NC Coherent Elastic ν-Nucleus Scattering (CEvNS): Current probes and ν-nuclear responses on conventional & exotic ν-physics"

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Επιχειρησιακό Πρόγραμμα
Ανάπτυξη Ανθρώπινου Δυναμικού, Εκπαίδευση και Διά Βίου Μάθηση

Outline

- Introduction
    - Important ν-sources and the role of ν-Nuclear responses in modern searches
- COHERENT experiment: First Observation of NC CEνNS events $\nu + (A, Z) \rightarrow \nu + (A, Z)$
    - Analysis and Interpretation with the Standard Model
- ν-nuclear responses on conventional processes
    - Phenomenological and Realistic Nuclear form factors, Neutron FF and Nuclear Radii
    - Nuclear Structure Calculations, QRPA, SM, DSM, MQPM, etc. (for NC, CC) for various ν-sources
- Connection of CEνNS to exotic Physics
    - WIMP-nucleus rates (neutrino floor)
    - NSIs: New mediators Z' and scalar ϕ. Electromagnetic neutrino properties
- Summary and Outlook

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Neutrino as key-role particle in Modern Physics searches

- Fundamental E-W-Is, Non-Standard (NSIs) with New mediators: ν-EM properties, ν-millicharge, Vectorial/Tensorial ν-quark NSIs
- Study of the deep sky: SN, Neutron stars, Black Hole Micro-quasars, AGN, etc.
- Neutrinos as irreducible background in rare event experiments, e.g. direct DM detection (neutrino floor)
- Strong constraints are extracted from a combined analysis of ν from various sources: π-DAR, reactor-ν, atmospheric-ν, solar-ν, SN-ν, DSNB, etc.
- In such processes the nucleus works as excellent micro-laboratory towards their investigation

- **Nuclear calculations are needed to provide reliable nuclear ingredients and support relevant EXPs**

Three interesting NC Coherent elastic Electro-Weak processes in nuclei

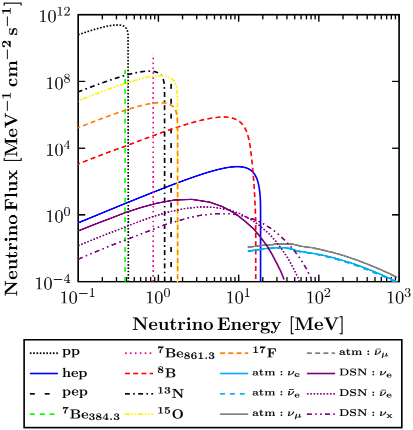
- There are three very interesting Neutral-Current Electro-Weak processes taking place in the presence of Nuclei
  - $\nu + (A, Z) \rightarrow \nu + (A, Z)$ (ν-Nucleus scattering)
  - $\chi + (A, Z) \rightarrow \chi + (A, Z)$ (Scattering CDM-candidate on Nuclei)
  - $\mu^- + (A, Z) \rightarrow e^- + (A, Z)$ (muon-to-electron conversion in Nuclei)
- The above three processes are dominated by the COHERENT Elastic channel
- The first two involve neutral particles
- The third involves charged particles
- For all of them the signal is a sharp coherent forward peak

Solar neutrinos

- Solar-ν are ν_e neutrinos produced in the Sun's interior ($0.1MeV \leq \varepsilon_\nu \leq 18$ MeV). They depend on the nuclear processes and the densities/temperatures in the Sun
- Dominant Solar-ν component the p-p channel ($\sim 86\%$ of Φ_{solar}), Borexino EXP. measured recently Φ_{solar} with uncertainty 1%
- The total Solar neutrino flux $\Phi_{solar} \sim 6.5 \times 10^{11}/cm^2/s$ hitting the Earth may appreciably limit the sensitivity of DM experiments
- Solar neutrinos produce a dominant background for direct CDM detection experiments (at low energies)

Solar neutrino, background in direct CDM detection

- Direct DM detection experiments are sensitive to ^{8}B and hep ν-sources (they cover the high-energy tail of Solar ν-spectrum)
- To explore the neutrino-floor one needs to extend the analysis to low ν-energies as:
- The pep neutrino line
- The ^{7}Be neutrino which gives two monochromatic beams: $E_\nu = 384.3$ keV, $E_\nu = 861.3$ keV
- The CNO cycle neutrinos appear as three continuous spectra (^{13}N, ^{15}O, and ^{17}F sources) with end point E_ν close to pep-ν



Atmospheric Neutrinos

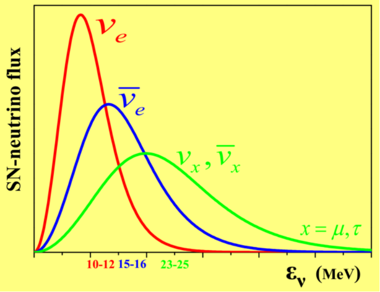
- Atmospheric-ν are decay products of ($\pi^{\pm}$, $K^{\pm}$, $\mu^{\pm}$, produced from the cosmic-ray-scattering in Earth's atmosphere
- The generated secondary particles decay to ν_e, $\tilde{\nu}_e$, ν_μ, $\tilde{\nu}_\mu$
- These neutrinos constitute significant background to DM searches for WIMP masses $\mu_\chi \geq 100$GeV.
- The direct detection DM experiments, are sensitive to the lowest energies atmospheric-ν ($E_\nu \preceq 100$ MeV)

