Measurement of the muon neutrino CCQE cross section on carbon with the T2K off-axis near detector

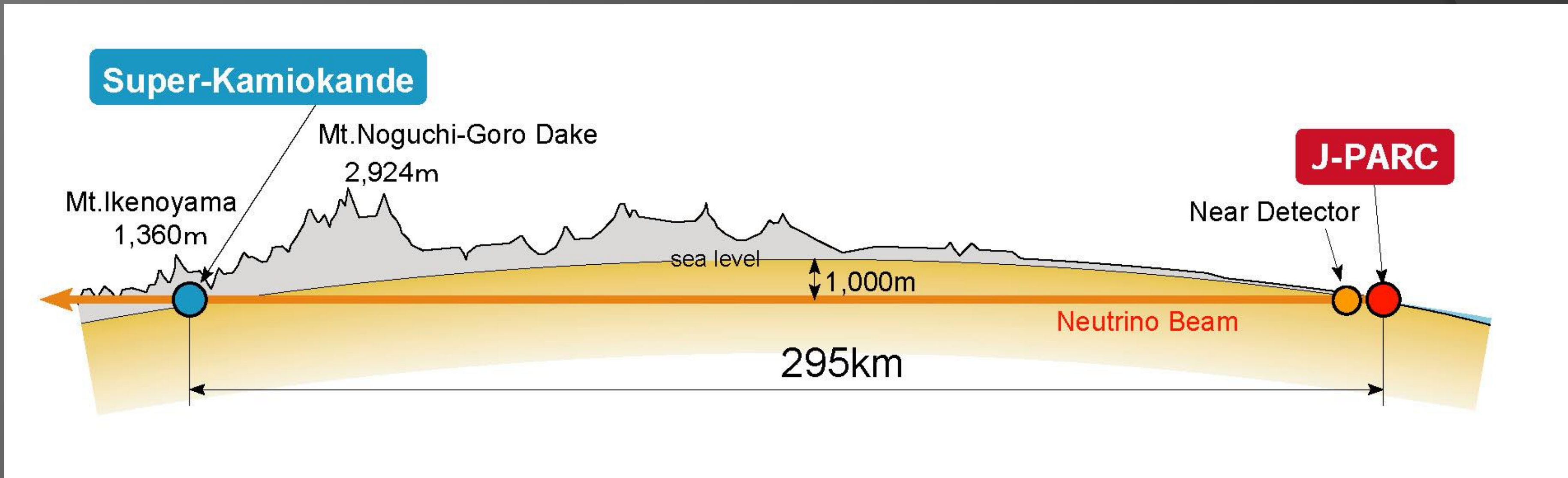
M. Tzanov (LSU) on behalf of T2K

NuInt 14, Surrey, UK, June 19-24, 2014

Outline

- T2K experiment
- CCQE Event Selection
- CCQE cross section extraction method
- Results
- Future and Conclusion

The T2K Experiment



T2K is a long-baseline neutrino experiment

Main goals:

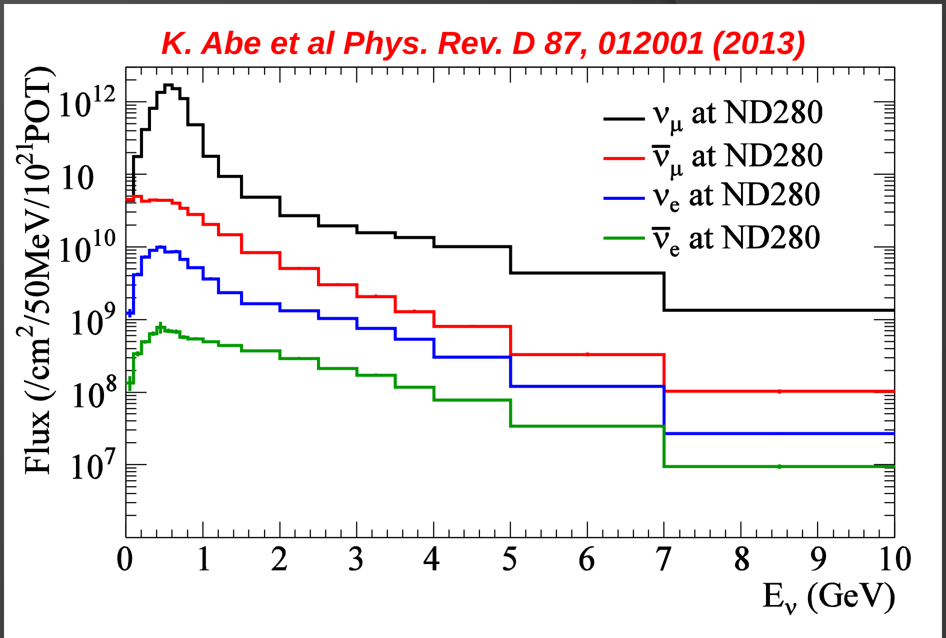
- Observe $\nu_\mu \rightarrow \nu_e$ oscillations
  K. Abe et al., Phys.Rev.Lett. 112 (2014) 061802.

- Measure precisely $\nu_\mu \rightarrow \nu_\mu$ disappearance parameters
  K. Abe et al., Phys.Rev.Lett. 112 (2014) 181801

Measure neutrino cross sections in the near detector.

T2K Flux Prediction

- Narrow-band neutrino beam at 2.5º off-axis angle
- 92.5% pure ν_μ beam with 0.6GeV peak energy.

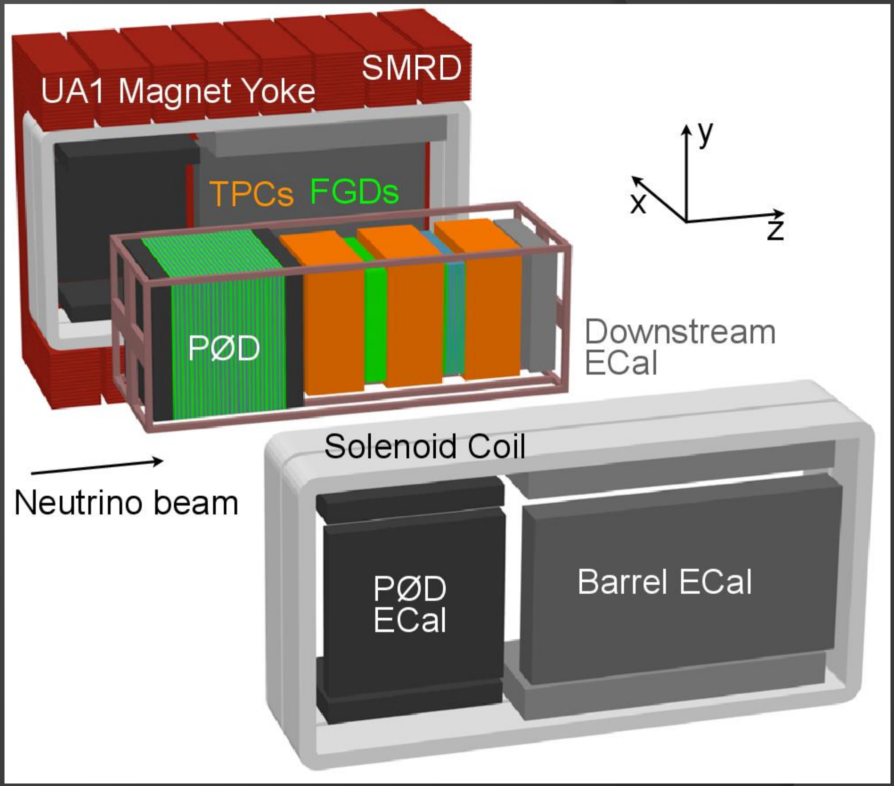


- Flux prediction is based on NA61/SHINE hadron production cross section measurements
- Constrained by T2K proton beam and muon and hadron beam monitors measurements.

See talk by M. Posiadala on Friday

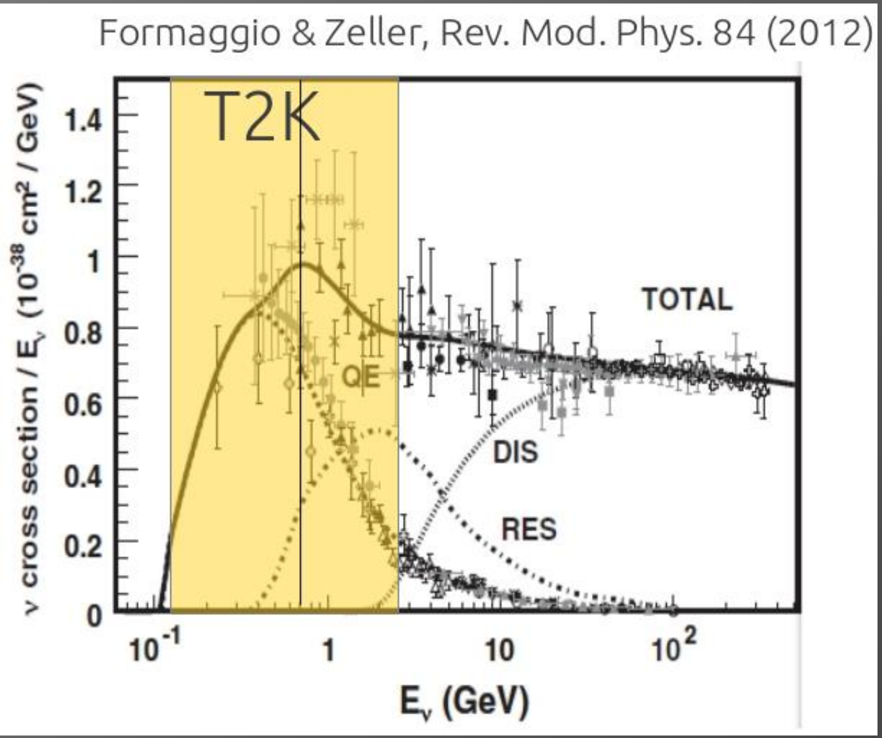
Off-Axis Near Detector Complex ND280

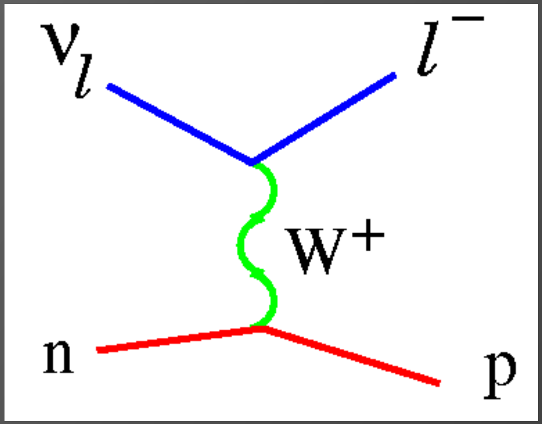
Refurbished UA1 magnet providing 0.2 T magnetic field surrounding



