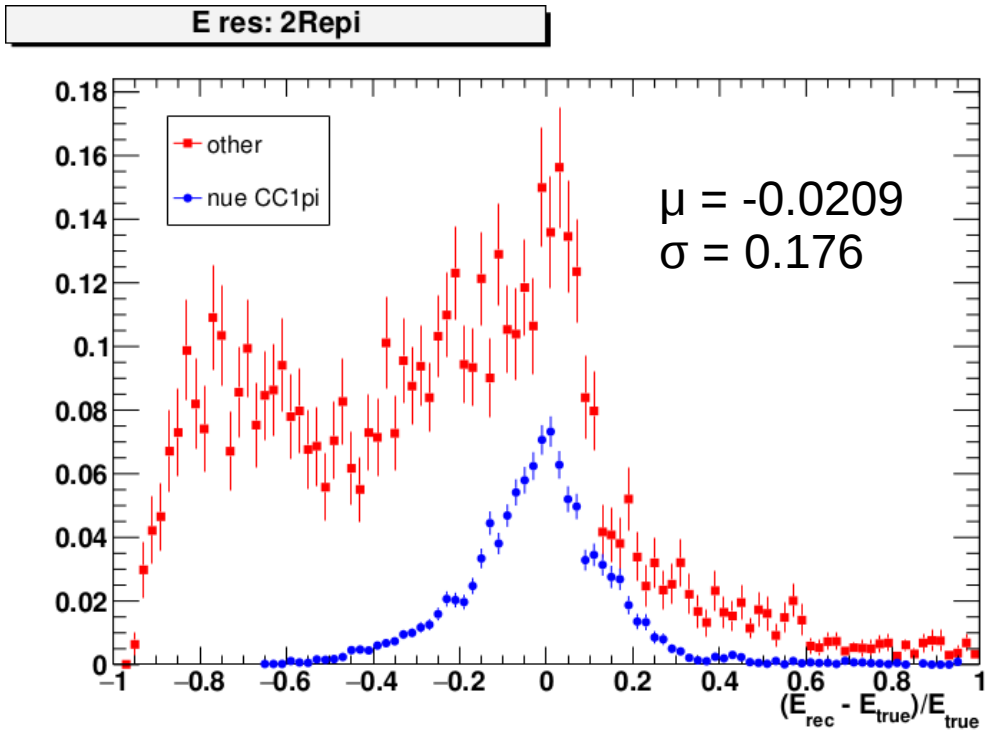
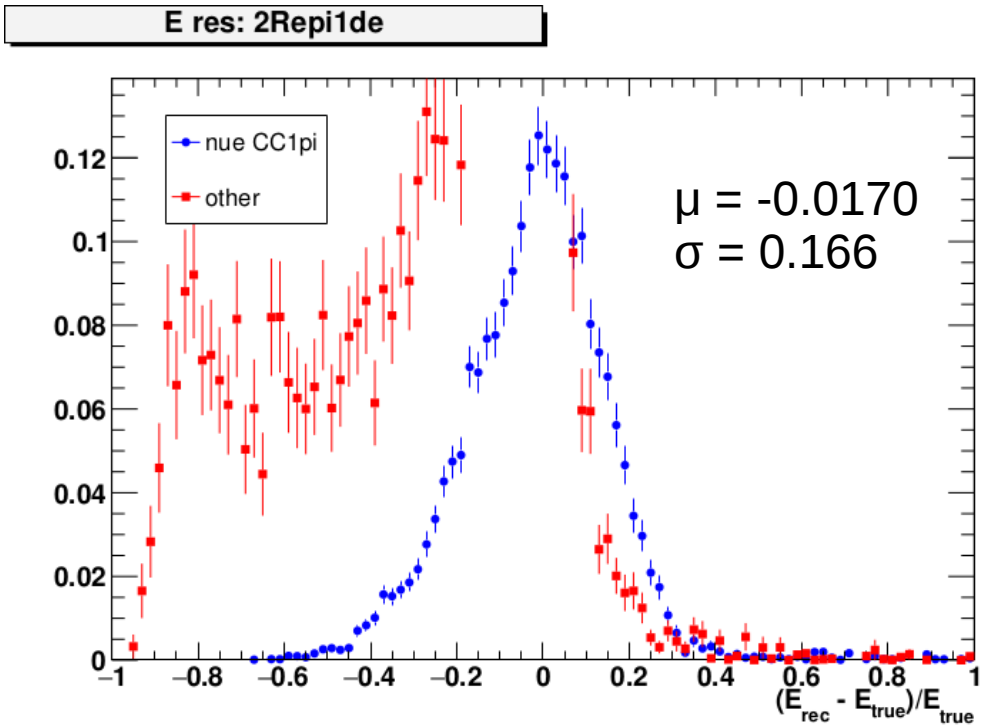
Progress Update

Trevor Towstego
UofT Neutrino/DM Meeting
November 23, 2017

Energy Resolution: Method 1



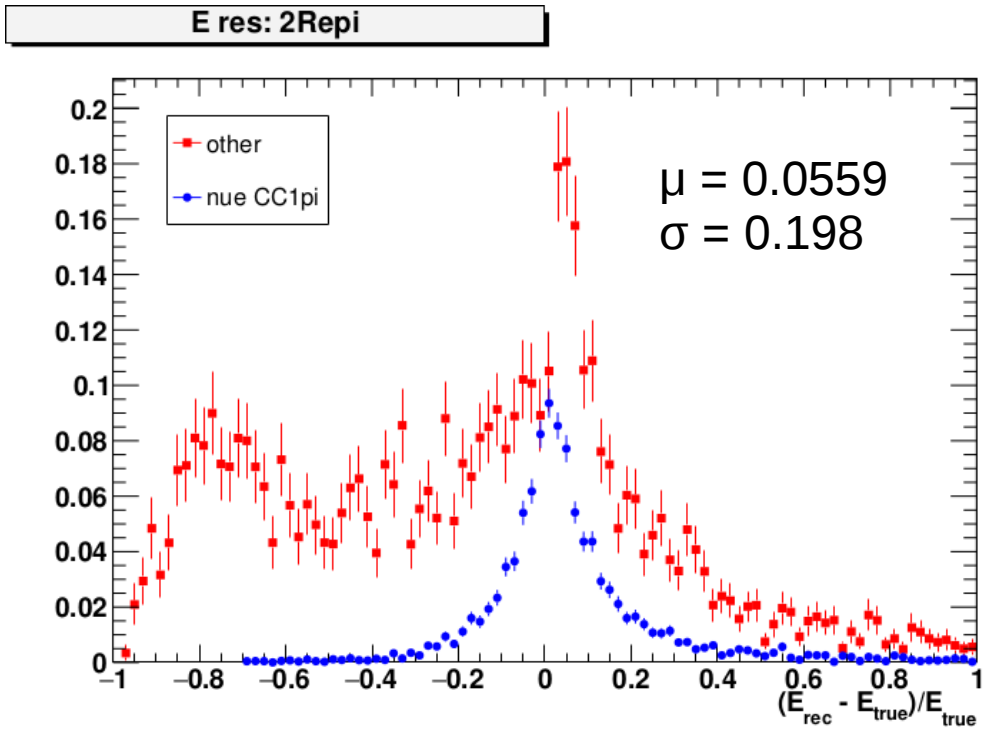


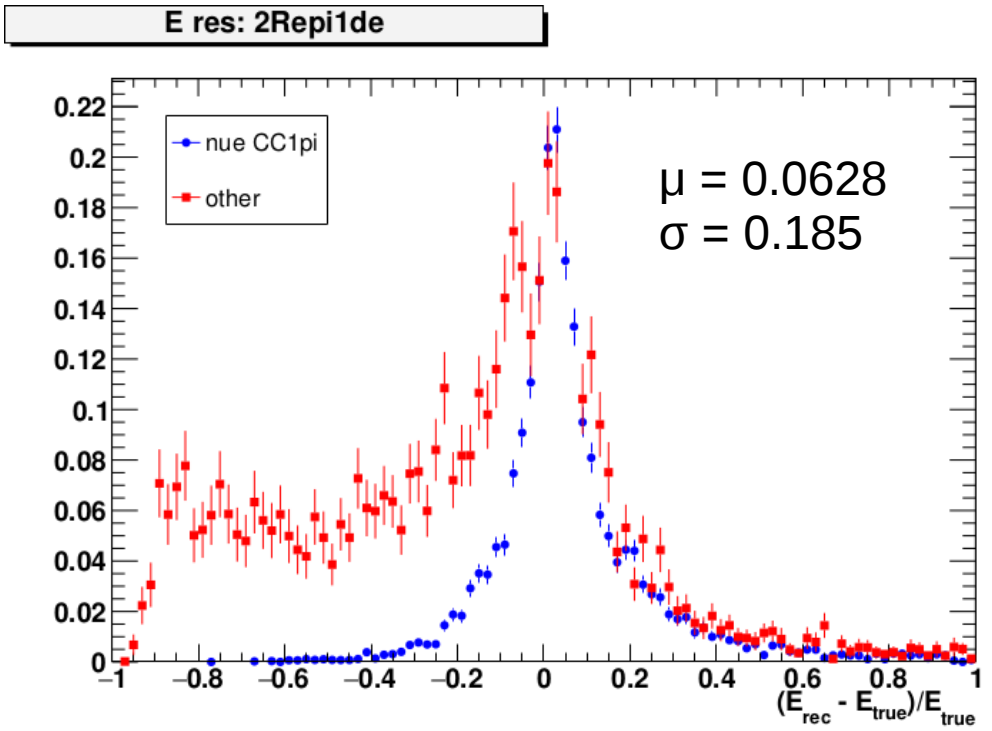

```
double Ee = sqrt(me*me + pe*pe);
double Epi = sqrt(mpi*mpi + ppi*ppi);
Enu = Ee + Epi + 140.;
```

