Current Status of 2-ring ν_e CC1π^+ Selection Studies

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2-Ring ν_e CC1π^+ Meeting

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Overview

- Moved from cuts-based selection to BDT-based selection
- Experimented with different pre-BDT cuts, different BDT variables, and BDT architectures
  - Architecture parameter space explored using grid search
- Starting to work on dealing with systematic uncertainties
- Some of the following slides are from my most recent (and only) T2K Collaboration Meeting plenary talk
  - Not very in-depth, but they give a good summary

$\nu_e + p/n \rightarrow e^-$	1Re, 0 decay e	**(1Re)**
$\rightarrow e^- + \pi^+ \; below\, CT$ $\rightarrow \mu \rightarrow e$	1Re, 1 decay e	**(1Re1de)**
$\rightarrow e^- + \pi^+ \; above\, CT$	2Reπ, 0 decay e	**(2Reπ)**
$\rightarrow e^- + \pi^+ \; above\, CT$ $\rightarrow \mu \rightarrow e$	2Reπ, 1 decay e	**(2Reπ1de)**

CT = Cherenkov Threshold

Baseline Cuts: 2Reπ0de

2Reπ0de baseline cuts	
FCFV	wall > 50 cm
2 rings	fiTQun N rings = 2
eπ-like	fiTQun PID = eπ or πe
0 decay e	1 sub-event
E_{rec}	$E_{rec}(p_e,p_\pi)$ < 1.5 GeV

$$E_\nu = \frac{m_e^2 + m_{\pi^+}^2 - 2m_N(E_e + E_{\pi^+}) + 2p_e \cdot p_{\pi^+}}{2(E_e + E_{\pi^+} - |p_e|\cos\theta_{\nu e} - |p_{\pi^+}|\cos\theta_{\nu\pi^+} - m_N)}$$

$$\mathrm{FOM} = \frac{S}{\sqrt{S+B}}$$

- Signal defined as "true 1e1π$^{+/-}$" events: one e and one charged π (above Cherenkov threshold + 30 MeV/c momentum)
- Efficiency calculated relative to number of 1e1π$^{+/-}$ events in FCFV, with E_{rec}<1.5 GeV, and 1 sub-event

(neutrino beam mode, normal mass hierarchy, δ_{CP} =0, 10^{21} POT)

Cuts	Signal	Bkgd	Purity	Efficiency	FOM
FCFV	13.08	693.36	1.9%	large efficiency loss at 2-ring cut	
2 rings	5.24	169.12	3.0%		
eπ-like	3.87	14.57	21.0%		
0 decay e	1.27	6.27	16.9%		
E_{rec}<1.5 GeV	0.71	3.10	**18.5%**	**27.5%**	**0.362**

CC-like					NC-like				
1e	**1e other**	**1μ1π$^{+/-}$**	**1μ**	**1μ other**	**0l$^{+/-}$ 1π$^+$**	**0l$^{+/-}$ 1π$^-$**	**0l$^{+/-}$ 1π^0**	**0l$^{+/-}$ Nπ**	**0l$^{+/-}$ other**
0.31	0.02	0.08	0.16	0.11	0.26	0.36	1.17	0.25	0.39

Baseline Cuts: 2Reπ1de

2Reπ1de baseline cuts	
FCFV	wall > 50 cm
2 rings	fiTQun N rings = 2
eπ-like	fiTQun PID = eπ or πe
1 decay e	2 sub-events
E_{rec}	$E_{rec}(p_e, p_\pi) < 1.5$ GeV

$$E_\nu = \frac{m_e^2 + m_{\pi^+}^2 - 2 m_N (E_e + E_{\pi^+}) + 2 p_e \cdot p_{\pi^+}}{2(E_e + E_{\pi^+} - |p_e| \cos\theta_{\nu e} - |p_{\pi^+}| \cos\theta_{\nu\pi^+} - m_N)}$$