- Side Muon Range Detector (SMRD)
- EM Calorimeters
- π^0 detector (P0D)
- ND280 Tracking detector:
  - Three Time Projection Chambers (TPCs) filled mainly with Ar gas provide particle ID based on dE/dx and momentum measurement.
  - Two Fine Grained Detectors (FGDs). FGD1 consists of layers of 10x10 mm plastic scintillator bars instrumented with Multi-Pixel Photon Counters (MPPCs).

ν_μCCQE Interactions





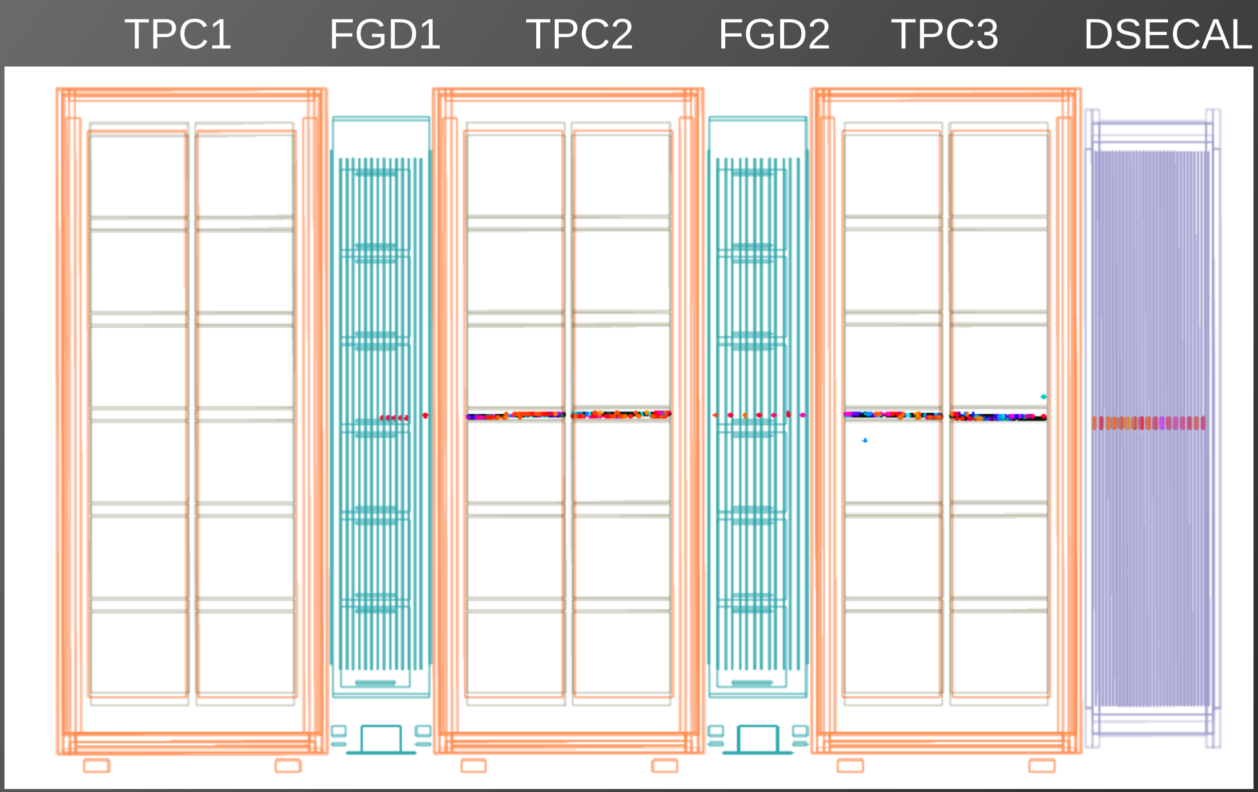
Why CCQE:

- Main signal channel for neutrino oscillation measurements.
- Few measurements on nuclear targets.
- T2K beam peak is near the quasi-elastic peak.

NEUT CCQE model:

- Smith-Moniz relativistic Fermi gas model CCQE
  - Dipole form factor ($M_A^{QE} = 1.2$ GeV)
- Semi-classical cascade model for FSI
- No multi-nucleon effects.

CCQE Event in ND280



CCQE signature for this analysis

- One negative muon-like track
- Vertex in FGD1 fiducial volume

CCQE Event Selection

CC inclusive event selection first:

- 1 good negative track with vertex in the FGD1 fiducial volume.

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- Upstream veto

CCQE Event Selection

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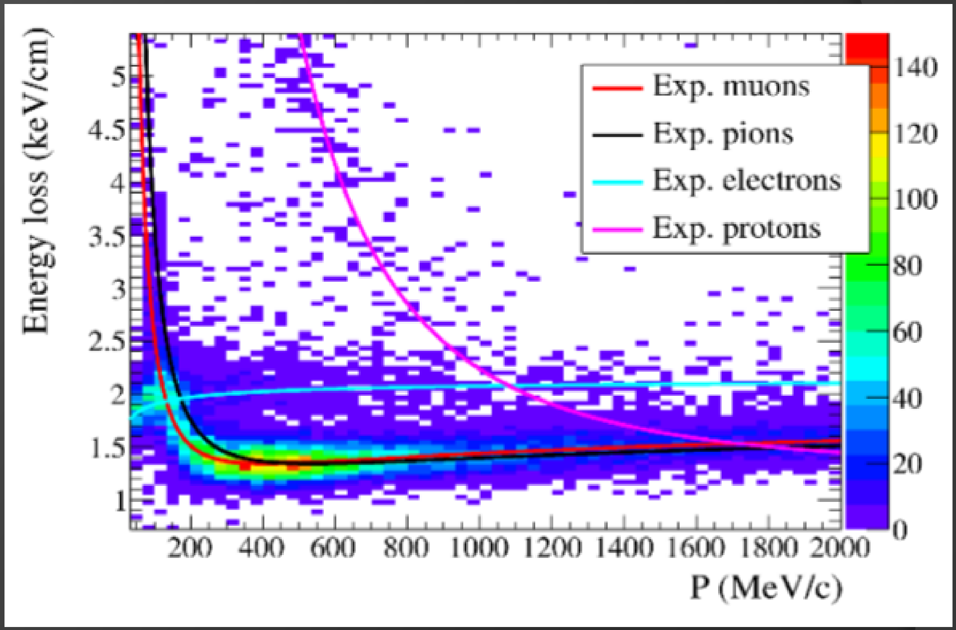
- Upstream veto
- Muon PID



CCQE Event Selection

CC inclusive event selection first:

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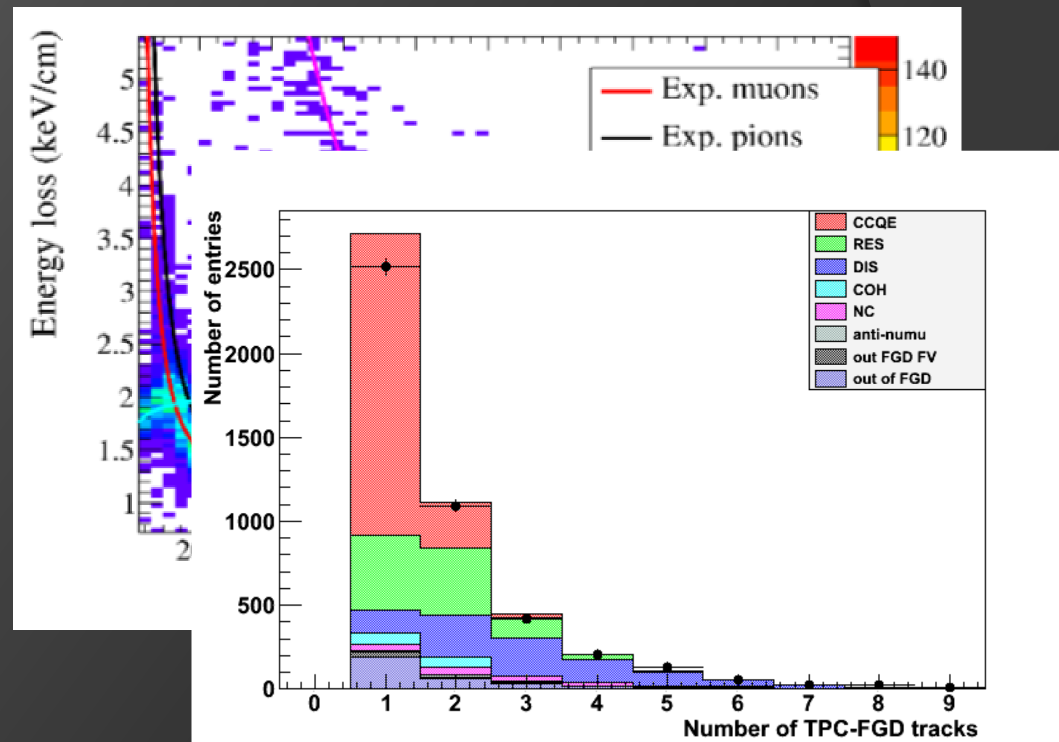
CCQE event selection:

