Some updates on DUNE-prism (Oct.30 2017)

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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

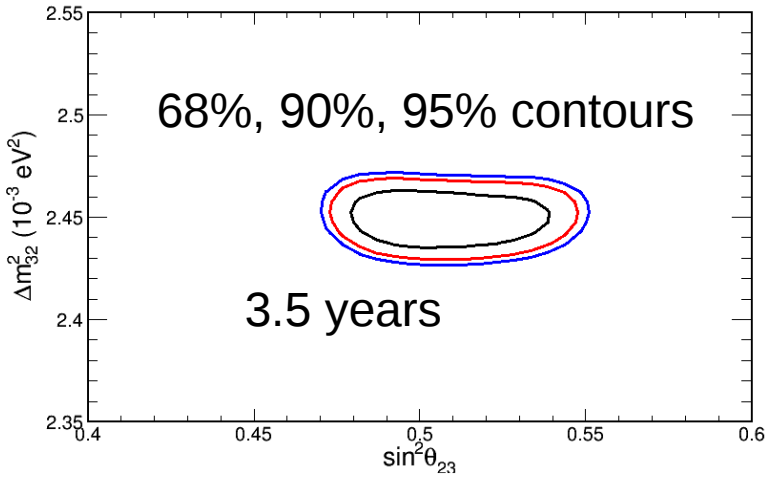
```
PredictionInterp& predNDFHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("nd_fhc")).release();
PredictionInterp& predNDRHC = *ana::LoadFrom<PredictionInterp>(fin.GetDirectory("nd_rhc")).release();

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.

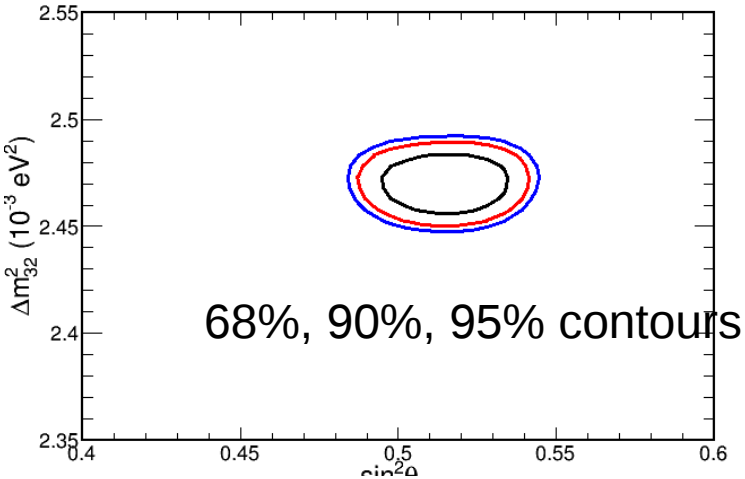
Last week

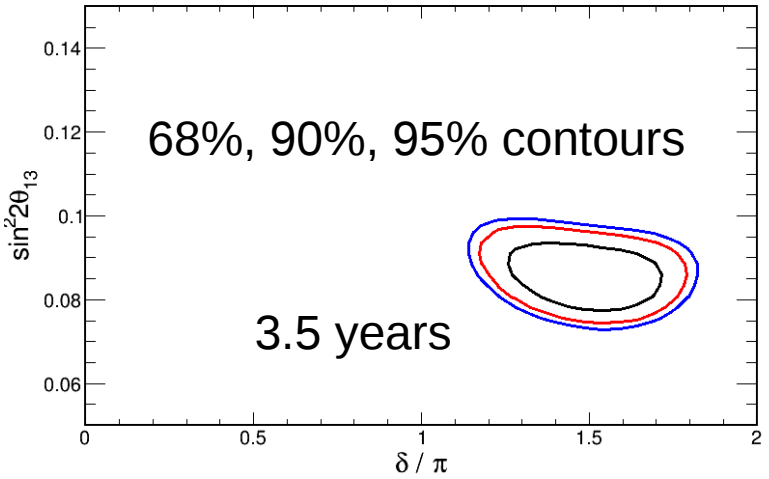
20% missing PE 3.5 years

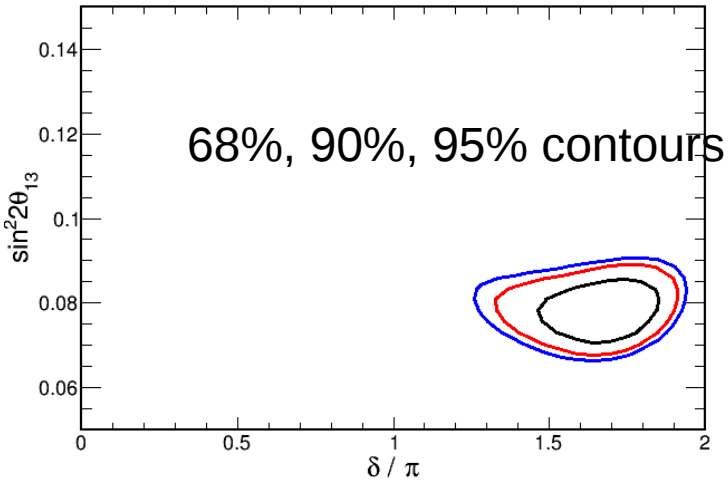
True



10% missing PE





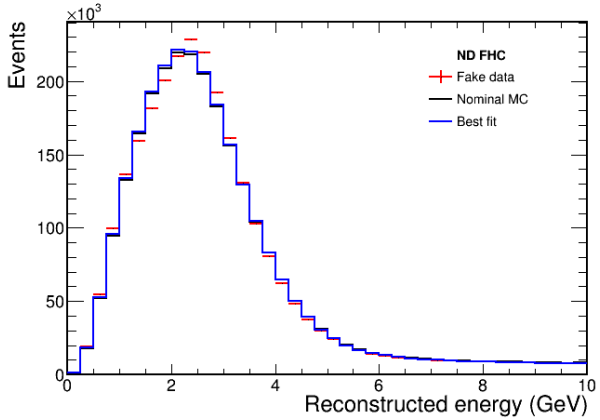


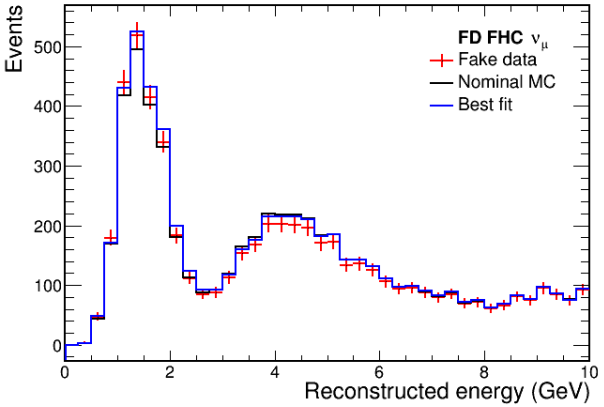
- The oscillation phase spaces change, but how ND performs?

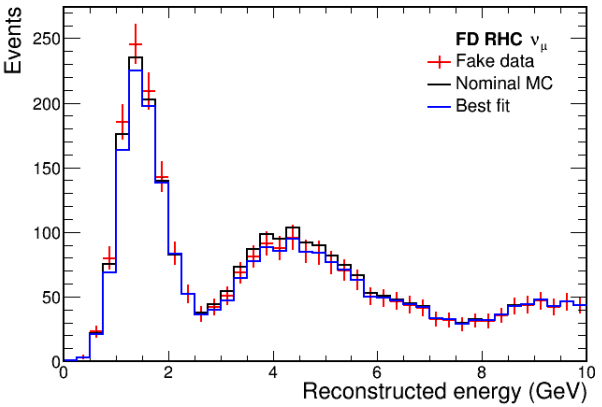
Last week

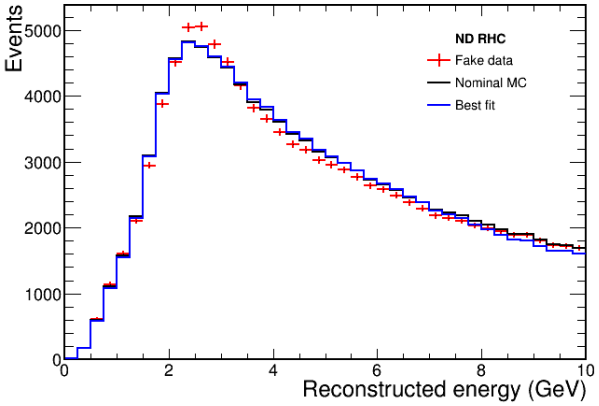
20% missing PE 3.5 years

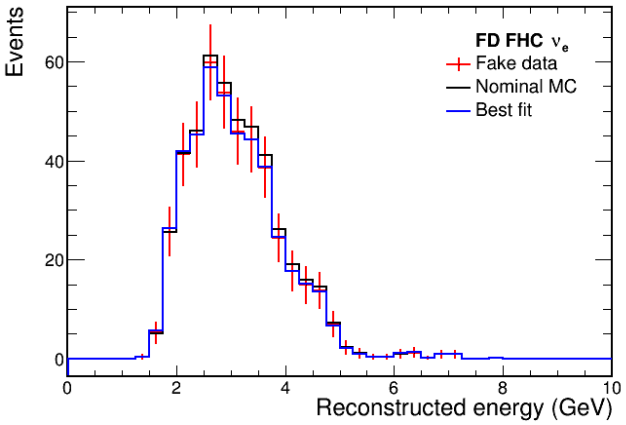
LL value: ND only fit: 4084 FD+ND: 4108 FD only fit: 9

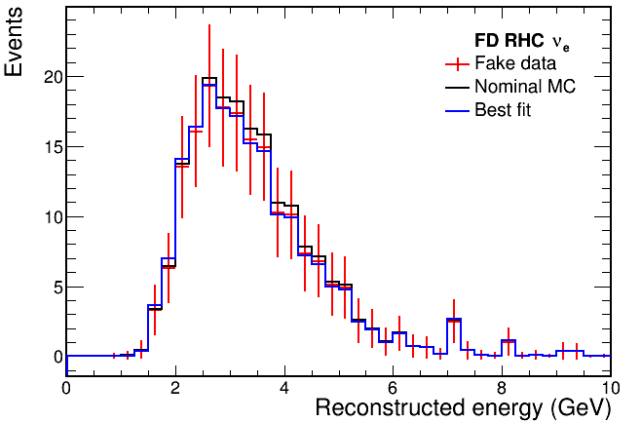












- Missing hadronic energy bring us a disaster, however, not only in FD, but in ND..
- I have major Xsec and flux systematics in backup slides.

Doing new samples with new dials

Use GENIE v.2.10.10 to generate :

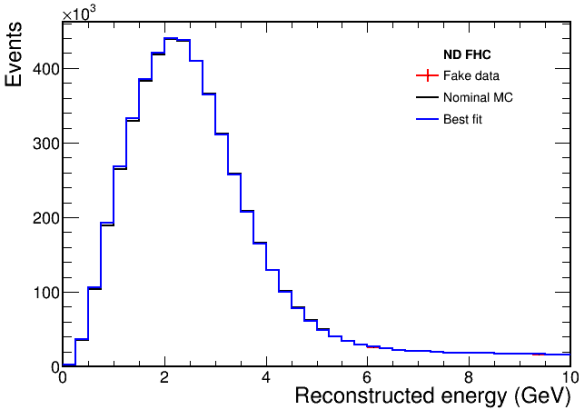
1. 20% missing proton energy sample for numu, numubar, nue and nuebar.
2. 20% missing pi0 and pi+/- energy sample for numu, numubar, nue and nuebar.
3. 10% missing muon energy sample for numu, numubar, nue and nuebar.

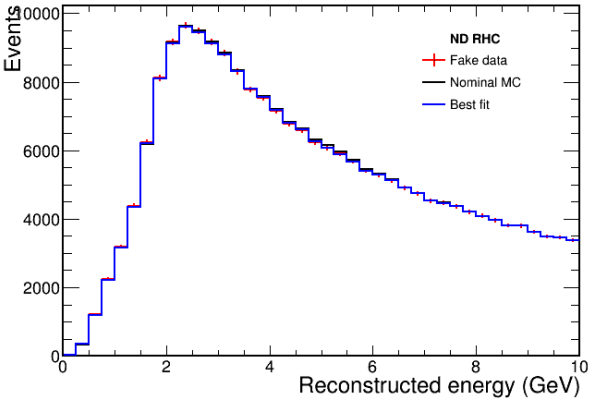
- Those samples are fit with Xsec+Flux systematics.

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

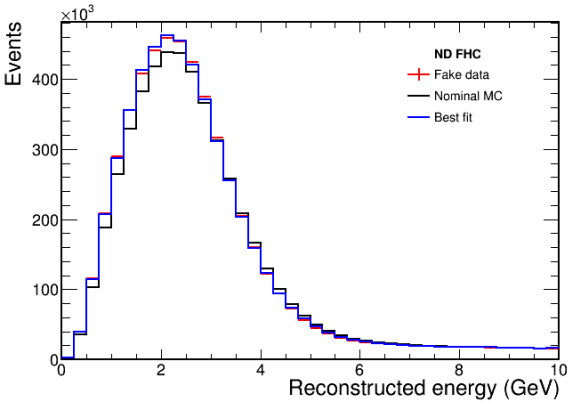
ND only fit with Xsec+Flux systematics

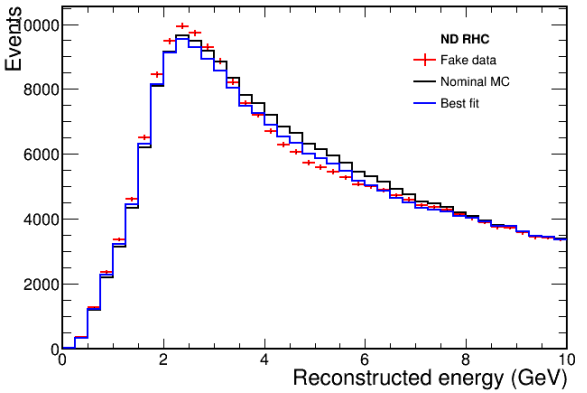
Missing Proton E



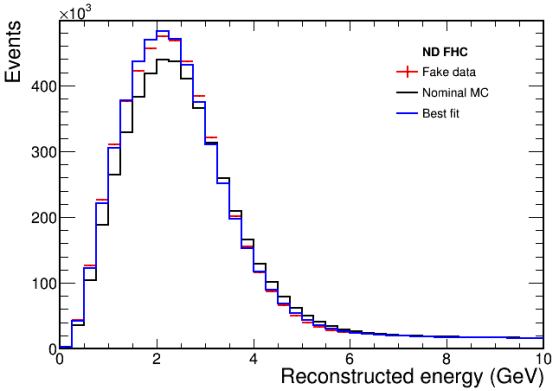


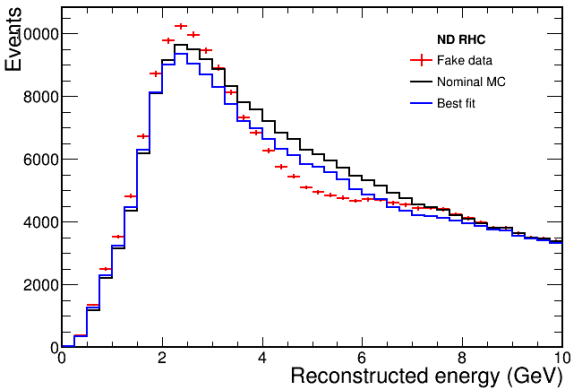
Missing Pion E





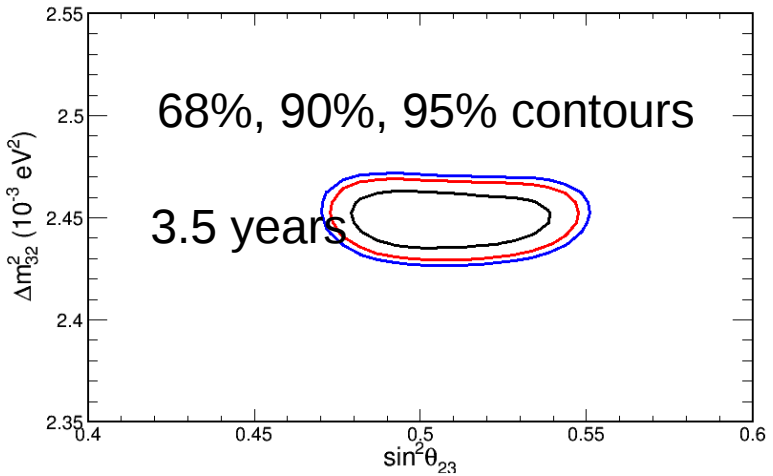
Missing Muon E



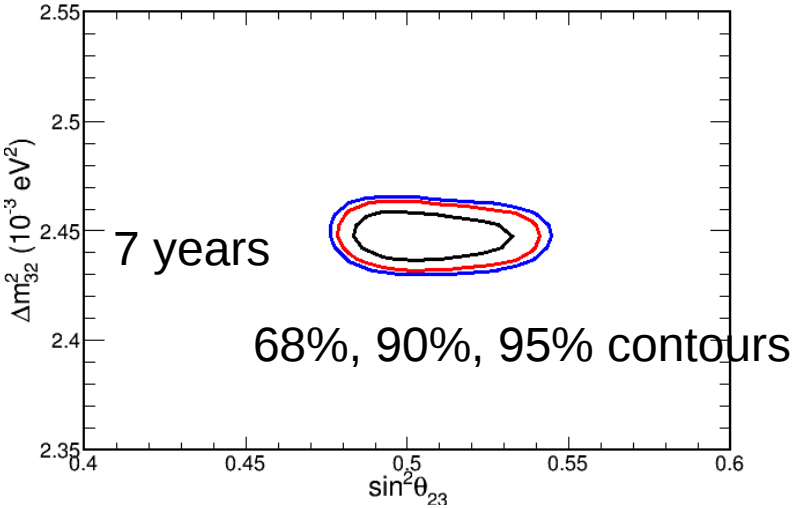


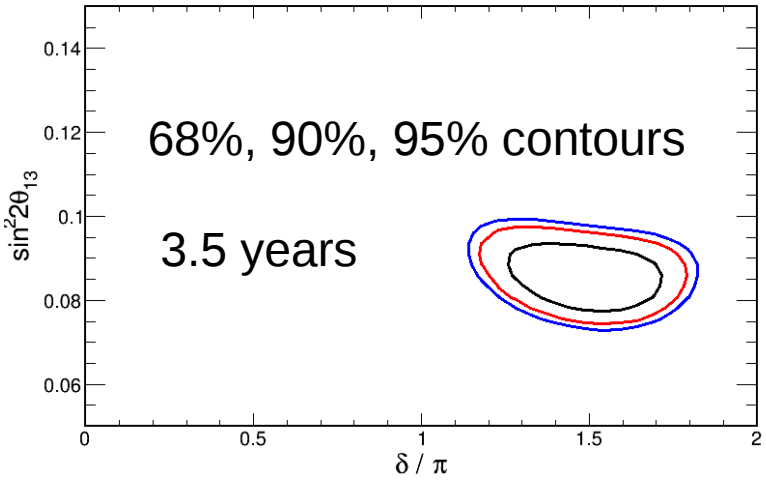
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

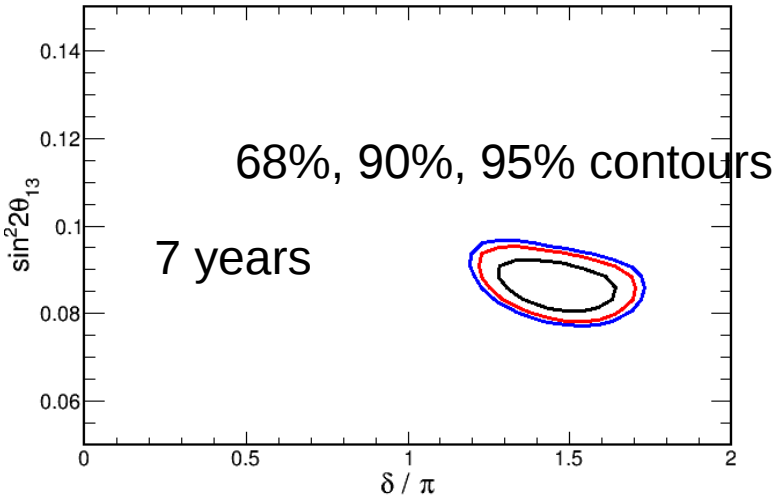
True



Varied







FD+ND fit with Xsec+Flux systematics
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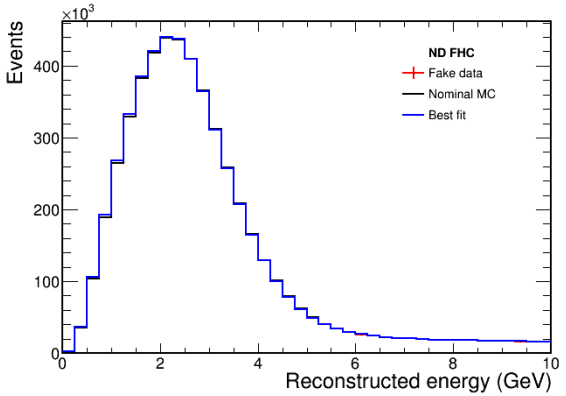

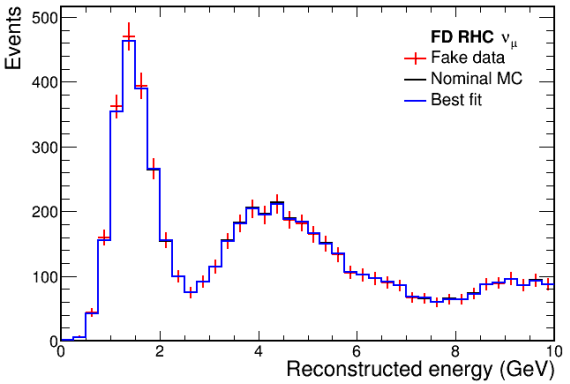

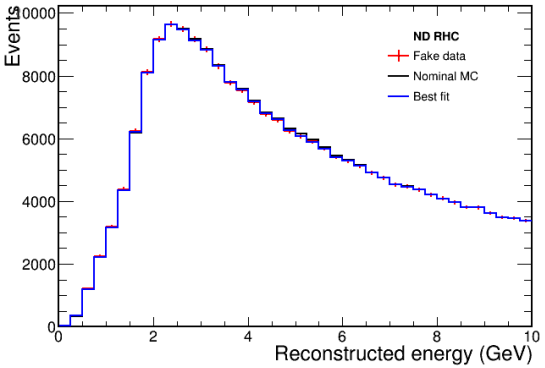

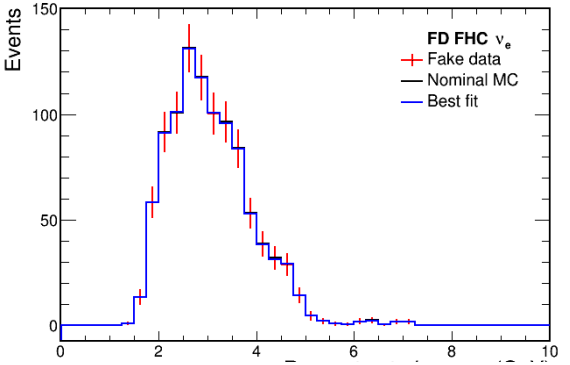

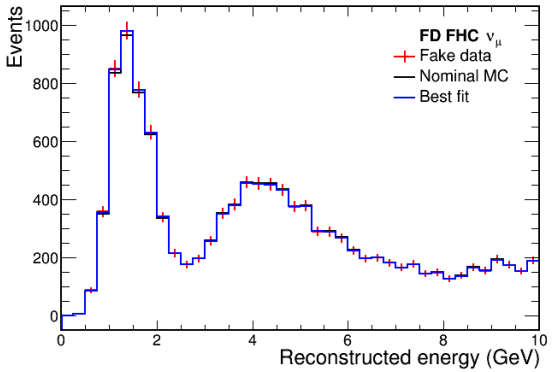

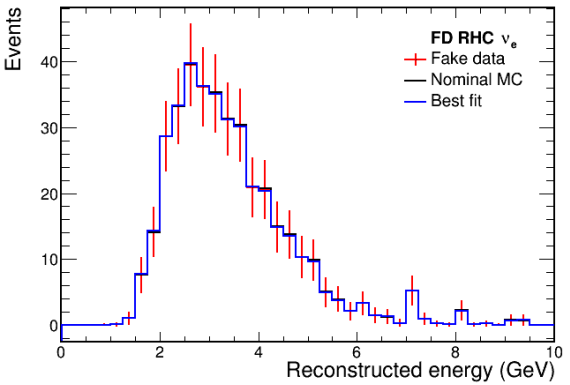


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Syst. shift  nubar_ccqe_2_scale 2.21973e-08
Syst. shift  nubar_ccqe_3_scale 6.68951e-09
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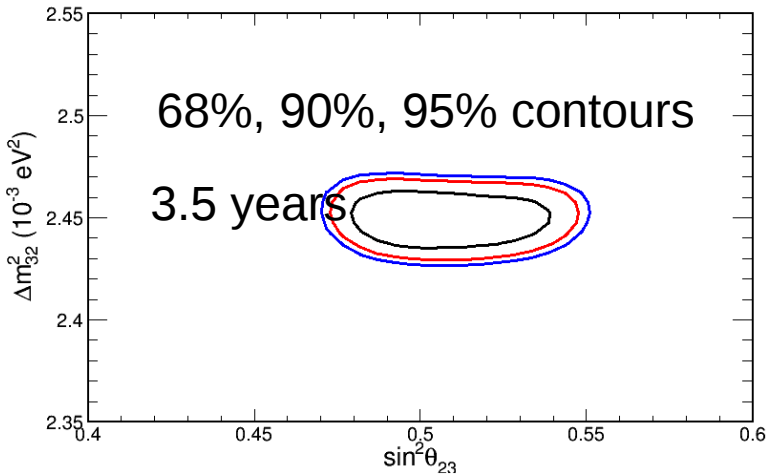
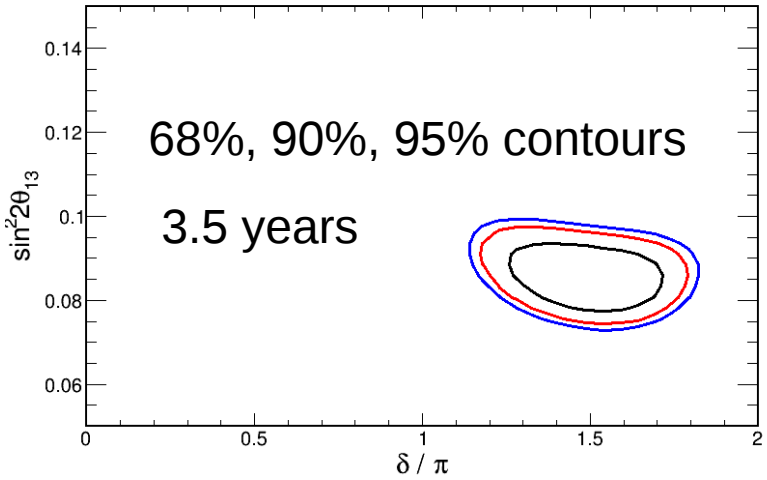
Syst. shift  nu_dis_2_scale -3.77185e-07
Syst. shift  nu_dis_3_scale 4.55557e-07
Syst. shift  nubar_dis_1_scale -4.4686e-07
Syst. shift  nubar_dis_2_scale -1.20103e-06
Syst. shift  nubar_dis_3_scale 8.38118e-07
Syst. shift  nu_coh_scale 3.01116e-08
Syst. shift  nubar_coh_scale -3.01945e-08
Syst. shift  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





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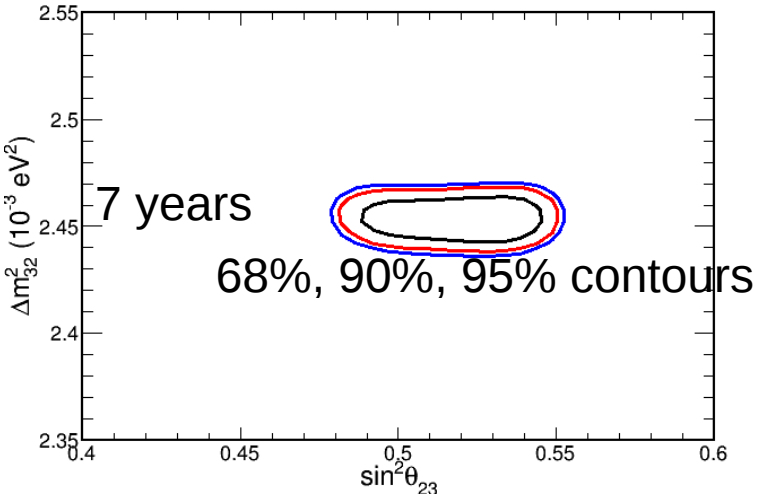
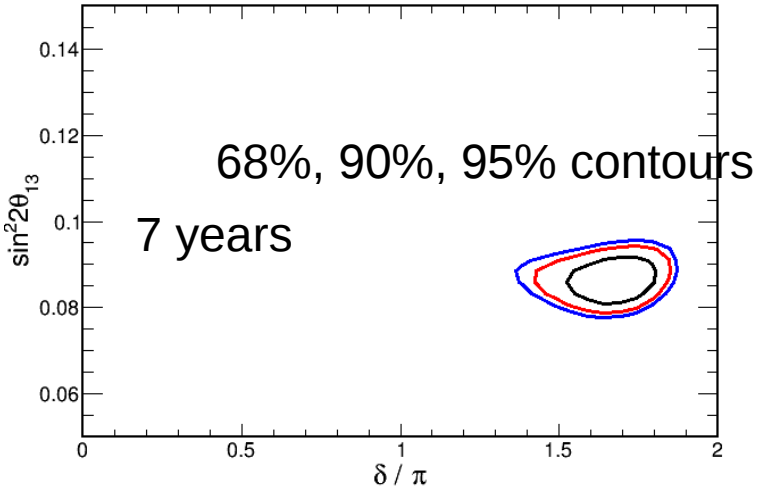
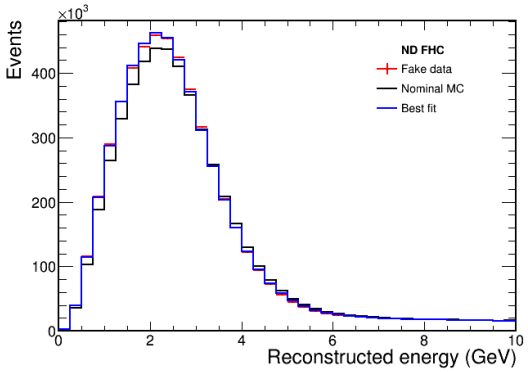
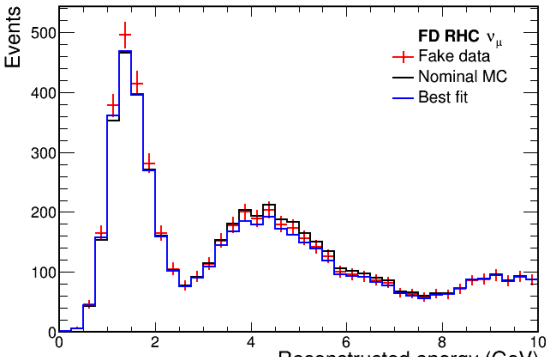
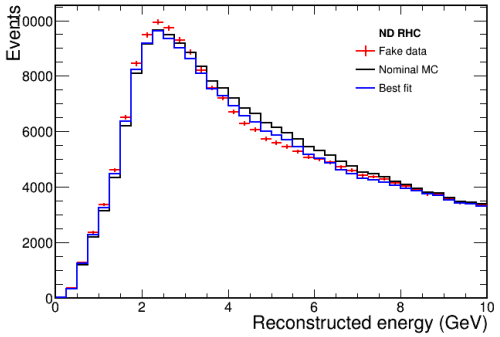


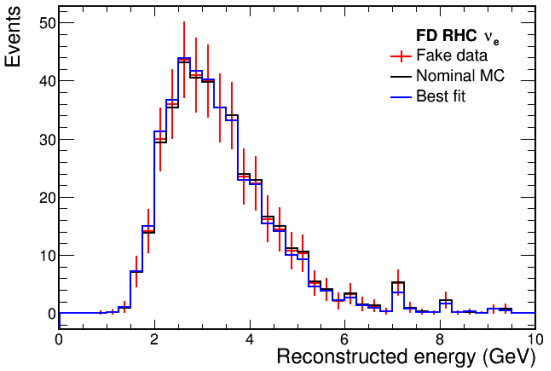


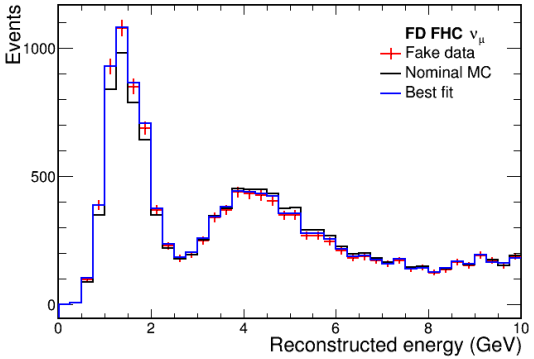
FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

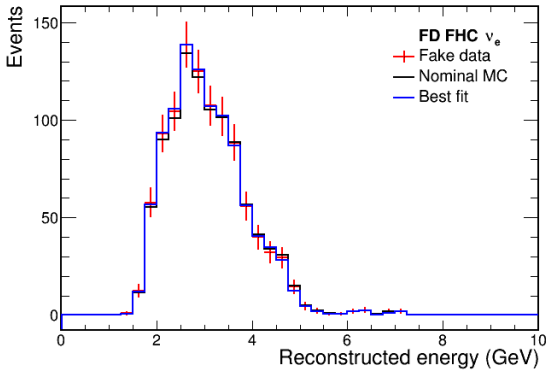













