The University Of Sheffield.

NUISANCE

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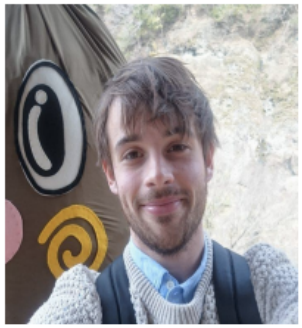


IOP Meeting

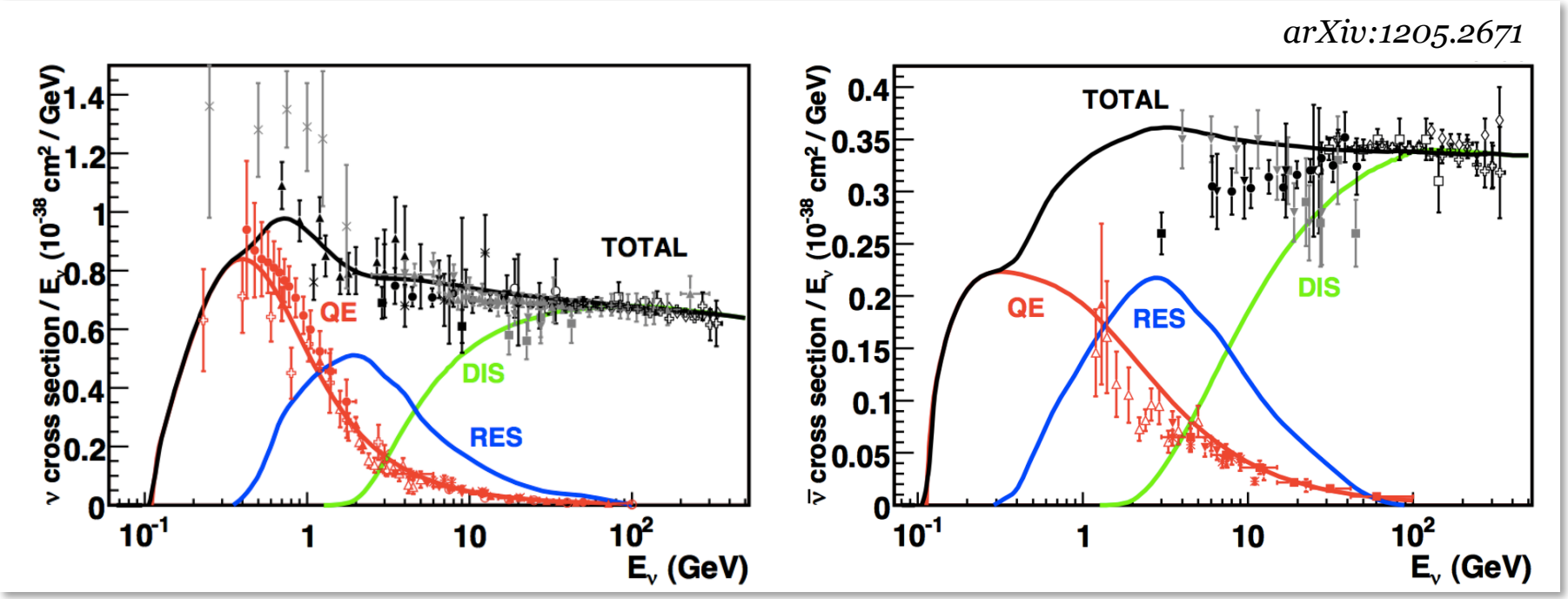
12/04/2017

T2K

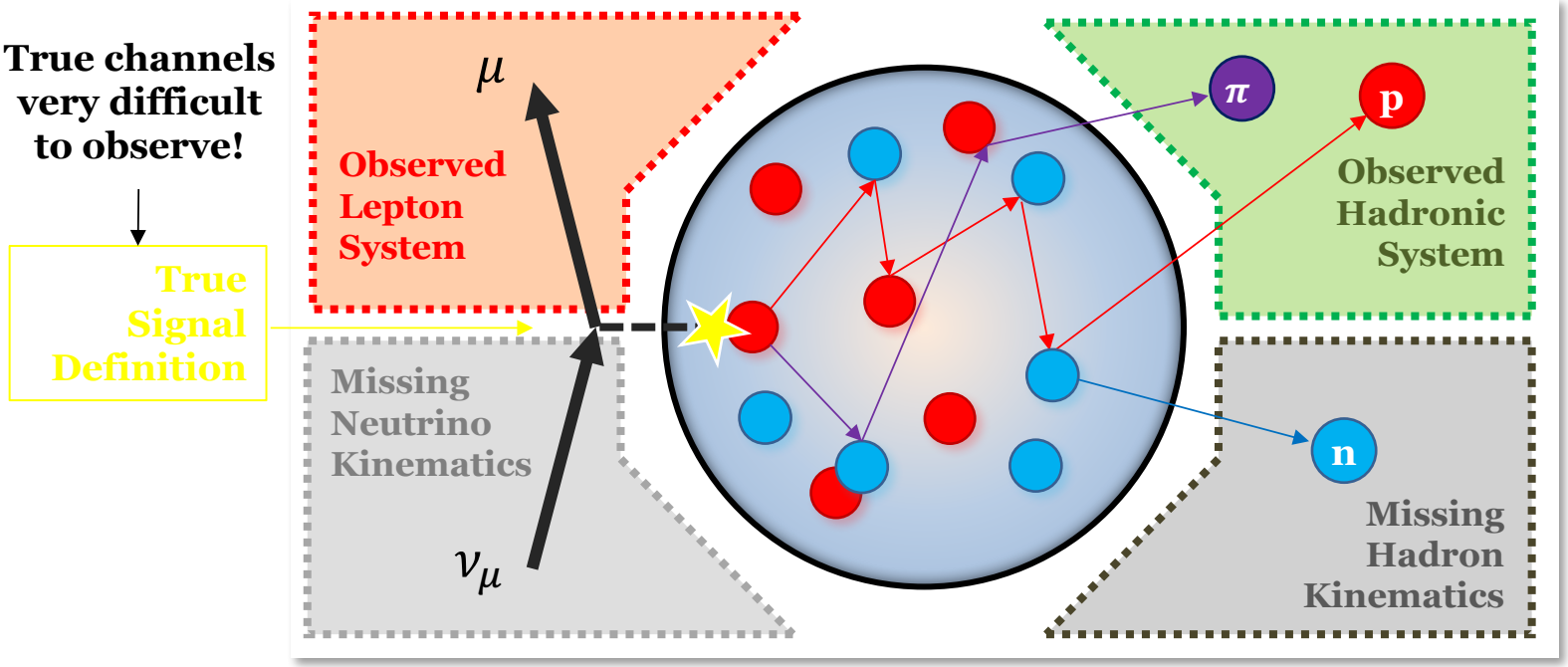
Introduction

- The neutrino interaction cross-section model contributes a large systematic to oscillation analyses