Supernova Neutrinos

- According to predictions, the creation of the supernova neutrino-fluxes is very complicated process.
- A thermal spectrum was intuitively employed in earlier studies to describe the SN-ν energy distribution
- The analytic expressions used are: the two-parameter Fermi-Dirac, and the simpler two parameter Power-Law (PL) distribution
- Both parameterizations FD and PL yield similar energy spectra

SN-ν Energies

- 10-12 MeV, for ν_e
- 15-16 MeV, for $\tilde{\nu}_e$
- 23-25 MeV, for ν_x and $\tilde{\nu}_x$, with $x = \mu, \tau$



Diffuse Supernova Neutrino Background (DSNB)

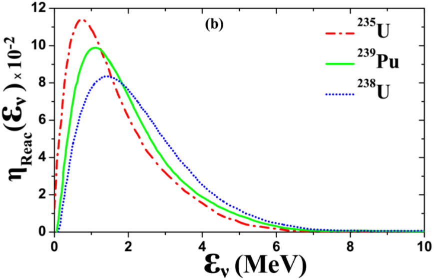
- The low-energy νs emitted from the total number of core collapse SN, is known as "Diffuse Supernova Neutrino Back-ground (DSNB)"
- These neutrinos create an important source of ν-background, for WIMP masses $\mu_\chi \approx 10 - 30$ GeV
- Despite the low flux of DSNB compared to Φ_{solar}, their ν-energies are higher than those of the Solar ν-spectrum.

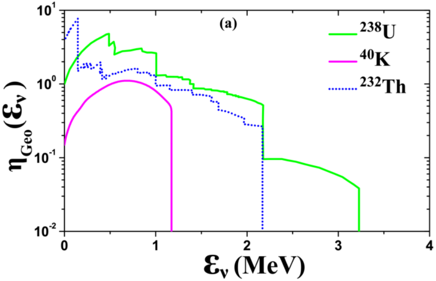
In our simulations we adopt FD and PL DSNB distributions as:

DSNB-ν Energies

- The peaks in the Fermi-Dirac or power-law type distribution correspond to energies:
- 3 MeV, for ν_e
- 5 MeV, for $\tilde{\nu}_e$
- 8 MeV, for ν_x and $\tilde{\nu}_x$, with $x = \mu, \tau$

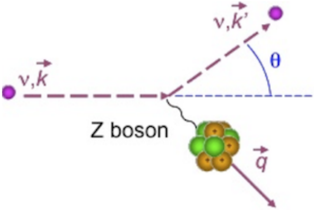
Reactor and Earth ν-sources





- Nuclear reactors provide $\widetilde{\nu}_e$ of $\Phi_{reac} \sim 10^{13}\, \widetilde{\nu}/cm^2 sec$ at $L \sim 10\ m$ from reactor core.
- The spectrum peaks at ($\sim$ 0.3 MeV) and extends up to $\sim$ 10 MeV
- Fuel composition: 62% ^{235}U, 30% ^{239}Pu and 8% ^{238}U
- Geo-neutrino flux is low, compared to that of other ν-sources producing, practically negligible, remaining irreducible background in DM Exps.

The Neutral Current (NC) ν-nucleus scattering



- Predicted 43 years before their first observation (August 2017)
- D.Z. Freedman. Phys.Rev.D 9(1974) 1389 NC scattering rate N^2

Nuclear Level Diagram

- In the SM description, Nuclear Form Factor and Nuclear Matrix Elements (NME) for the $|g.s.\rangle$ and all final states $|f\rangle$, are required
- Inelastic CC/NC Cross Section for Supernova
- Inelastic CC/NC Cross Section for Weak Physics, in general

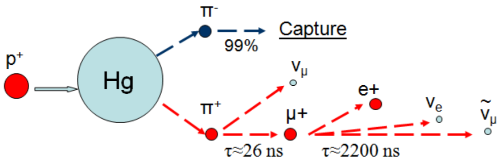
- Recently, models of Non-Standard Interactions of ν-quark can be tested through NC neutrino scattering
- Weak Mixing angle, Neutrino Magnetic Moment, Sterile Neutrino Oscillations

The Spallation Neutron Source at Oak Ridge

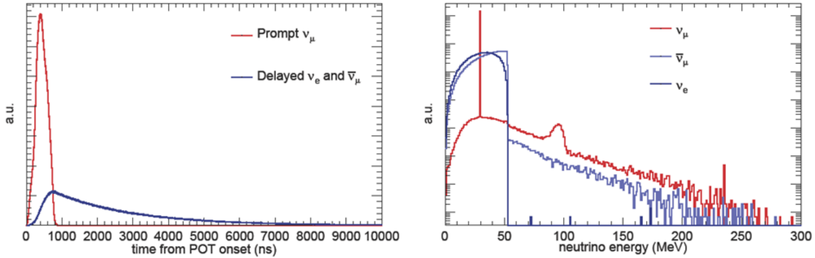
Spallation Neutron Source, Oak Ridge National Laboratory, TN

