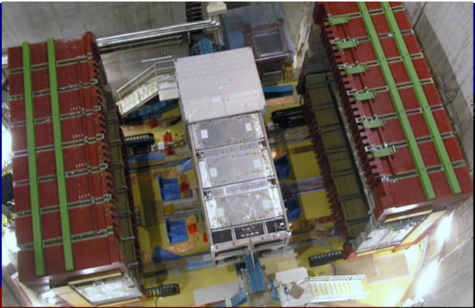
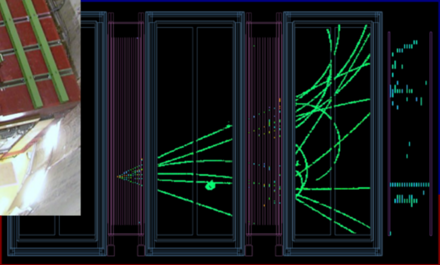
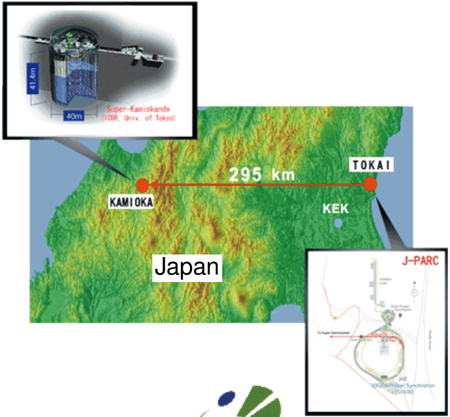




The ν and $\bar{\nu}$ interaction rate measurements in the T2K near detector

16th June 2014, Anthony Hillairet for the T2K collaboration

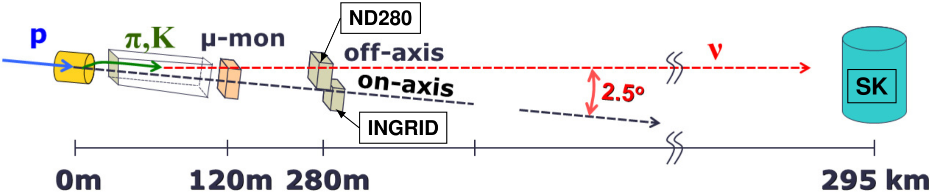
The Tokai to Kamioka experiment



The T2K experiment was designed to measure neutrino oscillations:

- ν_e appearance
  $\Longrightarrow \sin^2(2\theta_{13})$
- ν_μ disappearance
  $\Longrightarrow \sin^2(2\theta_{23})$ and $|\Delta m^2_{32}|$
- look for CP violation in the neutrino sector

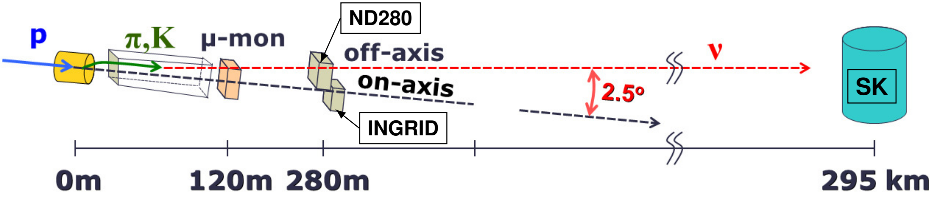
T2K apparatus



The T2K detection system is composed of multiple components:

- INGRID, near detector on-axis for neutrino beam monitoring
- Super-Kamiokande (SK) at 295km and off-axis to detect neutrinos after oscillation
- ND280, near detector off-axis measures neutrino interaction rate of the unoscillated beam going to SK

T2K apparatus



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- INGRID, near detector on-axis for neutrino beam monitoring
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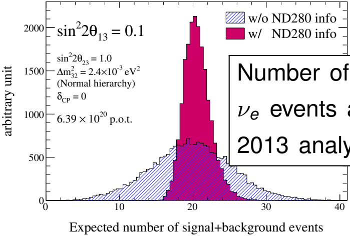
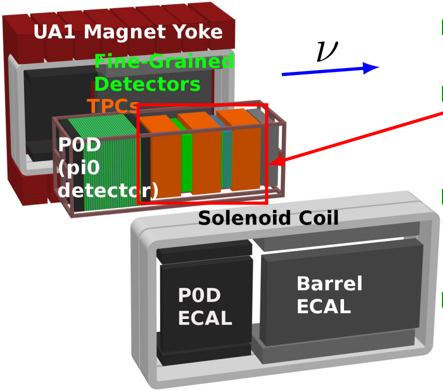


