New results from the T2K experiment

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on behalf of the T2K Collaboration

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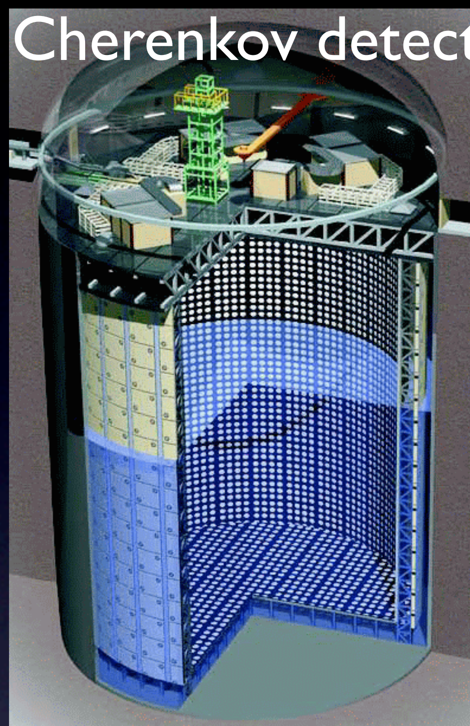
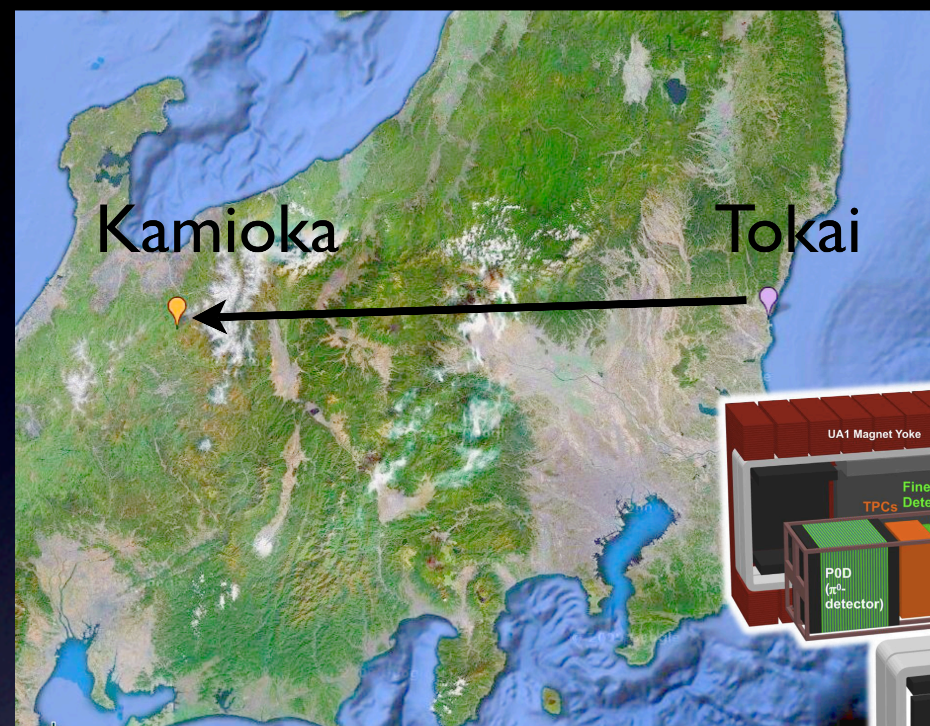
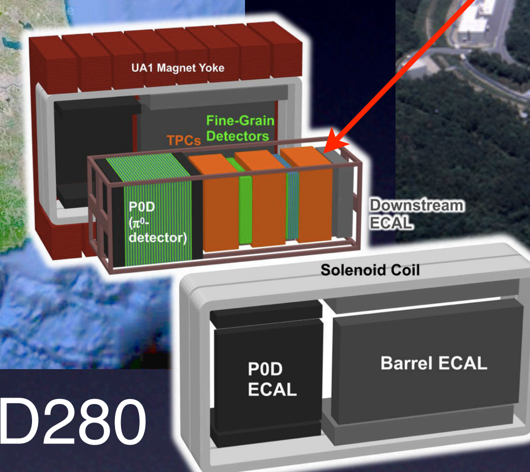
T2K experiment

Super-Kamiokande: 22.5 kt fiducial volume water Cherenkov detector



JPARC accelerator: Design power: 750 kW





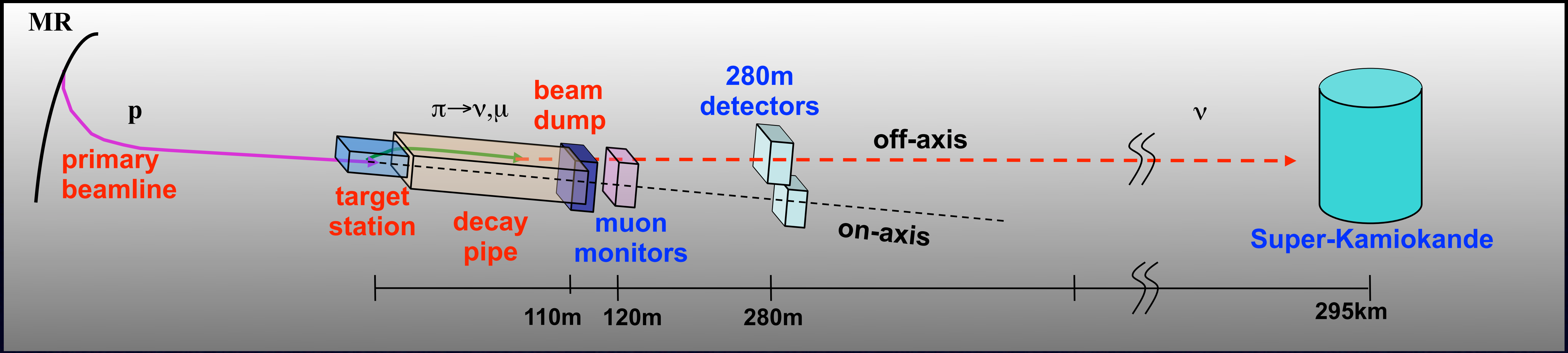
ND280

- Long baseline neutrino oscillation experiment
- High intensity ν_μ beam produced at JPARC (Japan)
- Neutrinos detected at the Near Detector (ND280) and at the Far Detector (Super-Kamiokande) at 295 km
- Main physics goals:
  - Discovery of ν_e appearance → determine θ_{13} (sensitivity >10 times better Chooz limit)
  - Precise measurement of ν_μ disappearance → Goal: $\delta(\sin^2(2\theta_{23}))\sim0.01, \delta(\Delta m^2_{23})<1\times10^{-4}$ eV^2

T2K Collaboration

~500 members, 59 institutes, 12 countries

T2K experimental setup

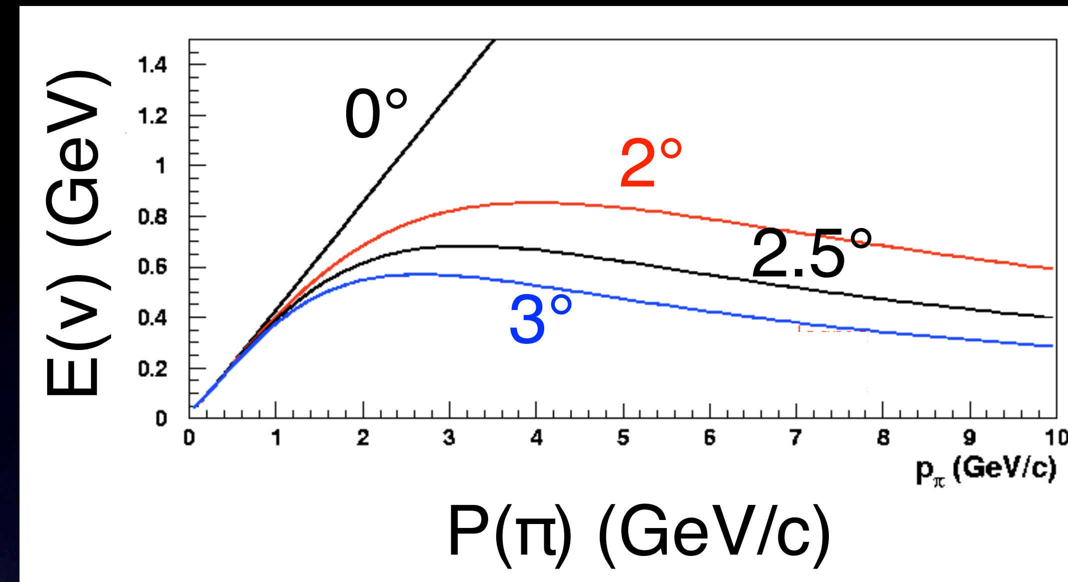


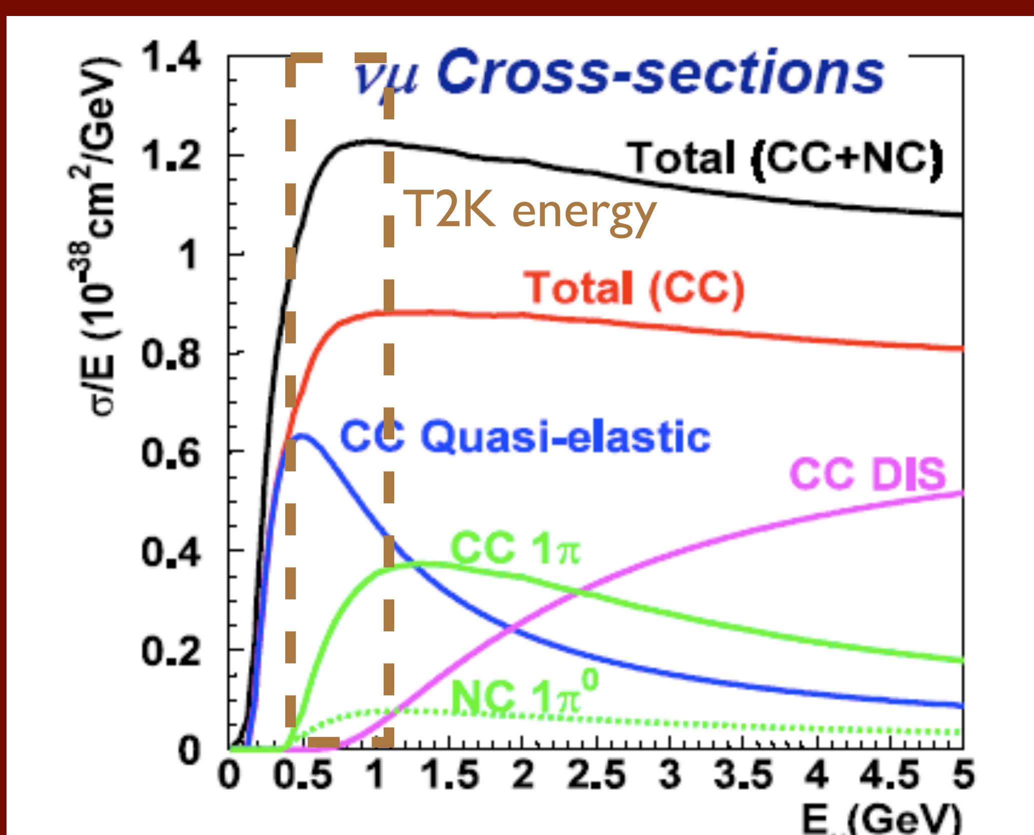
- Beamline:
  - Produce a narrow band neutrino beam (peak energy 600 MeV)
  - Off-axis beam: center of the beam 2.5° off from SK direction
  - Design beam power 750 kW (50 kW in 2010, 145 kW in 2011)
- Detectors:
  - Proton beam profile, position and intensity monitored in several detectors along the beamline
  - 2 detectors monitor neutrino beam stability and direction: Muon Monitor and INGRID
  - Off-axis Near Detector (ND280): measure ν interaction rates and flavors before the oscillation
  - Off-axis Far Detector (SK): measure ν interaction rates and flavors after the oscillation

Reference: The T2K experiment, NIM A, doi: 10.1016/j.nima.2011.06.067, arxiv 1106.1238

Off-axis narrow band beam

- T2K is the first long baseline experiment using off-axis technique
- Reduced dependence of E_ν from E_π
  - Intense beam where the oscillation effect is maximum (~0.6 GeV)
  - Enhance the CCQE sample, reducing the high energy tails of the beam → reduce the backgrounds to oscillation signal

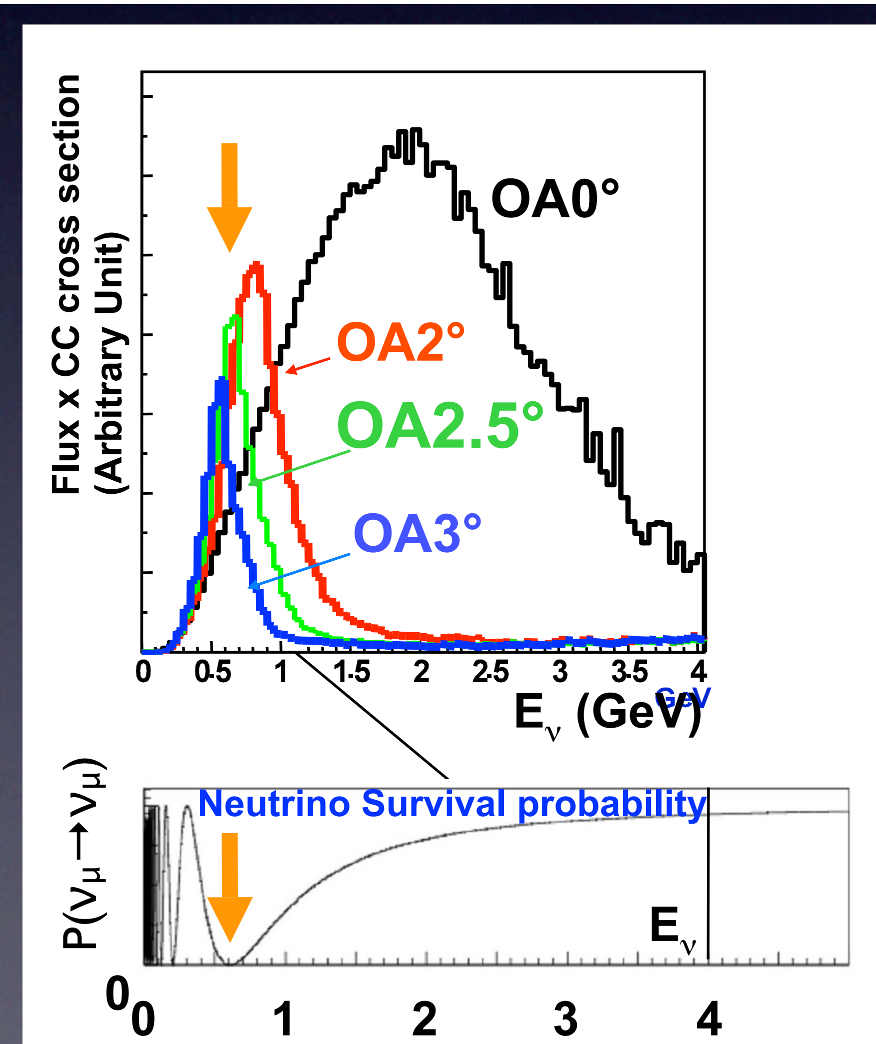




Signal: CCQE

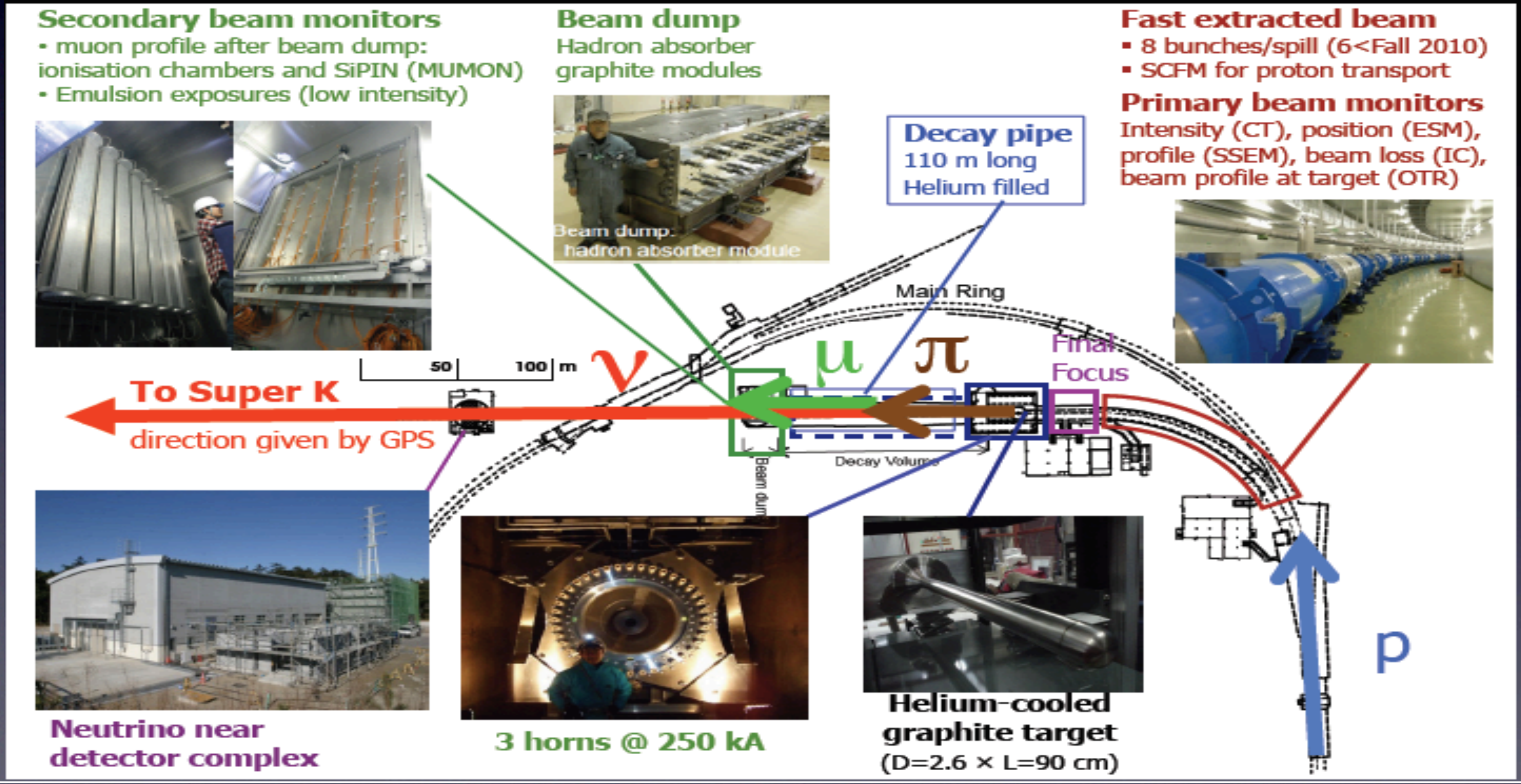
$\nu_{e(\mu)} + n \rightarrow e(\mu) + p$

Main backgrounds: CC1π, NC1π, π produced in DIS → coming from high energy ν



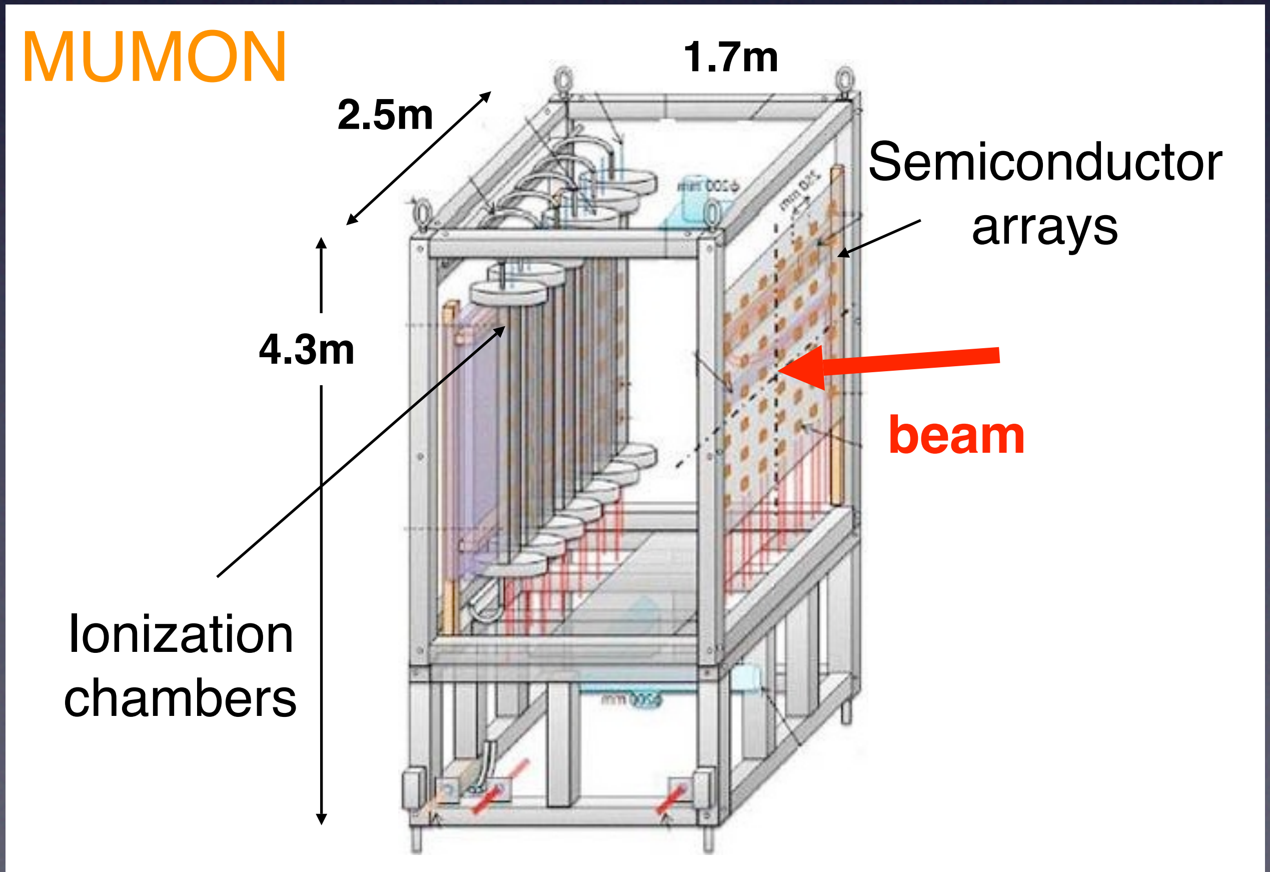
JPARC neutrino beamline

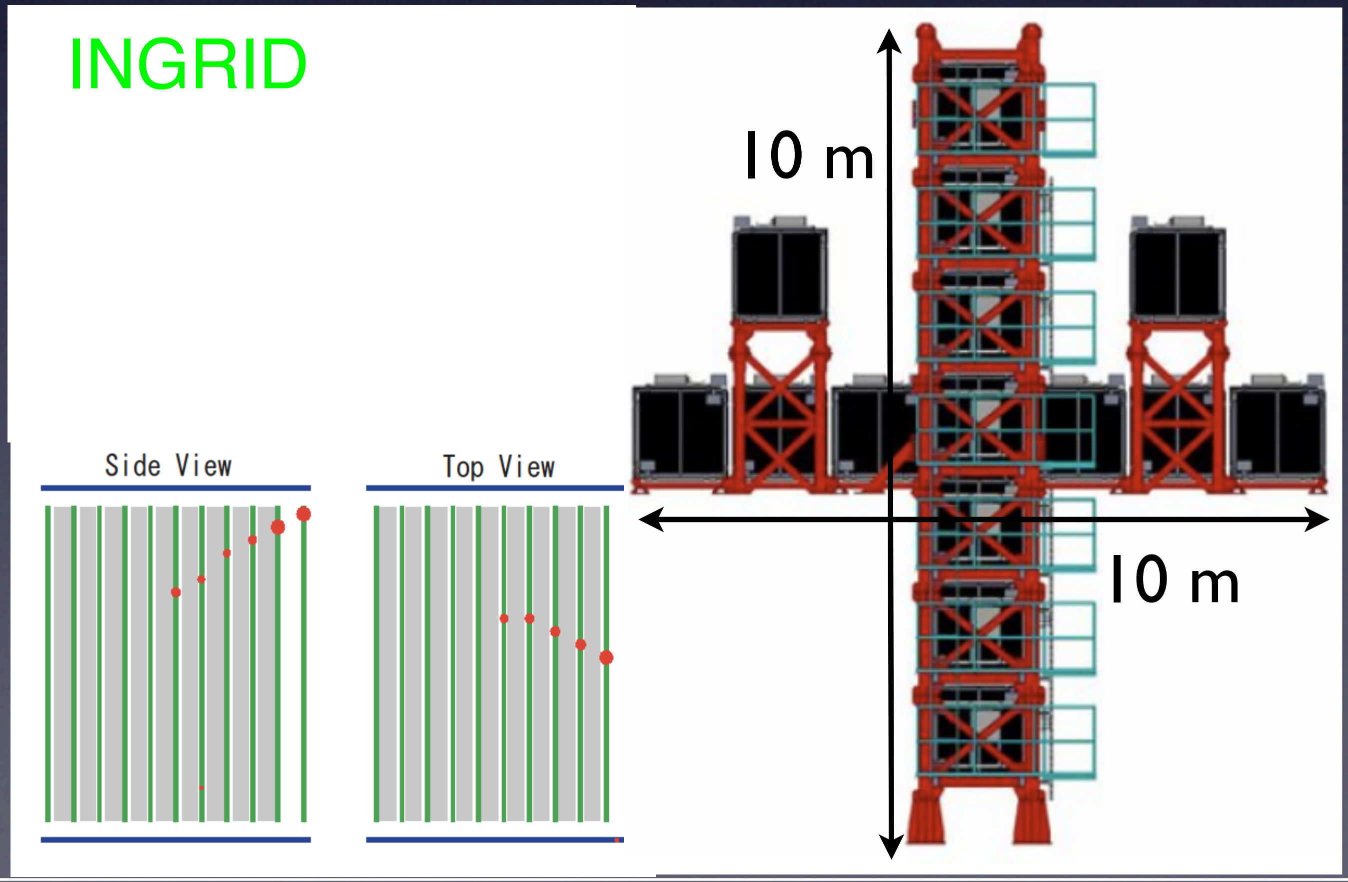
- 30 GeV proton Main Ring (MR) accelerator
- Single turn extraction of the protons from the MR to target station (8 bunches)
- Graphite target + 3 Horns: hadrons (π, K) are produced and charge selected
- Decay tunnel (110 m): $\pi \rightarrow \mu + \nu_\mu$
- The majority of muons and survived hadrons are stopped by the beam dump



MUMON and INGRID

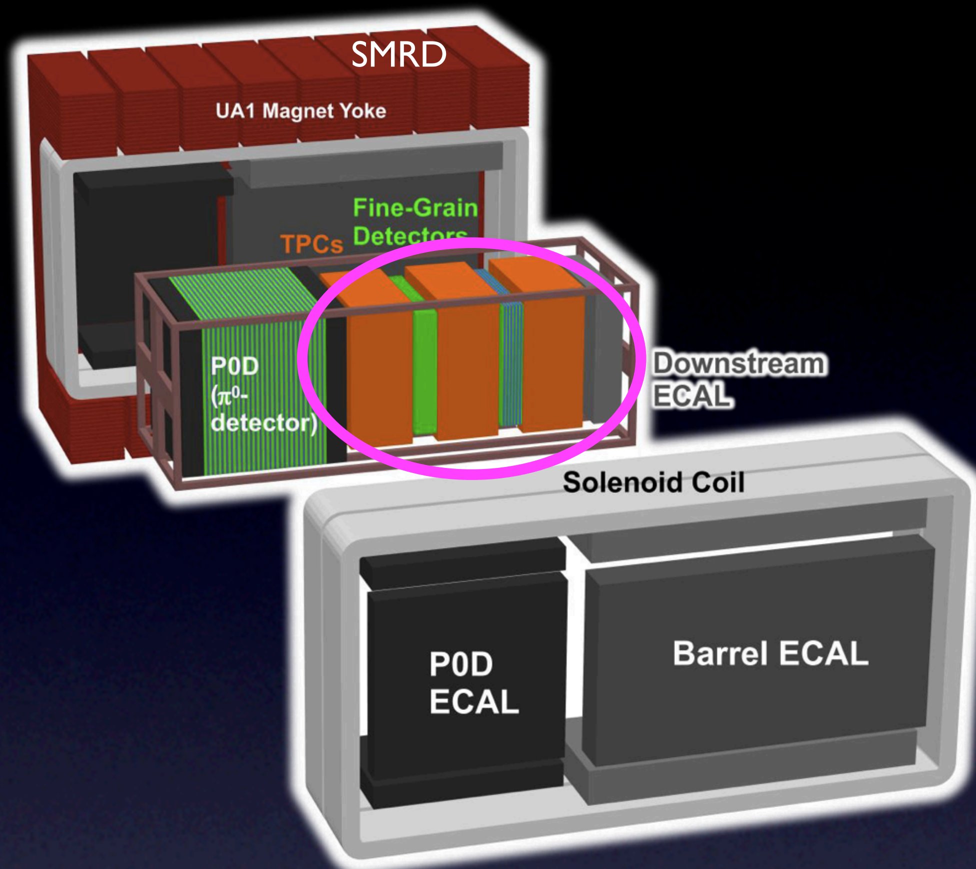
- Muon monitor (MUMON): installed after the beam dump
  - Monitor the beam on a spill-by-spill basis looking at high energy muons
  - Composed by ionization chambers and semiconductor arrays
- On-axis Near Detector (INGRID): on axis in the Near Detector complex
  - Monitor the beam stability on a day-by-day basis looking at ν interactions
  - 16 cubic modules: 1 module is a sandwich of 10 iron and 11 scintillator layers



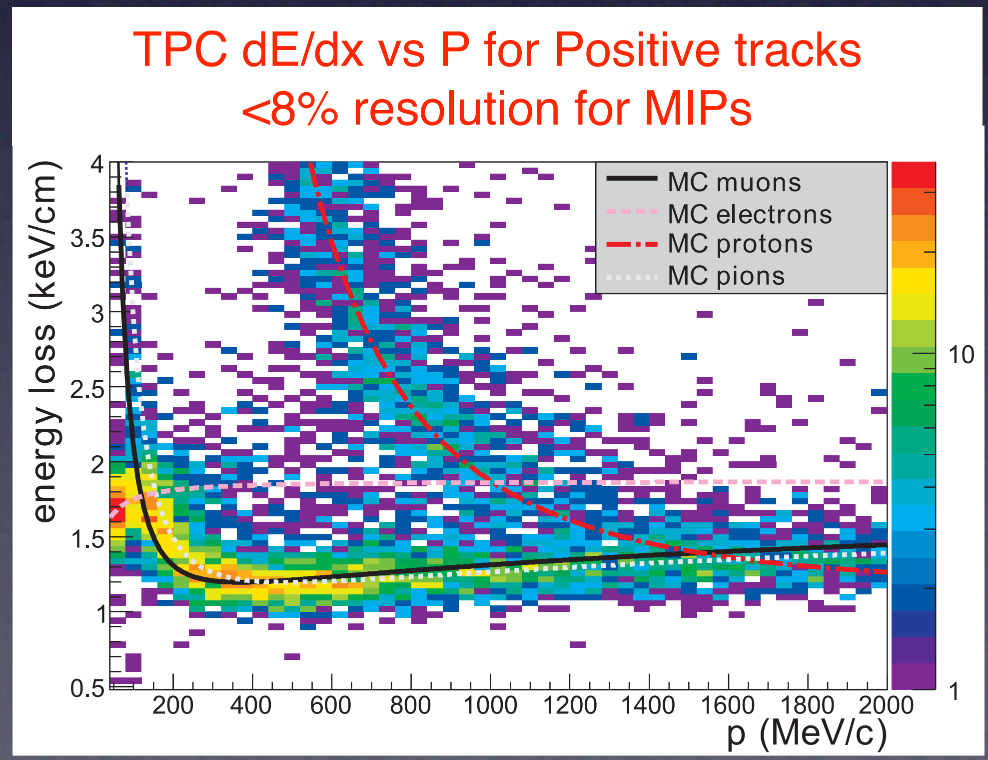


Off-axis ND280

- Set of detector installed inside the ex-UA1/NOMAD magnet (providing a 0.2 T magnetic field)
- Measure ν_μ and ν_e spectra before the oscillation
- Measure cross-sections for backgrounds to oscillation
- Dedicated π^0 detector (P0D), EM calorimeter to identify e/γ(ECAL), side muon range detector for high angle μ (SMRD)



