

Using Uncertainty-Based Fitting to Improve Neutrino Cross Section Modeling with MINERvA

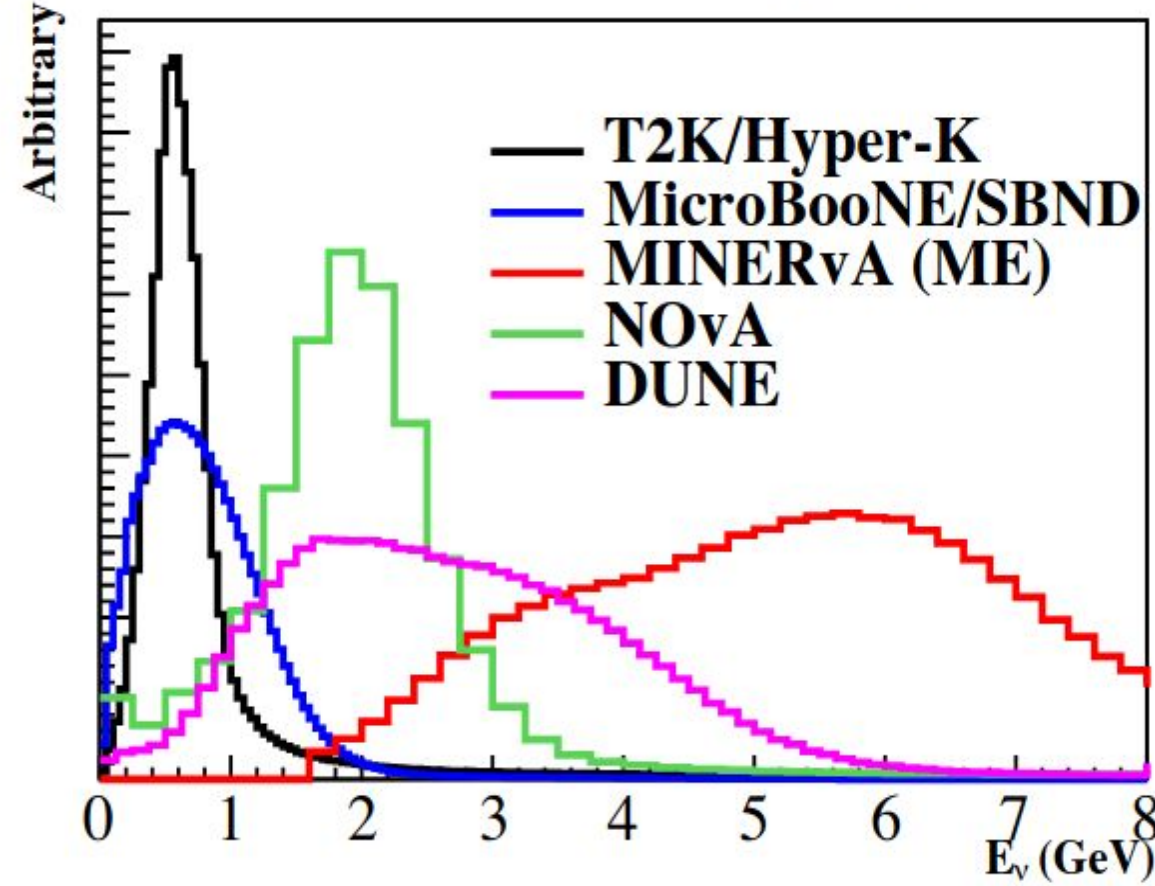


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Interaction Types, MINERvA

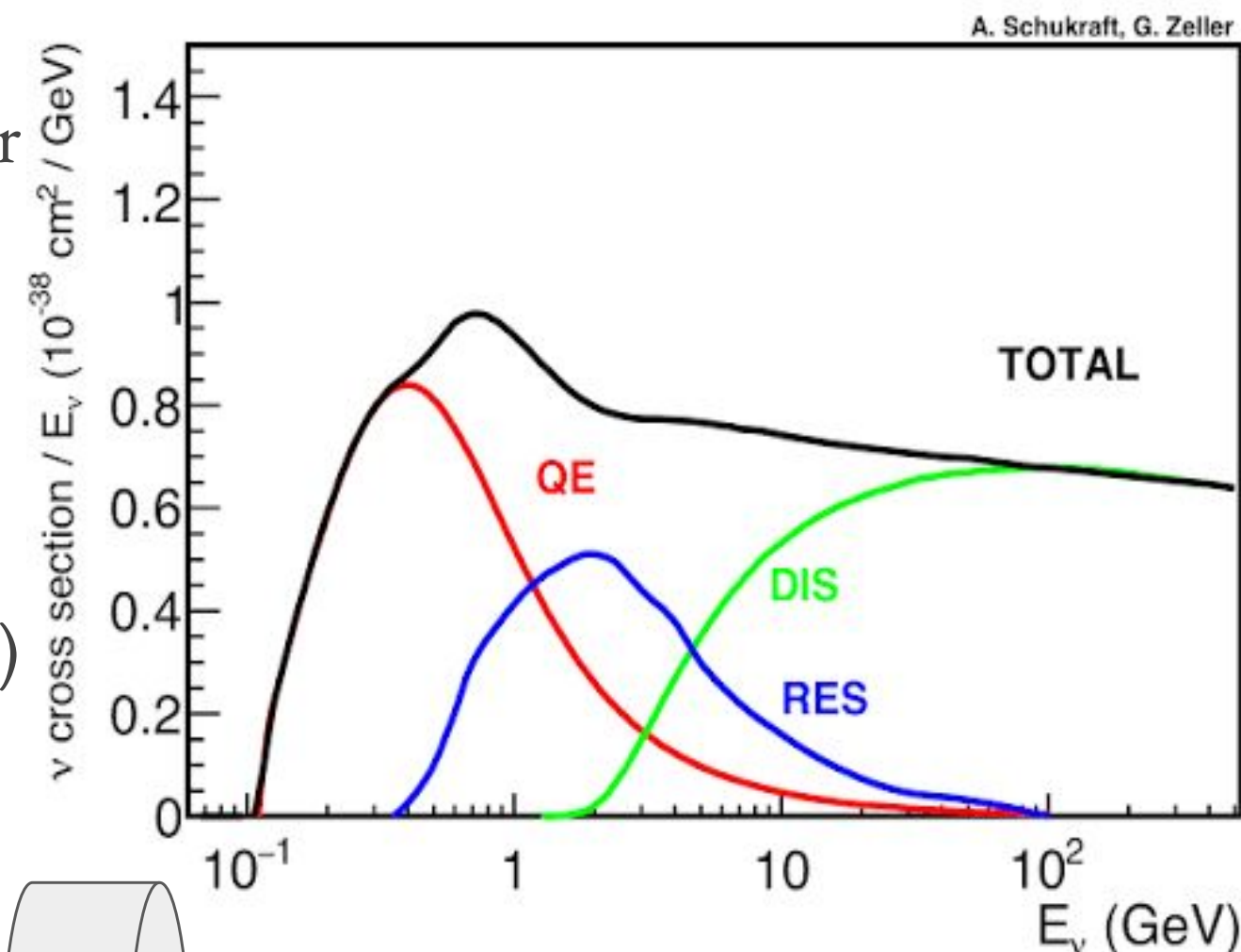
T. Katori and M. Martini, J.Phys. G45 (2018) no.1, 013001



- MINERvA covers the highest energy region of the DUNE sensitivity window, which has historically been poorly understood
- The experiment was designed to understand the interaction paths that neutrinos take with high energy beam, and many target materials

