4TH DUNE ND WORKSHOP, FERMILAB
2018-03-23

LUKE PICKERING, M. WILKING, C. VILELA, D. DOUGLAS

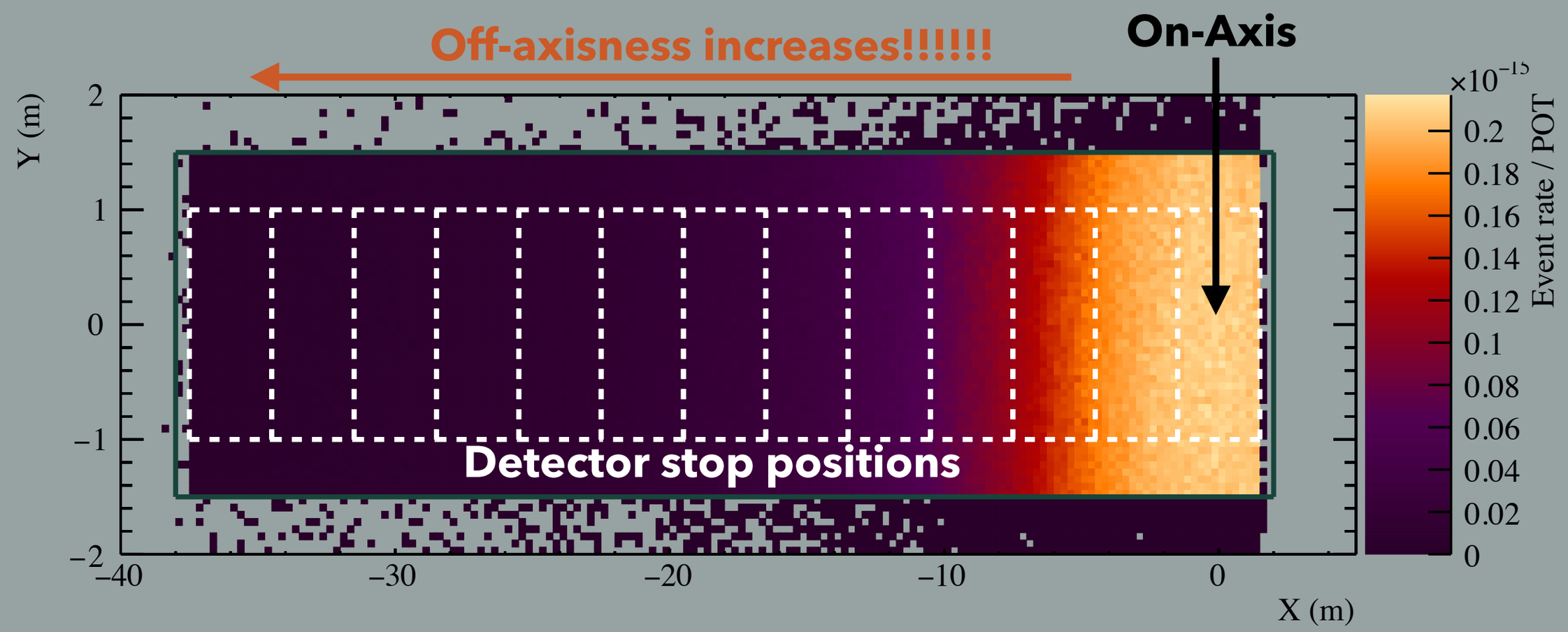
PROGRESS TOWARDS A PRISM ANALYSIS

MICHIGAN STATE UNIVERSITY

THIS TALK

- Simulation details
- Anatomy of a PRISM oscillation analysis
  - Flux fits
  - Near detector observations
  - Backgrounds
  - **Near/Far efficiency correction**
  - Far detector prediction
  - Systematic uncertainties

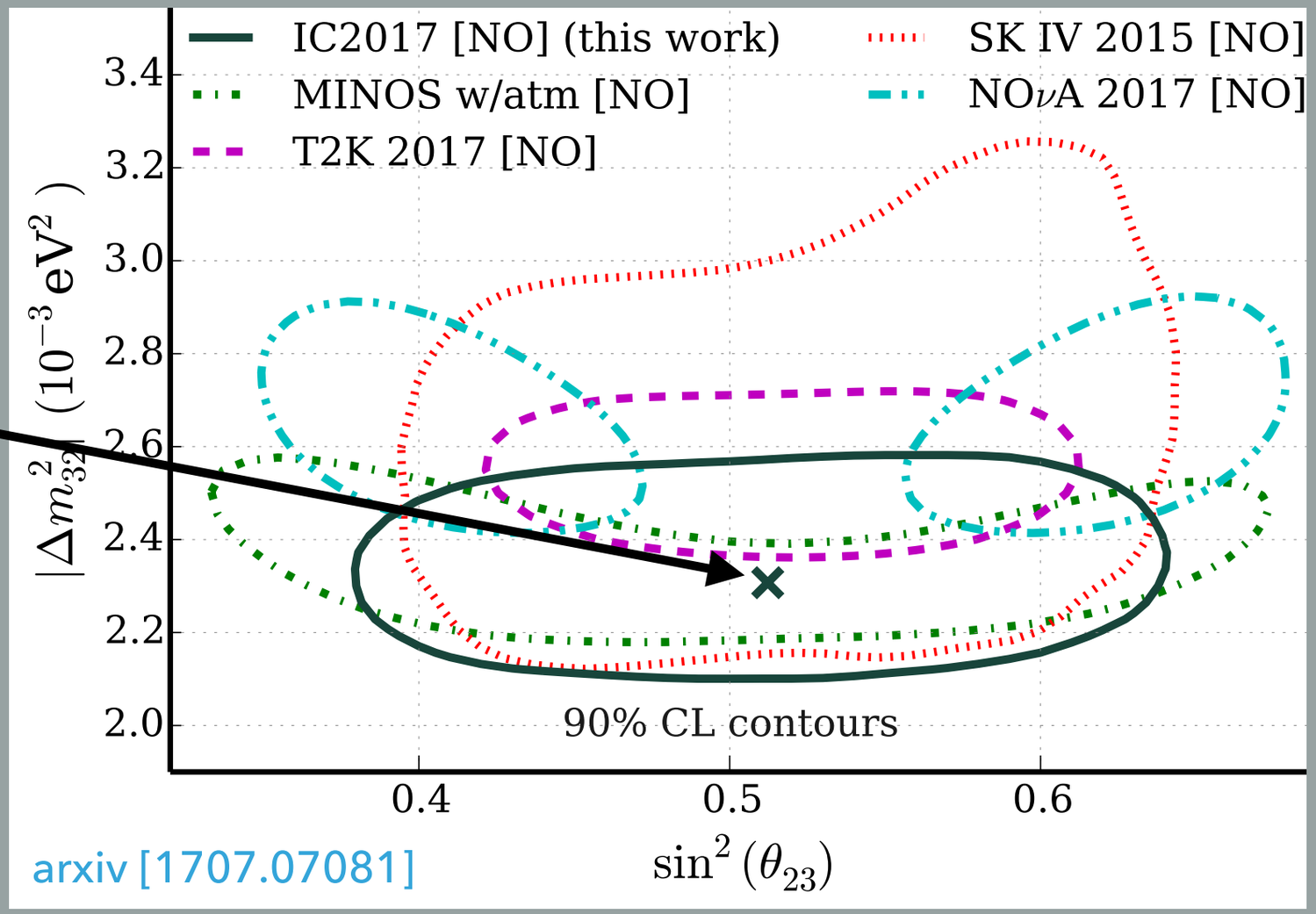
SIMULATION DETAILS – RECAP



- Generated:
  - FD: 1E23 POT data (~91 years...)
  - ND: 1.6E21 POT-equivalent data (~1.5 years)

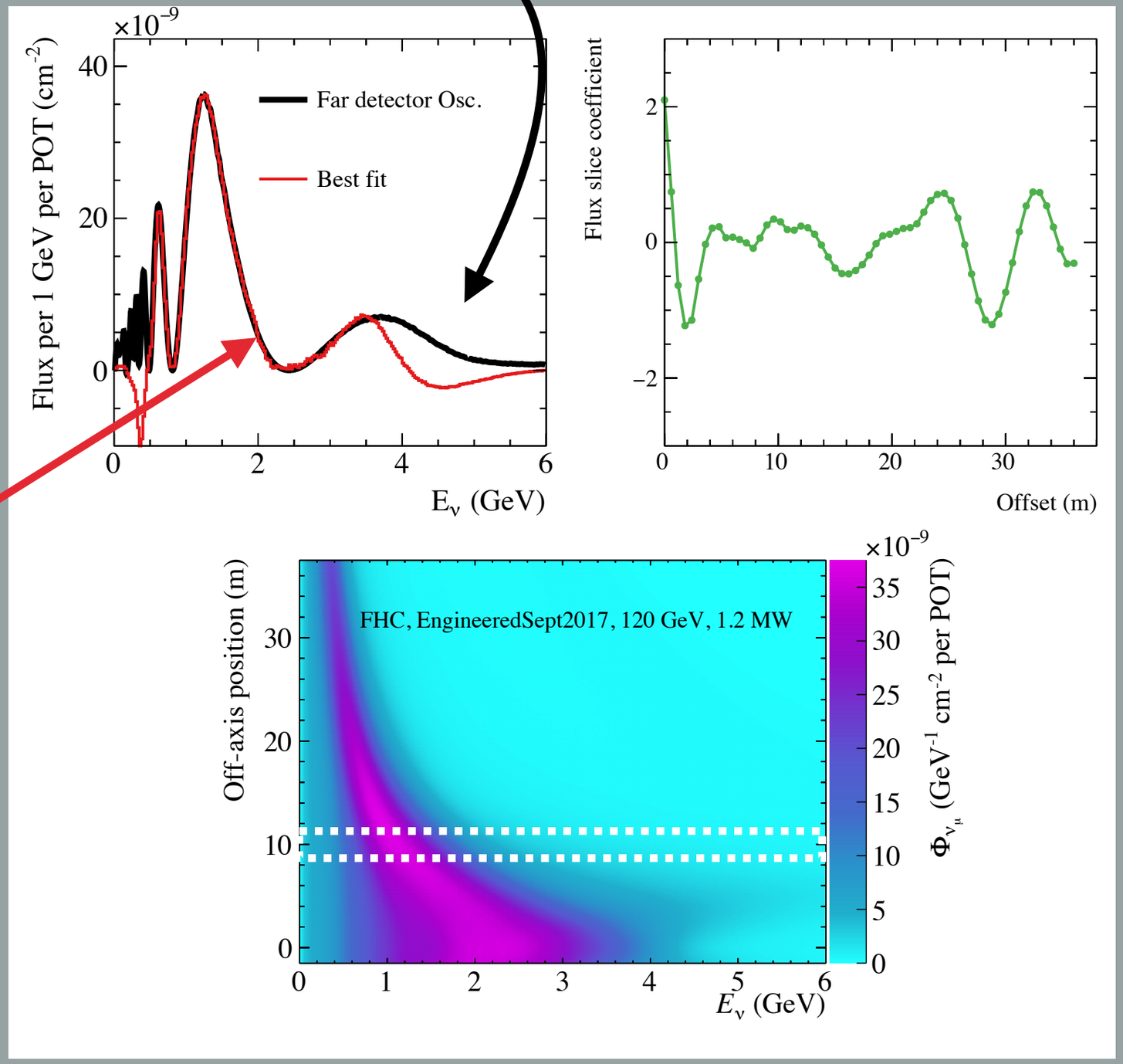
STEP 1: CHOOSE A SET OF OSCILLATION PARAMETERS

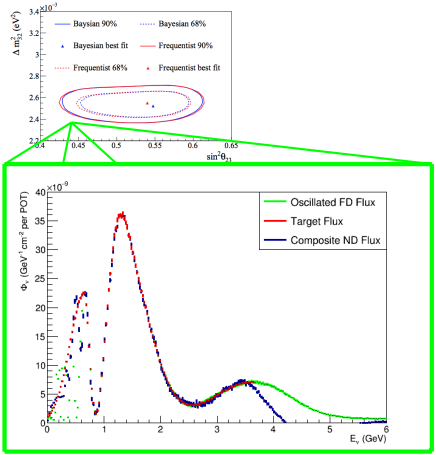
- Avoid implications of favouritism:
  - Choose **IC2017[NO]** parameters

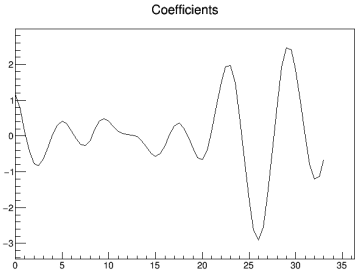


STEP 2: FITTING THE FAR DETECTOR FLUX

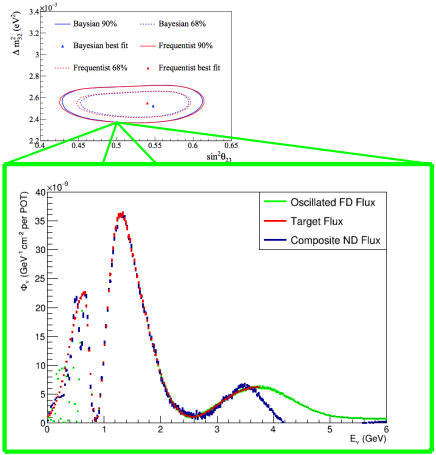
- Make **oscillated FD prediction** with your parameter choice.
- Use linear combinations of **near detector flux slices** to **build this FD flux prediction**.
- Obtain **coefficients** to build **linear sum of any near detector observable**.

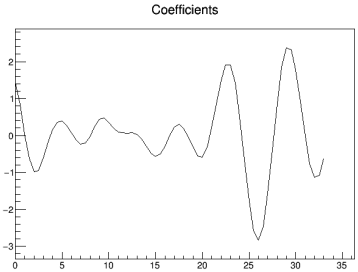






- $\Delta m^2_{23} = 0.0024$
- $\sin^2\theta_{23} = 0.43$





- $\Delta m^2_{23} = 0.0024$
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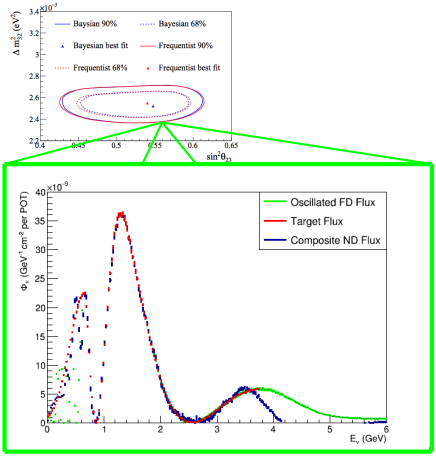
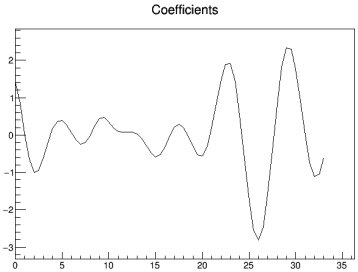
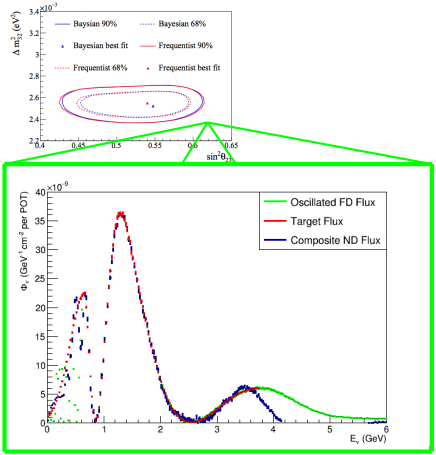
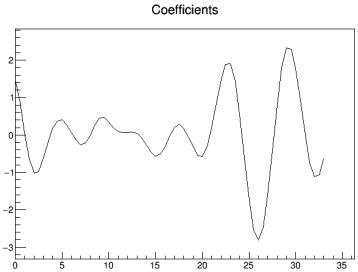




- $\Delta m^2_{23} = 0.0024$
- $\sin^2\theta_{23} = 0.556666666667$





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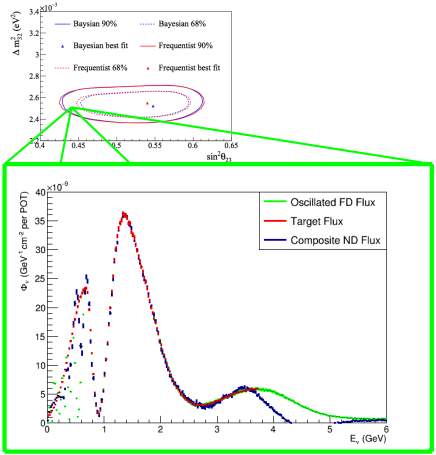
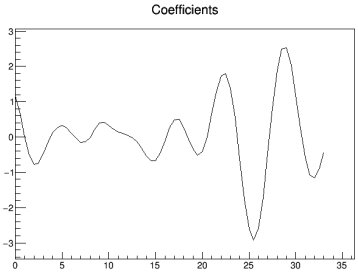
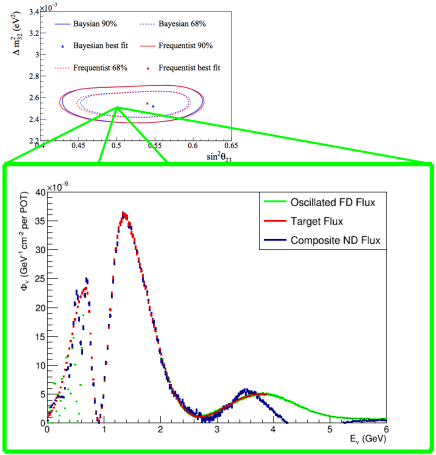
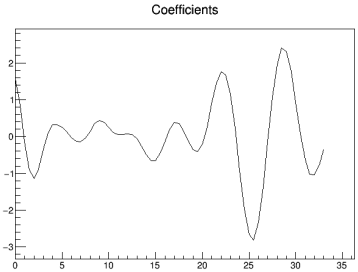




