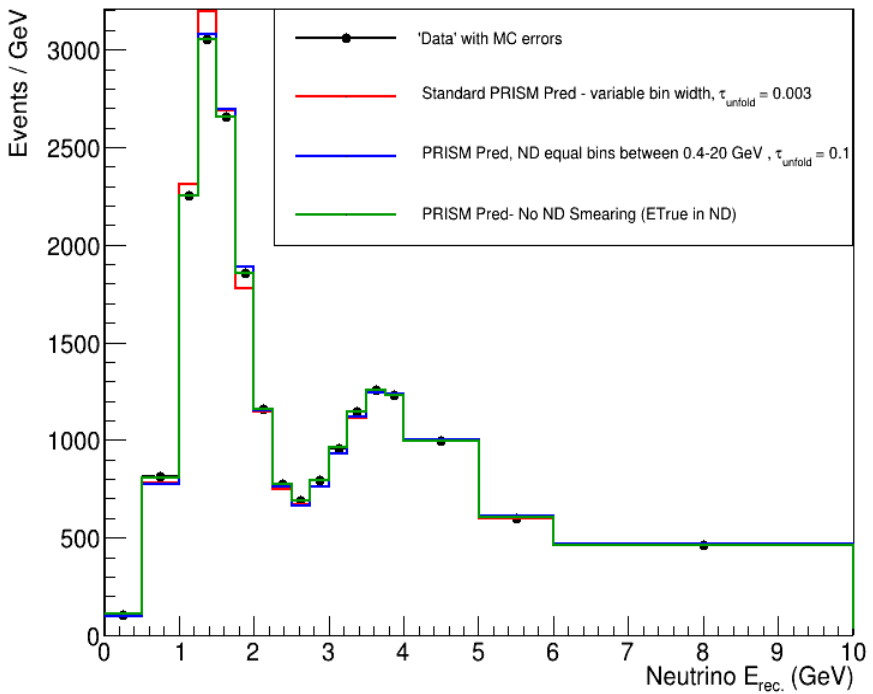
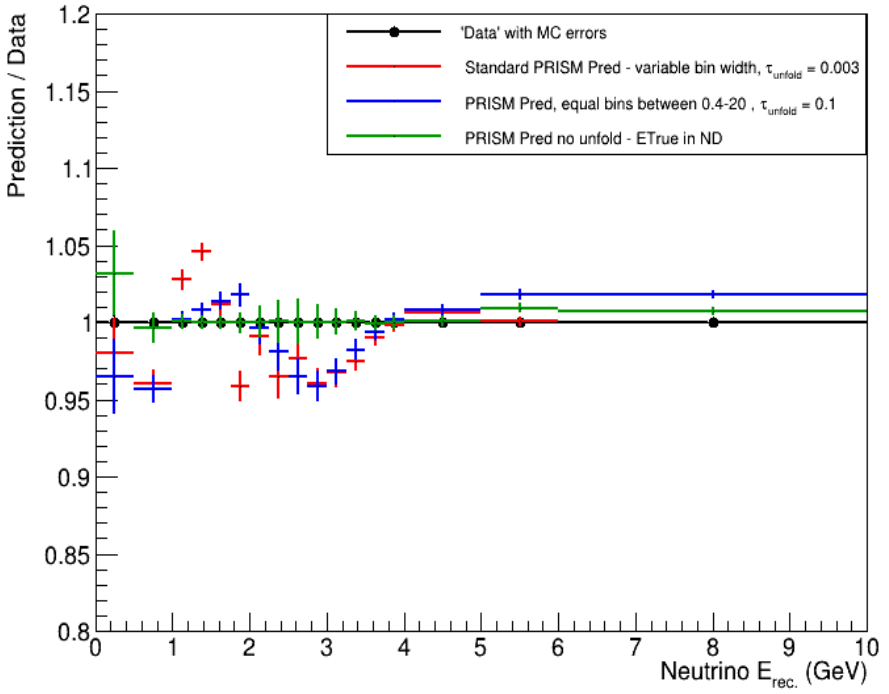
PRISM Prediction with the 2 regularization procedures – FD Standard binning

- **standard PRISM**: standard FD bin + standard ND bin + reg Mat for equal bin width regularization – for non-equal bins (+ regMat non-0 last 2 lines)
- **modified PRISM**: standard FD bin + modfied ND bin + regMat for non-equal bin width (regMat with 0s last 2 lines+ 1st element for 1st derivative, rest of elements for 2nd dervative)
- **no ND smearing**: standard FD + standard ND-only Etrue in ND: only Etrue → Erec in FD

standard FD binning : 18 bins (non-equal widhts)
standard ND binning : 67 bins (non-equal widths)
modified ND binning : 198 bins (uniform 0.4 – 20 GeV)

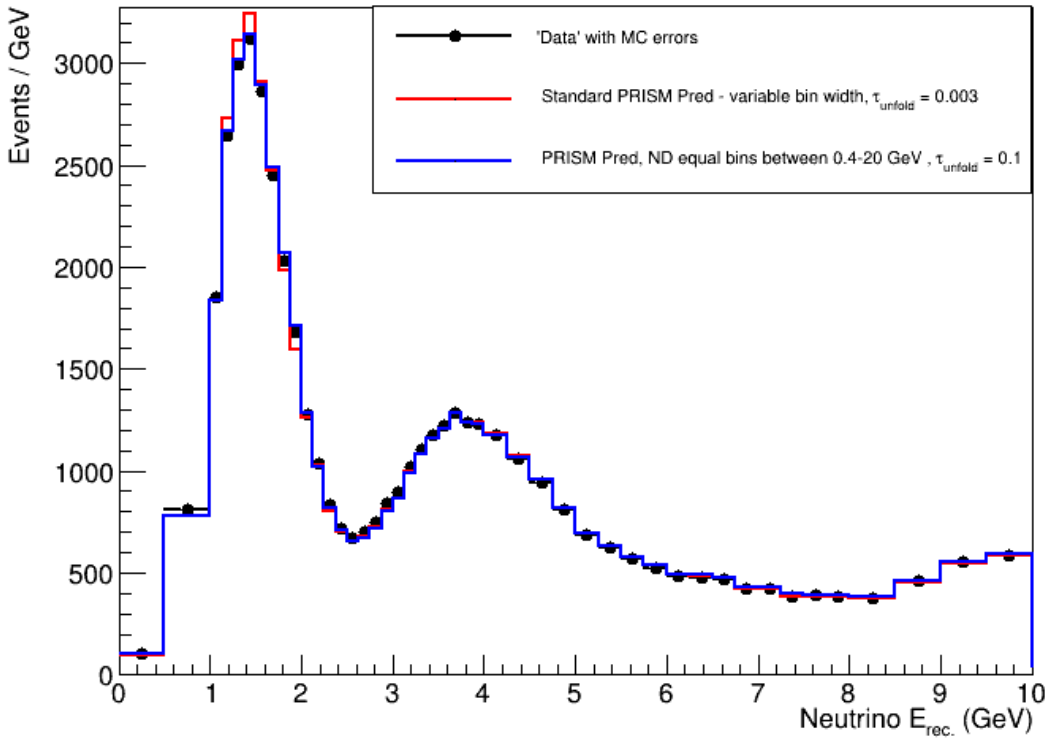


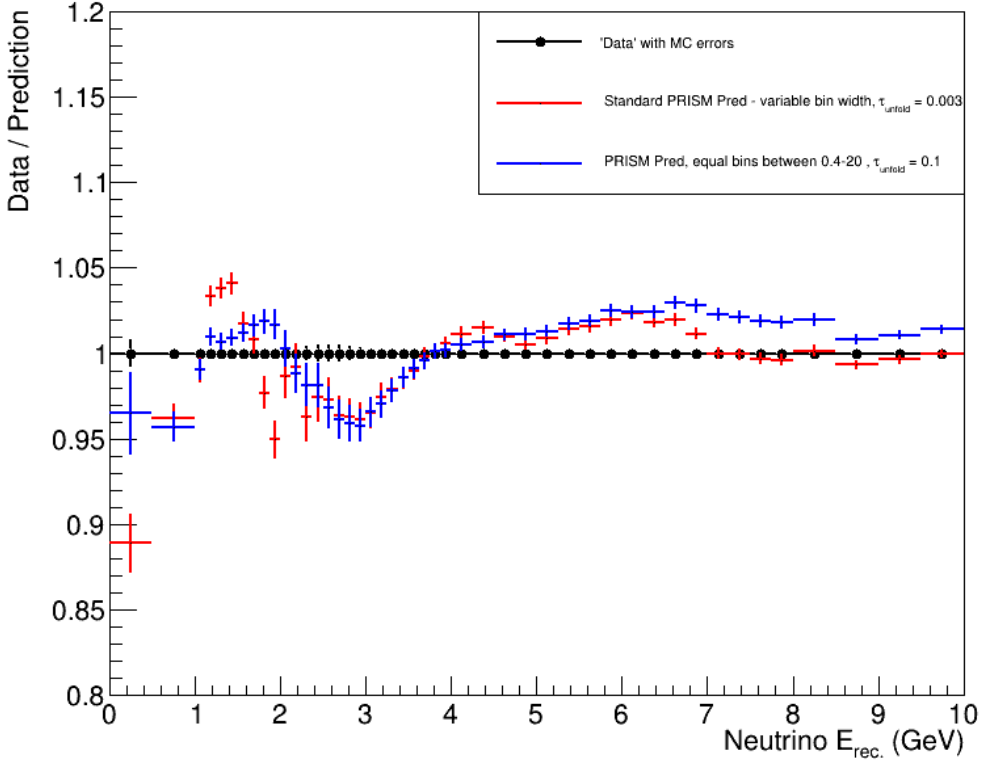


PRISM Prediction with the 2 regularization procedures – FD Fine binning

- **standard PRISM**: fine FD bin + standard ND bin + reg Mat for equal bin width regularization – for non-equal bins (+ regMat non-0 last 2 lines)
- **modified PRISM**: fine FD bin + modfied ND bin + regMat for non-equal bin width (regMat with 0s last 2 lines+ 1st element for 1st derivative, rest of elements for 2nd dervative)

fine FD binning : 47 bins (non-equal widhts)
standard ND binning : 67 bins (non-equal widths)
modified ND binning : 198 bins (uniform 0.4 – 20 GeV)





Where we are

→ a lot of changes (migration from SL 7 → Alma 9) + shutdowns of Fermi grid..things slowed down a lot by this..but now managed to rewrite the scripts and resubmit jobs..

- **state files with flux systematics** for the new ND binning + FD state files (with flux systs and fine binning → the ones with flux systs + standard binning already have)

  → can test for both FD binning

  - **state file (ND bins flat 0.4-20 + FD Standard binning) done**
  - **state file (ND bins flat 0.4-20 + FD Fine binning) – hadding at the moment**

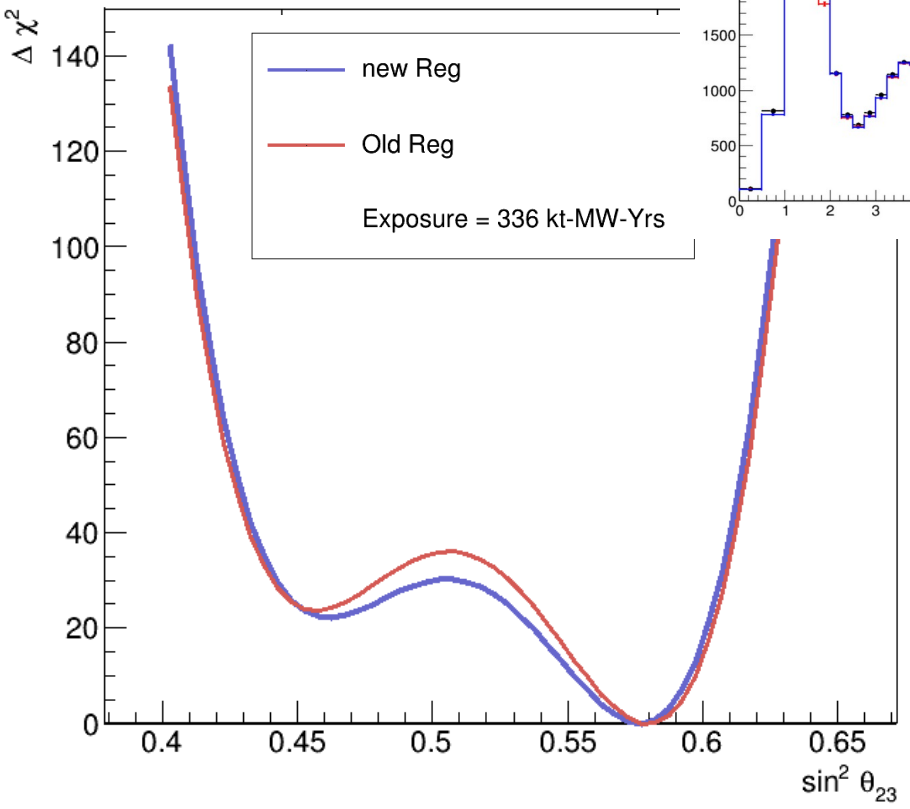
- once state files done: re-run oscillation fits with flux systematics with new reg method and compare to old results

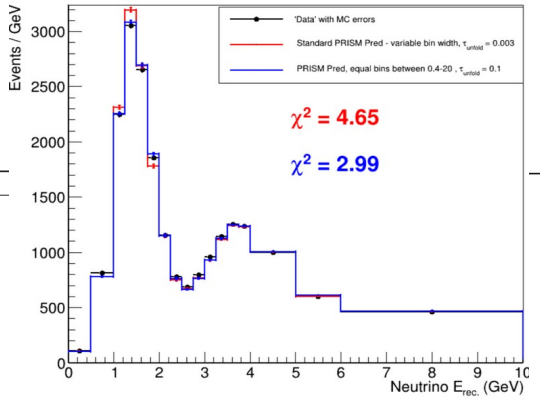
  → test osc fit with HordnCEccentrictiyX (bias with old regularization but no bias when no ND smearing)