- Current and future experiments sit at a transition region where many different interaction channels contribute

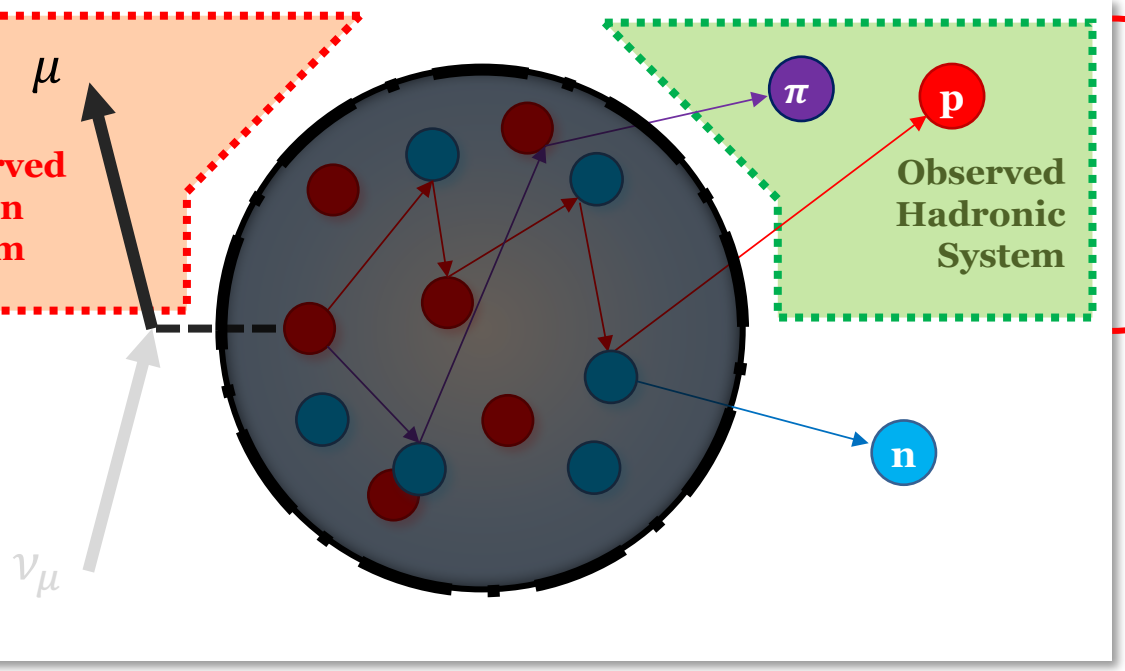


Underlying Cross-section



- Nuclear effects can modify the neutrino scattering cross-section
- Incredibly difficult to infer true vertex-level interaction channels from a given final state -> very model dependent!
- Experiments moving to 'topological cross-sections' with signal based only on final state particles after nuclear re-scattering

