The University Of Sheffield.

NUISANCE-MINERvA Generator Tuning

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MINERvA Meeting

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Introduction

- NUISANCE framework released to provide an open source generator tuning framework to the neutrino community.

- It provides a good platform to release tunings with; if new datasets/models are released the tunings can be updated quickly.

- NUISANCE team want to collaborate with MINERvA to produce the first public ‘MINERvA’ generator model constraint.

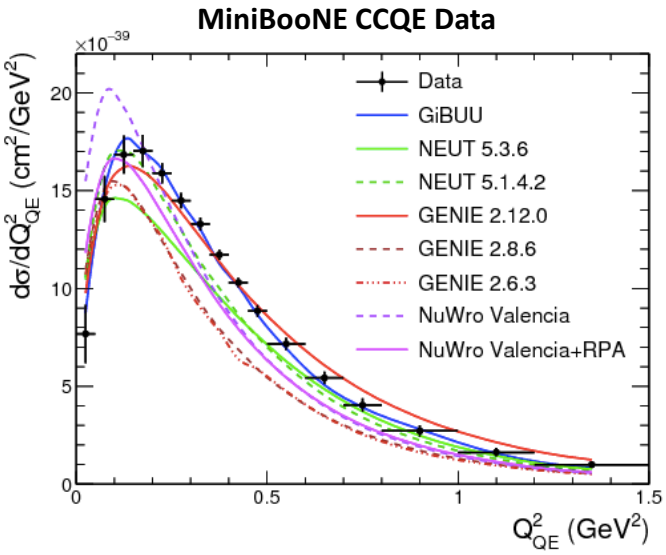
- Applied for NPC Scholar funding to come out to Fermilab just after NuInt for 2 months (think this is a good time as we can take all the newly released data and include that too)

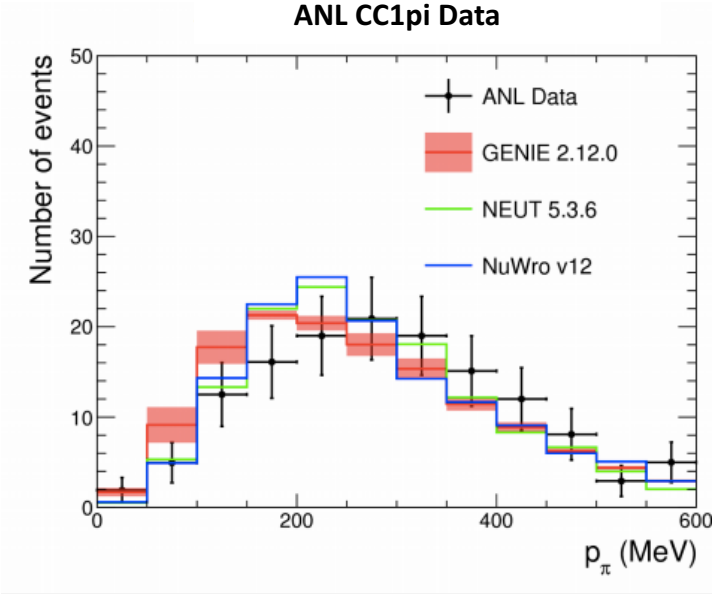
NUISANCE Generator Support

- Simple to perform model tunings in NUISANCE allowing reweight parameters to float freely until a likelihood is maximised.
- Supports multiple reweightable generators.
  - NEUT
  - GENIE
  - NuWro

NuWro has less free parameters but will probably be included in summer tunings/comparisons.

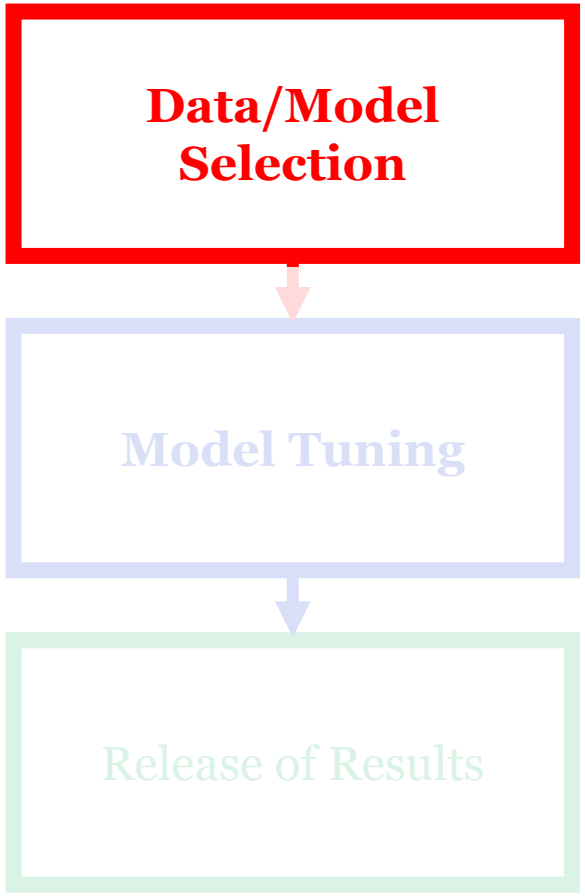
- NUISANCE allows us to take advantage of the different generator strengths when trying to understand fit results.





Stages of tuning

- Can split up model tuning into 3 main steps.



