Common tools for cross-section extractions and analyses

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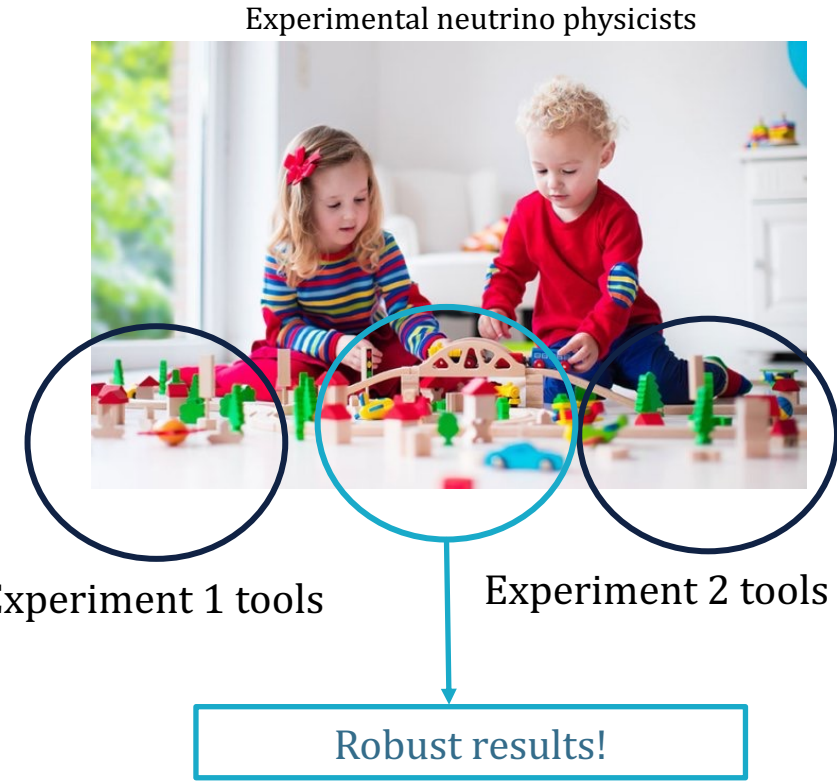
The importance of common tools

- Not reinventing the wheel
- Sharing the work
- Achieve thorough validation
- Improve data releases/preservation
- Work towards future joint analyses



Needs for cross-section measurements

- Propagating systematics
- Cross-section extraction
- Comparing measurements
- Aside – talking the same language and diagnosing tools

Propagating systematics

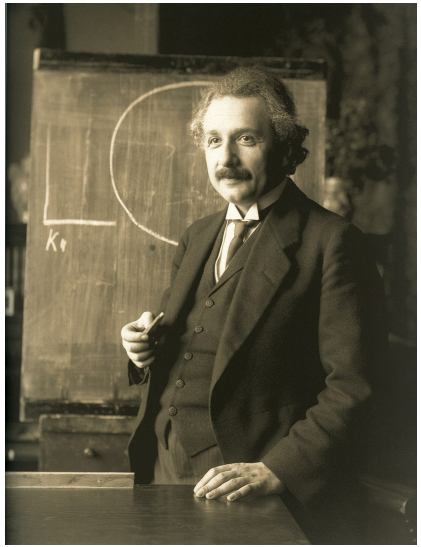
Propagating systematic uncertainties

- Essential part of any cross-section extraction, on the signal and especially on the background
- Usually categorized as
  - Flux
  - Detector

  } VERY experiment dependent
  - Neutrino interaction systematics

"Physics is experiment-invariant"

- Albert Einstein (I think?)



Reweighting software

- Custom-reweights
  - Parametrize your own uncertainty in your code
- Experiment-dependent software
  - E.g. T2KReWeight, NOvAReWeight – not usually shared with the community
  - But T2K has plans to make it open-source
- Generator-dependent software
  - E.g. NEUTReWeight, GENIEReWeight

Nusystematics

https://github.com/jedori0228/nusystematics/tree/feature/jskim_artless

- Originally developed for DUNE sensitivity studies
- Part of the LArSoft package, but can be run independently
- Can interface with GENIEReWeight, but independent dials can be introduced
- Primary development by DUNE collaborators, **but shared/receives contributions from ICARUS, SBND, NOvA and 2x2 analyses**
- Structure is also very similar to T2KReWeight so dial porting is trivial