Number of predicted ν_e events at SK in 2013 analysis

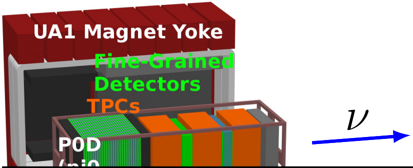
ND280, the T2K off-axis near detector

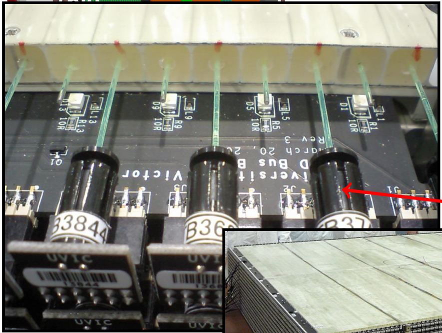
ND280 measures the characteristics of the unoscillated neutrino beam:



- 0.2T magnetic field
- Central component is the tracker
  Composed of 3 TPCs and 2 FGDs
- π^0 dedicated detector
  $\Longrightarrow$ P0D
- Electromagnetic calorimeters
  $\Longrightarrow$ ECal
- Yoke instrumented with scintillators
  $\Longrightarrow$ Side Muon Range Detectors (SMRDs)

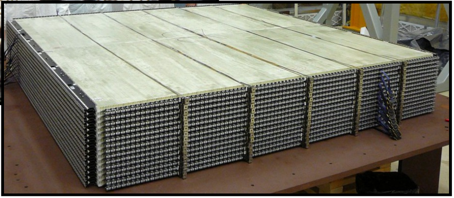
Fine-Grained Detectors (FGDs)





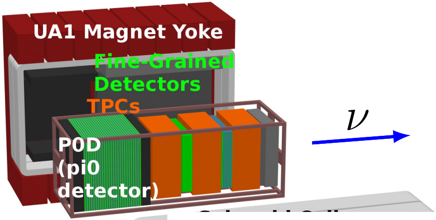
2 FGDs serving as active targets

- FGD1: Layers of X and Y scintillator bars
- FGD2: Layers of X and Y scintillator bars alternated with water layers
- Provides detailed vertex information
- Multi-Pixel Photon Counter



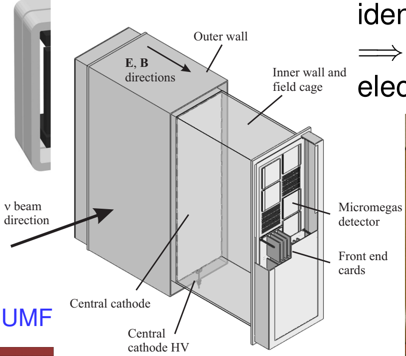
Made at TRIUMF

Time projection chambers (TPCs)



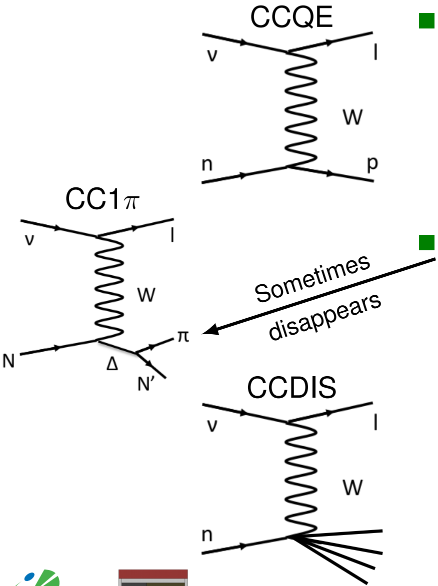
3 identical TPCs:

- filled with argon (95%), CF_4 (3%), isobutane (2%)
- MicroMegas detectors
- Perform momentum reconstruction and particle identification
  $\Longrightarrow$ Probability of identifying μ as electron $< 0.2\%$ ($p < 10$GeV/c)



