NUISANCE and you

NeUtrino Interaction Systematics ANalyser by Comparing Experiments
NeUtrino Interaction Synthesiser Aggregating Constraints from Experiments
NeUtrino Interaction Systematics from A-Neutrino sCattering Experiments

https://nuisance.hepforge.org/

Imperial College London

The University Of Sheffield.

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b UNIVERSITÄT BERN

State of the Nu-tion
24 June 2017, Toronto

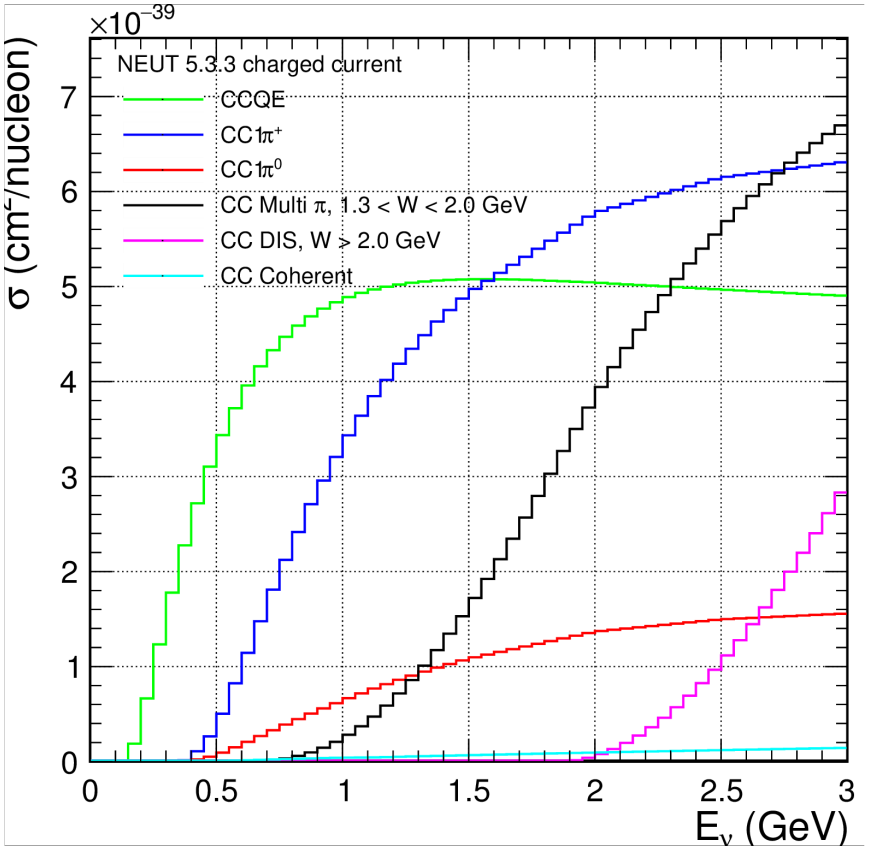
Clarence Wret, Patrick Stowell, Luke Pickering, Callum Wilkinson (main devs)
Help from S. Dytman, U. Mosel, Hayato-san, J. Sobczyk, C. Juszczak, K. Mahn, K. McFarland, G. Perdue, S. Dolan, P. Lasorak, J. Calcutt, C, L. O'Sullivan, and more...

Introduction

- Precision neutrino oscillation measurements require well modelled neutrino interaction: $E_\nu^{rec} \rightarrow E_\nu^{true}$ mapping

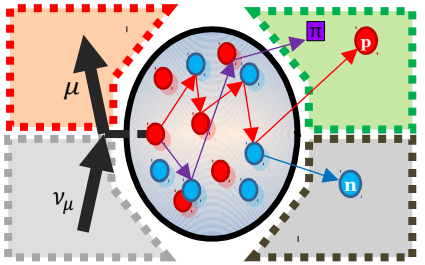
$$N_{SK} \sim \Phi_{SK}(E_\nu)\,\sigma(E_\nu)\,\epsilon_{SK} P(\nu_\alpha \rightarrow \nu_\beta)$$

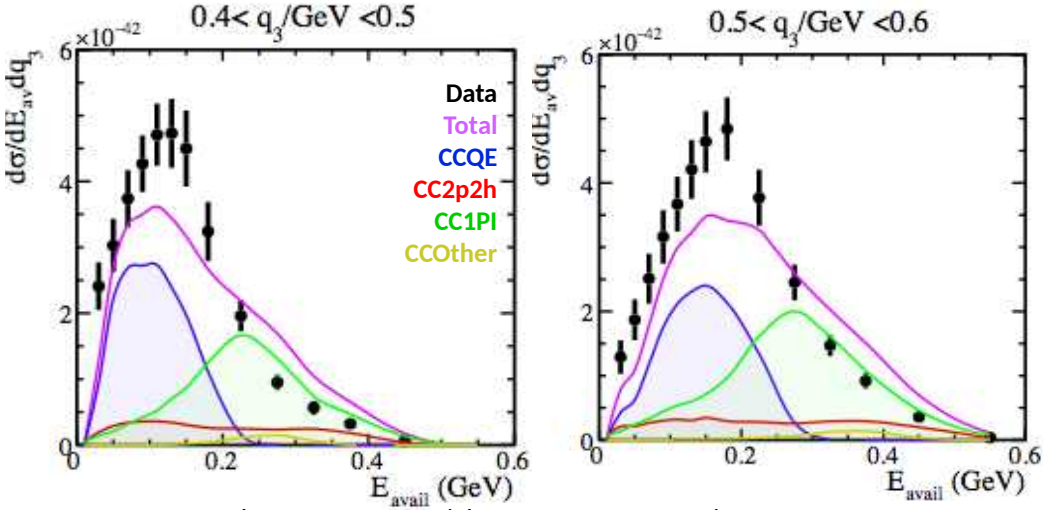
- Well modelled cross-section at near detector with $E_\nu \sim 1$ GeV? But what about
  - Far detector with oscillated E_ν
  - Different acceptance at far detector
  - Possibly different target materials
- Calorimetric reconstruction requires accounting for neutral particles
  - Effect partially informed from cross-section simulations



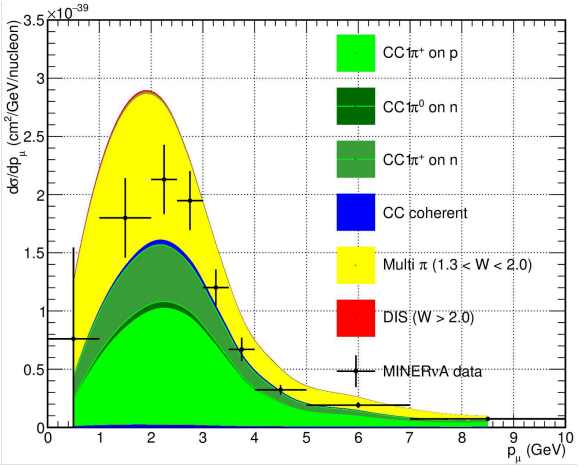
Introduction

- In an experiment, event selection is done by topology
  - e.g. CC0π selection has contributions from 2p2h, SPP, FSI
- The experiment requires a "full theory" in the generators
  - e.g. how does sophisticated FSI model "play" with simple Rein-Sehgal SPP
- Difficult to assign Data/MC disagreement to a particular interaction model from only one data-set, especially if only doing so "by-eye"