Event Topologies



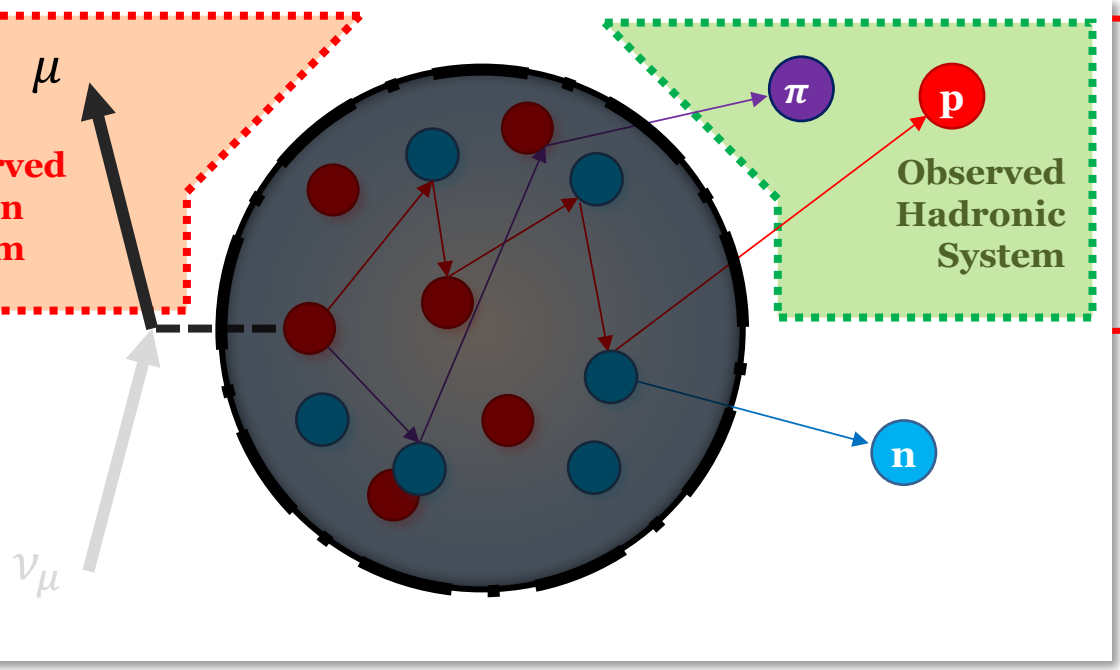
Topological Signal Definition

$$CC - Inclusive = 1\mu$$

$$CC0\pi = 1\mu 0\pi$$
$$CC1\pi^+ = 1\mu 1\pi^+$$
$$CCN\pi = 1\mu N\pi$$

$$NC0\pi = 0\mu 0\pi$$
$$NC1\pi^0 = 0\mu 1\pi^0$$

Event Topologies



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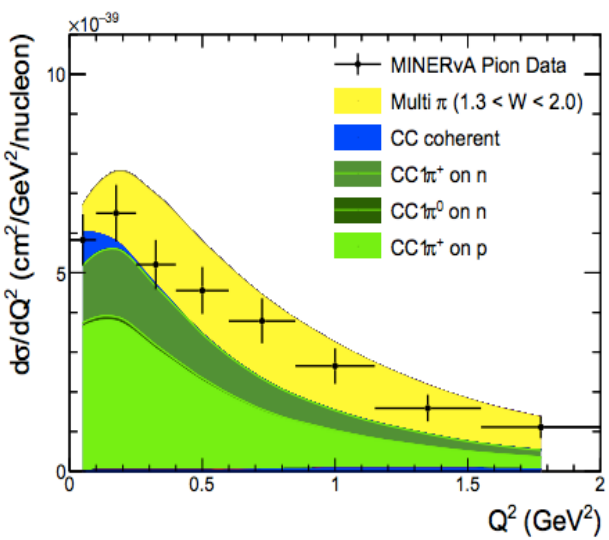
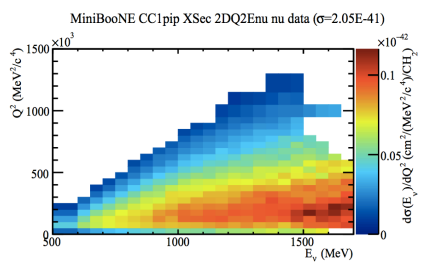
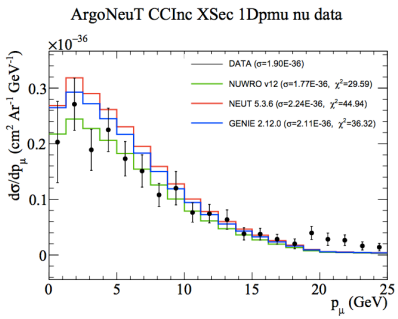
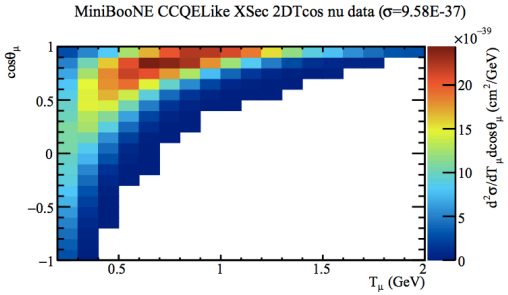
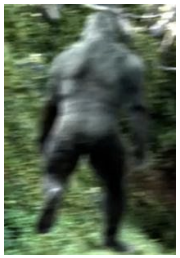










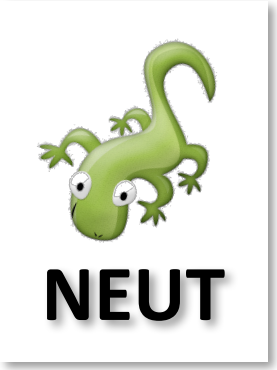
NUISANCE

- Open source neutrino Monte-Carlo event generator tuning framework

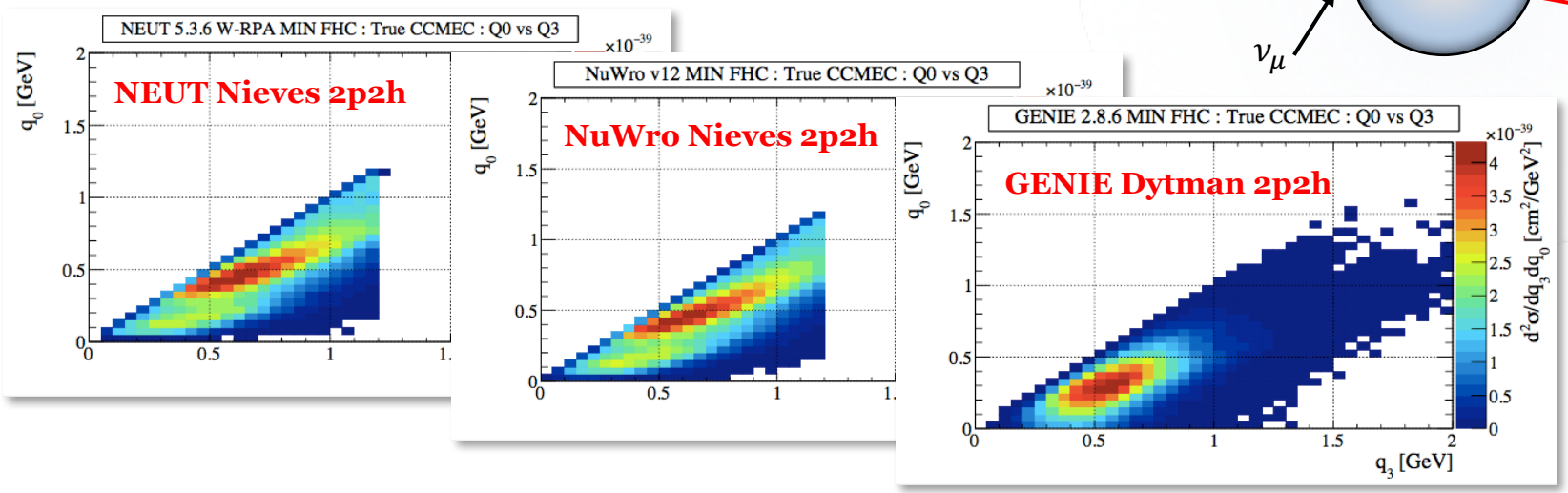
- Easily extendable framework, with a large range of dataset comparisons already included

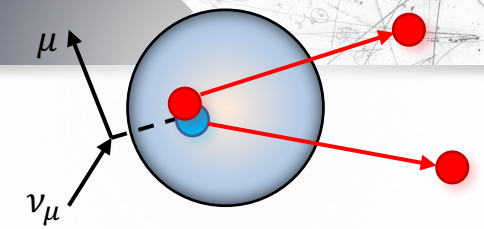
nuisance.hepforge.org

- Plan to create a set of model tunings for the main ‘reweightable’ generators:

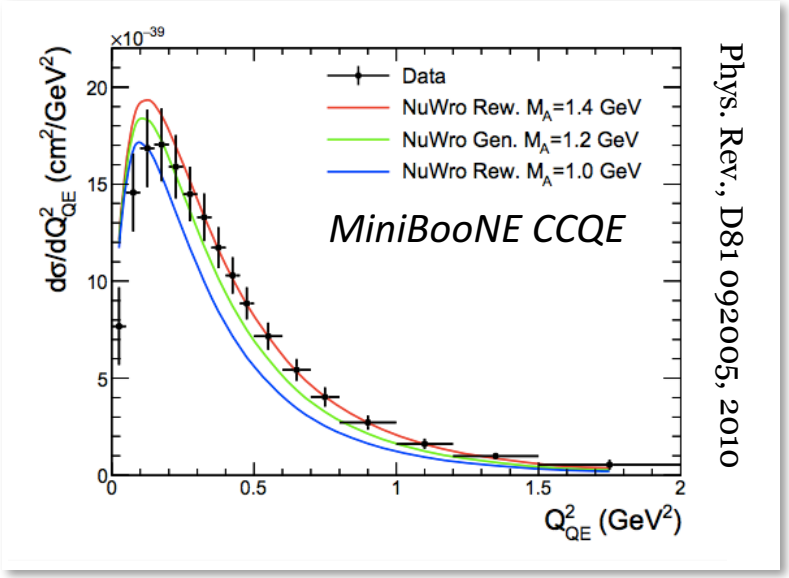


Generator Comparisons





- NUISANCE converts generator events into common format for use by analysis routines
- Can make consistent model comparisons across generators
- Reweight engines allows model predictions to be easily changed

