Muon antineutrinos in the T2K near detector

THE UNIVERSITY OF WARWICK

IoP HEPP & APP Group Meeting 2013

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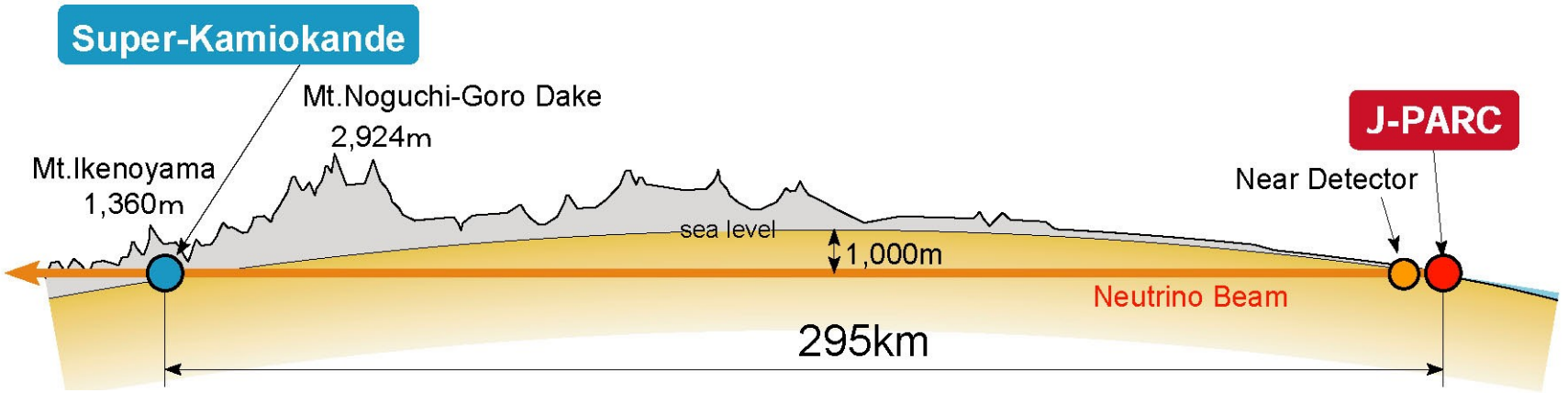
Outline

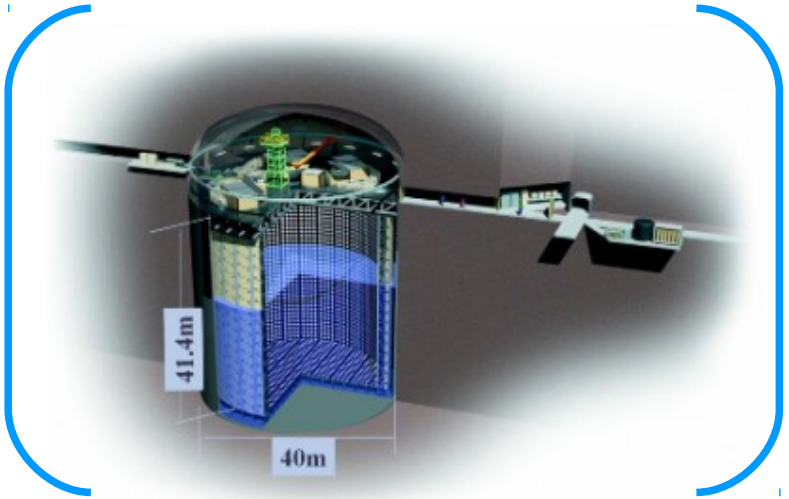
In this talk:

- Brief overview of T2K and the near detector
- Outline selection of muon antineutrino events in T2K's primarily muon neutrino beam
- Work towards a muon antineutrino inclusive charged-current cross-section on carbon

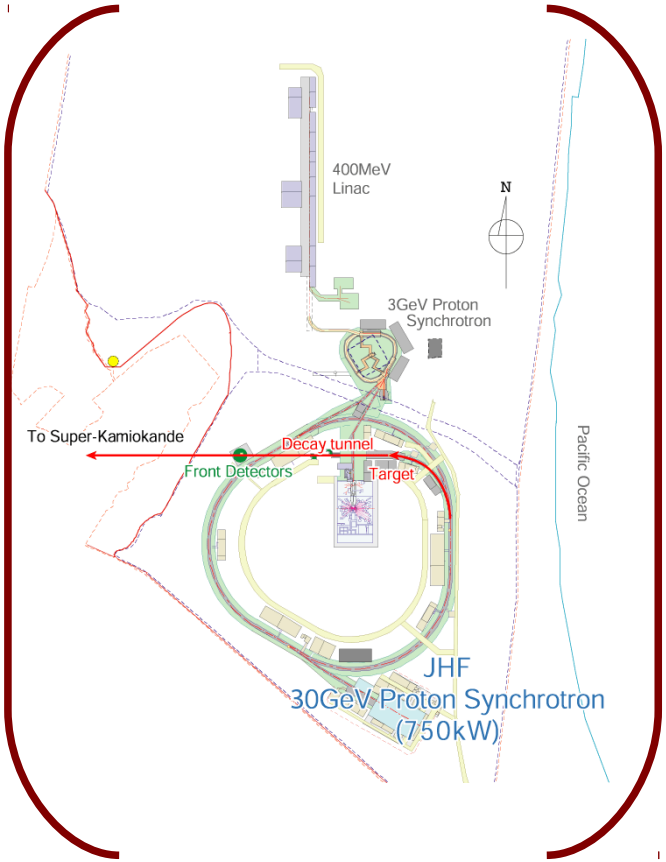


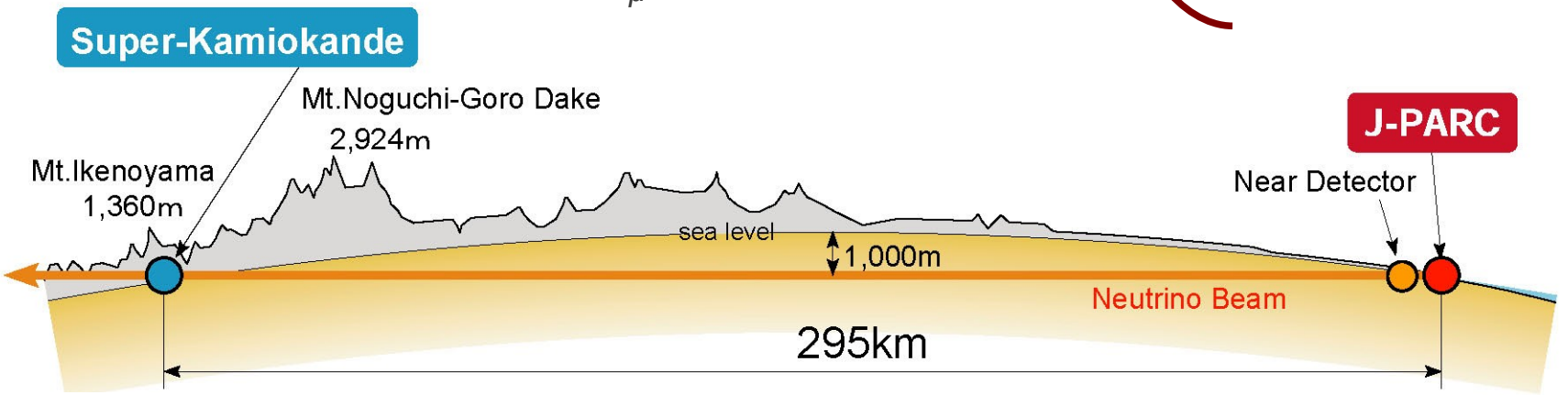
T2K

Main Goals



- θ_{13}: $\nu_\mu \rightarrow \nu_e$ *ν_e appearance*
- θ_{23}: $\nu_\mu \rightarrow \nu_\mu$ *ν_μ disappearance*