- $\Delta m^2_{23} = 0.00253333333333$
- $\sin^2\theta_{23} = 0.43$





- $\Delta m^2_{23} = 0.00253333333333$
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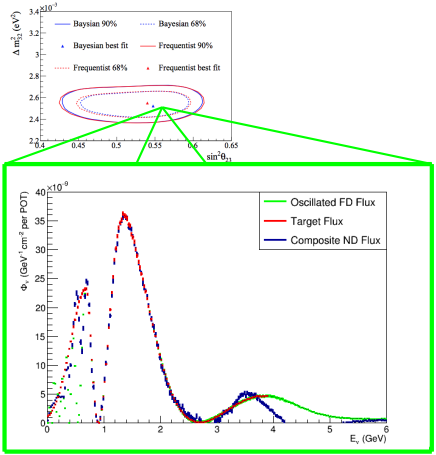

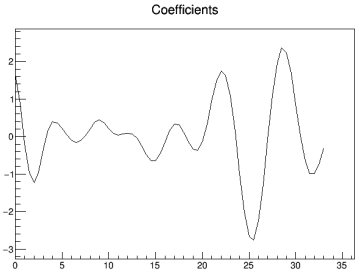

- $\Delta m^2_{23} = 0.00253333333333$
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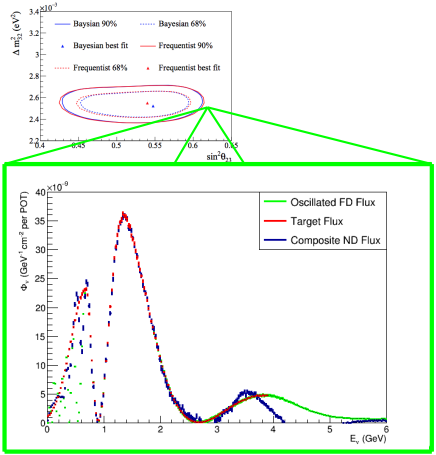

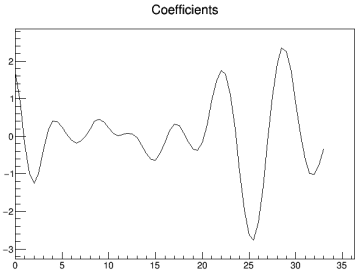

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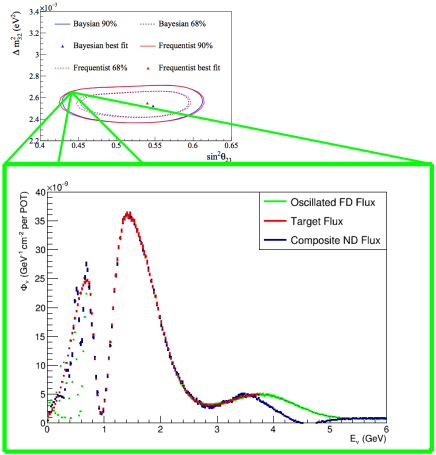

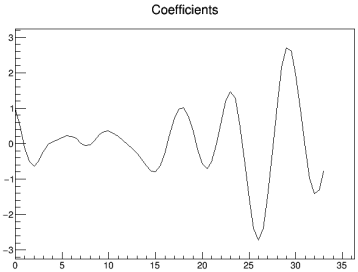

- $\Delta m^2_{23} = 0.00266666666667$
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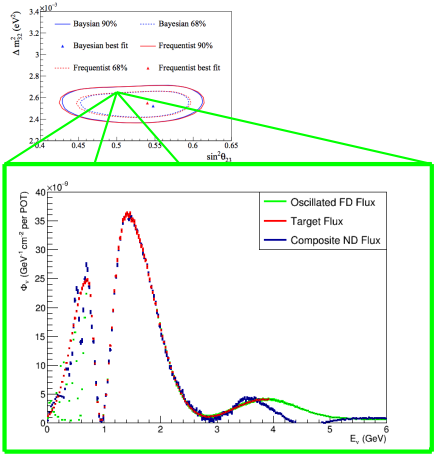

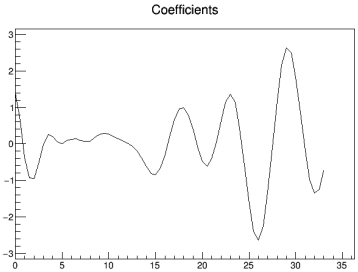

- $\Delta m^2_{23} = 0.00266666666667$
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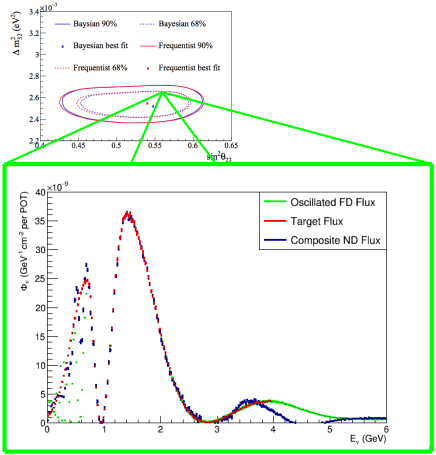

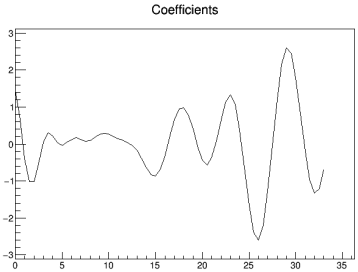

- $\Delta m^2_{23} = 0.00266666666667$
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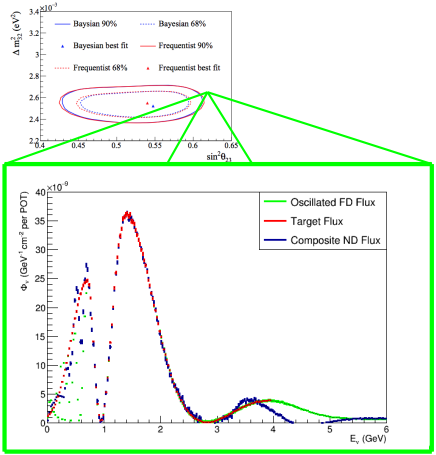

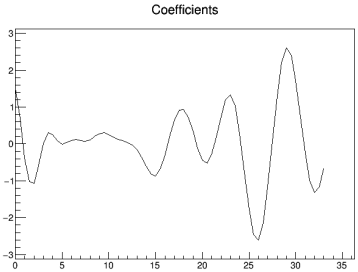

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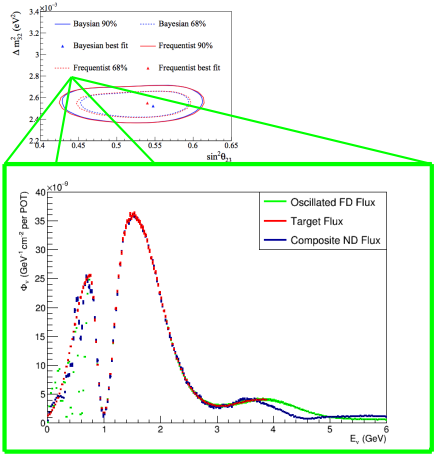
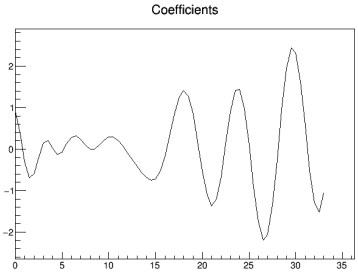
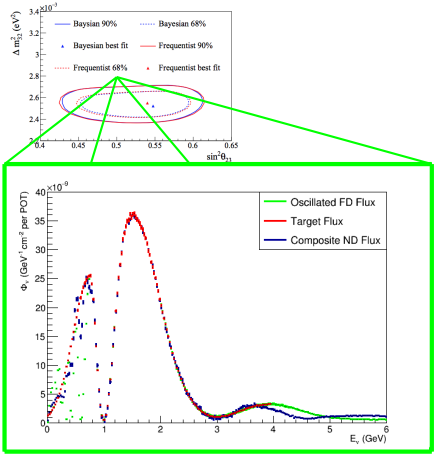
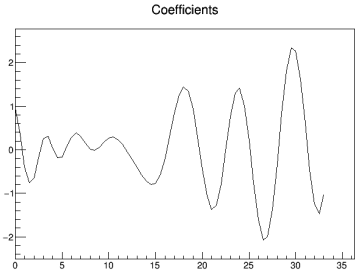




- $\Delta m^2_{23} = 0.0028$
- $\sin^2\theta_{23} = 0.43$





- $\Delta m^2_{23} = 0.0028$
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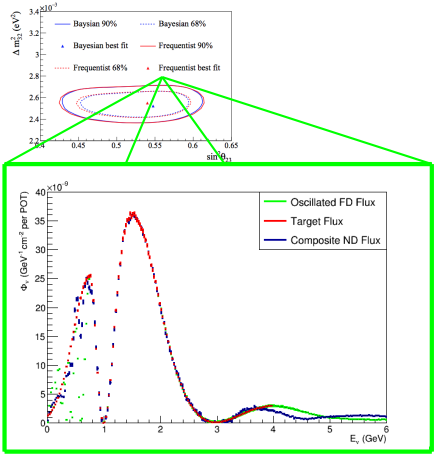

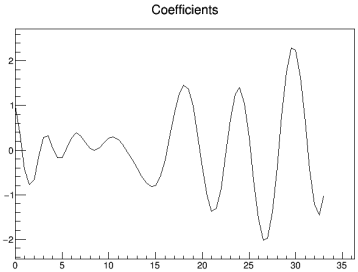

- $\Delta m^2_{23} = 0.0028$
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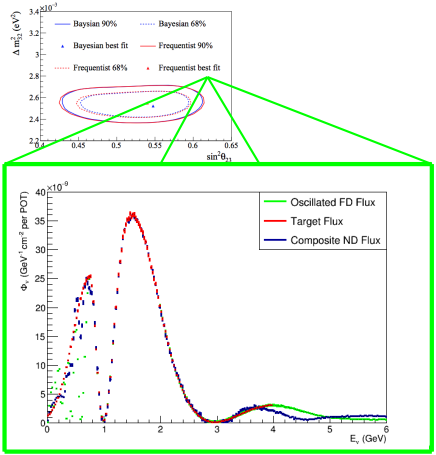
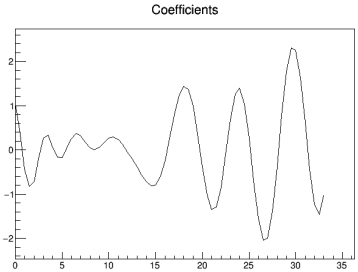
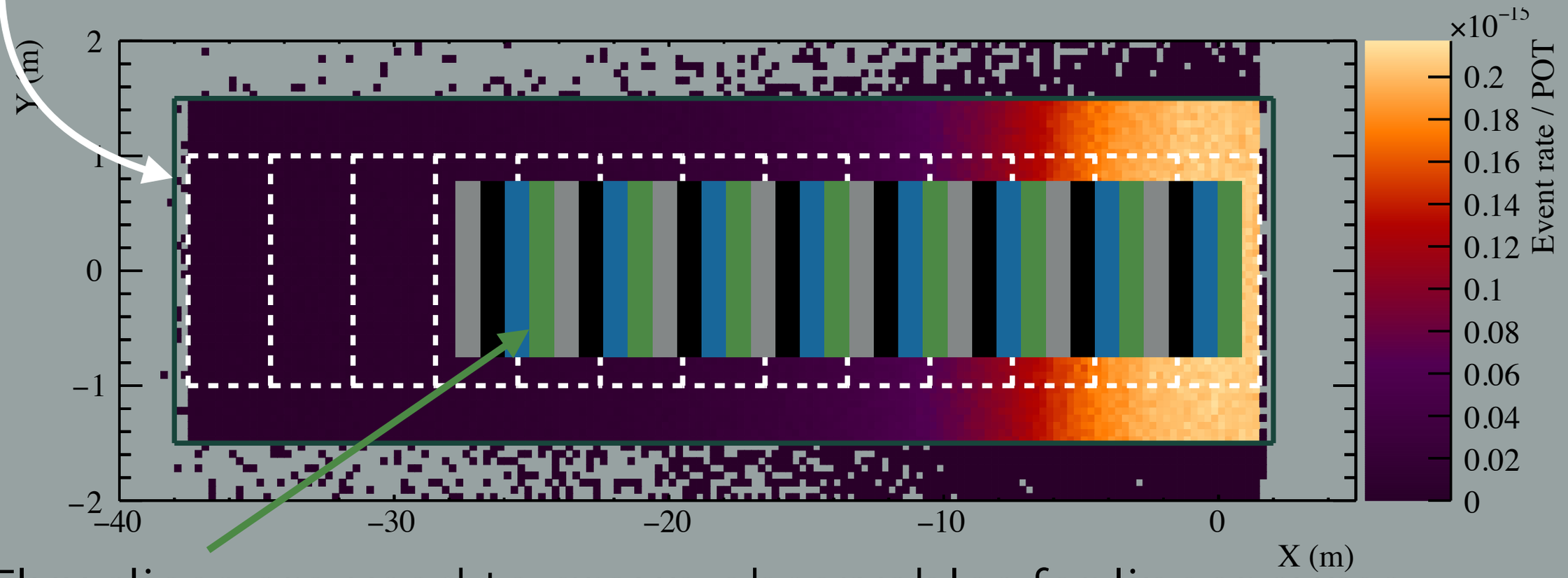




- $\Delta m^2_{23} = 0.0028$
- $\sin^2\theta_{23} = 0.62$

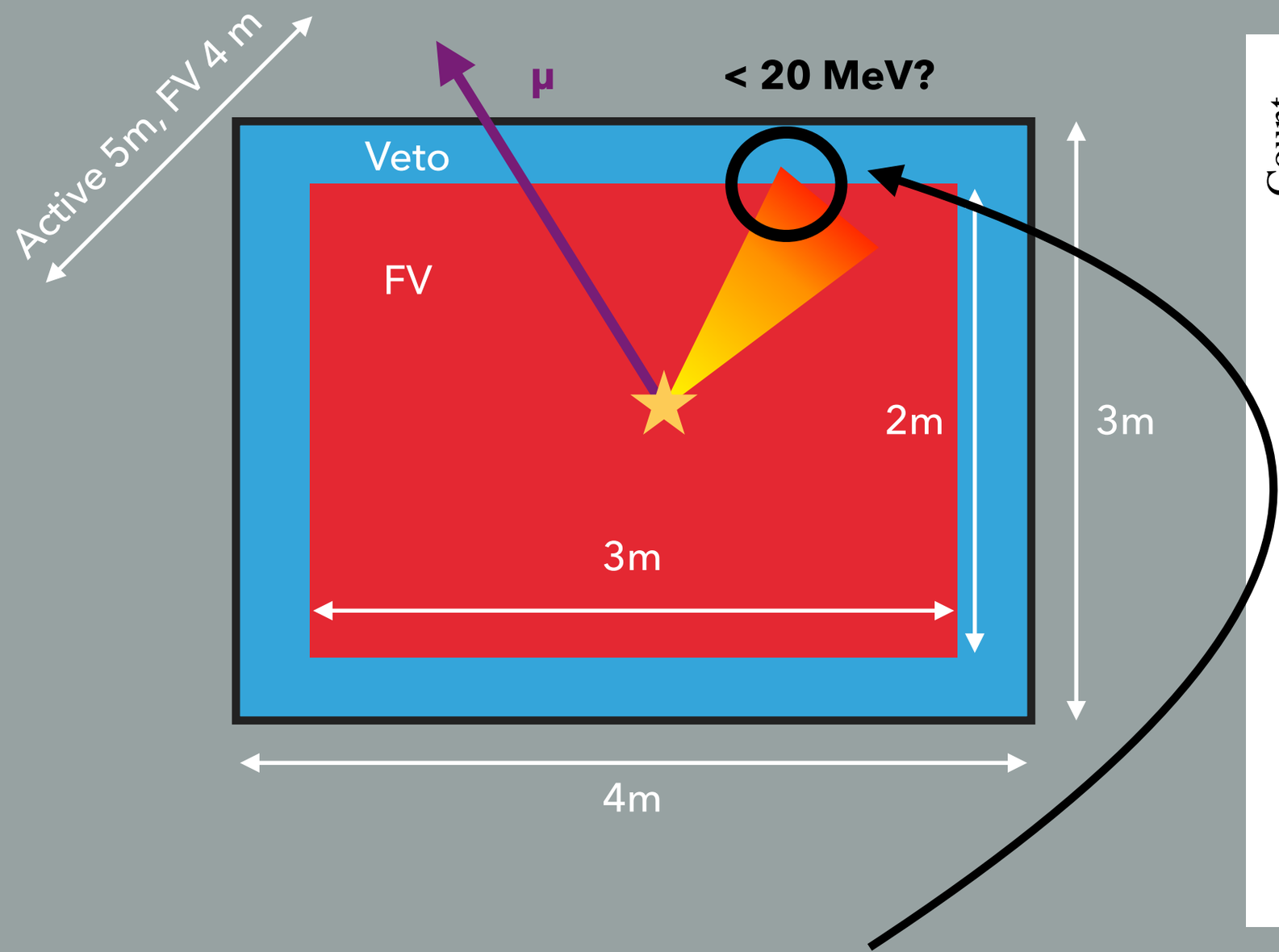
ASIDE: STOPS VS. FLUX SLICES

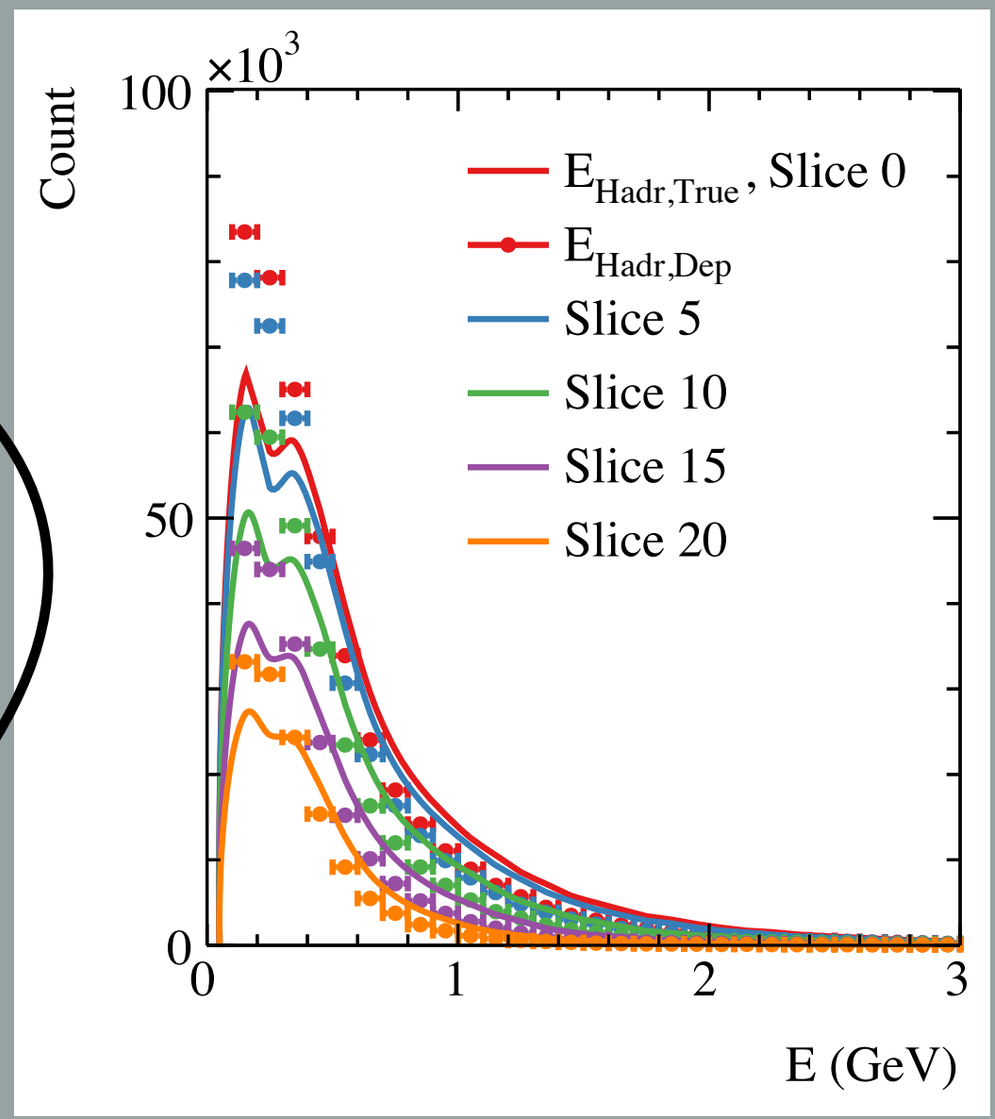
- **Detector stops** are set by a run plan:
  - Dictate acceptance coverage as a function of off-axis position.