- TPC track veto



CCQE Event Selection

CC inclusive event selection first:

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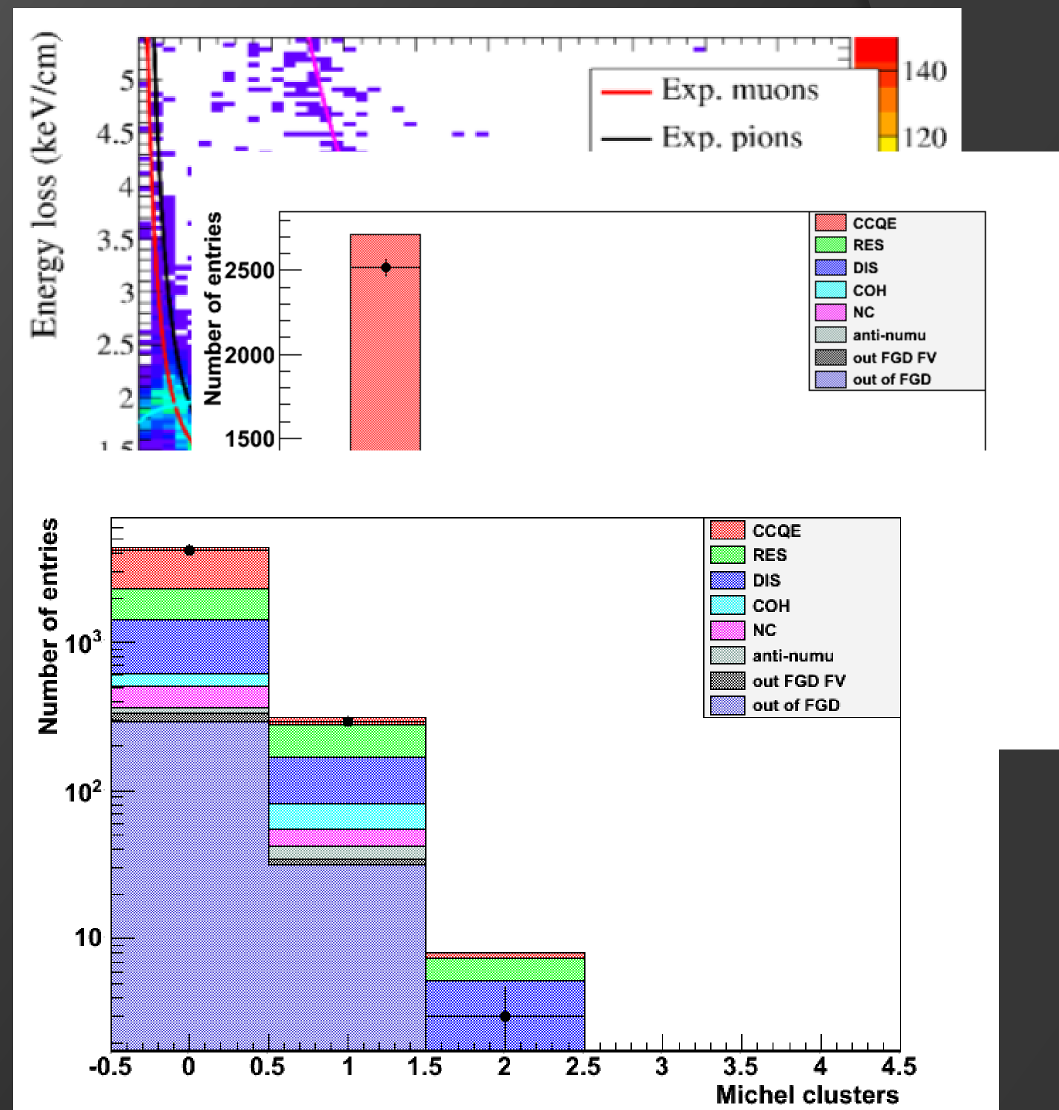
- Upstream veto
- Muon PID

CCQE event selection:

- TPC track veto
- Michel electron veto



CC Non-QE Event Sample

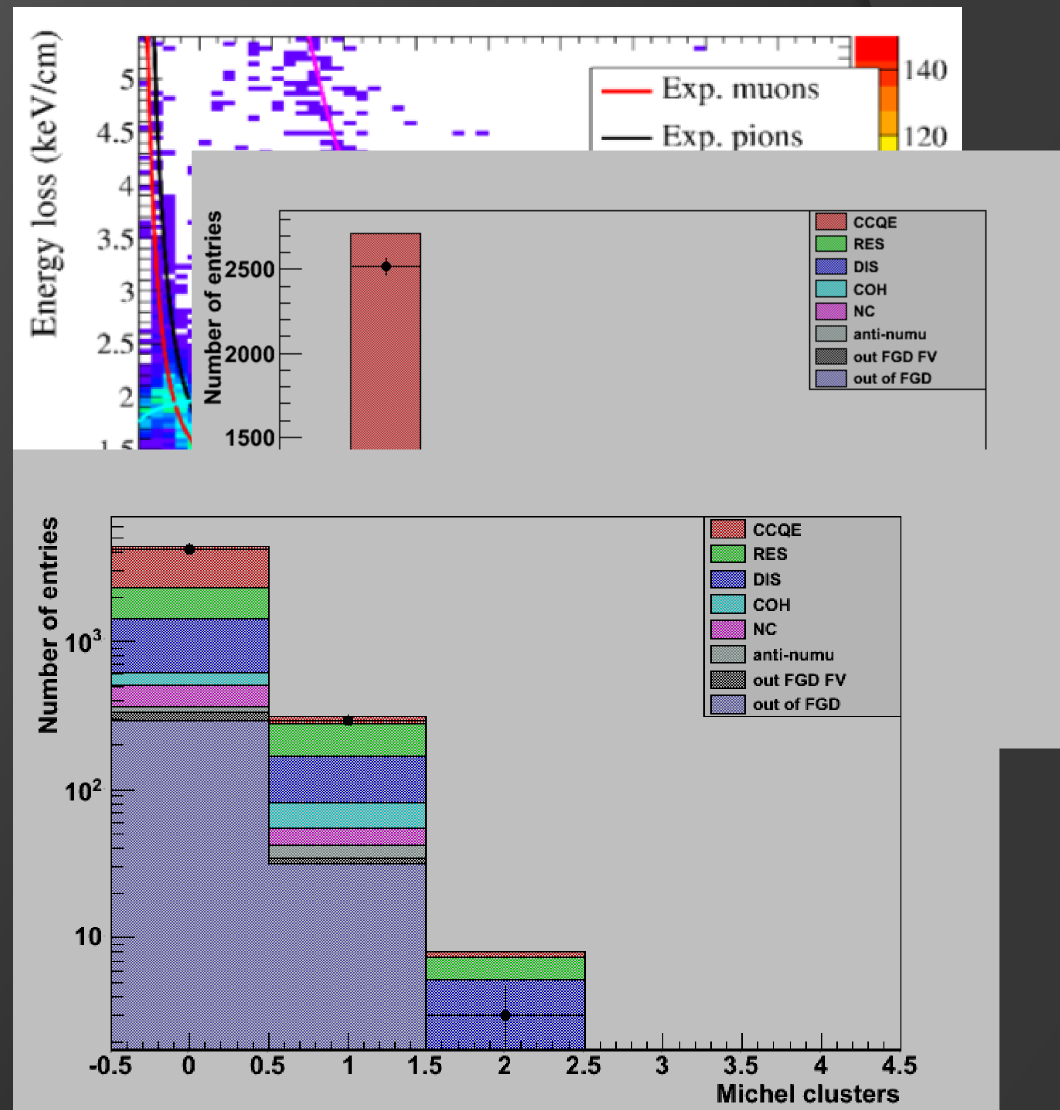
CC inclusive event selection first:

- 1 good negative track with vertex in the FGD1 fiducial volume.
- Upstream veto
- Muon PID

