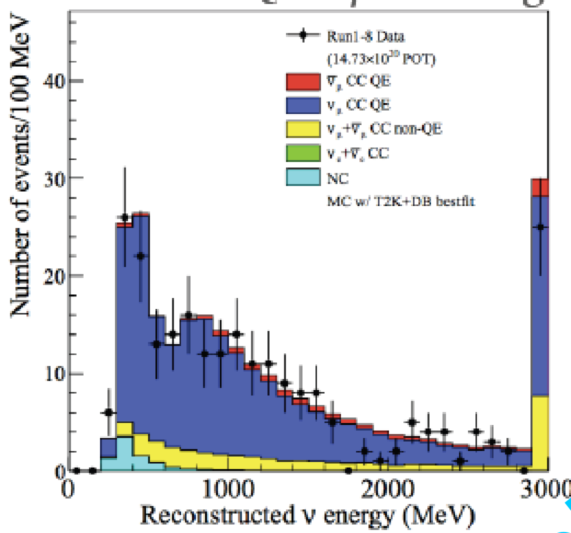
20% increase for anti-neutrino mode e-like sample

ν_e Far Detector Selection

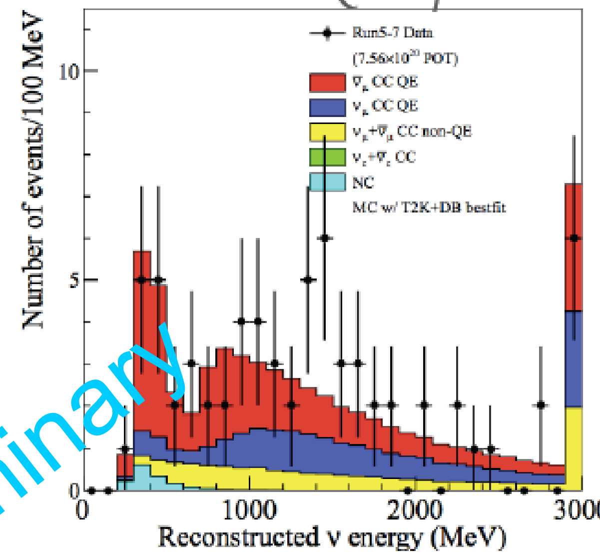


Observed Spectra (Far Detector)

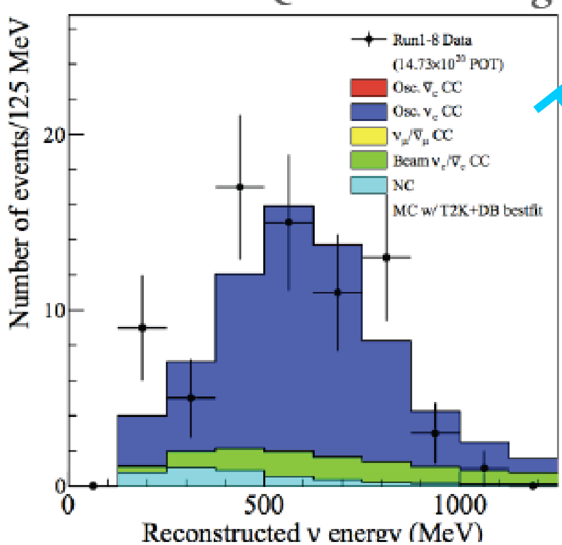
Neutrino CCQE 1 μ-like ring



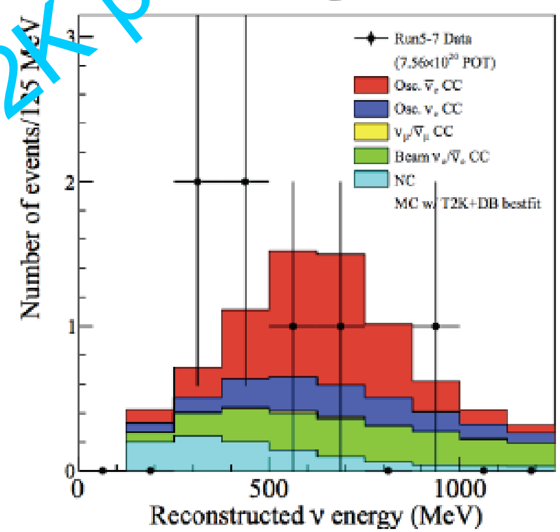
Antineutrino CCQE 1 μ-like ring



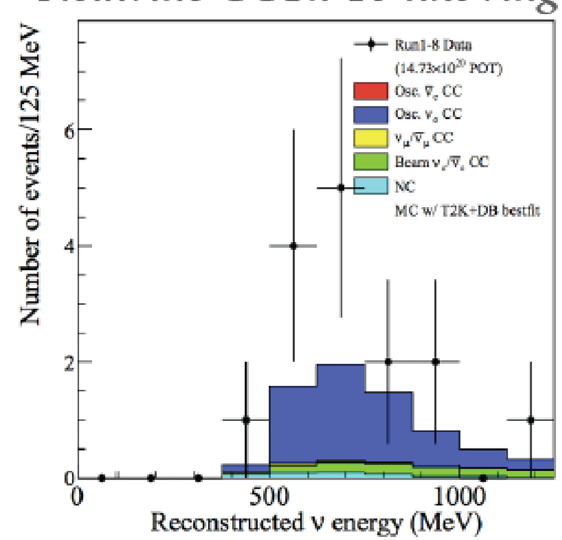
Neutrino CCQE 1 e-like ring



Antineutrino CCQE 1e-like ring



Neutrino CC1π 1e-like ring

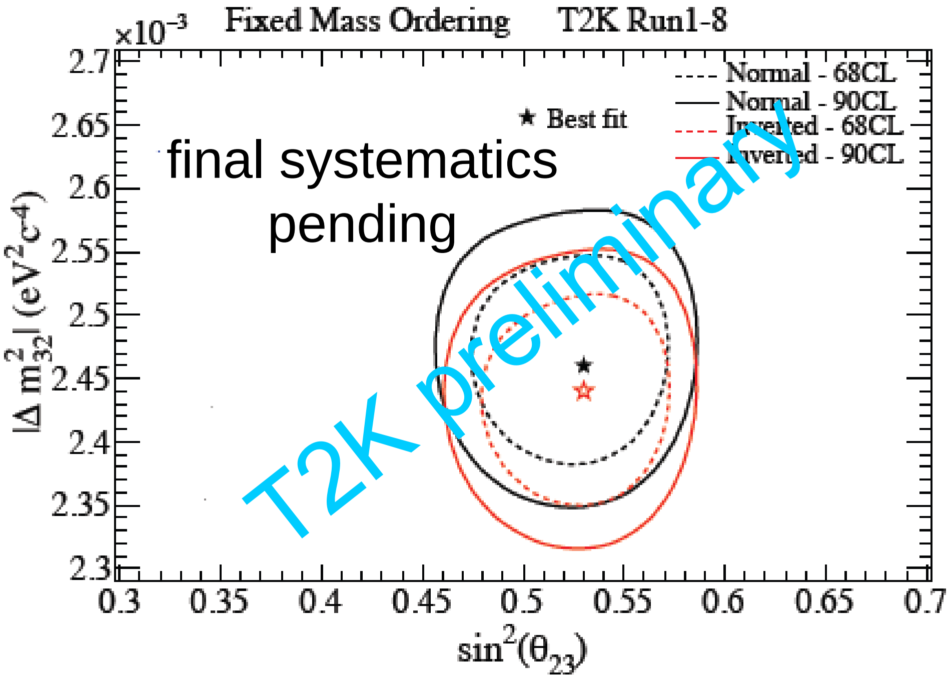


Atmospheric Parameters θ_{23} and $|\Delta m^2_{32}|$

Fit normal and inverted hierarchies separately

Joint analysis with reactor constraint on $\sin^2\theta_{13}$

Final systematic error pending



Posterior probabilities from Bayesian analysis (with reactor constraint)
(assumes equal probabilities for both hierarchy and octant hypothesis)