All nusystematics plots are courtesy of Jaesung Kim

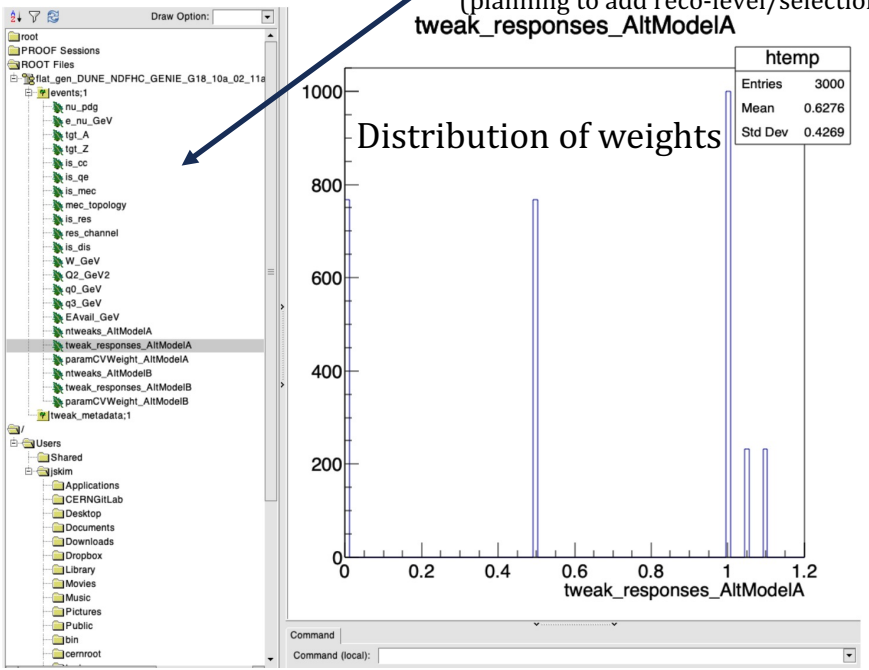
Details about nusystematics

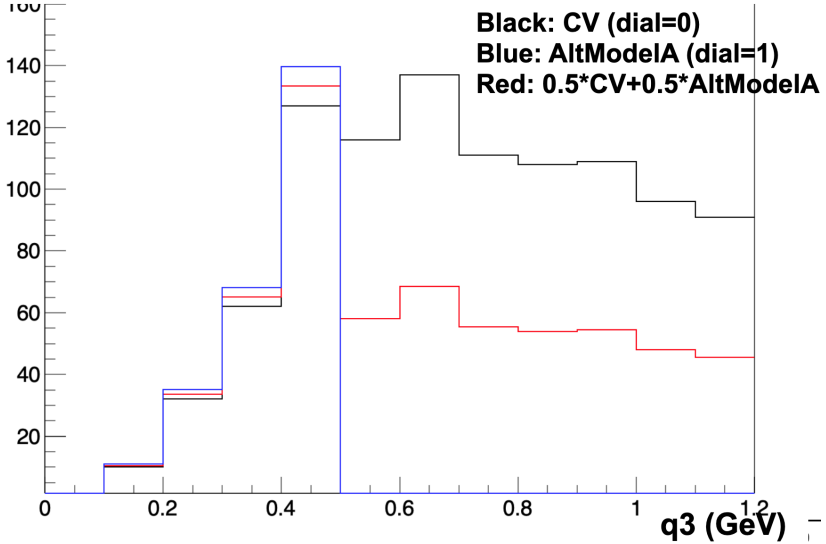
- For now, development version lives in Jaesung Kim's repository
- Configured by using user-friendly fcl files
- Uses GENIE Event Record so full event information can be accessed

```
$ cat paramHeader_DIRTExample.fcl
generated_systematic_provider_configuration: {
   DIRT_DEV_v1: {
      AltModelA: {
         centralParamValue: 0
         paramVariations: [
            0,
            0.5,
            1,
         ]
         prettyName: "AltModelA"
         systParamId: 0
      }
      AltModelB: {
         centralParamValue: 0
         paramVariations: [
            0,
            0.5,
            1,
         ]
         prettyName: "AltModelB"
         systParamId: 1
      }
      instance_name: "v1"
      parameter_headers: [
         "AltModelA",
         "AltModelB",
      ]
      tool_options: {
         OPT_STRING: "option_test"
         OPT_BOOL: true
         fill_valid_tree: false
      }
      tool_type: "DIRTExample"
   }
   syst_providers: [
      "DIRT_DEV_v1",
   ]
}
```

Diagnostic tools

Relevant truth-level variables
(planning to add reco-level/selection information)





Example for a reweight from a fictive model A to model B

Why you should consider adopting nusystematics

- LArTPC community – one of the most comprehensive efforts to include systematic uncertainties for high-stats analyses on Ar
- Share the workload between experiments
- Easy to use and interface with other softwares (inc. NUISANCE)
  - No LArSoft required!

