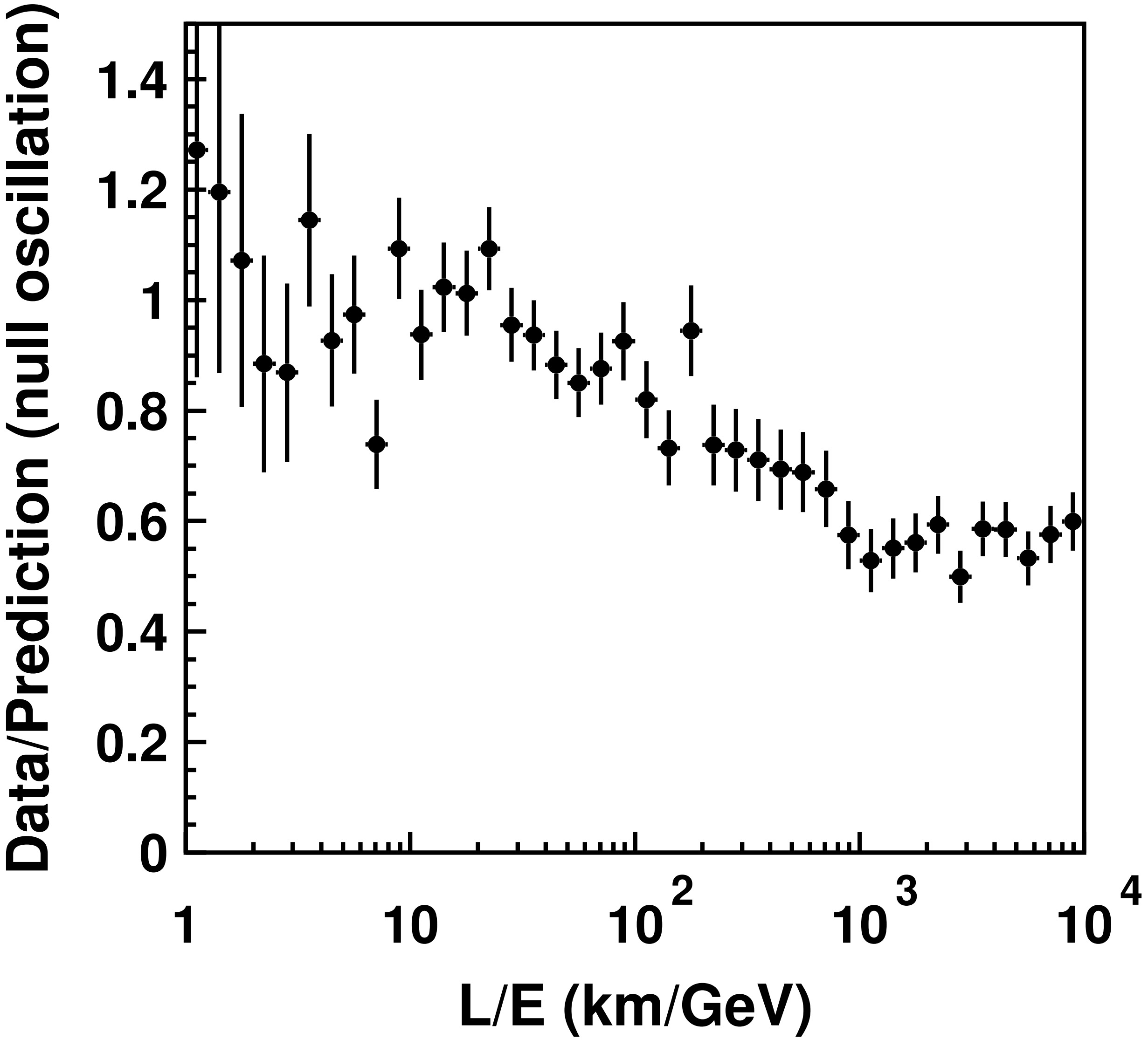
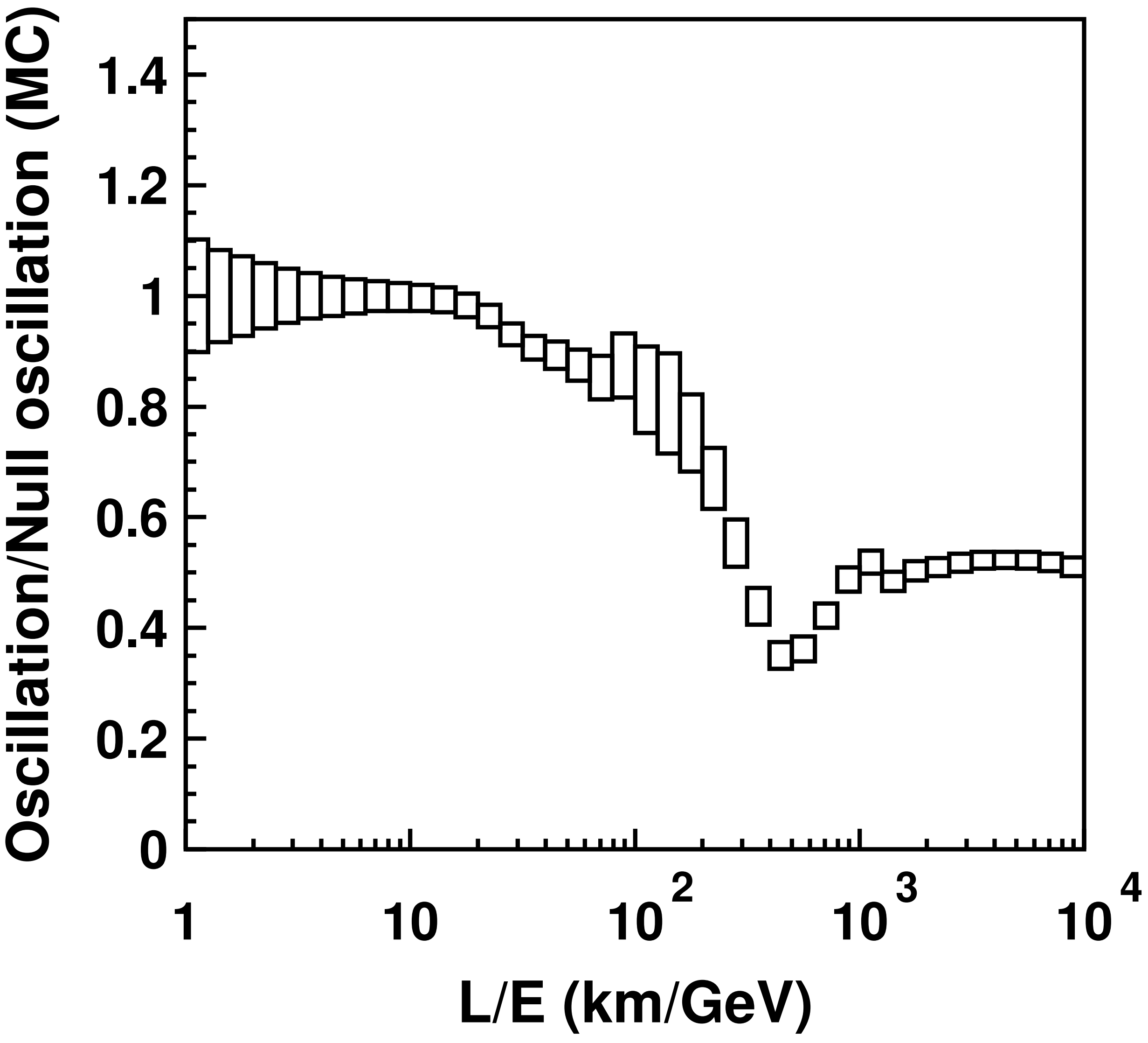
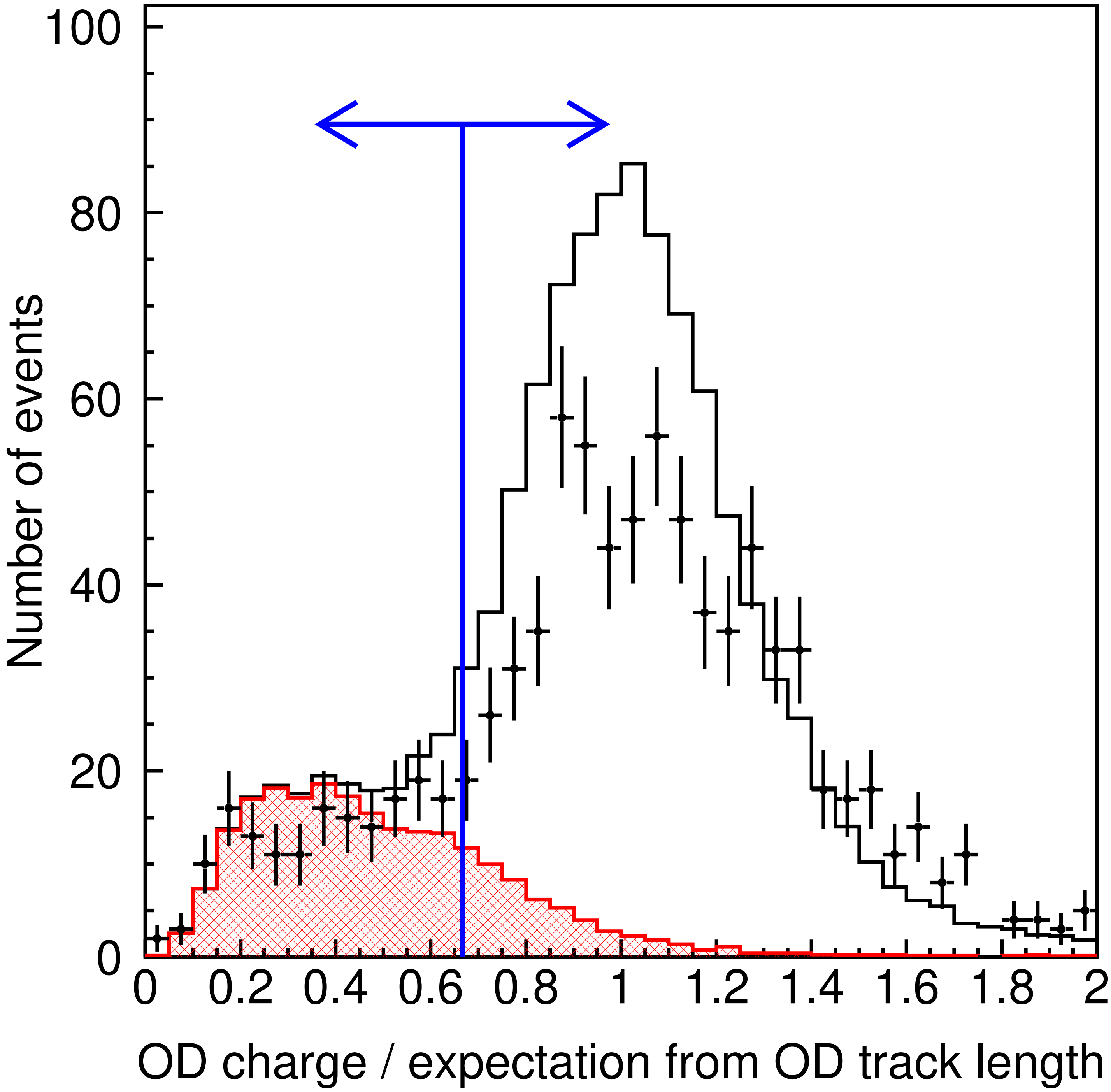
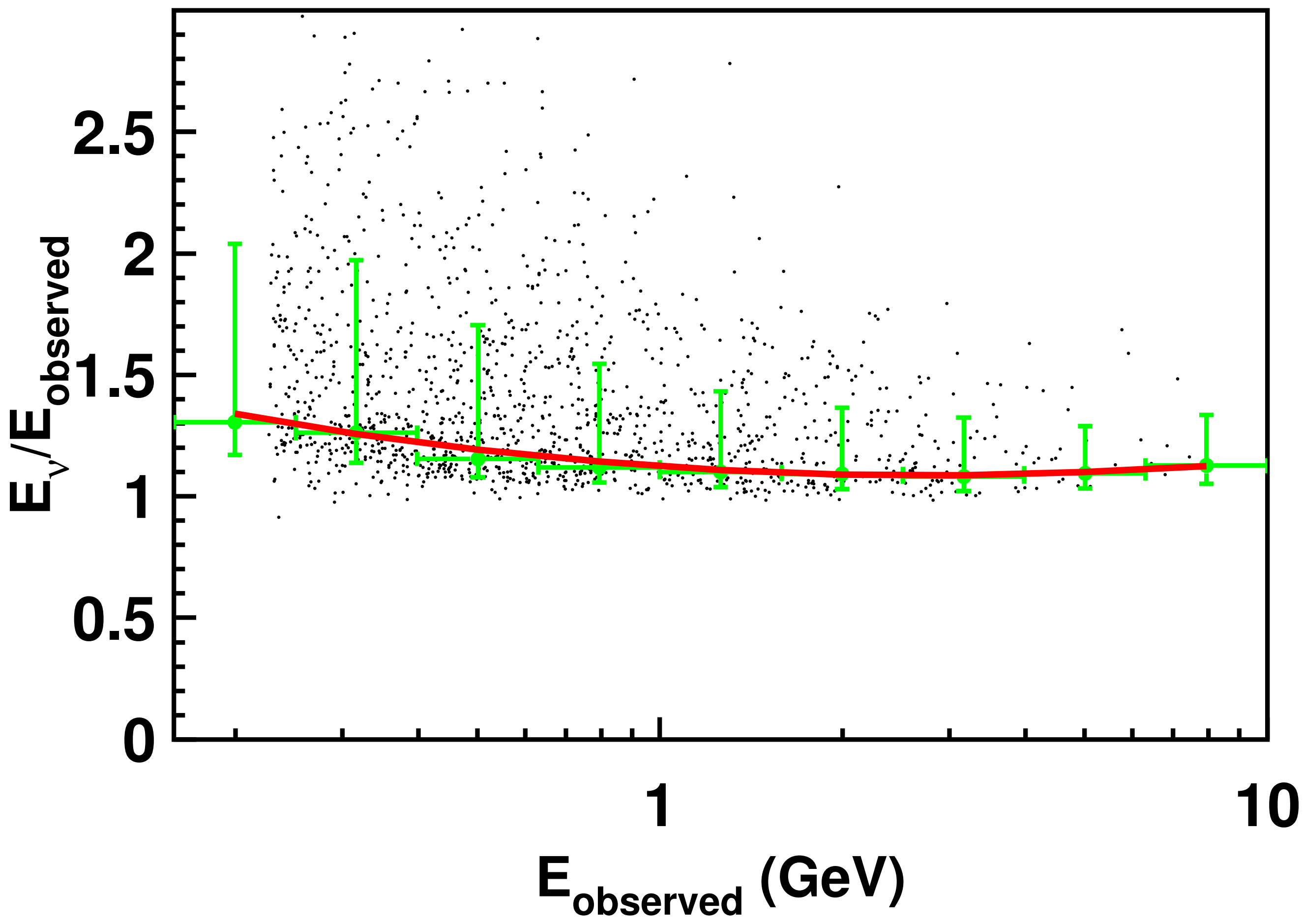

Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1
10
10^2
10^3
10^4



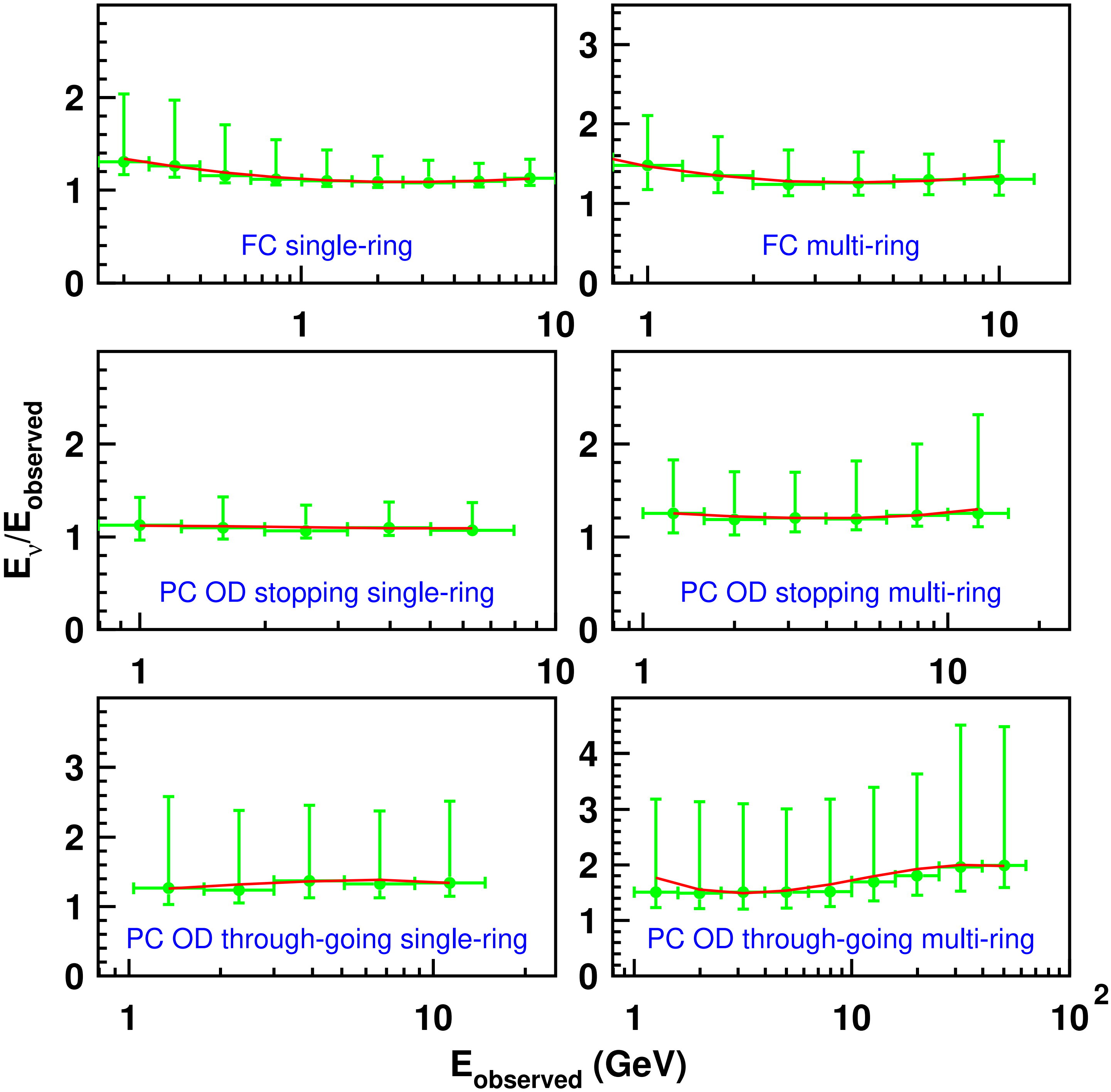
Oscillation/Null oscillation (MC)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1
10
10^2
10^3
10^4
L/E (km/GeV)



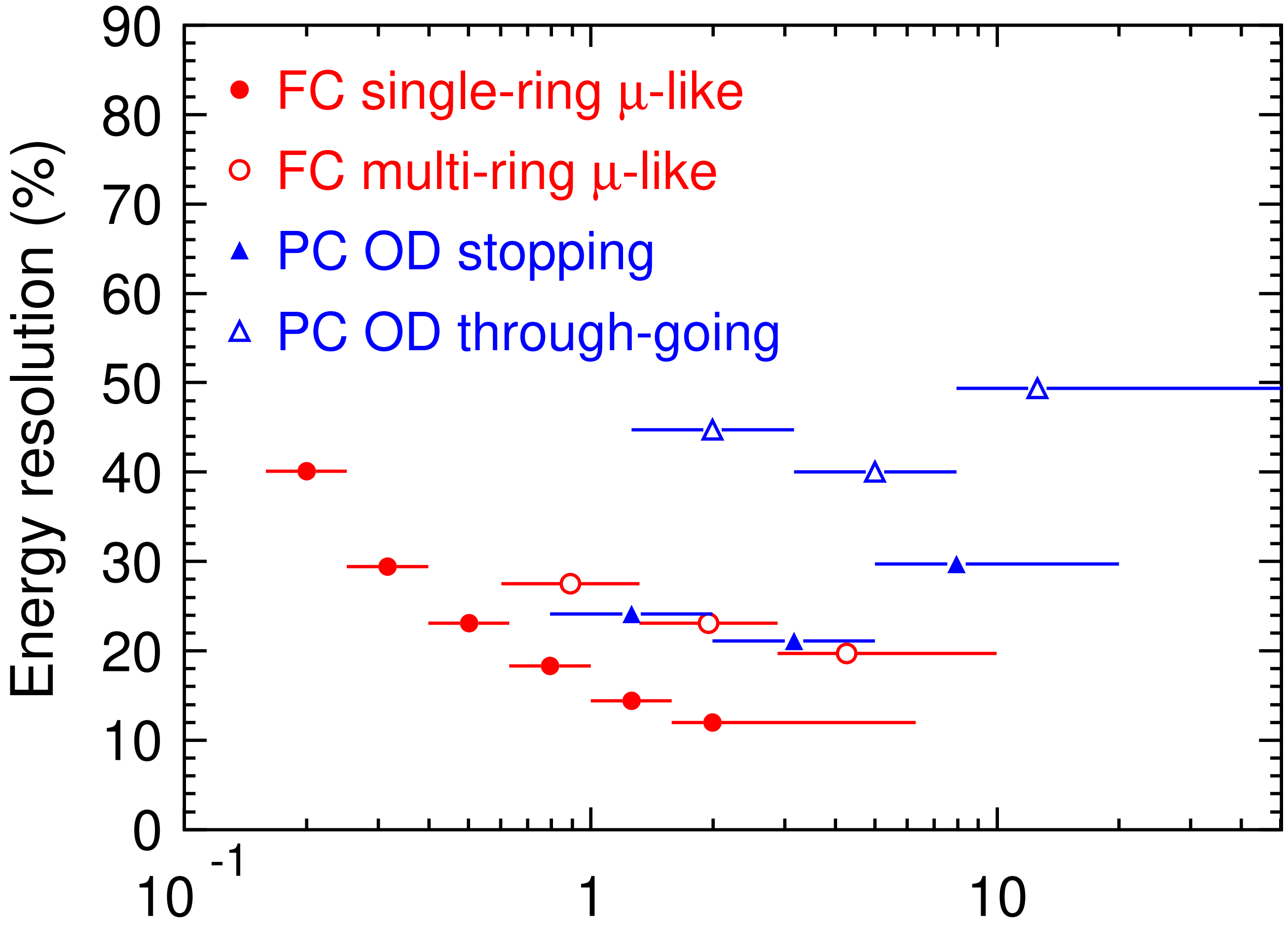
100
80
60
40
20
0
Number of events
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
OD charge / expectation from OD track length



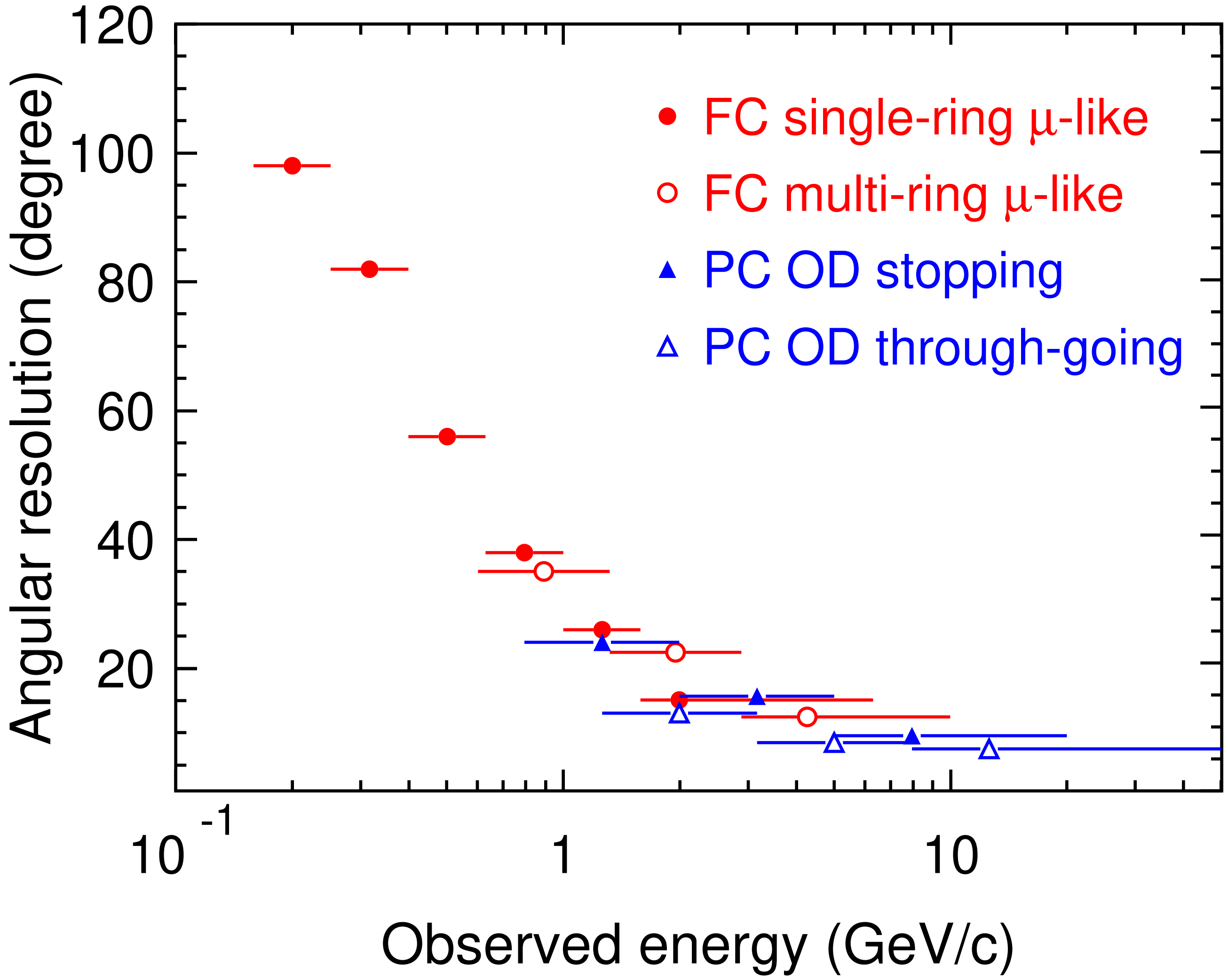
$E_\nu/E_{observed}$
0
0.5
1
1.5
2
2.5
1
10
$E_{observed}$ (GeV)



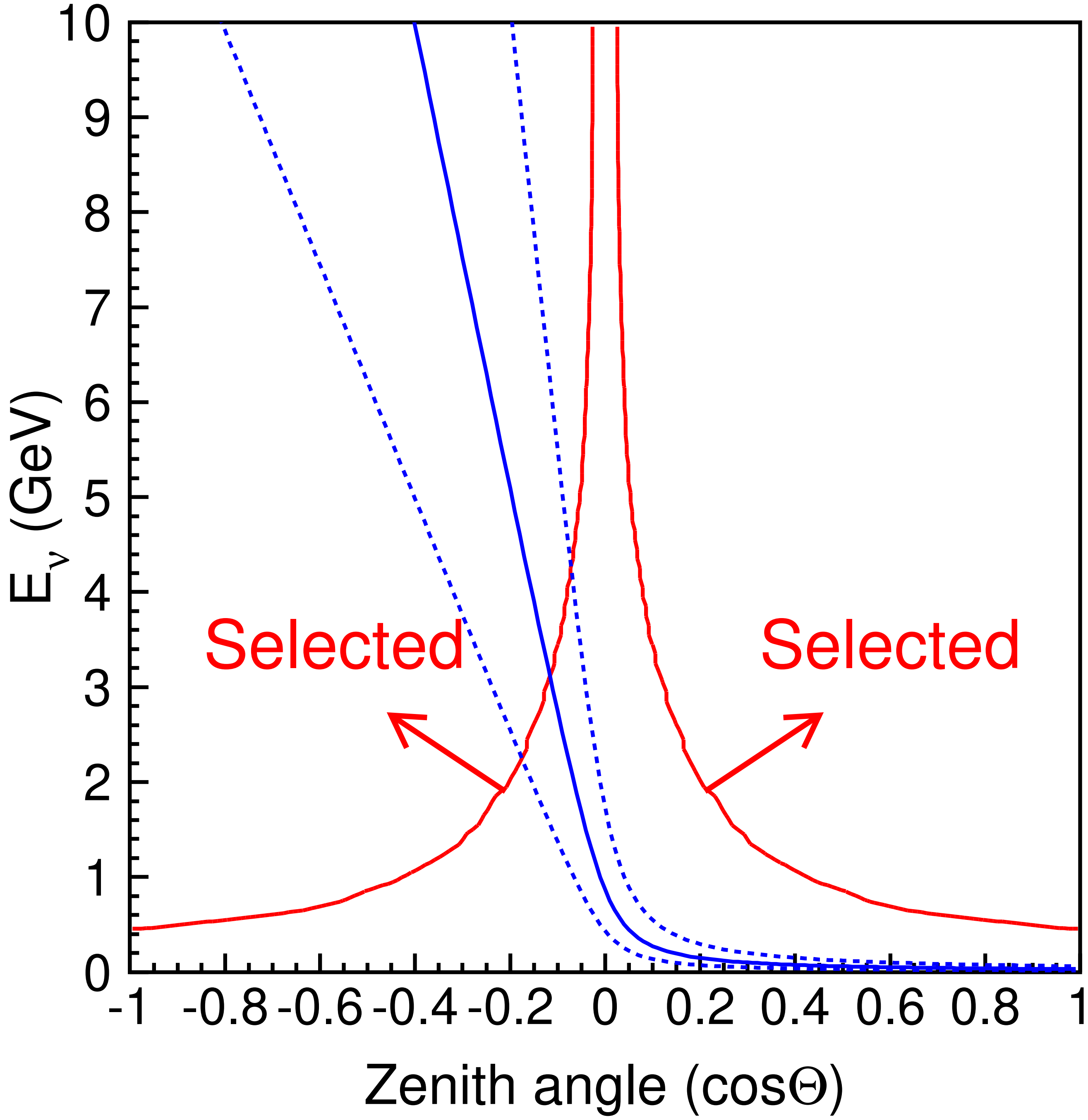
FC single-ring
FC multi-ring
PC OD stopping single-ring
PC OD stopping multi-ring
PC OD through-going single-ring
PC OD through-going multi-ring
$E_\nu/E_{observed}$
$E_{observed}$ (GeV)



