T2K Research at Warwick

- An introduction and status of T2K
- UK and Warwick contribution to T2K
- Cross section studies at Warwick
- Plans for the future

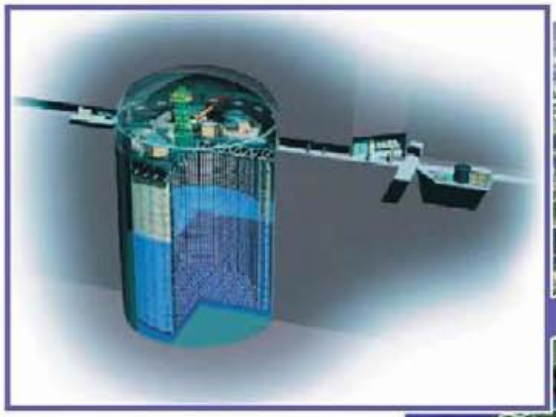
People

Principal Investigator : Gary Barker
Co-Investigator : Steve Boyd

Research Associates : David Hadley
Phill Litchfield (with U.Kyoto)

Students : Dan Scully
Callum Lister (LTA)
Andrew Furmanski
Steven Dennis

T2K



Super-Kamiokande
(ICRR, Univ. Tokyo)

J-PARC Main Ring
(KEK-JAEA, Tokai)

Long baseline neutrino oscillation experiment with the goal to measure θ_{13} and, possibly, CP violation in the lepton sector

Neutrino Oscillations

Flavour states $\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = U_{\mathrm{MNS}} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$ Mass States

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

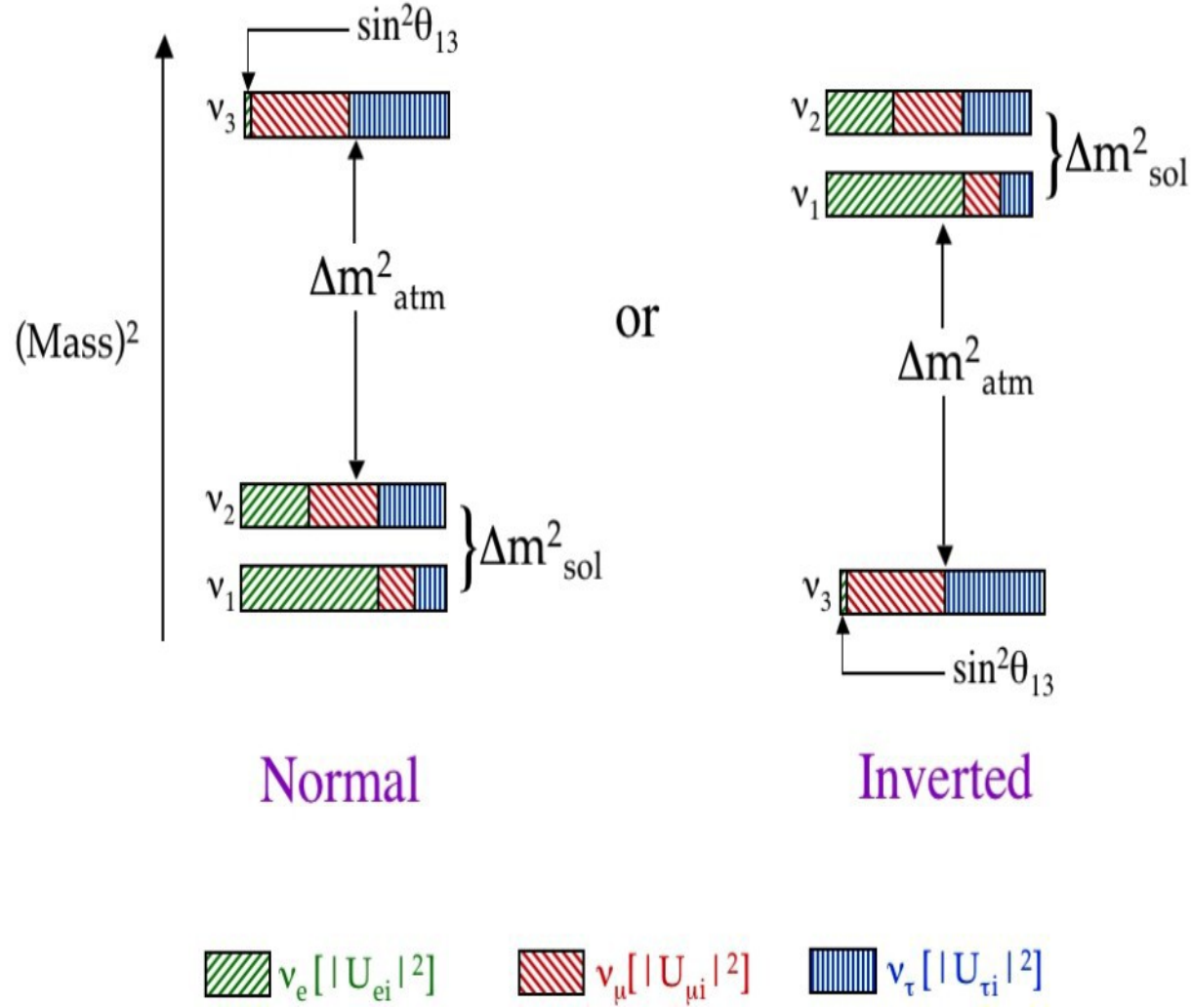
Atm and long baseline beams

reactor/LBL

Solar/reactor

Knowledge pre-Neutrino 2012

$$
\begin{aligned}
|\Delta m^2_{21}| &\simeq 7.6 \times 10^{-5}\mathrm{eV}^2 \\
|\Delta m^2_{31}| &\simeq 2.4 \times 10^{-3}\mathrm{eV}^2 \\
\theta_{12} &= 34^\circ \pm 3^\circ \\
\theta_{13} &< 0.15@90\%\mathrm{C.L} \\
\theta_{23} &= 45^\circ \pm 5^\circ
\end{aligned}
$$



T2K Physics Goals

1. Precise muon neutrino disappearance measurement

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

2. Measure parameters governing ν_e appearance

$$P\left(\nu_\mu \to \nu_e\right) = \sin^2 2\theta_{13} \sin^2 2\theta_{23} \sin^2\left(1.27\,\Delta m^2_{23} L/E\right)$$

3. Maybe see a hint of CP violation if θ_{13} large

$$\frac{P\left(\nu_\mu \to \nu_e\right) - P\left(\overline{\nu}_\mu \to \overline{\nu}_e\right)}{P\left(\nu_\mu \to \nu_e\right) + P\left(\overline{\nu}_\mu \to \overline{\nu}_e\right)} \approx \frac{\Delta m^2_{12} L \sin^2 2\theta_{12} \sin\delta_{CP}}{4 E_\nu \sin\theta_{13}}$$

Recent news on θ_{13}

T2K (June 2011) : $\sin^2 2\theta_{13} \sim 0.104^{+0.060}_{-0.045}$ ($\delta_{CP} = 0$, NH, $\theta_{23}=45^{o}$)

Daya Bay (arxiv:1203.1669)