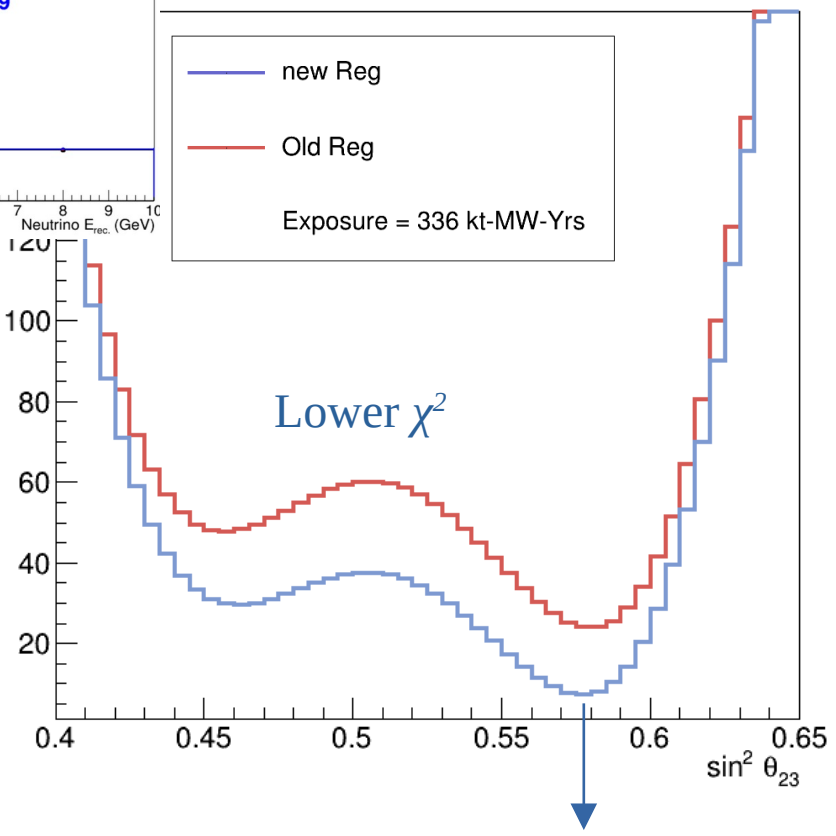
  - oscillation fits for (ND bins flat 0.4-20 + FD Standard binning) running as we speak

→ Soon to have oscillation fits with flux systematics for new regularization method for both FD fine binning and FD standard binning

Oscillation fit: 4 channels no systematics







Definite minimum at true value

TMS-like studies with PRISM

Run the analysis with different ND selection: (discussion with Luke)

1. no ND muon charge selection
2. worse ND momentum resolution

- No PRISM analysis run so far, but rather just “playing” with several CAF files and checking different distributions of interest (very early on study..)

  - PRISM ND data → ND cuts (data we would see, I.e includes ND background)
  - PRISM ND CC-Events → OnlyCC cuts (after ND background was subtracted, applied to smearing matrices as well as the true energy spectrum used for linear combinations)

  → look at both true and reconstructed energy distributions for different cuts for both ND_FHC and ND_RHC for an on-axis and far off-axis sample

TMS-like studies with PRISM: no ND muon charge selection

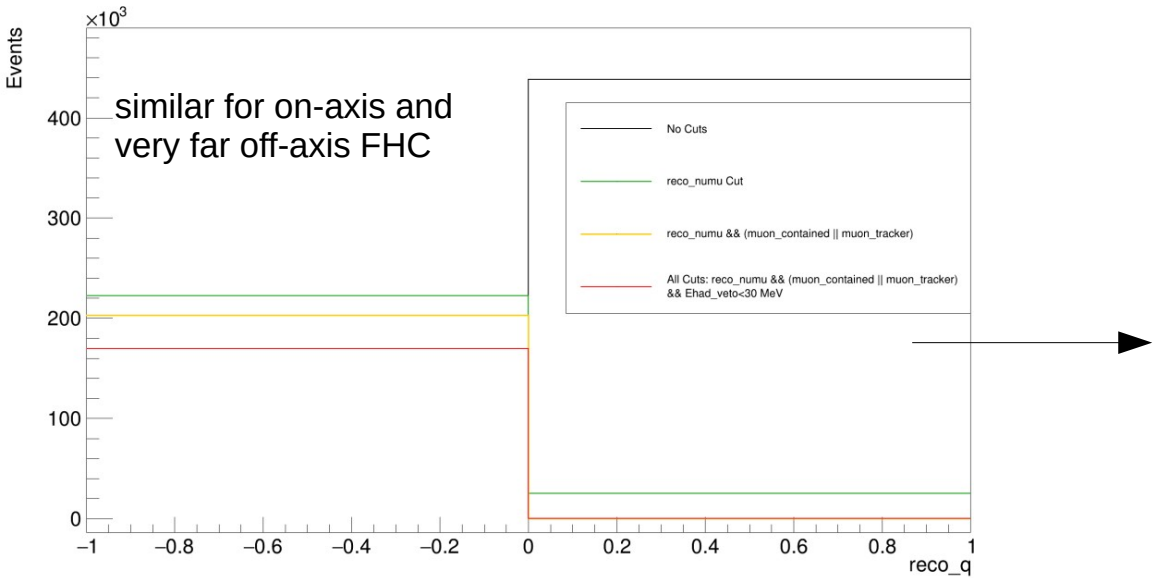
- reconstructed charge variable within CAF files: **reco_q**

ND_FHC: reco_q = – 1
ND_RHC: reco_1 = + 1

- **ND_FHC** case: no difference in any of the investigated distribution when reco_q cut is not applied → why?

NDCuts = reco_numu && (muon_contained || sr->muon_tracker) && **reco_q == -1** && Ehad_veto<30

→ applied to ND data (I.e before background subtraction)



all reco_q == +1 events are already disregarded when both the reco_numu() and containment (contained || tracker) cuts are applied

→ my **probably naive message** here:
If same containment and reconstruction cuts are applied than the (existence of a) muon charge reconstruction is not affecting the analysis

!!! Needs further discussion with Luke (what happens if shift in WSB?)

TMS-like studies with PRISM: TMS-like lepton energy

- from (older) message of C. Marshal: *some way to connect TMS momentum resolution to something oscillation physicsy.*

1) Estimate basically what the TMS would measure, i.e. E_TMS = Elep - 0.002*(600 - vtx_z)

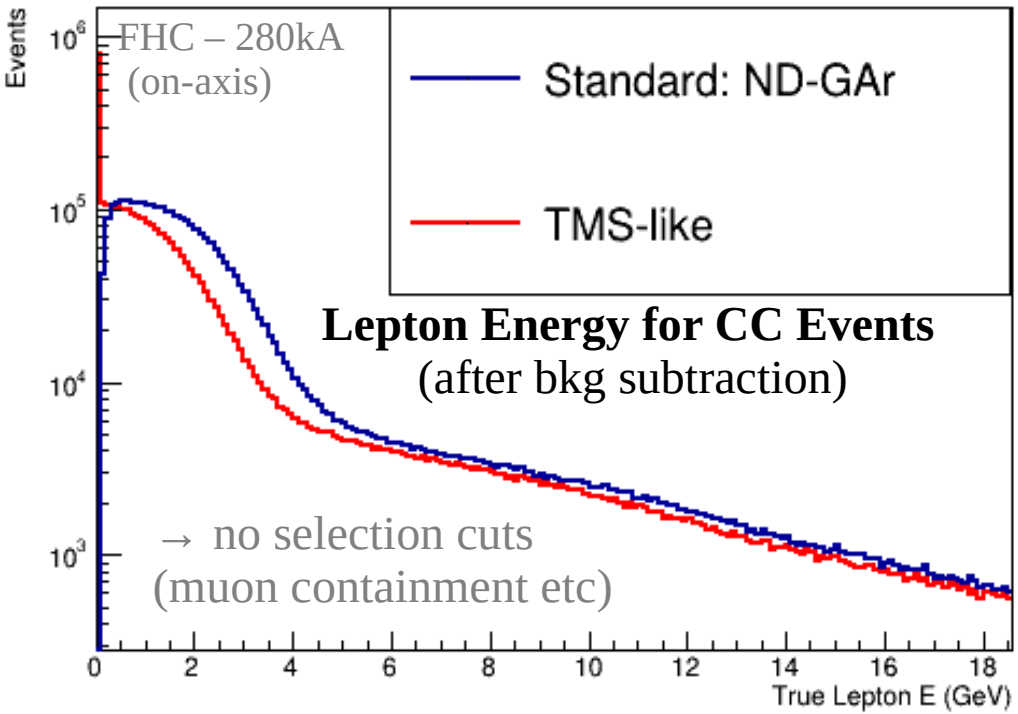
2) Smear the energy by some additional amount for TMS-matched (I know it's ND-GAr in the tDR files but whatever). Maybe 3%, 5%, 10% to start

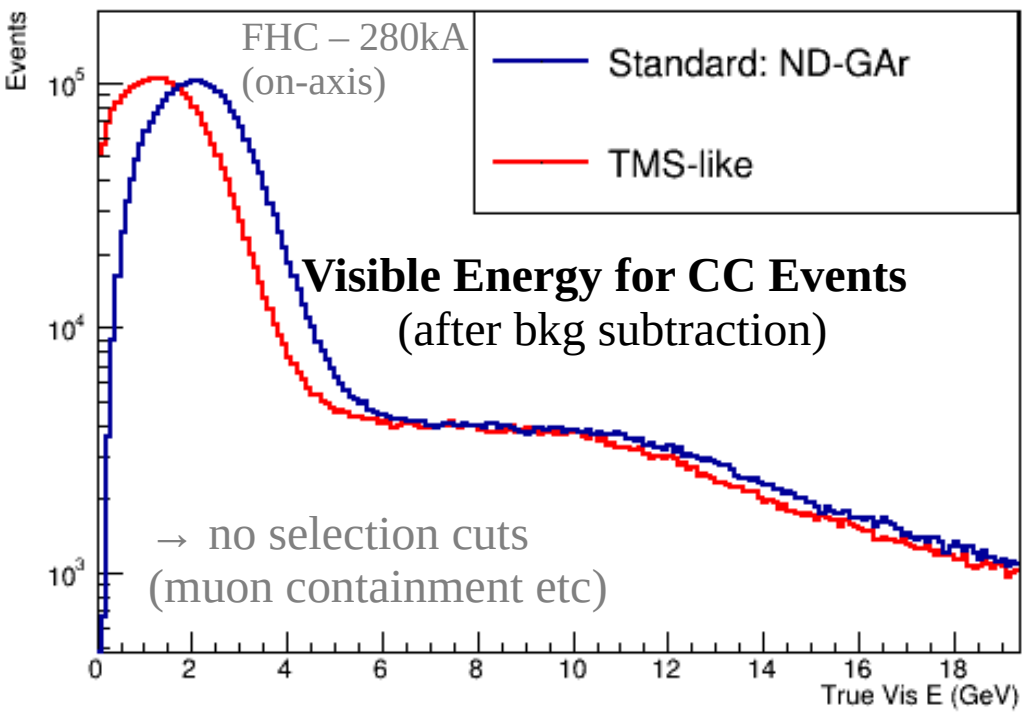
3) measure dm2_32 with the disappearance analysis

TMS-like studies with PRISM: TMS-like lepton energy

1) Estimate basically what the TMS would measure, i.e. E_TMS = Elep - 0.002*(600 - vtx_z)

true lepton energy with TMS: **LepETMS = LepE – 0.002*(600-vtx_z);**
true visible energy with TMS: **VisEtrueTMS = LepETMS + HadE**
(VisETrue standard = LepE + HadE)





TMS-like studies with PRISM: TMS-like lepton energy

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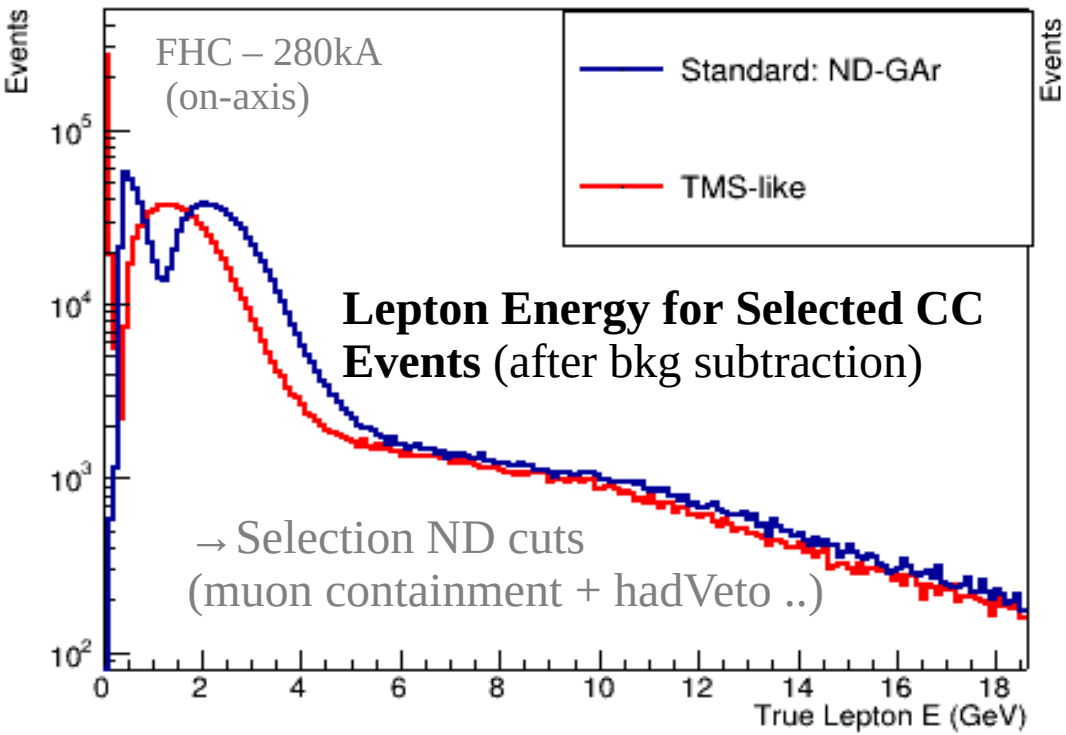
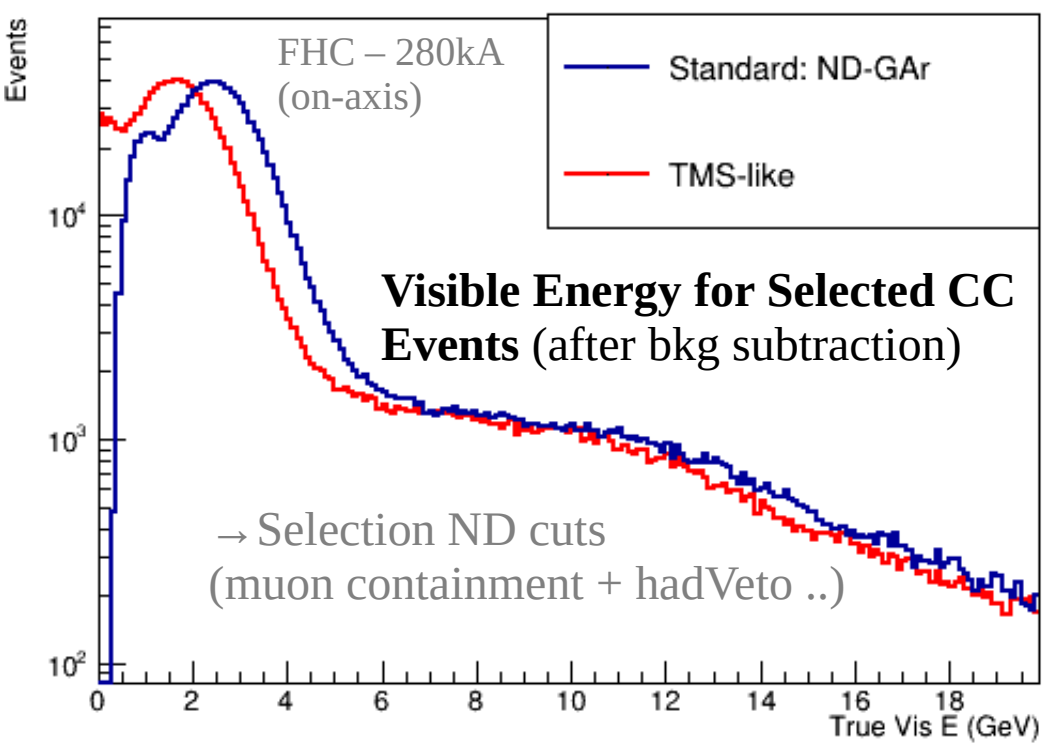