Cross section extraction

Cross section extraction tools

- No single “standard” tool shared in the community – most analyses/experiments use bespoke code for each analysis
- Heard at this workshop about many methods to extract cross sections
  - E.g. Omnifold, ReMU, RooUnfold etc.

- Similarity between oscillation fits and cross-section fitting tools
  - **We should harvest this experience**

GUNDAM

https://github.com/gundam-organization/gundam

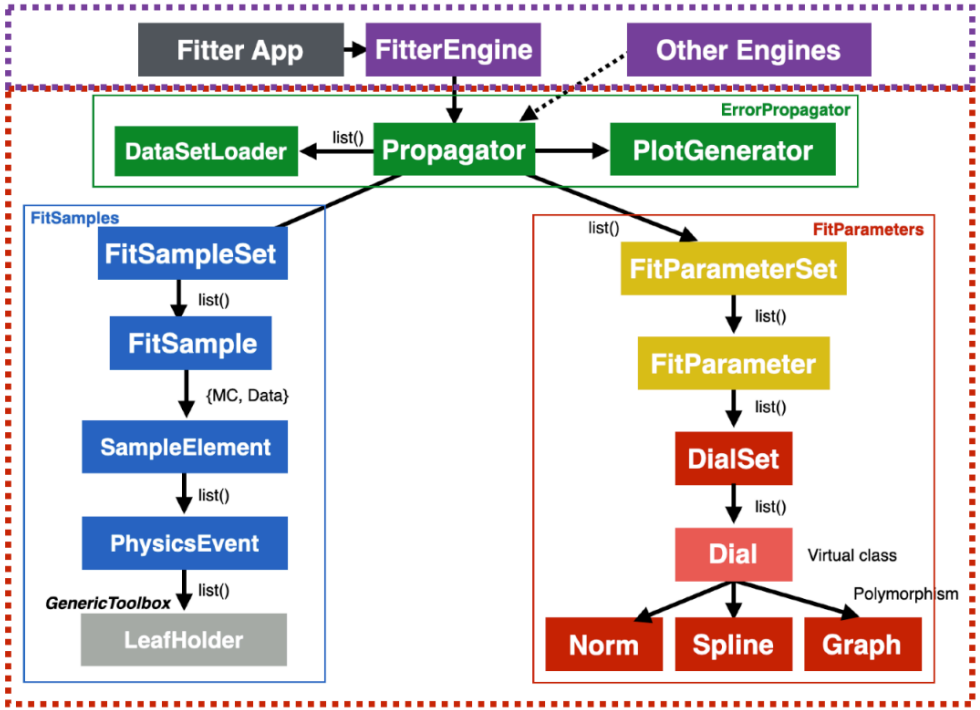
- Binned likelihood fitter, obtained from merging the standard T2K cross-section extraction tool and near detector fit framework
- Very user friendly – almost no analysis-dependent code
  - Can be used on any experiment as long as you can put information into ROOT trees!
- Reliable and highly validated diagnostic tools
- Extremely fast – O(1h) to run a full T2K cross-section analysis

All GUNDAM plots are courtesy of Adrien Blanchet and Margherita Buizza Avanzini (both GUNDAM coordinators)