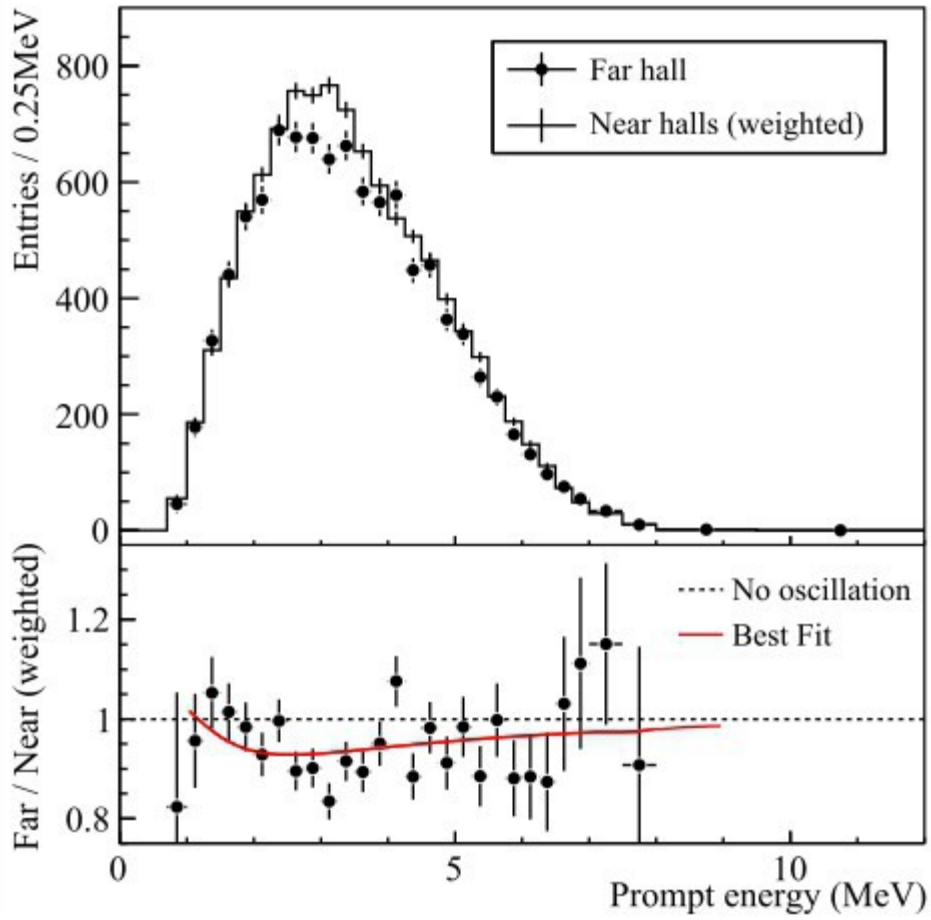
$\sin^2 2\theta_{13} = 0.089 \pm 0.01$

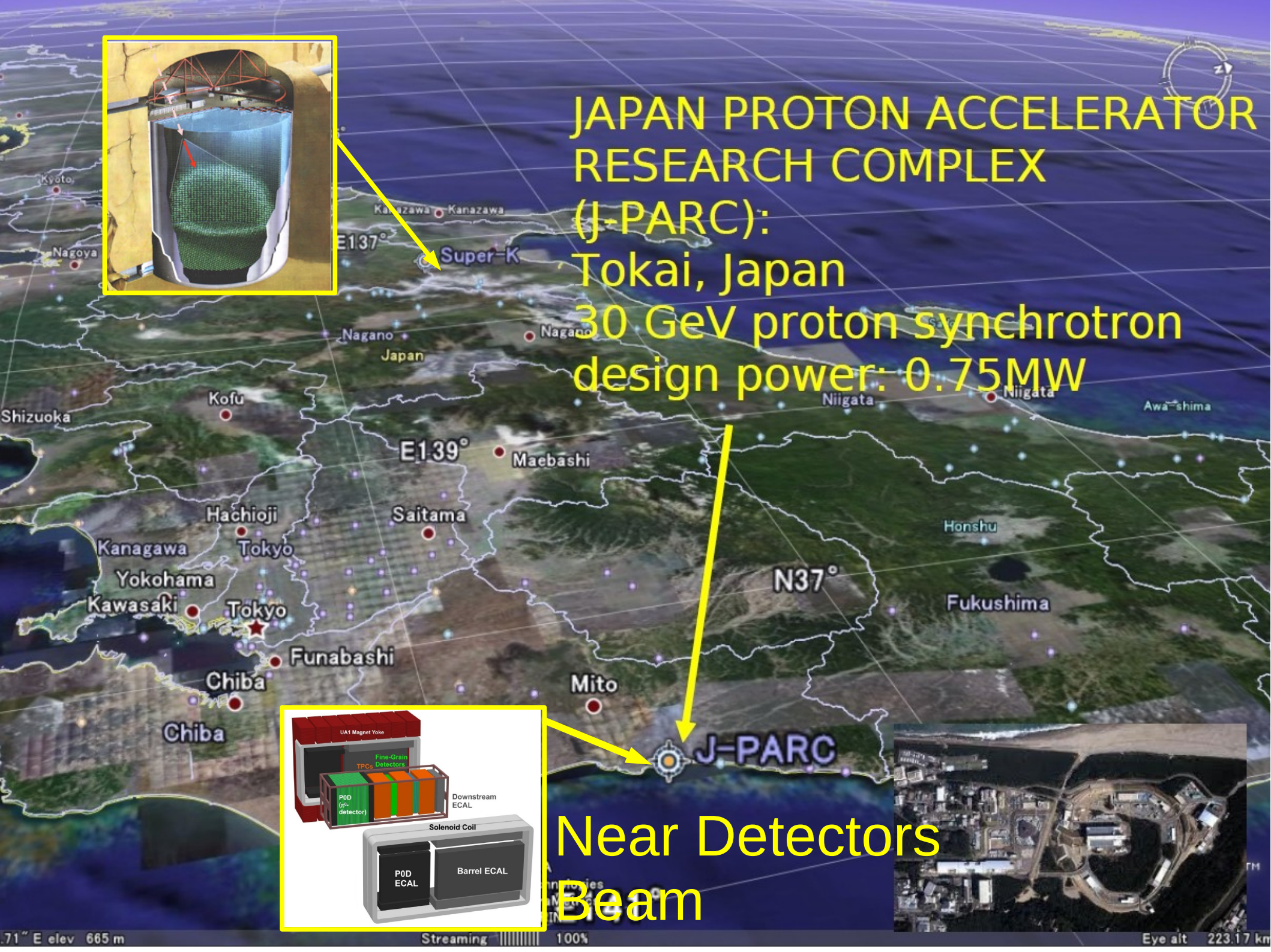
RENO (arxiv:1204.0626)

