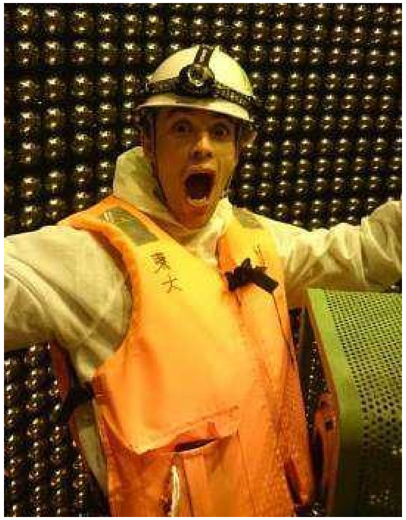
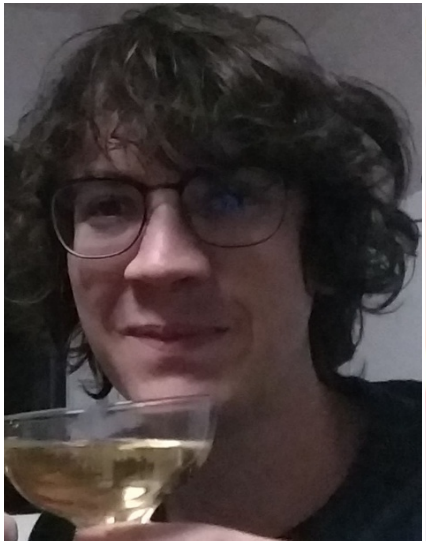
NUISANCE and global tuning

JINST 12 P01016 (2017)
nuisance.hepforge.org
github.com/NUISANCEMC/nuisance/
nuisance-xsec.slack.com



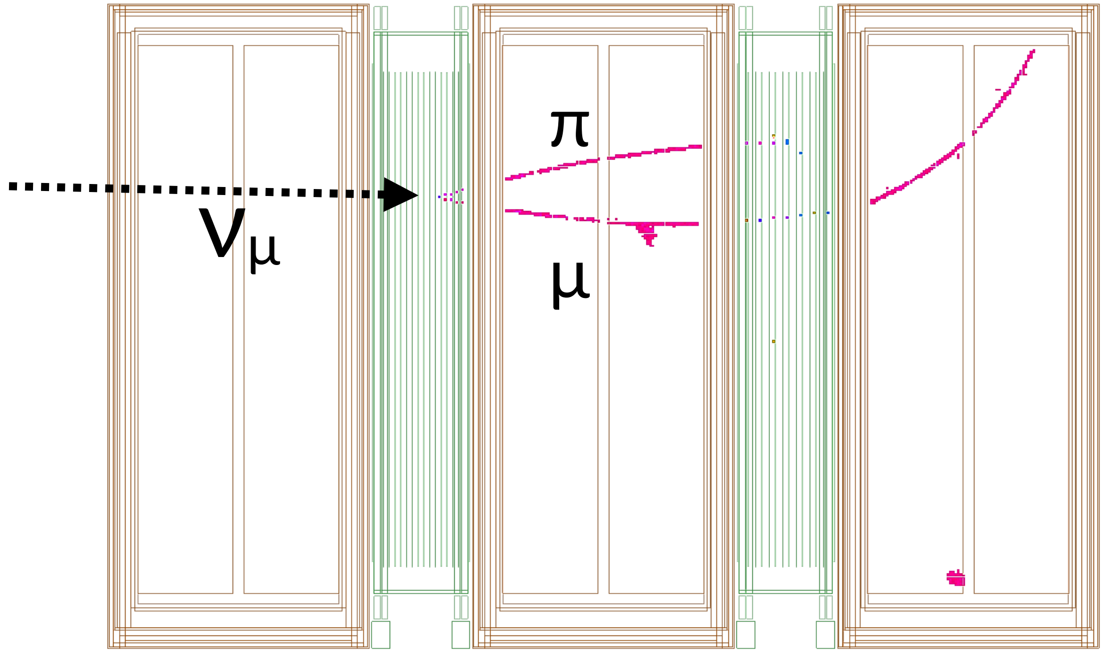




Clarence Wret — University of Oxford
Luke Pickering — UKRI Science and Technology Facilities Council
Callum Wilkinson — Berkeley Lab, Lawrence Berkeley National Laboratory
Stephen Dolan — CERN
Patrick Stowell — University of Sheffield

NuInt 2024, Sao Paolo
April 19 2024

Introduction

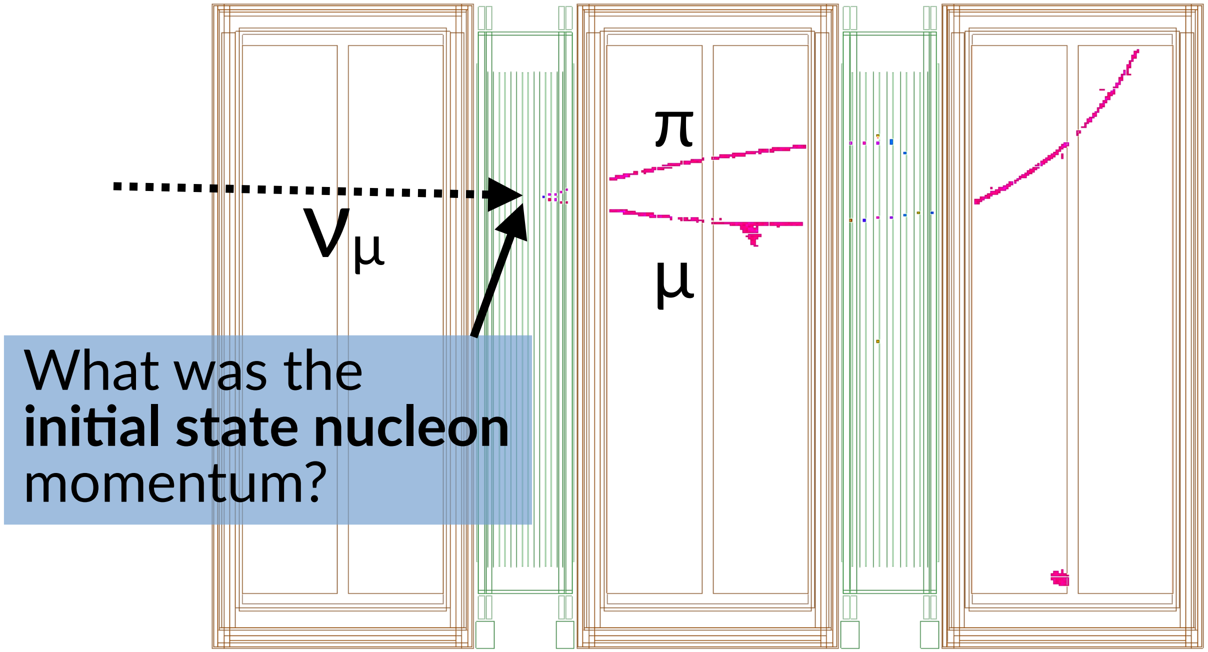
- Why do we need neutrino cross-section dependence at all?
  - Can't reliably measure the fundamental interaction quantities (E_ν, Q^2, W, q_0, $\mathbf{q_3}$, ...)



- Need to relate observed event to the true quantity through some model

Introduction

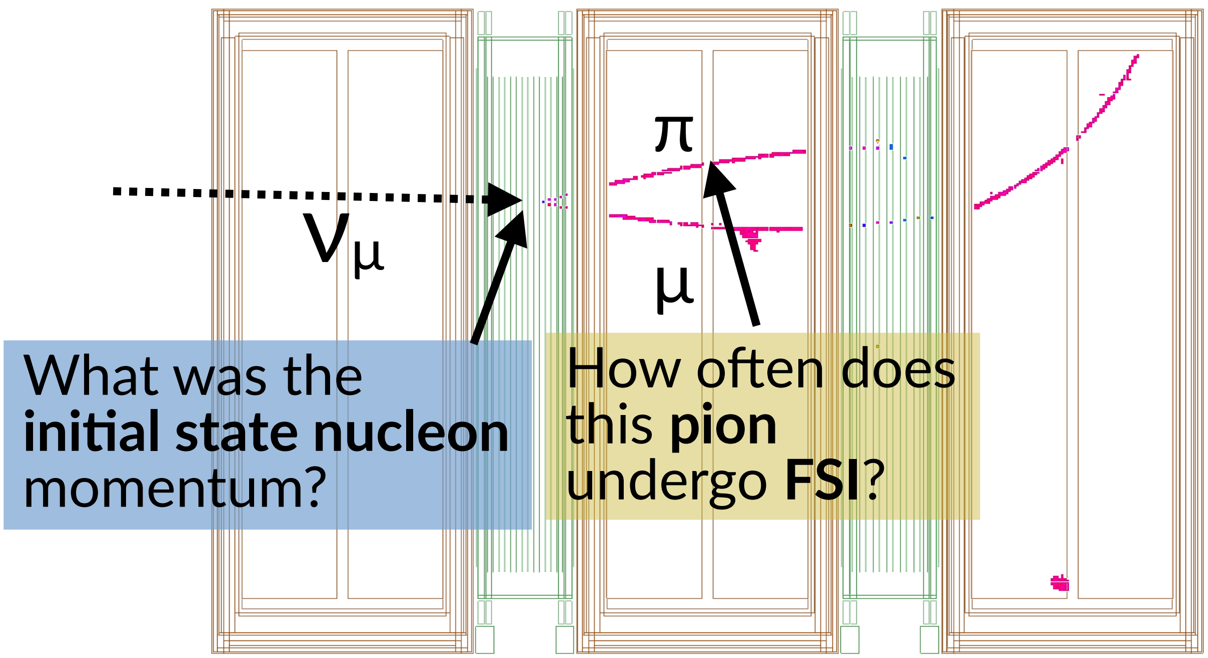
- Why do we need neutrino cross-section dependence at all?
  - Can't reliably measure the fundamental interaction quantities (E_ν, Q^2, W, q_0, $\mathbf{q_3}$, ...)



- Need to relate observed event to the true quantity through some model

Introduction

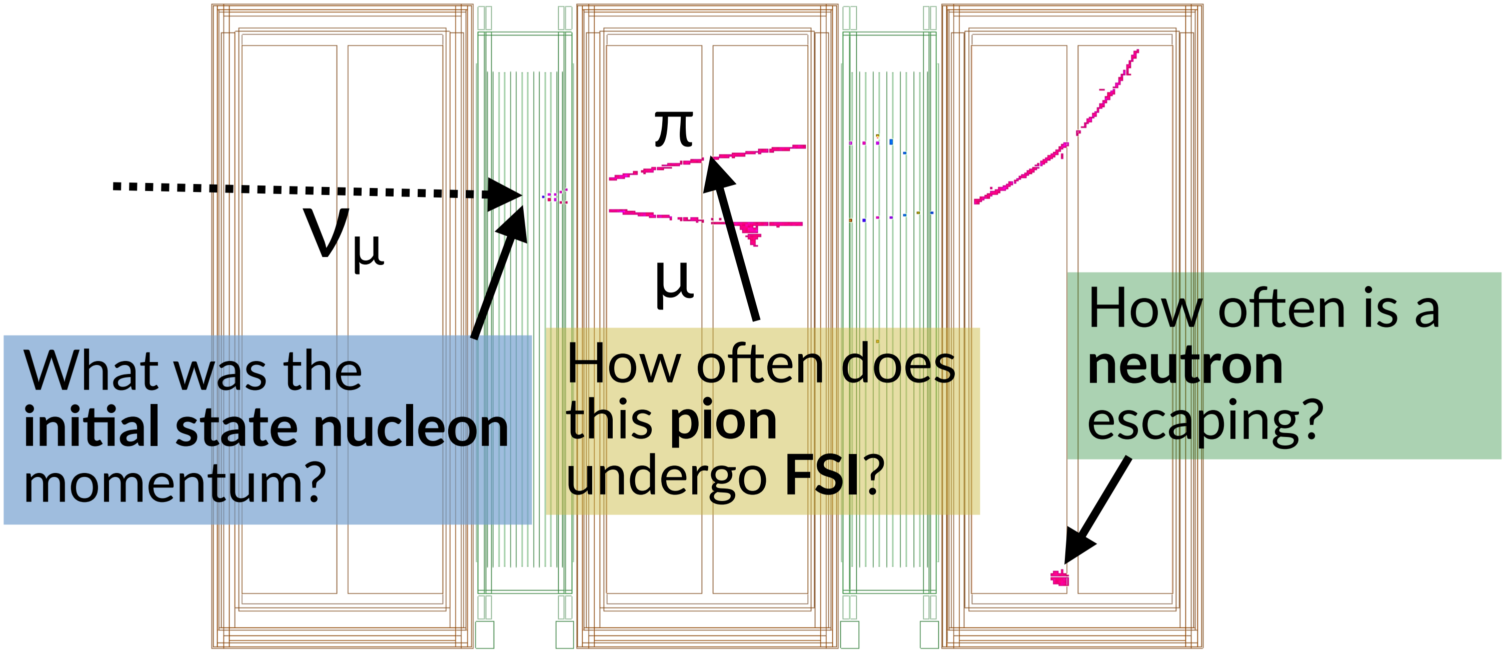
- Why do we need neutrino cross-section dependence at all?
  - Can't reliably measure the fundamental interaction quantities (E_ν, Q^2, W, q_0, $\mathbf{q_3}$, ...)



