FiTQun Workshop Format and Goals

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TRIUMF FiTQun Workshop

August 18th, 2015

Workshop Format

- As usual, much of the time will be filled with presentations of various fiTQun activities
  - Each presentation should be considered a discussion
  - Feel free to interrupt often with comments and suggestions
- Some working time is scheduled at the end of each day
  - Hopefully any computing/software/strategy issues can be resolved during this time
- A T2K-SK meeting is tentatively scheduled for Wednesday afternoon
  - For most people, this may just be used as additional working time

Workshop Overview

- **State of the software**
  - How can fiTQun be improved?
    - New scattered light treatment? Parametrize scattering tables for arbitrary geometries?
    - PMT angular acceptance: $\varepsilon_{PMT}(\eta,\varphi,R)$? Separate ε_{barrel} & ε_{cap}?
    - MCMC?
  - Other performance enhancements to be added: GPUs, avoiding θ_{ring}=0
- **How are we using fiTQun?**
  - Many analyses in both T2K and Super-K
  - Many new uses of fiTQun on WCSim (HK & NuPRISM so far)
  - What are the strategies for these applications and synergies between them?
- **Systematic uncertainties**
  - How do we determine “detector” systematic uncertainties?
  - Can analyses be accommodated on both short (e.g. <1 year) and long timescales?

Goals, Continued

- For systematic error discussion, there will be a will review Super-K calibration issues
  - How can we use calibration information to inform systematic errors?
    - Start by varying skdetsim parameters suggested by calibration studies to determine the effect they can have on high level reconstruction parameters
- Review of fiTQun for WCSim
  - NuPRISM, Hyper-K, & Multi-PMTs
  - Some discussion of fiTQun studies for electronics design

Existing FiTQun Analyses

- T2K 1-ring ν_e and ν_μ (Missert)
- T2K 2/3-ring CCπ^+ (Berkman)
- $p \rightarrow e^+\pi^0$ (Suda)
- $p \rightarrow \bar{K}^+\nu$ (Santucci)
- Atmospheric Neutrinos (Tobayama)

- Many common elements between analyses!
  - And some important differences!

