NUISANCE Tutorial

Comparing Generators

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Workshop Aims

Few different ways you can use NUISANCE. Today we will cover

1. Using NUISANCE to compare different MCs and data.
2. Performing simple model tunings, placing a constraint on free parameters in GENIE ReWeight

In the next session (September 7th)

3. Adding a new dataset to NUISANCE.

Workshop Layout

- Three different applications we want to cover today.
- Created a list of problems to solve for each application.
- Some of you have used NUISANCE before, so I've also included some more complex problems.

Excercises:

1. Will go through the first simple problem on the screen for each session.
2. Then briefly cover extra functionality of each application, which will be needed in the later exercises.

Snippets:

```
$ commands/card files shown in red snippets can be used to follow along
$ on your own machine!
```

Setting up NUISANCE

- On the FNAL machines NUISANCE can be setup using the following commands:

```
$ export NUPSBASE=/cvmfs/minerva.opensciencegrid.org/minerva/
$ export NUISANCE=$NUPSBASE/NUISANCE_080117/nuisance/v2r6/
$ source $NUISANCE/builds/genie2126-nuwrov11qrw/Linux/setup.sh
[INFO]: Adding NuWro library paths to the environment.
[INFO]: Adding PYTHIA6 library paths to the environment.
[INFO]: Adding GENIE paths to the environment.
```

- On a non-FNAL machine the setup script should be located in your build area under the install folder

```
$ cd /path/to/nuisance/build/folder/
$ source ${uname}/Linux/setup.sh
```

- Run the following command to check it works!

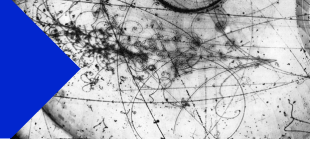
```
$ nuiscomp -h
```

What is NUISANCE?

1. Generator Convertors
   - Direct interface with generators and reweight engines.

2. Measurement Routines
   - Signal Selections
   - Data/MC Comparisons
   - Likelihood Calculations

3. Model Tuning+Systematics
   - Top-level analysis routines.
   - Interface with Migrad.

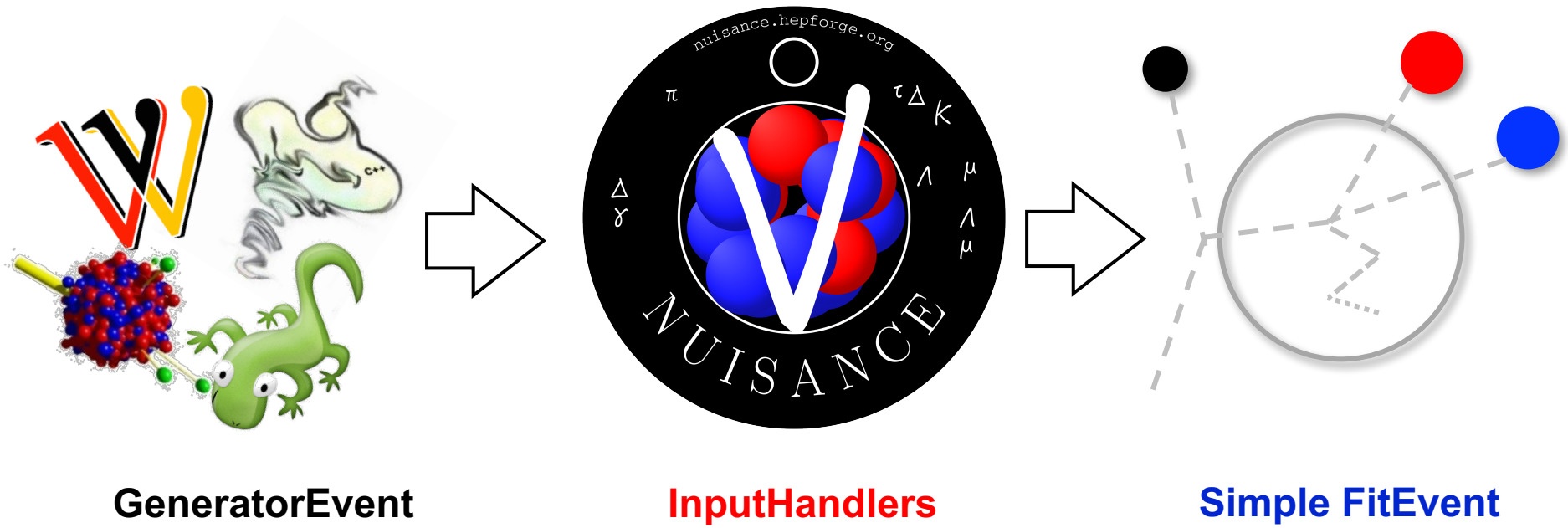


Comparisons

Generator vs Generator

Event Convertors (InputHandler)

- At the core of NUISANCE is a set of routines that convert generators into a common format.
- Designed with final state particle analysis routines in mind.

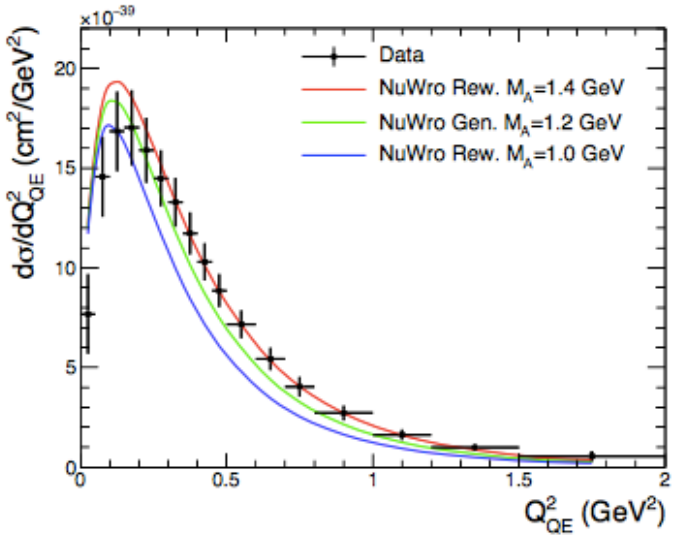


- FitEvent class is a common generator event wrapper

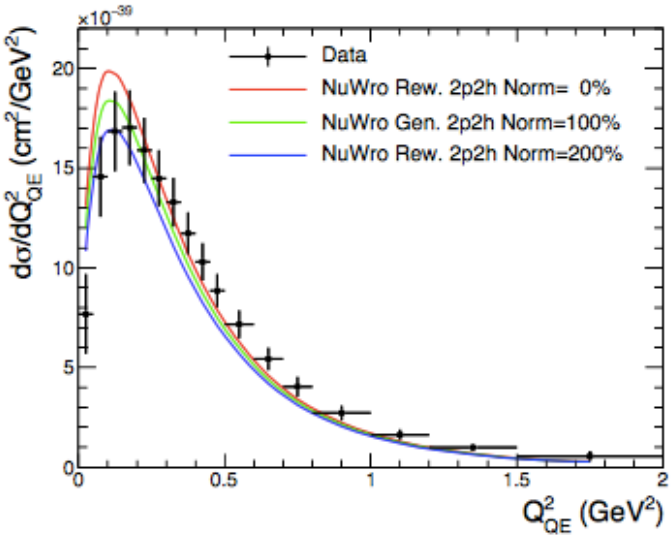
Event ReWeighting (FitWeight)

- FitEvent has original generator event that it was derived from enabling ReWeight (RW) support.