- Flux slices are used to group observables for linear sums:
  - **Here**: Using 60cm wide flux windows in flux fits and near detector observable selections.
  - Results in 60 flux slice samples used in linear combinations.

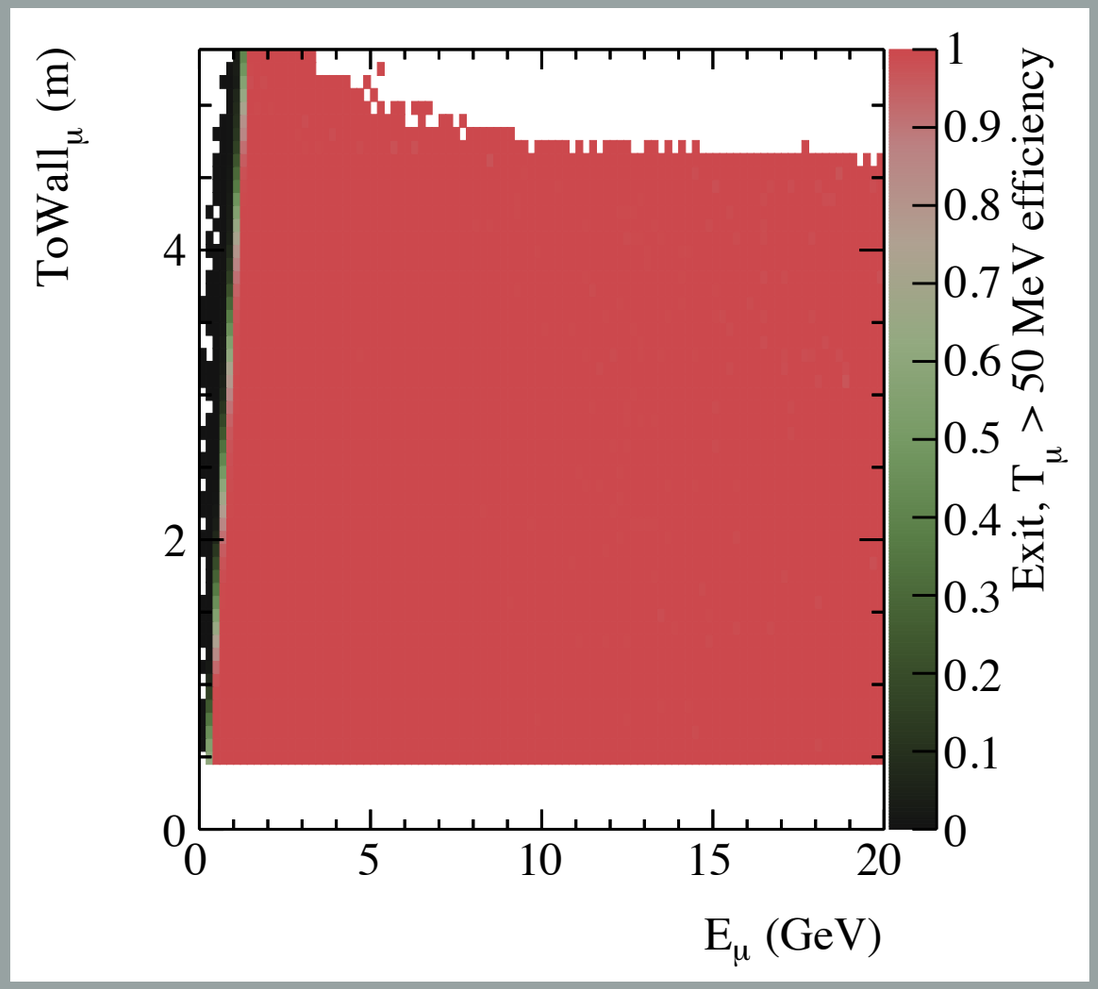
STEP 3: NEAR DETECTOR OBSERVATIONS – HADRON SHOWERS

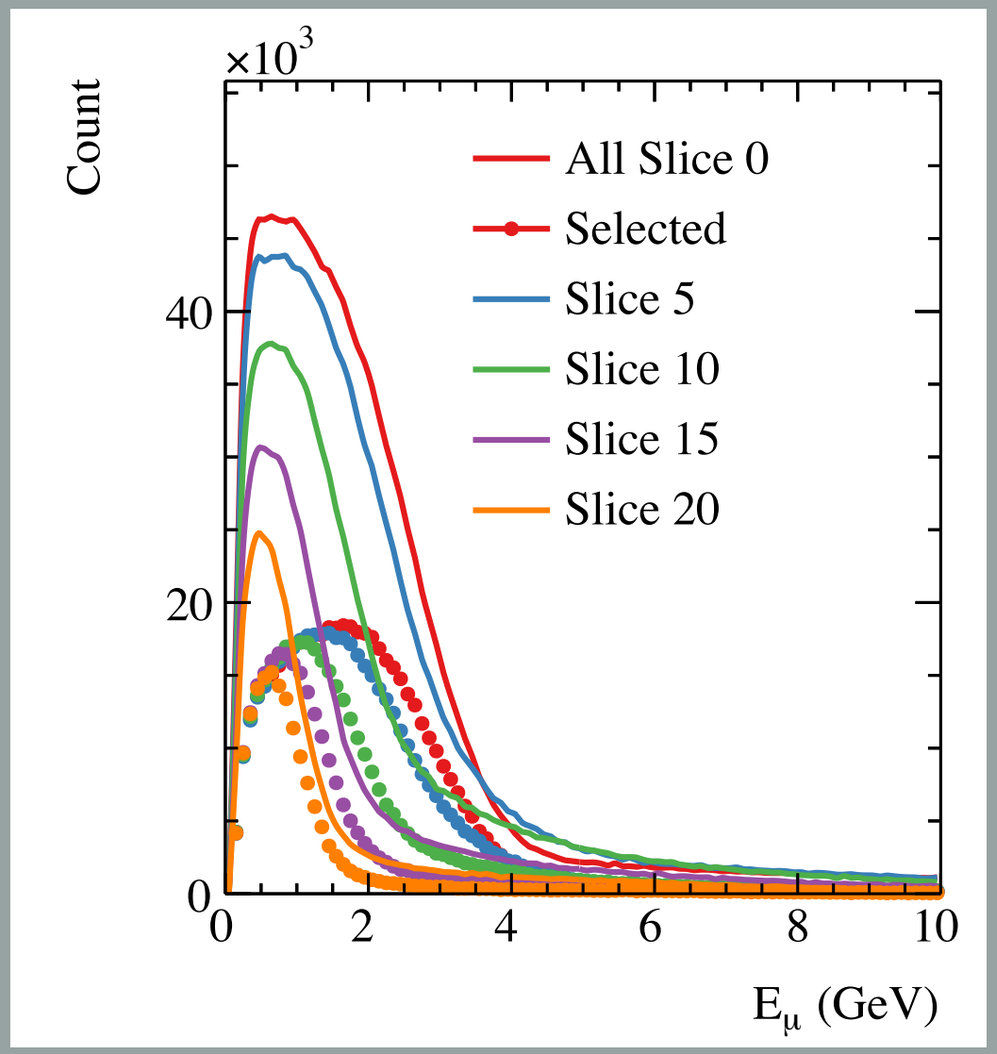




- Select events with contained hadronic showers:
  - **Here**: Energy deposited in veto volume < 20 MeV.

STEP 3: NEAR DETECTOR OBSERVATIONS – MUONS



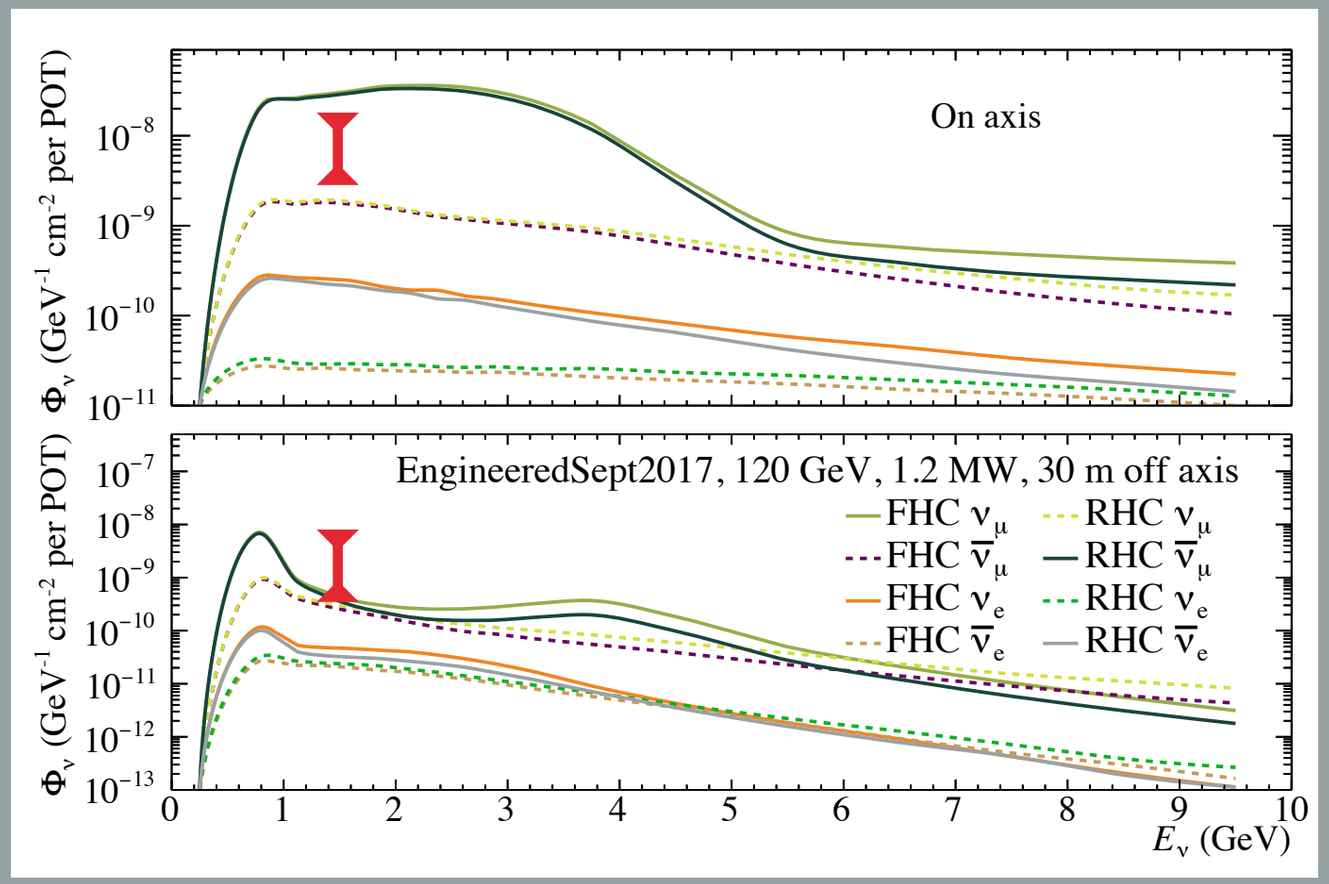


- Selection shape purely from correlation with hadronic cut:
  - low Eμ ➔ Low elasticity -> more hadronic shower energy -> more vetos.
- **Now**: Assuming perfect muon selection and reconstruction.
- **Future**: Use MPT/MIND to apply sign-selection and reconstruction effects to exiting muons.

USING THE ND DATA

- Using linear sum of near detector observables can build a prediction of far detector observables up to:
  - Flux error => obtain ‘wrong’ linear sum coefficients
    - **Last meeting**: Shown to be a small effect for focussing uncertainties.
    - **Next step**: hadron production uncertainties — Experience from NuPRISM suggests that this will unlikely be a significant problem.
  - Background differences Near/Far and On/Off axis.
  - **Efficiency differences Near/Far.**

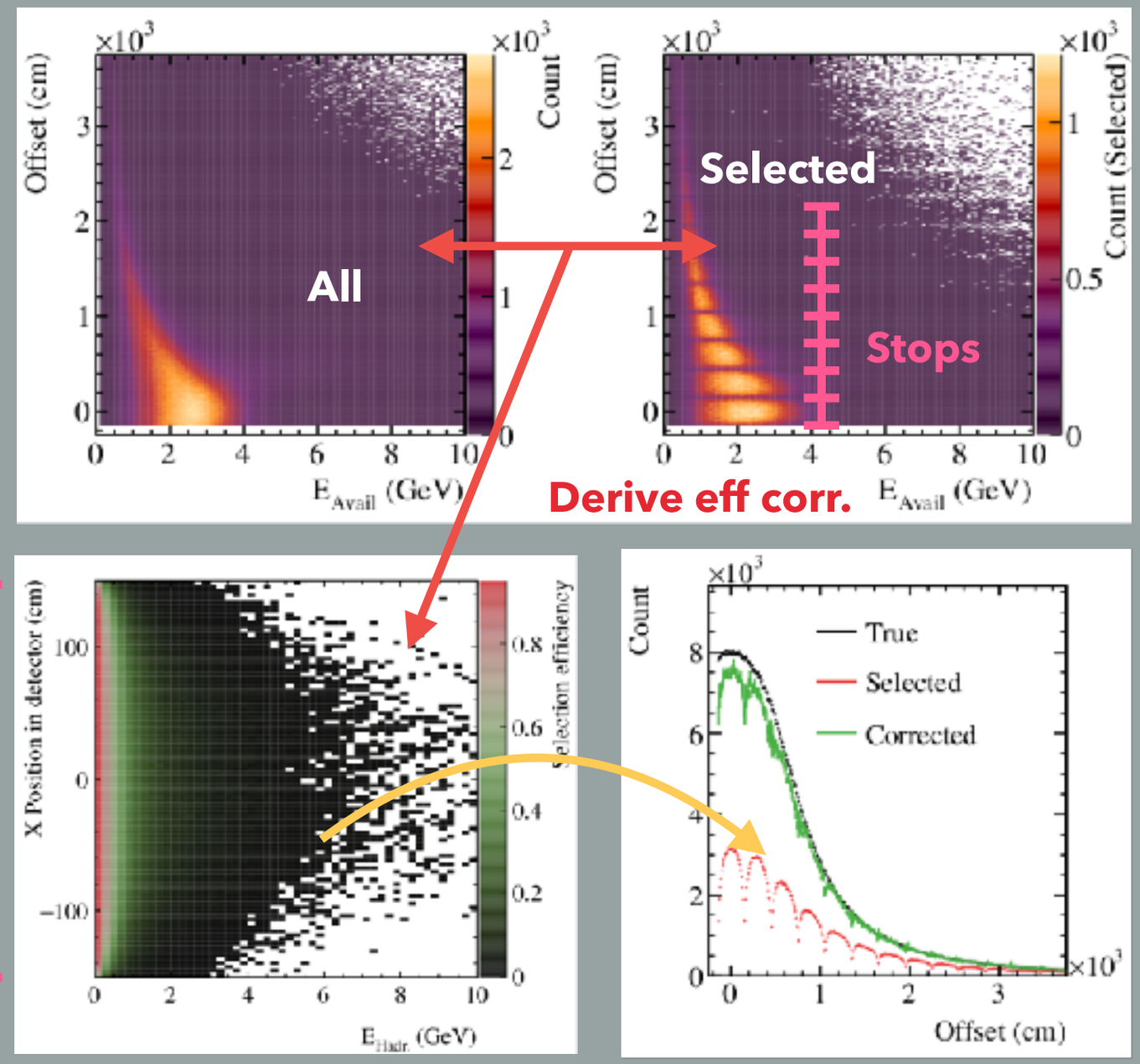
STEP 4: BACKGROUNDS — REMOVAL



- ***e.g.*** **Wrong-sign background** changes as a function of off-axis angle:
  - Subtract background from each ND observable.
- Other backgrounds. e.g. NC 1Hard Charged Pion, might look like a CC event.
- **Now**: Only use true CC muon neutrino interactions — no subtraction.
- **Future**: Sources of background identified, selected, subtracted — Hard to do effectively without reconstruction.

