COHERENT constraints on generalized neutrino-quark interactions

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Coherent Elastic Neutrino-Nucleus Scattering

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

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

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

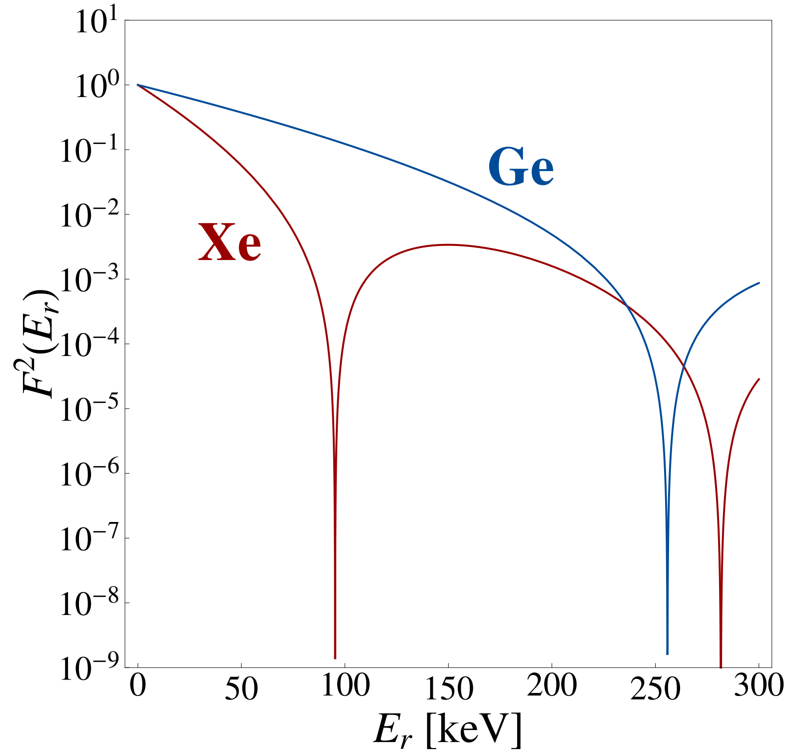
$$E_\nu \lesssim 100\ \text{MeV}$$

Freedman, 1974

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

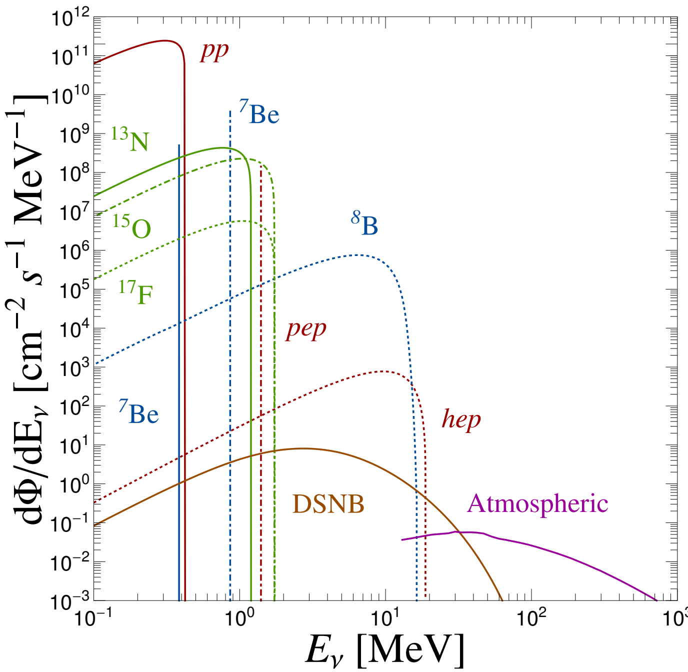
$$Q_{\text{SM}}^2 = [N - (1 - s_W^2) Z]^2 \simeq N^2$$

