Progress Update

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UofT Neutrino/DM Meeting
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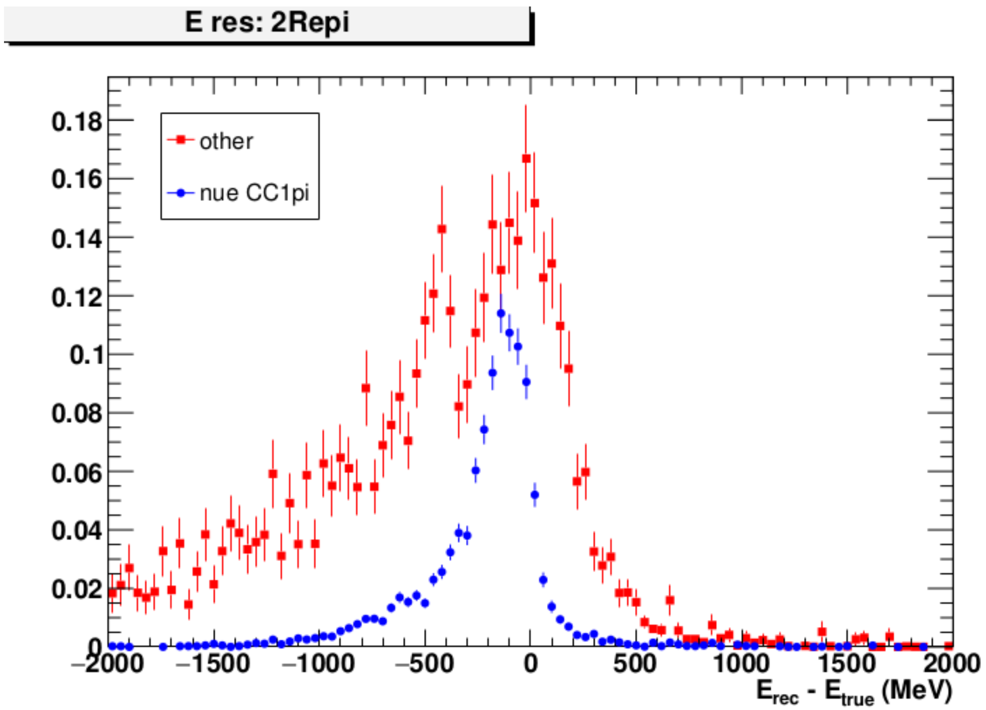
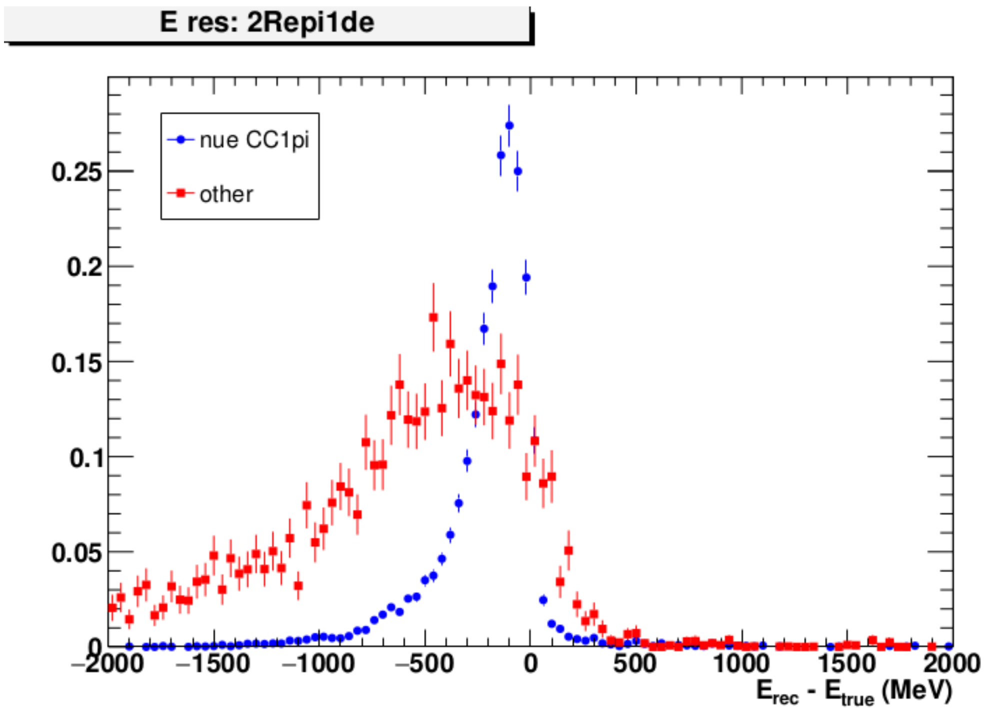
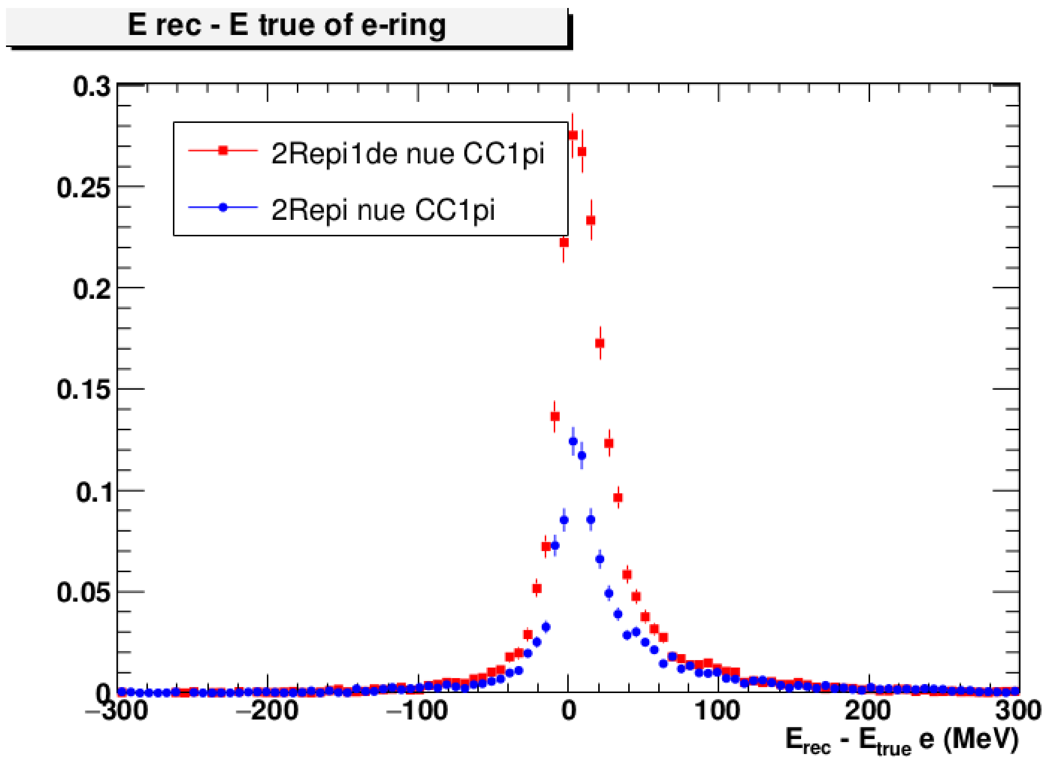
Energy Resolution

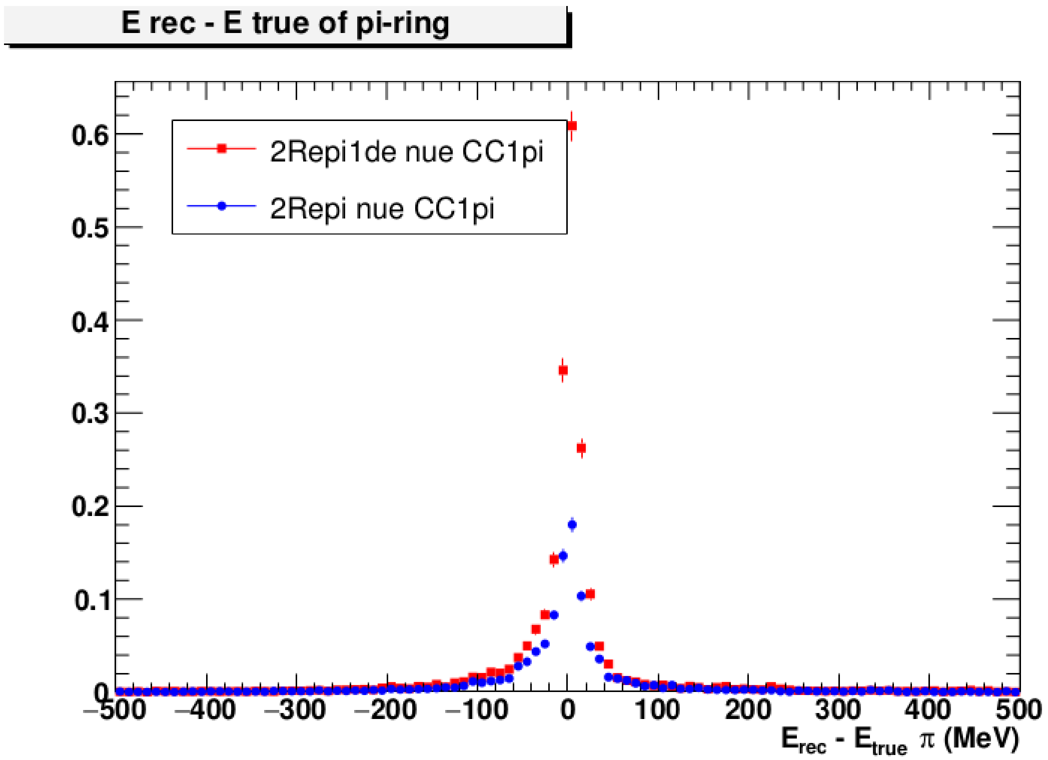





```
double Ee = sqrt(me*me + pe*pe);
double Epi = sqrt(mpi*mpi + ppi*ppi);
double Enu = Ee + Epi
```