Model Variations in NuWro ReWeight



(a) M_A variations



(b) 2p2h variations

- **FitWeight class is a common RW engine wrapper**
  - Generator RW (e.g. NEUT, NuWro, GENIE)
  - Experimental RW (e.g. T2KReWeight)

Common Formats

- FitEvent/FitWeight class design tries to keep any event analysis that happens above the core InputHandlers as generator independent as possible.

- Cross-section data shouldn't depend on the generator. Method we use to compare MC events to the data also shouldn't.

- **Design provides two advantages:**
  - Any new analysis automatically supports all generators.
  - Any new generator automatically supports all analyses.

Excercises : Generator Comparisons

1. Plot the event spectrum as a function of Neutrino energy for GENIE Default events.

2. Produce a differential cross-section in ELep for GENIE Default (hint: use fScaleFactor and divide by bin width)

3. Compare the pi+ momentum (PiP) spectrum between GENIE's AltPion and Default models.

4. Plot CC0pi TLep distributions for the models below:
   - GENIE Default
   - GENIE LocalFGNievesQEAndMEC
   - NuWro LocalFGNievesQEAndMEC

Requires building NUISANCE against NuWro!

nuisflat

- Simplest NUISANCE application "nuisflat" takes an event input and converts it into a simpler TTree format.

- Very similar to GENIE's gntpc convertor.

- Given the path to a NUISANCE-ready MC file of a given "INTYPE" it can be ran using the following:

```
$ nuisflat -i INTYPE:/path/to/inputfile.root \
           -o output.root \
           -f GenericFlux \
         [ -n NEVENTS ]
```

NUISANCE Ready?

- NUISANCE needs flux and cross-section histograms to normalize events to the correct rate

$$R(E_\nu) = \Phi(E_\nu) \times \sigma(E_\nu)$$

Predicted rate given the flux

Flux

Total Xsec spline

- Standard gevgen doesn't save this in the exact format we need.

- Have custom NUISANCE applications that can generate/prepare events with this information.

- Time consuming to make events so won't cover this today.

NUISANCE Ready

- Have placed prepared MC files here:

```
/minerva/data/users/jstowell/NUISTUTORIAL/MC/genie/
```

```
/minerva/data/users/jstowell/NUISTUTORIAL/MC/nuwro/
```

- Good idea to symbolic link these folders to working area

```
$ ln -s /minerva/data/users/jstowell/NUISTUTORIAL/MC/*
```

- We also keep MC on our website, if you are ever in need of some MC events to run NUISANCE with!

Models

- There are a number of models for you to choose from in those MC folders. I'll refer to each model by its tag in the exercises.

```
$ ls ./genie/ ./nuwro/
gntp.DefaultPlusMECWithNC.MINERvA_fhc_numu.CH.2500000.ghep.root
```

- Format: **GENERATOR.TAG.FLUX.TARGET.NEVENTS.root**

Tag (model)	Notes
gntp.Default	GENIE 2.12.6 Default
gntp.DefaultPlusMECWithNC	GENIE Default+Empirical 2p2h
gntp.LocalFGNievesQEAndMEC	GENIE Default+LFG+NievesQE/2p2h
gntp.ValenciaQEBergerSehgalCOHRES	GENIE LFG+NievesQE/2p2h+BergerSehgal
gntp.EffSFTEM	GENIE Default+EffectiveSF+TEM2p2h
gntp.AltPion	GENIE Default + Alternative Pion Model
nuwroev.LocalFGNievesQEAndMEC	NuWro Default+LFG+Nieves RPA/2p2h

Input Types

- We have our event sample, now we just have to tell NUISANCE what type it is when loading them in.

- Input Format: `"FILETYPE:/path/to/eventfile.root"`

- Format is the same for all applications as this string is passed to the InputHandler creator.
- Uses `FILETYPE` to figure out what InputHandler to create.

- Some possible `FILETYPE`s:

```
GENIE:/path/geniefile.root
NUWRO:/path/nuwrofile.root
NEUT:/path/neutfile.root
GiBUU:/path/gibuufile.root
FEVENT:/path/fitevent.root
```

Problem 1

1. Plot the event spectrum as a function of Neutrino energy for GENIE Default events.

- Can generate nuisflat output by running the following command

```
$ nuisflat \
  -i GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root \
  -o genie.Default.flat.root \
  -f GenericFlux \
  -n 50000
```

