Update on DUNE OA bias study

Guang Yang

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 : Added this time
This means ND is having impact on this study!

Fake data samples:1. GENIE vs. NUWRO
2. Luke’s 20% missing hadron energy(nuwro)

Status: Improving...

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.

Outline

1. Systematics validation:
- With Luke's 20% ME variation: Without systematics → cannot recover
- With Luke's 20% ME variation: With the same systematic involved → expect to recover

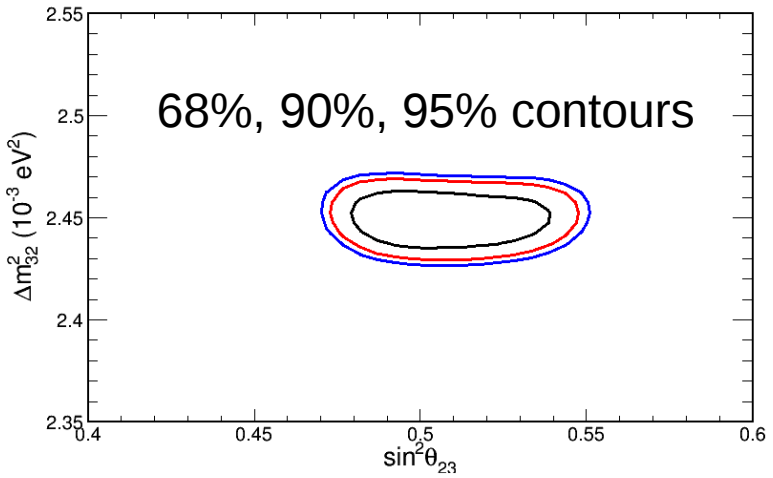
2. Fake data study
- With Luke's 20% ME variation, we only have Xsec systematics (32)
- With Luke's 20% ME variation, we have Xsec + flux systematics (32+10)

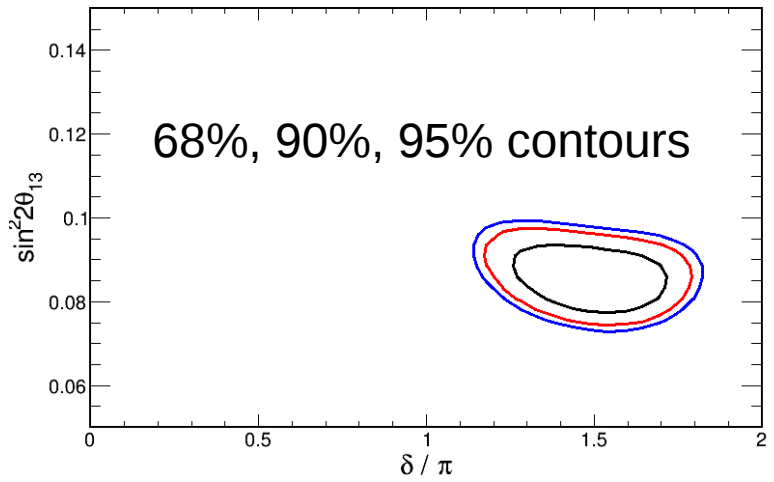
3. Fake data study
- With Nuwro/Genie variation, we only have Xsec systematics (32)
- With Nuwro/Genie variation, we have Xsec + flux systematics (32 + 10)

Systematics validation

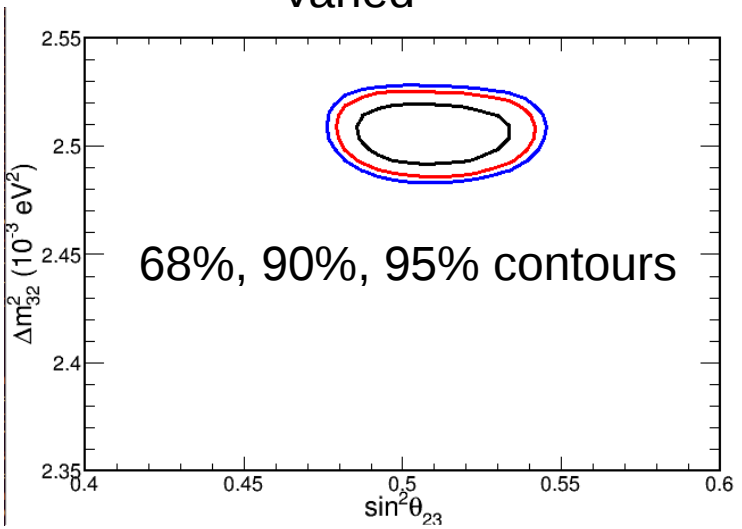
With Luke's variation and without systematics,
the true values cannot be recovered.