Energy Resolution: Method 2 (fixed)

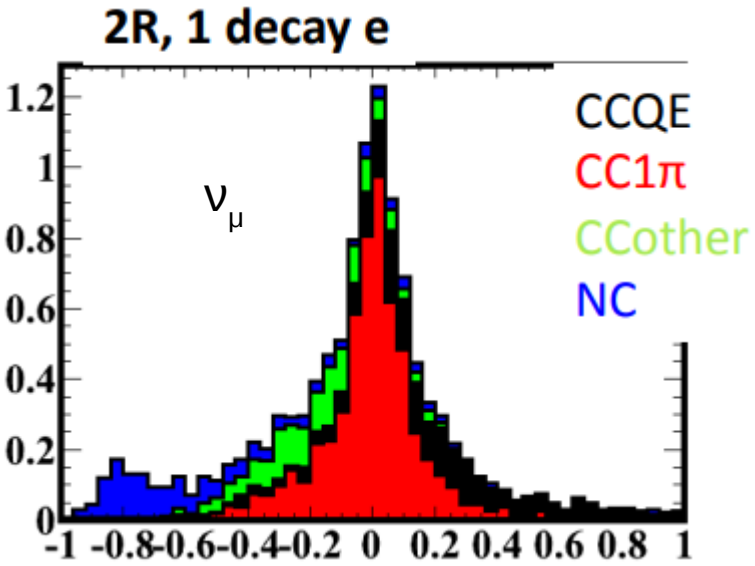
four-momentum!

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

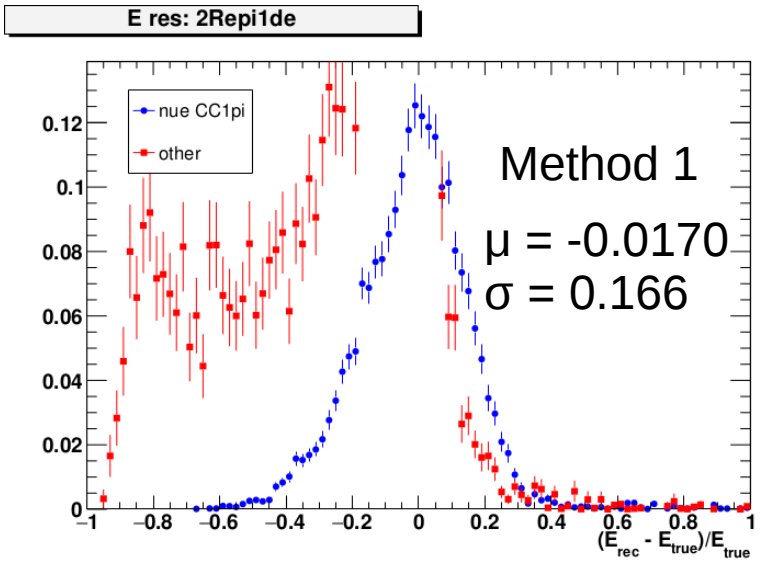


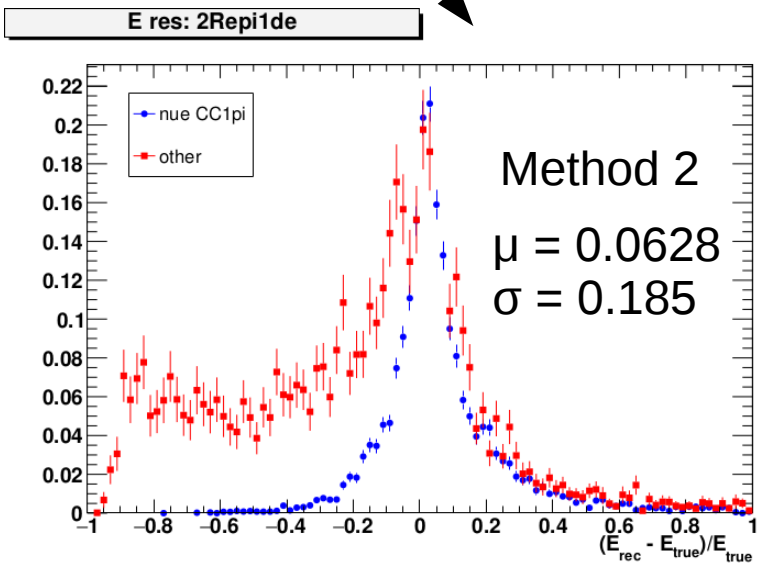


Comparison to ν_μ CC1π (Sophie)



