Optimizing fiTQun Cuts for T2K in MaCh3 Framework

Xiaoyue Li

Department of Physics and Astronomy,
Stony Brook University

xiaoyue.li@stonybrook.edu

December 17, 2014

Overview

Motivation

- fiTQun out-performs the current SK reconstruction algorithm in e-π^0 seperation, one-ring vertex and momentum resolution and e$/\mu$ particle identification.
- New functionality enabled by fiTQun such as $\pi^{\pm}$, $K^{\pm}$ and proton reconstruction, charged pion seperation from muons may be beneficial for both T2K and SK analyses.
- May be able to get better sensitivity to oscillation parameters with fiTQun-based analyses.

Implementation in MaCh3 I

- MaCh3 is a fitter developed for T2K that uses Markov Chain Monte Carlo (MCMC) technique. A Bayesian likelihood-ratio function is used to sample in the parameter space; nuisance parameters are marginalized over; credible invervals of oscillation parameters can be determined by its posterior probability distribution.
- T2K ν_e appearance $+$ ν_μ disappearance
- Bayesian likelihood ratio:
  $$\mathcal{L}_{tot}(\vec{o},\vec{o}',\vec{b},\vec{d},\vec{f}|M_{SK}) = \frac{P(M_{SK}|\vec{o},\vec{o}',\vec{b},\vec{d},\vec{f})\cdot\pi(\vec{o})\cdot\pi(\vec{o}')\cdot\pi(\vec{b})\cdot\pi(\vec{d})\cdot\pi(\vec{f})}{\int d\vec{o}'\ d\vec{b}\ d\vec{d}\ d\vec{o}\ d\vec{f}\ P(M_{SK}|\vec{o},\vec{o}',\vec{b},\vec{d},\vec{f})\cdot\pi(\vec{o})\cdot\pi(\vec{o}')\cdot\pi(\vec{b})\cdot\pi(\vec{d})\cdot\pi(\vec{f})}$$
  where $\pi(\vec{x})$ are the prior p.d.f.

Implementation in MaCh3 II

- $\mathcal{L}_{tot}(\vec{o}, \vec{o}', \vec{b}, \vec{d}, \vec{f}|M_{SK}) = P(M_{SK}|\vec{o}, \vec{o}', \vec{b}, \vec{d}, \vec{f}) \cdot \pi(\vec{o}) \cdot \pi(\vec{o}') \cdot \pi(\vec{b}) \cdot \pi(\vec{d}) \cdot \pi(\vec{f})$
  - $\vec{o}$: oscillation parameters to be fit; flat prior
  - $\vec{o}'$: PDG oscillation parameters; Gaussian prior
  - $\vec{b}$: BANFF flux and xsec parameters; correlated Gaussian prior
  - $\vec{d}$: SK errors; correlated Gaussian prior
  - $\vec{f}$: fiTQun cut parameters to be fit
  - M_{SK}: Fake dataset
- Fix θ_{23} and ΔM^2_{32} to T2K best-fit value
- Marginalize the likelihood over $\vec{o}'$, $\vec{b}$ and $\vec{d}$:
  $\mathcal{L}_{tot}(\theta_{13}, \delta_{CP}, \vec{f}|M_{SK}) = \int d\vec{o}'\, d\vec{b}\, d\vec{d}\, \mathcal{L}_{tot}(\vec{o}, \vec{o}', \vec{b}, \vec{d}, \vec{f}|M_{SK})\pi'(\vec{o}')\pi'(\vec{b})\pi'(\vec{d})$
- Optimize $\vec{f}$ based on the sensitivity to $\vec{o}$ (θ_{13} and δ_{CP}).

Implementation in MaCh3 III

- M_{SK}: Fake dataset that only passes FCFV pre-selection.
- At each step in the Markov chain, same fiTQun cut applies to both fake data and MC simultaneously.
- Generate two Markov chains with $\theta_{23} + \Delta M^2_{32}$ being T2K best-fit value and θ_{13} prior being PDG value and T2K best-fit value, respectively, such that enough phase space is covered.

Implementation in MaCh3 IV

- $$\hat{N}_k^{\nu_e/\nu_\mu} = \sum_h^{all\ events} \sum_i \sum_j \sum_l \sum_m b_{il}^{flux} b_{ijkl}^{xsec} d_{ijk} d_k^{escale} P_{ijl}(\vec{o}, \vec{o}') \delta_m(h)$$
  - $\delta_m(h) = \begin{cases} 0, & \text{if event h doesn't pass cut } f_m^{\nu_e/\nu_\mu} \\ 1, & \text{if event h passes cut } f_m^{\nu_e/\nu_\mu} \end{cases}$
  - i: flavor category ($\nu_\mu/\bar{\nu}_\mu$, intrinsic $\nu_e/\bar{\nu}_e$, oscillated ν_e)
  - j: neutrino interaction category
  - k: erec bin
  - l: true energy bin
  - m: fiTQun cut parameter
  - P: oscillation probability

