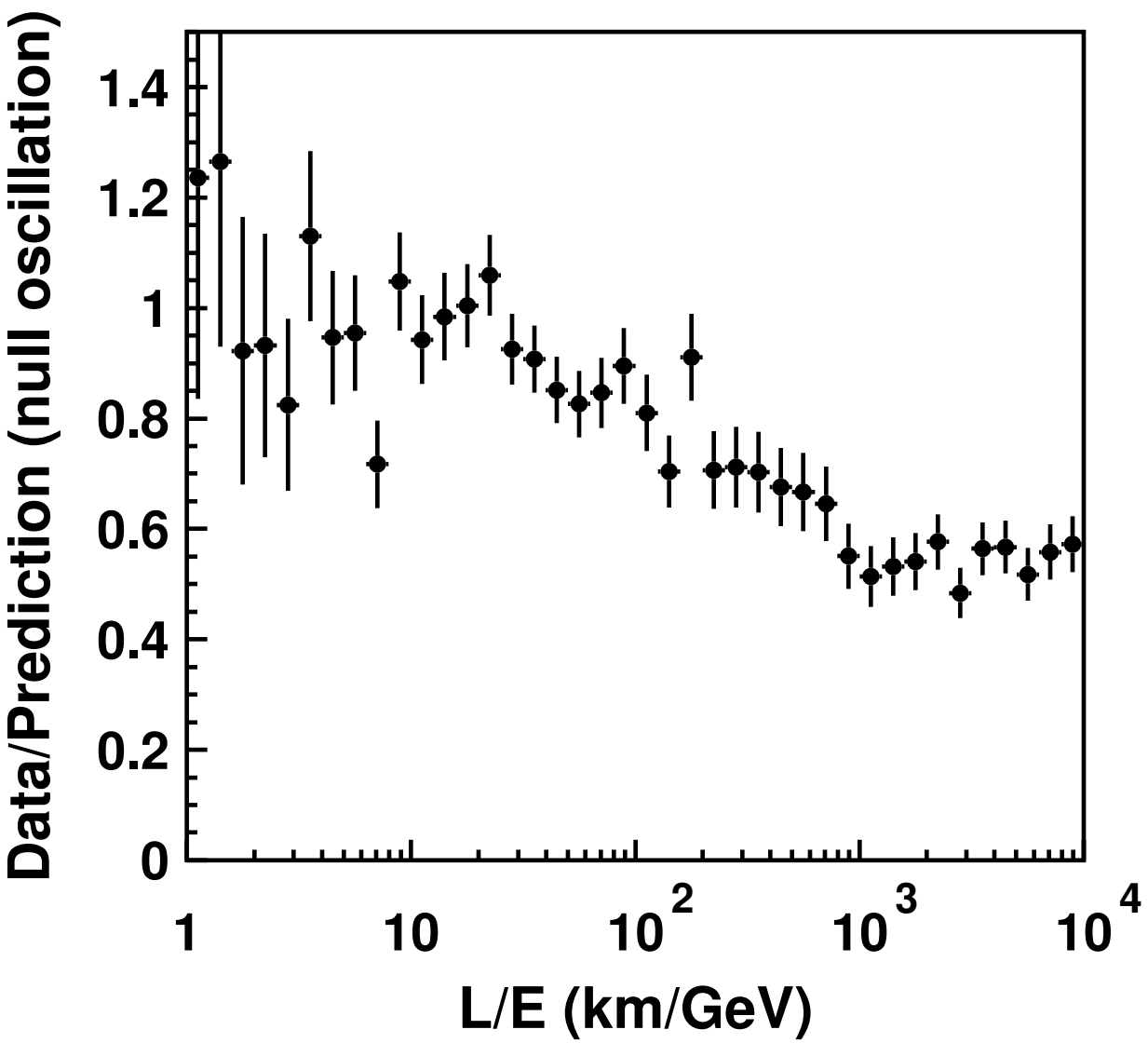
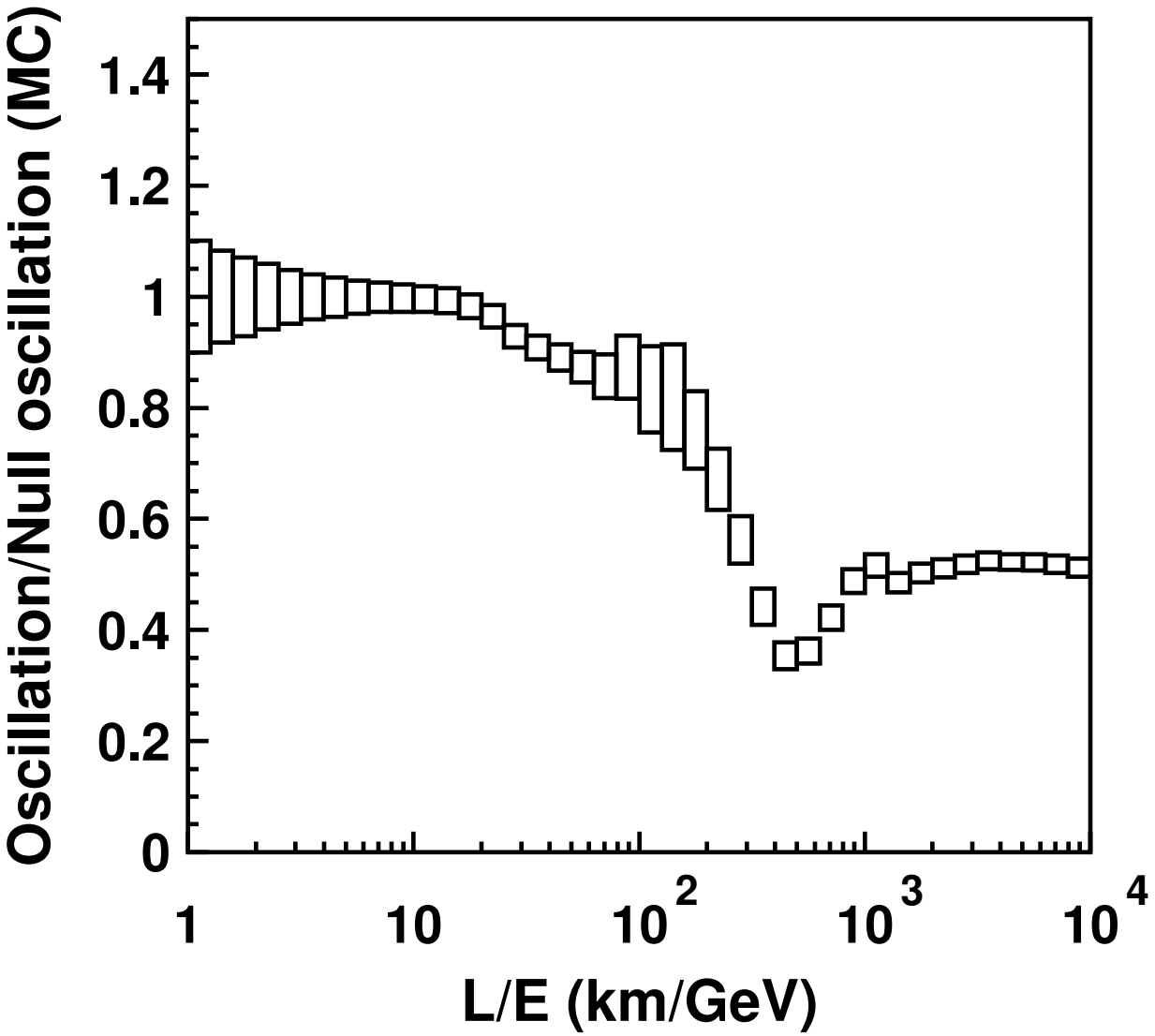
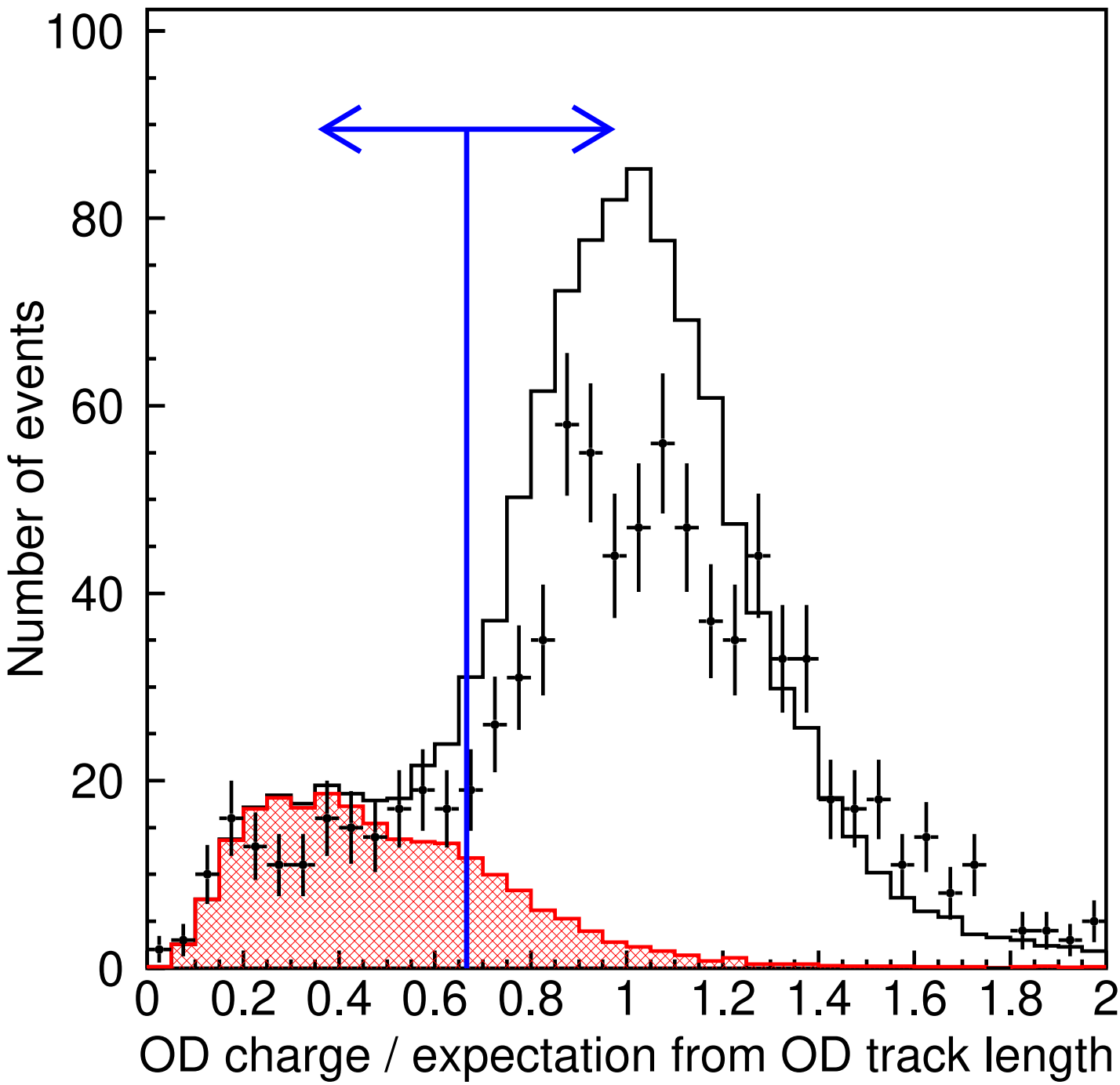
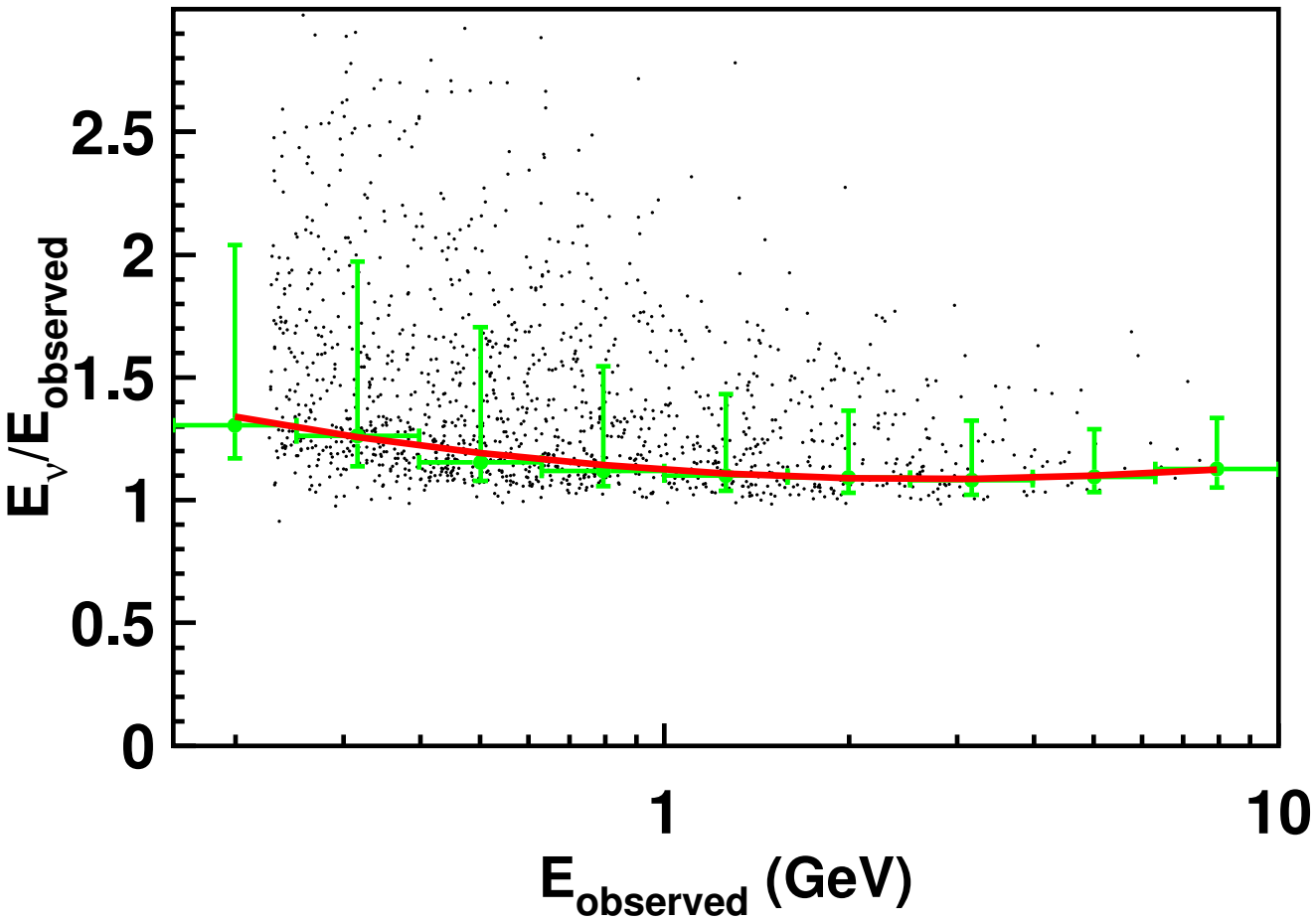
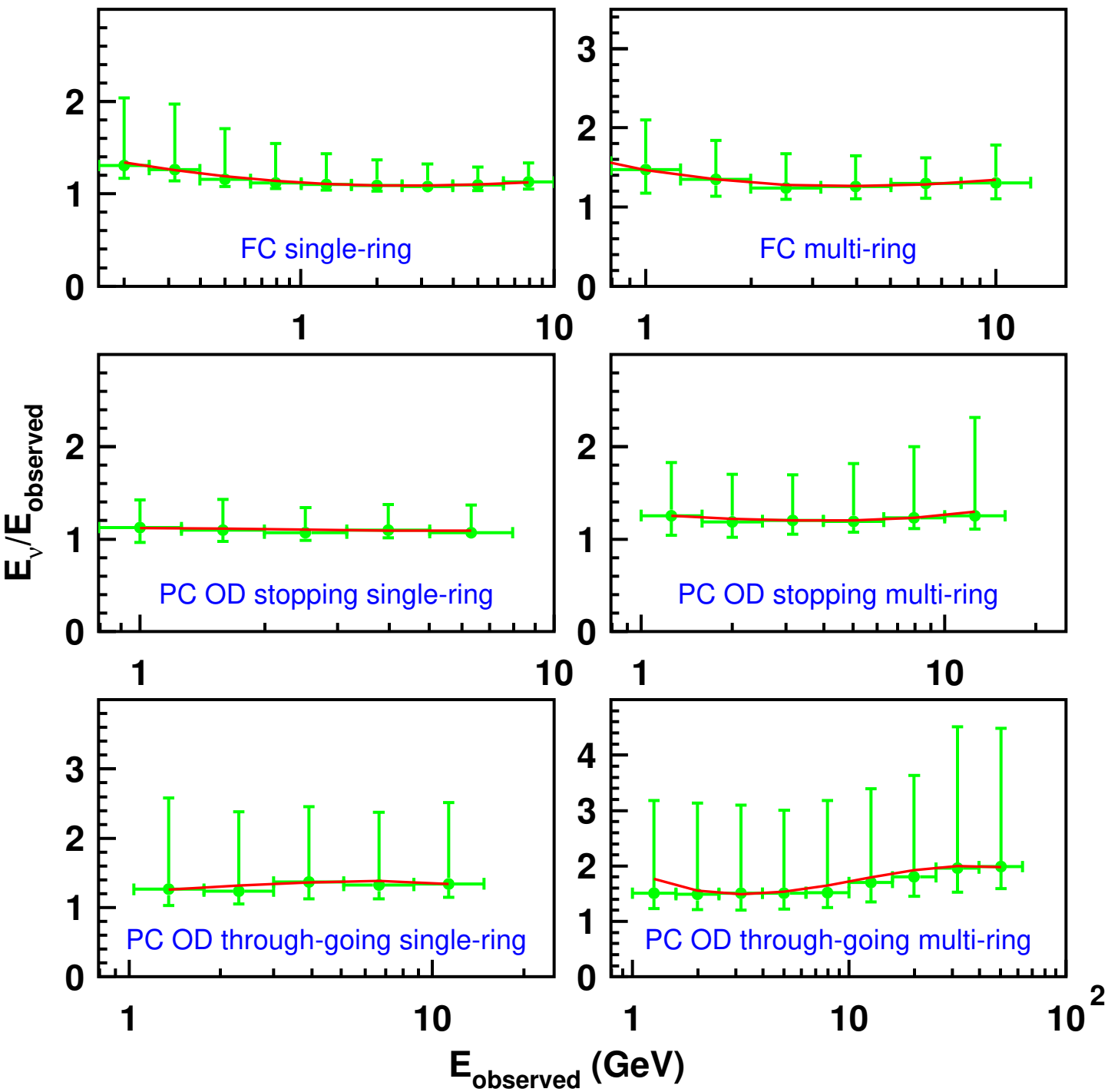
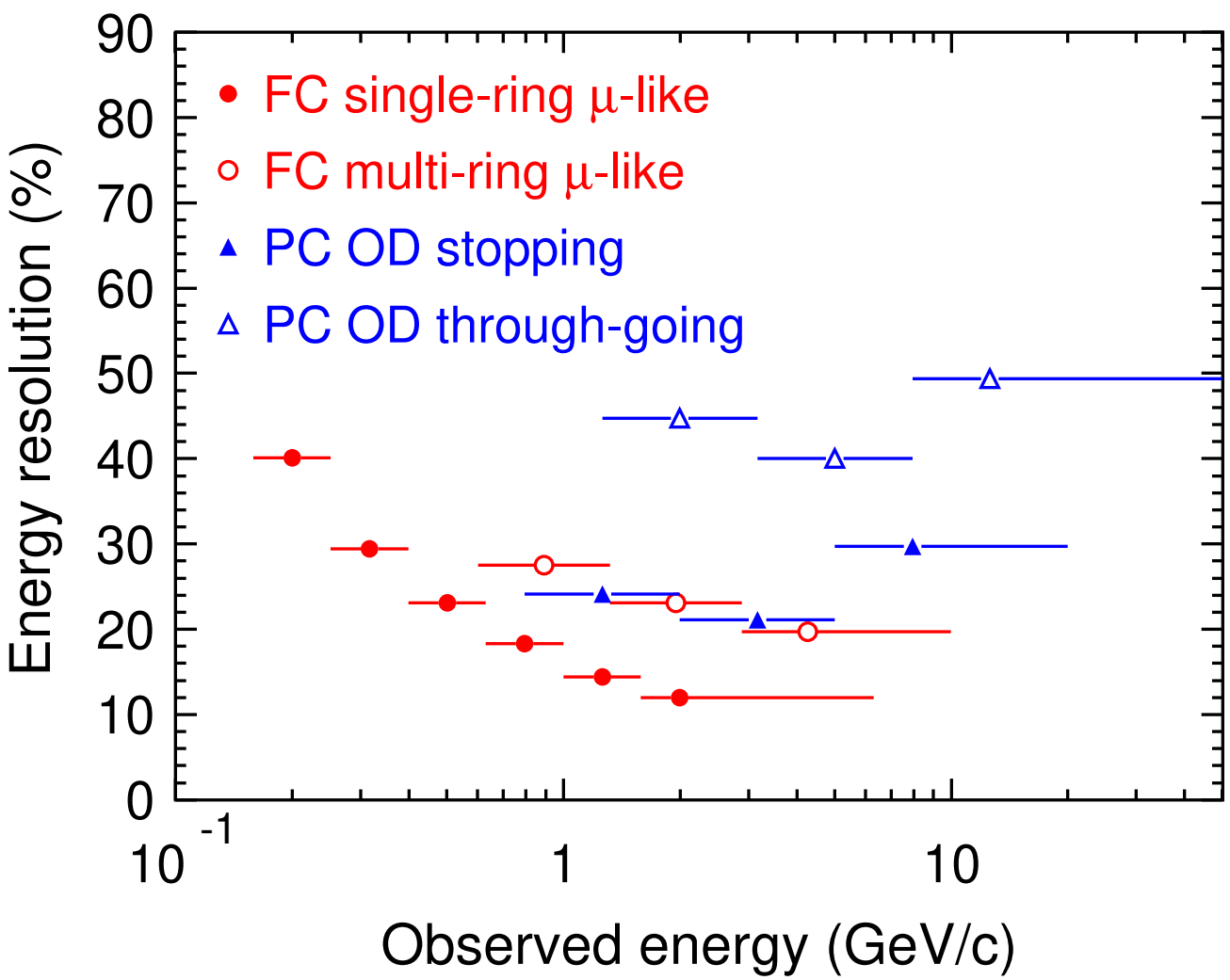

