

# Some updates on DUNE-prism

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# Introduction

Framework : CafAna fitter in DUNE

Statistics : based on 3.5 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

# 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)
  - 2 variables introduced by me (fake data variables..)
- “One sigma” means the standard variation in fake data.

# 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

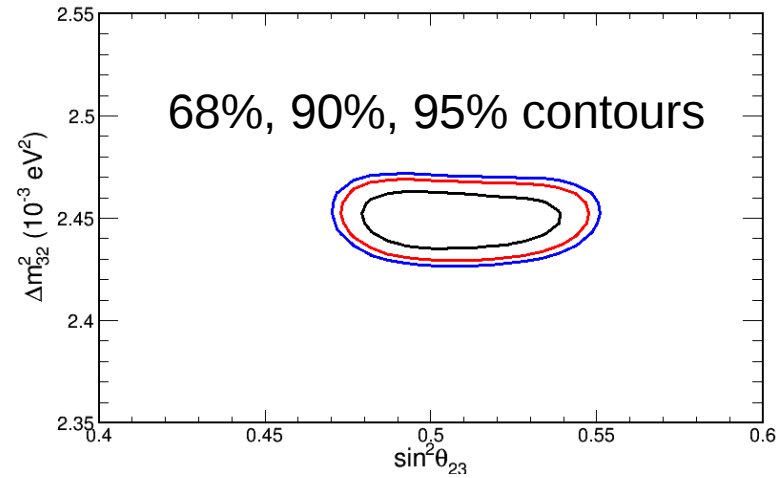
## 3. Fake data study

- 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

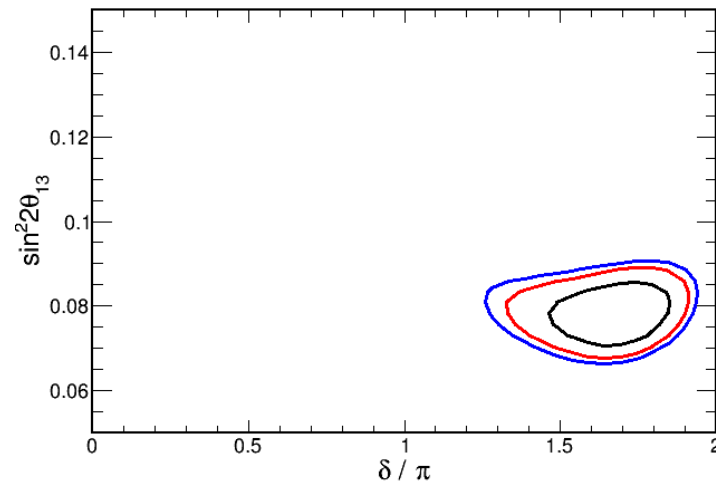
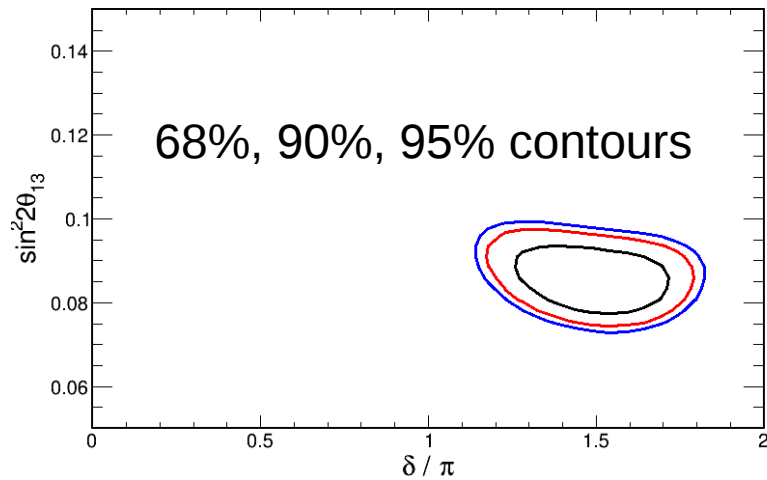
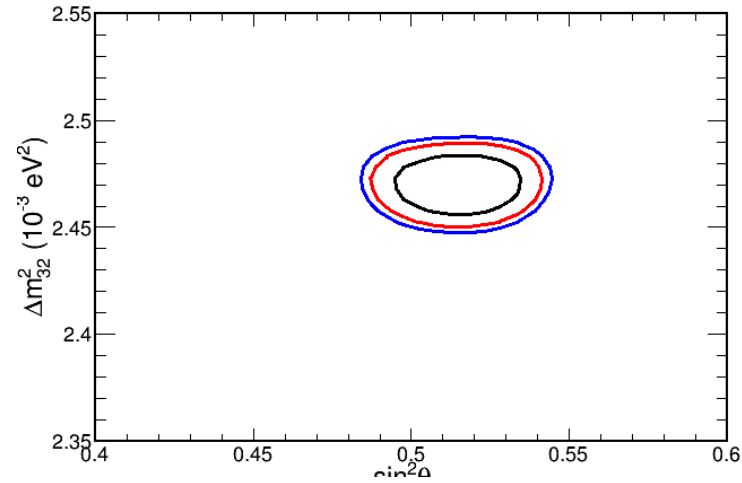
# The problem we are having..

## 20% missing PE 3.5 years

True



10% missing PE



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

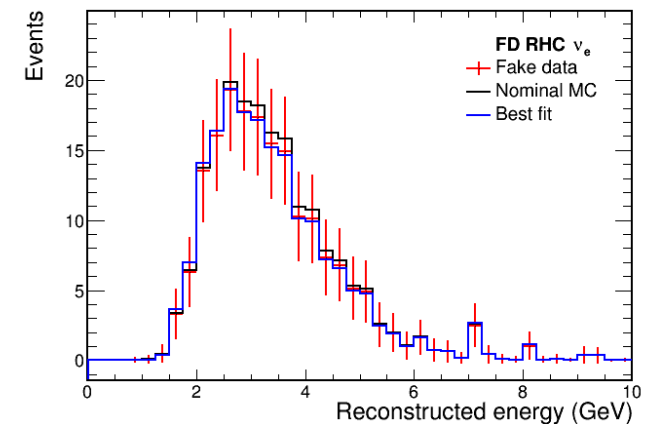
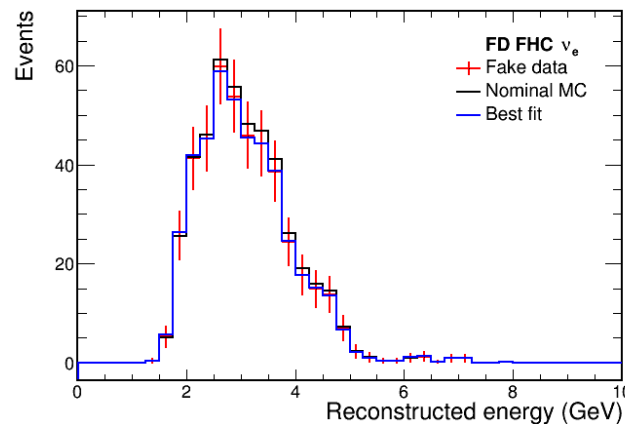
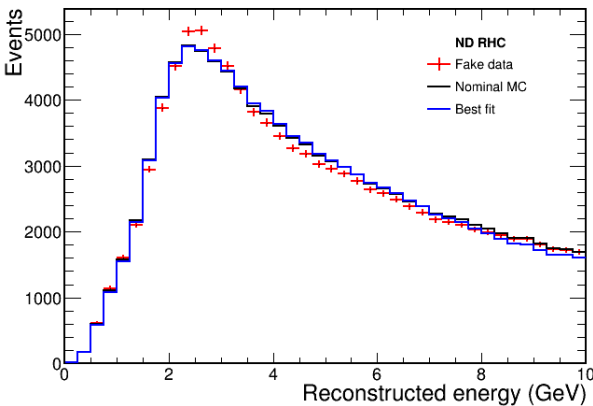
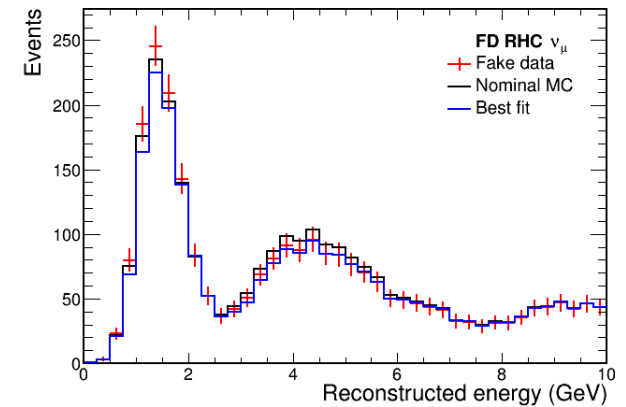
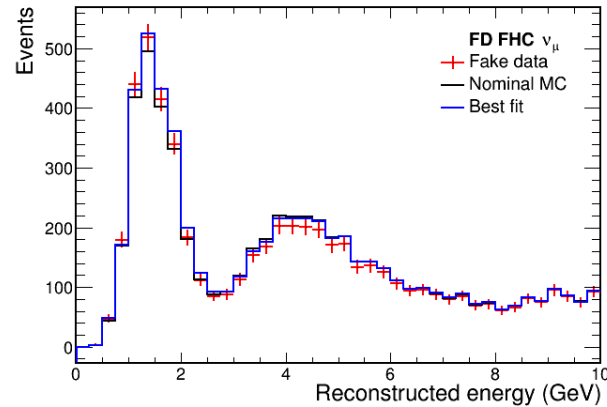
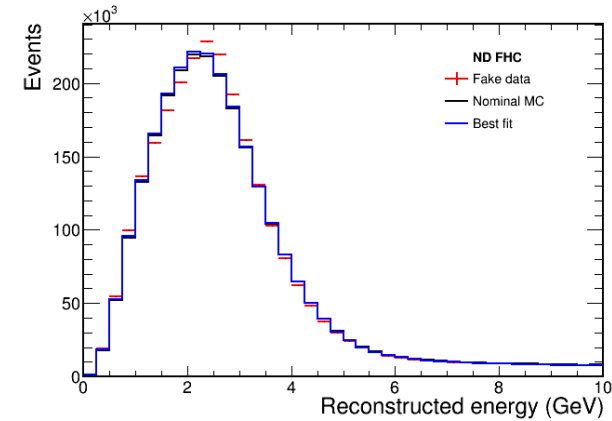
# The problem we are having..

## 20% missing PE 3.5 years

LL value: ND only fit: 4084

FD+ND: 4108

FD only fit: 9

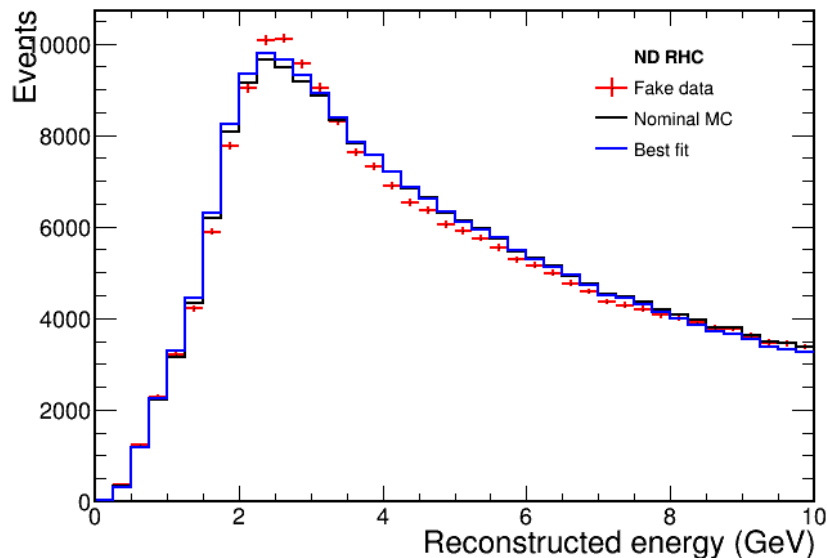
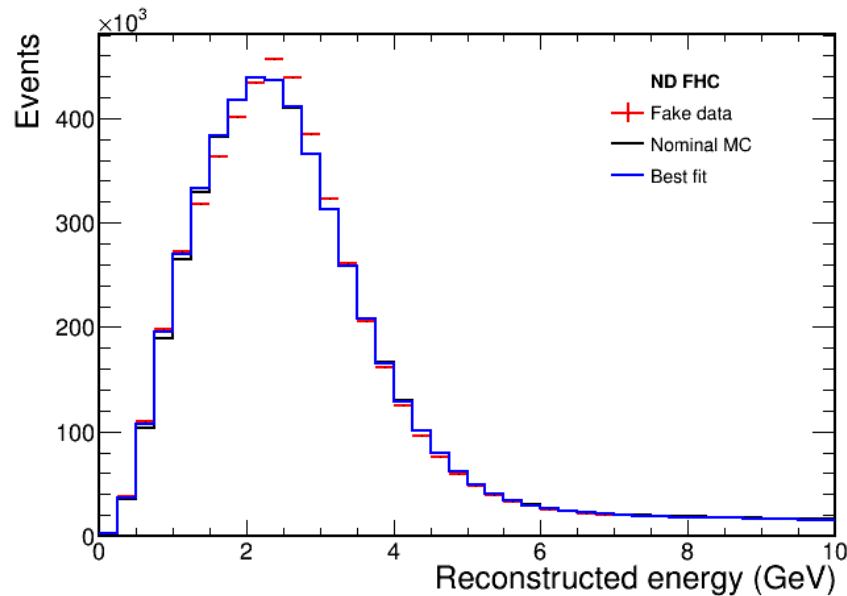


- Missing hadronic energy bring us a disaster, however, not only in FD, but in ND..
- I have major Xsec and flux systematics in backup slides.

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

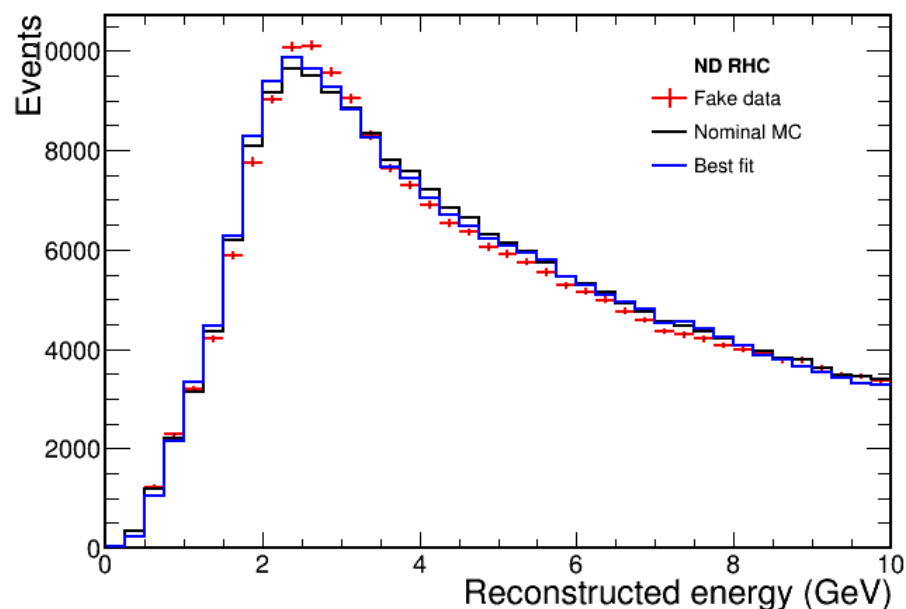
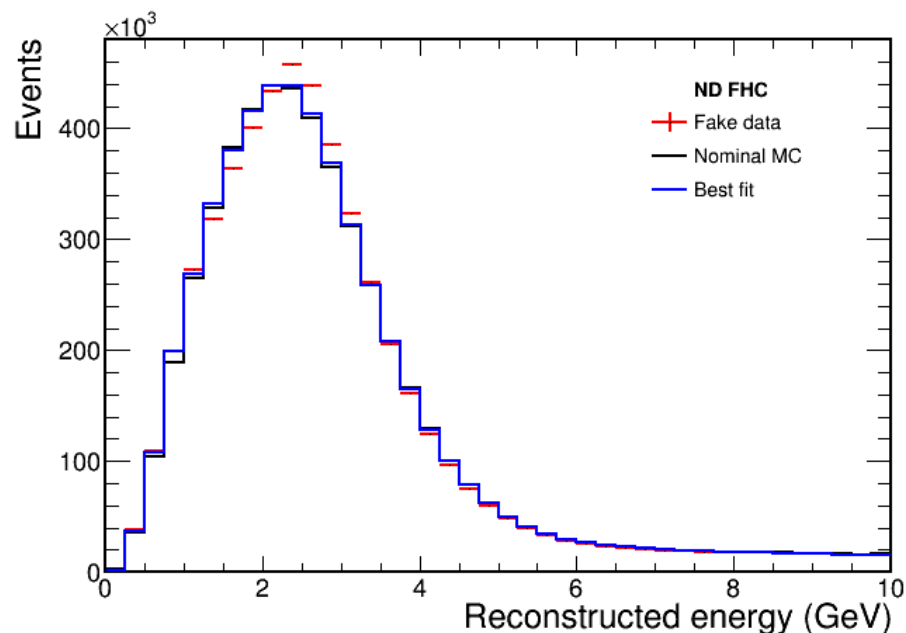
If I just do ND fit (7 years) ..



```

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..

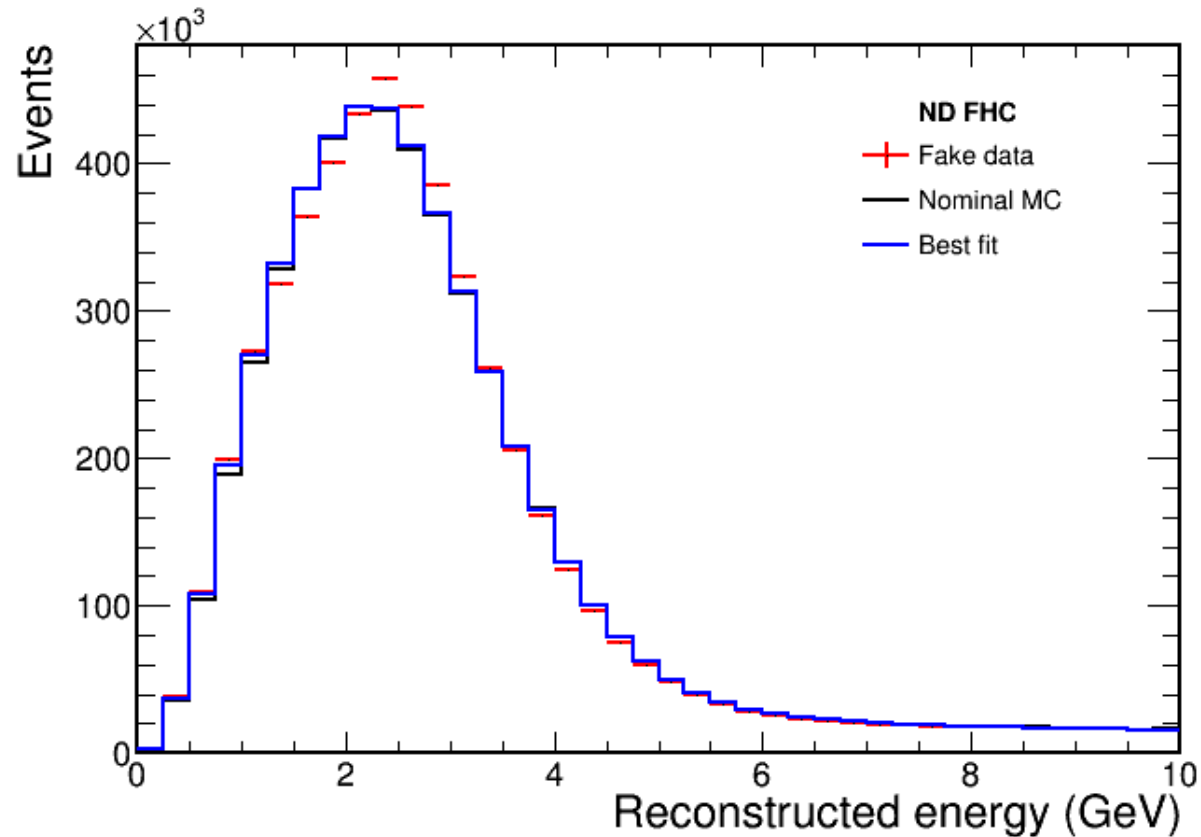


```

Syst. shift nu_ccqe_1_scale -3.35629e-05
Syst. shift nu_ccqe_2_scale -2.04855e-05
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
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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..