Made at TRIUMF

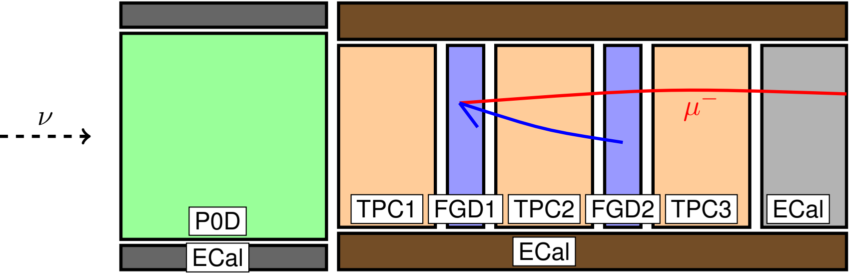
Neutrino interactions of interest



- To characterize the ν_μ component of the beam, we start by looking for μ^- from charged-current (CC) interactions
  $\Longrightarrow$ CC inclusive selection

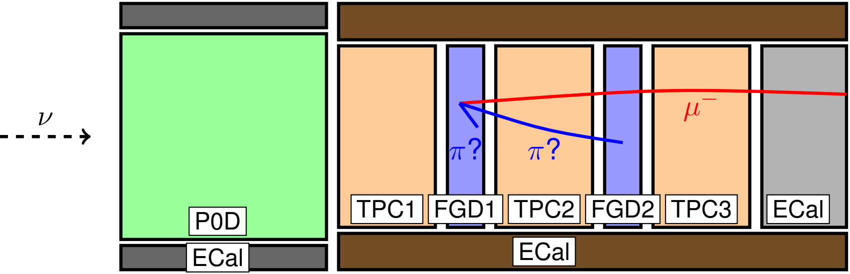
- Due to pion absorption before it leaves the nucleus, we analyzes the CC events according to the topologies of various number of outgoing pions:
  - CC0π: No pion observed
  - CC1π^+: One positive pion observed
  - CC-Other: All other CC interactions

