Simulation-based inference for neutrino interaction model parameter tuning

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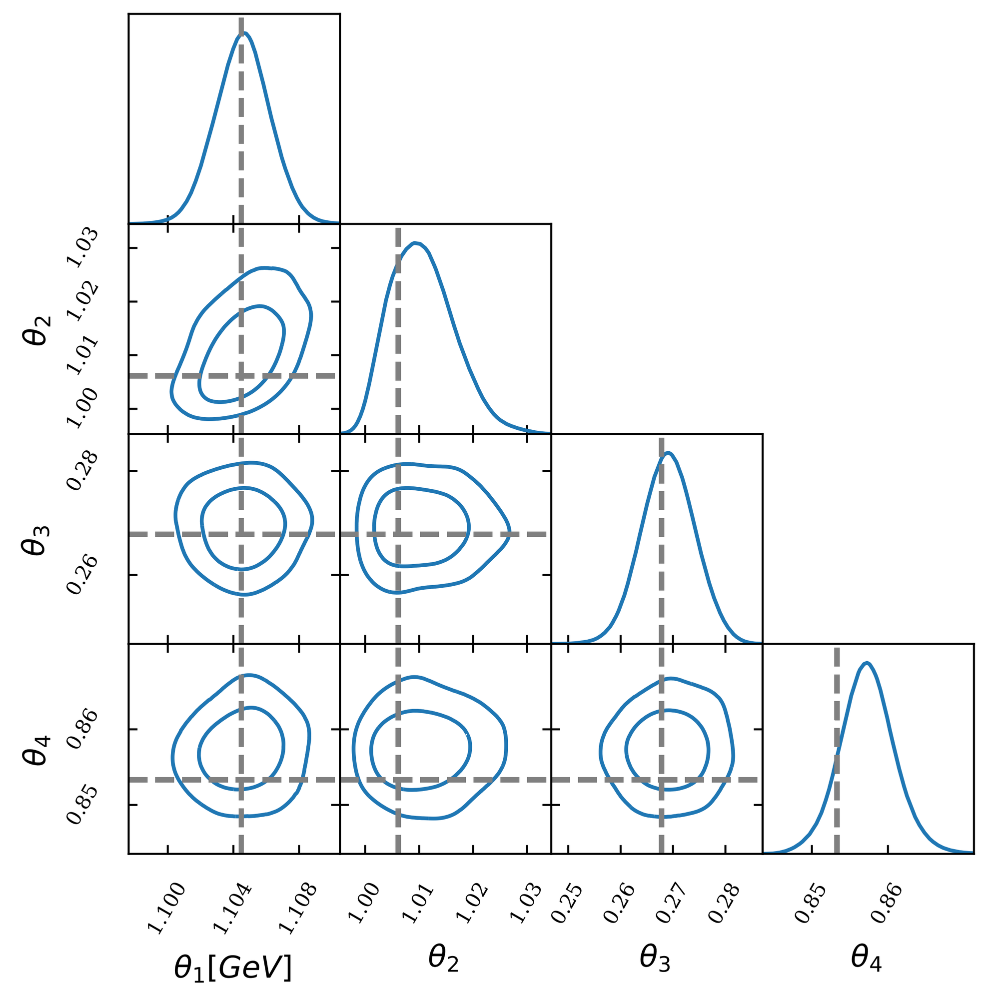