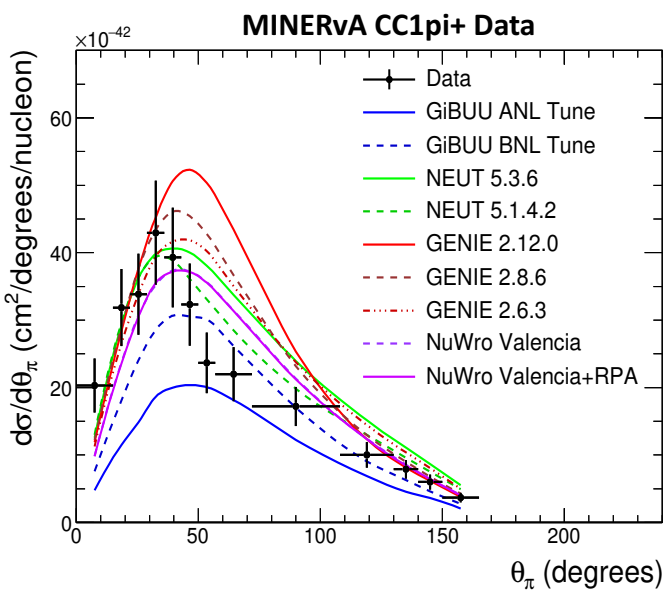
Choose datasets which will constrain which model free parameters.

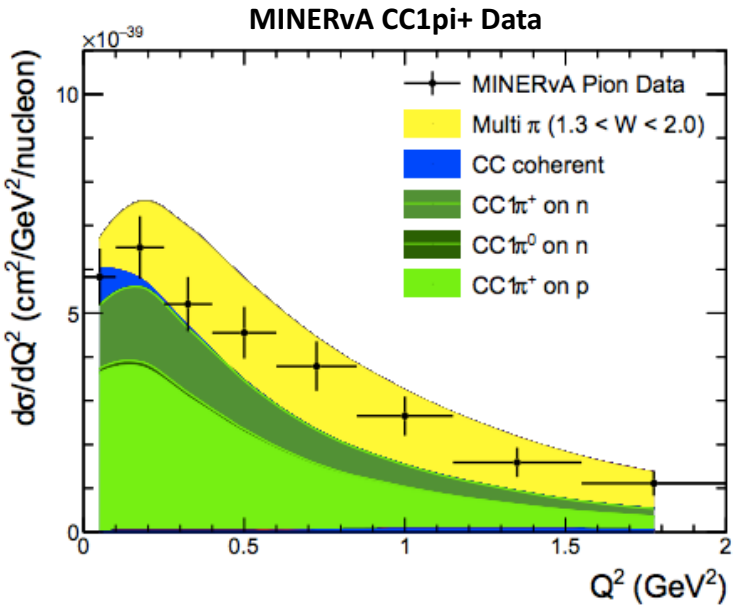
Run NUISANCE with parameters floating freely and find parameter set that maximises likelihood.

MINERvA Tuning Paper discussing the results

Data Selection

- Already a selection of MINERvA datasets included in NUISANCE.





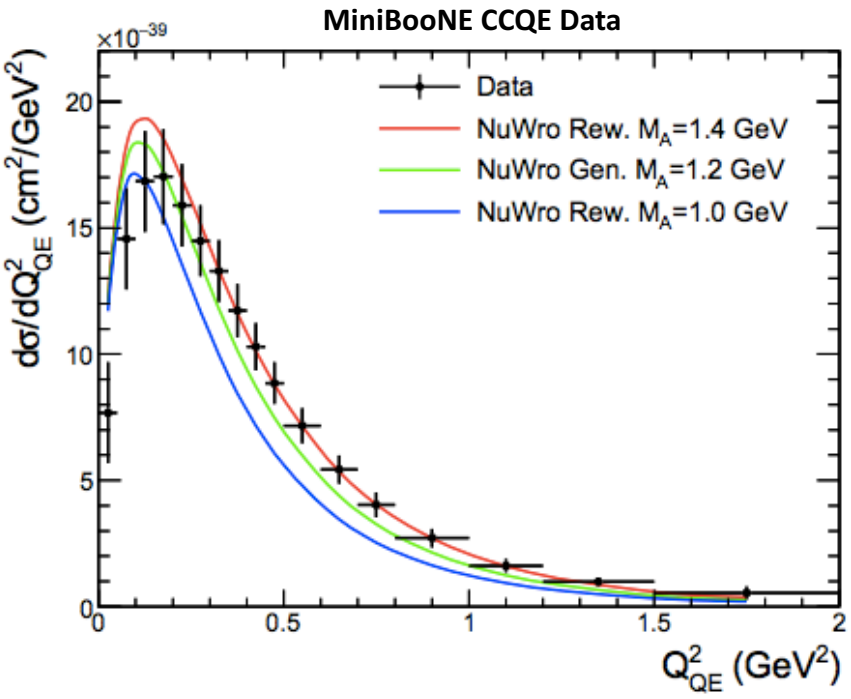
- Quick to add new datasets as they become available. Will aim to have all public datasets implemented before we start tuning.

- Want to tune to full MINERvA dataset, but will be important to understand which data subsets are sensitive to which parameters.

Event ReWeighting

- NUISANCE interfaces with the generator reweight engines and has access to any of their reweight dials.

- Modular design means additional reweight engines or custom dials can be added if necessary.

