Physics opportunities of coherent elastic neutrino-nucleus scattering experiments

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USM

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

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

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

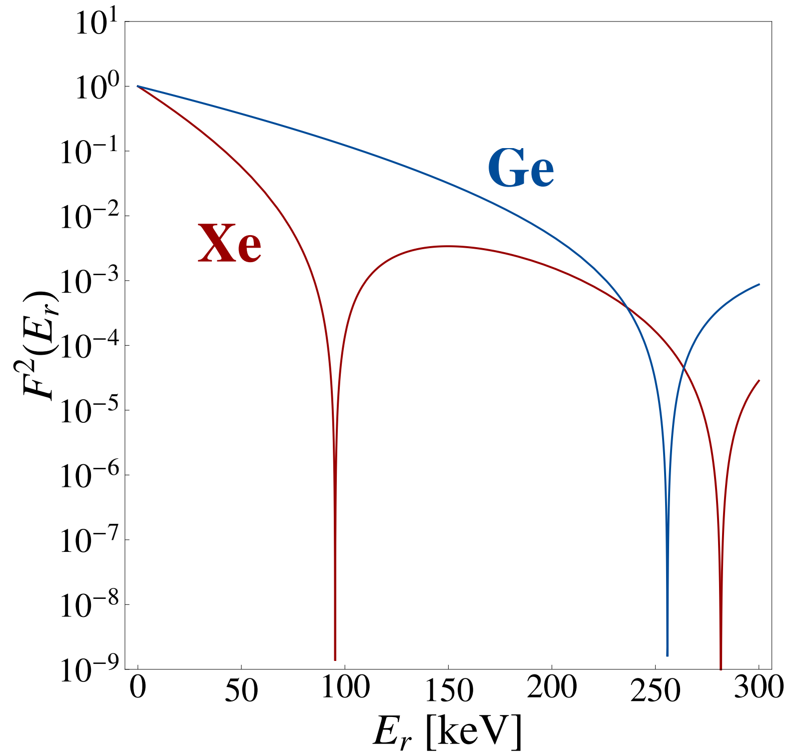
$$E_\nu \lesssim 200\ \text{MeV}$$

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

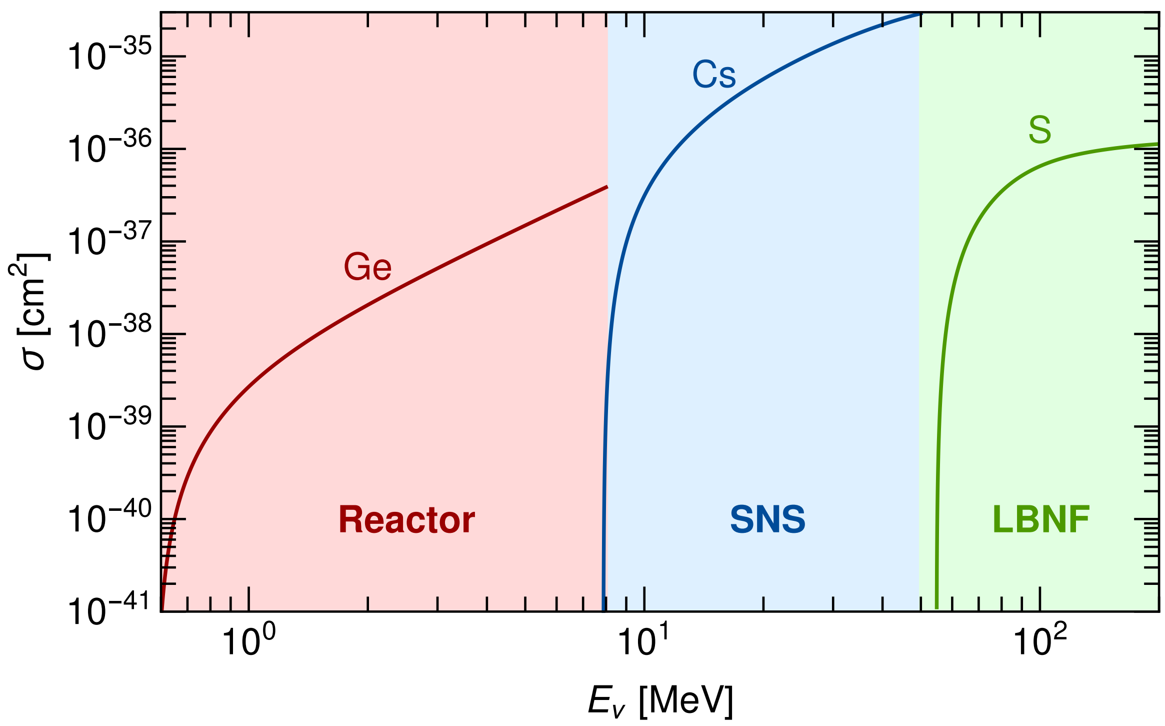


Neutrino sources and CEvNS "regimes"

"Laboratory" sources: Reactor neutrinos, SNS neutrinos, LBNF (NuMI)