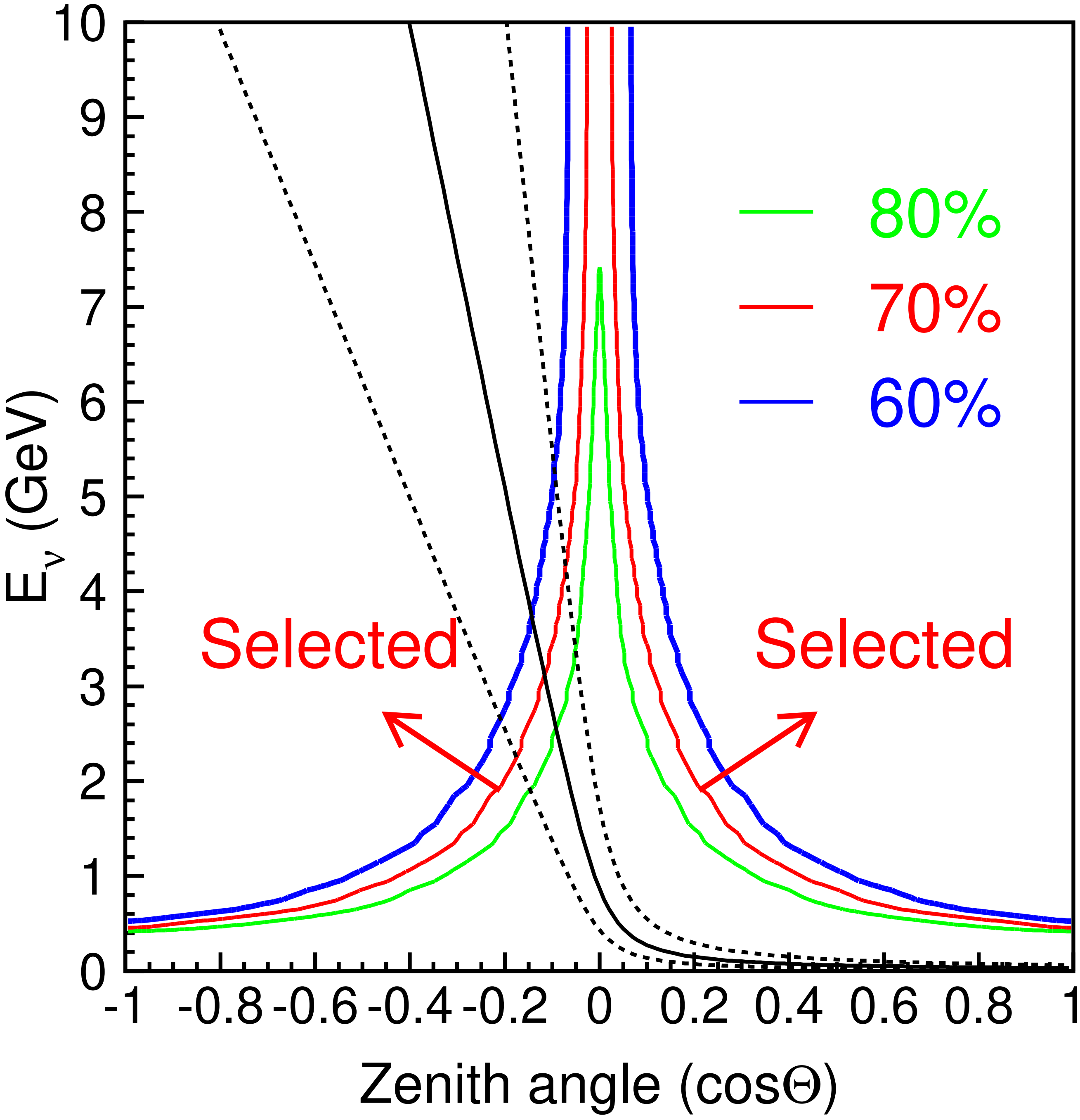
FC single-ring μ-like
FC multi-ring μ-like
PC OD stopping
PC OD through-going
Energy resolution (%)
Observed energy (GeV/c)
0
10
20
30
40
50
60
70
80
90
10^-1
1
10



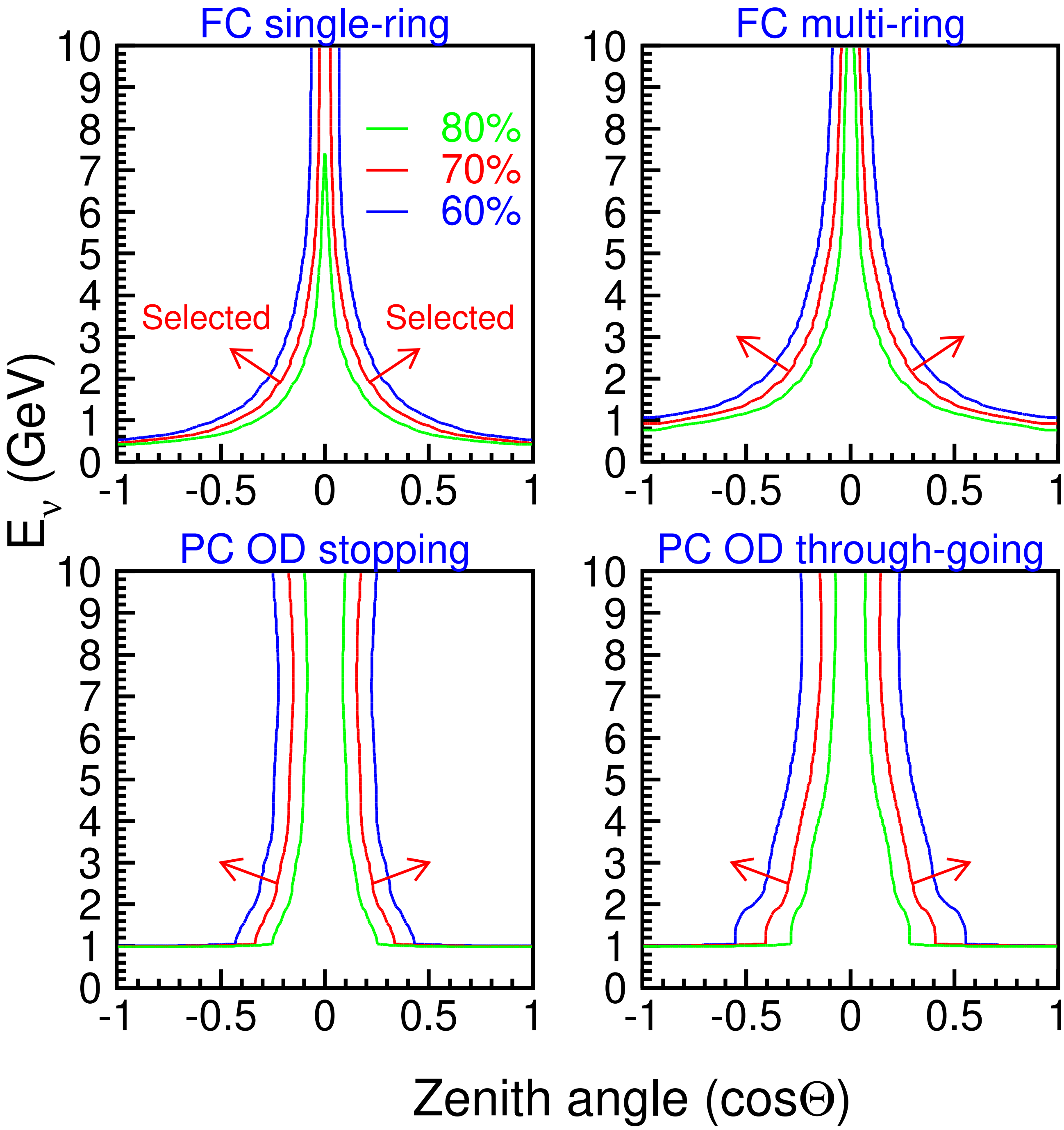
Angular resolution (degree)
120
100
80
60
40
20
10 -1
1
10
Observed energy (GeV/c)
FC single-ring μ-like
FC multi-ring μ-like
PC OD stopping
PC OD through-going



10
9
8
7
6
5
4
3
2
1
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
E_ν (GeV)
Zenith angle (cosΘ)
Selected
Selected



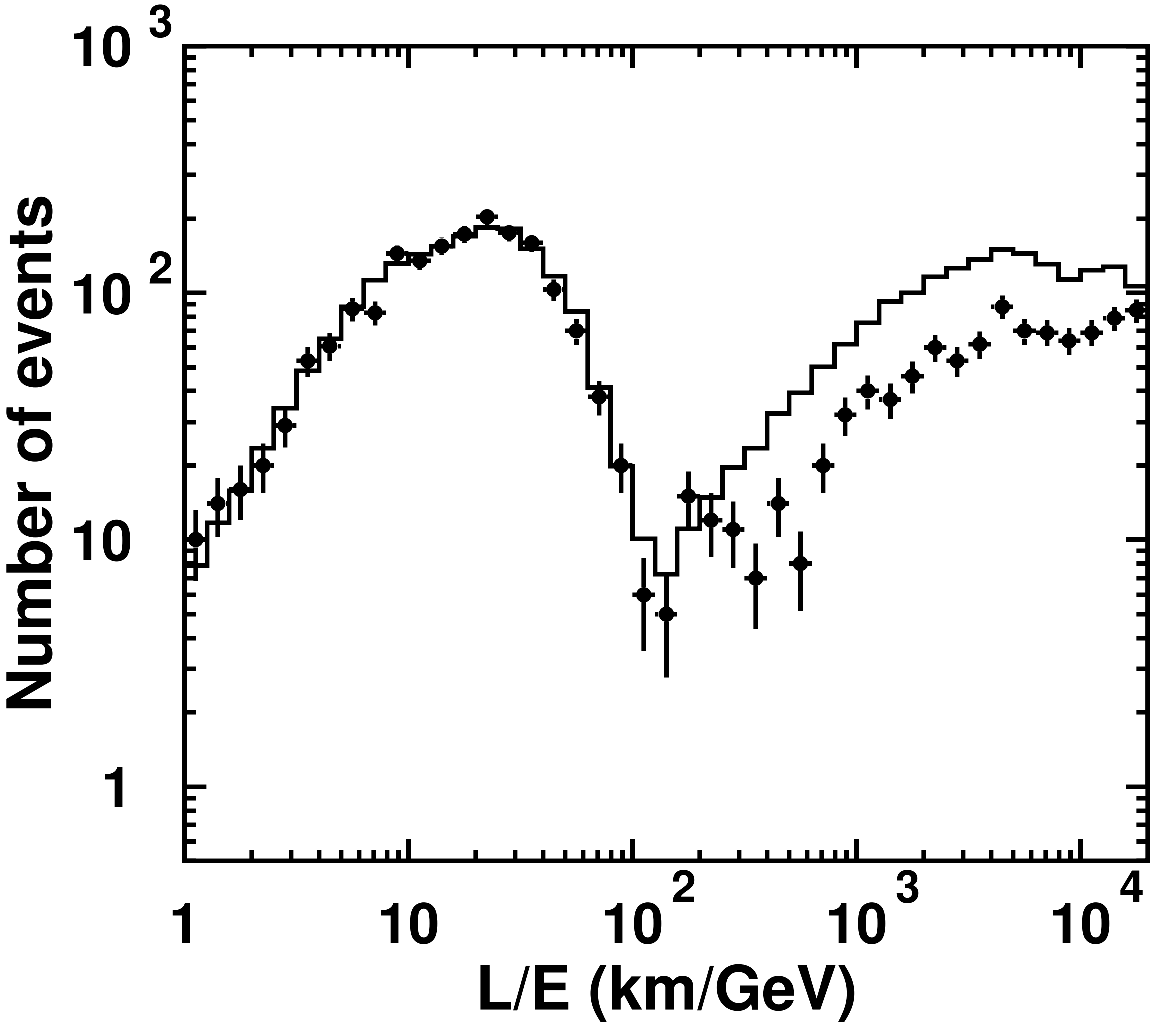
10
9
8
7
6
5
4
3
2
1
0
E_ν (GeV)
80%
70%
60%
Selected
Selected
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Zenith angle (cosΘ)


FC single-ring
FC multi-ring
PC OD stopping
PC OD through-going
80%
70%
60%
Selected
Selected
E_ν (GeV)
Zenith angle ($\cos\Theta$)

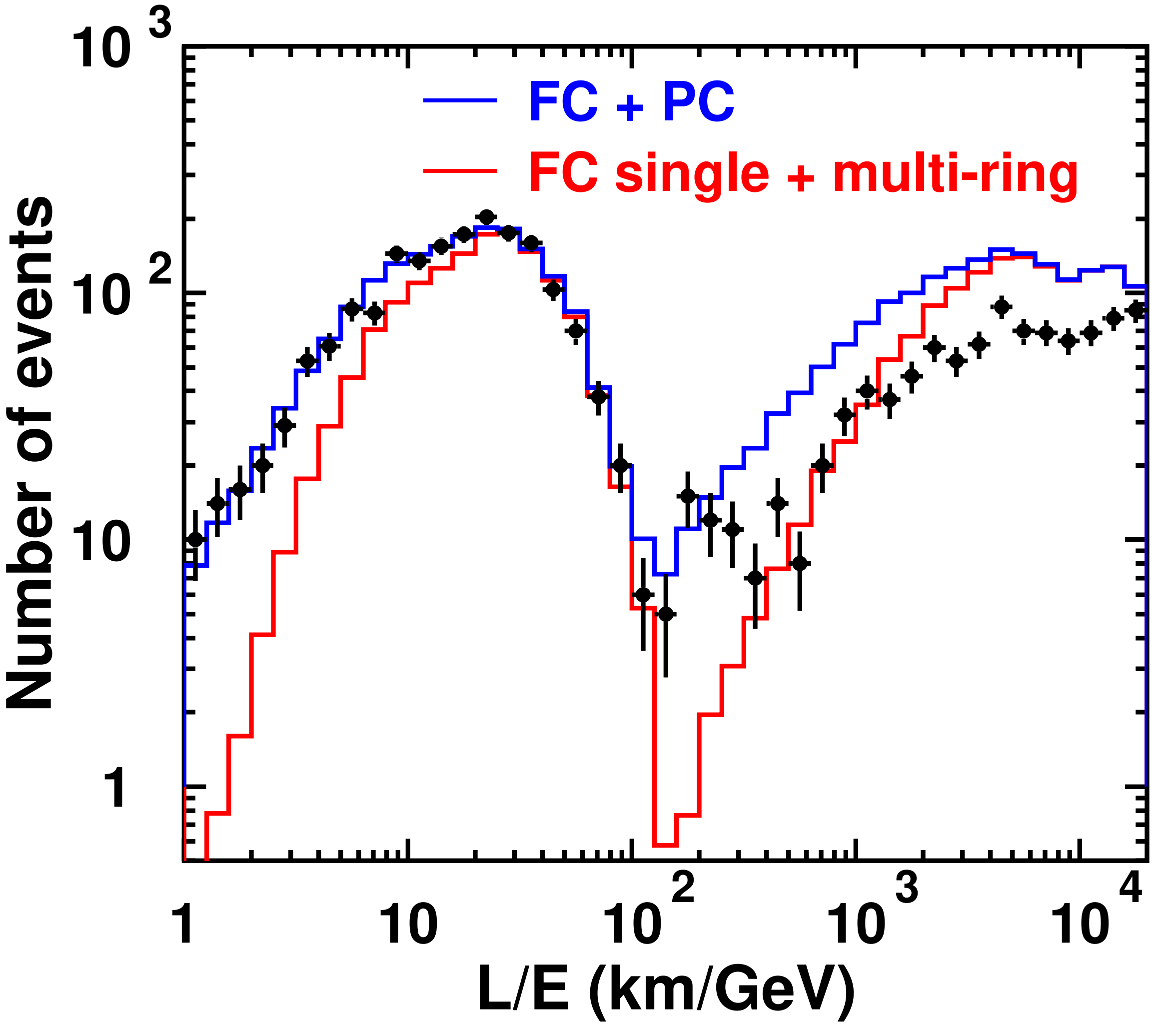
L/E event summary

($\Delta L/E < 70\%$)