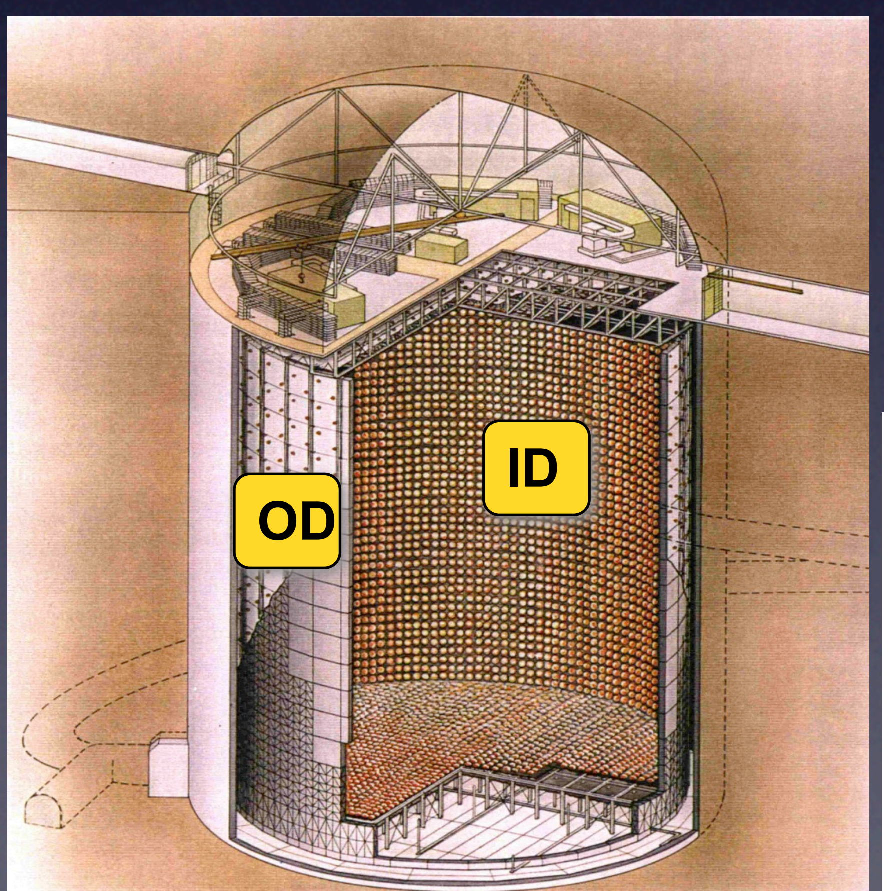
- The present analyses are based on the Tracker:
  - 2 fine grained detectors (FGD)
    - Active target for neutrino interactions (carbon and water)
    - 1.6 ton of Fiducial Volume
  - 3 time projection chambers (TPC)*
    - Instrumented with MicroMEGAS detectors
    - Reconstruct momentum and charge of the particles produced in ν interactions
    - PID capabilities measuring dE/dx in the gas

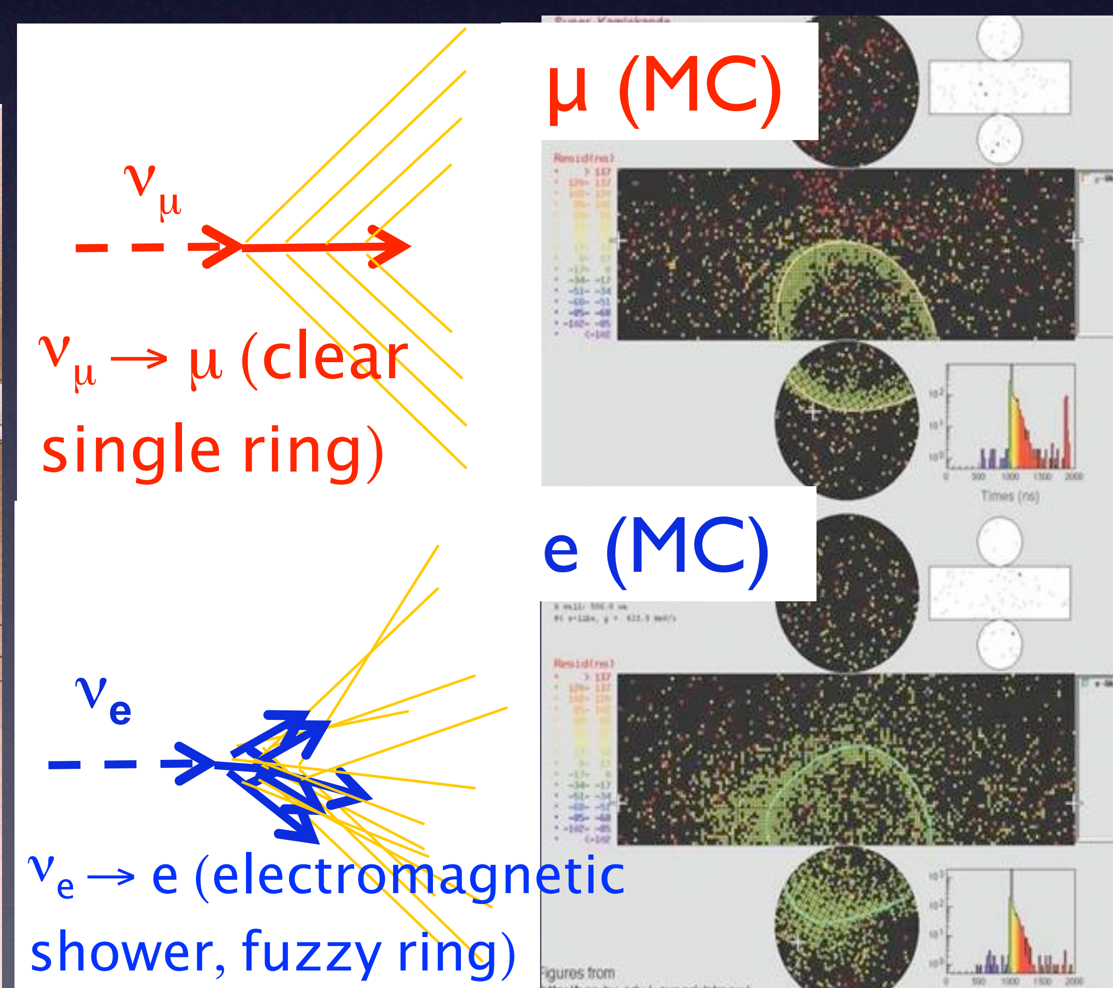


*NIM, A **637** (2011) pp. 25-46

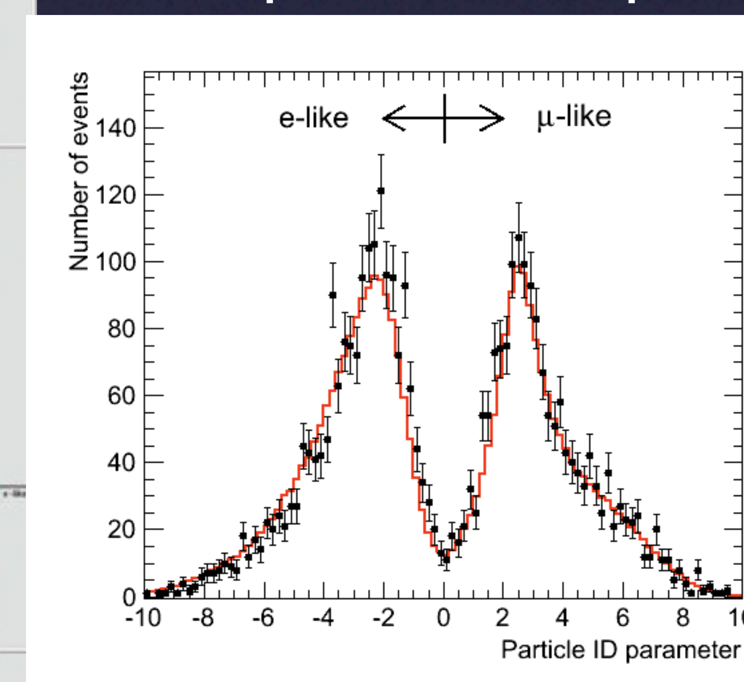
Far Detector: Super-Kamiokande

- 50 kton water Cherenkov detector (22.5 kton Fiducial Volume)
- Optically divided between an inner detector (ID) and an outer detector (OD)
  - 11129 20-inch Hamamatsu PMTs for the inner detector
- 1000 meters underground in the Kamioka mine (295 km from JPARC)
- Working since 1996, new readout electronic installed in 2006
- Very good PID capabilities: probability of a muon reconstructed as an electron of 1%





SK PID for atmospheric ν sample



T2K oscillation analysis

T2K Oscillation analysis method

<u>Flux prediction:</u>
- Proton beam measurement
- Hadron production (NA61 and others external data)

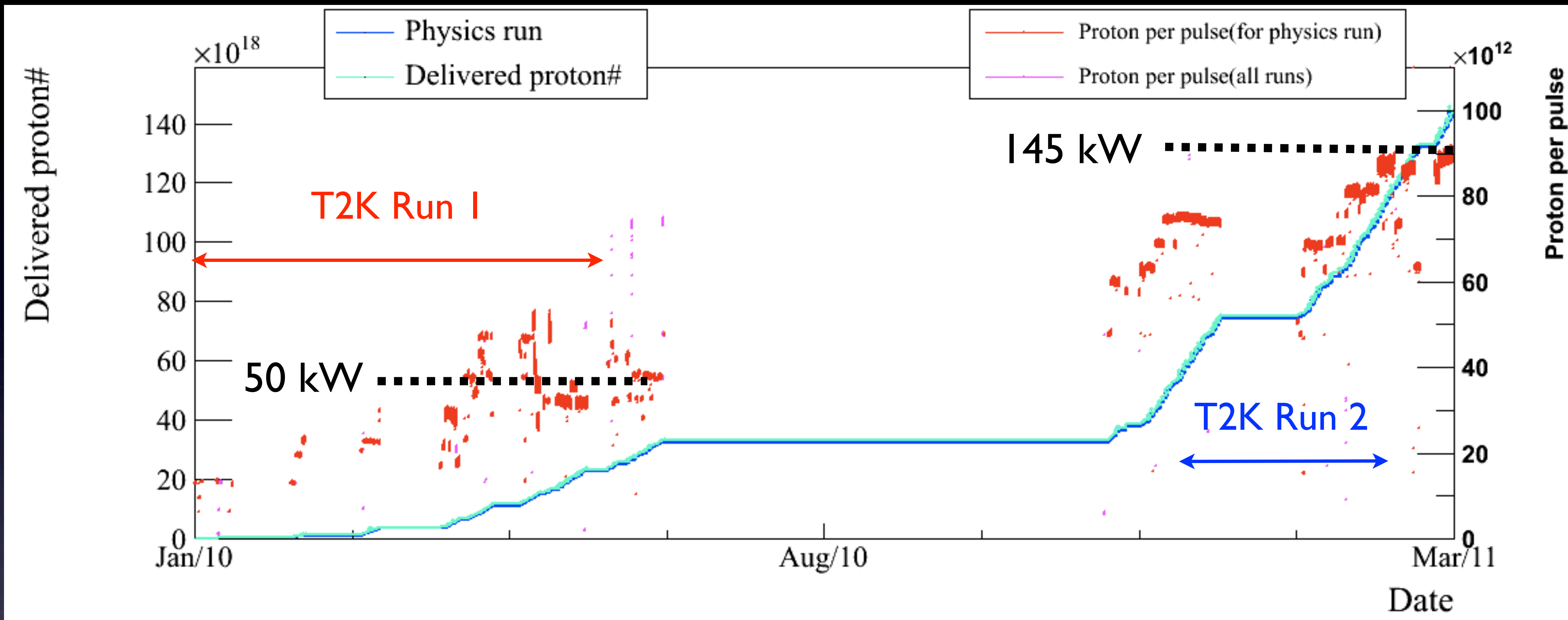
<u>ND280 measurements:</u>
- Inclusive CC ν_μ measurement:
  - Output: $R_\mu^{ND,data}/R_\mu^{ND,MC}$
- Cross-check: $N(\nu_e)/N(\nu_\mu)$

<u>Neutrino interactions:</u>
- Interaction models
- External cross-section data

<u>Super-Kamiokande measurements:</u>
- Select CC ν_μ and ν_e candidates
- Compute N_{MC}^{SK} without oscillations
- Adjust normalization with ND280:
  $N_{exp}^{SK} = (R_\mu^{ND,data}/R_\mu^{ND,MC}) \times N_{MC}^{SK}$
- Compare with N_{obs}^{SK} to evaluate oscillation parameters

ν_e analysis → 1 single bin (counting)
ν_μ analysis → number of events and shape information combined

Run1+Run2 data set



Run1 (Jan-Jun 2010)
3.23×10^{19} p.o.t for analysis
50 kW stable beam operation

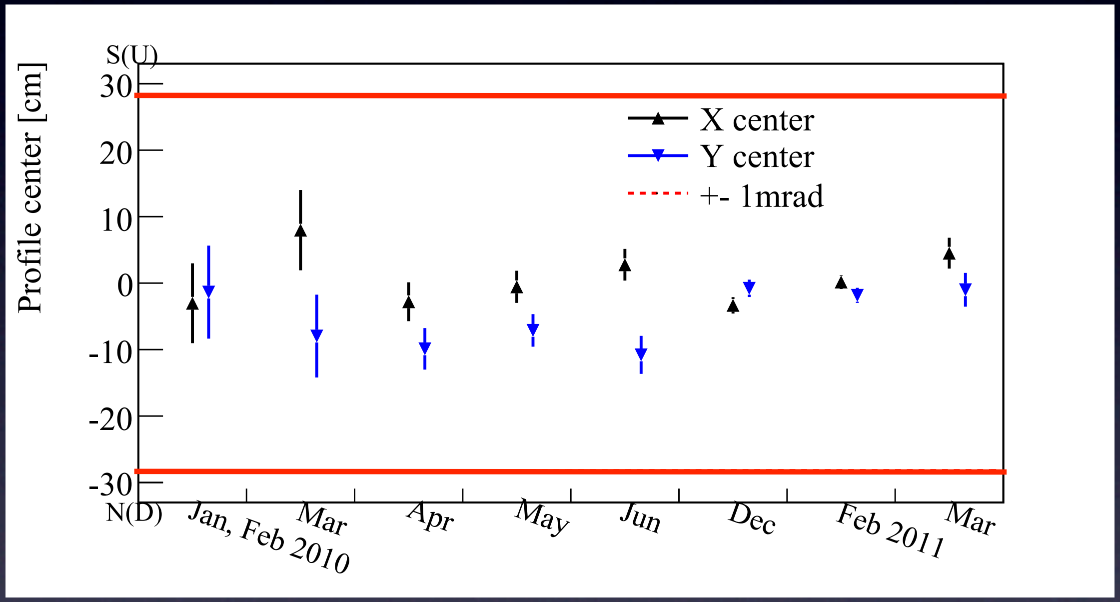
Run2 (Nov 2010 - Mar 2011)
11.08×10^{19} p.o.t for analysis
145 kW stable beam operation

- The total number of protons used for this analysis is 1.43×10^{20} p.o.t → 2% of the T2K final physics goal

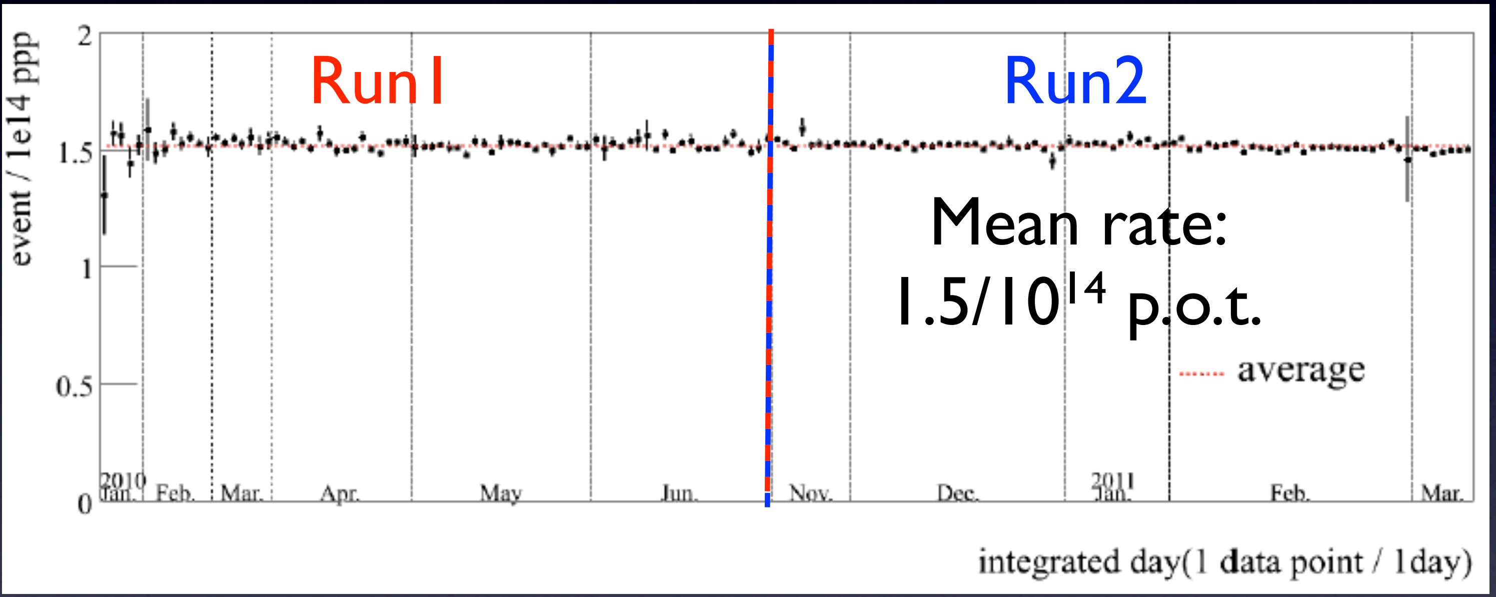
Beam stability

- Necessary to keep the beam direction stable to ensure the stability of the neutrino peak energy: δ(dir)<1 mrad → δ(E)/E<2% @ SK

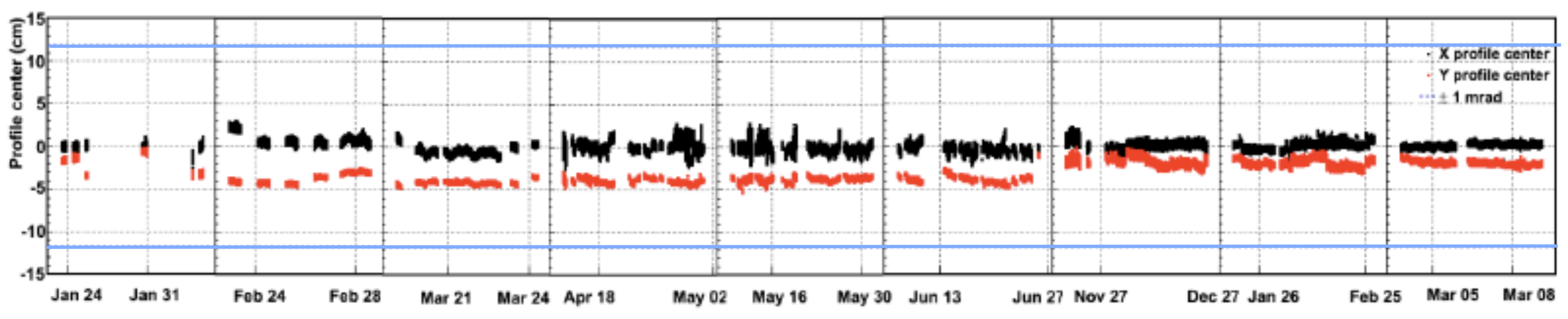
Beam center measured at INGRID well within 1 mrad



INGRID interaction rate stable for Run1 and Run2

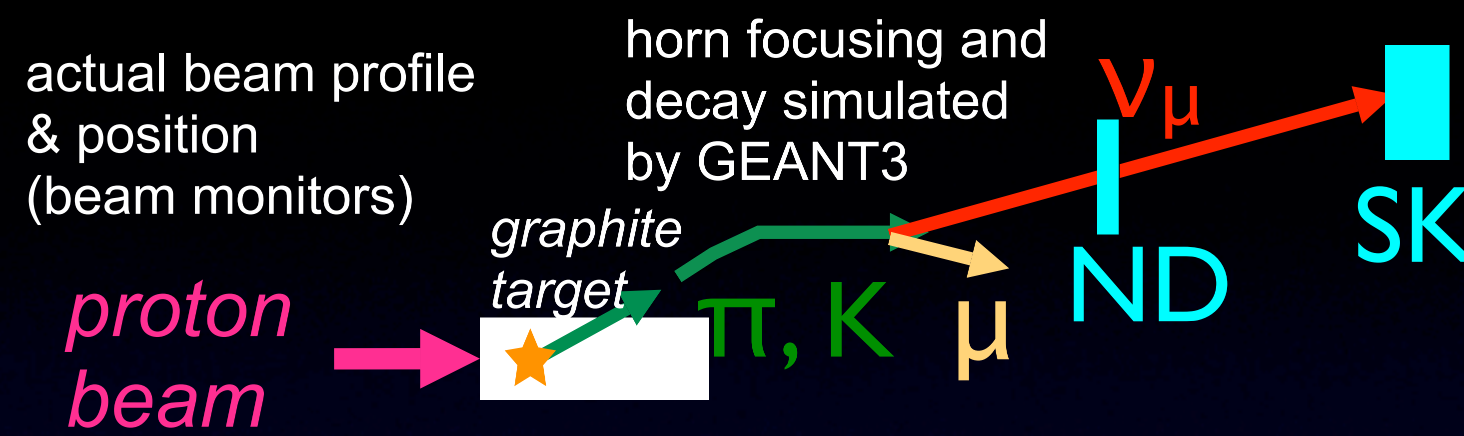


Beam center measured at MUMON well within 1 mrad



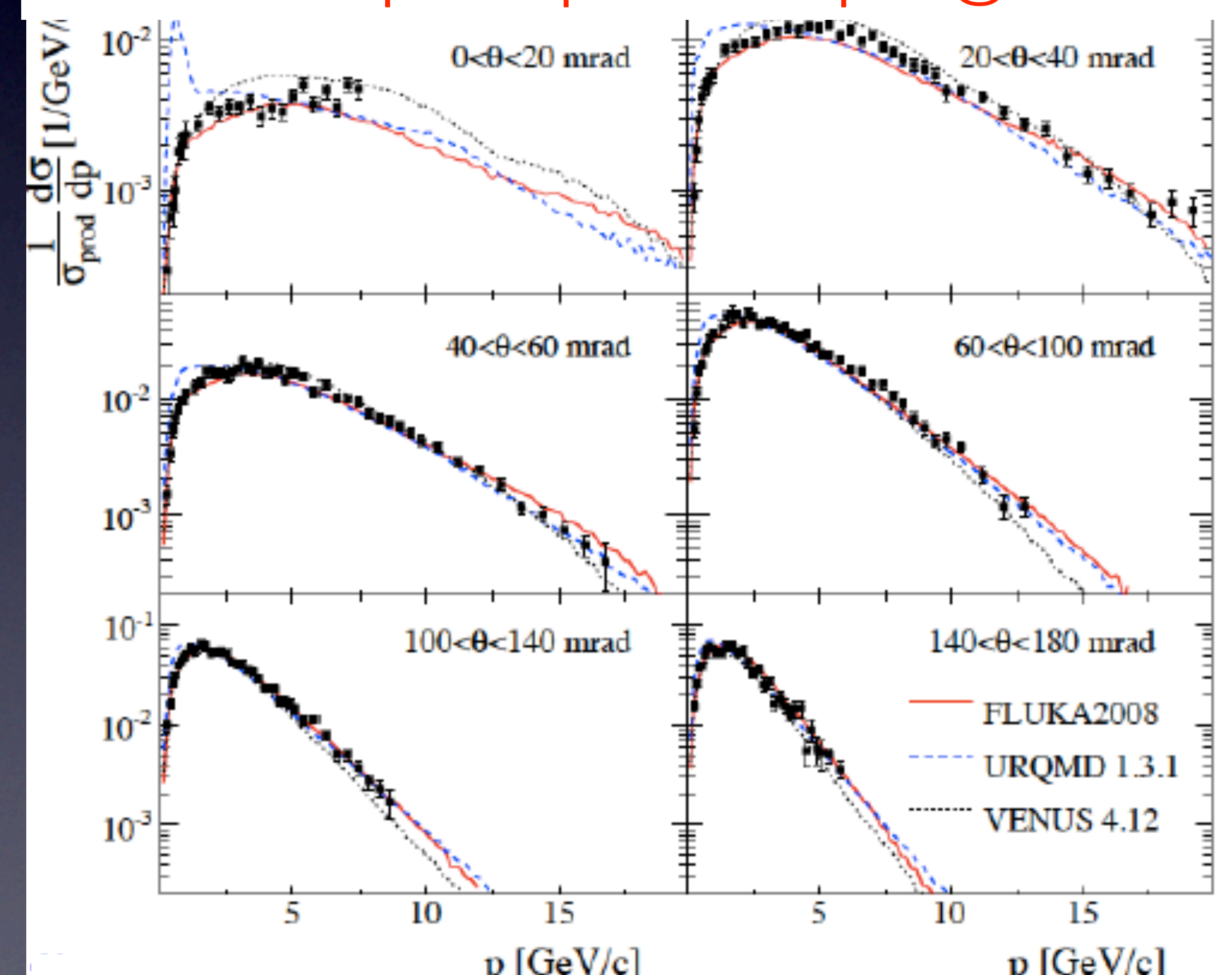
Simulation of neutrino flux

- T2K beam simulation based on hadron production measurements



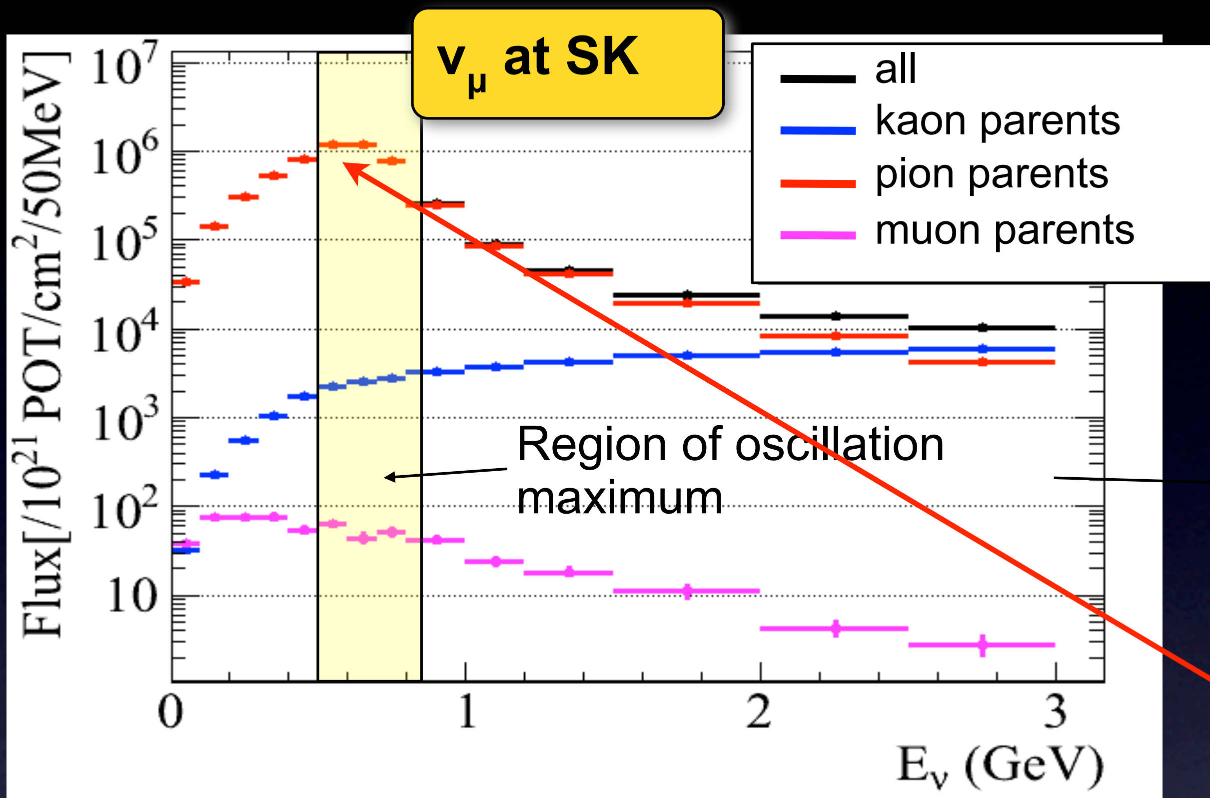
- <u>In target hadron production:</u>
  - NA61 experiment (@CERN) measured the pion production in p+C interactions (same proton energy and target material as T2K)
    - 5-10% errors on each NA61 point, 2.3% normalization error
  - Kaon production and pions outside NA61 acceptance modeled with FLUKA
- <u>Out of target production, horn focusing, particle decays</u>
  - GEANT3 (GCALOR) simulation
  - Interaction cross-section tuned to existing data

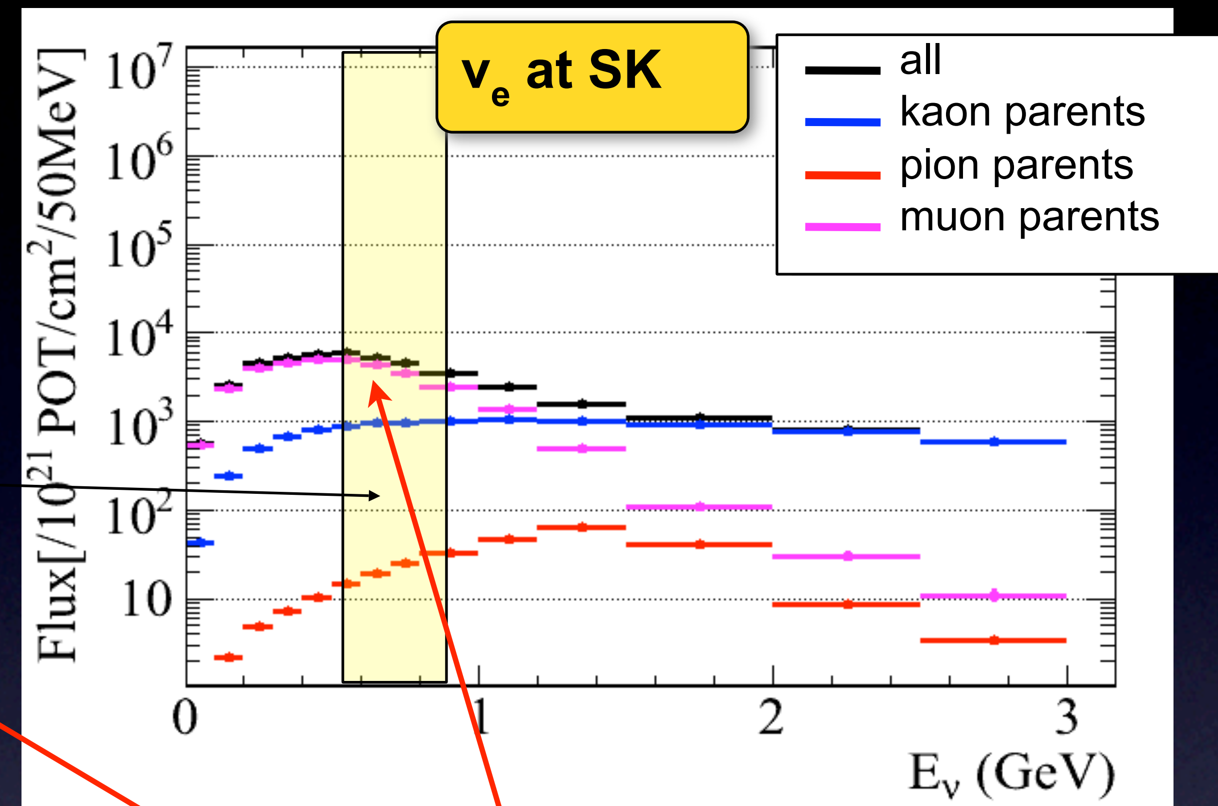
NA61: dσ/dp for π produced in p+C @31GeV



N.Abgrall et al., arXiv:1102.0983 [hep-ex], accepted by Phys.Rev.C (2011)

Expected ν fluxes and uncertainties





Systematics for ν_e appearance

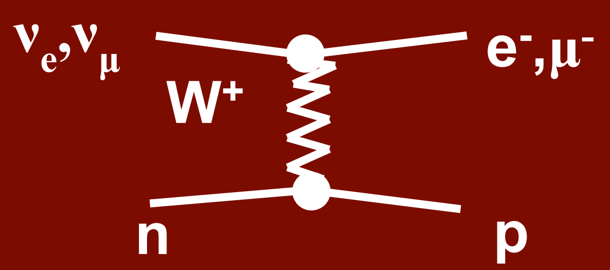
Error source	$R_{ND}^{\mu,MC}$	N_{SK}^{MC}	$\frac{N_{SK}^{MC}}{R_{ND}^{\mu,MC}}$
Pion production	5.7%	6.2%	2.5%
Kaon production	10.0%	11.1%	7.6%
Nucleon production	5.9%	6.6%	1.4%
Production x-section	7.7%	6.9%	0.7%
Proton beam position/profile	2.2%	0.0%	2.2%
Beam direction measurement	2.7%	2.0%	0.7%
Target alignment	0.3%	0.0%	0.2%
Horn alignment	0.6%	0.5%	0.1%
Horn abs. current	0.5%	0.7%	0.3%
Total	15.4%	16.1%	8.5%

Expected beam ν_e contamination: ~1% of the total flux in the oscillation region

The uncertainty on the fluxes is significantly reduced when the expected event rate at the near detector is used

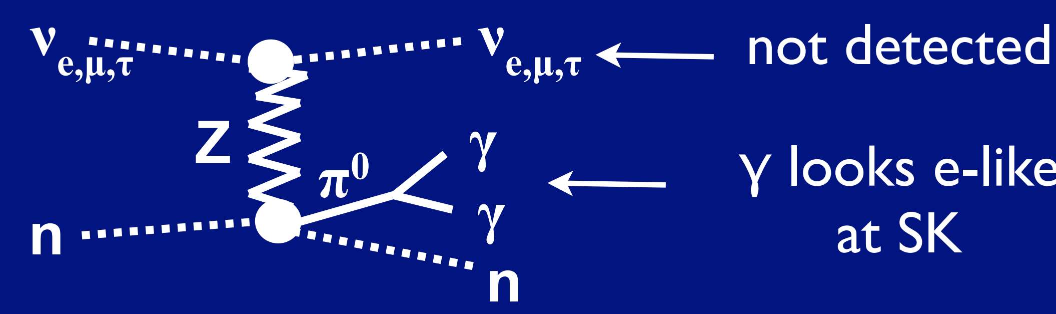
Neutrino interactions

Signal at SK: CCQE interactions producing μ from ν_μ or e from ν_e



CCQE residual cross-section uncertainty (assuming complete far-to-near cancellation) ~7% @ 500 MeV

