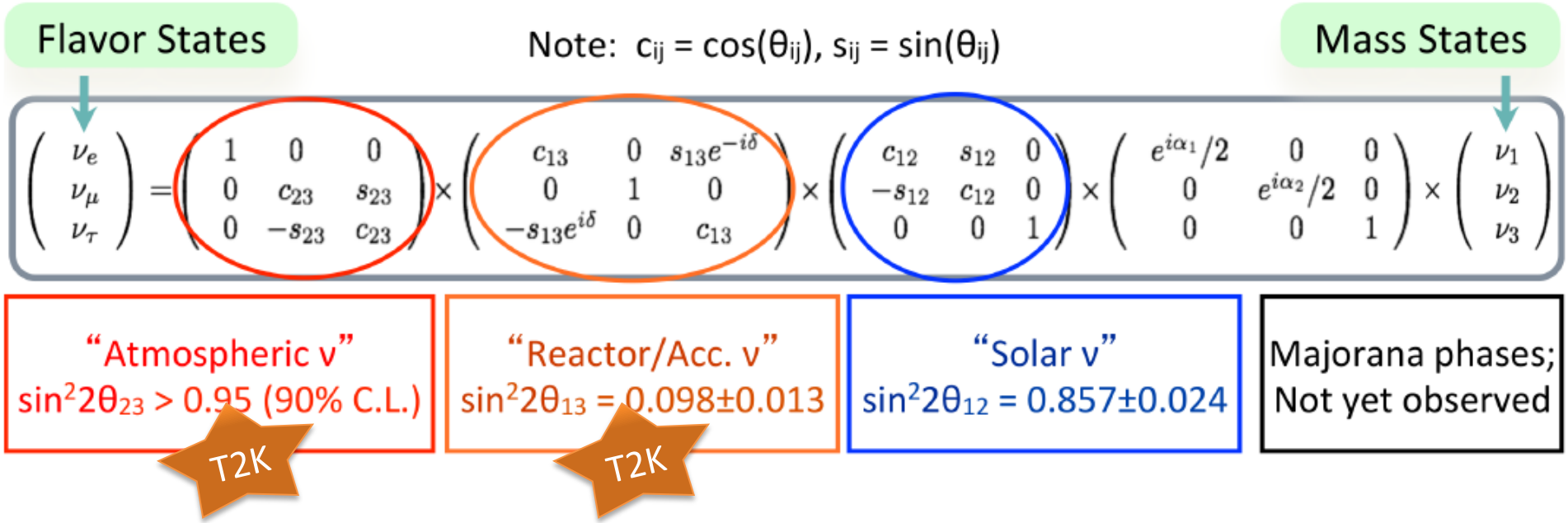
T2K: Contribution of Bern and general prospect

A. Ariga

on behalf of T2K-Bern and -Swiss group

T2K goals

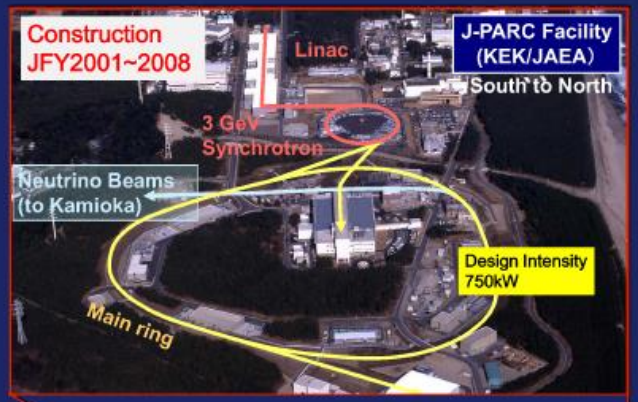


- Observation of $\nu_\mu \rightarrow \nu_e$ oscillation in appearance mode
- Precision measurement of ν_μ disappearance

