Measurement of Reconstructed Charged Particle Multiplicities of Neutrino Interactions in MicroBooNE

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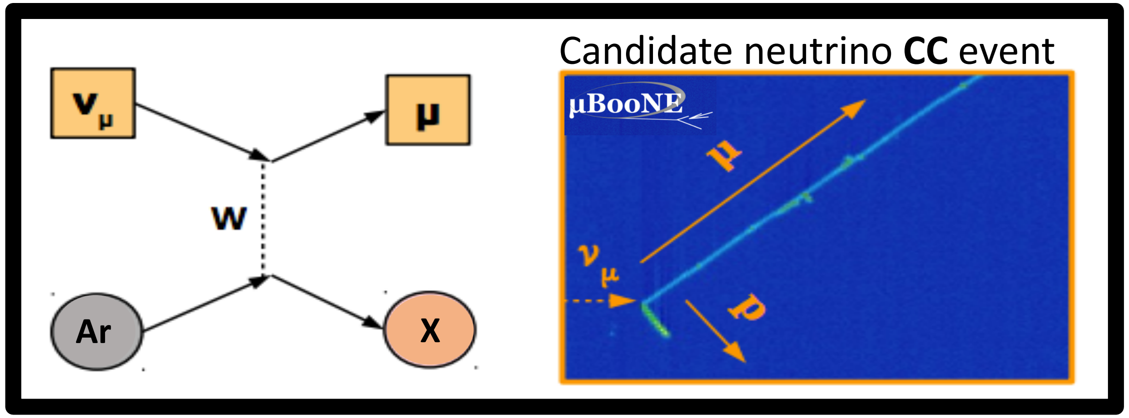
Physics Motivations

- Very little knowledge of ν-Ar interaction measurements exists till date
- Need to understand these interactions for future short and long baseline LArTPCs
- Need to test widely used GENIE for neutrinos interactions on Ar targets

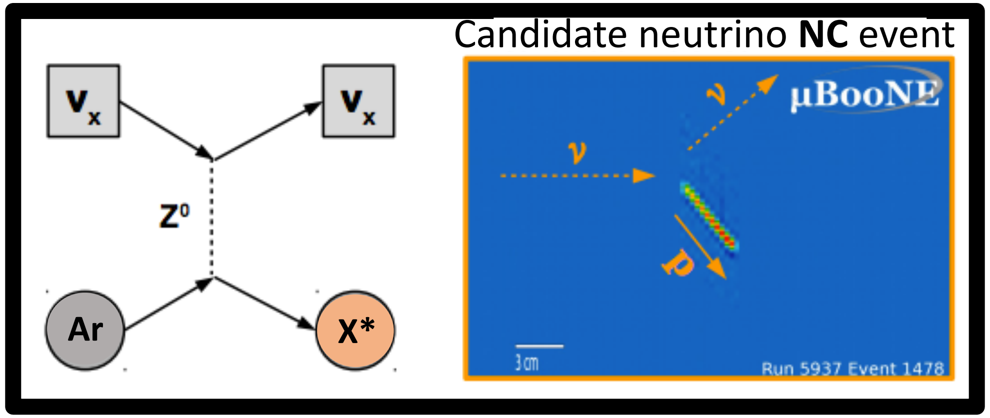
Neutrino Interactions

Charged Current Interactions

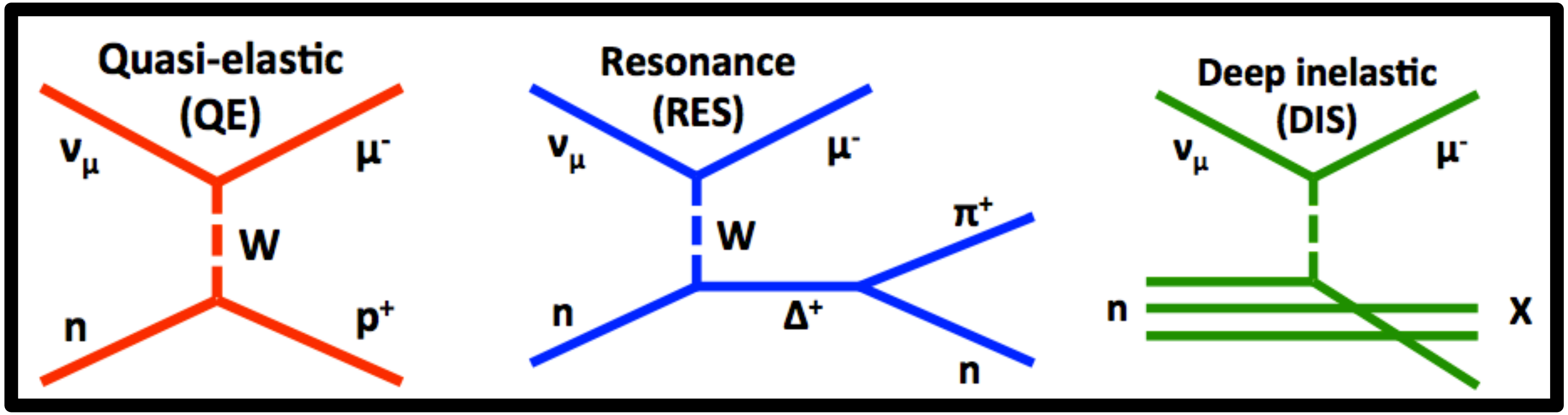


Gives information about neutrino flavor

Neutral Current Interactions

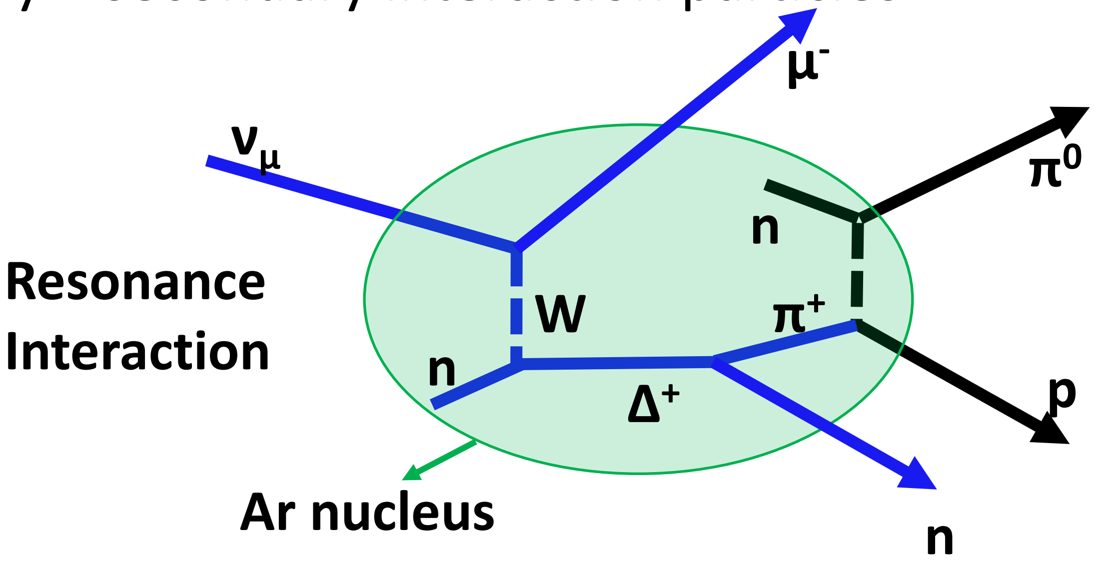


No information of neutrino flavor



Charged Particle Multiplicity

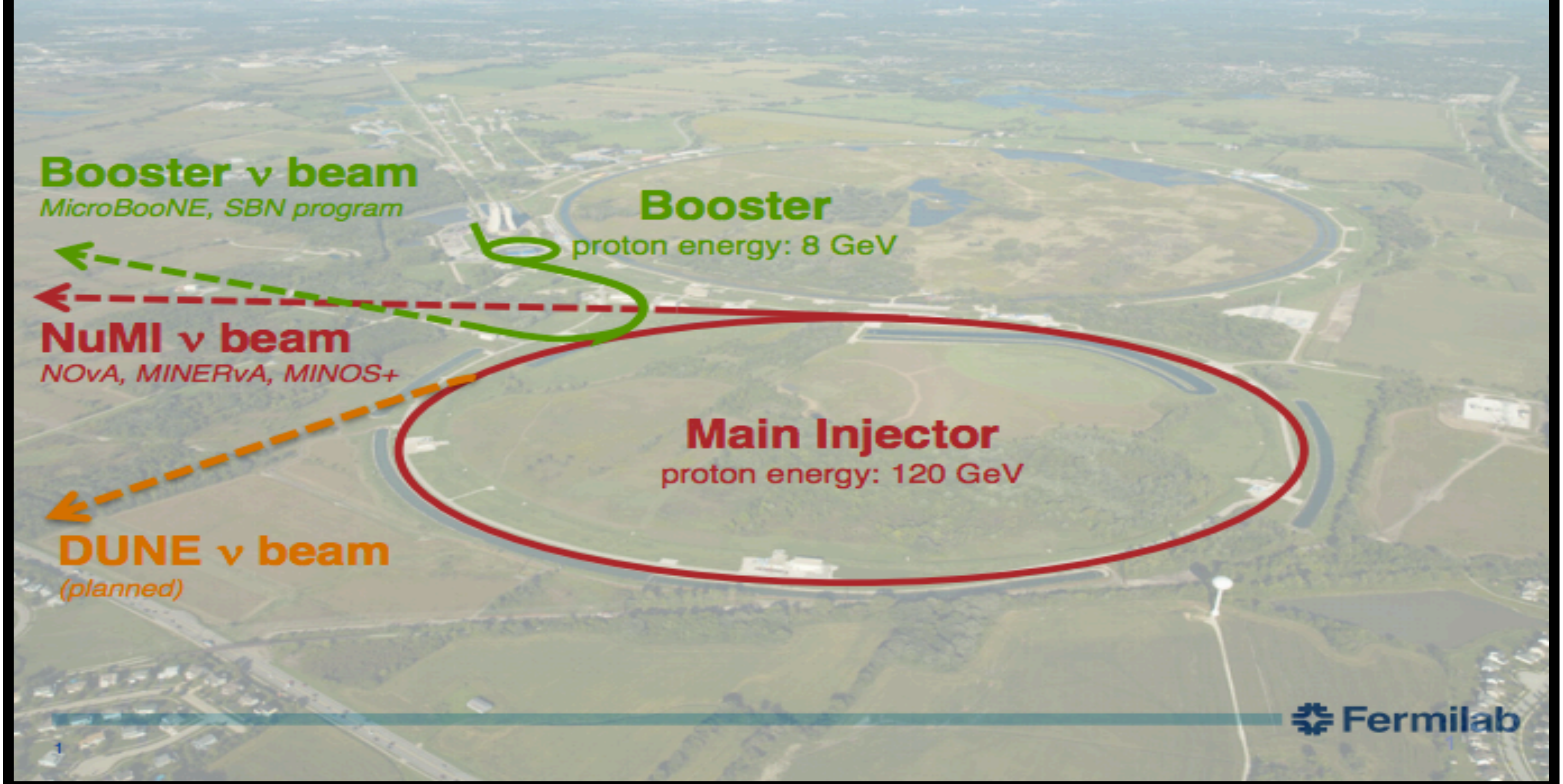
- Number of reconstructed charged particles exiting the target nuclei at the neutrino interaction point.
  - Inclusive study
  - Mainly $\mu^{\pm}$, $\pi^{\pm}$, and p
  - Track requirement imply kinetic energy thresholds ~82MeV for p, 37MeV for $\mu^{\pm}$ and $\pi^{\pm}$
  - Primary + secondary interaction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



