2-Ring ν_e CC1π^+ Selection Studies

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T2K-SK Meeting
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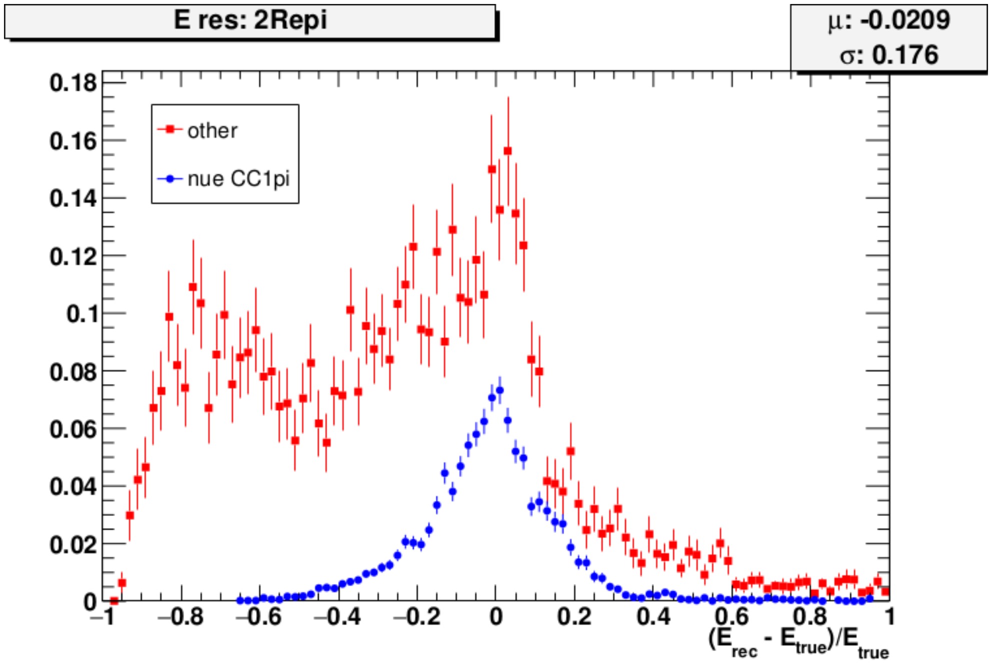
Overview

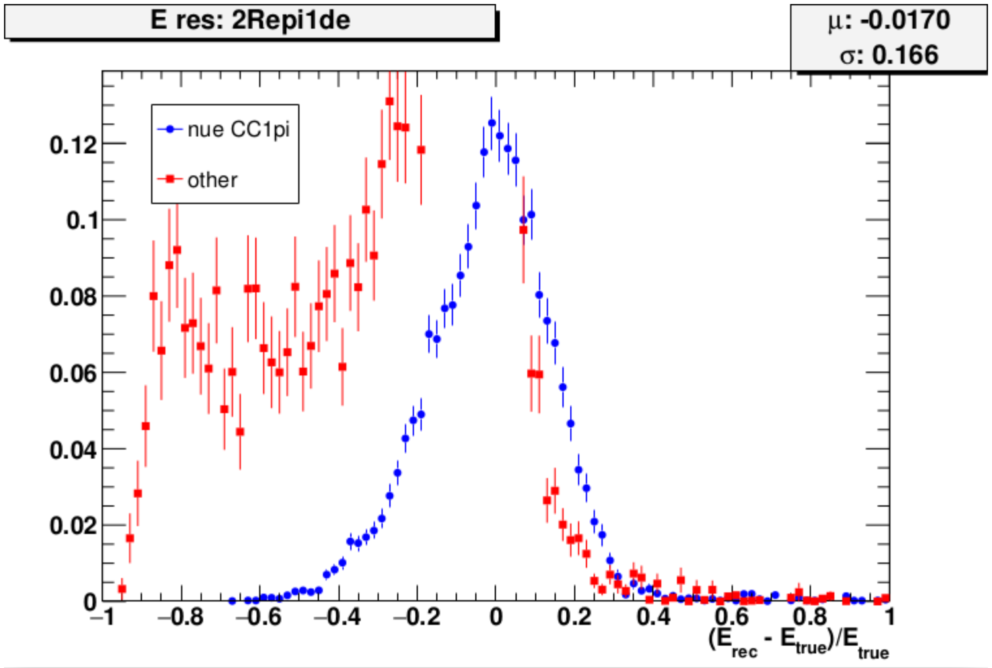
- Since October collaboration meeting, most time spent on identifying and targeting main backgrounds
  - Some time spent investigating energy reconstruction
- Wish to identify parameters for cuts that will be used in a grid search to optimize FOM:

$$FOM = S/\sqrt{S+B}$$

$\nu_e + p/n \rightarrow e^-$	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)**

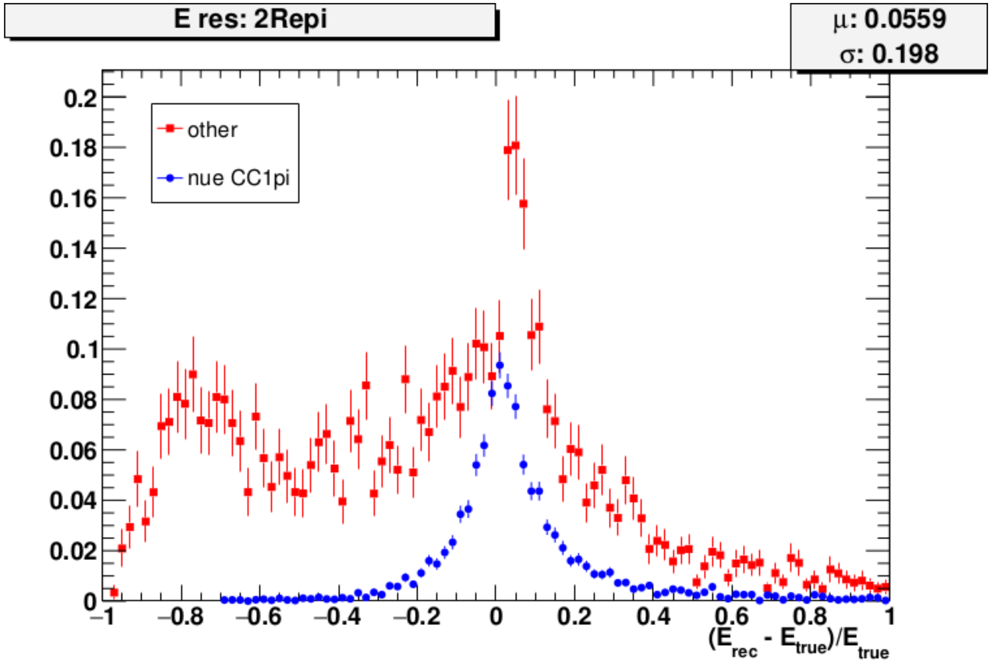
Energy Resolution: Method 1

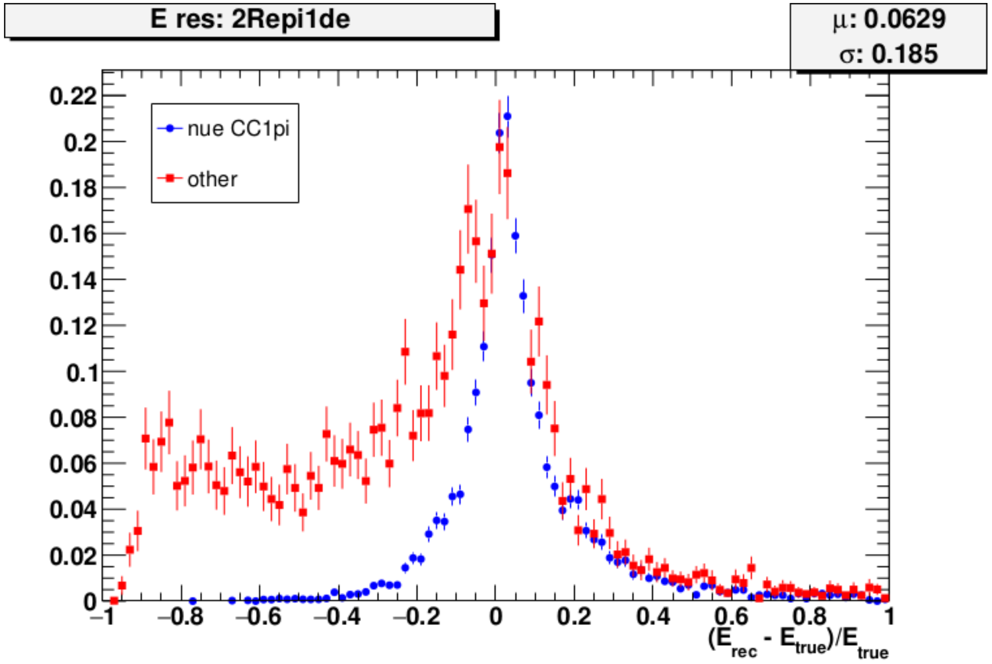




$$E_\nu = E_e + E_\pi + 140 \text{ MeV}$$

Energy Resolution: Method 2



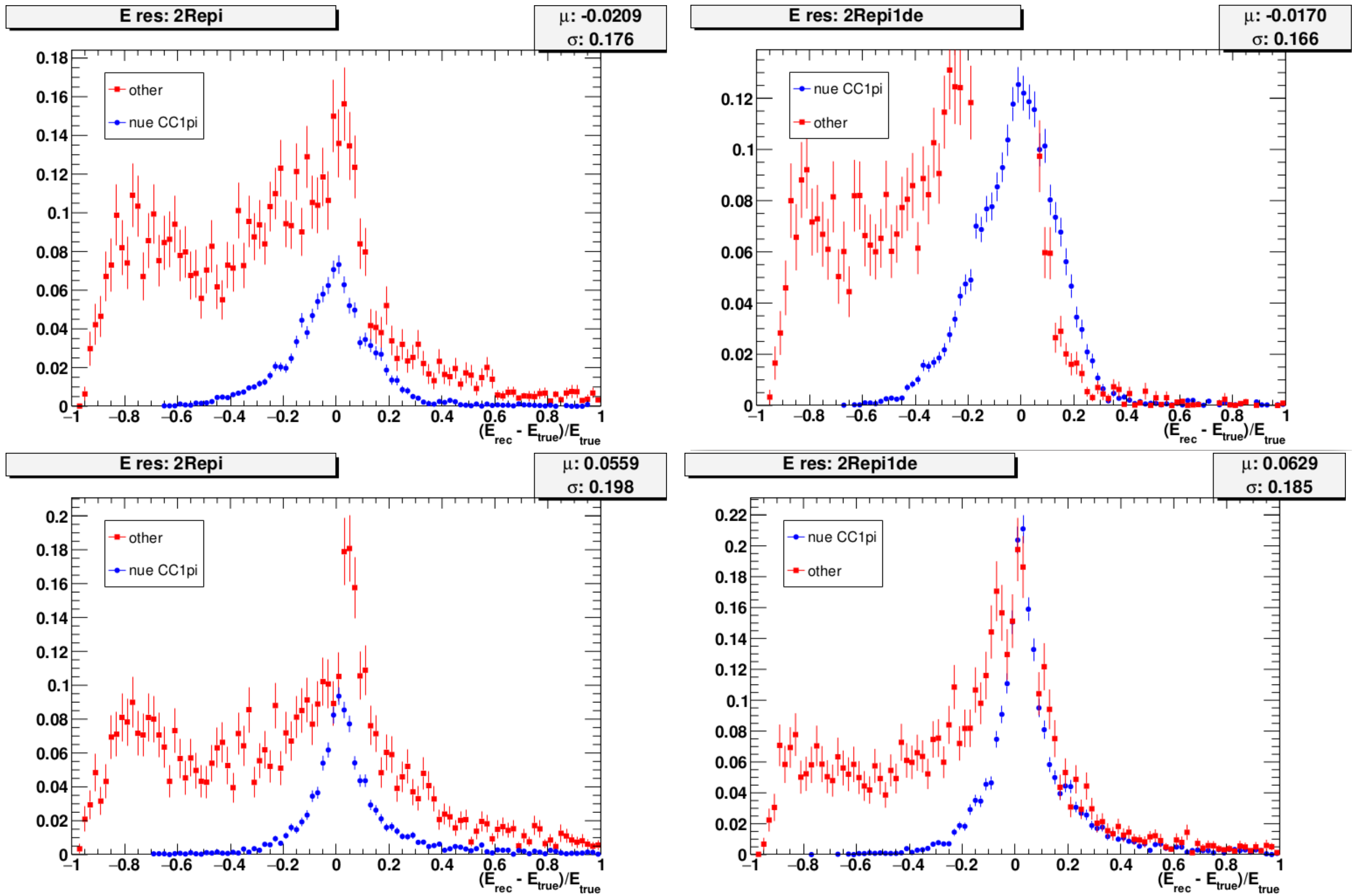


$$E_\nu = \frac{m_\mu^2 + m_{\pi^+}^2 - 2m_N(E_\mu + E_{\pi^+}) + 2p_\mu \cdot p_{\pi^+}}{2(E_\mu + E_{\pi^+} - |p_\mu|\cos\theta_{\nu\mu} - |p_{\pi^+}|\cos\theta_{\nu\pi^+} - m_N)}$$

Method 1 vs. Method 2

Method 1

Method 2



Baseline Cutflow

- Included $fqwall_{MR}$ > 100 cm to FCFV
  - "$fqwall_{MR}$" defined as the calculation of wall using the vertex of the best multi-ring fiTQun fit
  - not optimized, but wanted to include some wall cut to more appropriately evaluate FOM

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**
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**

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

signal = oscillated $\nu_e/\bar{\nu}_e$ CC

Baseline Breakdown: 2Reπ

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

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

nue CC1pi	Other	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

- Backgrounds investigated:
  - ν_μ CC other
  - ν_μ NC 0π
  - ν_μ NC $1\pi^0$

* NC pions counted above Cherenkov threshold *

Baseline Breakdown: 2Reπ1de

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

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
1 decay e	2.19	0.06	0.31	0.49	0.05	2.81