	$\sin^2\theta_{23} < 0.5$	$\sin^2\theta_{23} > 0.5$	Sum
NH ($\Delta m^2_{32} > 0$)	0.193	0.674	0.868
IH ($\Delta m^2_{32} < 0$)	0.026	0.106	0.132
Sum	0.219	0.781	

T2K preliminary

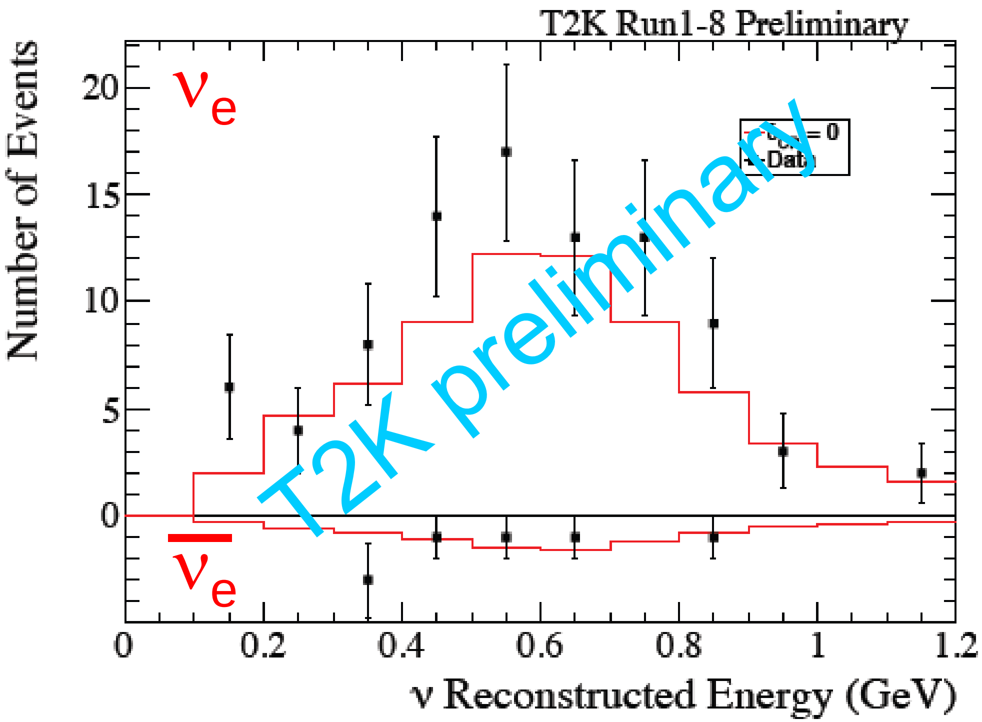
Data prefers normal hierarchy and upper octant

ν_e / $\bar{\nu}_e$ Appearance

Compared to prediction
with δ_{CP} = 0

Excess in neutrino mode

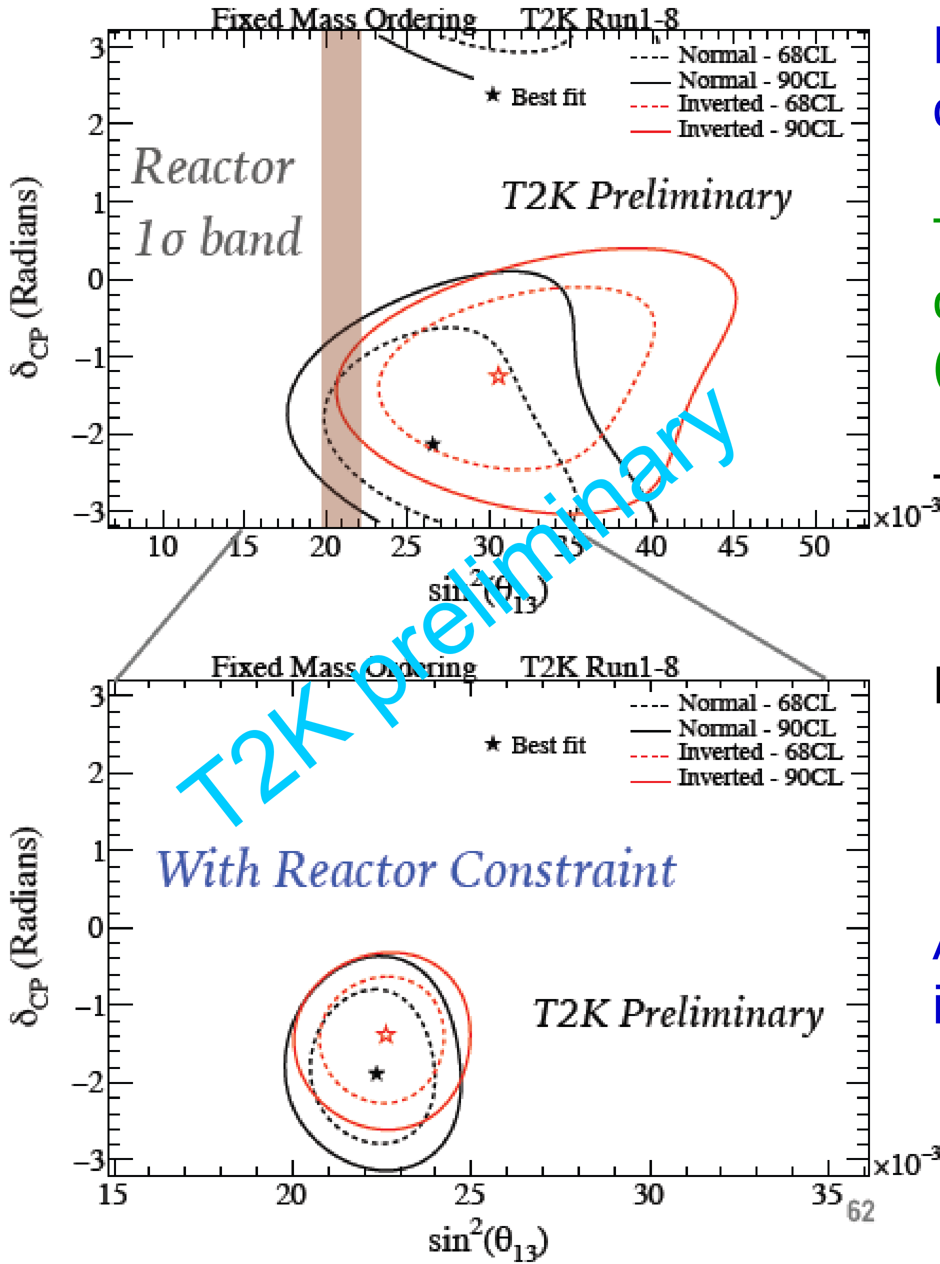
Deficit in antineutrino mode



Sample	Predicted Rates				Observed Rates
	δ_{cp}=-π/2	δ_{cp}=0	δ_{cp}=π/2	δ_{cp}=π	
CCQE 1-Ring e-like FHC	73.5	61.5	49.9	62.0	74
CC1π 1-Ring e-like FHC	6.92	6.01	4.87	5.78	15
CCQE 1-Ring e-like RHC	7.93	9.04	10.04	8.93	7
CCQE 1-Ring μ-like FHC	267.8	267.4	267.7	268.2	240
CCQE 1-Ring μ-like RHC	63.1	62.9	63.1	63.1	68