- Need to relate observed event to the true quantity through some model

Introduction

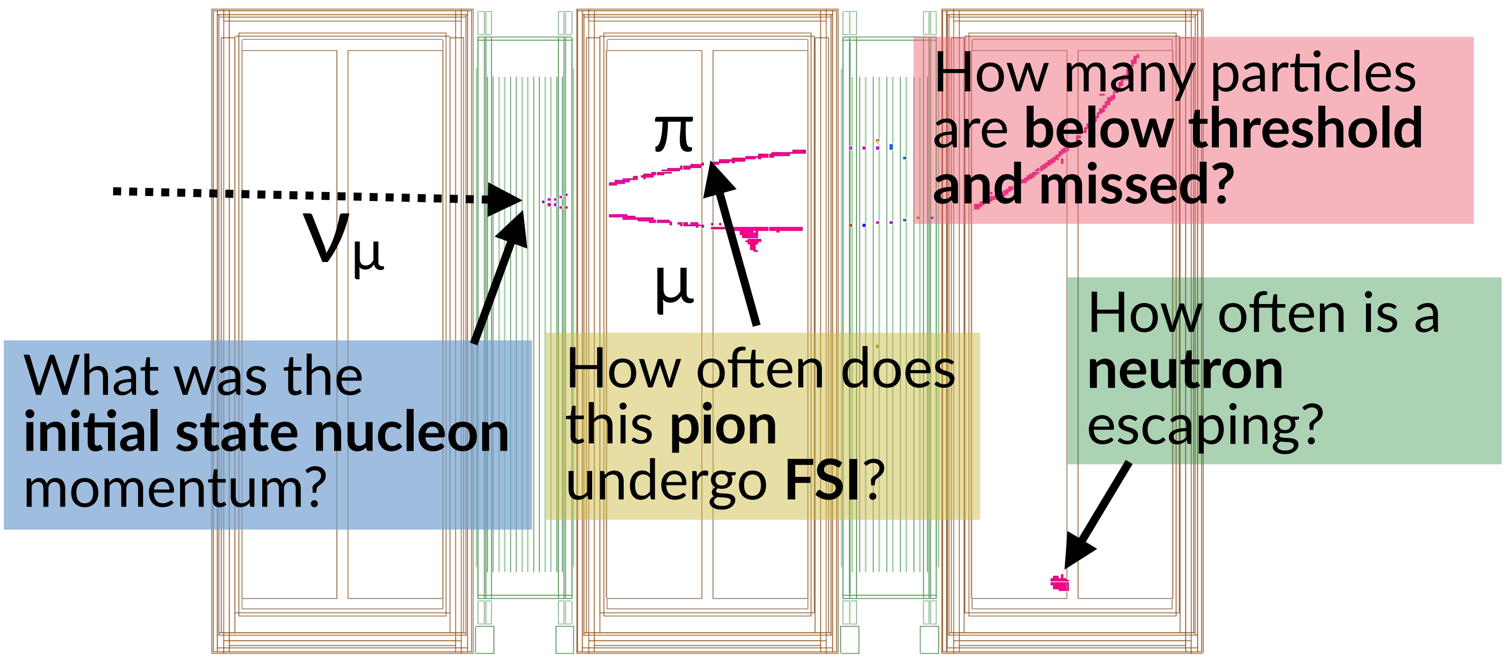
- Why do we need neutrino cross-section dependence at all?
  - Can't reliably measure the fundamental interaction quantities (E_ν, Q^2, W, q_0, $\mathbf{q_3}$, ...)



- Need to relate observed event to the true quantity through some model

Introduction

- Why do we need neutrino cross-section dependence at all?
  - Can't reliably measure the fundamental interaction quantities (E_ν, Q^2, W, q_0, $\mathbf{q_3}$, ...)



- Need to relate observed event to the true quantity through some model

Introduction

- Can we escape model dependence? **Arguably not**
  - Even a perfect neutron-capable detector won't be able to tell you about final-state interactions, or the initial state
- But we can **avoid dependence on models that have shaky foundations**!
  - Does the model fail to describe reliable data?
  - Is the model prediction very different to currently approved approaches?
  - Etc…
- NUISANCE is a tool which helps inform you where models are doing well, and where they aren't
  - Design physics analyses to expose weaknesses in modelling
  - Avoid physics analyses that depend on unreliable model predictions
  - Rinse, repeat, and get more robust and valuable measurements!

UNIVERSITY OF OXFORD

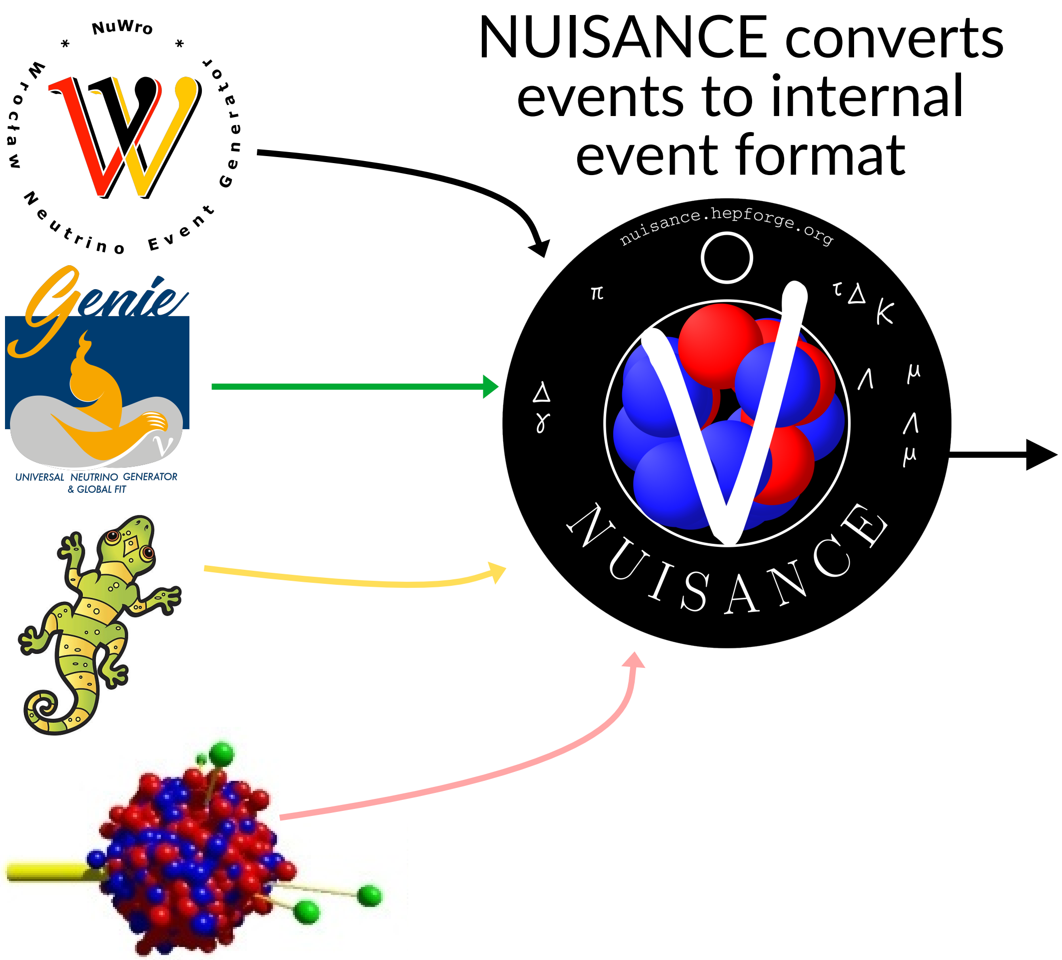
Introduction

- The generator market is vast, and expanding!
  - GENIE, NEUT, NuWro, GiBUU, Achilles, NUANCE, …
  - **No obvious winner for many**: some generators have excellent integration into experiments, others have very detailed nuclear model implementations, others have less developed uncertainty models, and so on…
- Wanted to easily compare multiple **different** generator predictions to each other and to **data**
  - Develop and estimate uncertainties in analyses, using both generators and external data
  - Expose differences between generators and models
  - Identify interesting measurements for experimentalists to pursue
  - Check effects of theory and phenomenology implementations against data and previous calculations
  - Get an idea of how model-dependent measurements may be

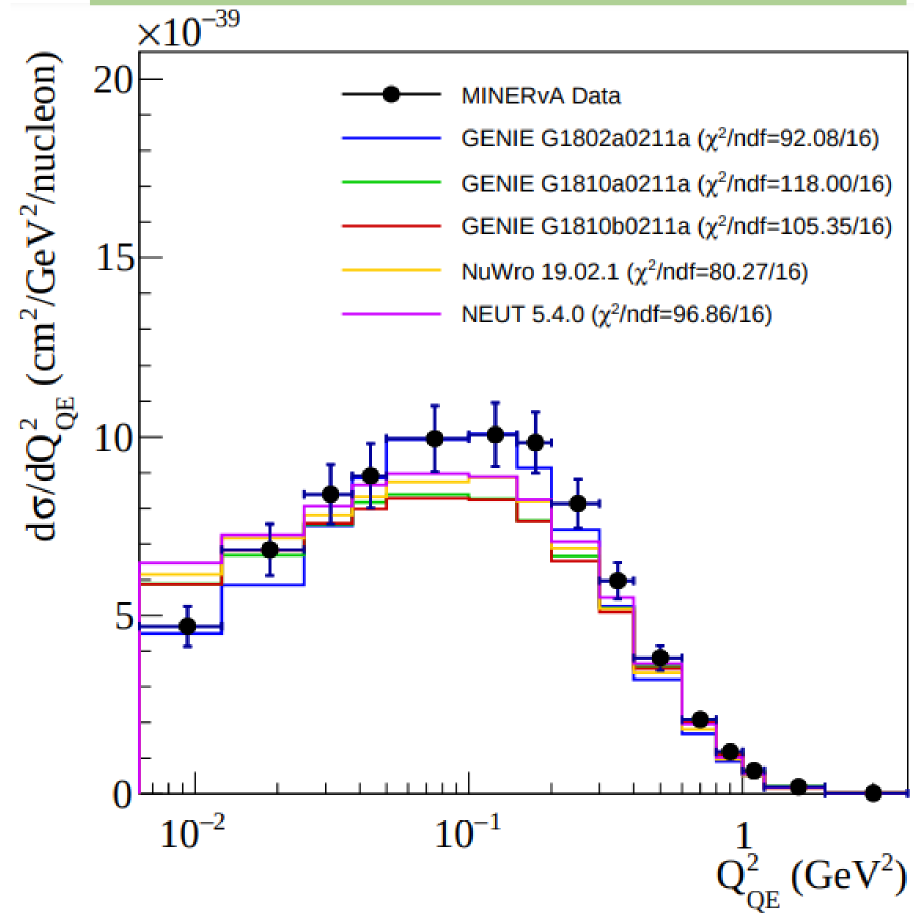
What can NUISANCE do?

- All driven by simple commands, where a config file with the measurement and systematic parameters are provided

Generate events



Compare generators to data



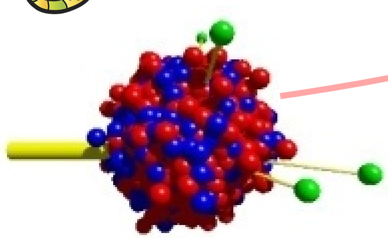
What can NUISANCE do?

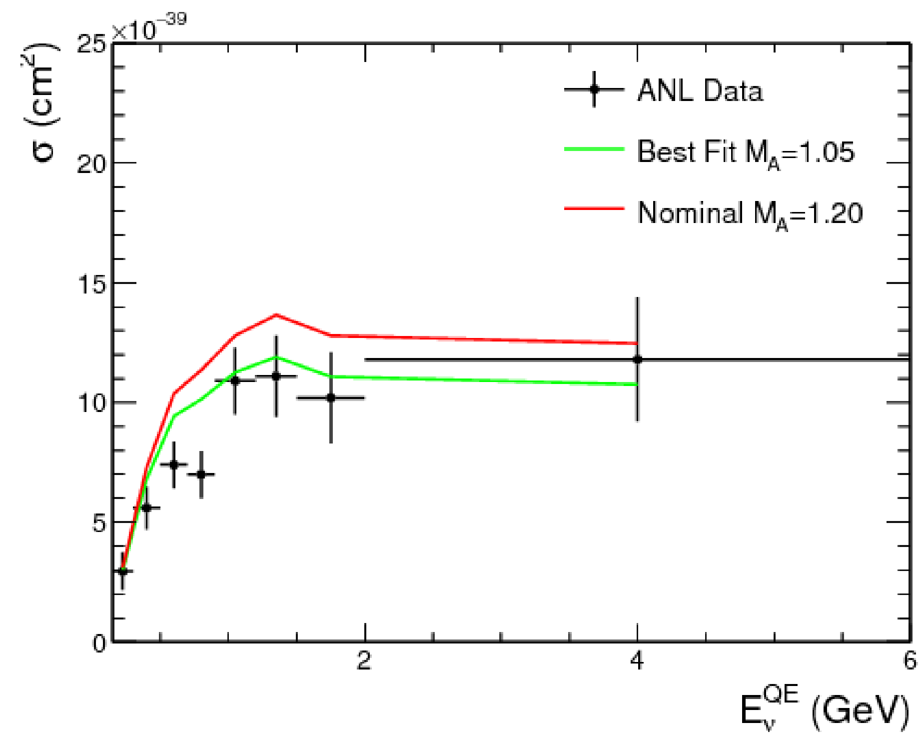
- All driven by simple commands, where a config file with the measurement and systematic parameters are provided

Generate events

NUISANCE converts events to internal event format

Fit generators model parameters to specific data



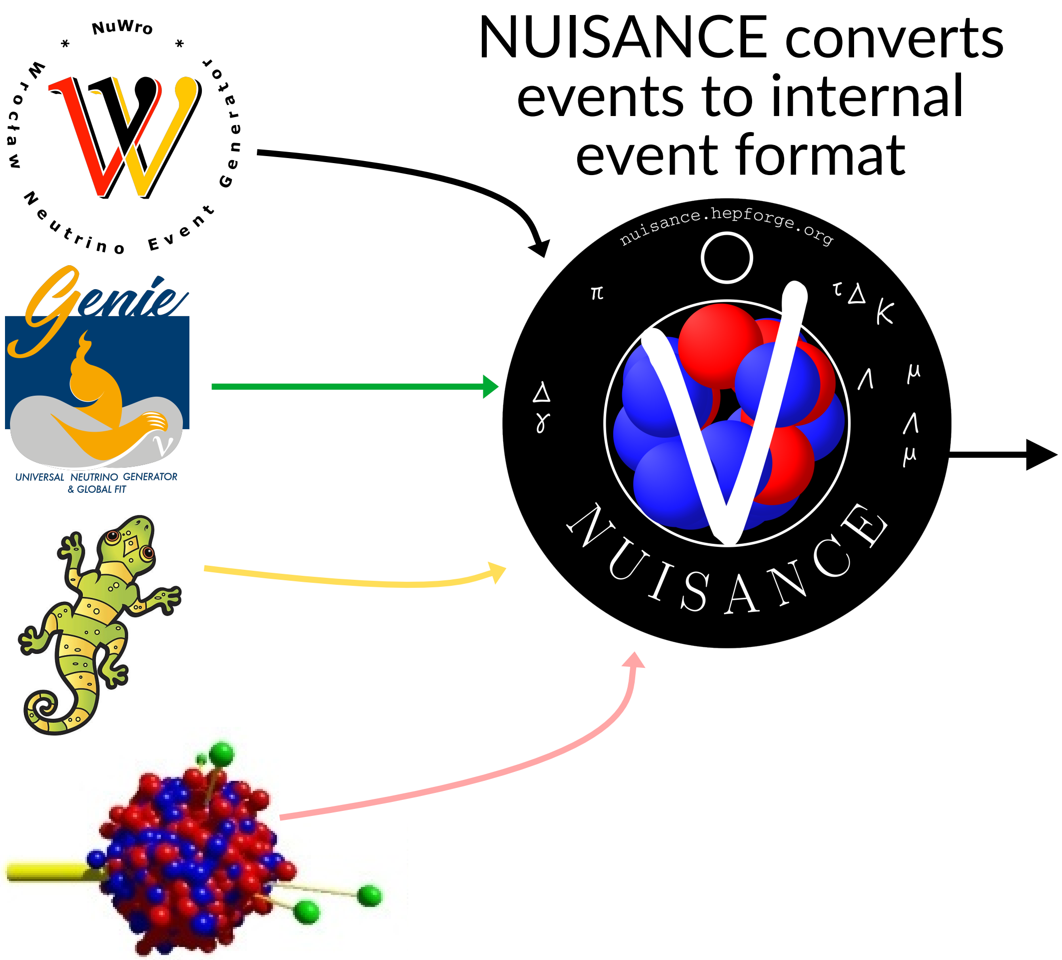


What can NUISANCE do?

