Working Group Contributions to the NDTF Efforts

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For the DUNE NDTF

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Role of the Flux WG for the NDTF

- Provide flux model
  - Histograms
  - Flux files for the GENIE FluxDriver / DK2NU
  - How dependent are the sensitivity results on the flux central values?
    - Wrong-sign backgrounds contributions
    - Low energy flux (~ 2nd maximum)
    - Different ND technologies may provide better/worse constraints for these areas
- Flux uncertainties
  - Need knobs to tune hadron production uncertainties
  - External Study:
    - Use a toy MC model to produce a covariance matrix in E_ν, ν species, and beam mode
    - Fluctuate knobs (hadron prod + beam optics) randomly many times
    - Fit parameters are determined by flux binning
    - VALOR already accepts this input – and has tools to rebin as needed
  - Direct use by fitter
    - Keep all relevant ν production information and reweight on the fly
    - Knobs value become fit parameters

Roll of the NDPWG

- In general: identify ND analysis topics and usher though analyses
- In the current stage of the experiment:
  - Determine ND requirements
    - Long-baseline Physics
    - ND analyses
  - Analysis strategies
    - How will each analysis be performed (selections, kinematic observables)
    - What are the limitations on each analysis (statistics, flux, backgrounds, etc)
- Work for the NDTF
  - Context: sensitivity to CPV and resolution on δ_{cp}
  - What ND physics samples are required to constrain the unoscillated FD prediction?
  - What observables do we need to simulate to make analysis selections?
  - What are the relevant kinematic quantities for each channel?
  - What are the main sources of systematic uncertainty and how can we simulate the allowed variation in each sample?

Roll of the NDWG in the NDTF

- Simulate ND event samples (Det Sim WGs)
  - Use models flux as an input
  - Full GEANT4 simulation of detector responses
  - Parameterized reconstruction
  - Produce n-tuples of observables required for sample definition and generating kinematic distributions
- Defining physics samples (Det Sim & ND Evaluations WGs)
  - Topologically defined
  - Must include separate channels to inform fit about flux and cross section models
  - Rely heavily on input from NDPWG
- Detector response uncertainties (Det Sim & ND Evaluations WGs)
  - Resolution on observables
  - Selection efficiencies
  - How will these be formatted / input to VALOR?
- Perform fits (ND Evaluations) – see VALOR talk by Costas

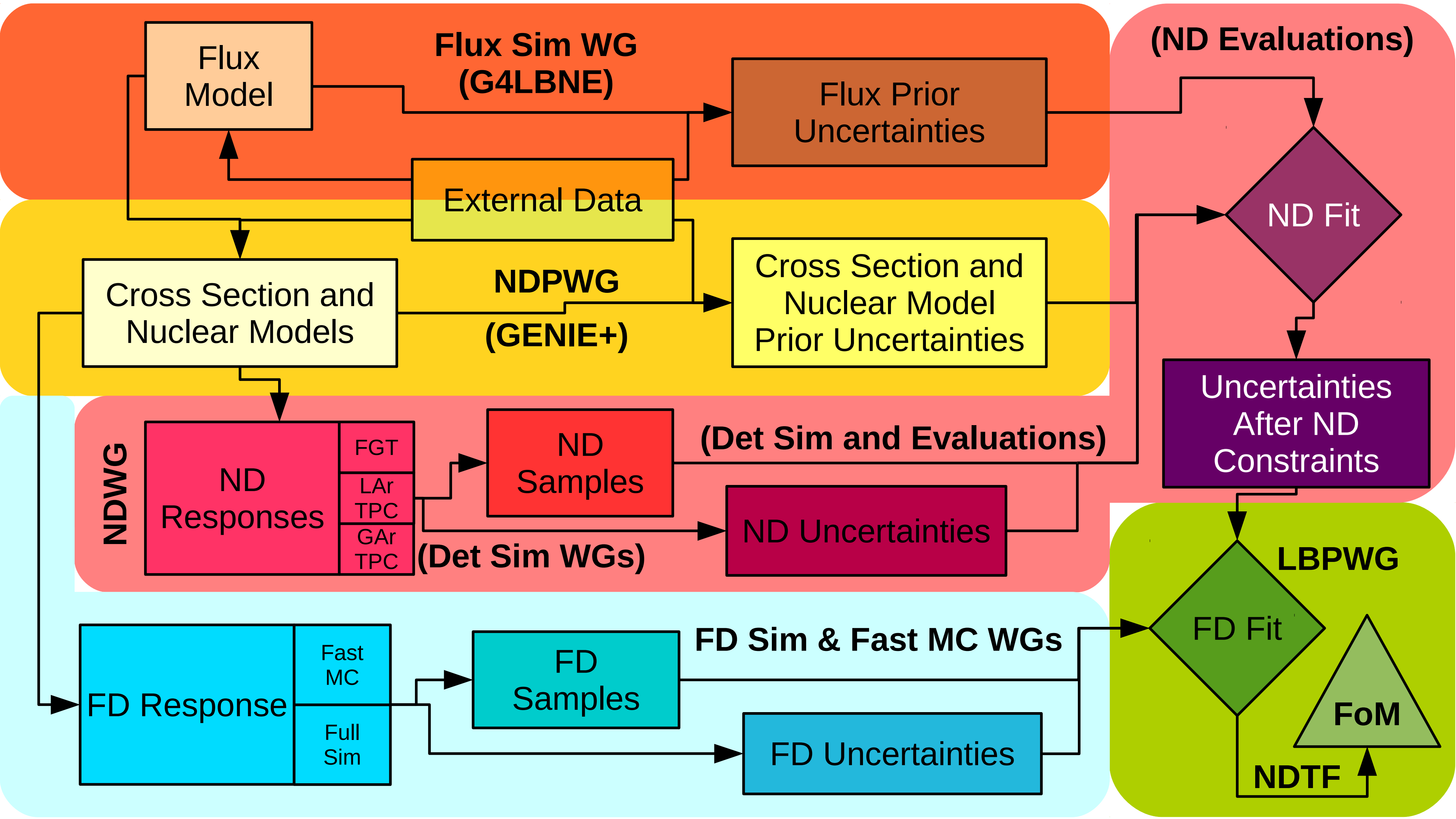
Interactions Between the NDPWG and the NDWG