2013 ND280 ν_μ event selection



One μ^- from FGD1 crossing TPC2 $\Longrightarrow$ **CC inclusive sample**

2013 ND280 ν_μ event selection



One μ^- from FGD1 crossing TPC2 $\Longrightarrow$ **CC inclusive sample**

- No pions found

$\Longrightarrow$ **CC0π sample**

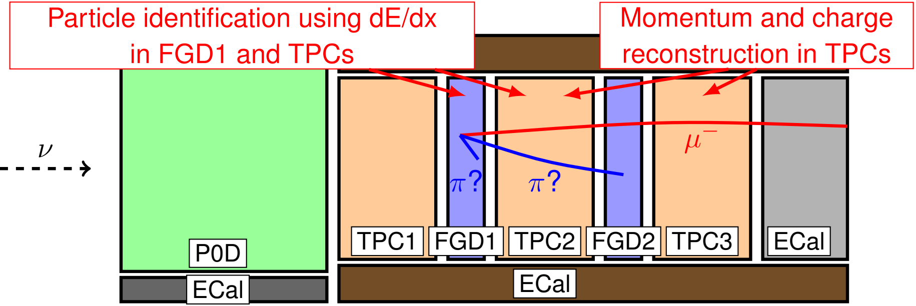
- $1\pi^+$ found

$\Longrightarrow$ **CC1π^+ sample**

- $> 0\pi^0$ or
- $> 0\pi^-$ or
- $> 1\pi^+$ found

$\Longrightarrow$ **CC-Other sample**

2013 ND280 ν_μ event selection



One μ^- from FGD1 crossing TPC2 $\Longrightarrow$ **CC inclusive sample**

- No pions found

$\Longrightarrow$ **CC0π sample**

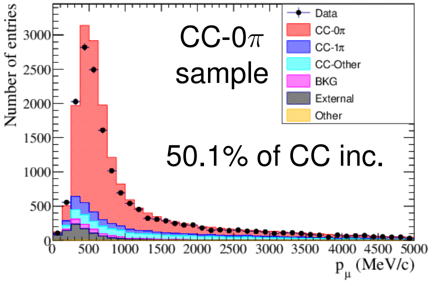
- $1\pi^+$ found

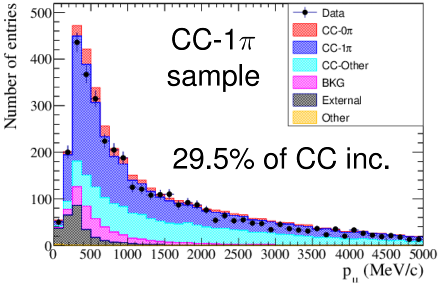
$\Longrightarrow$ **CC$1\pi^+$ sample**

- $> 0\pi^0$ or
- $> 0\pi^-$ or
- $> 1\pi^+$ found

$\Longrightarrow$ **CC-Other sample**

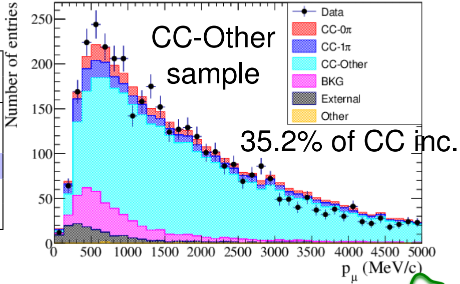
2013 results, 6.30×10^{20} *POT* of ν beam data





Data/MC distributions before any fit

	Purity		
	CC-0π	CC-1π	CC-Other
CC-0π	72.6%	6.4%	5.8%
CC-1π	8.6%	49.4%	7.8%
CC-Other	11.4%	31.0%	73.8%
Bkg (NC+$\bar{\nu}_\mu$)	2.3%	6.8%	8.7%
Out FGD1 FV	5.1%	6.5%	3.9%



Bkg (NC+$\bar{\nu}_\mu$) + Out FGD1 FV = 9.12% of CC inc.

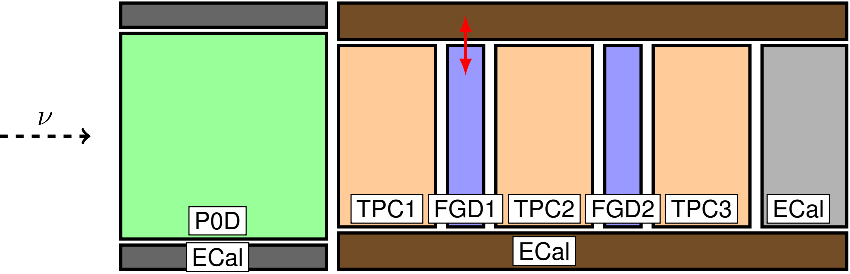
From the 2013 to the 2014 ND280 analysis

The 2013 analysis had many limitations:

- Only FGD1 used as neutrino target
  $\Longrightarrow$ only the neutrino cross section on carbon is measured
- Only CC interactions producing forward-going muons were selected
  $\Longrightarrow$ phase space very different from Super-Kamiokande's 4π acceptance

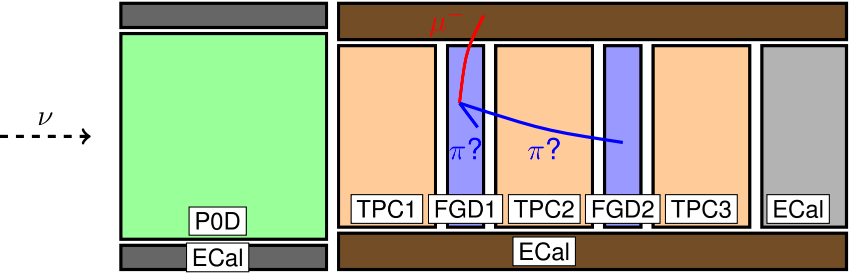
Many improvements have been made to the calibration and the reconstruction software for the 2014 analysis.

2014 ND280: FGD1 high angle selection



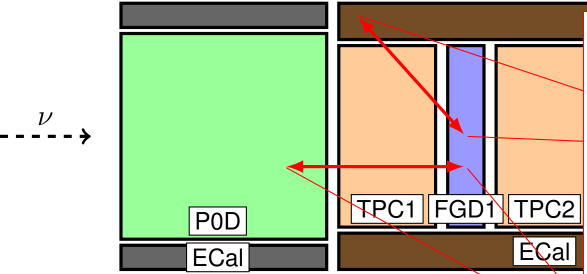
- FGD-ECal track matching improved $\Longrightarrow$ increased reconstruction efficiency for tracks not crossing the TPCs