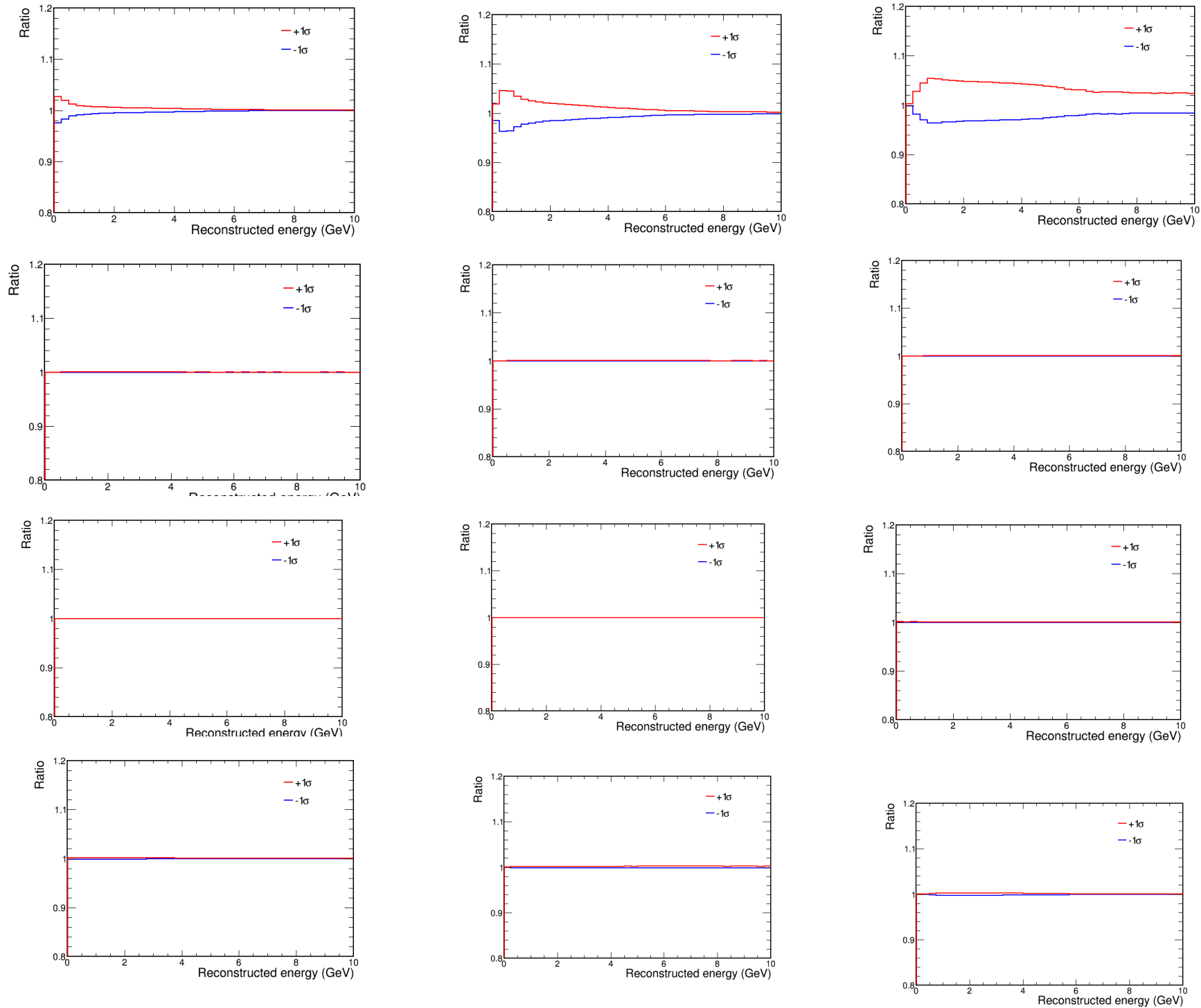
Systematics output table is similar to what you have seen before..

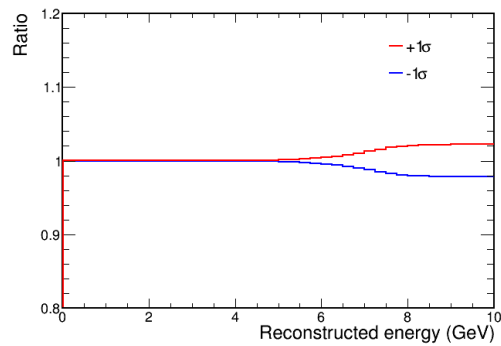
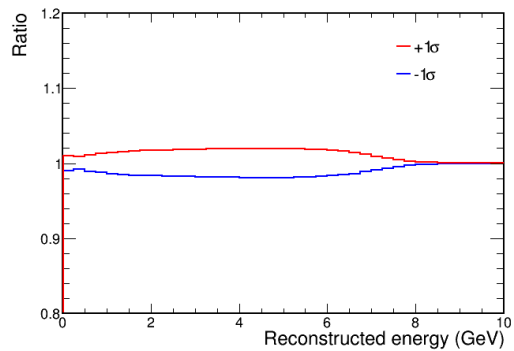
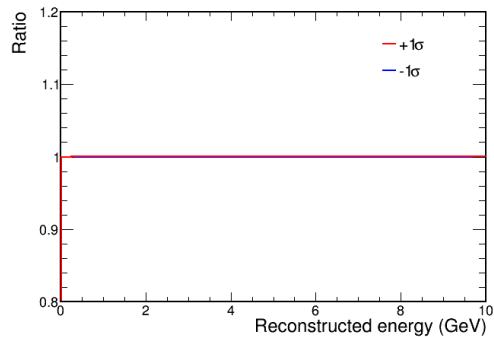
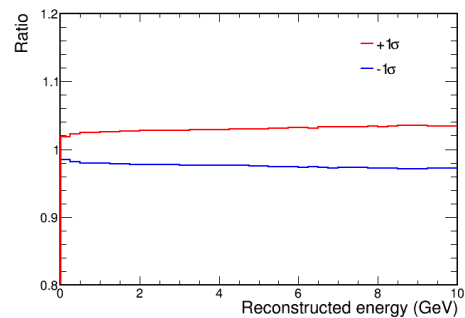
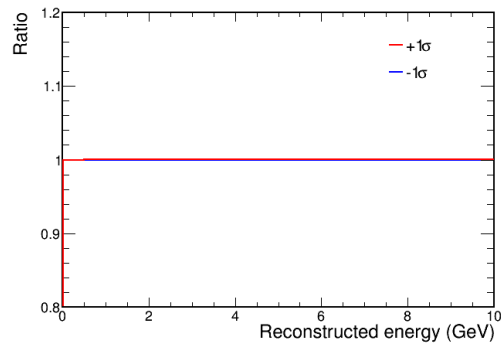
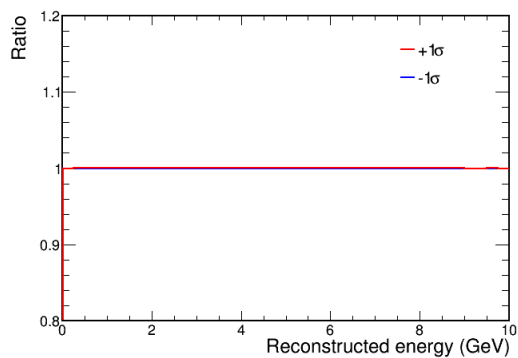
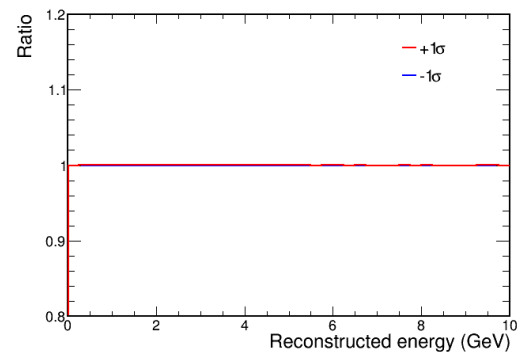
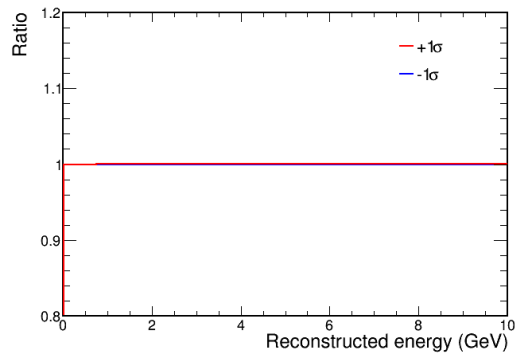
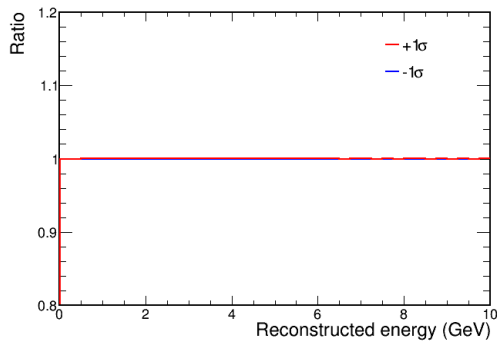
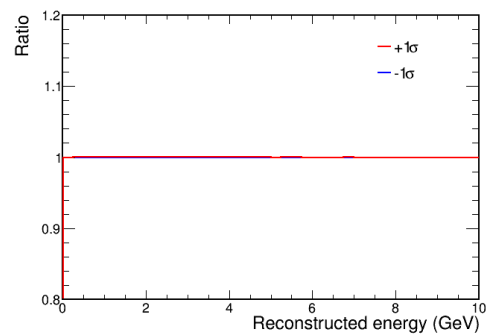
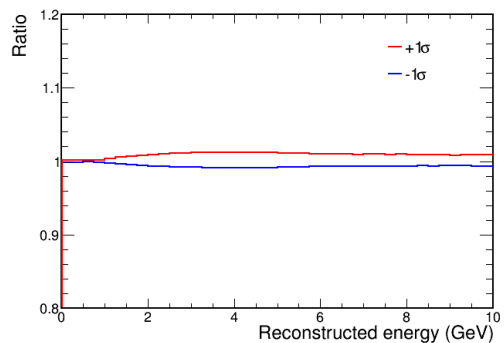
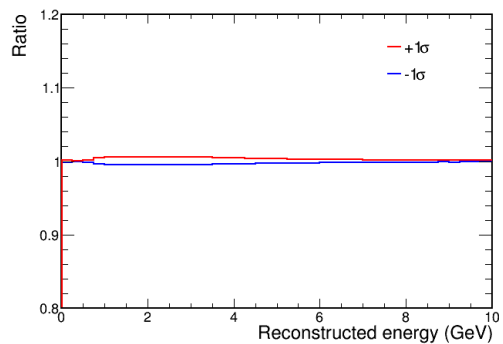
# The problem

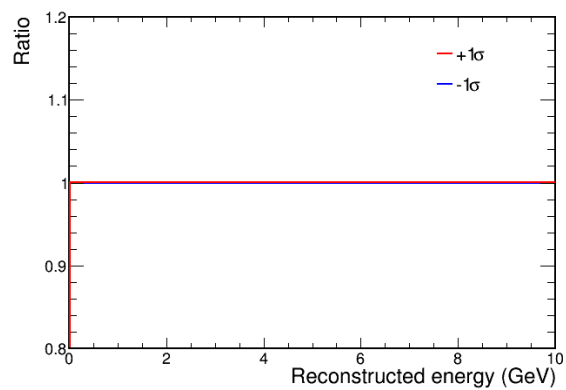
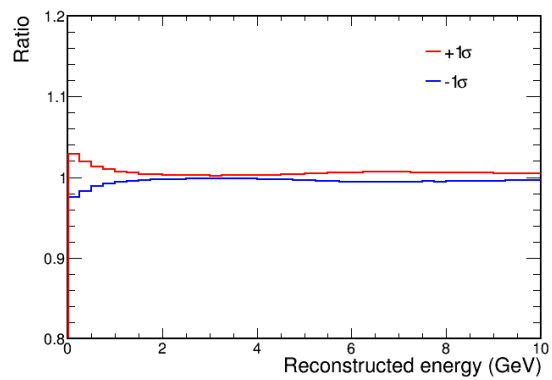
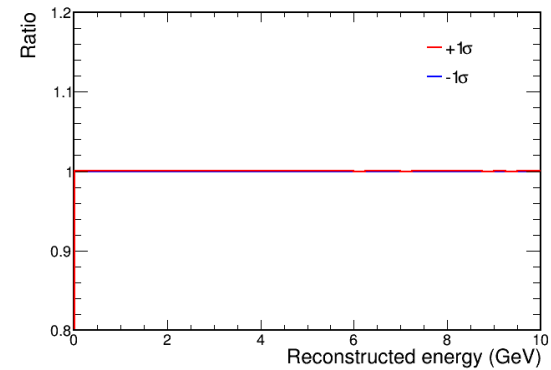
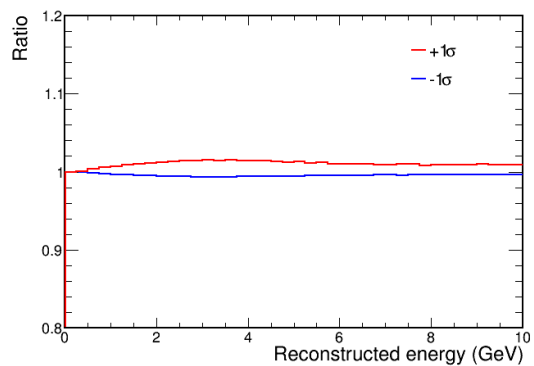
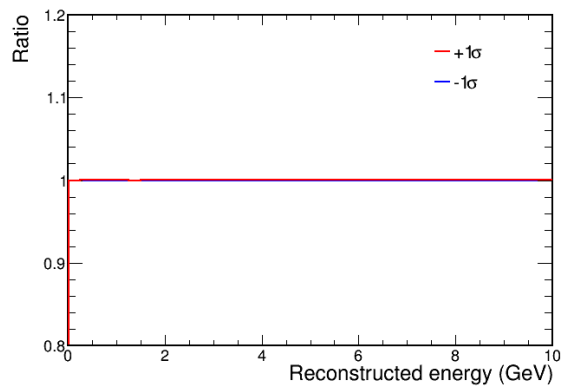
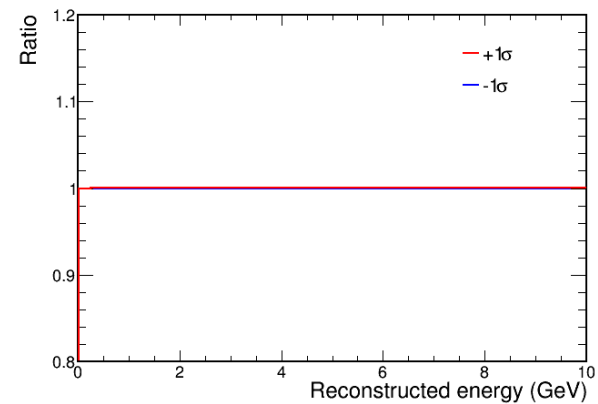
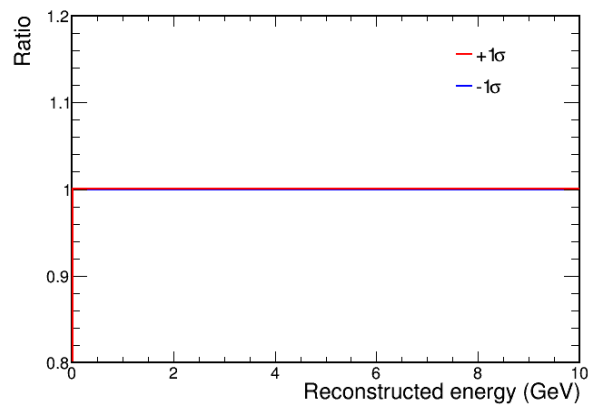
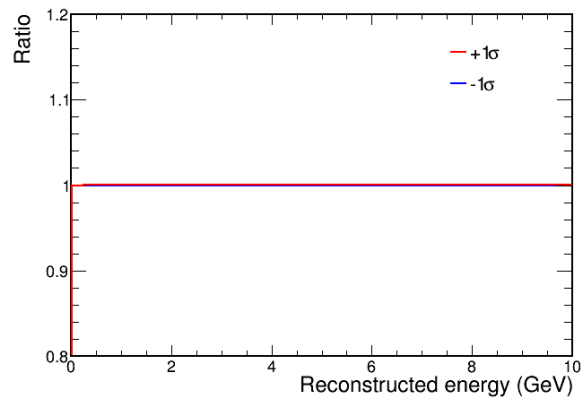
- ND does not like to move. Current Xsec, flux and E-scale cannot recover the 20% missing PE in ND.
- I need realistic antinu shift. Now I am using nu for antinu.
- I am trying to run GENIE to get some fake data..