- Mostly NDPWG is surrounds by various branches of the NDWG
- NDWG Detector Simulations Subgroups
  - Goal w.r.t. NDTF: provide full GEANT4 simulation and a parameterized reconstruction
  - The later requires knowing what to simulate and the required level of detail
  - This is directly linked to the observables required for analyses
- NDWG Evaluation Interfaces Subgroup
  - Goal w.r.t. NDTF: Incorporate ND physics samples into a combined fit that produces a “data based” covariance matrix of FD analysis nuisance parameter constraints
  - Requires knowledge of ND physics samples
    - Topological signatures
    - Kinematic variables of interest
  - Systematic uncertainties on each physics model
  - Independent studies of each analysis channel to validate and confirm results of combined fit
- NDTF will facilitate WG communication and software interface design

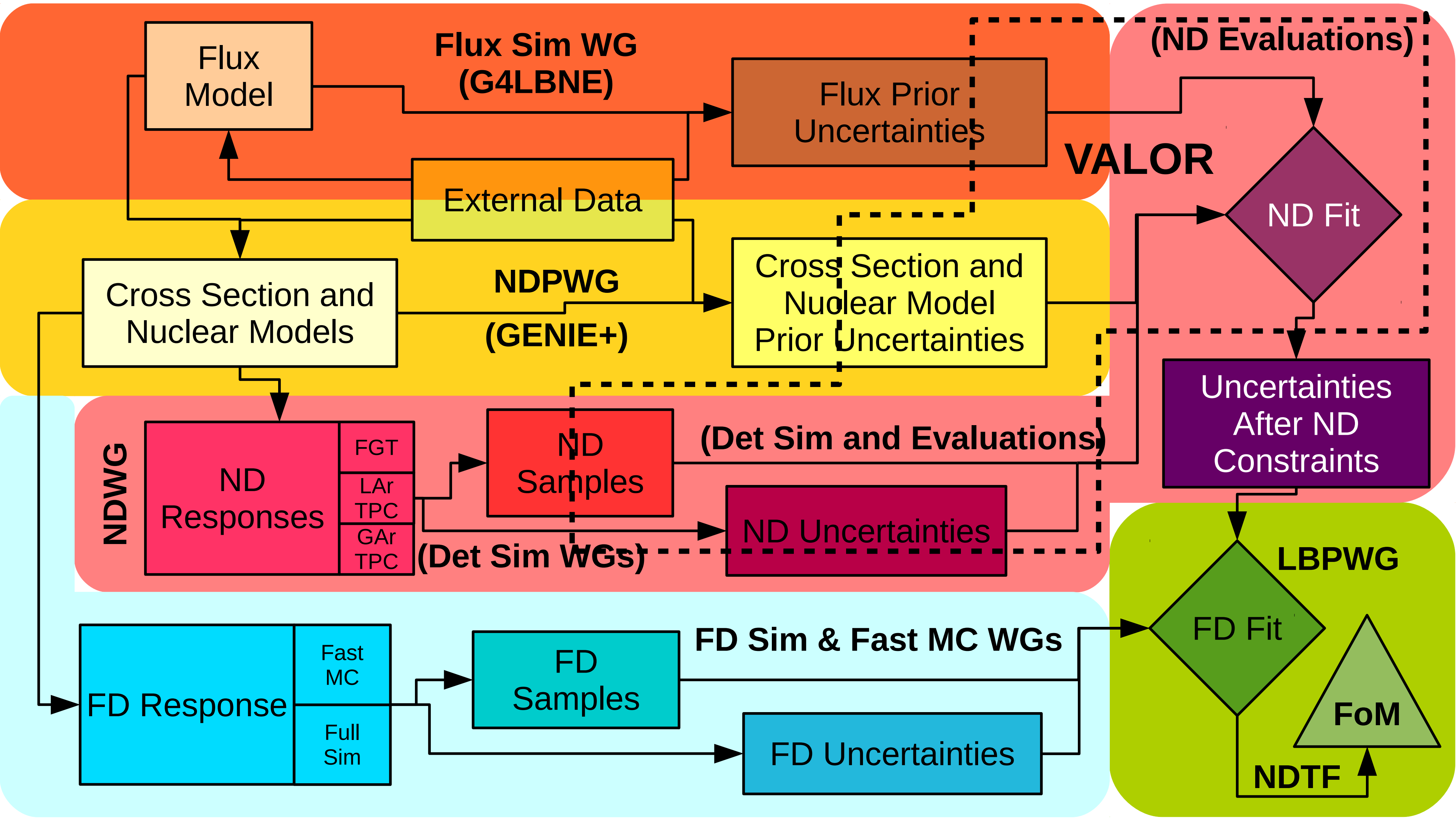
FD Sim and LBPWG in the NDTF

- Simulate the FD event samples
  - Start with the Fast MC
  - Move towards factorizing detector response and reconstruction
    - Detector response simulation include low level reconstruction like hit clusters, track lengths, dE/dx
    - Reconstruction determines PID, kinematic observables and is used to define analysis samples
  - Reconstruction should be able to read in full GEANT4 simulation or Fast MC inputs
- Perform oscillation parameter fits, marginalizing over all other fit parameters
  - Generation of analysis samples from reconstruction output
  - Systematic response functions
  - Use of input covariance matrix from ND fits
  - Independent priors for all parameters unconstrained by the ND fit

Near Detector Task Force Simulation and Analysis Chain



Near Detector Task Force Simulation and Analysis Chain



ND Evaluations WG Scheme: VALOR

- Based on talk from C. Andreopoulos (LBNE docdb-9409)
- A few slides about analysis samples and uncertainties
- Costas gave a lot more detail in his recent talk
- Context: given this scheme what suggestions and efforts can the NDPWG give to provide:
  - Useful samples / templates
  - Information on impact of relevant models missing from templates
  - Relevant systematic knobs
  - Verification of ultimate constraint level that can be extracted from the data

LBNE ND Samples for Systematics Constraint Fit

In our 2014v1 analysis, we include either fully inclusive samples or exclusive / semi-inclusive samples of low track multiplicities. Used separate samples for FHC and RHC running.