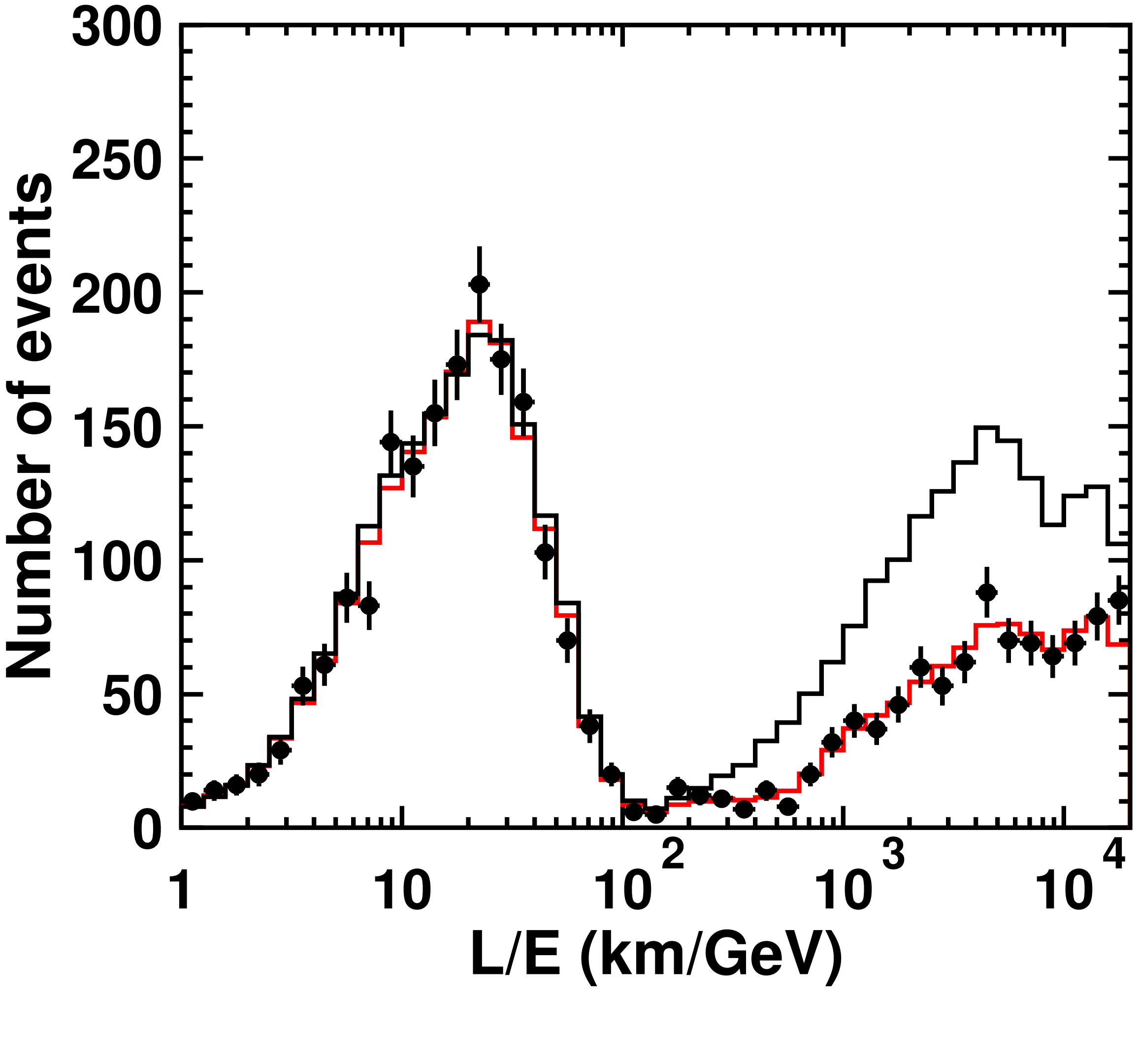
	DATA	MC	ν_μ CC
FC			
single-ring	1619	2039.0	(98.3%)
multi-ring	502	794.9	(94.2%)
PC			
OD stopping	114	134.6	(95.4%)
OD through-going	491	660.4	(99.2%)



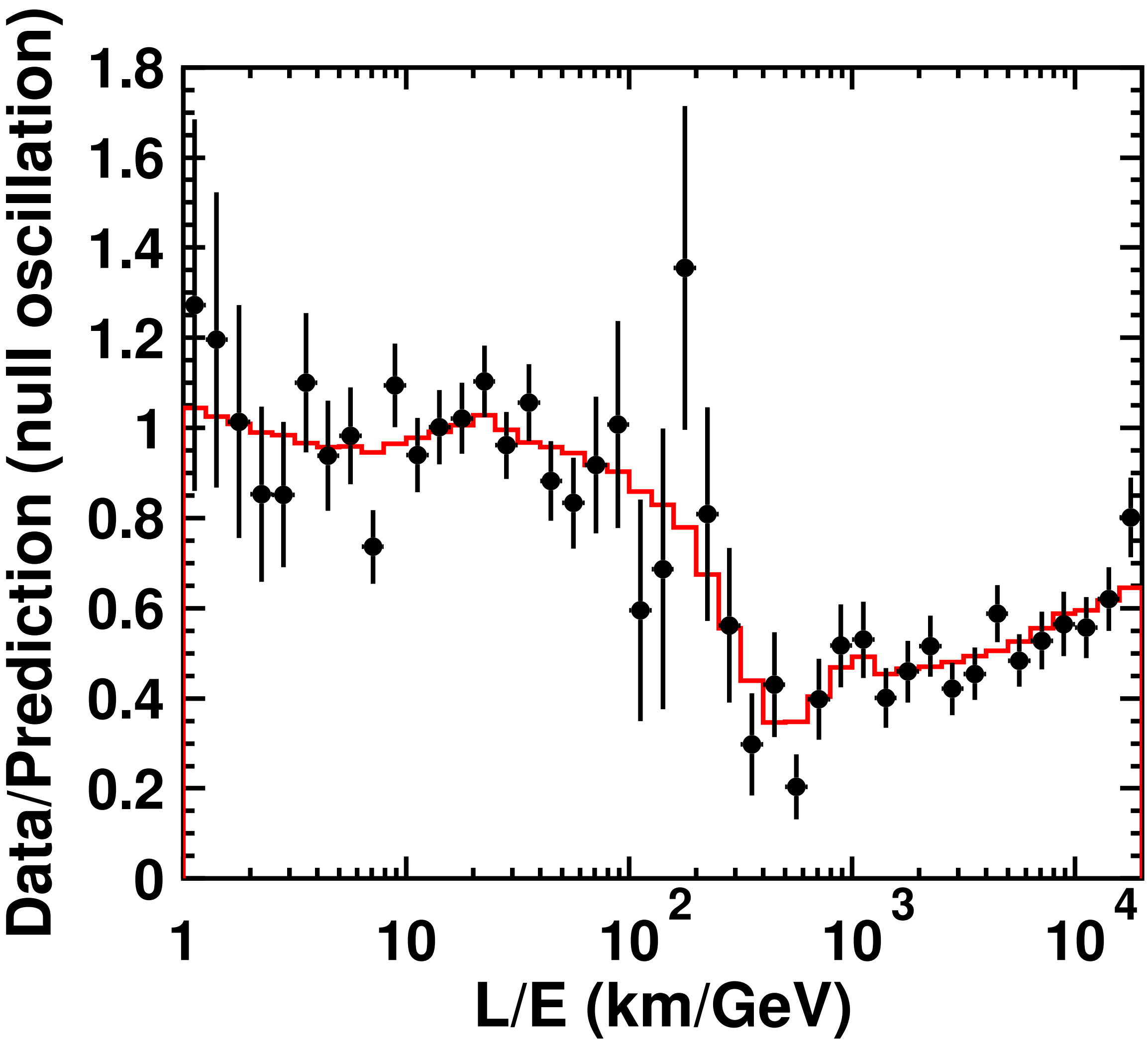
Number of events
L/E (km/GeV)
10 3
10 2
10
1
1
10
10 2
10 3
10 4



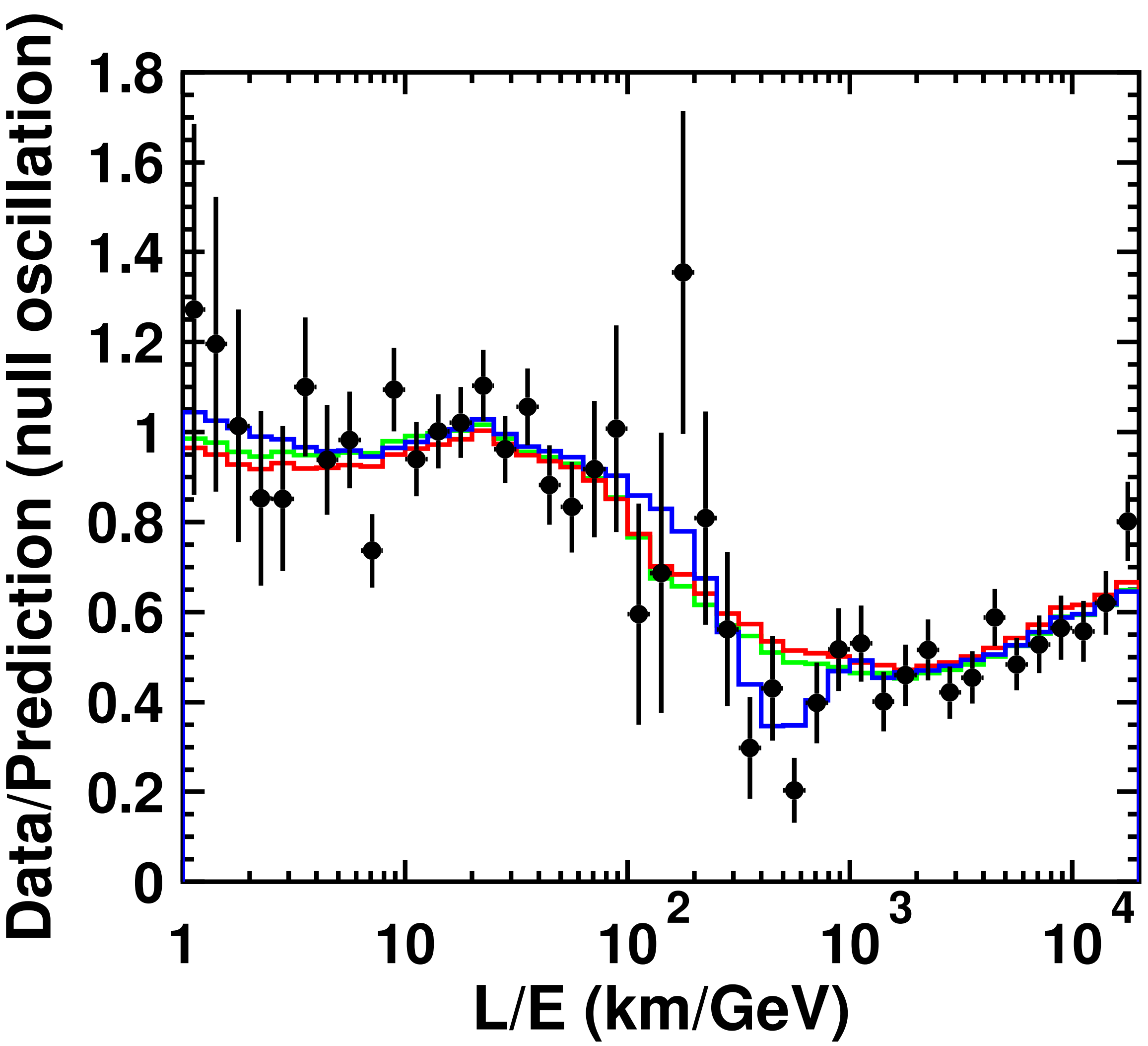
FC + PC
FC single + multi-ring
Number of events
L/E (km/GeV)



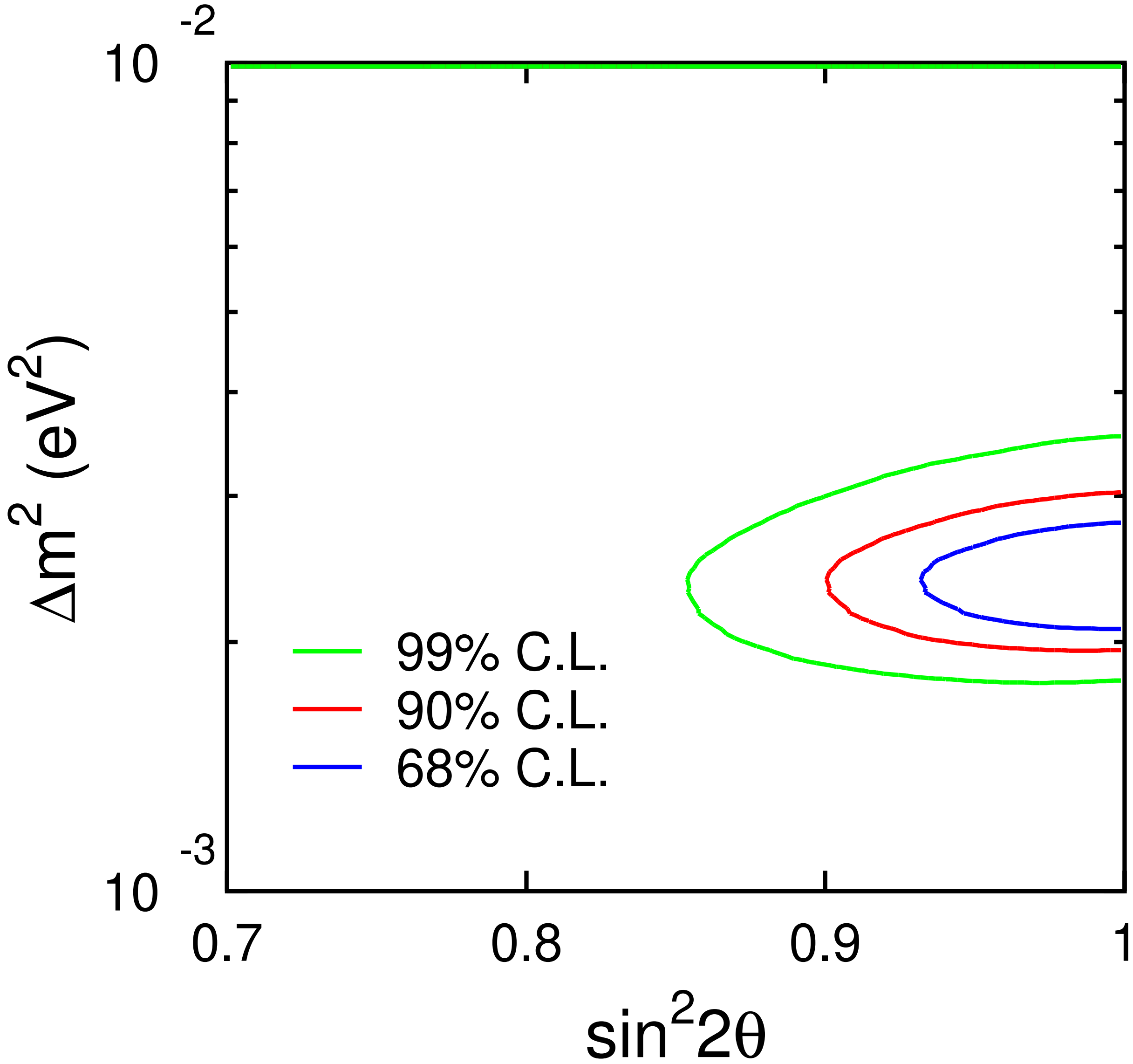
300
250
200
150
100
50
0
Number of events
1
10
10 2
10 3
10 4
L/E (km/GeV)



