Neutrinos as a probe for new physics

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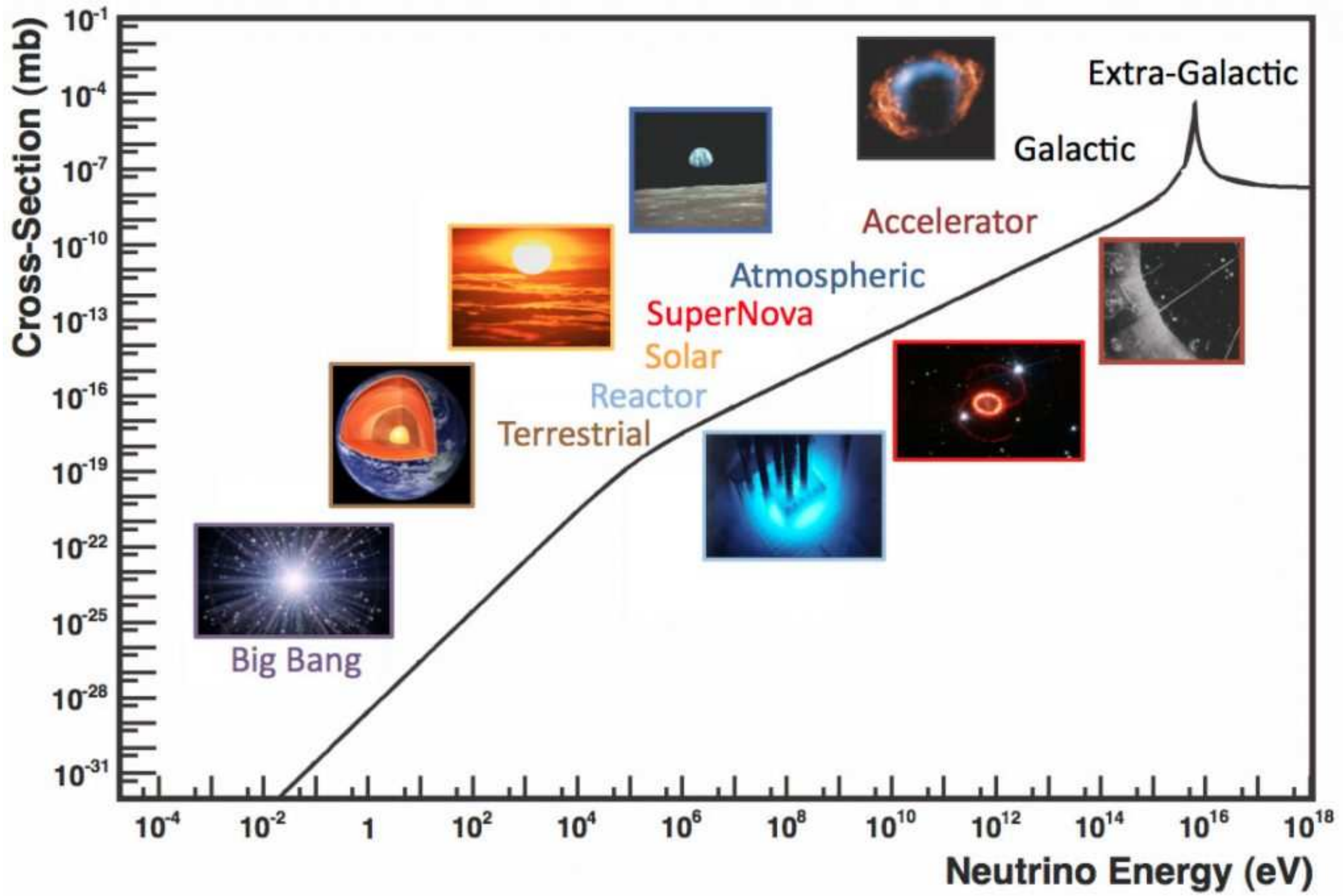
Introduction/motivation

Neutrinos as a probe

Depending on the production mechanism $E_\nu \sim 10^{-2} - 10^{18}$ eV and

$\sigma_\nu \sim 10^{-58} - 10^{-28}$ cm^2 ... Hard to think of any other particle with such characteristics