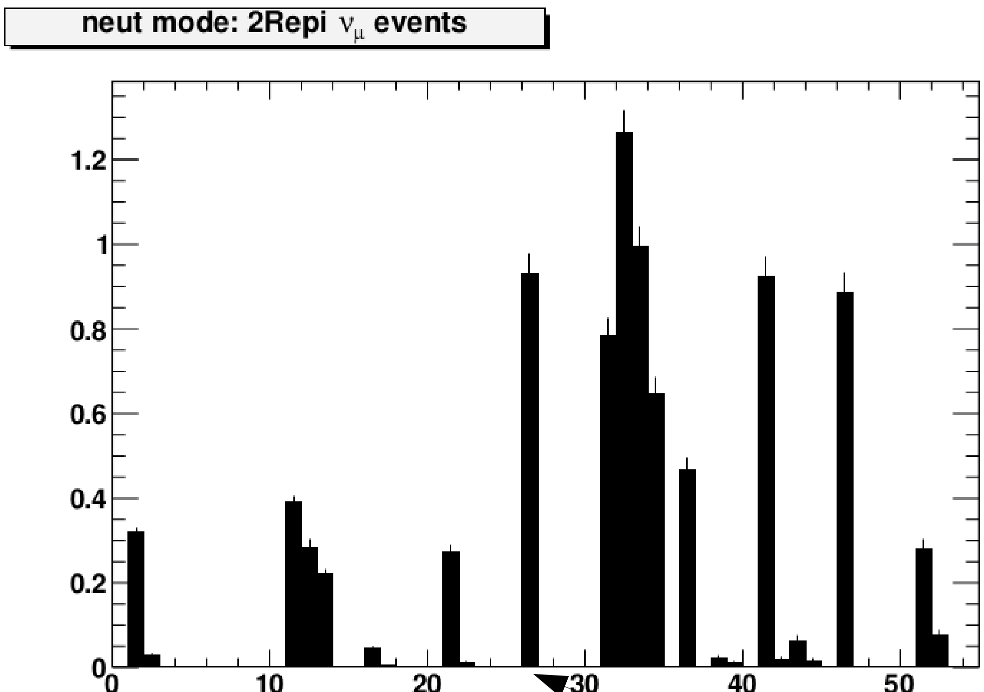
nue CC1pi	Other	Purity
19.07	638.71	0.03
5.03	156.23	0.03
3.33	13.41	0.20
2.19	5.42	0.29

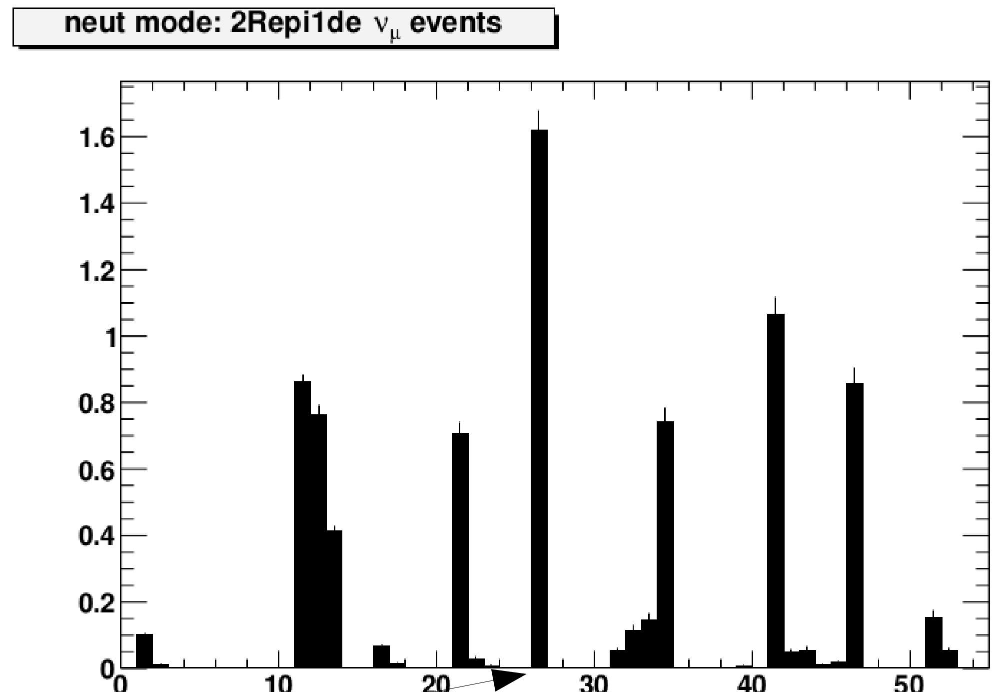
- Backgrounds investigated:
  - ν_μ CC other

* NC pions counted above Cherenkov threshold *

ν_μ CC other (2Reπ and 2Reπ1de)

Plots of neut modes for each baseline selection (ν_μ events only)

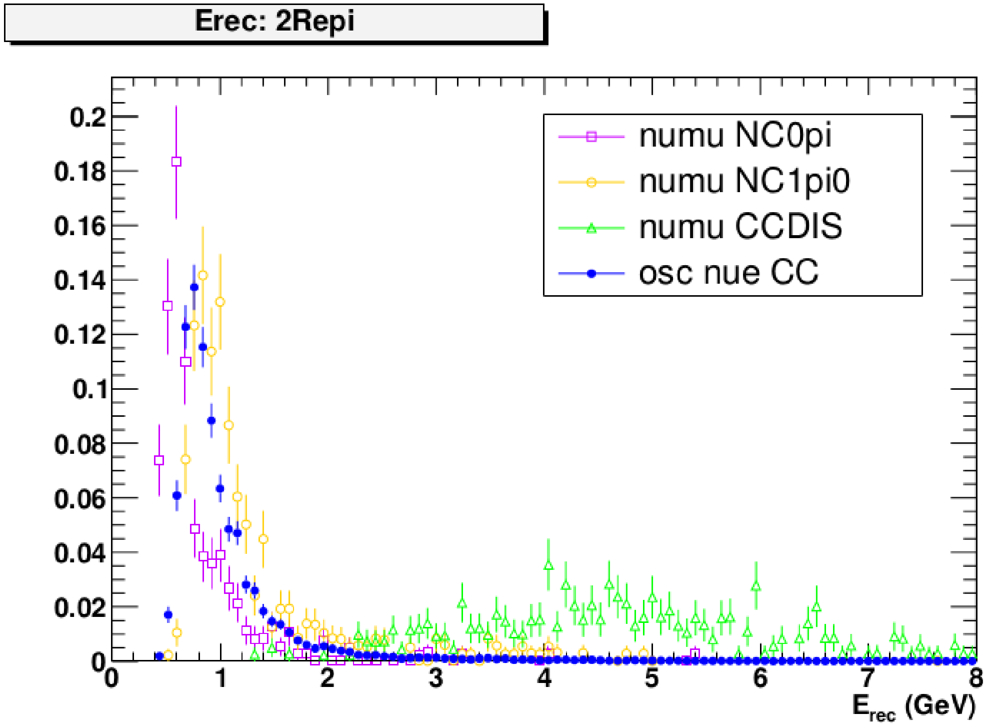


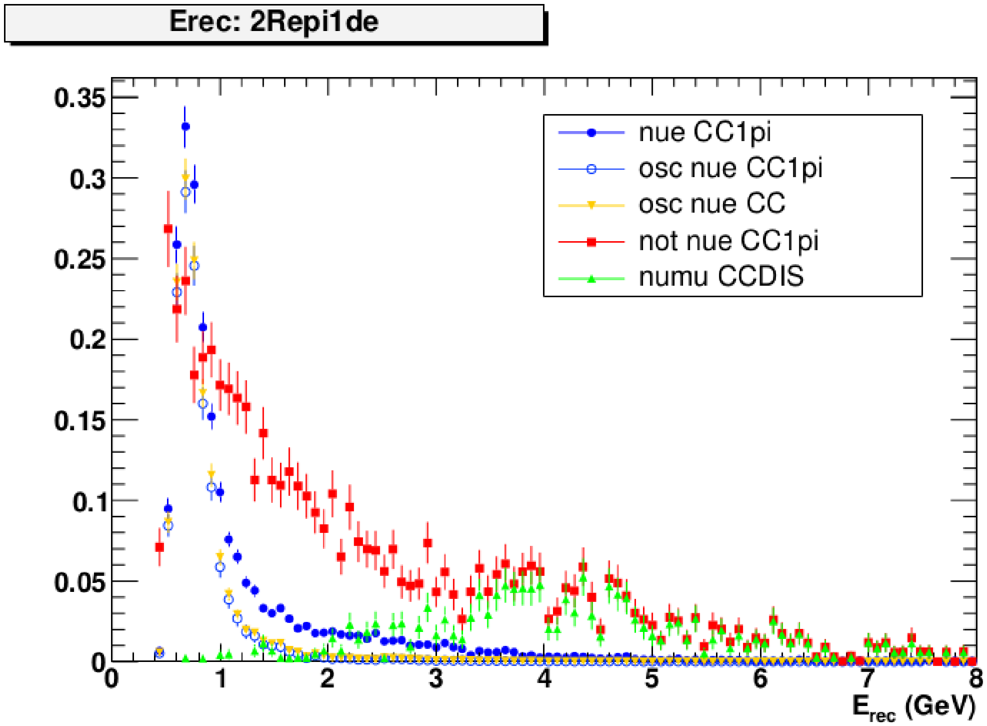


neut mode 26 – main component of ν_μ CC other background is ν_μ CC DIS

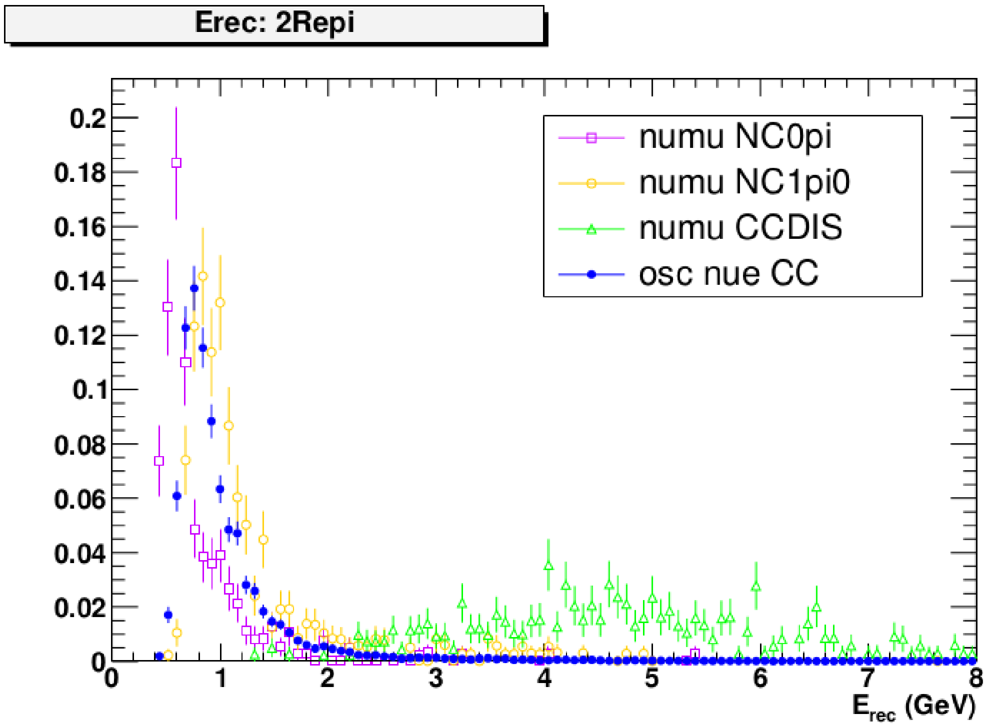
ν_μ CC DIS background

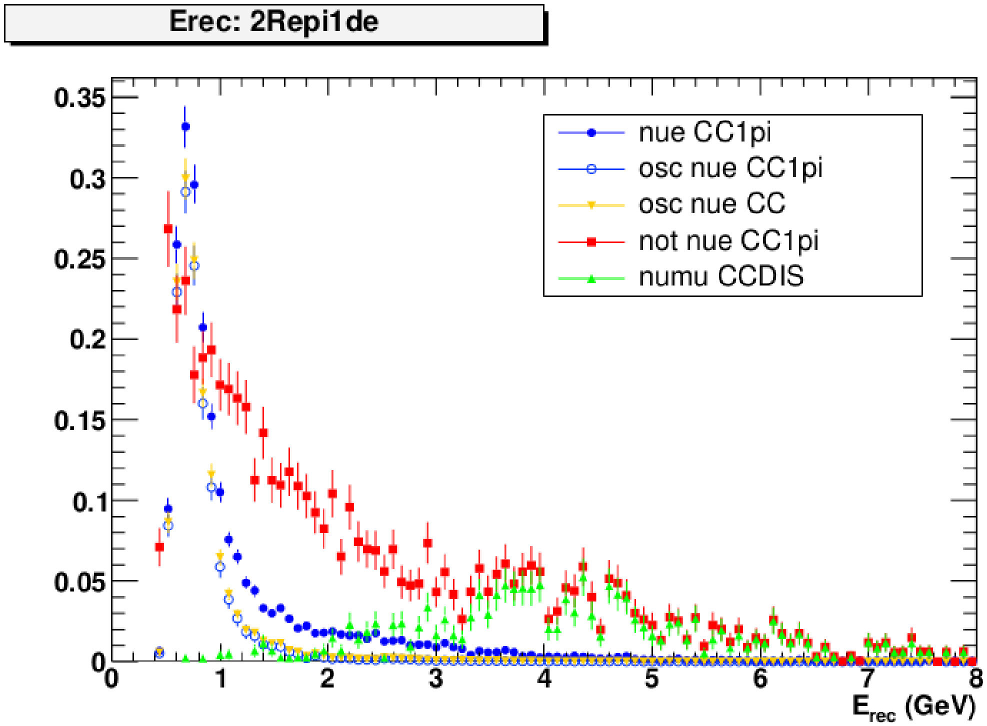
- ν_μ CC DIS expected to dominate at high energies (green triangles)