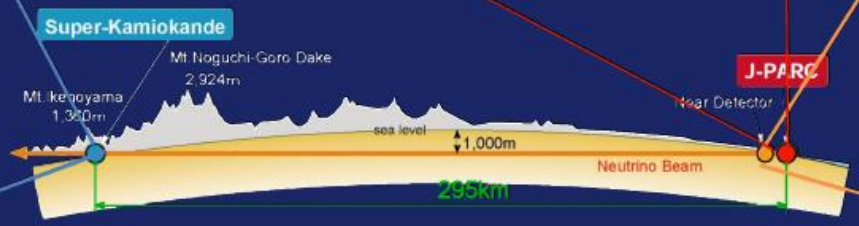
The T2K experiment

Long-baseline neutrino oscillation experiment with ν_μ beam

T2K = Tokai to Kamioka



ND280

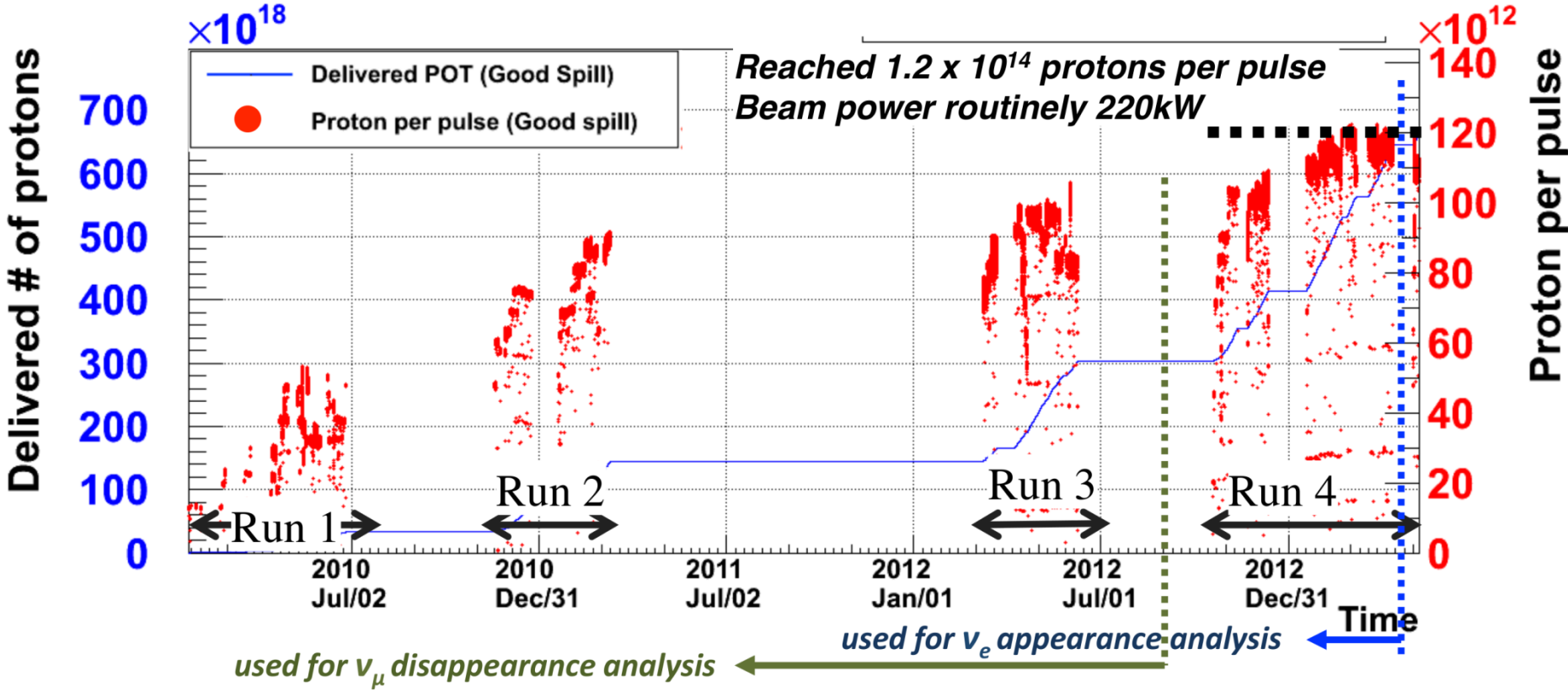


"far" detector

"near" detectors

INGRID

Data taking

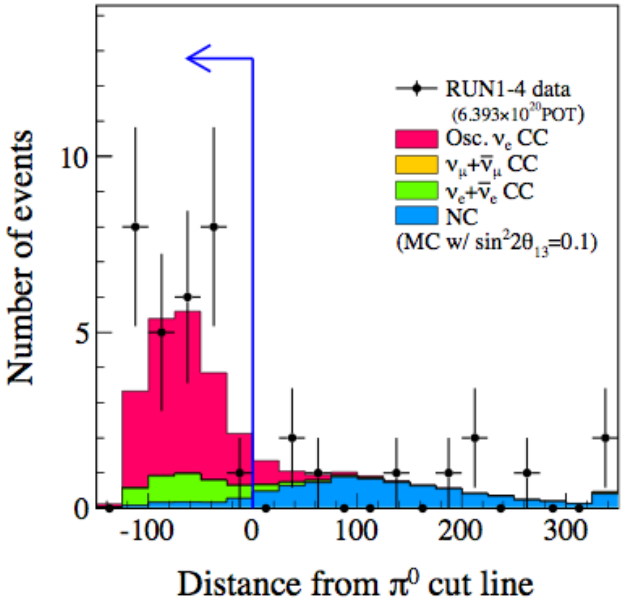


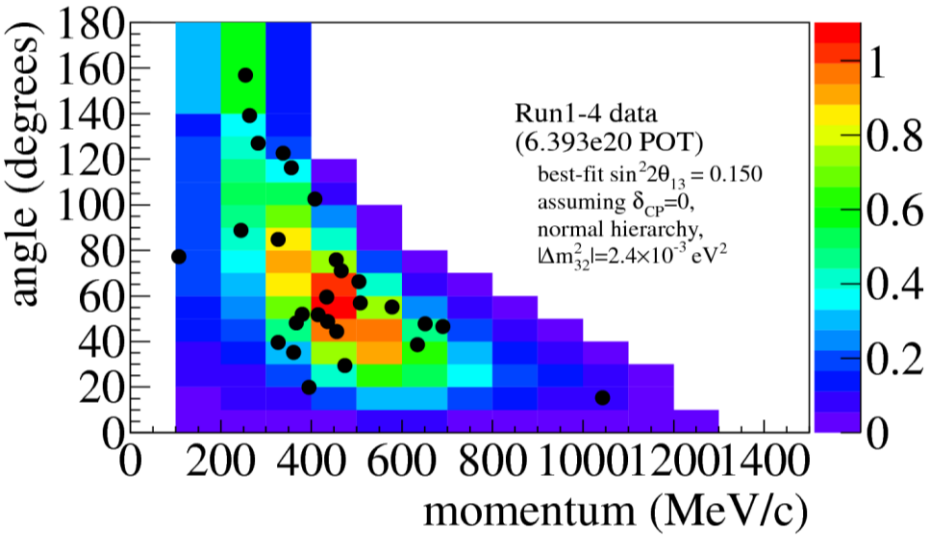
- Stable operation at 220kW
- 6.63 x 10^{20} POT has been delivered
  - 8.3% of the final total POT

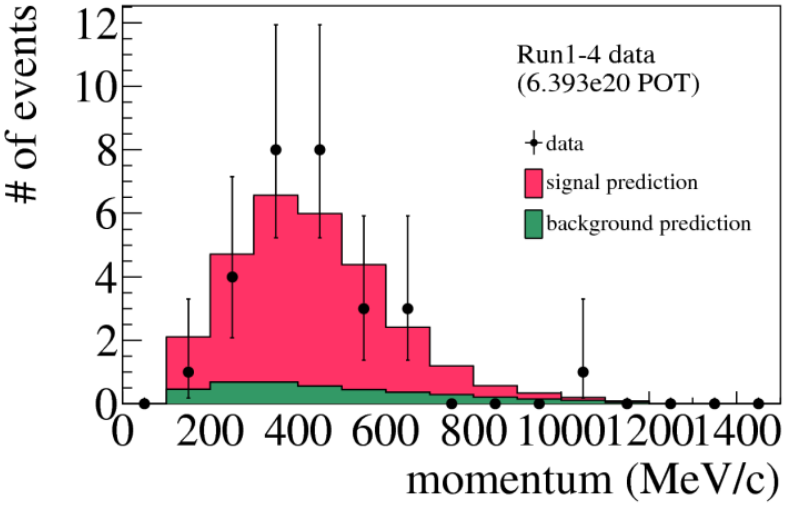
Observation of ν_e appearance

- **28** events selected (6.4x10^{20} pot)

  while 4.92+-0.55 events expected without oscillation.
- Best fit (errors =1σ C.L.)
  - NH :sin2(2q13)= 0.150 $^{+0.039}_{-0.034}$
  - IH : sin2(2q13) = 0.182 $^{+0.046}_{-0.040}$
- Excludes $\sin^2(2\theta_{13}) = 0$ at **7.3σ**

