



中山大學 物理与天文学院
SUN YAT-SEN UNIVERSITY SCHOOL OF PHYSICS AND ASTRONOMY

A Comprehensive Effective Field Theory Framework for Coherent Elastic Neutrino-Nucleus Scattering

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第十八届粒子物理、核物理和宇宙学交叉学科前沿问题研讨会

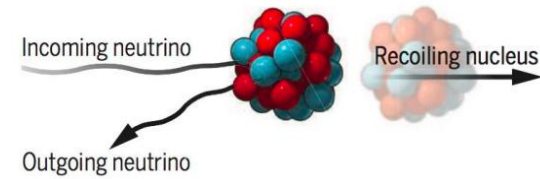
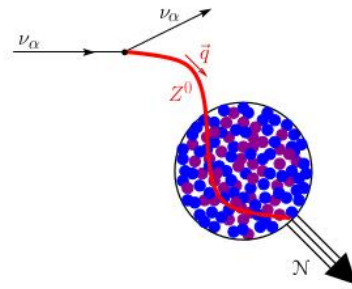
桂林，2026年4月12日

Outline

- Motivation: CEvNS as a precision probe for New Physics
- EFT Framework: From UV models to nuclear response
- Results: BSM constraints from SNS, Reactor, and Solar data
- Software: A universal automated code for CEvNS
- Summary

CEvNS: A New (ν) Frontier

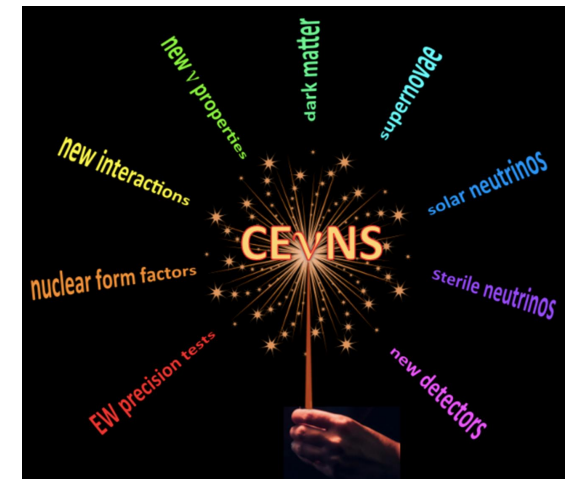
Coherent elastic neutrino-nucleus scattering



nuclear response

The nucleus recoils as a whole; **coherent** up to $E_\nu \sim 100$ MeV

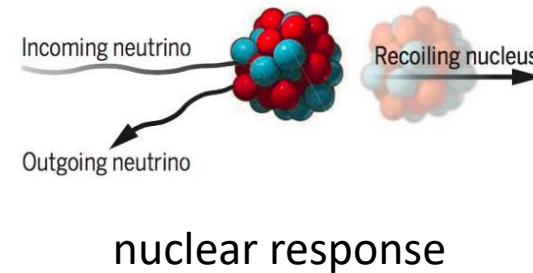
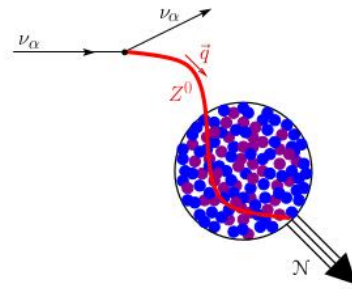
- CEvNS offers a clean SM prediction with a large cross section ($\sim N^2$)
- Any deviation from the SM prediction would signal new physics, such as Z' models, neutrino NSIs, or sterile neutrinos