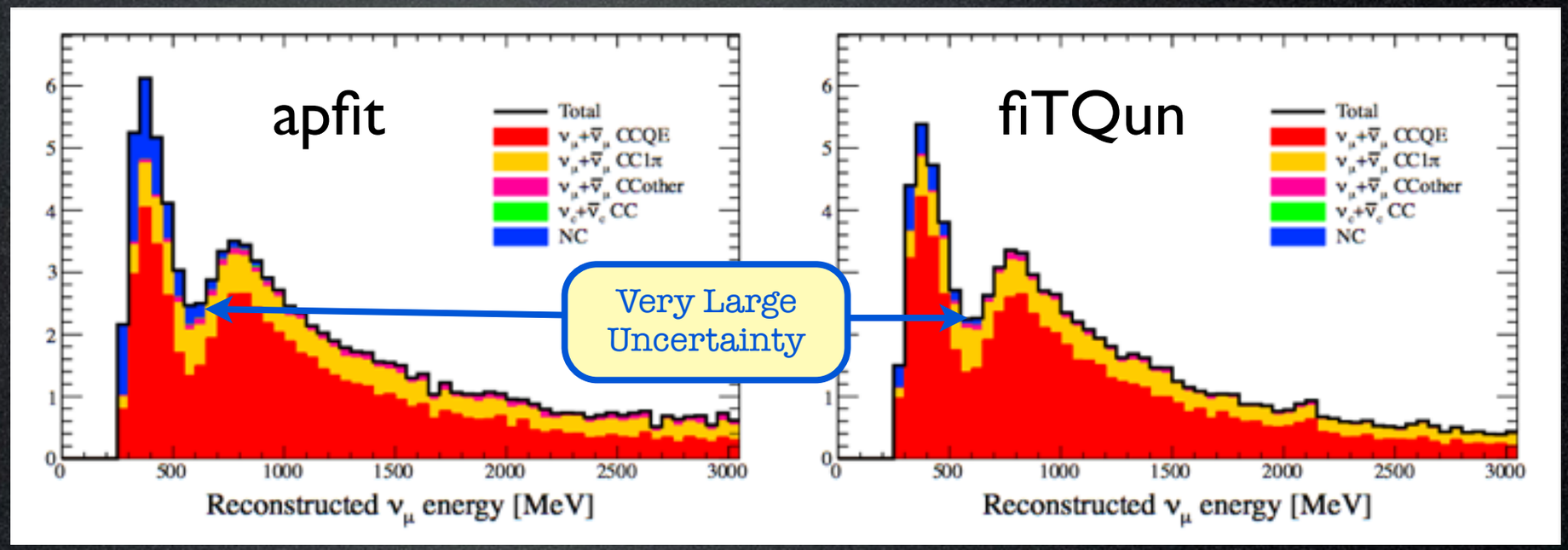
Goals of T2K Analyses

- **ν_e analysis**: increase statistics
  - For the foreseeable future, the ν_e analysis, and T2K's sensitivity to δ_{CP}, will be limited by statistics
  - It may make sense to sacrifice purity to gain more events
- **ν_μ analysis**: remove backgrounds in the oscillation region
  - NC events and CCπ^+ events

Shimpei's 2011 Study

Fraction of apfit selected events removed:

$\nu_\mu+\bar{\nu}_\mu$ CCQE	4.8%
$\nu_\mu+\bar{\nu}_\mu$ CC1π	21.5%
$\nu_\mu+\bar{\nu}_\mu$ CCother	53.7%
$\nu_e+\bar{\nu}_e$ CC	92.1%
NC	61.2%



Current T2K ν_e Selection

- CP violation sensitivity is limited by ν_e statistics
  - Current ν_e selection efficiency is **66%** (assuming 2 m fiducial volume cut)
- Cuts with the most efficiency loss:
  - Single-ring (86.7%)
  - Zero Michels (89.1%)
  - $E_{rec} < 1250$ MeV (95.9%)
  - fiTQun π^0 cut (92.0%)
- Further Improvements
  - Expanding the fiducial volume
    - ~30% of SK ID volume is not used
  - Improved reconstruction (fiTQun)
    - Better PID, ring-counting, etc.