$\sin^2 2\theta_{13} = 0.113 \pm 0.016$

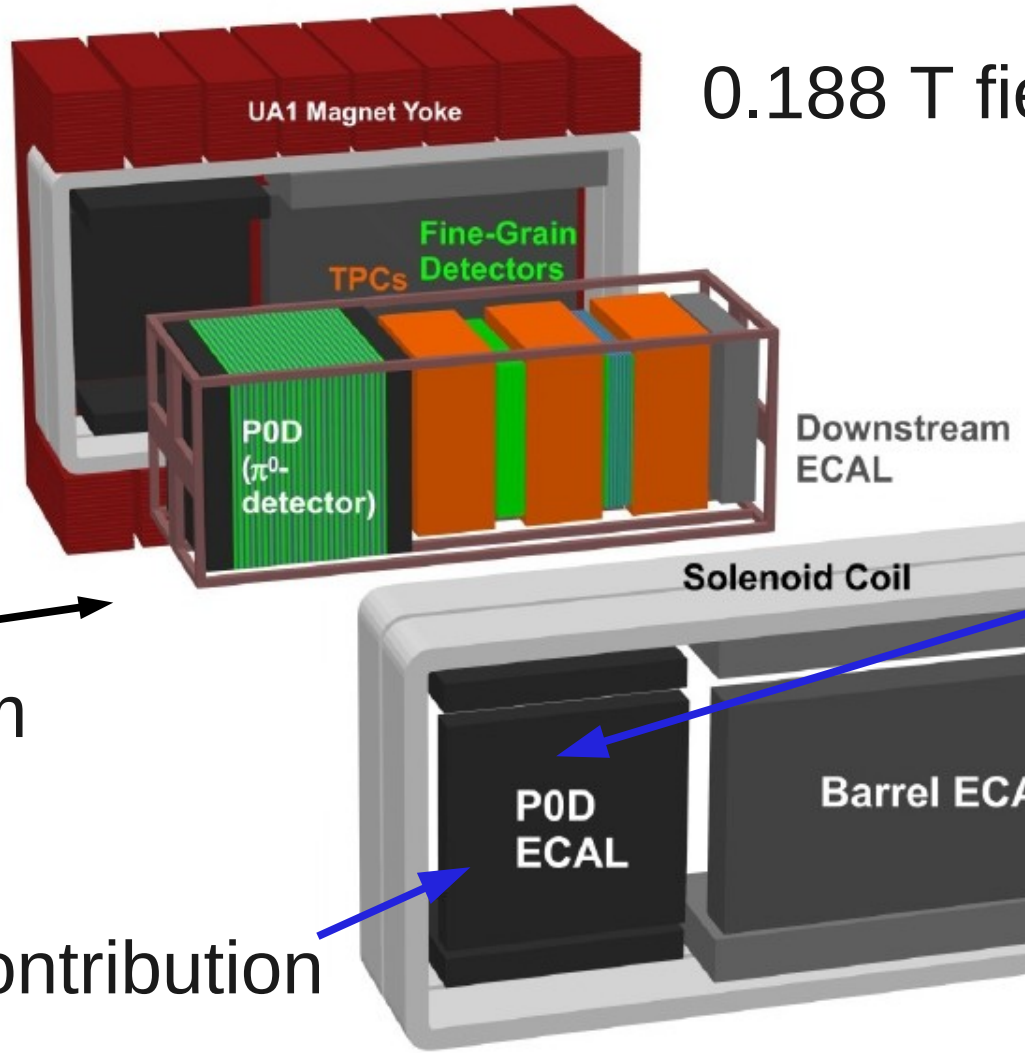
θ_{13} is large! Good!

Daya Bay




JAPAN PROTON ACCELERATOR RESEARCH COMPLEX (J-PARC):
Tokai, Japan
30 GeV proton synchrotron
design power: 0.75MW
Super-K
J-PARC
Near Detectors
Beam
UA1 Magnet Yoke
Fine-Grain Detectors
TPCs
P0D (π0-detector)
Downstream ECAL
Solenoid Coil
P0D ECAL
Barrel ECAL
Kyoto
Nagoya
Kanazawa
Nagano
Japan
Shizuoka
Kofu
Maebashi
Niigata
Awa-shima
Hachioji
Saitama
Kanagawa
Tokyo
Yokohama
Kawasaki
Tokyo
Funabashi
Chiba
Chiba
Mito
Honshu
Fukushima
E137°
E139°
N37°
Streaming
100%
Eye alt 223.17 km