Helm, 1956

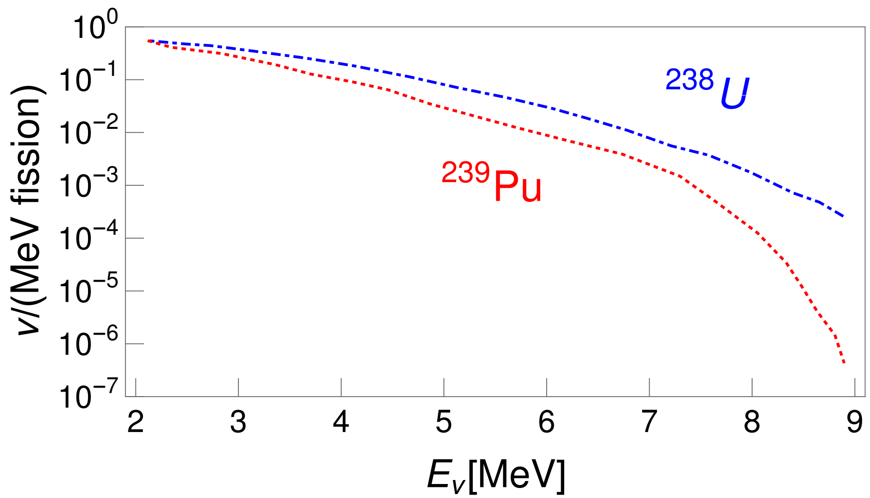


Relevant neutrino sources

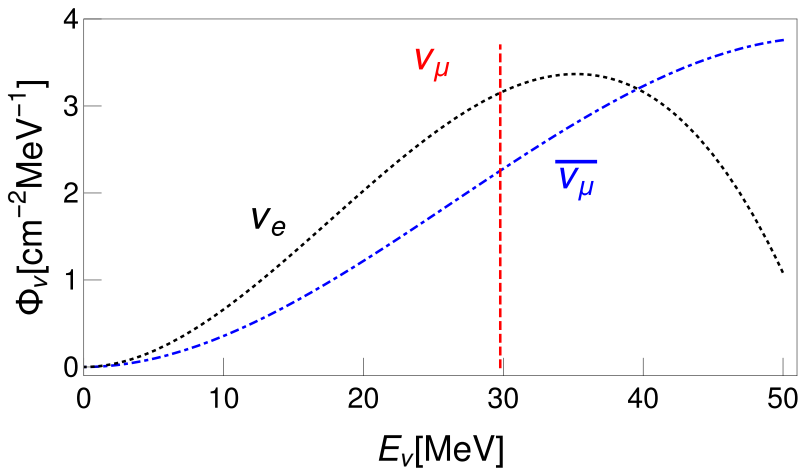
"Astrophysical" sources



Reactor Neutrinos



Fixed target



Solar+Atm: ν backgrounds DM detectors

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

Fixed target: COHERENT experiment

Talk by Grayson Rich

CEνNS observed by COHERENT more than 40 years after its prediction

Akimov et. al. 2017

COHERENT uses neutrinos produced in SNS

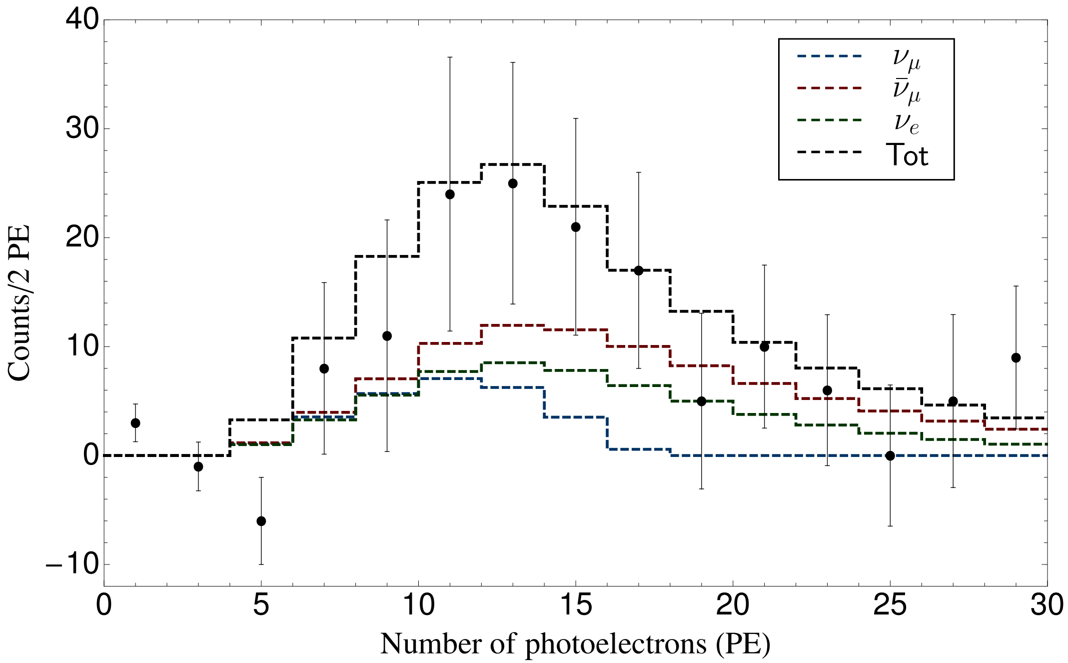
@ Oak Ridge National Laboratory in the collision $p-$Hg

$$\pi^+ \to \mu^+ + \nu_\mu$$

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

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

DAS, De Romeri, Rojas, 2018



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

There is still some room for NEW PHYSICS!