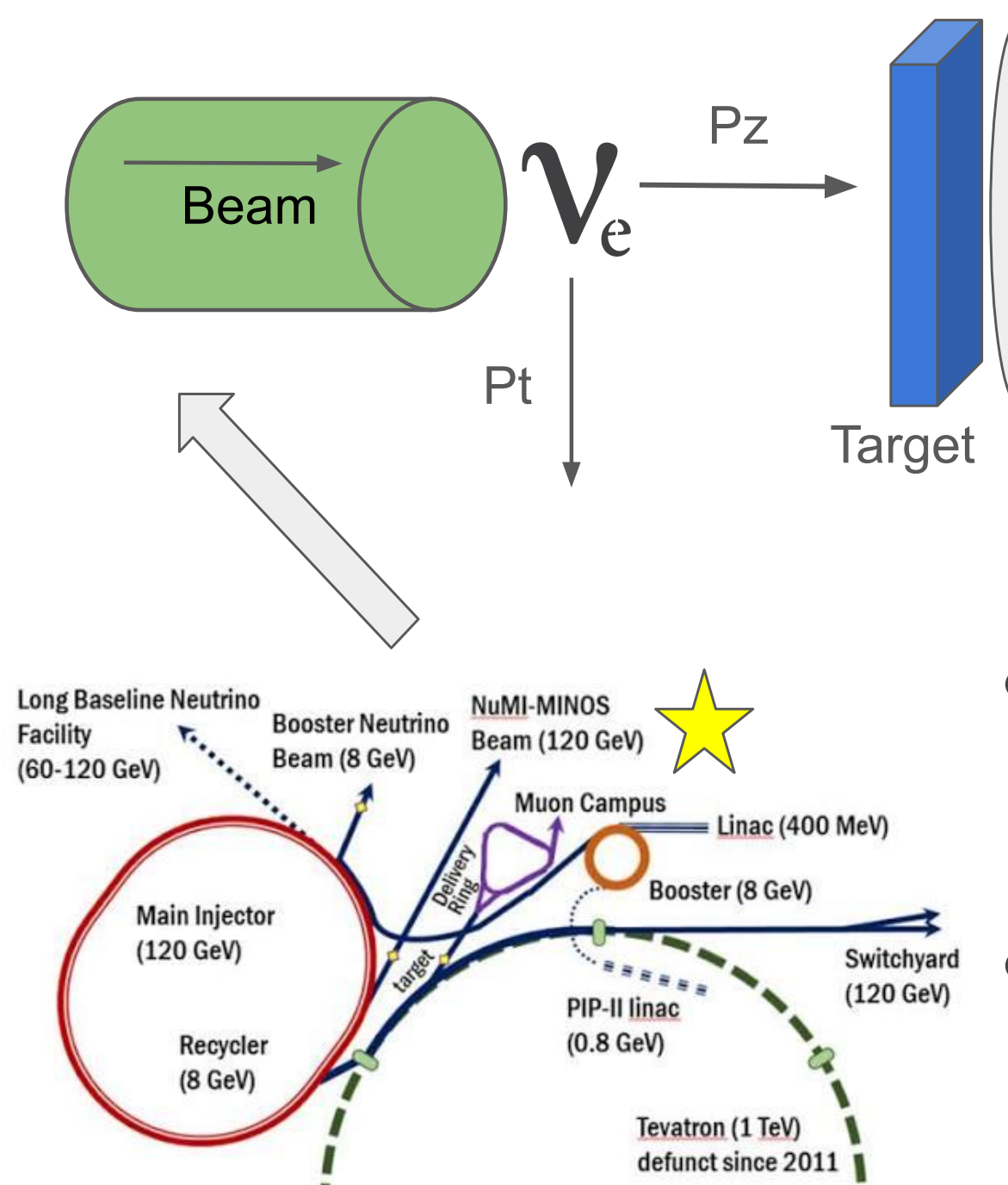
Neutrino interactions take one of four general types

- Quasi-Elastic (QE / Coherent)
 - 2p2h
- Resonance (Delta / Higher)
- Inelastic Scattering (Semi / Deep)



- We split the neutrino interactions by three axes
- Pz ~ neutrino energy
- Pt ~ neutrino momentum transfer
- EAvail ~ energy transfer

- Neutrinos strike the target layer, the resulting particle cascade can then be measured
- Approximately 10²¹ protons struck target during the run. 4 times that many were simulated.