ND280



0.188 T field

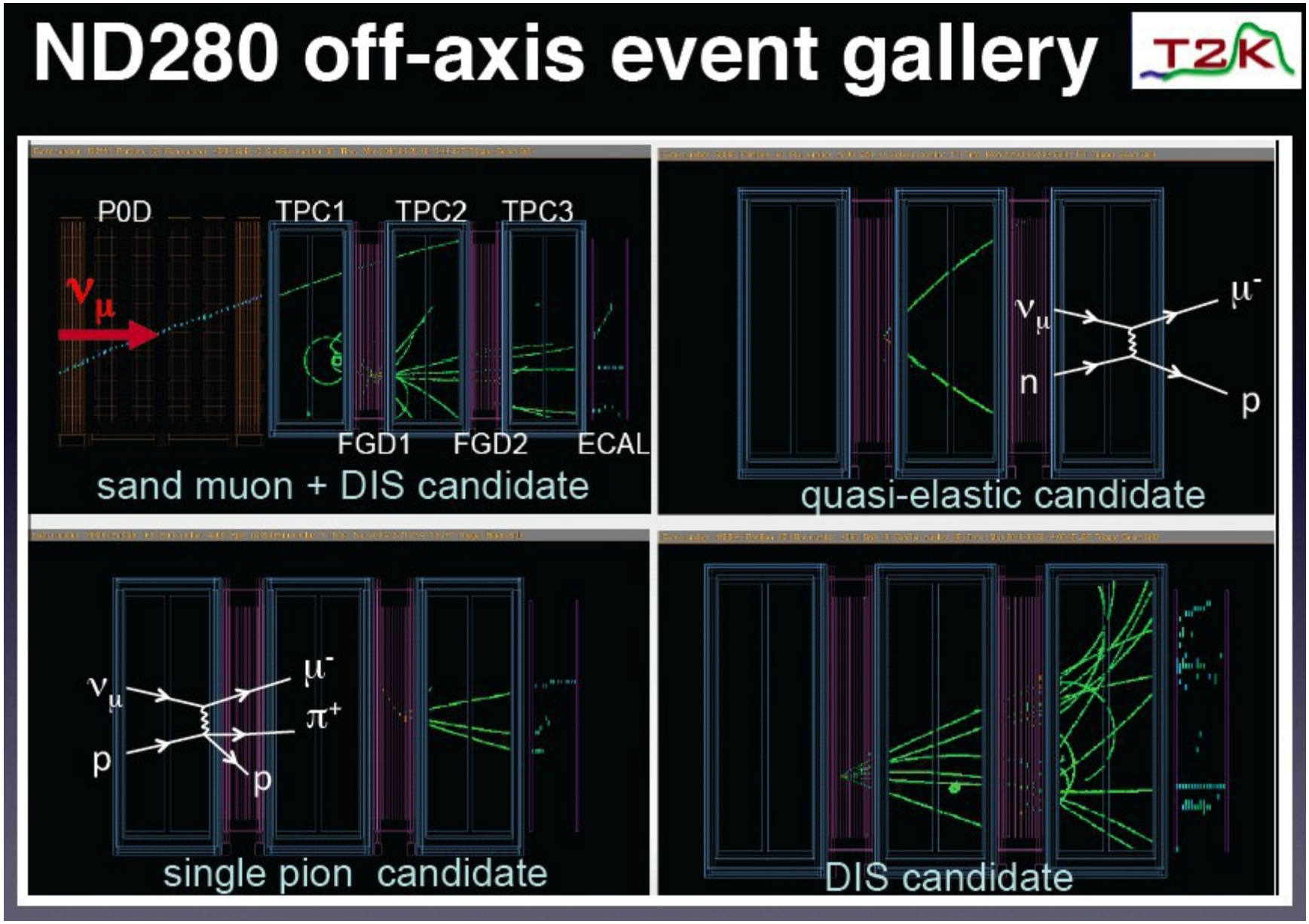
UK Responsibility

ν beam

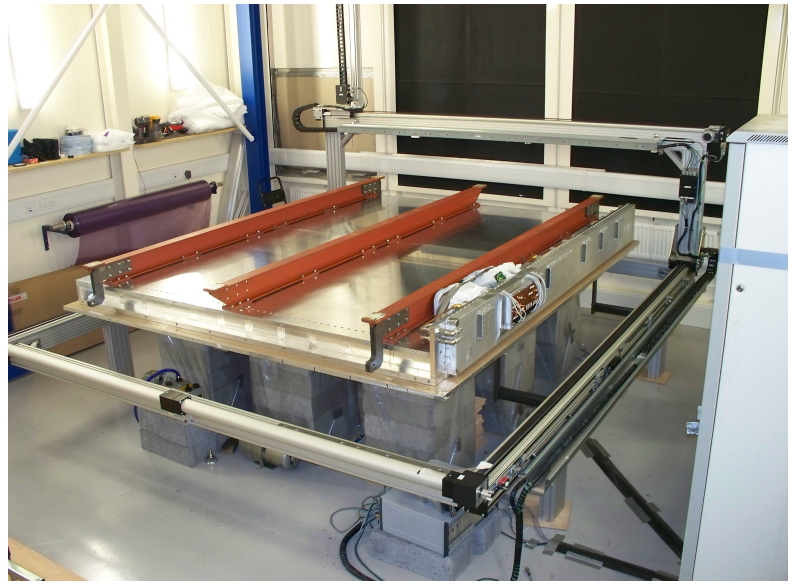
Warwick contribution

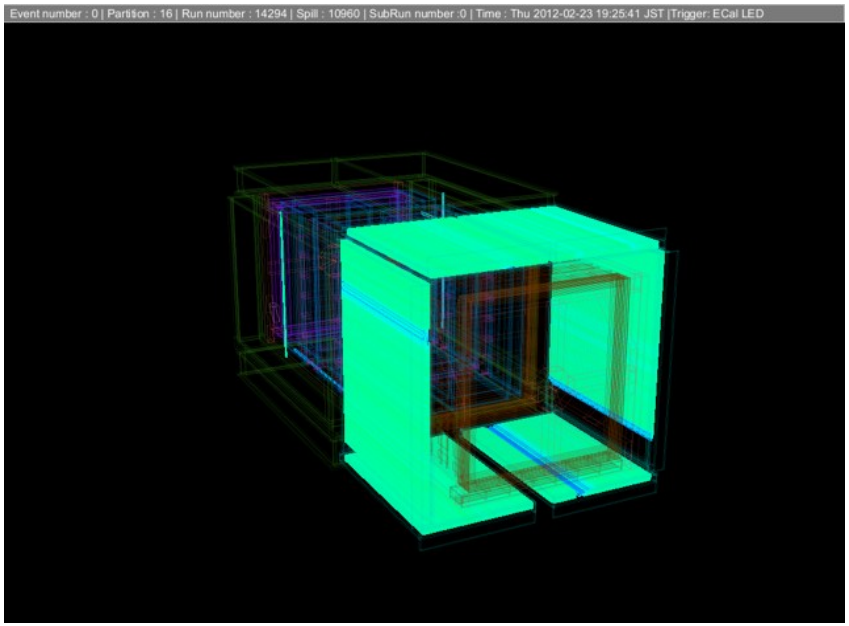
Measure flux and spectrum before neutrinos oscillate

Event Mug-shots

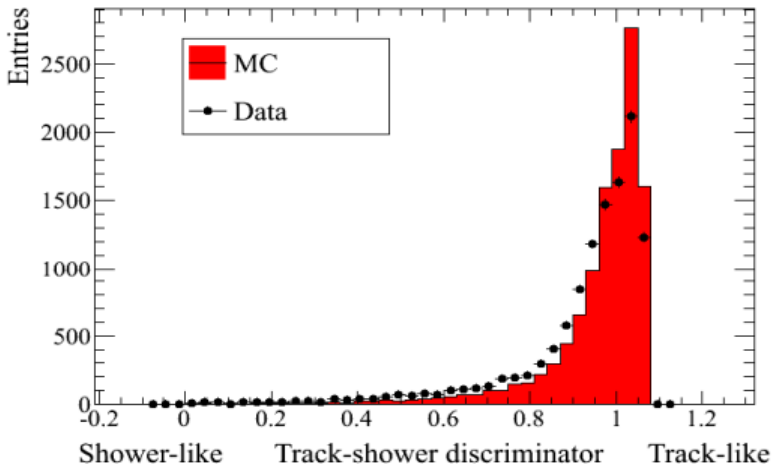


ECAL @ Warwick

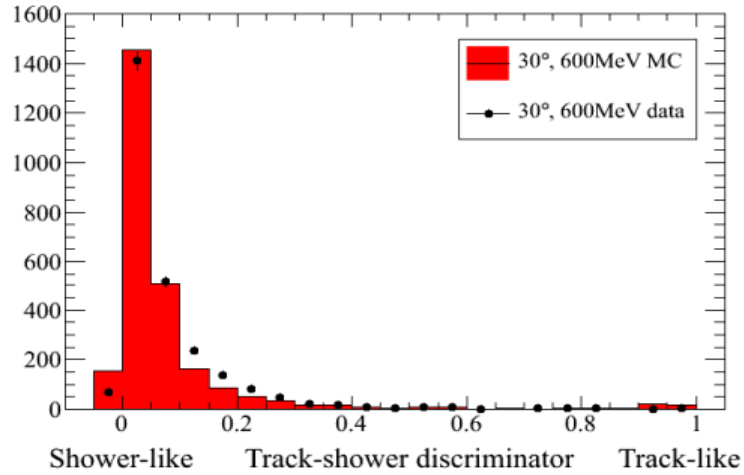




Warwick: PID with the ECAL



(a) Through-going muons in the T2K beam.



(b) Electrons in the DS ECAL test beam.

D. Hadley
A. Furmanski
C. Lister

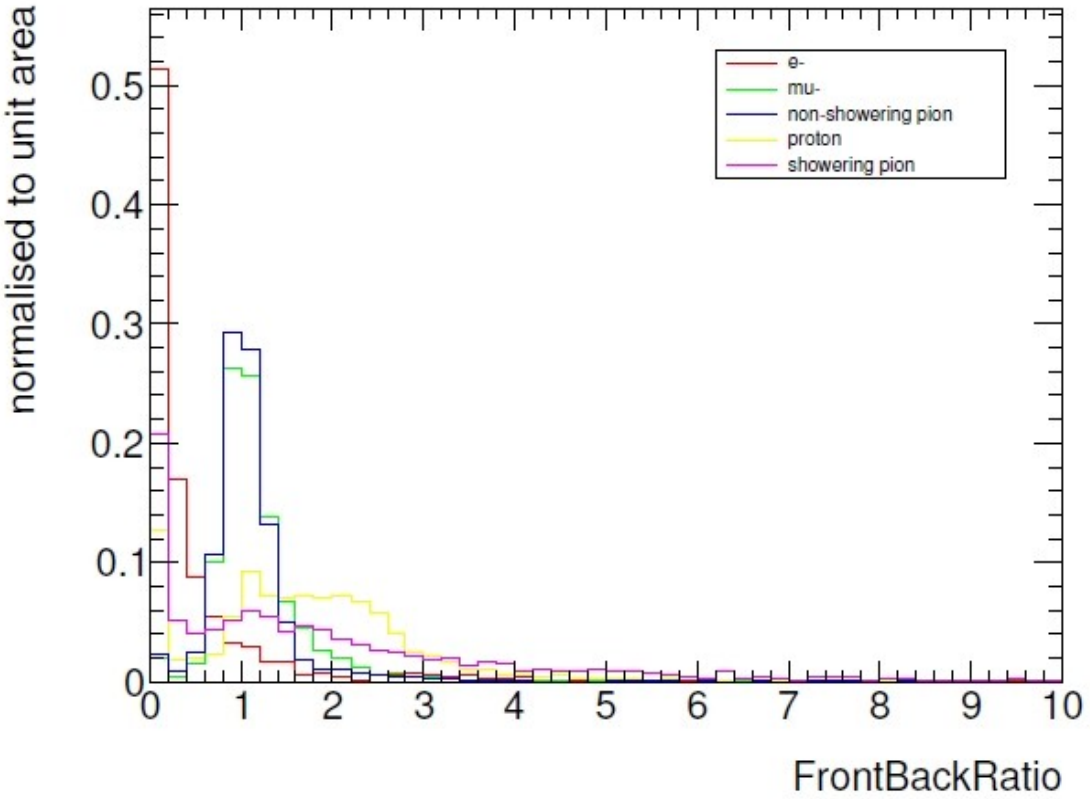
The ECAL has become vital for particle identification in the ND280