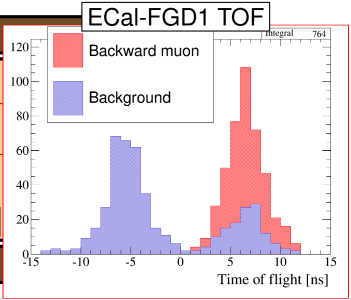
2014 ND280: FGD1 high angle selection

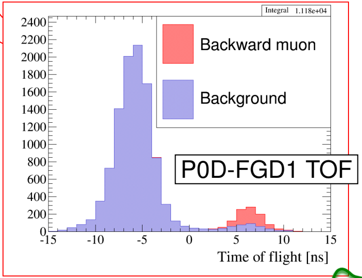


- FGD-ECal track matching improved $\Longrightarrow$ increased reconstruction efficiency for tracks not crossing the TPCs
- Events with μ^- at high angle can now be more efficiently reconstructed and selected in a CC inclusive sample
- Use momentum by range in ECals and SMRDs to get the μ^- momentum
- Pions are identified like for the 2013 analysis to create CC0π, CC1π^+ and CCOther samples as well

2014 ND280: backward-going muon selection



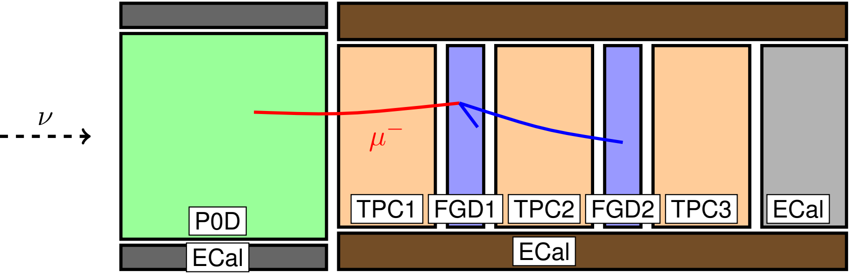




- Inter-detector timing calibration

  $\Longrightarrow$ track sense determination possible

2014 ND280: backward-going muon selection



- Inter-detector timing calibration

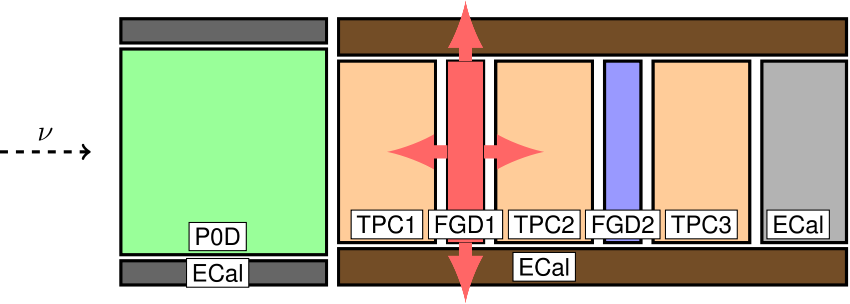
  $\Longrightarrow$ track sense determination possible

- New possibility to select backward going μ^-

- Only $\sim$ 2000 events in the available ND280 data

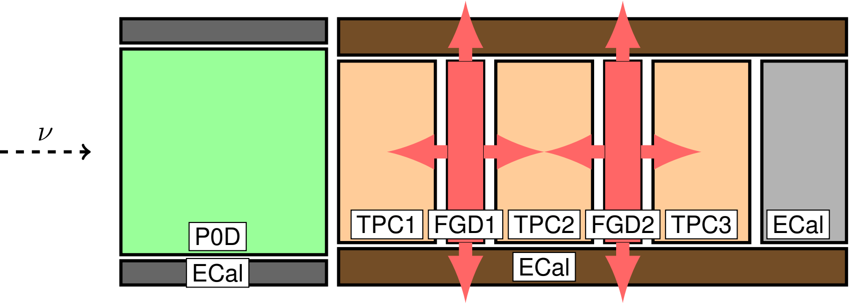
  $\Longrightarrow$ CC inclusive only, no sub-samples

2014 ND280: FGD1, FGD2 and more acceptance



- The acceptance of the FGD1 selection will be greatly increased in 2014 thanks to software improvements