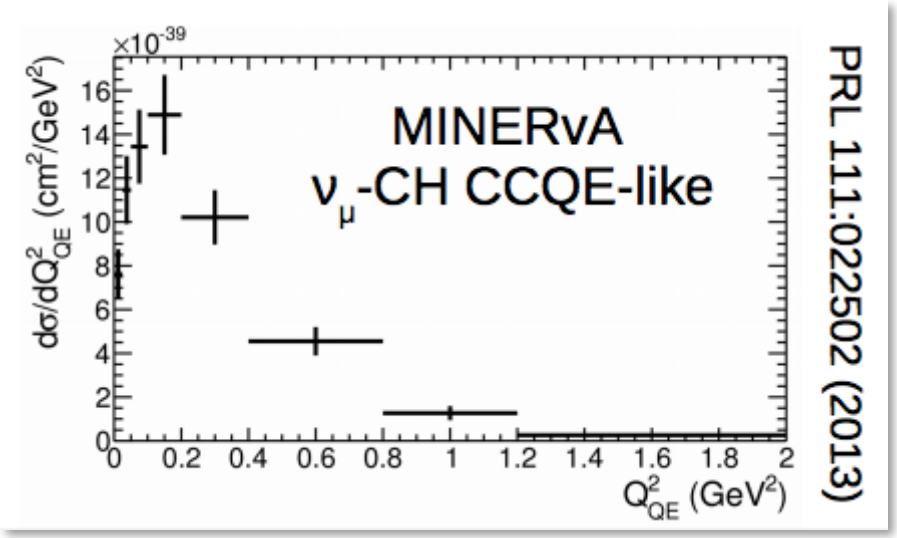



```
neut_parameter MaCCQE  +1.0
```

Data Comparisons

- To add a comparison you need:

  1. Data distribution
  2. Event signal definition
  3. Binning definition (e.g. Q2)



- Support for more complex dataset routines also included:

  - MC True -> Reco Smearing
  - Covariance likelihoods
  - Ratio distributions
  - Arbitrary category MC plots

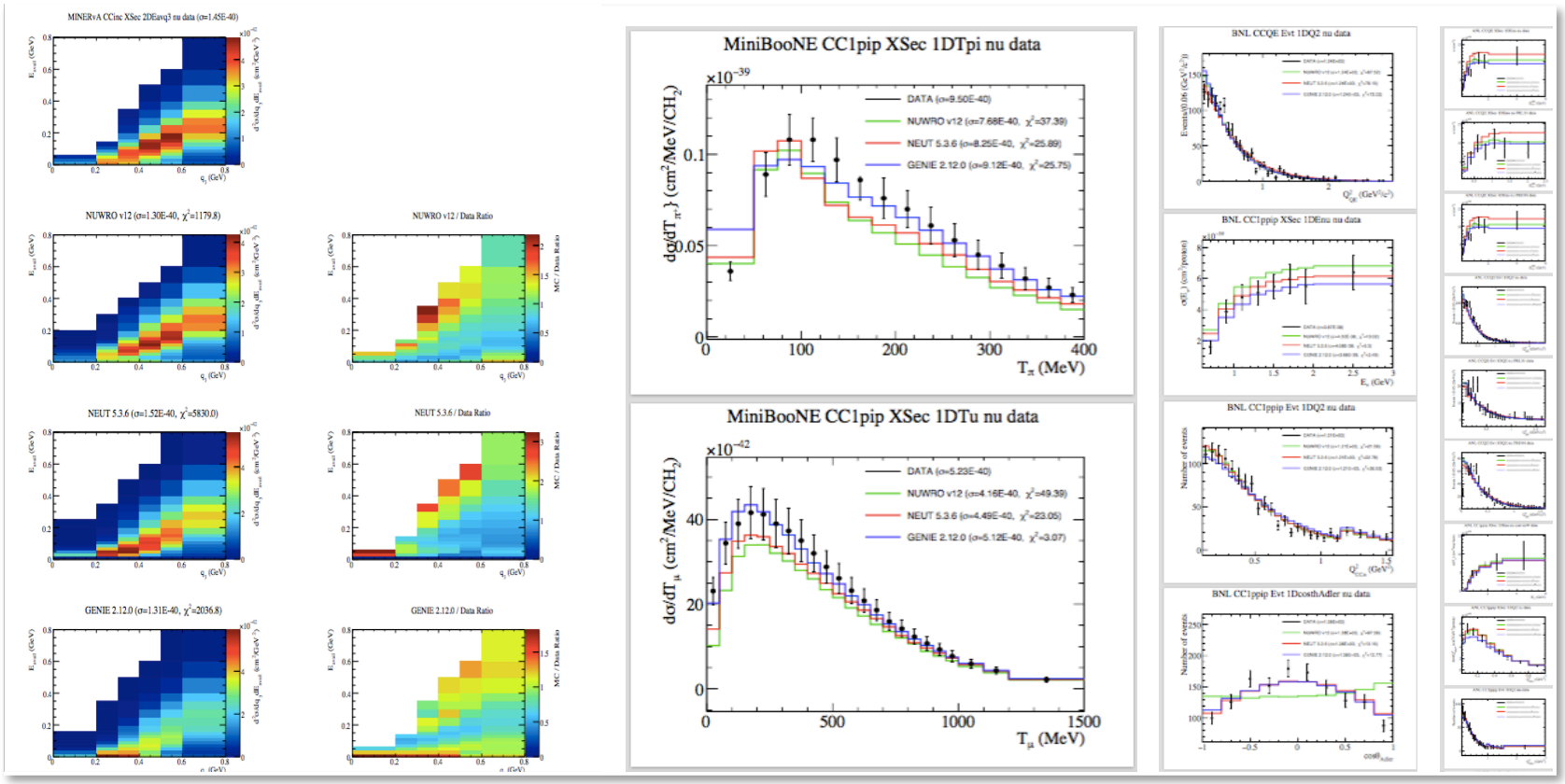
```
//*****************************************************************************
void MINERvA_CCQE_XSec_1DQ2_nu::FillEventVariables(FitEvent *event) {
//*****************************************************************************

  if (event->NumFSParticle(13) == 0)
    return;

  TLorentzVector Pnu  = event->GetNeutrinoIn()->fP;
  TLorentzVector Pmu  = event->GetHMFSParticle(13)->fP;

  double ThetaMu  = Pnu.Vect().Angle(Pmu.Vect());
  double q2qe     = FitUtils::Q2QErec(Pmu, cos(ThetaMu), 34., true);

  // Set binning variable
  fXVar = q2qe;
  return;
}
```

```
sample MINERvA_CCQE_Xsec_1DQ2_nu  NEUT:min_events.root
```

v1r0 Validation

- Perform NEUT, NuWro, and GENIE comparisons during validation of each version freeze to ensure sample predictions behave as expected.