E. Lisi

Experimental Landscape

Coherent elastic neutrino-nucleus scattering

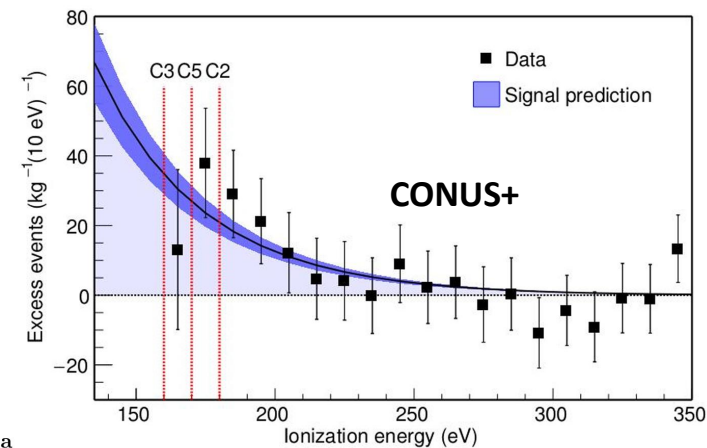
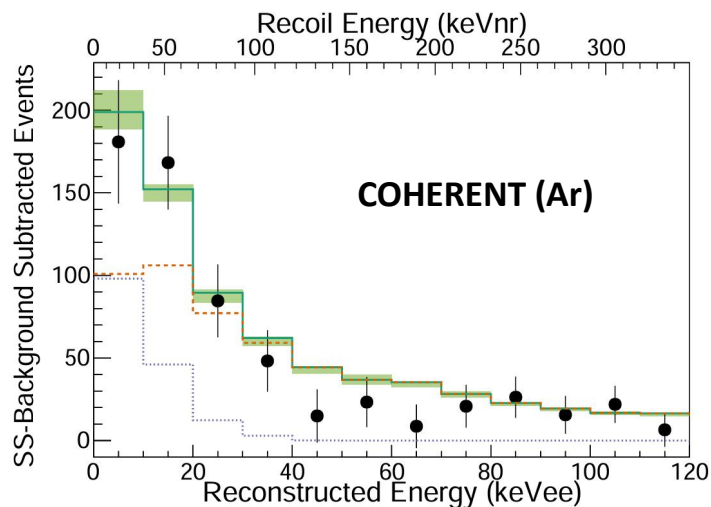
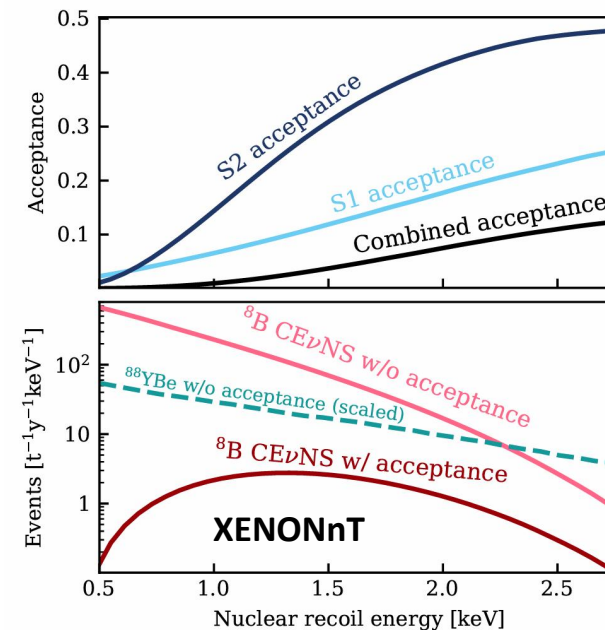
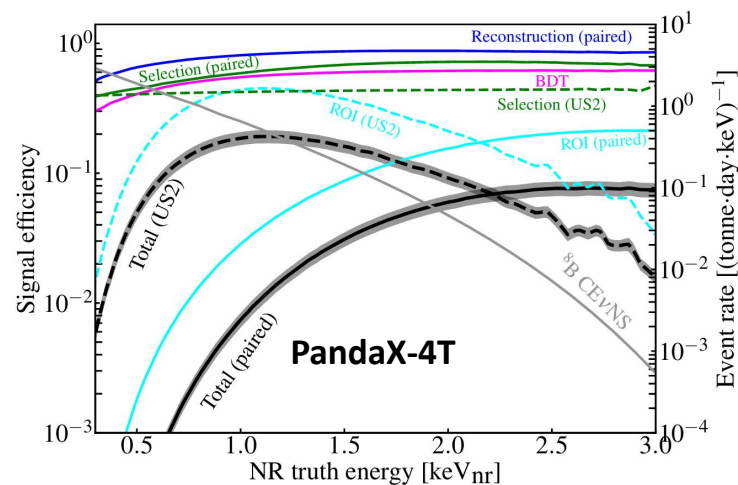
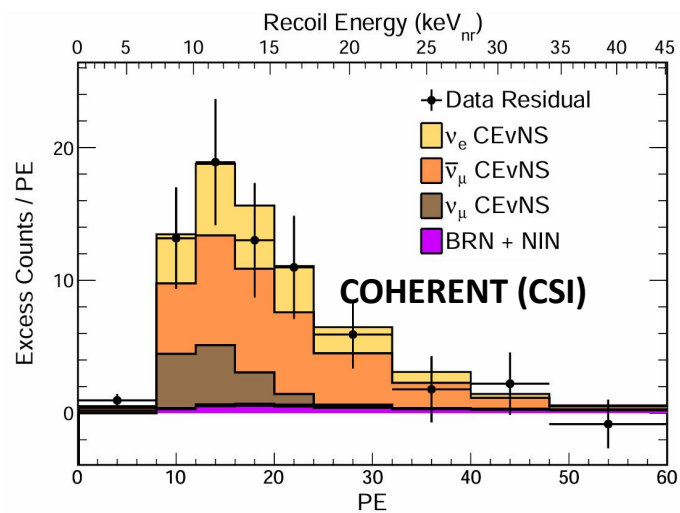