Individual ring energy resolution

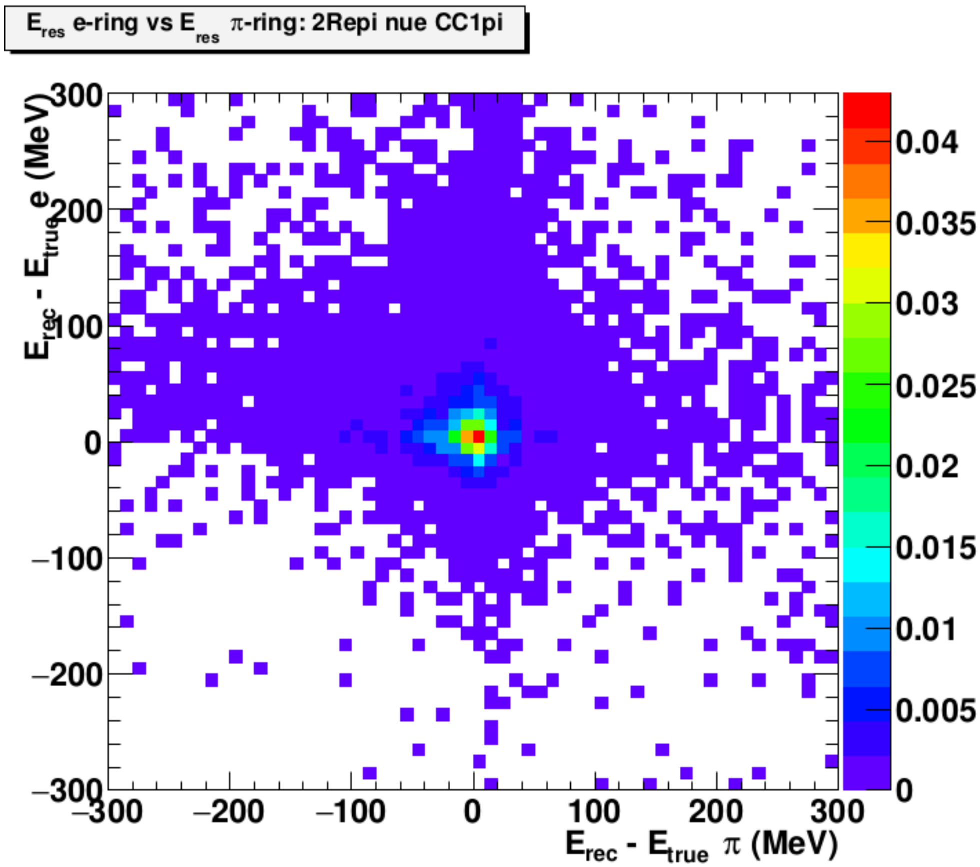


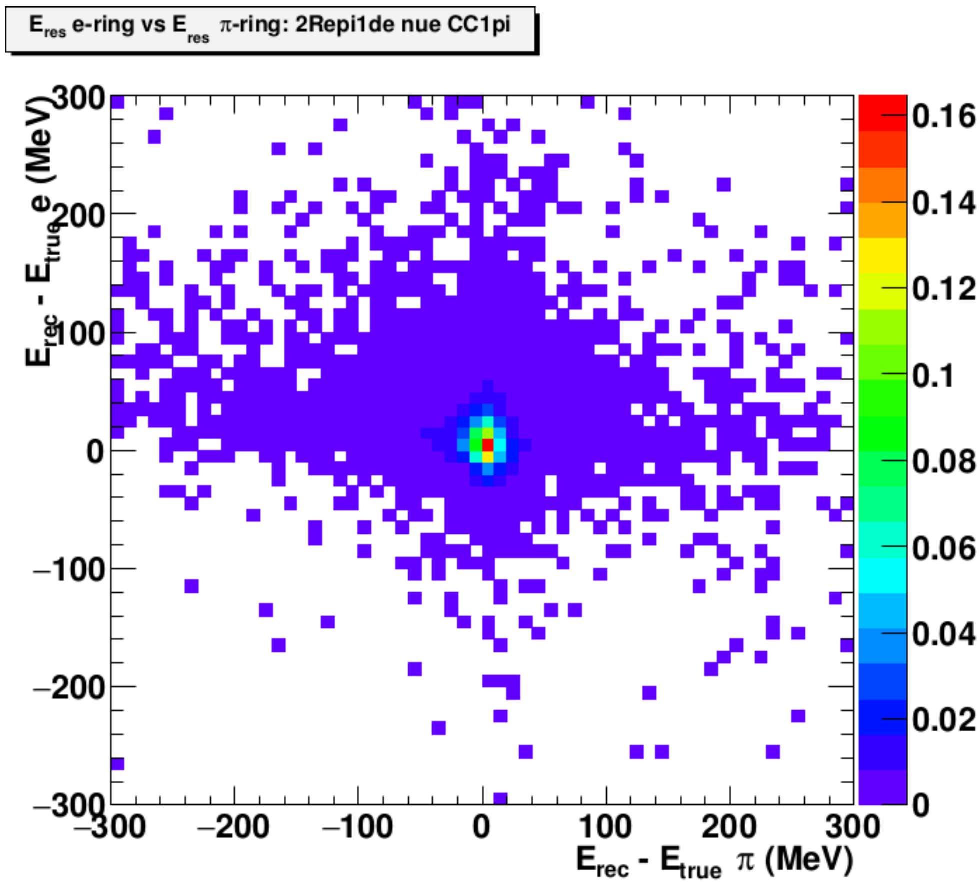


- No clear source of missing energy
- pions identified using VCWORK block

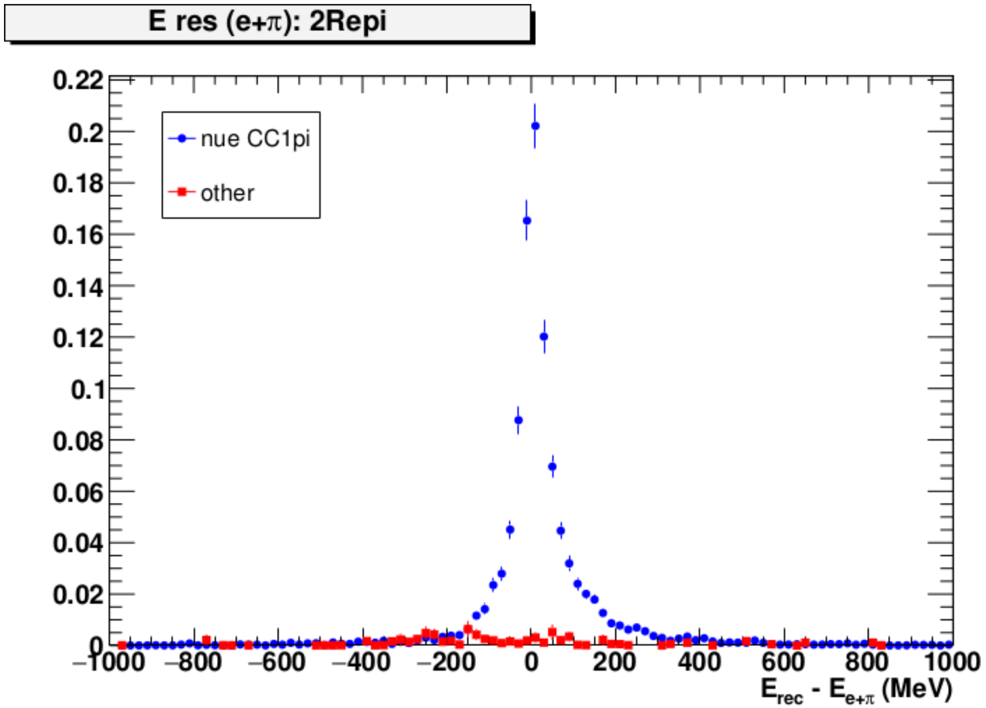
```
if (int_mode==1 && (Is2repi_exp || Is2repi1de_exp)){ // if true CC1pi event, determine energy resolution of e and pi rings (if they pass in 2Repi or 2Repi1de selections)
  Erese = sqrt(0.511*0.511 + fqmrmom[0][iering]*fqmrmom[0][iering]) - sqrt(0.511*0.511 + 1000000.*pnu[2]*pnu[2]);
  for (int i=0; i<Npvc; i++){
    if (abs(Ipvc[i])==PIDarr[ipip] && Ichvc[i]==1){
      Erespi = sqrt(139.57*139.57 + fqmrmom[0][ipiring]*fqmrmom[0][ipiring]) - sqrt(139.57*139.57 + Abspvc[i]*Abspvc[i]);
      ispi = true;
      break;
    }
  }

}
```