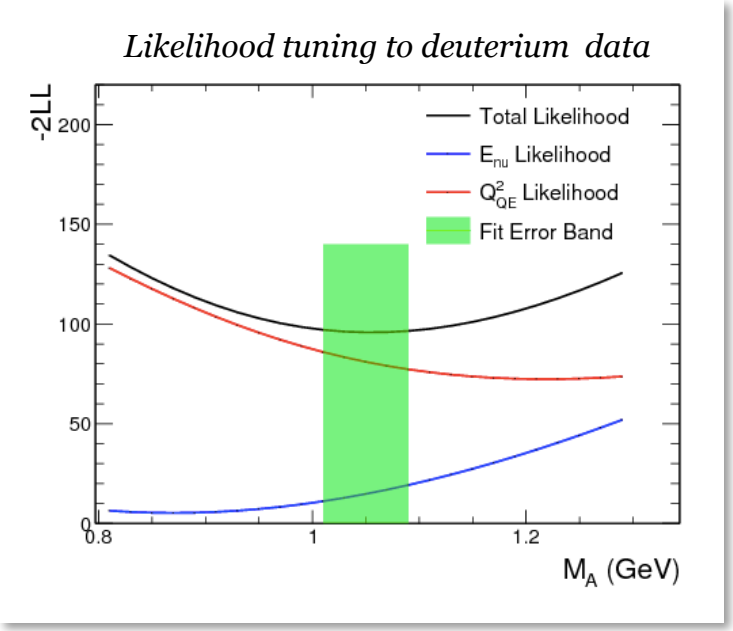
[NUISANCE Validation Link](#) : Comparison of generators to ~150 different datasets



host all the MC files used to make these comparisons on our site!

Tuning a model

- Likelihoods calculated for each dataset comparison can be used with Minuit to tune model parameters.



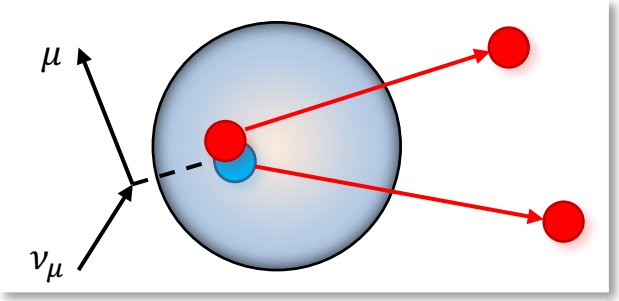

```
nuisance_tuning.card
neut_parameter MaCCQE   0.0 -3.0 3.0 1.0 FREE

sample ANL_CCQE_XSec_1DEnu_nu NEUT:anl_events.root
sample ANL_CCQE_Evt_1DQ2_nu   NEUT:anl_events.root
```

```
$ nuismin  -c nuisance_tuning.card
           -o nuisance_tuning.root
```

- Any reweight dial can be specified as a free parameter and tuned to improve the joint likelihood between many datasets.

Tuning results

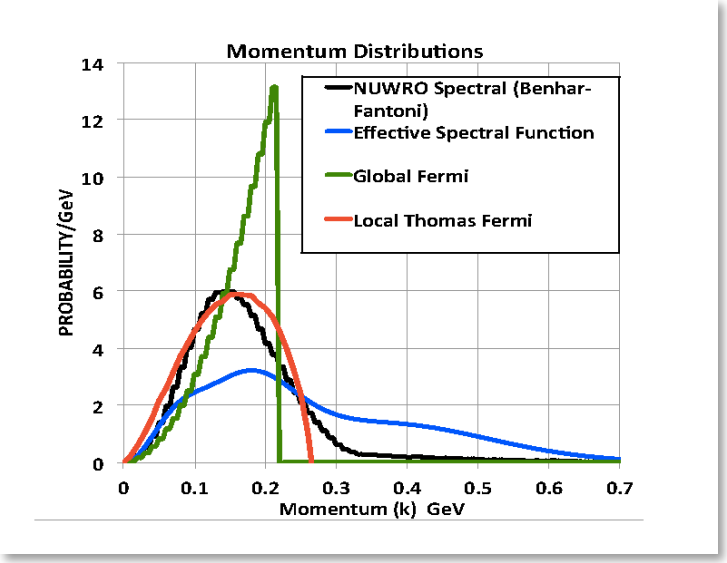
- T2K already had difficulties when running joint fits to external data.
- Fitting CCQE model to MINERvA+MiniBooNE with NEUT:
  - disagreement with theory, suppression of the multi-nucleon interaction model (2p2h)
  - disagreement between datasets

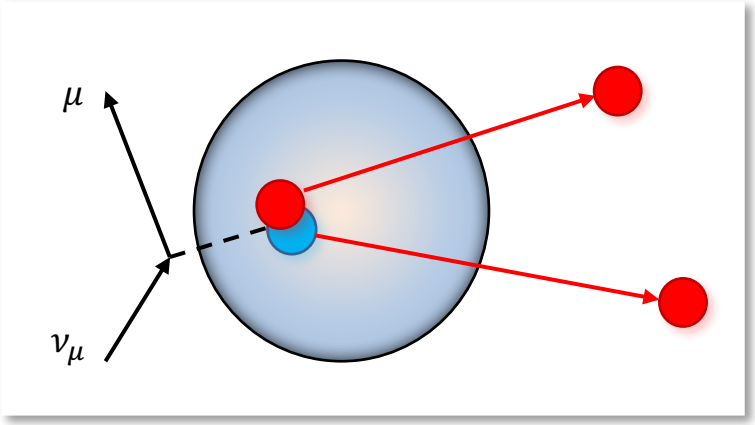


Model	M_A (GeV/c2)	2p2h Norm (%)	χ^2/NDOF
NEUT Relativistic Fermi Gas + Nieves-2p2h	1.14 ± 0.03	25.5 ± 12.4	106.25 / 229

T2K CCQE Tuning Results to MiniBooNE/MINERvA Data

Tuning results





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NEUT Relativistic Fermi Gas + Nieves-2p2h	1.14 ± 0.03	25.5 ± 12.4	106.25 / 229
NuWro Local Fermi Gas + Nieves-2p2h	1.16 ± 0.03	8.3 ± 11.9	100.74 /229