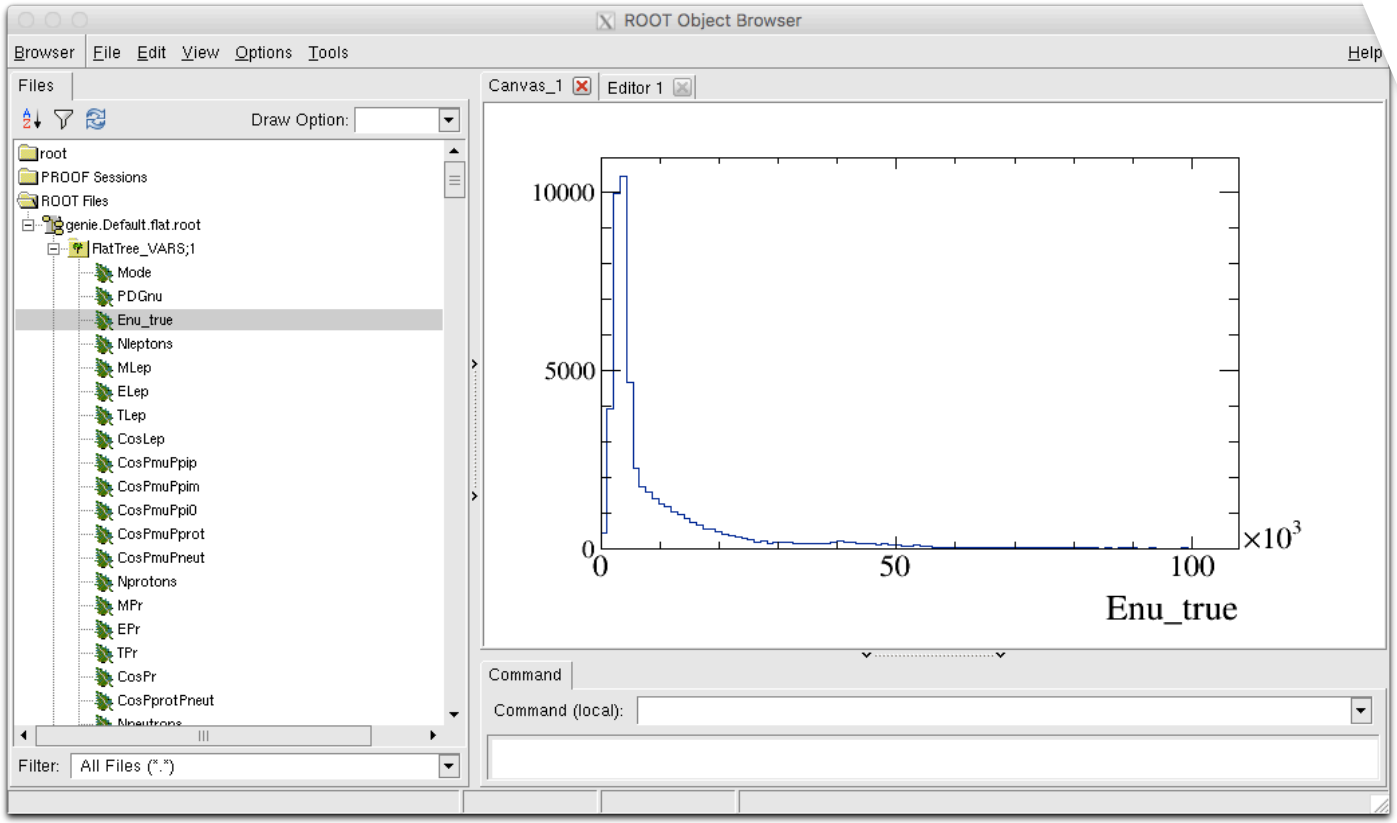
All applications let you restrict the total MC events processed using the (-n) argument.

For examples today we will be restricting the number of events to save time.

Problem 1

```
[jstowell@minervagpvm03 MC]$ root genie.Default.flat.root
root [0] Attaching file genie.Default.flat.root as _file0…
root [1] TBrowser b
root [2] FlatTree_VARS->Draw("ELep", "fScaleFactor");
```

Hint for problem 2.



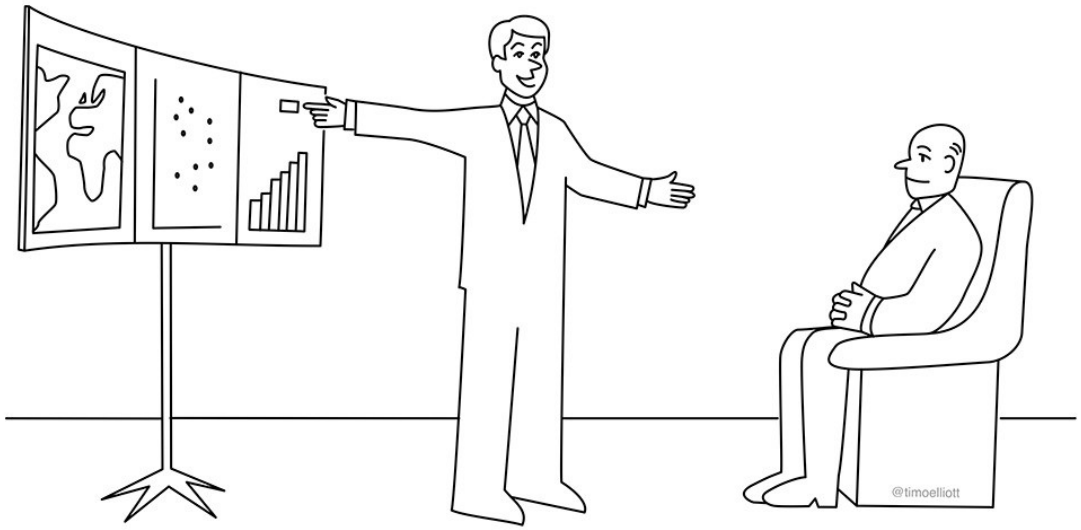
Excercises : Generator Comparisons

1. Plot the event spectrum as a function of Neutrino energy (Enu_true) for GENIE Default events.

2. Produce a differential cross-section in ELep for GENIE Default (hint: use fScaleFactor and divide by bin width)

3. Compare the pi+ momentum (PiP) spectrum between GENIE's AltPion and Default models.

4. Plot CC0pi TLep distributions for the models below:
   - GENIE Default
   - GENIE LocalFGNievesQEAndMEC
   - NuWro LocalFGNievesQEAndMEC



"And our unique JustifyIt™ feature uses deep learning to find data that agrees with your point of view!"

Comparisons

Generator vs Data

Data Comparison Classes

- Above the convertors are the measurement classes.
- Set of analysis classes that loop over a collection of FitEvent's and generate distributions.

- **These are called "samples" inside NUISANCE.**

```
$ ls $NUISANCE/src/MINERvA/

MINERvA_CCQE_XSec_1DQ2_nu.cxx
MINERvA_CCQE_XSec_1DQ2_nu
MINERvA_CCinc_XSec_1DEnu_nu.cxx
MINERvA_CCinc_XSec_1DEnu_nu.h
```

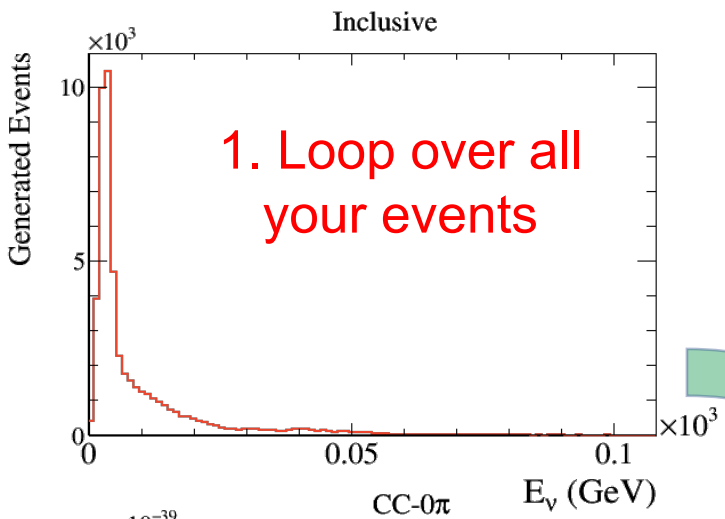
Usually one class implementation for each sample