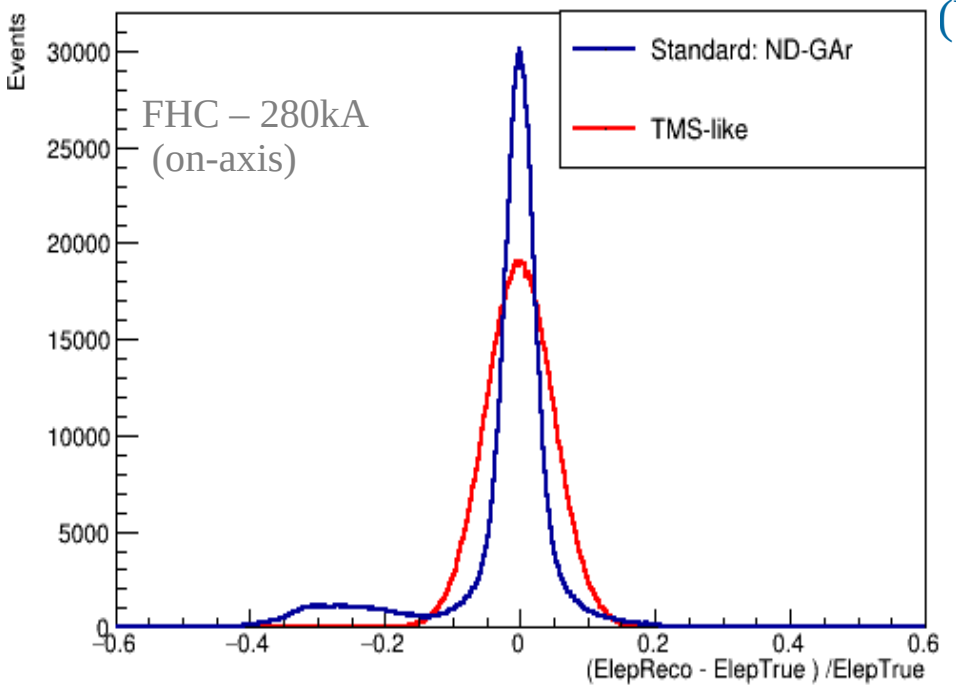


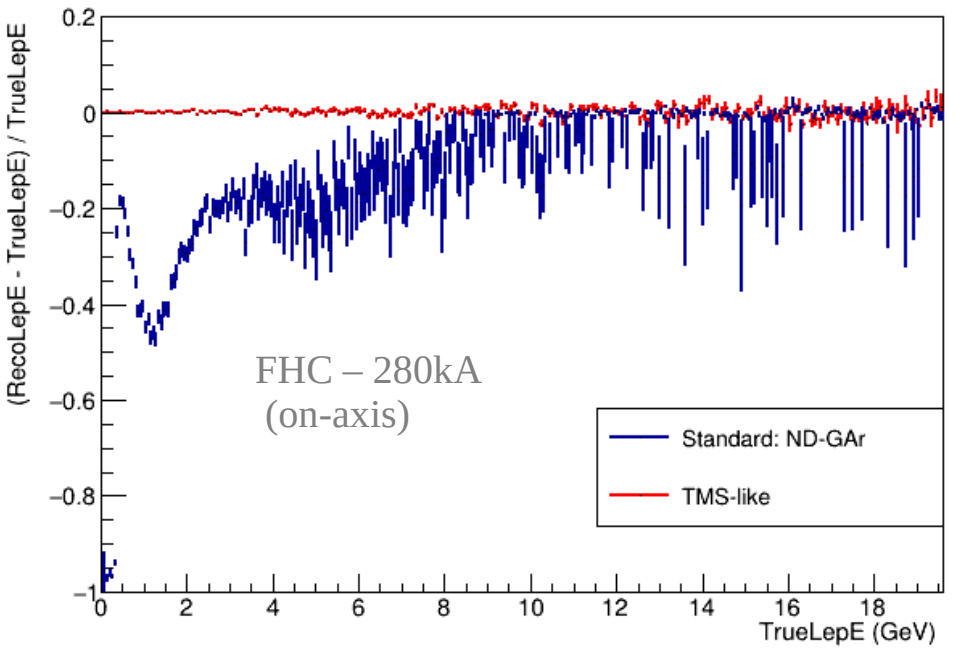
TMS-like studies with PRISM: TMS-like lepton energy

2) Smear the energy by some additional amount for TMS-matched (I know it's ND-GAr in the tDR files but whatever). Maybe 3%, **5%**, 10% to start

→ **Extract ELep_recoTMS from a Gaussian with mean = Etrue and sigma = 5%Etrue**
(not sure if the best way to go..maybe other ideas/formulas instead?)

reconstructed visible energy with TMS: VisERecoNDTMS = HadEvisReco_ND + Elep_recoTMS
(VisERecoND standard = HadEvisReco_ND + Elep_reco)





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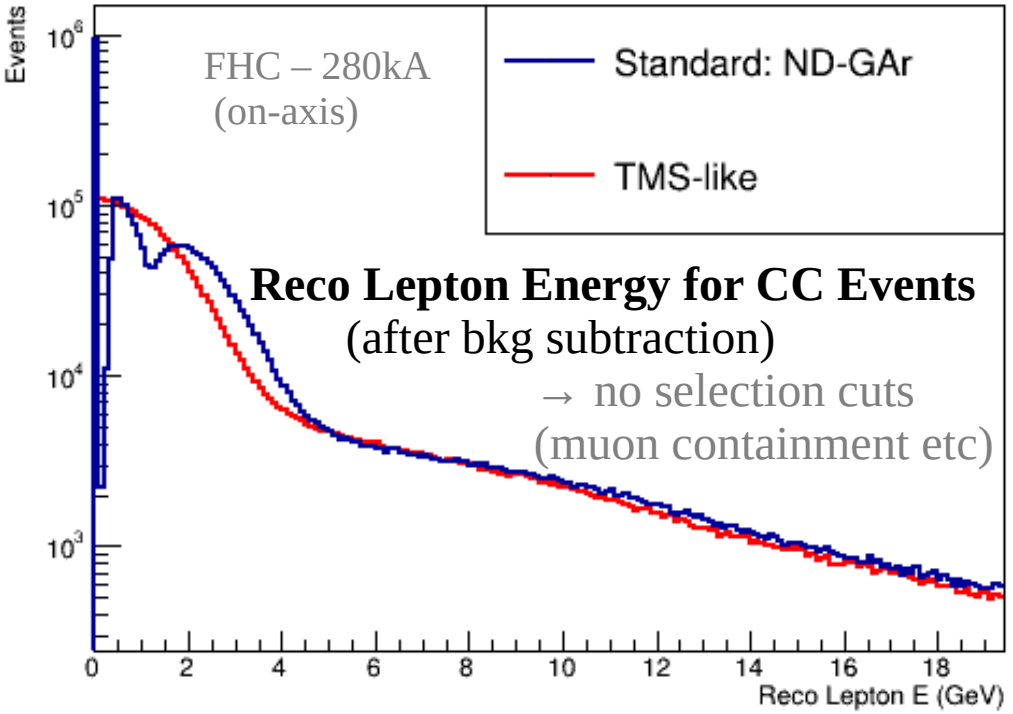