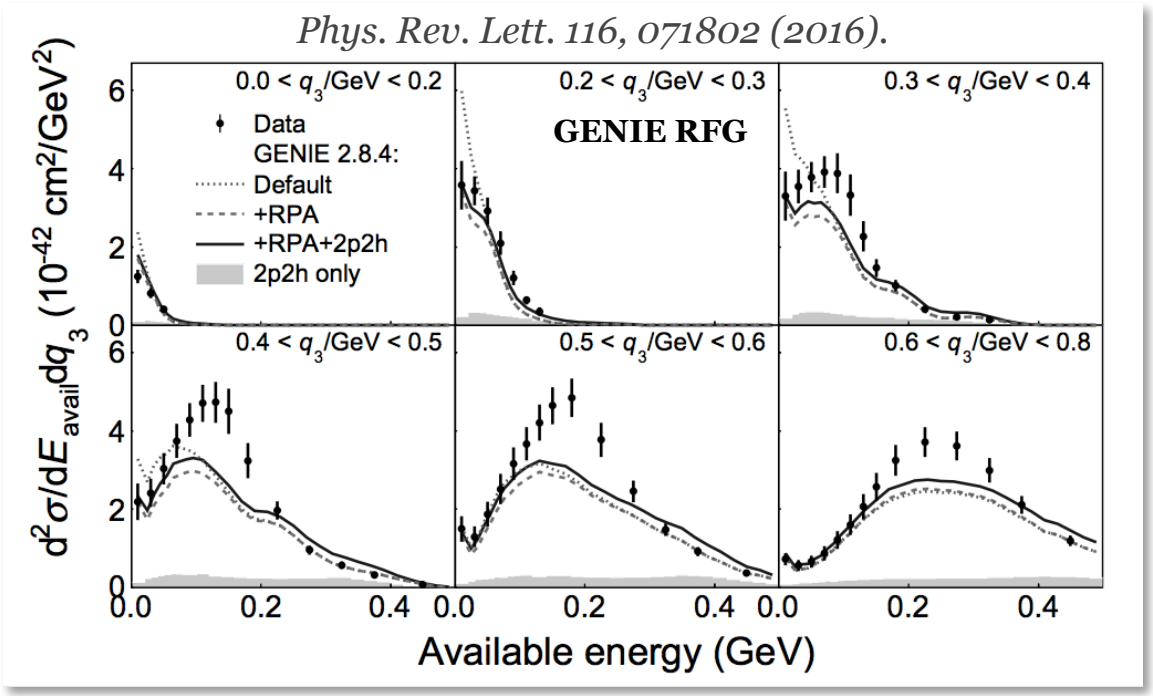
T2K CCQE Tuning Results to MiniBooNE/MINERvA Data

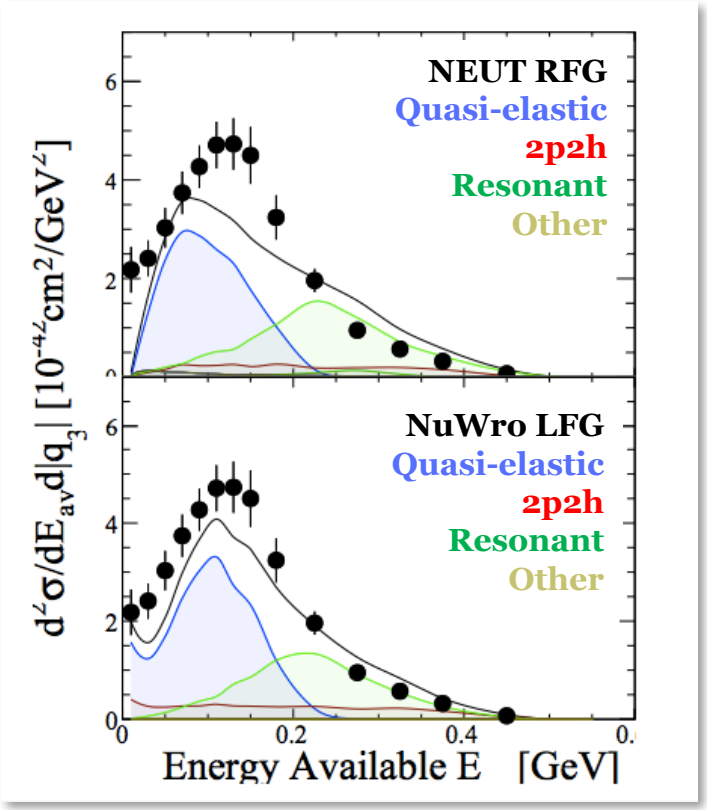
- Having the ability to make predictions with many different generators really helpful to understand fit results.

NEUT RFG / NuWro LFG

- MINERvA released inclusive cross-section measurement in 3-momentum transfer (q_3) and total hadronic energy (E_{av})

- NuWro with Local Fermi Gas (LFG) model found to perform better than NEUT's Relativistic Fermi Gas (RFG) at low hadronic energy.

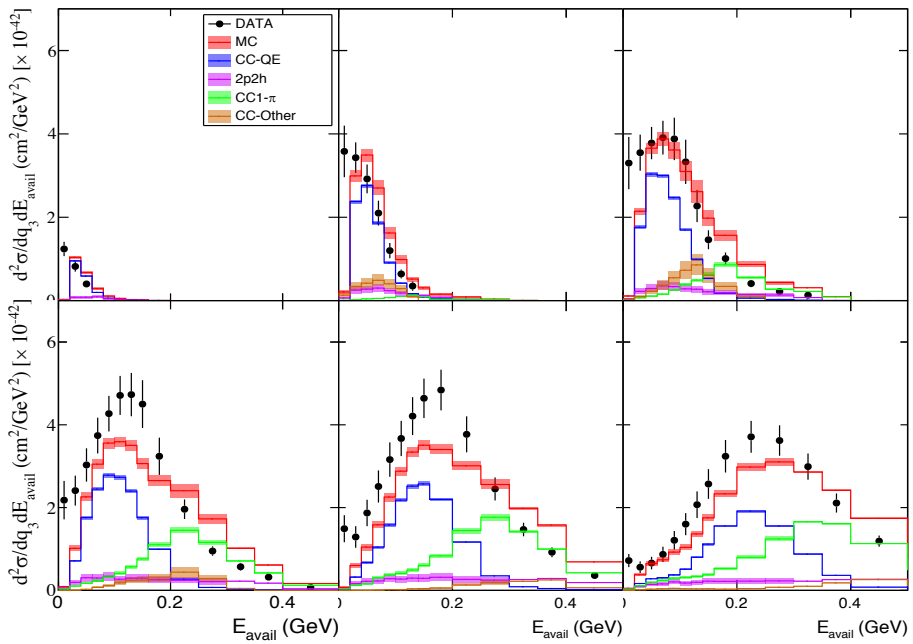




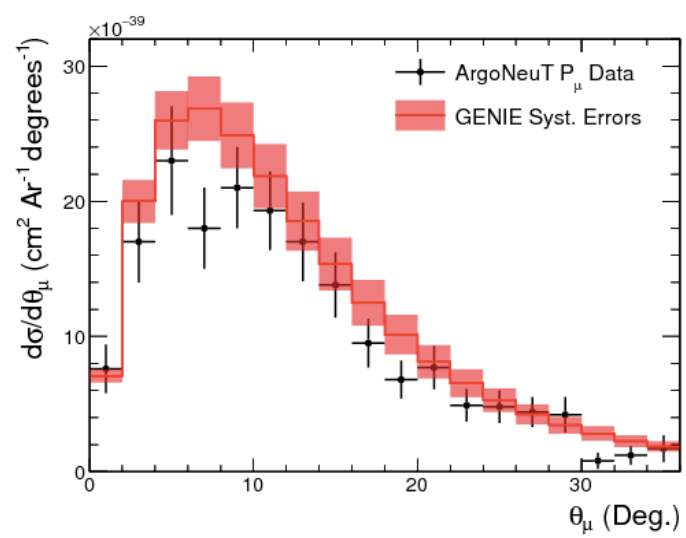
Error Bands

- Included support for systematic error band generation.
- Plan to release an error bands document similar to the NUISANCE v1r0 validation included with every set of model tunings.
- Compare tuning error bands to every dataset implemented in NUISANCE.