T2K preliminary

θ_{13} vs δ_{CP}



Fit without the reactor constraint: closed contours in δ_{CP} at 90% CL

T2K-only $\sin^2\theta_{13}$ measurement consistent with reactor measurements (PDG 2016)

T2K Best Fit (NH)

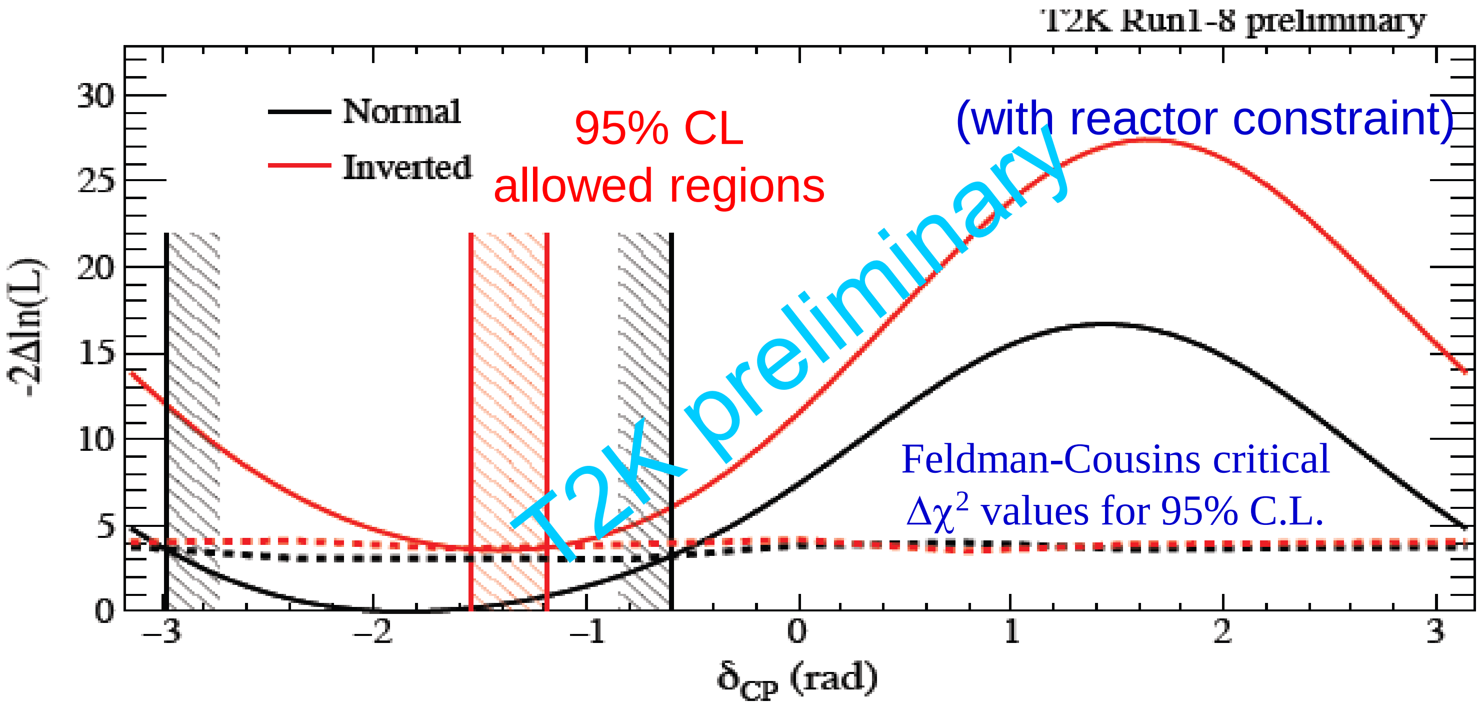
$\sin^2\theta_{13} = 0.0277\ (+0.0054, -0.0047)$

PDG 2016

$\sin^2\theta_{13} = 0.0210 \pm 0.0011$

Adding the reactor constraint improves the constraint on δ_{CP}

Measurement of δ_{CP}



Favors the δ_{CP} ~ - $\pi/2$ region, best fit point -1.83 (NH)

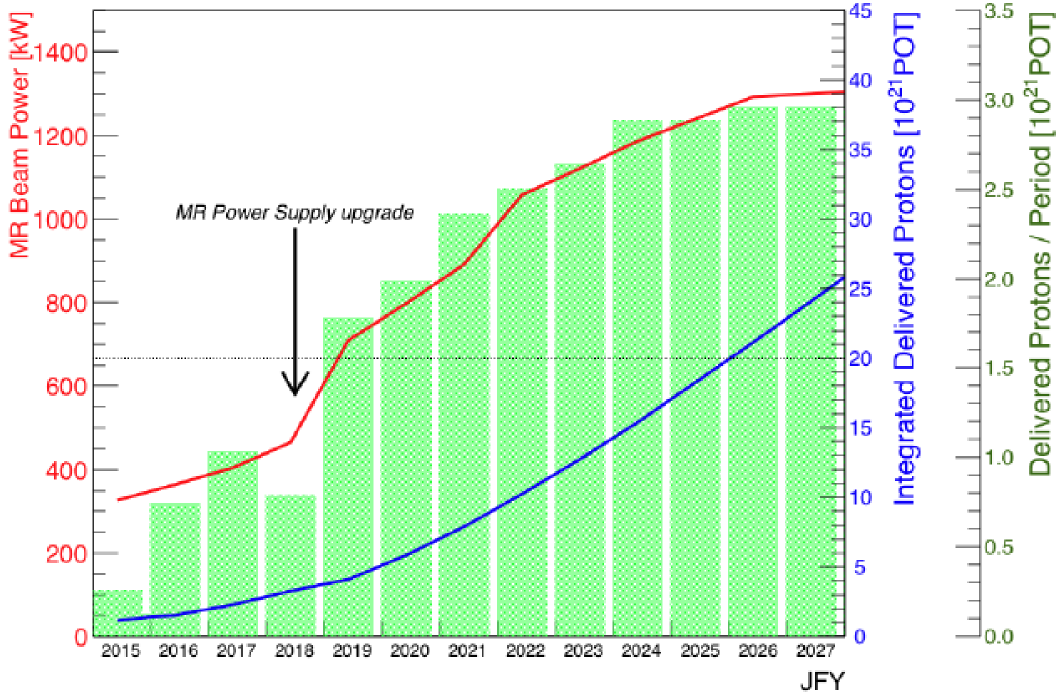
normal hierarchy: δ_{CP} = [-2.98, -0.60] [-171^0, -34^0] at 2 σ

inverted hierarchy: δ_{CP} = [-1.54, -1.19] [-88^0, -68^0] at 2 σ

CP conserving values (0, π) fall outside of the 2 σ interval

T2K Phase II (T2K-II)

Proposal to extend T2K run to 20 × 10^{21} POT by 2026
Currently T2K approved to 7.8 × 10^{21} POT