"Astrophysical" sources: Solar, DSNB, Atmospheric, SN burst

D.A. et al. arXiv:2103.10857

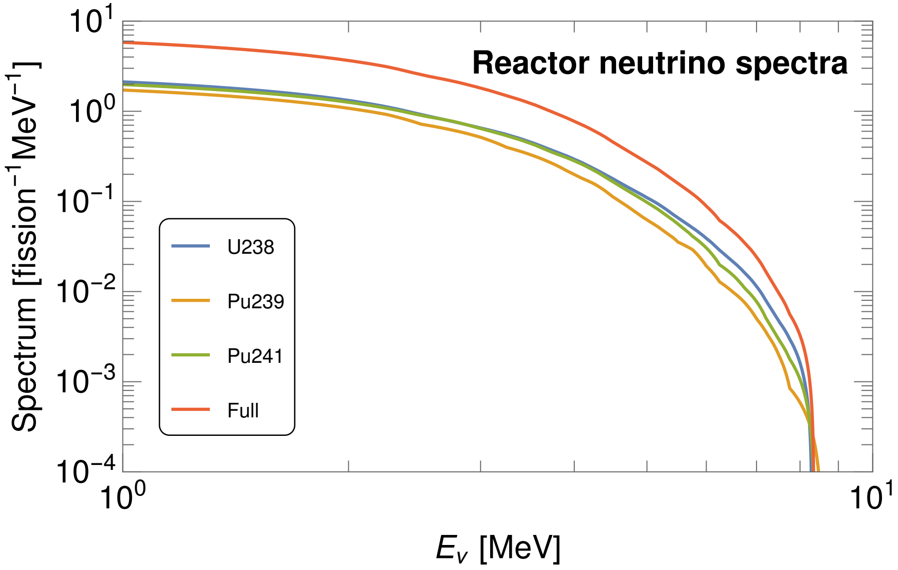


Entering the "high-energy" window requires a substantial amount of ν's in the low-enery tail

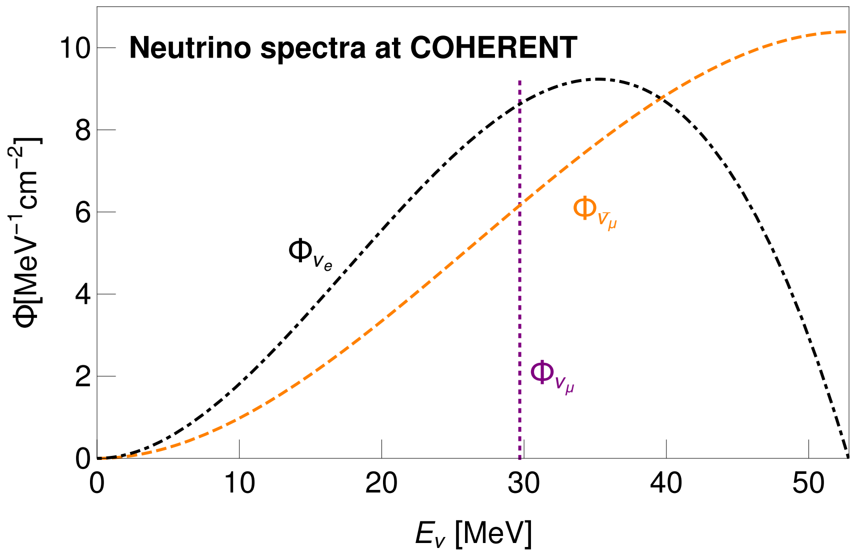
LBNF provides that!

CEvNS environments

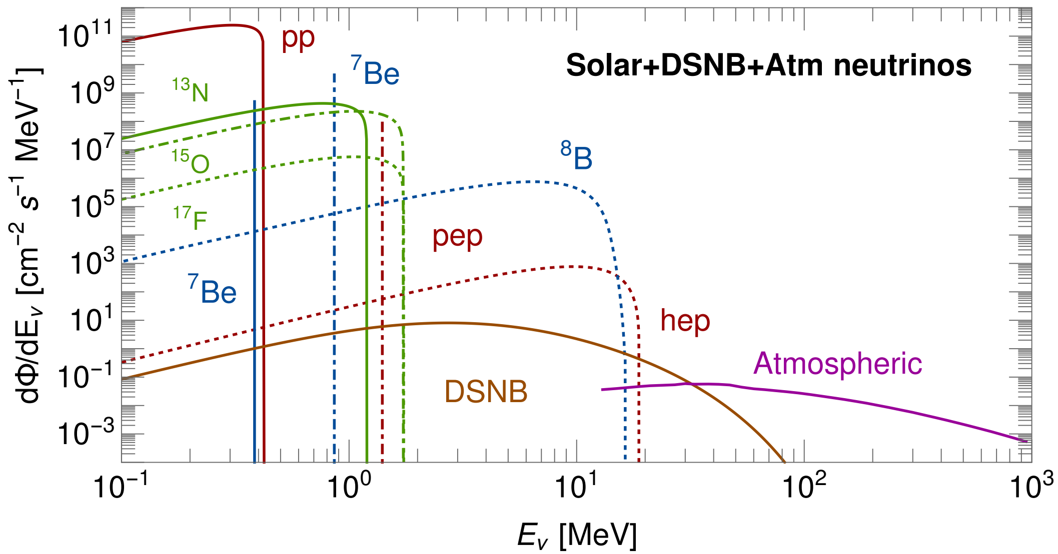
Reactor neutrinos (CONUS, CONNIE...)



Fixed target neutrinos (COHERENT)

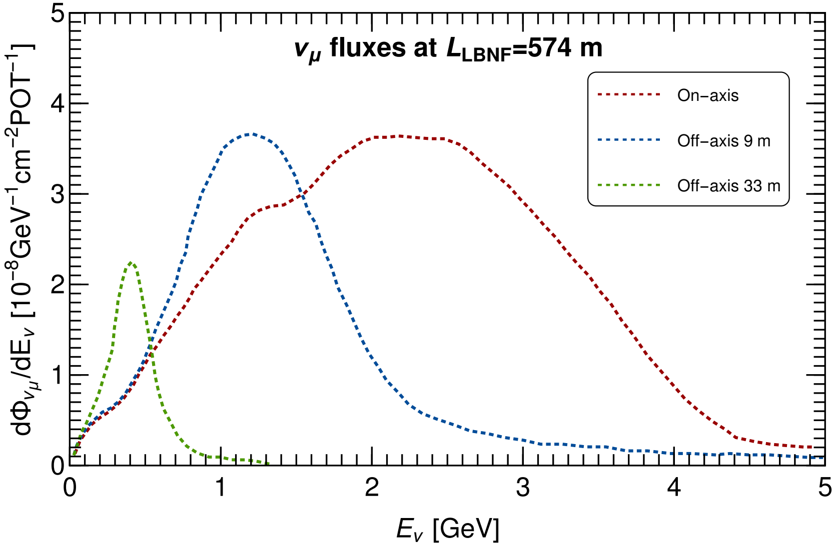


Solar+DSNB+Atm (DM detectors)



