Some updates on DUNE-prism (Nov.3 2017)

Guang Yang

Introduction

Framework : CafAna fitter in DUNE

Statistics : based on 7 year operation of ND and FD,
with 40kton FD and 100 ton ND. (1.47 POT/year)

Systematics : Flux + Xsec + user defined

Fake data samples (From Jake) : 1. 10% missing proton E
2. 20% missing proton E

Fake data samples (From GENIE) : 1. 20% missing proton mom.
2. 20% missing pion mom.
3. 20% missing muon mom.

Fitting samples

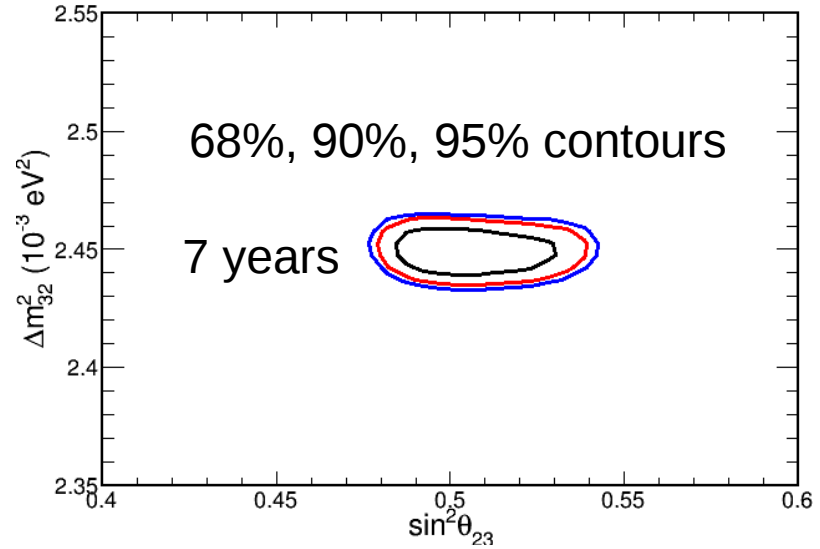
```
PredictionInterp& predNDFHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("nd_fhc")).release();
PredictionInterp& predNDRHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("nd_rhc")).release();

PredictionInterp& predFDNumuFHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("fd_numu_fhc")).release();
PredictionInterp& predFDNueFHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("fd_nue_fhc")).release();
PredictionInterp& predFDNumuRHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("fd_numu_rhc")).release();
PredictionInterp& predFDNueRHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("fd_nue_rhc")).release();
```

- ND : FHC and RHC numu
- FD: FHC numu, nue and RHC numu and nue
- Variables: oscillation parameters.
  Systematics variables:
    - 32 Xsec variables (channel specific, introduced later)
    - 10 Flux variables (Channel specific)
    - many variables introduced by me (fake data variables..)
      “One sigma” means the standard variation in fake data.

FD+ND fit with Xsec+Flux systematics
10% Missing charged pion energy

True



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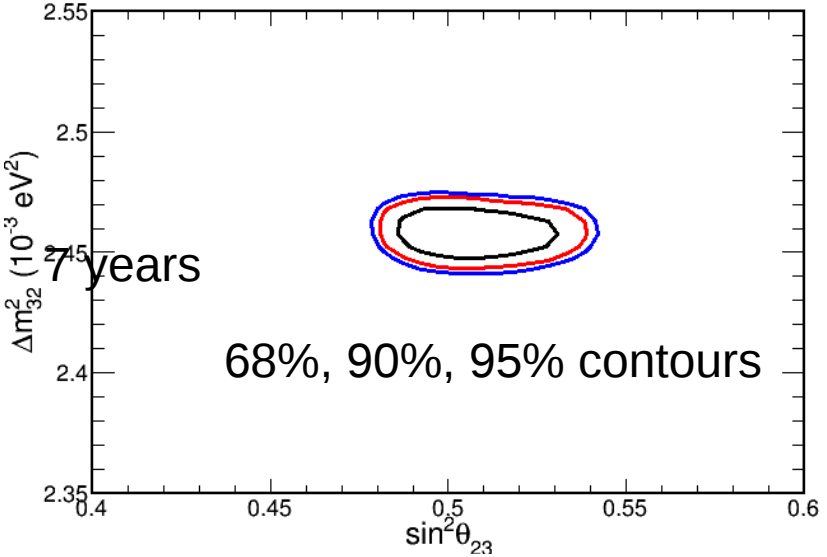

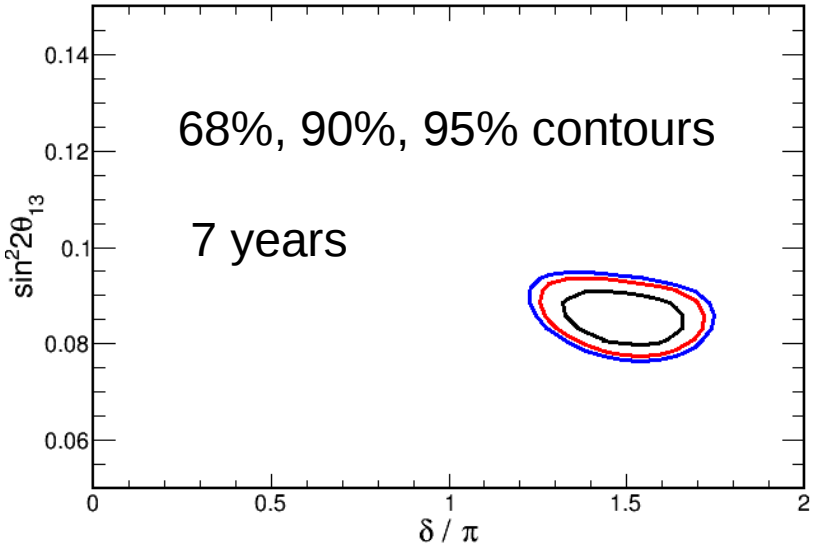

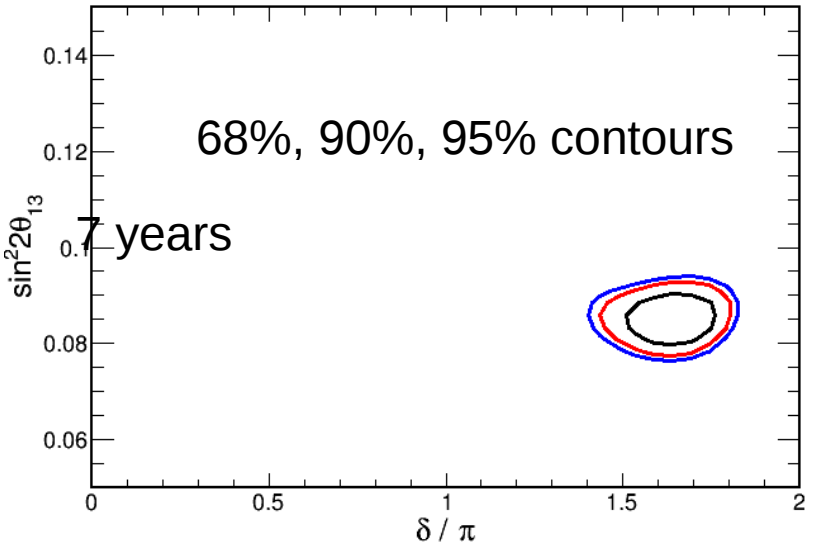

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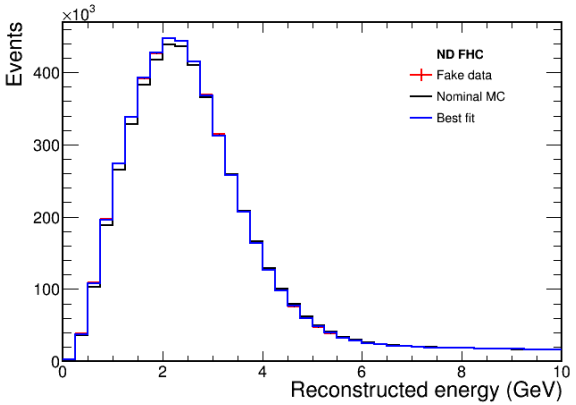
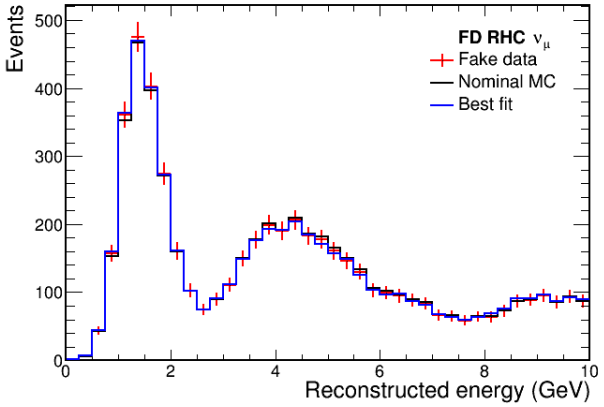
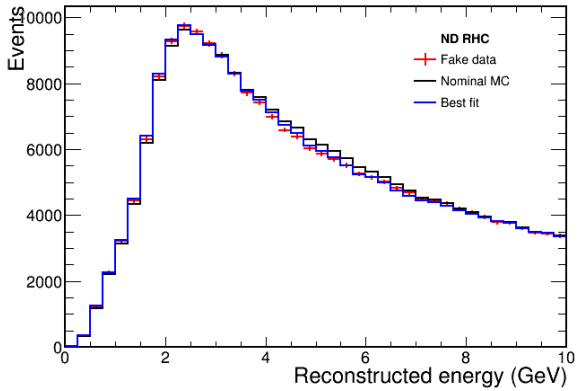
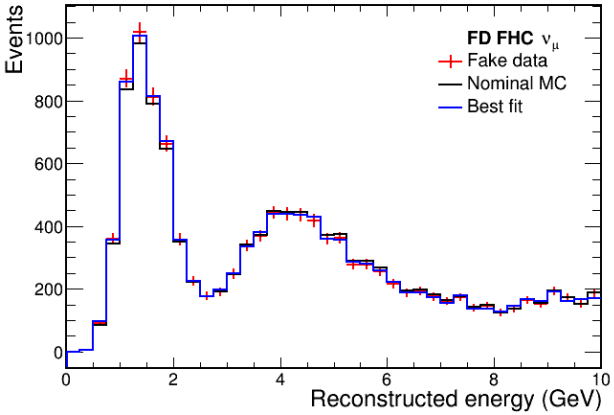
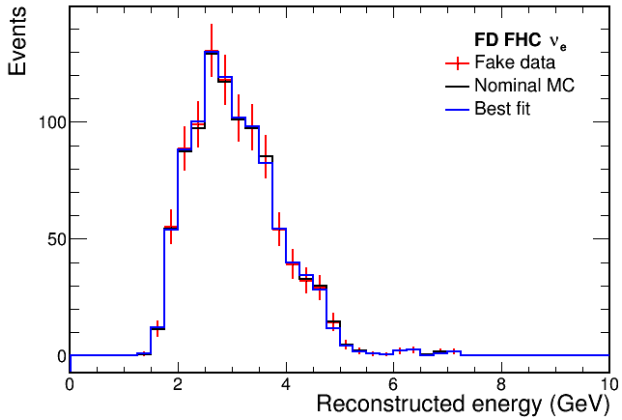
10% Missing charged pion energy

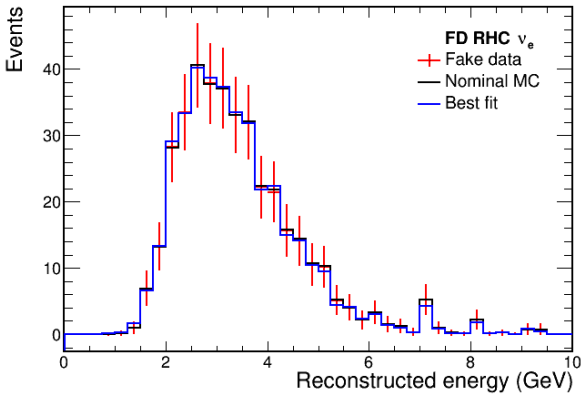










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Syst. shift  nu_ccqe_3_scale 6.23755e-09
Syst. shift  nubar_ccqe_1_scale -1.79358e-07
Syst. shift  nubar_ccqe_2_scale -5.90639e-08
Syst. shift  nubar_ccqe_3_scale 3.21598e-09
Syst. shift  nu_MEC_dummy_scale 9.89154e-13
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Syst. shift  nu_cc1piz_1_scale -9.43431e-08
Syst. shift  nu_cc1piz_2_scale -2.21027e-07
Syst. shift  nu_cc1piz_3_scale 1.74784e-07
Syst. shift  nu_cc1pic_1_scale -5.49109e-08
Syst. shift  nu_cc1pic_2_scale 6.7916e-08
Syst. shift  nu_cc1pic_3_scale -1.51179e-07
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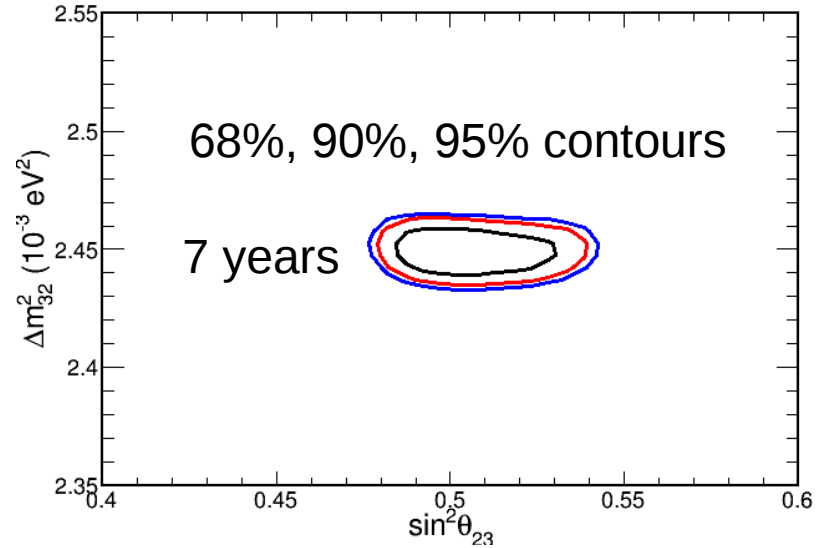
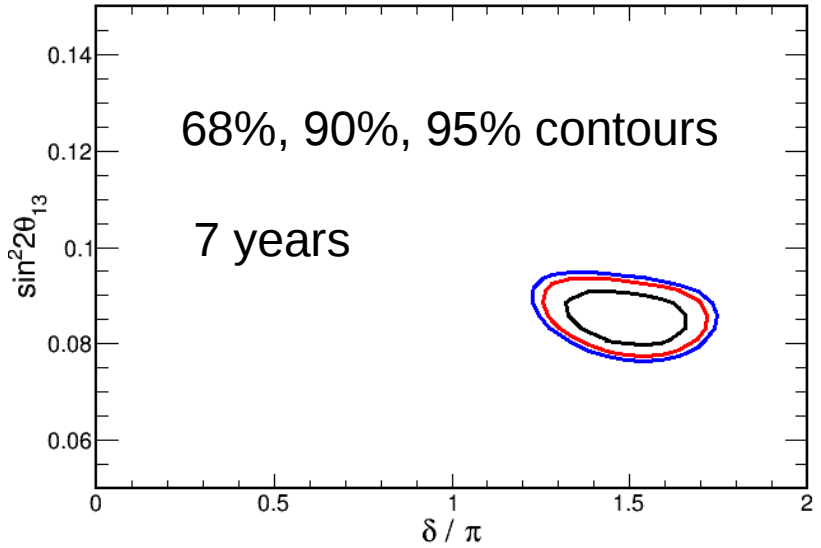
Syst. shift  nubar_cc1pic_3_scale 5.10973e-08
Syst. shift  nu_2pi_scale 0.000622163
Syst. shift  nubar_2pi_scale 8.75945e-05
Syst. shift  nu_dis_1_scale 2.82407e-07
Syst. shift  nu_dis_2_scale 7.92674e-07
Syst. shift  nu_dis_3_scale -9.57115e-07
Syst. shift  nubar_dis_1_scale -8.94287e-08
Syst. shift  nubar_dis_2_scale 2.98888e-06
Syst. shift  nubar_dis_3_scale -1.99581e-06
Syst. shift  nu_coh_scale -8.11339e-08
Syst. shift  nubar_coh_scale 8.11751e-08
Syst. shift  nu_nc_scale 6.99834e-07
Syst. shift  nubar_nc_scale 1.5864e-06
Syst. shift  flux19 0.0162091
Syst. shift  flux20 0.717444
Syst. shift  flux21 1.04878
Syst. shift  flux22 1.78853
Syst. shift  flux23 3.53346
Syst. shift  flux24 0.69048
Syst. shift  eScale -0.461785
Syst. shift  eRes 0.0524068
True dCP 0pi, best fit -0.234227pi, chi2 195.206 delta=0 chi2 184.841
```

FD+ND fit with Xsec+Flux systematics
20% Missing charged pion energy

True





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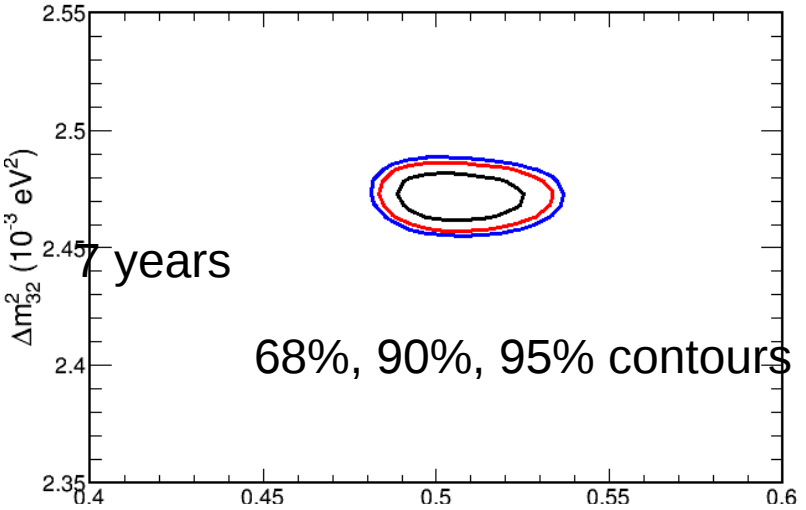

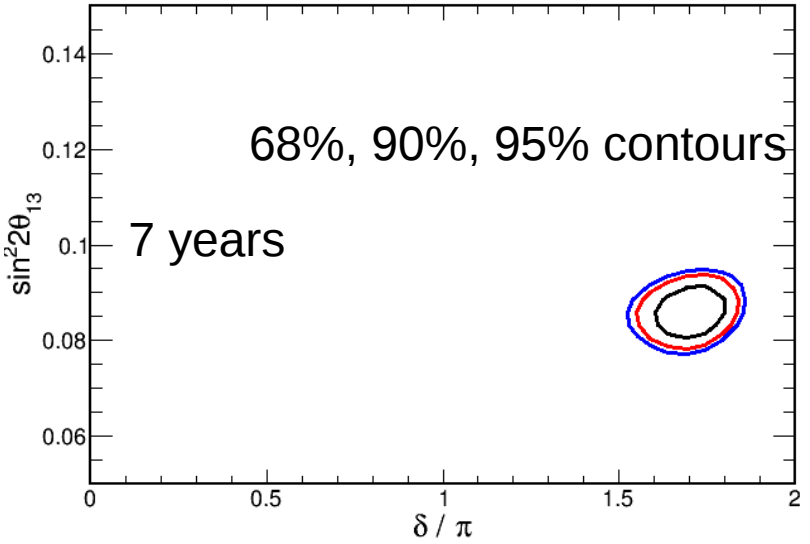

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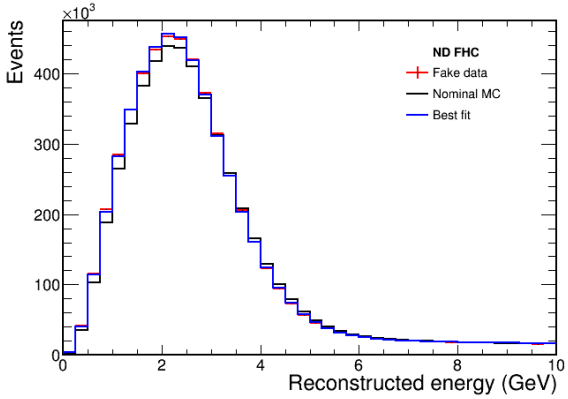
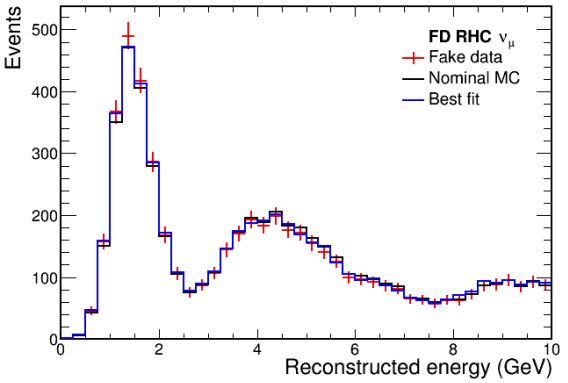
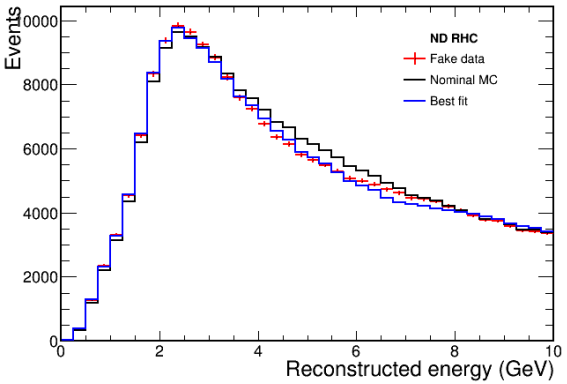
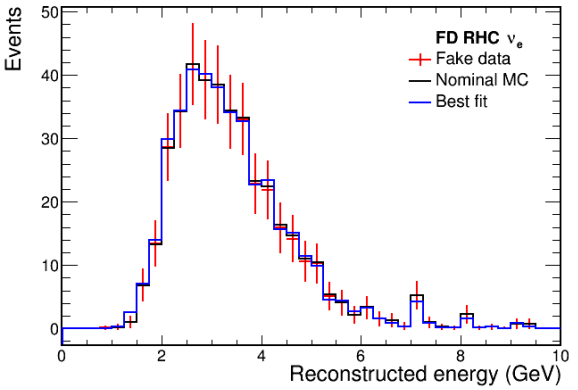
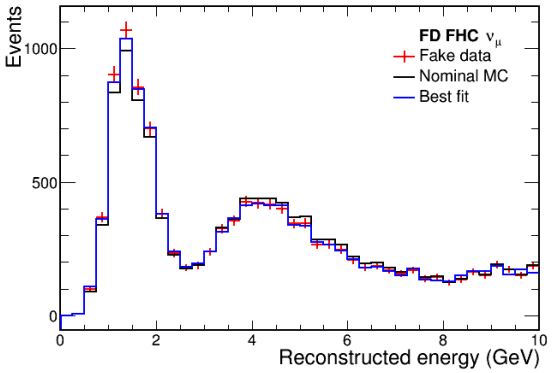
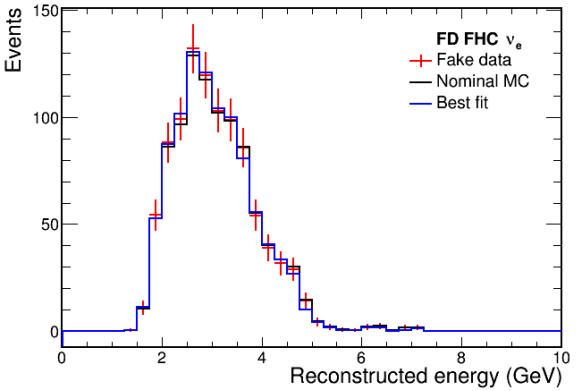






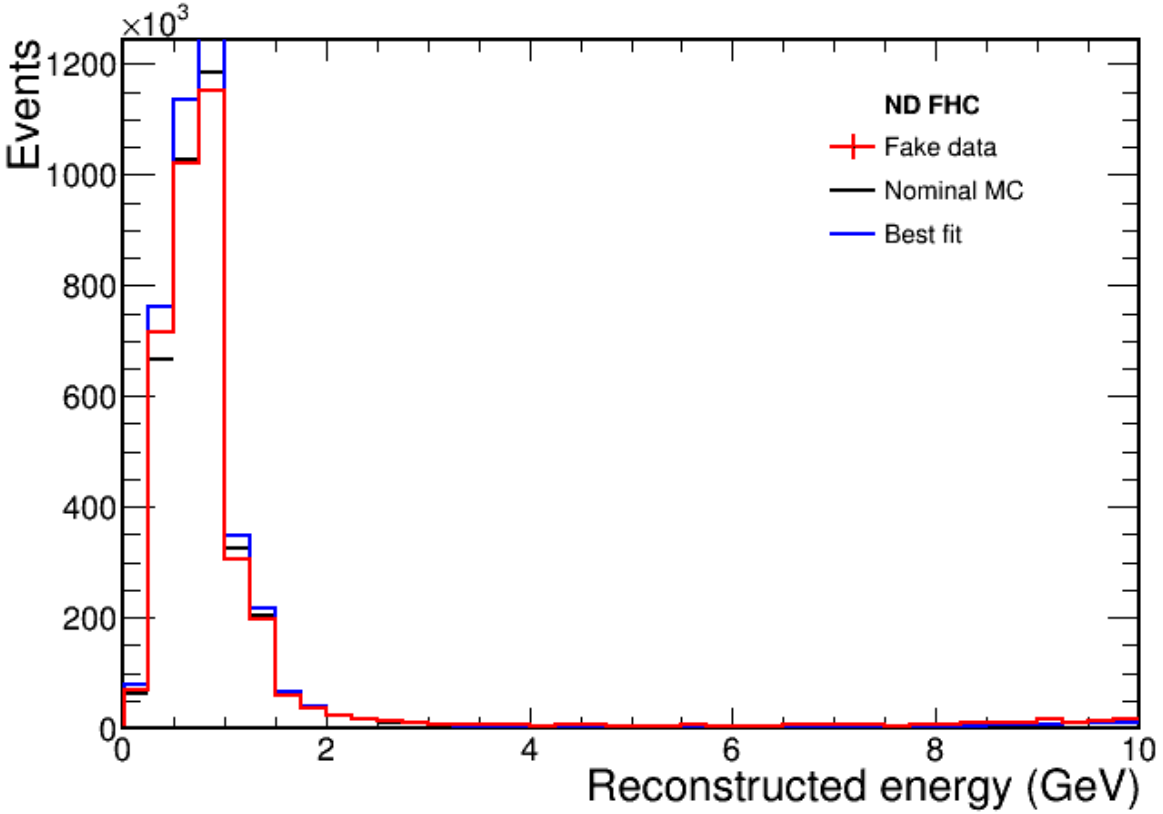







```
Syst. shift  nu_ccqe_1_scale 0.00013919
Syst. shift  nu_ccqe_2_scale 9.58104e-05
Syst. shift  nu_ccqe_3_scale 4.57286e-06
Syst. shift  nubar_ccqe_1_scale -0.000109965
Syst. shift  nubar_ccqe_2_scale -4.82583e-05
Syst. shift  nubar_ccqe_3_scale 6.36339e-06
Syst. shift  nu_MEC_dummy_scale -3.30396e-08
Syst. shift  nubar_MEC_dummy_scale -2.61794e-08
Syst. shift  nu_cc1piz_1_scale -9.11511e-05
Syst. shift  nu_cc1piz_2_scale -0.000182247
Syst. shift  nu_cc1piz_3_scale 0.000148794
Syst. shift  nu_cc1pic_1_scale -3.82152e-05
Syst. shift  nu_cc1pic_2_scale 5.60318e-05
Syst. shift  nu_cc1pic_3_scale -0.000145761
Syst. shift  nubar_cc1piz_1_scale 0.000323735
Syst. shift  nubar_cc1piz_2_scale 0.000264833
Syst. shift  nubar_cc1piz_3_scale -0.000134639
Syst. shift  nubar_cc1pic_1_scale 3.45314e-05
Syst. shift  nubar_cc1pic_2_scale -2.8385e-05
Syst. shift  nubar_cc1pic_3_scale 5.28605e-05
Syst. shift  nu_2pi_scale 0.504261
Syst. shift  nubar_2pi_scale 0.0649741
Syst. shift  nu_dis_1_scale 0.000221328
Syst. shift  nu_dis_2_scale 0.000601323
Syst. shift  nu_dis_3_scale -0.00074329
Syst. shift  nubar_dis_1_scale -0.000380512
Syst. shift  nubar_dis_2_scale 0.00250511
Syst. shift  nubar_dis_3_scale -0.00170257
Syst. shift  nu_coh_scale -6.80403e-05
Syst. shift  nubar_coh_scale 6.80608e-05
Syst. shift  nu_nc_scale 0.00463015
Syst. shift  nubar_nc_scale 0.000955851
Syst. shift  flux17 0.474425
Syst. shift  flux18 -2.2496
Syst. shift  flux19 1.92151
Syst. shift  flux20 5.7642
Syst. shift  flux21 2.47067
Syst. shift  flux22 1.0752
Syst. shift  eScale -0.60202
Syst. shift  eRes 0.192747
True dCP 0pi, best fit -0.739138pi, chi2 891.247 delta=0 chi2 891.319
```

FD+ND fit with Xsec+Flux systematics
20% Missing charged pion energy
30 mrad off-axis FHC



Black : nominal 30mrad off-axis

Blue : with on-axis best fit

Red : real 20% MPE

FD+ND fit with Xsec+Flux systematics
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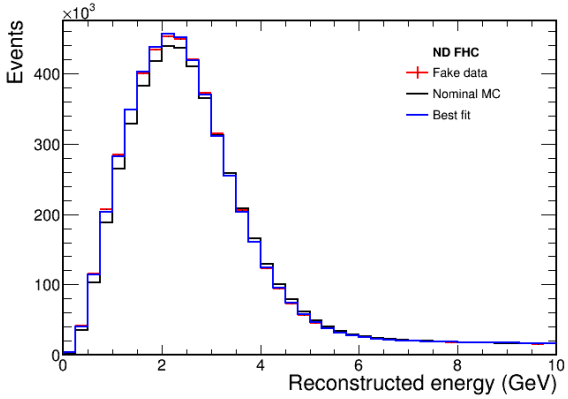

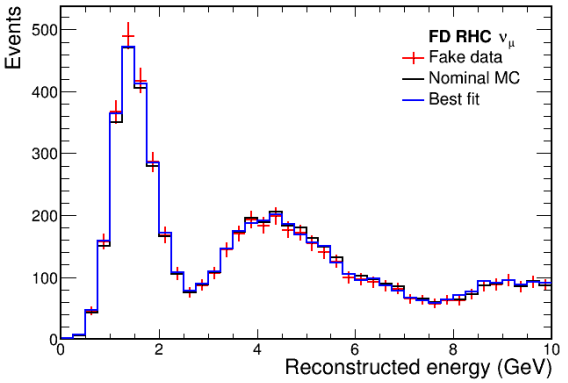

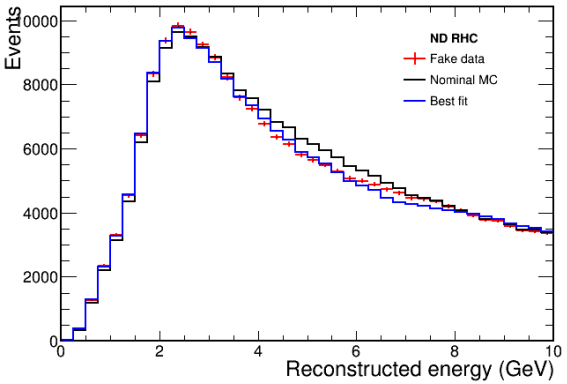

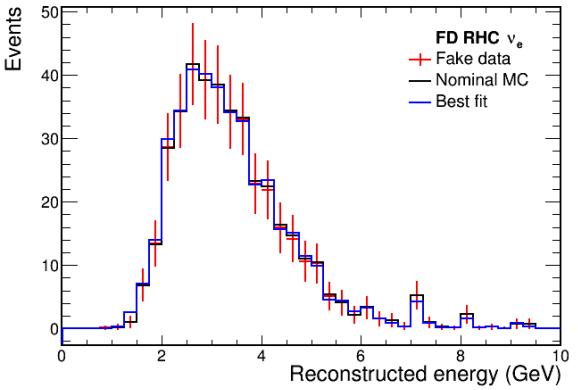

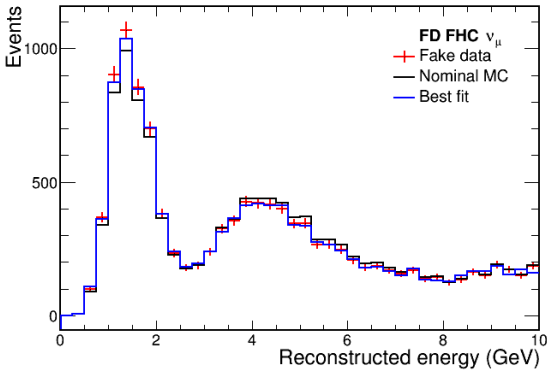

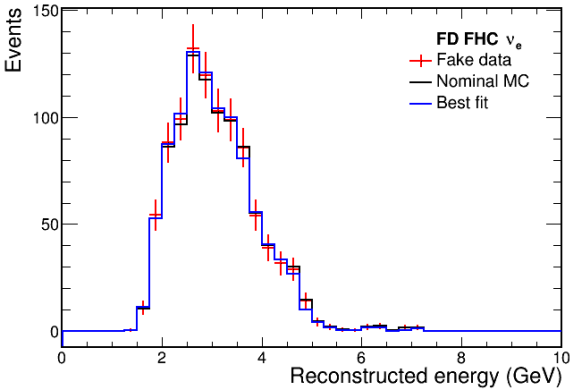


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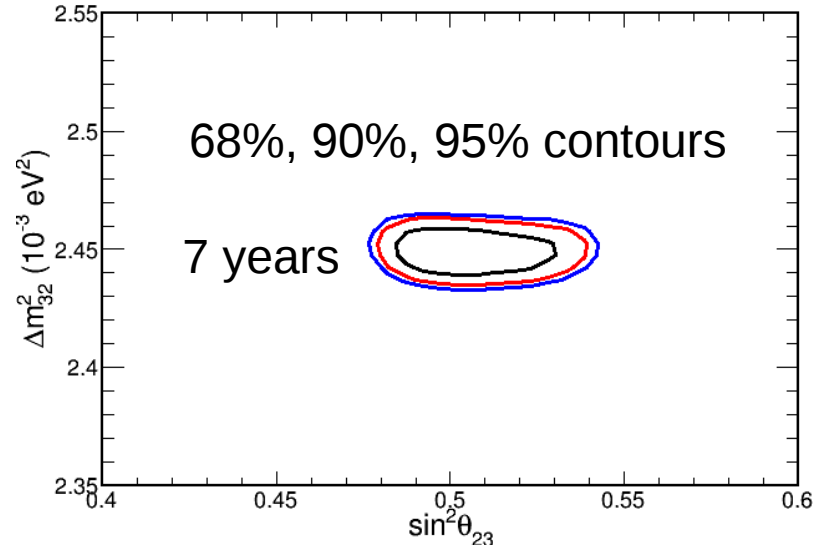
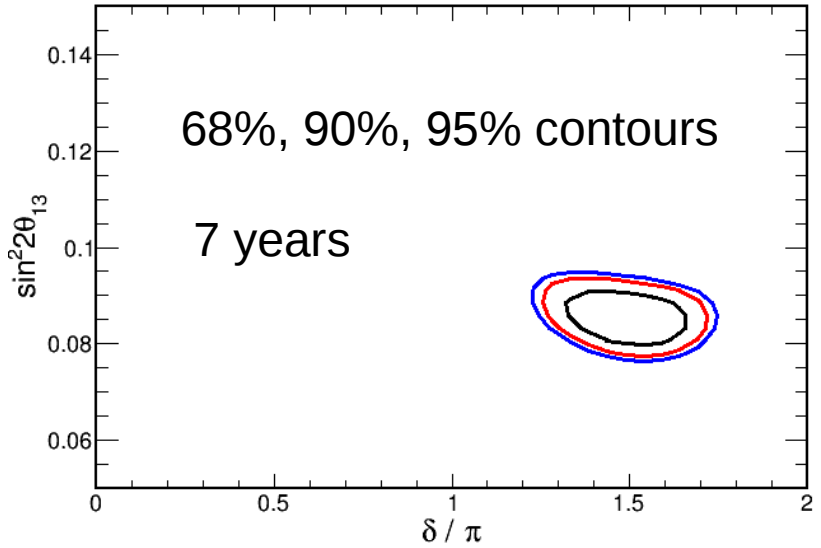
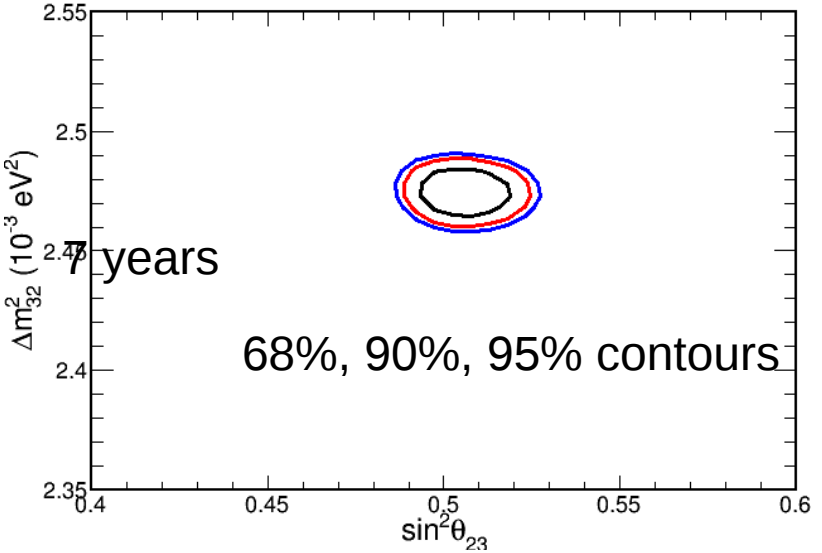
FD+ND fit with Xsec+Flux systematics
10% Missing proton energy

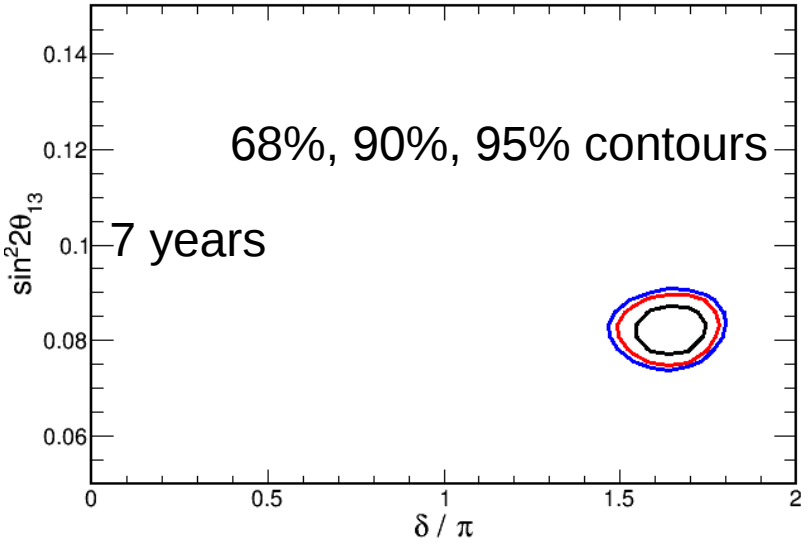
True





Varied





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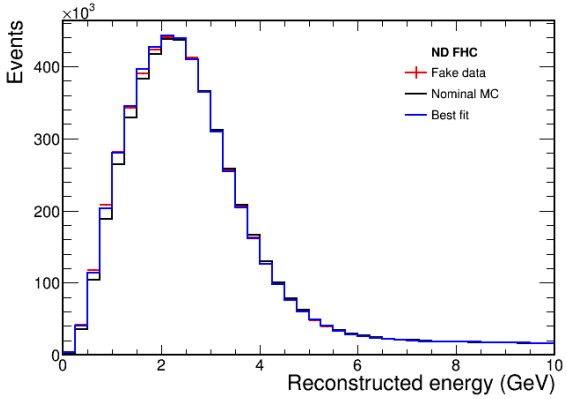

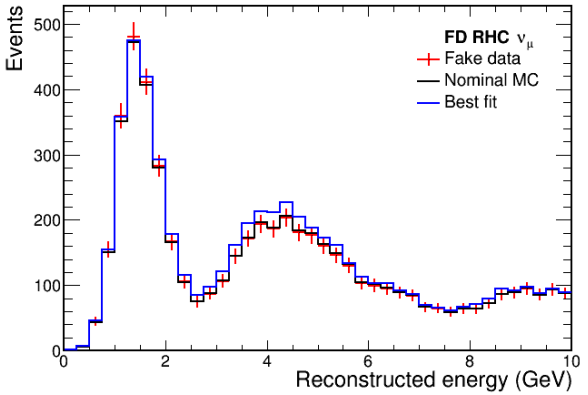

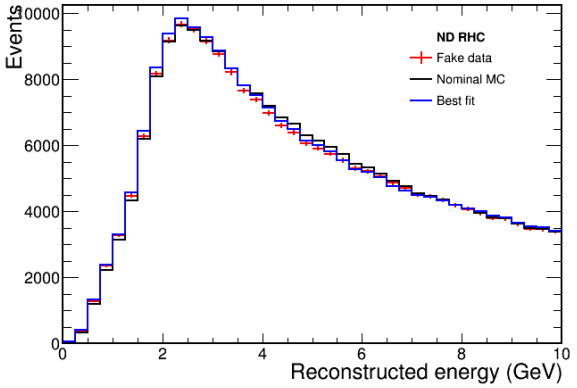

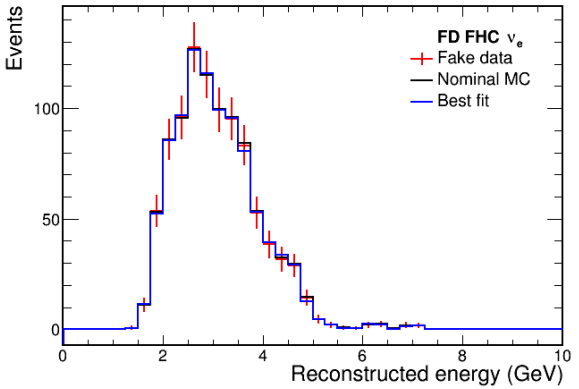

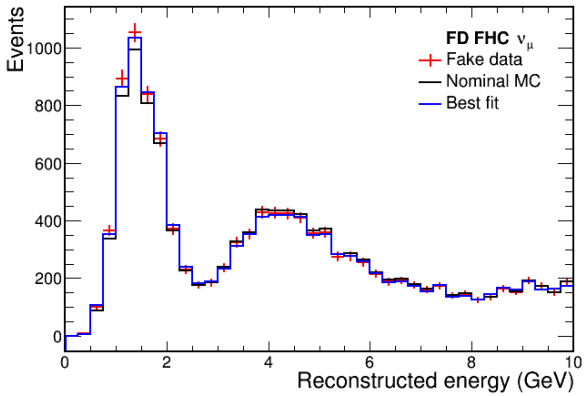

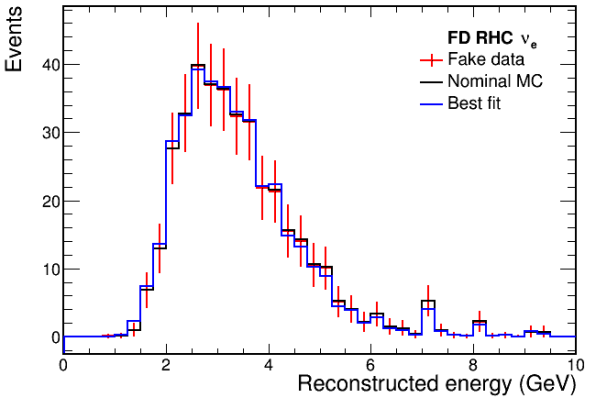


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Syst. shift  nu_ccqe_2_scale 7.96829e-05
Syst. shift  nu_ccqe_3_scale 8.6318e-06
Syst. shift  nubar_ccqe_1_scale -0.000161143
Syst. shift  nubar_ccqe_2_scale -5.71616e-05
Syst. shift  nubar_ccqe_3_scale -5.00956e-06
Syst. shift  nu_MEC_dummy_scale 7.62756e-09
Syst. shift  nubar_MEC_dummy_scale 1.60716e-08
Syst. shift  nu_cc1piz_1_scale -9.74635e-05
Syst. shift  nu_cc1piz_2_scale -0.000190376
Syst. shift  nu_cc1piz_3_scale 0.000155283
Syst. shift  nu_cc1pic_1_scale -5.93652e-05
Syst. shift  nu_cc1pic_2_scale 7.15333e-05
Syst. shift  nu_cc1pic_3_scale -0.000175531
Syst. shift  nubar_cc1piz_1_scale 0.000349021
Syst. shift  nubar_cc1piz_2_scale 0.000268768
Syst. shift  nubar_cc1piz_3_scale -0.000139735
Syst. shift  nubar_cc1pic_1_scale 4.70949e-05
Syst. shift  nubar_cc1pic_2_scale -3.84193e-05
Syst. shift  nubar_cc1pic_3_scale 6.30765e-05
Syst. shift  nu_2pi_scale 0.484259
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Syst. shift  nu_dis_2_scale 0.000803612
Syst. shift  nu_dis_3_scale -0.000767962
Syst. shift  nubar_dis_1_scale -0.00067837
Syst. shift  nubar_dis_2_scale 0.00288937
Syst. shift  nubar_dis_3_scale -0.00202681
Syst. shift  nu_coh_scale -7.21353e-05
Syst. shift  nubar_coh_scale 7.17911e-05
Syst. shift  nu_nc_scale 0.00846902
Syst. shift  nubar_nc_scale -0.000707316
Syst. shift  flux19 0.749549
Syst. shift  flux20 -0.164388
Syst. shift  flux21 4.71003
Syst. shift  flux22 -5.01411
Syst. shift  flux23 6.89113
Syst. shift  flux24 4.09184
Syst. shift  eScale -0.401653
Syst. shift  eRes 0.191535
True dCP 0pi, best fit -0.539389pi, chi2 980.048 delta=0 chi2 1050.58
```
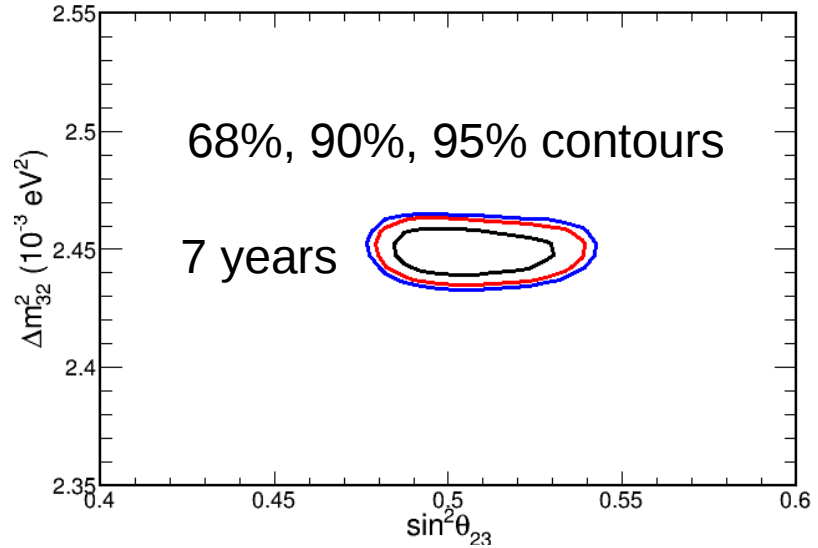
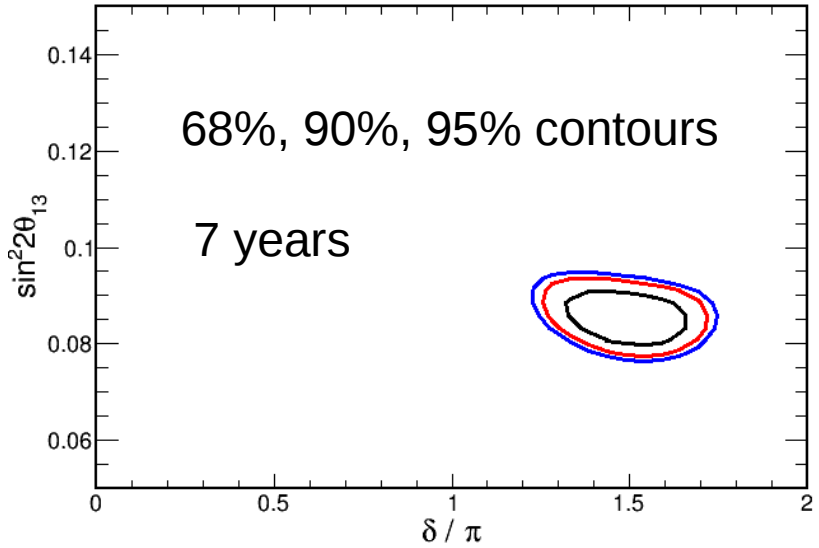
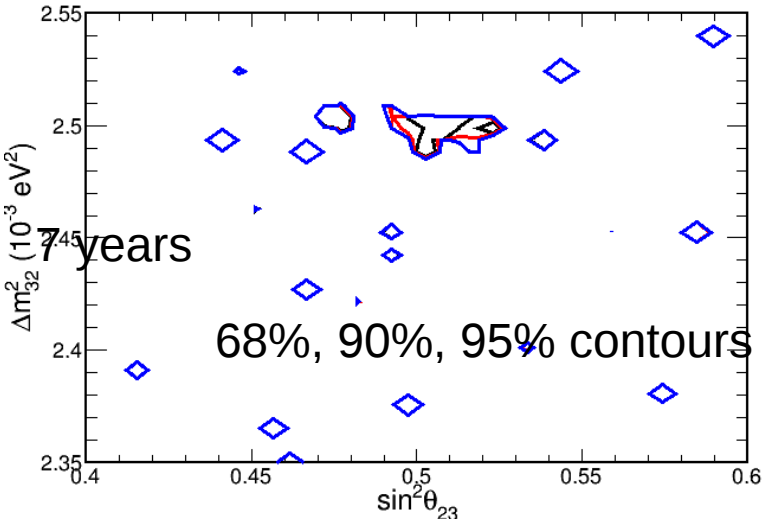

FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

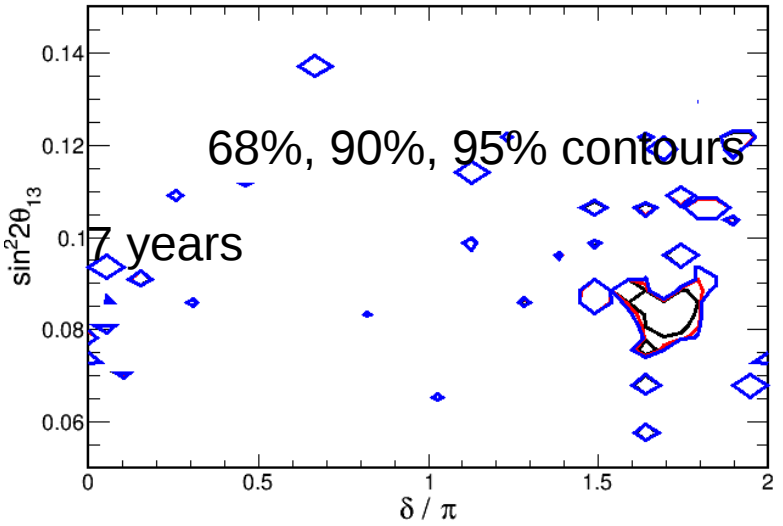
True



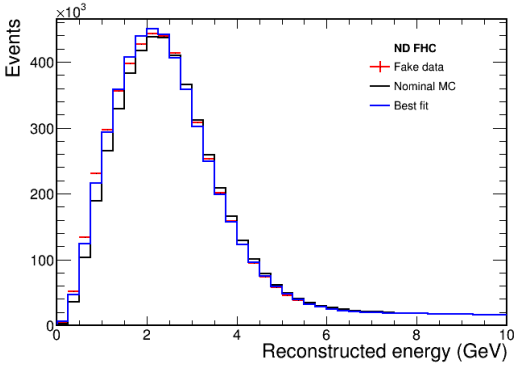


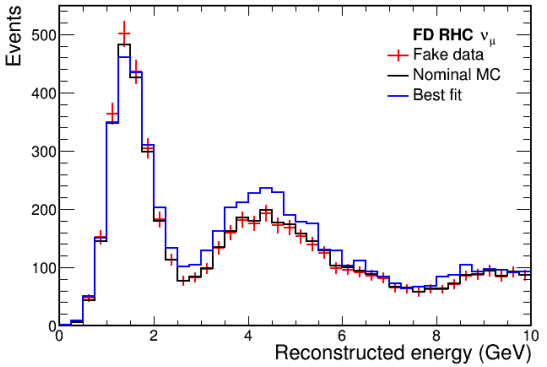
Varied

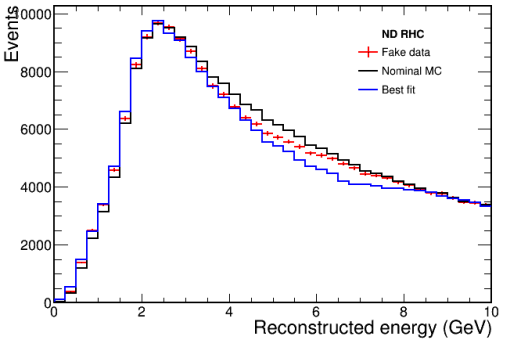


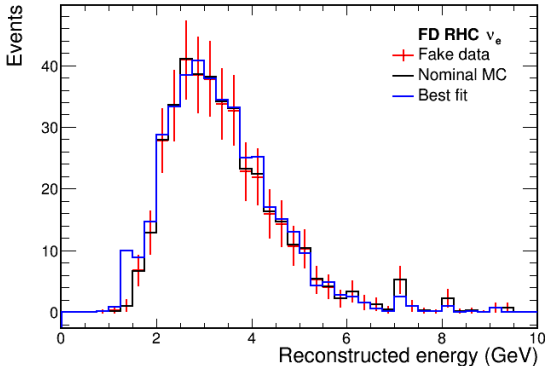


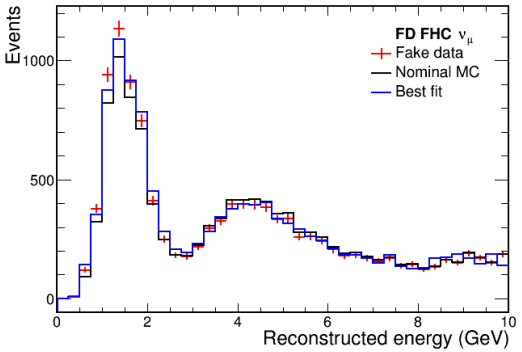
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

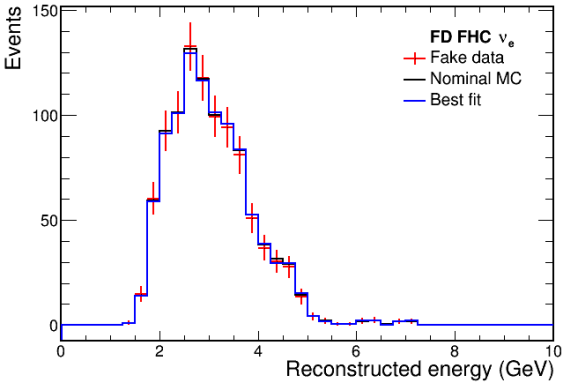










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Syst. shift  nu_ccqe_2_scale 2.5719e-06
Syst. shift  nu_ccqe_3_scale 2.30804e-07
Syst. shift  nubar_ccqe_1_scale -6.63749e-06
Syst. shift  nubar_ccqe_2_scale -2.0971e-06
Syst. shift  nubar_ccqe_3_scale 8.72399e-08
Syst. shift  nu_MEC_dummy_scale 3.39124e-10
Syst. shift  nubar_MEC_dummy_scale 6.45312e-11
Syst. shift  nu_cc1piz_1_scale -3.23203e-06
Syst. shift  nu_cc1piz_2_scale -8.03023e-06
Syst. shift  nu_cc1piz_3_scale 6.29317e-06
Syst. shift  nu_cc1pic_1_scale -2.01773e-06
Syst. shift  nu_cc1pic_2_scale 2.43547e-06
Syst. shift  nu_cc1pic_3_scale -5.3451e-06
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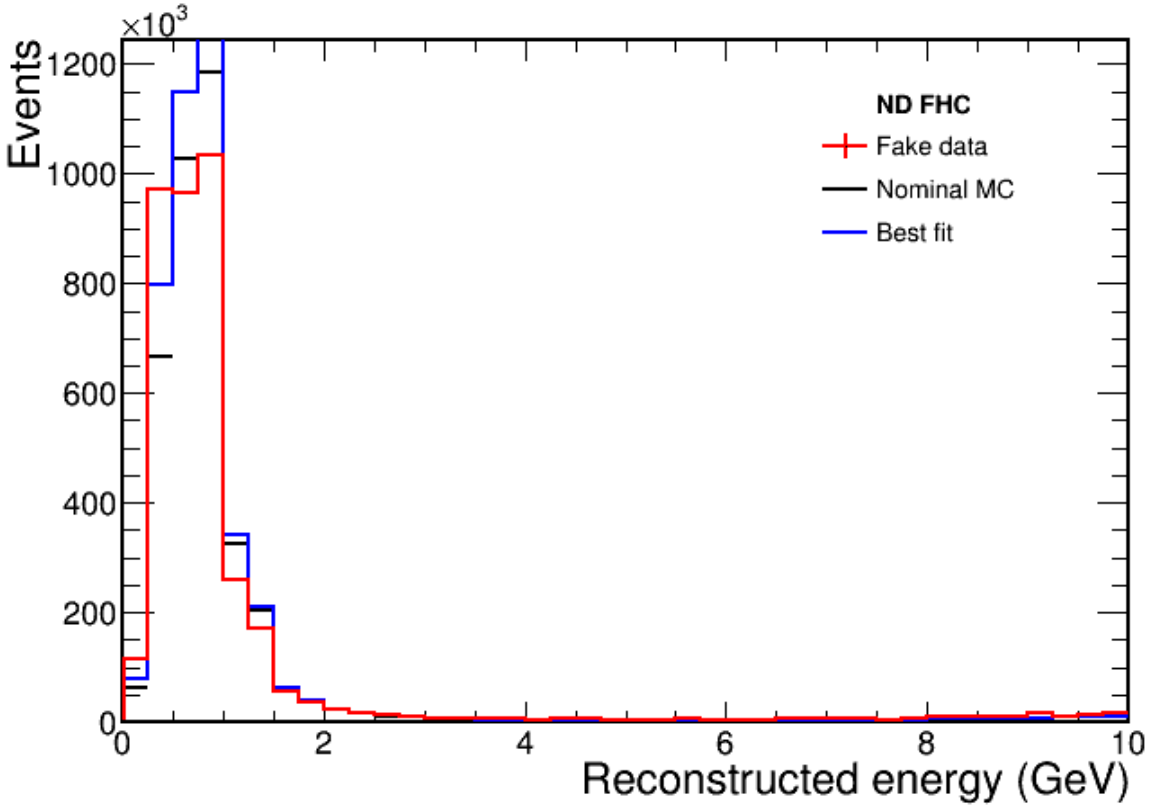
Syst. shift  nubar_cc1piz_3_scale -5.63108e-06
Syst. shift  nubar_cc1pic_1_scale 1.55168e-06
Syst. shift  nubar_cc1pic_2_scale -1.08615e-06
Syst. shift  nubar_cc1pic_3_scale 1.74139e-06
Syst. shift  nu_2pi_scale 0.022529
Syst. shift  nubar_2pi_scale 0.00330227
Syst. shift  nu_dis_1_scale 1.00799e-05
Syst. shift  nu_dis_2_scale 2.9089e-05
Syst. shift  nu_dis_3_scale -3.46567e-05
Syst. shift  nubar_dis_1_scale -1.20319e-06
Syst. shift  nubar_dis_2_scale 0.000108658
Syst. shift  nubar_dis_3_scale -7.35809e-05
Syst. shift  nu_coh_scale -2.92301e-06
Syst. shift  nubar_coh_scale 2.92425e-06
Syst. shift  nu_nc_scale -1.00766e-06
Syst. shift  nubar_nc_scale 6.28319e-05
Syst. shift  flux17 0.681569
Syst. shift  flux18 -2.6349
Syst. shift  flux19 4.3934
Syst. shift  flux20 7.19158
Syst. shift  flux21 10.9609
Syst. shift  flux22 -8.40738
Syst. shift  eScale -0.99919
Syst. shift  eRes 0.538219
True dCP 0pi, best fit -0.202421pi, chi2 5868.67 delta=0 chi2 3397.16
```

FD+ND fit with Xsec+Flux systematics
20% Missing proton energy
30 mrad off-axis FHC



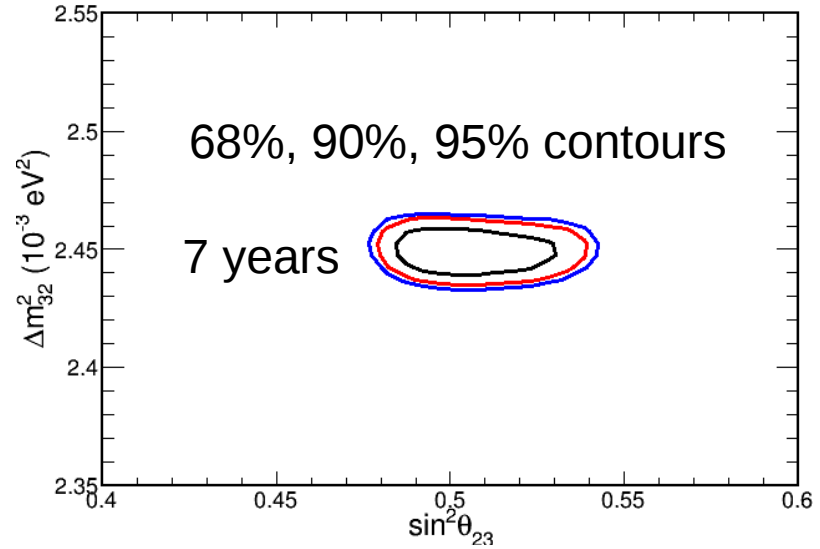
Black : nominal 30mrad off-axis

Blue : with on-axis best fit

Red : real 20% MPE

FD+ND fit with Xsec+Flux systematics
20% Missing proton energy with muon/pion dials

True



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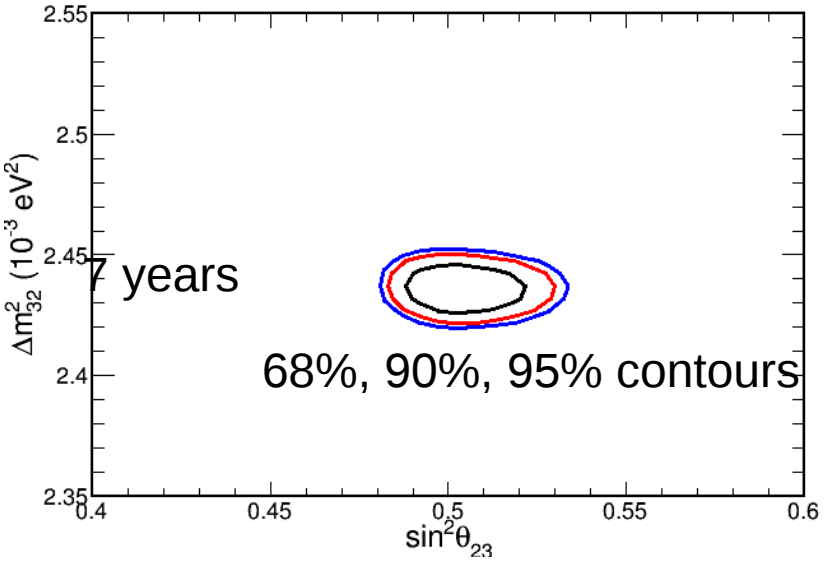
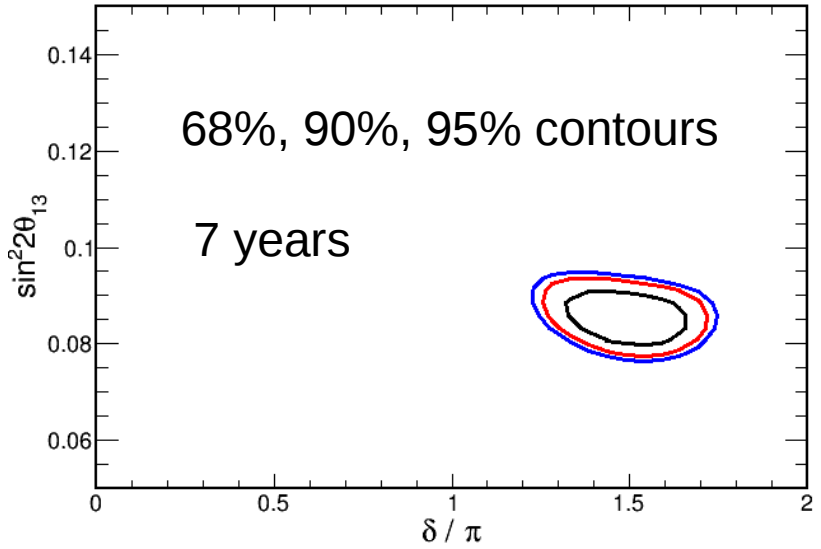
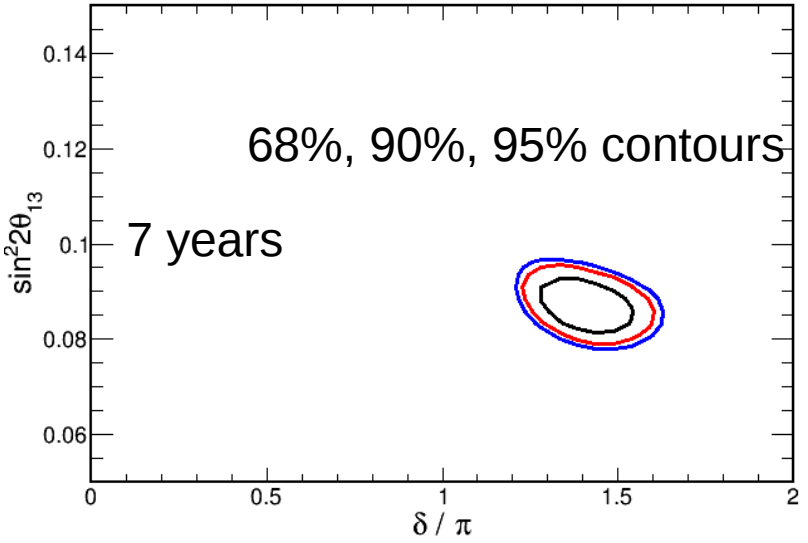
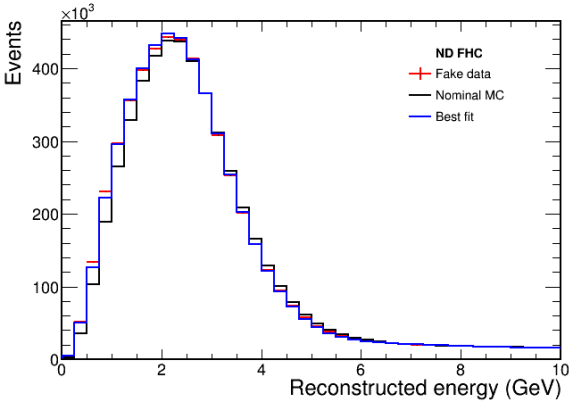
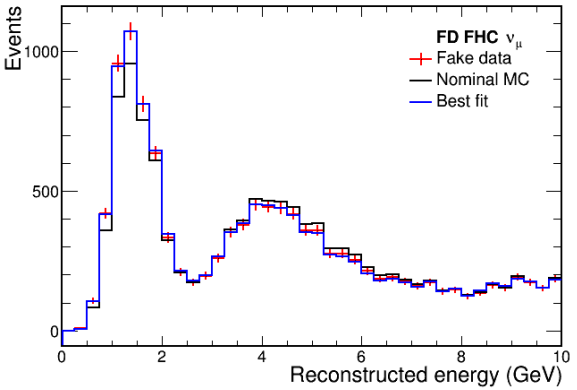


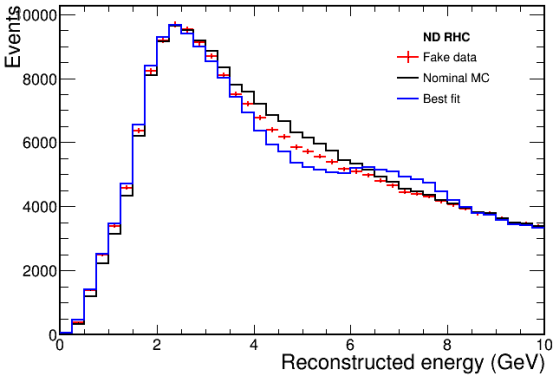


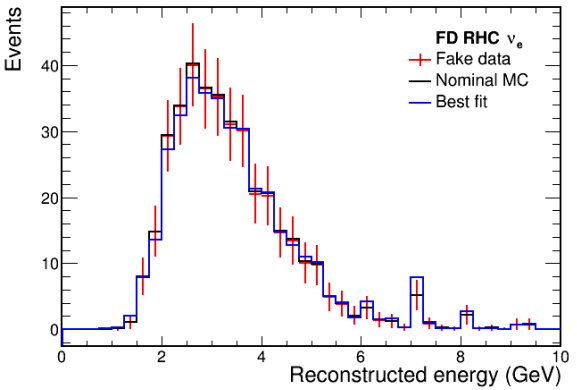


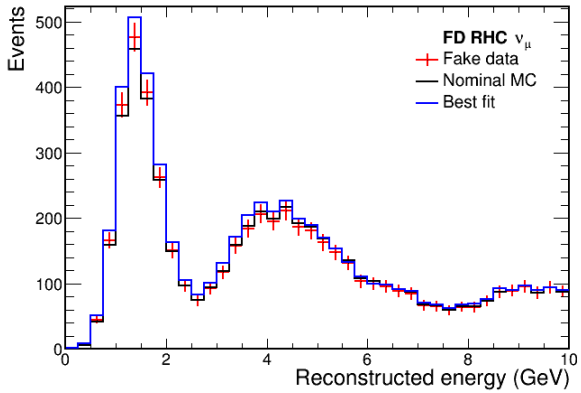
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy with muon/pion dials

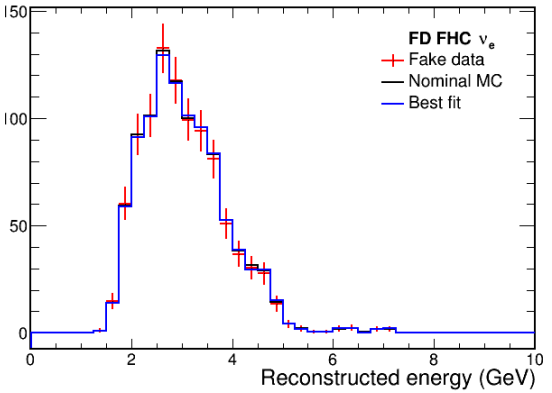










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Syst. shift  nu_ccqe_2_scale 1.84733e-07
Syst. shift  nu_ccqe_3_scale 7.97872e-09
Syst. shift  nubar_ccqe_1_scale -2.27972e-07
Syst. shift  nubar_ccqe_2_scale -9.77523e-08
Syst. shift  nubar_ccqe_3_scale 1.21222e-08
Syst. shift  nu_MEC_dummy_scale -2.50724e-13
Syst. shift  nubar_MEC_dummy_scale -9.58261e-12
Syst. shift  nu_cc1piz_1_scale -1.81543e-07
Syst. shift  nu_cc1piz_2_scale -3.65294e-07
Syst. shift  nu_cc1piz_3_scale 2.97555e-07
Syst. shift  nu_cc1pic_1_scale -7.86326e-08
Syst. shift  nu_cc1pic_2_scale 1.07434e-07
Syst. shift  nu_cc1pic_3_scale -2.98592e-07
Syst. shift  nubar_cc1piz_1_scale 6.44665e-07
Syst. shift  nubar_cc1piz_2_scale 5.30709e-07
Syst. shift  nubar_cc1piz_3_scale -2.69225e-07
Syst. shift  nubar_cc1pic_1_scale 6.88099e-08
Syst. shift  nubar_cc1pic_2_scale -5.64506e-08
Syst. shift  nubar_cc1pic_3_scale 1.04321e-07
Syst. shift  nu_2pi_scale 0.00101117
Syst. shift  nubar_2pi_scale 0.000134001
Syst. shift  nu_dis_1_scale 4.79187e-07
Syst. shift  nu_dis_2_scale 1.18445e-06
Syst. shift  nu_dis_3_scale -1.49465e-06
Syst. shift  nubar_dis_1_scale -6.71087e-07
Syst. shift  nubar_dis_2_scale 5.00174e-06
Syst. shift  nubar_dis_3_scale -3.39034e-06
Syst. shift  nu_coh_scale -1.36832e-07
Syst. shift  nubar_coh_scale 1.36426e-07
Syst. shift  nu_nc_scale 9.39591e-06
Syst. shift  nubar_nc_scale 2.00719e-06
Syst. shift  flux17 -1.29883
Syst. shift  flux18 -4.20468
Syst. shift  flux19 6.49293
Syst. shift  flux20 -7.79027
Syst. shift  flux13 0.0821084
Syst. shift  flux16 1.79153
Syst. shift  eScale 0.0595044
Syst. shift  eRes 0.300302
True dCP 0pi, best fit -0.378874pi, chi2 2345.34 delta=0 chi2 2344.41
```
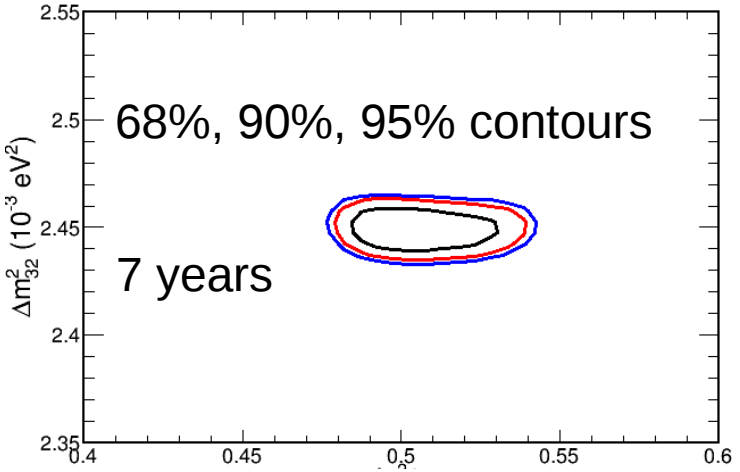
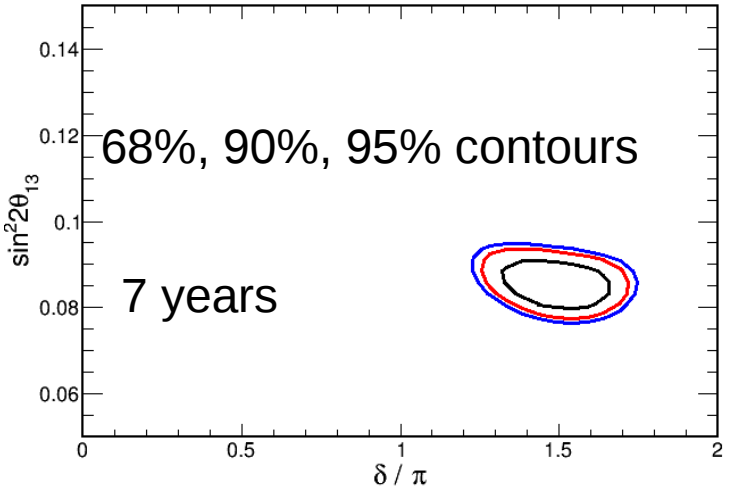

FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

True





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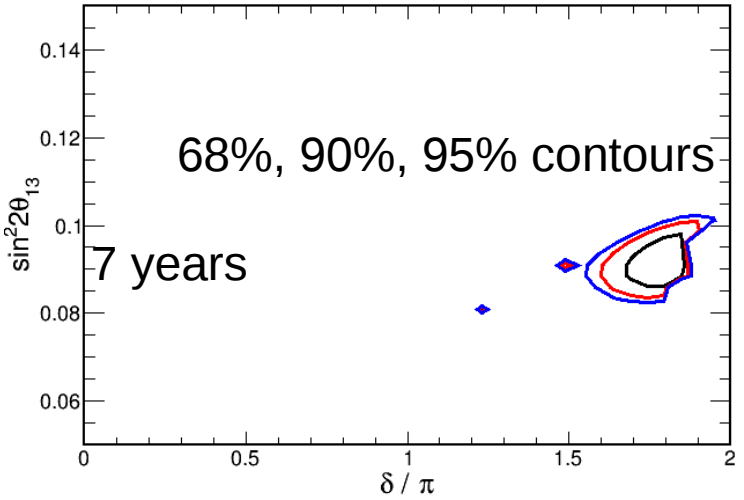
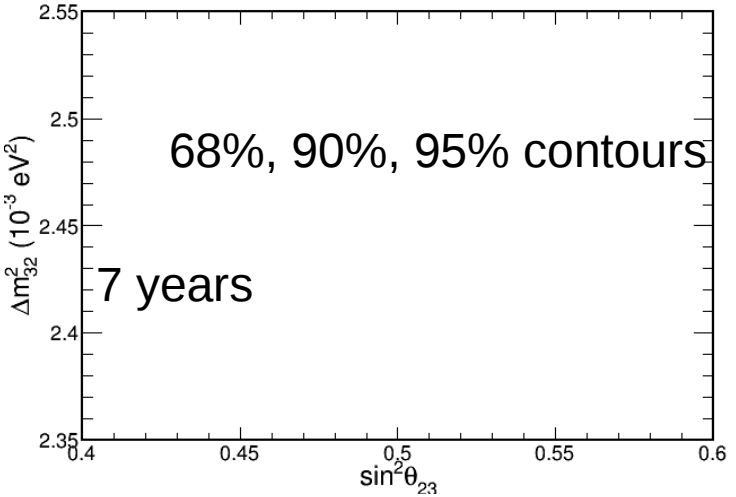
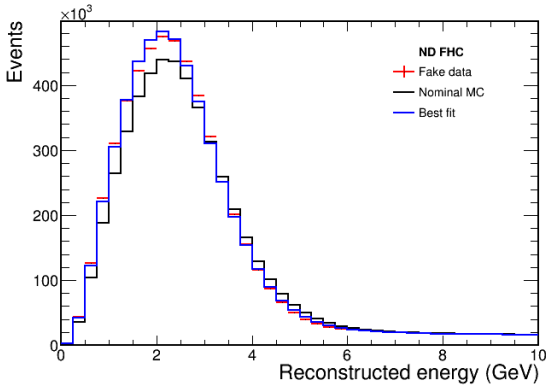
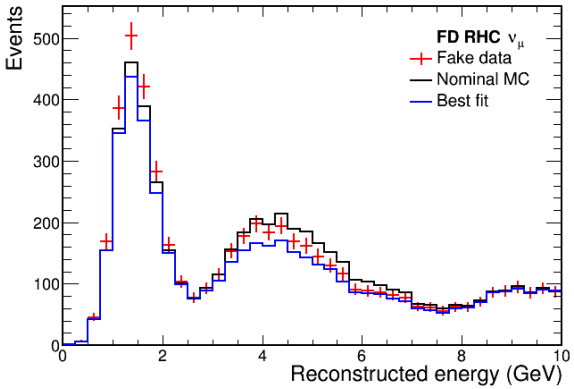
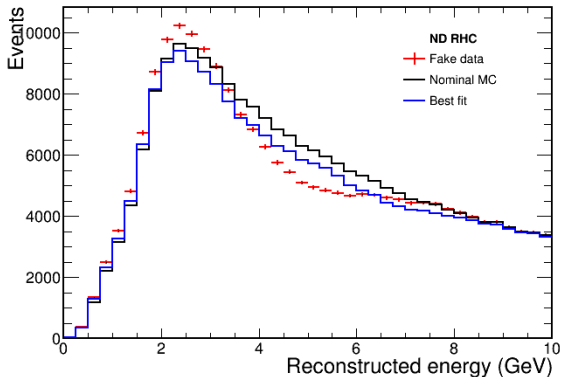


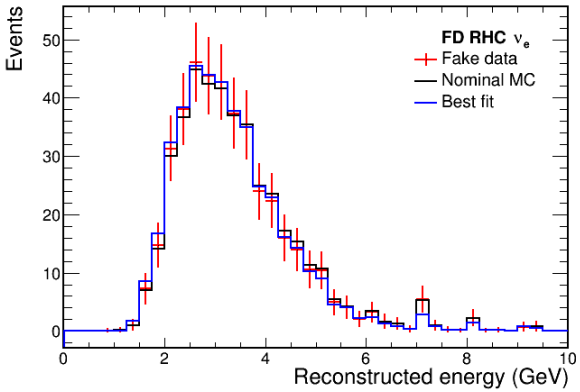


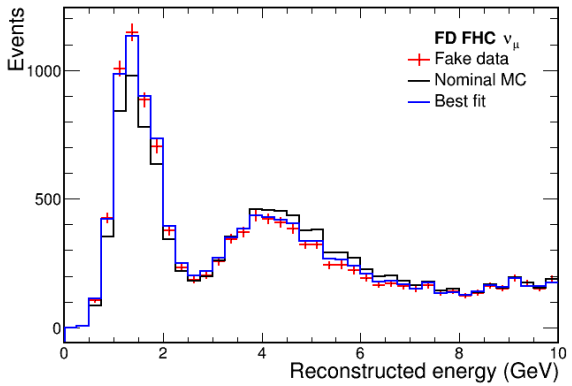
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