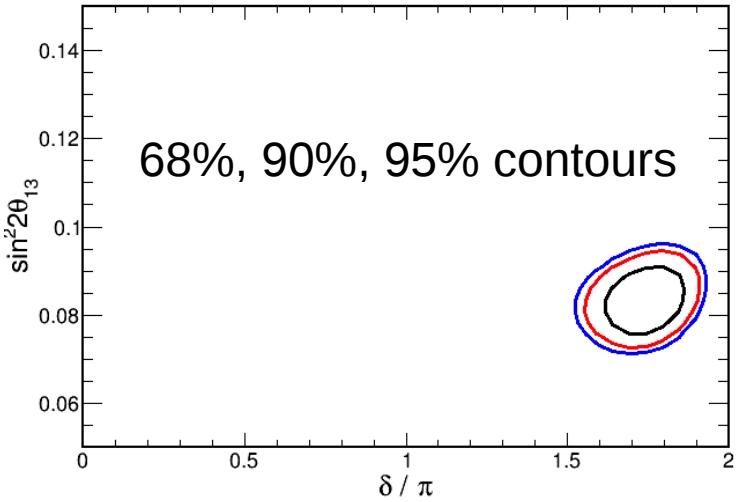
True





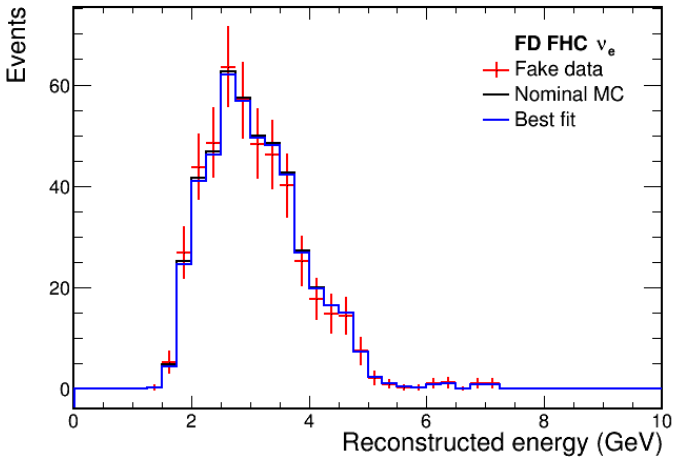
Varied

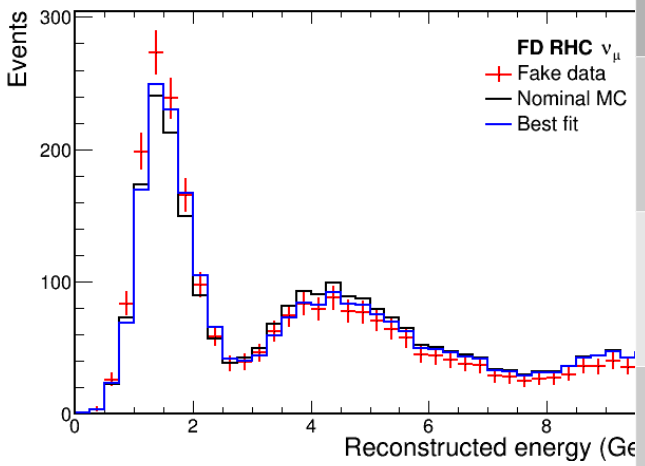


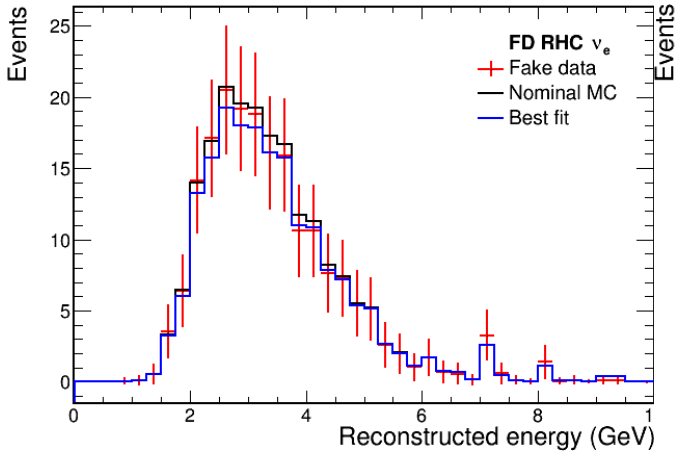


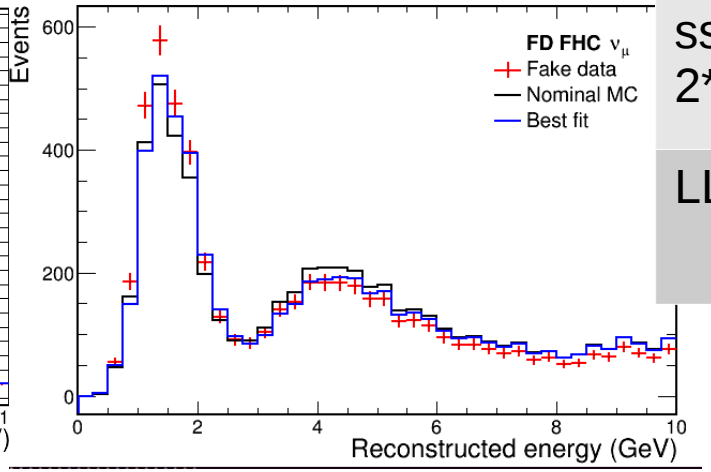
Systematics validation

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







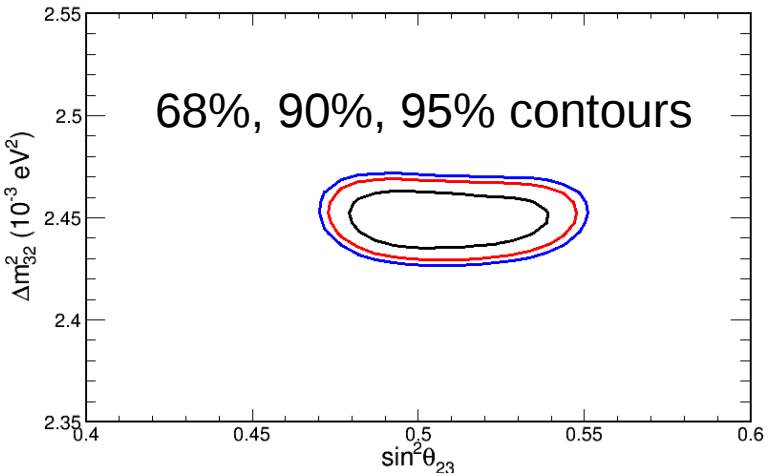


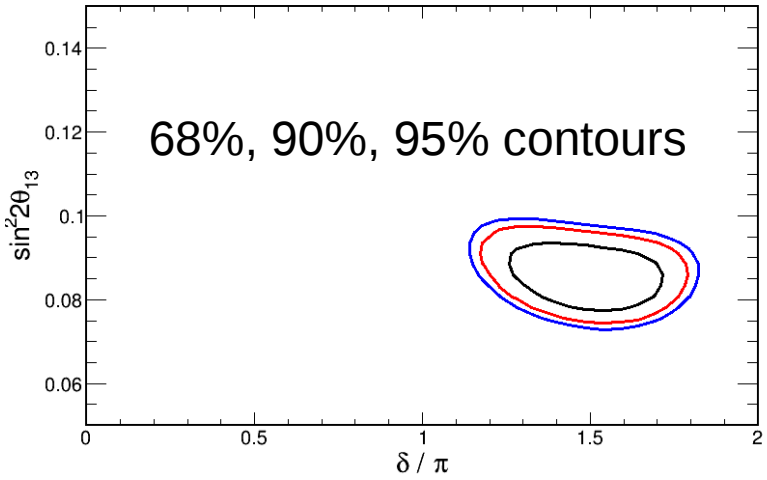
	true	FD+ND Best fit	FD only
CP (pi)	1.5	1.67	1.67
sst23	0.5	0.51	0.51
Dm32 (e-3)	2.45	2.57	2.57
ss(2*t13)	0.087	0.078	0.078
LL		126246	99.5

Systematics validation

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

True





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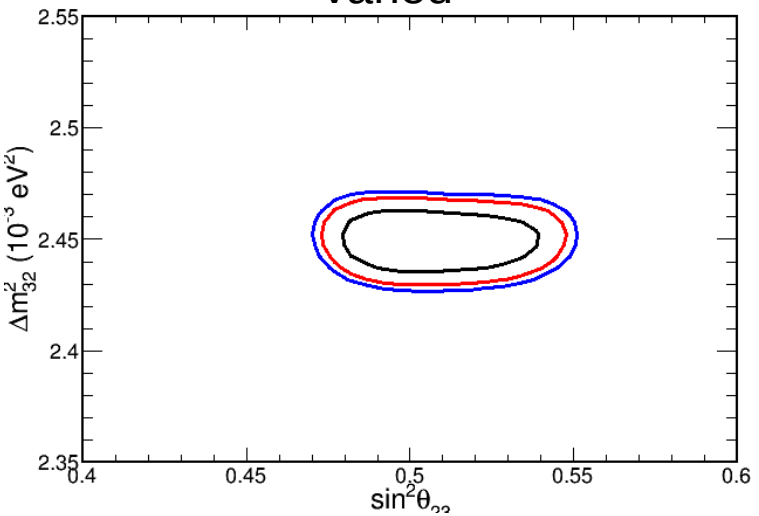
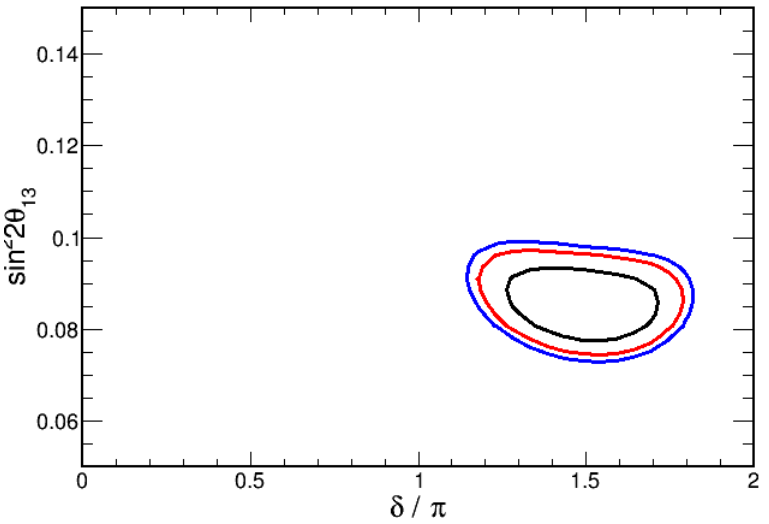
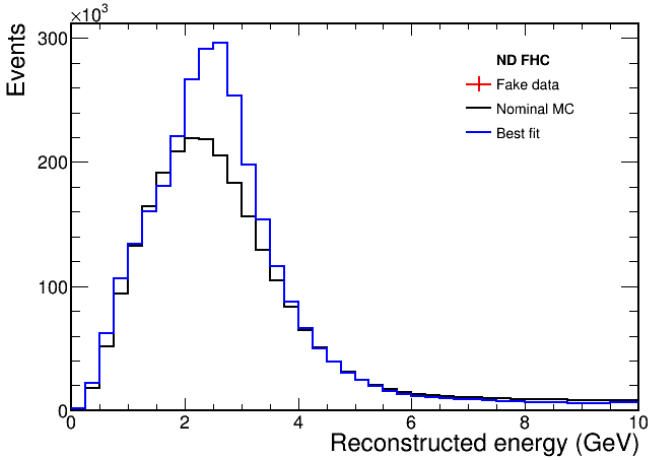
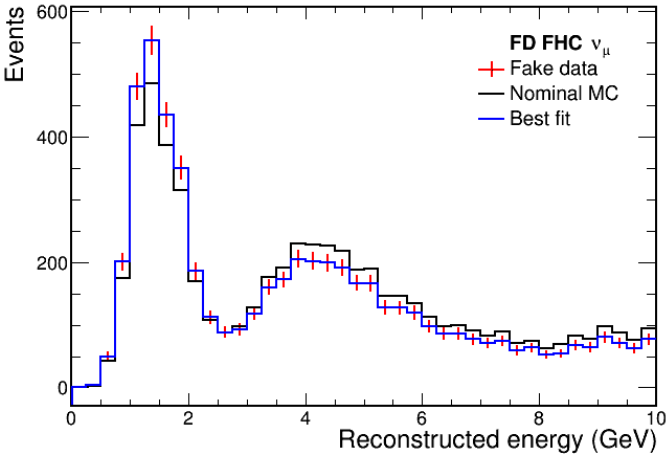