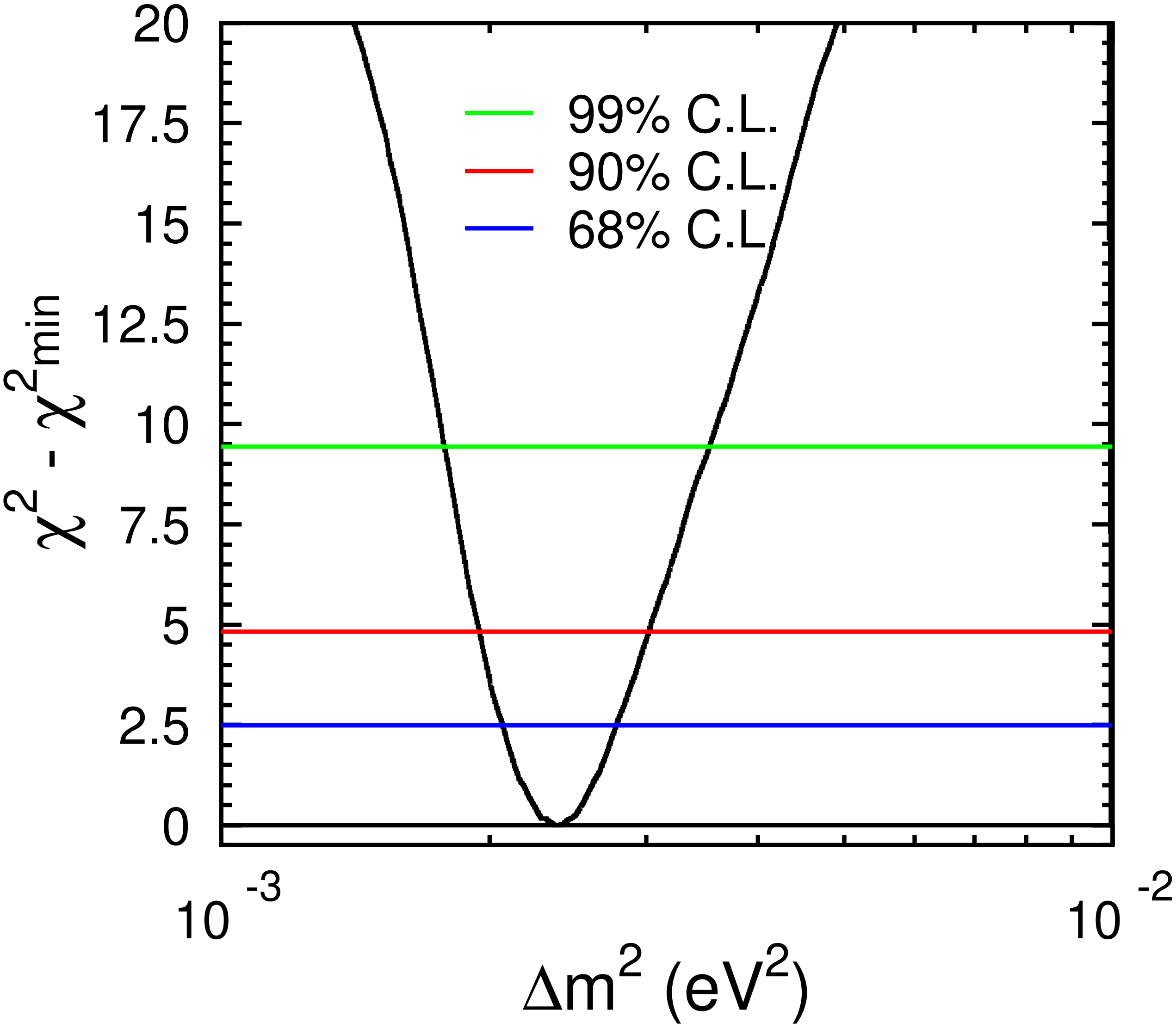
Data/Prediction (null oscillation)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10 2
10 3
10 4
L/E (km/GeV)

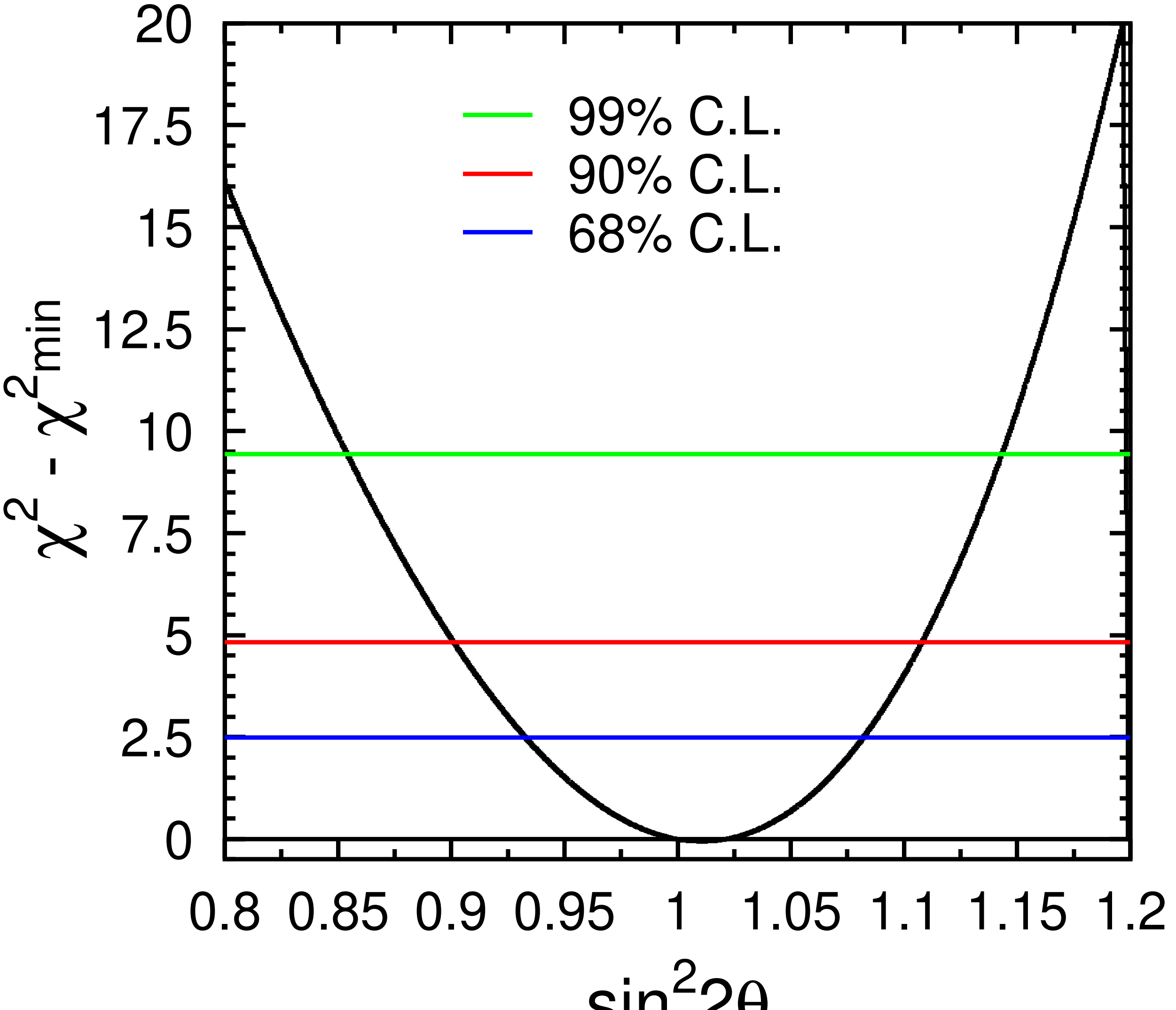


Data/Prediction (null oscillation)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10 2
10 3
10 4
L/E (km/GeV)

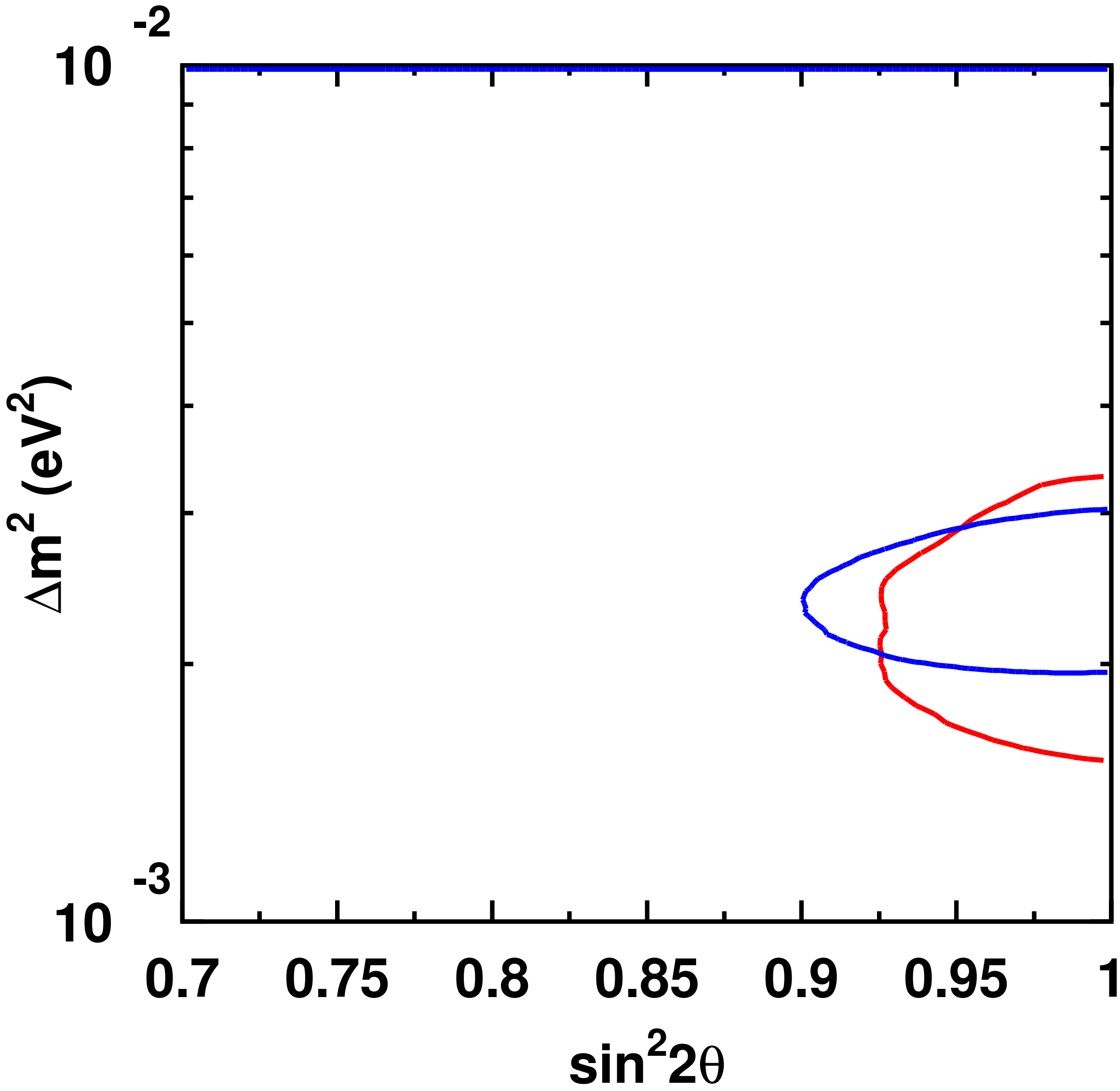


10^{-2}
10^{-3}
0.7
0.8
0.9
1
$\sin^2 2\theta$
Δm^2 (eV^2)
99% C.L.
90% C.L.
68% C.L.