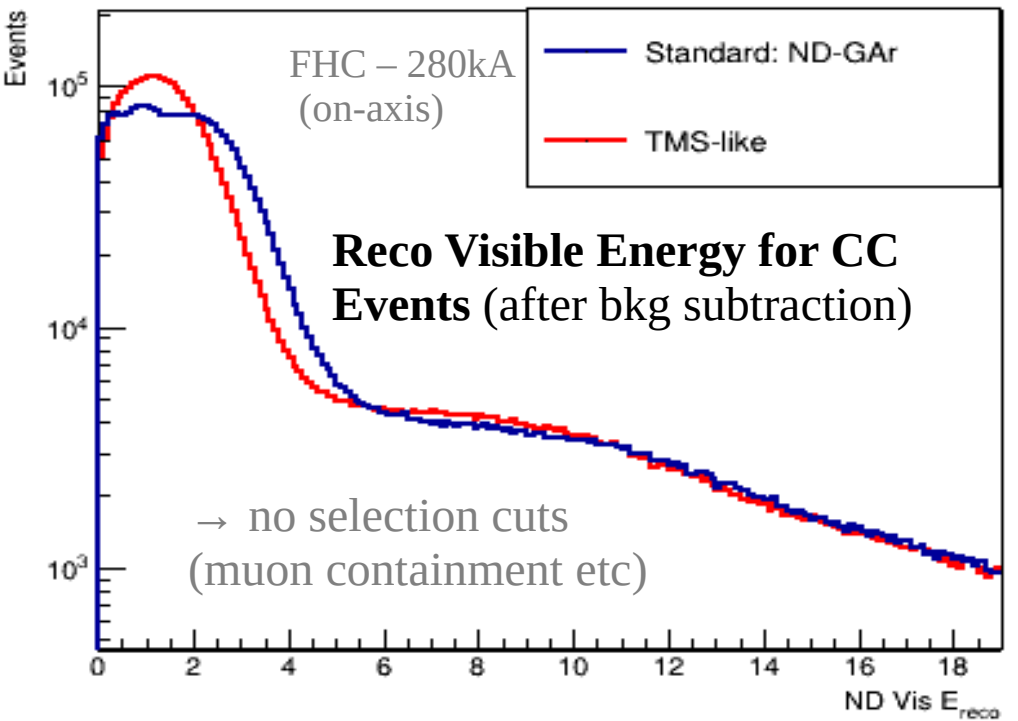

TMS-like studies with PRISM: TMS-like lepton energy

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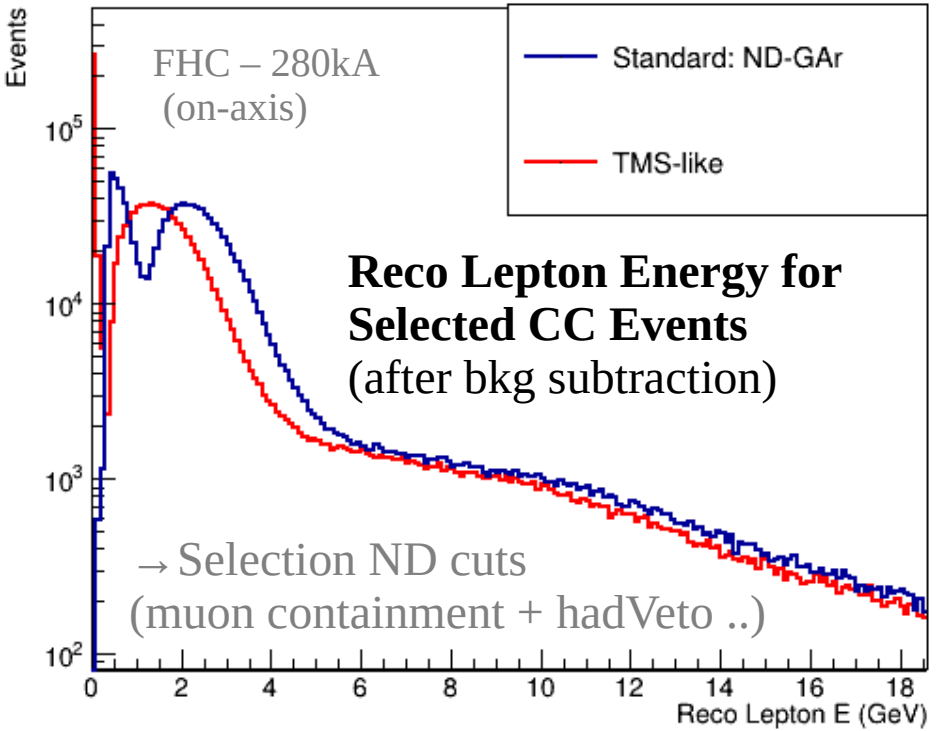
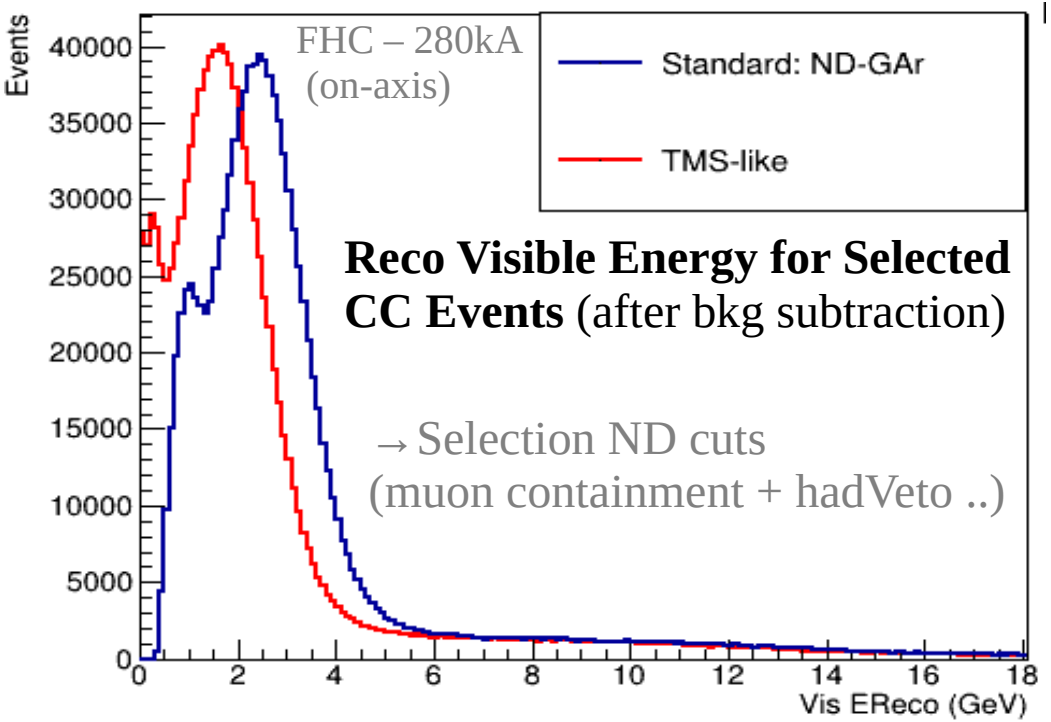
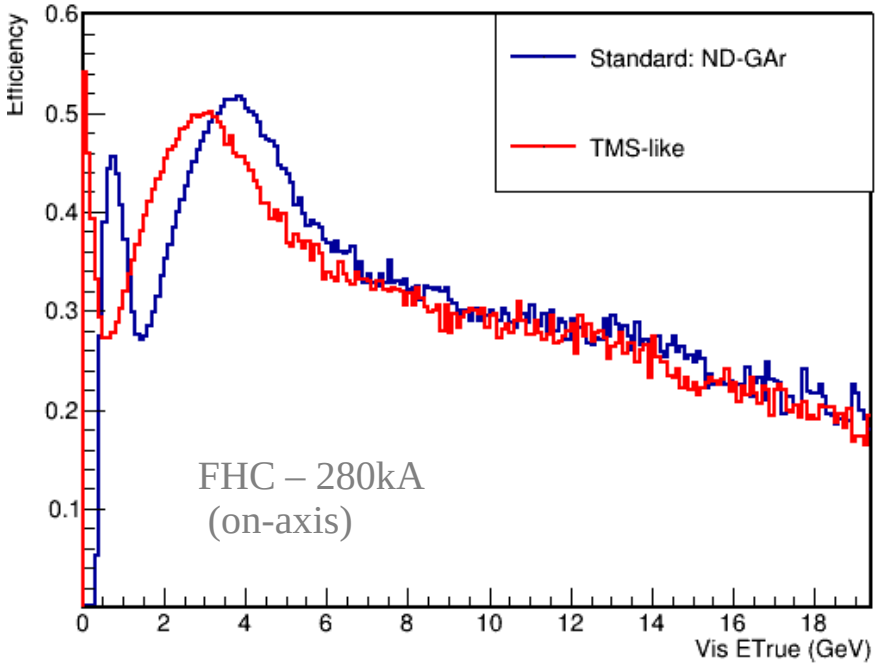




TMS-like studies with PRISM: TMS-like lepton energy



$$\text{ND Efficiency} = \frac{\text{Selected CC Events (ND cuts)}}{\text{Generated CC events (no selection cuts)}}$$

→ change in efficiency with TMS-like

So far...

- **TMS-like studies with PRISM**:

  – only briefly looked at FHC for an on-axis scenario (RHC + off-axis TO DO)
  – discussion with Luke needed on how to further proceed but in principle we have all the information needed

  –> once we decide what exactly we want to check for, integrating it within PRISM analysis and producing first oscillation plots (no-systs) should be doable before next CM

- **Flux Systematics** with new regularization method:
  – state files are now produced and hadded + oscillation fits (for FD standard binning) are running on the grid as we speak

  –> by the end of next week should have all the oscillation fits with the new flux systematics + new regularization method

PRISM prediction – regularization in unfolding procedure

- Tikhonov regularization:
  - minimize $||M_{ND}\ Etrue - Erec||^2 + ||\Gamma\ Etrue||^2$
  Γ – regularization matrix

$$\mathbf{D} = \left(\left(\mathbf{M^{ND}}\right)^{\mathrm{T}} \mathbf{M^{ND}} + \mathbf{\Gamma}^{\mathrm{T}}\mathbf{\Gamma} \right)^{-1} \left(\mathbf{M^{ND}}\right)^{\mathrm{T}},$$

$\mathbf{E_{true} = D \times E_{rec}}$

$$\mathbf{\Gamma} = \tau_{unf.} \begin{pmatrix} 1 & -2 & 1 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 1 & -2 & 1 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 1 & -2 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & 1 & -2 & 1 \\ 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \end{pmatrix}$$

regularization parameter

- this form of the matrix is corresponding to a regularization of the second derivative: approx. by $(x_{i+1} - x_i) - (x_i - x_{i-1})$.

$$L_{i,i} = 1,\ L_{i,i+1} = -2,\ L_{i,i+2} = 1.$$

$$\mathbf{\Gamma} = \tau_{unf.} \begin{pmatrix} -1 & 1 & 0 & 0 & \ldots & 0 & 0 \\ 0 & -1 & 1 & 0 & \ldots & 0 & 0 \\ 0 & 0 & -1 & 1 & \ldots & 0 & 0 \\ . & . & . & . & \ldots & . & 0 \\ . & . & . & . & \ldots & . & 0 \\ . & . & . & . & \ldots & . & 0 \\ 0 & 0 & 0 & 0 & \ldots & -1 & 1 \\ 0 & 0 & 0 & 0 & \ldots & 0 & 0 \end{pmatrix}$$

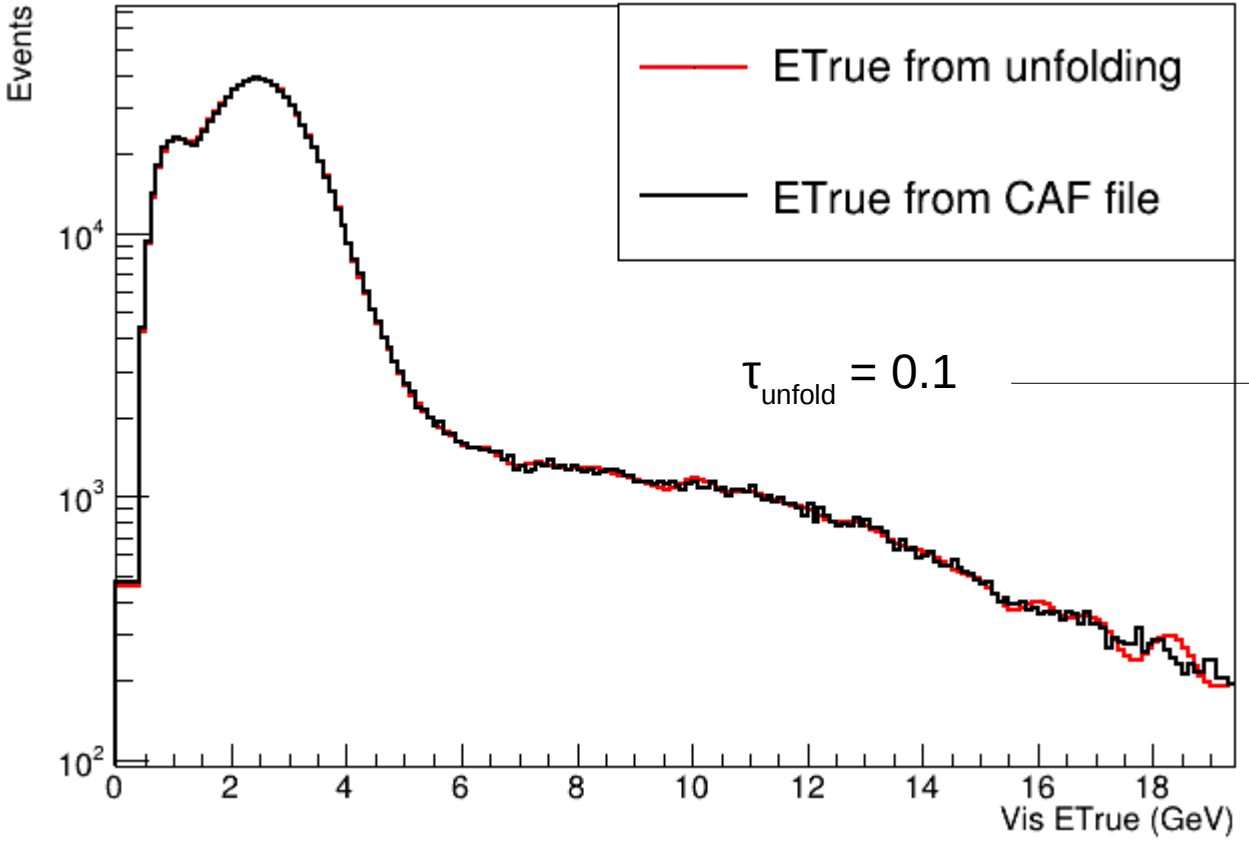
regularization parameter

- this form of the matrix is corresponding to a regularization of the first derivative: approx. by $x_{i+1} - x_i$

$$L_{i,i} = -1 \text{ and } L_{i,i+1} = 1$$

True Energy unfolded distribution – 280 kA sample (on-axis)

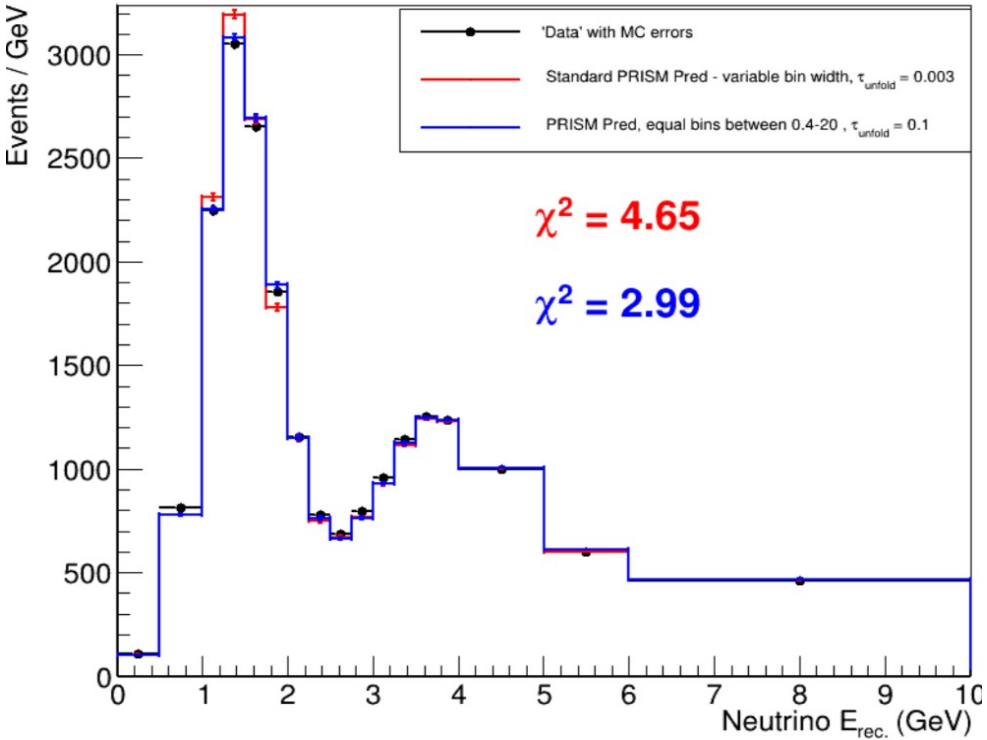
- currently: uniform binning between 0.4 – 20 GeV (1 bin 0-0.4 + 1 bin 20-120 GeV)
- regularization matrix for non-equal bin widths - 2nd derivative
  – solved the low energy miss-match problem (1st derivative regularization – only 1 neighboring bin for first bin)