List of topologically defined samples
Are they sufficient?

- ν_μ CC inclusive
  - ν_μCC 1-track QE enhanced (FHC: μ^- only)
  - ν_μCC 2-track QE enhanced (FHC: μ^- + p)
  - ν_μCC $1\pi^\pm$ (FHC: $\mu^- + 1\pi^\pm$ + X)
  - ν_μCC $1\pi^0$ (FHC: $\mu^- + 1\pi^0$ + X)
  - ν_μCC $1\pi^\pm + 1\pi^0$ (FHC: $\mu^- + 1\pi^\pm + 1\pi^0$ + X)
  - ν_μCC other

    $\rightarrow$ in future, subdivide further (3-track Δ-enhanced, νe)
- Wrong-sign ν_μCC inclusive (FHC: μ^+ + X)

  $\rightarrow$ in future, subdivide further
- ν_eCC inclusive (FHC: e^- + X)

  $\rightarrow$ in future, subdivide further
- NC inclusive

  $\rightarrow$ in future, subdivide further (NCEL, NC $1\pi^\pm$, NC $1\pi^0$)

Samples in red are included in the *current (2014v1) version* of our ND systematics constraint fit.

Inclusion of other samples, and their utility in constraining systematic uncertainties, will be tested in future iterations of this work.

VALOR/LBNE-ND: Building-up the predicted spectra

For the LBNE ND fits, initially, we are keeping track of the 52 MC templates shown on the right.

The choice is independently configurable for each beam / sample combination.

The granularity depends on the choice of cross-section and efficiency systematics that need to be applied to the MC templates.

Will keep on revisiting the selected granularity as we improve the fit.

- ν_μ CC QE
- ν_μ CC MEC
- ν_μ CC $1\pi^\pm$
- ν_μ CC $1\pi^0$
- ν_μ CC $2\pi^\pm$
- ν_μ CC $2\pi^0$
- ν_μ CC $1\pi^\pm + 1\pi^0$
- ν_μ CC coherent
- ν_μ CC other
- ν_μ NC $1\pi^\pm$
- ν_μ NC $1\pi^0$
- ν_μ NC coherent
- ν_μ NC other
- **similarly for** $\bar{\nu}_\mu$
- **similarly for** ν_e
- **similarly for** $\bar{\nu}_e$

Each sample is built of MC templates

Defined by physics models

Are these models sufficient?

What are the uncertainties?

VALOR/LBNE-ND: Building-up the predicted spectra

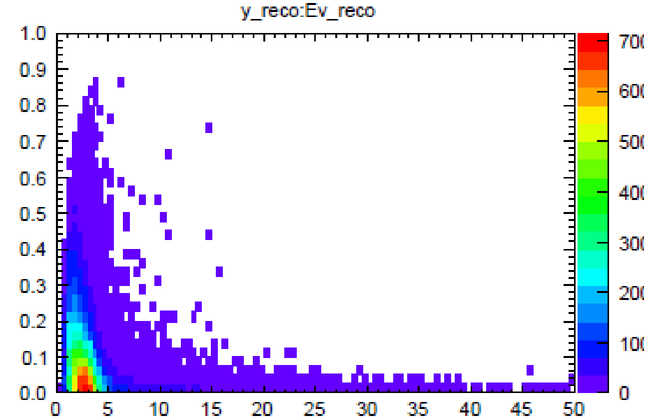
In the LBNE ND systematic constraint fits, we fit 2-D (E_{reco}, y_{reco}) distributions for CC-like samples (and E_{vis} for NC-like samples). The p.d.fs (for CC-like events) are constructed from 3-D (E_{reco}, y_{reco}, E_{true}) MC templates. Separate MC templates are constructed for each beam configuration, sample and true reaction mode.

The E_{reco}, y_{reco}, E_{true} binning granularity depends on the choice of flux and cross-section fit parameters and detector systematics (e.g. efficiency error matrix in E_{reco} bins). The binning is easily configurable and can be defined searately for each beam / sample. efficiency is a consideration. Binning is currently being optimised.

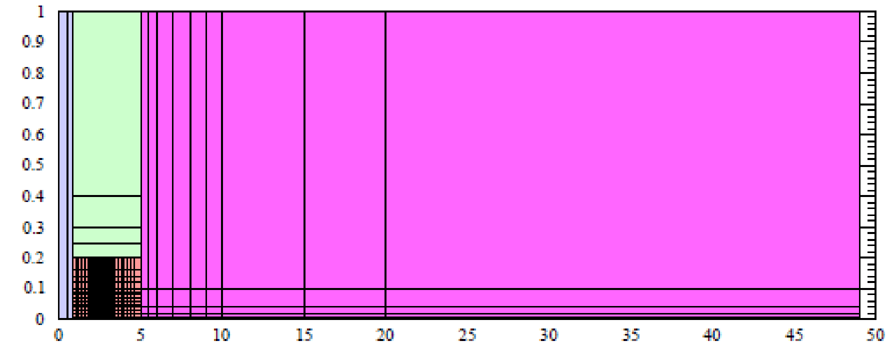
Is E_ν vs y best?

Can different samples have different variables for binning?

E_{reco}, y_{reco} distribution for a QE-enhanced sample.

