CEvNS in multi-ton DM experiments: Vector versus scalar new physics signals

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arXiv:1910.12437

Motivation
- Physics opportunities
- Vector interactions: Light versus heavy
- Identification of a “not expected” signal
- CEvNS environments

Strategy

Vector versus scalar

Final remarks

Motivation

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Physics opportunities

Standard Physics

✍ Determination of the root-mean-square radius of neutron distributions

⇒ Neutron skin ⇒ Neutron Stars EoS **Giunti et. al. 1710.02730**

✍ Improve understanding of EW parameters ⇒ Precise determination of the weak mixing angle at $\mu \simeq 1$ MeV **Miranda et. al. 1806.01310**

Talk by Matteo Cadeddu

Non-standard physics

✍ New dof ⇒ Light fermions (sterile ν's) **Aristizabal et. al. 1902.07398**

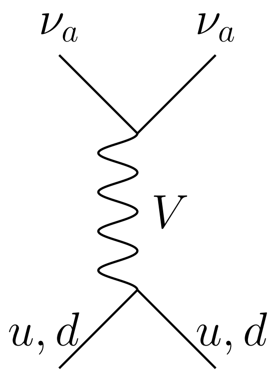
✍ New forces (for some reason) escaping observation at high intensity and/or high energy experiments **Talk by Pilar Coloma**