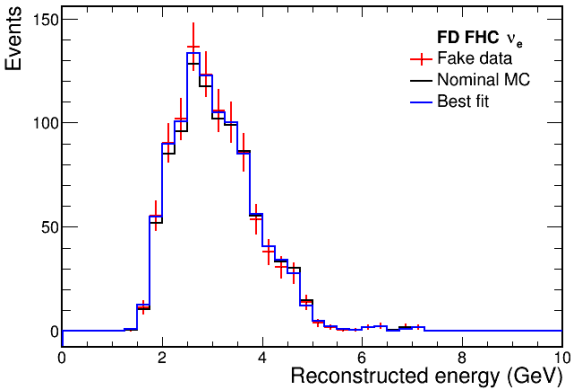










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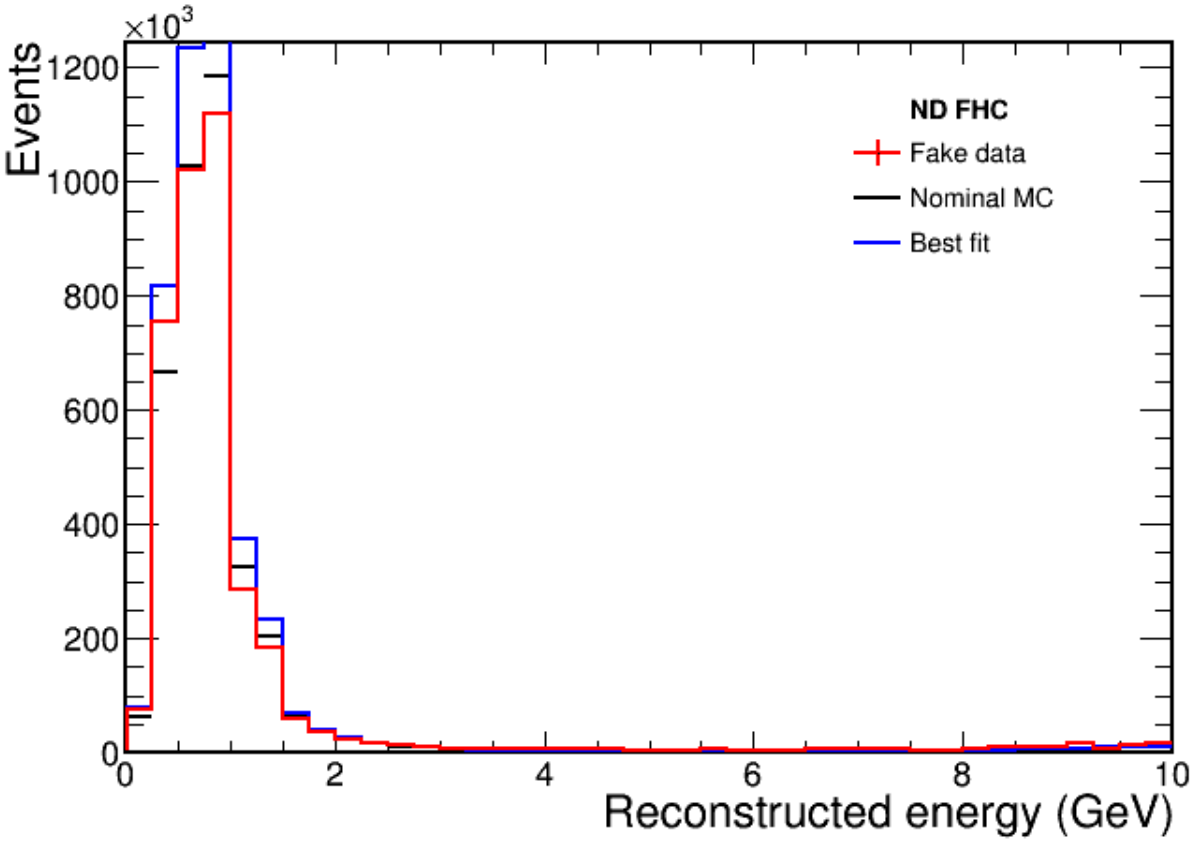
Syst. shift  nu_ccqe_2_scale 5.48346e-05
Syst. shift  nu_ccqe_3_scale -1.31682e-05
Syst. shift  nubar_ccqe_1_scale 0.000240049
Syst. shift  nubar_ccqe_2_scale 4.32893e-05
Syst. shift  nubar_ccqe_3_scale 2.31329e-05
Syst. shift  nu_MEC_dummy_scale 2.63595e-10
Syst. shift  nubar_MEC_dummy_scale -4.81268e-10
Syst. shift  nu_cc1piz_1_scale 2.49014e-05
Syst. shift  nu_cc1piz_2_scale 0.000150821
Syst. shift  nu_cc1piz_3_scale -0.000106878
Syst. shift  nu_cc1pic_1_scale 7.05402e-05
Syst. shift  nu_cc1pic_2_scale -6.75692e-05
Syst. shift  nu_cc1pic_3_scale 9.49418e-05
Syst. shift  nubar_cc1piz_1_scale -0.00022723
Syst. shift  nubar_cc1piz_2_scale -0.000180063
Syst. shift  nubar_cc1piz_3_scale 9.12625e-05
Syst. shift  nubar_cc1pic_1_scale -3.56228e-05
Syst. shift  nubar_cc1pic_2_scale 2.21128e-05
Syst. shift  nubar_cc1pic_3_scale -2.07316e-05
Syst. shift  nu_2pi_scale -0.370545
Syst. shift  nubar_2pi_scale 0.0624292
Syst. shift  nu_dis_1_scale -0.000143485
Syst. shift  nu_dis_2_scale -0.000731121
Syst. shift  nu_dis_3_scale 0.000670759
Syst. shift  nubar_dis_1_scale -1.56886e-05
Syst. shift  nubar_dis_2_scale -0.00245525
Syst. shift  nubar_dis_3_scale 0.00189108
Syst. shift  nu_coh_scale 5.24286e-05
Syst. shift  nubar_coh_scale -5.19093e-05
Syst. shift  nu_nc_scale 0.00274925
Syst. shift  nubar_nc_scale 0.00107068
Syst. shift  flux15 -1.70337
Syst. shift  flux16 -2.55197
Syst. shift  flux17 -0.482383
Syst. shift  flux18 -0.379664
Syst. shift  flux19 -8.80764
Syst. shift  eScale -0.368676
Syst. shift  eRes 0.0827317
True dCP 0pi, best fit 0.927749pi, chi2 5062.16 delta=0 chi2 5068.84
```

FD+ND fit with Xsec+Flux systematics
20% Missing muon energy
30 mrad off-axis FHC



Black : nominal 30mrad off-axis

Blue : with on-axis best fit

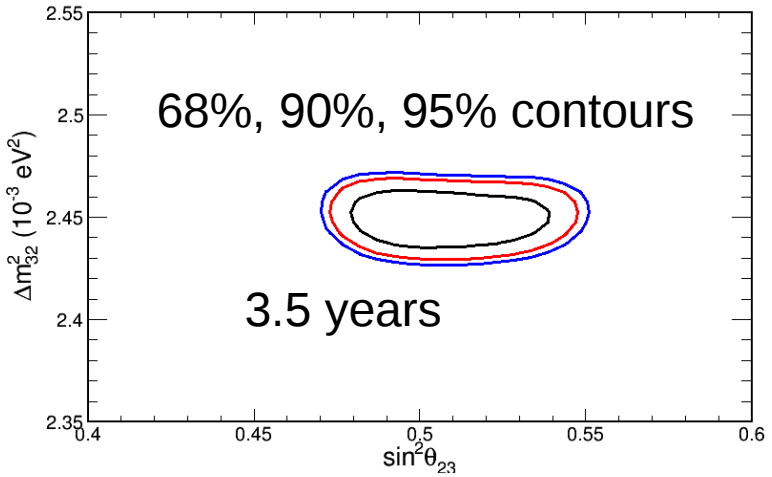
Red : real 20% MPE

Backup..

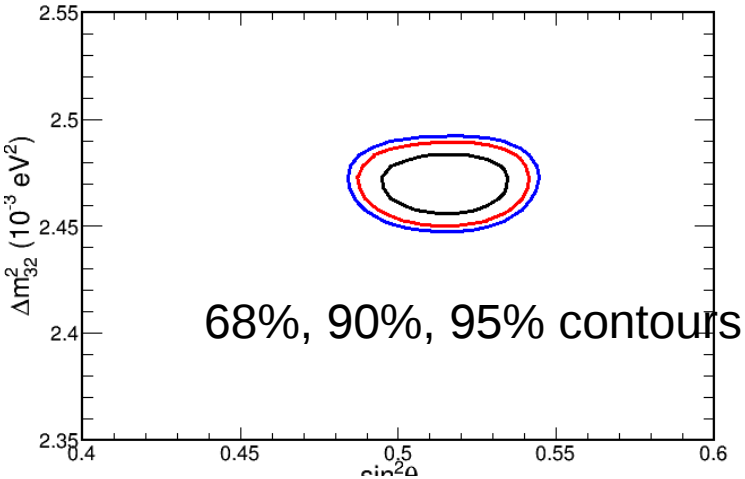
Last week

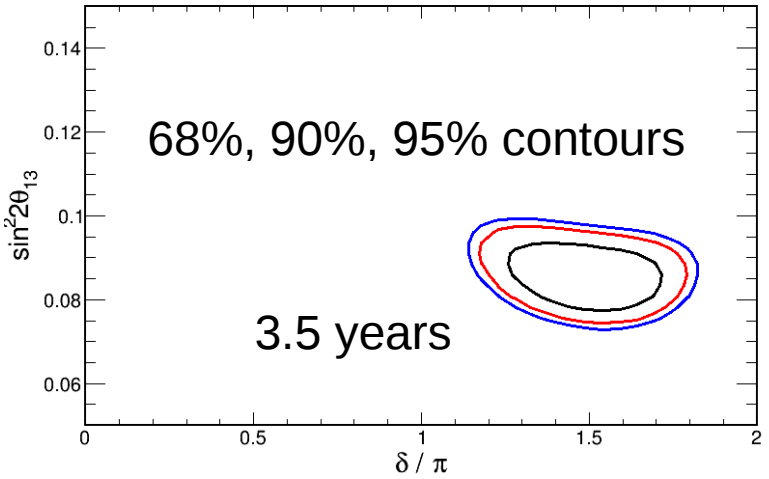
20% missing PE 3.5 years

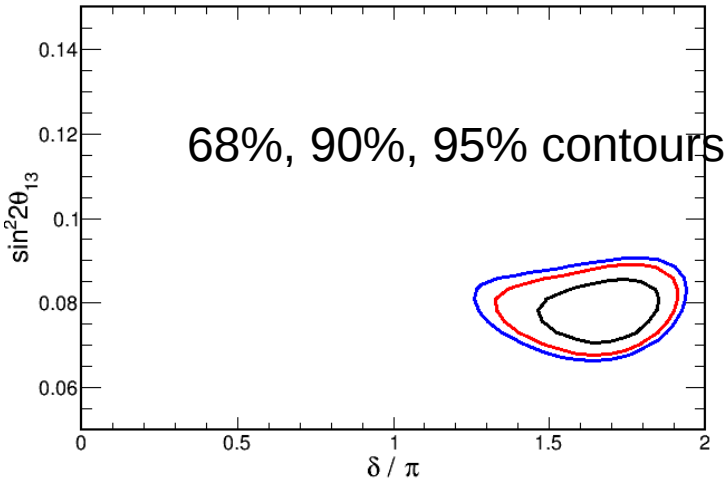
True



10% missing PE





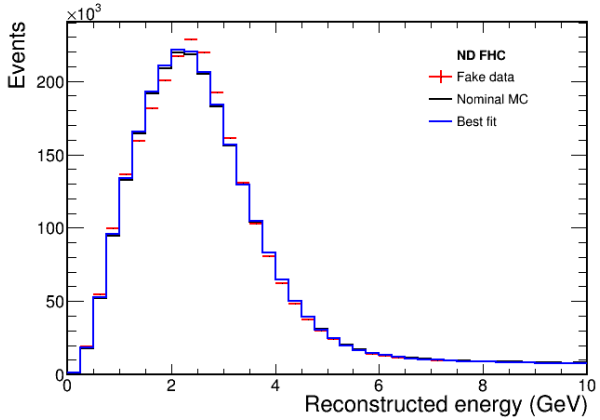


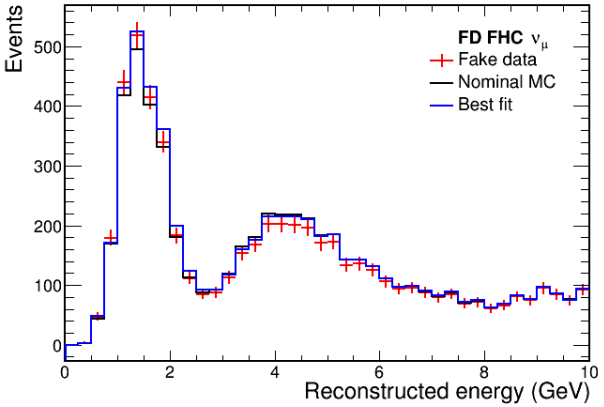
- The oscillation phase spaces change, but how ND performs?

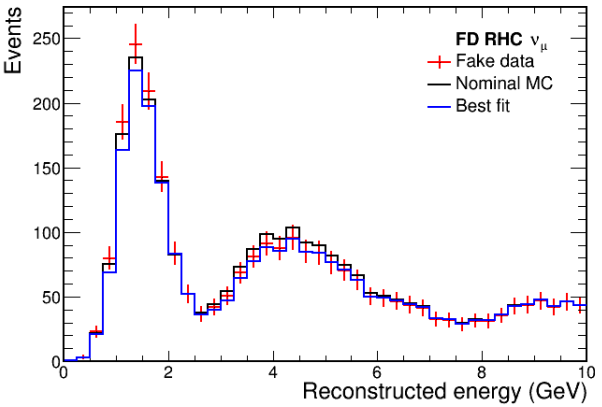
Last week

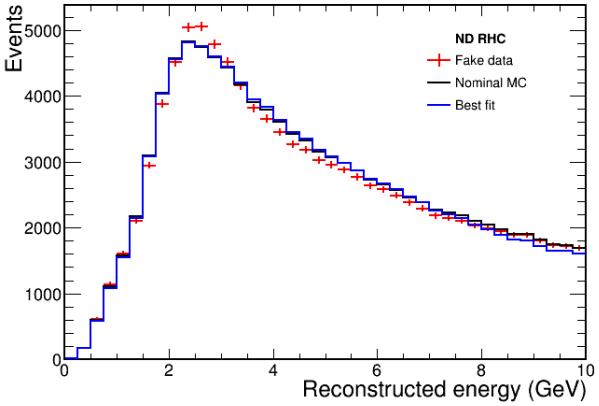
20% missing PE 3.5 years

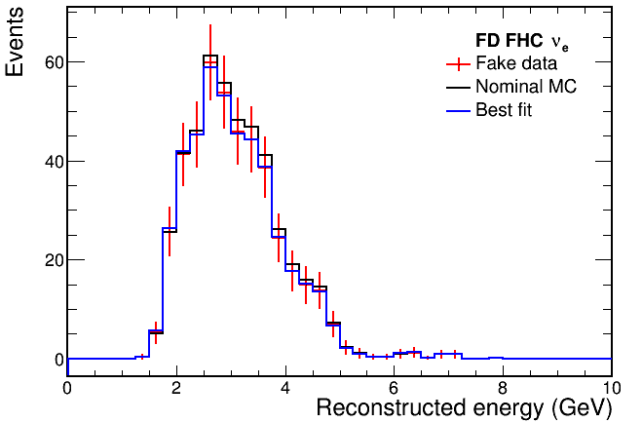
LL value: ND only fit: 4084 FD+ND: 4108 FD only fit: 9

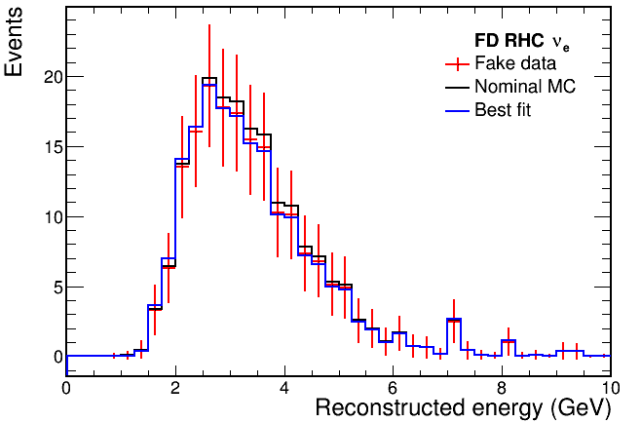












- Missing hadronic energy bring us a disaster, however, not only in FD, but in ND..
- I have major Xsec and flux systematics in backup slides.

Doing new samples with new dials

Use GENIE v.2.10.10 to generate :

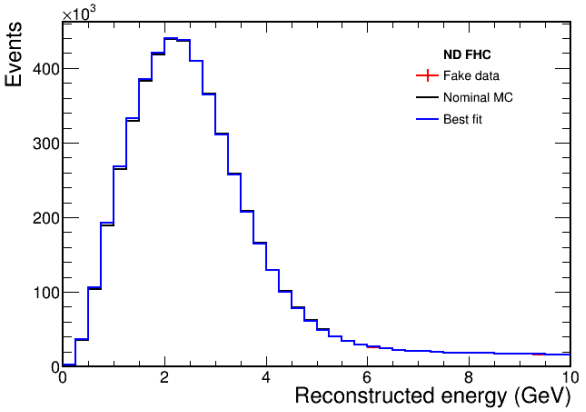
1. 20% missing proton energy sample for numu, numubar, nue and nuebar.
2. 20% missing pi0 and pi+/- energy sample for numu, numubar, nue and nuebar.
3. 10% missing muon energy sample for numu, numubar, nue and nuebar.

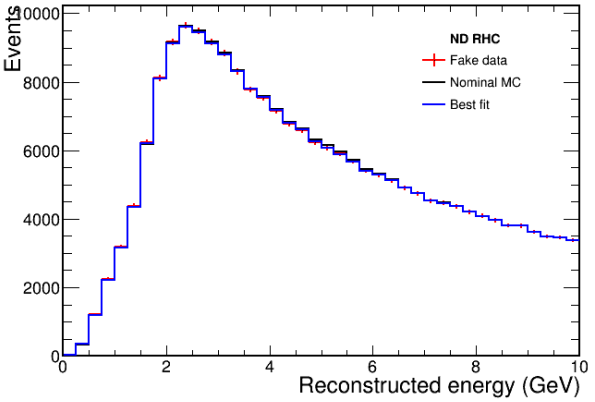
- Those samples are fit with Xsec+Flux systematics.

- In addition, those samples are fit with Xsec+Flux + “other two dials”.

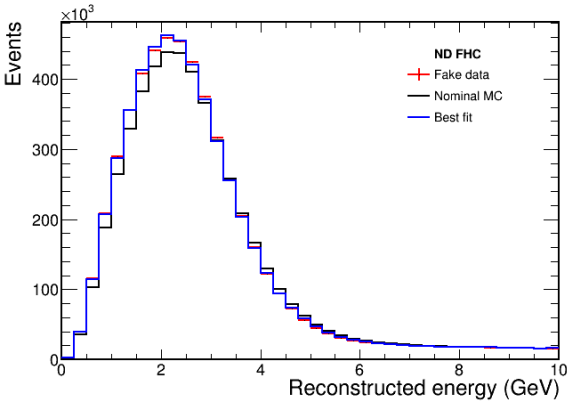
ND only fit with Xsec+Flux systematics

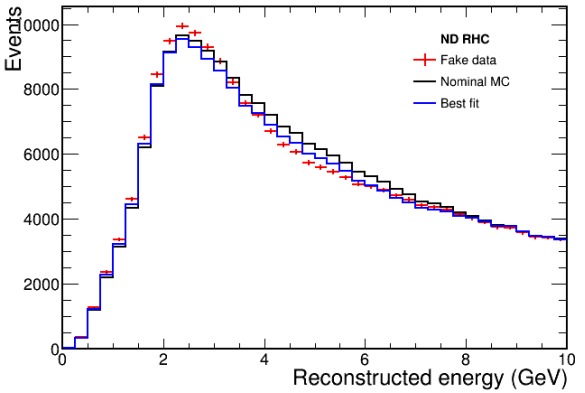
Missing Proton E



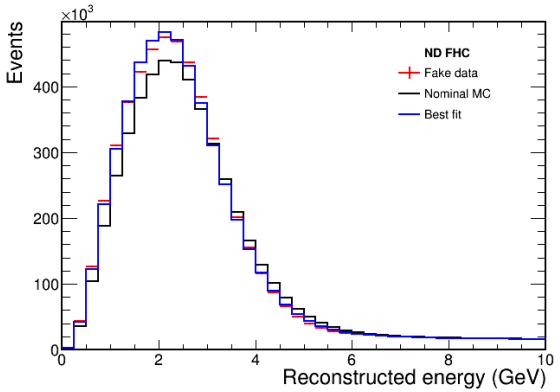


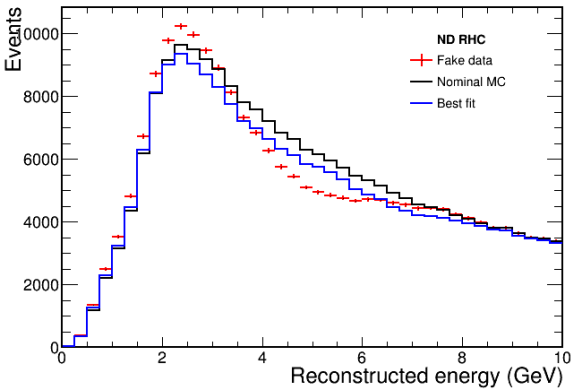
Missing Pion E





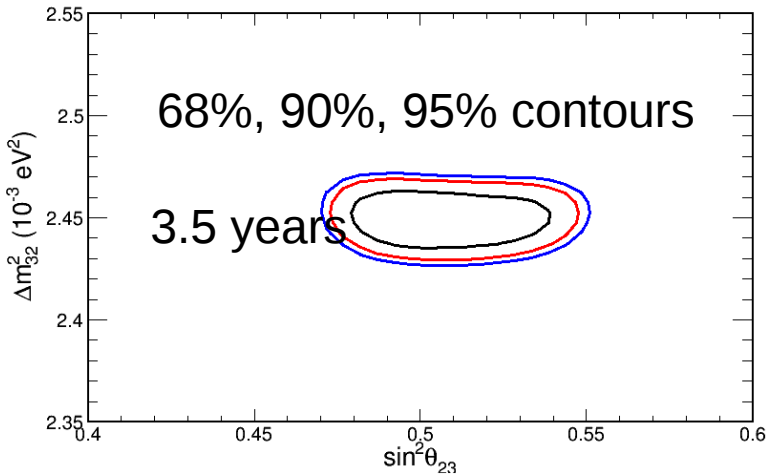
Missing Muon E



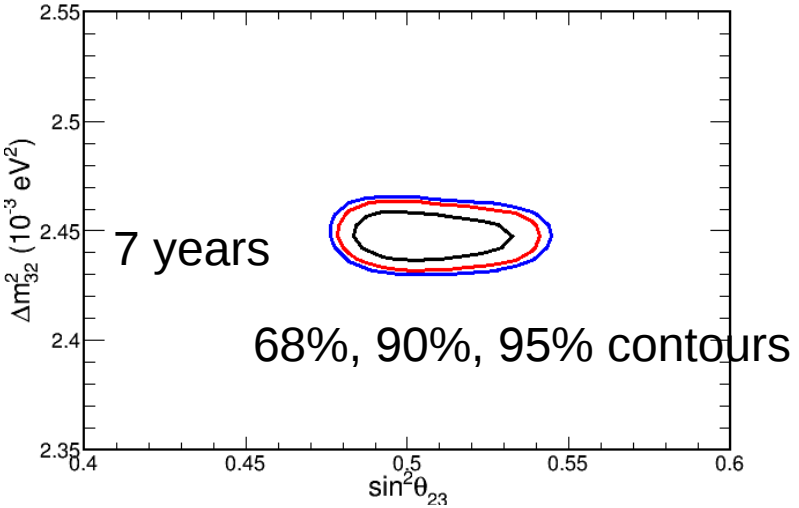


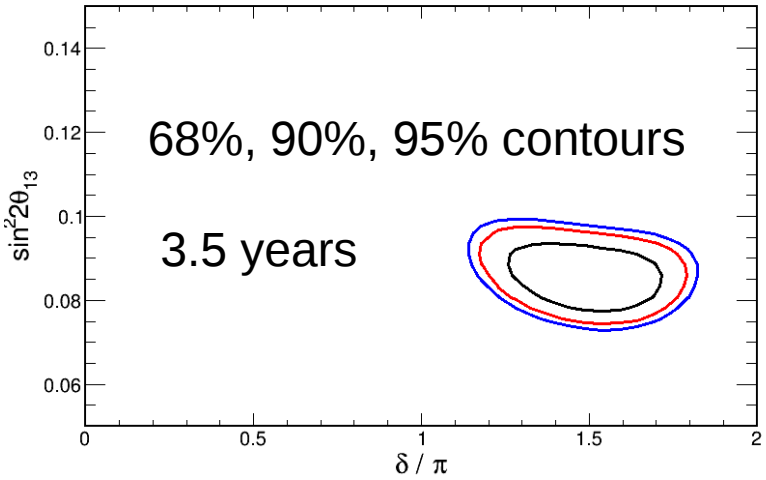
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

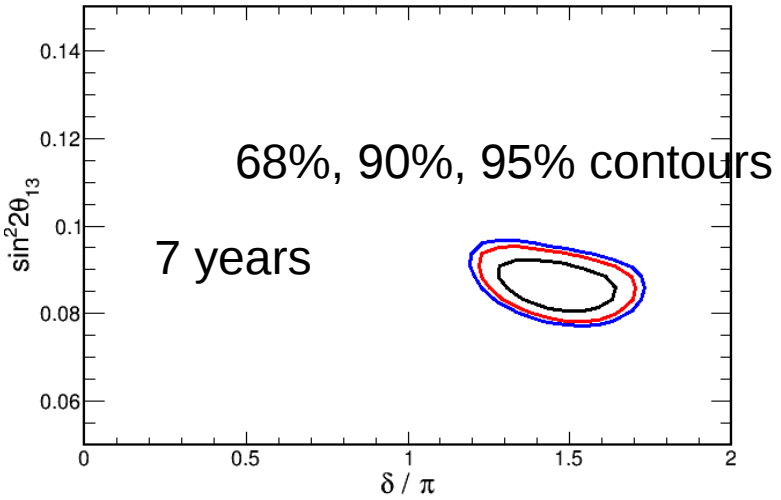
True



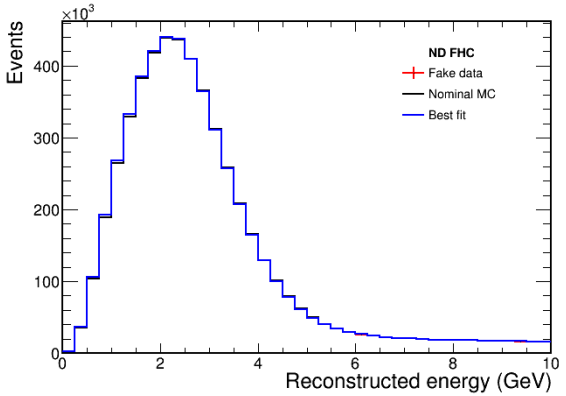
Varied

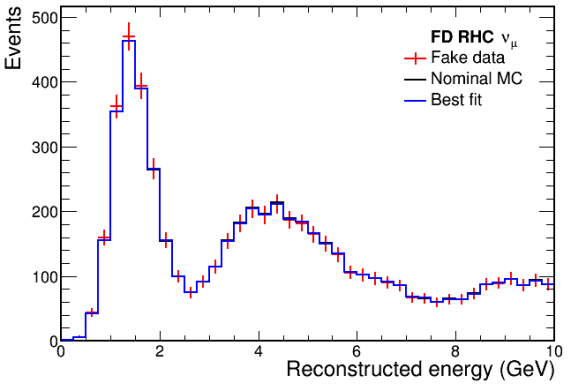


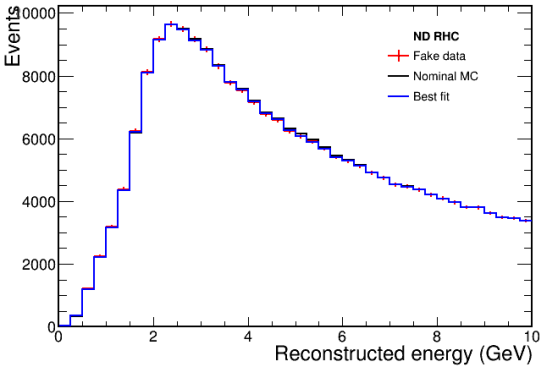


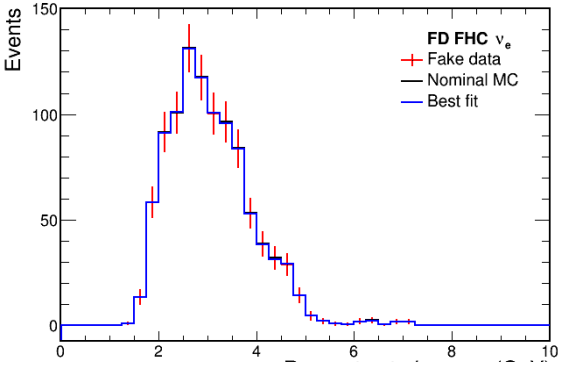


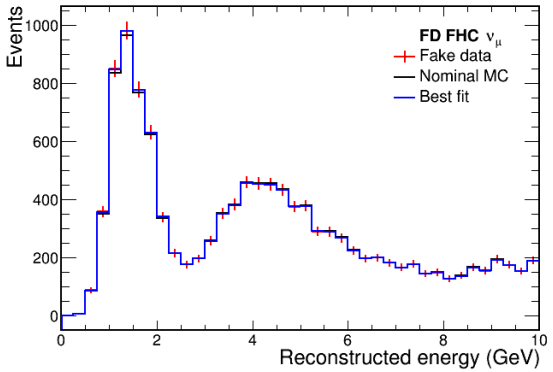
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

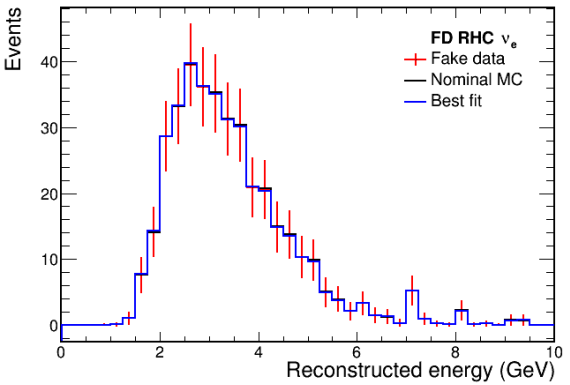










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Syst. shift  nu_ccqe_1_scale -4.39364e-08
Syst. shift  nu_ccqe_2_scale 2.65885e-08
Syst. shift  nu_ccqe_3_scale -4.46011e-09
Syst. shift  nubar_ccqe_1_scale 1.40632e-07
Syst. shift  nubar_ccqe_2_scale 2.21973e-08
Syst. shift  nubar_ccqe_3_scale 6.68951e-09
Syst. shift  nu_MEC_dummy_scale 2.95527e-13
Syst. shift  nubar_MEC_dummy_scale 8.7389e-13
Syst. shift  nu_cc1piz_1_scale 6.57702e-09
Syst. shift  nu_cc1piz_2_scale 9.10828e-08
Syst. shift  nu_cc1piz_3_scale -6.17652e-08
Syst. shift  nu_cc1pic_1_scale 3.35761e-08
Syst. shift  nu_cc1pic_2_scale -2.84971e-08
Syst. shift  nu_cc1pic_3_scale 2.1562e-08
Syst. shift  nubar_cc1piz_1_scale -1.1528e-07
Syst. shift  nubar_cc1piz_2_scale -1.12477e-07
Syst. shift  nubar_cc1piz_3_scale 5.26953e-08
Syst. shift  nubar_cc1pic_1_scale -1.65202e-08
Syst. shift  nubar_cc1pic_2_scale 5.84504e-09
Syst. shift  nubar_cc1pic_3_scale 1.20178e-09
Syst. shift  nu_2pi_scale -0.000250754
Syst. shift  nubar_2pi_scale -3.09845e-05
Syst. shift  nu_dis_1_scale -1.60329e-07
Syst. shift  nu_dis_2_scale -3.77185e-07
Syst. shift  nu_dis_3_scale 4.55557e-07
Syst. shift  nubar_dis_1_scale -4.4686e-07
Syst. shift  nubar_dis_2_scale -1.20103e-06
Syst. shift  nubar_dis_3_scale 8.38118e-07
Syst. shift  nu_coh_scale 3.01116e-08
Syst. shift  nubar_coh_scale -3.01945e-08
Syst. shift  nu_nc_scale 6.1404e-06
Syst. shift  nubar_nc_scale -2.91086e-07
Syst. shift  flux15 -0.926595
Syst. shift  flux16 -0.135392
Syst. shift  flux17 -0.911533
Syst. shift  flux18 -1.04161
Syst. shift  flux19 0.300055
Syst. shift  eScale 0.0727864
Syst. shift  eRes 0.0277421
True dCP 0pi, best fit -0.627831pi, chi2 30.7171 delta=0 chi2 30.7428
```
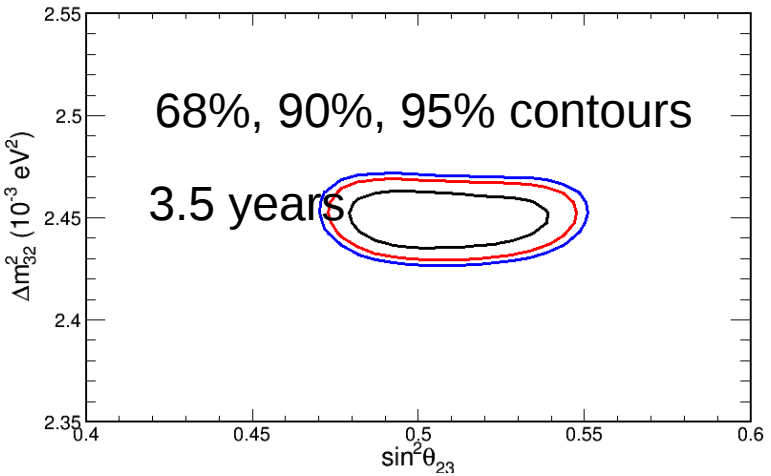
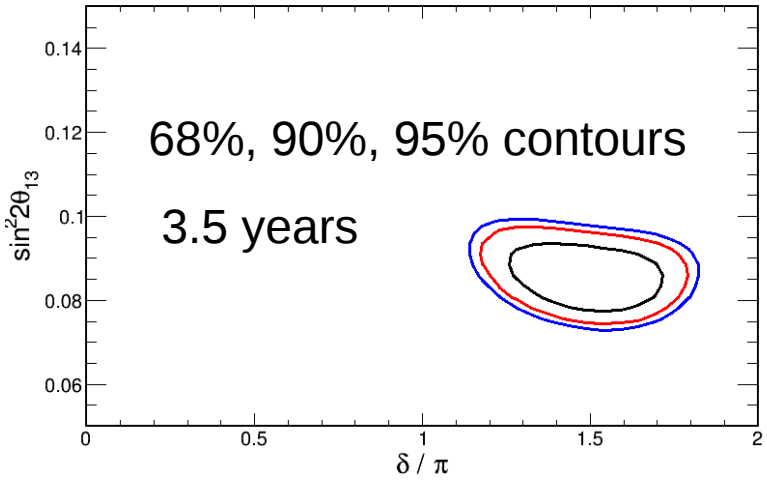
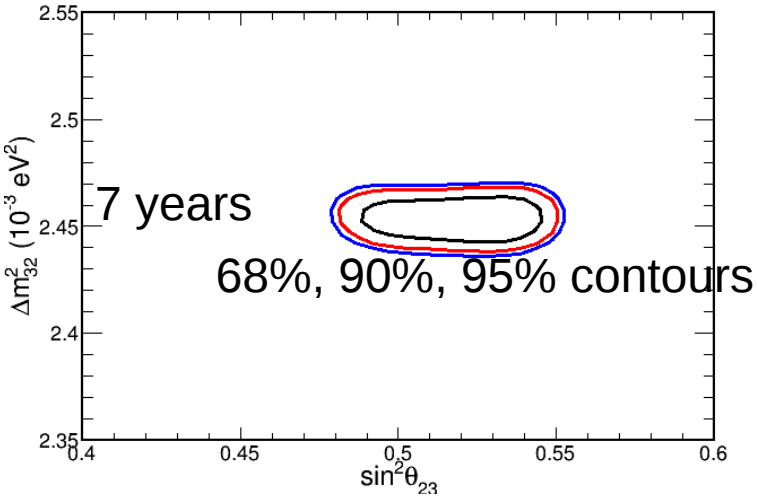

FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

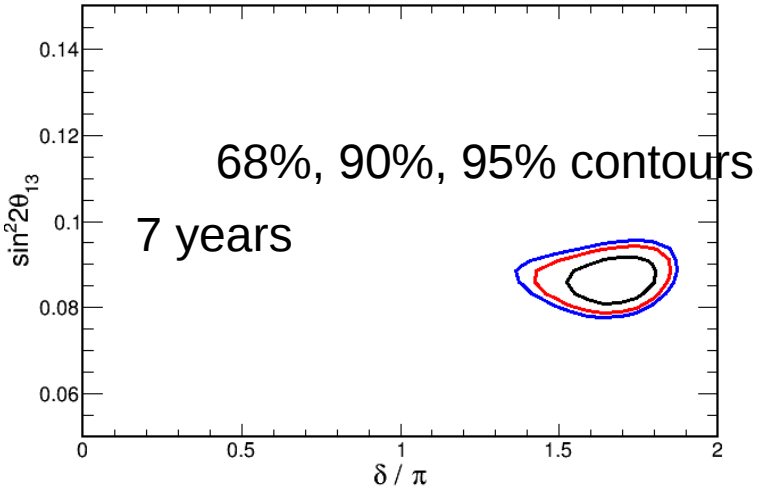
True



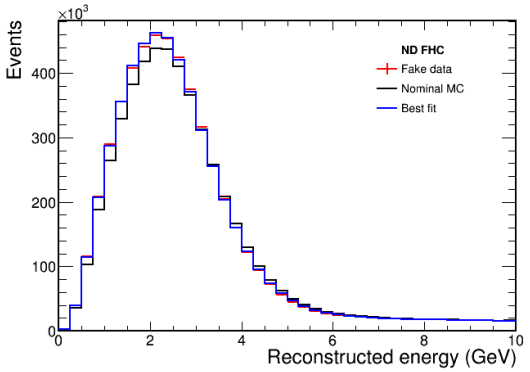


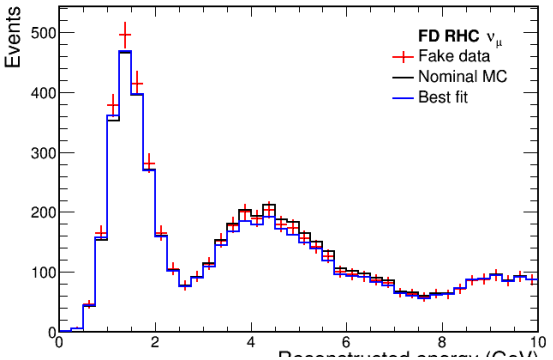
Varied

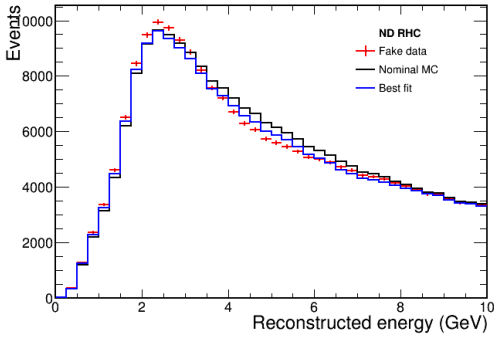


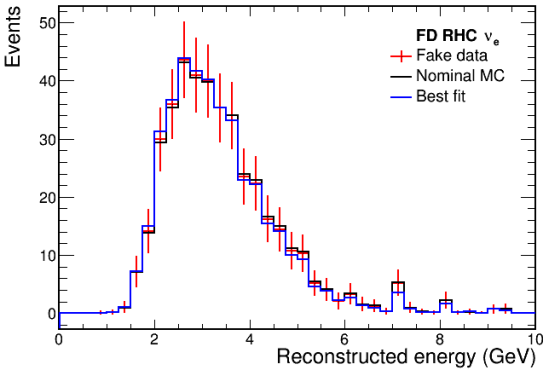


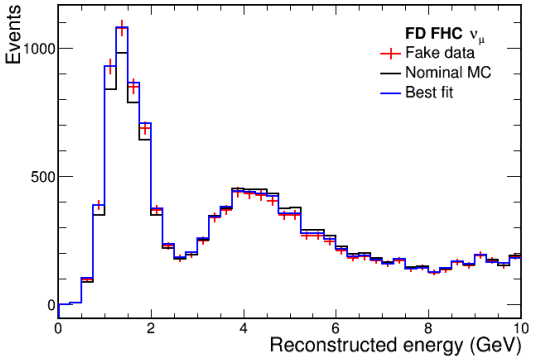
FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

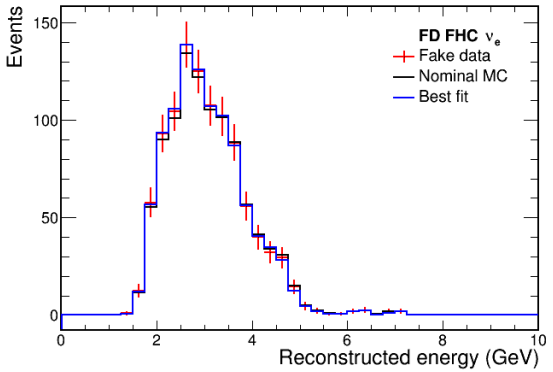













```
Syst. shift  nu_ccqe_1_scale -0.000126234
Syst. shift  nu_ccqe_2_scale -1.84484e-05
Syst. shift  nu_ccqe_3_scale -9.36032e-06
Syst. shift  nubar_ccqe_1_scale 0.000250424
Syst. shift  nubar_ccqe_2_scale 6.13958e-05
Syst. shift  nubar_ccqe_3_scale 8.37066e-06
Syst. shift  nu_MEC_dummy_scale -4.16416e-09
Syst. shift  nubar_MEC_dummy_scale -2.93872e-09
Syst. shift  nu_cc1piz_1_scale 7.31314e-05
Syst. shift  nu_cc1piz_2_scale 0.000221263
Syst. shift  nu_cc1piz_3_scale -0.00016783
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Syst. shift  nu_cc1pic_2_scale -7.51028e-05
Syst. shift  nu_cc1pic_3_scale 0.000134027
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Syst. shift  nubar_cc1piz_2_scale -0.000298867
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Syst. shift  nubar_cc1pic_3_scale -3.92705e-05
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Syst. shift  nubar_2pi_scale -0.0473457
Syst. shift  nu_dis_1_scale -0.000261898
Syst. shift  nu_dis_2_scale -0.000903475
Syst. shift  nu_dis_3_scale 0.000999125
Syst. shift  nubar_dis_1_scale -0.000139269
Syst. shift  nubar_dis_2_scale -0.00310264
Syst. shift  nubar_dis_3_scale 0.00212445
Syst. shift  nu_coh_scale 7.96327e-05
Syst. shift  nubar_coh_scale -7.94545e-05
Syst. shift  nu_nc_scale 0.002949
Syst. shift  nubar_nc_scale -0.000987732
Syst. shift  flux15 -2.22066
Syst. shift  flux16 -0.977563
Syst. shift  flux17 -0.669039
Syst. shift  flux18 -0.131174
Syst. shift  flux19 -3.82132
Syst. shift  eScale -0.320277
Syst. shift  eRes -0.00487637
True dCP 0pi, best fit -0.918716pi, chi2 852.392 delta=0 chi2 850.874
```
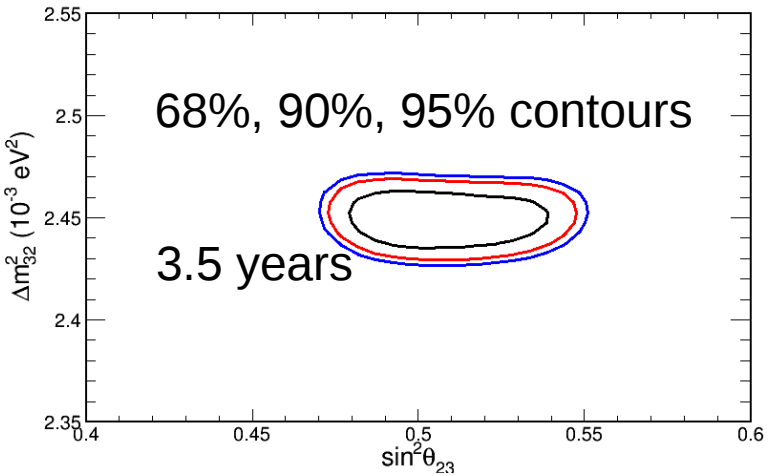
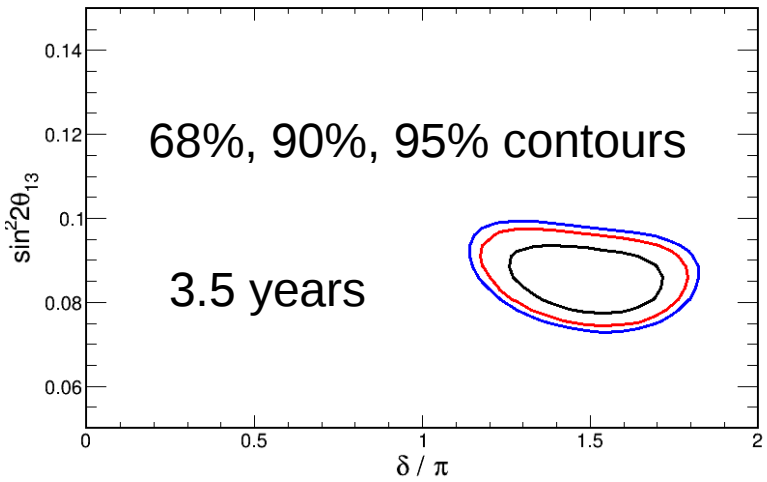
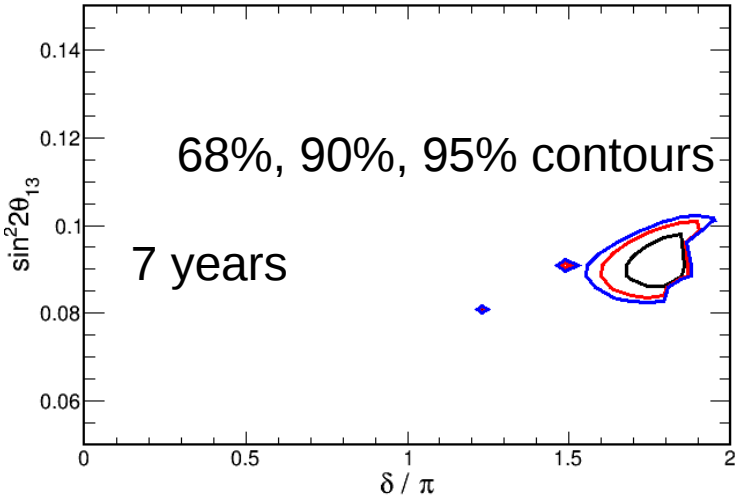

FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

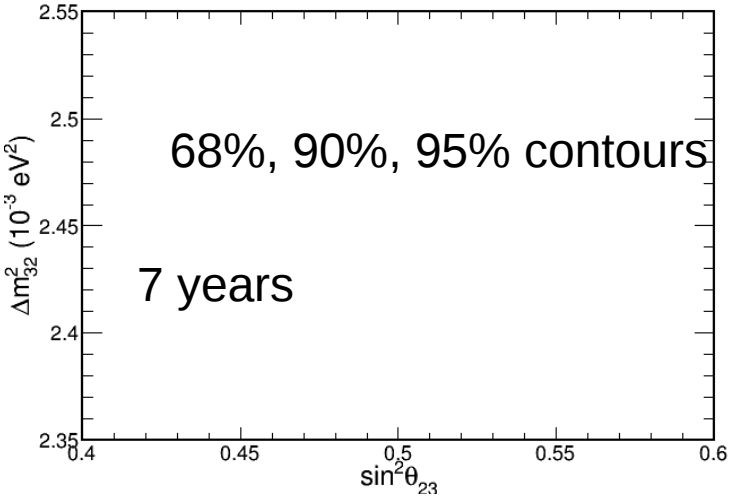
True



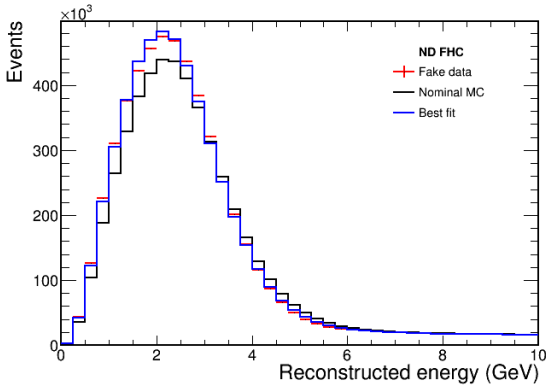


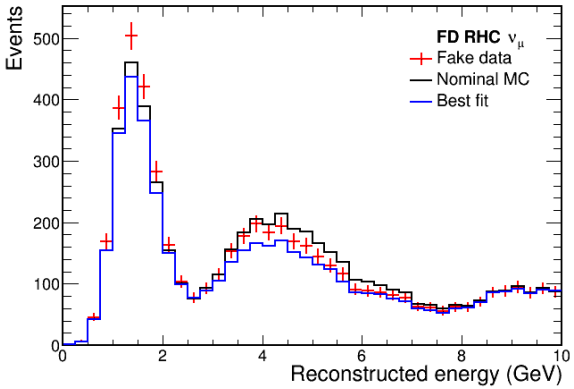
Varied

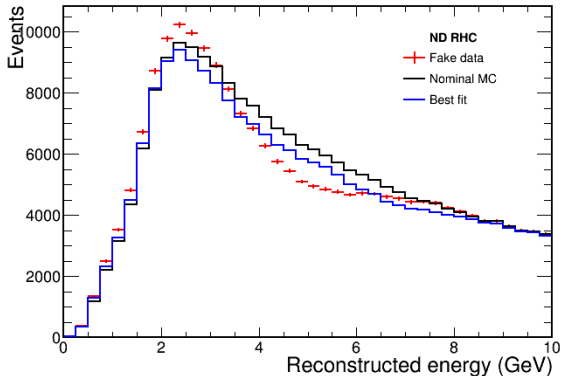


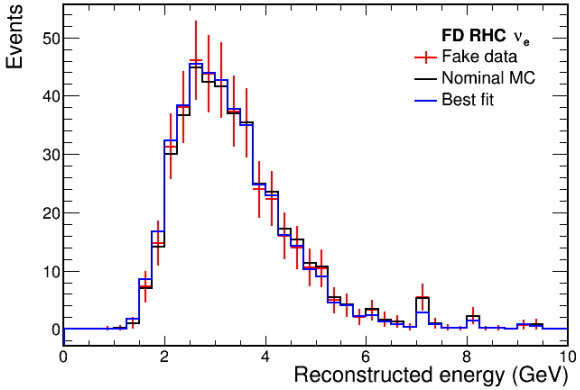


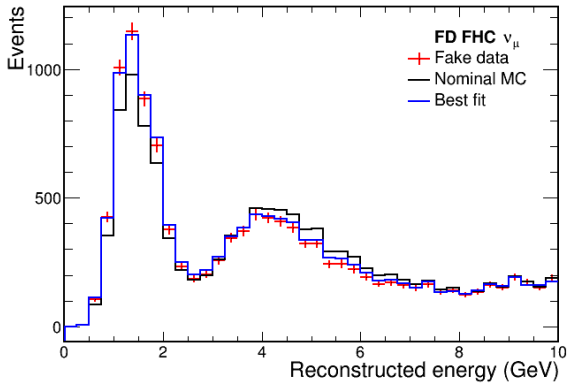
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

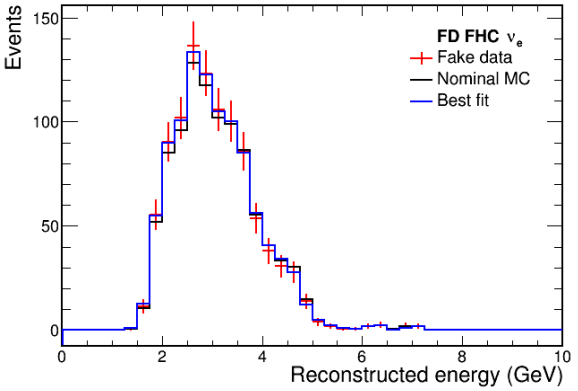










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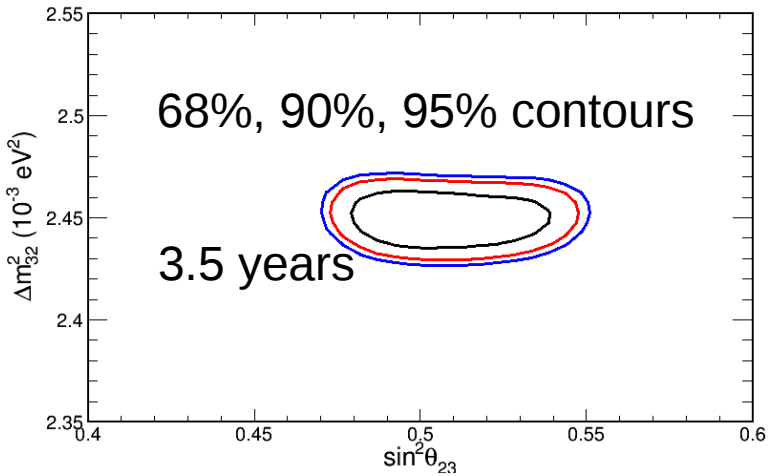
Syst. shift  nubar_ccqe_2_scale 4.32893e-05
Syst. shift  nubar_ccqe_3_scale 2.31329e-05
Syst. shift  nu_MEC_dummy_scale 2.63595e-10
Syst. shift  nubar_MEC_dummy_scale -4.81268e-10
Syst. shift  nu_cc1piz_1_scale 2.49014e-05
Syst. shift  nu_cc1piz_2_scale 0.000150821
Syst. shift  nu_cc1piz_3_scale -0.000106878
Syst. shift  nu_cc1pic_1_scale 7.05402e-05
Syst. shift  nu_cc1pic_2_scale -6.75692e-05
Syst. shift  nu_cc1pic_3_scale 9.49418e-05
Syst. shift  nubar_cc1piz_1_scale -0.00022723
Syst. shift  nubar_cc1piz_2_scale -0.000180063
Syst. shift  nubar_cc1piz_3_scale 9.12625e-05
Syst. shift  nubar_cc1pic_1_scale -3.56228e-05
Syst. shift  nubar_cc1pic_2_scale 2.21128e-05
Syst. shift  nubar_cc1pic_3_scale -2.07316e-05
Syst. shift  nu_2pi_scale -0.370545
Syst. shift  nubar_2pi_scale 0.0624292
Syst. shift  nu_dis_1_scale -0.000143485
Syst. shift  nu_dis_2_scale -0.000731121
Syst. shift  nu_dis_3_scale 0.000670759
Syst. shift  nubar_dis_1_scale -1.56886e-05
Syst. shift  nubar_dis_2_scale -0.00245525
Syst. shift  nubar_dis_3_scale 0.00189108
Syst. shift  nu_coh_scale 5.24286e-05
Syst. shift  nubar_coh_scale -5.19093e-05
Syst. shift  nu_nc_scale 0.00274925
Syst. shift  nubar_nc_scale 0.00107068
Syst. shift  flux15 -1.70337
Syst. shift  flux16 -2.55197
Syst. shift  flux17 -0.482383
Syst. shift  flux18 -0.379664
Syst. shift  flux19 -8.80764
Syst. shift  eScale -0.368676
Syst. shift  eRes 0.0827317
True dCP 0pi, best fit 0.927749pi, chi2 5062.16 delta=0 chi2 5068.84
```

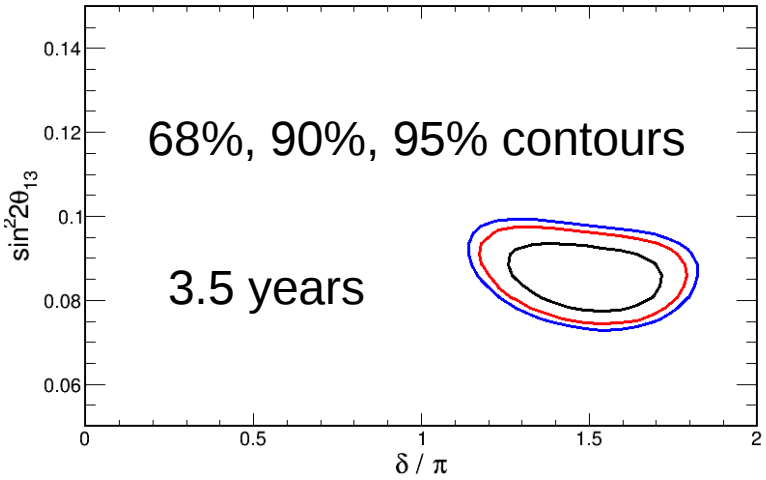
I add “other two dials”

e.g. for missing proton energy sample, missing pion and missing muon samples are used as sysmtematics dials.

FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

True





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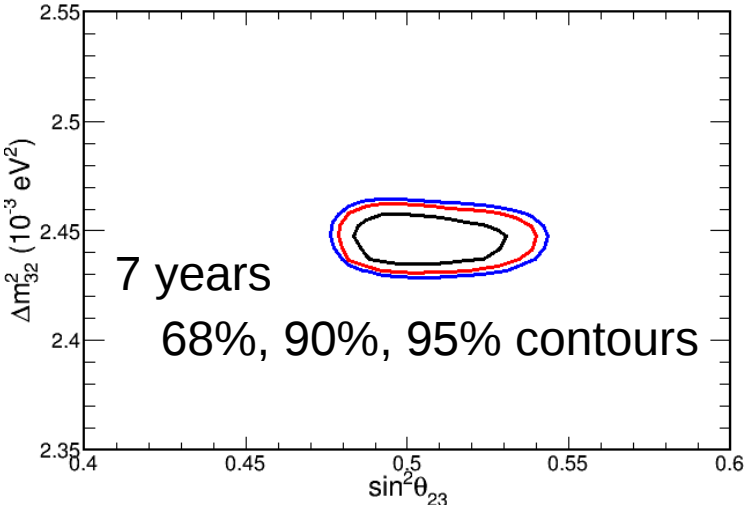
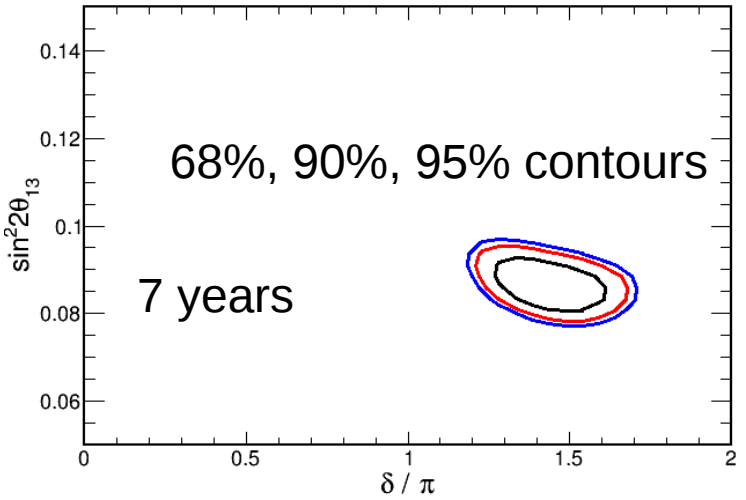
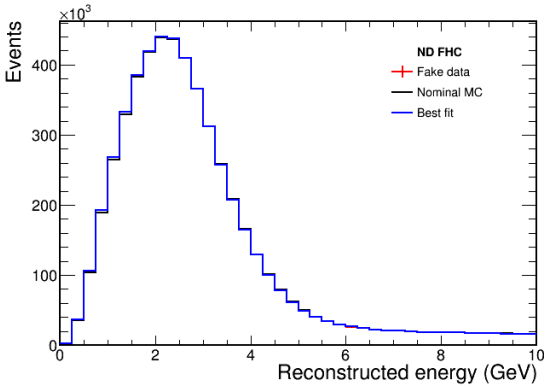
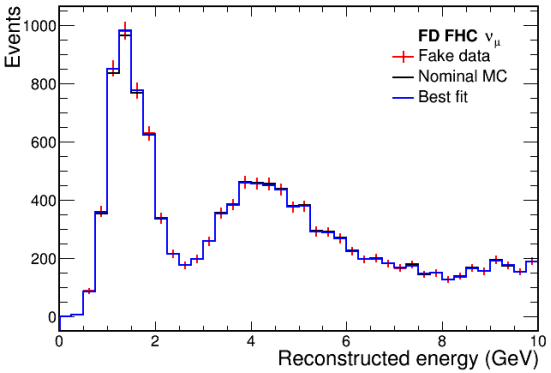
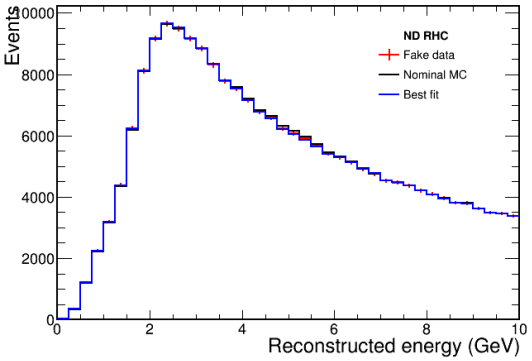


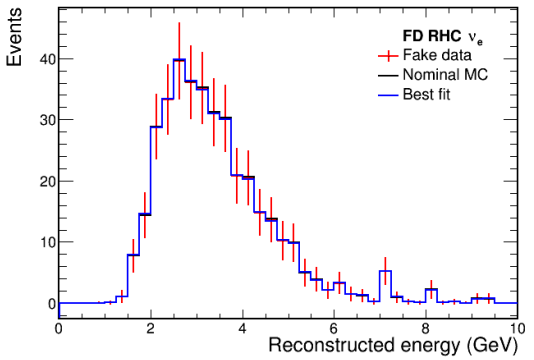


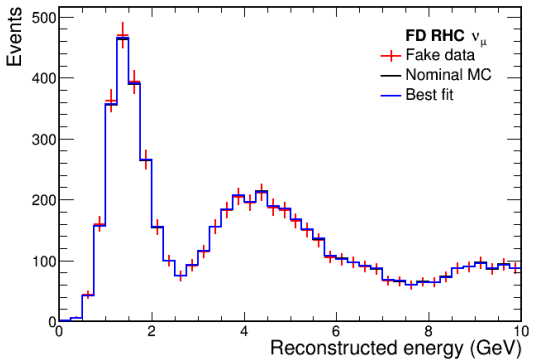
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

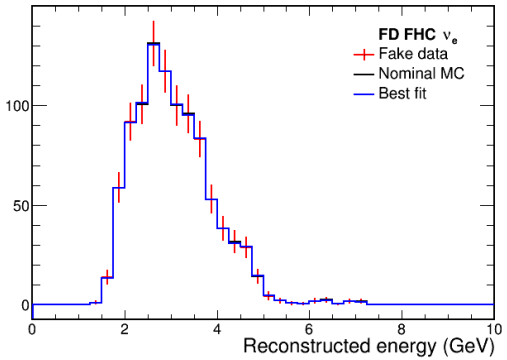










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Syst. shift  nu_ccqe_1_scale 5.49259e-08
Syst. shift  nu_ccqe_2_scale 4.34366e-08
Syst. shift  nu_ccqe_3_scale 2.47995e-09
Syst. shift  nubar_ccqe_1_scale -5.47001e-08
Syst. shift  nubar_ccqe_2_scale -2.61931e-08
Syst. shift  nubar_ccqe_3_scale 1.09037e-09
Syst. shift  nu_MEC_dummy_scale -3.02539e-14
Syst. shift  nubar_MEC_dummy_scale 6.84712e-13
Syst. shift  nu_cc1piz_1_scale -5.17583e-08
Syst. shift  nu_cc1piz_2_scale -8.43633e-08
Syst. shift  nu_cc1piz_3_scale 7.1381e-08
Syst. shift  nu_cc1pic_1_scale -2.23152e-08
Syst. shift  nu_cc1pic_2_scale 2.94812e-08
Syst. shift  nu_cc1pic_3_scale -8.22617e-08
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Syst. shift  nubar_2pi_scale 1.35304e-05
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Syst. shift  nu_dis_2_scale 3.32858e-07
Syst. shift  nu_dis_3_scale -3.40345e-07
Syst. shift  nubar_dis_1_scale -3.03215e-07
Syst. shift  nubar_dis_2_scale 1.23235e-06
Syst. shift  nubar_dis_3_scale -8.12986e-07
Syst. shift  nu_coh_scale -3.30228e-08
Syst. shift  nubar_coh_scale 3.28336e-08
Syst. shift  nu_nc_scale 3.41292e-06
Syst. shift  nubar_nc_scale 6.44116e-07
Syst. shift  flux12 0.132524
Syst. shift  flux13 -0.00104501
Syst. shift  flux15 -0.660567
Syst. shift  flux16 -0.0880146
Syst. shift  flux17 -0.871562
Syst. shift  flux18 -0.983286
Syst. shift  flux19 0.749454
Syst. shift  eScale 0.124023
Syst. shift  eRes 0.0275204
True dCP 0pi, best fit -0.648169pi, chi2 15.8614 delta=0 chi2 15.8483
```
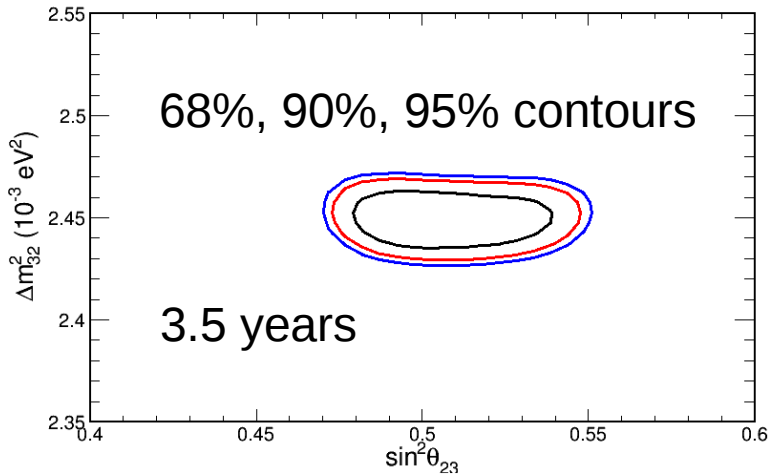

Missing pion

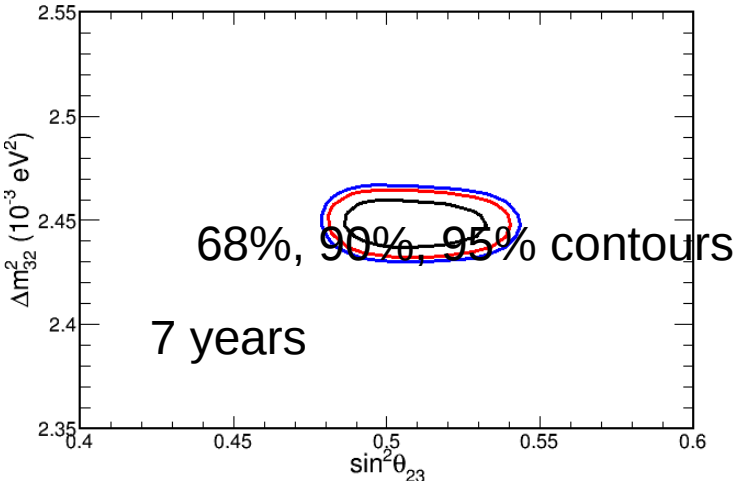
Missing muon

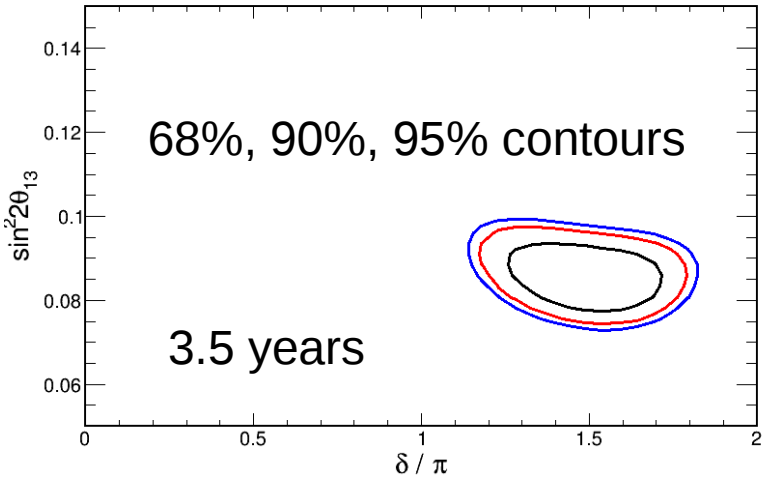
FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

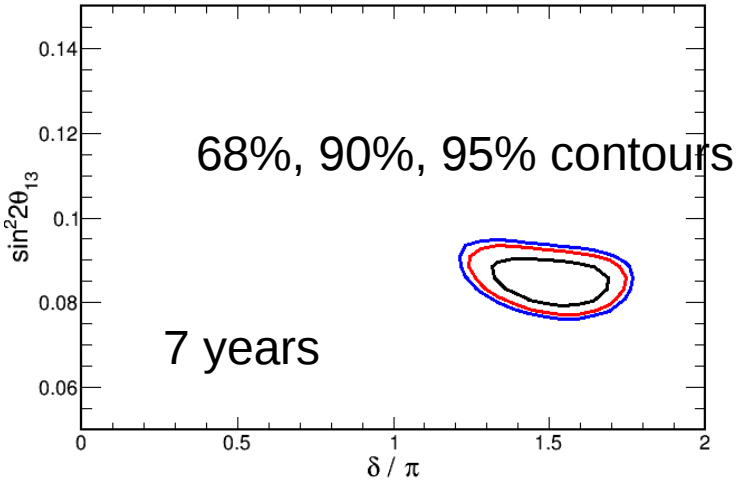
True



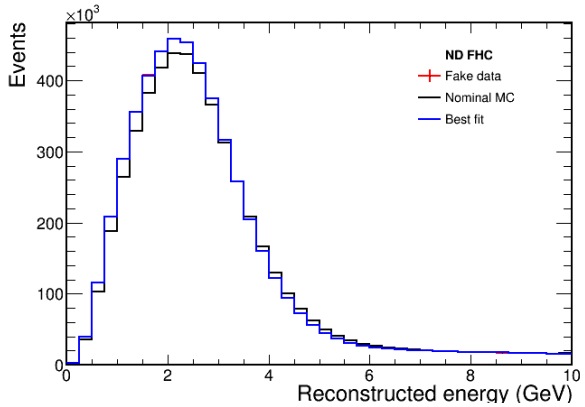
Varied

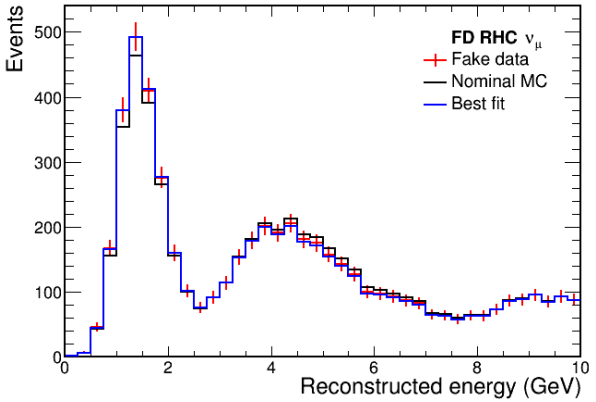


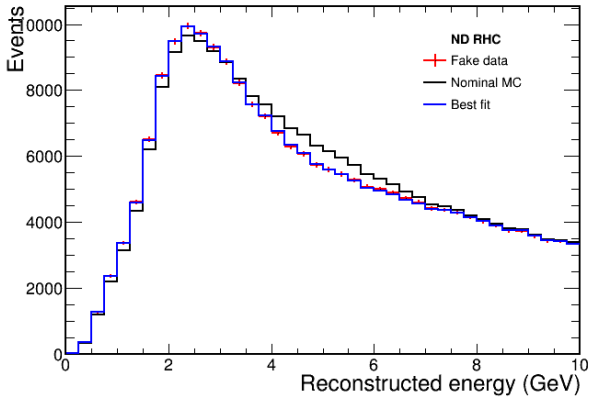


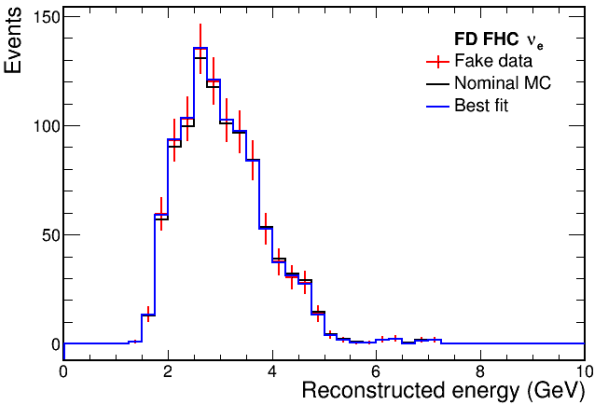


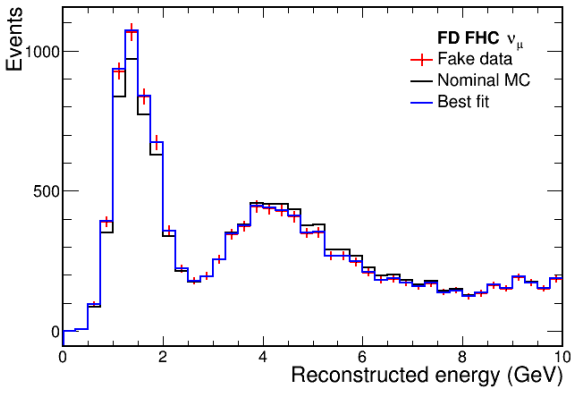
FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

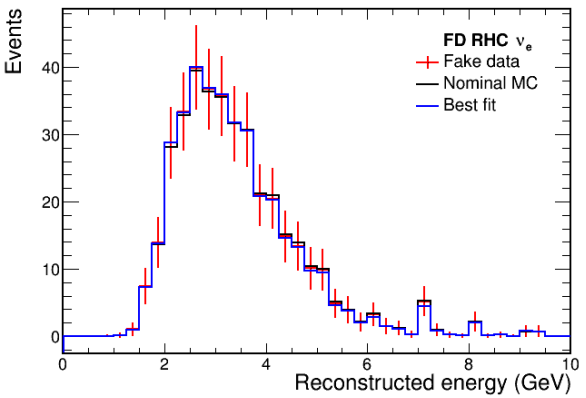










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Syst. shift  nu_ccqe_3_scale -3.58878e-06
Syst. shift  nubar_ccqe_1_scale 0.000131666
Syst. shift  nubar_ccqe_2_scale 3.78016e-05
Syst. shift  nubar_ccqe_3_scale -4.14354e-07
Syst. shift  nu_MEC_dummy_scale 4.97337e-09
Syst. shift  nubar_MEC_dummy_scale 7.19831e-09
Syst. shift  nu_cc1piz_1_scale 5.45695e-05
Syst. shift  nu_cc1piz_2_scale 0.000136222
Syst. shift  nu_cc1piz_3_scale -0.000106172
Syst. shift  nu_cc1pic_1_scale 3.77664e-05
Syst. shift  nu_cc1pic_2_scale -4.14056e-05
Syst. shift  nu_cc1pic_3_scale 8.32438e-05
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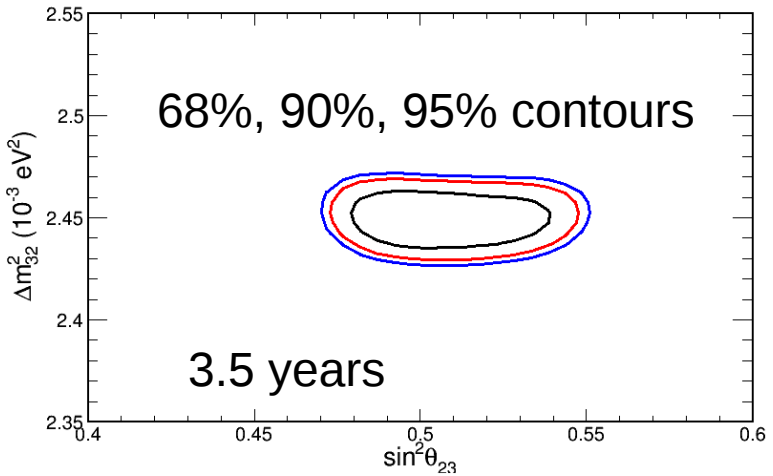
Syst. shift  nubar_cc1piz_2_scale -0.000192205
Syst. shift  nubar_cc1piz_3_scale 9.49229e-05
Syst. shift  nubar_cc1pic_1_scale -3.02543e-05
Syst. shift  nubar_cc1pic_2_scale 1.94044e-05
Syst. shift  nubar_cc1pic_3_scale -2.71946e-05
Syst. shift  nu_2pi_scale -0.386632
Syst. shift  nubar_2pi_scale -0.0580296
Syst. shift  nu_dis_1_scale -0.000164997
Syst. shift  nu_dis_2_scale -0.000523547
Syst. shift  nu_dis_3_scale 0.000617139
Syst. shift  nubar_dis_1_scale -8.56833e-05
Syst. shift  nubar_dis_2_scale -0.00180673
Syst. shift  nubar_dis_3_scale 0.00116626
Syst. shift  nu_coh_scale 4.98075e-05
Syst. shift  nubar_coh_scale -4.98217e-05
Syst. shift  nu_nc_scale 0.00132463
Syst. shift  nubar_nc_scale -0.00119135
Syst. shift  flux10 0.318903
Syst. shift  flux13 0.399117
Syst. shift  flux15 -1.38272
Syst. shift  flux16 0.128438
Syst. shift  flux17 -0.283199
Syst. shift  flux18 0.877064
Syst. shift  flux19 -1.33922
Syst. shift  eScale -0.061219
Syst. shift  eRes -0.0385796
True dCP 0pi, best fit -0.413147pi, chi2 25.4375 delta=0 chi2 25.4238
```

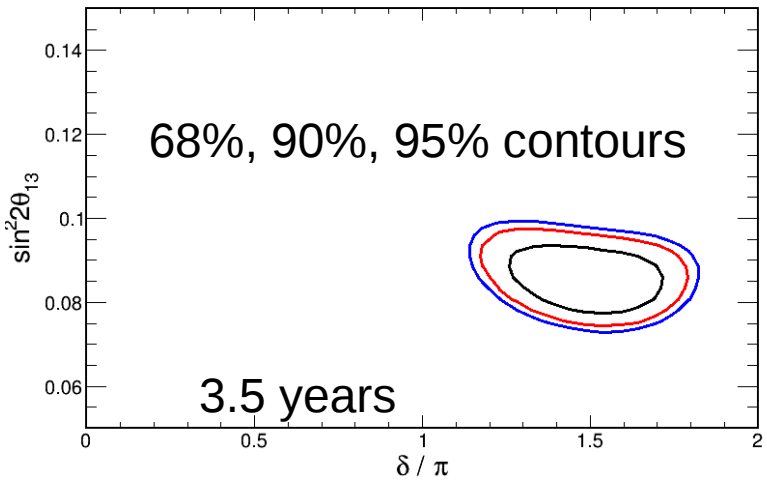
Missing proton

Missing muon

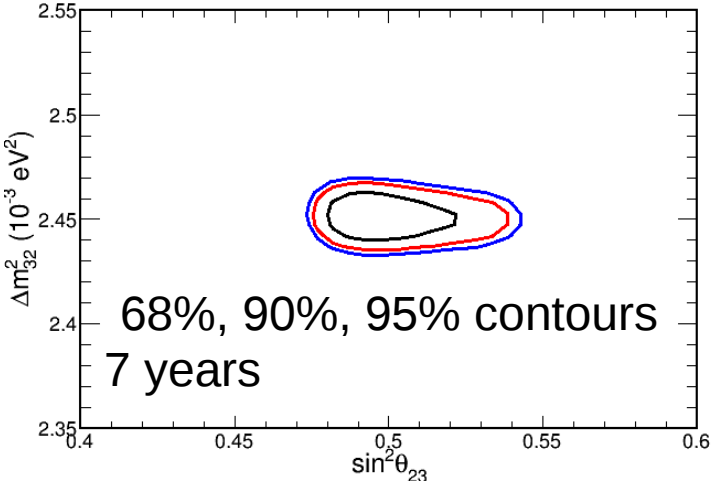
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

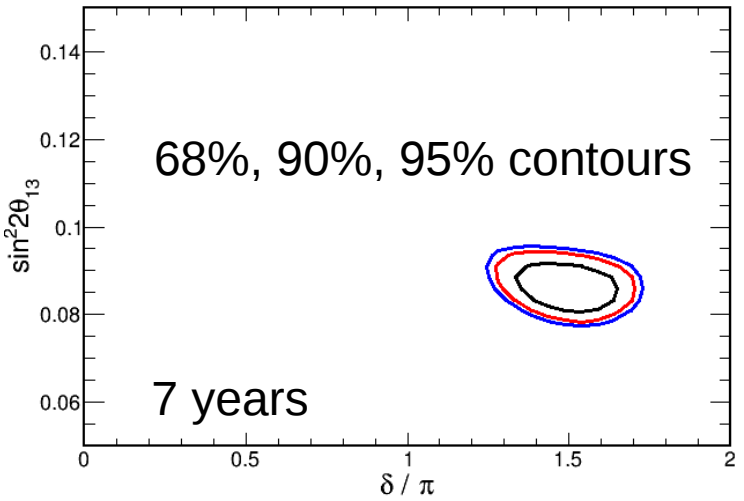
True



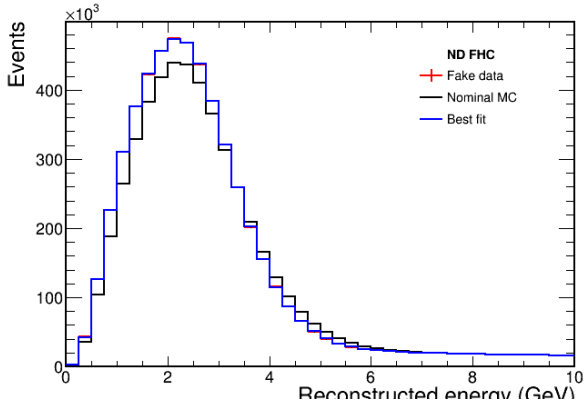


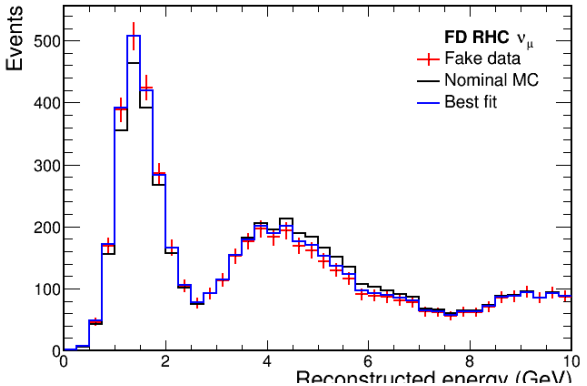
Varied

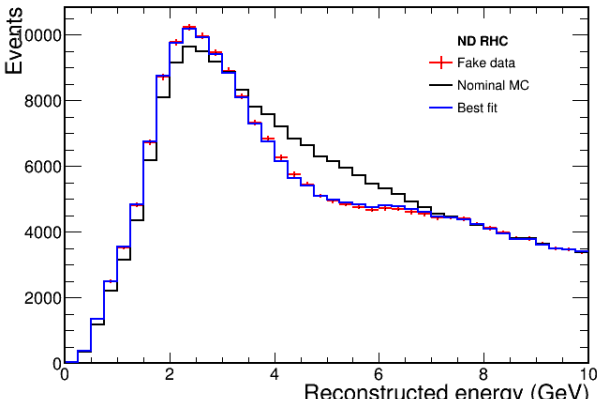


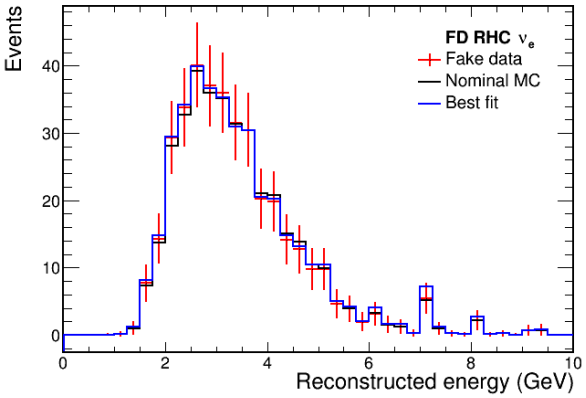


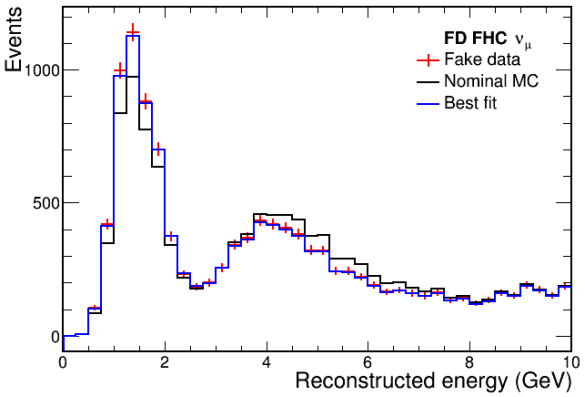
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

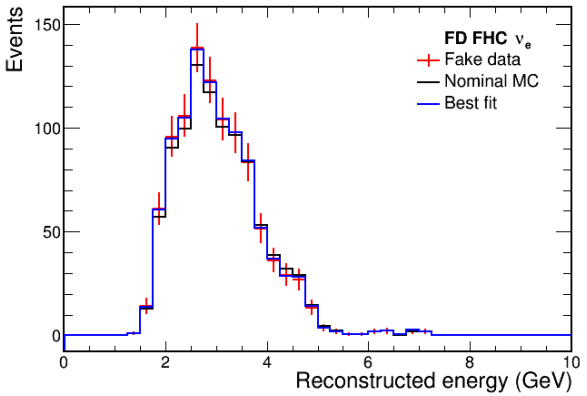