EFFICIENCY CORRECTIONS - MODEL DEPENDENCE

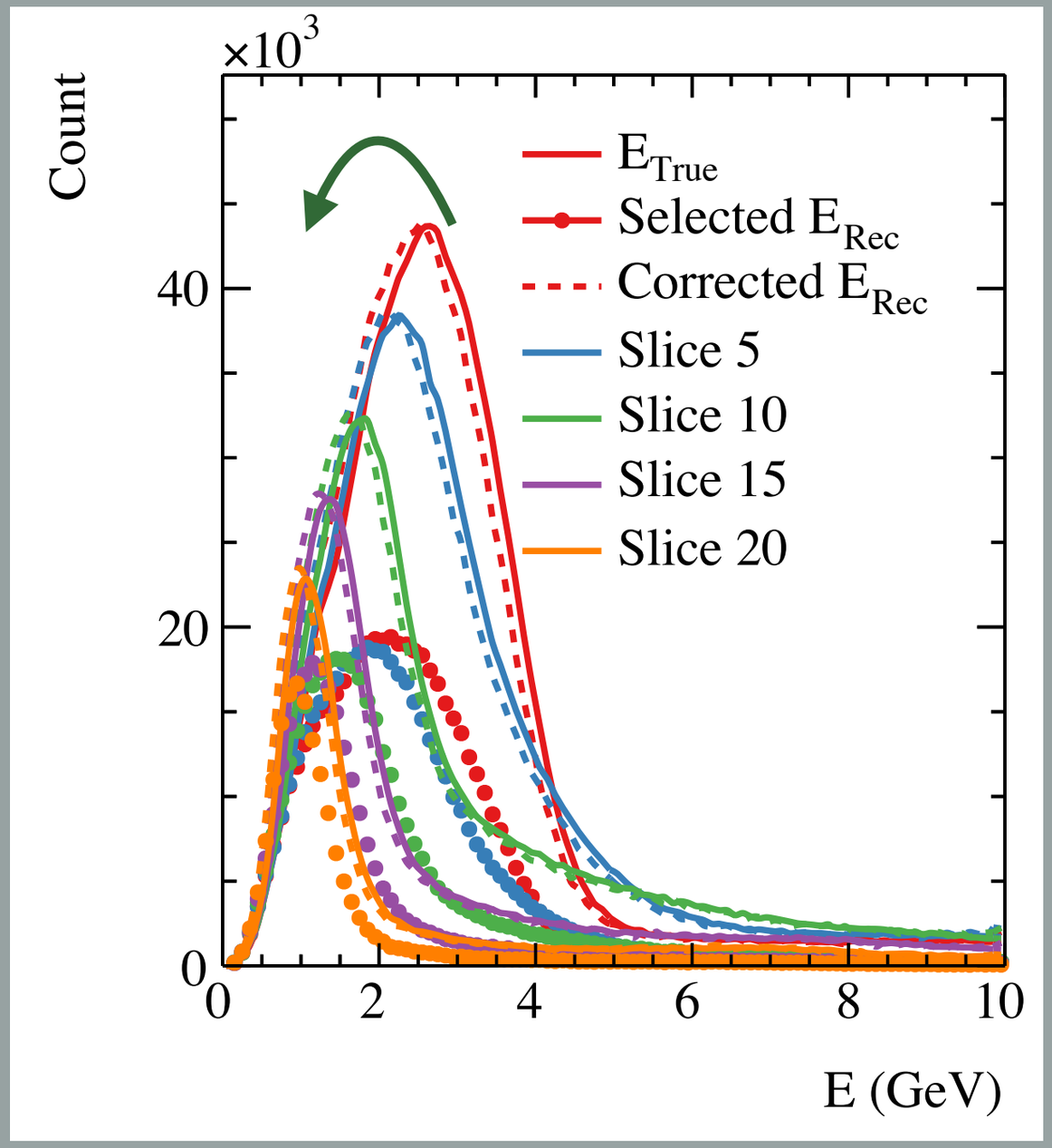
- Goal is to avoid strong model assumptions in the **efficiency correction**:
  - **True for any ND analysis.**
- Work on a **geometric efficiency** correction is on-going (c.f. Chris' talk yesterday).
  - Involved problem, beyond April/May timescale.



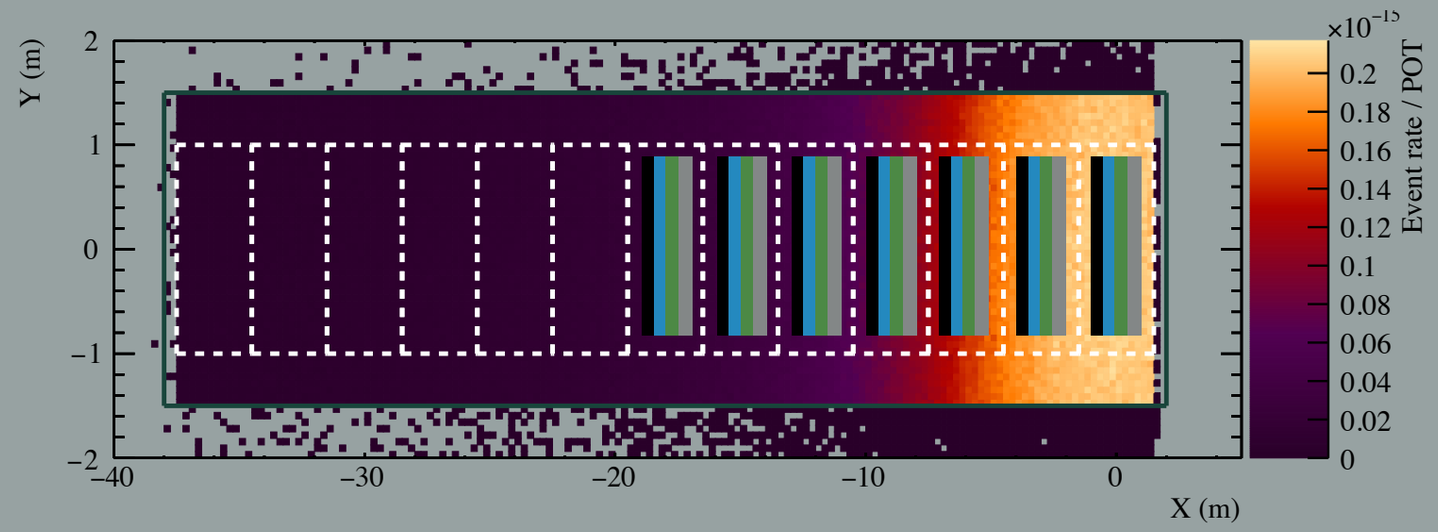
Dumb attempt to correct in true hadronic energy – not good enough

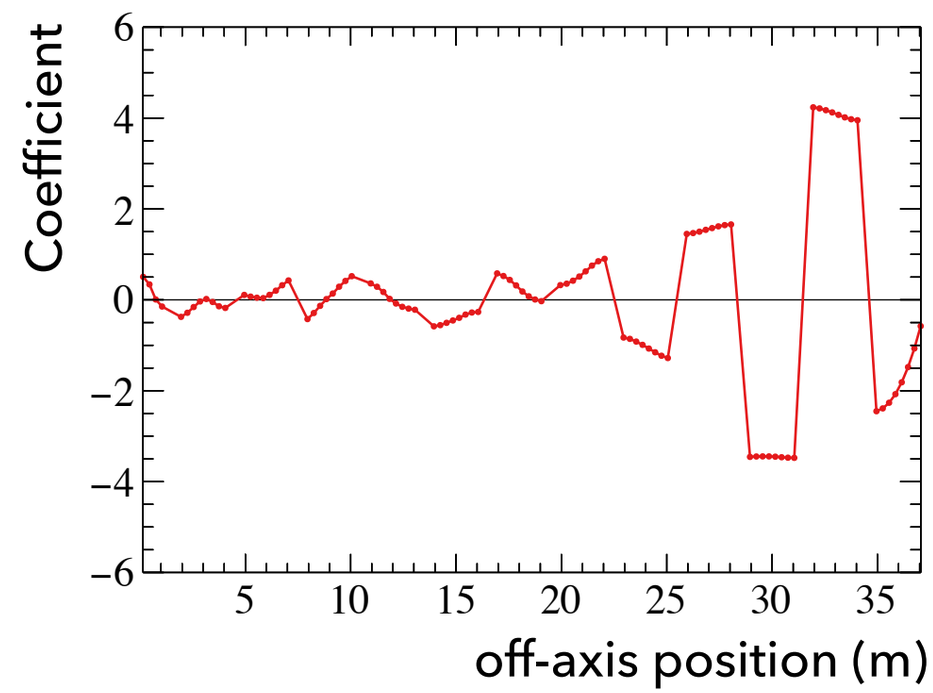
EFFICIENCY CORRECTIONS - A TOY

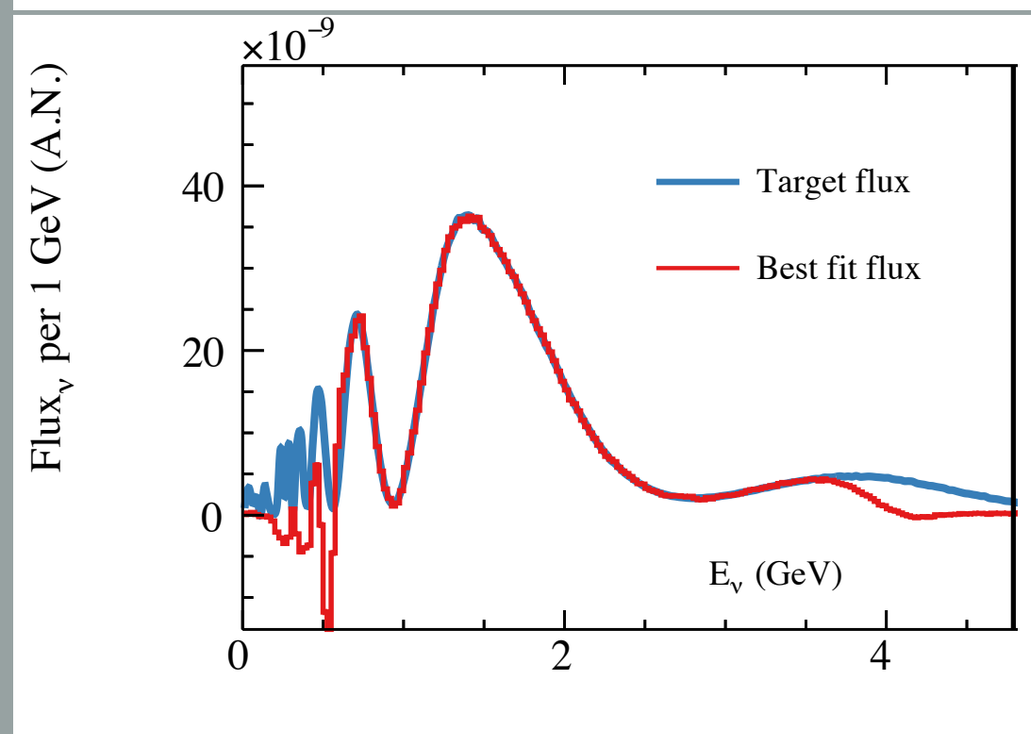
- **Now**: use perfect efficiency correction in EAvail = Eμ + TNuc. + EOther.
- Preserves ERec to Eν **feed down**.
- **Future**: Off-axis strategies to reduce sensitivity to model assumptions in efficiency correction.



EFFICIENCY CORRECTIONS - FEWER STOPS

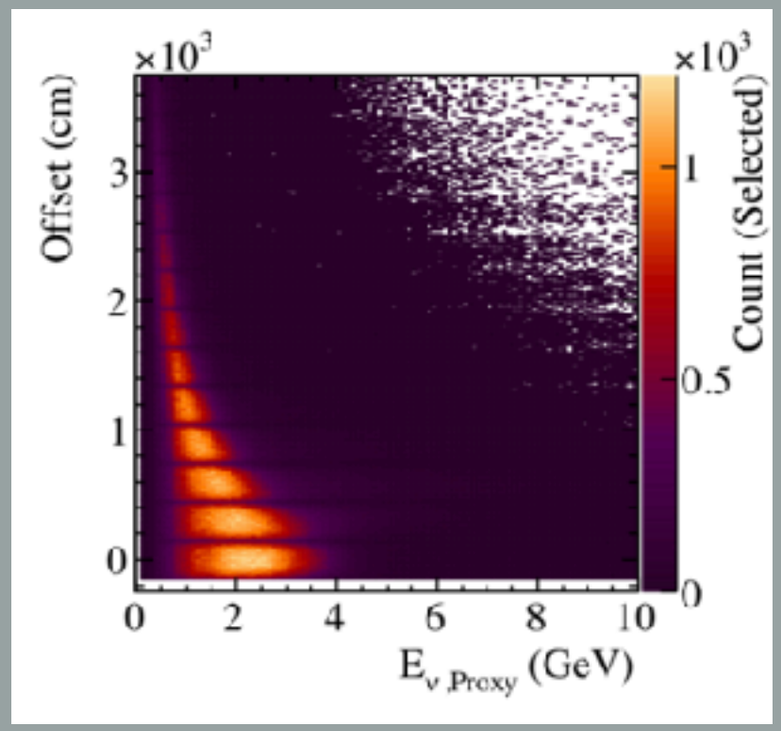




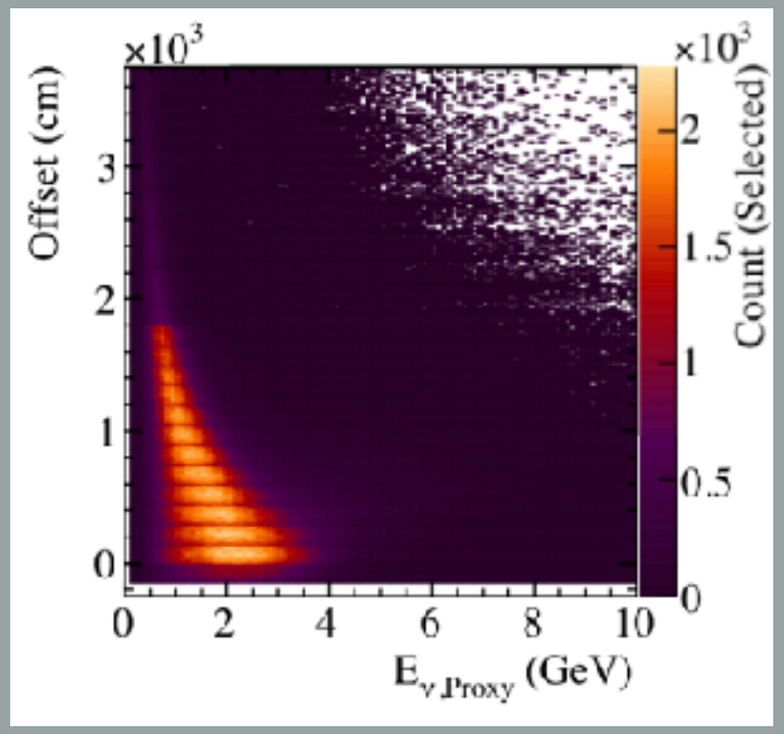


- Briefly investigated ignoring flux windows in flux fits.
  - Not able to miss large sections of off-axis position, but could mitigate efficiency problems near stop edges without needing more stops.
  - Larger coefficients produce couple to large statistical errors in linear combinations