GUNDAM

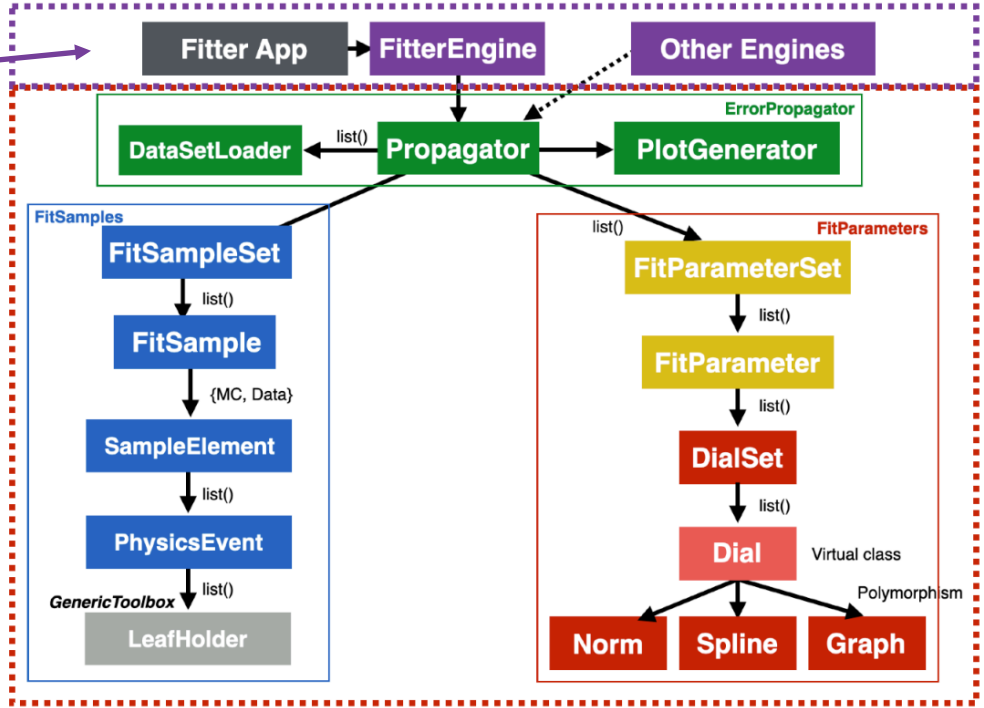
Analysis specific part

Common core (fully configurable via YAML/json files)



GUNDAM

Fitter engine (your statistical framework)
Currently Minuit or MCMC supported (scope to expand)



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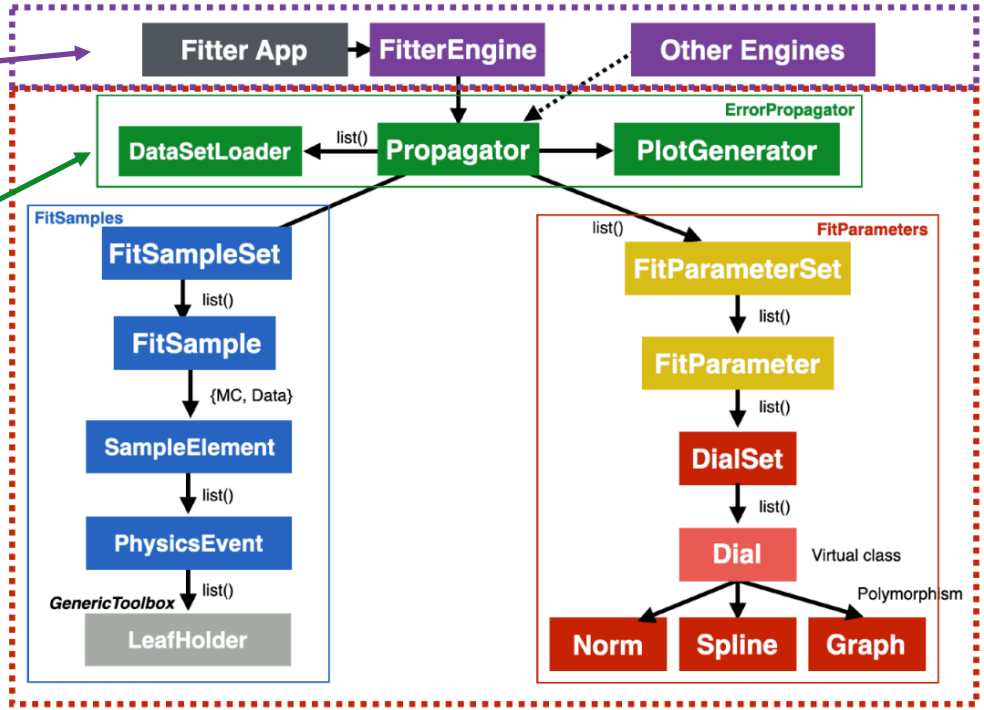
Any ROOT tree
(or even just histograms)