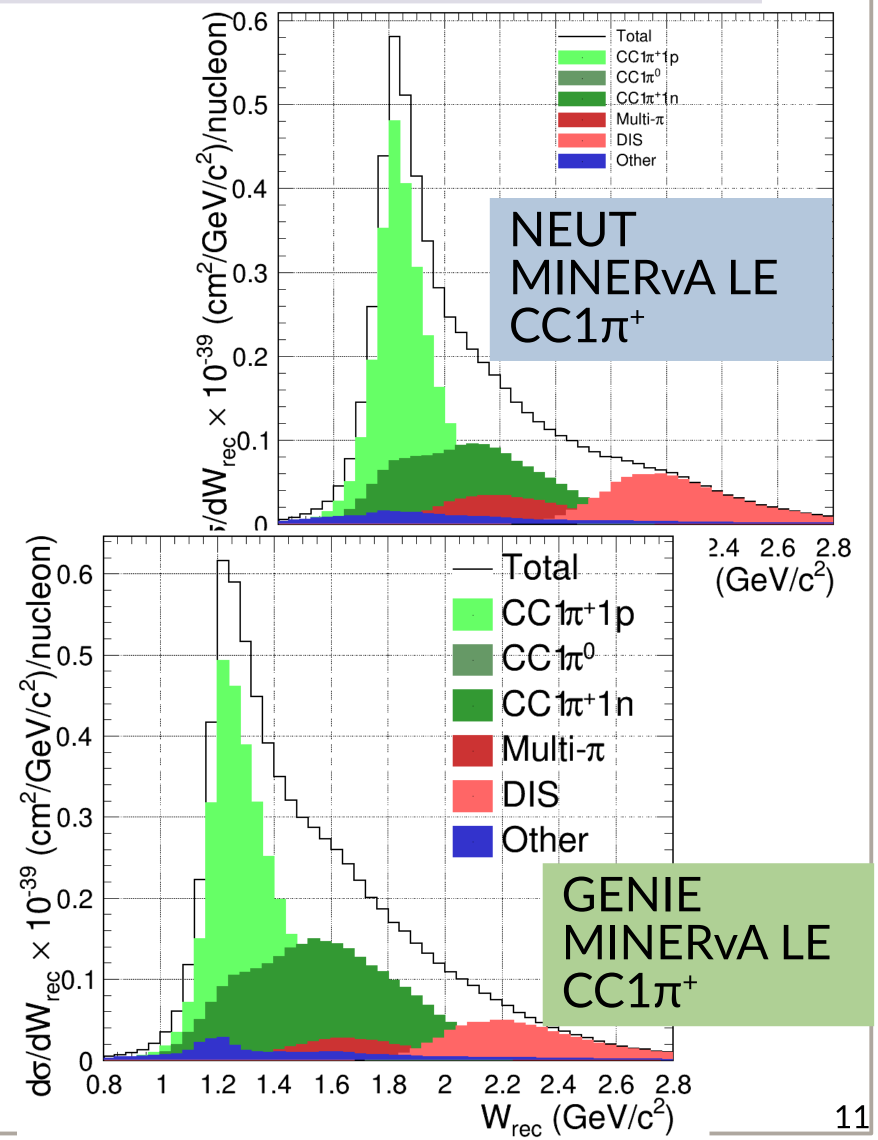
- All driven by simple commands, where a config file with the measurement and systematic parameters are provided

Generate events

NUISANCE converts events to internal event format



Compare generator features

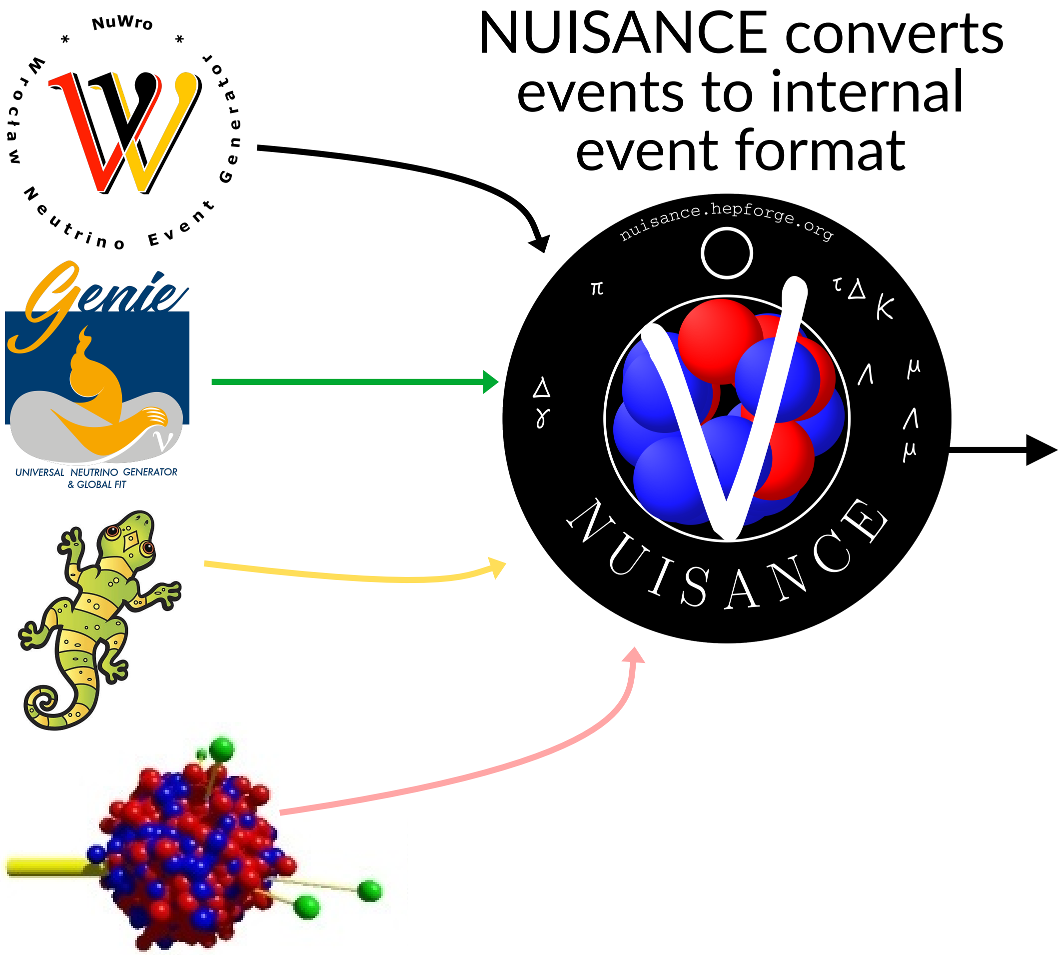


What can NUISANCE do?

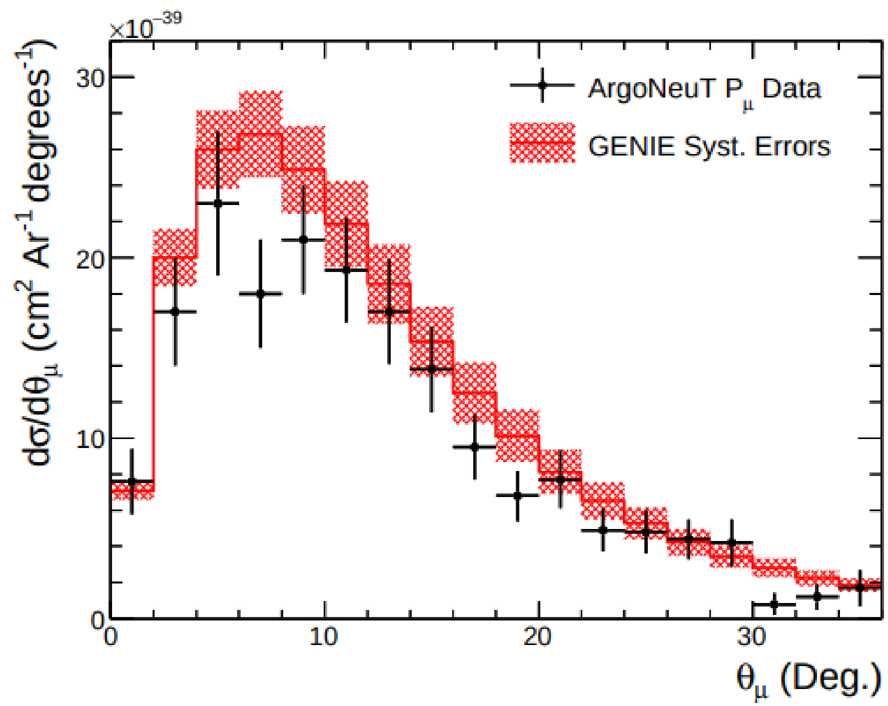
- All driven by simple commands, where a config file with the measurement and systematic parameters are provided

Generate events

NUISANCE converts events to internal event format



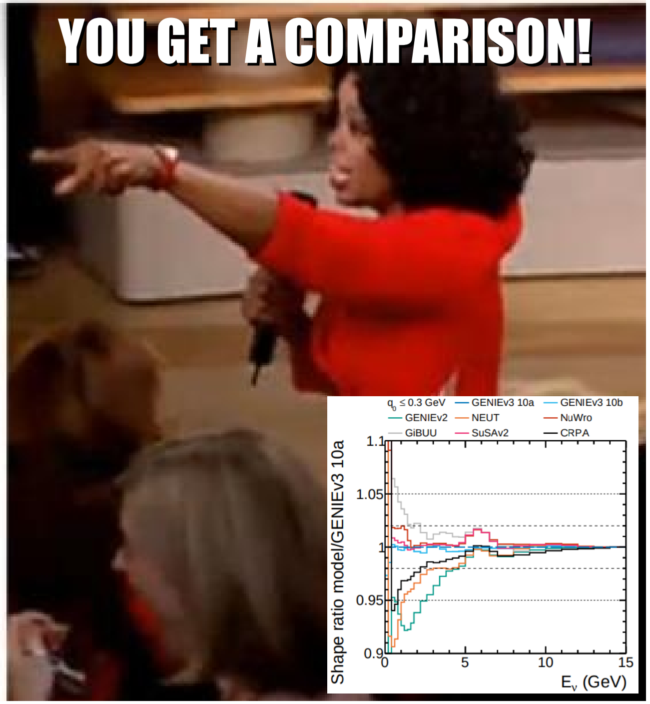
Evaluate uncertainty of model against data

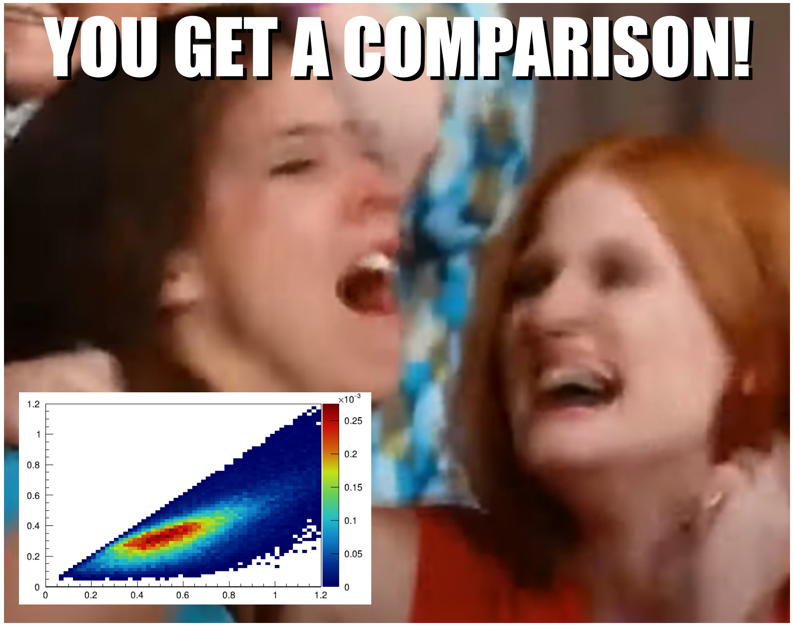


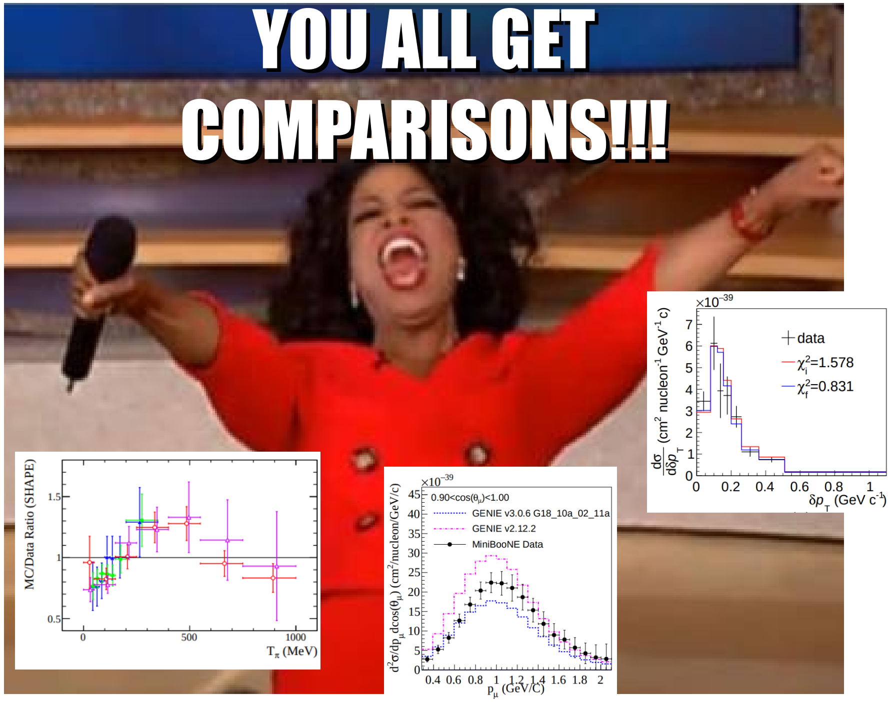
What can NUISANCE do?

