Title: First results from the T2K experiment

Date: Apr 19, 2011 12:30 PM

URL: http://pirsa.org/11040088

Abstract: Neutrino oscillations has been observed and confirmed at two mass splittings (\Delta m^2), which is consistent with three generations of neutrinos and an unitary mixing matrix. Despite the rapid progress in understanding neutrino oscillations in the last decade, two large questions remain about neutrino oscillation parameters at \Delta m^2 ~ 0.001 eV^2. Is \theta_{23} exactly 45 degrees, indicating an additional symmetry in neutrino mixing? Is \theta_{13} non-zero, which would mean there could be CP violation in the neutrino sector. If \theta_{13} is large enough, then such CP violation could be studied with future high intensity experiments such as the proposed Long Baseline Neutrino experiment in the US (LBNE). The Tokai-To-Kamioka (T2K) long baseline neutrino experiment is designed to precisely measure \nu_{\mu} disappearance (\Delta m^2_{23}, \theta_{23}) and search for \nu_e appearance (\theta_{13}). A beam of muon neutrinos is generated at the J-PARC facility in Tokai-mura, Japan, and is sampled by two near detectors, ND280 and INGRID, before reaching the Super-Kamiokande detector, 295km away. In this talk, a first look at \nu_{\mu} disappearance and \nu_e appearance will be shown from T2K, from the inaugural 6 month run ending in June 2010 (3.23x10^19 protons on target, at 15.5 kW x 10^7s).

Earthquake in Japan

On March 11^{th}, 2011, Japan experienced a severe earthquake followed by a tsunami

No reported injuries to members of the T2K collaboration or JPARC employees

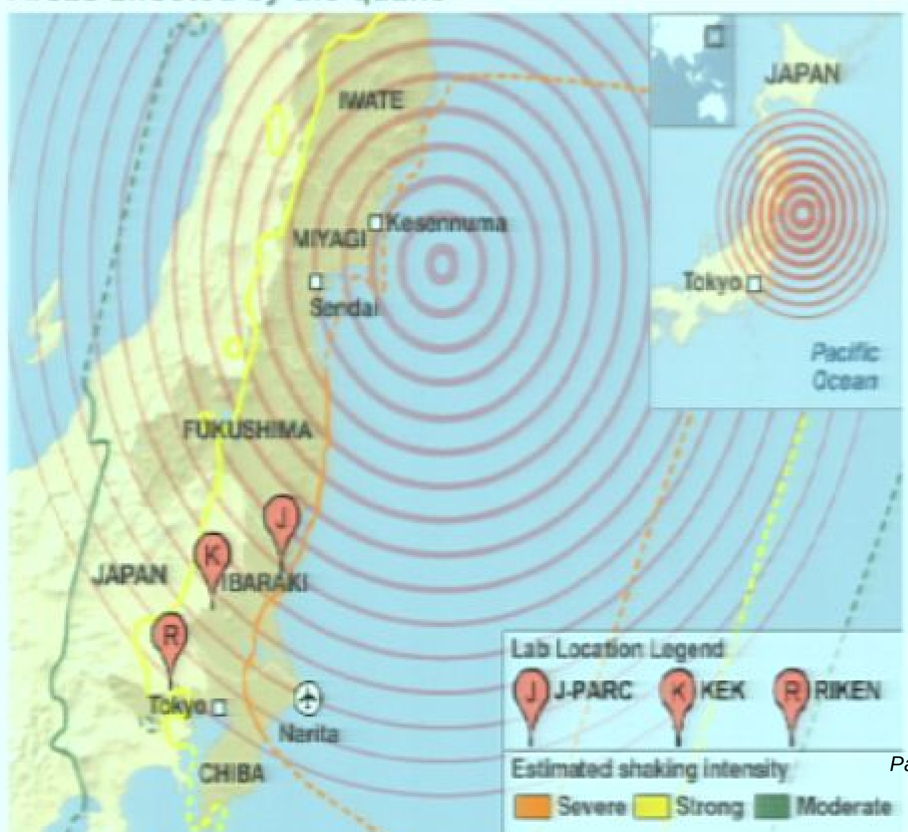
All foreign collaborators have returned home safely

The tsunami did not reach JPARC

Inspection of the lab is ongoing

Priority is to restore water, power, and gas systems

Areas affected by the quake



Introduction

A reminder about neutrinos

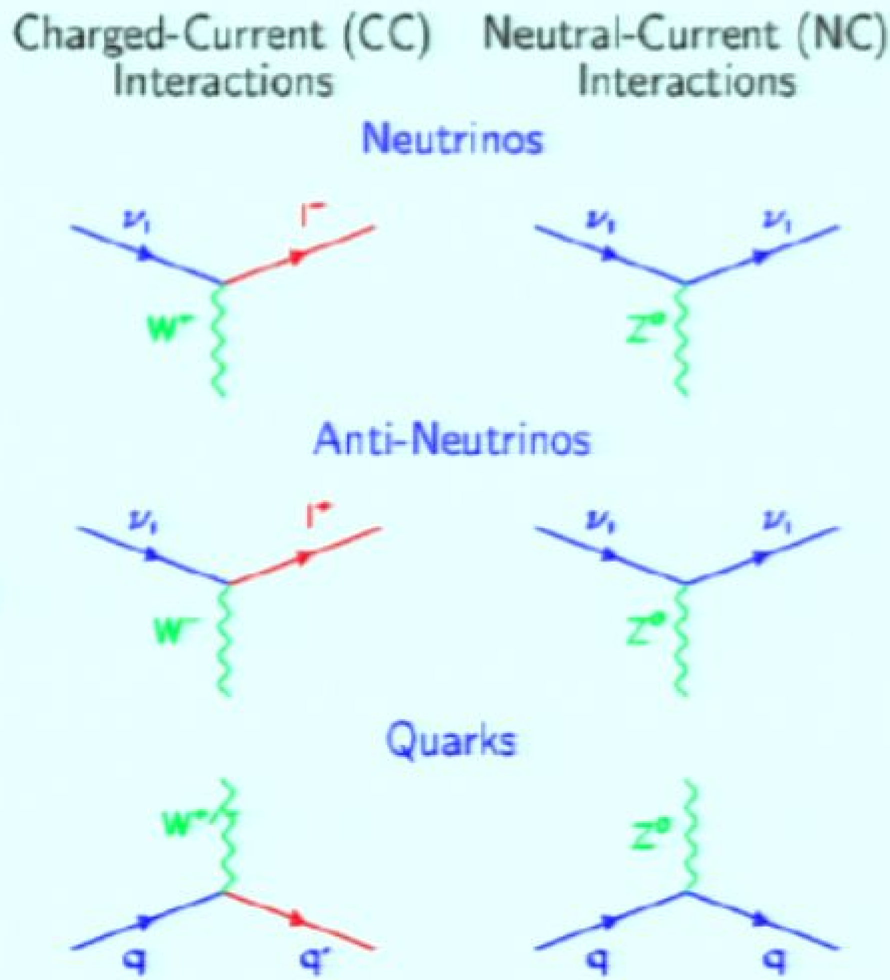
In the Standard Model, there are three neutrinos: ν_e, ν_μ, ν_τ
paired with an associated charged lepton partner: e, μ, τ

Neutrinos interact via the weak force (W, Z bosons)

To detect neutrinos:
Need ``nothing'' coming in

Detect the outgoing lepton to determine neutrino flavor (CC only)

Nucleus can be excited or additional particles emitted (NC or CC)



Neutrino mixing

The flavor state of the neutrino, ν_α, is related to the mass states, ν_i, by a non unity mixing matrix, $U_{\alpha i}$

$$|\nu_i> = \sum U_{\alpha i} |\nu_\alpha>$$

Since there are three observed flavors of neutrinos (ν_e, ν_μ, ν_τ), U contains three mixing angles (θ_{12}, θ_{23}, θ_{13}) and a CP violating phase δ.

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

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

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

"Atmospheric": θ_{23} ~37°-45°

"Reactor": θ_{13} <11°

"Solar": θ_{12} ~34°

Quark mixing: unitary matrix, small angles: θ^{CKM}_{12}~13.0°, θ^{CKM}_{23}~2.3°, θ^{CKM}_{13}~0.2°

- Is θ_{23} exactly 45 degrees, or not?
- Is θ_{13} zero, or just small?
- Is there CP violation in the neutrino sector? Is it large?

Neutrino oscillation

As the neutrinos propagate, the mass states interfere:

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

Depends on:

L (km): Distance the neutrino has travelled

E (GeV): Energy of the neutrino

Δm^2 (eV^2): Difference of the square of the mass eigenvalues

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

"Atmospheric": $\Delta m^2_{23} = 2.4 \times 10^{-3}\ eV^2$

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Probability for ν_μ oscillating into ν_x :
(ν_μ disappearance)

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{23} \sin^2\left(\frac{\Delta m^2_{23}L}{4E}\right)$$

Probability for ν_μ oscillating into ν_e
(ν_e appearance)

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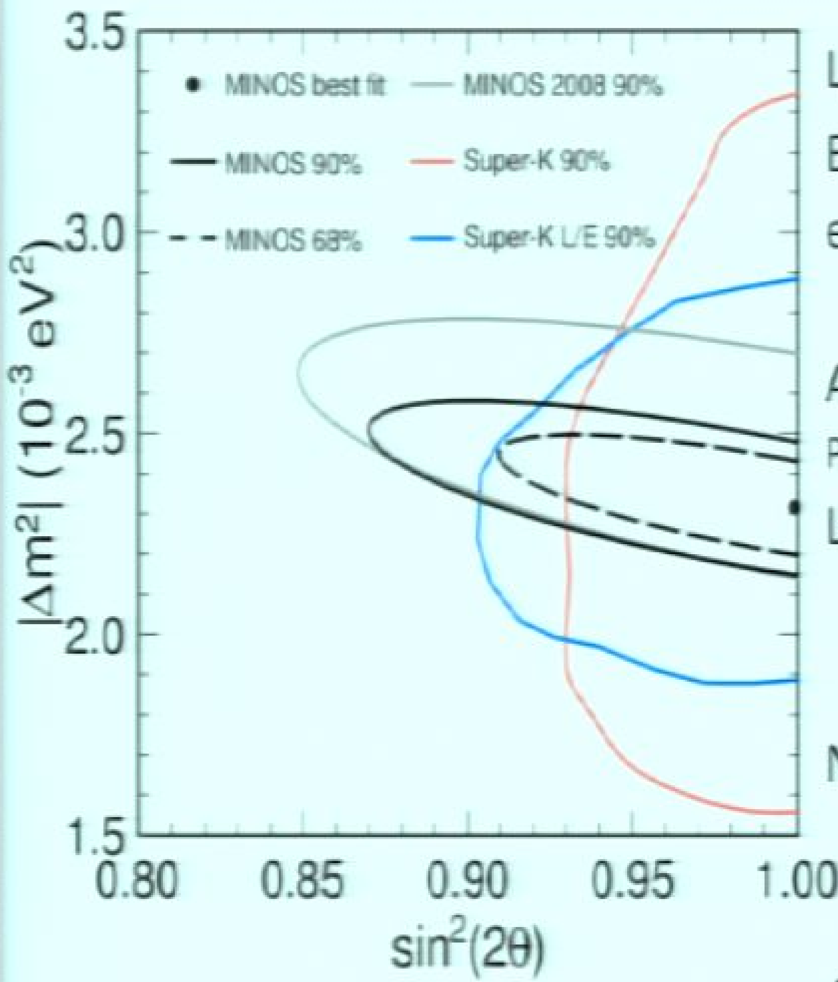
Existing measurements of ν_μ disappearance



L, E are fixed based on neutrino source

Extract $|\Delta m^2|$, $\sin^2 2\theta$ based on rate, energy spectrum after oscillation

Accelerator-produced neutrino beam (MINOS)

Phys. Rev. Lett. 101, 131802 (2008)

L=735km, E(peak) ~3 GeV

$\Delta m^2_{23} = 2.43 \pm 0.13 \times 10^{-3}$ eV^2

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New result (2011) 1103.0340 [hep-ex]

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Atmospheric neutrinos (Super-Kamiokande)

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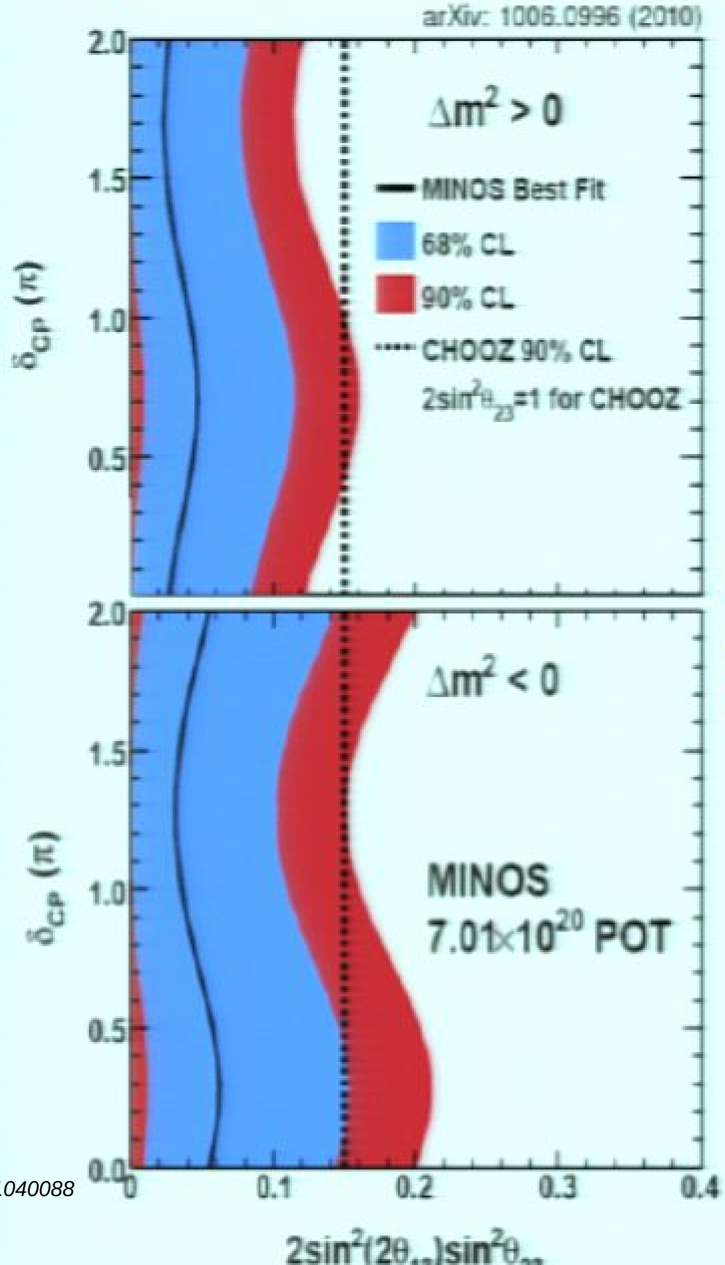

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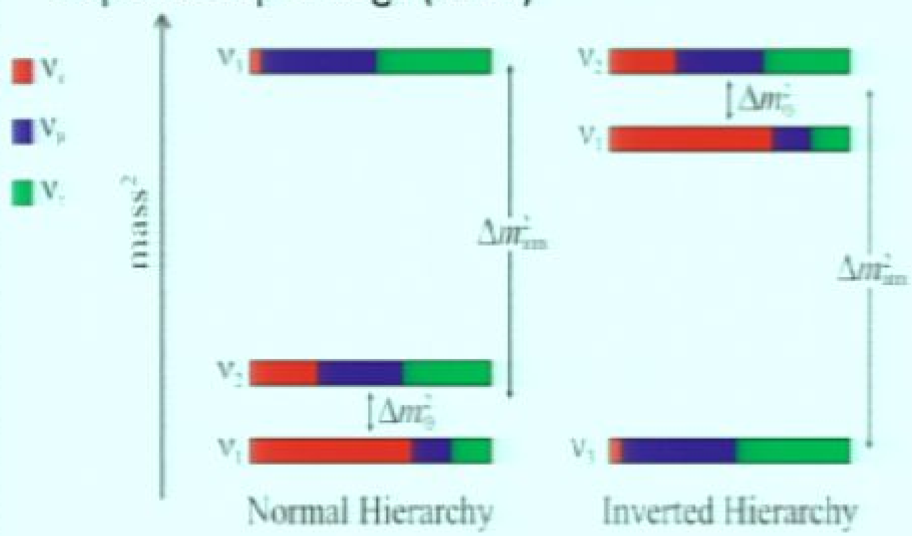
ν_e and ν_μ interact differently in matter vs vacuum, altering oscillation probability

Depends upon sign(Δm^2)



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L~1 km, E~3 MeV

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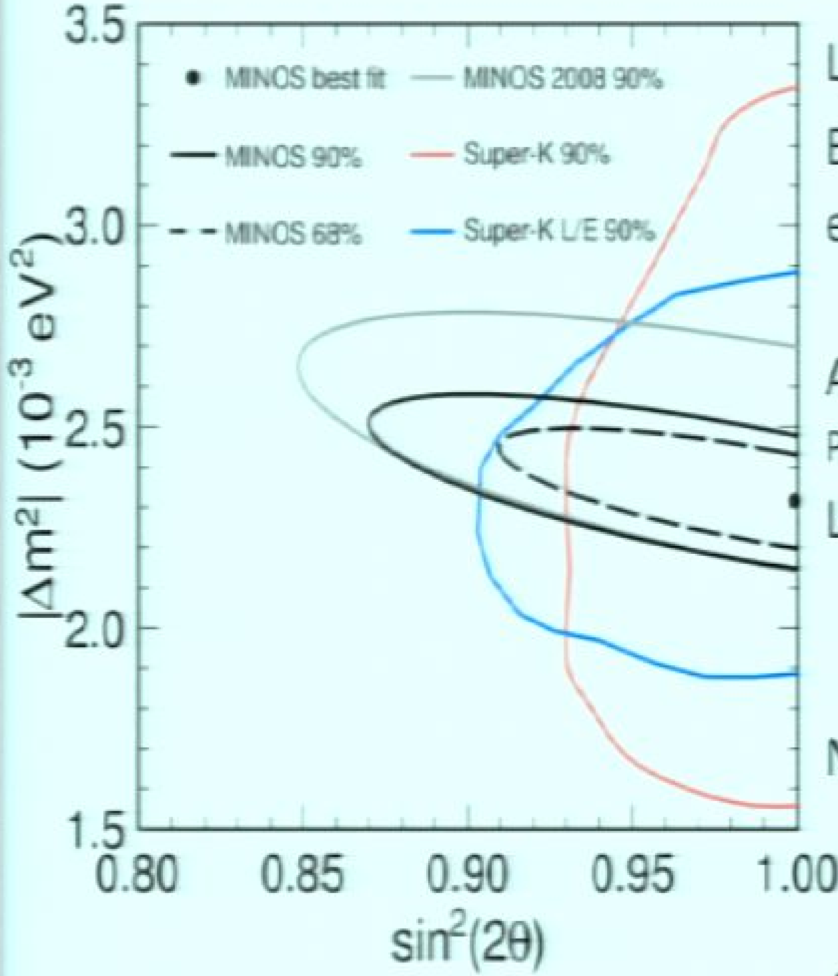

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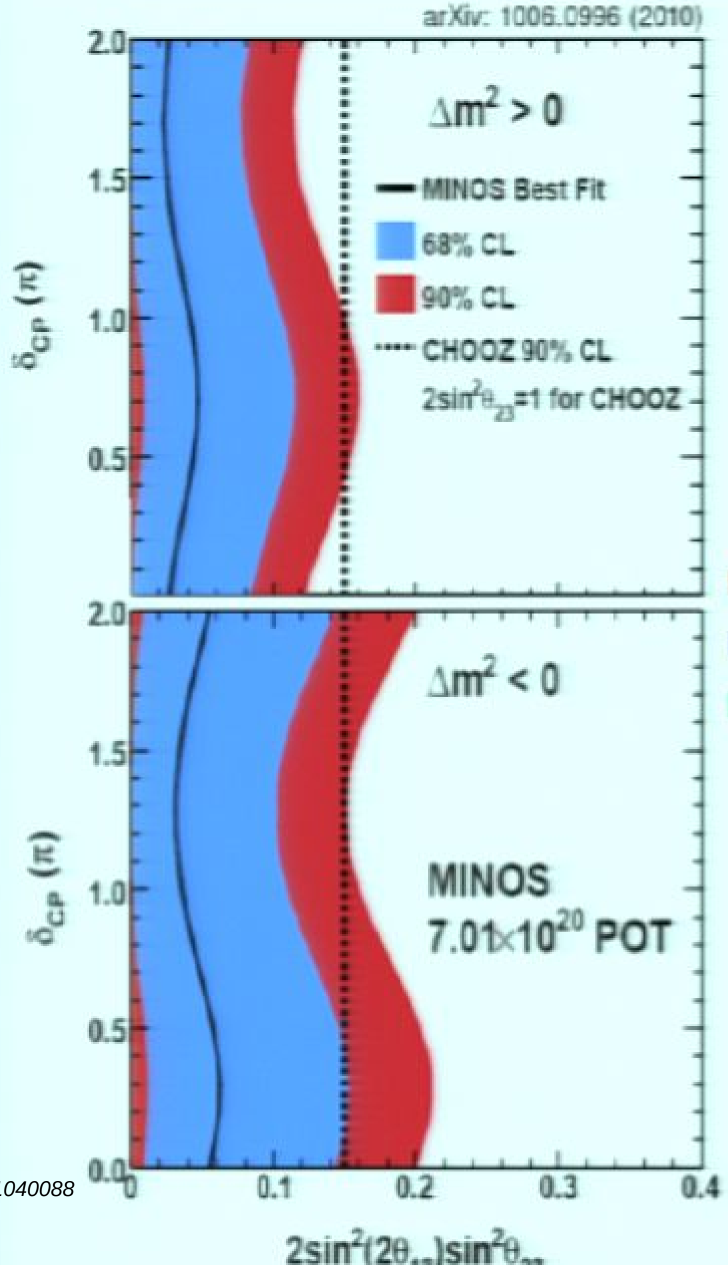

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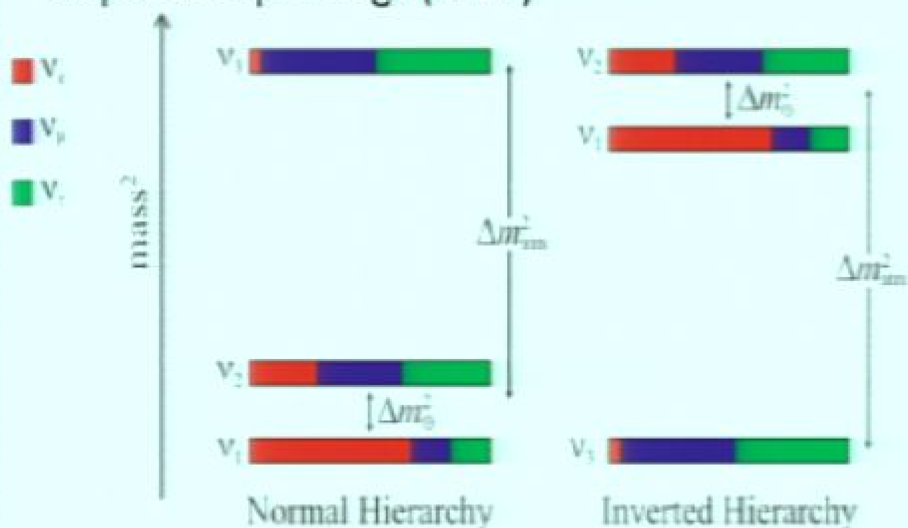

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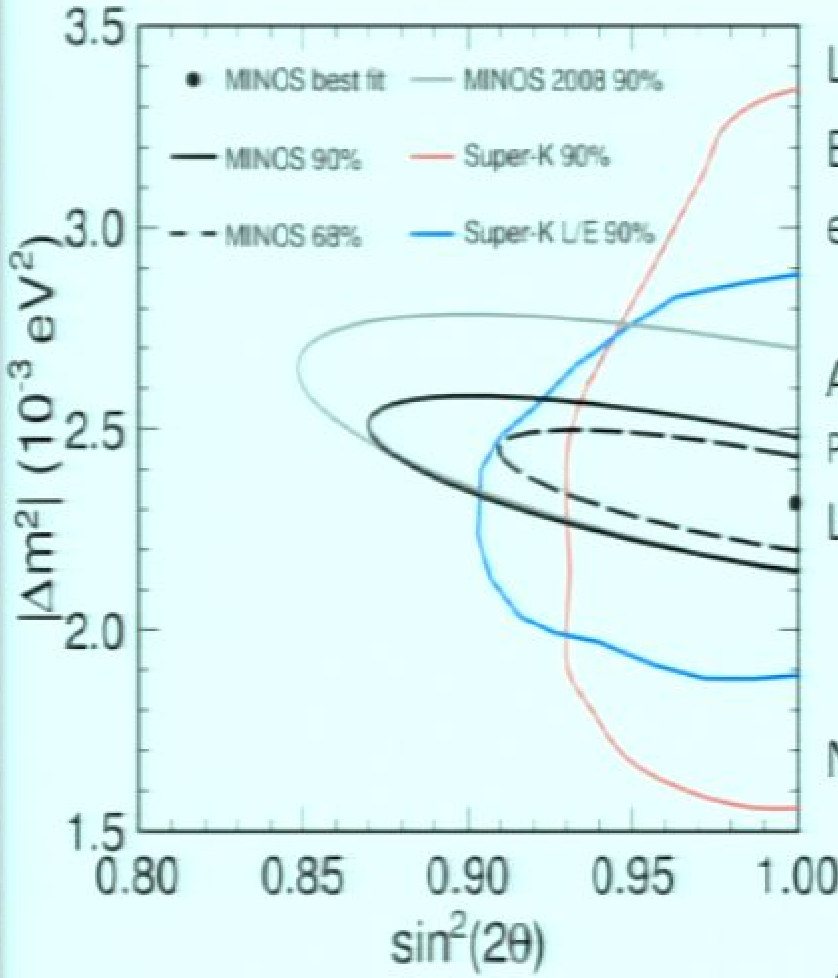

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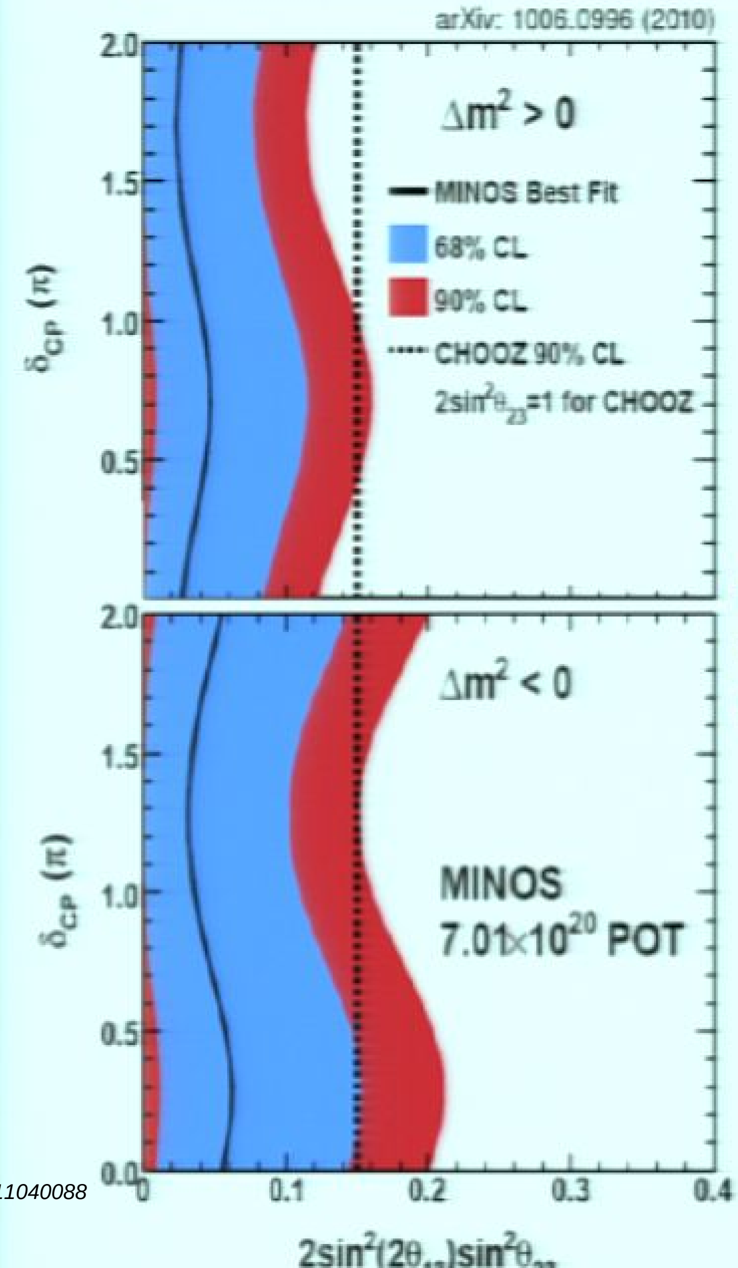

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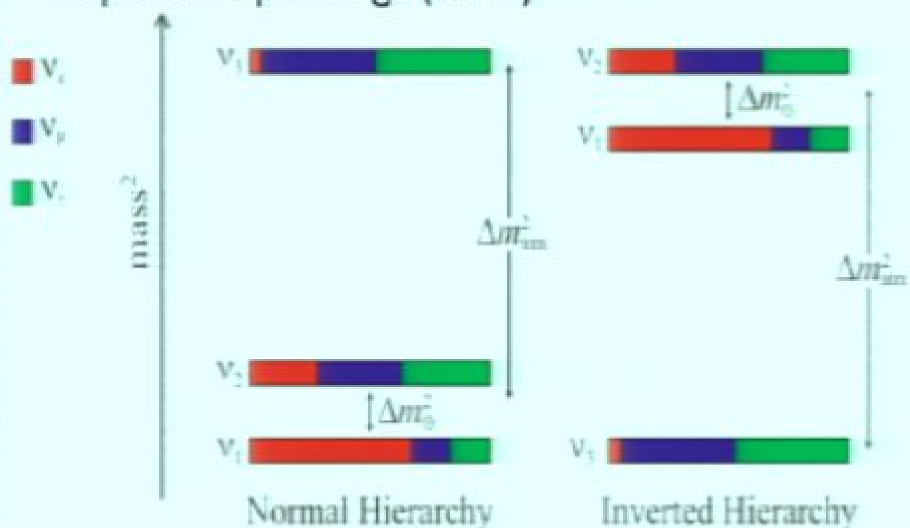

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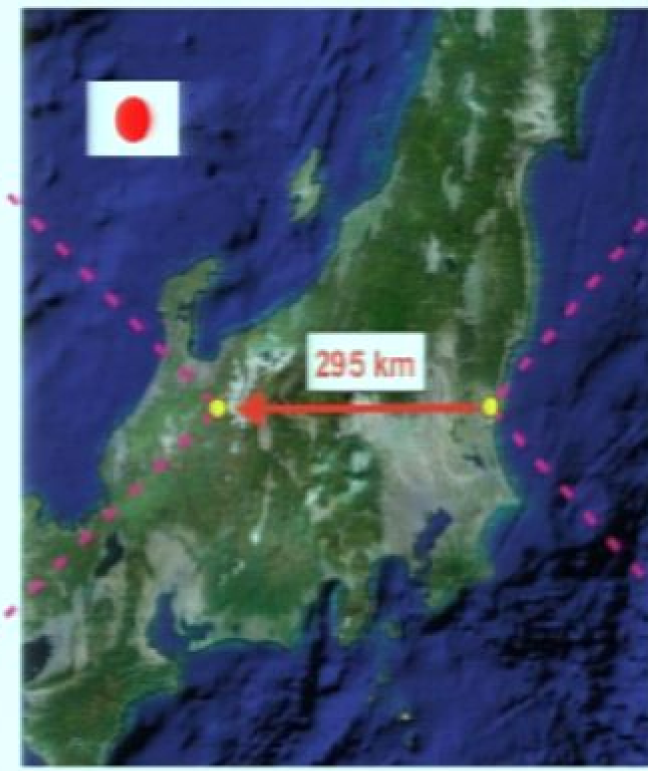
Measure ν_μ disappearance (Δm^2_{23}, θ_{23})

Discover ν_e appearance? (θ_{13})

Produce a beam of ν_μ on one side of Japan and detect it on the other

Super Kamiokande
50,000 tons of water
10,000 phototubes

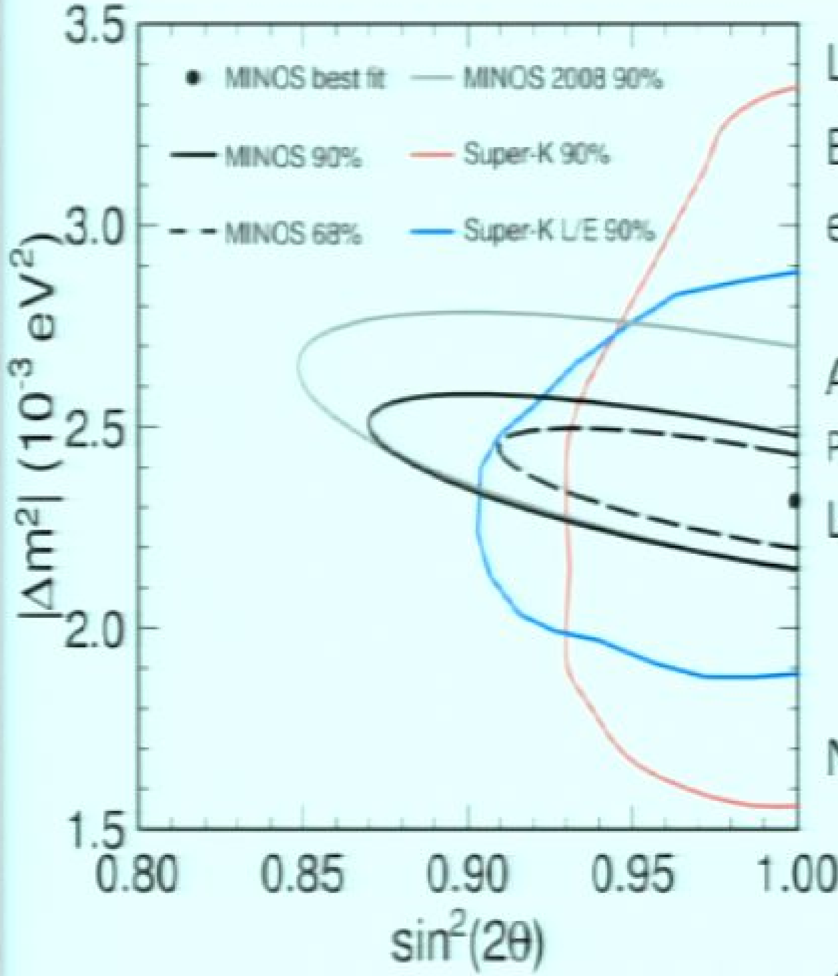
Neutrino beam directed across Japan



Tokai accelerator complex and location of near detector (ND280)

Largest oscillation with $\sin^2(L \, \Delta m^2 / E) \sim 1$

Existing measurements of ν_μ disappearance



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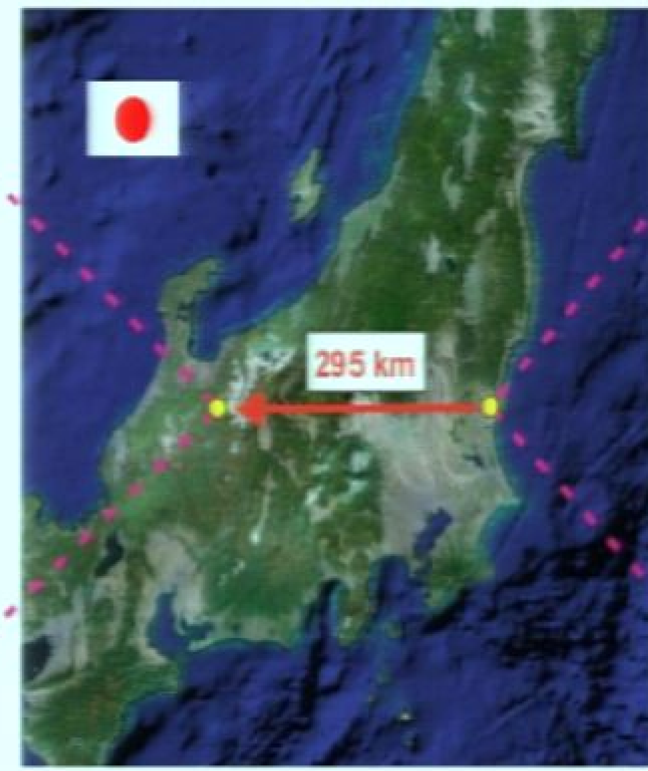

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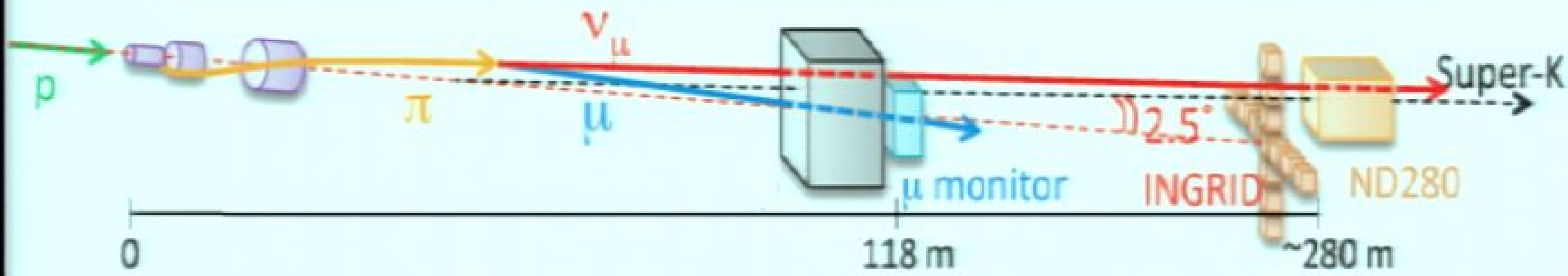
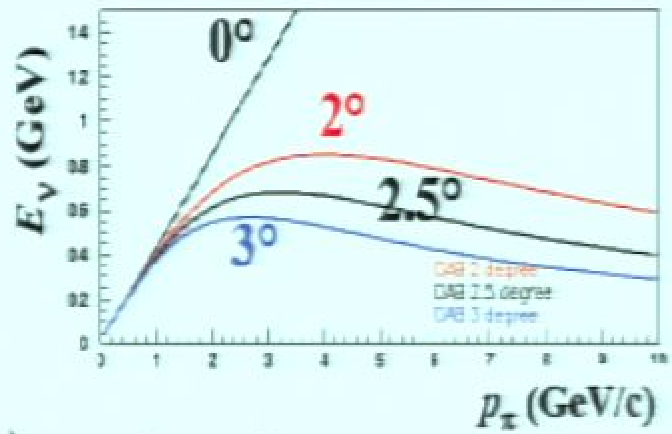
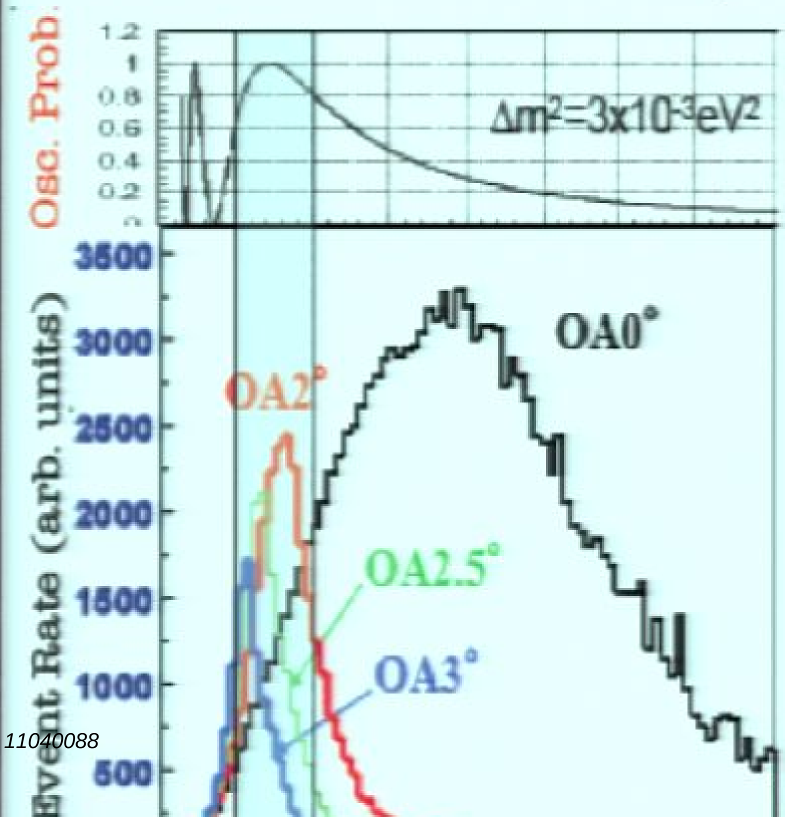
Largest oscillation with $\sin^2(L\,\Delta m^2 / E) \sim 1$