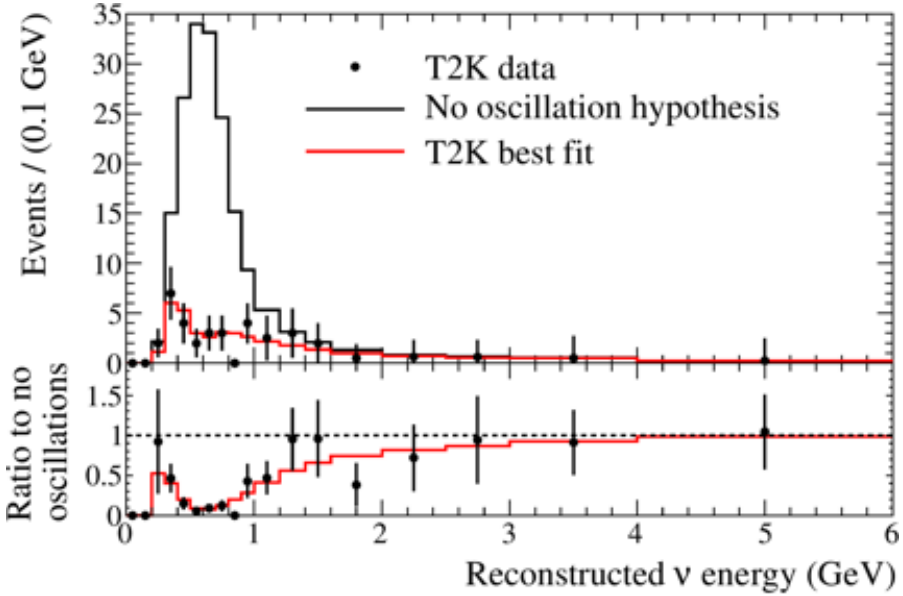


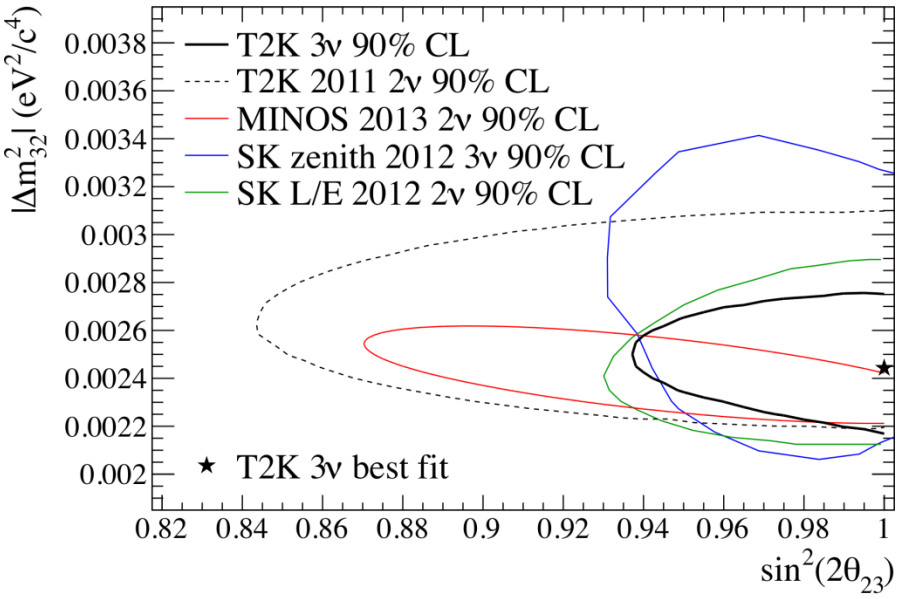




Disappearance

- Select ν_μ CCQE candidates in far detector
- 58 events in data (3.01x1020 POT)