- Compare your generators to over **350 implemented data sets**
- Interfaces with **reweighting engines**
  - GENIE ReWeight, custom reweighting, MINERvA reweighting, T2K and DUNE's systematics packages, etc
  - You can also add your own
- Estimate the **uncertainty band of your model** against a vast array of data
- Interfaces with an array of minimisers to **fit your model to data**
  - Fit whatever model you want, to whatever data you want
  - Can also fit GENIE model to NuWro fake data, and so on
- **Generator agnostic** and **completely open source**!

What can NUISANCE do?







UNIVERSITY OF OXFORD

Typical workflow

- Users and main developers put in pull requests for new measurements
- Collaborate with experiments on implementations

Jeffrey Kleykamp, MINERvA

- [ ] **Kleykamp minerva nukecc0pi muon ptpz**
  #46 by jdkio was merged on Jun 8, 2023
- [ ] **Add MicroBooNE CC1muNp** New samples
  #36 by mastbaum was merged on Jun 15, 2021

Andy Mastbaum, uBooNE

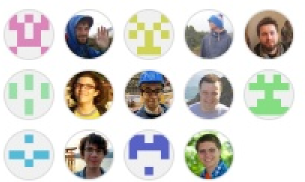
Stephen Gardiner, uBooNE

- [ ] **2019 MINERvA numubar CC 1π- sample** New samples
  #35 by sjgardiner was merged on Jun 16, 2021
- [ ] **Adding T2K 2018 CC0pi data sample and plotting script**
  #13 by kirsty-duffy was merged on Oct 14, 2020 • Approved

Kirsty Duffy, uBooNE

And many others!

Contributors 17



+ 3 contributors

- Validate against the generator prediction that is published using same generator
- Signal definition clarifications, defining variables, etc
- Work together on data releases and help identify needs
  - Avoids revisiting data release due to broken covariance matrix, unclear signal definitions, typos in papers… (all of which have happened)

UNIVERSITY OF OXFORD

Typical workflow

Carefully **validated** and implemented data release, in close collaboration with analyser on experiment

Multi-generator comparison for the publication, expanding scope for **discussion of physics**

Ensure measurement gets **physics usage for years, with many citations**

Uninvertible covariance matrix and vague **unclear signal definition**

Single generator comparison in paper, **limits physics discussions**

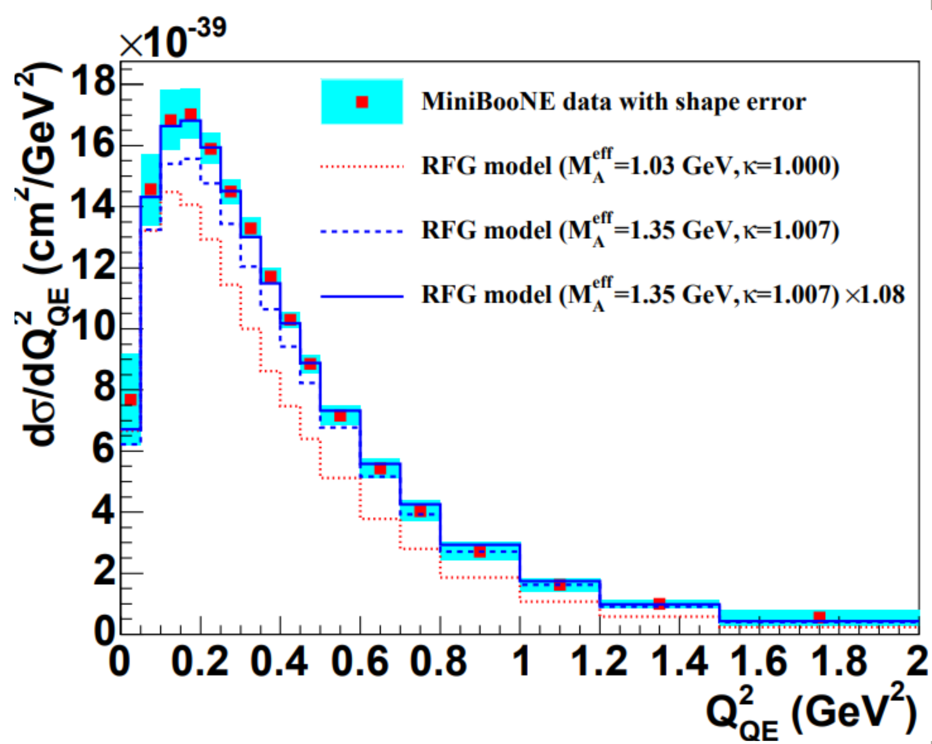
Student leaves for industry after graduation

Measurement **without much practical application**

“Tuning to global data”

Tuning to data

- **No one likes having to tune their model to data**
- No generator or theory model describes all data adequately → may need to make an "**effective model**" for **specific purposes**
  - e.g. does T2K really have to worry about 6 GeV DIS interactions on ^{40}Ar? What about 2 GeV interactions on ^{12}C?
- Have to be **very** careful with how far this "effective model" can go: **what physics are you tuning away**?
  - Fitting only M_A^{QE} and a scale factor to MiniBooNE **might fit the data**
  - **Completely sweeps profound physics under the carpet**, e.g. SRCs, 2p2h, ^{12}C nuclear effects
  - **These will likely not extrapolate correctly**, in for instance energy, Q^2, target material

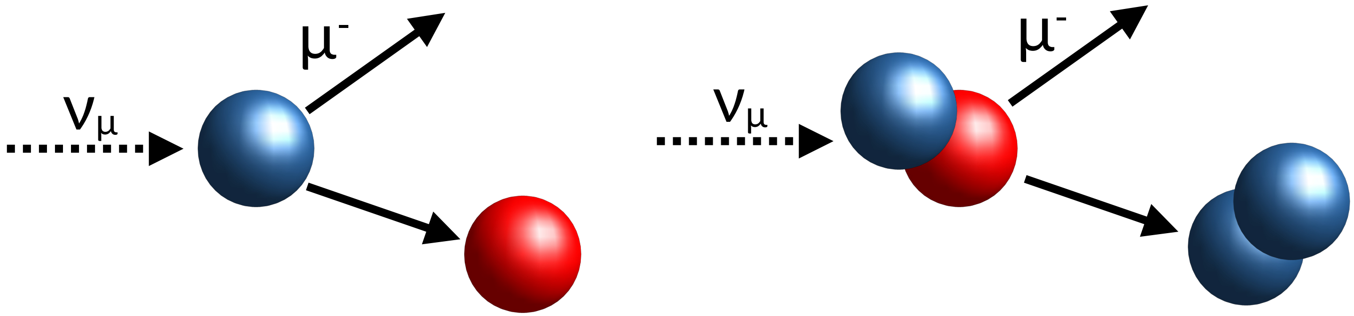


Tuning landscape

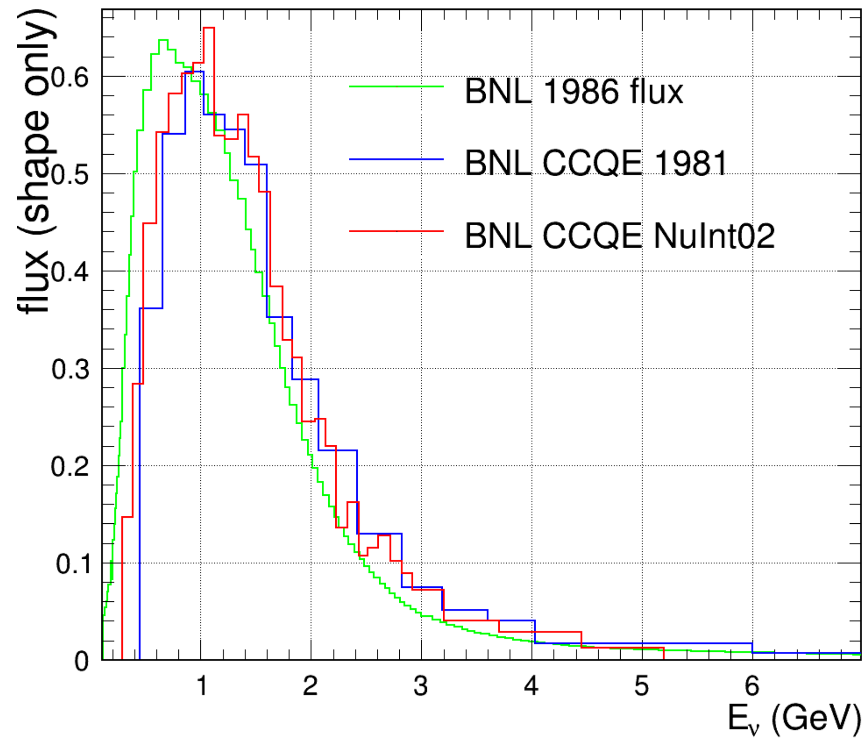
- With this in mind, experiments often develop their own custom tune for specific purposes
  - MINERvA tune (Dan Ruterbories et al)
  - MicroBooNE tune (Stephen Gardiner et al)
  - NOvA tune (Jeremy Wolcott et al)
  - GENIE comprehensive model configurations (CMC) (Julia Tena-Vidal et al)
  - T2K NEUT tune
  - Various NuWro tunes, e.g. bubble chambers (Jan Sobczyk et al)
  - Z-exp tuning to bubble chambers (Aaron Meyer et al)
  - ...
- None attempt to fit global data: **this is a nightmare statistically** and **you are bound to get physics very wrong**
- Instead often split into **nucleon** tune and **nuclear** tunes
  - Helps separate nucleon and nuclear level uncertainties

Tuning to bubble chambers

- Tune nucleon interaction model to selected ANL, BNL, FNAL, BEBC, Gargamelle data on light targets (H_2, D_2)



- Already **riddled with ambiguities**
  - D_2 nuclear effects
  - Unclear neutrino fluxes
  - Unclear H_2/D_2 mixes
  - Unclear efficiency corrections
  - ANL/BNL CC1π data “tensions”



(b) $\nu d \to \mu^- p \pi^0 p_s$

Background from		
$\mu^- p \pi^0 \pi^0$ and $\mu^- n \pi^+ \pi^0$	f_1	-0.202 ± 0.018
$\mu^- p$ and $\mu^- n \pi^+$	f_2	-0.032 ± 0.012
$\nu p \pi^-$	f_3	-0.084 ± 0.014
$nn \to np\pi^-$	f_4	-0.154 ± 0.043
Event assigned to $\mu^- n \pi^+$ and $\mu^- p$	f_5	$+0.235 \pm 0.071$
Scanning-measuring efficiency	g_1	1.13 ± 0.06
Correction for three prong	g_2	1.22 ± 0.01
Total correction		
$(1 + f_1 + f_2 + f_3 + f_4) g_1 g_2$		1.05 ± 0.14

https://nuisance.hepforge.org/files/BC_pion_archaeology.pdf
https://nuisance.hepforge.org/files/H2D2_experience.pdf

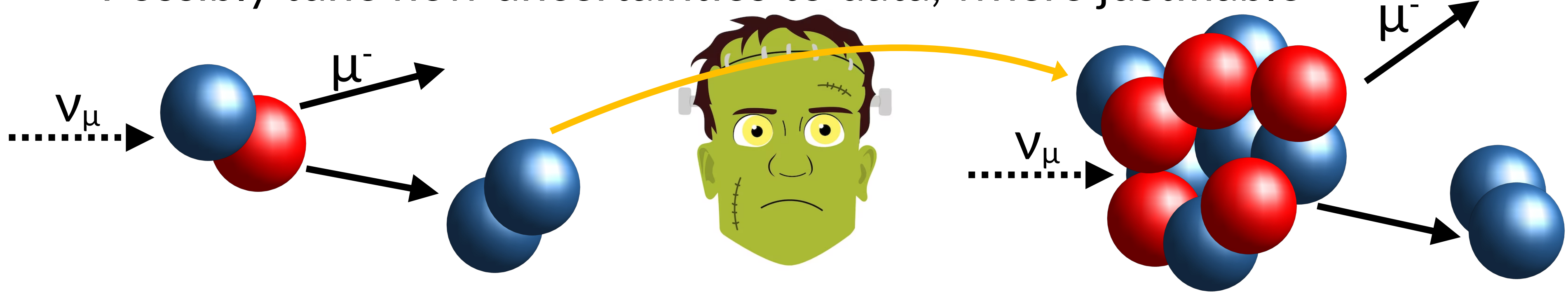
Tuning to nuclear data

- **Propagate** constrained **nucleon interaction model** to **nuclear-target** data, adding on nuclear effect
  - Often requires new uncertainties
  - Possibly tune new uncertainties to data, where justifiable

- Can inflate uncertainties to cover different data, e.g. bubble chamber W<1.4, 2.0 GeV/c^2, and nuclear data
  - We do this on T2K, but have **larger uncertainties** compared to GENIE CMC bubble chamber tune and other work

Tuning to nuclear data

- **Propagate** constrained **nucleon interaction model** to **nuclear-target** data, adding on nuclear effect
  - Often requires new uncertainties
  - Possibly tune new uncertainties to data, where justifiable



- Can inflate uncertainties to cover different data, e.g. bubble chamber W<1.4, 2.0 GeV/c², and nuclear data
  - We do this on T2K, but have **larger uncertainties** compared to GENIE CMC bubble chamber tune and other work

GENIE: M_A^{RES} (GeV/c^2) $\boxed{1.15 \pm 0.02}$ $\boxed{0.88 \pm 0.02}$ $\boxed{1.09 \pm 0.014}$