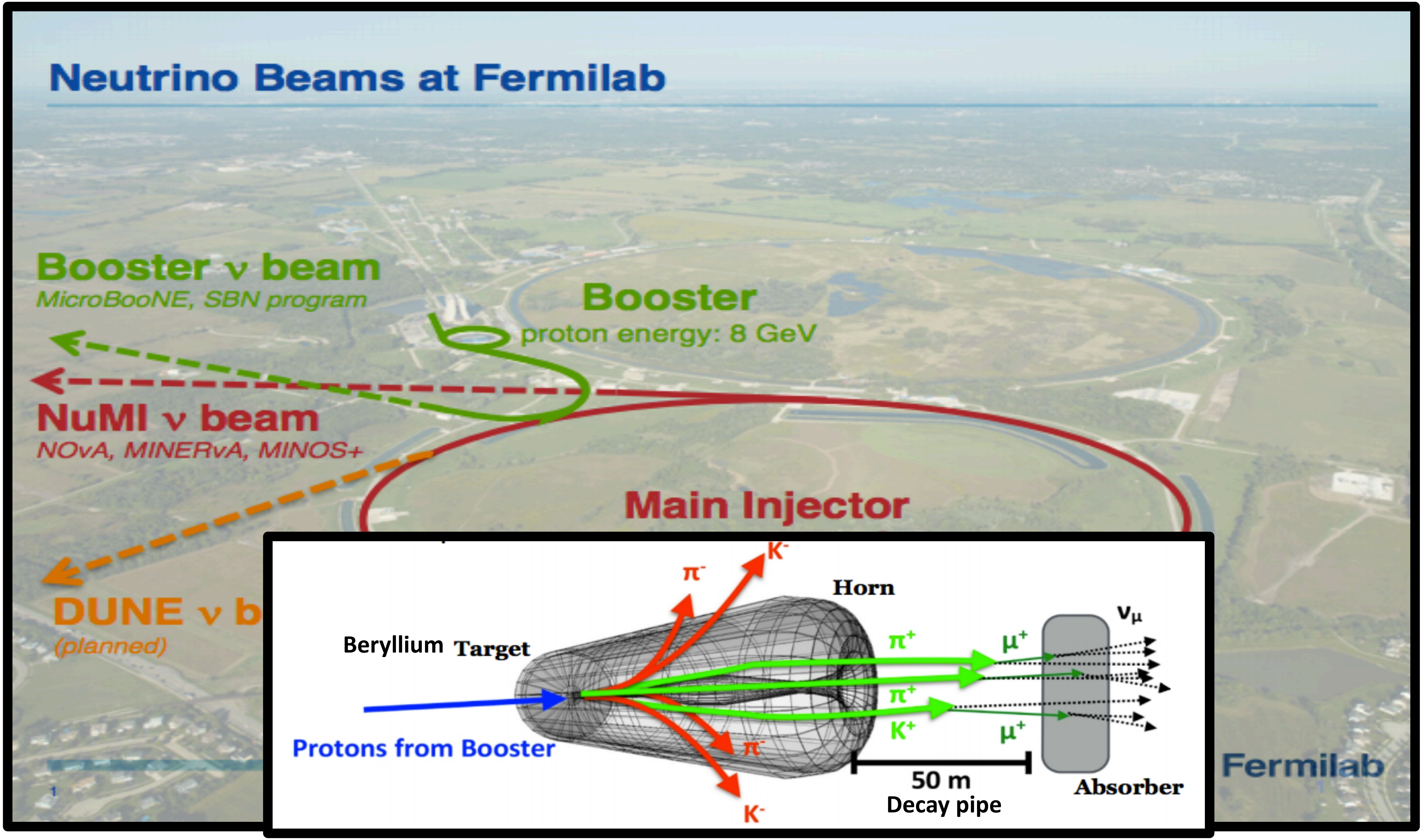
Why Charged Particle Multiplicity

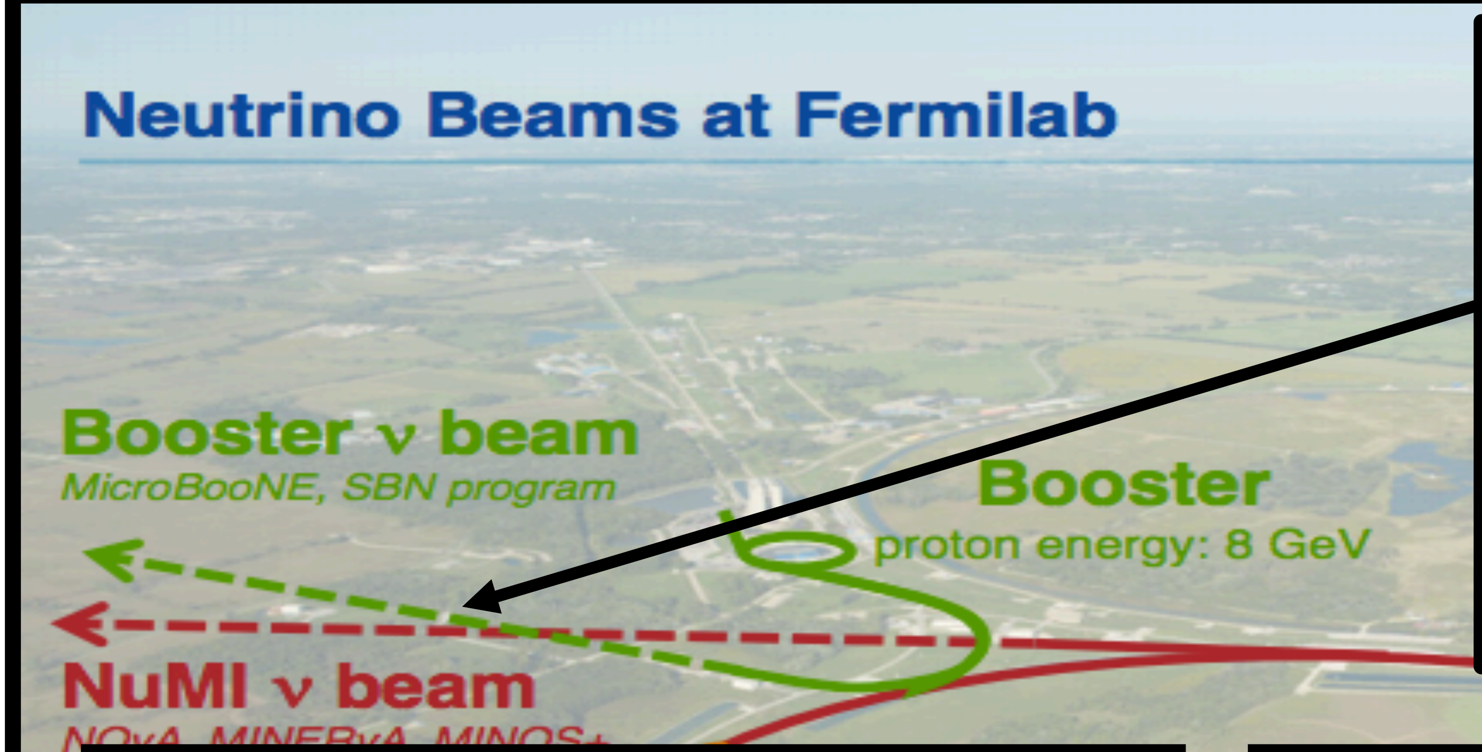
- Gives knowledge of ν-Ar interactions in form of directly observable quantity
- Provides a stringent test for neutrino event generators inclusively.
- Expand the knowledge of ν-Ar scattering required by the DUNE neutrino CP violation search experiment.
- Early and relatively simple measurement
  - minimal kinematic properties of the final state particles are imposed.
  - does not require complexity associated with particle ID
- First measurement of charged track multiplicity in ν_μ CC interactions in argon.

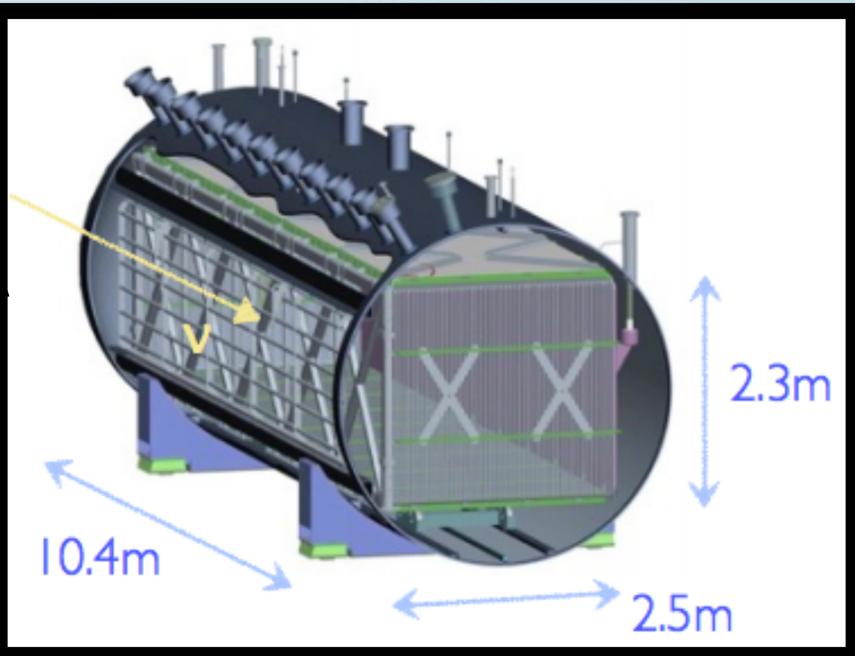
Neutrino Beams at Fermilab



Fermilab


Neutrino Beams at Fermilab
Booster ν beam
MicroBooNE, SBN program
Booster
proton energy: 8 GeV
NuMI ν beam
NOvA, MINERvA, MINOS+
Main Injector
DUNE ν b
(planned)
Fermilab
Beryllium Target
Protons from Booster
Horn
π⁻
K⁻
π⁺
K⁺
μ⁺
ν_μ
50 m
Decay pipe
Absorber