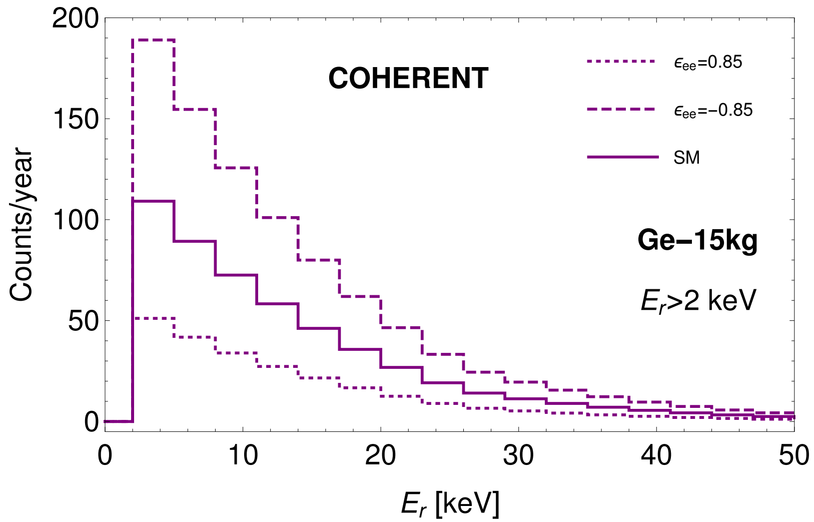
Marfatia & Liao/Dutta, Liao & Strigari

Kosmas, Papoulais/Aristizabal, De Romeri & Rojas

Vector interactions: Light versus heavy

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



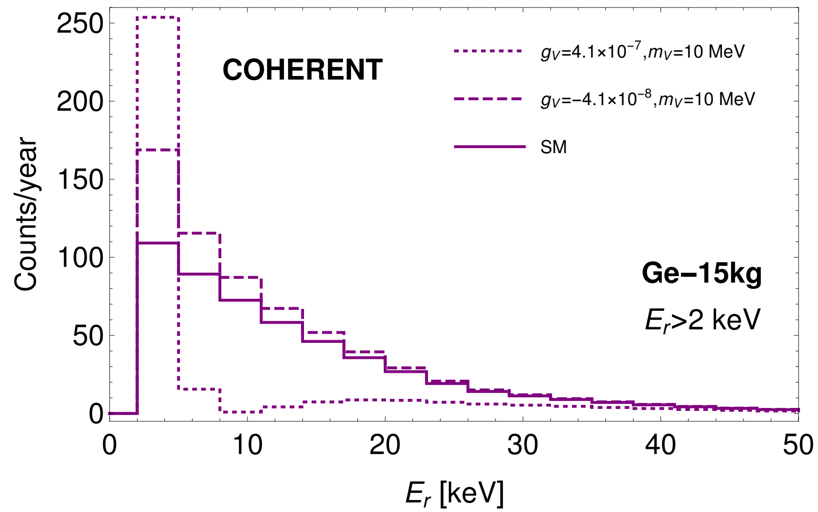


Light limit

Spectral distortions

Effective limit

Global enhancements



Identification of a “not expected” signal

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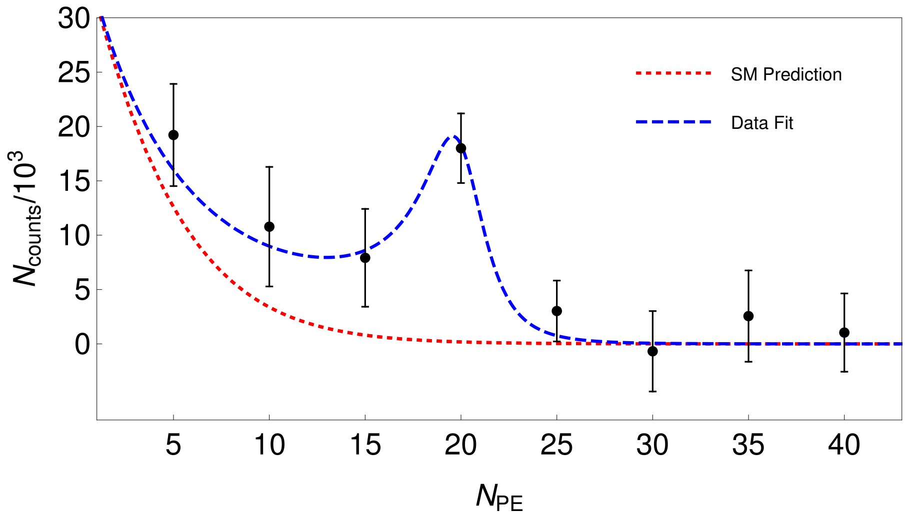


After the discovery...

What is the nature of the interaction?

What is the BSM physics behind?

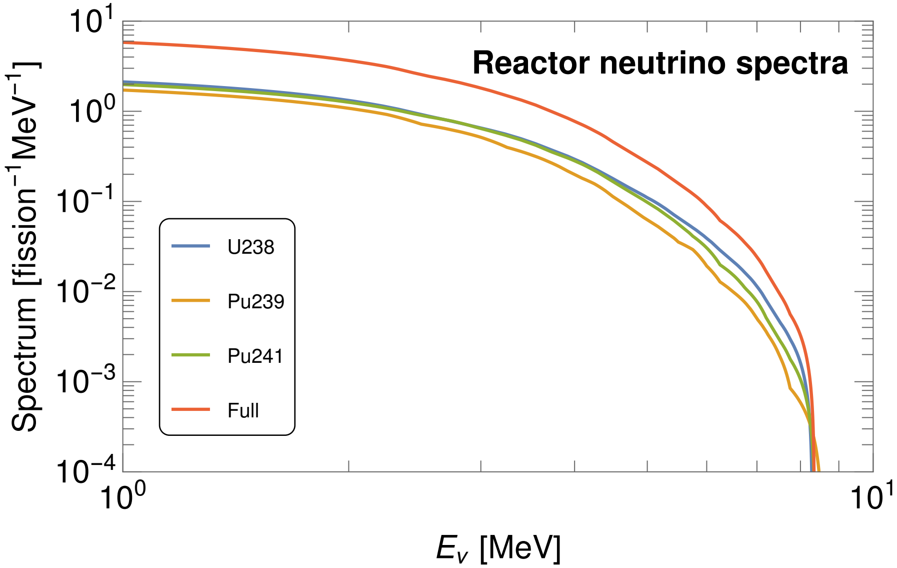
Light Physics

Heavy Physics

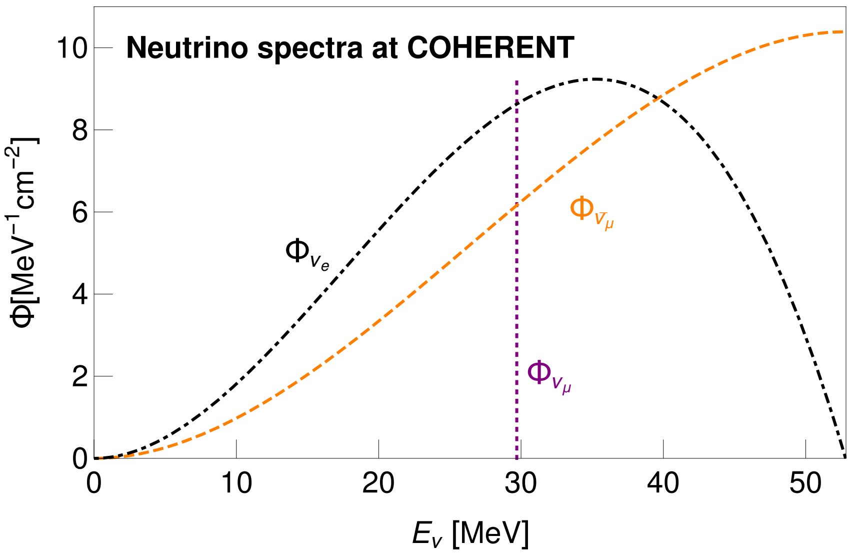
What CEvNS environment?

