New Results from the T2K experiment

Claudio Giganti
LPNHE (Paris)
IN2P3/CNRS

Outline

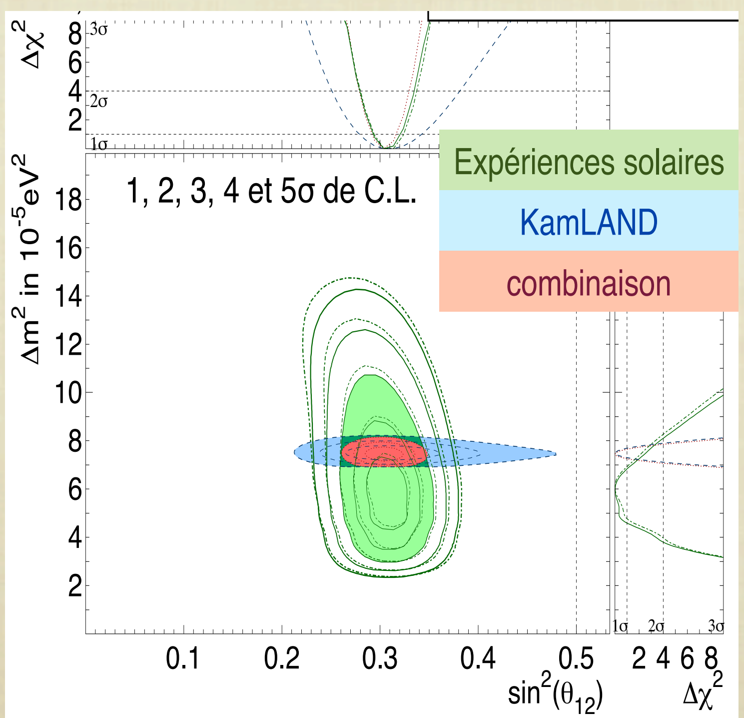
- The neutrino oscillations and θ_{13}
- Long baseline neutrino oscillation experiments
- T2K setup
  - Beam
  - Near Detector
  - Far Detector
- T2K oscillation analysis
  - ν_μ disappearance
  - ν_e appearance
- Other physics topics

Neutrino oscillations

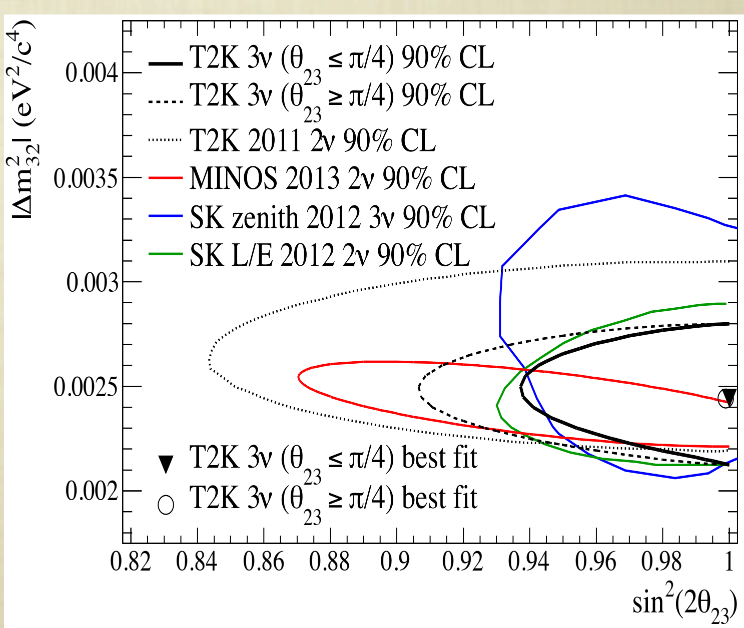
$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

- 6 parameters: 3 mixing angles, 2 mass differences, 1 CP violation phase
- Nowadays we know the 3 angles and the 2 mass differences
  - θ_{13} measured very recently by T2K and reactor experiments
  - CPV phase is completely unknown

Solar sector parameters (θ_{12}, Δm_{12}) Measured by solar (SNO) and reactor (KamLAND) experiments



Atmospheric sector parameters (θ_{23}, Δm_{23}) Measured by Super-Kamiokande and accelerator based experiments (MINOS, T2K)



The measurement of θ_{13}

Reactors (DChooz, RENO, Daya Bay)

- ✓ Disappearance of anti-νe $P(\bar{\nu}_e \rightarrow \bar{\nu}_e)$
- ✓ anti-ν_e produced in nuclear reactors
  - ✓ Neutrino energy few MeV
  - ✓ Distance L ~ 1 km
- ✓ Signature: disappearance of the anti-ν_e produced in the reactor → depends on θ_{13}

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - sin^2 2\theta_{13} sin^2 \Delta_{13} - cos^4\theta_{13} sin^2 2\theta_{12} sin^2 \Delta_{12}$$

Simple dependence on θ_{13}

Accelerators (T2K, Minos→Nova):

- ✓ Appearance experiment: $P(\nu_\mu \rightarrow \nu_e)$
- ✓ ν_μ neutrino beam
  - ✓ Neutrino energy ~1 GeV
  - ✓ Distance L >~ 300 km
- ✓ Signature: appearance of ν_e in the ν_μ beam
- ✓ Degeneracy of θ_{13} with δ_{CP}, sign of Δm^2

1st order → θ_{13}

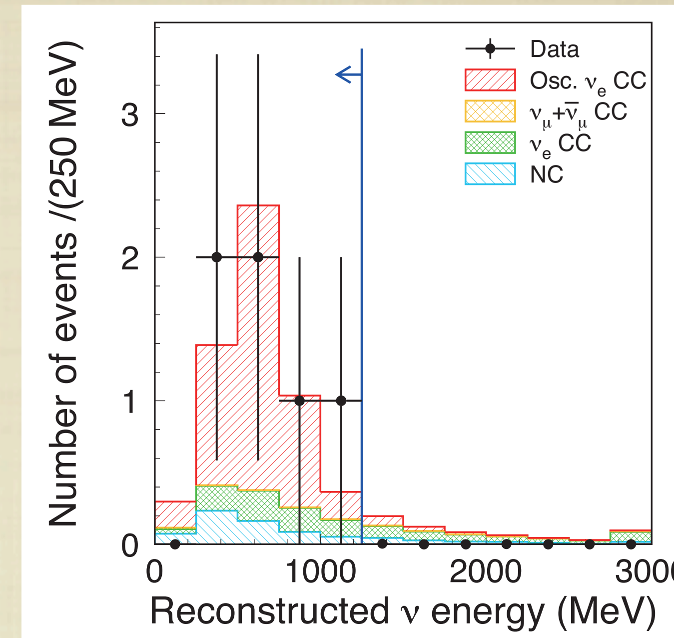
$$P(\nu_\mu \rightarrow \nu_e) \sim \sin^2\theta_{23} \frac{sin^2 2\theta_{13}}{(\hat{A}-1)^2} \sin^2((\hat{A}-1)\Delta) + \alpha \frac{8 J_{CP}}{\hat{A}(1-\hat{A})} \sin(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta) + \alpha \frac{8 I_{CP}}{\hat{A}(1-\hat{A})} \cos(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta) \alpha^2 \frac{cos^2\theta_{23}\sin^2\theta_{12}}{\hat{A}^2} \sin^2(\hat{A}\Delta)$$

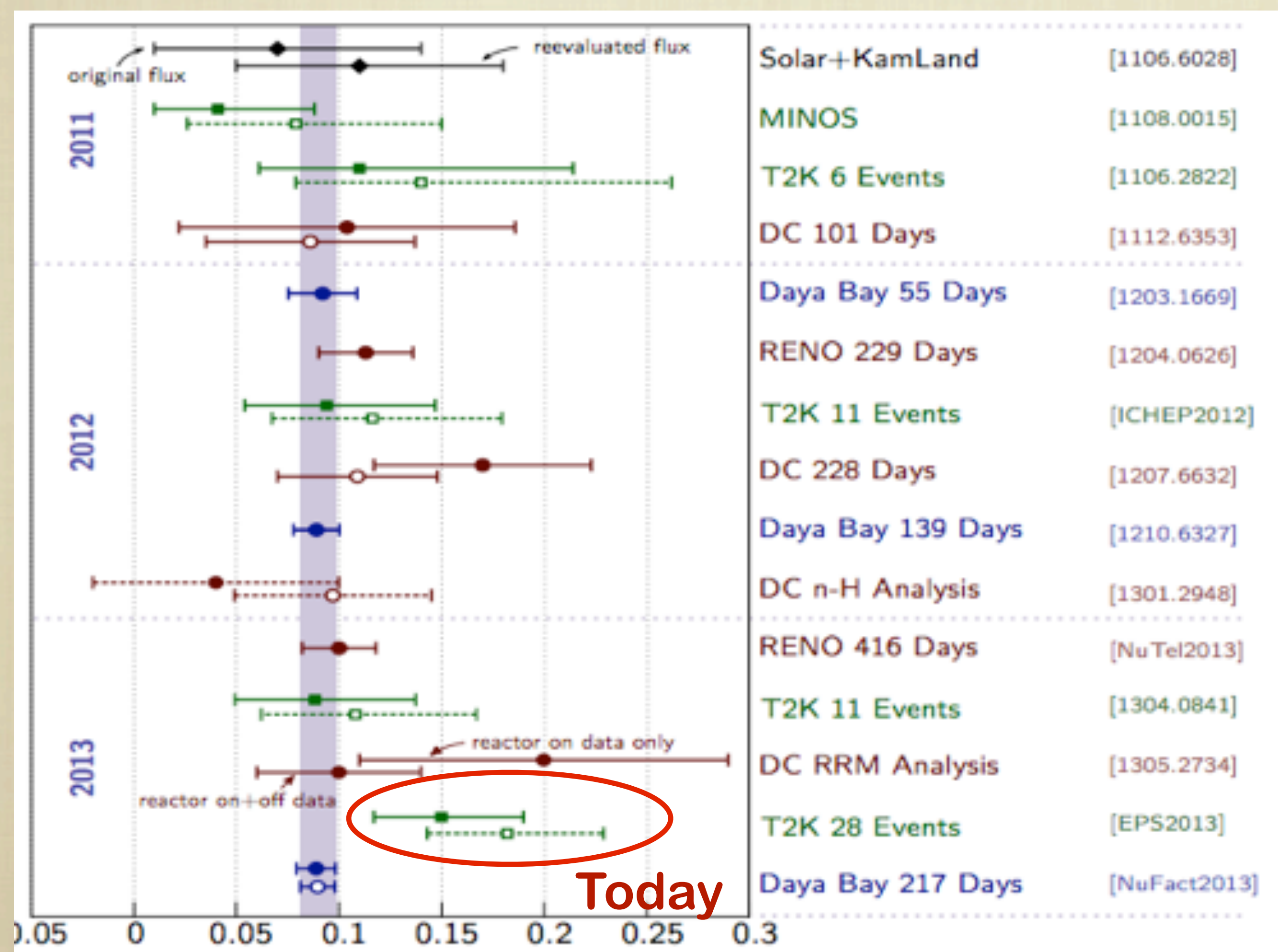
J_{CP}→CPV term
A depends on the sign of Δm^2

Measurements of θ_{13}

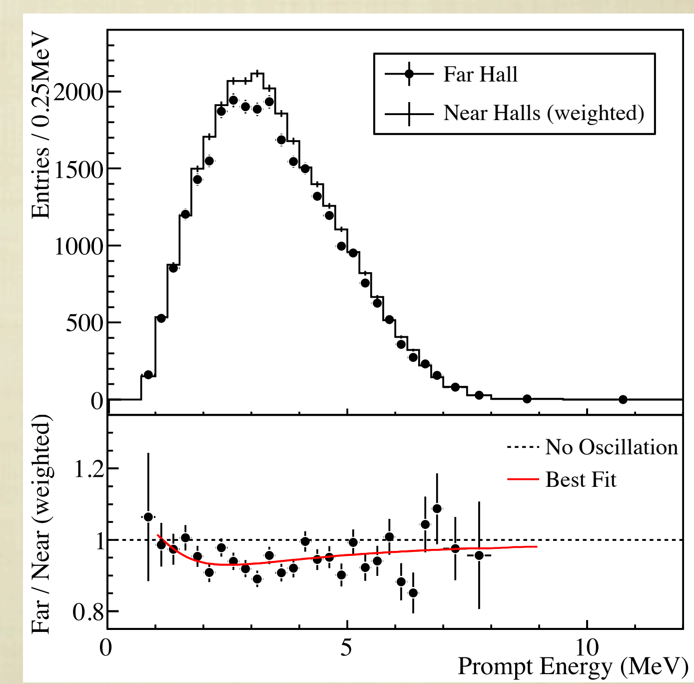
- First indications for large θ_{13}: T2K in 2011 (6 events, 2.5σ)
- Confirmed by Daya Bay (reactor experiment) with more than 5σ in 2012
- Today θ_{13} is known with <10% precision

T2K 2011



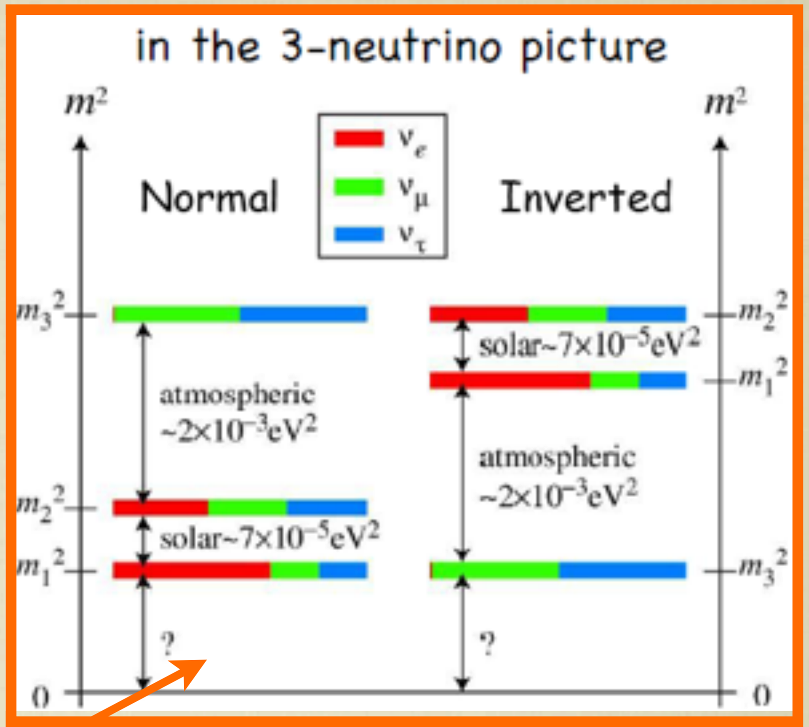


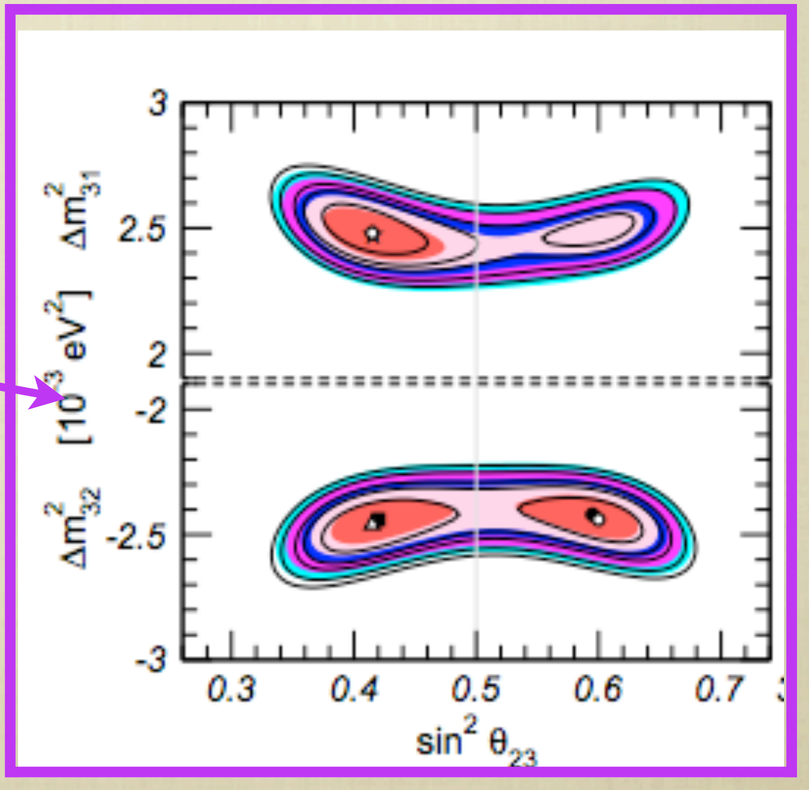
Daya Bay 2012



What's next

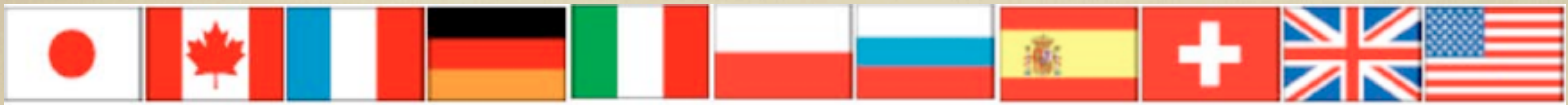
- θ_{13} is different from 0
  - Open the way to new measurements accessible with accelerator experiments
- Open questions (with accelerators):
  - Is CP violated in the leptonic sector ? → differences between ν and anti-ν and combination of reactors and accelerators
  - Mass hierarchy: is m_3 larger than m_1?
  - Is θ_{23} maximal?
  - Is there any sterile neutrinos?
- Open questions (without accelerators)
  - Which is the absolute neutrino mass?
  - Neutrinos are Dirac or Majorana particles?





T2K experiment

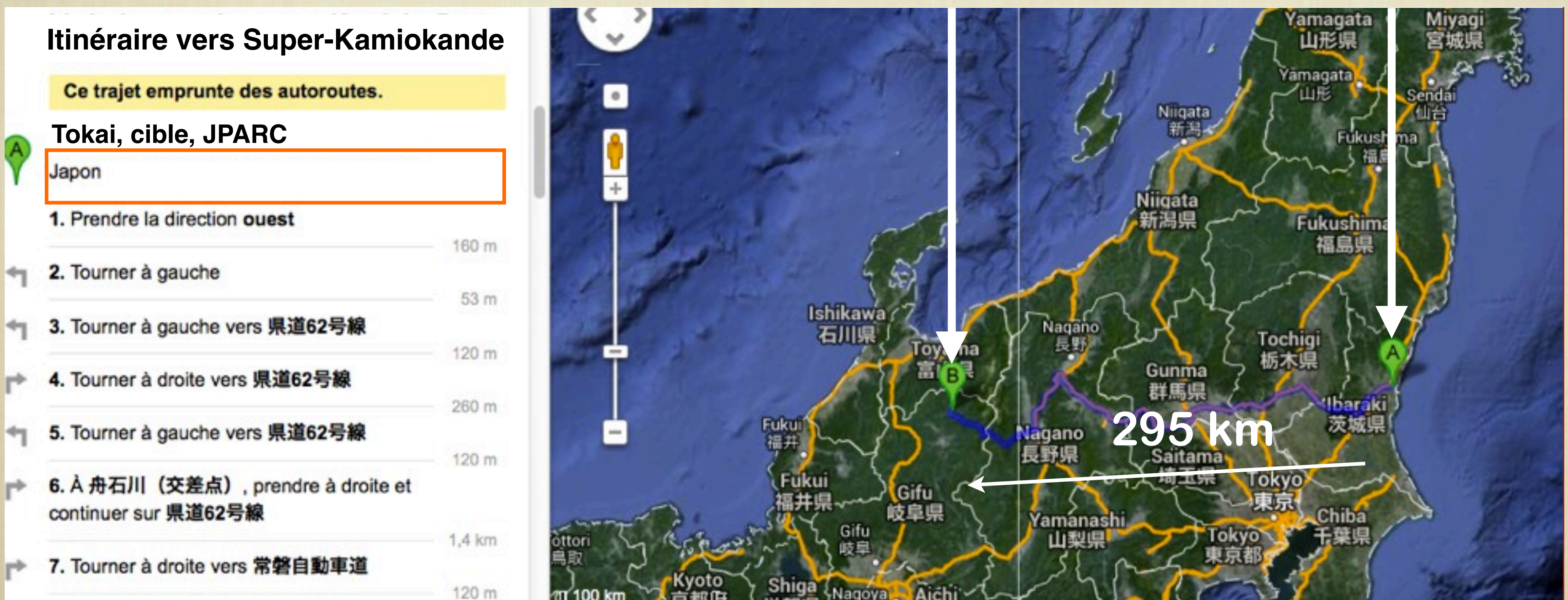
T2K Collaboration



~500 members, 59 institutes, 11 countries

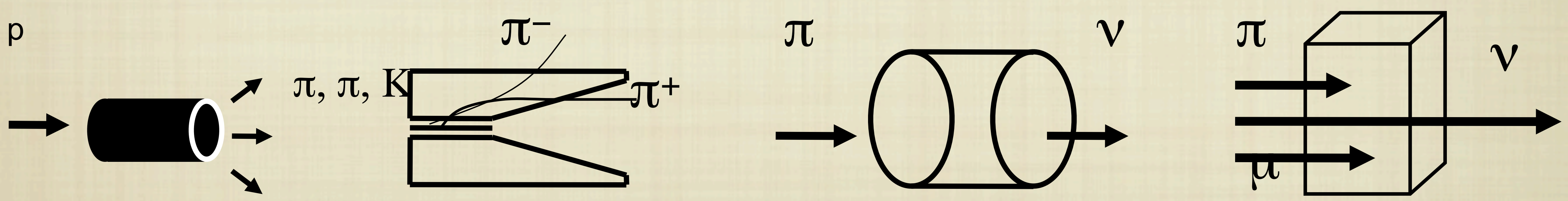
T2K experiment

- High intensity ~700 MeV ν_μ beam produced at J-PARC (Tokai, Japan)
- Neutrinos detected at the Near Detector (ND280) and at the Far Detector (Super-Kamiokande) 295 km from J-PARC
- Observation of ν_e appearance → determine θ_{13} and δ_{CP}
- Precise measurement of ν_μ disappearance → θ_{23} and Δm^2_{23}

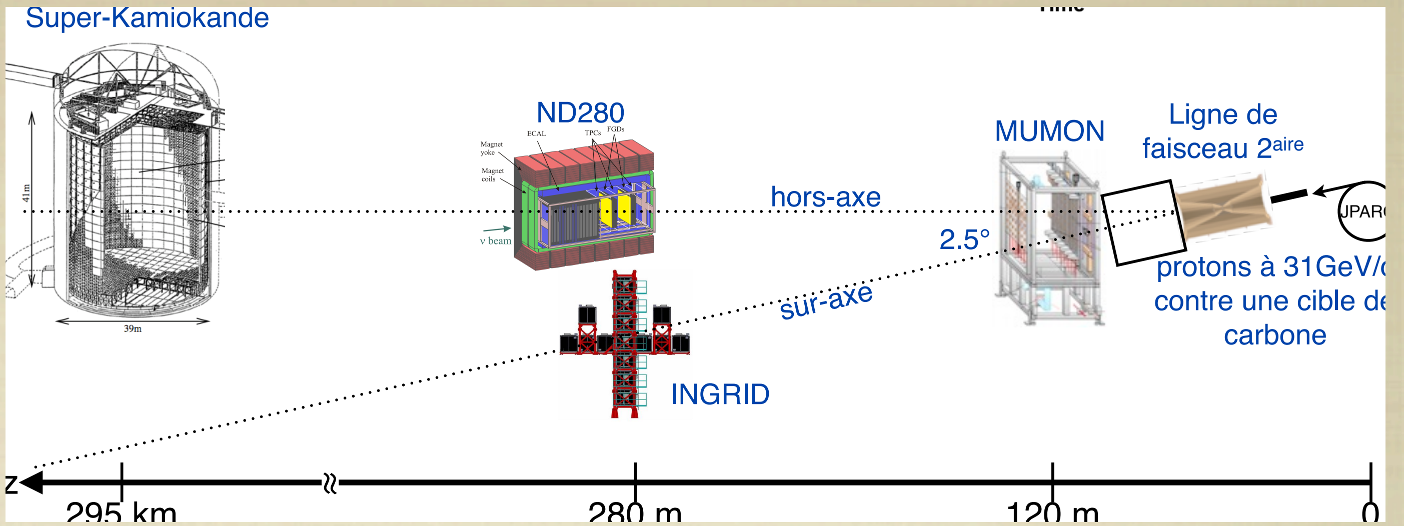


Long Baseline ν experiment

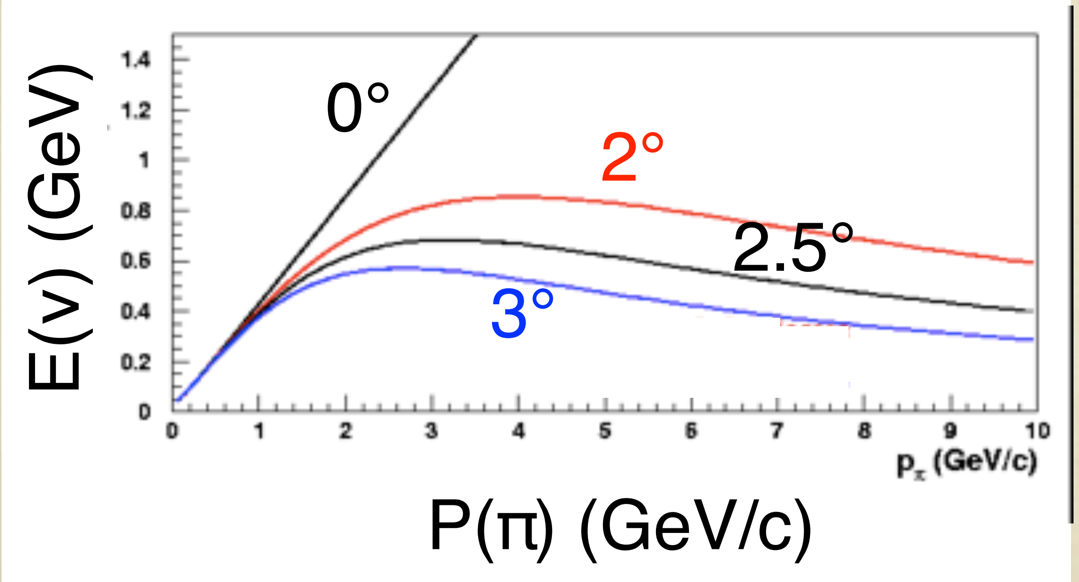
- Accelerate a proton beam that interact onto a Carbon target producing hadrons (π and K)
- Hadrons are focused and selected in charge by a system of magnetic horns (π+ and K+ are selected for a neutrino beam) and enter into a decay volume
- Decay volume: mainly $\pi^+ \rightarrow \mu^+ + \nu_\mu$ but also some ν_e and anti-ν
- The surviving charged particles are then absorbed by a beam dump



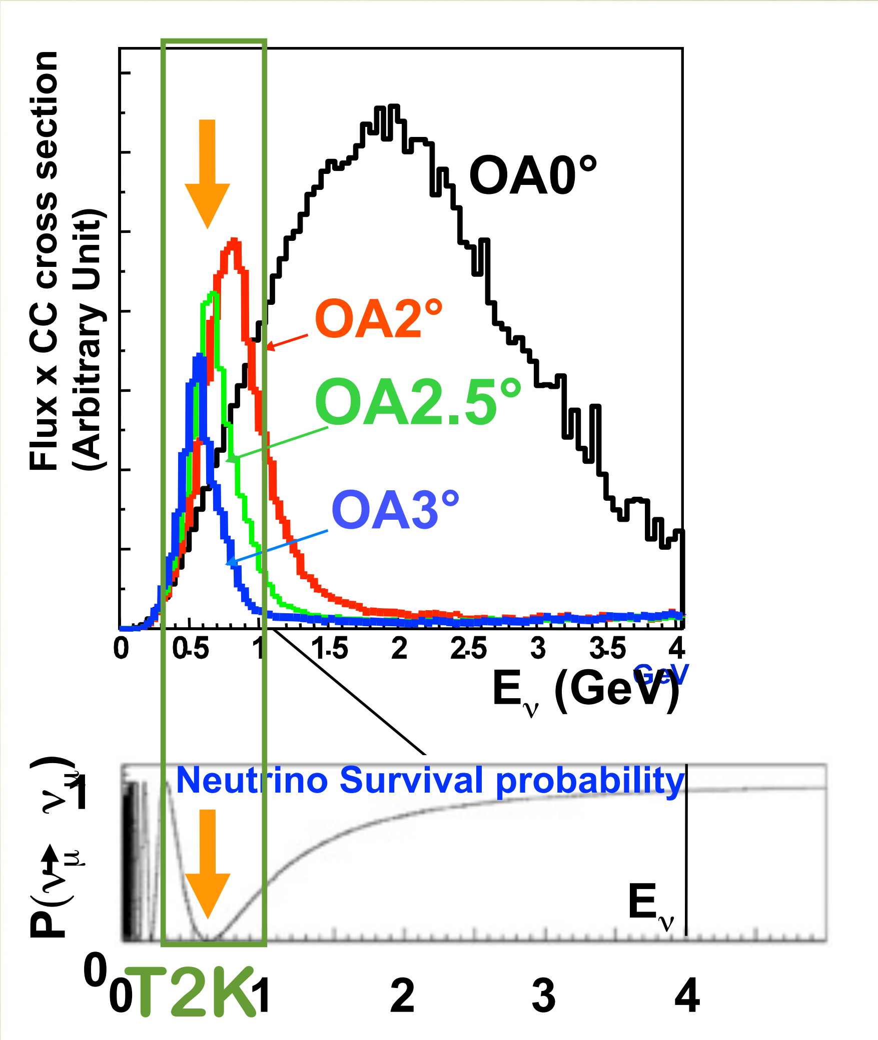
Off-axis beam



- First experiment using an off-axis technique (detectors at 2.5° with respect to the center of the beam)
  - Increase the intensity of the beam at the desired L/E → maximize oscillation probability