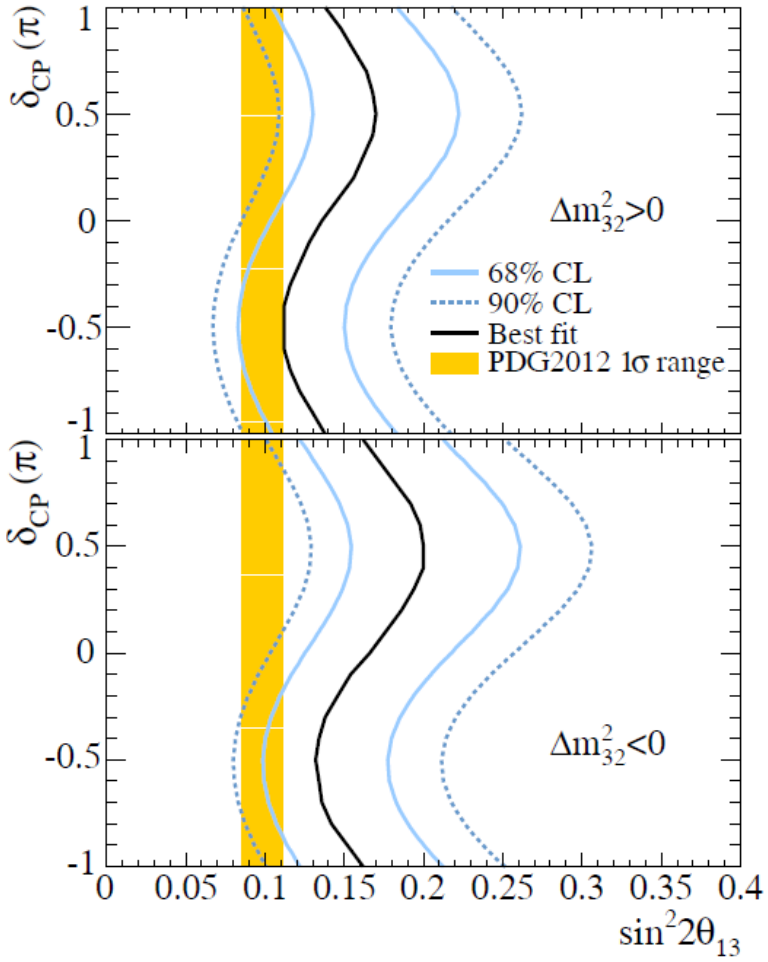




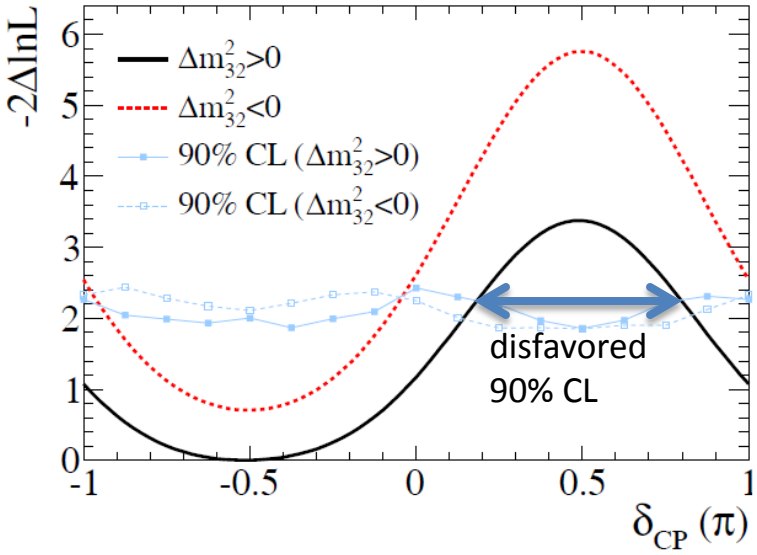
T2K 2011: K. Abe et al. (The T2K Collaboration), Phys. Rev. D 85, 031103 (Feb 2012)
SK: Y. Itow, Nuclear Physics B - Proceedings Supplements 235236, 79 (2013), ISSN 0920-5632
MINOS: P. Adamson et al. (MINOS Collaboration)(2013), arXiv:1304.6335 [hep-ex].

dependence of δ_{CP}

Allowed region of $\sin^2 2\theta_{13}$ for each value of δ_{CP}



Combination with reactor result disfavored a part of δCP space



Swiss contribution to T2K

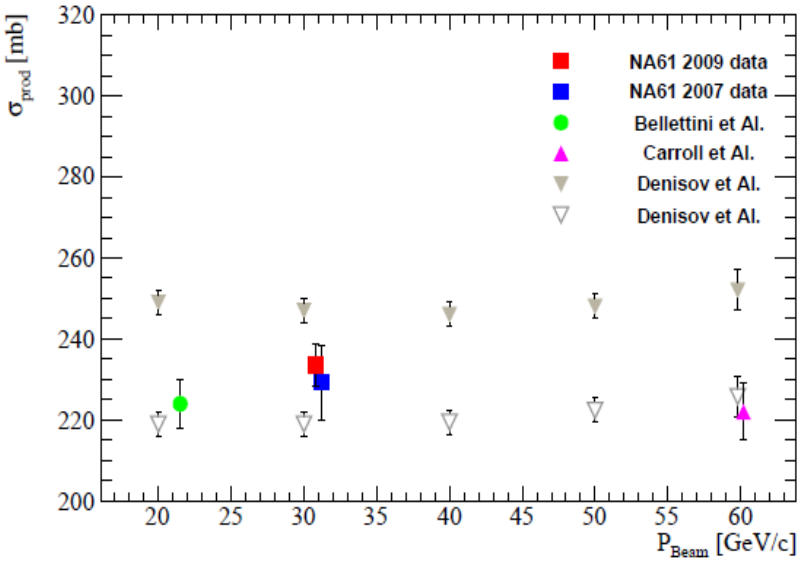
(sorry, I couldn’t cover all due to lack of time)

NA61/SHINE

- T2K requires a precise knowledge of neutrino beam flux
- Data taking in 2007,2009 and 2010 with proton momentum of 31 GeV/c on Carbon target
- Determination of total p+C cross-section and also π^{+-}, K^{+-}, K^0 differential production cross-section

$$\sigma_{prod} = 233.5 \pm 2.8(\text{stat}) \pm 4.2(\text{model}) \pm 1.0(\text{trig}) \text{ mb}$$

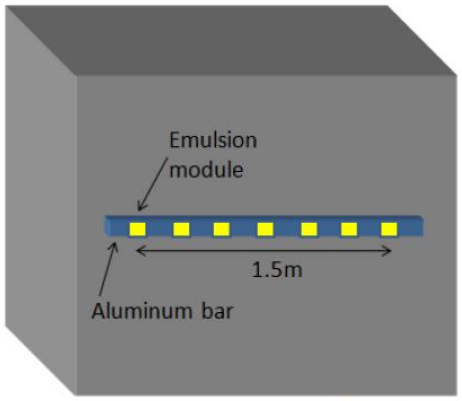
- The result has been taken into account in the T2K flux prediction



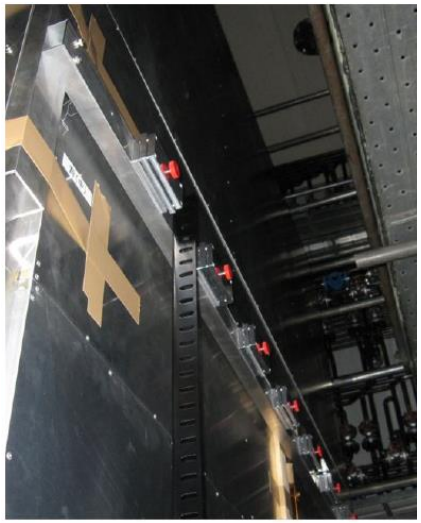
Akitaka Ariga, Tomoko Ariga (Bern)

