Constraints on neutrino generalized interactions from COHERENT data

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Magnificent CEvNS Workshop

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Coherent Elastic Neutrino-Nucleus Scattering

CEνNS

CEνNS occurs when the neutrino energy E_ν is such that nucleon amplitudes sum up coherently ⇒ cross section enhancement

$$\lambda \gtrsim R_N \Rightarrow q \lesssim 200 \text{ MeV}$$

$$E_R = q^2/2m_N \Rightarrow E_\nu \simeq \sqrt{E_R^{\text{max}} m_N/2}$$

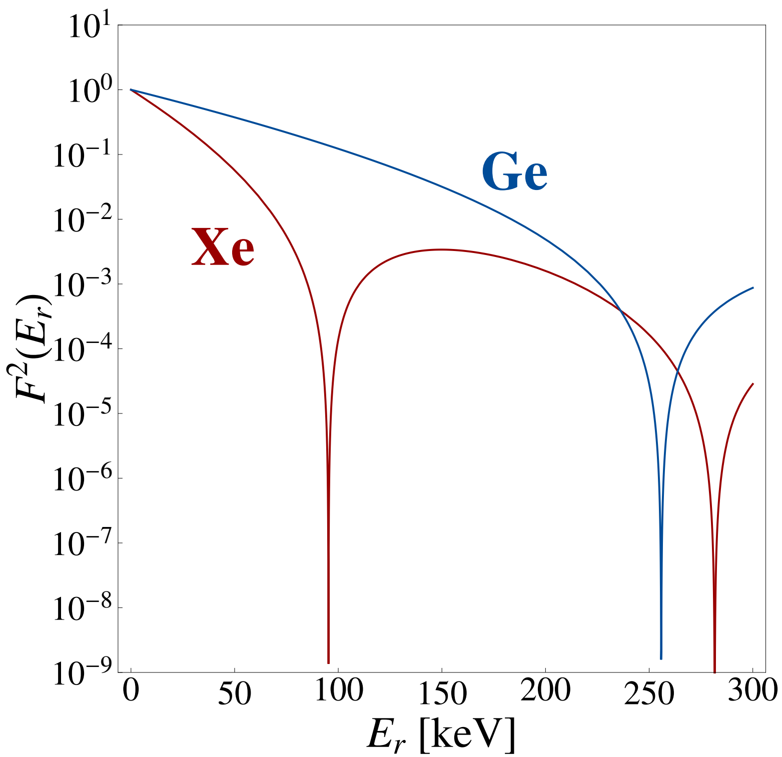
$$E_\nu \lesssim 100 \text{ MeV}$$

Freedman, 1974

$$\frac{d\sigma_\nu}{dE_R} = \frac{G_F^2}{4\pi} Q_{\text{SM}}^2 m_N \left(1 - \frac{E_r m_N}{2E_\nu^2}\right) \underbrace{F^2(E_r)}_{\text{Form factor}}$$

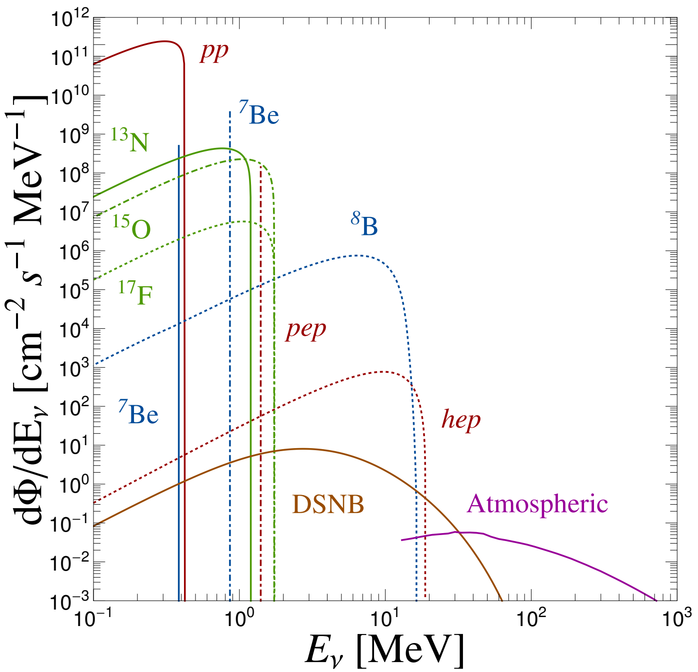
$$\boldsymbol{Q_{\text{SM}}^2 = [N - (1 - s_W^2) Z]^2 \simeq N^2}$$