NEUT 5.3.6 and MINERvA CC-inc (Phys. Rev. D 93, 071101)

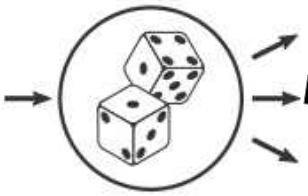


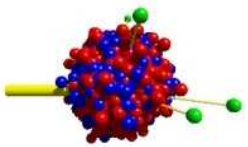
NEUT 5.3.6 and MINERvA CCNπ (Phys. Rev. Lett. 116)

- Identified a need for large custom Data/MC comparisons
  - Started with NEUT, grew to support GENIE, NuWro and GiBUU

What NUISANCE does

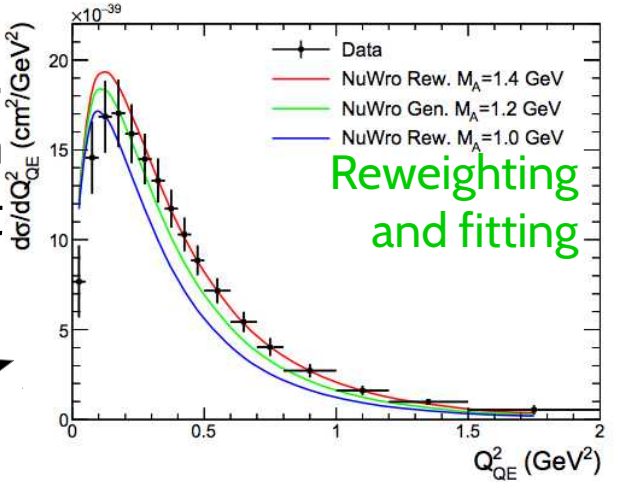
Particle kinematics, targets, etc

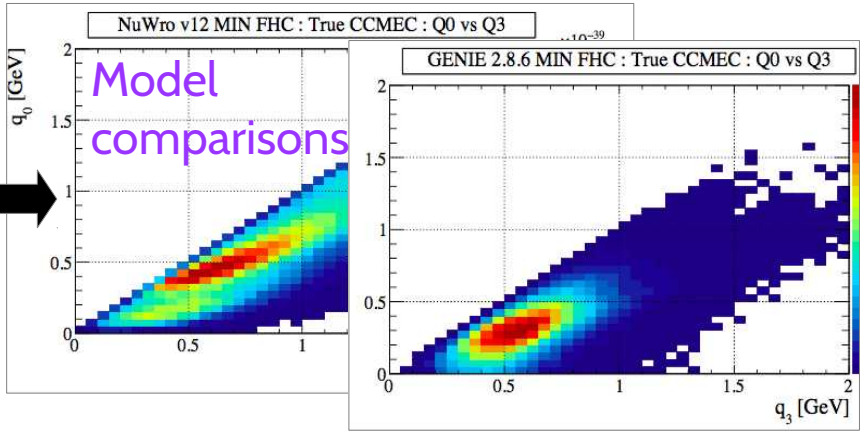


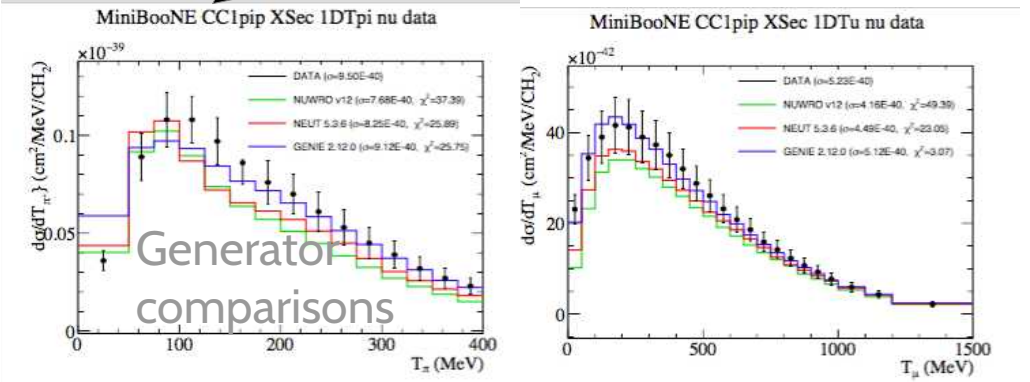


Common event format

Event selection, cross-section scaling, reweight







Using NUISANCE

- Have over 200 neutrino dataset for multi-generator cross-section comparisons, tunings and systematics studies
- hepforge, trac wiki, Slack channel, Github, mailing list
- MSc+early PhD student friendly
  - Model interpretation is the tricky bit, making the plot is easy!
- Large stand-alone repository for the data distributions
  - Working with Durham IPPP (HEPdata) on extending their database
- Unsure on a signal definition for an experiment? We've got them too
- Can't find the flux for an experiment? We have a long monologue on fluxes for all implemented experiments

How can NUISANCE help you?

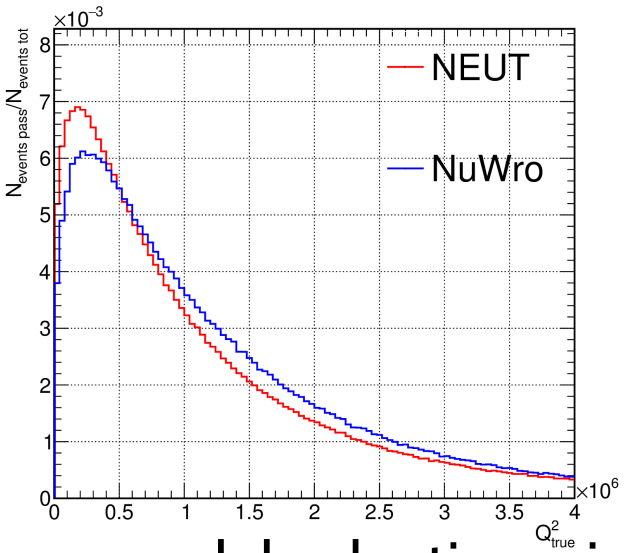
- Challenge the systematics in your analysis
  - Vary 1σ of M_A^{QE}: what does that mean for external data?
  - Dominated by an interaction which you don't have a sideband? Get informed from external data? Are the generators even close?
- What do previous measurements say about your final state?
  - Tensions? Interesting distributions? Where do the models differ?
  - Which theory/generator looks best for your measurement?