Backgrounds at SK: NC1π+ interactions for ν_μ NC1π^0 interactions for ν_e



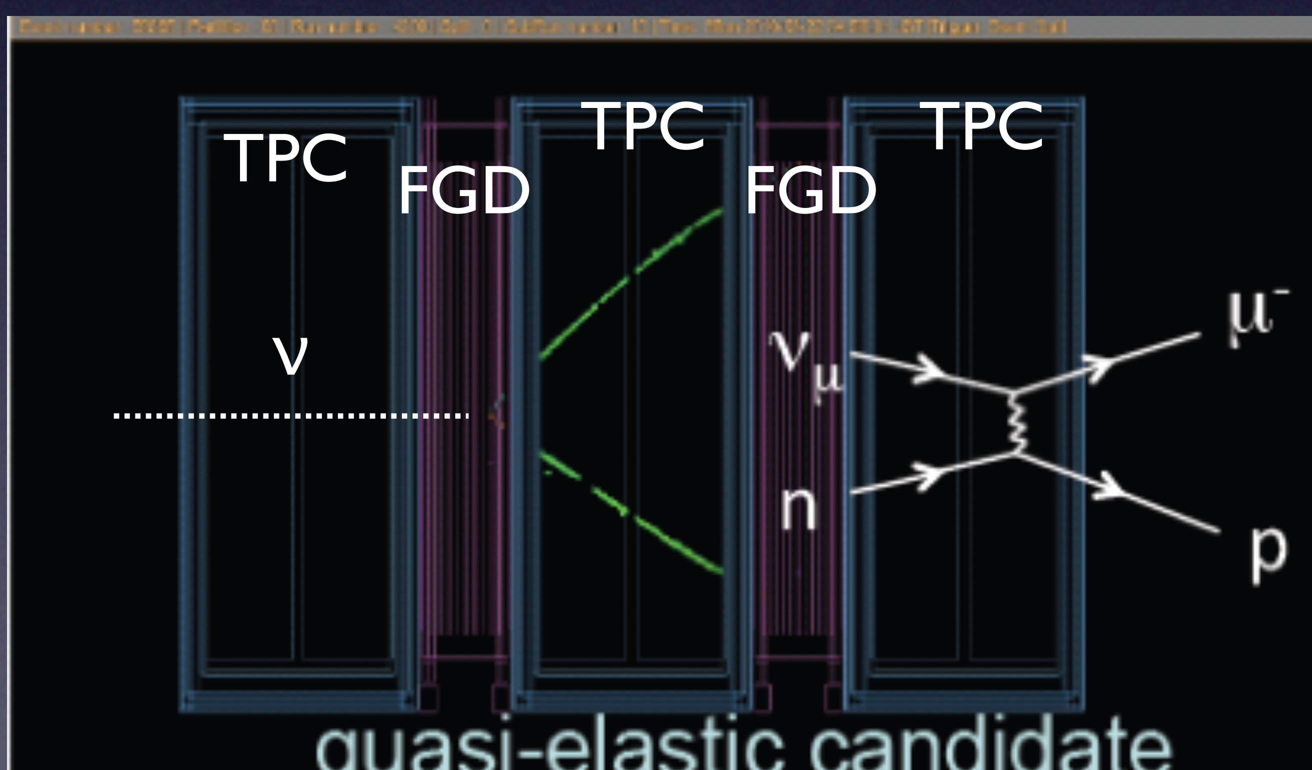
Estimated ~30% error on these processes with respect to CCQE cross-section

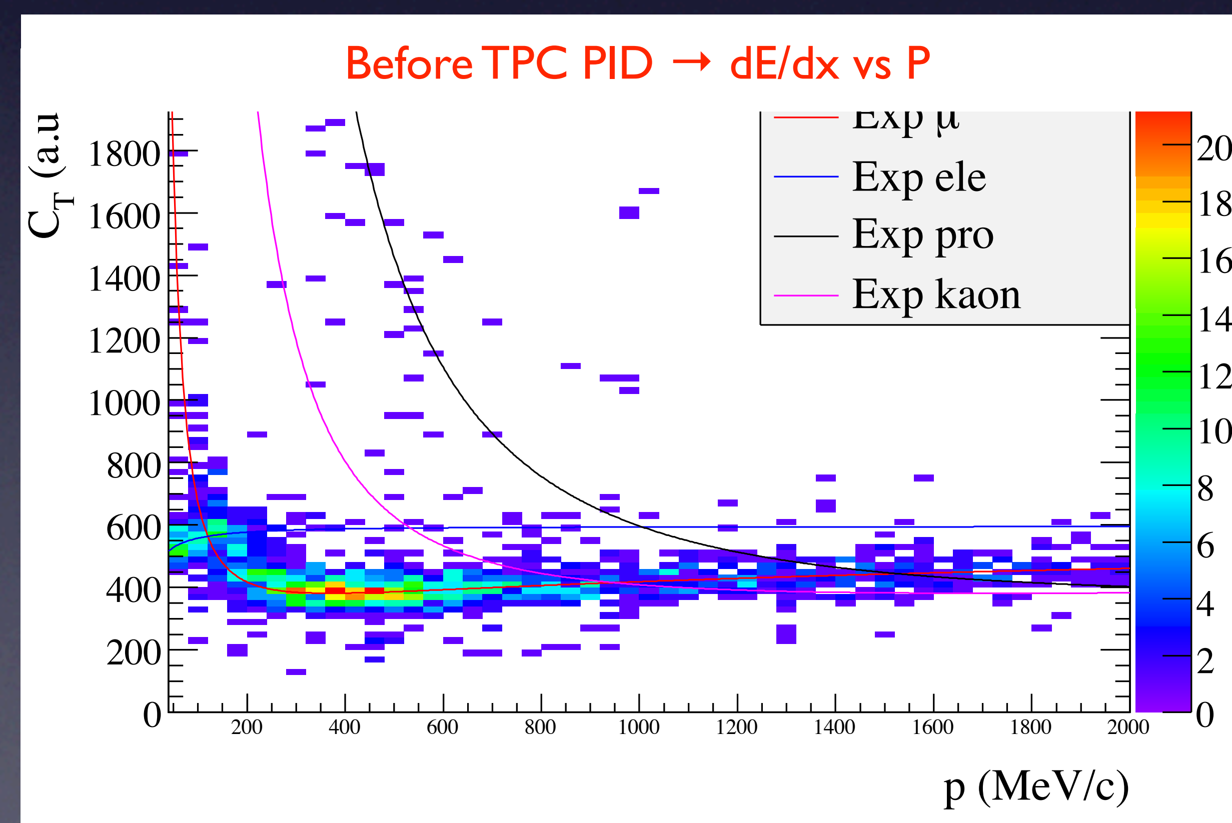
- Uncertainties from:
  - Parameter variations in the model
  - Different models
  - Comparison to external data (MiniBooNE, SciBooNE, SK atmospheric)
- Total systematics: 14% for background to ν_e appearance, 8% to ν_μ disappearance

Process	Cross section uncertainty relative to the CCQE total x-section
CCQE	energy dependent ($\sim \pm 7\%$ at 500 MeV)
CC 1π	30% ($E_\nu < 2$ GeV) – 20% ($E_\nu > 2$ GeV)
CC coherent π^0	100% (upper limit from [30])
CC other	30% ($E_\nu < 2$ GeV) – 25% ($E_\nu > 2$ GeV)
NC $1\pi^0$	30% ($E_\nu < 1$ GeV) – 20% ($E_\nu > 1$ GeV)
NC coherent π	30%
NC other π	30%
Final State Int.	energy dependent ($\sim \pm 10\%$ at 500 MeV)

ND280 analyses

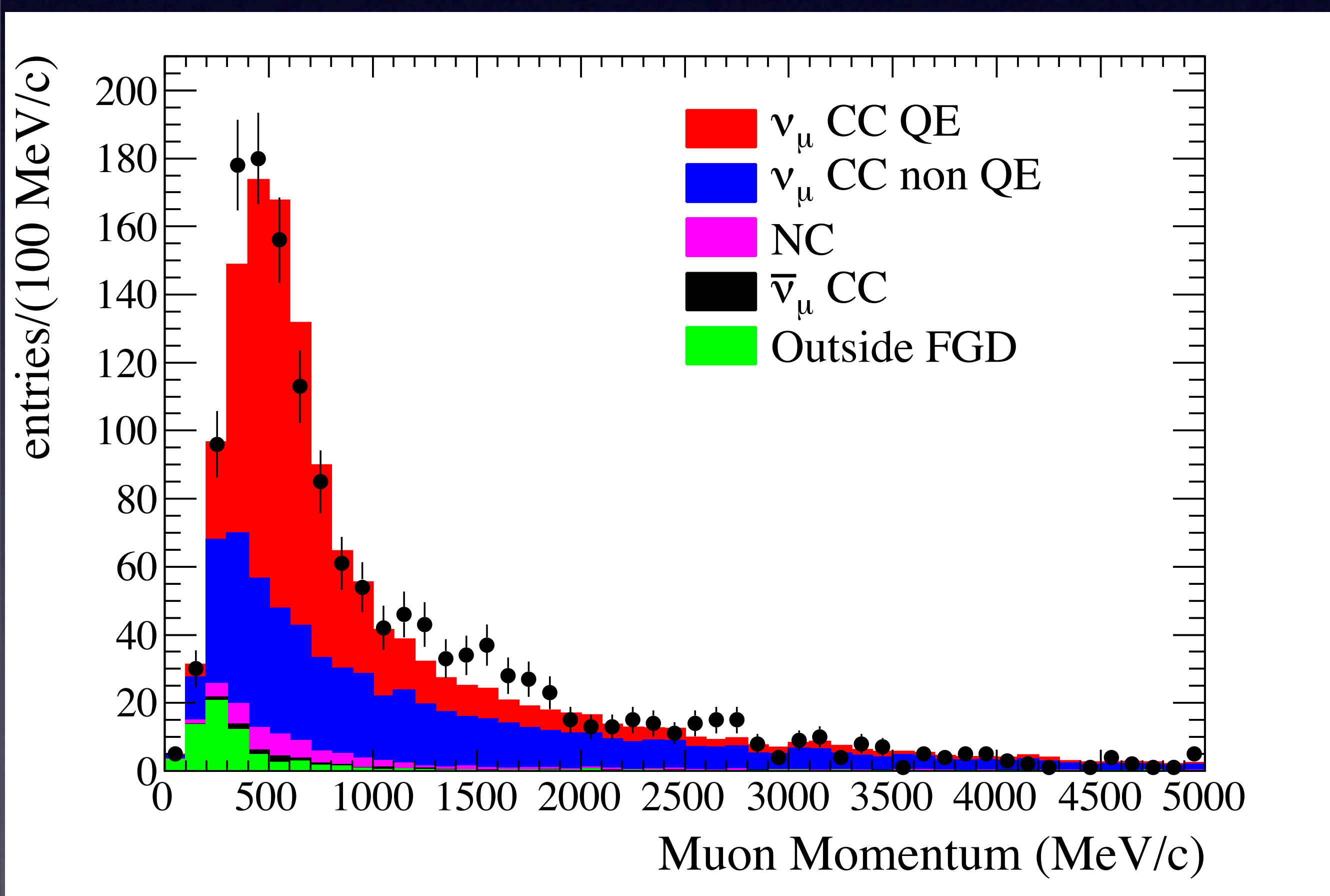
- ND280 analyses done on Run1 (2.9×10^{19} p.o.t)
- Measure inclusive CCν_μ event rate and ν_e beam component
- Select interactions in the Tracker: starting in the FGD FV producing at least 1 negative track in the downstream TPC → lepton candidate
- Measure track's momentum in the TPC
- Use TPC PID to select muons or electrons

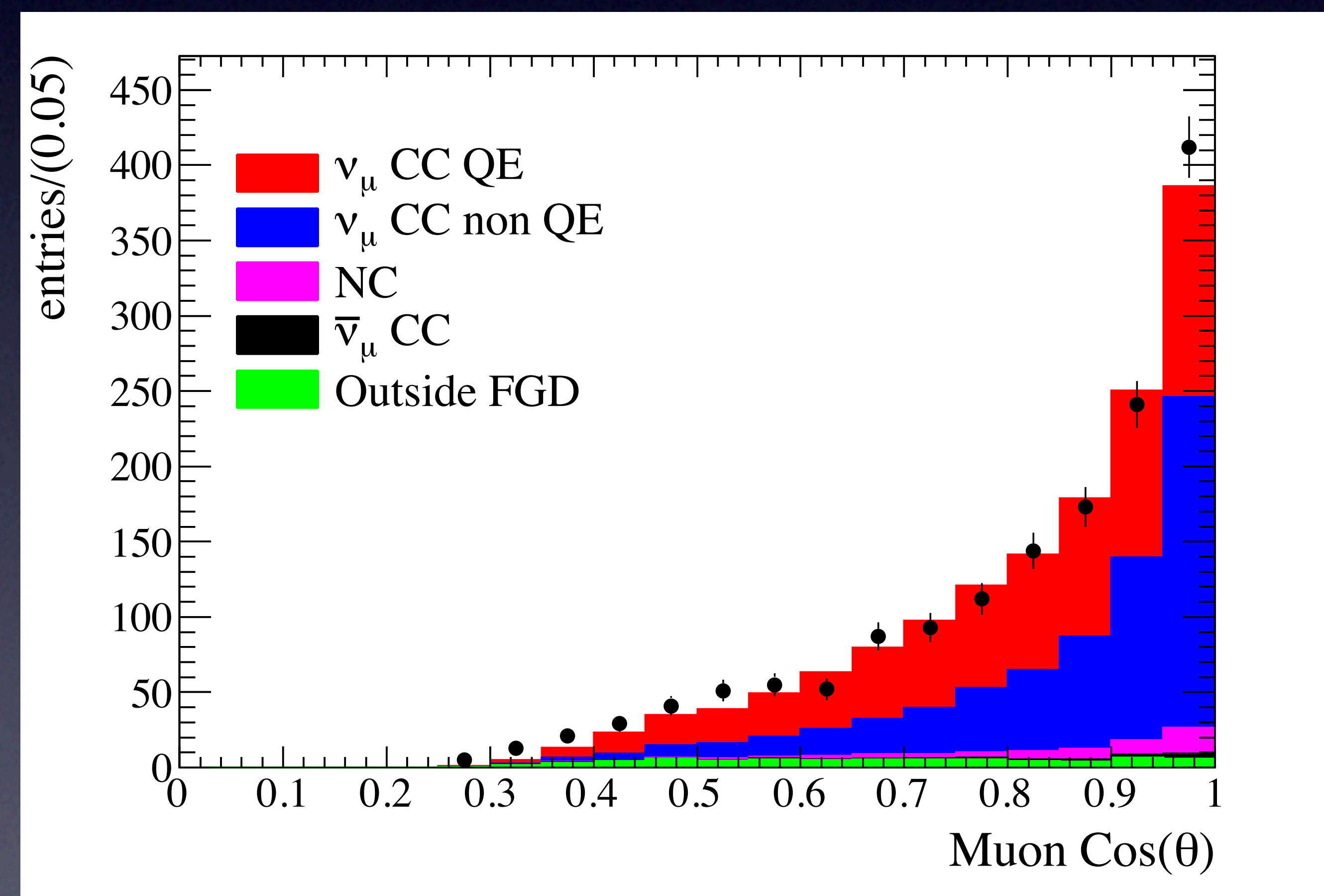




Inclusive CC ν_μ analysis

- Selection of μ-like tracks requiring dE/dx in the TPC compatible with muons
- Good agreement between data and MC (NEUT)
- 90% purity and 38% efficiency in CC selection
- Main detector systematics coming from tracking efficiency and TPC PID

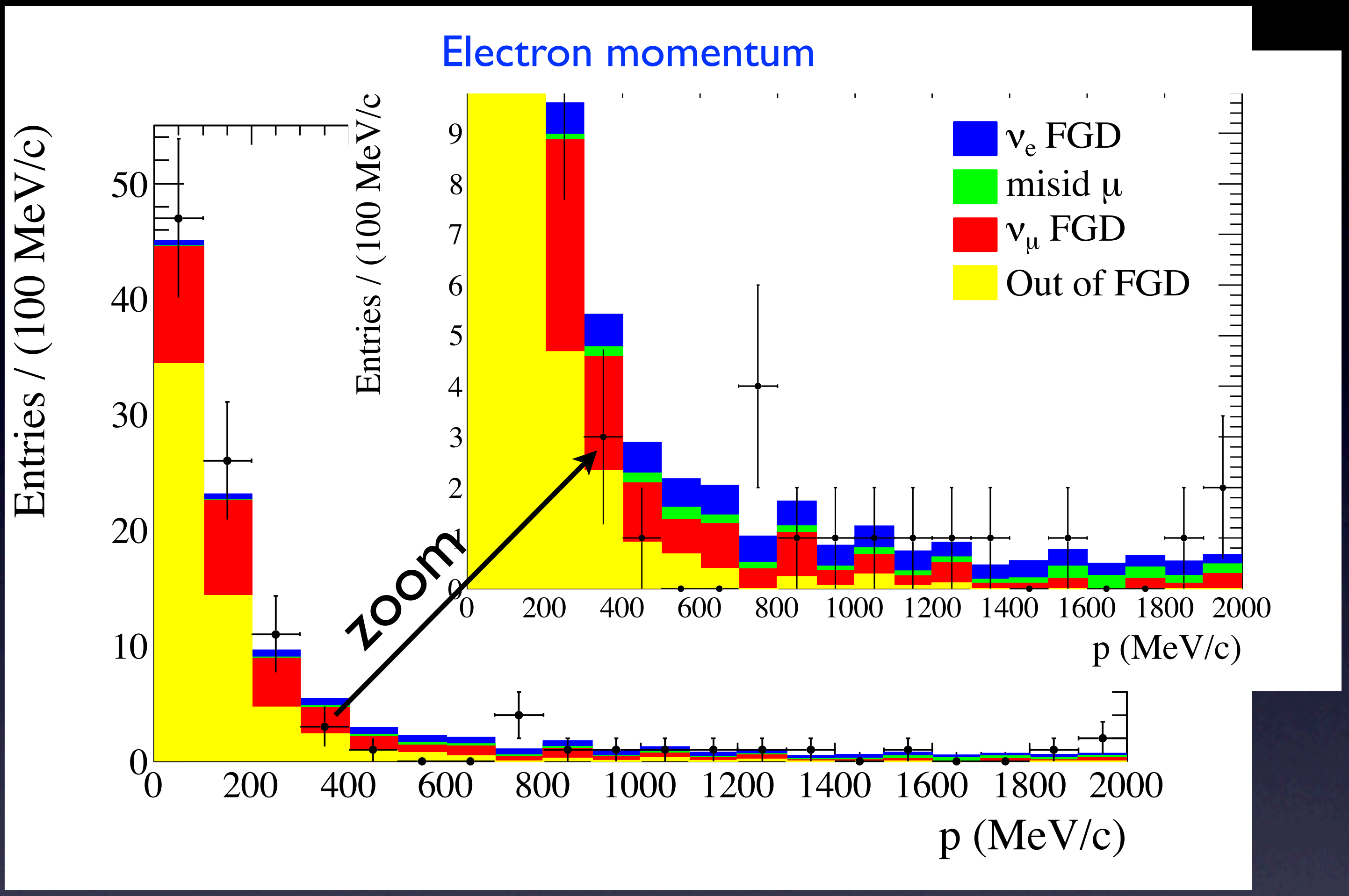




$$R(data/MC) = 1.036 \pm 0.028(stat)^{+0.044}_{-0.037}(det.\ syst) \pm 0.038(phys.\ model)$$

ND280 beam ν_e measurement

- Beam ν_e are the main background to ($\nu_\mu \rightarrow \nu_e$) oscillation signal at SK
- We measured them in the ND280 Tracker by selecting electrons via dE/dx in the TPC
- Background from misidentified μ estimated using a sample of sand muons in the data
- MC expectation for backgrounds from γ conversions constrained by control samples based on data
- Likelihood fit on the electron momentum to measure N(ν_e)
- The observed ν_e/ν_μ ratio at ND280 is consistent with the MC expectation confirming our beam prediction

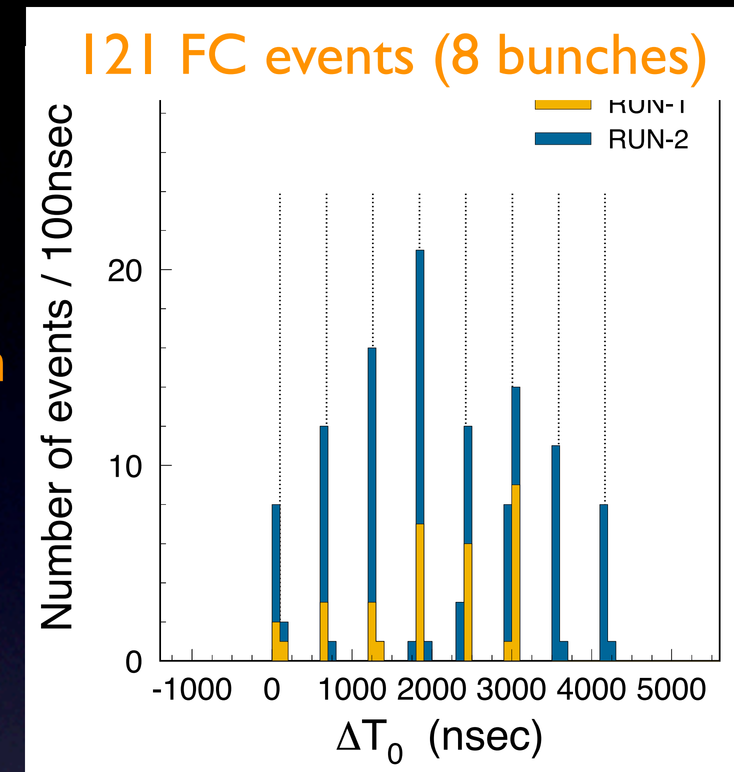


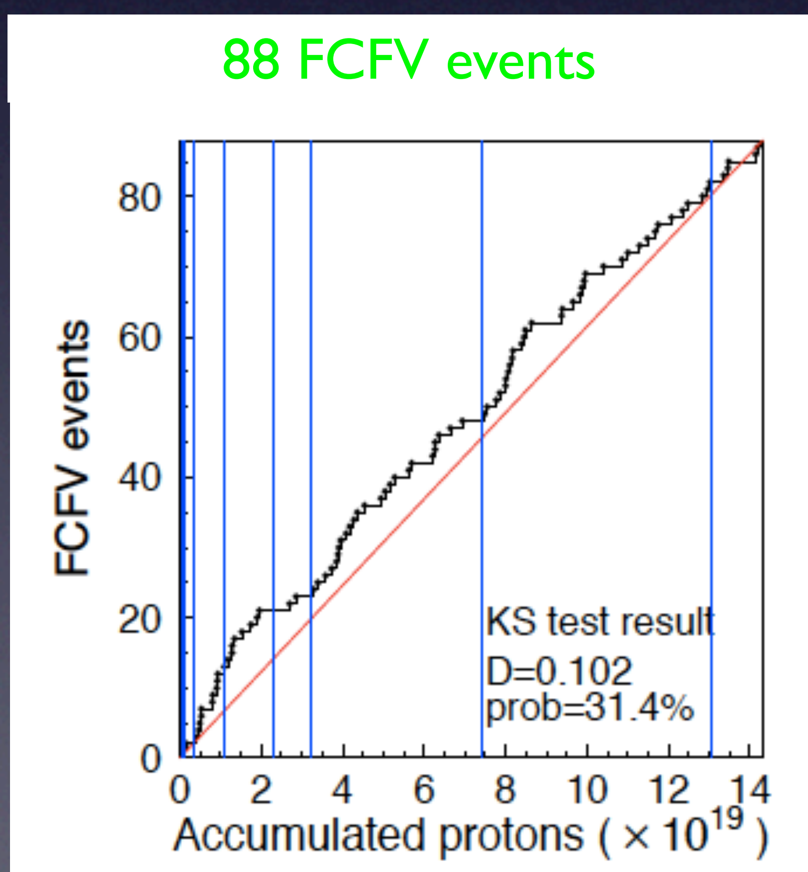
$$R(\nu_e/\nu_\mu) = (1.0 \pm 0.7(stat) \pm 0.3(syst))\%$$
$$< 2.0\% \ @ \ 90\% \ C.L.$$

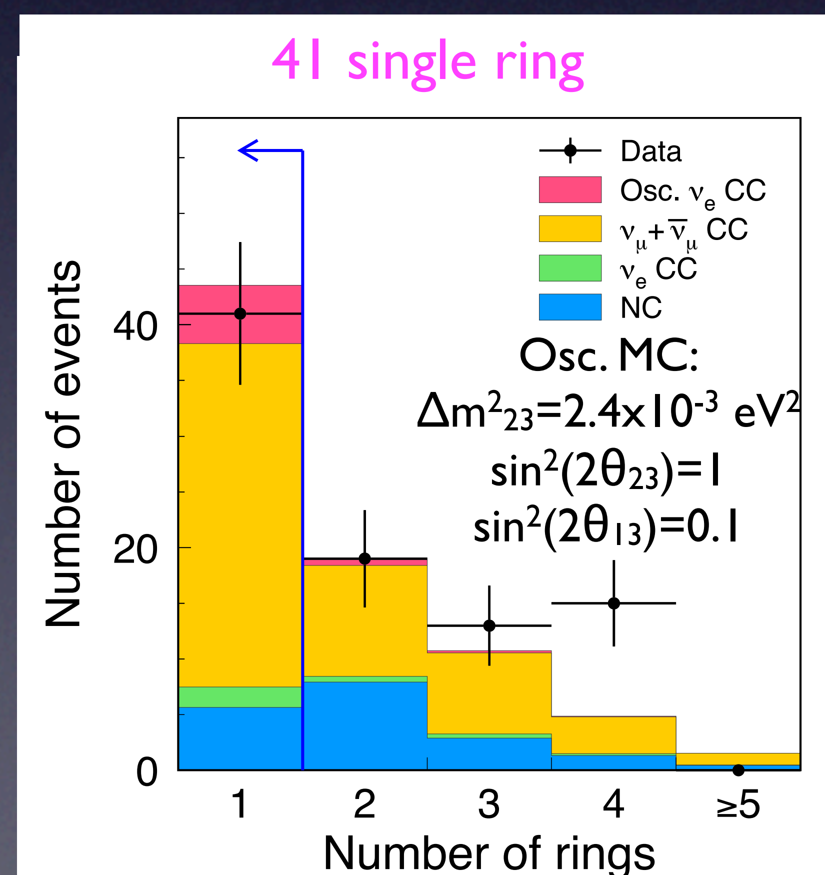
$$\frac{N(\nu_e)^{DATA} N(\nu_\mu)^{MC}}{N(\nu_\mu)^{DATA} N(\nu_e)^{MC}} = 0.6 \pm 0.4(stat) \pm 0.2(syst)$$

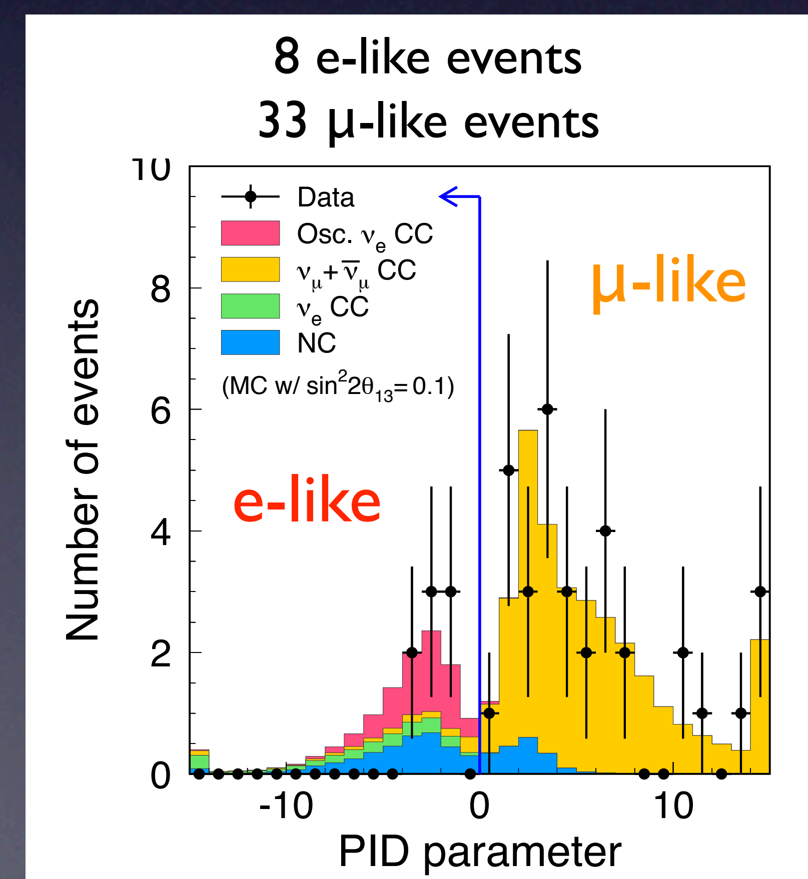
Super-Kamiokande event selection

- Predefined event selection for ν_μ and ν_e
- First steps that are common:
  - SK synchronized to beam timing using GPS
  - Fully contained events in the Inner Detector, minimal activity in the Outer Detector
  - Starting in the FV (FCFV)
  - Number of rings = 1
  - PID algorithm to distinguish e-like and μ-like events









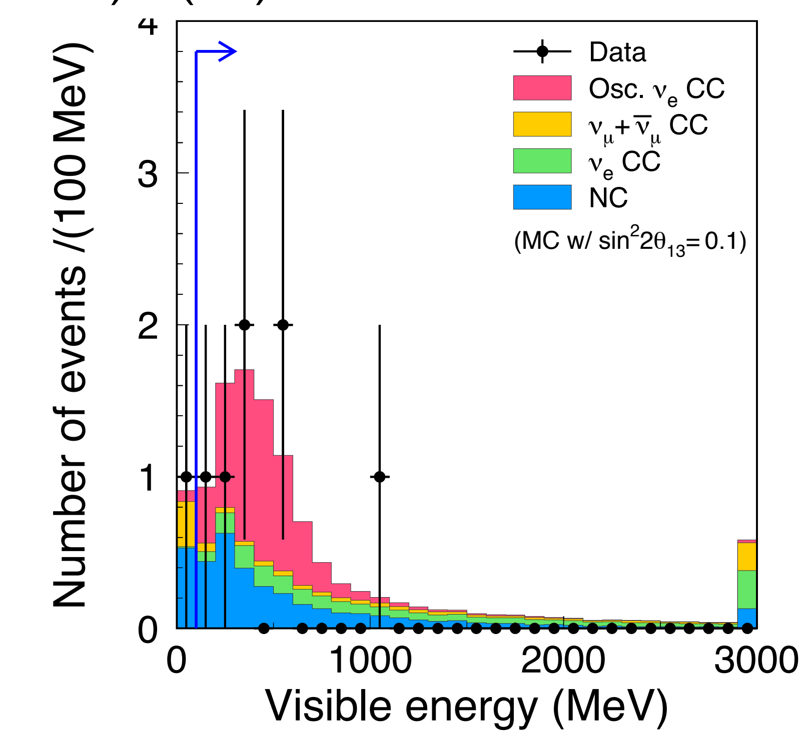
ν_e appearance results

SK ν_e event reduction

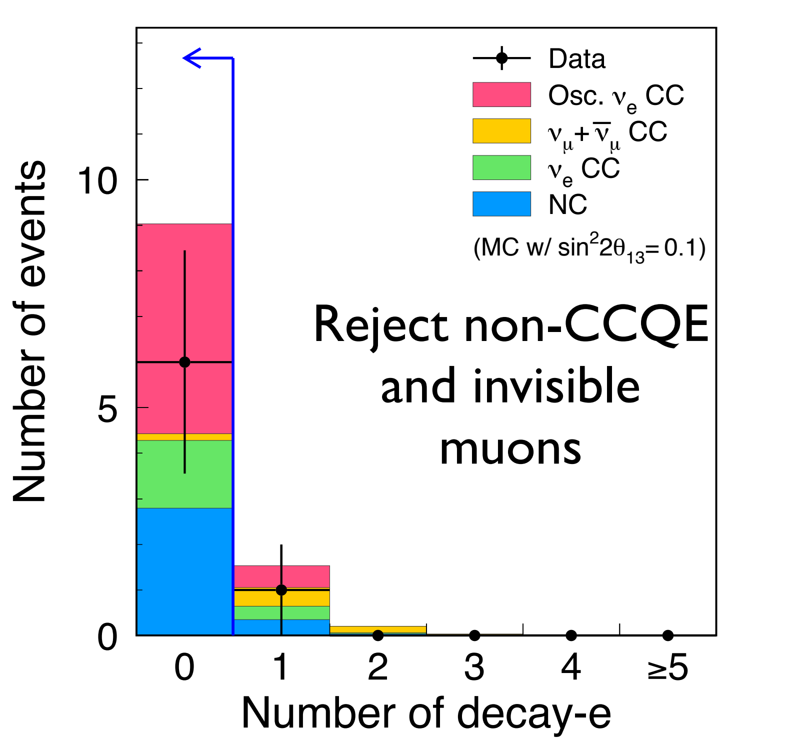
- After ring counting 8 single ring e-like events are selected
- SK “tight” cuts are applied to further reject the background:

Signal efficiency: 67%
Bkg rejection: 99% for NC, 77% for beam ν_e

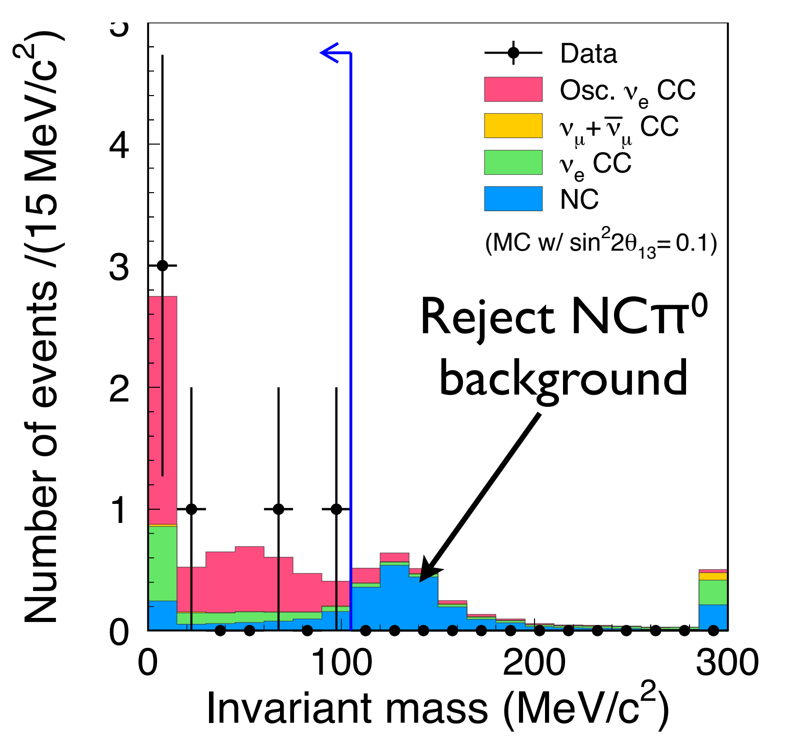
1) E(vis)>100 MeV → N=7



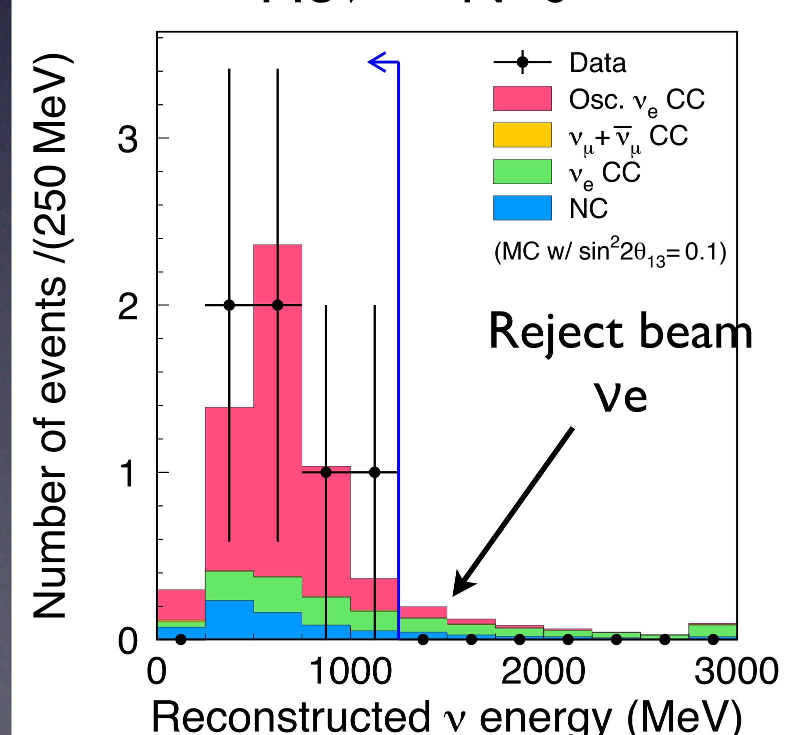
2) No decay electrons → N=6



3) M_{inv} with forced 2nd ring <105 MeV → N=6



4) Rec neutrino energy <1250 MeV → N=6



Number of expected events

- We observed 6 ν_e candidates
- The expected number of events from un-oscillated neutrinos is 1.5

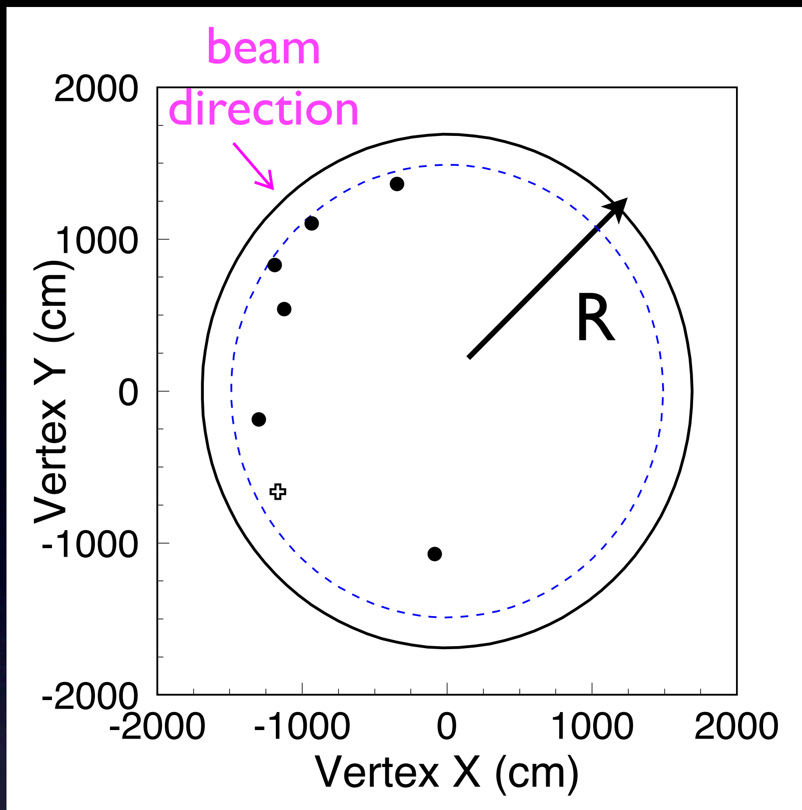
Source	Nexp
Beam ν_e	0.8
ν_μ Neutral Current	0.6
ν_μ Charged Current	0.1
Total	1.5±0.3

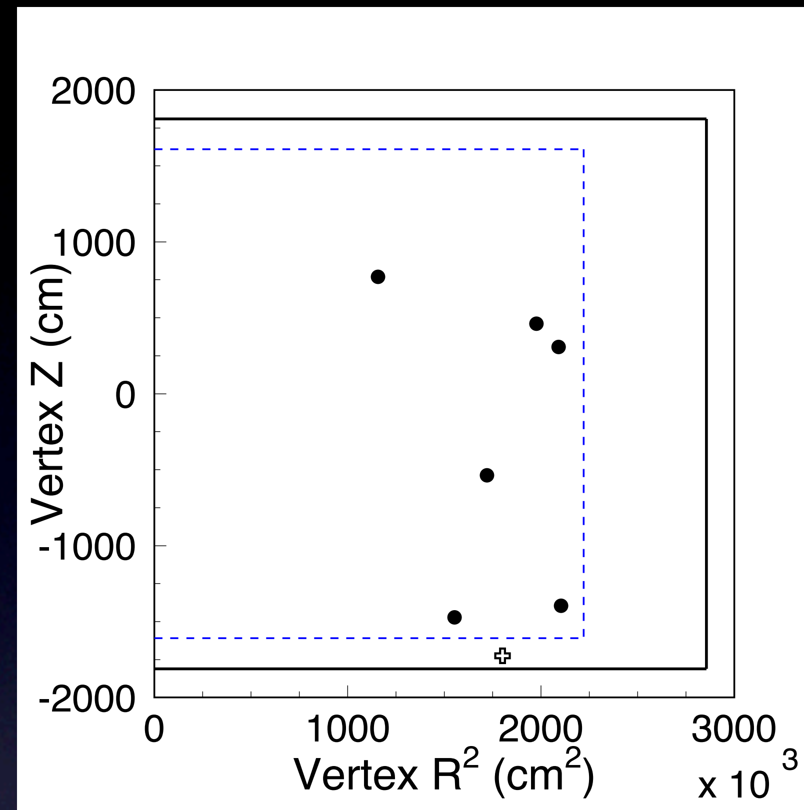
Syst for θ_{13}=0 → Nexp = 1.5±0.3

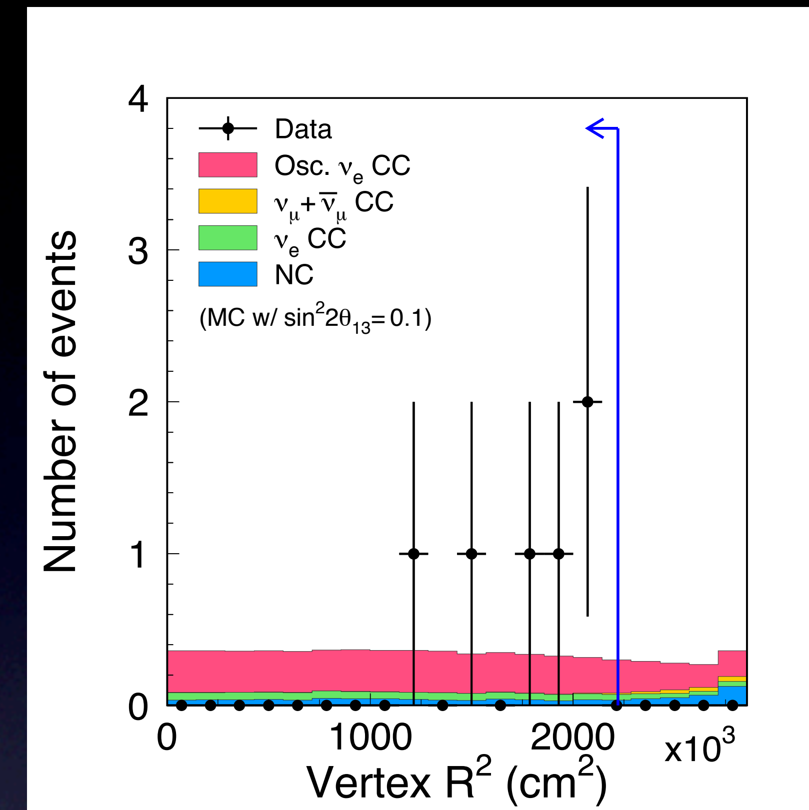
error source	syst. error
ν flux	$\pm 8.5\%$
ν int. cross section	$\pm 14.0\%$
Near detector	$^{+5.6}_{-5.2}\%$
Far detector	$\pm 14.7\%$
Near det. statistics	$\pm 2.7\%$
Total	$^{+22.8}_{-22.7}\%$

- ν flux: Dominated by hadron production
- ν int. cross section: Dominated by FSI and NCπ0 cross-section uncertainties
- Near detector: ND280 dominated by TPC tracking efficiency and ionization in the gas
- Far detector: SK dominated by ring counting, PID and π^0 mass systematics

Vertex distribution



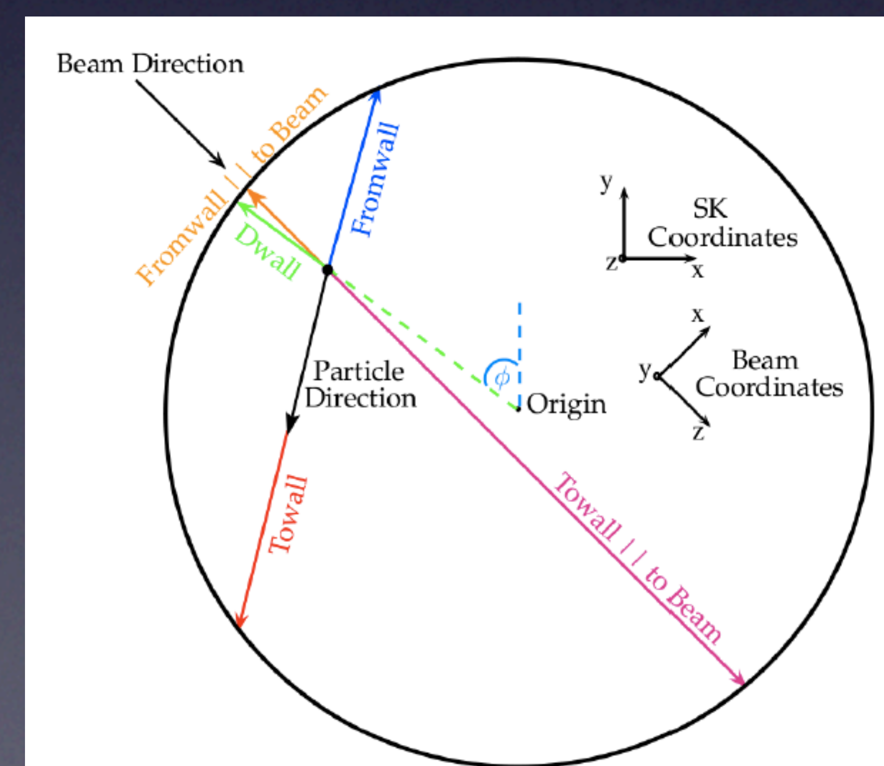




- Vertex distribution of the 6 events → clustering at large R
- KS p-value for this R^2 distribution → 0.03

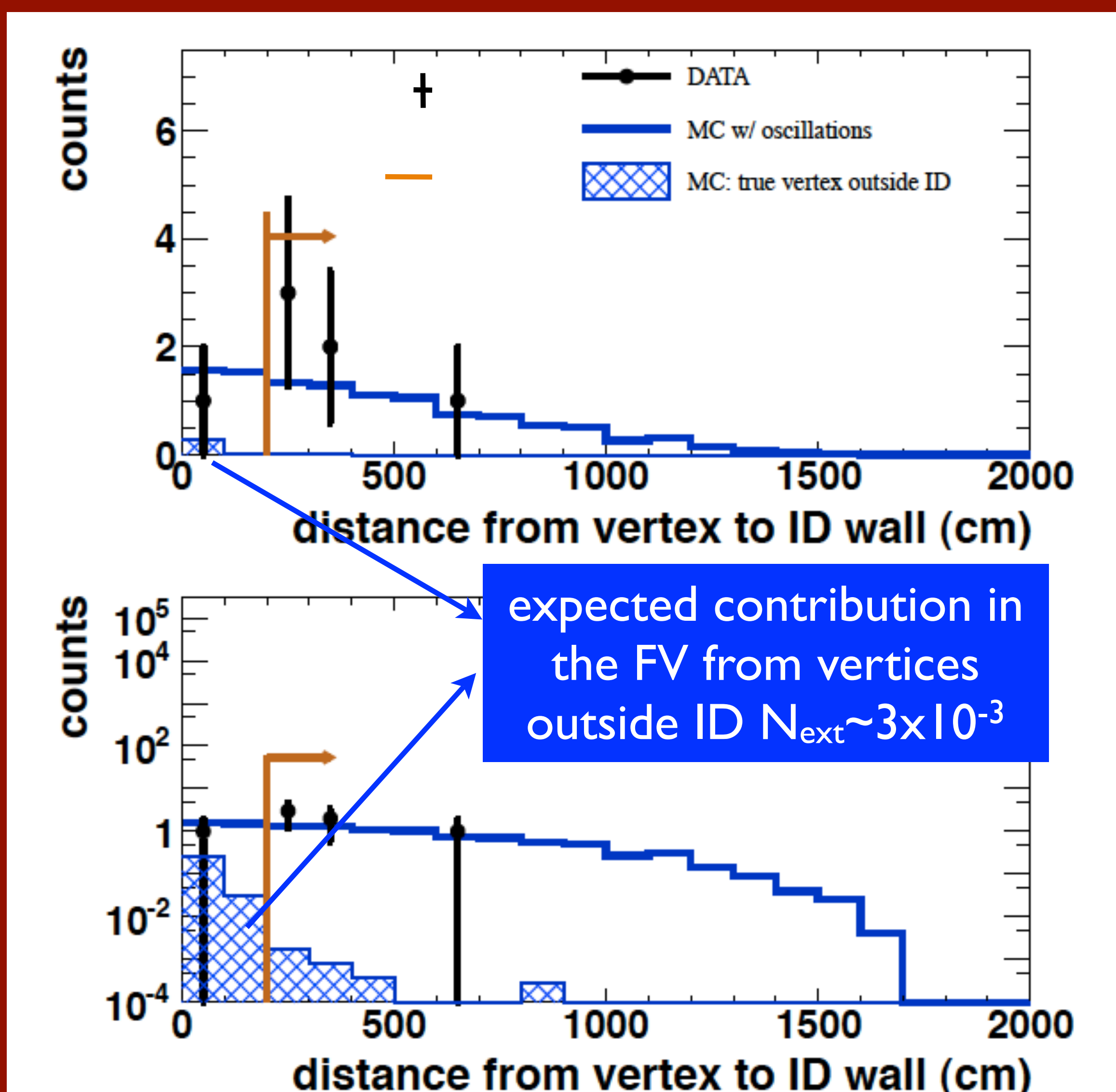
Vertex position tested against several distributions

Probability From Toy-MC		
Distribution	**7 FC Events**	**6 FCFV Events**
Dwall	22.6%	3.7%
Fromwall	22.8%	5.8%
Fromwall || *to Beam*	1.4%	0.14%
R^2	10.9%	3.1%

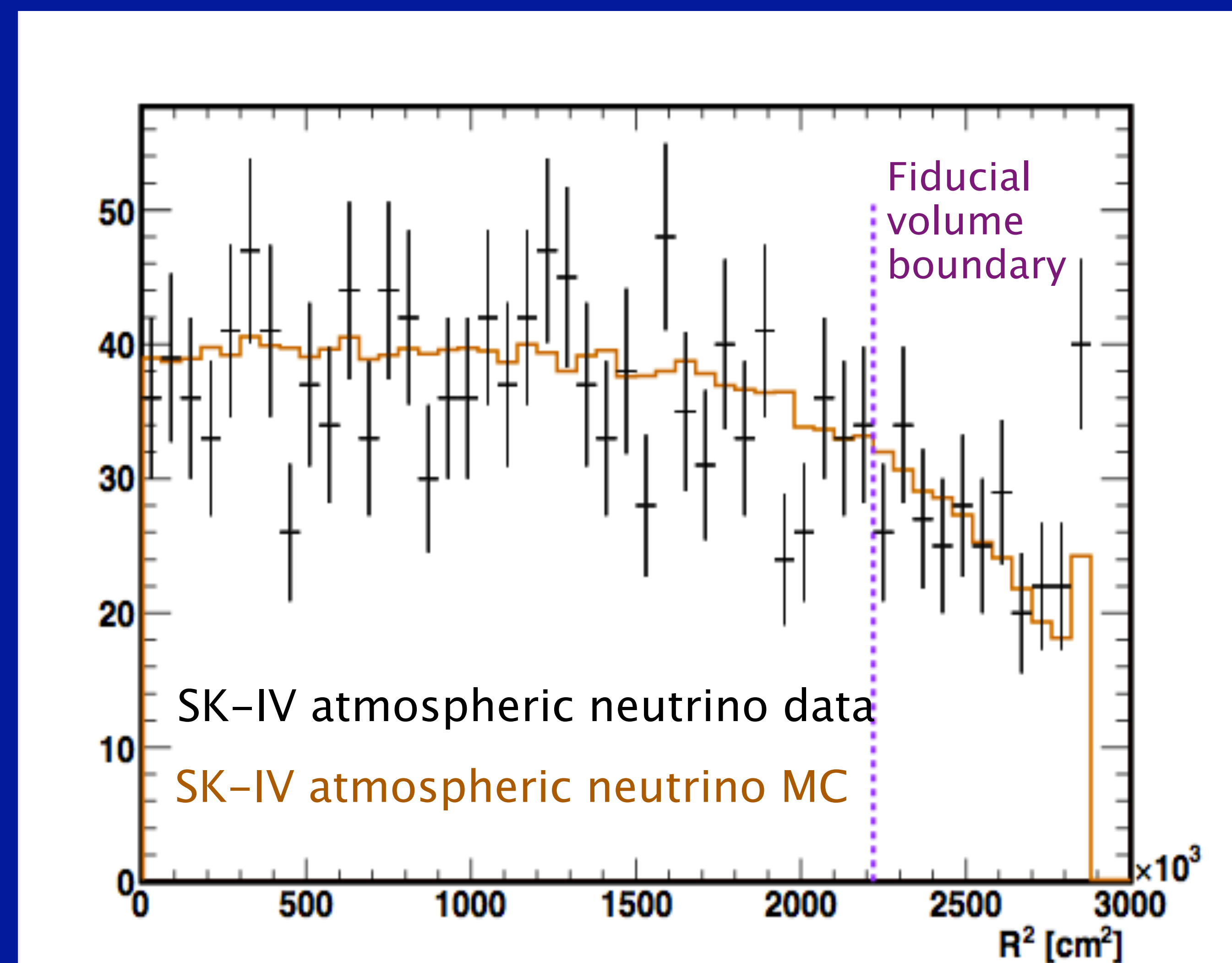


More on vertex distribution

Selection of events passing all the ν_e cuts except the FV → no excesses outside the FV → no indication of not accounted entering background

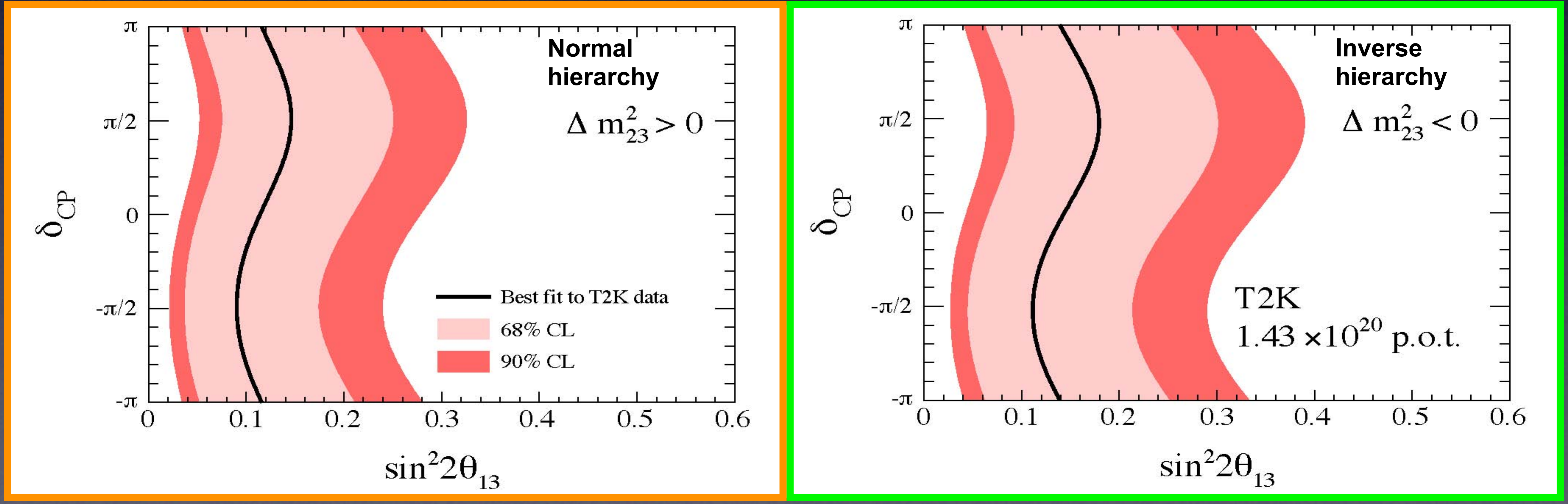


SK IV Sub-GeV e-like + T2K cuts → good agreement between data and MC inside and outside the FV



ν_e appearance analysis

- Probability of observing 6 events if $\sin^2(2\theta_{13})=0$ → 0.7% (2.5σ significance)
- Feldman-Cousins unified method used to produce the confidence intervals
- For $\sin^2(2\theta_{23})=1$ and $\Delta m^2_{23}=2.4\times10^{-3}$ eV^2:
  - Normal hierarchy, $\delta=0$:
    - Best fit → $\sin^2(2\theta_{13})=0.11$ and $0.03<\sin^2(2\theta_{13})<0.28$ at 90% C.L.
  - Inverted hierarchy, $\delta=0$:
    - Best fit → $\sin^2(2\theta_{13})=0.14$ and $0.04<\sin^2(2\theta_{13})<0.34$ at 90% C.L.



Published in Phys. Rev. Lett. 107, 041801 (2011)

New T2K result:
ν_μ disappearance

SK ν_μ event reduction

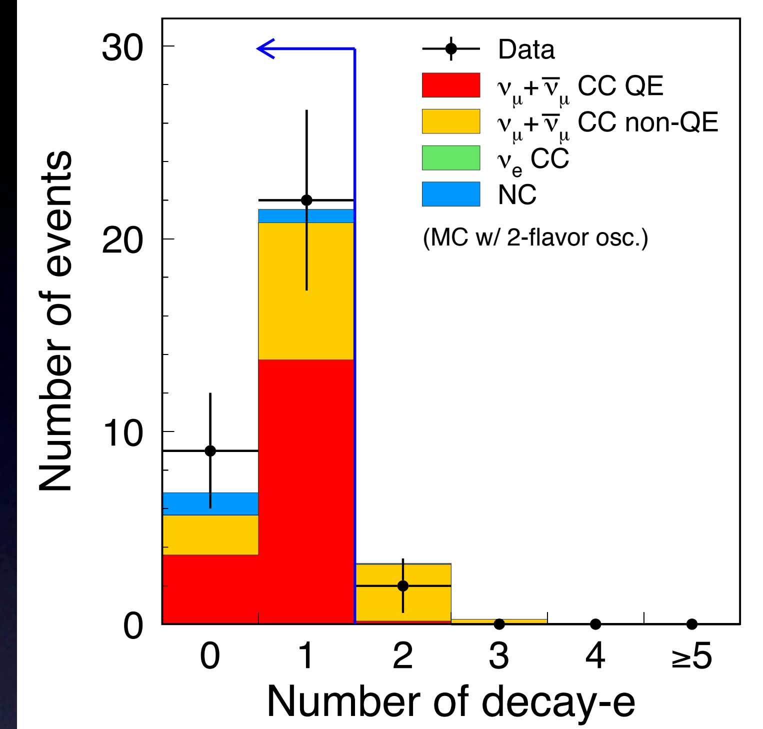
- 1 single ring μ-like → 33 events
- Additional cuts:
  - Less than 2 decay electrons
  - Reconstructed μ momentum larger than 200 MeV
- 31 events pass all the selections

Expected final sample composition with oscillations

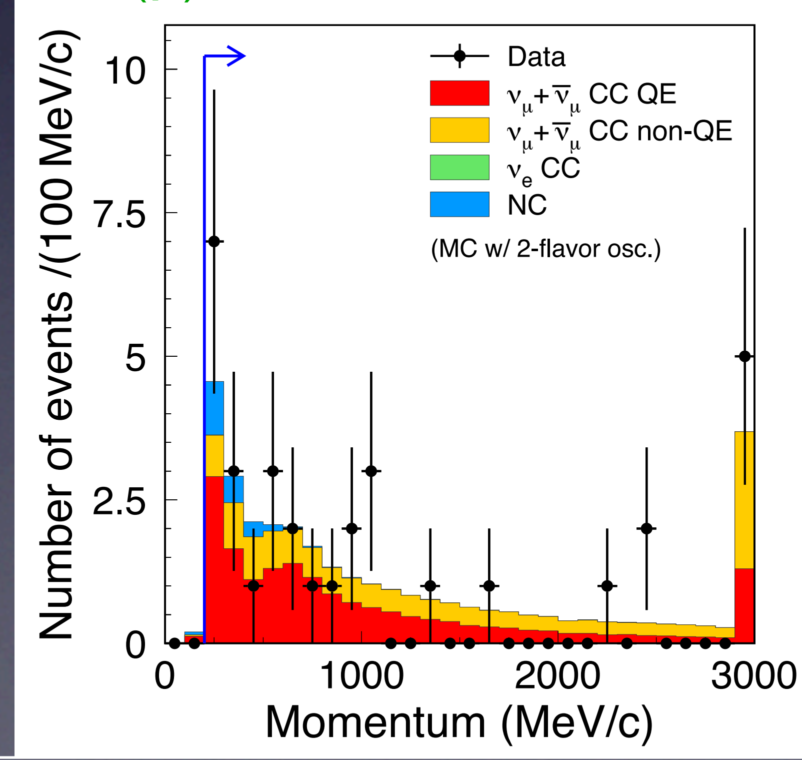
CCQE	CCnonQE	NC	ν_e
61%	32%	6%	<1%

- Systematics on the number of expected events computed using enriched samples of CCQE, CCnonQE and NC in SK atmospheric data
- Dominant systematics on SK efficiency given by the ring counting efficiency

N decay electrons <2→N=31



P(μ)^{rec}>200 MeV → N=31



ν_μ disappearance analysis method

- 2 flavor neutrino oscillation fit: $P(\nu_\mu \to \nu_\mu) = 1 - sin^2(2\theta_{23}) sin^2(1.27 \Delta m^2_{23} L/E)$
- We developed 2 independent oscillation analysis to extract the oscillation parameters

Method A:
Maximum likelihood with fitting of the systematics parameters:

$$L(sin^2 2\theta, \Delta m^2, \overrightarrow{f}) = L_{norm}(sin^2 2\theta, \Delta m^2, \overrightarrow{f}) \cdot L_{shape}(sin^2 2\theta, \Delta m^2, \overrightarrow{f}) \cdot L_{syst}(\overrightarrow{f})$$

L_{norm} → Poisson distribution of the total number of events
L_{shape} → un-binned spectrum shape

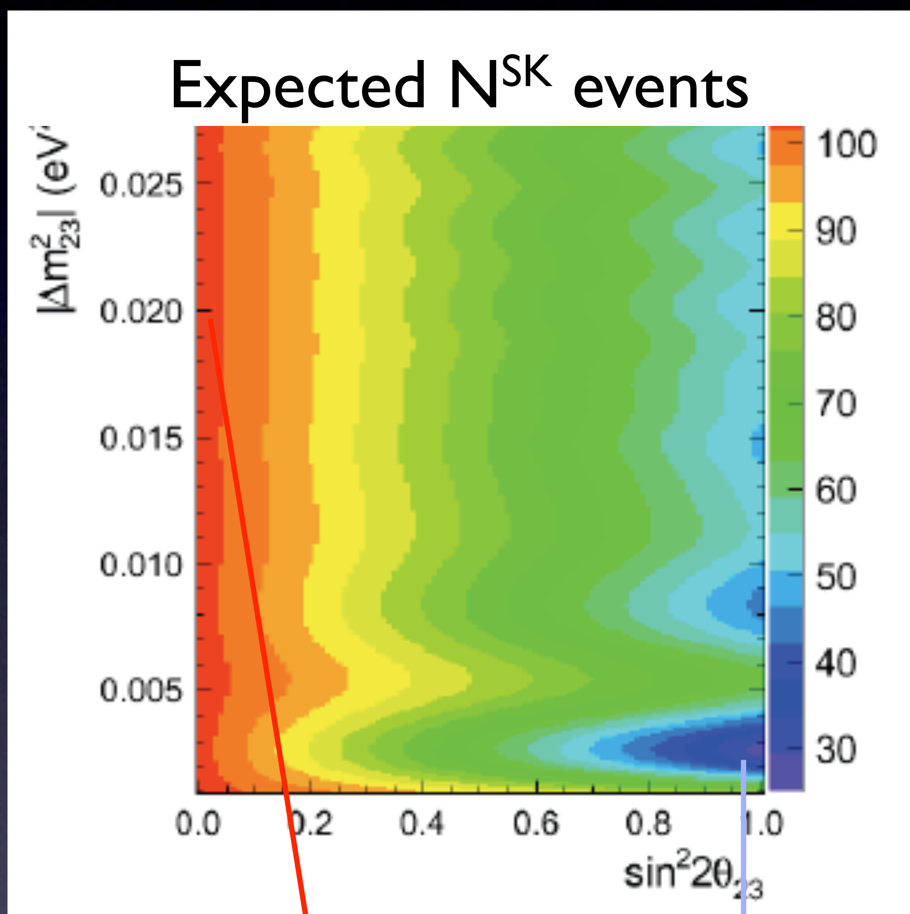
Method B:
Comparison of the observed spectrum with the expected spectrum varying oscillation parameters to minimize:

$$\chi^2 = 2 \sum_{i=1}^{N} \left[n_i^{obs} \cdot ln\left(\frac{n_i^{obs}}{n_i^{exp}}\right) + n_i^{exp} - n_i^{obs} \right]$$

i = bin number in SK energy
$n_i^{obs(exp)}$ number of observed (expected) events in the i-th bin
In this method systematic *f* parameters are not fitted

Number of events at SK

- Number of expected events as a function of the oscillation parameters (Δm^2_{23}, $\sin^2(2\theta_{23})$)



N_{exp} without oscillation: 103.6

N_{exp} with oscillation: 28.3
$\sin^2 2\theta=1$, $\Delta m^2=2.4\times10^{-3}$ eV^2