Helm, 1956

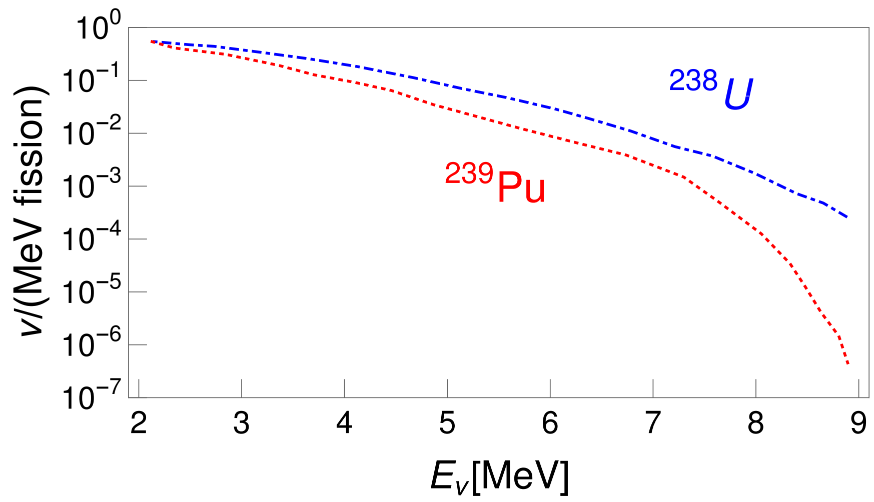


Relevant neutrino sources

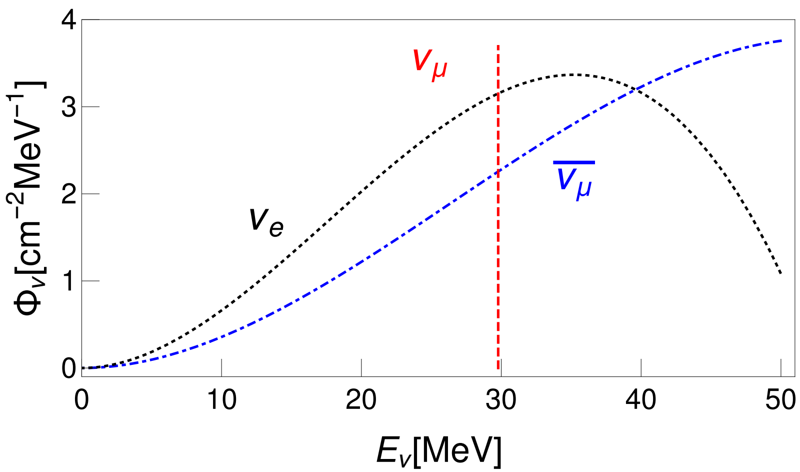
“Astrophysical” sources



Reactor Neutrinos



Fixed target



Solar+Atm: ν backgrounds DM detectors

Reactor: Basis for **CONUS**, **ν-CLEUS**

Fixed target: COHERENT experiment

COHERENT

CEνNS observed by COHERENT more than 40 years after its prediction

Akimov et. al. 2017

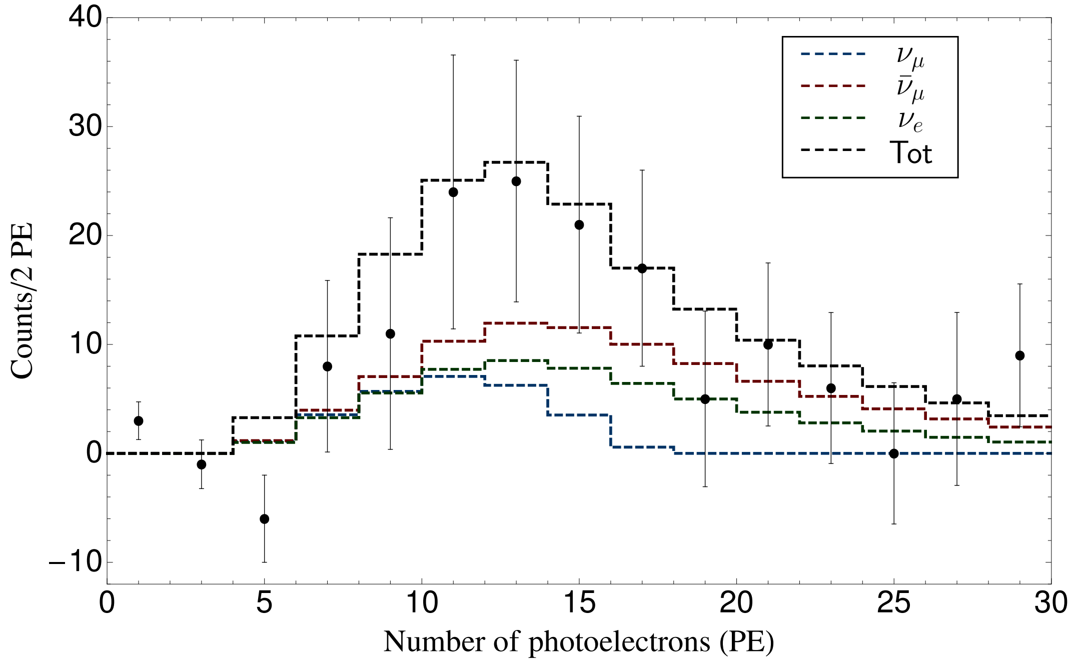
COHERENT uses neutrinos produced in SNS

@ Oak Ridge National Laboratory in the collision $p-$Hg

$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

Presence of CEνNS favored @ the 6.7σ level. Data consistent with SM @ the 1σ

DAS, De Romeri, Rojas, 2018



$$n_{\rm PE} = 1.17\,(E_R/\text{keV})$$

There is still some room for NEW PHYSICS!

Sensitivity to new physics

The case of NSI