Currently a track/shower discriminator

- Disappearance analysis
- θ_{13} measurement
- Antineutrino analysis
- CC inclusive analysis
- All pion channel analyses
- Coherent π^0 analyses

Upcoming work

Simple track-shower has been extremely useful. The ECAL can, however, provide more. Track/Shower is now being replaced with likelihoods to distinguish between different topologies



- Track/Shower
- Muon/Showering pion
- Electron/photon
- EM/Hadronic Shower
- Shower/Highly ionising tracks (protons)

D. Hadley
A. Furmanski

Service Operations

P. Litchfield - stationed in Japan - holds leading roles in T2K

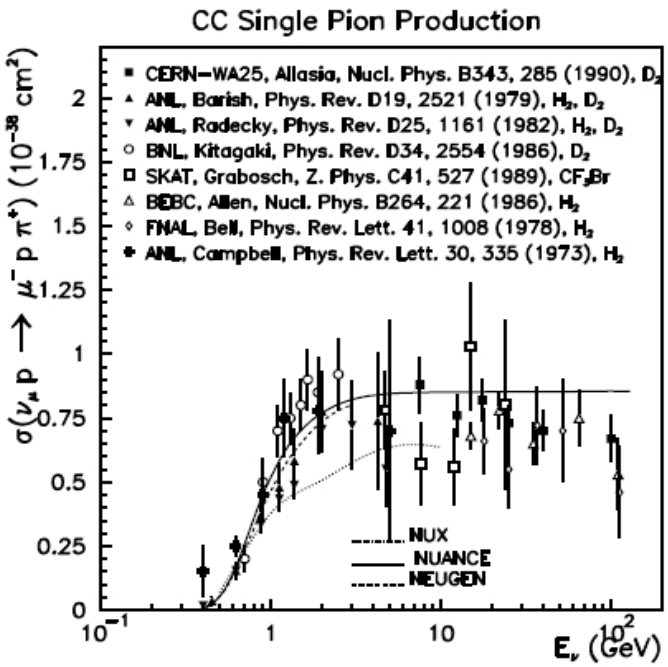
Run Coordinator
Post-earthquake and Safety committee
ECAL Calibration implementation
ND280 Software convener

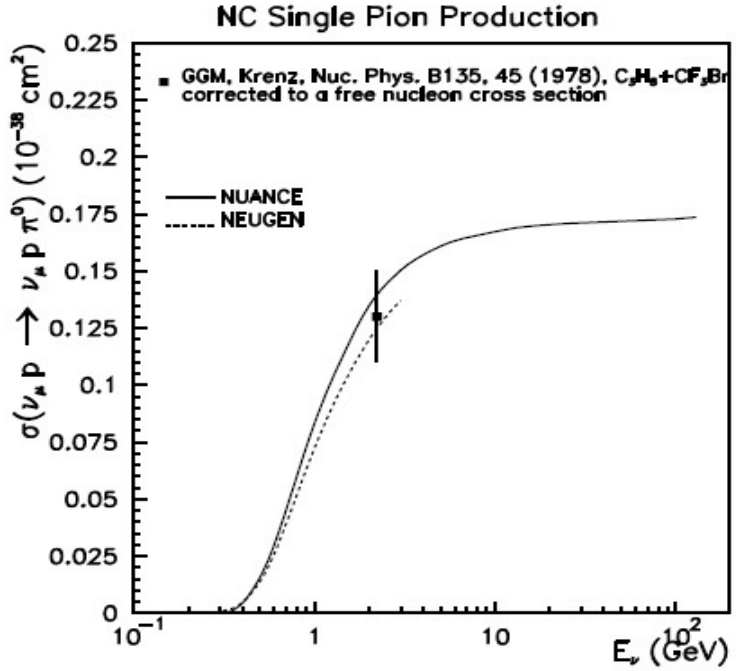
C. Lister, A. Furmanski, D. Hadley leading analysis of ECAL Testbeam which has been crucial to our understanding of ECAL PID (see later)

Cross sections

The ND280 and high beam power is a good opportunity to study neutrino cross sections at 1 GeV or so.

Data in this region is sparse (although getting better) and affected by poorly understood nuclear effects





Cross sections

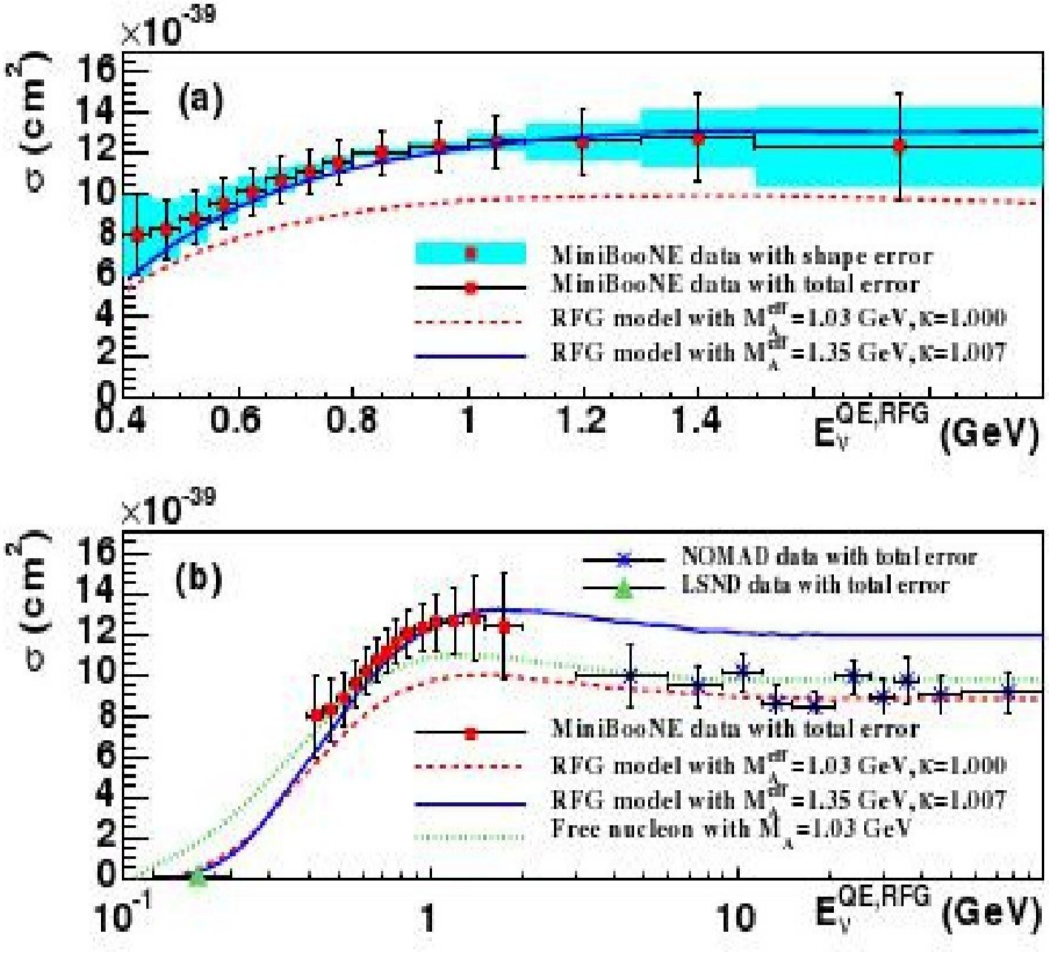
Source	$\sin^2 2\theta_{13} = 0$	$\sin^2 2\theta_{13} = 0.1$
(1) neutrino flux	$\pm$ 8.5%	$\pm$ 8.5%
(2) near detector	$^{+5.6}_{-5.2}$%	$^{+5.6}_{-5.2}$%
(3) near det. statistics	$\pm$ 2.7%	$\pm$ 2.7%
(4) cross section	$\pm$ 14.0%	$\pm$ 10.5%
(5) far detector	$\pm$ 14.7%	$\pm$ 9.4%
Total $\delta N_{SK}^{exp}/N_{SK}^{exp}$	$^{+22.8}_{-22.7}$%	$^{+17.6}_{-17.5}$%