MicroBooNE Detector:

1. 85 ton of liquid argon Time Projection Chamber (LArTPC)
2. Average beam energy = 800 MeV
3. Substantial cosmic ray backgrounds
4. 3 anode wire planes
5. 32 8-inch PMTs
6. Collecting neutrino data since Oct, 2015

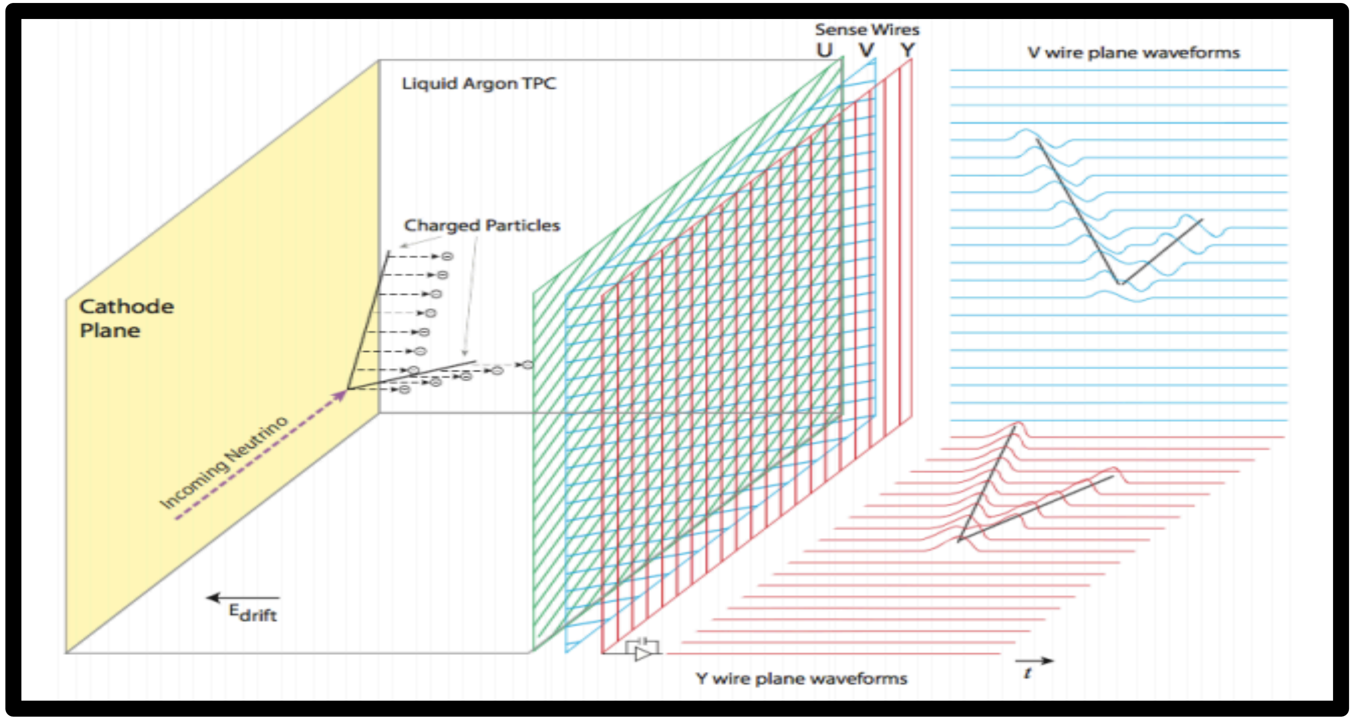
MicroBooNE Physics Goals:

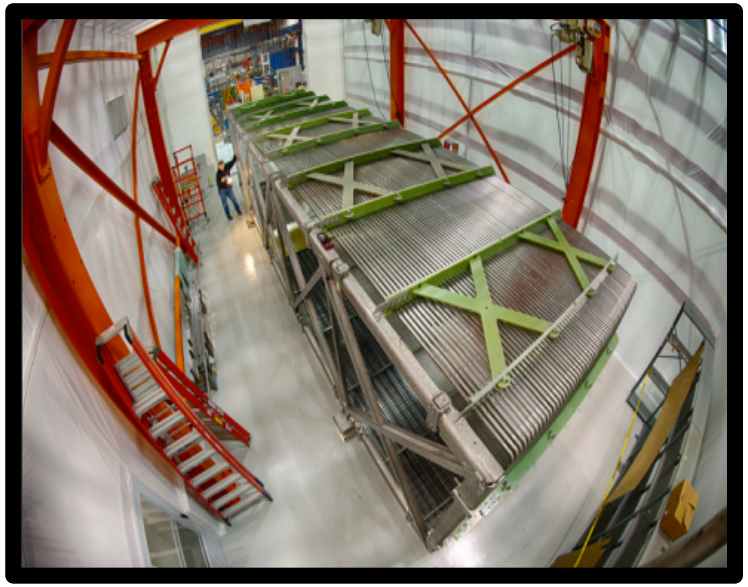
1. Knowledge of ν-Ar interactions in ~1 GeV range
2. Search for short baseline neutrino oscillations
3. Detector R&D for future large scale LArTPC detectors (e.g DUNE)

Principle of LArTPC

LArTPCs make 3D reconstruction possible.

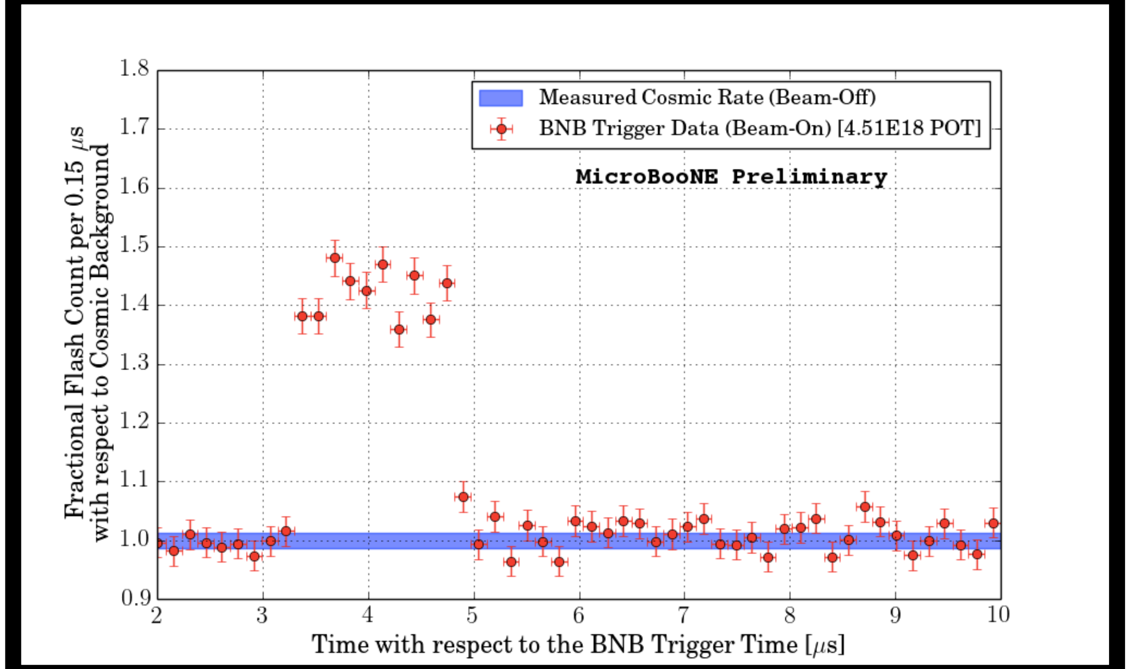
- Wire planes give 2D position information
- The third dimension is obtained by combining timing information (t_0) with drift velocity (v_d) → hence, a "**Time projection chamber**"