Muon measurement by emulsion

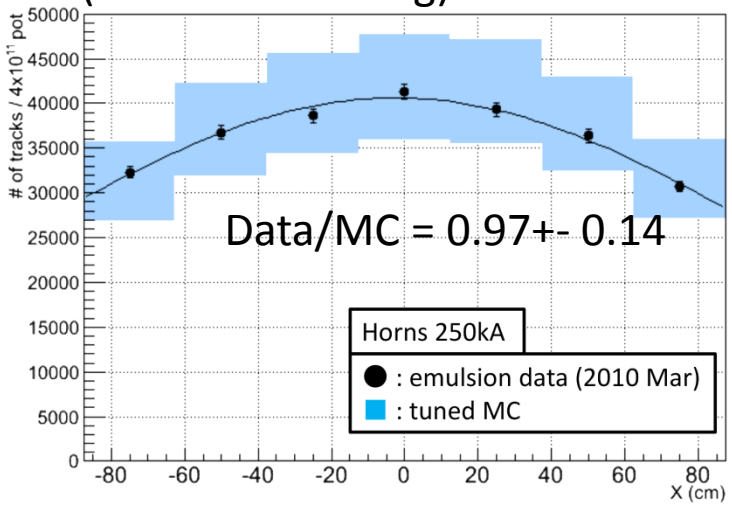
- Absolute muon flux measurement
- Momentum measurement



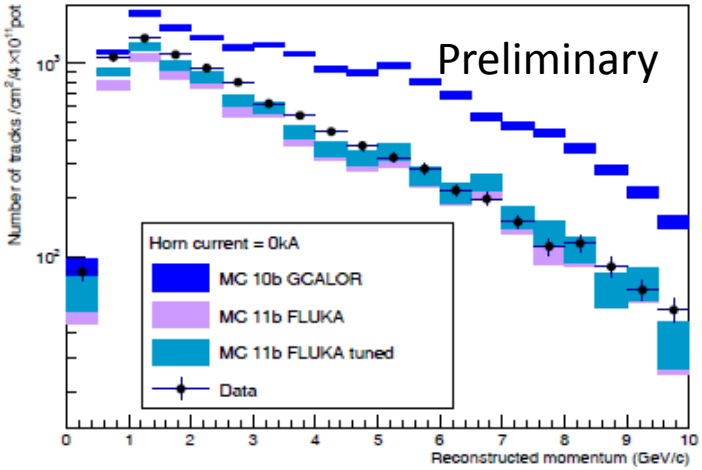
Downstream of MUMON

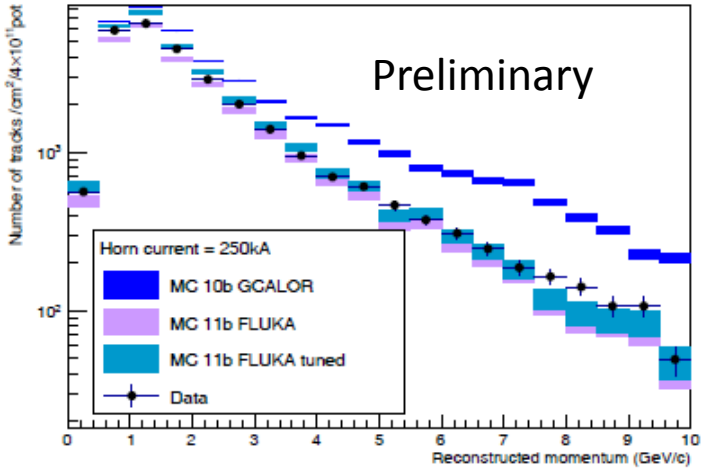


Observed flux and MC prediction (with NA61 tuning)