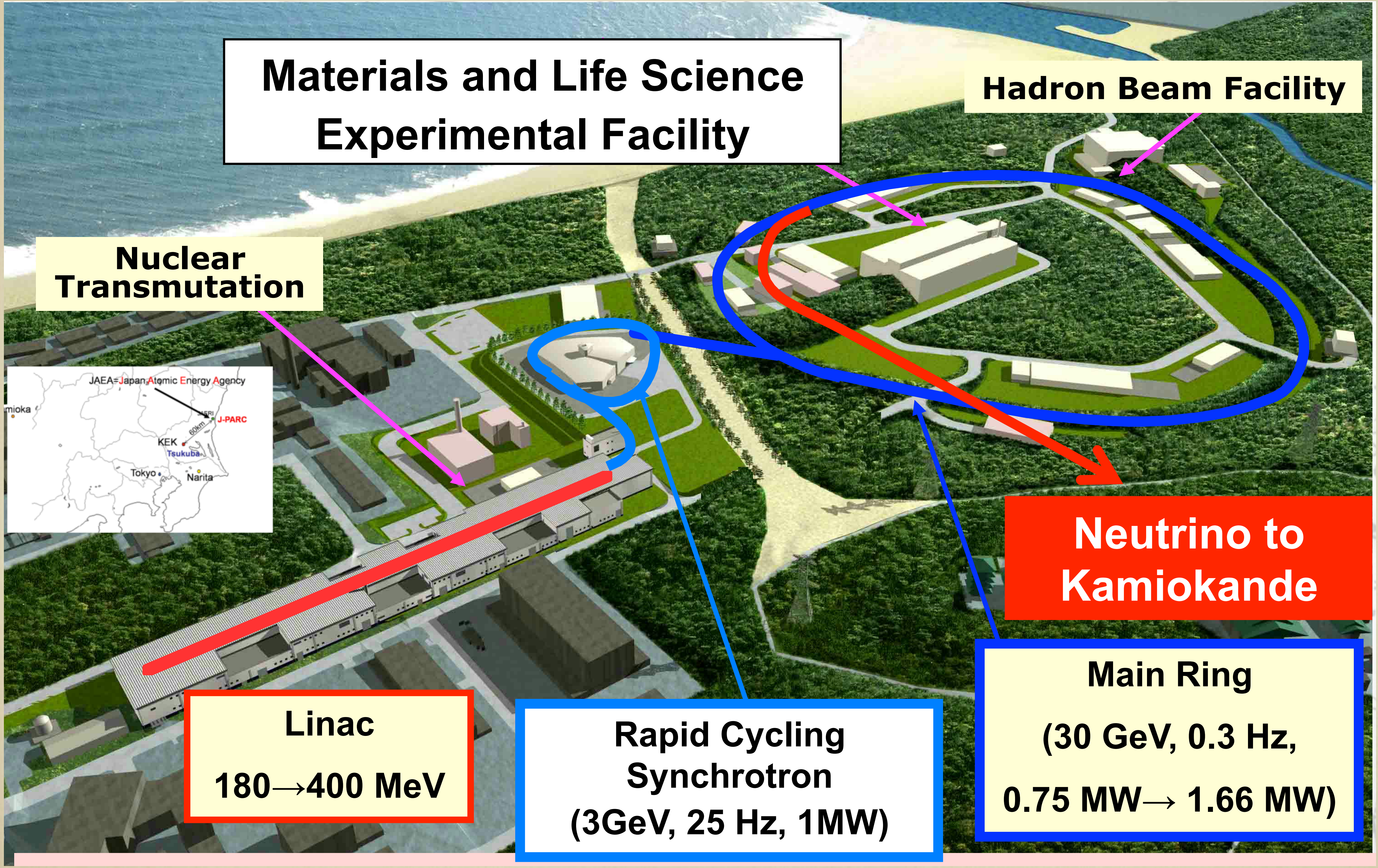


On-axis: E(ν) proportional at P(π)
Off-axis: different P(π) contribute to the same E(ν)



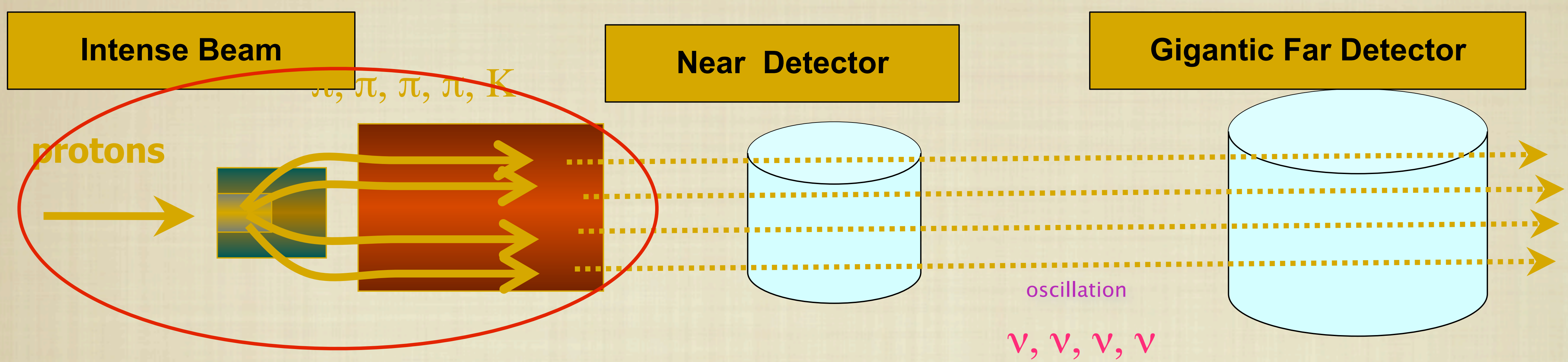
T2K experimental setup

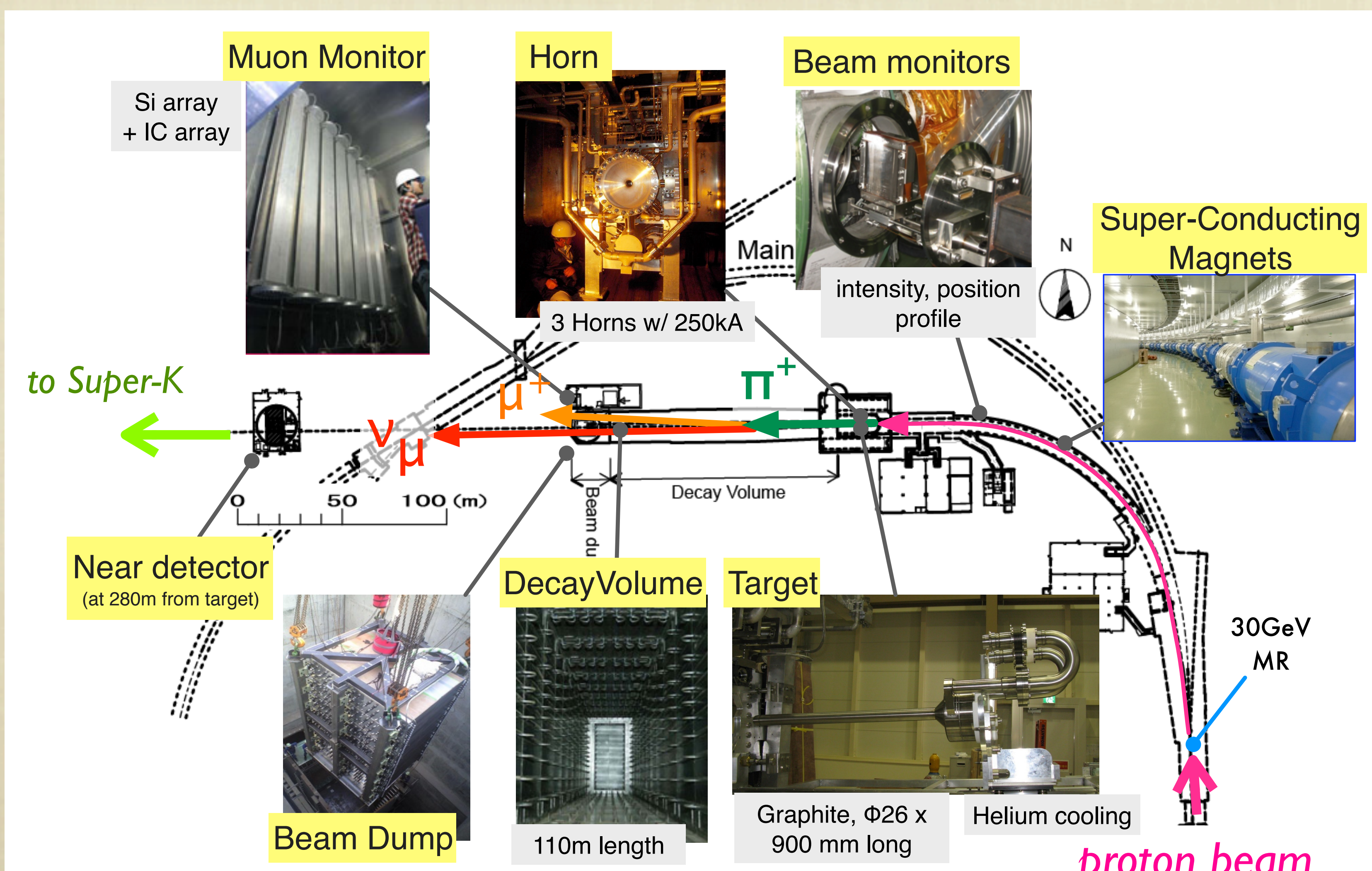
J-PARC (Japan Proton Accelerator Complex)



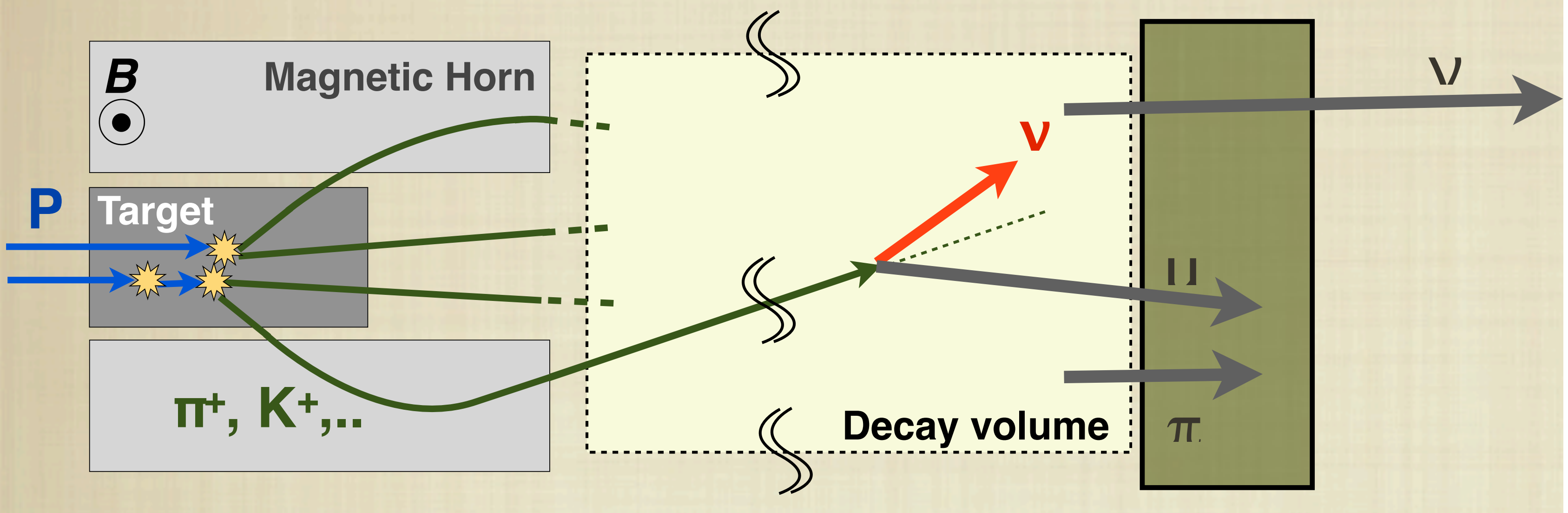
Neutrino beamline

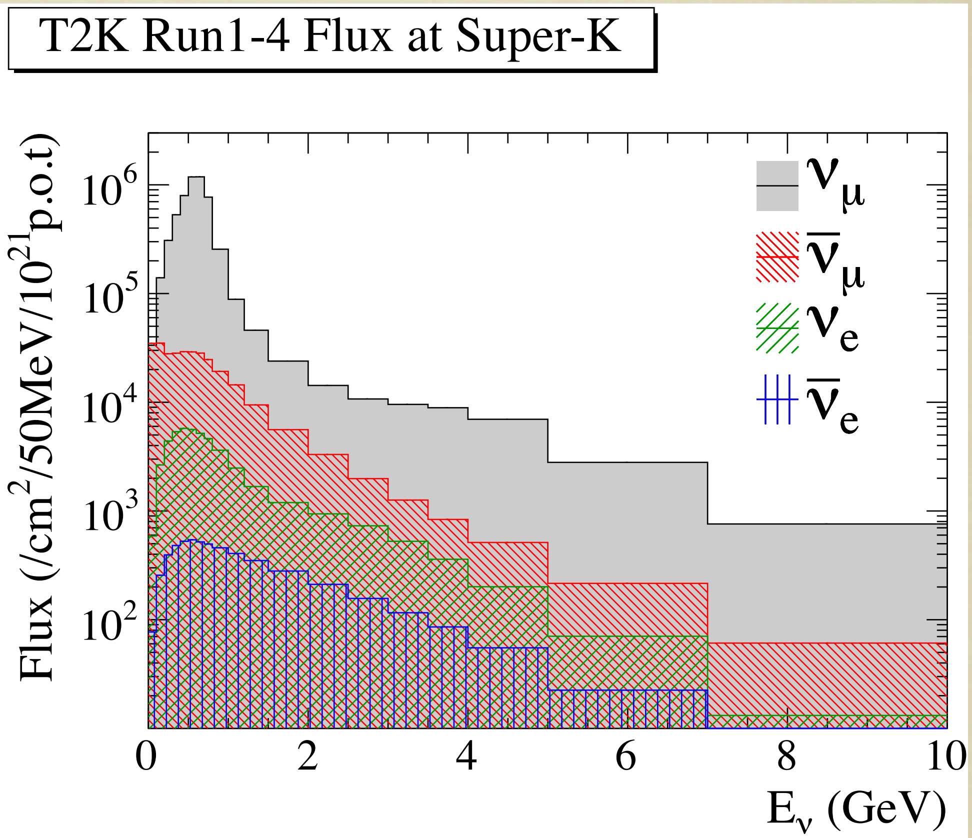
$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2 2\theta_{23} \sin^2 (1.27\, \Delta m^2_{23}\, L/E_\nu)$$





T2K neutrino beam





- ν_μ are mainly produced by pions and kaons
- Small intrinsic ν_e component (~1%) produced by decays of K and μ

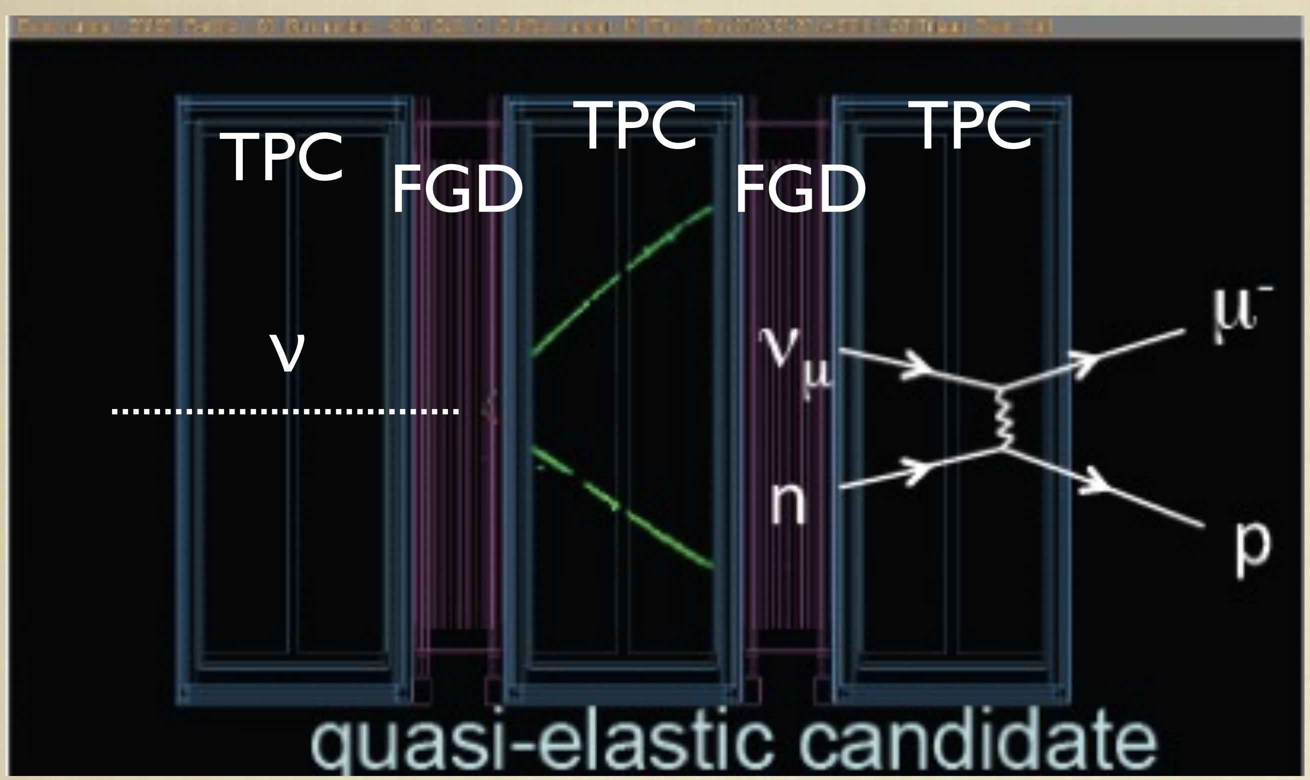
$\pi \rightarrow \mu\nu_\mu$ $\Gamma = 99.9\%$
$\rightarrow e\nu_e$ $\Gamma = 10^{-4}\%$

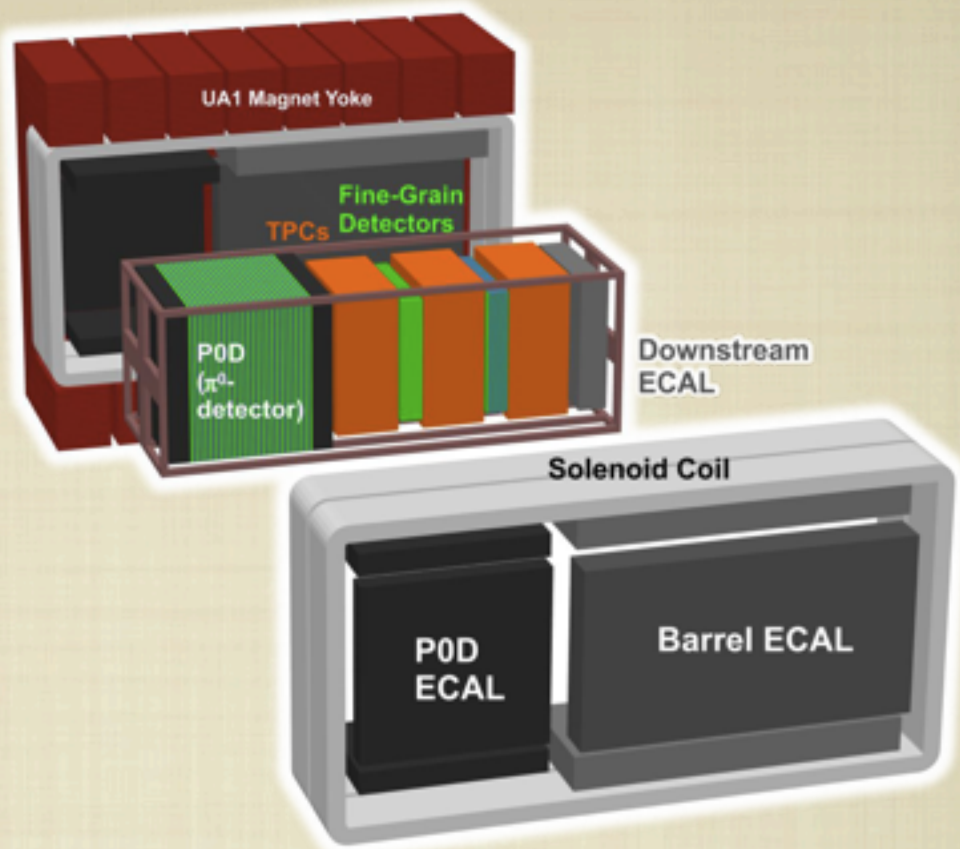
$K \rightarrow \mu\nu_\mu$ $\Gamma = 63.5\%$
$\rightarrow \pi^0 e\nu_e$ $\Gamma = 5.1\%$
$\rightarrow \pi^0 \mu\nu_\mu$ $\Gamma = 3.3\%$

$K^0_L \rightarrow \pi e\nu_e$ $\Gamma = 40.5\%$
$\rightarrow \pi\mu\nu_\mu$ $\Gamma = 27.0\%$

$\mu \rightarrow e\nu_e\nu_\mu$ $\Gamma = 100\%$

ND280

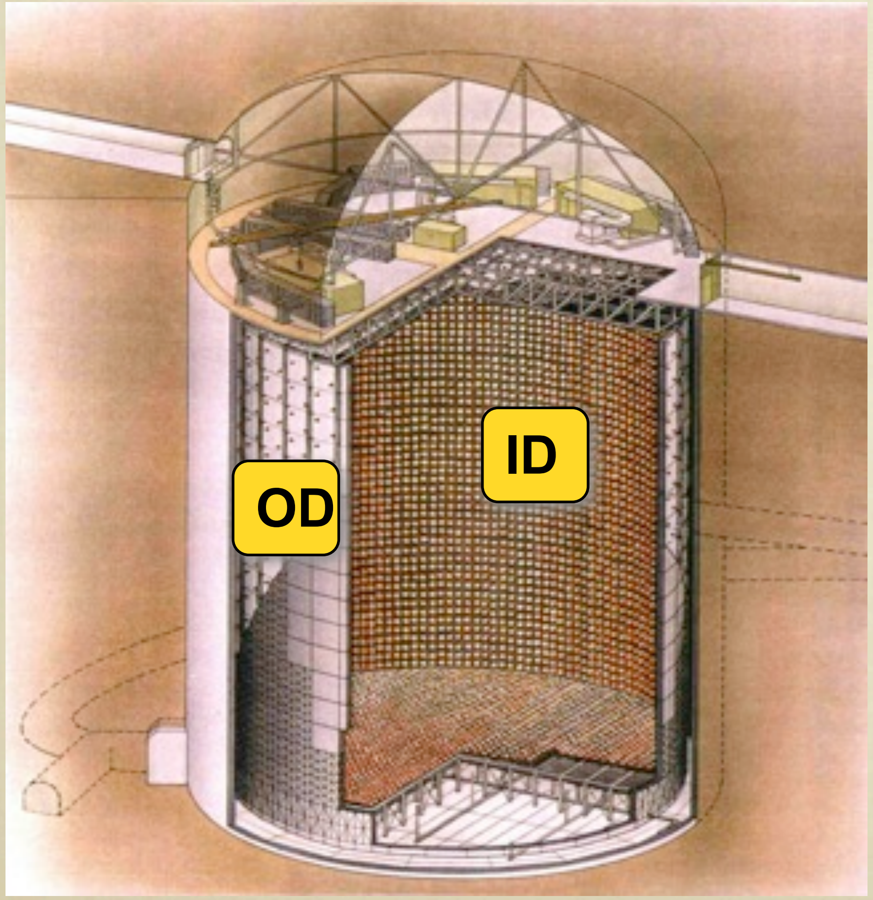


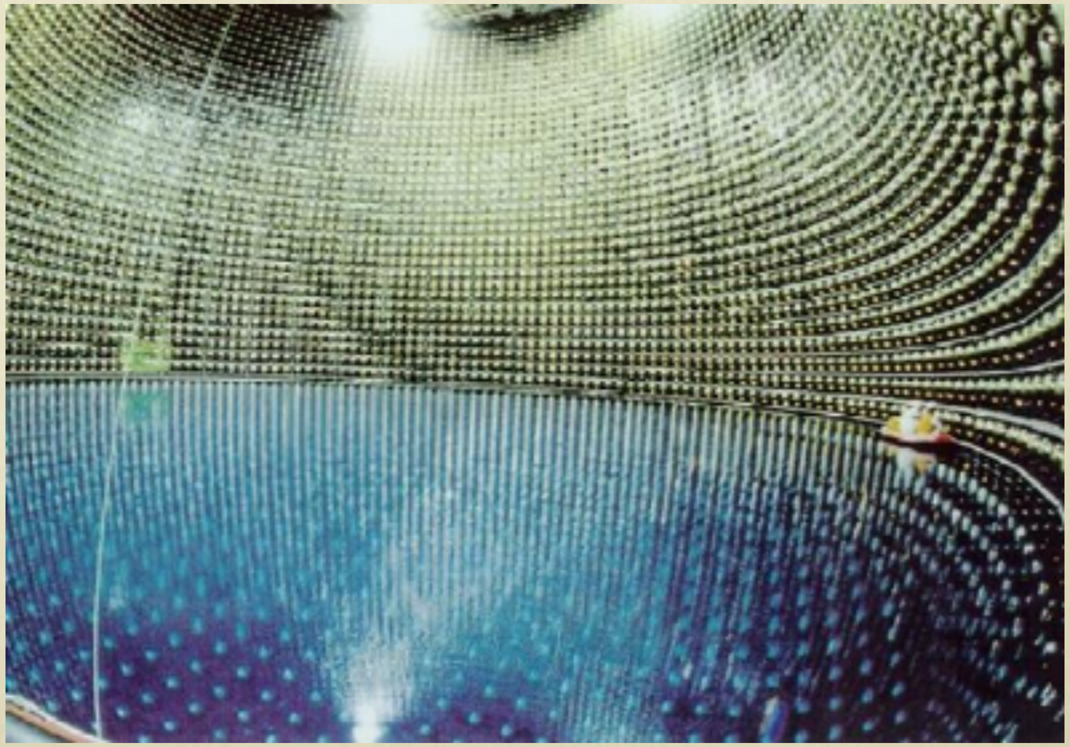


- Detectors installed inside the UA1/NOMAD magnet (0.2 T magnetic field)
  - Allow to select the charge of the particles from their curvature
- In the analysis described today we use the ND280 tracker:
  - 2 Fine Grained Detectors (target for neutrino interactions)
  - 3 Time Projection Chambers: reconstruct momentum and charge of the particles produced in ν interactions, PID based on ionization
  - Electromagnetic Calorimeter do distinguish tracks from showers