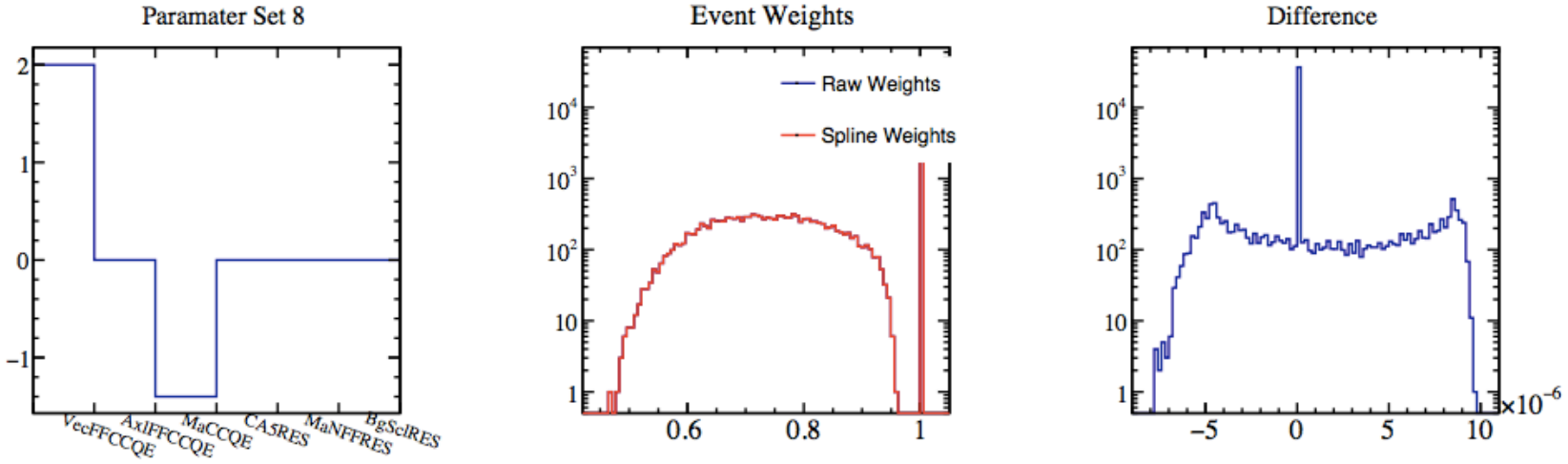


Warning

- Model parameters you want to tune NEED to be reweightable in some way if you want to use the standard NUISANCE tuner.
- We will need to run lots of separate fits at discrete values for parameters that are not reweightable (eg. SF/LFG/RFG).

Spline ReWeighting

- event-by-event NUISANCE splines can be calculated that parametrize event weight response to different parameters.
- Splines loaded into memory reducing prediction time significantly (~1 second)



Example Spline Validation for MaCCQE Dial Variations

- E.g. Single event spline set can be generated that covers all MINERvA FHC numu CH datasets.

Model Selection

- Need a starting model with wide enough parameter limits so that it can cover the range of data.

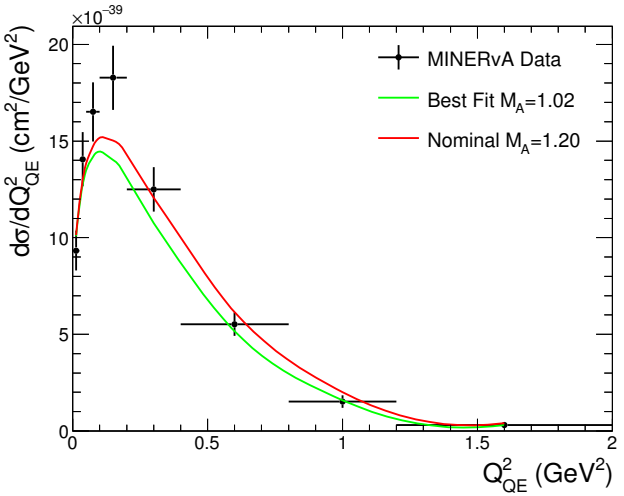
- For NEUT example model/dial variations are:

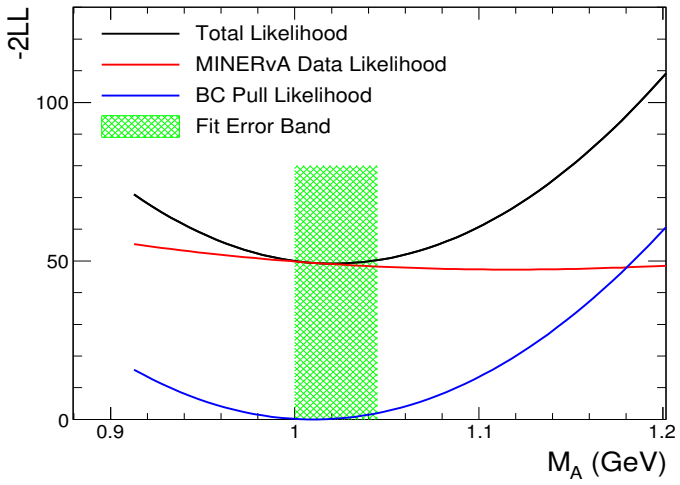
Category	Variations
CCQE	M_A, p_F, E_b, RPA
2p2h	Norm., Delta-Shape, PN/NN ratio
RES	M_A^{RES}, C_A^5, $I_{1/2}$
FSI	Pion/Nucleon Fractions
Other	Channel Norms., Nue-numu norm. ratio.
Nuclear	RFG, SF

- M_A, M_A^{RES}, C_A^5, $I_{1/2}$ can get initial constraints from free nucleon data and FSI constraints come from π-A data.