LBNF neutrino beamline low-energy tail

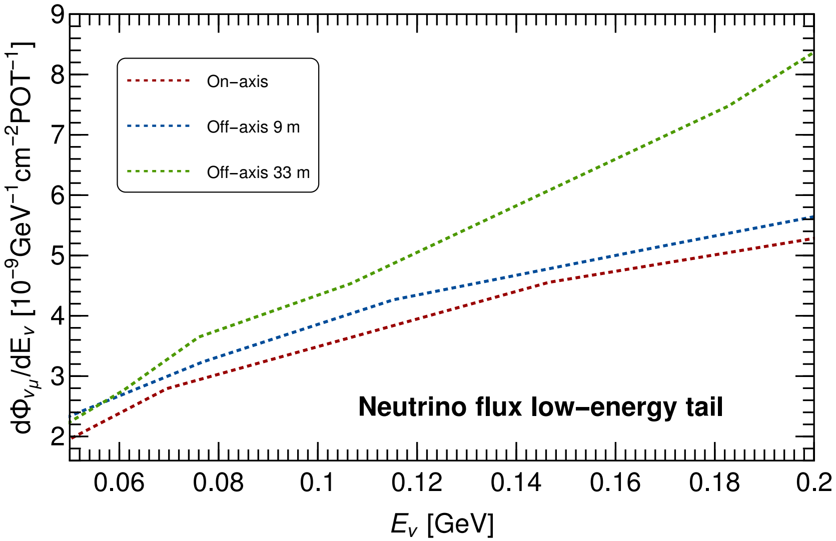
arXiv:2002.03005



Full spectrum $\Rightarrow n_\nu \simeq 10^{14}$/year/cm^2

Available e.g for $\nu - e$ scattering

arXiv:2002.03005



Low-energy tail: $n_\nu \simeq 10^{12}$/year/cm^2

$\sigma_{\text{CEvNS}} \sim N^2$

Sizable number of events!

Standard Physics

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

$\Rightarrow$ Neutron skin $\Rightarrow$ Neutron Stars EoS **Talk by Carlo Giunti**

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

Non-standard physics

✍ New dof $\Rightarrow$ Light fermions (sterile ν's) **Talk by Ian Shoemaker**

✍ New forces (for some reason) escaping observation at high intensity and/or high energy experiments **Marfatia & Liao/Dutta, Liao & Strigari/Shoemaker**

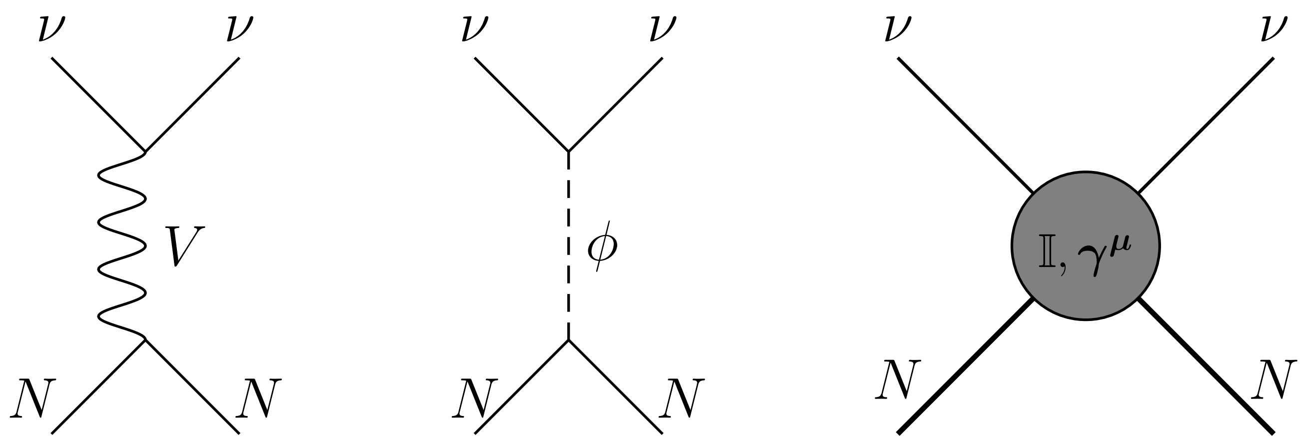
Kosmas, Papoulais/Aristizabal, De Romeri & Rojas

Giunti et al.

(Incomplete list!)