Neutrino Sources at SNS: π-DAR neutrinos

- Bunches of $E_p \sim 1$ GeV protons on the Hg target with 60 Hz frequency
- Total neutrino flux: $\Phi_\nu = 4.3 \times 10^7\ \nu s/cm^2/s$ at $L = 20$ m



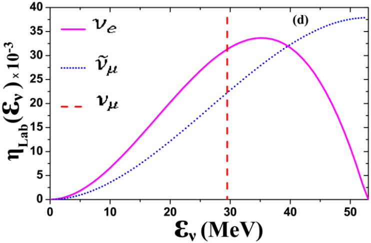
The ν-timing (left) and the ν-energy (right) suit well for CEνNS search



Sholberg, et al. ....

Advantages of π-Decay-At-Rest (π-DAR) ν_s at SNS

- Ideal Neutrino Energy $\rightarrow$ Coherence
- High Intensity, Ideal Beam Energy
- Complete Stopping: Point-like source
- Multiple Neutrino Flavors: ν_e, ν_μ, $\tilde{\nu}_\mu$
- Ideal Time Structure (Short Pulses)
- Prompt & delayed νs favor handling systematic errors



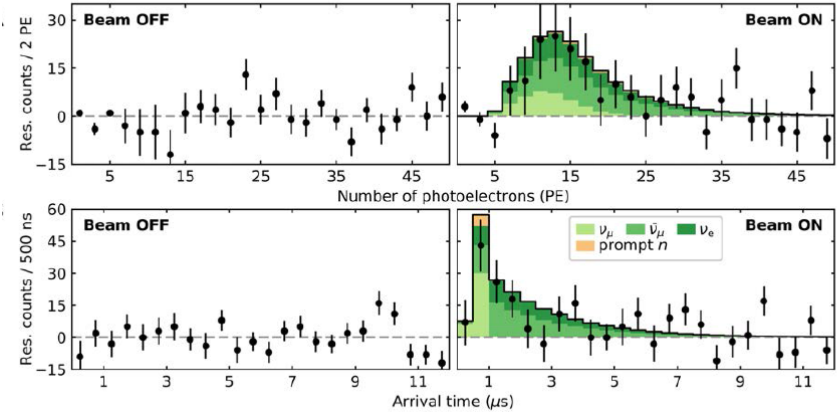
The energy-spectra of ν_e and $\tilde{\nu}_\mu$ are fitted by the distributions

$$\eta_{\nu_e}(\varepsilon_\nu) = 96\varepsilon_\nu^2\, M_\mu^{-4}\, (M_\mu - 2\varepsilon_\nu)\ ,$$

$$\eta_{\tilde{\nu}_\mu}(\varepsilon_\nu) = 16\varepsilon_\nu^2\, M_\mu^{-4}\, (3M_\mu - 4\varepsilon_\nu)\ ,$$

$M_\mu = 105.6$ MeV (muon rest mass). The maximum energy of ν_e and $\tilde{\nu}_\mu$ is $\varepsilon_\nu^{max} = 52.8 MeV = M_\mu/2$. $E_{\nu_\mu} = 29.8$ MeV

NC break-through observation: First CEvNS data (2017)



- **COHERENT** data on Na-doped CsI[Na] detector: m_{det}=14.57 kg
- Exposed to neutrinos from the π-DAR source SNS
- At a distance of $L = 19.3\ m$ (Short Base-Line ν-experiment)
- For a period of $t_{run} = 308.1\ d$ (live days)
- At 6.7 σ CL. Total number of events 136. $n_{\rm PE} = 1.17\frac{T_A}{(\rm keV)}$

The interpretation-analysis of CEνNS data

A good agreement with the Standard Model (SM) expectation was obtained (with the low-threshold sodium doped CsI[Na] scintillator)

- Phenomenological FF calculations (fit CEνNS data)
  - Klein-Nystrand (used by CEvNS Collaboration)
  - Helm-type
  - Symmetrized Fermi (Woods-Saxon)
- Realistic form factor calculations (fit CEνNS data)
  - The quasi-particle RPA (for even-even nuclei)
  - The deformed Shell Model (DSM)
- Realistic DSM fit better the CEvNS data compared to phenomenological FF

- CEvNS constitute best probe to investigate neutron nuclear FF
- CEvNS data encourage probes of physics within/beyond SM of EWIs
- **Nuclear Physics searches explore the potential of probing nuclear structure parameters (weak FFs) through CEvNS data**

Ejiri, Suhonen, Zuber, Phys.Rep. 797(2019)1-102 ,Fattoyev, et al., Phys.Rev.Lett. 120(2018)172702 ,

Papoulias,Kosmas,Sahu,Kota,Hota, Phys.Let.B 800(2020)135133

Standard Model CEνNS Cross sections

The SM CEνNS differential cross section with respect to the scattering angle θ reads

$$\frac{d\sigma_{\mathrm{SM},\nu_\alpha}}{d\cos\theta} = \frac{G_F^2}{2\pi} E_\nu^2 (1+\cos\theta) \left| \langle g.s. || \mathcal{M}_{V,\nu_\alpha}^{\mathrm{SM}} || g.s. \rangle \right|^2$$