$$\mathrm{FOM} = \frac{S}{\sqrt{S+B}}$$

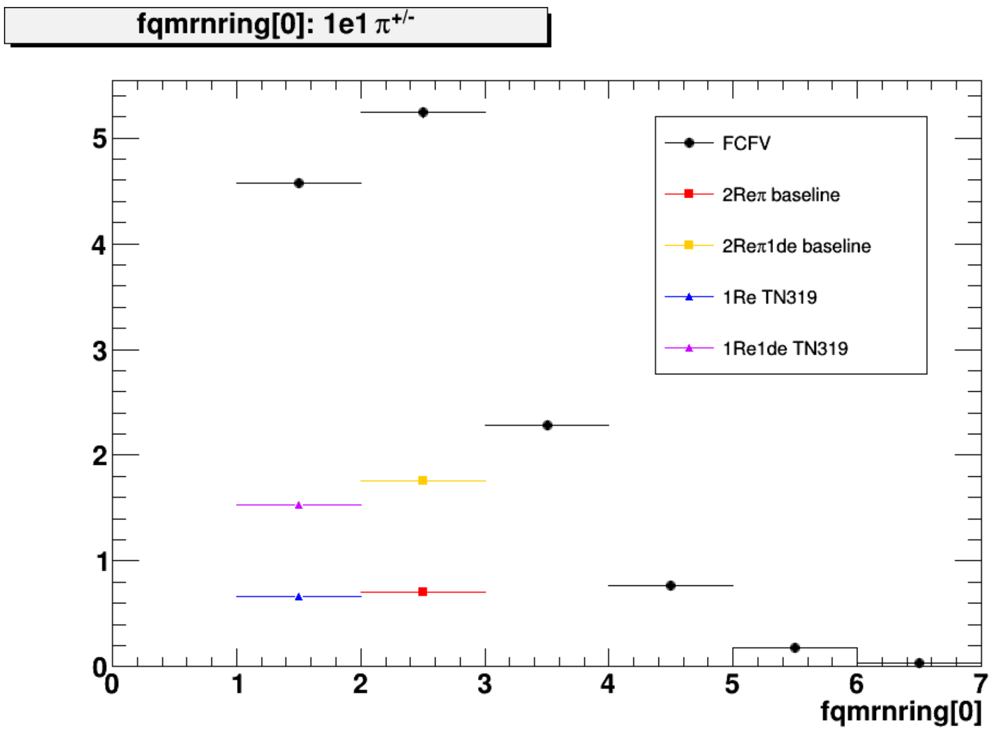
- Signal defined as "true 1e1π$^{+/-}$" events: one e and one charged π (above Cherenkov threshold + 30 MeV/c momentum)
- Efficiency calculated relative to number of 1e1π$^{+/-}$ events in FCFV, with E_{rec}<1.5 GeV, and 2 sub-events

(neutrino beam mode, normal mass hierarchy, δ_{CP} =0, 10^{21} POT)

Cuts	Signal	Bkgd	Purity	Efficiency	FOM
FCFV	13.08	693.36	1.9%	large efficiency loss at 2-ring cut	
2 rings	5.24	169.12	3.0%		
eπ-like	3.87	14.57	21.0%		
1 decay e	2.47	5.76	30.1%		
E_{rec}<1.5 GeV	1.75	2.15	**45.0%**	**34.9%**	**0.888**

CC-like					NC-like				
1e	**1e other**	**1μ1π$^{+/-}$**	**1μ**	**1μ other**	**0l$^{+/-}$ 1π$^+$**	**0l$^{+/-}$ 1π$^-$**	**0l$^{+/-}$ 1π^0**	**0l$^{+/-}$ Nπ**	**0l$^{+/-}$ other**
0.06	0.02	0.34	0.12	0.40	0.45	0.12	0.06	0.27	0.32

A Closer Look at N rings in fiTQun



- Plot of number of rings found by fiTQun for true 1e1$\pi^{+/-}$ events
  - FCFV events, as well as events passing specific selections, are shown
- Lots of 1e1$\pi^{+/-}$ events are being reconstructed as 1-ring, 3-ring, and 4-ring events

- The fiTQun variable that gives the number of rings is optimized generally to apply to all multi-ring events
  - But it is **not optimized for any one interaction type**

Sub-Samples

- In fiTQun, a fit index of 0 indicates preference for that fit
  - "2Reπ-like" events are those where the fit index is 0 for the 2-ring eπ (2Reπ) or 2-ring πe (2Rπe) fit
    - These two are distinct fits
- In general, a lower fit index suggests that fiTQun prefers that fit over fits with a higher index
- To improve efficiency, added additional "sub-samples" to the baseline
  - Sub-samples: where the fit index is 0 for some PID combination other than 1 e and 1 π
    - ex. 2Ree sub-sample contains events where the fit index of the 2-ring ee fit is 0
  - Of particular interest: 1Re, 2Ree, 2Rμe, and 3Reππ sub-samples