Since its discovery by COHERENT in 2017, diverse neutrino sources and targets are considered for CEvNS:

- Spallation Neutron Source: **high-energy** $\nu_\mu, \bar{\nu}_\mu, \nu_e$ ($\sim 30\text{-}50$ MeV) from pion decays [COHERENT with targets CsI, Ar, Ge]
- Reactors: **high-flux**, low-energy $\bar{\nu}_e$ (< 8 MeV) from nuclear fission [CONUS+ with target Ge]
- Solar Neutrinos (^8B): **all-flavor** (ν_e, ν_μ, ν_τ) flux with energies < 15 MeV, probing the neutrino floor/frog [PandaX-4T & XENONnT with target Xe]

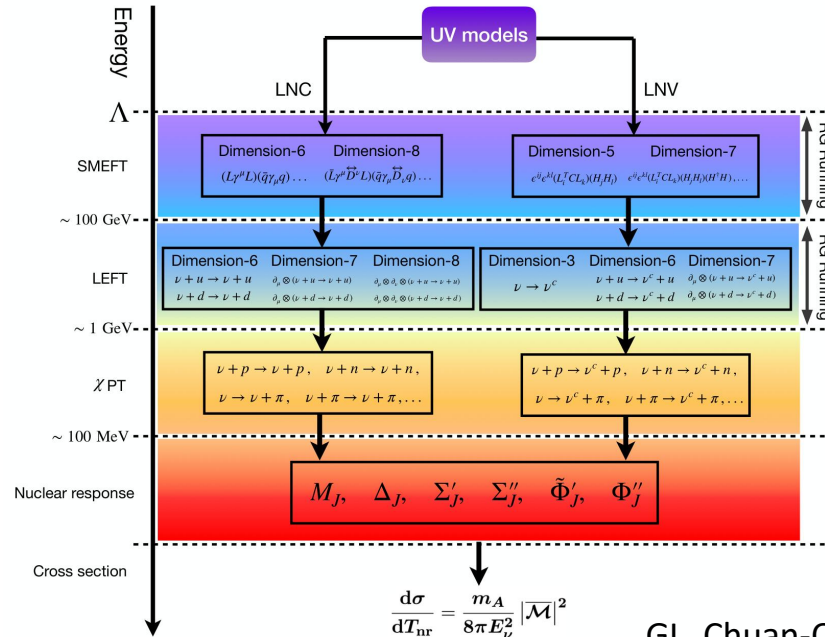
Experimental Landscape

Data available:



Effective Field Theory Framework

Multi-scale pipeline:



- ✓ full tree-level UV completions
- ✓ SMEFT operators up to dimension 8
- ✓ LEFT operators up to dimension 8
- ✓ chiral Lagrangian in the spurion method
- ✓ only 6 single-particle operators