Priors

- Plan to have a full set of free nucleon model tunings to bubble chamber data by the summer (M_A, M_A^{RES}, C_A^5, $I_{1/2}$)





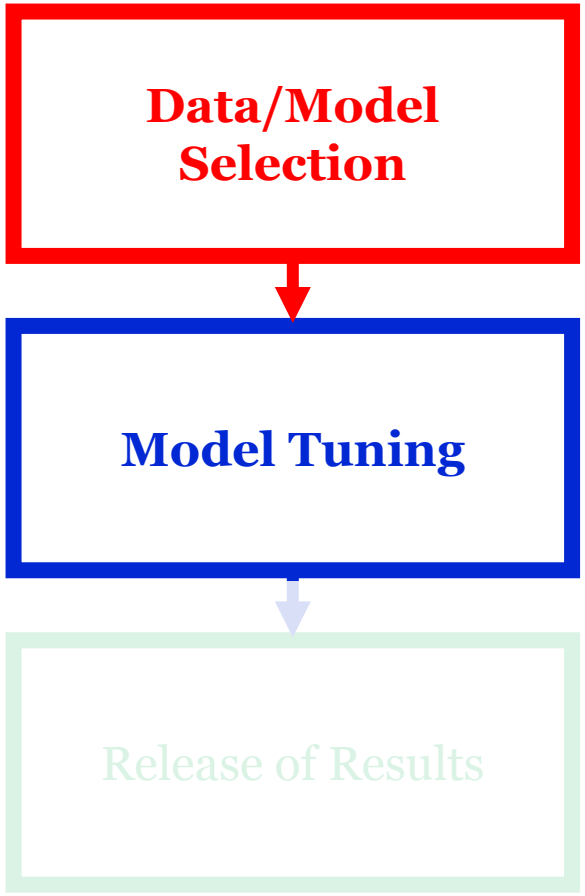
MINERvA MaCCQE tuning with bubble chamber (BC) prior included

- NUISANCE has added support to include prior model tunings by adding in additional penalties to the likelihood.

- Will most likely want to look at tunings with *and* without these bubble chamber tuning priors.

Stages of tuning

- Can split up model tuning into 3 main steps.



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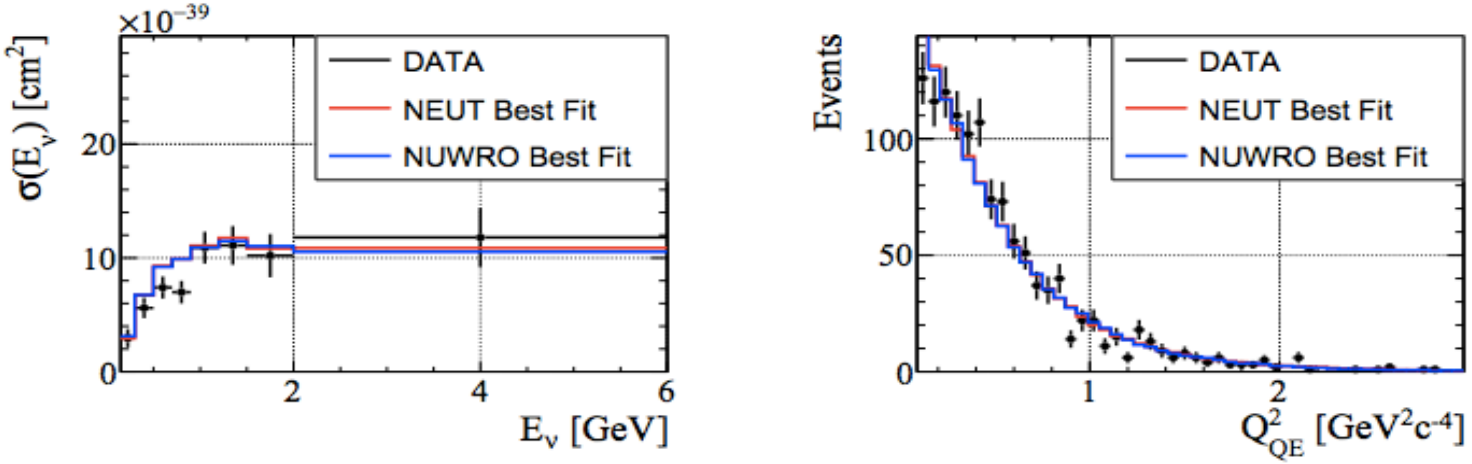
MINERvA Tuning Paper discussing the results

‘Migrad’ Tuning

- Frequentist Method
  1. Form a joint likelihood for all samples included in a fit.
  2. Use ROOT’s GSL minimizer libraries to find a best fit.
  3. Use MINOS to evaluate errors and parameter contours.



Best Fit Model Tunings to ANL CCQE Data obtained using NUISANCE minimizer

- Current method used by the T2K Neutrino Interactions Group when running external data fits.

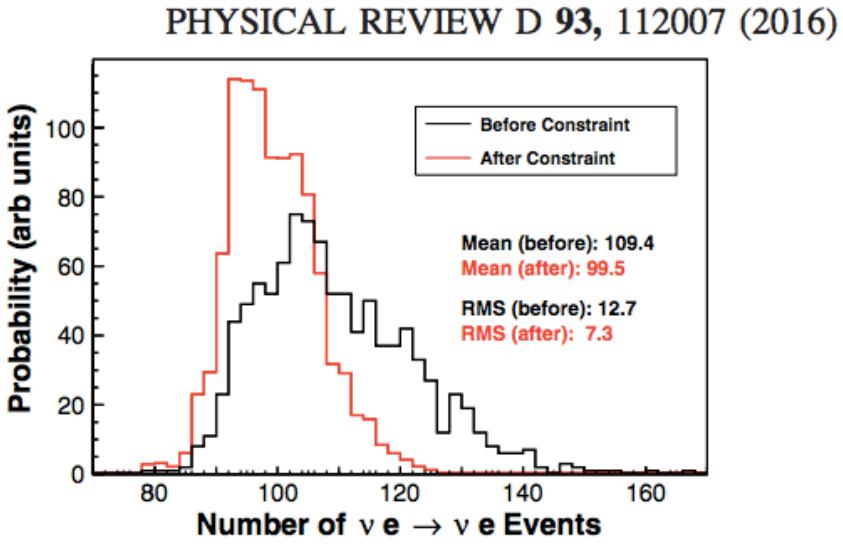
Parameter Throws Tuning

- Bayesian Method
  1. Throw 1-sigma prior uncertainties for all free params.
  2. Bin prior distribution with no weights for each param.
  3. Bin distribution again weighting each throw by the likelihood calculated below.