Data/Prediction (null oscillation)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
10^4
L/E (km/GeV)

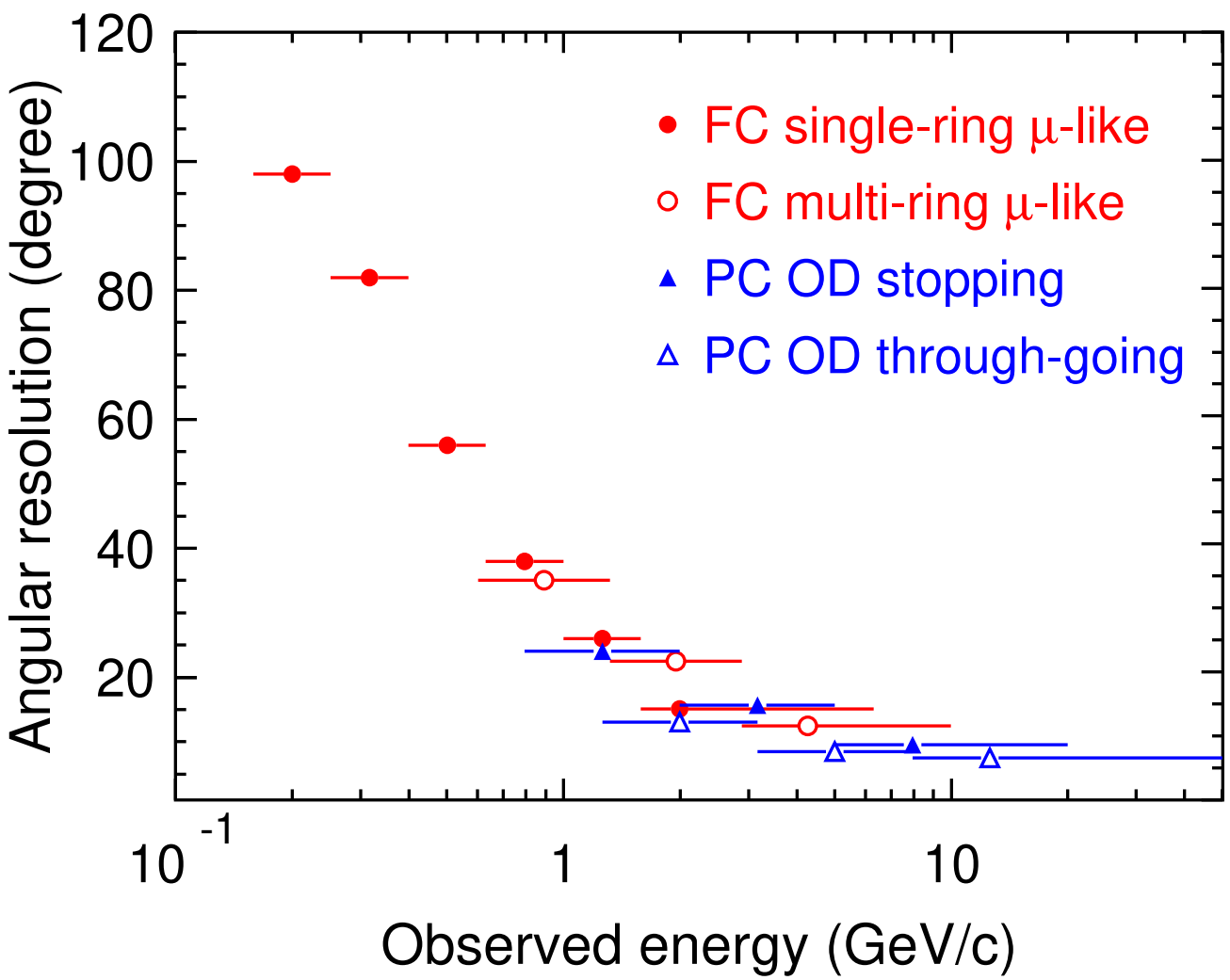

Oscillation/Null oscillation (MC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
10^4
L/E (km/GeV)

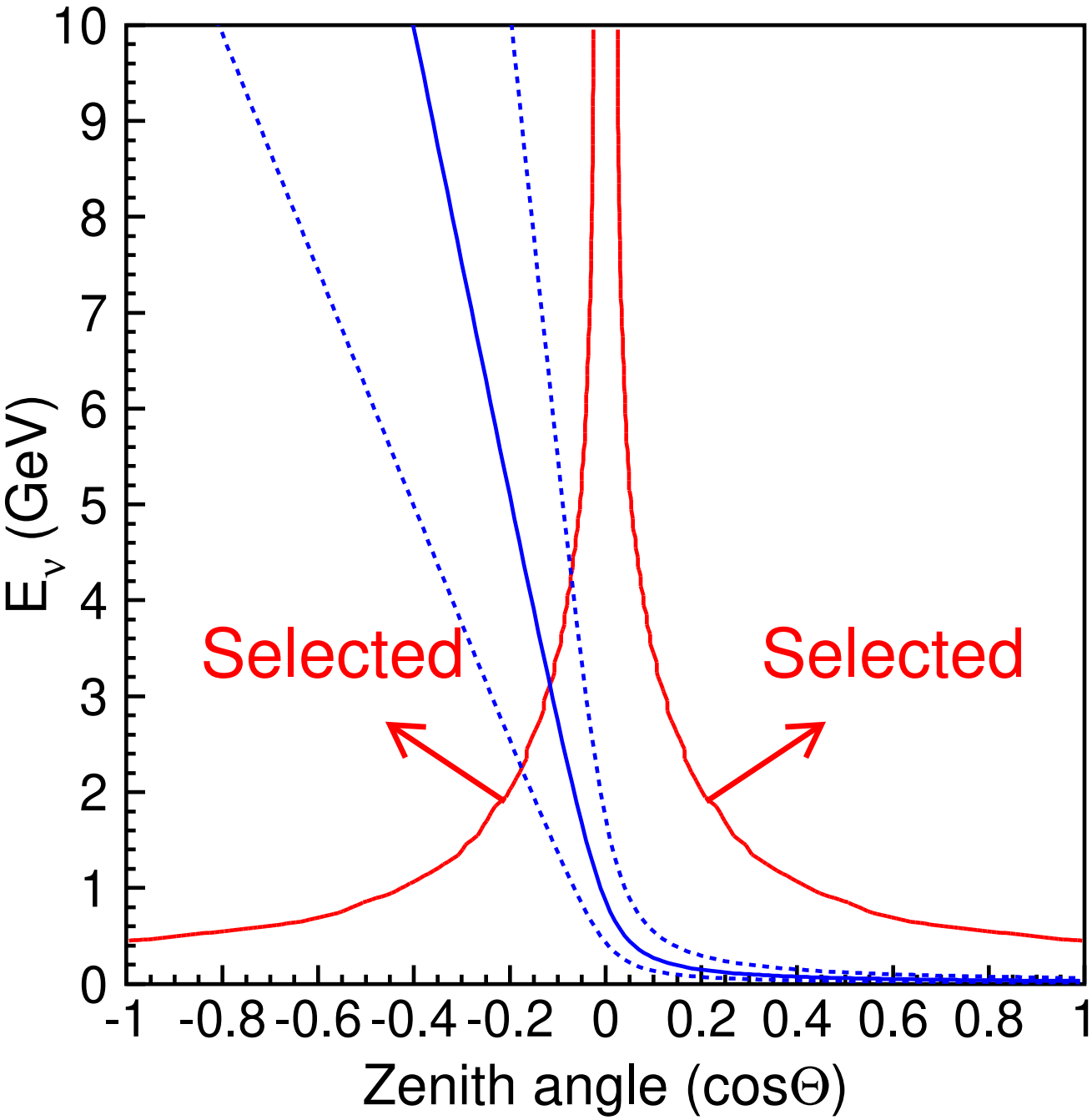

100
80
60
40
20
0
Number of events
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
OD charge / expectation from OD track length