CEvNS environments

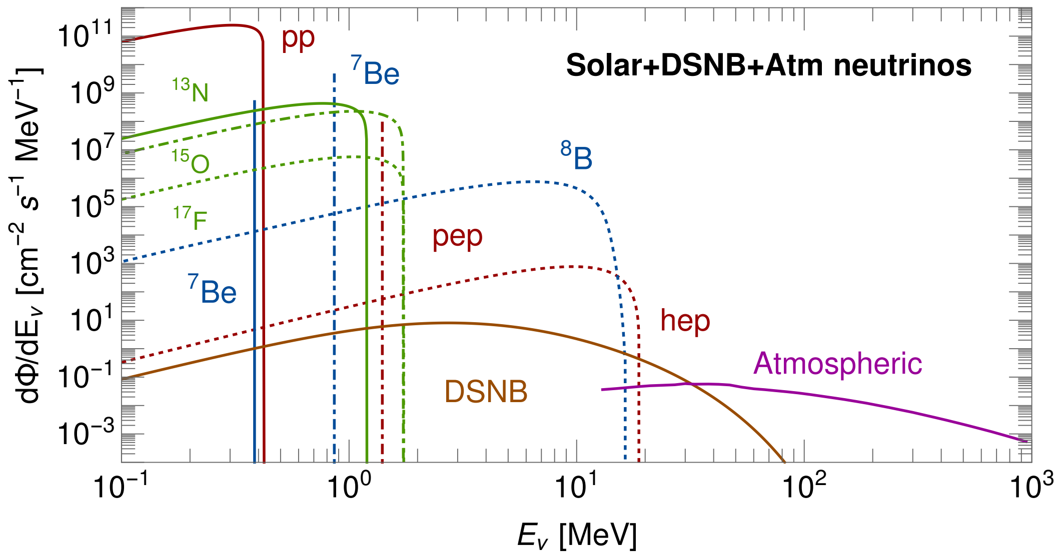
Reactor neutrinos (CONUS, CONNIE...)



Fixed target neutrinos (COHERENT)



Solar+DSNB+Atm (DM detectors)



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Strategy
● Program
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Strategy

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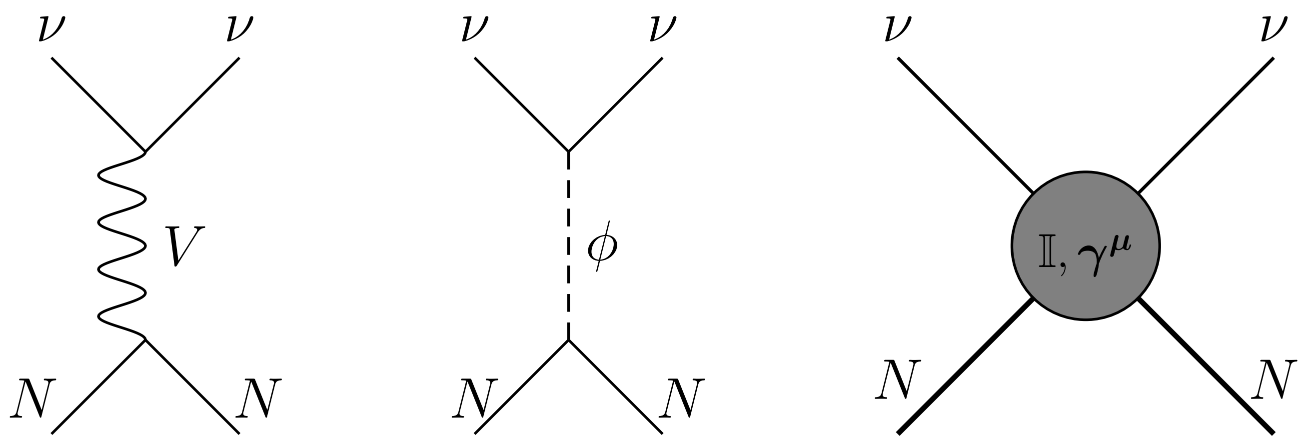
Program