- NUISANCE can throw parameters according to arbitrary prior distributions and saves the Data-MC χ^2 value for each dataset.

$$P(N_{\nu e \to \nu e}|M) = \frac{1}{(2\pi)^{K/2}} \frac{1}{|\Sigma_{\mathbf{N}}|^{1/2}} e^{-\frac{1}{2}(\mathbf{N}-\mathbf{M})^T \Sigma_{\mathbf{N}}^{-1} (\mathbf{N}-\mathbf{M})}$$

Can form these distributions using the standard NUISANCE 'nuissyst' app



Method Comparison

- Both methods have their strengths. If we can use splines for all model parameters then I would like to try both methods.

Method	Pros	Cons
'Migrad' Tuning	• Can quickly see if parameters are pulled to crazy values.	• Need to run many different fits when looking at subsets of the data. • Risk of getting stuck in local minima.
Bayesian Tuning	• One single large set of throws should cover all possible fits to subsets of the data. • Additional prior penalty terms (BC tuning) can be included after throws are made.	• Requires many throws when looking at many dimensional fits. • Need to make sure prior covers all datasets.

Stages of tuning

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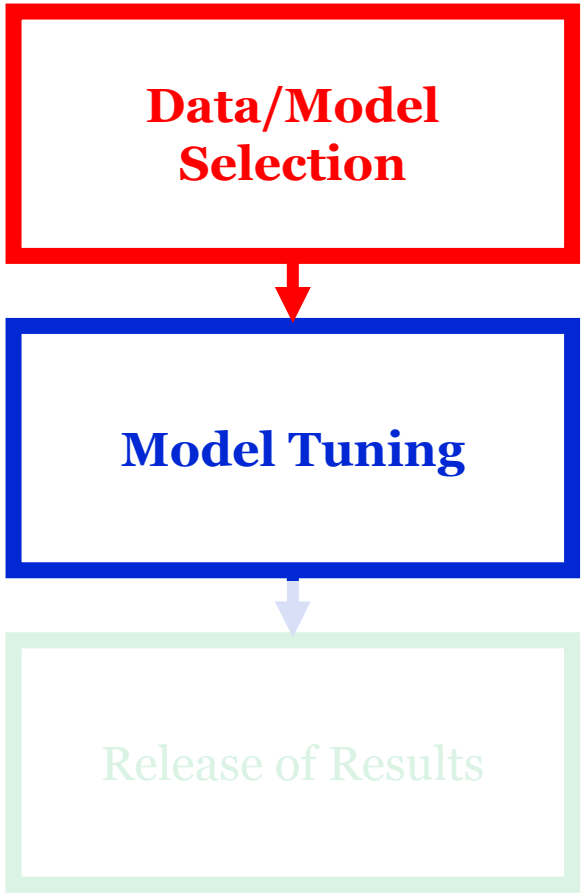