Improved Baseline

baseline: 2Reπ + 2Rπe only

	signal	other	purity	efficiency	FOM	net purity	net eff.
0de	0.71	3.10	18.5%	27.5%	0.362	31.9%	32.4%
1de	1.75	2.15	45.0%	34.9%	0.888		

2-ring cut + eπ-like cut —replaced with→ new eπ-like cut with more sub-samples + cuts

improved baseline: 1Re + 2Reπ + 2Rπe + 2Ree + 2Rμe + 3Reππ

	signal	other	purity	efficiency	FOM	net purity	net eff.
0de	0.70	2.32	23.3%	27.4%	0.405	32.6%	44.9%
1de	2.71	4.73	36.4%	53.8%	0.992		

net purity: 31.9% → 32.6%
net efficiency: 32.4% → 44.9%

New "sub-samples":
red = 1de only
blue = both 0de and 1de

- Replaced 2-ring and eπ-like cuts with expanded eπ-like cut
  - Sub-samples added, with additional cuts applied separately to each sub-sample
    - See backup slides for details on these cuts

Using BDTs

- Two separate BDTs: 0 decay e, 1 decay e
- Tested different pre-BDT cuts
  - Cuts applied to all events before feeding into BDT for training/testing
  - **v1** and **v0** define different pre-BDT cuts
    - Other pre-BDT cuts were tested – those systematically perform worse, so focus is on these two
- Tested different BDT variables
  - **Trial 8** and **Trial 9** variable sets perform the best so far
    - Other variable sets were tested, but those also performed worse, so focus is on these two

Pre-BDT cuts	
v1	**v0**
- FCFV - not 1Re/1Re1de - possible 2Repi • 0 de: 2Reπ, 2Rπe, and 3Reππ sub-samples • 1 de: 1Re, 2Ree, 2Reπ, 2Rπe, 2Rμe, and 3Reππ sub-samples - 1/2 sub-events - $E_{rec}(1e,1\pi) < 1.5$ GeV	- FCFV - not 1Re/1Re1de - 1/2 sub-events - $E_{rec}(1e,1\pi) < 1.5$ GeV

	BDT variables								
	1R v 1R nll	1R v 2R nll	2R v 2R nll	2R v 3R nll	3R v 3R nll	3R v 4R nll	1R+2R kinematics	E_{rec}, towall e, towall π, p_{low}, $m_{\pi 0}$, (*d2se*)	1R+2R+3R fit indices
Trial 8	■	■	■	■	■		■	■	■
Trial 9	■	■	■	■	■	■	■	■	■

BDT Grid Search Variables

- Four BDT architecture variables were explored using a grid search (320 points)
  - NTrees (100, 850, 1500, 10000)
    - Number of trees in the forest
  - MaxDepth (3, 4, 5, 6, 7)
    - Maximum allowed depth of each decision tree
  - MinNodeSize (5, 1, 0.5, 0.05)
    - Minimum percentage of training events required in a leaf node
  - NCuts (10, 20, 50, 100)
    - Number of grid points in variable range used in finding optimal cut in node splitting
- **v1** grid search (**trial 8** variables) is complete
- **v0** grid search (**trial 9** variables) is currently running

v1 (trial 8) BDT Grid Search Results

- ~~Unfortunately I don’t have a good visualization of the grid search results~~
- Maximum FOM (for 0de and 1de):
  - NTrees = 10000
  - MaxDepth = 7
  - MinNodeSize = 0.05
  - NCuts = 50
- In general, larger NTrees, larger MaxDepth, smaller MinNodeSize, and larger NCuts seem to improve FOM

BDT event breakdown

v1, trial 8, NTrees=10000, MaxDepth=7, MinNodeSize=0.05, NCuts=50

(best performing BDT architecture for both 0de and 1de)

0de											
	$1e1\pi^{+/-}$	1e	1e other	$1\mu1\pi^{+/-}$	1μ	1μ other	$0l^{+/-}$ $1\pi^{+}$	$0l^{+/-}$ $1\pi^{-}$	$0l^{+/-}$ $1\pi^{0}$	$0l^{+/-}$ Nπ	$0l^{+/-}$ other
FCFV	5.08	46.83	6.66	11.13	47.24	24.92	7.53	10.63	83.37	16.81	17.60
BDT in	0.79	0.32	0.03	0.07	0.16	0.14	0.34	0.41	1.22	0.36	0.46
BDT out	0.60	0.03	0.01	0.01	0.00	0.03	0.05	0.05	0.07	0.10	0.03