Super-Kamiokande

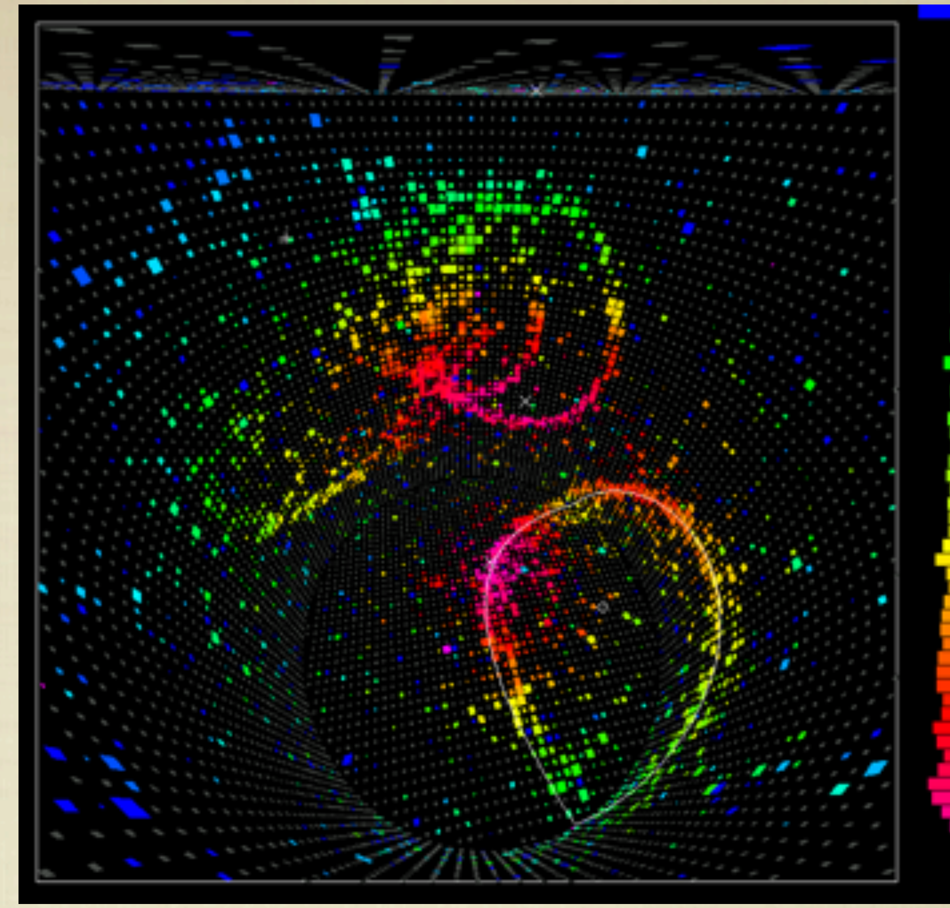
- 50 kton water Cherenkov detector (22.5 kton FV)
  - ~11000 20'' PMT inner detector (~2000 8'' PMT outer detector used as veto)
- ~1000 meters underground in the Kamioka mine
- Operated since 1996 (upgraded for T2K)
- Very good PID capabilities to distinguish electrons from muons

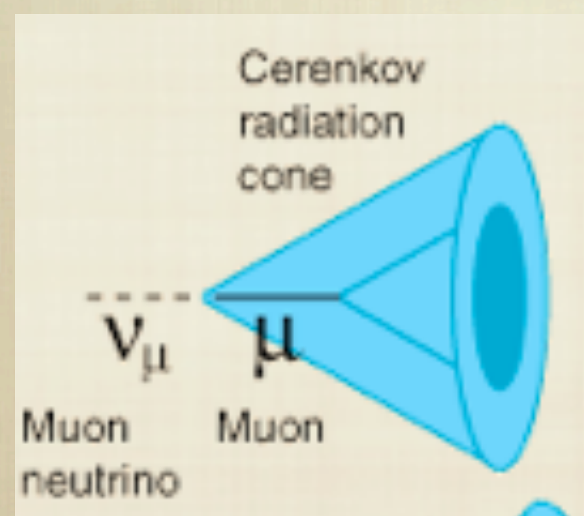


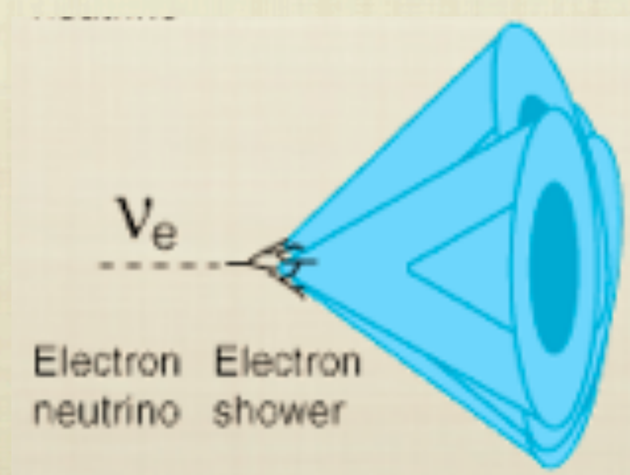


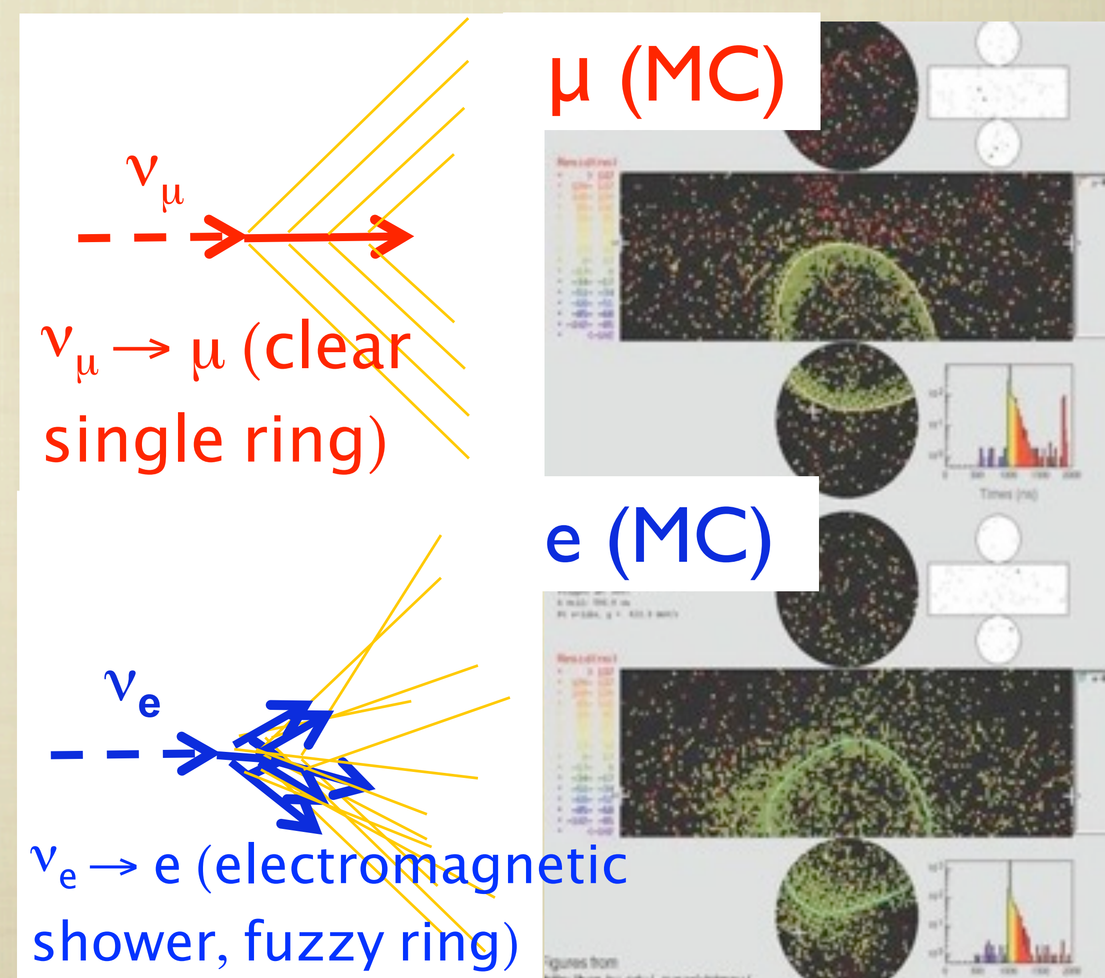
ν detection at SK

- Neutrinos interact in the water producing charged leptons (νμ → μ and νe → e)
- The charged lepton travels with a speed larger than the speed of the light in water (n_{water} = 1.3)
- The lepton emits bluish light in a cone (Cherenkov effect) that is then collected by the PMT on the wall



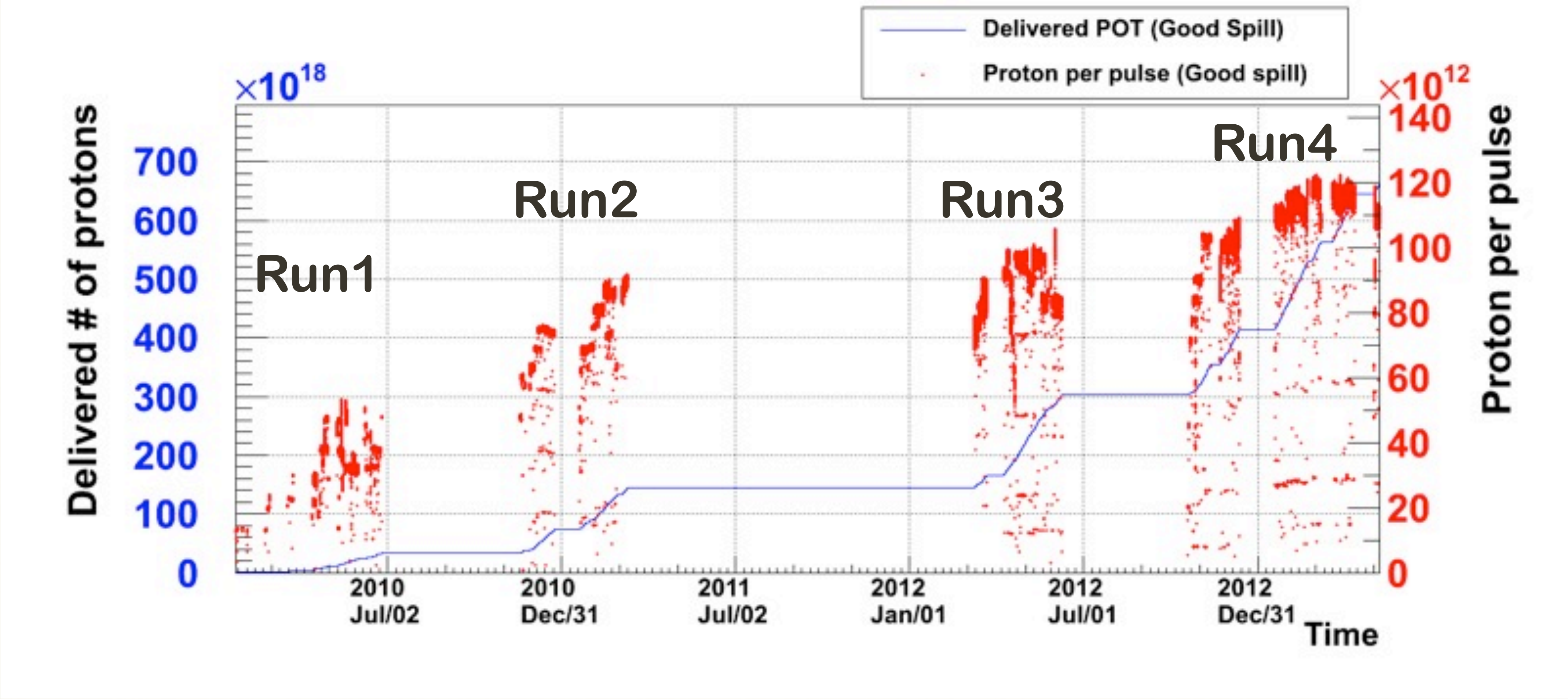






T2K oscillation analyses

Data-sets



- Total delivered: 6.33×10^{21} proton on target (pot)
- ν_e appearance analysis: 96.3% of Runs 1-4
- ν_μ disappearance analysis only use Run 1-3 (3.01×10^{21} pot)
  - Full data-set will be analyzed soon

Typical oscillation analysis

- Combination of several inputs

Flux prediction:
- ✓ Proton beam stability
- ✓ Hadron production (NA61 and others external data)

ND280 measurements:
- ✓ ν_μ selection to constrain flux and cross-sections
- ✓ Measure ν_e beam component

Neutrino interactions:
- ✓ Interaction models
- ✓ External cross-section data

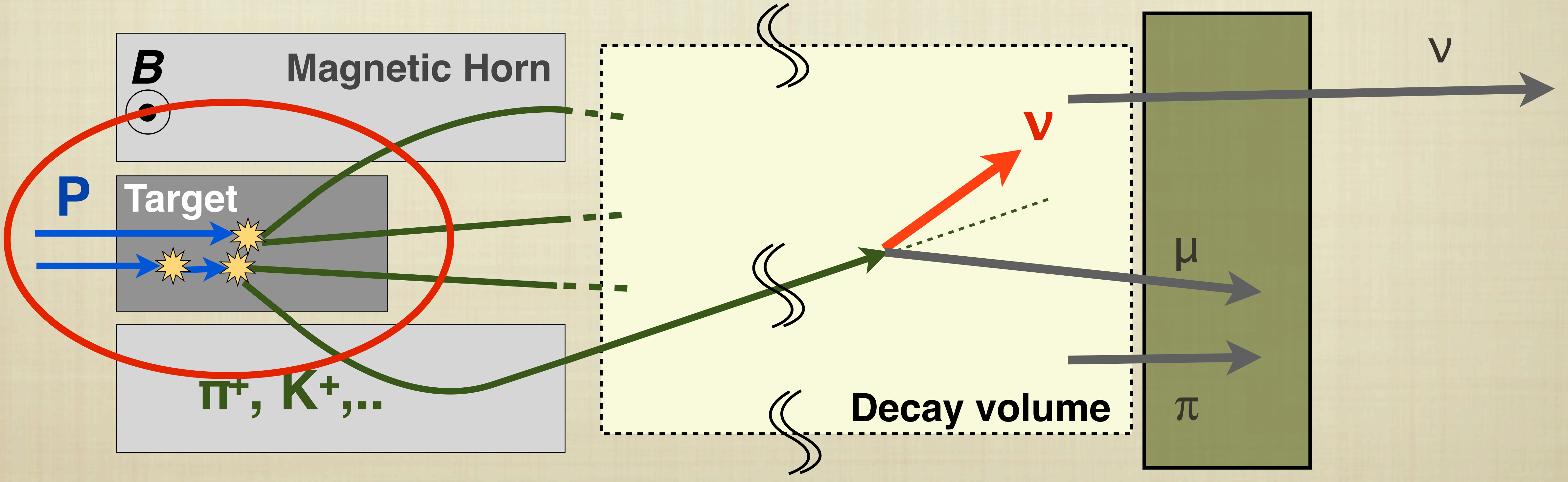
Prediction at the Far Detector:
- ✓ Combine flux, x-section and ND280 to predict the expected events at SK

Extract oscillation parameters!!!

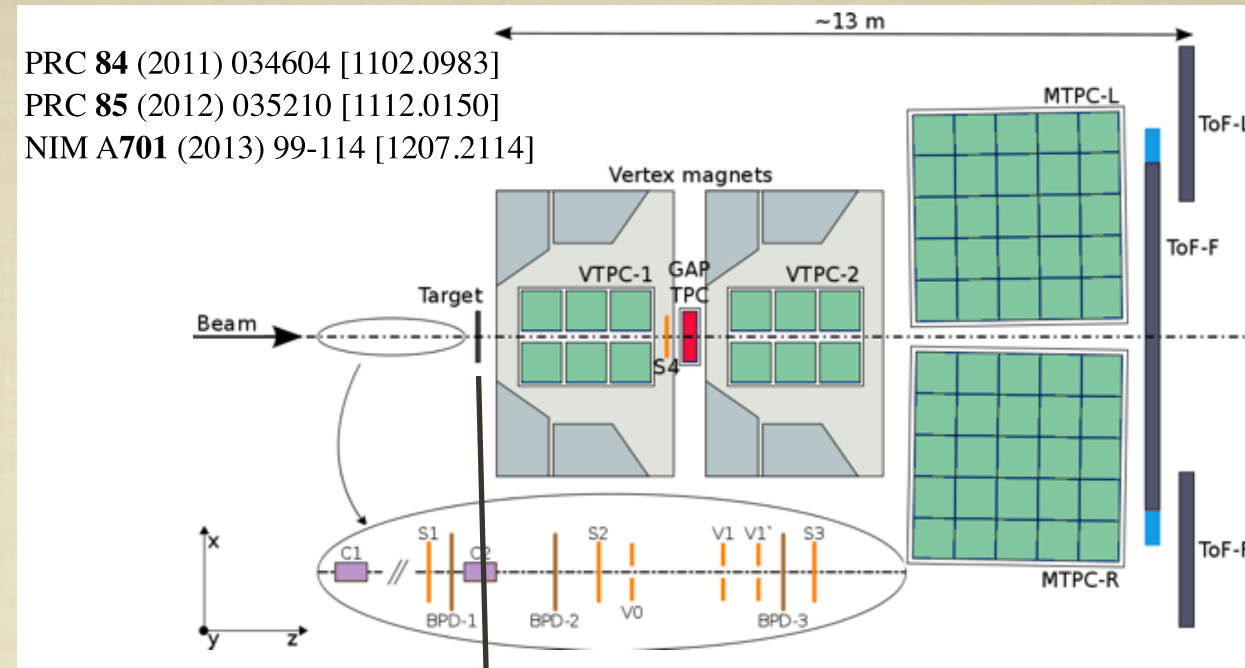
Super-Kamiokande measurements:
- ✓ Select CC ν_μ and ν_e candidates after the oscillations

Flux prediction

- Hadro-production cross-section
  - ν comes from π and K produced in p+C interactions
  - Cross-section for those processes not well known
  - Need of a dedicated experiment → NA61/SHINE
- Neutrino beam monitoring
  - Stability of the beam during the data taking
- Determination of the ν fluxes and uncertainties



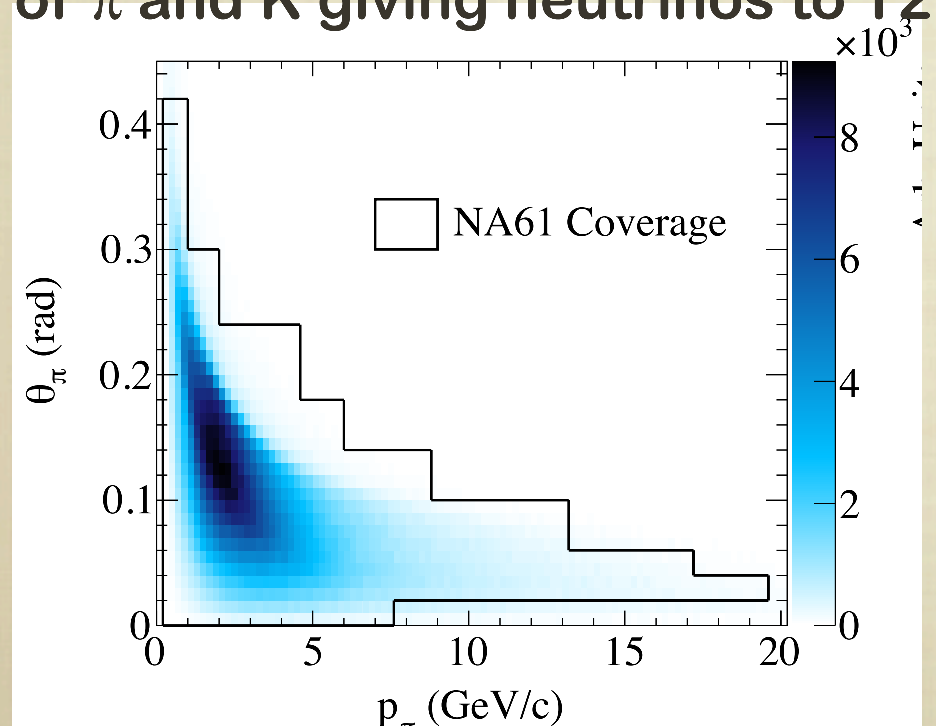
NA61/SHINE



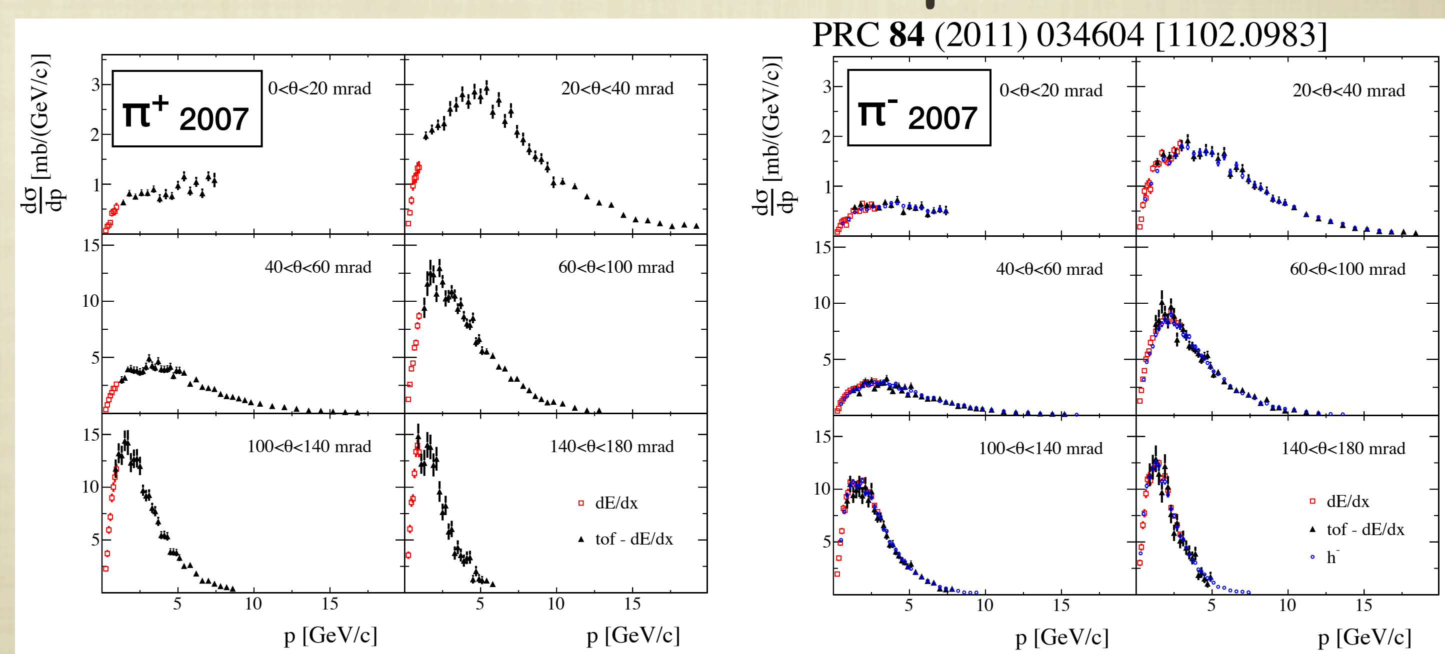
- T2K proton interacts on a 90 cm long Carbon target producing π and K → ν
- Main uncertainty comes from hadro-production cross-section → NA61/SHINE dedicated experiment @ CERN to measure hadro-production cross-section

2 targets: thin target and T2K target

Full coverage of the phase-space of π and K giving neutrinos to T2K

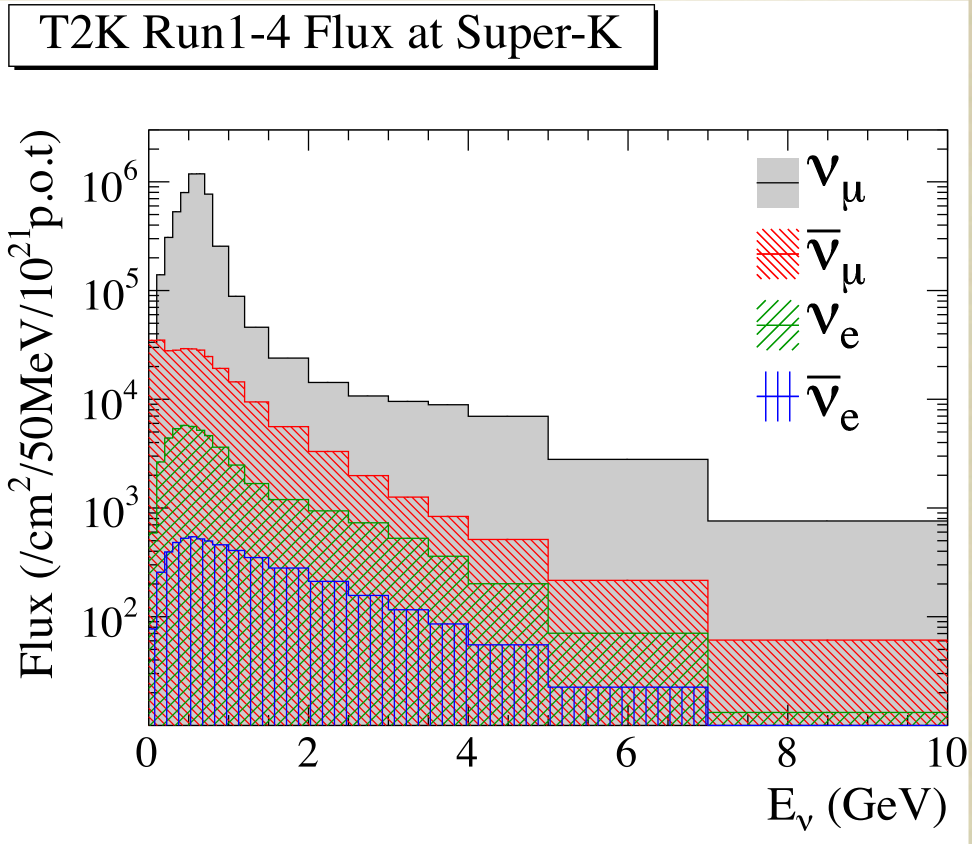


First NA61 data on thin target already added to T2K flux prediction

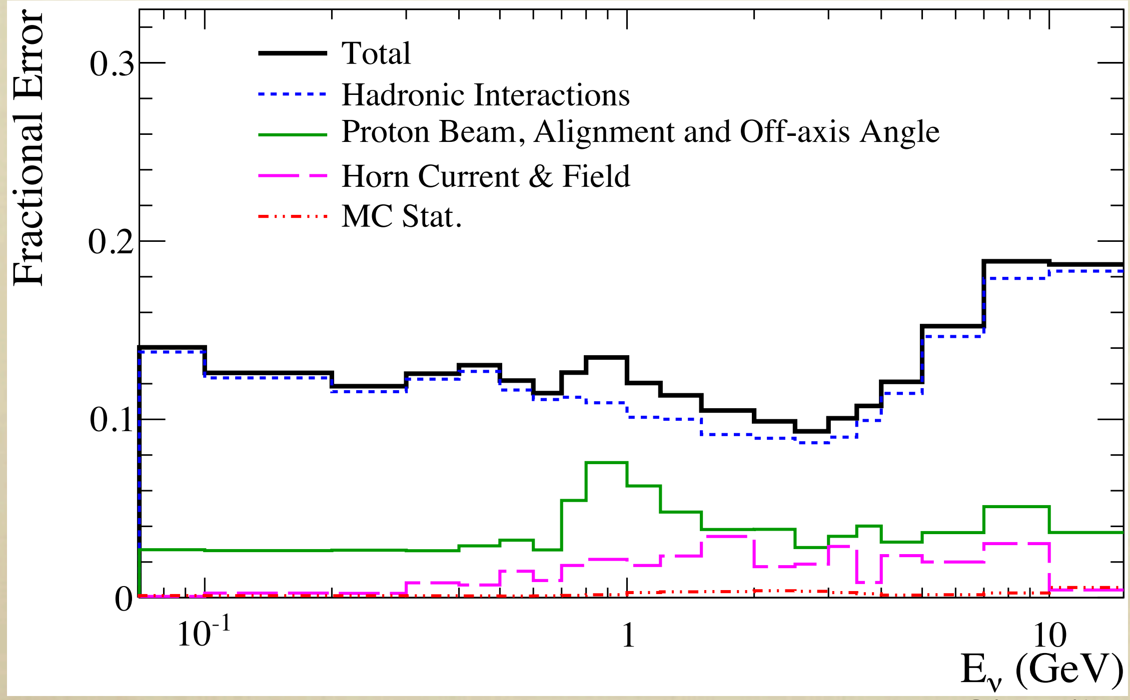


T2K predicted fluxes

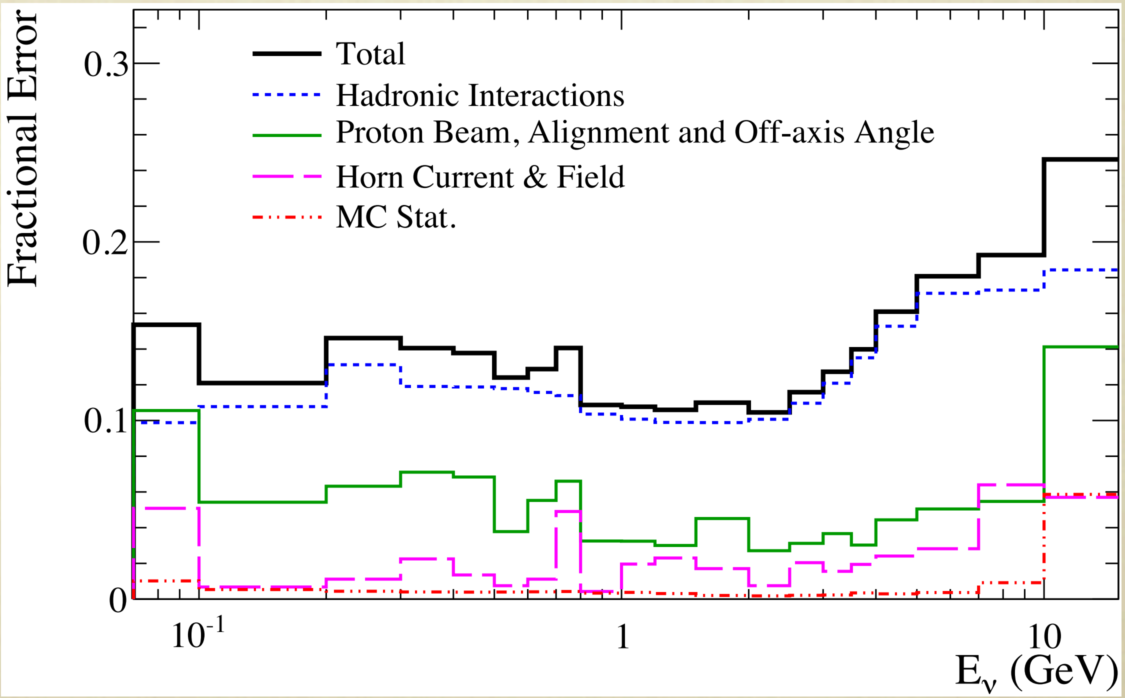
- Fluxes in T2K are predicted with a 10-15%
- Main error still come from hadronic interaction cross-section → to be further reduced with addition of more NA61 data
- Intrinsic ν_e component ~1.2% of the total flux