T2K NEUT Uncertainties vs MINERvA Data

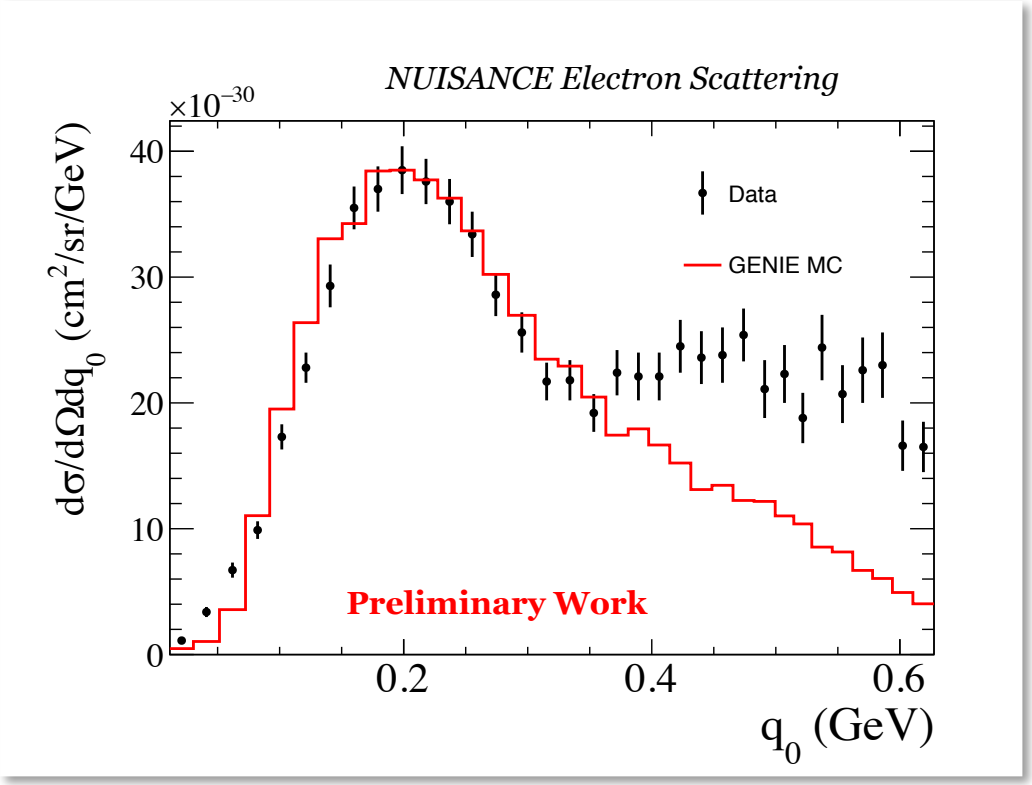


GENIE 1-sigma reweight dial throws vs ArgoNeut Data



NUISANCE Future Plans

- **V2r0 release coming soon:**
  - Automated input checks to provide a helping hand to users.
  - Electron Scattering comparisons
  - Spline reweighting for fast MC tunings



- Grand plan is to include all relevant electron, pion, and neutrino scattering data into a single framework.

NUISANCE and You

- NUISANCE is not just a for theorists to use after you have published your data.
- Can produce simple ROOT trees to make easy model comparisons.
- Can be used to estimate predicted number of events for arbitrary signal definitions at your chosen detector for each generator.
- Can constrain additional background uncertainties from external data.
- Add any early true event selections you have now and make pretty plots for your analysis!

Thanks for listening!

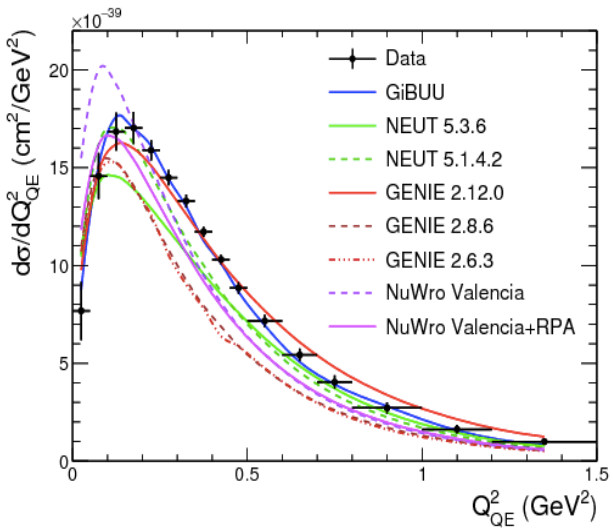
Join NUISANCE!

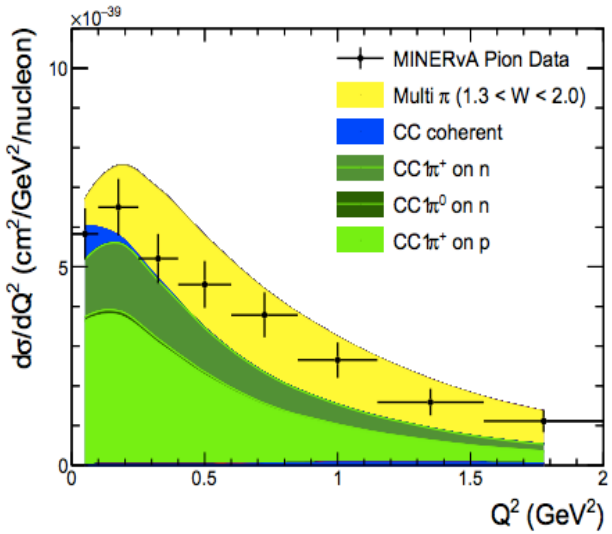
Backup Slides

NUISANCE Validation Link

- Latest validation plots can be found here:
- http://nuisance.hepforge.org/files/validation/nuisancevalidation_v1r0_280217/nuisance_v1r0_validation_280217.pdf