```
Syst. shift  nu_ccqe_1_scale 0.000168133
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Syst. shift  nu_ccqe_3_scale 7.33046e-06
Syst. shift  nubar_ccqe_1_scale -0.00028082
Syst. shift  nubar_ccqe_2_scale -8.07185e-05
Syst. shift  nubar_ccqe_3_scale 1.96024e-06
Syst. shift  nu_MEC_dummy_scale -4.75599e-08
Syst. shift  nubar_MEC_dummy_scale -5.57413e-08
Syst. shift  nu_cc1piz_1_scale -0.000116722
Syst. shift  nu_cc1piz_2_scale -0.000292893
Syst. shift  nu_cc1piz_3_scale 0.000228131
Syst. shift  nu_cc1pic_1_scale -7.9647e-05
Syst. shift  nu_cc1pic_2_scale 8.76261e-05
Syst. shift  nu_cc1pic_3_scale -0.000175778
Syst. shift  nubar_cc1piz_1_scale 0.000470988
Syst. shift  nubar_cc1piz_2_scale 0.000413953
Syst. shift  nubar_cc1piz_3_scale -0.000204001
Syst. shift  nubar_cc1pic_1_scale 6.42623e-05
Syst. shift  nubar_cc1pic_2_scale -4.08494e-05
Syst. shift  nubar_cc1pic_3_scale 5.71839e-05
Syst. shift  nu_2pi_scale 0.835203
Syst. shift  nubar_2pi_scale 0.134233
Syst. shift  nu_dis_1_scale 0.00036692
Syst. shift  nu_dis_2_scale 0.00111347
Syst. shift  nu_dis_3_scale -0.00133111
Syst. shift  nubar_dis_1_scale 0.000226423
Syst. shift  nubar_dis_2_scale 0.0038512
Syst. shift  nubar_dis_3_scale -0.00247315
Syst. shift  nu_coh_scale -0.000106948
Syst. shift  nubar_coh_scale 0.000107019
Syst. shift  nu_nc_scale -0.0033117
Syst. shift  nubar_nc_scale 0.00271464
Syst. shift  flux10 -0.221647
Syst. shift  flux12 2.33061
Syst. shift  flux15 3.11332
Syst. shift  flux16 -0.433924
Syst. shift  flux17 0.720915
Syst. shift  flux18 -2.11917
Syst. shift  flux19 3.11014
Syst. shift  eScale 0.0653441
Syst. shift  eRes 0.0644769
True dCP 0pi, best fit -0.708018pi, chi2 132.304 delta=0 chi2 158.739
```

Missing proton
Missing pion

Summary

- Without “other missing energy” dials, missing pion and muon energy cause biases in FD while looks good in ND.

- With “other missing energy” dials, no significant biases can be seen. Only missing muon energy gives slight bias.

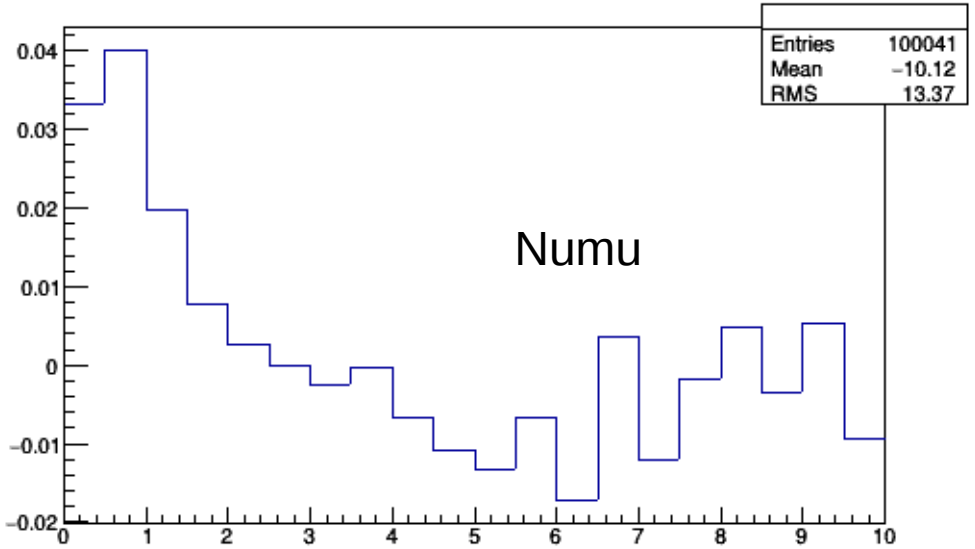
From before

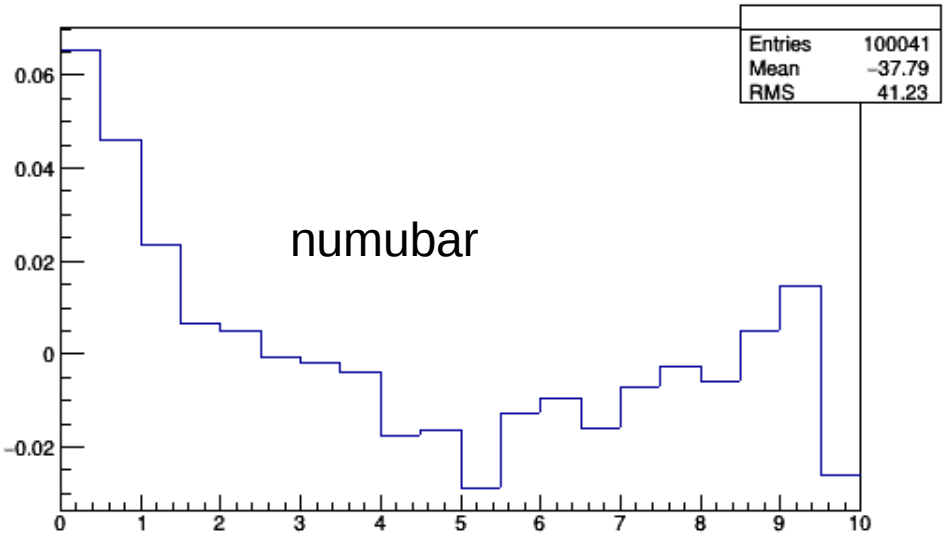
1. Systematics validation:
- With Luke's 20% ME variation: With the same systematic involved
→ recovered

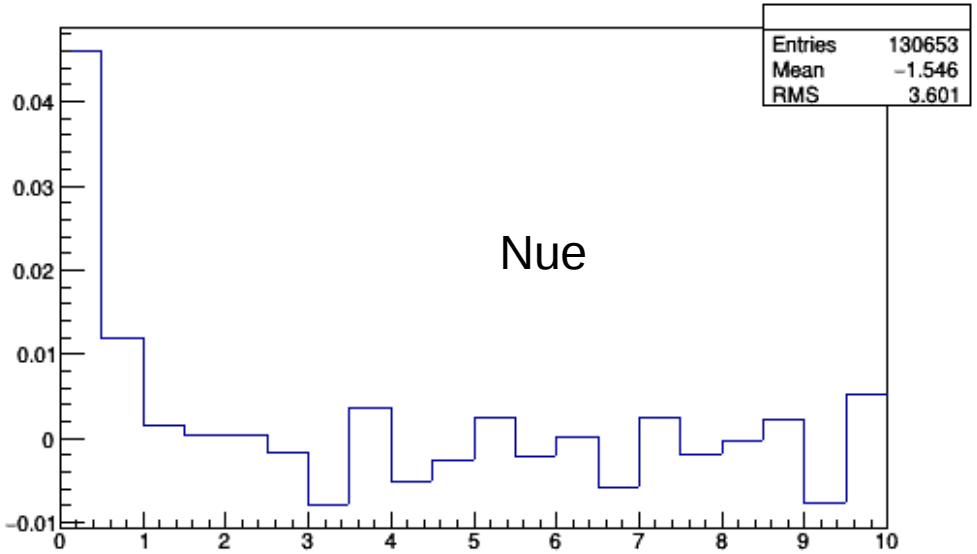
2. Fake data study
- With Luke's 20% ME variation, we only have Xsec systematics (32)
→ not recovered
- With Luke's 20% ME variation, we have Xsec + flux systematics (32+10)
→ not recovered

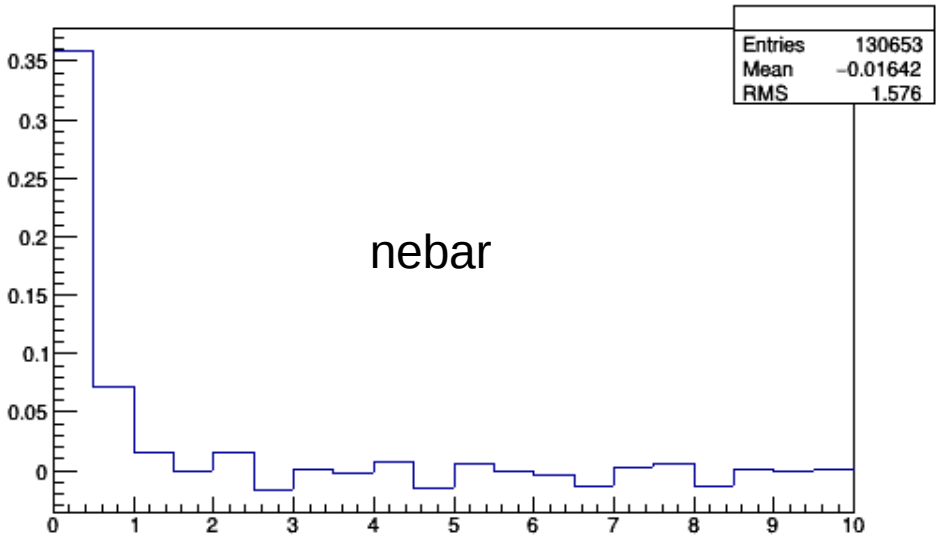
3. Fake data study
- With Nuwro/Genie variation, we only have Xsec systematics (32)
- With Nuwro/Genie variation, we have Xsec + flux systematics (32 + 10)
→ both can largely recover

20% missing proton energy

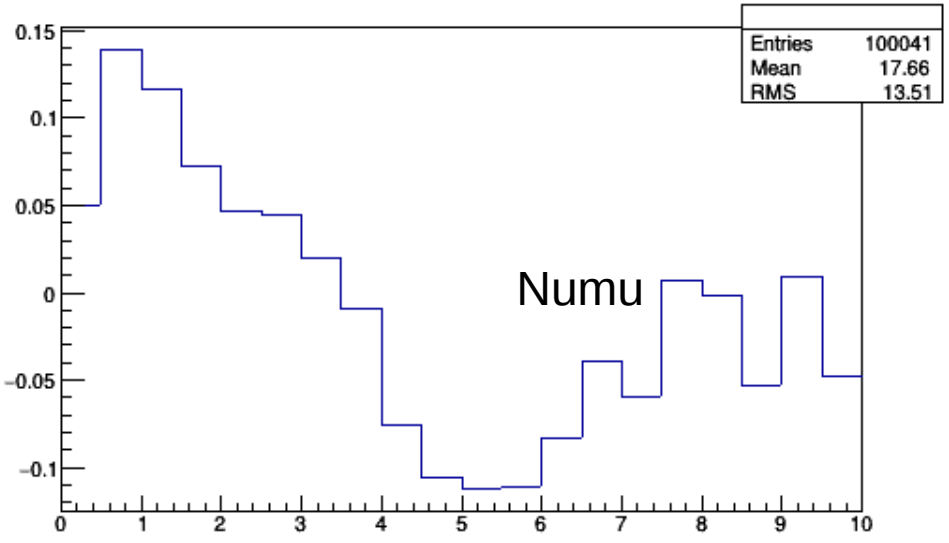


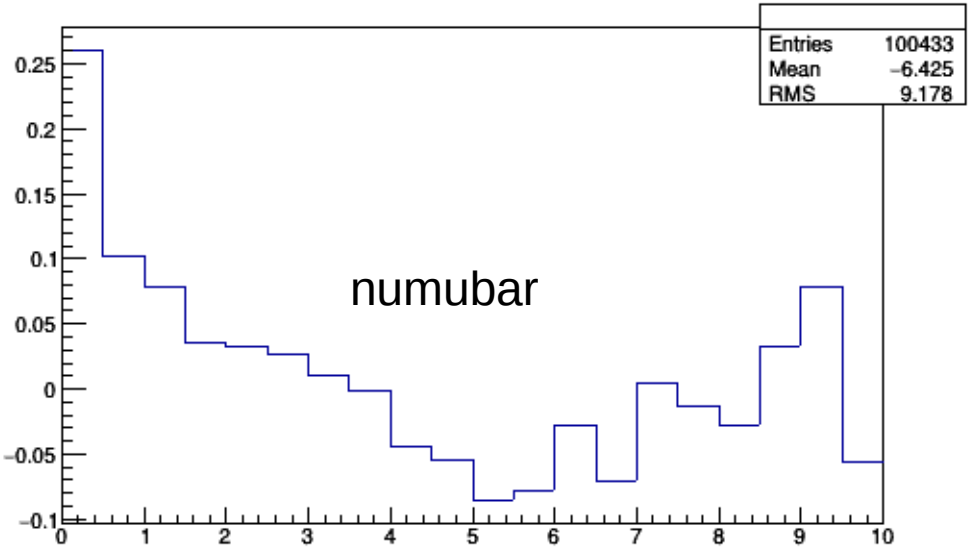


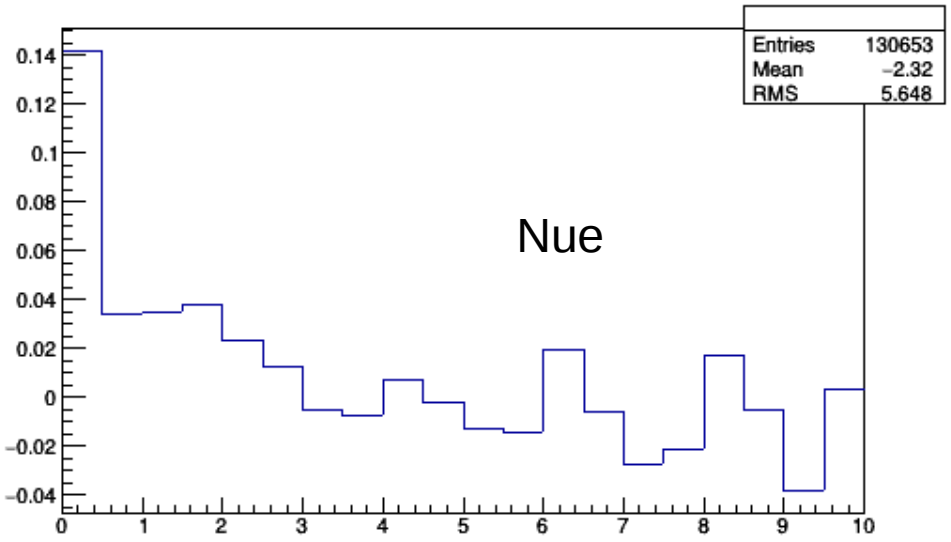


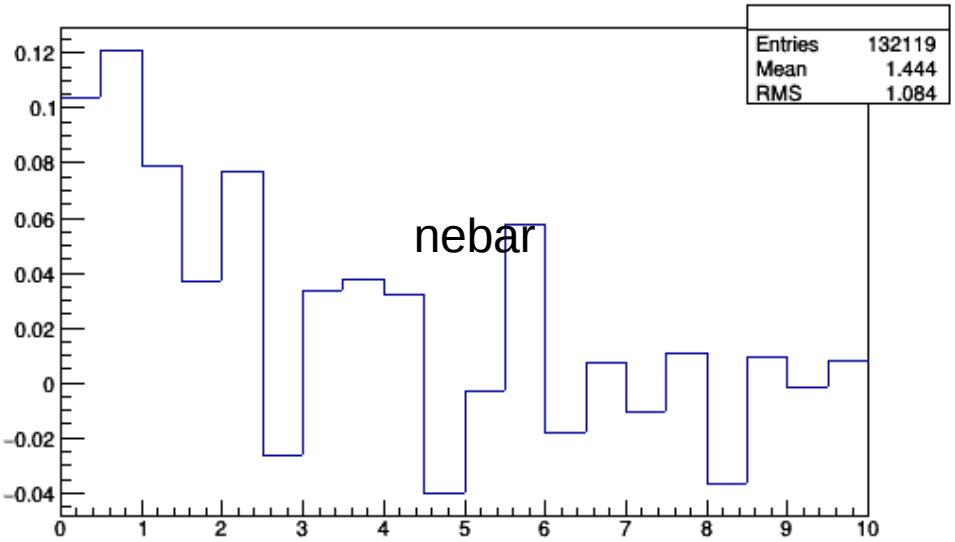


20% missing pion energy

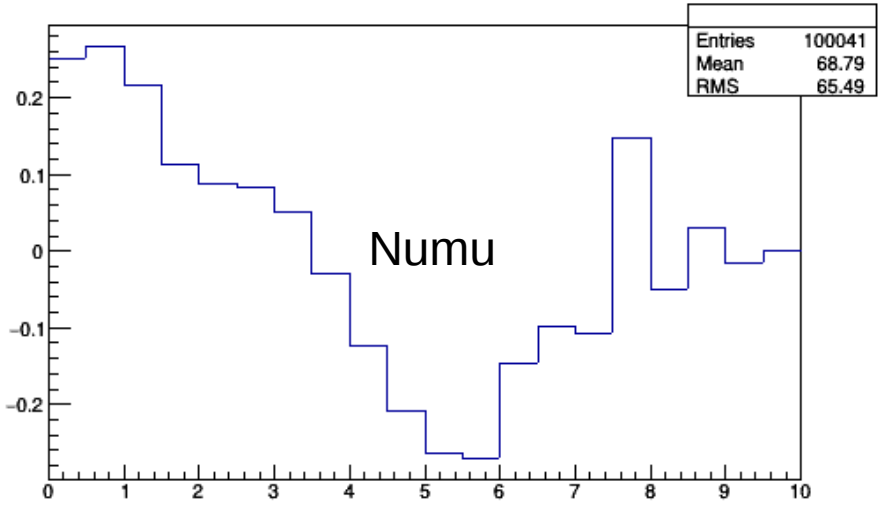


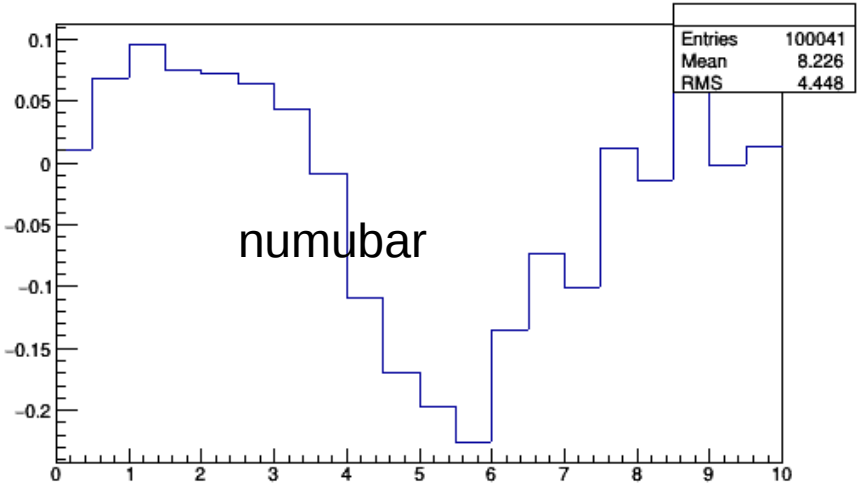


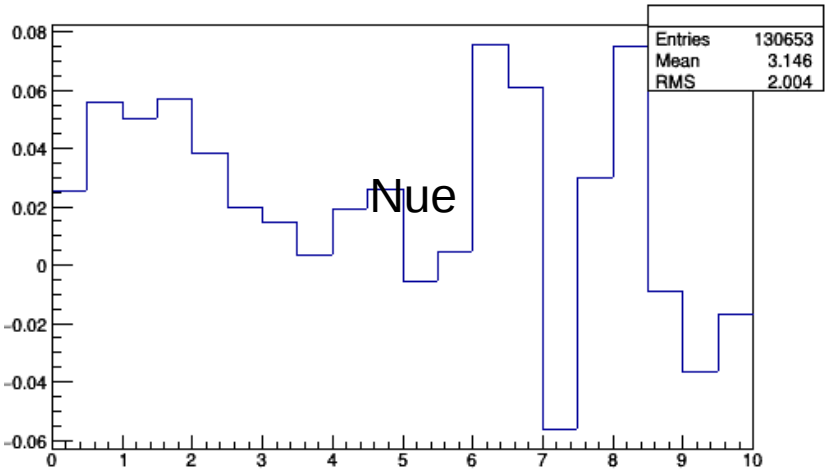


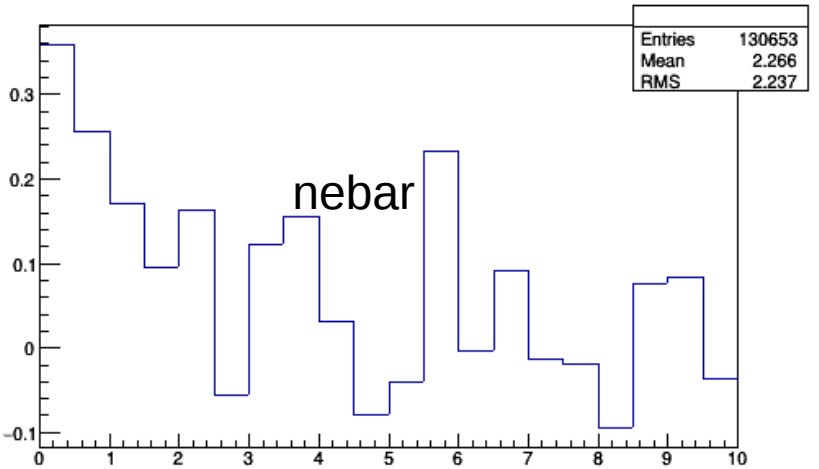


10% missing muon energy

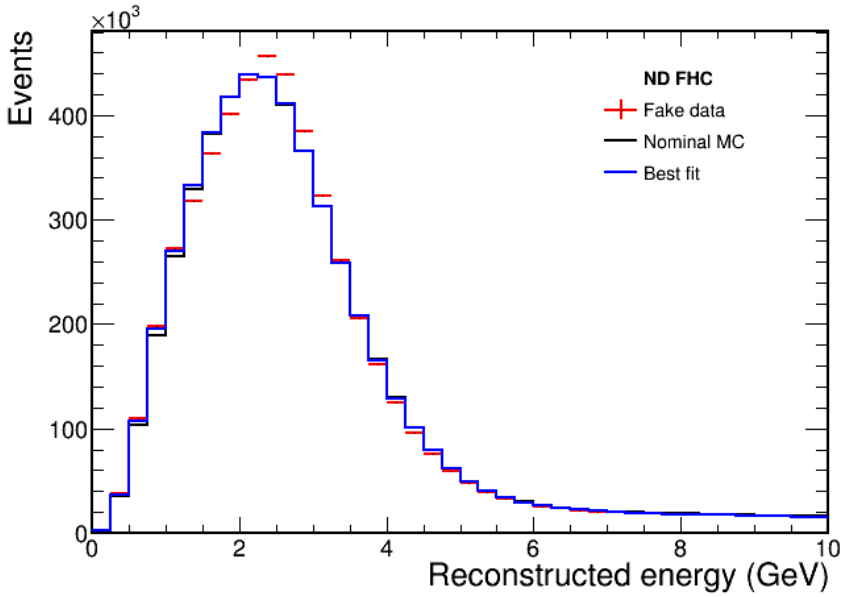


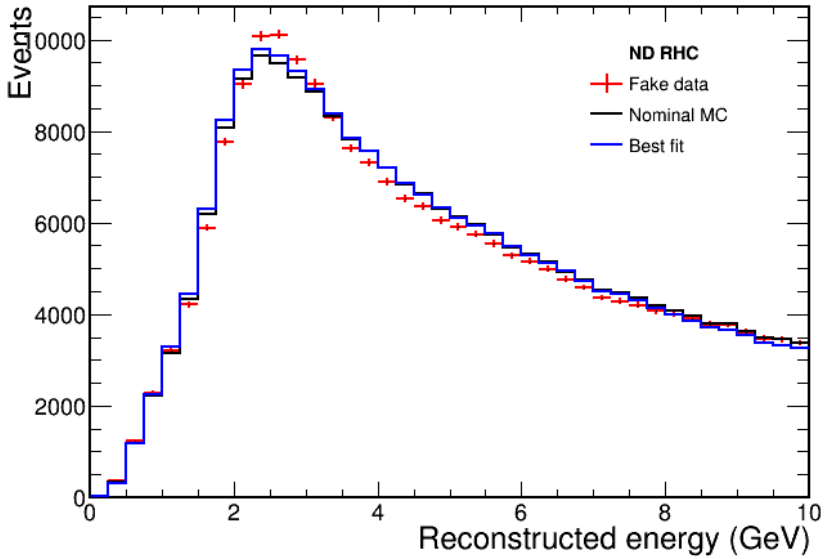






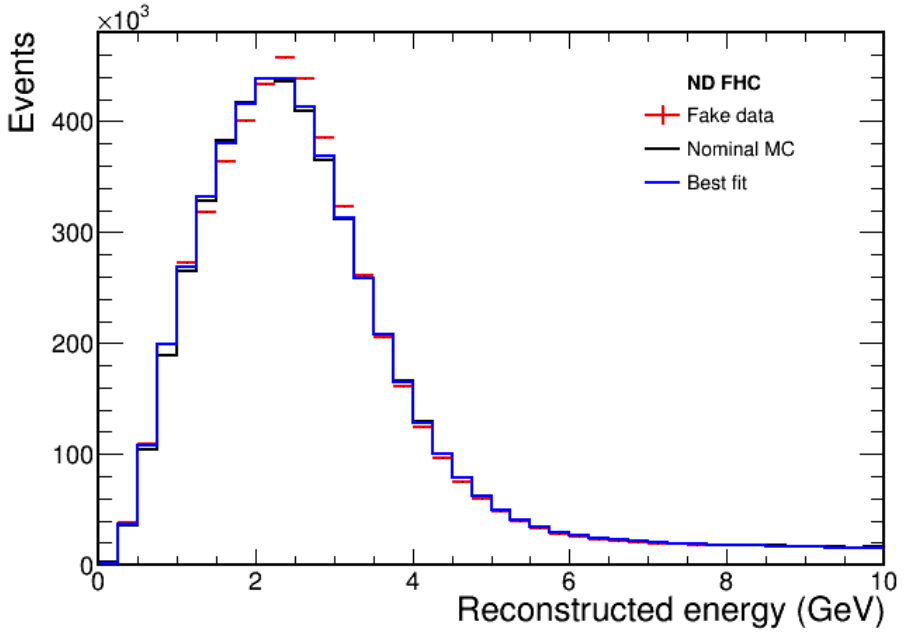
ND can see the problem. The Xsec + flux uncertainties are not enough for ND prediction to shift.
I add E-scale shifts (E-scale, resolution), then
If I just do ND fit (7 years) ..

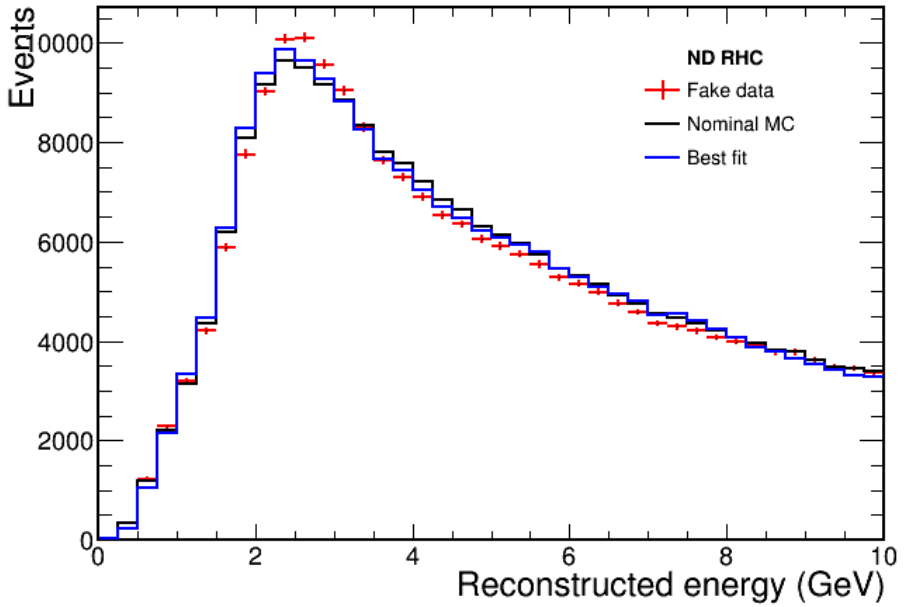





```
Syst. shift  nu_ccqe_1_scale -0.000215038
Syst. shift  nu_ccqe_2_scale -0.000117227
Syst. shift  nu_ccqe_3_scale -6.86019e-06
Syst. shift  nubar_ccqe_1_scale 0.000331283
Syst. shift  nubar_ccqe_2_scale 0.000115944
Syst. shift  nubar_ccqe_3_scale -9.75802e-06
Syst. shift  nu_MEC_dummy_scale 7.26251e-10
Syst. shift  nubar_MEC_dummy_scale 2.52921e-10
Syst. shift  nu_cc1piz_1_scale 0.00019385
Syst. shift  nu_cc1piz_2_scale 0.000416345
Syst. shift  nu_cc1piz_3_scale -0.00033349
Syst. shift  nu_cc1pic_1_scale 0.000101468
Syst. shift  nu_cc1pic_2_scale -0.000122697
Syst. shift  nu_cc1pic_3_scale 0.000300924
Syst. shift  nubar_cc1piz_1_scale -0.00070304
Syst. shift  nubar_cc1piz_2_scale -0.000602923
Syst. shift  nubar_cc1piz_3_scale 0.000300557
Syst. shift  nubar_cc1pic_1_scale -8.87063e-05
Syst. shift  nubar_cc1pic_2_scale 6.26232e-05
Syst. shift  nubar_cc1pic_3_scale -0.000101141
Syst. shift  nu_2pi_scale -1.18652
Syst. shift  nubar_2pi_scale -0.185608
Syst. shift  nu_dis_1_scale -0.000558347
Syst. shift  nu_dis_2_scale -0.00153882
Syst. shift  nu_dis_3_scale 0.00182059
Syst. shift  nubar_dis_1_scale 0.00015427
Syst. shift  nubar_dis_2_scale -0.00555103
Syst. shift  nubar_dis_3_scale 0.00356682
Syst. shift  nu_coh_scale 0.000155618
Syst. shift  nubar_coh_scale -0.000154922
Syst. shift  nu_nc_scale -0.00130729
Syst. shift  nubar_nc_scale -0.00379911
Syst. shift  flux13 2.02569
Syst. shift  flux14 -2.21609
Syst. shift  flux15 2.34529
Syst. shift  eScale 0.397312
Syst. shift  eRes -0.302201
True dCP 0pi, best fit 0pi, chi2 8174.92 delta=0 chi2 8174.92
```

If enlarge Xsec and E-scale systematics by a factor of 10..



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Syst. shift  nu_ccqe_3_scale -8.35739e-07
Syst. shift  nubar_ccqe_1_scale 5.00405e-05
Syst. shift  nubar_ccqe_2_scale 1.94822e-05
Syst. shift  nubar_ccqe_3_scale -2.21331e-06
Syst. shift  nu_MEC_dummy_scale -1.56728e-08
Syst. shift  nubar_MEC_dummy_scale -9.1404e-09
Syst. shift  nu_cc1piz_1_scale 3.4759e-05
Syst. shift  nu_cc1piz_2_scale 6.92779e-05
Syst. shift  nu_cc1piz_3_scale -5.62782e-05
Syst. shift  nu_cc1pic_1_scale 1.60893e-05
Syst. shift  nu_cc1pic_2_scale -2.033e-05
Syst. shift  nu_cc1pic_3_scale 5.34236e-05
Syst. shift  nubar_cc1piz_1_scale -0.000119783
Syst. shift  nubar_cc1piz_2_scale -0.000101613
Syst. shift  nubar_cc1piz_3_scale 5.09205e-05
Syst. shift  nubar_cc1pic_1_scale -1.47808e-05
Syst. shift  nubar_cc1pic_2_scale 1.09238e-05
Syst. shift  nubar_cc1pic_3_scale -1.85121e-05
Syst. shift  nu_2pi_scale -0.197651
Syst. shift  nubar_2pi_scale -0.0302787
Syst. shift  nu_dis_1_scale -9.928e-05
Syst. shift  nu_dis_2_scale -0.000261332
Syst. shift  nu_dis_3_scale 0.000297532
Syst. shift  nubar_dis_1_scale 6.28181e-05
Syst. shift  nubar_dis_2_scale -0.000928769
Syst. shift  nubar_dis_3_scale 0.000593476
Syst. shift  nu_coh_scale 2.61883e-05
Syst. shift  nubar_coh_scale -2.60259e-05
Syst. shift  nu_nc_scale -0.000682381
Syst. shift  nubar_nc_scale -0.000615575
Syst. shift  flux13 2.51891
Syst. shift  flux14 -2.77985
Syst. shift  flux15 2.9307
Syst. shift  eScale 0.0565777
Syst. shift  eRes -0.35228
```
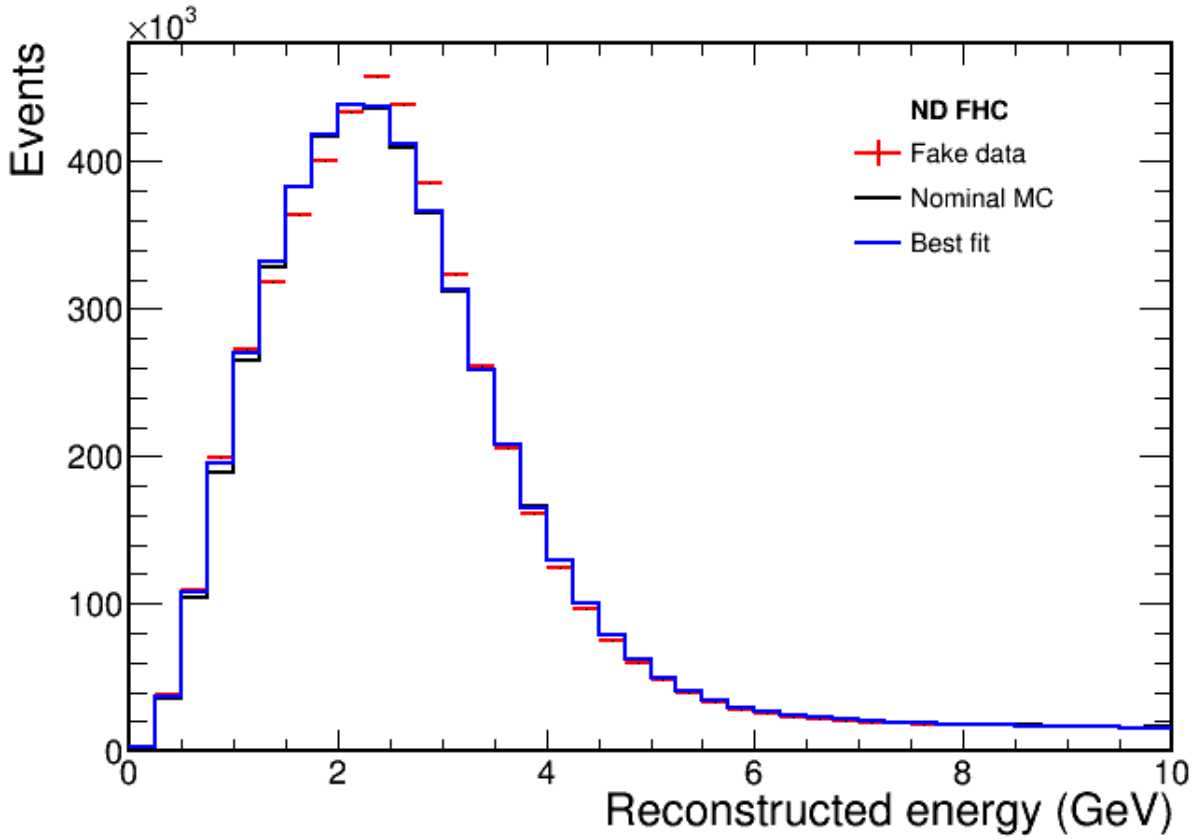

If enlarge Xsec and E-scale systematics by a factor of 10 and only shift FHC..



Systematics output table is similar to what you have seen before..

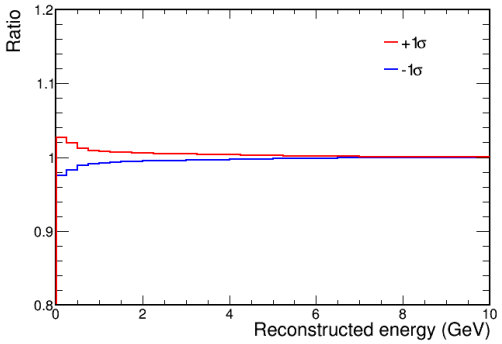
The problem

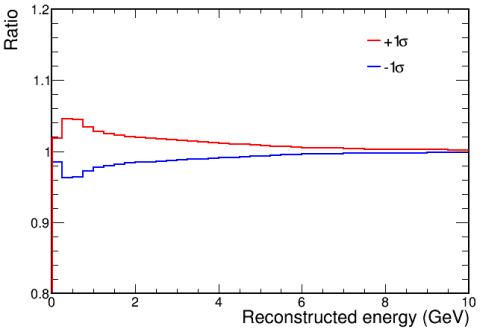
- ND does not like to move. Current Xsec, flux and E-scale cannot recover the 20% missing PE in ND.

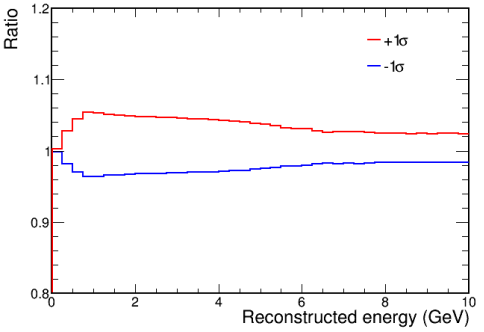
- I need realistic antinu shift. Now I am using nu for antinu.

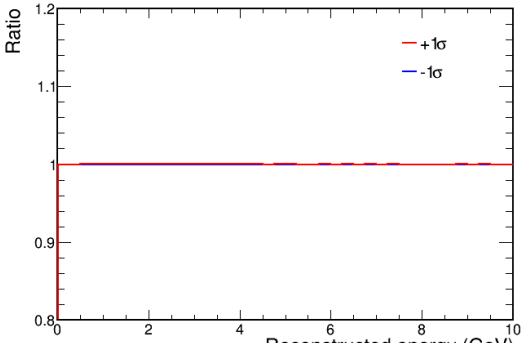
- I am trying to run GENIE to get some fake data..

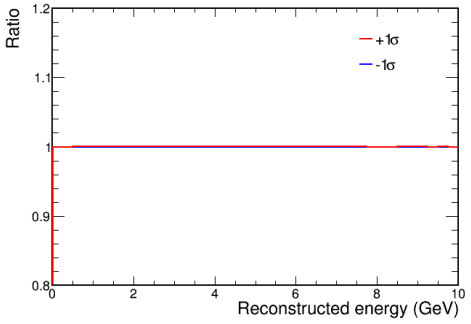
Xsec ND FHC

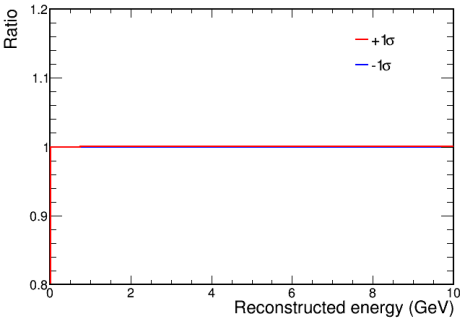

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

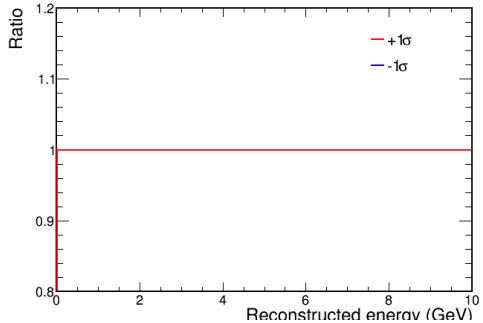

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

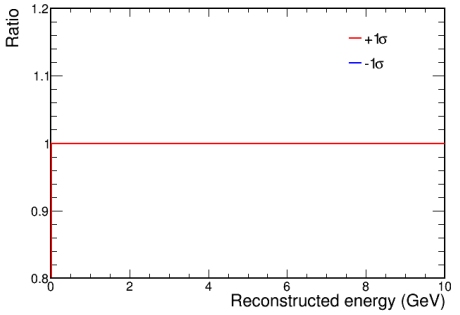

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

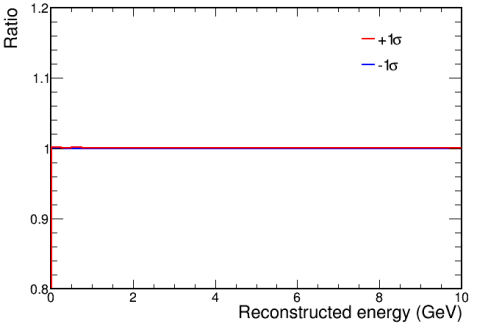

Ratio
+1σ
-1σ

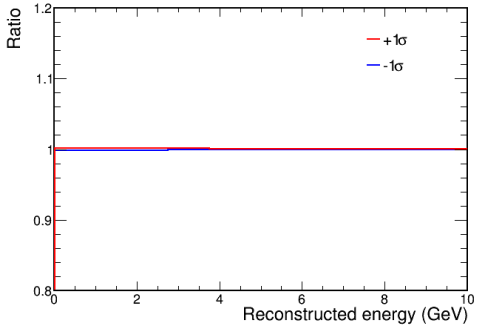

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

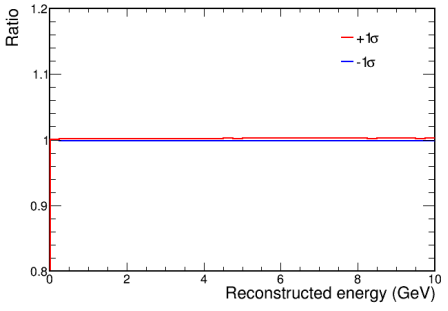

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

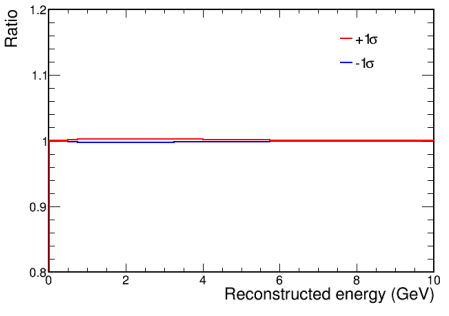

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

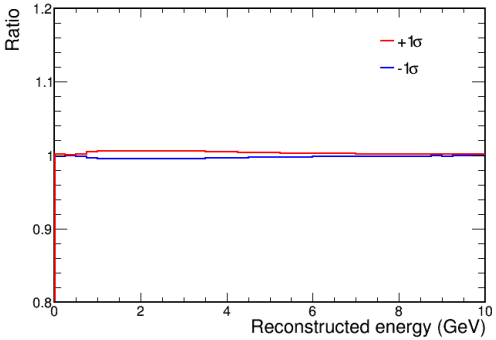

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

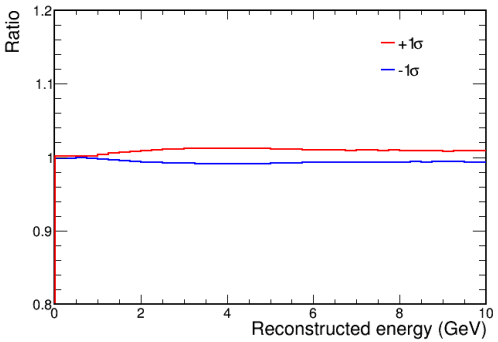

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

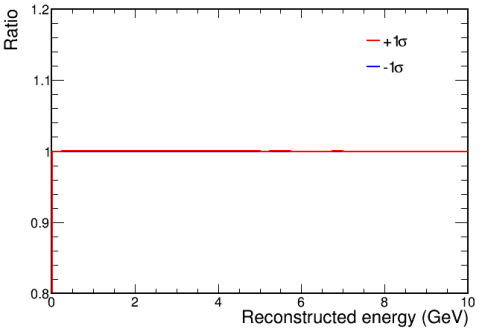

Ratio
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
+1σ
-1σ
Reconstructed energy (GeV)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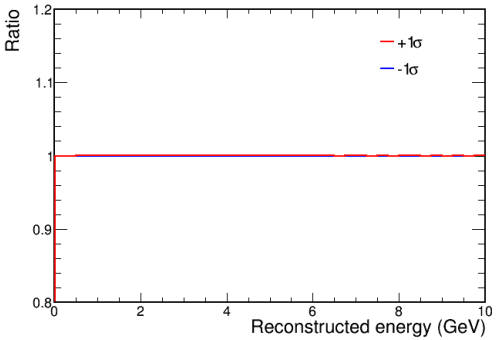
Reconstructed energy (GeV)