```
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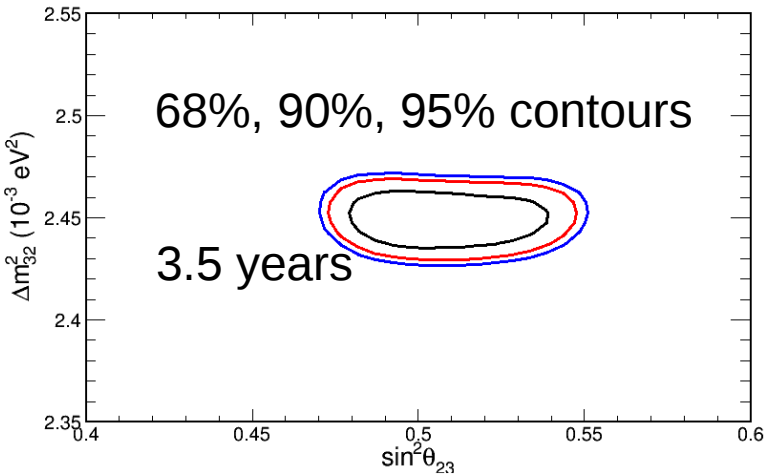
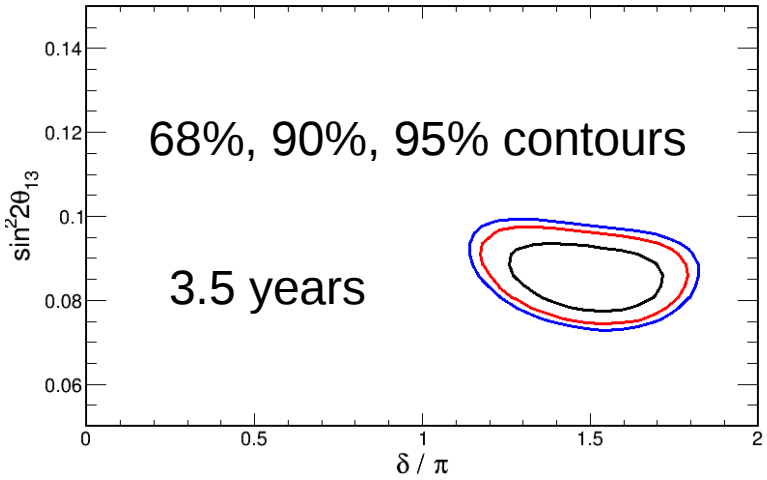
Syst. shift  nubar_coh_scale -7.94545e-05
Syst. shift  nu_nc_scale 0.002949
Syst. shift  nubar_nc_scale -0.000987732
Syst. shift  flux15 -2.22066
Syst. shift  flux16 -0.977563
Syst. shift  flux17 -0.669039
Syst. shift  flux18 -0.131174
Syst. shift  flux19 -3.82132
Syst. shift  eScale -0.320277
Syst. shift  eRes -0.00487637
True dCP 0pi, best fit -0.918716pi, chi2 852.392 delta=0 chi2 850.874
```

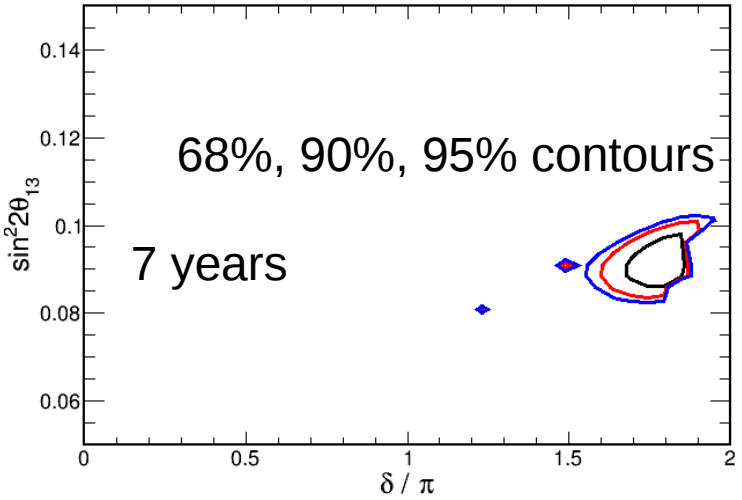
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

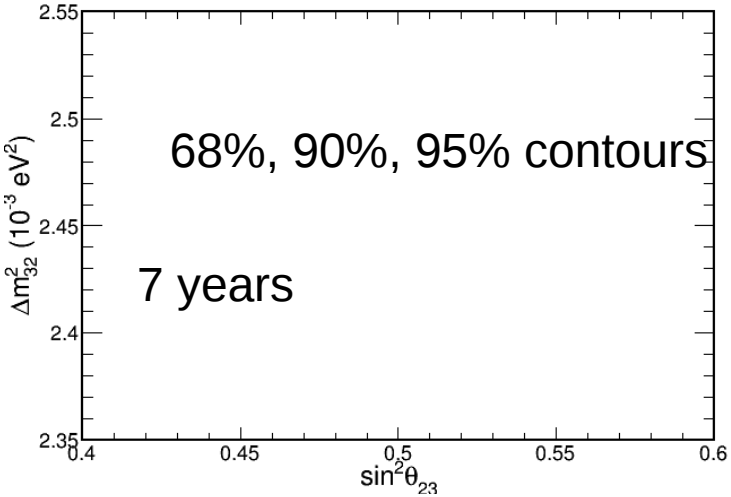
True



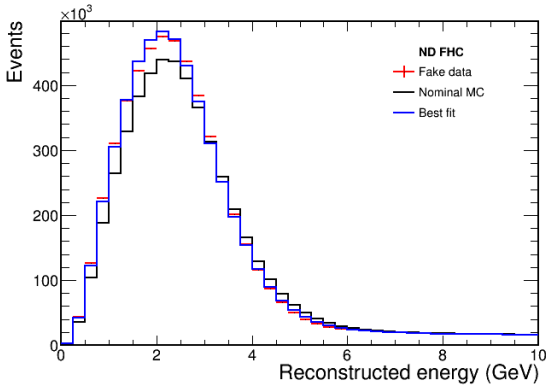


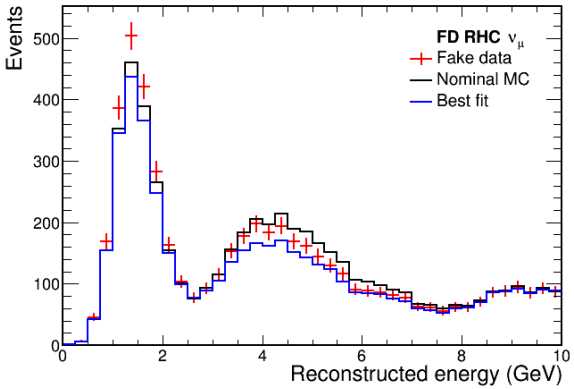
Varied

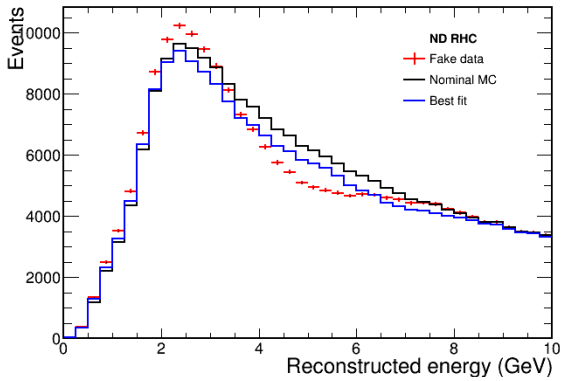


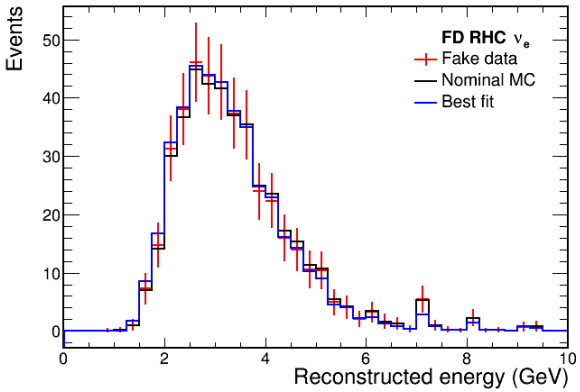


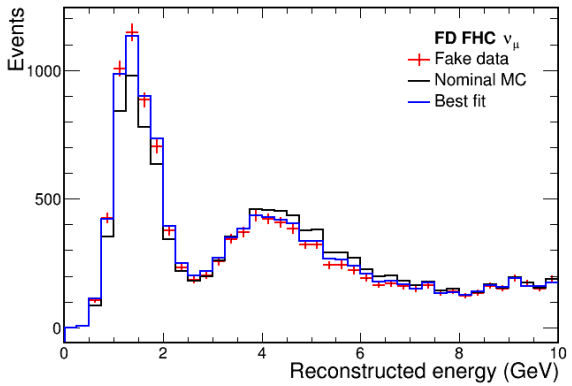
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

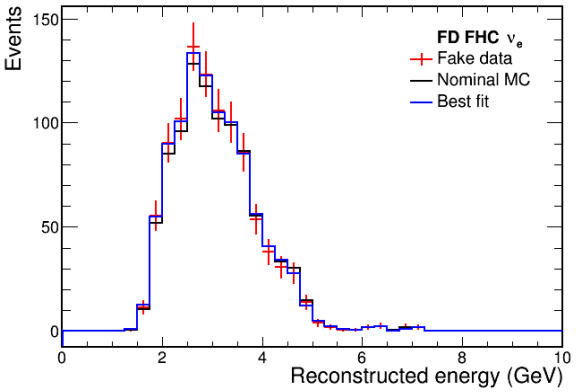










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Syst. shift  nu_ccqe_2_scale 5.48346e-05
Syst. shift  nu_ccqe_3_scale -1.31682e-05
Syst. shift  nubar_ccqe_1_scale 0.000240049
Syst. shift  nubar_ccqe_2_scale 4.32893e-05
Syst. shift  nubar_ccqe_3_scale 2.31329e-05
Syst. shift  nu_MEC_dummy_scale 2.63595e-10
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
```
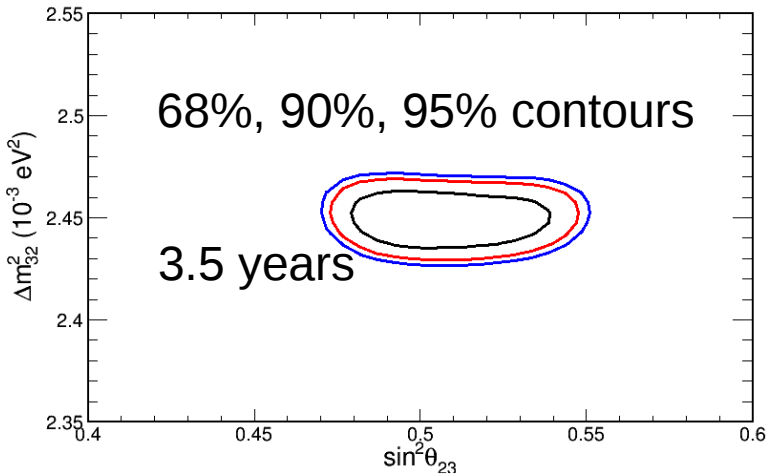
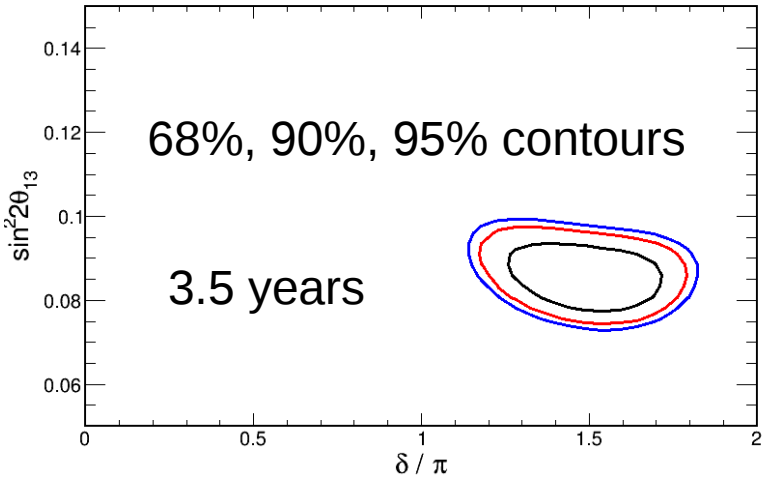

I add “other two dials”

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

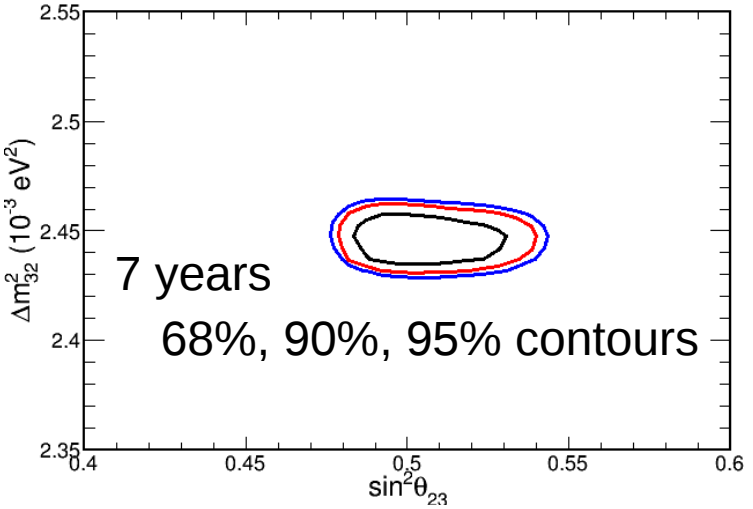
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

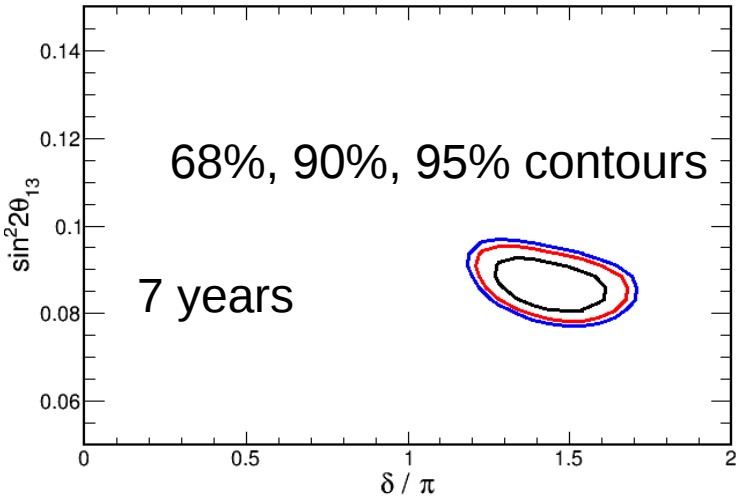
True



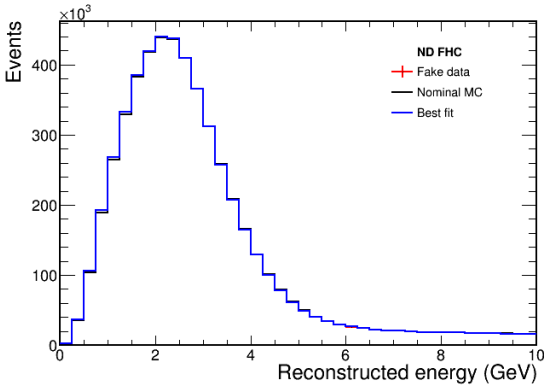


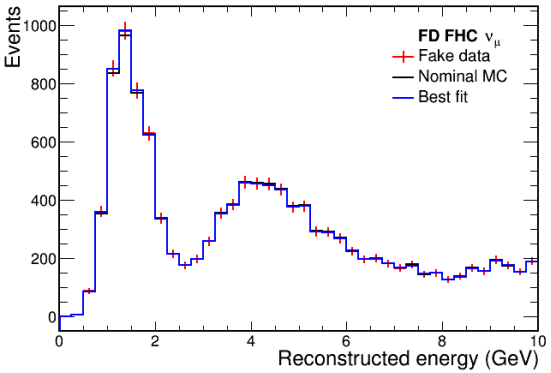
Varied

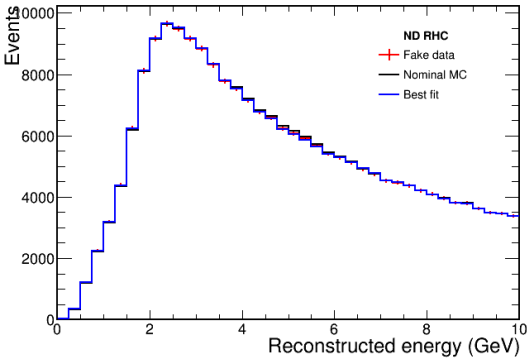


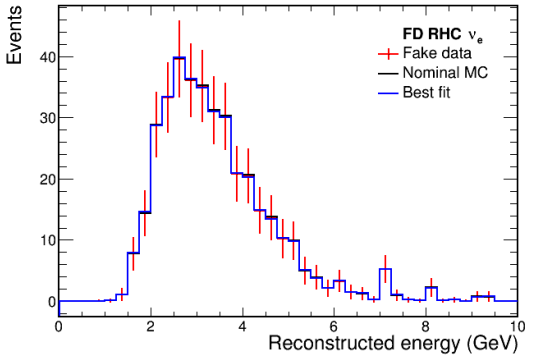


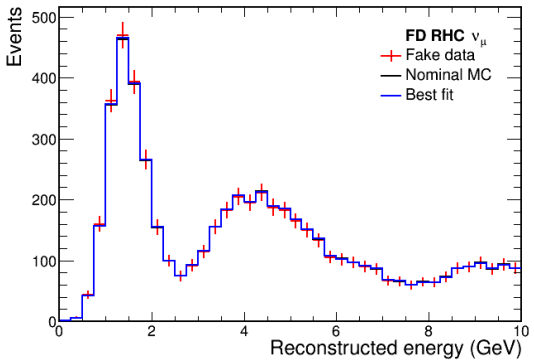
FD+ND fit with Xsec+Flux systematics
20% Missing proton energy

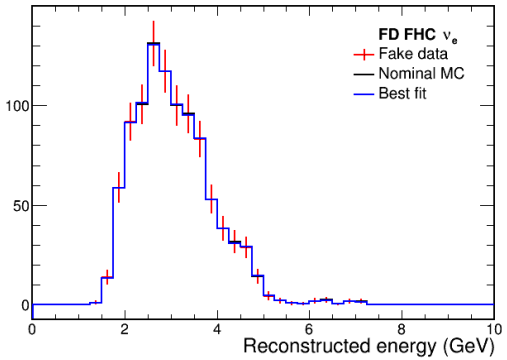










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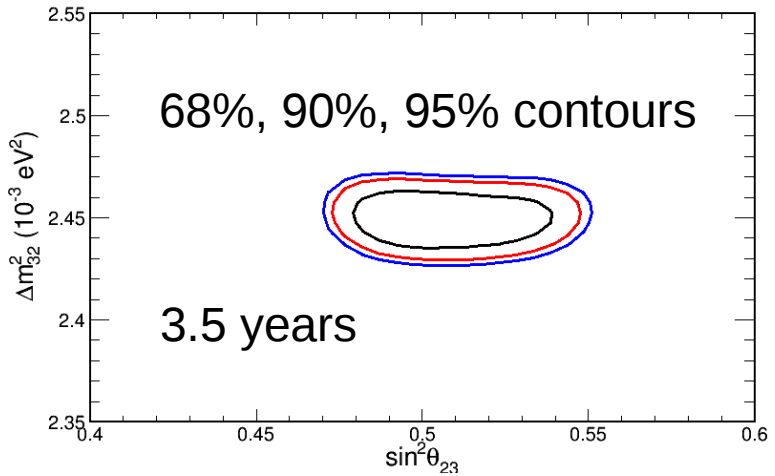
Syst. shift  nu_ccqe_1_scale 5.49259e-08
Syst. shift  nu_ccqe_2_scale 4.34366e-08
Syst. shift  nu_ccqe_3_scale 2.47995e-09
Syst. shift  nubar_ccqe_1_scale -5.47001e-08
Syst. shift  nubar_ccqe_2_scale -2.61931e-08
Syst. shift  nubar_ccqe_3_scale 1.09037e-09
Syst. shift  nu_MEC_dummy_scale -3.02539e-14
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
Syst. shift  nubar_cc1piz_1_scale 1.60381e-07
Syst. shift  nubar_cc1piz_2_scale 1.25608e-07
Syst. shift  nubar_cc1piz_3_scale -6.5047e-08
Syst. shift  nubar_cc1pic_1_scale 2.21544e-08
Syst. shift  nubar_cc1pic_2_scale -1.81241e-08
Syst. shift  nubar_cc1pic_3_scale 3.16438e-08
Syst. shift  nu_2pi_scale 0.000233892
Syst. shift  nubar_2pi_scale 1.35304e-05
Syst. shift  nu_dis_1_scale 5.25439e-08
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

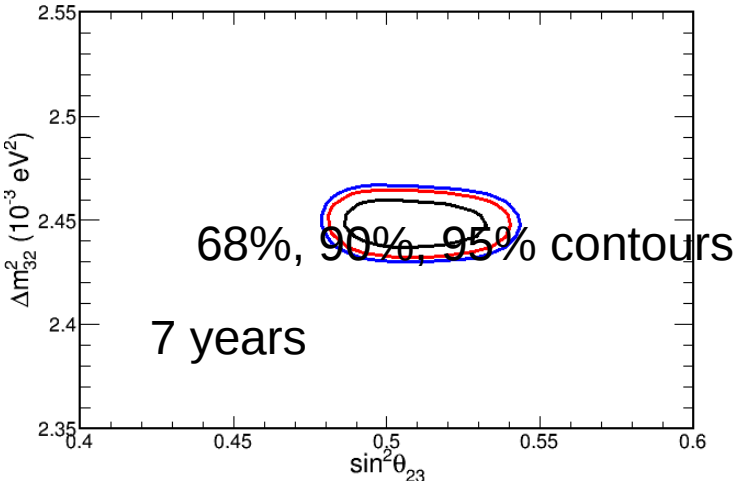
Missing muon

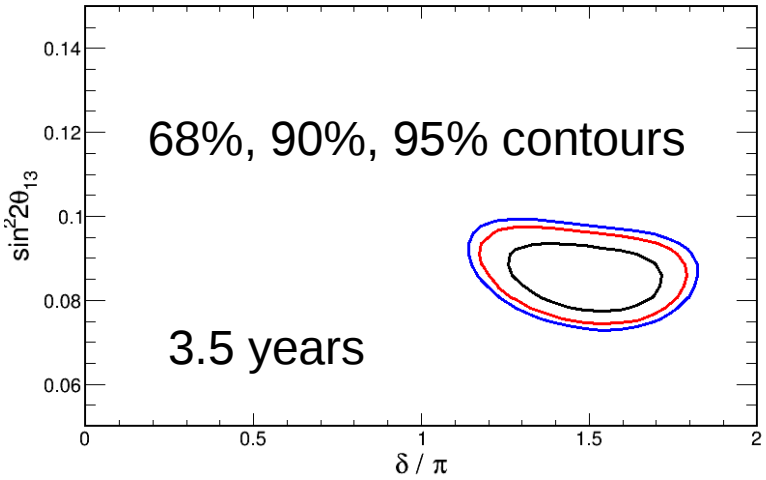
FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