Non-standard interactions parametrized in a model-independent and phenomenological way

Wolfenstein, 1978

$$\mathscr{L} \sim G_F \sum_{q=u,d} \bar{\nu}_i (1-\gamma_5)\gamma_\mu \nu_j \bar{q}(\epsilon_{ij}^{qV} - \epsilon_{ij}^{qA}\gamma_5)\gamma^\mu q$$

Phenomenological constraints from forward coherent scattering (matter potentials) DIS and COHERENT data

Scenarios

Gonzalez-Garcia et. al, 2017

- For $m_X^2 \ll q^2$ contributions of NSI to DIS are suppressed, $q^2_{\text{DIS}} \gtrsim (10\text{GeV})^2$
- Light mediator scenarios: $M_X \subset [10, 10^3]$ MeV $\Rightarrow$ DIS constraints evaded
- Heavy mediator scenarios: $M_X \subset [1, 10^3]$ GeV all constraints apply

COHERENT constraints are particularly relevant for light mediators

Constraints

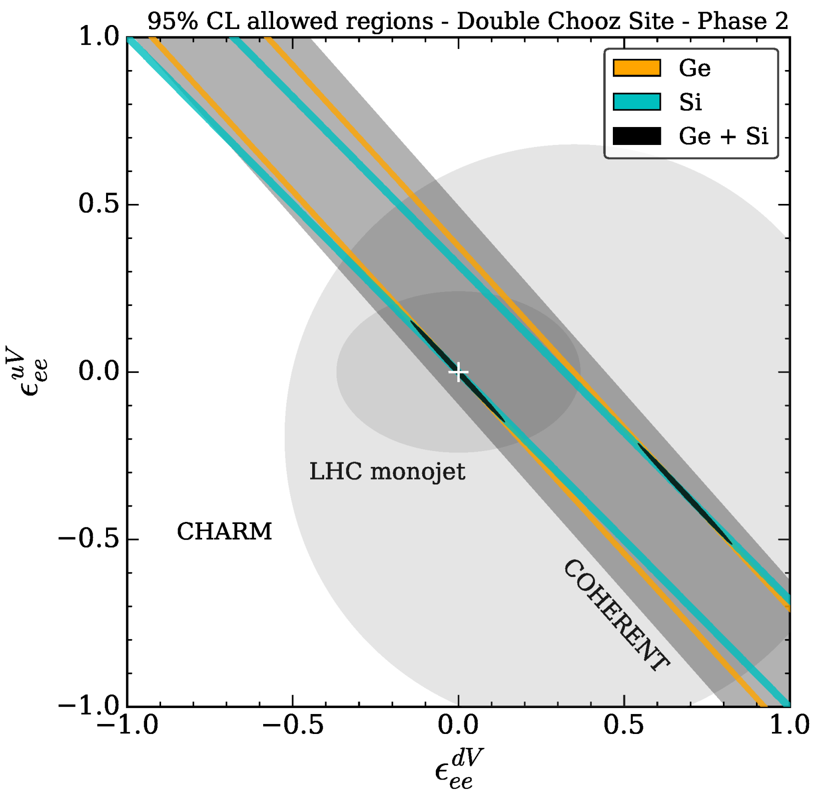
COHERENT data has been used to constraint NSI contributions to the CEνNS