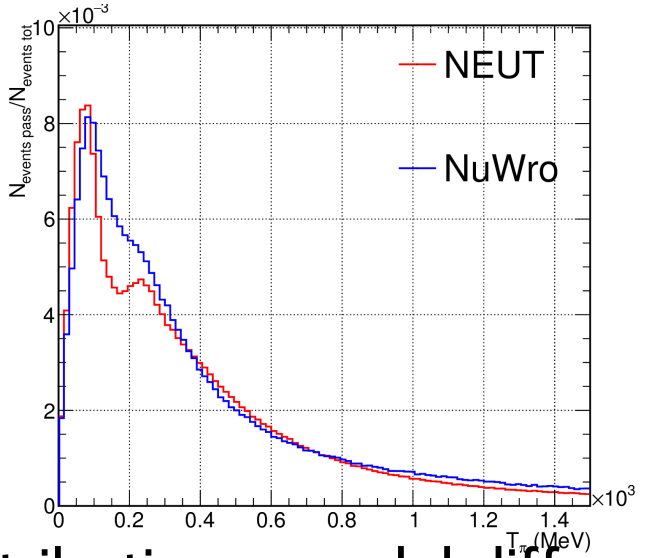
Implementing a new sample

- To implement a new sample we need
  - The data distribution (e.g. $d\sigma/dp_\mu$)
  - Method to construct a test-statistic (e.g. covariance matrix)
  - Neutrino flux distribution to generate events
  - Well-defined dependent variable (e.g. p_μ)
  - Well-defined signal definition (e.g. one $\mu^\pm$, no mesons, any nucleons)
- Measurements inherit from a `MeasurementBase` base class
- Measurements are entirely separated from the generators
  - Implement measurement once, then can use all the generators
  - All functionality enabled: compare, fit, make error bands
  - Does not require generator experts to create, modify or use measurements

Comparing flat trees

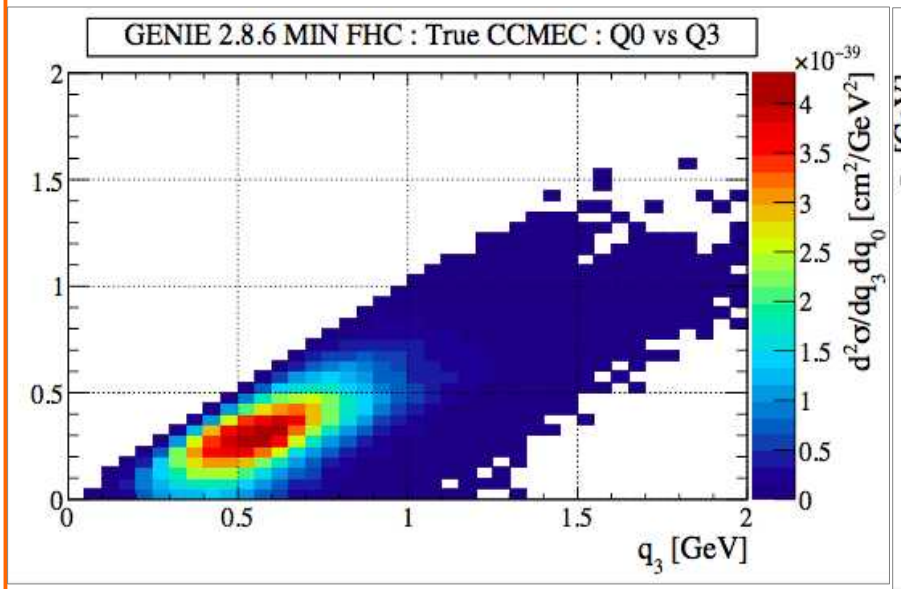
- Can make generator independent "flat-trees" for users who want to compare generators without using data

