

Measurement of Reconstructed Charged Particle Multiplicities of Neutrino Interactions in MicroBooNE

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New Perspectives 2017

06/05/2017

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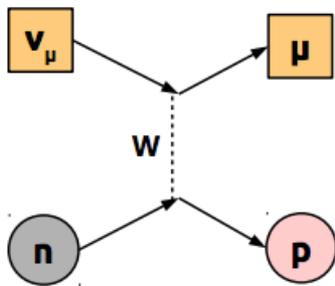
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Outline

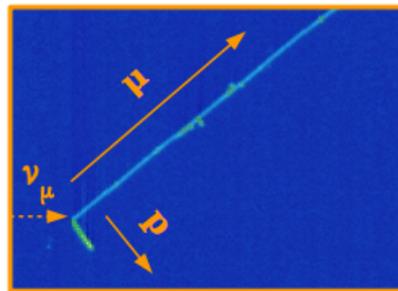
- Neutrino Interactions
- Introduction to charged particle multiplicity (CPM)
- Motivations
- Analysis Method
- Results
- Conclusion & Outlook

Neutrino Interactions

Charged Current Interactions

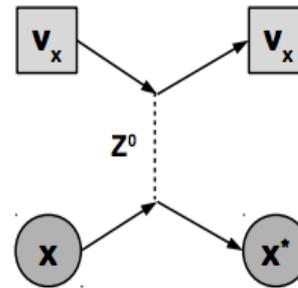


Candidate MicroBooNE CC event

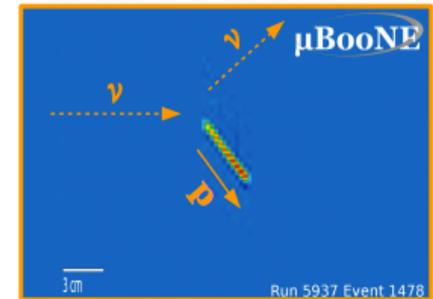


Gives information about neutrino flavor

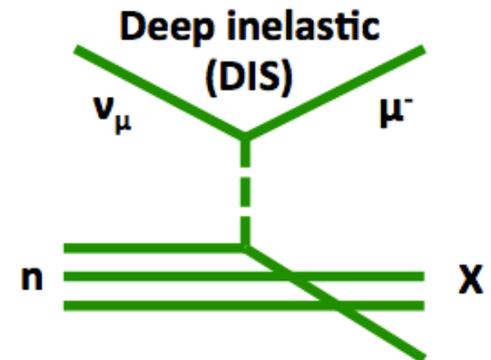
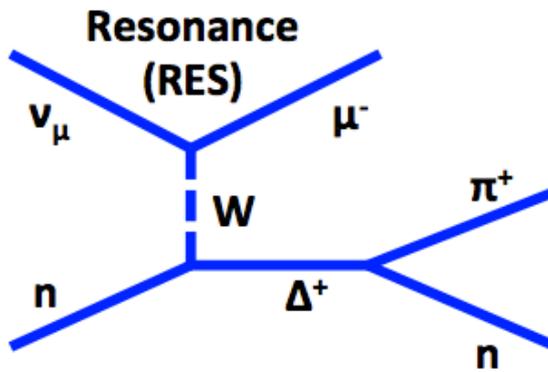
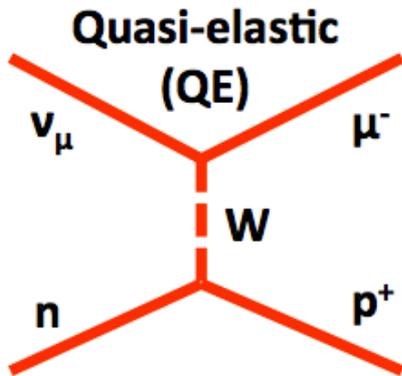
Neutral Current Interactions