- E_ν: incident neutrino energy
- $Q^2 = 4E_\nu^2 \sin^2 \frac{\theta}{2}$: 4-momentum transfer (from kinematics: $-q^2 \equiv Q^2 = -\omega^2 + \mathrm{q}^2 > 0$)
- $|g.s.\rangle = |J^\pi\rangle \equiv |0^+\rangle$: the nuclear ground state (for even-even nuclei is explicitly constructed by solving the BCS Eqs.)
- $g_V^{p(n)}$: polar-vector coupling of proton (neutron) to the Z boson

- The SM nuclear matrix element is given in terms of the electromagnetic proton(neutron) nuclear form factors $F_{Z(N)}(Q^2)$ (CVC theory)
- For $g.s. \rightarrow g.s.$ transitions (i.e. $|0^+\rangle \rightarrow |0^+\rangle$) only the Coulomb operator contributes

$$\left| \mathcal{M}_{V,\nu_\alpha}^{\mathrm{SM}} \right|^2 \equiv \left| \langle g.s. || \hat{\mathcal{M}}_{00} || g.s. \rangle \right|^2 = \left[g_V^p Z F_Z(Q^2) + g_V^n N F_N(Q^2) \right]^2$$

D.K. Papoulias and T.S. Kosmas, Phys.Lett. **B728** (2014) 482

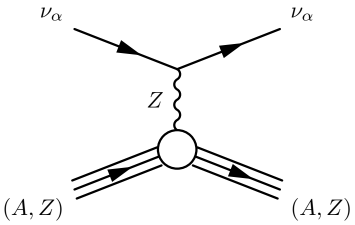
Simulation in terms of T_A of the COHERENT data

- **To simulate COHERENT data, we consider total cross section**
- This is the sum of the individual (atomic) cross sections by taking also into account the stoichiometric ratio η of the corresponding atom.
- For a neutrino flavor α and isotope x the given CEνNS events read

$$N_{\rm theor} = \sum_{\nu_\alpha} \sum_{x={\rm Cs,I}} \mathcal{F}_x \int_{E_\nu^{\rm min}}^{E_\nu^{\rm max}} \lambda_{\nu_\alpha}(E_\nu) dE_\nu \times \int_{T_A^{\rm min}}^{T_A^{\rm max}} \mathcal{A}(T_A) \frac{d\sigma_x}{dT_A}(E_\nu, T_A) dT_A \,,$$

$$\mathcal{F}_x = t_{\rm run} N_{\rm targ}^x \Phi_\nu$$

$t_{\rm run}$ denotes the time exposed to the ν-beam. $N_{\rm targ}^x$ is the number of target nuclei (in Avogadro's number N_A)



The beam neutrino flux and other parameters

- The neutrino flux is $\Phi_\nu = r\mathcal{N}_{\rm POT}/4\pi L^2$, with $r = 0.08$ representing the number of neutrinos per flavor produced for each proton on target (POT), where
- $\mathcal{N}_{\rm POT} = N_{\rm POT}/t_{\rm run}$ with $N_{\rm POT} = 1.76 \times 10^{23}$.
- Our calculations consider the recoil-energy signal of COHERENT data
- The flavor components $\nu_\alpha = \{\nu_e, \nu_\mu, \bar{\nu}_\mu\}$ of the SNS ν-spectrum including the monochromatic $E_{\nu_\mu} = 29.9$ MeV prompt beam from π-DAR, are denoted as $\lambda_{\nu_\alpha}(E_\nu)$ (or as $\eta_{\nu_\alpha}(E_\nu)$)
- For each isotope $x = \mathrm{Cs}, \mathrm{I}$, the number of target nuclei is expressed in terms of Avogadro's number N_A and the detector mass

$$N_{\rm targ}^x = \frac{m_{\rm det}\eta_x}{\sum_x A_x \eta_x} N_A$$

Contributions to event rate from the sodium dopant are of the order 10^{-5}–10^{-4} and can be safely ignored

Translation of recoil-energy to photoelectrons (PEs)

- The CEνNS signal at COHERENT experiment was based on photoelectron (PE) measurements
- To translate the nuclear recoil energy in terms of the number of PE, n_{PE}, we adopt the relation

$$n_{\mathrm{PE}} = 1.17 \frac{T_A}{(\mathrm{keV})}$$

The detector efficiency $\mathcal{A}(x)$ depends on the photoelectron number x as

$$\mathcal{A}(x) = \frac{k_1}{1 + e^{-k_2(x - x_0)}} \Theta(x) \,.$$

$$\mathrm{Heavisidefunction:} \qquad \Theta(x) = \begin{cases} 0 & x < 5 \\ 0.5 & 5 \leq x < 6 \\ 1 & x \geq 6 \,. \end{cases}$$

The parameters' values are $k_1 = 0.6655$, $k_2 = 0.4942$, $x_0 = 10.8507$.