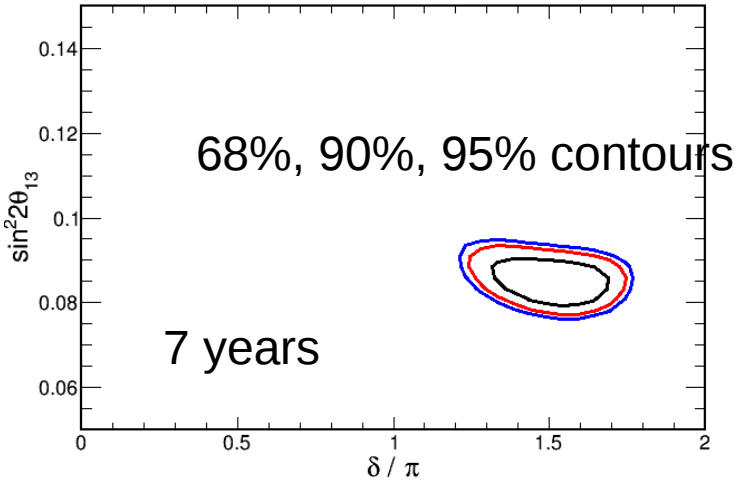
True



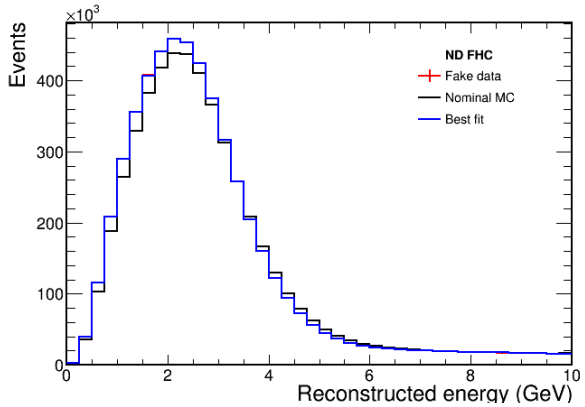
Varied

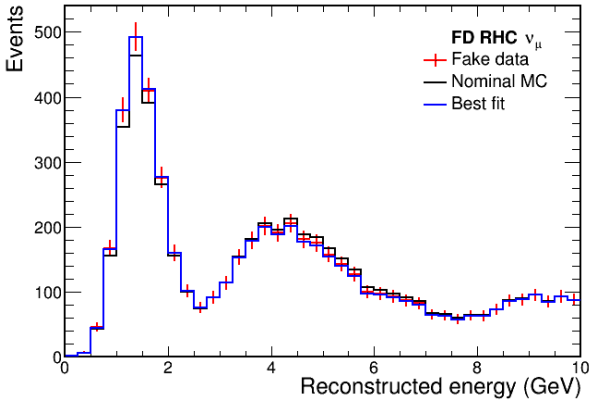


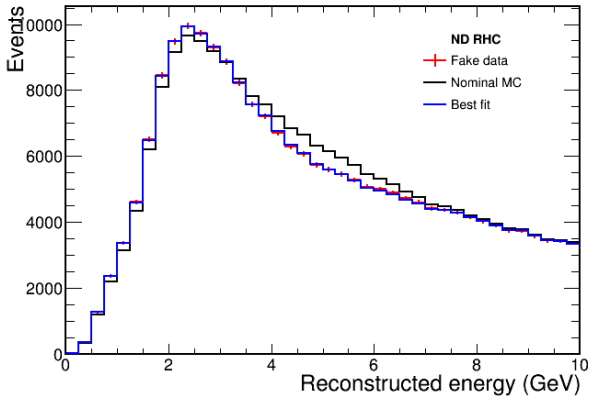


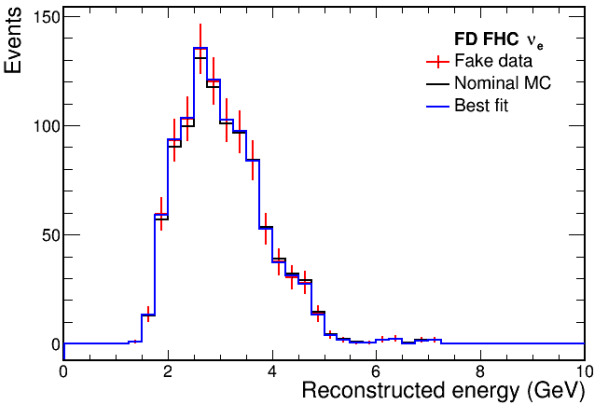


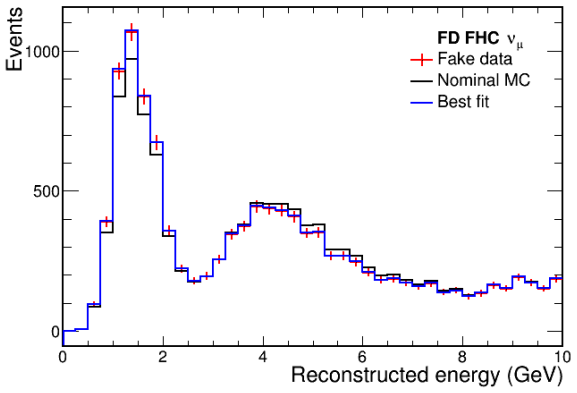
FD+ND fit with Xsec+Flux systematics
20% Missing pion energy

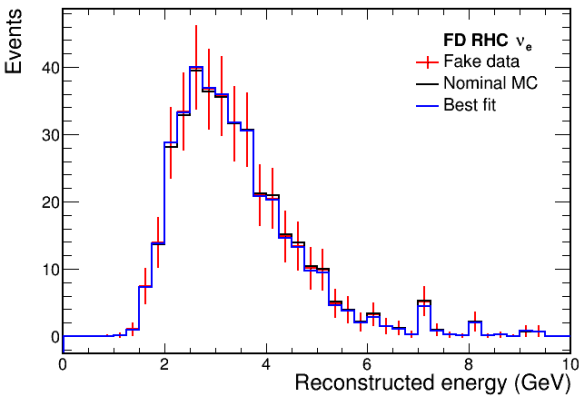










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Syst. shift  nu_ccqe_2_scale -3.44306e-05
Syst. shift  nu_ccqe_3_scale -3.58878e-06
Syst. shift  nubar_ccqe_1_scale 0.000131666
Syst. shift  nubar_ccqe_2_scale 3.78016e-05
Syst. shift  nubar_ccqe_3_scale -4.14354e-07
Syst. shift  nu_MEC_dummy_scale 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
Syst. shift  nubar_cc1piz_1_scale -0.000219962
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
```
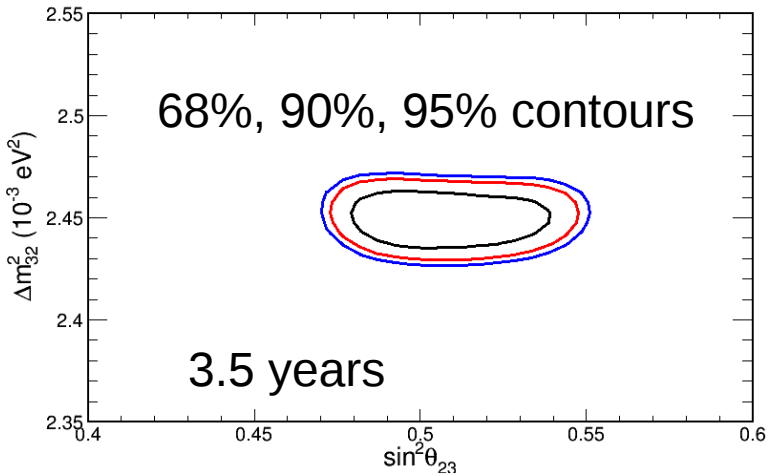

Missing proton

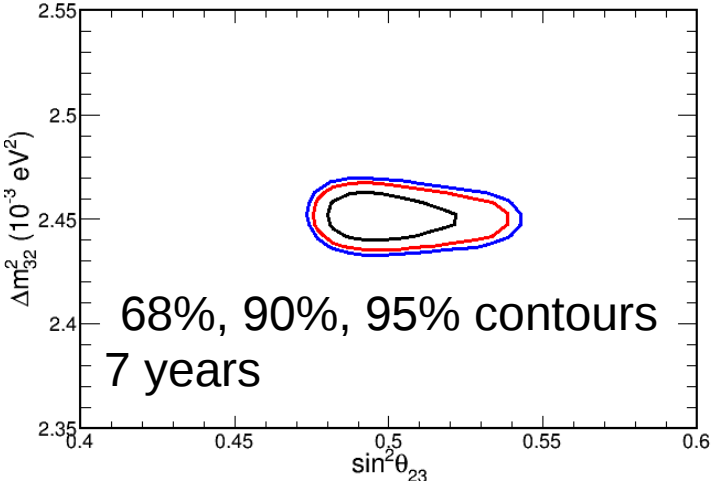
Missing muon

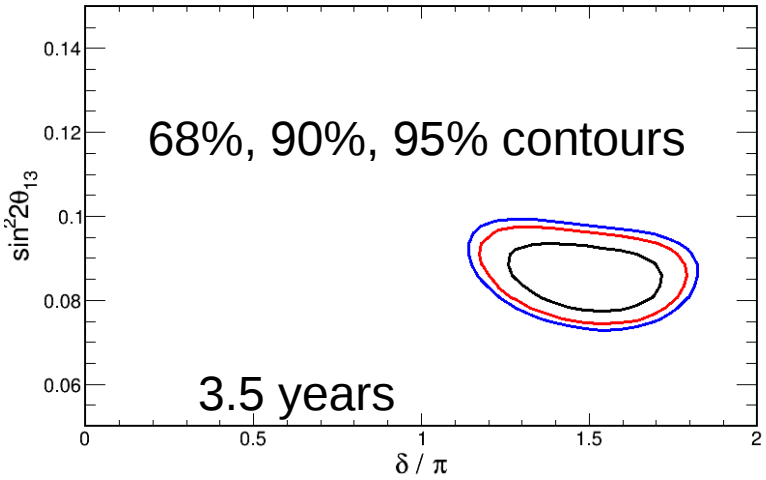
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

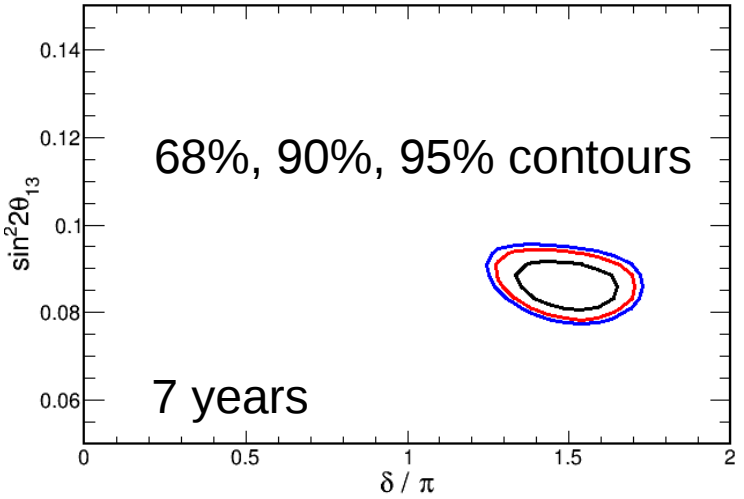
True



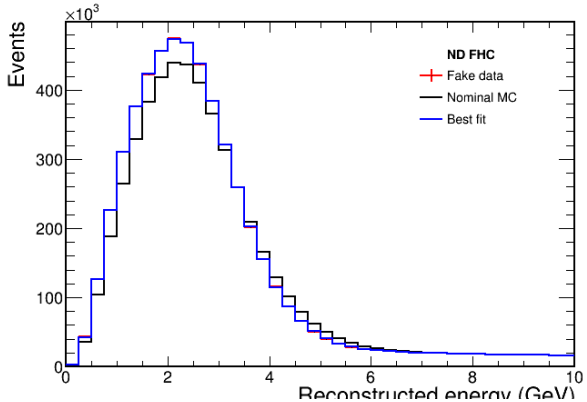
Varied

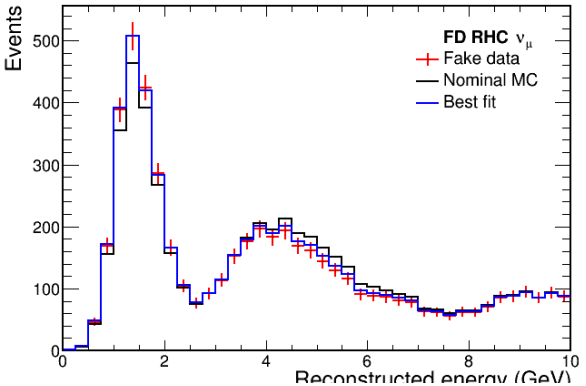


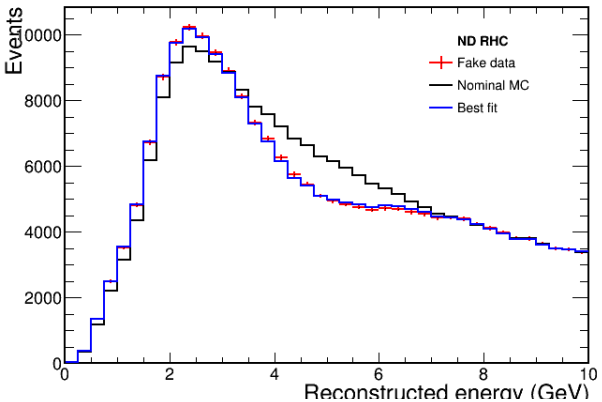


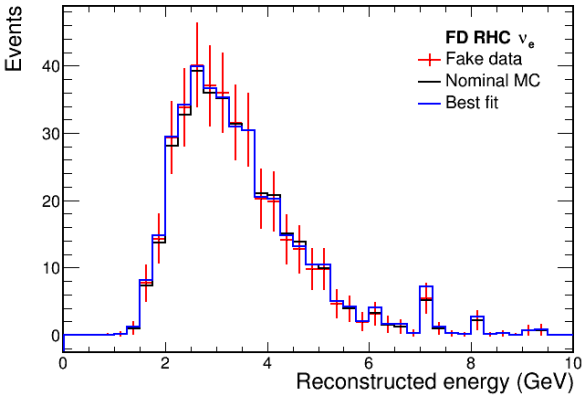


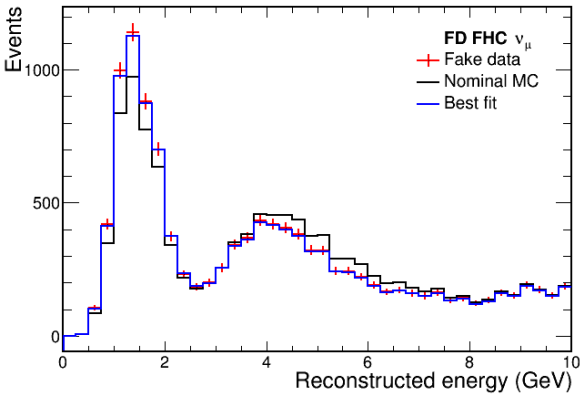
FD+ND fit with Xsec+Flux systematics
10% Missing muon energy

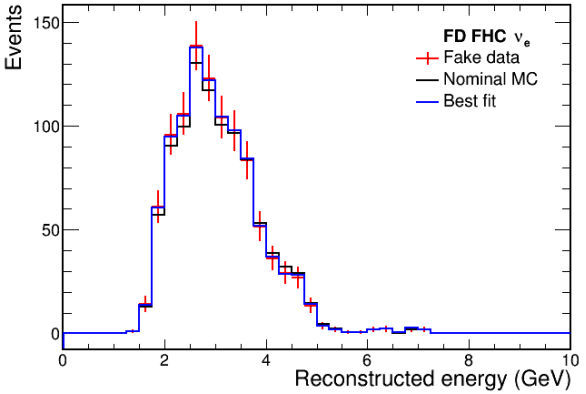













```
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Syst. shift  nu_ccqe_3_scale 7.33046e-06
Syst. shift  nubar_ccqe_1_scale -0.00028082
Syst. shift  nubar_ccqe_2_scale -8.07185e-05
Syst. shift  nubar_ccqe_3_scale 1.96024e-06
Syst. shift  nu_MEC_dummy_scale -4.75599e-08
Syst. shift  nubar_MEC_dummy_scale -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
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Syst. shift  nubar_cc1piz_2_scale 0.000413953
Syst. shift  nubar_cc1piz_3_scale -0.000204001
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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.

Backup..

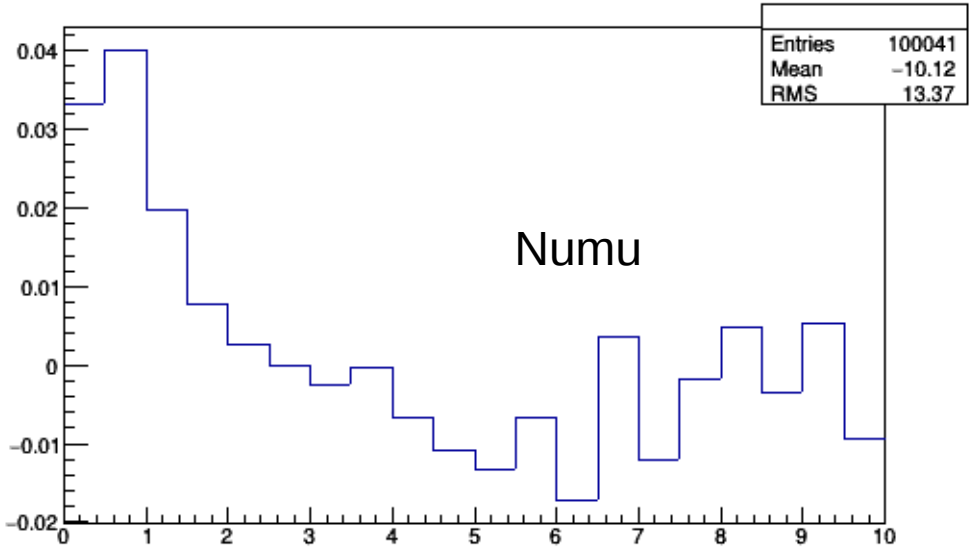
From before

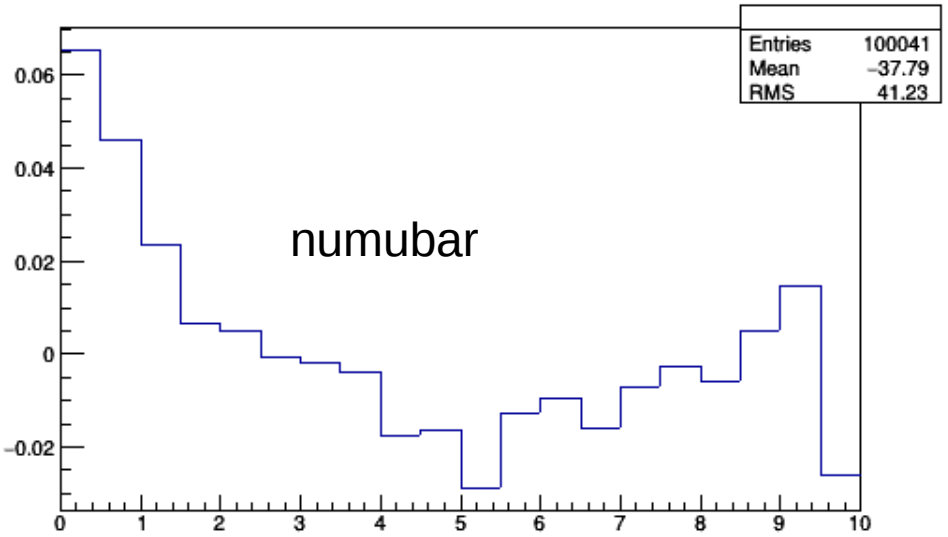
1. Systematics validation:
- With Luke's 20% ME variation: With the same systematic involved
→ recovered

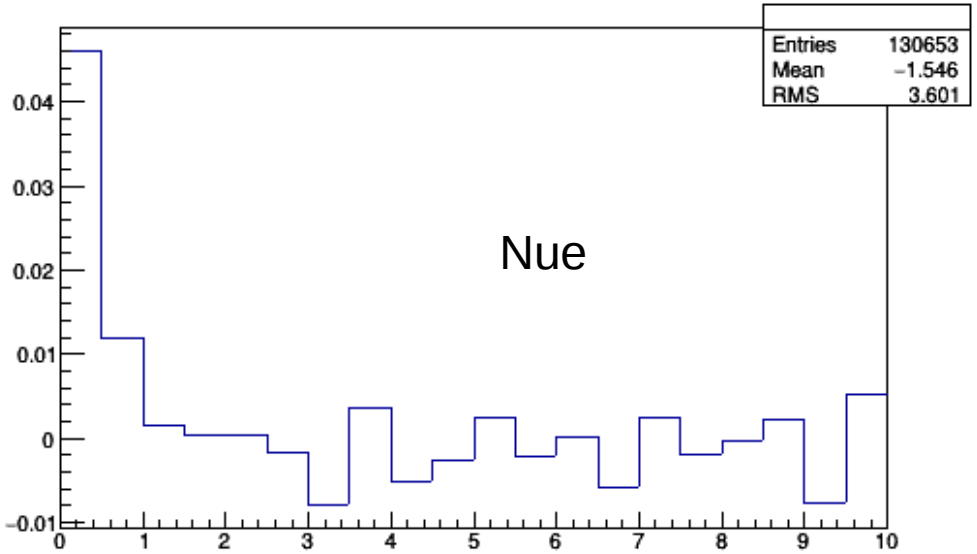
2. Fake data study
- With Luke's 20% ME variation, we only have Xsec systematics (32)
→ not recovered
- With Luke's 20% ME variation, we have Xsec + flux systematics (32+10)
→ not recovered

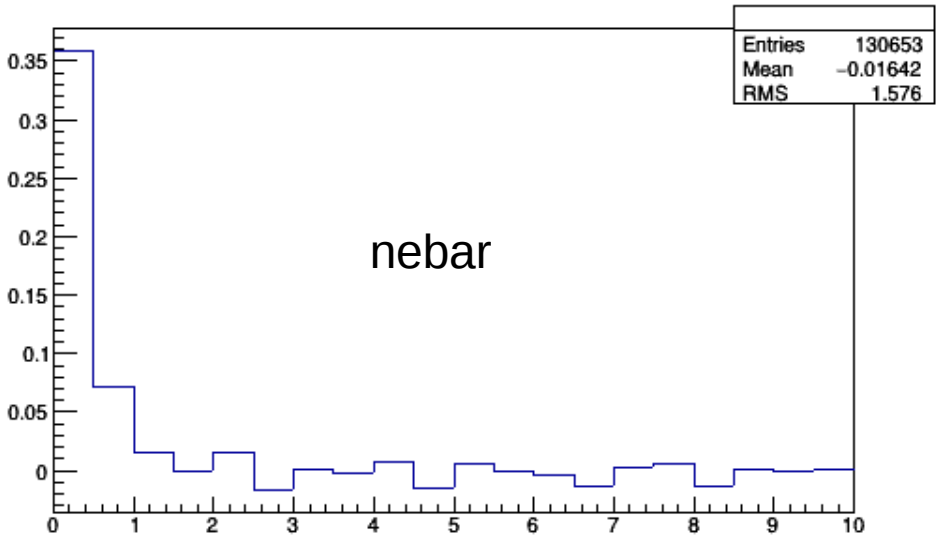
3. Fake data study
- With Nuwro/Genie variation, we only have Xsec systematics (32)
- With Nuwro/Genie variation, we have Xsec + flux systematics (32 + 10)
→ both can largely recover