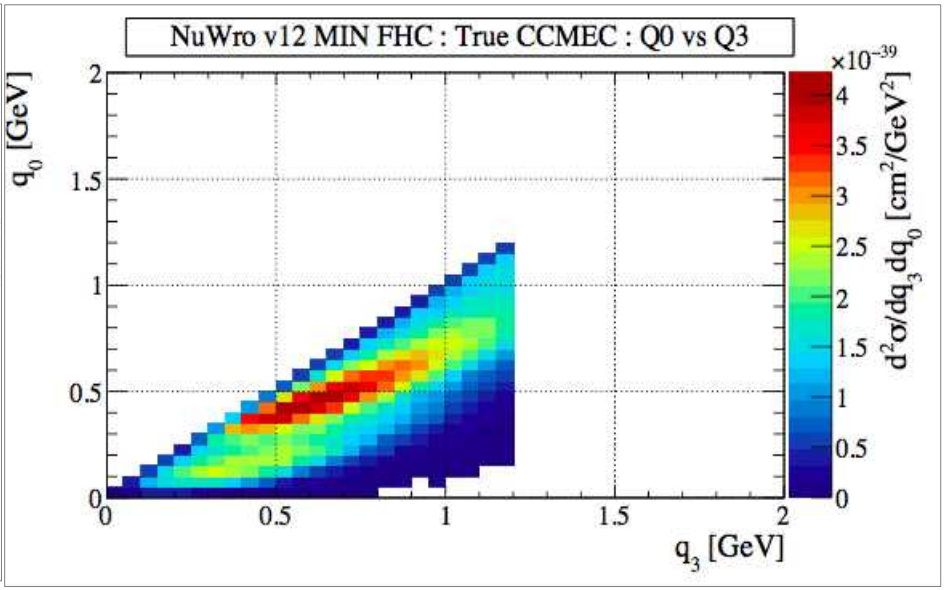




MiniBooNE flux, CH_2 target, $CC1\pi^+$ final state

- Inform model selections, interesting distributions, model differences

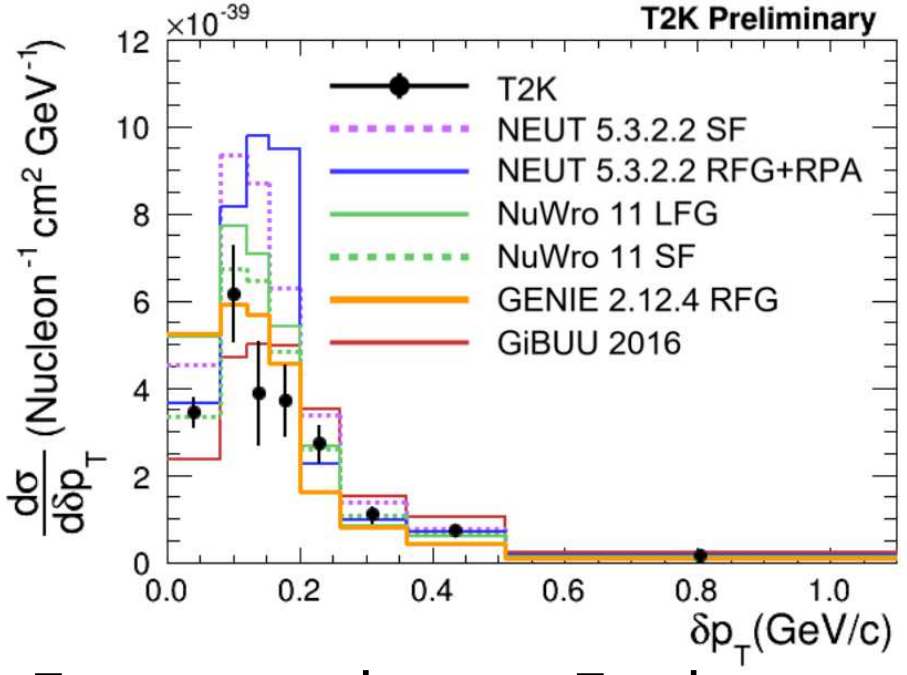


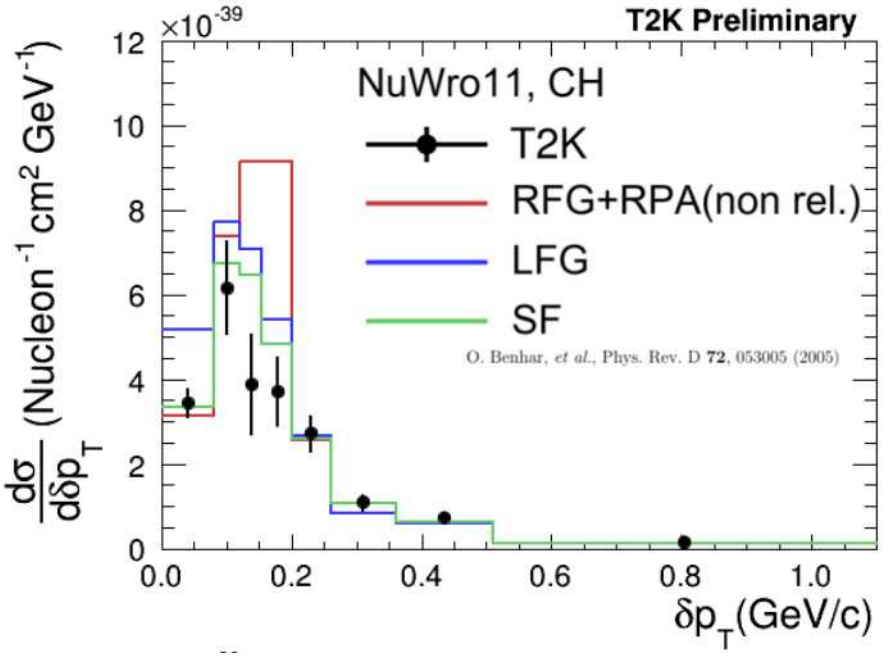


T2K flux, CH target, 2p2h true interaction

NUISANCE uses at T2K

- Stephen Dolan's CC0π transverse variable analysis was designed to be sensitive to nuclear effects
  - Implemented his measurement into NUISANCE
  - Compare results to multiple generators using different models

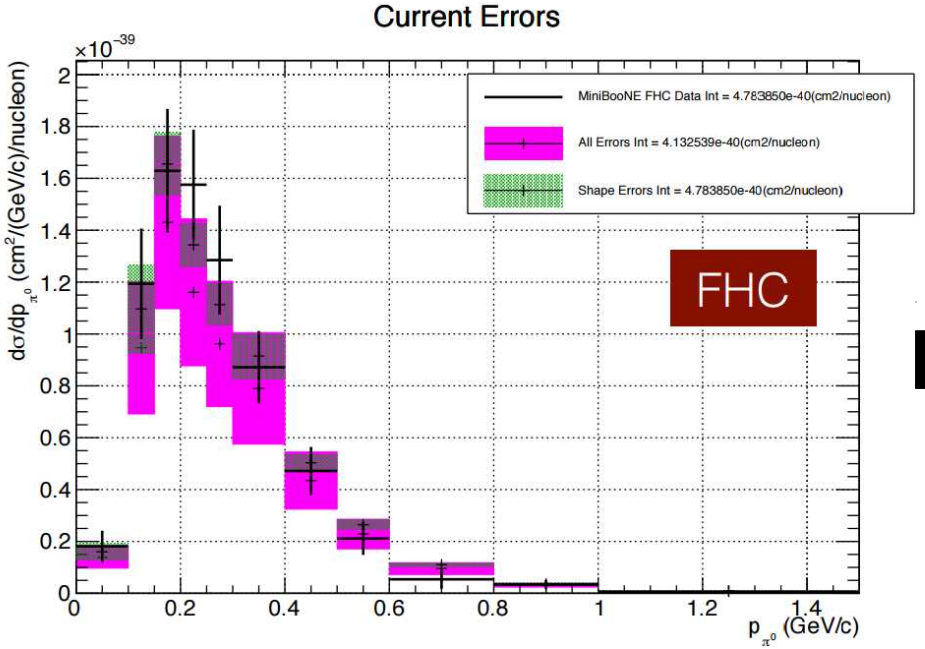


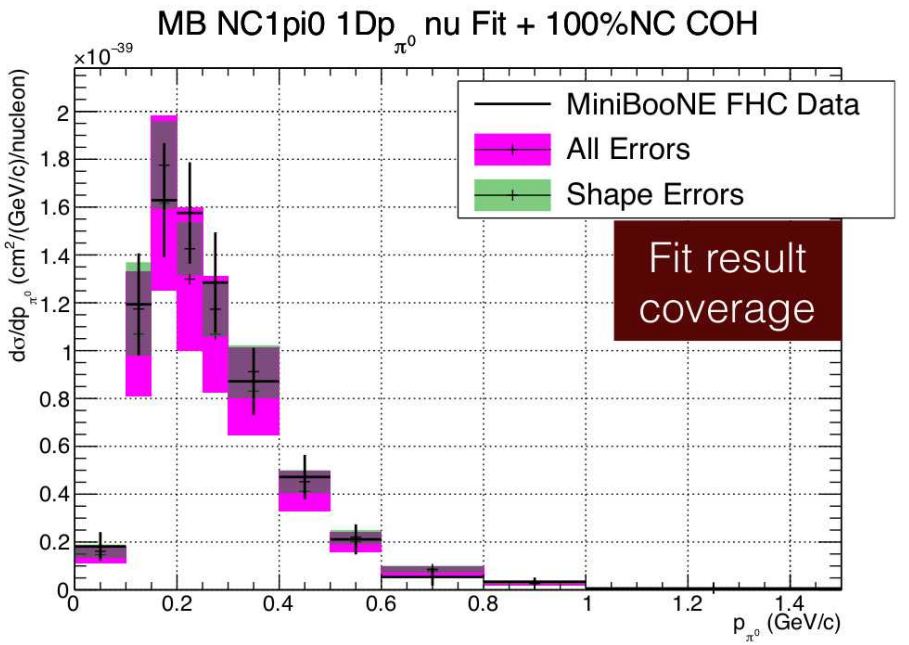


- Free to try whatever Franken-model possible to explain the data
- Now possible for anyone to use
- Also ensures data release is robust before publication stage