J-PARC plans to increase beam power from 475 kW to 1.3 MW in several steps

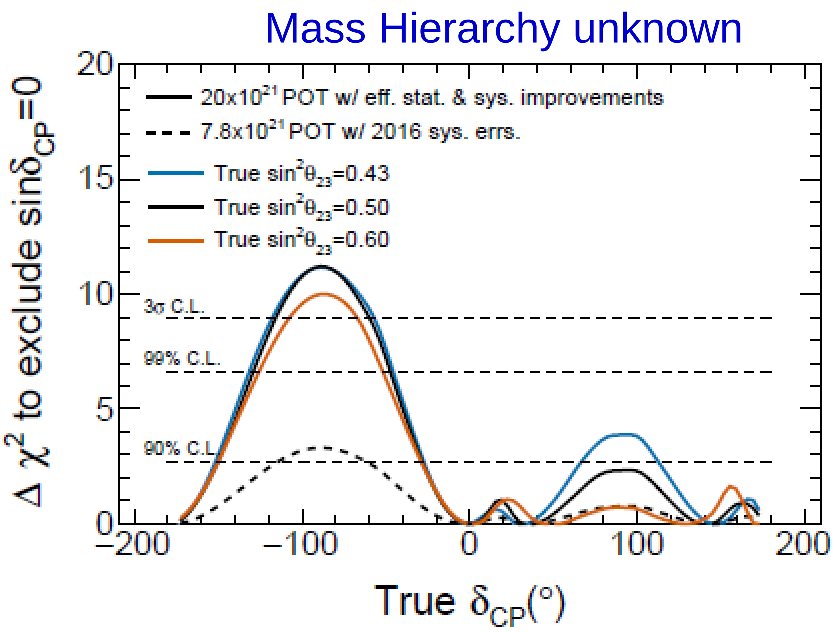
repetition cycle from 2.48 s to 1.3 s

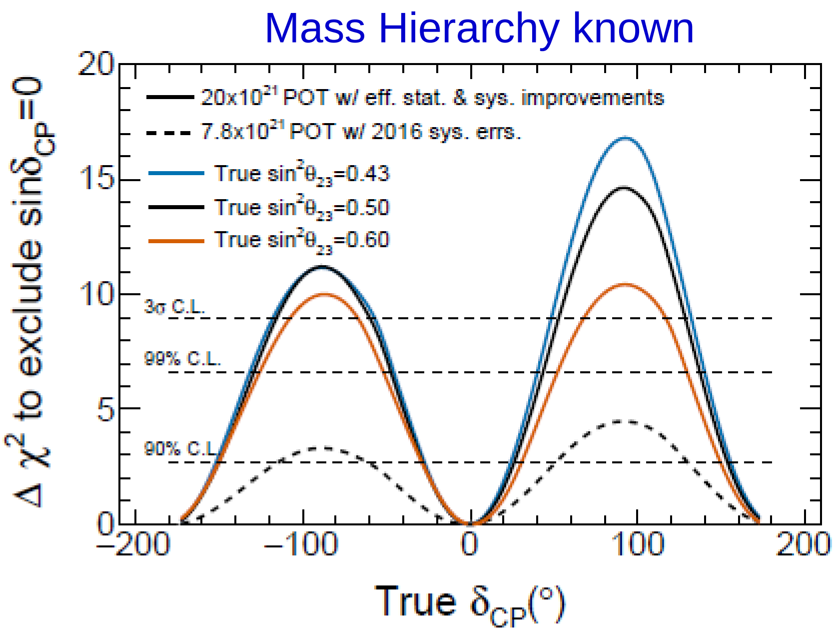
protons 2.4 × 10^{14} / spill to 3.2 × 10^{14} / spill

Stage-1 status given by J-PARC PAC

ND280 upgrade proposal under way

Physics Potential of T2K-II



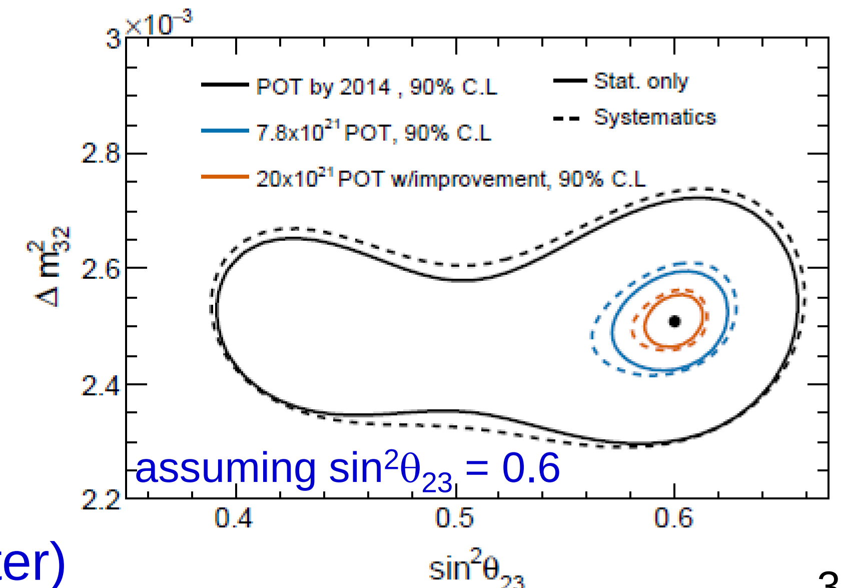


aim for 3σ CPV sensitivity for favorable (and currently favored) parameters

50% increase in effective POT
(increase horn current, enlarge fiducial volume)

reduction of systematic errors < 4%

precise measurement of θ_{23} (to 1.7^0 or better)



Conclusions

Accumulated ~22.5 $\times$ 10^{20} protons on target (POT)
Beam power continuously increasing (475 kW at the end of run 8)

Fully joint analysis across all modes of oscillation
ν_μ / $\bar{\nu}_\mu$ disappearance and ν_e / $\bar{\nu}_e$ appearance

Near detector and NA61 hadro-production data used to constrain rate at far detector (SK)
water target and "wrong sign" from ND280

Data prefer maximal θ_{23} mixing, $\delta_{CP} \sim -\pi/2$, normal hierarchy

"maximal" ν_μ / $\bar{\nu}_\mu$ disappearance, "large" ν_e appearance, "small" $\bar{\nu}_e$ appearance
δ_{CP} = [-2.98, -0.60] at 2 σ (NH)
δ_{CP} = [-1.54, -1.19] at 2 σ (IH)

T2K excludes CP conservation at 95% confidence level

Accelerator upgrade approved, aiming for 1.3 MW operation

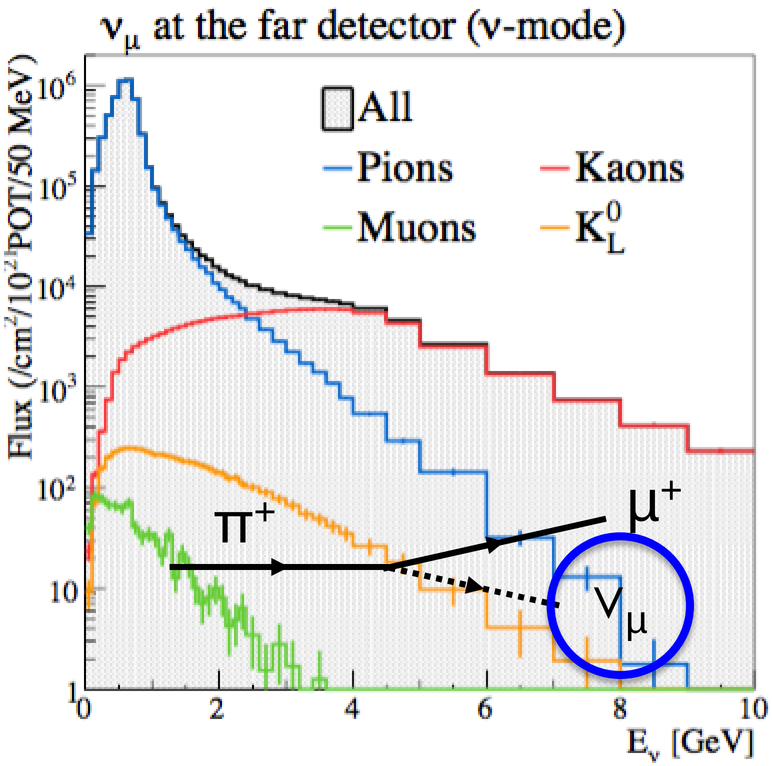
Proposal to extend T2K (T2K-II) Stage-1 status
Studies to upgrade ND280 detector under way

more ...