ν_μ

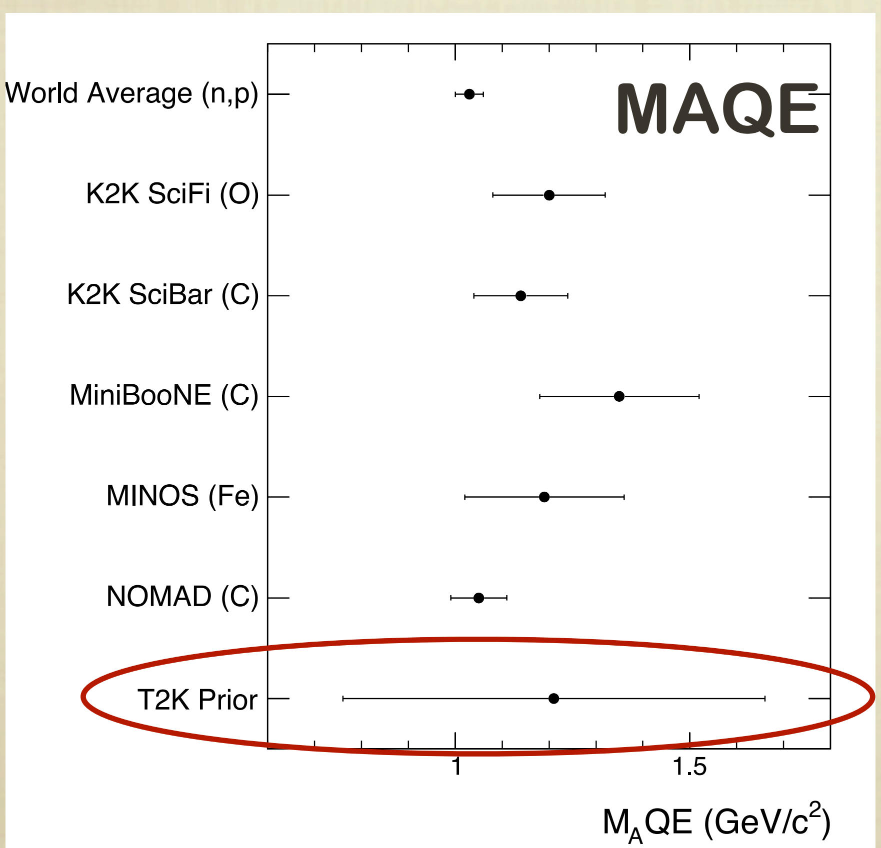


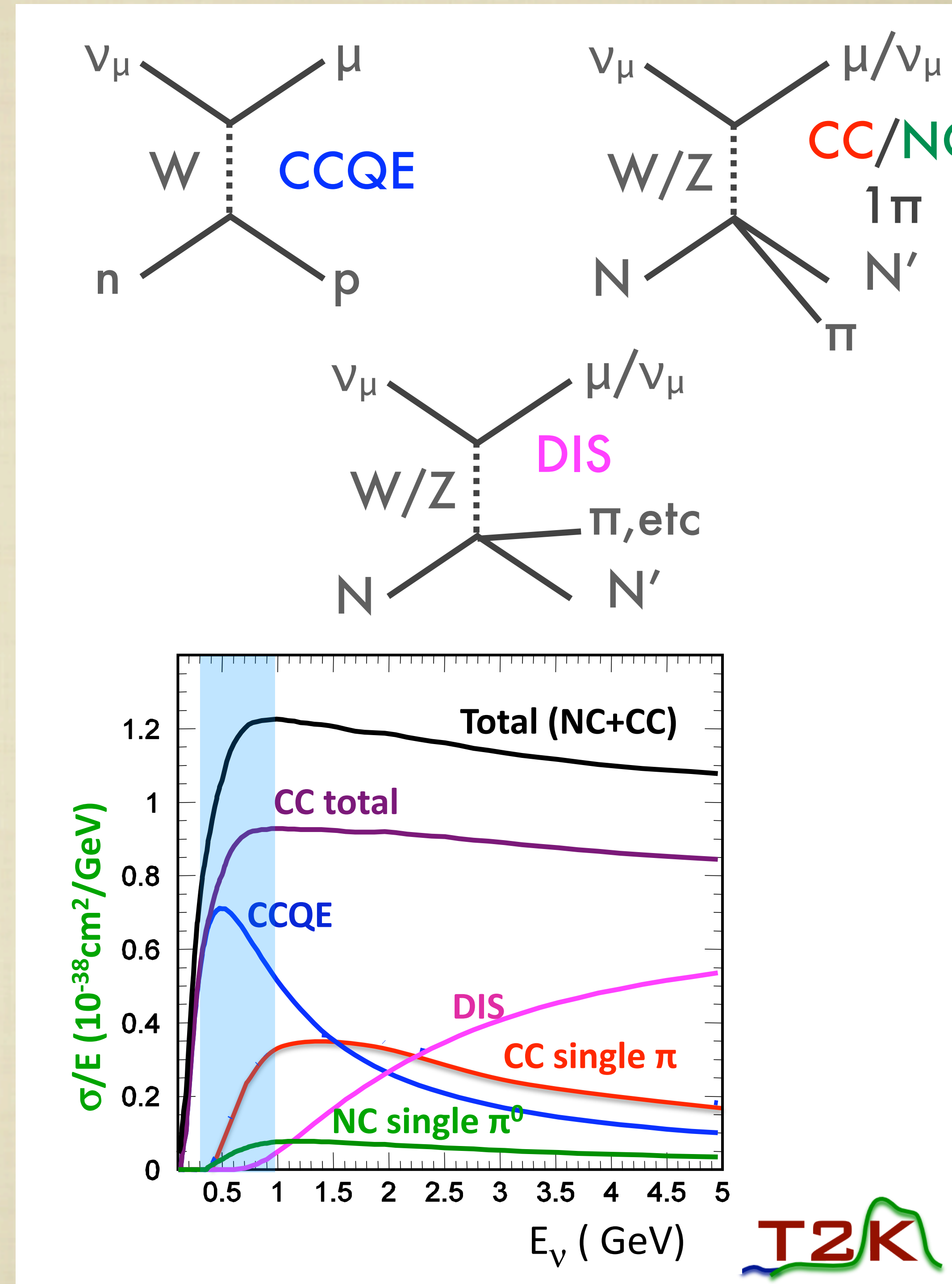
ν_e



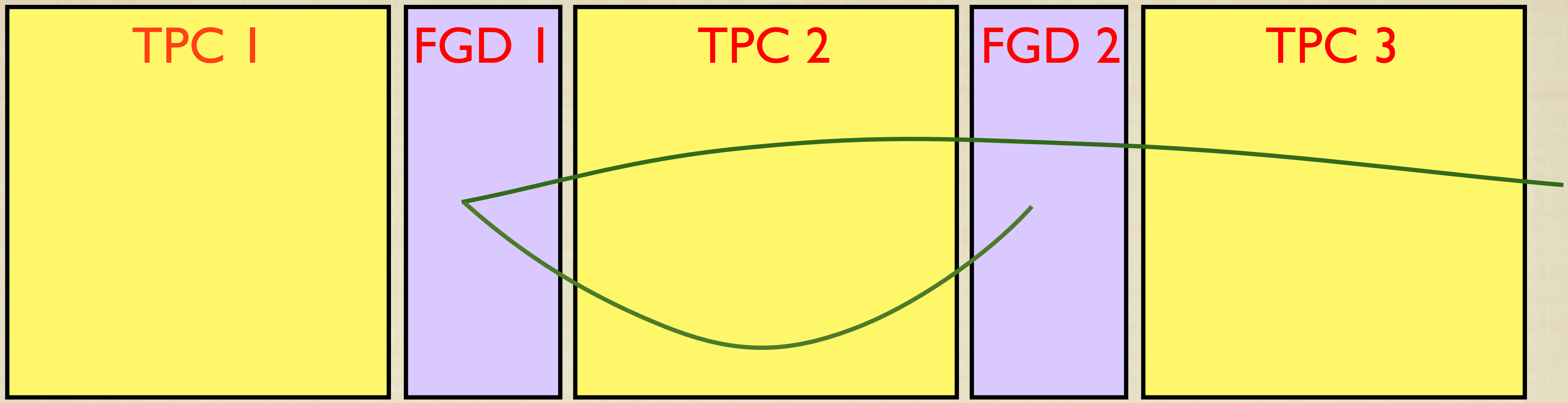
Cross-section models

- At the T2K energies ν interactions occurs through many processes (CCQE, CC1π, CC DIS, NC)
- Approach: use external data (mainly MiniBooNE data) and add effective parameters with uncertainties that span models and data
- Constrain those parameters using ND280

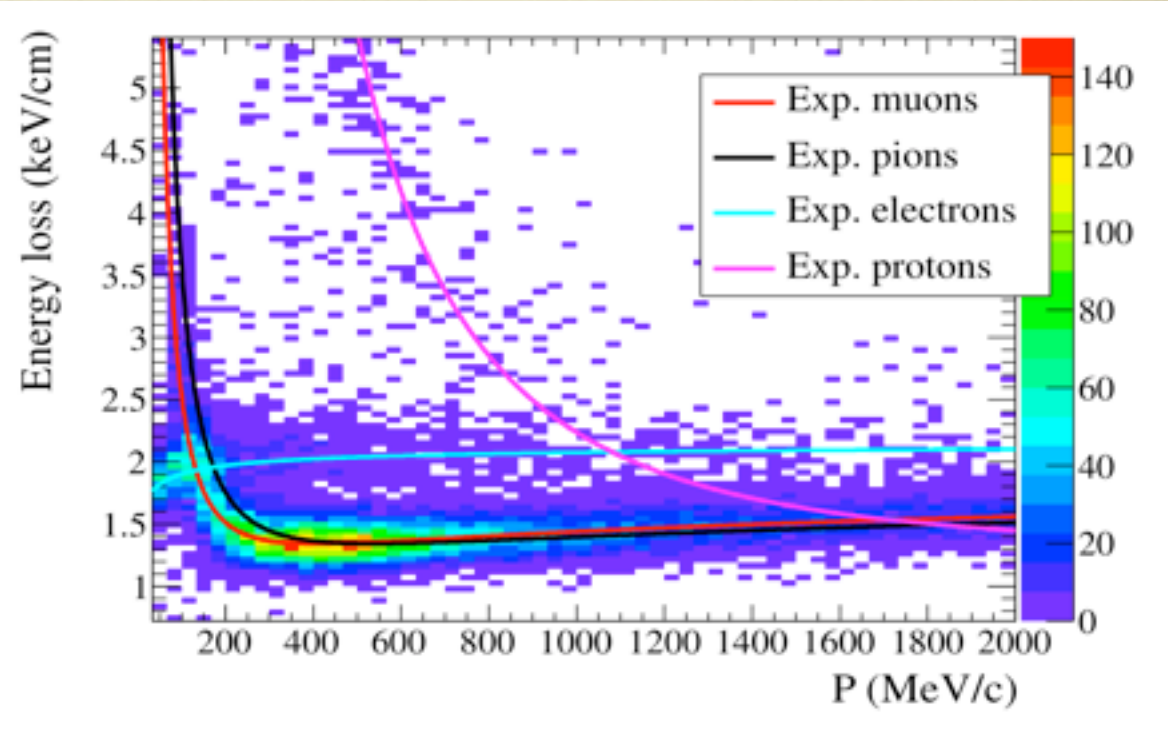




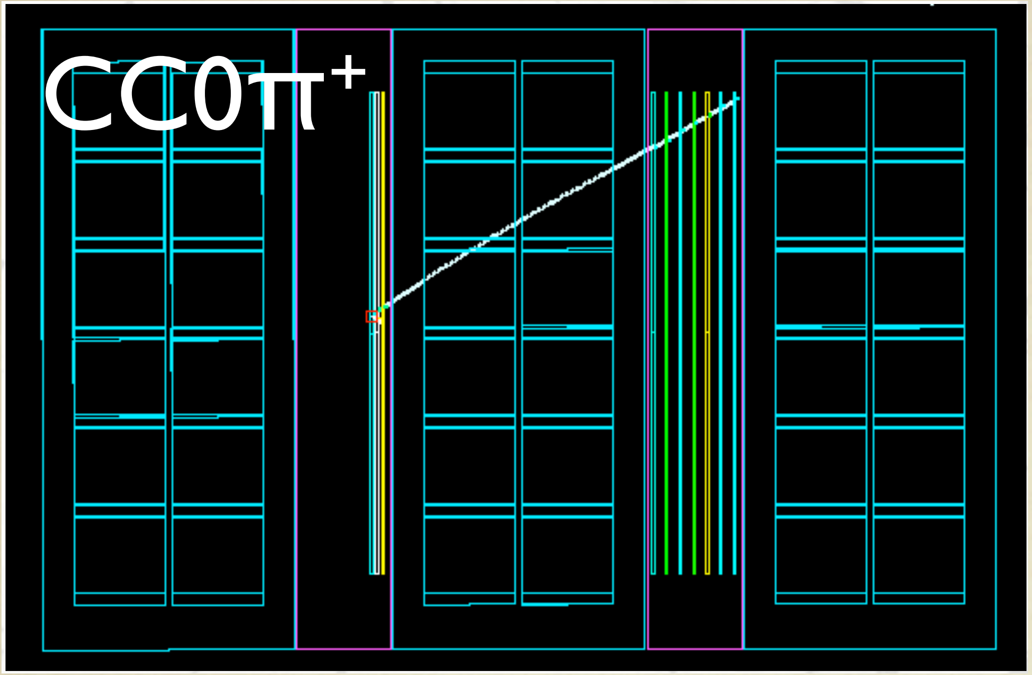
ND280: ν_μ analysis

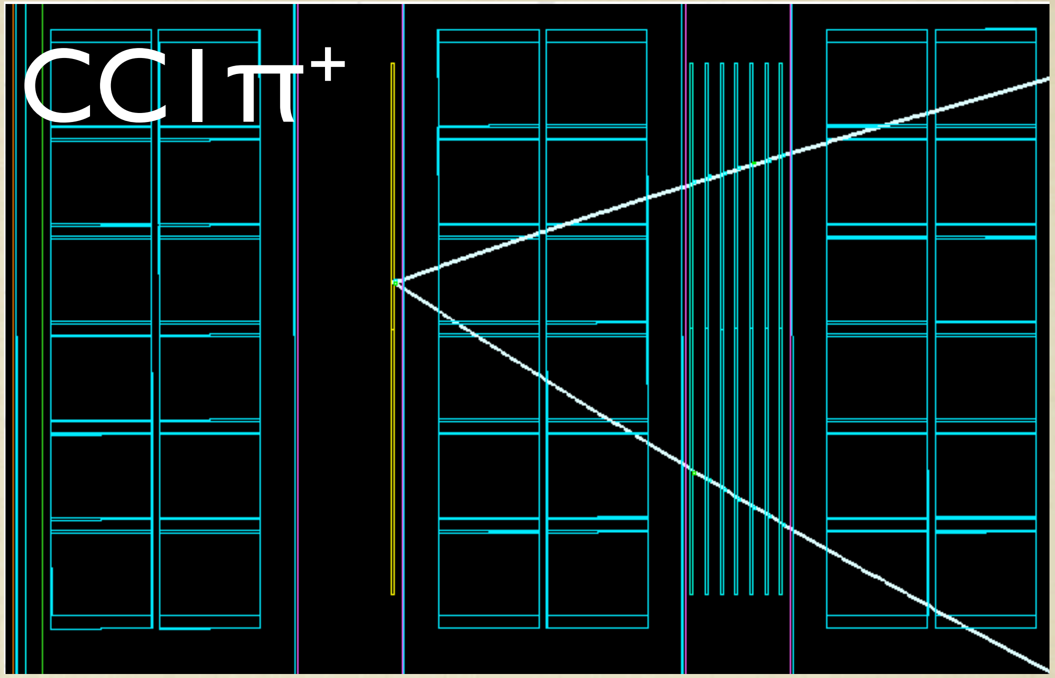


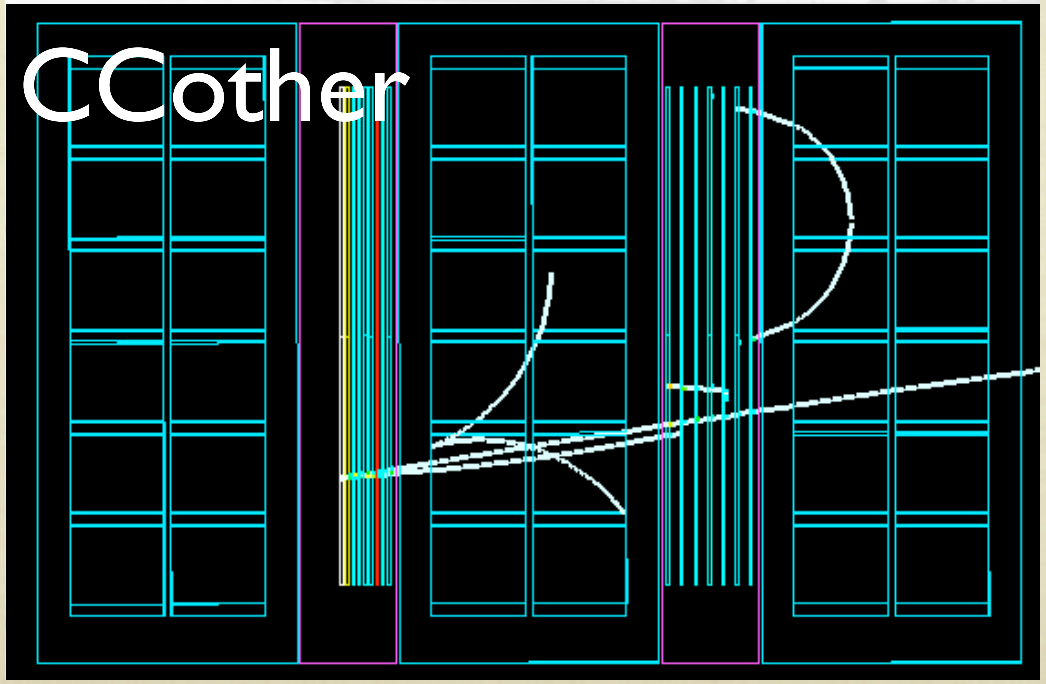
- Select neutrino interactions in the FGD FV with tracks entering the TPC
- Identify the lepton as the most energetic negative track → require the TPC PID compatible with a μ
- Distinguish 3 samples according to the topology of the other tracks
  - 0 π, 1 π^+, others



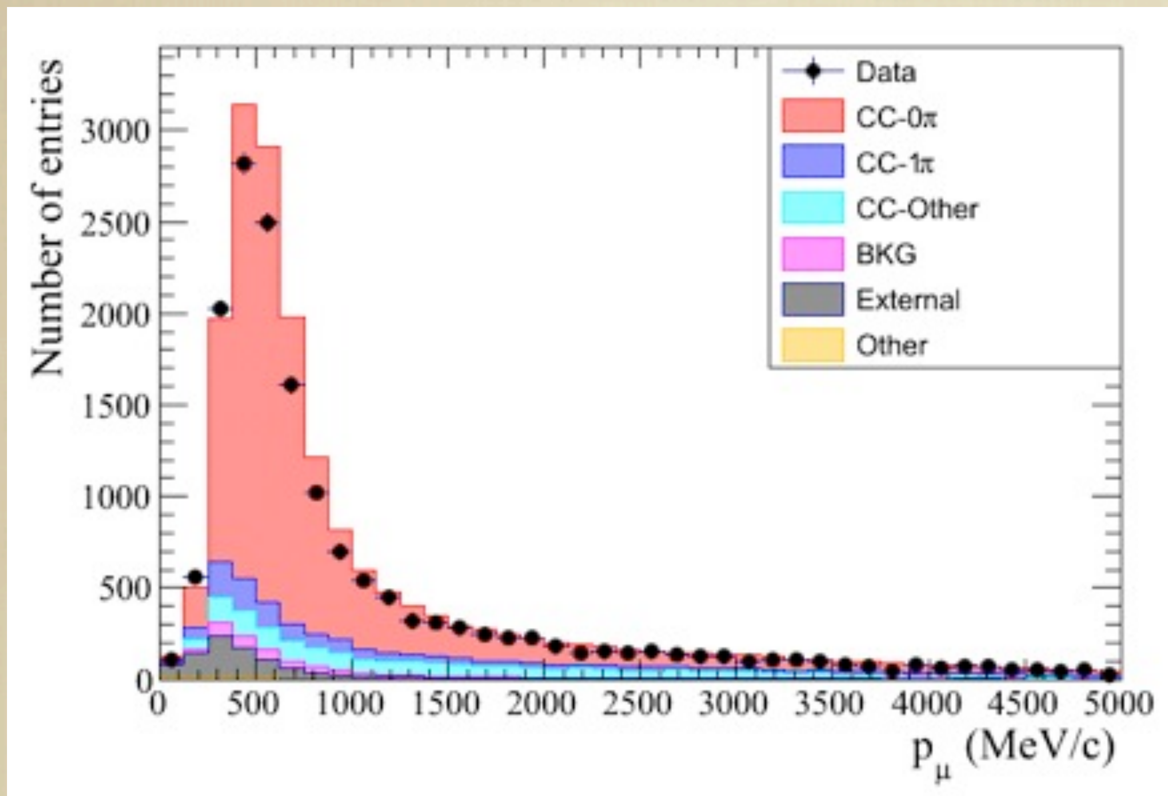
Event displays

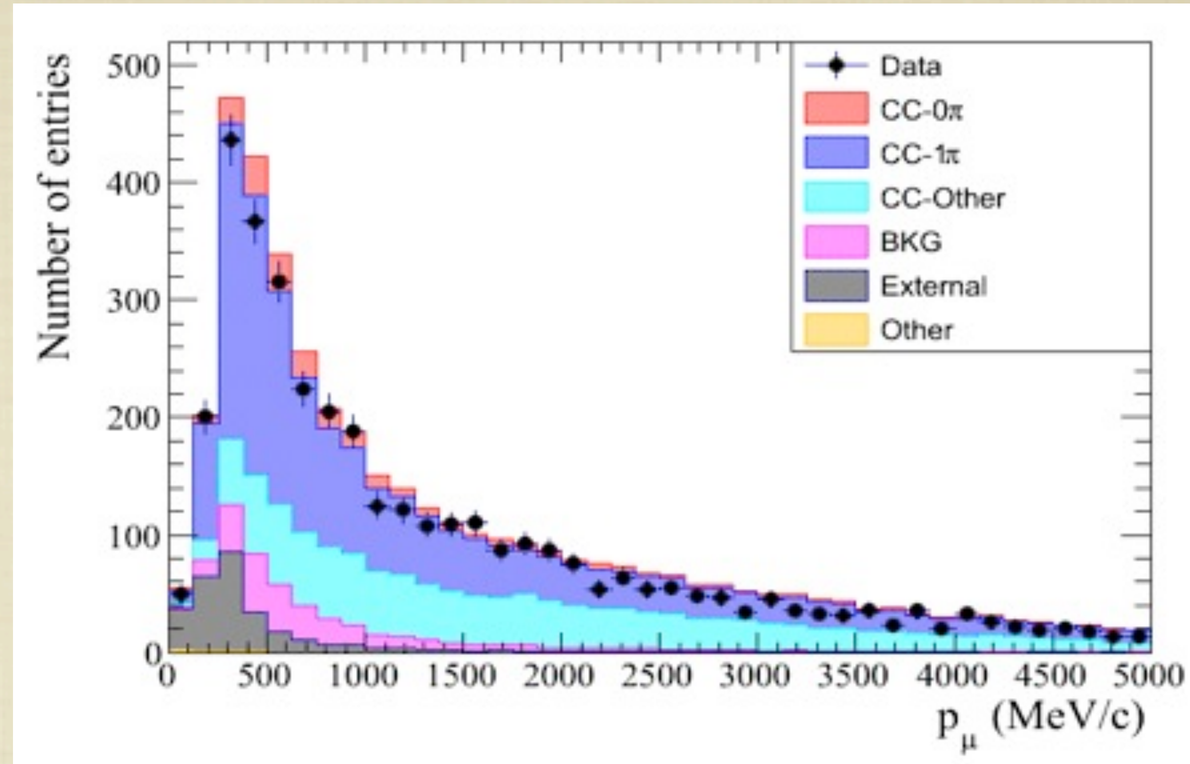


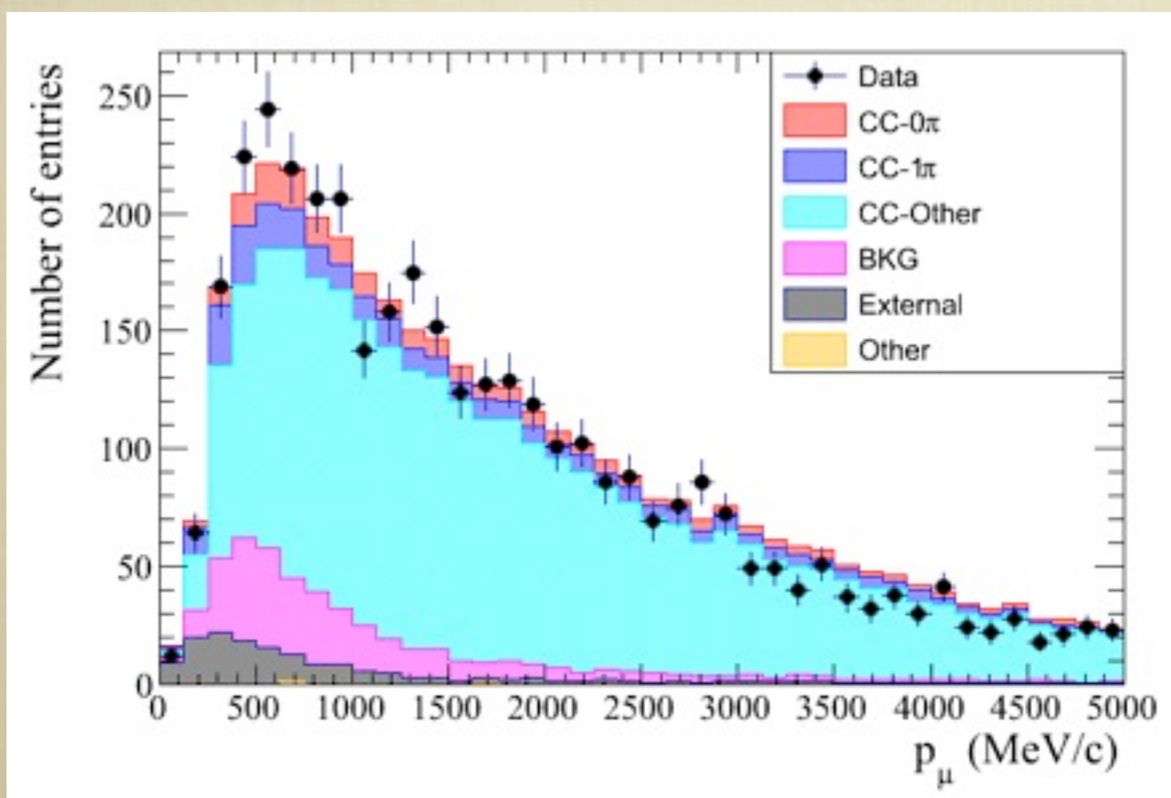




ND280 ν_μ analysis





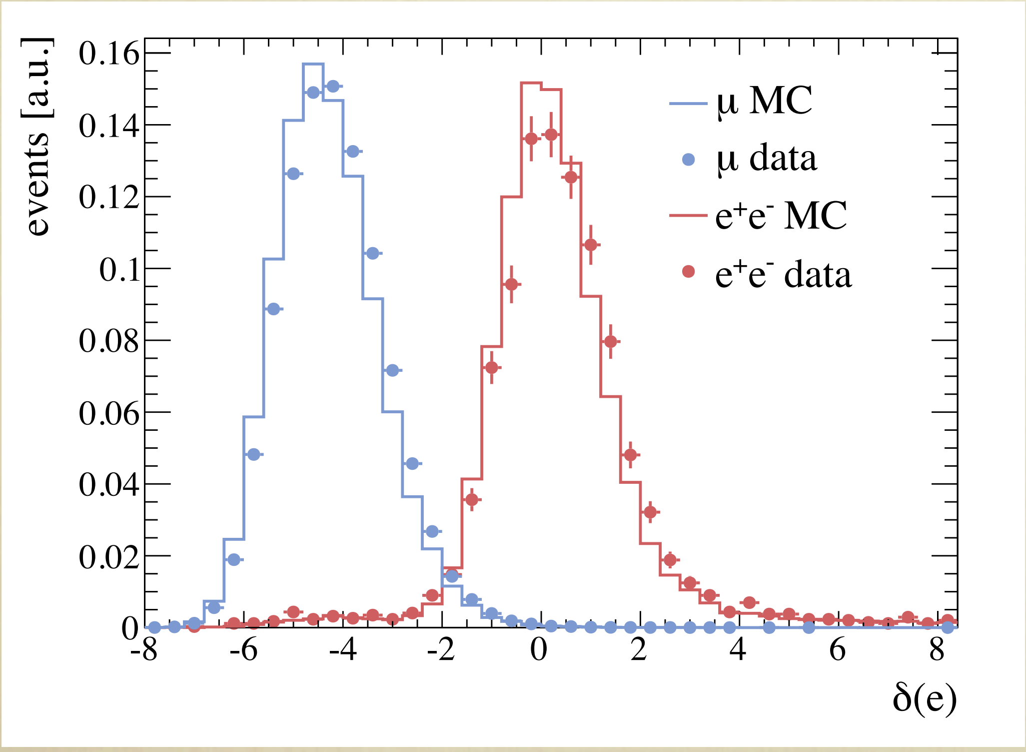


	Purities			Efficiency
	CC0π	CC1π	CCOther	
CC0π	73.5%	6.5%	6.1%	50.1%
CC1π	8.5%	50.5%	8.3%	29.5%
CCOther	10.9%	29.8%	72.9%	35.2%
Bkg	2.2%	6.8%	8.7%	
OOFDG1FV	4.9&	6.4%	4.0%	