T2K: M_A^{RES} (GeV/c^2) $\boxed{1.07 \pm 0.15}$

NuWro
dipole, only M_A, free target $\boxed{0.95 \pm 0.04}$

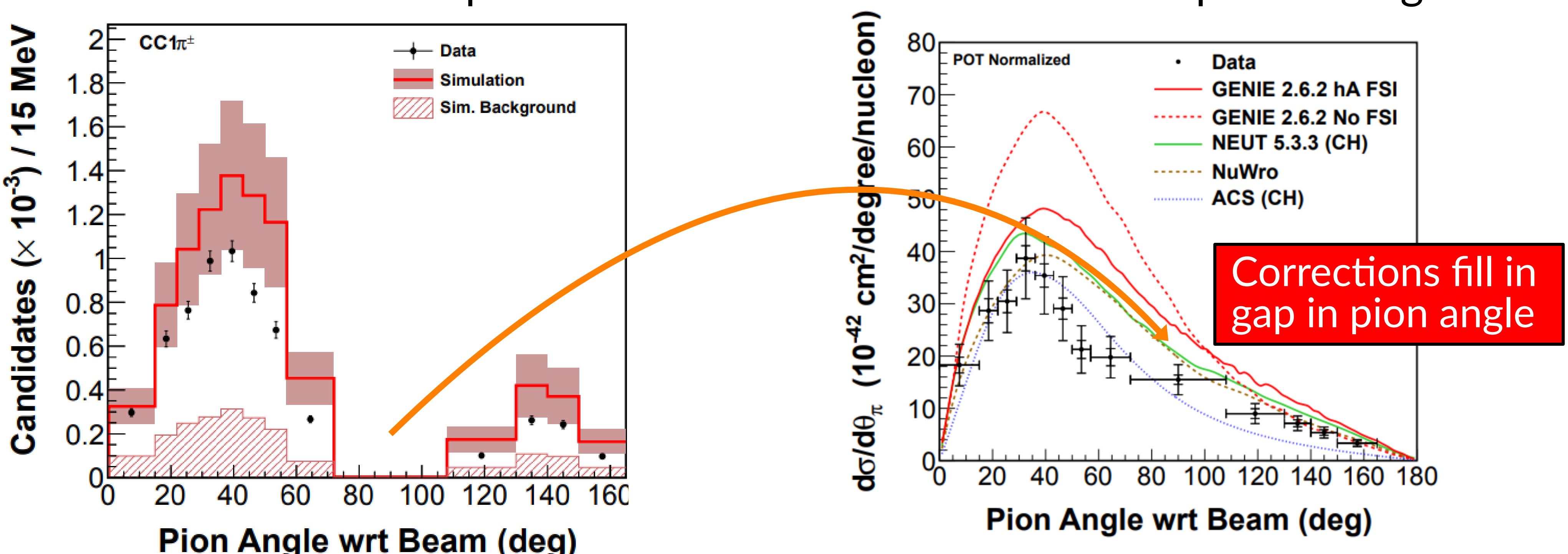
GENIE 2: M_A^{RES} (GeV) $\boxed{0.94 \pm 0.05}$

NuWro: Phys.Rev.D 80 (2009)
GENIE 2.12: Eur.Phys.J.C 76 (2016)

GENIE: Phys. Rev. D 104, 072009 (2021)
T2K and NEUT: Eur. Phys. J. C 83, 782 (2023)

Selecting nuclear data

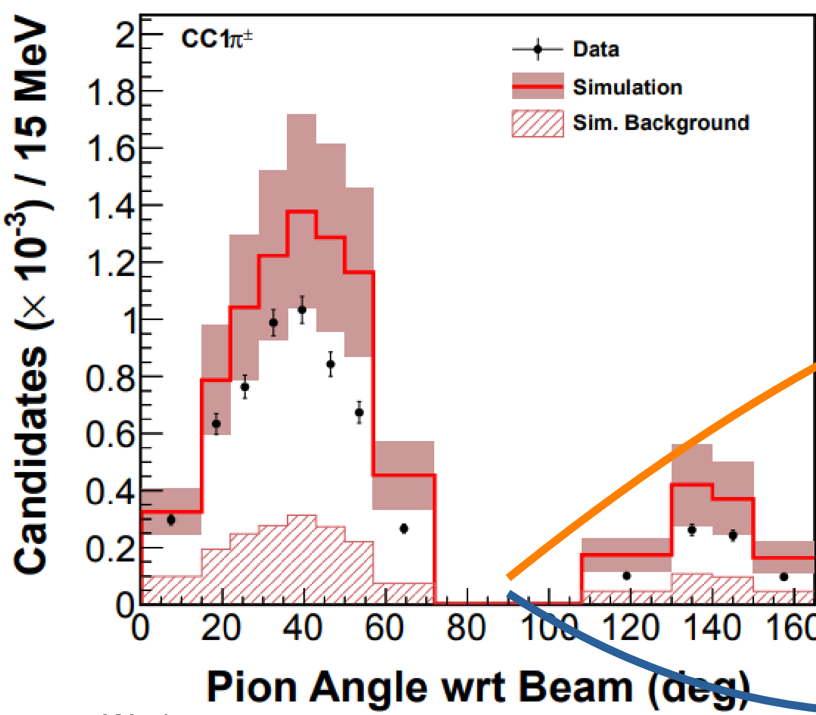
- Select data in some range relevant to your experiment
- Even in modern analyses, there may be **model-dependent** choices that **are not always obvious**
  - Signal definitions might not match detector capabilities
    - e.g. rely on modelling to tell you what you should have seen
  - Rapidly changing efficiencies in variables that are integrated over
    - e.g. **what happens to a gap in pion angular resolution** when the pion momentum is plotted → Where does this model-dependence go?



Phys. Rev. D 92, 092008 (2015)

Selecting nuclear data

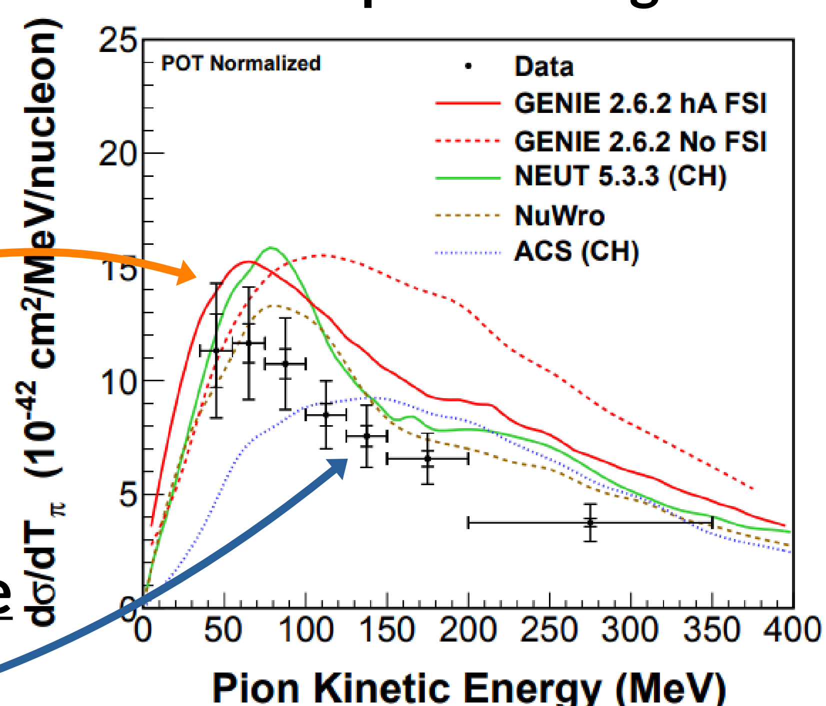
- Select data in some range relevant to your experiment
- Even in modern analyses, there may be **model-dependent** choices that **are not always obvious**
  - Signal definitions might not match detector capabilities
    - e.g. rely on modelling to tell you what you should have seen
  - Rapidly changing efficiencies in variables that are integrated over
    - e.g. what happens to a gap in pion angular resolution when the muon momentum is plotted → **Where does this model-dependence go?**



???

Unclear where this model dependence maps

???



Phys. Rev. D 92, 092008 (2015)

Selecting nuclear data

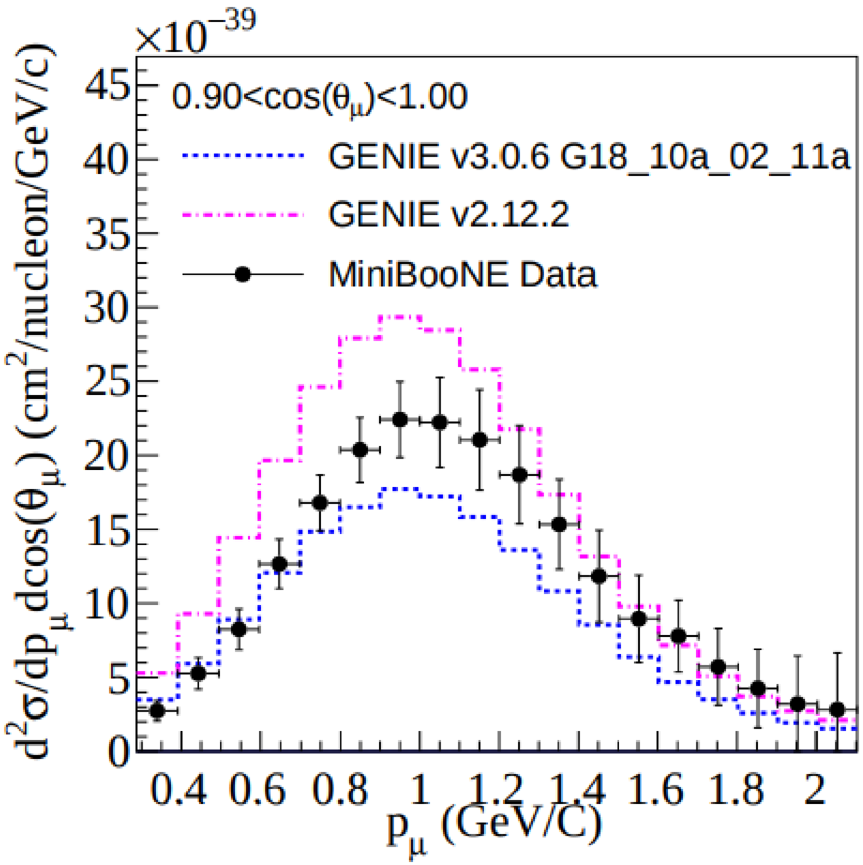
- Select data in some range relevant to your experiment
- Even in modern analyses, there may be **model-dependent** choices that **are not always obvious**
  - Signal definitions might not match detector capabilities
    - e.g. rely on modelling to tell you what you should have seen
  - Rapidly changing efficiencies in variables that are integrated over
    - e.g. what happens to a gap in pion angular resolution when the muon momentum is plotted → **Where does this model-dependence go?**
  - Unfolding procedures that cause biases
  - Variables that are inherently MC dependent, e.g. true neutrino energy, true Q^2, true W: **they are corrected for FSI** etc
- This is **much** better now, but need to be **vigilant** when using any data: new and old!
  - Generally speaking, **people seldom report their result as model dependent**

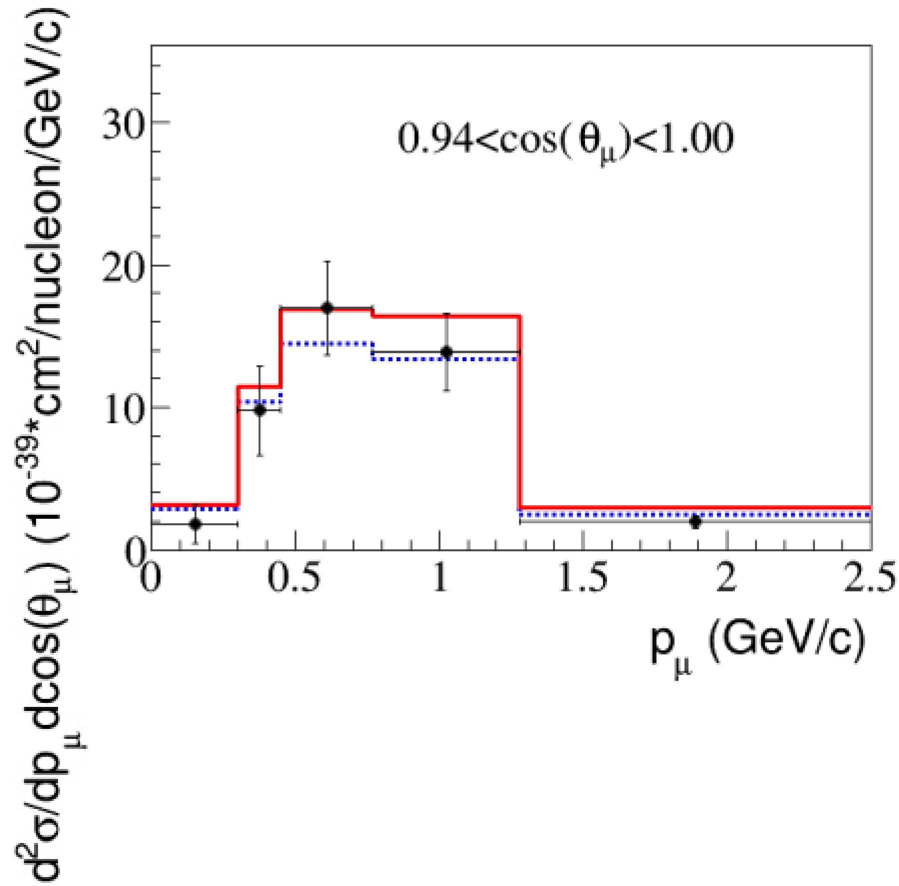
Finding uncertainties

- New models are coming into generators at fast pace, which is fantastic
- But, we often **miss a discussion of model uncertainties**
  - Need a set of uncertainties in the model for analysis
  - What is a reasonable range for parameters to vary in?
  - What are the consequences of going outside that range?
- Identifying these freedoms is very time consuming