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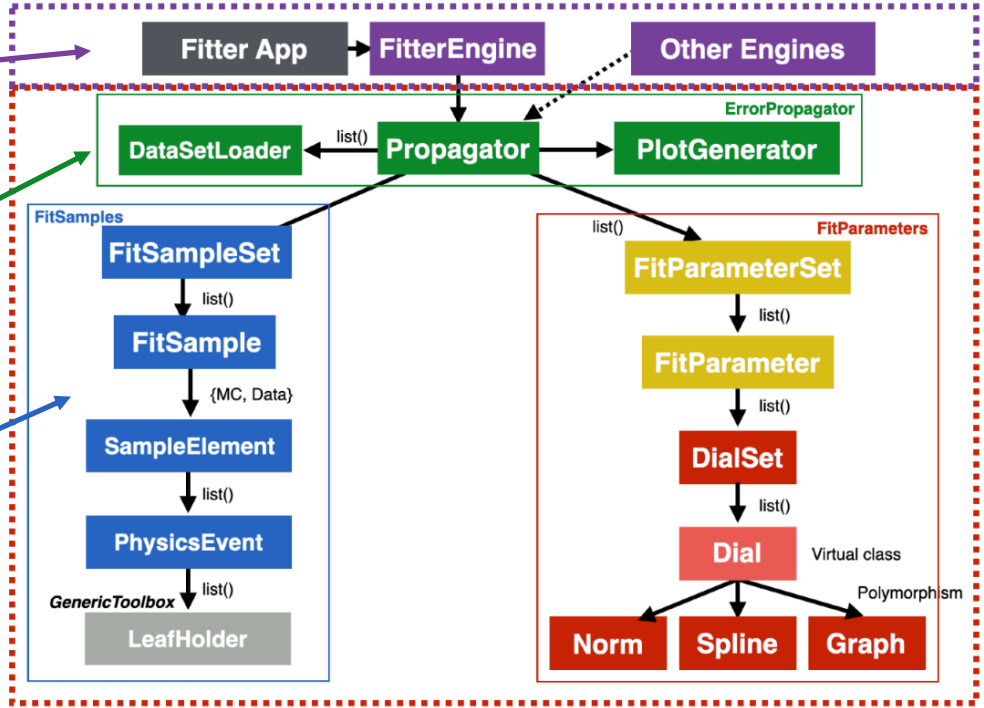
Any ROOT tree
(or even just histograms)

Your MC (any ROOT tree with the relevant branches to define samples)



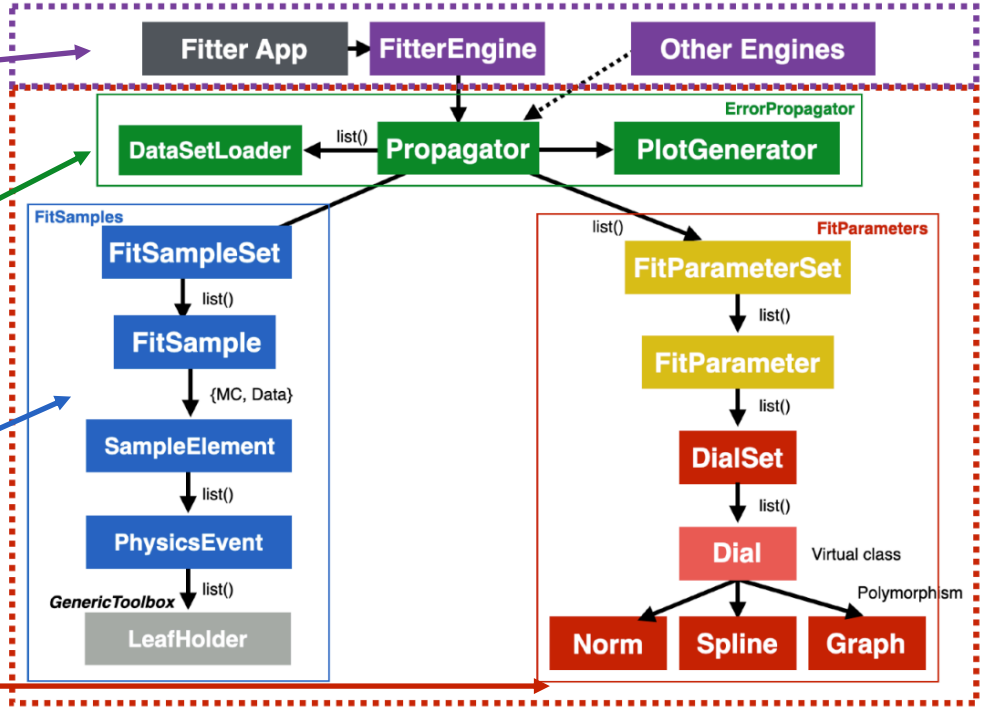
GUNDAM

Fitter engine (your statistical framework)
Currently Minuit or MCMC supported (scope to expand)

Any ROOT tree (or even just histograms)