Standard Model Analysis of the COHERENT data

- **SM differential cross section**

$$\frac{d\sigma_{\rm SM}}{dT_N}(E_\nu, T_N) = \frac{G_F^2 M}{\pi}\left[(\mathcal{Q}_W^V)^2\left(1-\frac{MT_N}{2E_\nu^2}\right) + (\mathcal{Q}_W^A)^2\left(1+\frac{MT_N}{2E_\nu^2}\right)\right]F^2(T_N)\,,$$

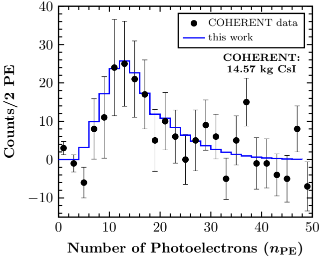
- **SM vector/axial vector couplings**

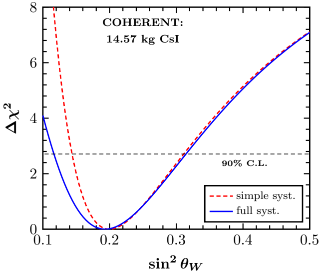
$$\mathcal{Q}_W^V = \left[g_p^V Z + g_n^V N\right]\,,$$
$$\mathcal{Q}_W^A = \left[g_p^A (Z_+ - Z_-) + g_n^A (N_+ - N_-)\right]\,,$$

- **single-bin counting problem (flux, quenching factor, and acceptance uncertainties are included)**

$$\chi^2(s_W^2) = \min_{\xi,\zeta}\left[\frac{\left(N_{\rm meas} - N_{\nu_\alpha}^{\rm SM}(s_W^2)[1+\xi] - B_{0n}[1+\zeta]\right)^2}{\sigma_{\rm stat}^2} + \left(\frac{\xi}{\sigma_\xi}\right)^2 + \left(\frac{\zeta}{\sigma_\zeta}\right)^2\right]\,,$$

- **search between $6 \leq n_{\rm PE} \leq 30$**





Papoulias and Kosmas, Phys.Rev. **D97** (2018) 033003

Cañas et al., Phys.Lett. B784 (2018) 159-162

Evaluation of the form factors (Klein-Nystrand)

Follows from the convolution of a Yukawa potential with range $a_k = 0.7$ fm over a Woods-Saxon distribution, approximated as a hard sphere with radius R_A.

$$F_{\mathrm{KN}} = 3\frac{j_1(QR_A)}{QR_A}\left[1 + (Qa_k)^2\right]^{-1}$$

The rms radius is: $\langle R^2 \rangle_{\mathrm{KN}} = 3/5 R_A^2 + 6a_k^2$

S. Klein and J. Nystrand, Phys.Rev. C60 (1999) 014903

Phenomenological FFs: Helm and Symmetrized Fermi

This is a two-parameter phenomenological form factor with a radius parameter R_0, the cut-off of the corresponding uniform charge density) and a surface thickness s parameter given by

$$F_{\text{Helm}}(Q^2) = 3\frac{j_1(QR_0)}{QR_0}\, e^{-(Qs)^2/2} \tag{1}$$

The first two moments

$$\langle R_n^2 \rangle = \frac{3}{5}R_0^2 + 3s^2, \quad \langle R_n^4 \rangle \quad = \frac{3}{7}R_0^4 + 6R_0^2 s^2 + 15 s^4$$

- $j_1(x)$ is the known first-order Spherical-Bessel function
- box or diffraction radius R_0 (interior density)
- $s = 0.9$ fm: surface thickness of the nucleus from spectroscopy data (Gaussian fallof).

The Symmetrized Fermi (Woods-Saxon) charge density distribution, provides the two parameter form factor with parameters (c, a)

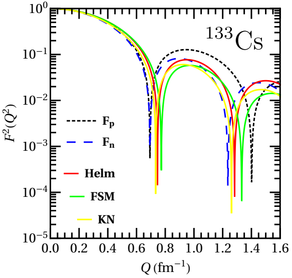
$$F_{\text{SF}}\left(Q^2\right) = \frac{3}{Qc\left[(Qc)^2 + (\pi Qa)^2\right]}\left[\frac{\pi Qa}{\sinh(\pi Qa)}\right]\left[\frac{\pi Qa\sin(Qc)}{\tanh(\pi Qa)} - Qc\cos(Qc)\right],$$

The first two moments

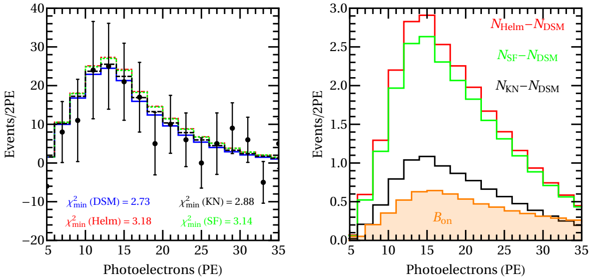
$$\langle R_n^2 \rangle = \frac{3}{5}c^2 + \frac{7}{5}(\pi a)^2, \quad \langle R_n^4 \rangle \quad = \frac{3}{7}c^4 + \frac{18}{7}(\pi a)^2 c^2 + \frac{31}{7}(\pi a)^4$$

c: half-density radius $\qquad$ a fm: diffuseness

Impact of form factor on CEνNS: COHERENT exp.