T2K-SK ν_e Selection

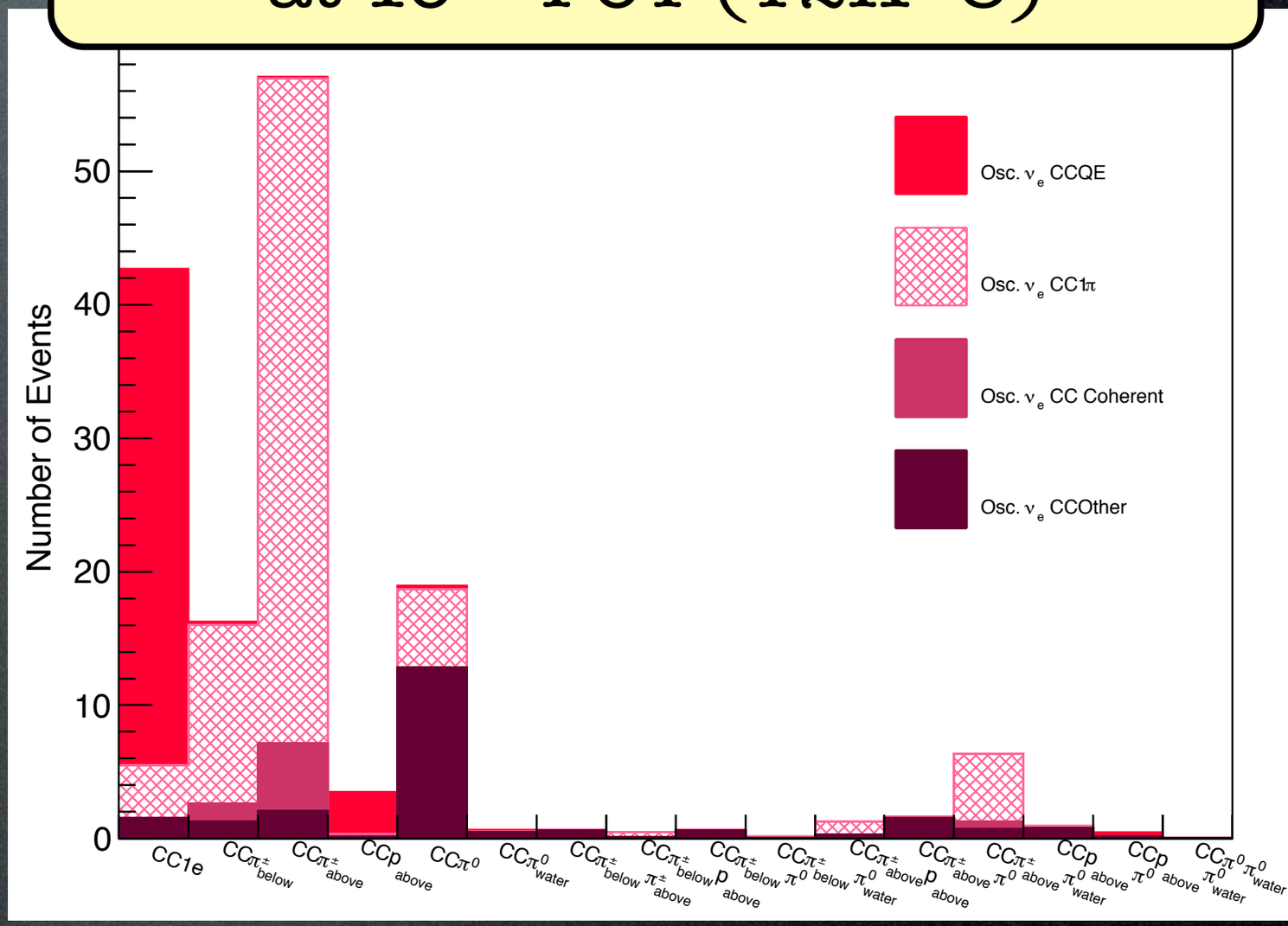
		$\nu_\mu + \overline{\nu}_\mu$	$\nu_e + \overline{\nu}_e$	$\nu + \bar{\nu}$	$\nu_\mu \to \nu_e$
	MC total	CC	CC	NC	CC
interactions in FV	656.83	325.67	15.97	288.11	27.07
FCFV	372.35	247.75	15.36	83.02	26.22
(1) single ring	198.44	142.44	9.82	23.46	22.72
(2) electron-like	54.17	5.63	9.74	16.35	22.45
(3) $E_{\rm vis} > 100\,{\rm MeV}$	49.36	3.66	9.68	13.99	22.04
(4) no Michel election	40.03	0.69	7.87	11.84	19.63
(5) $E_\nu^{\rm rec} < 1250\,{\rm MeV}$	31.76	0.21	3.73	8.99	18.82
(6) not π^0-like	21.59	0.07	3.24	0.96	17.32

(assuming $\sin^2 2\theta_{13} = 0.1$, $\sin^2\theta_{23} = 0.5$, $|\Delta m^2_{32}| = 2.4 \times 10^{-3}$ eV^2, $\delta_{CP} = 0$, $\Delta m^2_{32} > 0$)

Which Event Topologies are Being Lost?