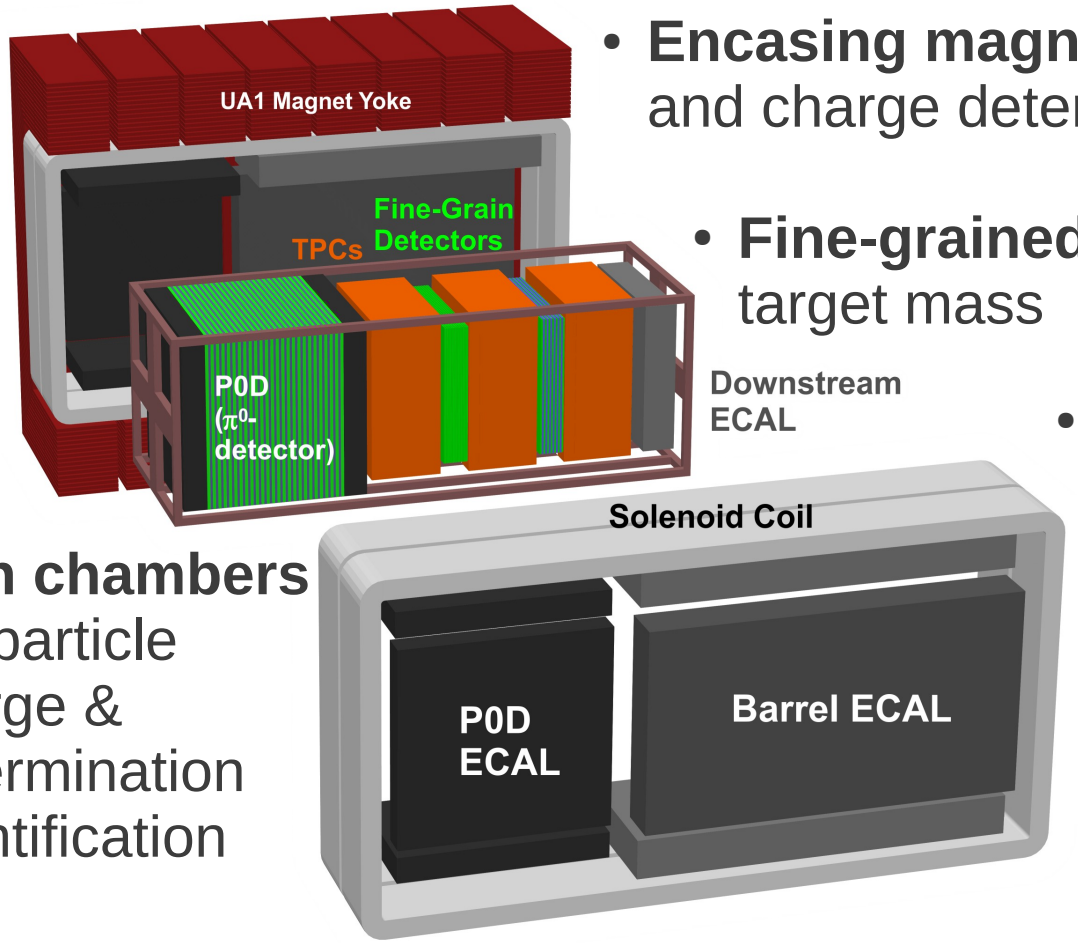




ND280

- Determine beam composition prior to neutrino oscillation
- Measure neutrino cross-sections

- **π^0 detector (P0D)** optimised for NC and CC π^0 detection



- **Encasing magnet** for momentum and charge determination
- **Fine-grained detectors** as target mass
- **Time projection chambers** High resolution particle tracking for charge & momentum determination and particle identification
- **Electromagnetic calorimeters** provide EM energy measurement and additional particle identification

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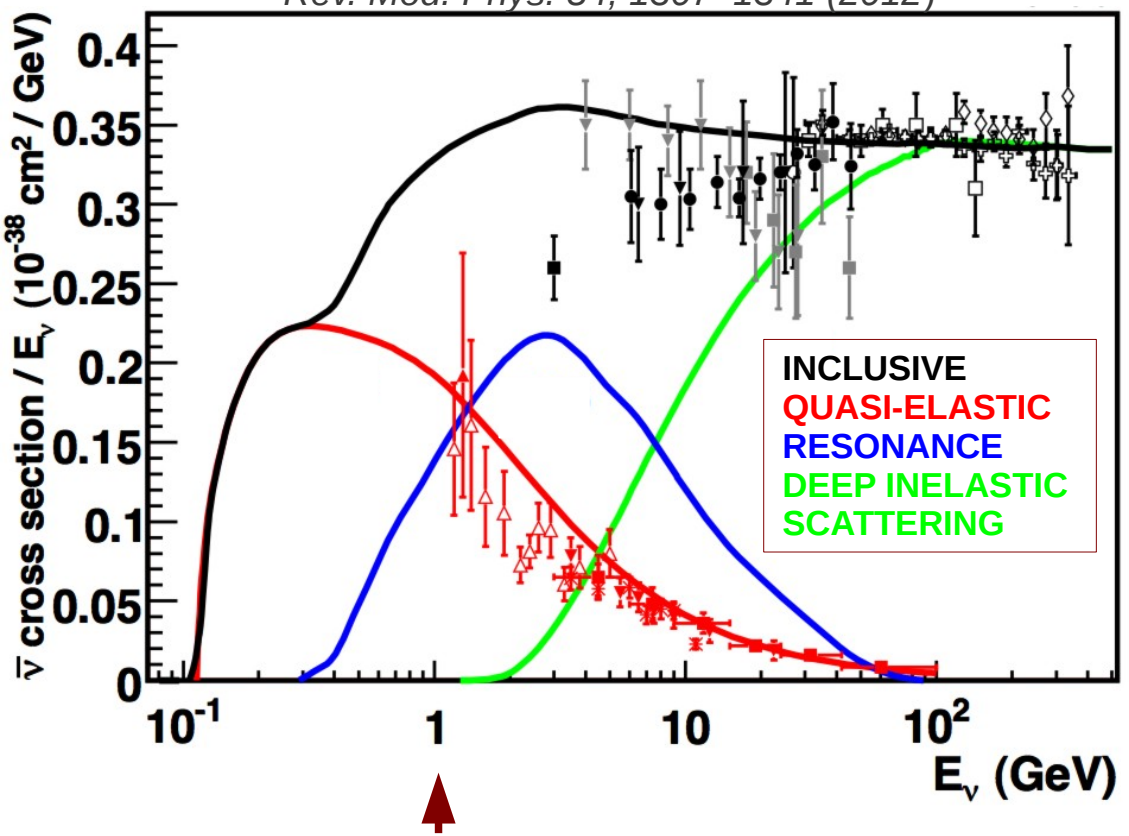
T2K