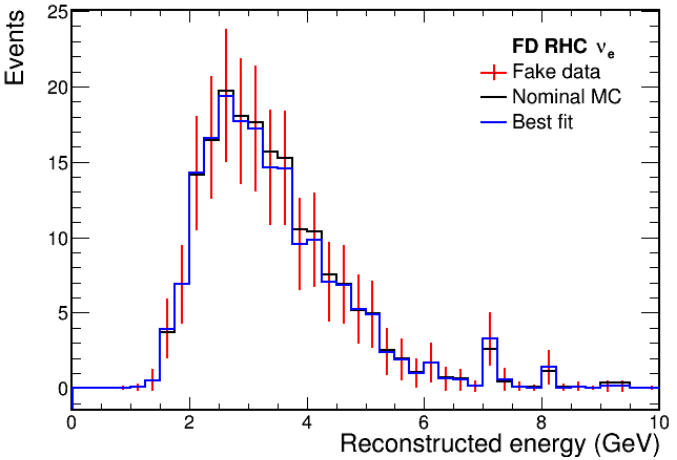


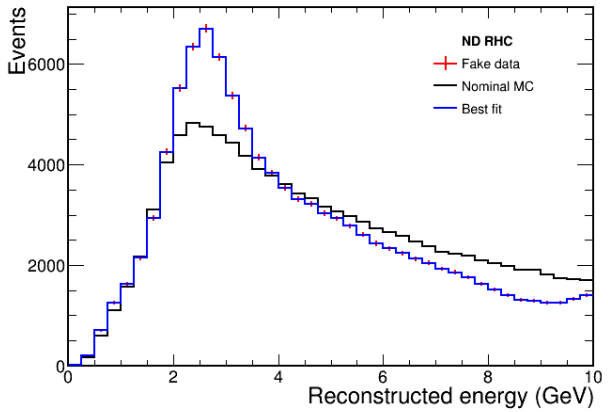
Systematics validation

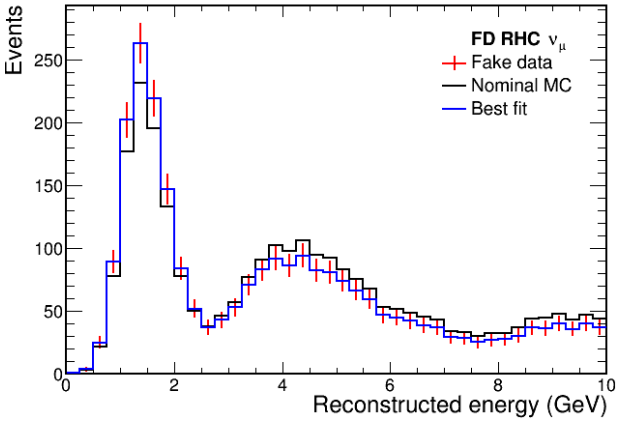
With Luke's variation and with the variation inserted as a systematic pull, the true values can be recovered.

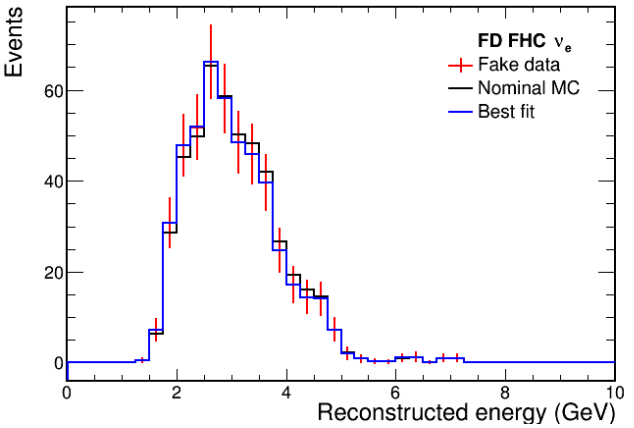








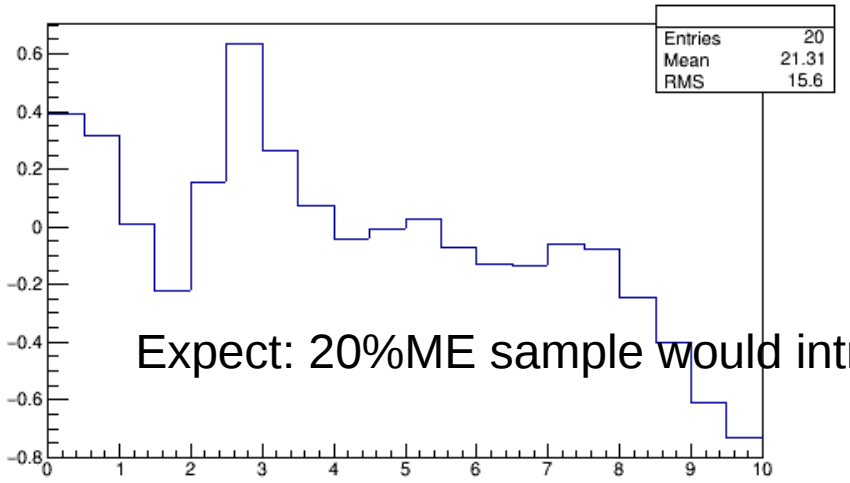




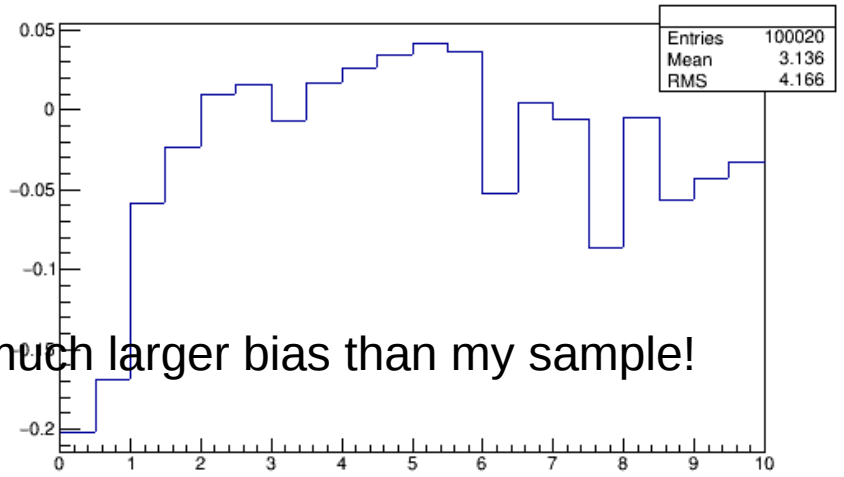
Fake data study

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`

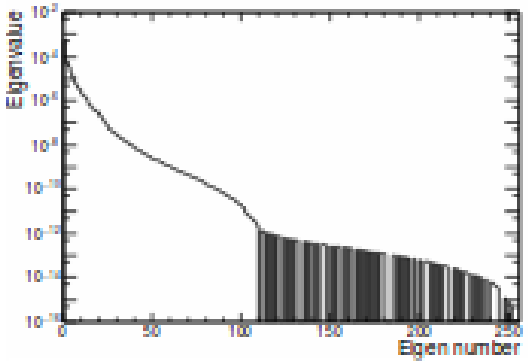
Correlations are included !