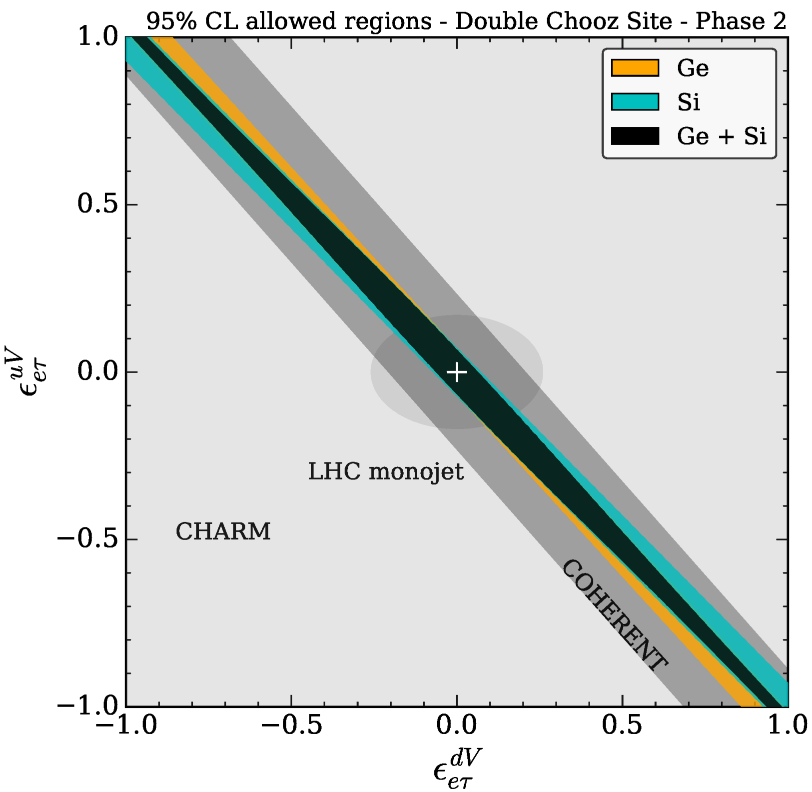
Gonzalez-Garcia et. al, 2017

J. Liao & D. Marfatia, 2017

Kosmas et. al, 2018

Billard et. al, 2018





The NGI case

NSI are a subset of a larger set of neutrino-quark interactions: Neutrino Generalized Interactions (NGI)

Lee & Yang (1957)

$$\mathcal{L} \sim G_F \sum_{q=u,d} (\bar{\nu}\Gamma_A \nu)\left[\bar{q}\Gamma_A\left(C_A^q + iD_A^q\gamma_5\right)q\right]$$

$$\Gamma_A = \{\mathbb{I}, i\gamma_5, \gamma_\mu, \gamma_5\gamma_\mu, \sigma_{\mu\nu}\}$$

Diagonal and non-diagonal LS

$$\Gamma_P : \mathcal{L} \sim \bar{\nu}\gamma_5\nu\bar{q}\left(\gamma_5 C_P^q + \mathbb{I} D_P^q\right)q$$