Cross-section Measurement

Antineutrino σ/E$_\nu$ measurements as of 2012

Rev. Mod. Phys. 84, 1307–1341 (2012)



T2K antineutrino flux mean energy

- T2K beam contains approximately 6% muon antineutrinos
- Muon antineutrino cross-section:
  - Reduce systematics in oscillation analysis
    - $\bar{\nu}_\mu$ background in ν_μ disappearance measurement
  - Sparse world CC inclusive antineutrino data at energies ~1 GeV
    - Benefit others in neutrino community

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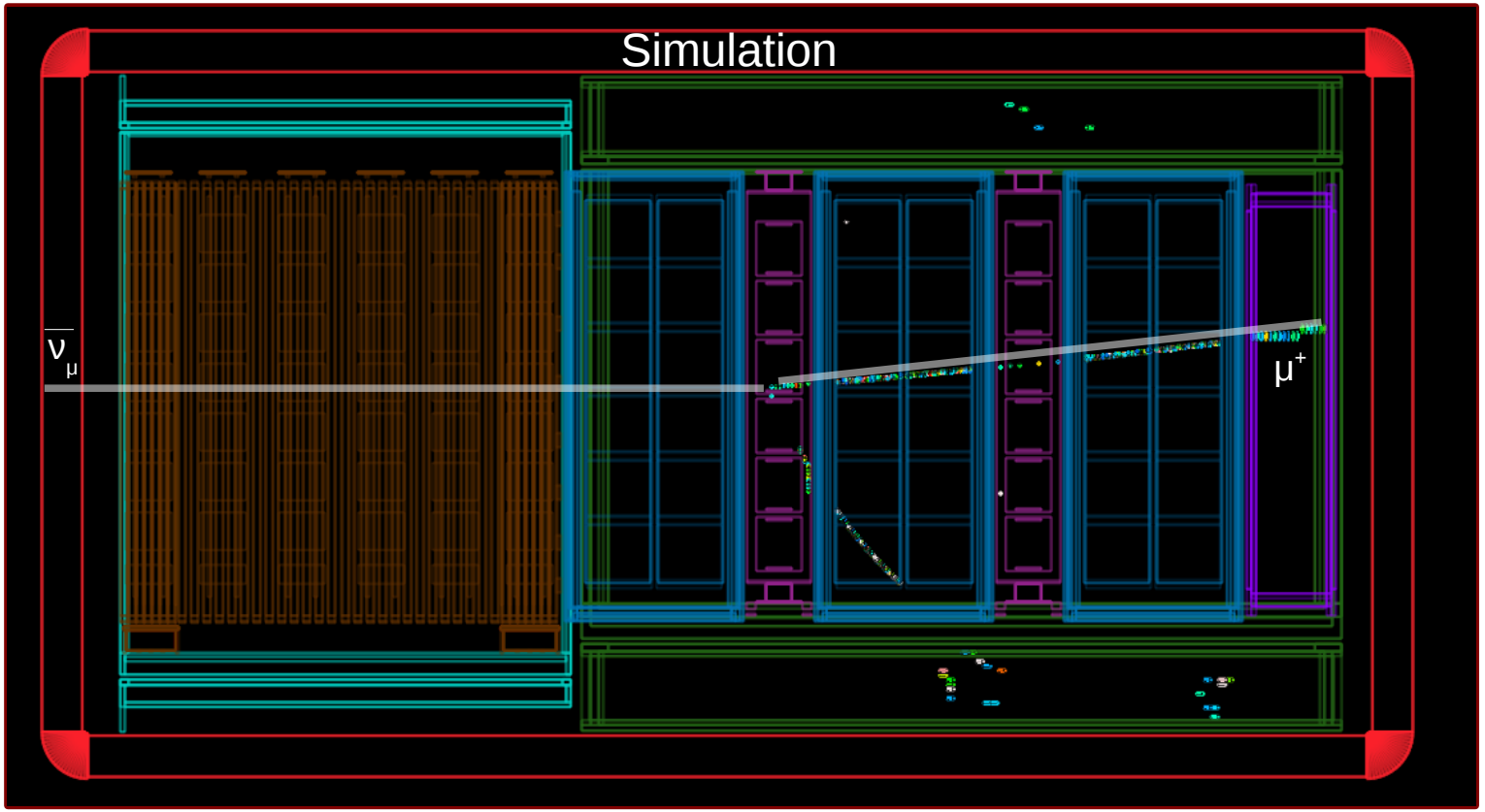
Cross-section Measurement

- **Aim:** Inclusive charged-current muon antineutrino cross-section on carbon (most upstream FGD)
- Final state includes positive muon, with no requirement on number of other particles