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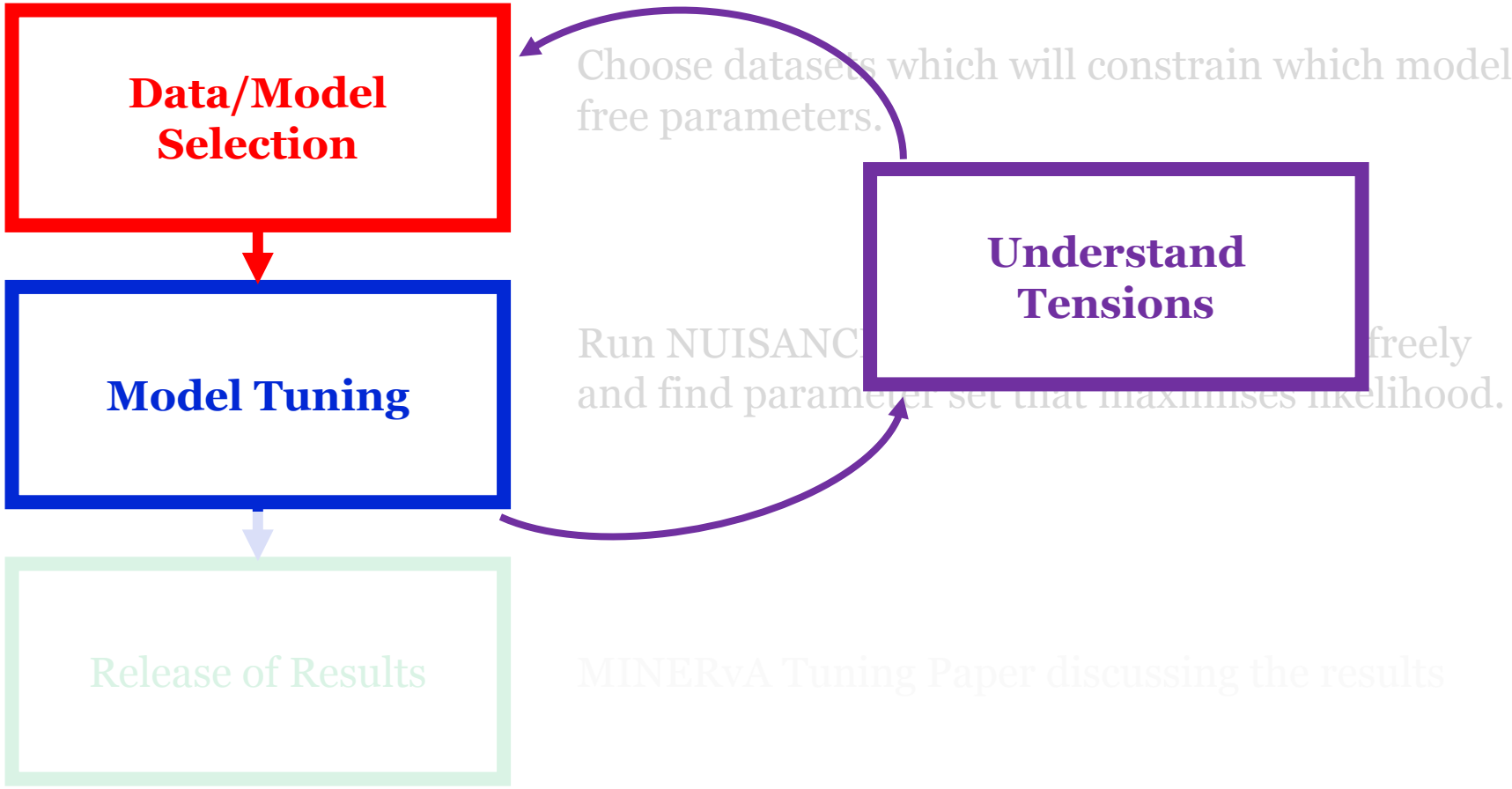
Stages of tuning (reality)

- Expect to have to go through a few tuning iterations if there are significant tensions between datasets.



Tensions

- T2K had difficulties when running joint fits to external data.
- Fitting CCQE model to MINERvA+MiniBooNE with NEUT:
  - disagreement with theory (suppression of 2p2h)
  - disagreement between datasets

Model	MA (GeV/c2)	2p2h Norm (%)	χ^2/NDOF
NEUT RFG + Nieves	1.14 ± 0.03	25.5 ± 12.4	106.25 / 229

T2K CCQE Tuning Results to MiniBooNE/MINERvA Data

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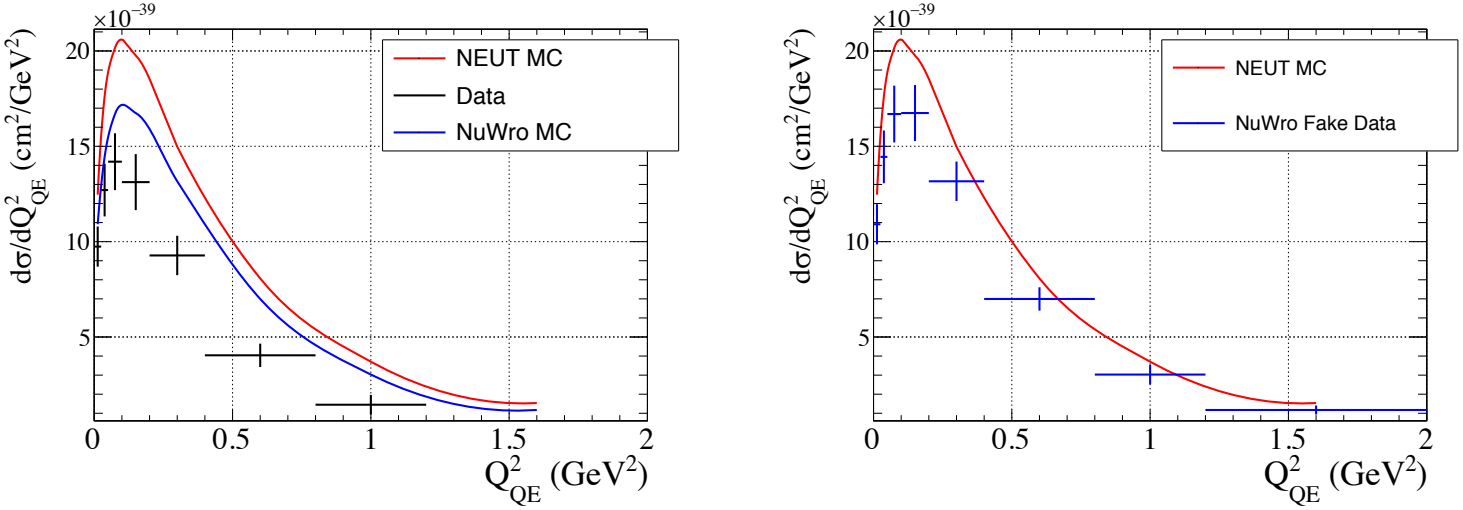
NEUT RFG + Nieves	1.14 ± 0.03	25.5 ± 12.4	106.25 / 229
NuWro LFG + Nieves	1.16 ± 0.03	8.3 ± 11.9	100.74 /229
NuWro RFG + TEM	1.15 ± 0.03	25.5 ± 12.4	93.62 / 229

T2K CCQE Tuning Results to MiniBooNE/MINERvA Data

- Having the ability to make predictions with many different generators will be really helpful at this stage.
- Expect similar issues to crop up when running an inclusive fit to many interaction channels.