Physics potential

- Determination of SN neutrino properties through measurement of the neutrino DSNB or neutrino emission in a single SN explosion
- Study of nuclear properties such as: Nuclear radius, skin depth,neutron form factor, neutron radius **Talk by Yufeng Li**
- Measurement, study and test of the SM axial nuclear current
- Unlocking the possible presence of new physics in the form of: Heavy or light mediators, EM neutrino properties such as μ_ν, $\langle r_\nu \rangle$

CEνNS opens a window to a full

neutrino theoretical/phenomenological program

Sensitivity to new physics

The case of NSI

Talk by Danny Marfatia

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

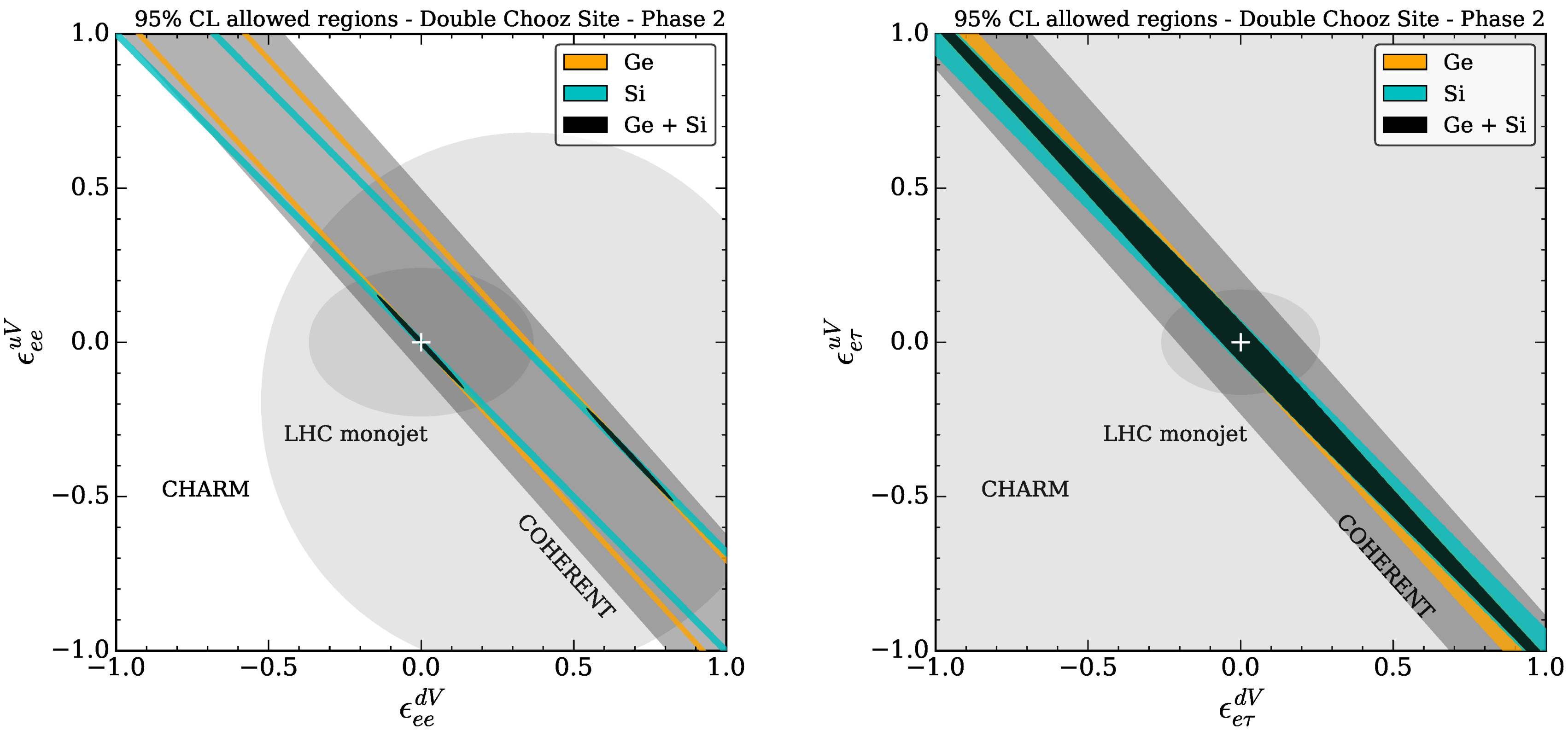
COHERENT data has been used to constraint NSI contributions to the CEνNS