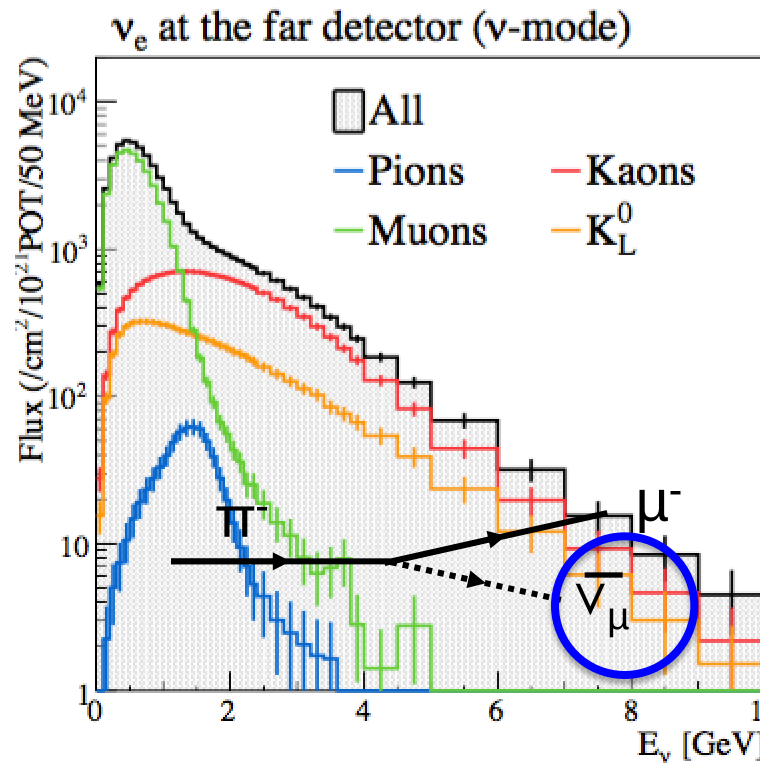
Need for Hadro-production Measurements

The flux predictions in accelerator-based neutrino experiments depend on hadro-production models of ν parents

Hadro-production at present is still one of the dominant uncertainties in flux estimates



ν_μ ($\overline{\nu_\mu}$): π at low E_ν, K at large E_ν

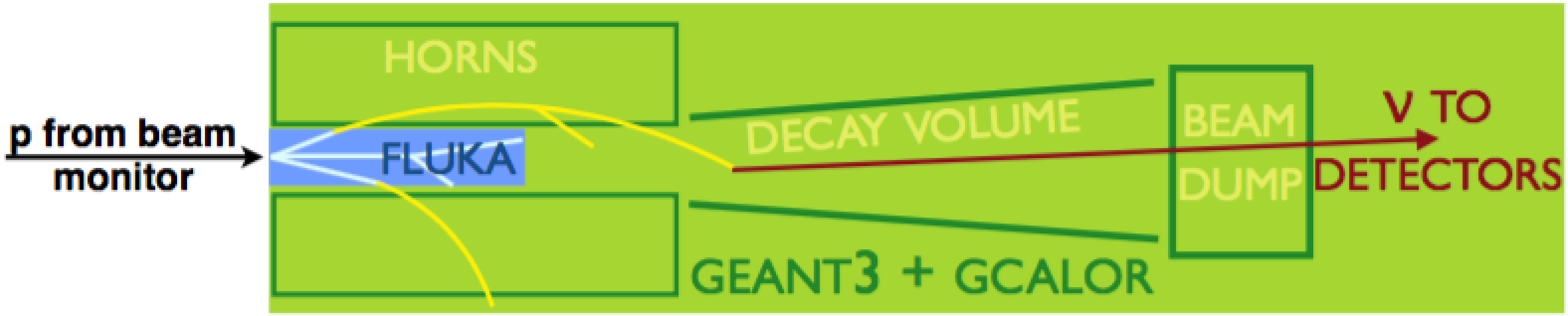


ν_e: μ at low E_ν, K at large E_ν; $\overline{\nu_e}$: K at all E_ν

NA61 measurements replace model-based calculations for hadro-production in ν flux estimates, thus reduce one of the largest sources of uncertainty

Modelling of T2K ν Flux

Data driven (NA61) FLUKA/Geant3 based neutrino beam simulation



FLUKA	GEANT3 + GCALOR	RE-WEIGTHING
primary p+C interaction in the target	tracking particles exiting the target target through horns, magnetic field and decay volume	π, K multiplicity and interaction rate are used to re-weight simulations
beamline monitors data are parameterized to obtain the proton beam profile	accurate description of secondary beamline in simula0on is required	external hadro-production measurements are used mostly NA61 data

To tune T2K flux, for each simulated neutrino interaction,
a weight is calculated for simulated event to adjust MC to data.

primary interactions can be directly re-weighted with NA61 thin target data for π, K

the kinematic coverage is extended by using parameterization from fit to data

scaling is used for secondary interactions and interactions on material other than C

Fitting ND280 Data

Since 2016, include FGD2 (water targets) to extract interactions on H_2O

Separate data sets in FGD1 and FGD2

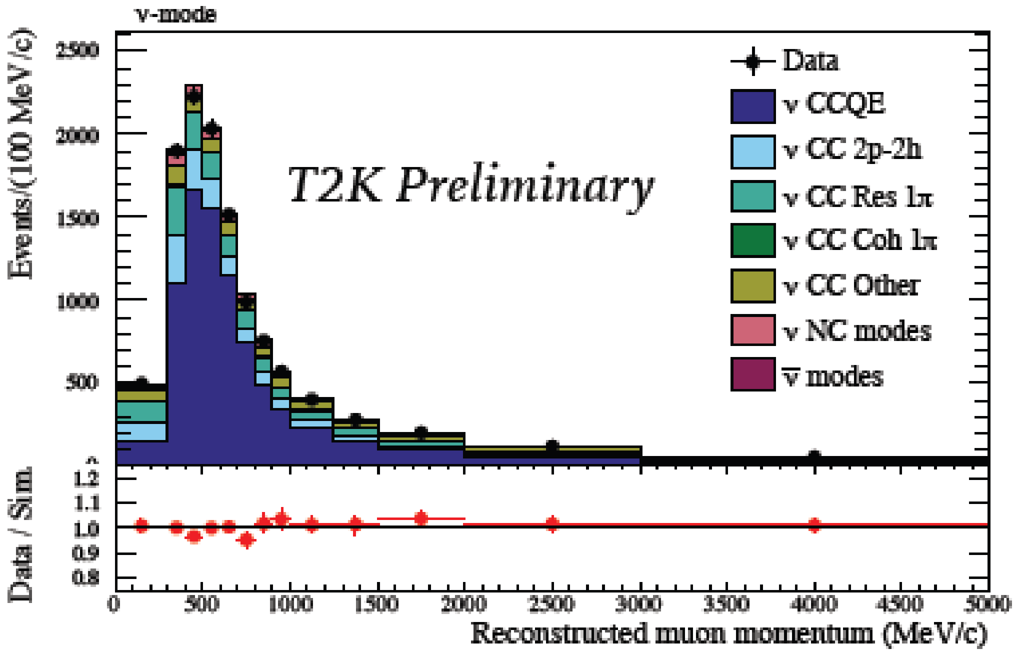
Neutrino mode separated by number of charged pions:
CC-0π, CC-1π, CC-Other