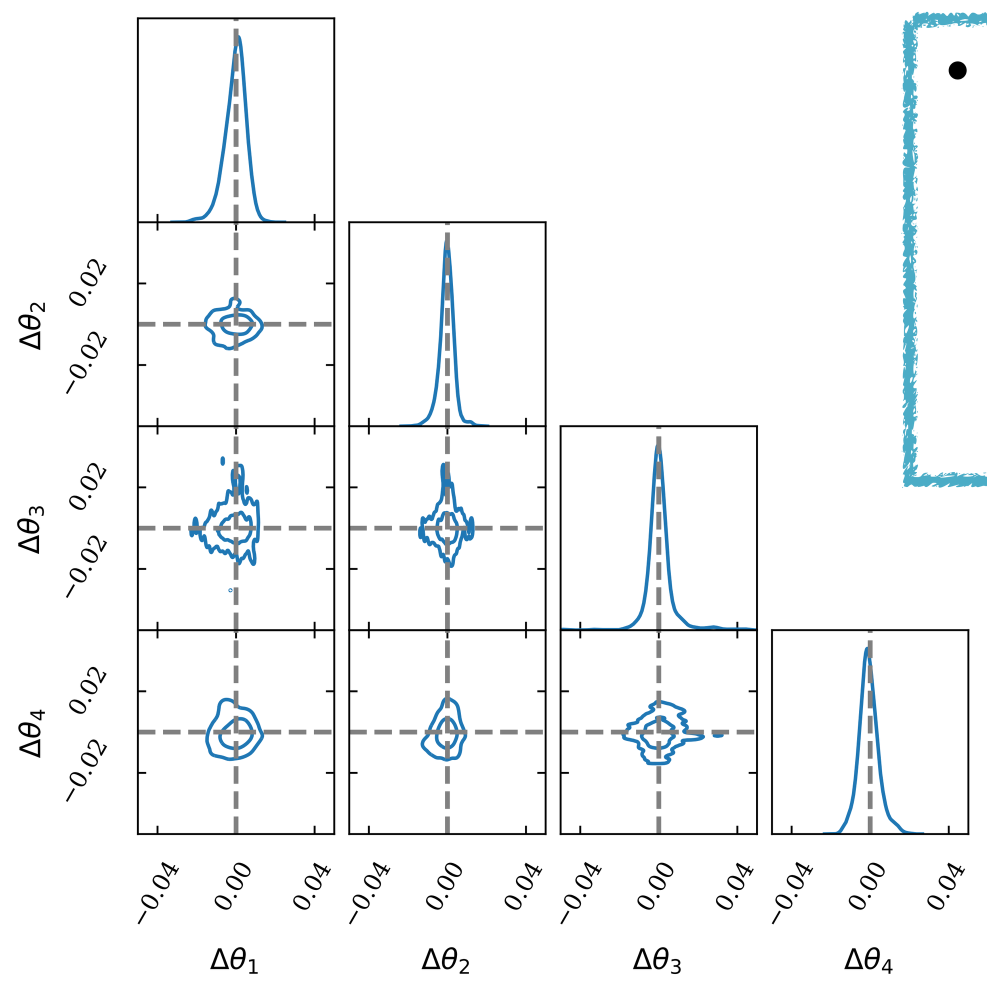
- **Motivation:** Neutrino experiments depend on accurate simulations of neutrino–nucleus interactions.