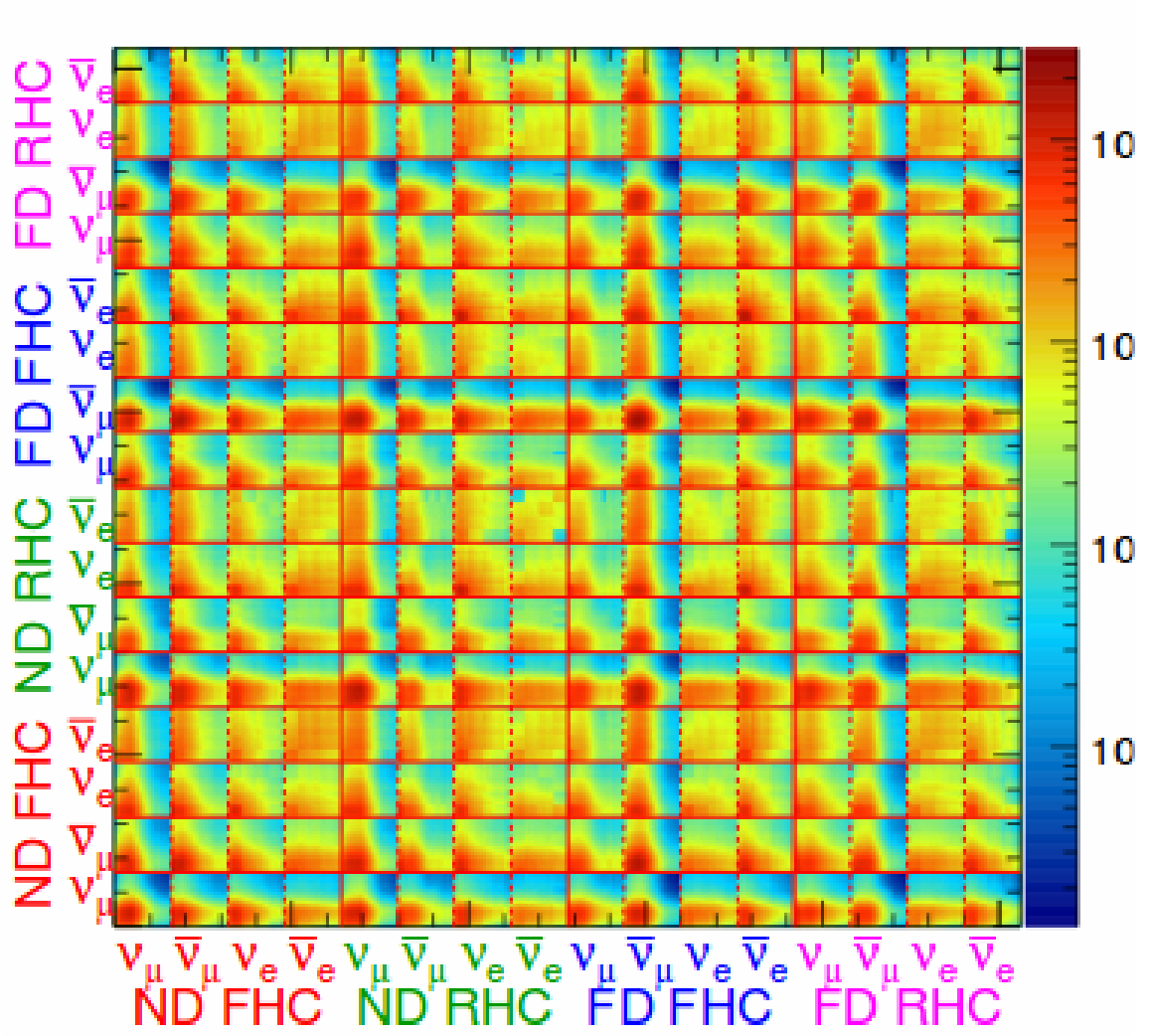
From Chris Backhouse

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



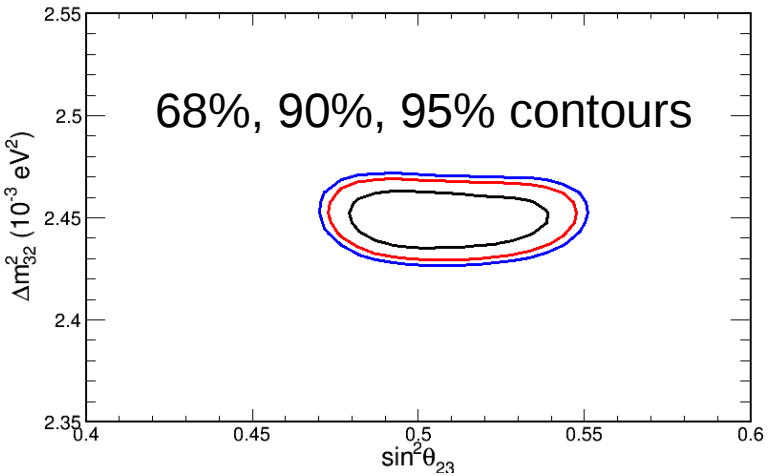


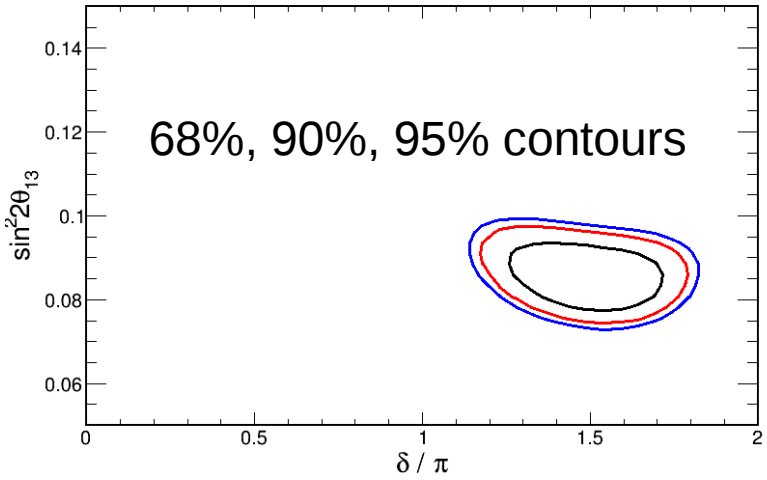
- Eigenvalues 108+ should be zero. Floating precision → some negative
- Limit eigenvalues to 10^{-14}. $M = V^T \Lambda V$, $M \rightarrow V^T \Lambda' V$

Fake data- 20% ME

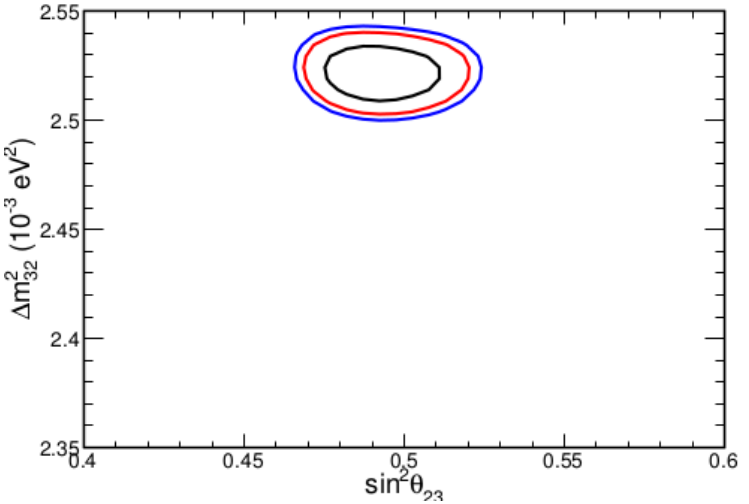
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