Select interactions: V+S (light+Eff)



Environment

Xenon ton-size dark matter detectors with low energy thresholds $E_r \lesssim 3.5$ keV: XENONnT, LZ, DARWIN

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- Bounds from neutrino masses
- Event rate spectra (LMs)
- Signal degeneracy
- Morphology of the new interaction (Effective case)
- Expectations at XENON1T (XENONnT, LZ)

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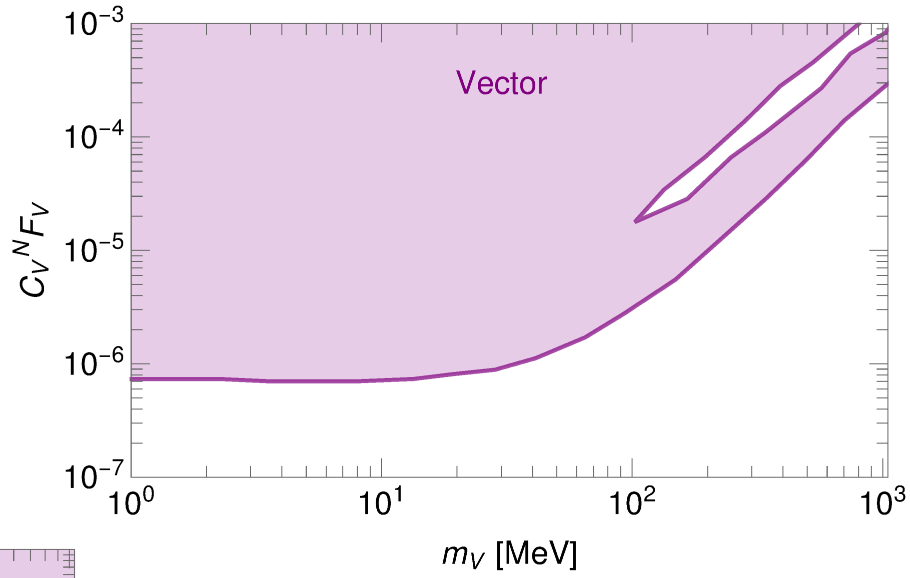
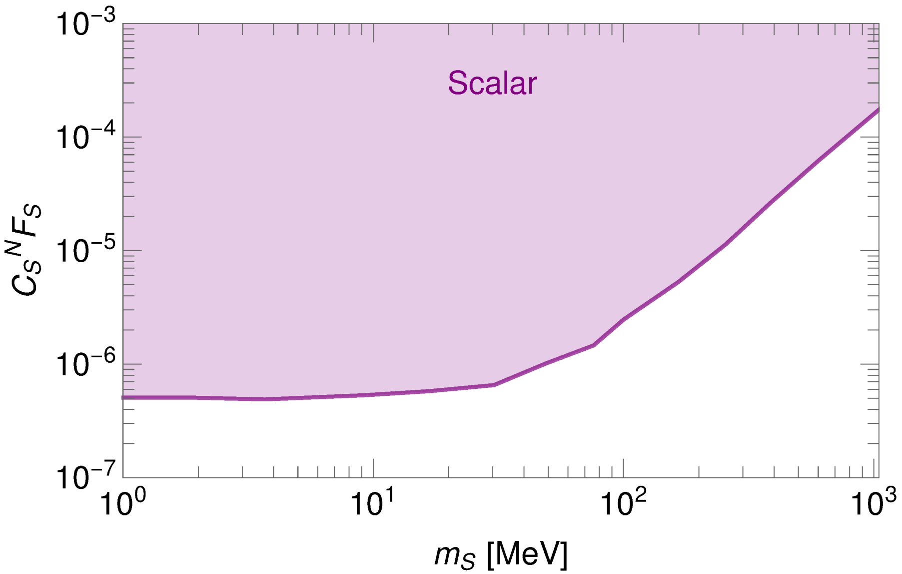
Constraints