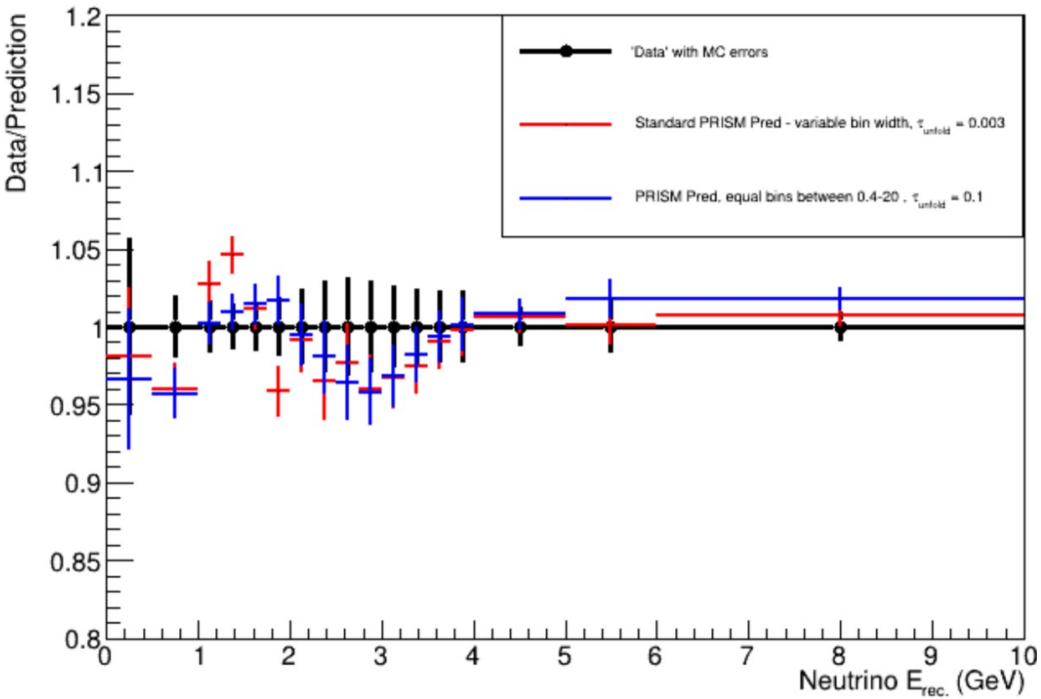


best unfolding I Could achieve so far

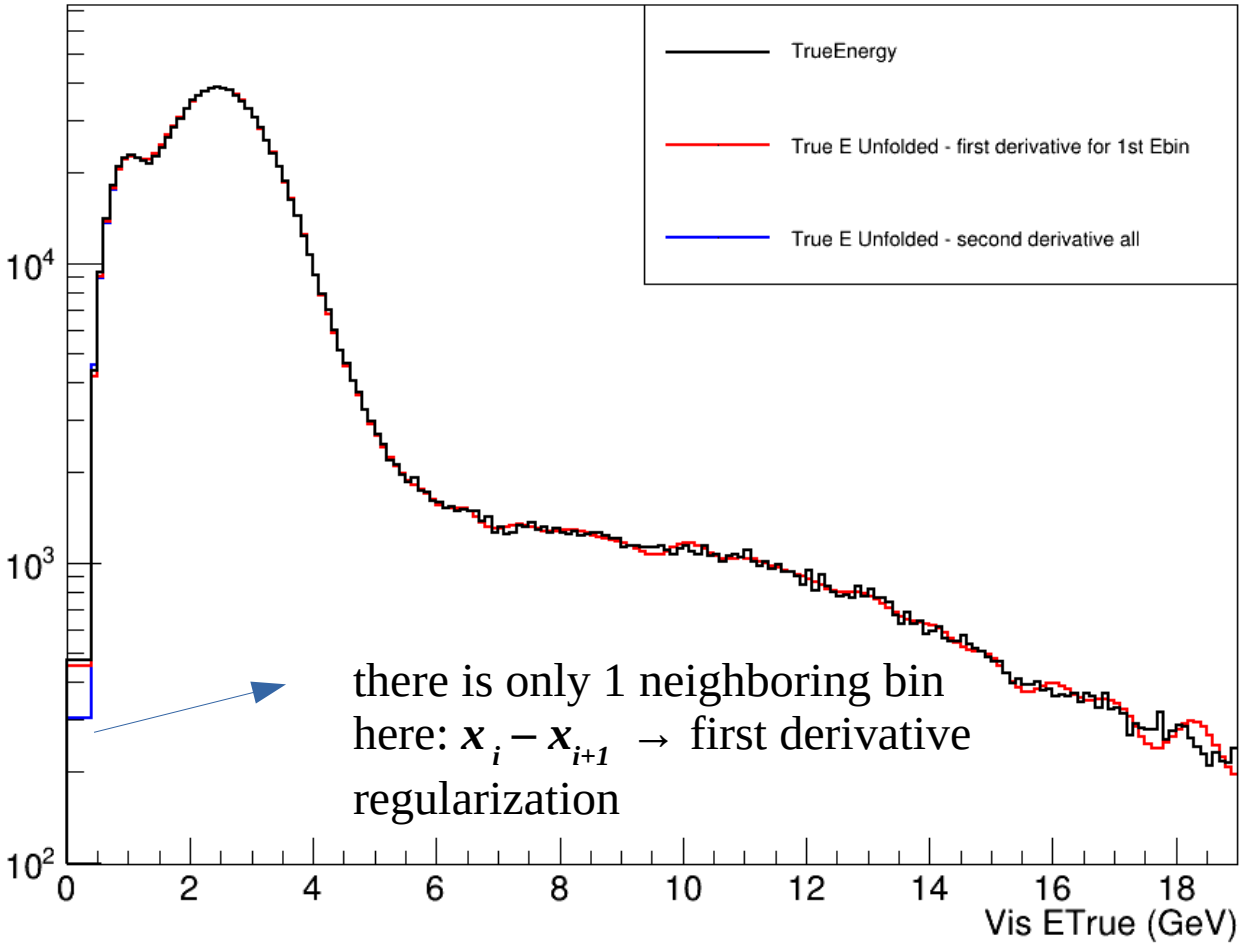
PRISM Prediction: different binning + zeros in Regularization matrix

- standard: non-uniform binning
- currently: uniform binning between 0.4 – 20 GeV (1 bin 0-0.4 + 1 bin 20-120 GeV)





→ **better** but still not perfect .. (not within the MC error bars at 0.8 GeV and getting slightly worse at highest energies – stays within the error bars @ 5.5 GeV but not at 8 GeV – very slightly out of the error bar region)

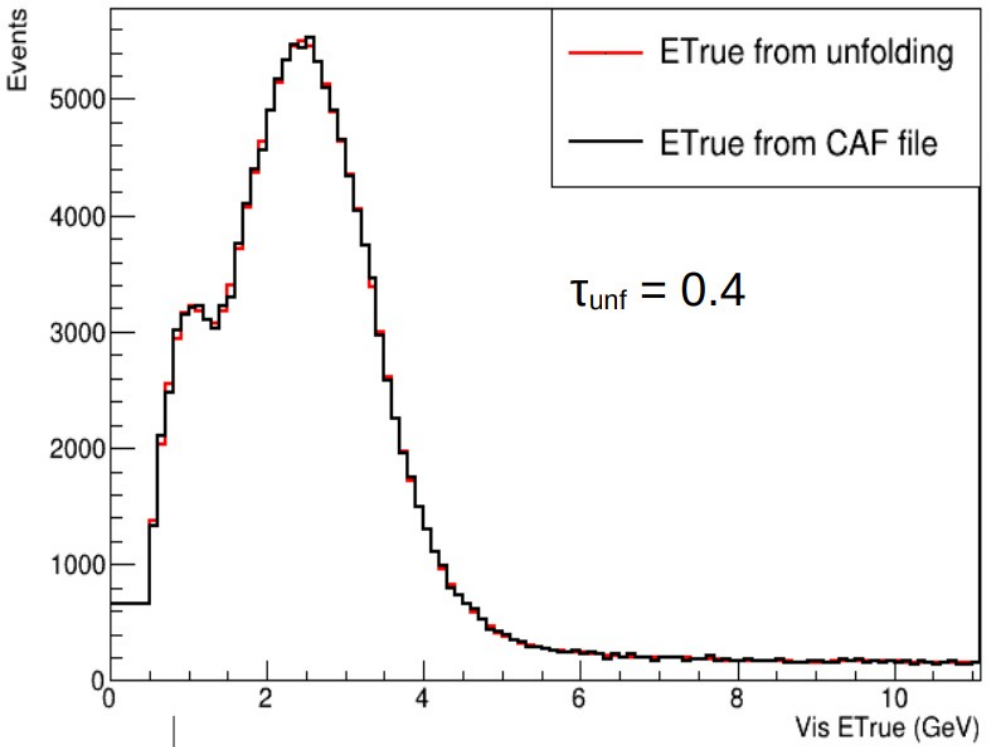


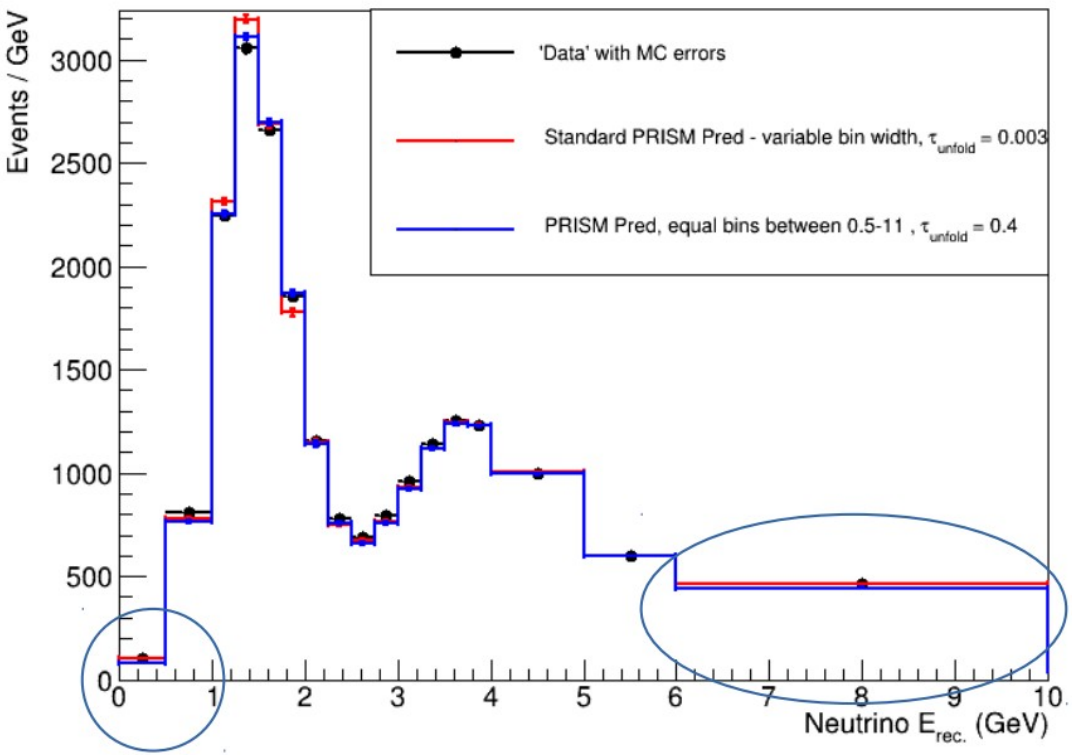
- second derivative regularization is looking at event counts in neighboring bins at both left and right..

$$(x_{i+1} - x_i) - (x_i - x_{i-1})$$

True energy – unfolded distributions and PRISM Prediction

→ correct regularization matrix with the last 2 rows with zeros

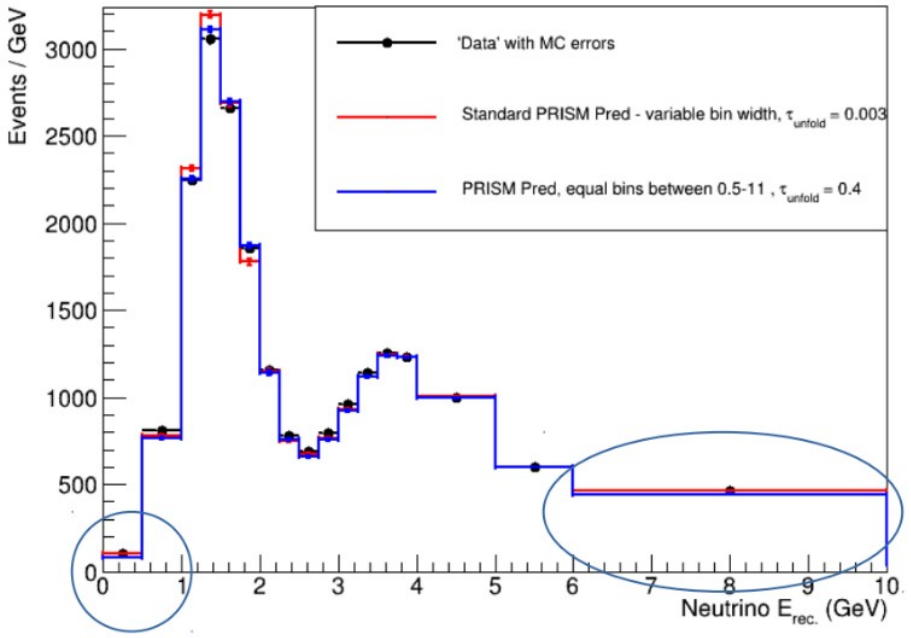


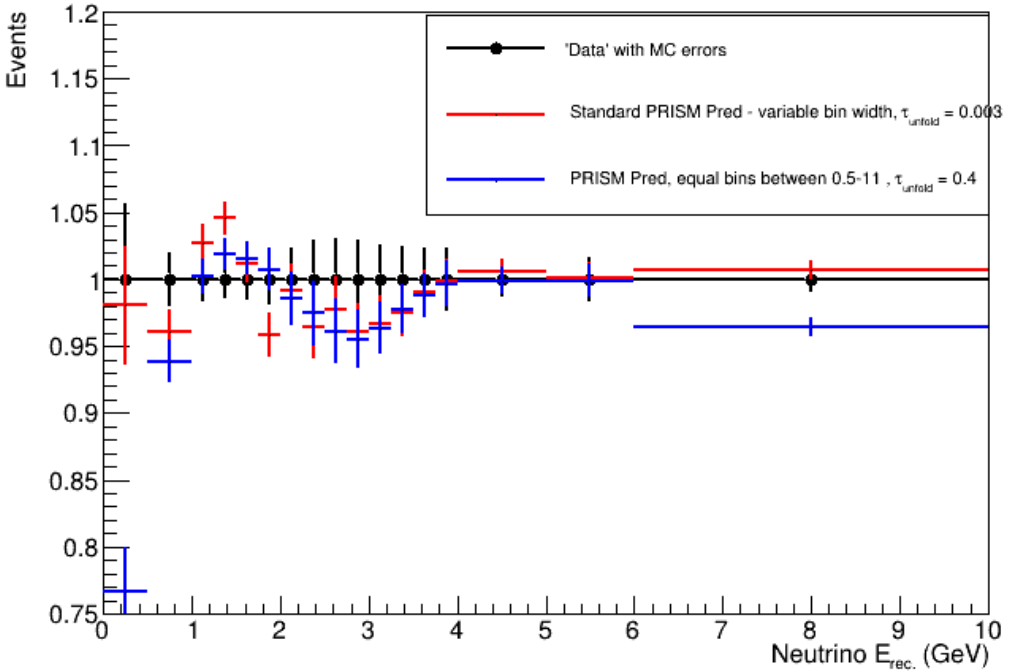


unfolding to true energy works quite well within the mini-script and 1 CAF file

PRISM Prediction: different binning + zeros in Regularization matrix

- standard: non-uniform binning
- currently: uniform binning between 0.5 – 11 GeV (1 bin 0-0.5 + 1 bin 11-120 GeV)