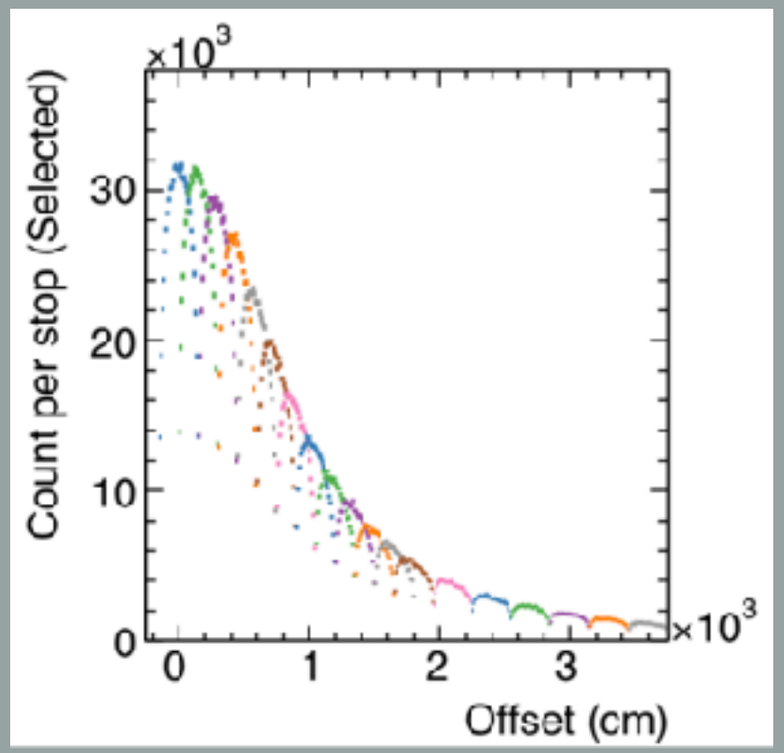
EFFICIENCY CORRECTIONS - MORE STOPS



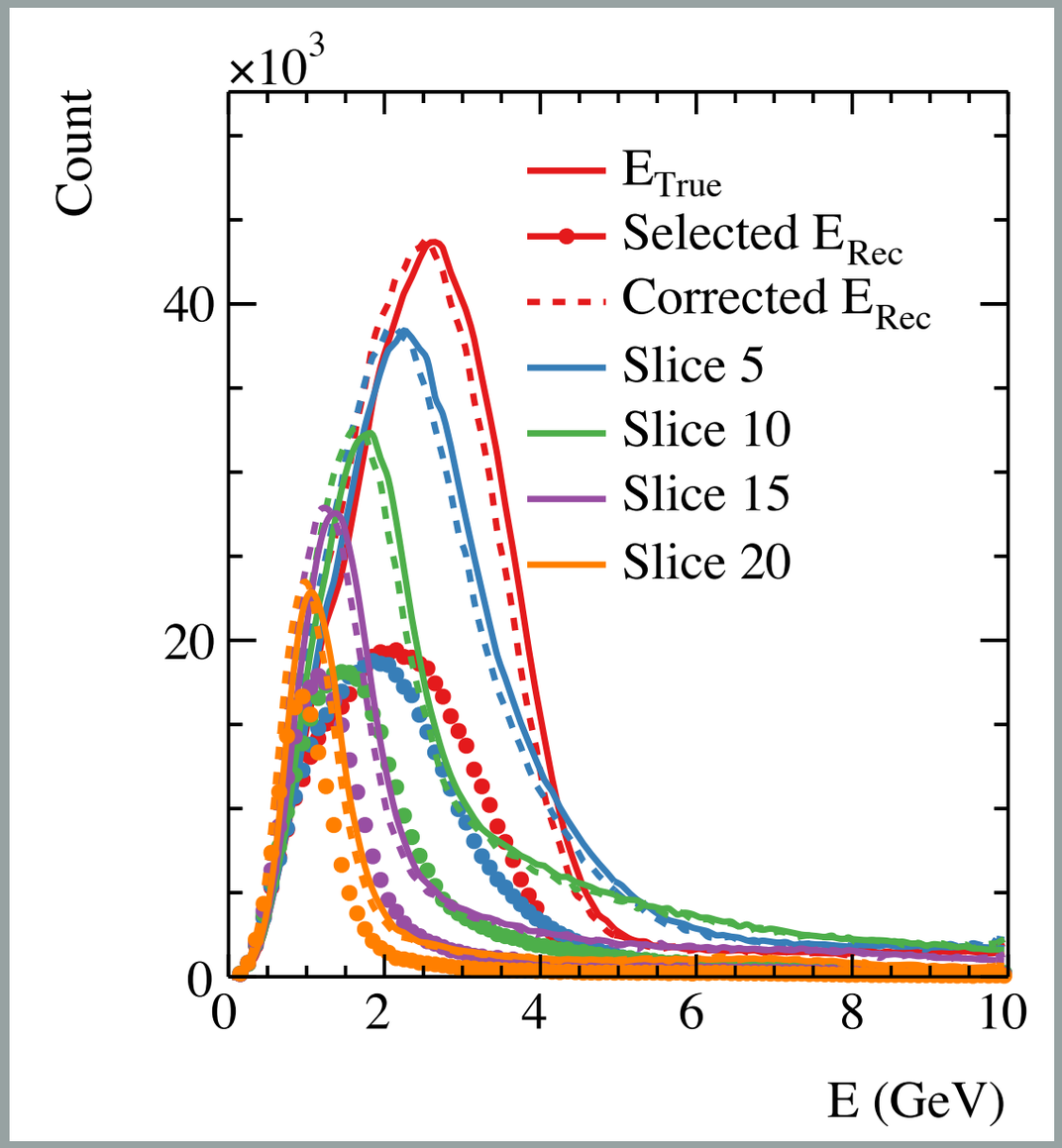
Stop more frequently near on-axis

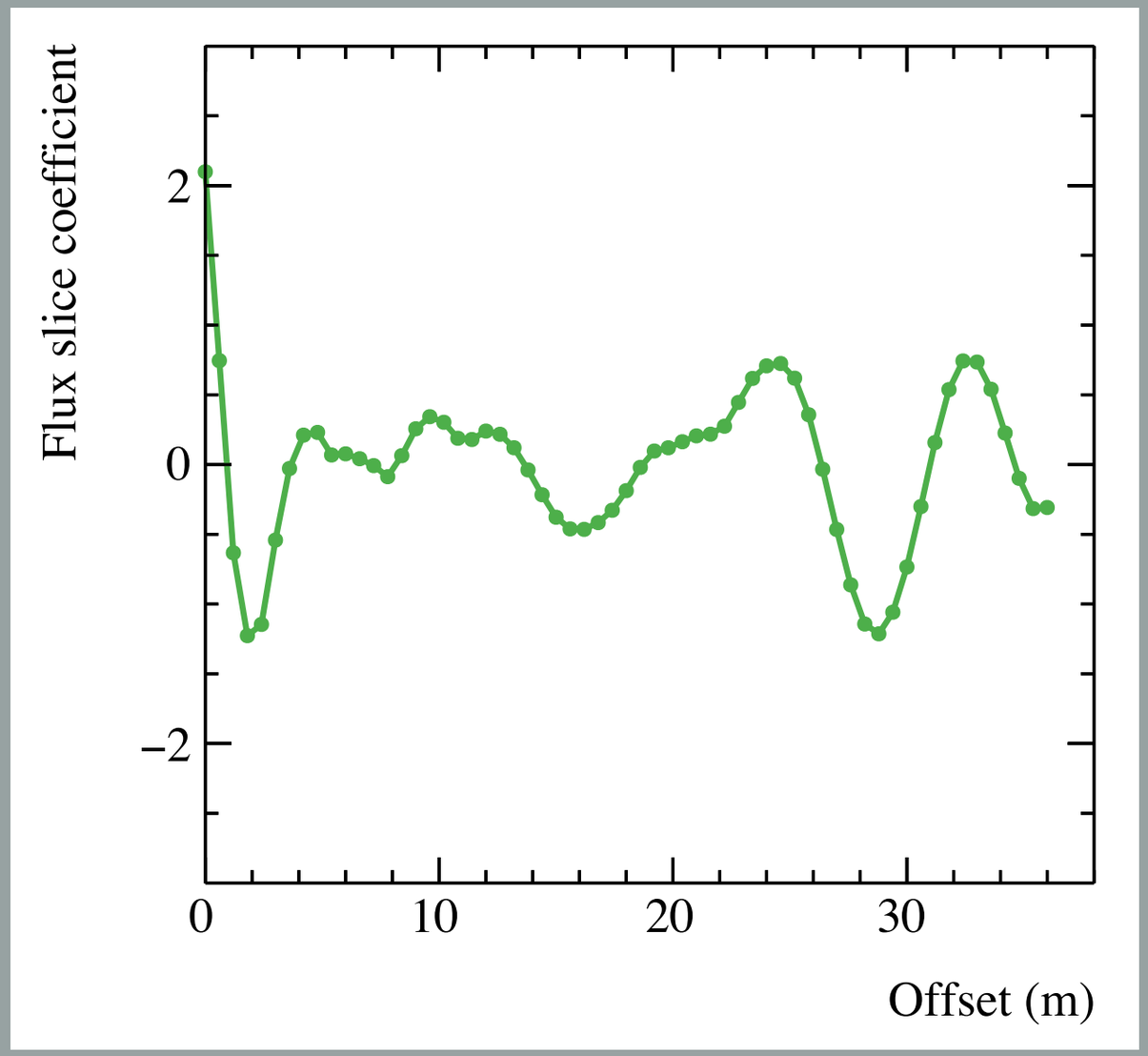


- Use overlapping detector stops to sample the same off-axis position with high-efficiency region of the detector.
- Can apply further fiducial volume selection to remove regions of lower average efficiency



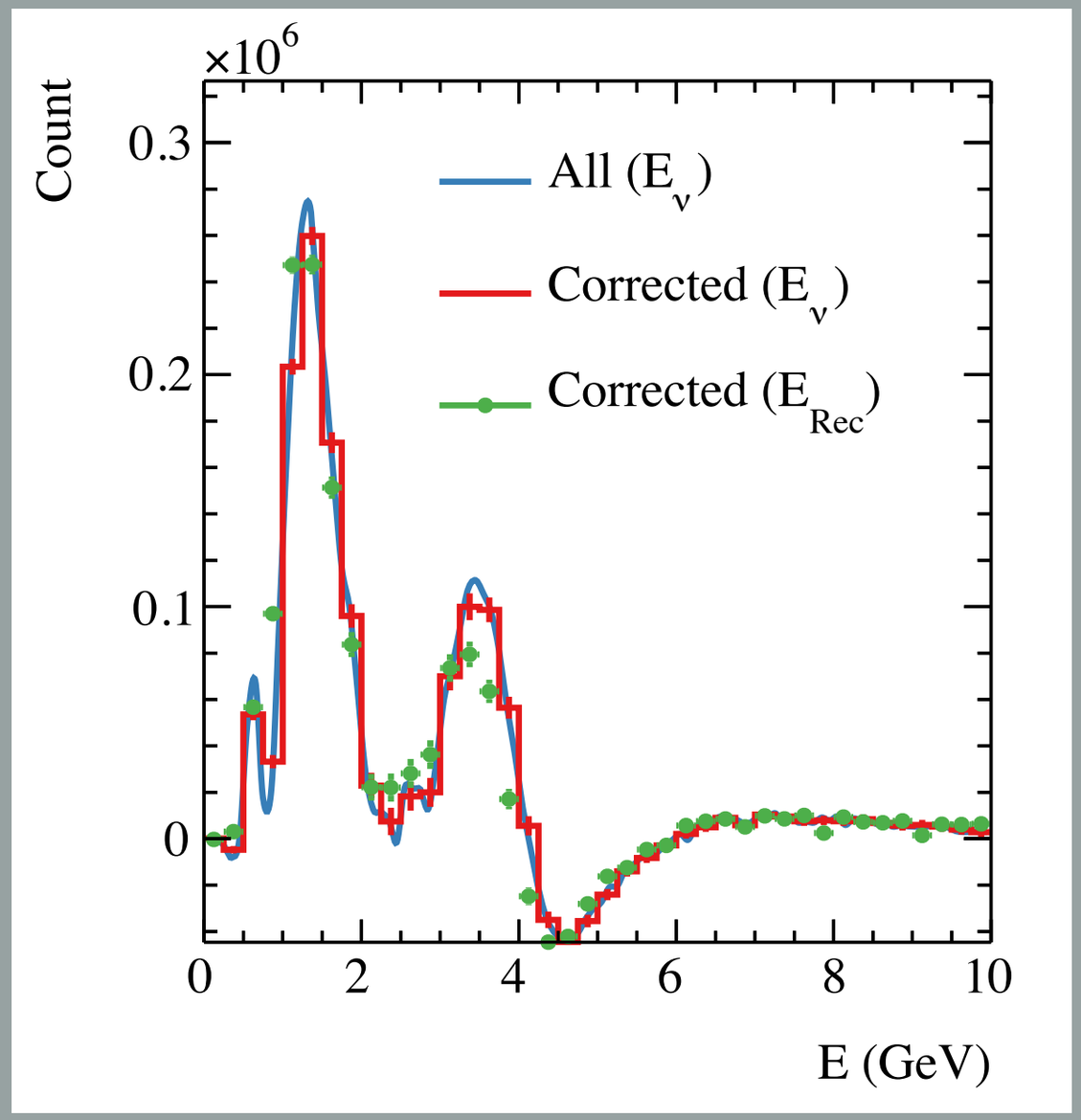
STEP 5: CORRECTED NEAR DETECTOR OBSERVATIONS



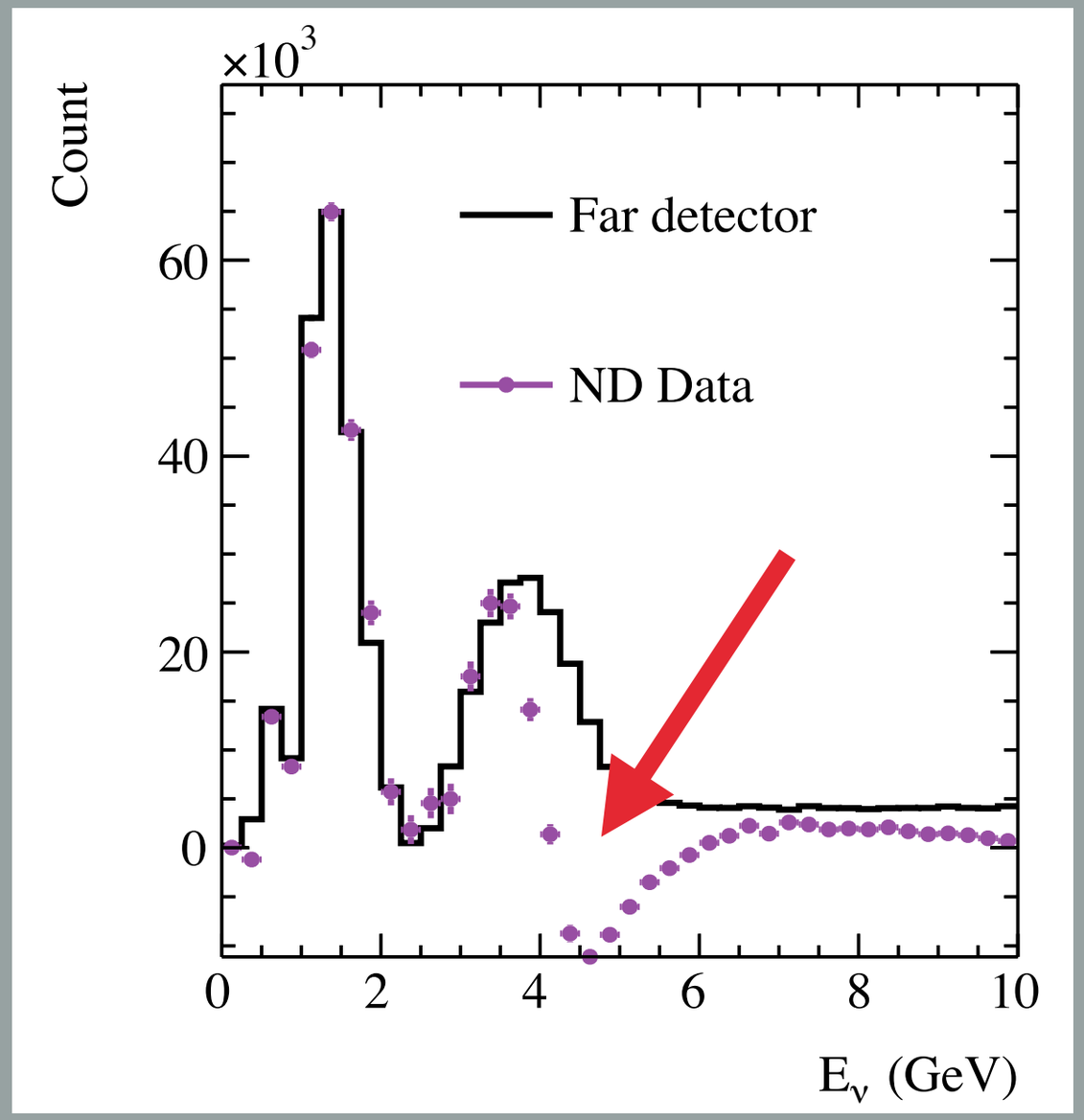


- Use observable: $E_{Rec} = E_{\mu} + E_{HadronsDeposited}$
- Have corrected near detector observables separated into flux slice windows.