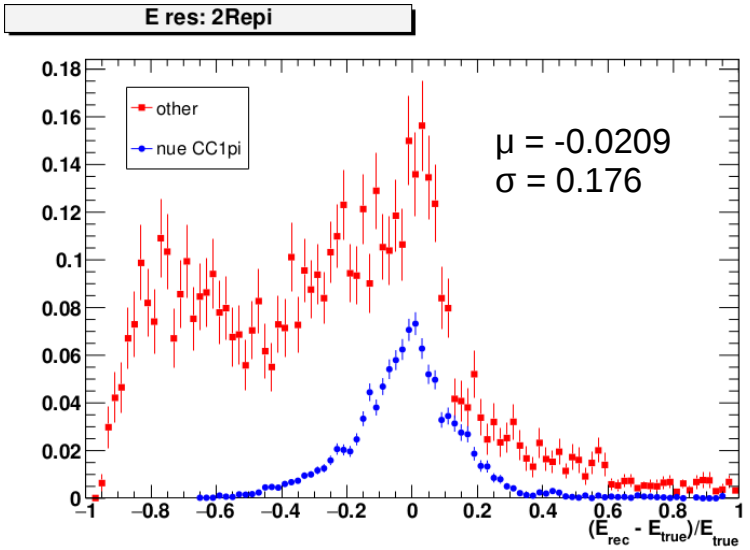
Same formula used

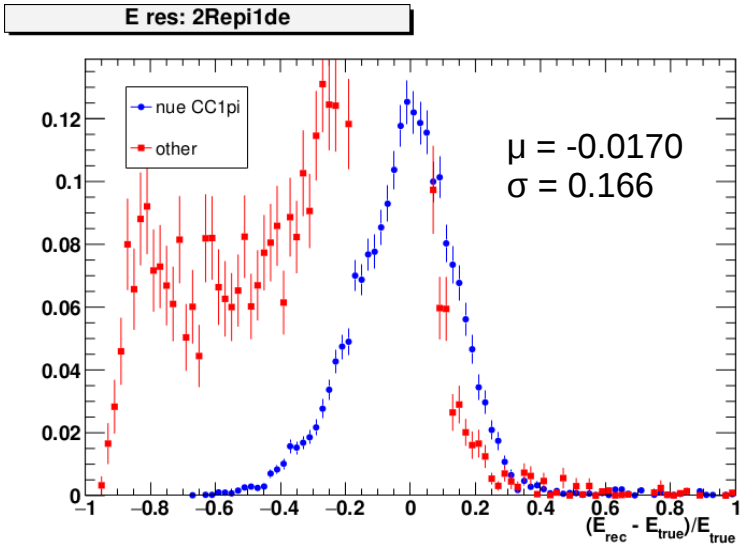




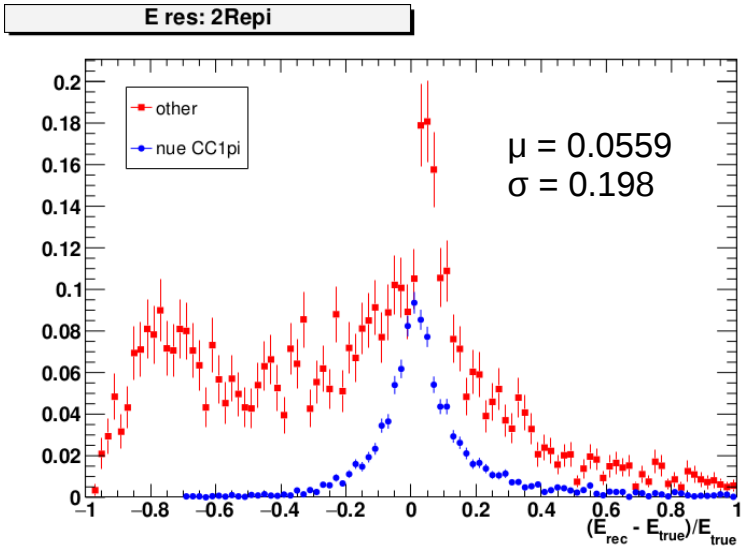
Method 1 vs. Method 2

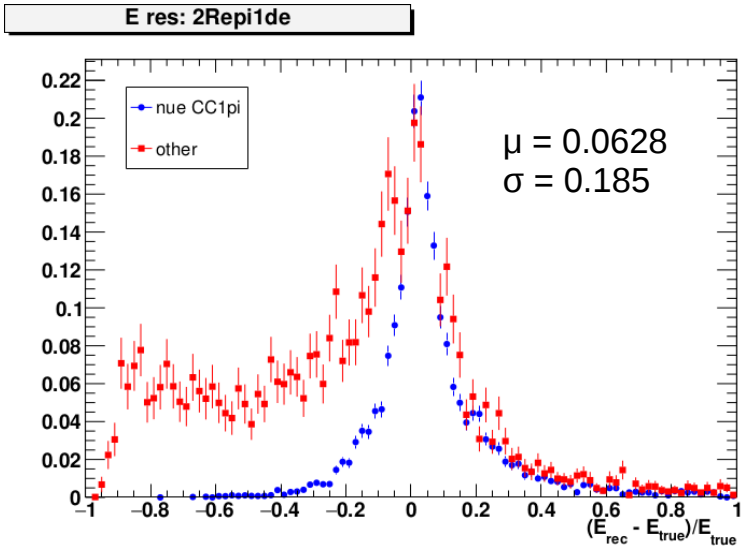
Method 1





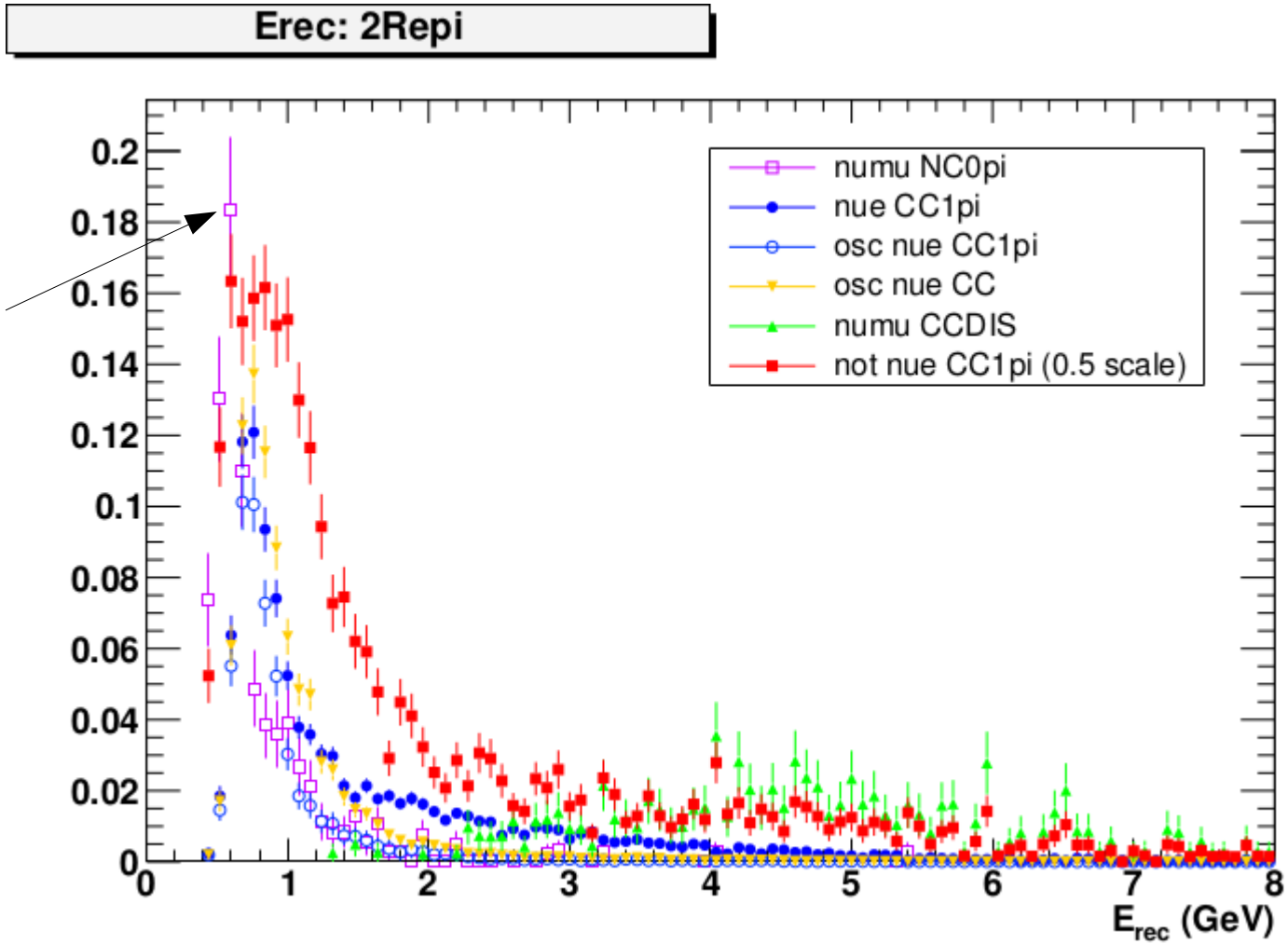
Method 2





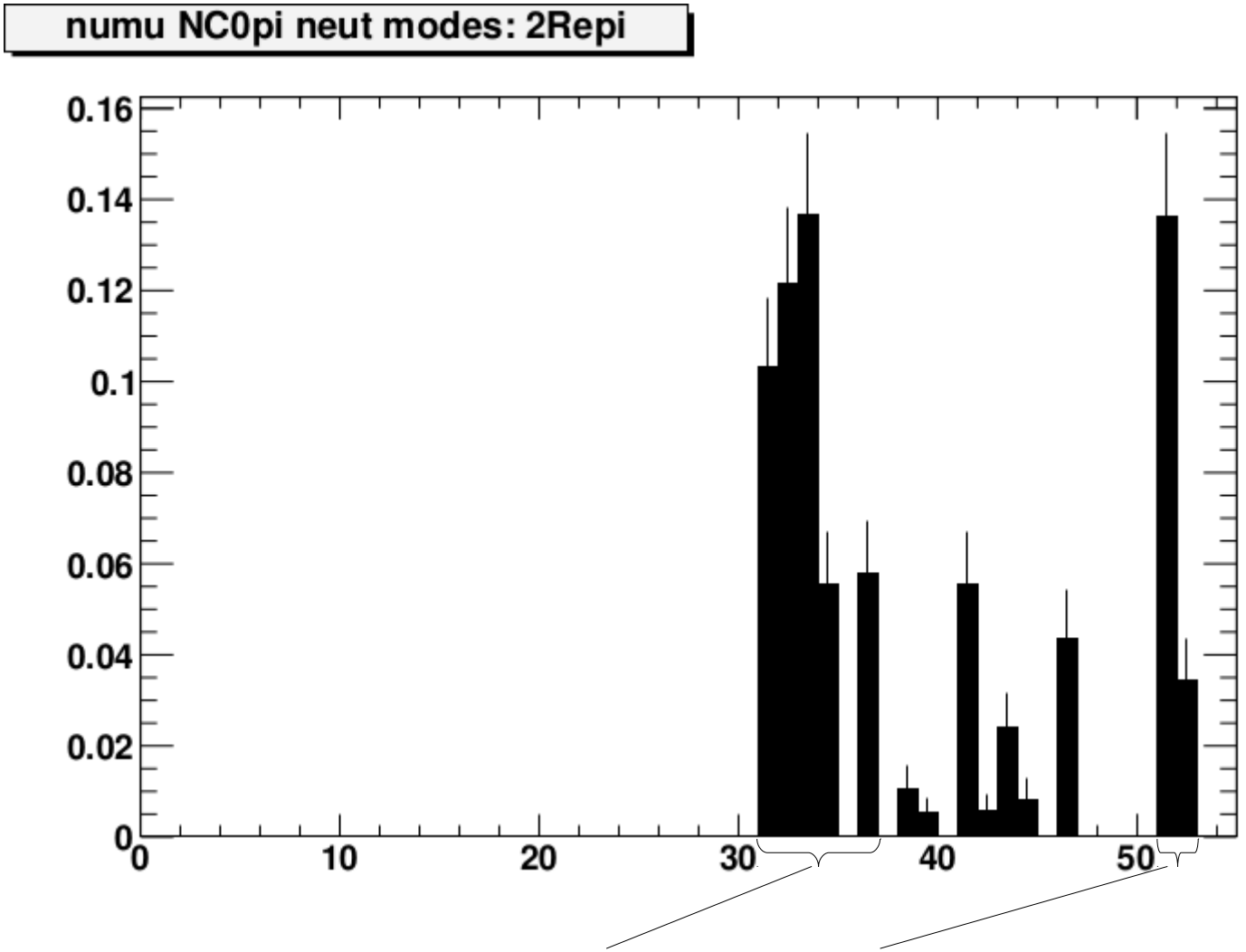
ν_μ NC0π background in 2Reπ sample

Peaks at low E (slightly below oscillation peak)