Nuclear tuning examples

- MicroBooNE CCQE model tuning



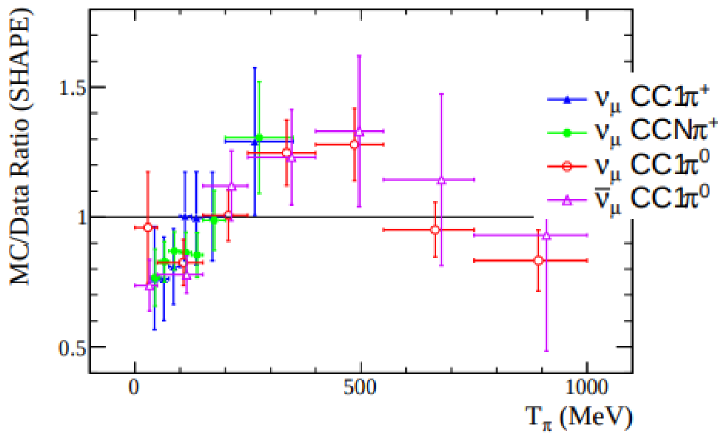


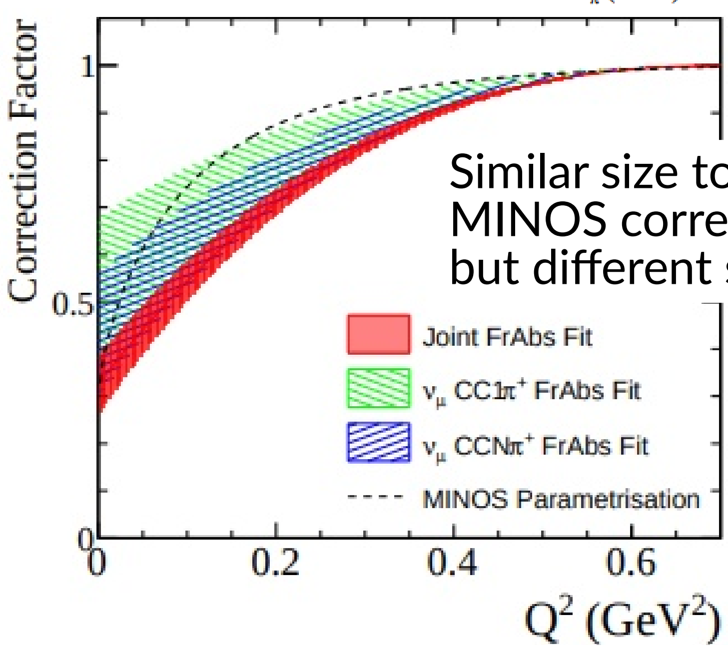
  - Tuned CCQE and 2p2h model to T2K CC0π to estimate input uncertainties into oscillation analysis
  - Similar flux, similar selections

Phys.Rev.D 105 (2022) 7, 072001

Nuclear tuning examples

- MINERvA single pion tune
  - Used publicly available CC pion data from MINERvA to develop a low Q^2 suppression for GENIE v2





Similar size to MINOS correction, but different shape

Was found **not needed on T2K and with NEUT**

Not needed for GENIE v3. GENIE v2 specific issue, related to form-factor in Q2 and lepton mass effects

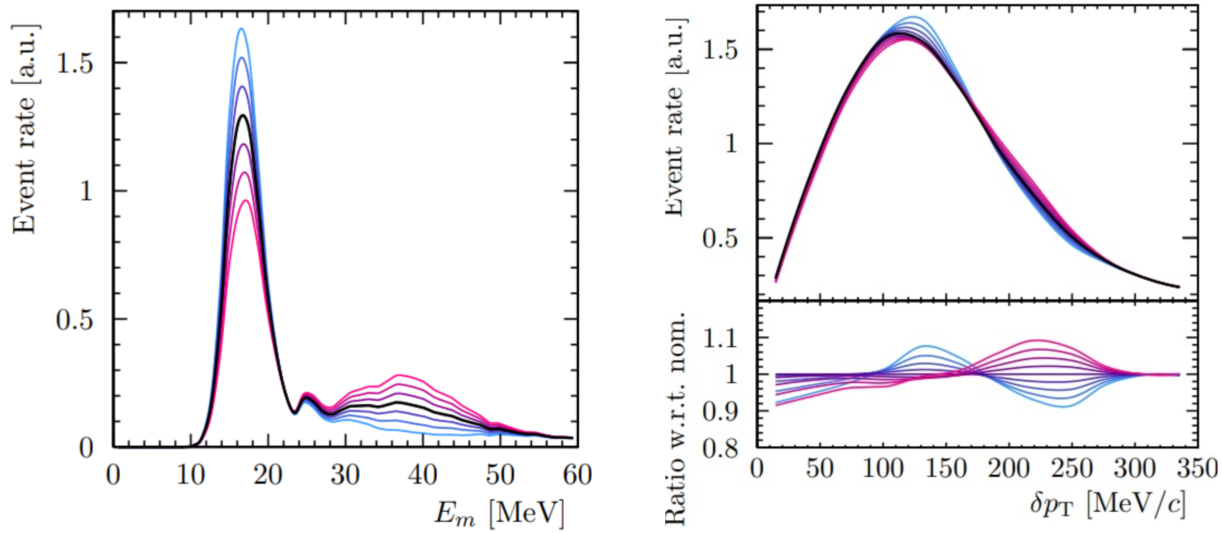
Good example of an "**effective tune**": did not know physics origin but saw consistent behaviour → ad-hoc uncertainty

Later **replaced by actual physics** form factor changes

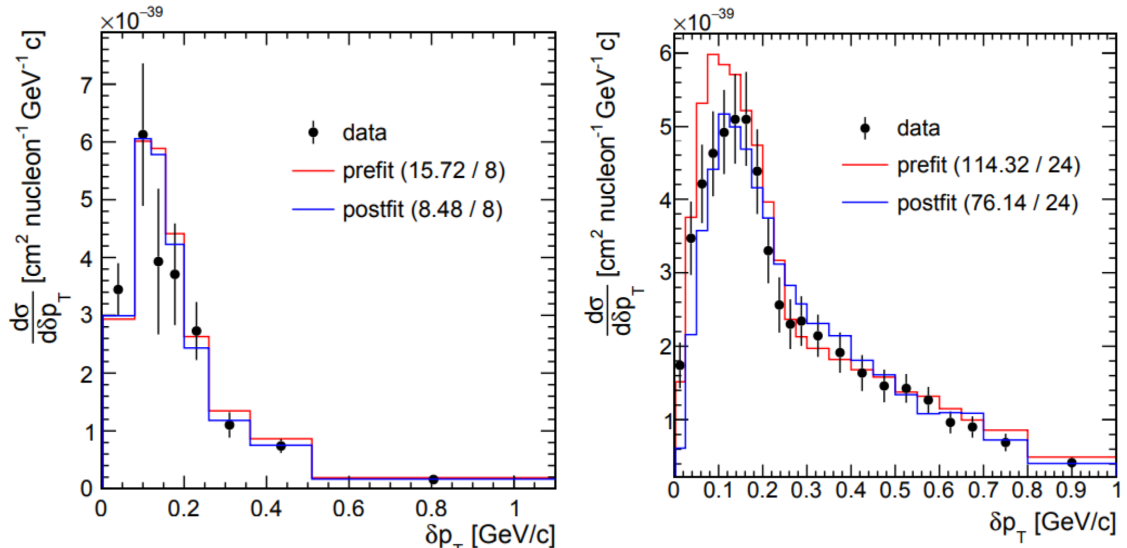
Phys.Rev.D 100 (2019) 7, 072005

Nuclear tuning examples

- Jaafar Chakrani and collaborators developed new uncertainties related to SF shell models, 2p2h and proton FSI



- Tried to fit to MINERvA and T2K data in lepton variables and STV



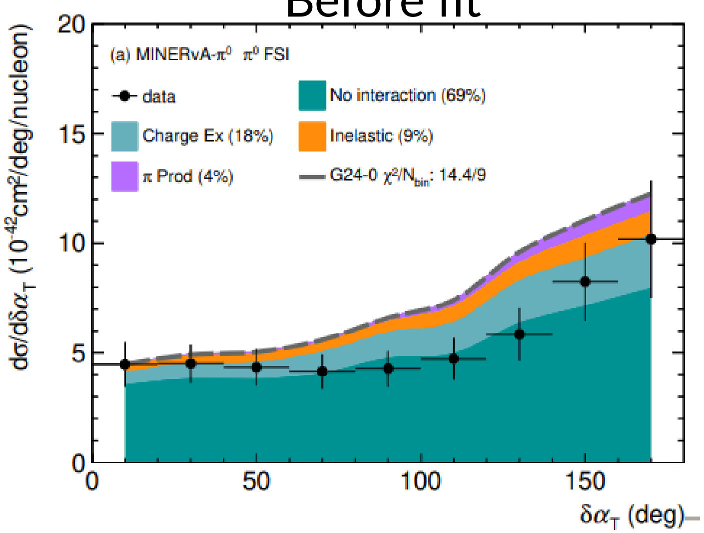
Phys.Rev.D 109 (2024) 7, 072006

Nuclear tuning examples

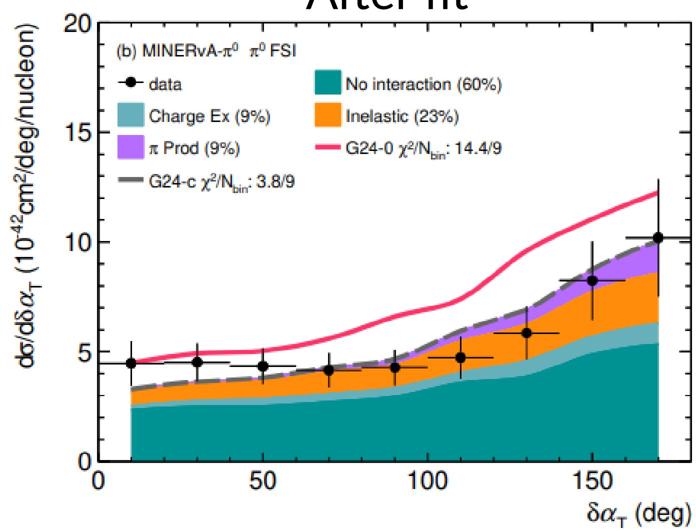
- GENIE collaborators recently attempted tuning T2K and MINERvA CC0π, CC1π⁺ and CC1π⁰ data
- Huge challenge with **very** complicated physics
- Tuned initial-state nuclear and final-state interaction parameters
  - Half of the charge exchange
  - Over twice the inelastic interactions
  - **Interesting how this compares to π-A data**

Parameter	Nominal (G24-0)	RedPar (G24-c)
		SF-LFG
R_{SRC}	0.12	0.15 ± 0.08
$E^{\mathrm{C}}_{\mathrm{RM}}$	0.01	0.01
		hA
$S^{\pi^\pm}_{\lambda}$	1.0 ± 0.2	1.0
$S^{\pi^0}_{\lambda}$	1.0 ± 0.2	0.22 ± 0.07
S^{N}_{λ}	1.0 ± 0.2	1.0
S^{π}_{CEX}	1.0 ± 0.5	0.26 ± 0.12
$S^{\mathrm{N}}_{\mathrm{CEX}}$	1.0 ± 0.4	1.43 ± 0.34
S^{π}_{INEL}	1.0 ± 0.4	1.0
$S^{\mathrm{N}}_{\mathrm{INEL}}$	1.0 ± 0.4	1.0
$S^{\pi^\pm}_{\mathrm{ABS}}$	1.0 ± 0.2	1.0
$S^{\pi^0}_{\mathrm{ABS}}$	1.0 ± 0.2	1.0
$S^{\mathrm{N}}_{\mathrm{ABS}}$	1.0 ± 0.2	0.25 ± 0.28
S^{π}_{PIPD}	1.0 ± 0.2	1.0
$S^{\mathrm{N}}_{\mathrm{PIPD}}$	1.0 ± 0.2	2.05 ± 0.48

Before fit



After fit



arXiv:2404.08510

Some personal thoughts

- The collider and parton distribution fitting groups have a fairly active community with healthy discussions
- Our community should think about standardisation and best practices
  - Process of selecting data
  - Evaluating robustness of data
  - Fitting methodology
  - Identifying freedoms in models
  - …?
- Some conversations started at NuXTract workshop at CERN

Recent "NUISANCE" dev

- HEPData integration
  - Previous effort stalled with HEPData due to format and required person power

< Hide Publication Information

Single neutral pion production by charged-current $\bar{\nu}_\mu$ interactions on hydrocarbon at $\langle E_\nu \rangle = 3.6$ GeV

The MINERvA collaboration

Le, T. , Palomino, J.L. , Aliaga, L. , Altinok, O. , Bercellie, A. , Bodek, A. , Bravar, A. , Brooks, W.K. , Butkevich, A. , Martinez Caicedo, D.A.

Phys.Lett.B 749 (2015) 130-136, 2015.

https://doi.org/10.17182/hepdata.73317

Journal INSPIRE

Abstract (data abstract)
Fermilab-NuMI. Single neutral pion production via muon antineutrino charged-current interactions in plastic scintillator (CH) is studied using the MINERvA detector exposed to the NuMI low-energy, wideband antineutrino beam at Fermilab. Measurement of this process constrains models of neutral pion production in nuclei, which is important because the neutral-current analog is a background for $\bar{\nu}_e$ appearance oscillation experiments. The differential cross sections for π^0 momentum and production angle, for events with a single observed π^0 and no charged pions, are presented and compared to model predictions. These results comprise the first measurement of the π^0 kinematics for this process.

Download All

Filter 2 data tables

Table 1
Data from Table 1
10.17182/hepdata.73317.v1/t1
Flux-averaged differential cross section in π^0 momentum, $d\sigma/dp_{\pi^0}(10^{-40}\mathrm{cm}^2/\mathrm{nucleon}/(\mathrm{GeV}/c))$, for $1\pi^0$ production with statistical (stat) and systematic (sys) uncertainties.

Table 2
Data from Table 2
10.17182/hepdata.73317.v1/t2
Flux-averaged differential cross section in π^0 angle, $d\sigma/d\theta_{\pi^0}(10^{-42}\mathrm{cm}^2/\mathrm{nucleon}/\mathrm{deg.})$, for $1\pi^0$ production with statistical (stat) and systematic (sys) uncertainties.

Table 1 10.17182/hepdata.73317.v1/t1 https://www.hepdata.net/rec
Data from Table 1

Flux-averaged differential cross section in π^0 momentum, $d\sigma/dp_{\pi^0}(10^{-40}\mathrm{cm}^2/\mathrm{nucleon}/(\mathrm{GeV}/c))$, for $1\pi^0$ production with statistical (stat) and systematic (sys) uncertainties.