Backup..

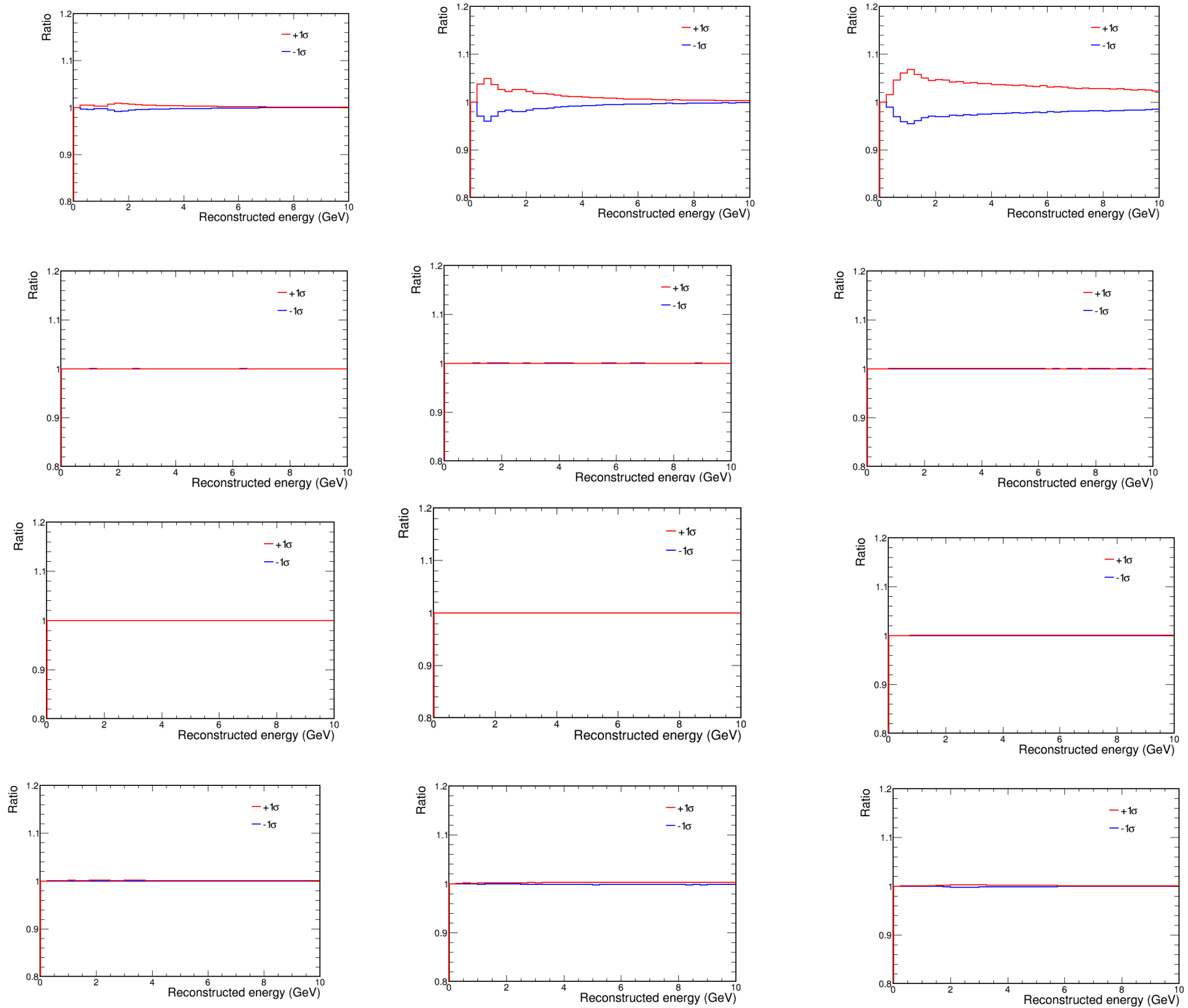
# Xsec ND FHC

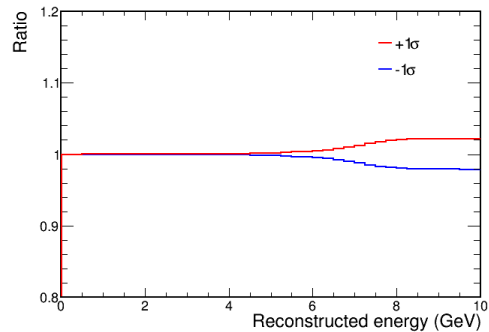
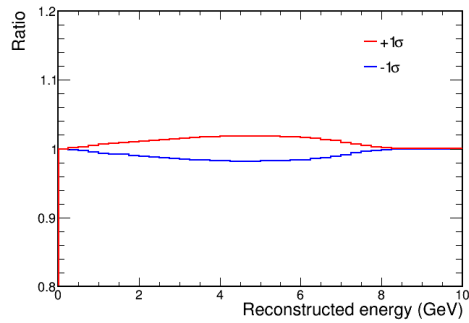
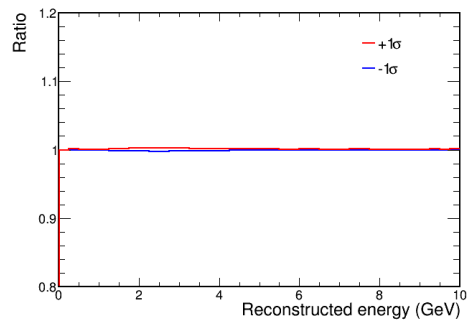
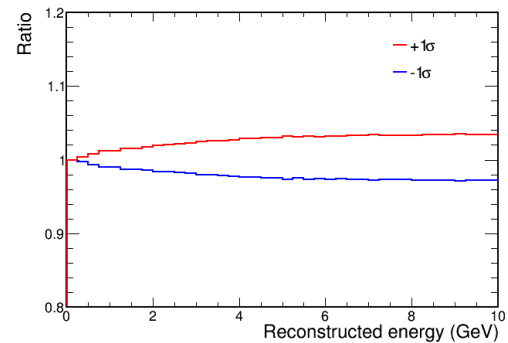
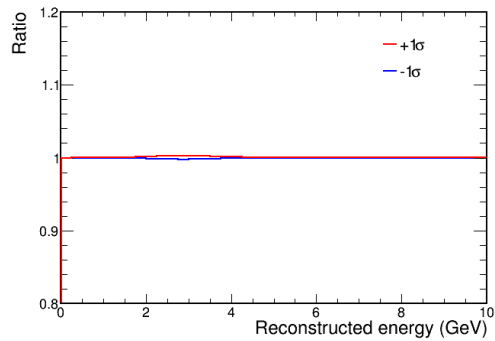
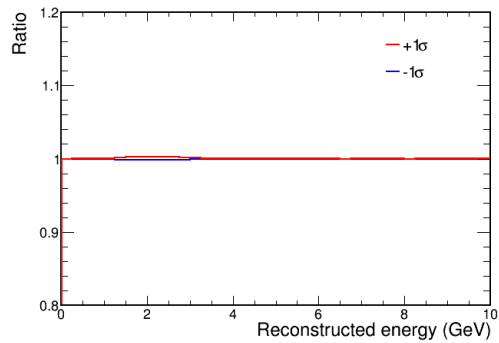
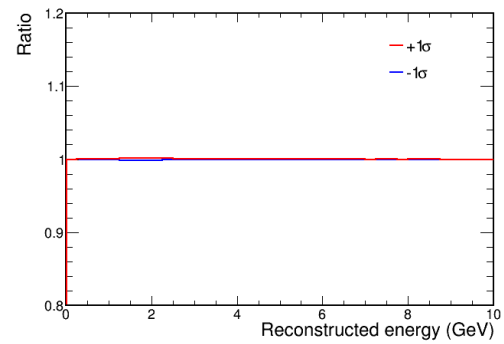
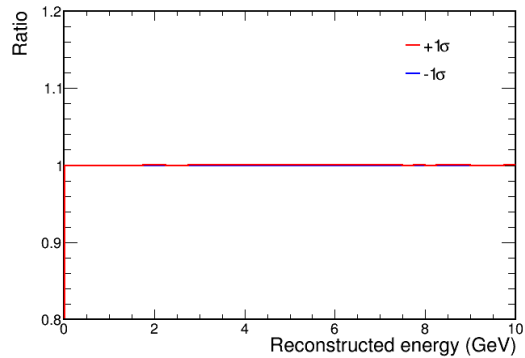
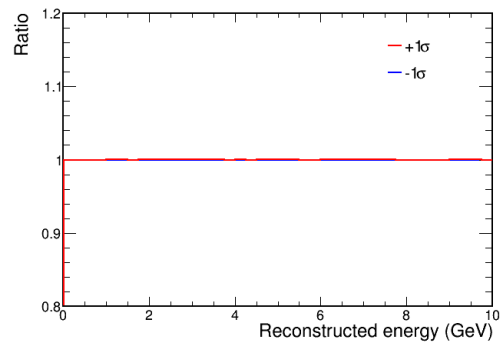
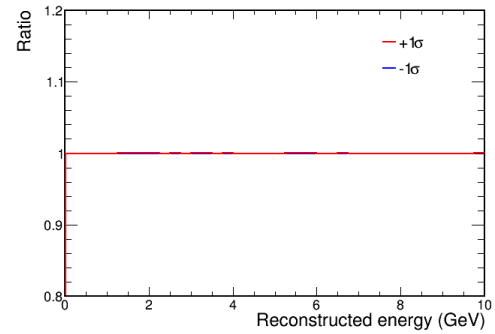
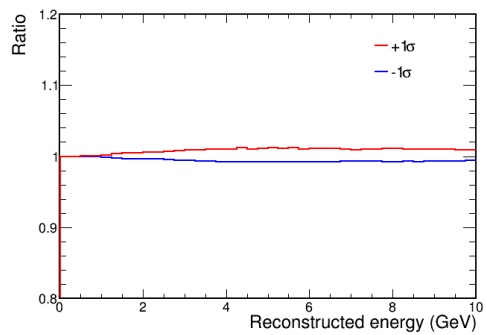
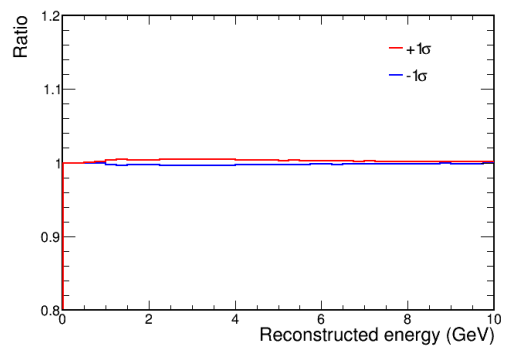




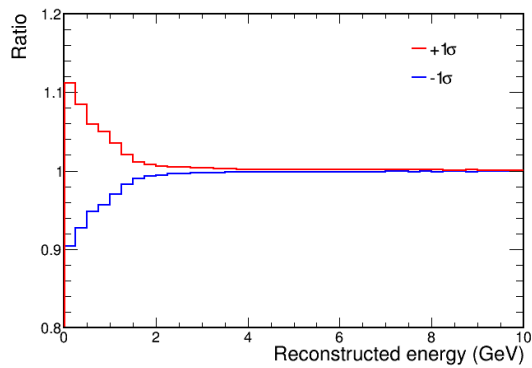
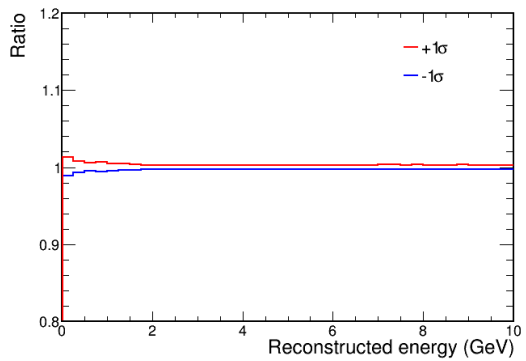
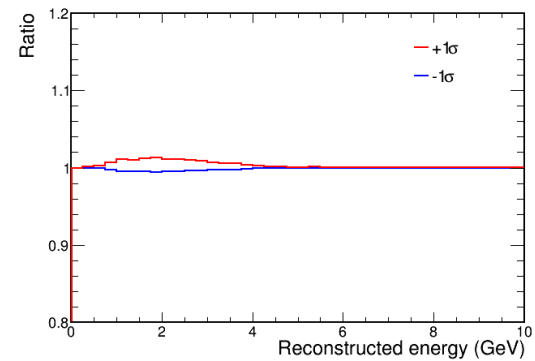
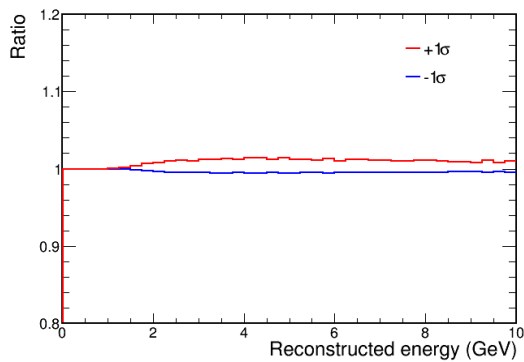
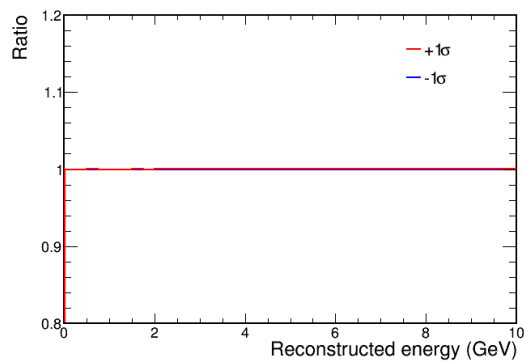
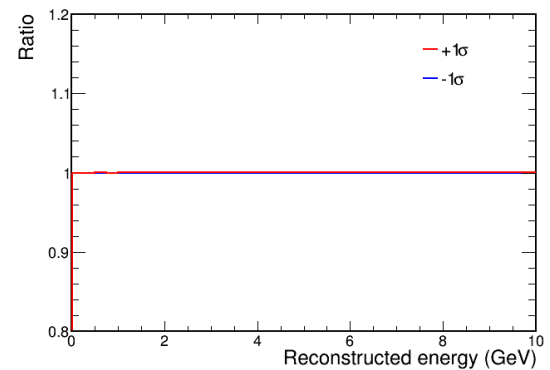
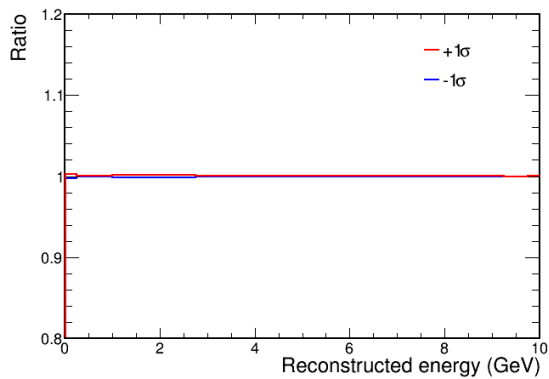
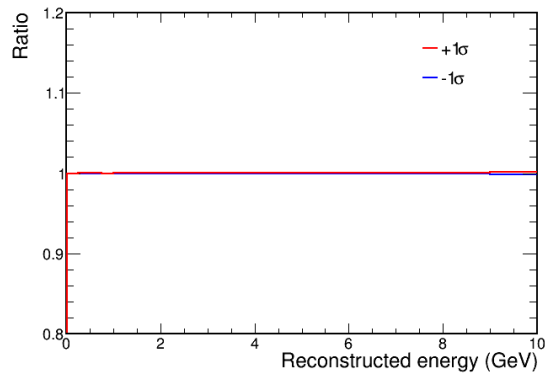