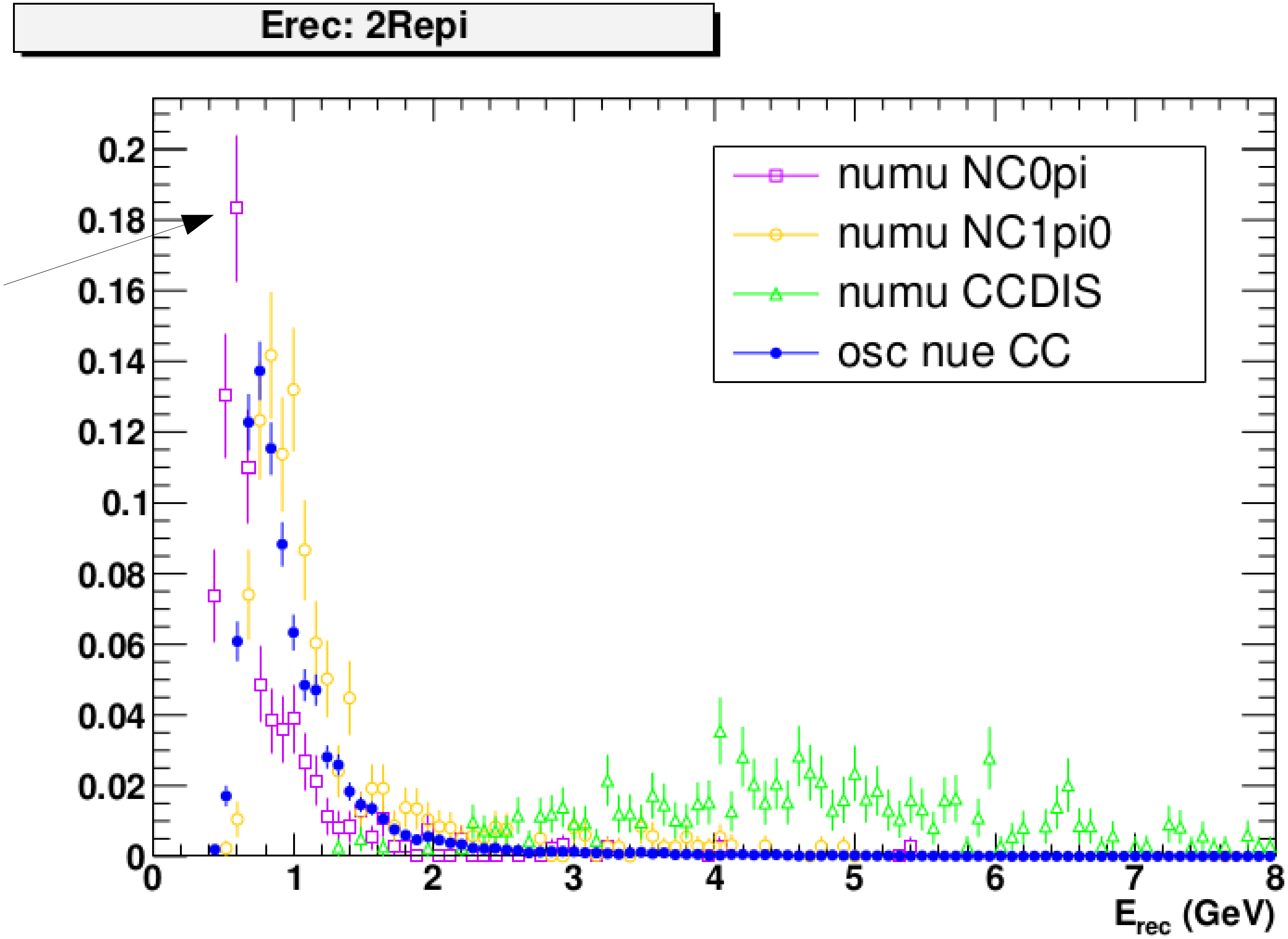
ν_μ CC DIS background





- Strategy: Include E_{rec} < ~1.5-2.0 GeV cut
  - This would reflect the fact that the oscillation peak is at much lower energies than the significant high E background
  - This cut is not meant to be included in the analysis, but rather gives a better picture of the purity and FOM at energies relevant to an oscillation analysis

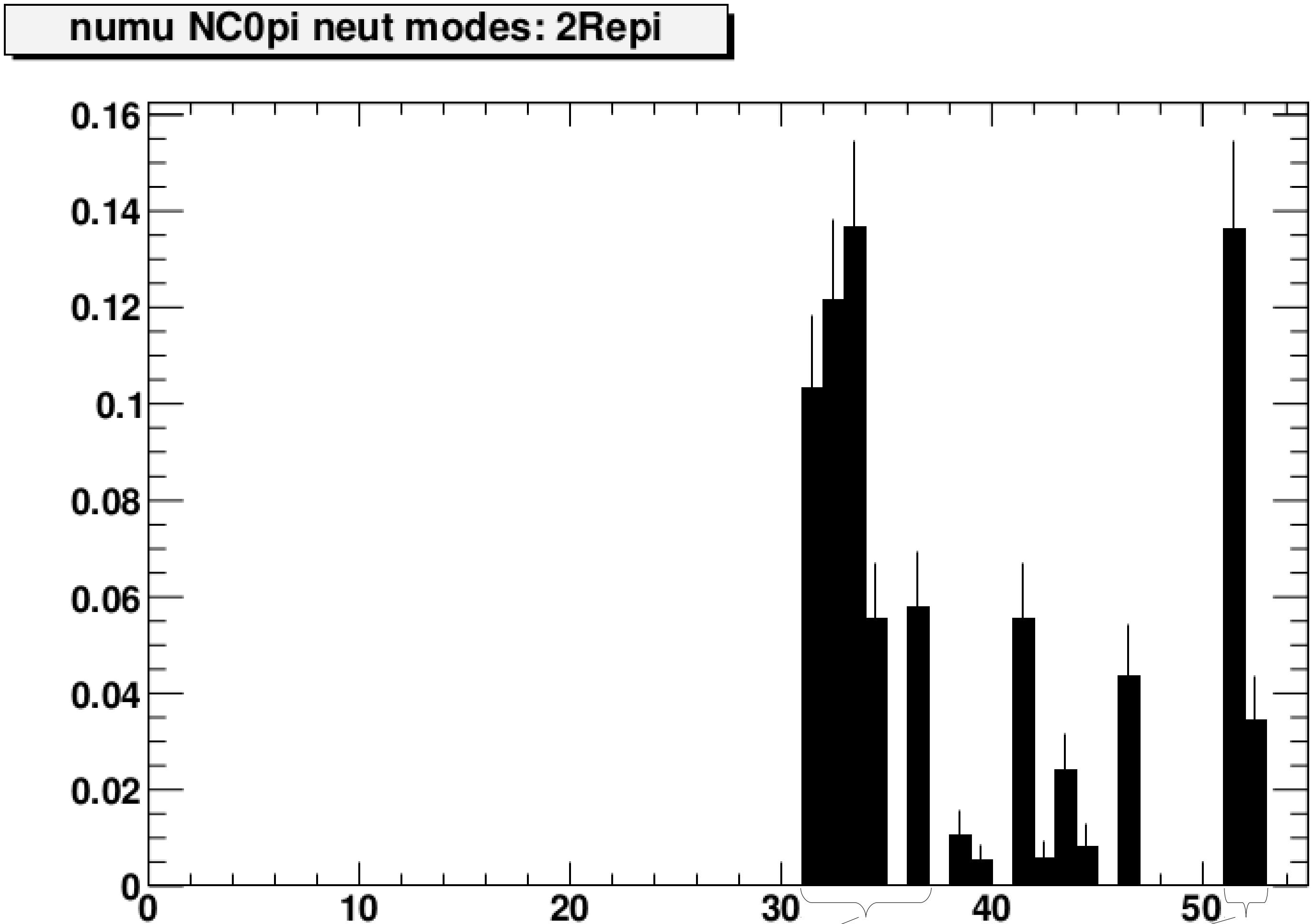
ν_μ NC 0π Background (2Reπ)



Peaks at low E (slightly below oscillation peak)

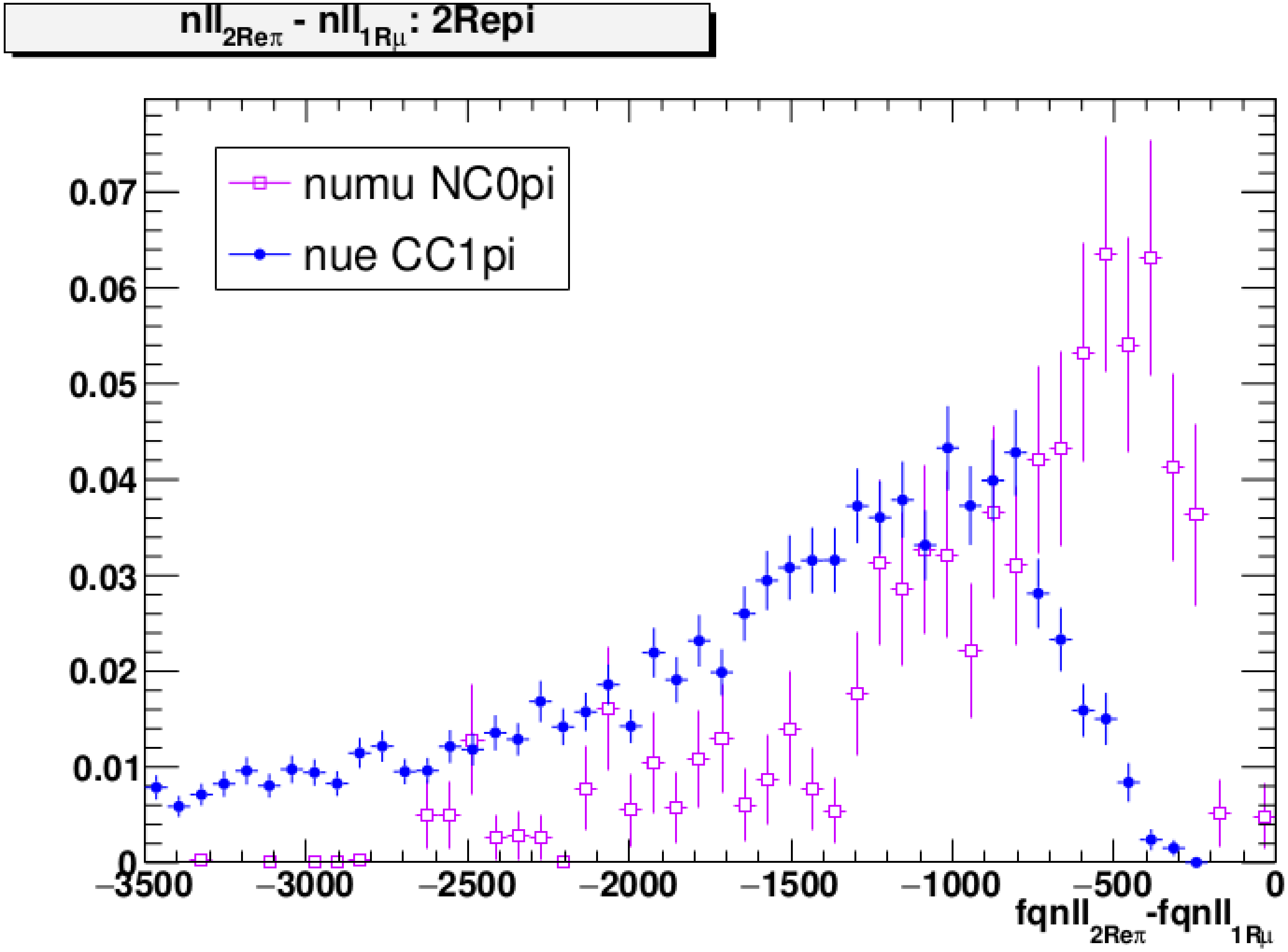
Note that this is 0π **above Cherenkov threshold**

ν_μ NC0π NEUT modes

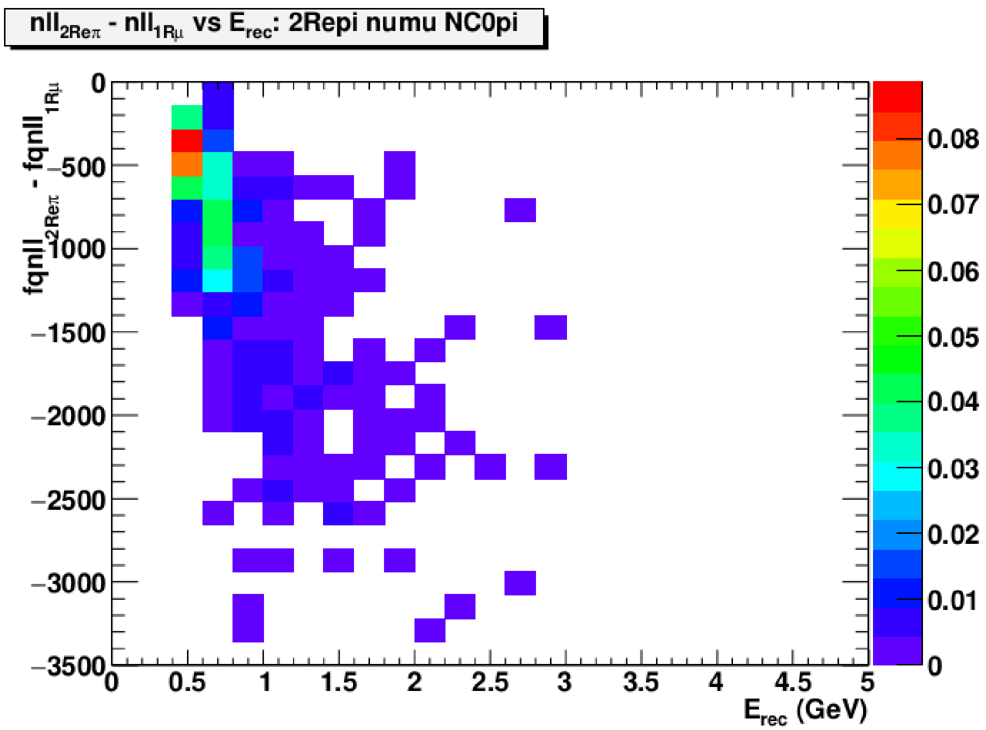


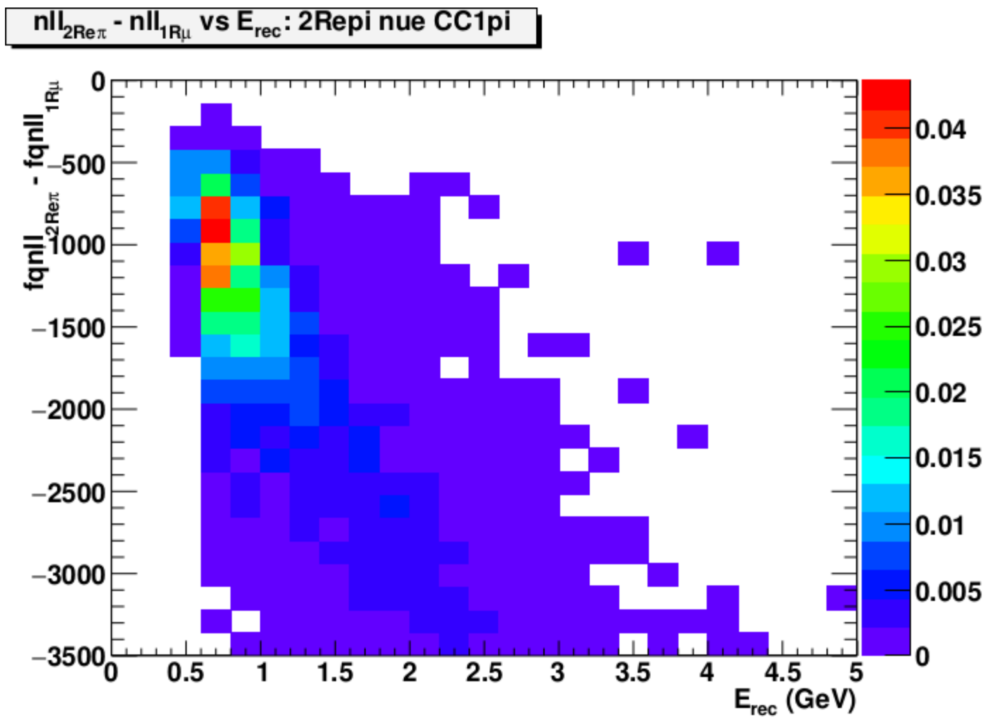
- Seems to primarily be low-energy ν_μ NC $1\pi^{0/+/-}$ and NC elastic events
- Not sure why these are being reconstructed as 2-ring events