For light mediators COHERENT provides the most stringent bounds

Astrophysical limits can either be evaded or provide order of magnitude estimates

Most stringent limits follow from a likelihood analysis using energy and timing spectral information





Scalar interactions are bounded from neutrino masses as well

$$m_\nu \propto \langle q\bar{q} \rangle$$

Bounds from neutrino masses

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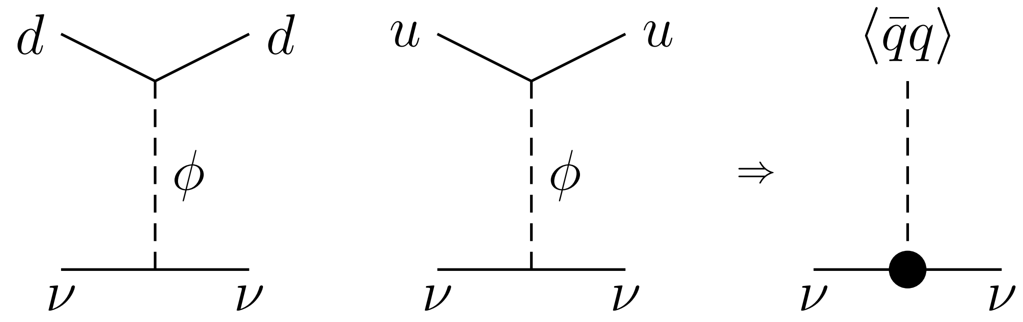

$$m_\nu = \frac{8\pi}{\sqrt{3}} G_F f_\pi F_S \sum_{q=u,d} h_S^q \simeq 122.5\,\text{eV}\, F_S \sum_{q=u,d} h_S^q$$

$$\frac{d\sigma_S}{dE_r} \propto |\xi_S|^2$$

Limits on cross section

Xe: $\xi_S \lesssim \left(\frac{302}{m_S/\text{GeV}}\right)^2$ Ge: $\xi_S \lesssim \left(\frac{225}{m_S/\text{GeV}}\right)^2$

Ar: $\xi_S \lesssim \left(\frac{167}{m_S/\text{GeV}}\right)^2$ Si: $\xi_S \lesssim \left(\frac{140}{m_S/\text{GeV}}\right)^2$

Neutrino mass limits are relevant only for $m_S \gtrsim 100$ GeV

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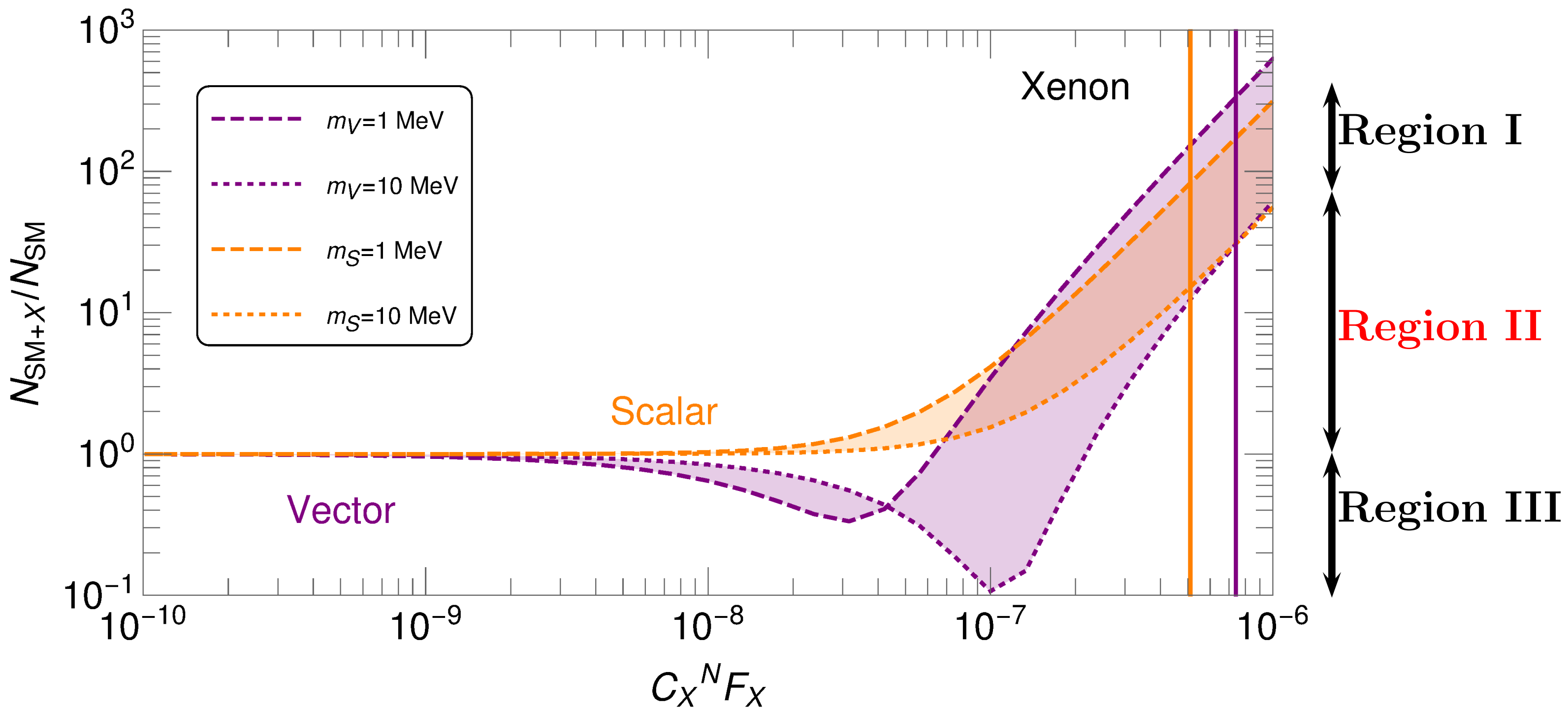
Event rate spectra (LMs)