NUISANCE uses at T2K

- Pierre Lasorak's NC1γ limit has a large NC1π⁰ background with difficult side-band
- Developed cross-section parameterisation to allow for better shape change, driven by MiniBooNE NC1π⁰ data





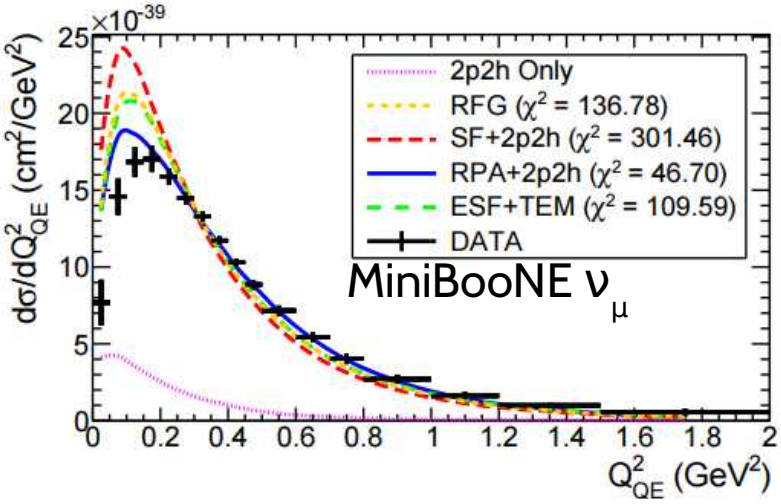
- Compared and fit effective parameters to the data set
- Similar studies by Dave Hadley for T2K NC0π using MiniBooNE NCQE measurement

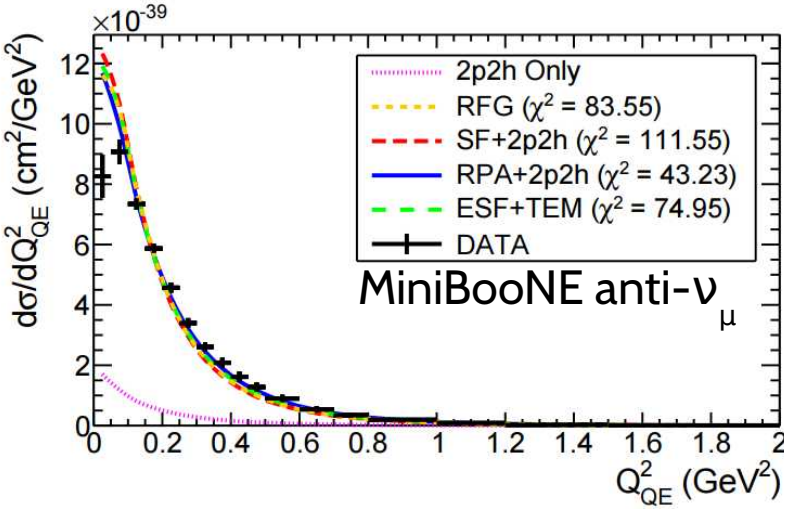
NUISANCE uses at T2K

- A precursor of NUISANCE was used for model selection for T2K OA 2015

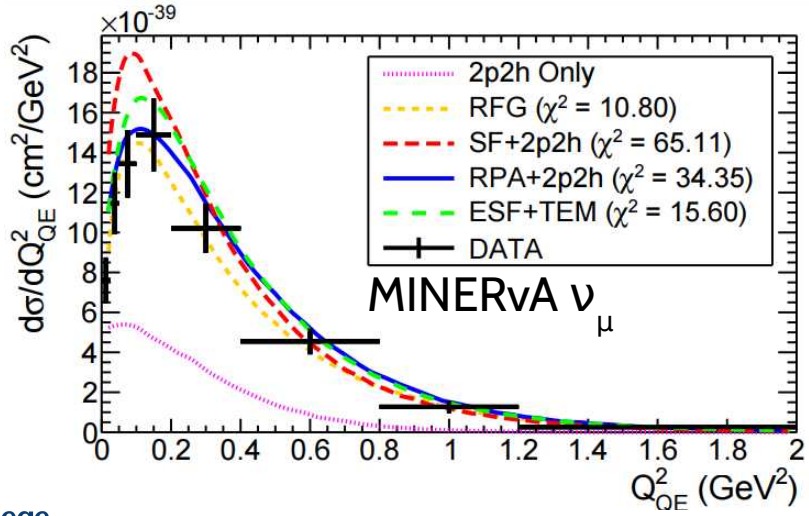
Phys. Rev. D 93, 072010

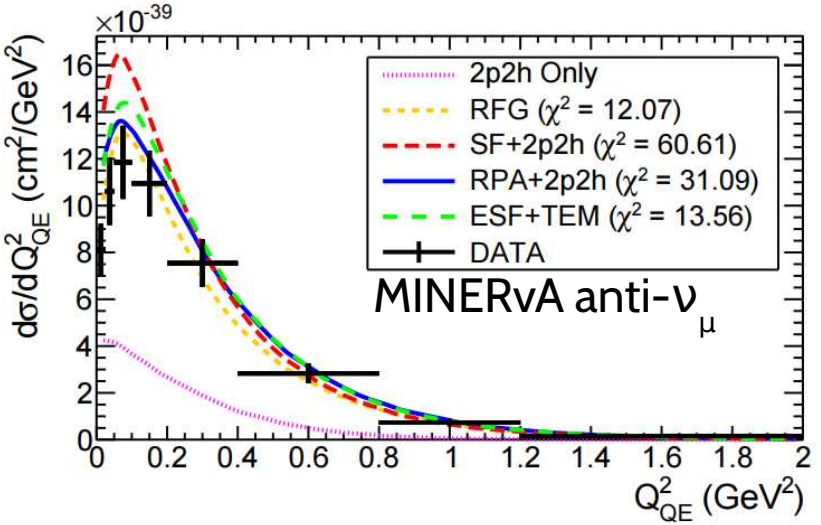
- Joint fit to MiniBooNE and MINERvA CCQE data