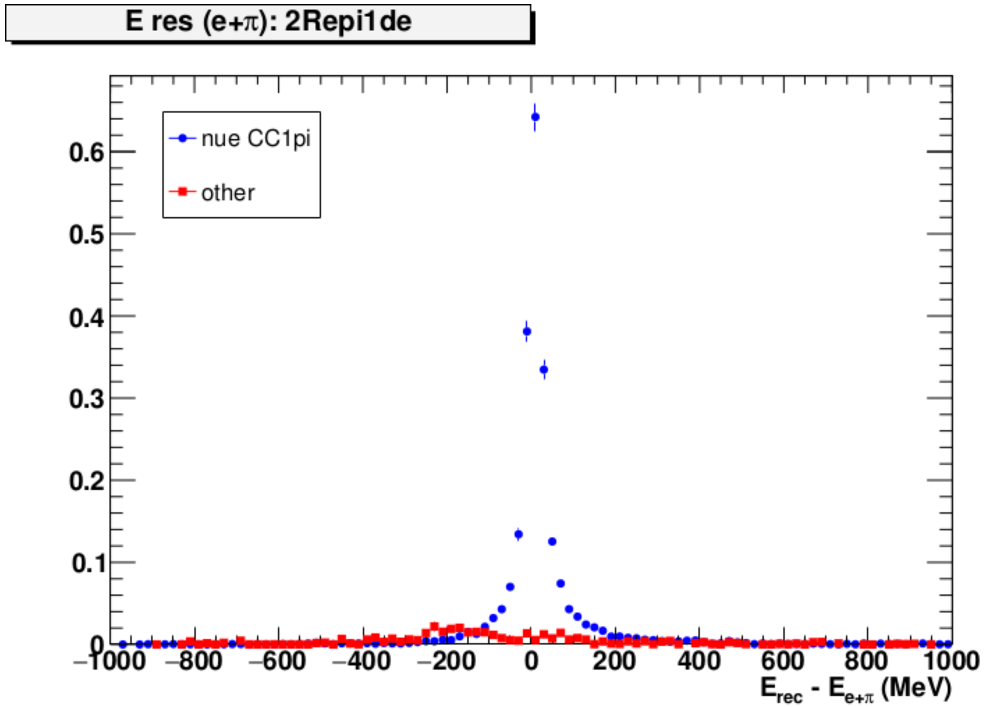
Eres e-ring vs. Eres pi-ring





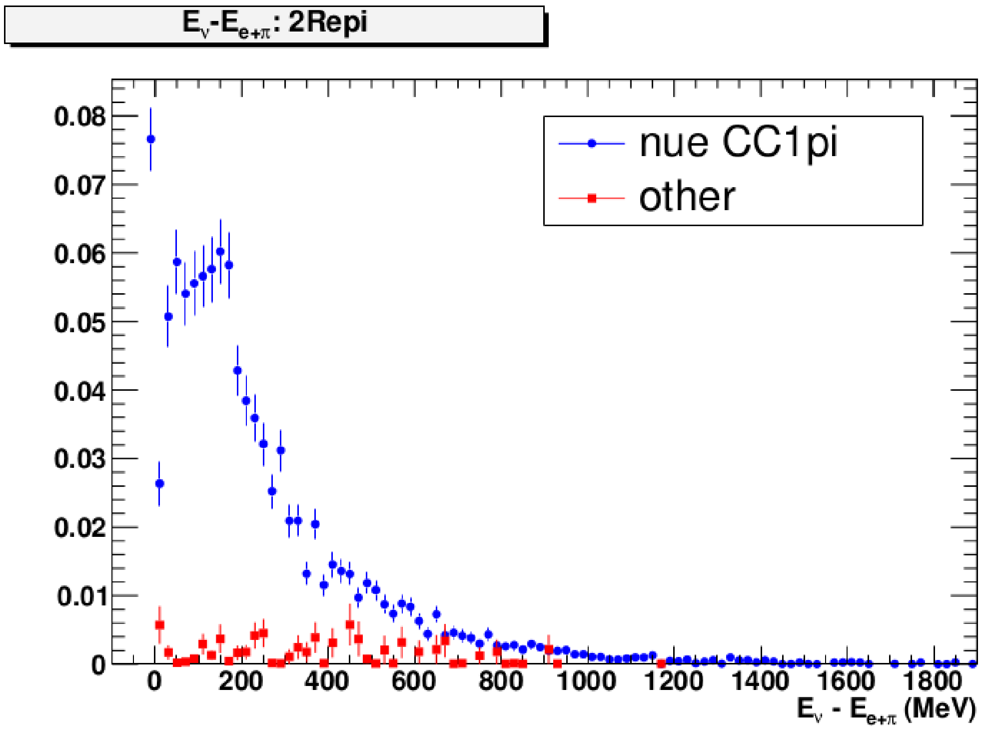
Energy Resolution (relative to true E of e + pi rings)