Systematics for N_{exp}^{SK} for different oscillation parameters

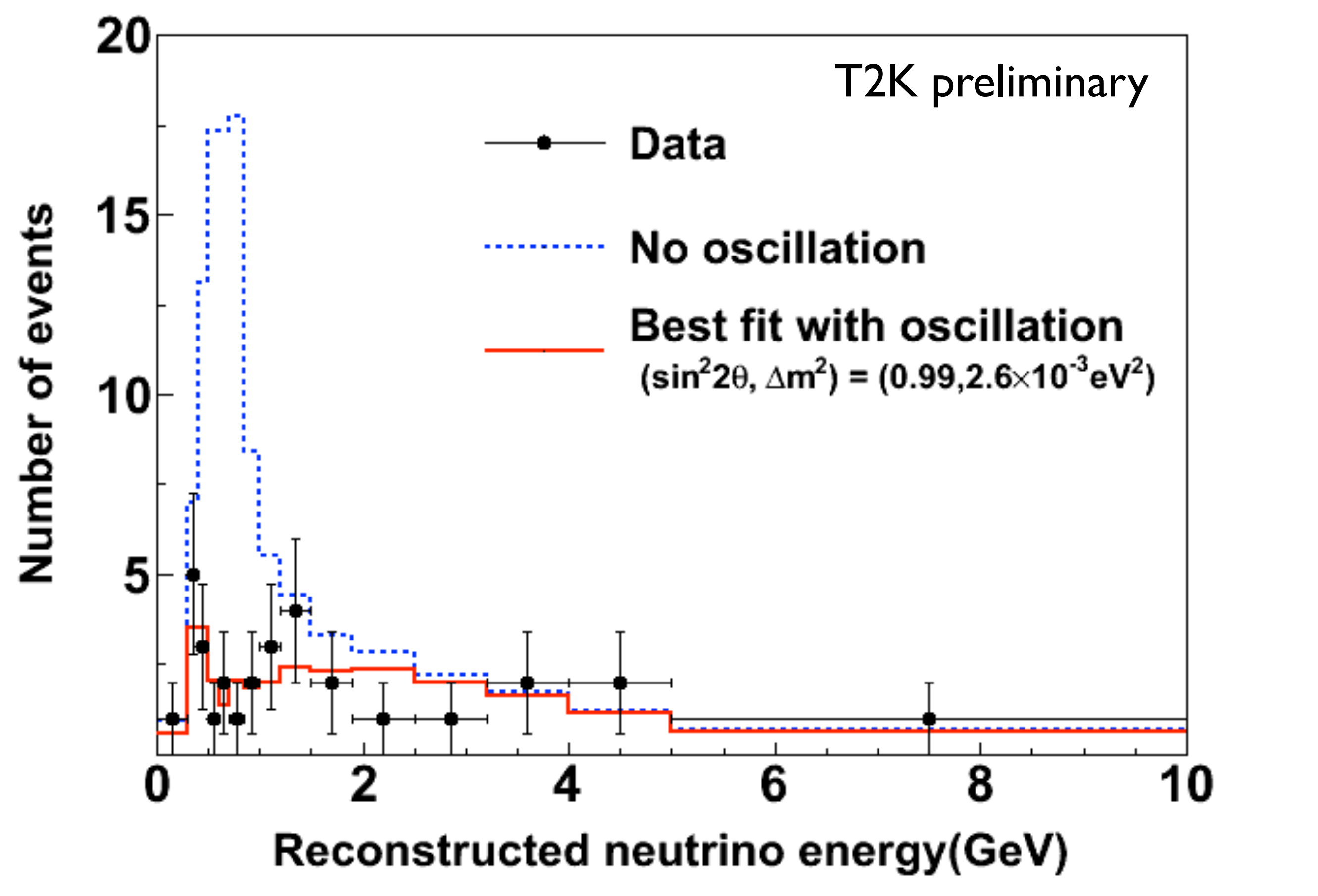
Error source	$\sin^2 2\theta=1$, $\Delta m^2=2.4\times10^{-3}$	No osc
SK Efficiency	+10.3% 10.3%	+5.1% -5.1%
Cross section and FSI	+8.3% -8.1%	+7.8% -7.3%
Beam Flux	+4.8% -4.8%	+6.9% -5.9%
ND Efficiency and Overall Norm.	+6.2% -5.9%	+6.2% -5.9%
Total	+15.4% -15.1%	+13.2% -12.7%

Systematics coming from SK efficiency, ND280 efficiency, cross-section and FSI, and beam flux simulation: ~15%

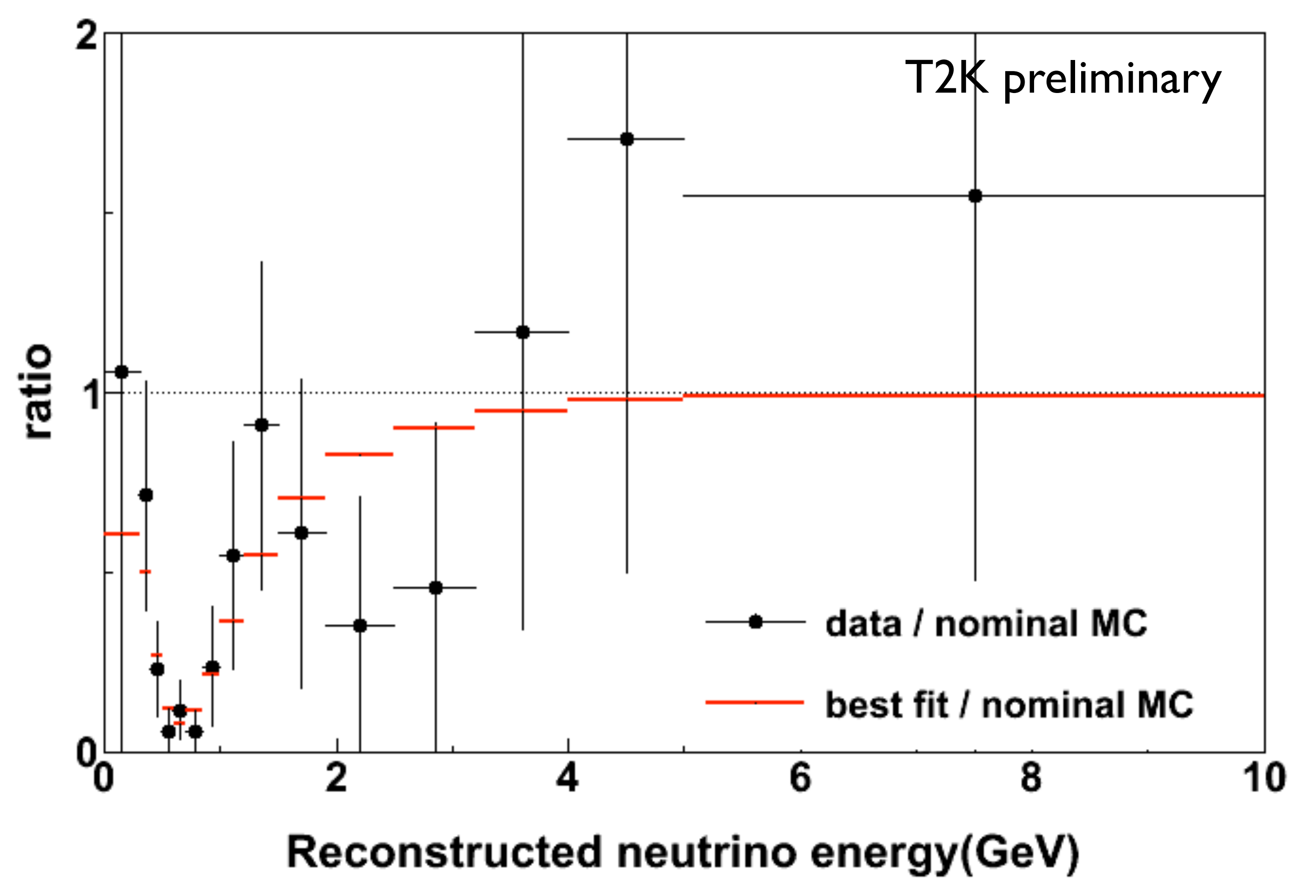
- Null-oscillation hypothesis excluded at 4.5 σ (only from N^{obs})

Neutrino energy spectrum

- Observed events at SK satisfying ν_μ disappearance criteria: 31
- Oscillation parameters extracted from an oscillation fit on $E(\nu)^{rec}$
- The oscillation pattern due to the disappearance of ν_μ is clearly visible in the reconstructed energy spectrum → advantage of using off-axis configuration



Ratio between data and MC without oscillation



T2K new result: ν_μ disappearance

- Both analyses use Feldman-Cousins unified method to build confidence intervals

Method A

Best fit:

$\sin^2(2\theta_{23}) = 0.99$, $|\Delta m^2_{23}| = 2.6\times10^{-3}$ eV^2

90% C.L:

$\sin^2(2\theta_{23}) > 0.85$

$2.1\times10^{-3} < \Delta m^2_{23}(\text{eV}^2) < 3.1\times10^{-3}$

Method B

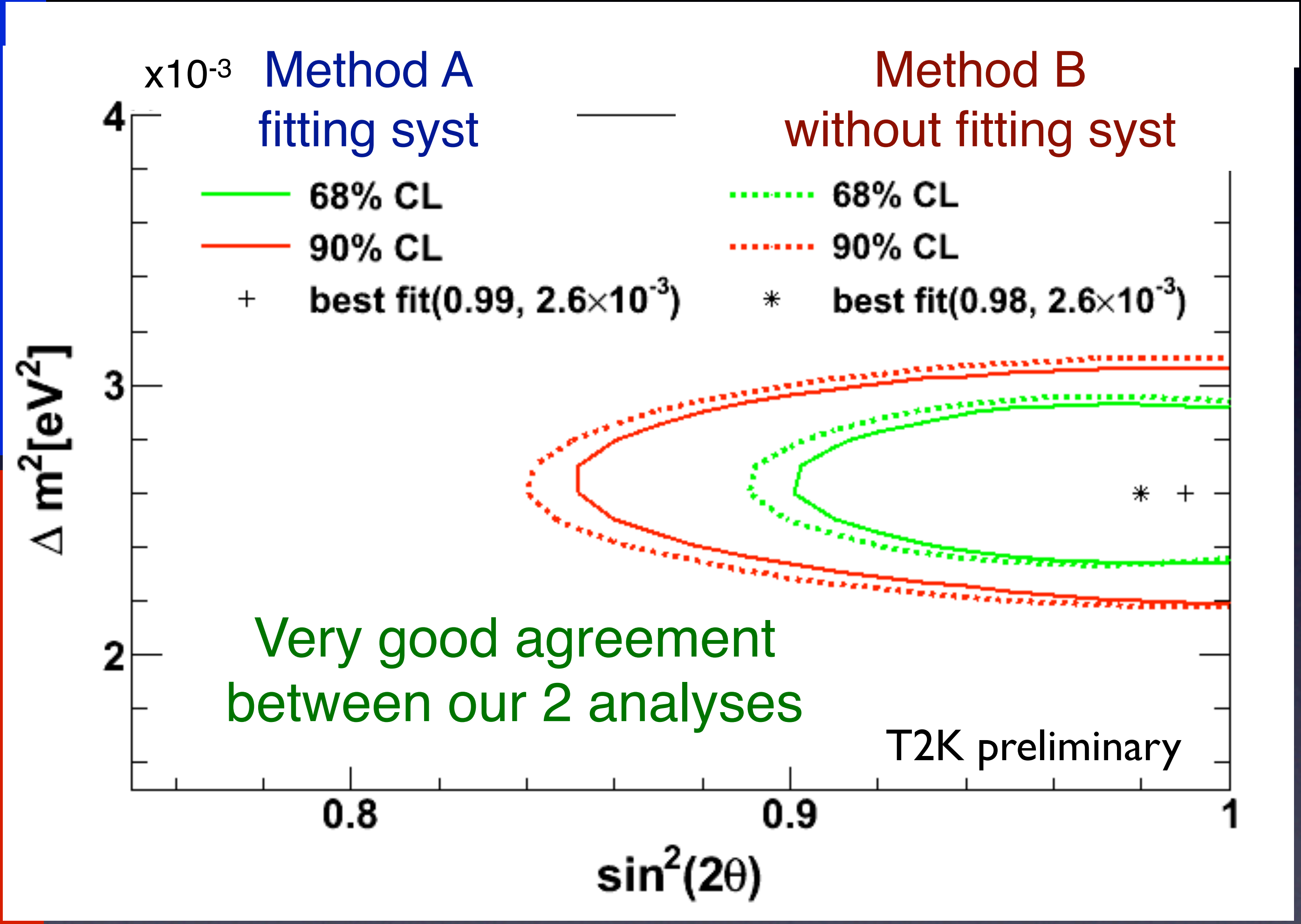
Best fit:

$\sin^2(2\theta_{23}) = 0.98$, $|\Delta m^2_{23}| = 2.6\times10^{-3}$ eV^2

90% C.L.:

$\sin^2(2\theta_{23}) > 0.84$

$2.1\times10^{-3} < \Delta m^2_{23}(\text{eV}^2) < 3.1\times10^{-3}$

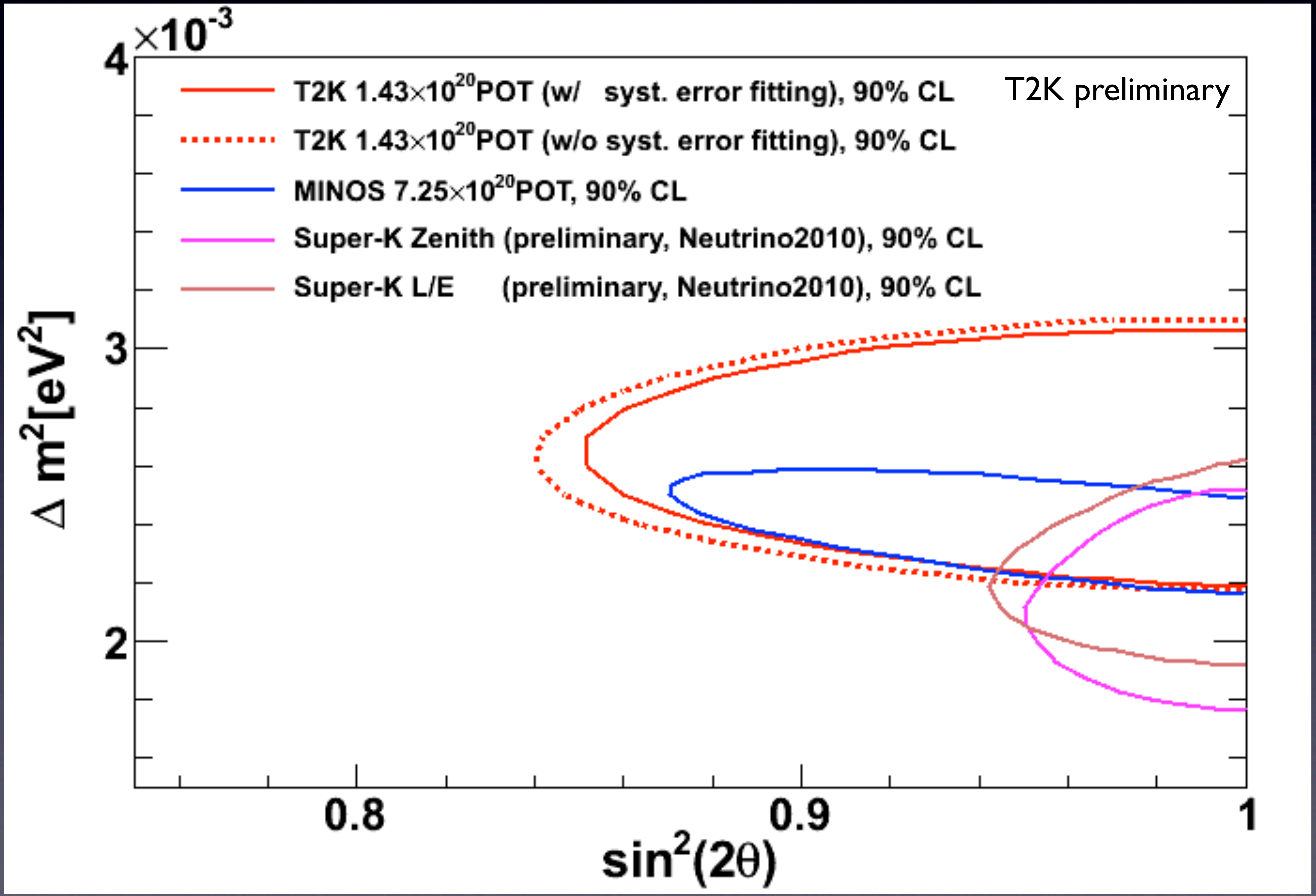


*90% C.L are given @ $|\Delta m^2_{23}|=2.6\times10^{-3}$ eV^2 and $\sin^2(2\theta_{23})=1.0$

- The main difference between the 2 analyses come from the fit of the systematics that is done in Method A

Comparison with SK and MINOS

- T2K results are in good agreement with results from SK and MINOS



Conclusions

- The T2K experiment has completed two oscillation analyses based on 1.43×10^{20} p.o.t (2% of T2K's goal)
- ν_e appearance analysis:
  - 6 events have been observed (1.5±0.3 expected)
  - The probability of 6 events with $\theta_{13}=0$ is 0.7% (2.5σ significance)
  - This lead to a 90% confidence interval of $0.03(0.04)<\sin^2(2\theta_{13})<0.28(0.34)$ for normal (inverted) hierarchy and $\delta_{CP}=0$
  - Result published in PRL
- ν_μ disappearance analysis:
  - No oscillation hypothesis excluded at 4.5σ
  - $\sin^2(2\theta_{23})>0.85$ and $2.1\times10^{-3}<\Delta m^2_{23}\ (eV^2)<3.1\times10^{-3}$ @ 90% C.L.
- The experiment is currently recovering from the 11th March earthquake
  - Investigations done so far indicate that all damage is repairable
  - Aim to restart JPARC operation in December 2011

Back up slides

Physics motivation: neutrino oscillations

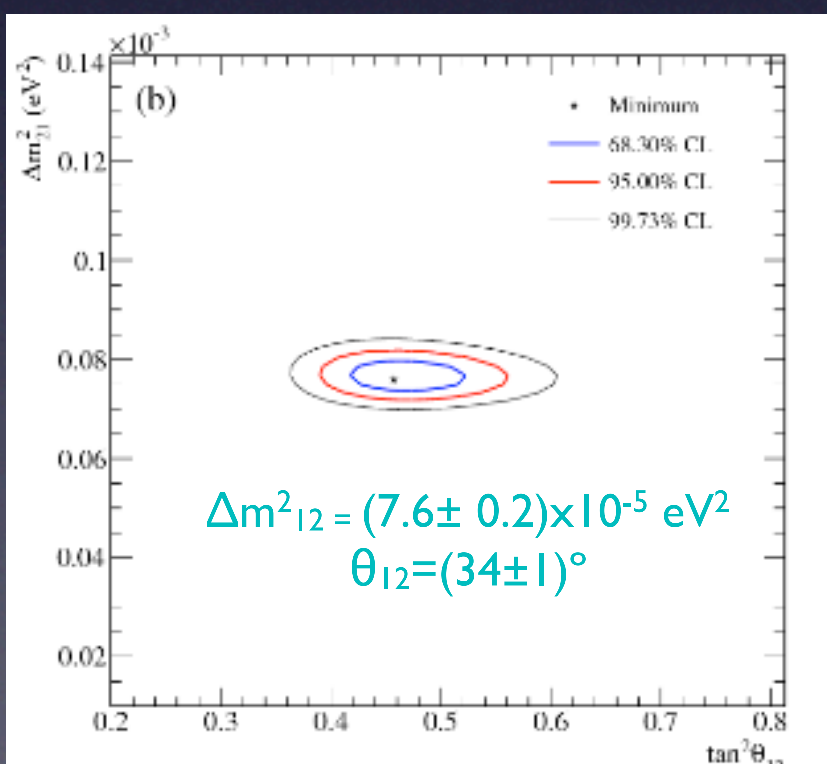
$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}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

Flavor eigenstates

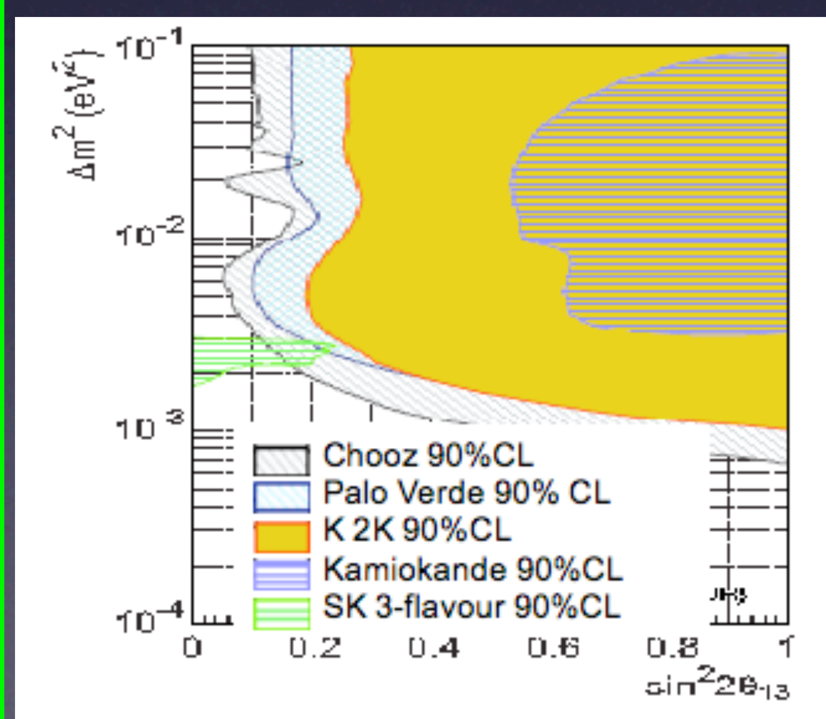
Mass eigenstates

- 3 angles (θ_{12}, θ_{23}, θ_{13})
- 1 CP violation phase δ
- 2 independent mass differences ($\Delta m_{ij}^2 = m_i^2 - m_j^2$)

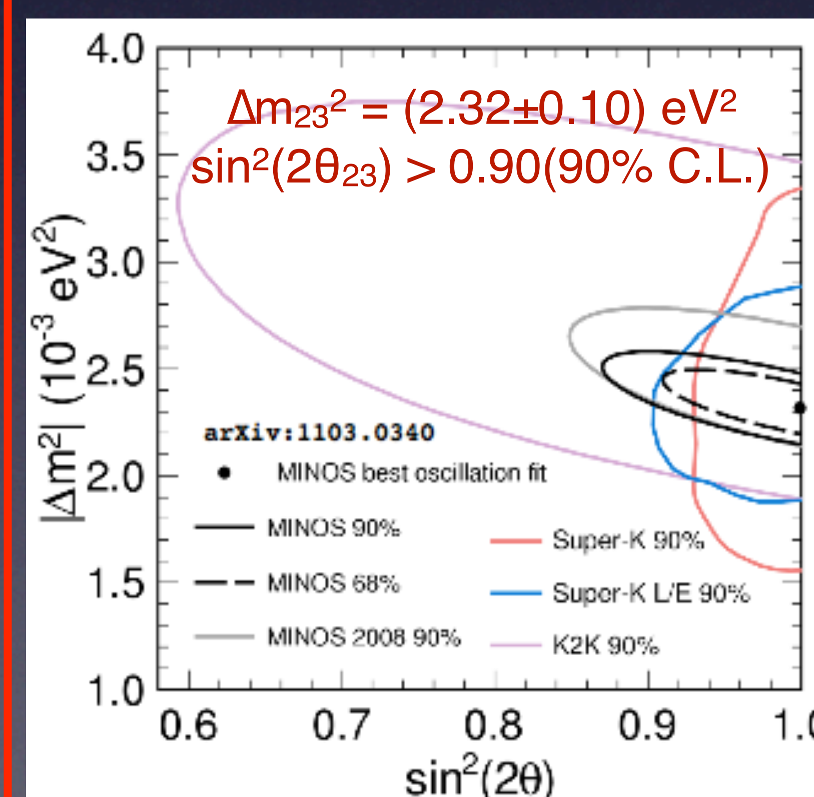
Solar (SNO, KamLand)
→ θ_{12}, Δm_{12}



Interference term → $\sin^2(2\theta_{13})<0.13$
δ completely unkwnown



Atmospheric (K2K, SK, Minos)
→ θ_{23}, Δm_{23}



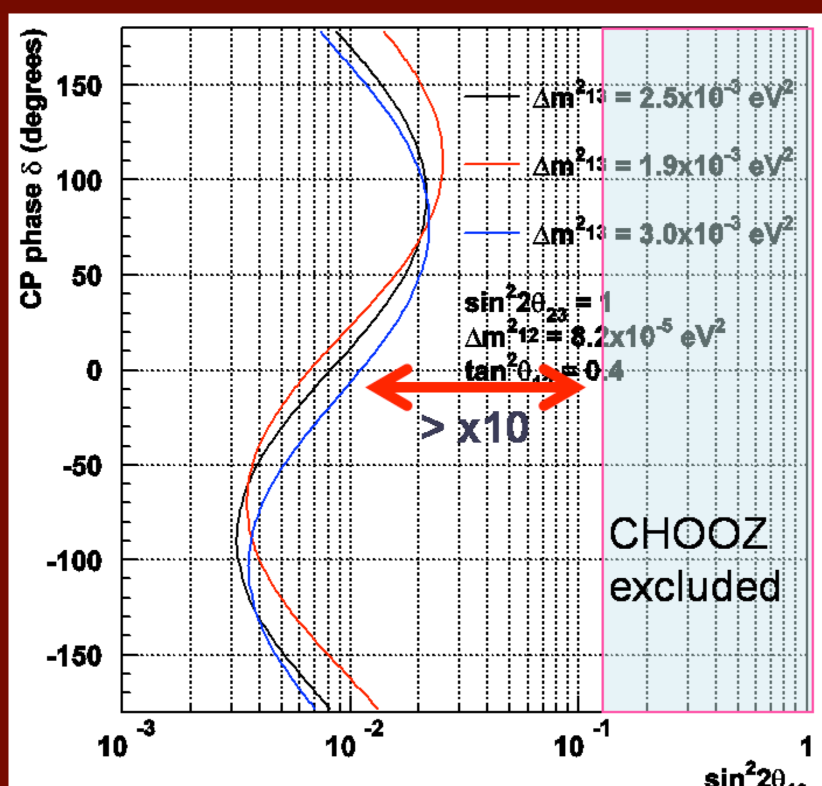
T2K physics goals

- Expected sensitivities with 8×10^{21} p.o.t. (full expected T2K data-set)
  - Today's results presented with 1.43×10^{20} p.o.t. (~2% of the total)

ν_e appearance

$$P(\nu_\mu \to \nu_e) = sin^2 2\theta_{13} sin^2\theta_{23} sin^2\Delta + \alpha f(\delta_{CP})$$

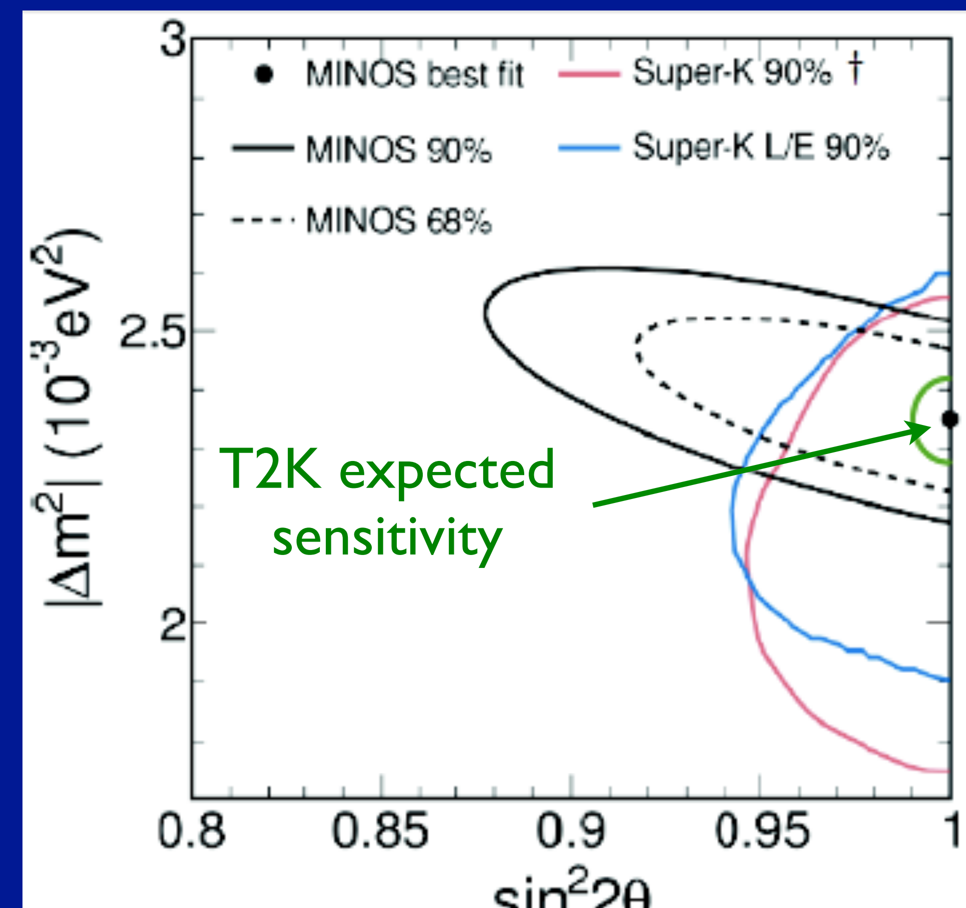
$$\Delta = 1.27\Delta m^2_{23} L/E \quad \alpha = \Delta m^2_{12}/\Delta m^2_{23} \sim 1/30$$



> 10 times improvement with respect to Chooz limit

ν_μ disappearance

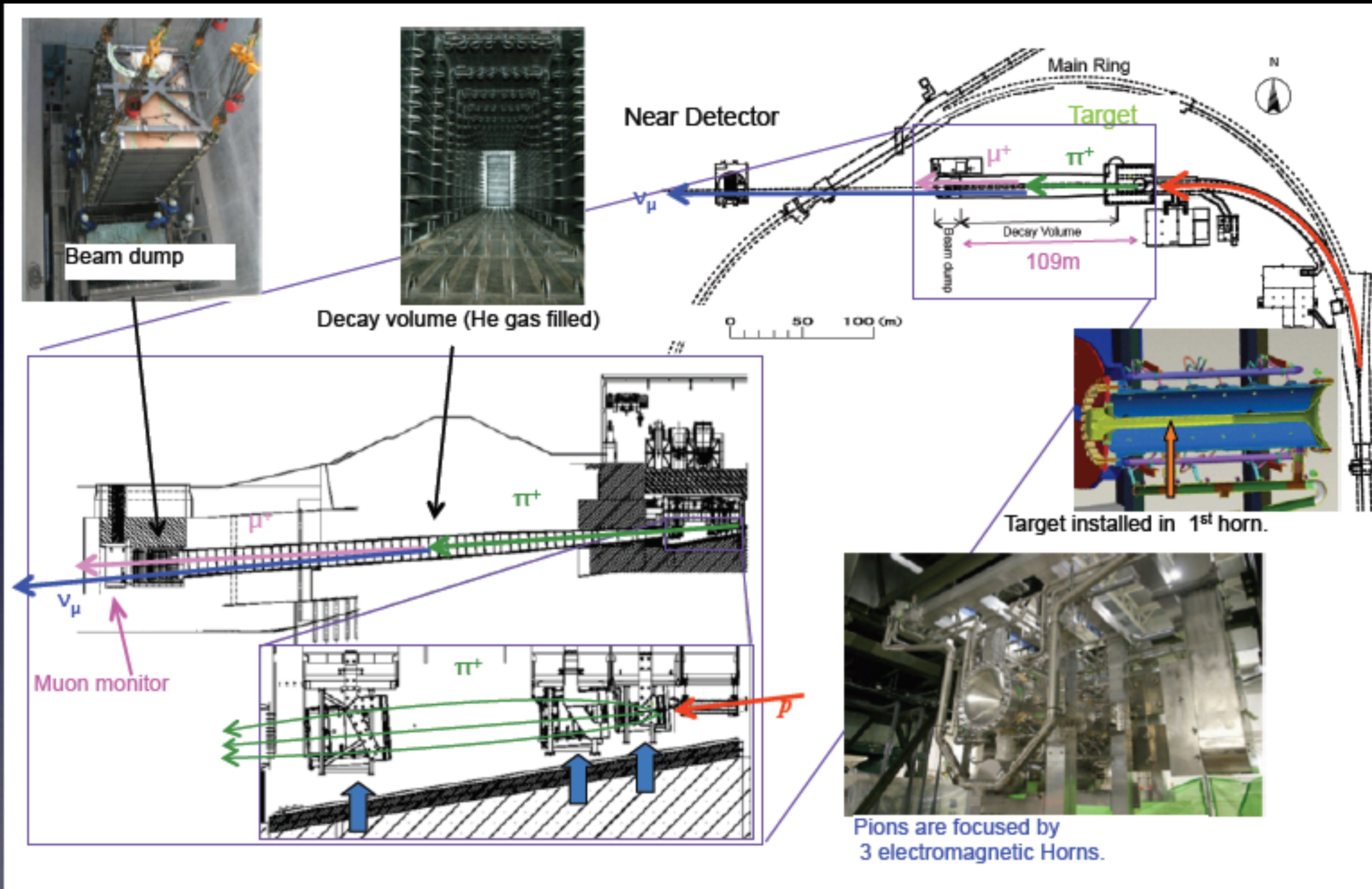
$$P(\nu_\mu \to \nu_\mu) = 1 - sin^2(2\theta_{23}) sin^2(1.27\Delta m^2_{23} L/E)$$



Goals: $\delta(sin^2(2\theta_{23}) \sim 0.01$

$\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ eV^2

JPARC beamline overview



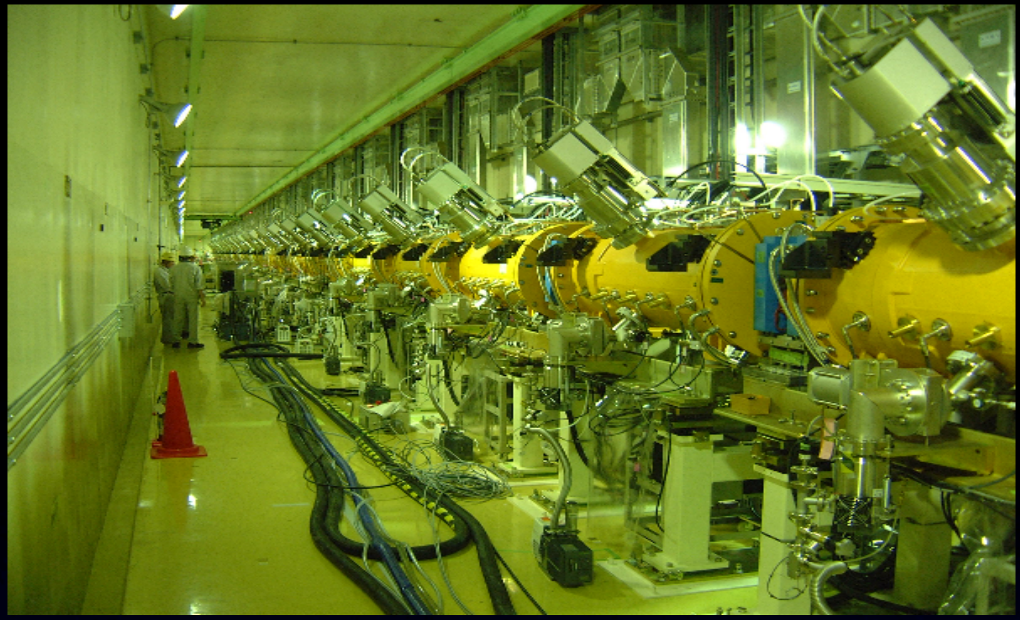
Linac

First stage accelerator, 330m in length.