Creating an (offaxis) neutrino beam



Primary protons hit a target (carbon) producing secondary unstable mesons (π, K) which decay to a tertiary ν_μ beam



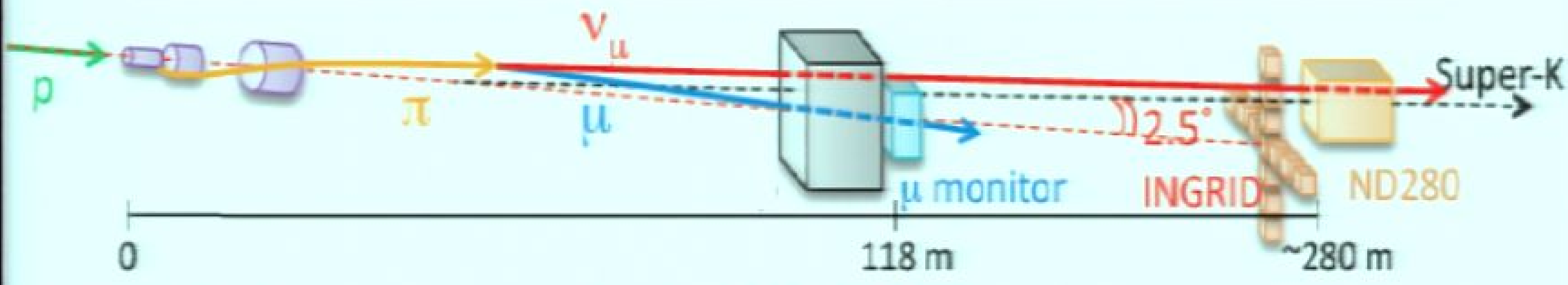


At angles away from the parent pion's direction, the neutrino energy is independent of pion momentum, resulting in a narrower neutrino energy spectrum

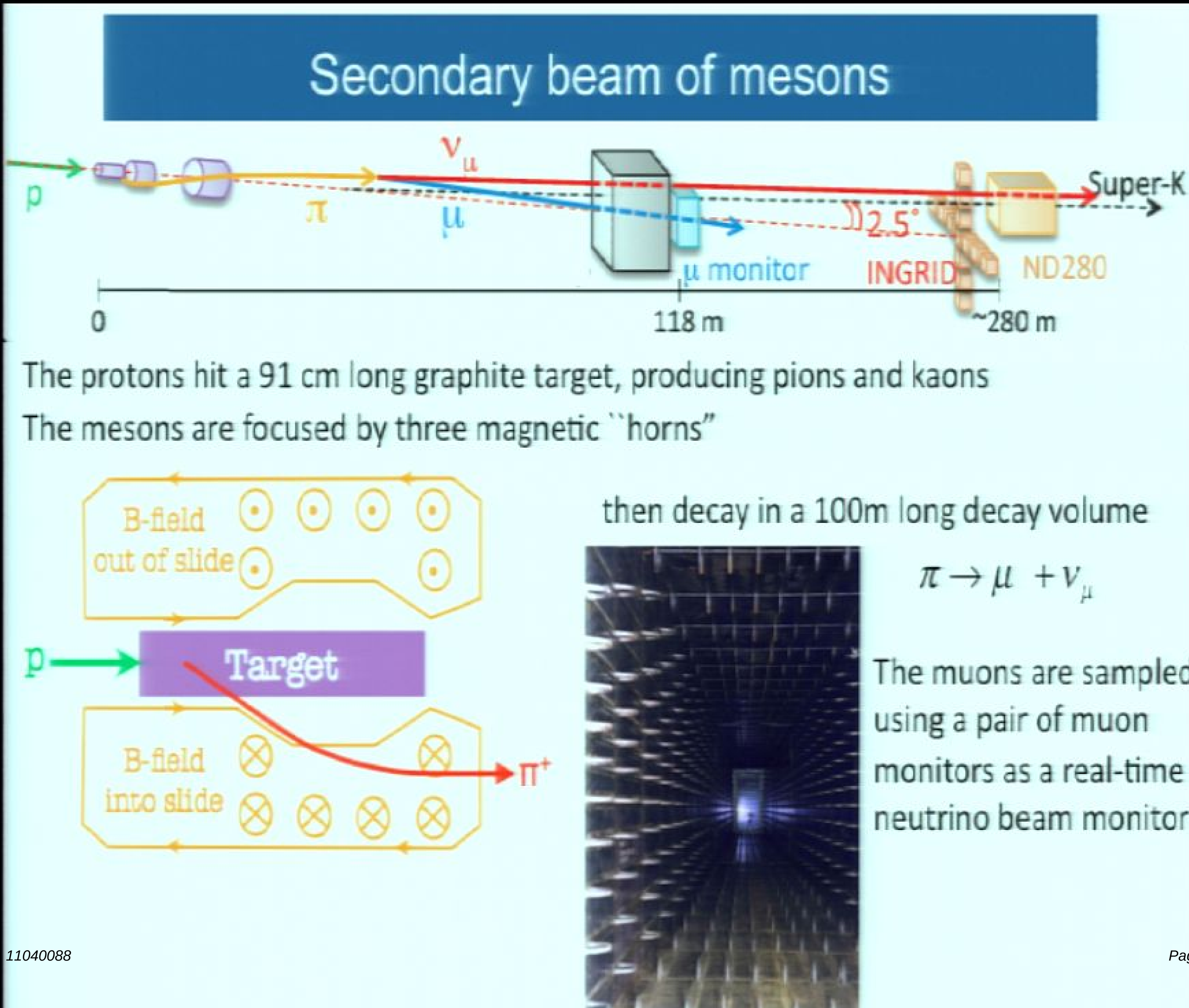
Peak corresponds to oscillation maximum

Reduces backgrounds from higher energy

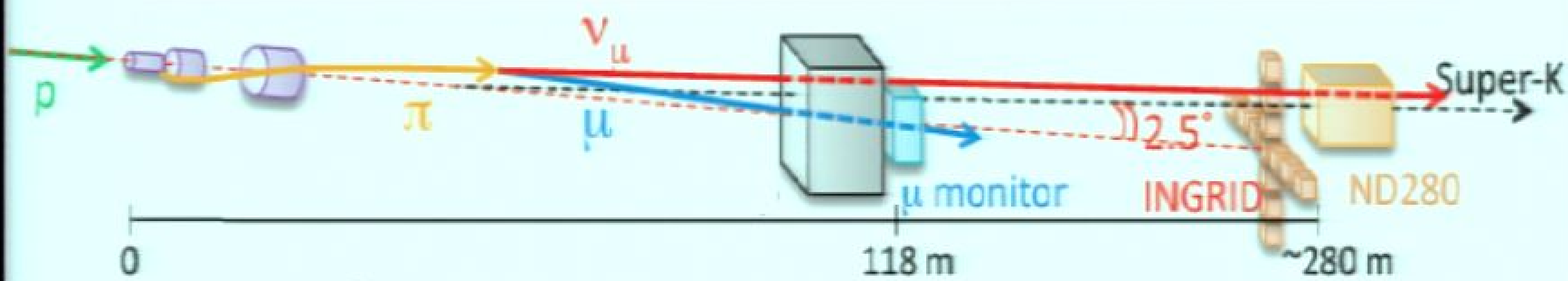
The proton beam

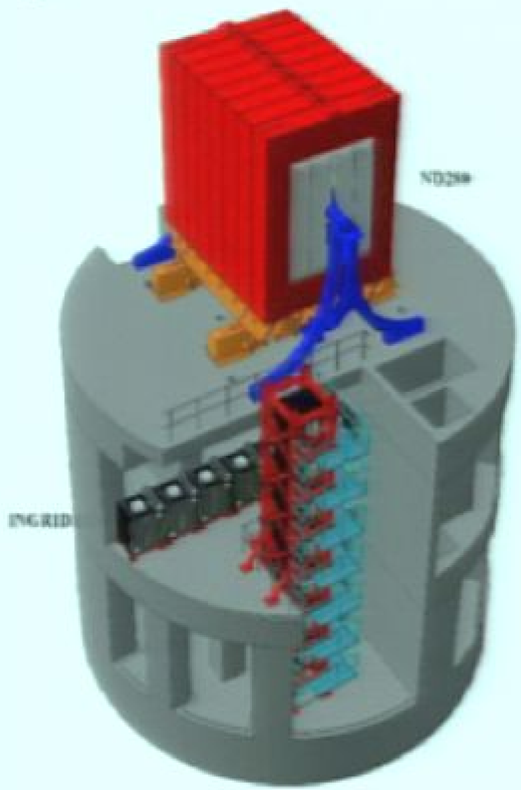


Start with 30 GeV protons, produced at JPARC in Tokai-mura, Japan


Secondary beam of mesons
p
ν_μ
π
μ
Super-K
2.5°
μ monitor
INGRID
ND280
0
118 m
~280 m
The protons hit a 91 cm long graphite target, producing pions and kaons
The mesons are focused by three magnetic ``horns"
B-field
out of slide
p
Target
B-field
into slide
π^+
then decay in a 100m long decay volume
$\pi \rightarrow \mu + \nu_\mu$
The muons are sampled
using a pair of muon
monitors as a real-time
neutrino beam monitor

Neutrino detectors



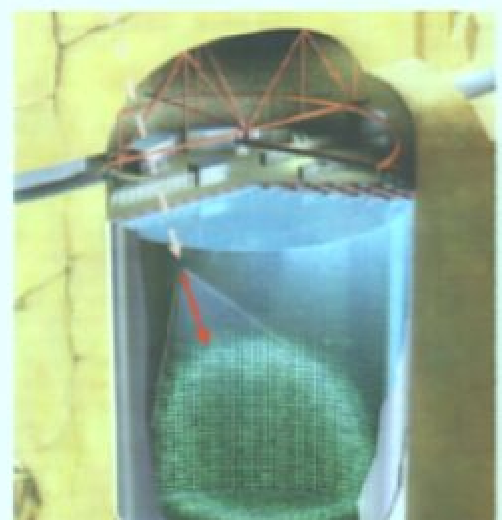


Off-axis with the ND280 detectors

- Measure the unoscillated ν_μ rate
- Constrain background processes

On-axis with the INGRID detector

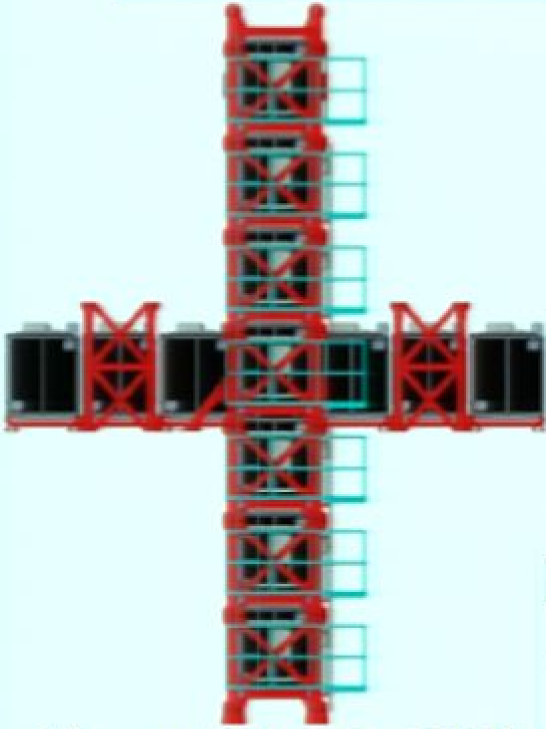
- Determine neutrino beam direction



Off-axis@295km with Super-Kamiokande

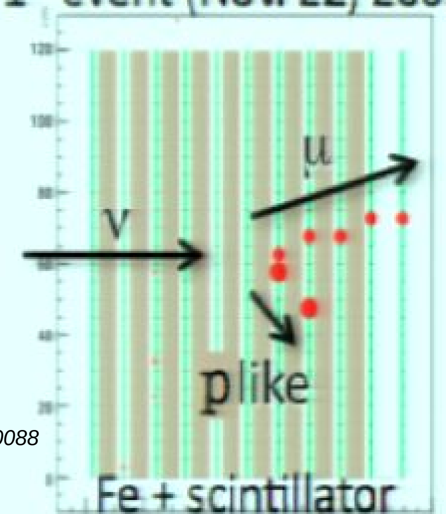
- Extract oscillation parameters

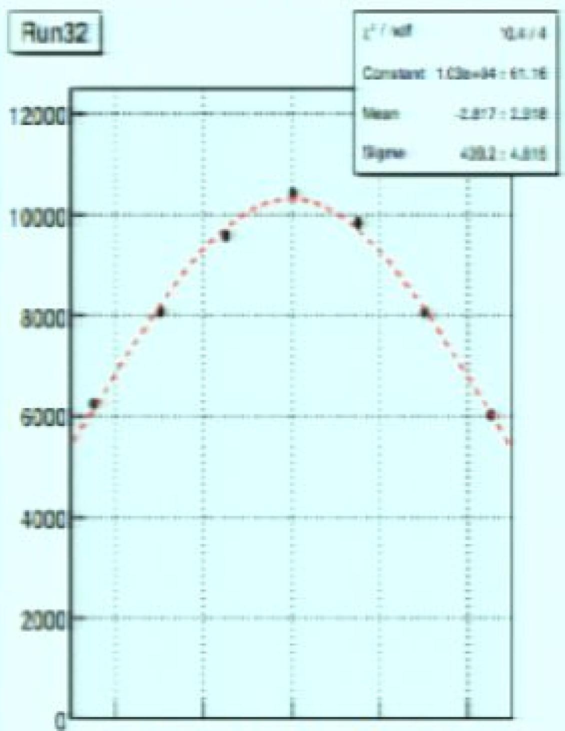
On-axis Interactive Neutrino GRID (INGRID)

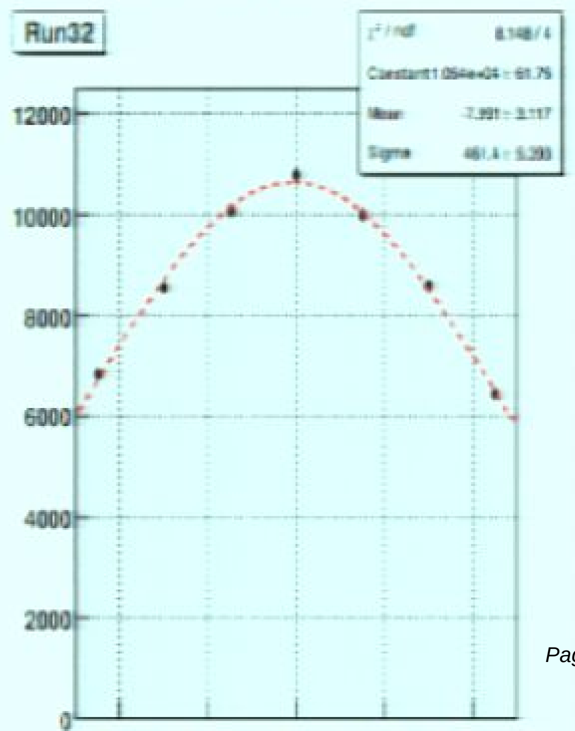


- 14 iron-scintillator modules arranged in a cross
  - X-Y scintillator layers
- Count neutrino interactions in each module to determine neutrino rate vs. position
  - ~1.5 ν / 10^{14} protons on target means 10,000 events / day
- Extract beam direction better than 0.5 mrad

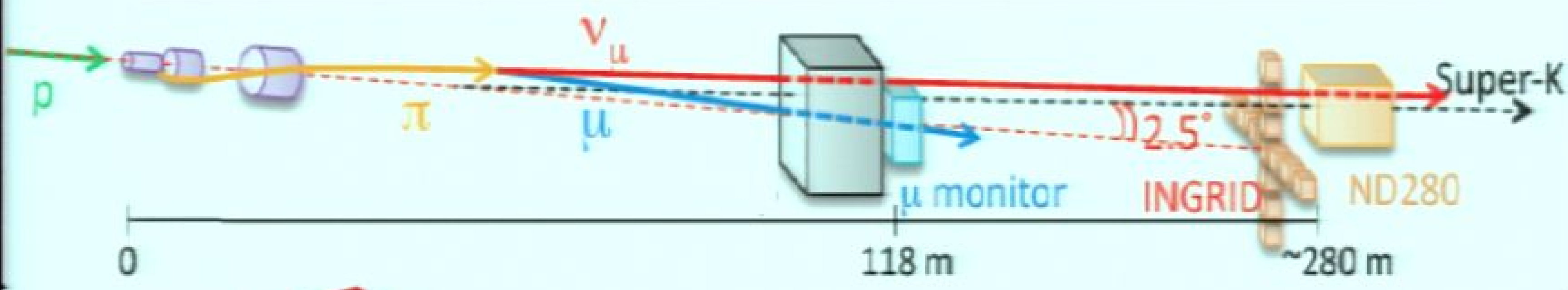
1st event (Nov. 22, 2009)

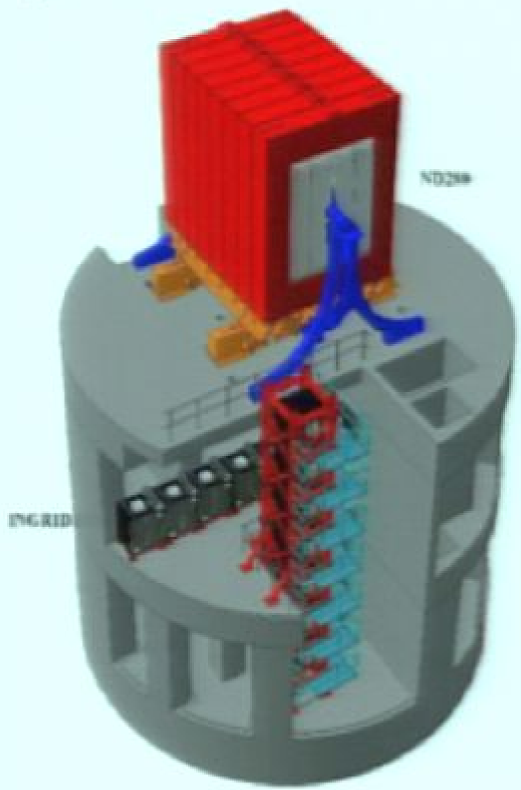






Neutrino detectors





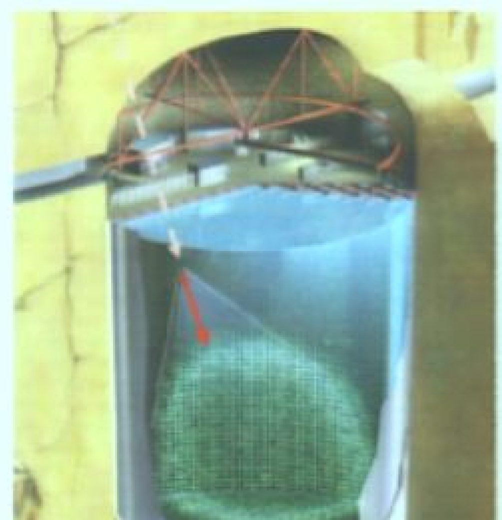
Off-axis with the ND280 detectors

Measure the unoscillated ν_μ rate

Constrain background processes

On-axis with the INGRID detector

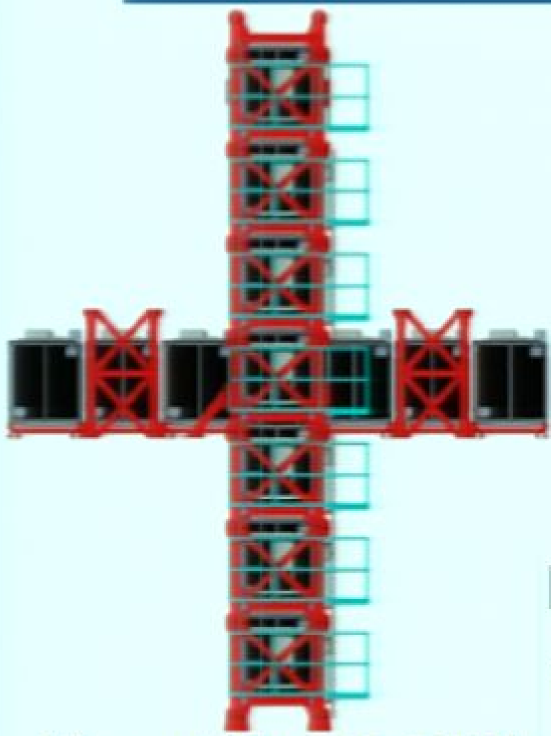
Determine neutrino beam direction



Off-axis@295km with Super-Kamiokande

Extract oscillation parameters

On-axis Interactive Neutrino GRID (INGRID)



14 iron-scintillator modules arranged in a cross

X-Y scintillator layers

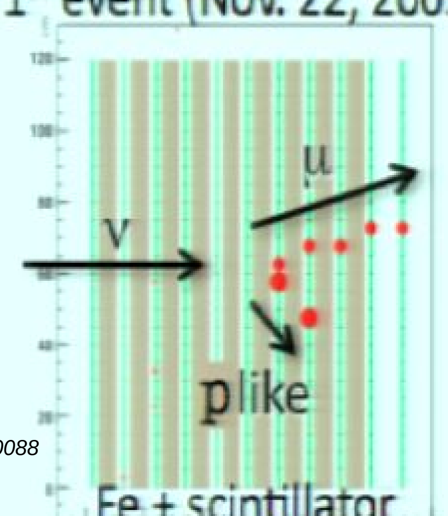
Count neutrino interactions in each module to determine neutrino rate vs. position

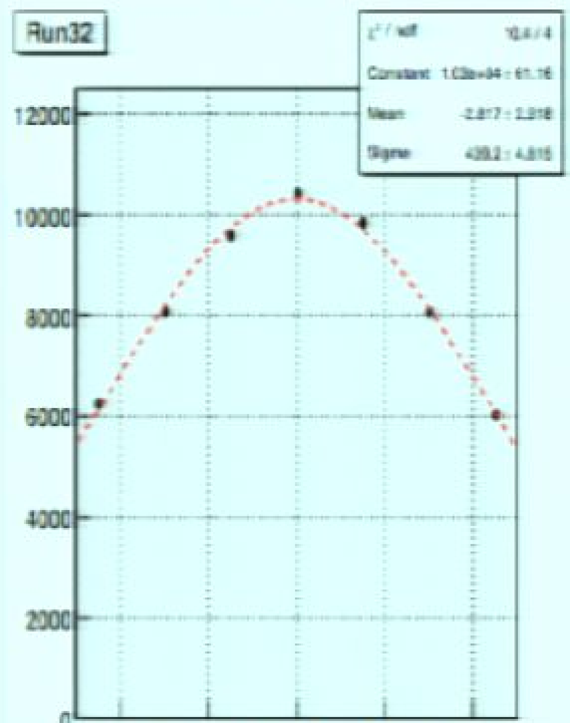
~1.5 ν / 10^{14} protons on target

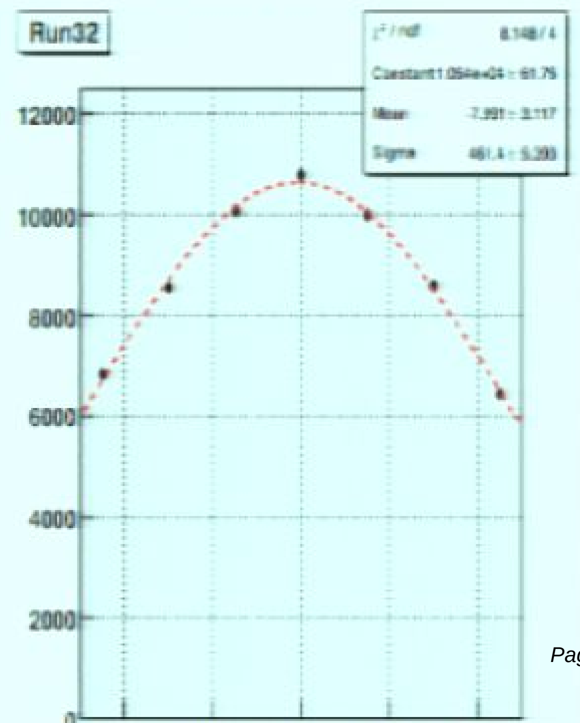
means 10,000 events / day

Extract beam direction better than 0.5 mrad

1st event (Nov. 22, 2009)







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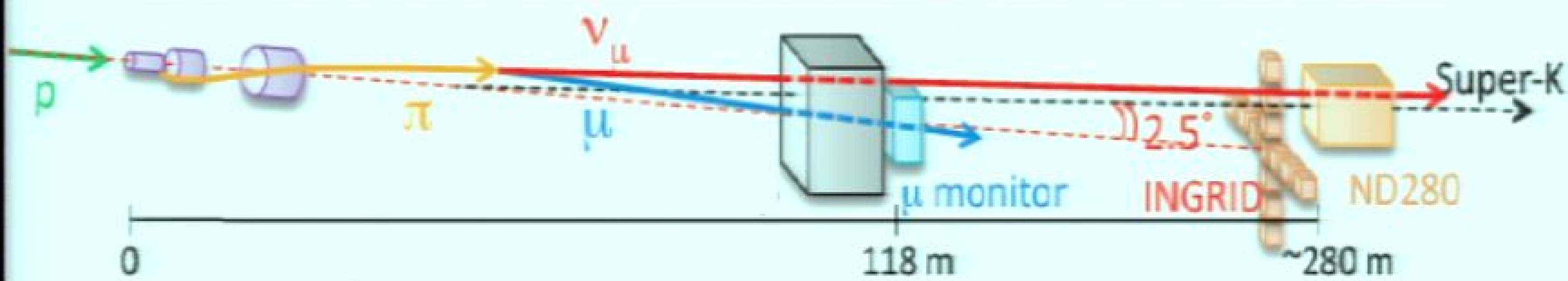

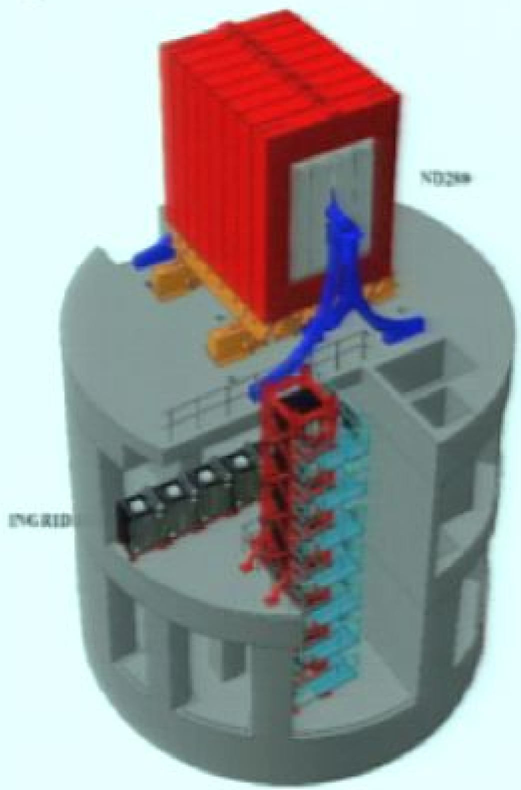

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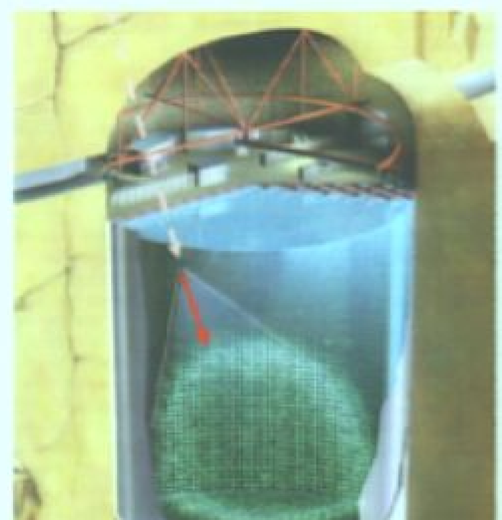

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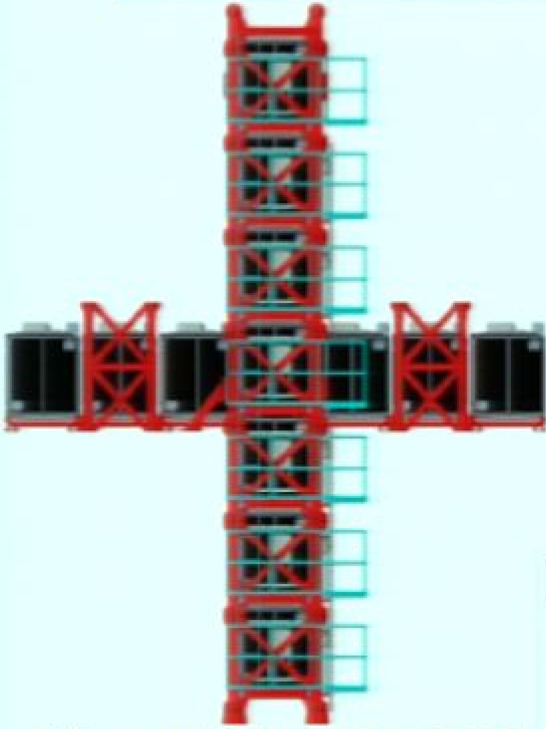

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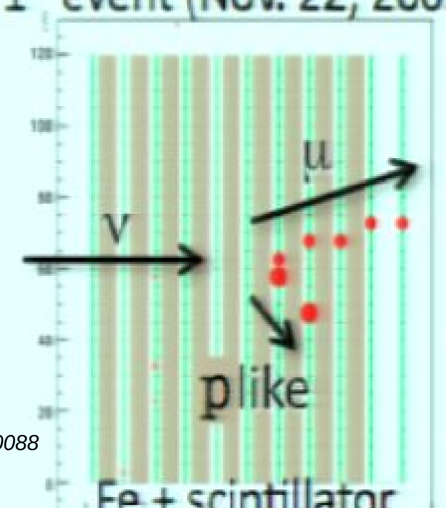

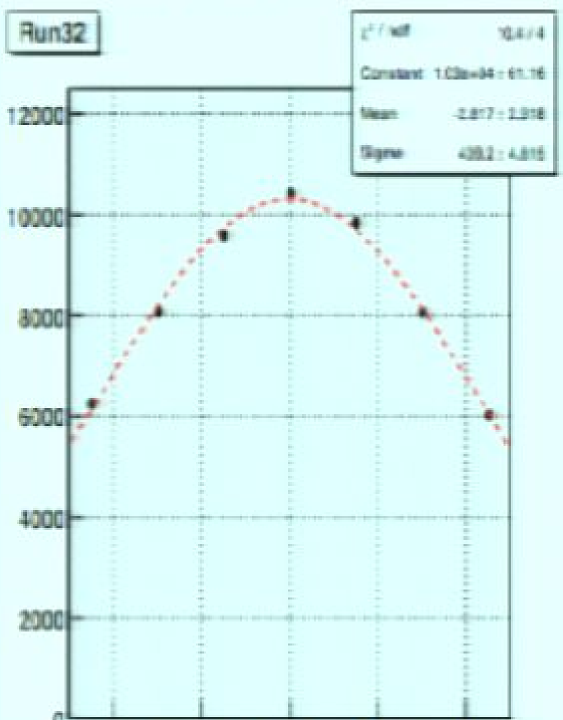

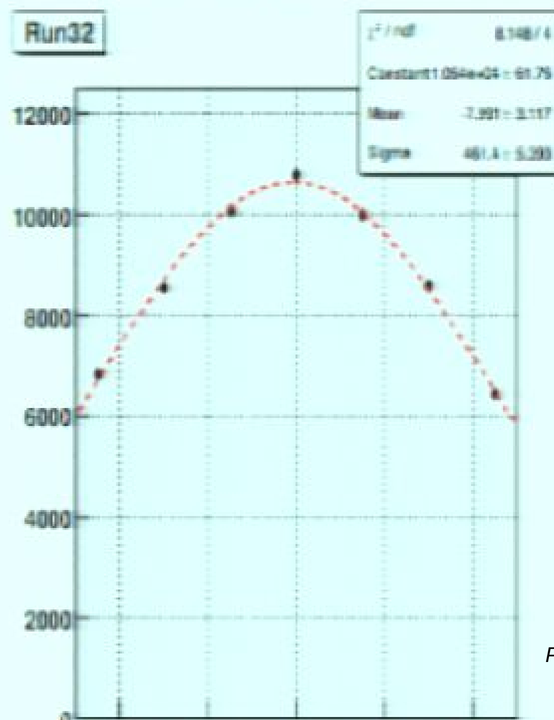

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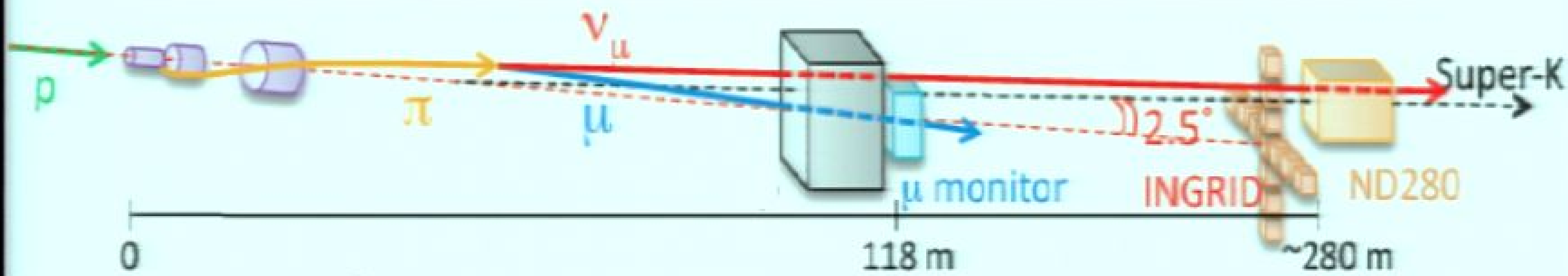

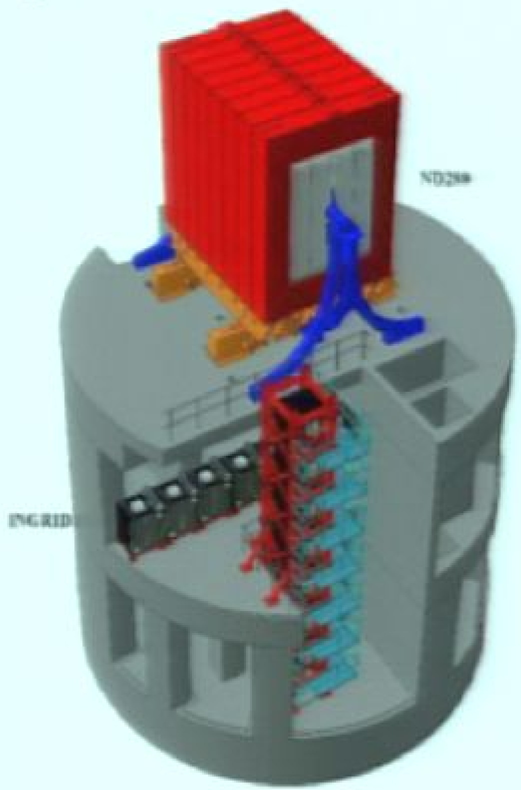

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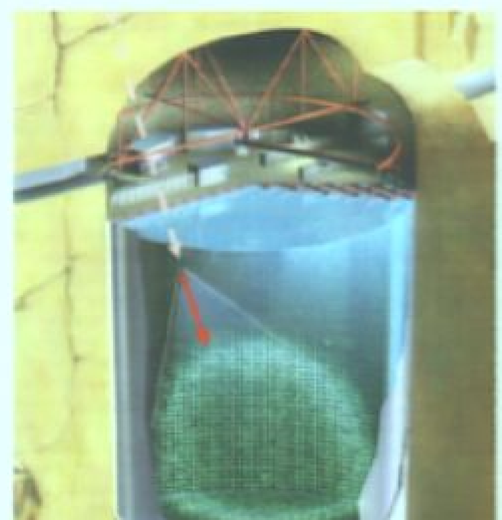

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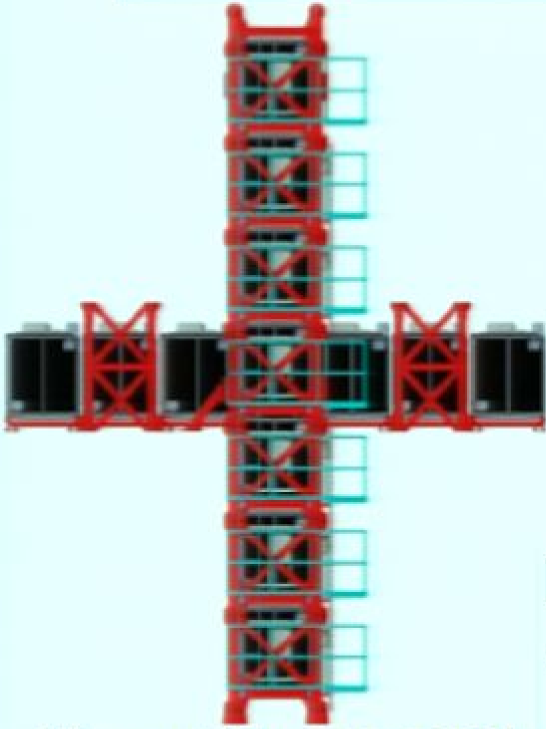