Strategy

Select interactions: V+S (light+Eff)

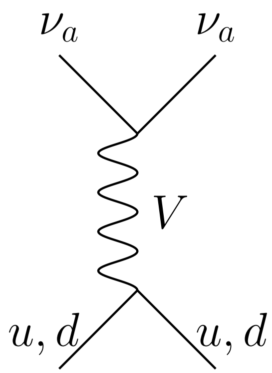


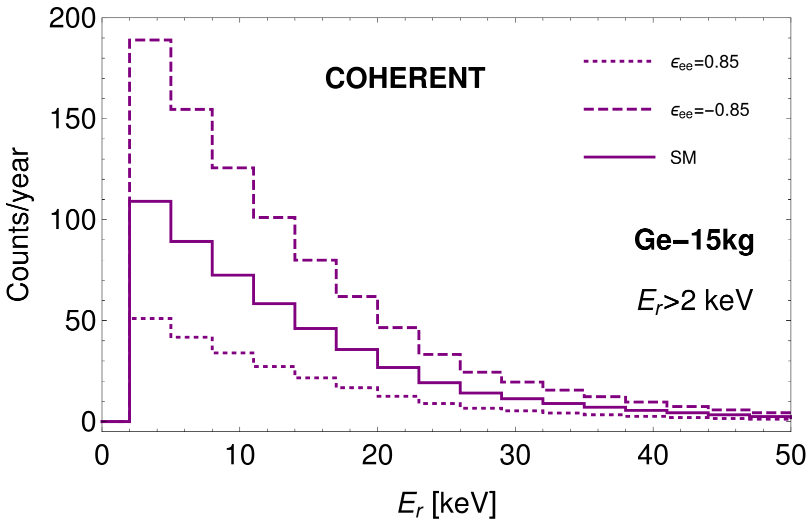
Environment

SNS, DM direct detection detectors, reactors, LBNF

What to expect

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



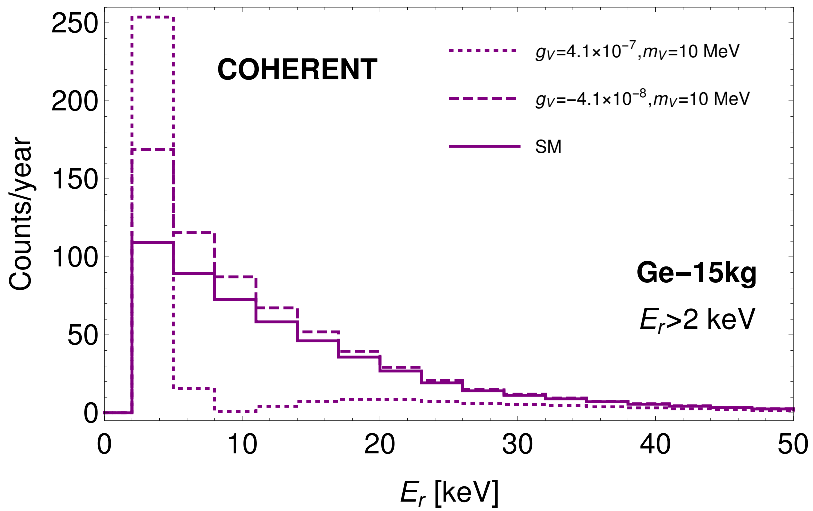


Effective limit

Global enhancements

Light limit

Spectral distortions

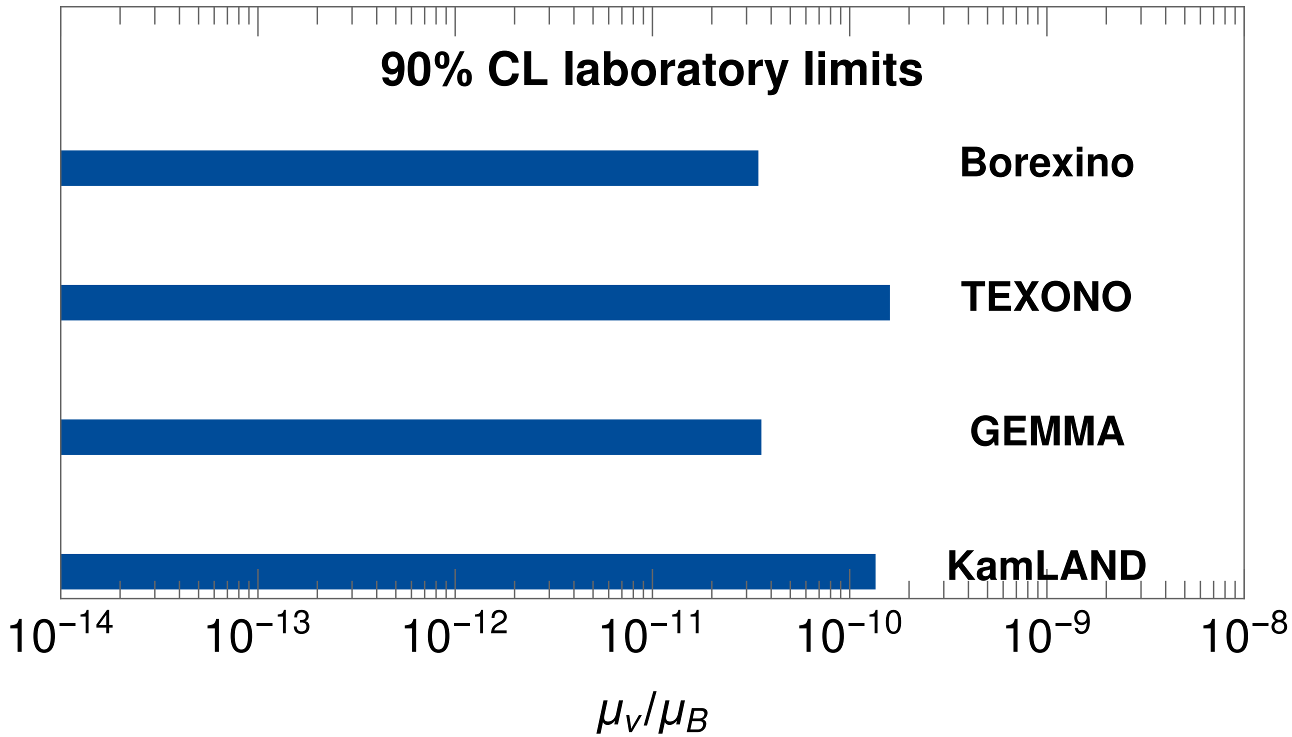


NMM in multi-ton DM detectors

NMM limits

Laboratory limits

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