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)

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

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

Diagonal and non-diagonal LS

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

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

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

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

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

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

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

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

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

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

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

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

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

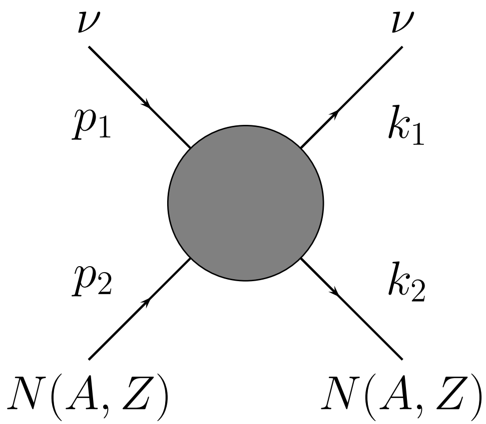
$$V_{A,T} \sim G_F n_f g_{A,T} \langle \frac{\sigma_f p_f}{E_f} \rangle + \cdots$$

Scalar & Pseudoscalar: Helicity suppressed

Axial & Tensor: Relevant only in polarized media

Constraints on NGI (apart from V) arise only from Scattering processes (order G_F^2 interactions)

Parameter space scenarios



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

Lidner, 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

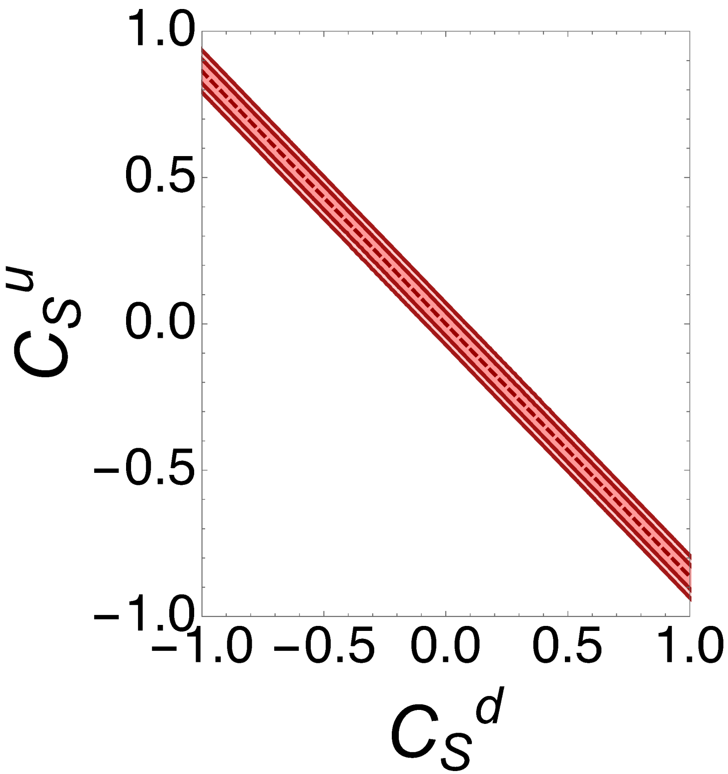
- Single parameter case: Only one nuclear current present at a time
- Two parameter case: Two nuclear currents are simultaneously present