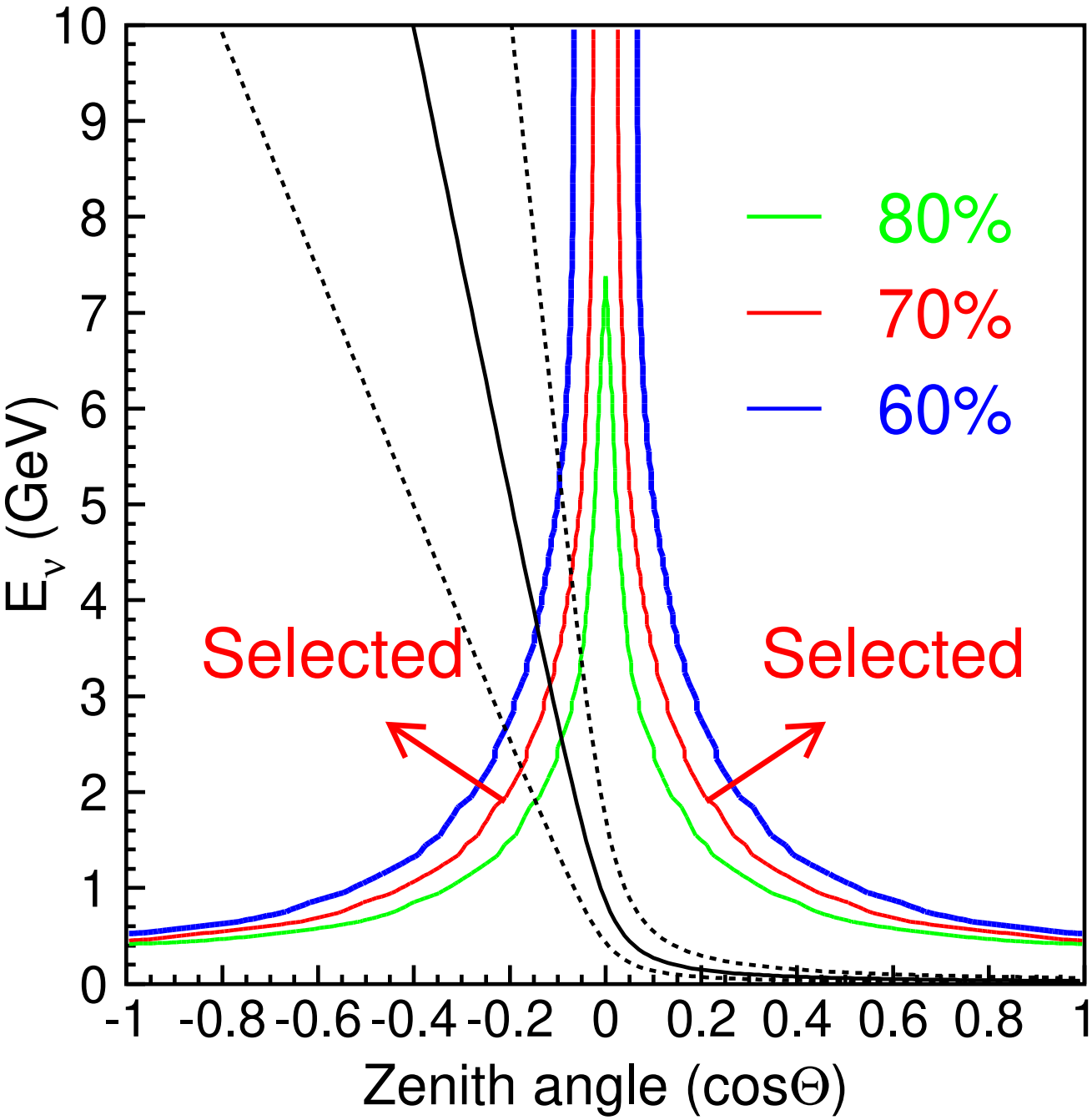

2.5
2
1.5
1
0.5
0
$E_\nu/E_{observed}$
1
10
$E_{observed}$ (GeV)

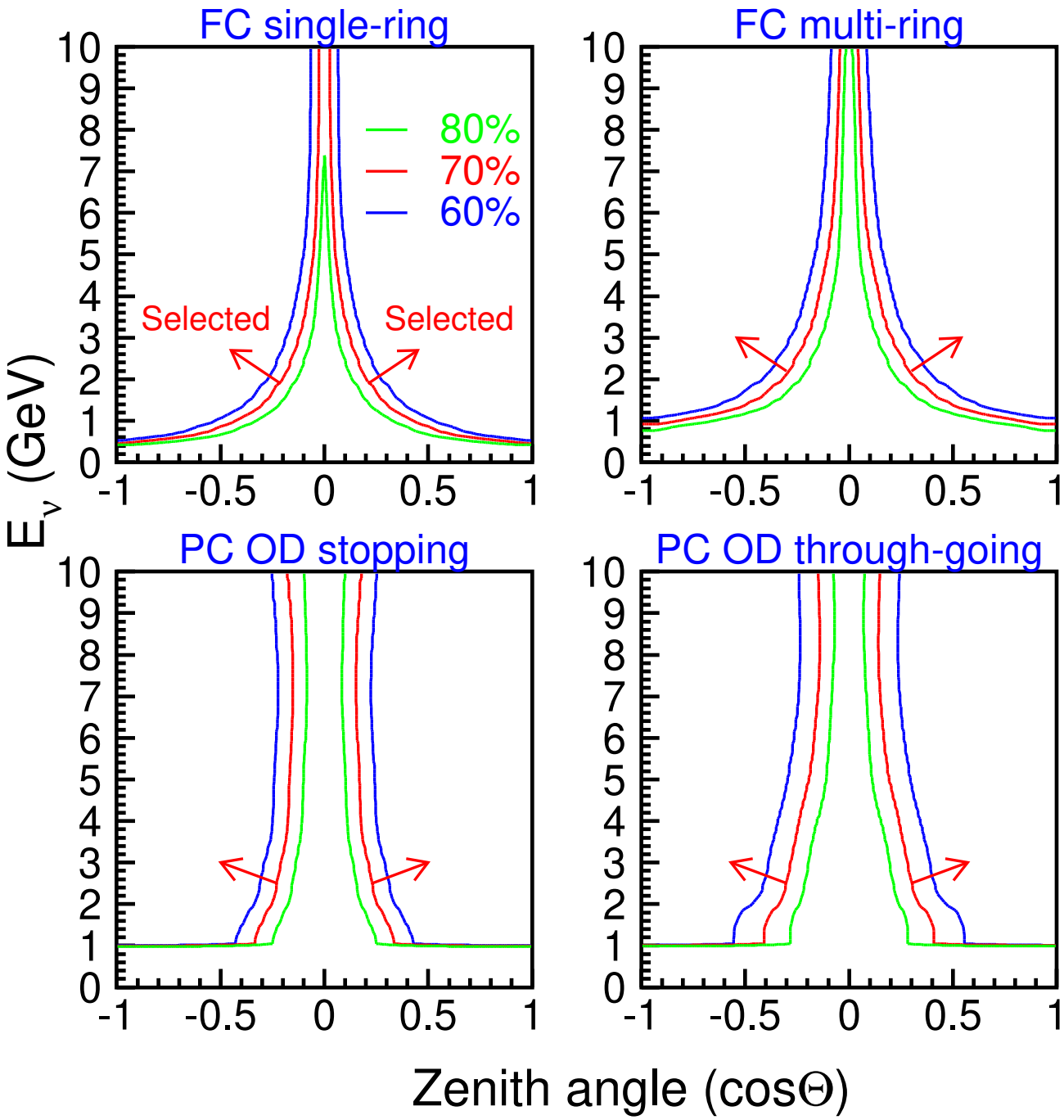

FC single-ring
FC multi-ring
PC OD stopping single-ring
PC OD stopping multi-ring
PC OD through-going single-ring
PC OD through-going multi-ring
$E_\nu/E_{observed}$
$E_{observed}$ (GeV)


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


120
100
80
60
40
20
Angular resolution (degree)
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
$E_\nu$ (GeV)
Selected
Selected
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Zenith angle (cosΘ)

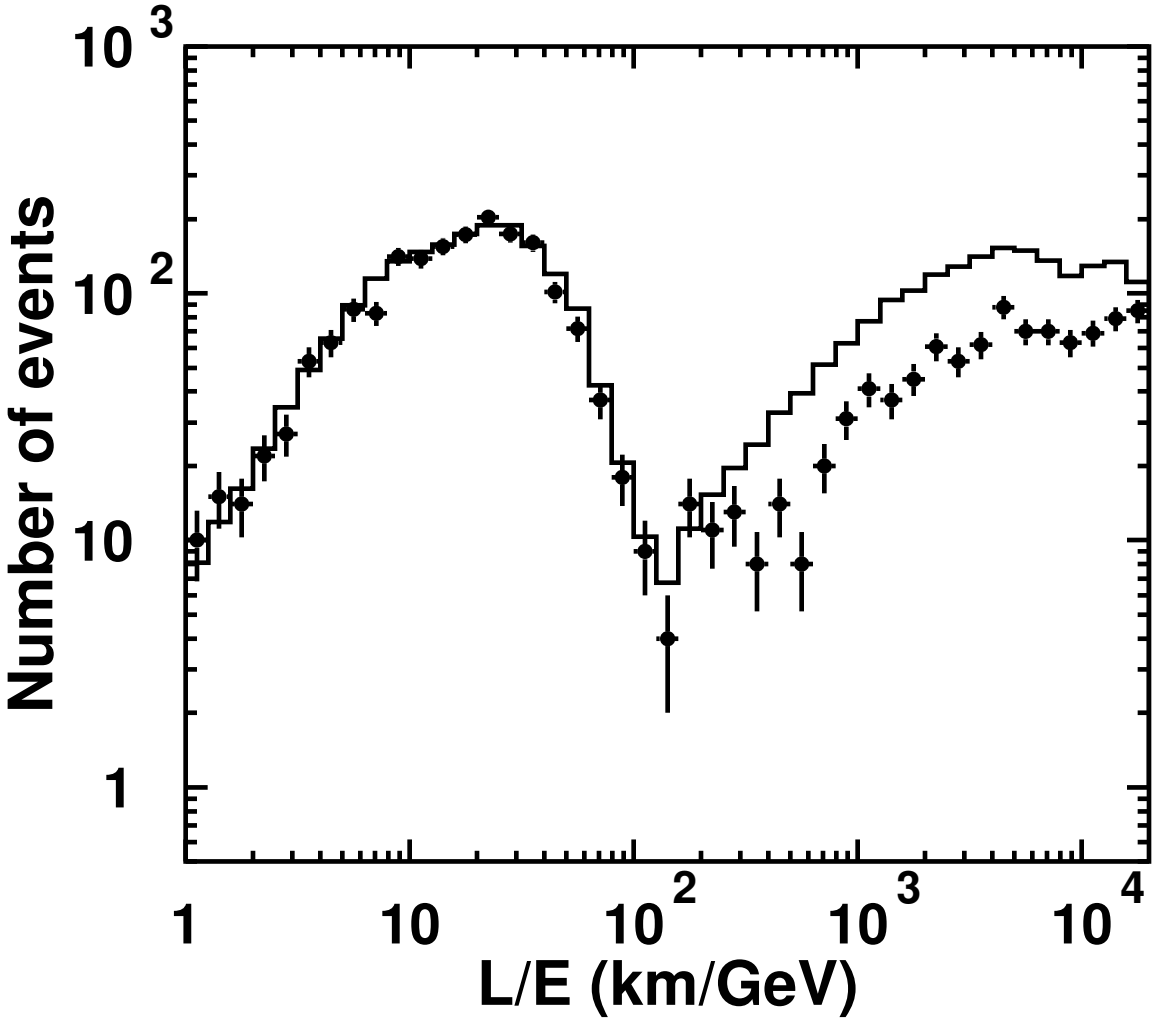

10
9
8
7
6
5
4
3
2
1
0
$E_\nu$ (GeV)
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Zenith angle (cosΘ)
80%
70%
60%
Selected
Selected

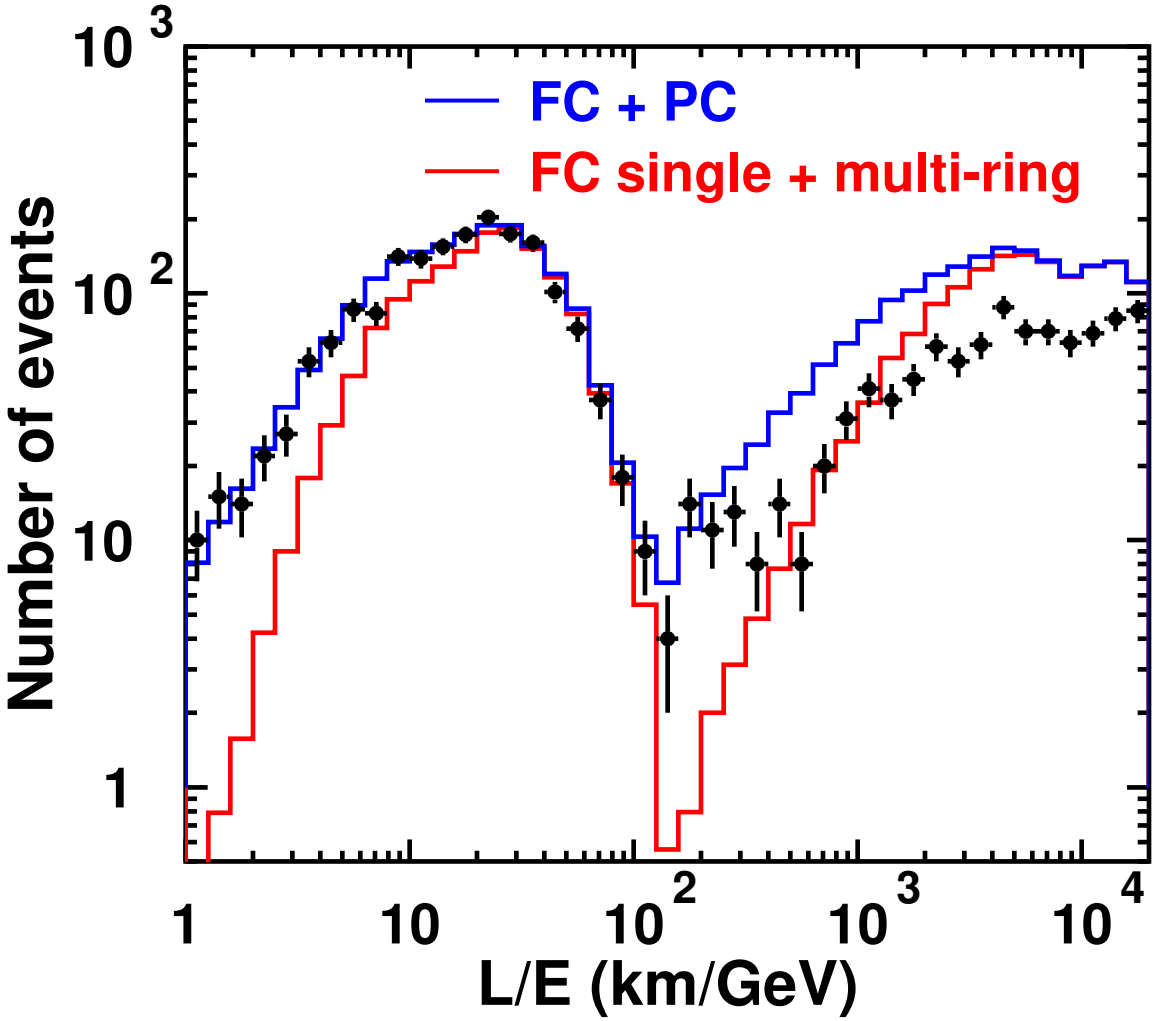

FC single-ring
FC multi-ring
PC OD stopping
PC OD through-going
80%
70%
60%
Selected
Selected
$E_\nu$ (GeV)
Zenith angle (cosΘ)