Use COHERENT bounds to systematically explore the parameter space of vector and scalar interactions



R-I ⊕ **R-III:** $R \gtrsim 84 \oplus R \lesssim 1 \Rightarrow$ Vector

R-II: V & S signals are degenerate

Identification of V & S can be done using measurements of recoil spectra

Signal degeneracy

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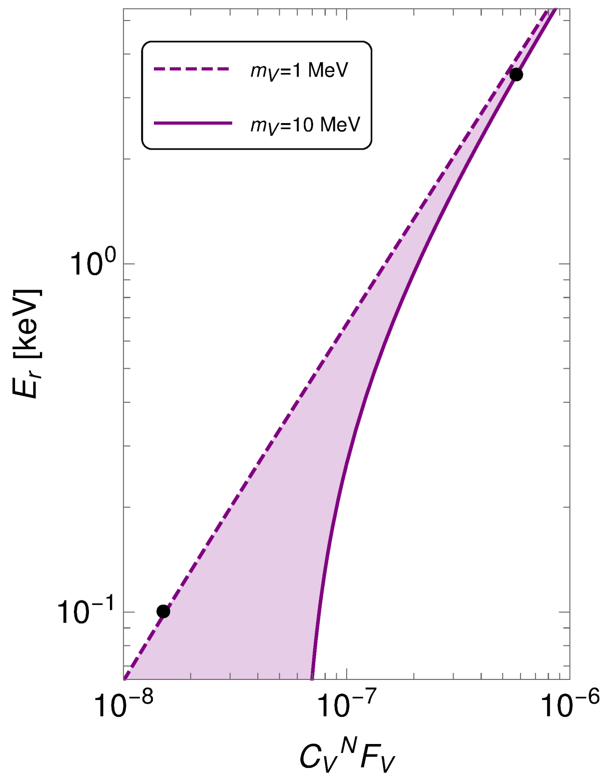
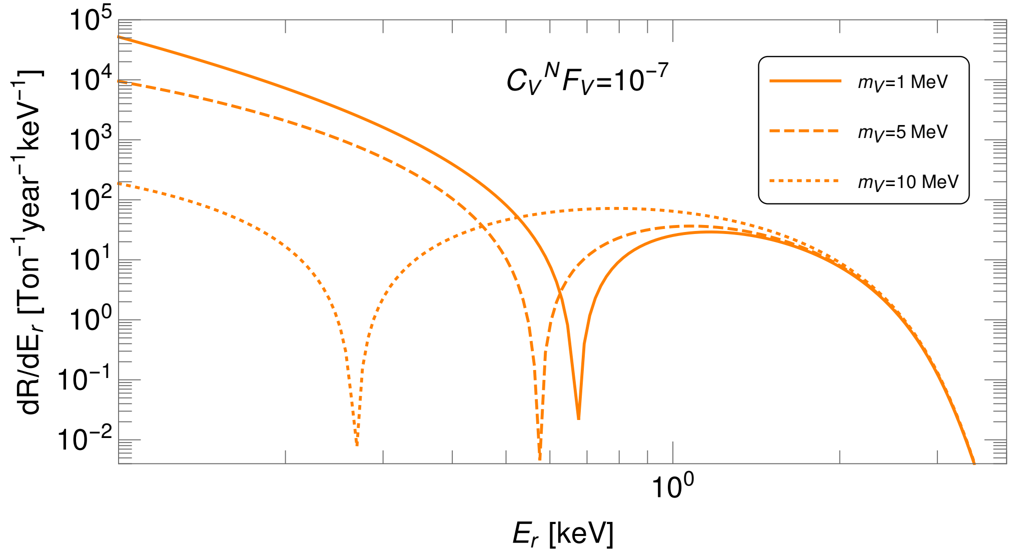
Key observation: Recoil spectra generated by vector interactions involve dips