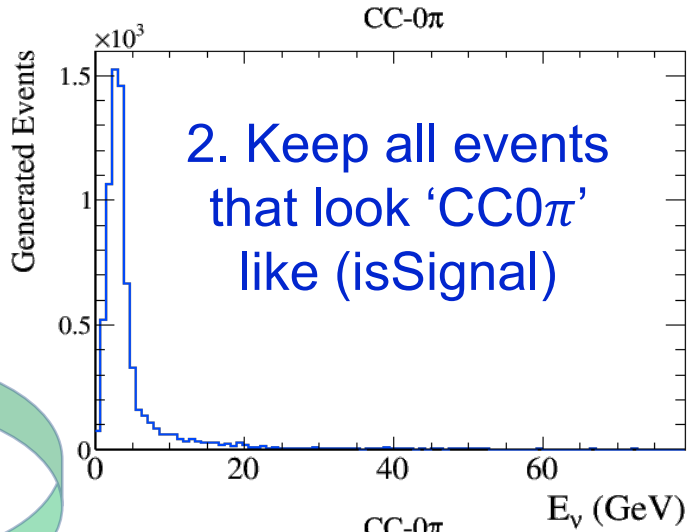
- Each sample inherits from a base "Measurement" class containing useful functions.
- Base classes help automate the processing chain.

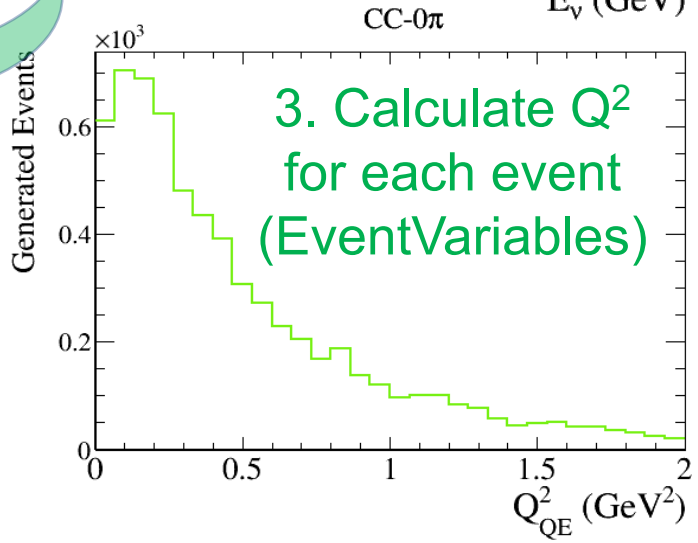
Analysis Process

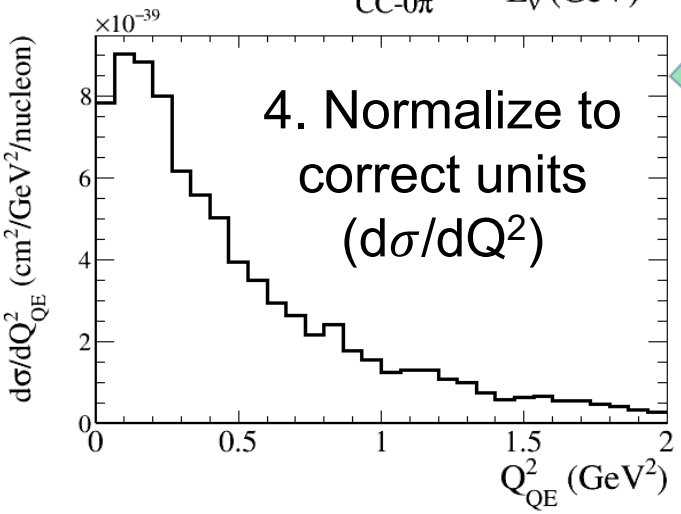
- Samples function in a similar way to a real cross-section (without detector/systematics...)

E.g. CC0π 1DQ^2_{QE} Distribution









Comparisons

- Event processing requirements (isSignal/EventVariables) on the previous slide are saved into a sample class.

- Samples can then be called easily by string, and passed an input file in a similar way to how we passed files to nuisflat.

```
<nuisance>

    <!-- Samples -->
    <sample name="MINERvA_CCQE_XSec_1DQ2_nu" input="GENIE:@GENIE_DIR/gntp.CH.root" />
    <sample name="MINERvA_CC1pip_XSec_1DTpi_nu" input="GENIE:@GENIE_DIR/gntp.CH.root" />
    <sample name="MINERvA_CC1pip_XSec_1Dth_nu" input="GENIE:@GENIE_DIR/gntp.CH.root" />

</nuisance>
```

- Adding your own sample that can be called here will be covered in the next workshop!

Excercises : Data Comparisons

1. Compare GENIE Default to MINERvA CCQE 1DQ2 data.
   (sample : MINERvA_CCQE_Xsec_1DQ2_nu)

2. Compare the GENIE Default to MINERvA CC1pip 1DTpi data with Ma^{RES} at set to $+1.0$ sigma.
   (sample : MINERvA_CC1pip_XSec_1DTpi_nu)
   (dial name : "MaCCRES" dial type: "genie_parameter")

3. Compare GENIE Default and AltPion to MINERvA CC1pip 1Dth data. *(sample : MINERvA_CC1pip_XSec_1Dth_nu)*

4. Compare the NuWro LocalFGNievesQE and GENIE LocalFGNievesQE models to MINERvA Low Recoil Data
   (sample : MINERvA_CCinc_XSec_2DEavq3_nu)

Running comparison

- Comparison application : **nuiscomp**

- nuiscomp requires you to write a card file to tell you what comparison you want it to create.

```
nuiscomp -c cardfile.xml -o output.root
```

cardfile.xml

```
<nuisance>
    <config GENIE_DIR="/path/to/my/genie/events/" />
    <parameter type="genie_parameter" name="MaCCQE" nominal="1.0" state="FIX" />
    <sample name="MINERvA_CCQE_XSec_1DQ2_nu" input="GENIE:@GENIE_DIR/gntp.CH.root" />
</nuisance>
```

- Cardfile is just a xml file listing the parameters and samples we want and the input files for each one.

Writing a card file

```
<nuisance>
  <!-- List of Samples -->

</nuisance>
```

- Open a new file in a text editor ***"samplecard.xml"***
- XML Card files wrapped in a nuisance statement so first we need to add those.
- Comments given as standard XML comments.

Writing a card file

```
<nuisance>
  <!-- List of Samples -->
  <sample name=""
          input="" />
</nuisance>
```

- To tell NUISANCE to load a new sample we need to include a "sample" XML structure.

```
<sample name="NAMEDEF"  input="INPUTDEF" />
```

Required Keys:

- "NAMEDEF" = Name of the sample to load
- "INPUTDEF" = Input MC File Information

Same format as nuisflat inputs!