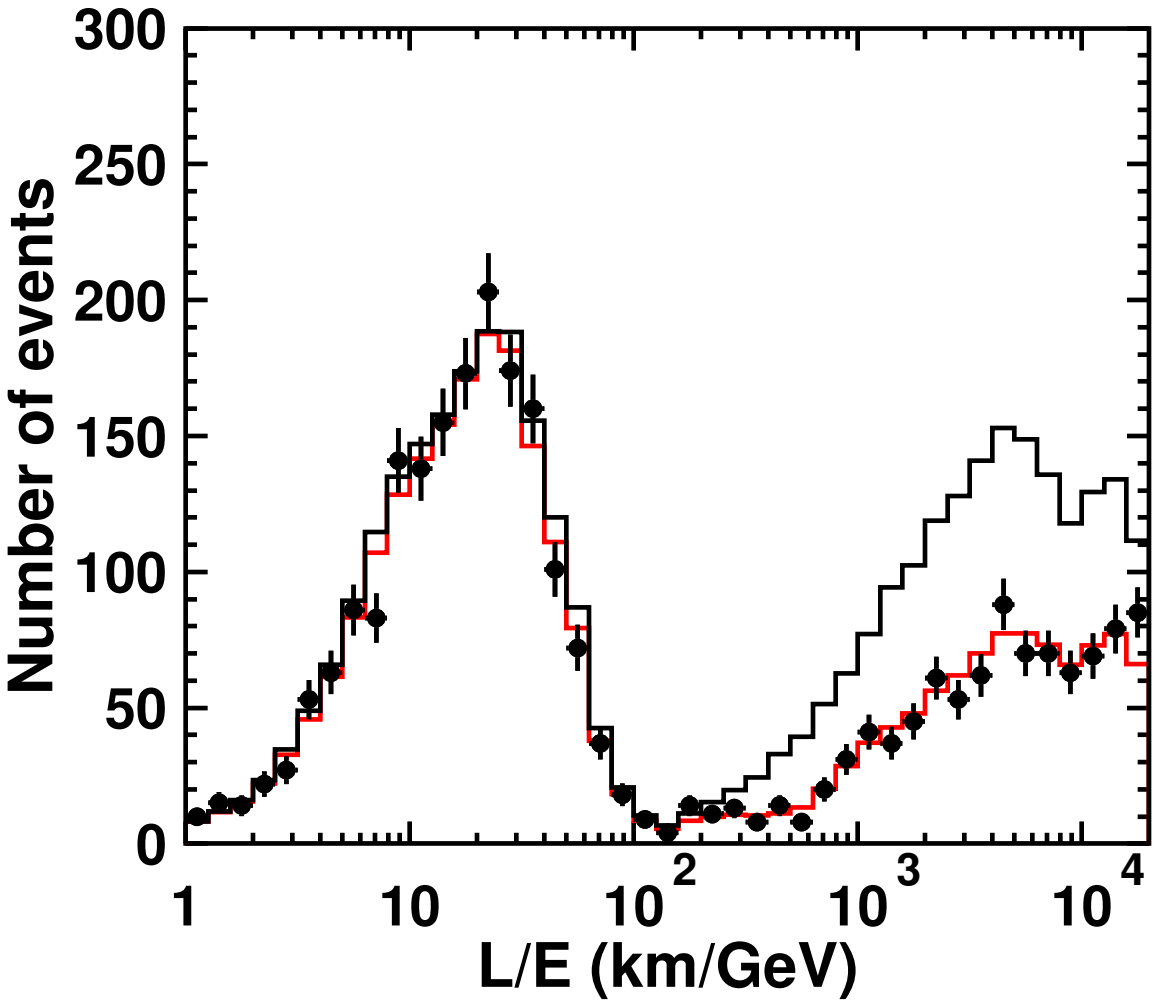
# L/E event summary

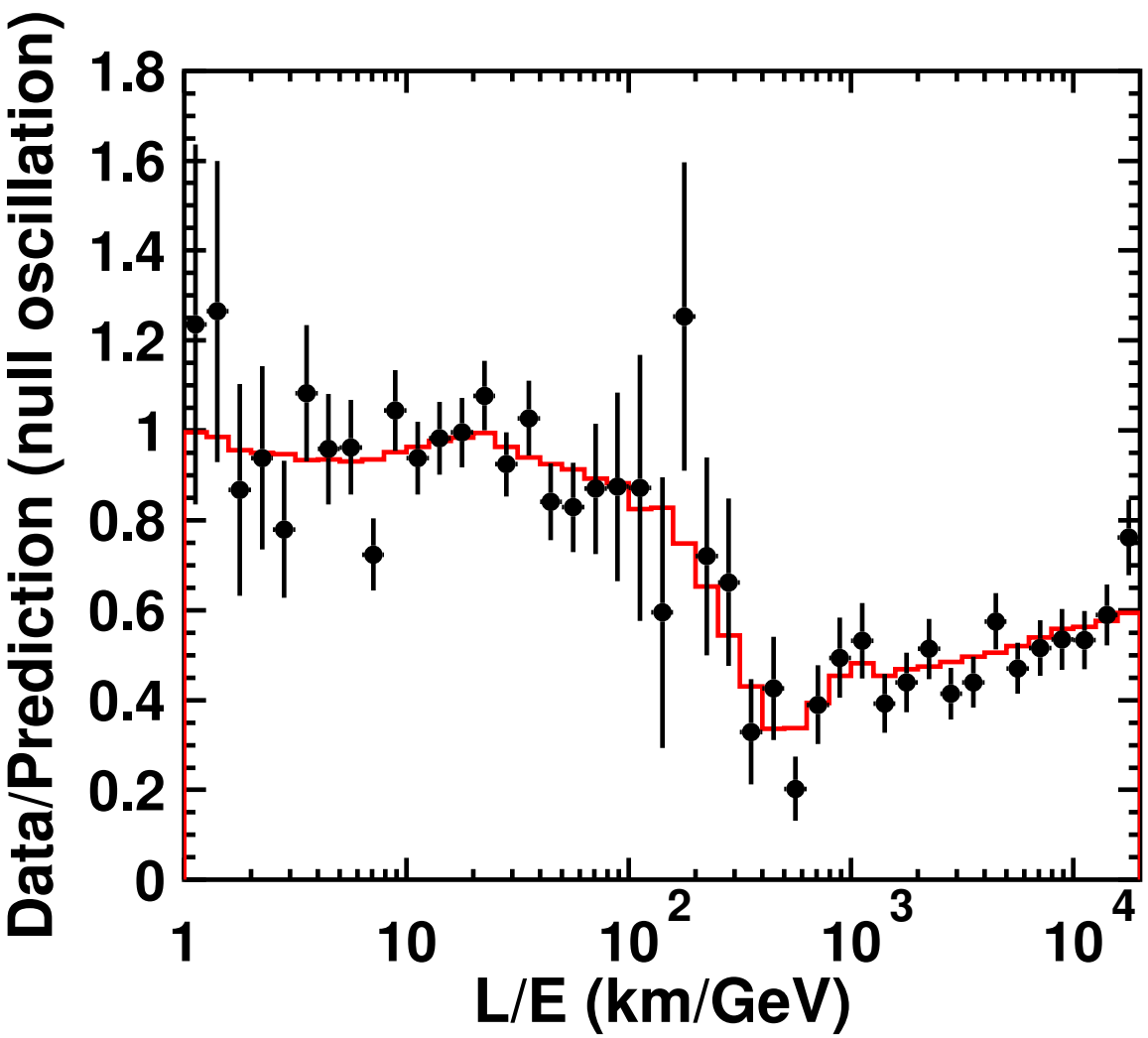
($\Delta$L/E < 70%)

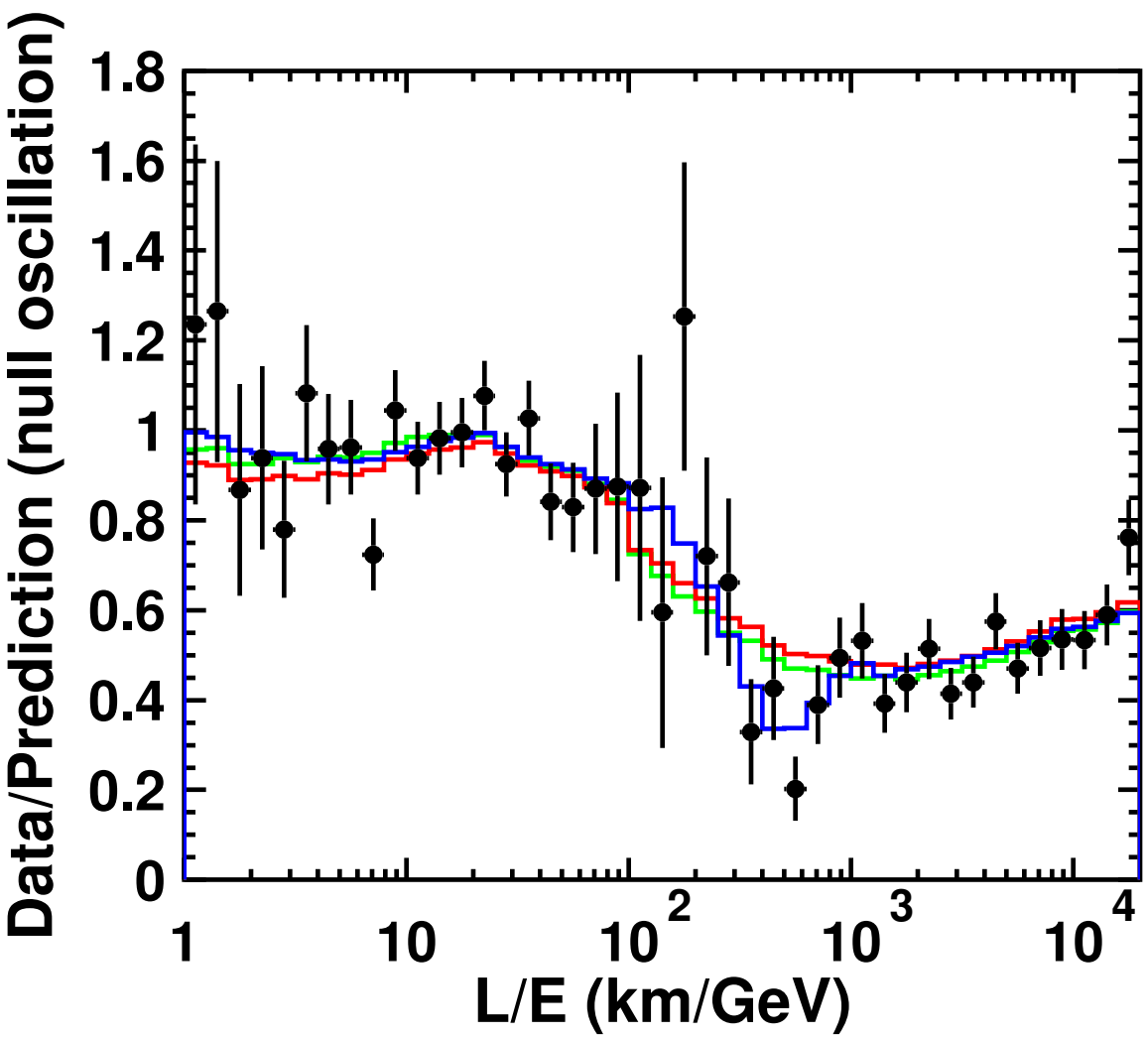
| | DATA | MC | $\nu_\mu$ CC |
|---|---|---|---|
| FC | | | |
| single-ring | 1619 | 2105.8 | ( 98.3%) |
| multi-ring | 502 | 813.0 | ( 94.2%) |
| PC | | | |
| OD stopping | 114 | 137.0 | ( 95.4%) |
| OD through-going | 491 | 670.4 | ( 99.1%) |

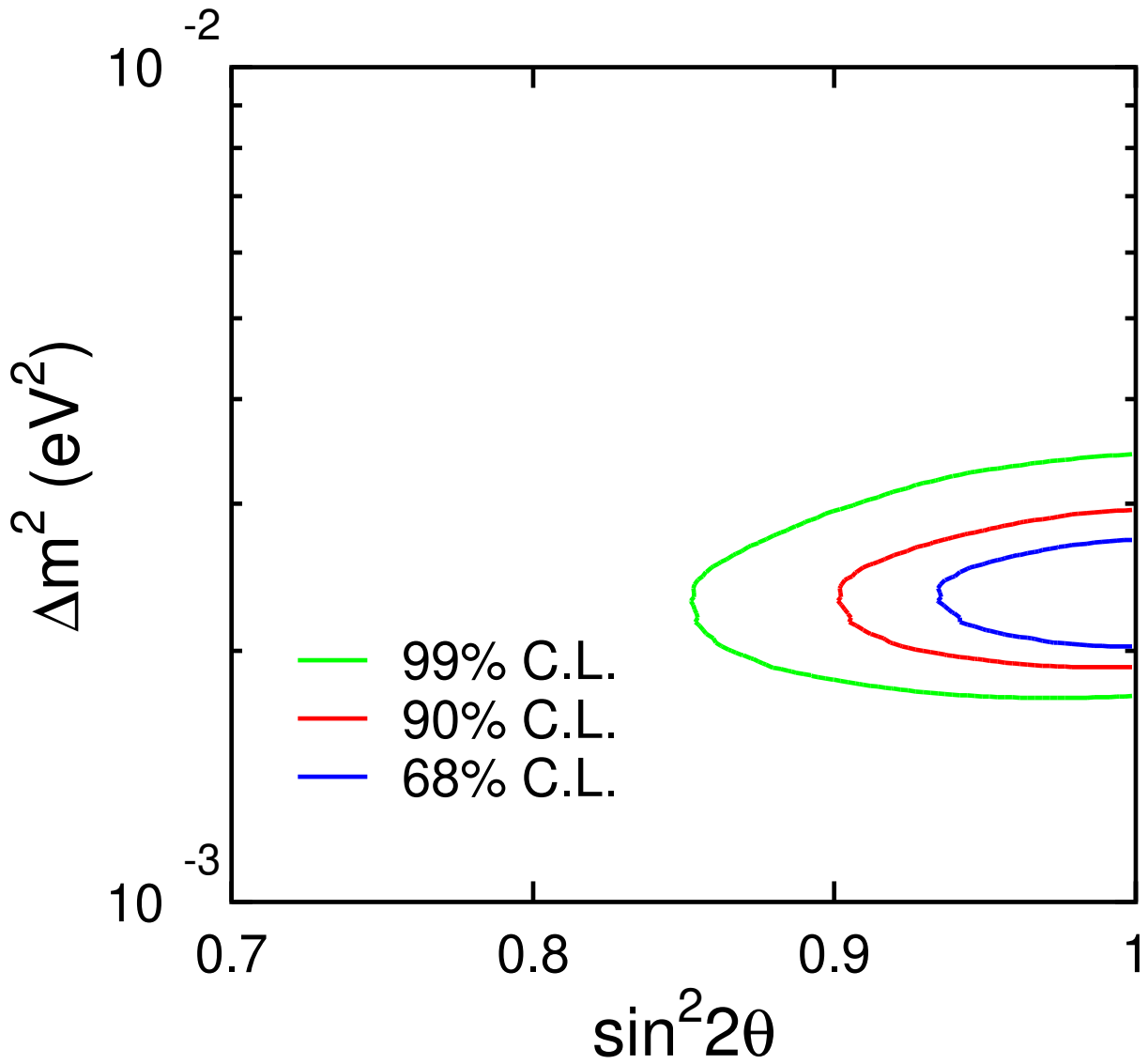

Number of events
10 3
10 2
10
1
1
10
10 2
10 3
10 4
L/E (km/GeV)