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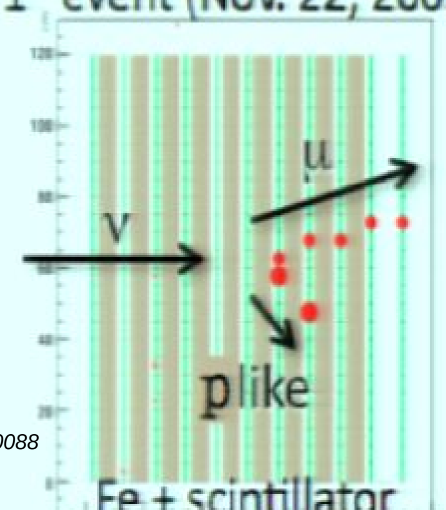
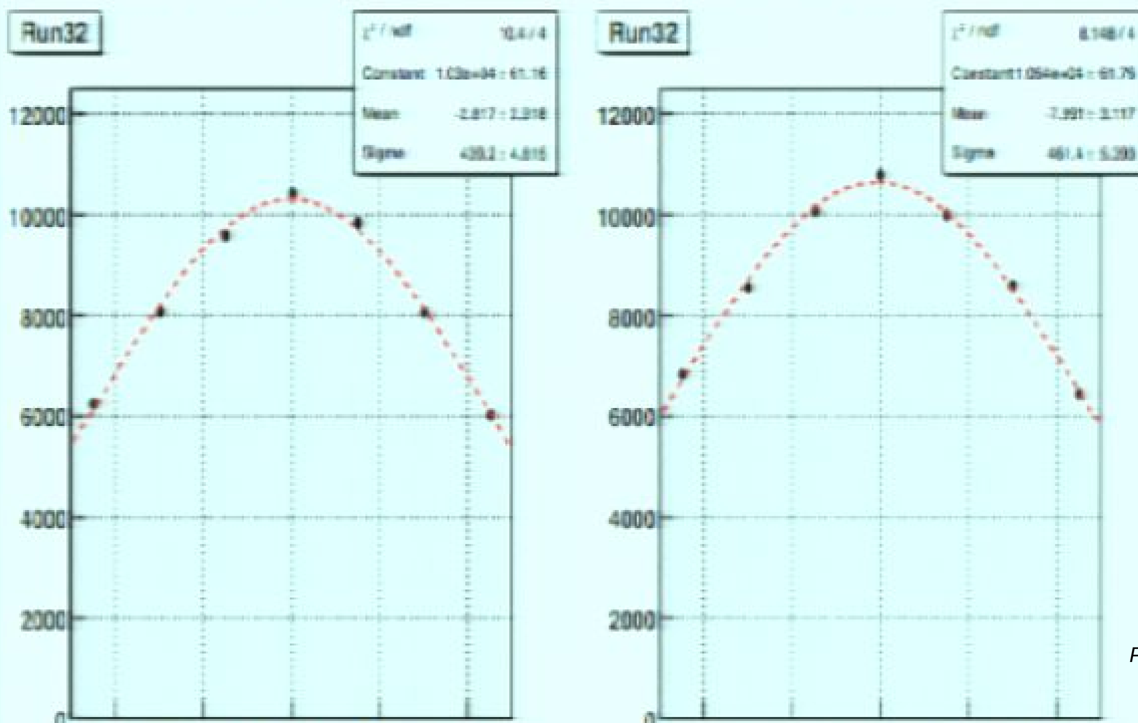
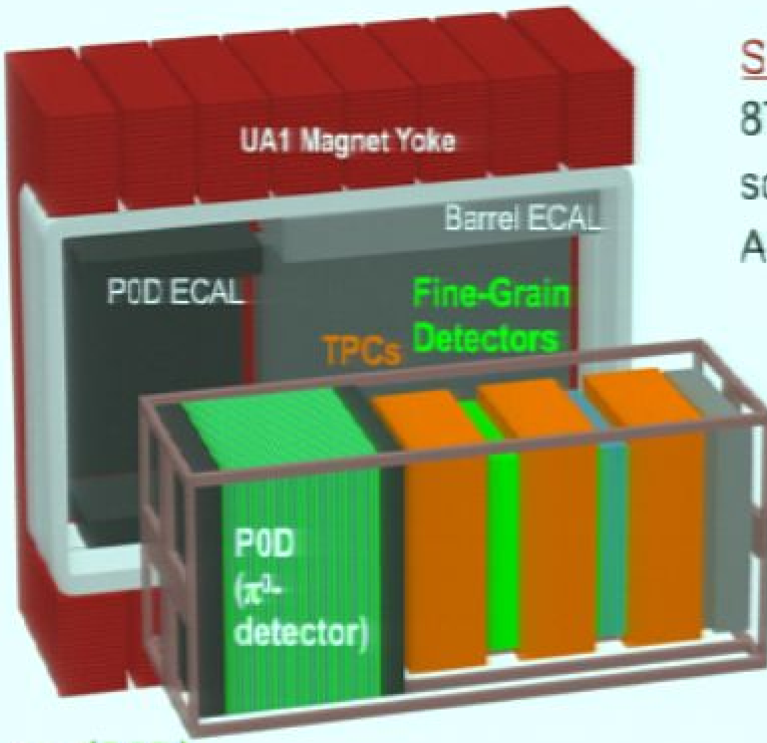




Off-axis: ND280 detector complex

Suite of near detectors sit within UA1 (B=0.2T) magnet to measure the unoscillated neutrino rate, and relevant background processes to the oscillation analysis



Side Muon Range Detector

87x17x0.7cm instrumented scintillator in magnet yoke

Active veto, cosmic trigger

Electronmagnetic Calorimeters

X-Y Pb/scintillator planes:

P0D, Barrel, TPC3

Tag photons, e from Tracker (CC ν_e) and P0D (NCπ^0)

Pi-zero Detector (P0D)

Pb/brass/scintillator planes interspersed with water bags

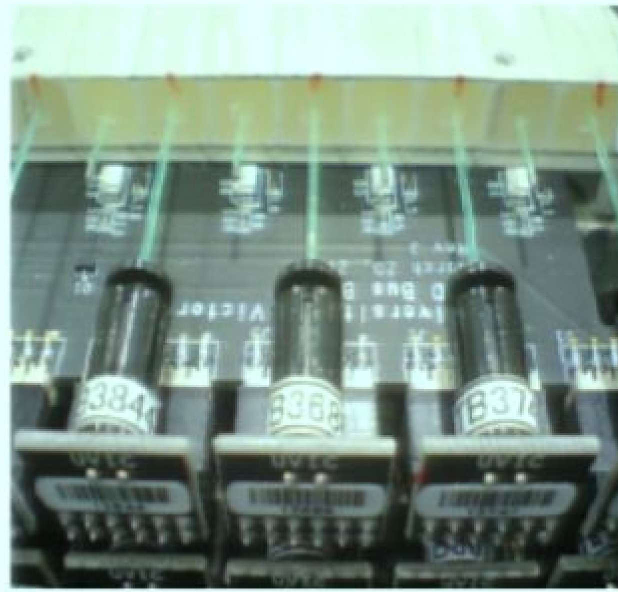
Measure NCπ^0 interactions

Tracker (FGD & TPC)

Measure CC ν_μ, ν_e interactions

Tracker: Fine Grained Detectors

Tracking detector with planes in x or y of scintillator bars (8448 in total)

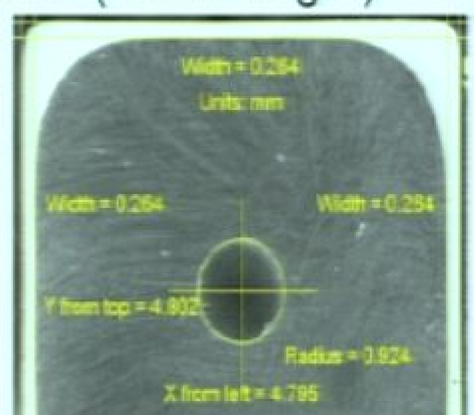


Read wavelength shifting fibers and Multi-Pixel-Photon-Counters (MPPCs)

- 667 avalanche photodiodes in parallel
- Functions in a magnetic field
- Used for INGRID and ND280 tracking detectors; first large scale use

FGDs are neutrino interaction target with

- 2nd FGD has water planes to compare to far detector (water target)



1cm x 1cm bar granularity provides vertex information

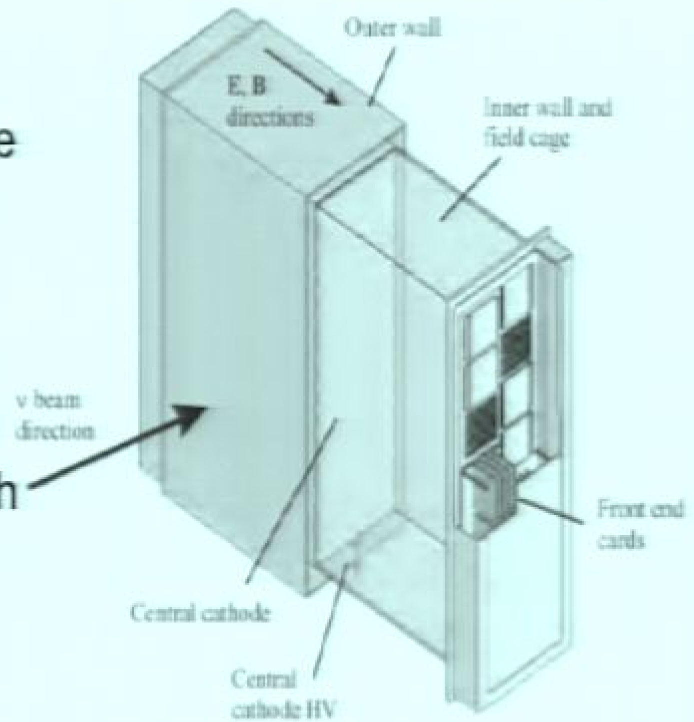
Particle identification from energy loss in scintillator

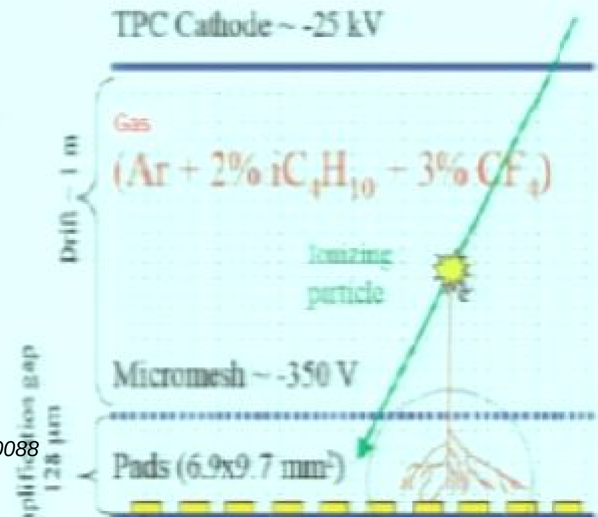
Tracker: Time Projection Chambers

Charged particles ionize the gas

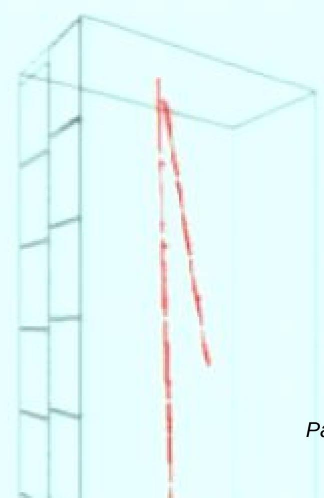
Electrons drift toward the readout plane due to the uniform E field (central cathode at -25kV)

"Wireless" TPC: Strong local field at the novel MicroMegas mesh creates a shower of electrons read out on 6.9x9.7mm^2 pads (1728 pads on each of 12 MicroMegas, 128 μm beyond the mesh)



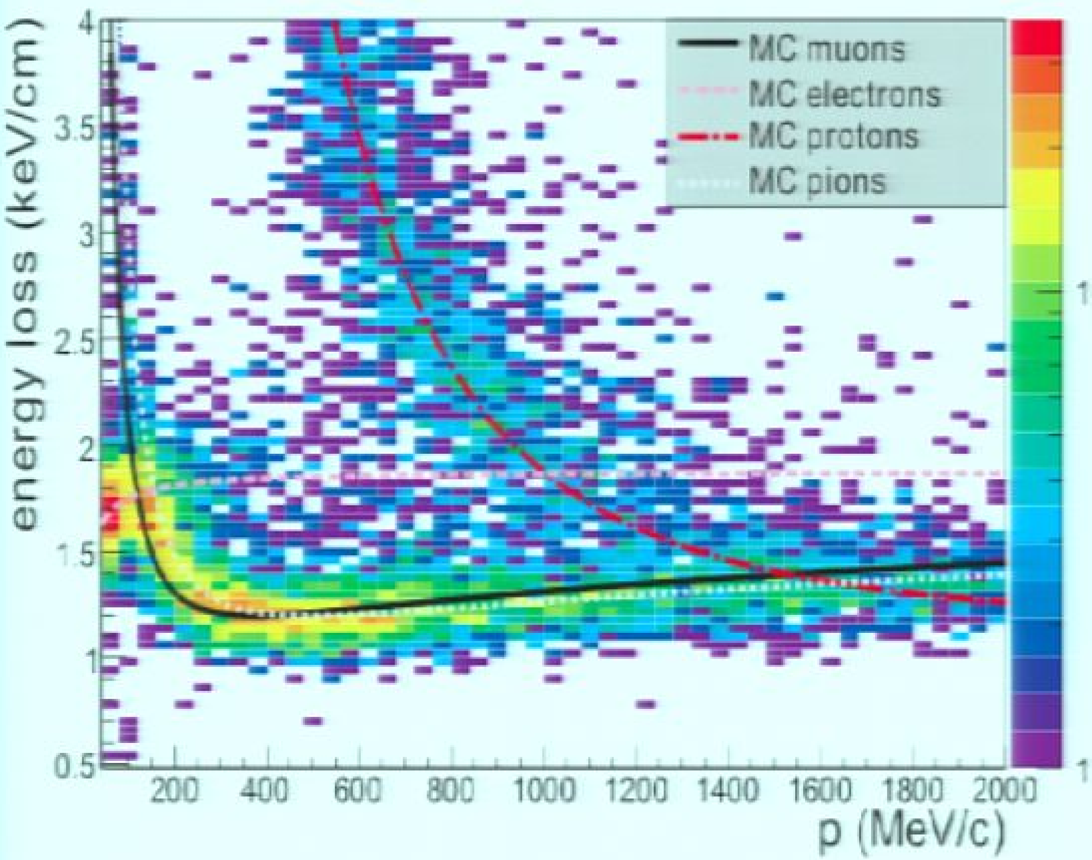


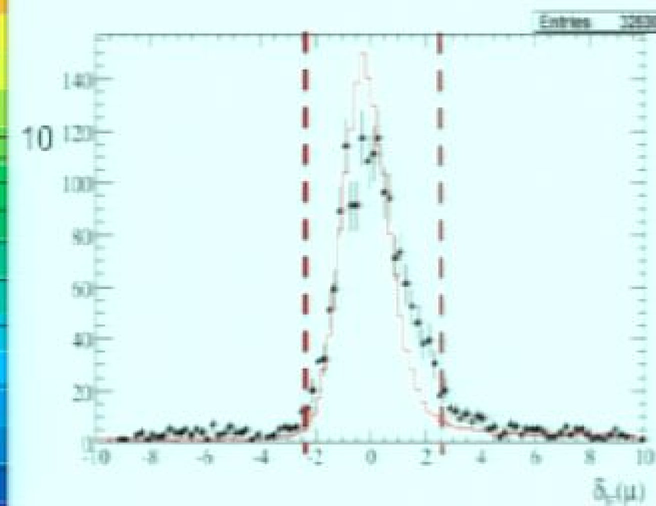
3D tracks are reconstructed provided drift velocity in the gas and timing of entry into TPC (from other subdetectors)



Spatial resolution:
600 μm @ 100cm drift distance

Particle ID with the TPC





PID variable (``pull'')

Energy loss (dE/dx) in the TPC can be used to distinguish particle types

dE/dx resolution ~8%

Select muon candidates for events consistent within 2.5 sigma of predicted muon energy loss, and more than 2 sigma away from electron energy loss

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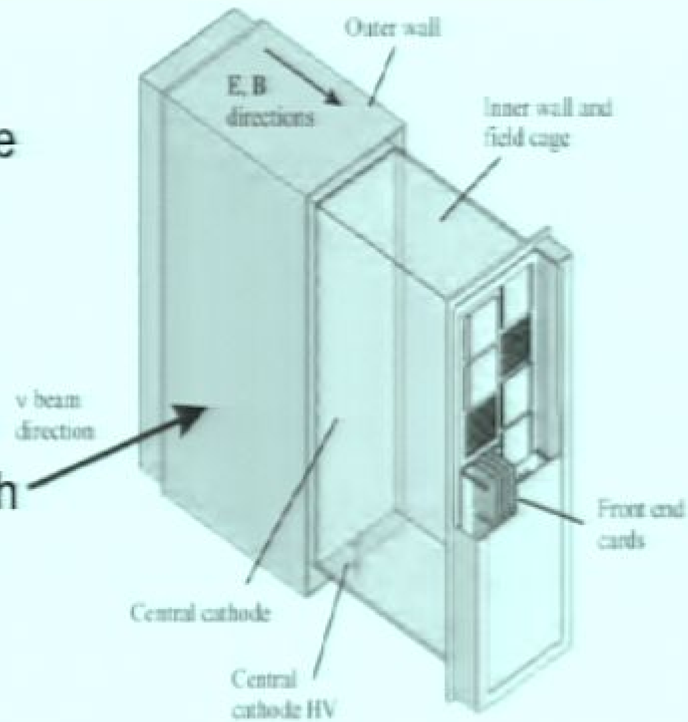

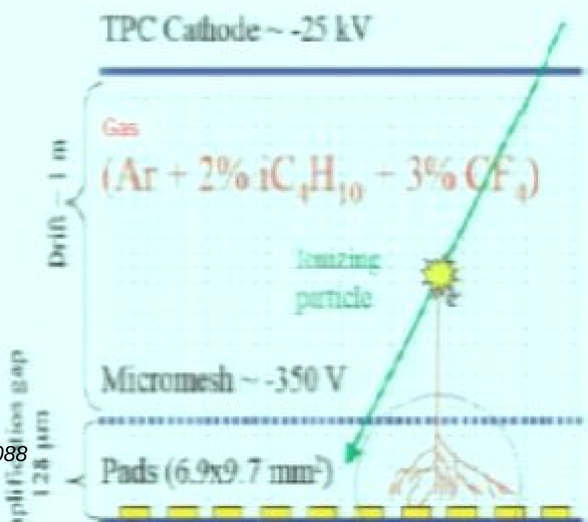

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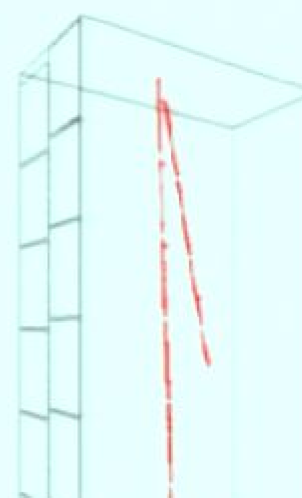

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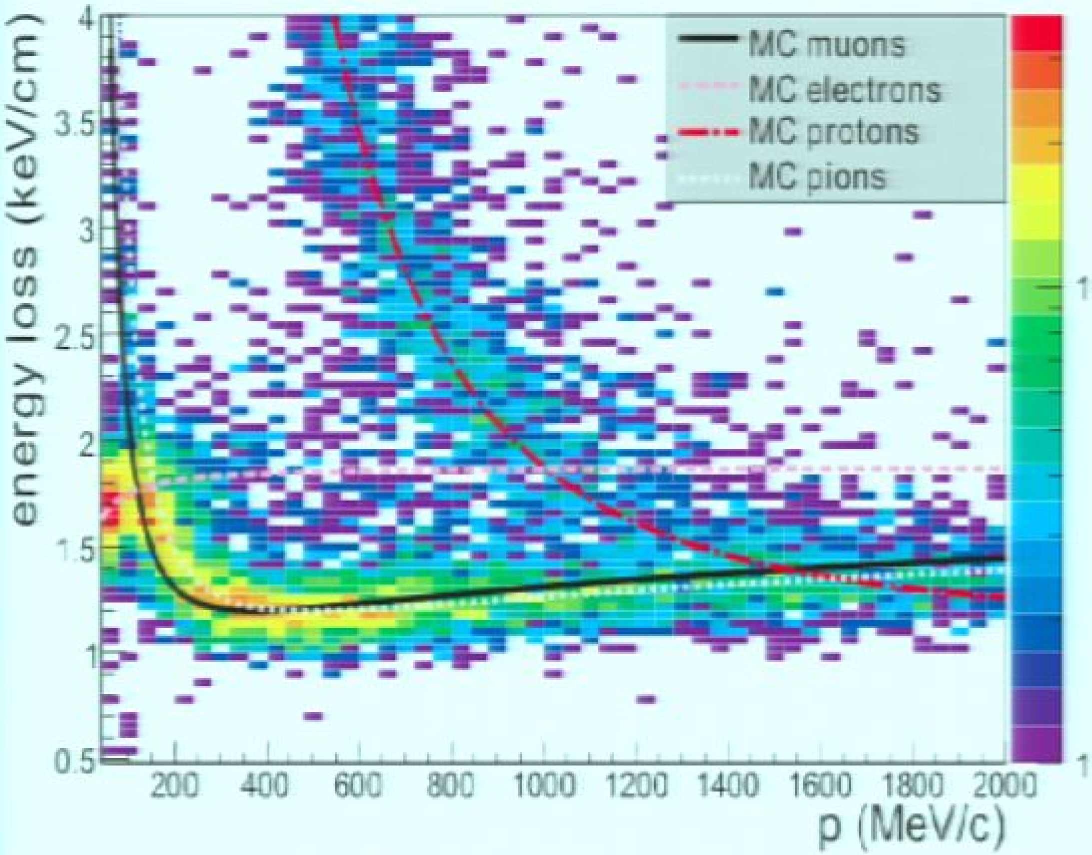

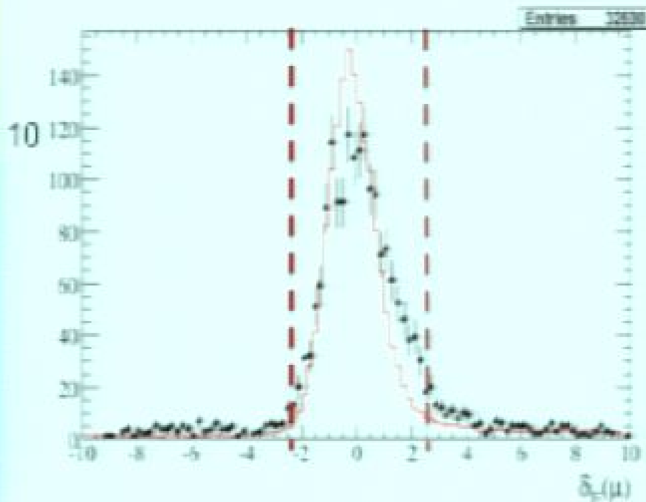

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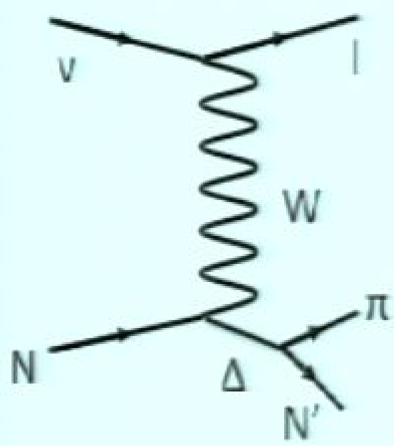
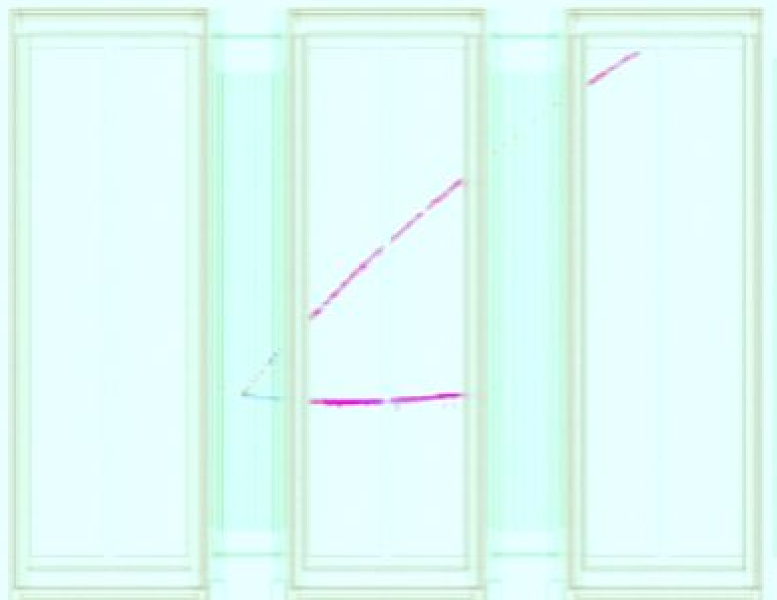
Example neutrino interactions in ND280

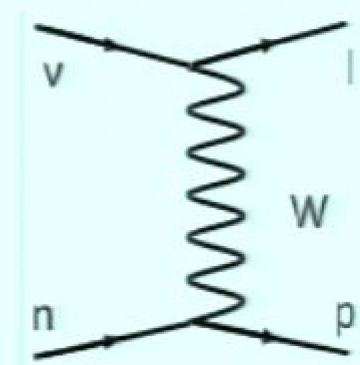
CCπ



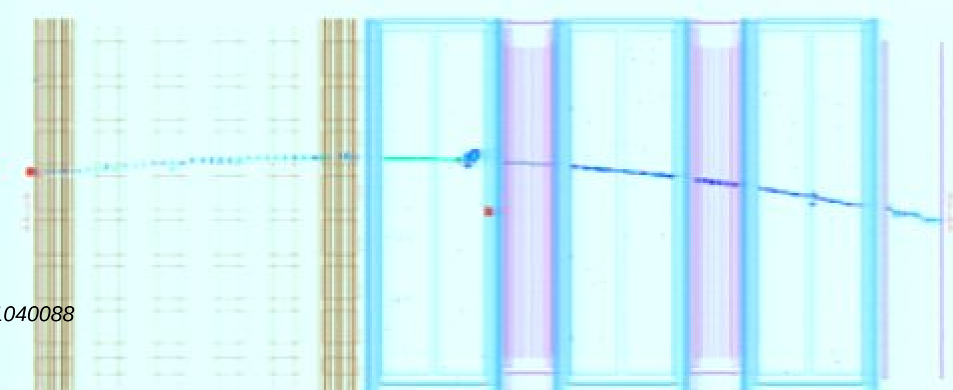
CC neutrino candidate



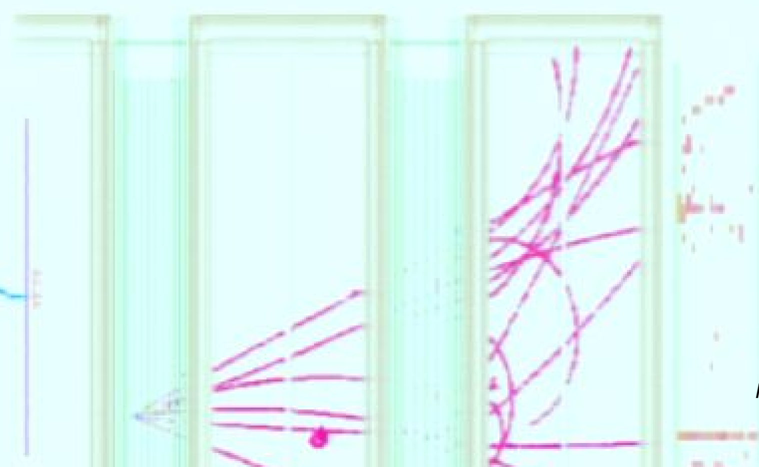
CCQE:



Neutrino interaction upstream of ND280 (sand muon)



More complex event (DIS?)



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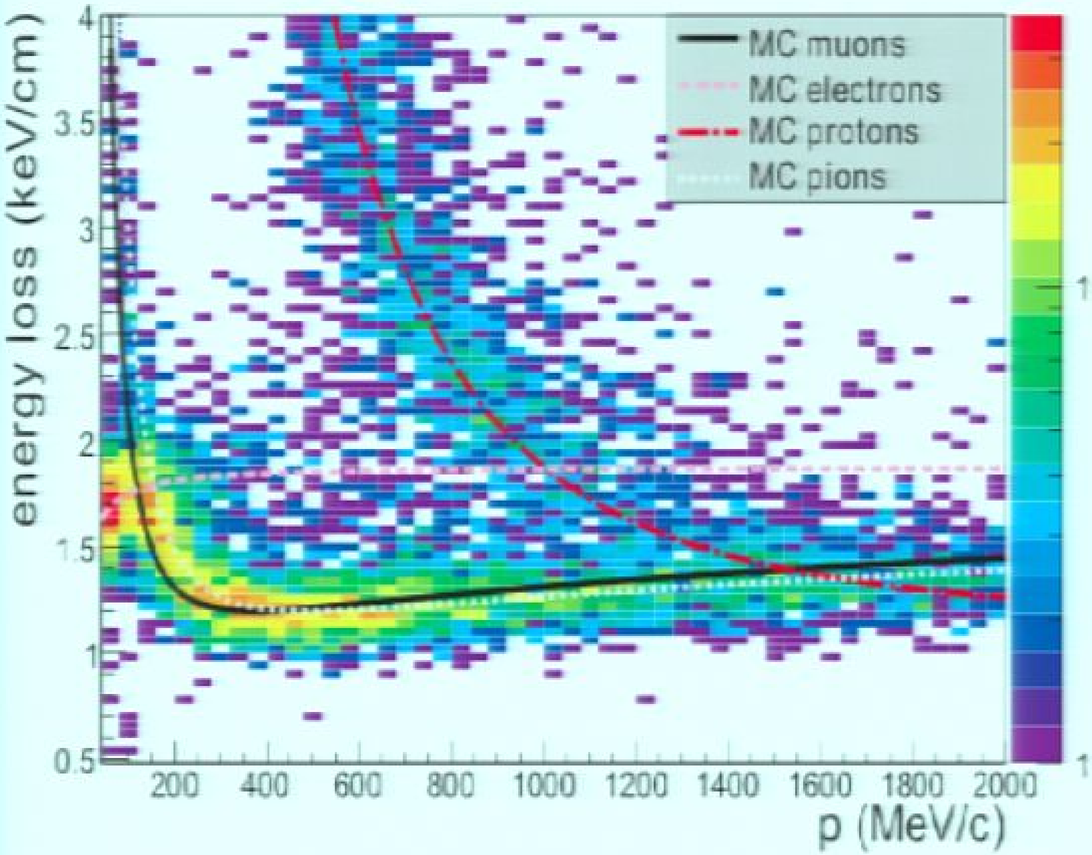

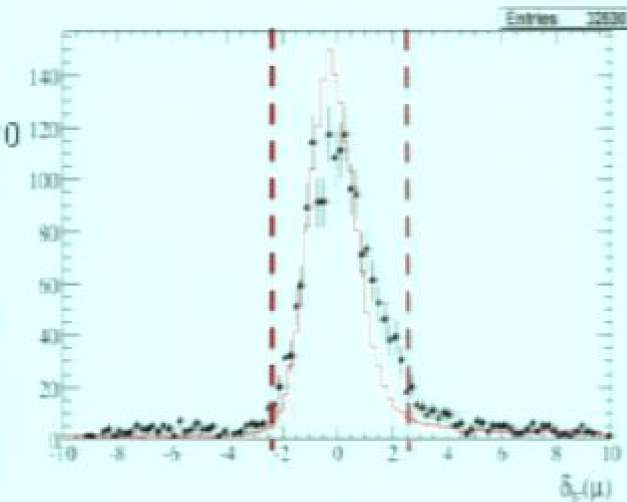

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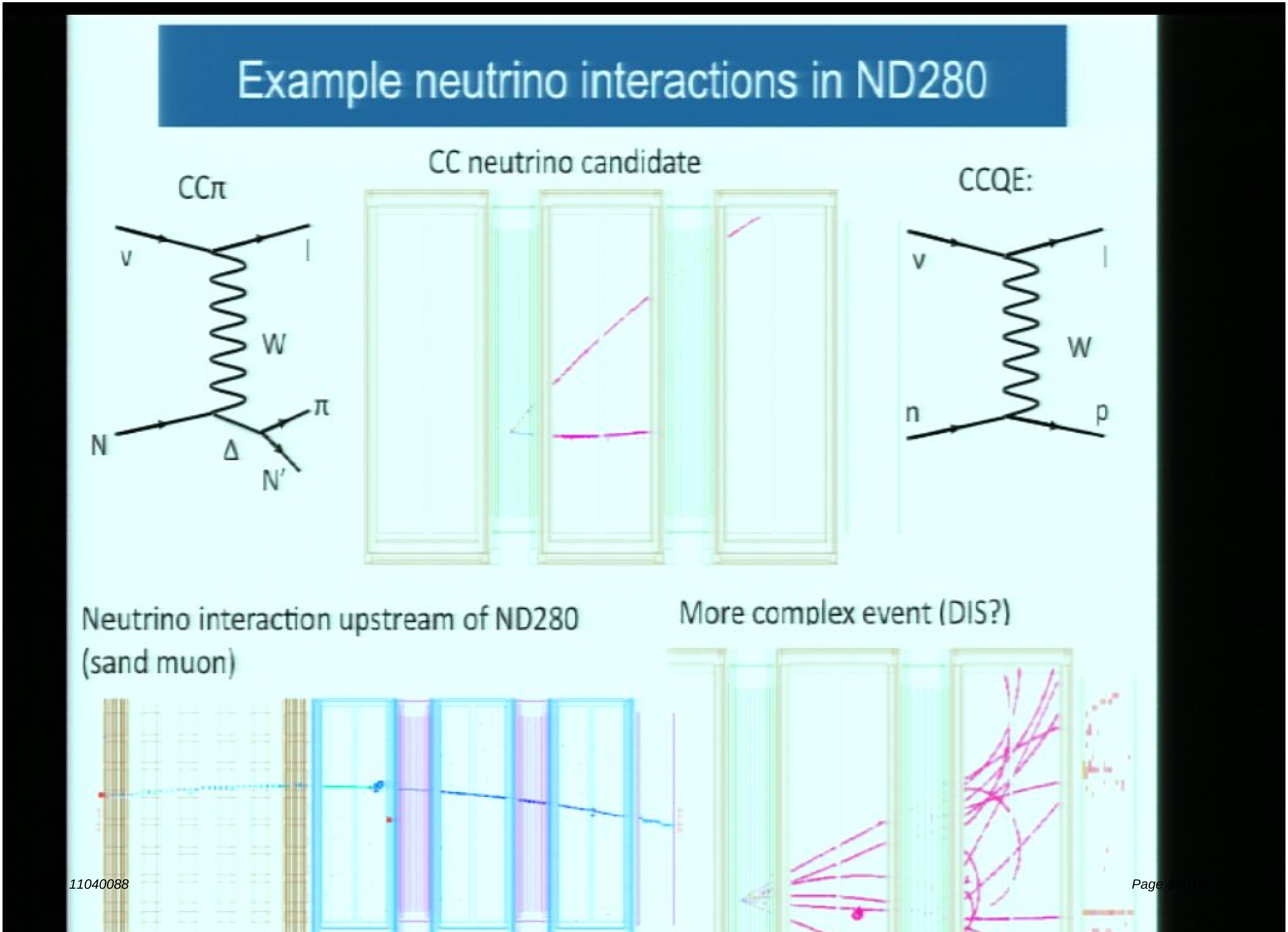
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ν
l
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π
N
Δ
N′
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ν
l
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n
p
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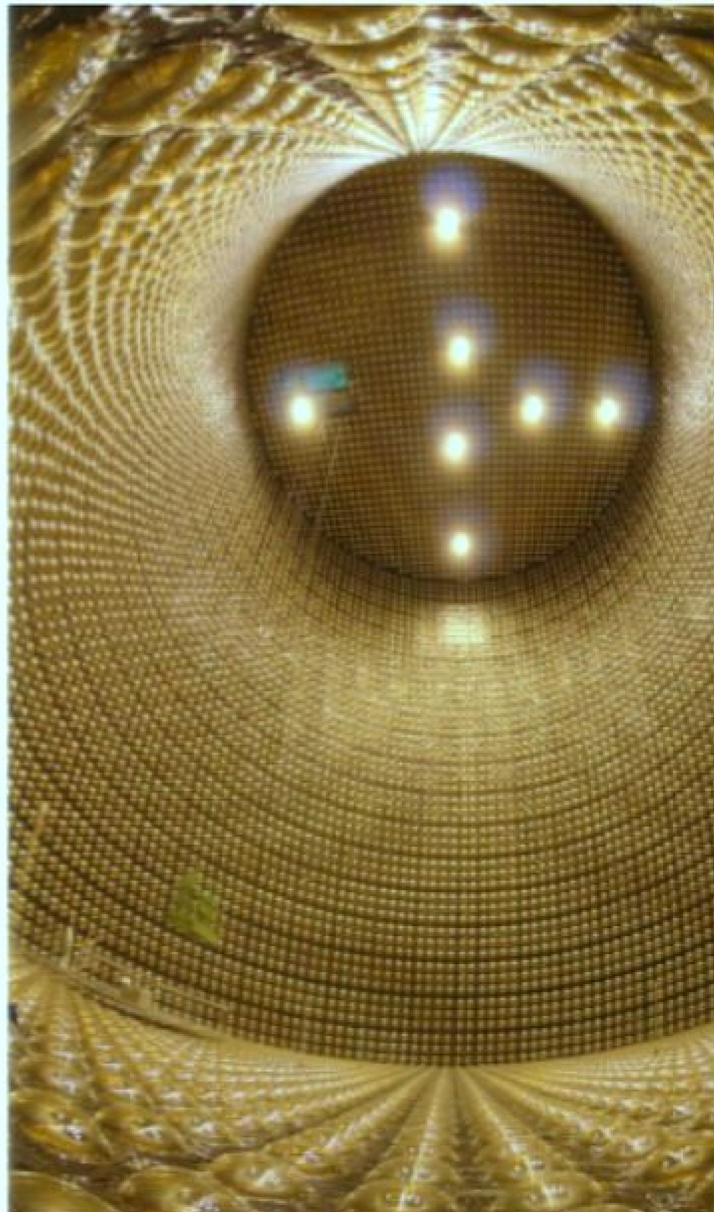
T2K far detector: Super-Kamiokande

50kton water Cherenkov detector
(22.5kton fiducial mass)

39.4 m diameter, 41.4 m tall
cylindrical tank lined with 11,129
photomultiplier tubes (PMTs)
40% photocathode coverage

1885 veto PMTs located on the outside
of the tank reject events entering the tank,
such as cosmic rays

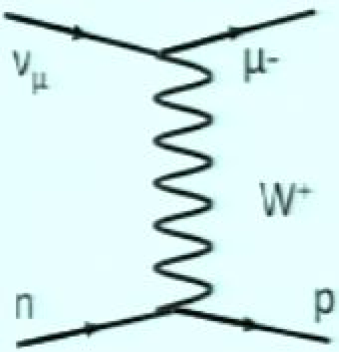
1.77 Hz rate of cosmics for an
overburden of 2700 meters,
water equivalent in Kamioka mine

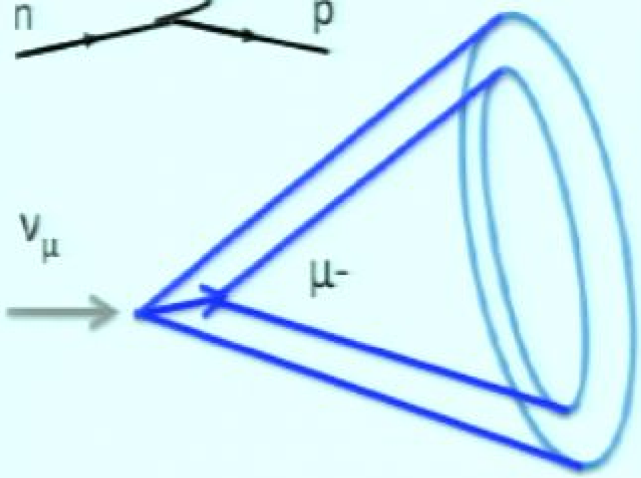


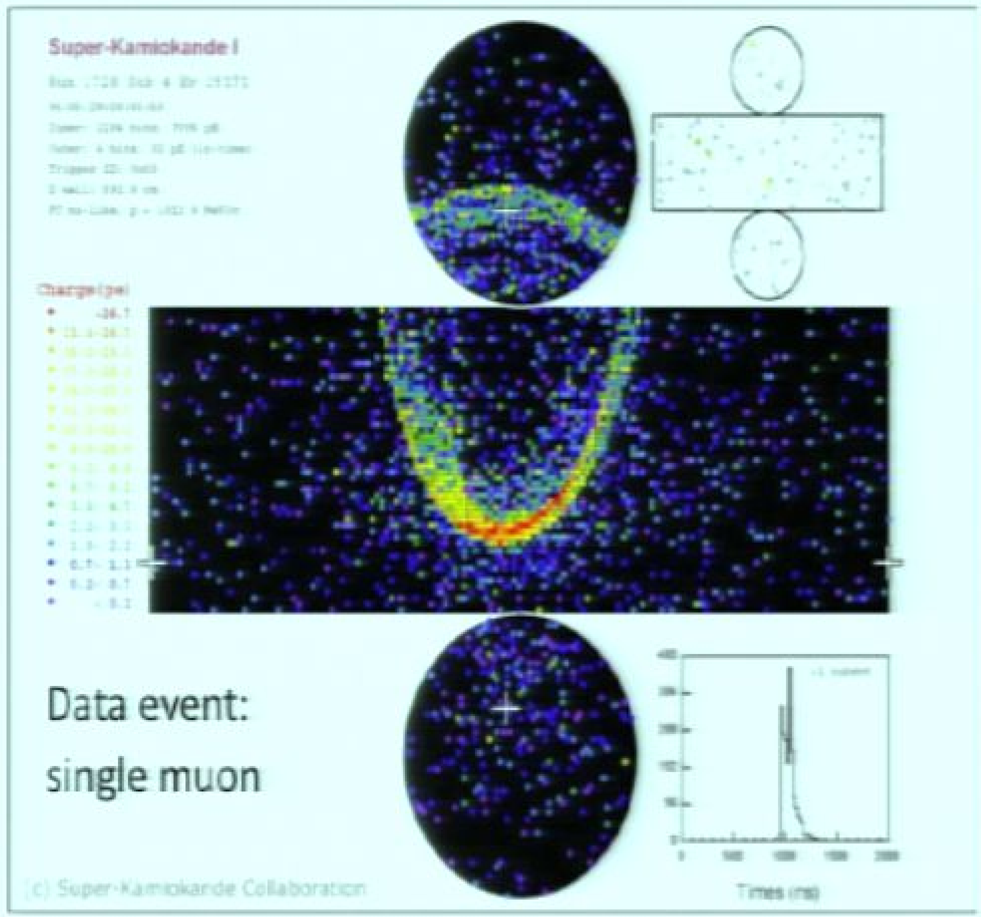
Neutrino events in Super-K

Cherenkov light emitted at a fixed angle produces ring(s) on the tank wall, recorded by PMTs