CEνNS

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

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

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

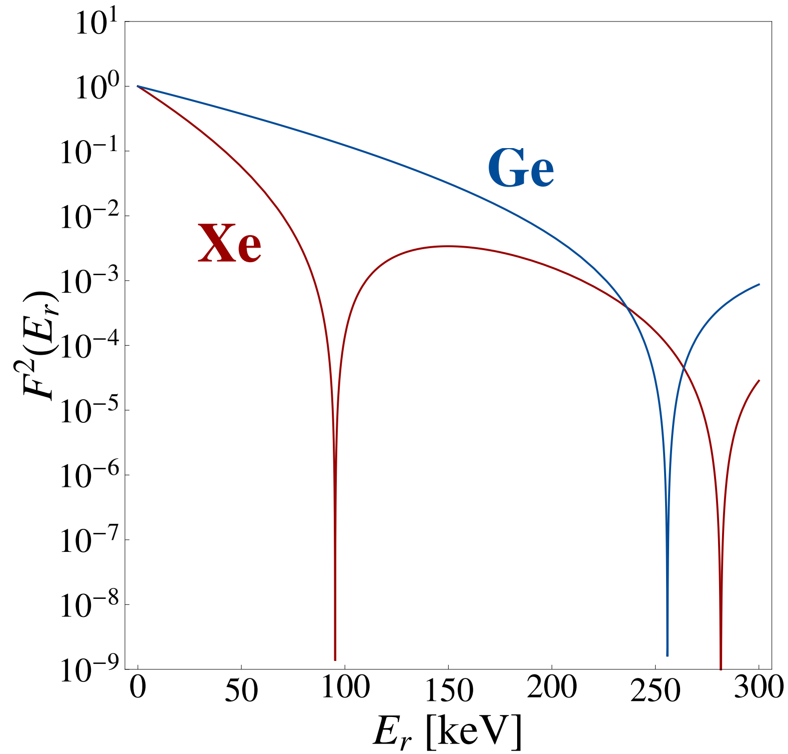
$$E_\nu \lesssim 100\ \text{MeV}$$

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



CEνNS observed by COHERENT more than 40 years after its prediction

Akimov et. al. 2017

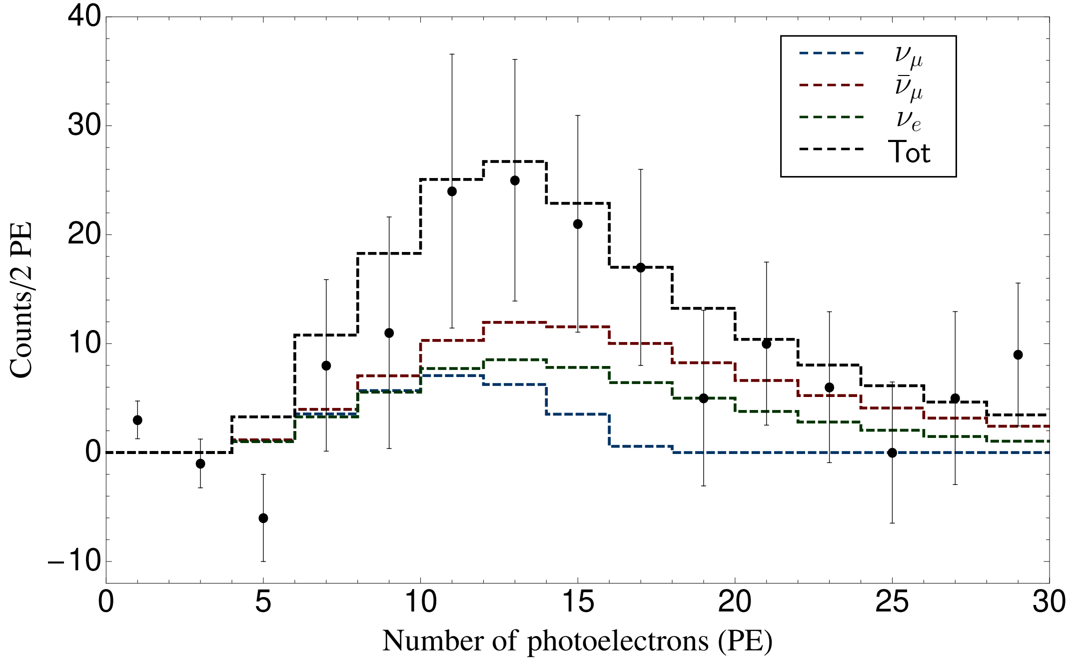
COHERENT uses neutrinos produced at the SNS

@ 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



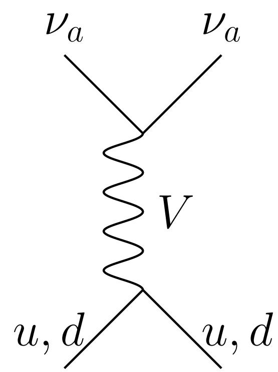
$$n_{\text{PE}} = 1.17\,(E_R/\text{keV})$$