Ratio
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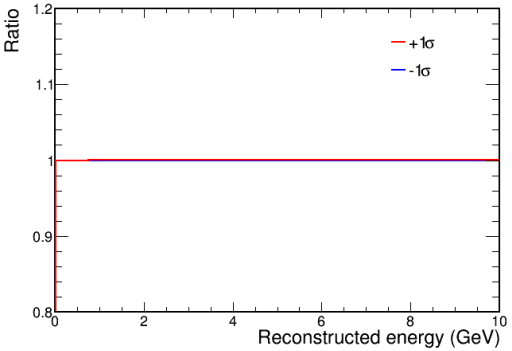
Reconstructed energy (GeV)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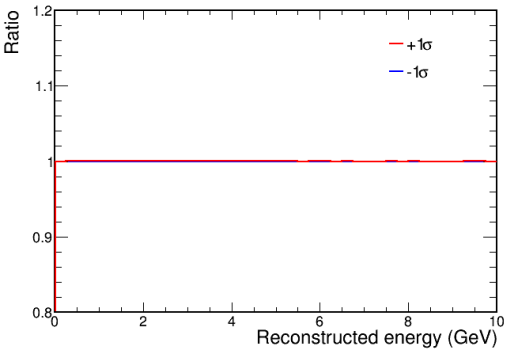
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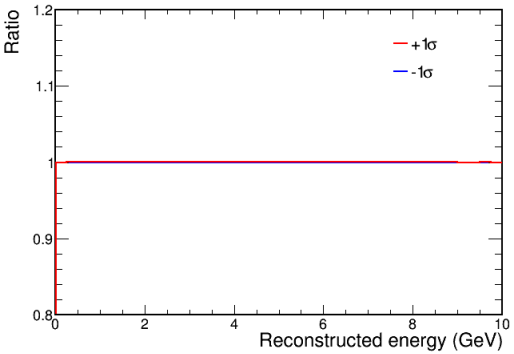
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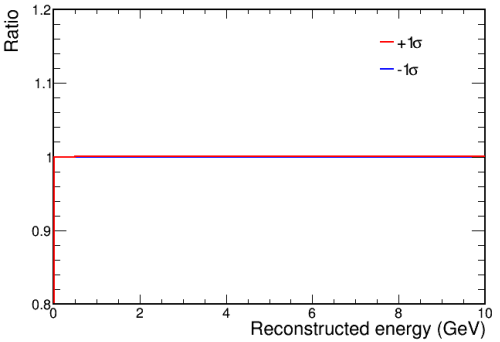
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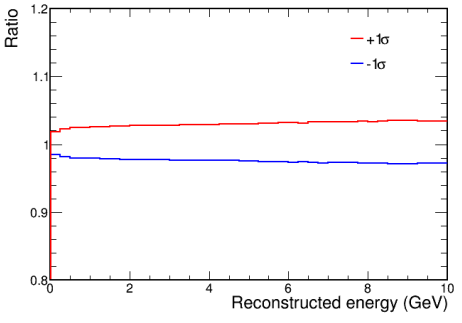
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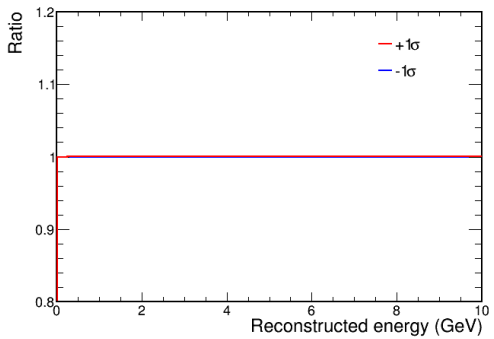
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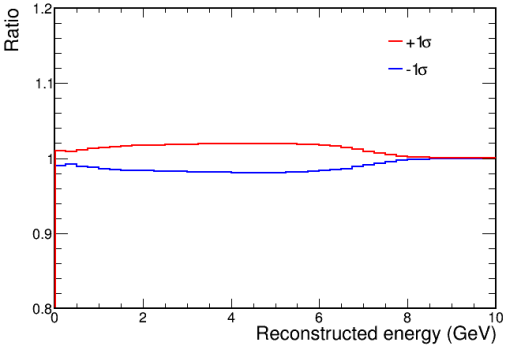
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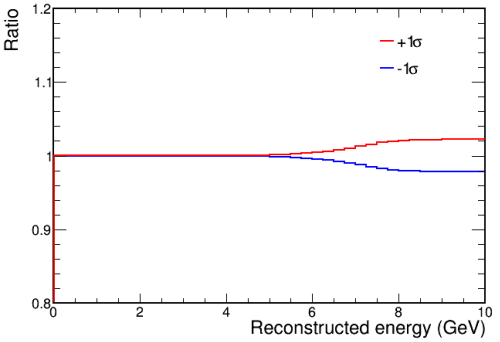
Reconstructed energy (GeV)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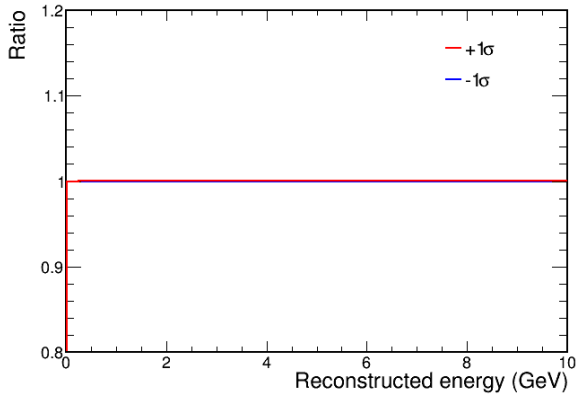
Reconstructed energy (GeV)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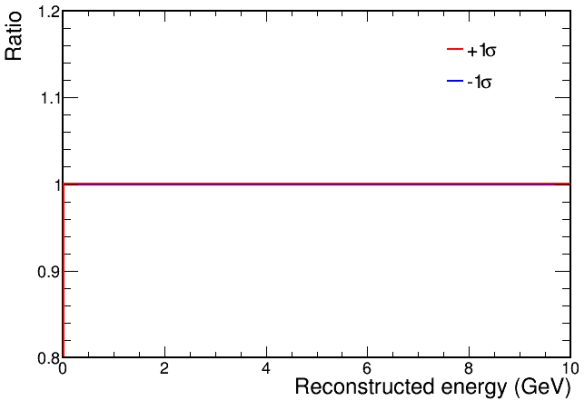
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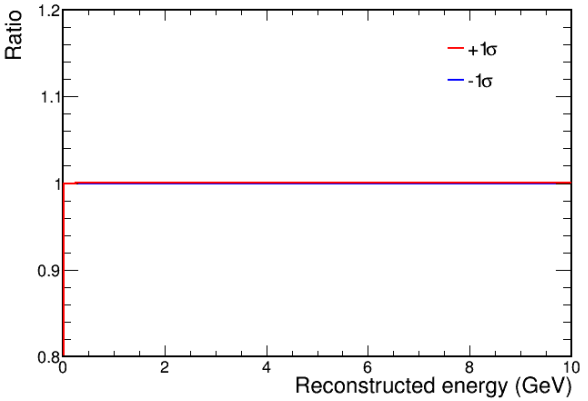
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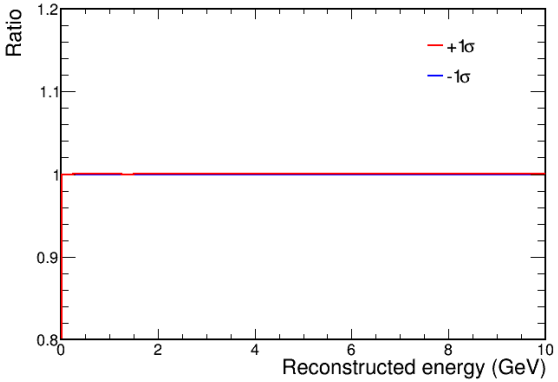
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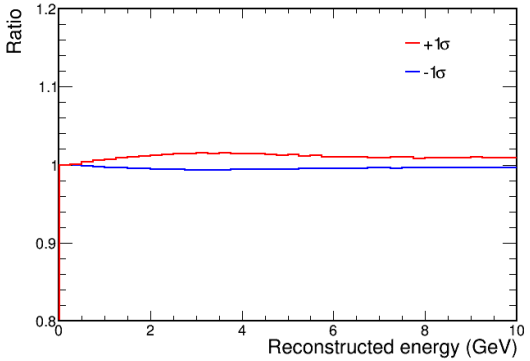
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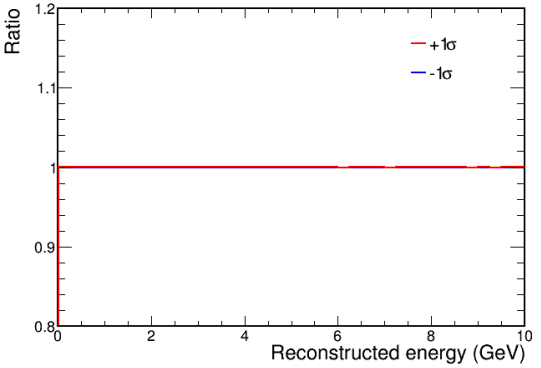
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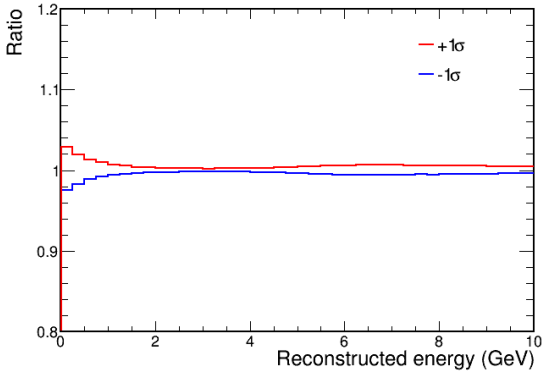
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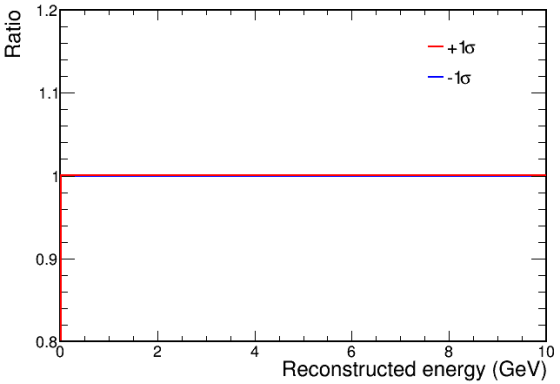
Ratio
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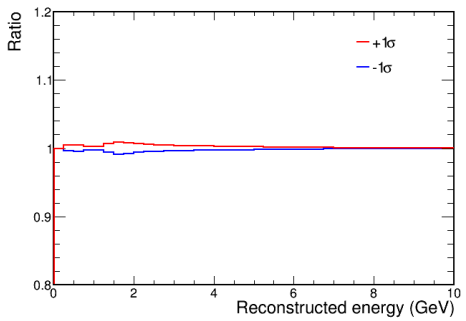
Reconstructed energy (GeV)

Xsec ND RHC


Ratio
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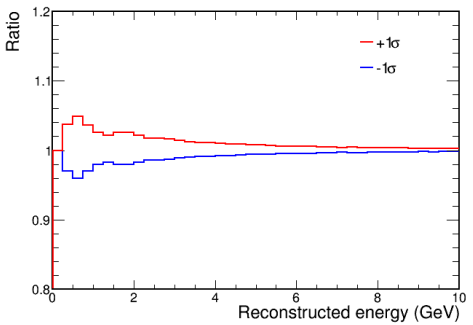
Reconstructed energy (GeV)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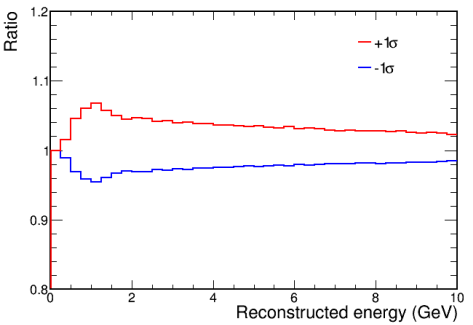
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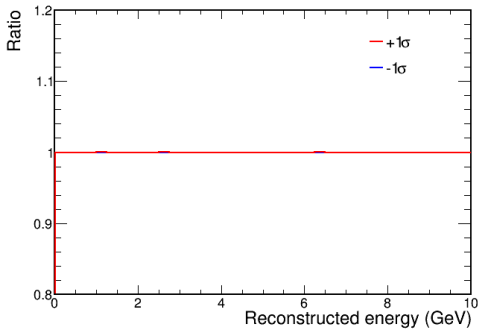
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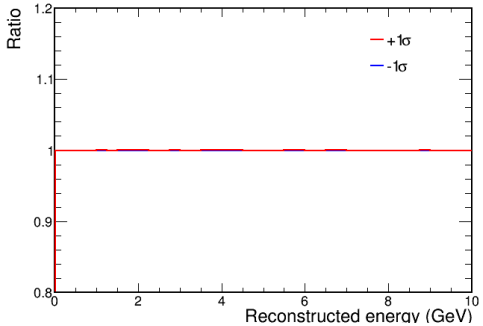
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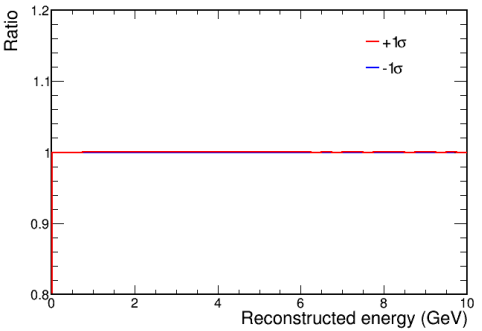
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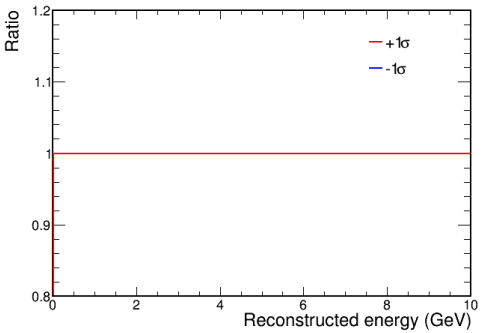
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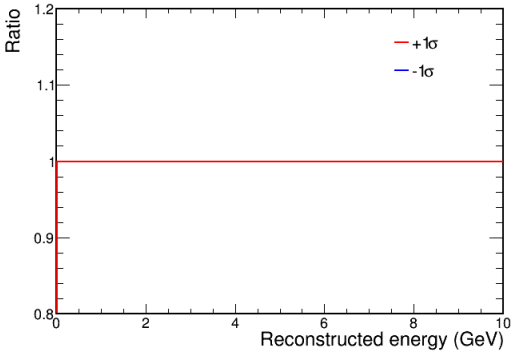
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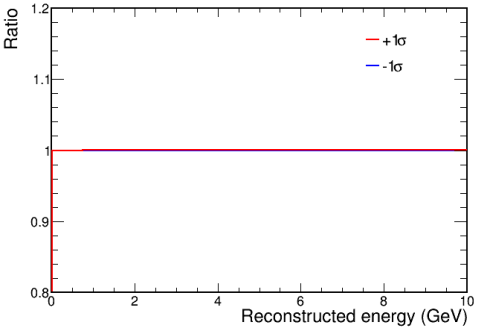
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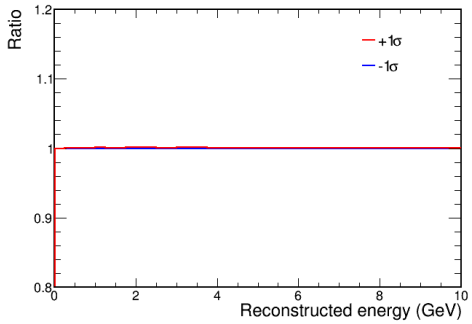
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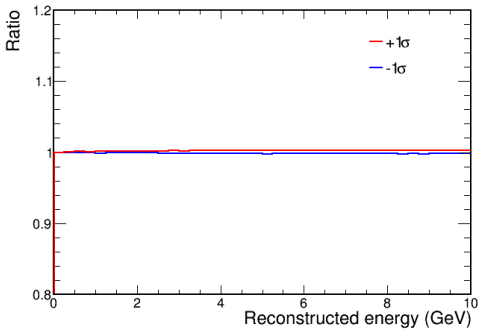
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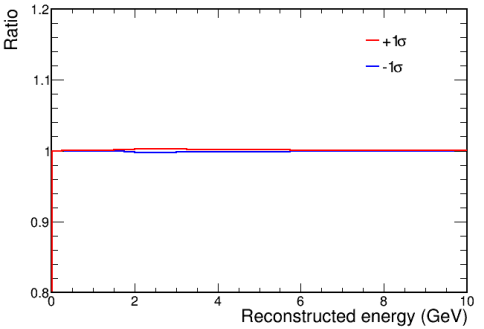
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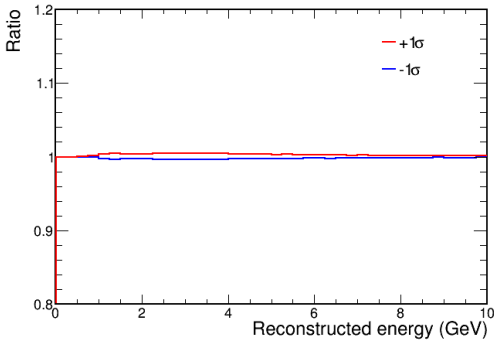
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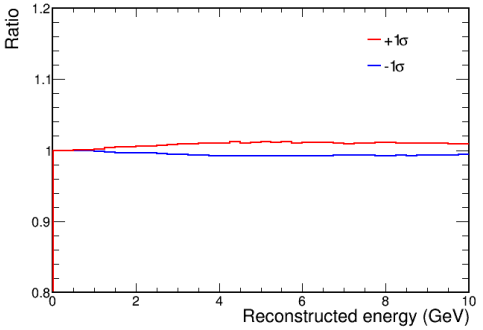
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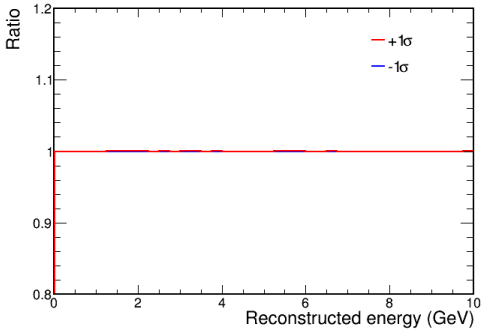
Ratio
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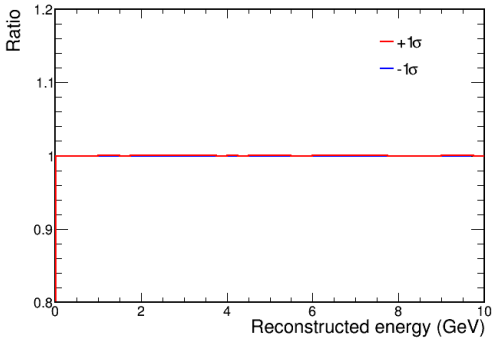
Reconstructed energy (GeV)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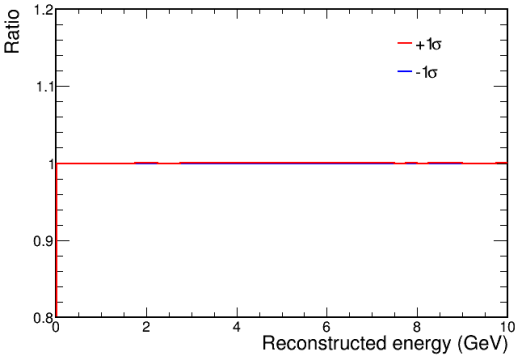
Reconstructed energy (GeV)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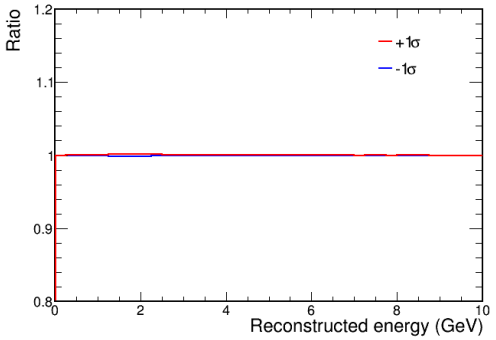
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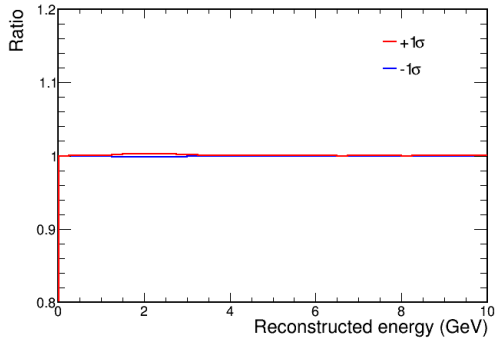
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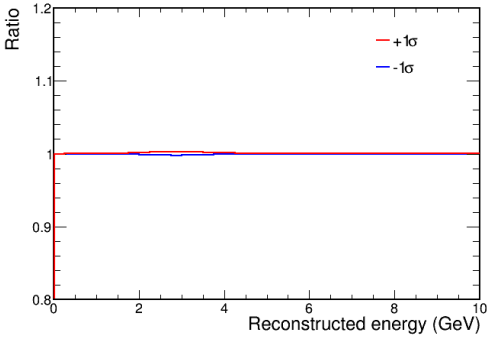
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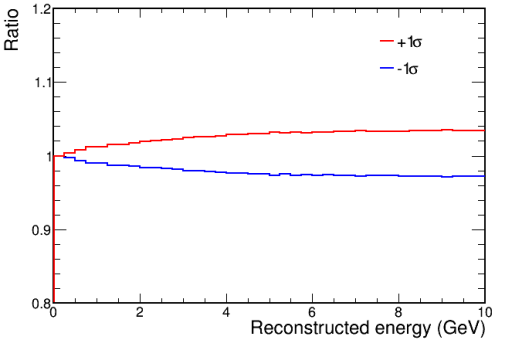
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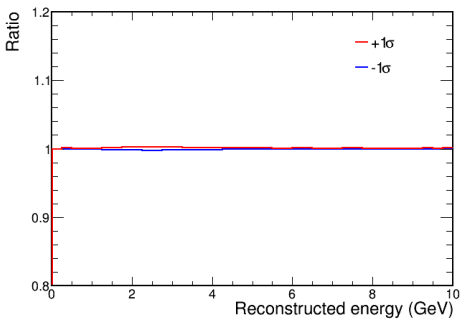
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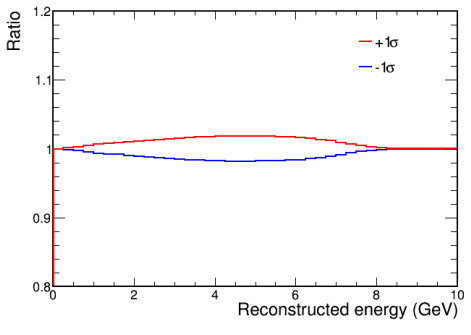
Ratio
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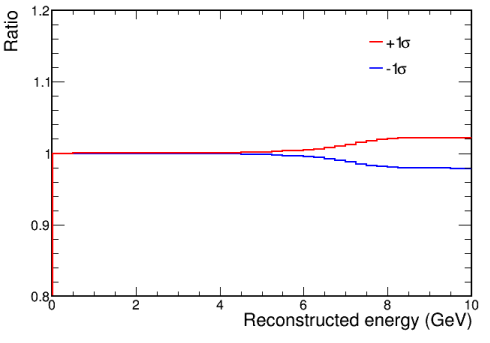
Ratio
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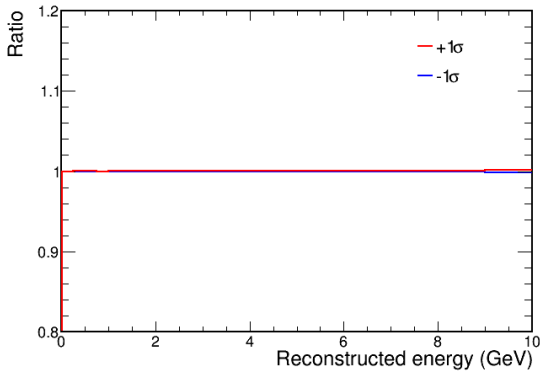
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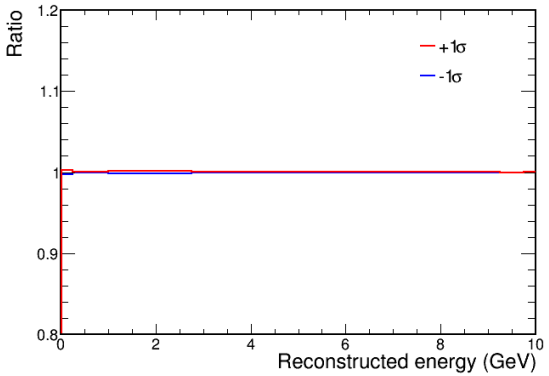
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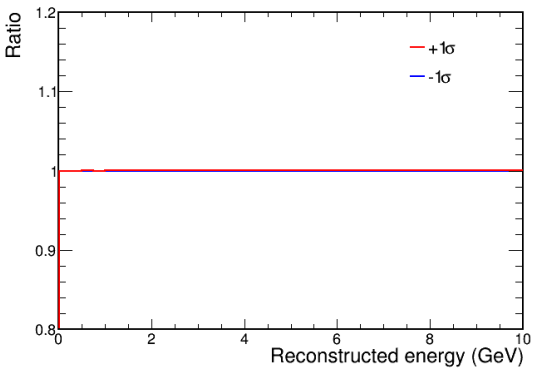
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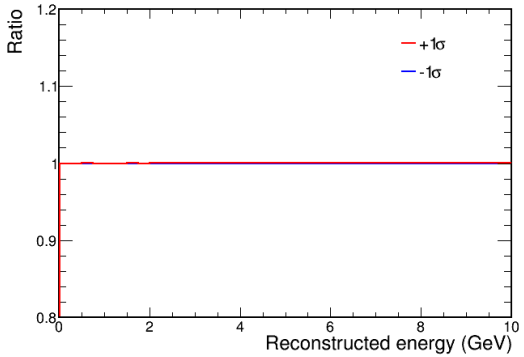
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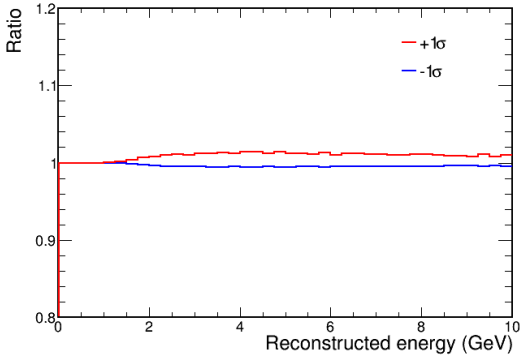
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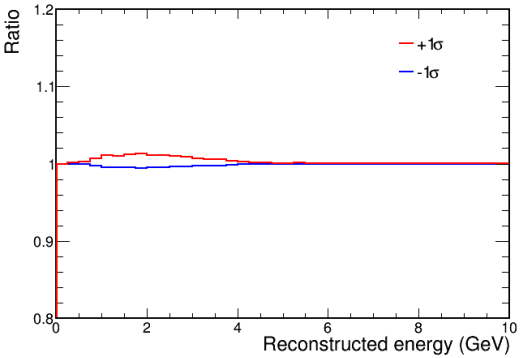
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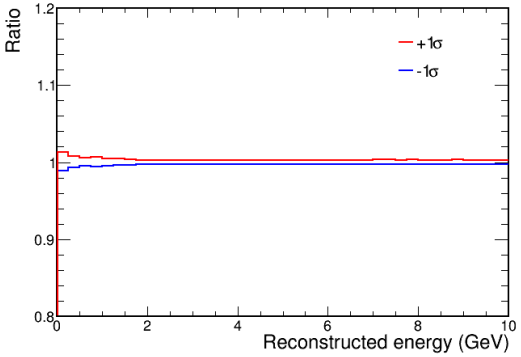
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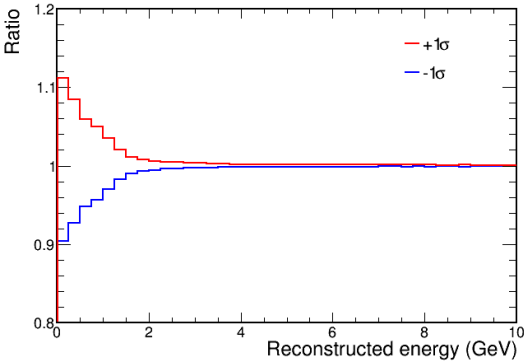
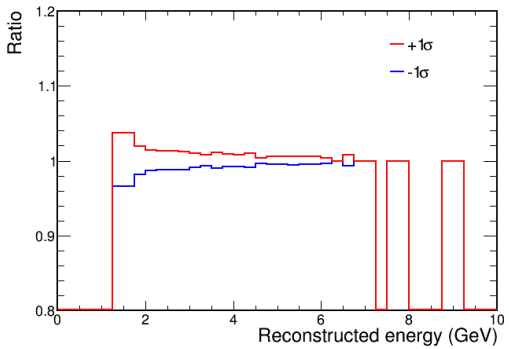
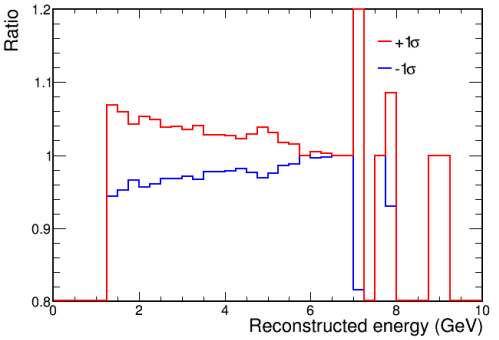
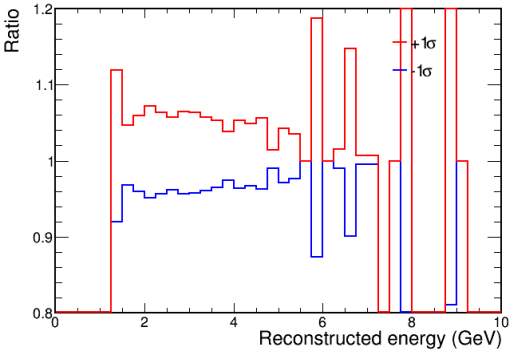
Reconstructed energy (GeV)

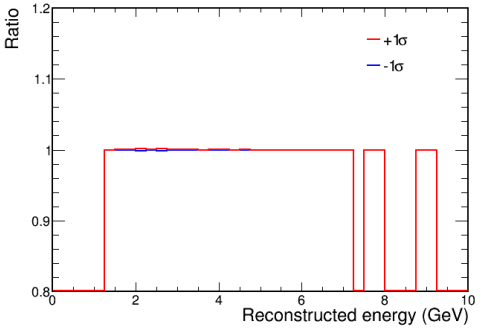

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

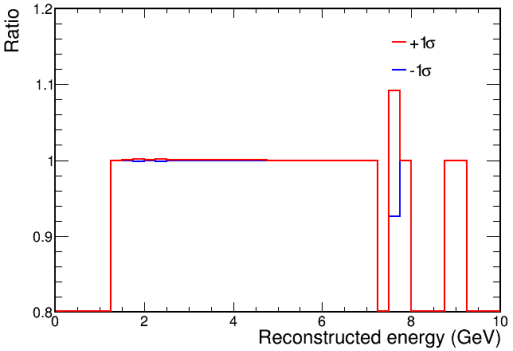
Xsec FD nue FHC

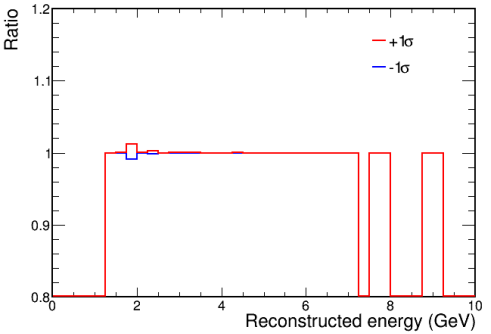


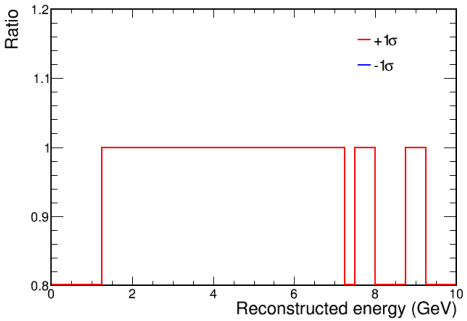


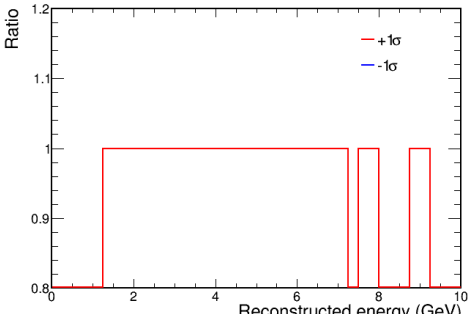


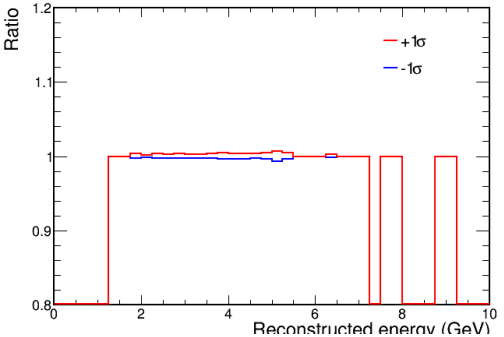


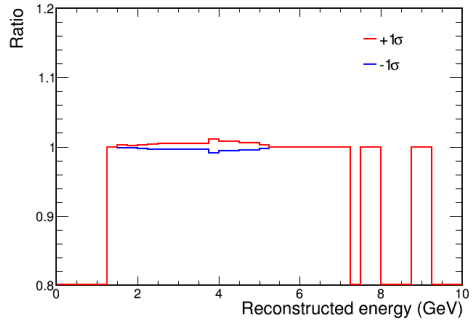


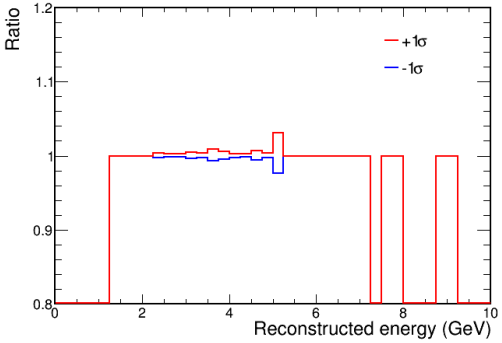


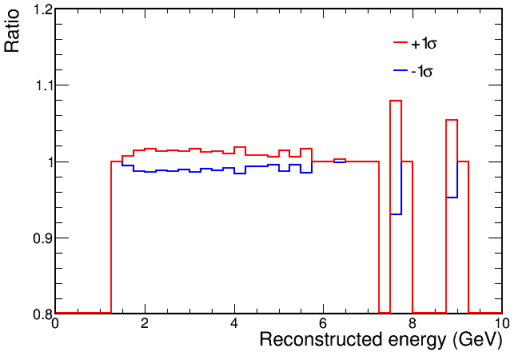


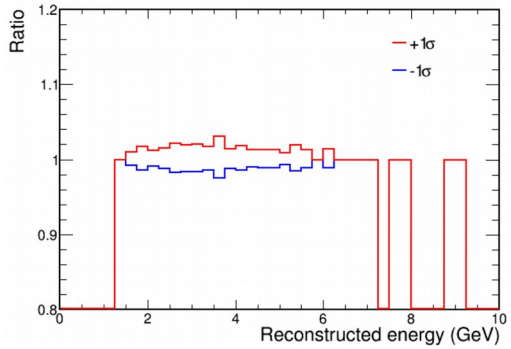


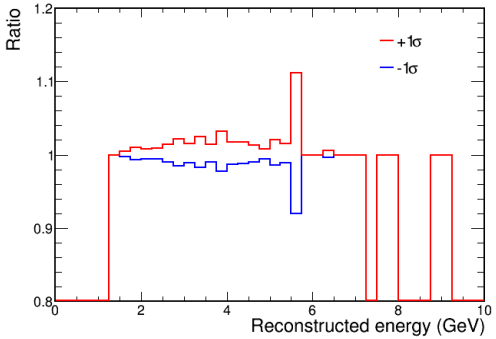


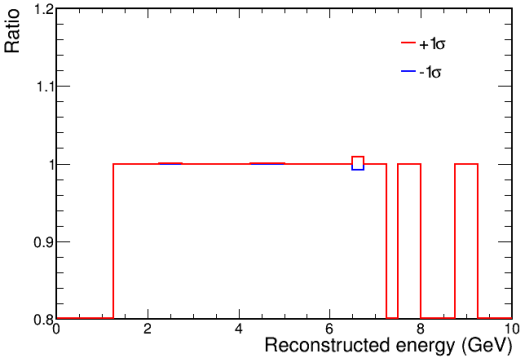


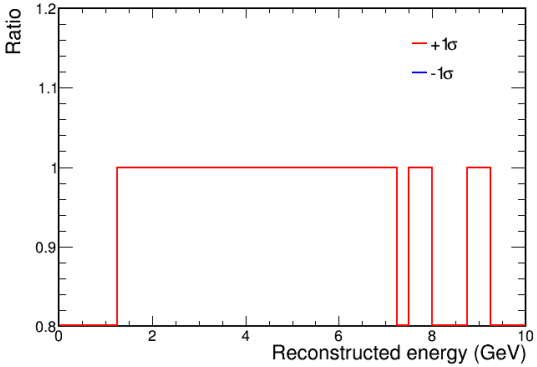


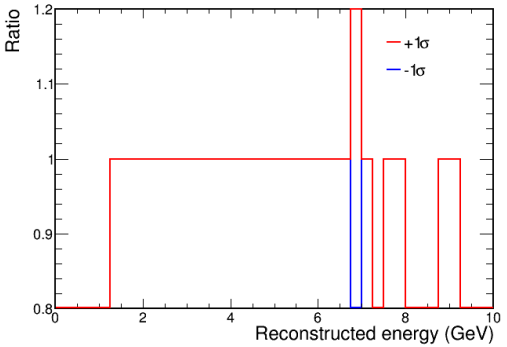


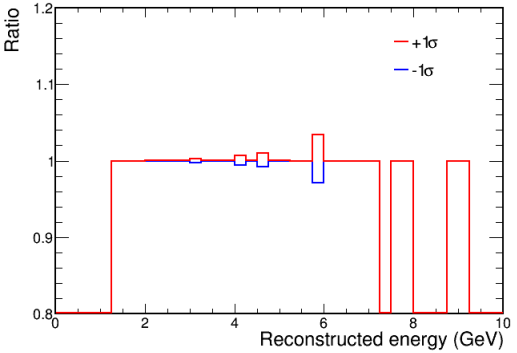

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

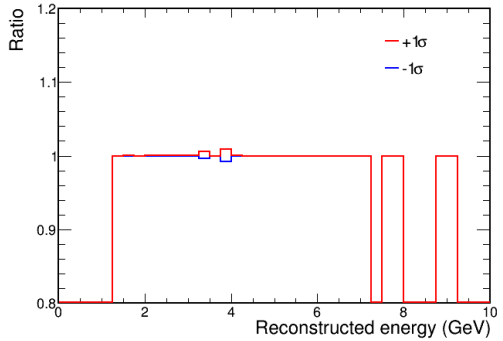

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

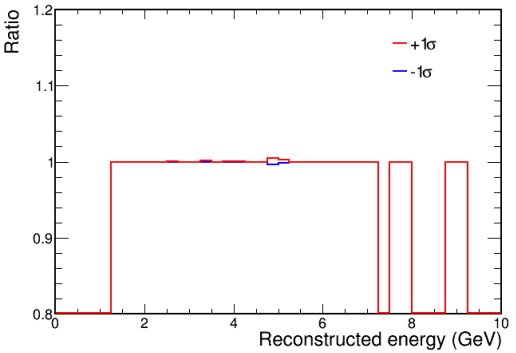

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

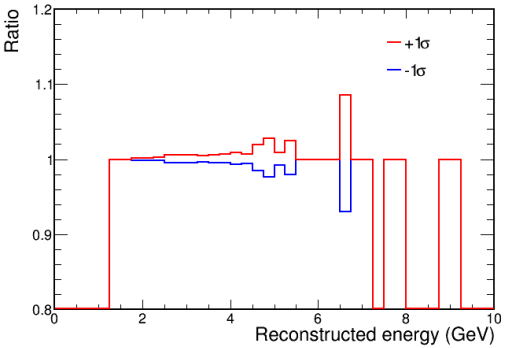

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

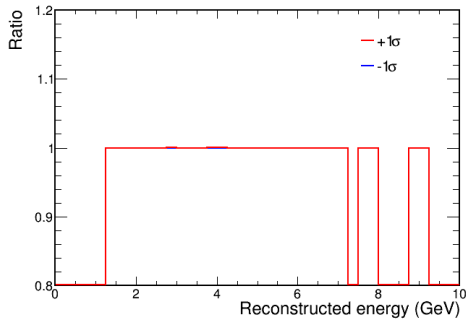

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

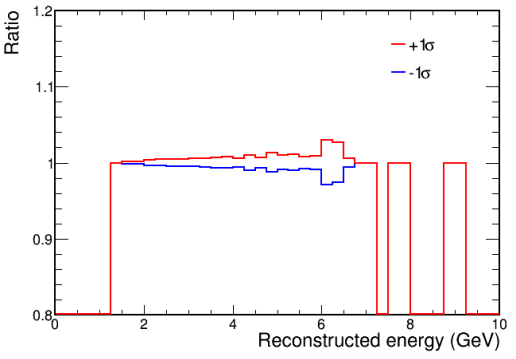

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

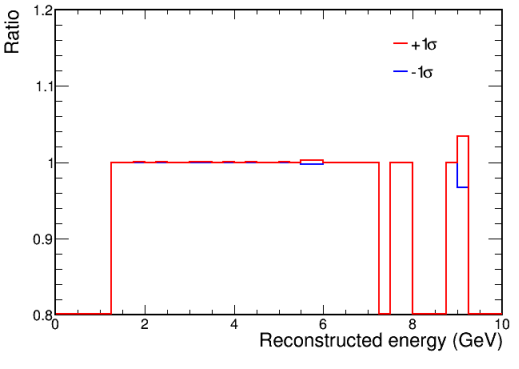

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

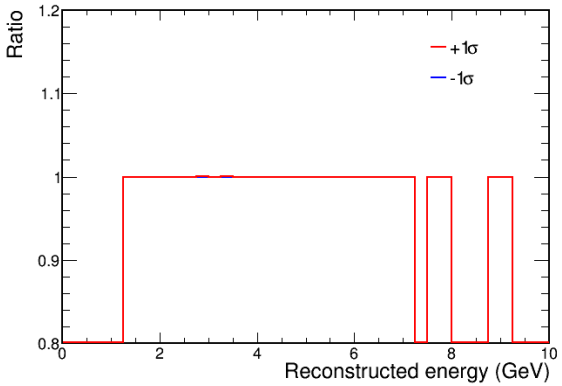

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

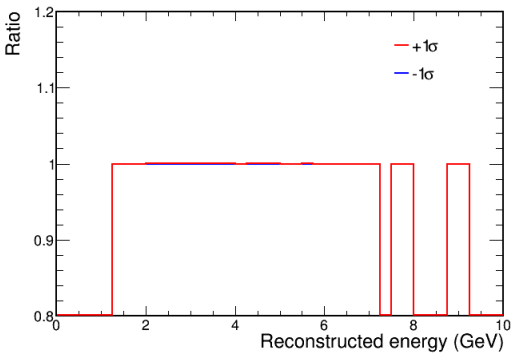

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

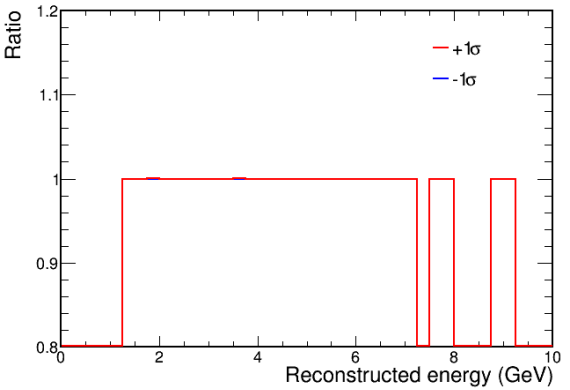

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

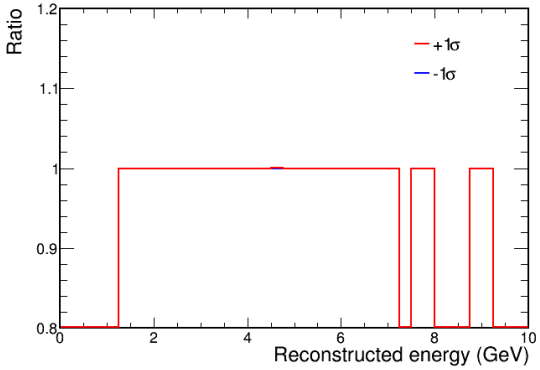

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

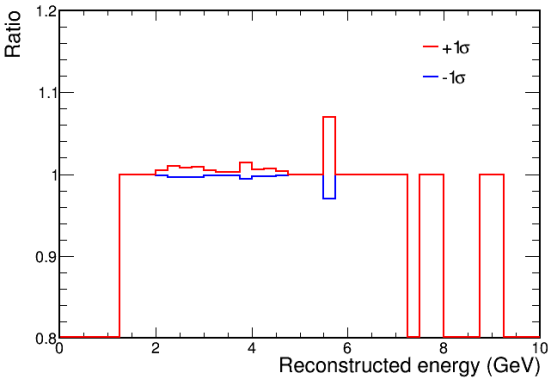

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

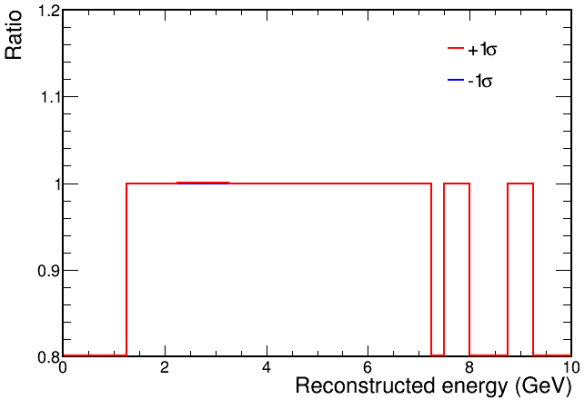

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

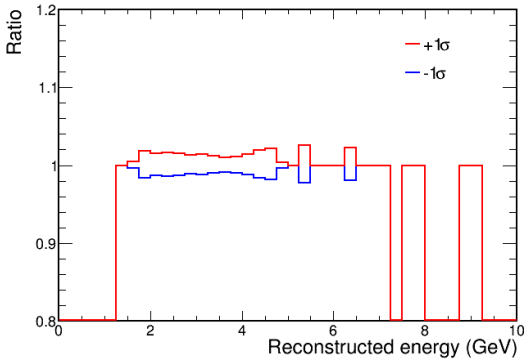

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

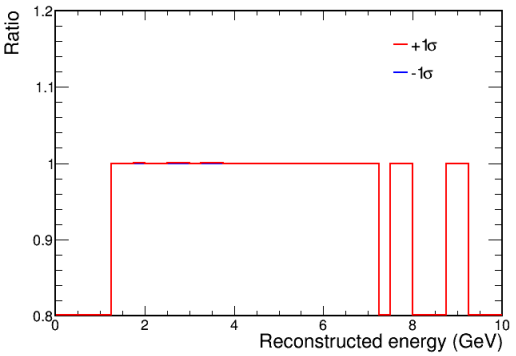

Ratio
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
+1σ
-1σ
Reconstructed energy (GeV)