Candidate MicroBooNE NC event

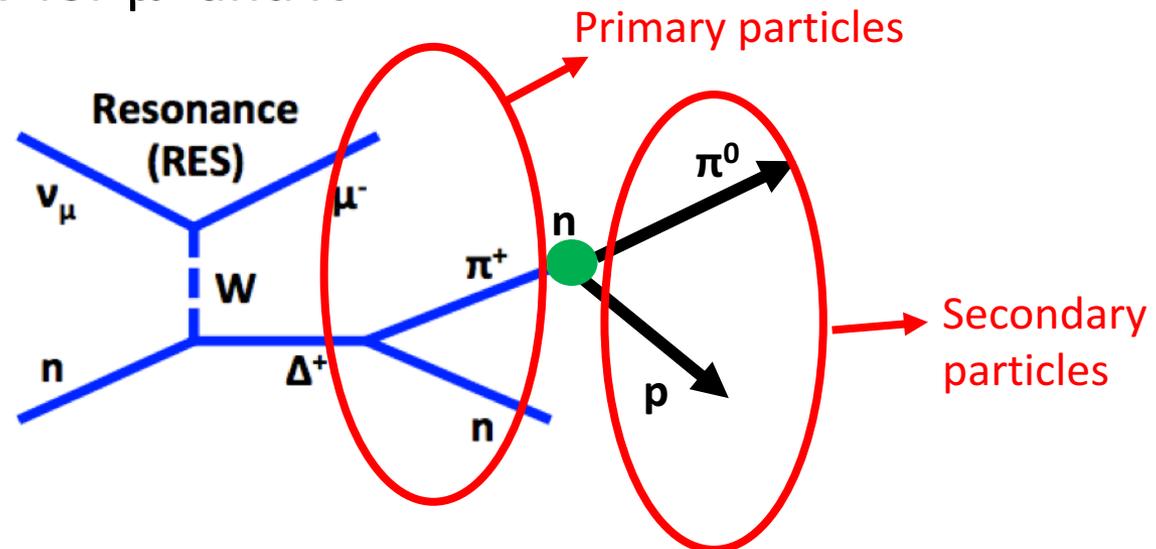


No information of neutrino flavor



Introduction to CPM

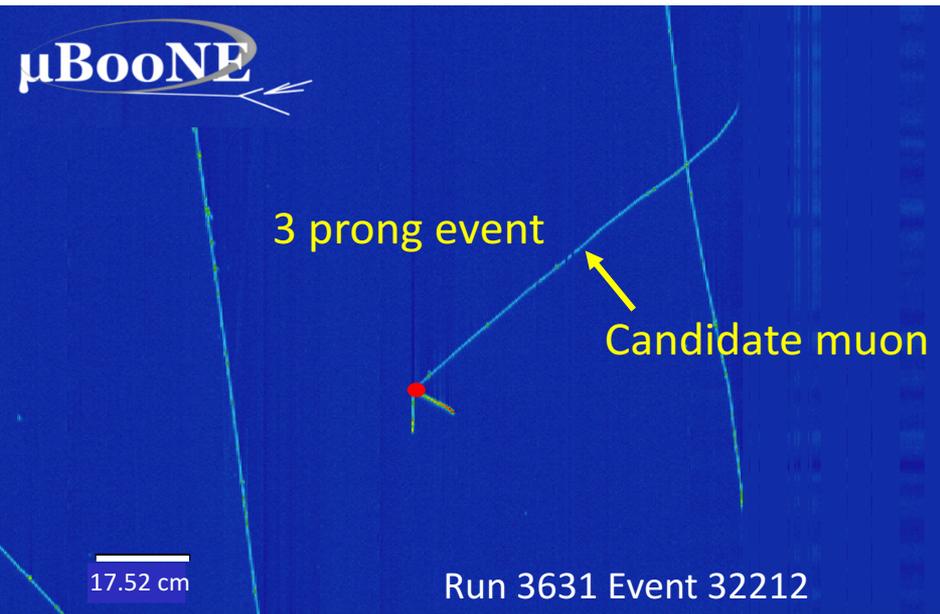
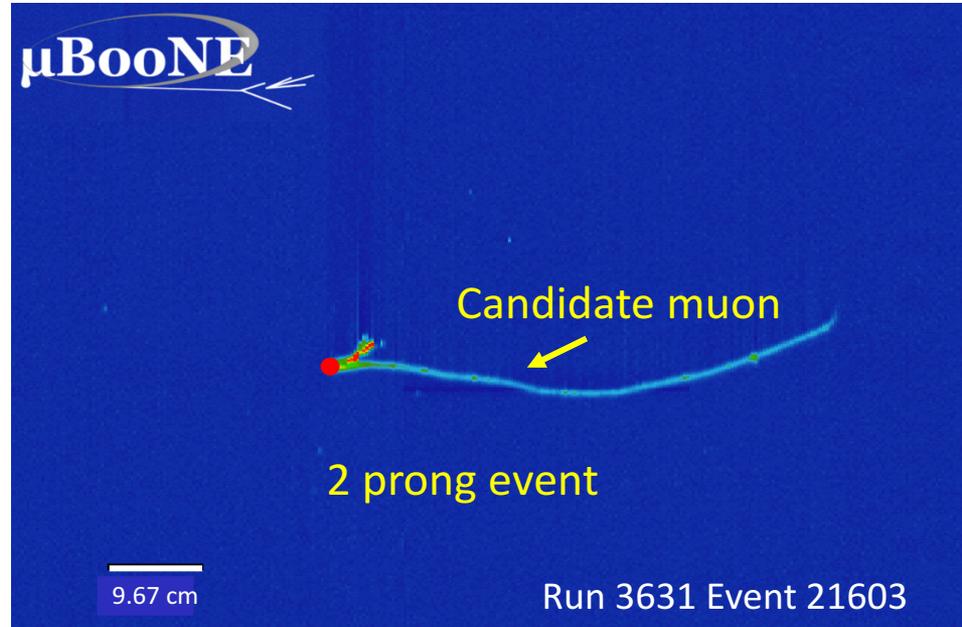
- Number of reconstructed charged particles exiting the target nuclei at the neutrino interaction point.
 - Inclusive study
 - Mainly μ^\pm , π^\pm , and p
 - Primary + secondary interaction particles
 - Track requirement imply kinetic energy thresholds $\sim 82\text{MeV}$ for p, 37MeV for μ^\pm and π^\pm



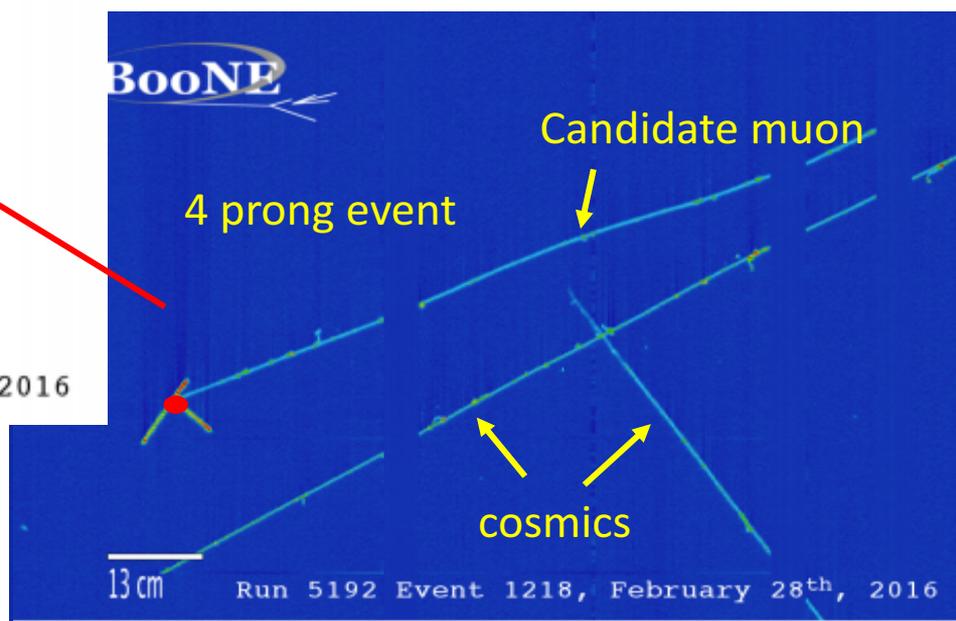
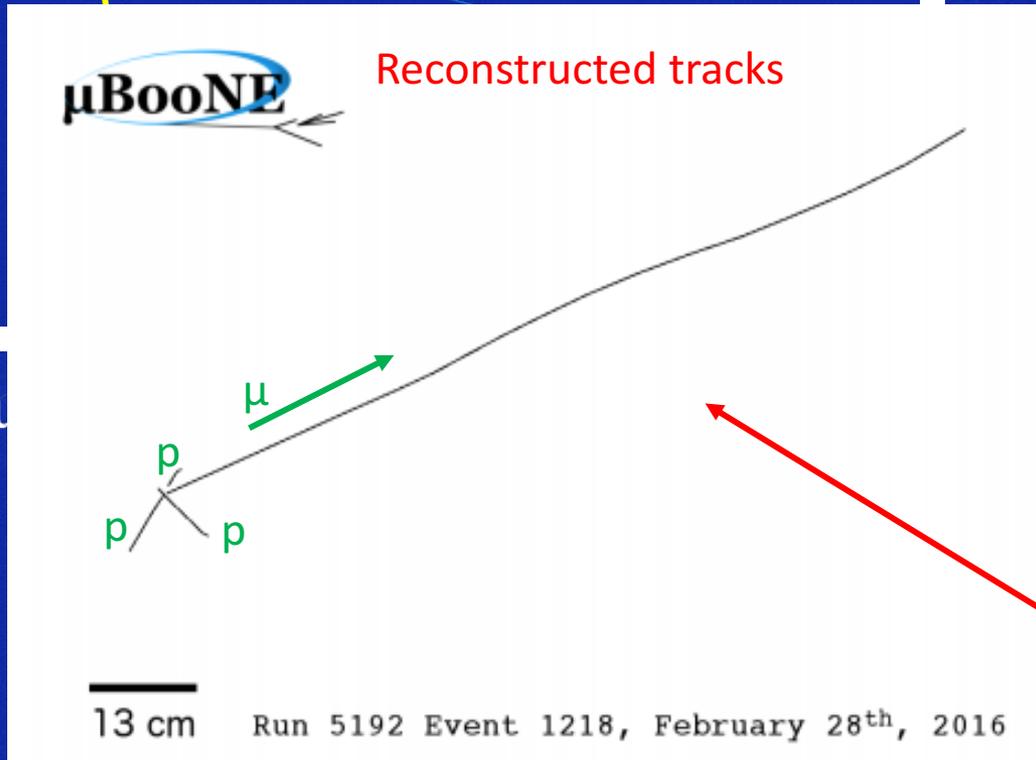
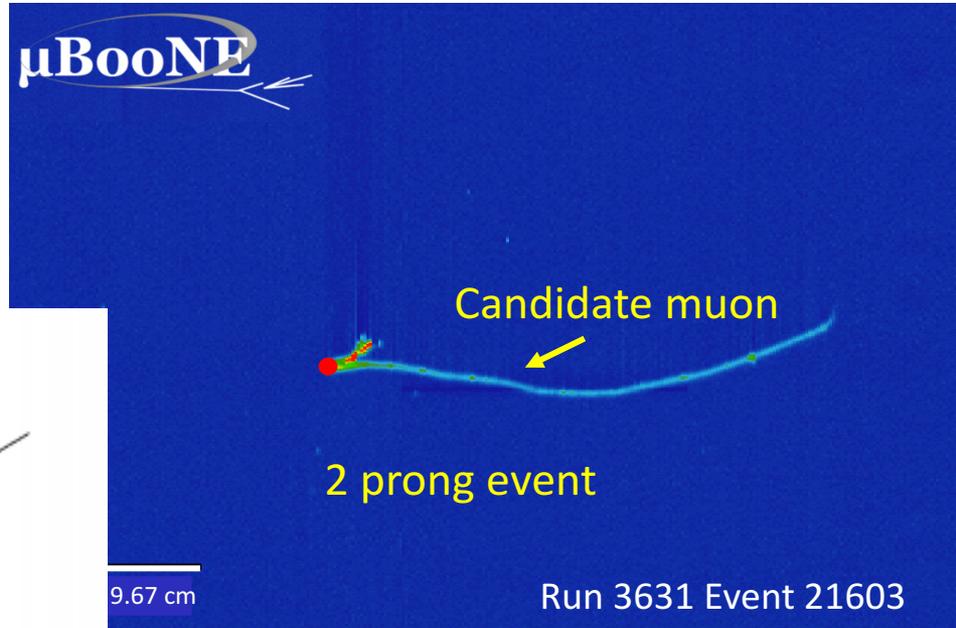
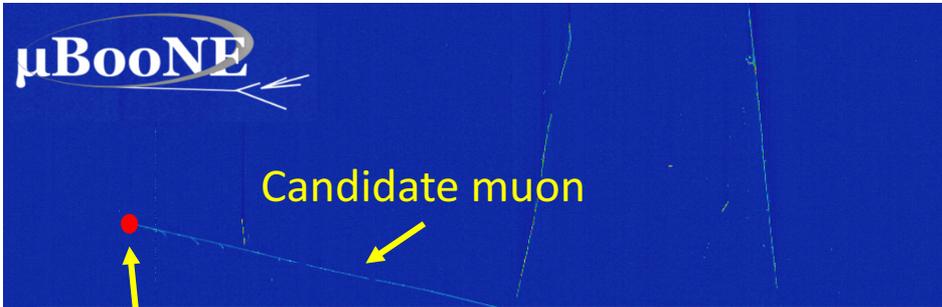
Analysis Motivations