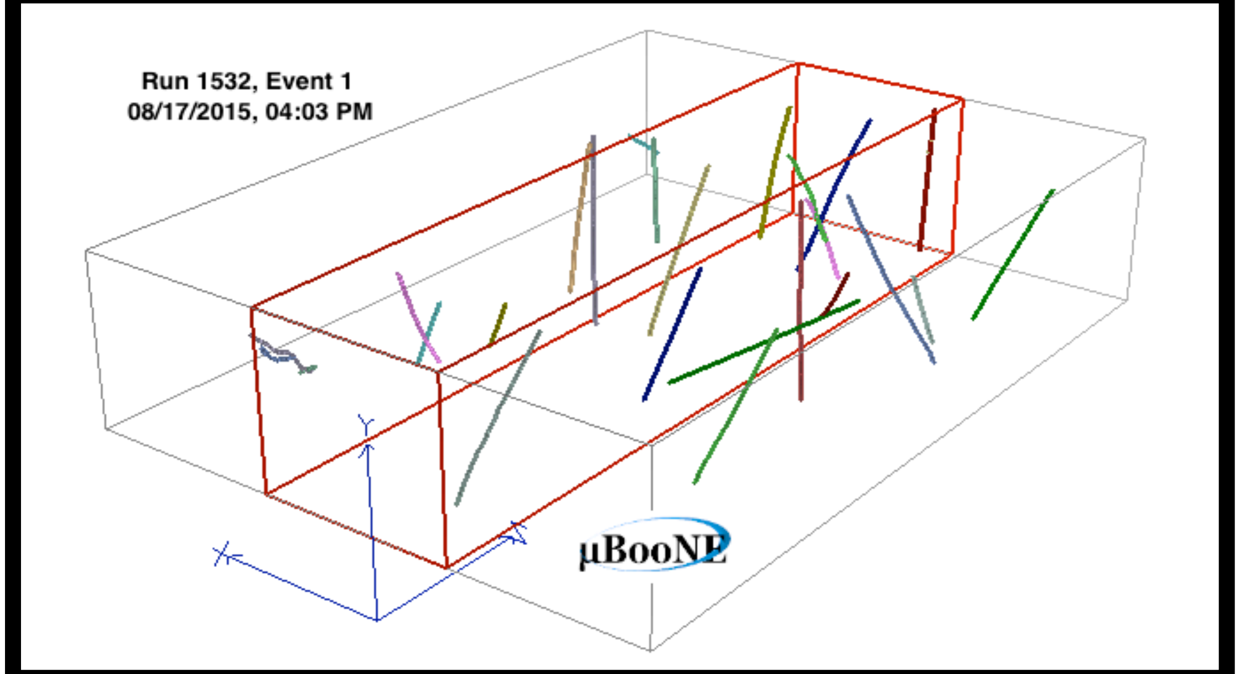


Cosmic rays in MicroBooNE

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

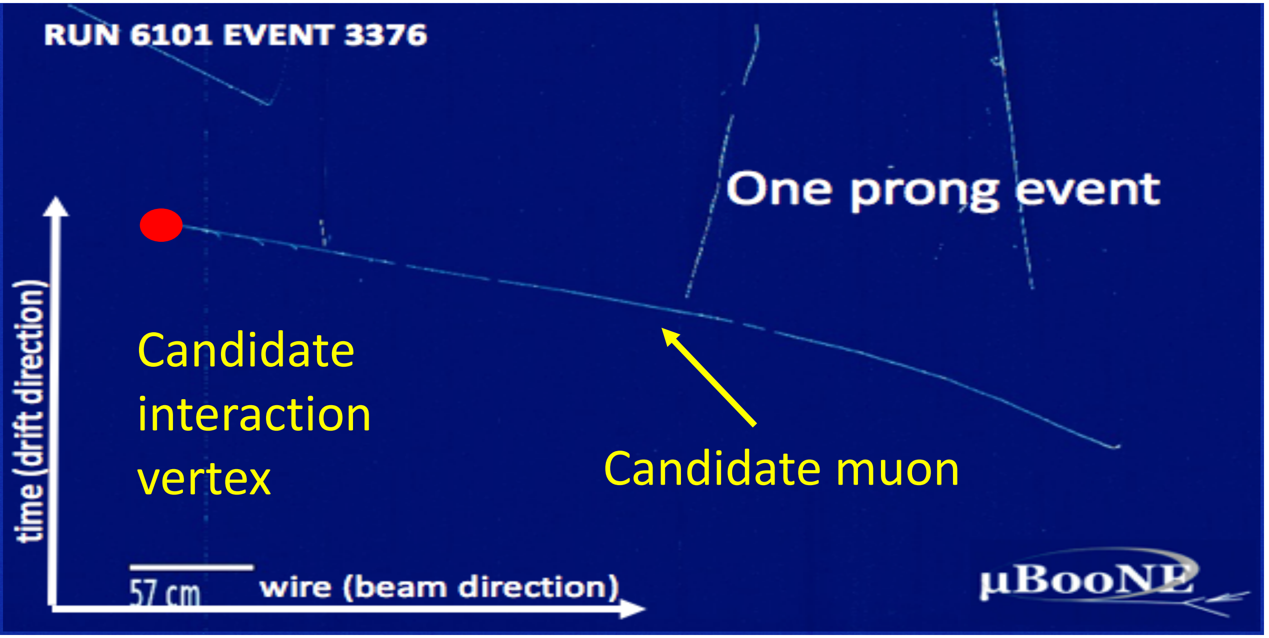


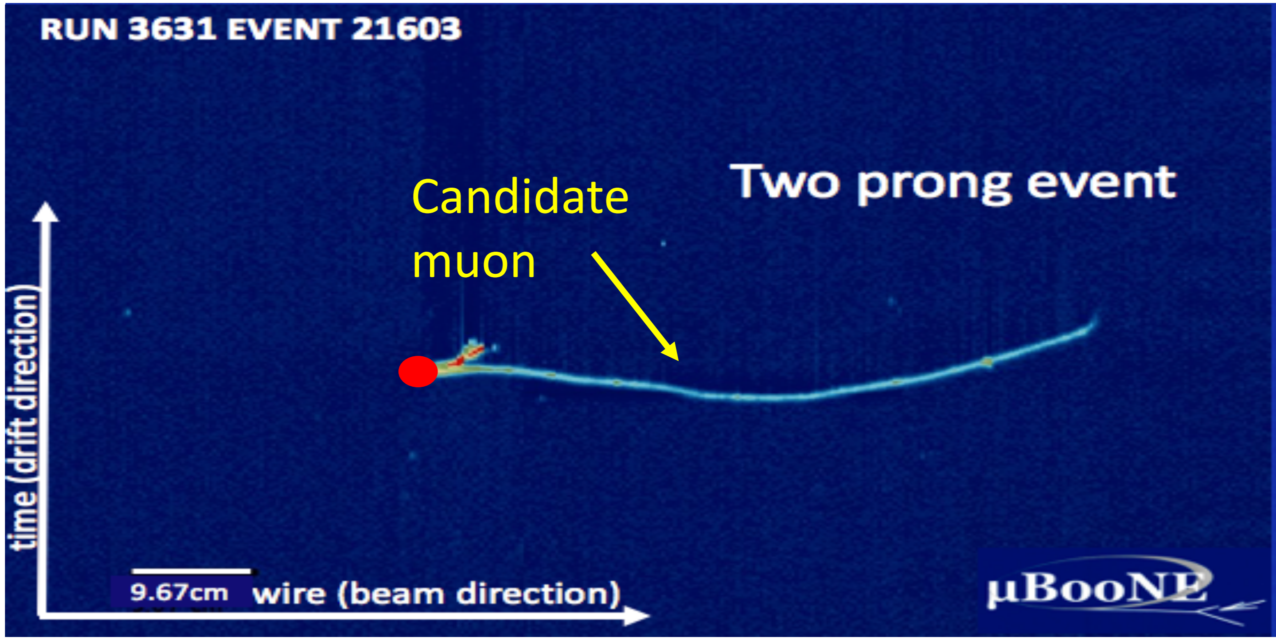
Cosmic removal first pass: Require scintillation light at the beam arrival time (1.6μs)

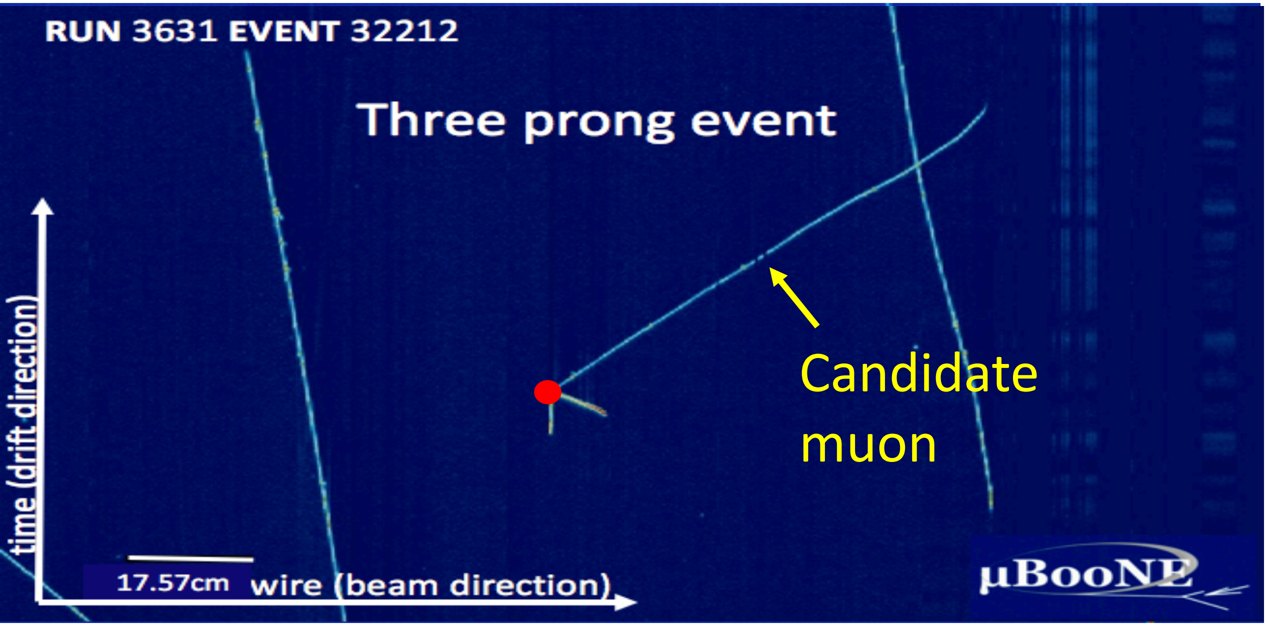


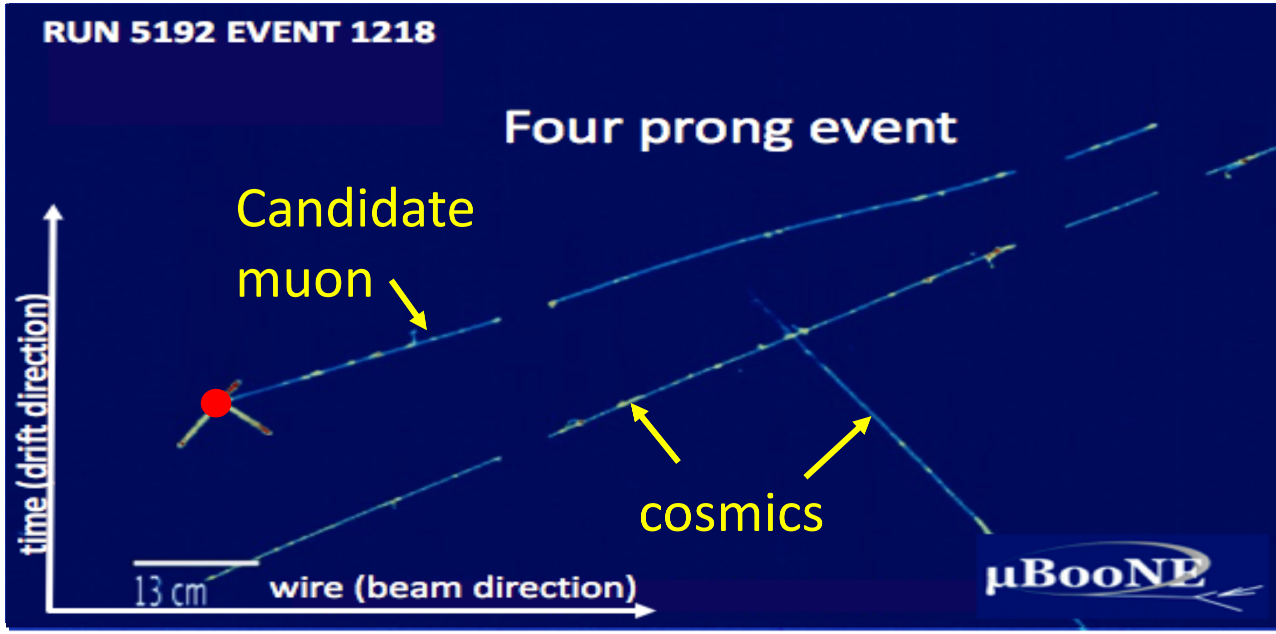
Challenge remains where cosmics and neutrinos are in same event