complete matching and possible QCD RG running

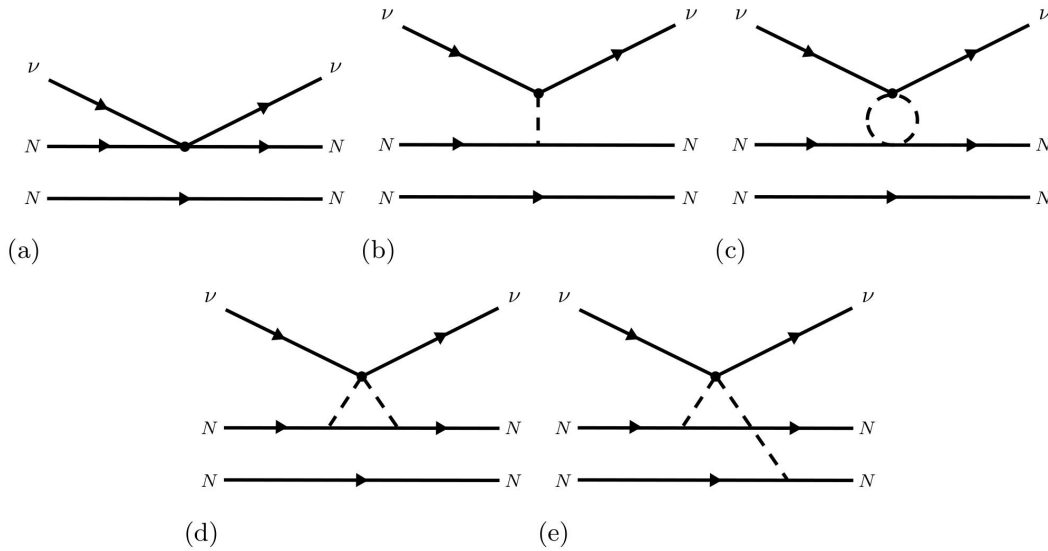
systematic power counting

GL, Chuan-Qiang Song, Feng-Jie Tang, Jiang-Hao Yu, 2601.19883 [hep-ph]

- **A unified platform:** covering all UV models and EFT operators across diverse neutrino sources and detector targets
- **Bridging the gap:** an end-to-end EFT tower connecting TeV-scale New Physics to MeV-scale nuclear observations

Power Counting

Nucleon level:



LEFT operator	One-body (a)	One-body (b)	One-body (c, d)	Two-body (e)
$\mathcal{O}_1^{6u/d}$	1	—	ϵ_χ^2	ϵ_χ^2
$\mathcal{O}_2^{6u/d}$	1	1	—	—
$\mathcal{O}_1^{7u/d}$	1	—	ϵ_χ^2	ϵ_χ^2
$\mathcal{O}_2^{7u/d}$	ϵ_N	—	ϵ_χ^2	ϵ_χ^2
$\mathcal{O}_3^{7u/d}$	ϵ_χ^2	—	ϵ_χ^4	ϵ_χ^4
$\mathcal{O}_4^{7u/d}$	ϵ_χ^2	—	ϵ_χ^4	ϵ_χ^4
$\mathcal{O}_5^{7u/d}$	$\epsilon_\chi^2 \epsilon_N$	ϵ_χ^4	—	—
$\mathcal{O}_6^{7u/d}$	ϵ_χ^2	—	ϵ_χ^4	ϵ_χ^4
$\mathcal{O}_7^{7u/d}$	$\epsilon_\chi^2 \epsilon_N$	ϵ_χ^4	—	—
$\mathcal{O}_1^{8u/d}$	1	—	ϵ_χ^2	ϵ_χ^2
$\mathcal{O}_2^{8u/d}$	1	—	—	—
$\mathcal{O}_9^{8u/d}$	1	—	ϵ_χ^2	ϵ_χ^2

$$\epsilon_\chi \equiv q/\Lambda_\chi \quad \epsilon_N \equiv q/m_N$$

One-body contributions dominate CEvNS

Power Counting

Nuclear level:

$$|\overline{\mathcal{M}}|^2 = \frac{4\pi}{2J_A + 1} \sum_{\tau, \tau'} \left\{ \left[R_{MM}^{\tau\tau'} W_{MM}^{\tau\tau'}(\mathbf{y}) + R_{\Sigma''\Sigma''}^{\tau\tau'} W_{\Sigma''\Sigma''}^{\tau\tau'}(\mathbf{y}) + R_{\Sigma'\Sigma'}^{\tau\tau'} W_{\Sigma'\Sigma'}^{\tau\tau'}(\mathbf{y}) \right] \right. \\ \left. + \frac{|\vec{q}|^2}{m_N^2} \left[R_{\Phi''\Phi''}^{\tau\tau'} W_{\Phi''\Phi''}^{\tau\tau'}(\mathbf{y}) + R_{\tilde{\Phi}'\tilde{\Phi}'}^{\tau\tau'} W_{\tilde{\Phi}'\tilde{\Phi}'}^{\tau\tau'}(\mathbf{y}) + R_{\Delta\Delta}^{\tau\tau'} W_{\Delta\Delta}^{\tau\tau'}(\mathbf{y}) \right] \right. \\ \left. - \frac{2|\vec{q}|}{m_N} \left[R_{\Phi''M}^{\tau\tau'} W_{\Phi''M}^{\tau\tau'}(\mathbf{y}) + R_{\Delta\Sigma'}^{\tau\tau'} W_{\Delta\Sigma'}^{\tau\tau'}(\mathbf{y}) \right] \right\}$$

nuclear response functions

$$W_{OO'} = \sum_J \langle j_{N'} || O_J || j_N \rangle \langle j_{N'} || O'_J || j_N \rangle$$

$$O_J, O_{J'} \in \{M_J, \Delta_J, \Sigma'_J, \Sigma''_J, \tilde{\Phi}'_J, \Phi''_J\}$$