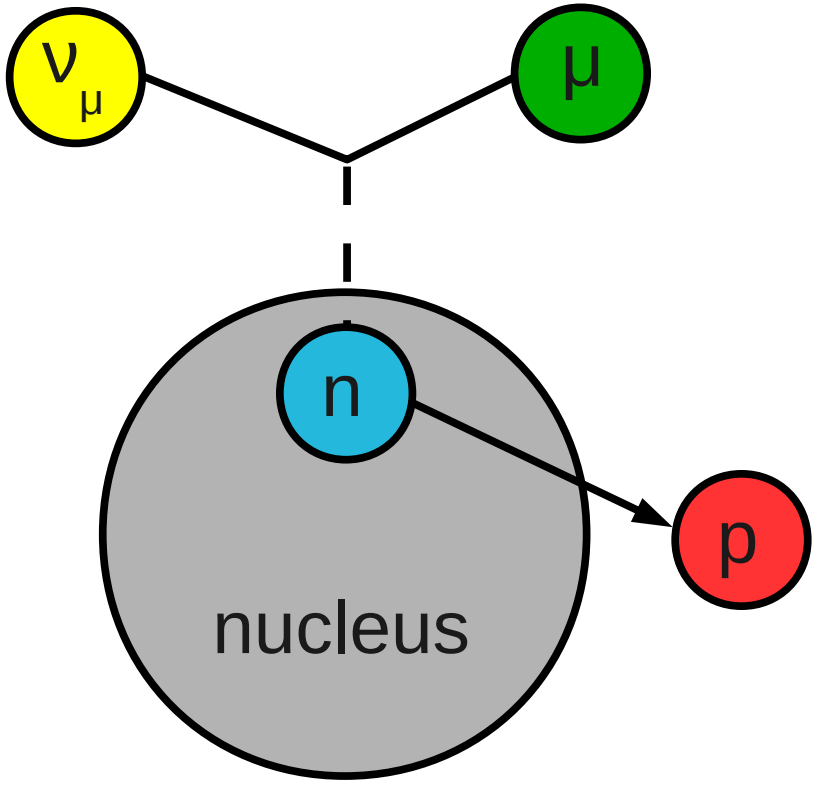
Channel contributions

Error source	syst. error on N_{SK}^{exp}	
CC QE shape	3.1%	→ D. Hadley
CC 1π	2.2%	
CC Coherentπ	3.1%	→ D. Scully
CC Other	4.4%	
NC $1\pi^0$	5.3%	
NC Coherentπ	2.3%	
NC Other	2.3%	
$\sigma(\nu_e)$	3.4%	
FSI	10.1%	→ All
Total	14.0%	

Quasi-Elastic Scattering

Most important process in T2K. Still there are issues with our understanding. **D. Hadley** is trying to make a measurement of the cross section on carbon