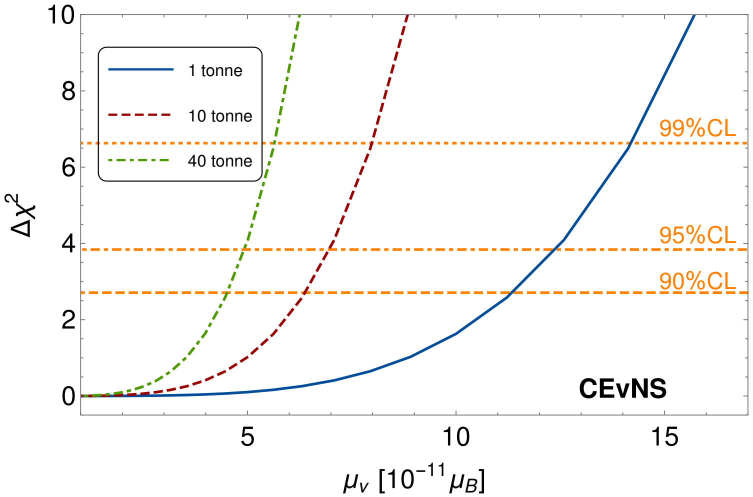


Nuclear recoils

Sensitivities in multi-ton DM detectors

D.A, Branada, Miranda, Sanchez, JHEP 12 (2020) 178

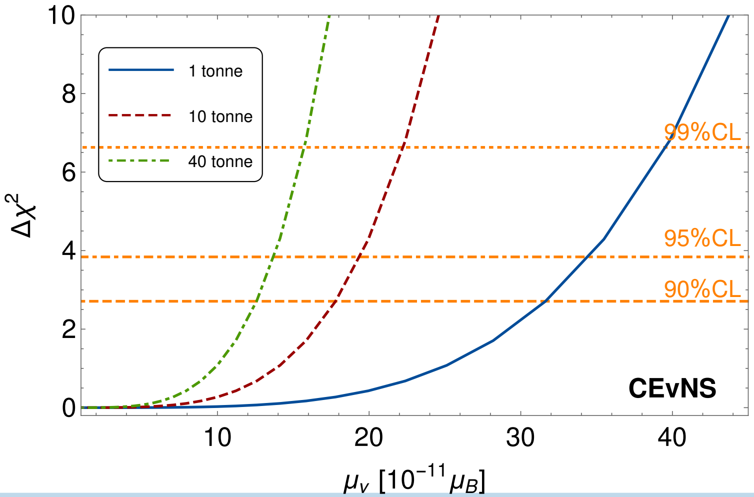
D.A. et al. 2008.05080



Best sensitivities found for

$E_r = 0.3$ keV and Bckg-2 hypothesis

D.A. et al. 2008.05080

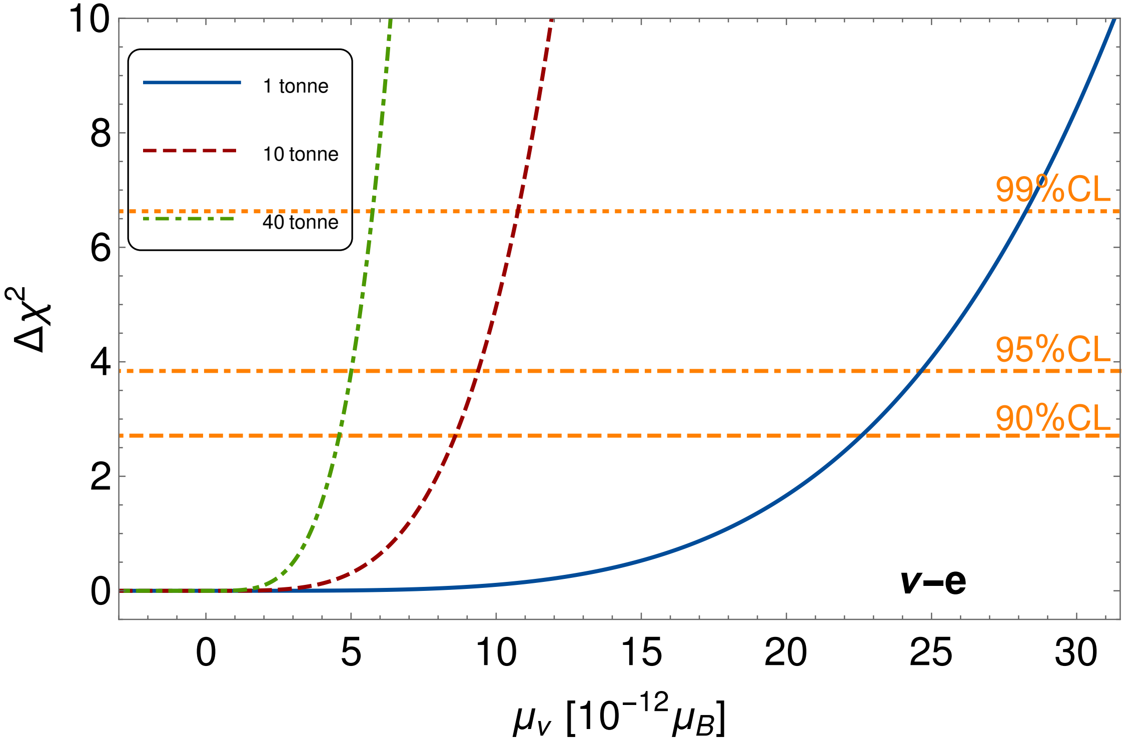


Worse sensitivities found for

$E_r = 1$ keV and Bckg-1 hypothesis

Electron recoils

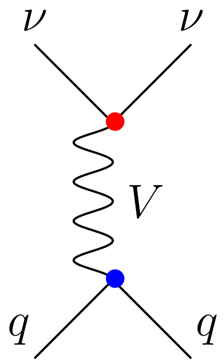
D.A. et al. 2008.05080