STEP 6: USING ALL THE ND DATA

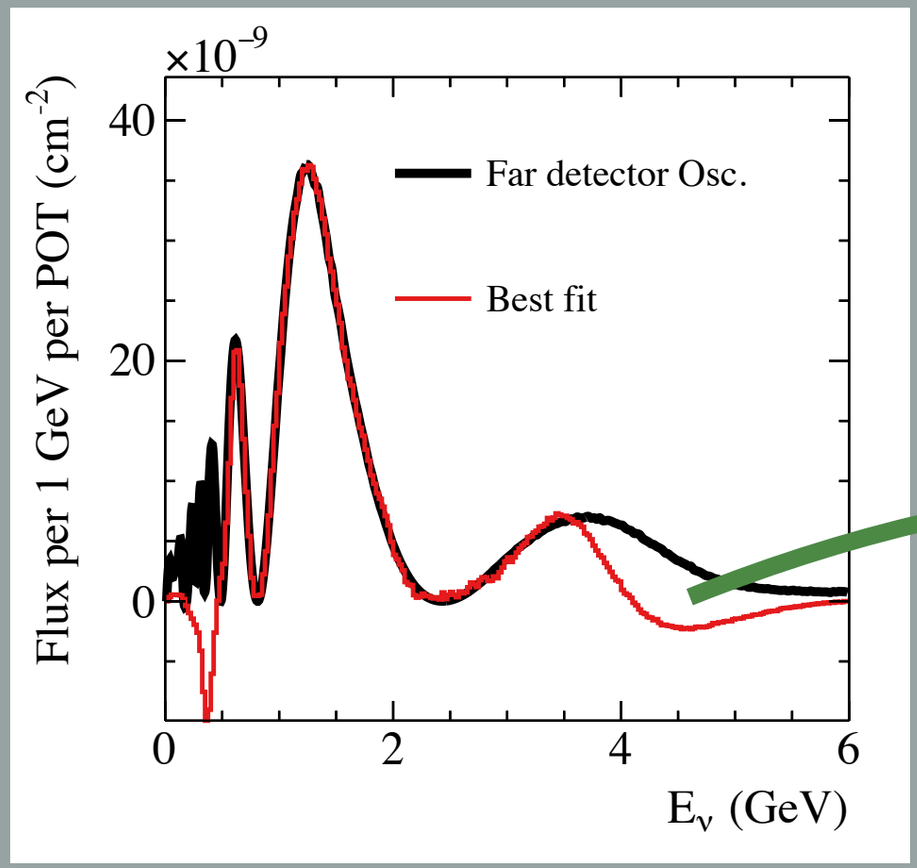


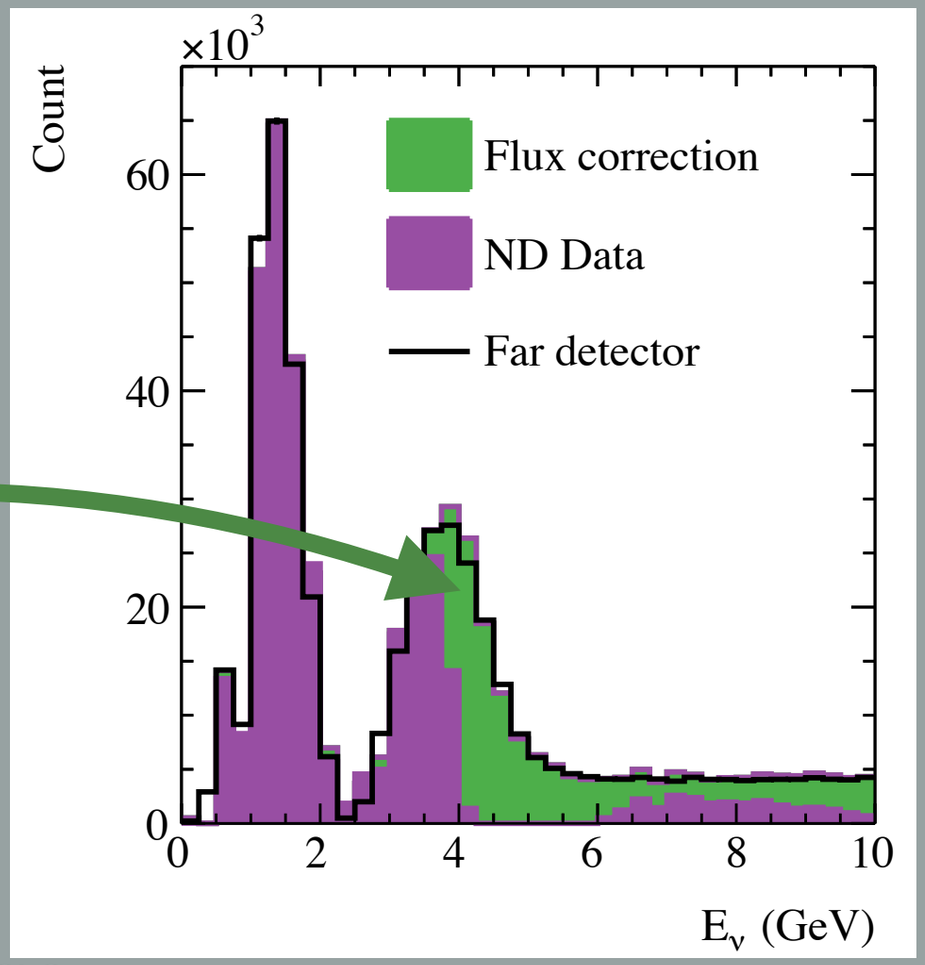
Linear combinations of ND distributions



Comparison to far detector distribution

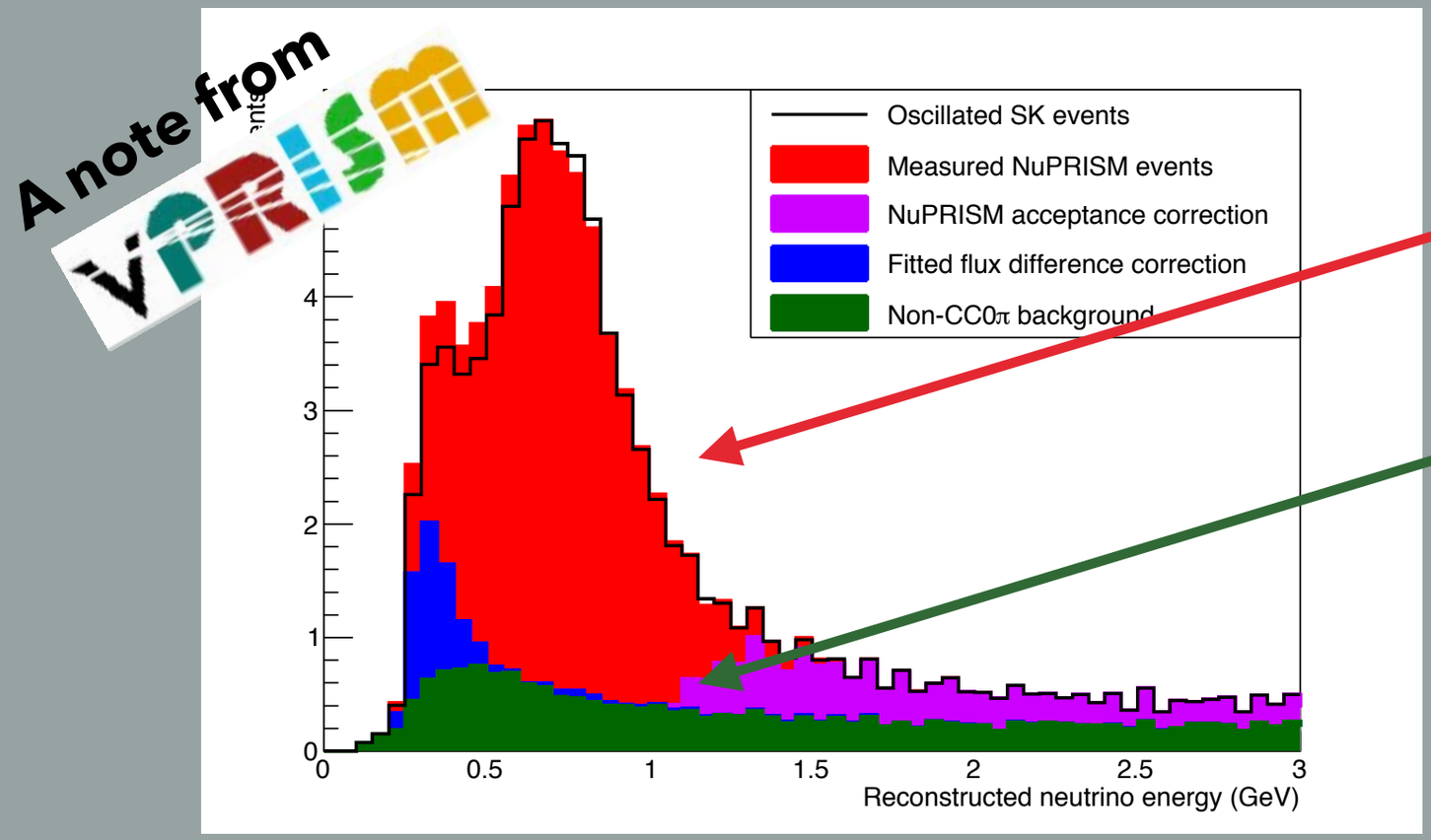
STEP 7: ADD IN THE MISSING FLUX





- Flux fits are not perfect over the full E range:
  - Must account for this in FD prediction.
  - Use FD MC events, weight by `(1 - BFFlux/FarFlux)*OscProb`
  - Project events to ERec.
  - Add to ND data linear combination.

STEP 8: BACKGROUNDS – ADDITION



Linear combination of ND measurements.

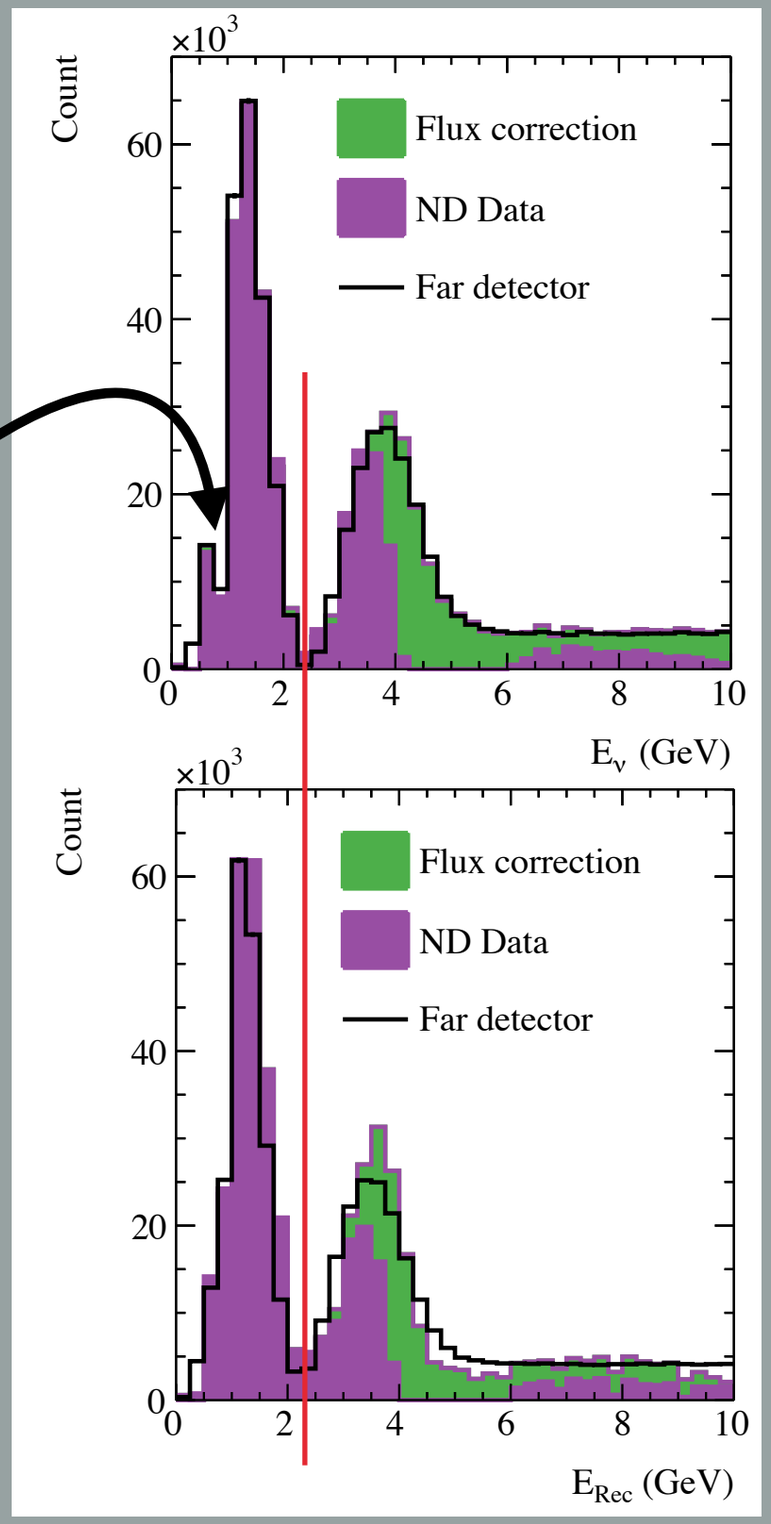
FD MC background component.

- **Now**: Only use CC muon neutrino interactions – no backgrounds at the FD.
- **Future**: Add in FD prediction of backgrounds.

FULL FAR DETECTOR PREDICTION

- Free to build linear combinations in any distribution.
  - For real data, use ERec.
- PRISM accounts for energy feed-down through the use of ND data around the oscillation dips.
- With enough statistics could resolve the second maxima.

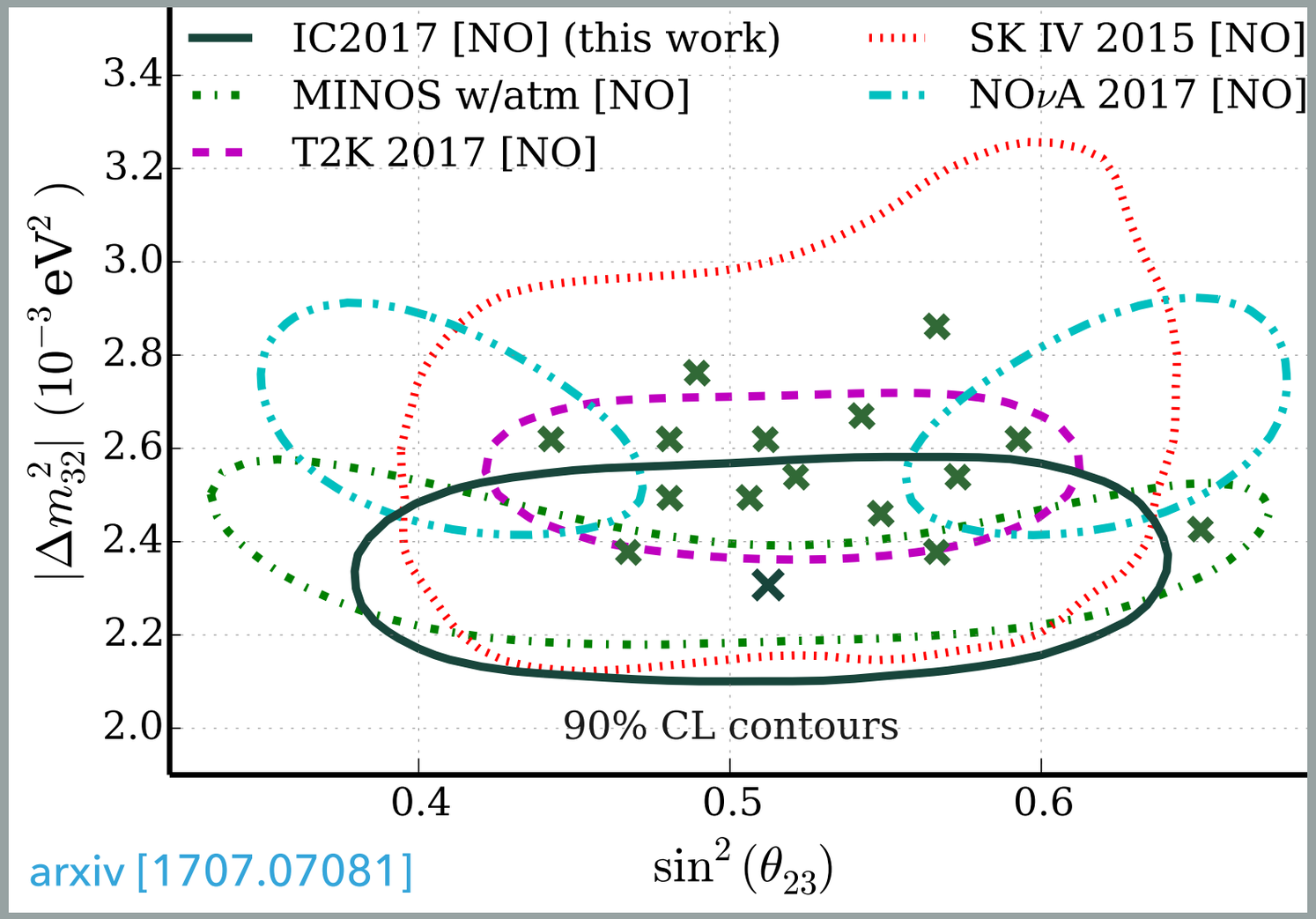
- **Caveat**: Some ERec(ETrue) difference between ND/FD MC, investigations on-going:
  - May be due to neutron energy differences or limitations of the toy efficiency correction.
  - ERec distribution here is WIP.



SYSTEMATIC ERROR EVALUATION

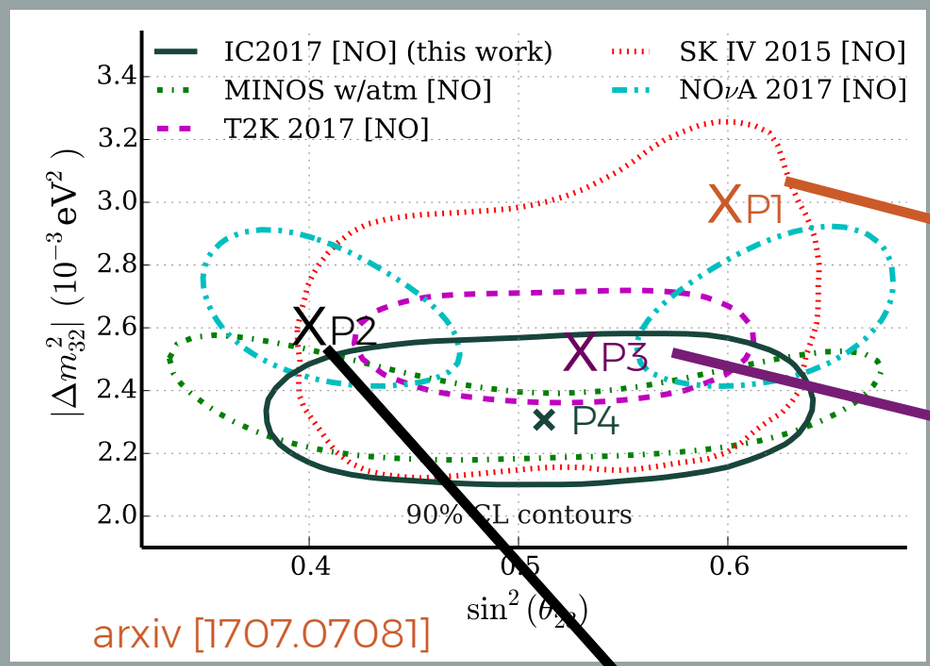
- General procedure:
  - Keep any FD MC corrections fixed, *e.g.*
    - Flux mis-fit correction
    - Background subtraction/addition
    - Efficiency correction
  - Throw Flux/XSec/Detector parameters and allow ND observations and FD observations to vary.
  - Build covariance matrix of allowed `(FDPrediction - FDObserved)` in relevant observables.
- Include in likelihood evaluation for chosen oscillation parameter set.
  - **Covariance must be re-built for each oscillation parameter choice.**