Design energy is 400MeV.

At present, protons are accelerated to 181MeV.

Upgrade to the design energy is under preparation.



RCS (Rapid Cycling Synchrotron)

Second stage accelerator, Proton Synchrotron of 348m circumference.

The acceleration up to 3GeV is successfully working.

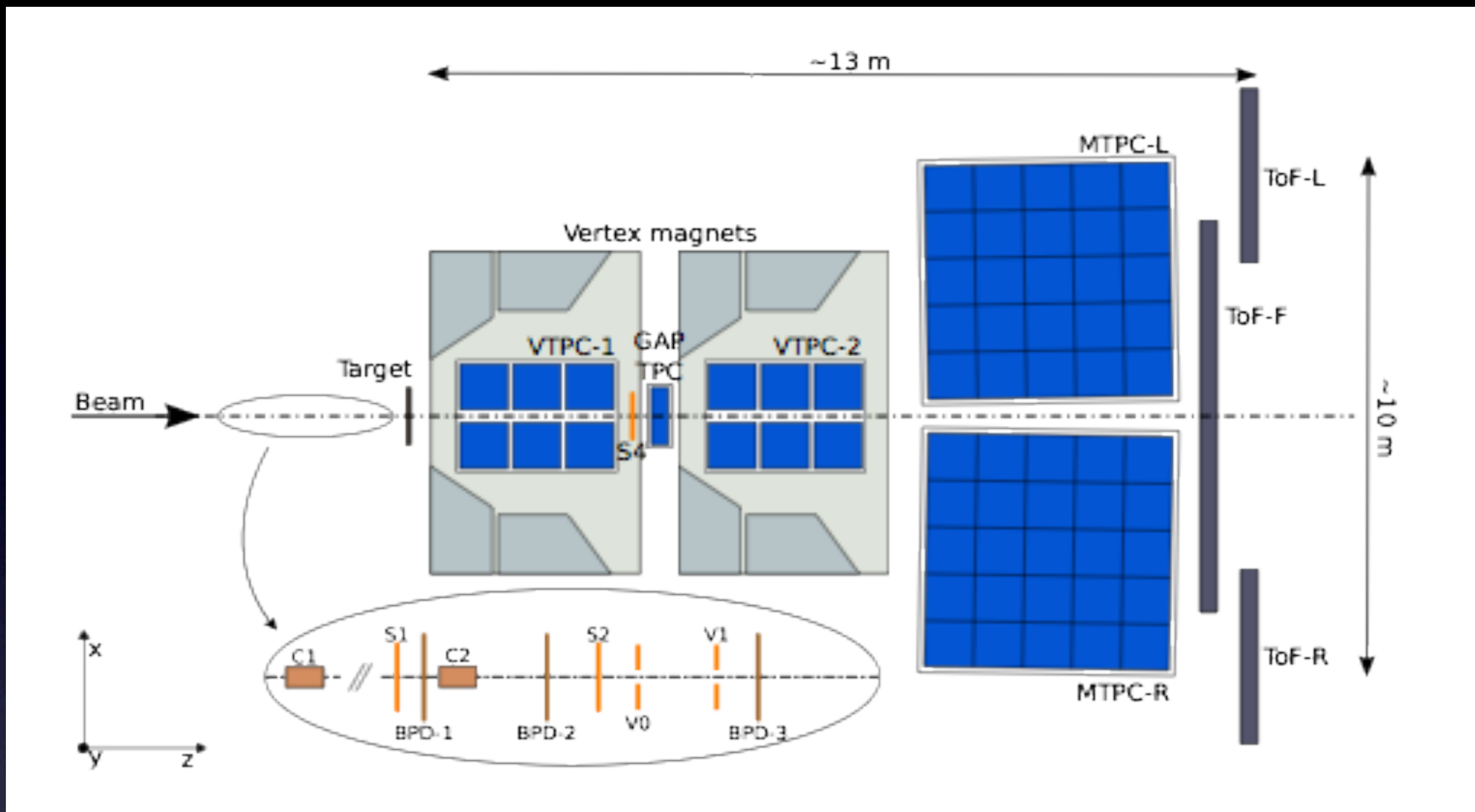
Main Ring

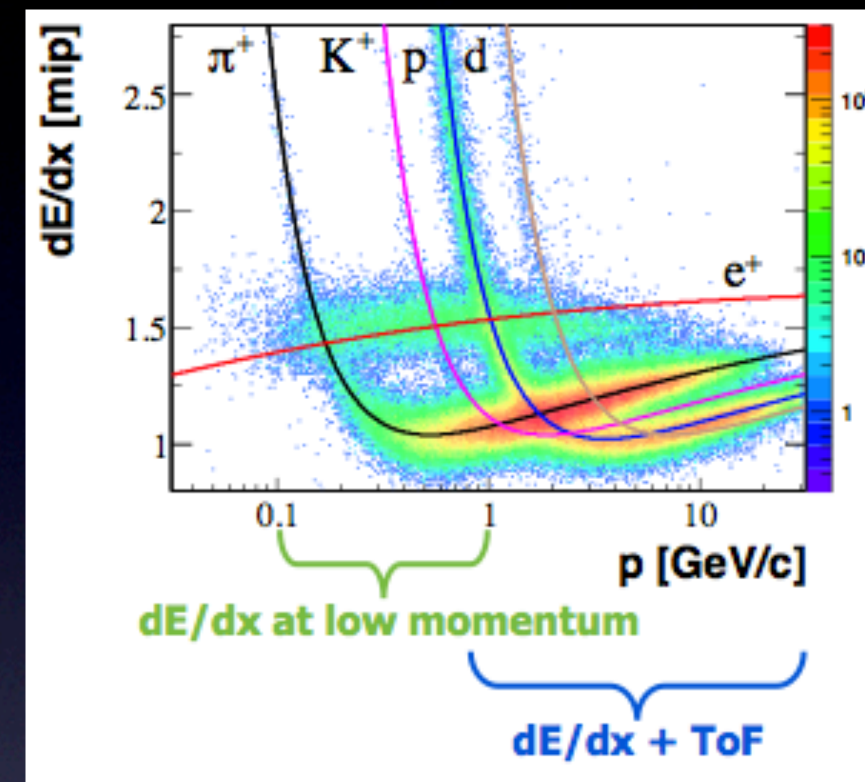
Third (and final) stage accelerator. Proton Synchrotron of 1568m circumference.

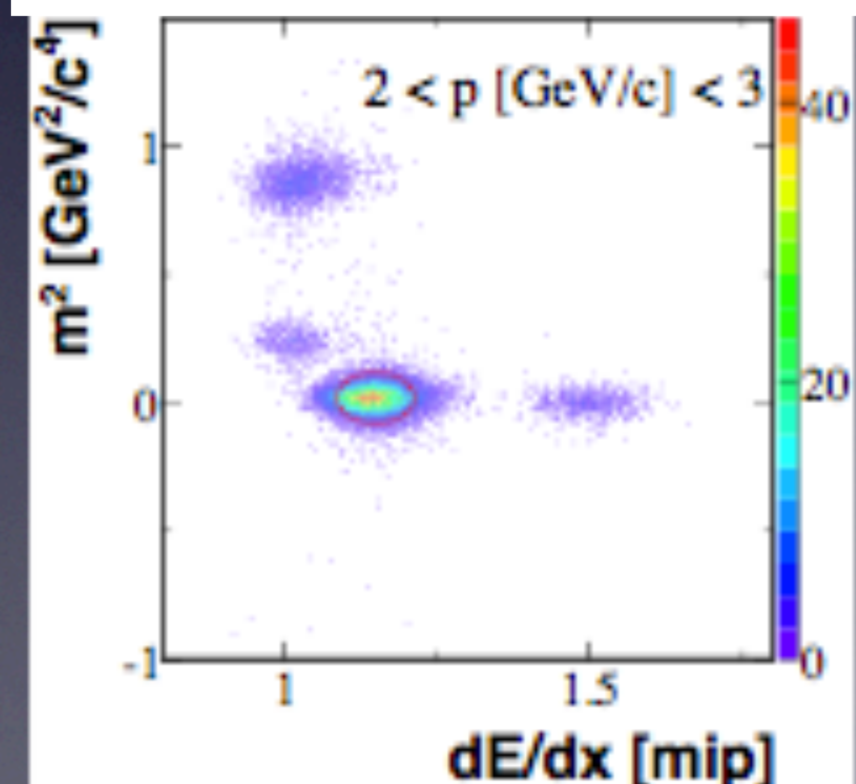
The 30 GeV proton beam is extracted to the neutrino beamline. The beam is shared by T2K and the experiments in the hadron hall.

CERN NA61/SHINE experiment

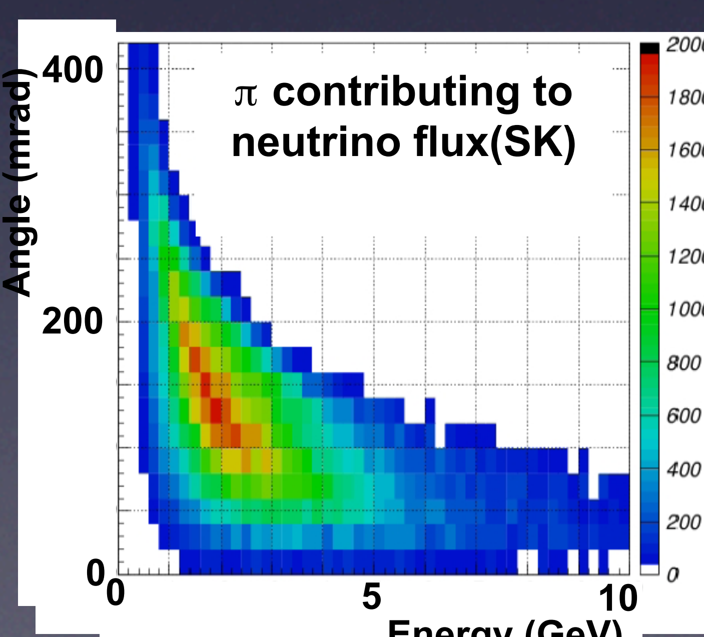
π^+ production: Two analysis for different momentum region







- Measure hadron(π, K) yield distribution in 30 GeV p + C inelastic interaction
- Thin target + T2K replica target

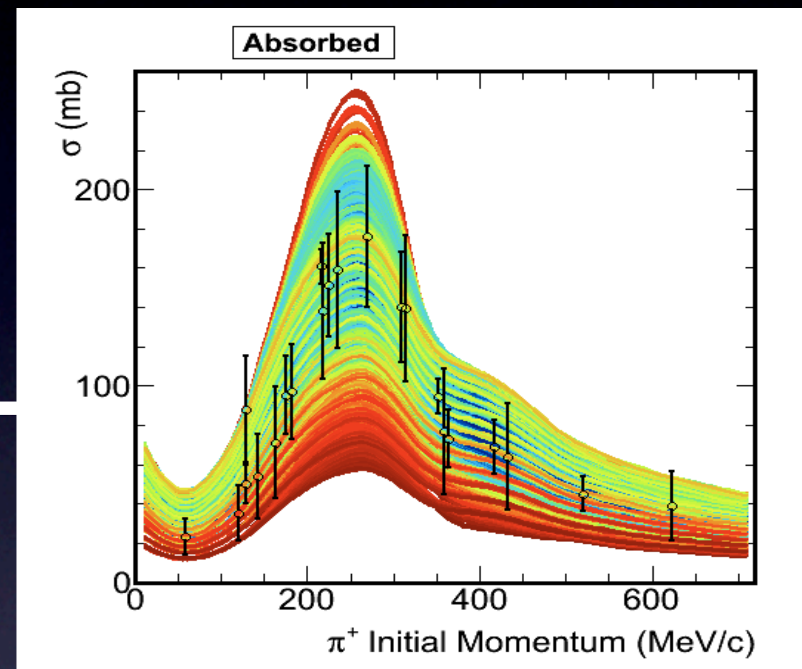


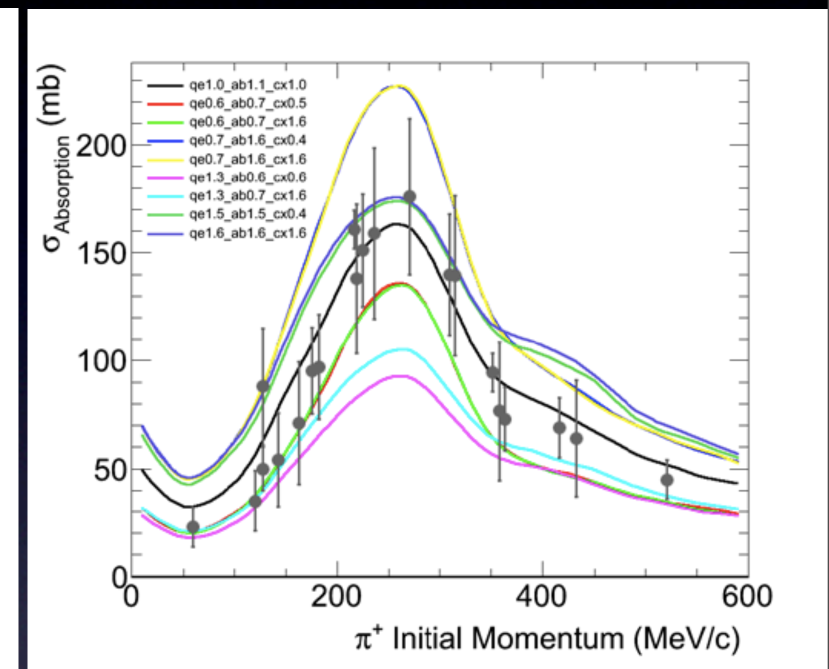
FSI tuning

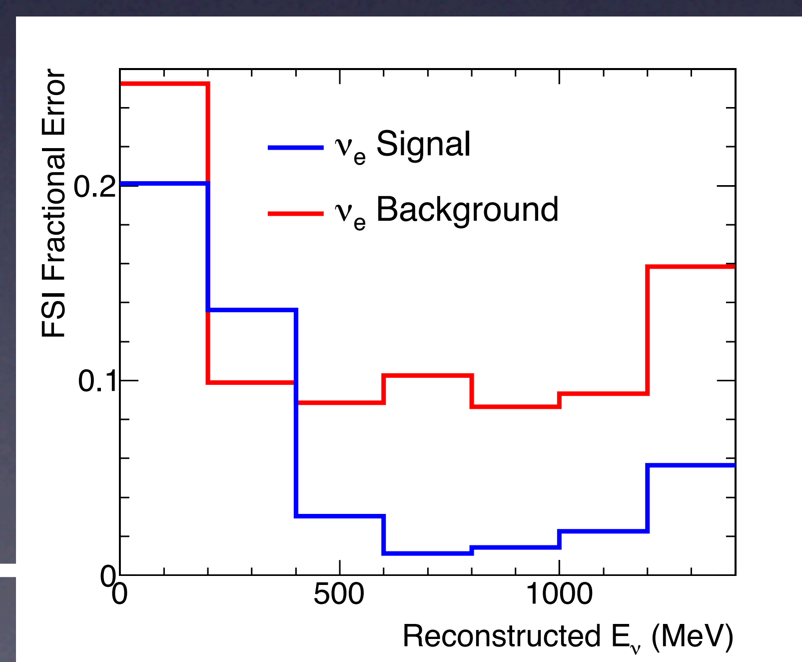
- 14% of the systematic on the background to the ν_e appearance, 8% to the ν_μ disappearance
- Principal source of uncertainty: pion final state interaction (FSI)

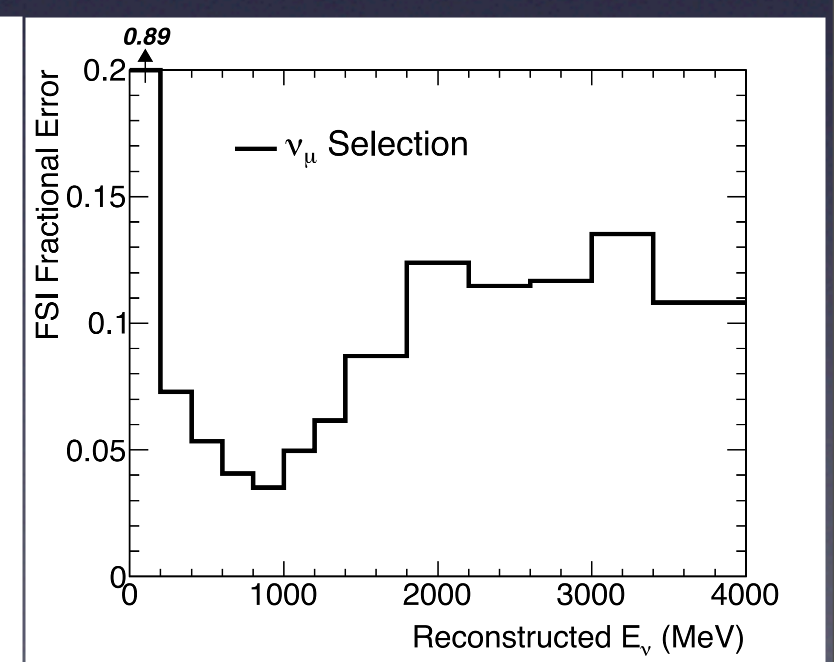
Error source	N^{exp}(SK)
CCQE shape	3.1%
CC1π	2.2%
CC coherent π	3.1%
CC other	4.4%
NC1π0	5.3%
NC coherent	2.3%
NC other	2.3%
σ(νe)	3.4%
FSI	10.1%
Total	14.0%

Studied by adjusting NEUT microscopic pion cross section model and comparing to pion cross section data









Off-axis ND280

- Same off-axis angle as Super-Kamiokande (2.5 degrees)
- Measure ν_μ and ν_e spectrum before the oscillation → TPCs + FGDs
- Measure background processes to oscillation (NCπ^0, NC1π, CC1π...)

ND280 installed in ex-UA1 magnet (0.2 T) 3.5x3.6x7.3 m

SMRD (Side Muon Range Detector):
scintillator planes in magnet yokes.
Measure high angle muons

P0D (π0 detector):
scintillator bars interleaved with fillable water target bags and lead and brass sheets.
Optimized for γ detection

2 FGDs (Fine Grained Detector):
active target mass for the tracker, optimized for p/π separation
Carbon+Water target in FGD2

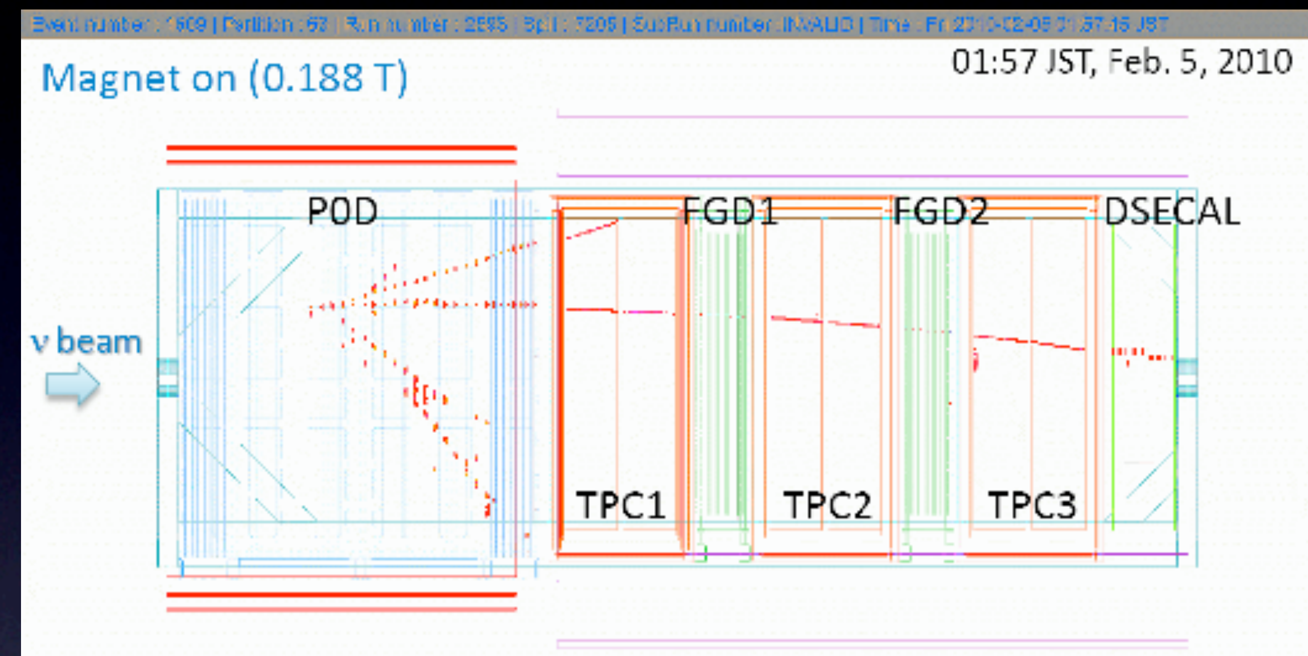
3 TPCs (Time Projection Chambers):
measure momentum and charge of particles from FGD and P0D, PID capabilities through dE/dx

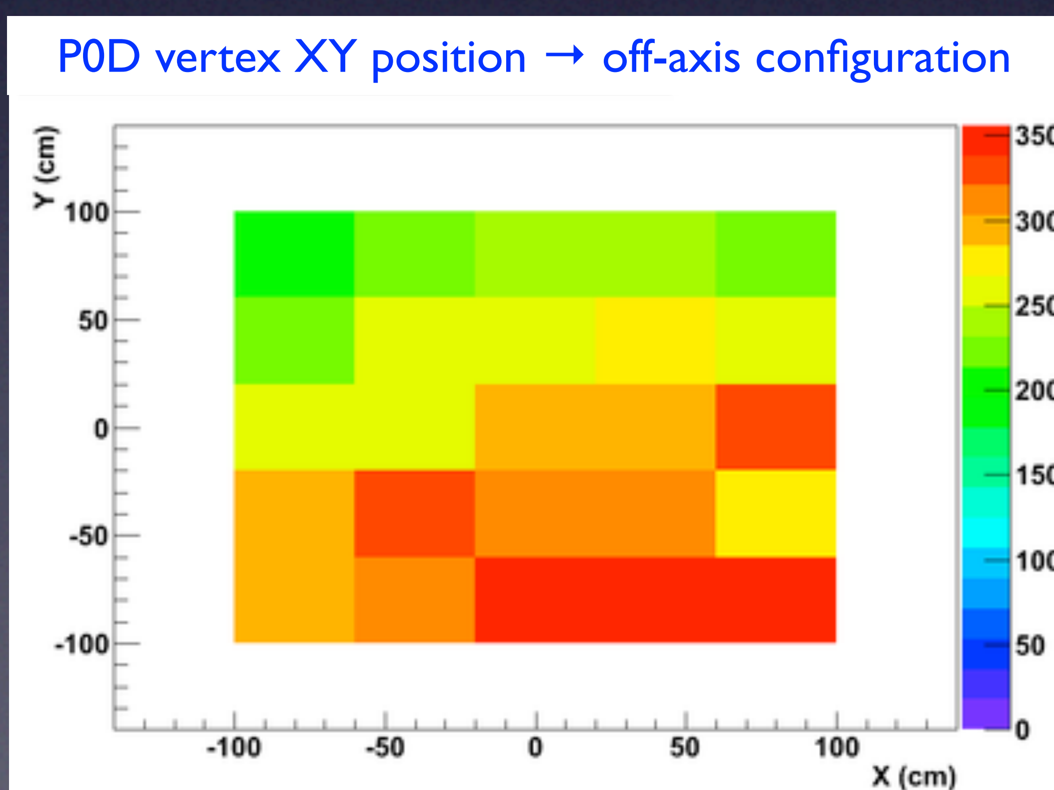
P0D, Barrel and Downstream ECAL:
scintillator planes with radiator to measure EM showers

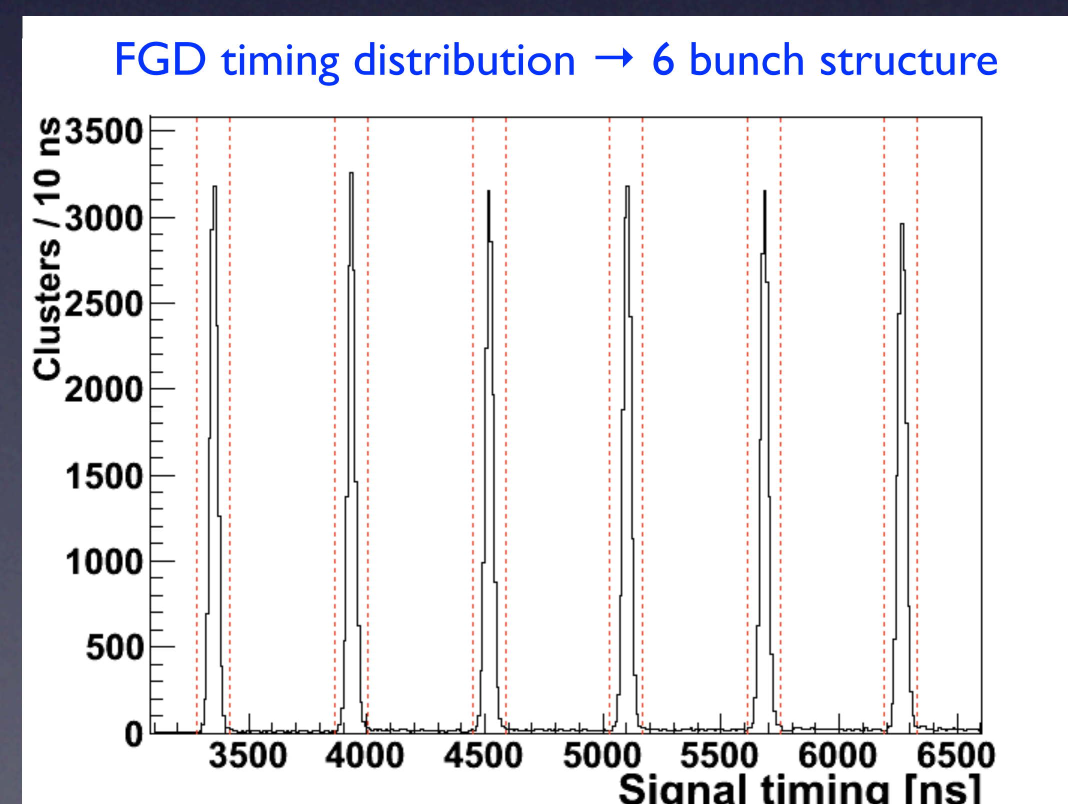
ND280 scintillator detectors

- The ND280 detectors except the TPCs use Multi-Pixel Photon Counters (MPPCs)
  - 1.3 x 1.3 mm, 667 pixels
  - ~60000 MPPCs used in ND280

The ND280 TPCs will be described with more details in the next slides

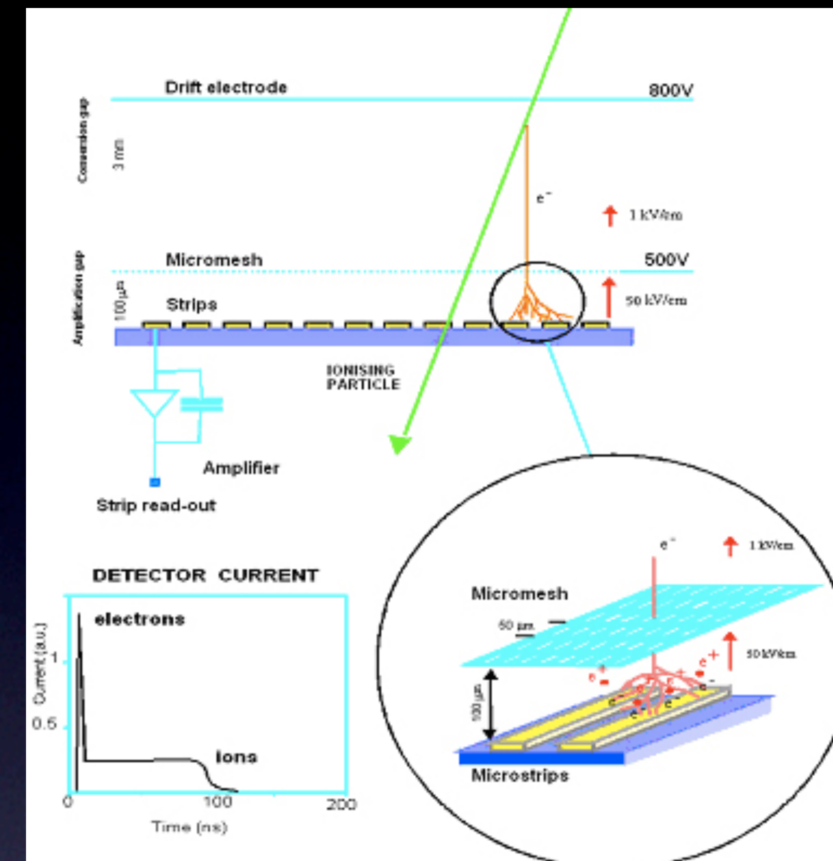


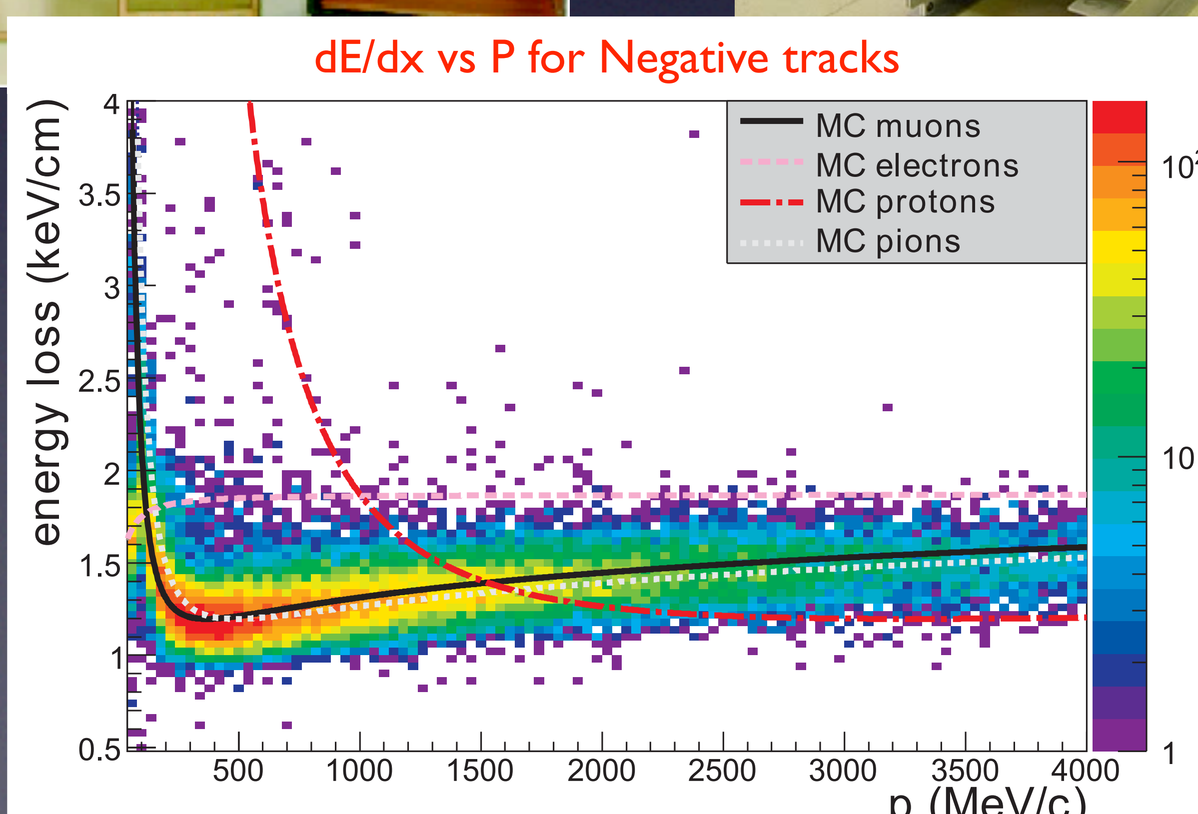


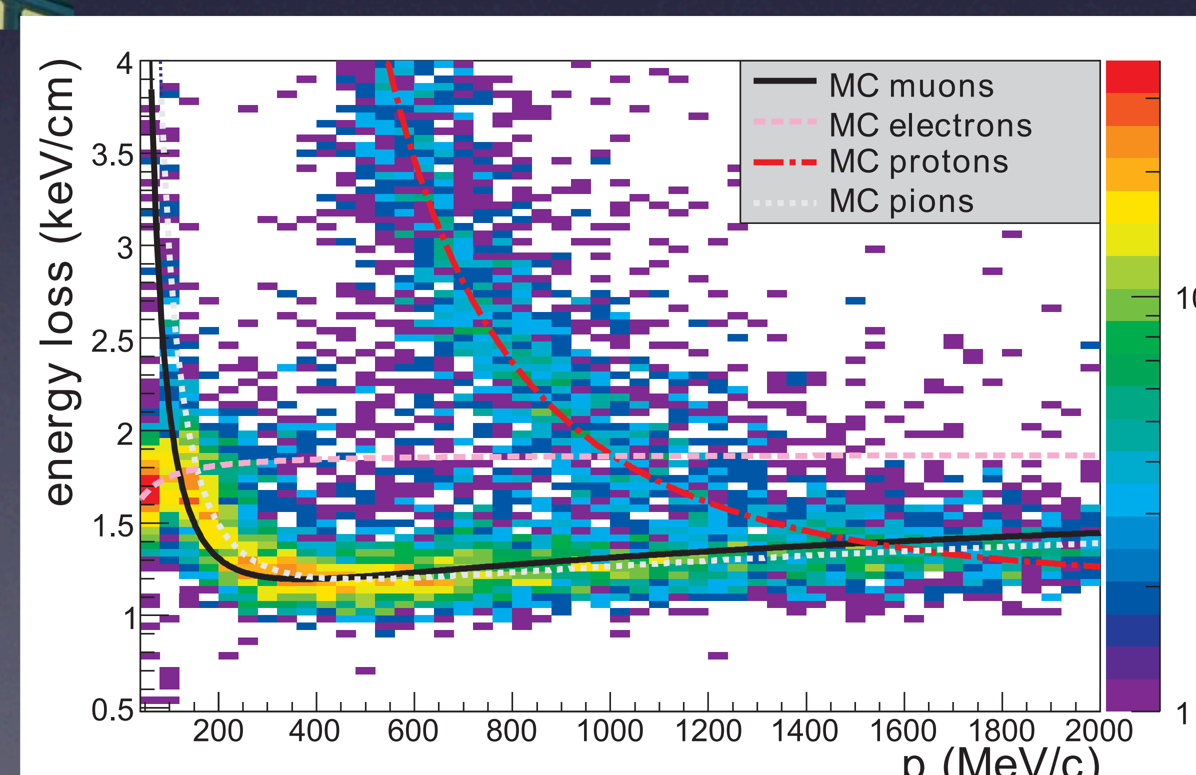


n center
→ off axis

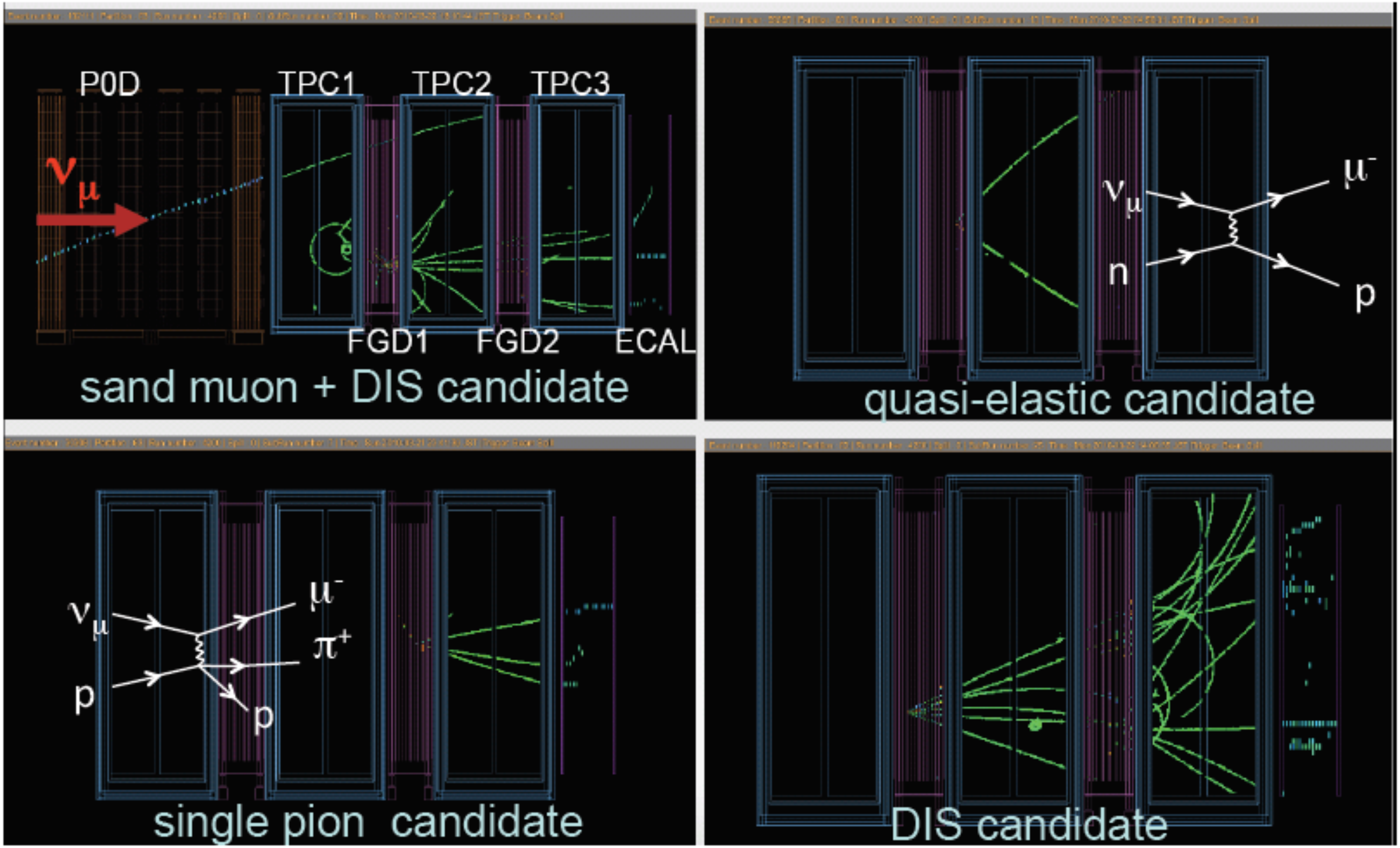
ND280 TPC


Drift electrode
800V
Micromesh
500V
Strips
IONISING PARTICLE
Amplifier
Strip read-out
DETECTOR CURRENT
electrons
ions
Time (ns)
Micromesh
Microstrips