# Xsec ND RHC

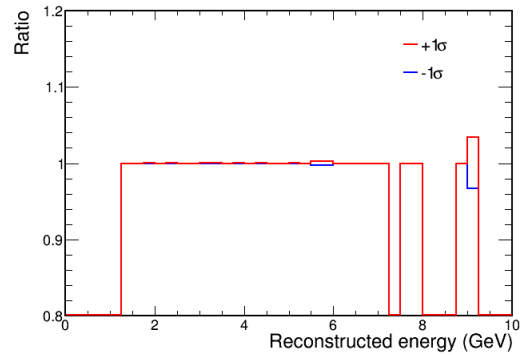
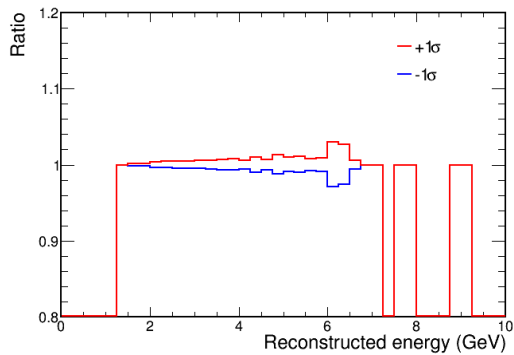
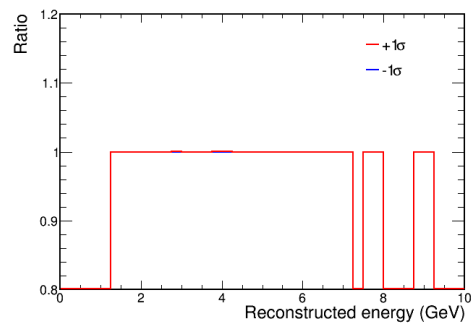
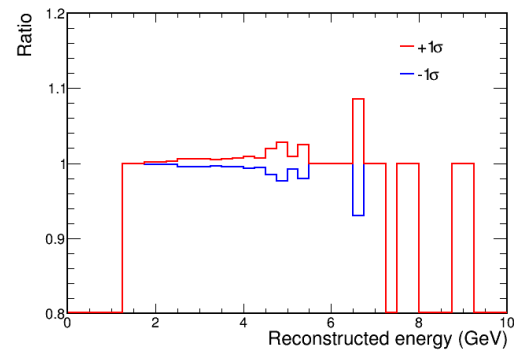
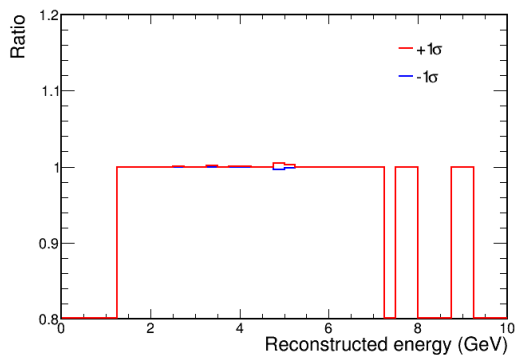
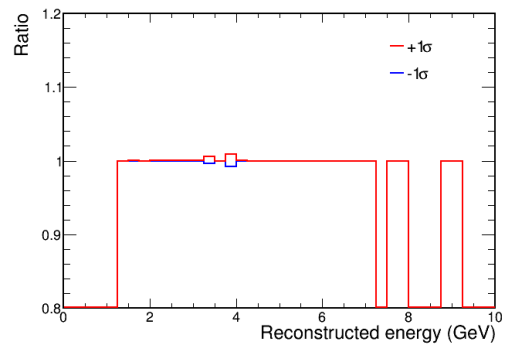
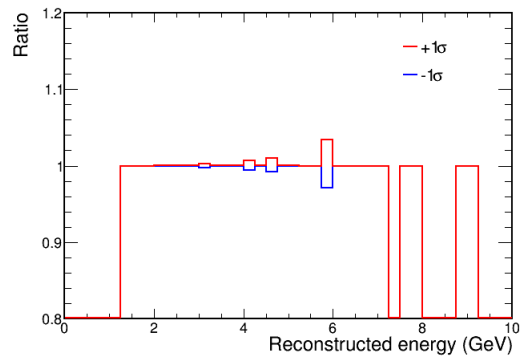
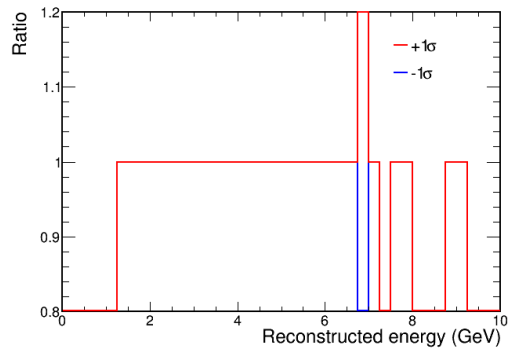
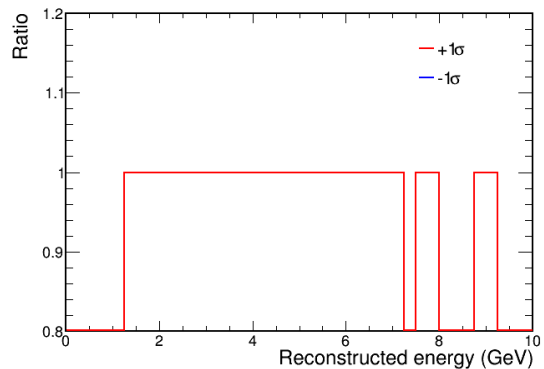
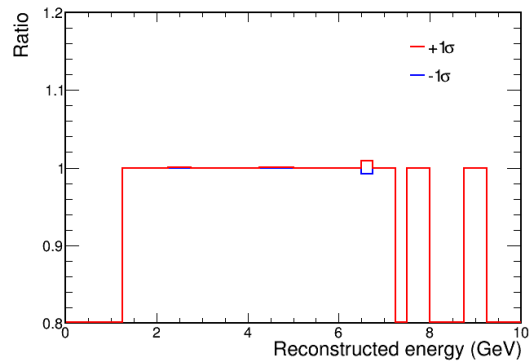
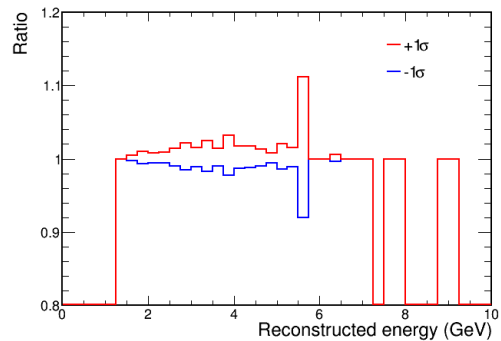
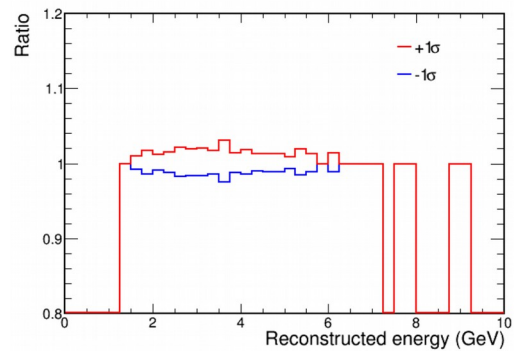


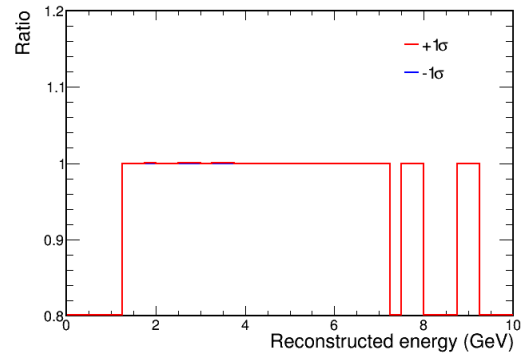
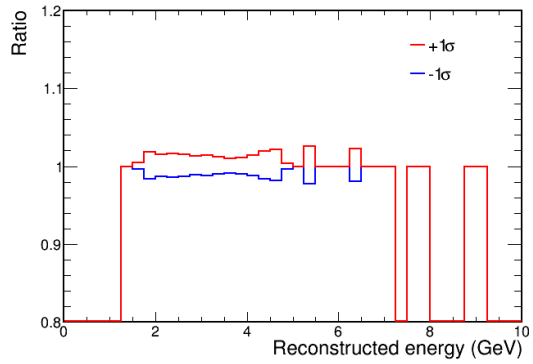
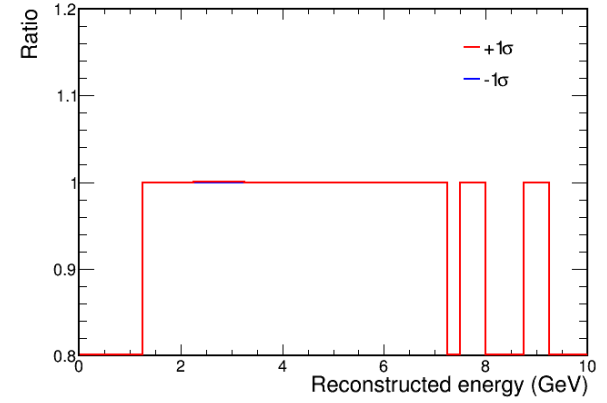
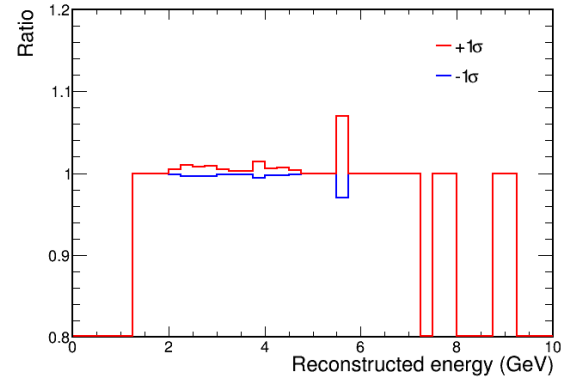
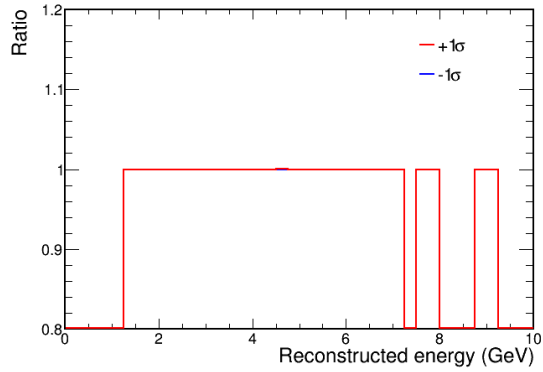
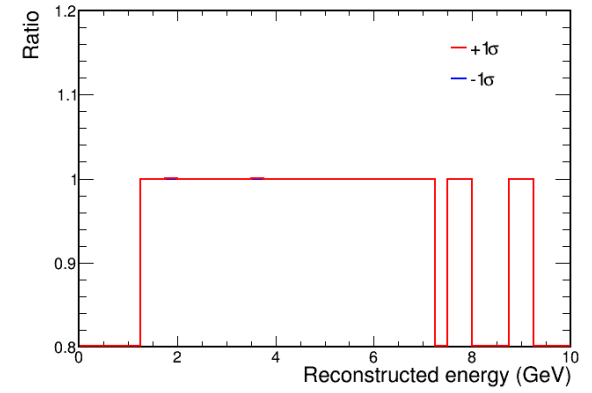
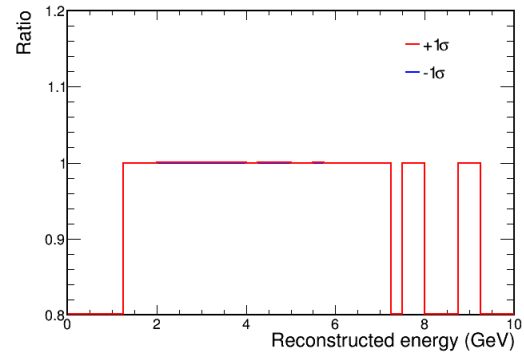
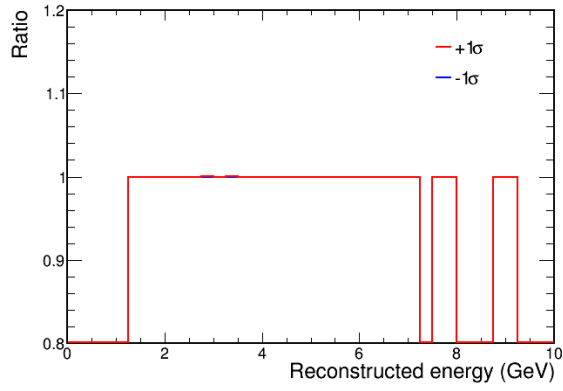




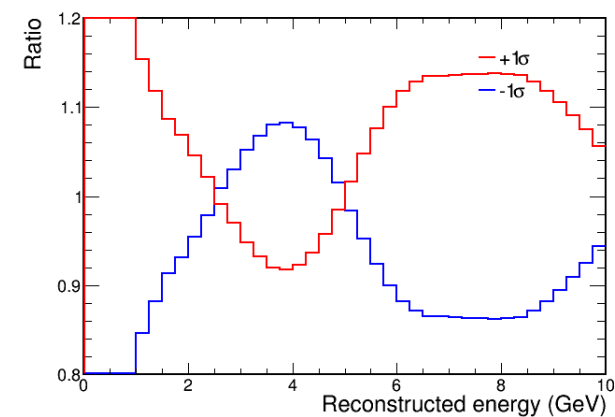
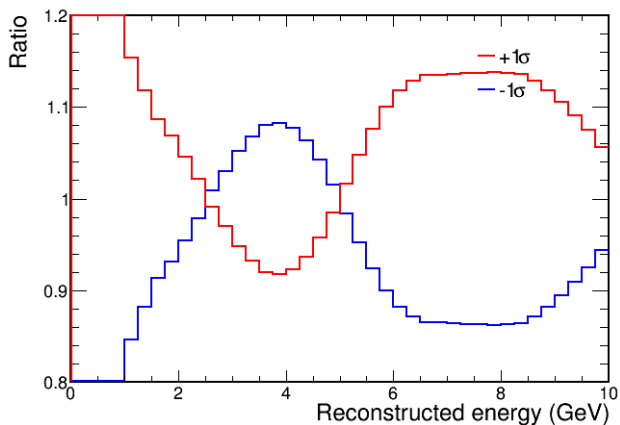
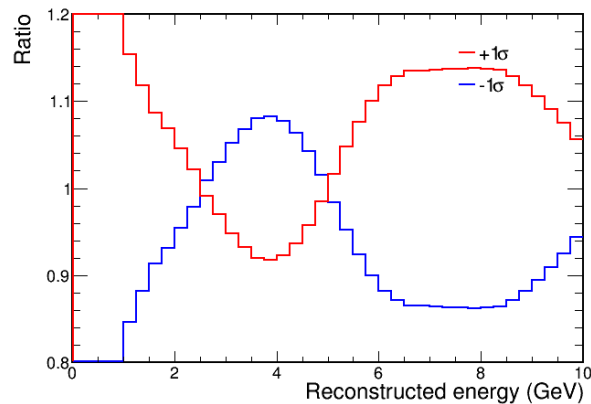
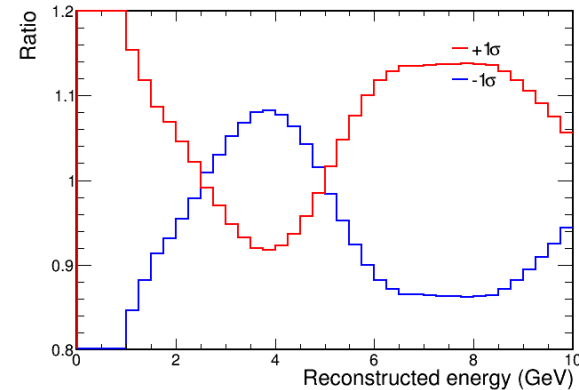
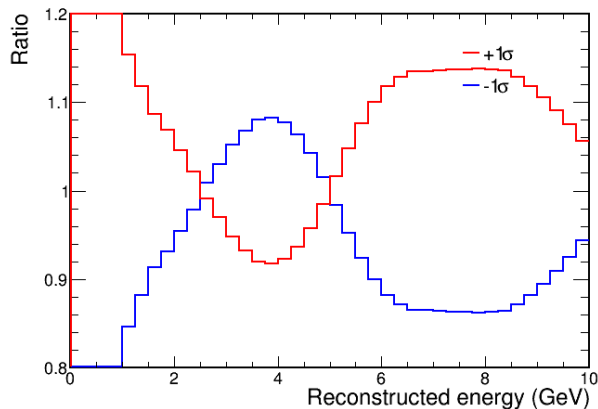
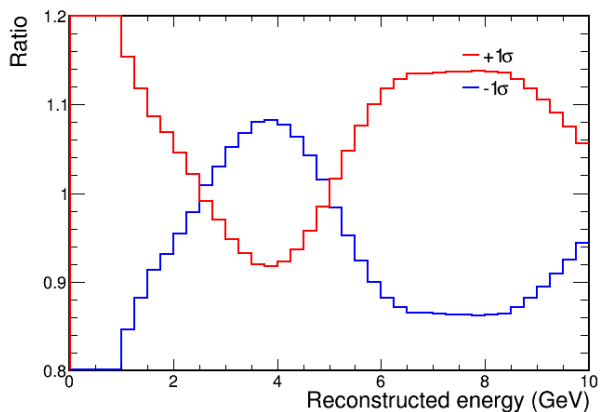
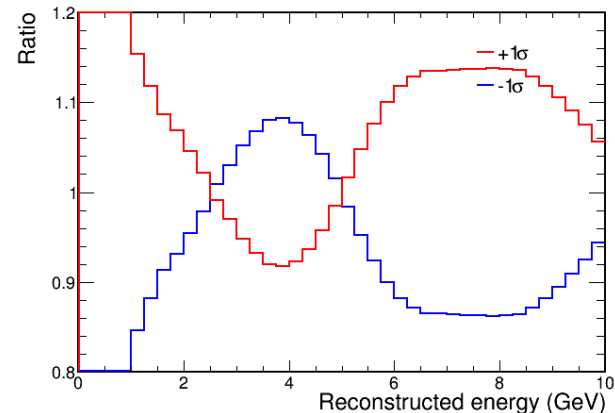
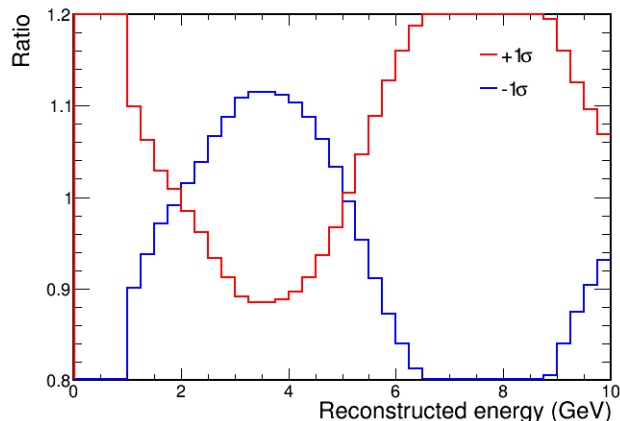
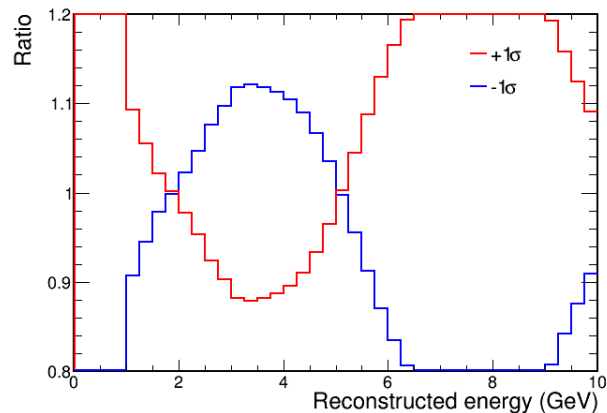