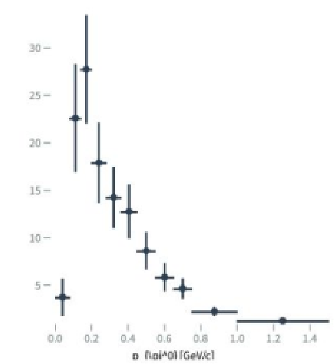
observables
DSIG/DP

phrases
Inclusive
Differential Cross Section
Muon Production
Charged Current
Deep Inelastic Scattering

reactions
NUMUBAR C --> MU+ PI0 X

RE	NUMUBAR C --> MU+ PI0 X
p_{π^0} [GeV/c]	$d\sigma/dp_{\pi^0}\,[10^{-40}\mathrm{cm}^2/\mathrm{nucleon}/(\mathrm{GeV}/c)]$
0.0 - 0.08	3.75 ±41.0% stat ±33.0% sys
0.08 - 0.14	22.6 ±14.0% stat ±21.0% sys
0.14 - 0.2	27.75 ±10.0% stat ±18.0% sys
0.2 - 0.28	17.92 ±11.0% stat ±21.0% sys
0.28 - 0.36	14.26 ±11.0% stat ±20.0% sys
0.36 - 0.45	12.77 ±10.0% stat ±20.0% sys
0.45 - 0.55	8.65 ±11.0% stat ±20.0% sys

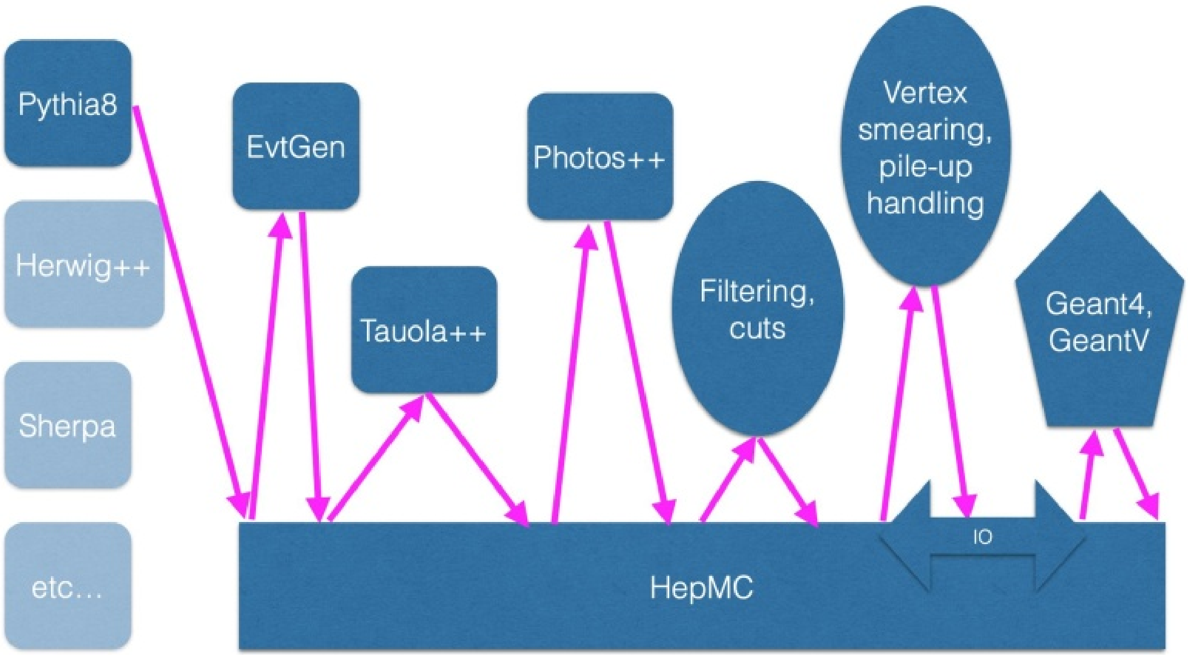
Visualize

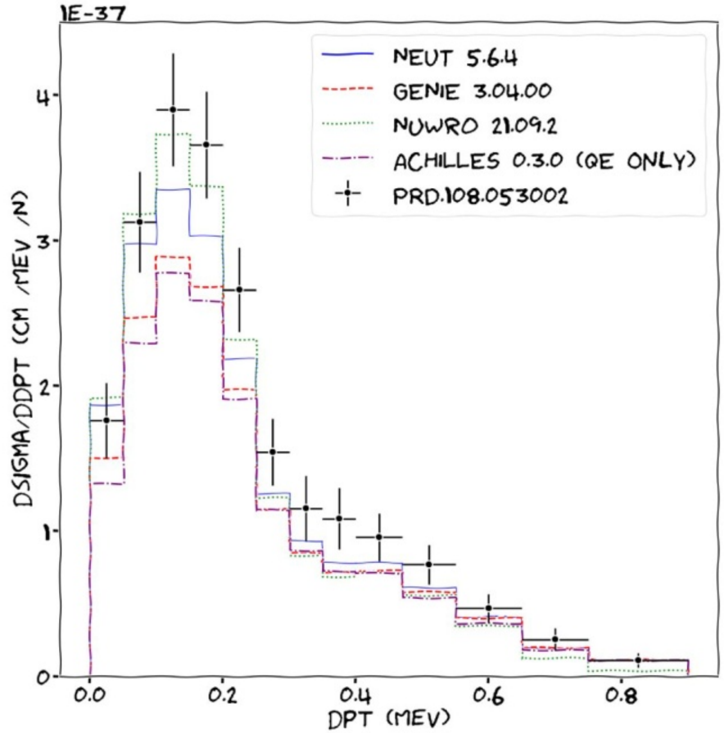


  - Luke and Patrick actively working with Durham and IPPP
  - Could discuss with theorists and GENIE devs about building common data base: make sure we have **all the data**

Recent "NUISANCE" dev

- NuHepMC universal event format
  - Luke, Stephen G, Joshua I
  - Get your favourite generator into production!





- Conversations with HEP software foundation (HSF)
  - Invitations to talk and learn more about collider and parton distribution fitting

Recent “NUISANCE” dev

- NUISANCE is slowly moving to v3, which simplifies much of the internal machinery and how to implement a sample
  - Increases user friendliness and performance
  - In need of a bit of an overhaul
- Planning some publications related to bubble chamber tuning, perhaps multi-generator

What is needed from community

- Full and reliable covariance matrices
  - If you don't understand the covariance matrix, **we probably won't either**
- Better understanding of the measurements
  - If the χ^2 for your measurement is huge, **where does it come from**?
- Clearly specified signal definitions
- Prefer a well understood selection efficiency over maximising the phase space coverage
  - **If you can't measure it, don't claim to measure it**
  - **Avoid model-dependent** cross-section extraction
- For theory development
  - Central value predictions are important
  - But we also need **realistic uncertainties and parameters**

Tutorial advertisement

- Did you find this interesting?
- Do you want to run multiple generators, compare them to data and each other, and even fit them?
- You're in luck! See workshop before NuInt: https://indico.fnal.gov/event/59963/timetable/#20240412.detailed

NUISANCEMC / **tutorials**

Interactive NUISANCE tutorials

GENIE

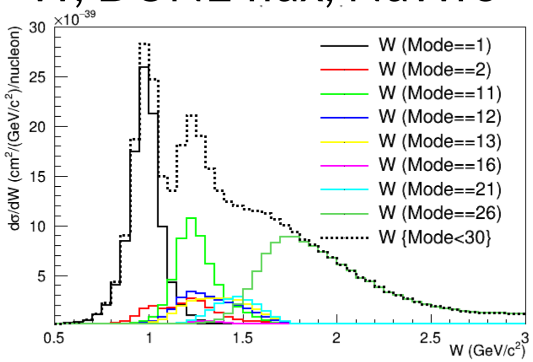
GENIE is the most widely used neutrino interaction simulation packages currently used in the field. It can simulate neutrino energies from MeV to PeV scales, and also has support for electron-nucleus scattering, photon-nucleus scattering, pion-nucleus scattering, and even provides support for simulating various dark matter models.

In this project, we will focus on neutrino interactions, for which the simplest event generation tool in GENIE is `gevgen`, which is fully documented here: https://genie-docdb.pp.rl.ac.uk/DocDB/0000/000002/006/man.pdf

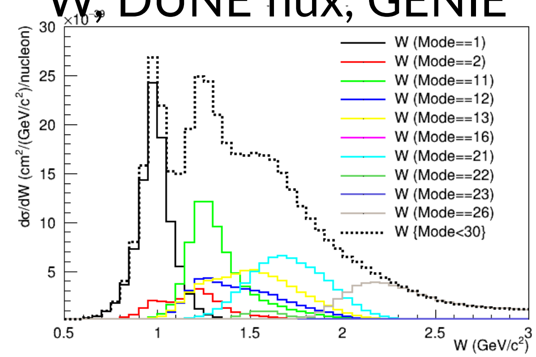
An example script to generate 100k muon neutrino-hydrocarbon interactions using the MINERvA LE flux is given in `generation_GENIEv3_example.sh` using the `AR23_20i_00_000` model, which has been developed by DUNE and is now being utilized by multiple experiments. Run it with a command like (which should take 5-10 minutes):

```
singularity exec nuisance_nuint2024.sif /bin/bash generation_GENIEv3_example.sh
```

W, DUNE flux, NuWro



W, DUNE flux, GENIE



- Also excellent and digestible talks from theorists, generator experts, and experimentalists!

Summary

- NUISANCE compares neutrino interaction generators to themselves and external data
- Developed for the community, and open to collaboration and use
- Interfaces to reweighting libraries and supports its own reweighting machinery
- Talks to minimisation routines (e.g. Minuit, MCMC) to fit models to data or fake data
- Global tuning effort generally split into **nucleon** and **nuclear** level tunes, often experiment specific
  - Community is growing, should **capitalise on joint efforts!**
  - Care should always be taken by experimentalists to produce **model-dependent results**, and be clear when there is model dependence
- Important to identify theory uncertainties and freedoms

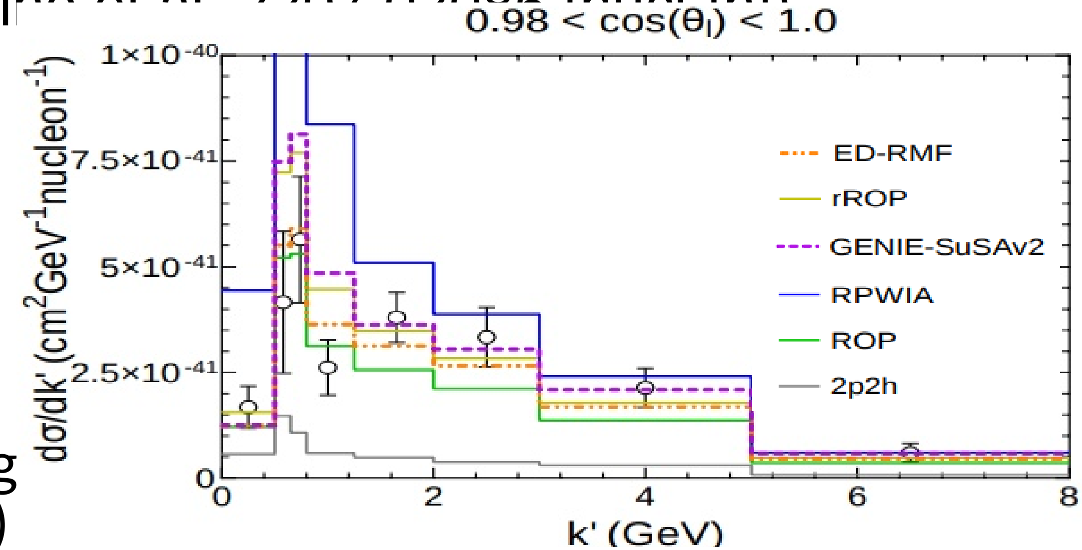
UNIVERSITY OF OXFORD

Thanks

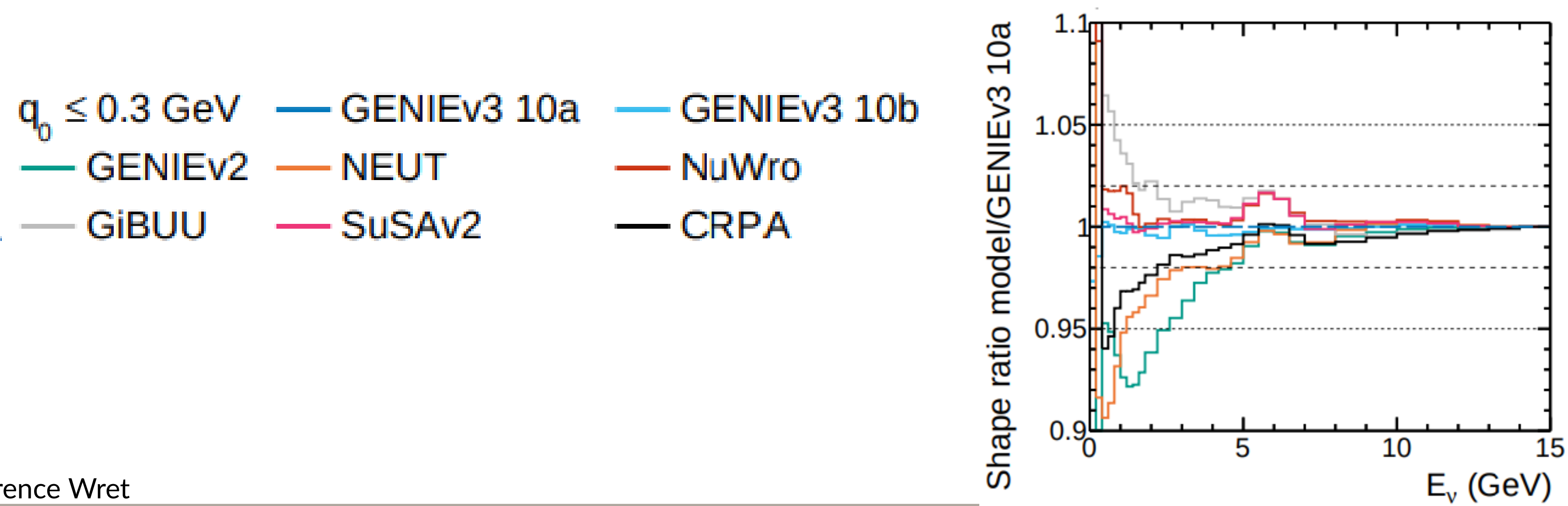
nuisance-xsec.slack.com

Recent examples

- Use GENIE predictions with SuSAv2 and compare to other 1p1h calculations (J.M. Franco-Patiño et al, 2207.02086 [nucl-th])