Candidate Neutrino Event Displays

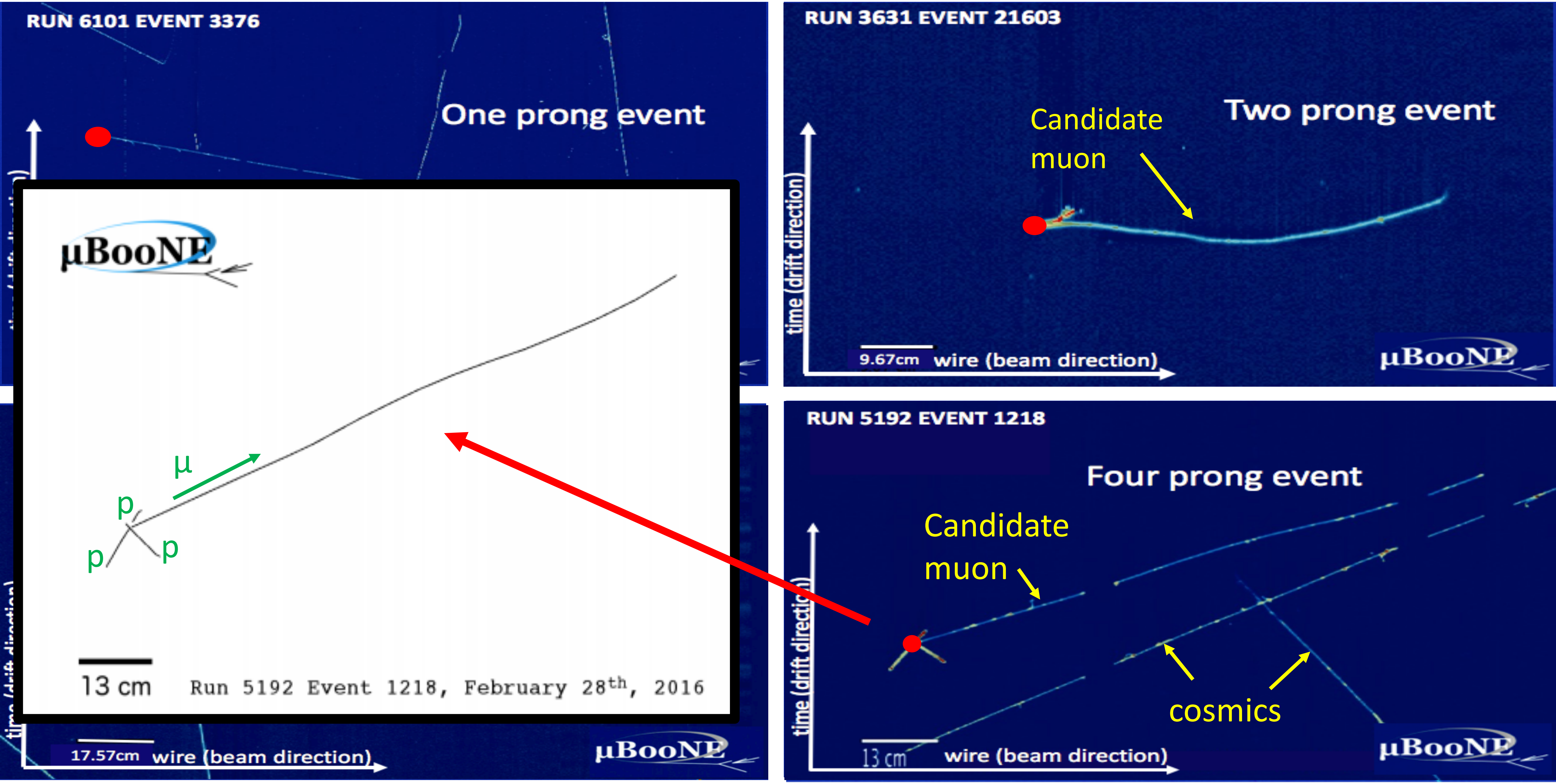








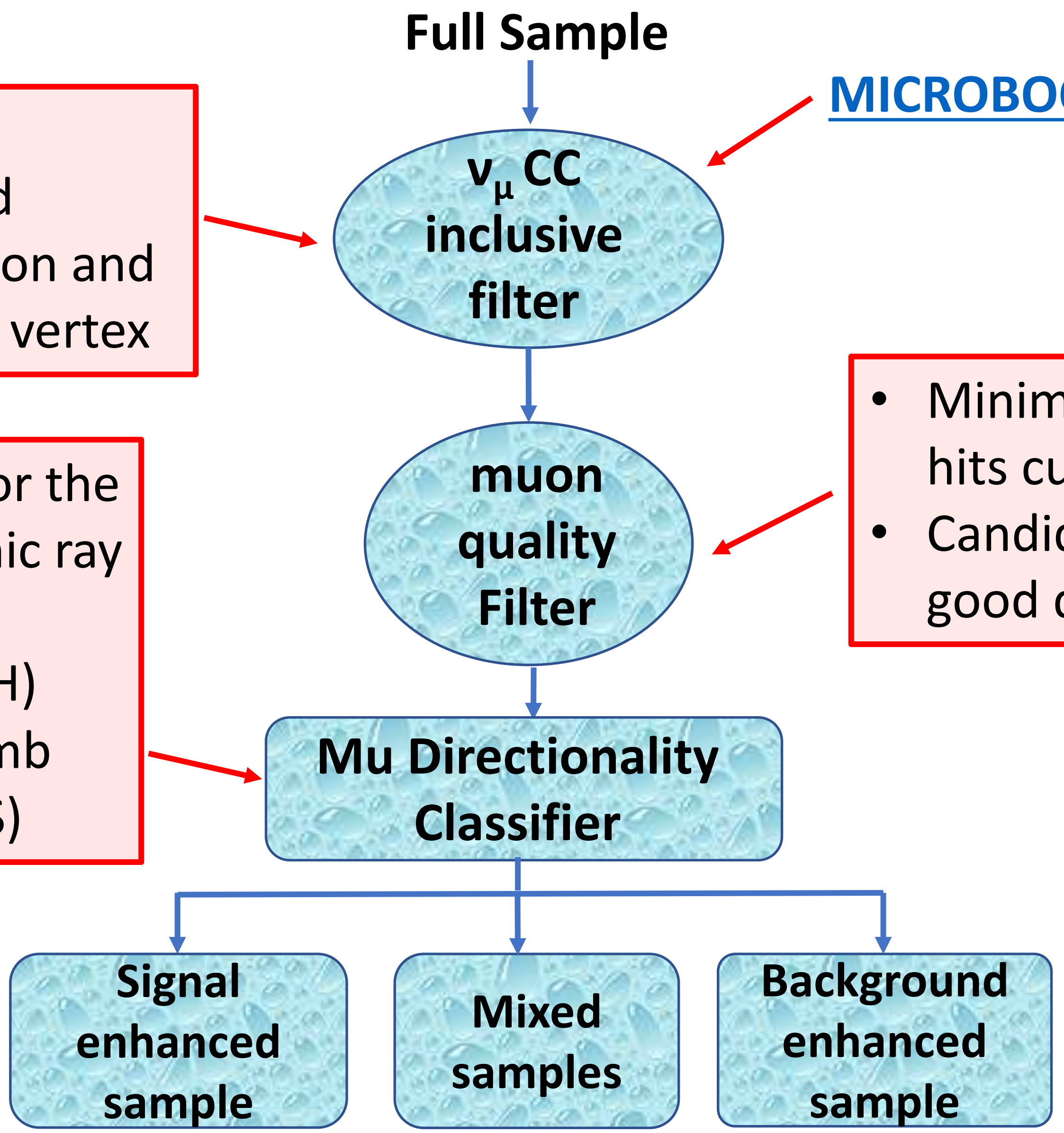
Candidate Neutrino Event Displays



Analysis Chain

MICROBOONE-NOTE-1010-PUB

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



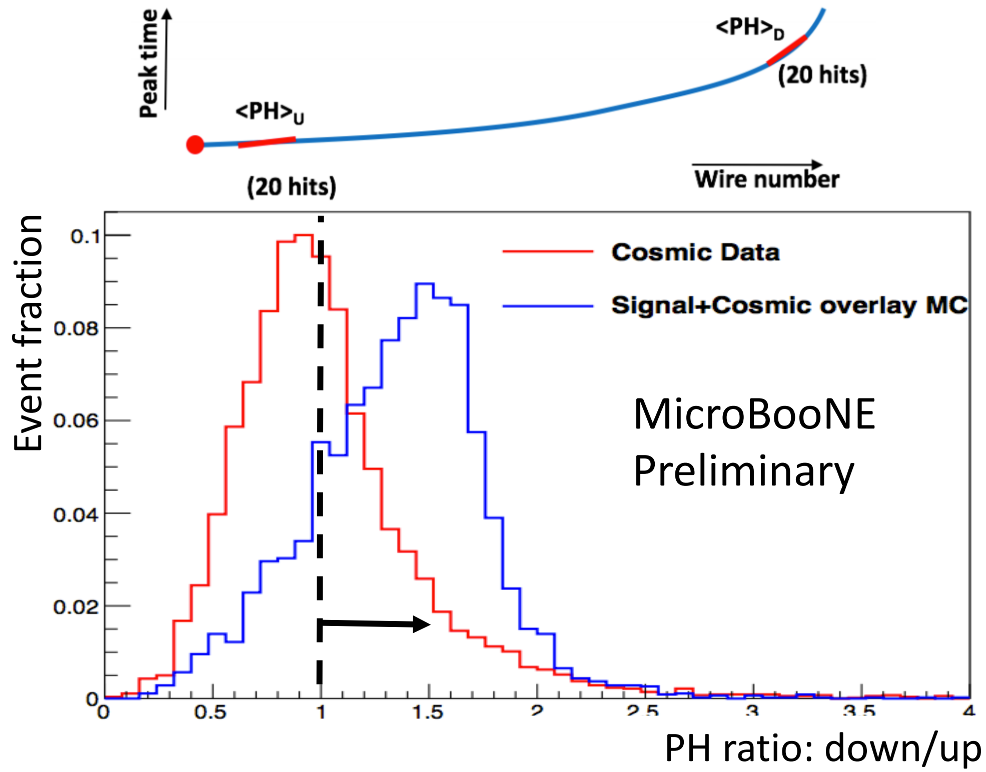
- Minimum collection plane hits cuts for candidate muon
- Candidate muon start/end good detector regions.