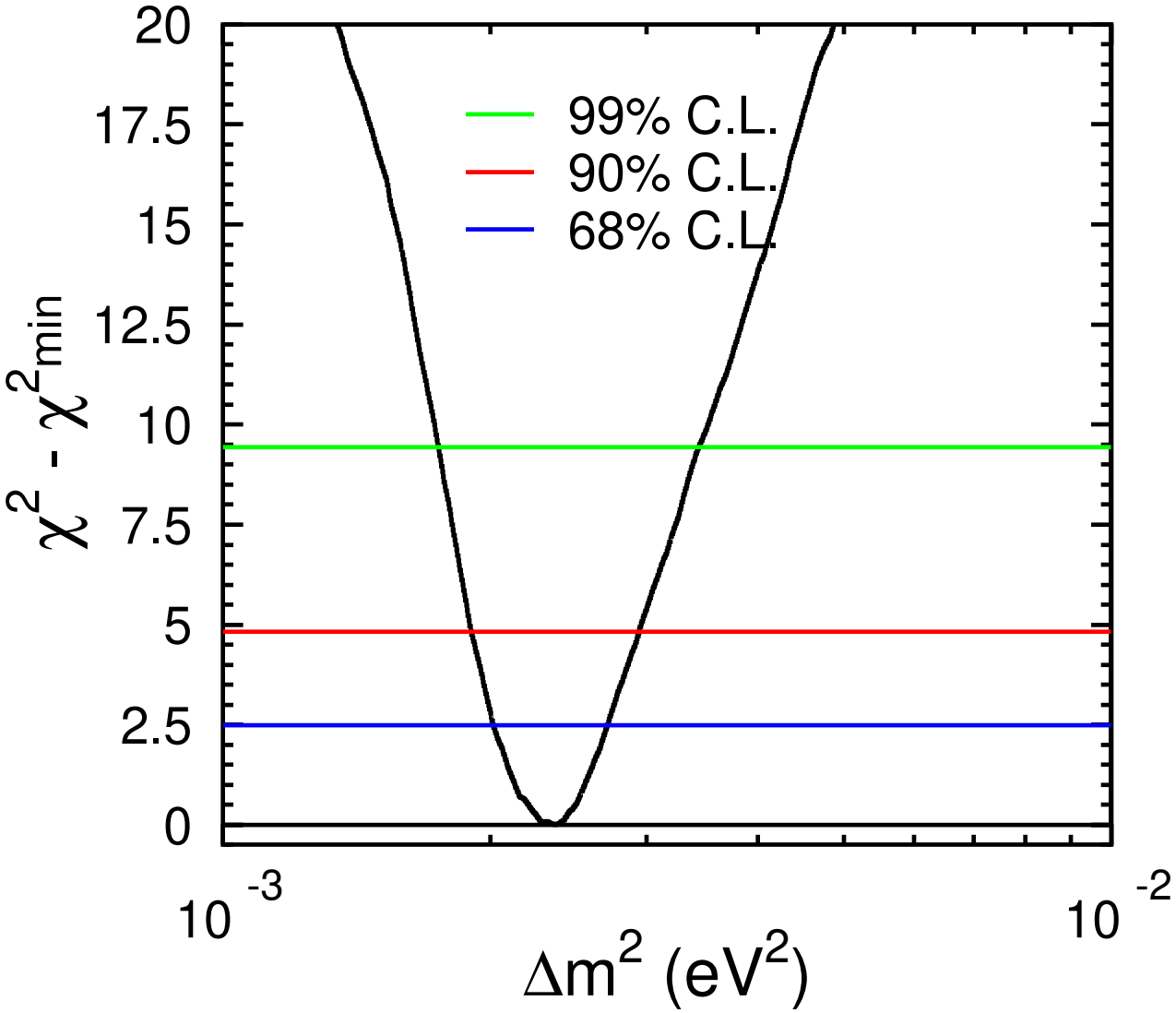

FC + PC
FC single + multi-ring
Number of events
L/E (km/GeV)
1
10
10 2
10 3
1
10
10 2
10 3
10 4

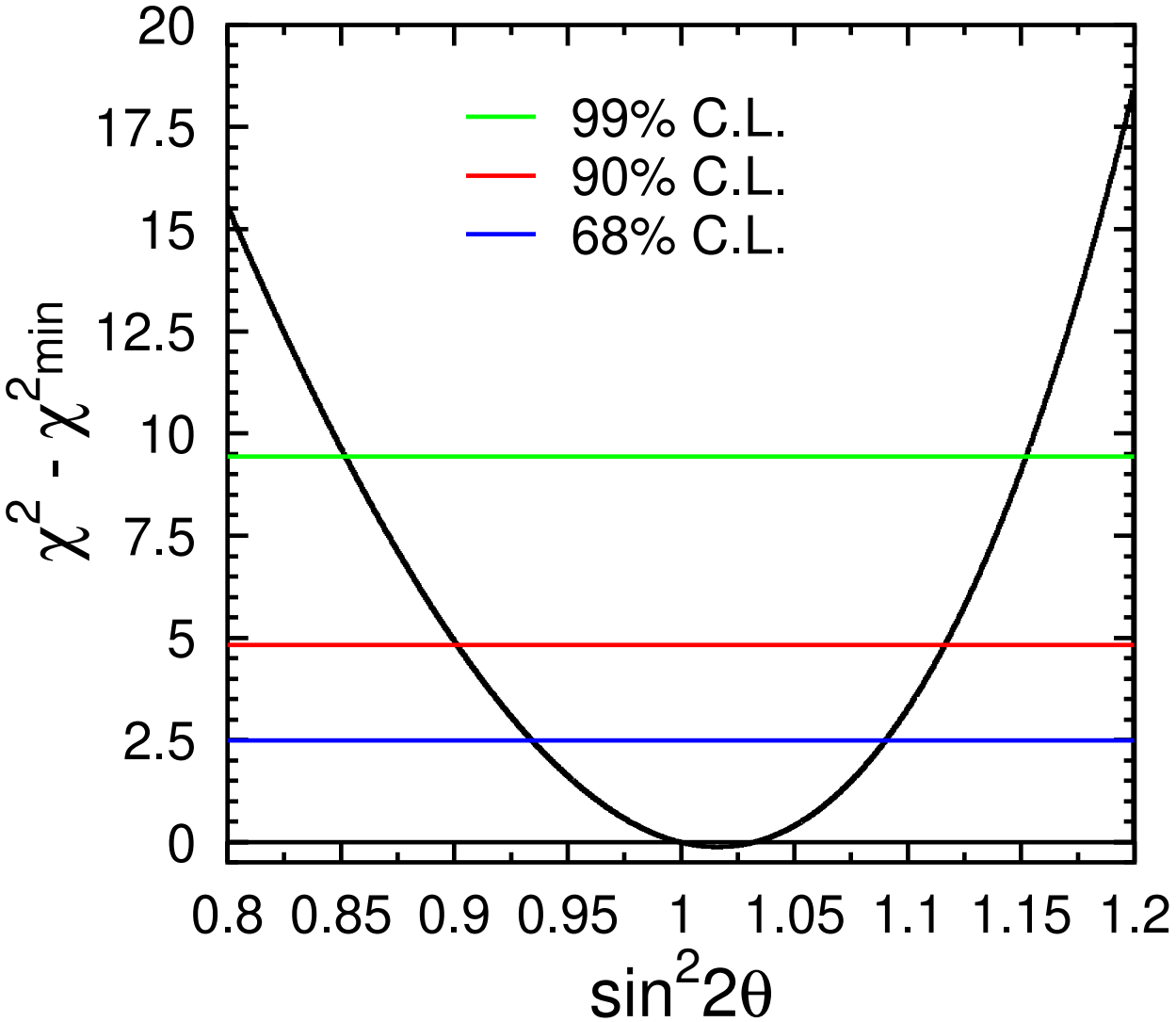

300
250
200
150
100
50
0
Number of events
1
10
10 2
10 3
10 4
L/E (km/GeV)

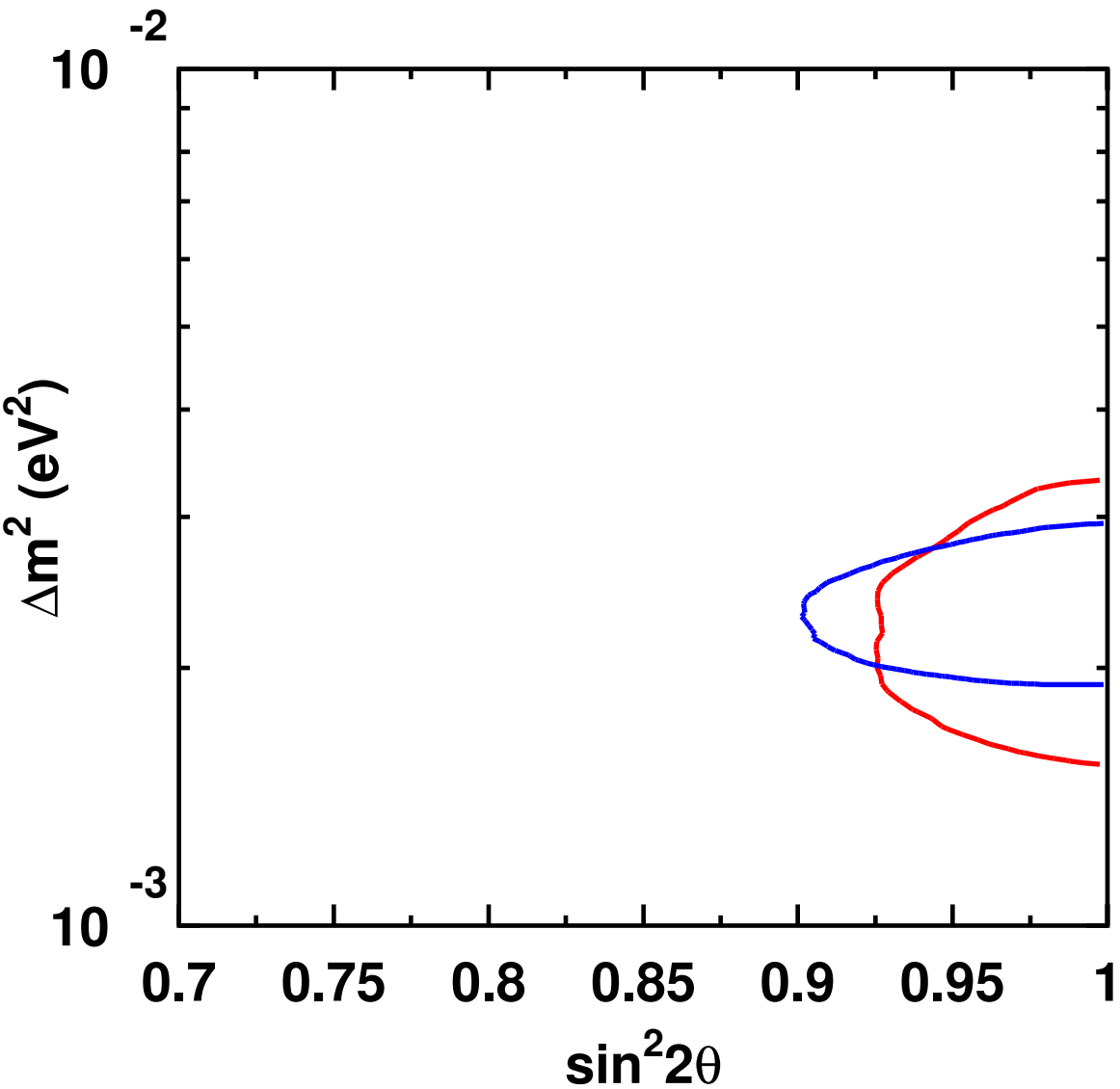

Data/Prediction (null oscillation)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
10^4
L/E (km/GeV)

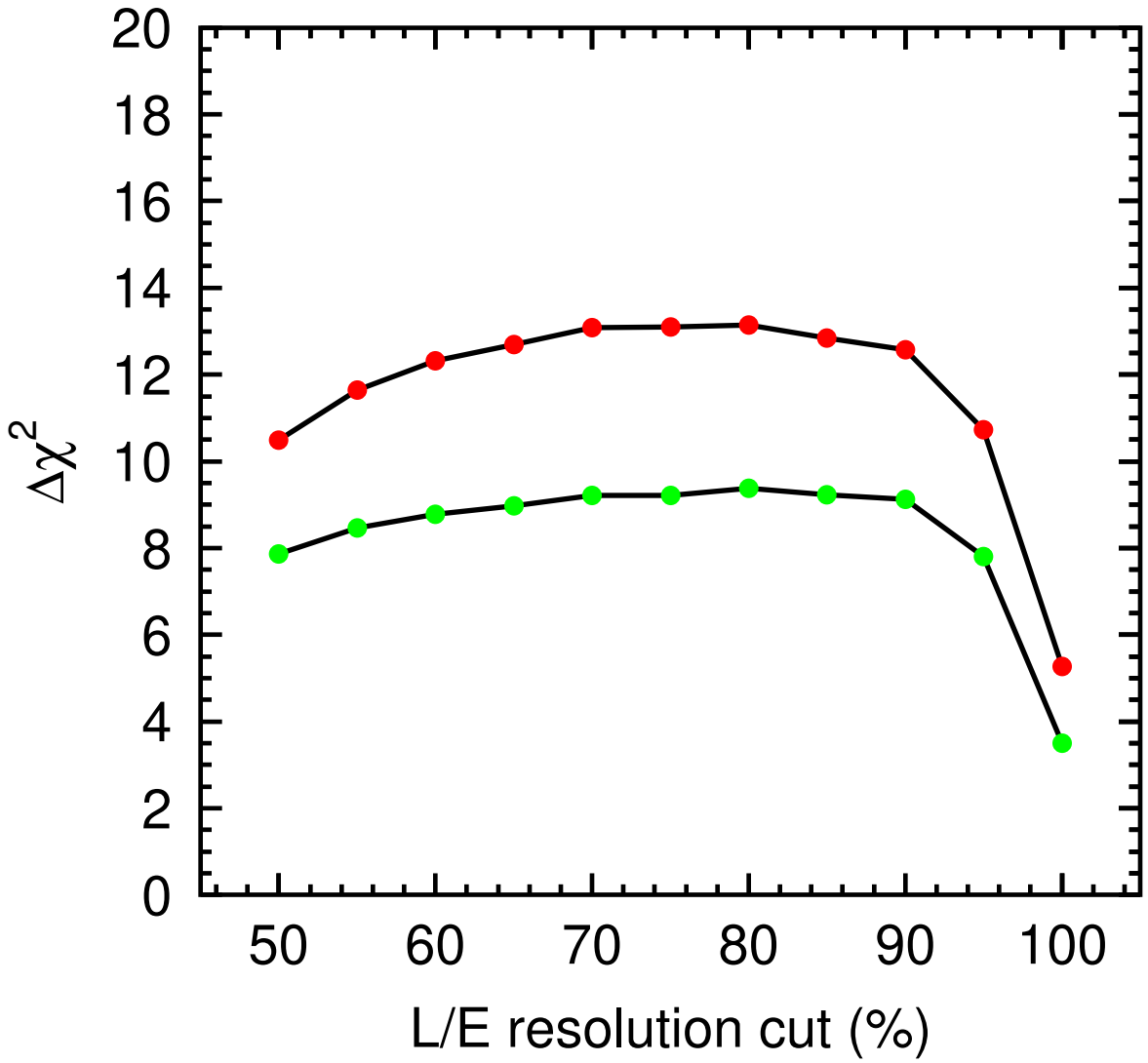

Data/Prediction (null oscillation)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
10^4
L/E (km/GeV)