Antineutrino mode separate by number of TPC tracks:
CC-1Track, CC-NTrack

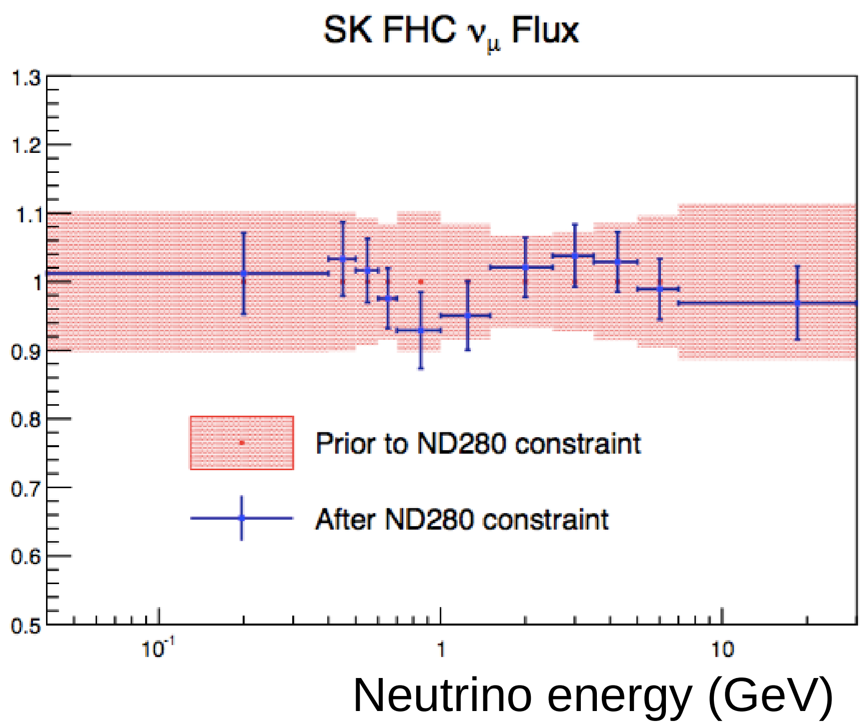
In antineutrino mode, separate samples for μ^+ and μ^- candidates

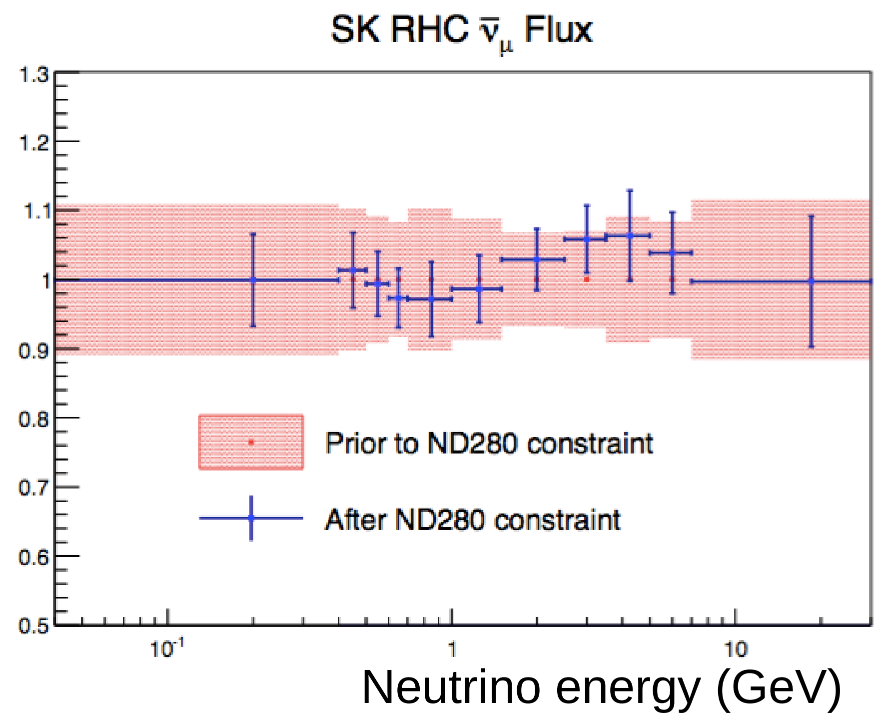
Example fitted FGD2 CC-0π muon momentum

The fit reproduces the data well with a p-value of 0.47



Fitted Flux Parameters

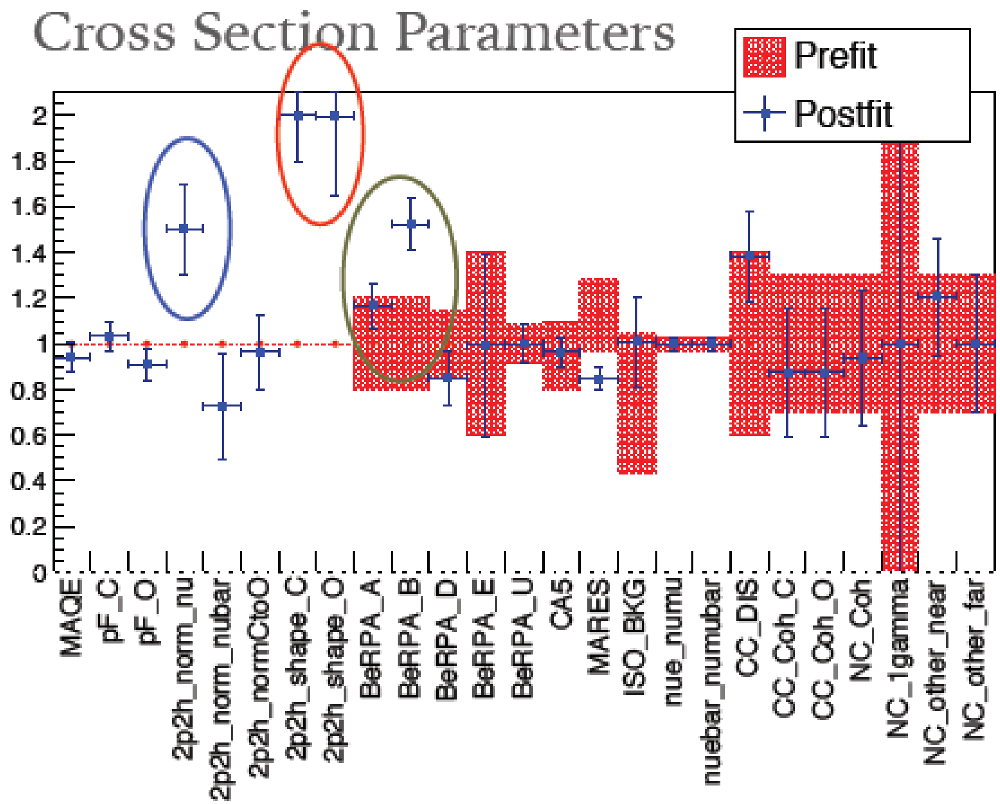




Fitted flux parameters are generally near their nominal value of 1.0

Most of the fitted flux parameters fall within their assigned 1 σ prior uncertainty

Fitted Interaction Model Parameters



The 2p-2h for neutrinos is enhanced by 50%

The 2p-2h shape is shifted so that the Δ-enhanced component of the cross-section is increased to maximum

The RPA parameters for Q^2 below 1 GeV^2 are increased, enhancing the cross-section in that region

Robustness of T2K Results

Neutrino interaction models are rapidly changing and this may impact T2K results

Check robustness of results against potential neutrino interaction modeling effects not yet included in T2K neutrino interaction model (NEUT generator)

- Apply data-driven or model-driven changes to the simulated event rates at ND280 and SK that aren't implemented in fitting model

- Fit this systematically varied Monte Carlo with current fitting model
  Data-driven variation based on the pre-fit data/prediction discrepancy in ND280