Momentum distributions

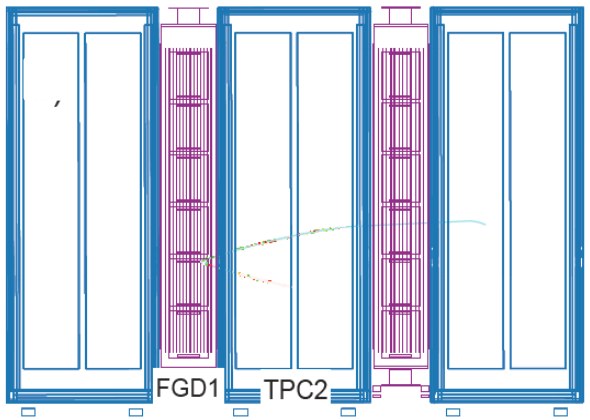




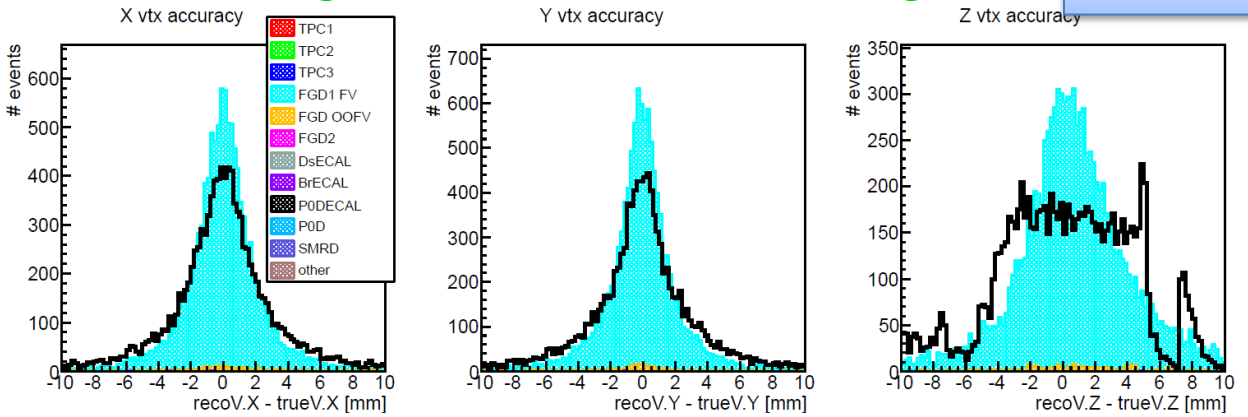
UniGe

TPC Micromegas

Development, testing…



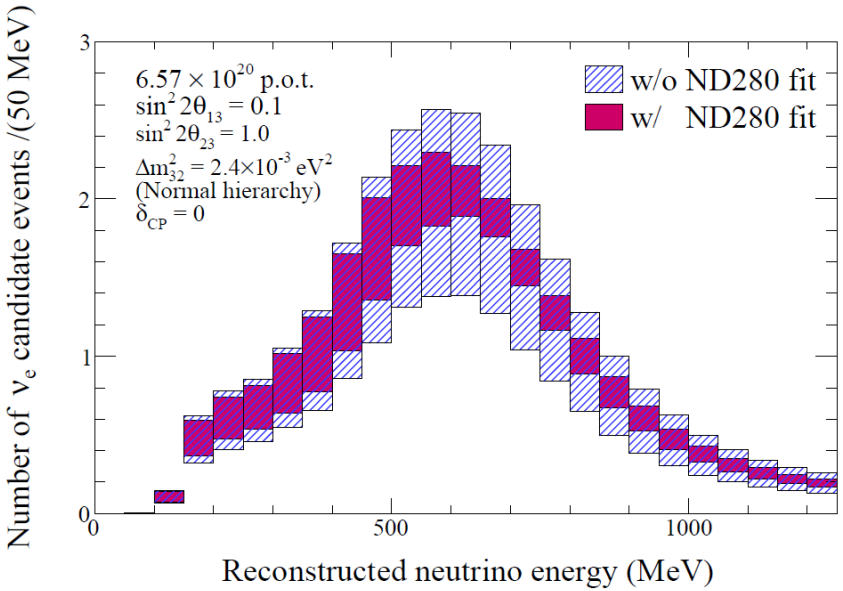
Global vertexing *via* Kalman Filter track fitting



A selection of *Université de Genève* contributions to T2K

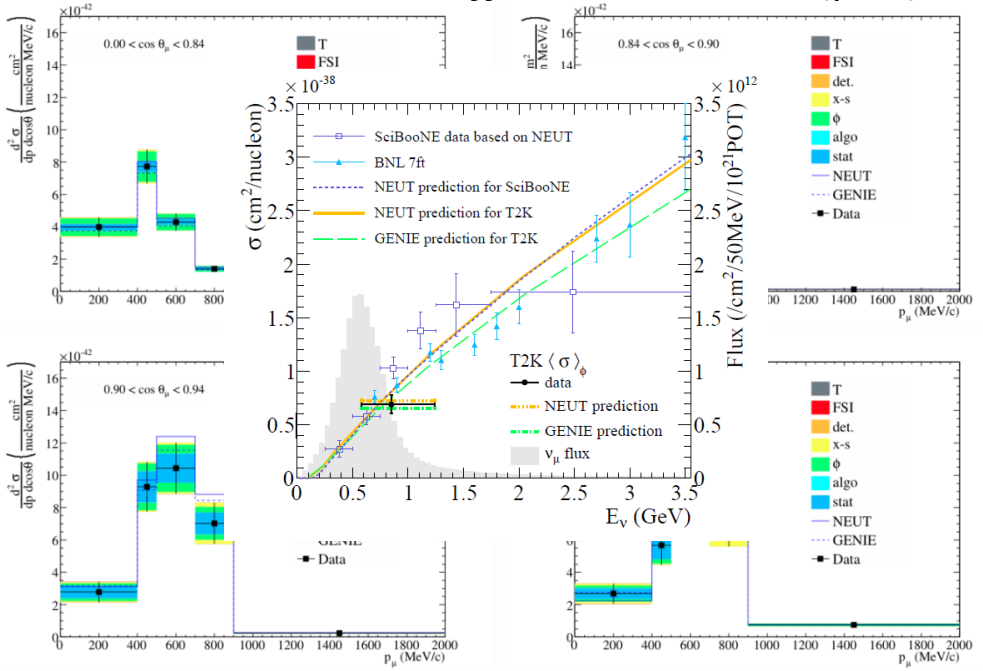
Systematics for ND280

OOFV, propagation within the software…



First cross-section measurement by T2K

Inclusive numu CCinc differential xsec vs. (p, ϑ)



Martin Hierholzer, Damian Goeldi (Bern)

Work on neutrino cross-section measurements in Bern

- **Model-independent measurement of the CC resonant π^+ production cross-section (mostly Δ^{++})**
  - Observe final states consisting of each one μ^-, p, π^+
  - Extract differential cross-sections depending on kinematic variables like T_μ, T_π, Θ_μ etc.
  - No measurement since ANL/BNL (~1980), large uncertainties in those measurements.
  - Good test for FSI models as well!

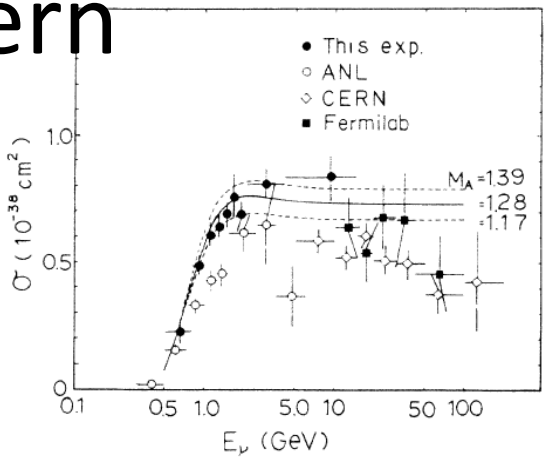
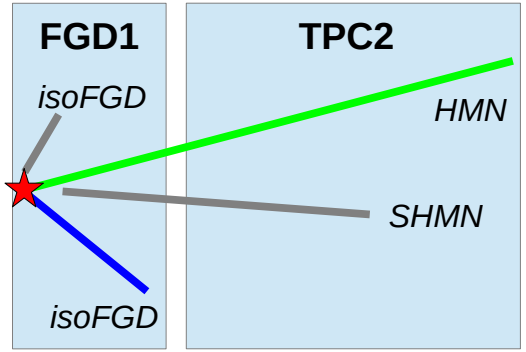


FIG. 14. Comparison of Δ^{++} production cross sections. The solid curve is from the prediction of the Adler model with $M_A = 1.28$ GeV. The dashed lines correspond to the predictions with $M_A = 1.28 \pm 0.11$ GeV.