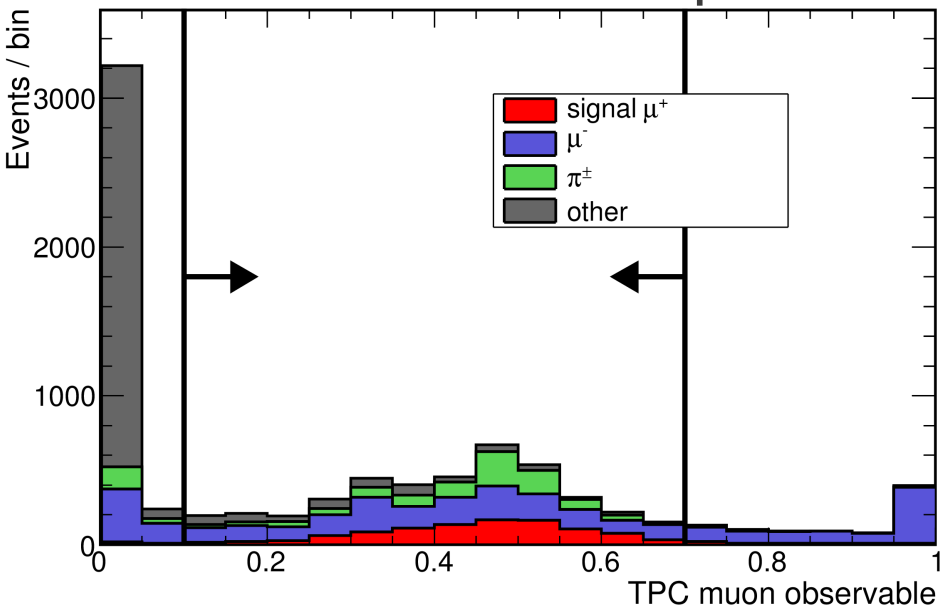
Selection

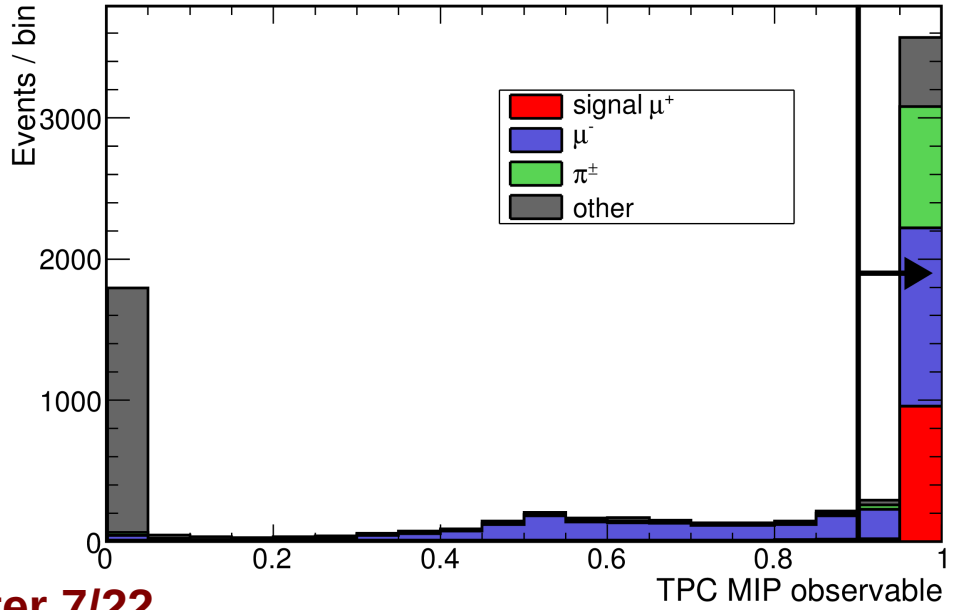
- Selection requires vertex in FGD1 with TPC and ECal components

TPC Component

- Track curvature consistent with positive charge
- TPC provides pulls based on expected dE/dx
- Cut on muon and MIP distributions formed from pulls:

$$L_i \equiv \frac{\exp(-\text{Pull}_i^2)}{\Sigma_k \exp(-\text{Pull}_k^2)}, \quad L_{MIP} \equiv \frac{L_\mu + L_\pi}{1 - L_p}$$



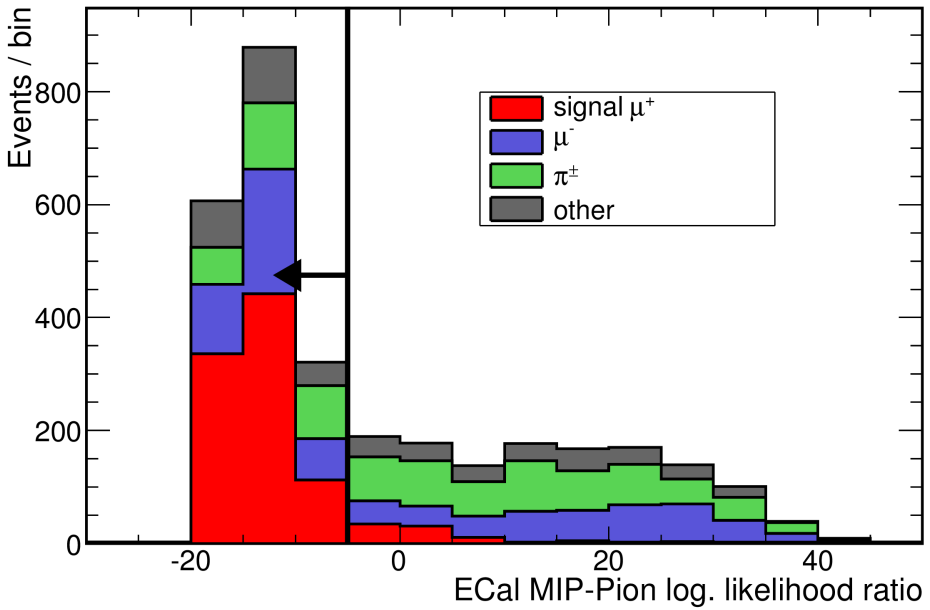


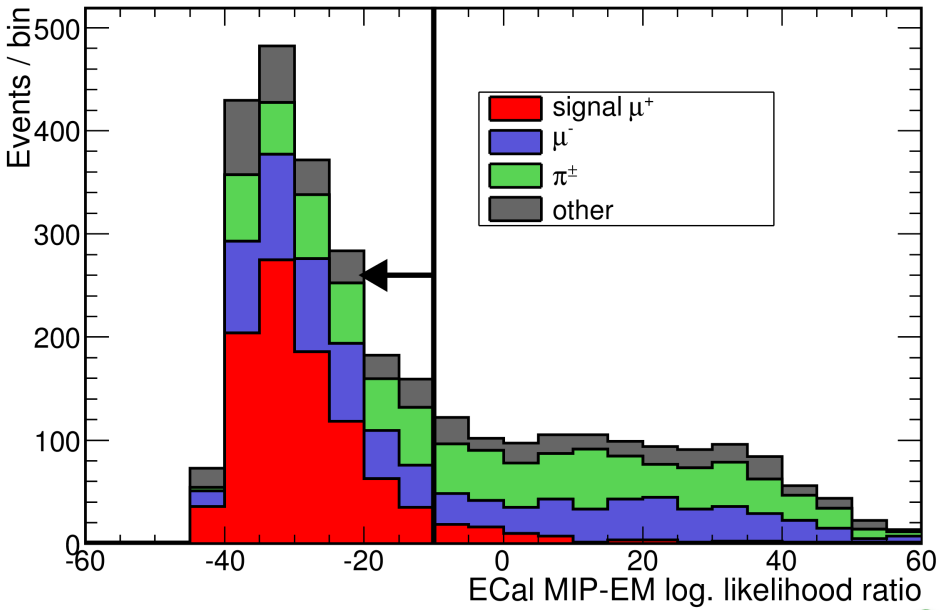
**All plots are simulation using NEUT event generator*