- **Can be used to test different simulation models and generators inclusively.**
- Expand the knowledge of ν -Ar scattering required by the DUNE neutrino CP violation search experiment.
- Early and relatively simple measurement
 - minimal kinematic properties of the final state particles are imposed.
 - does not require complexity associated with particle ID

Candidate Neutrino Event Displays

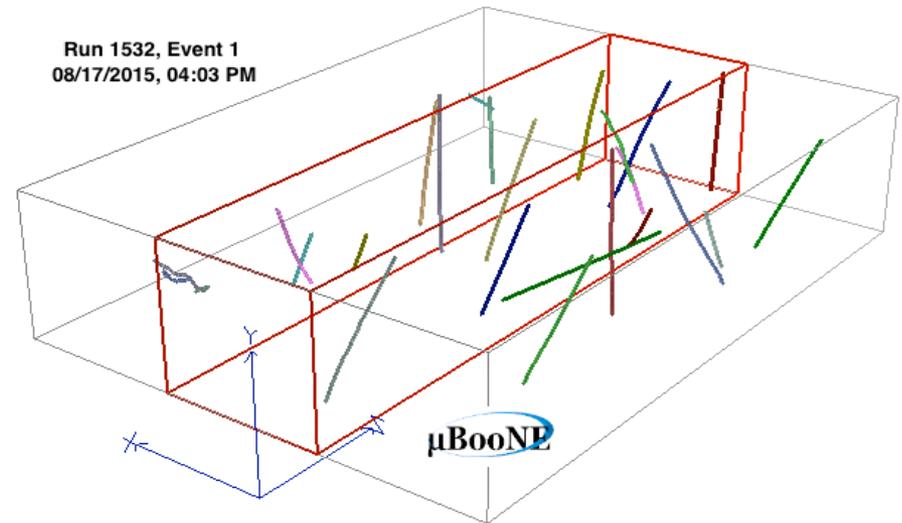


Candidate Neutrino Event Displays



Cosmic rays in MicroBooNE

- Causes of substantial cosmic rays in MicroBooNE:
 - Near to surface operation
 - Long electron drift window (about 2.3 msec maximum drift time)



Analysis Chain

Full Sample

MICROBOONE-NOTE-1010-PUB

ν_{μ} CC
inclusive
filter

muon
quality
Filter

Mu Directionality
Classifier

Signal
enhanced
sample

Mixed
samples

Background
enhanced
sample

- Picks a long, contained and forward-going candidate muon and an associated vertex

- Performs tests for the purpose of cosmic ray removal

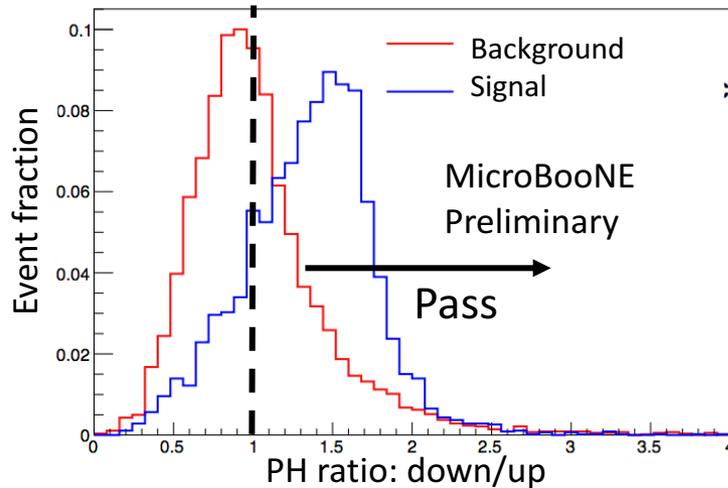
- Pulse height (PH)
- Multiple coulomb scattering (MCS)

- Minimum collection plane hits cuts for candidate muon
- Candidate muon start/end good detector regions.

PH and MCS Test

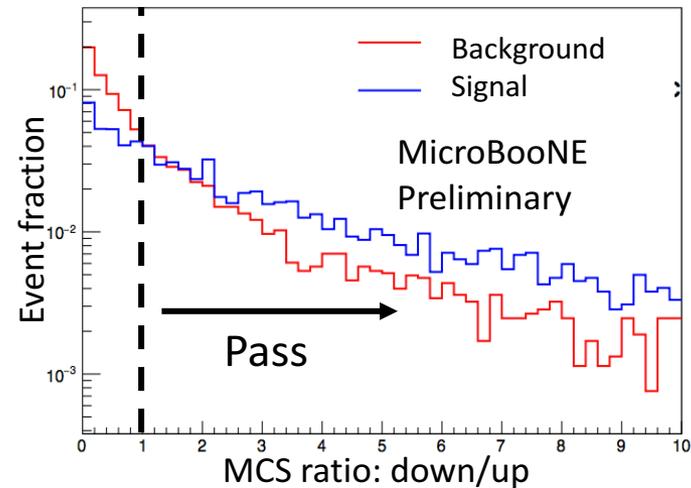
PH Test

Rate of energy loss increases along the track from upstream to downstream end



MCS Test

Scattering is more pronounced along the downstream end of the track as the momentum decreases.