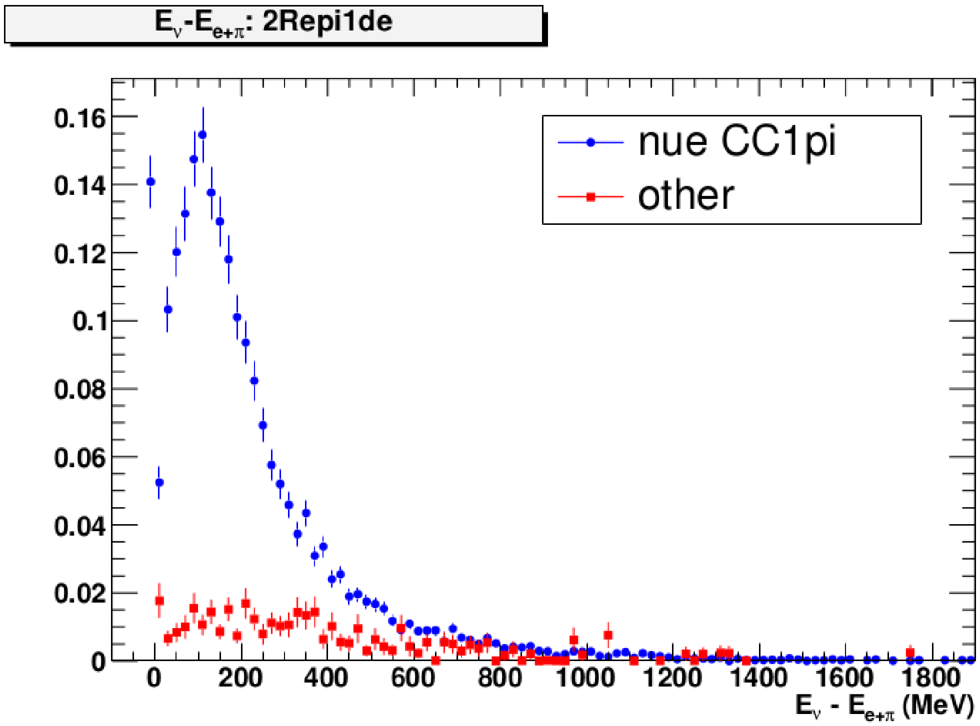




Energy reconstruction of rings seems to perform well

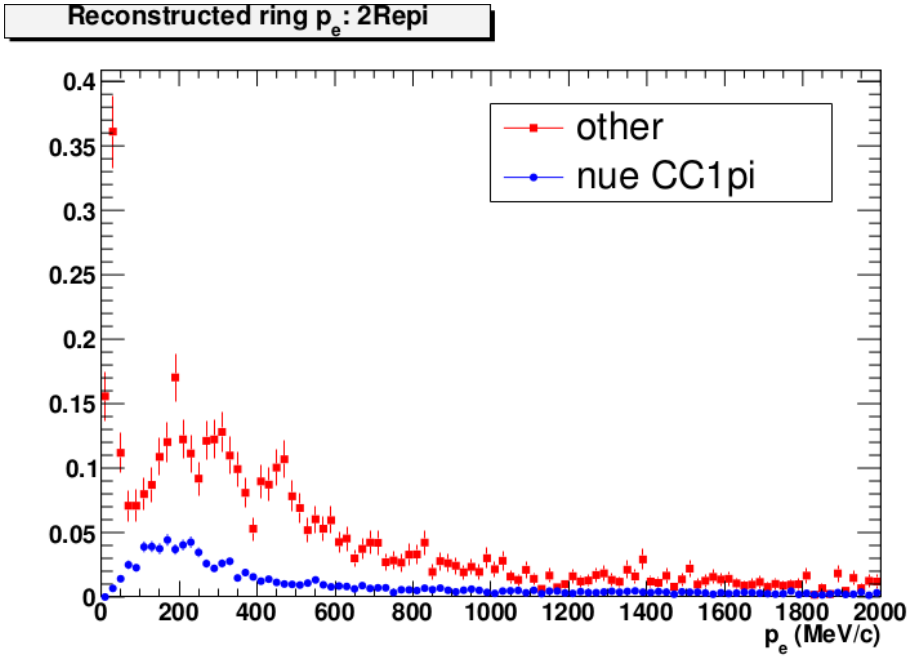
E true nu – E true e+pi

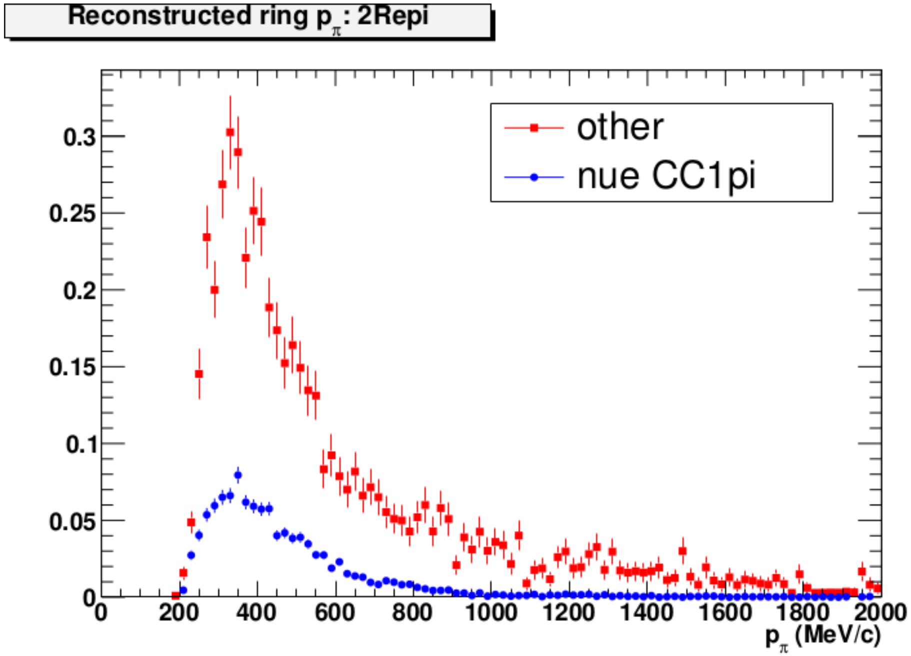


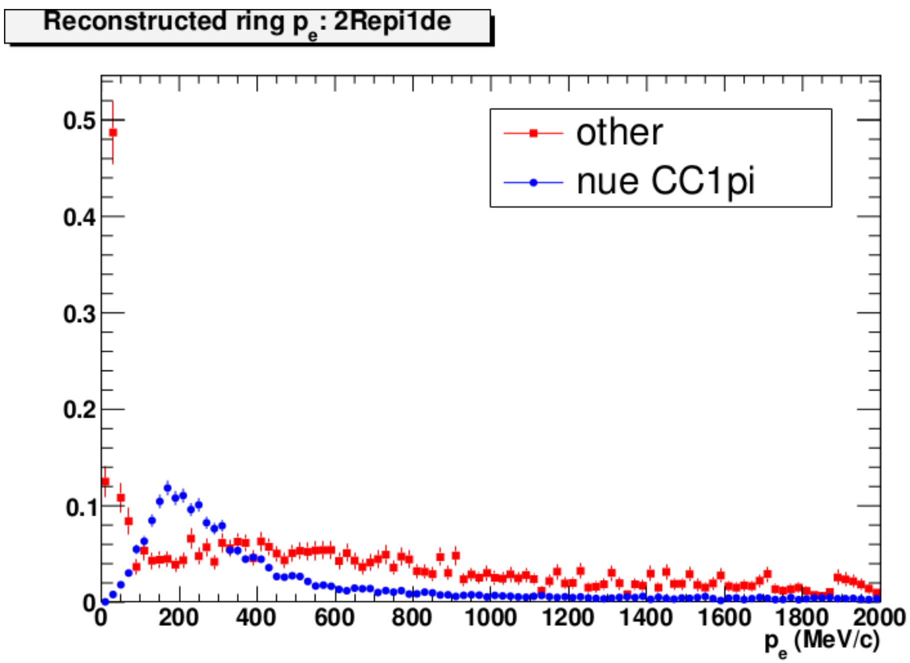


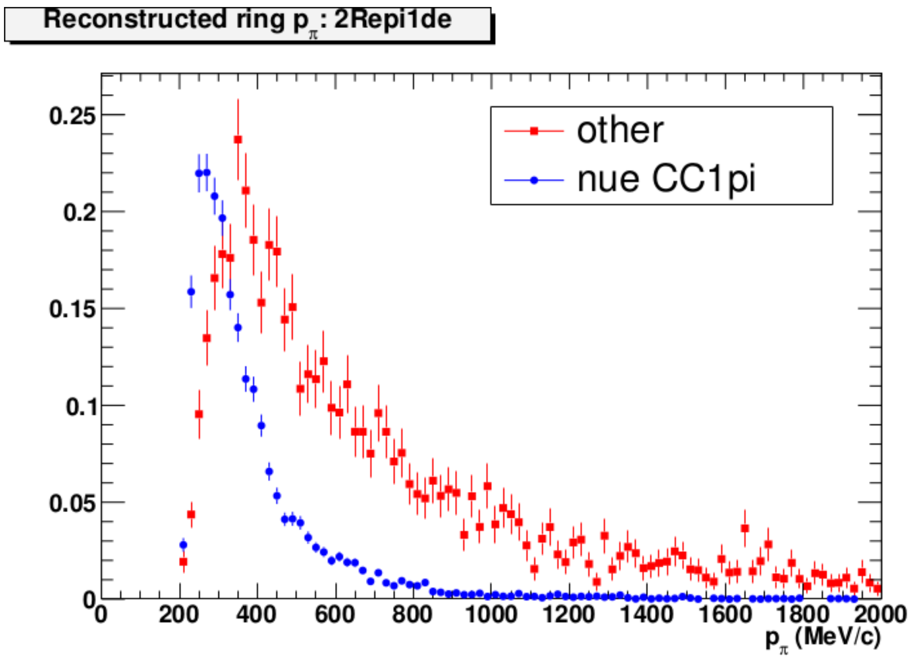
Missing energy is apparent

Reconstructed Ring Momenta



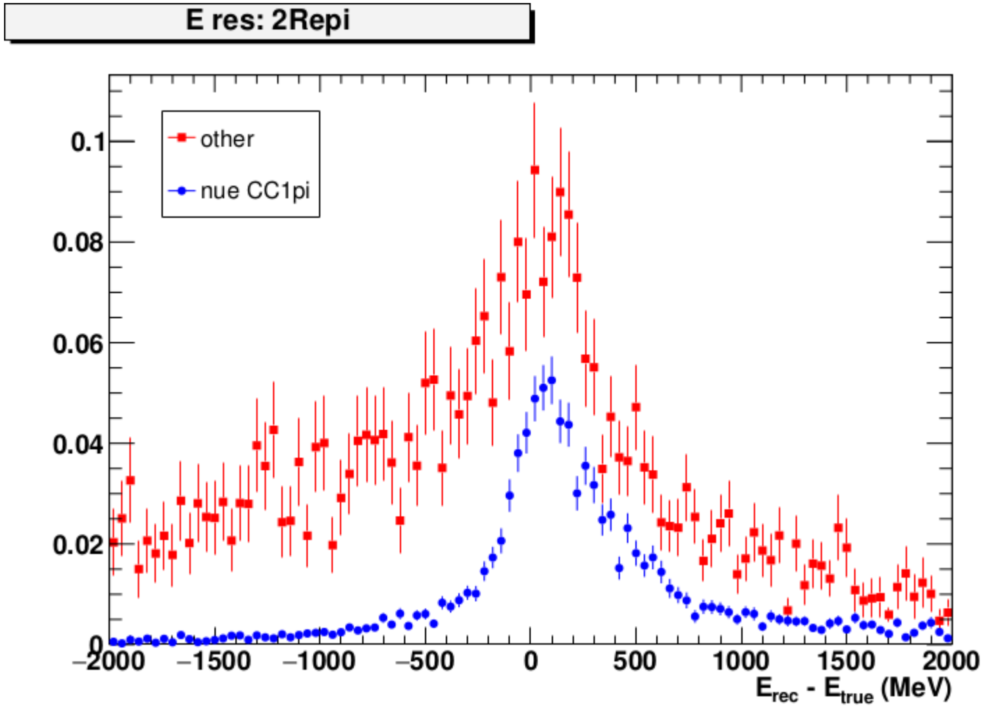


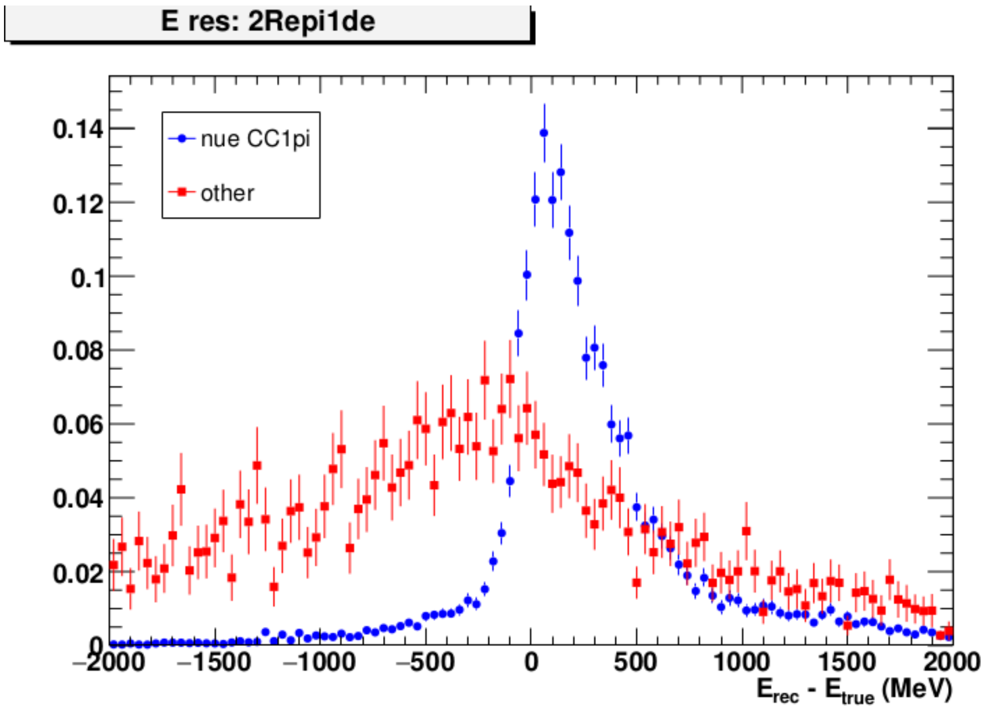




Energy Resolution: method 2

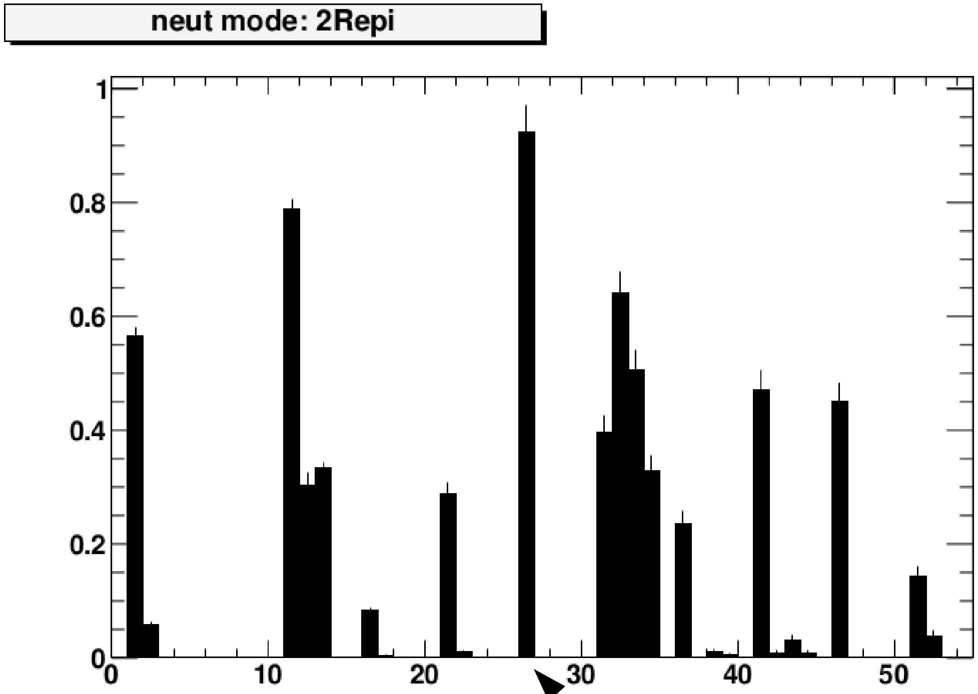
From Sophie's slides: $$E_\nu = \frac{m_\mu^2 + m_{\pi^+}^2 - 2m_N(E_\mu + E_{\pi^+}) + 2p_\mu \cdot p_{\pi^+}}{2(E_\mu + E_{\pi^+} - |p_\mu|\cos\theta_{\nu\mu} - |p_{\pi^+}|\cos\theta_{\nu\pi^+} - m_N)}$$