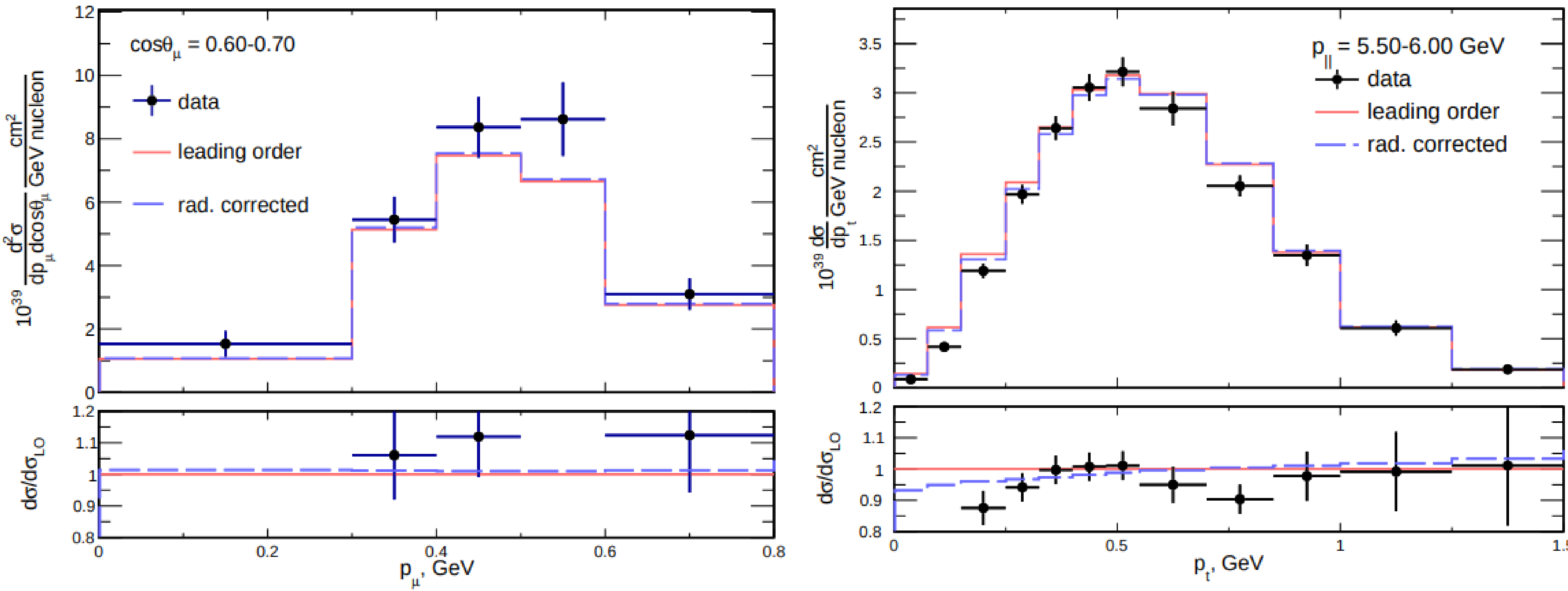


- Studies of low-ν method using
Eur.Phys.J.C 82 (2022) 9, 808)



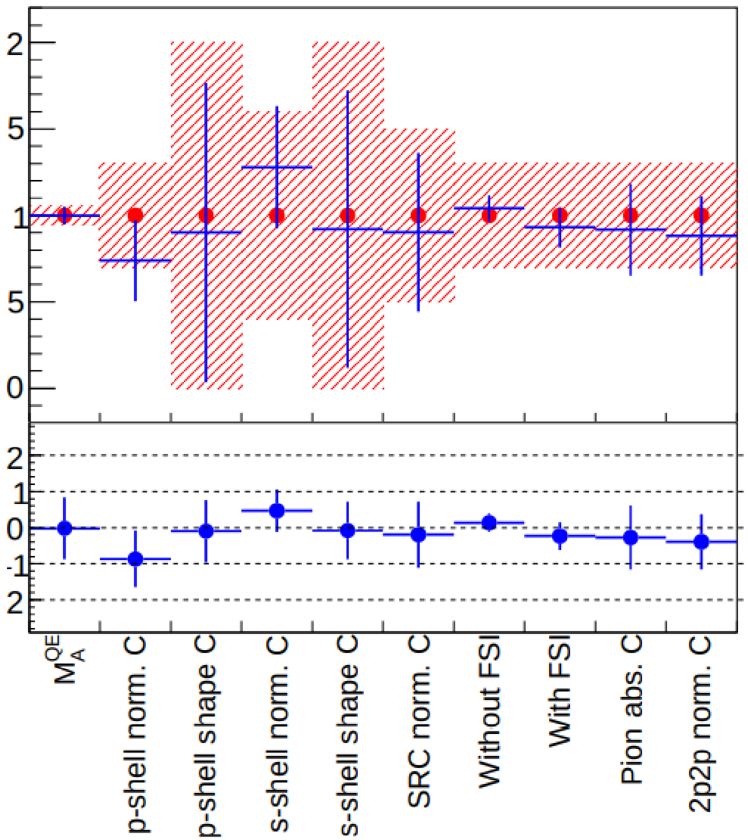
Recent examples

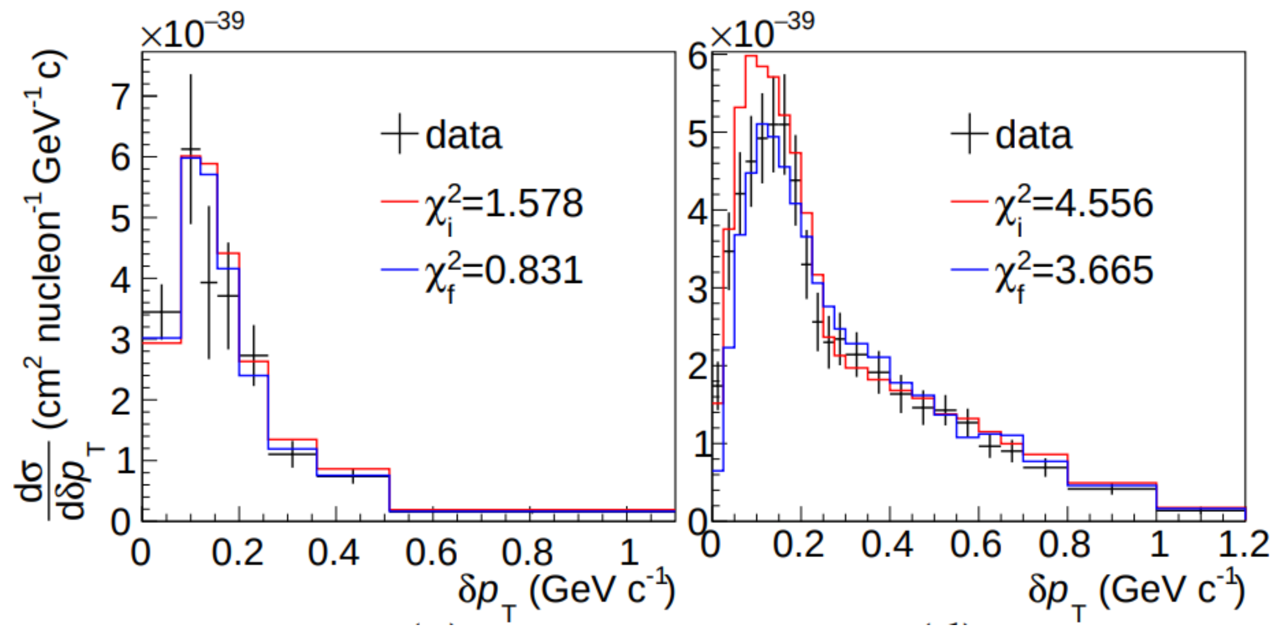
- Radiative corrections (O. Tomalak et al., 2204.11379 [hep-ph])
  - Found large effect for MINERvA, smaller effect for T2K
  - Implemented in NUISANCE; **<u>you can test it too!</u>**



Recent examples

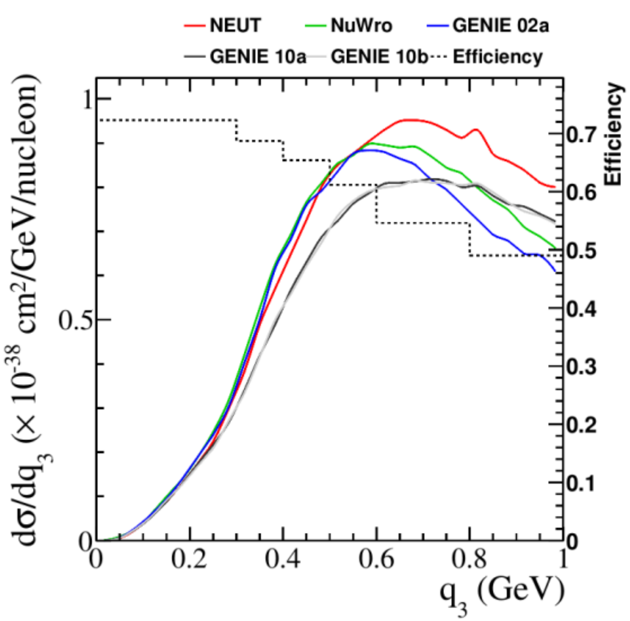
- ND280 Upgrade sensitivity studies and development of T2K interaction model (J. Chakrani et al. arXiv:2202.03219 [hep-ph])
  - Found a good parametrisation against published T2K data, but not MINERvA data

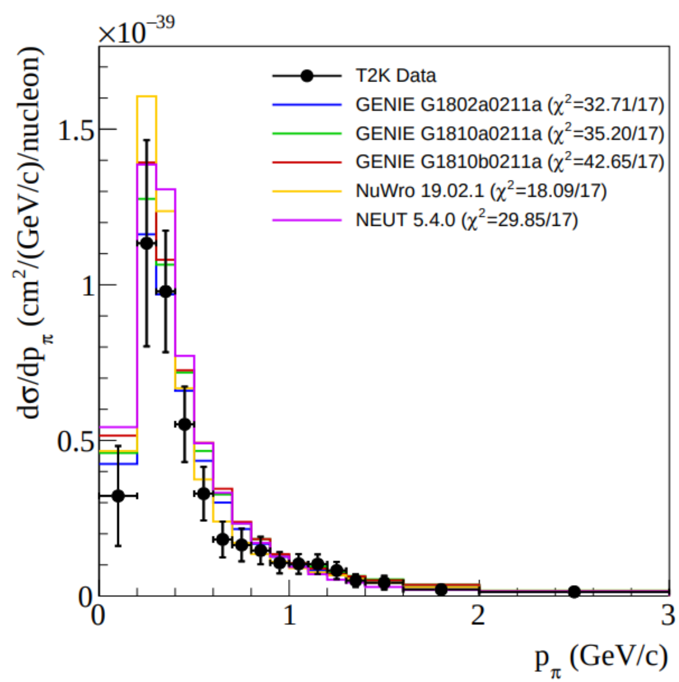


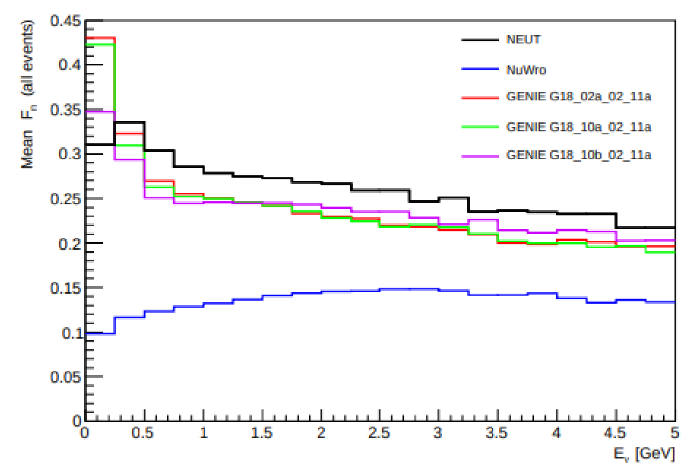


Recent examples

- Pittsburgh tensions workshop (M. Buizza Avanzini et al., Phys.Rev.D 105 (2022) 9, 092004)
  - Aimed to get experiment and generator experts together to understand model dependence and current experimental data (amongst others!)
  - Used multiple generators to form predictions against data, against efficiency curves, and how much energy carried away by neutral particles







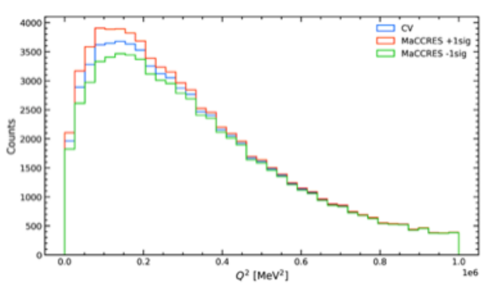
HEPData

Cleaner Analysis Operators committed to HEPDATA

```cpp
int MINERvA_CCINC_CCEavq3_Filter(HepMC3::GenEvent const &ev) {
  auto nu = ps::sel::Beam(ev, ps::pdg::kNuMu);
  if (!nu) return false;

  auto mu = ps::sel::OutPartHM(ev, ps::pdg::kMuon);
  if (!mu) return false;

  double angle = ps::proj::event::CosLep(ev);

  if (cos(angle) <  0.93969262078) return false;

  if (ps::proj::event::ELep(ev) < 1.5 * ps::units::GeV)
    return false;

  return true;
}
```

Direct access to multiple weighting tools

```python
weight_calculator = weight_factory.make(neut_src)
weight_calculator.set_parameters(
    {"MaRES": 0.95, "CA5RES": 1.01+0.15*CA5RES}
)
evs.add_column(f"CA5RES_offset", weight_calculator)
```



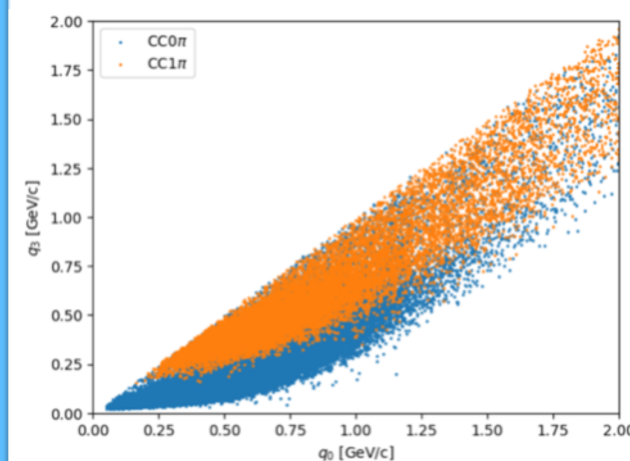
Quick data release prototyping with analysis hooks

```python
analysis = rfact.make_table({"type": "hepdata",
                             "release": "MicroBooNE/CCQE/182176/",
                             "table": "EventCounts-Q2"})
analysis.likelihood = custom_likelihood
analysis.weight    = deuterium_q2weight
analysis.finalize = deuterium_correction

# Run analysis as before
comp = hf.comparison()
for ev in src_neut:
    analysis.Fill( comp, src )
```

Full C++ to Python Interfaces

Dataframe analysis with user defined analysis functions

```python
src = pn.EventSource("T2KND_FHC_numu_C8H8_NEUT562_1M_0000.root")
evs = pn.EventFrameGen(src, 10000)
evs.add_column("proj.Q2", Q2)
evs.add_column("proj.q0", q0)
evs.add_column("proj.q3", q3)
```



Opening up analysis tools at every level