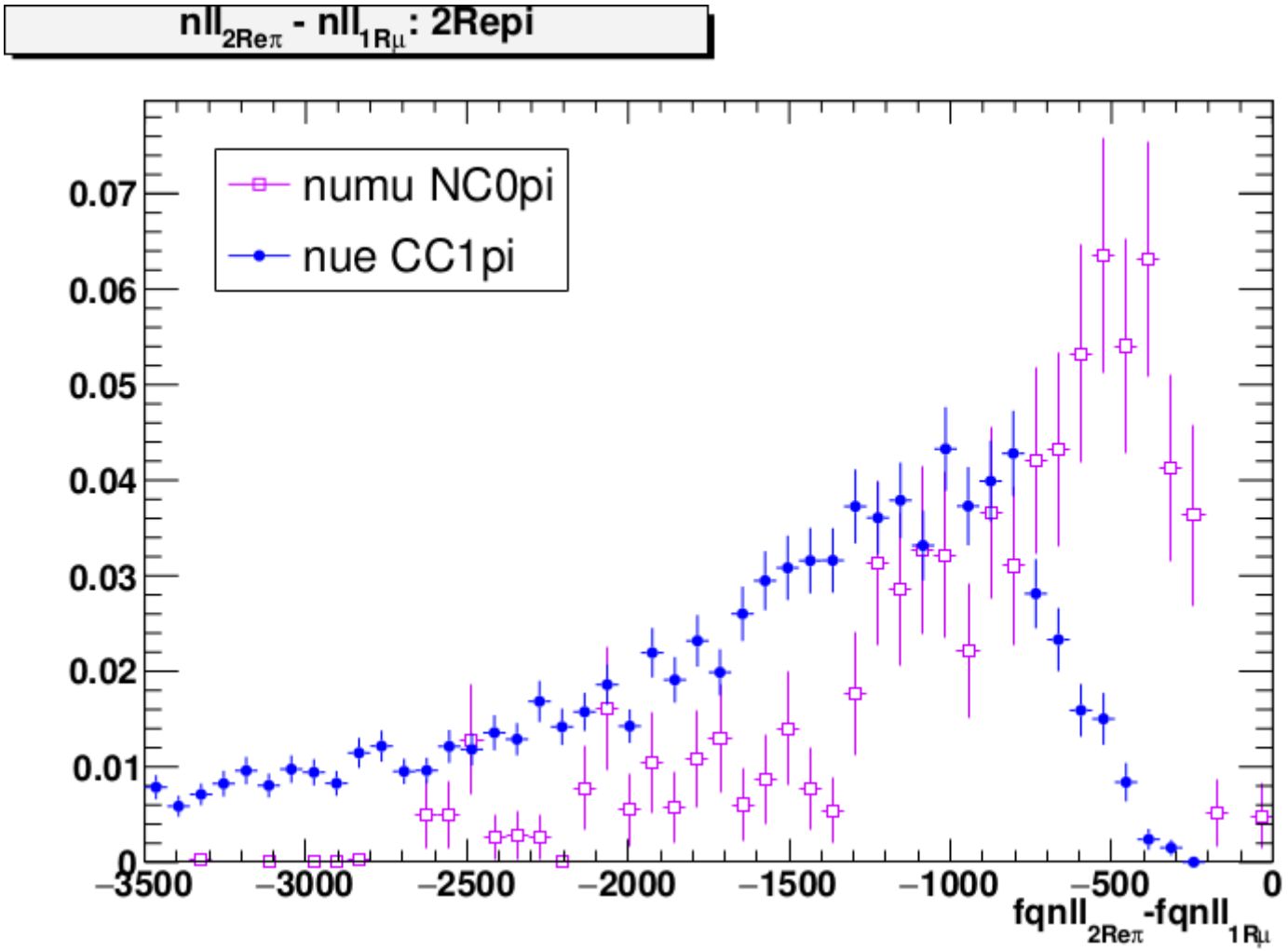
Note that this is 0π **above Cherenkov threshold**

ν_μ NC0π NEUT modes

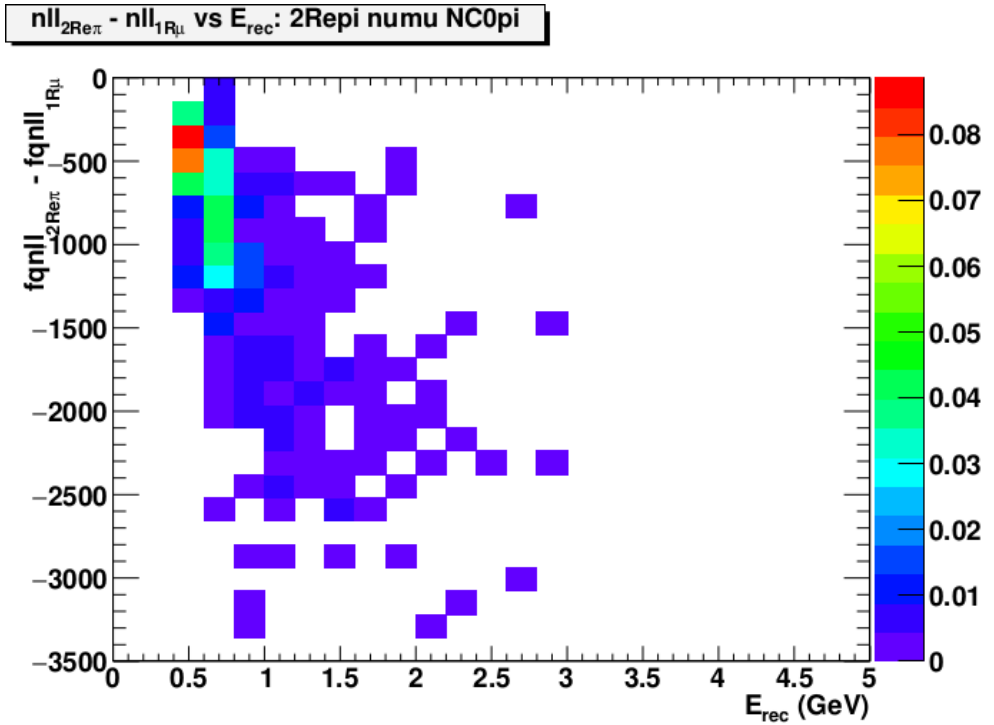


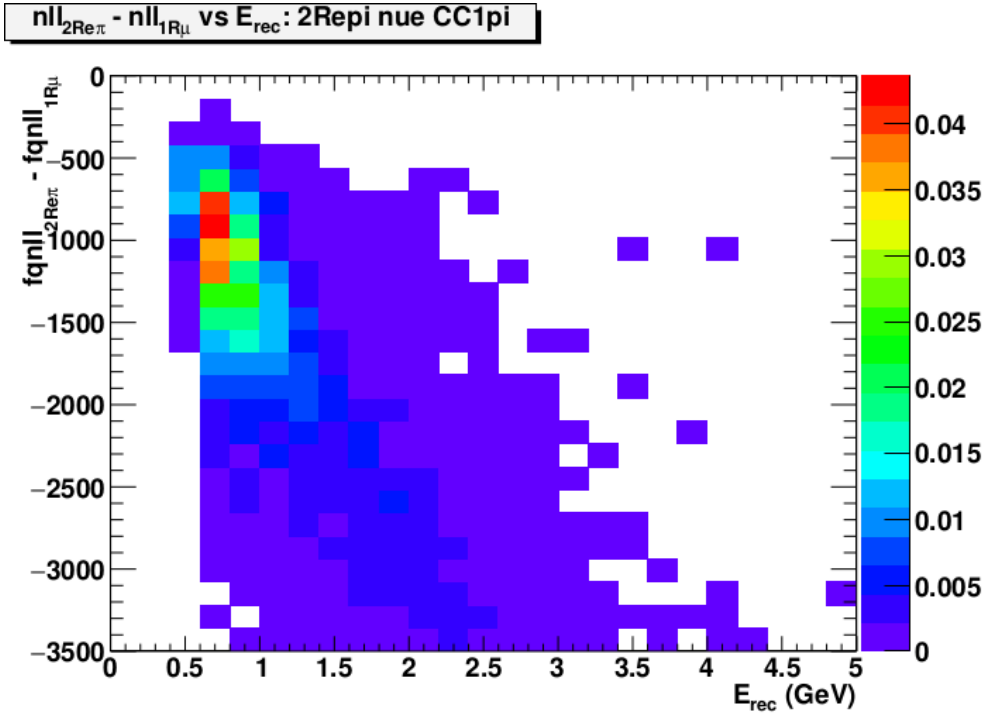
- Seems to primarily be low-energy ν_μ NC $1\pi^{0/+/-}$ and NC elastic events
- Not sure why these are being reconstructed as 2-ring events