Finding a sample

- Want to compare to MINERvA CCQE data.
- "nuissamples" script provided to search for sample names that can be used.

```
$ nuissamples [substring]
```

1st argument is a search substring. If none given, the full sample list is returned.

```
$ nuissamples MINERvA_CCQE
MINERvA_CCQE_XSec_1DQ2_nu
MINERvA_CCQE_XSec_1DQ2_nu_20deg
MINERvA_CCQE_XSec_1DQ2_nu_oldflux
MINERvA_CCQE_XSec_1DQ2_nu_20deg_oldflux
MINERvA_CCQE_XSec_1DQ2_antinu
...
```

This is the one we need!

Name Format: EXPERIMENT_CHANNEL_TYPE_DISTRIBUTION_EXTRAIDs

Writing a card file

```
<nuisance>
  <!-- List of Samples -->
  <sample name="MINERvA_CCQE_XSec_1DQ2_nu"
          input="" />
</nuisance>
```

- Now we just need to include our input file. Can use the same input files we used for nuisflat. e.g.

```
input="FILETYPE:/path/to/file.root"
```

- Want to compare to GENIE Default:

```
input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root"
```

Writing a card file

```
<nuisance>
  <!-- List of Samples -->
  <sample name="MINERvA_CCQE_XSec_1DQ2_nu"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- Combining everything we should have a cardfile ready.
- We can now run it using

```
$ nuiscomp -c samplecard.xml -o sampleccqe.root -n 100000
```

Again we are using 1E5 events to save time, but proper comparisons should use full event sample.

NUISCOMP Output

```
[LOG Minmzr]:- Getting likelihoods...                          : -2logL
[LOG Minmzr]:- -> MINERvA_CCQE_XSec_1DQ2_nu                    : 17.289/8
[LOG Fitter]: Likelihood for JointFCN:                          17.289
[LOG Fitter]: ------------
[LOG Fitter]: Saving current full FCN predictions
[LOG Minmzr]:- Writing each of the data classes...
[LOG Sample]:-- Written Histograms: MINERvA_CCQE_XSec_1DQ2_nu
[LOG Fitter]: ----------------------------------- -
[LOG Fitter]: Comparison Complete.
[LOG Fitter]: ----------------------------------- -
```

- NUISANCE Automatically calculates you a χ^2/NDOF value for the data/MC comparison.
- Tries to use full covariance information where possible.

- Saves all the histograms produced into our output file.

NUISCOMP Output (2)

- Number of different objects saved into the output file.
- Each one has been prepended with the sample name.
- **Examples**
  - samplename**_data** : Data distribution
  - samplename**_MC** : MC distribution in data binning
  - samplename**_MC_FINE** : MC in fine binning
  - samplename**_MC_SHAPE** : MC normalised to data
  - samplename**_data_ratio** : data/MC ratio
  - samplename**_MODES** : THStack true interaction channels

Hint: Use gPad->BuildLegend() to see all the included true interaction channel labels.

Excercises : Data Comparisons

1. Compare GENIE Default to MINERvA CCQE 1DQ2 data.
   (sample : MINERvA_CCQE_Xsec_1DQ2_nu)

2. Compare the GENIE Default to MINERvA CC1pip 1DTpi+1Dth data with Ma^{RES} at set to +1.0 sigma.
   (sample : MINERvA_CC1pip_XSec_1DTpi_nu)
   (dial name : "MaCCRES" dial type: "genie_parameter")

3. Compare GENIE Default and AltPion to MINERvA CC1pip 1Dth data. *(sample : MINERvA_CC1pip_XSec_1Dth_nu)*

4. Compare the NuWro LocalFGNievesQE and GENIE LocalFGNievesQE models to MINERvA Low Recoil Data
   (sample : MINERvA_CCinc_XSec_2DEavq3_nu)

Multiple Samples

```
<nuisance>
  <!-- List of Samples -->
  <sample name="MINERvA_CC1pip_XSec_1DQ2_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
  <sample name="MINERvA_CC1pip_XSec_1Dth_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- NUISANCE reads events from disk, and then distributes them to relevant sample classes.
- Minimal extra overhead when loading a number of different distributions or datasets from one MC file.

- Just add an extra sample xml entry for every dataset you care about and NUISANCE will load them all at once.

Multiple Sample Output

- Run this joint sample in a similar fashion.

```
$ nuiscomp -c samplecc1pip.xml -o samplecc1pip.root -n 100000
```

- Likelihoods for both samples added uncorrelated, to form a joint total likelihood for the comparison.

```
[LOG Minmzr]:- Getting likelihoods...                    : -2logL
[LOG Minmzr]:- -> MINERvA_CC1pip_XSec_1DTpi_nu           : 44.6792/7
[LOG Minmzr]:- -> MINERvA_CC1pip_XSec_1Dth_nu            : 260.352/13
[LOG Fitter]: Likelihood for JointFCN:                    305.031
```

- Two sets of histograms also now contained in the output file.

ReWeighting Predictions

```
<nuisance>
  <!-- List of parameters -->
  <parameter type="" name="" nominal="" />

  <!-- List of Samples -->
  <sample name="MINERvA_CC1pip_XSec_1DQ2_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
  <sample name="MINERvA_CC1pip_XSec_1Dth_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- Reweight parameters can be added to NUISANCE card files using a "parameter" xml structure.

```
<parameter type="DIAL_TYPE" name="NAME" nominal="DIAL_VALUE" />
```

- **Requirements:**
  - NAME : Name of the dial inside the RW Engine
  - DIAL_TYPE : RW Type (e.g. genie_parameter)
  - DIAL_VALUE : Current Value to use

Finding ReWeight Dials

```
<nuisance>
  <!-- List of parameters -->
  <parameter type="genie_parameter" name="" nominal="" />

  <!-- List of Samples -->
  <sample name="MINERvA_CC1pip_XSec_1DQ2_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
  <sample name="MINERvA_CC1pip_XSec_1Dth_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- Any dial name recognised by the RW engine is supported.
- List is in **$GENIE/src/ReWeight/GSyst.h**

```
$ grep case $GENIE/src/ReWeight/GSyst.h
case ( kXSecTwkDial_MaNCEL          ) : return "MaNCEL";              break;
case ( kXSecTwkDial_EtaNCEL         ) : return "EtaNCEL";             break;
case ( kXSecTwkDial_NormCCQE        ) : return "NormCCQE";            break;
...
```

- We want the Resonant Axial Mass ("MaCCRES")

Adding ReWeight

```
<nuisance>
  <!-- List of parameters -->
  <parameter type="genie_parameter" name="MaCCRES" nominal="" />

  <!-- List of Samples -->
  <sample name="MINERvA_CC1pip_XSec_1DQ2_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
  <sample name="MINERvA_CC1pip_XSec_1Dth_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- Now need to choose our current dial value.