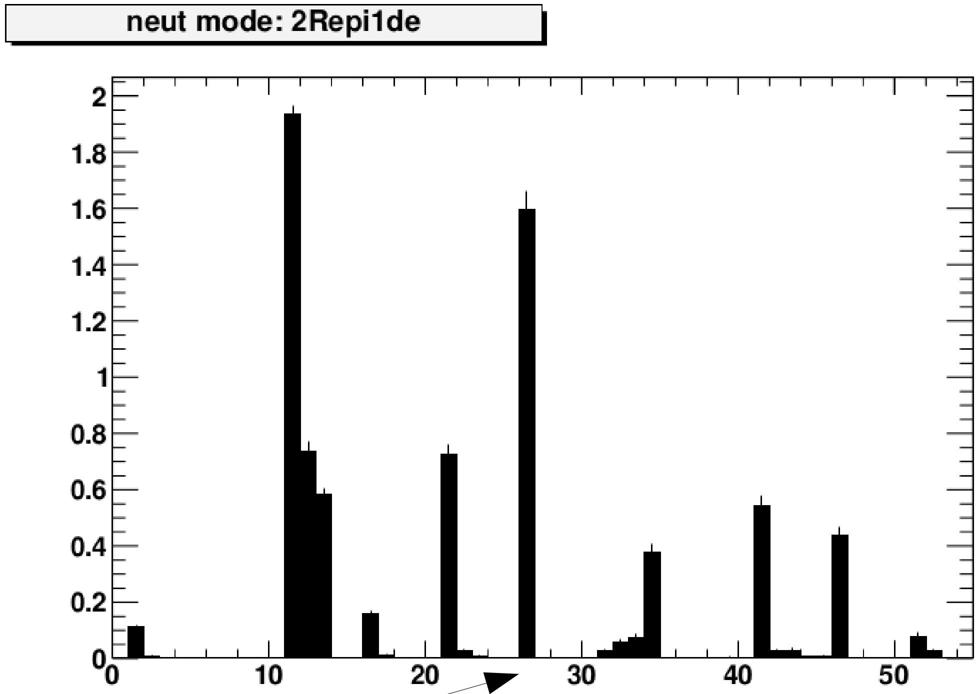





```
double Ee = sqrt(me*me + pe*pe);
double Epi = sqrt(mpi*mpi + ppi*ppi);
double cosnue = dnu[0]*de[0] + dnu[1]*de[1] + dnu[2]*de[2];
double cosnupi = dnu[0]*dpi[0] + dnu[1]*dpi[1] + dnu[2]*dpi[2];
double cosepi = de[0]*dpi[0] + de[1]*dpi[1] + de[2]*dpi[2];

double numerator   = me*me + mpi*mpi - 2*mN*(Ee+Epi) + 2*pe*ppi*cosepi;
double denominator = 2*(Ee + Epi - pe*cosnue - ppi*cosnupi - mN);
Enu = numerator / denominator;
```

Investigating Backgrounds





neut mode 26 – CC DIS

particularly numu CC DIS (see next slide)

Sample	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
2Repi	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>100MeV	0.01	0.01	0.03	0.01	0.01	0.22	0.29	1.08	0.42	0.48
	|p_e-p_pi|<800MeV	**0.01**	**0.01**	**0.03**	**0.01**	**0.01**	**0.16**	**0.23**	**0.97**	**0.23**	**0.44**
2Repi1de	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>100MeV	0.01	0.00	0.00	0.01	0.01	0.18	0.12	0.13	0.36	0.14
	|p_e-p_pi|<800MeV	0.01	0.00	0.00	0.01	0.01	0.13	0.08	0.09	0.24	0.12
	d2se<200cm	**0.01**	**0.00**	**0.00**	**0.01**	**0.01**	**0.12**	**0.07**	**0.08**	**0.22**	**0.11**

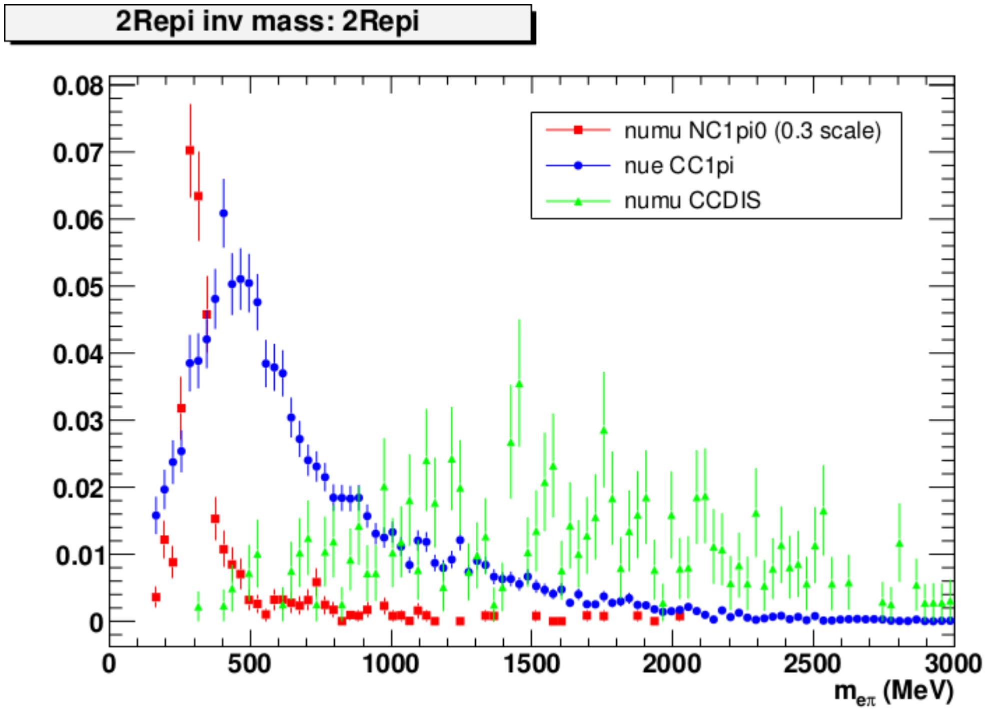
Sample	cut	nue CC1pi	nue CCQE	nue CCother	numu CC1pi	numu CCQE	numu CCother	Signal	Background	Purity	FOM
2Repi	FCFV	19.07	32.69	18.11	93.86	126.25	194.71	19.07	638.71	0.03	0.74
	2 rings	5.03	2.19	2.88	29.36	10.50	26.18	5.03	156.23	0.03	0.40
	epi-like	3.33	0.56	0.74	0.94	0.14	5.66	3.33	13.41	0.20	0.81
	0 decay e	1.09	0.49	0.30	0.11	0.07	1.29	1.09	5.55	0.16	0.42
	p_e>100MeV	1.02	0.49	0.29	0.10	0.04	1.29	1.02	4.78	0.18	0.42
	|p_e-p_pi|<800MeV	**0.75**	**0.37**	**0.18**	**0.09**	**0.04**	**0.56**	**0.75**	**3.34**	**0.18**	**0.37**
2Repi1de	FCFV	19.07	32.69	18.11	93.86	126.25	194.71	19.07	638.71	0.03	0.74
	2 rings	5.03	2.19	2.88	29.36	10.50	26.18	5.03	156.23	0.03	0.40
	epi-like	3.33	0.56	0.74	0.94	0.14	5.66	3.33	13.41	0.20	0.81
	1 decay e	2.19	0.06	0.31	0.49	0.05	2.81	2.19	5.42	0.29	0.79
	p_e>100MeV	2.08	0.06	0.31	0.41	0.05	2.79	2.08	4.57	0.31	0.81
	|p_e-p_pi|<800MeV	1.74	0.04	0.18	0.37	0.04	1.44	1.74	2.76	0.39	0.82
	d2se<200cm	**1.70**	**0.03**	**0.17**	**0.27**	**0.03**	**0.77**	**1.70**	**1.89**	**0.47**	**0.90**