2Reπ vs 1Rμ Likelihood Ratio

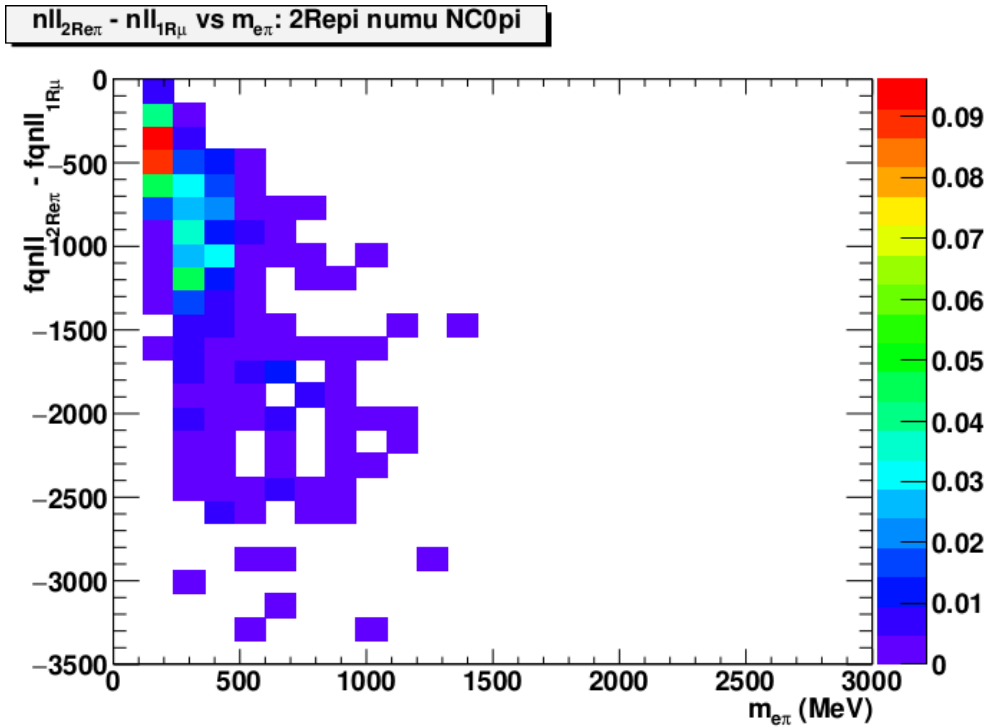


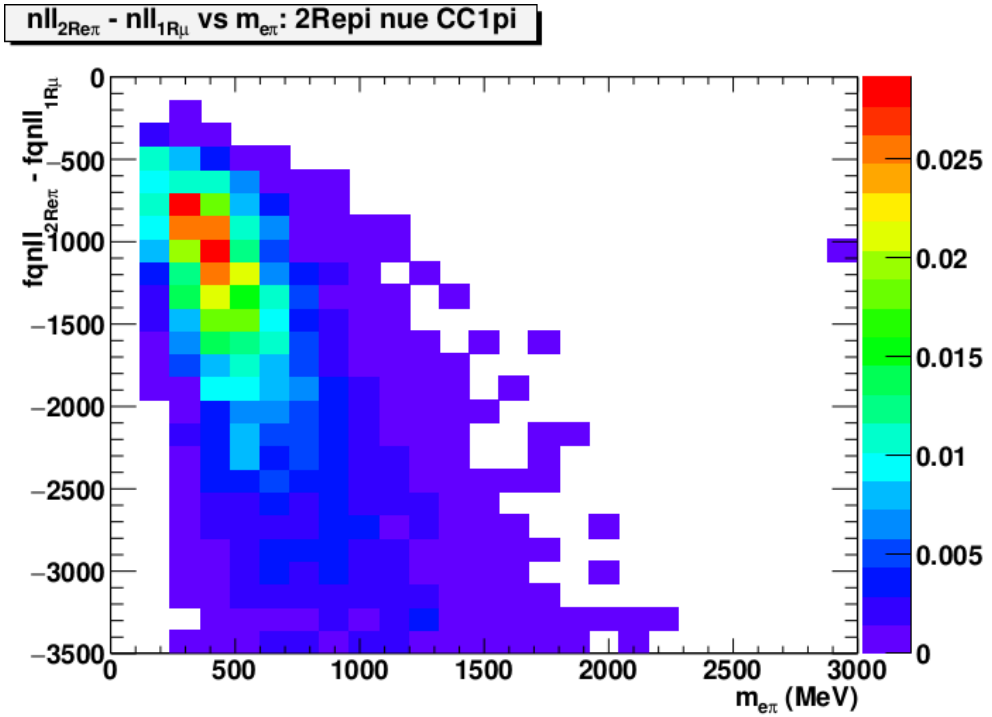
Likelihood Ratio vs. E_{rec}





Likelihood Ratio vs. $m_{e\pi}$





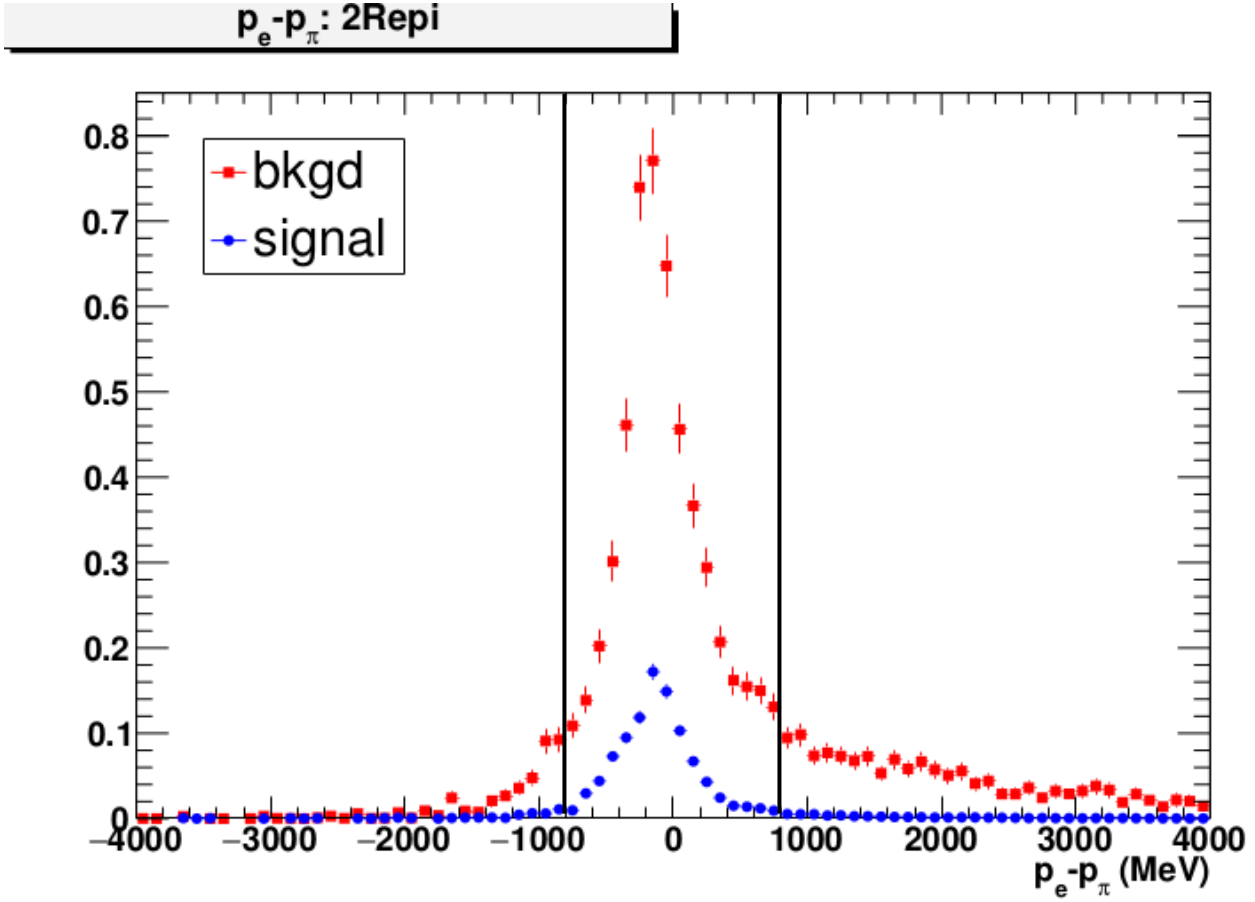
Cutflow Test

2Repi
FCFV
2 rings
eπ-like
0 decay e
$\lvert p_e - p_\pi \rvert$ < 800 MeV
cos(θ)<0.7 || cos(θ)>0.9
E_{rec} < 1.5 GeV
$m_{e\pi}$ > 240MeV || $nll_{2Re\pi} - nll_{1R\mu}$ < -700