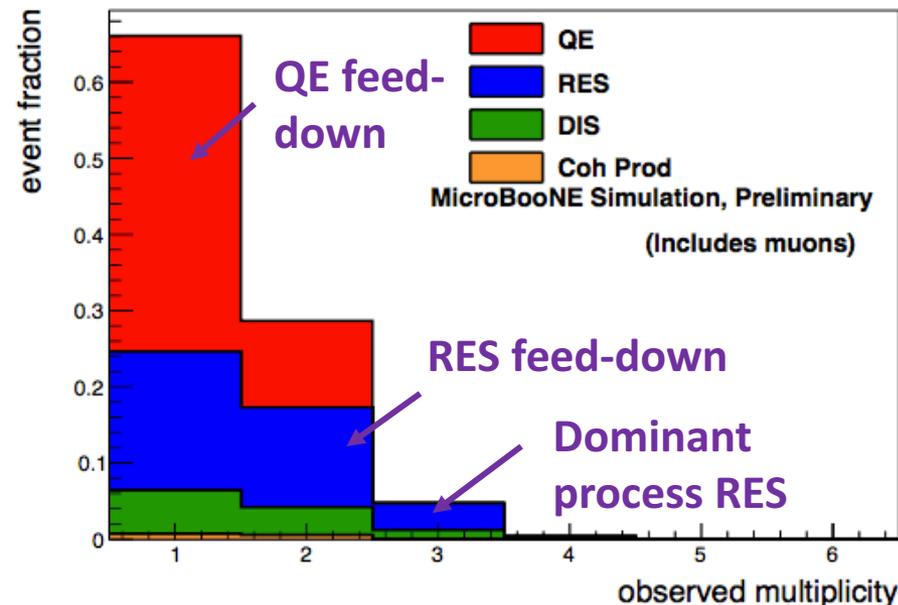


Sub samples PH, MCS	On-beam Data		Off-beam Data		BNB+Cosmic Default MC	
	events	acceptance rates	events	acceptance rates	events	acceptance rates
pass, pass	847	(44%)	1263	(24%)	2629	(62%)
pass, fail	367	(19%)	1087	(21%)	737	(18%)
fail, pass	321	(17%)	1141	(22%)	440	(10%)
fail, fail	387	(20%)	1776	(34%)	403	(10%)

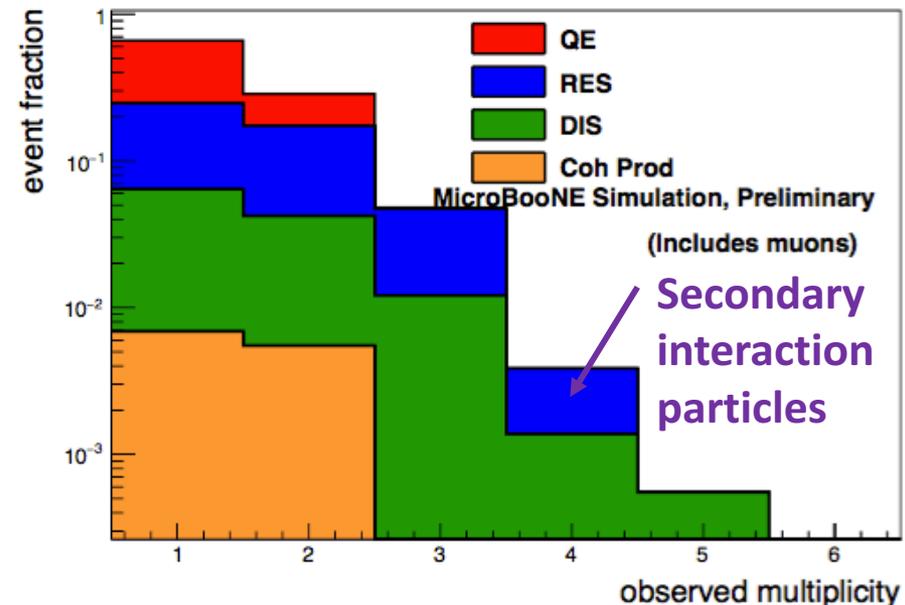
Cosmic rays travel forward and backward with roughly equal prob.^{s10}

Expectations for Observed CPMD

Interaction Types in Observed Multiplicity Bins



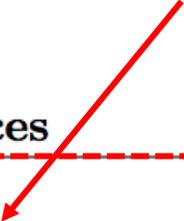
Interaction Types in Observed Multiplicity Bins



Common feed-down occurrence can be observed due to efficiency*acceptance effects.

Uncertainty Estimates

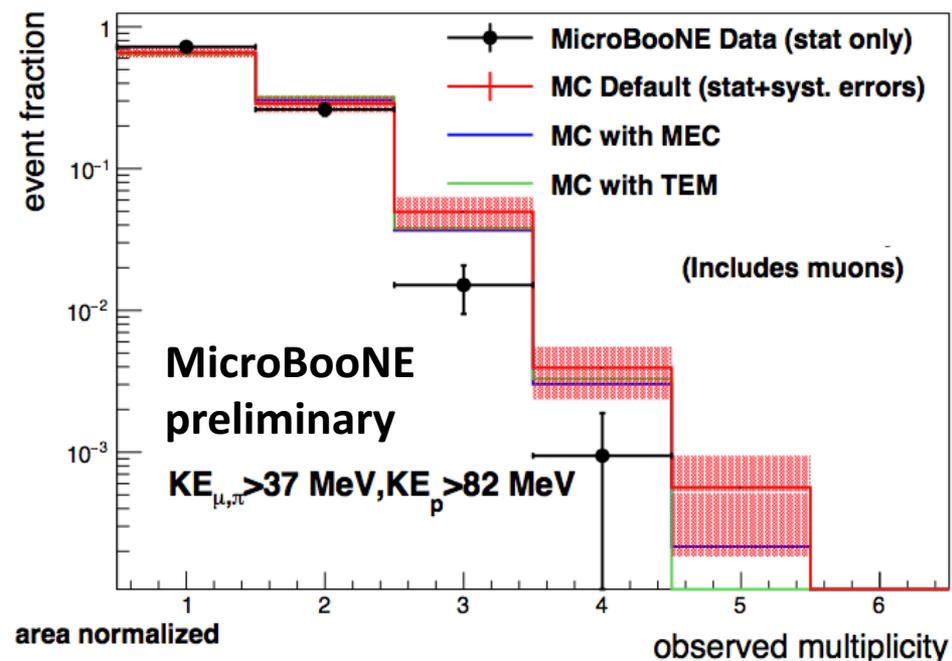
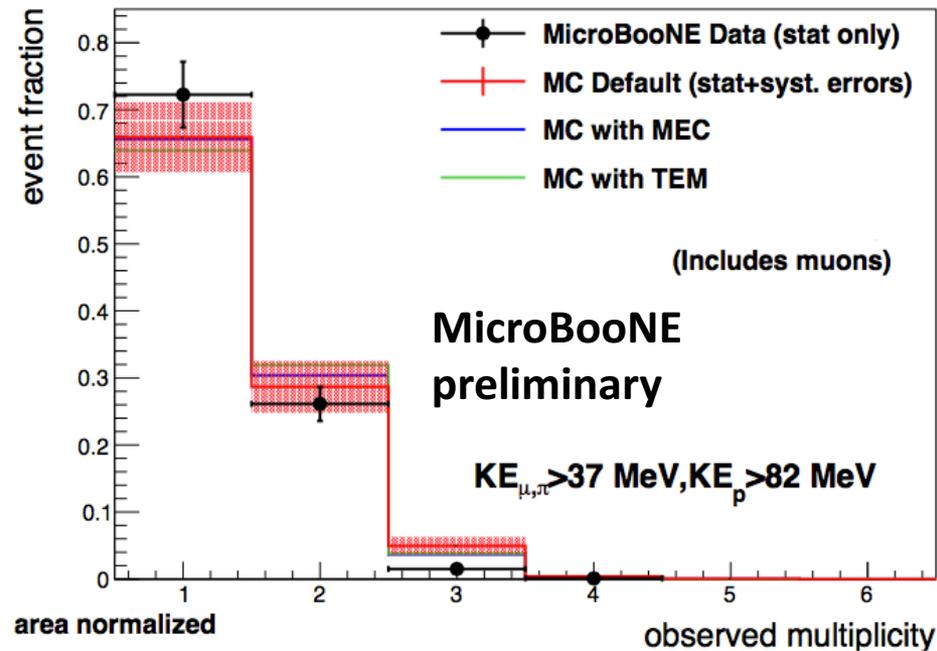
Dominant uncertainties sources