Running a comparison : ‘nuiscomp’





- Card files can be written listing comparisons to be made

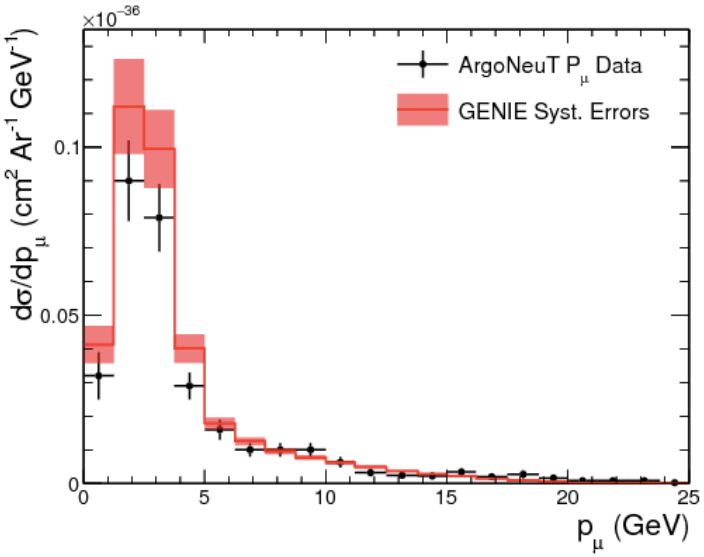
```
nuisance_comparison.card
sample MiniBooNE_CCQE_XSec_1DQ2_nu    NEUT:miniboone_numu_neut.root
sample MINERvA_CCQE_XSec_1DQ2_nu      NUWRO:minerva_numu_nuwro.root
sample ANL_CCQE_Xsec_1DQ2_nu          GENIE:anl_numu_genie.root
```

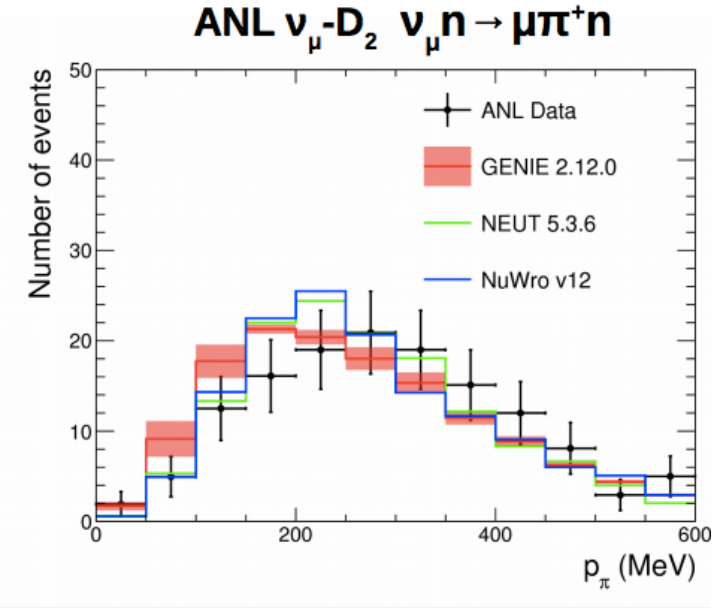
- Comparisons then generated with nuiscomp app

```
$ nuiscomp -c nuisance_comparison.card -o nuisance_comparison.root
```

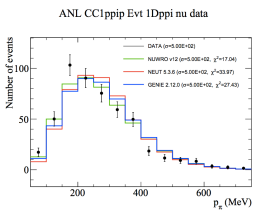
Systematics 'nuissyst'

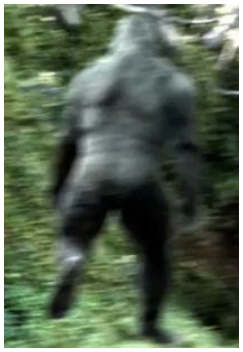
- Systematics app included to throw arbitrary input covariance matrices and generate MC error bands.
- Can be used to evaluate how well your model describes a given set of data.
- Can also be used to look at MC uncertainties in other regions of interest e.g. early background uncertainty studies for a ND280 selection.

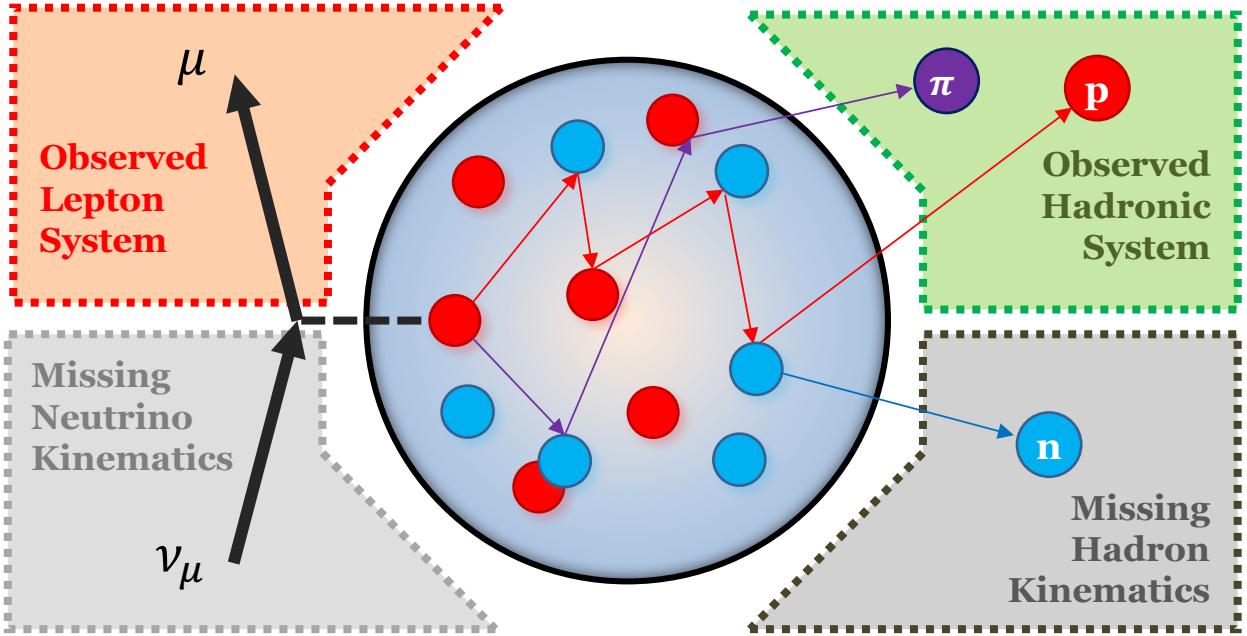




The underlying cross-section







Topological Signal Definition