20% missing proton energy

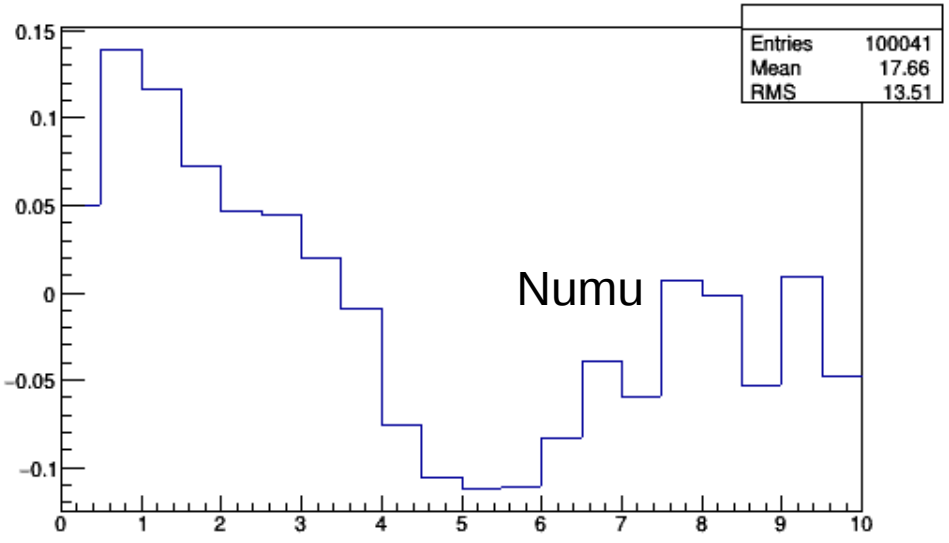


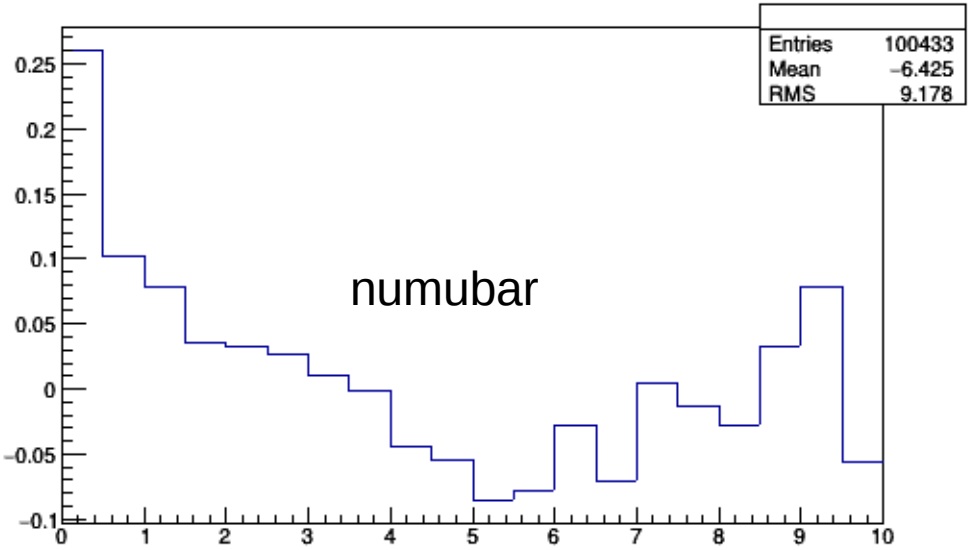


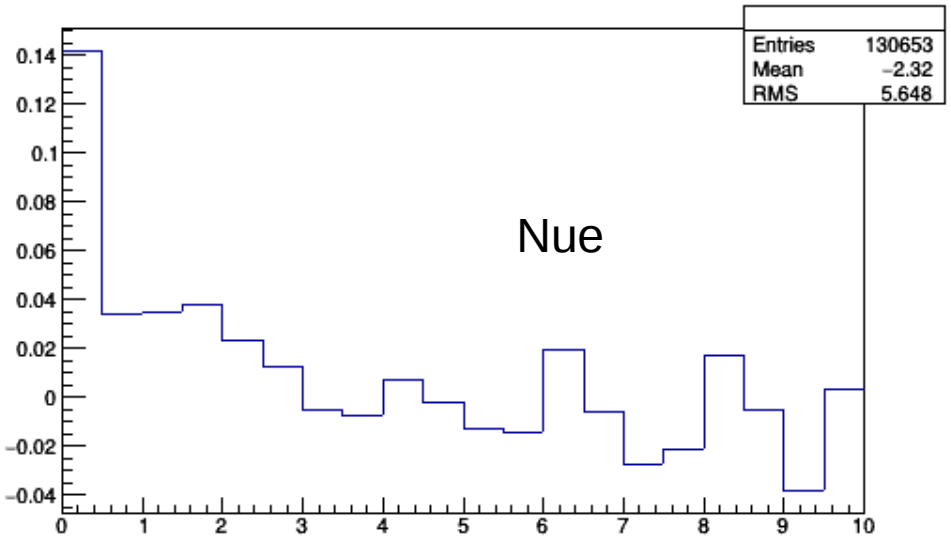


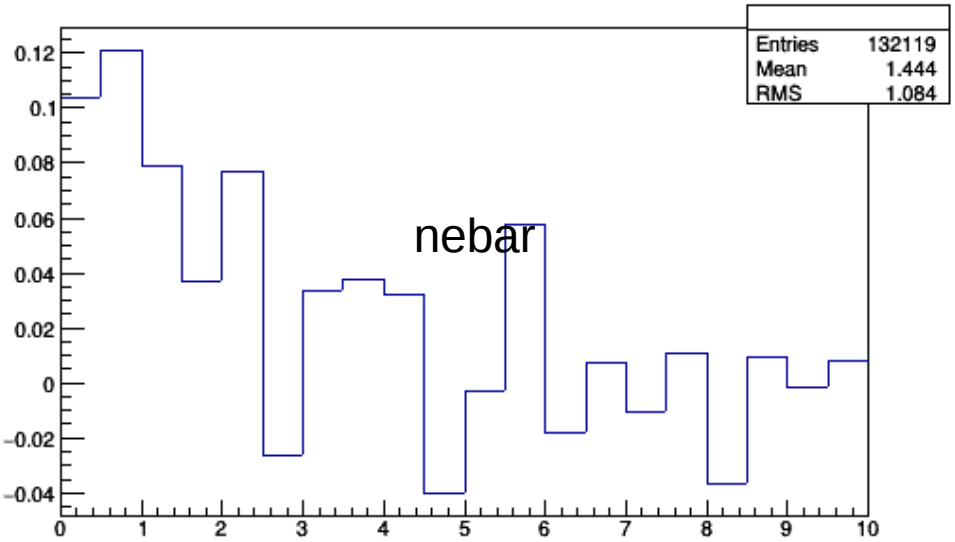


20% missing pion energy

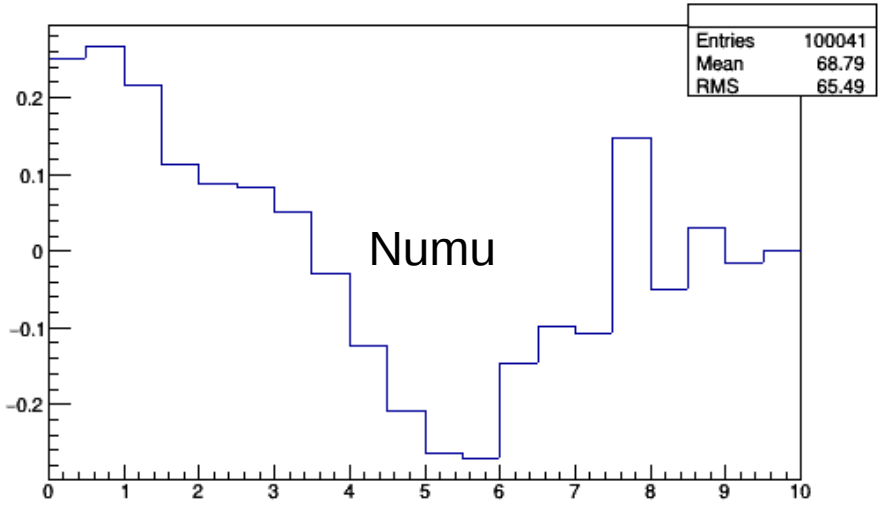


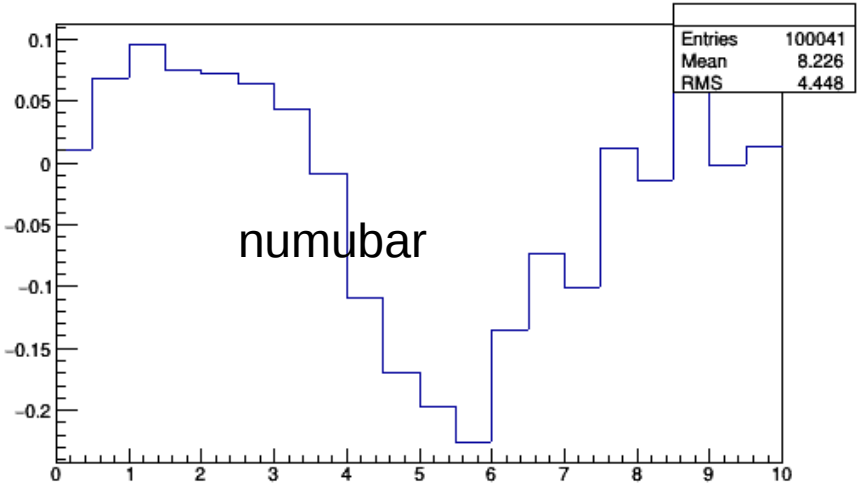


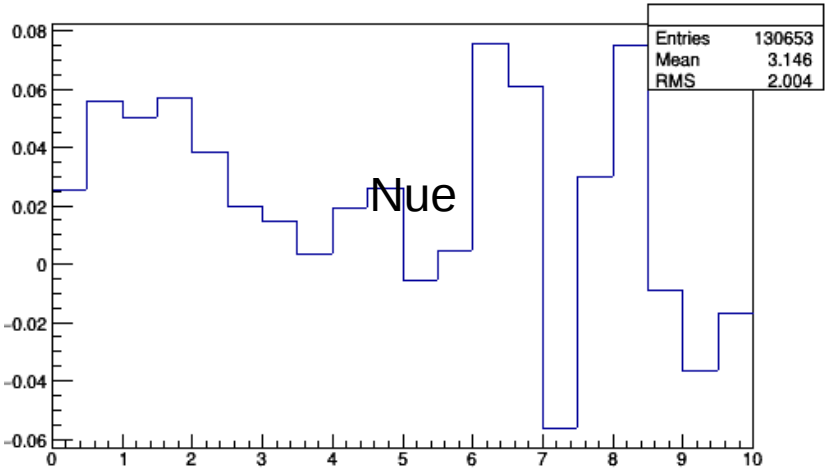


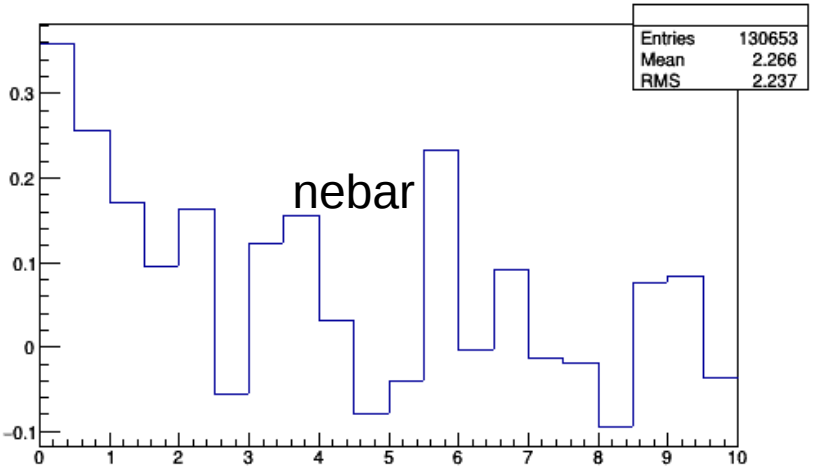


10% missing muon energy

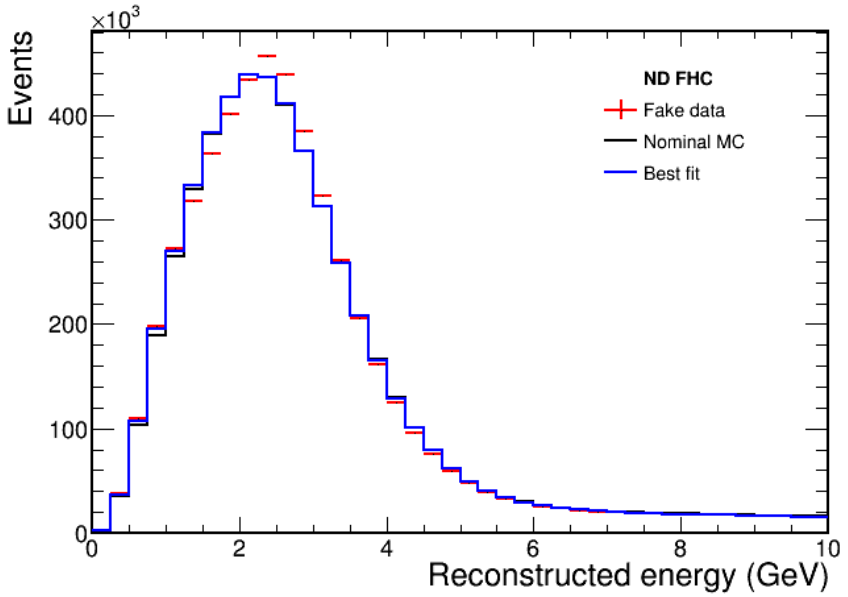


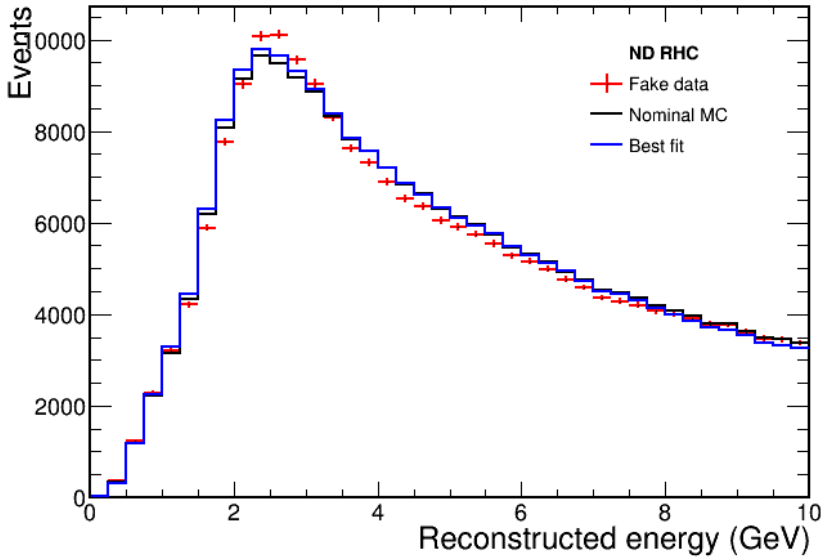






ND can see the problem. The Xsec + flux uncertainties are not enough for ND prediction to shift.
I add E-scale shifts (E-scale, resolution), then
If I just do ND fit (7 years) ..






```
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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
```
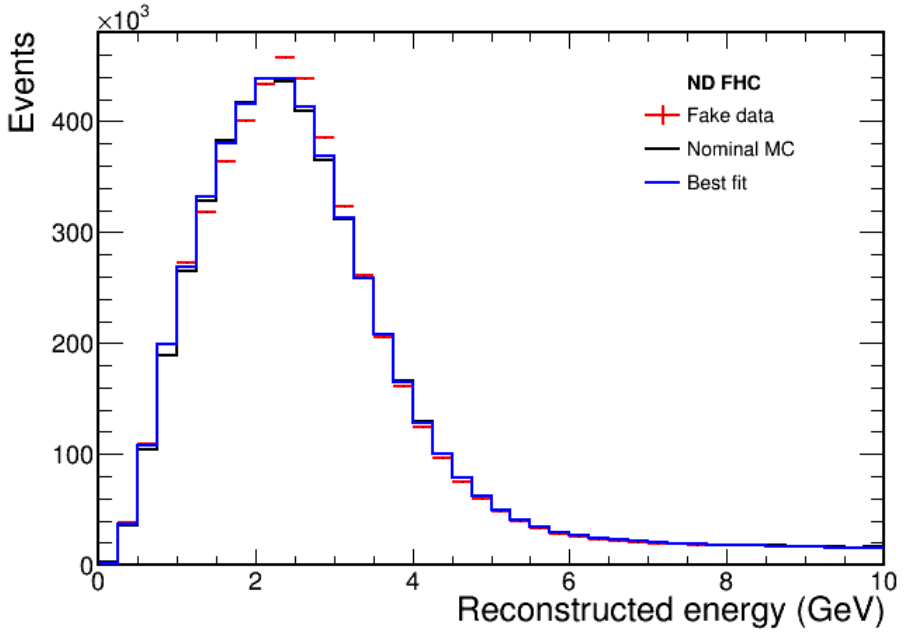
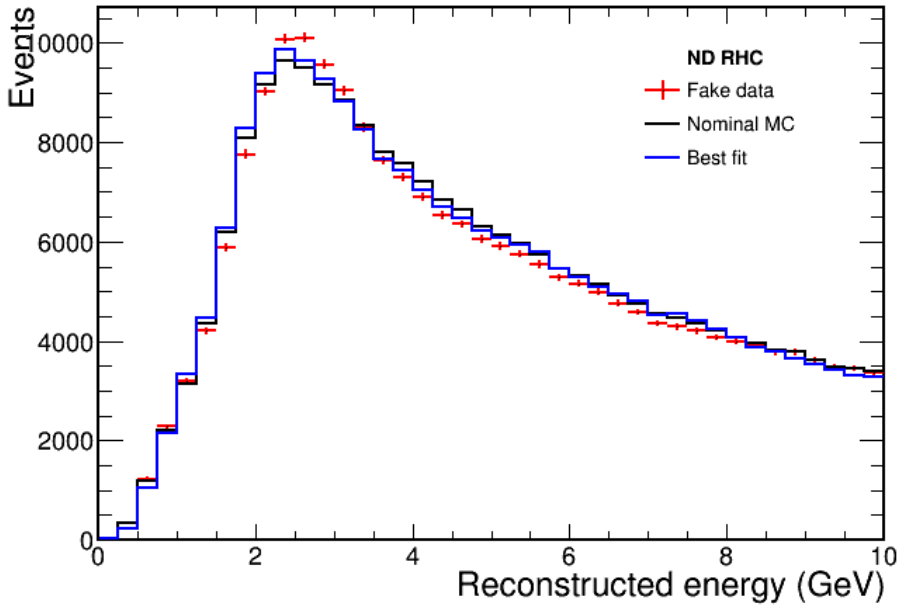

If enlarge Xsec and E-scale systematics by a factor of 10..






```
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Syst. shift  nu_ccqe_2_scale -2.04855e-05
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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
```
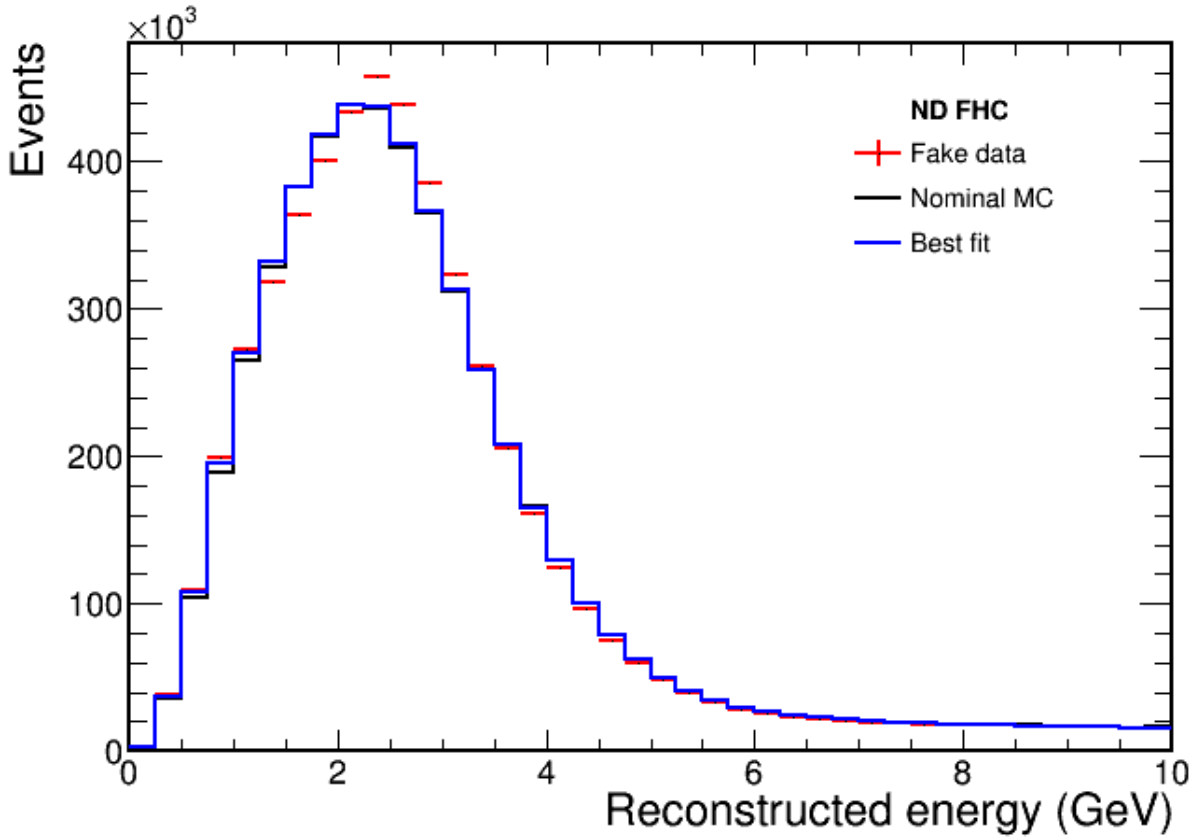

If enlarge Xsec and E-scale systematics by a factor of 10 and only shift FHC..



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

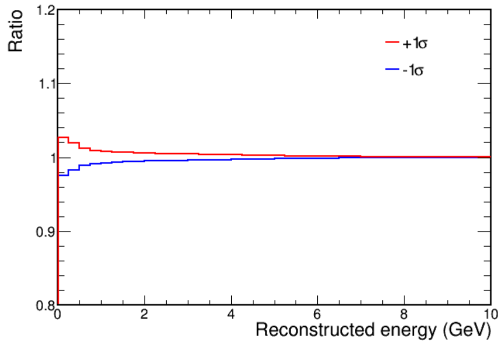
The problem

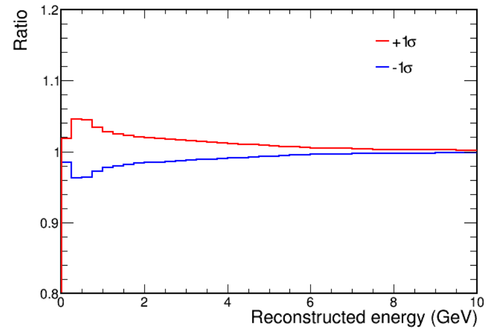
- ND does not like to move. Current Xsec, flux and E-scale cannot recover the 20% missing PE in ND.

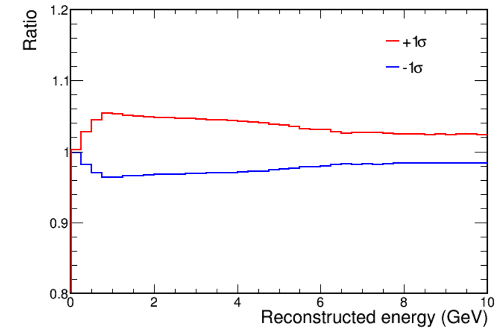
- I need realistic antinu shift. Now I am using nu for antinu.

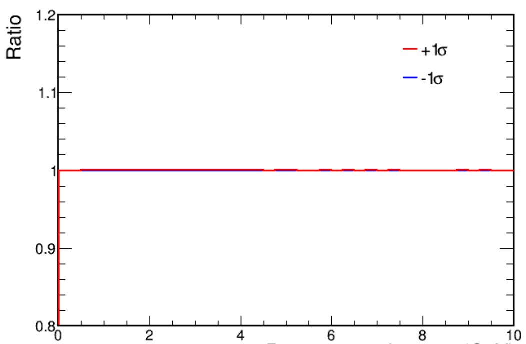
- I am trying to run GENIE to get some fake data..

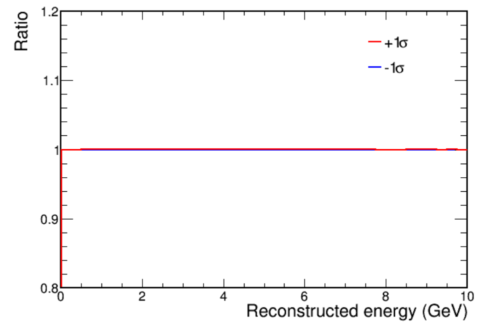
Xsec ND FHC

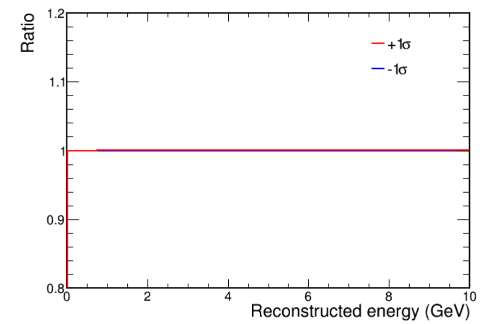

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

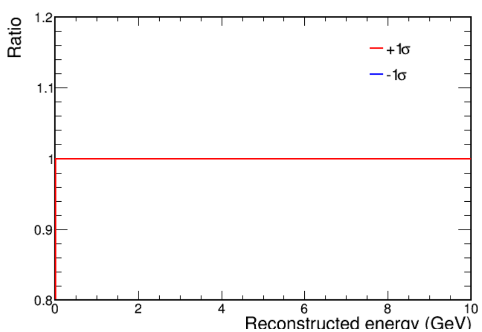

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

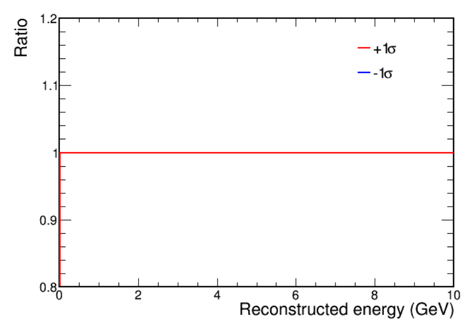

Ratio
+1σ
-1σ
Reconstructed energy (GeV)

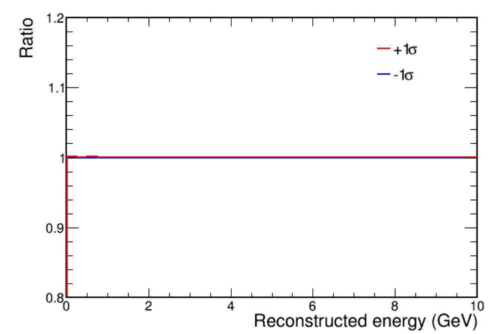

Ratio
+1σ
-1σ


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


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


Ratio
+1σ
-1σ


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


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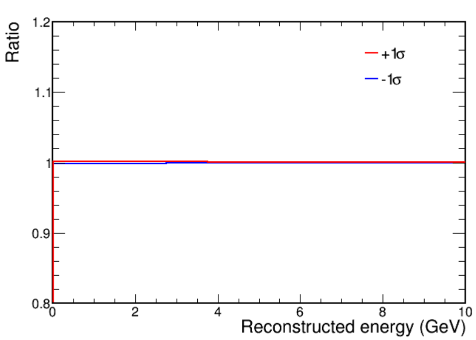
Reconstructed energy (GeV)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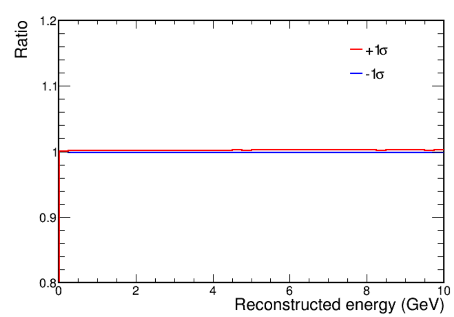
-1σ
Reconstructed energy (GeV)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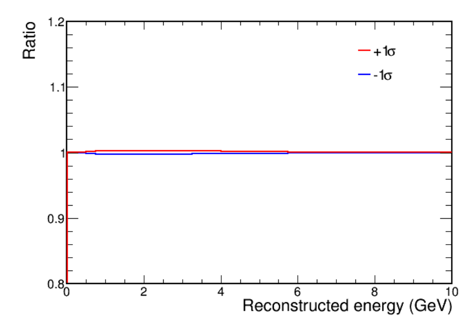
Reconstructed energy (GeV)