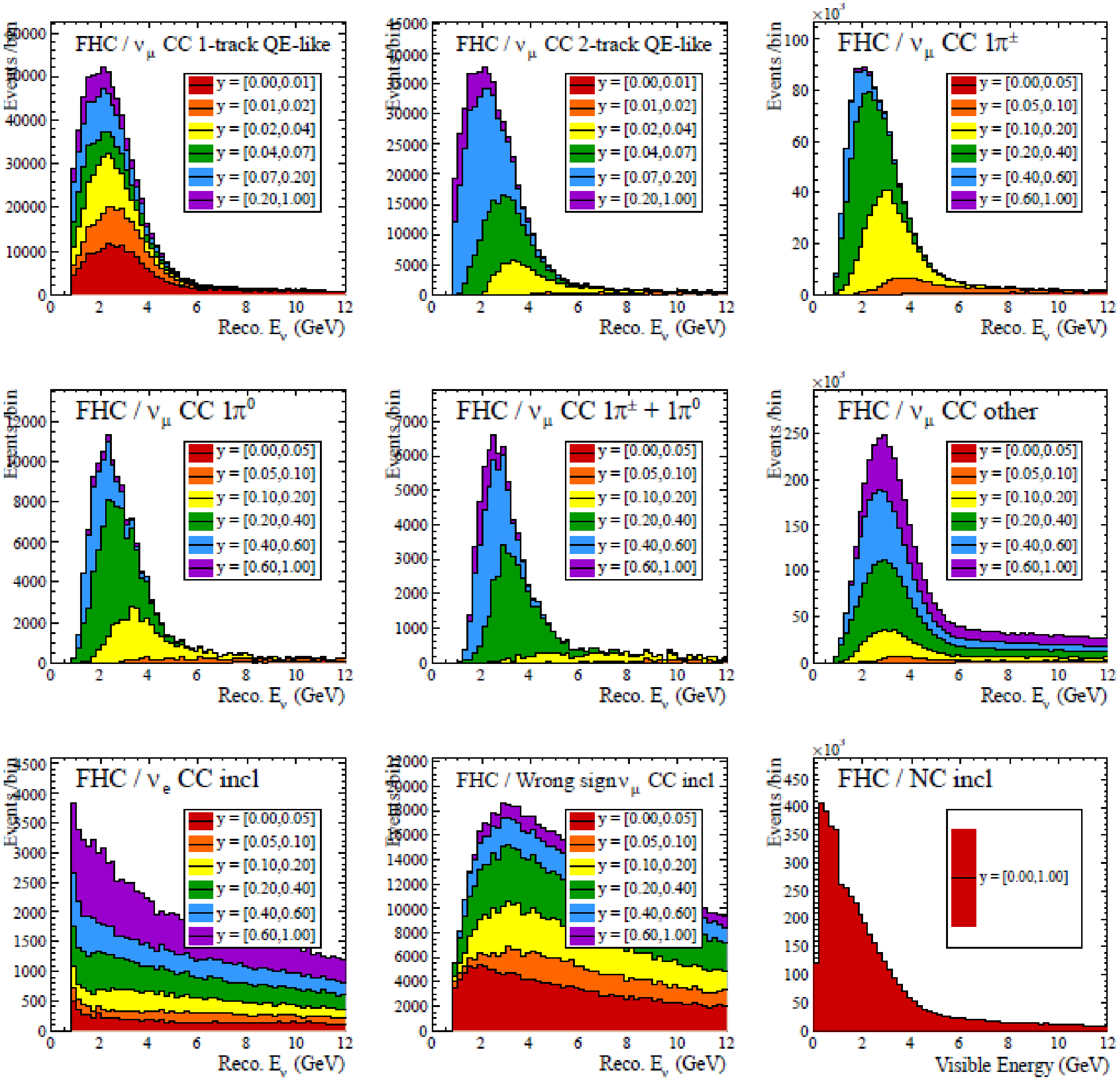


A somewhat optimised (albeit too fine) binni of zones are defined and a different variable-s (~ constant number of MC events / per bin



Generally, the binning that optimizes fit CPU-efficiency is not that great for plots. Note that all (most) plots will be shown using a more regular and fine binning.

VALOR/LBNE-ND: Example ND spectra



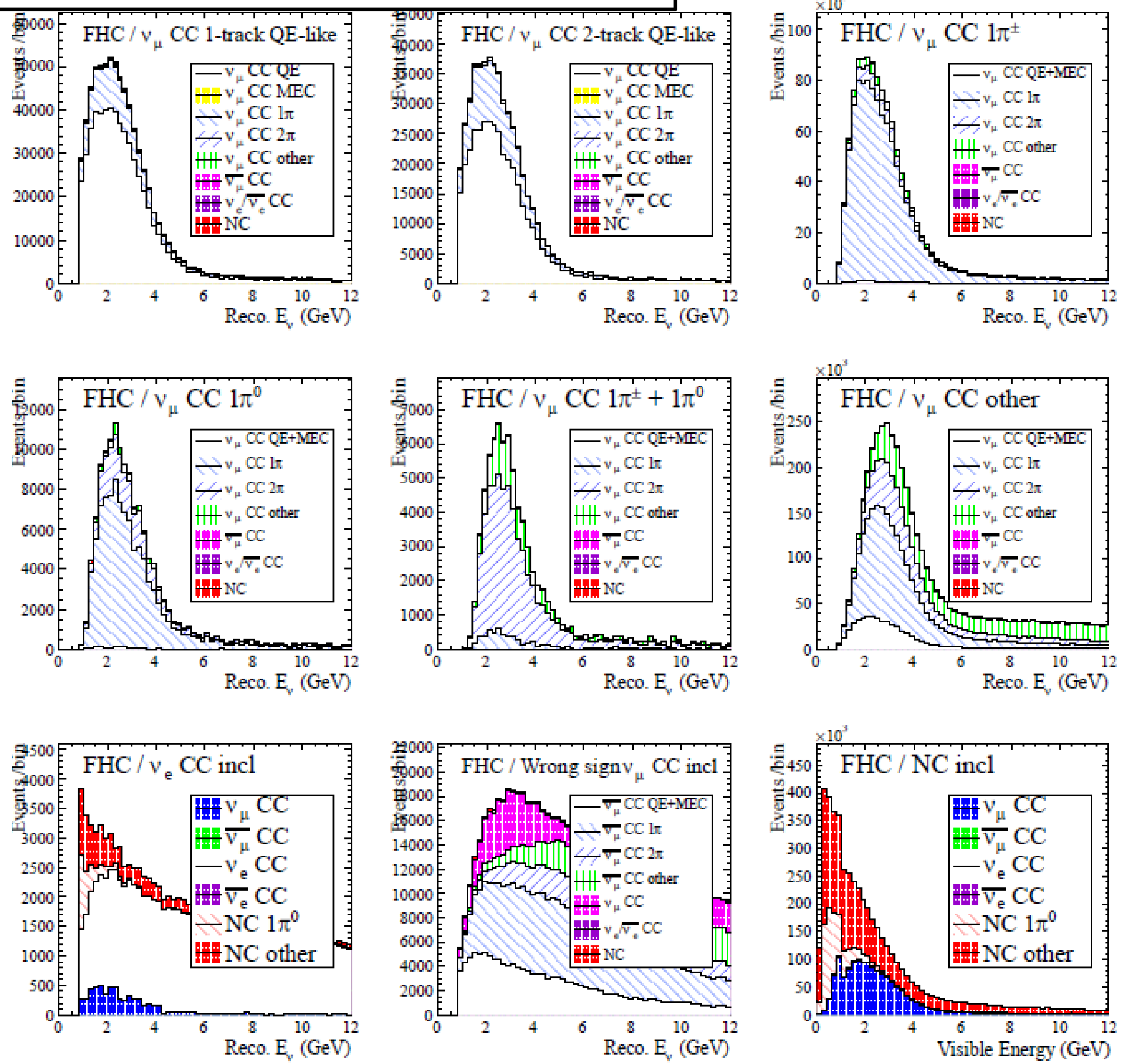
Nominal ND E_{reco} (or $E_{visible}$) spectra are shown for the 9 FHC samples included in the 2014v1 VALOR LBNE-ND fit.