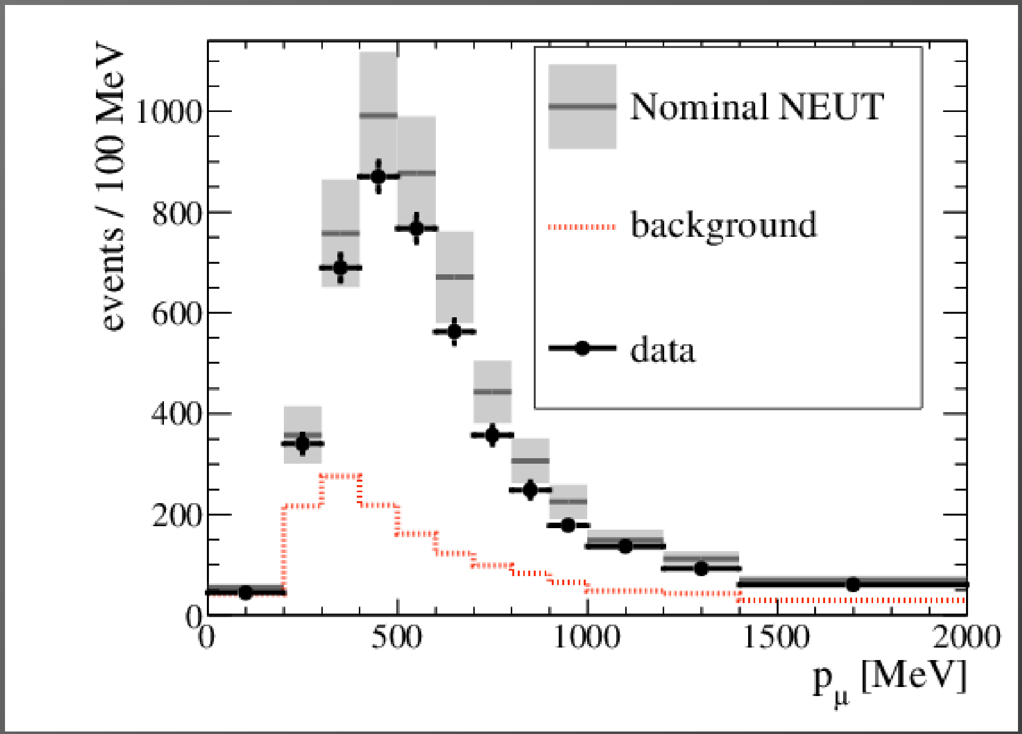
CCQE event selection:

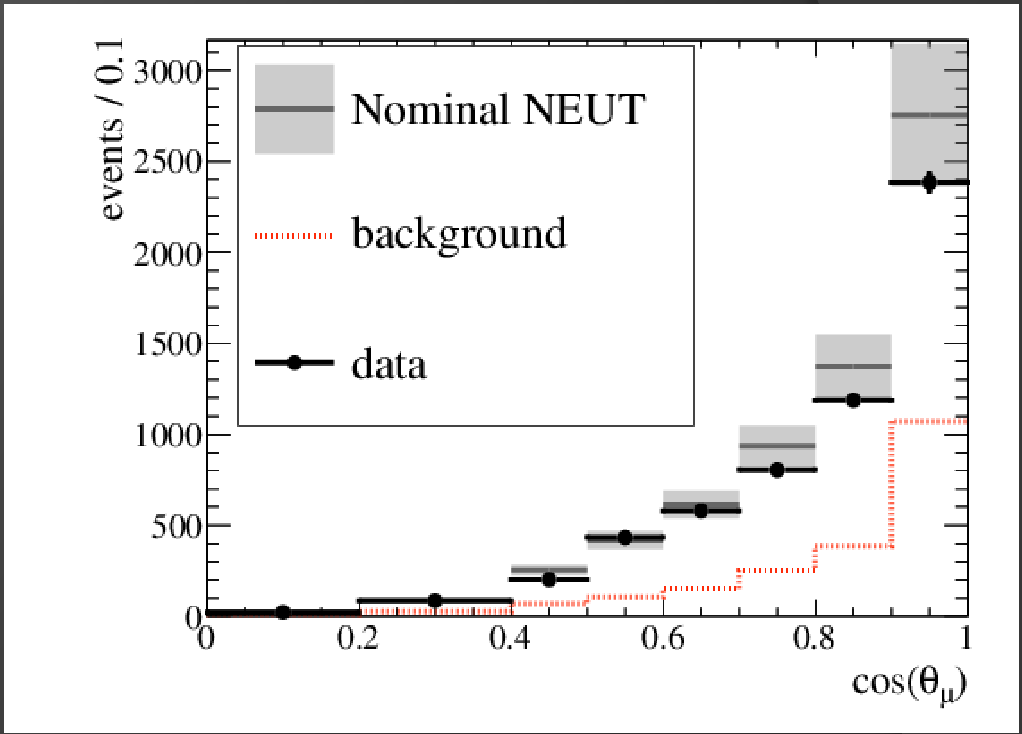
- TPC track veto
- Michel electron veto

CC Non-QE – failing CCQE cuts



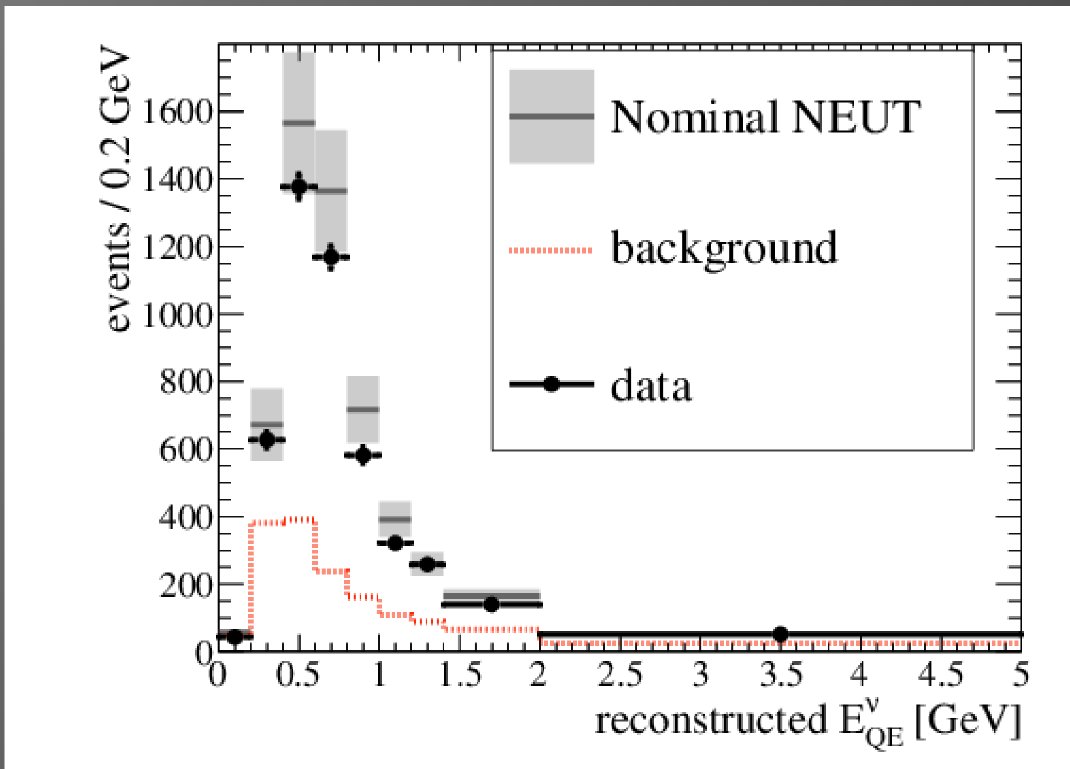
CCQE Muon Kinematics

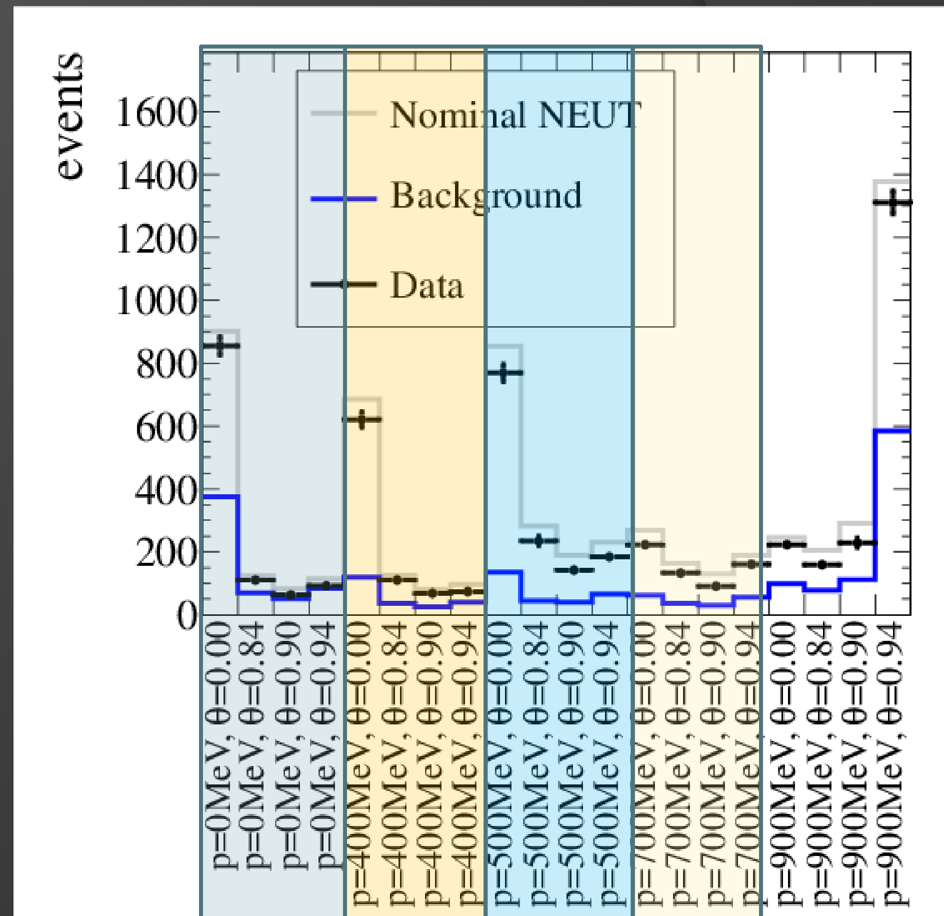




- CCQE selection efficiency is 40%
- CCQE purity is 72%
- CC resonant is the dominant background