FULL DISAPPEARANCE ANALYSIS

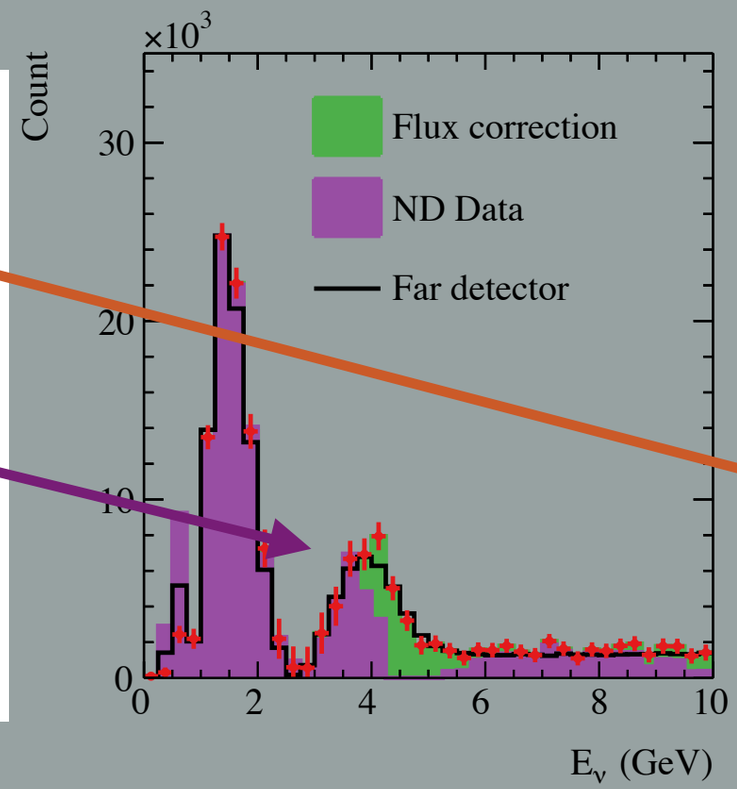


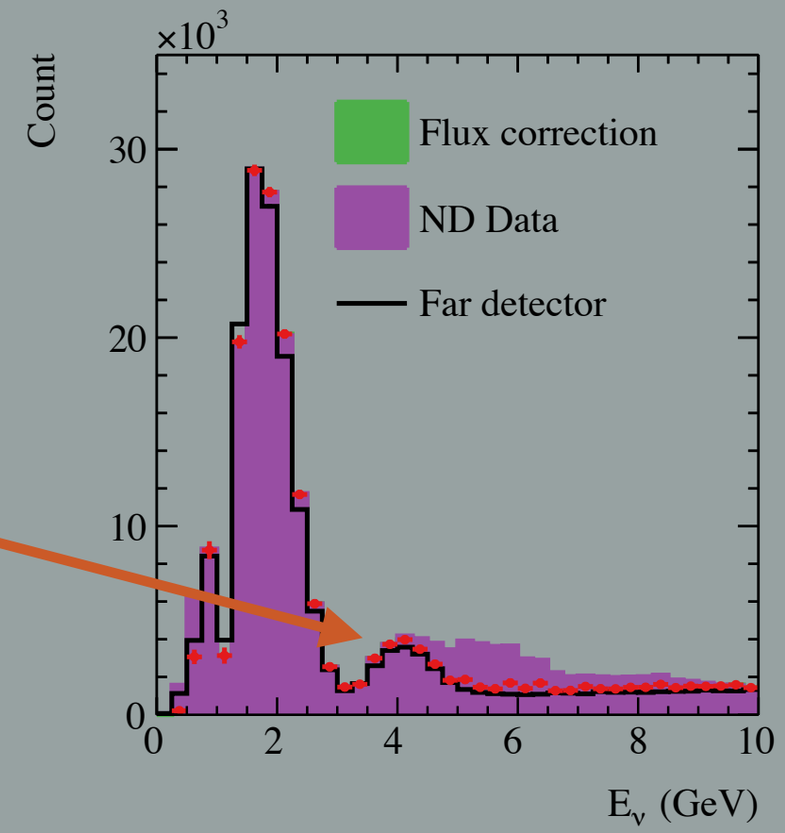
- Disappearance analysis involves running this procedure for many points in this space and building a $\Delta\chi^2$ map.

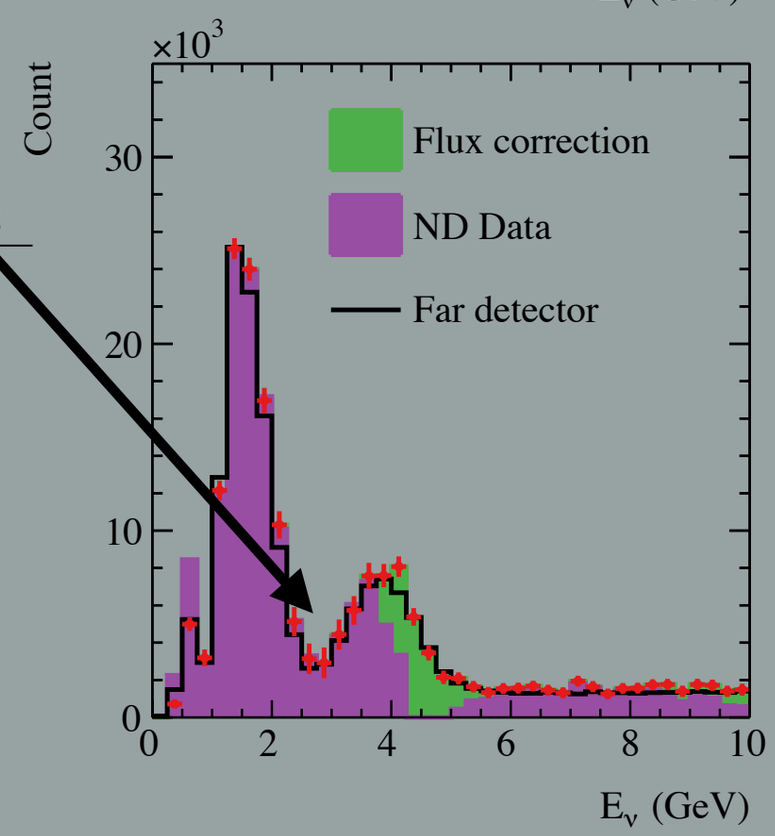
EXAMPLE PREDICTIONS

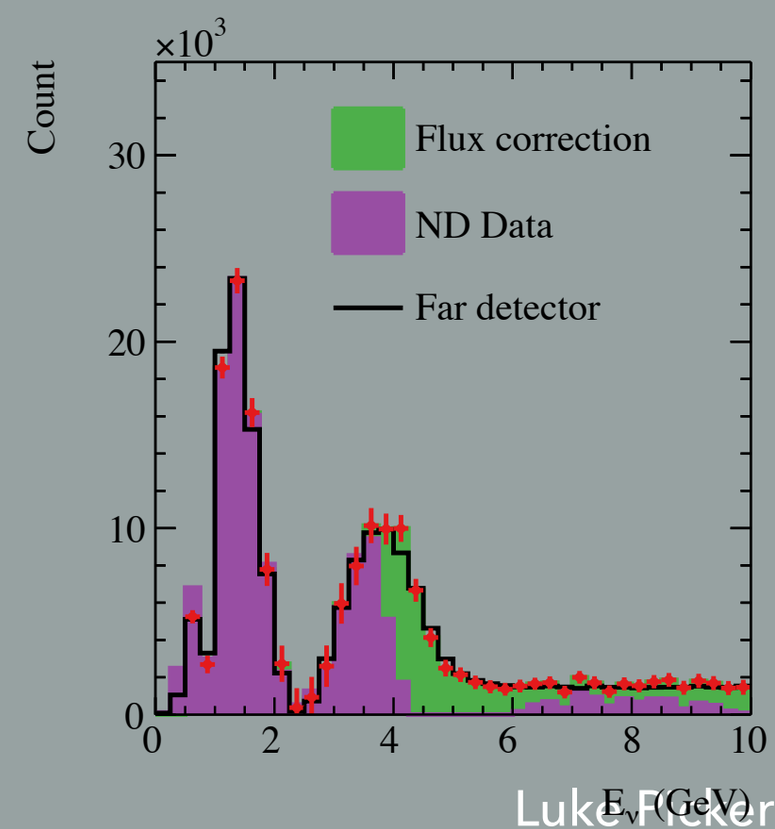


arxiv [1707.07081]









Point	$\lvert\Delta\rvert m^2_{32}$ $(10^{-3}\mathrm{eV}^2)$	$\sin^2\theta_{23}$
P1	3.0	0.6
P2	2.6	0.4
P3	2.539	0.534
P4	2.31	0.51

WRAP UP

- Rapid progress building a PRISM disappearance analysis in run-up to this workshop:
  - Idealised case near functional.

- Studies into geometric acceptance correction, optimising run plans, appearance analysis will occur on longer timescales.

WE APOLOGISE FOR ANY INCONVENIENCE

THANK YOU

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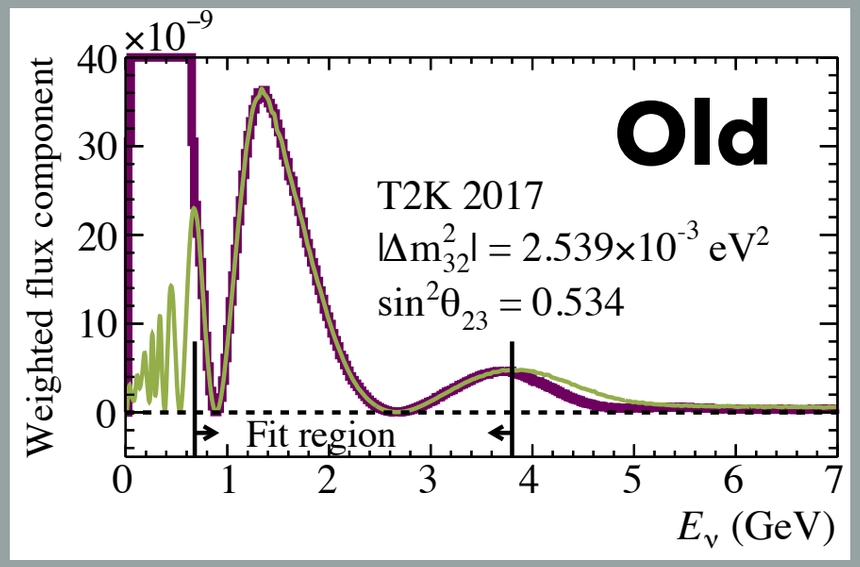
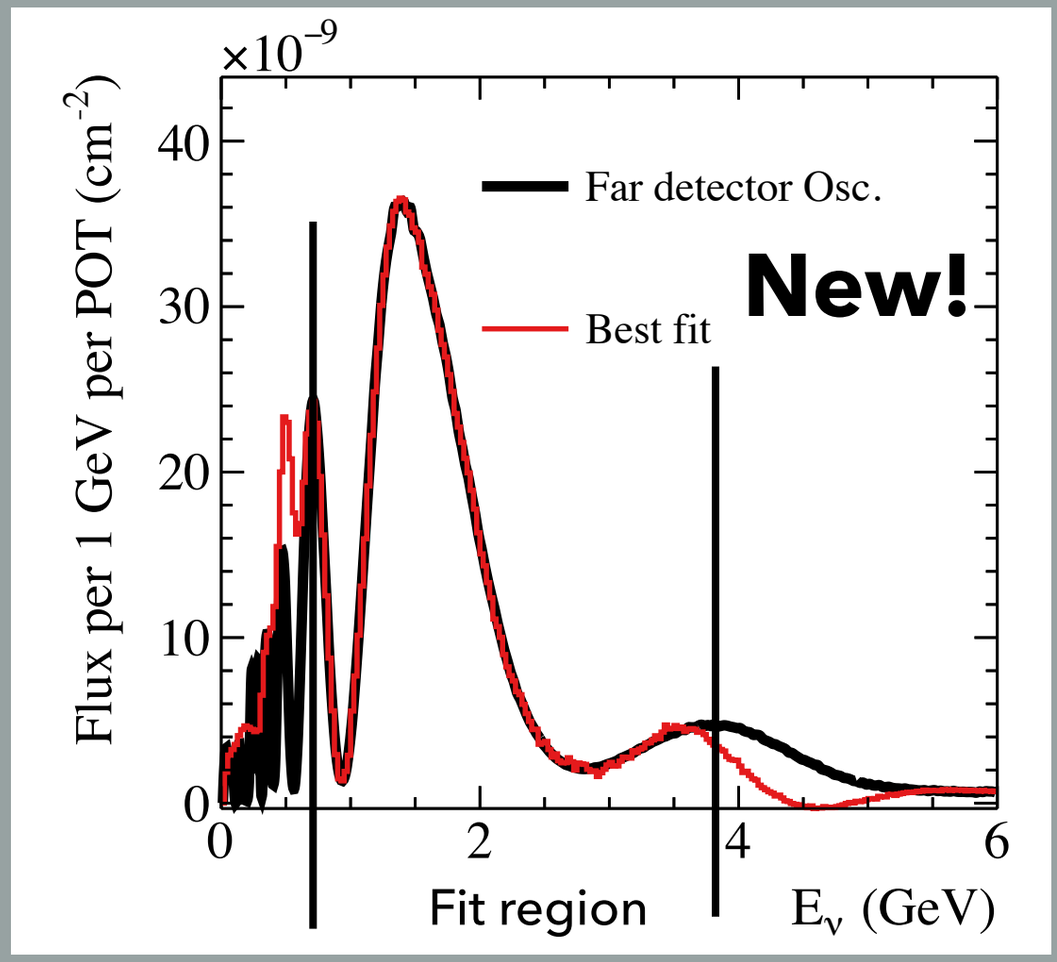
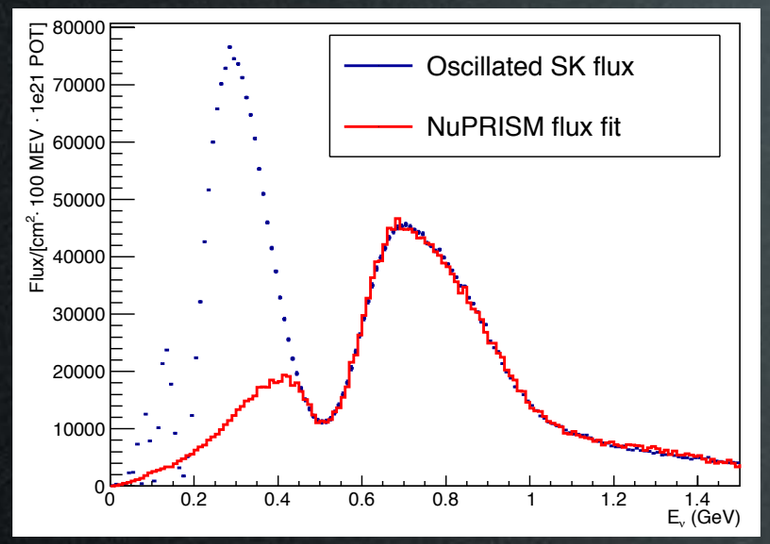
FLUX FITTING — IMPROVEMENTS

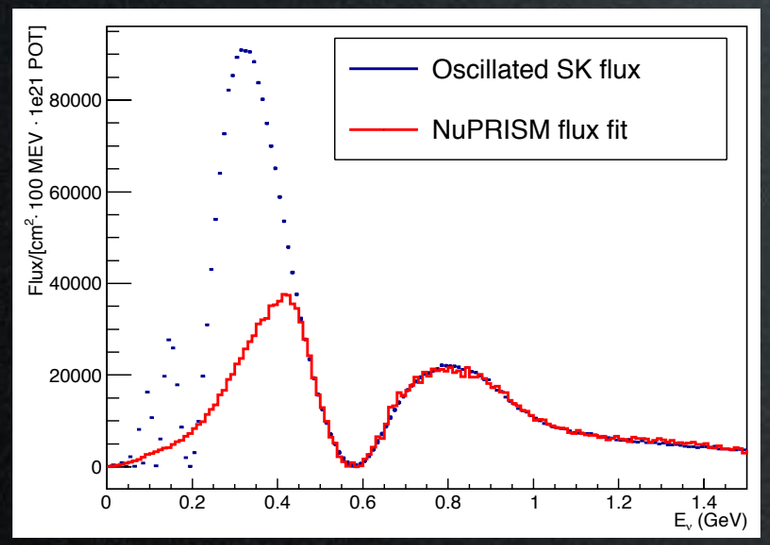
- Work by D. Douglas @ MSU.
- Outside of 'Fit region' contributes to FOM:
  - Limits low energy 'blow up'
- Fit region based on peak-finding:
  - Changes for different oscillation parameter sets.
- Still possible room for incremental FOM improvements @ higher energy.