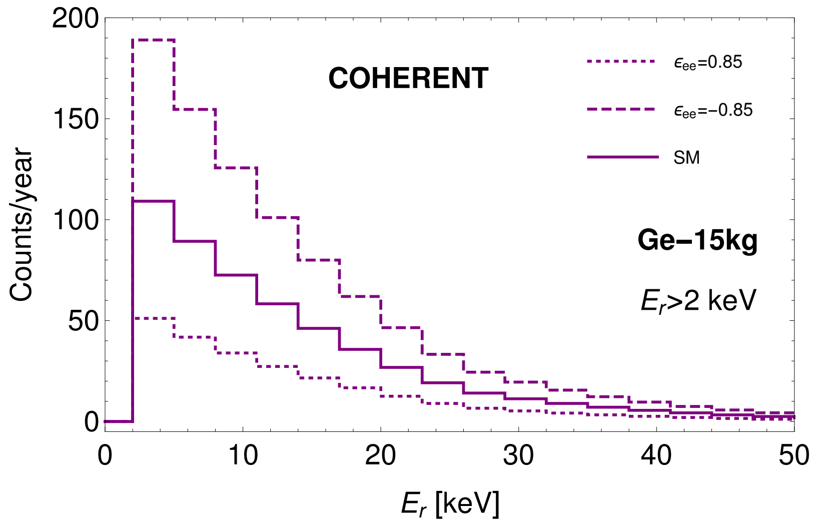
Recently measured in LAr (CENNS-10)

2003.10630

Vector interactions: Light versus heavy

Each scenario comes along with distinctive features signal degeneracies are expected!