$$E_r = \frac{C_V^N F_V - \sqrt{2} G_F |g_V^{\text{SM}}| m_V^2}{2\sqrt{2} G_F |g_V^{\text{SM}}| m_N}$$





V+S signal degeneracy in **R-III** can be broken via measurements of the recoil spectrum

Morphology of the new interaction (Effective case)

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Morphology: Once the nature of the new interaction is experimentally fixed

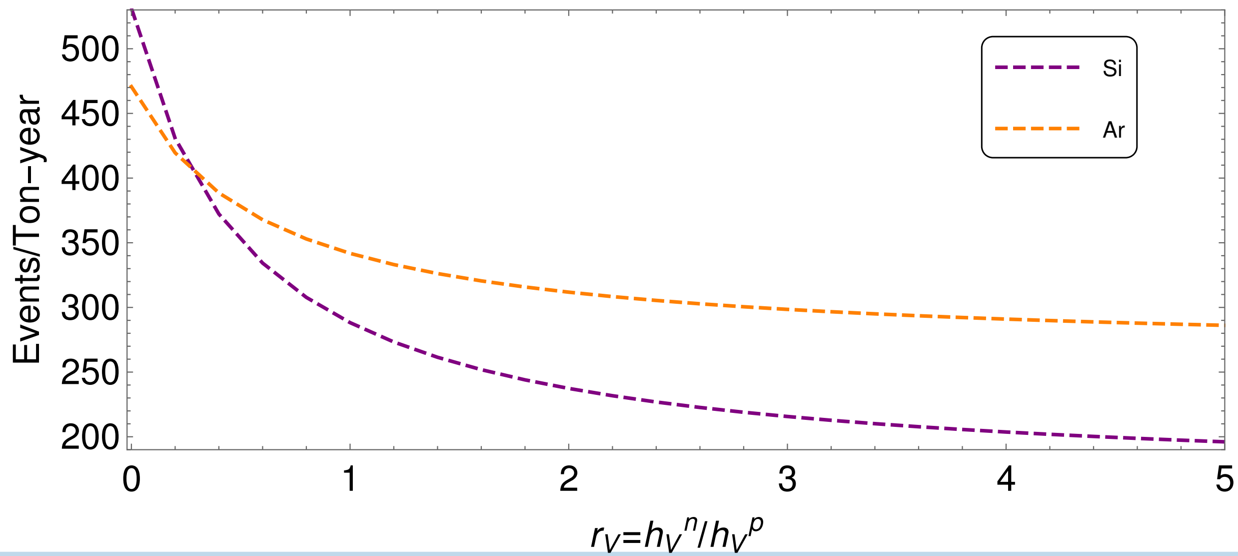
Can one learn how does it "speaks" with protons and neutrons?

$$\frac{d\sigma_V}{dE_r} \propto g_V^{\text{SM}} + \xi_V$$

✔ Measurement 1 $\Rightarrow N_{\text{Ev}}$: $\xi_V = \underbrace{F_V C_V^N}_{\text{Det}-1} [Z + r_V(A - Z)]$ $[r_V \equiv h_V^n / h_V^p]$