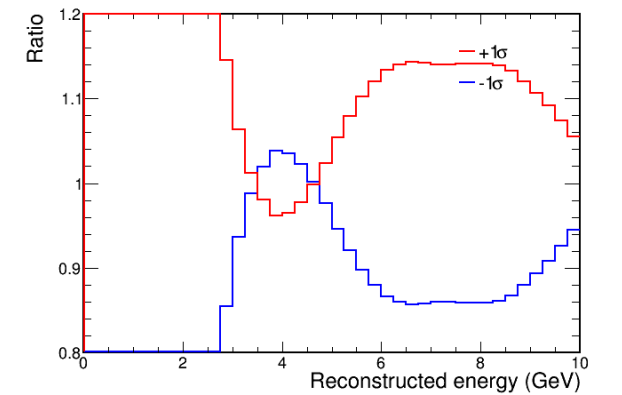
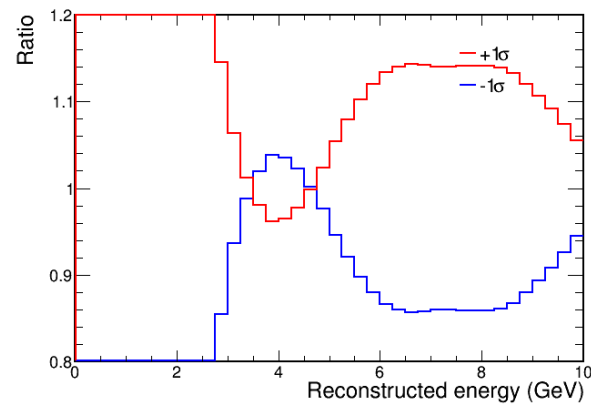
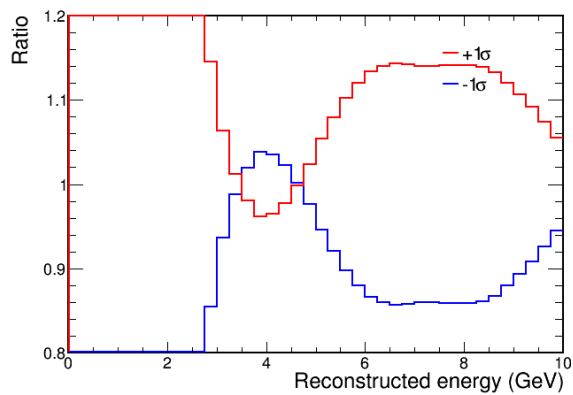
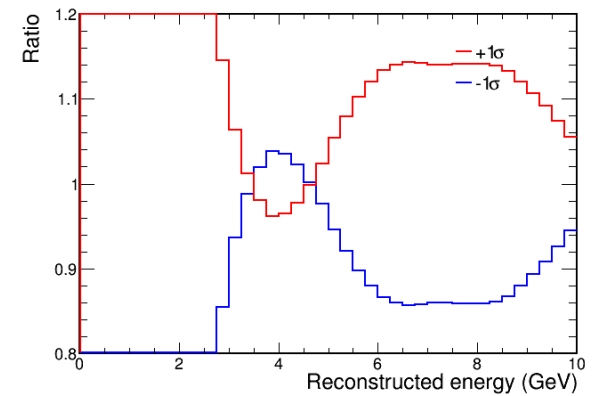
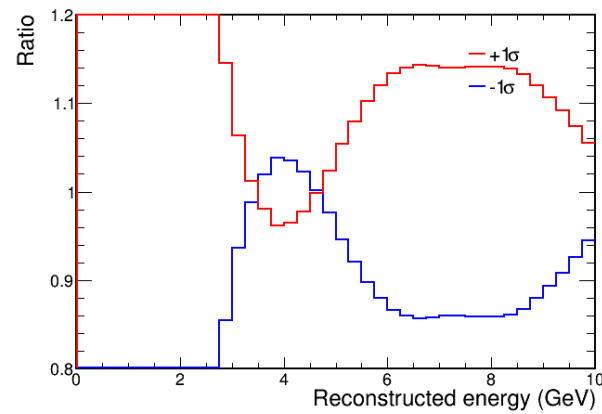
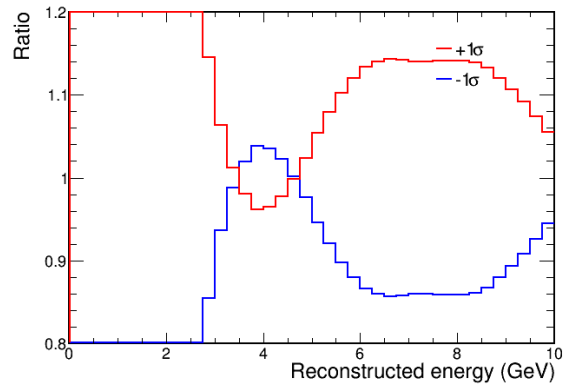
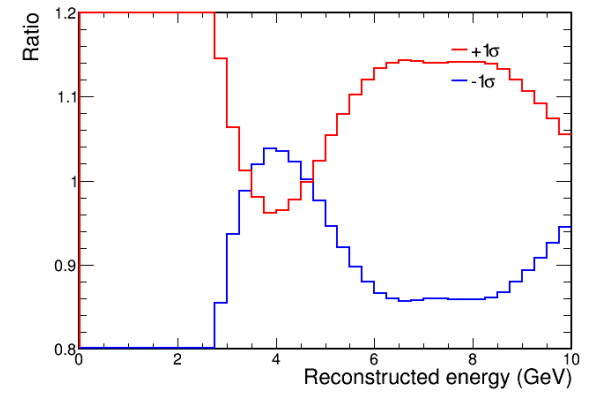
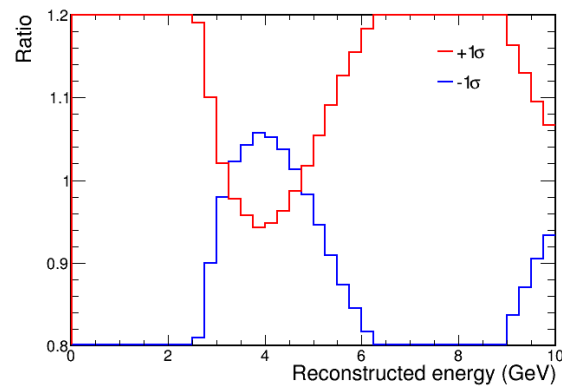
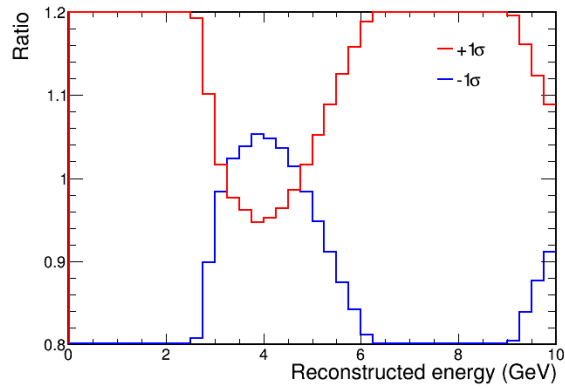




# Flux systematics ND FHC



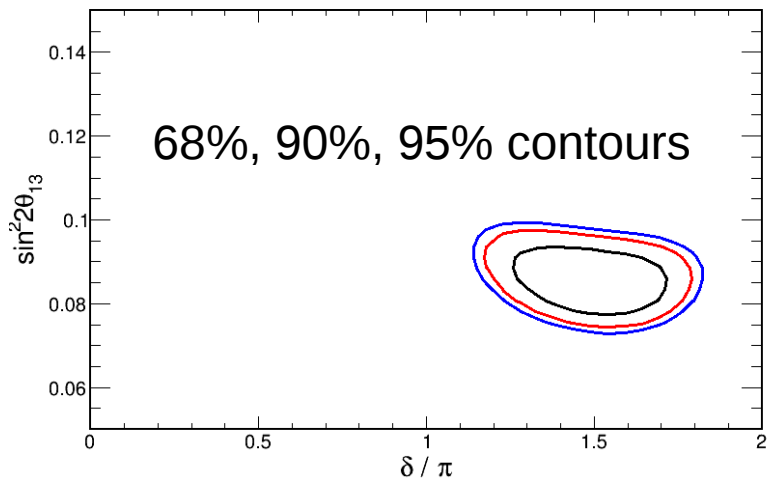
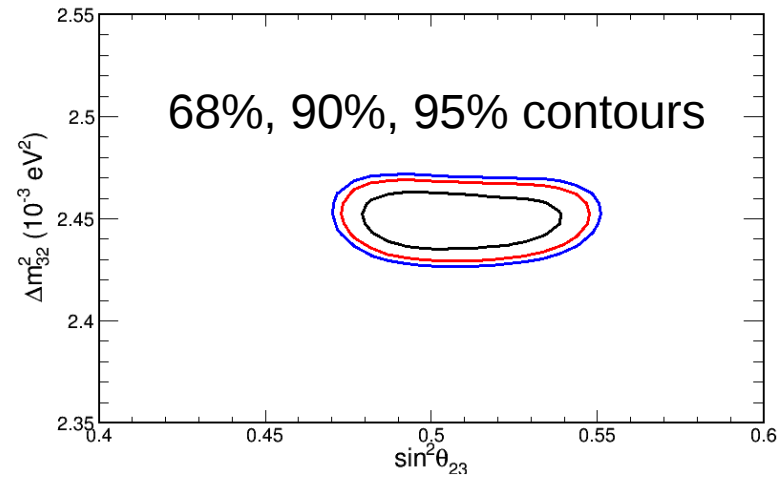
# Flux systematics ND RHC



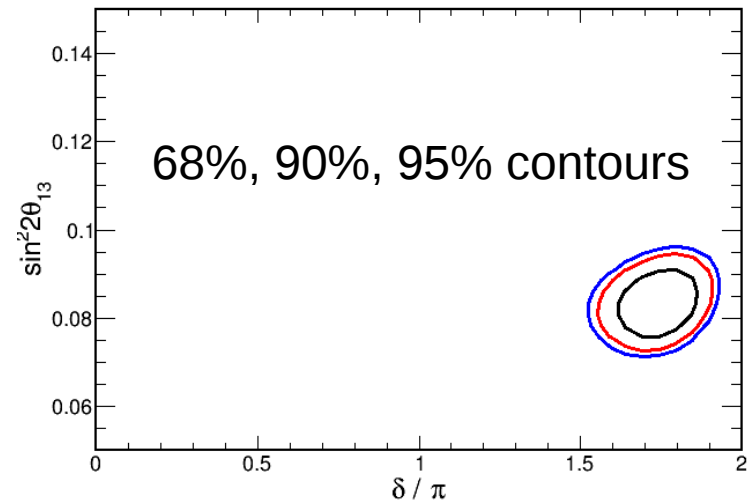
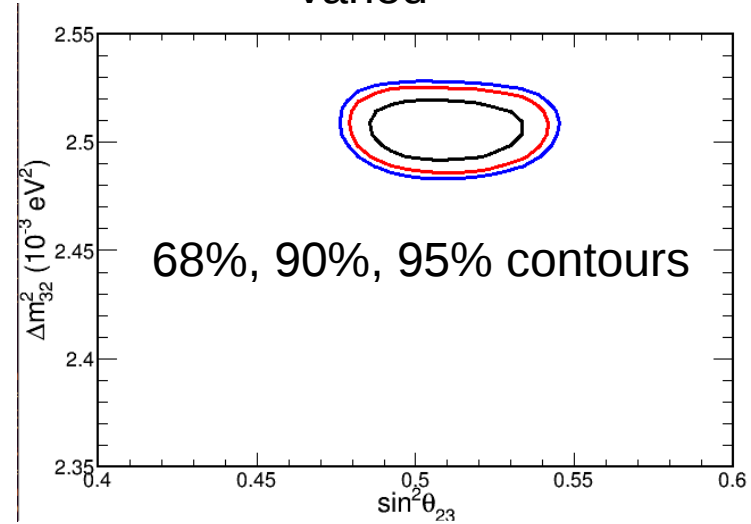
# Systematics validation

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

True

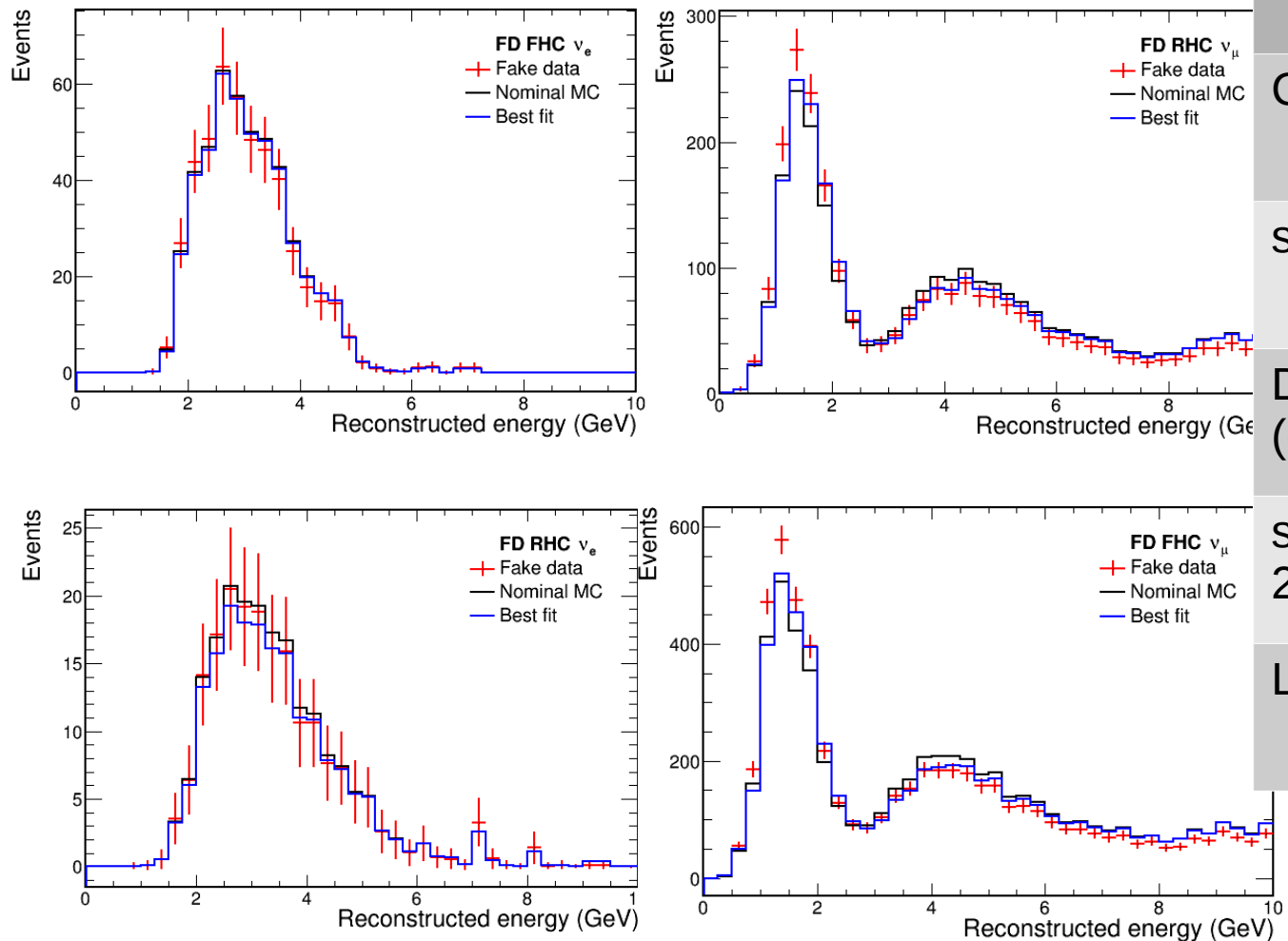


Varied



# Systematics validation

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



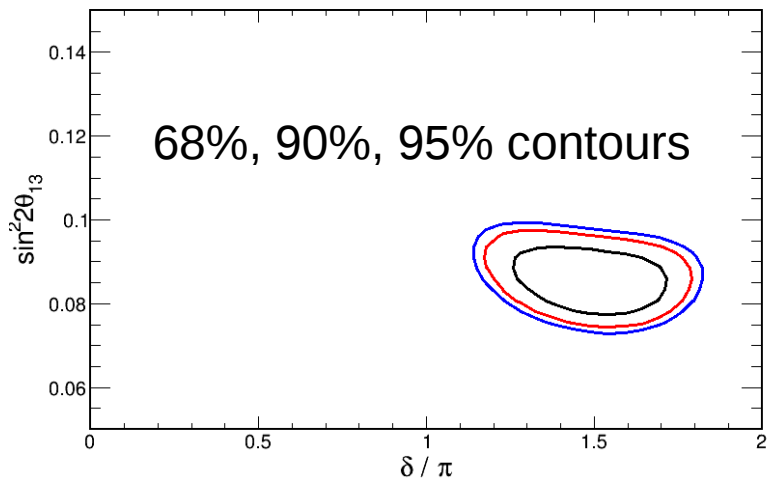
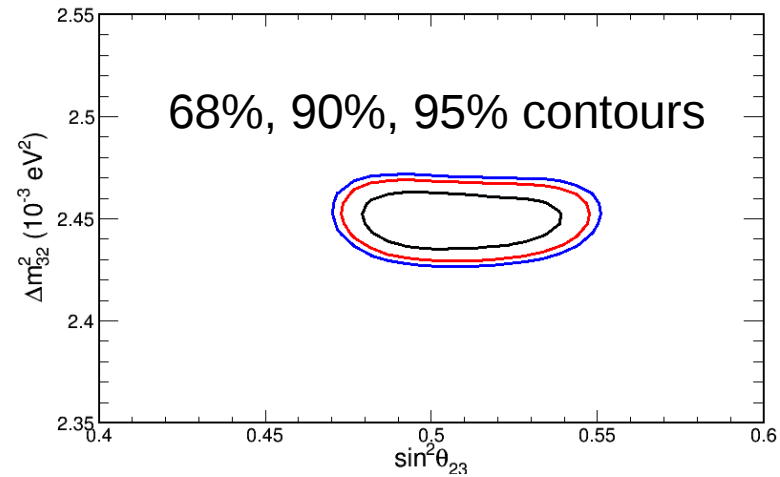
	true	FD+ND Best fit	FD only
CP (pi)	1.5	1.67	1.67
sst23	0.5	0.51	0.51
Dm32 (e-3)	2.45	2.57	2.57
ss( 2*t13)	0.087	0.078	0.078
LL		126246	99.5