Papoulias et al. arXiv:1903.03722



Beyond the SM Analysis of COHERENT data: EM properties

- **Neutrino magnetic moment contrbution**

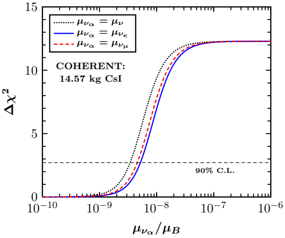
$$\left(\frac{d\sigma}{dT_N}\right)_{\mathrm{SM+EM}} = \mathcal{G}_{\mathrm{EM}}(E_\nu, T_N)\frac{d\sigma_{\mathrm{SM}}}{dT_N} \,,$$

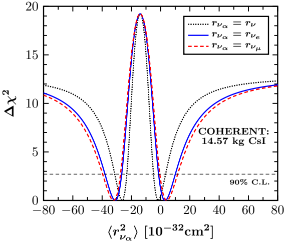
$$\mathcal{G}_{\mathrm{EM}} = 1 + \frac{1}{G_F^2 M}\left(\frac{\mathcal{Q}_{\mathrm{EM}}}{\mathcal{Q}_W^V}\right)^2 \frac{\frac{1-T_N/E_\nu}{T_N}}{1-\frac{MT_N}{2E_\nu^2}} \,.$$

- **EM charge:** $\mathcal{Q}_{\mathrm{EM}} = \frac{\pi a_{\mathrm{EM}} \mu_{\nu_\alpha}}{m_e} Z$
  Vogel et al. Phys.Rev. D39 (1989) 3378

- **Neutrino charge radius**
- **redefinition of the weak mixing angle**

$$\sin^2\theta_W \to \sin^2\overline{\theta_W} + \frac{\sqrt{2}\pi a_{\mathrm{EM}}}{3G_F}\langle r^2_{\nu_\alpha}\rangle \,.$$





Vector Z' mediator of NSI in COHERENT data analysis

- **Vector Z' mediator Lagrangian**

$$\mathcal{L}_{\rm vec} = Z'_\mu \left(g_{Z'}^{qV} \bar{q}\gamma^\mu q + g_{Z'}^{\nu V} \bar{\nu}_L \gamma^\mu \nu_L \right) + \frac{1}{2} M_{Z'}^2 Z'_\mu Z'^\mu$$

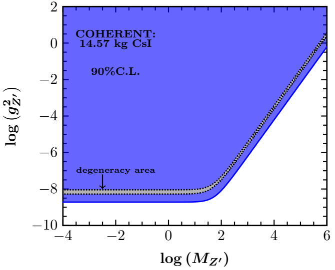
- **Z' contribution to CEνNS cross section**

$$\left(\frac{d\sigma}{dT_N} \right)_{\rm SM+Z'} = \mathcal{G}_{Z'}^2(T_N) \frac{d\sigma_{\rm SM}}{dT_N} \,,$$

$$\mathcal{G}_{Z'} = 1 - \frac{1}{2\sqrt{2}G_F} \frac{\mathcal{Q}_{Z'}}{\mathcal{Q}_W^V} \frac{g_{Z'}^{\nu V}}{2MT_N + M_{Z'}^2} \,,$$

- **Z' charge:** $\mathcal{Q}_{Z'} = \left(2g_{Z'}^{uV} + g_{Z'}^{dV} \right) Z + \left(g_{Z'}^{uV} + 2g_{Z'}^{dV} \right) N$

for NSI in CEνNS see Refs. below



Papoulias and Kosmas, Phys.Rev. **D97**(2018)033003 Liao et al. PLB 775 (2017) Abdullah et al. PRD98 (2018) 015005

Scalar ϕ mediator of NSI in COHERENT data Analysis

- **Interaction Lagrangian of Scalar ϕ mediator**

$$\mathcal{L}_{\rm sc} = \phi\left(g_\phi^{qS}\bar{q}q + g_\phi^{\nu S}\bar{\nu}_R\nu_L + \text{H.c.}\right) - \frac{1}{2}M_\phi^2\phi^2$$

- **ϕ contribution to CEνNS cross section**

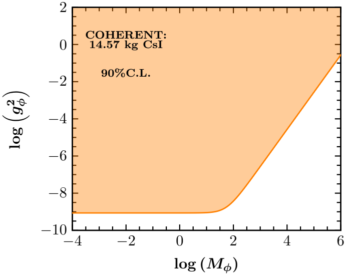
$$\left(\frac{d\sigma}{dT_N}\right)_{\rm scal} = \frac{G_F^2 M^2}{4\pi}\frac{\mathcal{G}_\phi^2 M_\phi^4 T_N}{E_\nu^2\left(2MT_N + M_\phi^2\right)^2}F^2(T_N)$$

- **Scalar Coupling**

$$\mathcal{G}_\phi = \frac{g_\phi^{\nu S}\mathcal{Q}_\phi}{G_F M_\phi^2}$$

- **scalar charge:**

$$\mathcal{Q}_\phi = \sum_{\mathcal{N},q} g_\phi^{qS}\frac{m_\mathcal{N}}{m_q}f_{T,q}^{(\mathcal{N})}$$