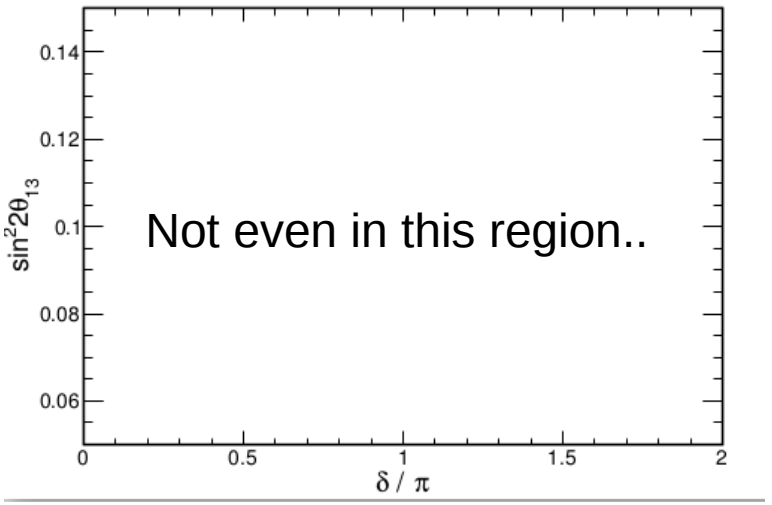
True





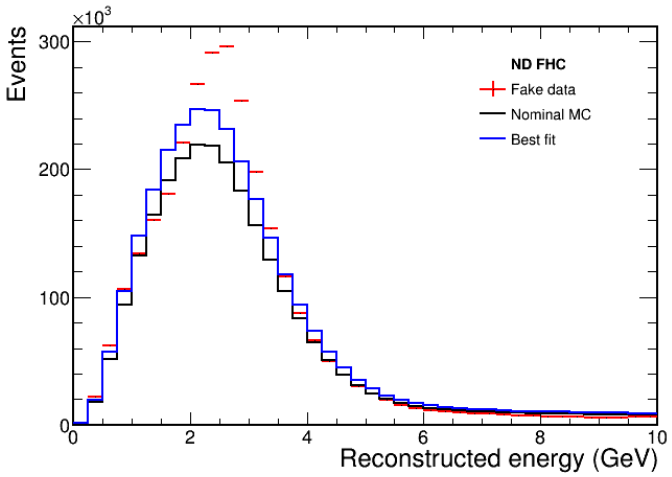
Fake data

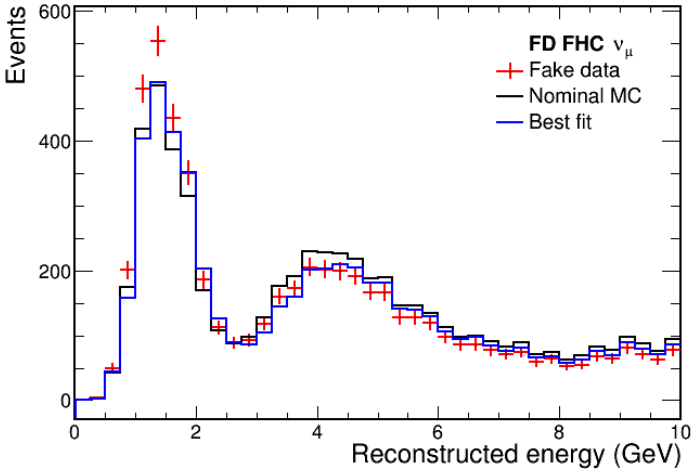


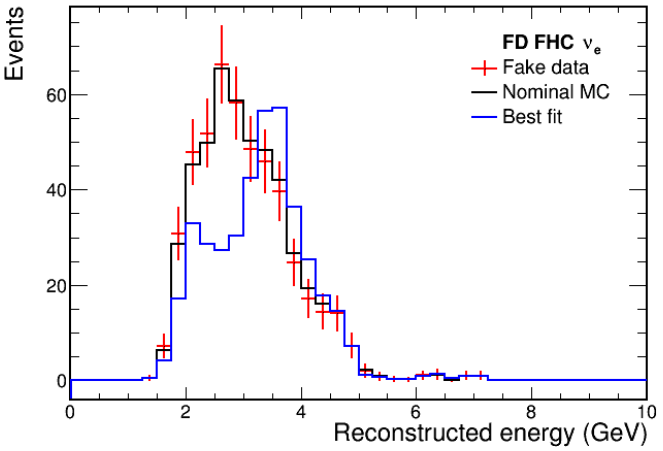


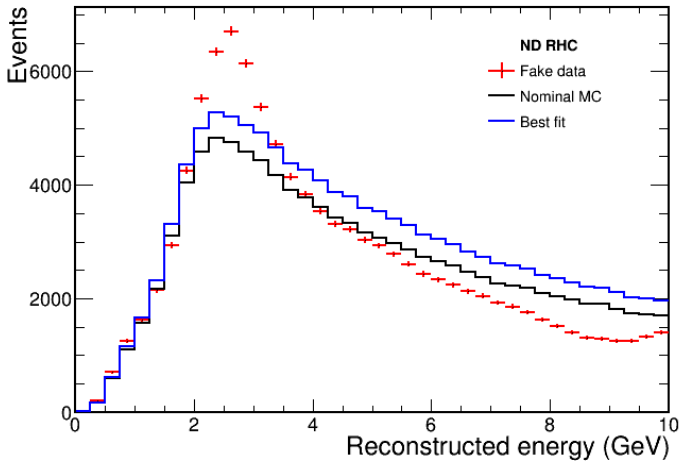
Fake data- 20% ME

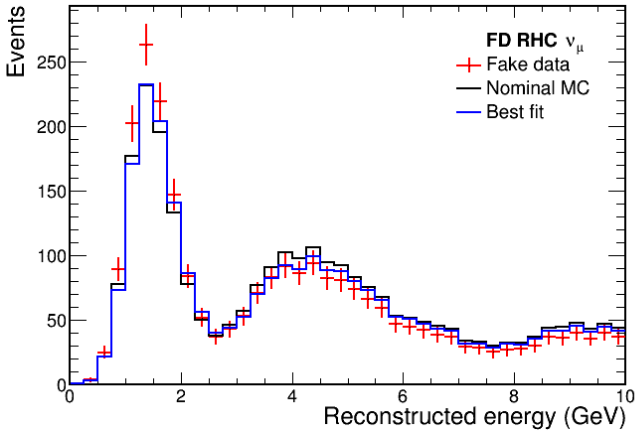
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

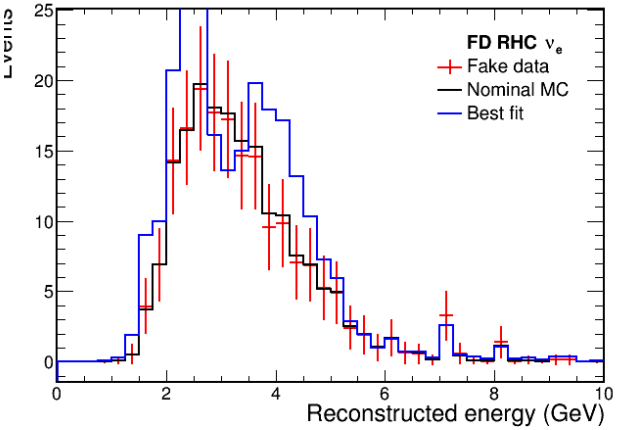










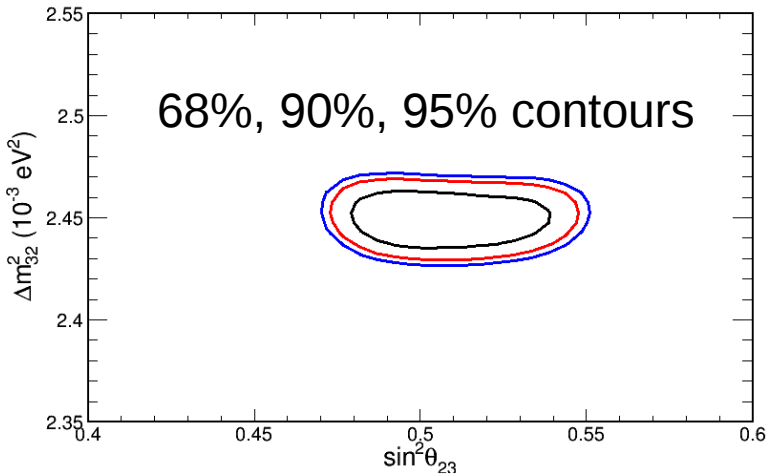


- ND distortion is too significant so that oscillation parameters are less cared by fitter.

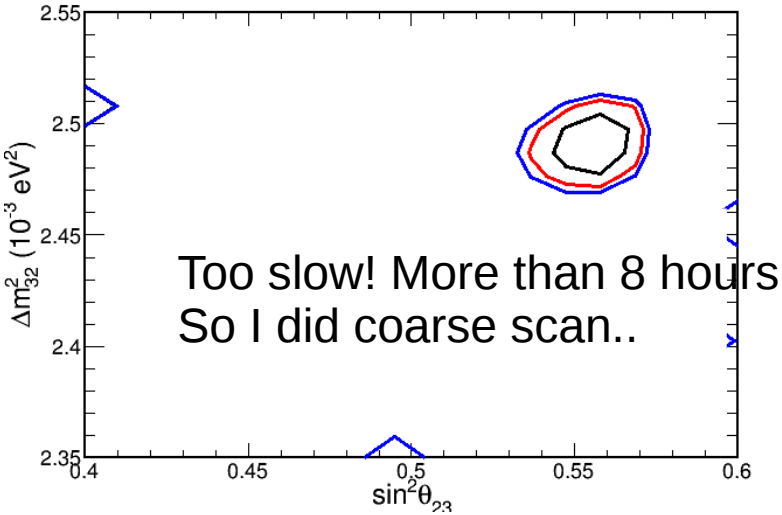
Fake data- 20% ME

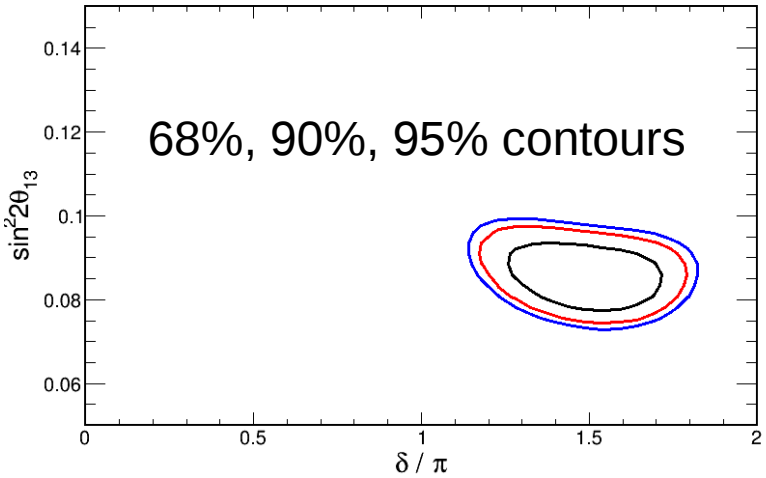
- ND and FD have 20% ME shift, we have Xsec+ flux parameters to recover it.