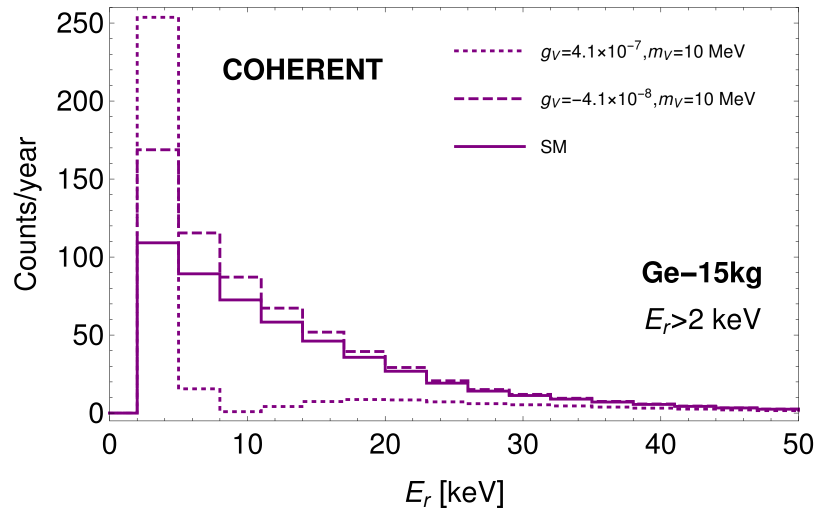


Effective limit

Global enhancements

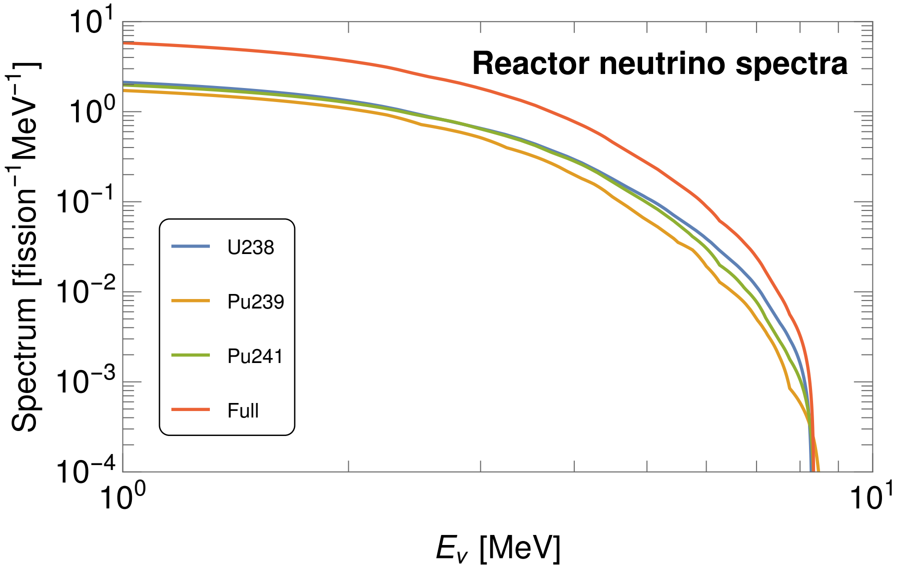
Light limit

Spectral distortions

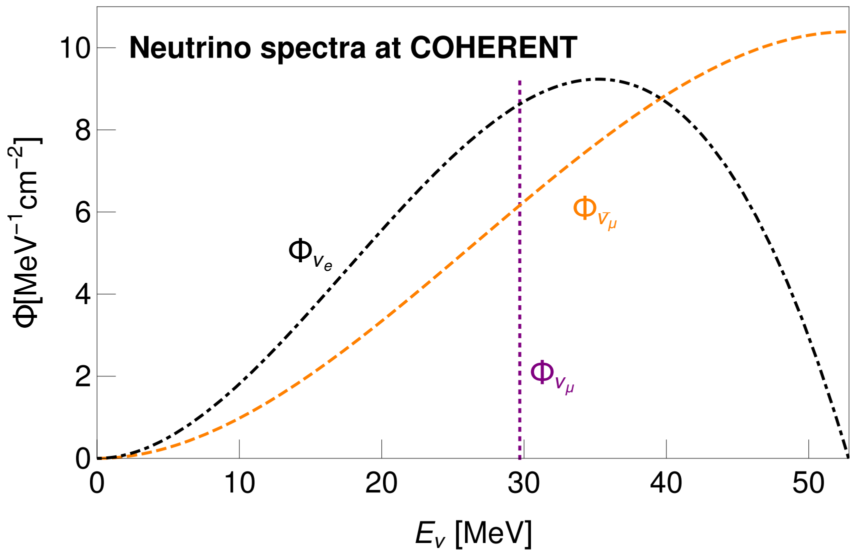


CEvNS environments

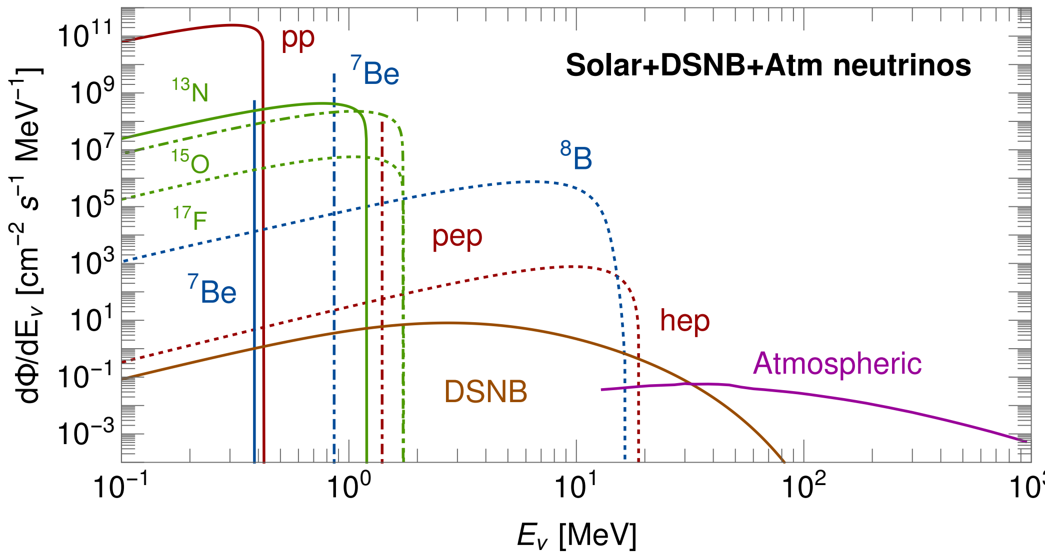
Reactor neutrinos (CONUS, CONNIE...)



Fixed target neutrinos (COHERENT)



Solar+DSNB+Atm (DM detectors)

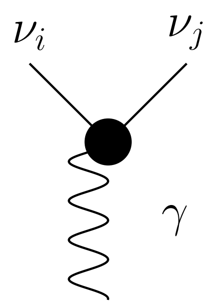


The case of neutrino magnetic moments

Neutrino EM current

Parametrization and model-independent results derived by

Kayser PRD 26, 1982 (1662) and Nieves PRD, 26, 1982 (3152)



$$\langle \nu_i | j_\mu | \nu_j \rangle = f_Q(q^2)_{ij}\gamma_\mu + f_A(q^2)_{ij}(q^2\gamma_\mu - q_\mu \not{q}) + i\sigma_{\mu\nu}q^\nu[f_M(q^2)_{ij} - i f_E(q^2)_{ij}\gamma_5]$$

⇒ Diagonal EM FFs ($q^2 \to 0$): $f_Q \to Q_\nu$ $f_A \to a_\nu$ $f_M \to \mu_\nu$ $f_E \to \epsilon_\nu$

⇒ Diagonal EM FFs: $\underbrace{f_E(q^2)_{ii} = 0 \text{ (CP conserved)}}_{\text{Dirac } \nu}$ $\underbrace{f_A(q^2)_{ii} \neq 0}_{\text{Majorana } \nu}$

⇒ Off-diagonal EM FFs: Non-zero for ν_D and ν_M ⇒Transitions

Constraints I

These couplings contribute to a variety of processes

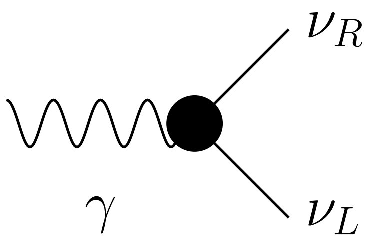
The most widely considered: μ_ν

Astrophysical bounds

Raffelt, Phys. Rep. 198 (1990)