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

CPV at COHERENT

LVM + CPV

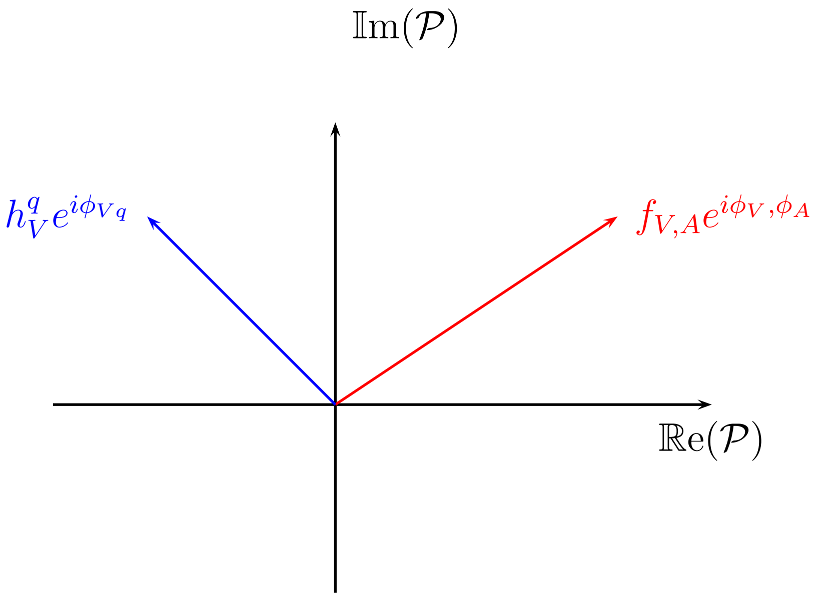


D.A, De Romeri, Rojas, JHEP 09 (2019) 069

$$\mathcal{L} = \bar{\nu}\gamma_\mu(f_V + i f_A\gamma_5)\nu V^\mu + \sum_{q=u,d}\bar{q}\gamma_\mu h_V^q q V^\mu$$

Remarks

☐ Axial quark current neglected ⇒ Leads to (spin) suppressed effects



$$\frac{d\sigma}{dE_r} \sim \frac{G_F^2 m_N}{2\pi}\left|g_V^{\text{SM}} + \overbrace{\frac{h_V(f_V - i f_A)}{2m_N E_r + m_V^2}}^{|H_V|e^{i\phi}\in\mathbb{C}}\right|^2$$