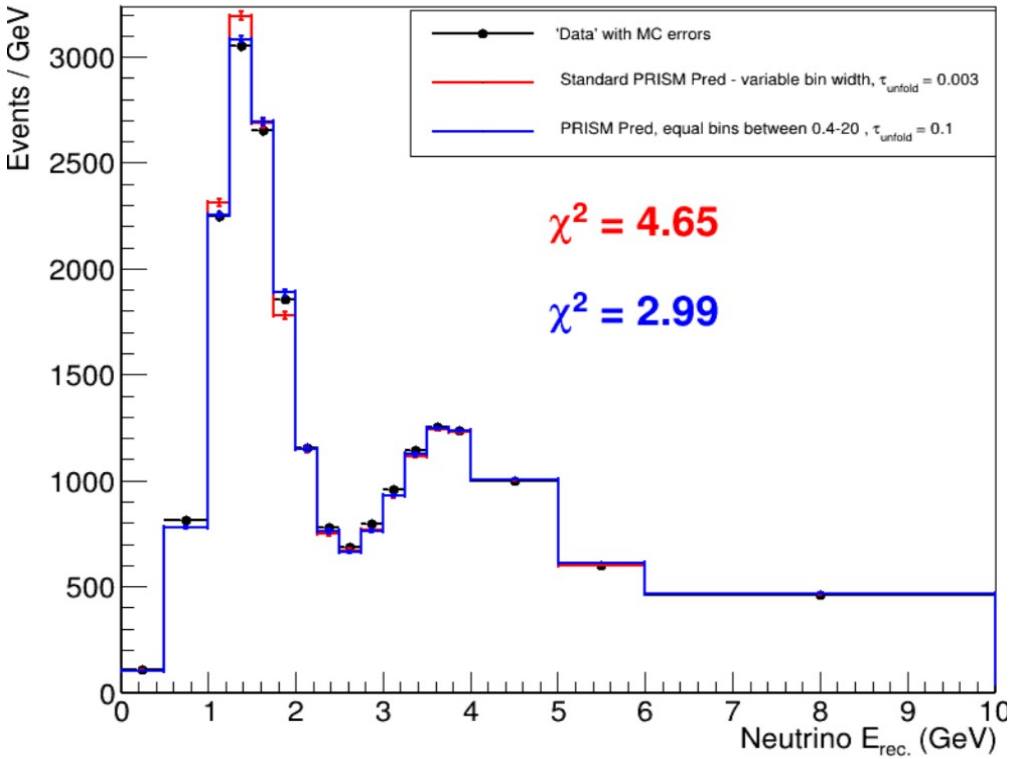




→ better match at peak but worse at edges.. (non-uniform bins – need finer binning..?)

PRISM Prediction: different binning + zeros in Regularization matrix

- standard: non-uniform binning
- currently: uniform binning between 0.4 – 20 GeV (1 bin 0-0.4 + 1 bin 20-120 GeV)



Are we happy with this agreement?

- if yes: remake state files with this binning + add systematics + re-evaluate oscillation fits

+ better prediction than before (MC errors)

+ procedure established only takes some time to re-run state files + oscillation fits (1 week)

– still not a perfect match (even if better biases could still appear..even though theoretically chances are lower than before)

– need to re-evaluate all systematics fits

– if not: probably need different regularization method (could use Tunfold..) – out of ideas what else to try for the current one

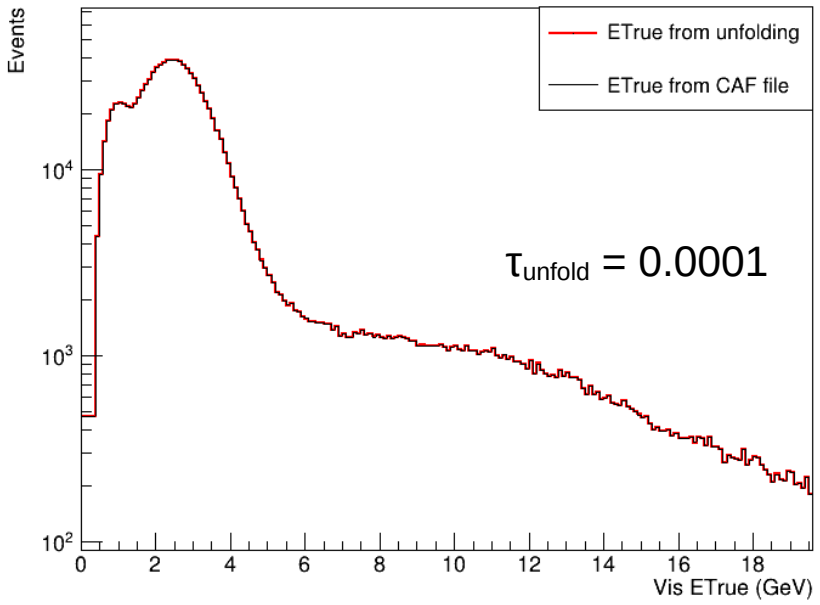
+ maybe get perfect match and avoid any kind of bias

+ no need to regenerate state files

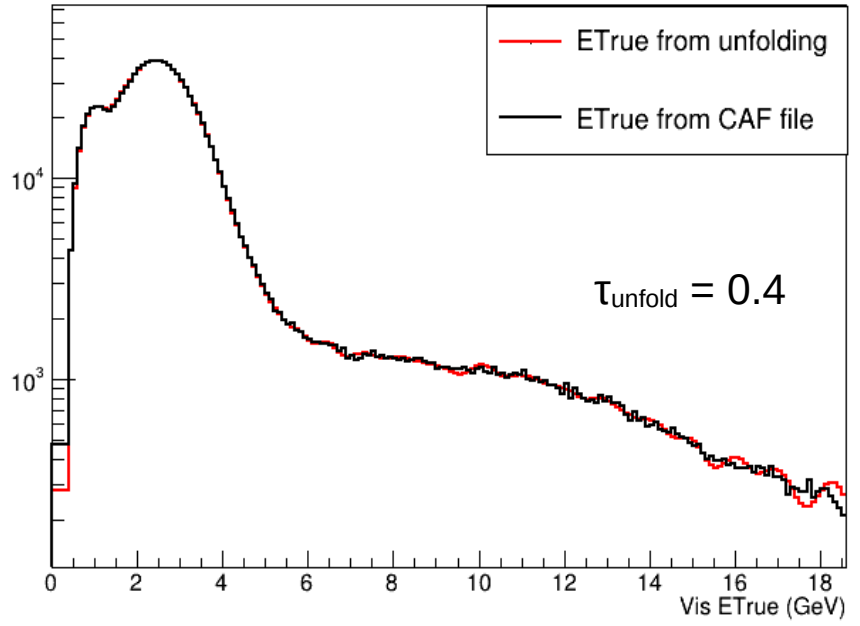
– not sure if it works / how much time it would take to make it work

Unfolded Distributions – 280 kA sample

- Using script (280kA only) smearing matrix

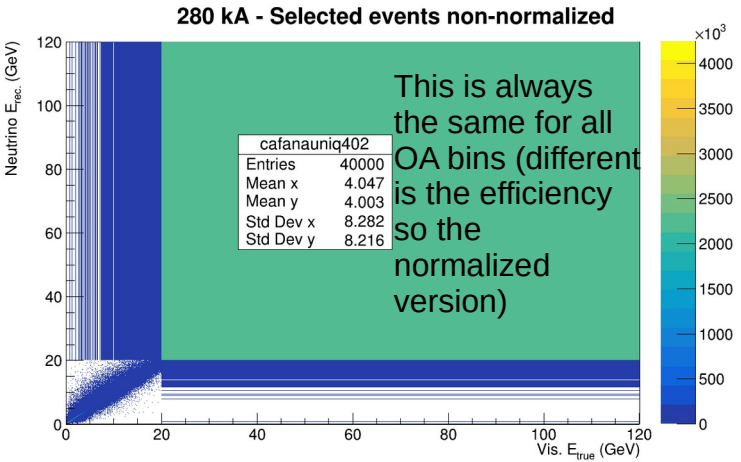


- Using PRISM (all OA summed) smearing matrix – best agreement ..

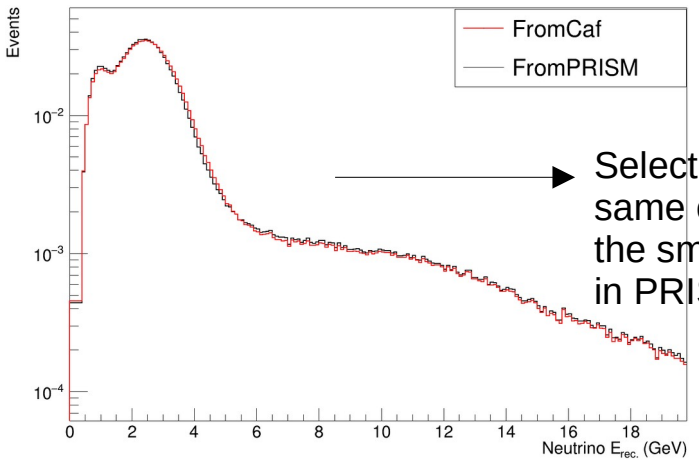


Always some compromise between first bin (best match at low reg param and the high energy ones → best match at high reg param

From PRISM prediction



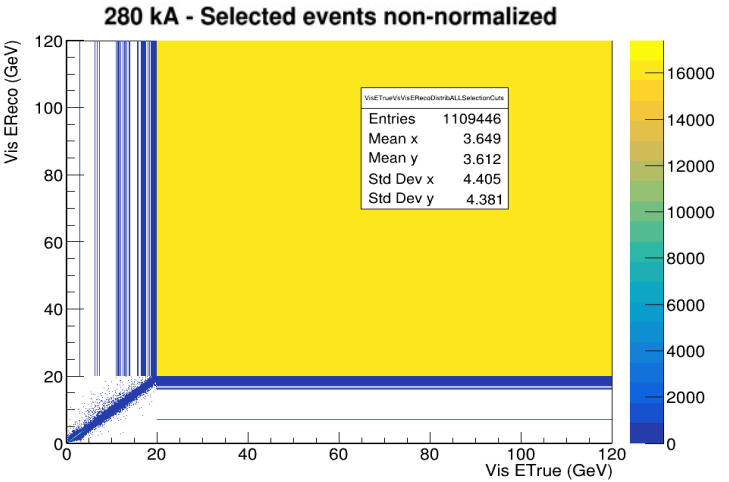
This is always the same for all OA bins (different is the efficiency so the normalized version)

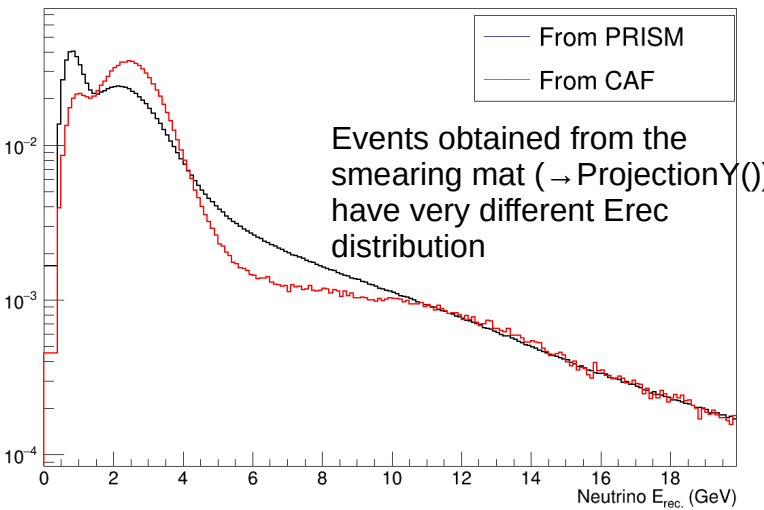


Selected events (Erec) have the same energy distribution both in the small script – From CAF and in PRISM analysis

→ **not the correct smearing matrix used within PRISM..?**

From CAF files (all 280kA)



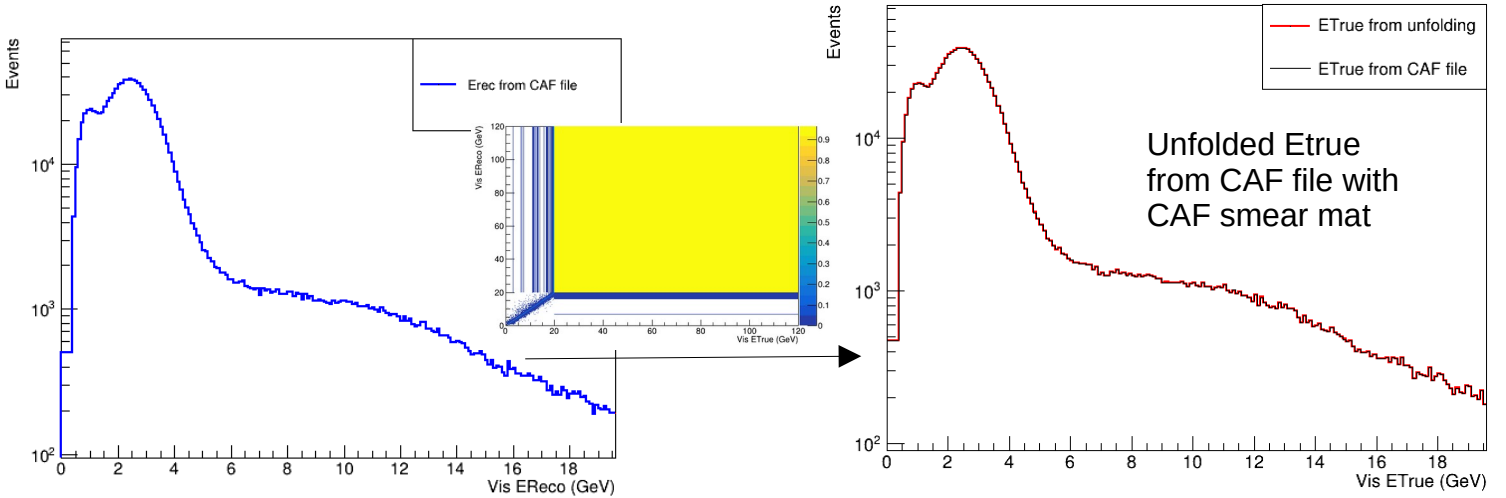


Events obtained from the smearing mat (→ProjectionY()) have very different Erec distribution