Selection

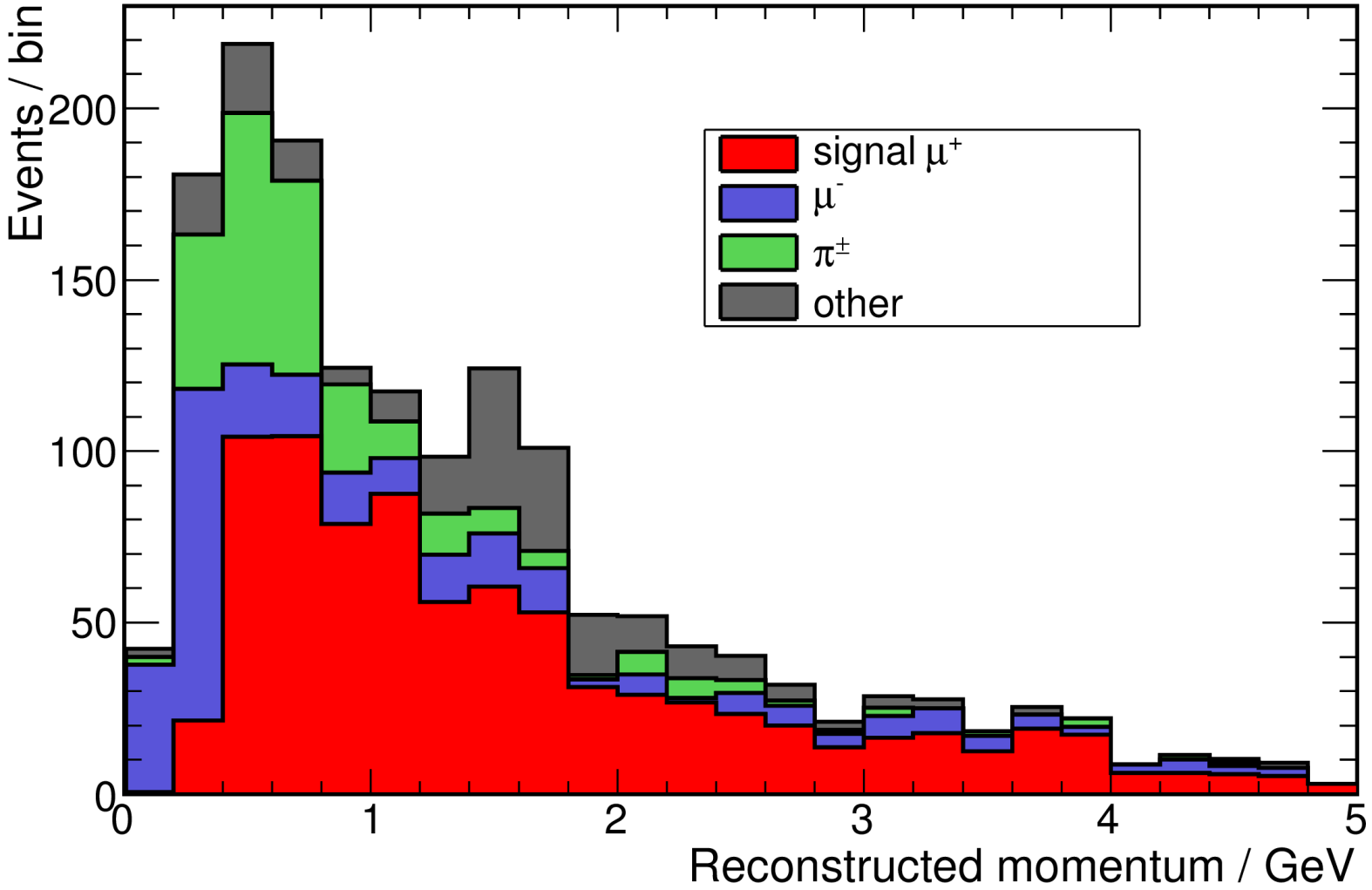
ECal Component

- ECal provides log likelihood ratio variables
- Cut on:
  - log (Likelihood of being MIP-like / Likelihood of Showering Pion)
  - log (Likelihood of being MIP-like / Likelihood of EMShower)





Performance



Efficiency: 37.7±1.0%, **Purity:** 49.3±1.2%

Systematic Error

- Initial systematic error studies, using a T2K software tool to reweight final distributions rather than generating new NEUT simulation

- Systematics separated into three categories:
  - Interaction modelling
  - Flux
  - Detector

- Will only outline modelling and flux systematics here as detector systematics are yet to be studied

Systematic Error

Interaction modelling

- Reweighting approximates variation of nuclear modelling and interaction parameters by error associated to them
- Extract percentage change on inferred number of events

$$N^{inf.} = \frac{N(obs.) - N^{bg,\ MC\ sel}}{Efficiency}$$

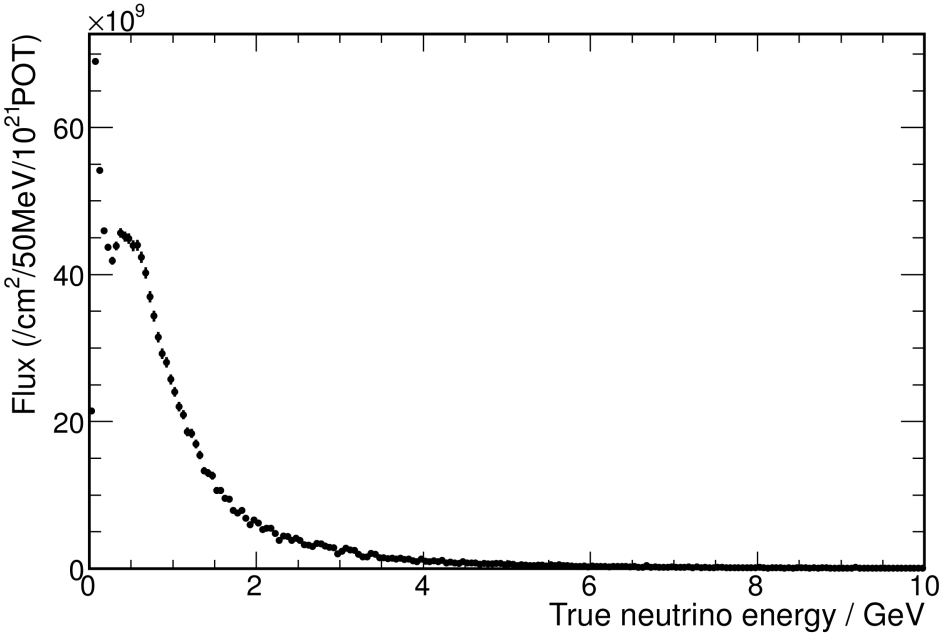
- Largest errors summed in quadrature for total error

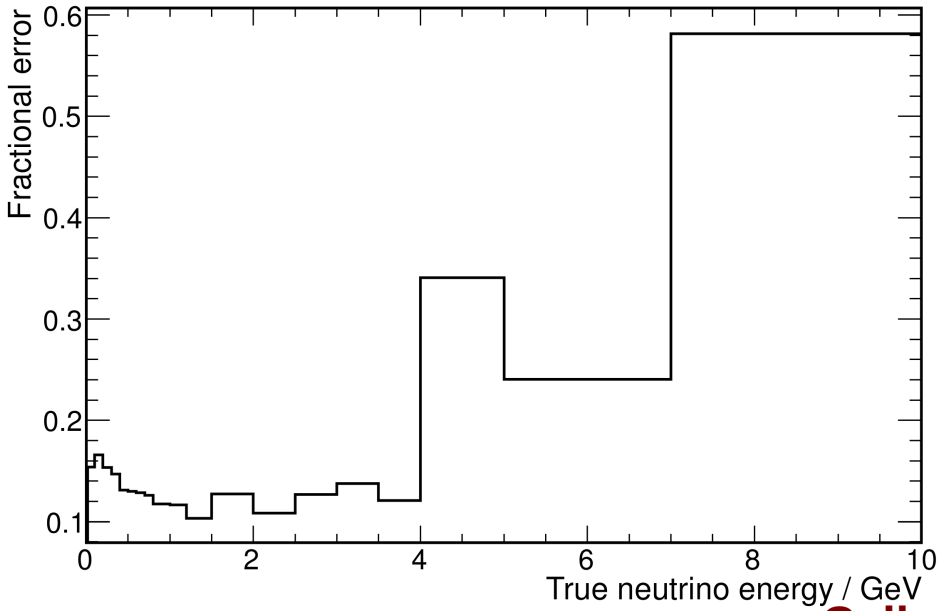
~12%

Parameter	+1σ uncert. / %	-1σ uncert. / %
ν_μ background		
CCQE norm.	8.4	-8.4
CC1π norm.	7.4	-7.4
Spectral function	0.0	0.0
Fermi momentum	-0.3	0.7
MaCCQE	1.8	-1.8
MaRES	2.3	-2.2
Neutral current		
NC1$\pi^{\pm}$ norm.	1.8	-1.8
NC other	0.8	-1.4