CCQE Event Kinematics

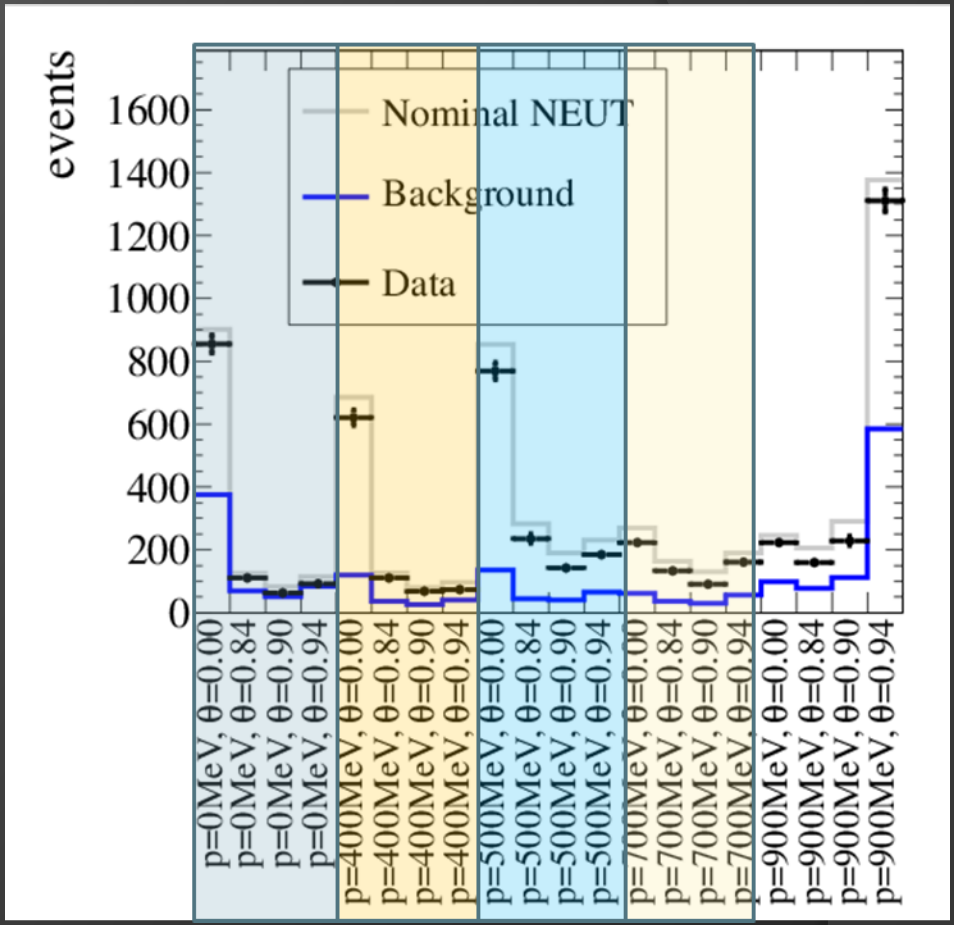




E_{ν} and Q^2 calculated form muon angle and momentum assuming QE kinematics with target at rest.

Cross Section Extraction Method

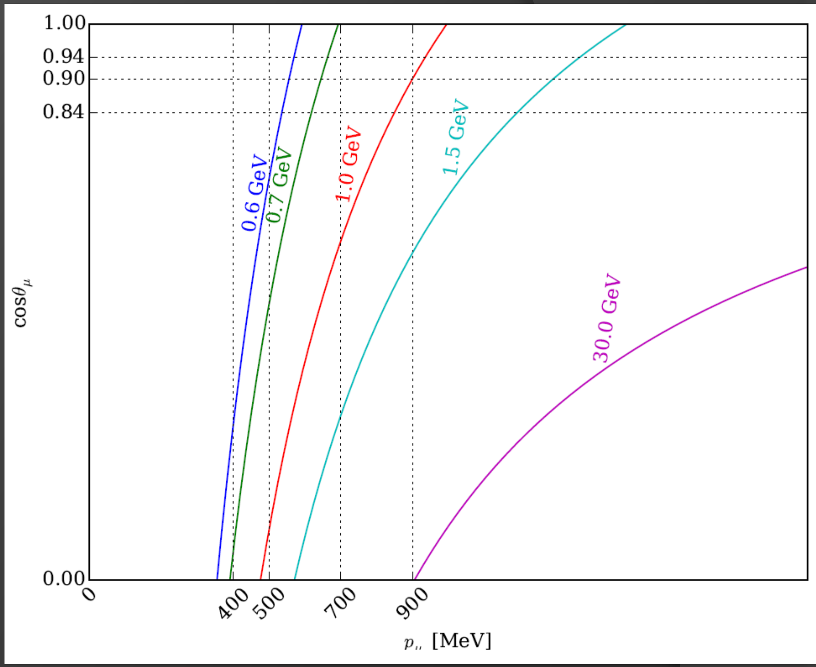
Template fit to background subtracted p_μ-$\cos\theta_\mu$ data distribution.



Cross Section Extraction Method

Template fit to background subtracted p_μ-$\cos\theta_\mu$ data distribution.

- CCQE E_ν cross section was extracted by weighing the p_μ-$\cos\theta_\mu$ templates for 5 E_ν bins

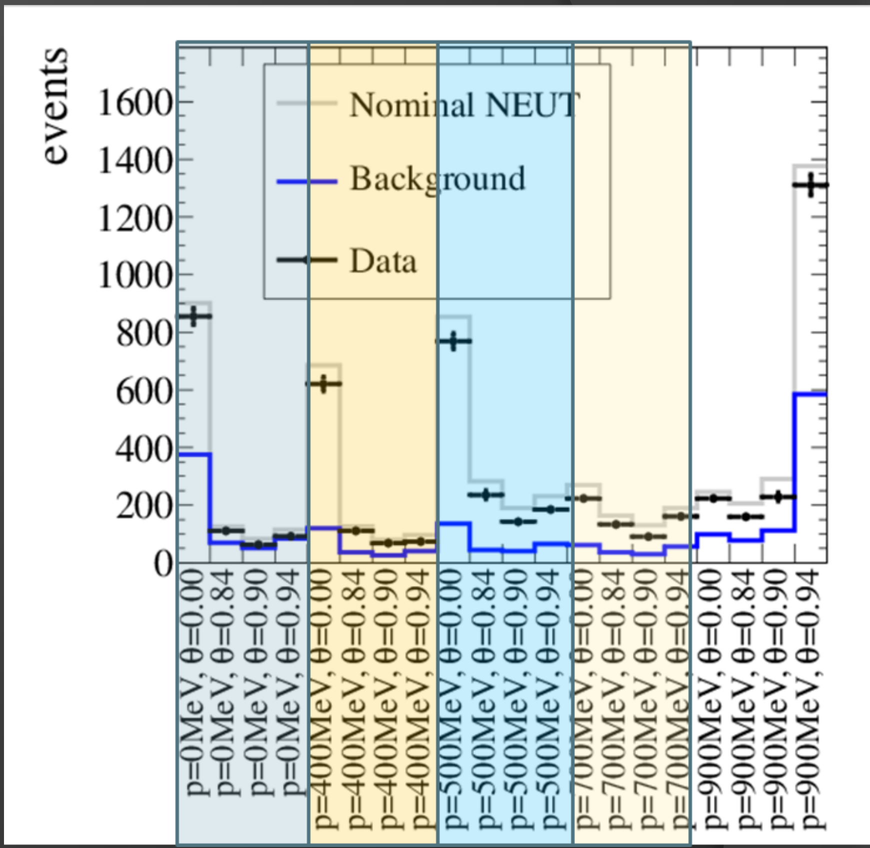


Cross Section Extraction Method

Template fit to background subtracted p_μ-$\cos\theta_\mu$ data distribution.

- CCQE E_ν cross section was extracted by weighing the p_μ-$\cos\theta_\mu$ templates for 5 E_ν bins

- Systematic variations drawn from multi-variate Gaussian distributions



Maximum log-likelihood ratio fit to find the best parameters:

- Poisson statistics likelihood
- penalty terms for systematics

$$-2\ln\lambda(\theta) = 2\sum_{i=1}^{\{p_\mu,\cos\theta_\mu\}\ \mathbf{bins}}\left[N_i^{\mathbf{pred}}(\theta) - N_i^{\mathbf{obs}} + N_i^{\mathbf{obs}}\ln\frac{N_i^{\mathbf{obs}}}{N_i^{\mathbf{pred}}(\theta)}\right] + $$
$$+\ln\frac{\pi_d(\boldsymbol{\theta}_d)}{\pi_d(\theta_d^{\mathbf{nom}})} + \ln\frac{\pi_f(\boldsymbol{\theta}_f)}{\pi_f\left(\theta_f^{\mathbf{nom}}\right)} + \ln\frac{\pi_x(\boldsymbol{\theta}_x)}{\pi_x(\theta_x^{\mathbf{nom}})}$$