- Performs tests for the purpose of cosmic ray removal

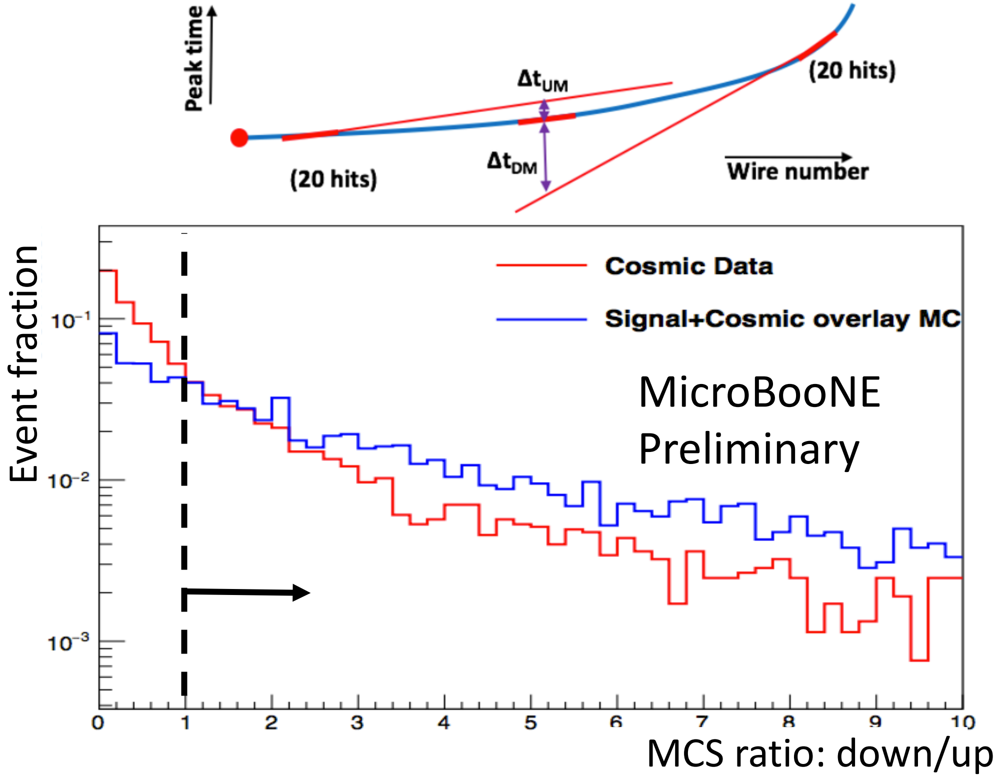
1. Pulse height (PH)
2. Multiple coulomb scattering (MCS)

Event Classification

Pulse Height Test



Multiple Coulomb Scattering

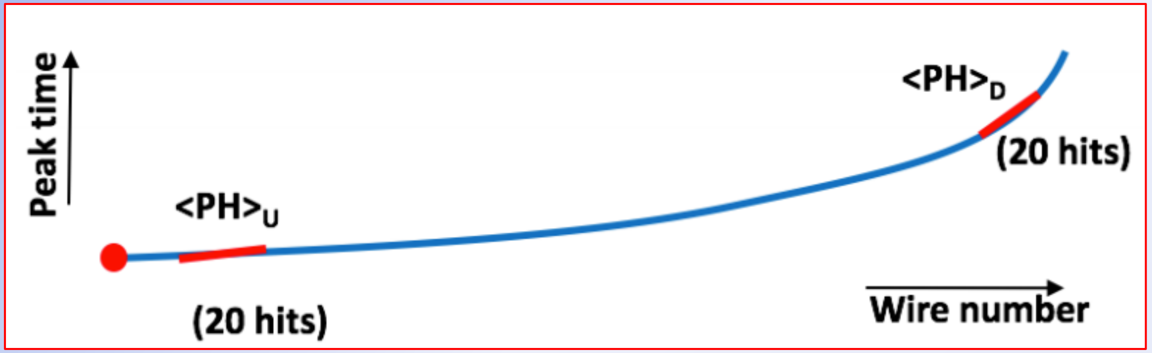


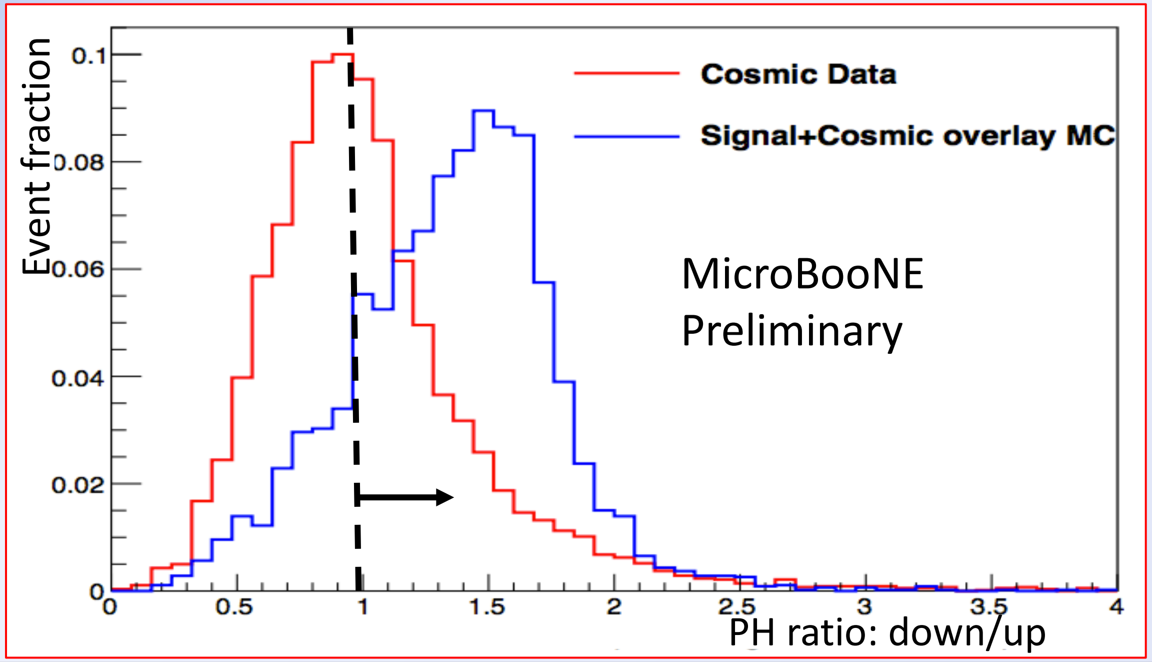
Sub samples	On-beam Data		Off-beam Data		BNB+Cosmic Default MC	
PH, MCS	events	acceptance rates	events	acceptance rates	events	acceptance rates
pass, pass	847	(44%)	1263	(24%)	2629	(62%)
pass, fail	367	(19%)	1087	(21%)	737	(18%)
fail, pass	321	(17%)	1141	(22%)	440	(10%)
fail, fail	387	(20%)	1776	(34%)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

Event Classification

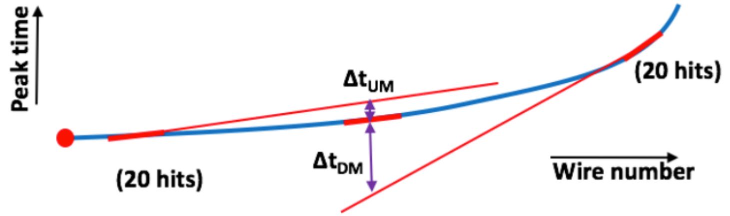
Pulse Height Test

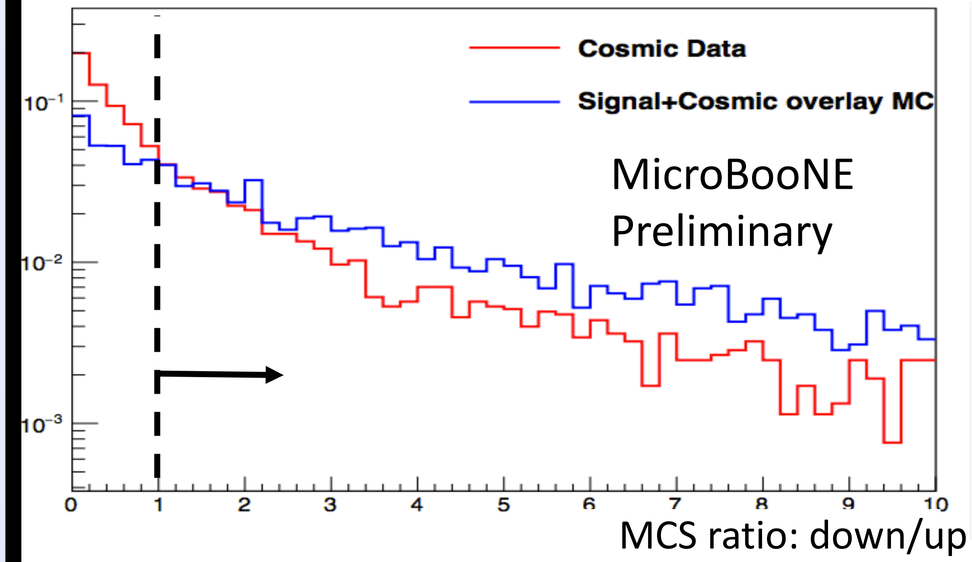
Rate of energy loss increases along the track from upstream to downstream end





Multiple Coulomb Scattering





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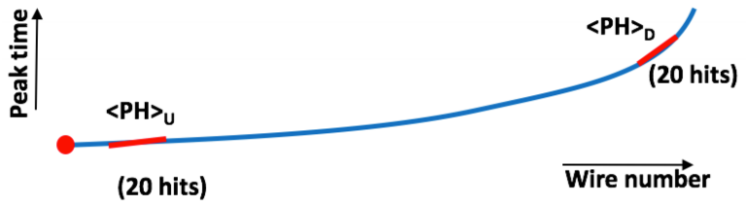
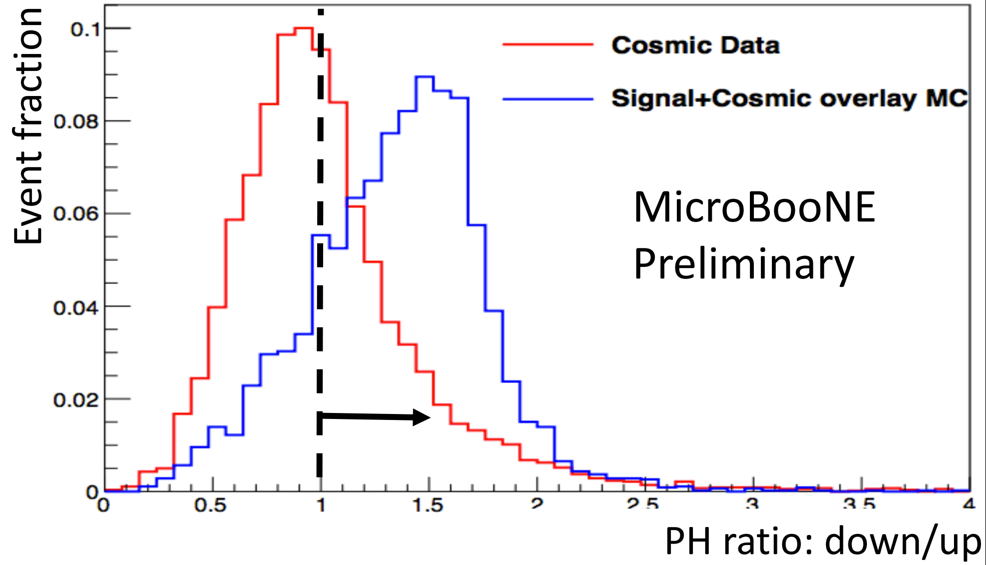
Event Classification