Spin-flip scattering in SN

ν's are trapped by EW int

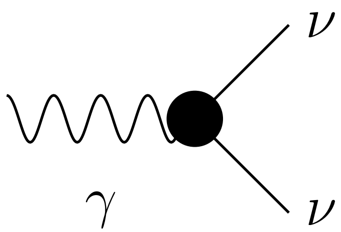


$\mu_\nu \lesssim 3 \times 10^{-12} \mu_B$

Arceo et. al, arXiv:1910.10568

Globular cluster stars

$\omega^2 + |\vec{k}|^2 \geq 0$



$\mu_\nu \lesssim 2.2 \times 10^{-12} \mu_B$

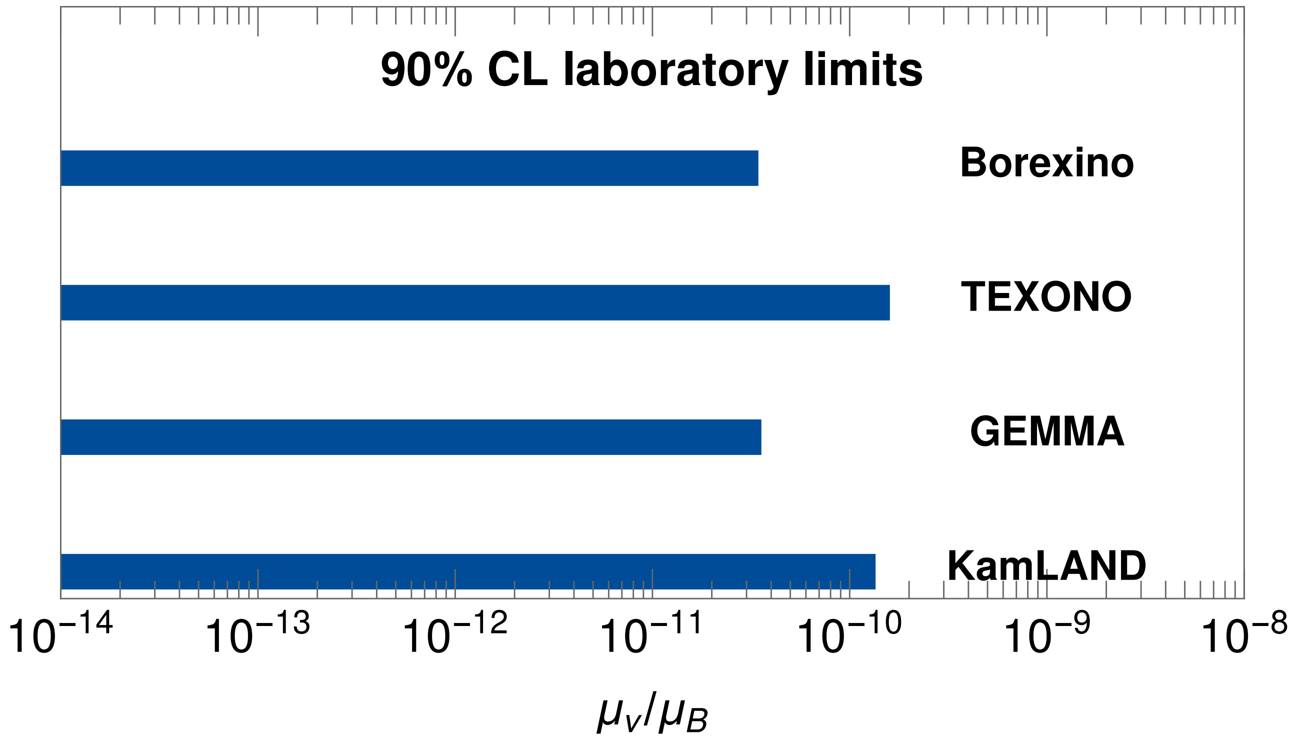
My view/understanding:

These bounds should be understood as order of magnitude estimations

Constraints II

Laboratory limits

More robust than astrophysical bounds. Follow from $\nu - e$ scattering using solar and reactor neutrino fluxes



Contributions to CEvNS and $\nu - e$ ES

μ_ν contribution to CEvNS (NR) event rates

Vogel & Engel, PRD, 39 (1989)

$$\frac{d\sigma_{\nu-N}}{dE_r} = \pi\alpha Z^2 \frac{\mu_{\text{eff}}^2}{m_e^2}\left(\frac{E_\nu - E_r}{E_\nu E_r}\right) F^2(E_r)$$