- Percentages relative to current signal:
- CC1e (16%)
- CCπ⁺ (28%)
- CCπ⁰ (7%)
- CCπ⁺ with $\pi^+ \rightarrow \pi^0$ (2%)
- Other (2%)

Number of ν-mode Events Cut at 10^{22} POT (T2K*3)



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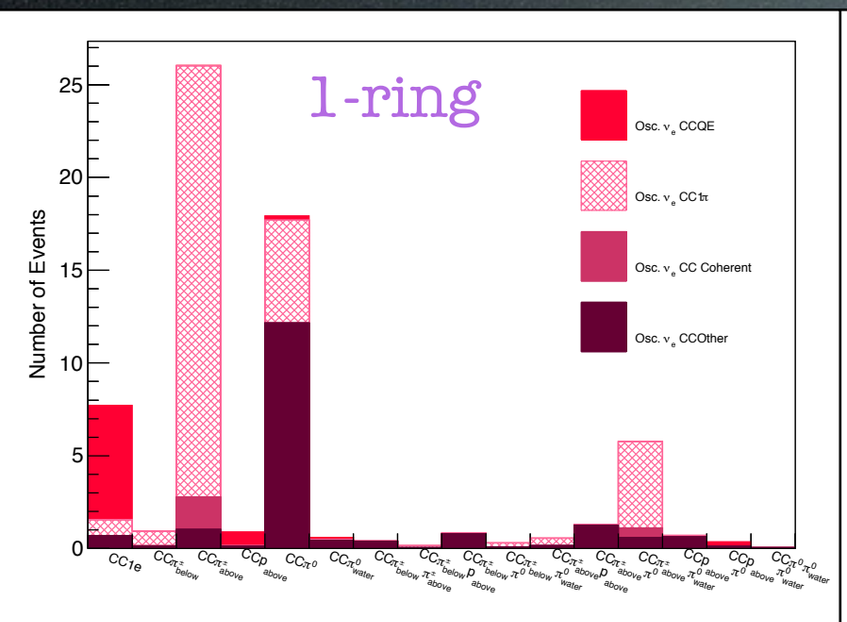
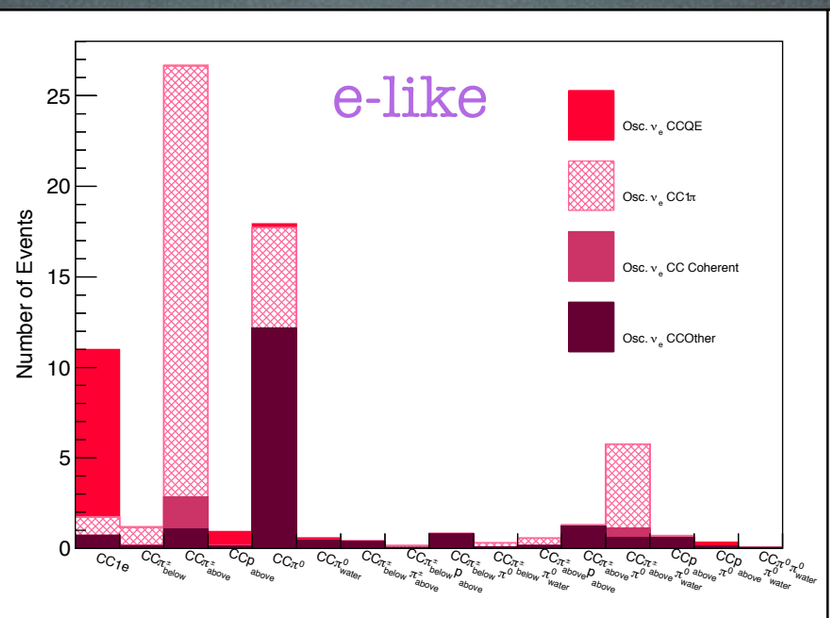
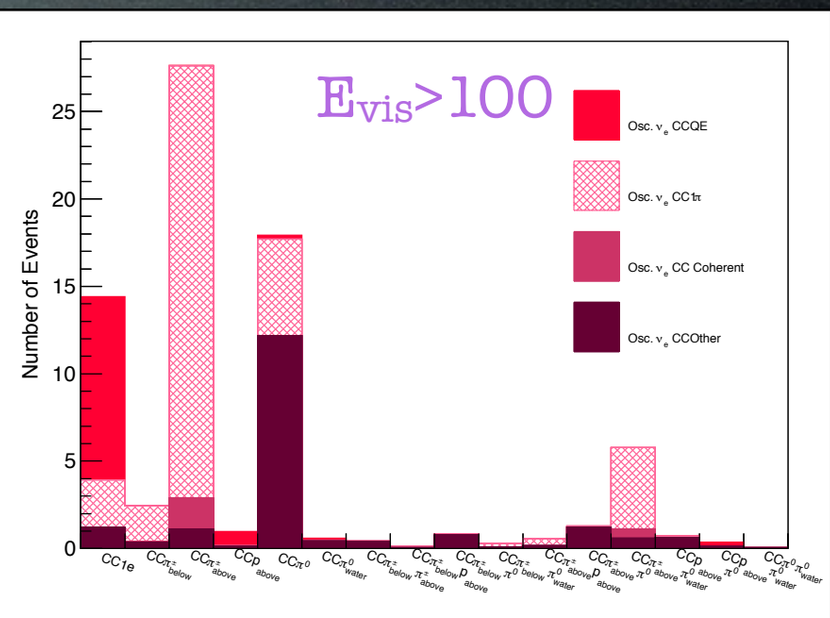
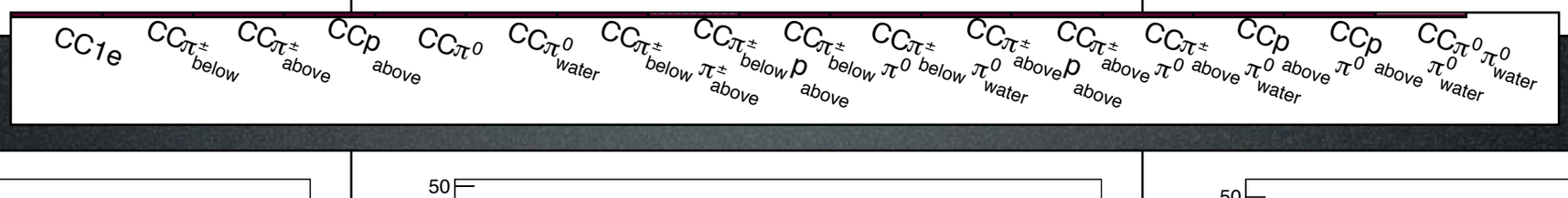
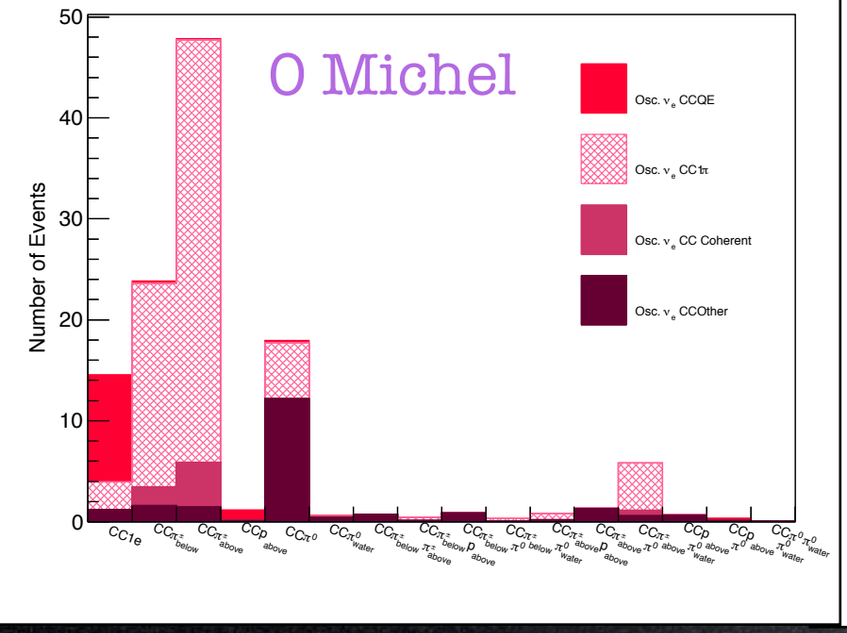
Event Rejection Breakdown (10^{22} POT)