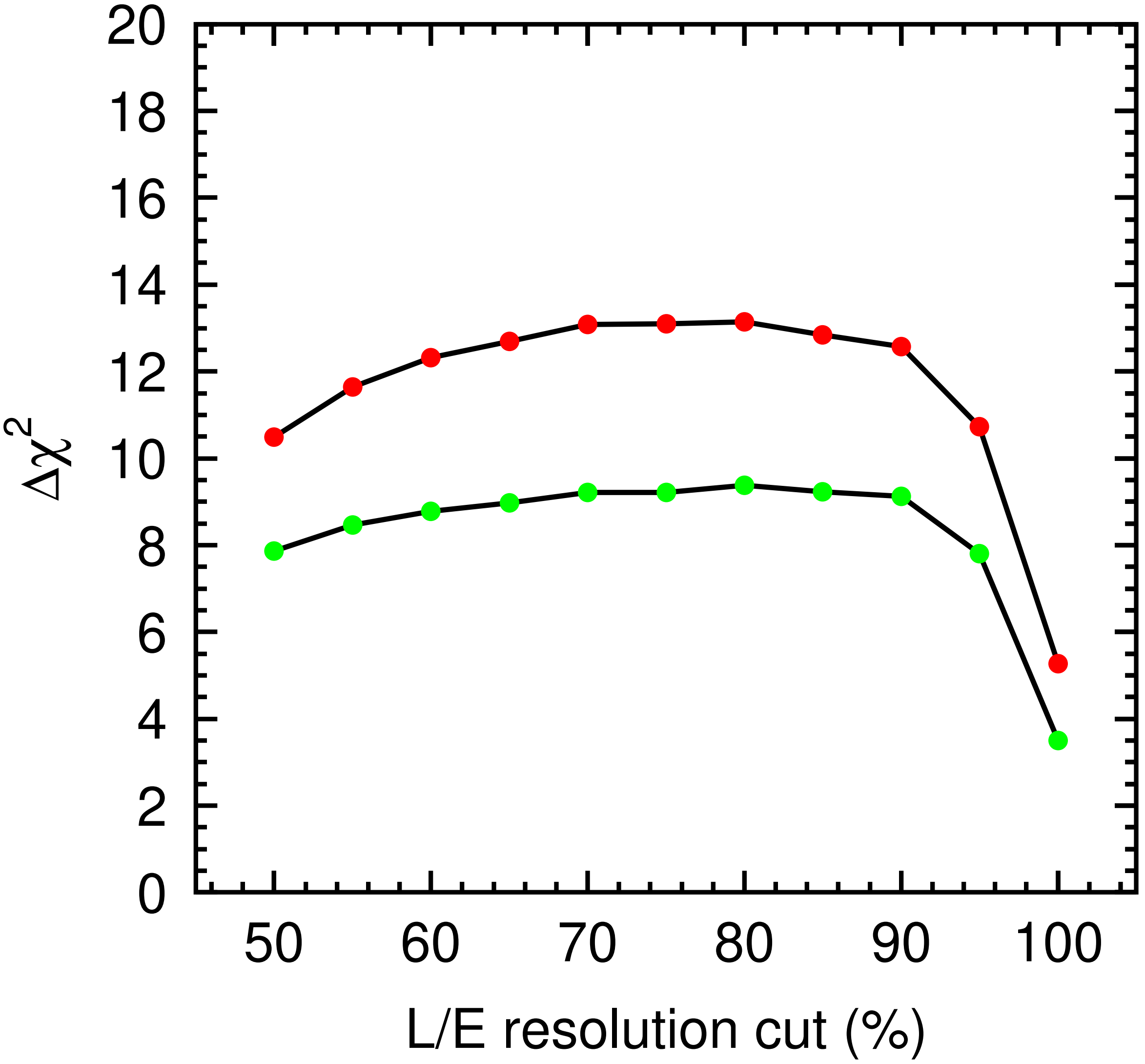

99% C.L.
90% C.L.
68% C.L
$\chi^2 - \chi^2_{min}$
Δm^2 (eV^2)
20
17.5
15
12.5
10
7.5
5
2.5
0
10^{-3}
10^{-2}



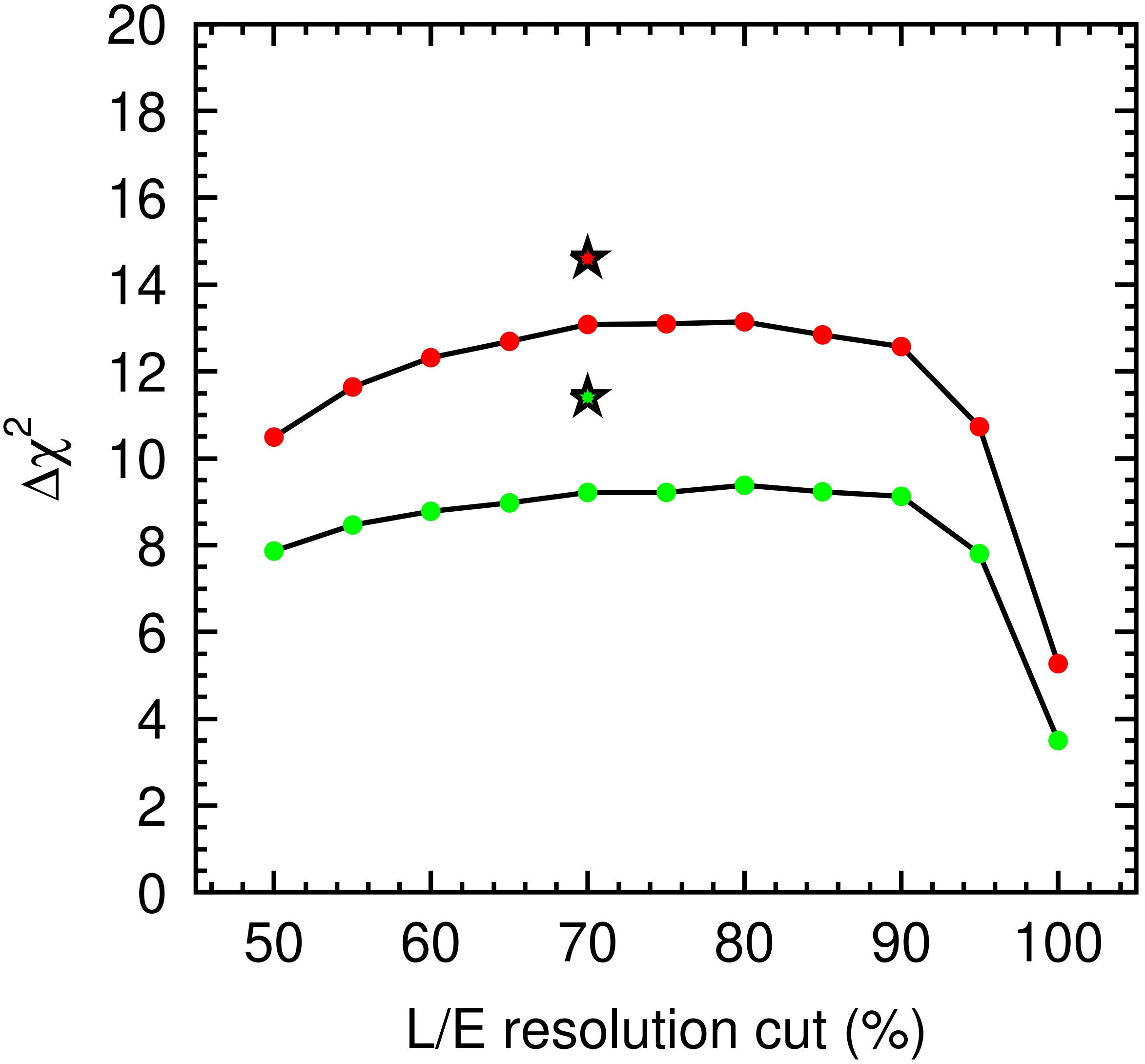
99% C.L.
90% C.L.
68% C.L.
$\chi^2 - \chi^2_{min}$
0
2.5
5
7.5
10
12.5
15
17.5
20
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
$\sin^2 2\theta$



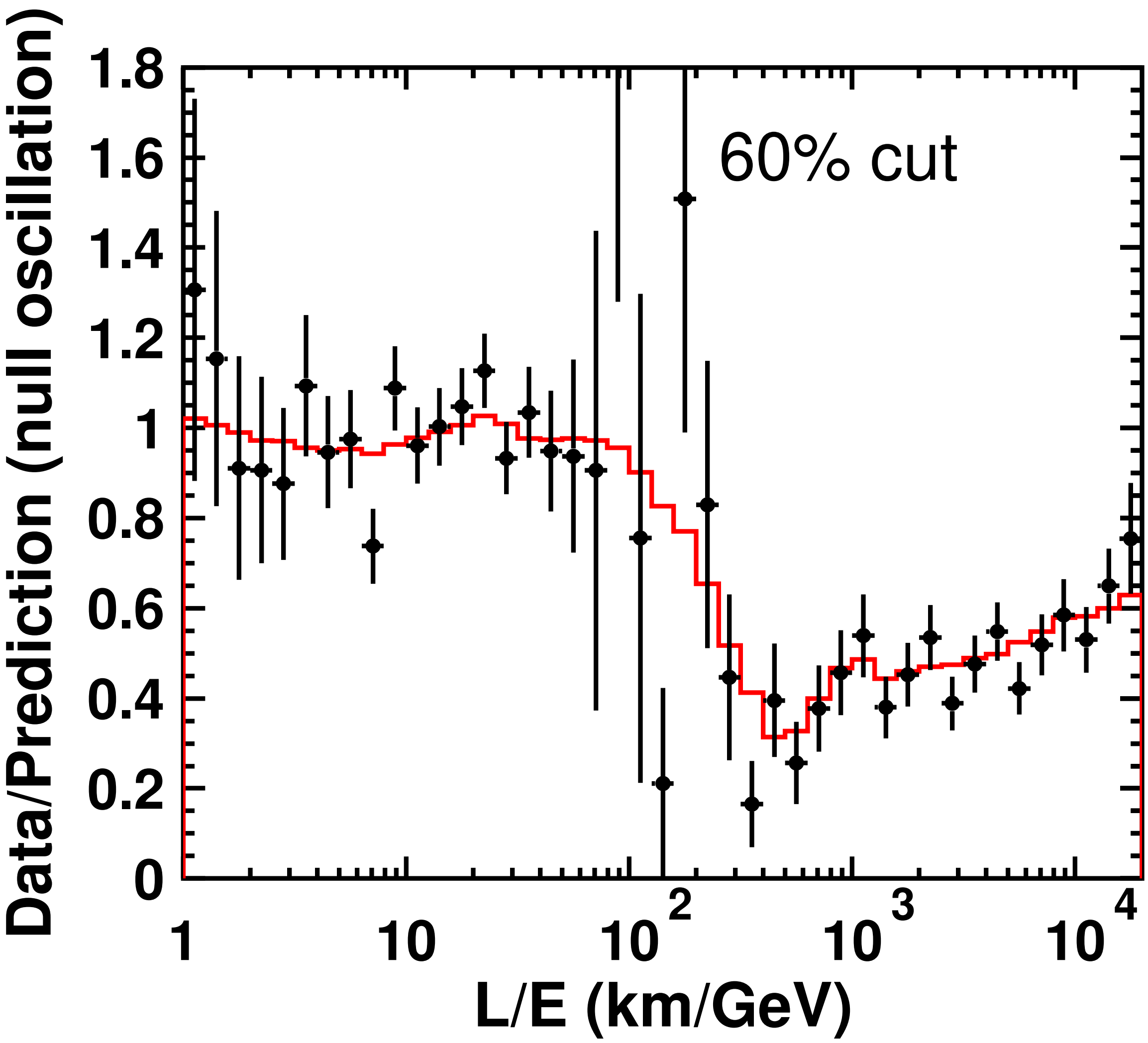
10^{-2}
10^{-3}
Δm^2 (eV^2)
0.7
0.75
0.8
0.85
0.9
0.95
1
$\sin^2 2\theta$



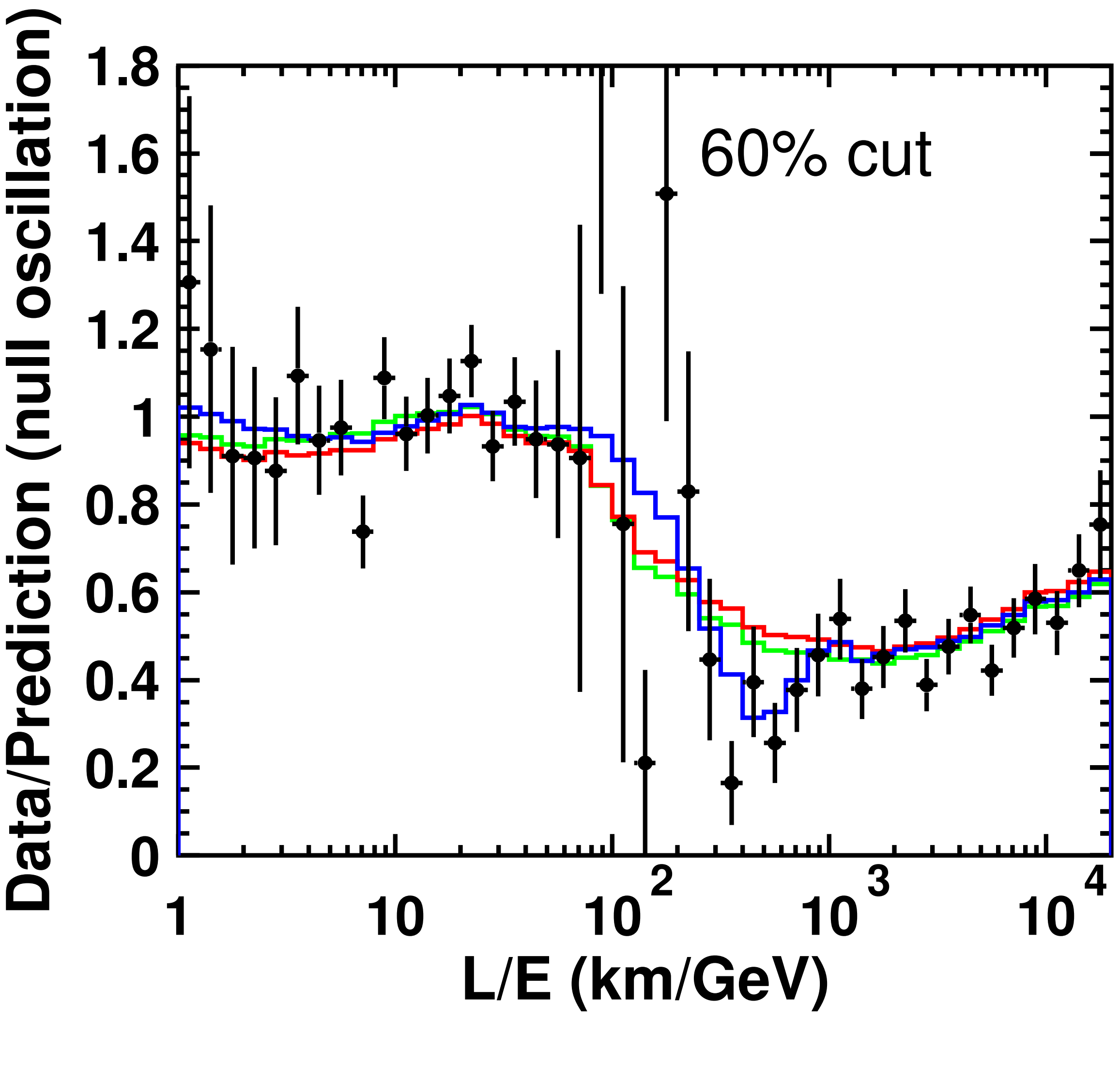
20
18
16
14
12
10
8
6
4
2
0
$\Delta\chi^2$
50
60
70
80
90
100
L/E resolution cut (%)