Implementation in MaCh3 V

- $$-\ln P(M_{SK}^{\nu_e/\nu_\mu}|\vec{o},\vec{o}',\vec{b},\vec{d},\vec{f}) = -\sum_k \ln\left[\lambda_{Poisson}(N_k^{\nu_e/\nu_\mu},\hat{N}_k^{\nu_e/\nu_\mu})\right]$$
$$= \sum_k \left[(\hat{N}_k^{\nu_e/\nu_\mu} - N_k^{\nu_e/\nu_\mu}) + N_k^{\nu_e/\nu_\mu}\ln\left(\frac{N_k^{\nu_e/\nu_\mu}}{\hat{N}_k^{\nu_e/\nu_\mu}}\right)\right]$$
- $$-\ln \mathcal{L}_{tot}(M_{SK}|\vec{o},\vec{o}',\vec{b},\vec{d},\vec{f}) = \sum_k \left[(\hat{N}_k^{\nu_e} - N_k^{\nu_e}) + N_k^{\nu_e}\ln\left(\frac{N_k^{\nu_e}}{\hat{N}_k^{\nu_e}}\right)\right] + \sum_k \left[(\hat{N}_k^{\nu_\mu} - N_k^{\nu_\mu}) + N_k^{\nu_\mu}\ln\left(\frac{N_k^{\nu_\mu}}{\hat{N}_k^{\nu_\mu}}\right)\right] + \frac{1}{2}\Delta b\left(V_b^{-1}\right)\Delta b^T + \frac{1}{2}\Delta d\left(V_d^{-1}\right)\Delta d^T - \ln\pi(\vec{o}') - \ln\pi(\vec{f}) - \ln\pi(\vec{d})$$

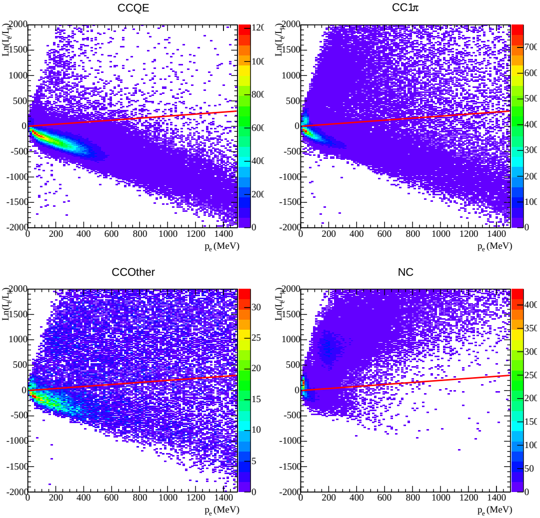
fiTQun Cut Variables Parametrization I

- PID $\rightarrow$ e-like and μ-like
  - e-like
    - Ring counting cut $\rightarrow$ one-ring events
    - π^0 rejection
  - μ-like
    - Ring counting cut $\rightarrow$ one-ring events
    - π^+ rejection
- Need to parametrize these cuts.

fiTQun Cut Variables Parametrization II

- PID cut
- $y = a_1 + b_1 x$
- e.g. $a_1 = 0,\ b_1 = 0.2$
- $a_1 \in [-200, 200]$
- $b_1 \in [-0.3, 0.3]$

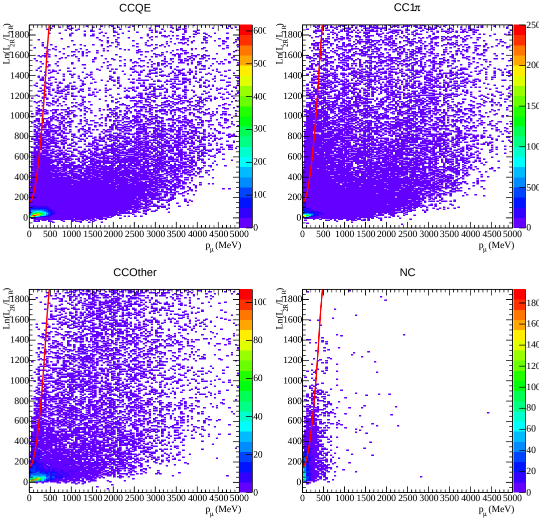
*T2K-SK 13a MC ν_μ FCFV selection applied



fiTQun Cut Variables Parametrization III

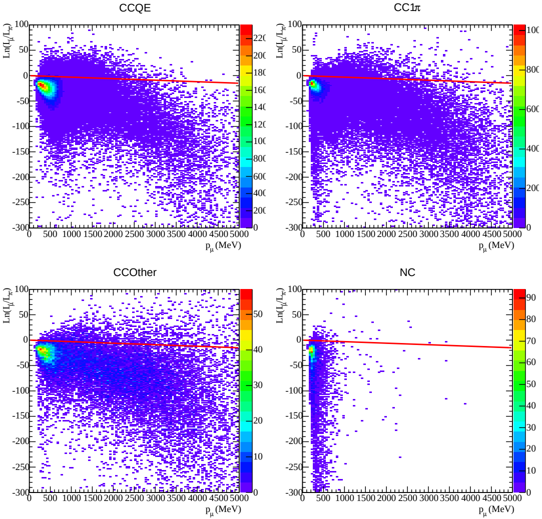
- Ring counting cut for μ-like events
- $y = a_2 + b_2 x + c_2 x^2$
- e.g. $a_2 = 150,\ b_2 = 0,\ c_2 = \frac{1}{120}$
- $a_2 \in [0, 500]$
- $b_2 \in [-1000, 1000]$
- $c_2 \in [-1, 1]$