The 9-parameter problem reduces to 3 parameters

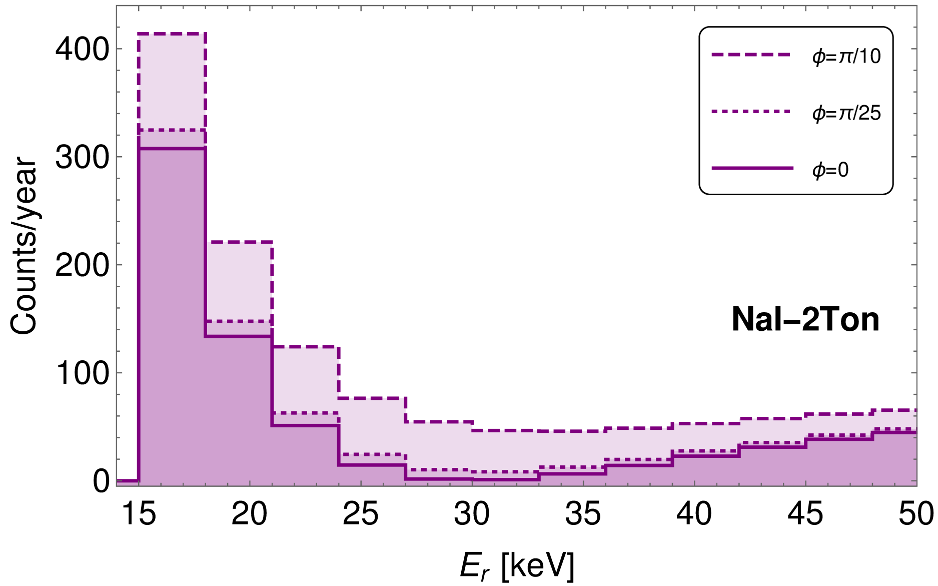
$$\mathcal{P} = \{m_V, |H_V|, \phi\}$$

Dips CPV effects in ^{23}Na

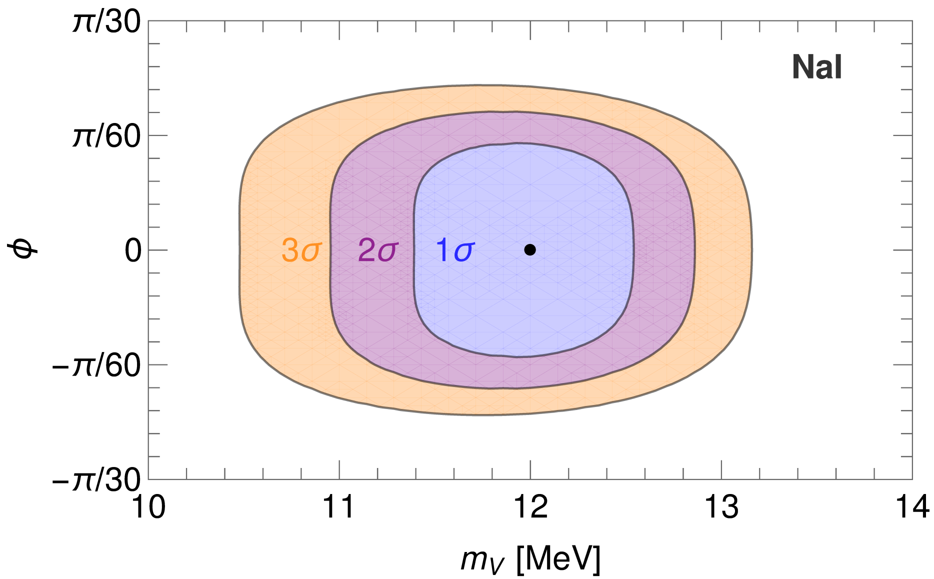
Departures from a dip in N_{counts}

"measure" the amount of CP violation

The structure of the dip gives info on CPV!



Run a pseudoexperiment with a dip and see what are the limits on ϕ



Observation of a dip in the spectrum

will not rule out CPV interactions

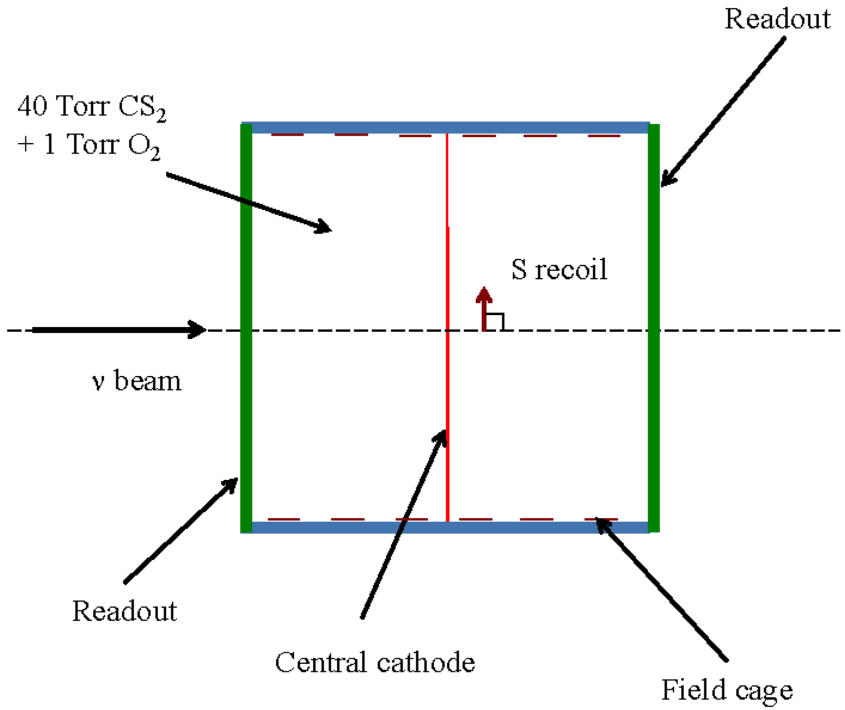
... But will set tight bounds

CEvNS with the νBDX-DRIFT detector

νBDX-DRIFT: Sketch

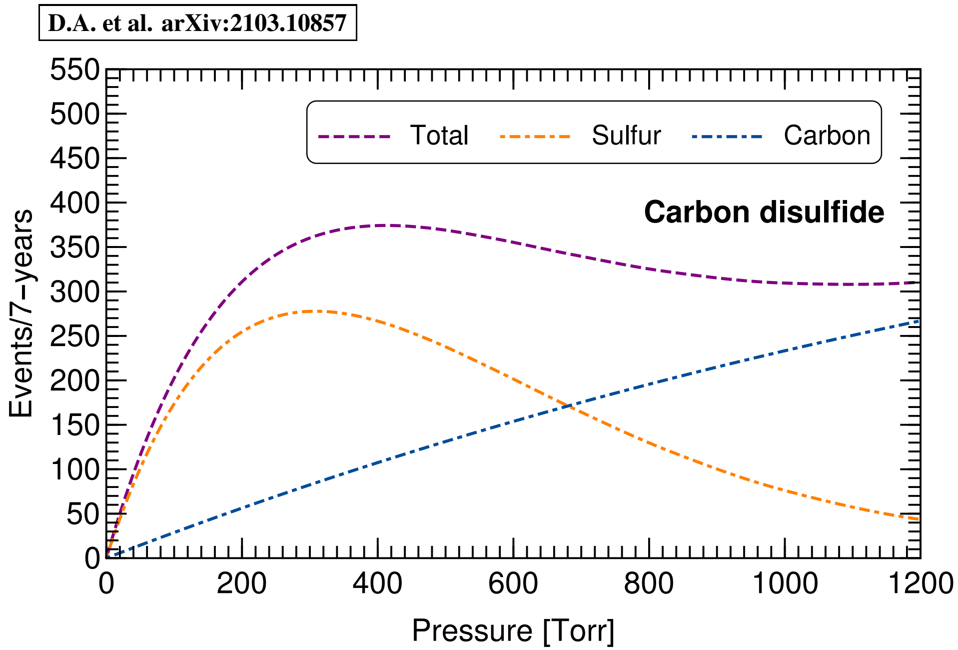
D.A, Dutta, Kim, Snowden-Ifft, Strigari, arXiv:2103.10857

- Directional low pressure TPC detector
- Operates with CS_2 (other gases possible CF_4, $C_8H_{20}Pb$...)