CCQE:







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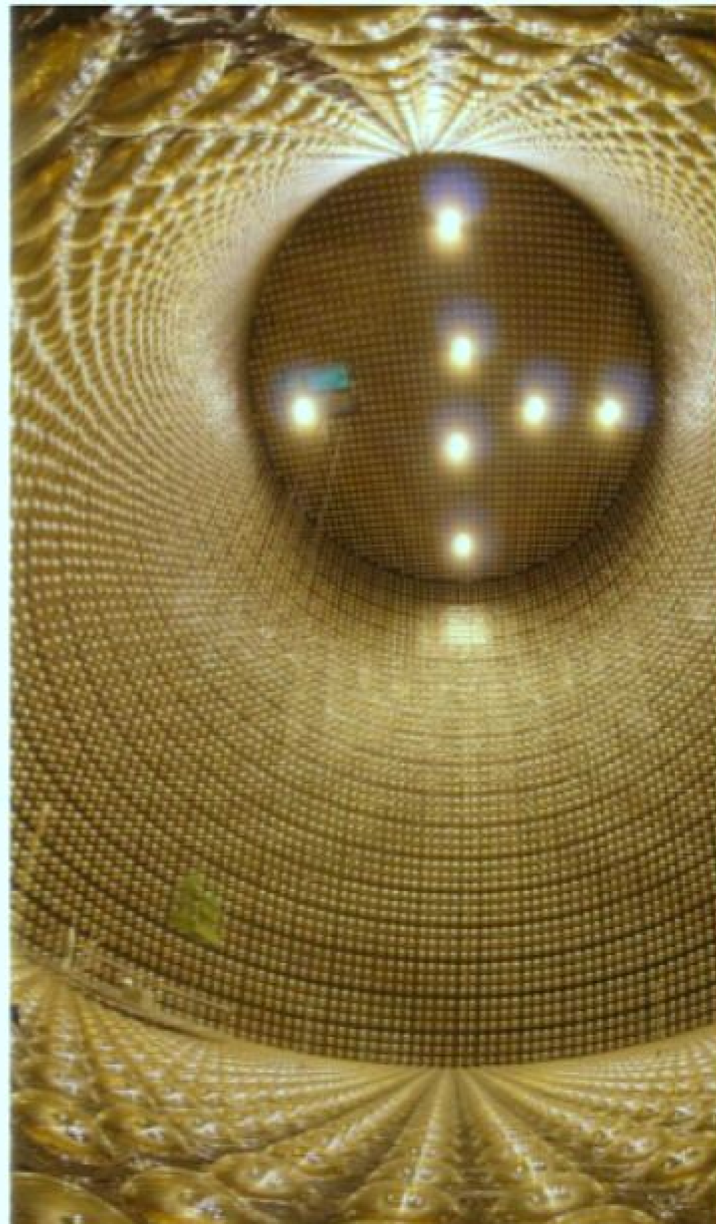

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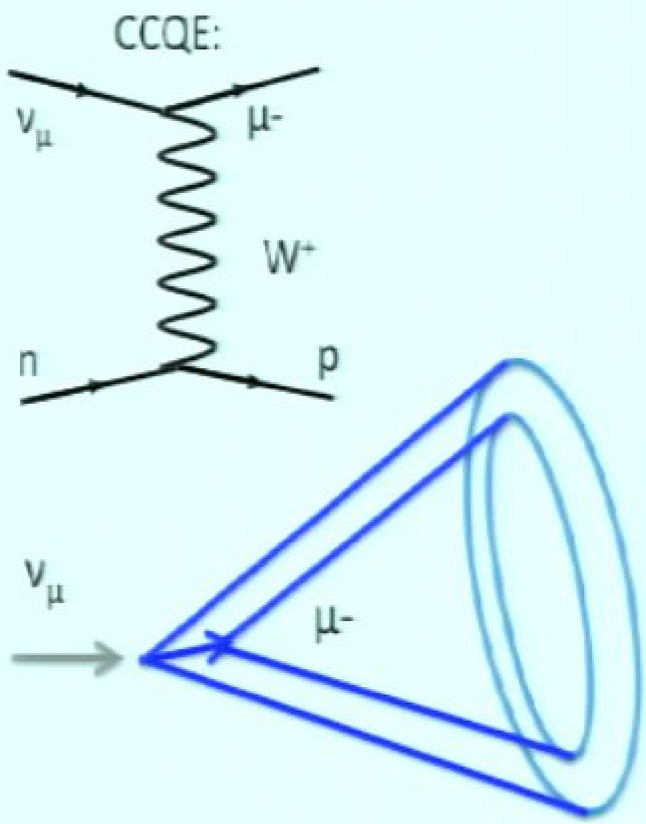
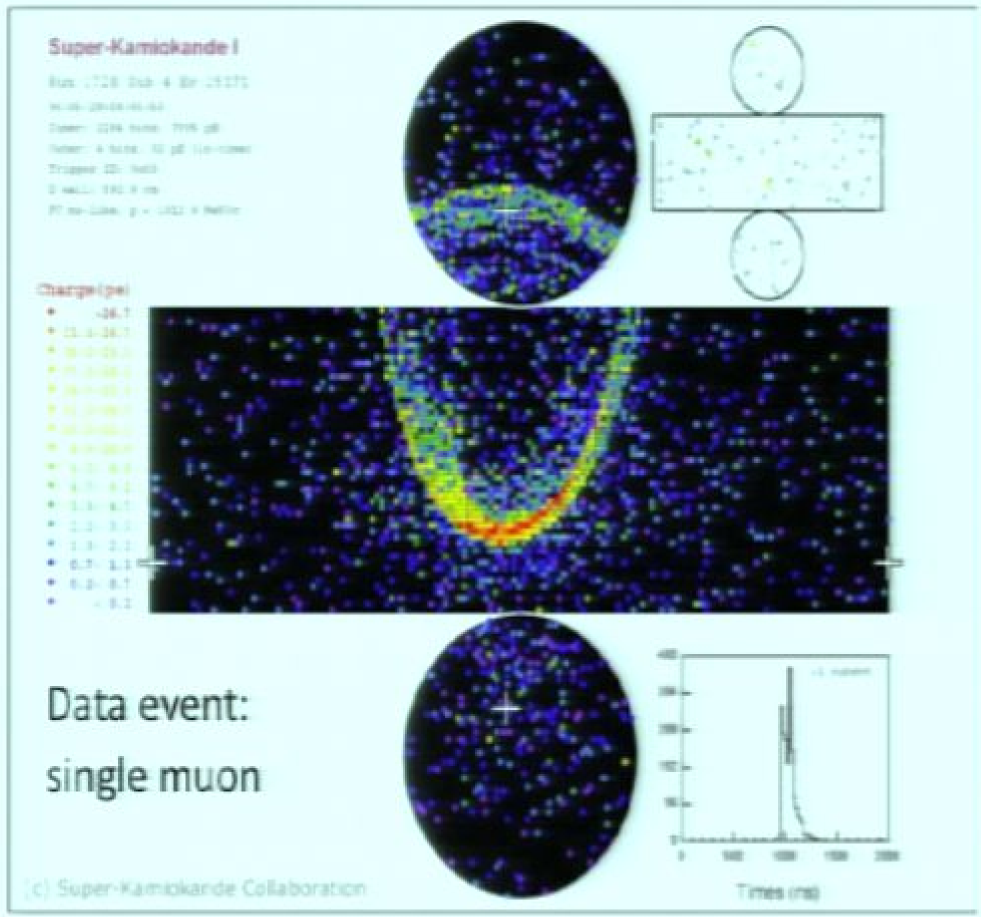




Muons produce well defined rings

Neutrino events in Super-K

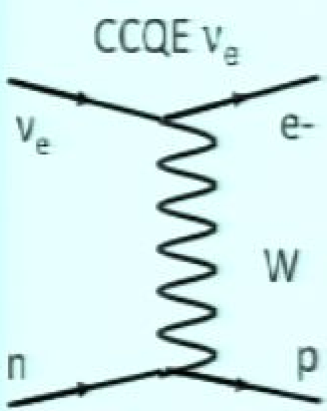
Electrons produce ``fuzzy'' rings, due to multiple scattering and showering

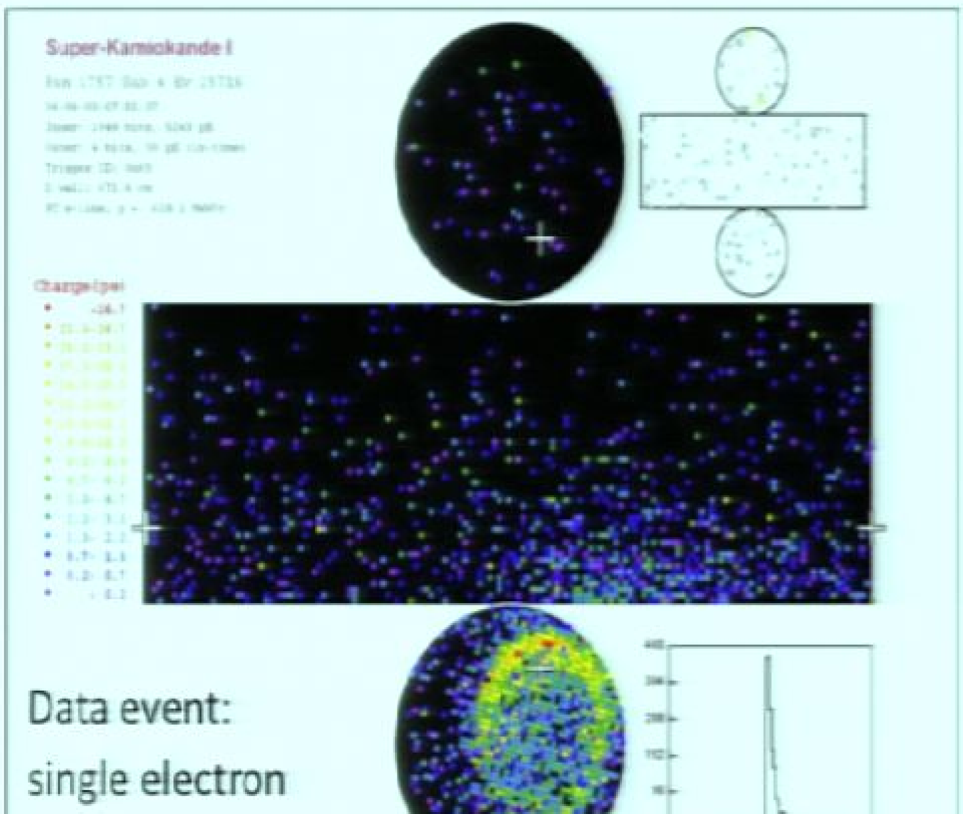
Electrons from CC ν_e interactions

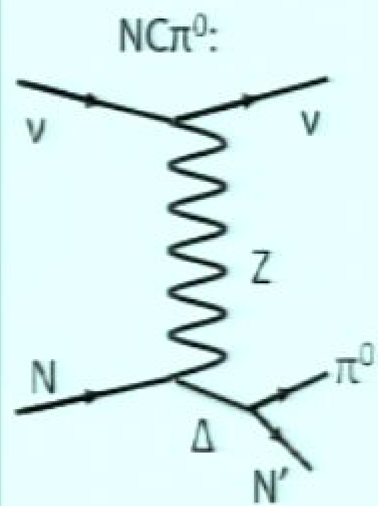
Electrons from μ decay from CC μ (deadtime-less DAQ)

Neutral pions produce two electron-like rings from decay photons

If one ring is not reconstructed, mimics CCQE ν_e signal







NC π^0 background rejection

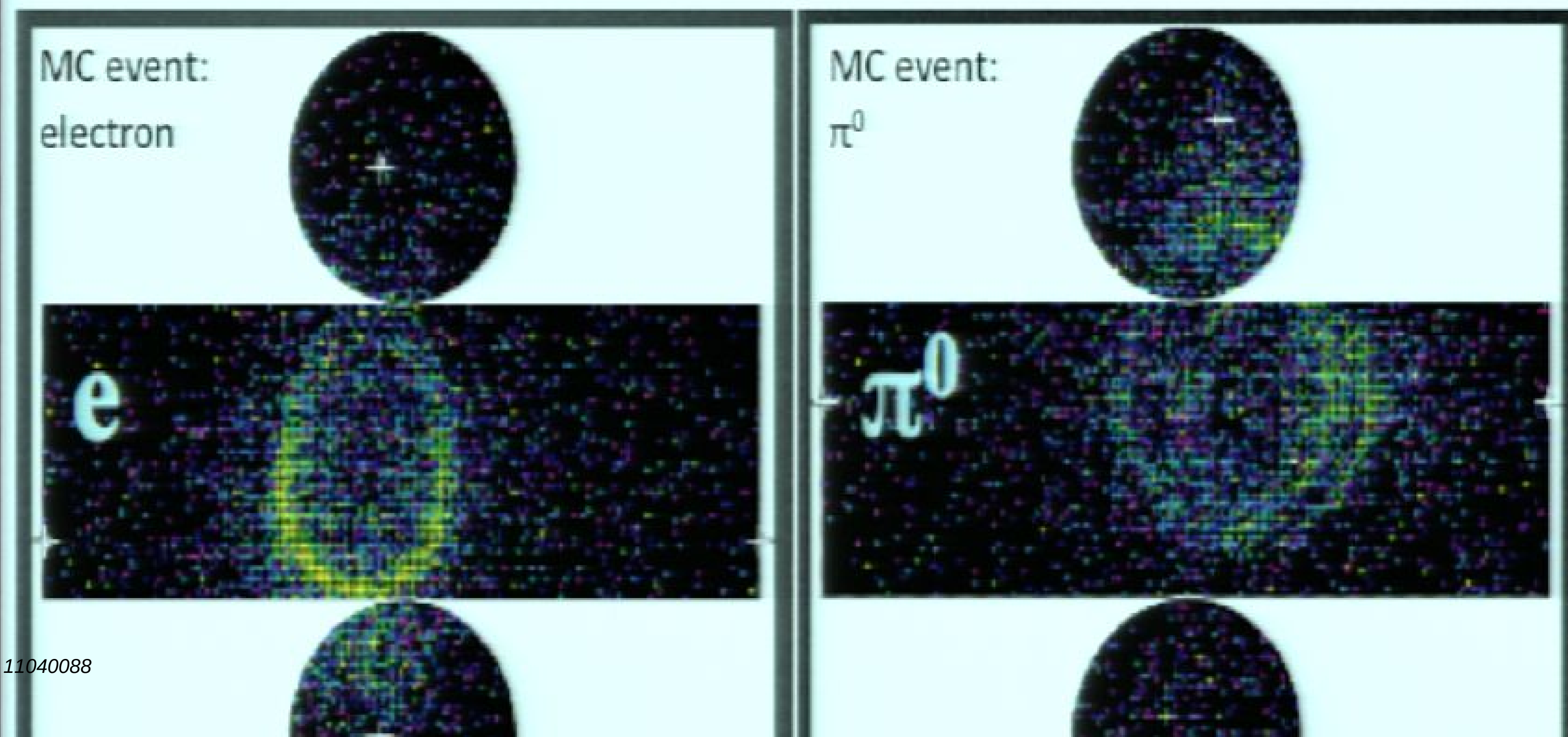
Simulate expected energy distribution for a faint second ring

Scan over possible second ring directions and energies

Select best match for observed light pattern

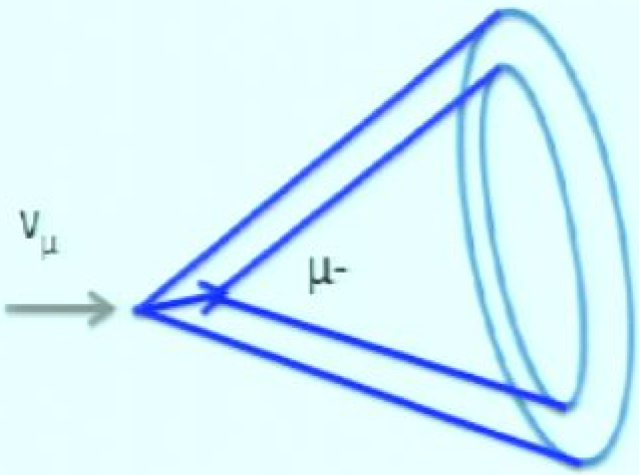
Cut on resulting invariant mass of two rings ($m\ \pi^0$) or $L_{2\gamma}/L_e$

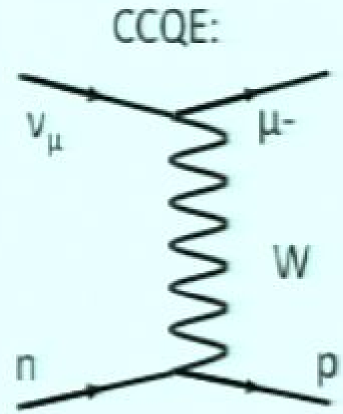
Events with two true rings will have an invariant mass consistent with π^0



Determining neutrino energy

Energy of the outgoing lepton is determined from charge collected by the PMTs





For CCQE events, reconstruct neutrino energy from just the lepton kinematics provided:

- ✓ The neutrino direction is known
- ✓ The recoiling proton mass is known
- ✗ The target nucleon is at rest

$$E_\nu^{QE} = \frac{2M'_n E_\mu - [M'^2_n + m_\mu^2 - M_p^2]}{2[M'_n - E_\mu + p_\mu \cos\theta_\mu]}$$

Complications:

The target nucleus is not at rest, so additional smearing to the reconstructed E_ν

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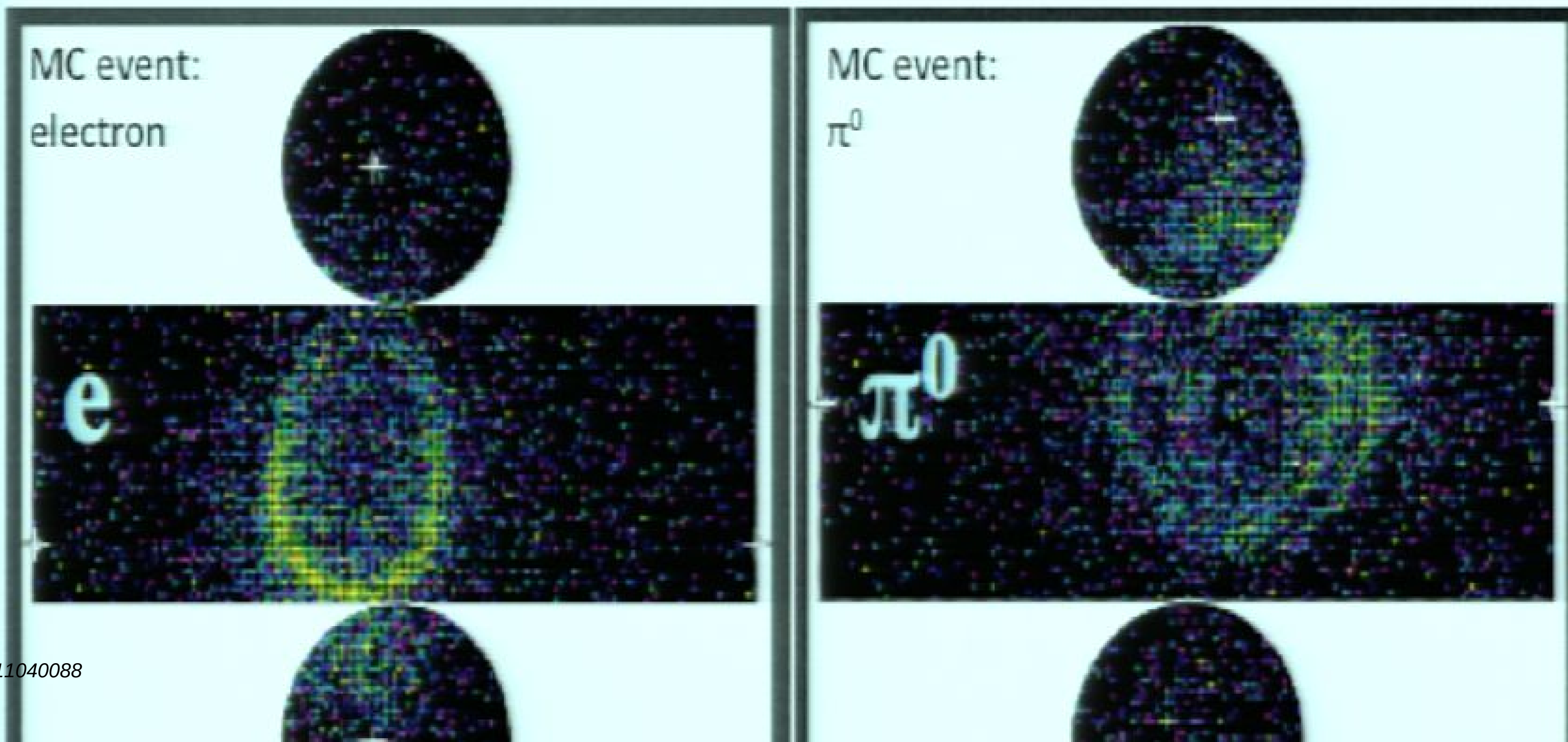
Scan over possible second ring directions and energies

Select best match for observed light pattern

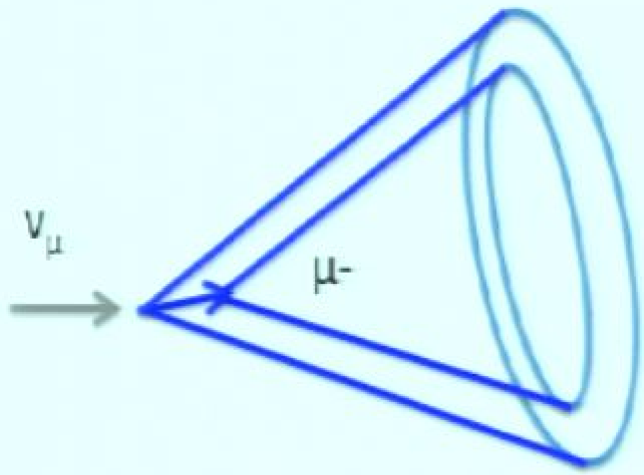
Cut on resulting invariant mass of two rings ($m\ \pi^0$) or $L_{2\gamma}/L_e$

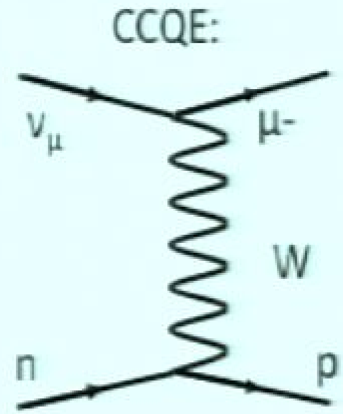
Events with two true rings will have an invariant mass consistent with π^0



Determining neutrino energy

Energy of the outgoing lepton is determined from charge collected by the PMTs





For CCQE events, reconstruct neutrino energy from just the lepton kinematics provided:

- ✓ The neutrino direction is known
- ✓ The recoiling proton mass is known
- ✗ The target nucleon is at rest

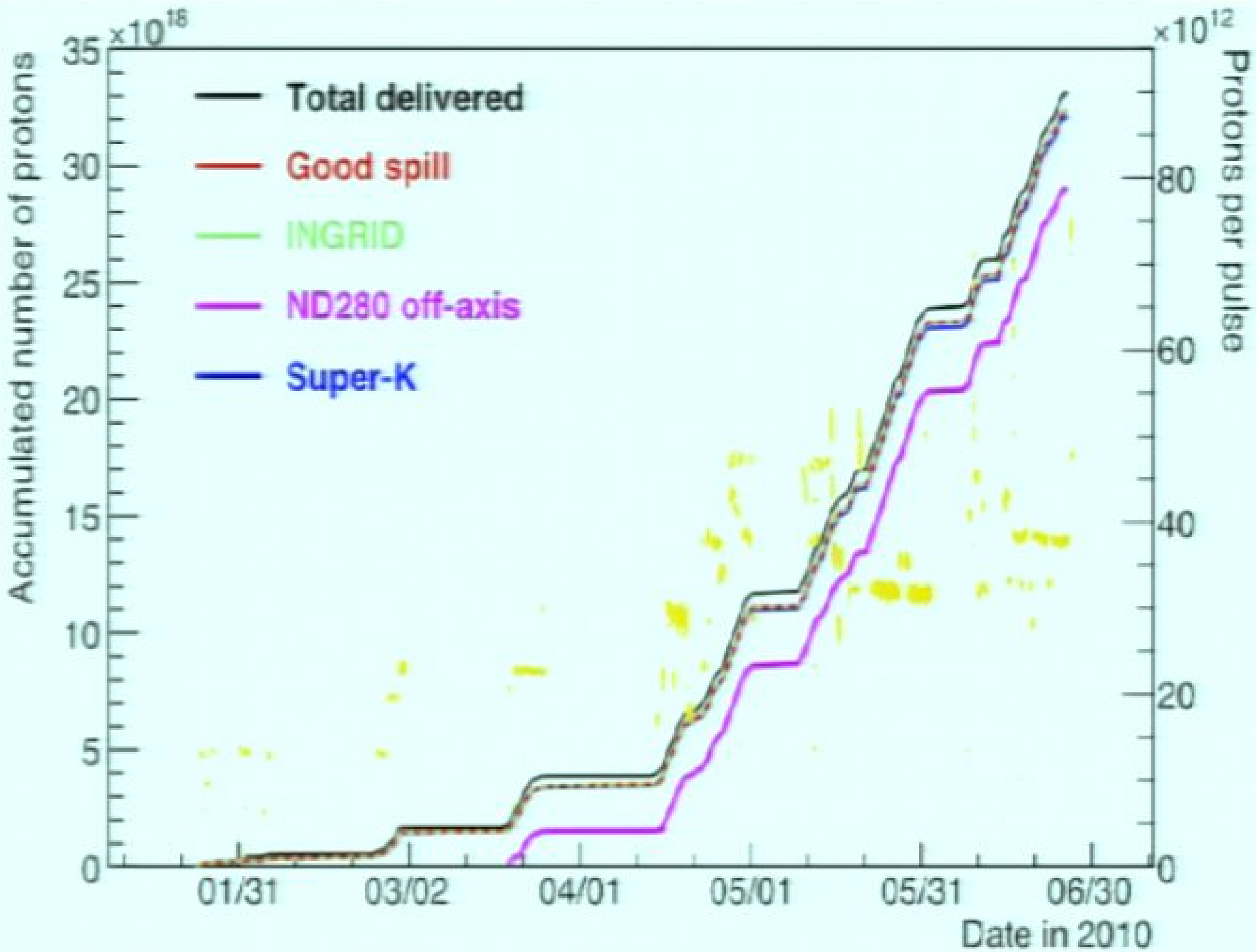
$$E_\nu^{QE} = \frac{2M'_n E_\mu - [M'^2_n + m^2_\mu - M^2_p]}{2[M'_n - E_\mu + p_\mu \cos\theta_\mu]}$$

Complications:

The target nucleus is not at rest, so additional smearing to the reconstructed E_ν

Analysis of first dataset

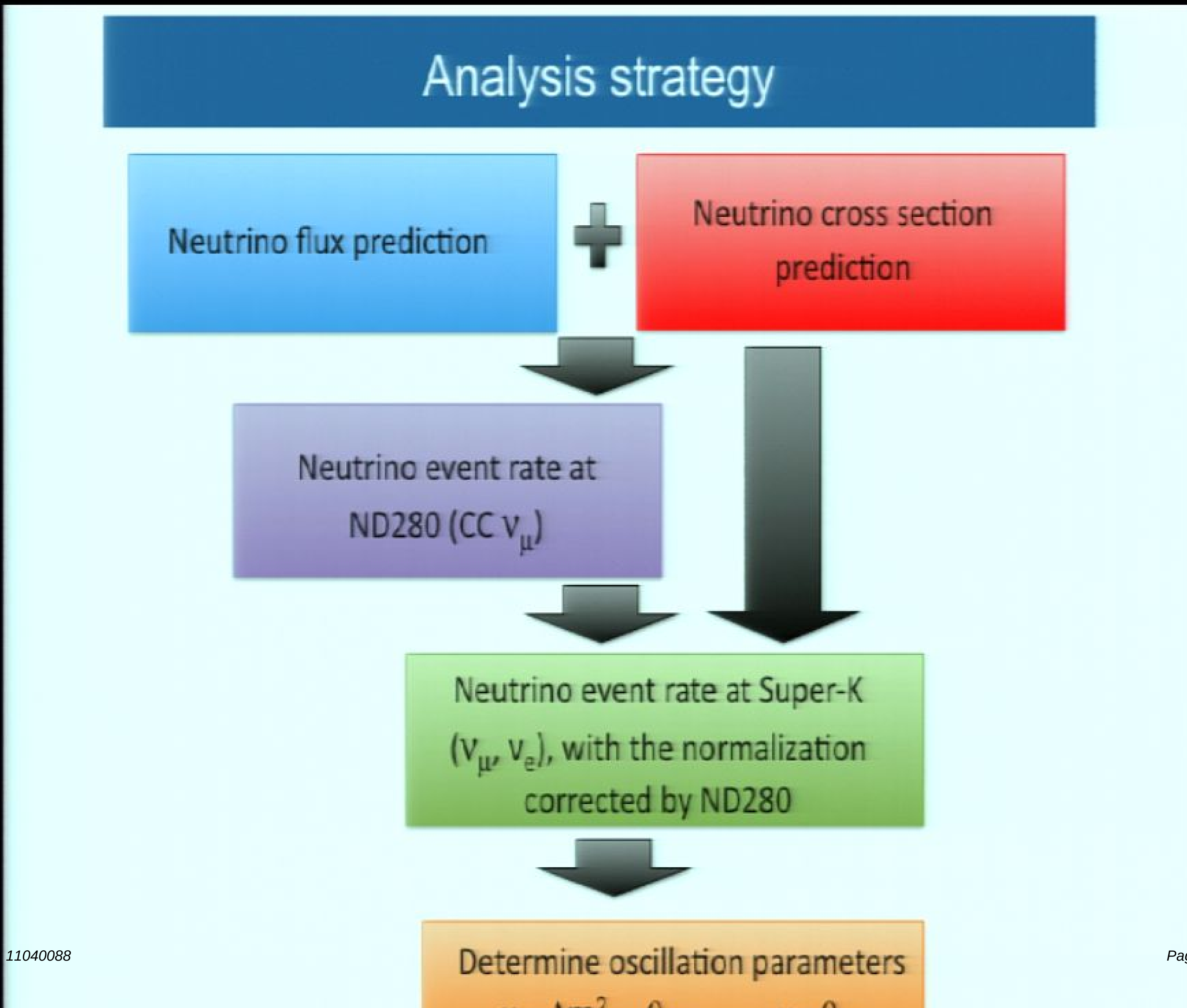
Run 1 dataset



First run between Jan – Jun 2010:

6 bunches / spill / 3.54s

Stable running at 3.3 x 10^{13} POT/spill (≈54 kW) with maximum at 100 kW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Neutrino cross section prediction
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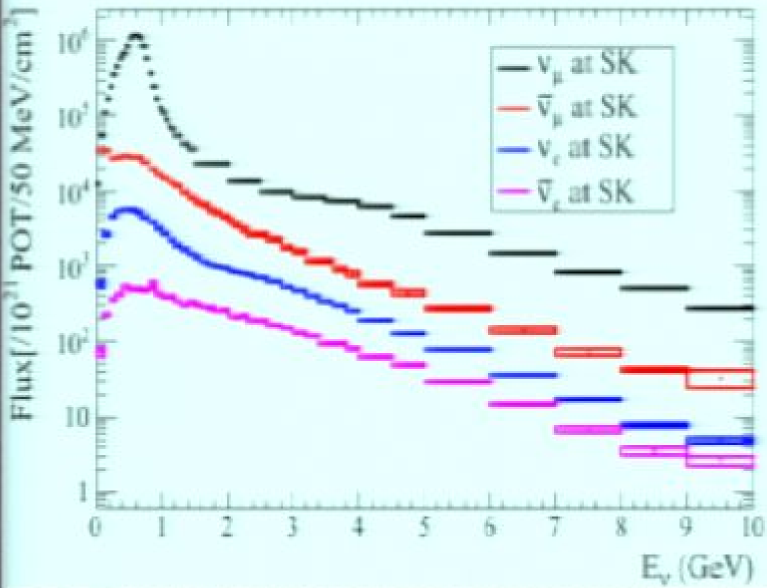
Neutrino event rate at Super-K (ν_μ, ν_e), with the normalization corrected by ND280
Determine oscillation parameters

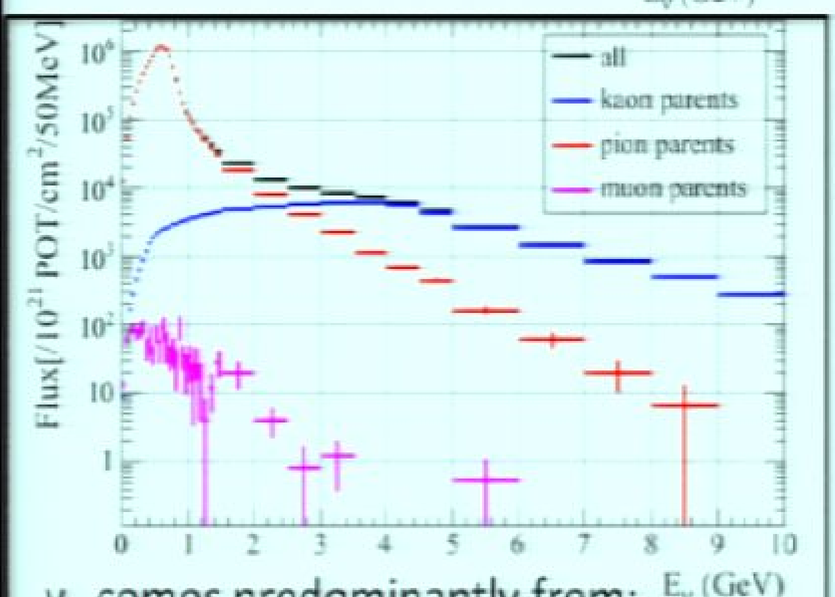
Neutrino flux prediction



Majority of neutrino flux at Super-K is ν_μ

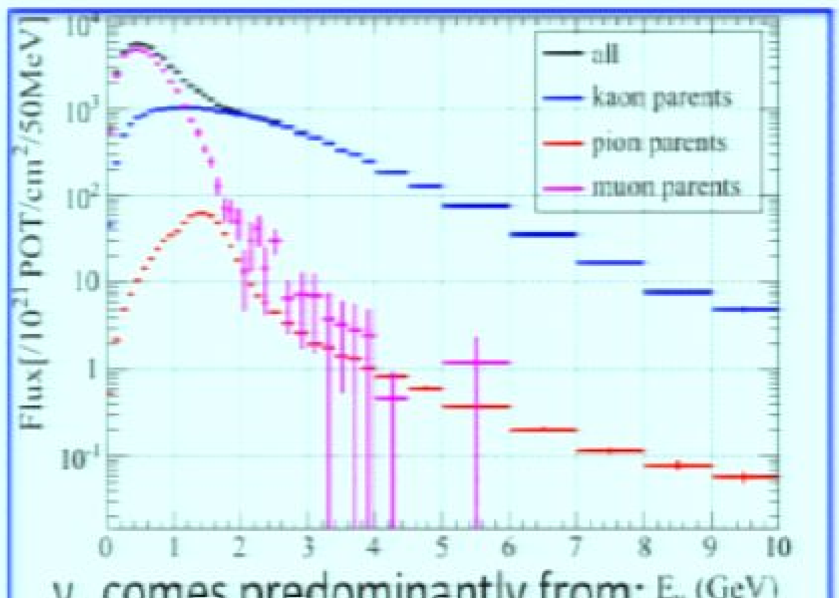
Also $\overline{\nu_\mu}$ (~6%) and

ν_e components (~1%)



ν_μ comes predominantly from:

$\pi^+ \rightarrow \nu_\mu$ decay



ν_e comes predominantly from:

$\pi \rightarrow \mu \rightarrow \nu_e$ decay chain (E_ν < 1.5 GeV)

Neutrino flux uncertainties

Source	Uncertainty	Change at Peak	Max Change(<3GeV)
Pion Multiplicity	20%	16%	22%
Kaon Multiplicity	20-25%	1%	20%
Prod. Cross Sections	10-50%	7%	8%
Proton Beam	0.5mm, 0.3mrad	3%	9%
ν_μ Beam Direction	0.44mrad	1%	8%
Target Alignment	1.3mrad	<1%	1%
Horn Alignment	1mm	1%	3%
Horn Current	5kA	2%	2%
Horn Field Asymmetry	1.25%	0.5%	1%

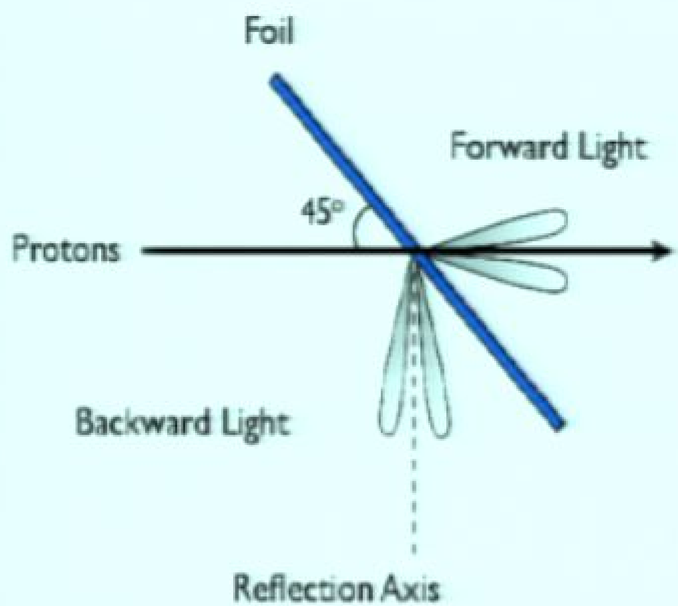
Constrained by in-situ measurements:

e.g. beamline monitors for the proton beam shape

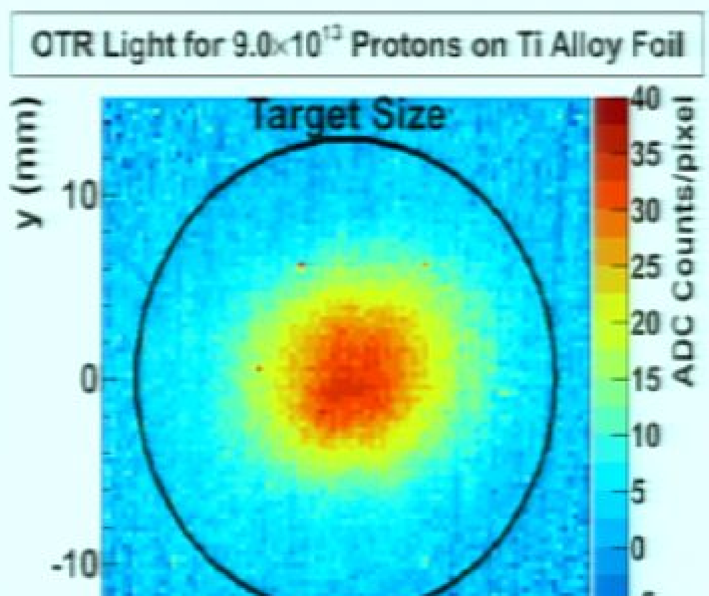
Constrained by external experiments or data:

Proton beam monitoring

Multiple beam monitors measure the proton beam on the way to the neutrino target



Optical Transition Radiation is produced by the the protons as they pass through a thin Ti foil in in front of the neutrino target.
The light is emitted perpendicular to the beam direction, and is recorded with a 40mm camera
OTR light is used to determine the beam profile and position on the target