2Reπ vs 1Rμ Likelihood Ratio

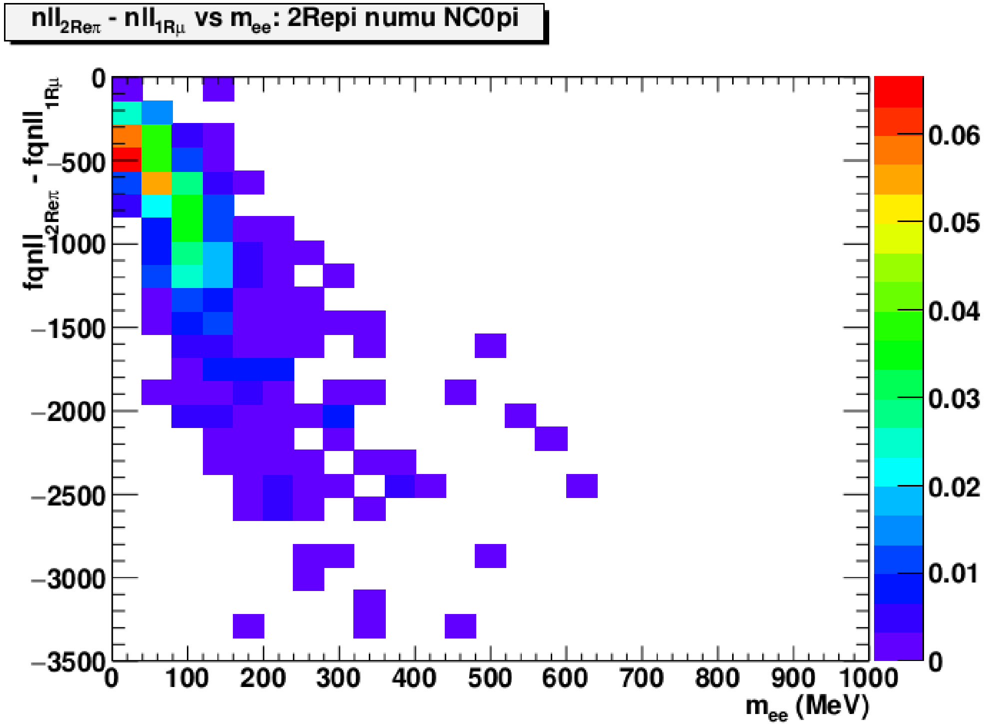


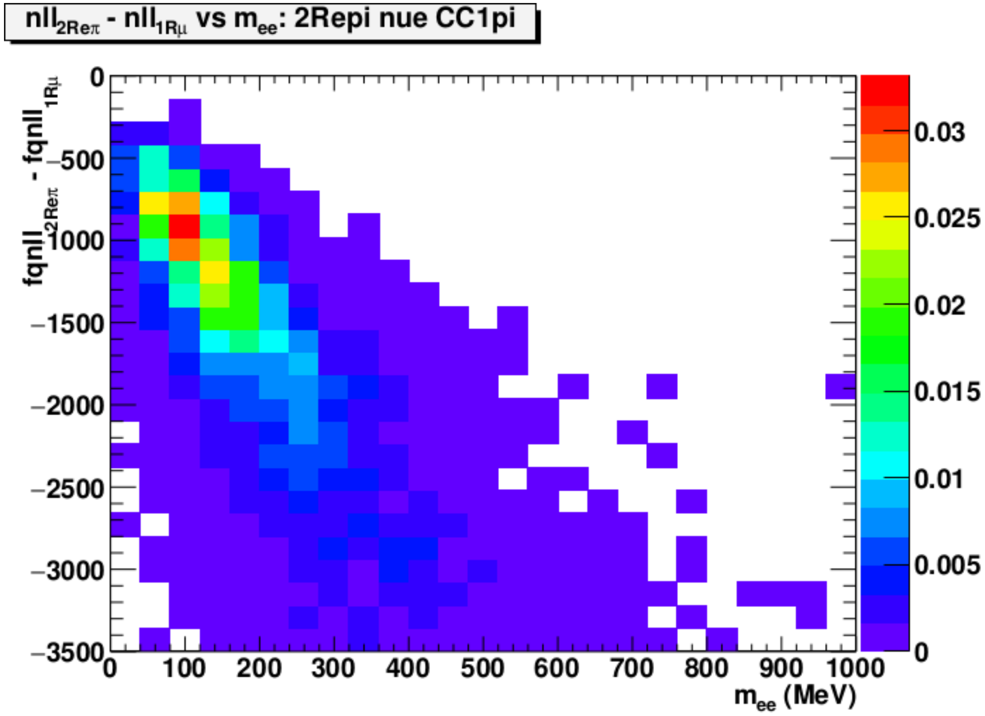
Likelihood Ratio vs. E_{rec}



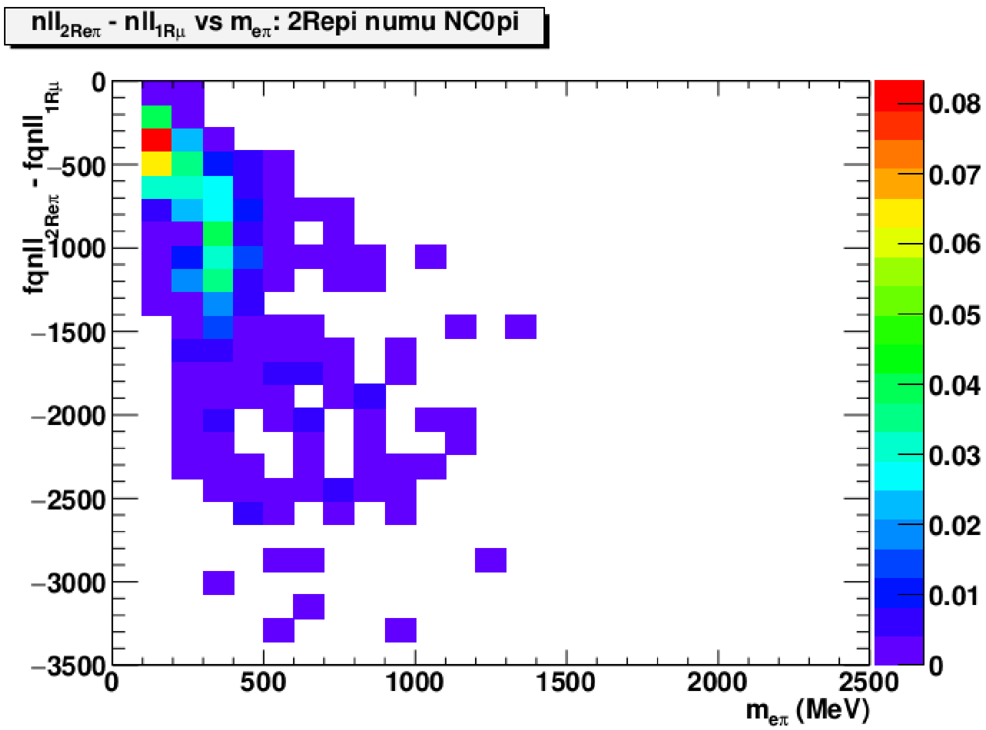


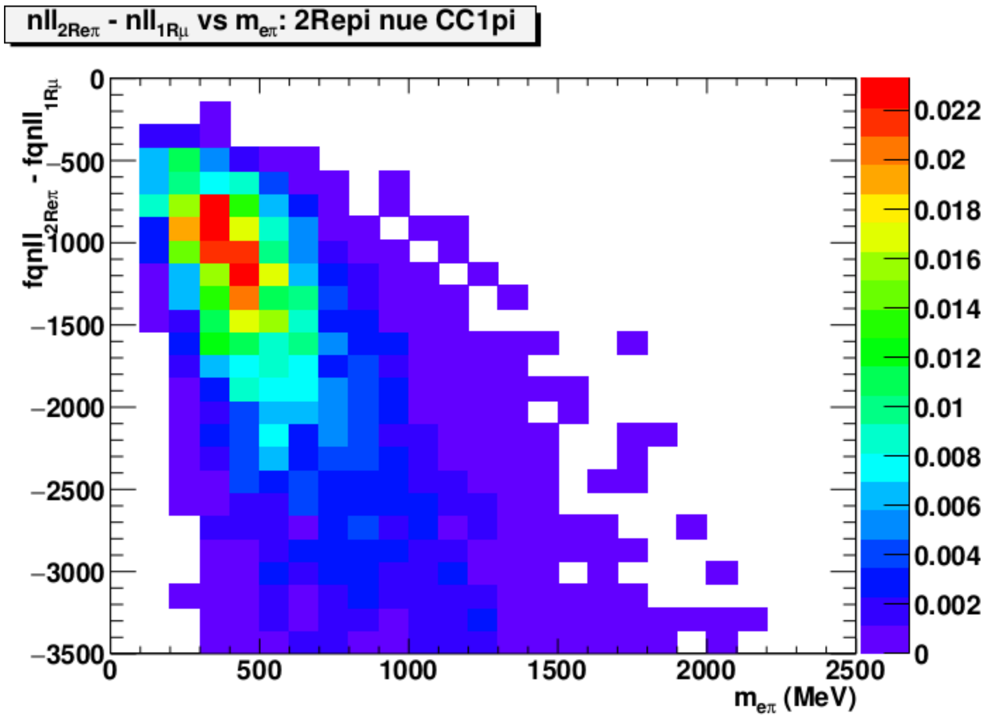
Likelihood Ratio vs. m_{ee}



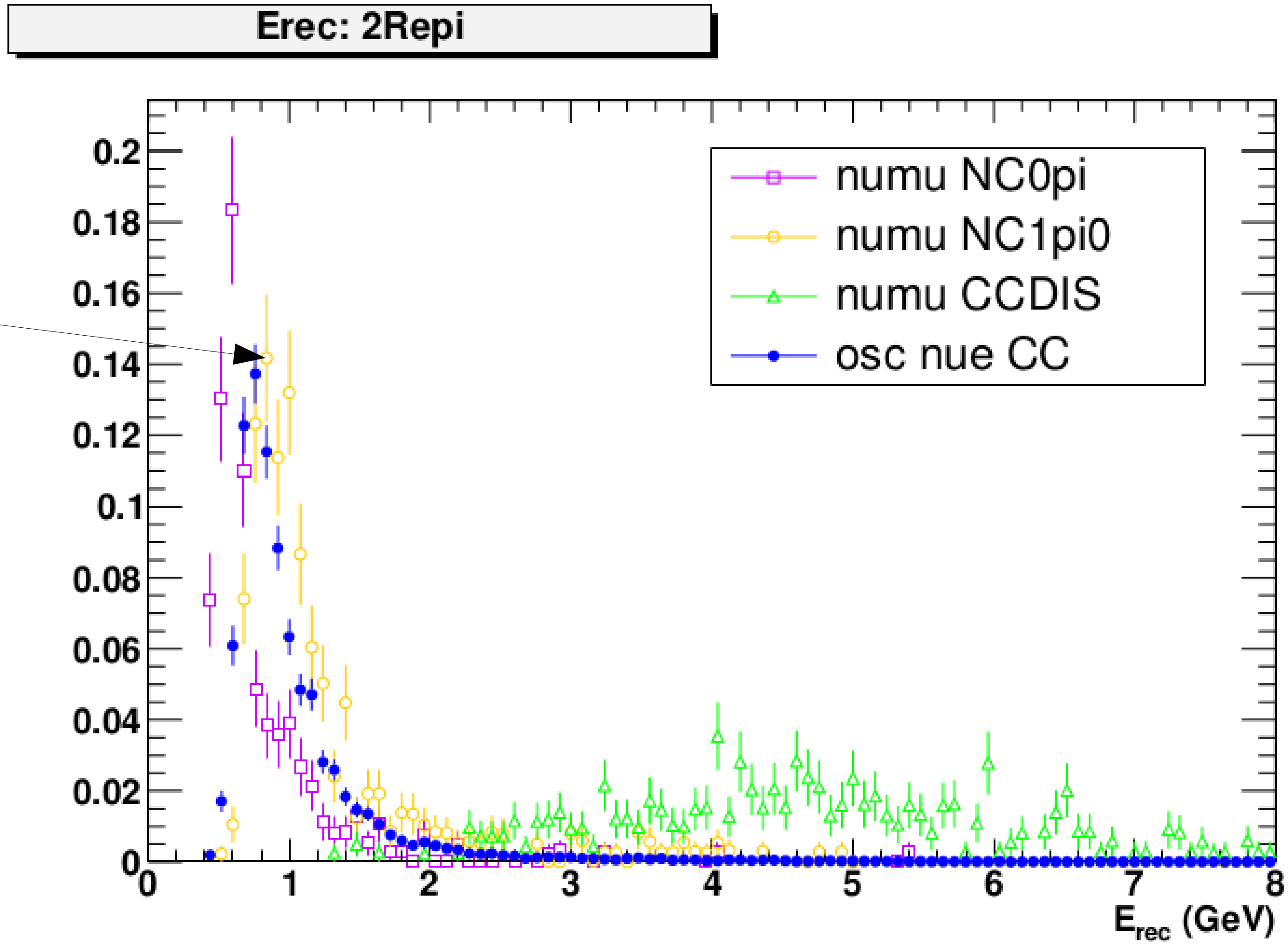


Likelihood Ratio vs. $m_{e\pi}$



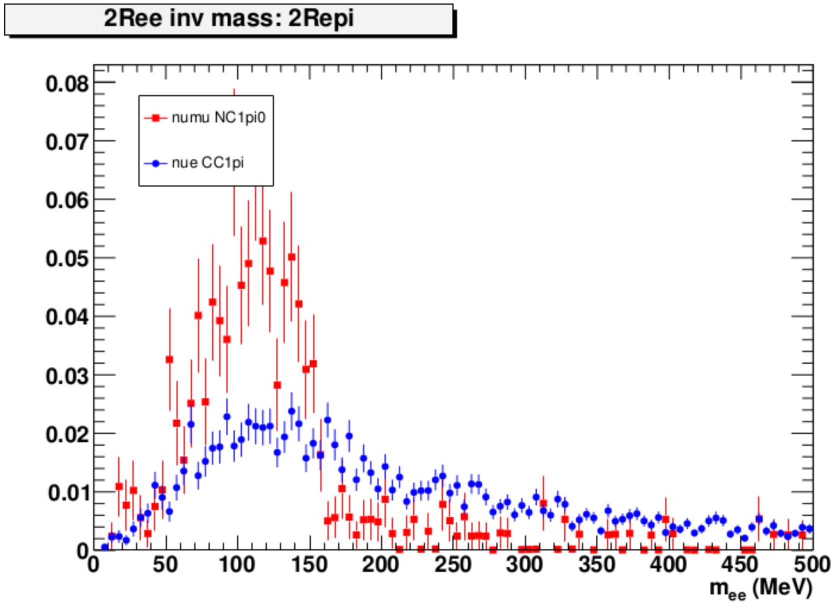


ν_μ NC $1\pi^0$ Background (2Reπ)