- **Development of a multi-purpose cross-section measurement tool**
  - Attempt to unify efforts for cross-section analyses within T2K
  - Designed to be flexible and expandable for use in different scenarios
    - different detectors like ND280 and INGRID
    - different event selections as input
    - allow use of multiple algorithms to extract the cross-section, e.g. unfolding and fitting
    - handle systematic errors from detector, background cross-sections, FSI and beam (based on existing systematic studies and tools)

Global vertexing validation

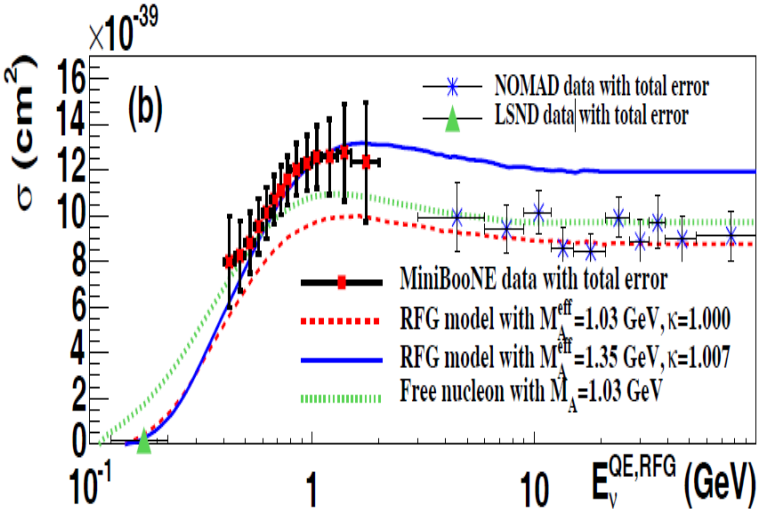
- ND280 reconstruction software contains an algorithm to fit a global vertex to reconstructed subdetector tracks. (see fig.)
- This code is currently being validated.
- Control samples have been developed to evaluate systematic effects for potential analyses using global vertices.



- Outlook: Use events with multiple global vertices (due to e.g. particle decays) to look for “rare” physics such as strangeness production from neutrino interactions.

CCQE cross-section

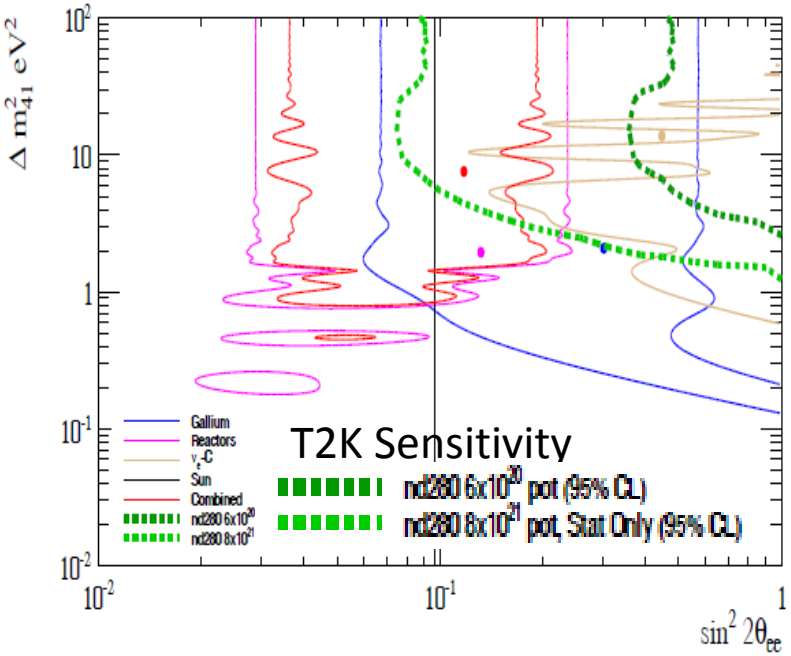
- Recent experiments report higher value of axial mass M_A=1.35 from the fit CCQE data.
- These effects could be attributed to the nuclear effects from the use of heavy nucleus target. Theory models available.
- With increase of statistics in T2K, the systematic coming from these effects will limit the precision measurement of oscillation parameters.
- NEUT, generator used for T2K analysis, is being updated for new interaction models like
  - Multi-nucleon ejection model. *
  - Random Phase Approximation.*
  - Spectral function
- Bern group contributed in these *.
  Further will do model dependent cross-section measurement to test these new models against T2K data



ETHZ

Sterile neutrino search

- Search of ν_e disappearance
  - $\nu_e \rightarrow \nu_s$ in "3+1 model"
- Use of electron selection algorithm developed by ETHZ
- Sensitivity study has been done
- The fit result from data will be obtained soon