2014 ND280: FGD1, FGD2 and more acceptance

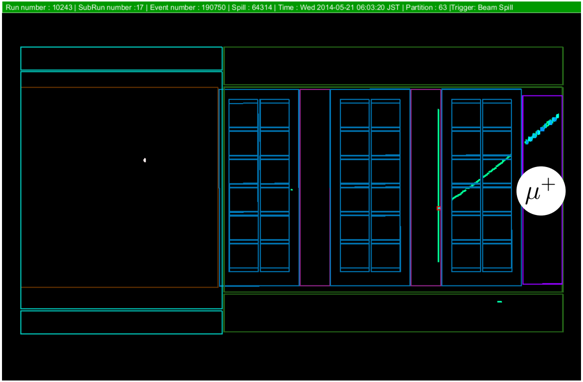


- The acceptance of the FGD1 selection will be greatly increased in 2014 thanks to software improvements
- FGD2 contains water layers between the scintillator layers

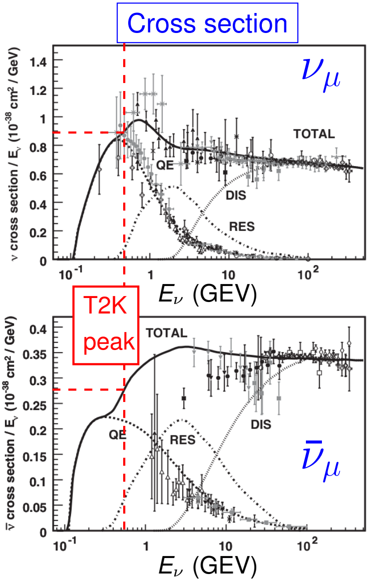
$\Longrightarrow$ The FGD2 measurement will provide constraints on the neutrino cross section on oxygen

New data: $\bar{\nu}$ beam mode started !

- T2K will now measure $\bar{\nu}_\mu$ disappearance, $\bar{\nu}_e$ appearance
  $\Longrightarrow$ search for CP violation
- T2K taking data in anti-neutrino beam mode since 5th June
- First $\bar{\nu}_\mu$ event candidate found in FGD2:



ND280 $\bar{\nu}_\mu$ measurement crucial for T2K



- $\bar{\nu}_\mu$ cross section has never been measured at T2K E_ν range
- Expected $\sigma_{\bar{\nu}_\mu} \sim 1/3\ \sigma_{\nu_\mu}$
  $\Longrightarrow$ ν_μ interaction rate not negligible compared to $\bar{\nu}_\mu$
- SK is a water Cherenkov detector
  $\Longrightarrow$ No reconstruction of lepton charge
- ND280 has charge reconstruction from the TPCs
  $\Longrightarrow$ ND280 can measure the interaction rate ratio $\bar{\nu}_\mu/\nu_\mu$

Summary

The ND280 measurements of the neutrino and anti-neutrino beams are crucial to the T2K neutrino oscillation measurement

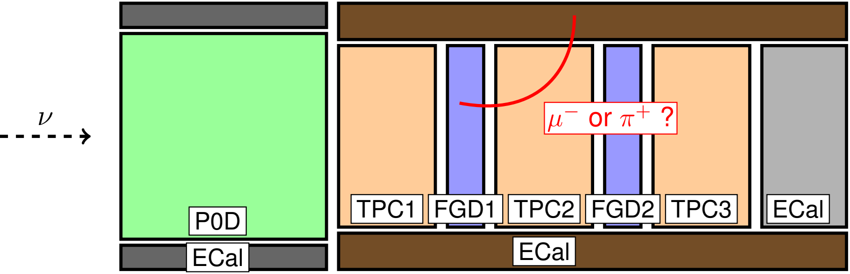
- The software and calibration improvements will provide a 4π acceptance and FGD2 measurement (with oxygen)
- We are getting ready to analyze the new anti-neutrino beam mode data
- All these new measurements from ND280 will be used in a fit to improve constraints on flux and cross section at SK

  $\Longrightarrow$ See Jordan's talk next

Thank you for your attention !