Spectral distortions, particularly relevant at low recoil energies

μ_ν contribution to $\nu - e$ (ER) event rates

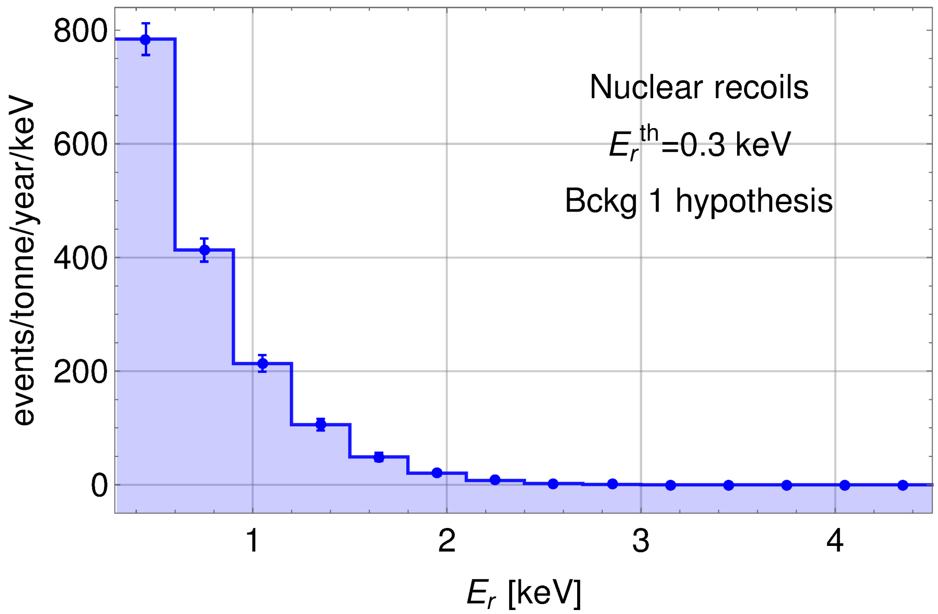
Vogel & Engel, PRD, 39 (1989)

$$\frac{d\sigma_{\nu-e}}{dE_r} = \pi\alpha \frac{\mu_{\text{eff}}^2}{m_e^2}\left(\frac{E_\nu - E_r}{E_\nu E_r}\right)$$

Same spectral features

A detector sensitive to both allows an interplay between ER and NR measurements

Expectations at a 1-ton detector (XENON1T)



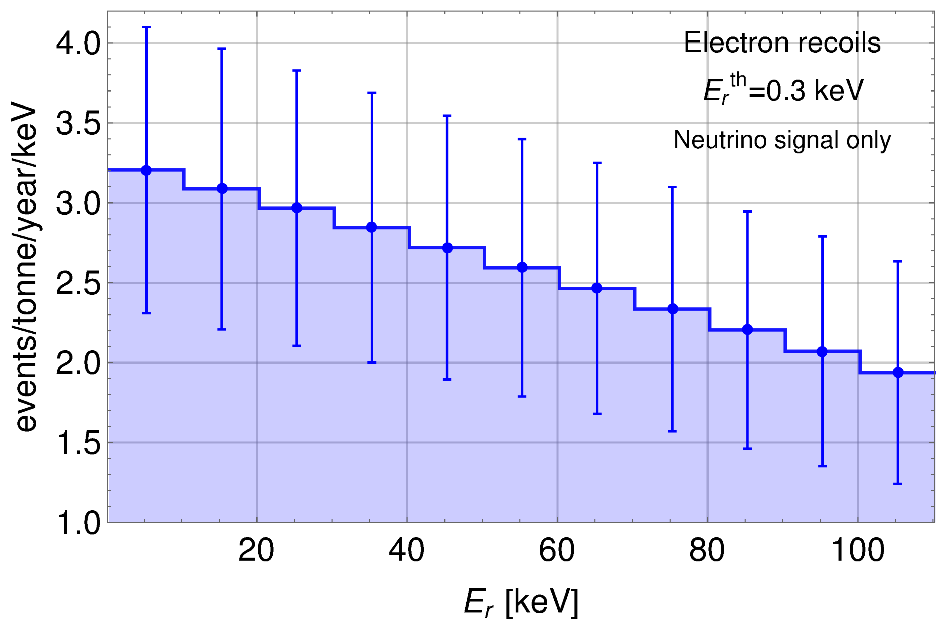
Signal dominated by ^{8}B

Rather sensitive to E_r thresholds

Signal dominated by pp

subdominant ^{7}Be (0.8 MeV)

less sensitive to E_r thresholds



Sensitivities: procedure

✍ Generate *toy experiments* assuming SM signals

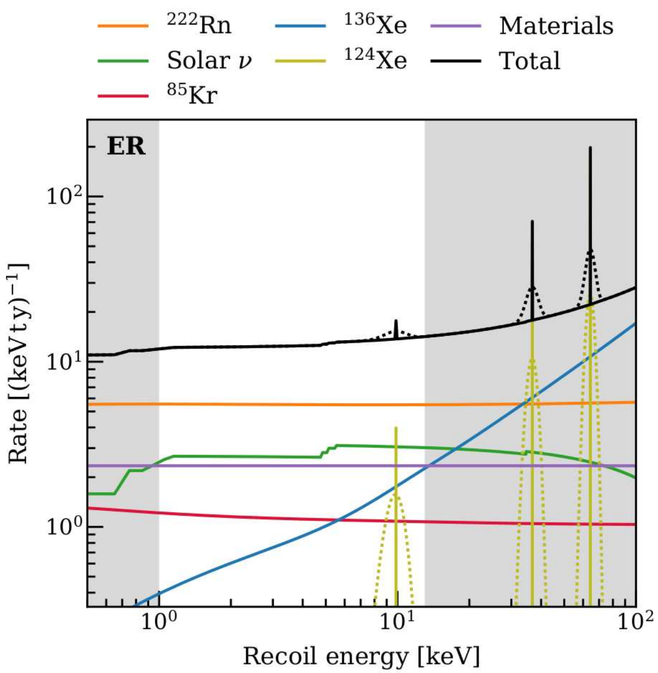
✍ For CEvNS assume two background hypotheses + two thresholds