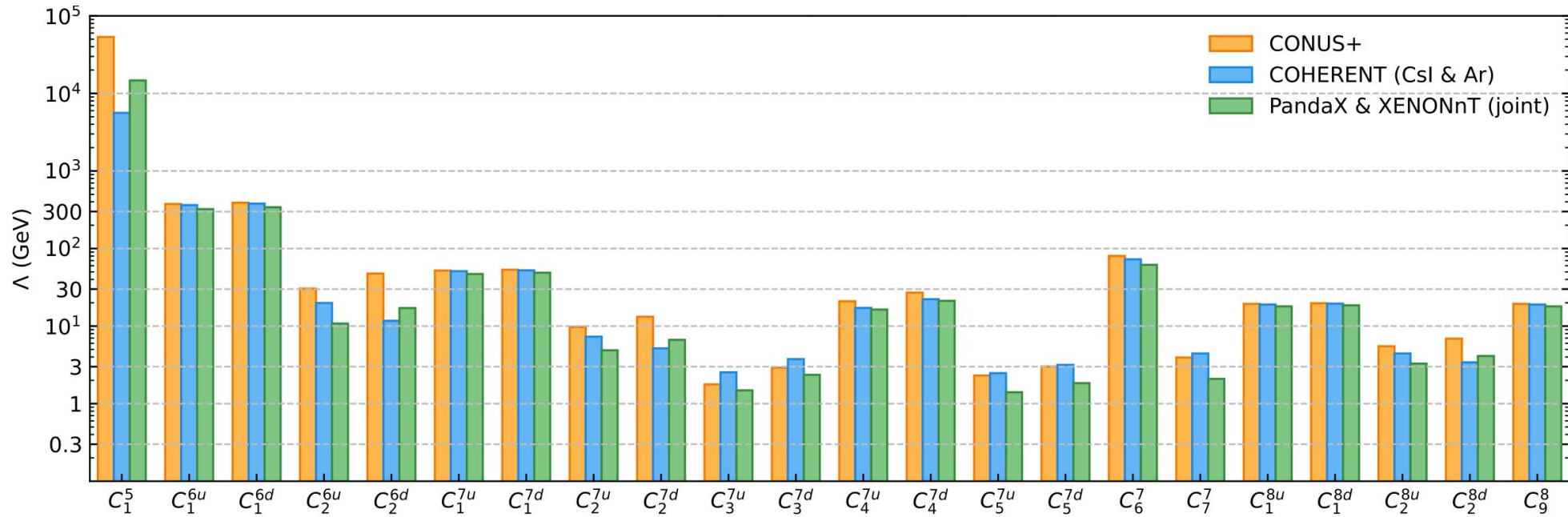
$$W_{MM}, W_{\Phi''\Phi''}, W_{\Phi''M} \sim A^2$$