The contributions from different y_{reco} ranges are shown.

Kinematics of each sample

VALOR/LBNE-ND: Example ND spectra

Cross section channels in each sample



Nominal ND E_{reco} (or $E_{visible}$) spectra are shown for the 9 FHC samples included in the 2014v1 VALOR LBNE-ND fit.

In the fit, 52 true reaction mode components are kept track of for each sample. Here these components have been bundled in just a few broad categories and their contribution to each sample is shown.

Flux and cross-section parameters in VALOR/LBNE-ND fit

51 parameters are included in the 2014v1 VALOR/LBNE-ND fit.

- f (FHC; $\Phi\nu_\mu$; 0-2.0 GeV)
- f (FHC; $\Phi\nu_\mu$; 2.0-2.5 GeV)
- f (FHC; $\Phi\nu_\mu$; 2.5-3.0 GeV)
- f (FHC; $\Phi\nu_\mu$; 3.0-3.5 GeV)
- f (FHC; $\Phi\nu_\mu$; 3.5-4.0 GeV)
- f (FHC; $\Phi\nu_\mu$; 4.0-5.0 GeV)
- f (FHC; $\Phi\nu_\mu$; 5.0-7.0 GeV)
- f (FHC; $\Phi\nu_\mu$; 7.0-10.0 GeV)
- f (FHC; $\Phi\nu_\mu$; 10.0-25.0 GeV)
- f (FHC; $\Phi\nu_\mu$; $>$ 25.0 GeV)
- f (FHC; $\Phi\bar{\nu}_\mu$; 0-3.0 GeV)
- f (FHC; $\Phi\bar{\nu}_\mu$; 3.0-5.0 GeV)
- f (FHC; $\Phi\bar{\nu}_\mu$; 5.0-7.0 GeV)
- f (FHC; $\Phi\bar{\nu}_\mu$; 7.0-10.0 GeV)
- f (FHC; $\Phi\bar{\nu}_\mu$; $>$ 10.0 GeV)
- f (FHC; $\Phi\nu_e/\bar{\nu}_e$; 0-5.0 GeV)
- f (FHC; $\Phi\nu_e/\bar{\nu}_e$; 5.0-10.0 GeV)
- f (FHC; $\Phi\nu_e/\bar{\nu}_e$; $>$ 10.0 GeV)

- f (RHC; $\Phi\nu_\mu$; 0-3.0 GeV)
- f (RHC; $\Phi\nu_\mu$; 3.0-4.0 GeV)
- f (RHC; $\Phi\nu_\mu$; 4.0-5.0 GeV)
- f (RHC; $\Phi\nu_\mu$; 5.0-7.0 GeV)
- f (RHC; $\Phi\nu_\mu$; 7.0-10.0 GeV)
- f (RHC; $\Phi\nu_\mu$; 10.0-25.0 GeV)
- f (RHC; $\Phi\nu_\mu$; $>$ 25.0 GeV)
- f (RHC; $\Phi\bar{\nu}_\mu$; 0-2.0 GeV)
- f (RHC; $\Phi\bar{\nu}_\mu$; 2.0-3.0 GeV)
- f (RHC; $\Phi\bar{\nu}_\mu$; 3.0-4.0 GeV)
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- f (RHC; $\Phi\bar{\nu}_\mu$; 10.0-25.0 GeV)
- f (RHC; $\Phi\bar{\nu}_\mu$; $>$ 25.0 GeV)
- f (RHC; $\Phi\nu_e/\bar{\nu}_e$; 0-5.0 GeV)
- f (RHC; $\Phi\nu_e/\bar{\nu}_e$; 5.0-10.0 GeV)
- f (RHC; $\Phi\nu_e/\bar{\nu}_e$; $>$ 10.0 GeV)

- f (σ; CC QE)
- f (σ; CC $1\pi^\pm$)
- f (σ; CC $1\pi^0$)
- f (σ; CC other)
- f (σ; NC)
- f (σ; ν_e/ν_μ)

- f (ϵ; ν_μ CC; 1-trk QE-like)
- f (ϵ; ν_μ CC; 2-trk QE-like)
- f (ϵ; ν_μ CC; $1\pi^\pm$)
- f (ϵ; ν_μ CC; $1\pi^0$)
- f (ϵ; ν_μ CC; $1\pi^\pm$+$1\pi^0$)
- f (ϵ; ν_μ CC; other)
- f (ϵ; ν_e CC)
- f (ϵ; Wrong sign ν_μ CC)
- f (ϵ; NC)

Φ: flux
σ: cross-se
ϵ: efficienc

What fit parameters are needed?

Do knobs / responses adequately express uncertainties?