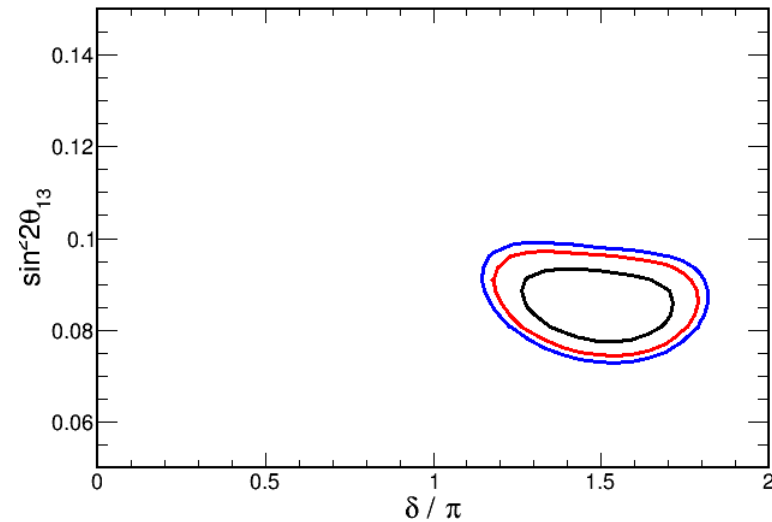
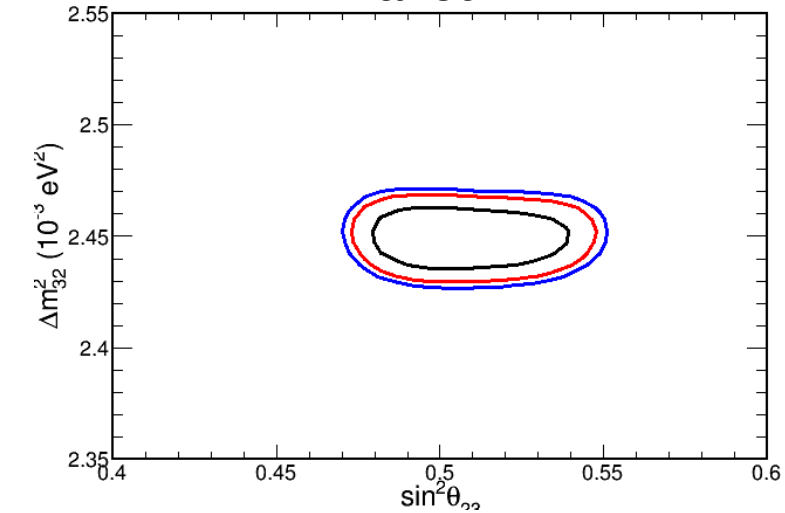
# Systematics validation

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

True

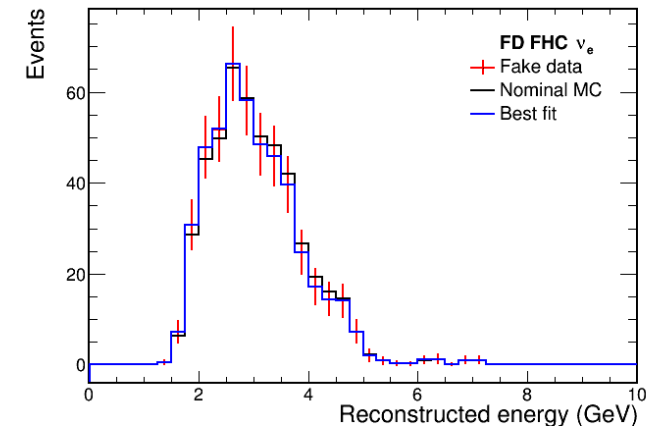
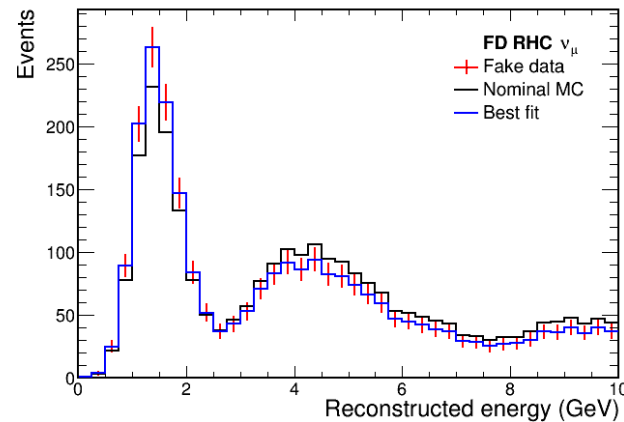
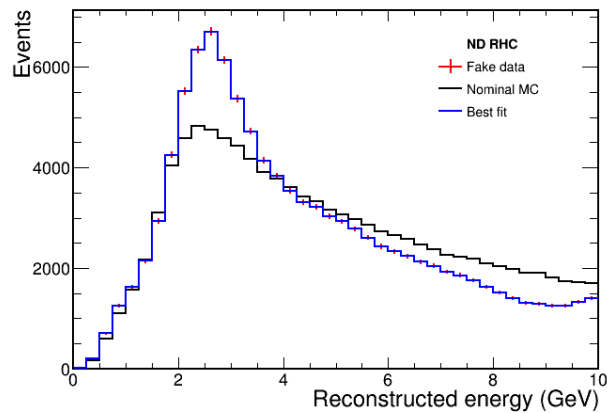
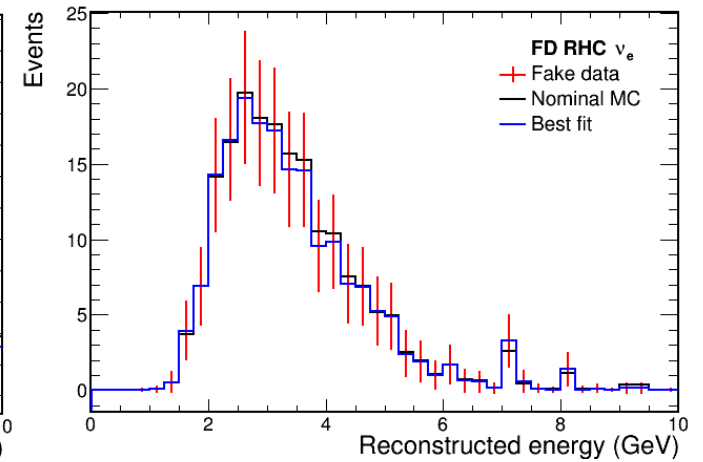
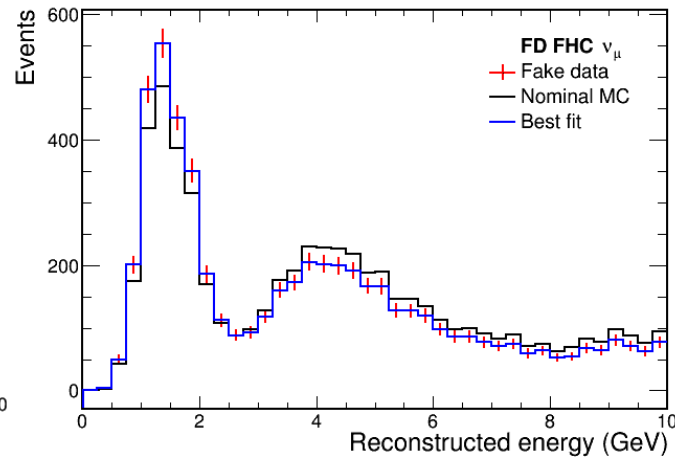
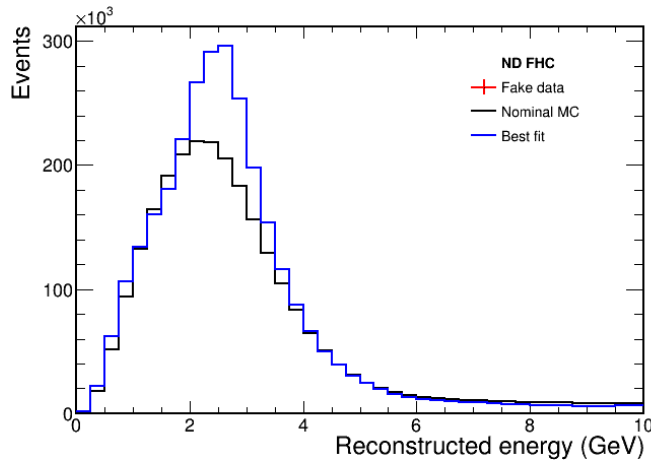


Varied



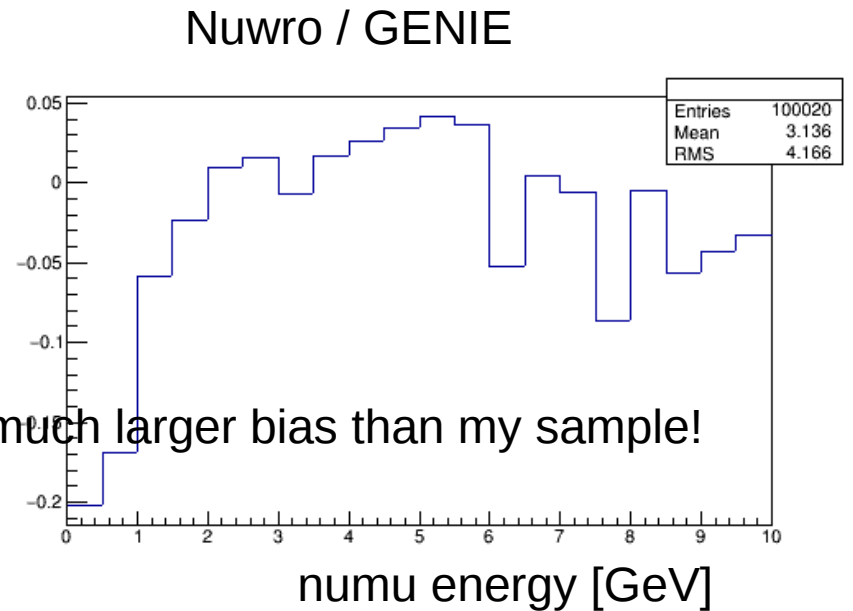
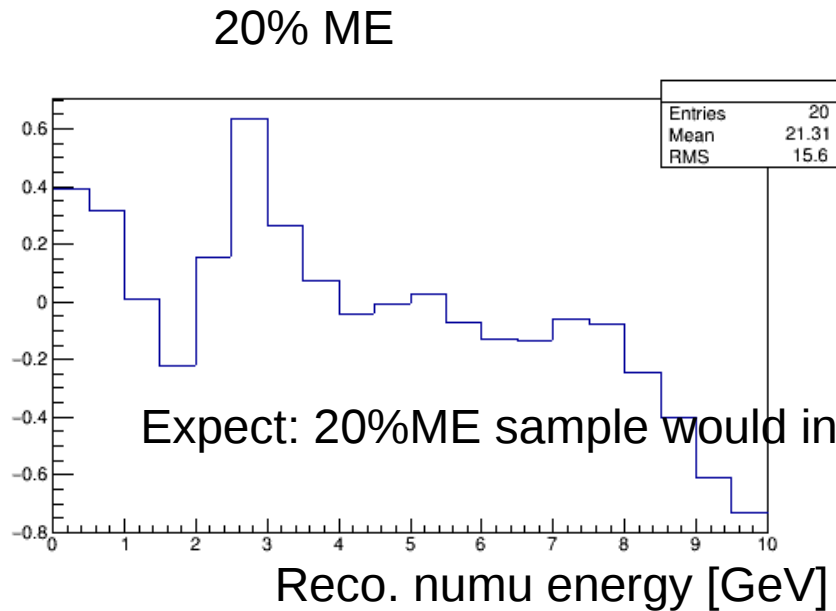
# Systematics validation

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



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  $\rightarrow$  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.