Systematic Uncertainties

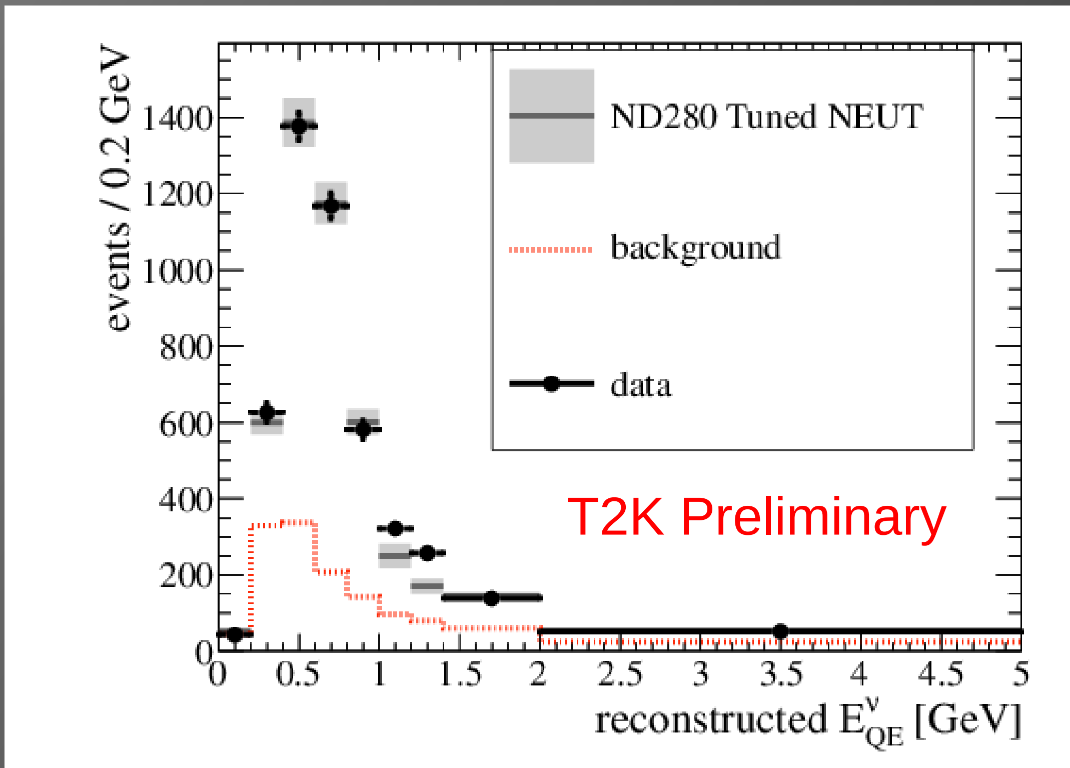
- Detector – Dominant uncertainties are from TPC momentum measurement and out of FV backgrounds.

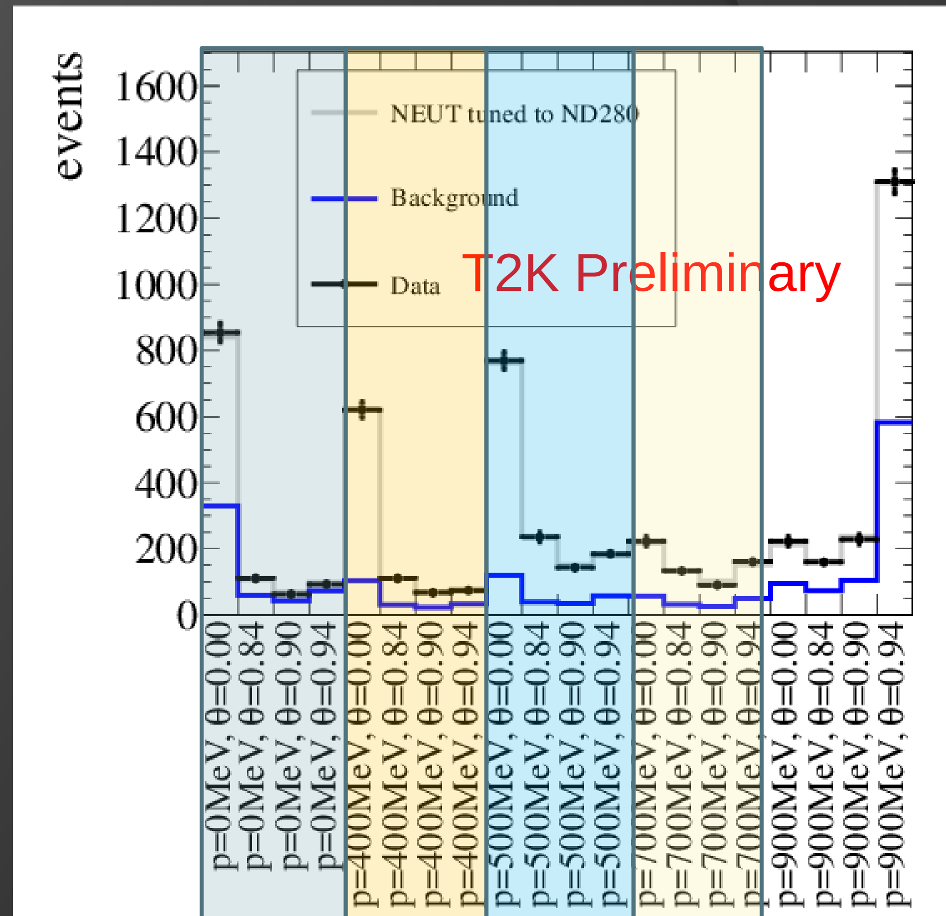
- Flux – Dominant uncertainty is due to the hadron production cross section uncertainties. Other sources constrained by *in-situ* beam monitors and INGRID. See talk by M. Posiadala on Friday.

- Interaction model – Uncertainties obtained from comparison between NEUT and external data. Vary model parameters like M_A^{RES}, p_F, etc.
- See talk by T. Dealtry on Monday

Error Source	Frac. Err. on $\langle\sigma\rangle$ (%)
Detector	4
Beam flux	12
Interaction model	4
Statistical	8
Total	16