Example ND Analysis: Fully Leptonic Electoproduction

- Based on work of X. Tian and collaborators (LBNE docdb-9418)
- Reaction channel: $\nu + e^- \rightarrow \nu + e^-$
- Well known cross section can be used to constrain absolute flux (0.5 – 10 GeV)
- Key component of DUNE experimental design
- How does this fit into the VALOR framework?
  - Currently in ν_e CC inclusive
  - Move to ν_e CC 0π sample?
  - Sits in y_{reco} = 0 bin(s)
  - Does sample need alternate template or selection to be used adequately?
- Needs from the NDPWG:
  - How to include in ND Evaluations scheme
  - Independent validation of analysis strengths
  - Realistic evaluation of systematic uncertainties
    - Resolution on cut / kinematic variables
    - Uncertainties on background processes
    - Theoretical uncertainties on the cross section

Selection Cuts

Cut	Sig.	Sig. Eff.	Back.	Back. Surv. Prob.
Fiducial	1.052e+04	1	9.747e+07	1
$p_e > 0.2$ GeV/c & $n_e^{\text{hits}} \geq 4$	9784	0.9301	9.607e+07	0.9856
μ-veto	9784	0.9301	3.476e+07	0.3566
$\pi^0/n/K_0$ veto	9784	0.9301	1.69e+07	0.1734
no positive track	9784	0.9301	2.961e+06	0.03038
1 negative track	8724	0.8294	2.288e+04	0.0002347
$E_e > 0.5$ GeV & $n_e^{\text{hits}} \geq 12$	7680	0.7301	331.5	3.401e-06
$p_e^T < 0.1$ GeV	7677	0.7298	324.9	3.333e-06
$\theta_e < 0.1$ Rad	7677	0.7298	324.9	3.333e-06

- μID:
  $\mu\text{ID} = 60\%$ @ $p_\mu \in [0.2, 0.6]$ GeV/c,
  $\mu\text{ID} = 80\%$ @ $p_\mu \in [0.6, 1.0]$ GeV/c,
  $\mu\text{ID} = 95\%$ @ $p_\mu > 1.0$ GeV/c.
- π^0 veto: Require $p_\gamma < 0.08$ GeV,
- neutron veto: Require $T_n < 0.25$ GeV,
- K_0 veto: Require $T_{K_0} < 0.25$ GeV,
- TRD efficiency applied: 90% for electron, 10^{-3} for $\mu^\pm, \pi^\pm, K^\pm$, *etc.*

Can we simulate each of these quantities for each ND technology?

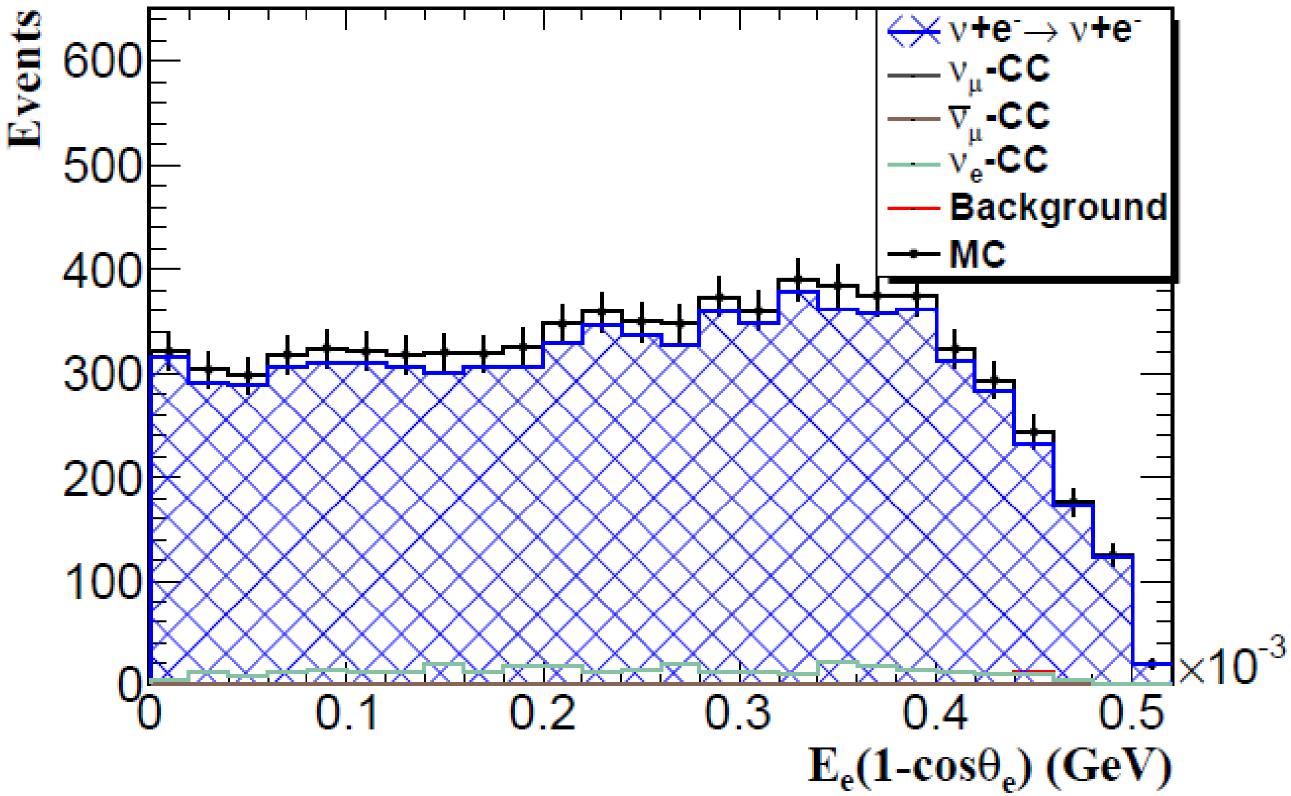
How important is the simulation accuracy?

What is the sensitivity to Δcut value?