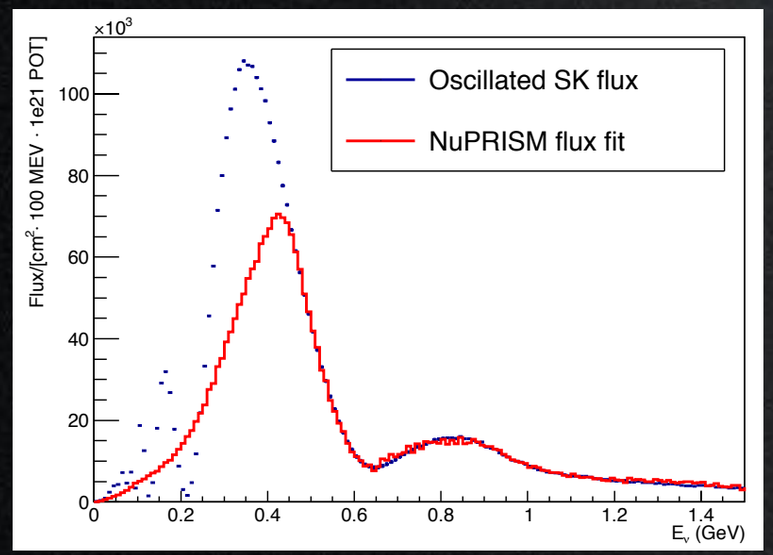




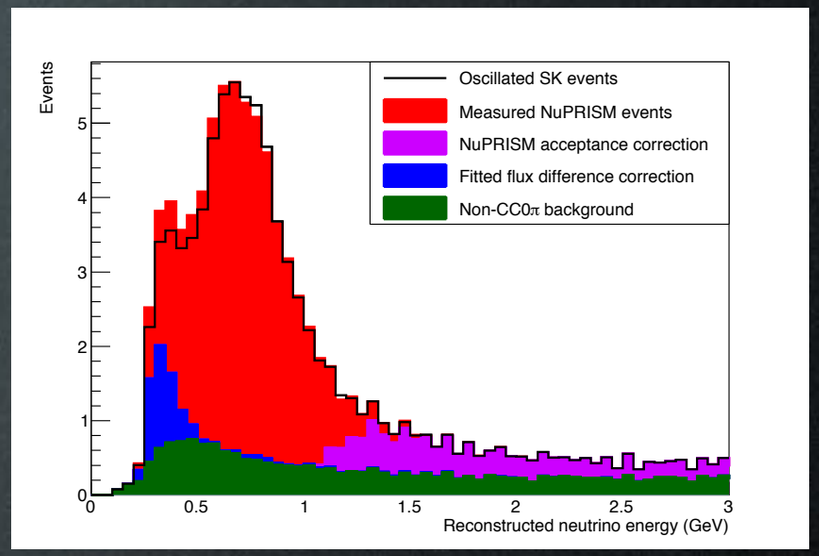
“Oscillations” in a Near Detector

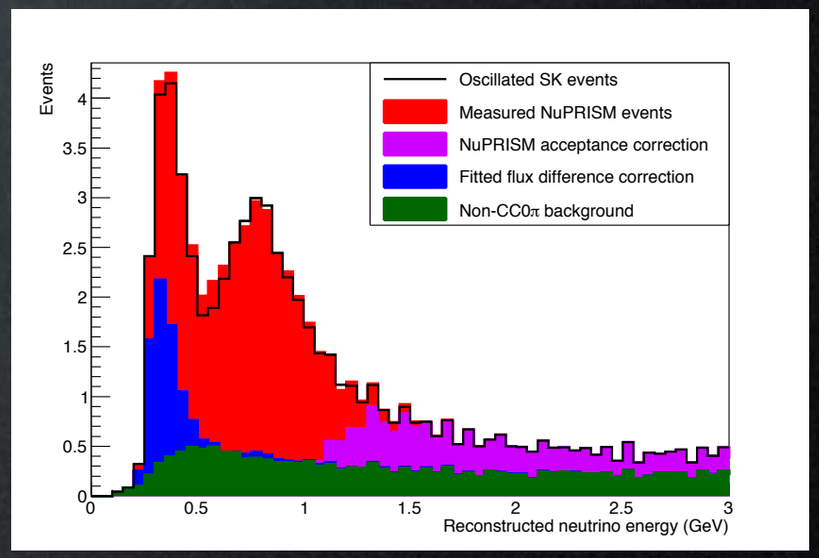


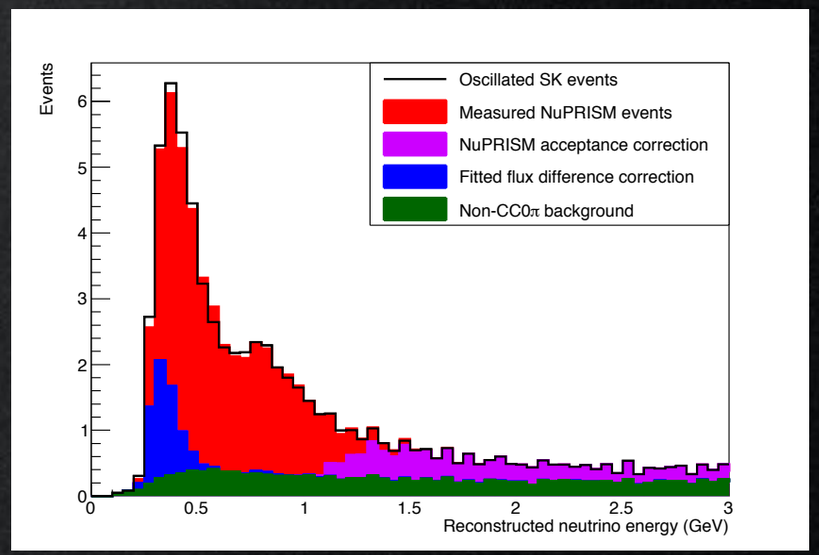




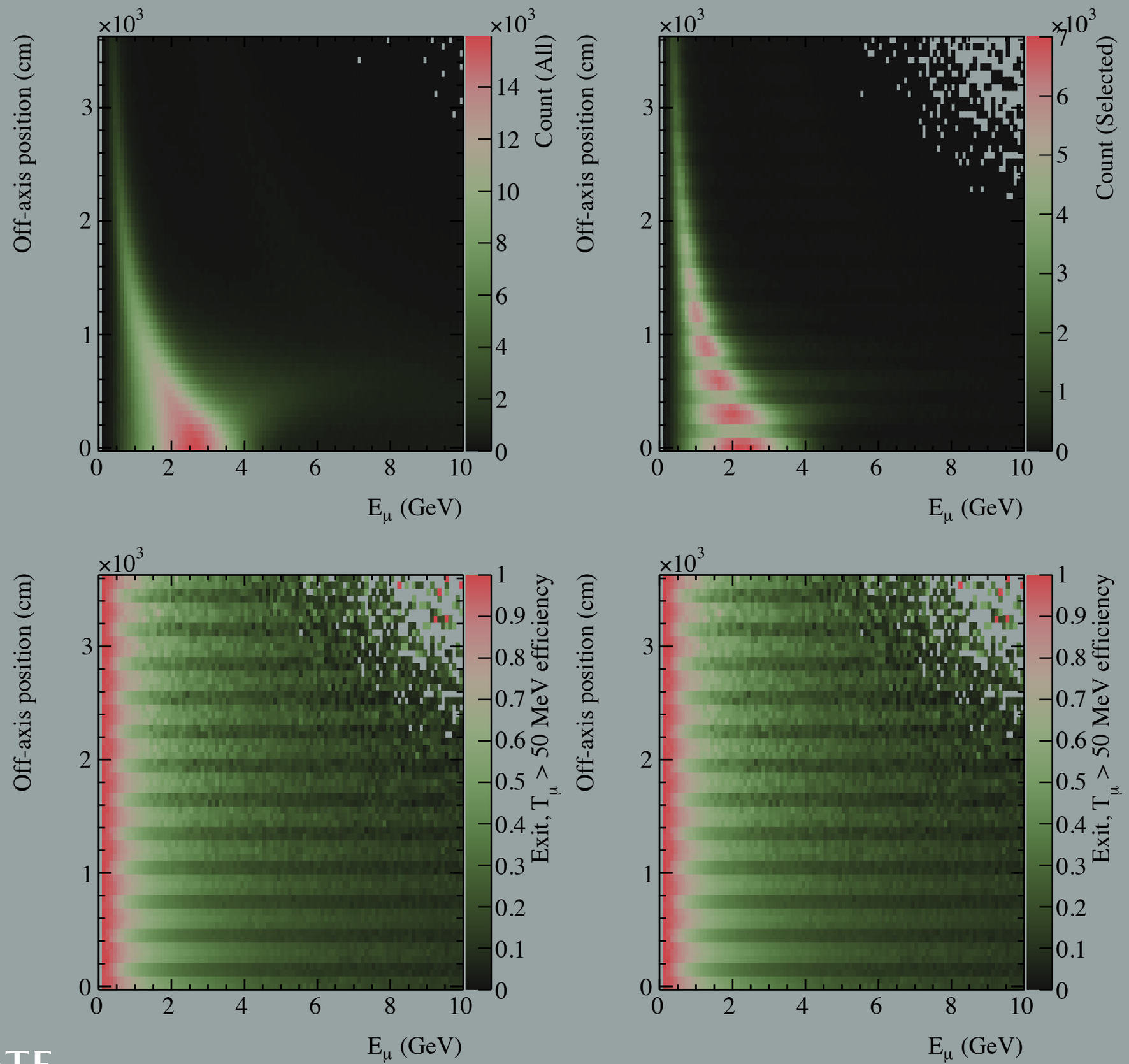
- Red region is directly measured by NuPRISM
- Blue region is flux difference correction
- Green is SK non-CC0π background
  - Partially cancels with already-subtracted NuPRISM CC0π background
- Magenta is acceptance correction
  - (geometric muon acceptance)
- SK prediction is largely from directly measured component







WE APOLOGISE FOR ANY INCONVENIENCE



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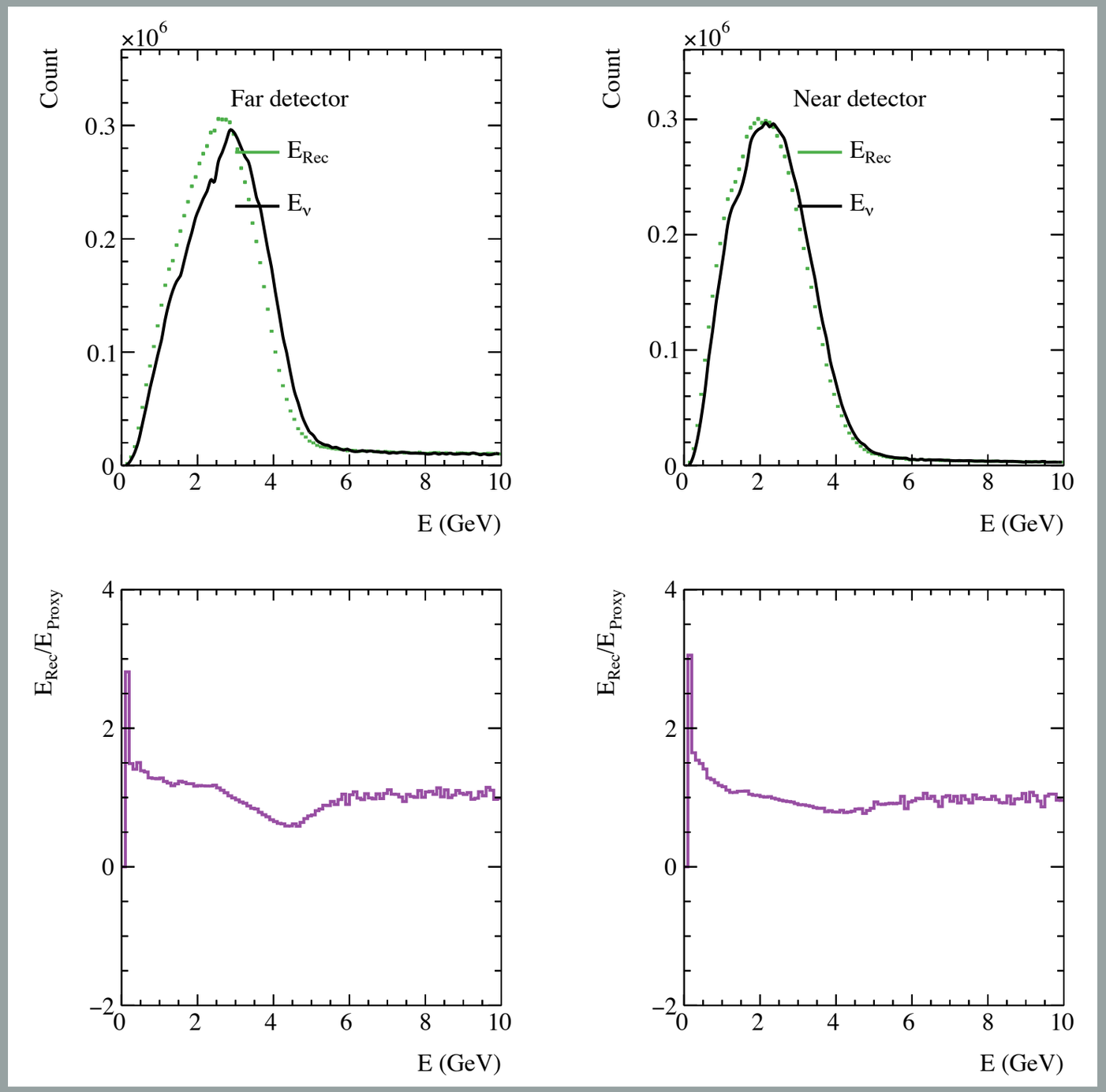
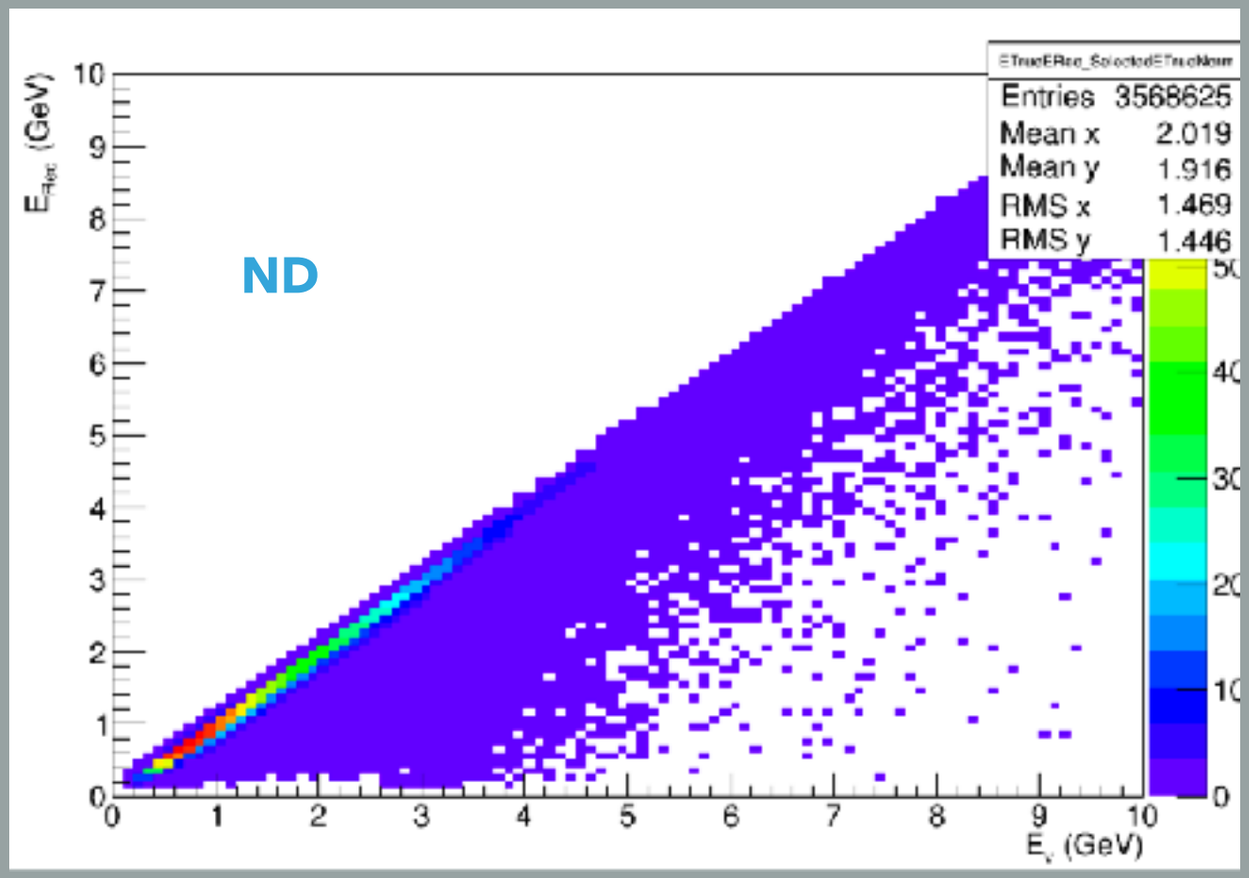
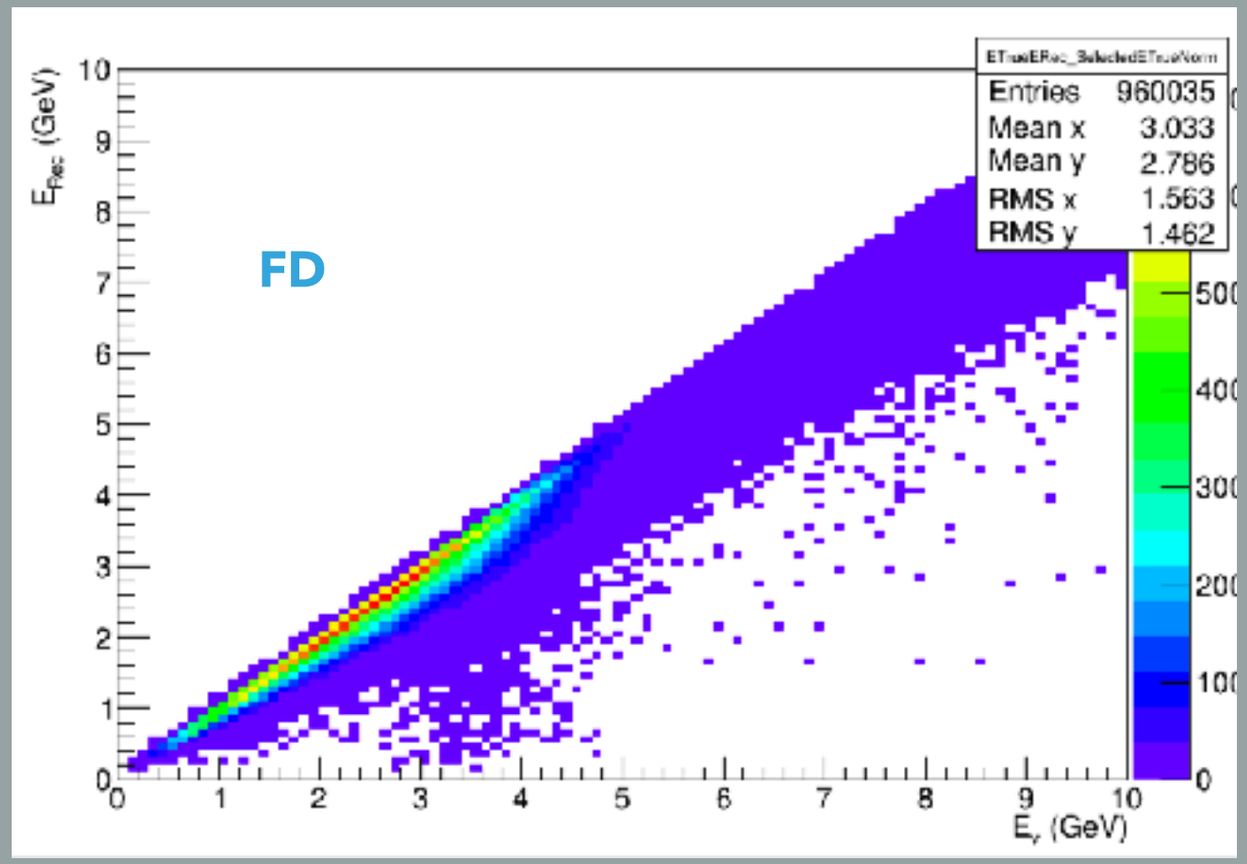
EREC(ETRUE)


Far detector
Near detector
Count
×10^6
E_Rec
E_ν
E (GeV)
E_Rec/E_Proxy

EREC(ETRUE)


ND
Entries 3568625
Mean x 2.019
Mean y 1.916
RMS x 1.469
RMS y 1.446
E_{Rec} (GeV)
E_ν (GeV)


FD
Entries 960035
Mean x 3.033
Mean y 2.786
RMS x 1.563
RMS y 1.462
E_{Rec} (GeV)
E_ν (GeV)