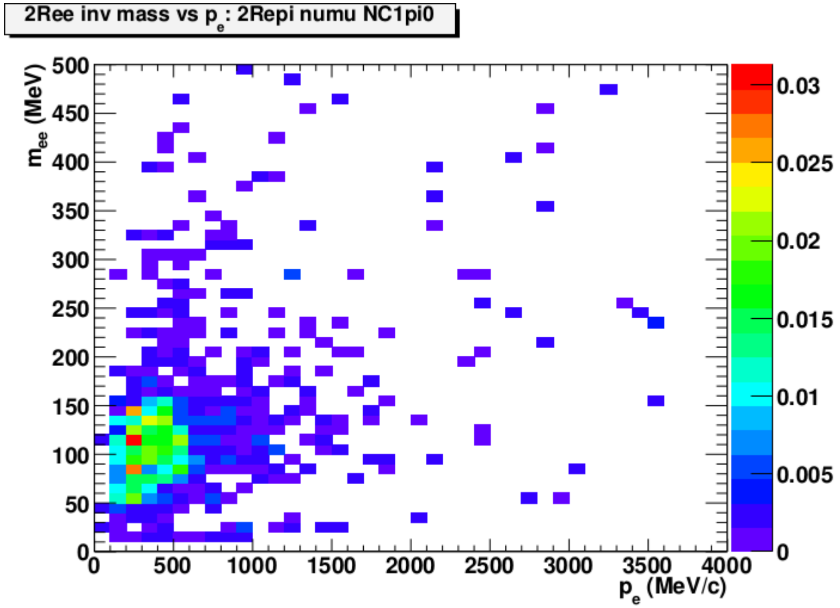


Peaks near oscillation peak

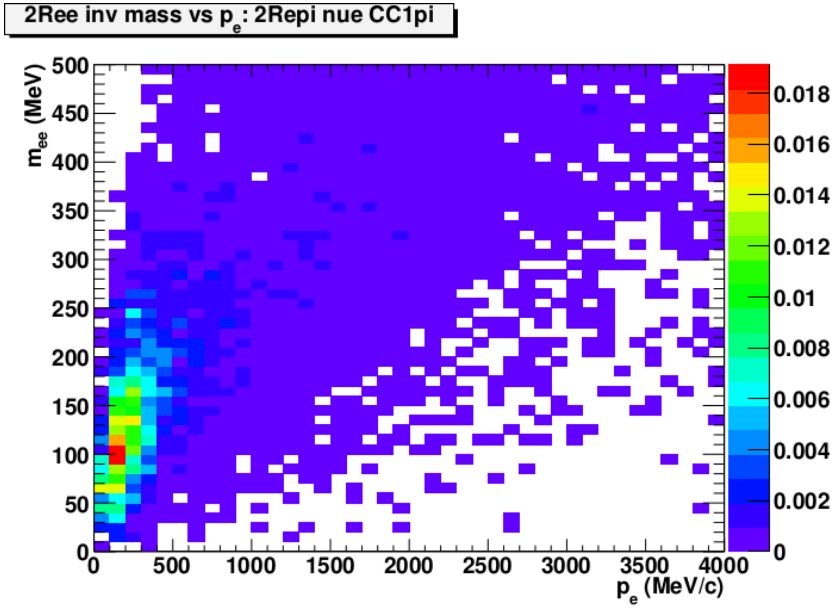
m_{ee} (vs p_e)



2Ree inv mass: 2Repi
numu NC1pi0
nue CC1pi
m_ee (MeV)

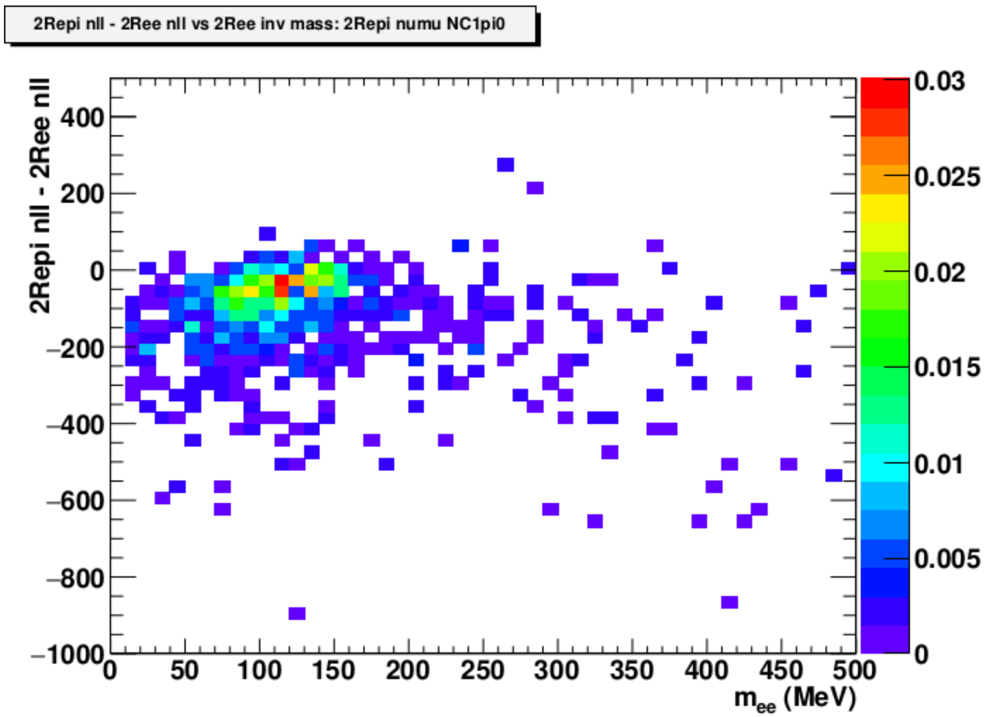


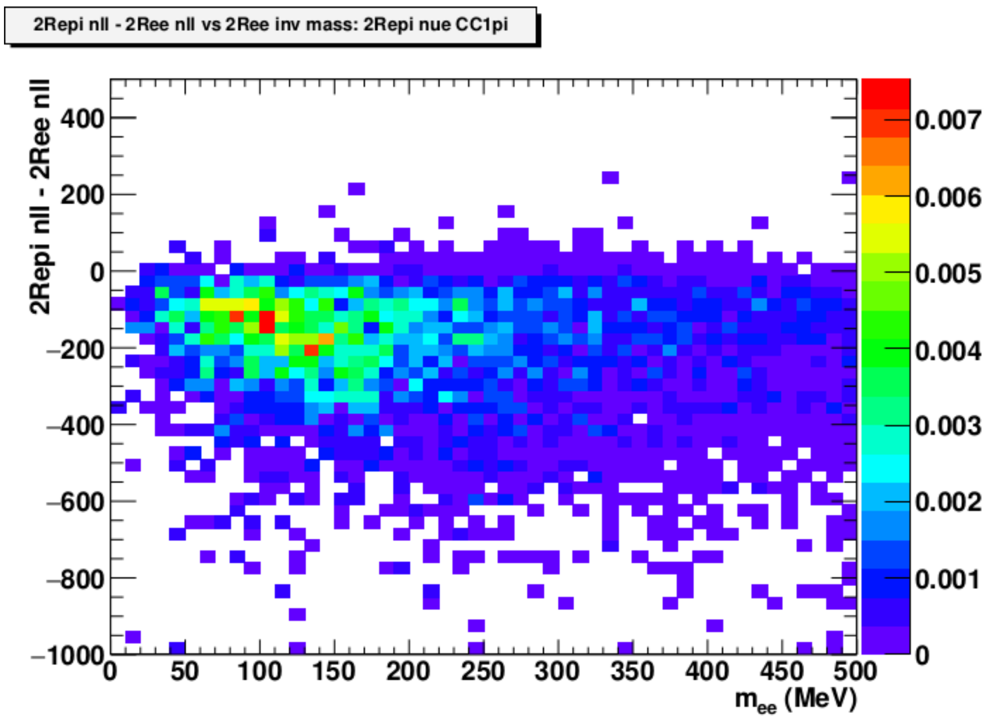
2Ree inv mass vs p_e: 2Repi numu NC1pi0
m_ee (MeV)
p_e (MeV/c)



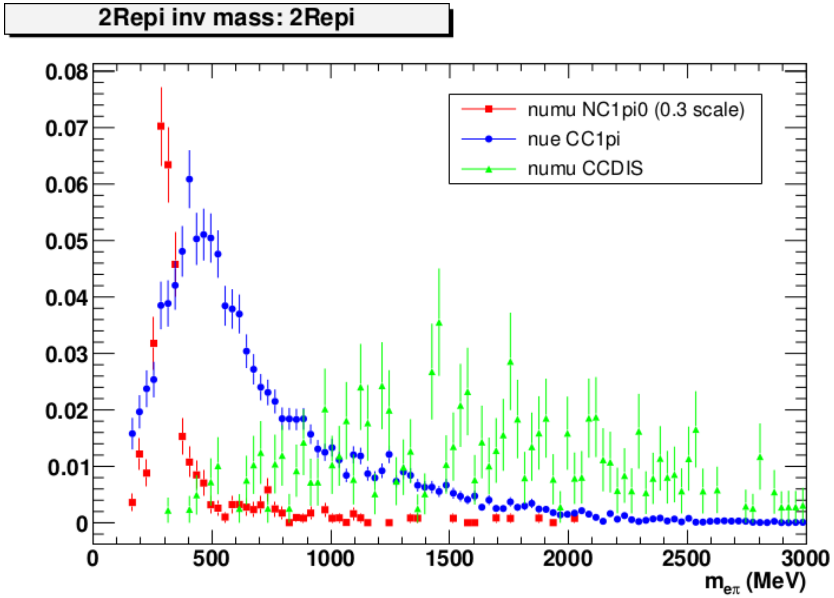
2Ree inv mass vs p_e: 2Repi nue CC1pi
m_ee (MeV)
p_e (MeV/c)

$nll_{2Re\pi} – nll_{2Ree}$ vs. m_{ee}

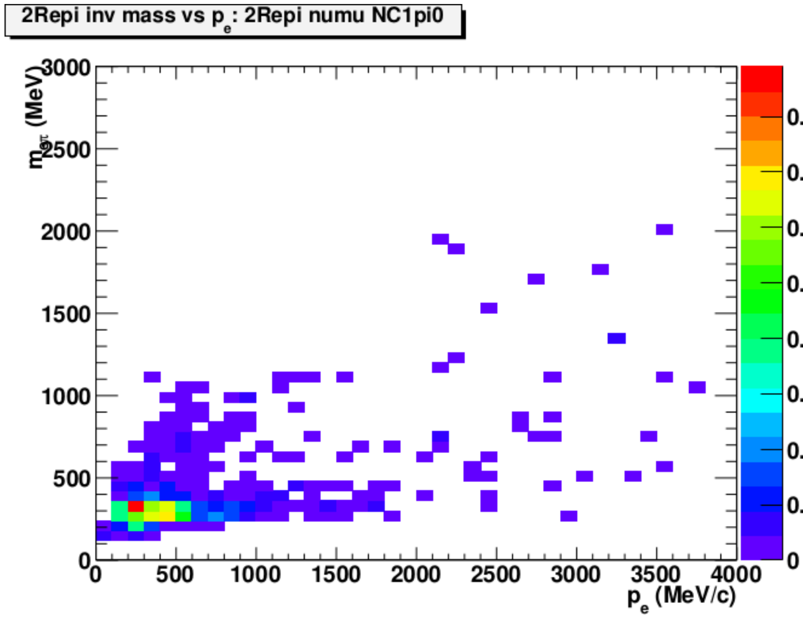




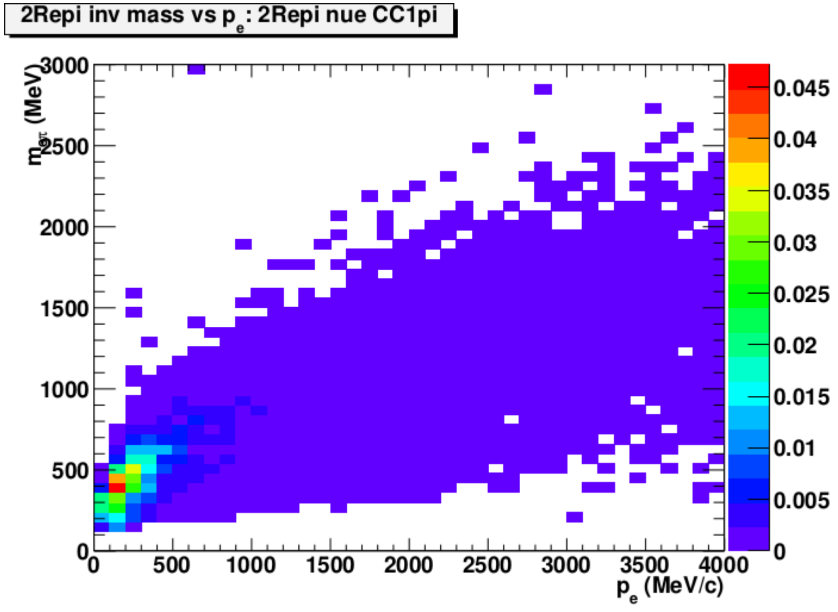
$m_{e\pi}$ (vs p_e)