$\mathcal{Z}_e$ distribution

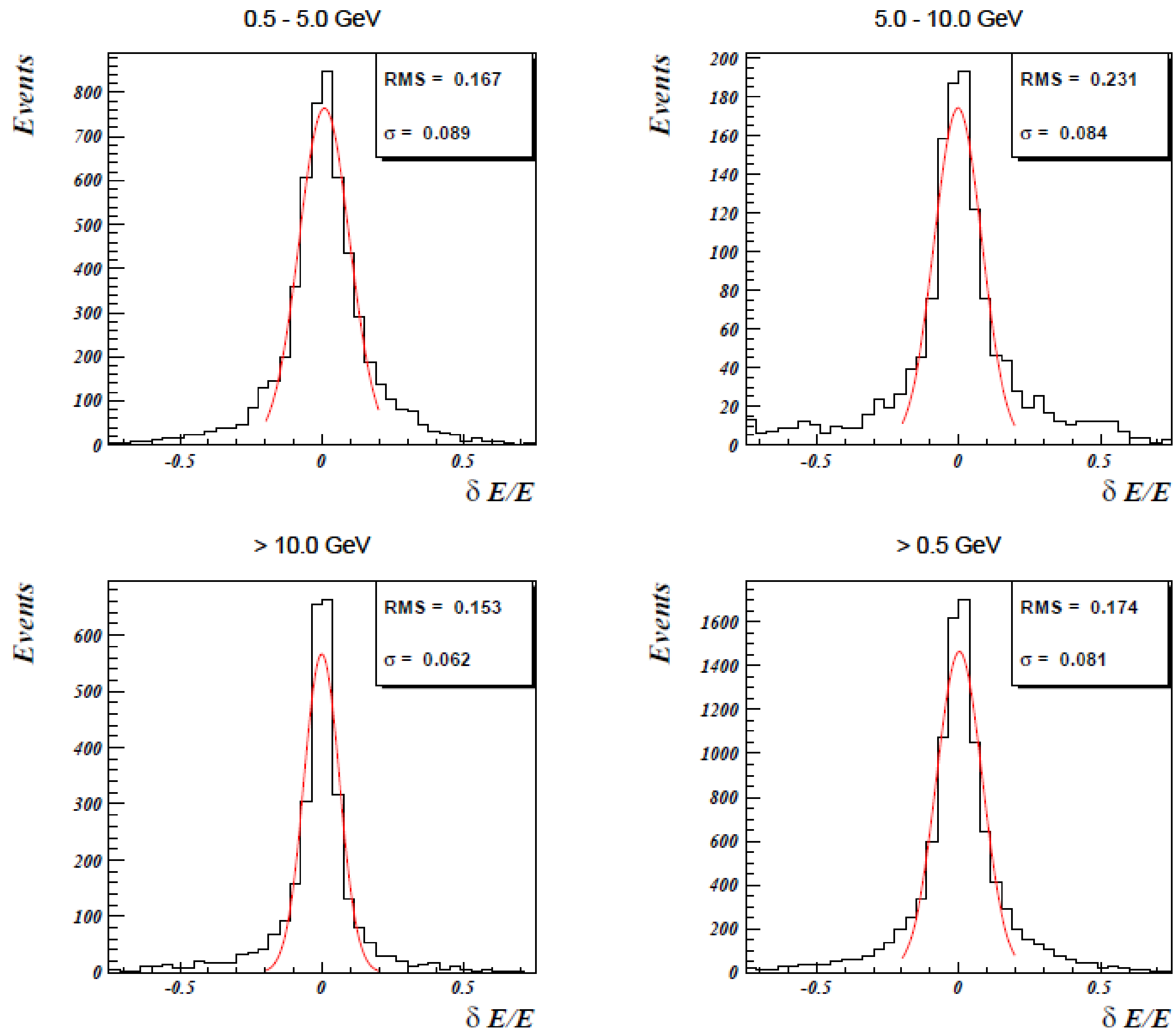
How do we include this kinematic cut in a topologically defined sample?

In which ways can this tight range for the signal be degraded (angular resolution, beam dispersion, etc)?



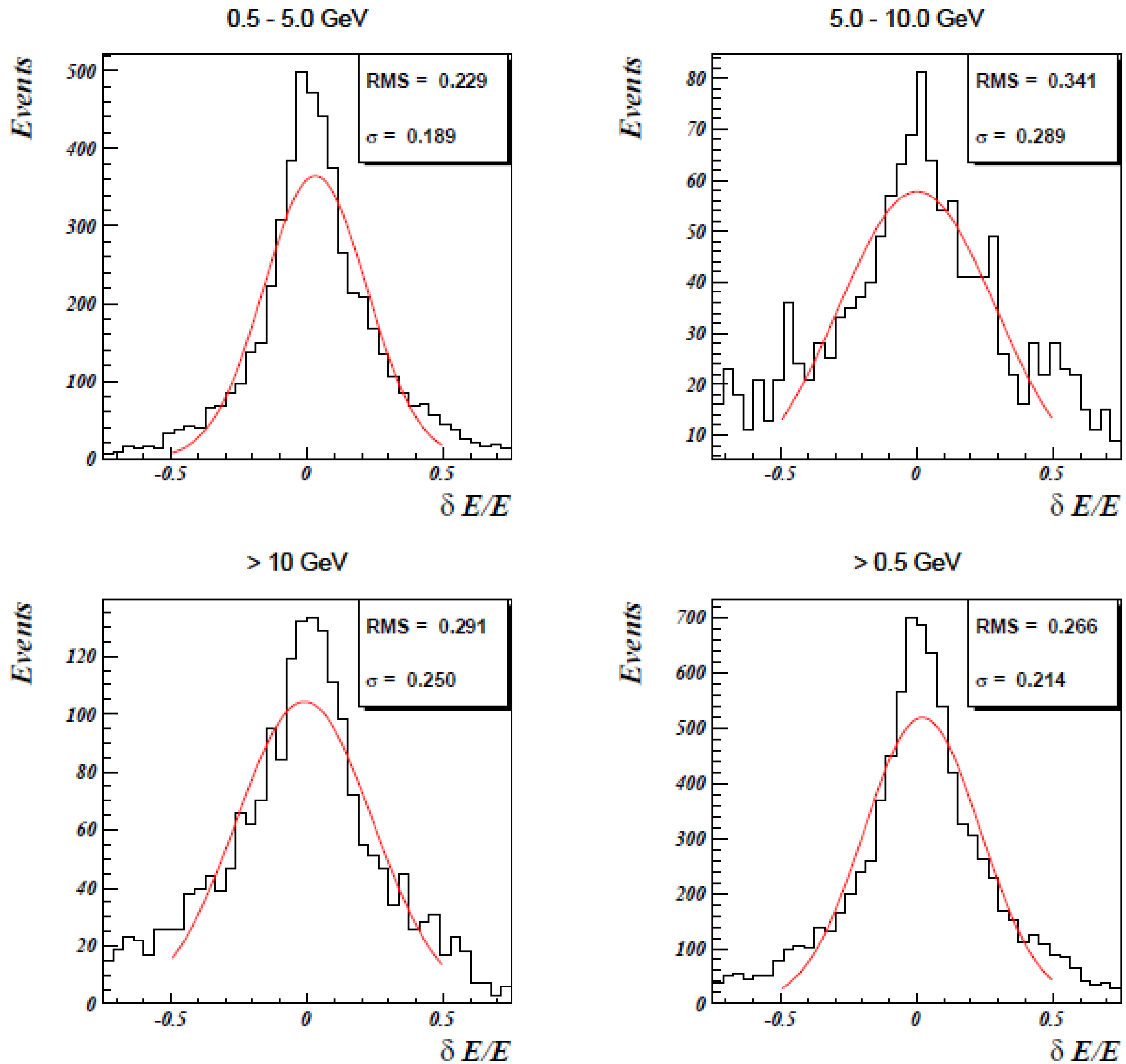
Example of importance of simulation detail