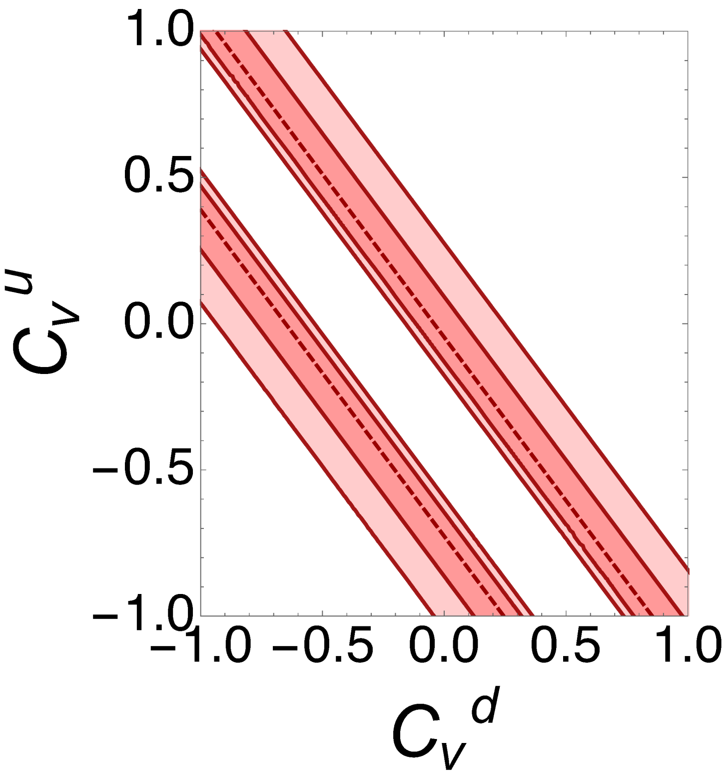
One-parameter analysis

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	$[-0.591, 0.591]$	$[-1.071, 1.072]$

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

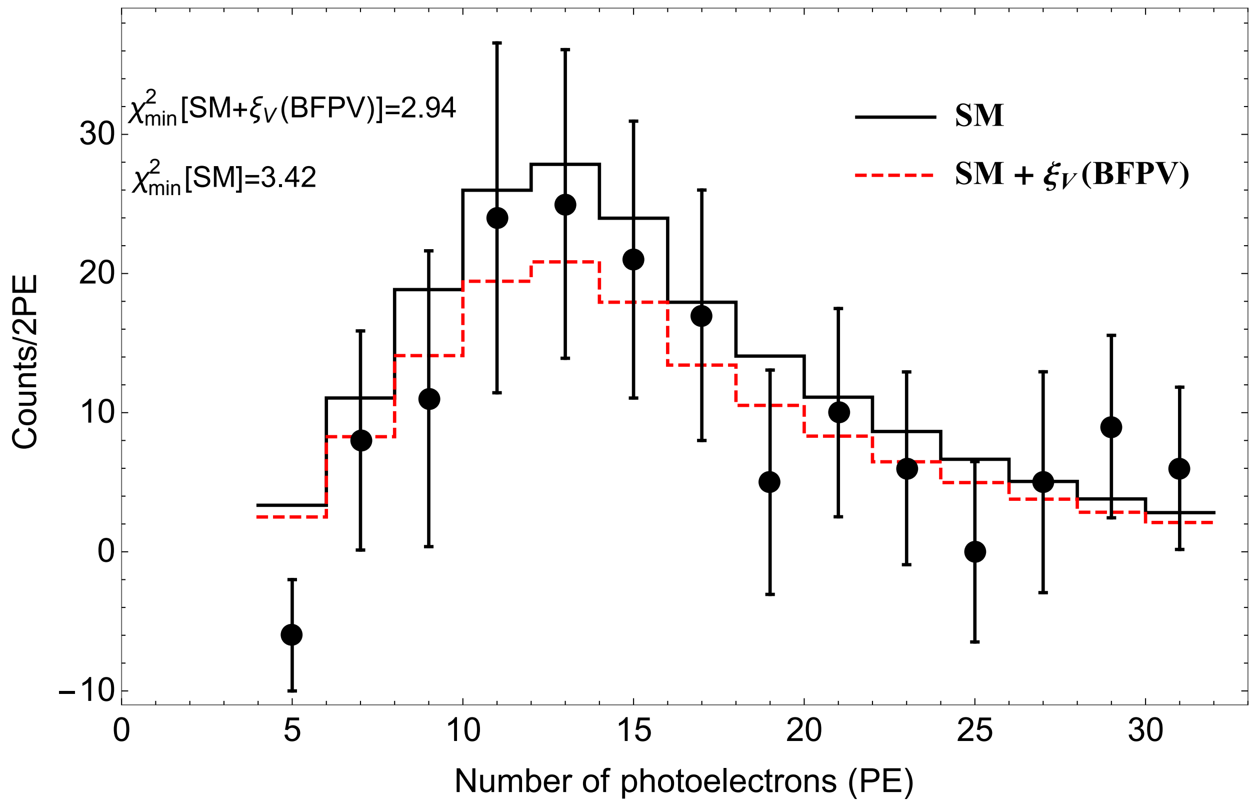
$$C_S = Z \sum_{q=u,d} C_S^{(q)} \frac{m_p}{m_q} f_{T_q}^p + (A-Z) \sum_{q=u,d} C_S^{(q)} \frac{m_n}{m_q} f_{T_q}^n$$





Improving data fit

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