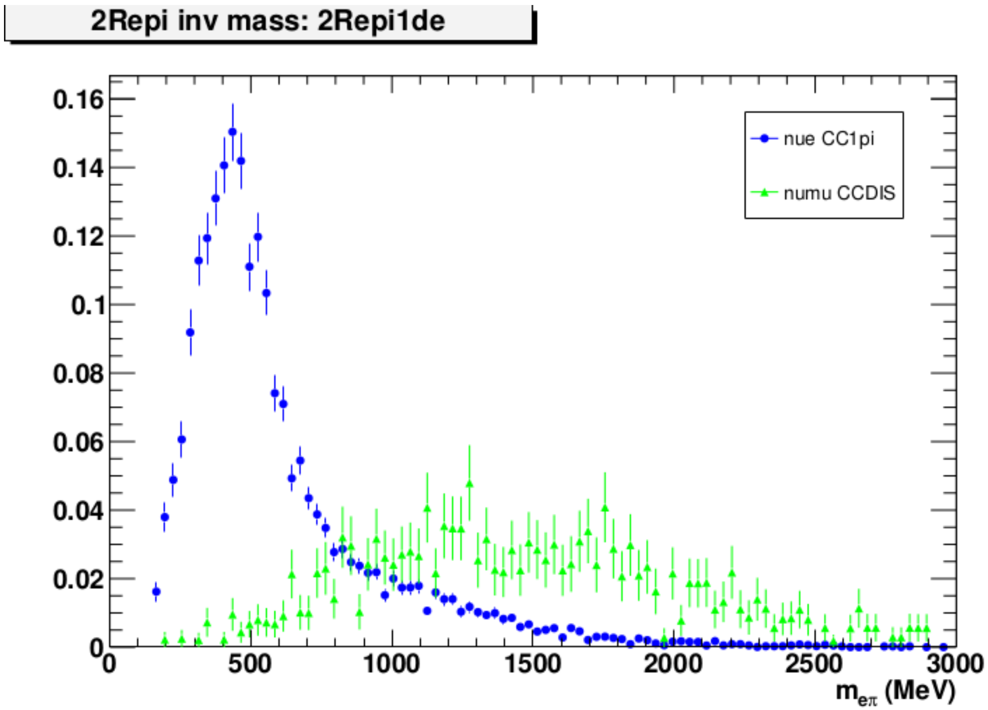
signal = nue CC1pi

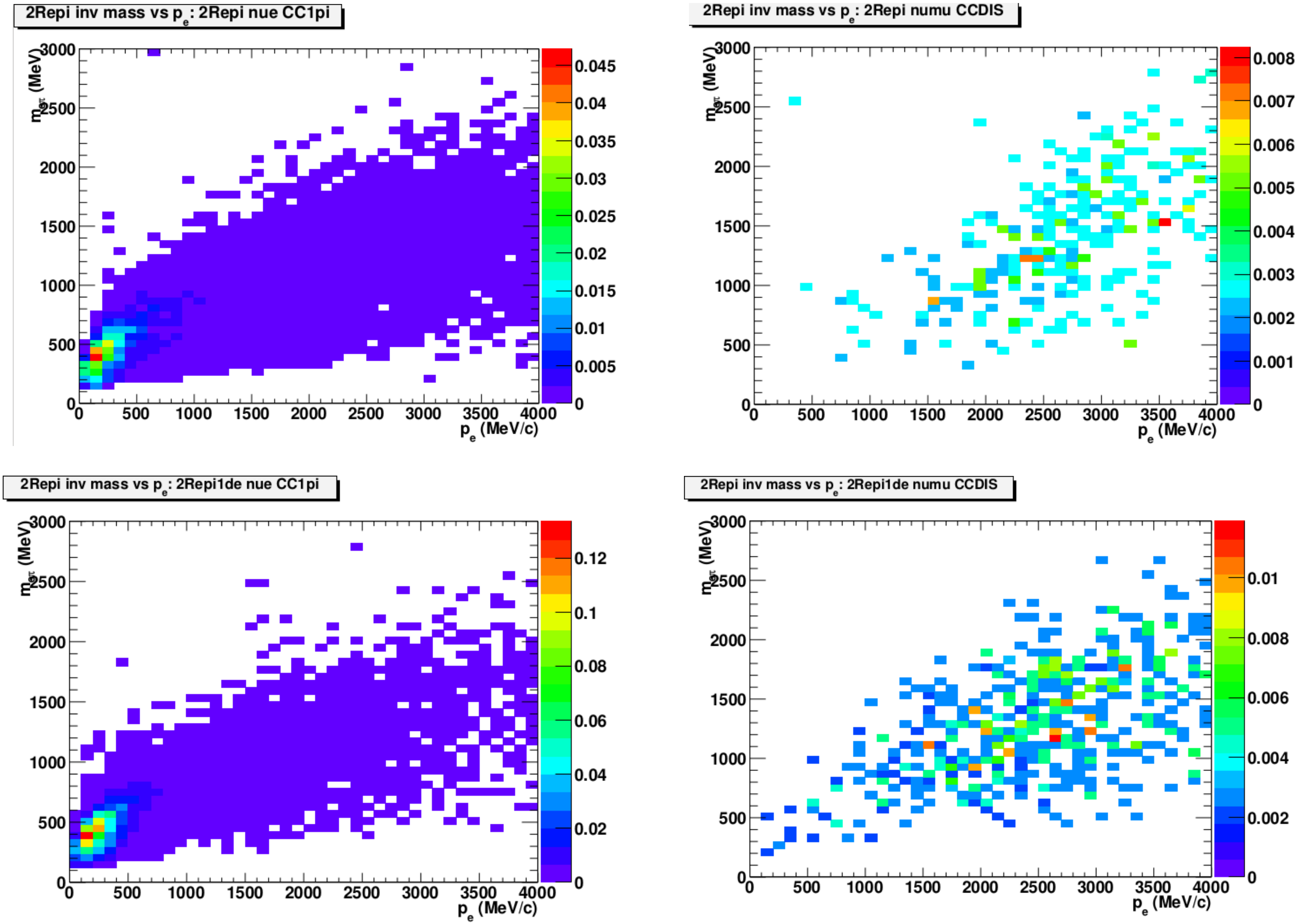
numu CC DIS investigation

- numu CC DIS is another major background for both 2Repi and 2Repi1de selections
- Based on expectation that DIS is more prominent at higher energies:
  - Look at numu CC DIS behaviour with p_e and reconstructed e+pi mass
  - plot best 2R fit nll – best 3R fit nll
    - Encountered issue: most events don’t actually have 3R fits
  - Other recommendations?

Invariant Mass






2Repi inv mass vs p_e: 2Repi nue CC1pi
2Repi inv mass vs p_e: 2Repi numu CCDIS
2Repi inv mass vs p_e: 2Repi1de nue CC1pi
2Repi inv mass vs p_e: 2Repi1de numu CCDIS
m_eπ (MeV)
p_e (MeV/c)

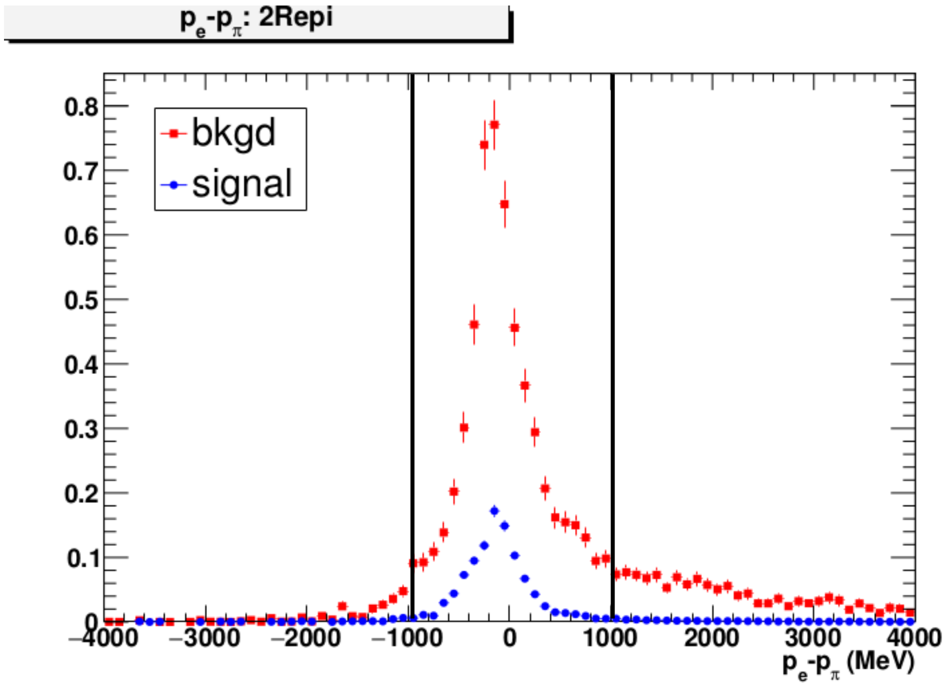
Cutflow Test

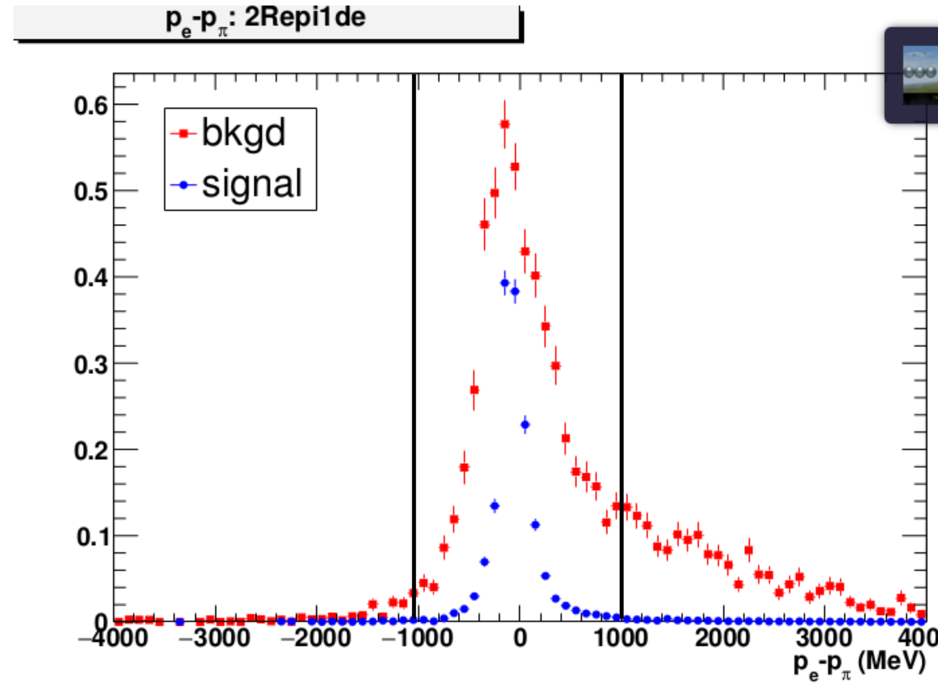
<table>
<tr><th>2Repi</th></tr>
<tr><td>FCFV</td></tr>
<tr><td>2 rings</td></tr>
<tr><td>epi-like</td></tr>
<tr><td>0 decay e</td></tr>
<tr><td>|p_e-p_pi| < 1000 MeV</td></tr>
<tr><td>cos<0.7 || cos>0.9</td></tr>
<tr><td>m_epi<260 || m_epi>350 || 2repi_nll-2ree_nll<-150 || 2repi_nll-2ree_nll>50</td></tr>
<tr><td>p_e<2200 || p_e>3700 || m_epi<1100 || m_epi>1800</td></tr>
</table>

<table>
<tr><th>2Repi1de</th></tr>
<tr><td>FCFV</td></tr>
<tr><td>2 rings</td></tr>
<tr><td>epi-like</td></tr>
<tr><td>1 decay e</td></tr>
<tr><td>|p_e-p_pi| < 1000 MeV</td></tr>
<tr><td>cos<0.7 || cos>0.9</td></tr>
<tr><td>p_e<1800 || p_e>3400 || m_epi<900 || m_epi>1800</td></tr>
<tr><td>d2se<200</td></tr>
</table>

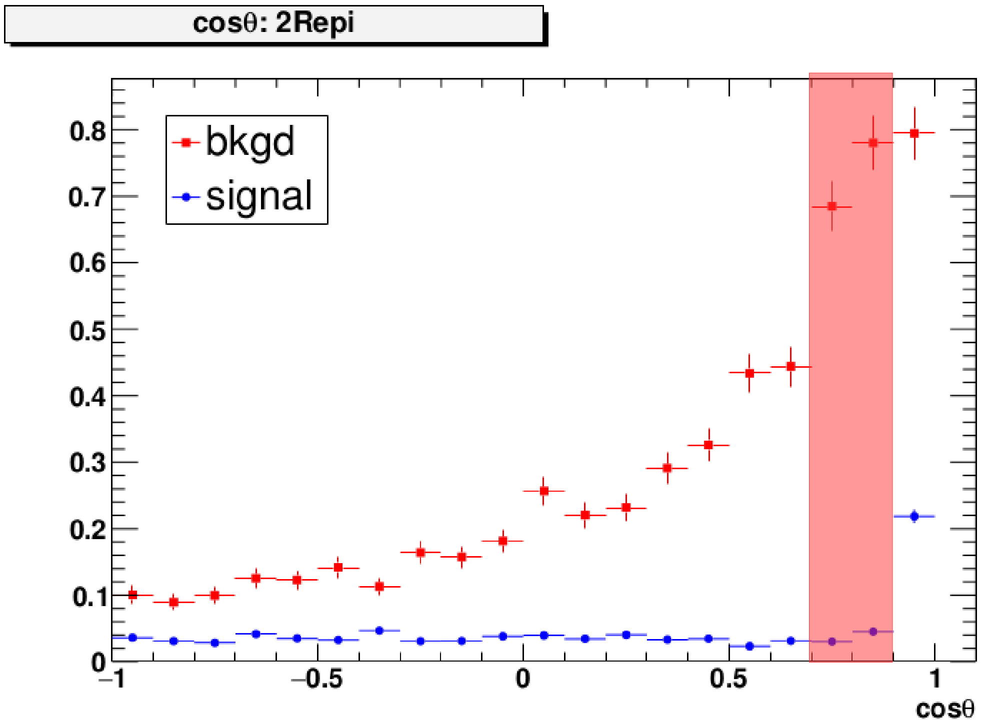
FCFV: evclass==1 && evis>30. && nhitac<16 && fqwall_2r>100.