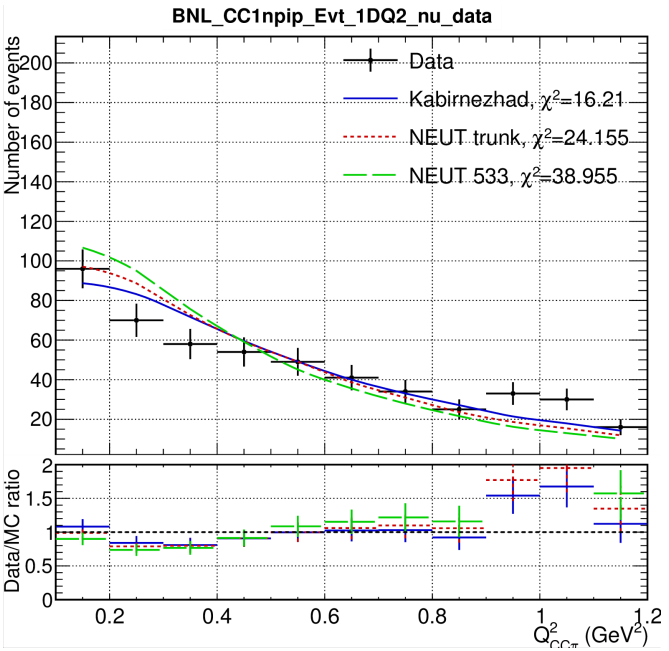
- Found RFG+2p2h+RPA was preferred over Spectral Function (Benhar) implementation

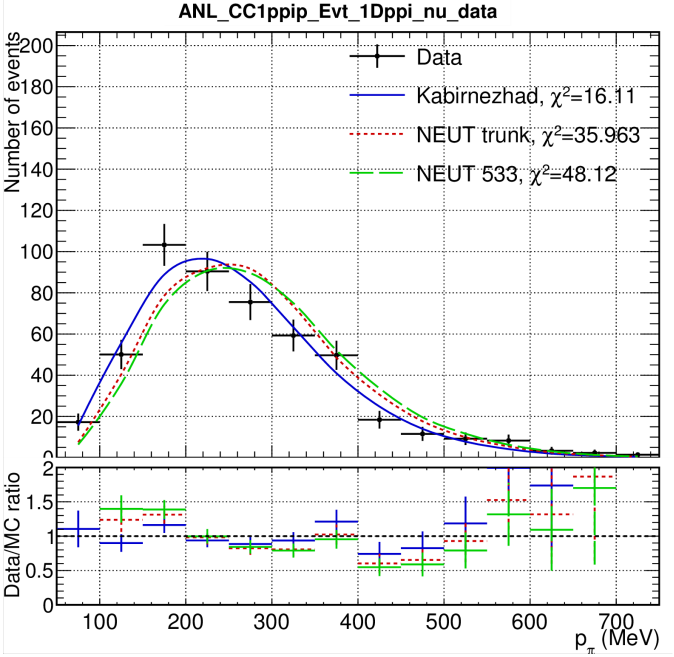


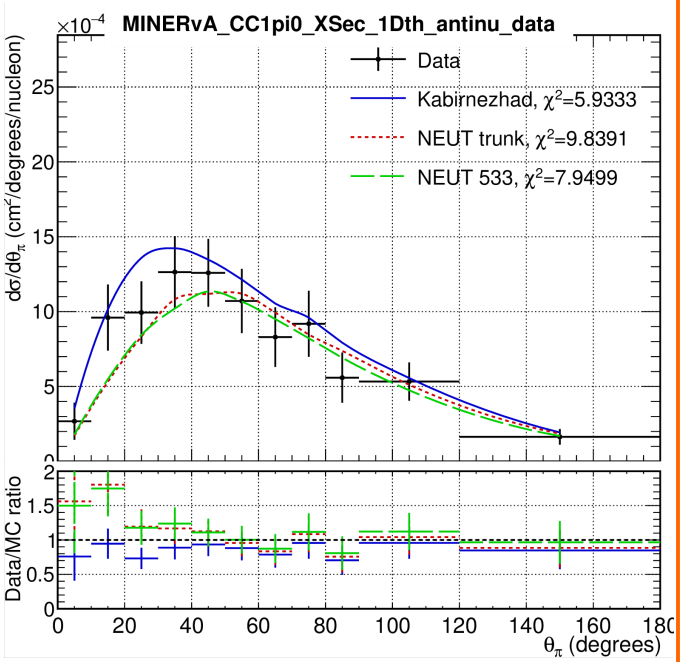


NUISANCE uses at T2K

- Minoo Kabirnezhad and I have been evaluating her SPP model implementation in NEUT







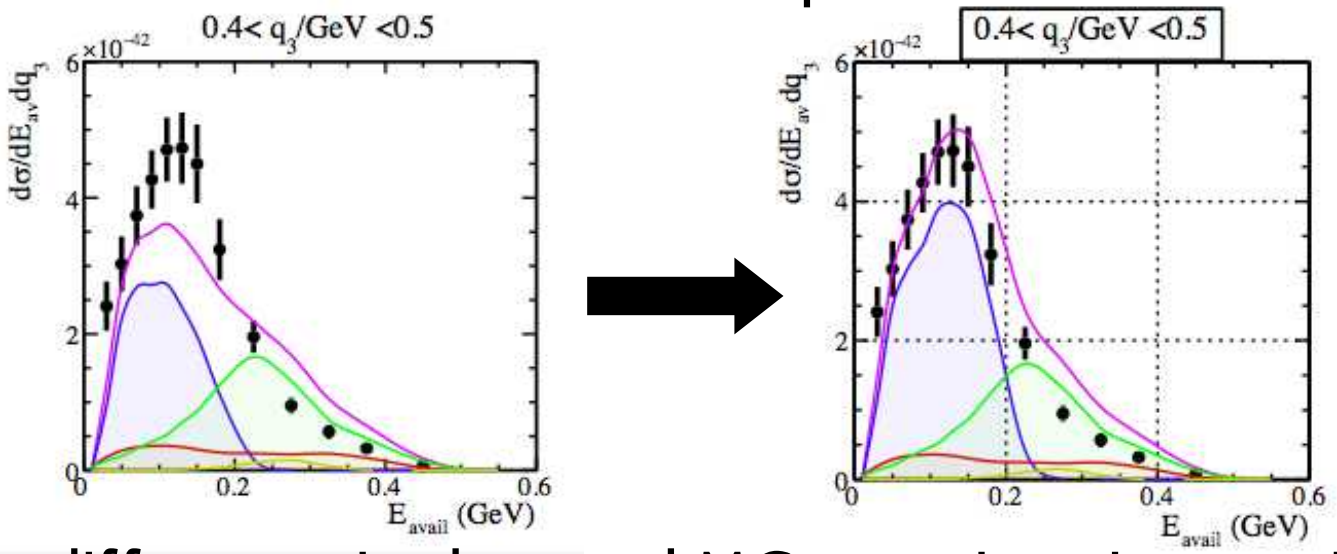
- Evaluating impact of model selection on external data and internal T2K data
- Parameter tuning to nucleon data
- How does NEUT's initial state and FSI get along with her model

NUISANCE uses at T2K

- Can also use for fake-data studies
- MINERvA CC-inclusive data indicates the NEUT prediction is missing ingredients in mid-E_{avail}

$$E_{av} = \sum_{i=p,\pi^{\pm}} T_i^K + \sum_{i=\pi^0,e,\gamma} E_i$$

- Is the difference from CCQE? From 2p2h? From CC1π?