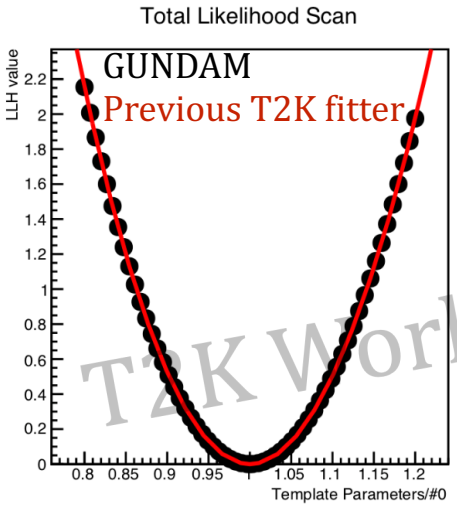
Your MC (any ROOT tree with the relevant branches to define samples)

Fit parameters
(currently norm, spline, graphs supported)

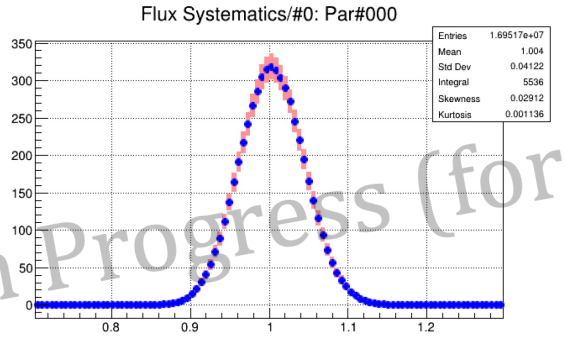


Diagnostic tools

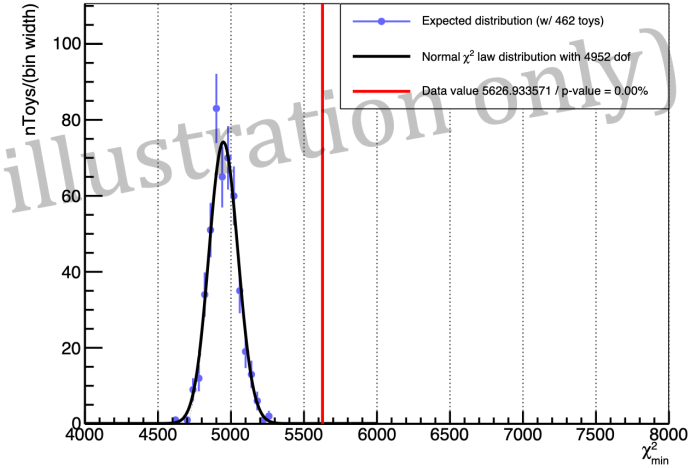
- Heavily inspired by T2K near detector fit for oscillation analyses
  - Wealth of diagnostic tools for both frequentist and bayesian analyses



Likelihood scans as function of parameters



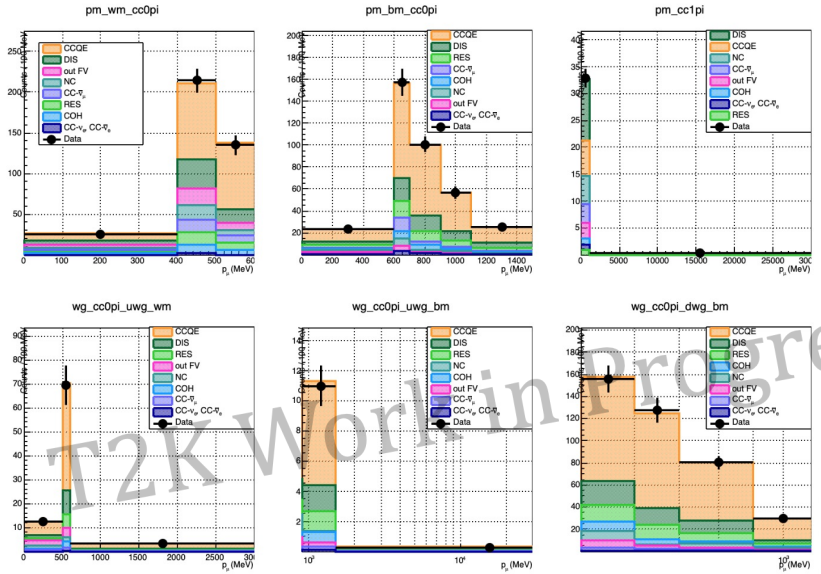
Posterior probability distributions (for MCMC)