P and A quark currents are nuclear spin-dependent $\Rightarrow Z_\uparrow - Z_\downarrow,\ N_\uparrow - N_\downarrow$

$$\mathcal{L}_S \sim (\bar{\nu}\nu)\left[\bar{q}\left(C_S^q + i\gamma_5 D_S^q\right)q\right]$$

$$\mathcal{L}_P \sim (\bar{\nu}\gamma_5\nu)\left[\bar{q}\left(\gamma_5 C_P^q + iD_P^q\right)q\right]$$

$$\mathcal{L}_V \sim (\bar{\nu}\gamma^\mu\nu)\left[\bar{q}\left(\gamma_\mu C_V^q + i\gamma_\mu\gamma_5 D_V^q\right)q\right]$$

$$\mathcal{L}_A \sim (\bar{\nu}\gamma^\mu\gamma_5\nu)\left[\bar{q}\left(\gamma_\mu\gamma_5 C_A^q + i\gamma_\mu D_A^q\right)q\right]$$

$$\mathcal{L}_T \sim (\bar{\nu}\sigma^{\mu\nu}\nu)\left[\bar{q}\left(\sigma_{\mu\nu} C_T^q + i\sigma_{\mu\nu}\gamma_5 D_T^q\right)q\right]$$

$\mathscr{P}_1 = \{C_S^q, D_P^q, C_V^q, D_A^q, C_T^q\}$ ✓

$\mathscr{P}_2 = \{C_P^q, D_S^q, C_A^q, D_V^q, D_T^q\}$ ✗

Constraints on $\mathscr{P}_2$ are weak!

Constraints from oscillations

Constraints from forward coherent scattering are only relevant for vector interactions

Matter potentials

Bergmann, Grossman, Nardi, 1999

$$\mathscr{L}_{\text{int}} \sim \sum_{a,f} \left(\bar{\nu}\Gamma^a \nu\right) \underbrace{V_a^f}_{\text{Matter potential}}$$

$$V_{S,P} \sim G_F n_f g_{S,P} \langle \frac{m_f}{E_f} \rangle$$

$$V_V \sim G_F n_f + \cdots$$

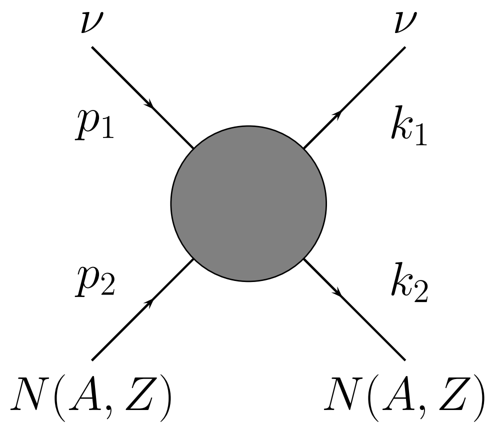
$$V_{A,T} \sim G_F n_f g_{A,T} \langle \frac{\sigma_f p_f}{E_f} \rangle + \cdots$$

Scalar & Pseudoscalar: Helicity suppressed

Axial & Tensor: Relevant only in polarized media

Only vector NGI are constrained by forward coherent scattering

Parameter space scenarios



Cross section parameterized in terms of nuclear currents: Scalar, Vector and Tensor

Lindner, Rodejohann, Xu, 2016

DAS, De Romeri, Rojas, 2018

$$\frac{d\sigma^a(q^2=0)}{dE_r} = \frac{G_F^2}{4\pi} m_{N_a} N_a^2 \left[\xi_S^2 \frac{E_r}{E_r^{\text{max}}} + \xi_V^2 \left(1 - \frac{E_r}{E_r^{\text{max}}} - \frac{E_r}{E_\nu}\right) + \xi_T^2 \left(1 - \frac{E_r}{2E_r^{\text{max}}} - \frac{E_r}{E_\nu}\right) - R\,\frac{E_r}{E_\nu}\right]$$