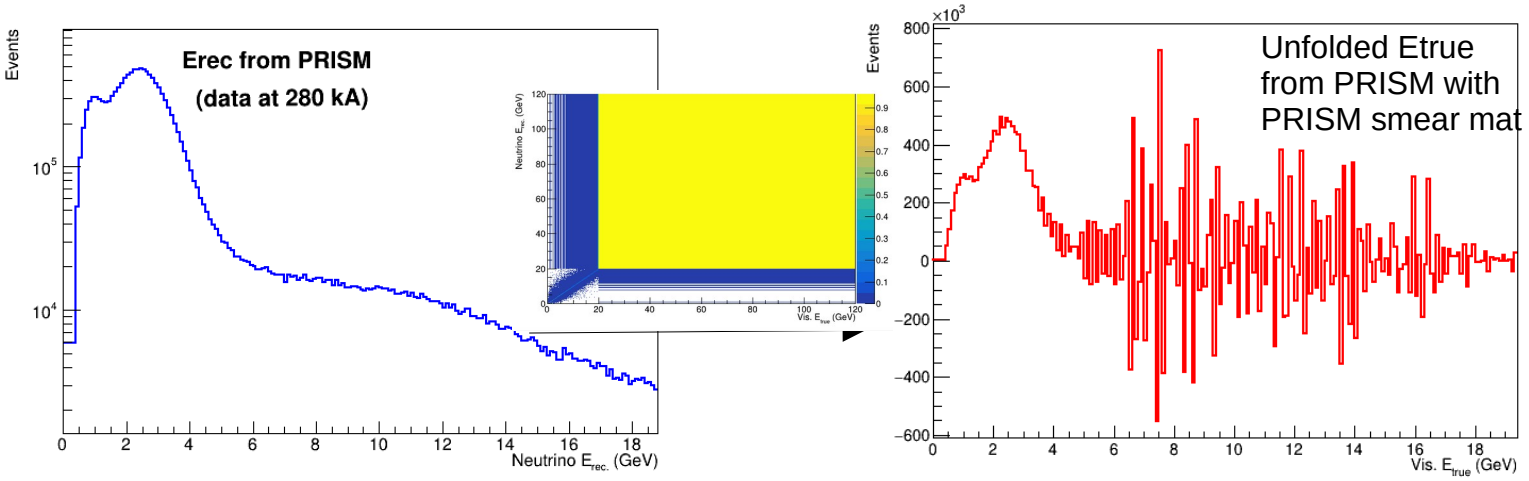
Only Selected Events: Events in Erec → unfold to Etrue (no efficiency correction)

- 280 kA

CAF file Only
(E rec, smear mat from CAFs)



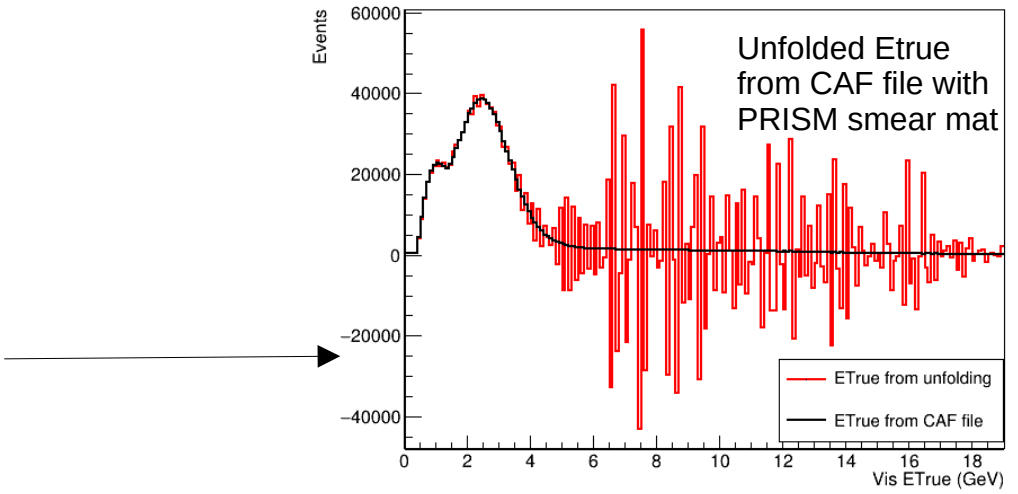
PRISM Only
(E rec, smear mat from PRISM)



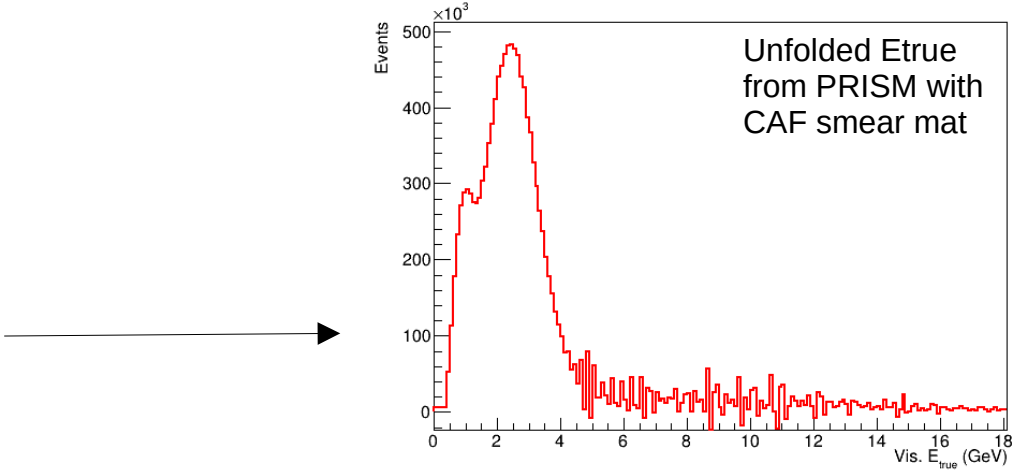
Only Selected Events: Events in Erec → unfold to Etrue (no efficiency correction)

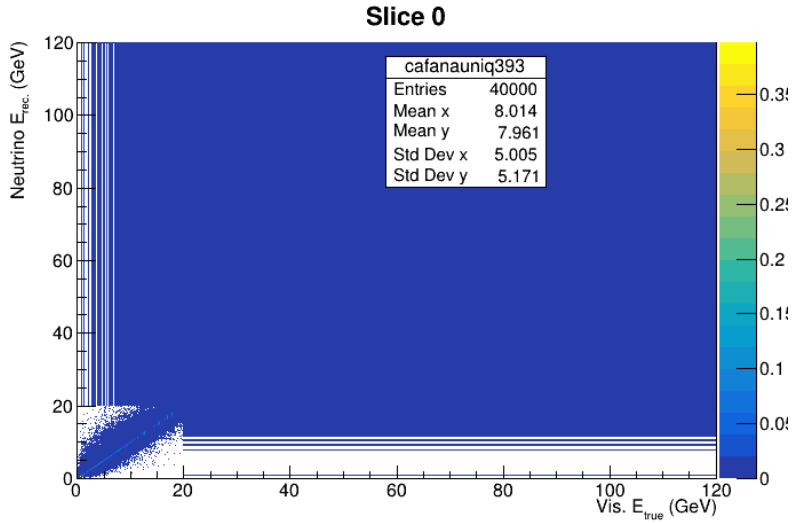
- 280 kA

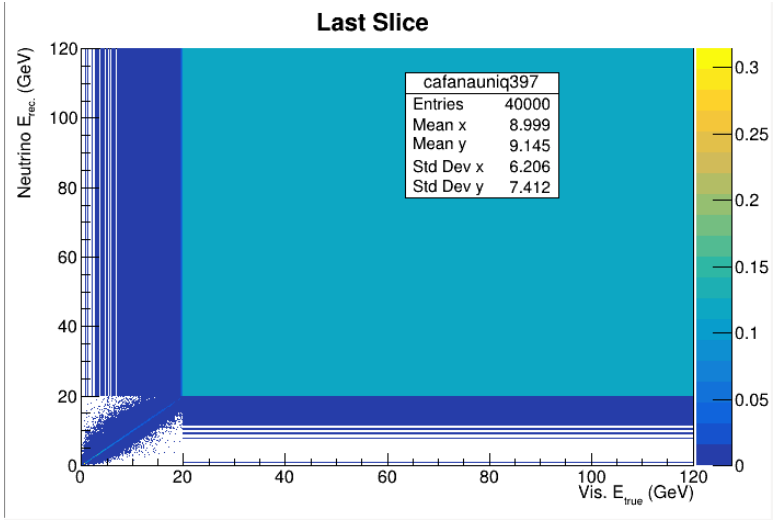
CAF file + PRISM smear mat (E rec - CAF, smear mat from PRISM)

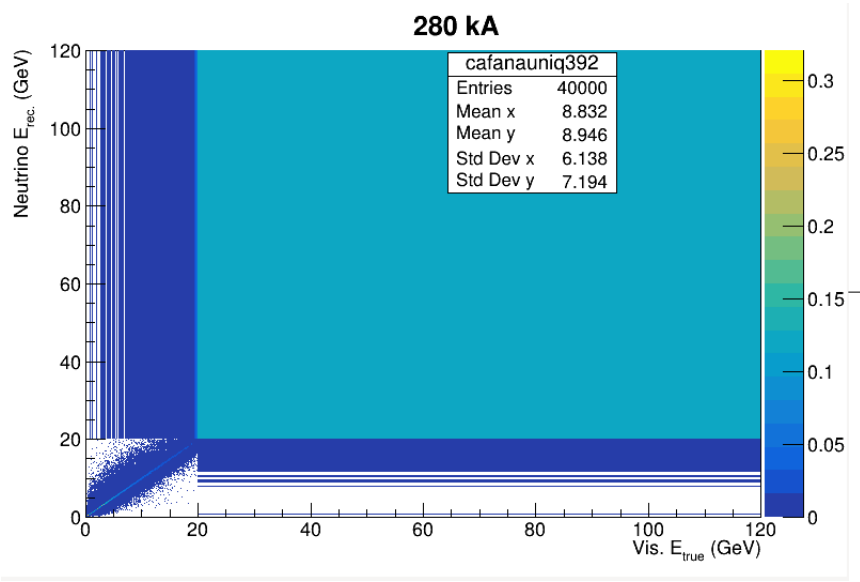


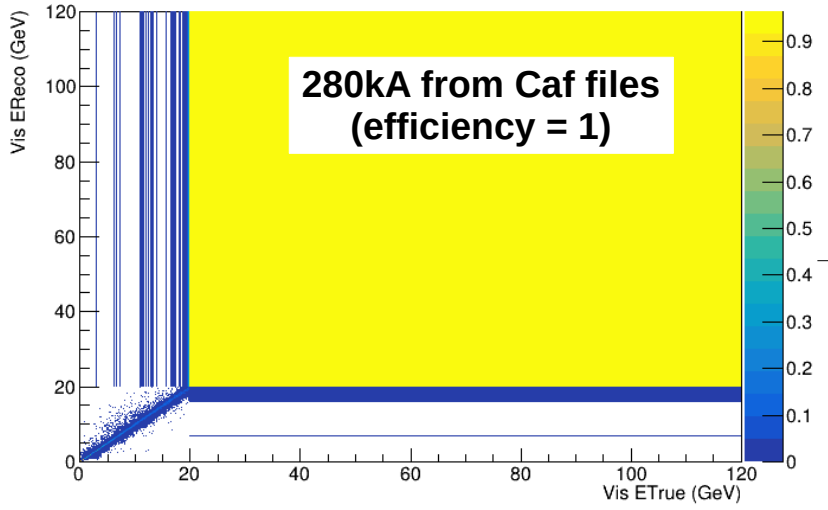
PRISM Only (E rec PRISM, smear mat from CAFs)





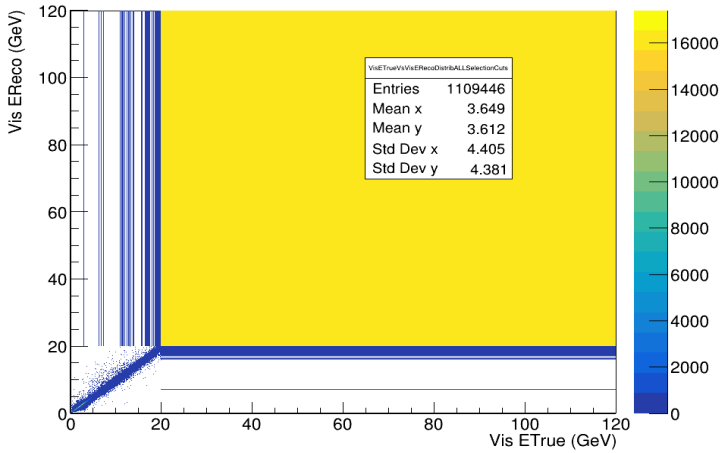




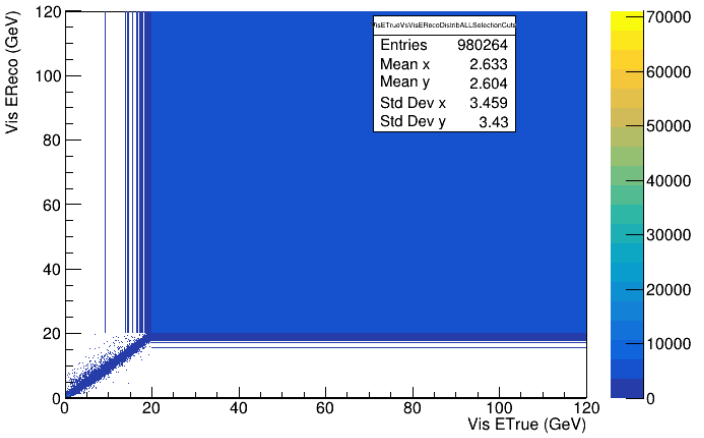


Should have entries at the same places (only value should vary)