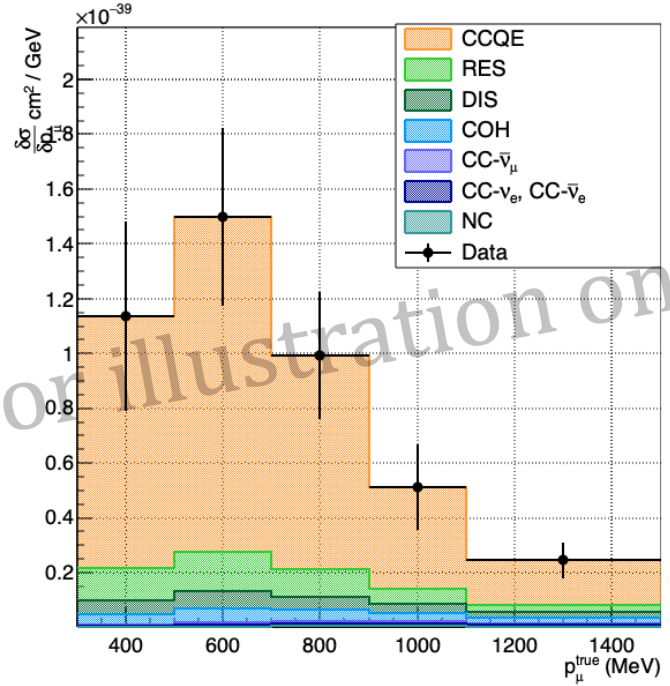


p-value/toy throws/coverage tests

Extracting cross sections

- Monitoring tools for the analysis

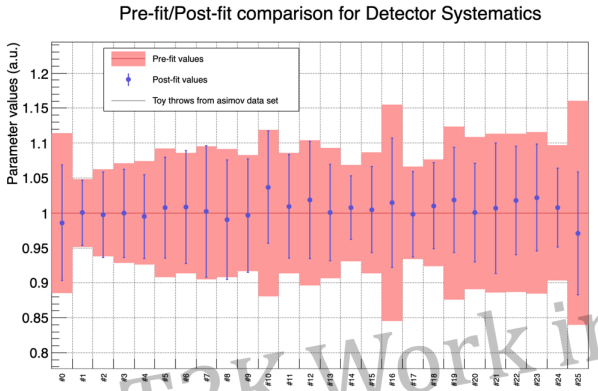




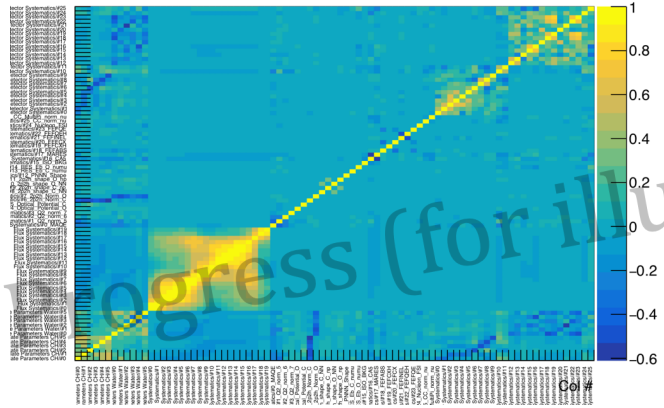
From event rates → To cross sections

Extracting cross sections

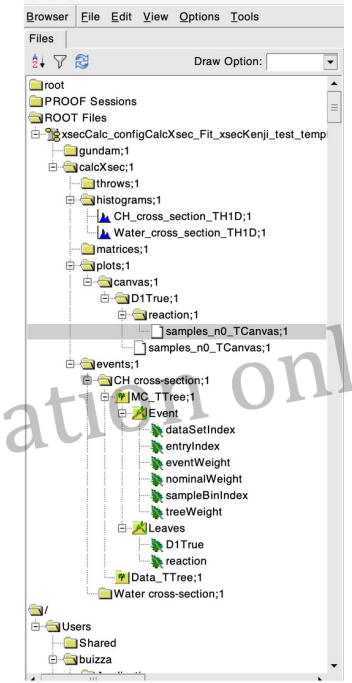
- Monitoring tools for the analysis



Parameter constraints



Covariance matrices



Access to projections in all variables

With a LOT of information about the details

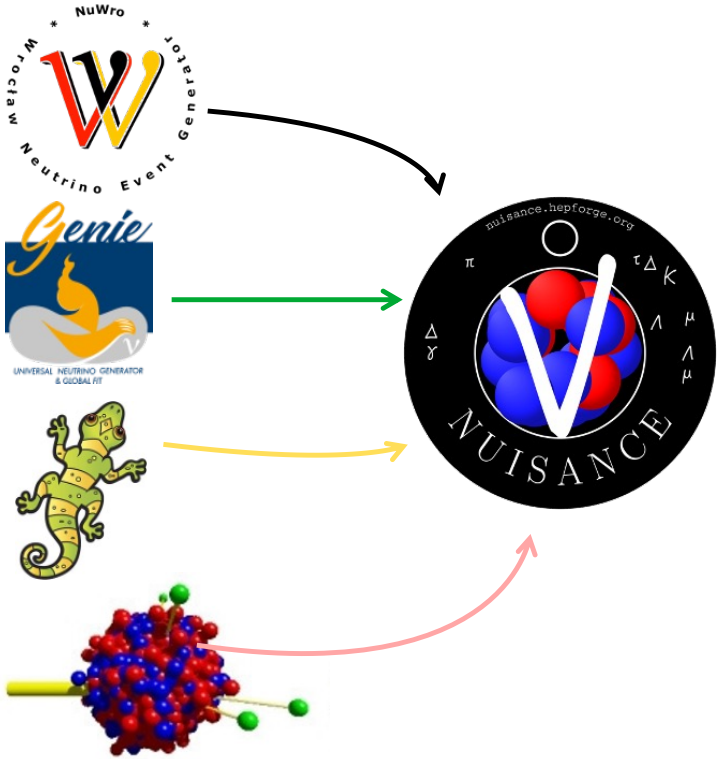
Comparing measurements

We need to talk about NUISANCE

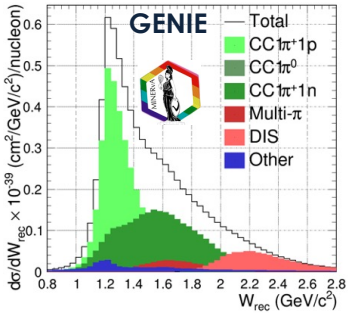
- Multi-purpose framework:
  - Compare measurements with multiple generator predictions
  - Perform fits to measurements where systematic parameters are varied consistently