- **Challenge:** Theoretical models remain incomplete, requiring experimental tuning of **simulation** parameters.

- **Limitation of traditional methods:** Conventional Likelihood-based fits are slow and scale poorly with dimensionality.

- **Our approach:** Use **Simulation-Based Inference (SBI)** to learn the mapping between observables and model parameters.

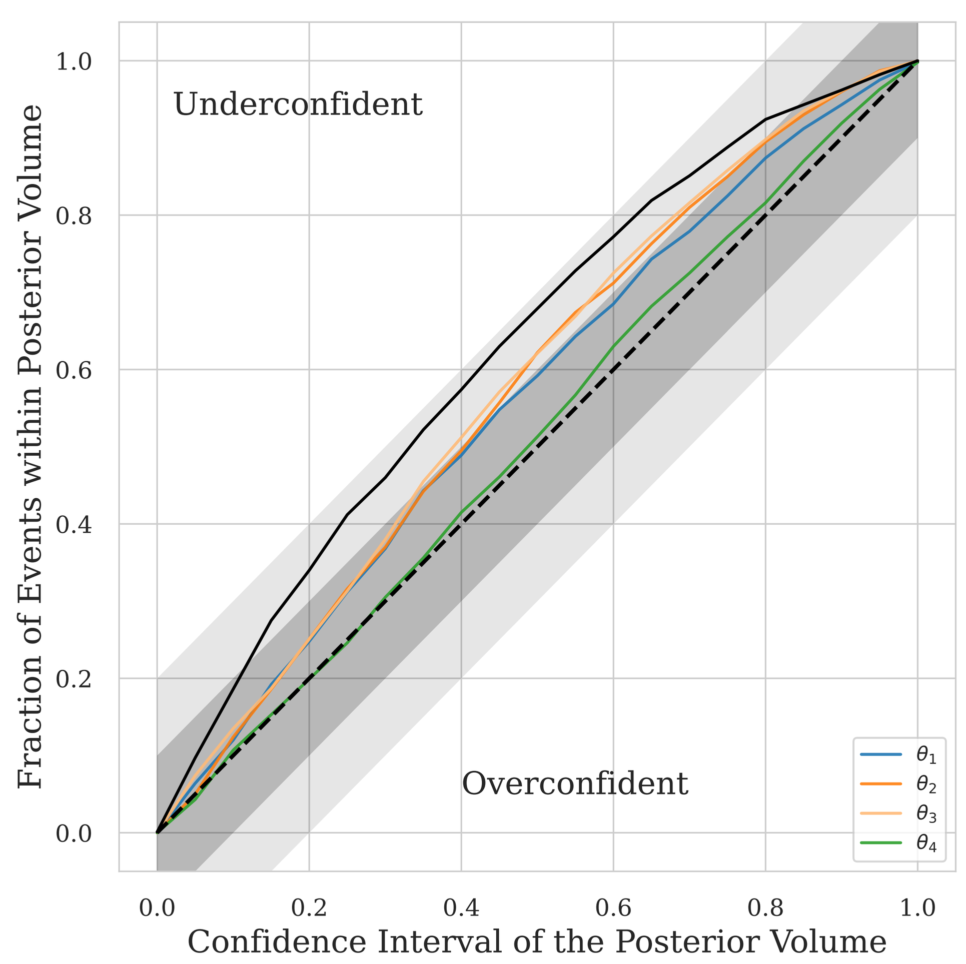


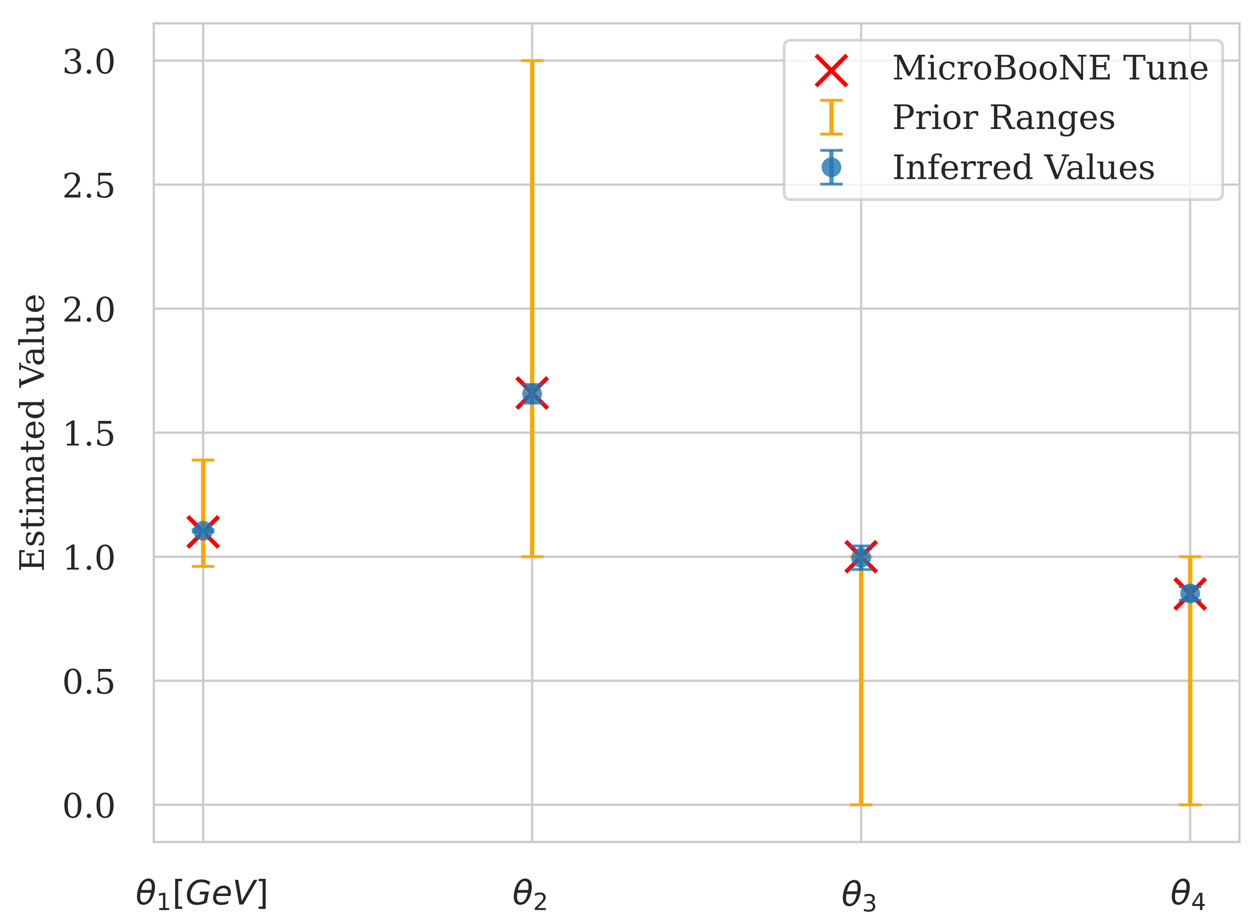


- **Advantages:**
  - Fast, amortized inference after training
  - Handles high-dimensional parameter spaces
  - Well suited for large-scale, next-generation neutrino experiments such as **DUNE**

Simulation setup

- **Frameworks:** GENIE + NUISANCE
- **Data:** Each configuration → 58-bin histogram (T2K dataset [2])
- **GENIE Parameters:** θ1 (MaCCQE), θ2(NormCCMEC), θ3(XSecShape_CCMEC) and θ4(RPA_CCQE).
- **Samples:** 200k for training, 1k for testing





Model

- **Framework:** sbi python library with Neural Posterior Estimation.
- **Embedding network:** 3 layers → reduces 58 bins → 24 features
- **Density estimator:** Masked Autoregressive Flow (6 transformations, 55 hidden units)
- **Training:** Batch size of 512, converges at ~215 epochs, learning rate 10^{-2}
- **Performance:** Once trained, inference completes in under 5 min.