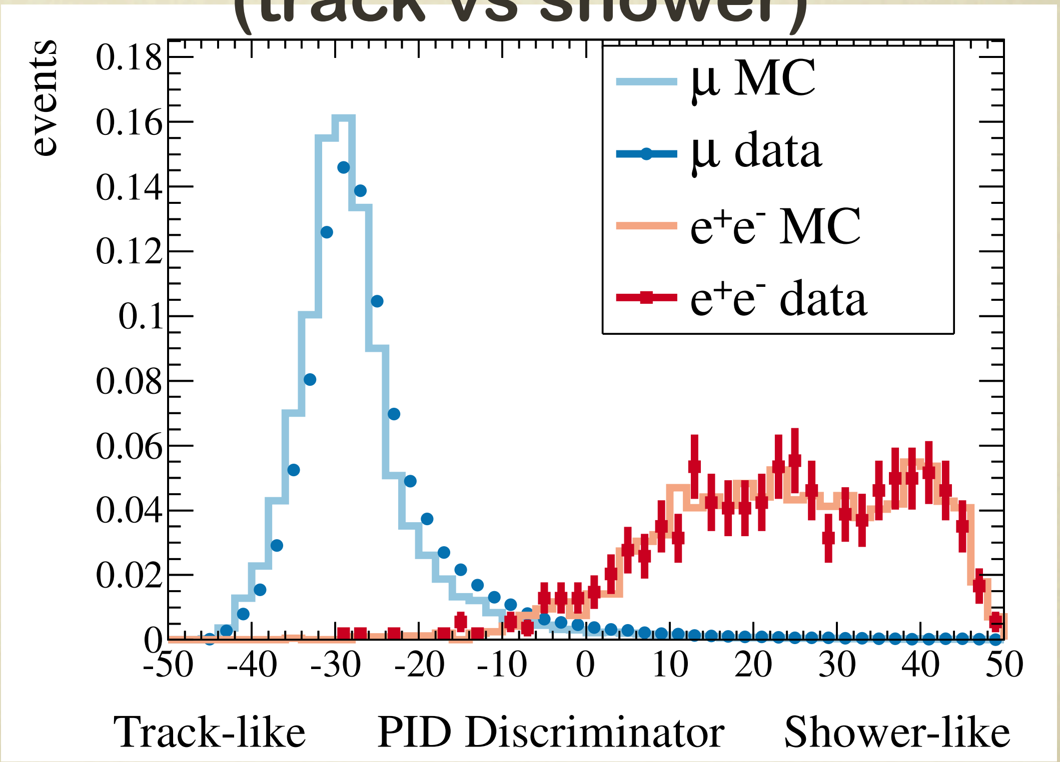
PID capabilities of ND280

- Beam νe component is the main background to the νe appearance analysis → ~1.2% of the flux is composed by intrinsic νe
  - Has to be measured at ND280
- To select electrons is fundamental to fully exploit the PID capabilities of ND280 detectors → TPC and ECal

TPC → based on dE/dx

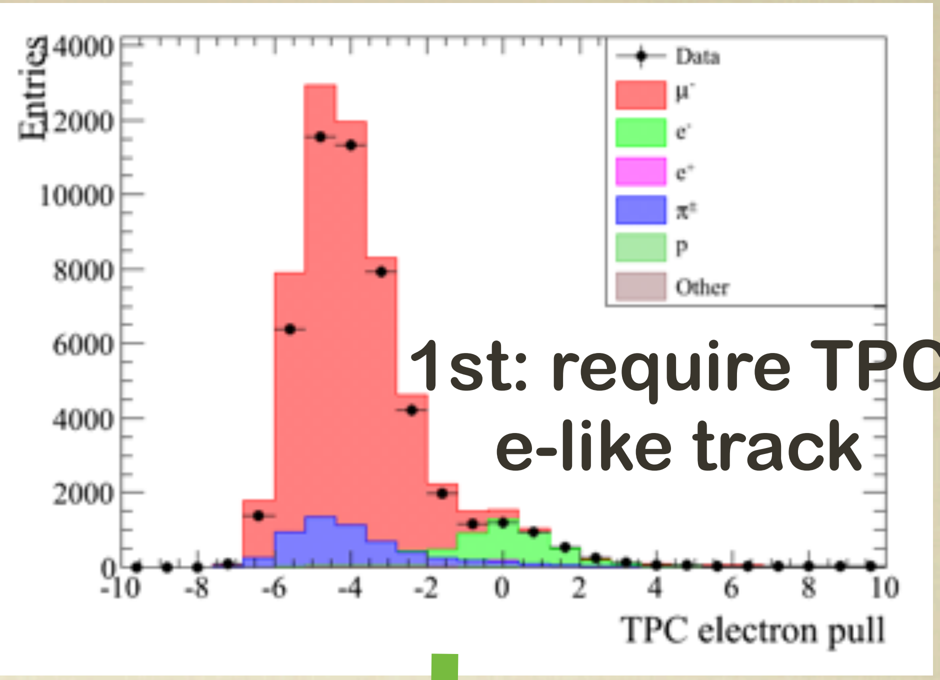


ECal → based on MVA (track vs shower)

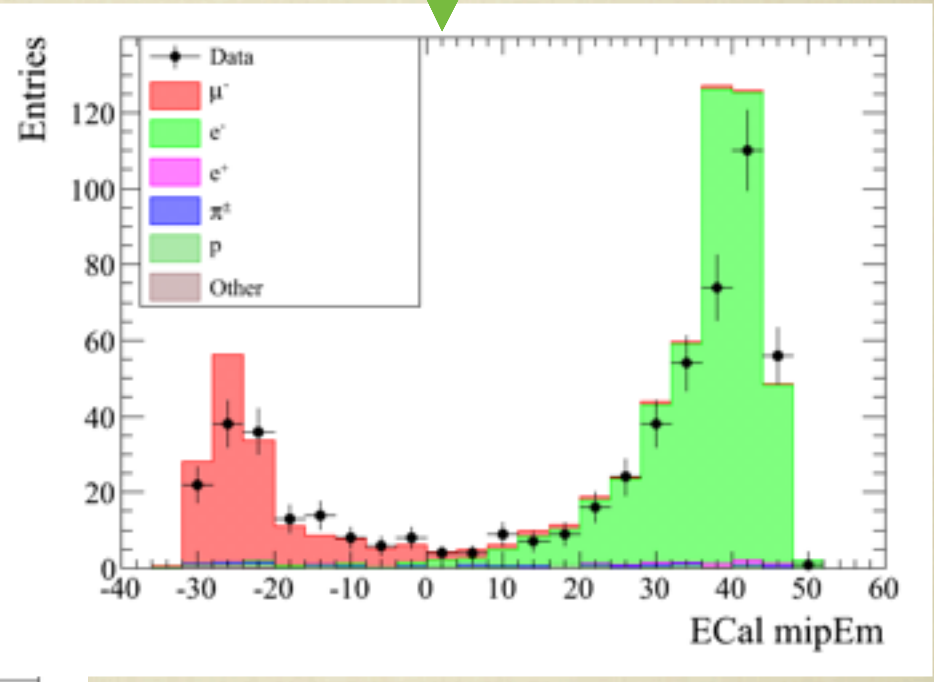


ND280 ν_e analysis

- Combine TPC and ECAL PID capabilities
  - 99.9% of muons are rejected
  - Purity in selecting electrons 92%

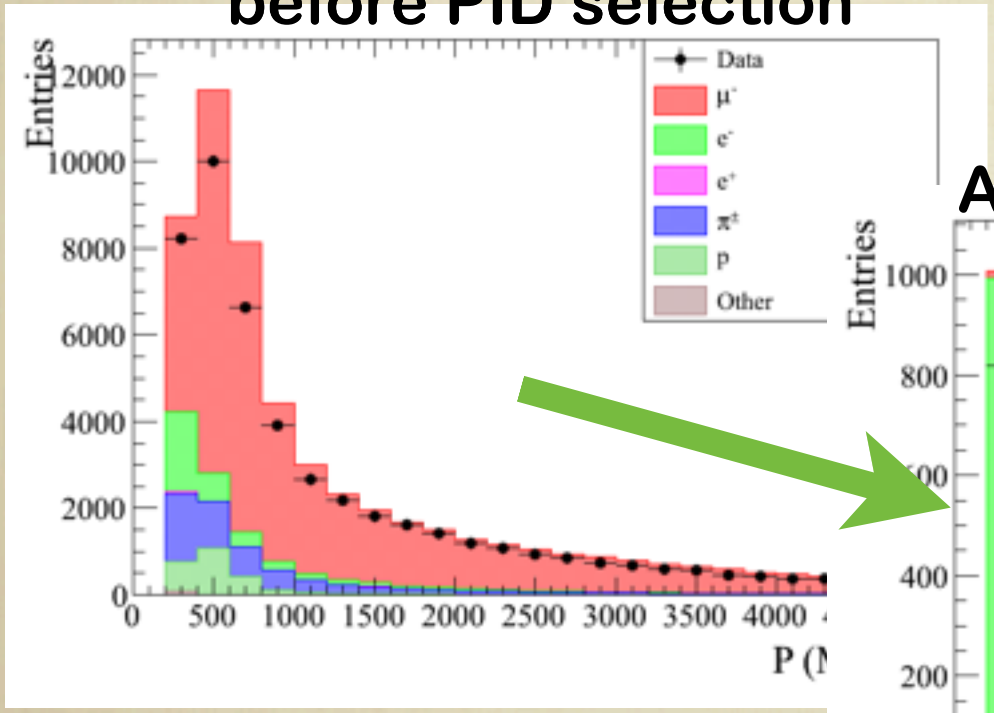


1st: require TPC e-like track

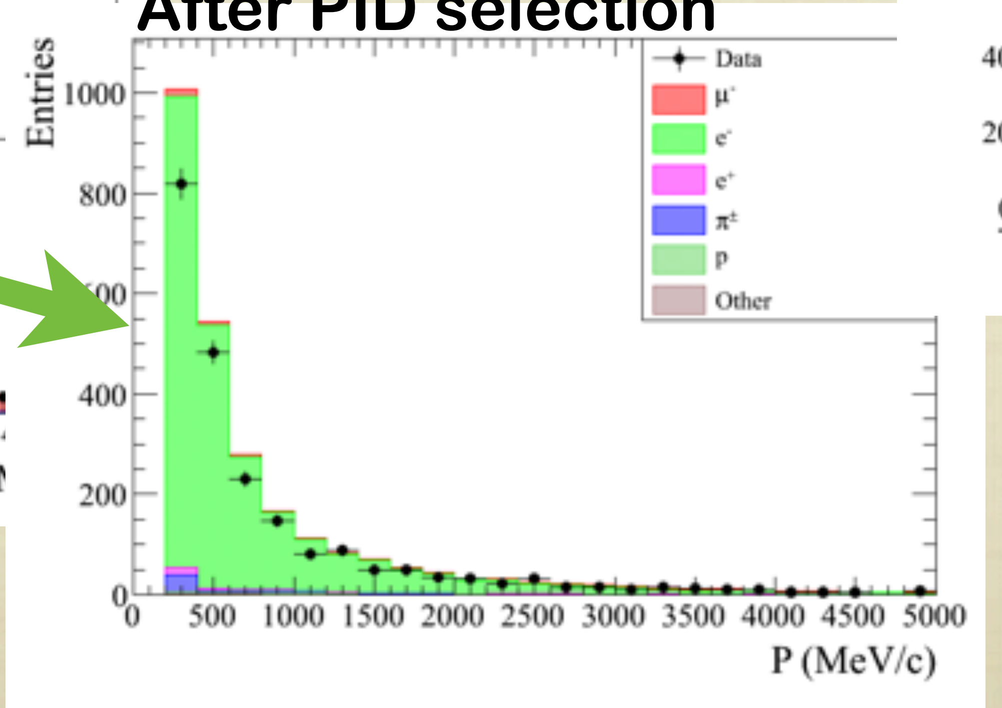


2nd: require ECal shower like track

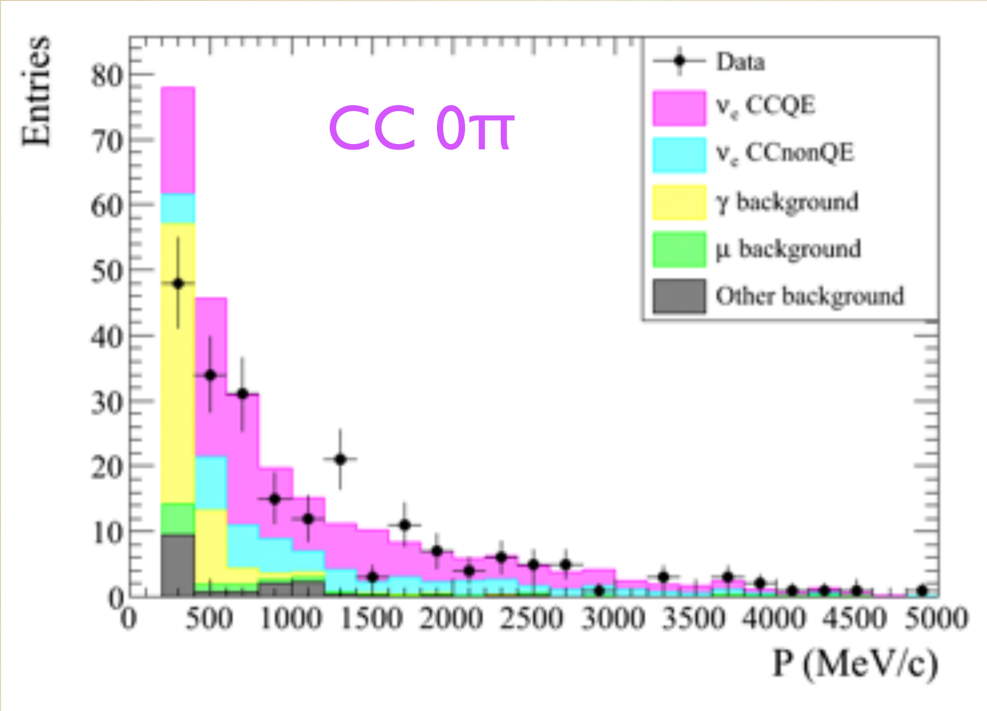
Momentum before PID selection

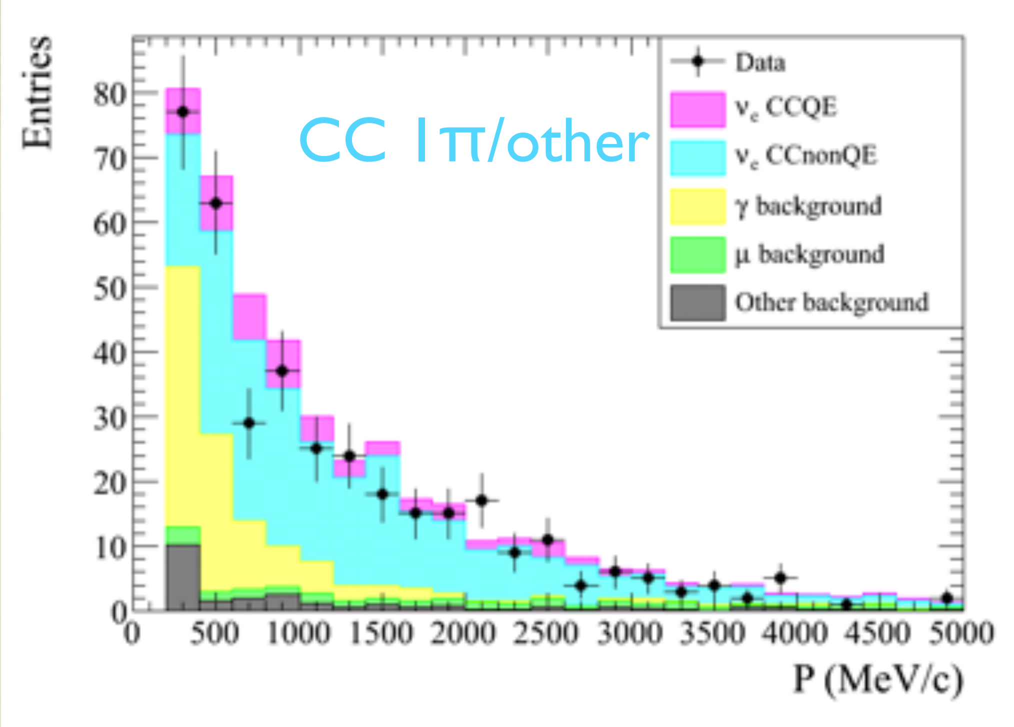


After PID selection



ND280 ν_e analysis

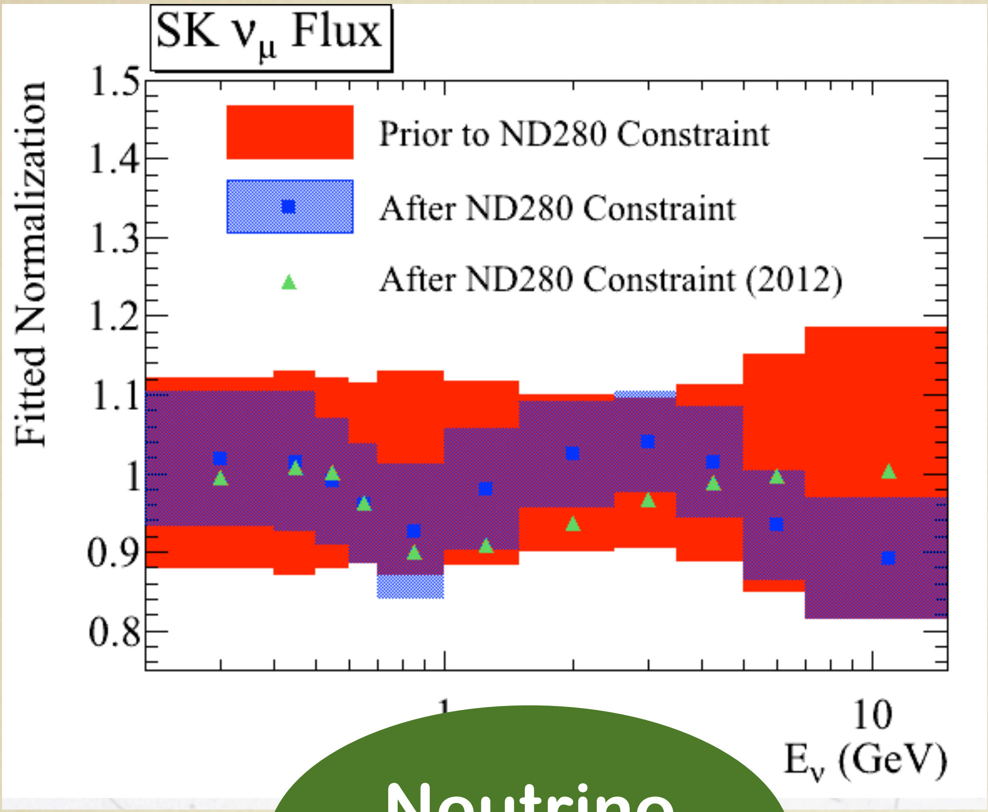




$$f(\nu_e) = 1.055 \pm 0.058(\text{stat.}) \pm 0.079(\text{syst.})$$

- **Largest background from γ conversions in the FGD**
  - **65% νe purity**
  - **γ background constrained using a pure sample of γ conversions**
  - **Separated between 1 track (CC0π) and > 1 track (CC1π/other)**
- **Fit to extract the νe component → direct confirmation of the expected ν_e component at the 10% level**

Predicted events at SK

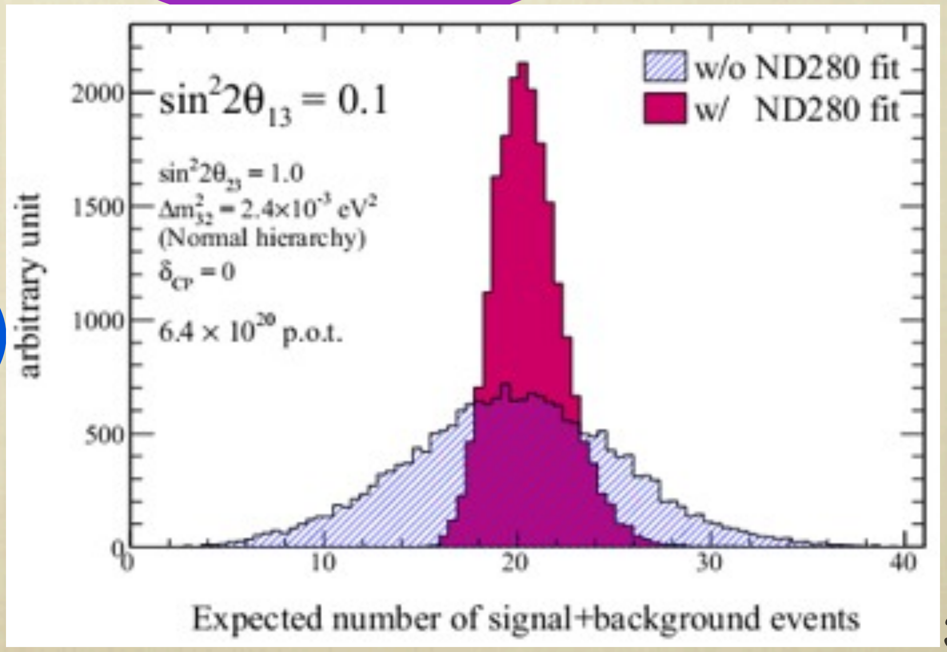


Neutrino flux models

Parameter	Prior to ND280 Constraint	After ND280 Constraint
M_A^{QE} (GeV)	1.21 ± 0.45	1.223 ± 0.072
M_A^{RES} (GeV)	1.41 ± 0.22	0.963 ± 0.063
CCQE Norm.	1.00 ± 0.11	0.961 ± 0.076
CC1π Norm.	1.15 ± 0.32	1.22 ± 0.16
NC1π^0 Norm.	0.96 ± 0.33	1.10 ± 0.25

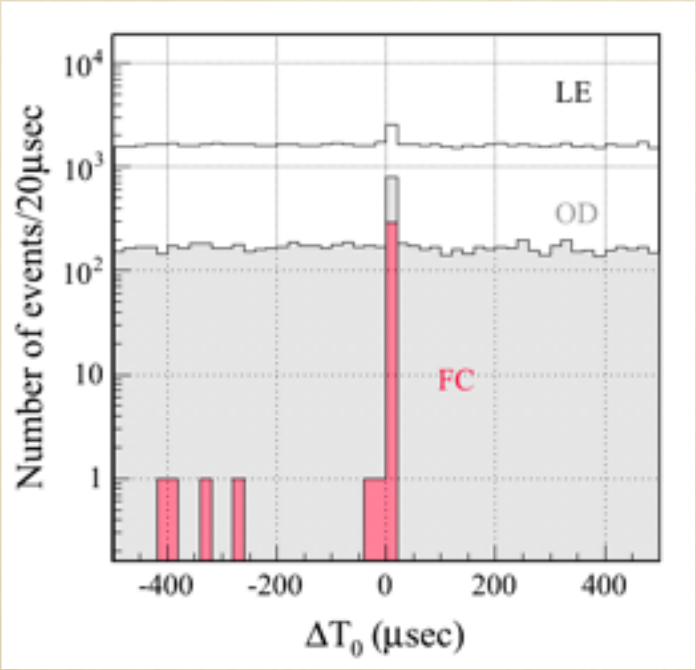
Neutrino x-sec models

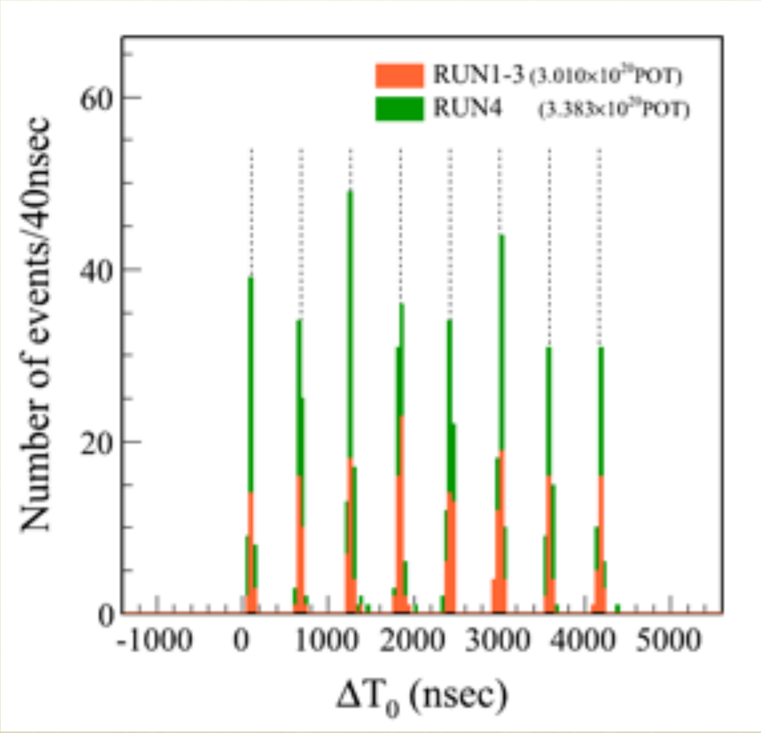
Constrained with
ND280 ν_μ data (0, 1, multi-π)
Reduce the error on the envelop
from 27% to 3%!