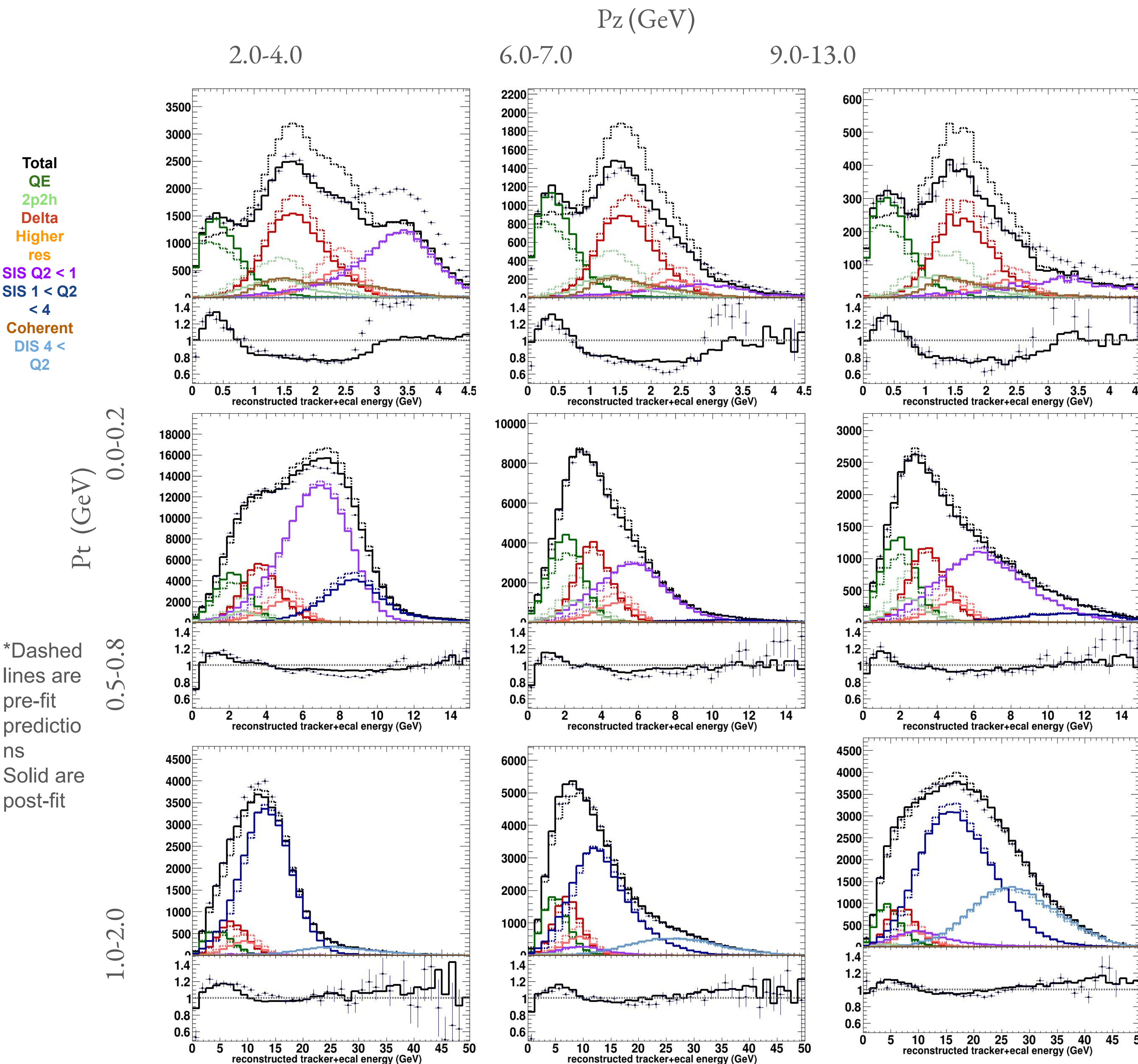


Introduction

Precise neutrino cross section models are critical to the next generation of long-baseline detectors like DUNE. The MINERvA experiment succeeded in measuring the interaction rates of neutrinos in the DUNE energy sensitivity window at both higher precision and statistics than any similar experiment before. In this work, we fit an improved neutrino interaction model to the MINERvA data based on the latest GENIE event generator and the Gundam fitter built on Minuit 2. We supply the prior uncertainties for approximately 30 model parameters, and create 10 novel ones that contribute to the event predictions, then minimize the total system likelihood from the data uncertainty and parameter adjustments. The result is a tuned parameter set that when applied to GENIE creates an improved description of the MINERvA data, allowing future works to more accurately measure neutrino interactions in this energy band.

The Fit

- The new parameter values provide a notably better prediction of data, in particular in the low delta resonance and 2p2h regions.
- The low Pt Pz region still has trouble with highest EAvail, likely as low SIS has no unique parameters.