Uncertainty Sources	Uncertainty Estimates				
	mult=1	mult=2	mult=3	mult=4	mult=5
Data statistics	7%	10%	38%	100%	–
MC statistics	3%	4%	7%	21%	50%
Short track efficiency	7%	11%	25%	33%	44%
Long track efficiency	1%	2%	4%	7%	9%
Fixed model parameter systematics	2%	2%	0%	0%	0%
Flux shape systematics	0%	0.4%	0.2%	0.5%	0.8%
Electron lifetime systematics	0.5%	0.1%	6%	5%	5%

* See backup slides for details

Experimental Result



Conclusion & Outlook

- **Conclusion:**

- Developed and validated method to isolate cosmic ray from neutrino events
- Compared CPMD from data and different generator models
- Models are consistent within uncertainties with the data
- Hint for slight discrepancy in data and MC in higher multiplicity bins

- **Public Note:**

- <http://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1024-PUB.pdf>

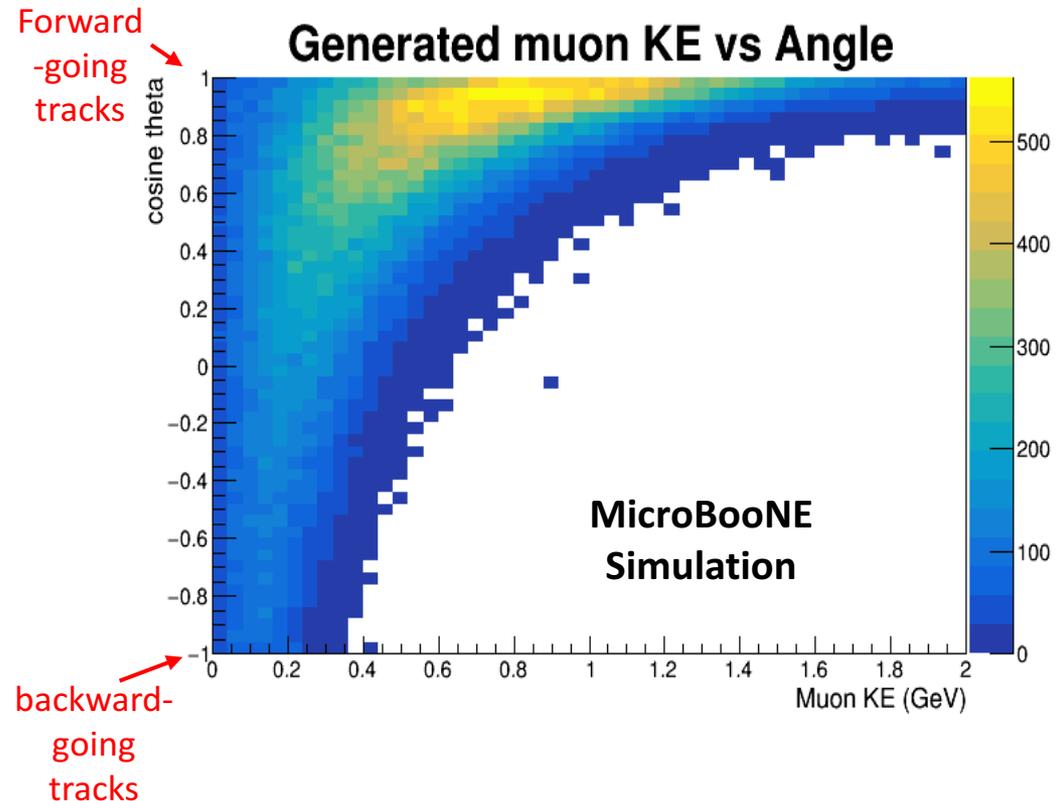
- **Outlook:**

- Compare data with wider range of models
- Present results using high statistics MC and data samples

Backup Slides

Muon Directionality Tests

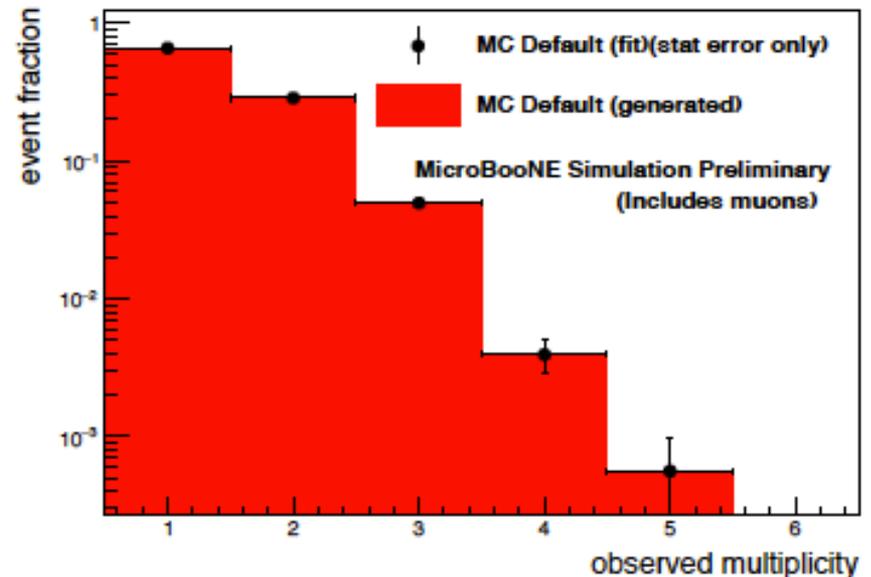
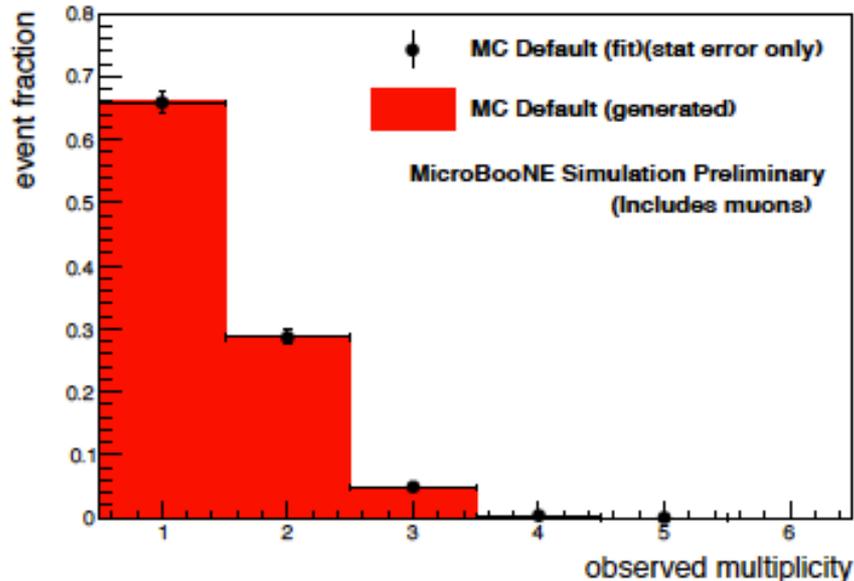
- Muons from neutrino CC interactions:
 - Usually move **from upstream to downstream**.
- Horizontal cosmic ray muons
 - Move upstream or downstream with **equal probability**.
- Performed tests
 - Pulse height (PH) test.
 - Multiple coulomb scattering (MCS) test.