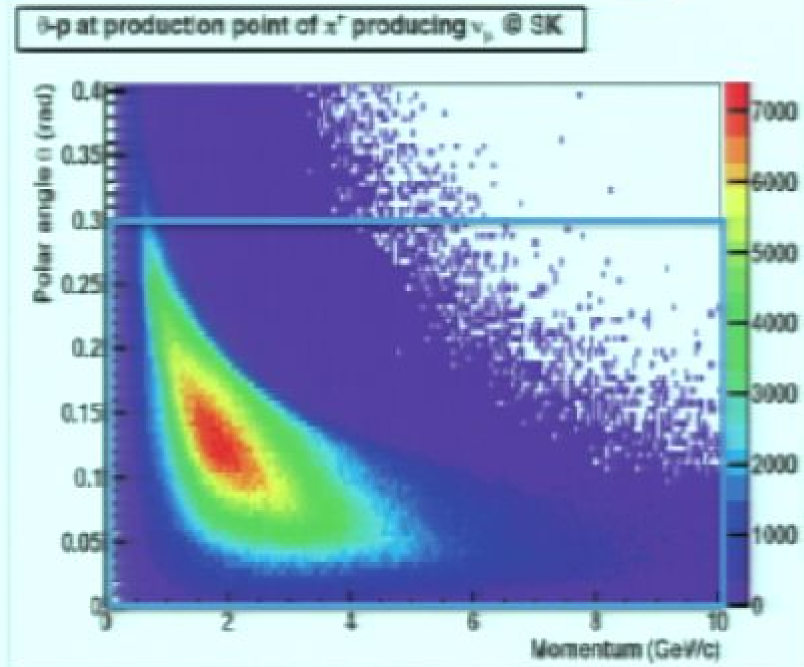
π production from p+C

NA61/SHINE experiment at CERN

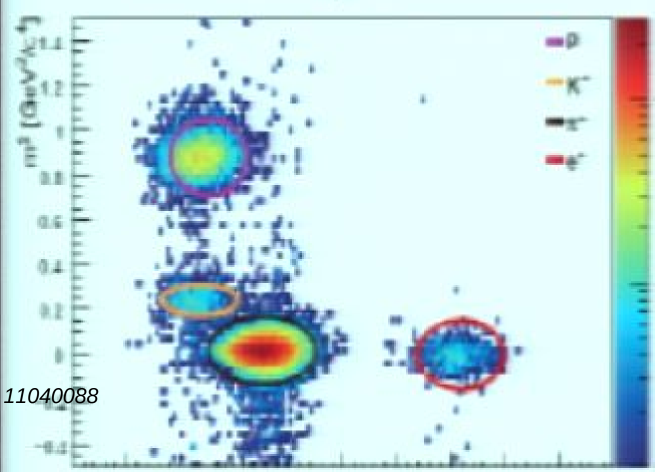
Designed to measure hadron production

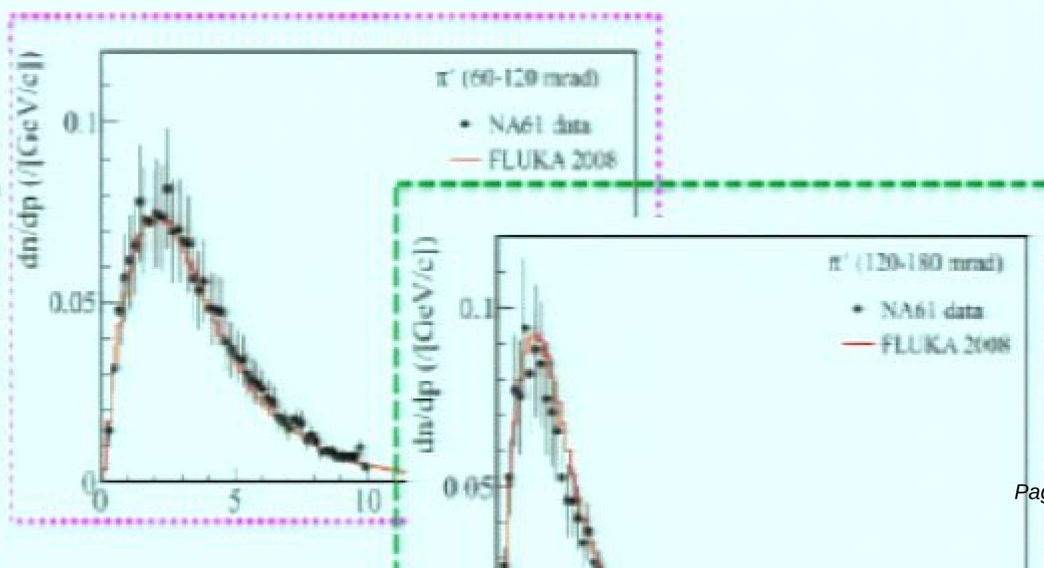
Used thin target (2cm) in 2007-2009 run, T2K replica target (91cm, 1.9λ) in 2010 run

Use TOF and dE/dx to measure particle type; extract particle production cross section



2 GeV/c < p < 3 GeV/c

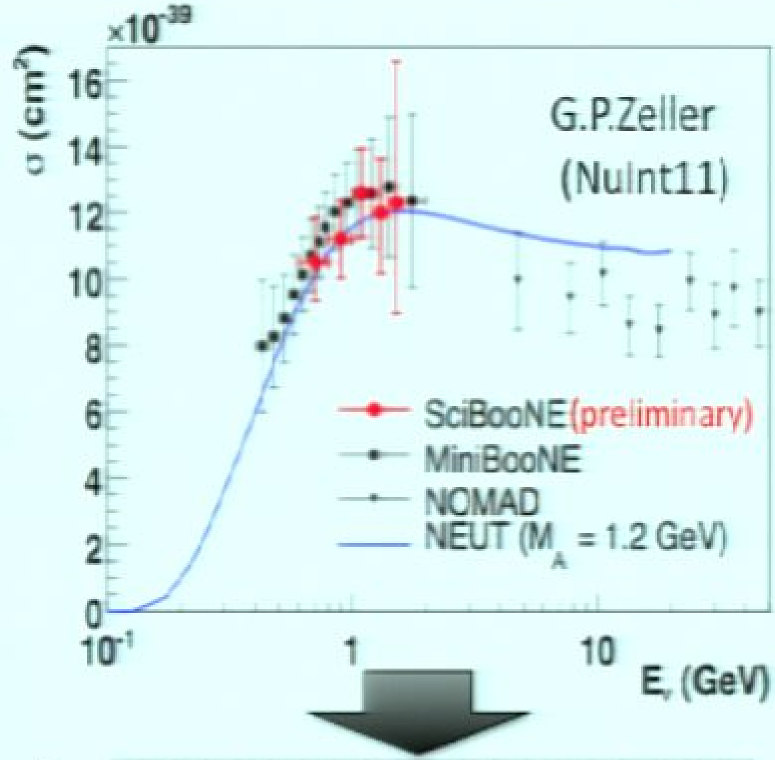




Neutrino cross section prediction, uncertainties

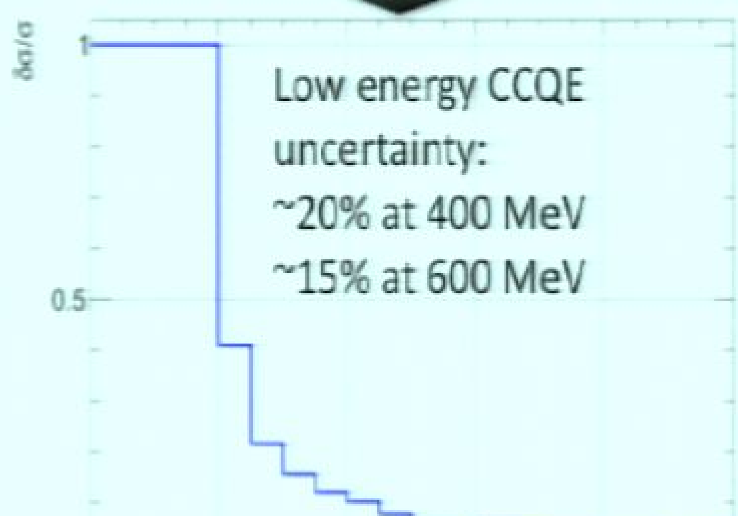
Cross section model set from external data

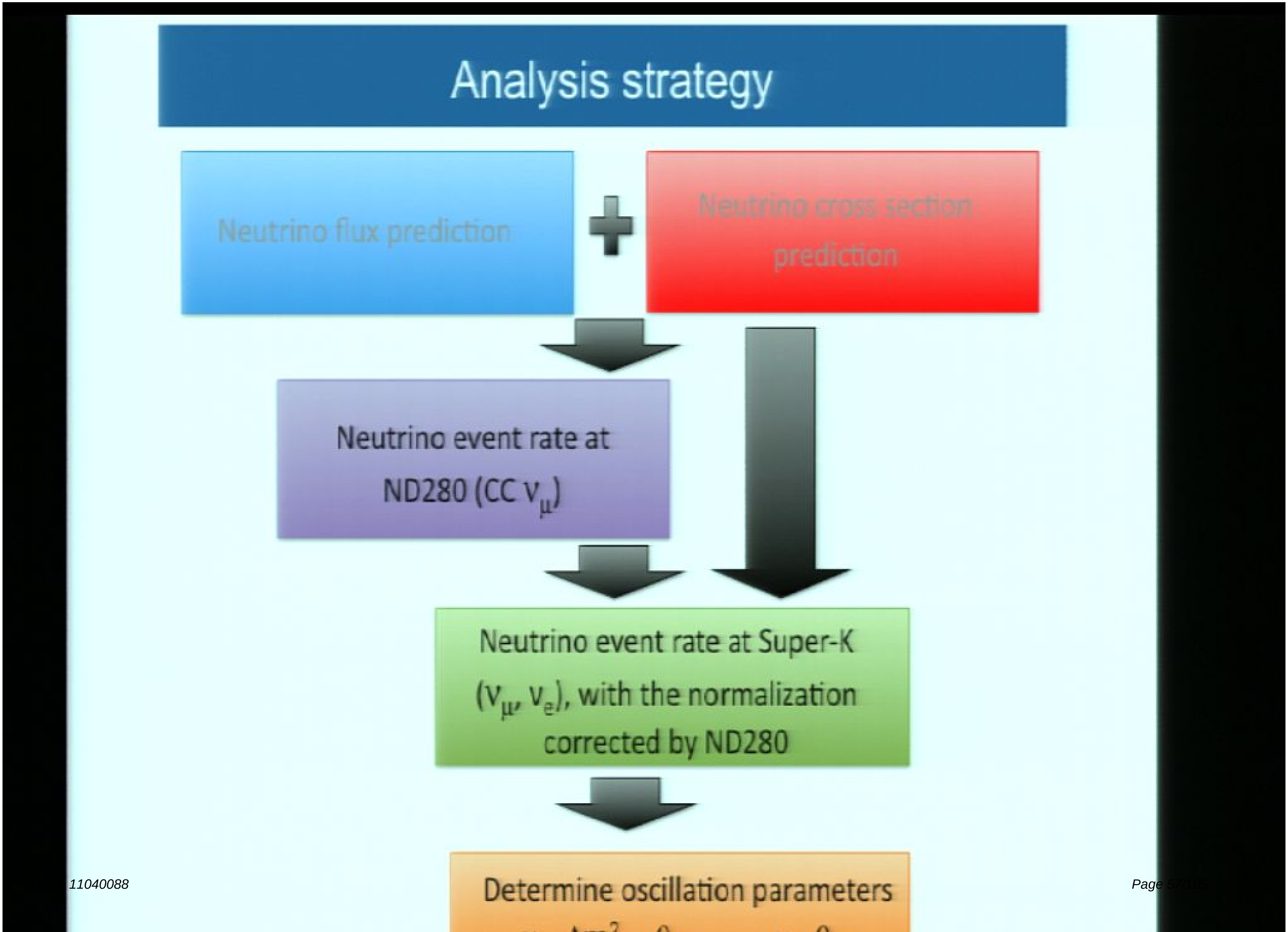
- MiniBooNE, SciBooNE, K2K
- Super-K atmospheric data



Uncertainties set from external data constraints (includes variations to underlying parameters and difference between models)

Source	Uncertainty < 2GeV	Uncertainty >2 GeV
CCQE	energy dependent	energy dependent
CC1π	30%	20%
CC coherent	100%	100%
NCπ^0	30%	25%
NC coherent/other	30%	30%

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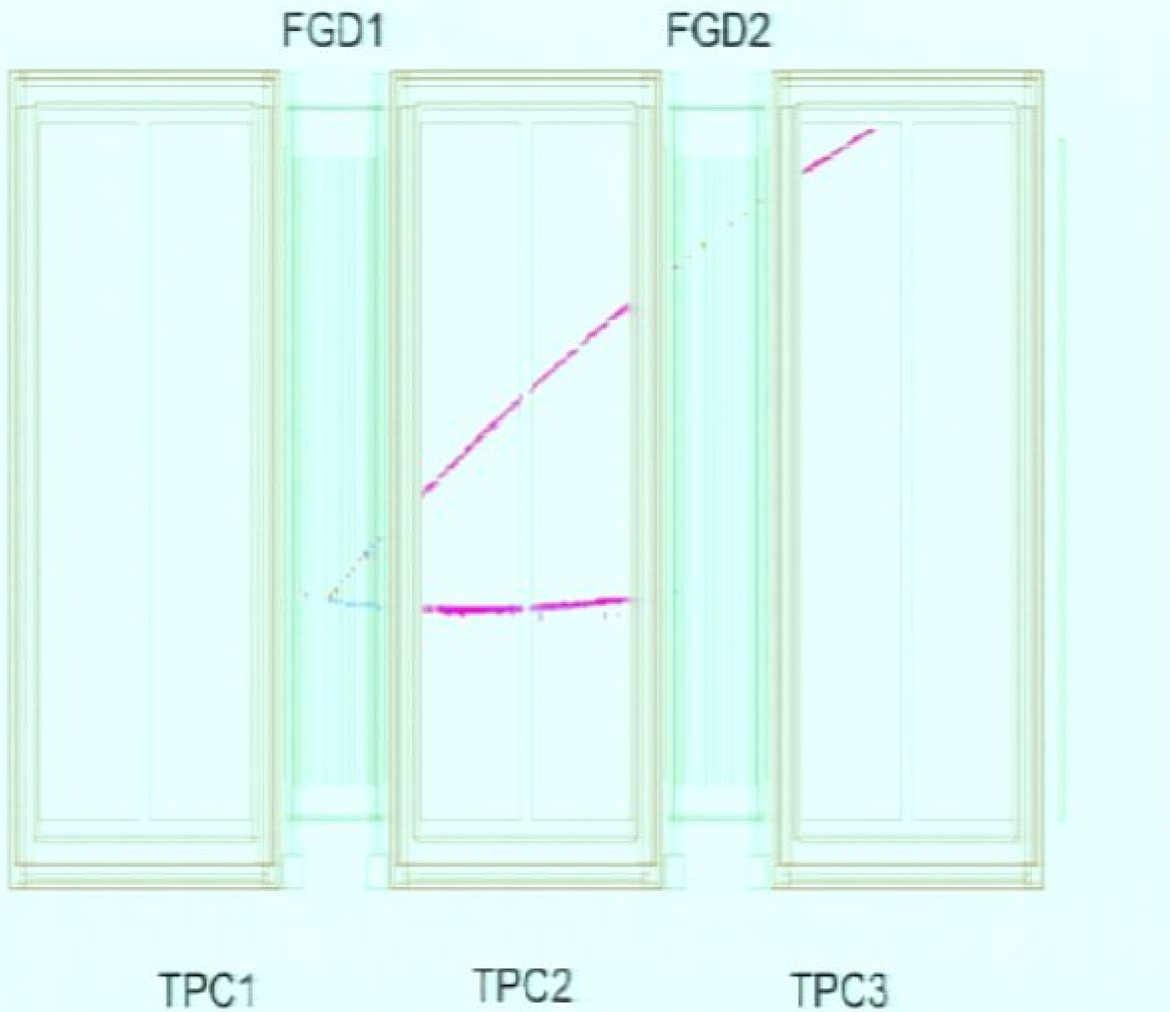
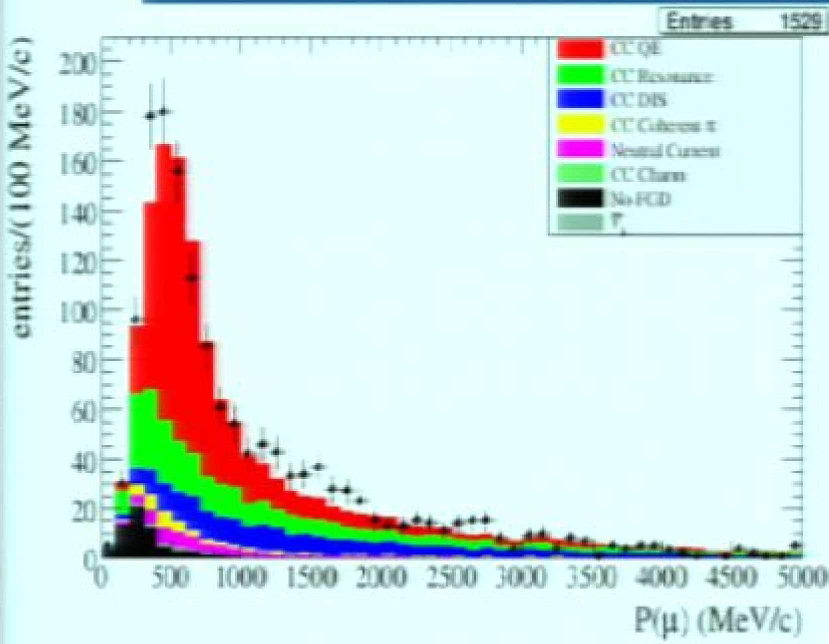
Neutrino event rate at Super-K (ν_μ, ν_e), with the normalization corrected by ND280
Determine oscillation parameters

Basic CC selection in ND280



1. Select neutrino events: Use TPC1 as a veto (no tracks in TPC1)
2. Select events which originate in FGD1 or FGD2 fiducial volume
3. Use the highest momentum, negative TPC2 or TPC3 track

ND280 CC ν_μ sample



Reconstructed momentum and angle of the CC ν_μ candidates after selection

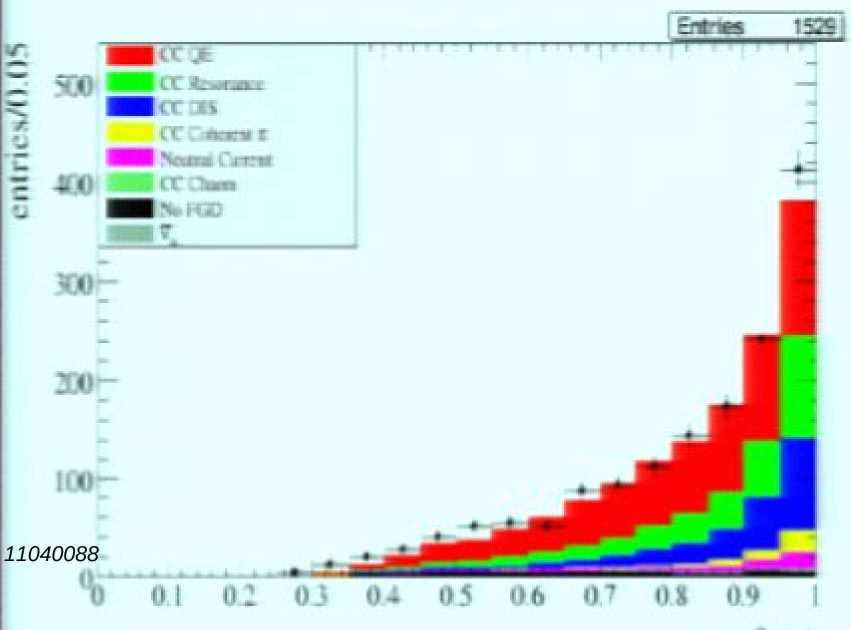
- CC ν_μ purity: 91%
- CCQE purity: 49%

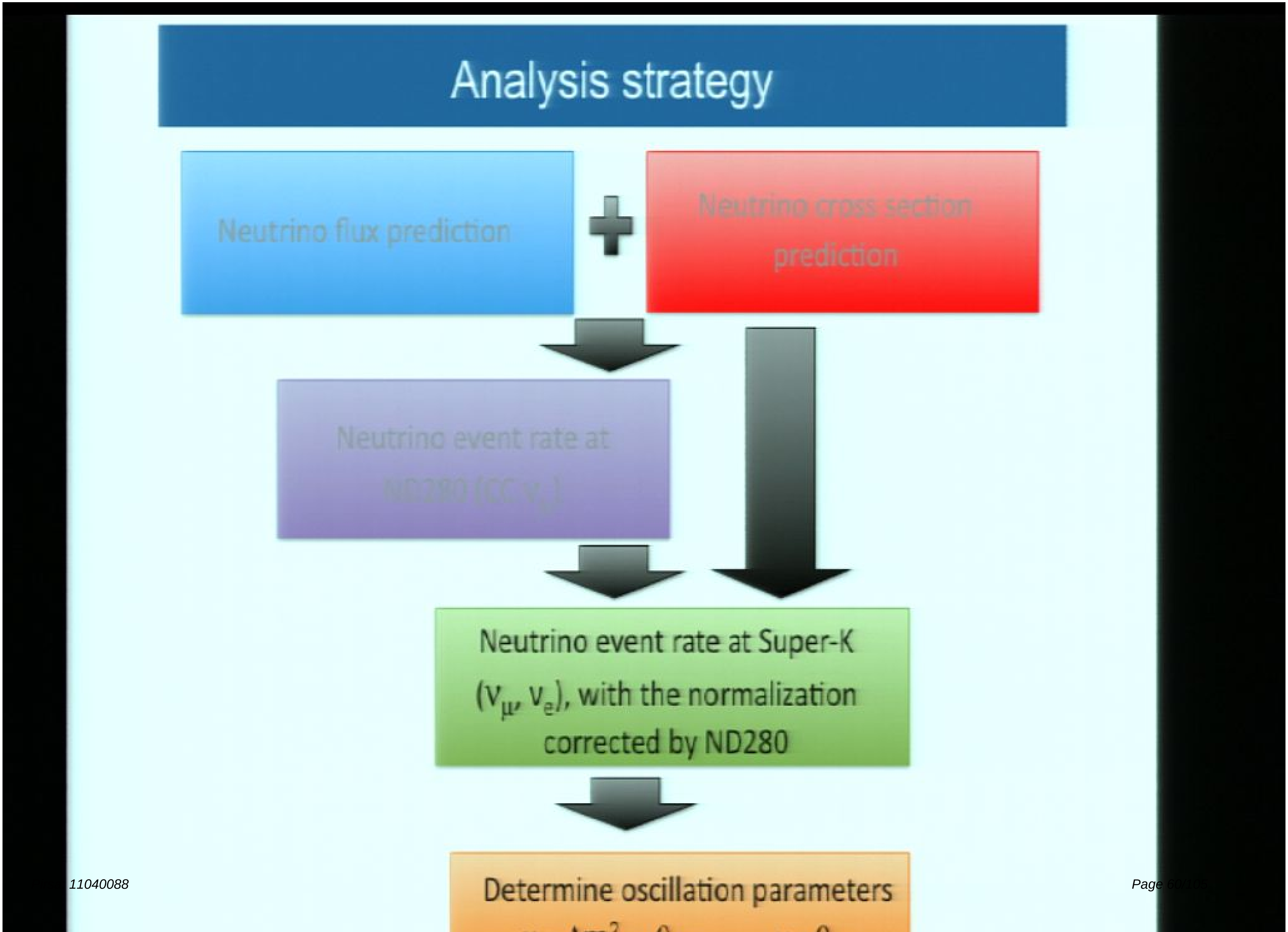
No tuning to flux or cross section applied

R(data/MC) = 1.061 ± 0.028 (statistics) $^{+0.044}_{-0.038}$(det systematics) ± 0.039 (flux, xsec model)

Dominant uncertainties:

- TPC PID pull: 3.0%
- TPC-FGD matching: 2.1%

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Determine oscillation parameters

Far detector neutrino event selection

Basic neutrino selection (precuts)
Event time within beam window
No activity in the veto
Reconstructed vertex >2m from wall
Single reconstructed ring

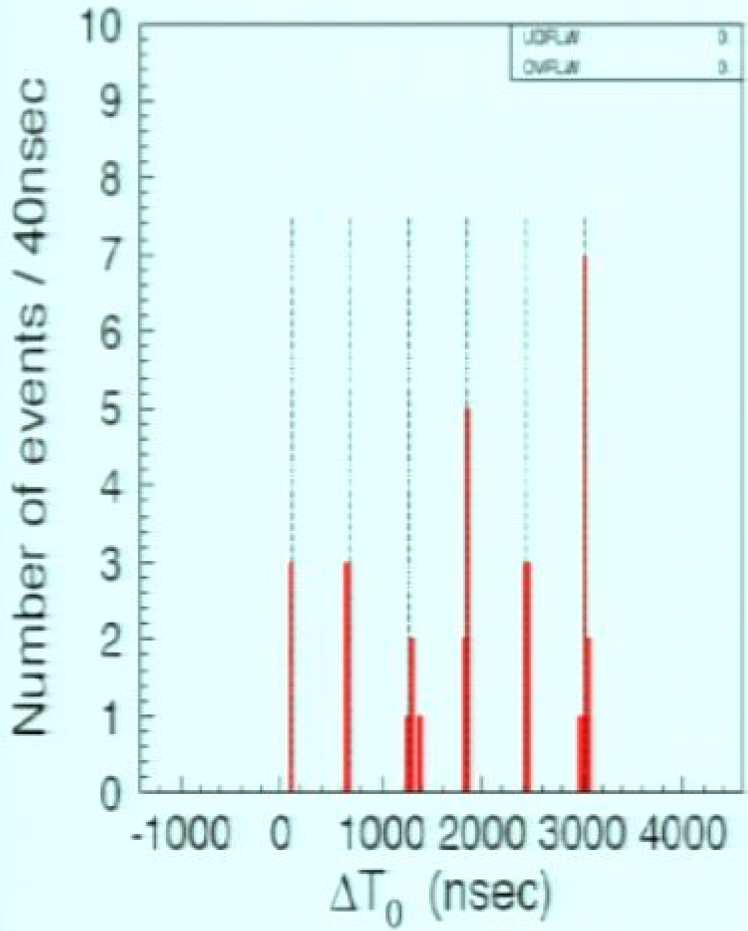
ν_μ selection
Visible energy > 30 MeV
μ-like ring
Eμ >200MeV
decay electrons <2

ν_e selection
Visible energy > 100 MeV
e-like ring
No decay electron
Invariant mass < 105 MeV/c^2
Eν <1250 MeV

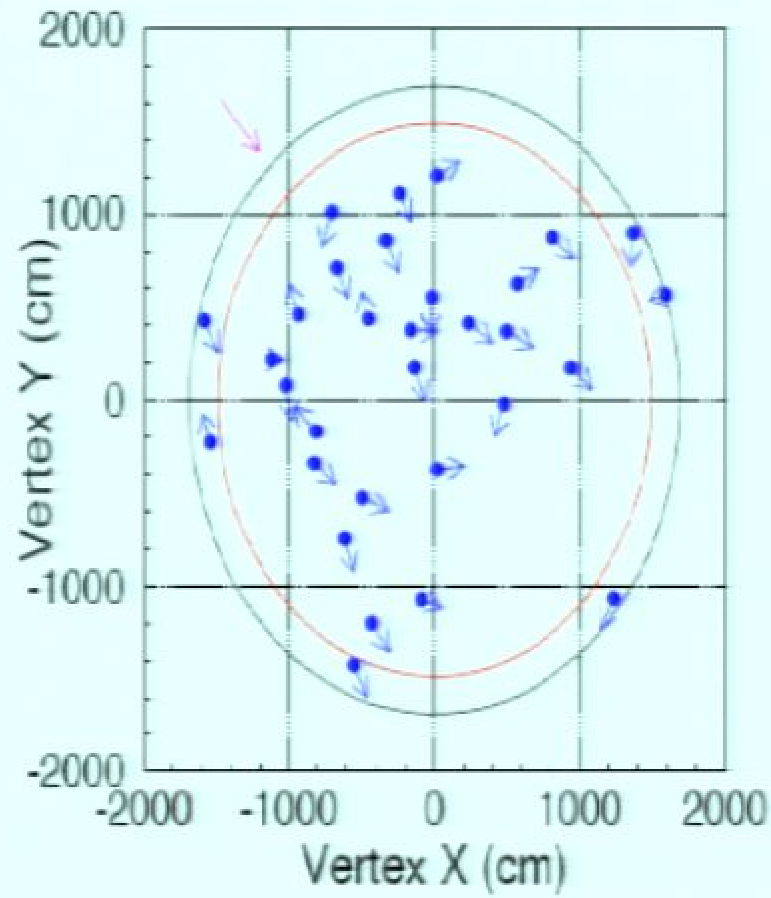
Cuts were set before looking at data from T2K

Feasible because of many years of experience with the Super-K detector (atmospheric neutrino analyses)

Basic neutrino event selection

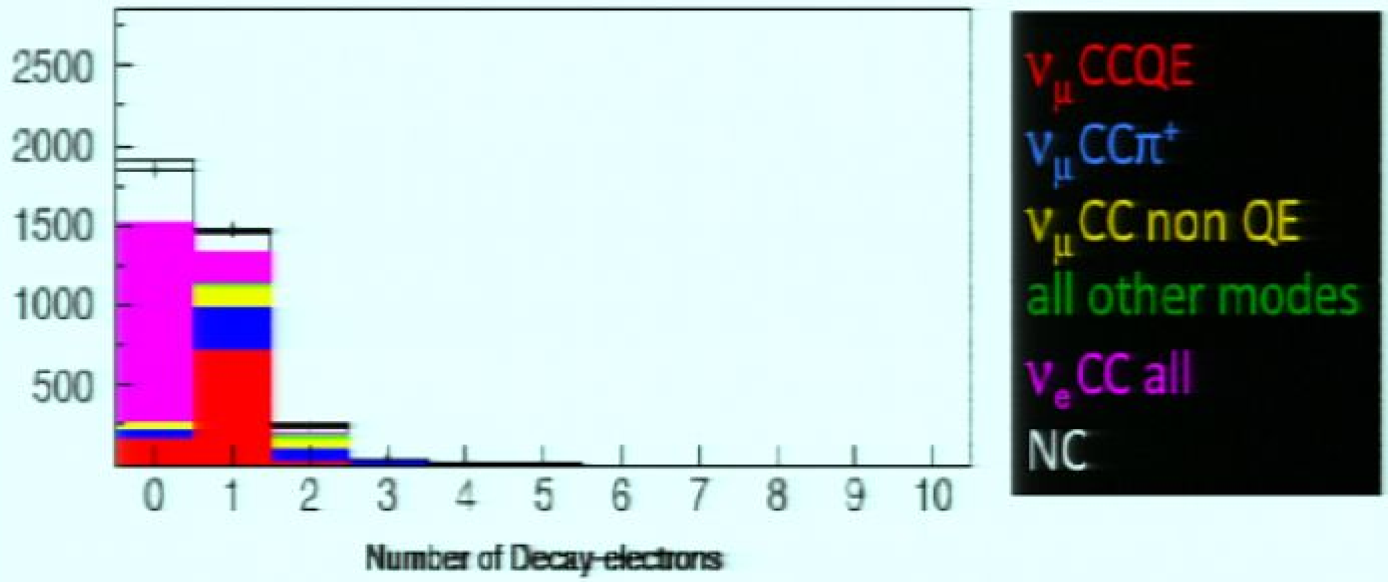


Events are consistent with beam timing, established with GPS



Distribution within tank and reconstructed event direction

Far detector uncertainties



ν_μ dominant uncertainties: ring counting, muon PID

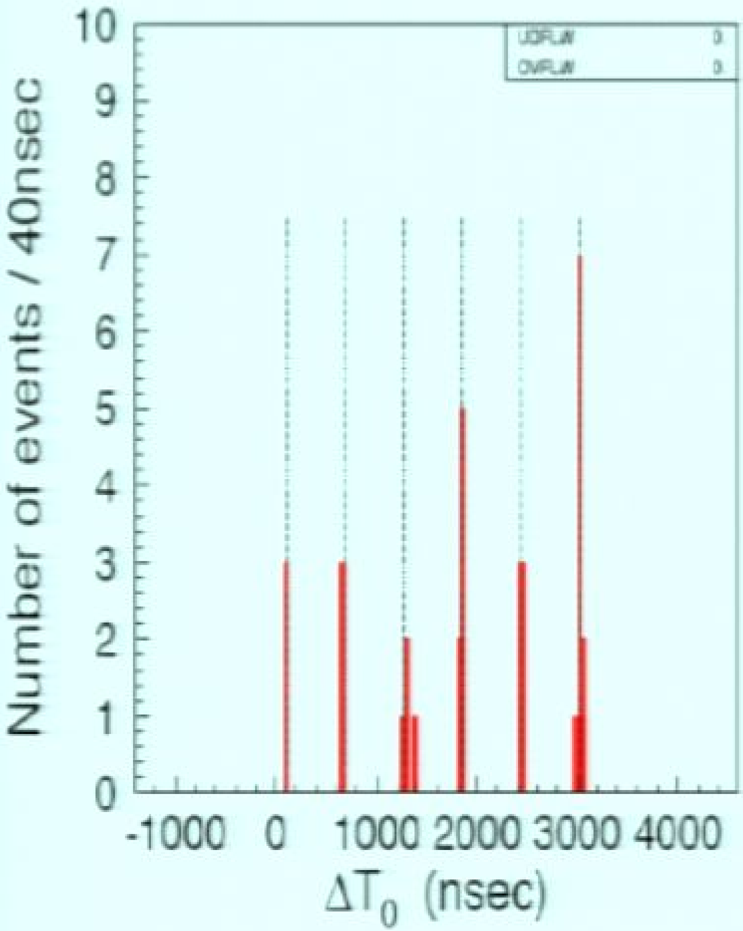
ν_e dominant uncertainties: ring counting, electron PID, invariant mass selection

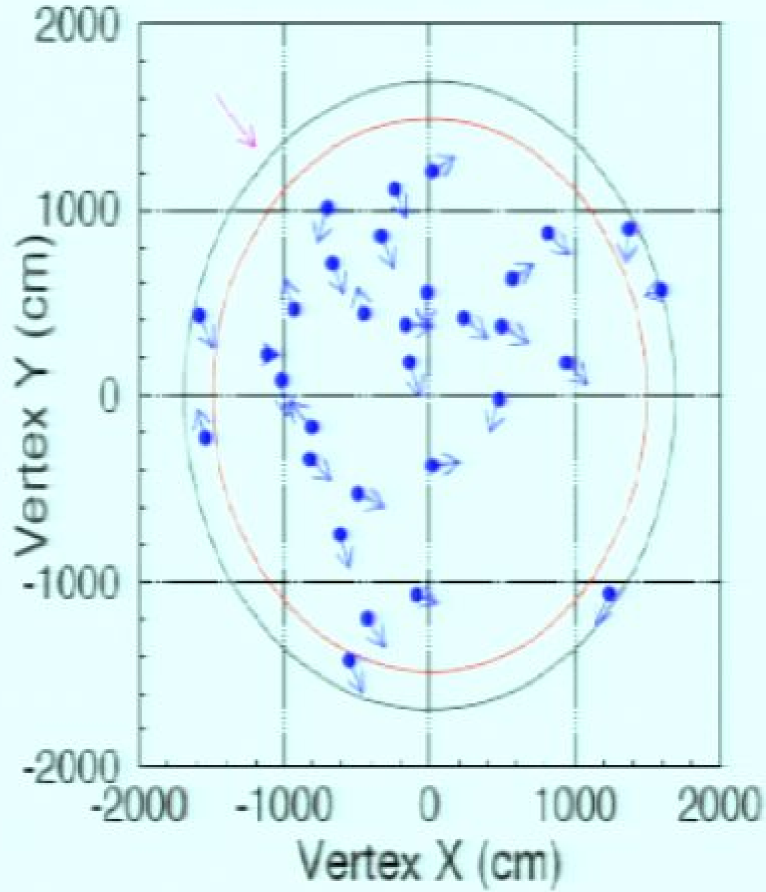
Use atmospheric ν sample, select unbiased sample using decay electron tagging

- 0 decay electrons: NC event, CCQE ν_e events
- 1 decay electrons: CCQE ν_μ
- 2 decay electrons: CC non QE (pion, multipion events)

Evaluate data/MC differences in number of events in the ring counting

Basic neutrino event selection





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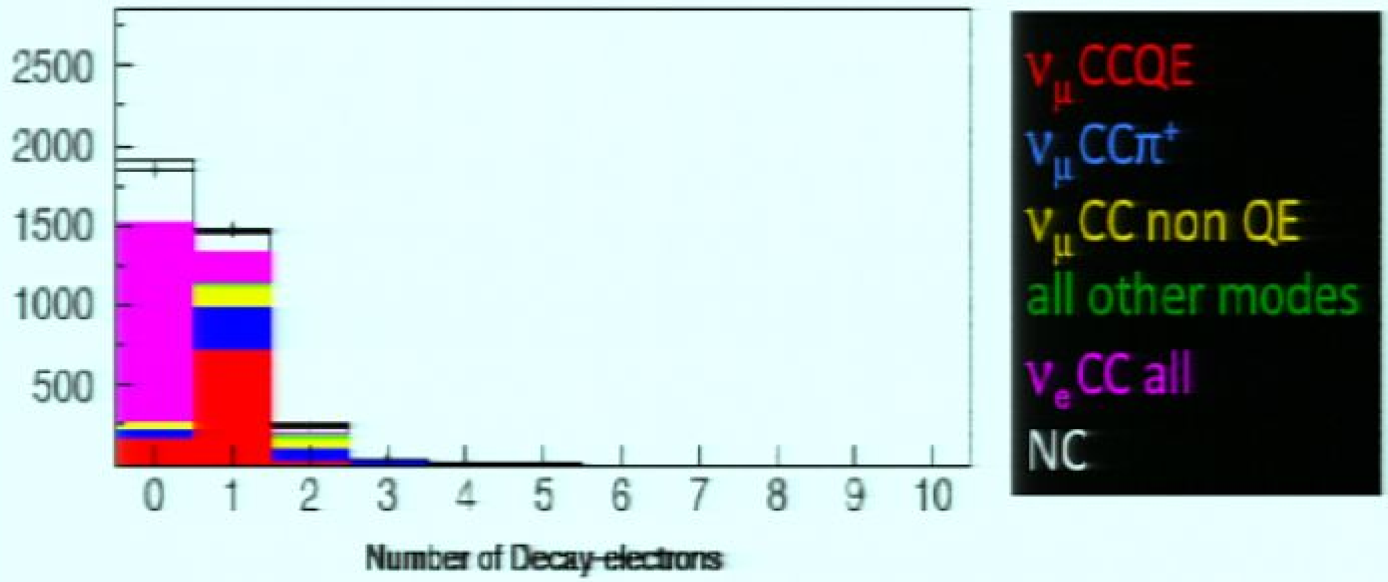

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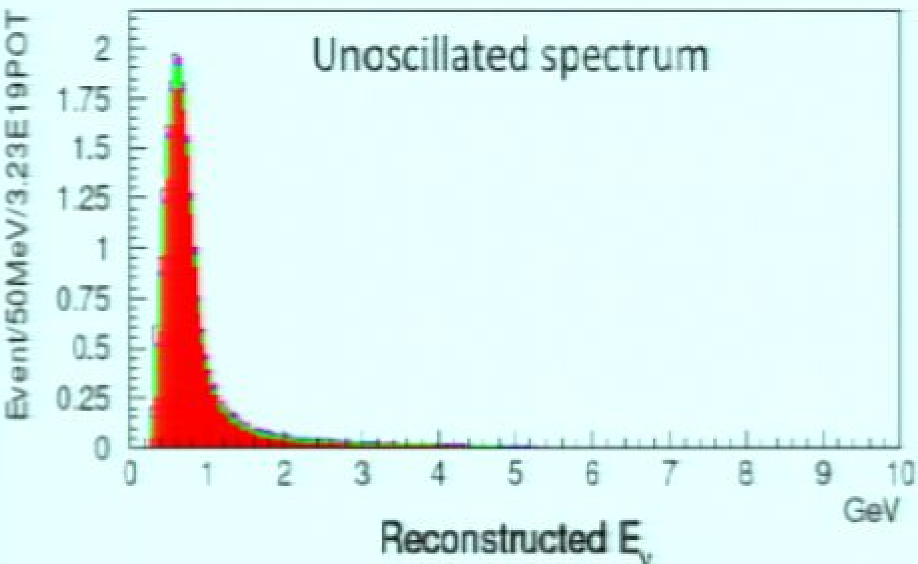
Evaluate data/MC differences in number of events in the ring counting

ν_μ disappearance results

ν_μ disappearance at T2K

For a fixed baseline (L=295km) neutrinos of energy E_1 and E_2 will have different probabilities for oscillation