The Parameters

```
"truth_genie_wgt_AGRYxFipi",
"truth_genie_wgt_AntiB",
"truth_genie_wgt_BhCBY",
"truth_genie_wgt_CQCPauliupVlaRF",
"truth_genie_wgt_CVluBY",
"truth_genie_wgt_CV2uBY",
"truth_genie_wgt_EtaNCS",
"truth_genie_wgt_FrAbs_N",
"truth_genie_wgt_FrAbs_pi",
"truth_genie_wgt_FrCBX_N",
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"truth_genie_wgt_FrEla_N",
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"truth_genie_wgt_NormCCRES",
"truth_genie_wgt_NormDISCC",
"truth_genie_wgt_NormNCRES",
"truth_genie_wgt_RDecBRgamma",
"truth_genie_wgt_Rvn2pi",
"truth_genie_wgt_Rvp2pi",
"truth_genie_wgt_Rvp2pi",
"truth_genie_wgt_Theta_Delta2Npi",
"truth_genie_wgt_VecFFCCQEShape",
"truth_genie_wgt_shifts"
```

- GENIE provides 36 parameters out of the box, of which 20 worked immediately. 10 required additional engineering. 2 failed.
- We engineered an additional 10 parameters based on theory.
 - Five sets of FR parameters are circularly dependant, we can safely remove one set
- Yellow indicates engineering required, usually interpolating from the 1 sigma values.
- Shifts parameter seems to be a bug/leftover in Genie

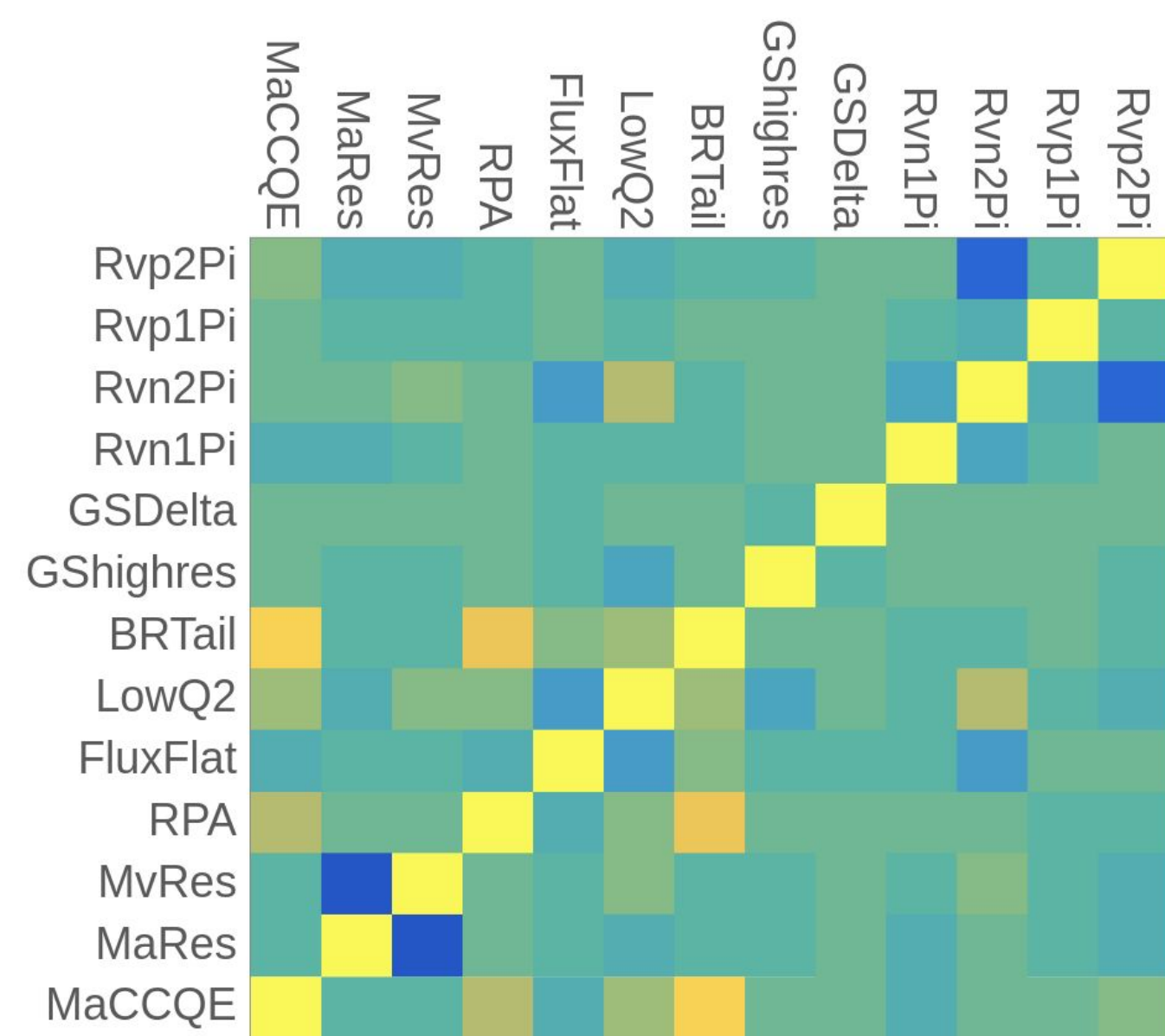
Non-Genie Parameters:

- RPA
 - Increase low QE events
- Flux Flat
 - Global shift up/down
- Low Q2 Resonance
 - Increase low q2 events in resonance type interactions
- Bodek-Ritchie Tail
 - Increase weight of high momentum final state nucleon population
- Gratchek-Sobchek Delta & Resonance
 - Implemented from recent research
- 2p2h Scaling
 - Reweight of all 2p2h events
- High Energy Flux Reweight
- Low Energy Flux Reweight

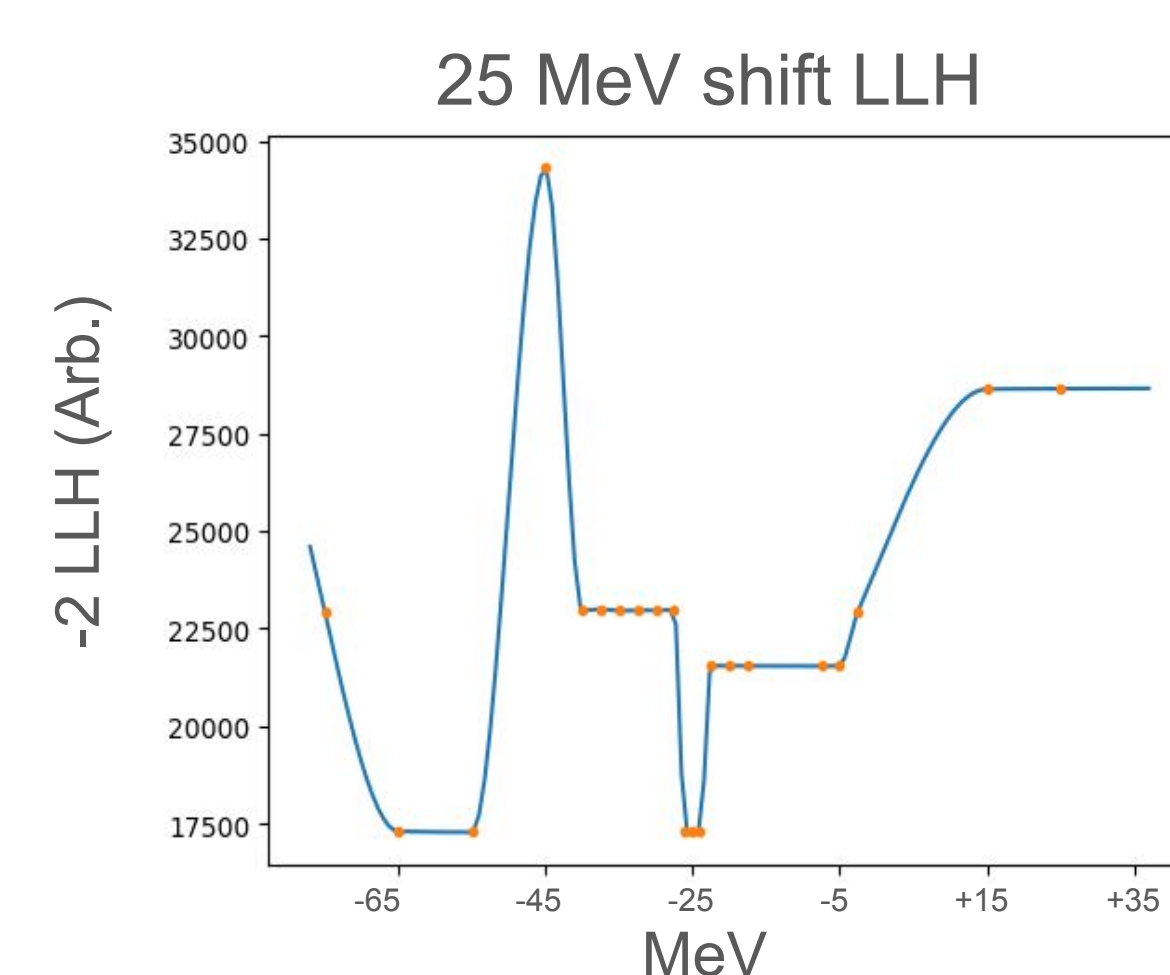
Otherwise, the MINERvA pipeline was set to Marvin's tune and best flux configuration.