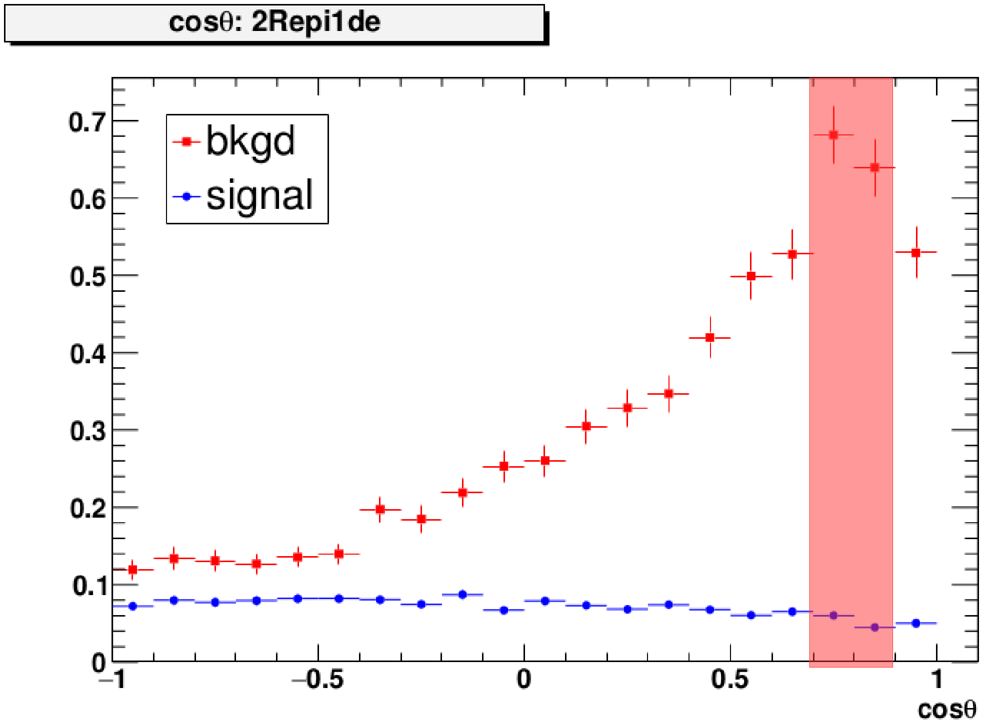
|p_e-p_pi| < 1000MeV



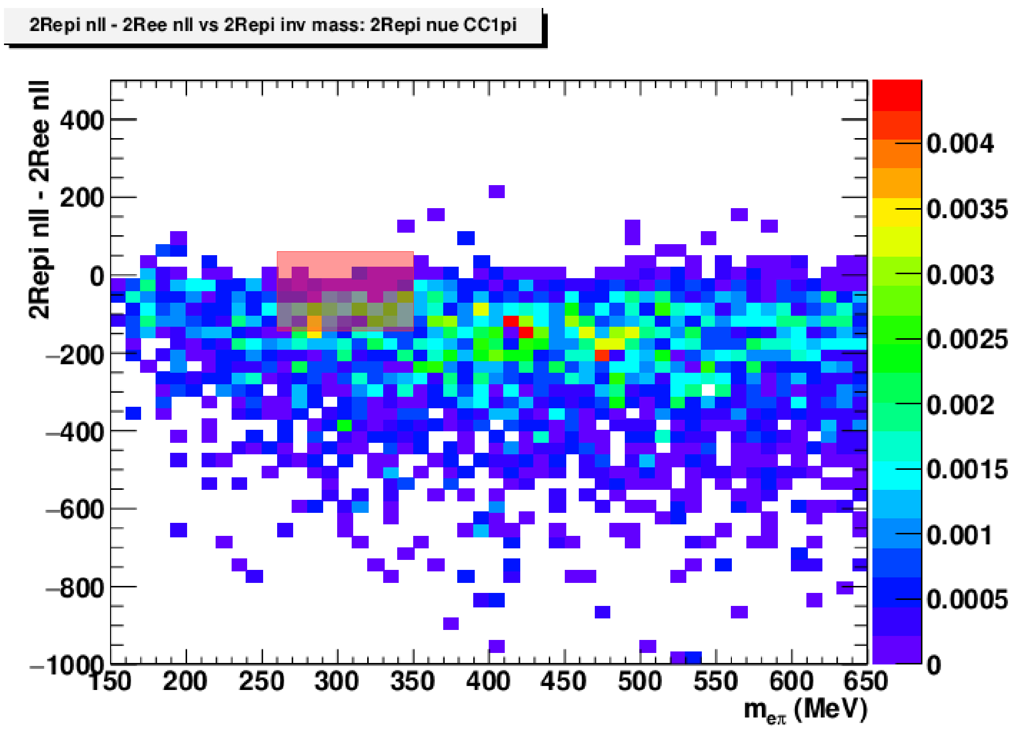


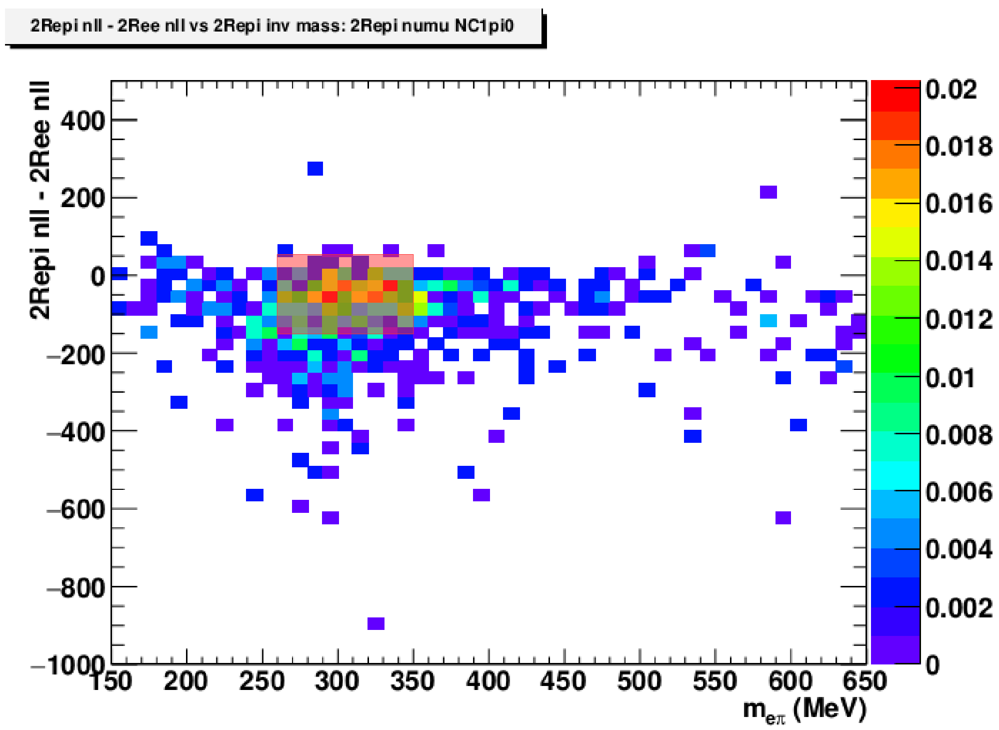
cos(θ)


cosθ: 2Repi
bkgd
signal
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
–1
–0.5
0
0.5
1
cosθ