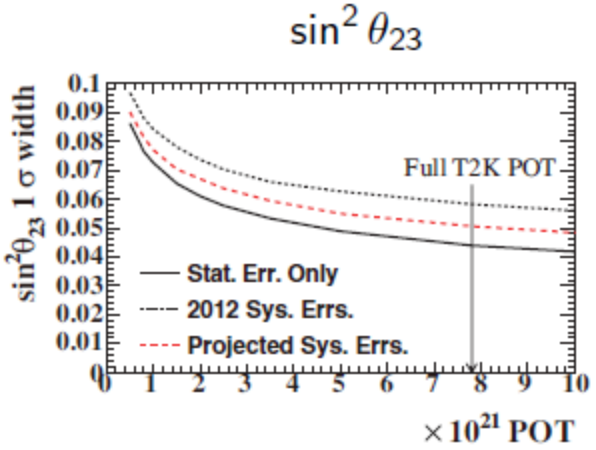


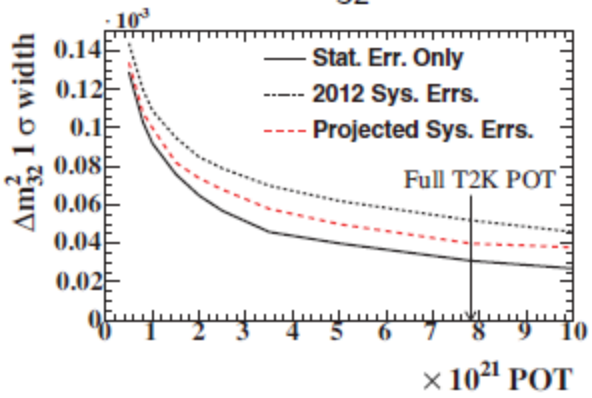
Oscillation analysis

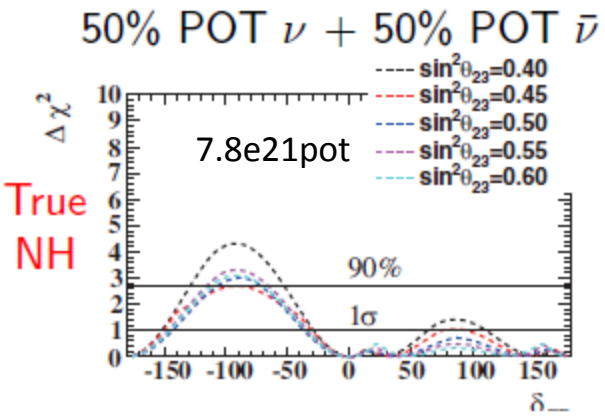
- Combining data from the ND280, SK, Neutrino flux using NA61.
- Precision measurement of Δm^2_{23} (10^{-4} eV^2) and $\sin^2 2\theta_{23}$ (0.01)
- Strengthen the interpretation of non-zero θ_{13} results.
- ETHZ takes part of physics data analysis group (VALOR, in collaboration with Liverpool, Oxford and Barcelona)
  - 3-flavour disappearance oscillation analysis.

Future plan

- Total POT approved is **750kW x 5x10^{7}s = 7.8x10^{21}POT**
  - **so far 0.66 x 10^{21}POT**
- Accelerator/beamline upgrades as early as possible
  - 220 kW operation in 2013, integrated 6.7 · *1020 POT to date*
  - Linac upgrade to be completed this year. Expect up to 400 kW
  - Planned MR upgrade by 2018 (depends on funding). Up to 750 kW
- Updated T2K main goals are
  - **Precision measurements of ν_μ disappearance**
    - $\delta(\sin^2\theta_{23})\sim\pm 0.05 \sim \delta(\sin^2 2\theta_{23})\sim 0.01$
    - $\delta(\Delta m^2_{23})\sim<10^{-4}\text{eV}^2$
  - **Precision measurements of ν_e appearance**
    - Syst err ~ 5% (~10%) for nu(anti-nu) to be less than stat error
  - **Initial measurement of CP violation**
- In addition,
  - **Various precious data of interaction cross sections**
  - Other topics
- **We request anti-ν test run of 1x10^{20}POT (25.3day at 220kW) data in 2014**
- Near detector improvements are under discussion







Summary

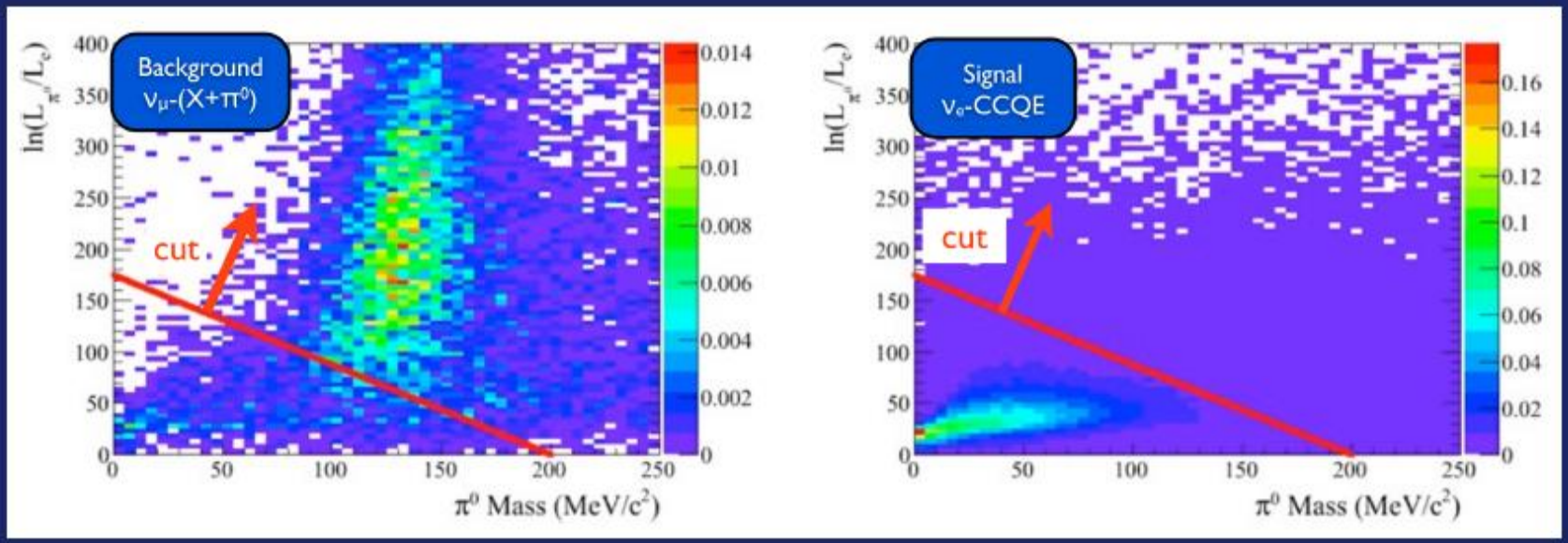
- Measured non-zero θ_{13} with 7 σ significance by observation of $\nu_\mu \rightarrow \nu_e$ *oscillations*
- Disfavouring region of δ_{CP} in combination with reactor results
- Also measurement of ν_μ disappearance which favours maximal mixing

- Accelerator-based oscillation experiments at “atmospheric” baselines are now precision measurements
- Measurements of neutrino cross sections (CC incl., CCQE)
- More statistics in near future

Backup

Enhanced π^0 rejection

- New algorithm: use likelihood based on charge and time of each PMT hit



ne-appearance selection

- E_{vis} > 100 MeV
- Veto hits < 16
- Fully contained
- (Fid. Vol. = 200 cm)
- Single ring
- Muon-like
- p_μ > 200 MeV
- 0 or 1 Michel e

- 28 events selected
- while 4.92+-0.55 events expected without oscillation.