nuisance-xsec.slack.com

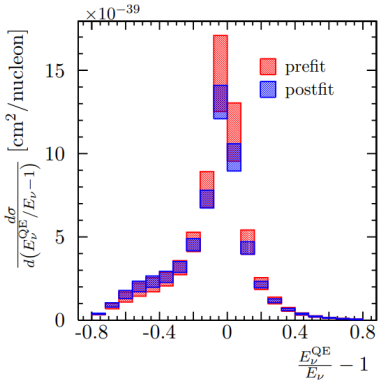
We need to talk about NUISANCE



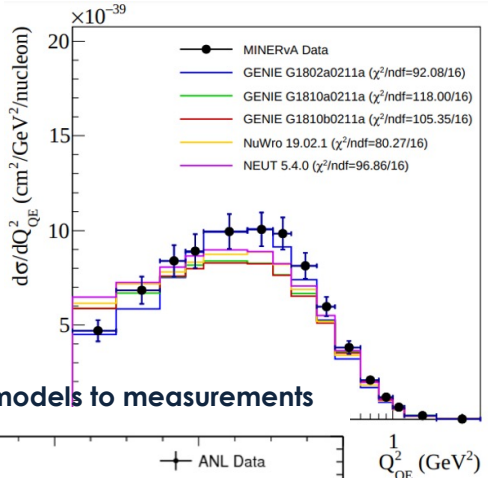
Compare event generator features



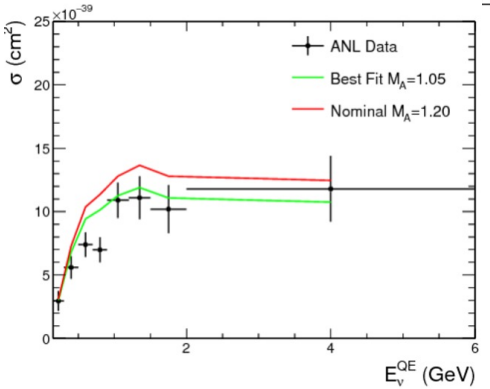
Evaluate error bands from parameter uncertainties



Compare generators to data



Fit models to measurements



For more detail, see Clarence's talk

Summary

- Providing cross-section measurements is hard
- There is no one-size-fits-all needs, but common tools exist
- We should share the joys and sorrows of statistical analyses
- Converging on tools that speak the same language is essential (see Luke's talk)
- Essential to work as a community in order to ensure the longevity, robustness and accessibility of our measurements