```
nominal="DIAL_VALUE"
```

- Units are whatever the reweight engine uses.
- E.g. GENIE ReWeight usually considers dials in units of "1-sigma" from nominal with 0.0 being the default value

Running nuiscomp (3)

```
<nuisance>
  <!-- List of parameters -->
  <parameter type="genie_parameter" name="MaCCRES" nominal="1.0" />

  <!-- List of Samples -->
  <sample name="MINERvA_CC1pip_XSec_1DQ2_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
  <sample name="MINERvA_CC1pip_XSec_1Dth_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- **Can rerun our edited card file and save the output somewhere else for later comparisons**

```
$ nuiscomp -c samplecc1pip.xml -o samplecc1pip-rw.root -n 100000
```

- All MC curves have now been weighted with GENIE ReWeight set to MaCCRES $= +1$

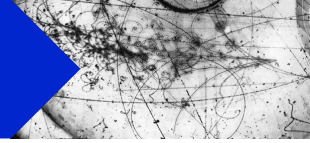
Excercises : Data Comparisons

1. Compare GENIE Default and LocalFGNievesQE to MINERvA CCQE 1DQ2 data. *(sample : MINERvA_CCQE_Xsec_1DQ2_nu)*

2. Compare the GENIE Default to MINERvA CC1pip 1DTpi data with Ma^{RES} at set to $+1.0$ sigma.
   (sample : MINERvA_CC1pip_XSec_1DTpi_nu)
   (dial name : "MaCCRES" dial type: "genie_parameter")

3. Compare GENIE Default and AltPion to MINERvA CC1pip 1Dth data. *(sample : MINERvA_CC1pip_XSec_1Dth_nu)*

4. Compare the NuWro LocalFGNievesQE and GENIE LocalFGNievesQE models to MINERvA Low Recoil Data
   (sample : MINERvA_CCinc_XSec_2DEavq3_nu)



Tuning

Reweight vs Data

Minimiser Routines

- Final layer of NUISANCE takes the convertor+comparison routines and tries to use it for model tuning.

- Direct interface with ROOT's minimiser libraries.

  (Creating a Minimizer via the Plug-In Manager)

  https://root.cern.ch/numerical-minimization

- Can treat any reweight parameter as free and try to minimise the joint χ^2 value between all samples.

- Mostly automated procedure, just list the datasets you want and the parameters you want to tune and leave it to run.

Excercises : Tuning M_A

1. Tune MaCCRES to MINERvA CC1pip 1DQ^2 data

2. Extract a value for MaCCQE when fitting to MiniBooNE CCQE 1DQ2 data with a floating flux norm (HINT:FREE)

3. Tune MaCCRES to MINERvA CC1pip 1DQ^2 data with a prior of M_A=$0.0 \pm 1.0\sigma$

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NuisMin Application

- Tuning application : **nuismin**

```
$ nuismin -c samplecard.xml \
           -o sampleccqe.root \
          [-n NEVENTS ]
```

- Runs using XML card just like nuiscomp. Can take our previous card files as a starting point.

- Main difference is in nuismin we must specifiy that we want some parameters to be treated as FREE.

Free Parameter Structures

- Free parameter structures are very similar to fixed parameters, but they require you to tell NUISANCE the limits, and what state it is in FIX or FREE.

```
<parameter type="genie_parameter" name="MaCCRES"
           nominal="" low="" high="" step="" state="" />
```

Requirements:

- Nominal = Current (Starting) Value
- Low = Lower Limit
- High = Upper Limit
- Step = Migrad Starting Step Size
- State = Parameter state : FIX or FREE

Multiple Parameters

- NUISANCE will take all "FREE" parameters and load them into a multi-dimensional ROOT minimisation.

```
<parameter type="genie_parameter" name="MaCCRES"
            nominal="1.0" low="-3.0" high="3.0" step="1.0" state="FREE" />
<parameter type="genie_parameter" name="MaCCQE"
            nominal="1.0" low="-3.0" high="3.0" step="1.0" state="FREE" />
```

- Possible to keep some parameters fixed at nominal in the fit by instead putting the state to "FIX"

```
<parameter type="genie_parameter" name="MaCCRES"
            nominal="1.0" low="-3.0" high="3.0" step="1.0" state="FREE" />
<parameter type="genie_parameter" name="MaCCRES"
            nominal="1.0" low="-3.0" high="3.0" step="1.0" state="FIX" />
```

Tuning MaCCRES

```
<nuisance>
  <!-- List of parameters -->
  <parameter type="genie_parameter" name="MaCCRES"
             nominal="0.0" low="-3.0" high="3.0" step="1.0" state="FREE" />

  <!-- List of Samples -->
  <sample name="MINERvA_CC1pip_XSec_1DQ2_nu_2017"
          input="GENIE:genie/gntp.Default.MINERvA_fhc_numu.CH.2500000.root" />
</nuisance>
```

- We just want to float MaCCRES freely so we change our new parameter line to treat it as FREE.
- This card file will vary MaCCRES between $\pm 3\sigma$ and find the best fit it can to the 1DQ2 dataset.

Making a nominal plot

- Before we start tuning, we can use this new card file to create a nominal prediction for later comparisons.

- Running **nuiscomp** first over your new minimisercard.xml will produce the MC output at your starting values.

```
$ nuiscomp -c minimisercard.xml \
           -o minimiser-nominal.root \
           -n 100000
```

- This is a good practice as it also lets you check if all your samples are setup correctly before running a long fit.

Running

- Once you've written your card file it can be run in the same fashion but using nuismin this time.

```
$ nuismin -c minimisercard.xml \
          -o minimiser-tuned.root \
          -n 100000
```

- Minuit will scan the parameter space and try to find best fit.

```
[LOG Reconf]:---  -> Par 0. MaCCRES 0
[LOG Reconf]:--- Starting Reconfigure iter. 0
[LOG Minmzr]:- -> MINERvA_CC1pip_XSec_1DQ2_nu_2017          : 21.4312/8
...
[LOG Reconf]:---  -> Par 0. MaCCRES 0.0101951
[LOG Reconf]:--- Starting Reconfigure iter. 1
[LOG Minmzr]:- -> MINERvA_CC1pip_XSec_1DQ2_nu_2017          : 21.4962/8
```

Long Iterations

- Fits with multiple parameter scan take on the order of a day.

- NUISANCE is very I/O heavy. Have to read the full MC event so that it can be passed to the RW engine.
- 90% of each event loop is just reading events from disk. ☹

- Event loop optimized for multiple samples (each event is read from disk only once per event loop)

- Additional config flag (SignalReconfigures) can speed it up further by looping over only signal events after the first pass.

```
$ nuismin [ options ]  -q SignalReconfigures=1
```

Running Faster

```
$ nuismin -c minimisercard.xml \
          -o minimiser-tuned.root \
          -n 100000 \
          -q SignalReconfigures=1
```

- Turning on SignalReconfigures will speed things up quite a bit.