Additional Utilities

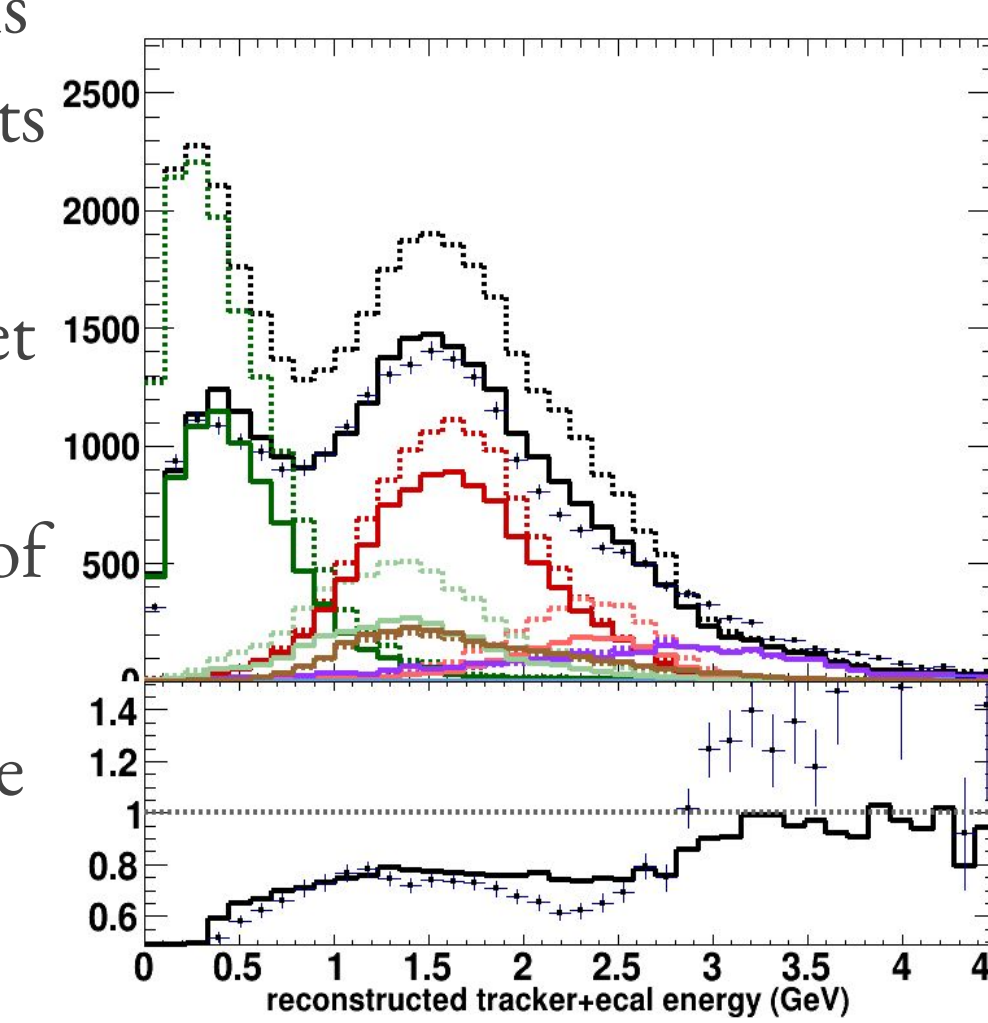
- Covariance of the parameters can be interesting in building future models
- Natively output from the fitter software
- Mv parameters strongly anti-correlated
- Rv*2Pi anti-correlated



- Horizontal shift parameters are harder for a histogram fitter
- There is a historically motivated global 25MeV shift applied to the detector
- Manually change the value, let the fitter converge for the remaining ones?



- Fitting even from a very bad starting point seems to still give decent results
- Manually set RPA parameter to 2 sigma, let the fitter converge
- Fitter returned a value of -2.18 for RPA, almost exactly 2 below what we got on the normal run
- Fit appears about as accurate to data either way



Conclusion

We were able to produce a new set of parameters, and generate several more, increasing the accuracy of the neutrino event generator, allowing future experiments to both better computationally model their apparatuses, and understand the results they get with higher accuracy.

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