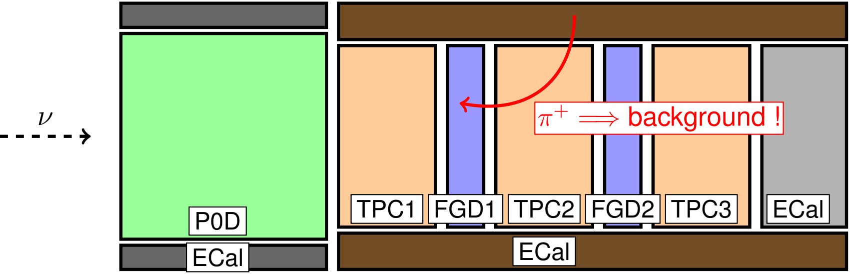
BACKUP SLIDES

2014 ND280: backward going background



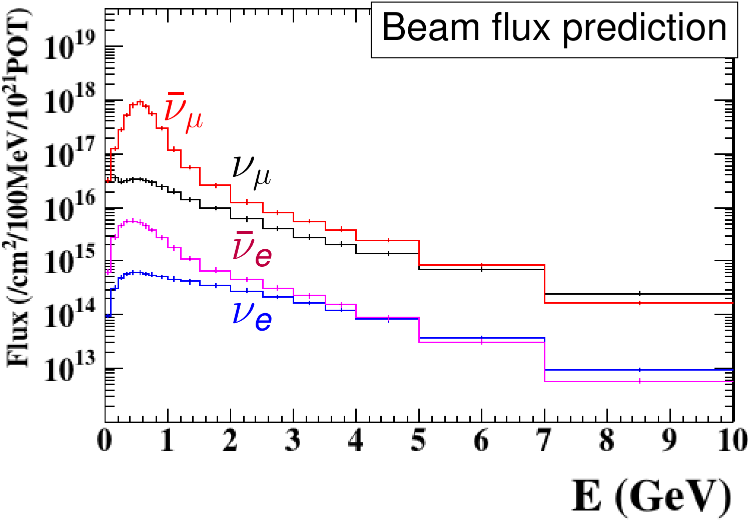
- Improved matching of low momentum tracks from TPCs
$\Longrightarrow$ increased reconstruction efficiency for out-of-fiducial volume background

2014 ND280: backward going background

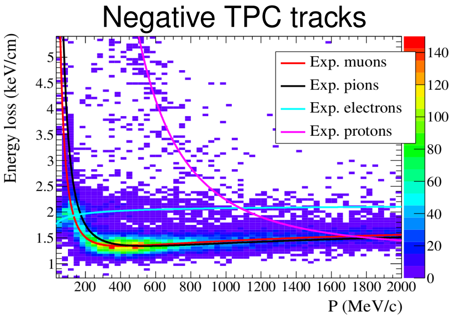


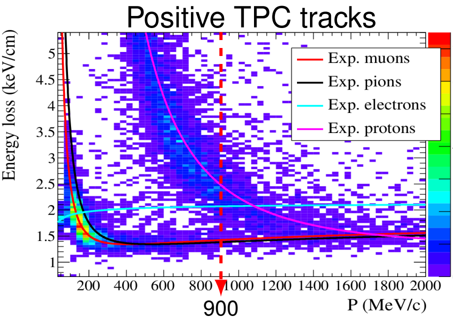
- Improved matching of low momentum tracks from TPCs $\Longrightarrow$ increased reconstruction efficiency for out-of-fiducial volume background
- Inter-detector timing can help identify backward going background
- More than 90% of this background is rejected by track sense determination