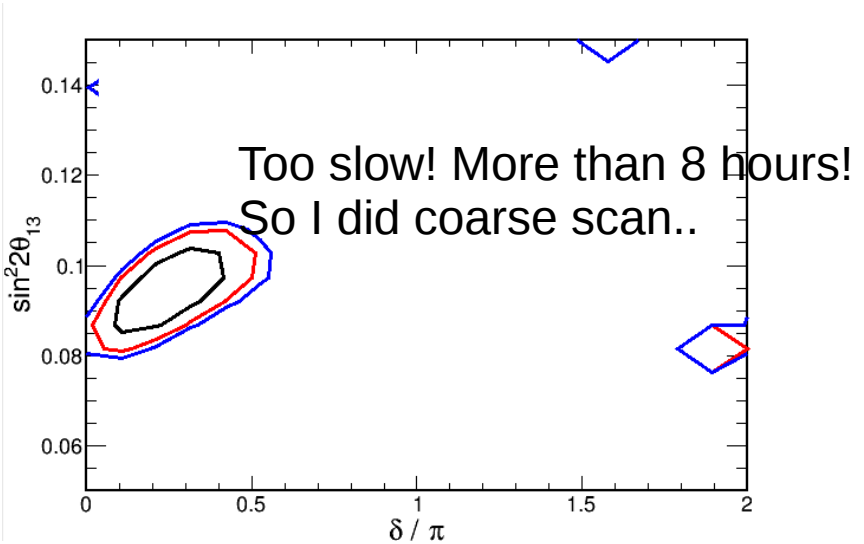
True



Fake data



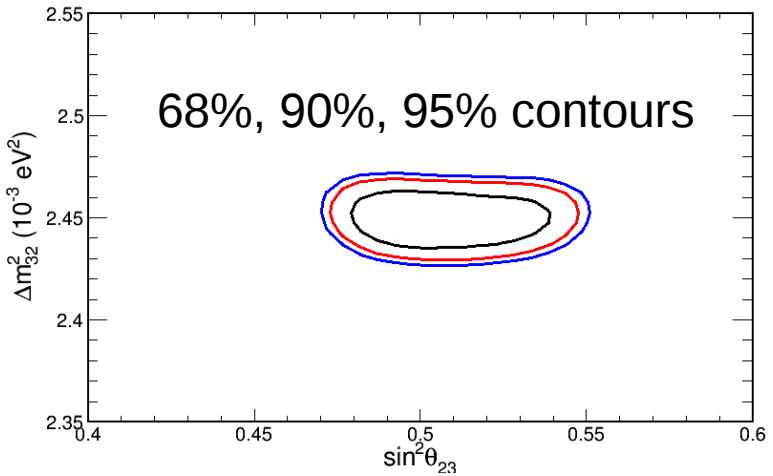


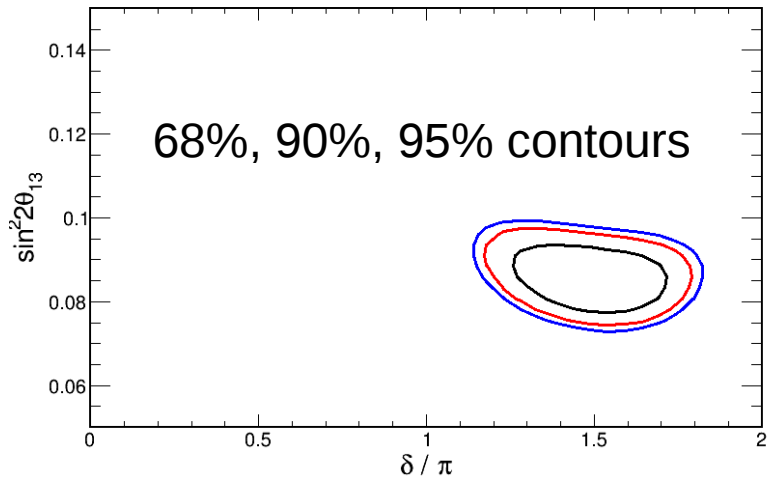


Fake data- Nuwro/GENIE

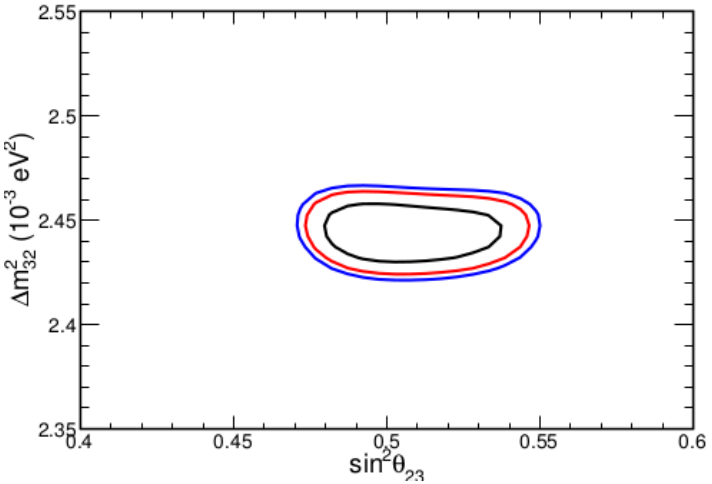
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

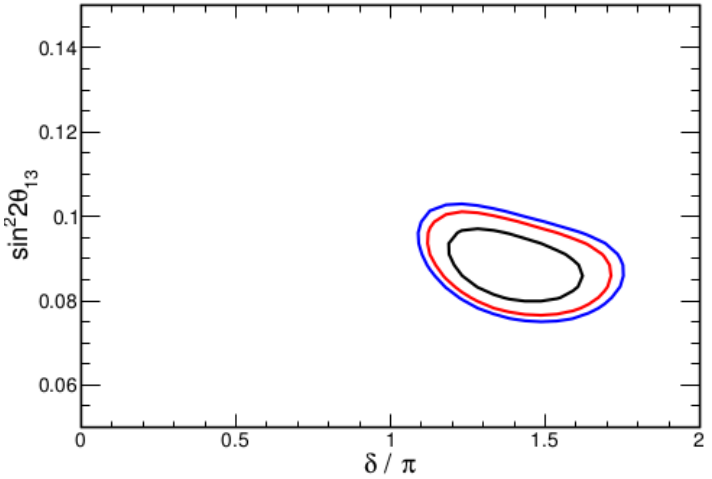
True





Fake data

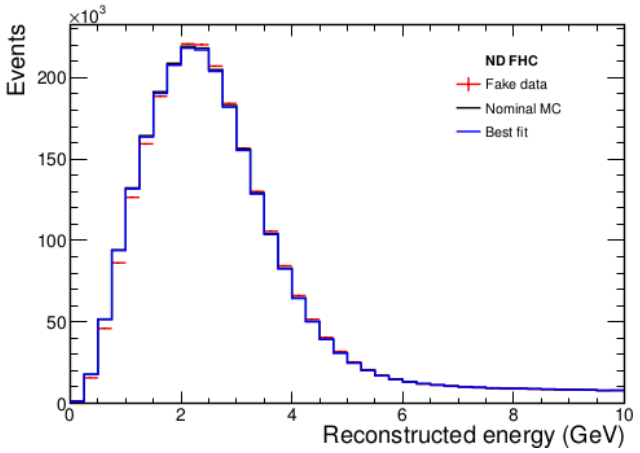


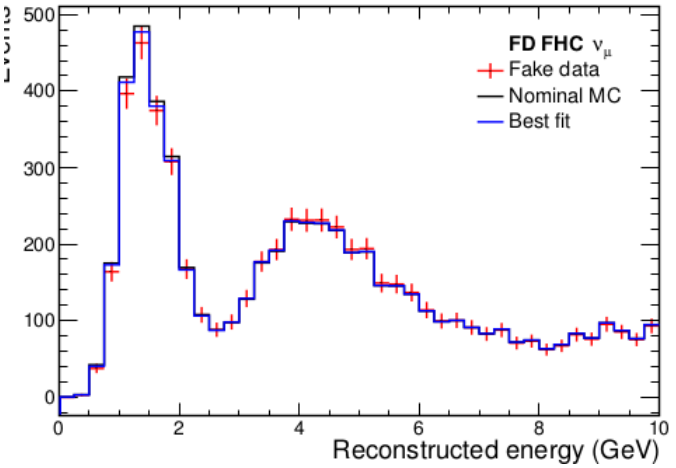


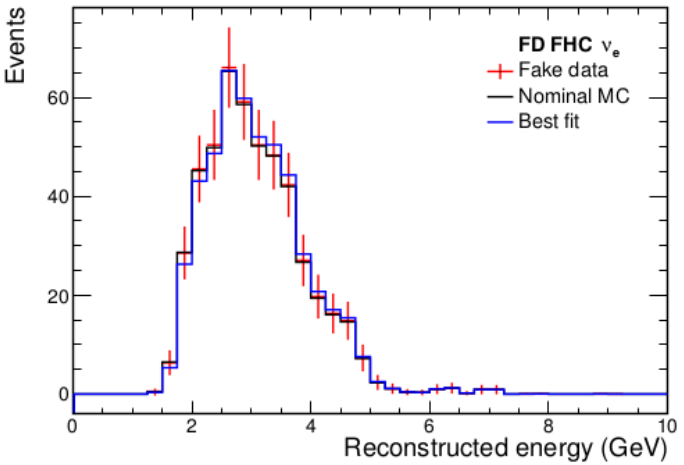
- Only with Xsec parameters, delta CP cannot be fully recovered.

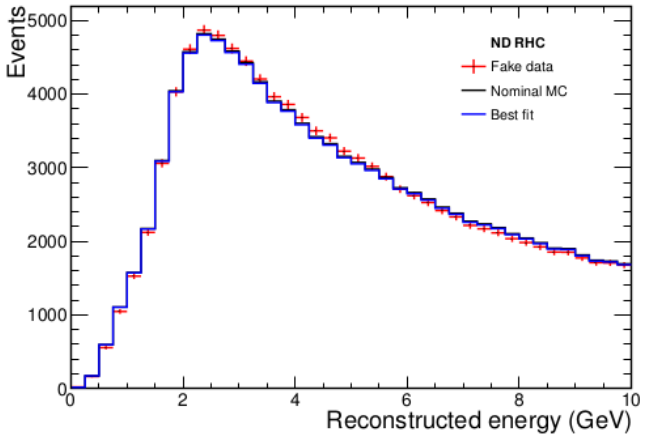
Fake data- Nuwro/GENIE

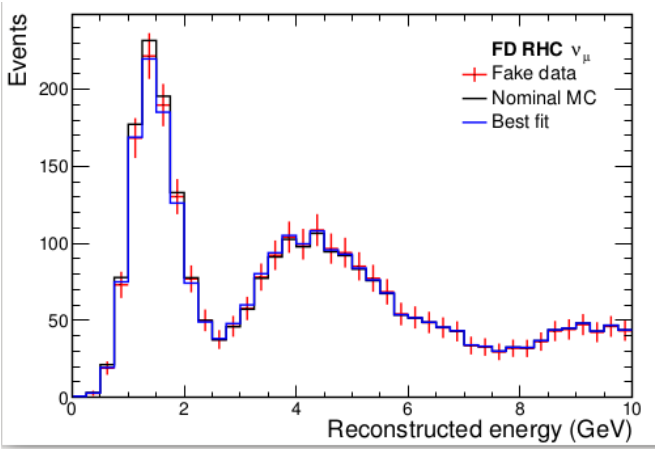
- ND and FD have 20% ME shift, we have Xsec parameters to recover it.