Closure Test Result on Simulation

Bin by bin
fit

Multiplicities	Fit N_ν	True N_ν	True-Fit χ^2
1	2340 ± 65	2405	1.0
2	1018 ± 41	1043	0.4
3	176 ± 13	175	0.0
4	14 ± 3	14	0.0
5	2 ± 1	2	0.0



Signal Extraction

Subsample #	On/off-beam	PH	MCS
1	On-beam	pass	pass
2	On-beam	pass	fail
3	On-beam	fail	pass
4	On-beam	fail	fail
5	Off-beam	pass	pass
6	Off-beam	pass	fail
7	Off-beam	fail	pass
8	Off-beam	fail	fail

Relate number of events in each of 8 subsamples to:

- Number of on-beam neutrinos
- Number of on-beam cosmics
- Number of off-beam cosmics
- Probability that a neutrino or cosmic passes the PH or MCS tests

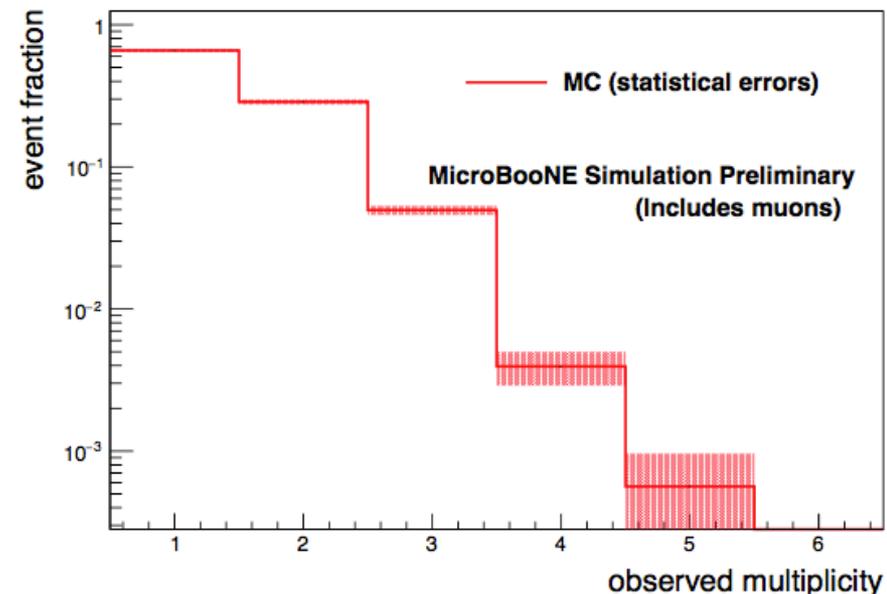
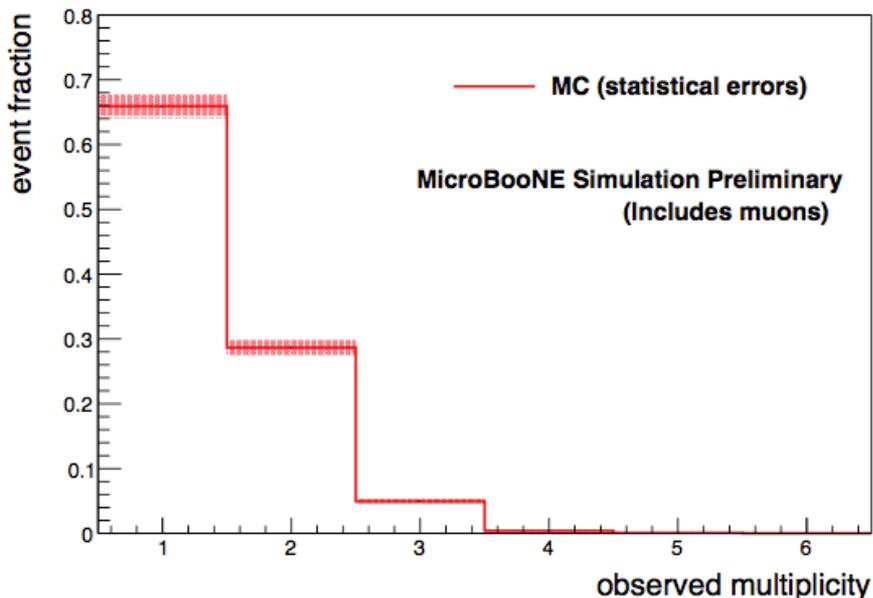
8 equations, 7 unknowns. Perform maximum likelihood fit for 7 parameters

[Note: two conditional probabilities estimated from MC and fixed in the fit]

Statistical Uncertainties

- Statistical errors obtained from the fit returned from MINIUT package

Dominant source of uncertainty

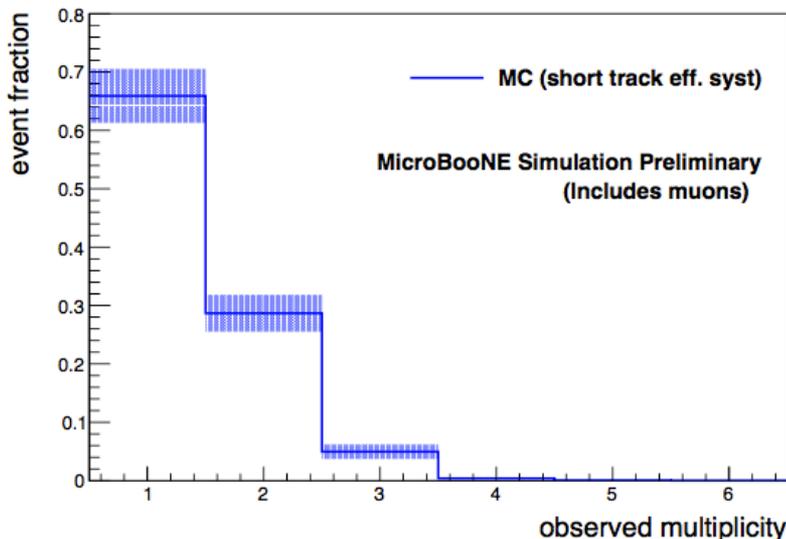


Short Track Efficiency Uncertainties

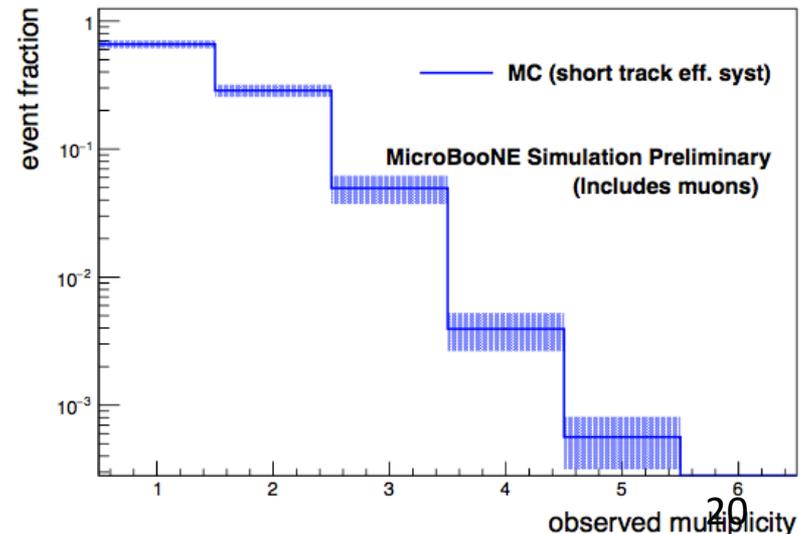
- From Pandora public note, reco efficiency of proton/pion at 20 hit threshold is 0.45 ± 0.05

Observed multiplicity	$\frac{\Delta P_n}{P_n}$ Default	$\frac{\Delta P_n}{P_n}$ MEC	$\frac{\Delta P_n}{P_n}$ TEM
1	+7%	+7%	+8%
2	-11%	-12%	-12%
3	-25%	-25%	-25%
4	-33%	-36%	-39%
5	-44%	-48%	-