$$A \sim 40 - 133, \quad \varepsilon \sim q/m_N \sim 0.02 - 0.1$$

		\overline{\mathcal{M}} \propto	
	LEFT operator	Response function	Overall scaling
		W_{MM}	A
$\mathcal{O}_1^{6u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \nu_{L\beta})(\bar{q} \gamma_\mu \tau^{u/d} q)$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	1
		$W_{\Delta\Delta}$	$\varepsilon \cdot 1$
		$W_{\Delta\Sigma'}$	$\varepsilon \cdot 1$
$\mathcal{O}_2^{6u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \nu_{L\beta})(\bar{q} \gamma^5 \gamma_\mu \tau^{u/d} q)$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	1
$\mathcal{O}_1^{7u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \nu_{L\beta})(\bar{q} \overleftrightarrow{\partial}_\mu \tau^{u/d} q)$	W_{MM}	A
$\mathcal{O}_2^{7u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \nu_{L\beta})(\bar{q} \gamma^5 \overleftrightarrow{\partial}_\mu \tau^{u/d} q)$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	ε
		W_{MM}	$\varepsilon^3 \cdot A$
$\mathcal{O}_3^{7u/d}$	$m_q (\nu_{L\alpha}^T C \sigma^{\mu\nu} \nu_{L\beta})(\bar{q} \sigma_{\mu\nu} \tau^{u/d} q)$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	$\varepsilon^2 \cdot 1$
		$W_{\Phi''\Phi''}$	$\varepsilon^3 \cdot A$
		$W_{\tilde{\Phi}'\tilde{\Phi}'}$	$\varepsilon^3 \cdot 1$
		$W_{\Phi''M}$	$\varepsilon^3 \cdot A$
$\mathcal{O}_4^{7u/d}$	$m_q (\nu_{L\alpha}^T C \nu_{L\beta})(\bar{q} \tau^{u/d} q)$	W_{MM}	$\varepsilon^2 \cdot A$
$\mathcal{O}_5^{7u/d}$	$m_q (\nu_{L\alpha}^T C \nu_{L\beta})(\bar{q} \gamma^5 \tau^{u/d} q)$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	$\varepsilon^3 \cdot 1$
$\mathcal{O}_6^{7u/d}$	$(\nu_{L\alpha}^T C \nu_{L\beta}) G_{\mu\nu}^A G^{A\mu\nu}$	W_{MM}	$\varepsilon^2 \cdot A$
$\mathcal{O}_7^{7u/d}$	$(\nu_{L\alpha}^T C \nu_{L\beta}) \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	$\varepsilon^3 \cdot 1$
$\mathcal{O}_1^{8u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \overleftrightarrow{\partial}^\nu \nu_{L\beta})(\bar{q} \gamma_\mu \overleftrightarrow{\partial}^\nu \tau^{u/d} q)$	W_{MM}	A
$\mathcal{O}_2^{8u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \overleftrightarrow{\partial}^\nu \nu_{L\beta})(\bar{q} \gamma^5 \gamma_\mu \overleftrightarrow{\partial}^\nu \tau^{u/d} q)$	$W_{\Sigma'\Sigma'}, W_{\Sigma''\Sigma''}$	1
$\mathcal{O}_9^{8u/d}$	$(\bar{\nu}_{L\alpha} \gamma^\mu \overleftrightarrow{\partial}^\nu \nu_{L\beta}) G_{\mu\rho}^A G_\nu^{A\rho}$	W_{MM}	A

New Physics Constraints from CEvNS

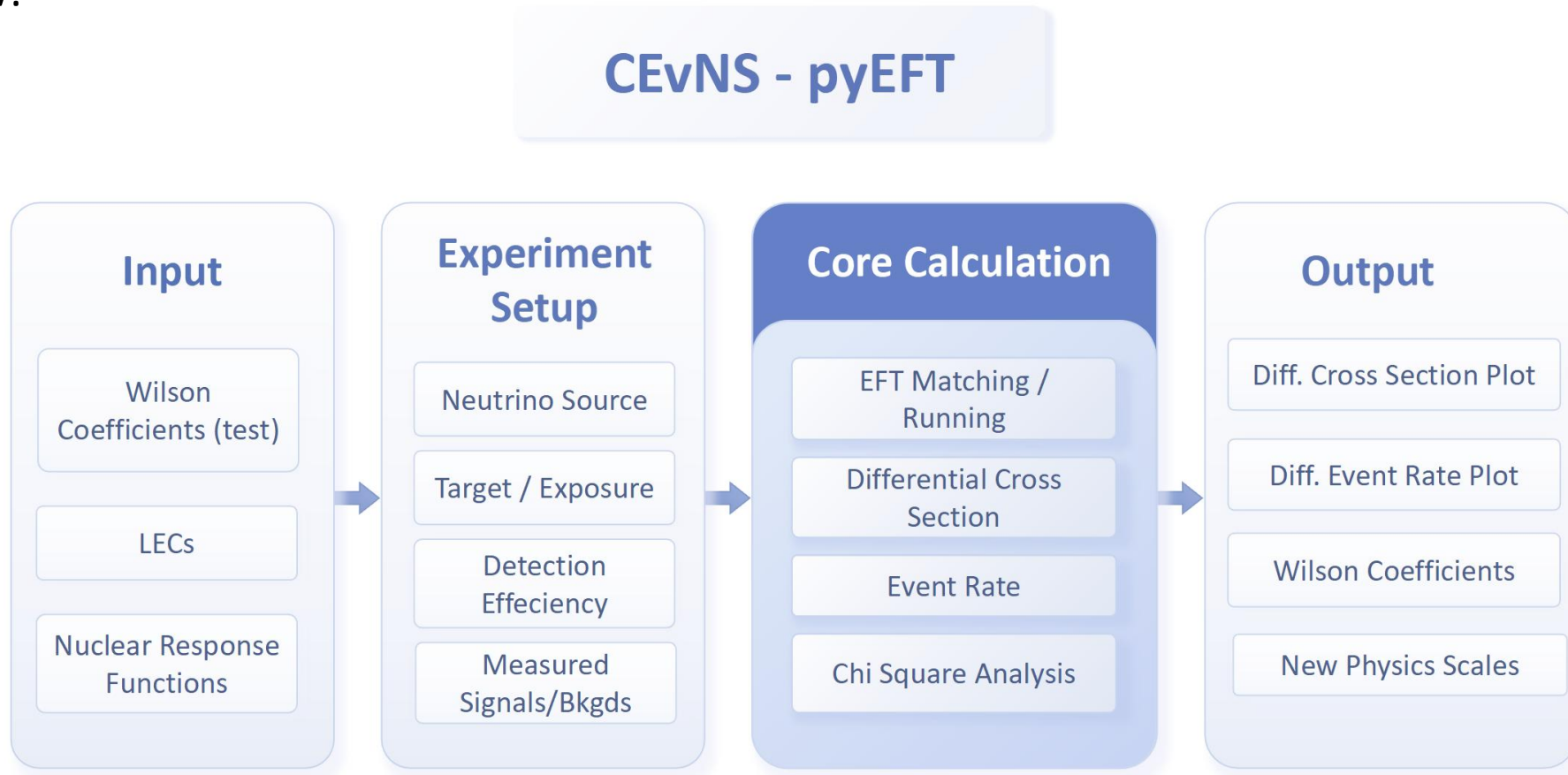
From data to New Physics scales:



Cutoff scales of LEFT operators

Universal Automated Code

Workflow:



Universal Automated Code

User Interface:

CEvNS - pyEFT
An end-to-end EFT platform for coherent elastic neutrino-nucleus scattering

Dataset: Cs12021
Local figure folder: F:\Python\20260304 CEvNSMMA2Py\2026-04

PROJECT OVERVIEW
A CEvNS analysis platform that links Wilson-coefficient input, low-energy matching, nuclear response, CEvNS observables, detector-level event simulation, statistical inference, and EFT cutoff-scale interpretation.

Based on A Comprehensive Effective Field Theory Framework for Coherent Elastic Neutrino-Nucleus Scattering, Reference: Li, Song, Tang, Yu (2026), arXiv:2601.19883.

Supported datasets: 3
Response nuclei: 20
Operator groups: 20
Main workflow: 6

Physics workflow

```

    graph LR
      Input[Input] --> Experiment[Experiment Setup]
      Experiment --> Core[Core Calculation]
      Core --> Output[Output]
  
```

Modules

- Scattering Cross Section**: Differential CEvNS cross section for selected nuclei and Wilson-coefficient inputs.
- Differential Event Rate**: Flux-folded differential event-rate spectrum derived from the CEvNS cross section.
- Binned Event Counts**: Detector-level CEvNS event simulation including efficiency, PE response, and binning.
- 2D Chi-square**: Two-dimensional statistical comparison between predicted and measured CEvNS spectra.
- Cutoff Scale**: EFT cutoff-scale interpretation of coefficient constraints derived from CEvNS data.
- Wilson Matching / Running**: Wilson-coefficient organization across scales and operator bases for the CEvNS EFT workflow.

Differential Event Rate

This module folds the CEvNS differential cross section with the neutrino flux. It connects the theory-level cross section to an experiment-oriented differential event-rate spectrum and shows how the EFT input propagates through the neutrino-energy distribution.

Dataset: Cs12021
Target: Cs133
Flux components: 3
Output mode: dR/dT

KEY FORMULA
Differential event rate spectrum

$$\frac{dR_{\text{total}}}{dT_{\text{det}}} = \int_{E_{\text{recoil}}(T_{\text{det}})}^{E_{\text{max}}} dE_{\nu} \Phi_{\nu}(E_{\nu}) \frac{d\sigma}{dT_{\text{det}}}(E_{\nu}, T_{\text{det}})$$

This module turns the theory-level cross section into an experiment-oriented differential event-rate spectrum by folding it with the neutrino flux.

Plot: Table Export Metadata

Differential Event Rate | Cs12021 | Cs133

Events / detector / keV vs T_{det} [keV]

Binned Event Counts

This module converts the recoil event rate into detector-level binned counts by including the detector efficiency, the PE smearing model, and the analysis binning. It is the natural bridge between CEvNS theory predictions and experimental spectra.

Binning: 9 bins
Efficiency model: Cs12021
Target mode: Cs1
Statistical overlay: Optional

KEY FORMULA
Binned event prediction

$$N_{\text{Binned}}^{\text{total}} = n_{\nu} \sum_{\mu} \int_{E_{\text{recoil}}(T_{\text{det}})}^{E_{\text{max}}} dE_{\nu} \epsilon(E_{\nu}) \int dT_{\text{det}} P(T_{\text{det}}) \frac{dR_{\text{total}}}{dT_{\text{det}}}$$

This plot converts the recoil event rate into detector-level binned counts, ready for direct comparison with experimental spectra.