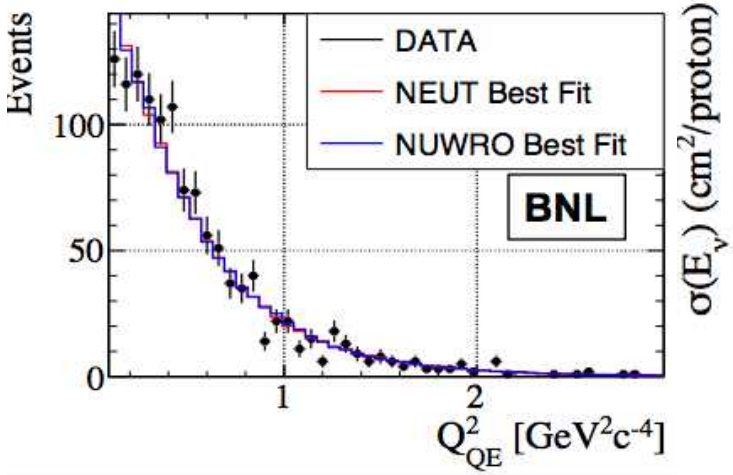
- Assign the difference in data and MC to various interaction modes
  - External data-driven MC correction to interaction model
- Investigate the effect of such correction on oscillation parameters and how it may bias E_ν reconstruction

Other bonus T2K uses

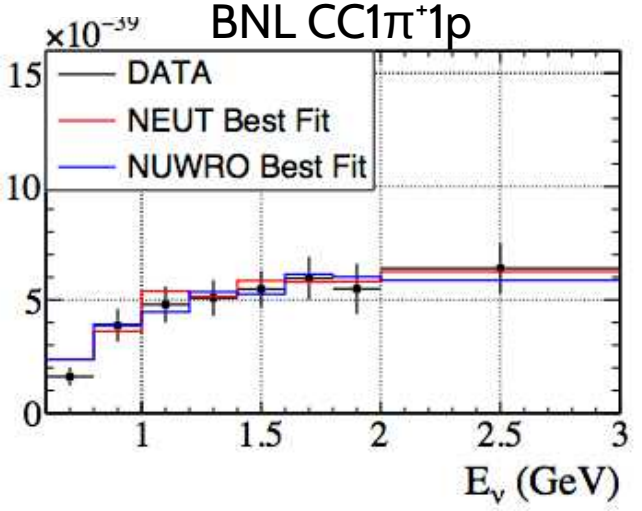
- Luke and Patrick developed and tested NuWro ReWeight for CCQE and SPP interactions
- Similar models to NEUT for free nucleon CCQE and SPP in the W < 1.4 GeV regime: expect similar results

	QE		RES		
Fit Results	M_A [GeV/c^2]	χ^2/NDOF	M_A^{RES} [GeV/c^2]	C_A^5	χ^2/NDOF
NEUT (v5.3.6)	1.04 ± 0.03	159.8 / 146	0.89 ± 0.04	1.02 ± 0.05	102.8 / 102
NuWro (v12)	1.03 ± 0.03	154.4 / 146	0.92 ± 0.03	1.04 ± 0.05	111.9 / 102