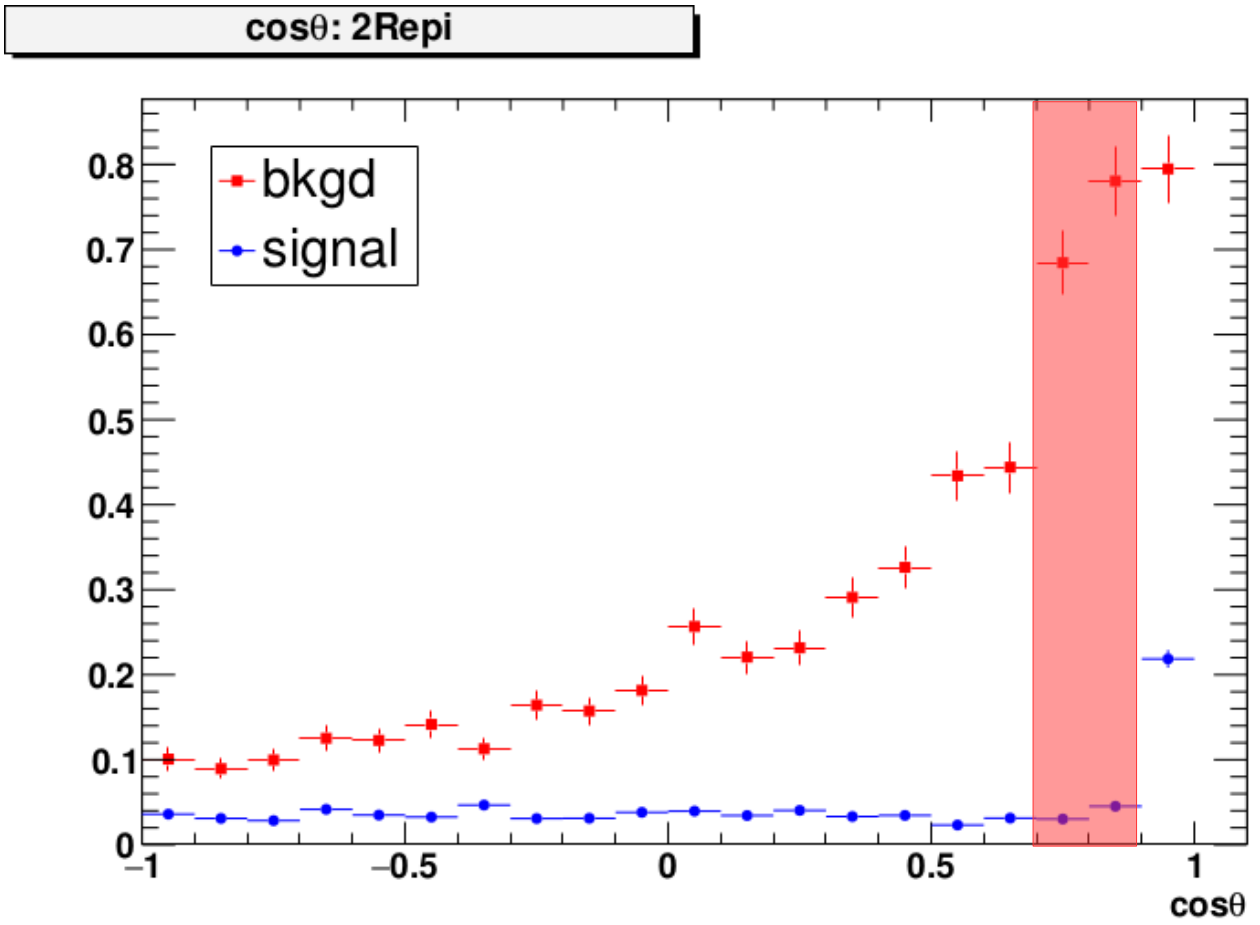
2Repi1de
FCFV
2 rings
eπ-like
1 decay e
$\lvert p_e - p_\pi \rvert$ < 800 MeV
cos(θ)<0.7 || cos(θ)>0.9
E_{rec} < 1.5 GeV
d2se < 200cm

FCFV: evclass==1 && evis>30. && nhitac<16 && fqwall_2r>100.

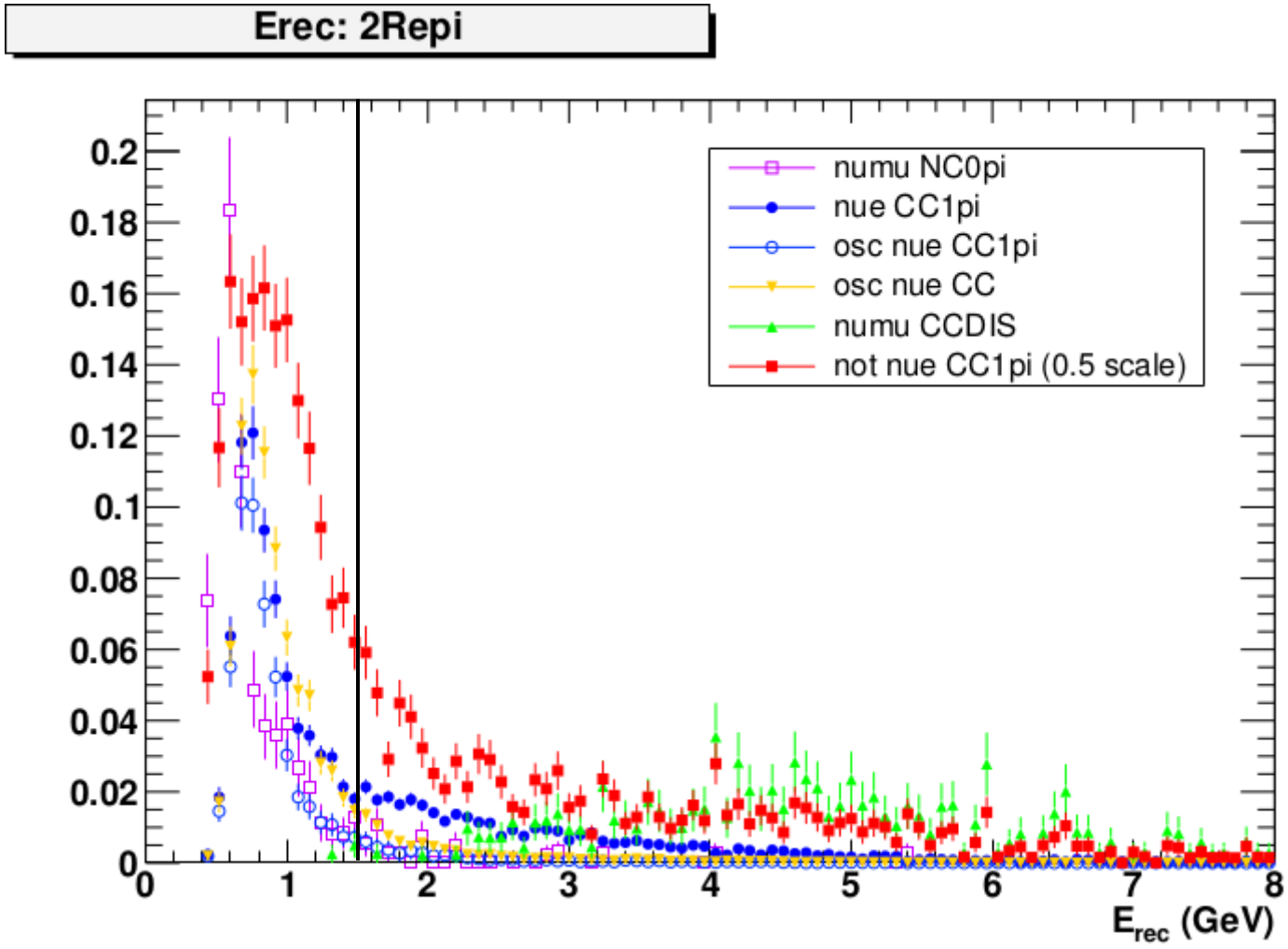
$|p_e - p_\pi| < 800MeV$



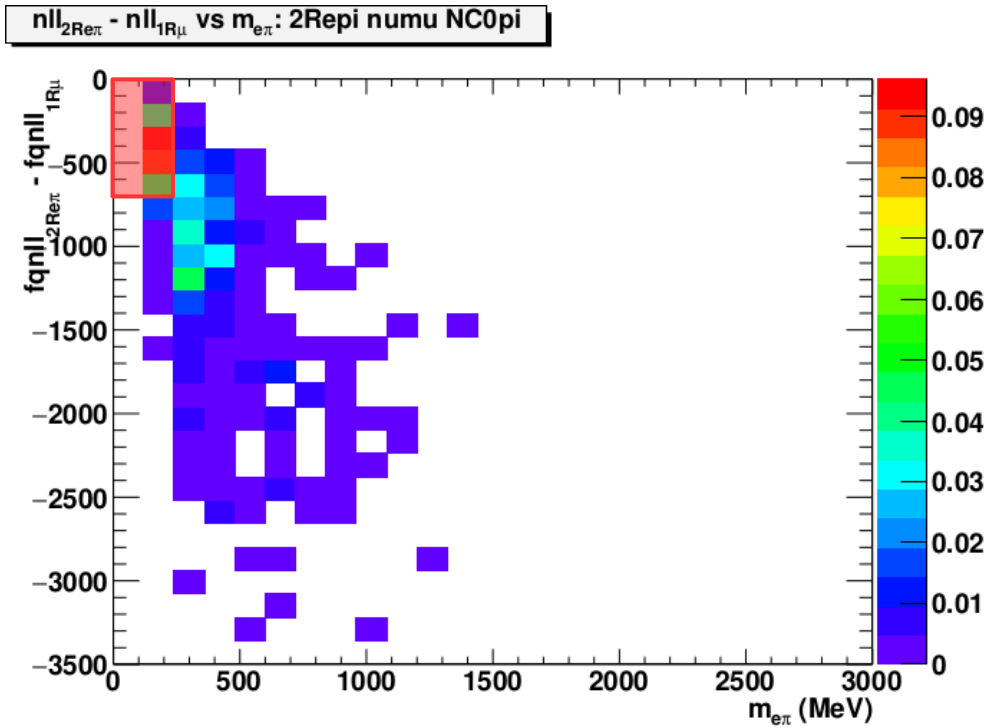
cos(θ)