Flux in anti-neutrino beam mode



TPC PID for secondary tracks

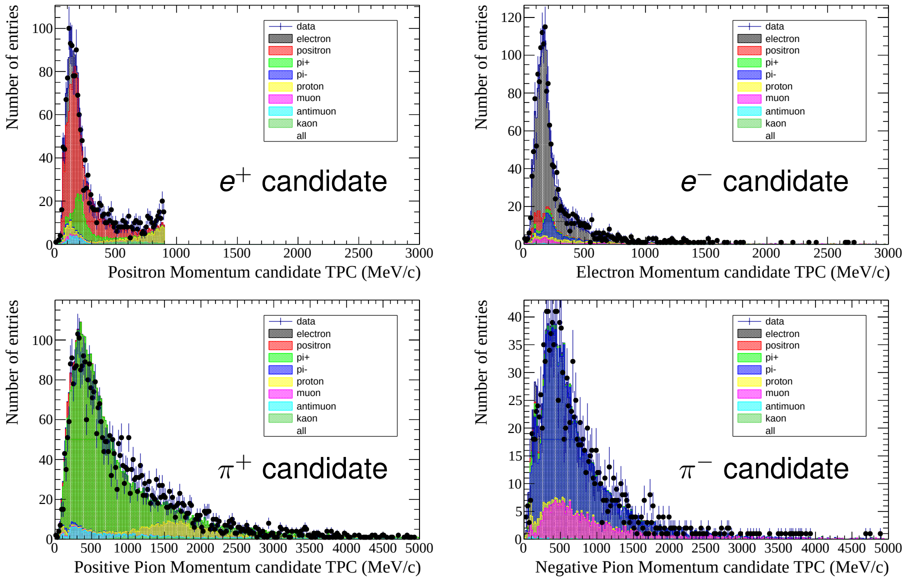




After the muon has been identified, the TPC particle identification (PID) is slightly modified:

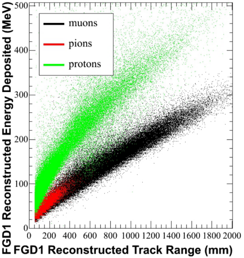
- Possible types for negative particles: electron or pion
- Possible types for positive particles: positron, proton or pion
  Special case:
  if PID = positrons & p > 900 MeV/c $\Longrightarrow$ reclassify as a proton

TPC PID for secondary tracks



FGD PID for secondary tracks

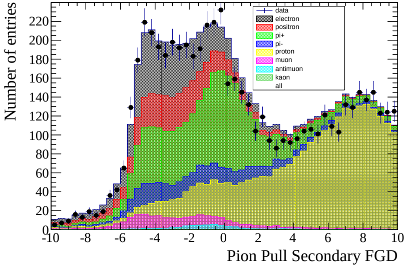
- Also in FGD1, the dE/dx information provides very good separation between protons and pions:



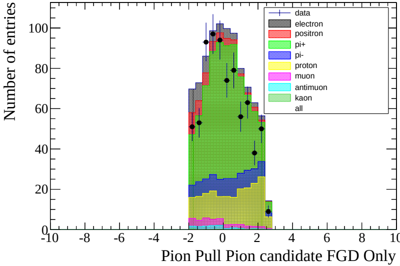
FGD secondary track selection:

1. Select FGD tracks fully contained in FGD1
2. Use measured dE/dx to select π-like tracks

Before FGD PID selection

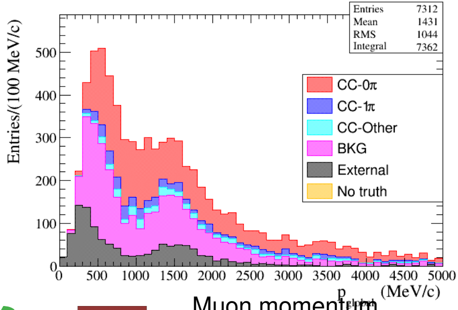


After FGD PID selection



ND280 $\bar{\nu}_\mu$ measurement started in ν beam

- The $\bar{\nu}_\mu$ contamination in the neutrino beam mode was used to develop an $\bar{\nu}_\mu$ selection
- Start with 2013 CC inclusive selection but select positive muons instead
- The ECals particle identification is used to reduce the positive pions and protons background from the ν_μ interactions



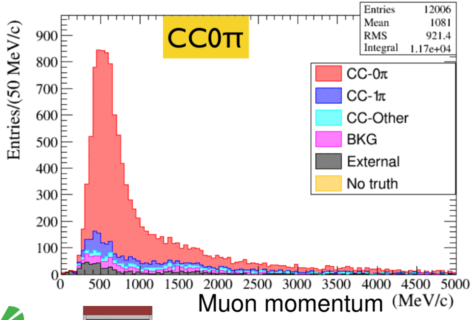
Muon momentum

CC inclusive selection:

- Purity ~50%
- Preliminary result show consistency with Monte Carlo prediction

ND280 $\bar{\nu}_\mu$ measurement started in $\bar{\nu}$ beam

- Again start with 2013 CC inclusive selection but selecting positive muons instead
- CC0π sample purity at 74% even without using ECal information
- CC1π and CCOther have contamination from ν_μ interactions
  $\Longrightarrow$ We may use a CC$n\pi$, $n > 0$, sample instead



$\Longrightarrow$ Ready to analyze data being collected now