- $\rightarrow$  Genie : default v2.10.10, numu on Ar target.
- $\rightarrow$  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
```

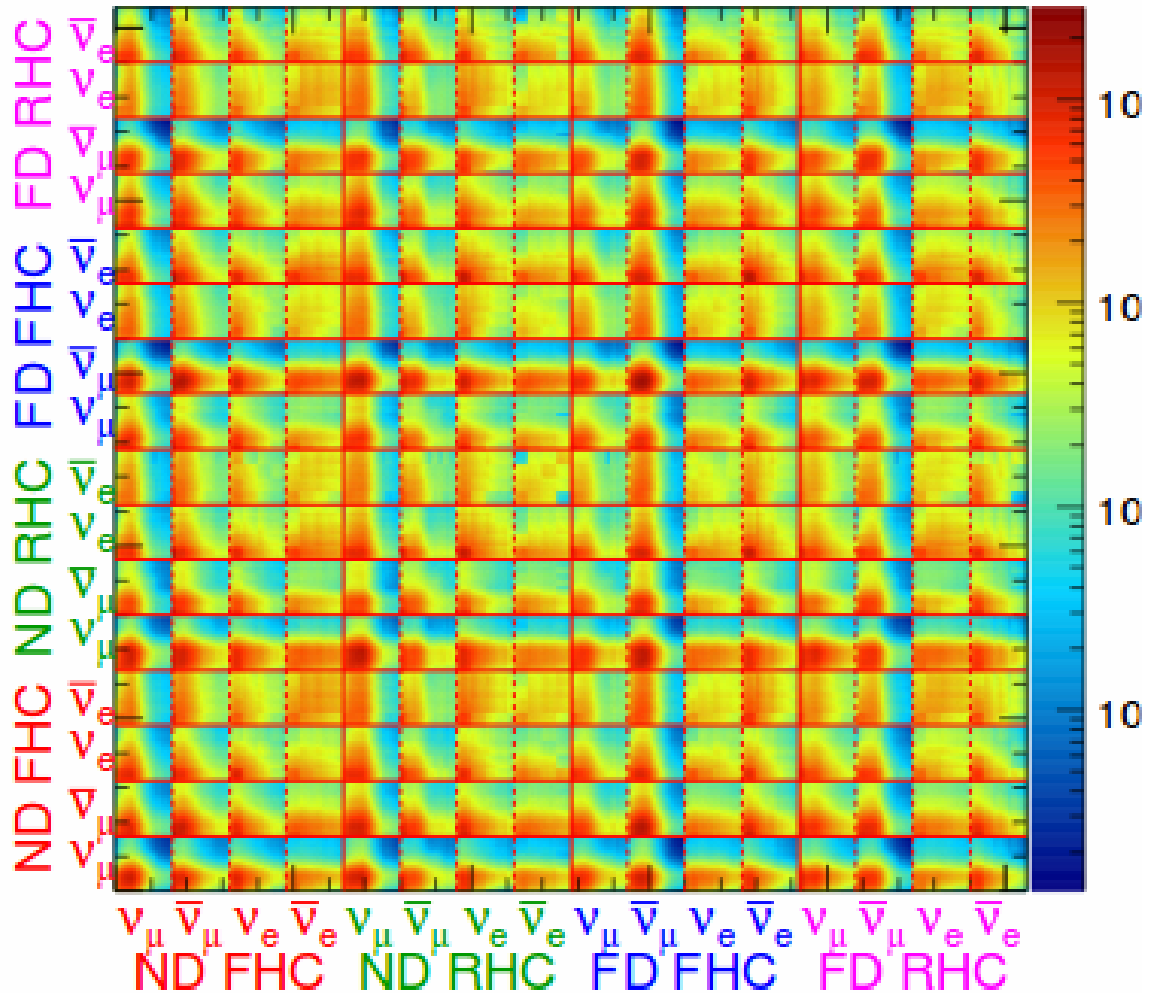
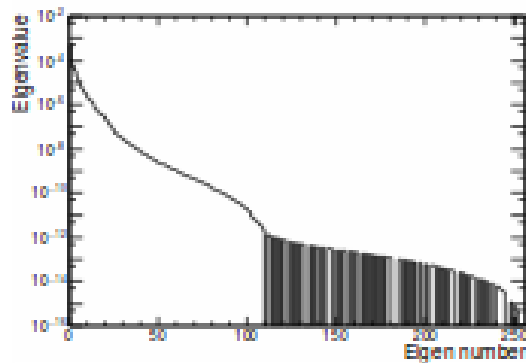
Correlations are included !

From Chris Backhouse

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

# Flux Systematics (10)

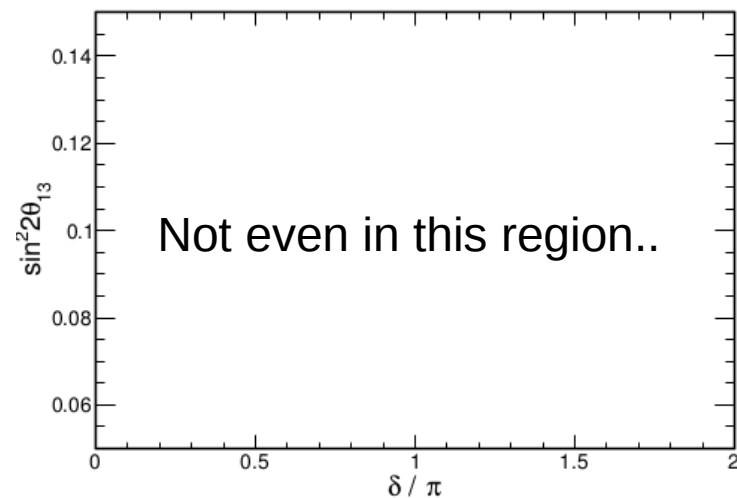
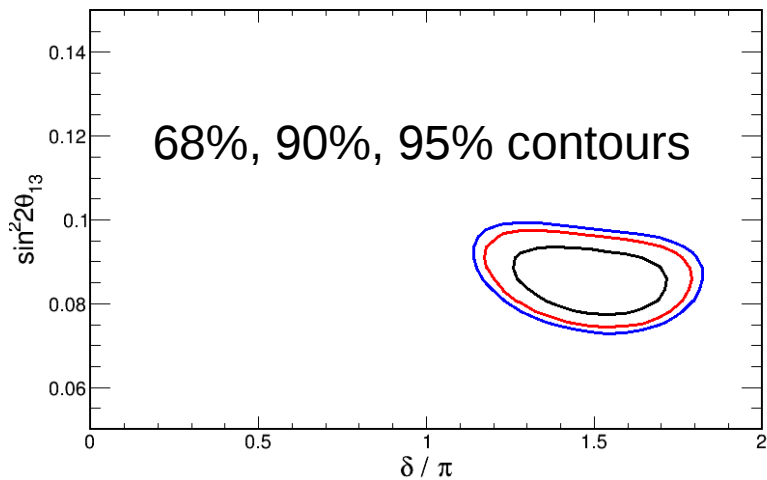
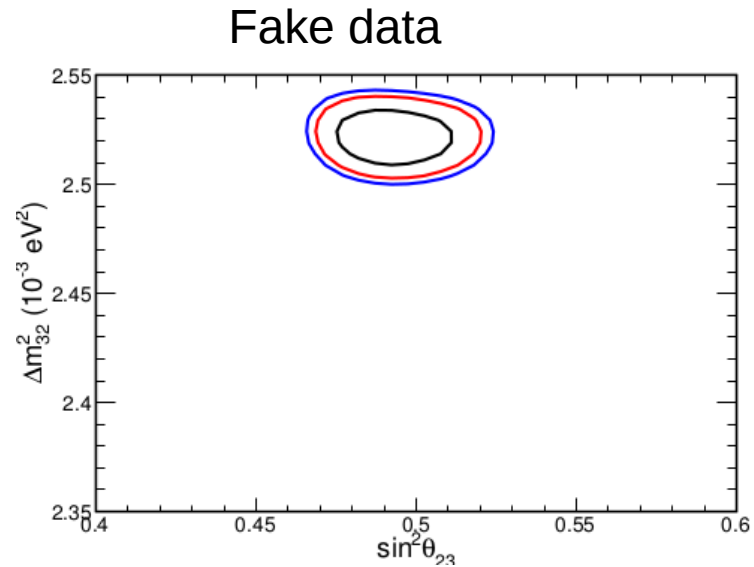
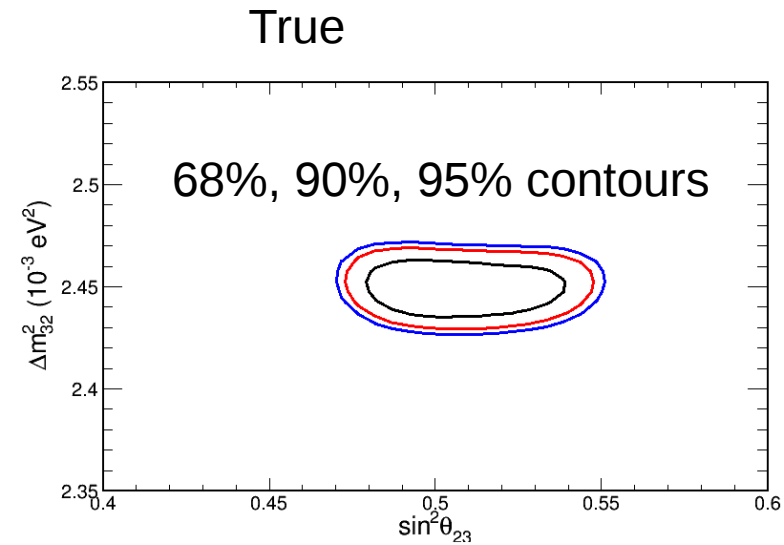
Covariance matrix



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

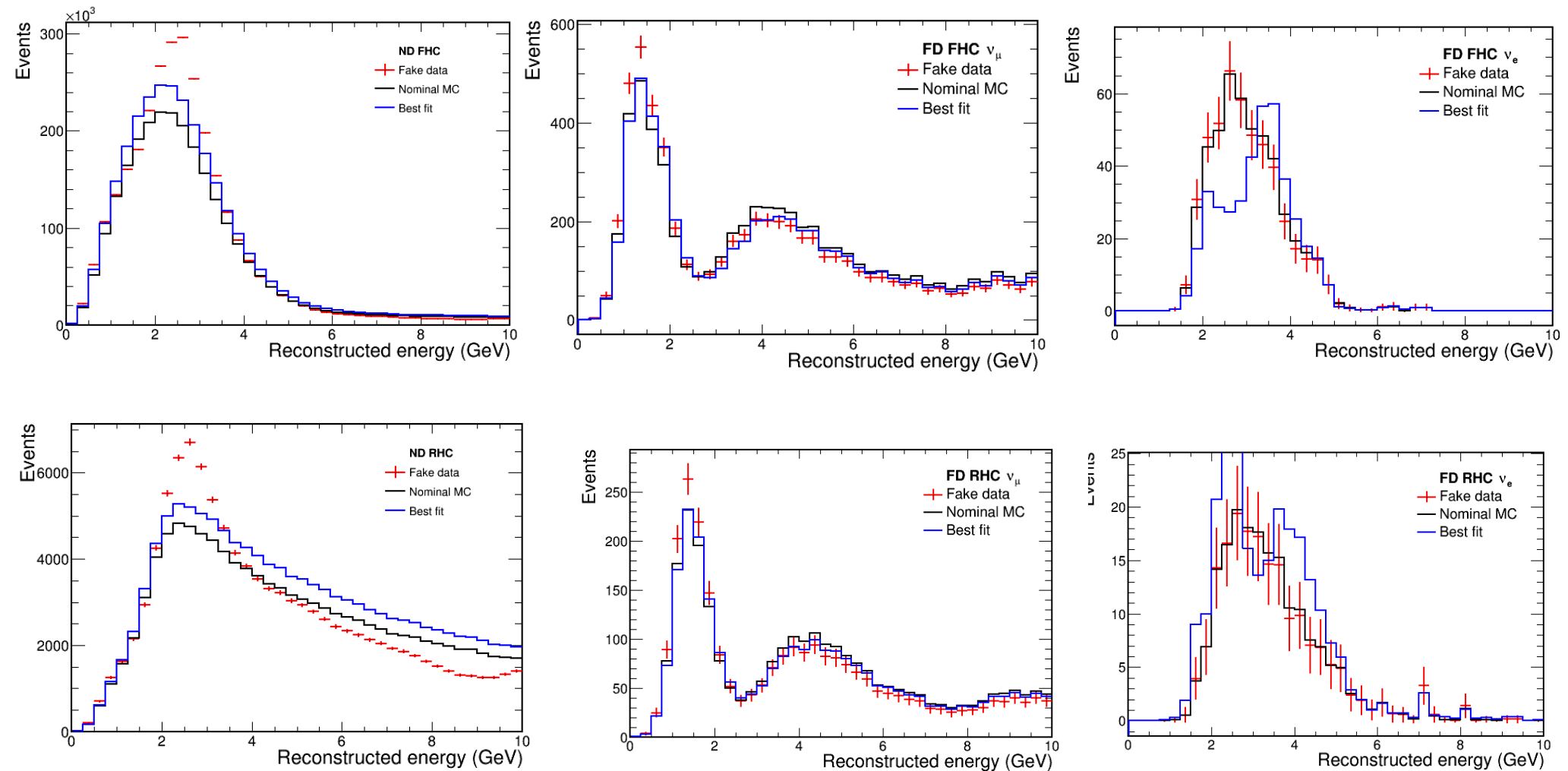
# Fake data- 20% ME

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



# Fake data- 20% ME

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

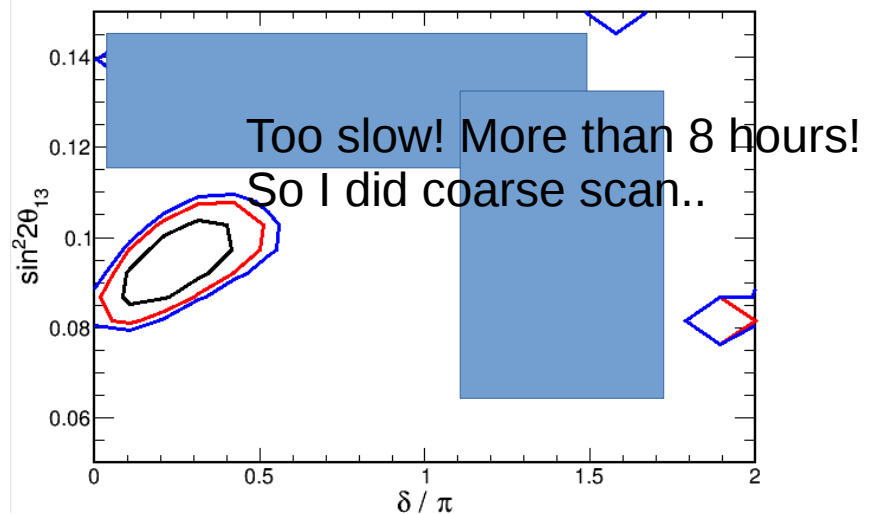
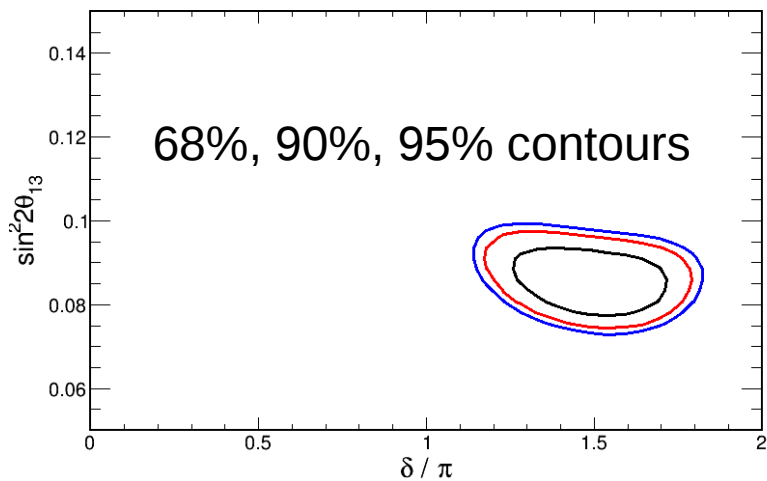
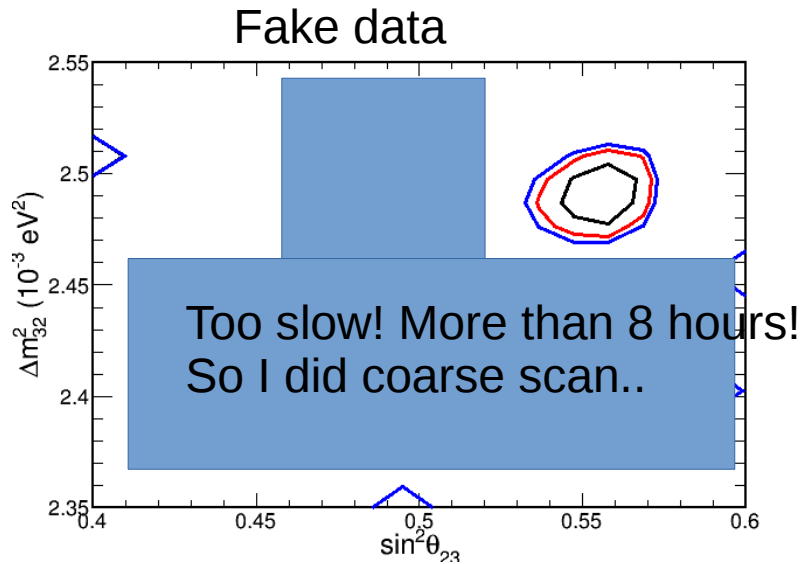
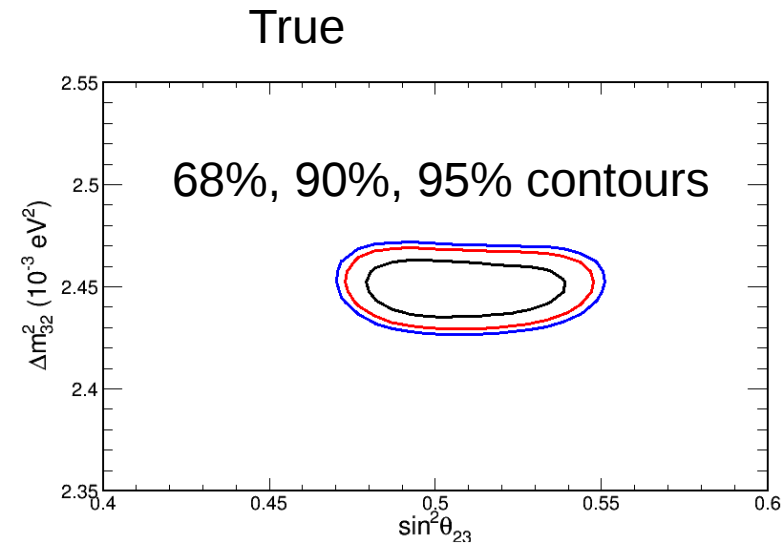


- ND distortion is too significant so that oscillation parameters are less cared by fitter.



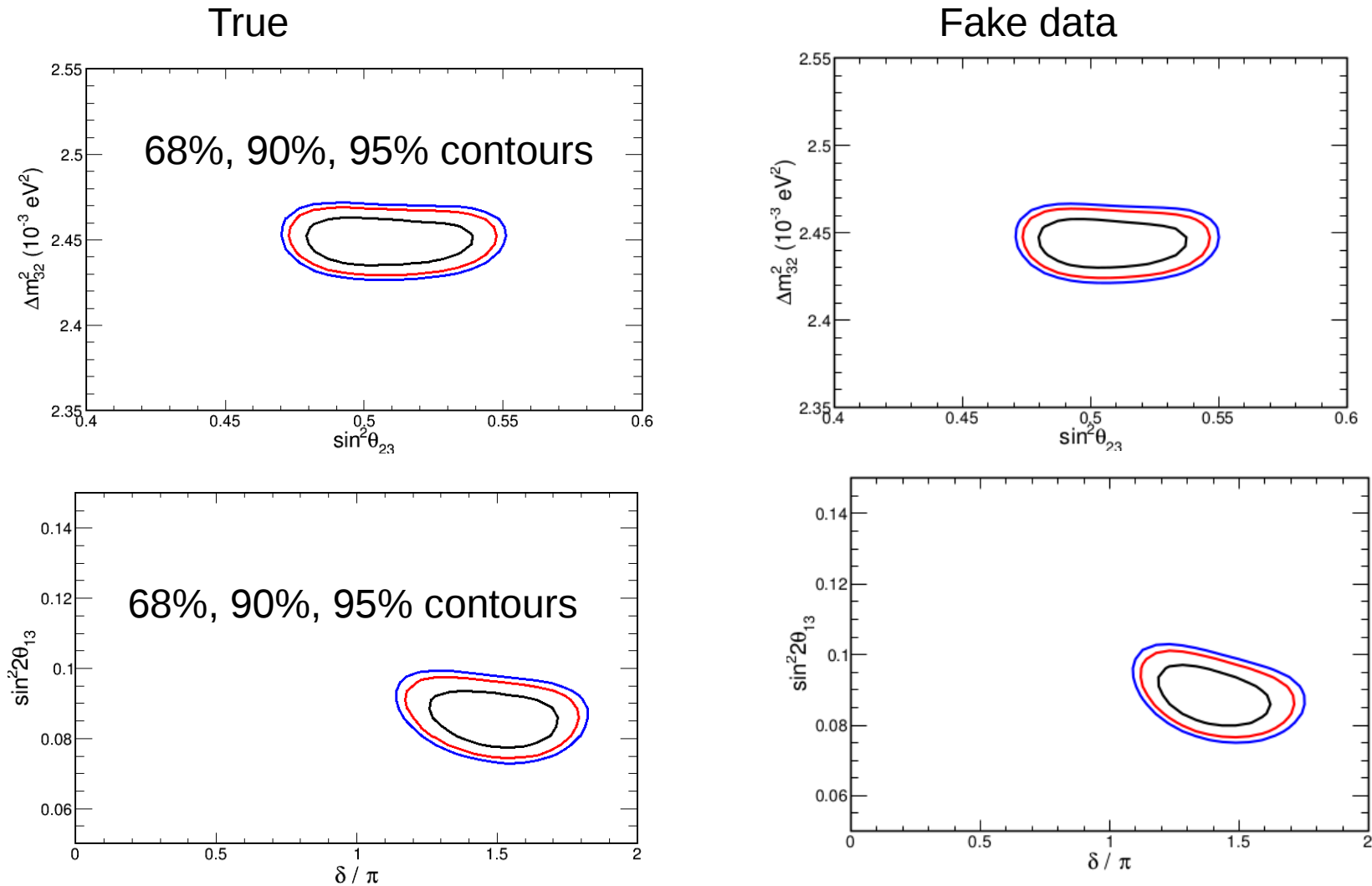
# Fake data- 20% ME

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



# Fake data- Nuwro/GENIE

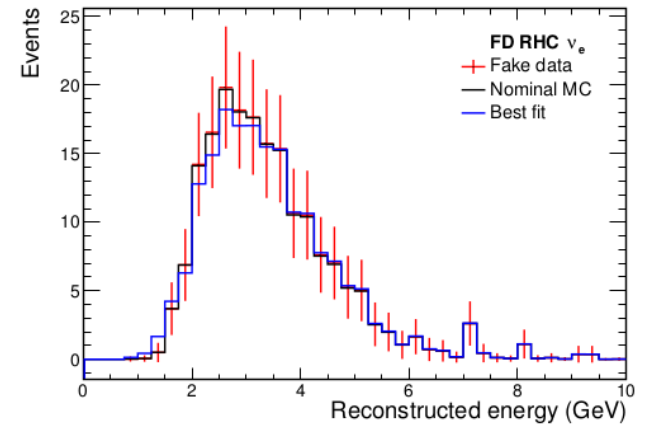
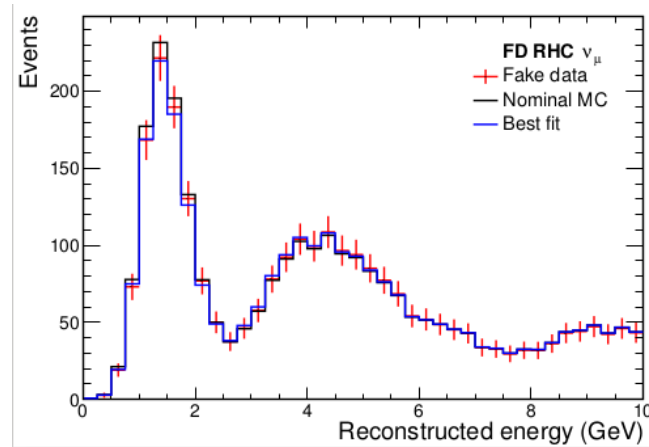
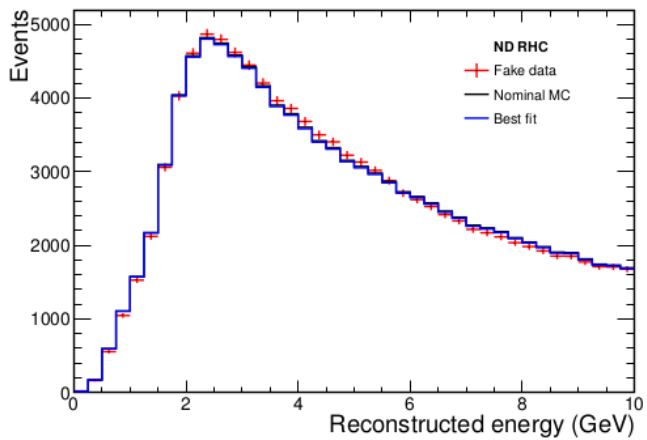
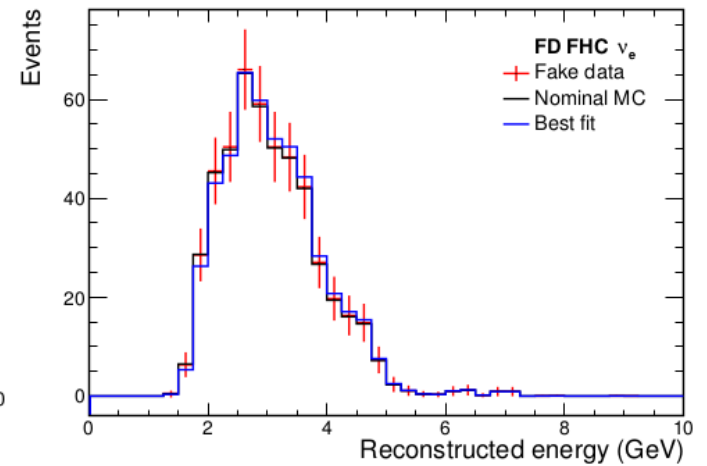
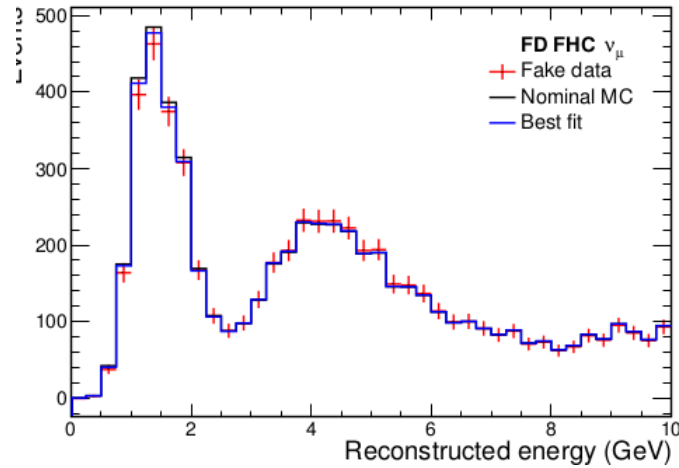
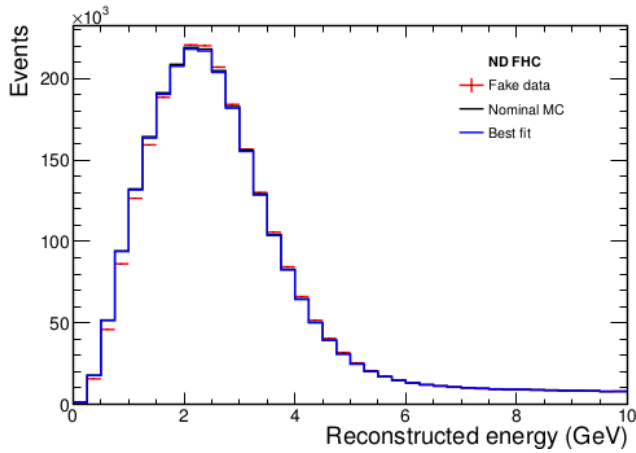
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.



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

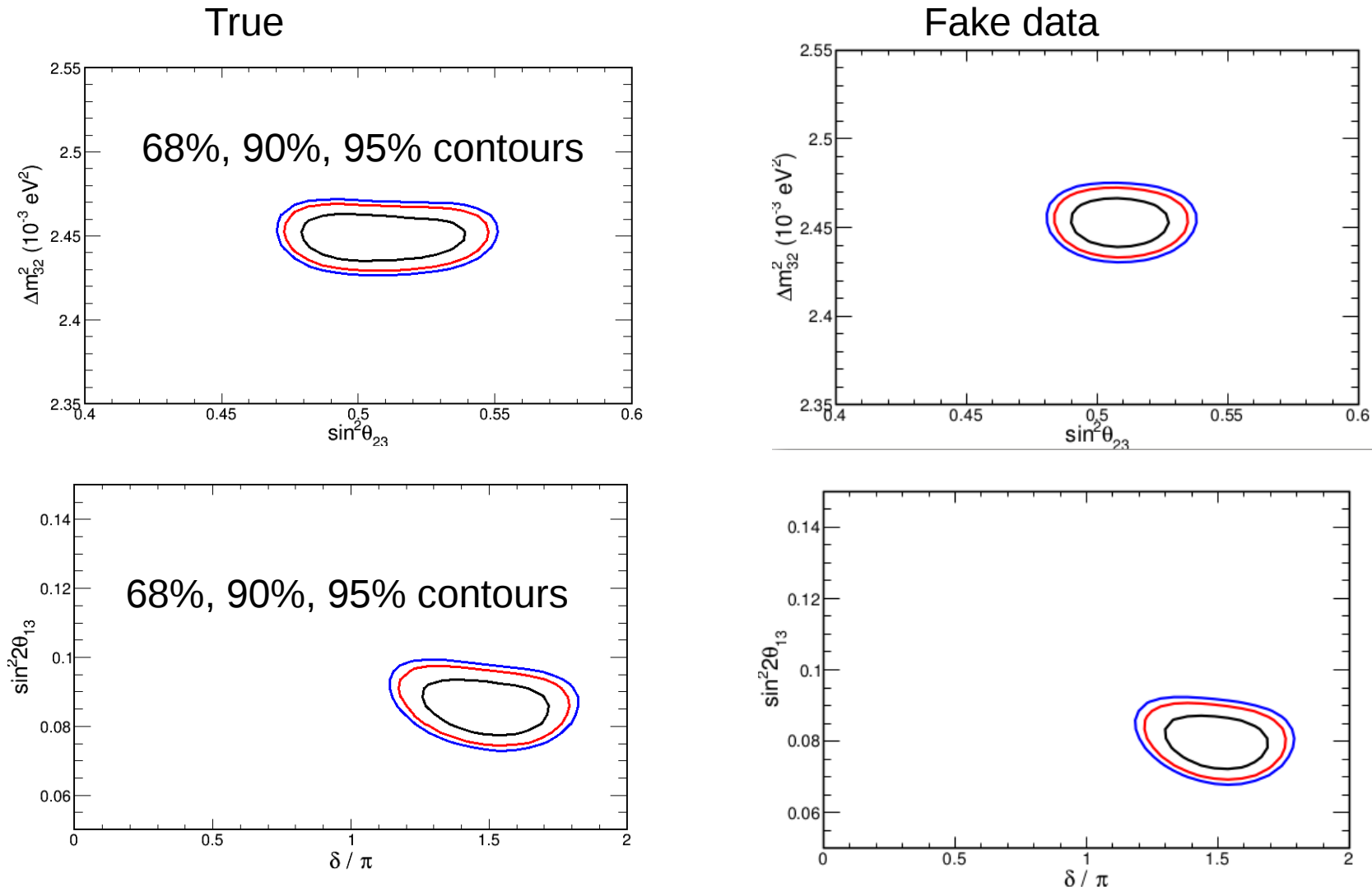
# Fake data- Nuwro/GENIE

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



# Fake data- Nuwro/GENIE

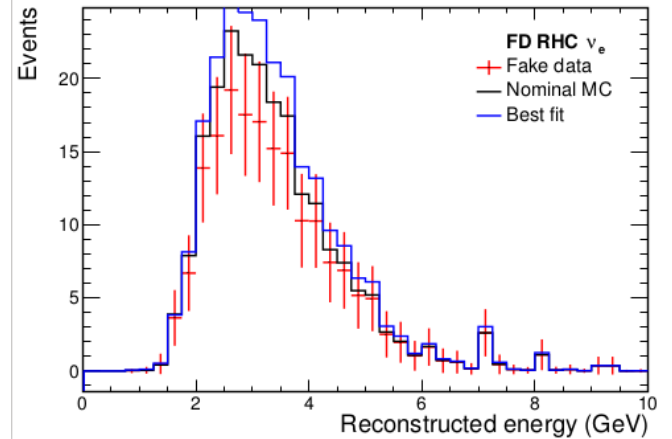
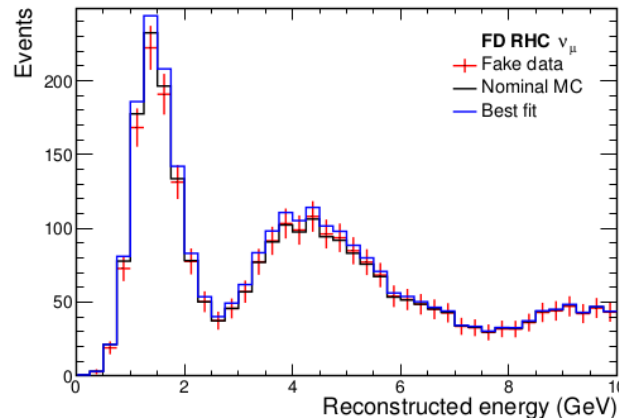
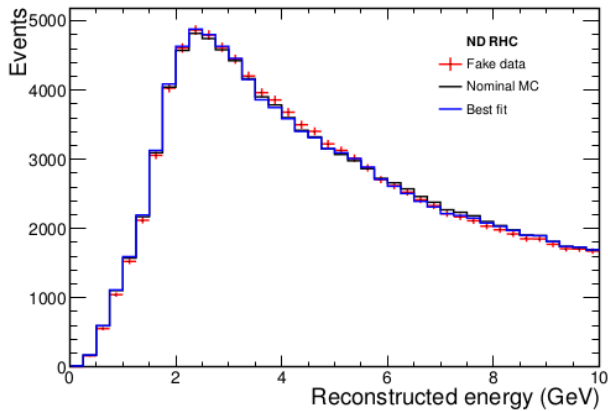
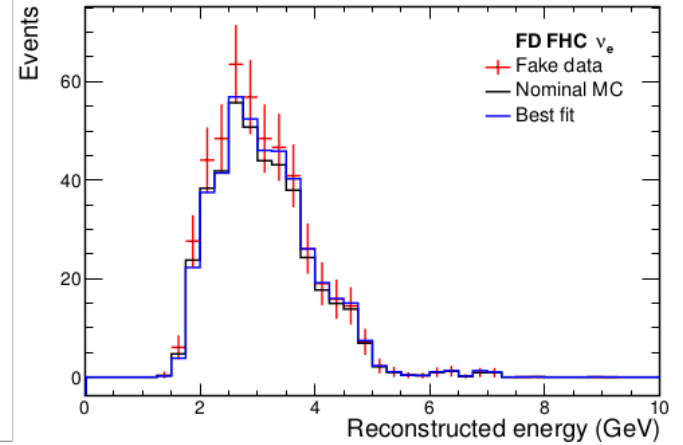
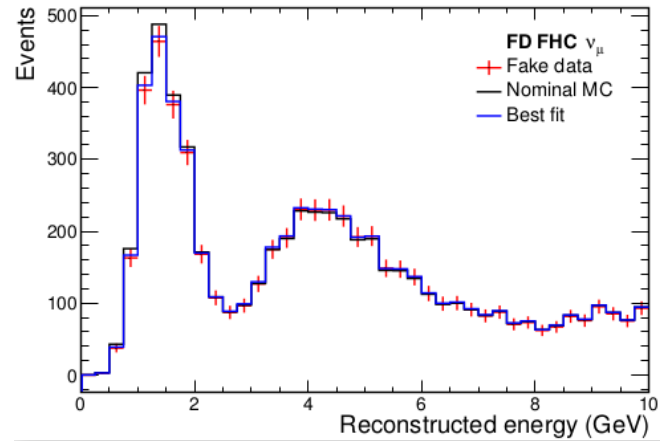
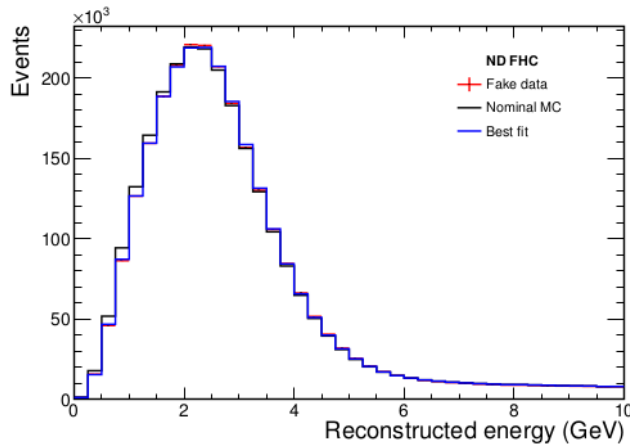
- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.



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

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

static const EnergyScaleSyst kEnergyScaleSyst;
```