Fake Data

- NUISANCE has a fake data study option that replaces all data histograms with a given MC prediction.



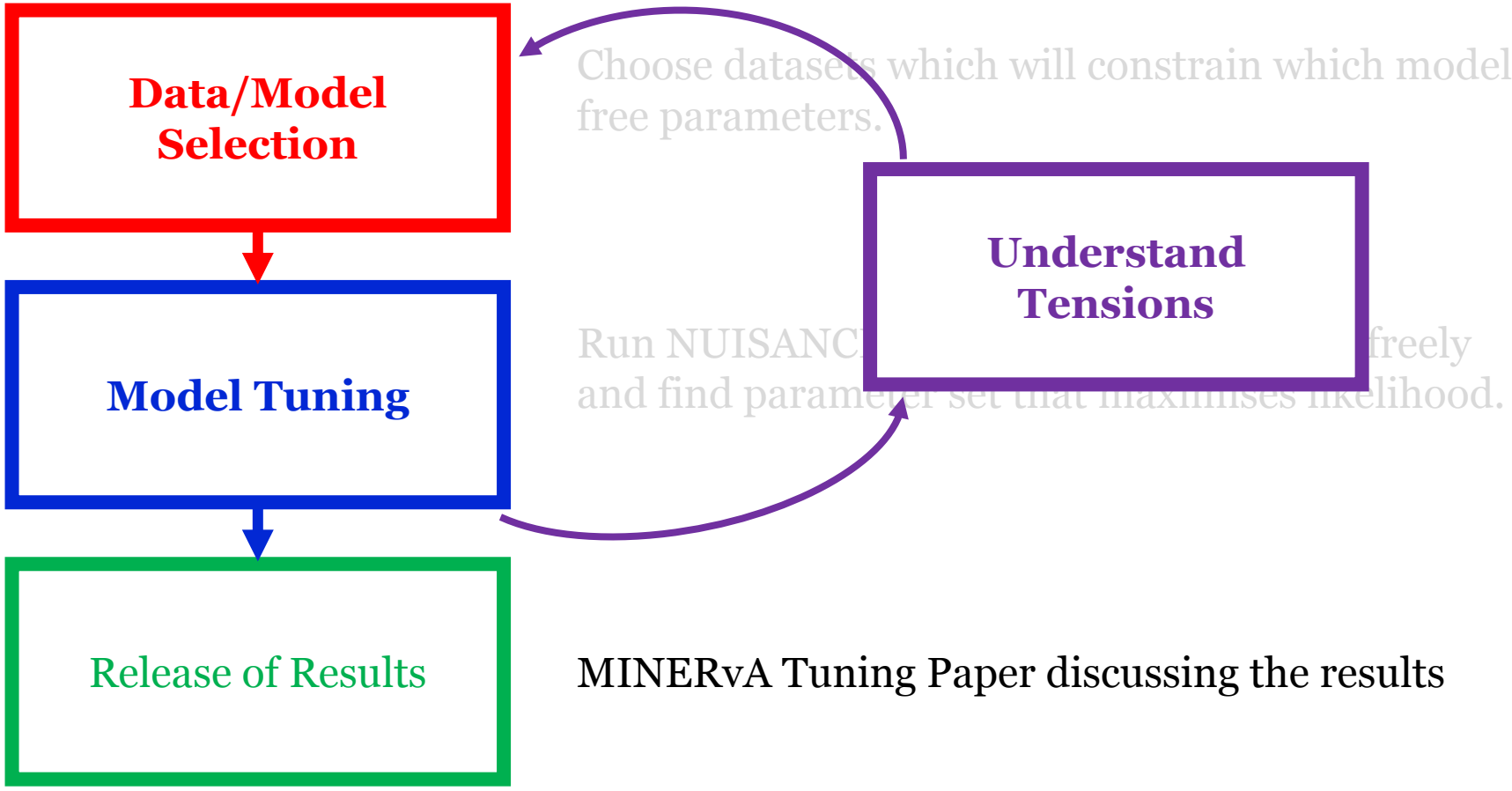
Fake Data Examples Generated for MINERvA CCQE data

- Allows you to run fake data studies to see whether one model can be faked by another:
  - e.g. Forcing an RFG to resemble an SF by shifting the fermi momentum.

- Helps to understand how bias a tuning may be, and whether model deficiencies in the generator could be causing tensions.

Stages of tuning (reality)

- Expect to have to go through a few tuning iterations if there are significant tensions between datasets.



Tuning Results

- Plan to write up tuning results and methods in a paper at the end of the summer.

- Running the fits in NUISANCE allows us to publish the configuration card files used for each stage.
- Gives users the ability to repeat the fits with alternative models/datasets if they need to.
- MINERvA will also be able to easily update tunings as new data becomes available using NUISANCE.