Ratio
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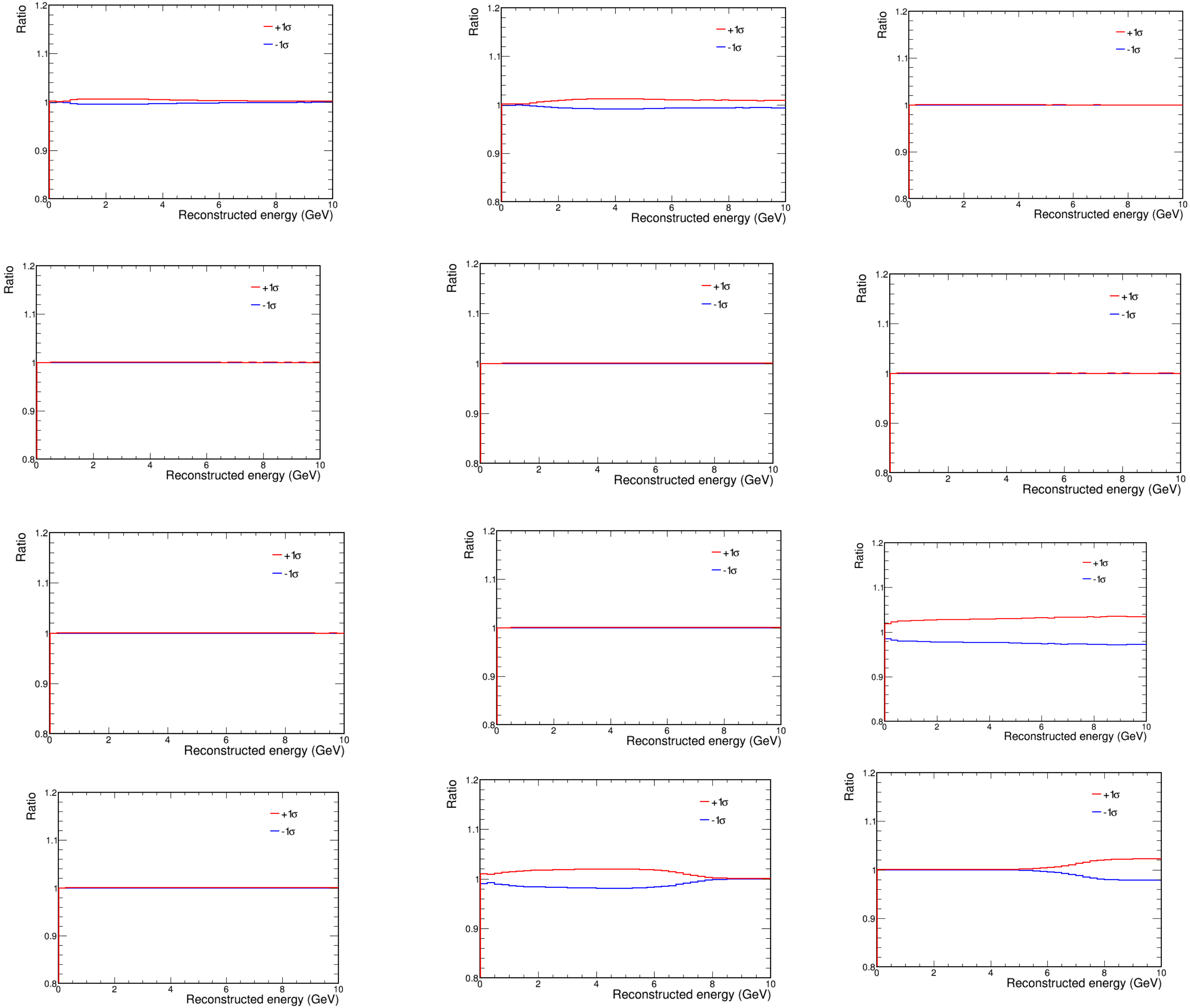
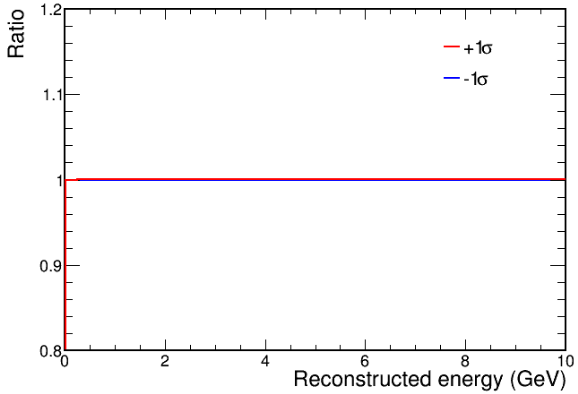
-1σ
Reconstructed energy (GeV)


Ratio
+1σ
-1σ
Reconstructed energy (GeV)
1.2
1.1
1
0.9
0.8
0
2
4
6
8
10


Ratio
1.2
1.1
1
0.9
0.8
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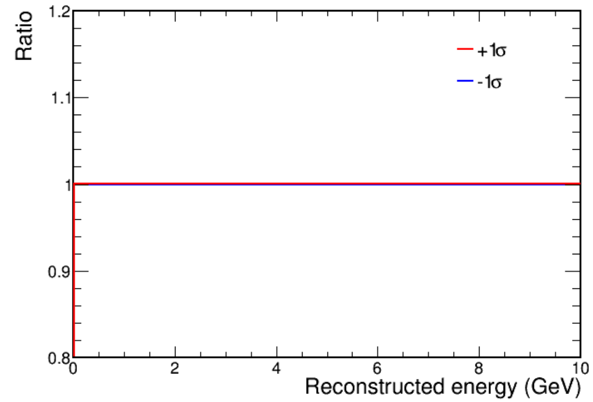
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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1.1
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0.9
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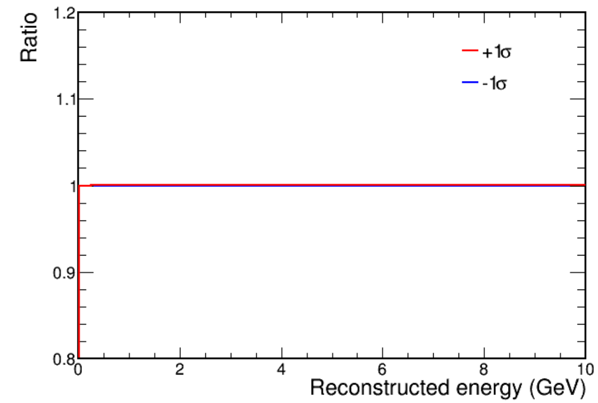
8
10
Reconstructed energy (GeV)
+1σ
-1σ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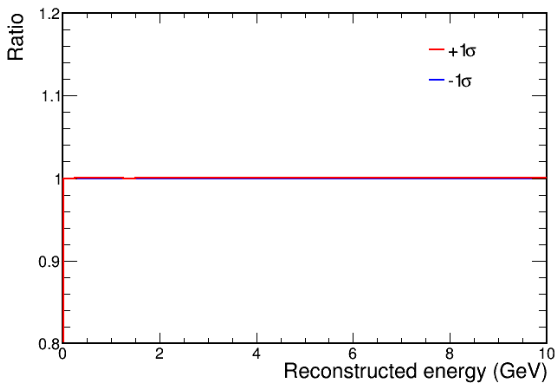
8
10
Reconstructed energy (GeV)
+1σ
-1σ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0.9
0.8
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2
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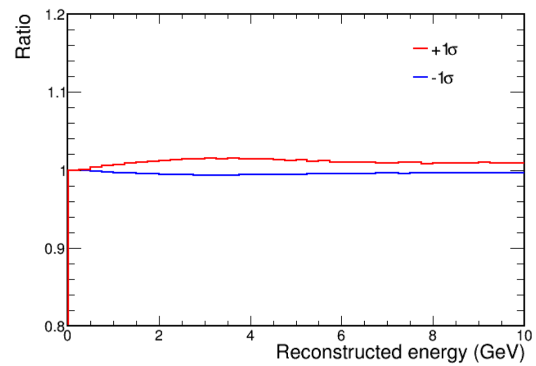
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ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1.1
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0.9
0.8
0
2
4
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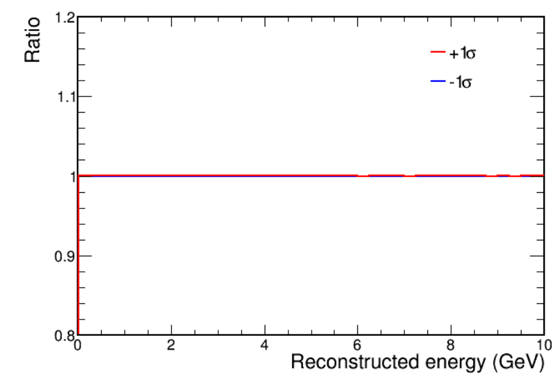
8
10
Reconstructed energy (GeV)
+1σ
-1σ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1.1
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0.9
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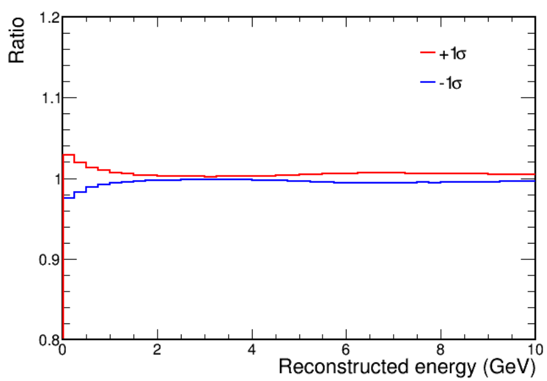
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ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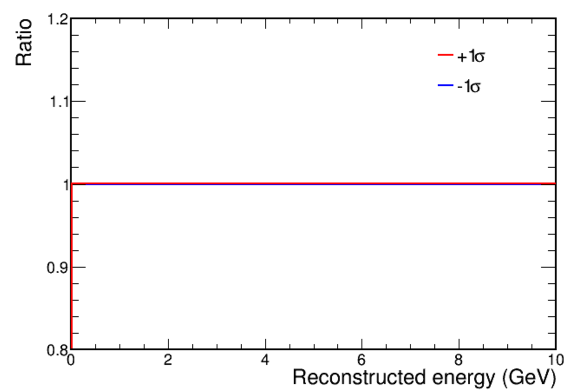
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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1.1
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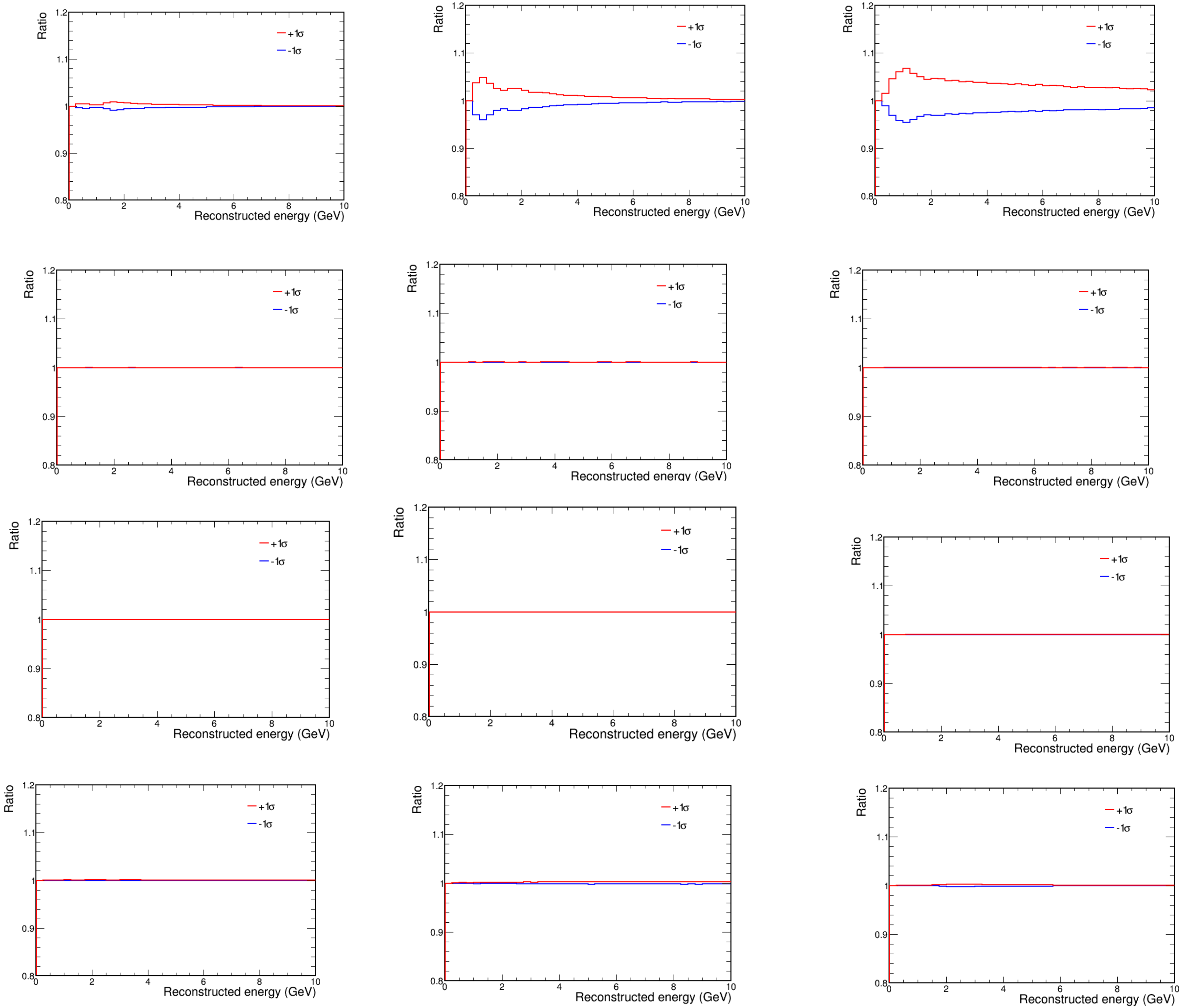
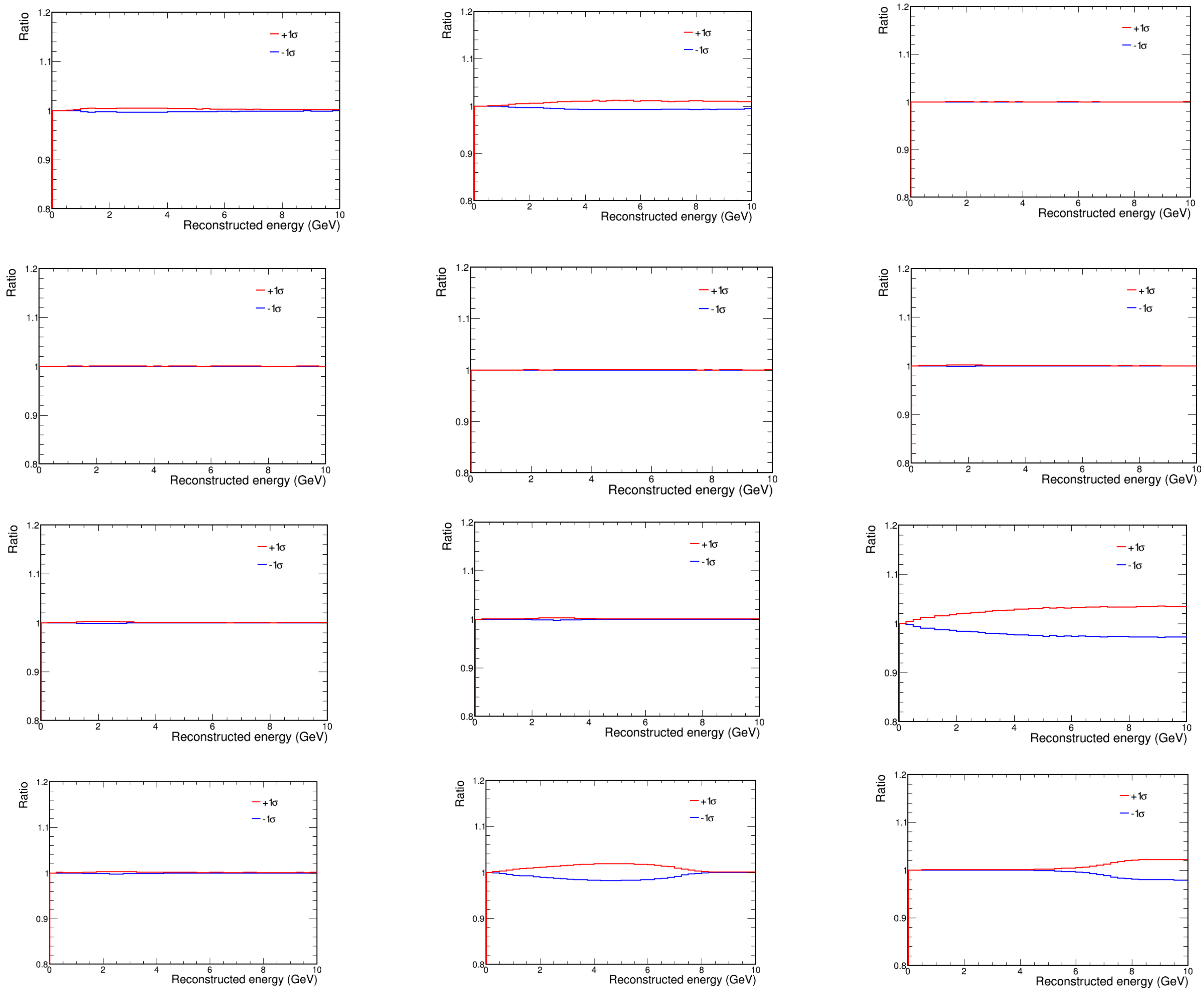
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ

Xsec ND RHC




Ratio
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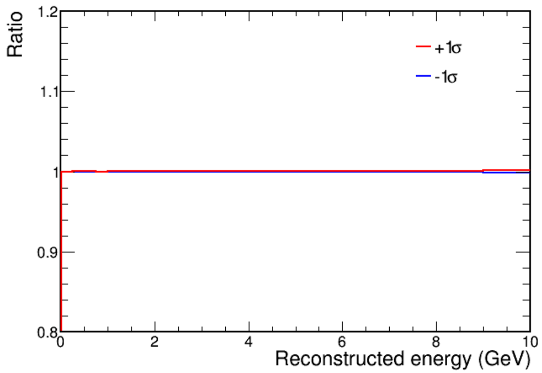
-1σ
Reconstructed energy (GeV)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0.9
0.8
0
2
4
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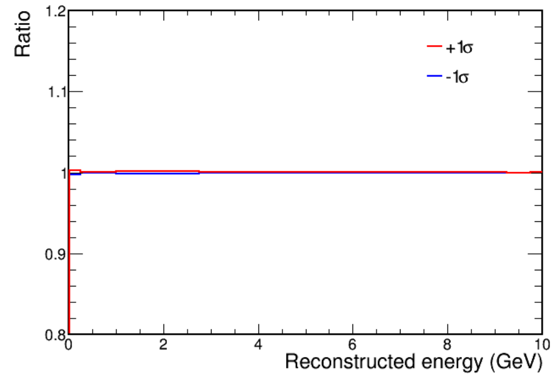
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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0.8
0
2
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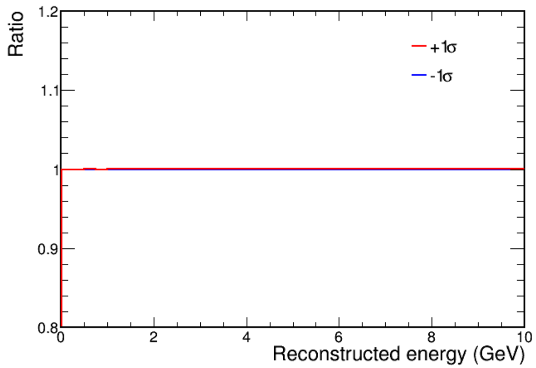
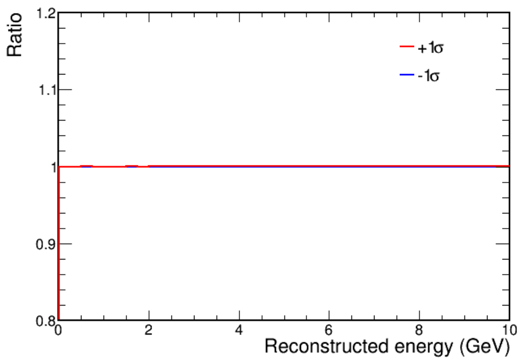
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
1.2
1.1
1
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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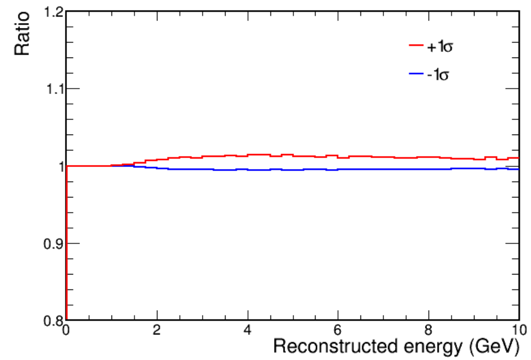
1.1
1
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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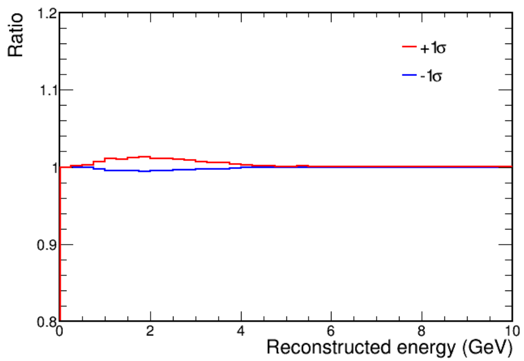
1.1
1
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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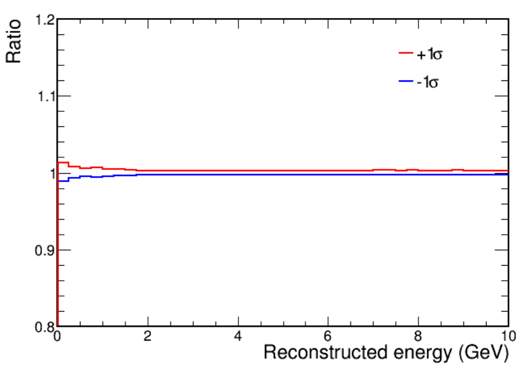
1.1
1
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
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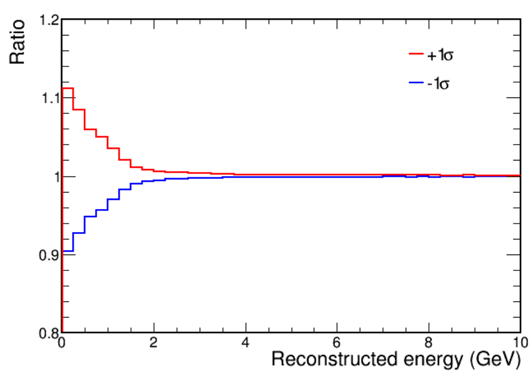
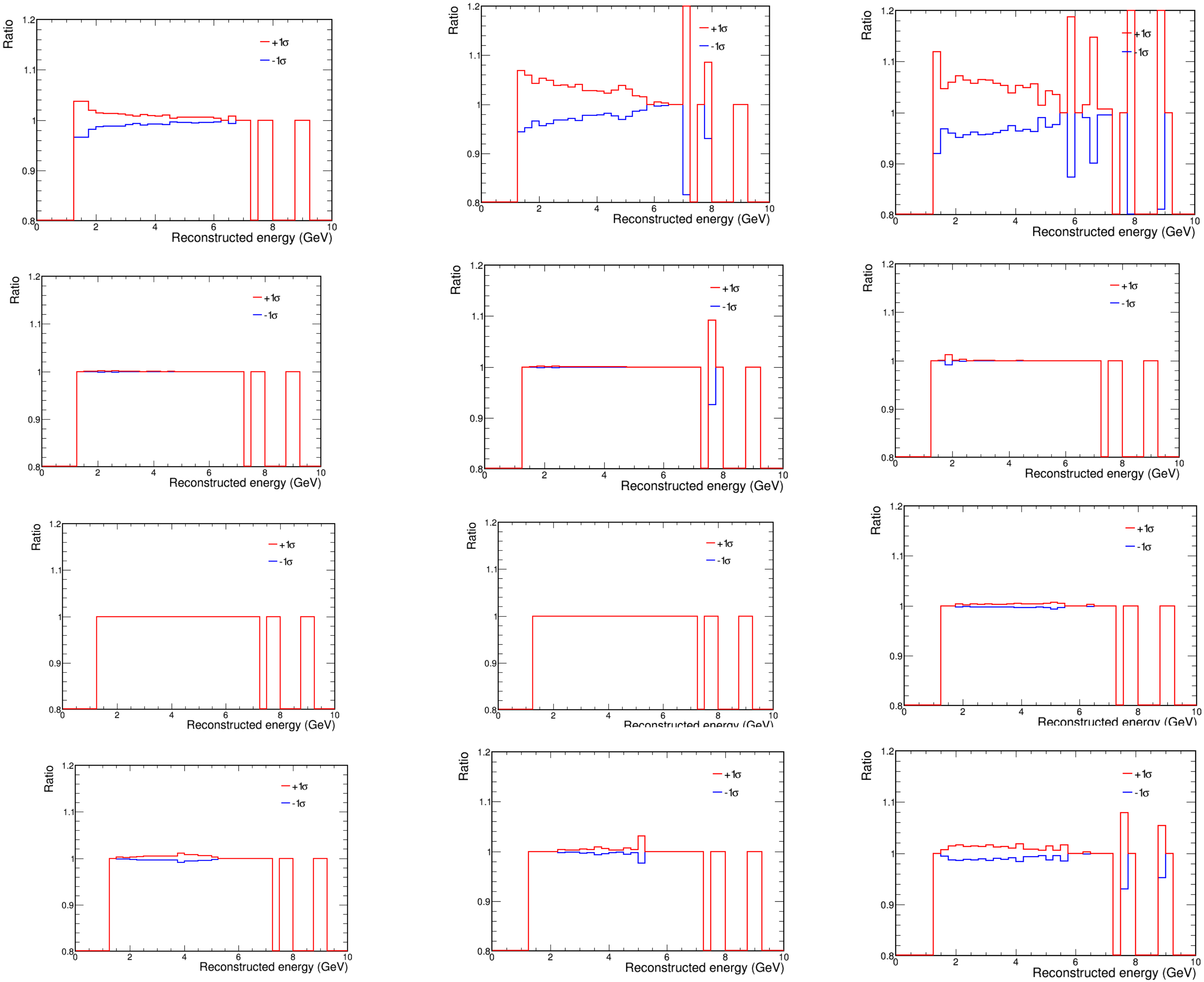
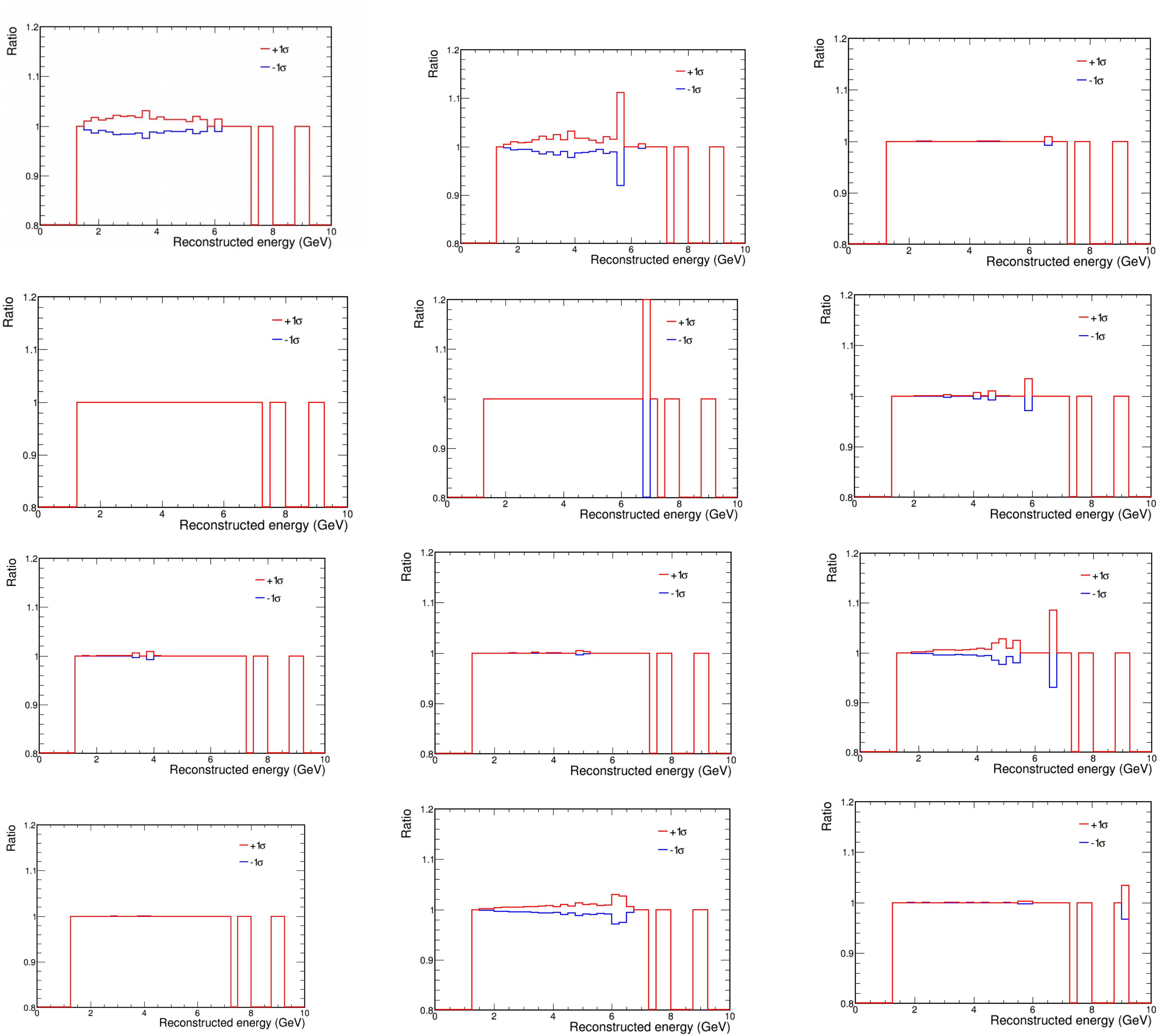
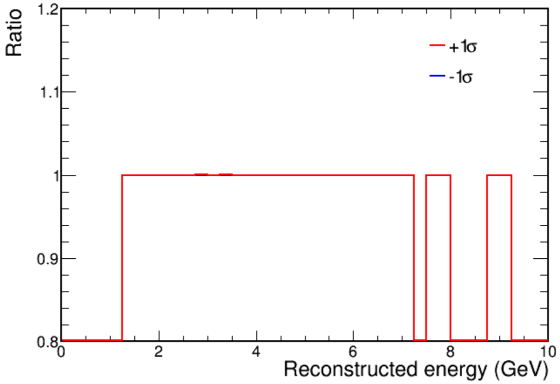
1.1
1
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ


Ratio
1.2
1.1
1
0.9
0.8
0
2
4
6
8
10
Reconstructed energy (GeV)
+1σ
-1σ

Xsec FD nue FHC




Ratio
+1σ
-1σ
Reconstructed energy (GeV)
0.8
0.9
1
1.1
1.2
0
2
4
6
8
10


Ratio
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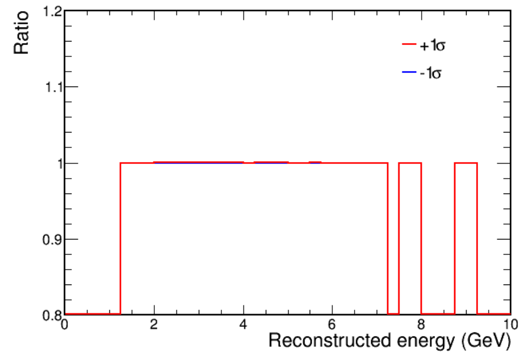
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
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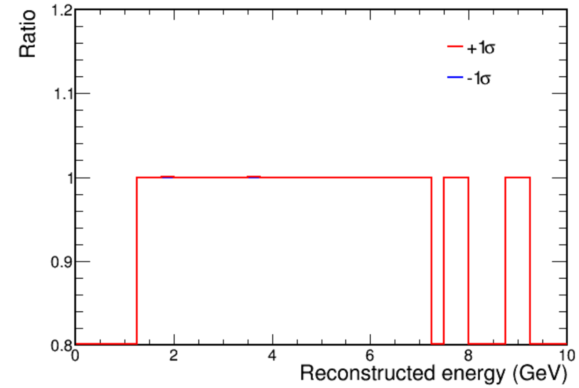
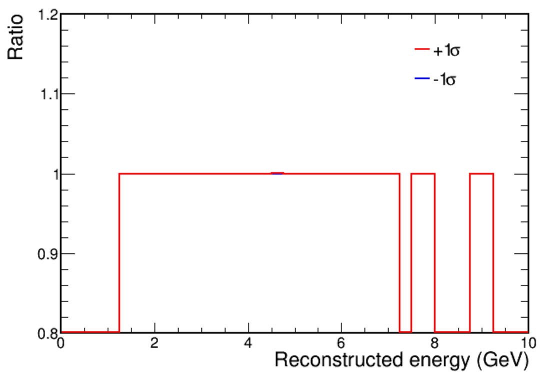
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
1.2
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
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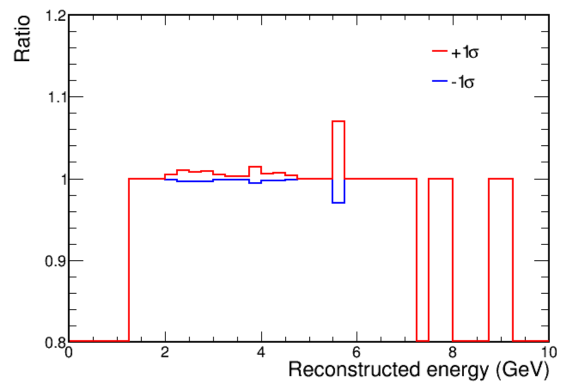
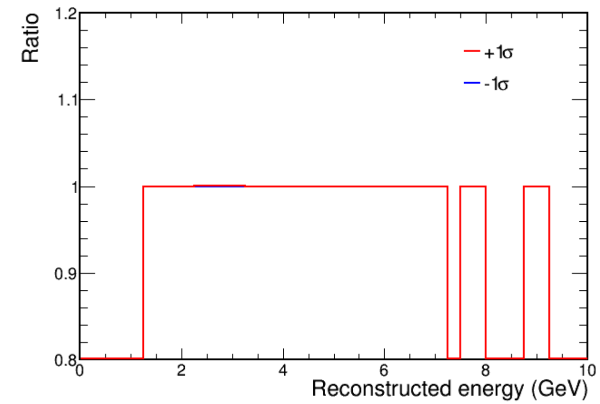
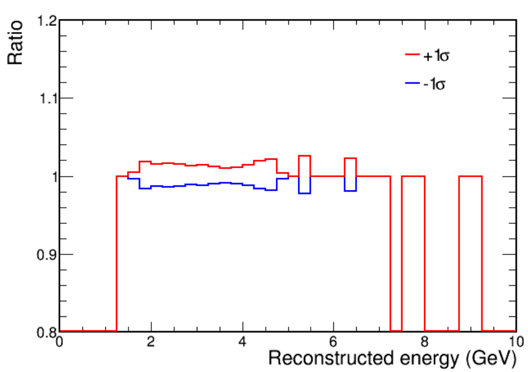
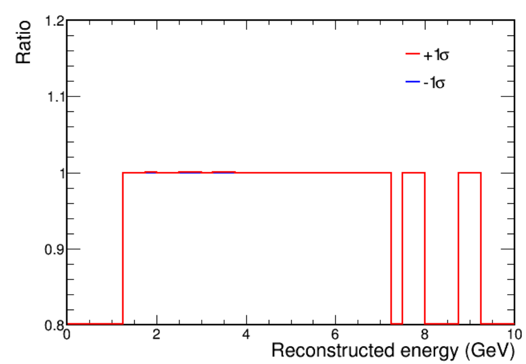
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)

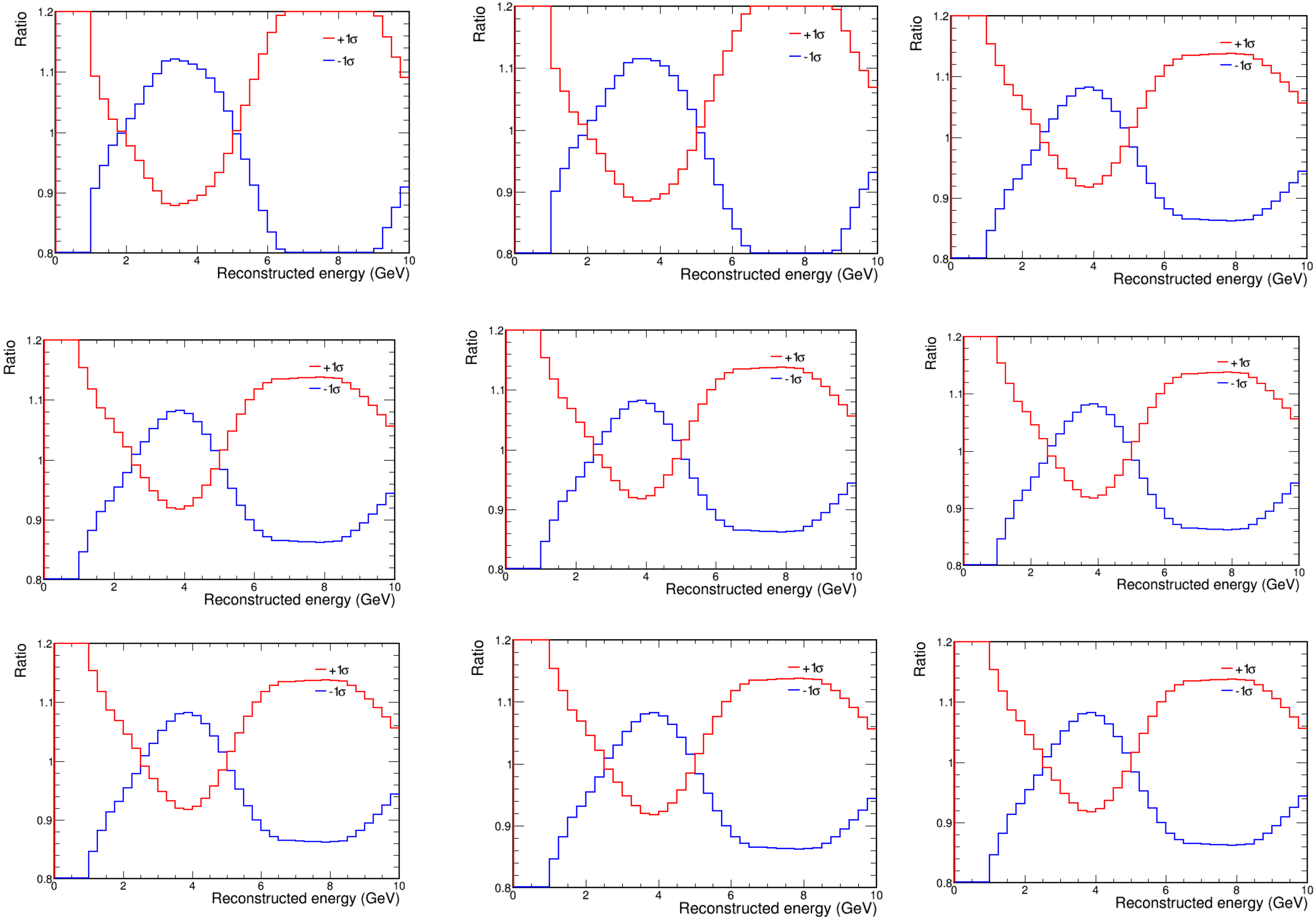

Ratio
1.2
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
1.2
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)

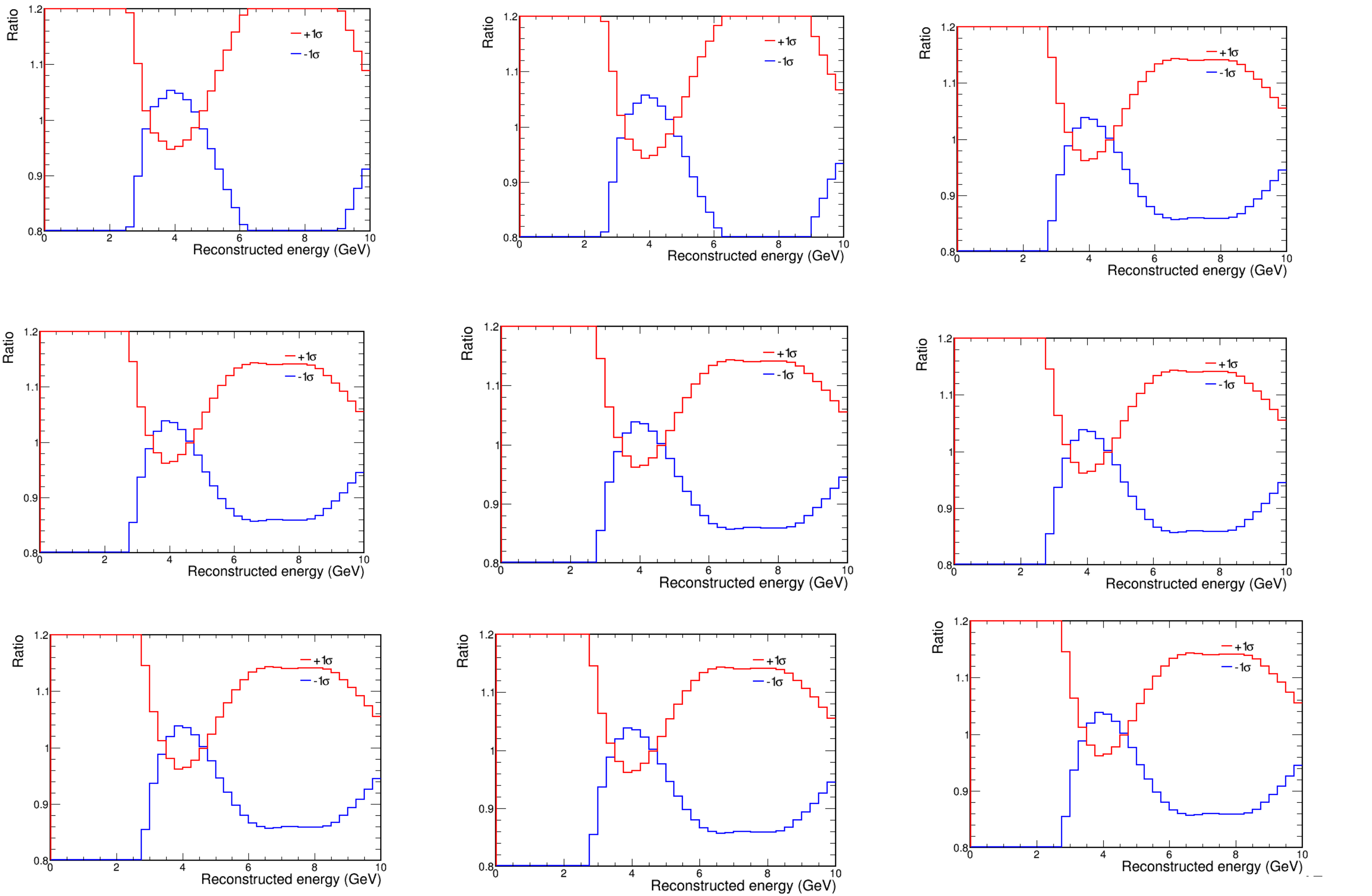

Ratio
1.2
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)


Ratio
1.2
1.1
1
0.9
0.8
0 2 4 6 8 10
+1σ
-1σ
Reconstructed energy (GeV)

Flux systematics ND FHC



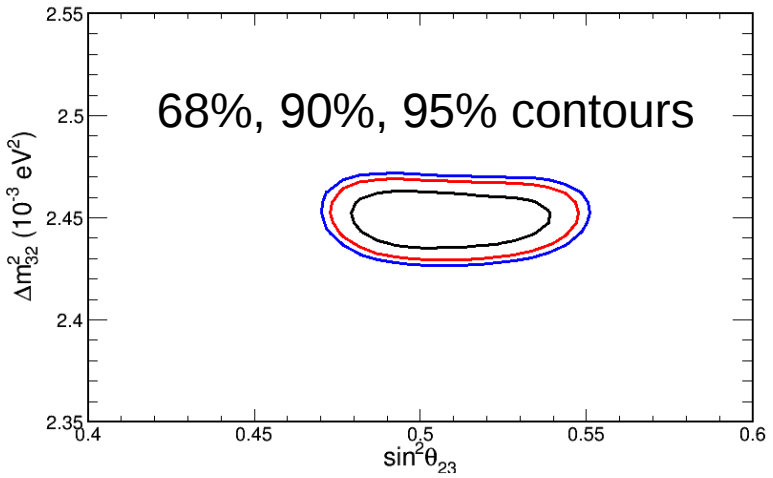
Flux systematics ND RHC

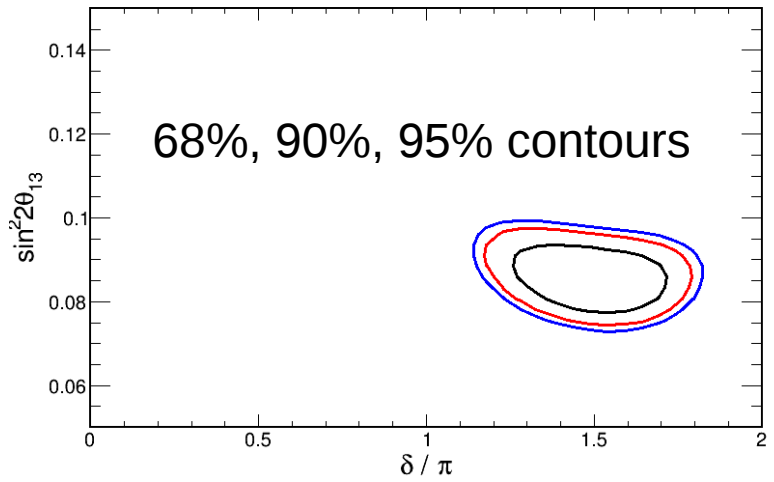


Systematics validation

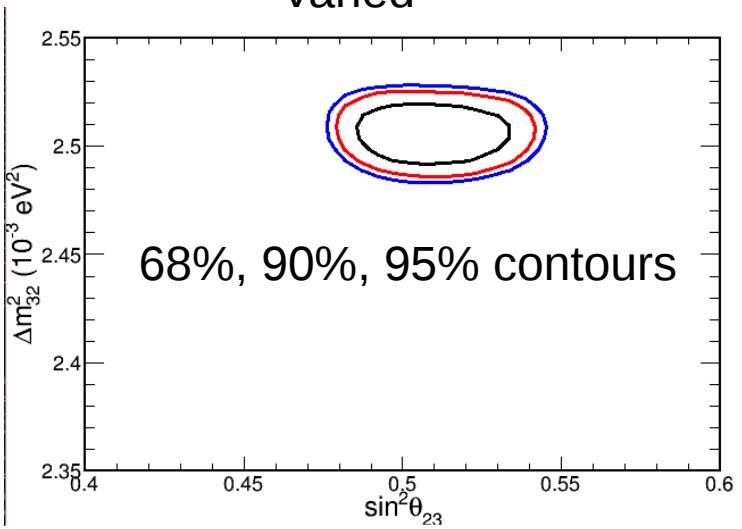
With Luke's variation and without systematics,
the true values cannot be recovered.

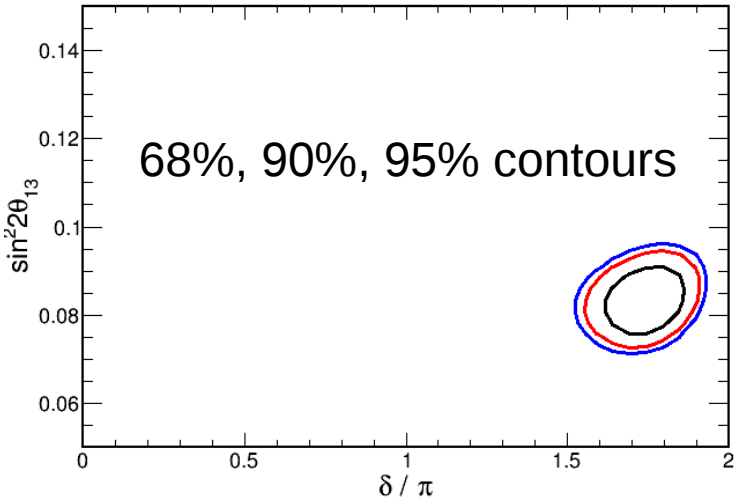
True





Varied





Systematics validation

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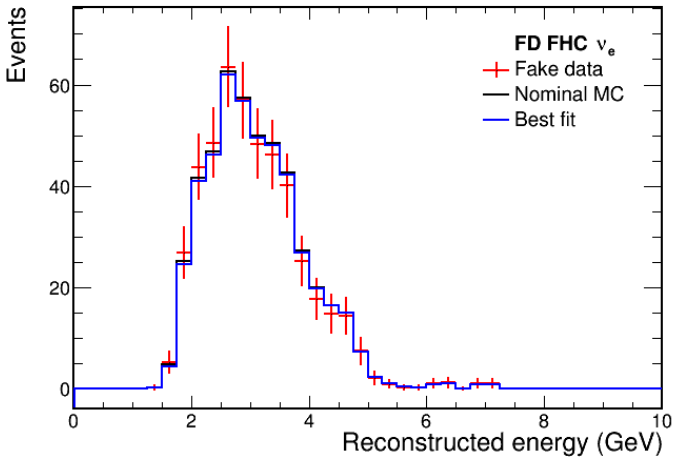
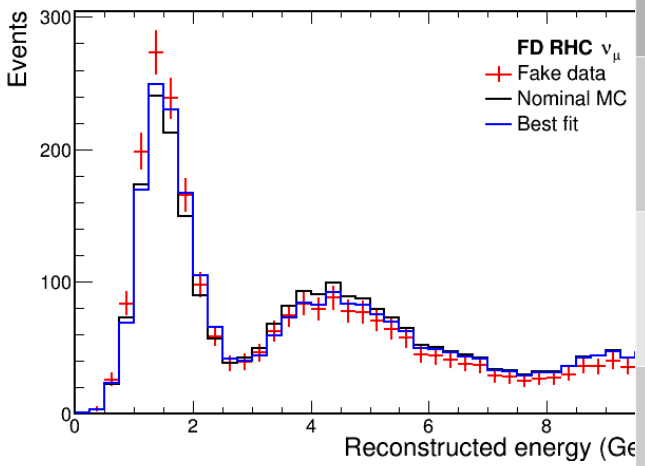
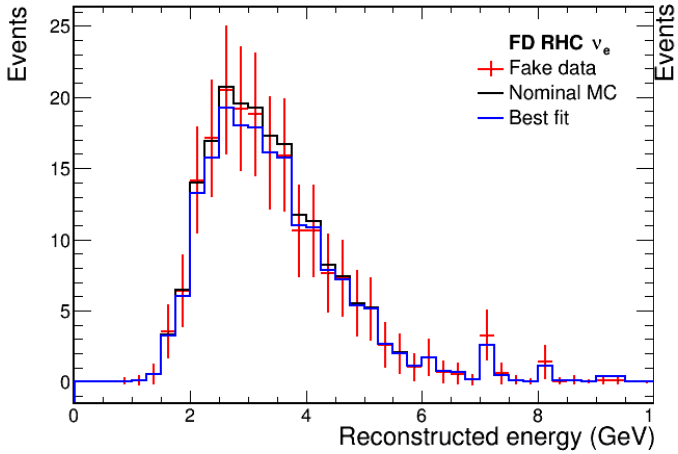
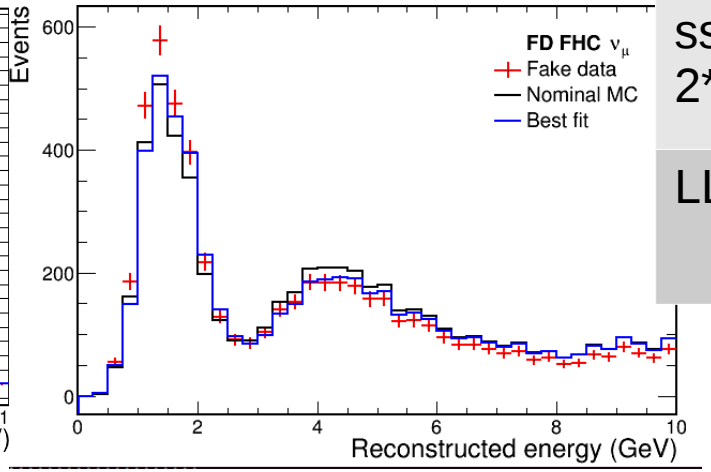






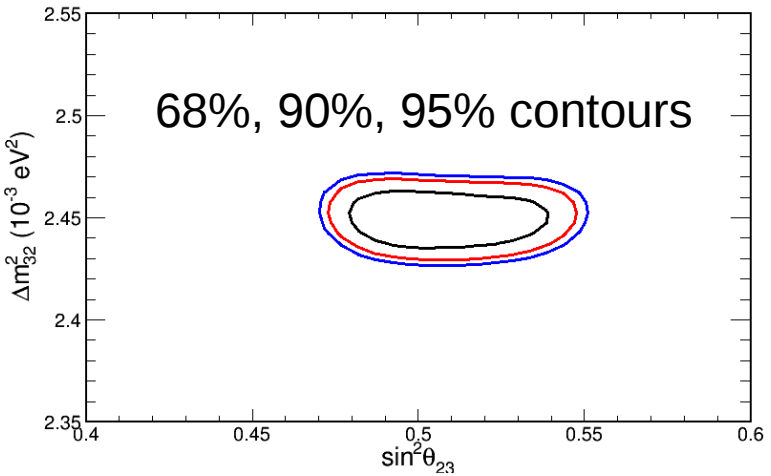


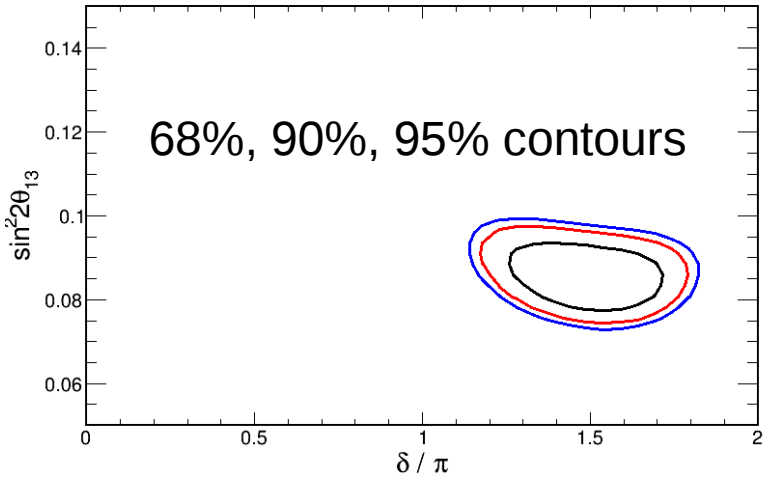
	true	FD+ND Best fit	FD only
CP (pi)	1.5	1.67	1.67
sst23	0.5	0.51	0.51
Dm32 (e-3)	2.45	2.57	2.57
ss(2*t13)	0.087	0.078	0.078
LL		126246	99.5

Systematics validation

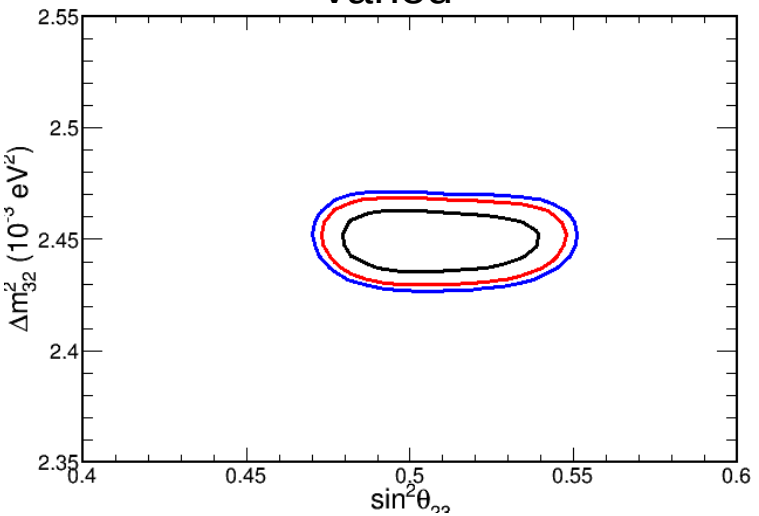
With Luke's variation and with the variation inserted as a systematic pull, the true values can be recovered.