Dominant systematic uncertainty



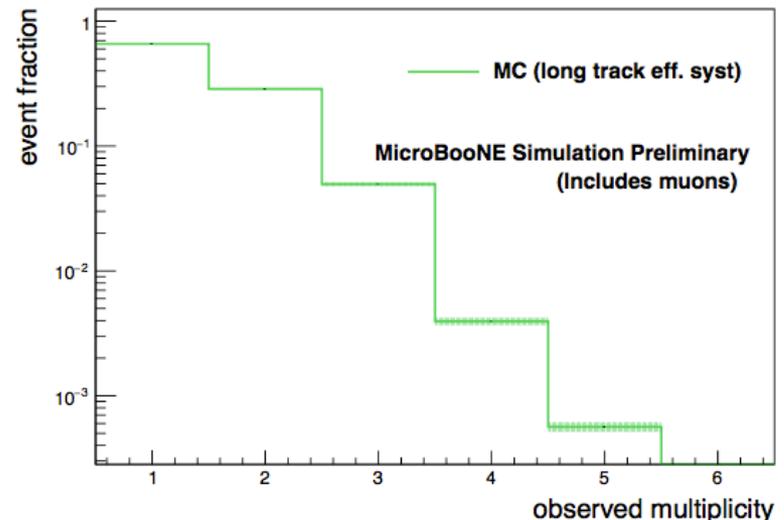
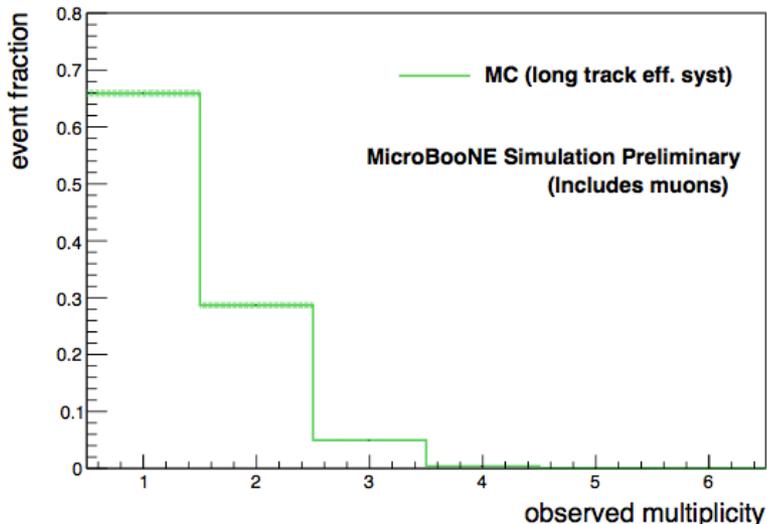
Overall eff. $\propto \epsilon$ (no of short tracks)



Long Track Efficiency Uncertainties

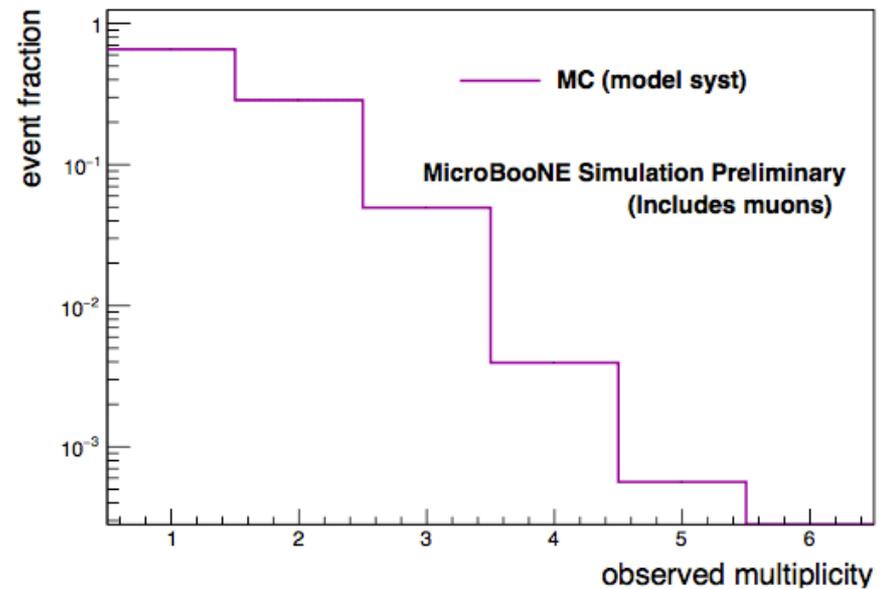
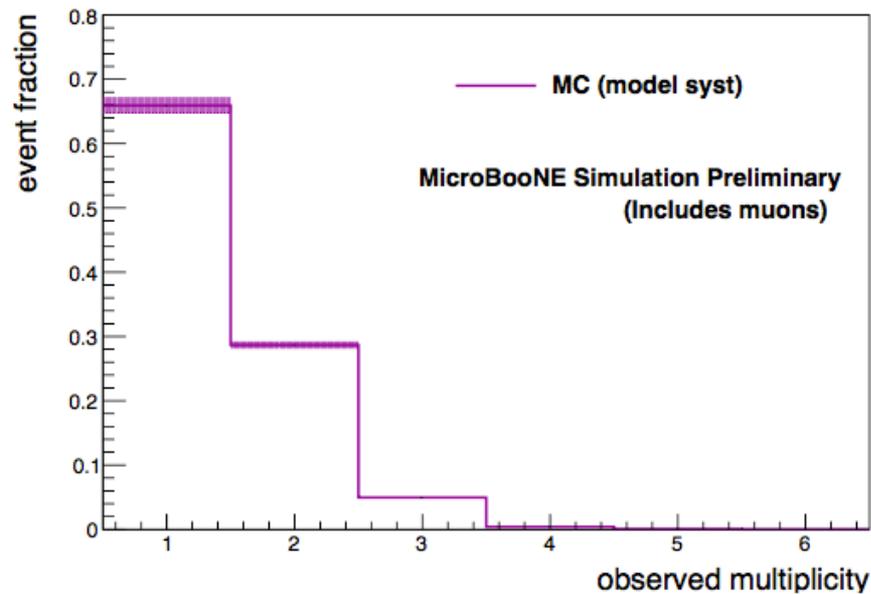
- Long track is common in all bins
- Pandora finds vertex better in high mult events.
- Calculated **muon efficiency** in QE and RES events where all tracks were reconstructed: **3% higher reco muon eff. in RES events**

Observed multiplicity	$\frac{\Delta P_n}{P_n}$ Default	$\frac{\Delta P_n}{P_n}$ MEC	$\frac{\Delta P_n}{P_n}$ TEM
1	-1%	-1%	-1%
2	+2%	+2%	+2%
3	+4%	+4%	+2%
4	+7%	+7%	+7%
5	+9%	+9%	-