Example NUISANCE configuration file

```
<nuisance>

<!-- Parameter Set Definition -->
<parameter name="VecFFCCQE"  type="neut_parameter"  nominal="2"  state="FIX"/> <!--FIXED-->
<parameter name="AxlFFCCQE"  type="neut_parameter"  nominal="0"  state="FIX"/> <!--FIXED-->
<parameter name="MaCCQE"     type="neut_parameter"  nominal="0.0" low="-3.0" high="3.0" step="0.50" state="FREE"/>
<parameter name="CA5RES"     type="neut_parameter"  nominal="0.0" low="-3.0" high="3.0" step="0.50" state="FREE"/>
<parameter name="MaNFFRES"   type="neut_parameter"  nominal="0.0" low="-3.0" high="3.0" step="0.50" state="FREE"/>
<parameter name="BgSclRES"   type="neut_parameter"  nominal="0.0" low="-3.0" high="3.0" step="0.50" state="FREE"/>

<!-- Sample Joint-fit Definition -->
<sample name="MINERvA_CCQE_XSec_1DQ2_nu" input="NEUT:./MIN_CH_fhc_numu_events.root" />

</nuisance>
```

Error Bands

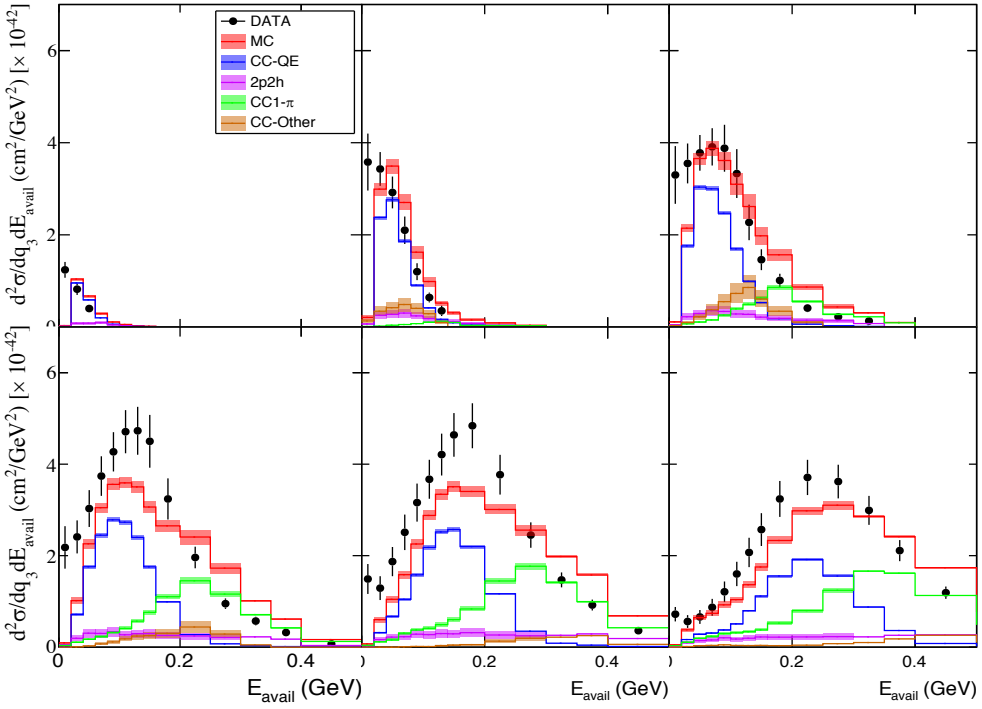
- Alongside tuning results I would like to include an error bands document similar to the NUISANCE v1r0 validation document:

NUISANCE Validation Link

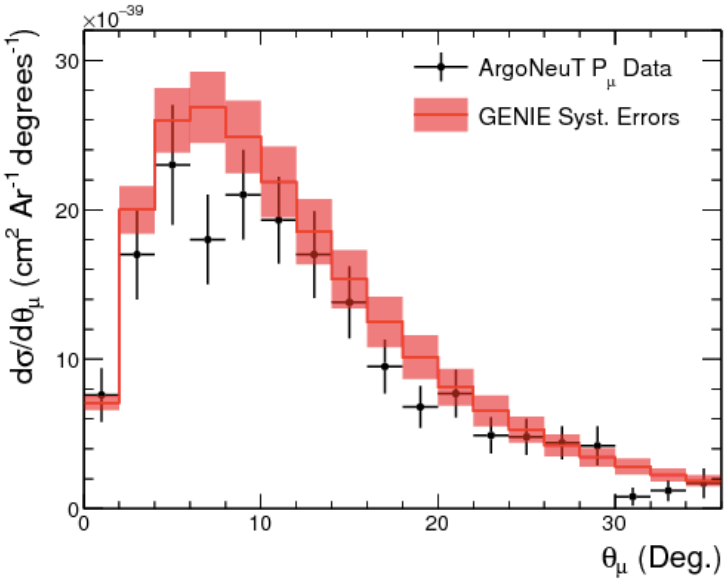
(http://nuisance.hepforge.org/files/validation/nuisancevalidation_v1r0_280217/nuisance_v1r0_validation_280217.pdf)

- Compare tuning result error bands to every dataset implemented in NUISANCE.

T2K NEUT Uncertainties vs 'Low Recoil' Data



GENIE 1-sigma Uncertainties vs ArgoNeut Data



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Summer Tuning Plan

1. Discuss generator models to be tuned
2. Discuss possible data subsets to fit to (eg. CC0pi, CC1pi)

Before summer

3. Add in any new MINERvA datasets
4. Add extra support for MINERvA reweight engines

First week after NuInt

5. Generate model splines
6. Run sensitivity studies
7. Run fake data bias studies
8. Tune to data
9. Interpret results

Iterative Procedure
Will take up the most time

10. Produce full set of NUISANCE error bands
11. Write up results
12. Commit configuration files to data release page.

Early September

Summary

- Want to have a ’MINERvA’ generator tune finished by the end of summer.
- NUISANCE is an ideal framework for performing these studies.
- Hoping to get funding to come out to Fermilab to work on this. Minerba, Gabe, and Laura have already kindly agreed to help out.
- Should be a number of NUISANCE developers in Fermilab at various stages in the summer, so a NUISANCE-MINERvA collaboration on generator tunings would be really nice.