Dent et al. PRD 96 (2017) 095007

WIMP-nucleus cross section

Weakly interacting massive particles (WIMPs) are among the most promising non-baryonic cold DM candidates

- Event rates for WIMP-N scattering, expected to be detected in ton-scale rare-event detectors, are required
- There is a close connection between DM and NC ν-Nucleus scattering experiments (low threshold, high sensitivity)
- Experiments as DarkSide, DEAP-3600, CDEX, SuperCDMS, LUX, XENON1T, DARWIN, PandaX-II, are looking for tiny WIMP signals
- The most appealing WIMP: Lightest Supersymmetric Particle (LSP), expected to be neutral, stable, interacting very weakly with matter
- Among the most popular detector nuclei, for both WIMP-nucleus and CEvNS searches are the odd-A isotopes ^{127}I, ^{133}Cs, and ^{133}Xe

Up to now the Axion Dark Matter Experiment (ADMX), at Washington Univ., reported "the first experiment achieved the sensitivity to hunt for DM axions"

WIMP-nucleus cross section

- Cross section in laboratory frame

$$\frac{d\sigma(u,\upsilon)}{du} = \frac{1}{2}\sigma_0 \left(\frac{1}{m_p b}\right)^2 \frac{c^2}{\upsilon^2}\frac{d\sigma_A(u)}{du}\,,$$

$$u = \frac{1}{2}q^2 b^2, \quad \text{(dimensionless parameter)}$$

- spin (axial current) & scalar contributions

$$\begin{aligned}\frac{d\sigma_A}{du} &= \left[f_A^0 \Omega_0(0)\right]^2 F_{00}(u) \\ &+ 2 f_A^0 f_A^1 \Omega_0(0)\Omega_1(0) F_{01}(u) \\ &+ \left[f_A^1 \Omega_1(0)\right]^2 F_{11}(u) + \mathcal{M}^2(u)\,.\end{aligned}$$

- coherent contribution

$$\mathcal{M}^2(u) = \left(f_S^0\left[Z F_Z(u) + N F_N(u)\right] + f_S^1\left[Z F_Z(u) - N F_N(u)\right]\right)^2\,.$$

- model dependent parameters

f_A^0, f_A^1 for the isoscalar and isovector parts of the axial-vector current
f_S^0, f_S^1 for the isoscalar and isovector parts of the scalar current

Differential WIMP-nucleus event rate

- differential WIMP-nucleus event rate

$$\frac{dR(u,\upsilon)}{dq^2} = N_t \phi \frac{d\sigma}{dq^2} f(\upsilon)\, d^3\upsilon$$

  - $\phi = \frac{\rho_0 \upsilon 1}{m_\chi}$
  - ρ_0 the local WIMP density

Folding with Maxwell-Boltzmann WIMP's velocity distribution

- $f(\upsilon)$: distribution of WIMP velocity (Maxwell-Boltzmann)
  for consistency with the LSP

- WIMP-nucleus rate

$$\langle R \rangle = (f_A^0)^2 D_1 + 2 f_A^0 f_A^1 D_2 + (f_A^1)^2 D_3 + A^2 \left(f_S^0 - f_S^1 \frac{A-2Z}{A} \right)^2 |F(u)|^2 D_4 \,.$$

with

$$D_i = \int_{-1}^{1} d\xi \int_{\psi_{\rm min}}^{\psi_{\rm max}} d\psi \int_{u_{\rm min}}^{u_{\rm max}} G(\psi,\xi) X_i \, du \,,$$

and

$$X_1 = [\Omega_0(0)]^2 F_{00}(u) \,, \qquad X_2 = \Omega_0(0)\Omega_1(0) F_{01}(u) \,,$$
$$X_3 = [\Omega_1(0)]^2 F_{11}(u) \,, \qquad X_4 = |F(u)|^2 \,.$$

D.K. Papoulias et al., Adv. Adv.High Energy Phys. 2018 (2018) 6031362

Expected neutrino-floor on Ga, Ge, As, I

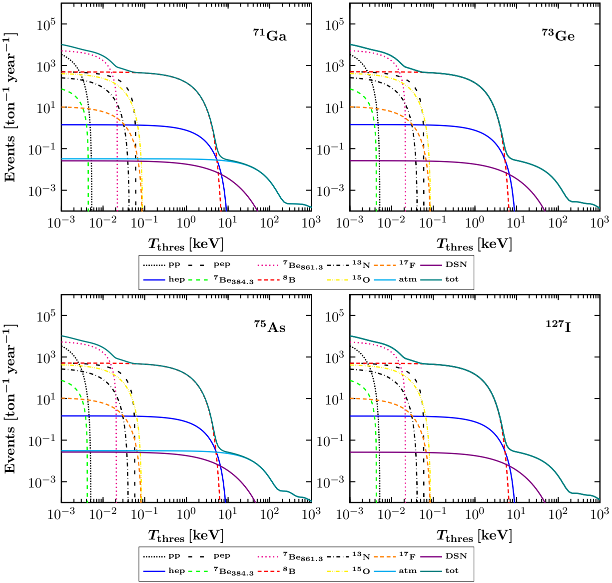
- We evaluated the expected event rates for the chosen nuclei assuming elastic WIMP scattering for WIMP mass $m_\chi = 110$ GeV, by adopting known nucleonic-current parameters. f_j^k.
- There is a strong dependence of the event rate on the studied isotope.
- Among the four studied nuclei, the larger event rate found for ^{71}Ga detector
- For each component of the Solar, Atmospheric, and DSNB neutrino distributions, we calculate (for all the above detector media) the expected neutrino-floor due to CEvNS
- We neglect possible recoil events arising from Geoneutrinos (we expect them to be at least one order of magnitude less than the above ν-sources
- For neutrino-floor, we do not consider neutrino oscillations (we assume CEvNS to be flavour blind process in the SM)