Plot: Table Export Metadata

Binned Event Counts | Cs12021 | Cs1 | counts / nPE

Counts / nPE vs Photoelectron bin

GL, Chuan-Qiang Song, Feng-Jie Tang (汤丰杰), Jiang-Hao Yu

Summary

- Comprehensive EFT Framework for CEvNS:
 - **A unified platform**: covering all UV models and EFT operators across diverse neutrino sources and detector targets
 - **Bridging the gap**: an end-to-end EFT tower connecting TeV-scale New Physics to MeV-scale nuclear observations
- Global Phenomenological Analysis:
 - Extracted robust, model-independent constraints on New Physics scales by leveraging the complementarity of different experimental measurements
- Automated Implementation:
 - `CEvNS-pyEFT`, a universal automated code designed for CEvNS calculations

LEFT operators

Lepton number conserving (LNC):

$$\mathcal{O}_1^{6u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma_\mu\tau^{u/d}q),$$

$$\mathcal{O}_1^{7u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\overleftrightarrow{D}_\mu\tau^{u/d}q),$$

$$\mathcal{O}_1^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\overleftrightarrow{D}^\nu\nu_{L\beta})(\bar{q}\gamma_\mu\overleftrightarrow{D}_\nu\tau^{u/d}q),$$

$$\mathcal{O}_3^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma^\nu T^A\tau^{u/d}q)G_{\mu\nu}^A,$$

$$\mathcal{O}_5^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})D^2(\bar{q}\gamma_\mu\tau^{u/d}q),$$

$$\mathcal{O}_7^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma^\nu T^A\tau^{u/d}q)\tilde{G}_{\mu\nu}^A,$$

$$\mathcal{O}_9^8 = (\bar{\nu}_{L\alpha}\gamma^\mu\overleftrightarrow{D}^\nu\nu_{L\beta})G_{\mu\rho}^AG_{\nu}^{A\rho}.$$

$$\mathcal{O}_2^{6u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma^5\gamma_\mu\tau^{u/d}q),$$

$$\mathcal{O}_2^{7u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma^5\overleftrightarrow{D}_\mu\tau^{u/d}q),$$

$$\mathcal{O}_2^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\overleftrightarrow{D}^\nu\nu_{L\beta})(\bar{q}\gamma^5\gamma_\mu\overleftrightarrow{D}_\nu\tau^{u/d}q),$$

$$\mathcal{O}_4^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma^5\gamma^\nu T^A\tau^{u/d}q)G_{\mu\nu}^A,$$

$$\mathcal{O}_6^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})D^2(\bar{q}\gamma^5\gamma_\mu\tau^{u/d}q),$$

$$\mathcal{O}_8^{8u/d} = (\bar{\nu}_{L\alpha}\gamma^\mu\nu_{L\beta})(\bar{q}\gamma^5\gamma^\nu T^A\tau^{u/d}q)\tilde{G}_{\mu\nu}^A,$$

$$\mathcal{L}_{\text{LEFT}} = \sum_{d,a} \hat{\mathcal{C}}_a^d \mathcal{O}_a^d, \quad \hat{\mathcal{C}}_a^d \equiv \frac{\mathcal{C}_a^d}{\Lambda_a^{d-4}}$$

Lepton number violating (LNV):

$$\mathcal{O}_1^5 = \frac{e}{8\pi^2}(\nu_{L\alpha}^T C \sigma^{\mu\nu} \nu_{L\beta})F_{\mu\nu},$$

$$\mathcal{O}_4^{7u/d} = m_q(\nu_{L\alpha}^T C \nu_{L\beta})(\bar{q}\tau^{u/d}q),$$

$$\mathcal{O}_6^7 = \frac{\alpha_s}{\pi}(\nu_{L\alpha}^T C \nu_{L\beta})G_{\mu\nu}^A G^{A\mu\nu},$$

$$\mathcal{O}_3^{7u/d} = m_q(\nu_{L\alpha}^T C \sigma^{\mu\nu} \nu_{L\beta})(\bar{q}\sigma_{\mu\nu}\tau^{u/d}q),$$

$$\mathcal{O}_5^{7u/d} = m_q(\nu_{L\alpha}^T C \nu_{L\beta})(\bar{q}\gamma^5\tau^{u/d}q),$$

$$\mathcal{O}_7^7 = \frac{\alpha_s}{\pi}(\nu_{L\alpha}^T C \nu_{L\beta})\tilde{G}_{\mu\nu}^A G^{A\mu\nu},$$