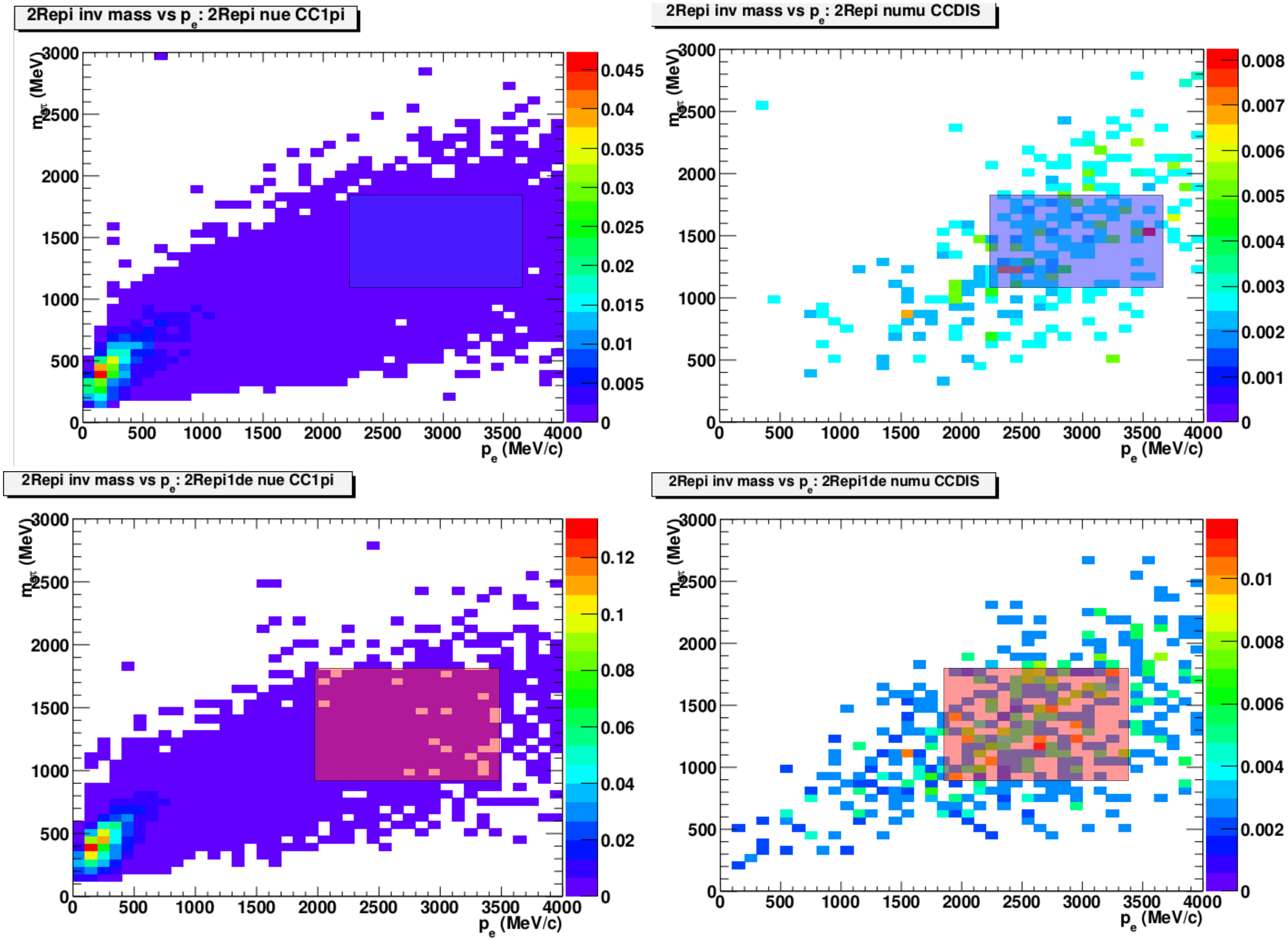

cosθ: 2Repi1de
bkgd
signal
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
–1
–0.5
0
0.5
1
cosθ

260MeV<m_epi<350MeV &&
-150<2repi_nll-2ree_nll<50
(2Repi only)

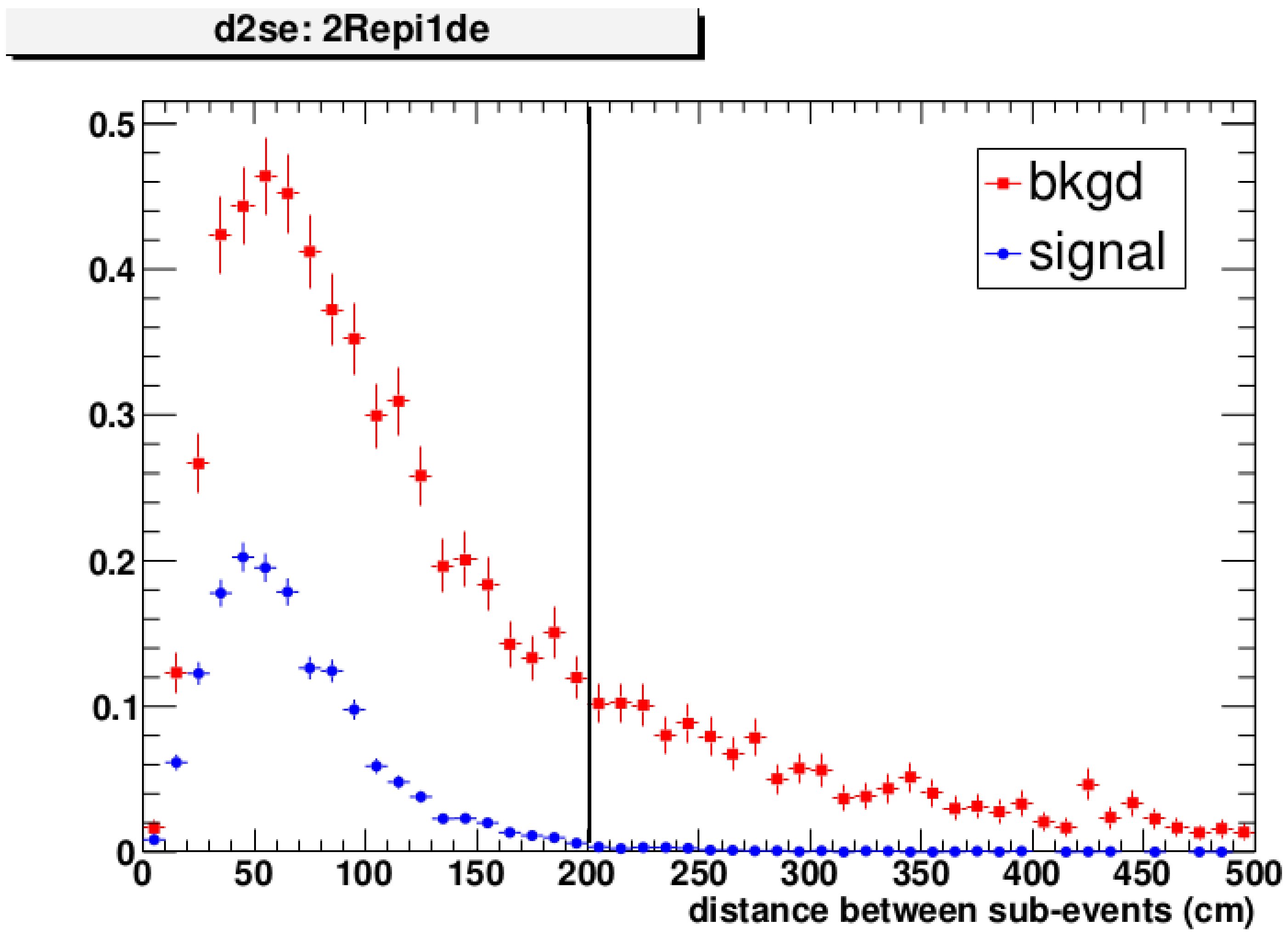




2Repi: p_e<2200 || p_e>3700 || m_epi<1100 || m_epi>1800
2Repi1de: p_e<1800 || p_e>3400 || m_epi<900 || m_epi>1800



d2se < 200 cm (2Repi1de only)



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	1.66
	2 rings	66.04	5.10	4.99	83.02	2.11	4.99	156.26	0.03	0.39
	epi-like	6.74	2.28	2.34	5.19	0.19	2.34	14.40	0.14	0.57
	0 decay e	1.48	1.00	0.88	3.17	0.11	0.88	5.76	0.13	0.34
	|p_e-p_pi| <1000MeV	0.81	0.62	0.84	2.81	0.09	0.84	4.33	0.16	0.37
	cos(theta)	0.54	0.55	0.77	2.07	0.07	0.77	3.22	0.19	0.39
	m_epi v nll_2Repi-nll_2Ree	0.53	0.53	0.72	1.68	0.06	0.72	2.79	0.21	0.38
	m_epi v p_e	**0.52**	**0.53**	**0.72**	**1.68**	**0.06**	**0.72**	**2.79**	**0.21**	**0.38**
2Repi1de	FCFV	414.82	27.42	42.45	168.32	4.77	42.45	615.33	0.06	1.66
	2 rings	66.04	5.10	4.99	83.02	2.11	4.99	156.26	0.03	0.39
	epi-like	6.74	2.28	2.34	5.19	0.19	2.34	14.40	0.14	0.57
	1 decay e	3.35	1.14	1.43	1.63	0.06	1.43	6.18	0.19	0.52
	|p_e-p_pi| <1000MeV	2.11	0.76	1.39	1.38	0.06	1.39	4.31	0.24	0.58
	cos(theta)	1.66	0.69	1.29	1.09	0.05	1.29	3.49	0.27	0.59
	m_epi v p_e	1.59	0.69	1.29	1.09	0.05	1.29	3.42	0.27	0.59
	d2se<200cm	**1.02**	**0.66**	**1.27**	**1.02**	**0.04**	**1.27**	**2.75**	**0.32**	**0.63**

signal = oscillated nue/nueb CC

Previous FOM Bests
2Repi: 0.37
2Repi1de: 0.66

Sample	cut	nue CC1pi	numu CCother	numu NC 1pi0	Signal	Background	Purity
2Repi	FCFV	19.07	194.71	50.38	19.07	638.71	0.03
	2 rings	5.03	26.18	34.72	5.03	156.23	0.03
	epi-like	3.33	5.66	1.22	3.33	13.41	0.20
	0 decay e	1.09	1.29	1.08	1.09	5.55	0.16
	|p_e-p_pi| <1000MeV	0.85	0.63	1.00	0.85	4.32	0.16
	cos(theta)	0.76	0.40	0.63	0.76	3.23	0.19
	m_epi v nll_2Repi-nll_2Ree	0.72	0.39	0.40	0.72	2.79	0.21
	m_epi v p_e	**0.72**	**0.39**	**0.40**	**0.72**	**2.78**	**0.21**
2Repi1de	FCFV	19.07	194.71	50.38	19.07	638.71	0.03
	2 rings	5.03	26.18	34.72	5.03	156.23	0.03
	epi-like	3.33	5.66	1.22	3.33	13.41	0.20
	1 decay e	2.19	2.81	0.13	2.19	5.42	0.29
	|p_e-p_pi| <1000MeV	1.91	1.60	0.09	1.91	3.79	0.33
	cos(theta)	1.76	1.22	0.07	1.76	3.02	0.37
	m_epi v p_e	1.76	1.15	0.07	1.76	2.94	0.37
	d2se<200cm	**1.72**	**0.68**	**0.07**	**1.72**	**2.29**	**0.43**

signal = nue CC1pi

Thoughts

- cos(θ) cut seems to be effective for both selections
- $m_{e\pi}$ vs $nll_{2Re\pi}$-nll_{2Ree} cut improves purity, but worsens FOM of 2Reπ selection
- $m_{e\pi}$ vs p_e cut not very effective
  - Better ways to address ν_μ CCDIS background?