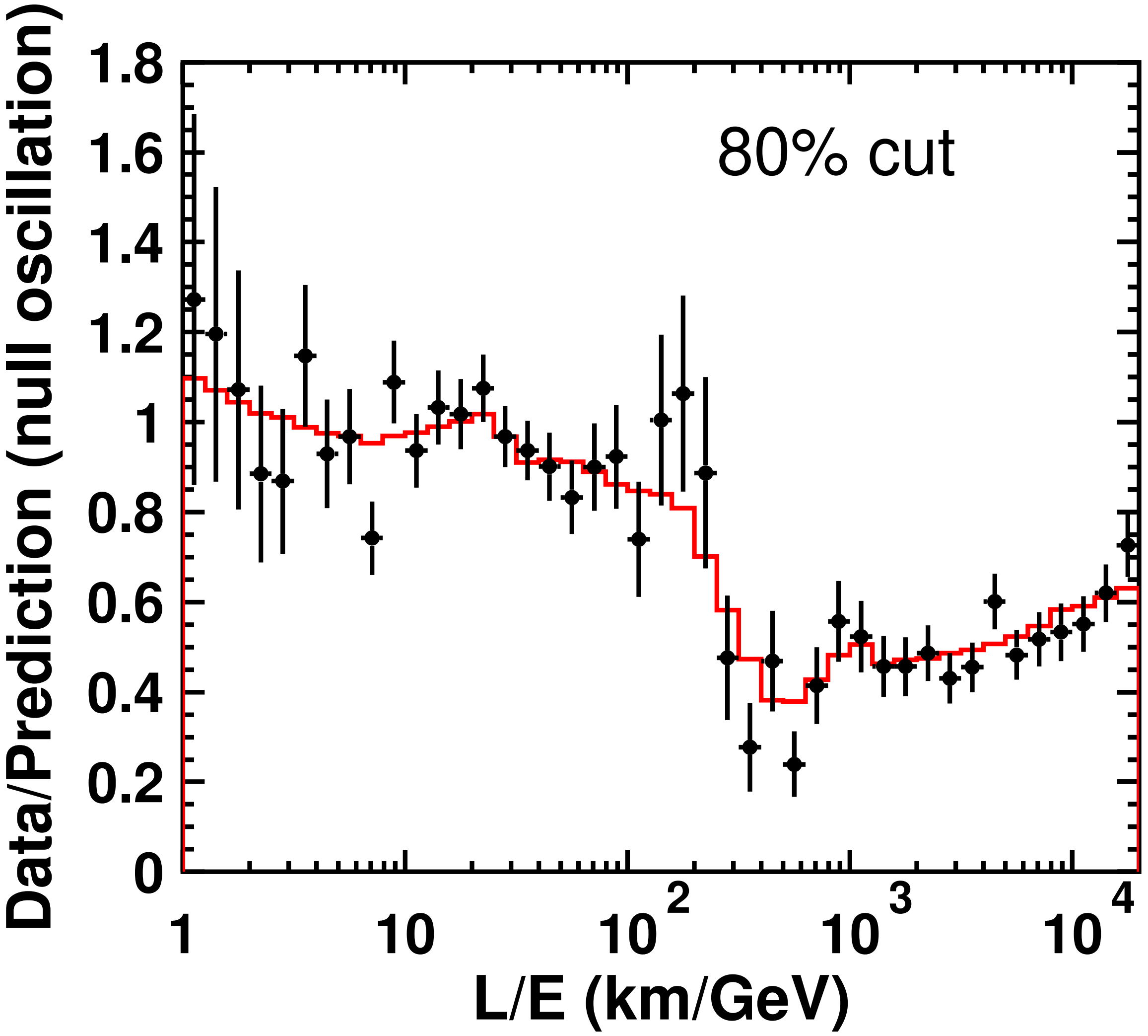
20
18
16
14
12
10
8
6
4
2
0
$\Delta\chi^2$
50
60
70
80
90
100
L/E resolution cut (%)



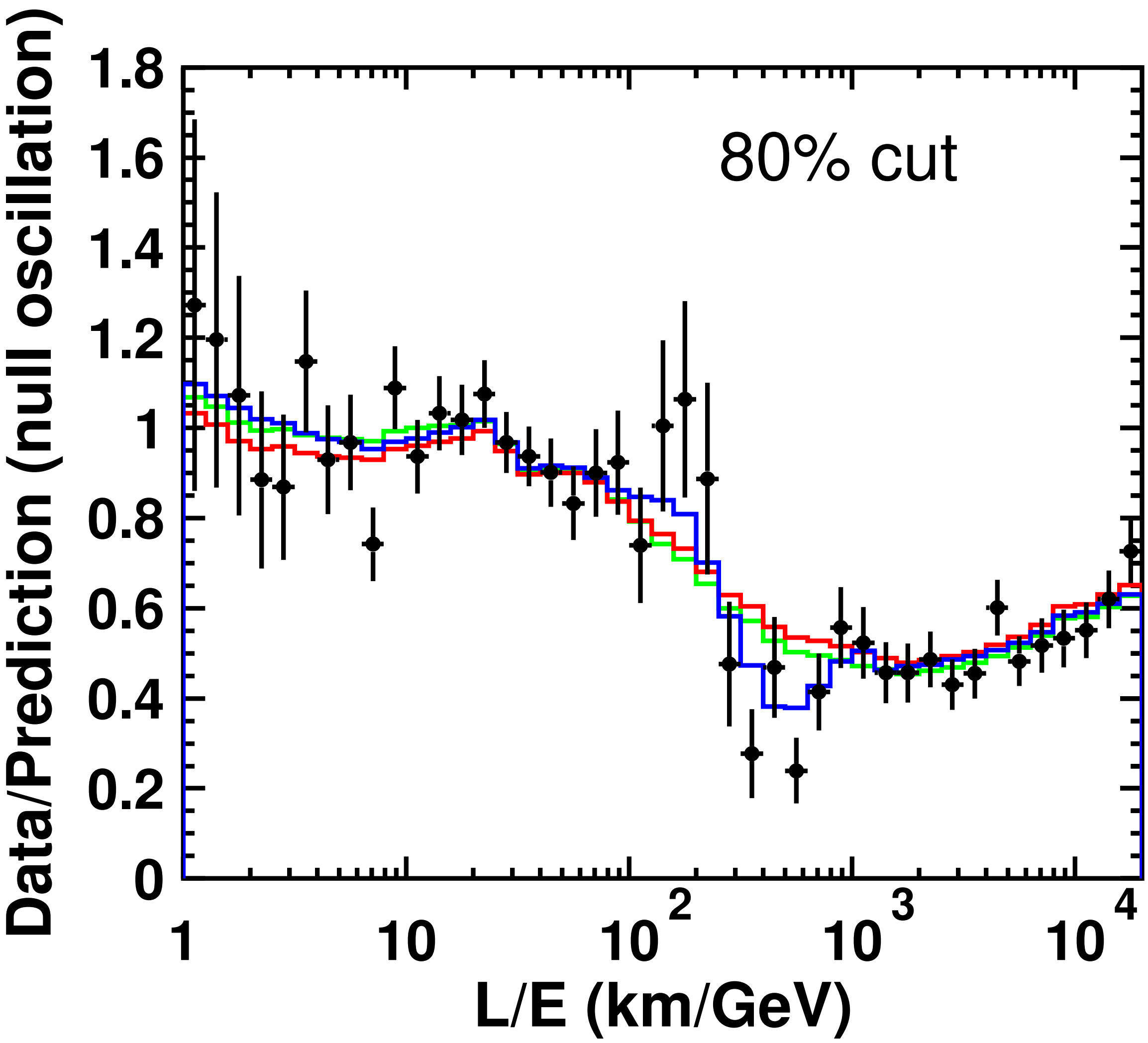
60% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
10^4



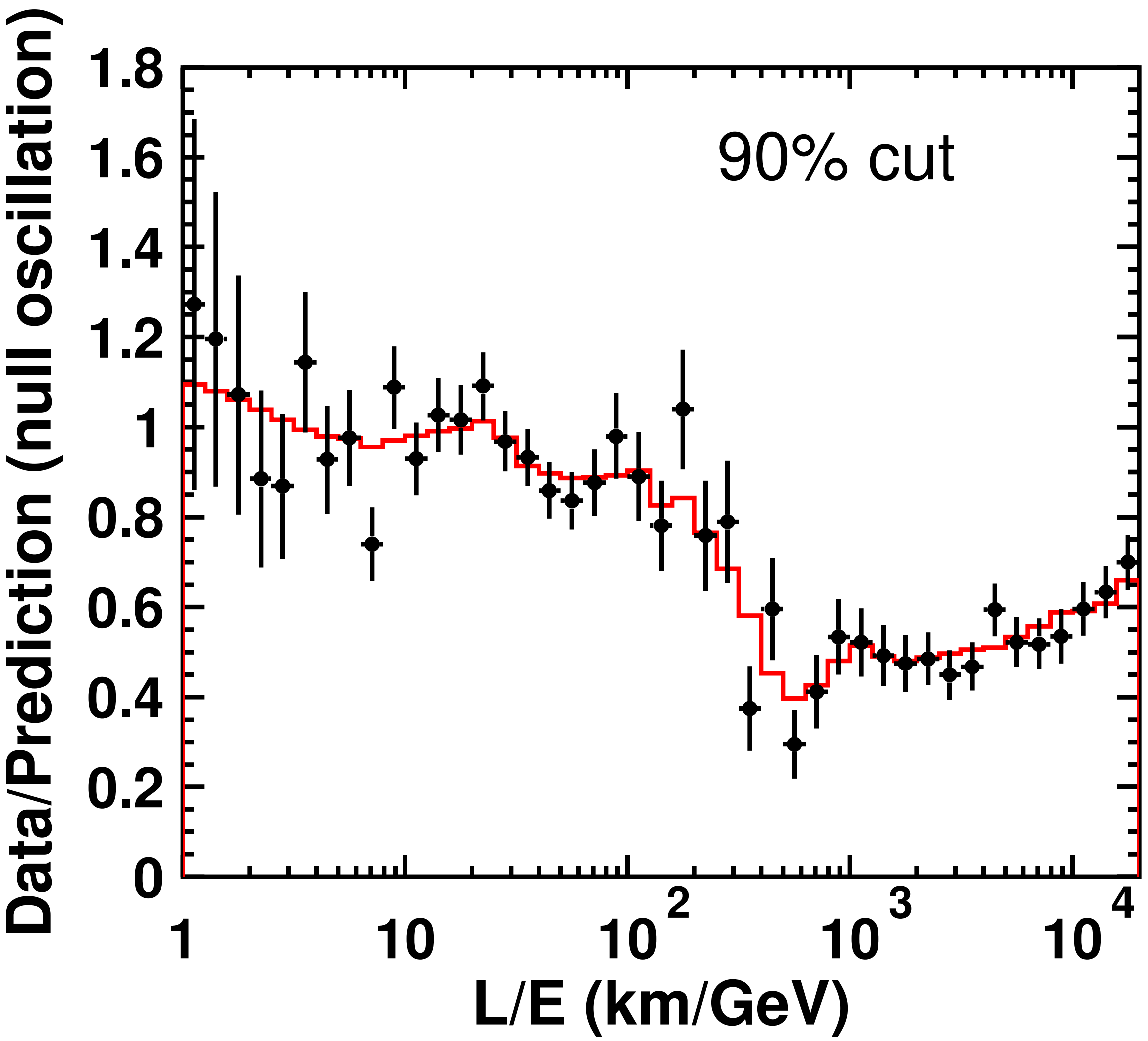
Data/Prediction (null oscillation)
60% cut
L/E (km/GeV)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10 2
10 3
10 4



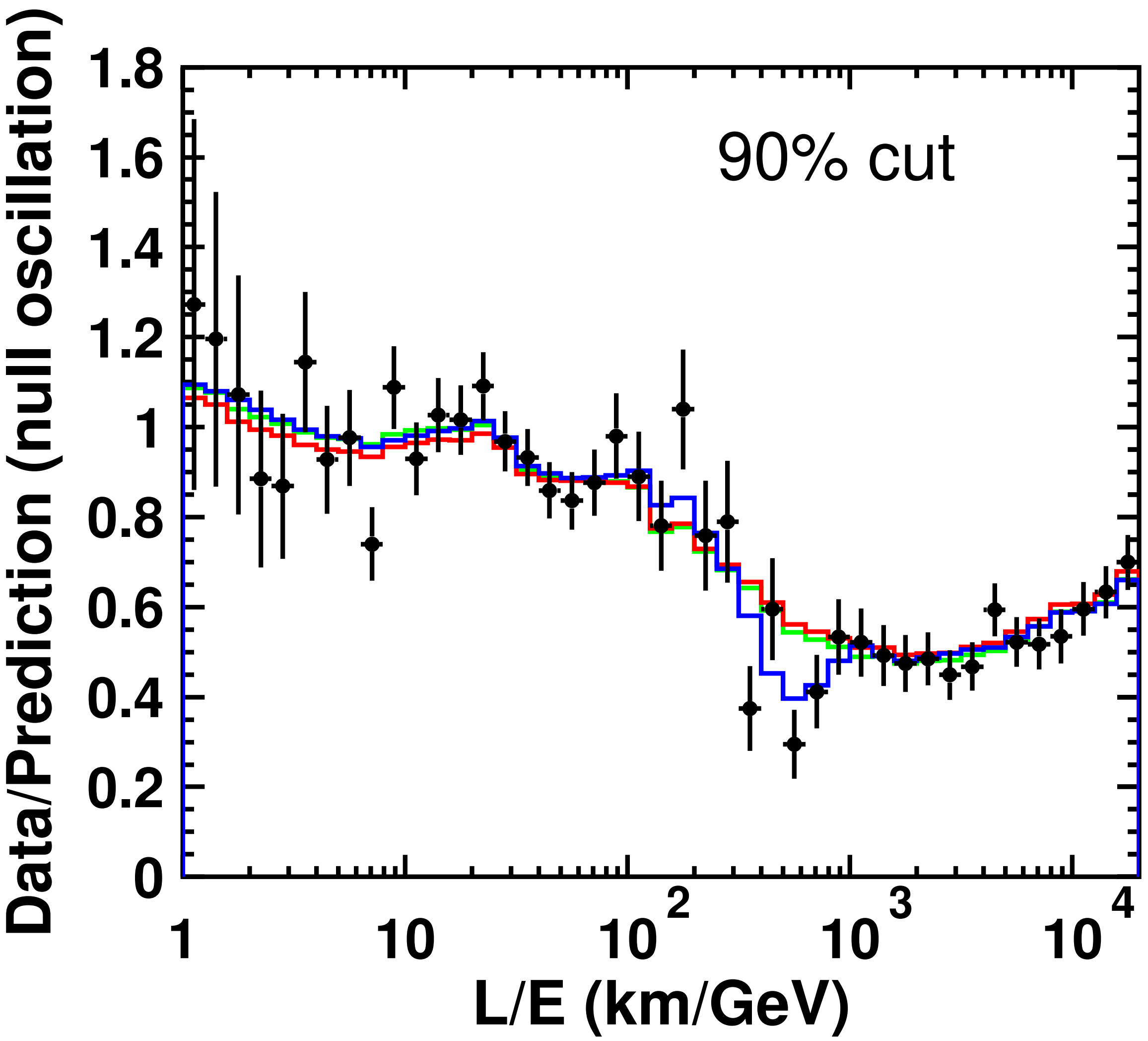
80% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4