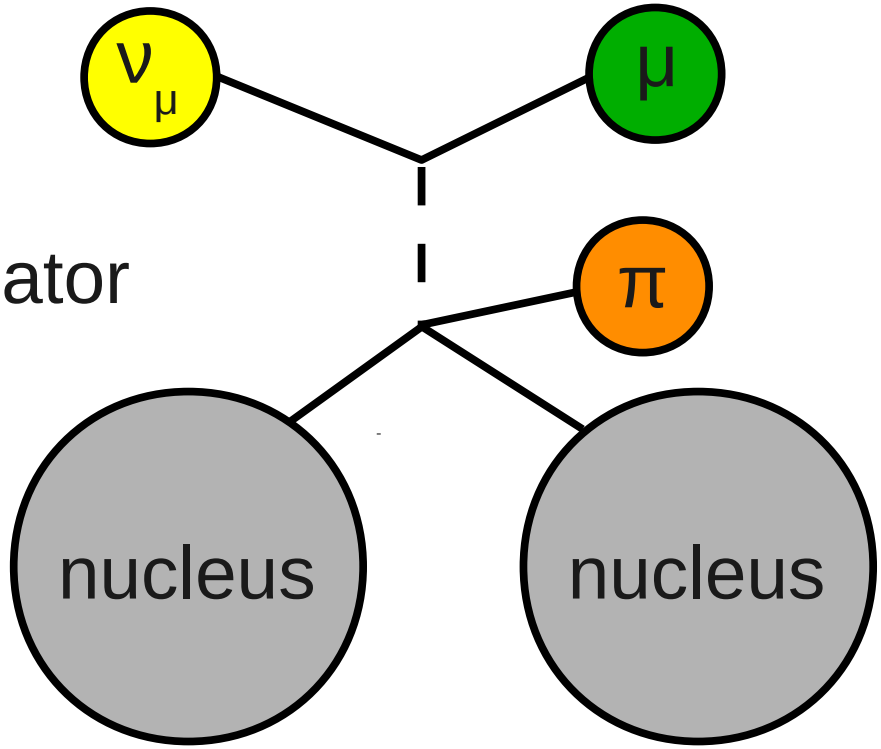


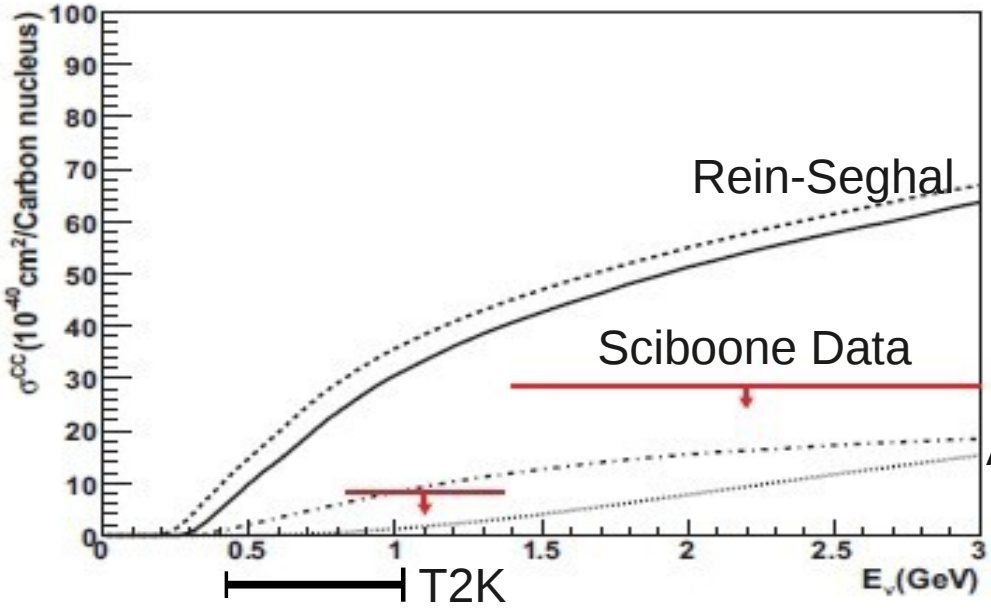


Coherent pion production

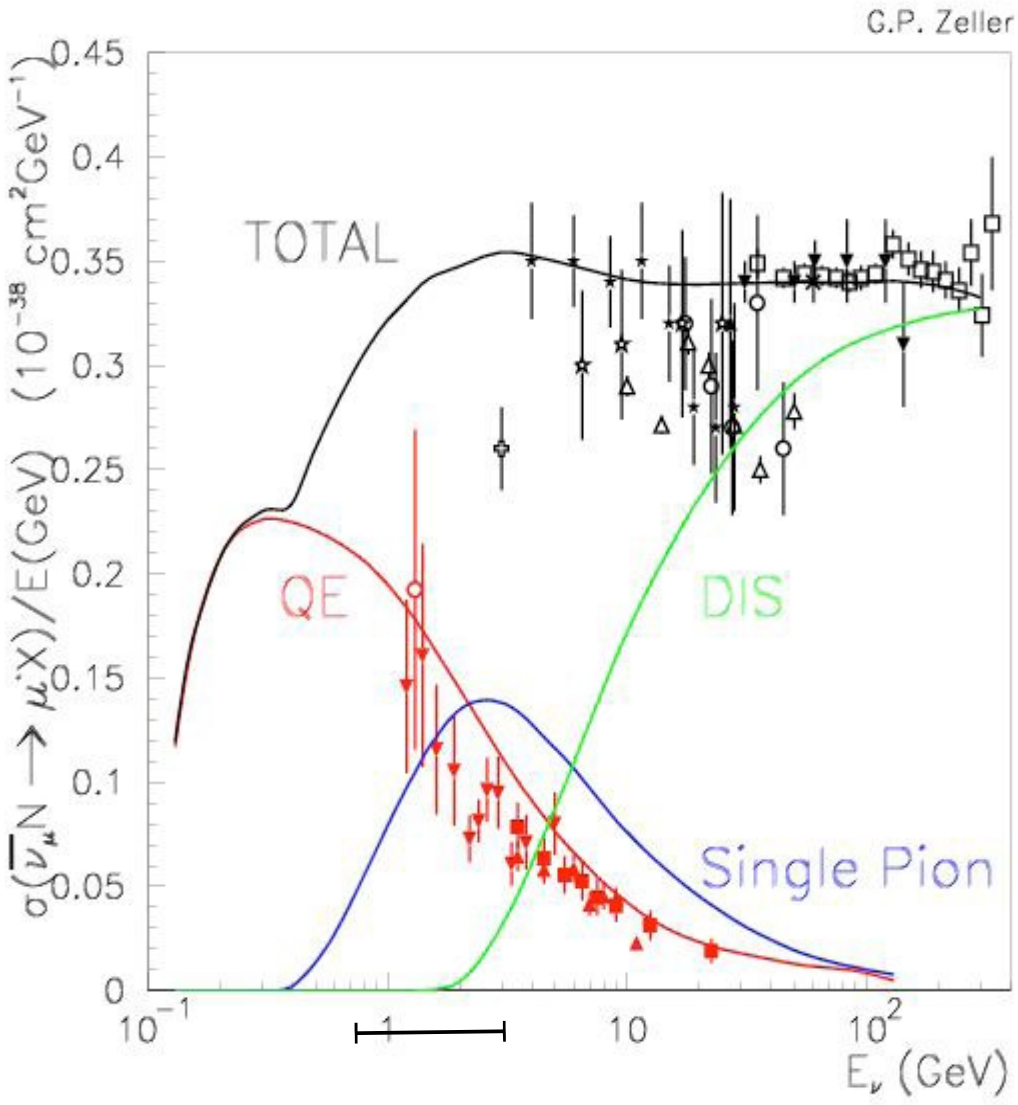
Coherent process is not well understood

<u>D. Scully</u> is implementing a new model in GENIE - the event generator commonly used in neutrino experiments





Antineutrino Cross-sections



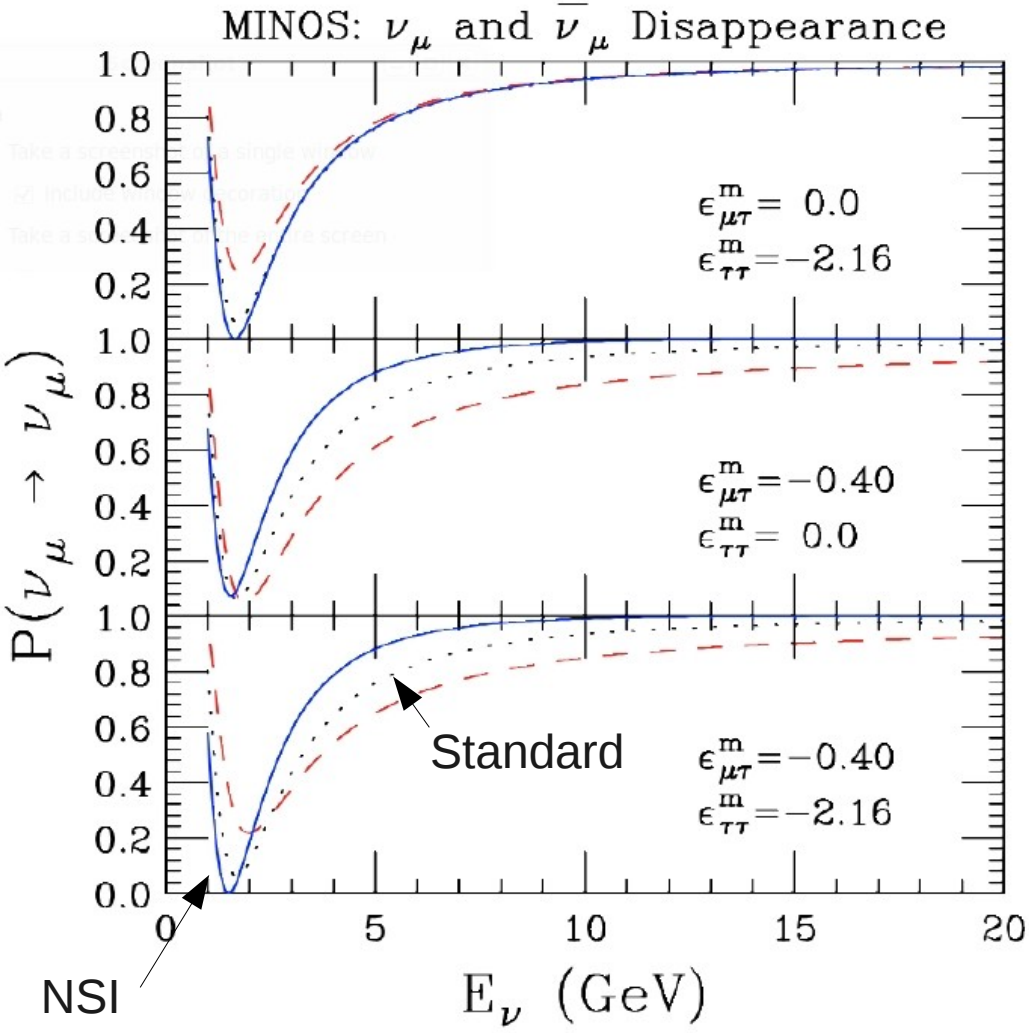
Total antineutrino cross section at a few GeV is very poorly, or even **not**, known