1de											
	$1e1\pi^{+/-}$	1e	1e other	$1\mu1\pi^{+/-}$	1μ	1μ other	$0l^{+/-}$ $1\pi^{+}$	$0l^{+/-}$ $1\pi^{-}$	$0l^{+/-}$ $1\pi^{0}$	$0l^{+/-}$ Nπ	$0l^{+/-}$ other
FCFV	7.48	5.24	2.68	38.78	148.00	60.21	10.26	3.33	4.58	15.24	6.31
BDT in	3.08	0.89	0.09	1.94	3.60	2.37	1.79	0.51	1.79	1.61	2.23
BDT out	2.15	0.19	0.02	0.06	0.02	0.24	0.04	0.02	0.08	0.13	0.09

0de				
	sig	bkg	FOM	δFOM
FCFV	5.08	272.72		
BDT in	0.79	3.51		
BDT out	0.60	0.37	0.611	0.019

1de				
	sig	bkg	FOM	δFOM
FCFV	7.48	294.57		
BDT in	3.08	16.82		
BDT out	2.15	0.90	1.230	0.019

To Compare: "Improved Baseline" Selection

0de											
	$1e1\pi^{+/-}$	1e	1e other	$1\mu1\pi^{+/-}$	1μ	1μ other	$0l^{+/-}\ 1\pi^{+}$	$0l^{+/-}\ 1\pi^{-}$	$0l^{+/-}\ 1\pi^{0}$	$0l^{+/-}\ N\pi$	$0l^{+/-}$ other
FCFV	13.08	52.30	10.20	90.54	216.44	136.26	19.53	15.01	88.74	39.20	25.13
eπ-like	5.40	2.35	0.24	1.20	1.37	4.95	0.99	0.65	2.20	1.77	0.71
0 decay e	1.26	0.61	0.08	0.13	0.20	1.22	0.33	0.38	1.54	0.59	0.21
E_{rec}<1.5 GeV	0.70	0.24	0.02	0.05	0.09	0.11	0.18	0.20	1.07	0.23	0.13
1de											
	$1e1\pi^{+/-}$	1e	1e other	$1\mu1\pi^{+/-}$	1μ	1μ other	$0l^{+/-}\ 1\pi^{+}$	$0l^{+/-}\ 1\pi^{-}$	$0l^{+/-}\ 1\pi^{0}$	$0l^{+/-}\ N\pi$	$0l^{+/-}$ other
FCFV	13.08	52.30	10.20	90.54	216.44	136.26	19.53	15.01	88.74	39.20	25.13
eπ-like	5.40	2.35	0.24	1.20	1.37	4.95	0.99	0.65	2.20	1.77	0.71
1 decay e	4.14	1.74	0.16	1.05	1.17	3.71	0.66	0.27	0.66	1.17	0.50
E_{rec}<1.5 GeV	2.71	0.75	0.03	0.56	0.78	0.69	0.50	0.17	0.31	0.51	0.44

0de			
	sig	bkg	FOM
FCFV	13.08	693.36	
eπ-like	5.40	16.43	
1 decay e	1.26	5.28	
E_{rec}<1.5 GeV	0.70	2.32	0.405

1de			
	sig	bkg	FOM
FCFV	13.08	693.36	
eπ-like	5.40	16.43	
1 decay e	4.14	11.09	
E_{rec}<1.5 GeV	2.71	4.73	0.992

Approaching Systematics

- Starting point: look at signal kinematic distributions before/after BDT
  - Understand which kinematic regions the selection is sensitive to
  - Currently working on this
- Neutrino interaction uncertainties
  - Explore other event generators (NUWRO, GENIE)
    - Single and multi-pion variations
  - BDT for re-weighting MC to different generators? (Cris)
- Pion hadronic interactions (FSI and SI uncertainties)
  - TN325 (Elder) on tuning of the NEUT cascade model
  - Throws of possible FSI parameter set values using covariance matrix from TN325
- Detector systematics
  - Try to develop hybrid samples for different backgrounds