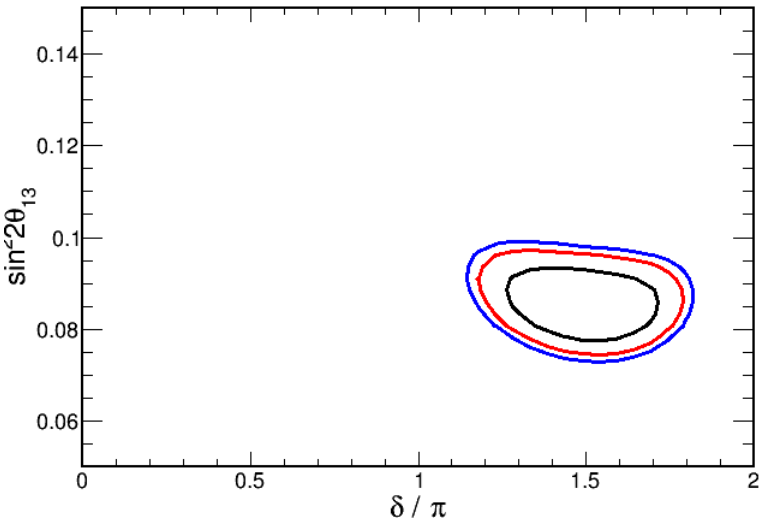
True





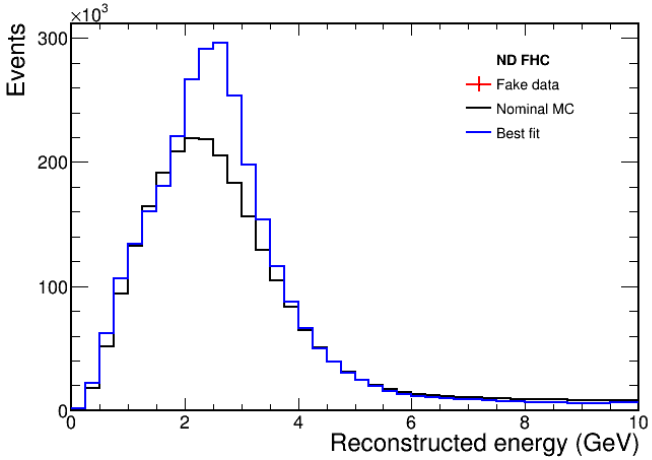
Varied

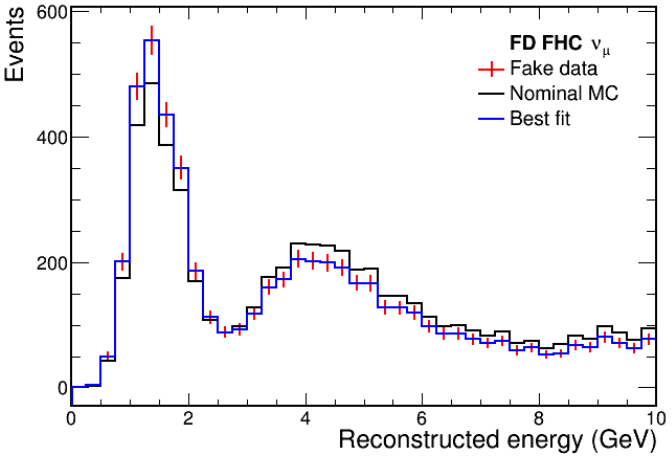


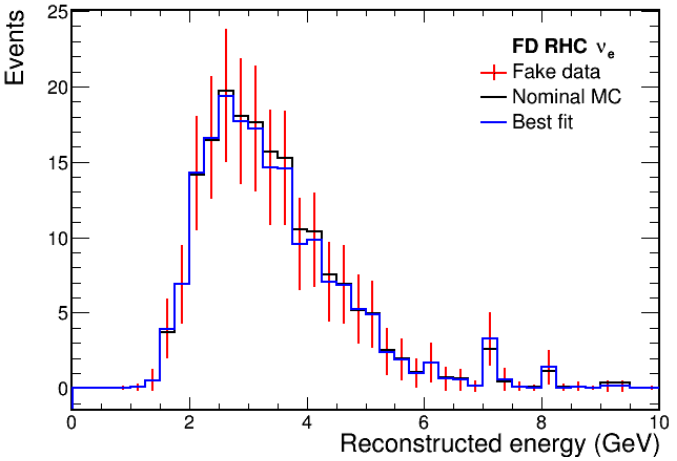


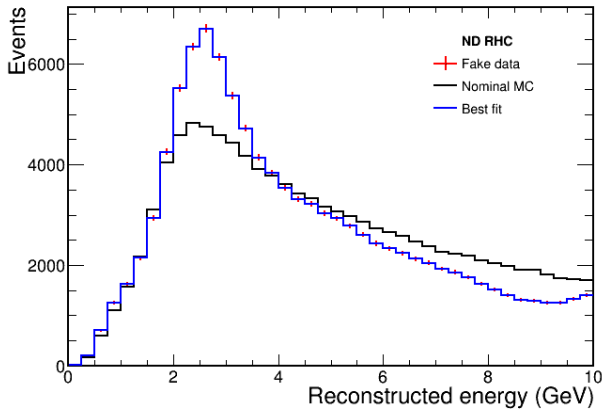
Systematics validation

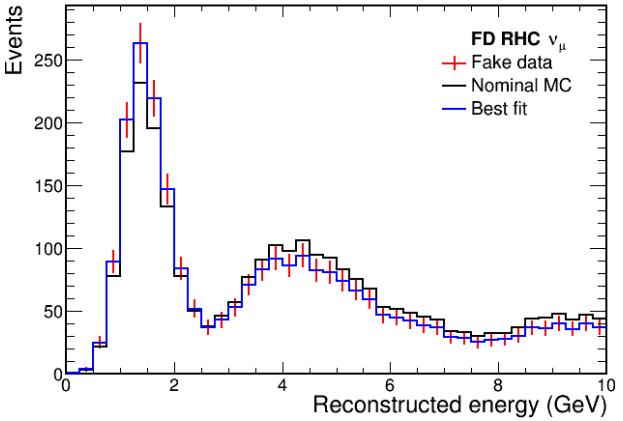
With Luke's variation and with the variation inserted as a systematic pull, the true values can be recovered.

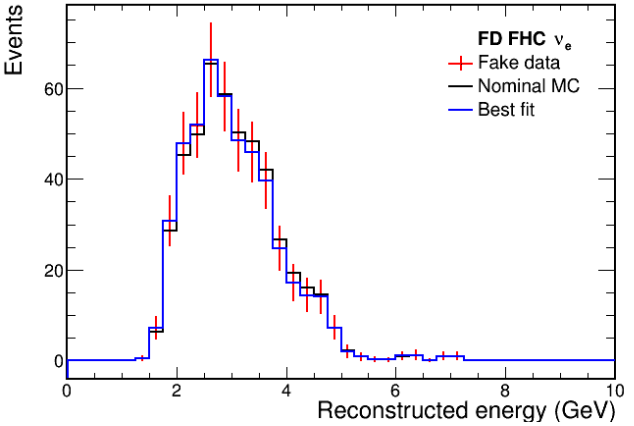








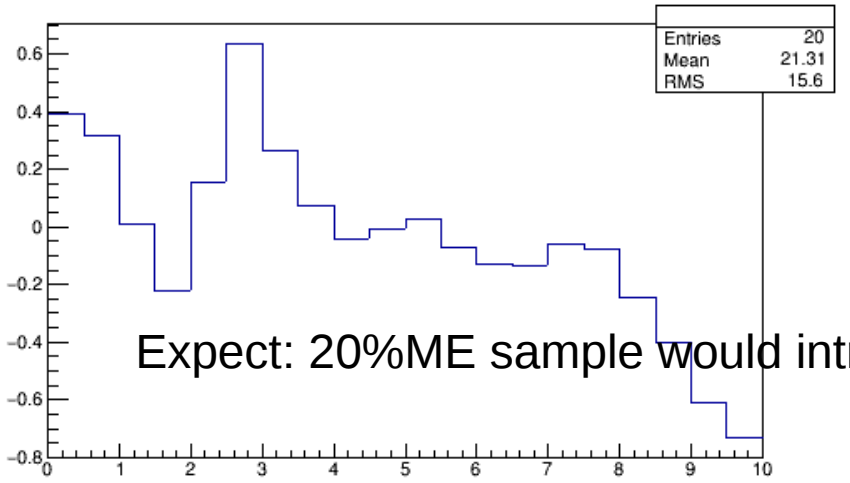




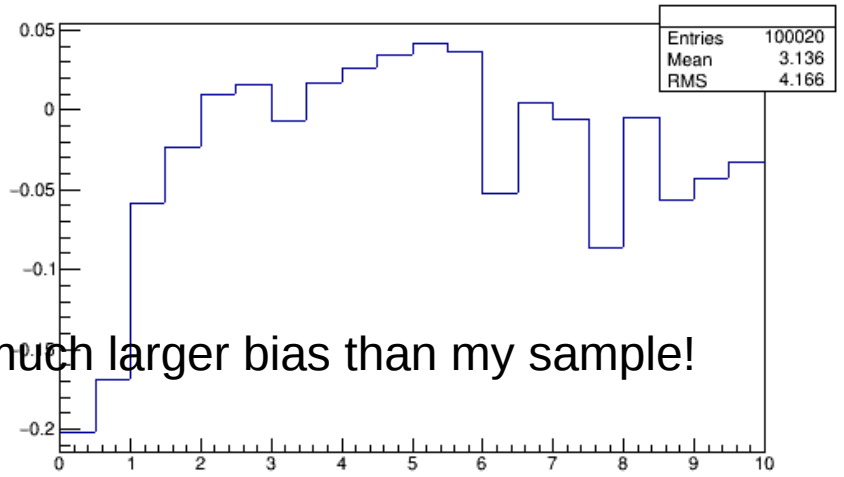
Fake data study

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`

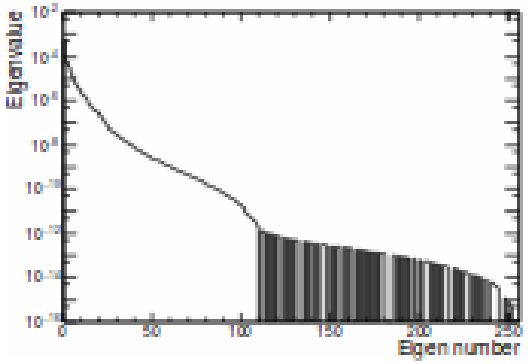
Correlations are included !

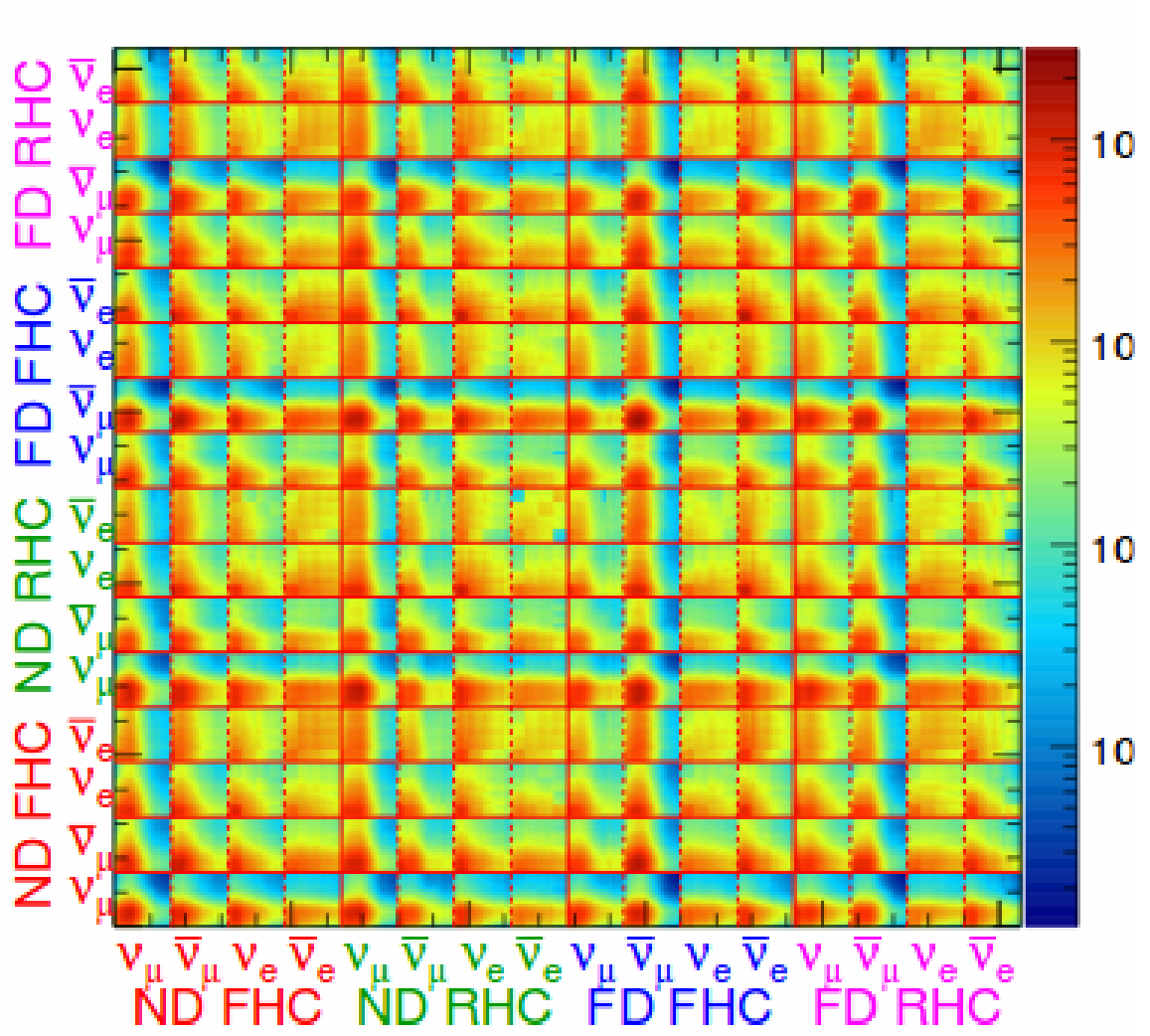
From Chris Backhouse

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



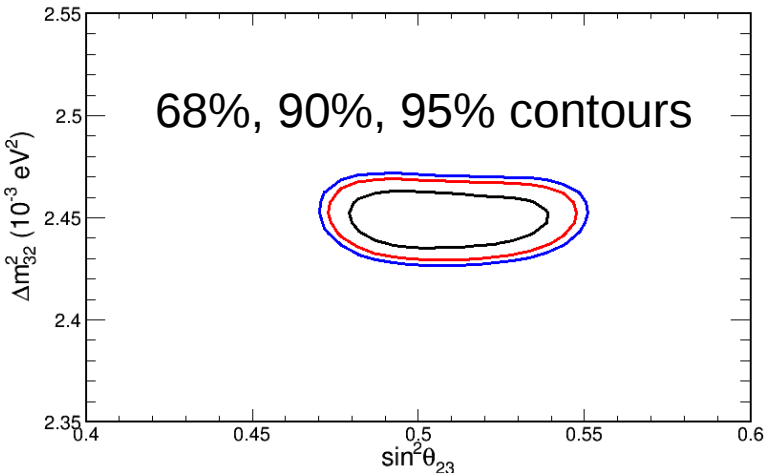


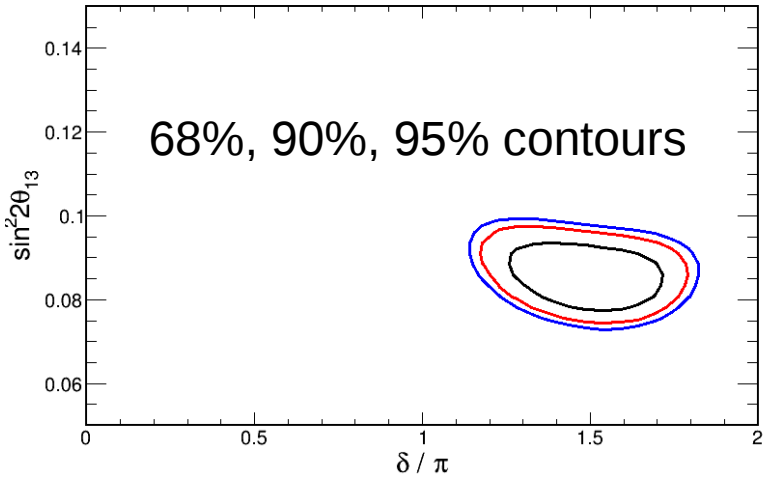
- Eigenvalues 108+ should be zero. Floating precision → some negative
- Limit eigenvalues to 10^{-14}. $M = V^T \Lambda V$, $M \rightarrow V^T \Lambda' V$

Fake data- 20% ME

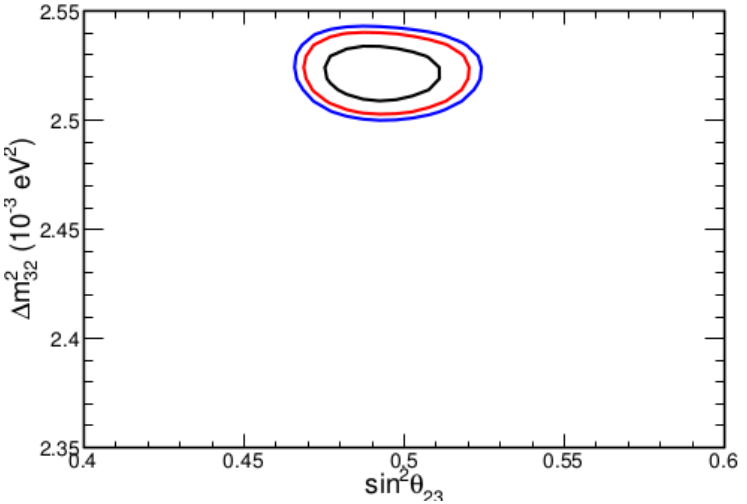
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

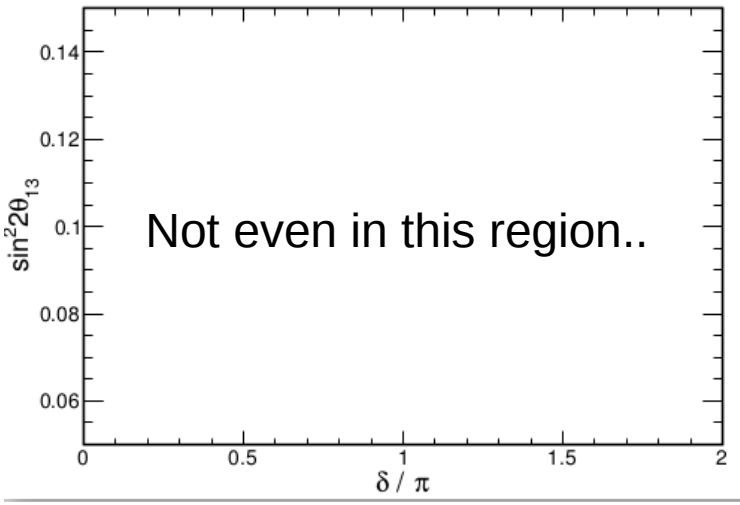
True





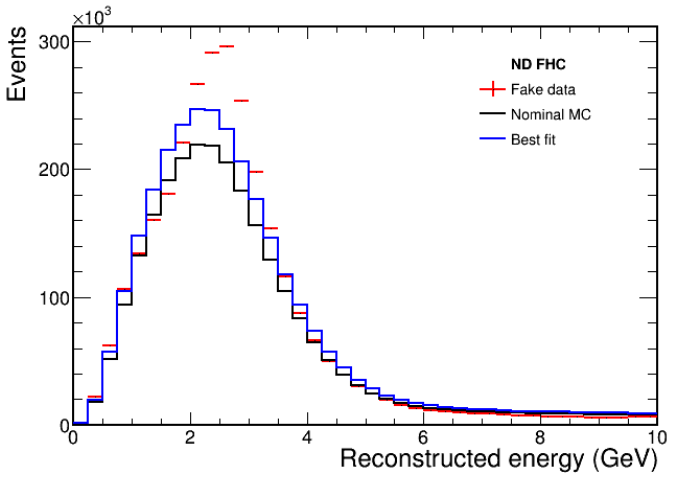
Fake data

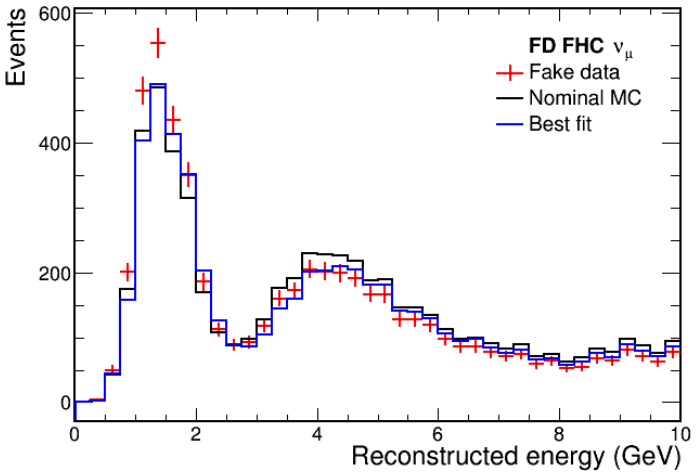


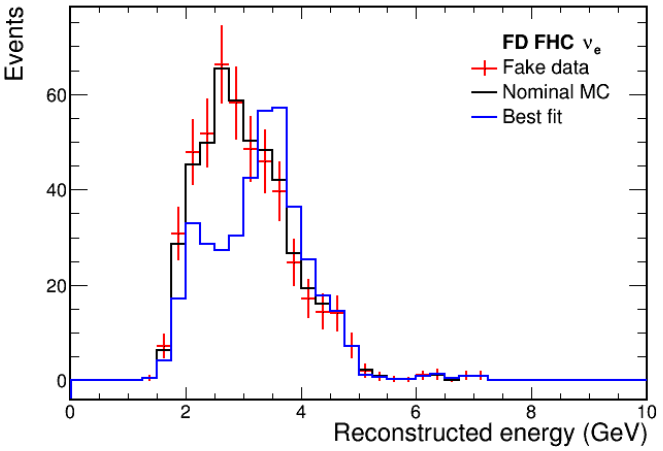


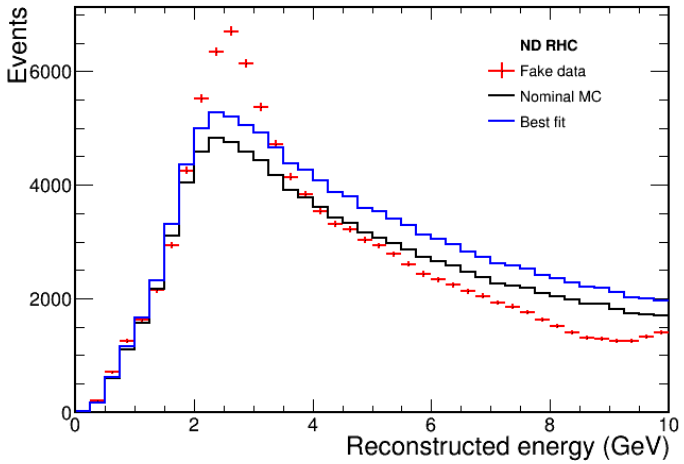
Fake data- 20% ME

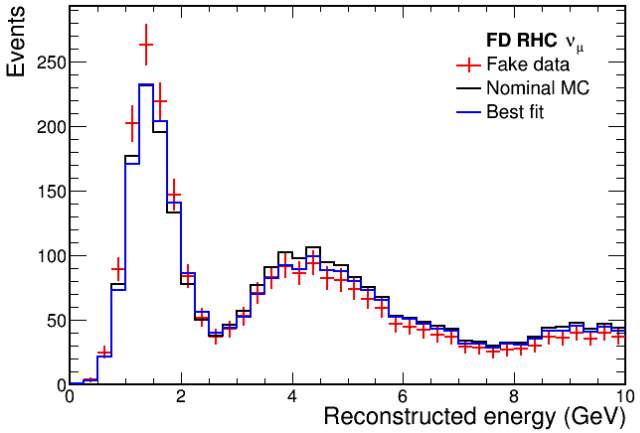
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

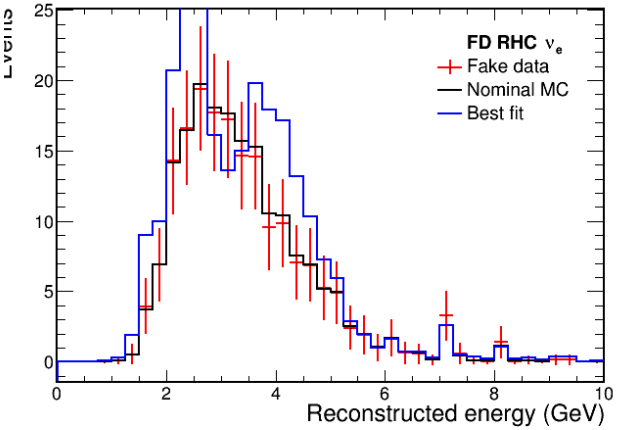










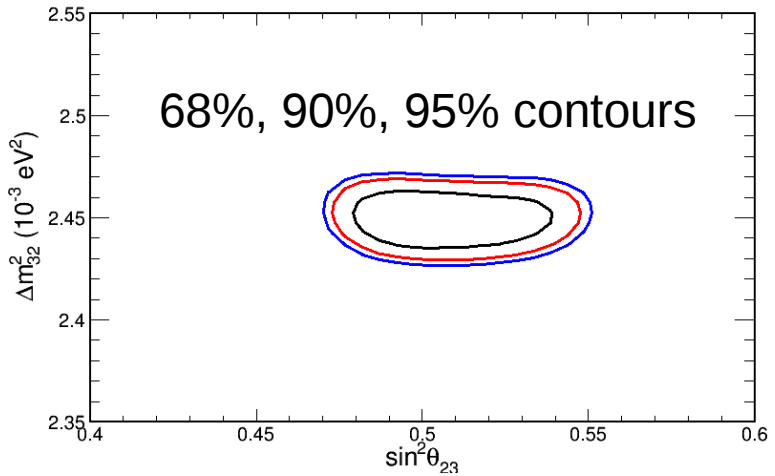


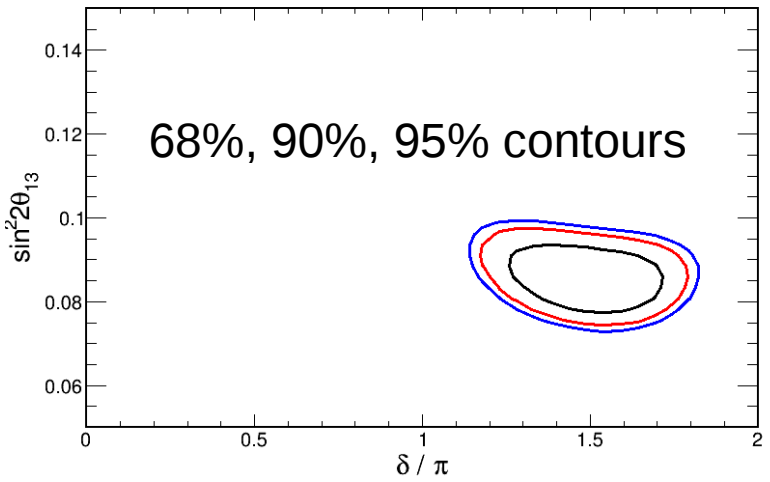
- ND distortion is too significant so that oscillation parameters are less cared by fitter.

Fake data- 20% ME

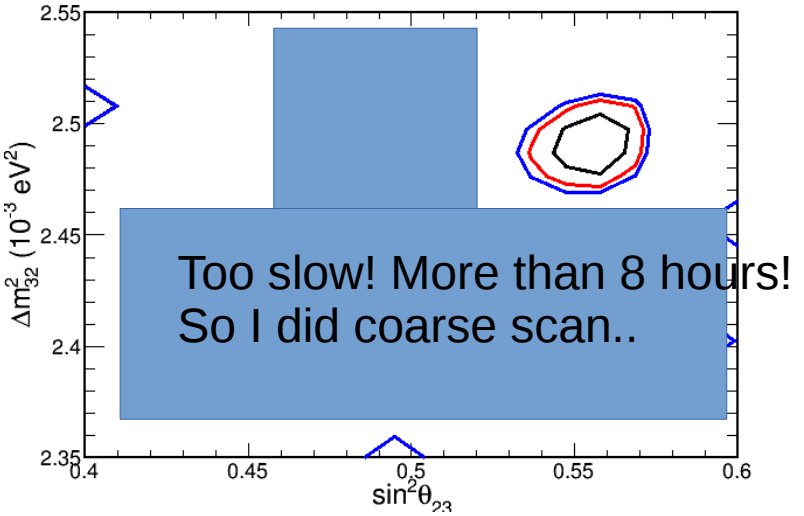
- ND and FD have 20% ME shift, we have Xsec+ flux parameters to recover it.