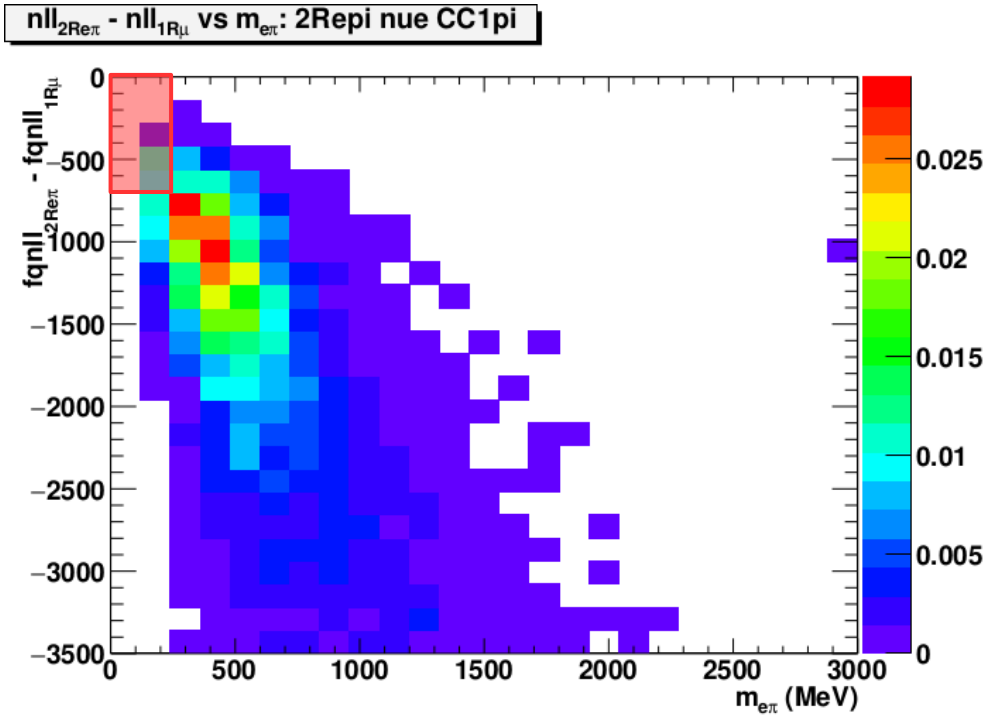


E_{rec} < 1.5 GeV


Erec: 2Repi
numu NC0pi
nue CC1pi
osc nue CC1pi
osc nue CC
numu CCDIS
not nue CC1pi (0.5 scale)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
6
7
8
E_rec (GeV)

$m_{e\pi} > 240MeV \,||\, nll_{2Re\pi}\text{-}nll_{1R\mu} < -700$





Cutflow

Sample	cut	numu/numub CC	intrinsic nue/nueb CC	osc nue/nueb CC	numu/numub NC	intrinsic nue/nueb NC	Signal	Bkgd	Purity	FOM
2Repi	FCFV	414.82	27.42	42.45	168.32	4.77	42.45	615.33	0.06	1.655
	2 rings	66.04	5.10	4.99	83.02	2.11	4.99	156.26	0.03	0.393
	epi-like	6.74	2.28	2.34	5.19	0.19	2.34	14.40	0.14	0.572
	0 decay e	1.48	1.00	0.88	3.17	0.11	0.88	5.76	0.13	0.342
	|p_e-p_pi| < 800MeV	0.75	0.56	0.82	2.64	0.09	0.82	4.03	0.17	0.372
	cos(theta)<0.7>0.9	0.51	0.50	0.75	1.93	0.07	0.75	3.01	0.20	0.389
	Erec < 1.5 GeV	0.23	0.38	0.73	1.76	0.06	0.73	2.43	0.23	0.409
	m_epi || nll_2Repi-nll_1Rmu	**0.20**	**0.37**	**0.68**	**1.36**	**0.04**	**0.68**	**1.98**	**0.25**	**0.415**
2Repi1de	FCFV	414.82	27.42	42.45	168.32	4.77	42.45	615.33	0.06	1.655
	2 rings	66.04	5.10	4.99	83.02	2.11	4.99	156.26	0.03	0.393
	epi-like	6.74	2.28	2.34	5.19	0.19	2.34	14.40	0.14	0.572
	1 decay e	3.35	1.14	1.43	1.63	0.06	1.43	6.18	0.19	0.517
	|p_e-p_pi| < 800MeV	1.95	0.70	1.37	1.32	0.05	1.37	4.02	0.25	0.592
	cos(theta)<0.7>0.9	1.53	0.63	1.28	1.04	0.04	1.28	3.25	0.28	0.600
	Erec < 1.5 GeV	0.83	0.51	1.26	0.92	0.04	1.26	2.30	0.35	0.666
	d2se < 200cm	**0.70**	**0.50**	**1.24**	**0.87**	**0.04**	**1.24**	**2.11**	**0.37**	**0.679**

signal = oscillated nue/nueb CC

Previous FOM Bests
2Repi: 0.40
2Repi1de: 0.66

2Reπ breakdown

cut	nue NC 1pi+	nue NC 1pi-	nue NC 1pi0	nue NC Npi	nue NC 0pi	numu NC 1pi+	numu NC 1pi-	numu NC 1pi0	numu NC Npi	numu NC 0pi
FCFV	0.61	0.49	1.34	0.83	1.51	18.96	14.91	50.38	26.47	57.60
2 rings	0.17	0.14	0.83	0.15	0.81	5.02	3.79	34.72	4.25	35.23
epi-like	0.04	0.03	0.03	0.03	0.05	0.96	0.74	1.22	1.04	1.23
0 decay e	0.02	0.02	0.03	0.01	0.03	0.37	0.48	1.08	0.44	0.80
|p_e-p_pi| < 800MeV	0.01	0.02	0.03	0.01	0.03	0.28	0.39	0.97	0.24	0.74
cos(theta)<0.7>0.9	0.01	0.01	0.02	0.01	0.02	0.23	0.33	0.61	0.16	0.61
Erec < 1.5 GeV	0.01	0.01	0.01	0.00	0.02	0.22	0.30	0.52	0.12	0.60
m_epi || nll_2Repi-nll_1Rmu	**0.00**	**0.01**	**0.01**	**0.00**	**0.01**	**0.15**	**0.22**	**0.50**	**0.11**	**0.39**

cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother
FCFV	19.07	32.69	18.11	93.86	126.25	194.71
2 rings	5.03	2.19	2.88	29.36	10.50	26.18
epi-like	3.33	0.56	0.74	0.94	0.14	5.66
0 decay e	1.09	0.49	0.30	0.11	0.07	1.29
|p_e-p_pi| < 800MeV	0.82	0.37	0.19	0.10	0.07	0.57
cos(theta)<0.7>0.9	0.73	0.36	0.16	0.09	0.05	0.37
Erec < 1.5 GeV	0.65	0.33	0.13	0.07	0.04	0.11
m_epi || nll_2Repi-nll_1Rmu	**0.64**	**0.29**	**0.12**	**0.06**	**0.03**	**0.11**

Signal	Background	Purity
19.07	638.71	0.03
5.03	156.23	0.03
3.33	13.41	0.20
1.09	5.55	0.16
0.82	4.04	0.17
0.73	3.03	0.20
0.65	2.50	0.21
0.64	**2.02**	**0.24**