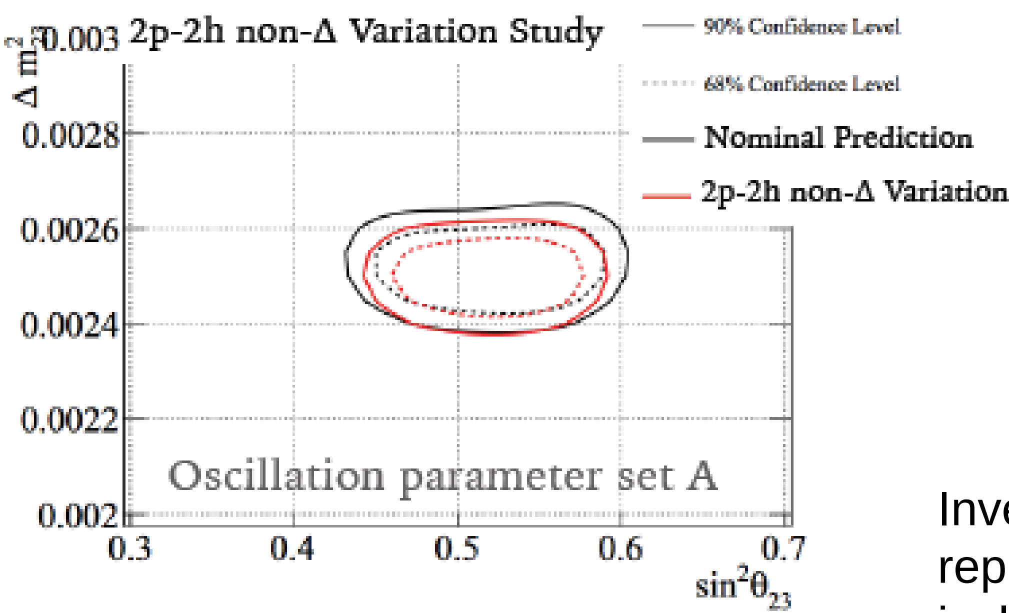
- Take excess of data over prediction prior to ND280 fitting and assign the excess to 1 of 3 types of interactions:
  - CCQE
  - 2p-2h Δ-enhanced
  - 2p-2h non-Δ-enhanced

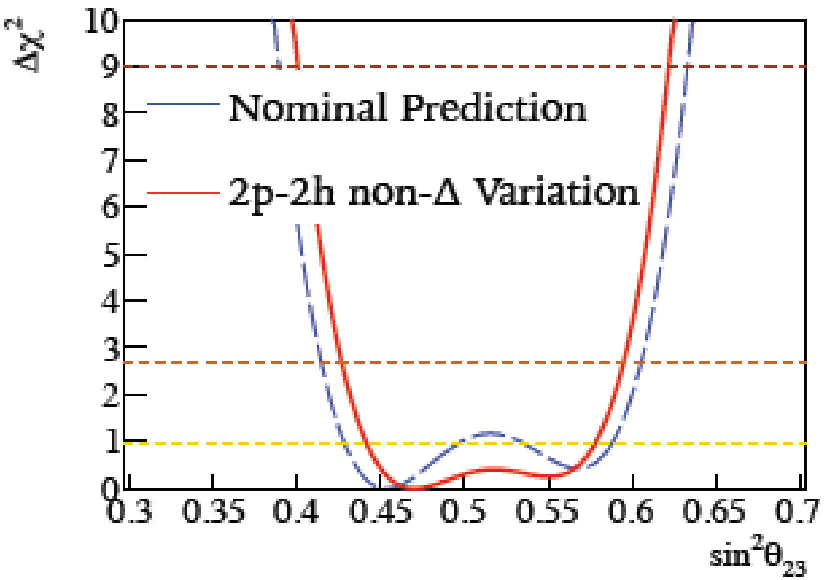
  and pply modeled excess to predict rates at ND280 and SK

Effect seen on $\sin^2\theta_{23}$ and Δm^2_{32} (next slide)

No significant impact on the measured intervals for δ_{CP} (next to next slide)

Impact on Atmospheric Parameters





In this study

Δm^2_{32} is biased to lower values

$\sin^2\theta_{23}$ is biased towards maximal disappearance

This leads to narrower contour than fit to nominal prediction

Investigating if this type of variation represents a physical effect that should be included as a systematic uncertainty

We present Δm^2_{32} vs. $\sin^2\theta_{23}$ contours with caveat that the systematic error model may be updated in the future

Neutrino interaction model systematic effects will be addressed by

- use of 4π samples in the fit to ND280 data
- study of the hadronic recoil system
- ND280 upgrades

Impact on CP Phase

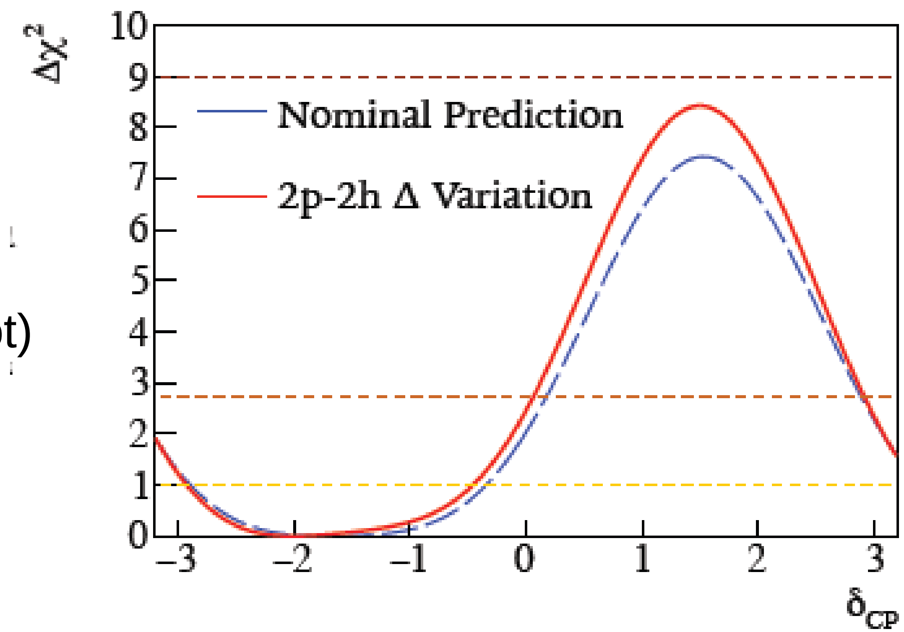
Consider how changes to the $\Delta\chi^2$ impact confidence intervals calculated from data

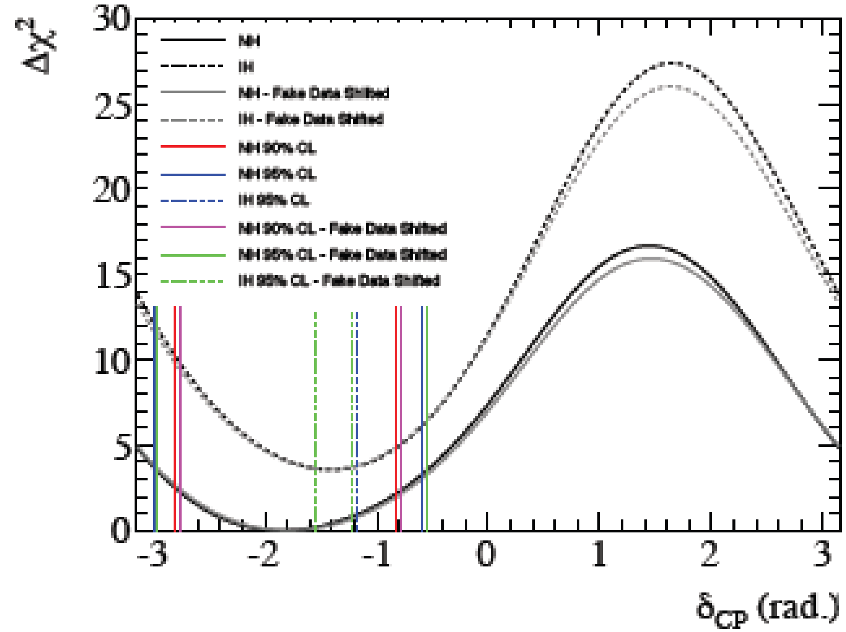
> Shift $\Delta\chi^2$ observed in data (bottom plot) by difference observed in systematic study (top plot)