ν_μ CCQE

ν_μ CCπ^+

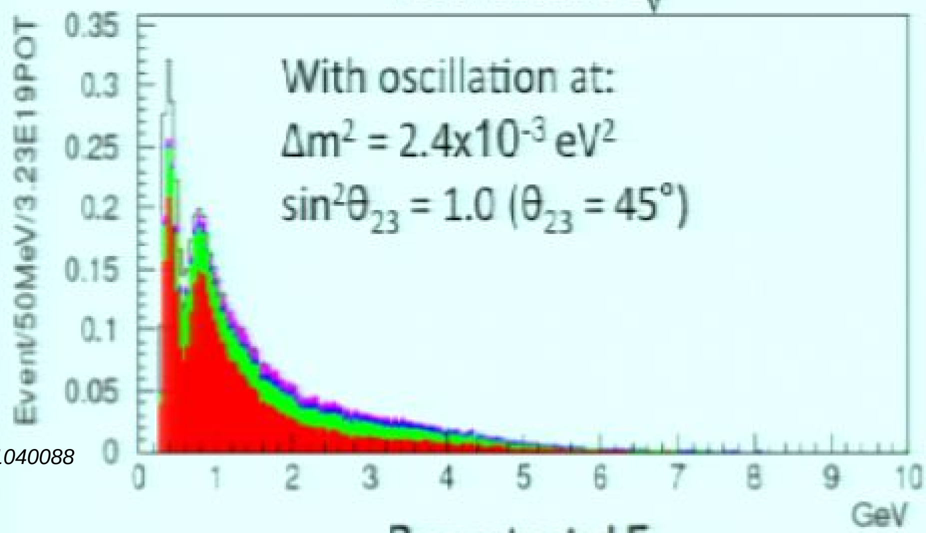
ν_μ CC other (multipion, etc)

$\bar{\nu}_\mu$ CC all

CC ν_e all

NC

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2 2\theta_{23} \sin^2\left(\frac{\Delta m^2_{23} L}{4E}\right)$$



Extract Δm^2, $\sin^2 2\theta_{23}$ from the change in overall rate and spectrum distortion observed

Backgrounds are events where pion is unobserved (absorbed)

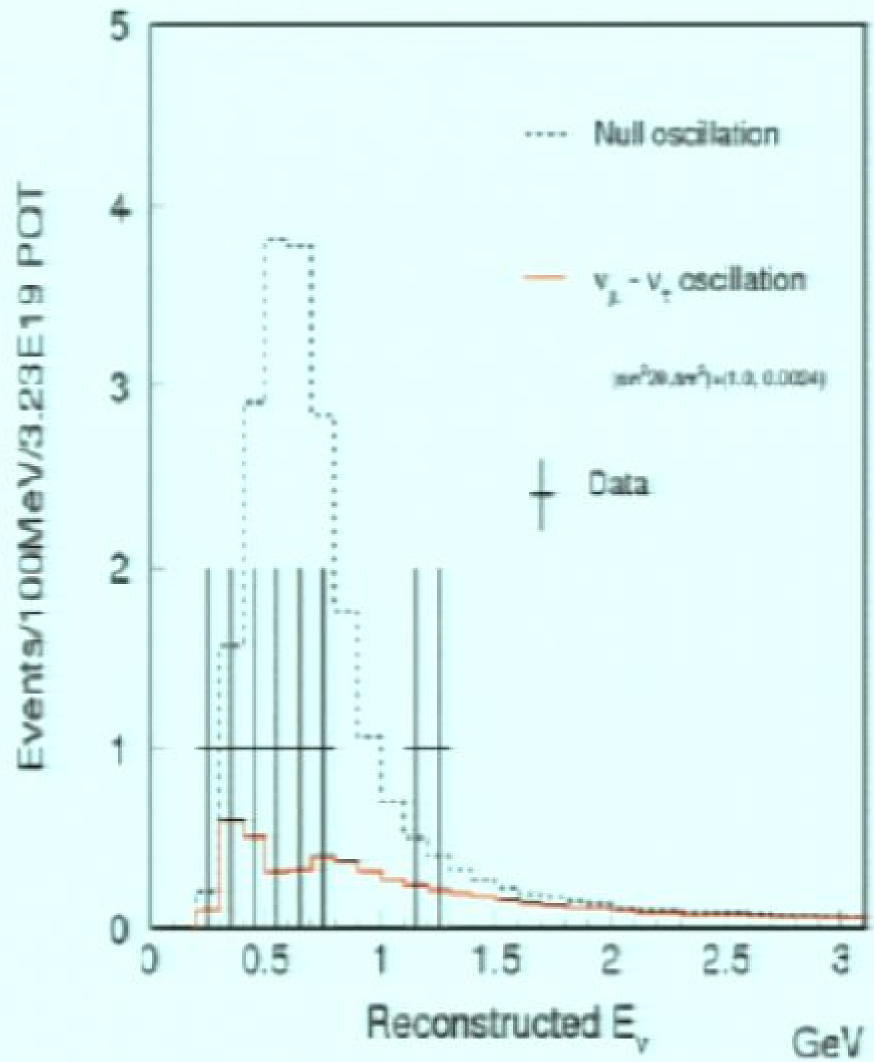
ν_μ disappearance results

8 events after selection

No-oscillation prediction:
22.81 ± 3.19 (systematics)

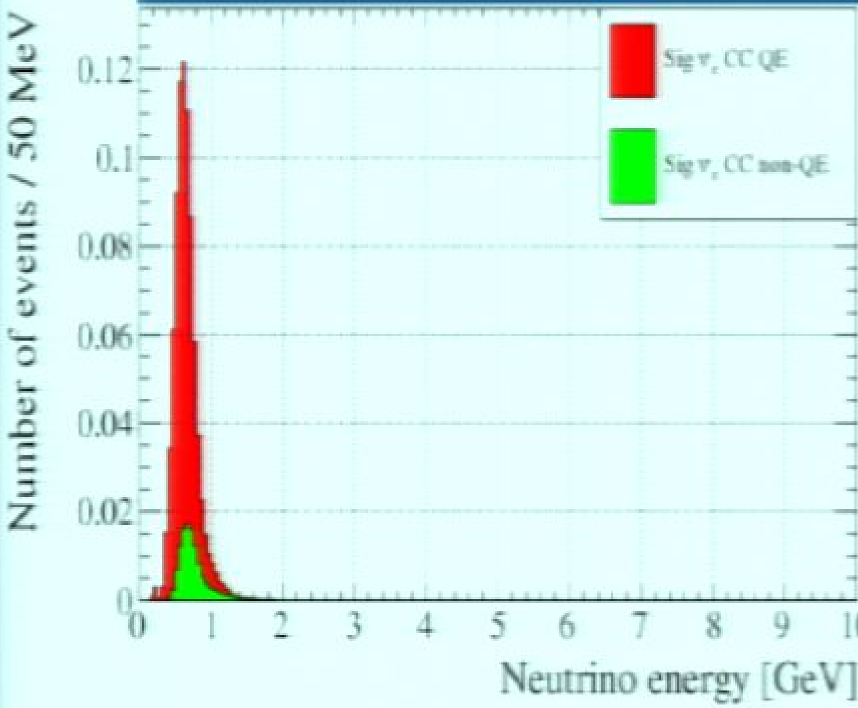
With oscillation:
6.34 ± 1.04 (systematics)

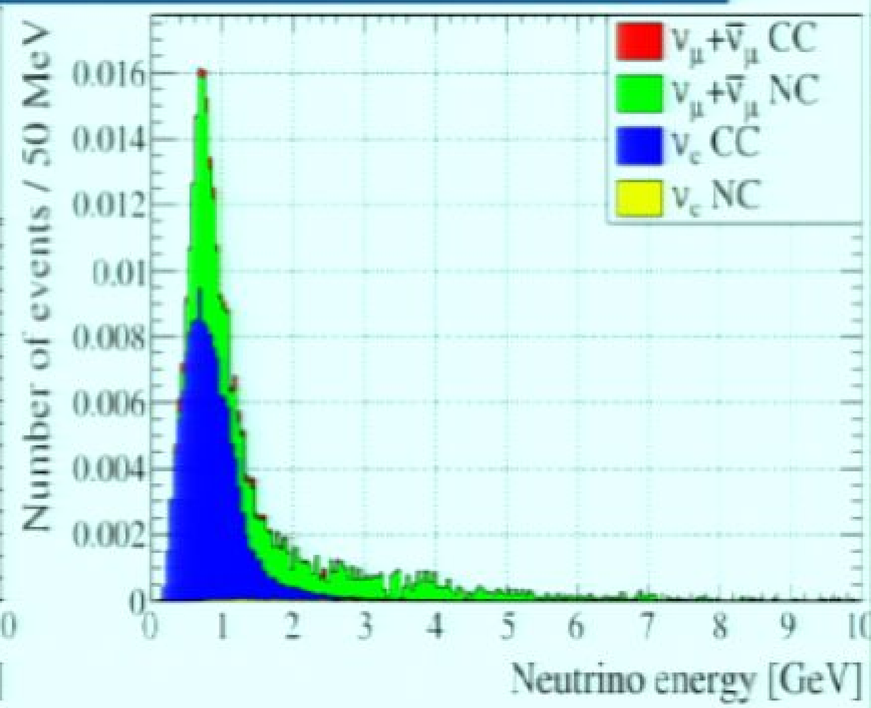
at MINOS experimental best fit:
$\Delta m^2 = 2.4\text{x}10^{-3}\ eV^2$
$\sin^2 2\theta_{23} = 1.0$



ν_e appearance results

ν_e appearance at T2K





Signal: CC interactions of ν_e from ν_μ to ν_e oscillations

Signal	# events
@$\sin^2 2\theta_{13}=0.1, \delta cp=0$	0.9

Background	# events
intrinsic ν_e	0.16
ν_μ (70% $NC\pi^0$)	0.13
$\bar{\nu}_\mu$	0.01
total:	0.30±0.07 (sys)

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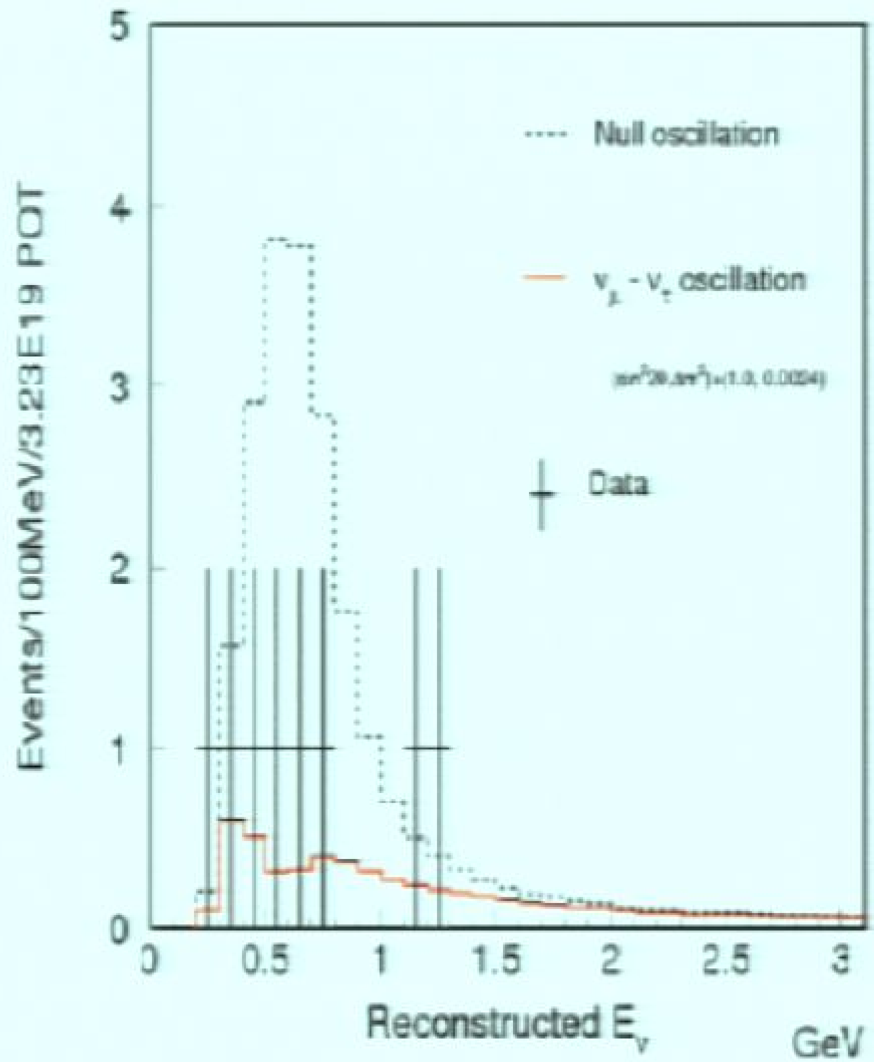

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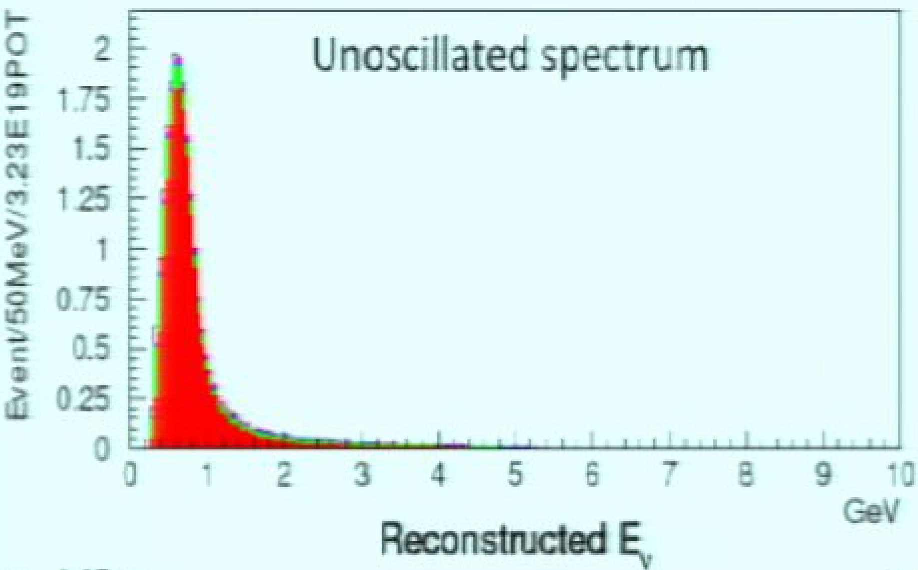

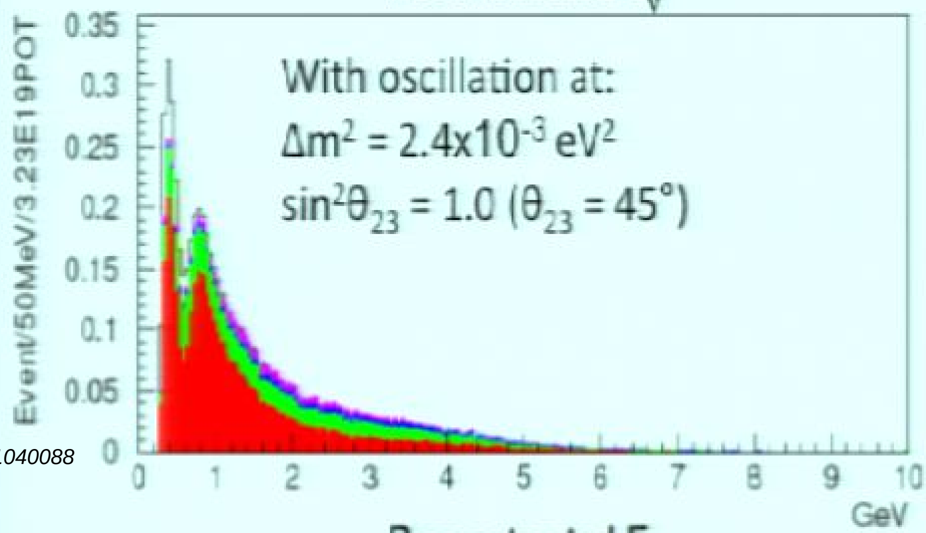

- ν_μ CCQE
- ν_μ CCπ^+
- ν_μ CC other (multipion, etc)
- $\bar{\nu}_\mu$ CC all
- CC ν_e all
- NC

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2 2\theta_{23} \sin^2\left(\frac{\Delta m^2_{23} L}{4E}\right)$$

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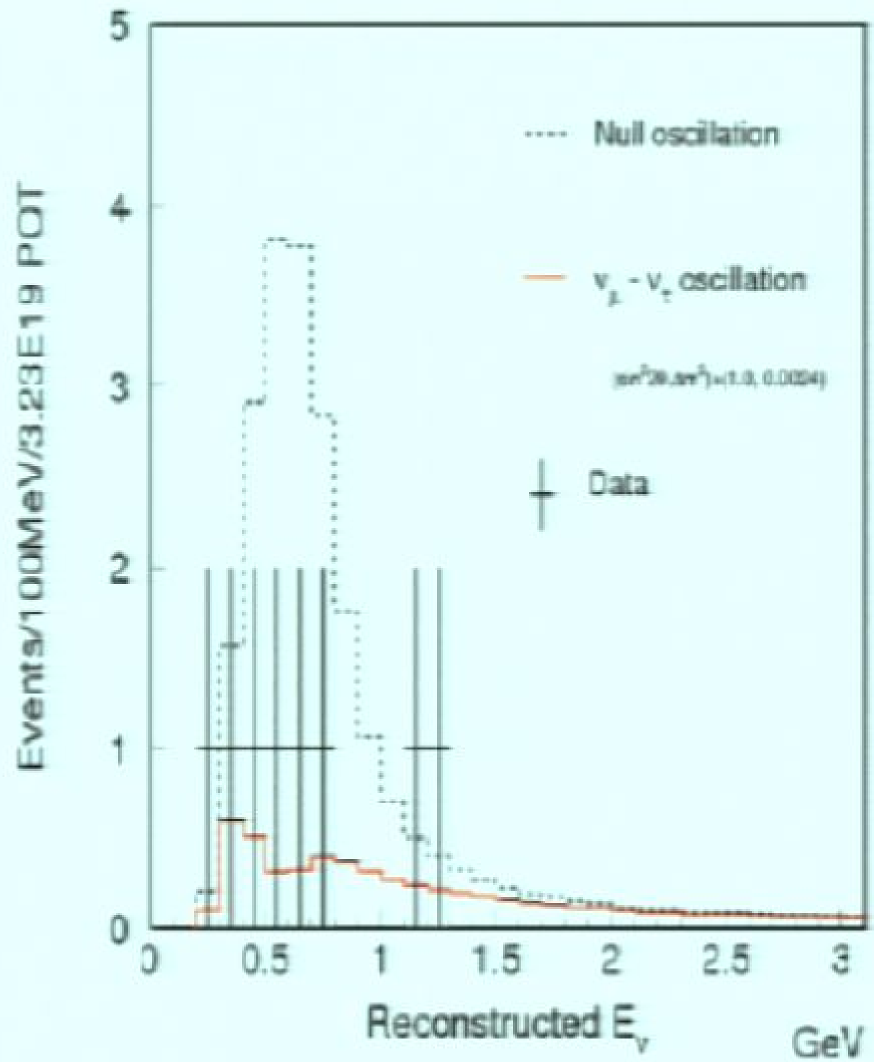

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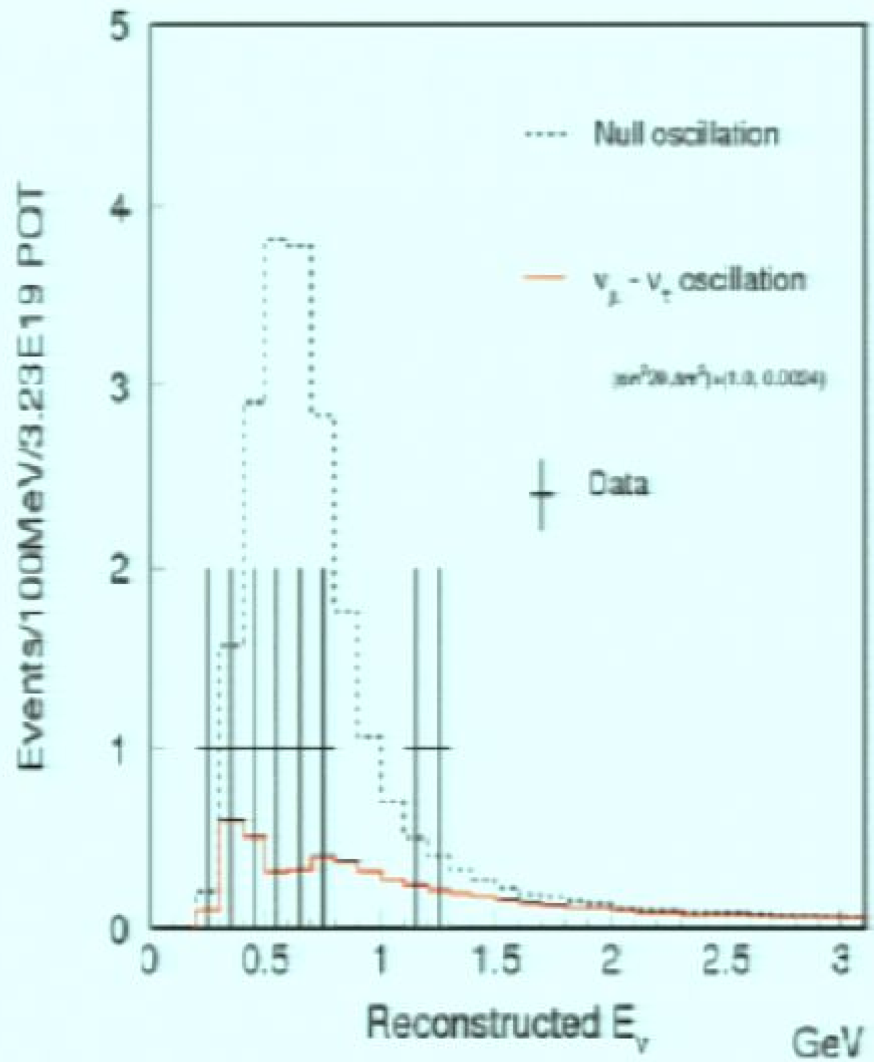
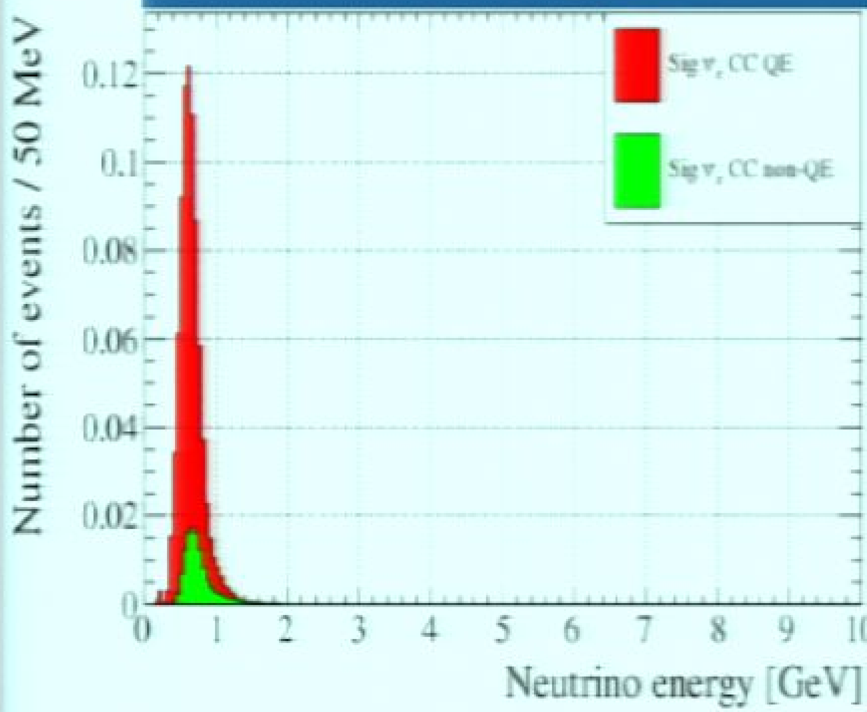
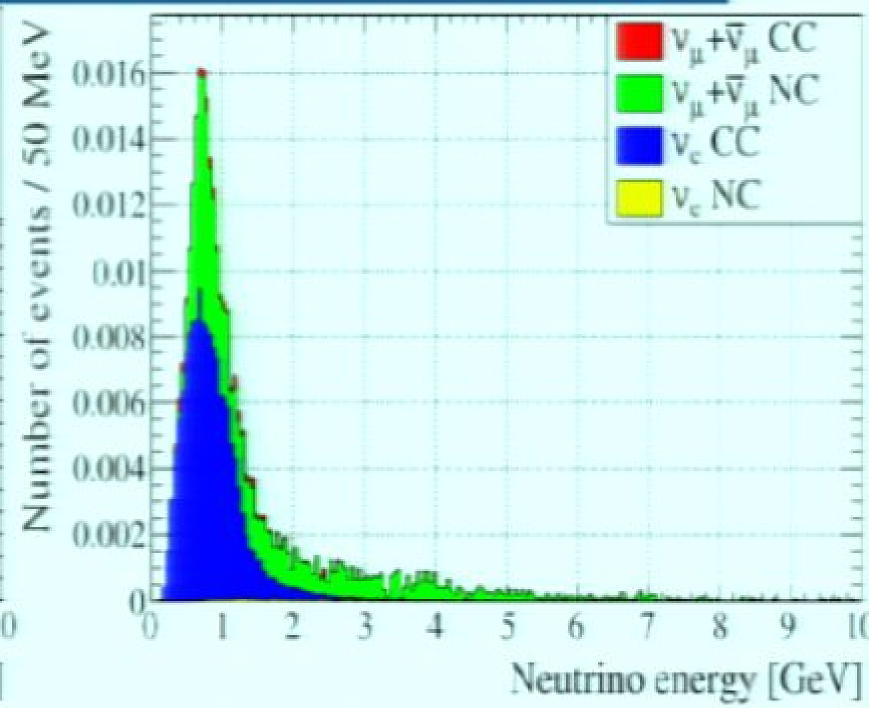


ν_e appearance at T2K





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Signal	# events
@$\sin^2 2\theta_{13}$=0.1,δcp=0	0.9

Background	# events
intrinsic ν_e	0.16
ν_μ (70% NCπ^0)	0.13
$\bar{\nu}_\mu$	0.01
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ν_μ disappearance results

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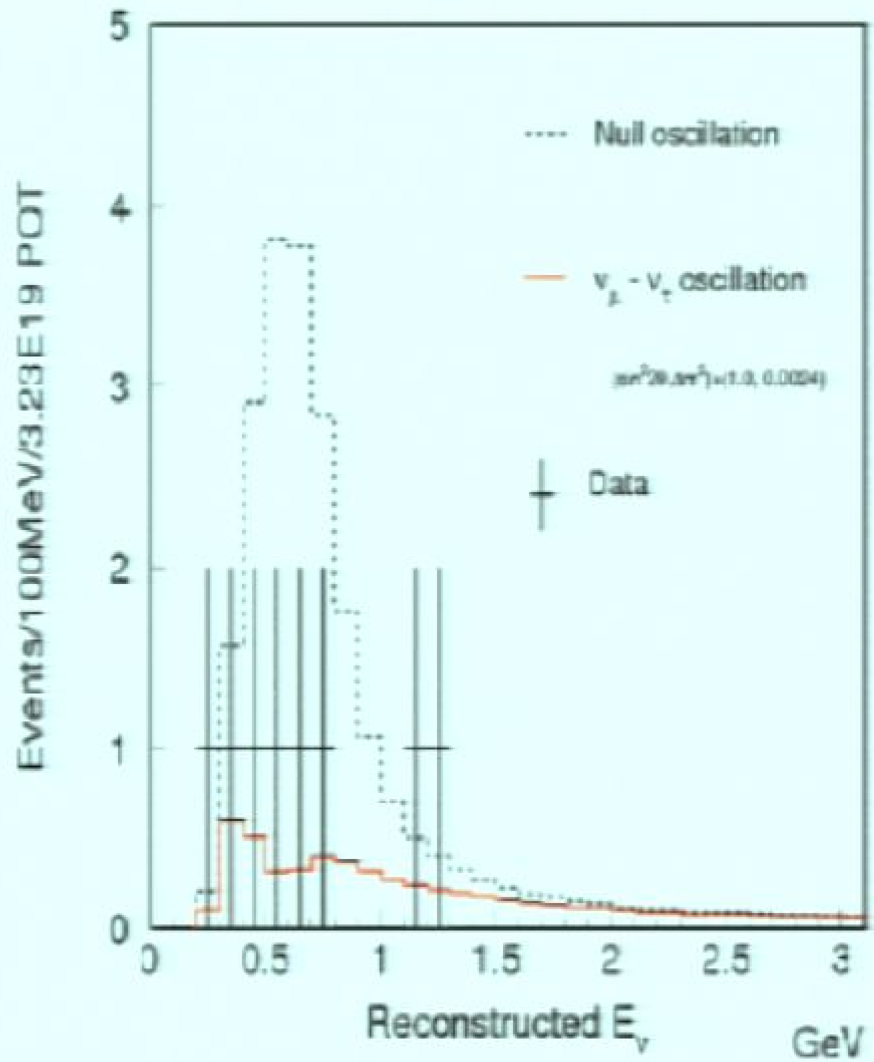
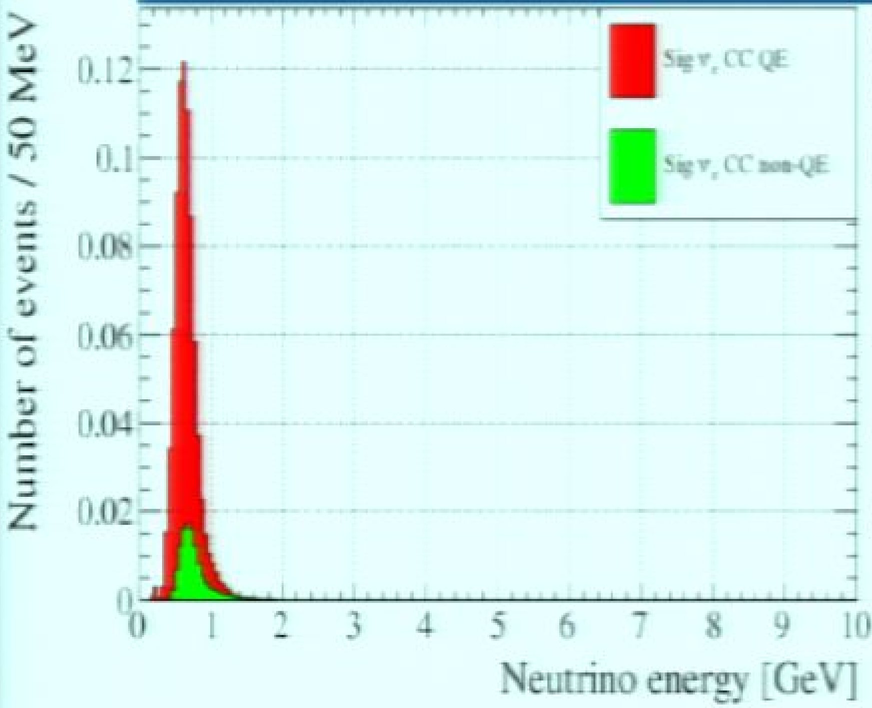
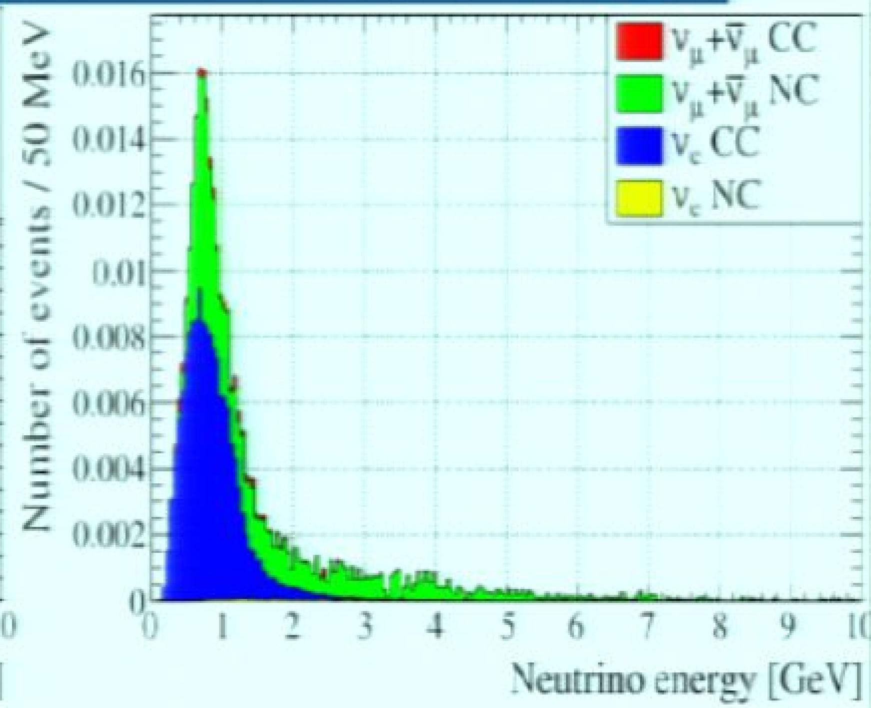


ν_e appearance results

ν_e appearance at T2K





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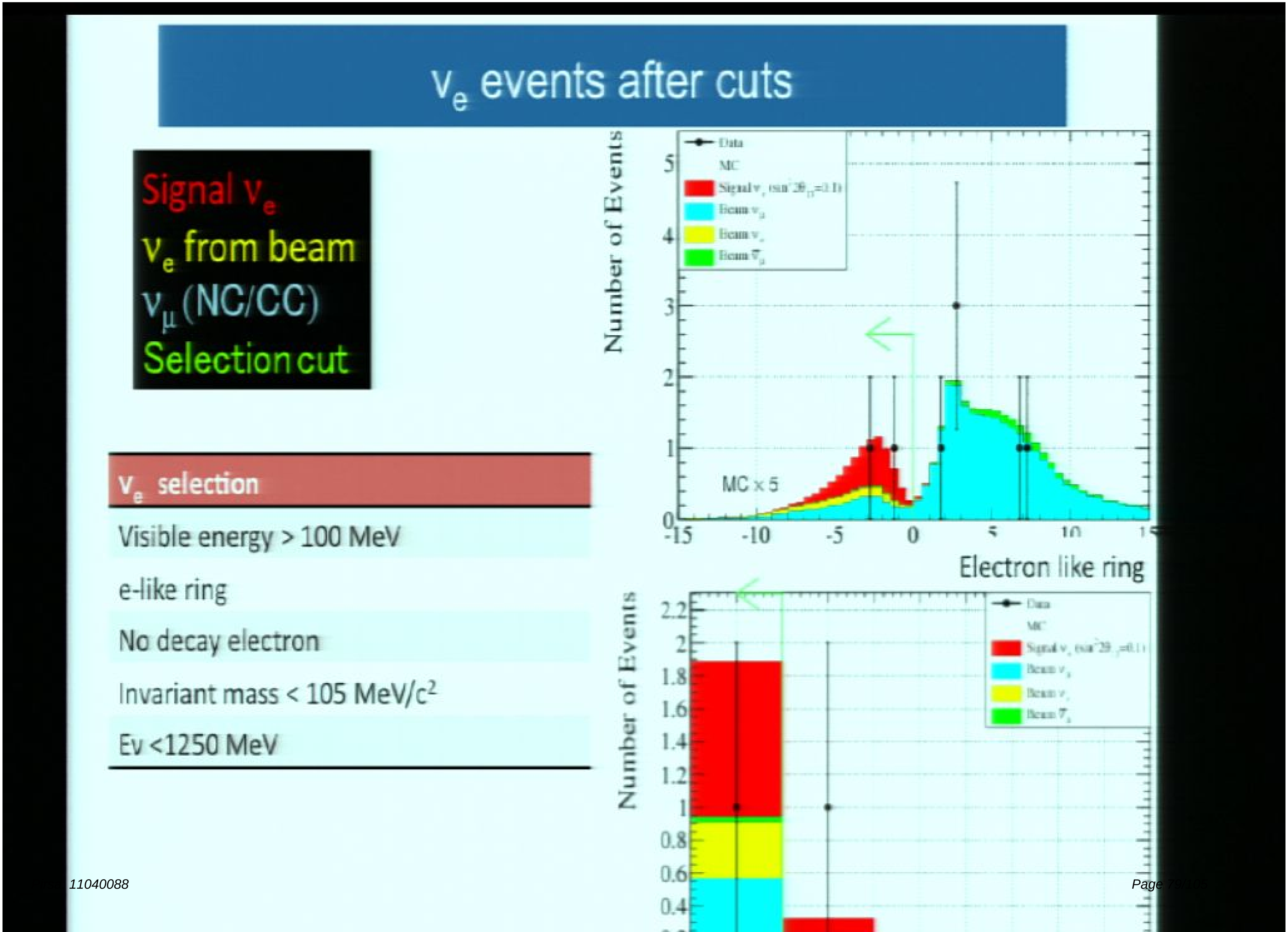
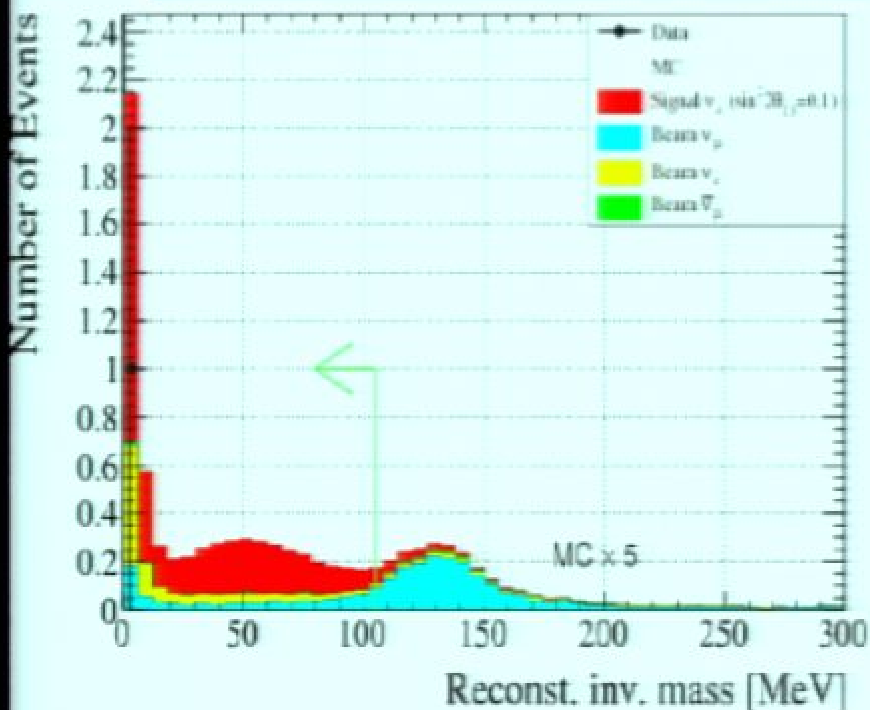
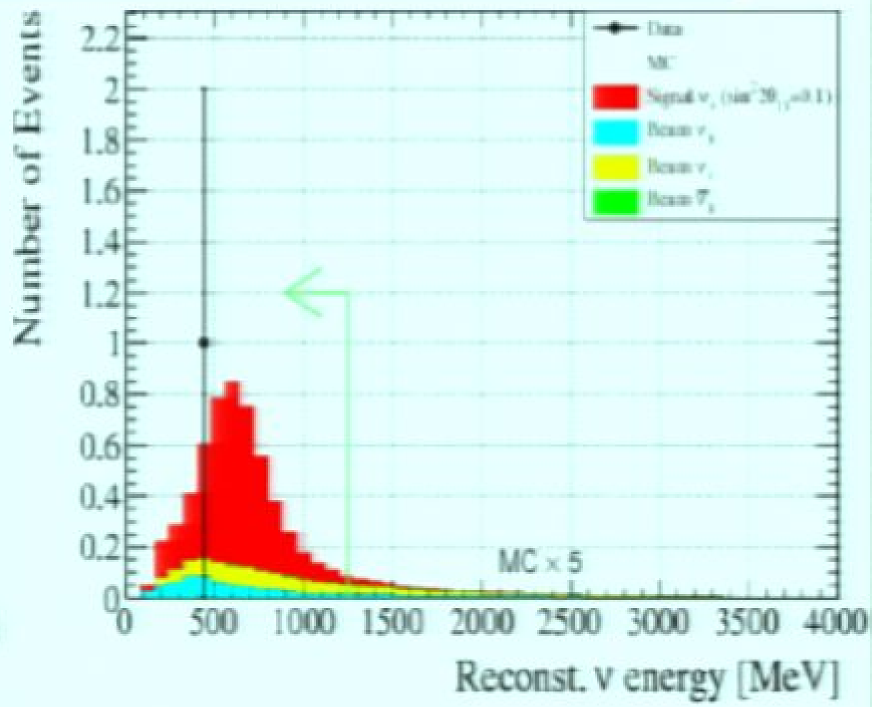