2Repi inv mass: 2Repi
numu NC1pi0 (0.3 scale)
nue CC1pi
numu CCDIS
m_eπ (MeV)

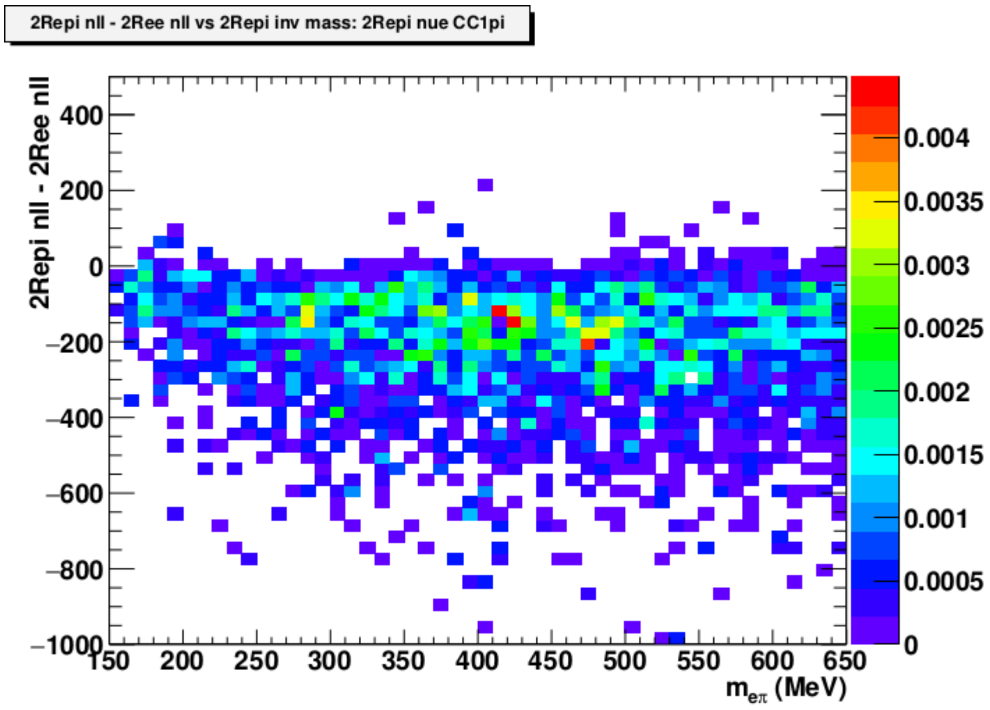


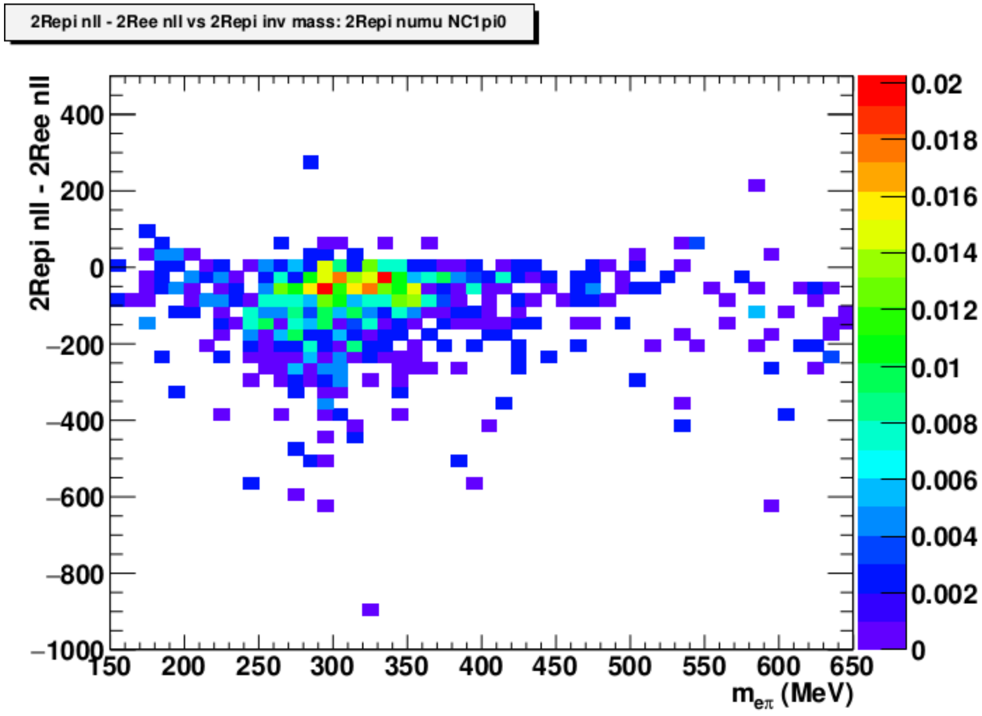
2Repi inv mass vs p_e: 2Repi numu NC1pi0
m_eπ (MeV)
p_e (MeV/c)



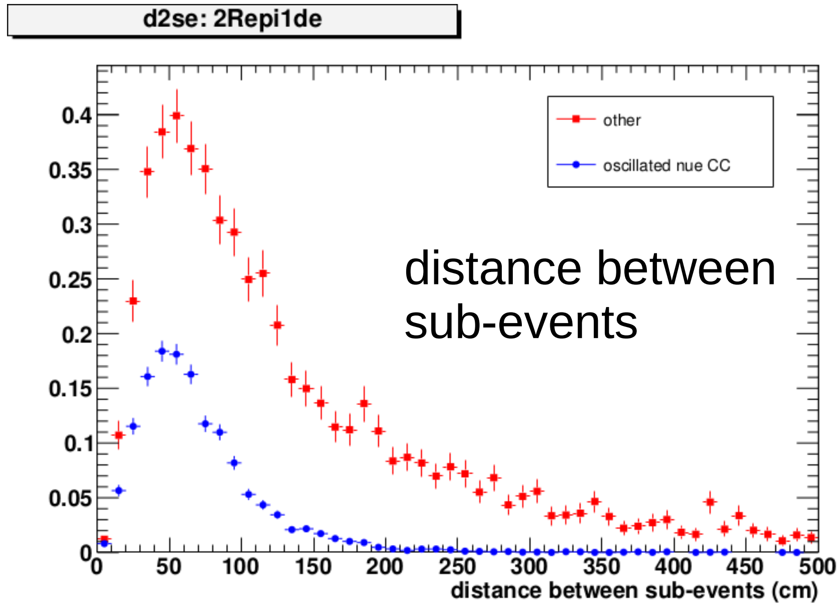
2Repi inv mass vs p_e: 2Repi nue CC1pi
m_eπ (MeV)
p_e (MeV/c)

$nll_{2Re\pi} – nll_{2Ree}$ vs. $m_{e\pi}$

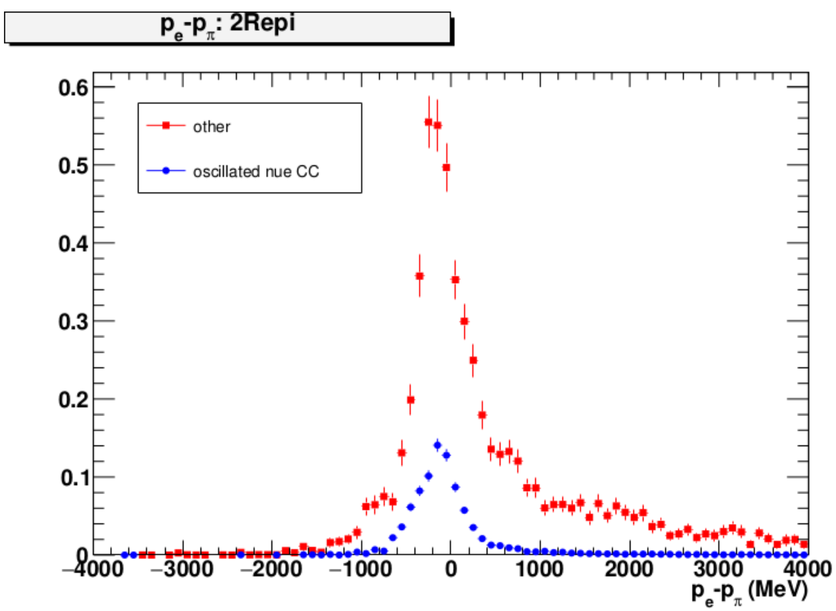


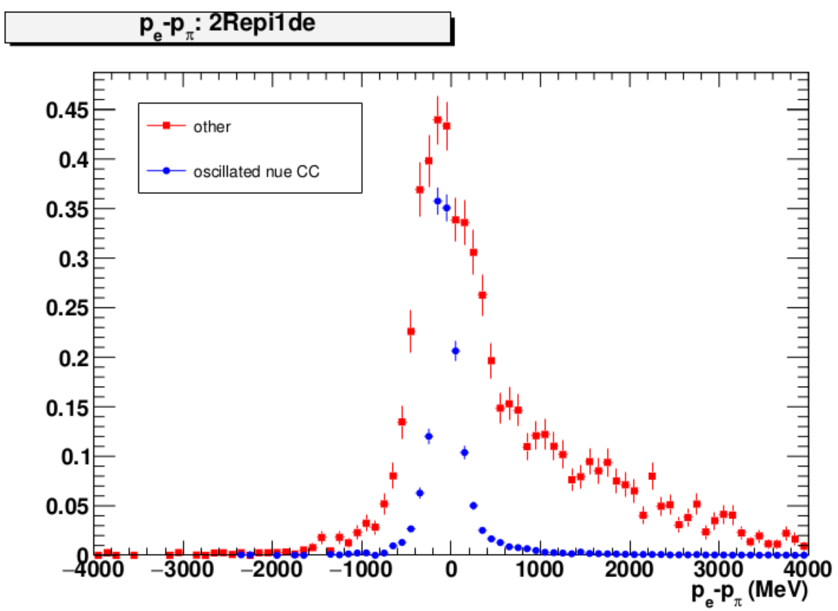


Other Useful Cuts

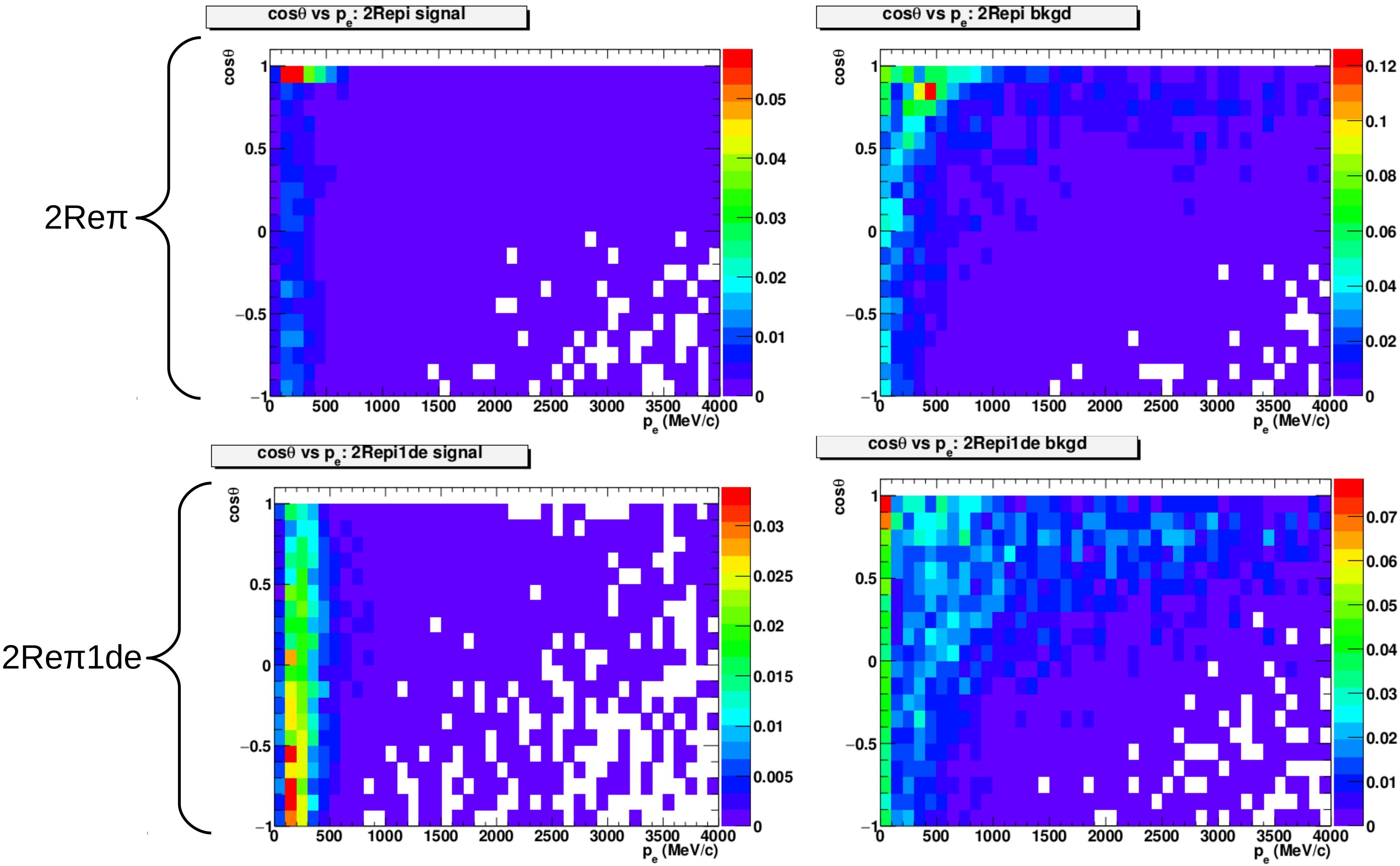


p_e-p_π





Potentially Useful: cos(θ)