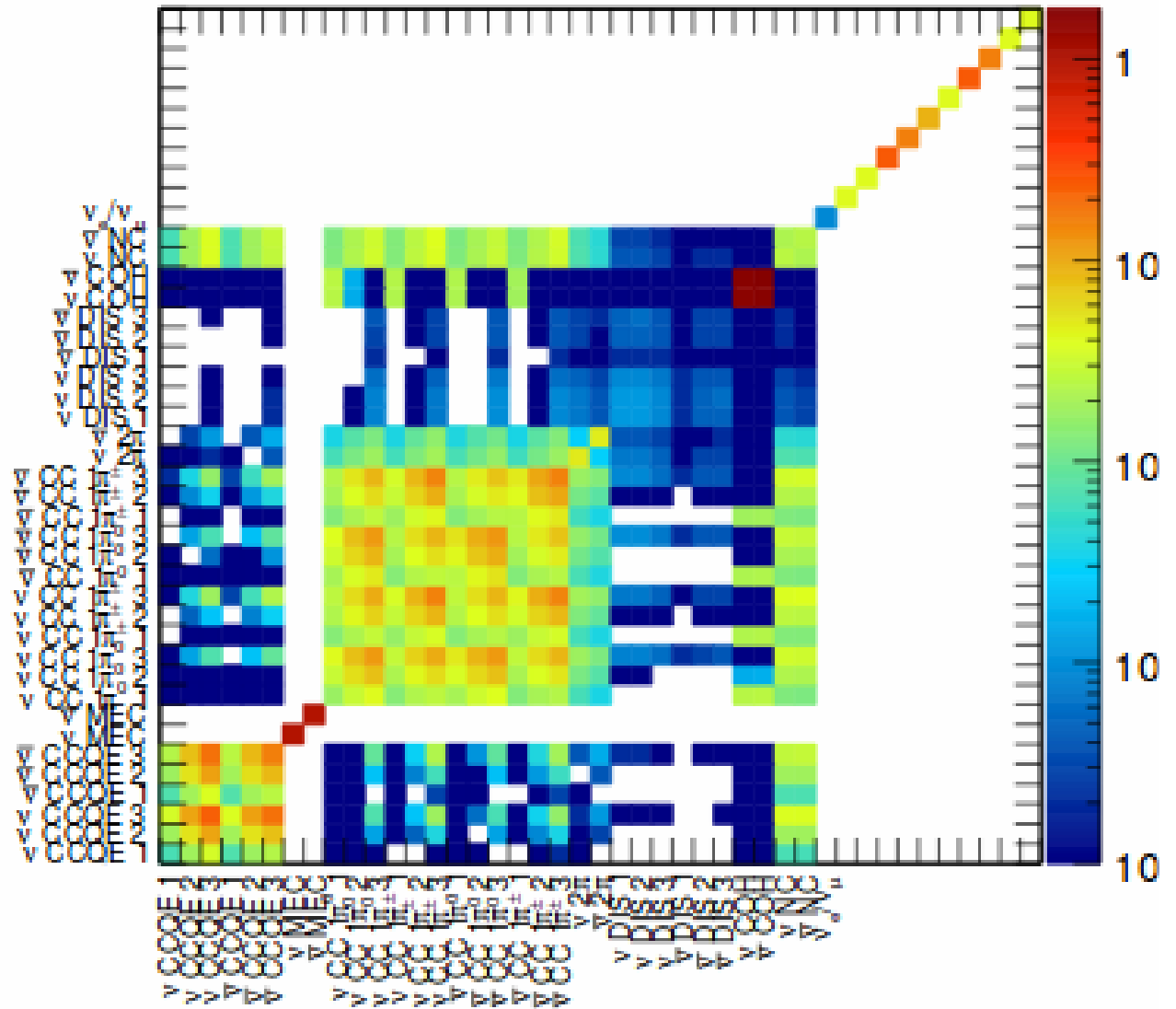
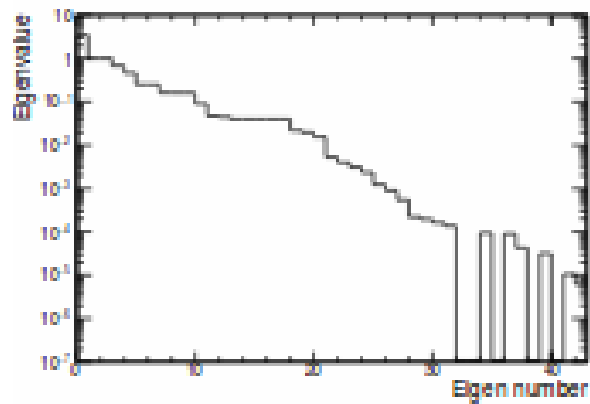
```
/// 5% normalization syst for MC on numu analysis
class NCSyst: public ISyst
{
public:
    std::set<std::string> Requires() const override
    {
        return {"dune.Ev","dune.Ev_reco", "dune.ccnc"};
    }
    std::string ShortName() const override {return "NC";}
    std::string LatexName() const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

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

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