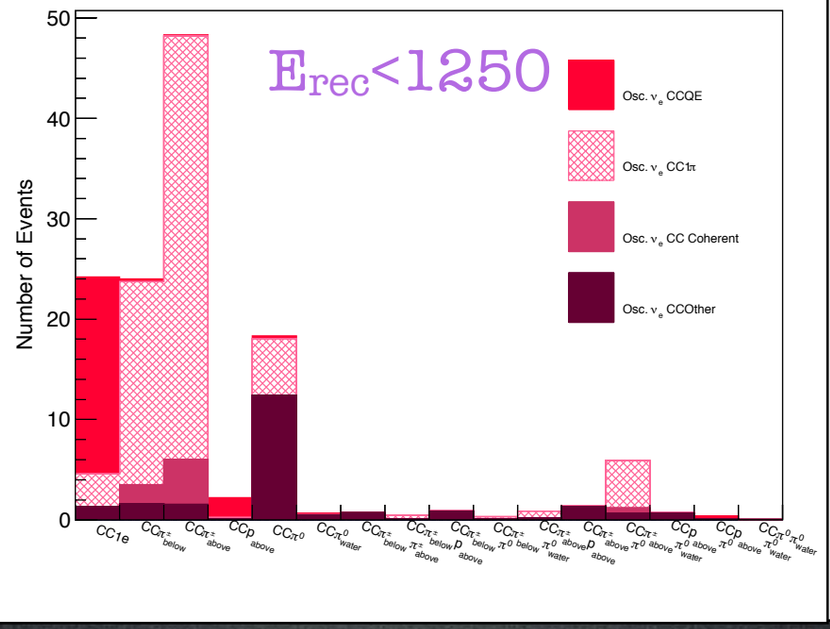


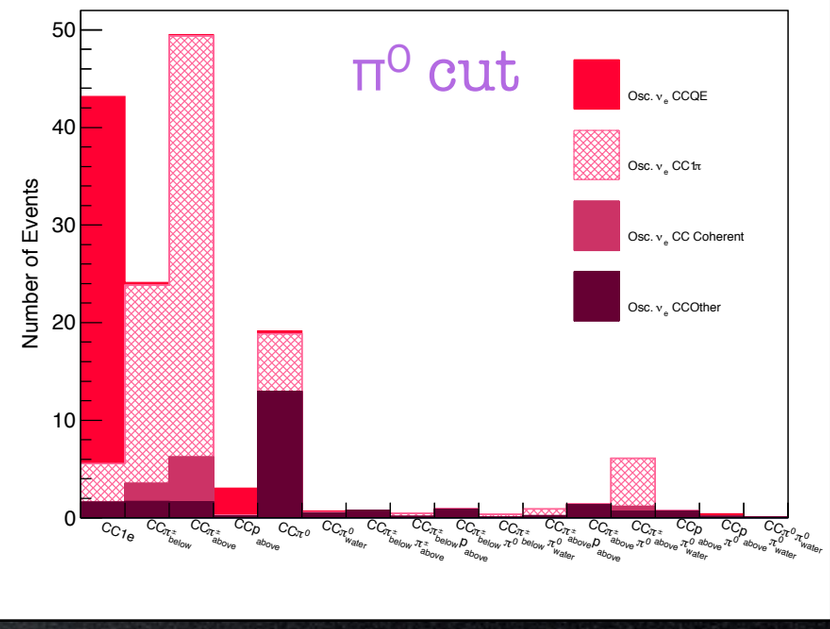








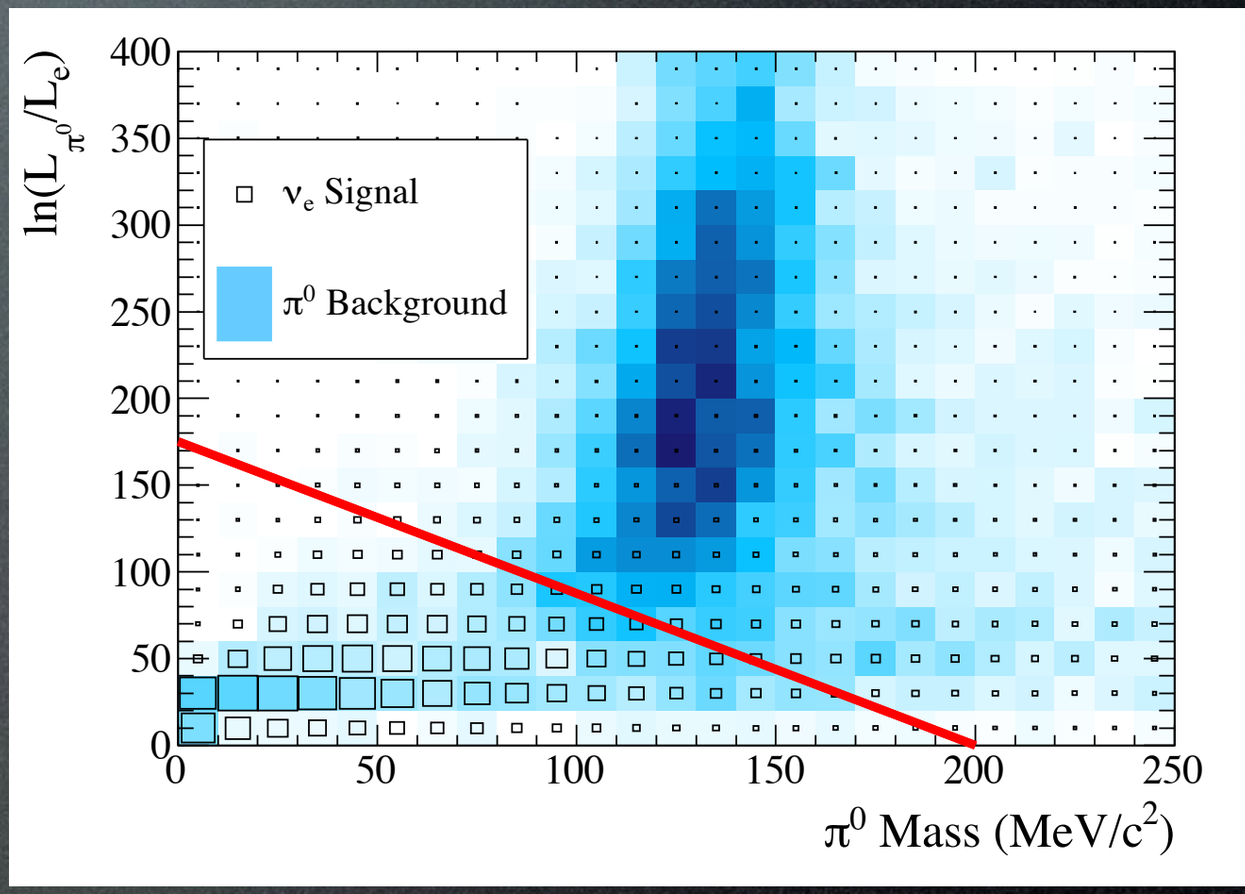




- Plots are cumulative
- Where can we gain back events, and how differently will the fiTQun selection perform?