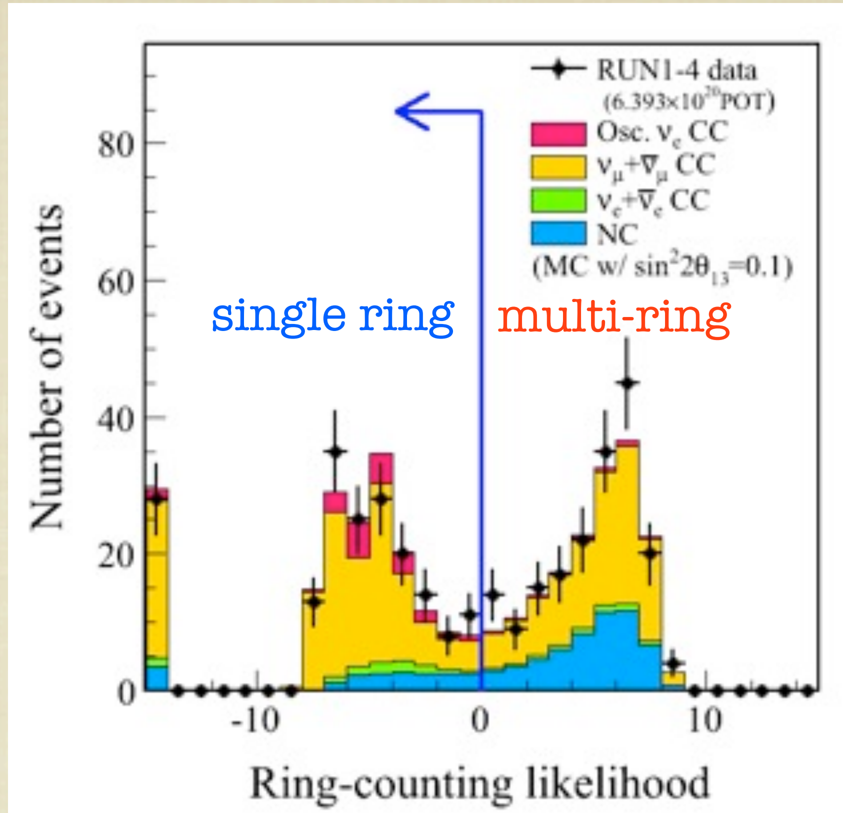
Observed events at SK

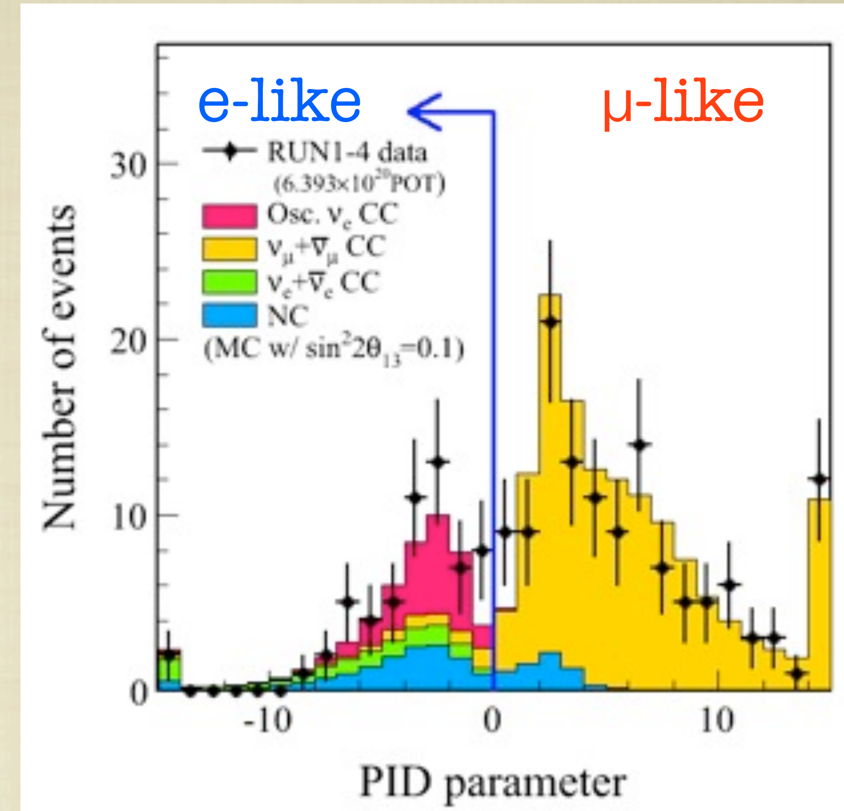
- Define event selection at Super-Kamiokande for ν_μ and ν_e candidates
- First steps are common:
  - Select events compatible with beam timing
  - Fully contained events in the SK FV (FCFV)
- Then the selection is separated between ν_μ and ν_e essentially looking for single-ring events compatible wiht a muon or with an electron





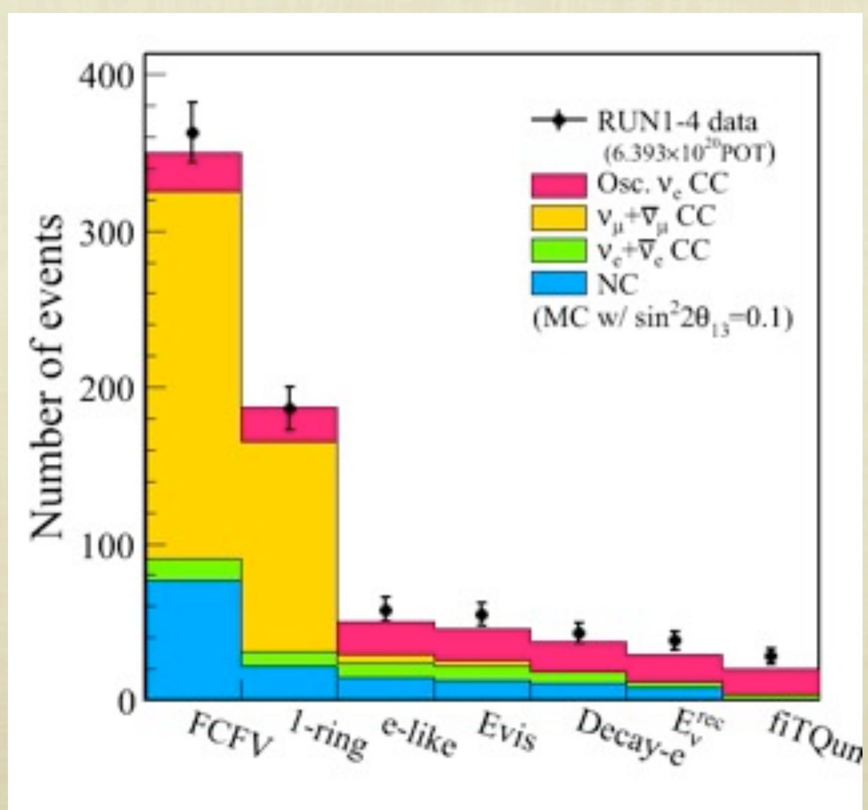
SK ν_e event selection

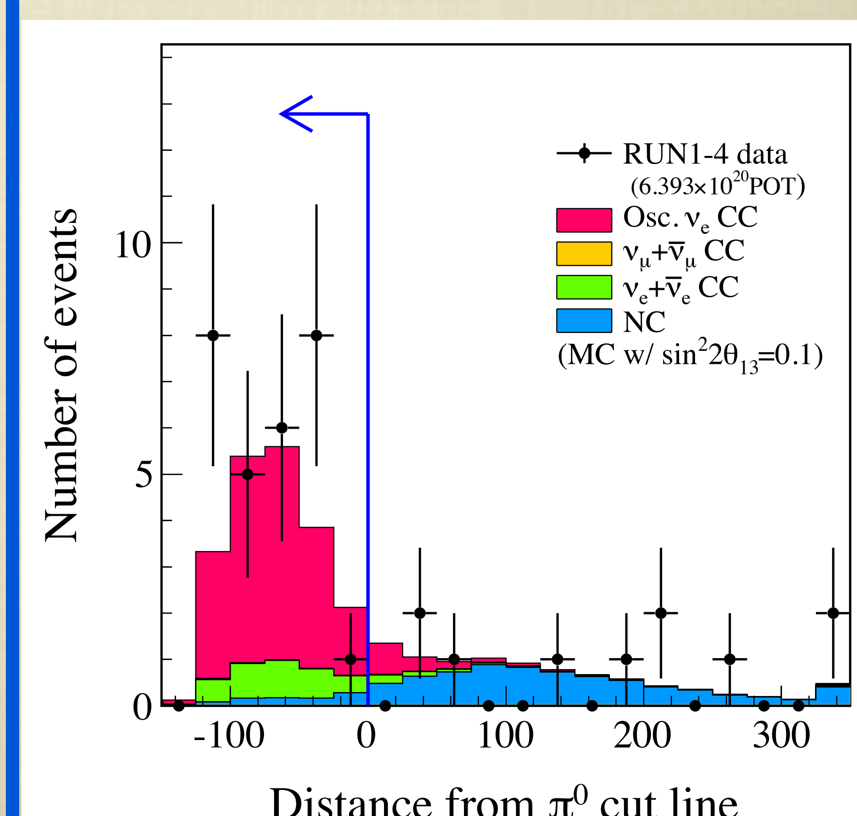




ν_e Selection Cuts

- Fully Contained FV events
- # of rings = 1
- Ring is e-like
- $E_{visible}$ > 100 MeV
- no Michel electrons
- 0 < E_ν < 1250 MeV
- fiTQun π^0 cut





28 events are selected
Exp. Bcg 4.6 events
(mainly from beam ν_e)

fiTQun: new reconstruction algorithm

$$L(\mathbf{x}) = \prod_{\text{unhit}} P(i\text{unhit};\mathbf{x}) \prod_{\text{hit}} P(i\text{hit};\mathbf{x}) f_q(q_i;\mathbf{x}) f_t(t_i;\mathbf{x})$$

- For each event → **measured charge and time** on each PMT
- A single track in the detector can be specified by a particle type and 7 kinematic variables (**x**):
  - Vertex position (**X,Y,Z,T**), momentum (**P**) and direction (θ, φ)
- For a given **x** the charge and time PDF is produced for each PMT
- All 7 track parameters are fit simultaneously
- To perform PID: compare final likelihood for different particle hypotheses
- Can improve the PID for all the tracks → for now it has been used only for the π^0 rejection

Time PDF

Charge PDF

PMT Charge Response:

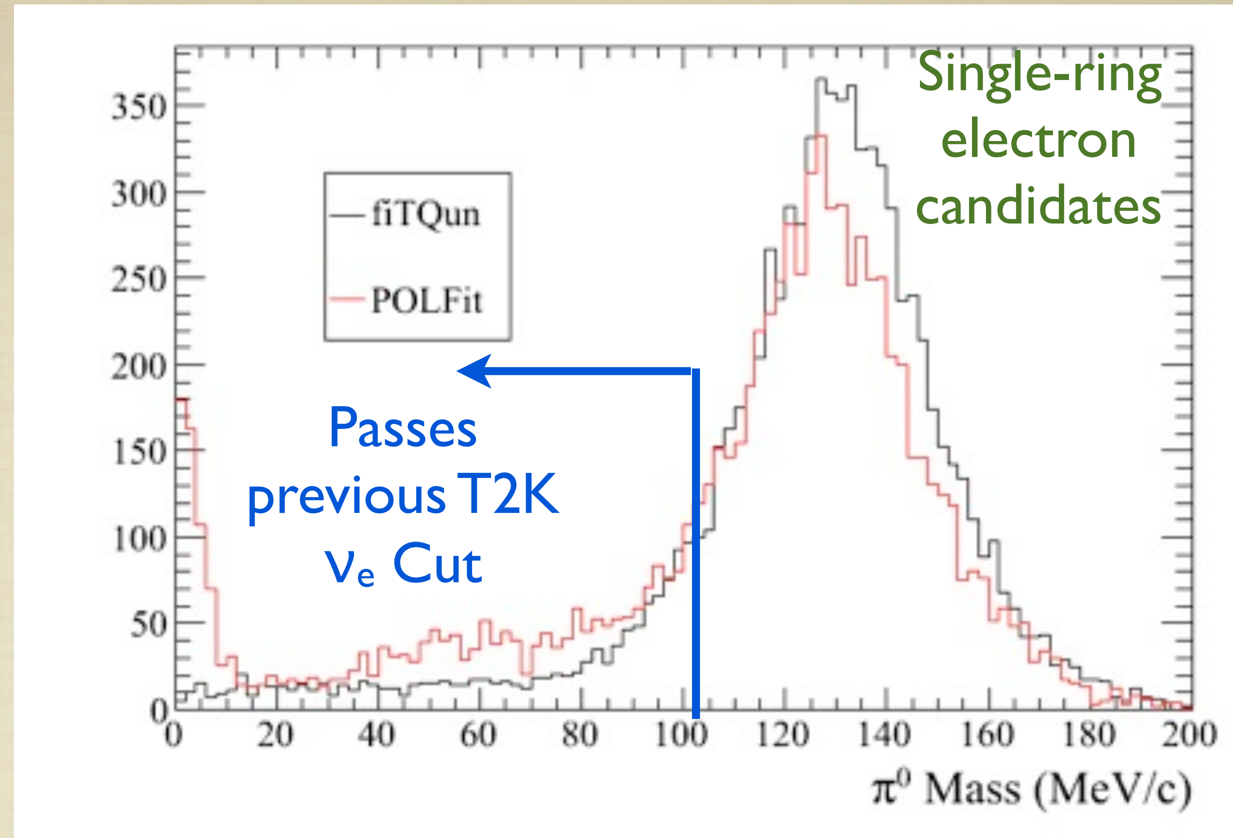
Property of the electronics and PMT properties

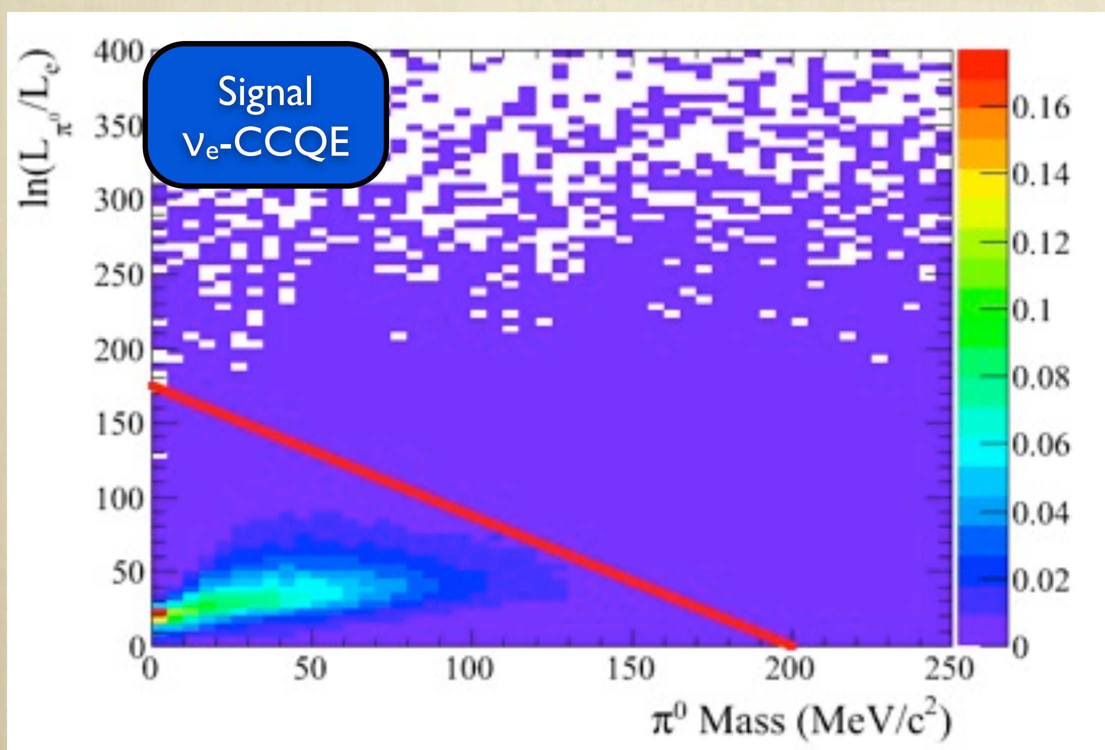
Predicted Charge (μ):

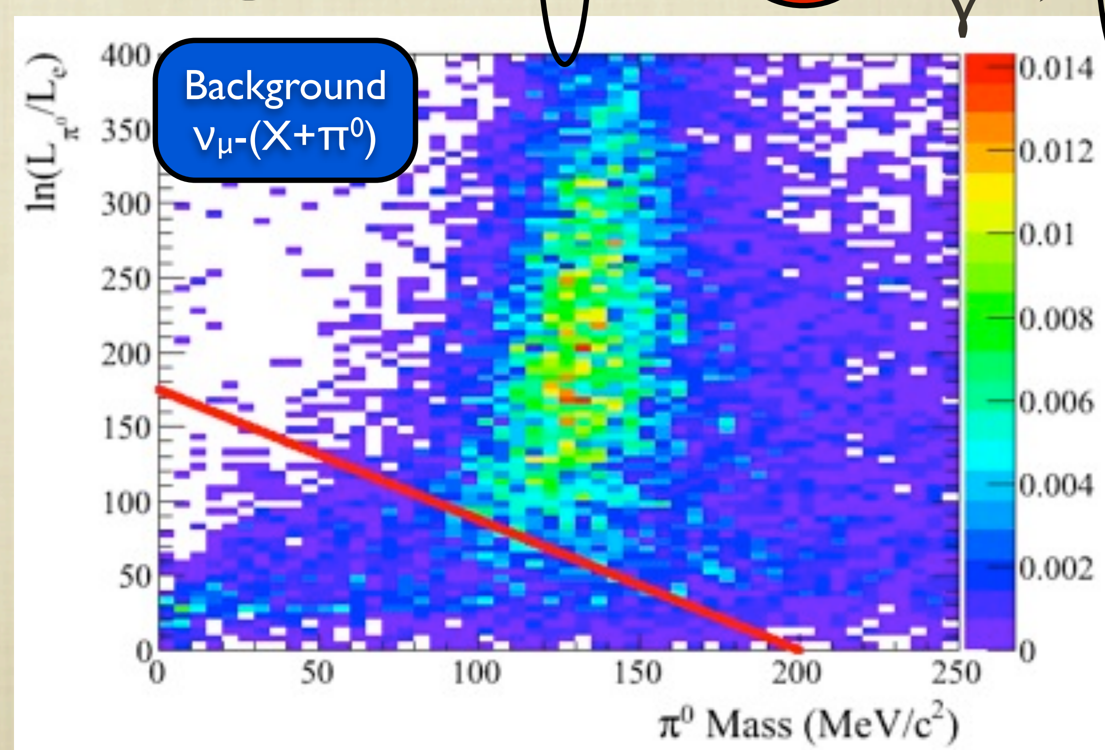
- Number of photons that reach the PMT
- Depends on detector properties (scat, abs, etc.)

π^0 rejection at SK

- 2 backgrounds to ν_e appearance: intrinsic ν_e component and $\pi^0 \rightarrow \gamma\gamma$
- $\pi^0 \rightarrow \gamma\gamma$ if the 2 rings overlap → it might be identified as 1 single ring
- fiTQun reduce 70% more of the π^0 background than previous methods



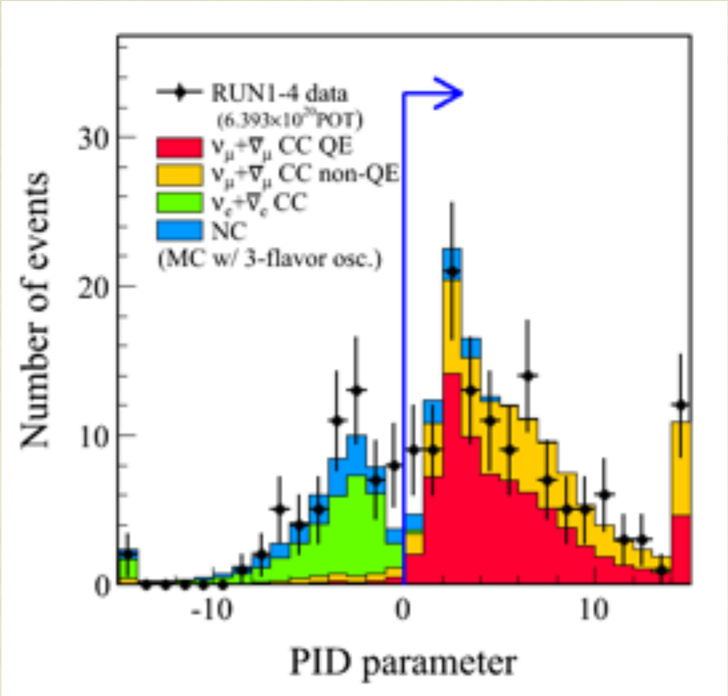


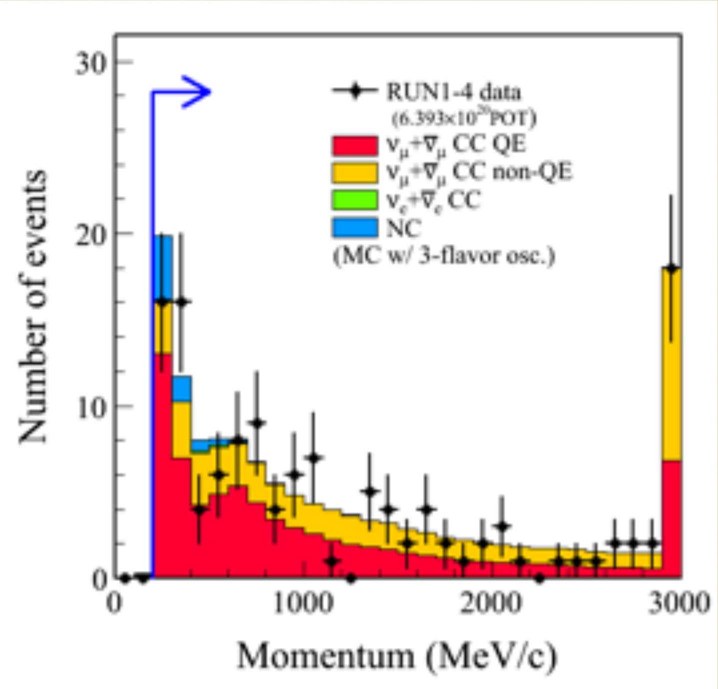


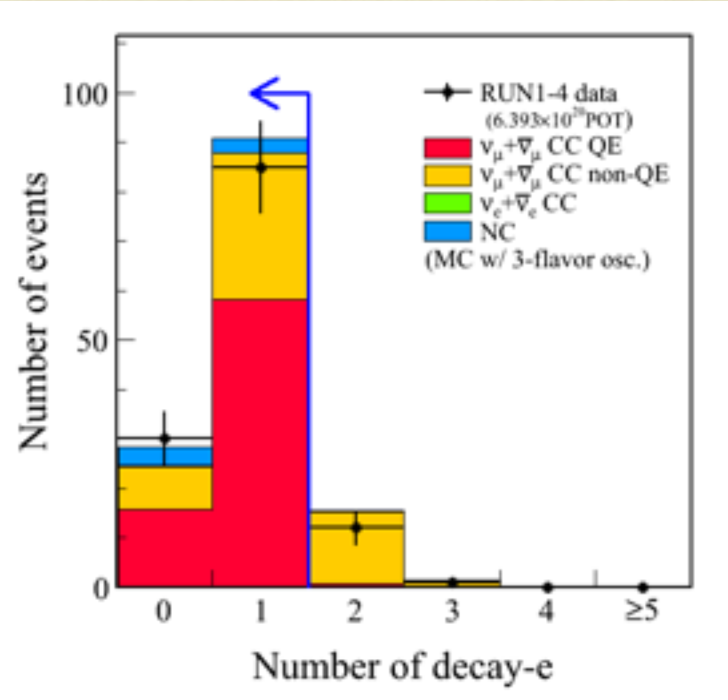
ν_μ selection

ν_μ Selection Cuts

- Fully Contained FV events
- # of rings = 1
- Ring is μ-like
- Pμ> 200 MeV
- Less than 2 Michel electrons







115 events are selected (but I will present results only for Run1-3 → 58 events, 3.01×10^{20} pot)

Typical oscillation analysis

Flux prediction:
- ✓ Proton beam stability
- ✓ Hadron production (NA61 and others external data)

ND280 measurements:
- ✓ ν_μ selection to constrain flux and cross-sections
- ✓ Measure ν_e beam component

Neutrino interactions:
- ✓ Interaction models
- ✓ External cross-section data

Prediction at the Far Detector:
- ✓ Combine flux, x-section and ND280 to predict the expected events at SK

Extraction of the oscillation parameters!!!

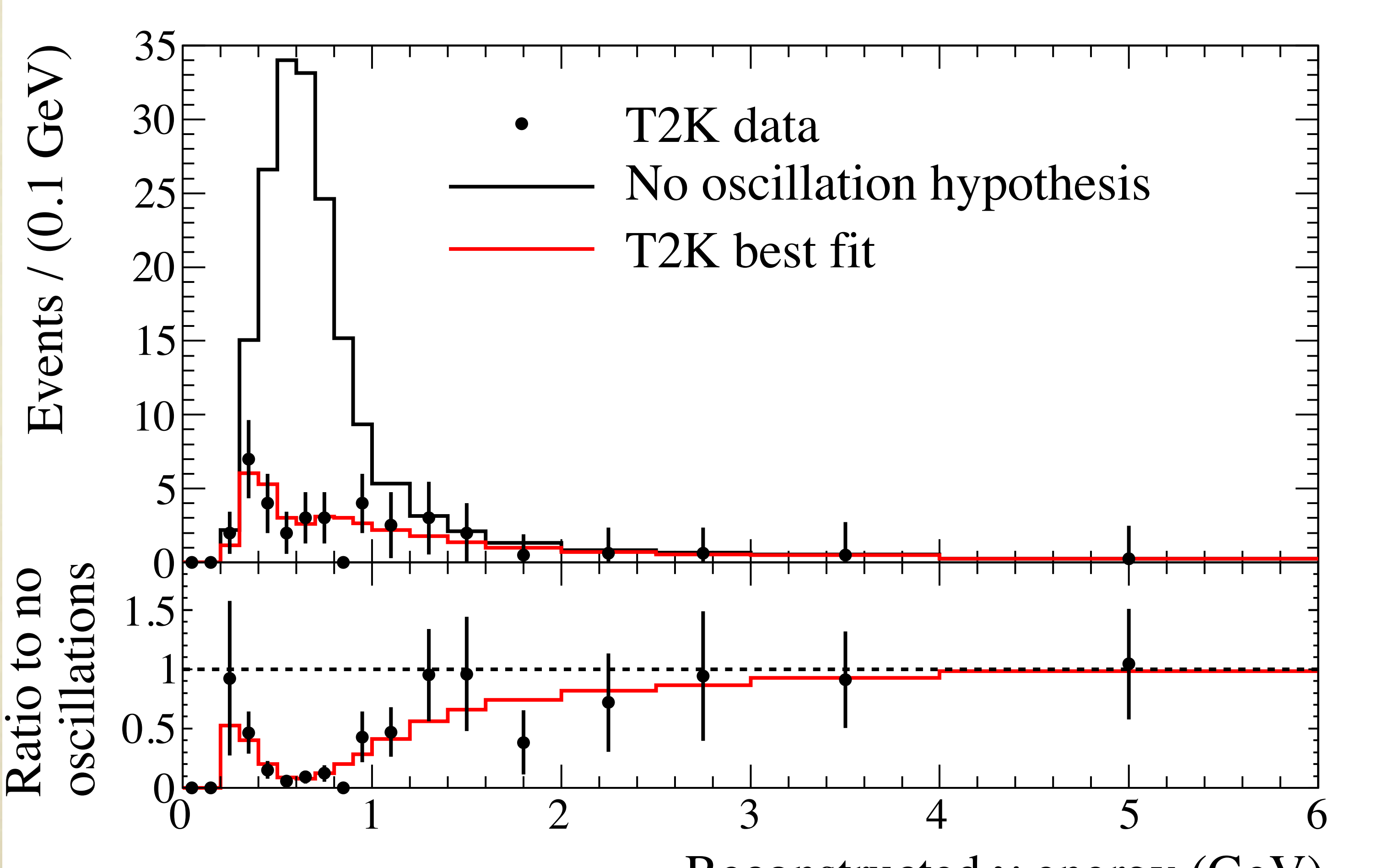
Super-Kamiokande measurements:
- ✓ Select CC ν_μ and ν_e candidates after the oscillations

Oscillation results

ν_μ disappearance

- Observed number of events: 58
- Expect numbers 205±17 → 78% CCQE
- Full disappearance thanks to the off-axis configuration

$$N_{obs}(\theta_{23}, \Delta m^2_{32}) = \varphi(\nu) \times \sigma_{int}(\nu) \times \varepsilon_{sel} \times P_{\nu_\mu\to\nu_\mu}(\theta_{23}, \Delta m^2_{32})$$



accepted for publication on PRL

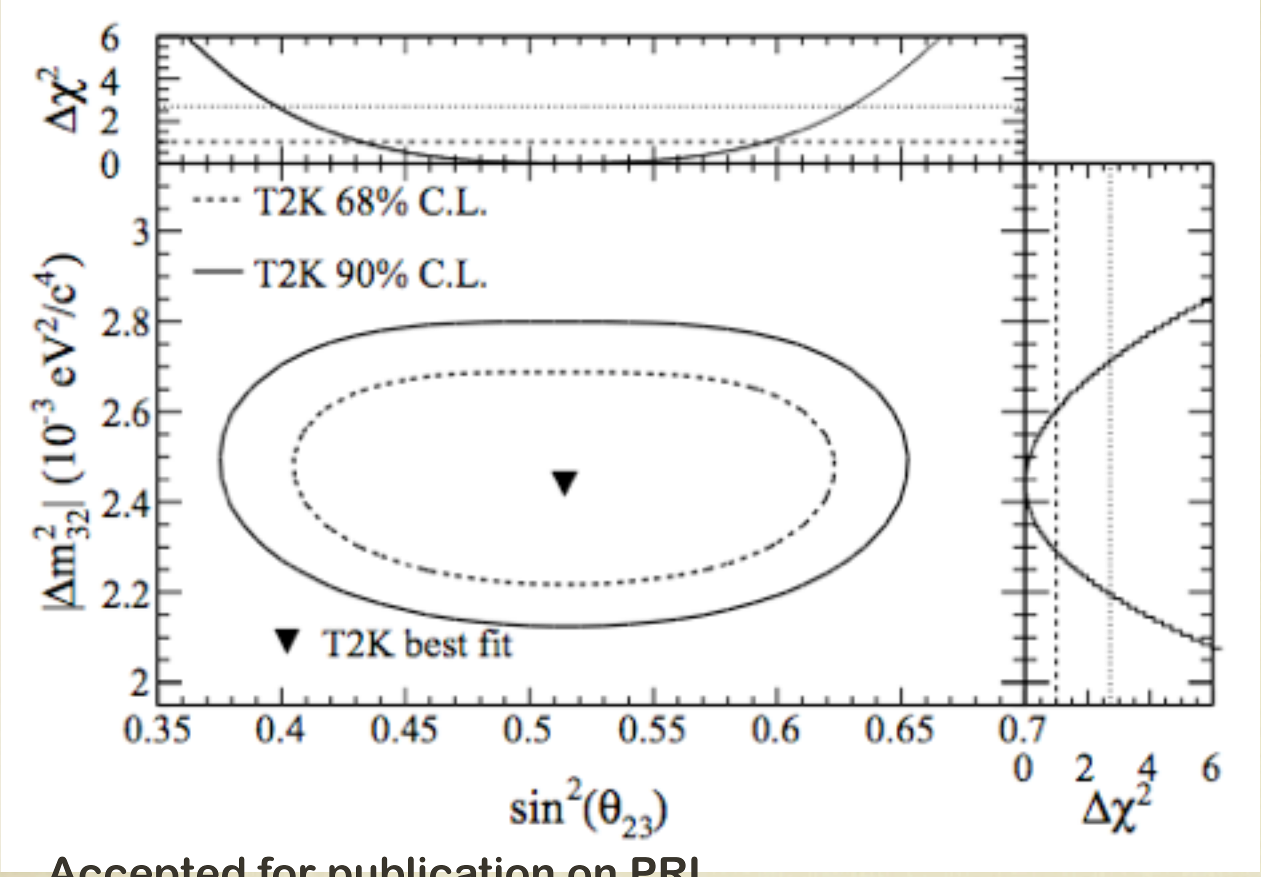
$\nu\mu$ disappearance octant

- Disappearance probability:

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - 4cos^2(\theta_{13})sin^2(\theta_{23})[1 - cos^2(\theta_{13})sin^2(\theta_{23})]sin^2(1.27\Delta m^2_{32}L/E)$$

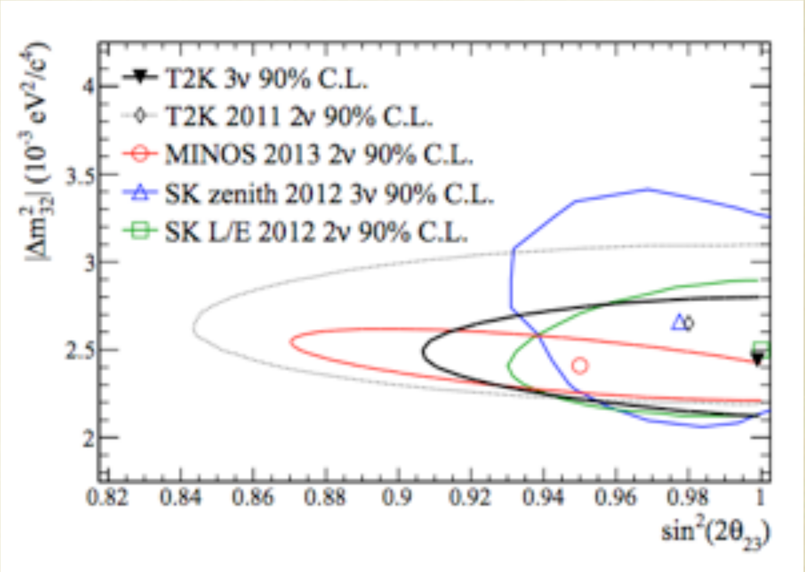
- If $\theta 13 = 0 \rightarrow P(\nu\mu \rightarrow \nu\mu) = 1 - 2\sin^2(2\theta_{23})\sin 2(1.27\Delta m^2 L/E)$
  - Not sensitive to θ_{23} octant
- θ_{13} is not 0:
  - The ν_μ disappearance is sensitive to the octant (θ_{23} > or < 45°)
- Neutrino oscillation experiments → precision experiments
  - The uncertainty on θ_{13} propagate to uncertainties on θ_{23}
  - 2 flavor approximation not valid anymore → Need a full 3 flavor analysis
  - Present results in (Δm^2_{23}, θ_{23}) plane

ν_μ disappearance results



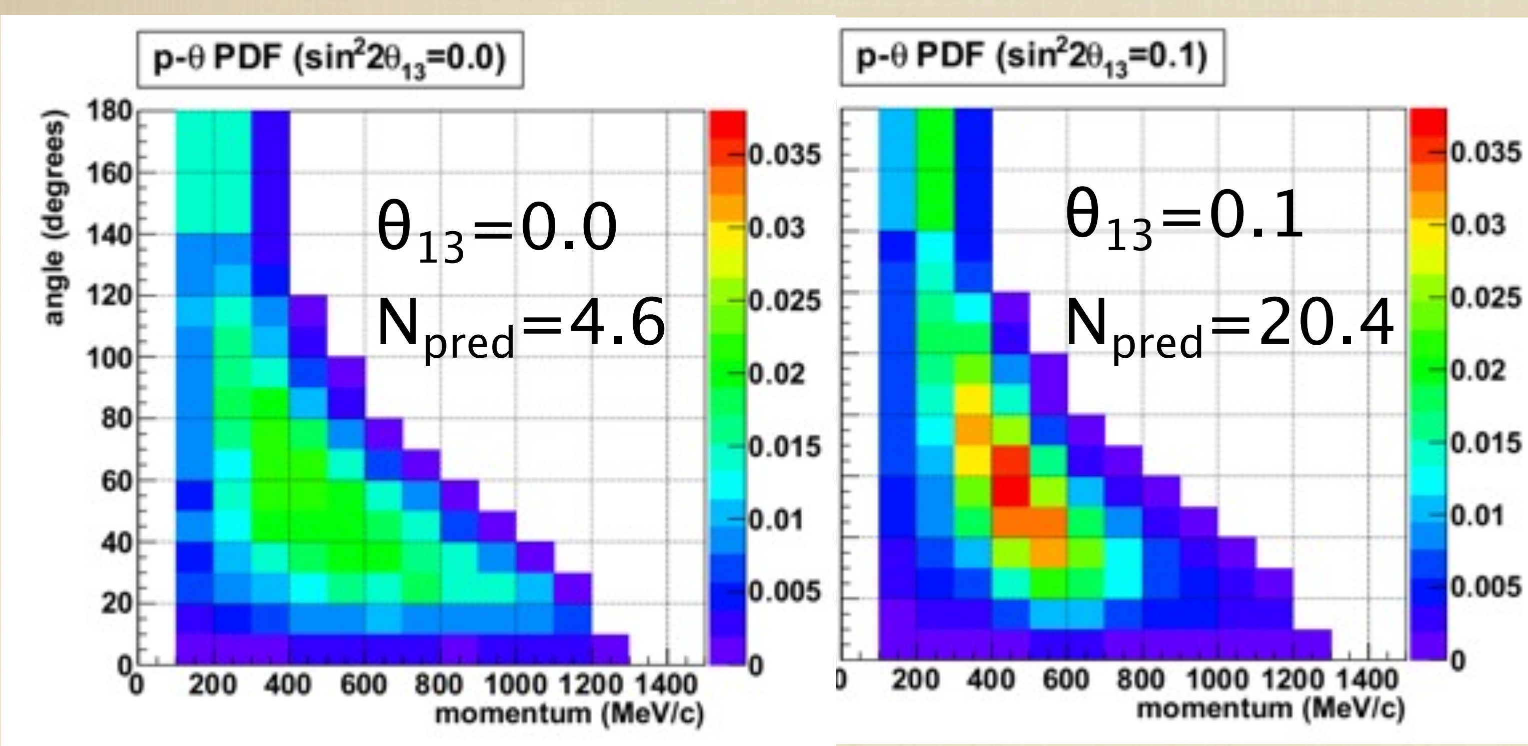
Accepted for publication on PRL
http://arxiv.org/pdf/1308.0465v2.pdf

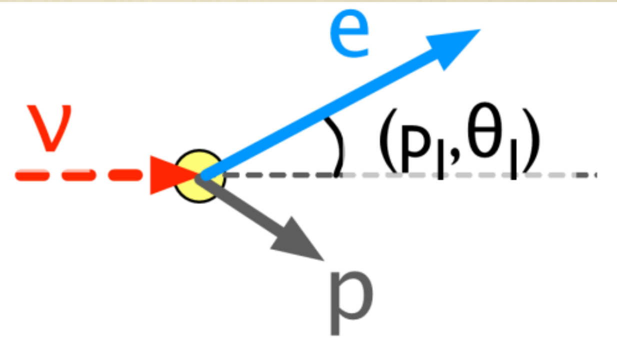
For comparison



- With half of the statistics taken so far → most precise measurement of θ_{23} in accelerator based experiments
- Analysis with the full available statistics is on-going and will provide world best measurement of θ_{23}

ν_e appearance analysis





- Scan over $\sin^2(2\theta_{13})$ space to find the best fit value
- Likelihood is calculated by comparing the number of observed events (N_{obs}) and the electron momentum and angle (p-θ) distribution with MC

$$\mathcal{L} = \mathcal{L}_{norm} \times \mathcal{L}_{shape} \times \mathcal{L}_{syst}$$

$\mathcal{L}_{syst}$ → Systematic parameter constraint term

$\mathcal{L}_{norm}$: $Poisson(N_{obs})_{\text{mean}=N_{pred}}$

$\mathcal{L}_{shape}$: $\prod_{i=1}^{N_{obs}} \phi(p_i, \theta_i)$

ν_e appearance systematics

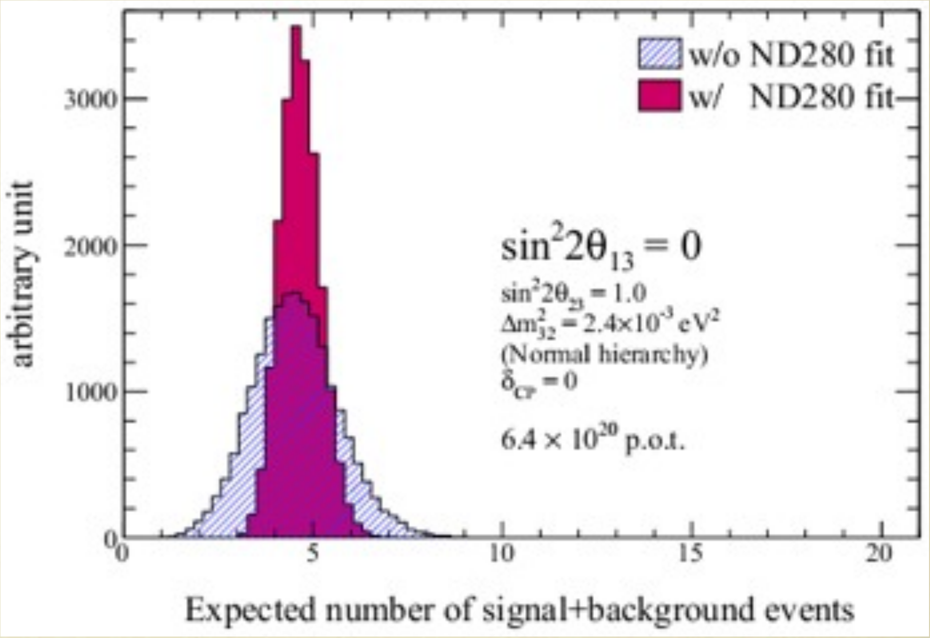
	$\sin^2(2\theta_{13})$=0.1
ν_e app. signal	17.3
ν_e background	3.2
ν_μ background (π0)	1.1
Total	20.44

Main background comes from beam νe → directly checked at ND280

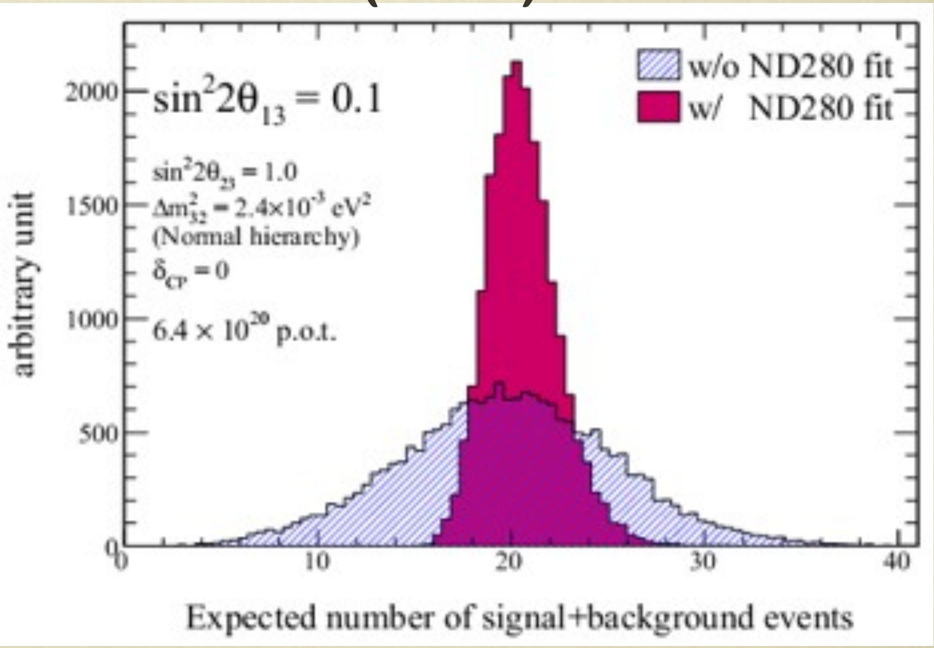
	$\sin^2(2\theta_{13})$=0	$\sin^2(2\theta_{13})$=0.1
Beam flux and ν int.	4.9%	3.0%
Far Detector	6.7%	7.5%
FSI + SI	7.3%	3.5%
Total	11.1%	8.8%

<10% systematics!

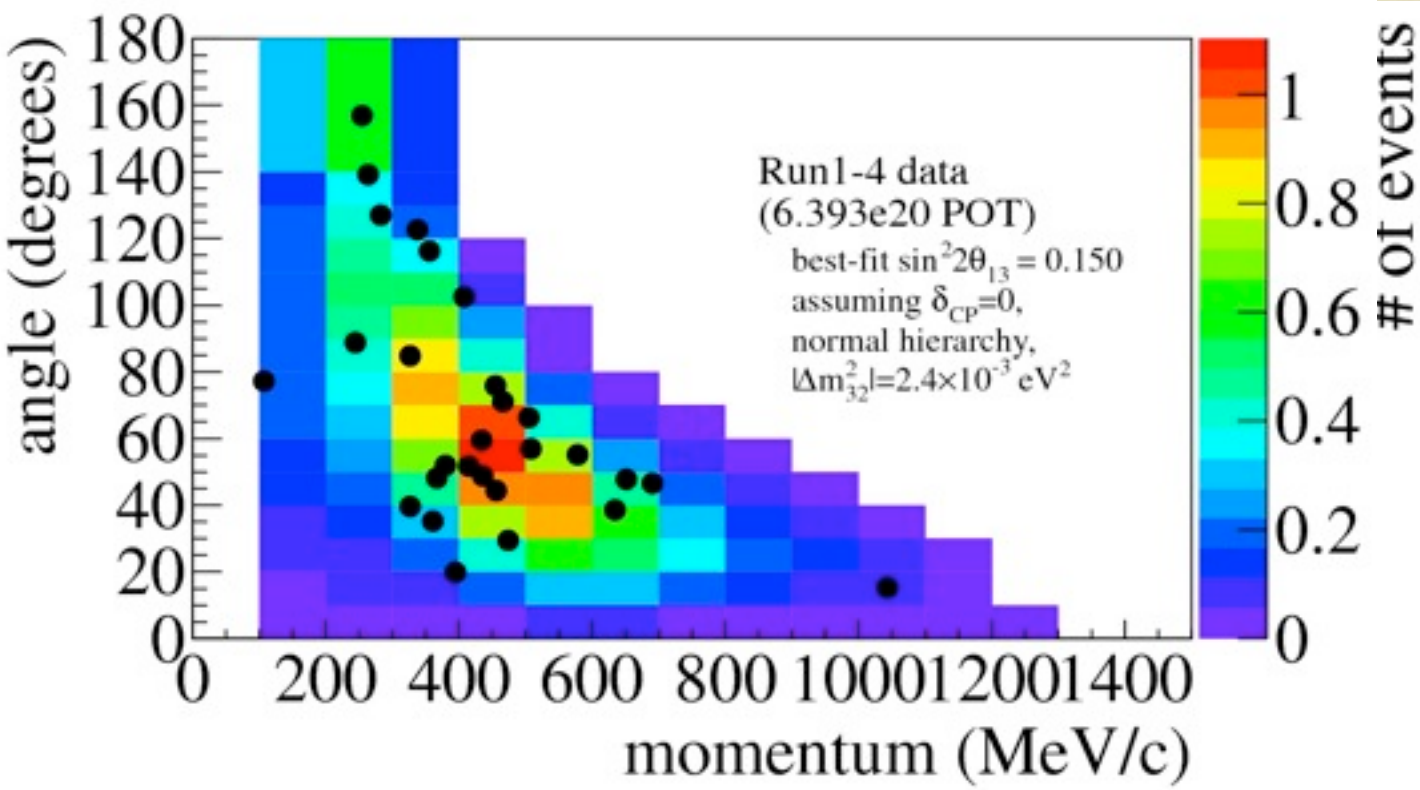
$\sin^2(2\theta_{13}) = 0$

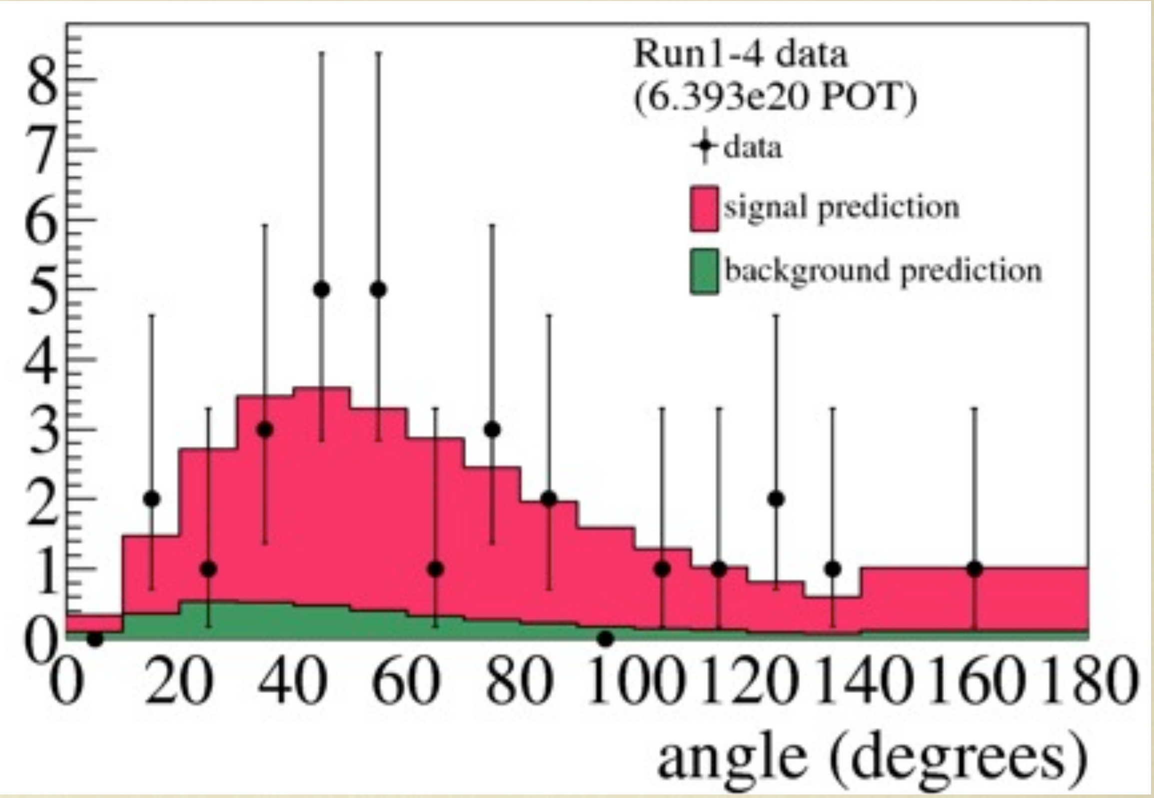


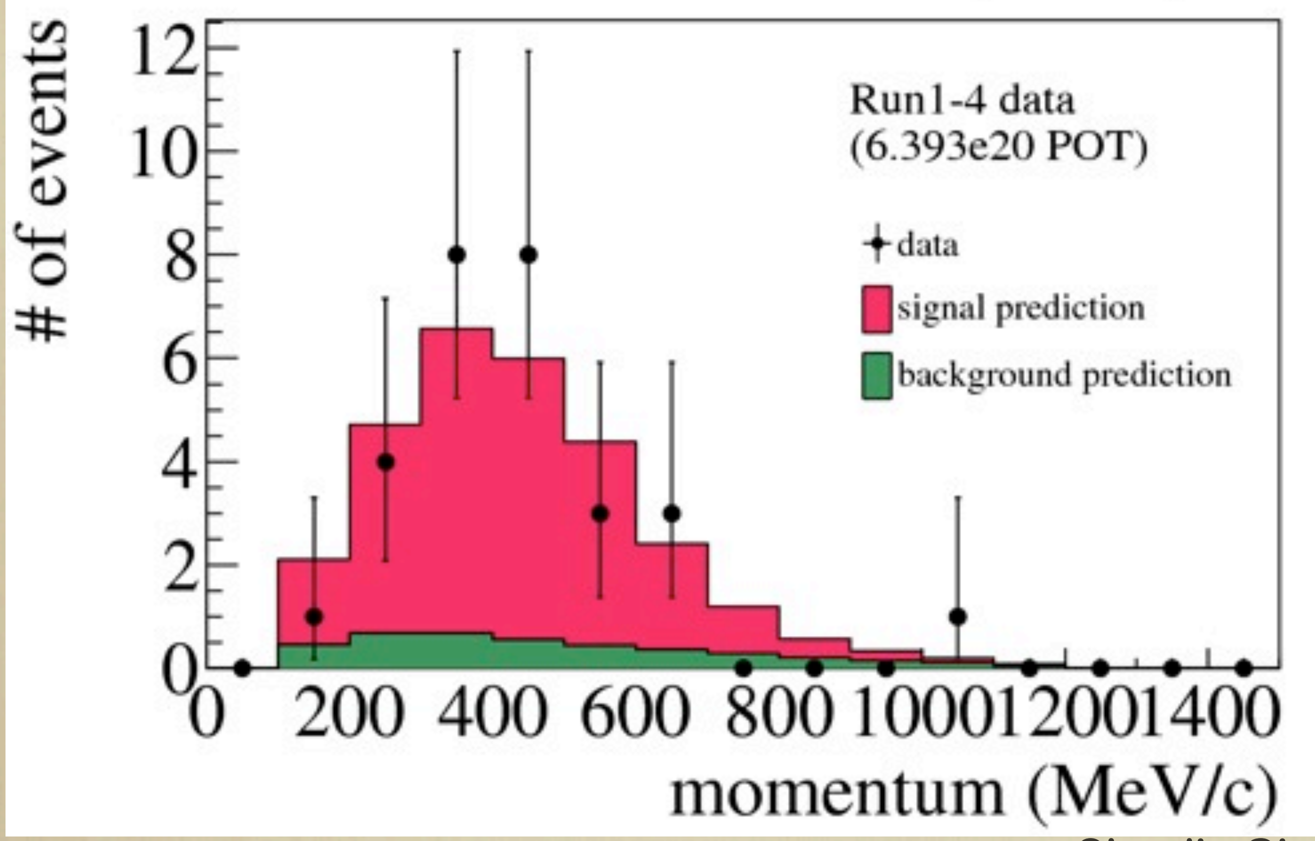
$\sin^2(2\theta_{13}) = 0.1$



ν_e appearance results







Assuming δ_{CP}=0, normal hierarchy, $|\Delta m^2_{32}|=2.4\times10^{-3}$ eV^2, $\sin^2 2\theta_{23}=1$

Best fit w/ 68% C.L. error:

$$\sin^2 2\theta_{13} = 0.150^{+0.039}_{-0.034}$$

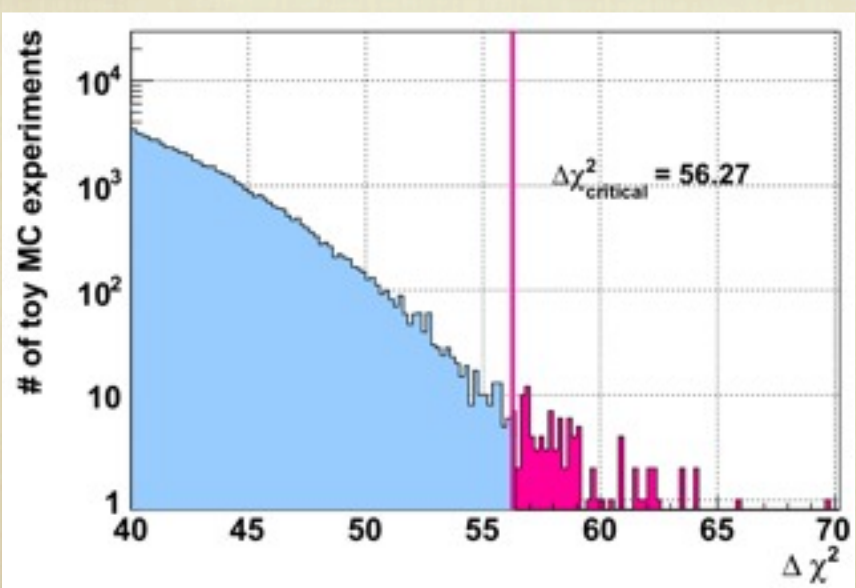
90% allowed region:

$$0.097 < \sin^2 2\theta_{13} < 0.218$$

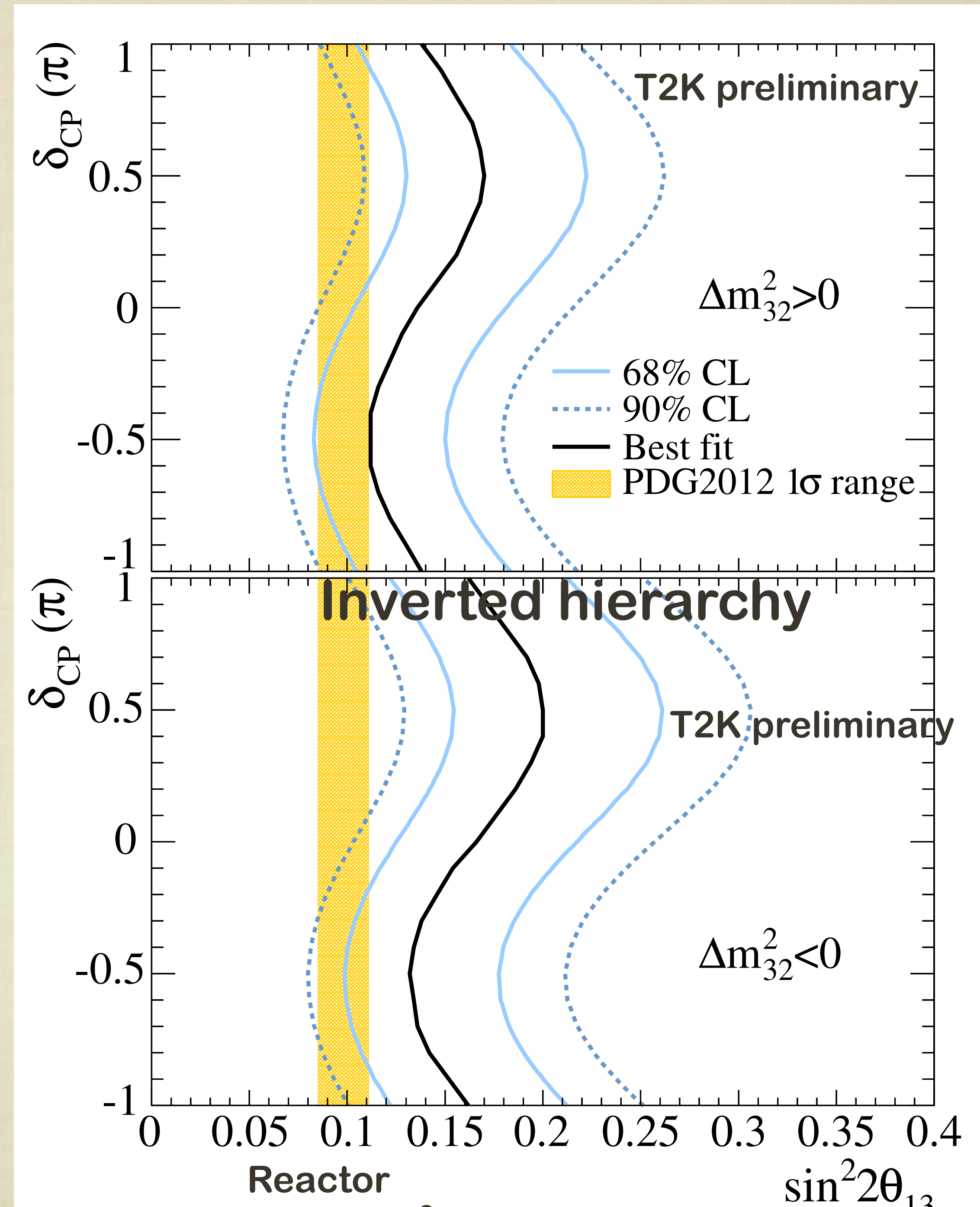
ν_e appearance results

- T2K allowed region of $\sin^2(2\theta_{13})$ for different values of CP violation δ
- Compared to the measurements of the reactor experiments (Daya Bay 2013) → some sensitivity to δ_{CP} from the combination