*PID cut applied



fiTQun Cut Variables Parametrization IV

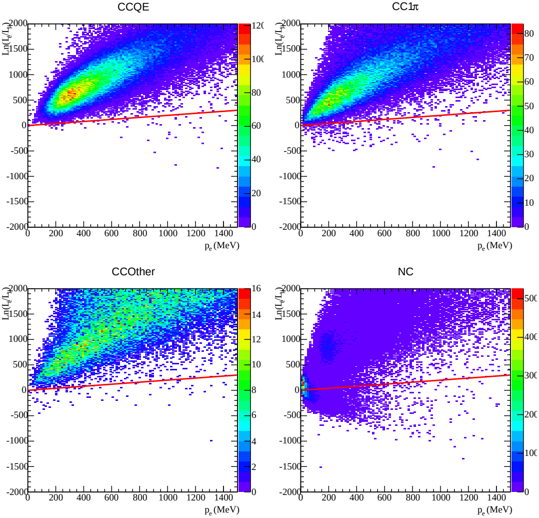
- π^+ rejection
- $y = a_3 + b_3 x$
- e.g. $a_3 = 0, \; b_3 = 0.003$
- $a_3 \in [-20, 20]$
- $b_3 \in [-1, 0]$



*PID cut applied

fiTQun Cut Variables Parametrization V

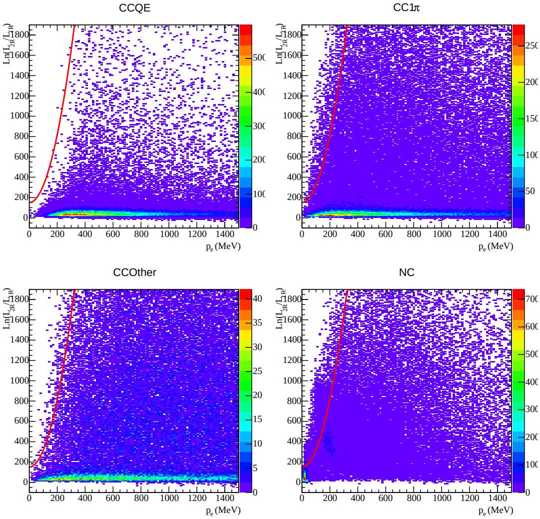
- PID cut
- $y = a_1 + b_1 x$
- e.g. $a_1 = 0, \; b_1 = 0.2$
- $a_1 \in [-200, 200]$
- $b_1 \in [-0.3, 0.3]$



*T2K-SK 13a MC ν_e FCFV selection applied

fiTQun Cut Variables Parametrization VI

- Ring counting cut for e-like events
- $y = a_4 + b_4 x + c_4 x^2$
- e.g. $a_4 = 150,\ b_4 = 0,\ c_4 = \frac{1}{60}$
- $a_4 \in [0, 500]$
- $b_4 \in [-1000, 1000]$
- $c_4 \in [-1, 1]$

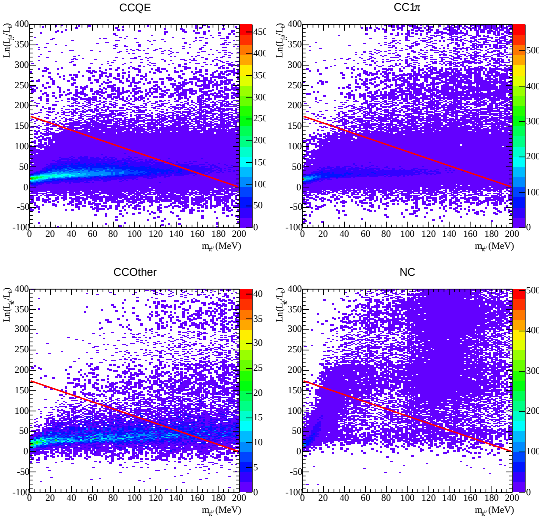


*PID cut applied

fiTQun Cut Variables Parametrization VII

- π^0 rejection
- $y = a_5 + b_5 x$
- e.g.
  $a_5 = 175, \; b_5 = 0.875$
- $a_5 \in [50, 300]$
- $b_5 \in [-3, 0]$

*PID cut applied



Current Status and Future Work

- Have figured out a way to optimize fiTQun cut for T2K using MaCh3.
- The parametrization scheme may not be ideal.
- Coding is ongoing.