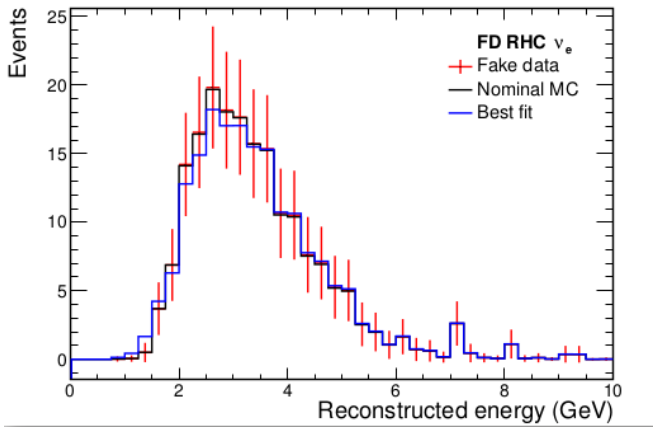








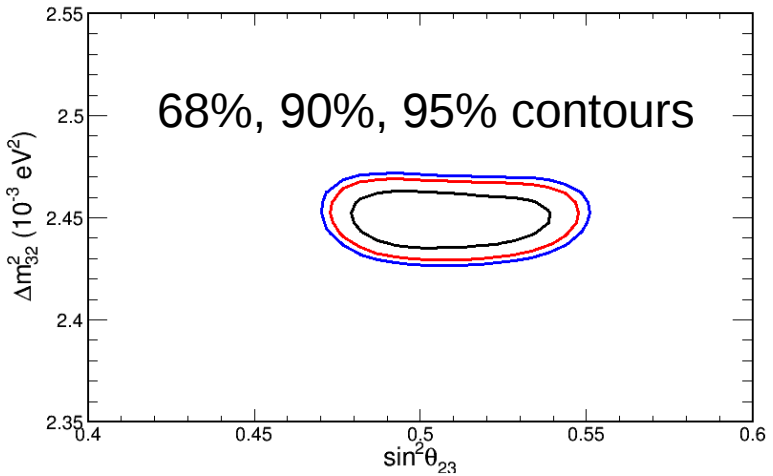




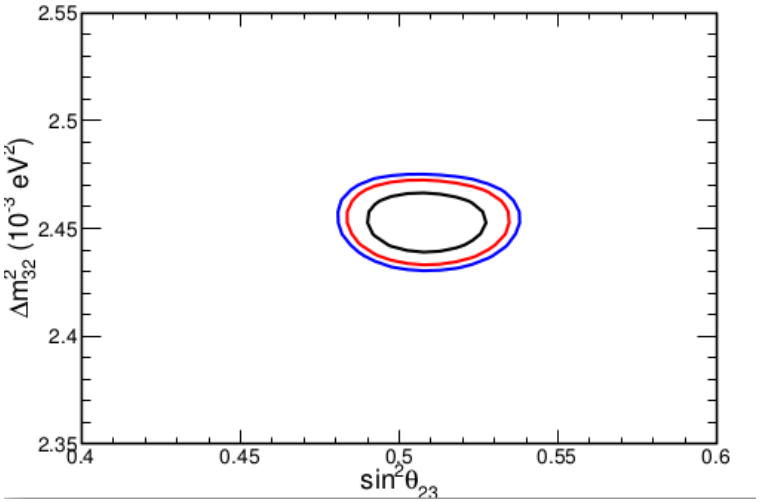
Fake data- Nuwro/GENIE

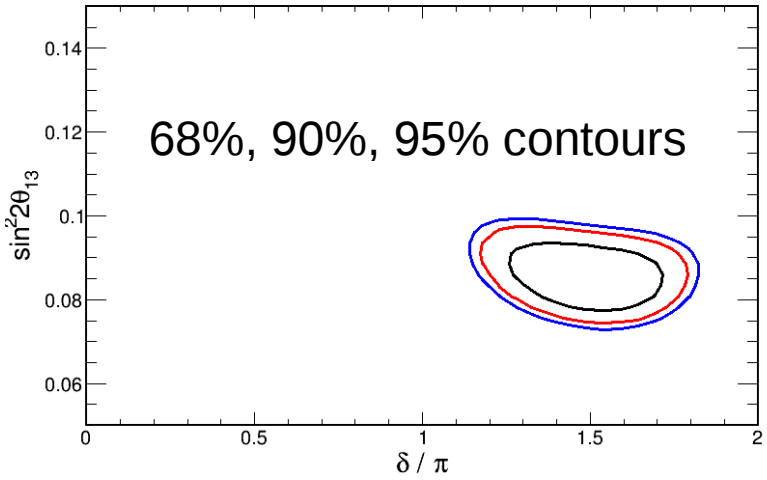
- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.

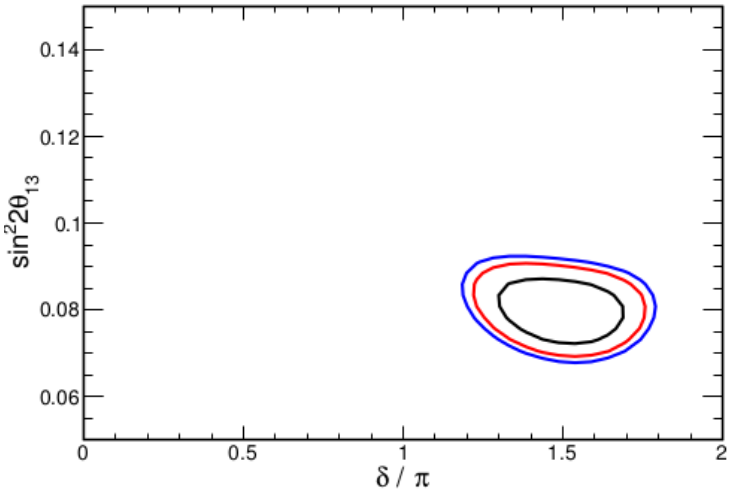
True



Fake data



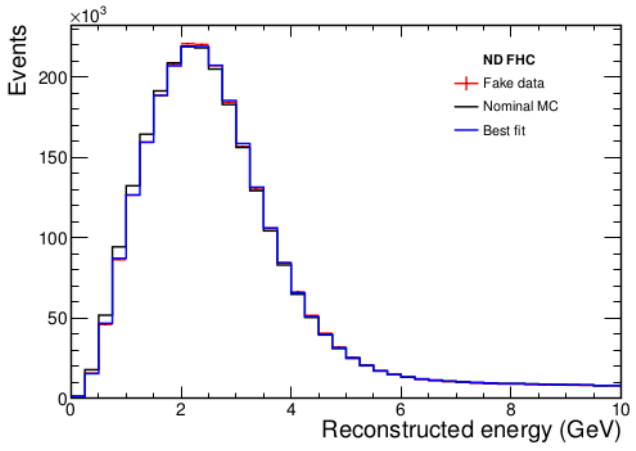


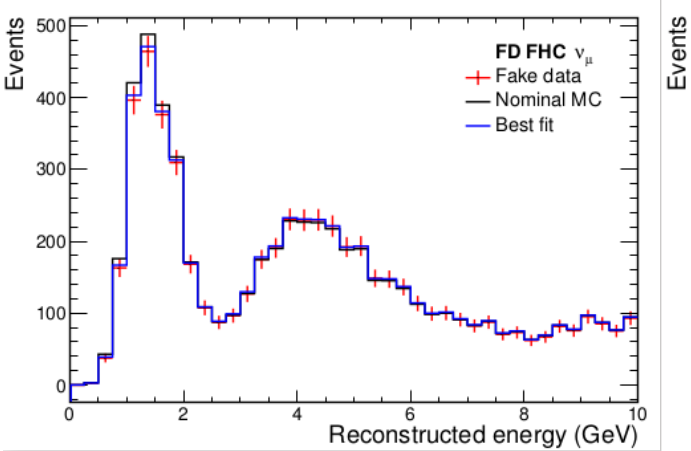


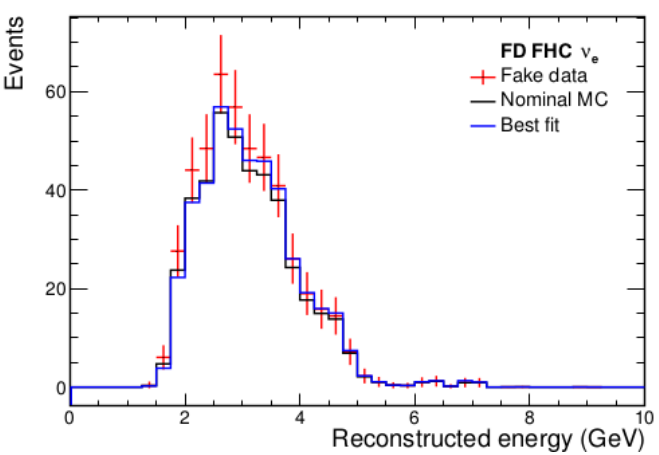
- With Xsec+flux parameters, delta CP can be mostly recovered.