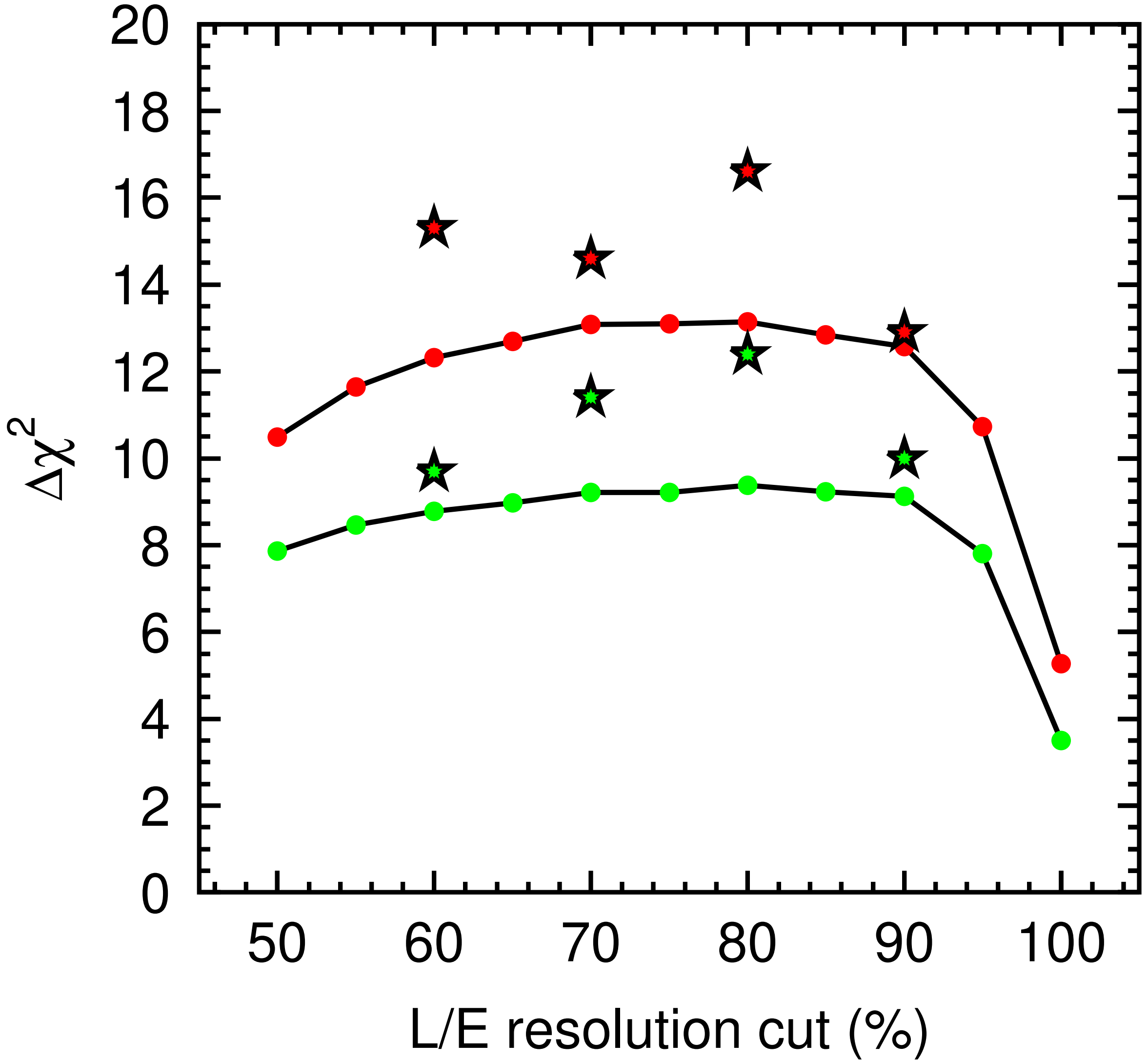
80% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10 2
10 3
10 4



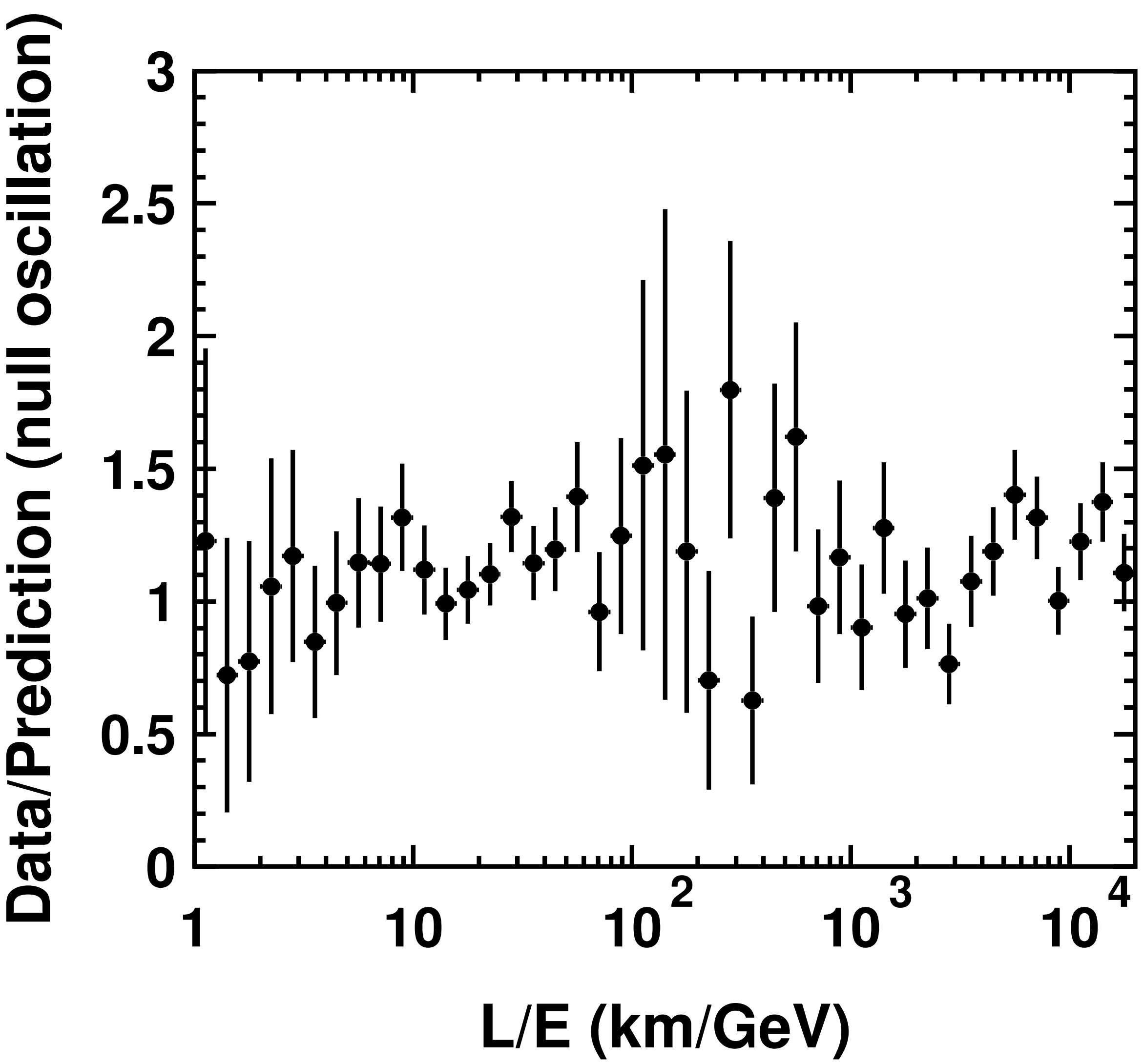
90% cut
Data/Prediction (null oscillation)
L/E (km/GeV)



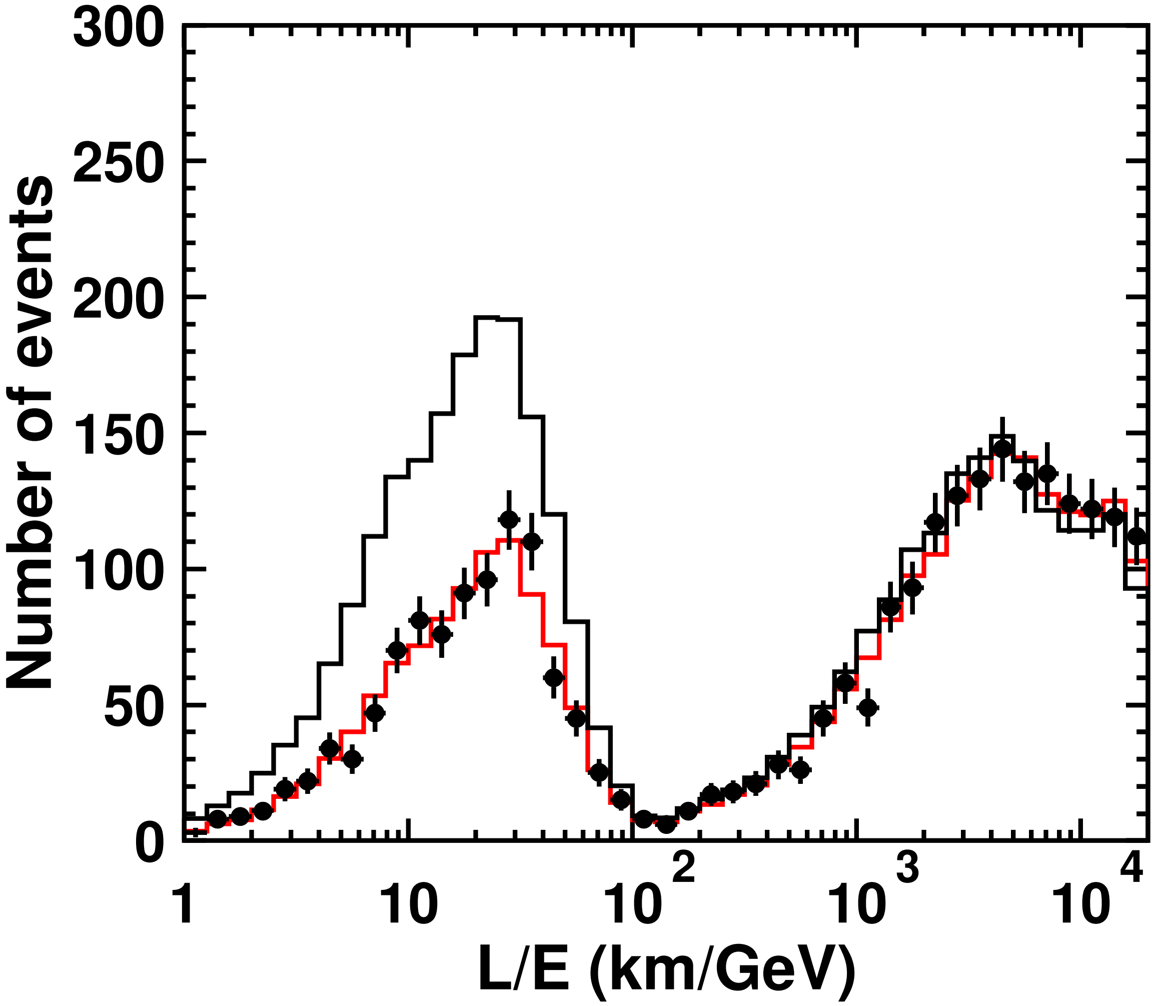
90% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4



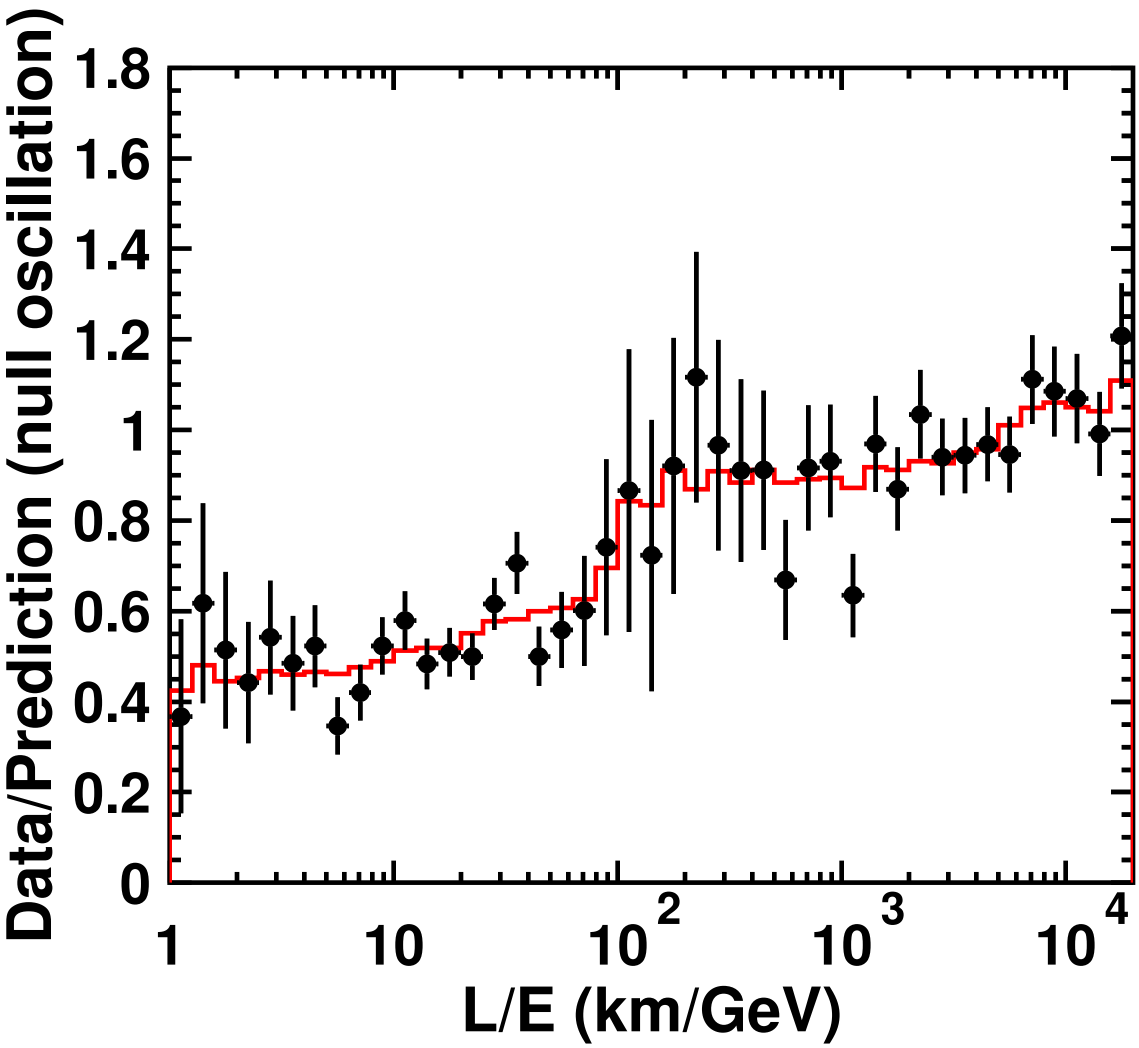
20
18
16
14
12
10
8
6
4
2
0
50
60
70
80
90
100
L/E resolution cut (%)
$\Delta\chi^2$



Data/Prediction (null oscillation)
3
2.5
2
1.5
1
0.5
0
1
10
10^2
10^3
10^4
L/E (km/GeV)



Number of events
300
250
200
150
100
50
0
1
10
10^2
10^3
10^4
L/E (km/GeV)



Data/Prediction (null oscillation)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
10^4
L/E (km/GeV)

Results of L/E Analysis
(1489 days FC + PC)

- **Assuming $\nu_\mu \leftrightarrow \nu_\tau$ Oscillation**

  Best Fit:

  χ^2_{min} = 38.0 / 40 d.o.f

  at ($\sin^2 2\theta$, Δm^2) = (1.00 , 2.4E-03 eV^2)

  (including unphysical region)

  χ^2_{min} = 37.9 / 40 d.o.f

  at ($\sin^2 2\theta$, Δm^2) = (1.01 , 2.4E-03 eV^2)

  90% confidence level allowed region:

  $\sin^2(2\theta) > 0.9$

  $1.9 \times 10^{-3}\ \mathrm{eV}^2 < \Delta m^2 < 3.0 \times 10^{-3}\ \mathrm{eV}^2$

- **Assuming Neutrino Decay**

  χ^2_{min} = 51.0 / 40 d.o.f

  $\Delta\chi^2$ = 13.0 / 40 d.o.f (3.6 standard deviations)

- **Assuming Neutrino Decoherence**

  χ^2_{min} = 54.0 / 40 d.o.f

  $\Delta\chi^2$ = 16.0 / 40 d.o.f (4.0 standard deviations)