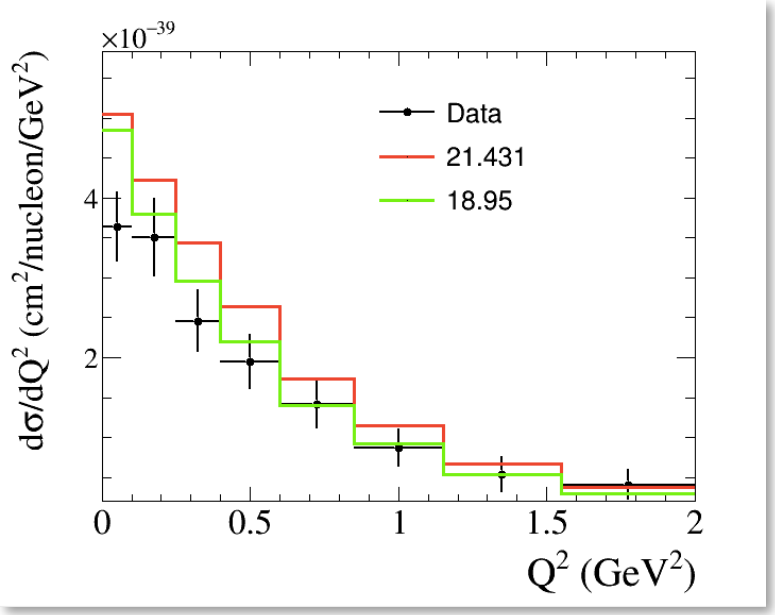
```
[LOG Minmzr]:- Finished Reconfigure iter. 4 in 3s
[LOG Minmzr]:- Getting likelihoods...                    : -2logL
[LOG Minmzr]:- -> MINERvA_CC1pip_XSec_1DQ2_nu_2017       : 21.4239/8
```

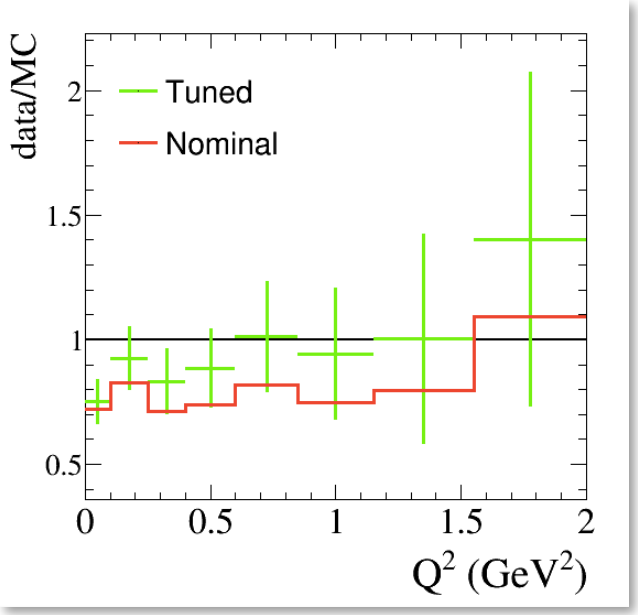
- Option still not fully validated with all samples so I advise caution for now!

Minimiser Output

```
#    Parameter  = Value      +- Error      (Units)  Conv. Val  +- Conv. Err  (Units)
0  . MaCCRES    = -0.789184  +- 0.510301   (sig.)   -0.789184  +- 0.510301   (sig.)
```

- **nuismin** saves the same MC histograms as **nuiscomp** did.



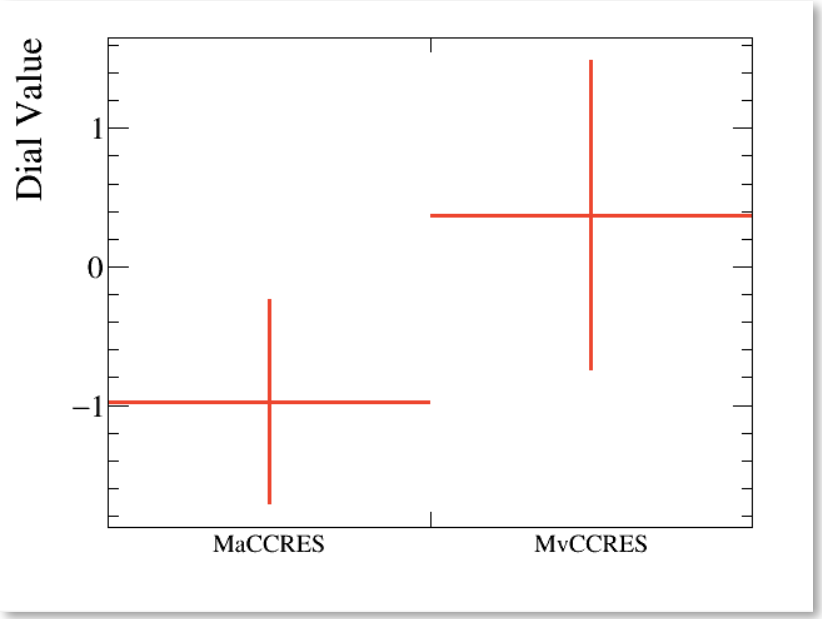


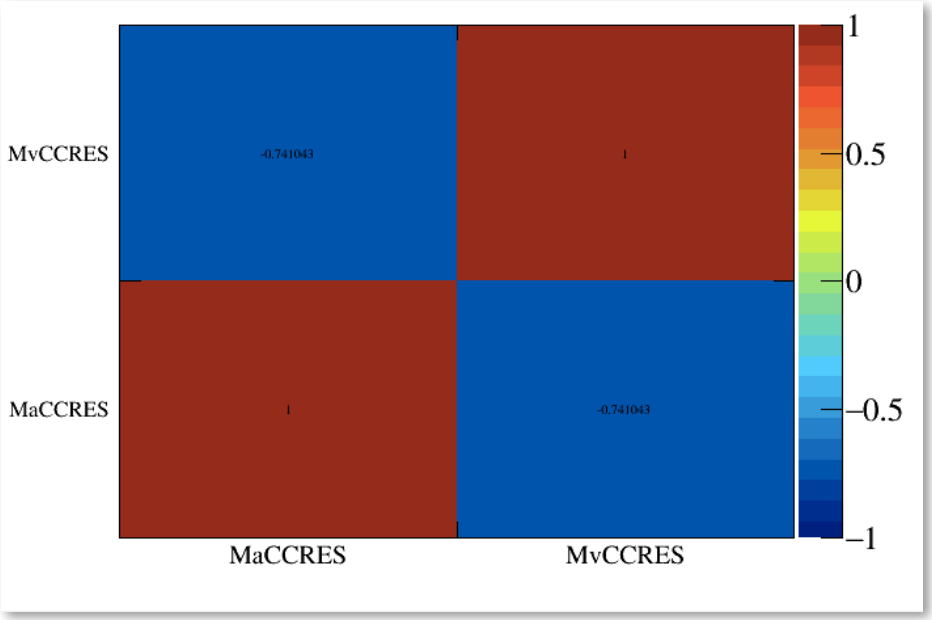
- Can compare our "nominal" and "tuned" results

```
$ root minimiser-tuned.root minimiser-nominal.root
```

Minimiser Output (2)

- Lots of other fit information saved into the output file.