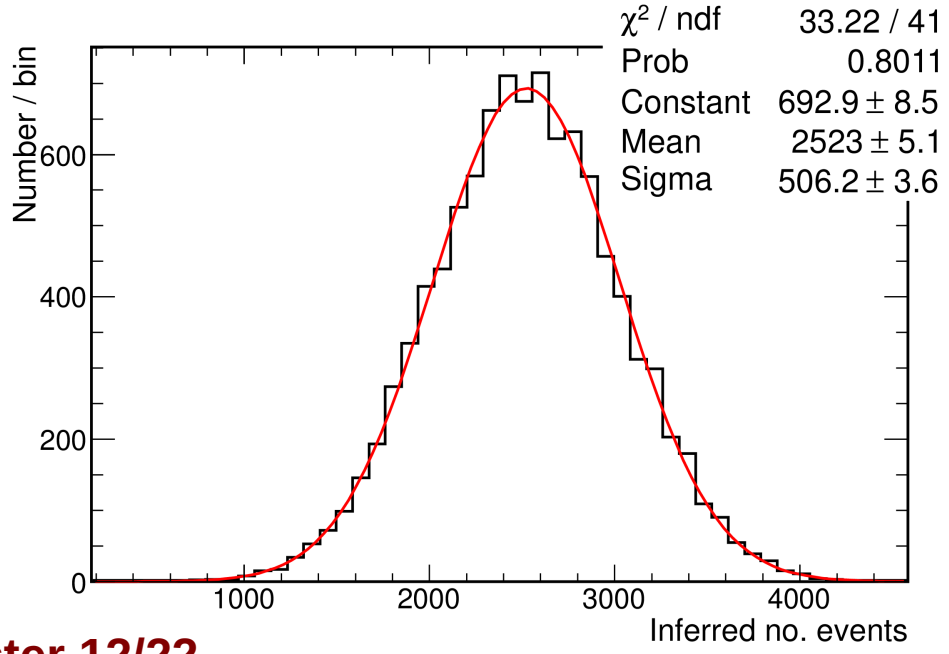
Systematic Error

Flux





- 10000 fake data sets generated by reweighting simulation by flux uncertainty
- Gaussian fit to distribution of inferred number of events gives flux error **~20%**



Summary

- T2K's ND280 can select muon antineutrinos in the muon neutrino beam using TPC and ECal particle identification
  - **Efficiency:** 38%
  - **Purity:** 49%

- Will put T2K in a strong position should the beam polarity be reversed for CP violation studies

- A muon antineutrino CC inclusive cross-section measurement on carbon is under-way, with selection nearing finalisation and systematic errors currently being studied
  - Should be a useful addition to sparse world antineutrino data at neutrino energies ~1 GeV

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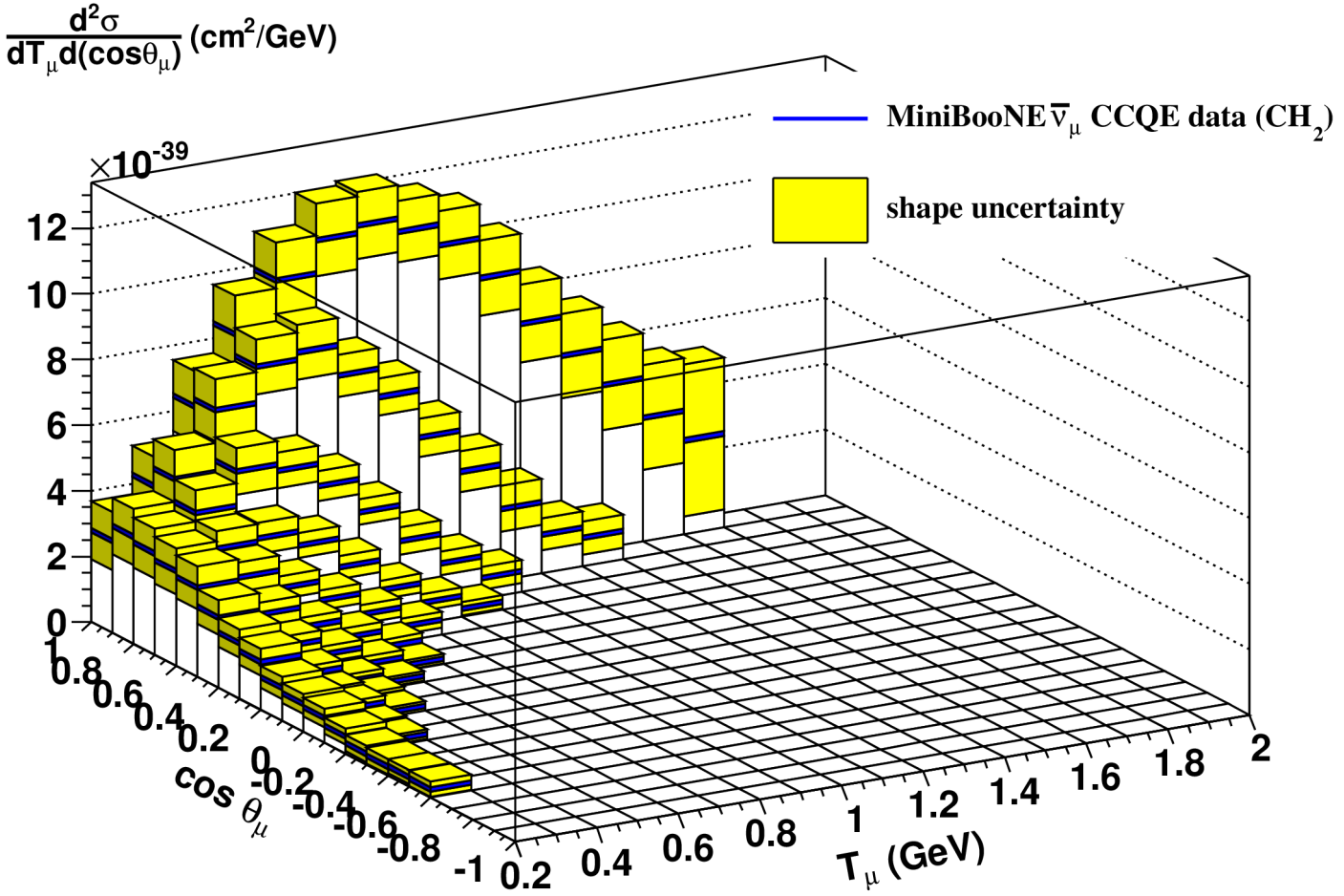
Backup slides