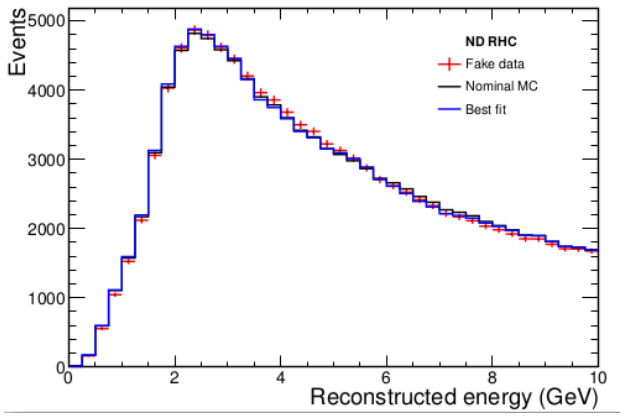
Fake data- Nuwro/GENIE

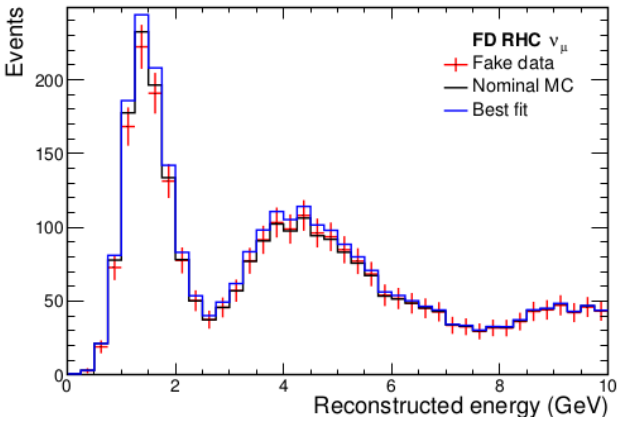
- ND and FD have 20% ME shift, we have Xsec + flux parameters to recover it.

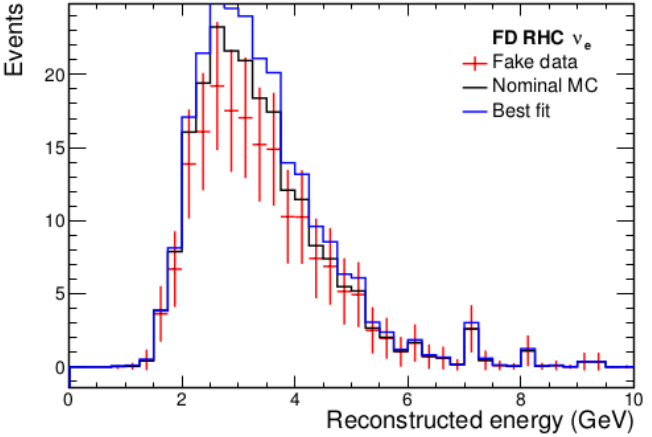












Conclusion

- Contacted Experts and have added the systematics to the fitter.

- The OA bias is sensitive to the fake data we input. My shift spectrum is not strong enough to introduce significant bias.
    - What is the best fake data that cover all of our uncertainties?

- Consider to move to the dunePrism method.

Backup

Systematics

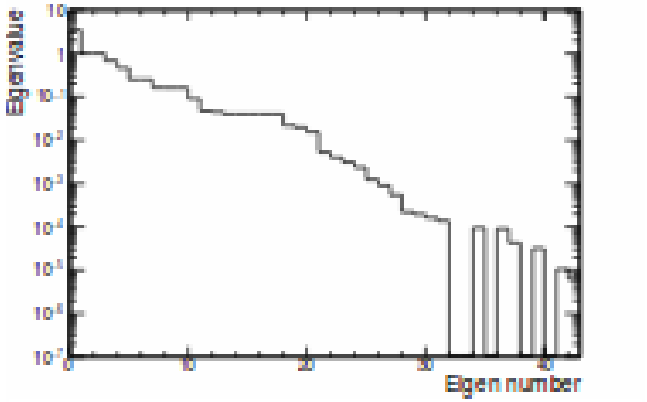
```cpp
/// Absolute energy scale systematic
class EnergyScaleSyst: public ISyst
{
public:
  std::set<std::string> Requires() const override
  {
    return {"dune.Ev_reco"};
  }
  std::string ShortName() const override {return "eScale";}
  std::string LatexName() const override {return "Energy Scale";}

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

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

static const EnergyScaleSyst kEnergyScaleSyst;
```

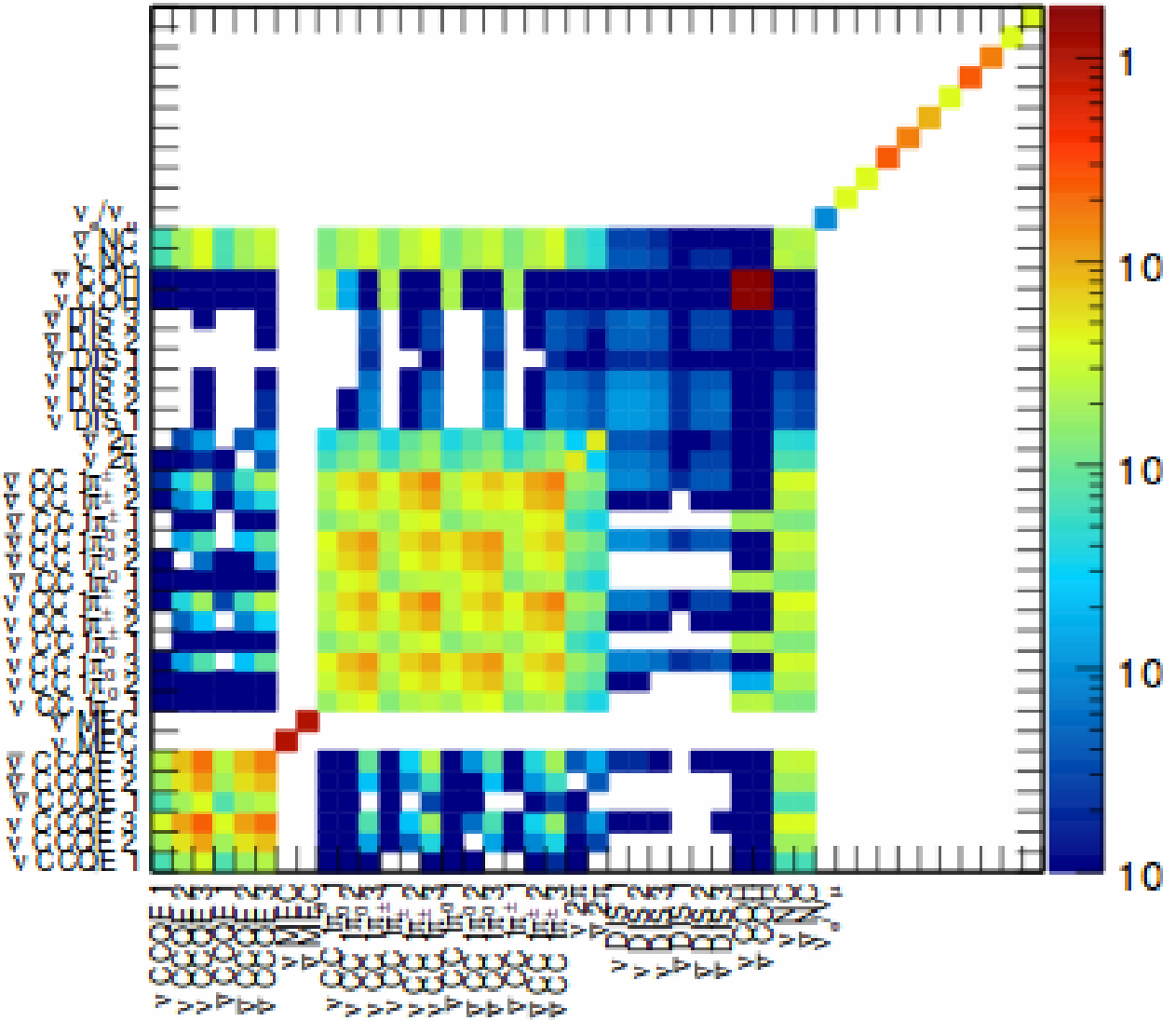
```cpp
/// 5% normalization syst for NC on numu analysis
class NCSyst: public ISyst
{
public:
  std::set<std::string> Requires() const override
  {
    return {"dune.Ev","dune.Ev_reco", "dune.ccnc"};
  }
  std::string ShortName() const override {return "NC";}
  std::string LatexName() const override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

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

static const NCSyst kNCSyst;
```

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

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

Cross-sections





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