2Reπ1de breakdown

cut	nue NC 1pi+	nue NC 1pi-	nue NC 1pi0	nue NC Npi	nue NC 0pi	numu NC 1pi+	numu NC 1pi-	numu NC 1pi0	numu NC Npi	numu NC 0pi
FCFV	0.61	0.49	1.34	0.83	1.51	18.96	14.91	50.38	26.47	57.60
2 rings	0.17	0.14	0.83	0.15	0.81	5.02	3.79	34.72	4.25	35.23
epi-like	0.04	0.03	0.03	0.03	0.05	0.96	0.74	1.22	1.04	1.23
1 decay e	0.02	0.01	0.00	0.02	0.02	0.50	0.19	0.13	0.44	0.37
|p_e-p_pi| < 800MeV	0.02	0.01	0.00	0.01	0.02	0.44	0.14	0.09	0.32	0.35
cos(theta)<0.7>0.9	0.01	0.01	0.00	0.01	0.01	0.36	0.11	0.07	0.22	0.28
Erec < 1.5 GeV	0.01	0.01	0.00	0.01	0.01	0.35	0.09	0.04	0.16	0.28
d2se < 200cm	**0.01**	**0.00**	**0.00**	**0.01**	**0.01**	**0.33**	**0.09**	**0.04**	**0.15**	**0.26**

cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother	Signal	Background	Purity
FCFV	19.07	32.69	18.11	93.86	126.25	194.71	19.07	638.71	0.03
2 rings	5.03	2.19	2.88	29.36	10.50	26.18	5.03	156.23	0.03
epi-like	3.33	0.56	0.74	0.94	0.14	5.66	3.33	13.41	0.20
1 decay e	2.19	0.06	0.31	0.49	0.05	2.81	2.19	5.42	0.29
|p_e-p_pi| < 800MeV	1.85	0.04	0.19	0.44	0.05	1.46	1.85	3.55	0.34
cos(theta)<0.7>0.9	1.71	0.04	0.17	0.38	0.04	1.11	1.71	2.82	0.38
Erec < 1.5 GeV	1.62	0.03	0.12	0.30	0.04	0.49	1.62	1.94	0.45
d2se < 200cm	**1.59**	**0.03**	**0.12**	**0.26**	**0.03**	**0.41**	**1.59**	**1.76**	**0.47**

A quick look at RHC cutflow

Sample	cut	numu/numub CC	intrinsic nue/nueb CC	osc nue/nueb CC	numu/numub NC	intrinsic nue/nueb NC	Signal	Bkgd	Purity	FOM
2Repi	FCFV	179.41	13.16	11.63	71.45	2.44	11.63	266.46	0.04	0.697
	2 rings	28.83	2.38	1.26	36.50	1.08	1.26	68.79	0.02	0.150
	epi-like	2.57	0.99	0.53	2.21	0.09	0.53	5.86	0.08	0.210
	0 decay e	0.51	0.55	0.37	1.35	0.05	0.37	2.46	0.13	0.219
	|p_e-p_pi| < 800MeV	0.28	0.26	0.34	1.16	0.05	0.34	1.74	0.16	0.233
	cos(theta)<0.7>0.9	0.20	0.22	0.29	0.87	0.03	0.29	1.33	0.18	0.228
	Erec < 1.5 GeV	0.06	0.12	0.24	0.62	0.02	0.24	0.82	0.23	0.234
	m_epi || nll_2Repi-nll_1Rmu	**0.05**	**0.12**	**0.23**	**0.45**	**0.02**	**0.23**	**0.64**	**0.27**	**0.249**
2Repi1de	FCFV	179.41	13.16	11.63	71.45	2.44	11.63	266.46	0.04	0.697
	2 rings	28.83	2.38	1.26	36.50	1.08	1.26	68.79	0.02	0.150
	epi-like	2.57	0.99	0.53	2.21	0.09	0.53	5.86	0.08	0.210
	1 decay e	1.41	0.38	0.15	0.69	0.03	0.15	2.51	0.06	0.093
	|p_e-p_pi| < 800MeV	0.91	0.20	0.13	0.56	0.03	0.13	1.69	0.07	0.099
	cos(theta)<0.7>0.9	0.73	0.18	0.12	0.44	0.02	0.12	1.37	0.08	0.100
	Erec < 1.5 GeV	0.26	0.10	0.10	0.34	0.01	0.10	0.70	0.12	0.108
	d2se < 200cm	**0.21**	**0.09**	**0.09**	**0.32**	**0.01**	**0.09**	**0.63**	**0.13**	**0.111**

2Reπ breakdown (RHC)

cut	nue NC 1pi+	nue NC 1pi-	nue NC 1pi0	nue NC Npi	nue NC 0pi	numu NC 1pi+	numu NC 1pi-	numu NC 1pi0	numu NC Npi	numu NC 0pi
FCFV	0.30	0.25	0.67	0.44	0.78	7.51	5.96	22.27	10.97	24.74
2 rings	0.08	0.07	0.43	0.08	0.42	2.09	1.63	15.45	1.83	15.50
epi-like	0.02	0.01	0.02	0.02	0.02	0.39	0.31	0.55	0.43	0.53
0 decay e	0.01	0.01	0.02	0.01	0.01	0.15	0.20	0.50	0.18	0.33
|p_e-p_pi| < 800MeV	0.00	0.01	0.02	0.00	0.01	0.11	0.16	0.46	0.11	0.31
cos(theta)<0.7>0.9	0.00	0.01	0.01	0.00	0.01	0.10	0.14	0.29	0.08	0.27
Erec < 1.5 GeV	0.00	0.00	0.00	0.00	0.01	0.07	0.10	0.18	0.04	0.22
m_epi || nll_2Repi-nll_1Rmu	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.04**	**0.06**	**0.18**	**0.04**	**0.14**

cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother	Signal	Background	Purity
FCFV	5.99	11.33	7.47	41.43	60.03	77.95	5.99	272.09	0.02
2 rings	1.59	0.78	1.27	12.79	5.11	10.92	1.59	68.46	0.02
epi-like	1.02	0.17	0.33	0.35	0.06	2.15	1.02	5.37	0.16
0 decay e	0.63	0.15	0.14	0.04	0.03	0.43	0.63	2.20	0.22
|p_e-p_pi| < 800MeV	0.43	0.10	0.07	0.04	0.03	0.21	0.43	1.64	0.21
cos(theta)<0.7>0.9	0.37	0.09	0.06	0.03	0.02	0.15	0.37	1.26	0.23
Erec < 1.5 GeV	0.29	0.04	0.03	0.02	0.02	0.03	0.29	0.78	0.27
m_epi || nll_2Repi-nll_1Rmu	**0.28**	**0.04**	**0.03**	**0.02**	**0.01**	**0.03**	**0.28**	**0.59**	**0.32**

2Reπ1de breakdown (RHC)

cut	nue NC 1pi+	nue NC 1pi-	nue NC 1pi0	nue NC Npi	nue NC 0pi	numu NC 1pi+	numu NC 1pi-	numu NC 1pi0	numu NC Npi	numu NC 0pi
FCFV	0.30	0.25	0.67	0.44	0.78	7.51	5.96	22.27	10.97	24.74
2 rings	0.08	0.07	0.43	0.08	0.42	2.09	1.63	15.45	1.83	15.50
epi-like	0.02	0.01	0.02	0.02	0.02	0.39	0.31	0.55	0.43	0.53
1 decay e	0.01	0.00	0.00	0.01	0.01	0.20	0.09	0.04	0.20	0.16
|p_e-p_pi| < 800MeV	0.01	0.00	0.00	0.01	0.01	0.17	0.07	0.03	0.13	0.15
cos(theta)<0.7>0.9	0.01	0.00	0.00	0.00	0.00	0.14	0.06	0.03	0.09	0.12
Erec < 1.5 GeV	0.01	0.00	0.00	0.00	0.00	0.11	0.04	0.01	0.06	0.11
d2se < 200cm	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.11**	**0.04**	**0.01**	**0.05**	**0.10**

cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother	Signal	Background	Purity
FCFV	5.99	11.33	7.47	41.43	60.03	77.95	5.99	272.09	0.02
2 rings	1.59	0.78	1.27	12.79	5.11	10.92	1.59	68.46	0.02
epi-like	1.02	0.17	0.33	0.35	0.06	2.15	1.02	5.37	0.16
1 decay e	0.38	0.02	0.14	0.21	0.03	1.17	0.38	2.29	0.14
|p_e-p_pi| < 800MeV	0.25	0.01	0.07	0.19	0.03	0.69	0.25	1.58	0.14
cos(theta)<0.7>0.9	0.23	0.01	0.06	0.16	0.02	0.55	0.23	1.27	0.15
Erec < 1.5 GeV	0.16	0.00	0.03	0.09	0.01	0.15	0.16	0.64	0.19
d2se < 200cm	**0.15**	**0.00**	**0.03**	**0.08**	**0.01**	**0.13**	**0.15**	**0.58**	**0.21**

Thoughts

- Moving Erec cut from 2 GeV to 1.5 GeV seemed to be beneficial for both samples
  - targeting ν_μ CCDIS background
- $m_{e\pi}$ vs $nll_{2Re\pi}$-$nll_{1R\mu}$ cut effective at reducing ν_μ NC0π backgrounds in 2Reπ sample
- Have yet to identify promising cut for ν_μ NC1π^0 background in 2Reπ sample
  - $m_{e\pi}$ vs $nll_{2Re\pi}$-nll_{2Ree} cut improved purity, but not FOM
  - ν_μ NC1π^0 remains as largest background in 2Reπ sample
- Start preparing code for grid search