MiniBooNE result



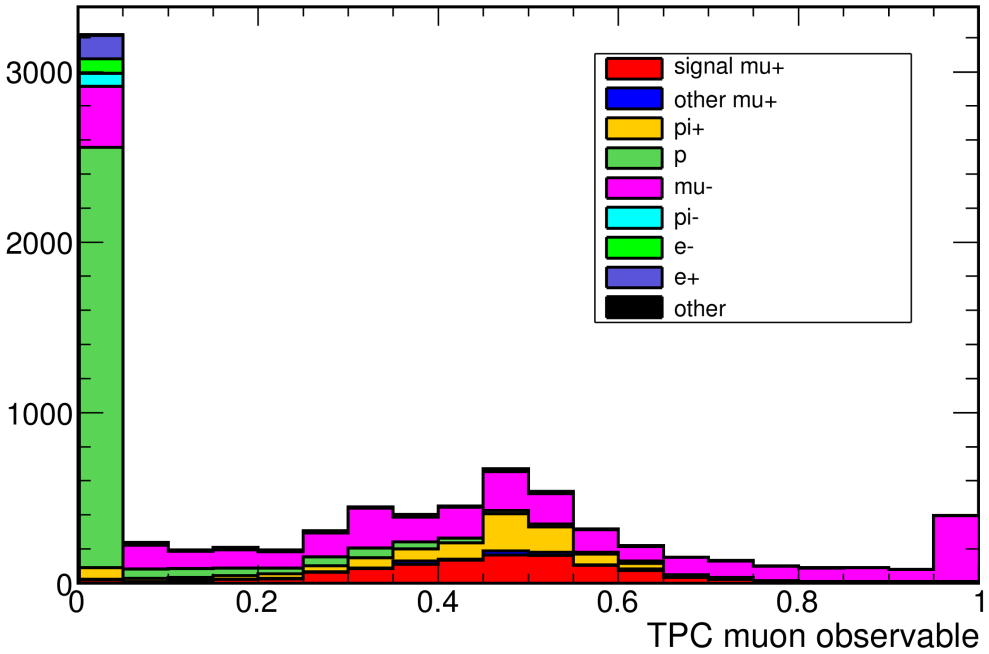
A.A. Aguilar-Arevalo et al., "First Measurement of the Muon Anti-Neutrino Double-Differential Charged Current Quasi-Elastic Cross Section", arXiv:1301.7067 [hep-ex]

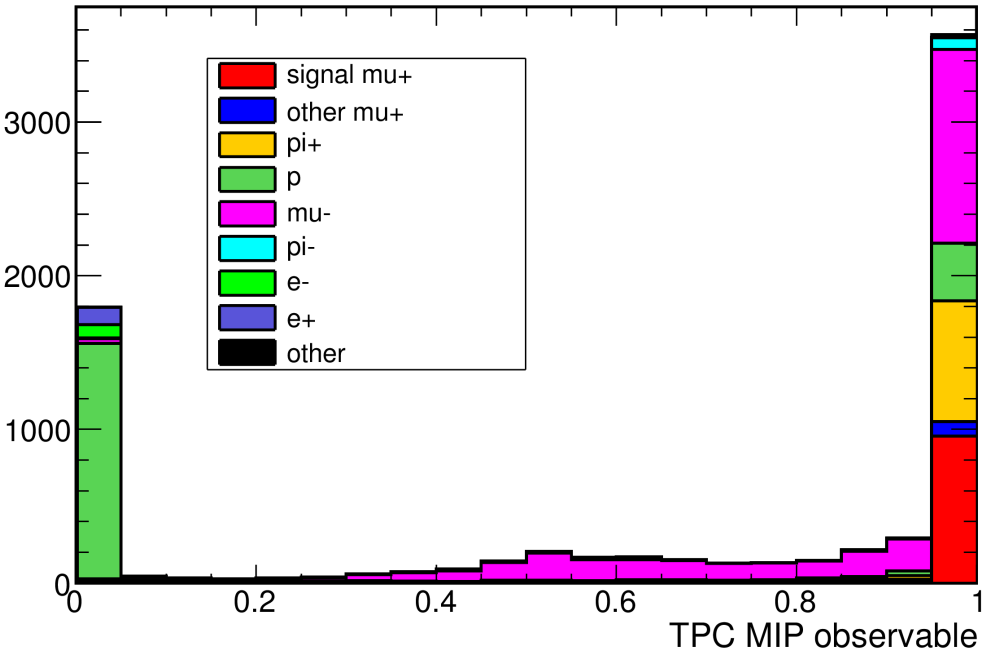
Selection in depth

- Highest momentum track in event is selected as positive muon candidate
- Then must satisfy following requirements:

Cut no.	Cut
1&2	FGD1 fiducial volume & bunch cut
3	Number TPC Hits > 18
4	Matched FGD1-TPC2 track
5	ECal component
6	Positive track
7	Rec. momentum > 50 MeV
8	TPC1 veto
9	TPC PID: 0.1 < Mulik < 0.7 && Miplik < 0.9, if mom. >= 500MeV
10	ECal PID: mipEm < -10 && mipPion < -5