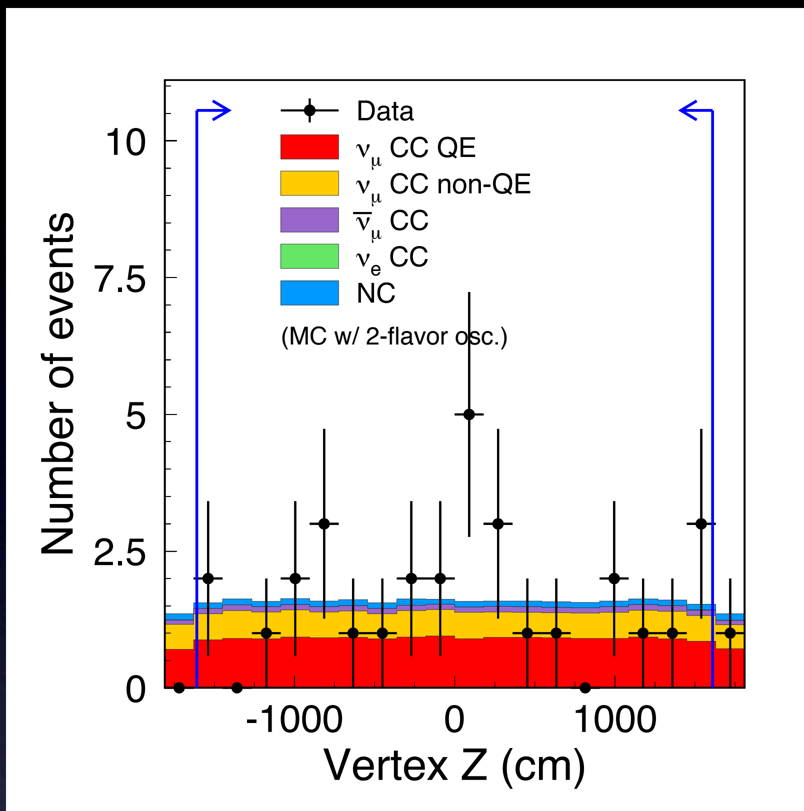

dE/dx vs P for Negative tracks
energy loss (keV/cm)
p (MeV/c)
MC muons
MC electrons
MC protons
MC pions

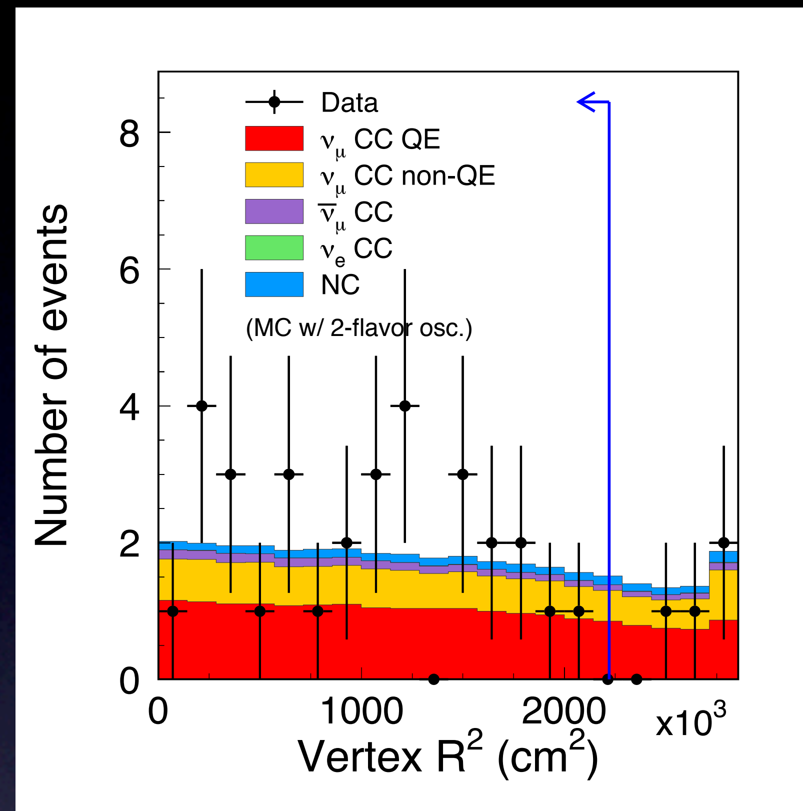

energy loss (keV/cm)
p (MeV/c)
MC muons
MC electrons
MC protons
MC pions

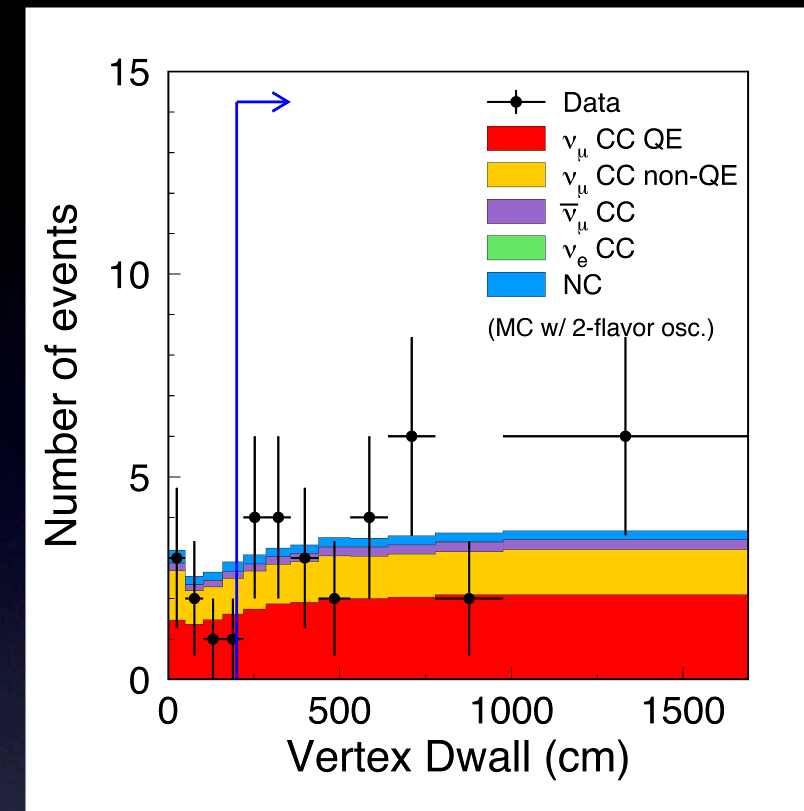
ND280 tracker event gallery

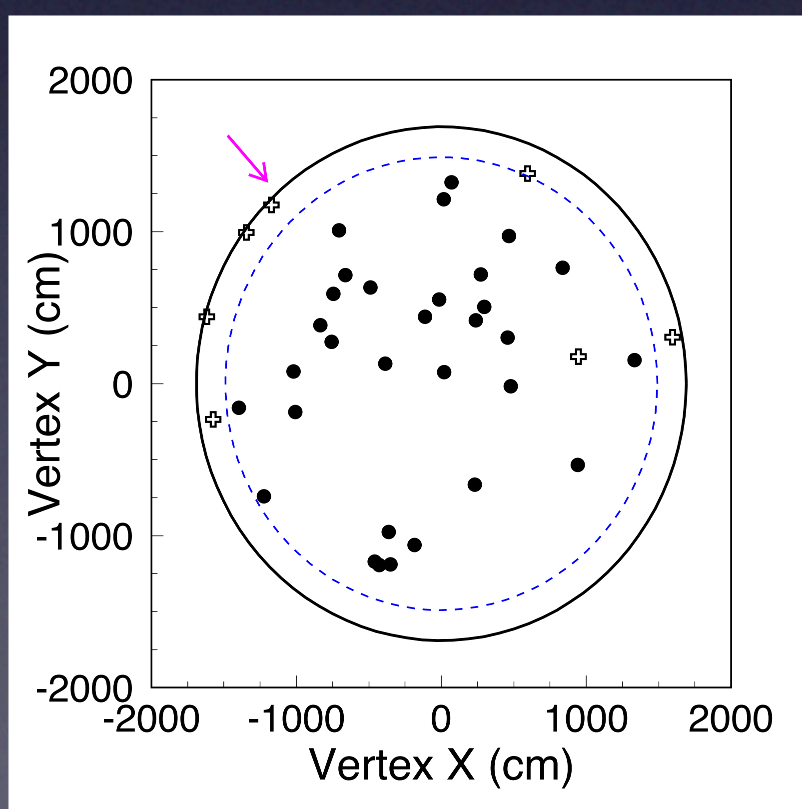


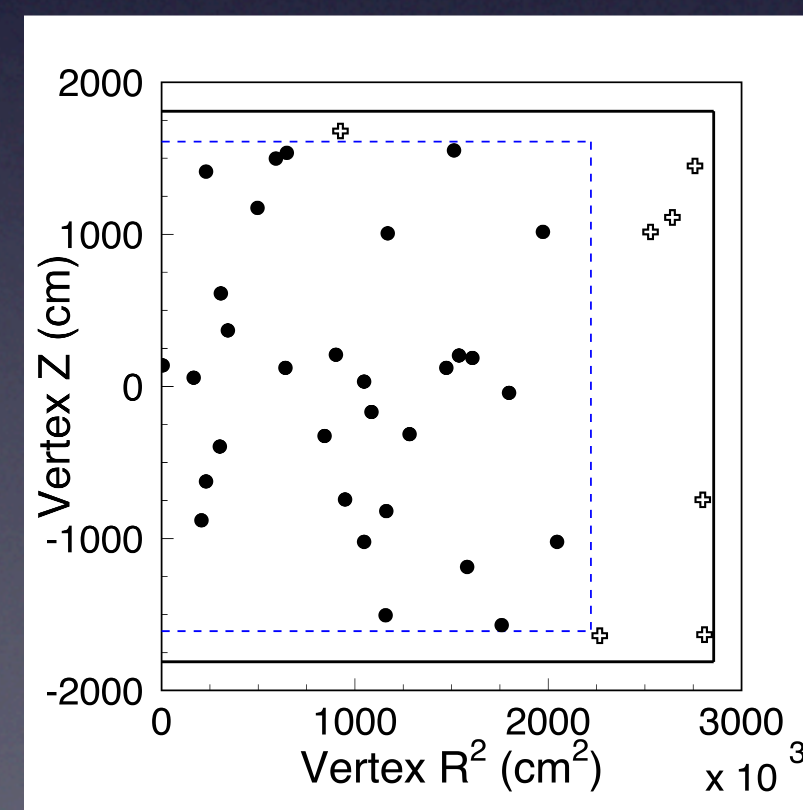
ν_μ disappearance vertex position





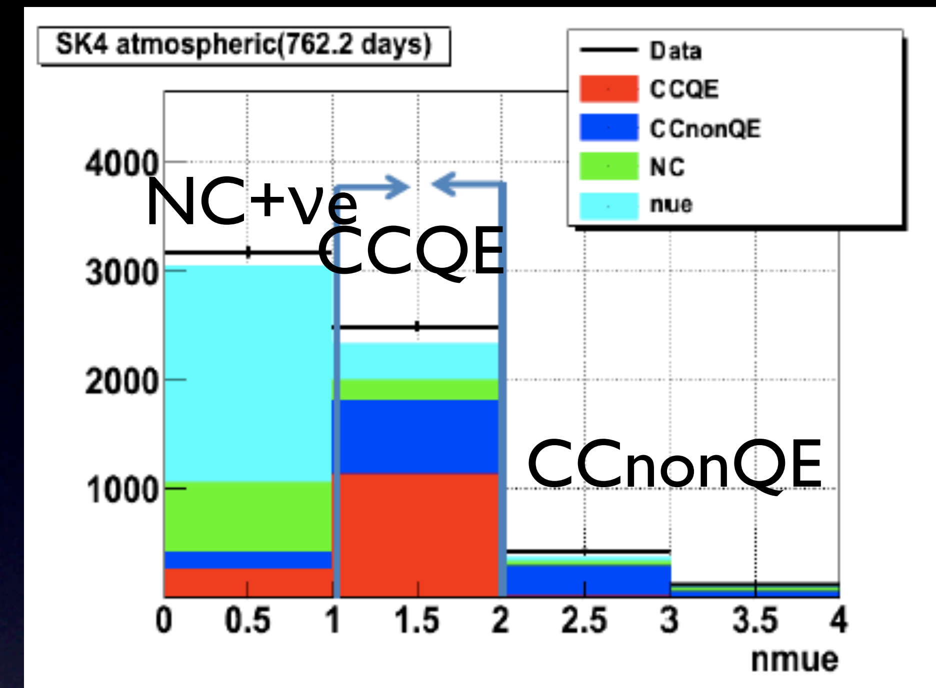


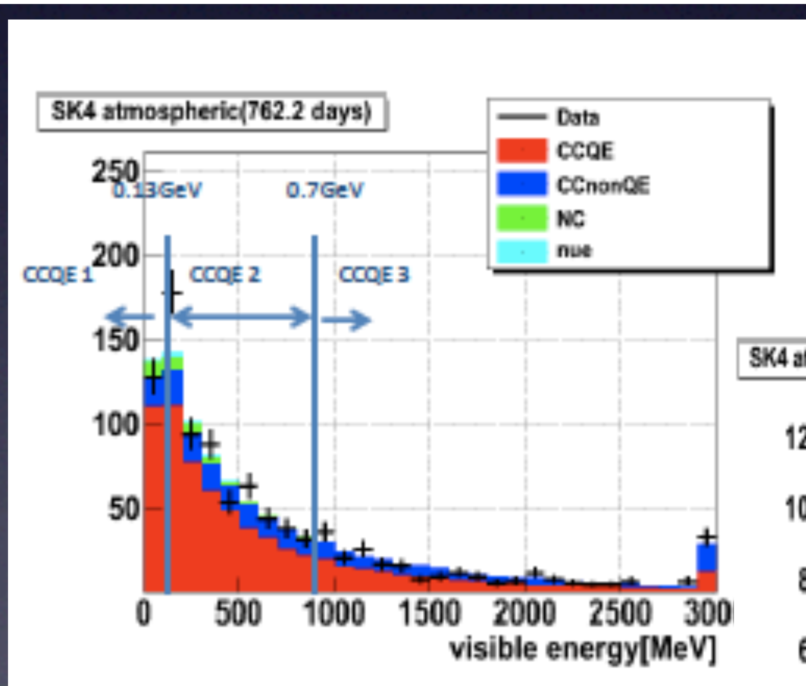


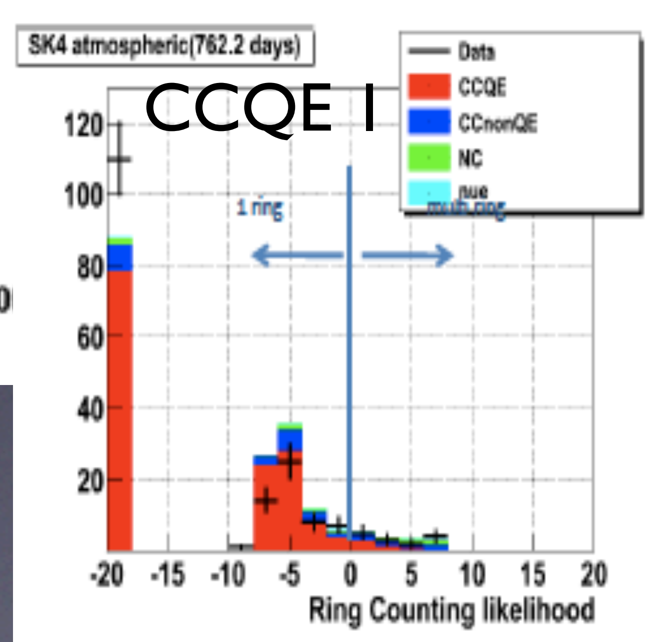


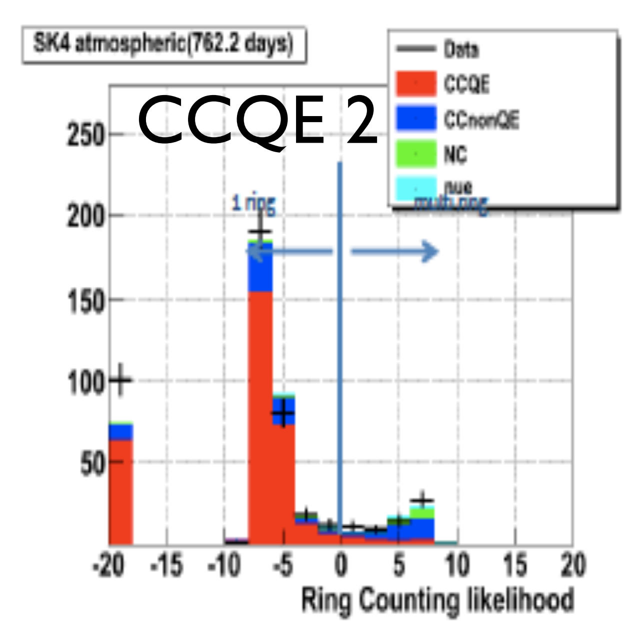
SK ν_μ systematics

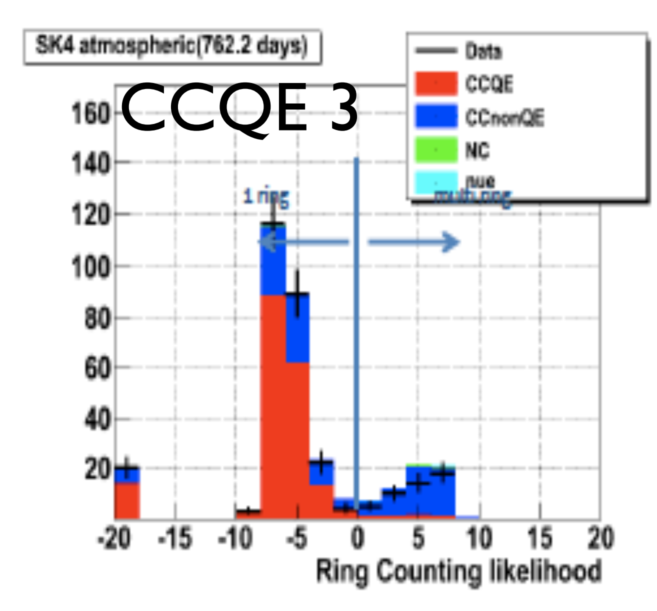
Name of Samples	selection criteria
ν_μ CCQE enriched sample 1	# of decay electrons = 1 distance from the muon stopped point to decay electron < 80 cm $E_{vis.} < 0.13$GeV
ν_μ CCQE enriched sample 2	# of decay electrons = 1 distance from the muon stopped point to decay electron < 80 cm $E_{vis.} = 0.13 \sim 0.7$GeV
ν_μ CCQE enriched sample 3	# of decay electrons = 1 distance from the muon stopped point to decay electron < 80 cm $E_{vis.} > 0.7$GeV
ν_μ CC non-QE enriched sample	# of decay electrons > 1 distance from the muon stopped point to nearest decay electron < 160 cm
NC enriched sample	# of decay electrons = 0 not ν_e sample
ν_e CC enriched sample	brightest ring is e-like $E_{vis.} > 100$MeV POLfit mass < 105 MeV





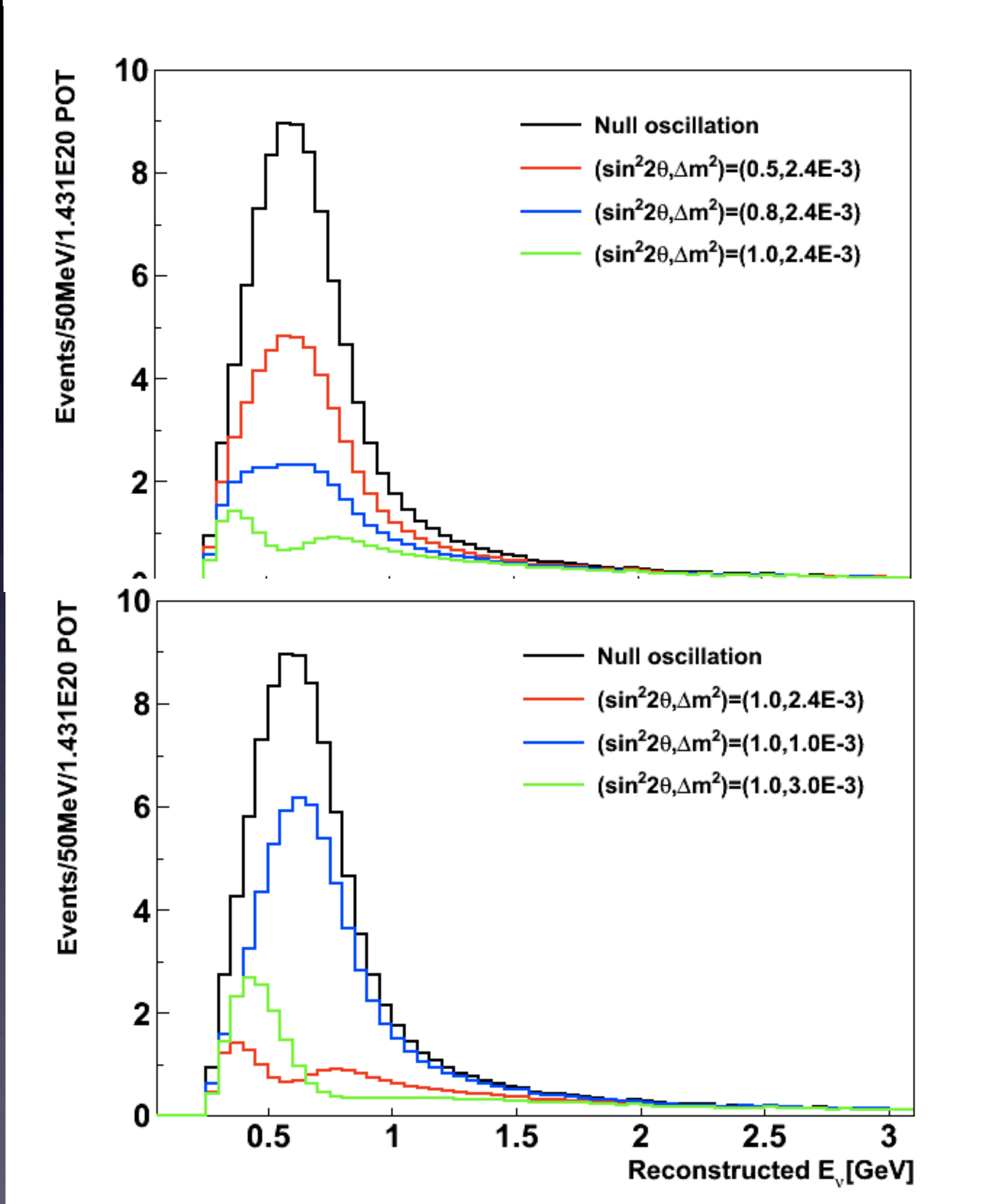




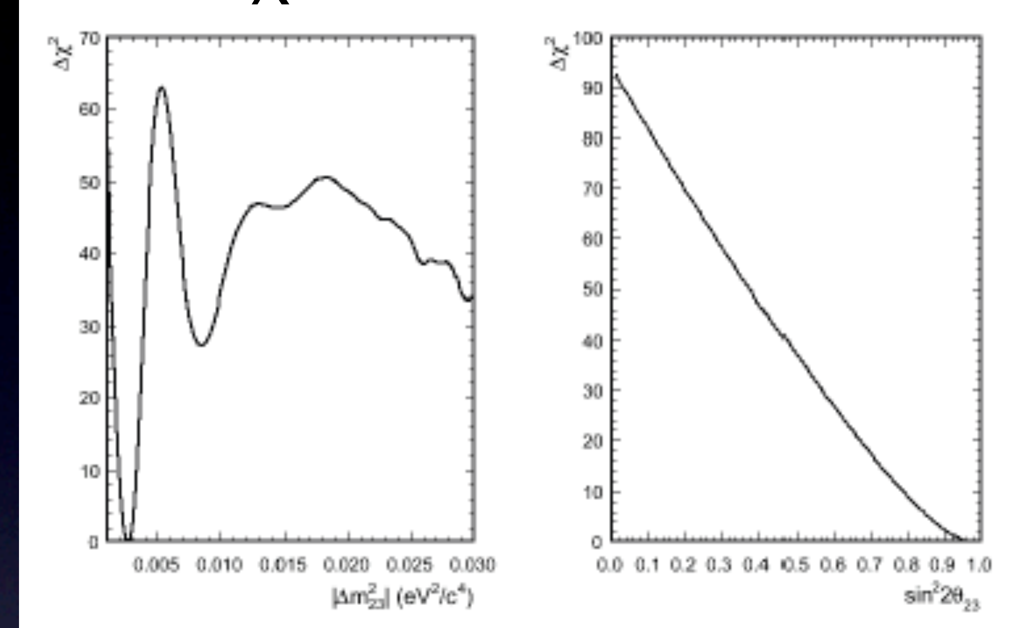


ν_μ disappearance

Expected spectrum

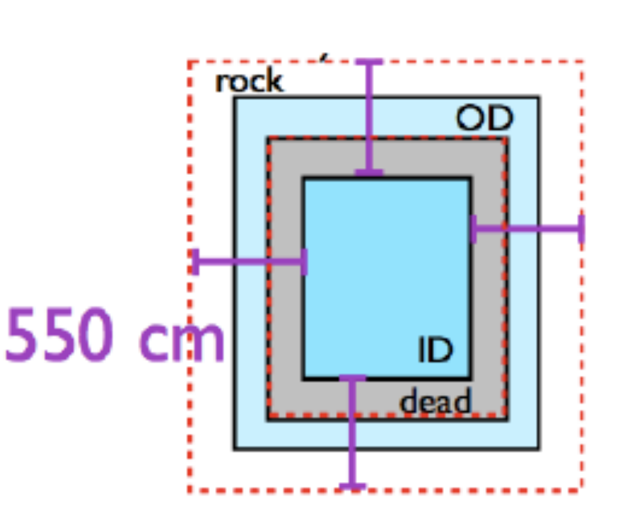


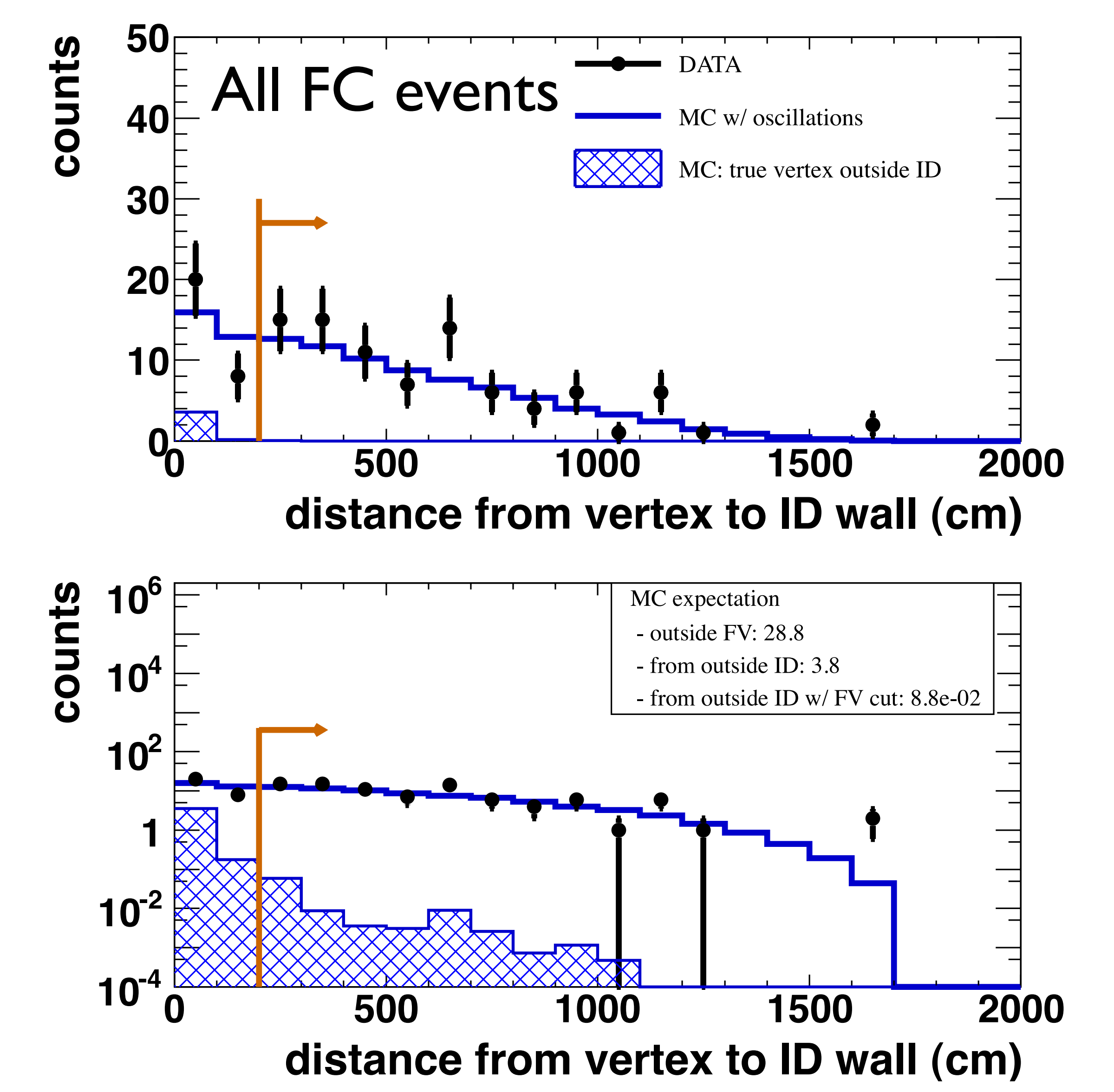
$\Delta\chi^2$ for Δm^2 and $\sin^2 2\theta$