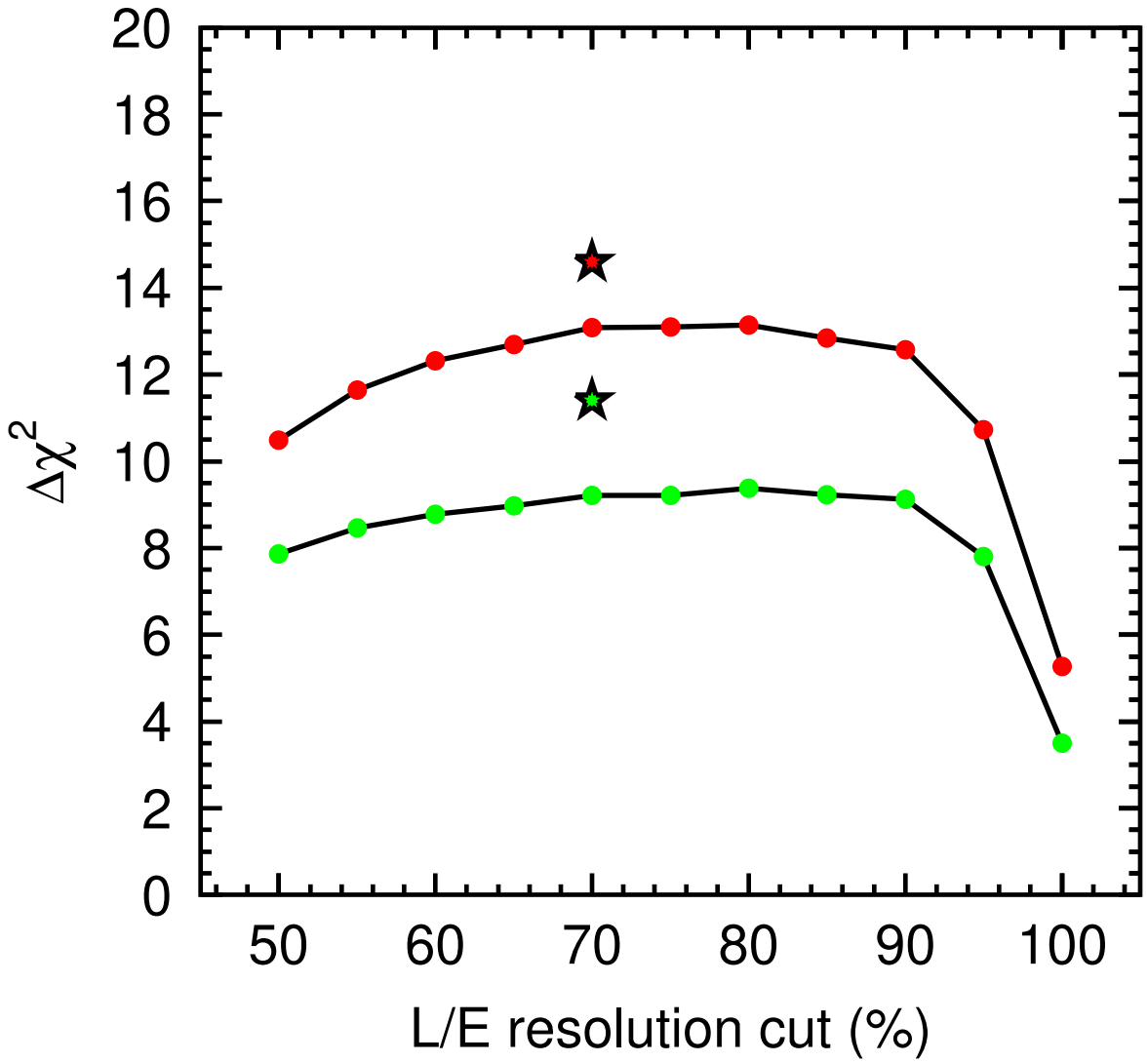

10^-2
10^-3
0.7
0.8
0.9
1
Δm^2 (eV^2)
sin^2 2θ
99% C.L.
90% C.L.
68% C.L.

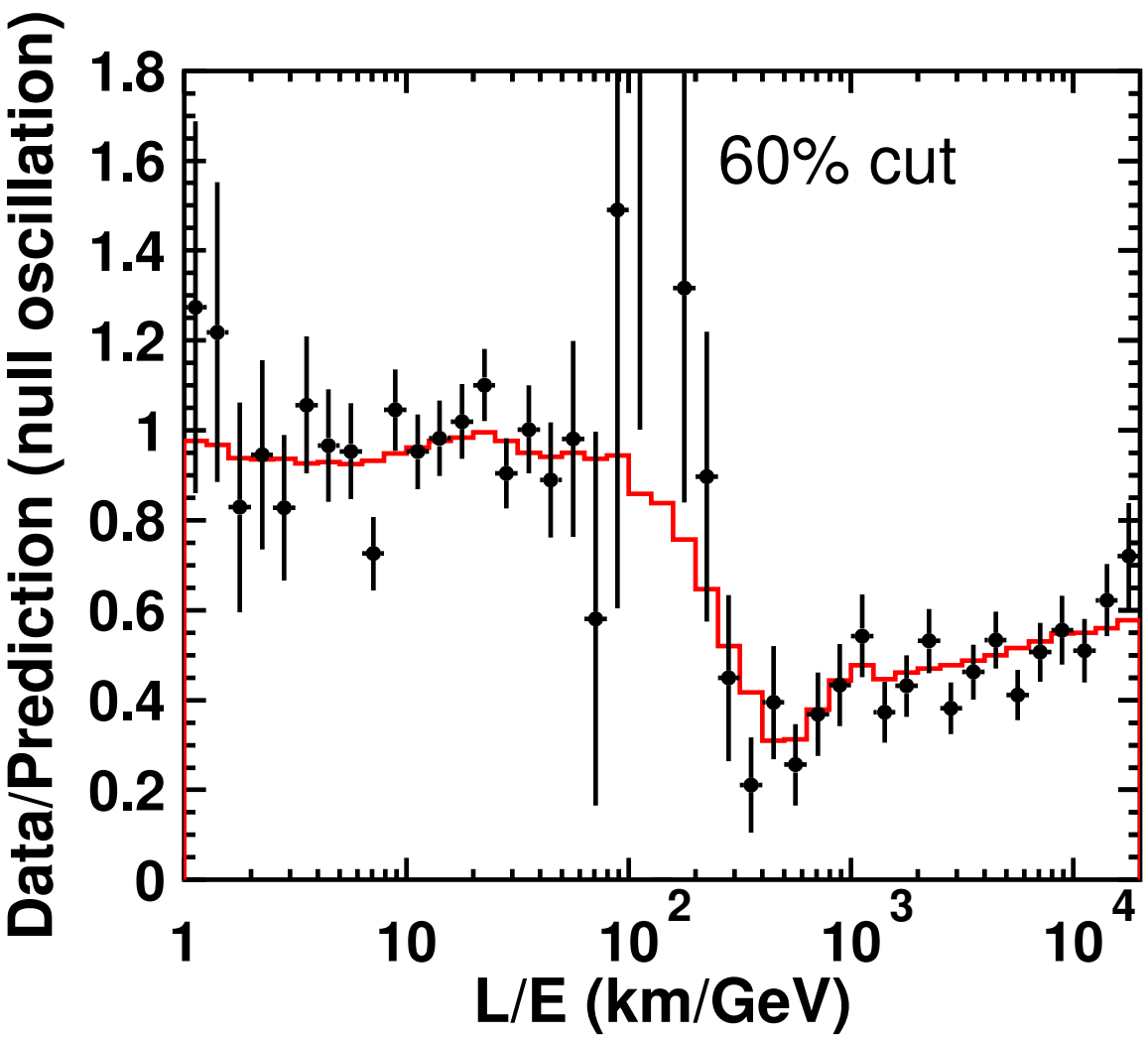

20
17.5
15
12.5
10
7.5
5
2.5
0
$\chi^2 - \chi^2_{min}$
99% C.L.
90% C.L.
68% C.L.
$10^{-3}$
$10^{-2}$
$\Delta m^2$ ($eV^2$)

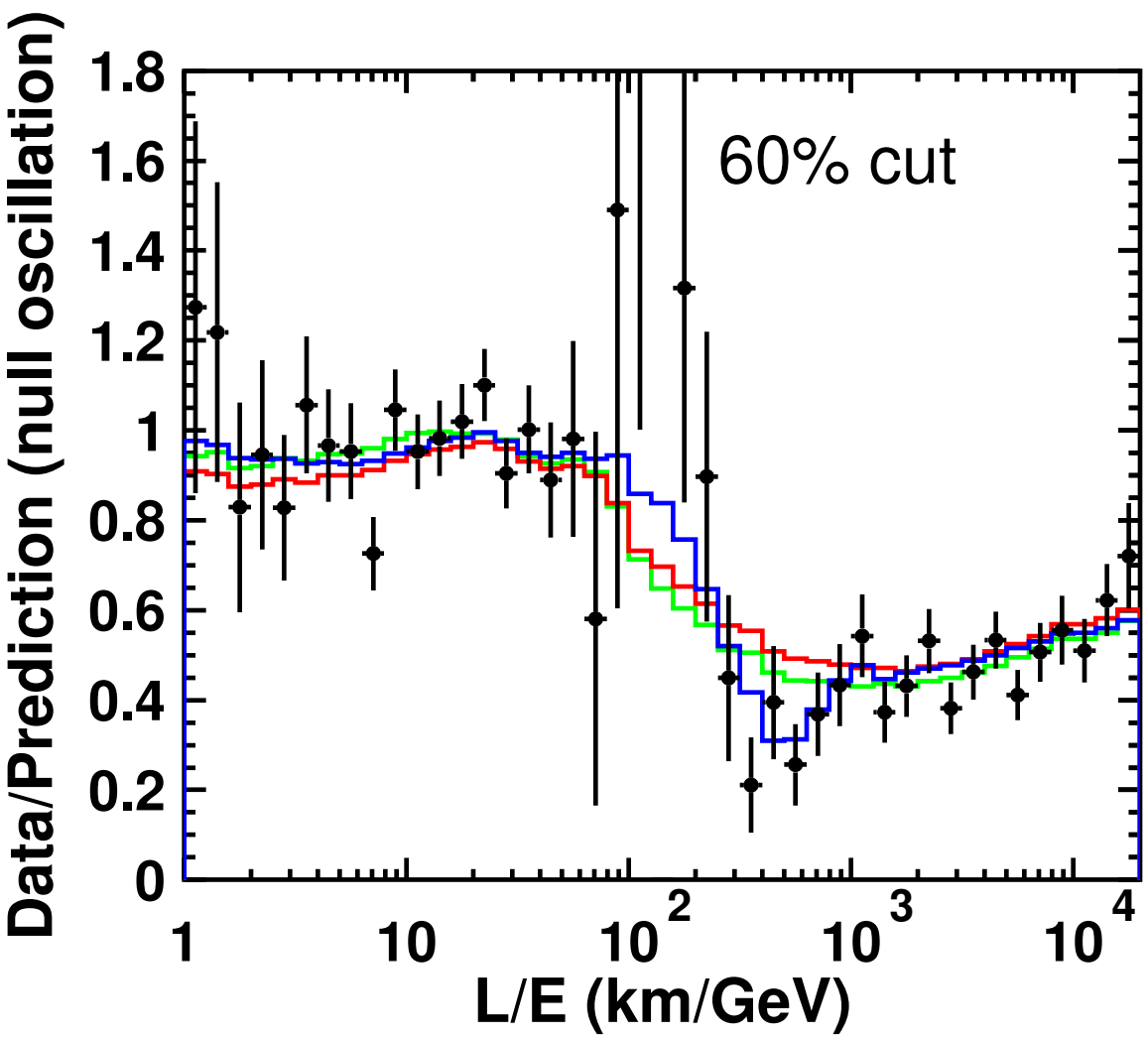

20
17.5
15
12.5
10
7.5
5
2.5
0
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
99% C.L.
90% C.L.
68% C.L.
$\chi^2 - \chi^2_{min}$
$\sin^2 2\theta$