Expected background events due to CEvNS on Ga, Ge, As, I detectors

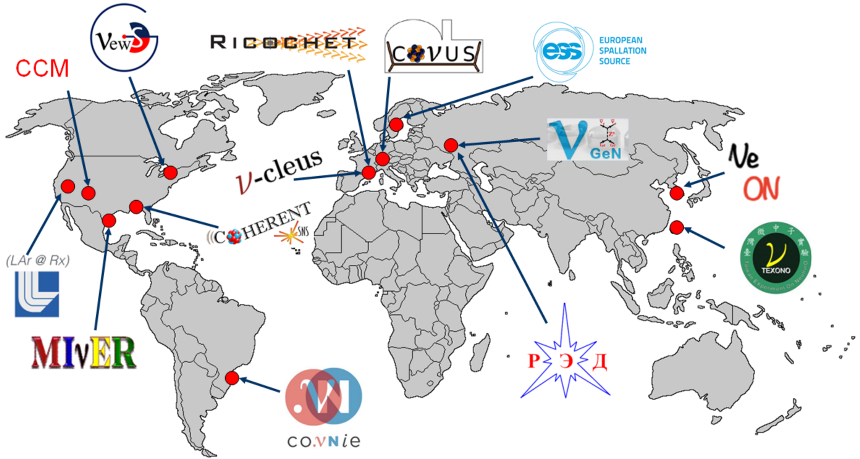
The number of expected background events due to CEvNS for each component of the Solar, Atmospheric, and DSNB neutrino fluxes is illustrated in the figure.

- At low energies the neutrino background is dominated by the Solar neutrino spectrum with dominant components the hep and ^{8}B neutrino sources
- The results imply that future multi-ton scale detectors with sub-keV sensitivities may be also sensitive to ^{7}Be and pp neutrinos.
- Such sensitivities will be further limited due to the quenching effect of the nuclear recoil spectrum (it is not taken into account in this study)
- We mention that neutrino-induced and WIMP-nucleus scattering processes provide similar recoil spectra (the recoil spectrum of ^{8}B neutrinos may mimic that of a WIMP with m_χ6 GeV (or 100 MeV).

The number of expected background events CEνNS rates



NC ν-Nucleus Scattering Experiments around the World



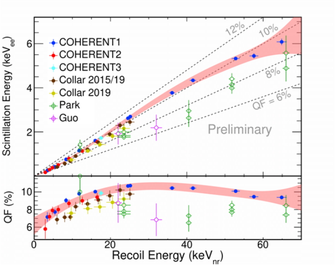
Ongoing/planned/designed NC ν-Nucleus Experiments in the World

(i) CONUS, CONNIE, MINER, NU-CLEUS, Ricochet, vGEN, and TEXONO experiments, use ^{73}Ge as detector

(ii) RED100 experiment will use ^{133}Xe isotope as detector

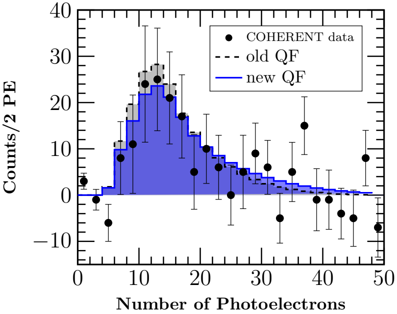
Improved fits through the new Quenching Factor results

- An important quantity in CEvNS measurements is the known as Quenching Factor (QF)
- For QF, an improved value came out recently (see below)



D.K. Papoulias, PRD (2020)

- By introducing the new Quenching Factor in the previous calculations new interesting fits are obtained as



A. Konovalov: https://indico.cern.ch/event/943069/"

Summary and Outlook

- We evaluated realistic cross sections and predicted expected signals for NC ν-processes (within the SM and exotic ones)
- Detailed studies for nuclear systems throughout the periodic table (for several ν-sources) are required for promising detectors (with low-threshold and high sensitivity) for future CEνNS and direct DM detection experiments
- The neutrino floor constitutes an irreducible background in direct DM detection experiments
- From our results we conclude that, for recoil energies $T_A \geq 10$ keV, Atmospheric neutrinos dominate the neutrino background event rates (from the DSNB spectrum a tiny contribution is coming)
- Advanced nuclear physics methods may enable the accurate determination of the neutrino floor in various DM searches and other nuclear structure quantities (weak neutron form factor, rms radius, etc)
- Study of contributions due to new physics interactions (NSIs, new light mediators as Z', ϕ, etc.) improve the fits to CEνNS observations

Thank you for your attention !