Dominant systematic for conventional long-baseline CP violation measurement

C. Lister looking at $\bar{\nu}$ in the current ν beam in expectation of $\bar{\nu}$ running after 2014

PID is extremely important for this study

Non-Standard Oscillations



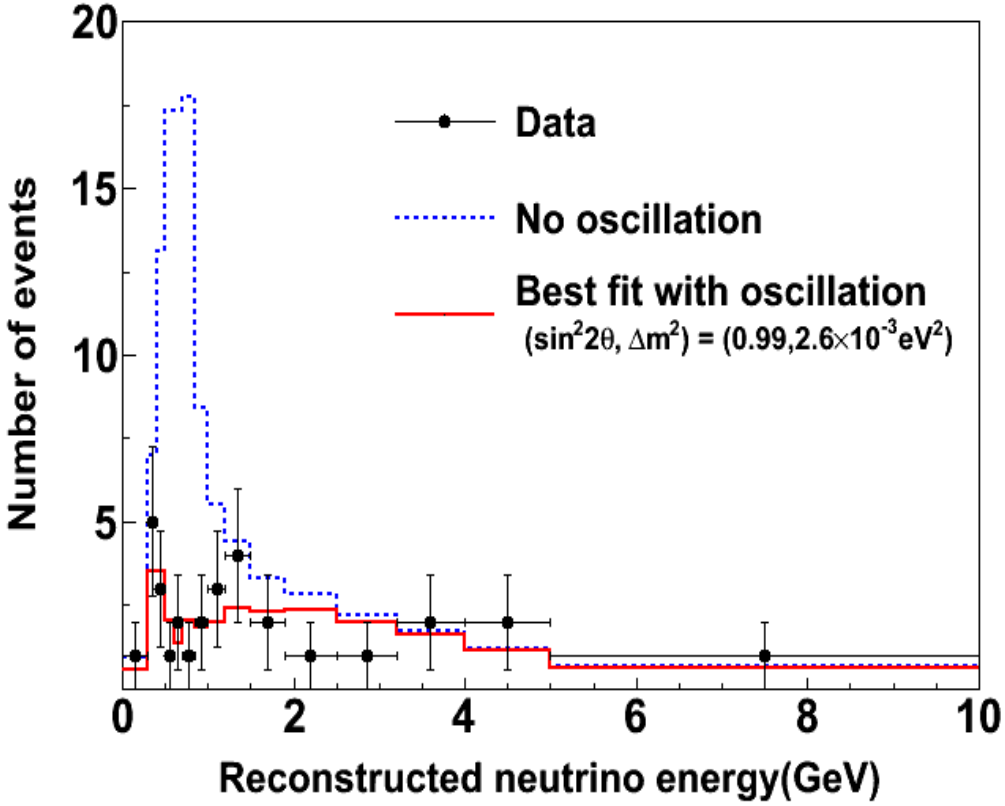
Kopp, Machado and Parke (2010)

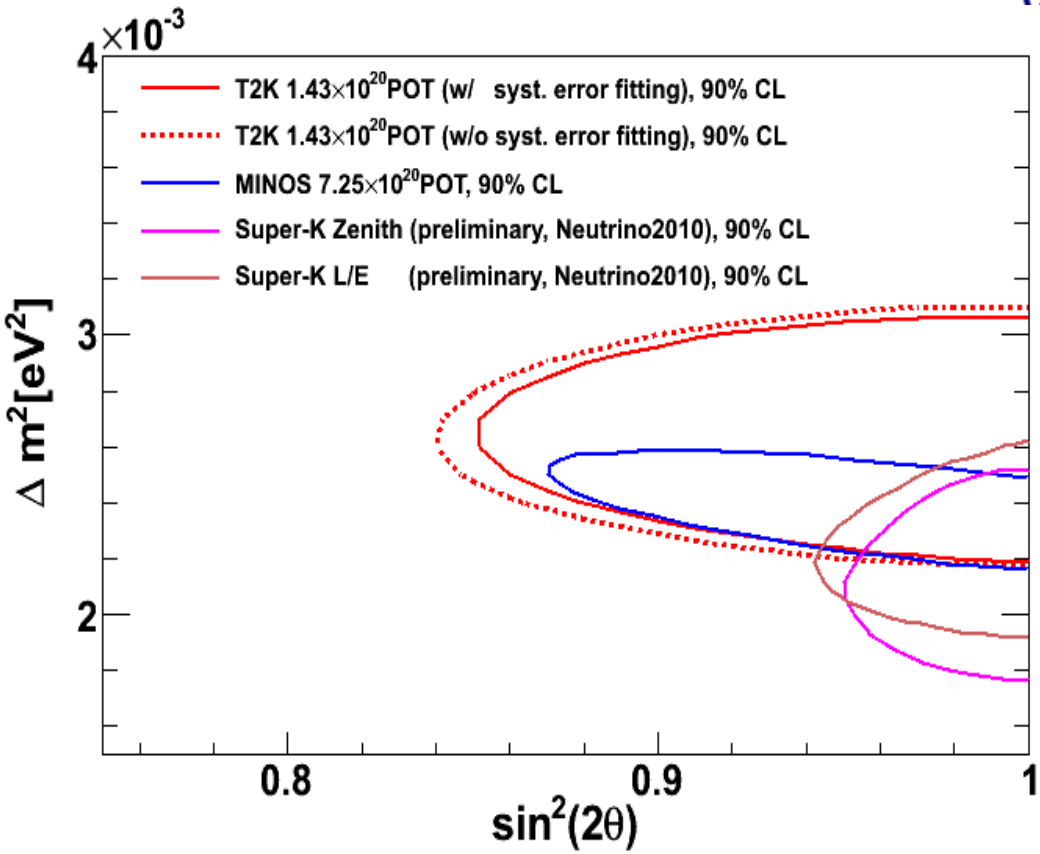
Neutrino oscillations are sensitive to non-standard interactions, steriles and extra-dimensions

P. Litchfield studying T2K sensitivity to sterile signals

S. Dennis (Warwick/RAL) looking at Lorentz violation effects.

Disappearance Analysis





Already competitive with 2% of the data. Recent data suggets that the mixing angle is not maximal. Significant improvement in θ_{23} and tests of maximal mixing expected.

P. Litchfield studying measurement of θ_{23} octant

T2K Future

- Verify reactor θ_{13} measurements with neutrinos
- World-leading measurement of disapperance paramters
- World-leading measurement of low energy cross sections
- Onwards to CP violation
- T2K has only taken about 4% of it's total data.
- Warwick group taking leading roles in many of the key areas