π^0 Cut

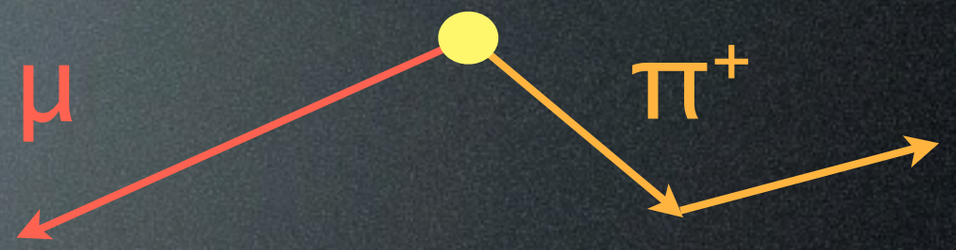
- Initial cut was tuned for ν_e appearance search
  - 8% signal loss was acceptable for stronger π^0 background rejection
- For CP violation search, more π^0 background is acceptable
  - Particularly with 50/50 ν/anti-ν running
- Additional improvements can also increase the efficiency
  - e.g. moving the cut as a function of E_{rec}
- May allow us to remove E_{rec} cut completely (4% of signal)



T2K 1-Ring Selections

- Need to optimize sensitivity (efficiency, purity, systematics) for δ_{CP} sensitivity
  - This may require a looser pi0 cut
  - We must understand pi0 likelihood shifts!
    - This is somewhat limiting the scope of the analysis to lower neutrino energies
- Looser Michel cut by default? (i.e. include below Cherenkov CCπ^+?)
- Still need to determine the appropriate fiducial volume cut
  - Will this work be applicable to multi-ring analyses?
- Need to revisit π/μ separation
  - Use proton fitter?
- Systematics! (tomorrow)

T2K CCpi+



- Great progress in new fitter development
- How well can pion counting be done?
  - e.g. stitching together rings from the same pion
    - Can these events be separated from multi-pi events?
  - How do pions affect ν_e/ν_μ separation?
- How can we understand CCπ^+ systematics?
  - Hybrid CCpi+ events?
    - Seems difficult to choose “data pions” unless these are restricted to 1 ring
      - Select 2-pion-ring events in data and MC?
  - Hybrid π^0 assumes the source of systematic uncertainty is the probability of finding a low energy photon in the presence of a high energy photon
    - i.e. absolute photon efficiency for low energy photons is not tested with this sample
  - Is this strategy, then, applicable to CCπ^+ events?

Atmospheric Neutrino Fit

- How finely can fiTQun reliably subdivide the atmospheric neutrino sample?
- For systematics, need to understand detector response for a variety of different final state topologies
  - Much more complicated than any of the previous analyses
  - Are hybrid samples sufficient?

$p \rightarrow e^{+}\pi^{0}$

- Currently using the default multi-ring fitter
  - Is a dedicated fitter useful or necessary for this analysis?
    - Can a constrained-mass pi0 fit be helpful?
- Detector systematics issues are a subset of those for the atmospheric neutrino sample
  - Some cancelation of detector systematics with ν_e-CCπ^0 background events should be possible

$p \rightarrow K^{+}\nu$

- These events have a prompt de-excitation photon (6 MeV), followed by a mono-energetic muon from a kaon decay at rest
- New fitter has been developed to fit this topology (more on this on Thursday)
  - photon + muon constrained to the same vertex (or not) with a fitted time difference
  - This fitter behaves much like the pi0 fitter (low energy ring in the presence of a higher energy ring), but with a ΔT
- Detector systematics should be well-addressed using a hybrid mu+gamma sample

Effort Organization

- One of the main goals of the workshop is to formulate a comprehensive plan for systematic error evaluation
  - This will be discussed more extensively tomorrow
- We will need to ensure that errors can be produced on timescales that useful for the different analyzers
  - i.e. a short term and a longer term plan
- During the error discussion tomorrow, please consider where you can contribute to this effort

Summary

- Several fiTQun improvements are begin studied, and more improvement is possible
- Many analyses are underway in both T2K and Super-K
  - Many of these analyses still need some optimization
- There are likely to be many common detector systematic errors across analyses
  - By the end of the workshop, we should have a comprehensive plan for addressing these errors