Probability of observing >=28 events if $\theta_{13} = 0$
p-value 9.9×10^{-14} → 7.4σ



Normal hierarchy

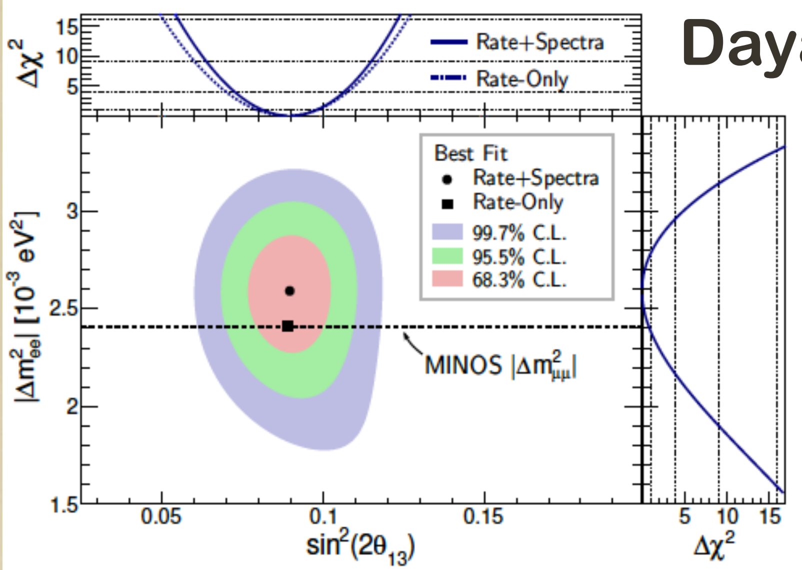


Reactor constraint on θ_{13}

submitted for publication on PRL

Other θ_{13} measurements

Daya-Bay result NuFact201



$$\sin^2 2\theta_{13} = 0.090^{+0.008}_{-0.009}$$

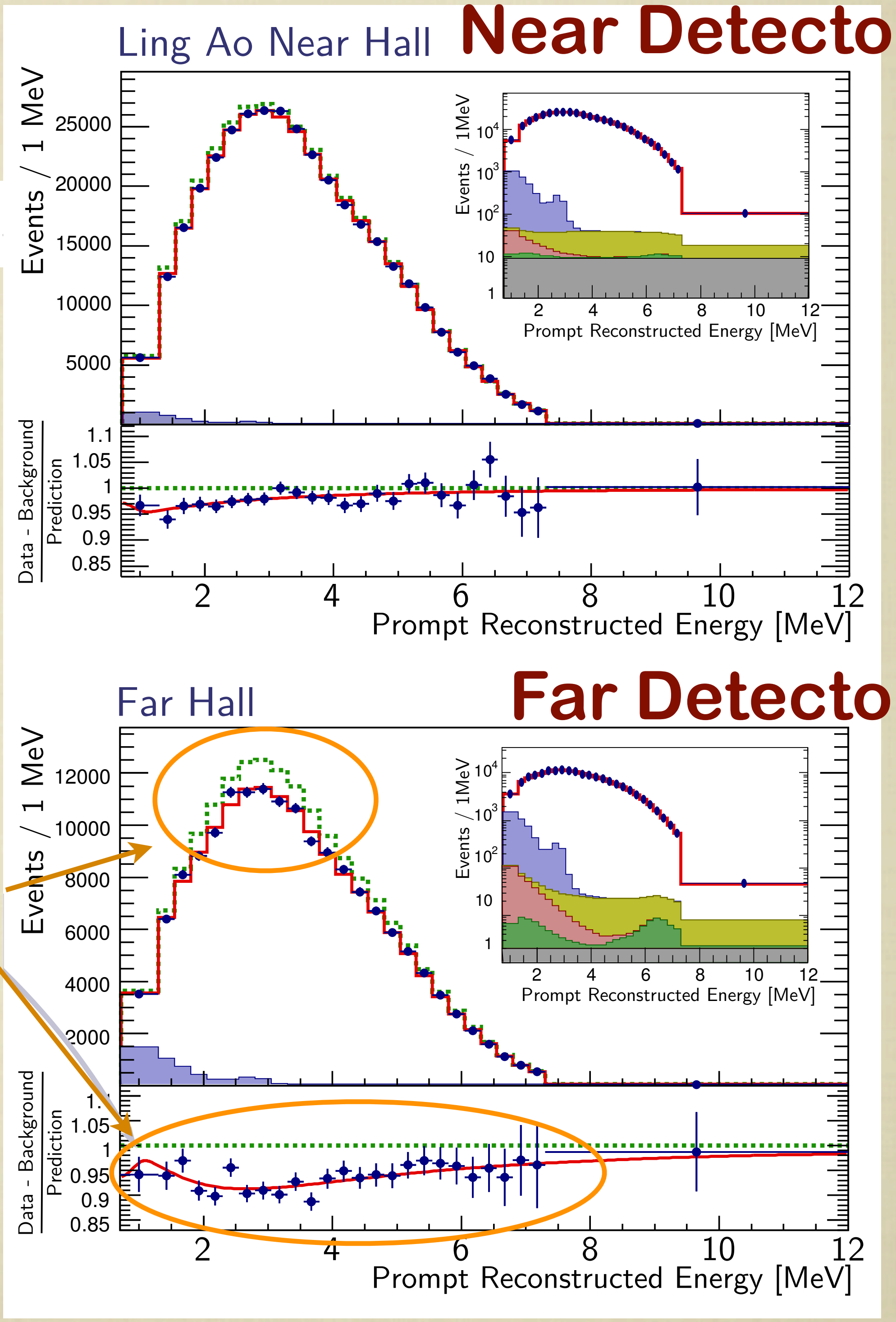
$$|\Delta m^2_{ee}| = 2.59^{+0.19}_{-0.20} \cdot 10^{-3}\text{eV}^2$$

$$\chi^2/N_{\text{DoF}} = 162.7/153$$

Strong confirmation of oscillation-interpretation of observed $\bar{\nu}_e$ deficit

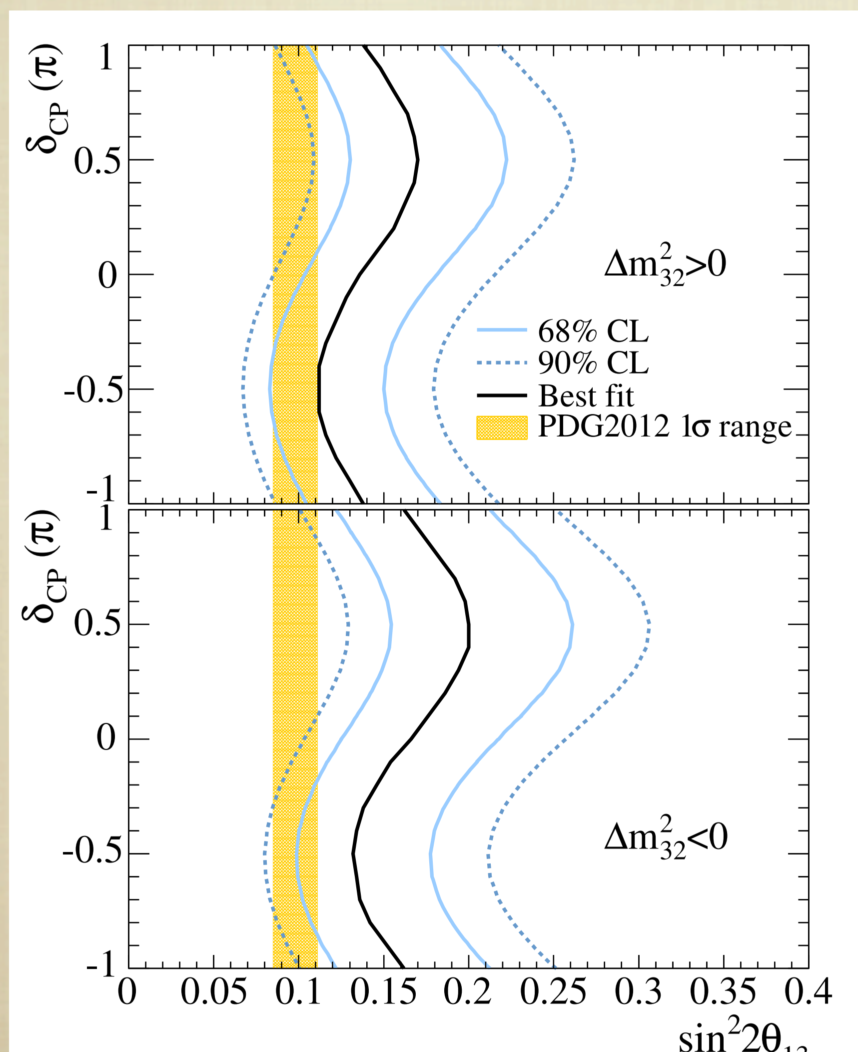
	Normal MH Δm^2_{32} [10^{-3}eV^2]	Inverted MH Δm^2_{32} [10^{-3}eV^2]
From Daya Bay Δm^2_{ee}	$2.54^{+0.19}_{-0.20}$	$-2.64^{+0.19}_{-0.20}$
From MINOS $\Delta m^2_{\mu\mu}$	$2.37^{+0.09}_{-0.09}$	$-2.41^{+0.12}_{-0.09}$

[João, NuFact2013]

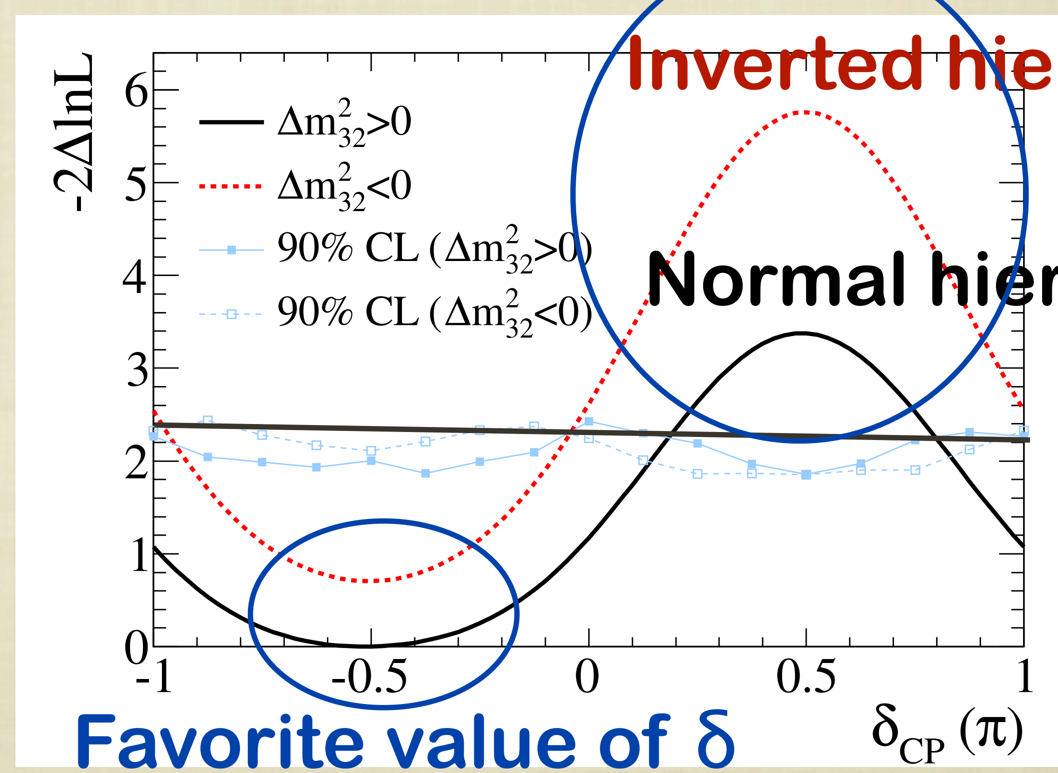


Complementarity

- Look at the θ_{13} vs δ_{CP} plane
- Reactor experiments measure θ_{13} → straight line
- T2K measures a combination of θ_{13} and the CP violation phase δ
  - S-shape in the θ_{13} vs δ_{CP} plane
- Combine them to measure CP violation!



Excluded at 90% CL



Inverted hierarchy

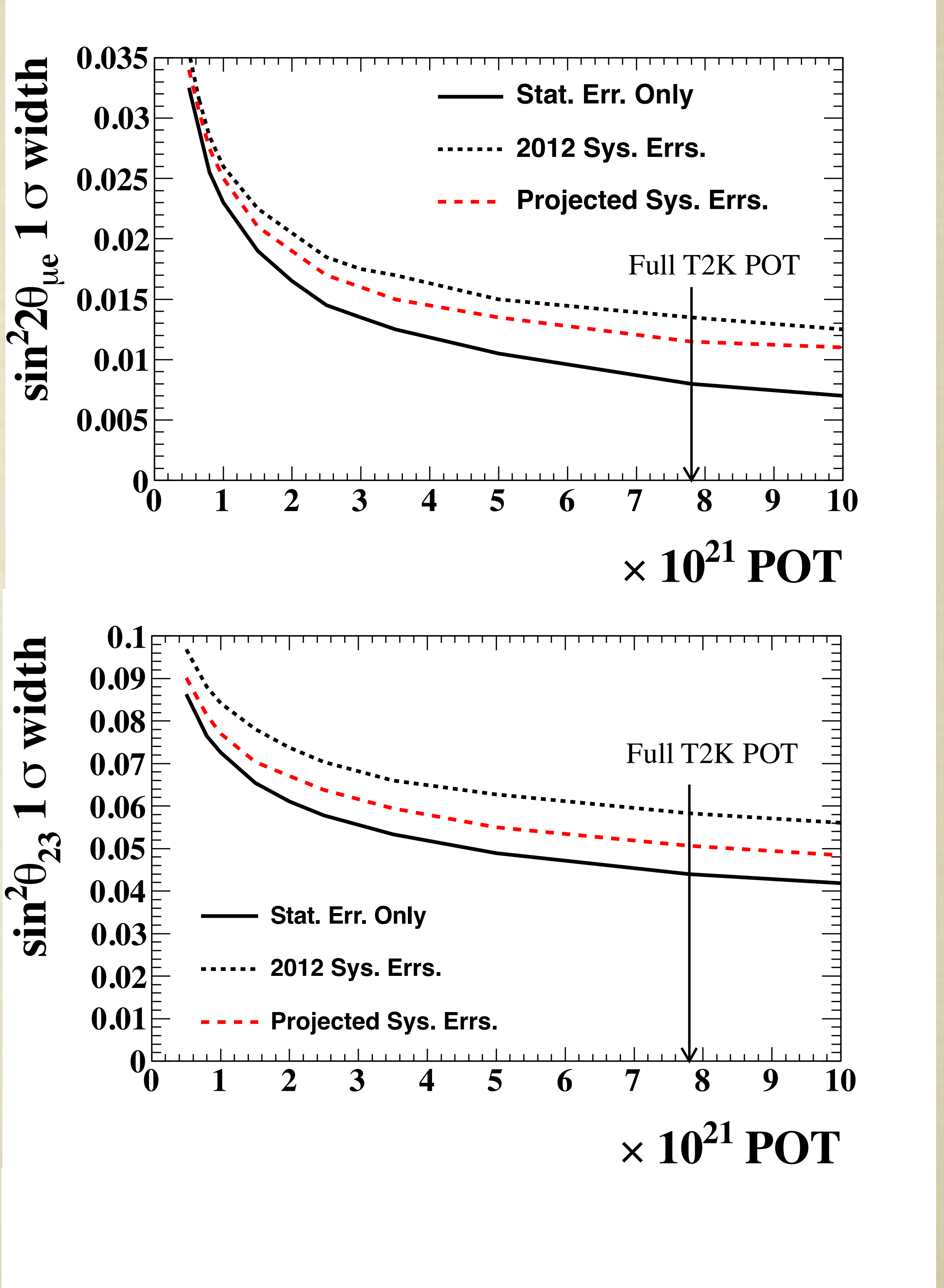
Normal hierarchy

Favorite value of δ
(CP violation phase)
from the combination of
T2K and reactors

Future prospects

Expected sensitivities

- T2K results are still limited by the **statistical uncertainties**
- With 3 times more data the error on θ_{13} will be reduced of a factor of ~2
  - Very important for T2K/reactor combination to extract δ_{CP}
  - For this combination it's also important to further reduce the error on θ_{23}
- We also plan to run in anti-ν mode to observe anti-ν_e appearance
- ν and anti-ν add additional information on δ_{CP}

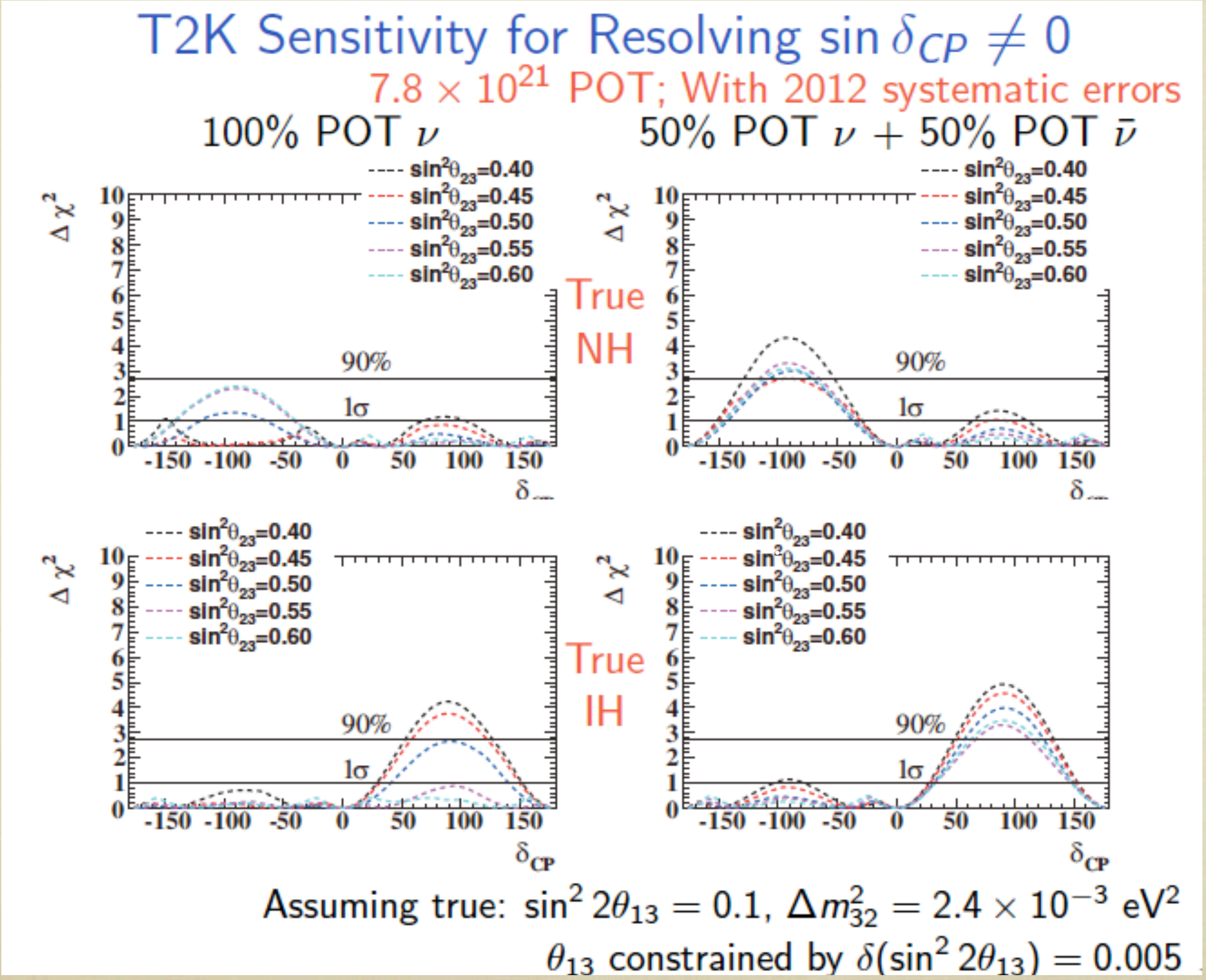


Upgrade plans

- T2K is currently not taking data → J-PARC hadron hall accident + some upgrades already foreseen
  - LINAC upgrade → should be able to increase the neutrino beam power up to 400 kW
  - Restart the operation in April 2014
  - Main Ring upgrade by 2018 → up to nominal power (750 kW)
- Possible scenario:
  - Double current pot by early 2015
  - Next-to-next doubling by early 2017
  - Full planned statistics → end 2020

T2K future sensitivity

2012 systematic errors



Systematics

- T2K reached ~10% systematics for νe appearance
- Improve flux knowledge → NA61
- Improve cross-section modeling
- Measure cross-section at ND280 → see next slide
- Add extra samples
  - ND280 ν_e measurement
  - Far detector π^0 sample
- Reduce uncertainties on the oscillation parameters
  - Combined fit of ν_e and ν_μ samples expected early 2014

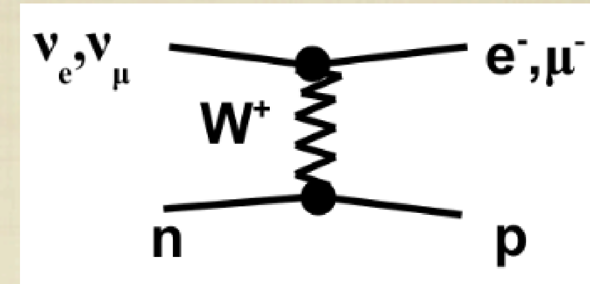
	$\sin^2(2\theta_{13})=0$	$\sin^2(2\theta_{13})=0.1$
Beam flux and ν int.	4.9%	3.0%
Far Detector	6.7%	7.5%
FSI + SI	7.3%	3.5%
Total	11.1%	8.8%

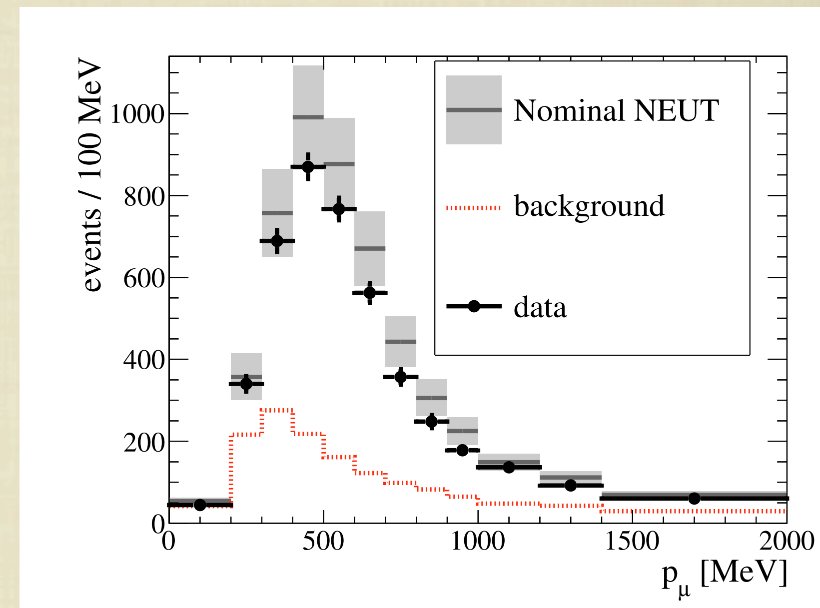
Appearance analysis predictions

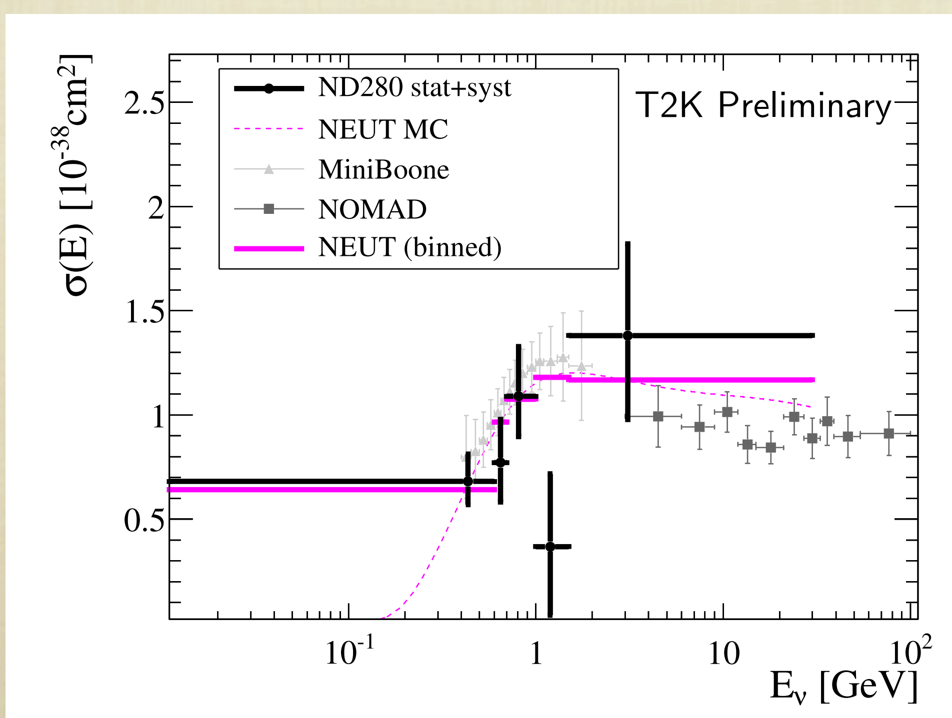
	Predicted N_{SK}	Percent Error
No ND280 constraint	22.6	26.5%
ND280 constraint 2012	21.6	4.7%
ND280 constraint 2013	20.4	3.0%

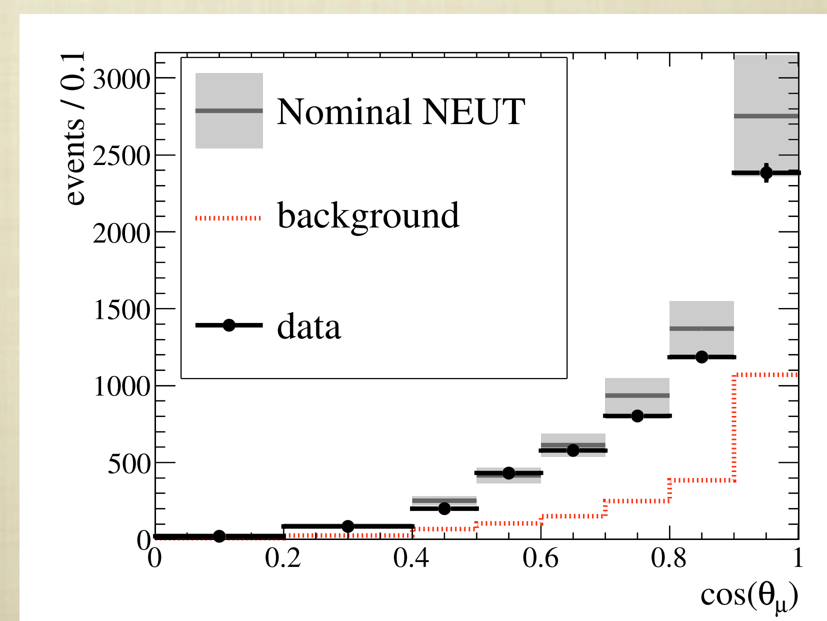
Cross-section analyses @ ND280

- CCQE: select CCQE νμ interactions at ND280 → single track events with 1 μ
- Bin in (Pμ, θμ) → model independent
- Fit to extract CCQE σ vs true neutrino energy
- Future improvements: reconstruct also the proton
- Many other cross-section analyses are on-going (CC1π, NC, νe cross-section measurements)









Conclusions

- T2K is running well and we collected 8.3% of the expected statistics
- First observation (7.4σ) of ν_e appearance (ν appearance?)
  - Measurement of θ_{13} independent from the one of the reactor → combination allow to put some constraint on δ_{CP}
- Precise measurement of ν_μ disappearance parameters
  - Try to determine the θ_{23} octant
- T2K will restart in 2014 with an upgraded setup
  - Able to reach larger beam power to increase statistics faster
- Plans to start running in anti-neutrino mode
  - Pilot run foreseen in 2014

Back-up slides

νe candidates: vertex