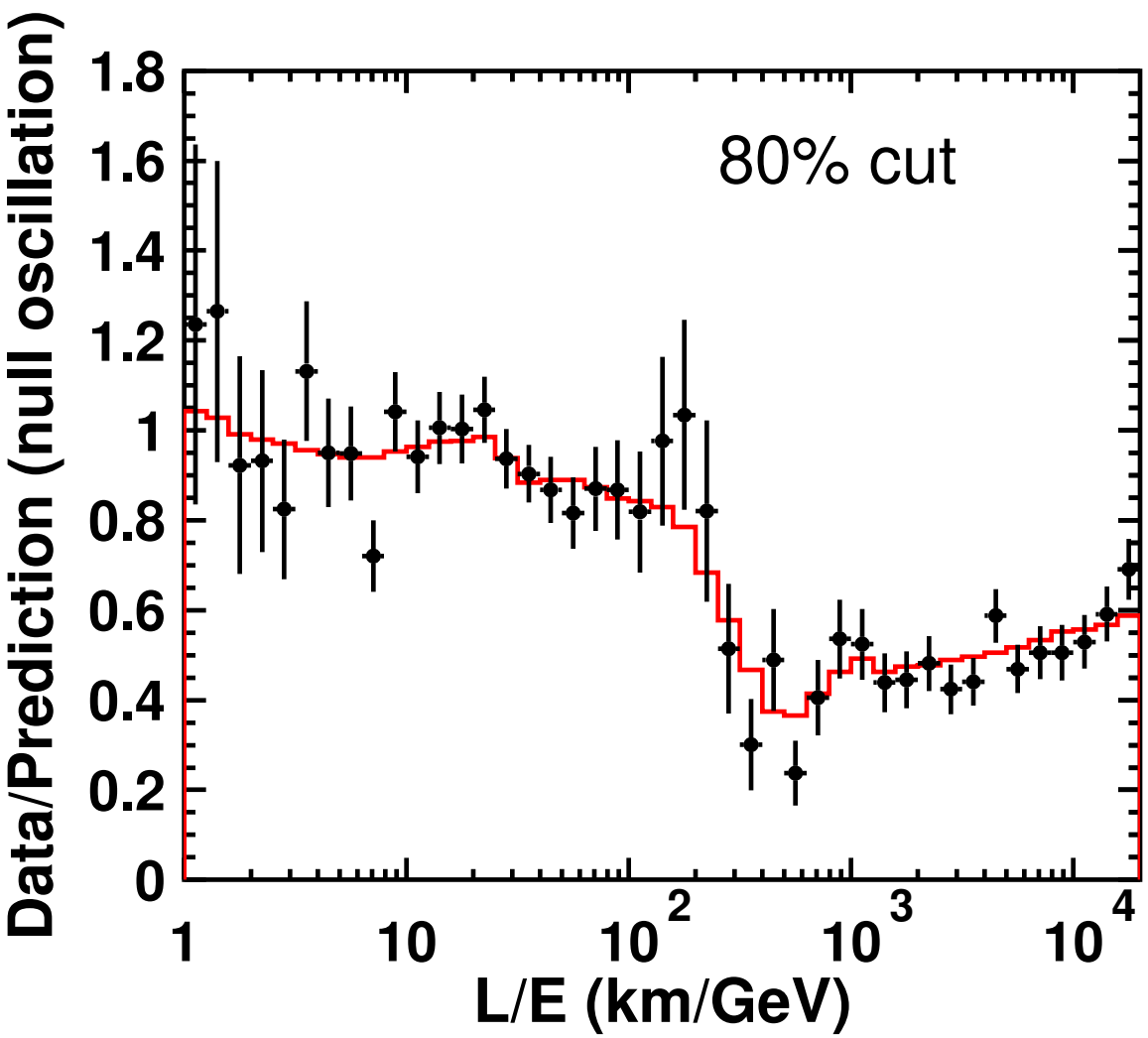

10^-2
10^-3
Δm^2 (eV^2)
0.7
0.75
0.8
0.85
0.9
0.95
1
sin^2 2θ

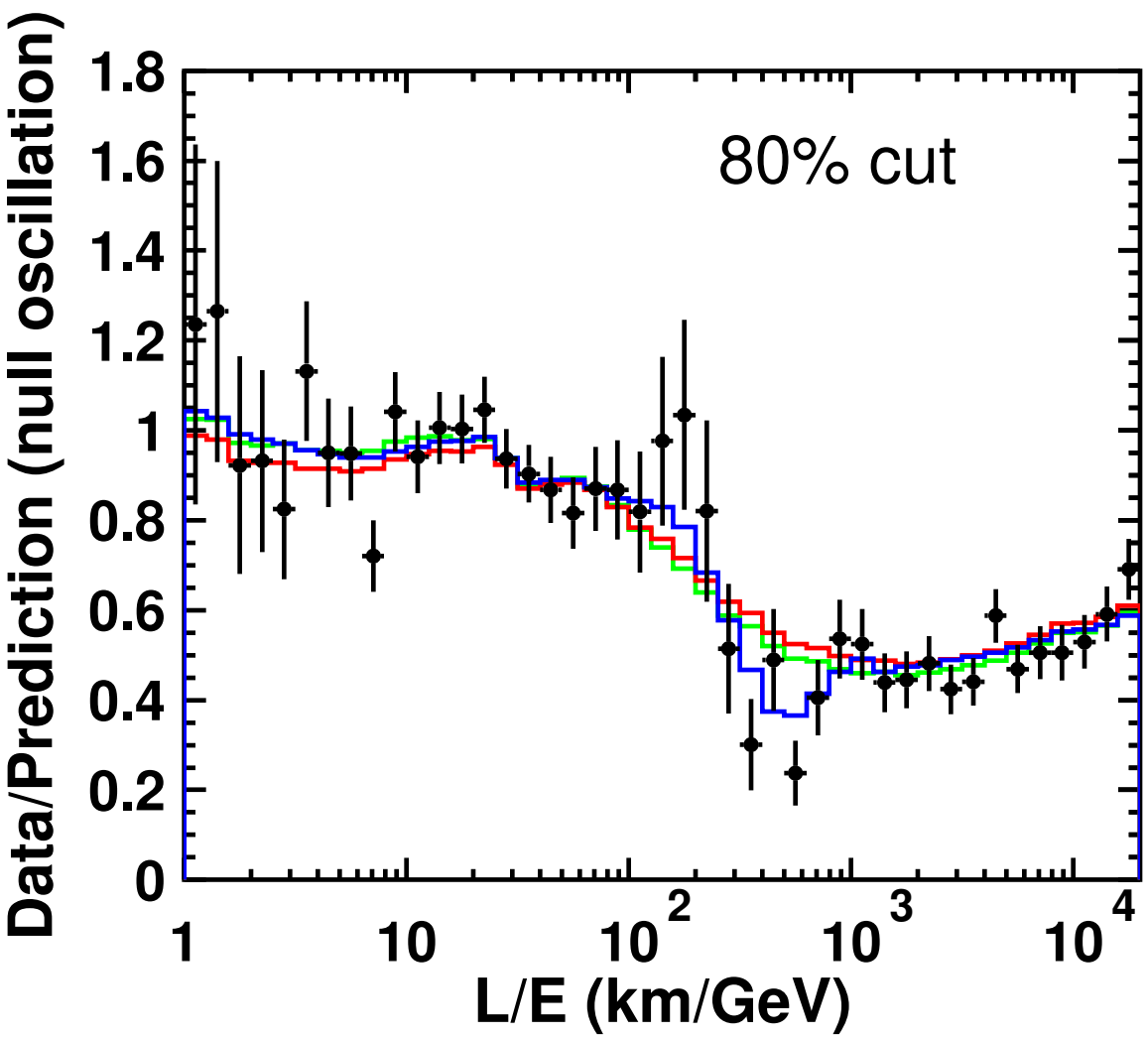

20
18
16
14
12
10
8
6
4
2
0
$\Delta\chi^2$
50
60
70
80
90
100
L/E resolution cut (%)

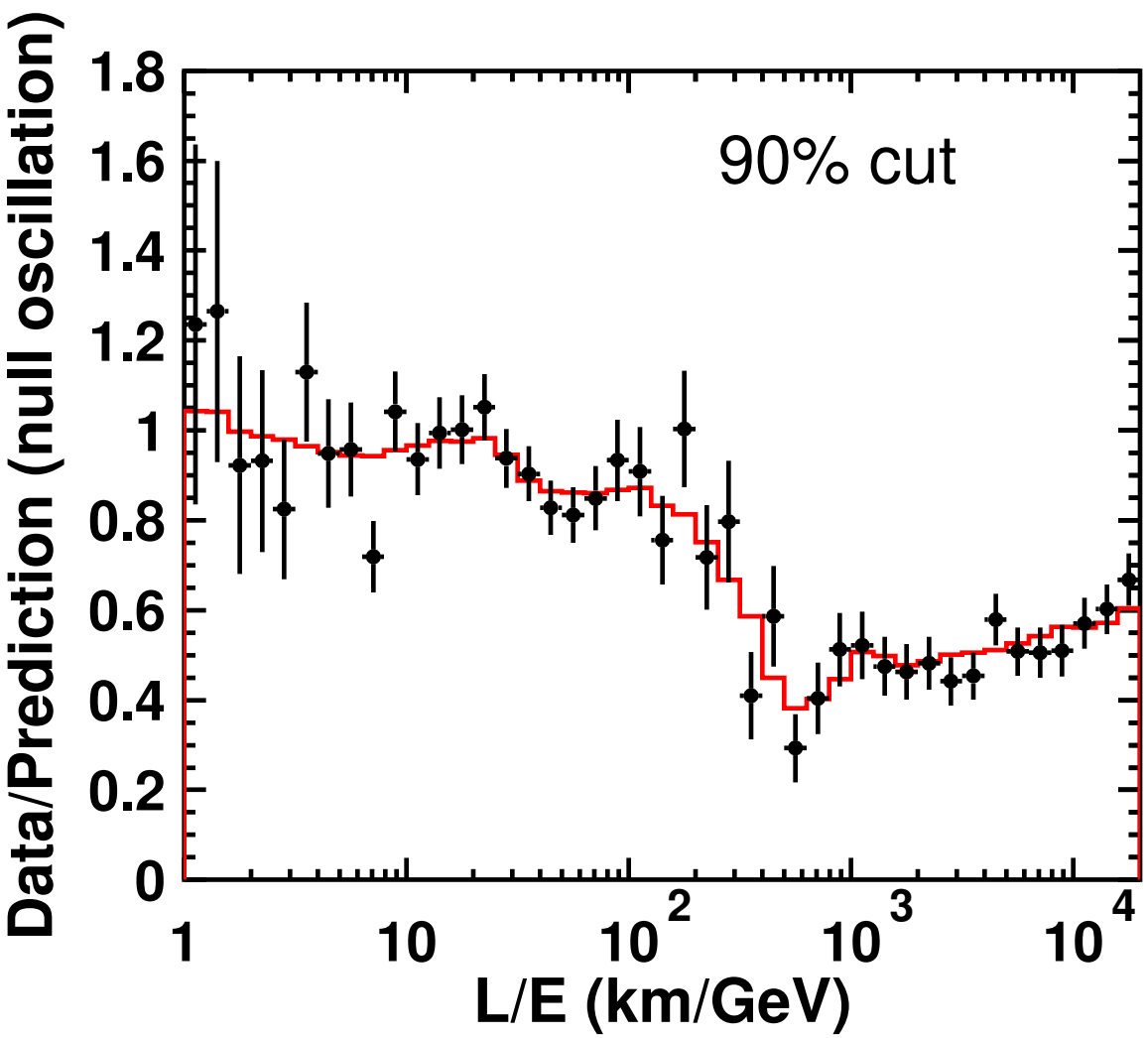

20
18
16
14
12
10
8
6
4
2
0
$\Delta\chi^2$
50
60
70
80
90
100
L/E resolution cut (%)