Scenarios

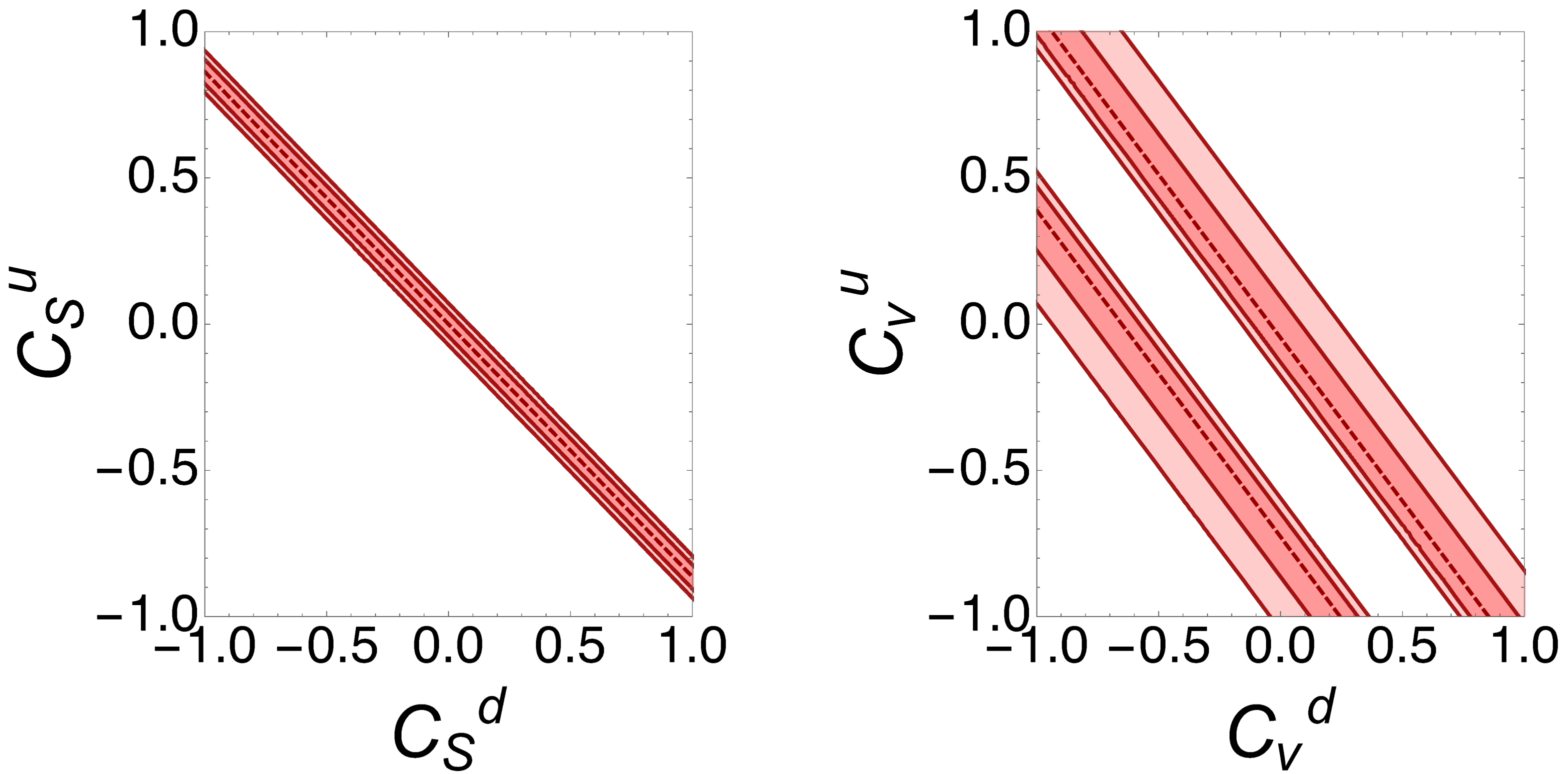
- Single parameter case: Only one nuclear current present at a time
- Two parameter case: Two nuclear currents are simultaneously present