✔ 25% and 68% of the signal rate & 1 keV and 0.3 keV

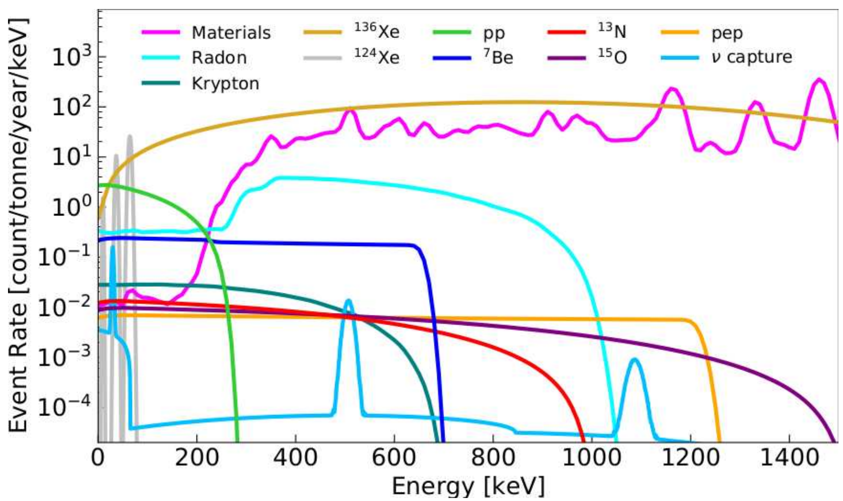
✍ For $\nu - e$ scattering use predicted background

✔ material radioactivity, $\beta\beta$ of ^{136}Xe...