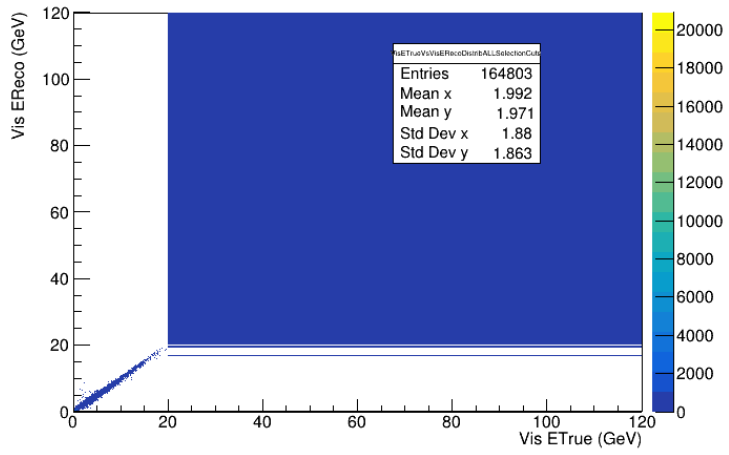
280 kA – Selected Events (non-normalized)



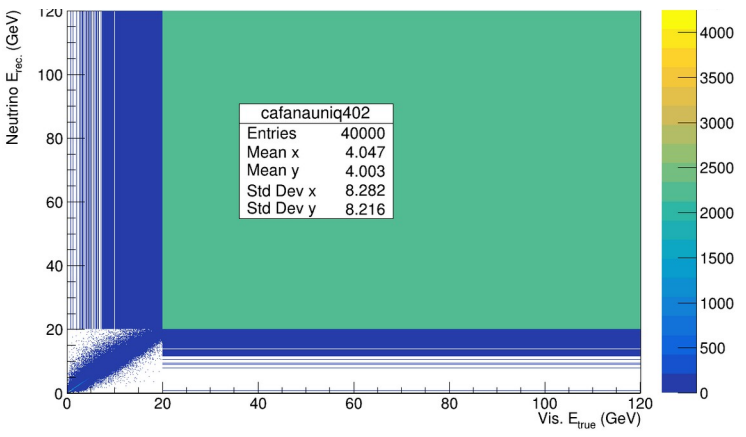
13.75 m OA – Selected Events (non-normalized)

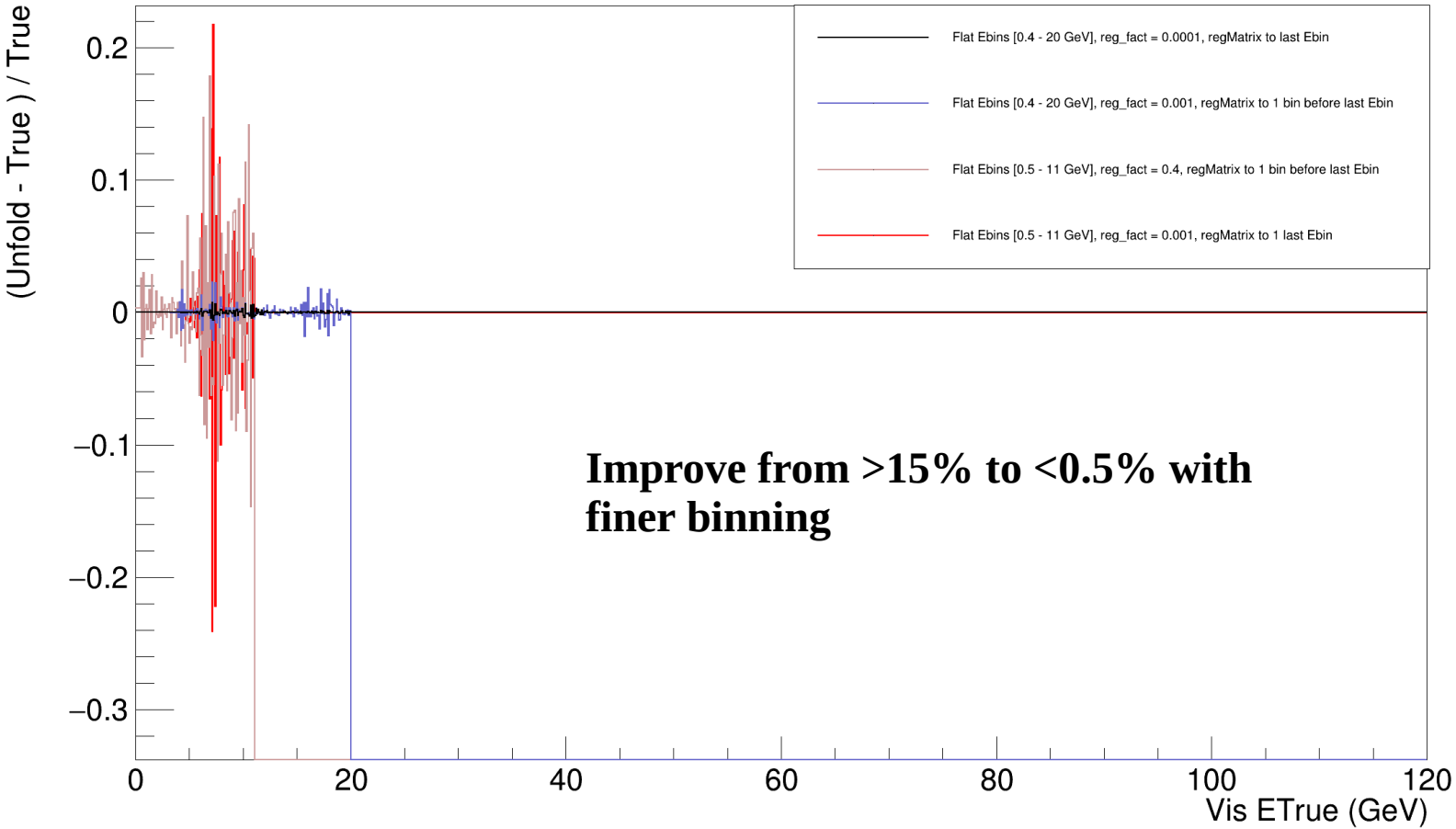


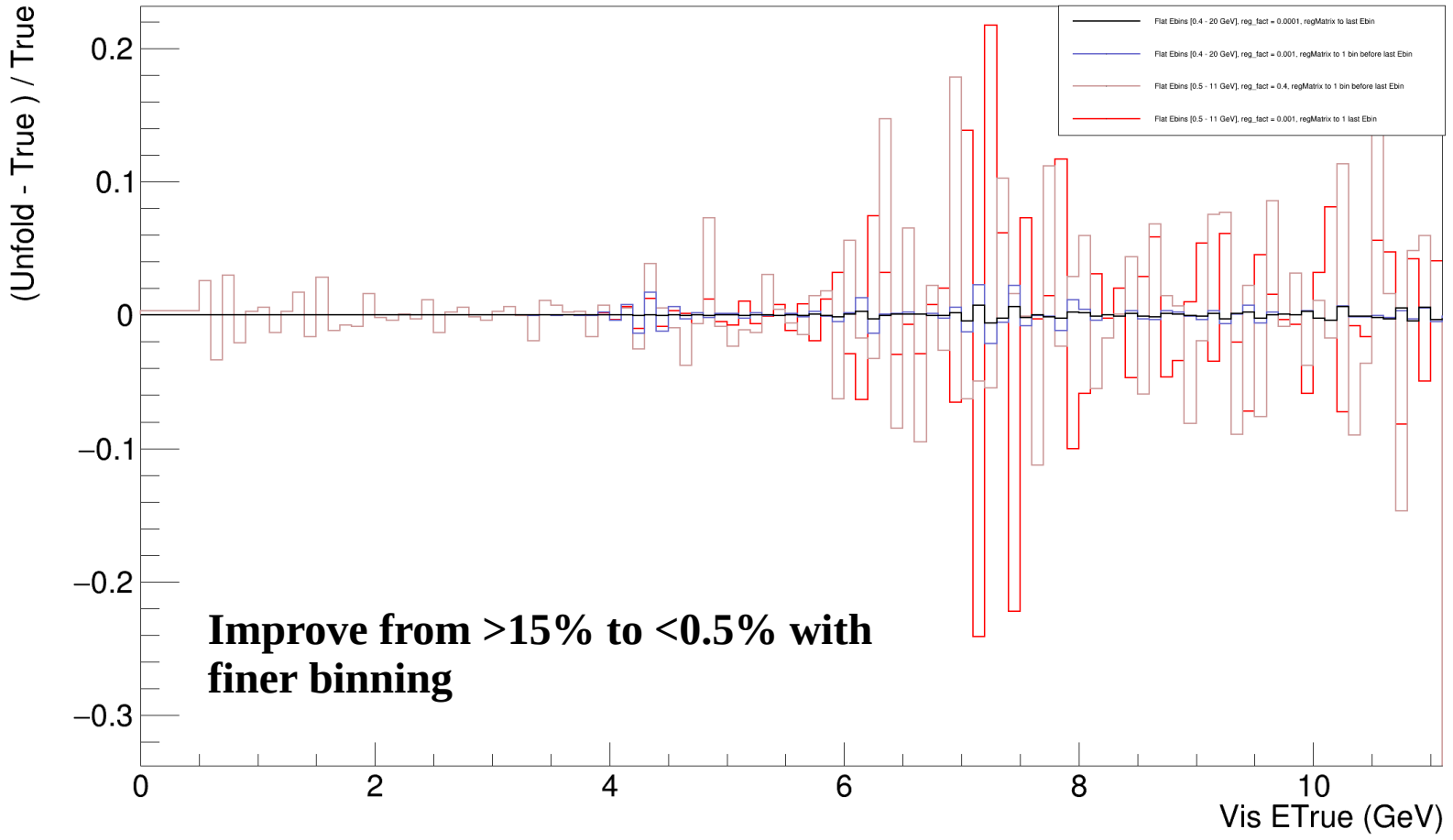
28.5 m OA – Selected Events (non-normalized)

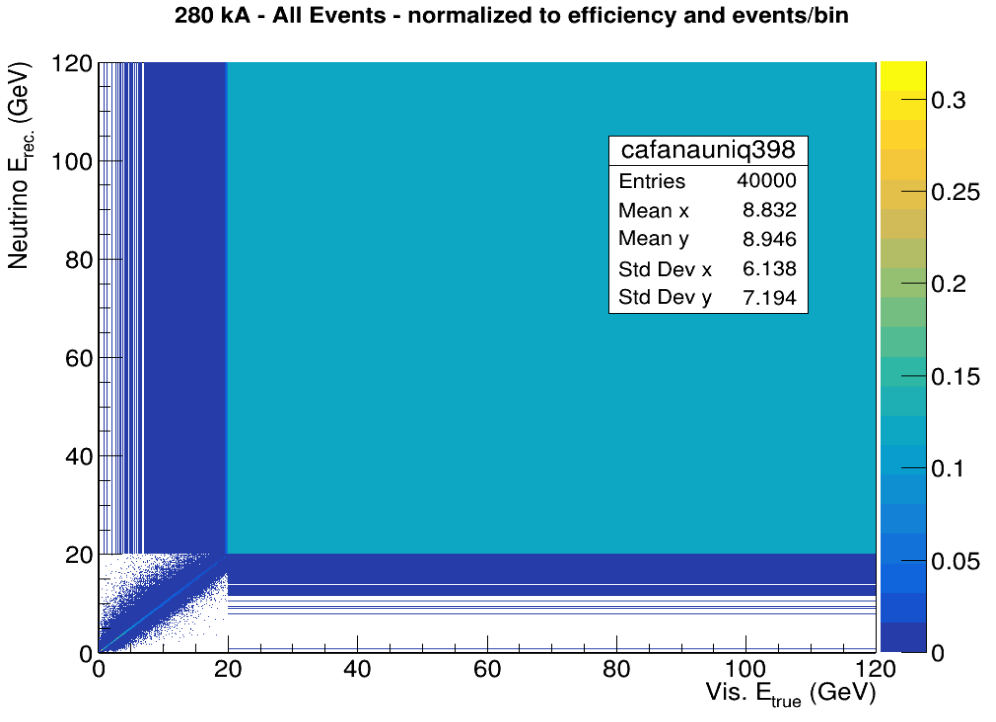


PRISM – smear Mat we start from at all OA positions (non-normalized)




(Unfold - True) / True
0.2
0.1
0
−0.1
−0.2
−0.3
0
20
40
60
80
100
120
Vis ETrue (GeV)
Flat Ebins [0.4 - 20 GeV], reg_fact = 0.0001, regMatrix to last Ebin
Flat Ebins [0.4 - 20 GeV], reg_fact = 0.001, regMatrix to 1 bin before last Ebin
Flat Ebins [0.5 - 11 GeV], reg_fact = 0.4, regMatrix to 1 bin before last Ebin
Flat Ebins [0.5 - 11 GeV], reg_fact = 0.001, regMatrix to 1 last Ebin
Improve from >15% to <0.5% with finer binning


(Unfold - True) / True
0.2
0.1
0
−0.1
−0.2
−0.3
0
2
4
6
8
10
Vis ETrue (GeV)
Flat Ebins [0.4 - 20 GeV], reg_fact = 0.0001, regMatrix to last Ebin
Flat Ebins [0.4 - 20 GeV], reg_fact = 0.001, regMatrix to 1 bin before last Ebin
Flat Ebins [0.5 - 11 GeV], reg_fact = 0.4, regMatrix to 1 bin before last Ebin
Flat Ebins [0.5 - 11 GeV], reg_fact = 0.001, regMatrix to 1 last Ebin
Improve from >15% to <0.5% with finer binning


280 kA - All Events - normalized to efficiency and events/bin
cafanauniq398
Entries 40000
Mean x 8.832
Mean y 8.946
Std Dev x 6.138
Std Dev y 7.194
Neutrino E_rec. (GeV)
Vis. E_true (GeV)
0
20
40
60
80
100
120
0.3
0.25
0.2
0.15
0.1
0.05