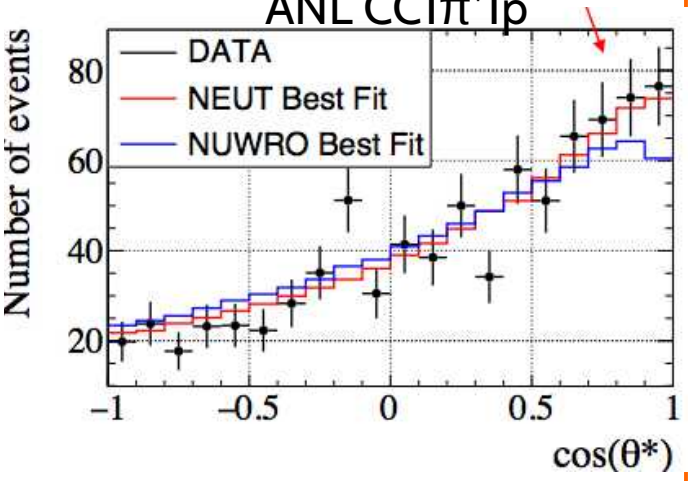
BNL CCQE



BNL CC1π⁺1p

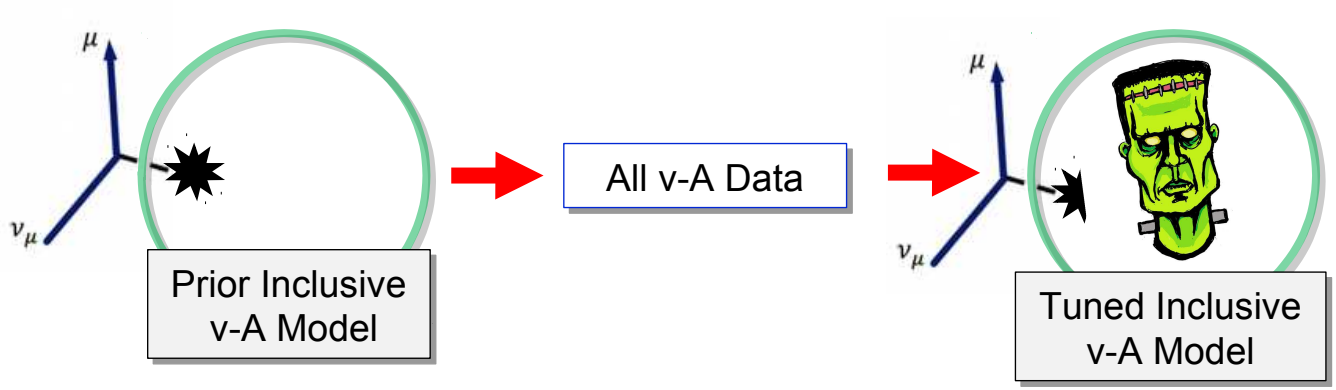


ANL CC1π⁺1p



Long-term fit goal

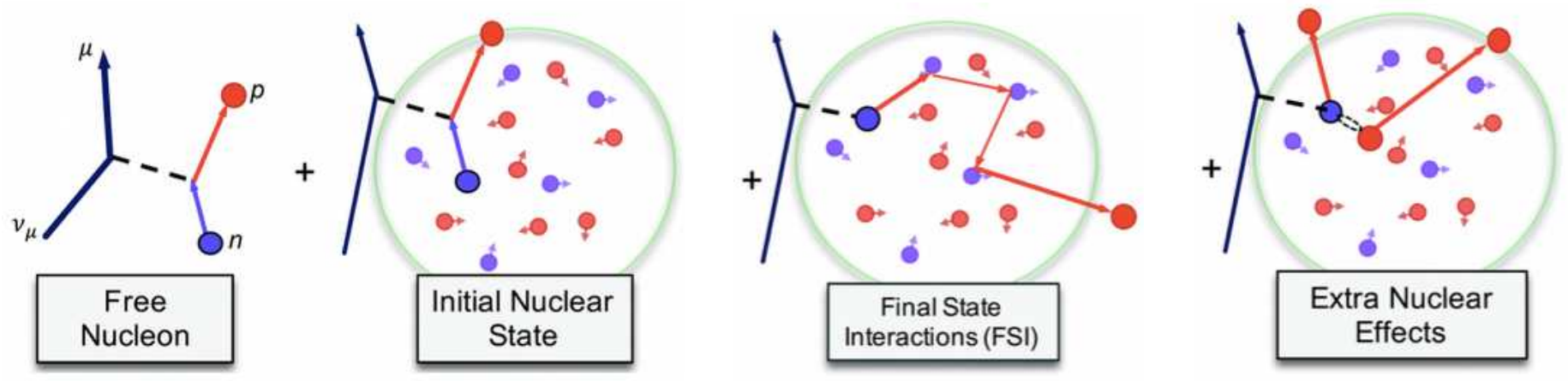
- Large ensemble of data available in NUISANCE
- Blindly fitting all parameters tells us little about physics
  - Very likely to end up with a Frankenmodel, e.g. unnaturally high M_A^{QE}, $C_A^5(0)$ far from ~1.2...
  - Not necessarily statistically correct because of missing covariances, leading to a poor test-statistic



- Instead develop a step-by-step tune using priors from earlier NUISANCE fits

Long-term fit goal

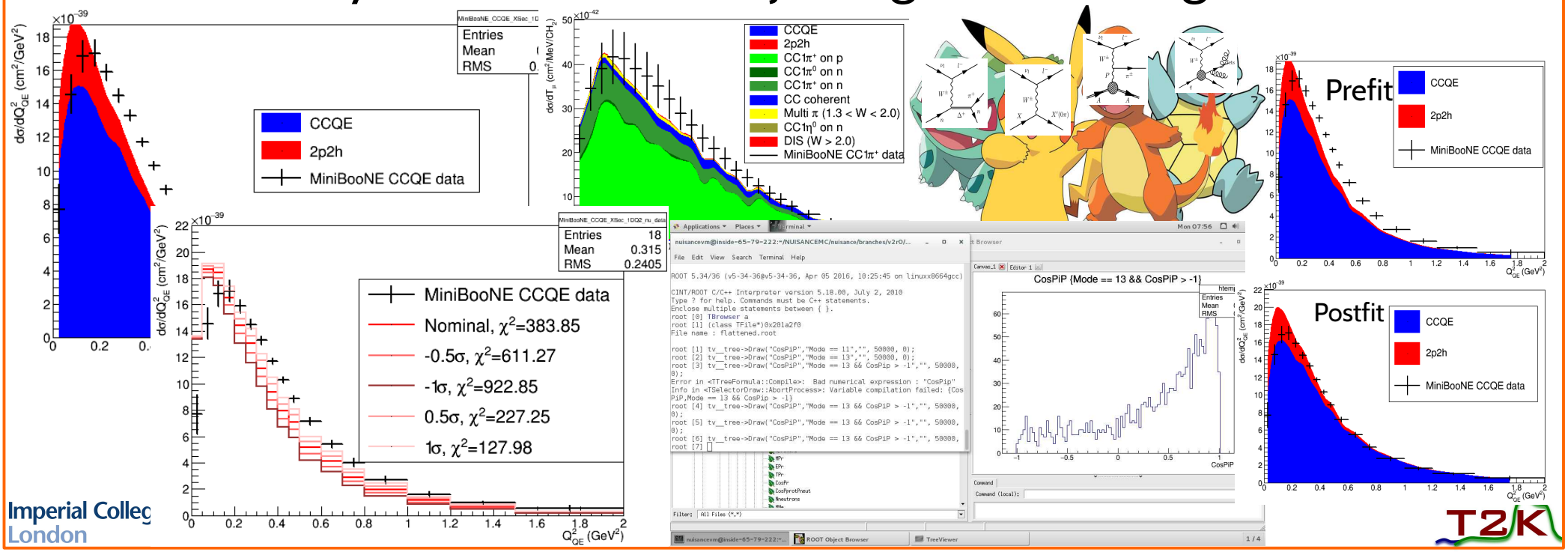
- First fit to exclusive bubble chamber data
  - Constrain the fundamental interaction without nuclear effects
- Include exclusive data from nuclear target (e.g. CC0π, CC1π^+)
  - Use priors from BC fit, include the relevant nuclear parameters
- Include inclusive data from nuclear targets (e.g. E_{avail})
  - Use priors from earlier fit(s)



- All whilst checking for dataset compatibilities and possible tensions

Bonus: NUISANCE for everyone!

- NUISANCE Tutorial at T2K Pre-NuInt workshop
  - A pre-compiled virtual box which you can "just run"
  - Includes the generators, ROOT and NUISANCE
  - Pre-generated MC provided; can also generate your own
- Patrick is giving a tutorial at NuSTEC Fermilab later this year
- Chat to us if you're interested in joining and/or using!



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T2K

Future projects

- Attempt multiple generator fits and comparisons
  - Requires the knowledge of generator and theory experts
- Agree on "HepMC"-like format from theorists
  - Produce outgoing particles by e.g. accept-reject method(s)
  - Compile these stacks into a common format; compare to generators
- Electron scattering interface for GENIE, eWro, GiBUU
  - Vishvas Pandey (Virginia Tech, formerly Ghent) has joined in and is collecting theory predictions
  - Hoping for a large Data/MC/theory collection
- Pion and photon scattering interfaces are being discussed
- Accessible website for fast Data/MC comparisons
  - Publish nominal predictions of generator A, B, C with models X, Y, Z

Lessons from handling neutrino data

- Have handled a lot of neutrino data with varying degrees of success

- Publish and test your final **covariance matrices**
  - Statisticians consider **data without covariances to be incomplete**
  - Bob Cousins, Louis Lyons (CMS), Pumplin, Stump (CTEQ/CT10) **recommended simply excluding these "useless measurements"**
  - If you want maximum juice from your measurement, consider **distribution-to-distribution correlations**

- Signal definition needs to be reproducible in raw MC (truth)
- Don't correct for blind detector regions. **Data is pure, data is sacred**

Conclusions

- NUISANCE is a large open source neutrino cross-section comparison framework
- Supports simple Data/MC comparisons, systematics evaluations parameter fitting
- Developed from efforts at T2K in selecting default interaction models and parameter constraints without using T2K data
- NEUT, GENIE, NuWro and GiBUU support
  - Additionally links to reweighting libraries
- Can inform the cross-section analyser of model "goodness", previous measurements, error coverage, multi-generator predictions...
- Lots of plans in the near future
- Could certainly use non-T2K people: we welcome any collaboration

Thanks!