νe events after cuts
Signal νe
νe from beam
νμ (NC/CC)
Selection cut
νe selection
Visible energy > 100 MeV
e-like ring
No decay electron
Invariant mass < 105 MeV/c²
Ev <1250 MeV
Number of Events
Data
MC
MC x 5
Electron like ring
Number of Events
Data
MC

ν_e events after cuts



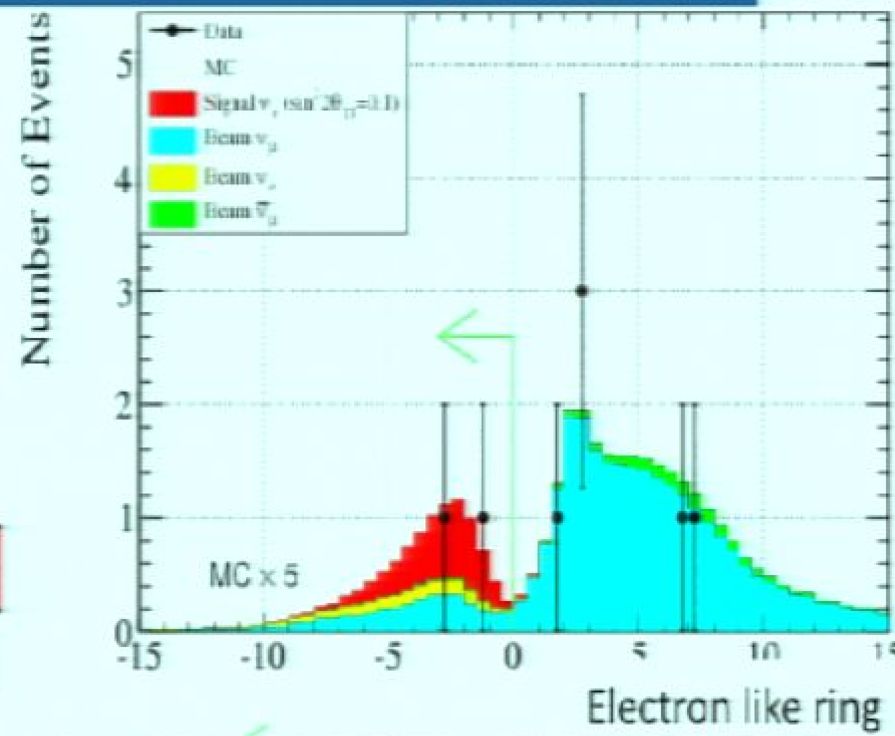


ν_e selection
Visible energy > 100 MeV
e-like ring
No decay electron
Invariant mass < 105 MeV/c^2
Eν <1250 MeV

Signal ν_e
ν_e from beam
ν_μ (NC/CC)
Selection cut

ν_e events after cuts

Signal ν_e
ν_e from beam
ν_μ (NC/CC)
Selection cut



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Visible energy > 100 MeV
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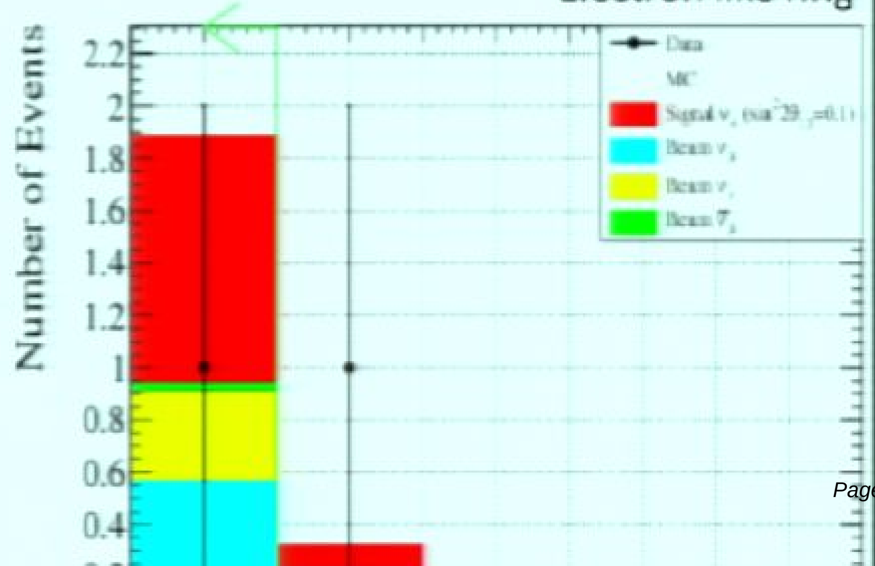
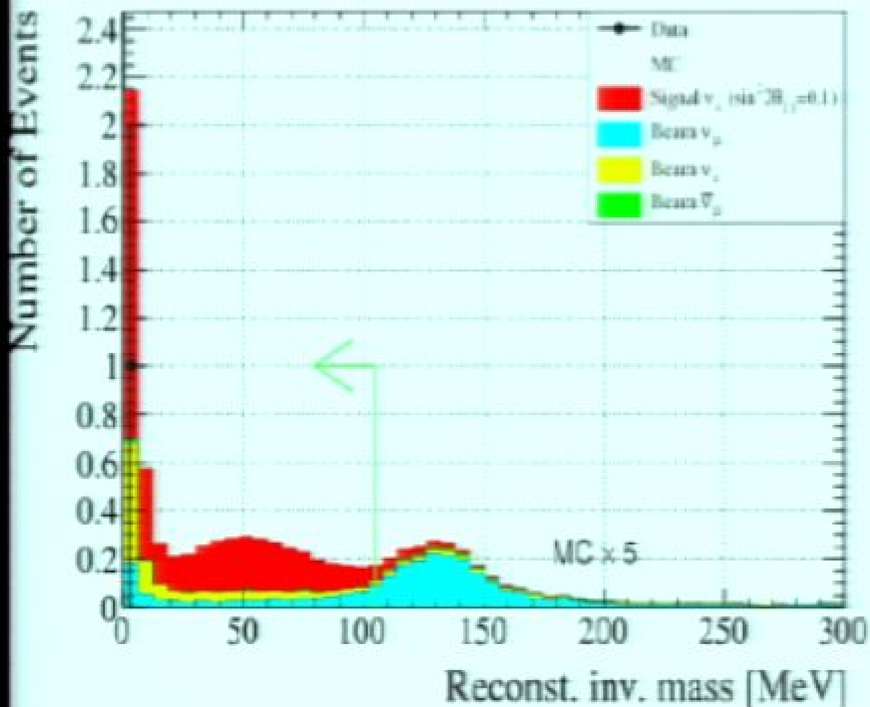
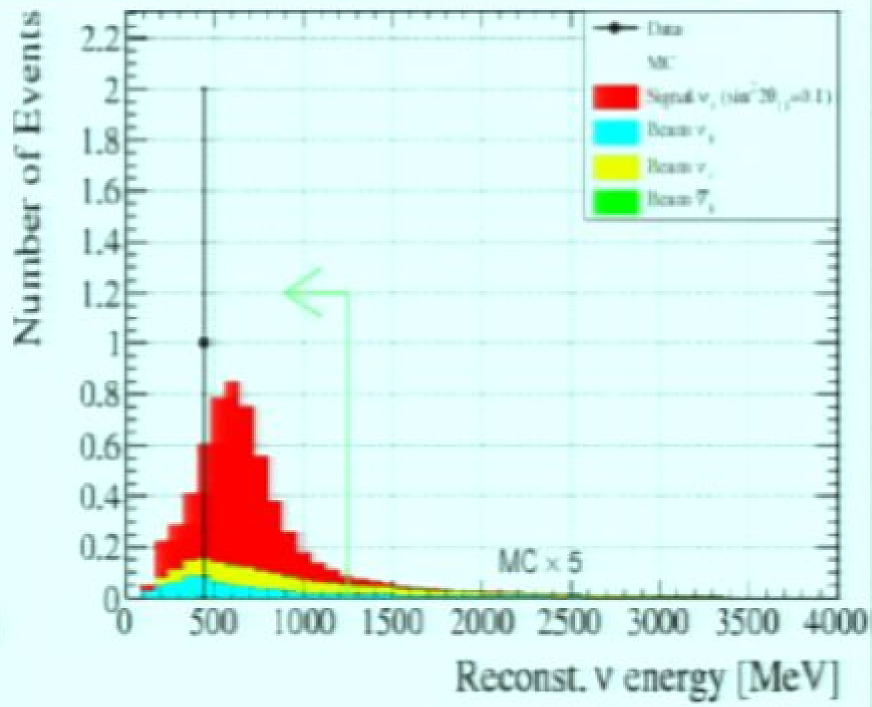


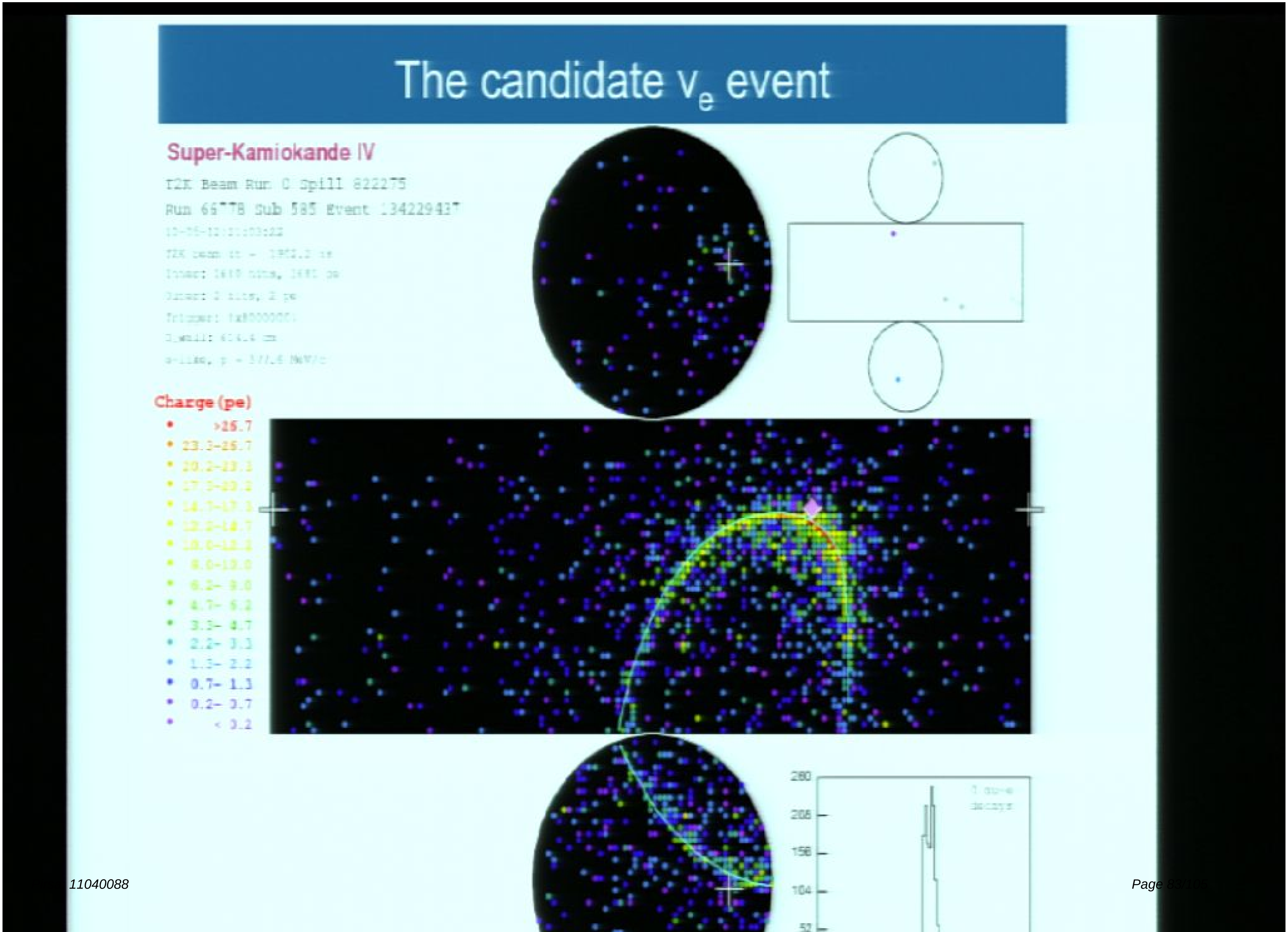
ν_e events after cuts





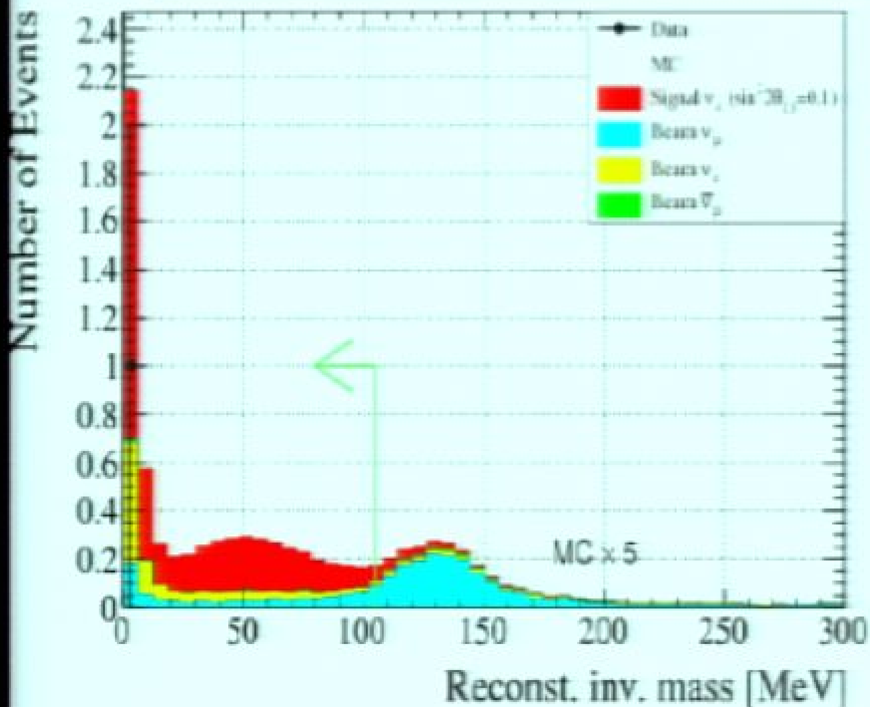
ν_e selection
Visible energy > 100 MeV
e-like ring
No decay electron
Invariant mass < 105 MeV/c^2
Eν <1250 MeV

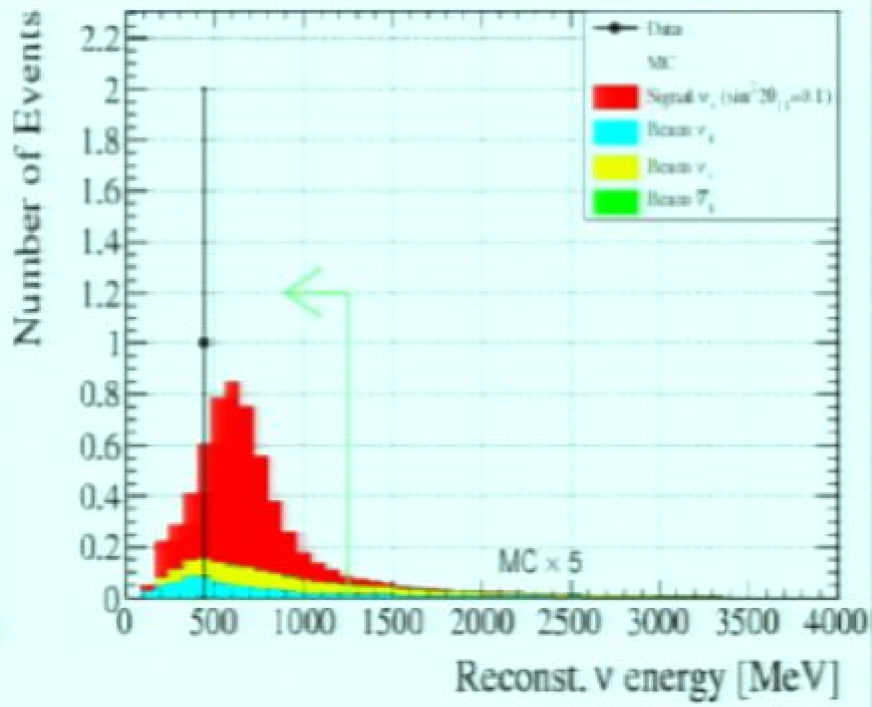
Signal ν_e
ν_e from beam
ν_μ(NC/CC)
Selection cut



The candidate ν_e event
Super-Kamiokande IV
T2K Beam Run 0 Spill 822275
Charge (pe)
>26.7
23.3-26.7
20.2-23.3
17.3-20.2
14.7-17.3
12.2-14.7
10.0-12.2
8.0-10.0
6.2- 8.0
4.7- 6.2
3.3- 4.7
2.2- 3.3
1.3- 2.2
0.7- 1.3
0.2- 0.7
< 0.2
260
208
156
104
52

ν_e events after cuts





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Visible energy > 100 MeV
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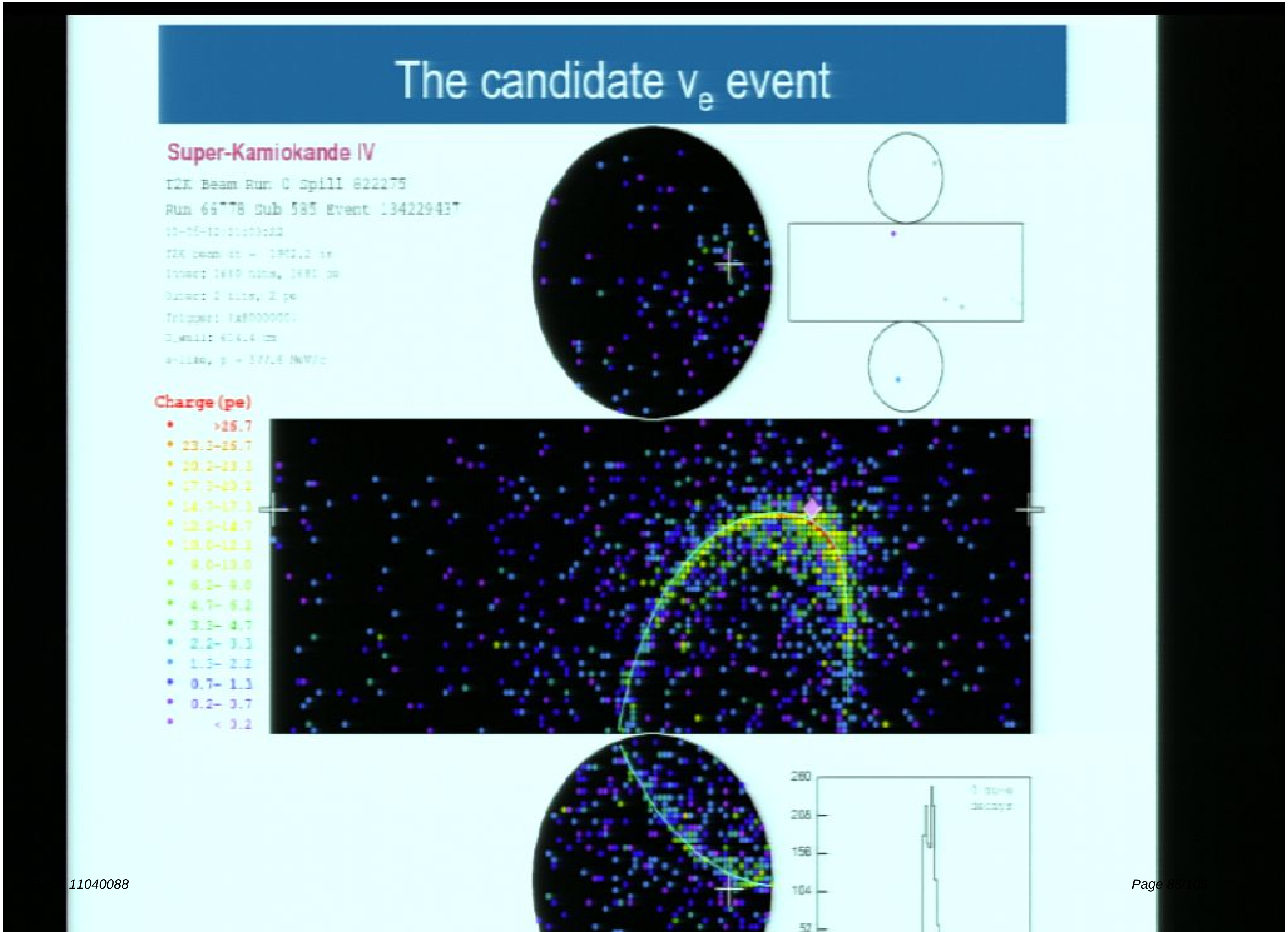
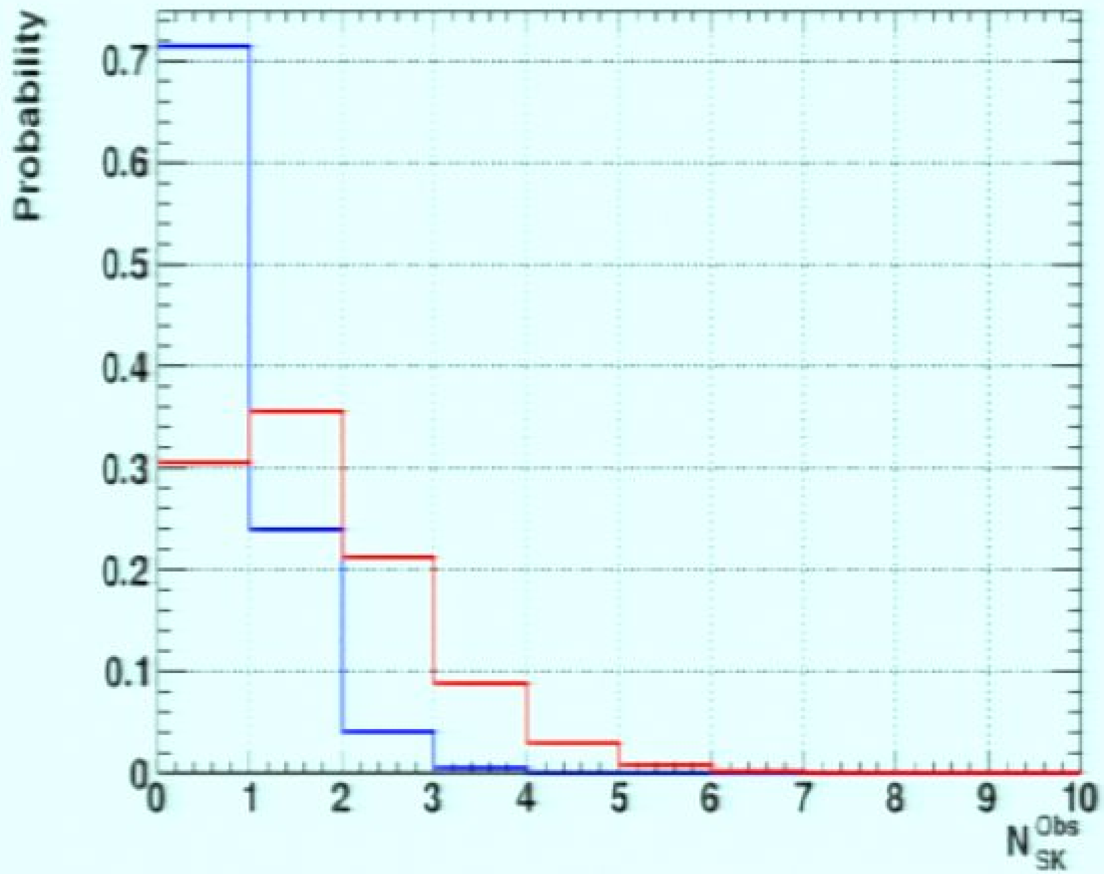
Signal ν_e
ν_e from beam
ν_μ (NC/CC)
Selection cut


The candidate ν_e event
Super-Kamiokande IV
T2K Beam Run 0 Spill 822275
Run 66778 Sub 585 Event 134229437
Charge (pe)
>26.7
23.3-26.7
260
208
156
104
52

ν_e appearance results

One candidate event remains after selection



Blue: $\sin^2 2\theta_{13}=0$

Red: $\sin^2 2\theta_{13}=0.1$

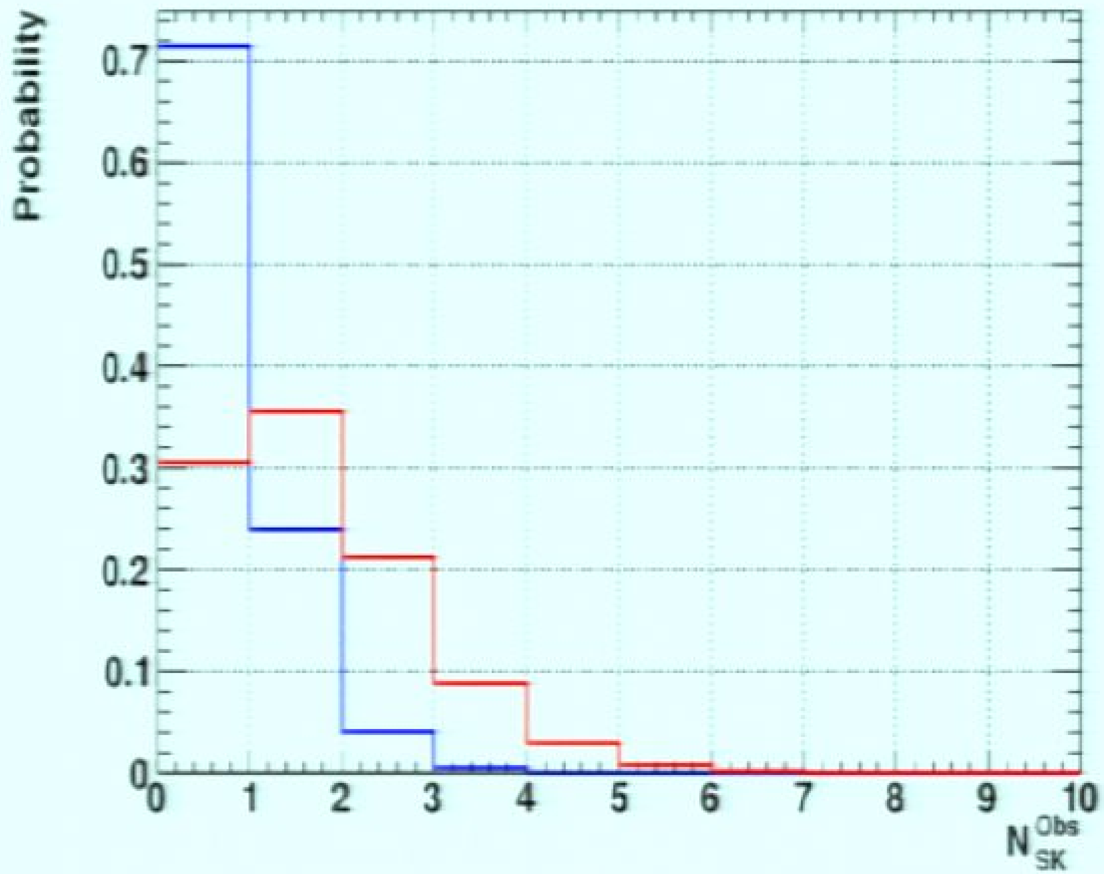
$\Delta m^2 = 2.4 \times 10^{-3}\ eV^2$

$\delta cp=0$

PDF for expected number of Super-K ν_e events, including statistical and systematic errors

ν_e appearance results

One candidate event remains after selection



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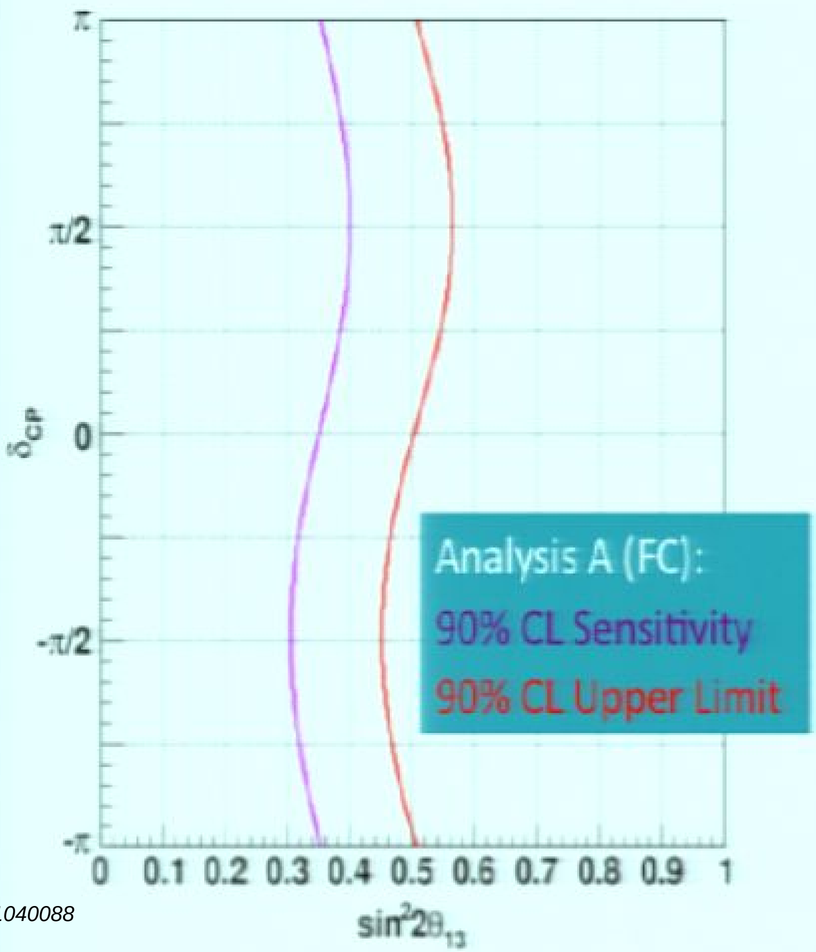
$\Delta m^2 = 2.4 \times 10^{-3}\ eV^2$

$\delta cp=0$

PDF for expected number of Super-K ν_e events, including statistical and systematic errors

ν_e oscillation sensitivity and limits

Two separate methods used to determine sensitivities and limits



Analysis A: Feldman-Cousins

Hierarchy	Upper Limit	Sensitivity
Normal ($\Delta m^2_{23} > 0$)	0.50	0.35
Inverted ($\Delta m^2_{23} < 0$)	0.59	0.42

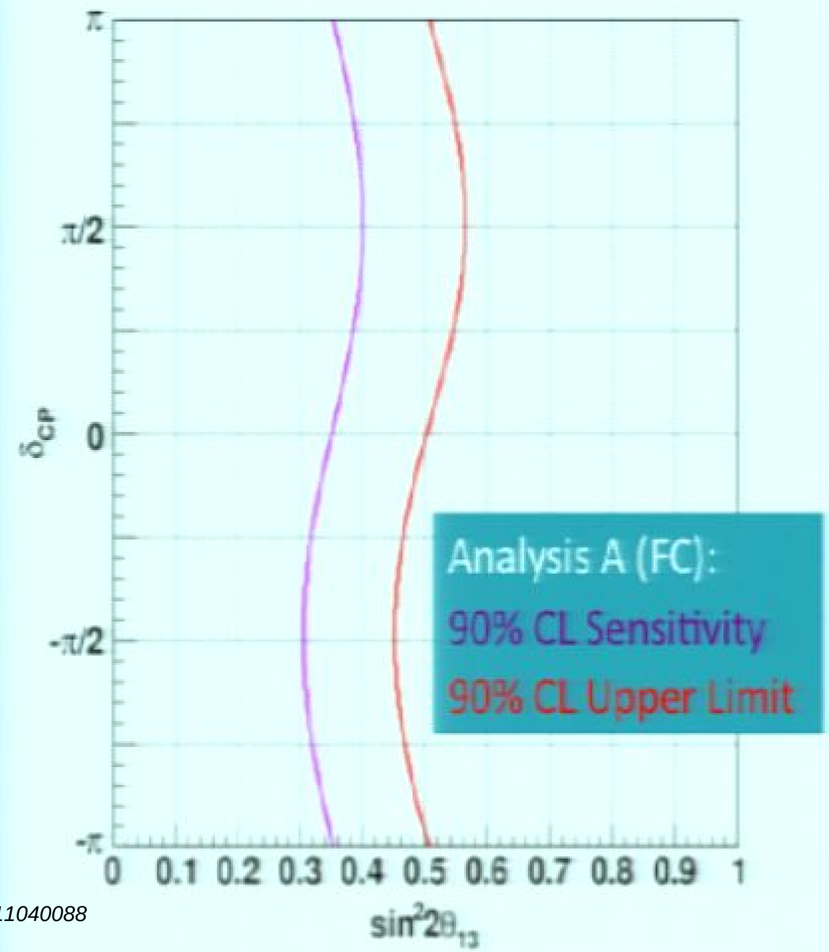
Analysis B: Classical one-sided limit

Hierarchy	Upper Limit	Sensitivity
Normal ($\Delta m^2_{23} > 0$)	0.44	0.32
Inverted ($\Delta m^2_{23} < 0$)	0.53	0.39

Future T2K analysis prospects

ν_e oscillation sensitivity and limits

Two separate methods used to determine sensitivities and limits



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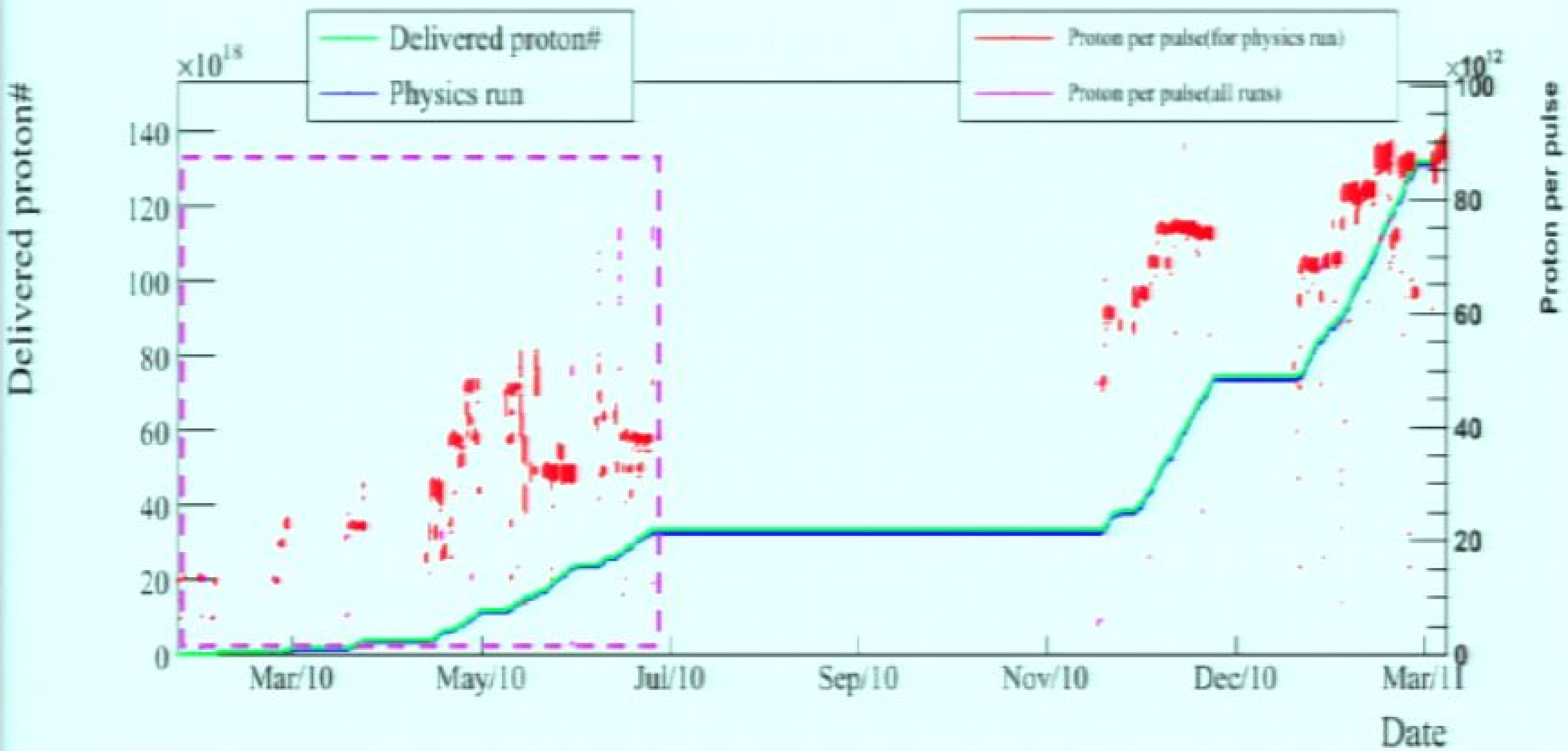
Run 2



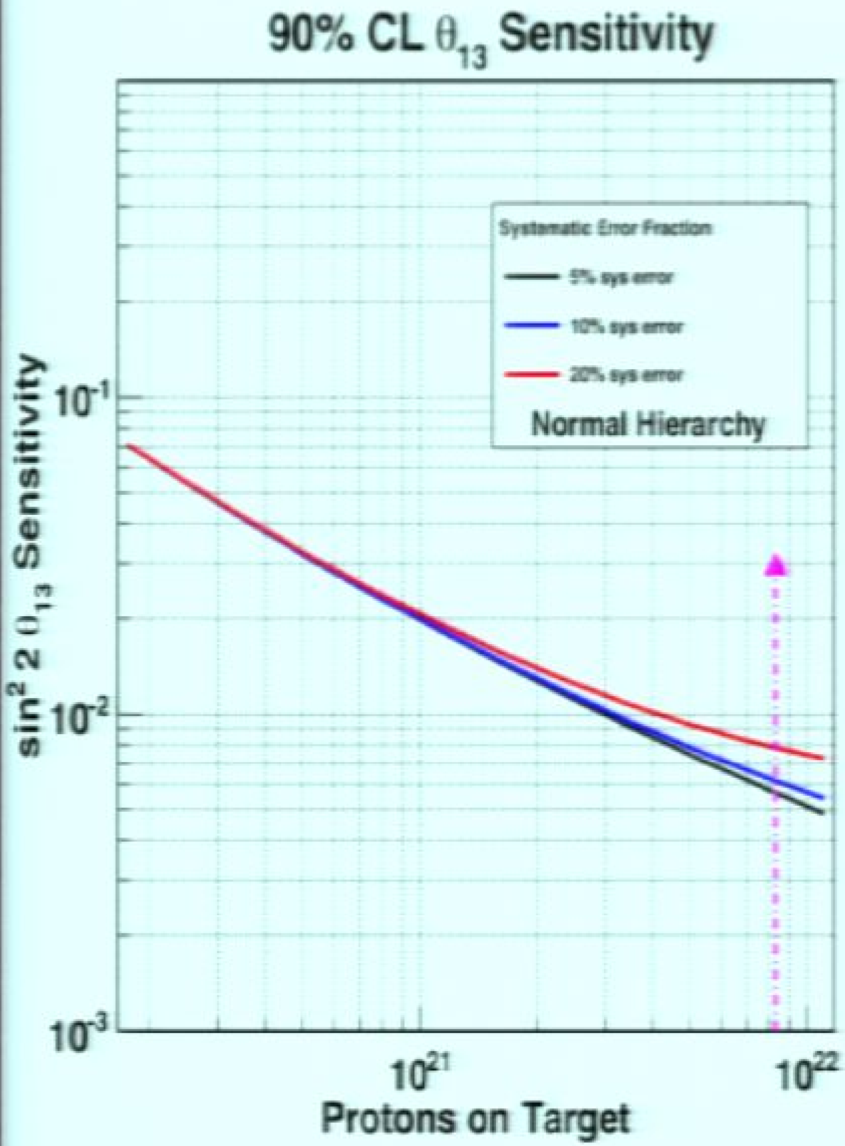
Achieved 145kW stable run in March prior to earthquake