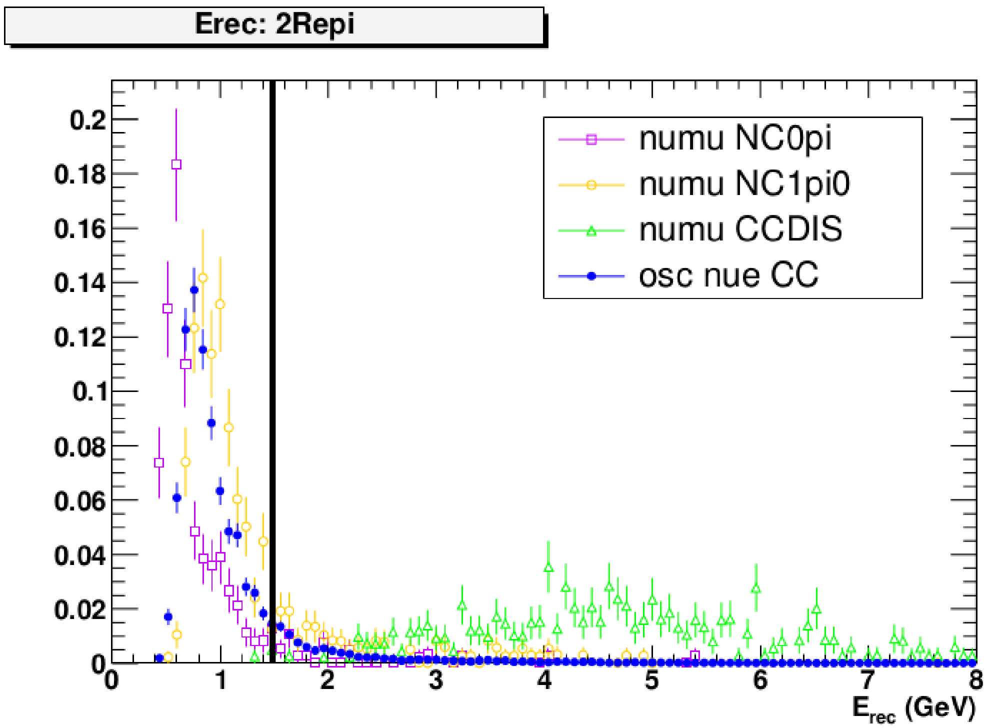
Cutflow Test (not optimized)

baseline: FCFV, 2 rings, eπ-like, 0 decay e (2Repi); FCFV, 2 rings, eπ-like, 1 decay e (2Repi1de)

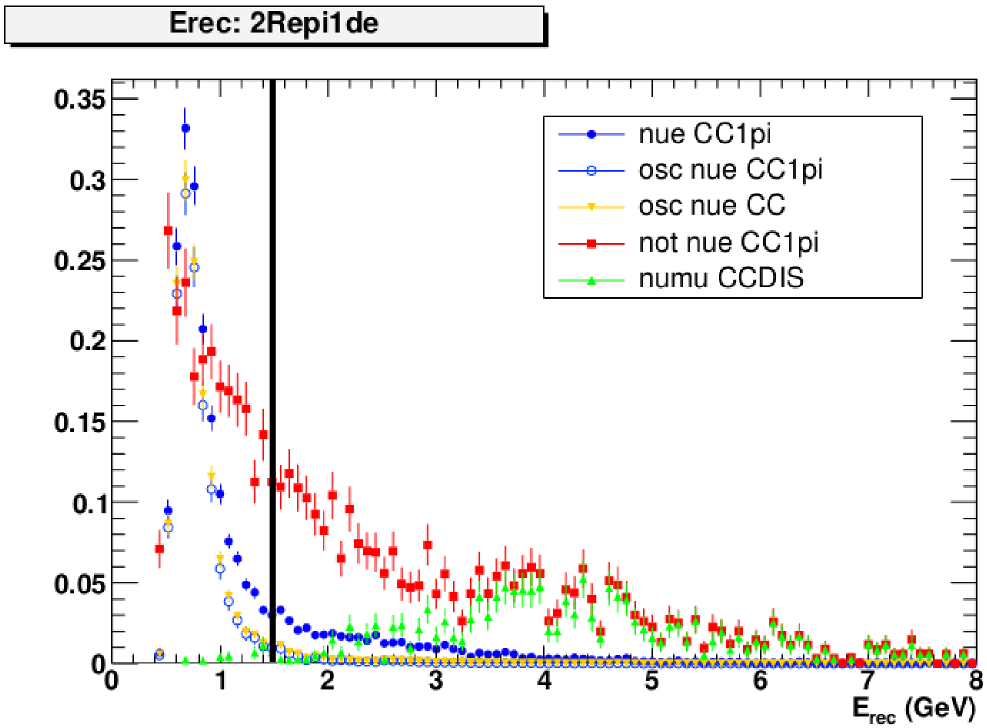
2Repi
FCFV
2 rings
eπ-like
0 decay e
E_{rec} < 1.5 GeV
$\|p_e - p_\pi\|$ < 800 MeV
$m_{e\pi}$ > 240 MeV || $nll_{2Re\pi} - nll_{1R\mu}$ < -700
$m_{e\pi}$<280 || $m_{e\pi}$>340 || $nll_{2Re\pi} - nll_{2Ree}$<-100 || $nll_{2Re\pi} - nll_{2Ree}$>0

2Repi1de
FCFV
2 rings
eπ-like
1 decay e
E_{rec} < 1.5 GeV
$\|p_e - p_\pi\|$ < 800 MeV
d2se < 200cm

E_{rec} < 1.5 GeV

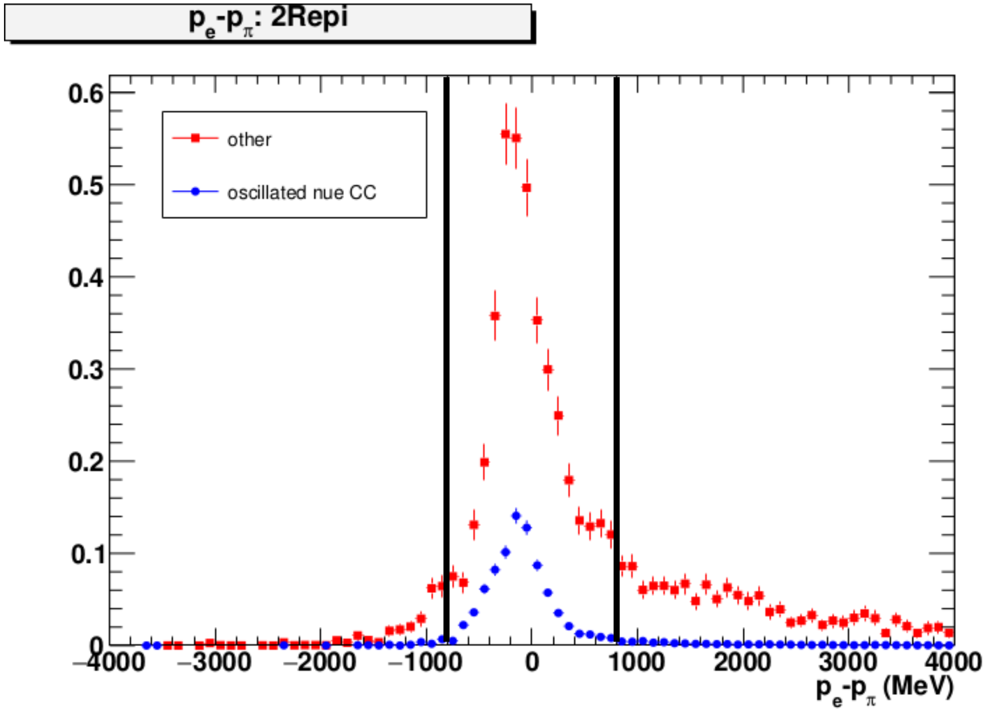


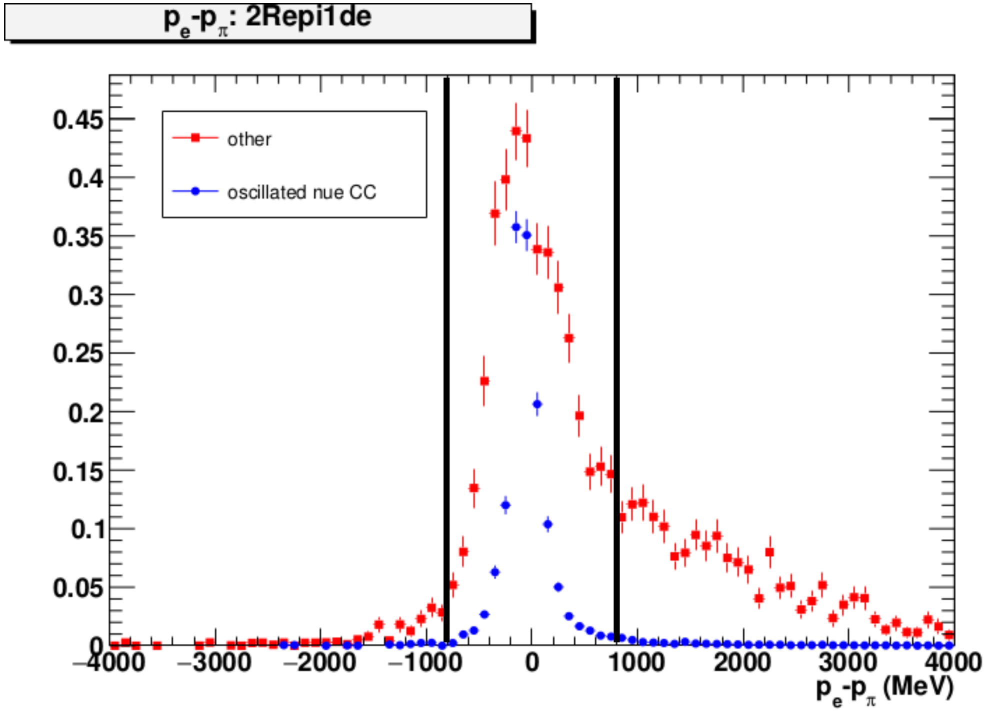
Erec: 2Repi
numu NC0pi
numu NC1pi0
numu CCDIS
osc nue CC
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
1
2
3
4
5
6
7
8
E_{rec} (GeV)



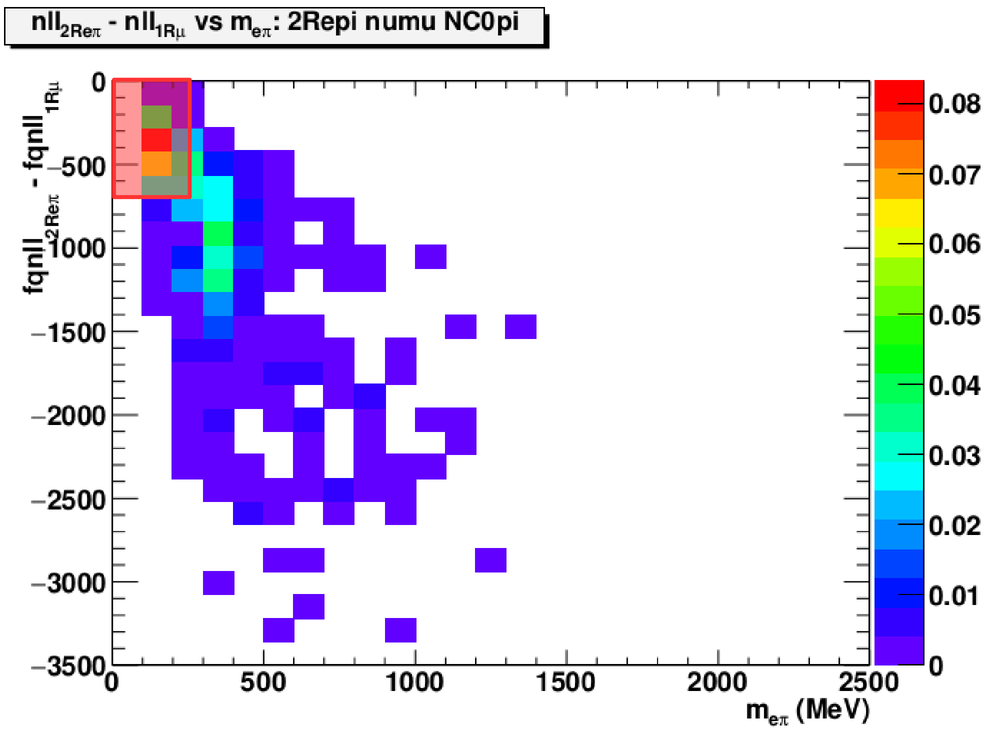
Erec: 2Repi1de
nue CC1pi
osc nue CC1pi
osc nue CC
not nue CC1pi
numu CCDIS
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0
1
2
3
4
5
6
7
8
E_{rec} (GeV)