Pulse Height Test





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PH, MCS	events	acceptance rates	e
pass, pass	847	(44%)	
pass, fail	367	(19%)	
fail, pass	321	(17%)	
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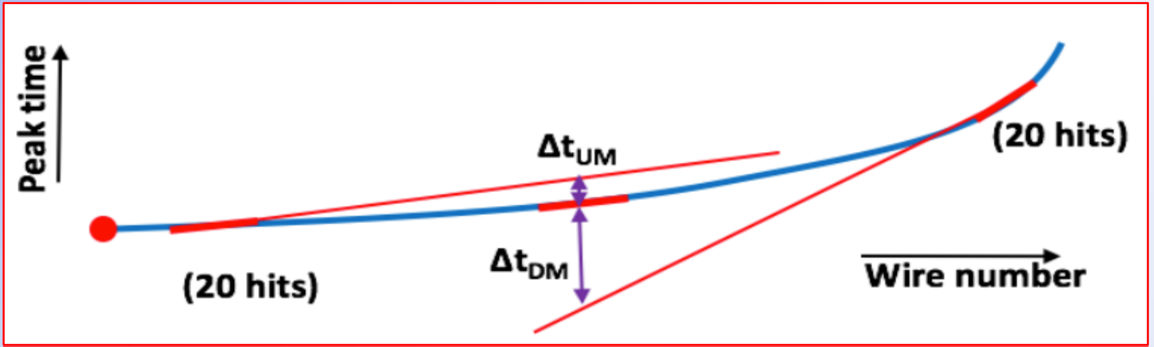
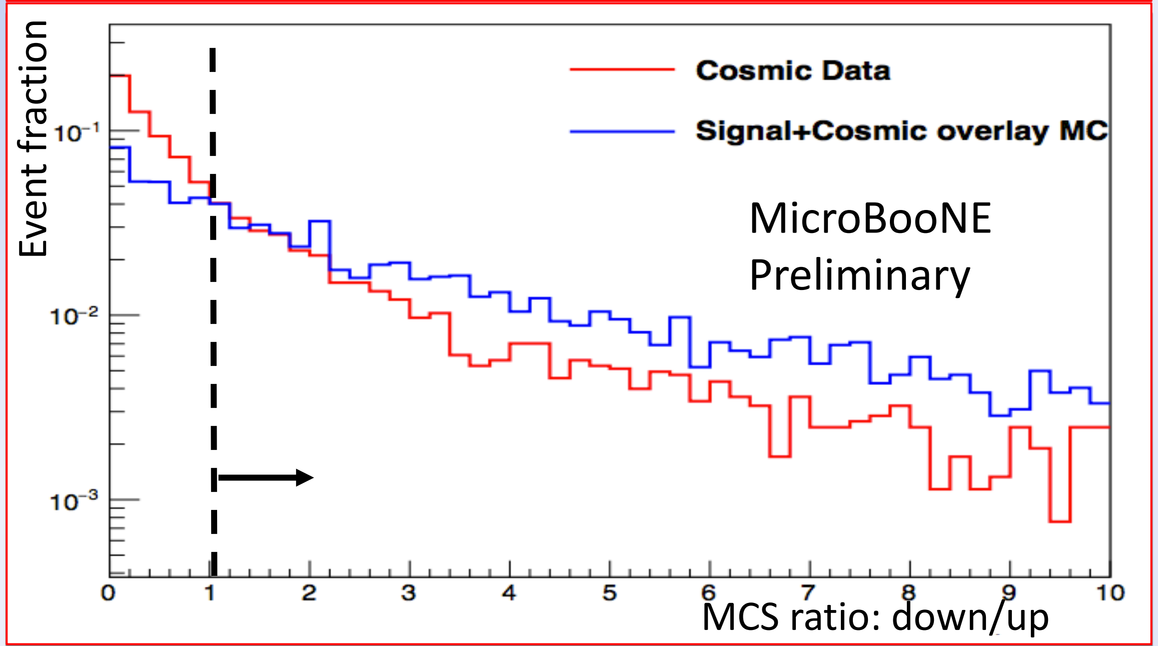
Multiple Coulomb Scattering

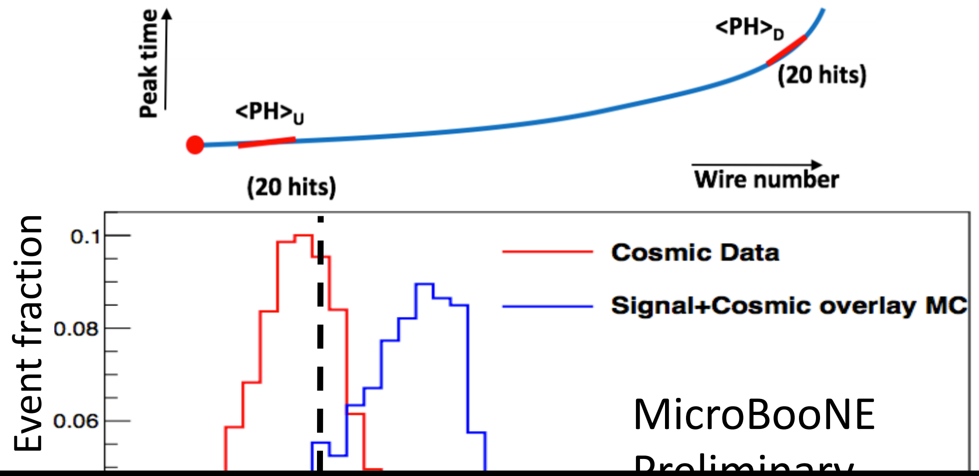
Scattering is more pronounced along the downstream end of the track as the momentum decreases.



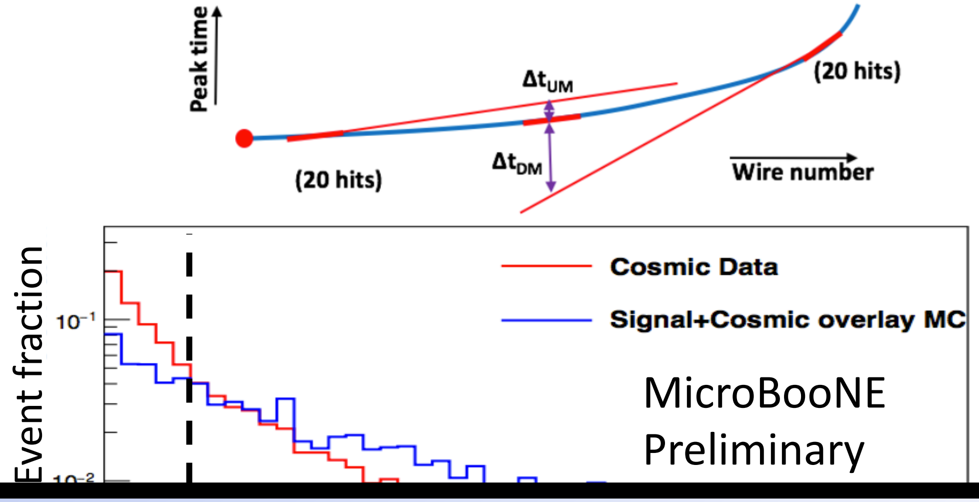


Event Classification

Pulse Height Test



Multiple Coulomb Scattering



- **Muons from neutrinos CC interactions are usually forward-going.**
- **Cosmic rays travel forward and backward with roughly equal prob.**

Sub samples PH, MCS	On-beam Data events	On-beam Data acceptance rates	Off-beam Data events	Off-beam Data acceptance rates	BNB+Cosmic Default MC events	BNB+Cosmic Default MC 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%)
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Signal Extraction Model

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

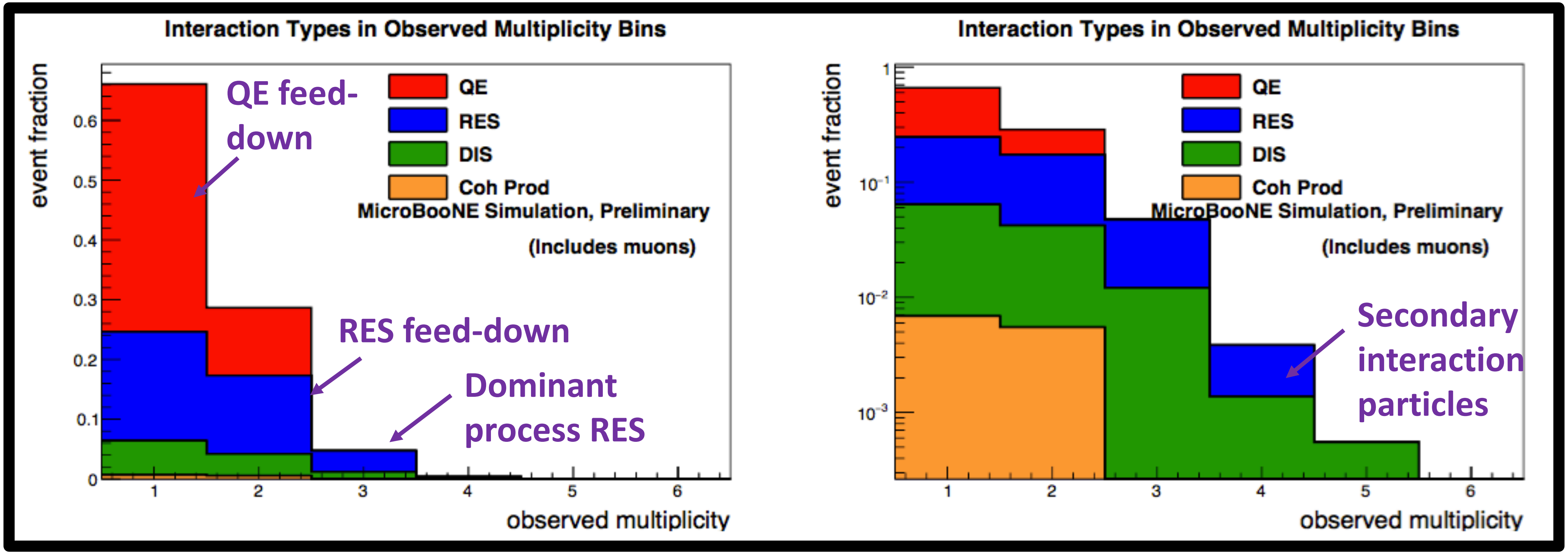
Relate number of events in each of 8 subsamples to:

- 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

No dependence on off-beam to on-beam normalization

Nearly model independent

Expectations for Observed Charged Particle Multiplicity Distributions



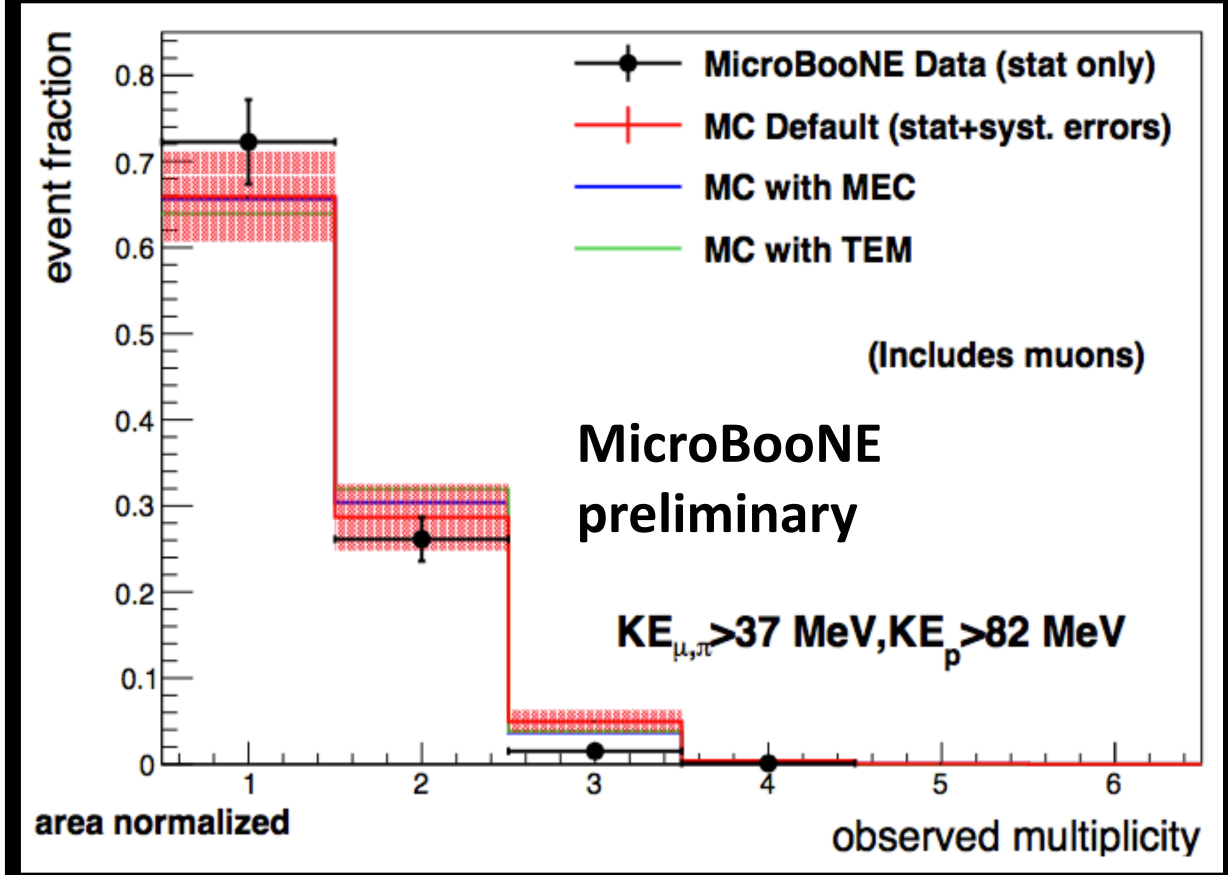
Common feed-down occurrence is due to efficiency*acceptance effects.

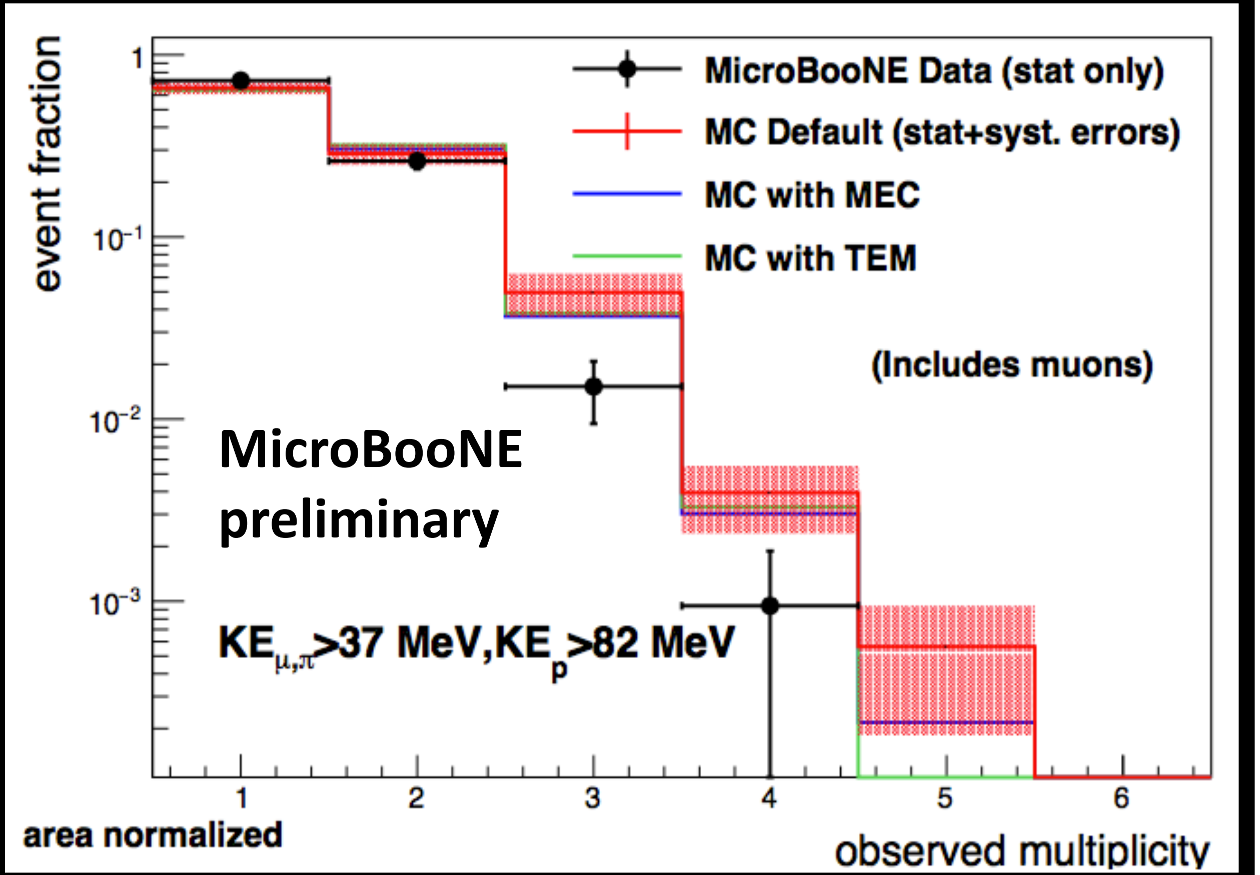
Uncertainty Estimates

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%

Multiplicity Result Plot





Public Note: MICROBOONE-NOTE-1024-PUB

Conclusion & Outlook

- **Conclusion:**
  - Measured charged particle multiplicity in ν_μ CC interactions in Ar for first time
  - Developed and validated data driven method to determine signal and cosmic ray background contributions
  - Compared charged particle multiplicity 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 other kinematic properties of particles emerging from interaction vertex with different models.
  - Compare data with wider range of models
  - Working towards a publication (stay tuned)

Thank you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Backup Slides

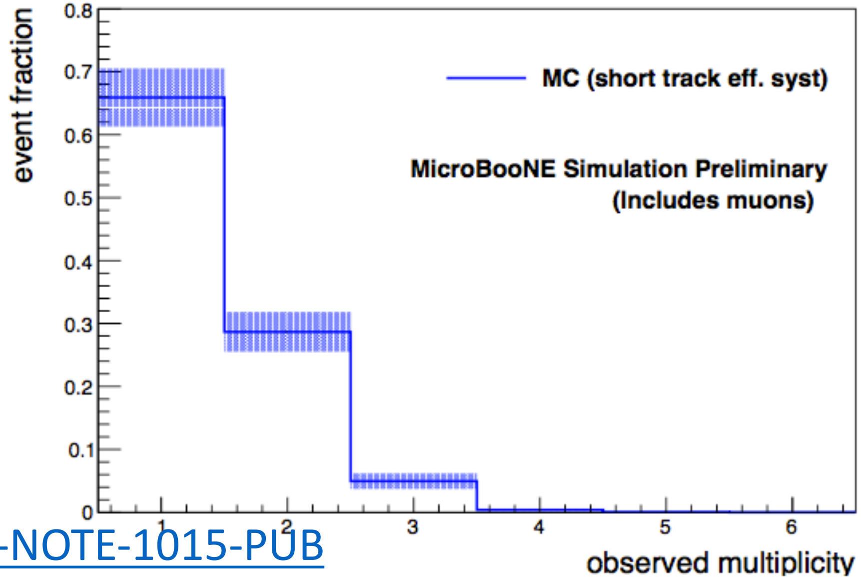
Short Track Efficiency Uncertainties

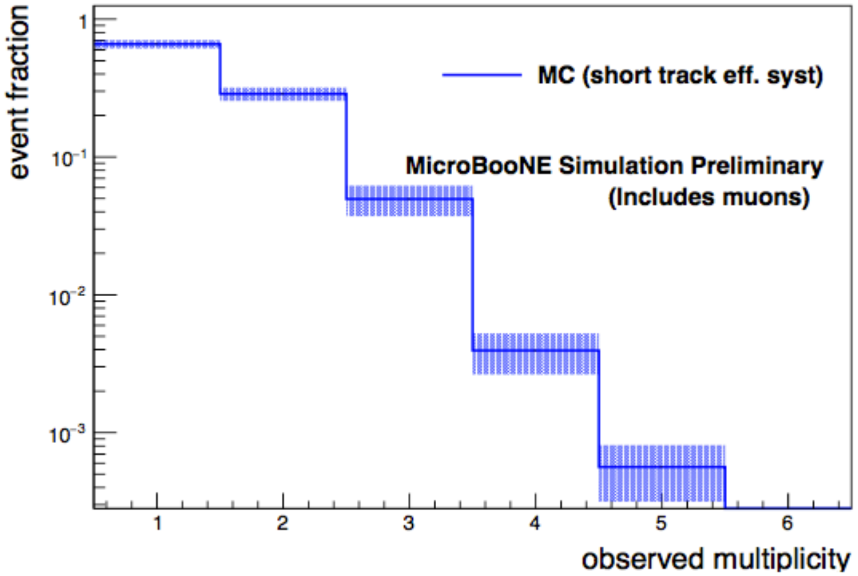
- From Pandora public note*, reco efficiency of proton/pion at 20 hit threshold is 0.45±0.05

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. $\propto \varepsilon^{\text{(no of short tracks)}}$





*MICROBOONE-NOTE-1015-PUB