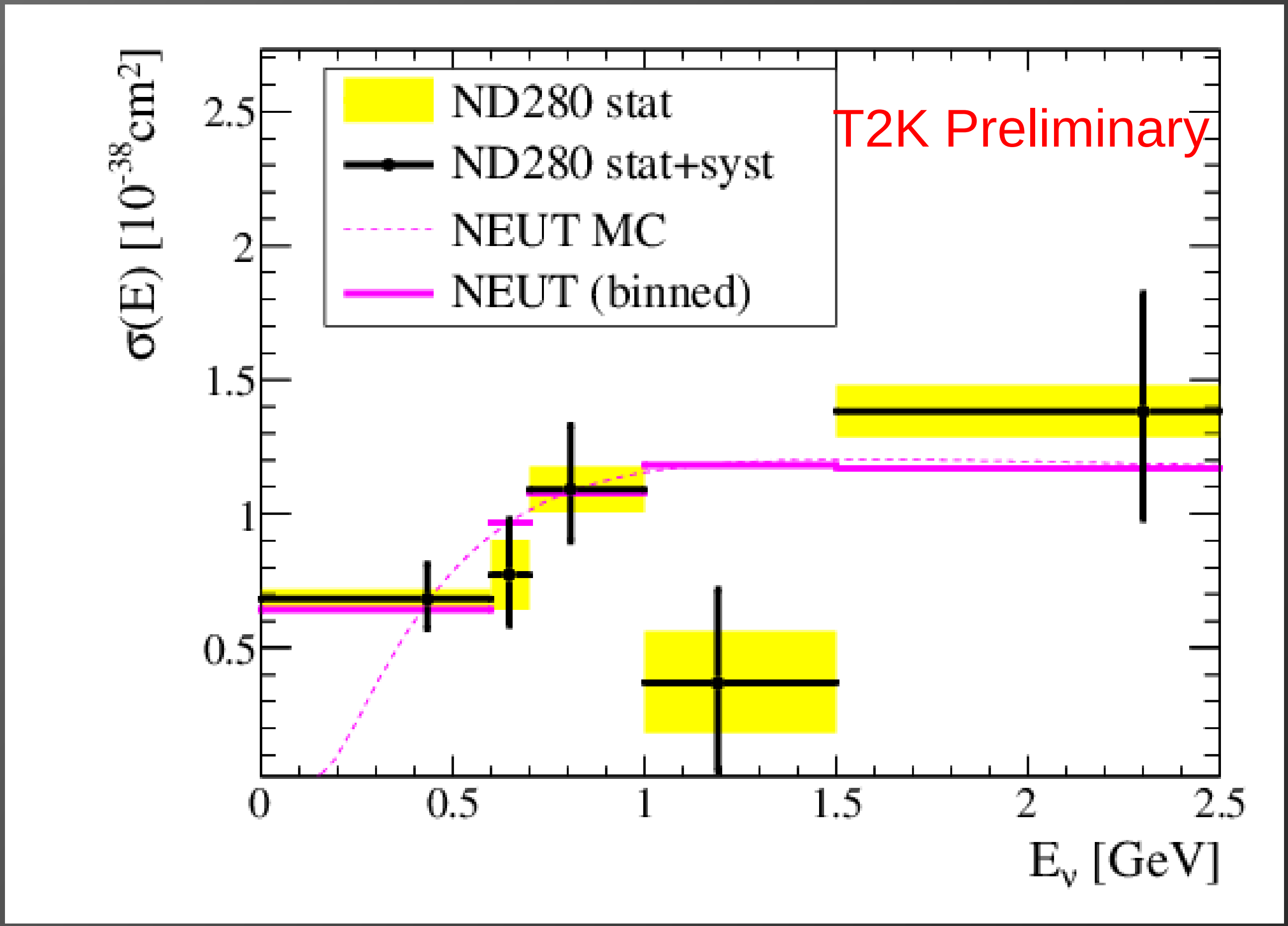
CCQE Event Kinematics After the Fit





- Good agreement with data after the fit

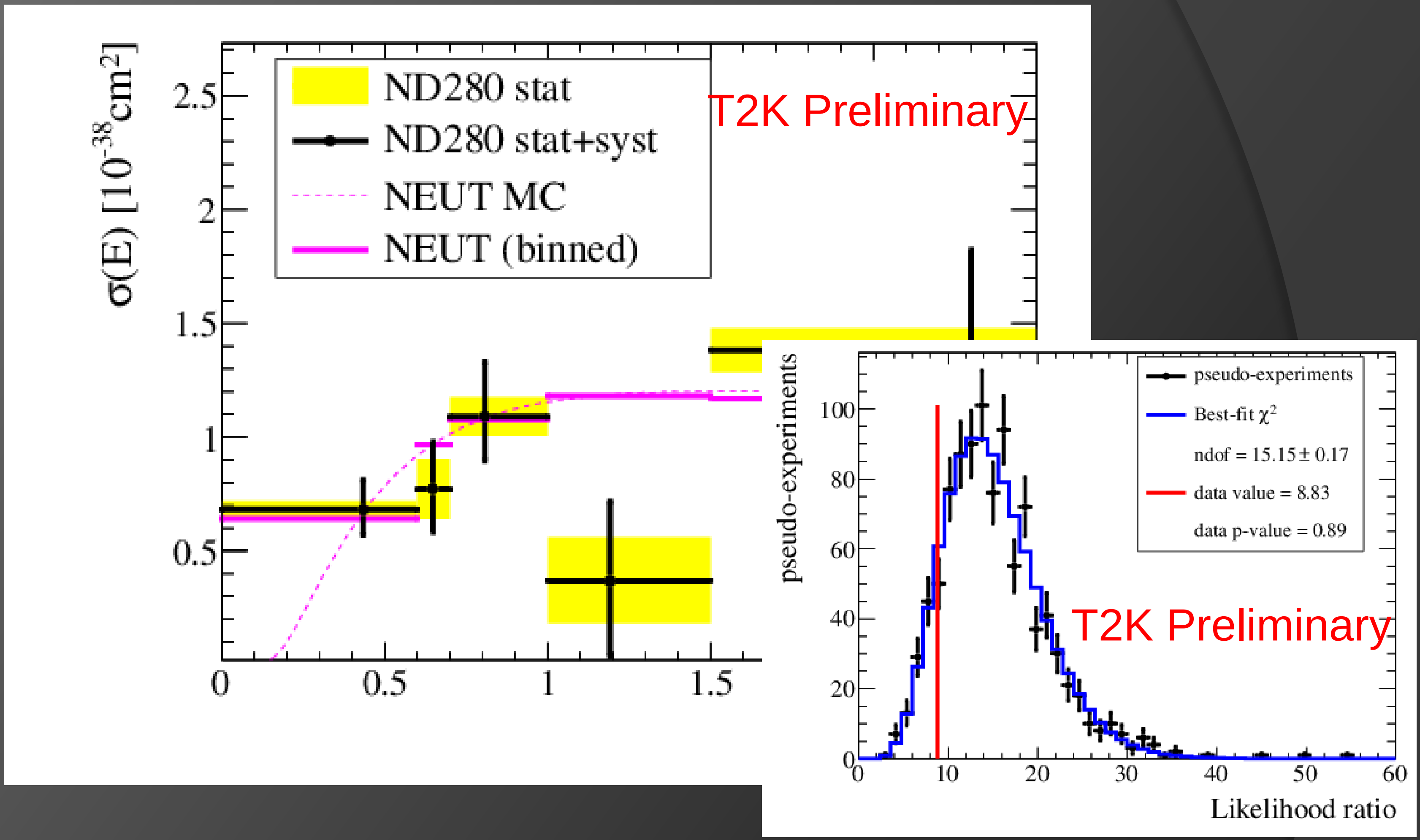
T2K CCQE Result



- Large errors – more statistics is needed

T2K

T2K CCQE Result



- Large error – more statistics is needed
- Good agreement with NEUT model

χ^2 goodness-of-fit gives p-value of 17% when comparing the fit with NEUT (M_A^{QE} =1.2 GeV) model.

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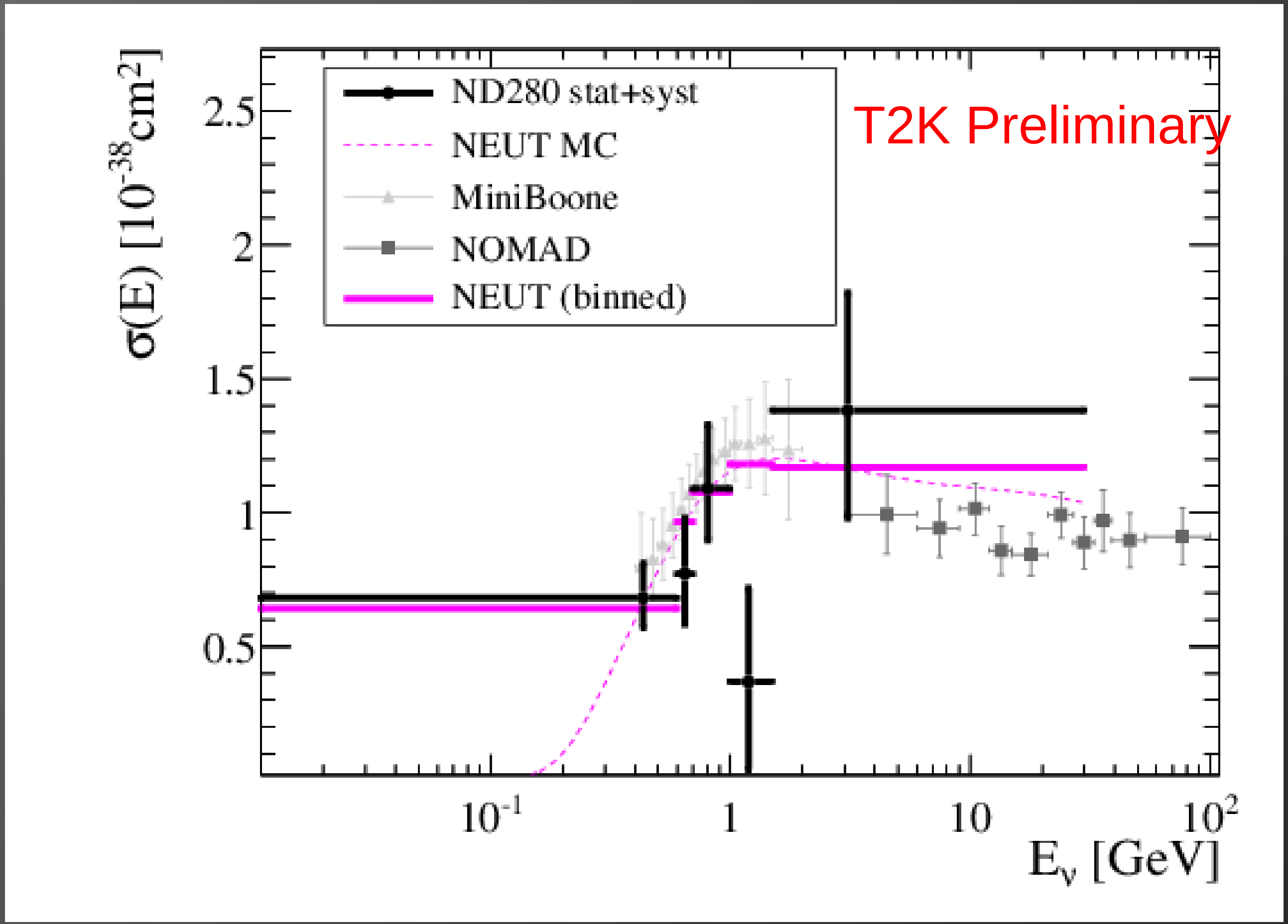
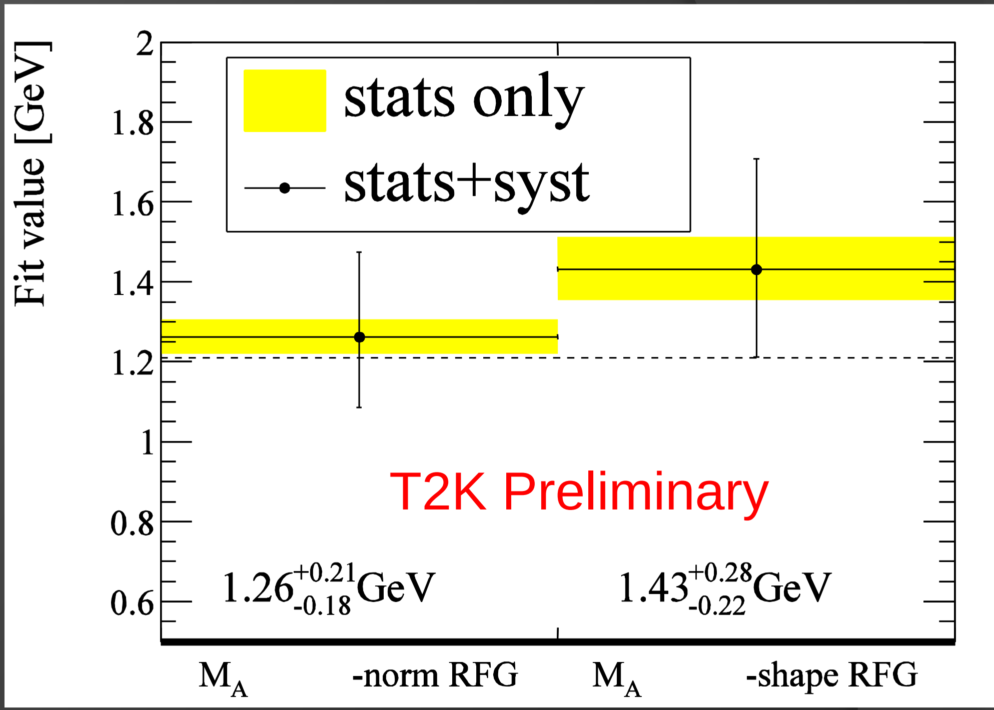
T2K Result
Compared to NOMAD and MiniBooNE



- Large errors – can not resolve the MB and NOMAD discrepancy.
- New CCQE analyses with full statistics (6.6x10^{20} POT) are in the works.