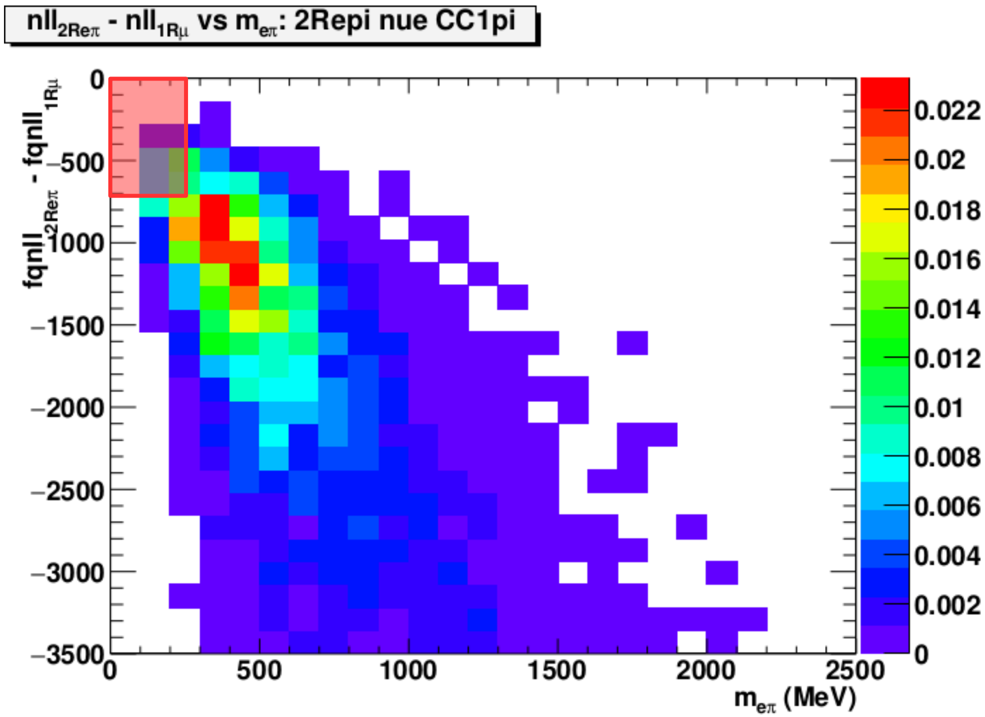
$|p_e - p_\pi| < 800\text{MeV}$





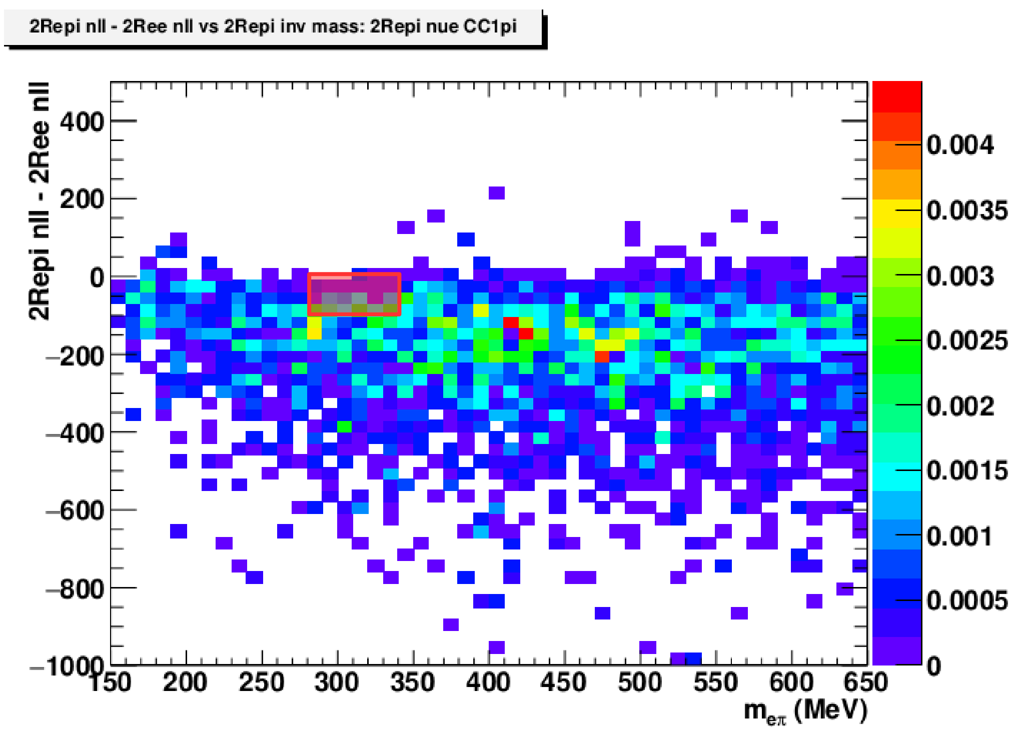
$m_{e\pi}$ > 240MeV || $nll_{2Re\pi}$-$nll_{1R\mu}$ < -700

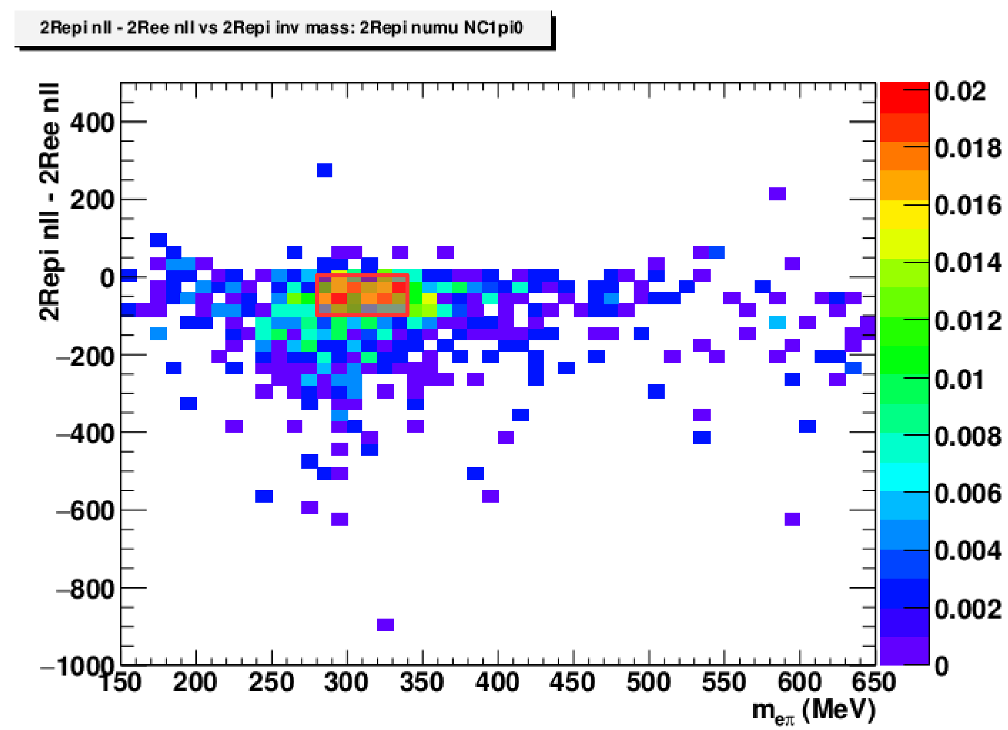




2Reπ only

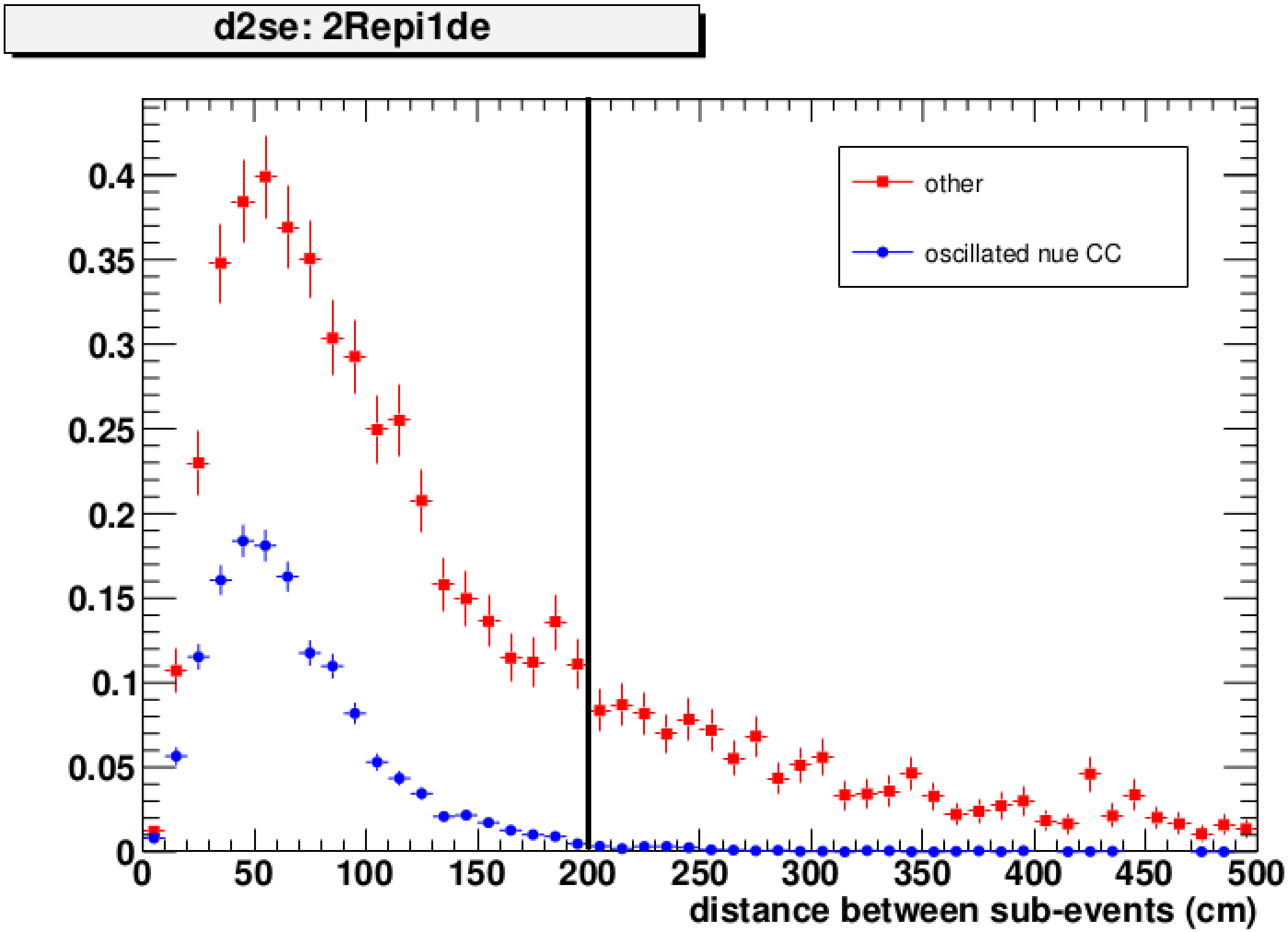
$m_{e\pi}<280 \mid\mid m_{e\pi}>340 \mid\mid$
$nll_{2Re\pi}-nll_{2Ree}<-100 \mid\mid nll_{2Re\pi}-nll_{2Ree}>0$





2Reπ only

d2se < 200 cm



2Reπ1de only

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	baseline	1.48	1.00	0.88	3.17	0.11	0.88	5.76	0.13	0.342
	E_{rec} < 1.5 GeV	0.28	0.41	0.79	2.45	0.08	0.79	3.22	0.20	0.392
	$\|p_e-p_\pi\|$ < 800 MeV	0.28	0.41	0.78	2.37	0.08	0.78	3.14	0.20	0.395
	$m_{e\pi}$ > 240 MeV || $nll_{2Re\pi}-nll_{1R\mu}$ < -700	0.25	0.40	0.72	1.87	0.06	0.72	2.58	0.22	0.398
	$m_{e\pi}$<280 || $m_{e\pi}$>340 || $nll_{2Re\pi}-nll_{2Ree}$<-100 || $nll_{2Re\pi}-nll_{2Ree}$>0	**0.24**	**0.40**	**0.70**	**1.54**	**0.05**	**0.70**	**2.22**	**0.24**	**0.410**
2Repi1de	baseline	3.35	1.14	1.43	1.63	0.06	1.43	6.18	0.19	0.517
	E_{rec} < 1.5 GeV	0.96	0.55	1.35	1.17	0.05	1.35	2.73	0.33	0.670
	$\|p_e-p_\pi\|$ < 800 MeV	0.95	0.55	1.35	1.14	0.05	1.35	2.68	0.33	0.672
	d2se < 200cm	**0.80**	**0.53**	**1.33**	**1.08**	**0.04**	**1.33**	**2.45**	**0.35**	**0.686**

signal = oscillated $\nu_e/\bar{\nu}_e$ CC

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
baseline	0.02	0.02	0.03	0.01	0.03	0.37	0.48	1.08	0.44	0.80
E_{rec} < 1.5 GeV	0.01	0.02	0.02	0.01	0.03	0.28	0.37	0.88	0.17	0.75
$\|p_e-p_\pi\|$ < 800 MeV	0.01	0.01	0.02	0.01	0.03	0.26	0.35	0.88	0.16	0.73
$m_{e\pi}$ > 240 MeV || $nll_{2Re\pi}-nll_{1R\mu}$ < -700	0.01	0.01	0.02	0.01	0.01	0.17	0.23	0.85	0.15	0.46
$m_{e\pi}$<280 || $m_{e\pi}$>340 || $nll_{2Re\pi}-nll_{2Ree}$<-100 || $nll_{2Re\pi}-nll_{2Ree}$>0	**0.01**	**0.01**	**0.02**	**0.00**	**0.01**	**0.17**	**0.21**	**0.62**	**0.14**	**0.39**

cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother	nue CC1pi	Other	Purity
baseline	1.09	0.49	0.30	0.11	0.07	1.29	1.09	5.55	0.16
E_{rec} < 1.5 GeV	0.71	0.34	0.14	0.09	0.06	0.14	0.71	3.30	0.18
$\|p_e-p_\pi\|$ < 800 MeV	0.71	0.34	0.14	0.09	0.06	0.14	0.71	3.21	0.18
$m_{e\pi}$ > 240 MeV || $nll_{2Re\pi}-nll_{1R\mu}$ < -700	0.69	0.31	0.13	0.08	0.04	0.13	0.69	2.62	0.21
$m_{e\pi}$<280 || $m_{e\pi}$>340 || $nll_{2Re\pi}-nll_{2Ree}$<-100 || $nll_{2Re\pi}-nll_{2Ree}$>0	**0.67**	**0.30**	**0.13**	**0.07**	**0.04**	**0.13**	**0.67**	**2.25**	**0.23**

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
baseline	0.02	0.01	0.00	0.02	0.02	0.50	0.19	0.13	0.44	0.37
E_{rec} < 1.5 GeV	0.02	0.01	0.00	0.01	0.02	0.43	0.12	0.06	0.21	0.35
$\|p_e-p_\pi\|$ < 800 MeV	0.01	0.01	0.00	0.01	0.02	0.41	0.11	0.06	0.21	0.34
d2se < 200 cm	**0.01**	**0.01**	**0.00**	**0.01**	**0.01**	**0.39**	**0.11**	**0.06**	**0.20**	**0.32**

cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother	nue CC1pi	Other	Purity
baseline	2.19	0.06	0.31	0.49	0.05	2.81	2.19	5.42	0.29
E_{rec} < 1.5 GeV	1.74	0.03	0.13	0.35	0.04	0.57	1.74	2.34	0.43
$\|p_e-p_\pi\|$ < 800 MeV	1.74	0.03	0.13	0.34	0.04	0.57	1.74	2.30	0.43
d2se < 200 cm	**1.71**	**0.03**	**0.13**	**0.29**	**0.03**	**0.47**	**1.71**	**2.07**	**0.45**

Thoughts

- Which energy reconstruction method should be used?
- 2Reπ has significantly more backgrounds
  - ν_μ NC $1\pi^0$ background has been difficult to reduce
  - ν_μ NC 0π background reduced somewhat effectively
- Starting to prepare code for grid search