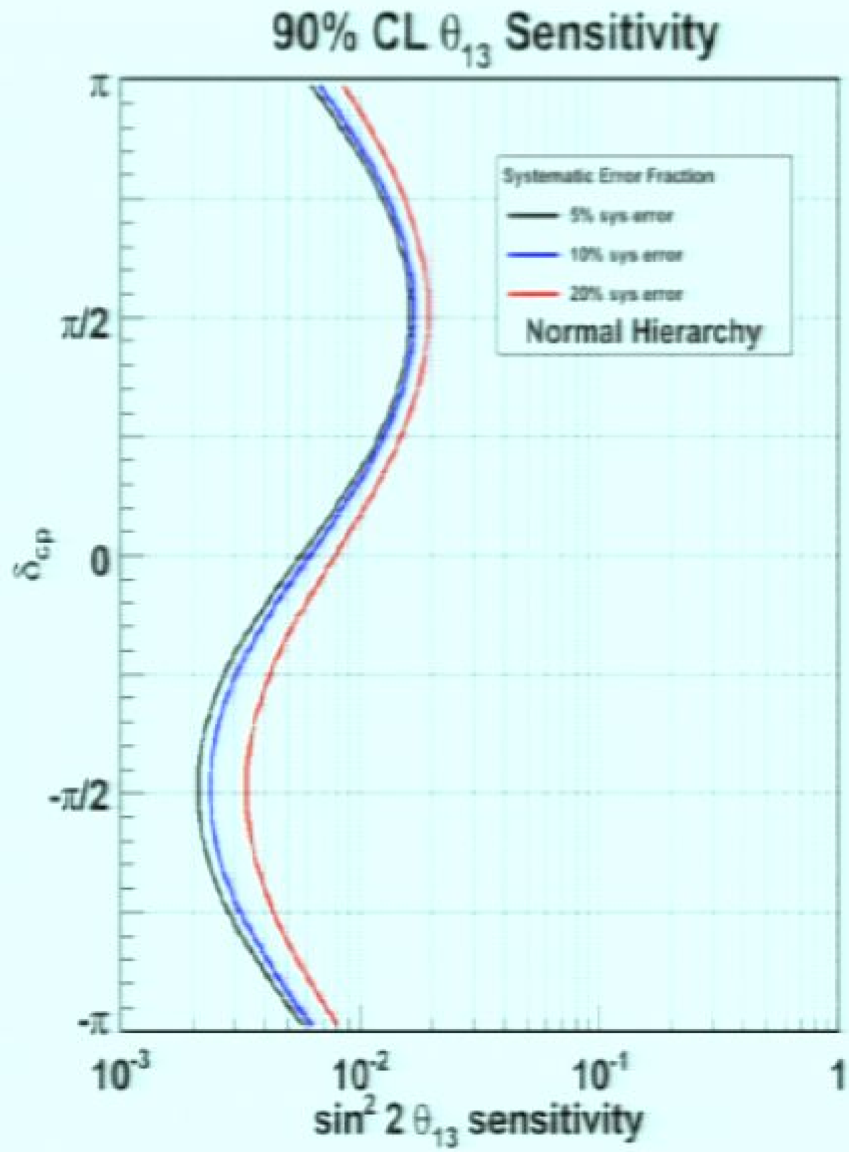
Entire run at 8 bunches / spill / 3.04s

1.45×10^{20} POT collected total

Extra POT is ~4x dataset presented today

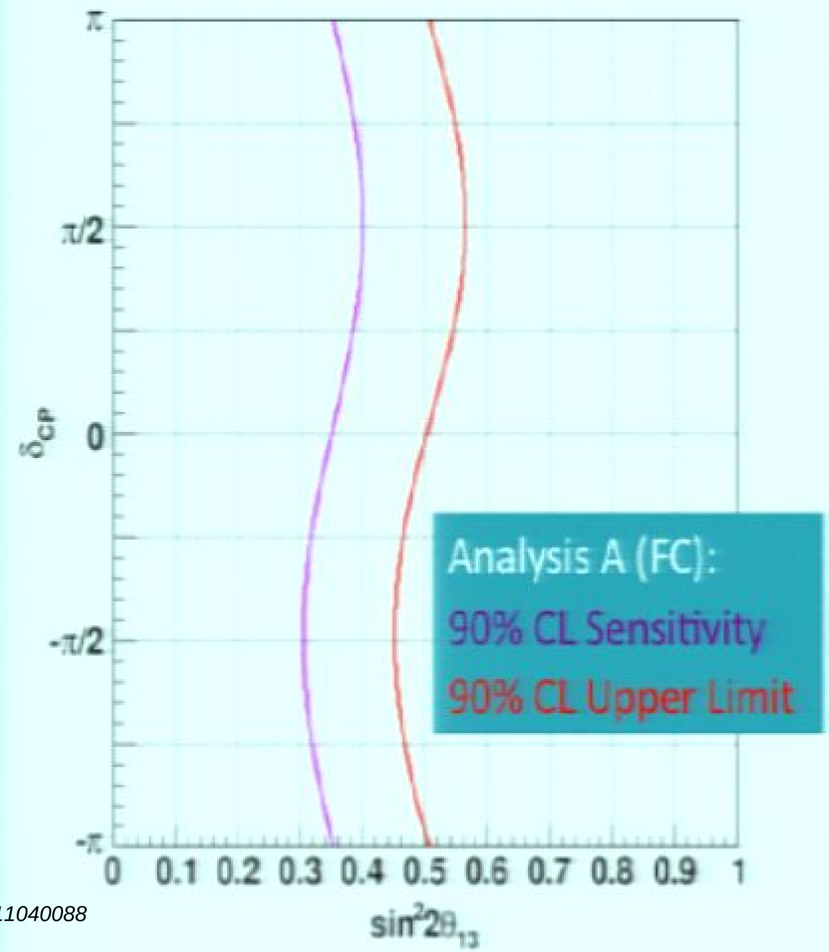
Future ν_e appearance sensitivity





ν_e oscillation sensitivity and limits

Two separate methods used to determine sensitivities and limits



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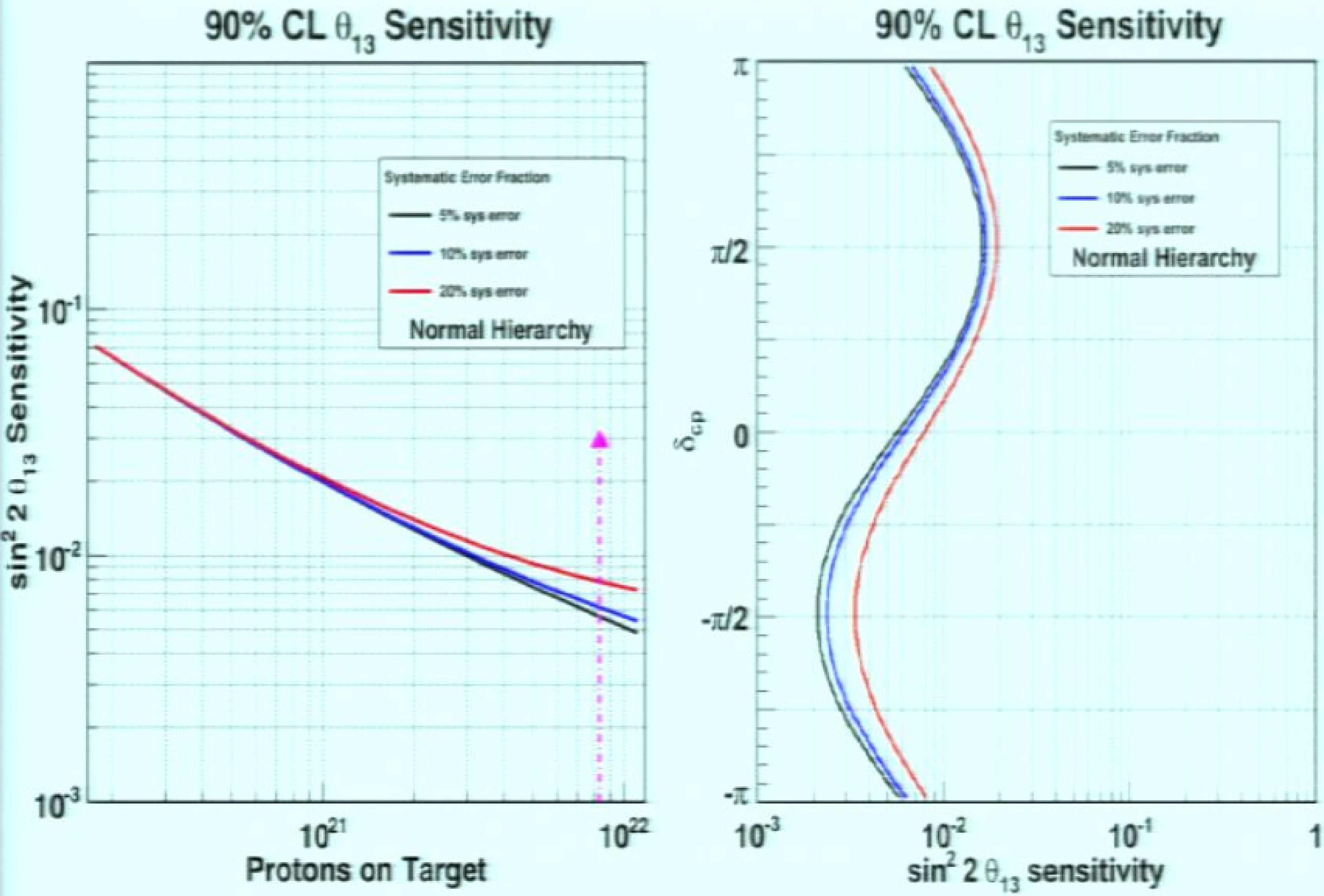
Future ν_e appearance sensitivity



Planned improvements to the analysis

Improvements to the flux uncertainties:

Reduced π production systematics from NA61

Addition of NA61 kaon data

Error (+)	N^{Sig}_{SK}	N^{bkd}_{SK}	N^{S+B}_{SK}	N_{ND}	N^{bkd}_{SK}/N_{ND}	N^{S+B}_{SK}/N_{ND}
Flux	21.97	18.12	20.49	19.83	9.17	11.88
CCQE	4.91	2.62	4.33		2.72	4.33
CC1π	4.28	3.76	4.15	5.93	2.10	1.78
NCπ^0	-	5.86	1.48	0.05	5.56	1.43
FSI	3.83	10.34	5.47	-	10.32	5.47
ND detector	-	-	-	5.60	5.60	5.60
ring counting	3.90	8.40	5.03	-	8.40	5.03
electron PID	3.80	8.10	4.88	-	8.10	4.88
invariant mass	5.10	8.70	6.01	-	7.70	6.01

Planned improvements to the analysis

Improvements to the constraints provided by ND280:

- ν_μ spectrum measurement
- CCQE, CCπ rate measurements
- Intrinsic ν_e measurement

Error (+)	N^{Sig}_{SK}	N^{bkd}_{SK}	N^{S+B}_{SK}	N_{ND}	N^{bkd}_{SK}/N_{ND}	N^{S+B}_{SK}/N_{ND}
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Planned improvements to the analysis

Improved Super-K selection cuts

Improved Super-K detector uncertainties

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Summary

The T2K experiment is designed to make precision measurements of:

ν_μ disappearance ($\Delta m^2_{23,}\ \theta_{23}$)

ν_e appearance (θ_{13})

With the initial 6 month run ending in Jun 2010:

the ν_μ dataset of 8 events is consistent with disappearance measured by previous experiments (MINOS, Super-K,K2K)

One candidate ν_e event was observed

Expected background is 0.30 ± 0.07

Analysis of the 1.45×10^{20} POT collected thus far is underway

Expected sensitivity is better than the current MINOS/CHOOZ limit

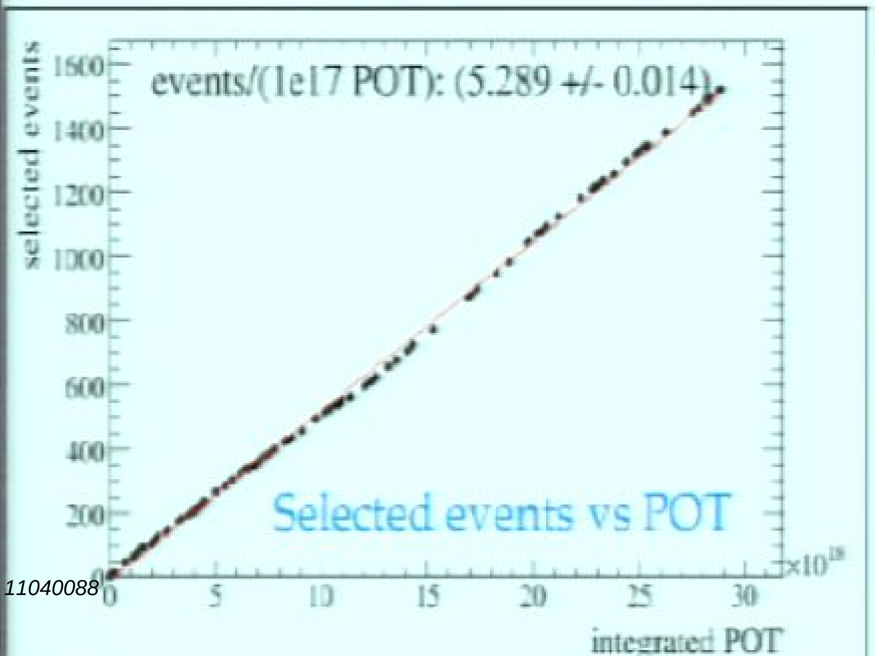
ND280 performance

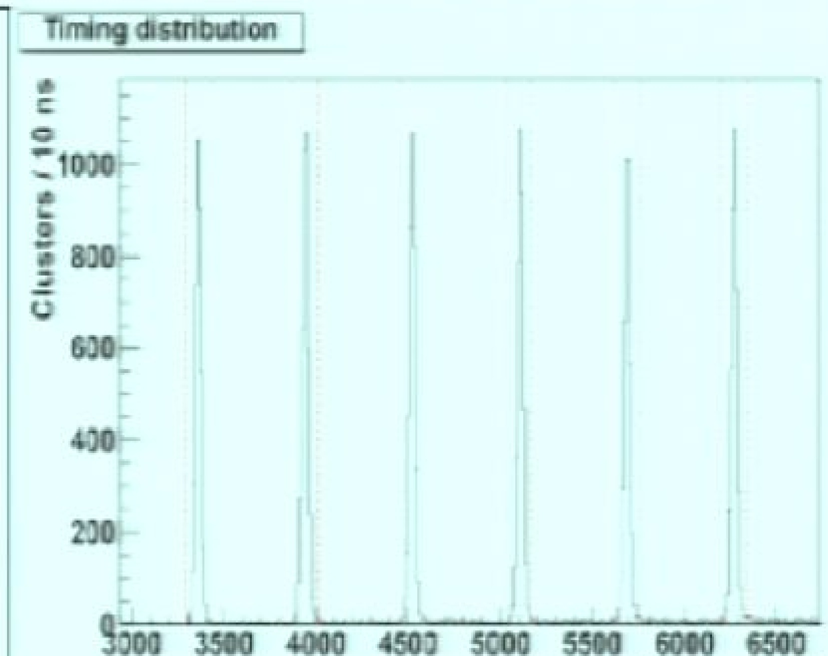
Low rate of broken channels

Events / POT stable

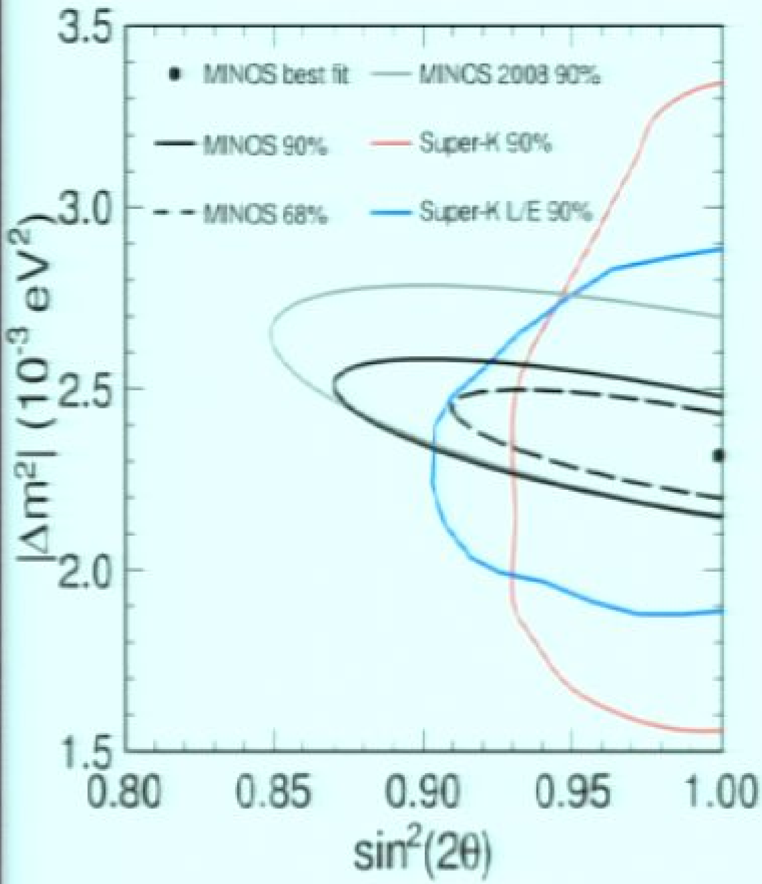
Timing consistent with beam (FGD)

Detector	Channels	Bad ch.	Bad fraction
ECAL (DSECAL)	22,336 (3,400)	35 (11)	0.16% (0.32%)
SMRD	4,016	7	0.17%
P0D	10,400	7	0.07%
FGD	8,448	20	0.24 %
INGRID	10,796	18	0.17 %
TPC	124,416	160	0.13 %

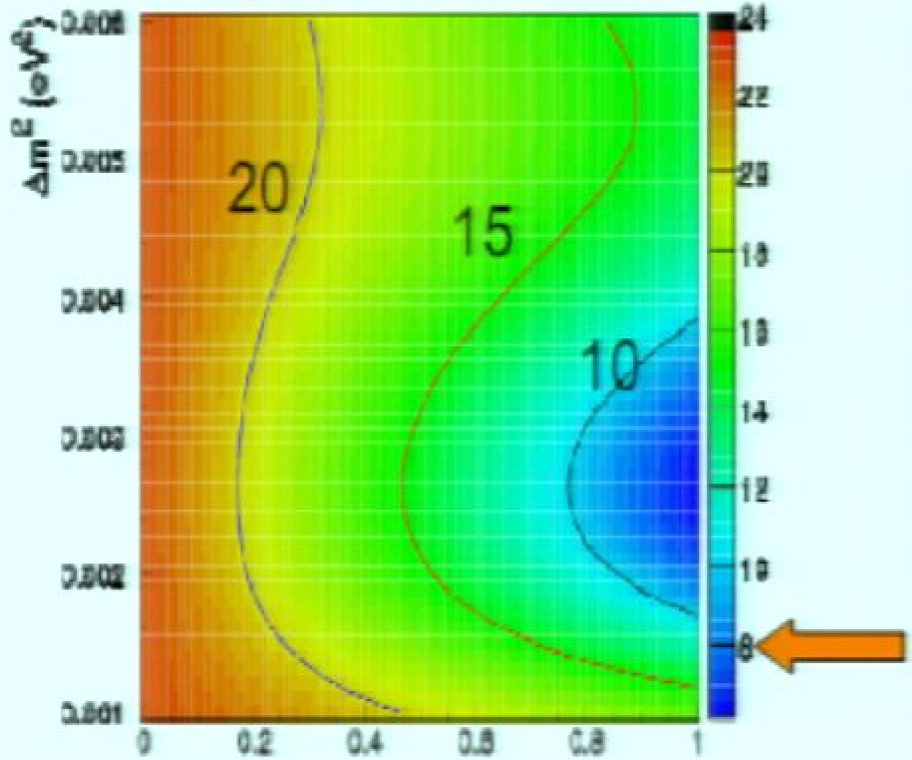




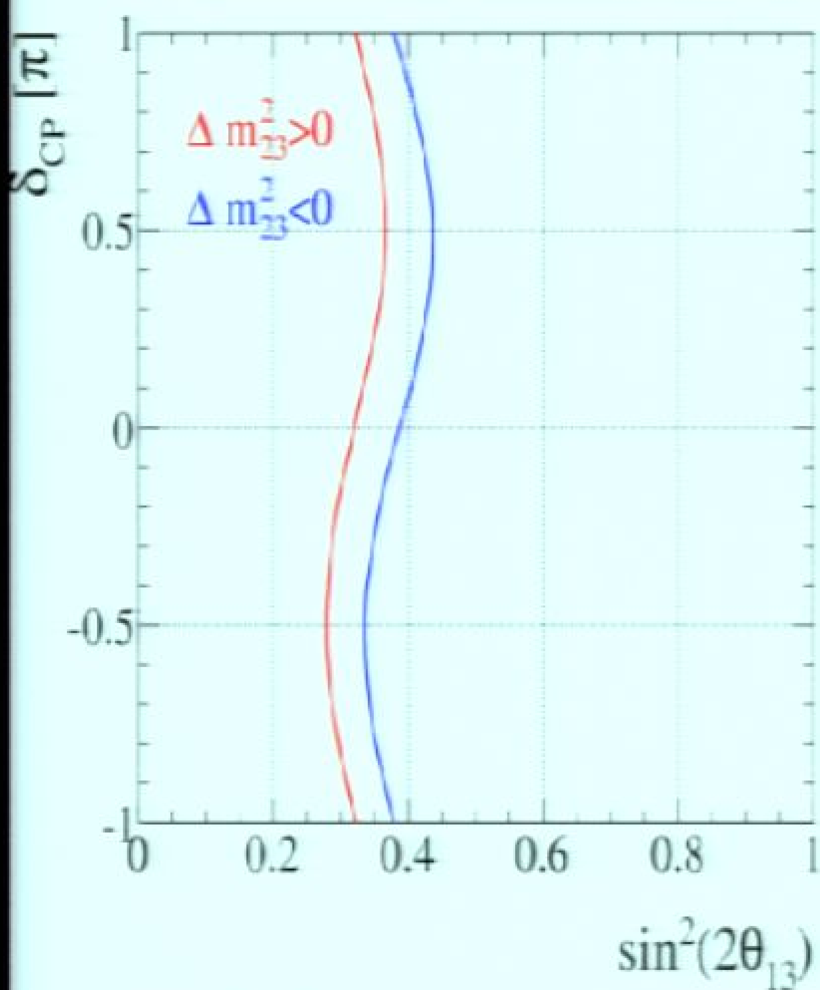
ν_μ disappearance consistency



Expected # of events as a function of Oscillation parameters.



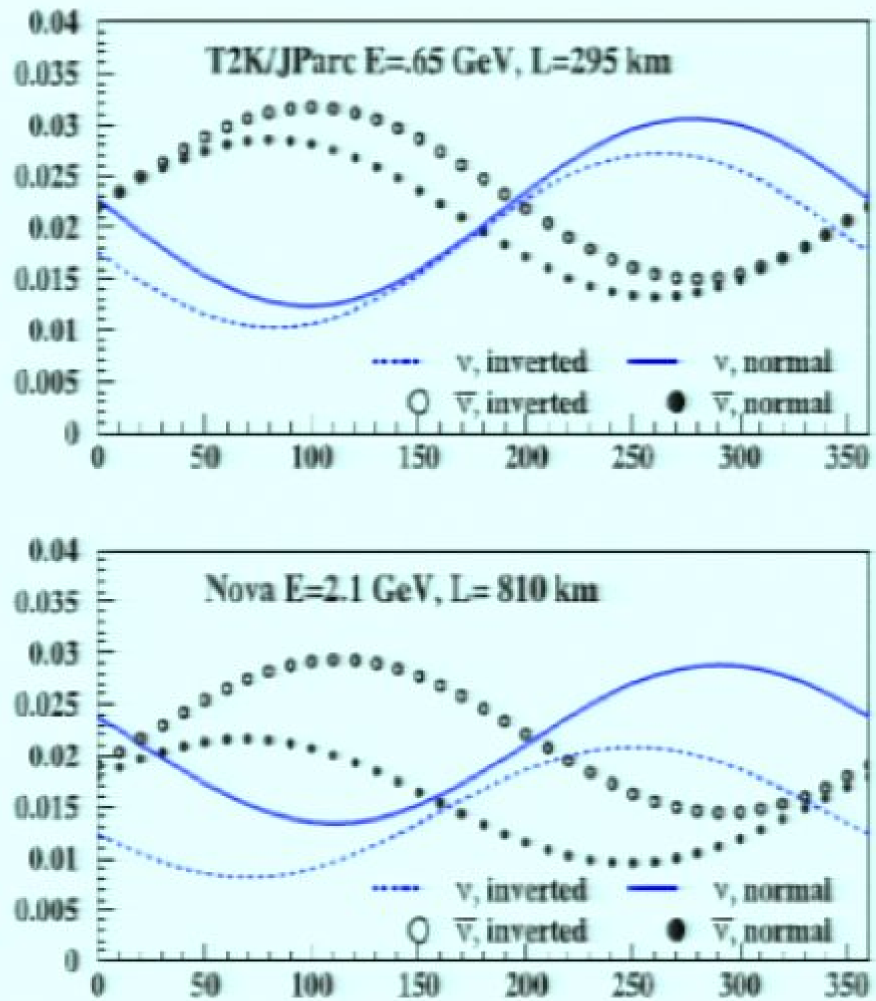
ν_e results: normal vs. inverted hierarchy



Analysis B:

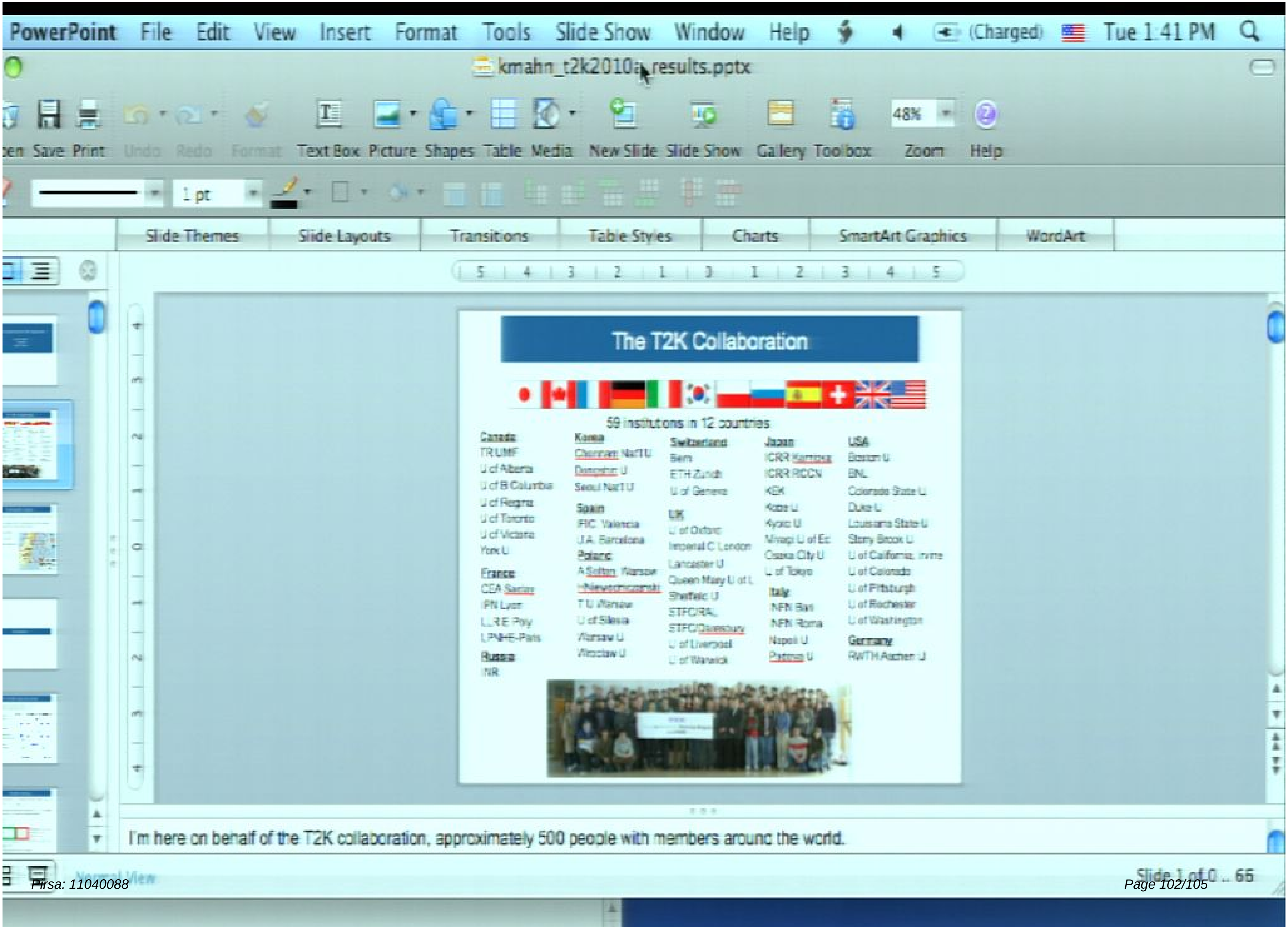
Normal hierarchy

Inverted hierarchy



Oscillation probability vs. dCP (deg)

Int. J.Mod. Phys. A 21, 3825 (2006)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Save Print Undo Redo Format Text Box Picture Shapes Table Media New Slide Slide Show Gallery Toolbox Zoom Help
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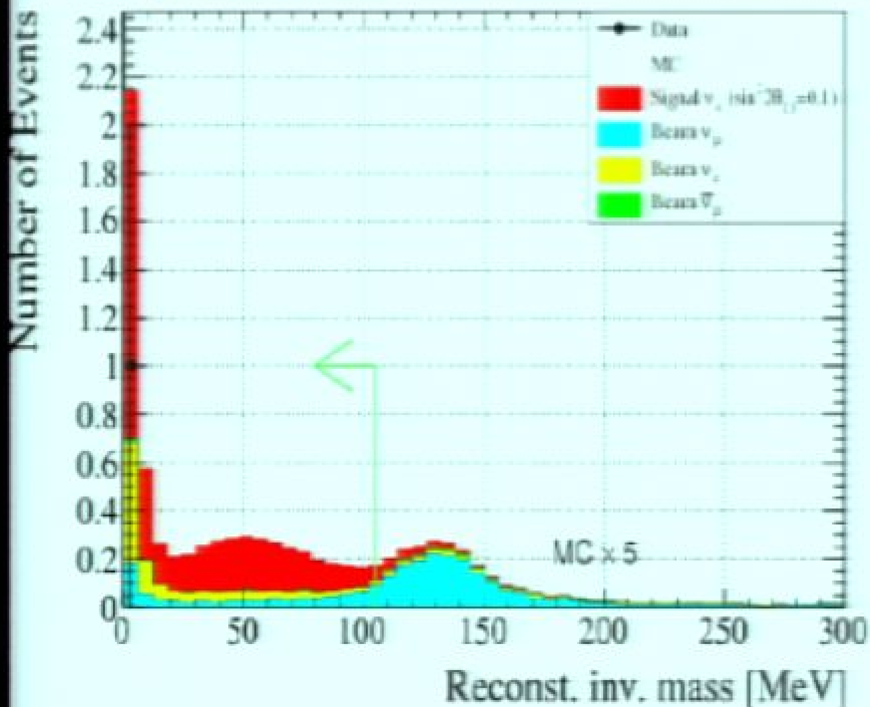
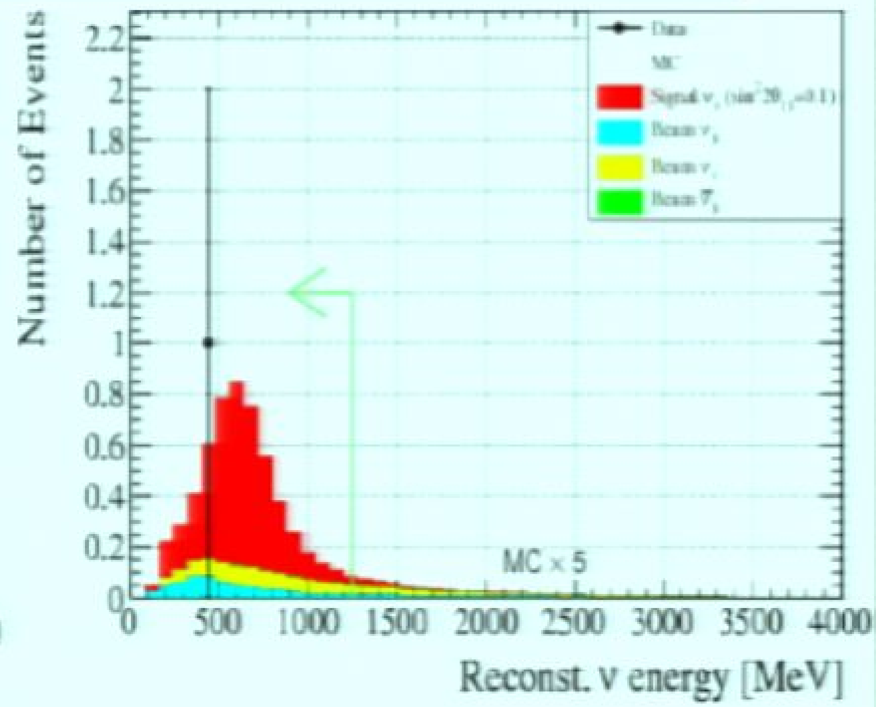
Slide Layouts
Transitions
Table Styles
Charts
SmartArt Graphics
WordArt
The T2K Collaboration
59 institutions in 12 countries
Canada
Korea
Switzerland
Japan
USA
Spain
UK
Poland
France
Italy
Germany
Russia
I'm here on behalf of the T2K collaboration, approximately 500 people with members around the world.
Normal View
Slide 1 of 0 .. 65

ν_e events after cuts





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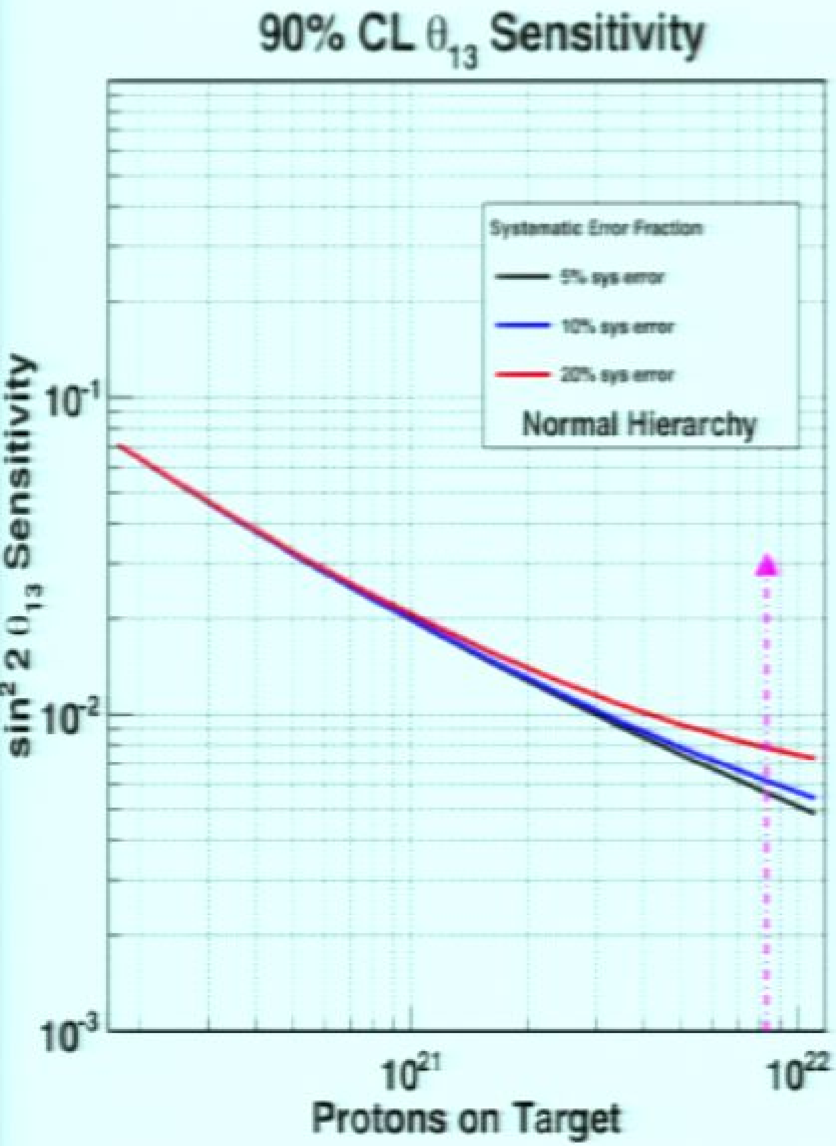

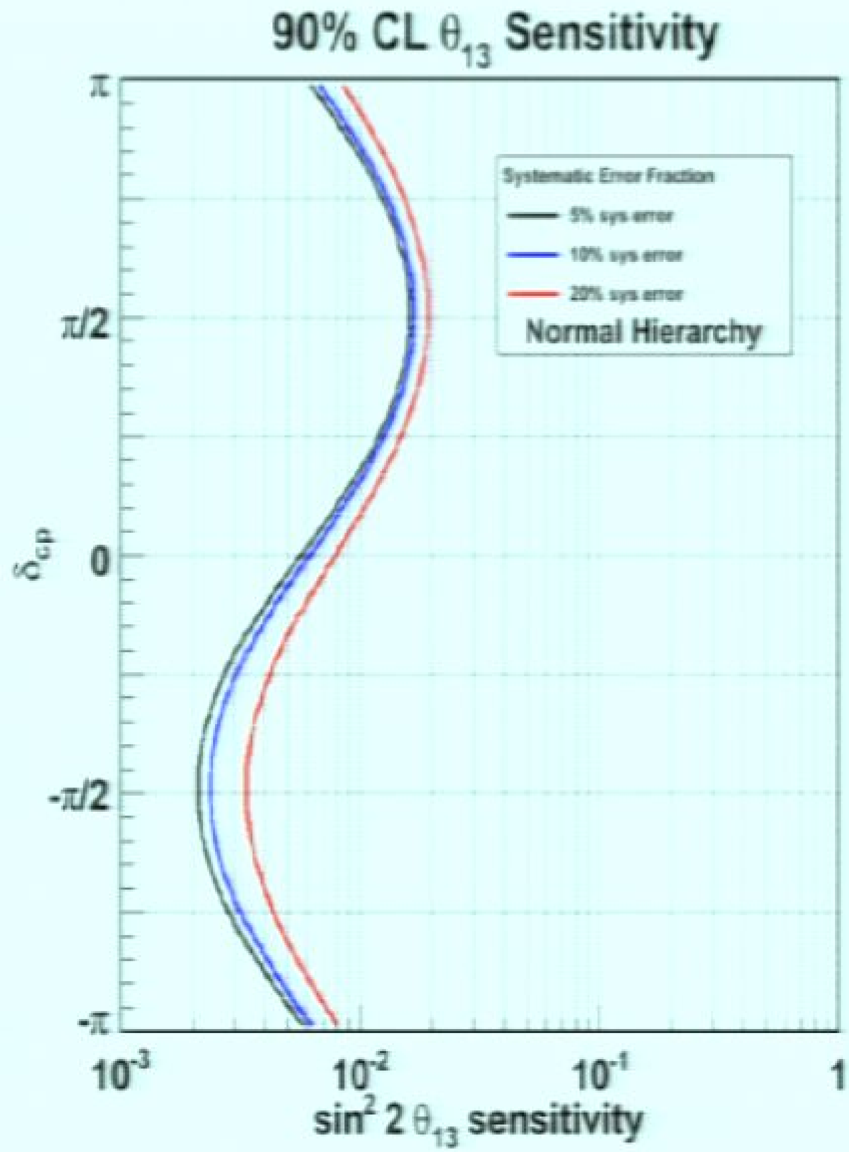

Future ν_e appearance sensitivity