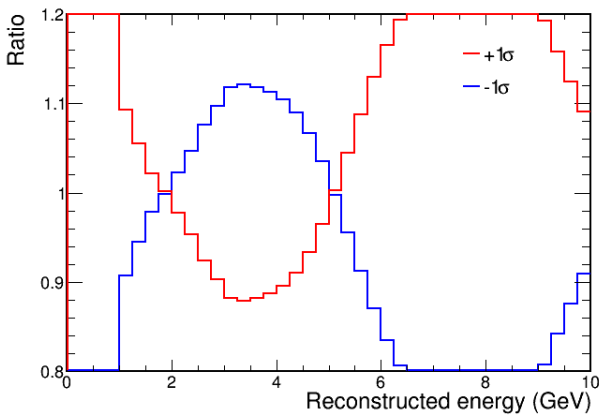

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

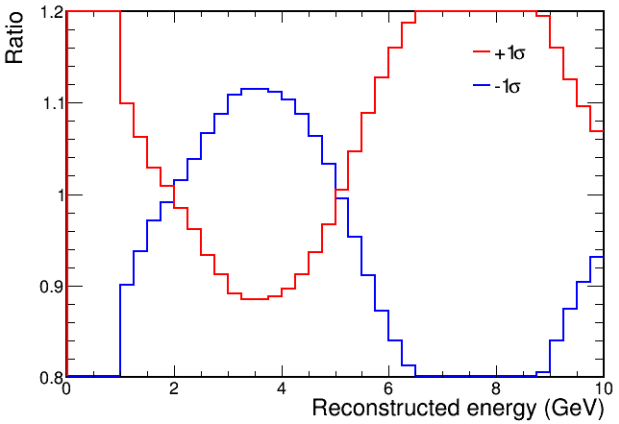

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

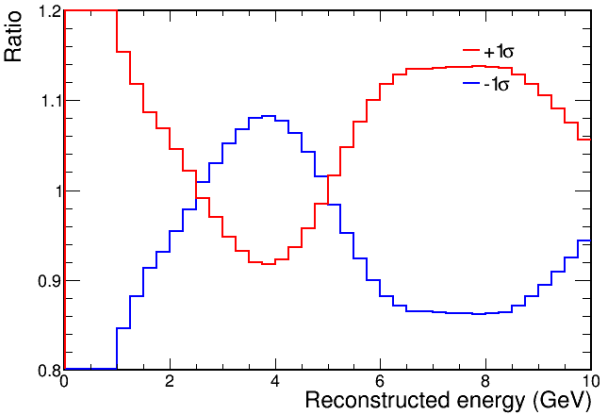

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

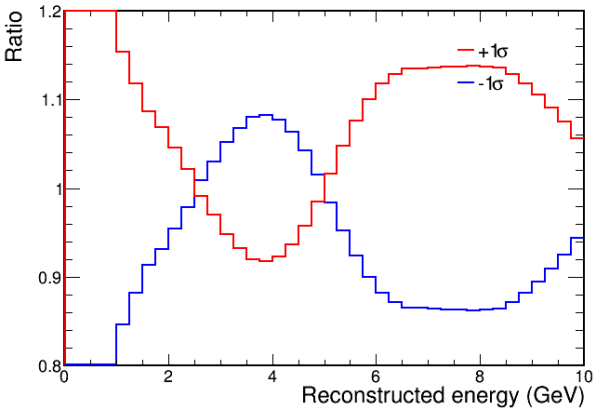

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

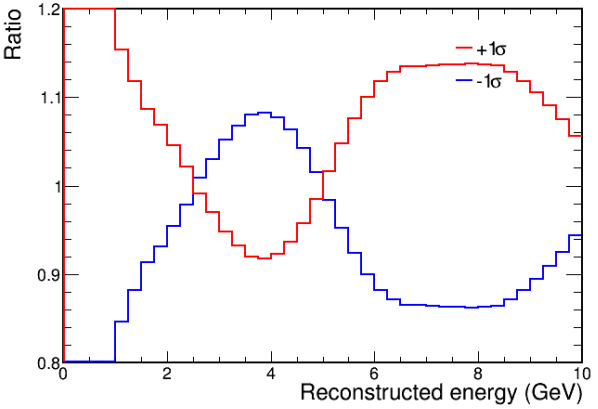
Flux systematics ND FHC

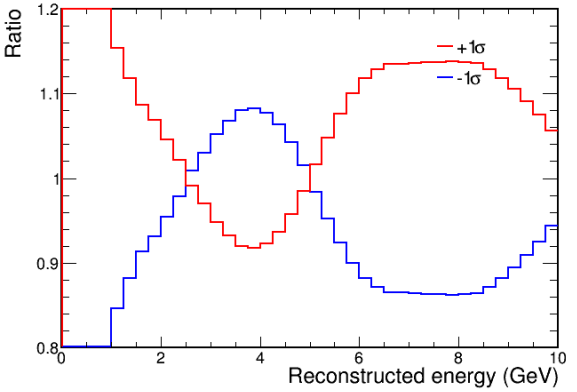


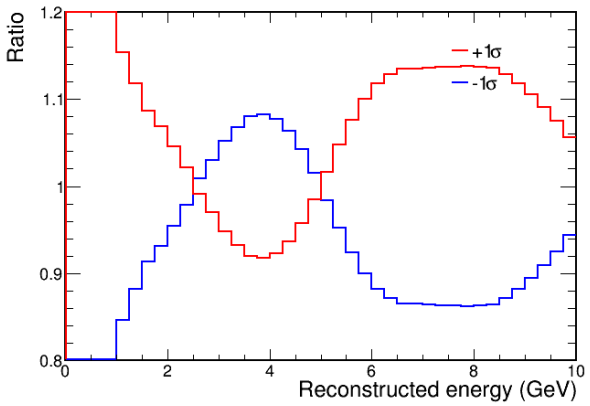


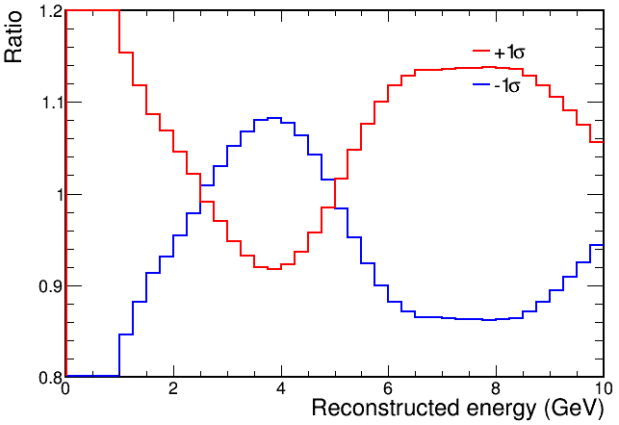


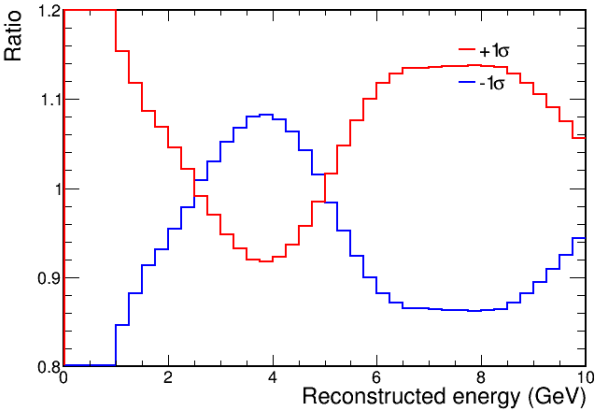




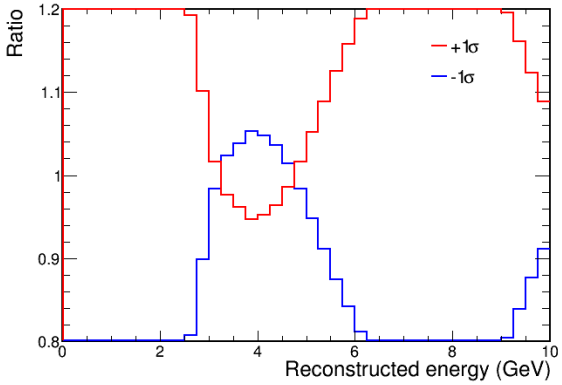


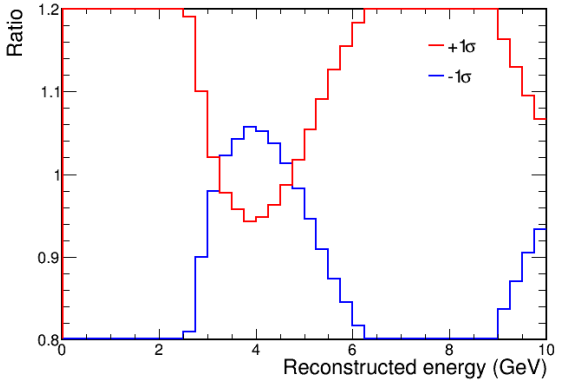


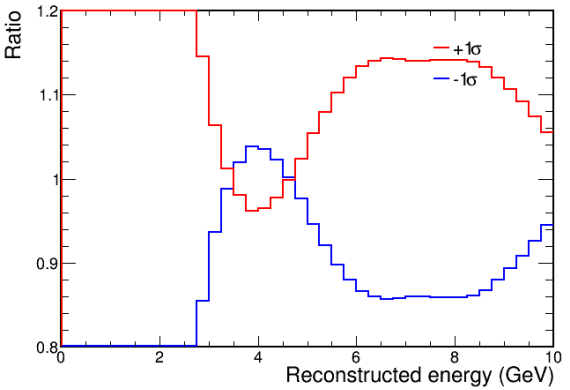


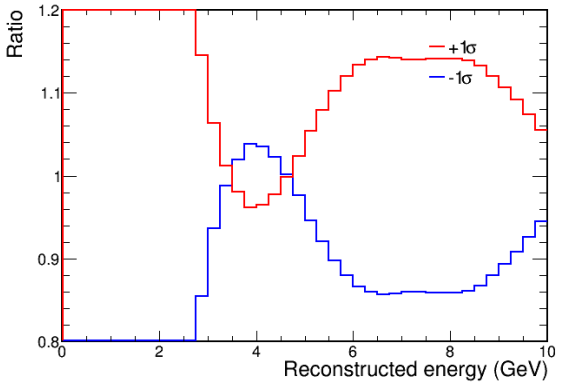


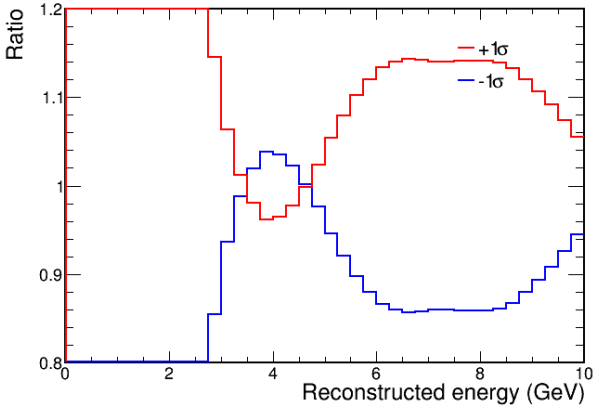
Flux systematics ND RHC

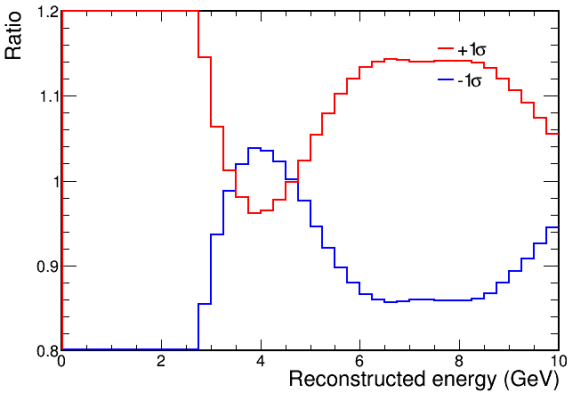


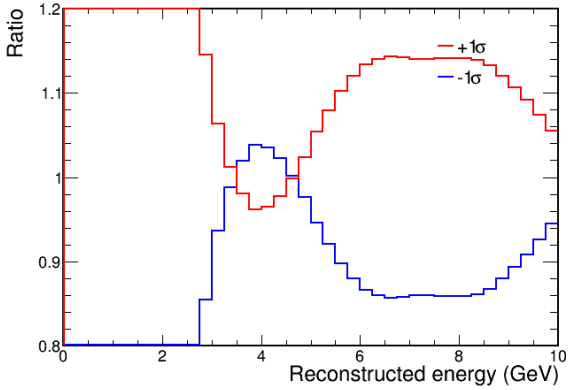


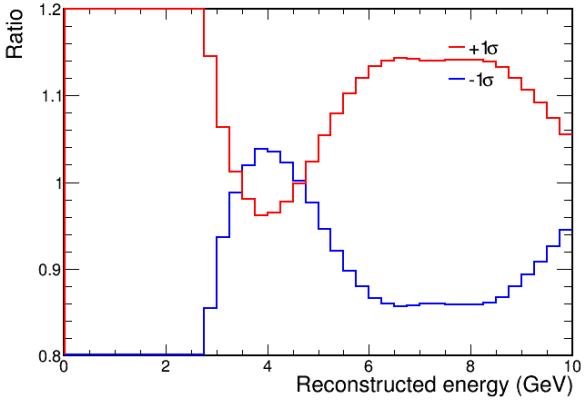


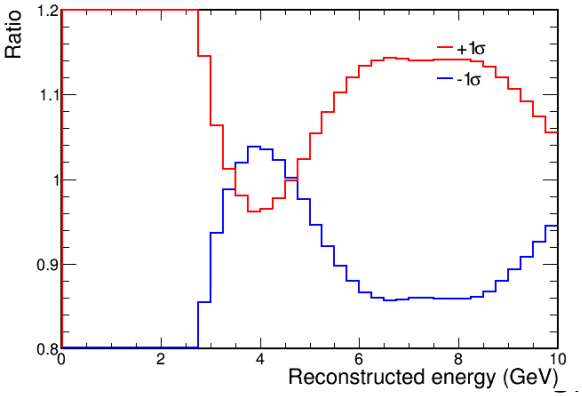








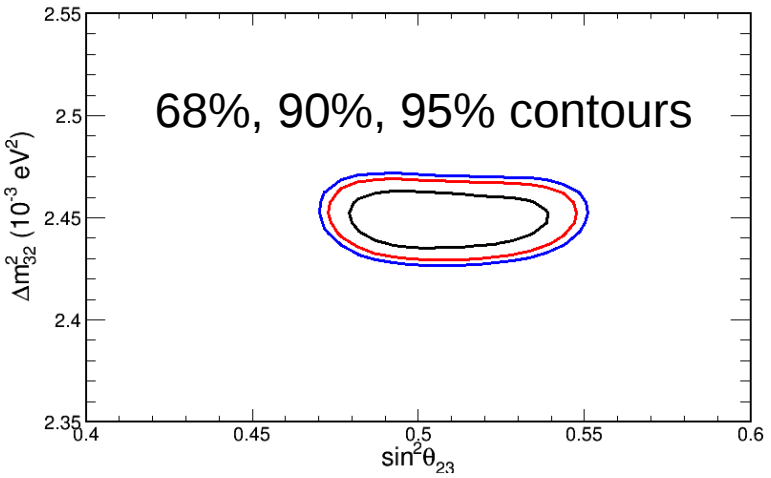


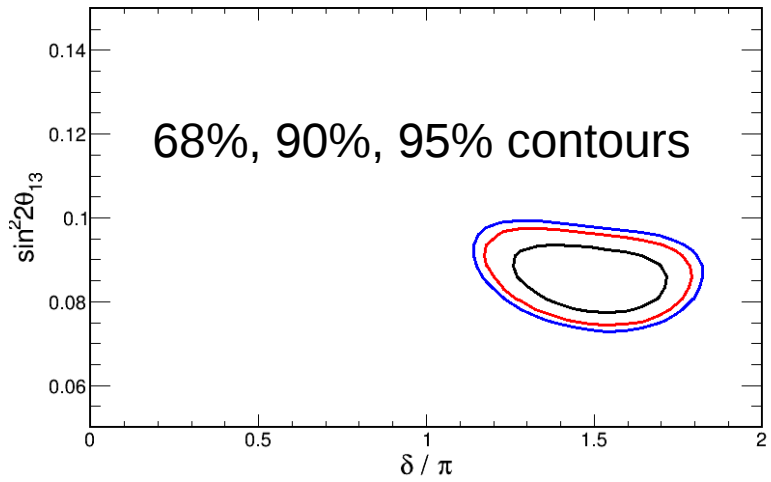


Systematics validation

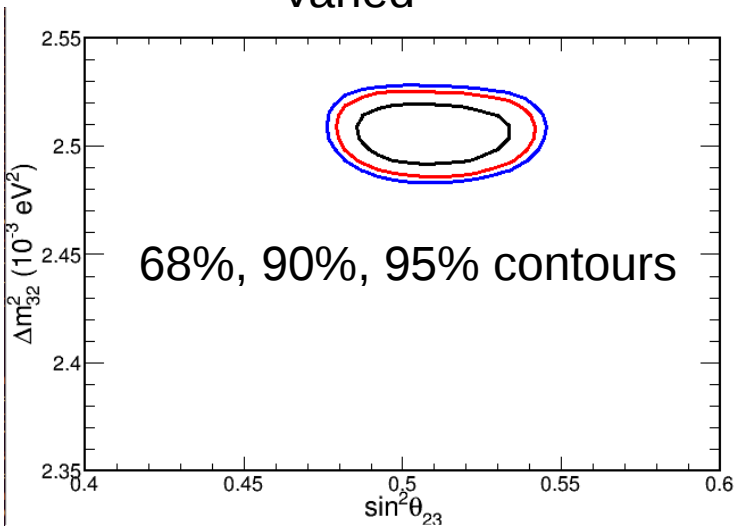
With Luke's variation and without systematics,
the true values cannot be recovered.

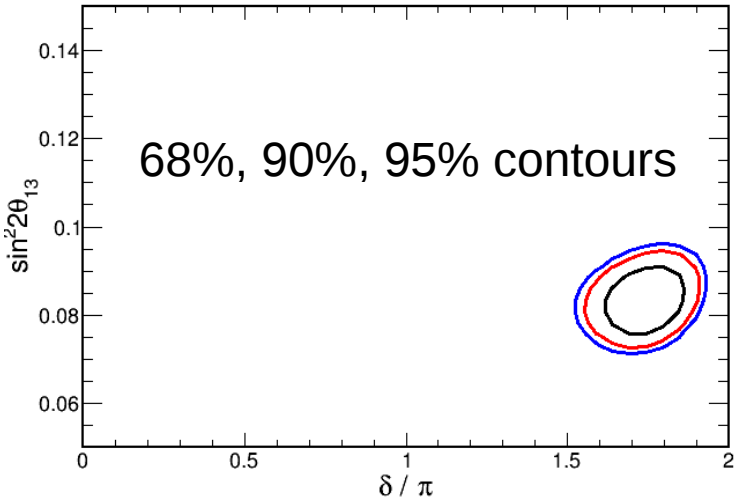
True





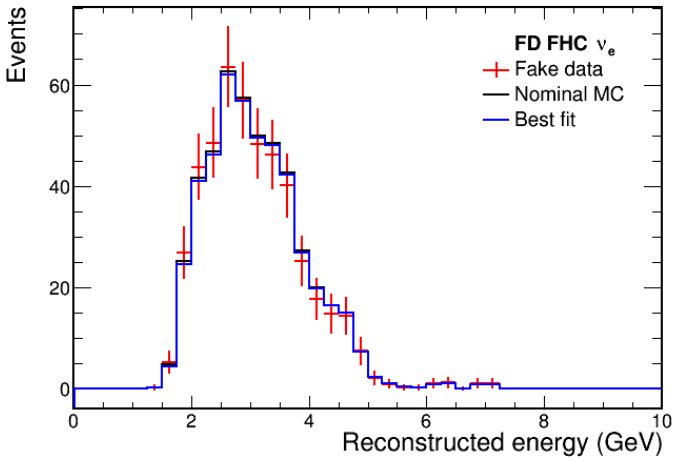
Varied

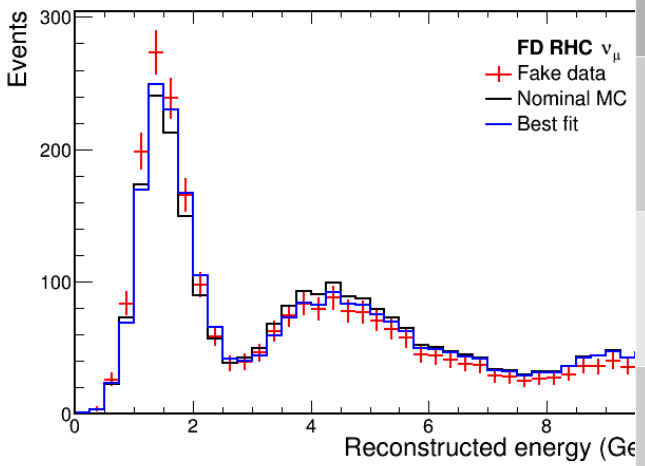


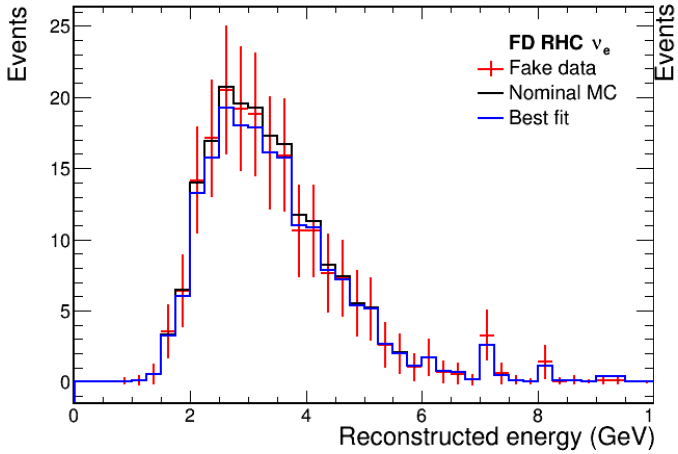


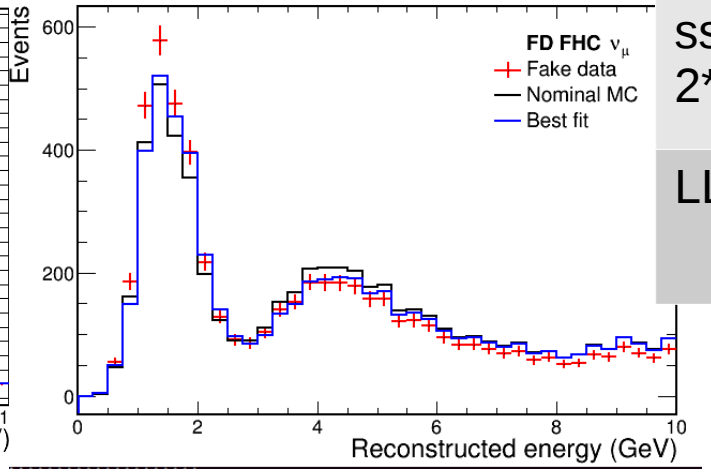
Systematics validation

With Luke's variation and without systematics, the true values cannot be recovered.







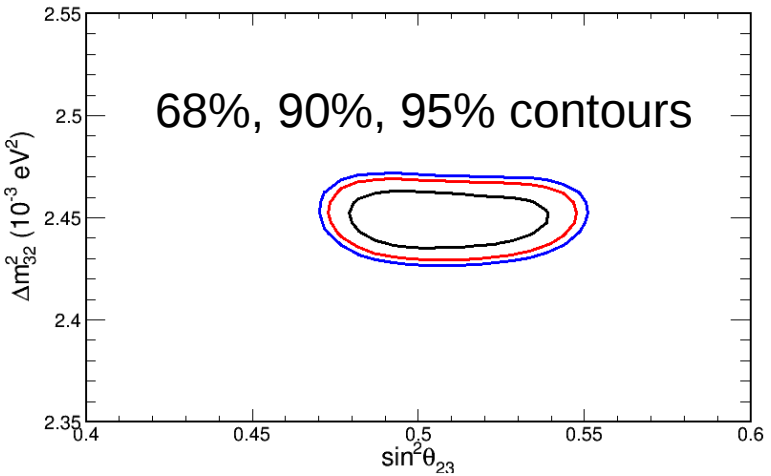


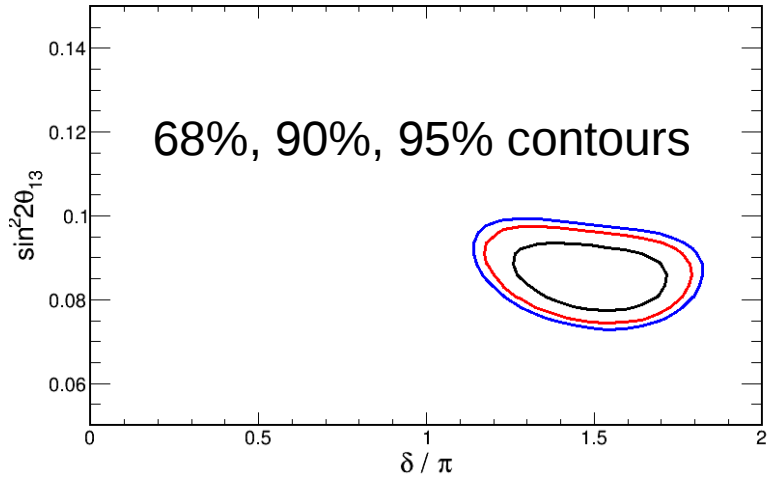
	true	FD+ND Best fit	FD only
CP (pi)	1.5	1.67	1.67
sst23	0.5	0.51	0.51
Dm32 (e-3)	2.45	2.57	2.57
ss(2*t13)	0.087	0.078	0.078
LL		126246	99.5

Systematics validation

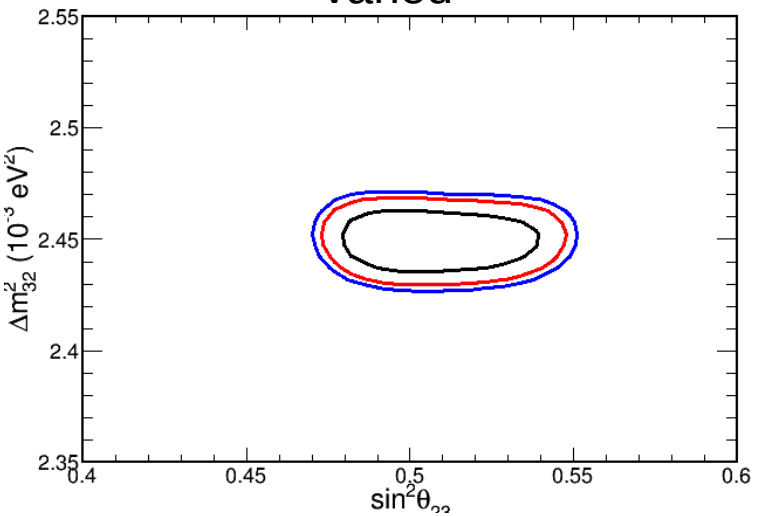
With Luke's variation and with the variation inserted as a systematic pull, the true values can be recovered.

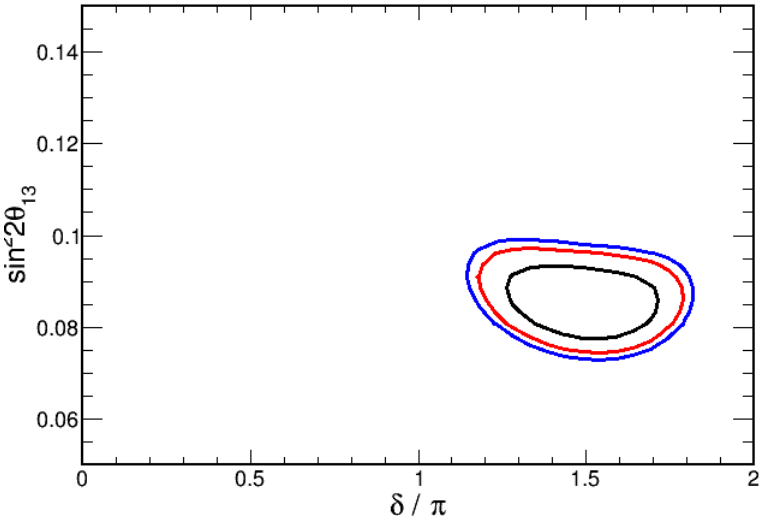
True





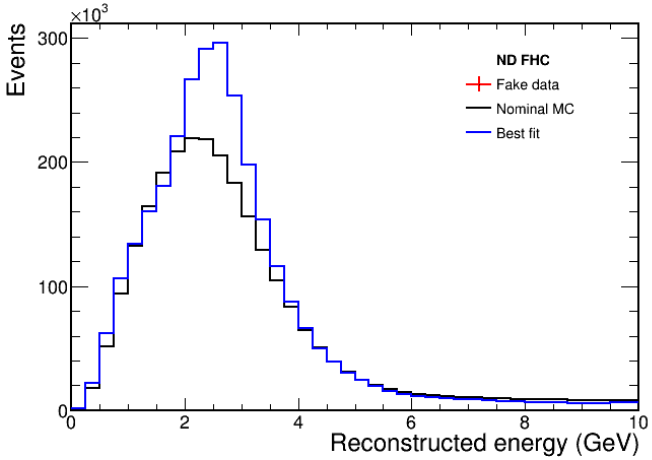
Varied

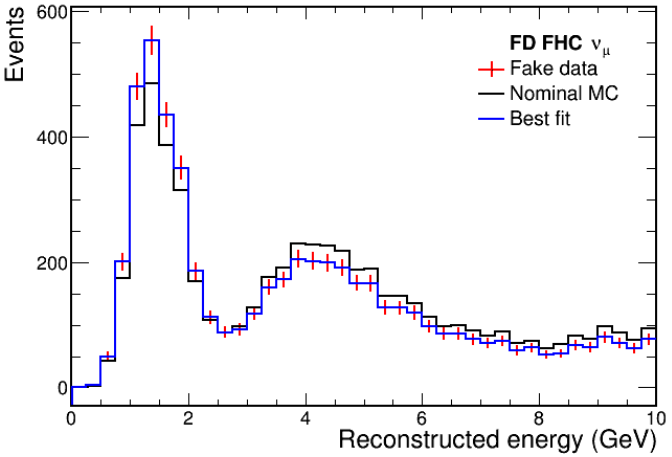


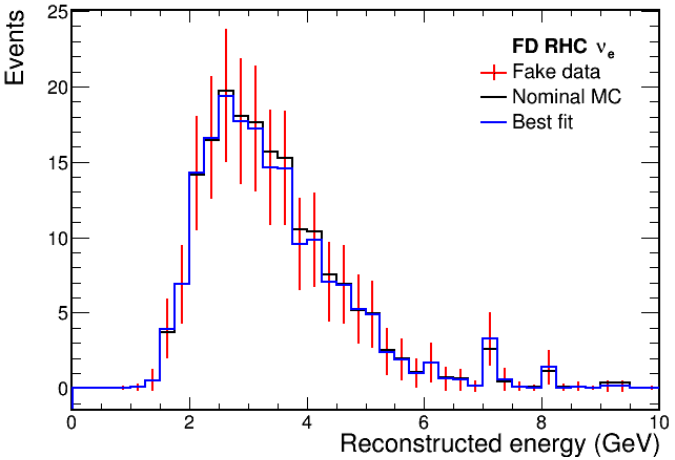


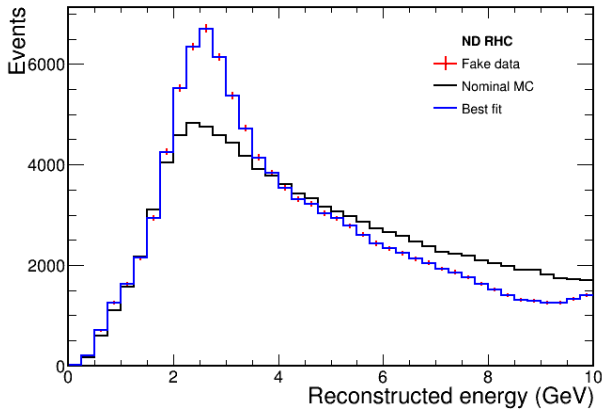
Systematics validation

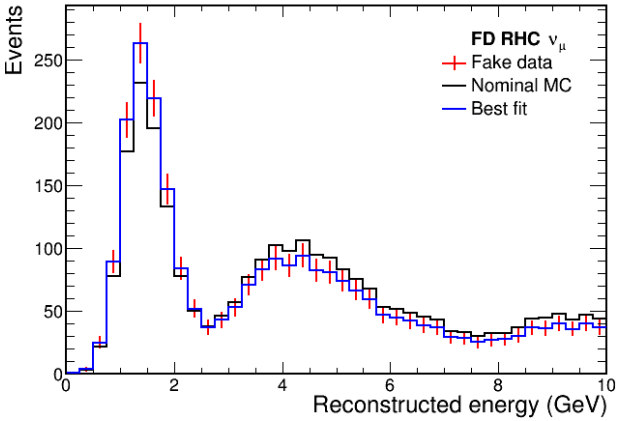
With Luke's variation and with the variation inserted as a systematic pull, the true values can be recovered.

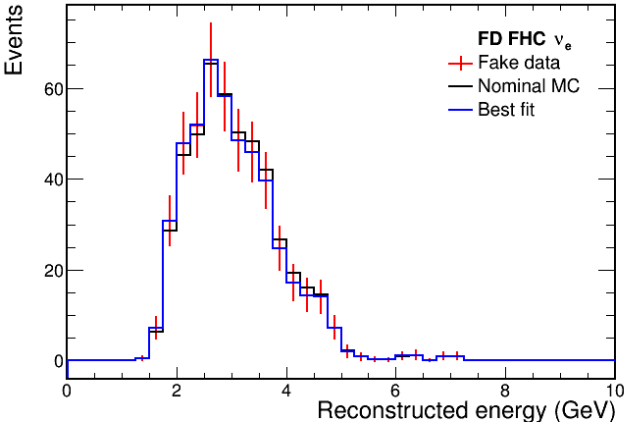








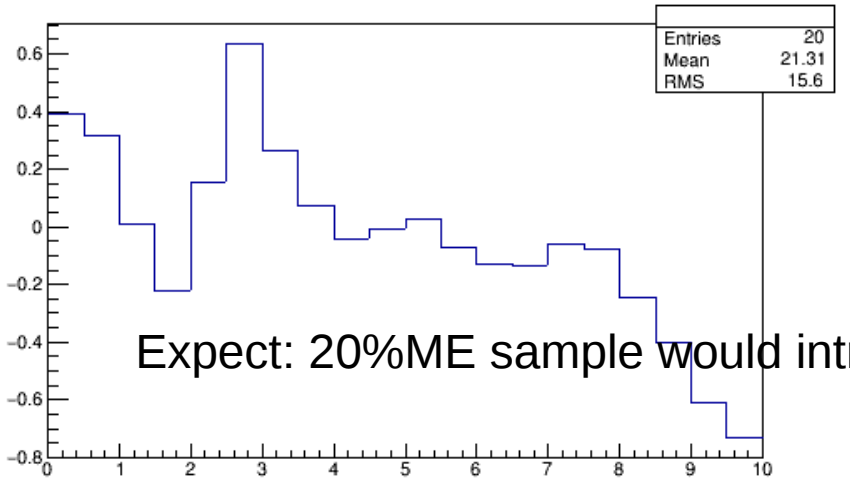




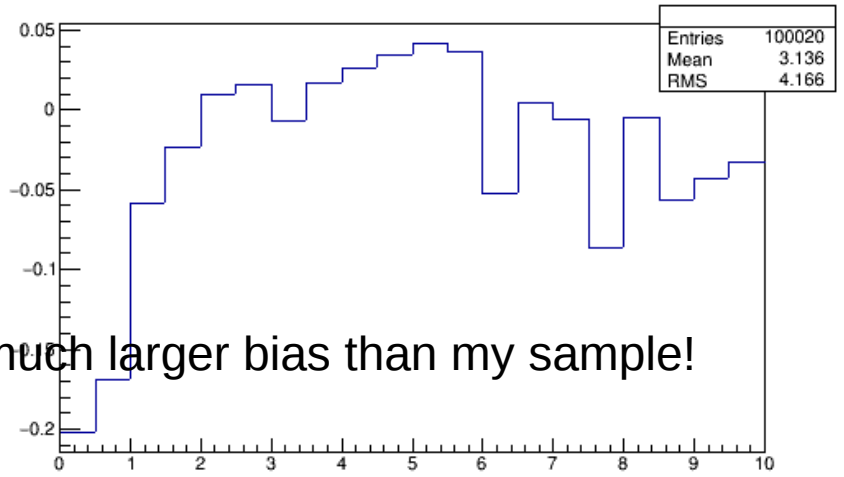
Fake data study

Fake data samples

20% ME



Nuwro / GENIE



Expect: 20%ME sample would introduce much larger bias than my sample!

Sample 1: Luke's 20% ME from Nuwro. ND/ FD numu/nue available. Numubar/nuebar Use the same numu/nue.

– This accounts for the bias on true → reco.

Sample 2: I generate Nuwro and GENIE ratio sample. Only numu, numubar/nuebar have no spectrum shift. ND and FD use the same spectrum shift.

→ Genie : default v2.10.10, numu on Ar target.

→ Nuwro : 2017 version with default parameter setup, numu on Ar target.

– This accounts for the bias on true spectra (flux x Xsec)

Xsec systematics (32)

Cross section systematics

- 32 "VALOR categories"
- With covariance matrix

  `/dune/data/users/marshalc/`

  `total_covariance_XS.root`

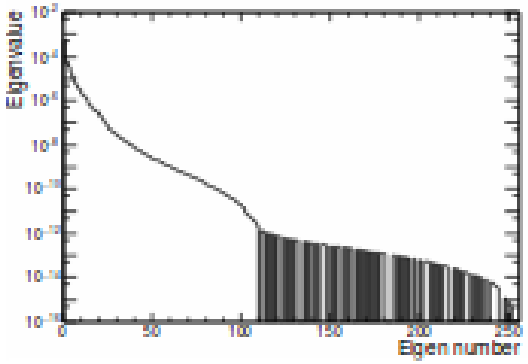
Correlations are included !