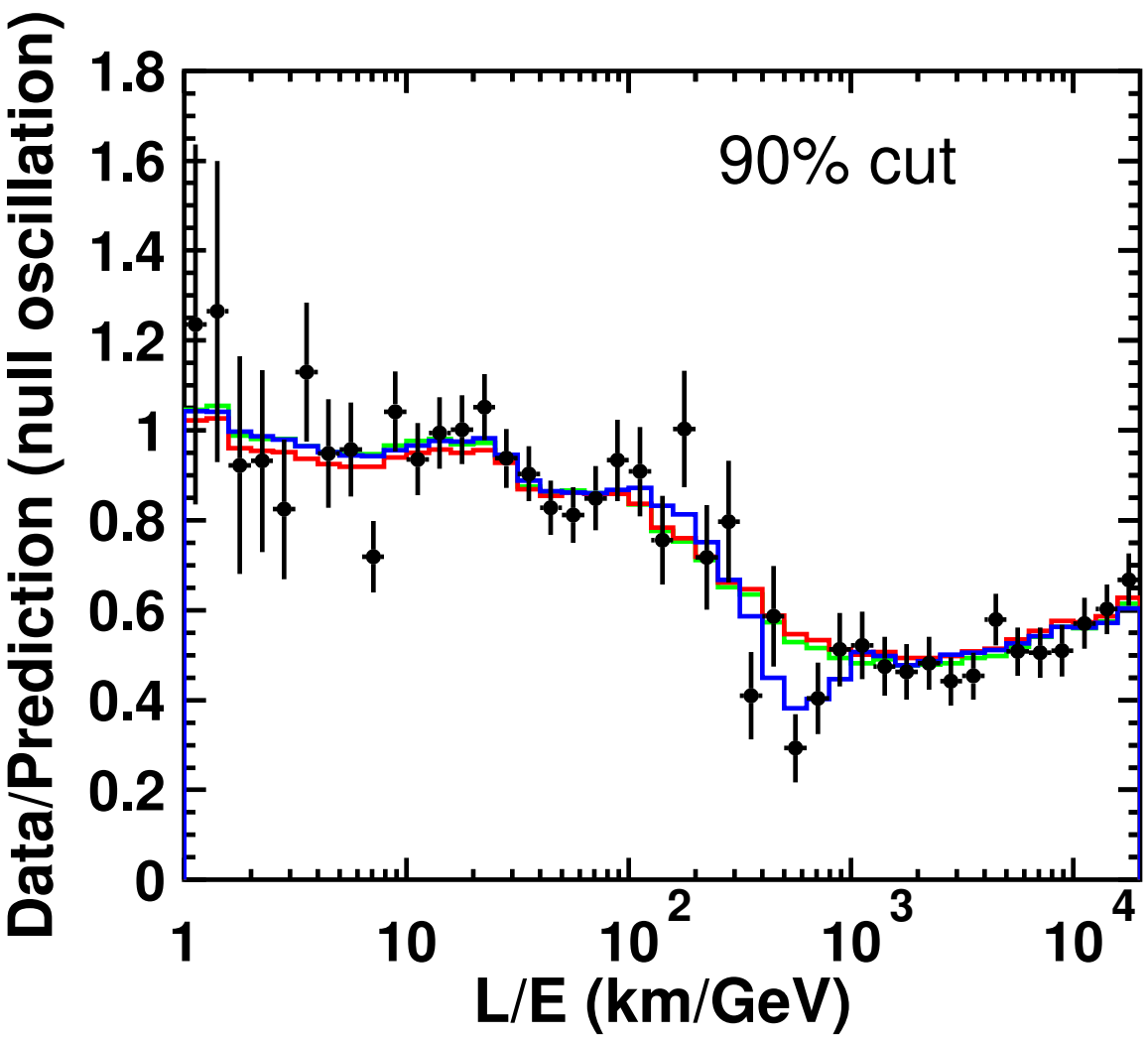

60% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4

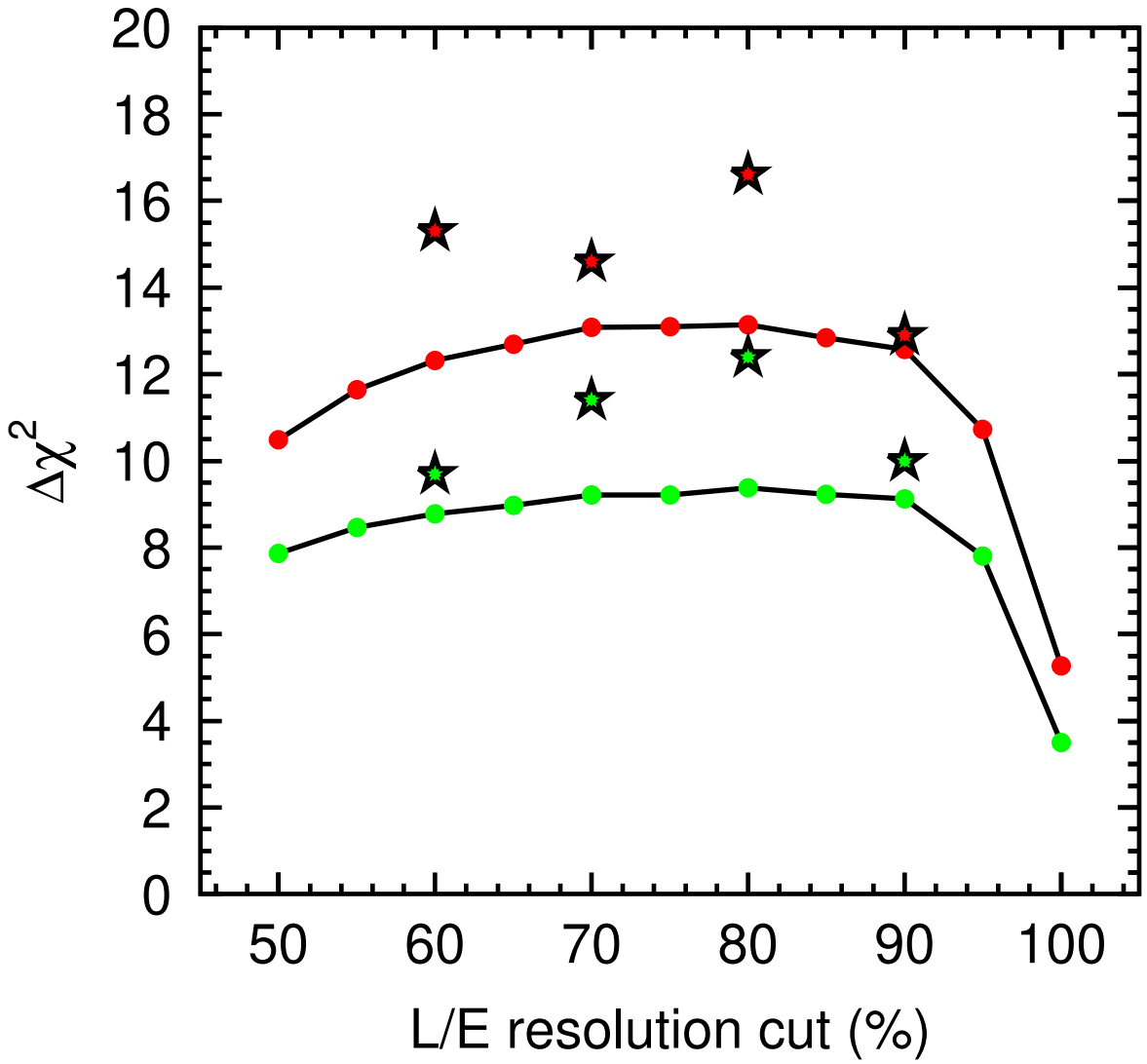

60% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4

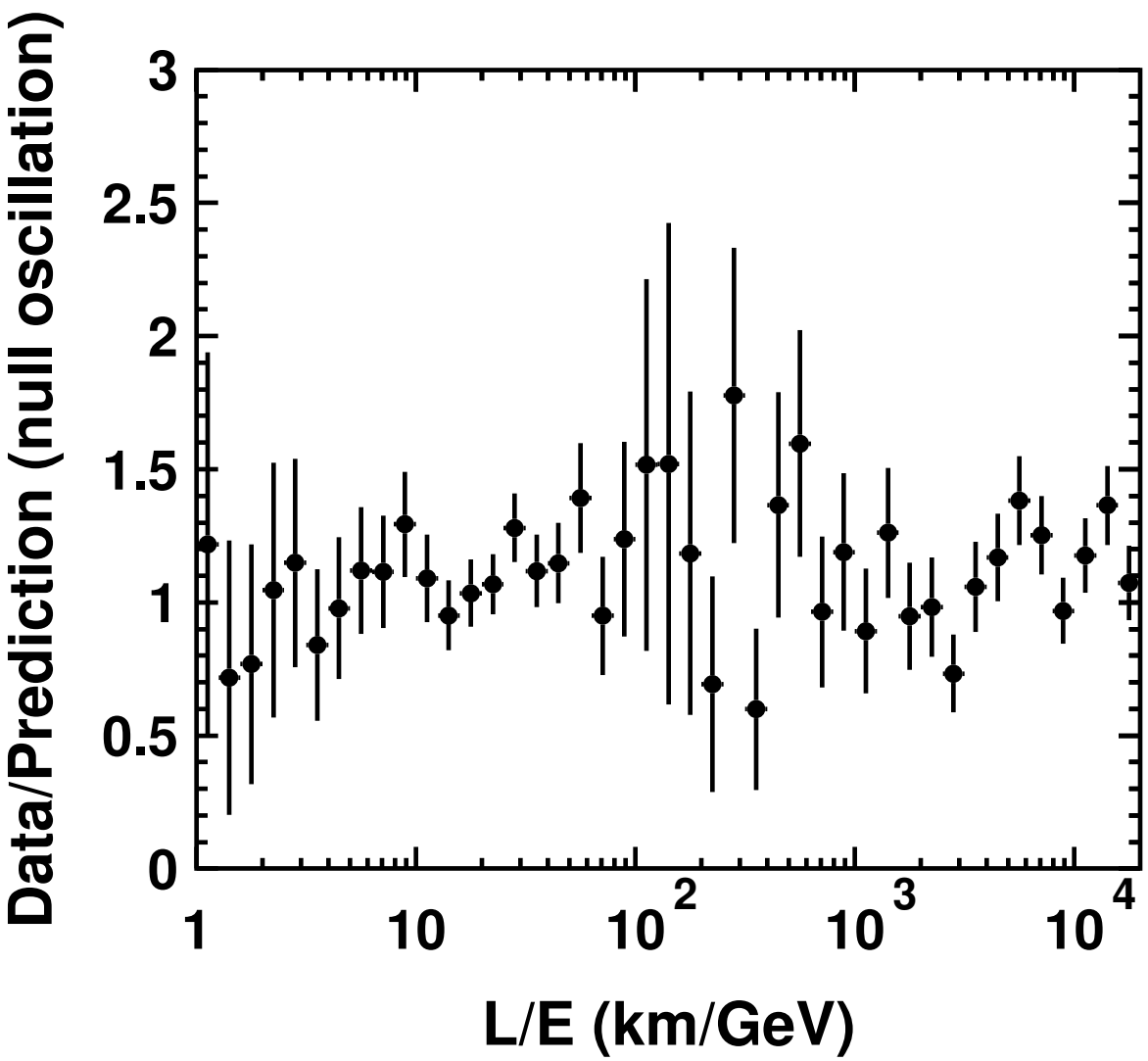

80% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4

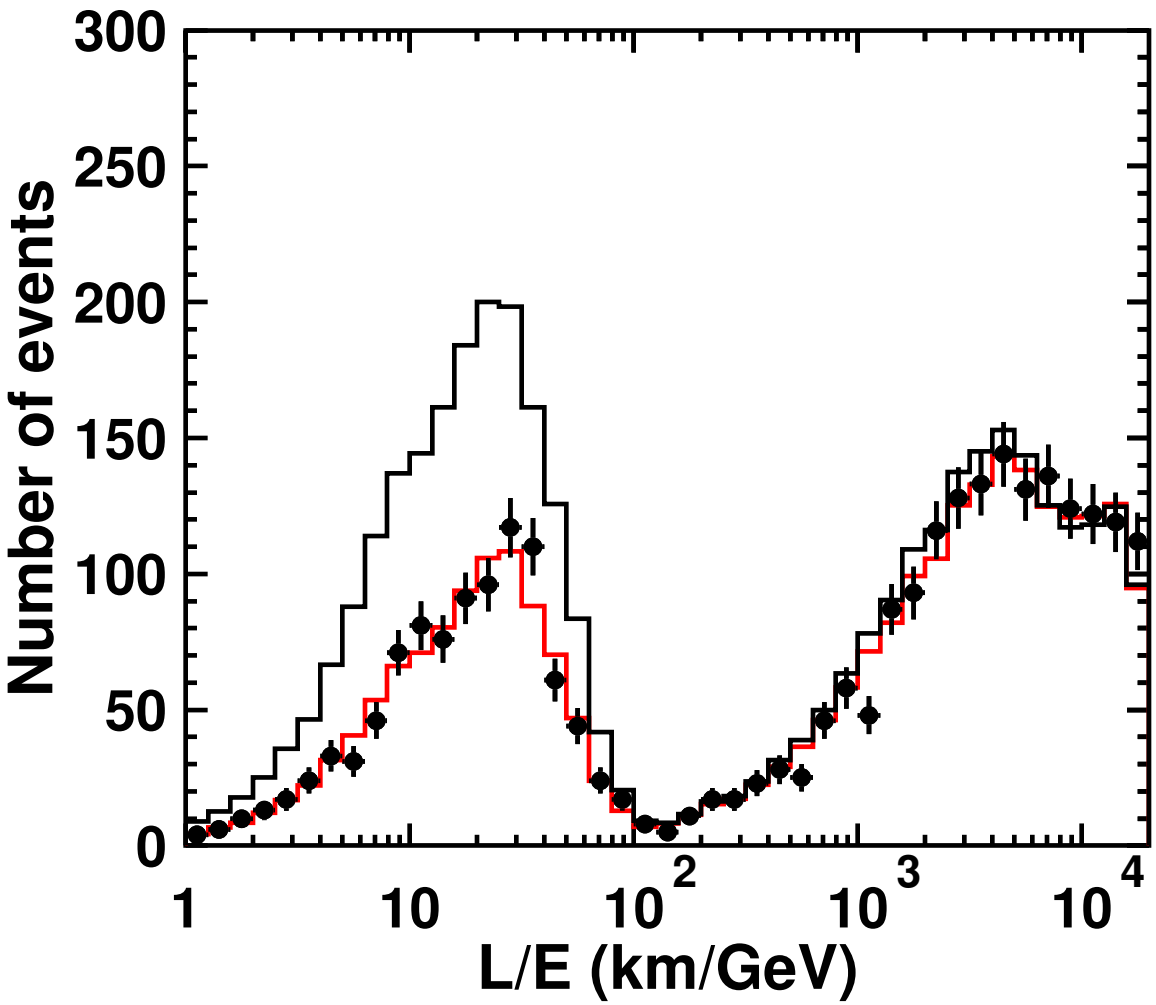

80% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4

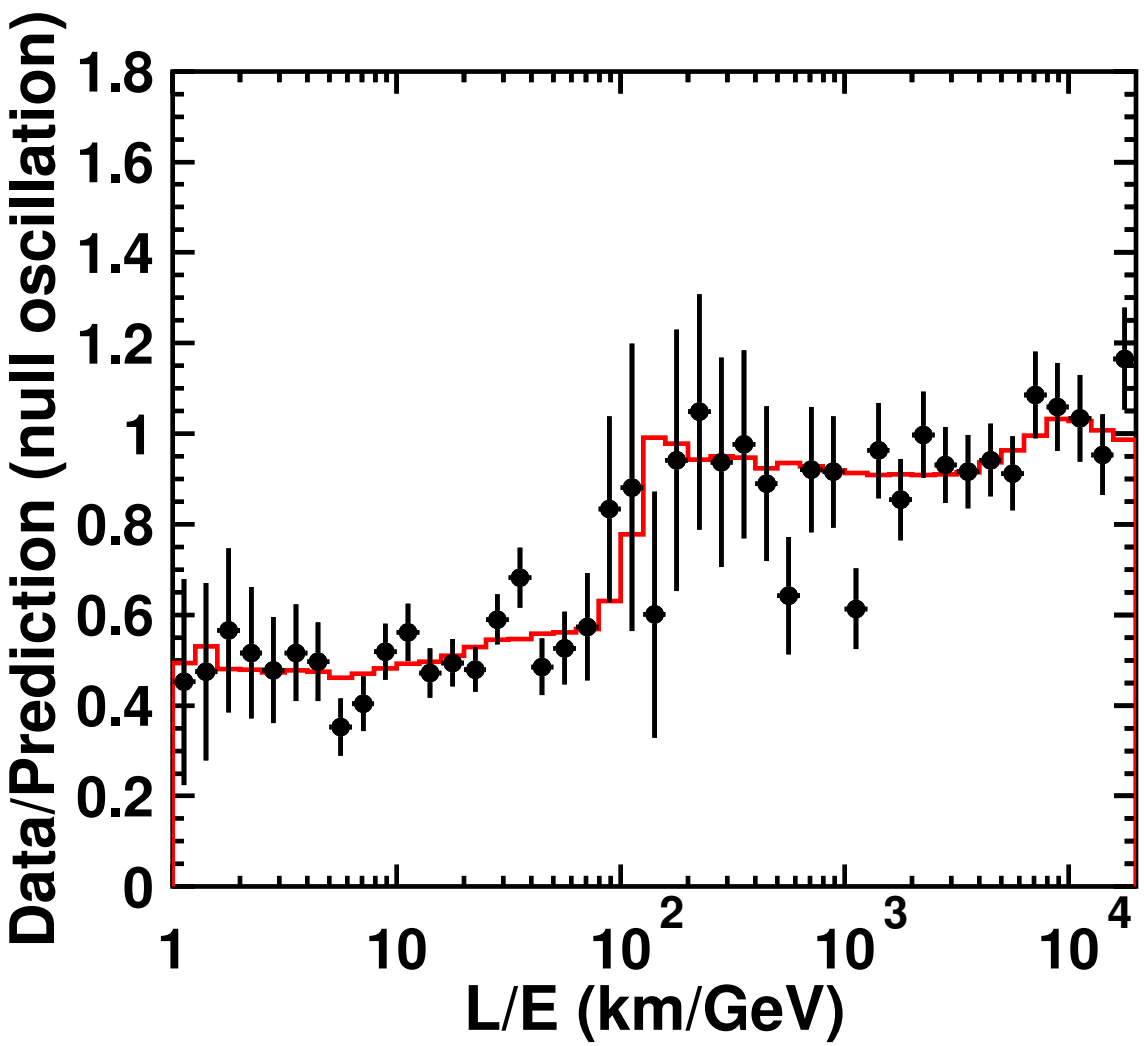

90% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2
10^3
10^4


90% cut
Data/Prediction (null oscillation)
L/E (km/GeV)
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
$\Delta\chi^2$
50
60
70
80
90
100
L/E resolution cut (%)


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)


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)

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

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

  Best Fit:

  $\chi^2_{min}$ = 37.9 / 40 d.o.f

  at $(\sin^2 2\theta , \Delta m^2) = ( 1.00 , 2.4\times10^{-3}\ eV^2)$

  (including unphysical region)

  $\chi^2_{min}$ = 37.7 / 170 d.o.f

  at $(\sin^2 2\theta , \Delta m^2) = ( 1.02 , 2.4\times10^{-3}\ eV^2)$

  90% confidence level allowed region:

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

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

- **Assuming Neutrino Decay**

  $\chi^2_{min}$ = 49.1 / 40 d.o.f

  $\Delta\chi^2$ = 11.3 / 40 d.o.f (3.4 standard deviations)

- **Assuming Neutrino Decoherence**

  $\chi^2_{min}$ = 52.4 / 40 d.o.f

  $\Delta\chi^2$ = 14.5 / 40 d.o.f (3.8 standard deviations)