Maximum shift in the NH 2-σ confidence interval mid-point was 1.7%

Maximum change to the NH 2-σ confidence interval was 2.3%

Impact on δ_{CP} intervals is small

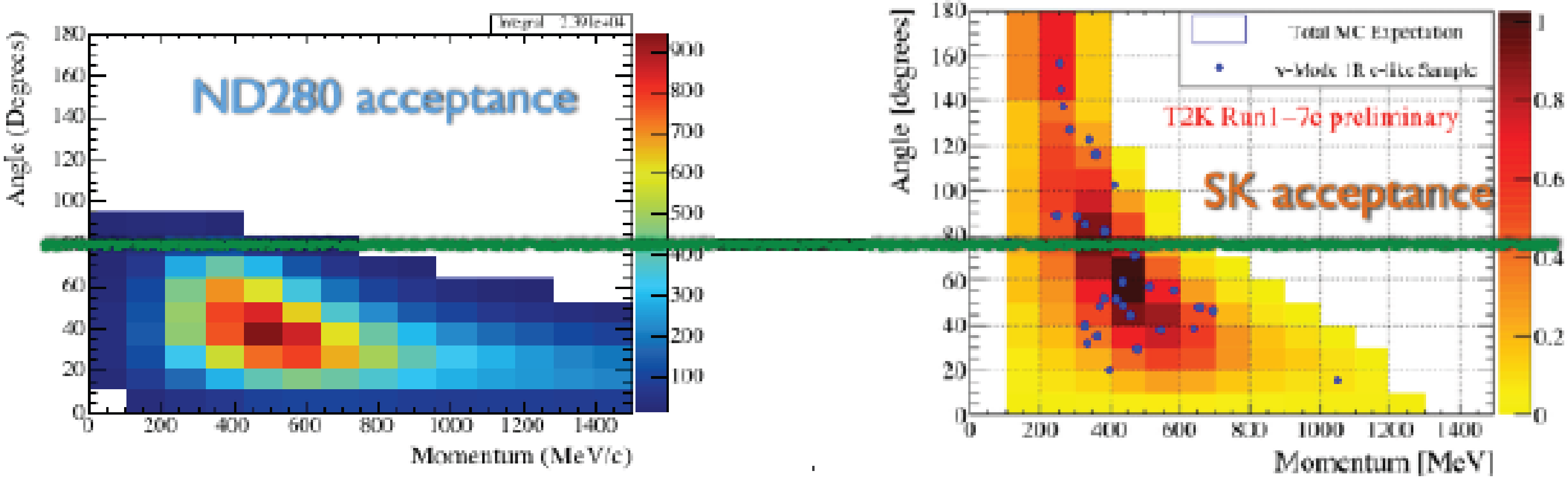




ND280 Upgrade

ND280 upgrade to understand the neutrino-nucleus interactions and improve on systematics

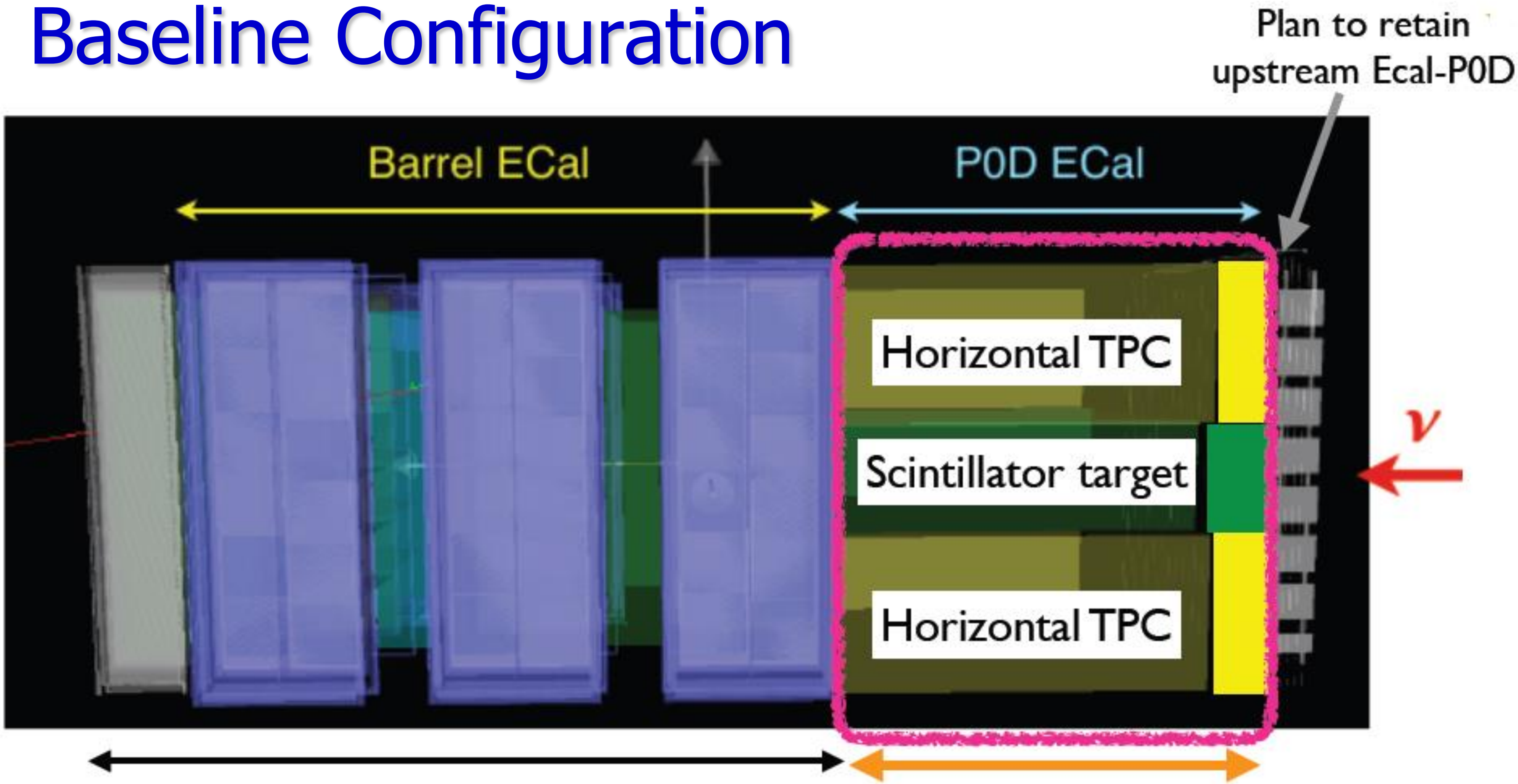
Current ND280 has an excellent performance for forward tracks, however limited performance for large angle tracks



Basic criteria for upgrading ND280

- Enlarge phase space – cover full polar angle (Super-K has 4π uniform acceptance)
- Retain ND280 TPC capabilities
- Efficiency for short hadron tracks
- Improve electron neutrino selection

Baseline Configuration



Keep current tracker + downstream Ecal

New Detectors

Magnet and surrounding Ecal
also preserved

2 horizontal TPCs
Scintillator target
(different options studied)
ToF detectors