- **Upper left:** Posterior distributions of one test event (gray-dashed = true-values).
- **Lower left:** Posterior coverage of 1k test events (black-dashed = perfect calibration; gray = 10–20% miscalibration).

- **Upper right:** Residuals for 1k test events (gray dashed = true).
- **Lower right:** MicroBooNE fit parameters (red) [3] vs. network-inferred parameters with 1σ errors (blue); prior ranges in orange.

Summary and Outlook

- **Successfully** applied simulation-based inference with neural posterior estimation to recover GENIE model parameters from mock "MicroBooNE Tune" data.
- SBI provides **fast, accurate, and scalable** parameter inference for complex neutrino interaction models.
- **Next steps:** Apply to T2K data, include correlated uncertainties, and benchmark against the original MicroBooNE likelihood fit to improve future tuning efficiency.

Bibliography

[1] Simulation-based inference for neutrino interaction model parameter tuning Karla Tame-Narvaez et.alle-Print: 2510.07454v1 [hep-ph]

[2] Measurement of double-differential muon neutrino charged-current interactions onC8H8 without pions in the final state using the T2K off-axis beam. Ko Abe et al. Phys. Rev. D, 93(11):112012

[3] New CC0π GENIE model tune for MicroBooNE. P. Abratenko et al. Phys. Rev. D, 105:072001

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