Effective Axial Mass M_A Fit

Effective M_A is extracted from a template fit to background subtracted p_μ-$\cos\theta_\mu$ data distribution.



Two different settings:

- 1-parameter fit for M_A^{QE} shape only
- 2-parameter fit for M_A^{QE} normalisation and shape.

Fitted effective M_A^{QE} value in both settings is consistent with the NEUT model.

Fitted effective M_A^{QE} value in both settings is consistent with previous low neutrino energy measurements (MB, K2K)

Conclusions and Future

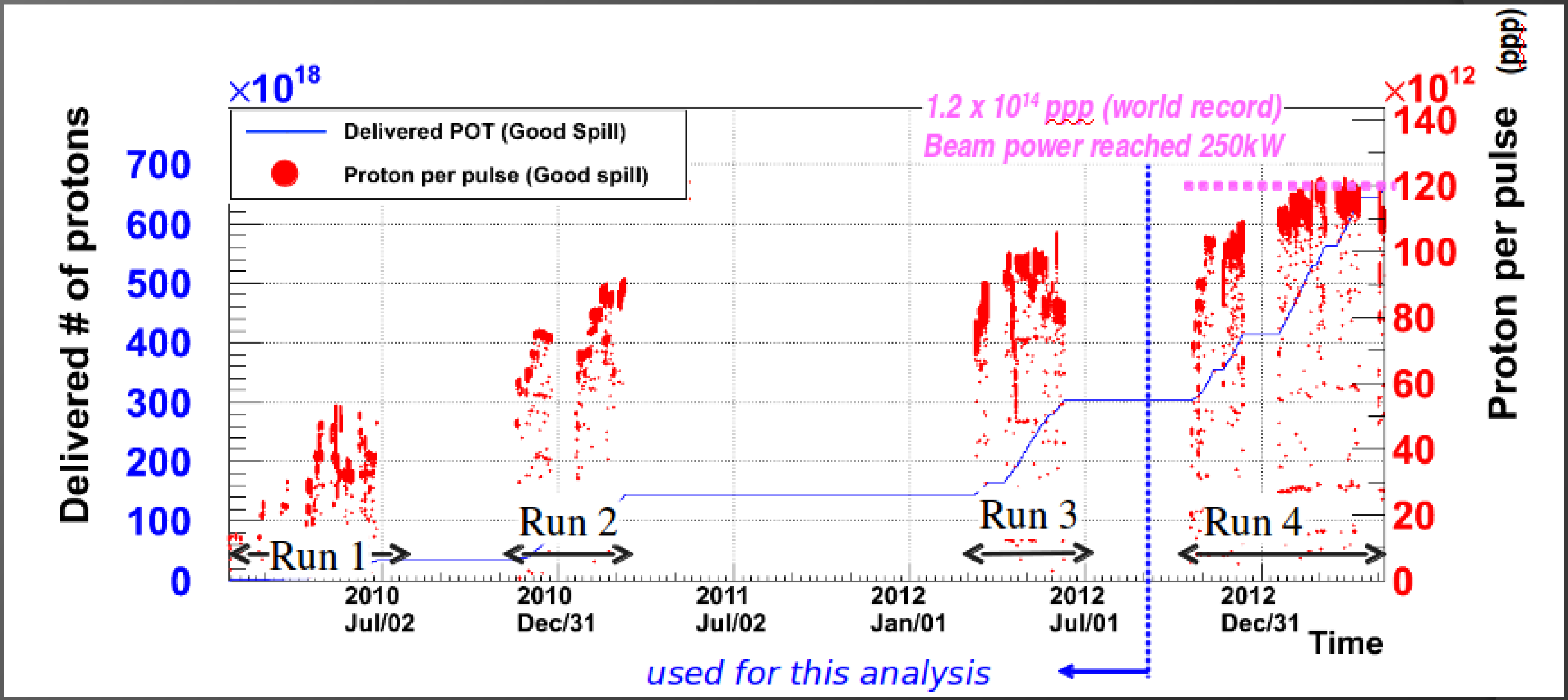
- T2K has its first preliminary measurement of the CCQE cross section. (Work by D. Hadley, University of Warwick)
  - only ~ 40% of the data on tape was used.
  - obtained from a fit to the p_μ-$\cos\theta_\mu$ distribution in 5 E_ν bins
  - Effective M_A^{QE} value is consistent with both NEUT model and previous ~1GeV neutrino energy measurements on nuclear targets.

- New T2K analyses to study CCQE
  - improved event reconstruction
  - more than twice the statistics
  - exclusive event selection to study multi-nucleon effects. 2p-2h enhanced sample.

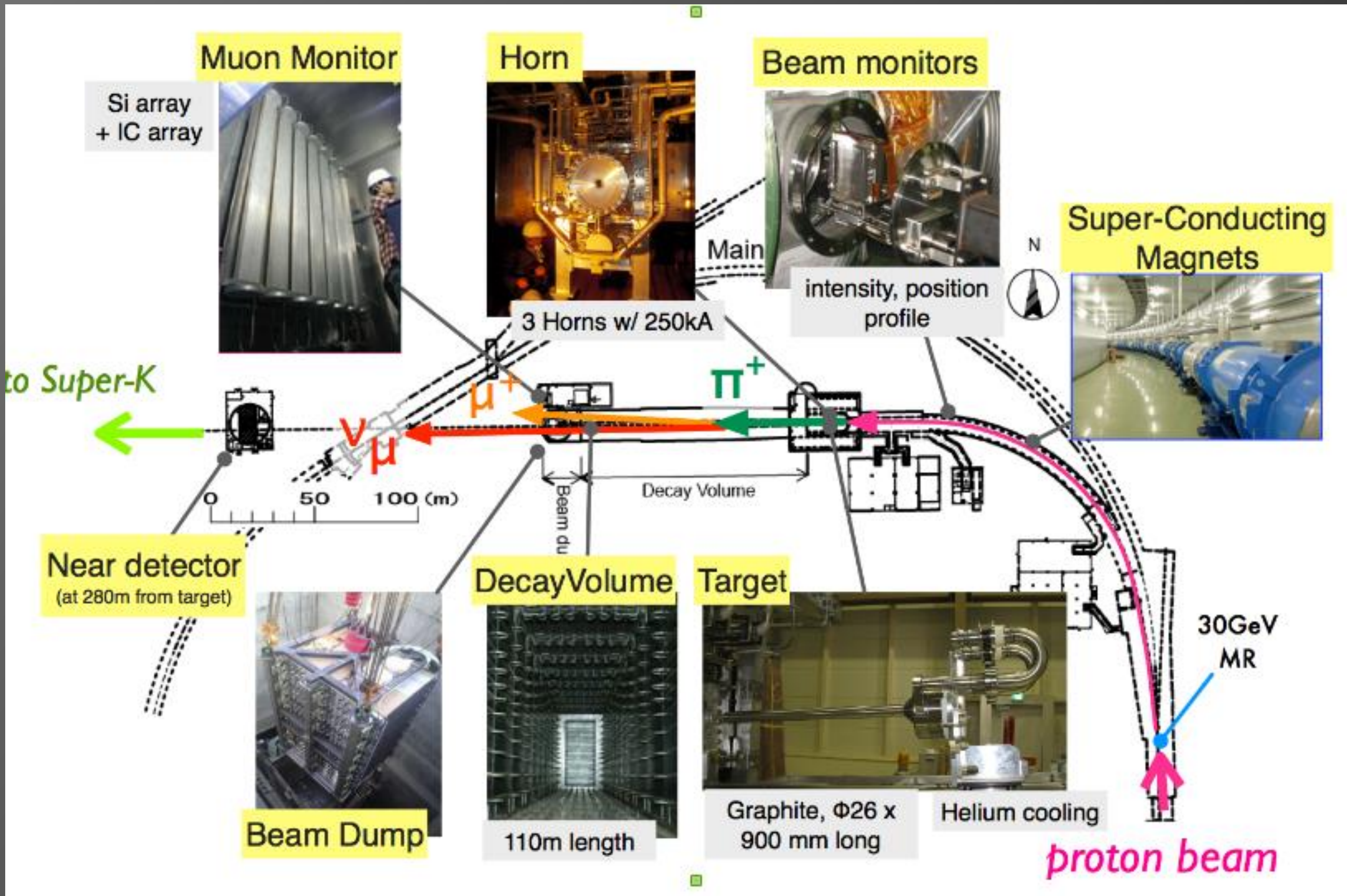
    Talk by P. Sinclair on Wednesday
  - More nuclear targets.

BACKUPS

Protons Delivered



J-PARC Neutrino Beamline



- High intensity 30 GeV proton
- Delivered 6.6×10^{20} POT to date
  - this analysis includes 2.7×10^{20} POT
- Three-horn focusing