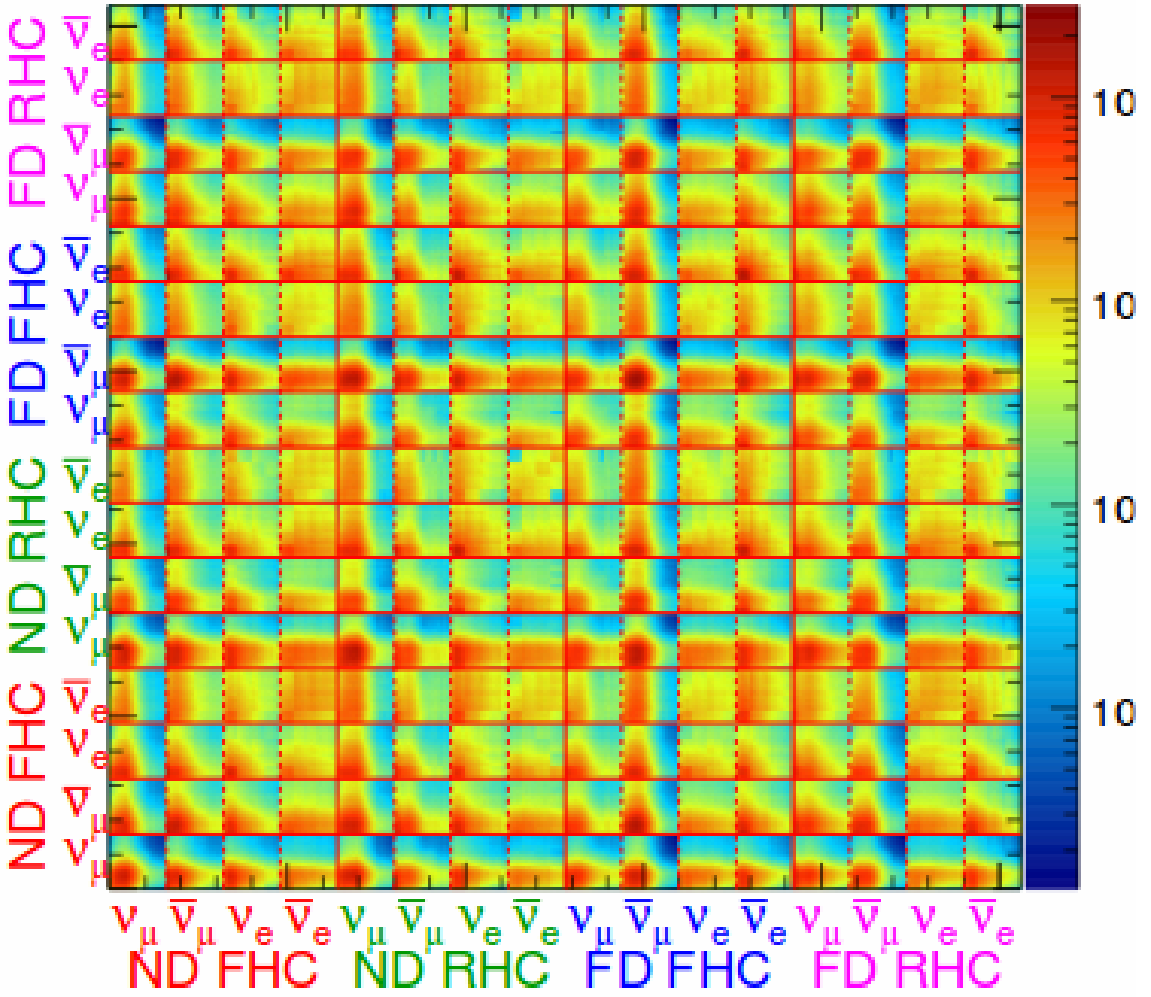
From Chris Backhouse

Component	Magnitude	Comment
ν CCQE 1	8.2%	$Q^2 < 0.2$
ν CCQE 2	23%	$0.2 < Q^2 < 0.55$
ν CCQE 3	48%	$Q^2 > 0.55$
$\bar{\nu}$ CCQE 1	8.7%	$Q^2 < 0.2$
$\bar{\nu}$ CCQE 2	24%	$0.2 < Q^2 < 0.55$
$\bar{\nu}$ CCQE 3	40%	$Q^2 > 0.55$
ν MEC dummy	100%	-
$\bar{\nu}$ MEC dummy	100%	-
ν CC1π^0 1	13%	$Q^2 < 0.35$
ν CC1π^0 2	23%	$0.35 < Q^2 < 0.90$
ν CC1π^0 3	35%	$Q^2 > 0.90$
ν CC1$\pi^\pm$ 1	13%	$Q^2 < 0.30$
ν CC1$\pi^\pm$ 2	24%	$0.30 < Q^2 < 0.80$
ν CC1$\pi^\pm$ 3	40%	$Q^2 > 0.80$
$\bar{\nu}$ CC1π^0 1	16%	$Q^2 < 0.35$
$\bar{\nu}$ CC1π^0 2	27%	$0.35 < Q^2 < 0.90$
$\bar{\nu}$ CC1π^0 3	35%	$Q^2 > 0.90$
$\bar{\nu}$ CC1$\pi^\pm$ 1	16%	$Q^2 < 0.30$
$\bar{\nu}$ CC1$\pi^\pm$ 2	30%	$0.30 < Q^2 < 0.80$
$\bar{\nu}$ CC1$\pi^\pm$ 3 3	40%	$Q^2 > 0.80$
ν 2π	22%	-
$\bar{\nu}$ 2π	22%	-
ν DIS 1	3.5%	$E_\nu < 7.5$
ν DIS 2	3.5%	$7.5 < E_\nu < 15$
ν DIS 3	2.7%	$E_\nu > 15$
$\bar{\nu}$ DIS 1	1%	$E_\nu < 7.5$
$\bar{\nu}$ DIS 2	1.7%	$7.5 < E_\nu < 15$
$\bar{\nu}$ DIS 3	1.7%	$E_\nu > 15$
ν COH	128%	-
$\bar{\nu}$ COH	134%	-
ν NC	16%	-
$\bar{\nu}$ NC	16%	-
ν_e/ν_μ dummy	3%	Not implemented yet

Flux Systematics (10)

Covariance matrix



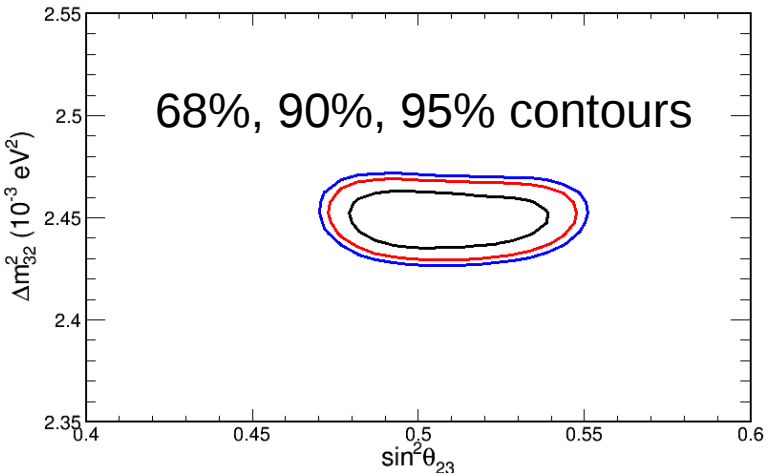


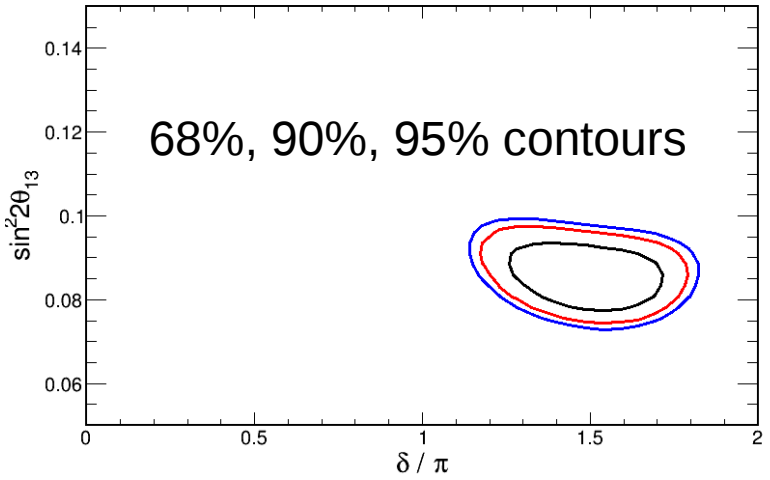
- Eigenvalues 108+ should be zero. Floating precision → some negative
- Limit eigenvalues to 10^{-14}. $M = V^T \Lambda V$, $M \rightarrow V^T \Lambda' V$

Fake data- 20% ME

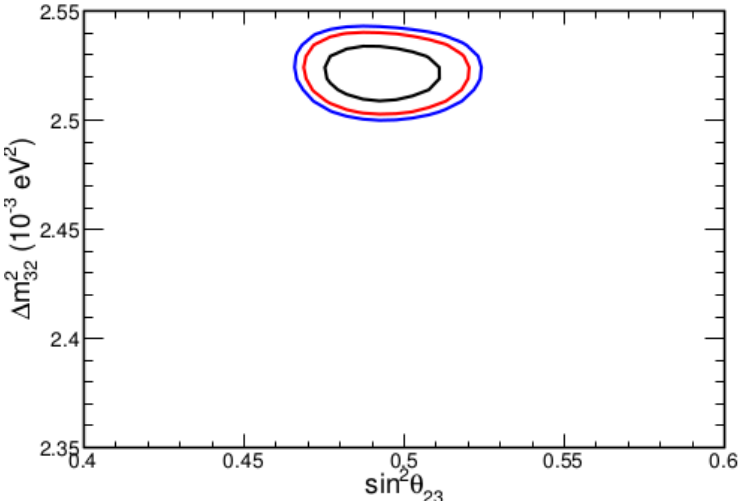
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

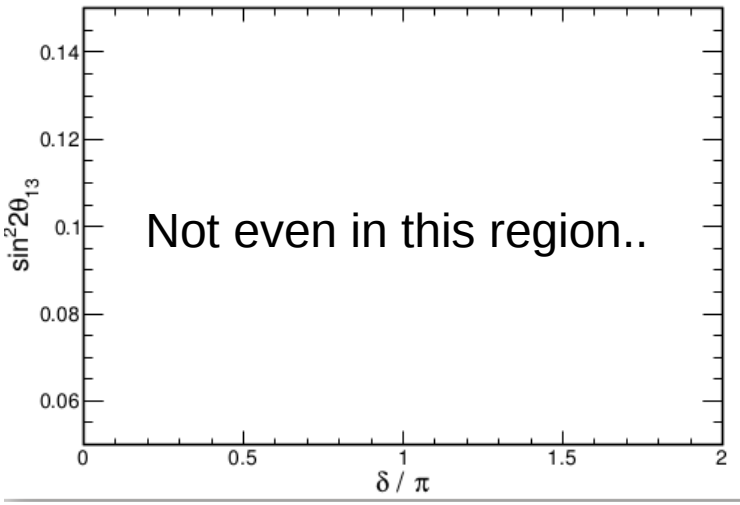
True





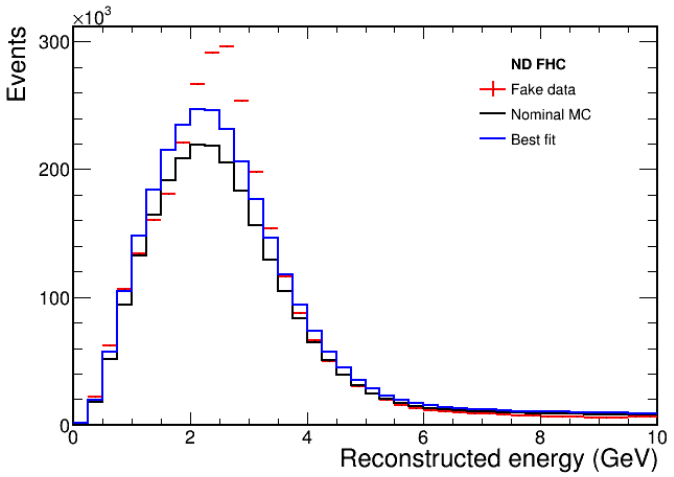
Fake data

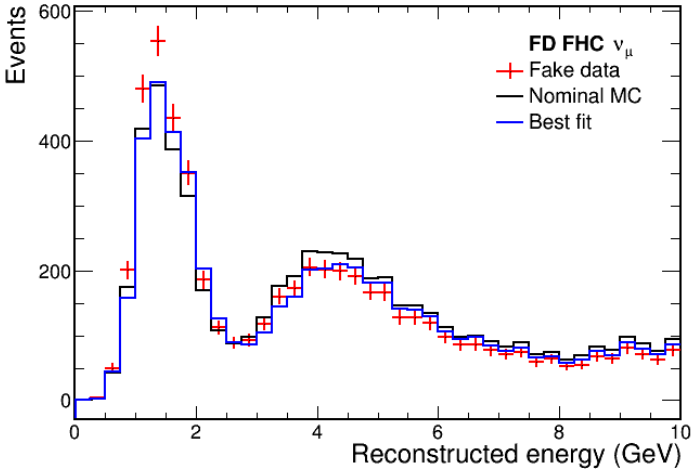


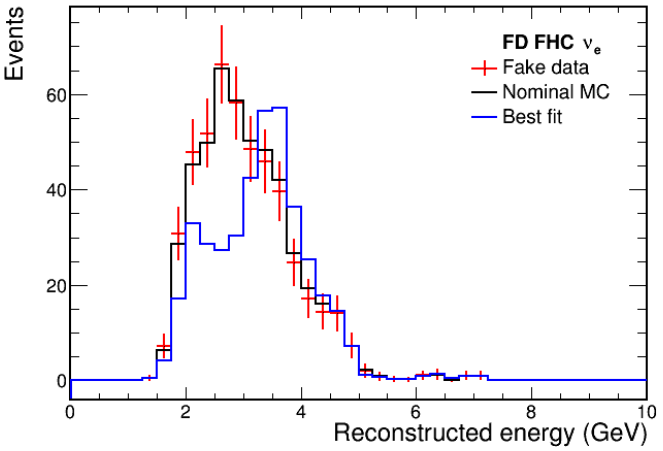


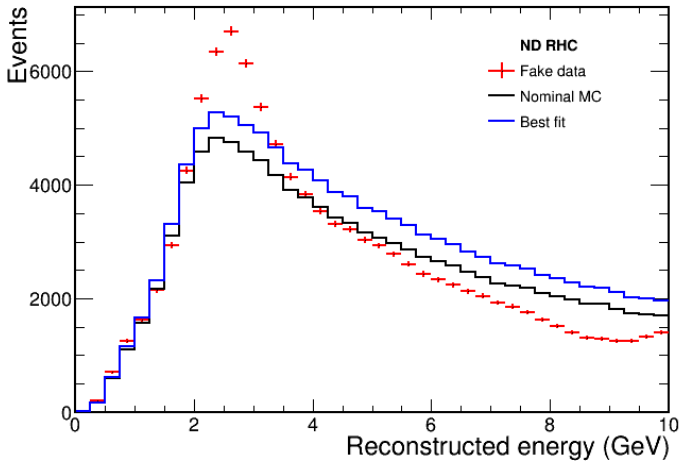
Fake data- 20% ME

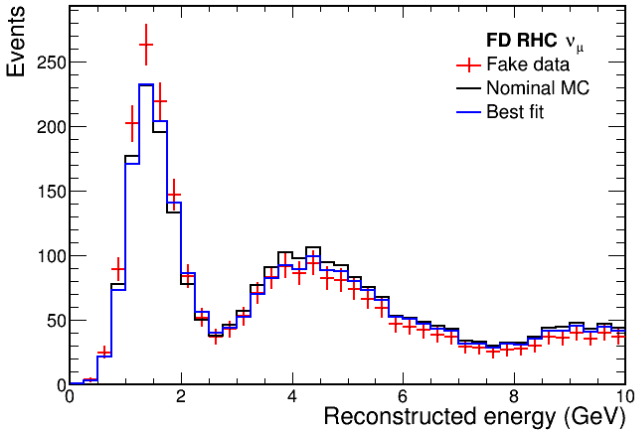
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

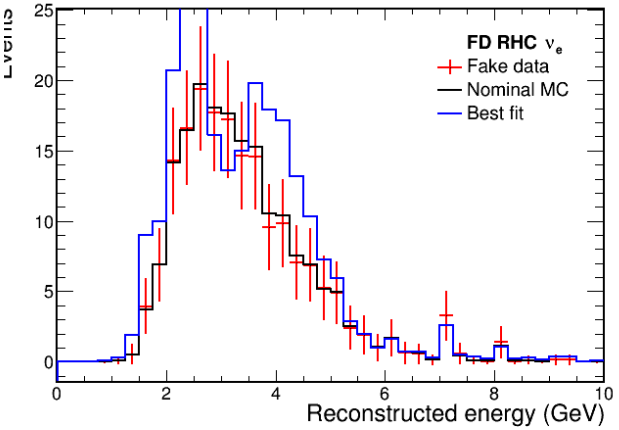










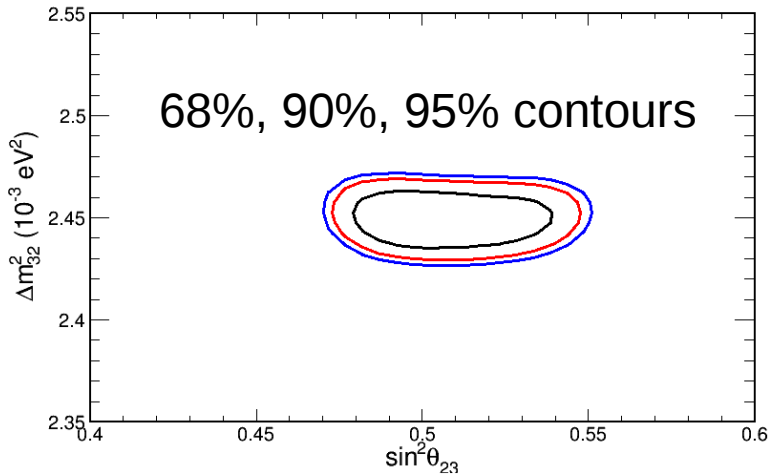


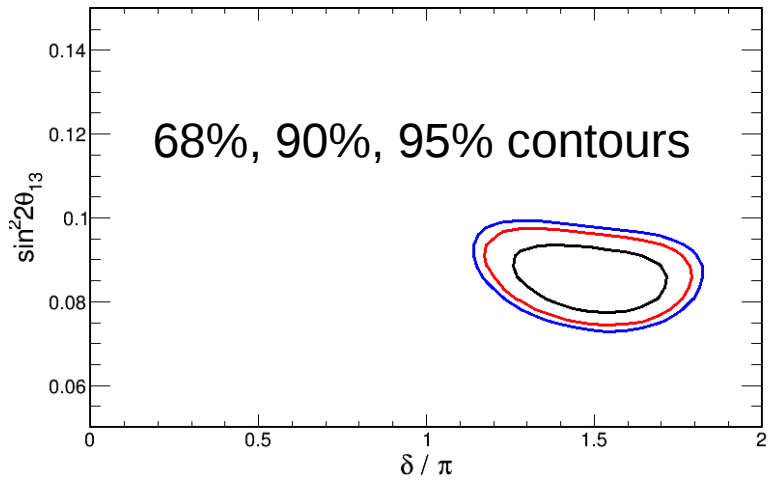
- ND distortion is too significant so that oscillation parameters are less cared by fitter.

Fake data- 20% ME

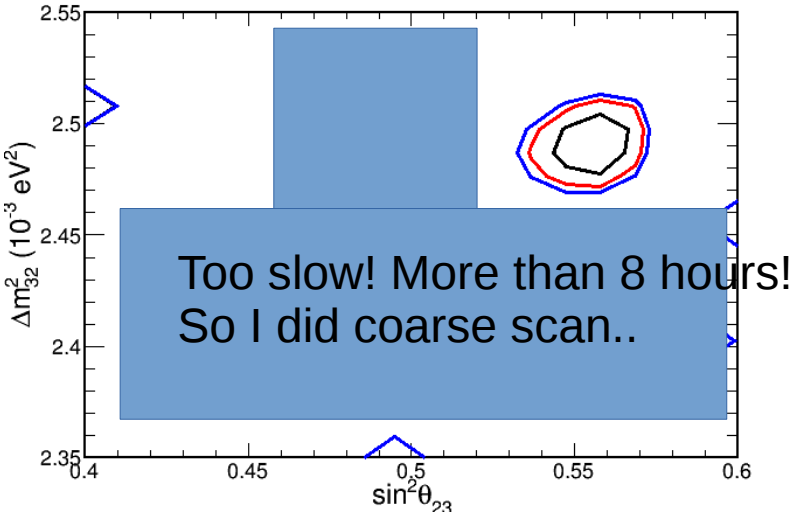
- ND and FD have 20% ME shift, we have Xsec+ flux parameters to recover it.

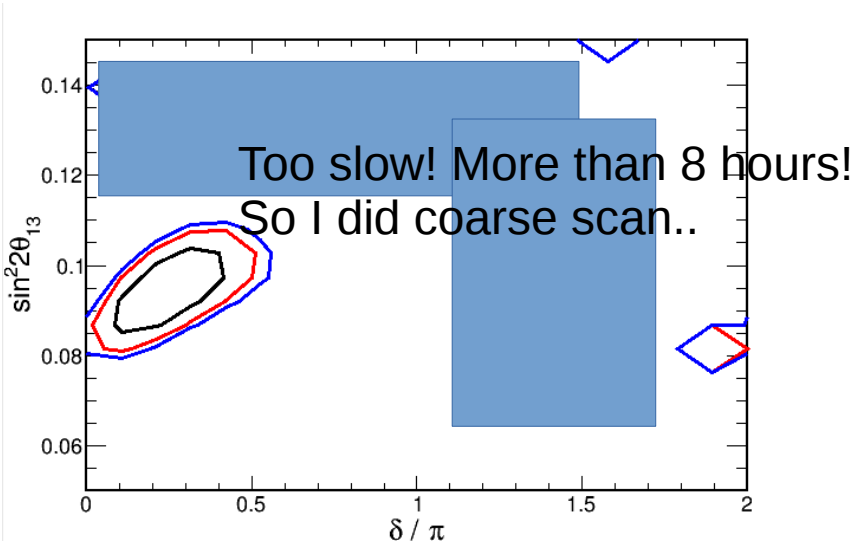
True





Fake data

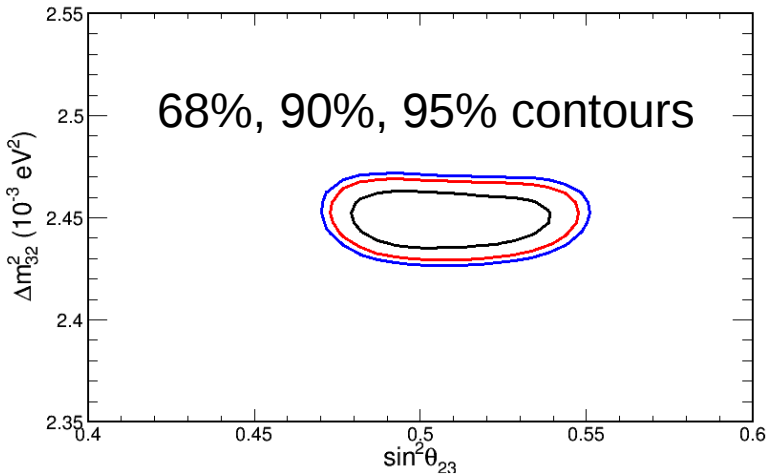


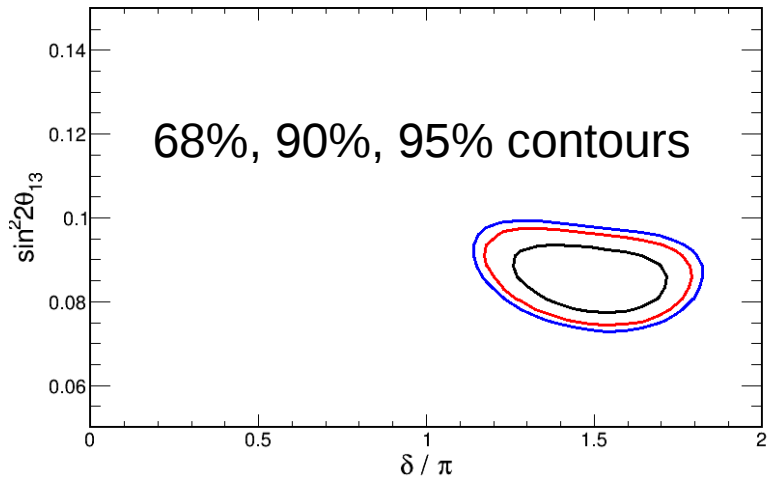


Fake data- Nuwro/GENIE

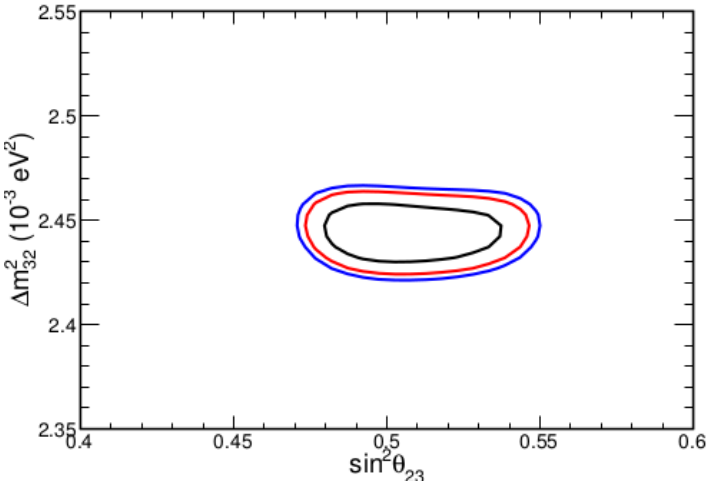
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

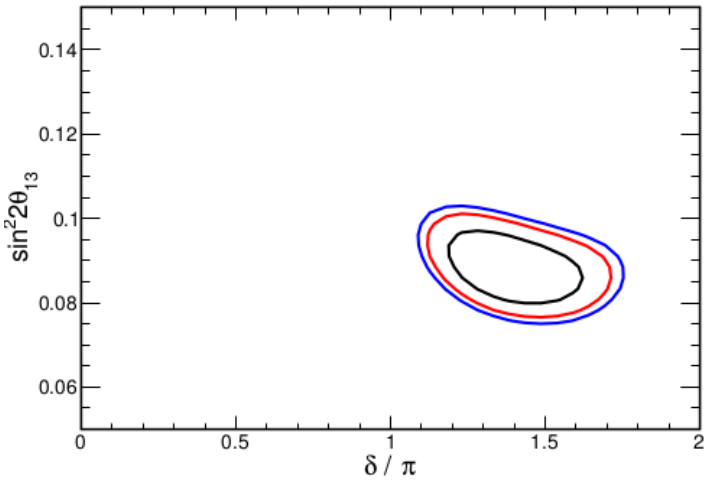
True





Fake data

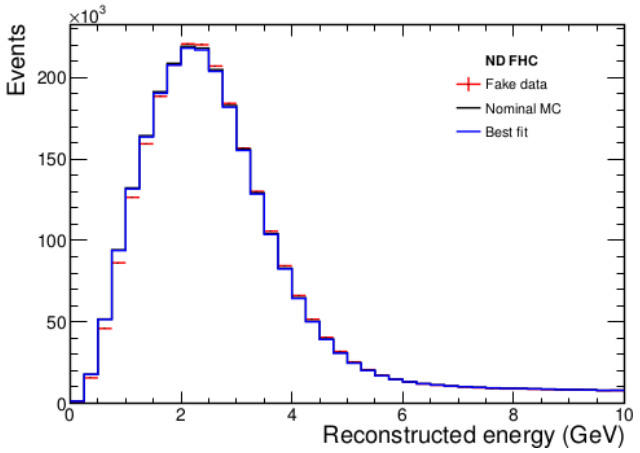


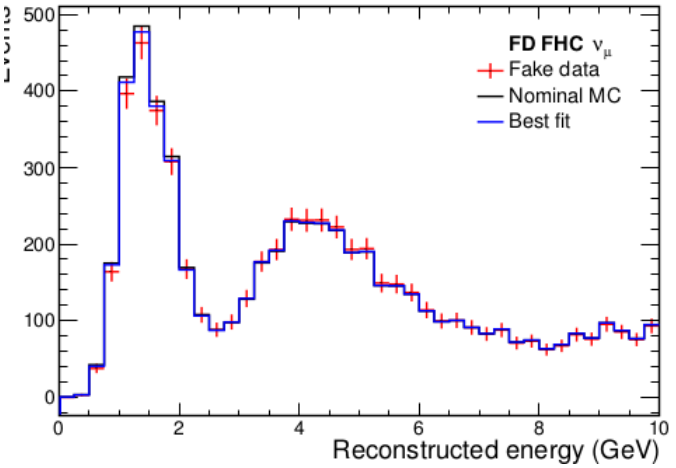


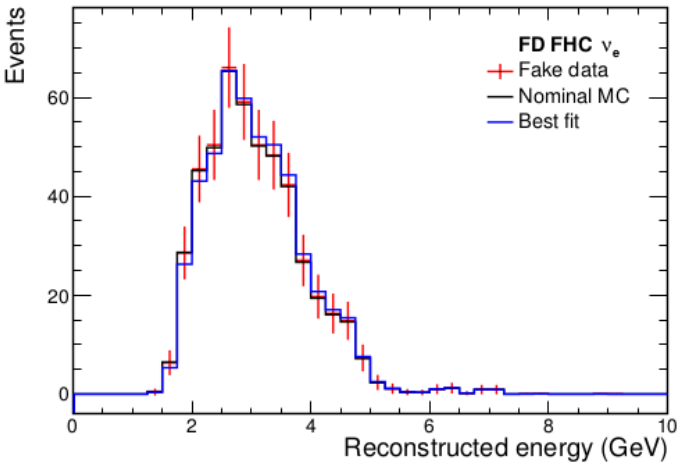
- Only with Xsec parameters, delta CP cannot be fully recovered.

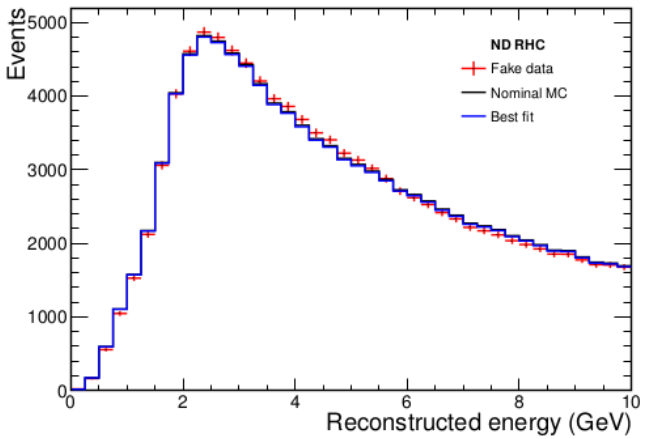
Fake data- Nuwro/GENIE

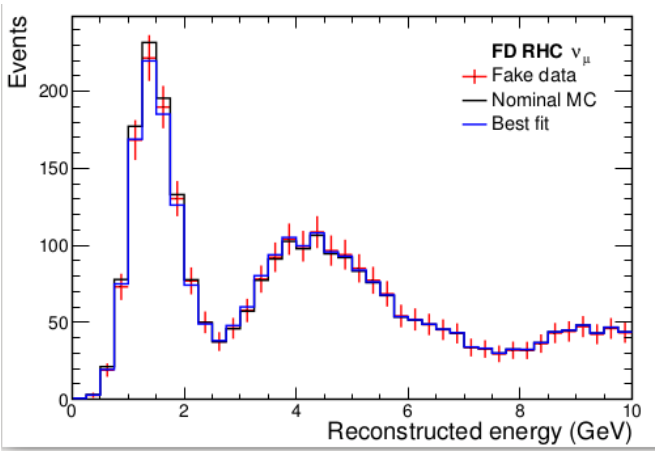
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

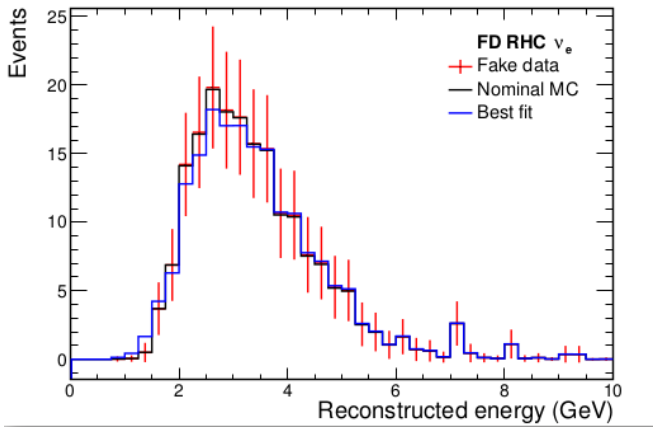








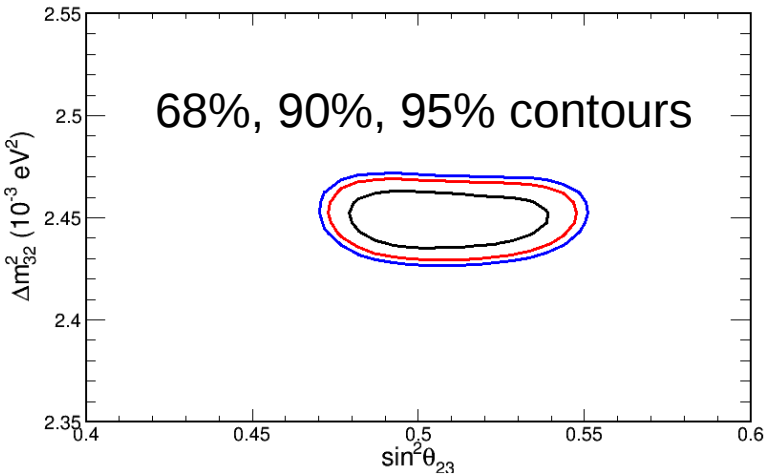




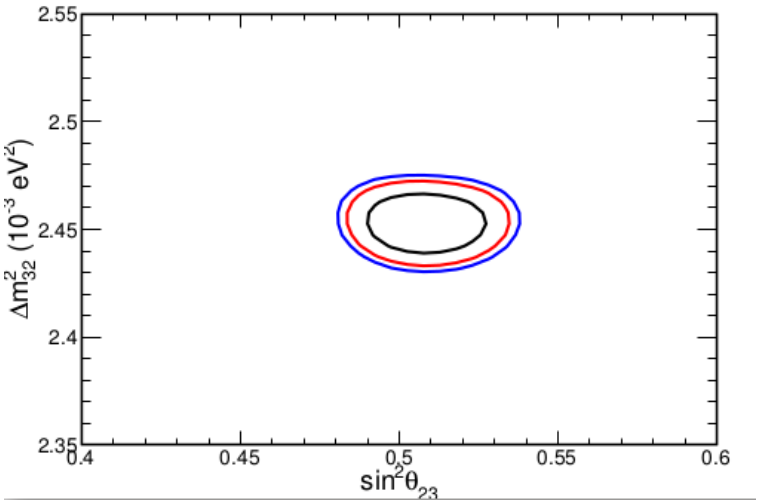
Fake data- Nuwro/GENIE

- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.

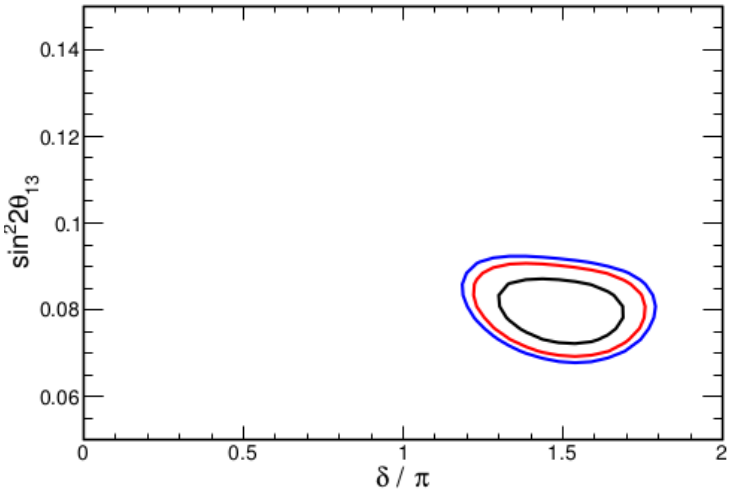
True



Fake data



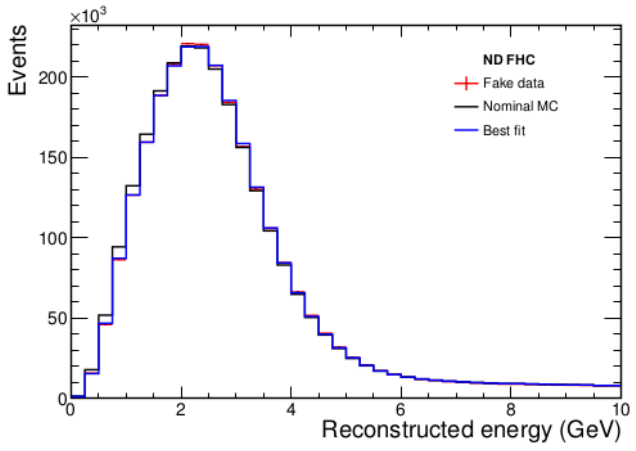
68%, 90%, 95% contours

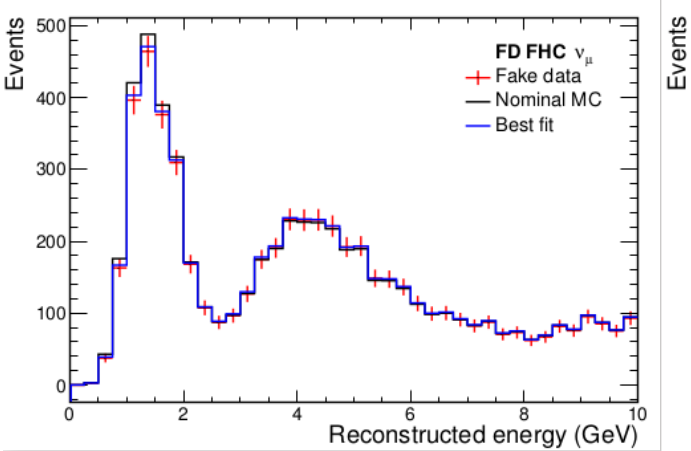


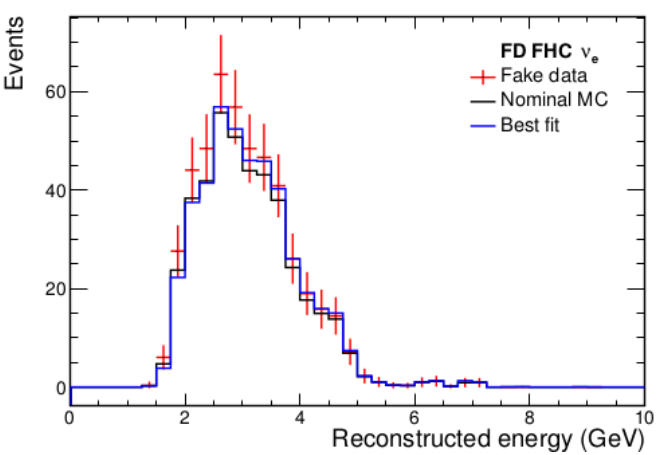
- With Xsec+flux parameters, delta CP can be mostly recovered.

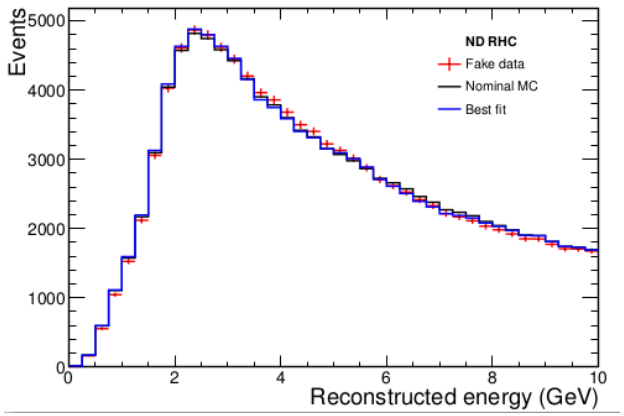
Fake data- Nuwro/GENIE

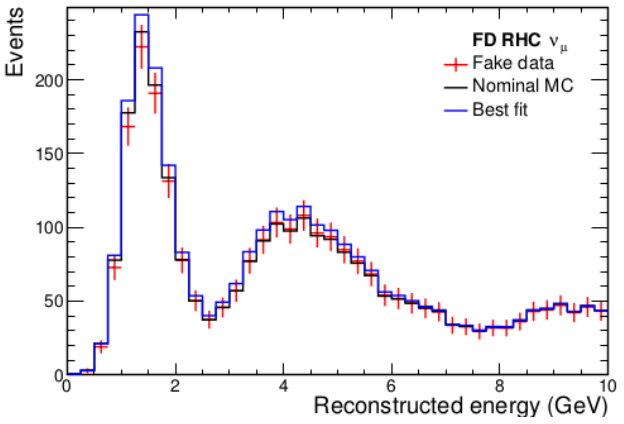
- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.

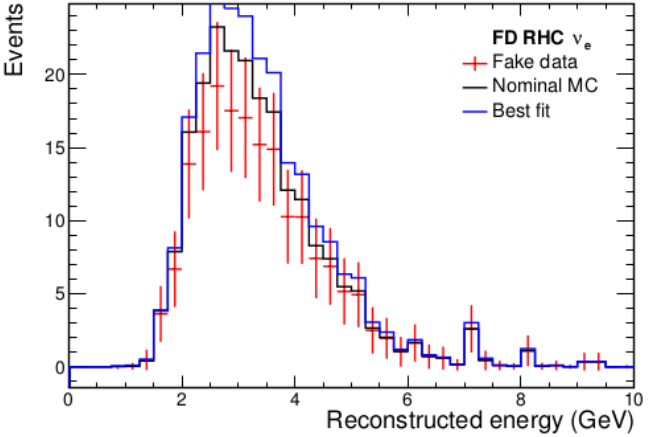












Systematics

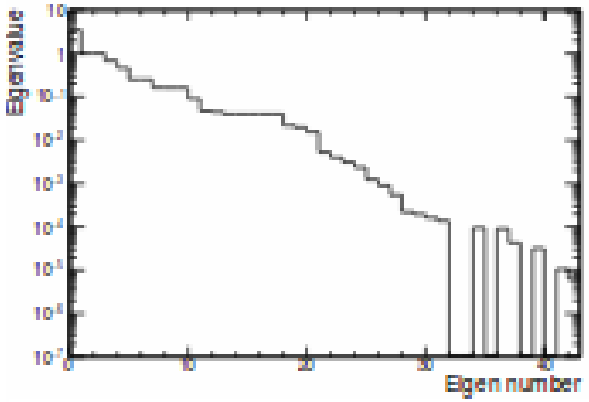
```cpp
/// Absolute energy scale systematic
class EnergyScaleSyst: public ISyst
{
public:
  std::set<std::string> Requires() const override
  {
    return {"dune.Ev_reco"};
  }
  std::string ShortName() const override {return "eScale";}
  std::string LatexName() const override {return "Energy Scale";}

  void Shift(double sigma,
             Restorer& restore,
             caf::StandardRecord* sr, double& weight) const override
  {
    restore.Add(sr->dune.Ev_reco);

    const double scale = 1 + .02*sigma;
    sr->dune.Ev_reco *= scale;
  }
};

static const EnergyScaleSyst kEnergyScaleSyst;
```

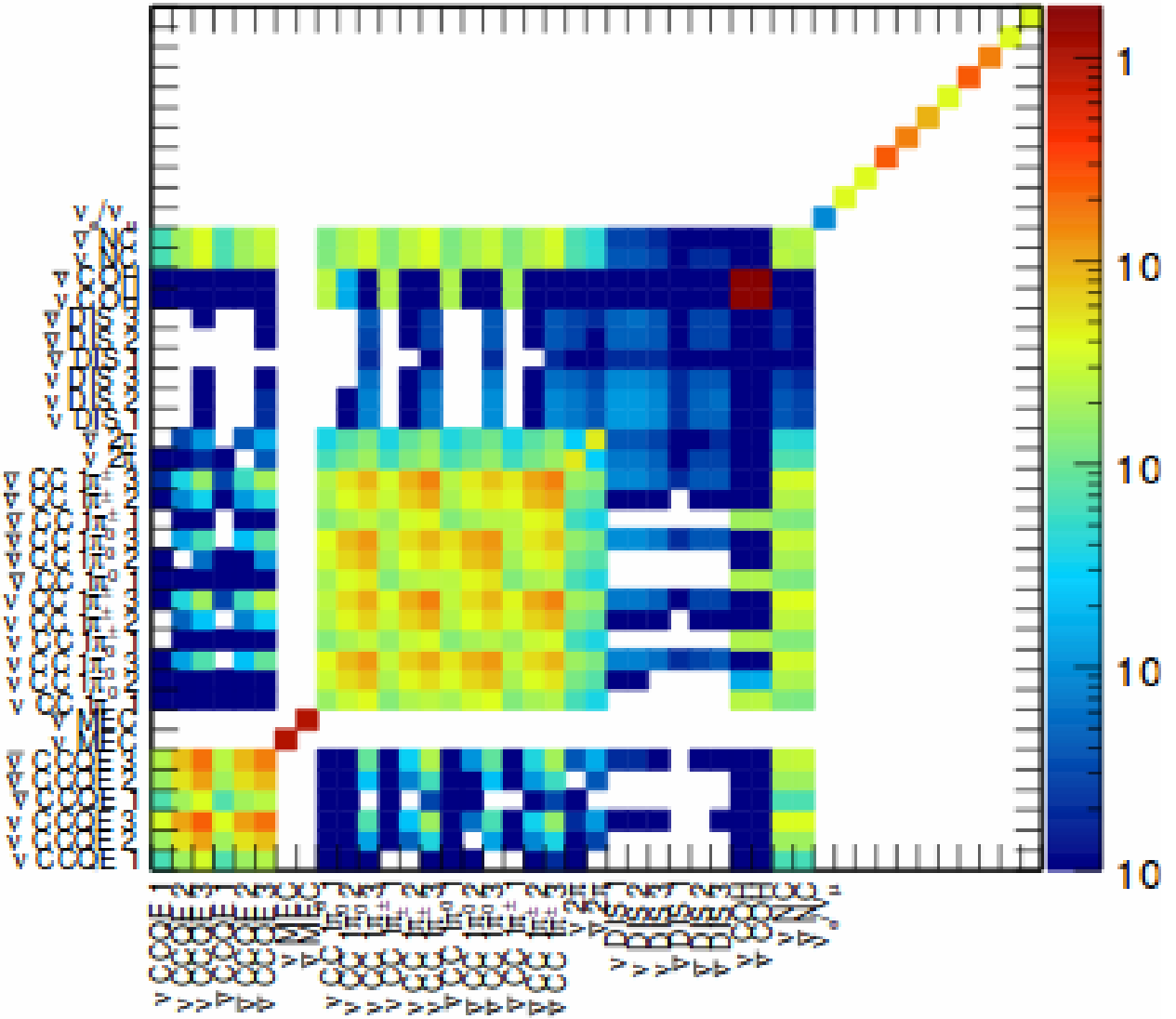
```cpp
/// 5% normalization syst for NC on numu analysis
class NCSyst: public ISyst
{
public:
  std::set<std::string> Requires() const override
  {
    return {"dune.Ev","dune.Ev_reco", "dune.ccnc"};
  }
  std::string ShortName() const override {return "NC";}
  std::string LatexName() const override {return "NC Norm Syst";}

  void Shift(double sigma,
             Restorer& restore,
             caf::StandardRecord* sr, double& weight) const override
  {
    if(sr->dune.ccnc == 1) weight *= 1 + .05*sigma;
  }
};

static const NCSyst kNCSyst;
```

- An `ISyst` modifies or weights an event record as it's being loaded in
- Optional argument to `Spectrum` constructor taking a `SystShifts`

- `PredictionInterp` takes Predictions with various systematics applied and uses cubic interpolation between them
- If you only need scale systematics try `PredictionScaleComp`
- NOvA heritage means this machinery is a bit FD-centric (though ND sterile analyses have worked out), focus of upcoming development

Cross-sections





- Scale each vector by corresponding eigenvalue $\vec{v}_i \rightarrow \sqrt{\lambda_i}\vec{v}_i$
- Check normalization: $\vec{v}_i^T M^{-1} \vec{v}_i = 1$
- Check orthogonality: $(\vec{v}_i + \vec{v}_j)^T M^{-1} (\vec{v}_i + \vec{v}_j) = 2$
- Divide by flux to express as fractional error and save to root file