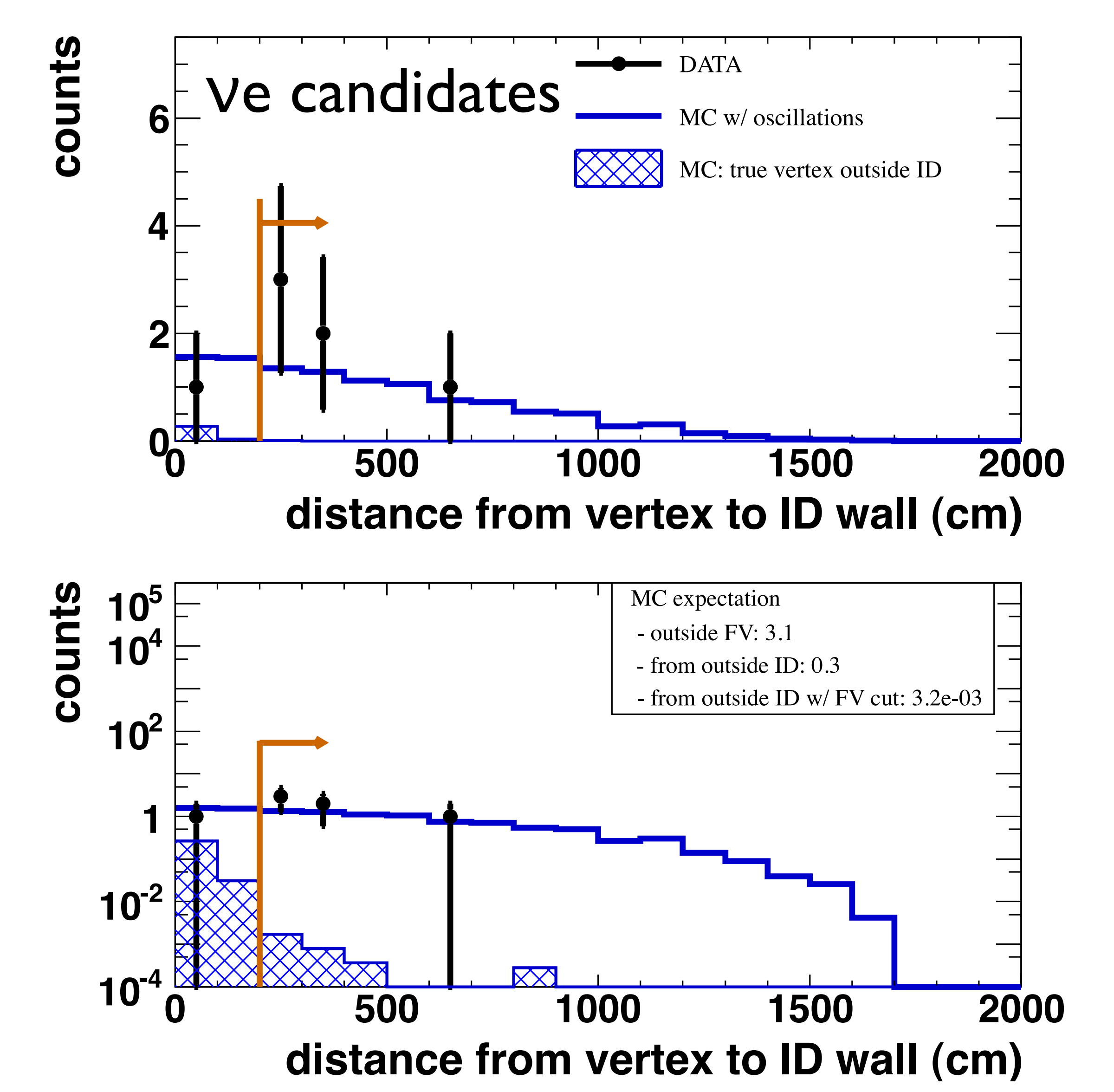


Out of FV contamination

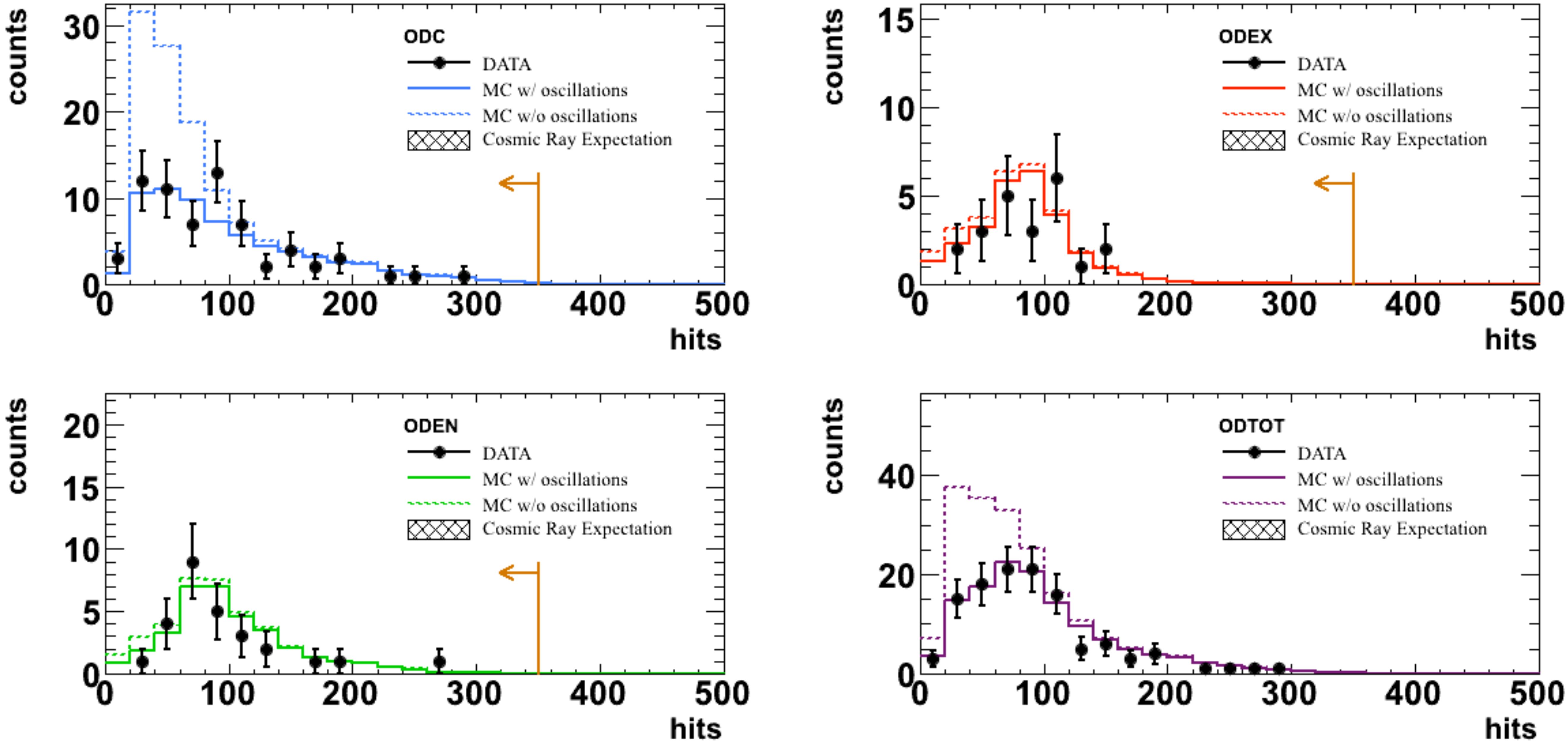
- Number of selected events with the exception of the fiducial volume cut
- Hatched histograms represent the contribution from vertices outside the ID





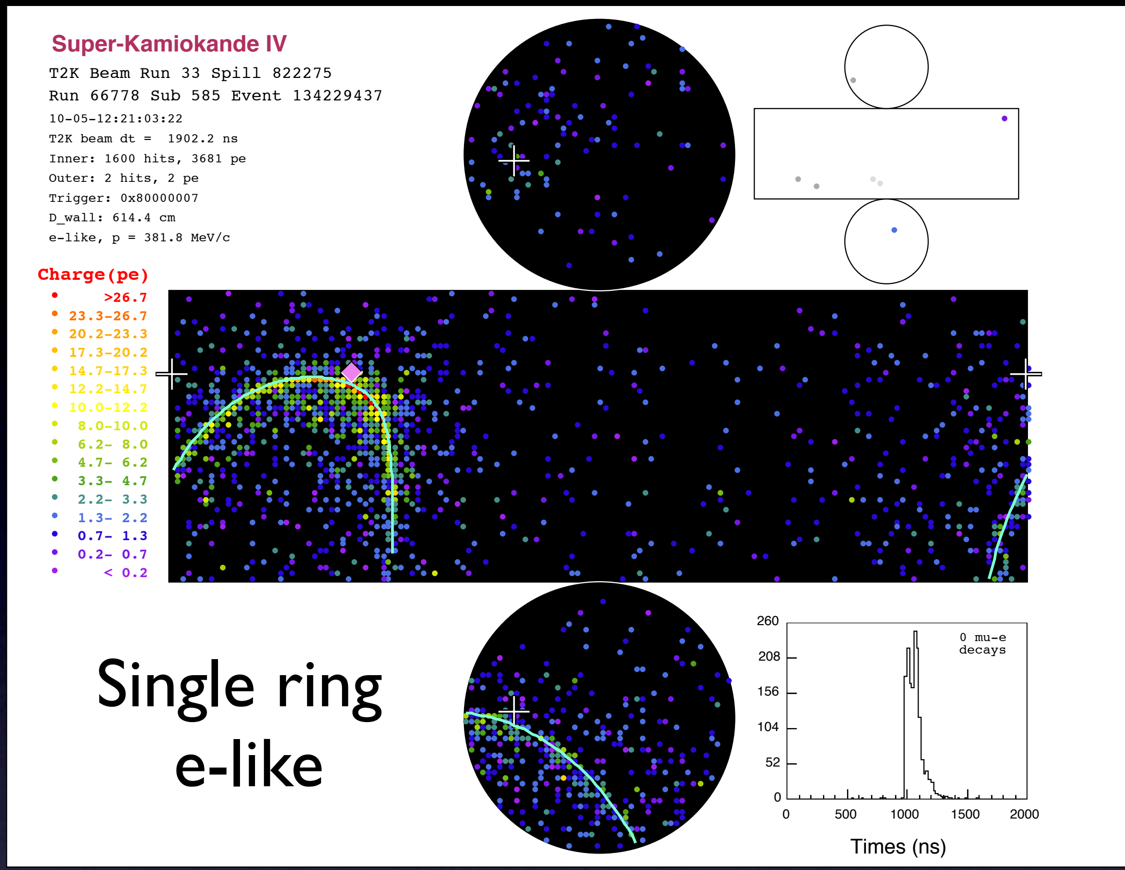


SK Outer Detector analysis

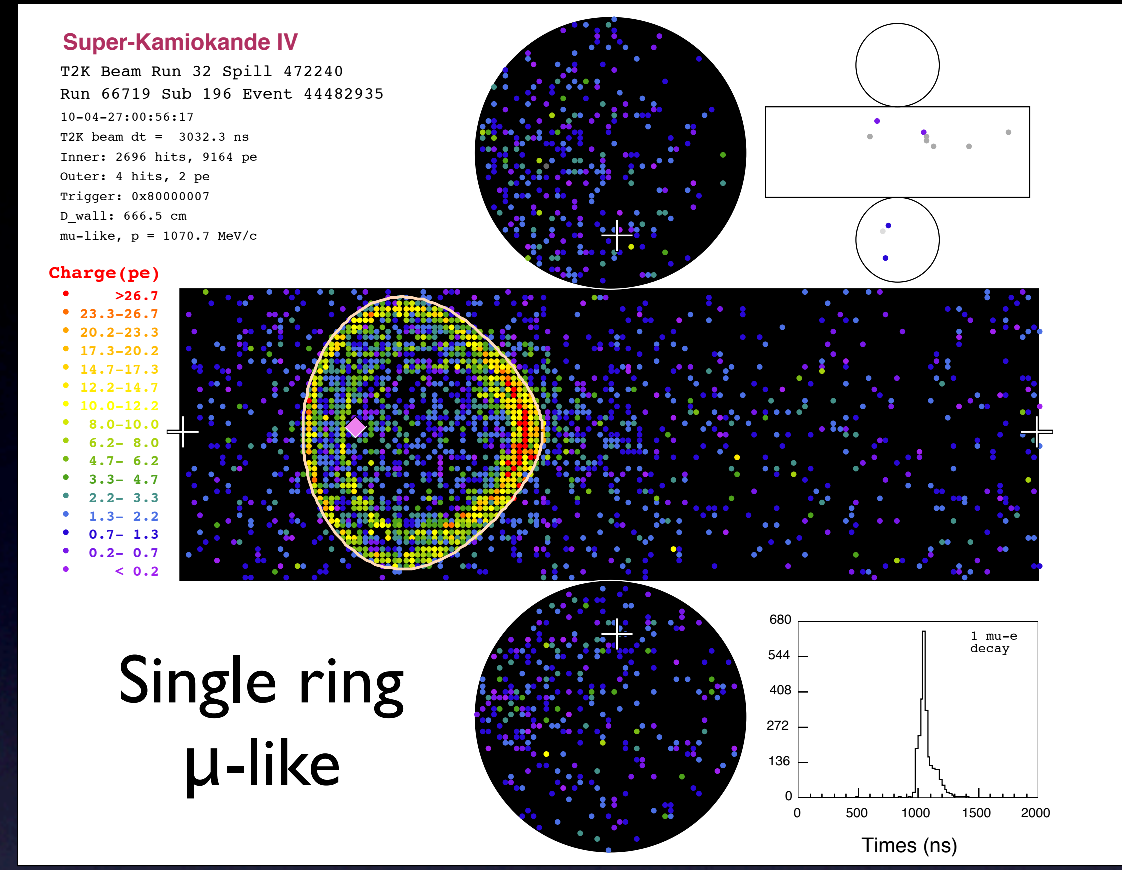


- Number of events observed in the OD compatible with the expected events from oscillations

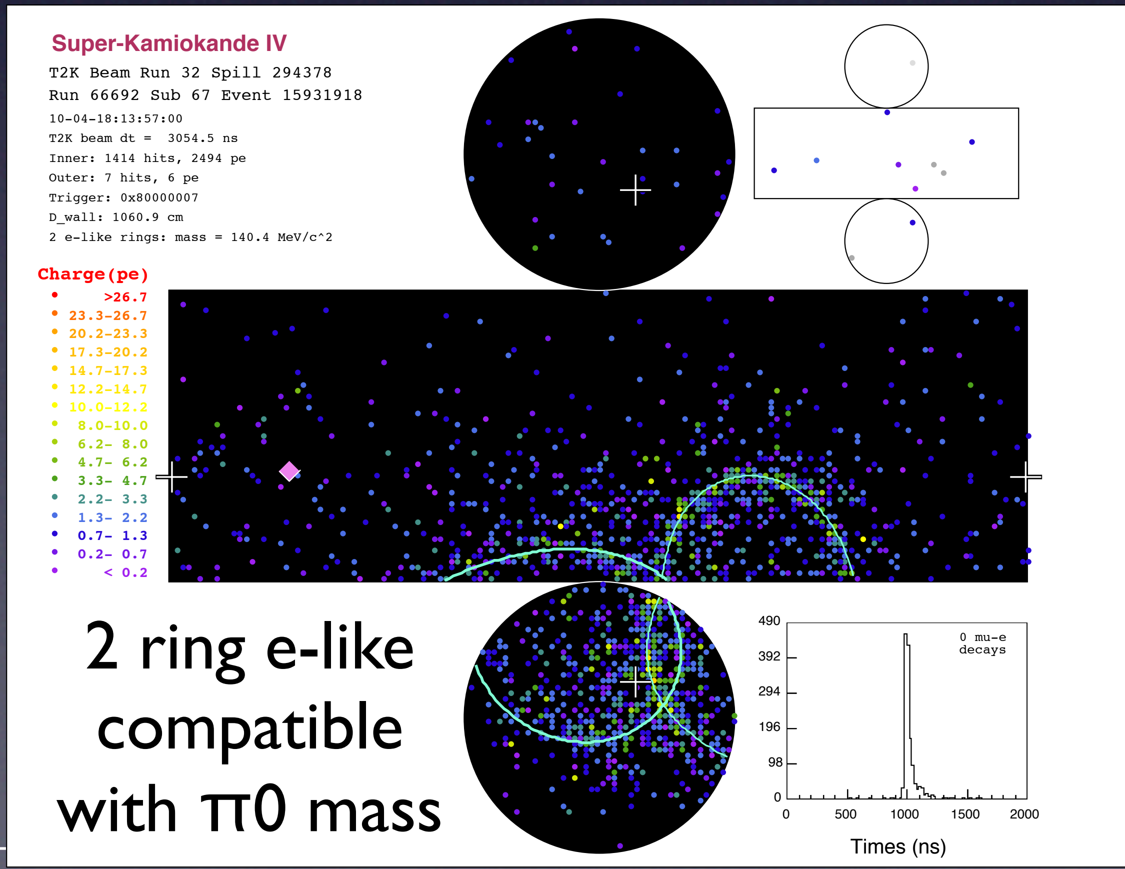
SK event display



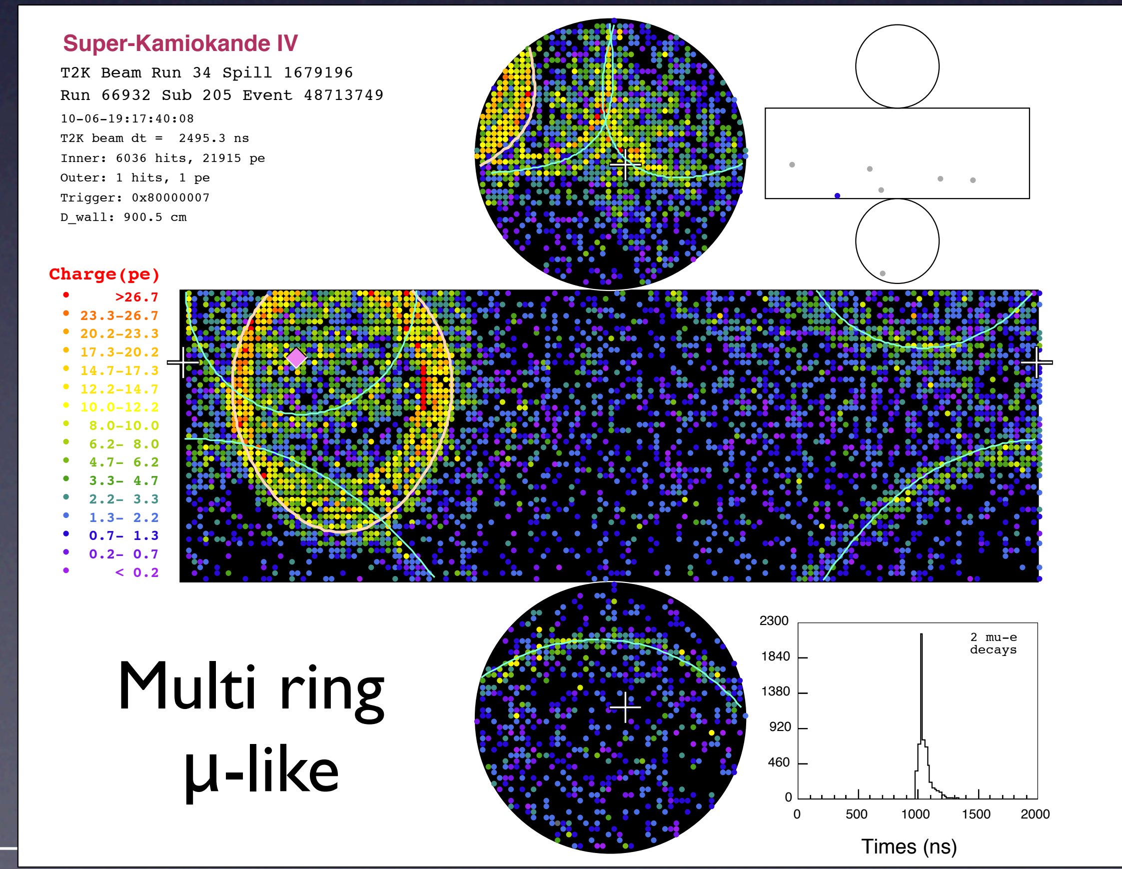
Single ring e-like



Single ring μ-like



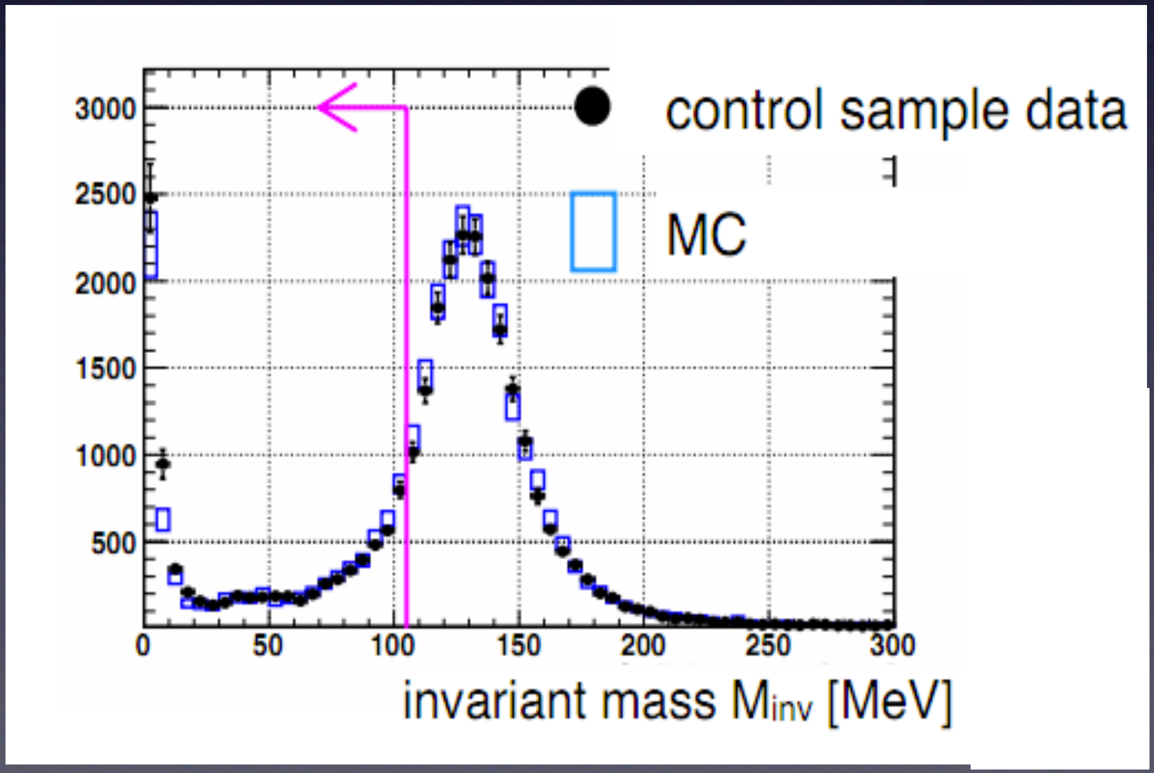
2 ring e-like compatible with π0 mass



Multi ring μ-like

SK π0 control sample

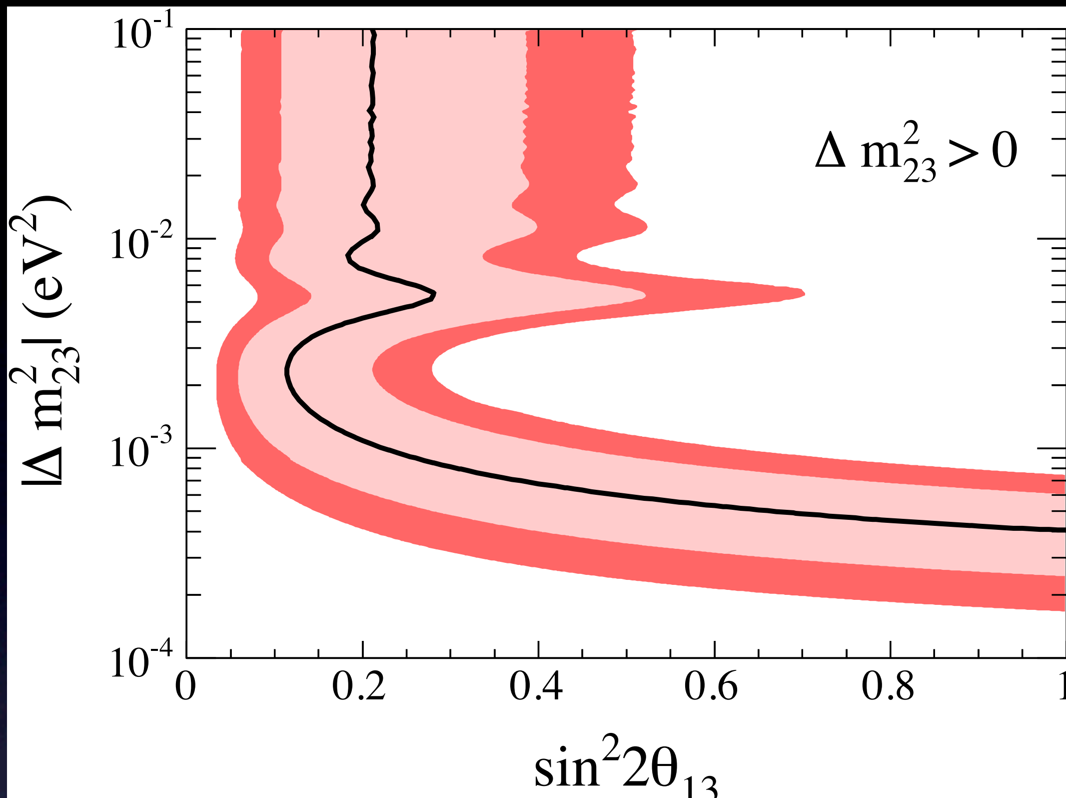
- Control sample to evaluate the uncertainties on the π0 mass reconstruction
- Take 1 e-like events from atmospheric sample
- Add 1 simulated γ

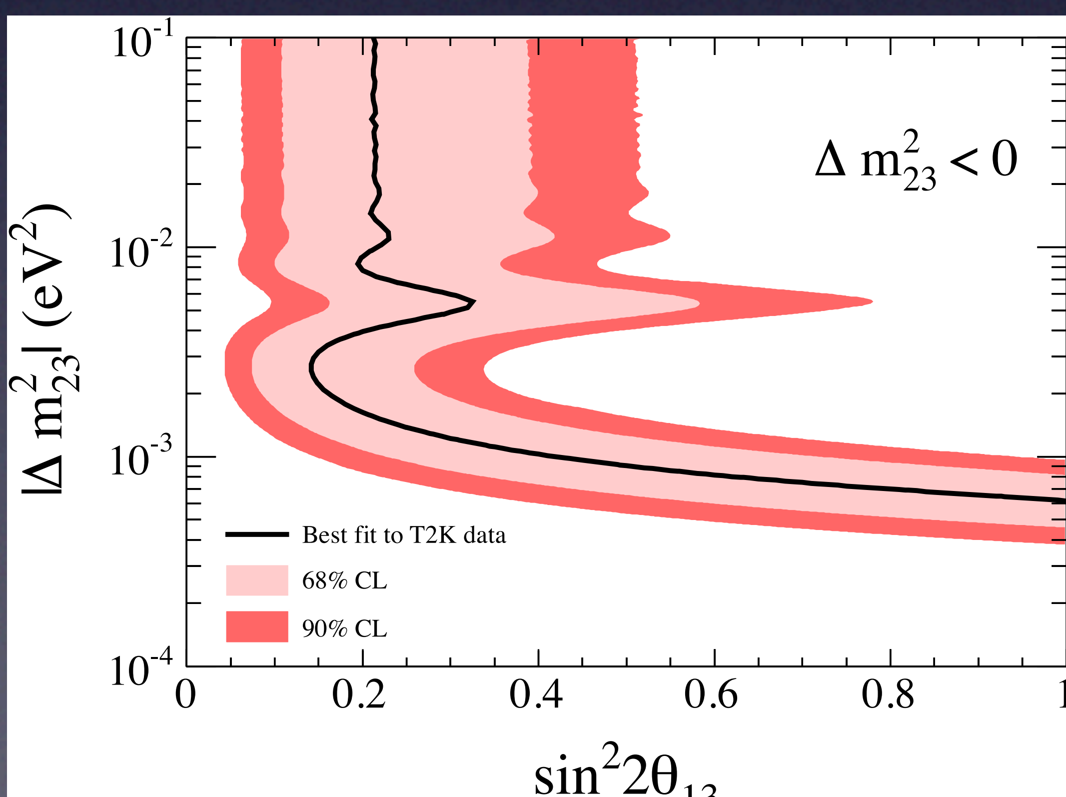


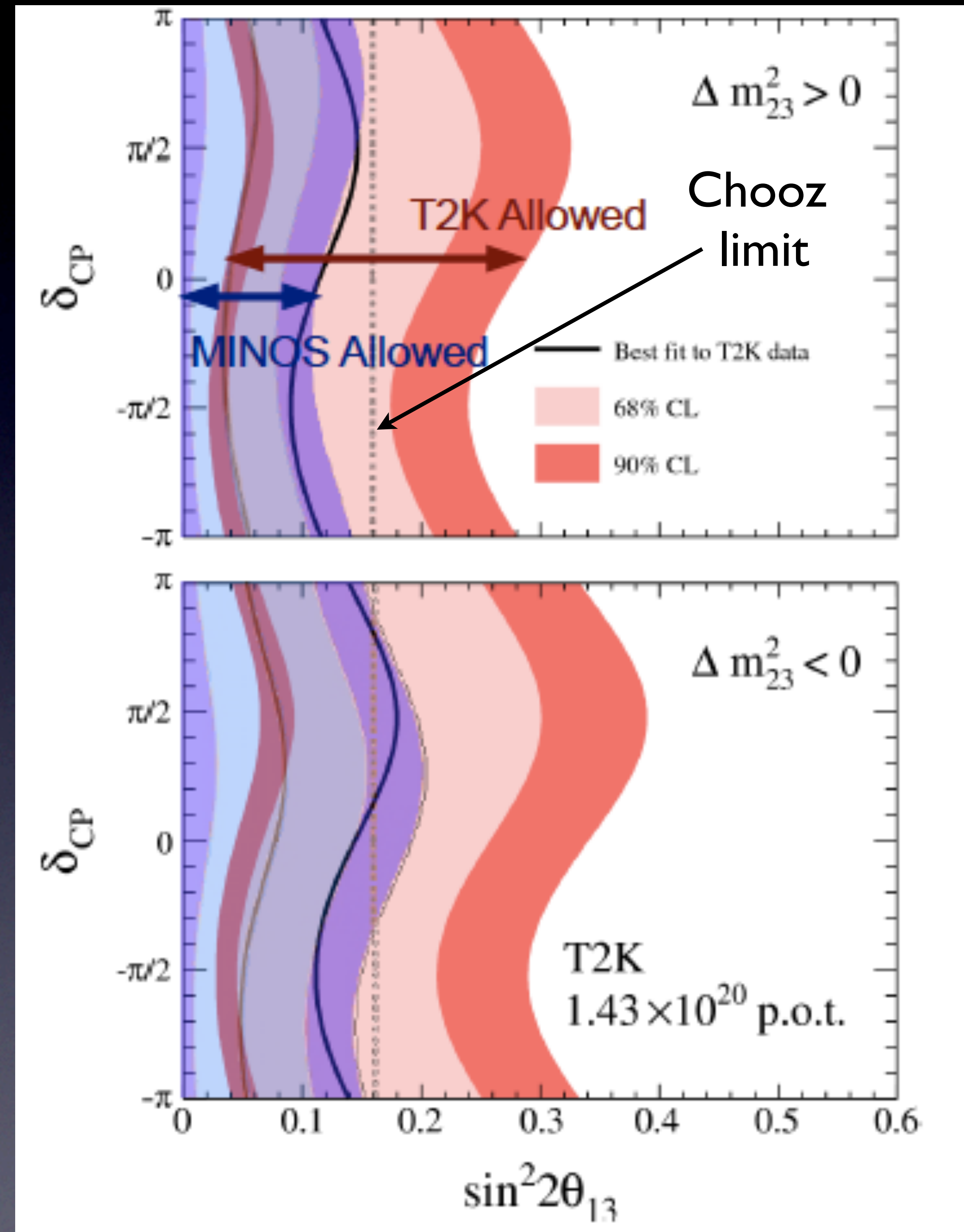
Compare the hybrid π0 sample to a pure MC sample

Differences in the efficiency between data and MC give the systematic on the π0 mass cut

ν_e appearance







JPARC status after Earthquake

- Ground level damages → rapidly repaired
- Equipments → no fatal damages
- LINAC floor, MR tunnel side pit, Near Detector bottom floor submerged under water
  - Fixed in few weeks
  - No serious damages on components
- Tunnel moved or bent of ~ several cm
  - Major alignment of many components need to be done

- We plan to resume JPARC beam operation in December 2011
- Two physics runs (~1 month each) for users before March 2012

- Future milestone:
  - 0.5 MW x 10^7 s (1×10^{21} p.o.t.) in Summer 2013
    - Conclude θ13 different from 0 (more than 5 σ at present T2K best fit