Energy resolution - nominal angular resolution



Example of importance of simulation detail

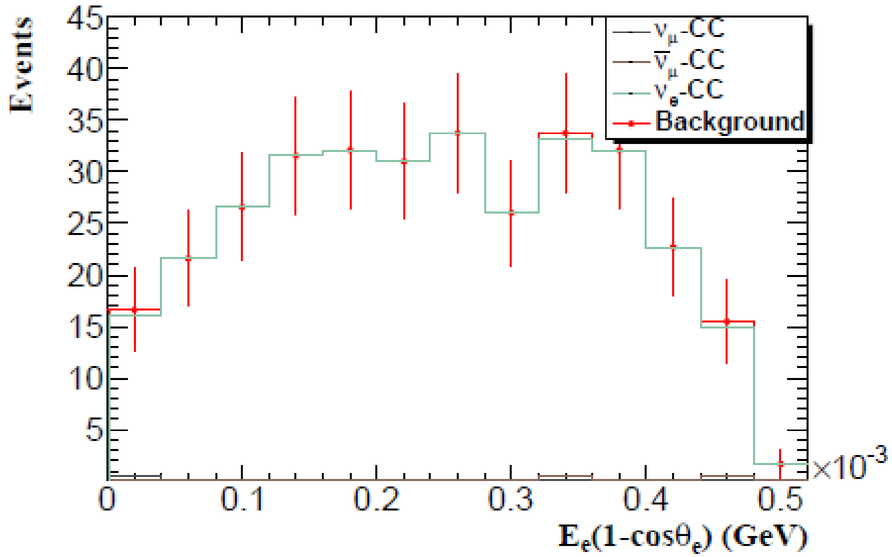
Energy resolution - nominal angular resolution + neutrino intrinsic angle

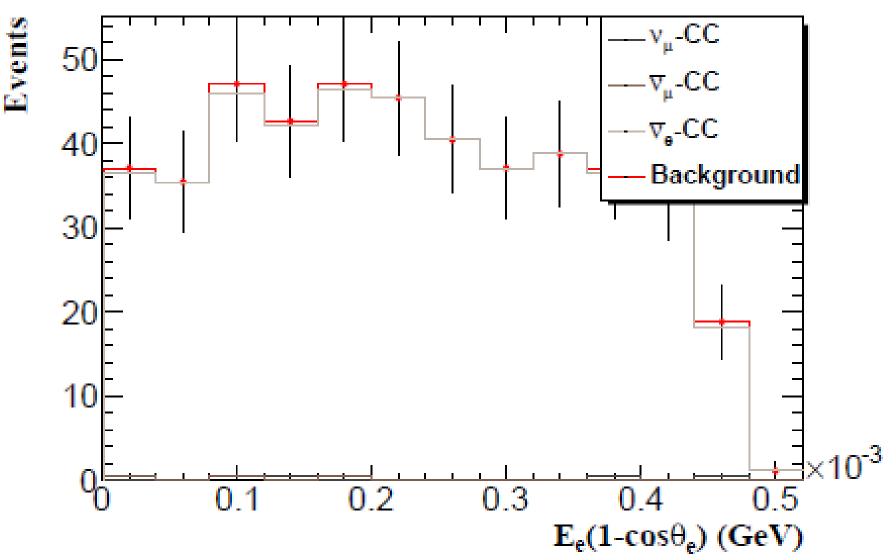


e^- vs e^+ sample background

Background uncertainties and propagation of errors?

If theoretical uncertainty is a few %, then can this be limited to a similar level?





Conclusion:
Inclusion of this simple selection and analysis already introduces some interesting questions

How does one include the low-ν_0 sample / analysis in a multi-sample fit?

Conclusions

- Each WG needs to make a significant contribution to NDTF goals and each has a lot of work left to do
- Contributions from Flux and FD/LBPWG are straight-forward, while NDWG and NDPWG contributions have many unknowns
- The work of the NDTF, NDPWG, and NDWG are closely aligned
- Defining samples for “stand alone” and “multi-sample fit” analyses have large overlaps
- Performing stand alone analyses will provide valuable information on multi-sample fit samples and analysis performance
- Can the NDPWG focus on analyses germane to the long-baseline oscillation analyses (esp. CPV) for the next 6-12 months?
- The NDTF will facilitate communication with the relevant WGs, especially the NDWG subgroups