## A Monte Carlo study of the $CC1\pi^0$ Selection at the T2K Near Detector

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- T2K
- Detectors
- $CC1\pi^0$  Monte Carlo studies in the Near Detector
- Early Monte Carlo based selection.

(First T2K Beam Neutrino Events seen)

(Left: ND280, Dec 09 Right: SK, Feb 10)





#### T2K – Aims and Motivation

#### - A bit of neutrino oscillation theory...



- Aim to measure  $\theta_{13} \Delta m_{23}^2$  and  $\theta_{23}$
- Study into whether  $\theta_{23}$  is maximal, needed to constrain mass models.
- $\theta_{13}$   $\rightarrow$  phase parameter ( $\delta$ )
  - Possible leptonic CP violation.
- T2K aims to investigate these by studying the possible oscillation  $v_{\mu} \rightarrow v_{e}$

$$P(\nu_{\mu} \rightarrow \nu_{e}) \approx \sin^{2} \theta_{13} \sin^{2} 2 \theta_{23} \sin^{2} \left(\frac{1.27 \Delta m_{23}^{2} L}{E_{\nu}}\right)$$

### T2K – Experimental set up



Synchrotro

### T2K Near Detector - ND280



- 280m from the T2K graphite target.

- Understand flux and cross-sections close to beam neutrino source.

- Contained inside the refurbished UA1 Magnet.

- Two detection media,

- - Scintillator based – P0D, FGD, Ecals and SMRD.

- - Gas filled TPCs.

**UA1 Magnet Yoke Fine-Grain** Detectors Downstream P0D (π<sup>0</sup>-ECAL detector Solenoid Coil **Barrel ECAL** P0D **ECAL** 

Two neighbouring but separate detectors
 <u>P0D</u> - Specifically built to provide information on π<sub>0</sub> cross sections.

<u>Tracker</u> – FGDs, TPCs, Ecals - More general setup aims to profile other important cross sections.

### $CC1\pi$ – Interaction & Cross-sections 5

 $CC1\pi \rightarrow$  Neutrino interacts weakly through the exchange of a W Boson with a target nucleon to create one neutral pion and no other mesons.



E, (GeV)

# $CC1\pi^0$ – Motivation and Signal

#### **Motivation**

- Previously  $\pi^0$  production in this energy range is not well investigated.
- 'Known' vertex position,
  - $CC1\pi^0$  interactions provide known events to help in  $NC1\pi^0$ 
    - Major background at SK to resolve  $v_e$  interactions.
- Understood event  $\rightarrow$  help with tuning the energy scale of the detector for example.

#### <u>Signal</u>

- $\pi^0$  decay to  $2\gamma$  with a fraction =  $98.823 \pm 0.034$
- Target  $\rightarrow$  FGD
- The signal we are looking for -
  - 1 x Muon Track.
  - 2 x Photon Showers
  - Possible Proton/Neutron Track/Showers.



## $CC1\pi^0$ – MC Acceptance Study

- Acceptance study was made to examine the signal topology in the Tracker region of the ND280.

- Monte Carlo Events used;

- $CC1\pi^0$  Interactions only in FGDs
- 6428 Events Total (~  $4.5 \times 10^{20}$  POT, expect  $8.1 \times 10^{21}$  POT over 5 years)

#### **Muons**

- Muons tend to be highly boosted and often pass through the TPCs. This allows good momentum resolution



## $CC1\pi^0 - MC$ Acceptance Study

#### <u>Photons</u>

#### - Isotropic.

- Lower energy photon spectrum close to the reconstruction limit of Tracker ECals (50MeV).

- Many photons interact early outside ECal  $\rightarrow$  Poor  $\pi^0$  invariant mass reconstruction.





## $CC1\pi^0$ – Early Selection

#### Preliminary MC results...

- Acceptance study showed just 20% of  $CC1\pi^0$  interactions had both  $\gamma$ 's reach ECals.
- First look at a selection using these know events:

#### Cuts used

- 1. Reconstructed vertex within fiducial volume of either FGD.
- 2. One negative track leaving vertex.
- 3. Two reconstructed showers seen in the ECals, within 50ns of the initial vertex time.

Cuts	Number of Events	Percentage of Events
True Vertex in FGD Fiducial	2903	100
Recon Vertex in FGD Fiducial	1509	52
Negative Track in TPC	932	32
2 Ecal Showers in time	149	5

## $CC1\pi^0$ – Pion Mass Reconstruction

Preliminary MC results...

Early <u>preliminary</u> first pass at pion mass reconstruction of Monte Carlo.

$$m_{\pi}^{2} = 2 E_{1}^{\gamma} E_{2}^{\gamma} (1 - \cos(\theta))$$

 $E_1^{\gamma}$  = Energy of the higher energy Photon  $E_2^{\gamma}$  = Energy of the lower energy Photon  $\theta$  = Opening angle of the two Photons



## **Conclusions and Future Work**

- Investigate backgrounds and purity using 'mock data' Monte Carlo.
- Use this to research new cuts to better selection.
- Improve reconstruction tools allowing for better vertexing and shower reconstruction.

- Aim to conclude the early stage of this study to allow processing of first data after summer shutdown.

#### Questions...

#### T2K – Sensitivity

 $\theta_{13}$ 

Current Limit -

 $\sin^2 2\theta_{13} < 0.13$  is the limit by CHOOZ for  $\Delta m_{32}^2 = 2.8 \times 10^{-3} \text{ eV}^2 (90\% \text{ CL.})$ 

T2K Limit Goal-

 $\sin^2 2\theta_{13} < 0.006 @ 90 CL$  $\Delta m_{32}^2 = 2.4 \times 10^{-3} eV^2 (90\% CL.)$ 

#### $\theta_{23}$ and $\Delta m_{23}^2$

Current Limit -

 $\sin^2 2\theta_{23} > 0.92 @ 90\% C.L. (SK)$  $|\Delta m_{23}^2| = 2.43 \pm 0.13 \times 10^{-3} eV^2$ (90% CL.(MINOS))



T2K Limit Goal -

 $\delta(\sin^2 2\theta_{23}) < 0.01$  $\delta(\Delta m_{23}^2) < 10^{-4} \text{ eV}^2 \text{ (a) 90\% CL.}$