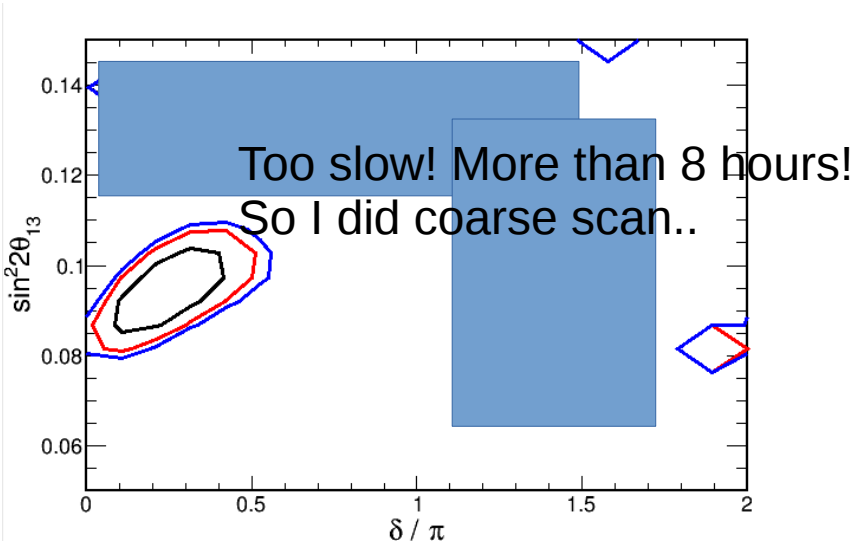
True





Fake data

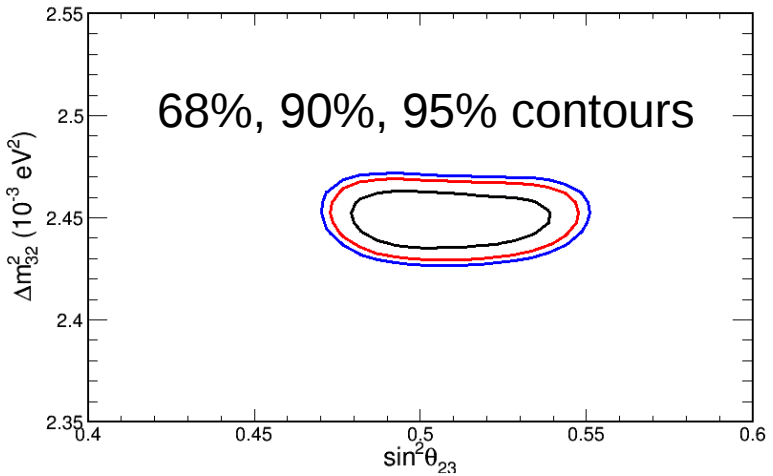


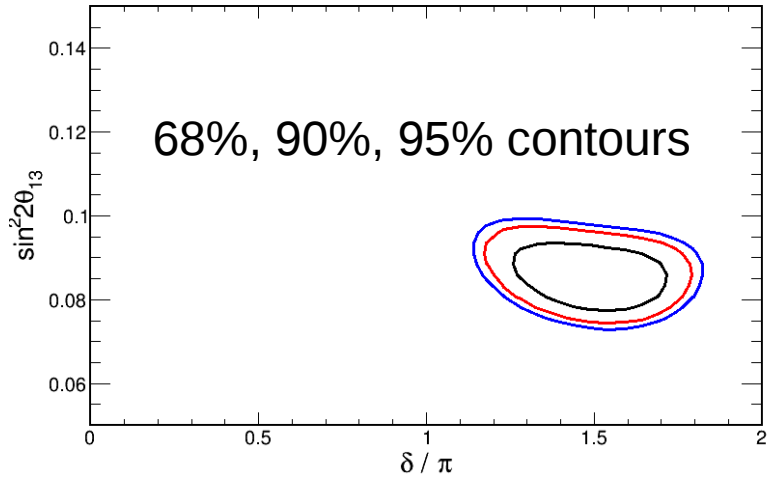


Fake data- Nuwro/GENIE

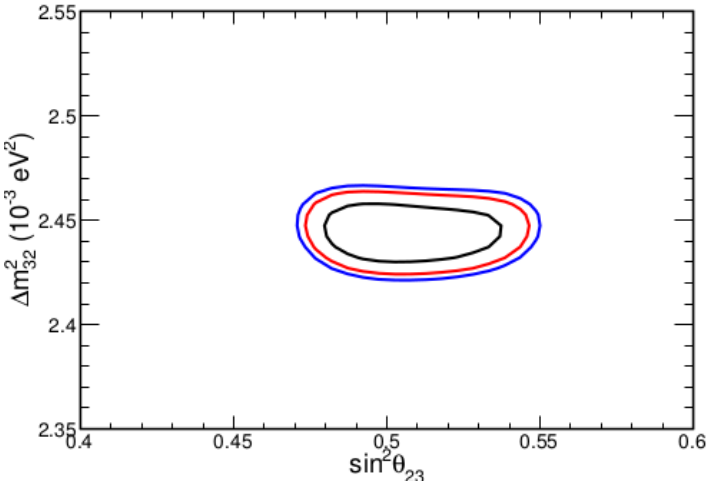
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

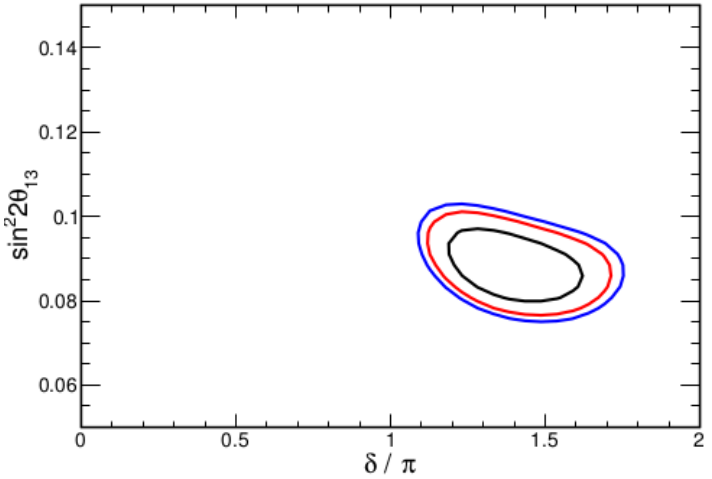
True





Fake data

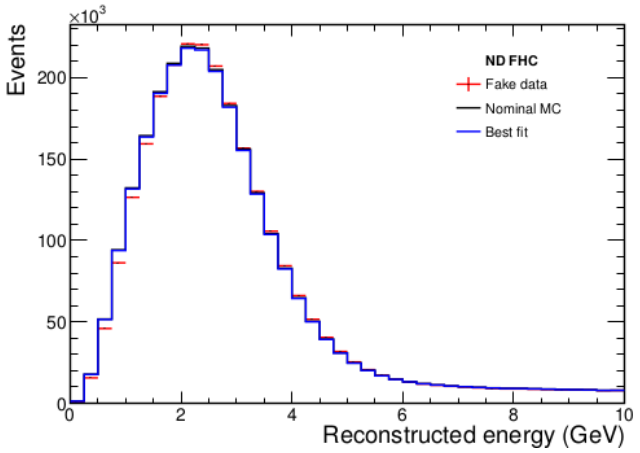


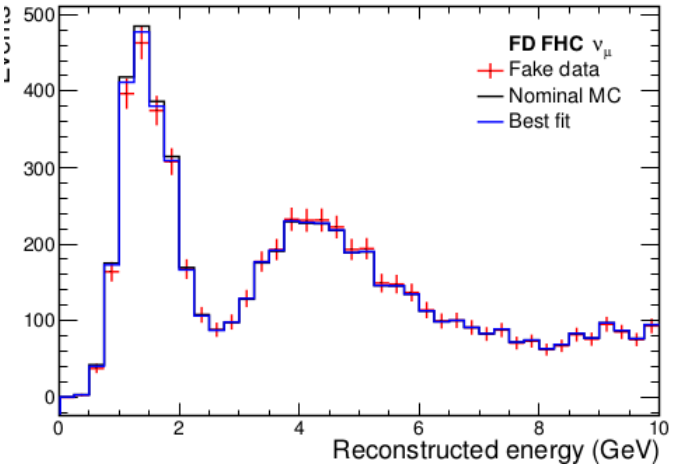


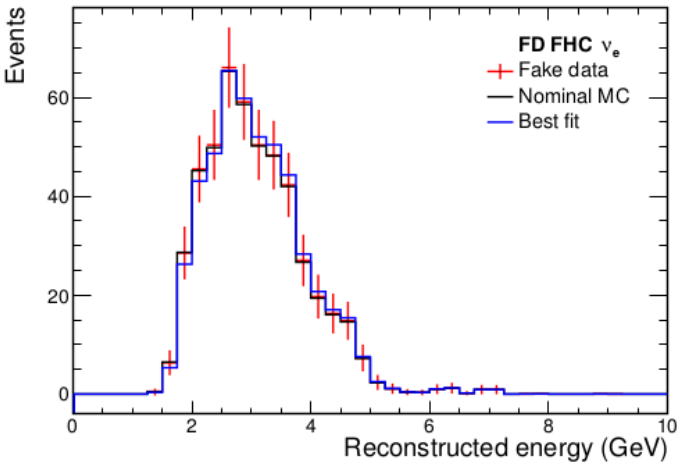
- Only with Xsec parameters, delta CP cannot be fully recovered.

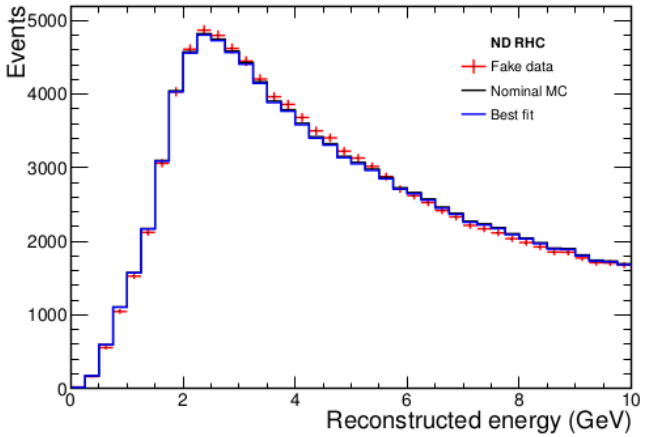
Fake data- Nuwro/GENIE

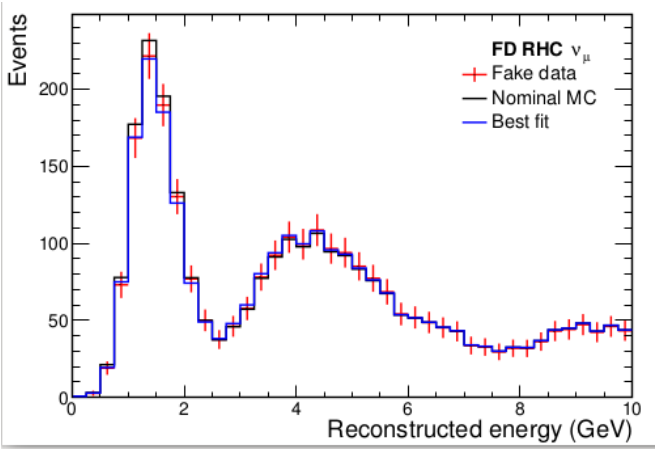
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

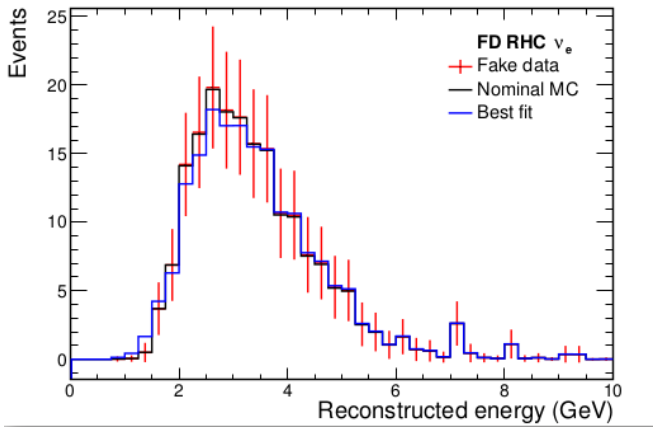








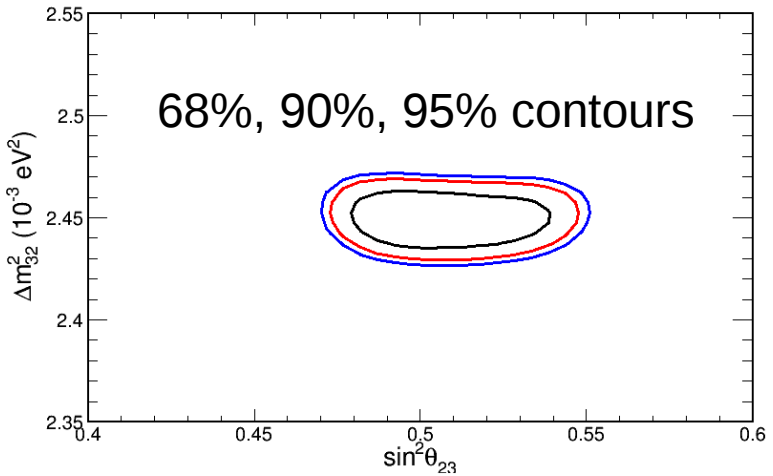




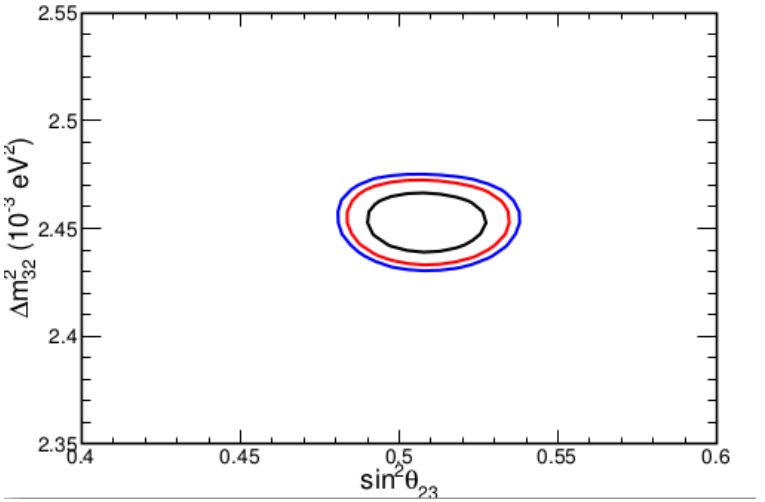
Fake data- Nuwro/GENIE

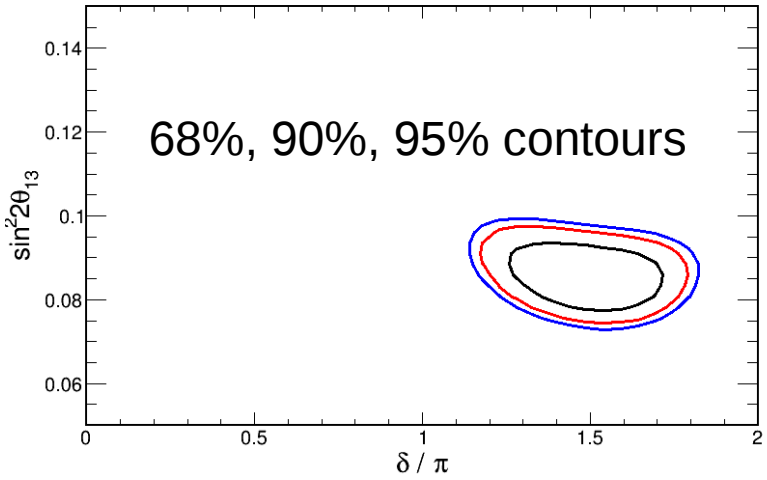
- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.

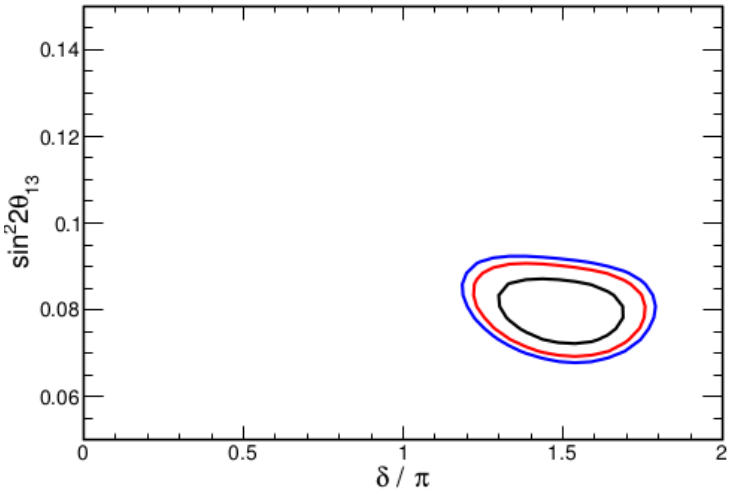
True



Fake data



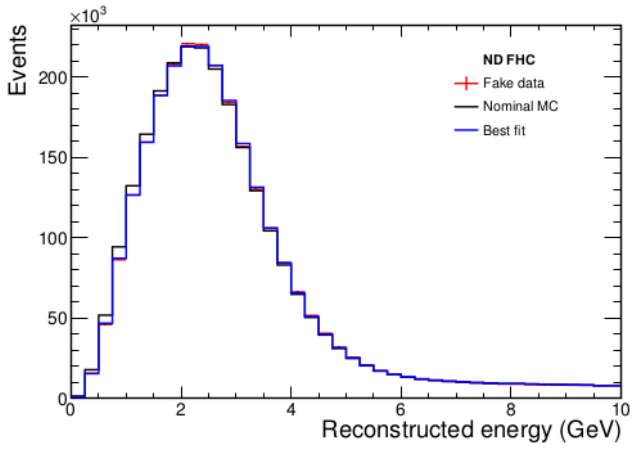


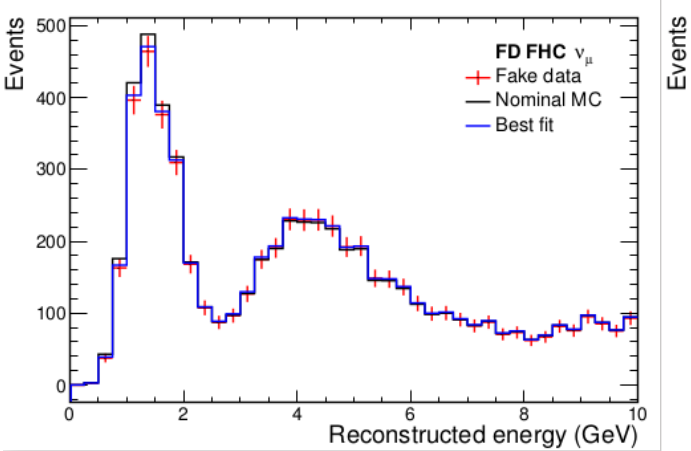


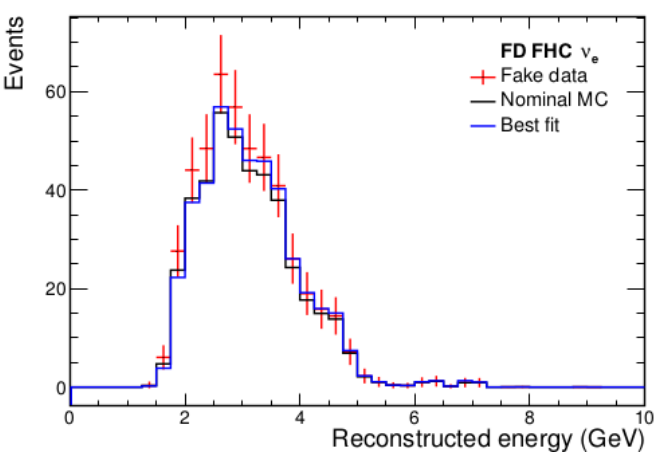
- With Xsec+flux parameters, delta CP can be mostly recovered.

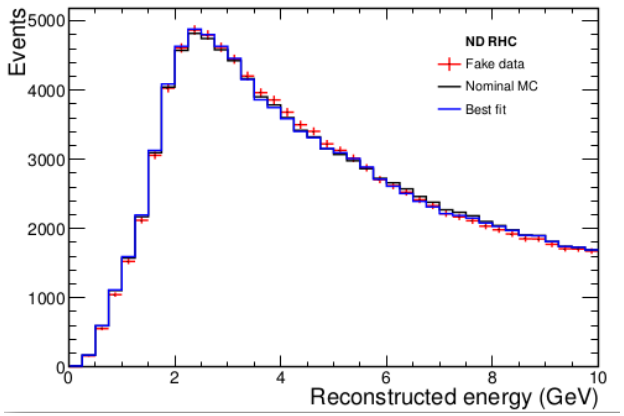
Fake data- Nuwro/GENIE

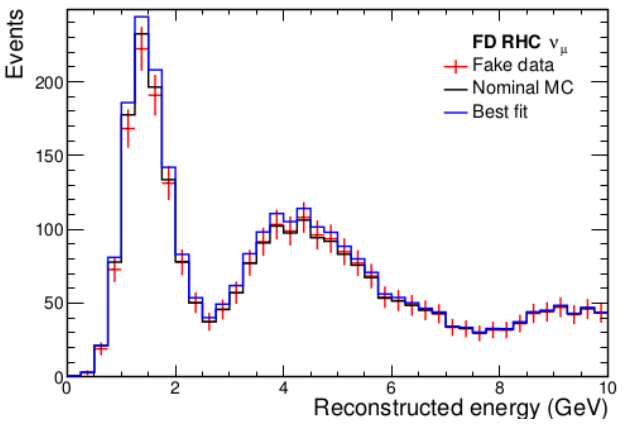
- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.

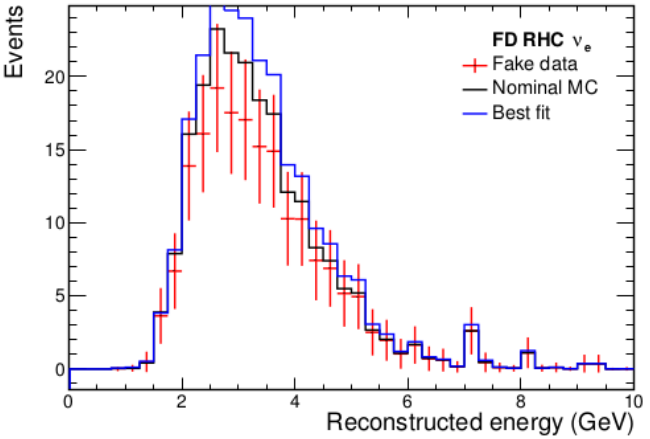












Systematics

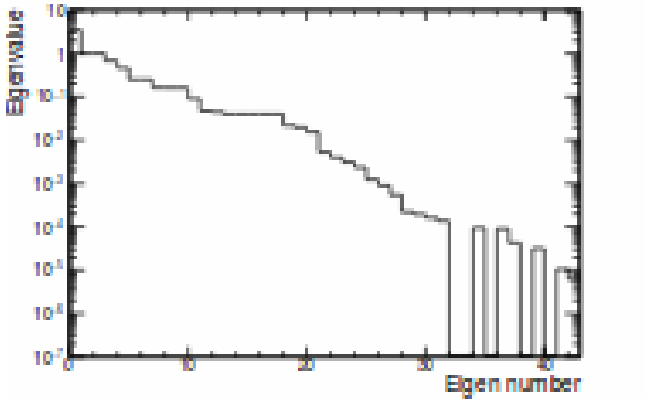
```
/// Absolute energy scale systematic
class EnergyScaleSyst: public ISyst
{
public:
  std::set<std::string> Requires() const override
  {
    return {"dune.Ev_reco"};
  }
  std::string ShortName() const override {return "eScale";}
  std::string LatexName() const override {return "Energy Scale";}

  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;
```

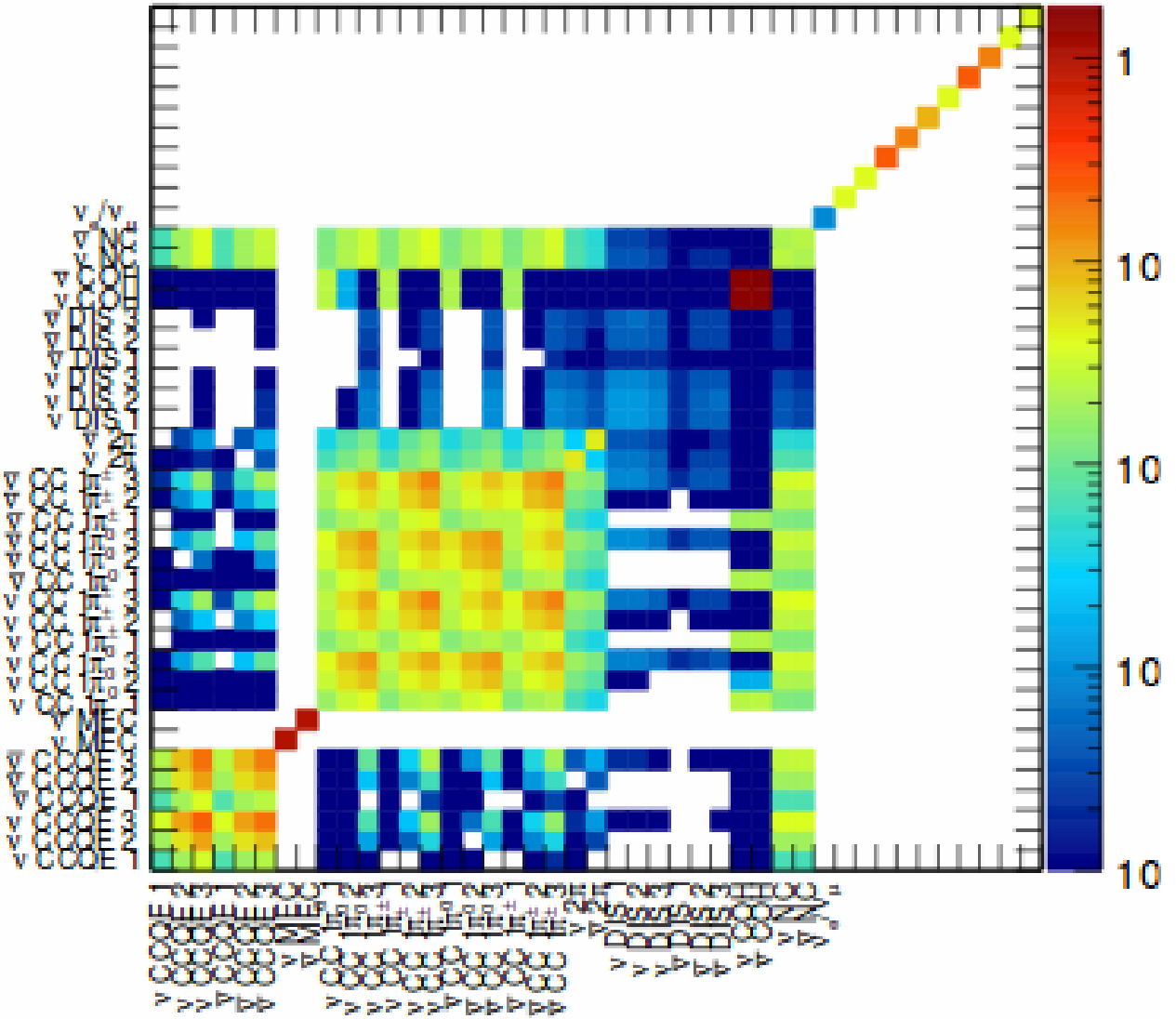
```
/// 5% normalization syst for NC on numu analysis
class NCSyst: public ISyst
{
public:
  std::set<std::string> Requires() const override
  {
    return {"dune.Ev","dune.Ev_reco", "dune.ccnc"};
  }
  std::string ShortName() const override {return "NC";}
  std::string LatexName() const override {return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