One-parameter analysis

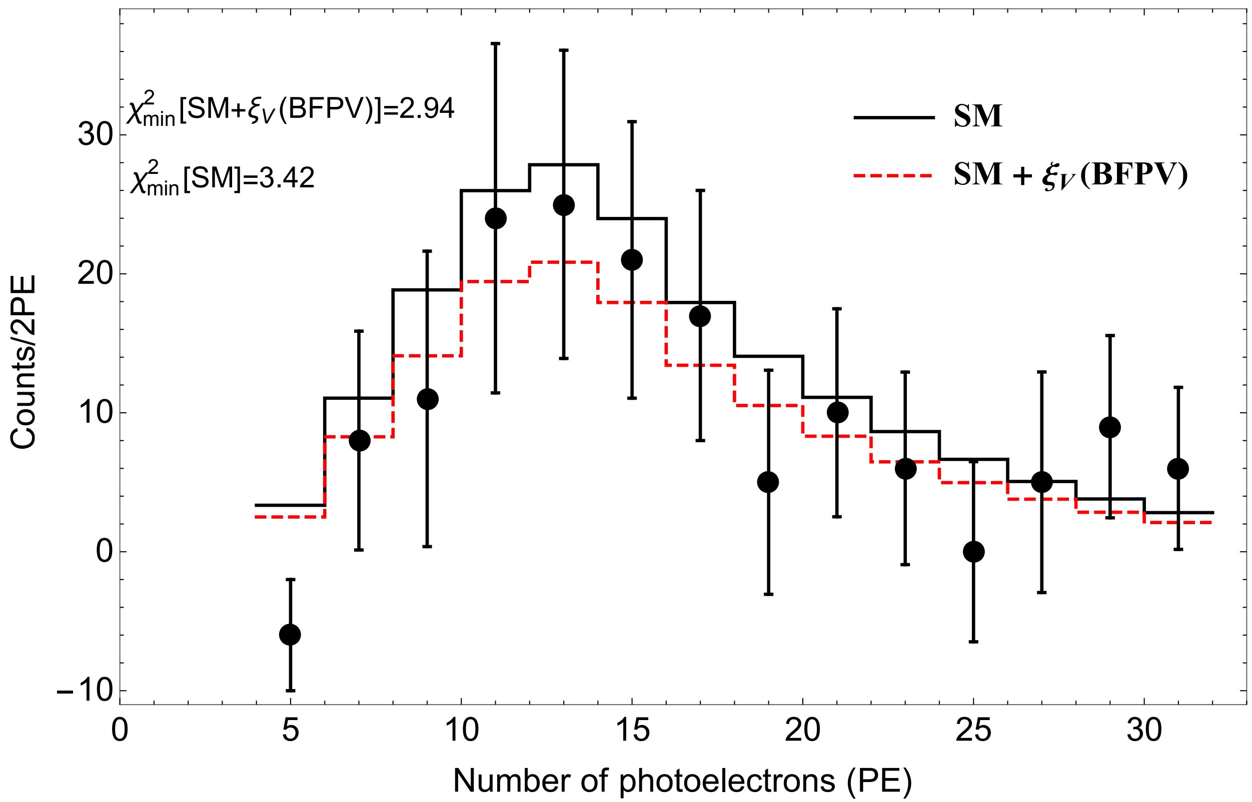
Param	**BFP value**	90% CL	99% CL
ξ_S	0	$[-0.62, 0.62]$	$[-1.065, 1.065]$
ξ_V	-0.113 -1.764	$[-0.324, 0.224]$ $[-2.102, -1.554]$	$[-0.436, 0.67]$ $[-2.545, -1.442]$
ξ_T	0	$[-0.591, 0.591]$	$[-1.071, 1.072]$

$$\xi_S^2 = \frac{C_S^2 + D_P^2}{N^2}$$

$$C_S = Z \sum_{q=u,d} C_S^{(q)} \frac{m_p}{m_q} f_{T_q}^p + (A-Z) \sum_{q=u,d} C_S^{(q)} \frac{m_n}{m_q} f_{T_q}^n$$



The presence of NGI can indeed improve the data fit... In particular for the vector NGI



If such trend persist with further data... Is there BSM physics hidden in CEνNS [??]

Summary

Résumé

- COHERENT data and forthcoming data from CONUS and e.g. ν-CLEUS will allow unraveling the presence of new physics
- Good understanding of the SM contribution including the axial piece, nuclear physics form factors...
- NGI are the most general set of effective interactions. Using current data we have derived constraints: **NGI can still be fairly large**
- If new interactions are present in the neutrino sector, forthcoming data might allow their discovery