TPC PID variables





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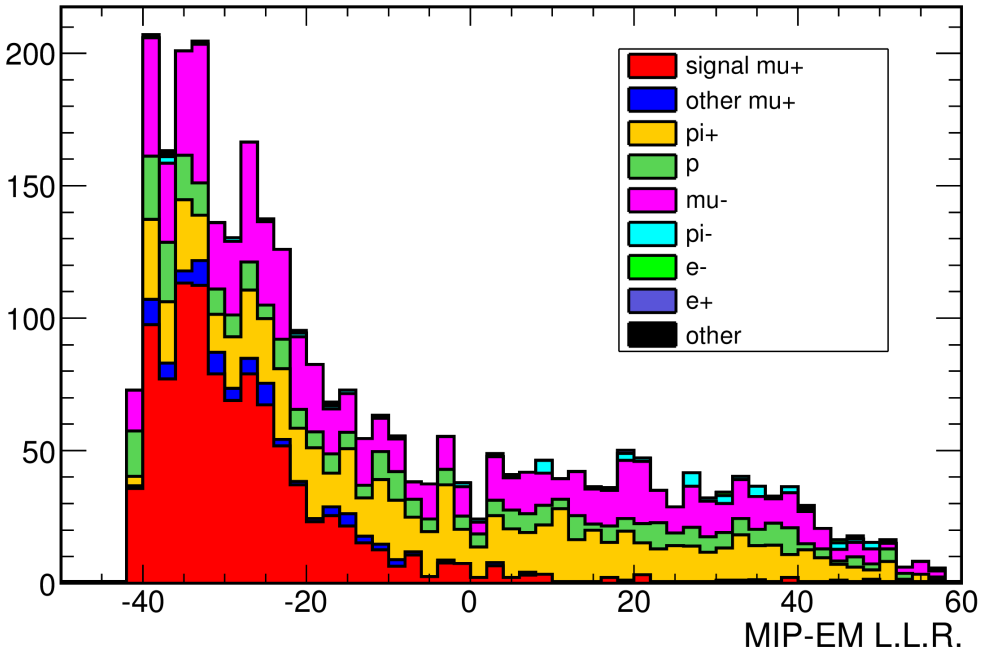
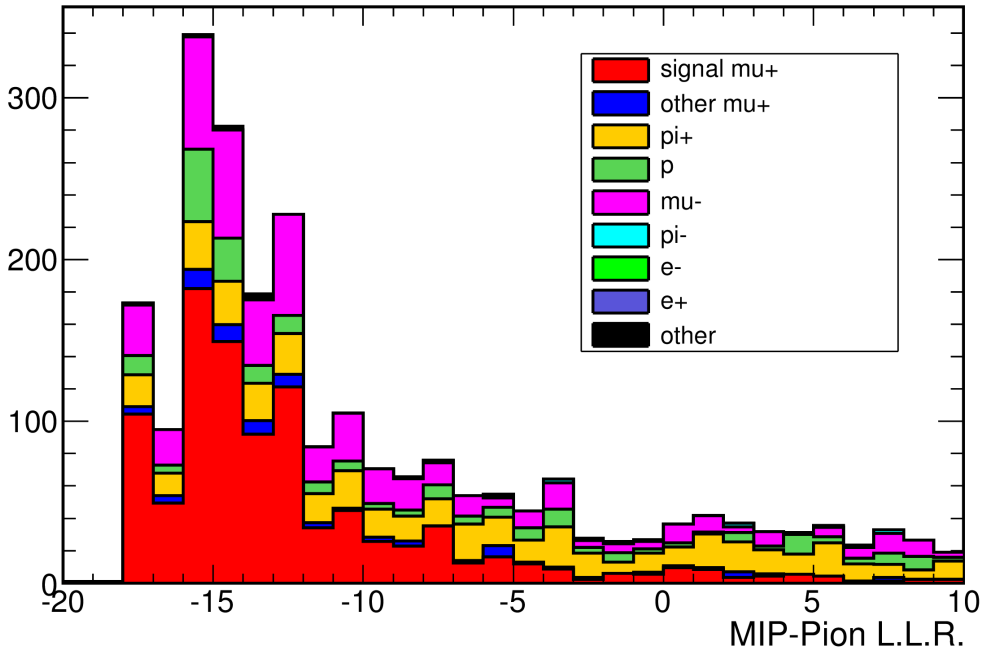
ECal PID variables

- Log likelihood ratio variables:
  - mipPion = log (Likelihood for being MIP-like / Likelihood of Showering Pion)
  - mipEm = log (Likelihood for being MIP-like / Likelihood of EMShower)

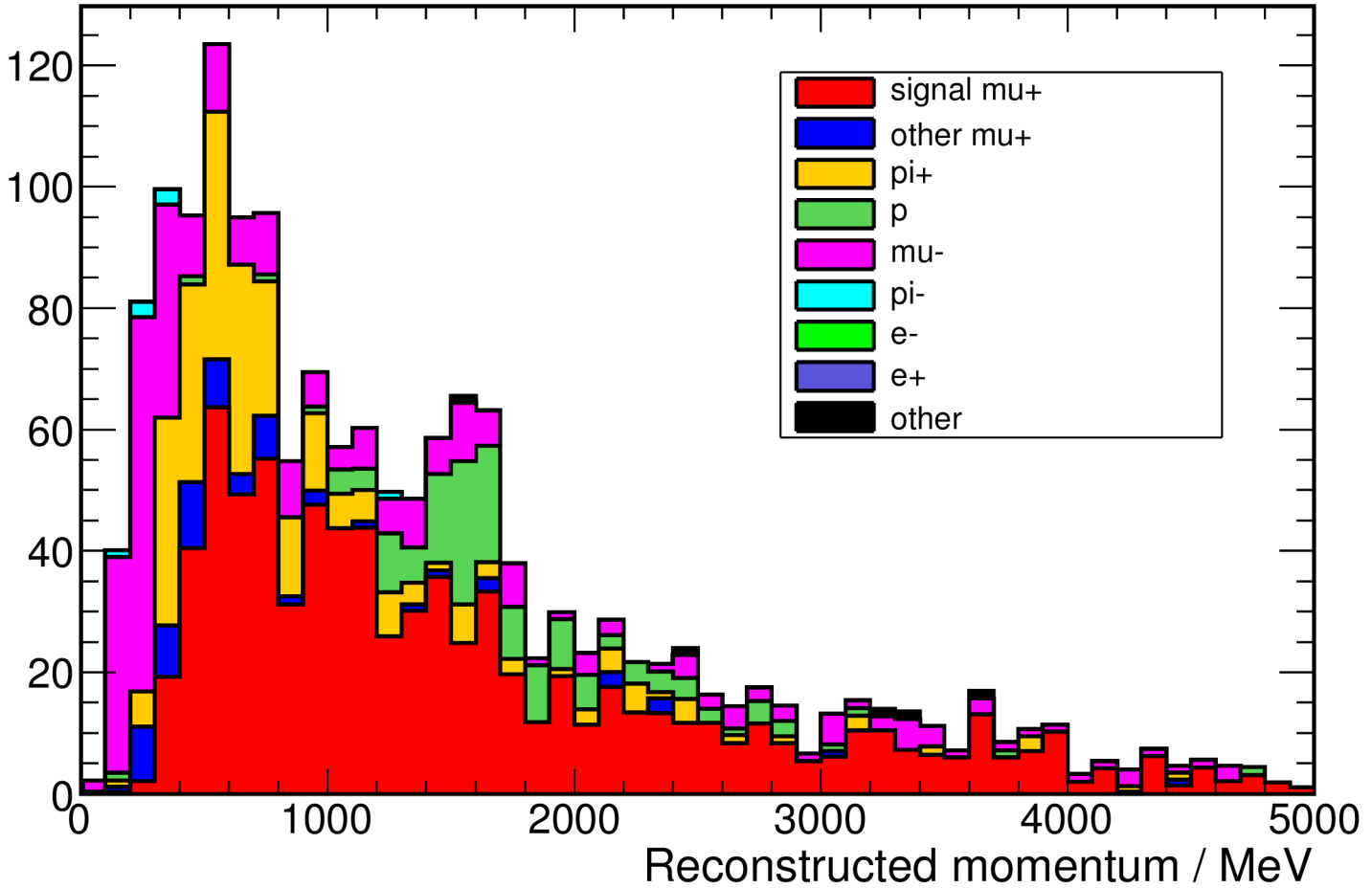
- Use the following variables as inputs:
  - **Circularity:** measure of cluster width in comparison to its length
  - **QRMS:** root mean square of the cluster's charge distribution
  - **Transverse charge ratio:** Create cylinder along shower direction. Then, Outer Hits Charge / Inner Hits Charge
  - **Truncated max. ratio:** remove highest/lowest 20% hit charges. Then, Max(Qlayer)/Min(Qlayer)
  - **FrontBackRatio:** Ratio of charge at the end of track to the start

ECal PID variables





Selection


signal mu+
other mu+
pi+
p
mu-
pi-
e-
e+
other
120
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
Reconstructed momentum / MeV

Muon neutrino flux