- Some interesting ones:
  - **start_dials** : starting parameters
  - **fit_dials** : best fit parameters
  - **fit_iterations** : Parameter/Likelihood state at each iter.
  - **fit_result** : best fit parameter result (CHI2 = best joint fit likelihood)

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Fit Types

- Extra handling options can be passed to each sample through the optional "type" field.

```
<sample name="NAME"    type="TYPEDEF"    input="INPUT" />
```

- Usually handles likelihood options. Many non-conflicting terms can be passed at once (e.g. DIAG/FREE/NORM).

- **A few examples for TYPEDEF:**
  - DIAG : Use diagonal errors instead of a covariance
  - SHAPE : Treat as a shape-only likelihood
  - FREE : Freely float the normalisation as a fit parameter
  - NORM : Add a floating norm penalty term (works only for some samples e.g. MiniBooNE CCQE)

Changing the Routines

- Minimiser interface has a few different minimiser routines.

```
Brute
Simplex
Minuit
Combined
Fumili
```

```
ConjugateFR
ConjugatePR
BFGS
BFGS2
SteppDesc
```

```
GSLSimAn
```

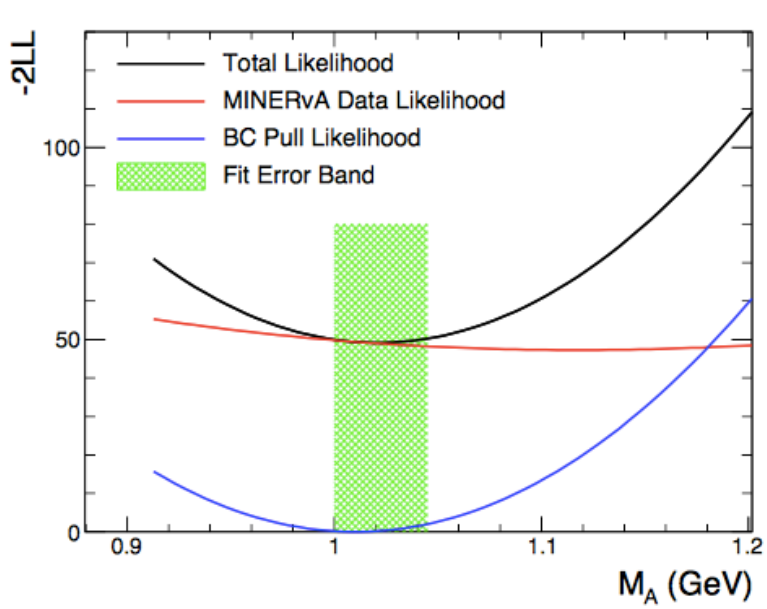
- Can use the (-f) flag in nuismin to choose which routine to run.

- Routines are comma seperated and ran in sequence, with the results of one routine being passed into the other.
- **Example** : run a brute force ND scan, then run Minuit from the new starting point.

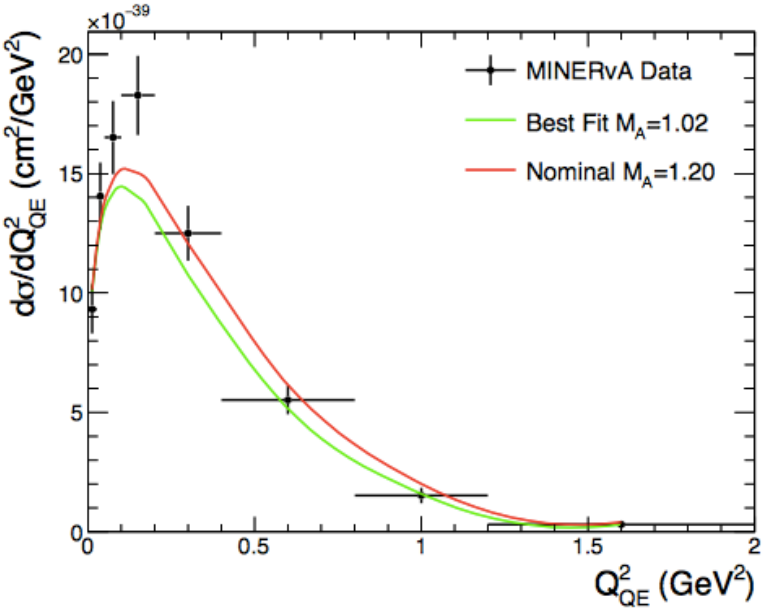
```
$ nuismin -c card.xml -o out.root -f Brute,Minuit
```

Running with simple priors

- Can include χ^2 penalty terms in fit using "covar" objects.



(a) χ^2 scan across the M_A parameter space



(b) Nominal and best fit MINERvA distribution

- Allows you to use the results of previous internal/external fits as an additional constraint in your tuning.

Simple Priors : DIAL

- Simplest "covar" type is an uncorrelated Gaussian **DIAL** pull.

- If you already have a parameter included in your card file called PARNAME you can place a Gaussian prior on it with:

```
<covar name="PARNAME_prior"
       input="DIAL:PARNAME;CENTRAL_VALUE;ERROR_VALUE"
       type="GAUSPULL" />
```

- **Example:** Float MaCCRES, but include an additional constraint of MaCCRES = -0.5 +- 1.0 sigma in the fit.

```
<parameter name="MaCCRES" type="genie_parameter"
           nominal="0.0" low="-3.0" high="3.0" step="1.0" state="FREE" />
<covar name="MaCCRES_prior" input="DIAL:MaCCRES;-0.5;1.0" type="GAUSPULL" />
```

Simple Priors : ROOT

- Can also specify similar Gaussian priors with full correlations between parameters.

- Requires TH1D central values (TH1DCV) and TH2D covariance (TH2DCOV) with the bin labels set to match the dial names.

```
<covar name="ID" input="ROOT:FILEPATH;TH1DCV;TH2DCOV" type="GAUSPULL" />
```

- Exact histogram format that NUISANCE saves outputs, so can easily use a previous fit result as a future prior.

```
<parameter name="MaCCRES" type="genie_parameter"
           nominal="0.0" low="-3.0" high="3.0" step="1.0" state="FREE" />
<parameter name="NonResBkgvnCC1pi" type="genie_parameter"
           nominal="0.0" low="-3.0" high="3.0" step="1.0" state="FREE" />
<covar name="fit_prior" input="ROOT:result.root;fit_dials;covariance" type="GAUSPULL" />
```

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