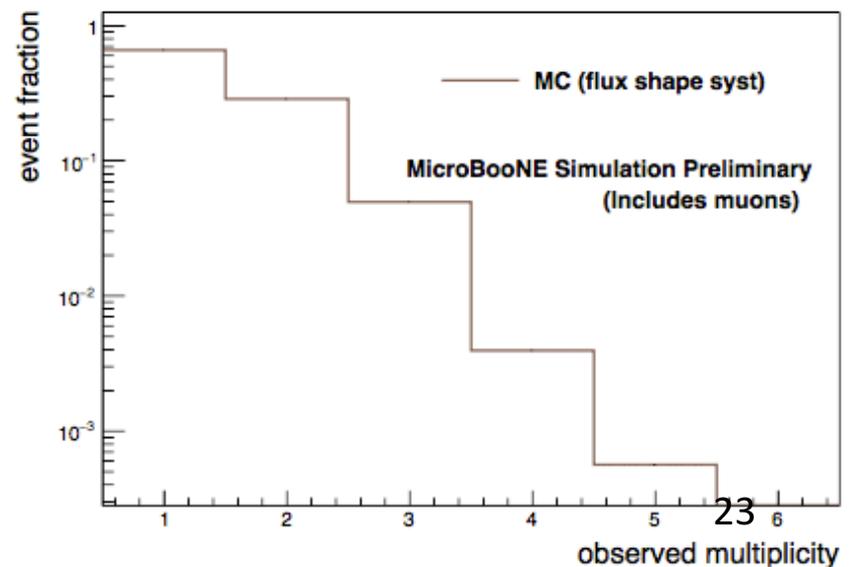
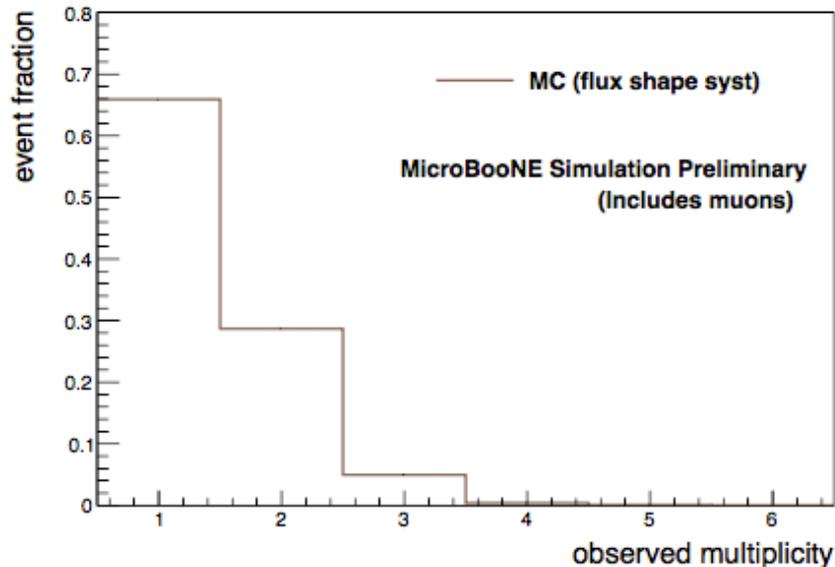
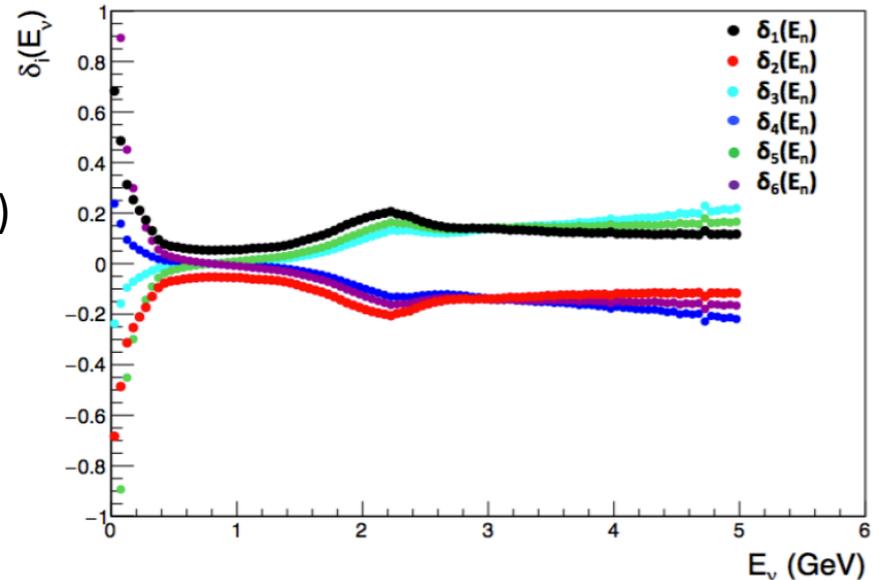
Background Model Uncertainties

- Varied values of fixed MC parameters by $\pm 1\sigma$ of their statistical errors



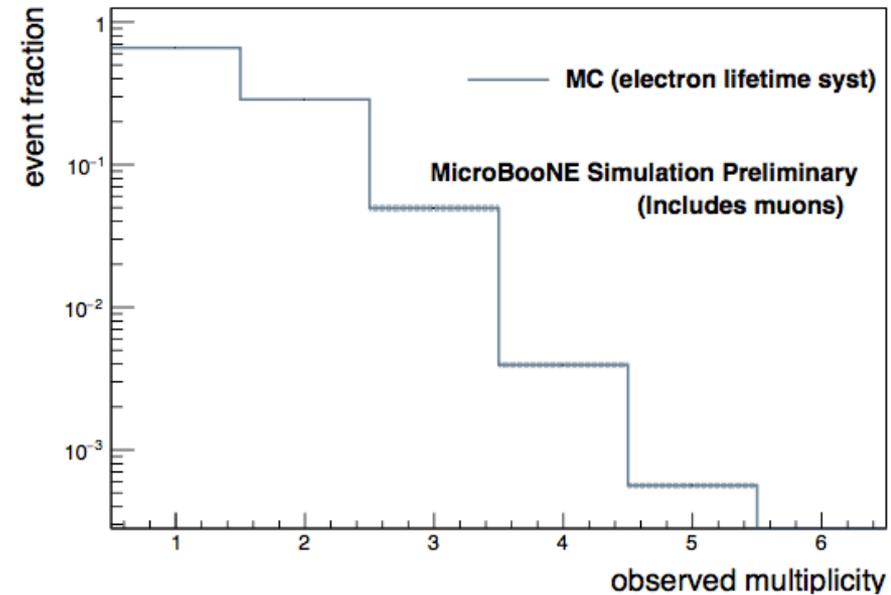
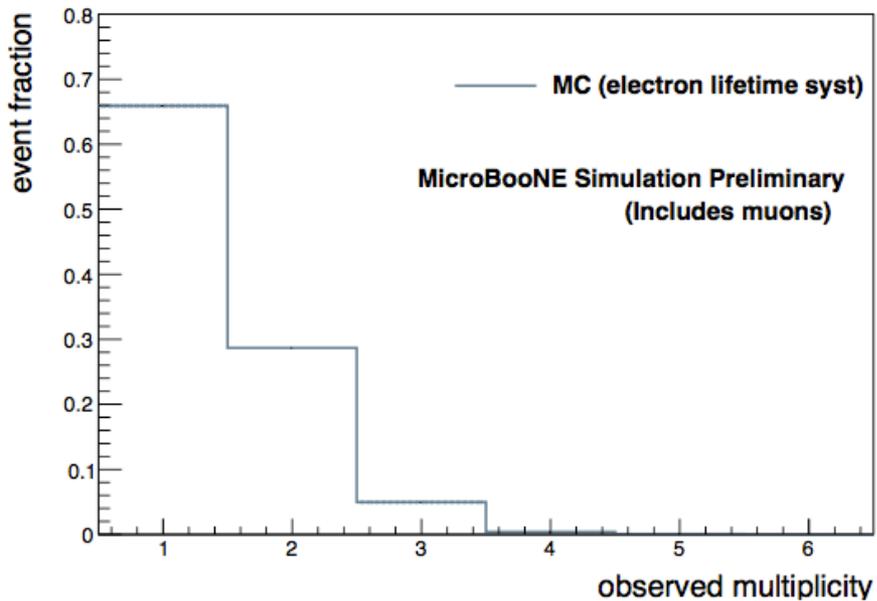
Flux Shape Uncertainties

- Got flux uncertainty estimates from MiniBooNE data
- $\delta_1(\delta_2)$ simply shift all flux values up(down)
- $\delta_3(\delta_4)$ enhances high(low) energy flux linearly
- $\delta_5(\delta_6)$ enhances high(low) energy flux logarithmically



Electron Lifetime Uncertainties

- Changed $\tau = 6 \text{ msec} \rightarrow \infty$



Other Systematics

- Time-dependent detector response
 - Divided data into two samples
 - No evidence for this systematic
- Kinematic distribution comparison in off-beam data and CORSIKA cosmic MC
 - No statistically significant discrepancies observed.