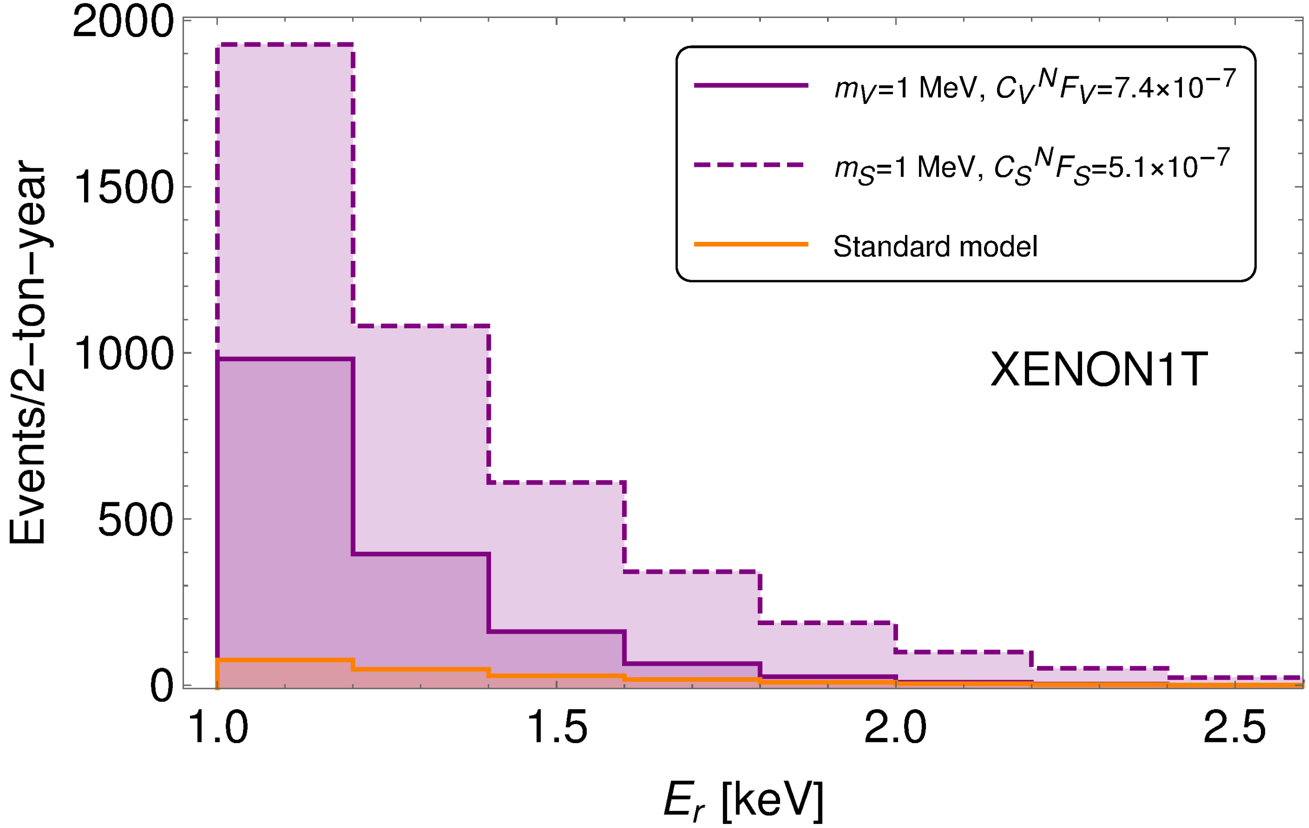
✔ Measurement 2 $\Rightarrow N_{\text{Ev}}^{\text{Det-2}}$: Calculate $N_{\text{theo}}^{\text{Det-2}}$ in terms of r_V

$N_{\text{theo}}^{\text{Det-2}} = N_{\text{Ev}}^{\text{Det-2}} \Rightarrow$ Pin down r_V



Expectations at XENON1T (XENONnT, LZ)

What are the chances of these interactions being observed at XENON1T, XENONnT and LZ?



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● Rèsumè

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● Rèsumè

⇒ If a deviation of the SM CEvNS prediction is observed its nature can be identified!

⇒ It can be done in any CEvNS environment!

⇒ In multi-ton DM detectors recoil+event spectra are sufficient to pin down its nature

... But you can do more

⇒ Determine its morphology (isospin nature) by combining multiple data sets

⇒ Remove detector degeneracies

To do so we encourage XENONnT and LZ to lower thresholds to 1 keV!