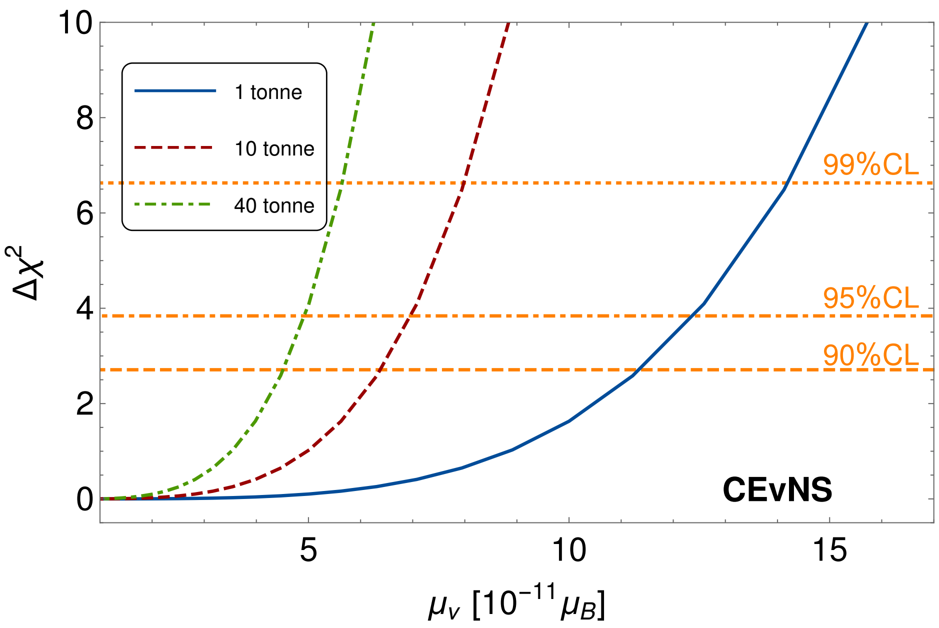
XENONnT, 2007.08796



DARWIN, 2006.03114



Nuclear recoils

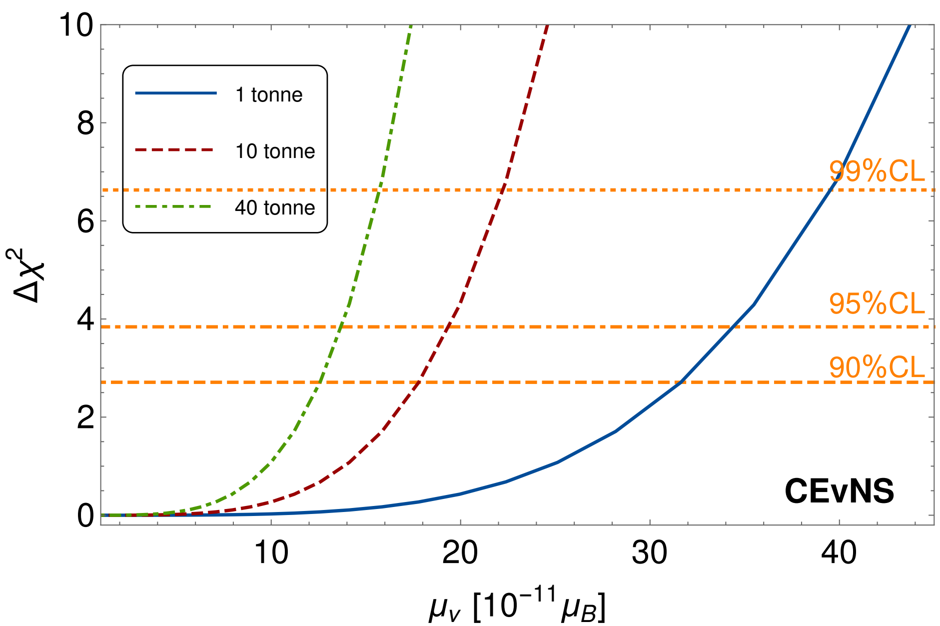


Best sensitivities found for

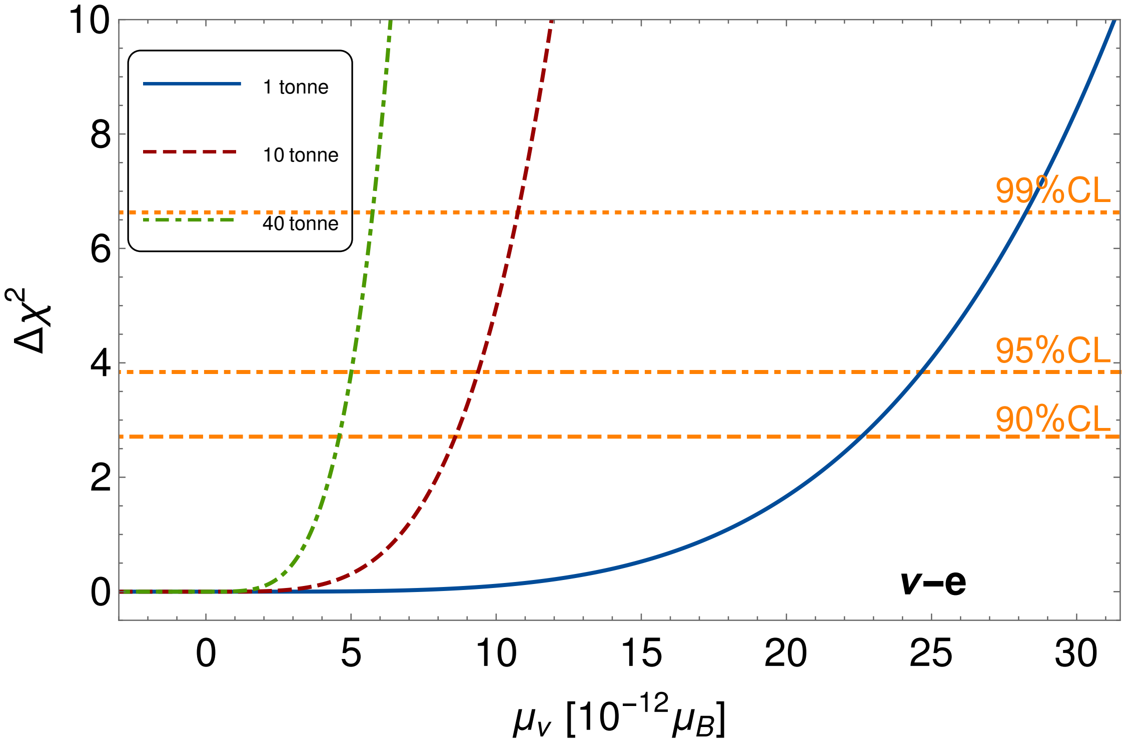
$E_r = 0.3$ keV and Bckg-2 hypothesis

Worse sensitivities found for

$E_r = 1$ keV and Bckg-1 hypothesis



Electron recoils



Sensitivities enter the region not constrained by astrophysical arguments... Region where some TeV-related new physics predicts $\mu_\nu \neq 0$

Résumé

✍ CEvNS experiments provide an ideal environment where to look for new interactions

✍ Neutrino electromagneitc properties, in particular NMM, can produce sizable signatures

✍ Direct detection experiments will (are) lead NMM signal searches

✍ Even in the NR channel, sensitivities will be as competitive as those from ER in Borexino

✍ In the ER channel, sensitivities will explore regions not ruled out by astrophysical arguments

✍ Test of TeV models predictions in that region is possible