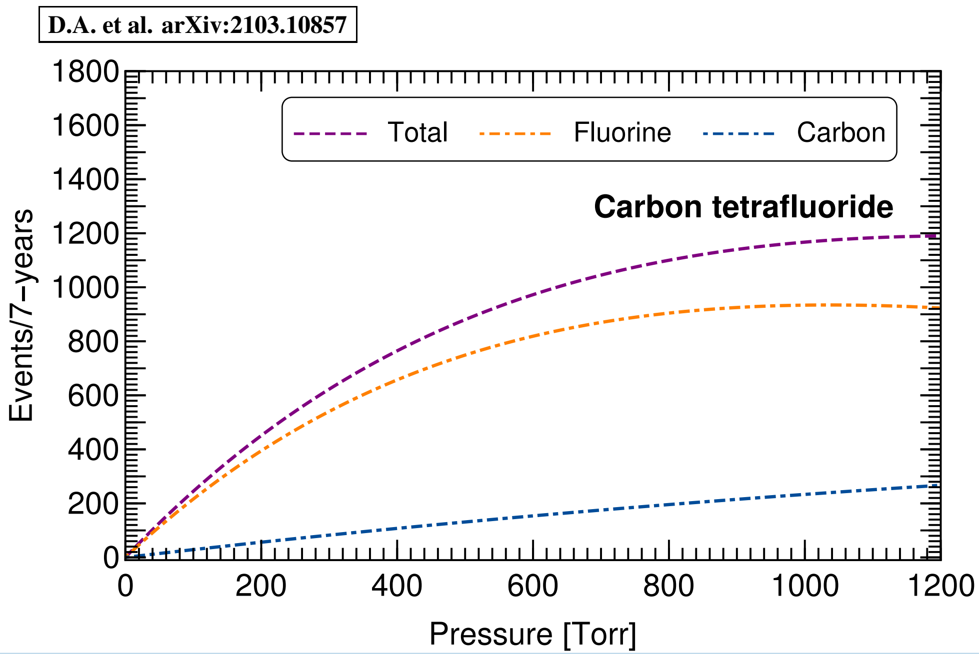
- NRs mainly in sulfur induce ionization
- CS_2^- ions used to transport the ionization to the readout planes (MWPCs)

Signals in CS_2 and CF_4



Signal peaks at 400 Torr

Expected signal: 370 events

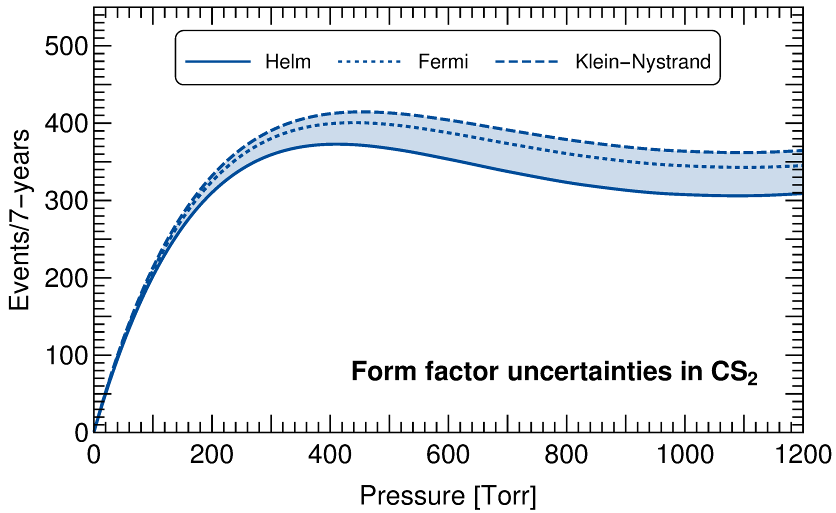


100% filled with CF_4

Expected signal: 880 events

Neutron density distributions

D.A. et al. arXiv:2103.10857

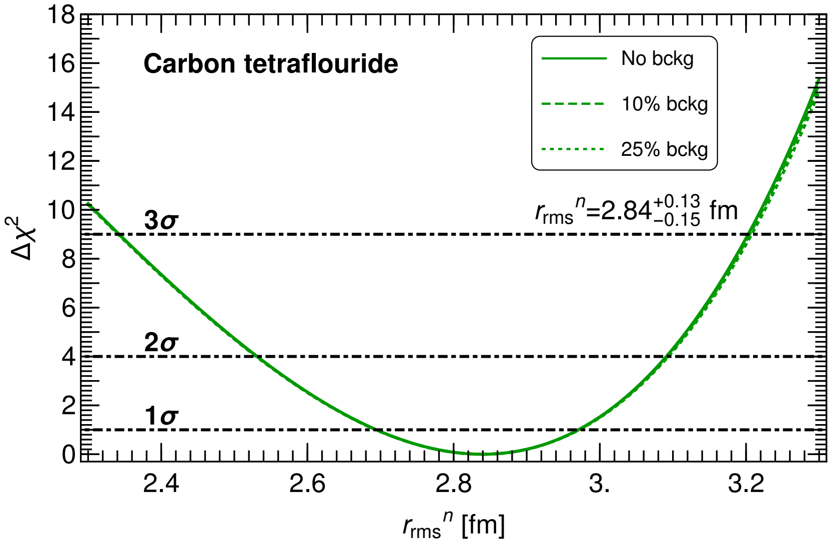


High-energy nature of the flux

⇒ Moderate dependence on the FF

⇒ Accounted for in signal uncertainty $\sim 10\%$

D.A. et al. arXiv:2103.10857



Approximation: $r^n_{\rm rms}|_{\rm C} = r^n_{\rm rms}|_{\rm F}$

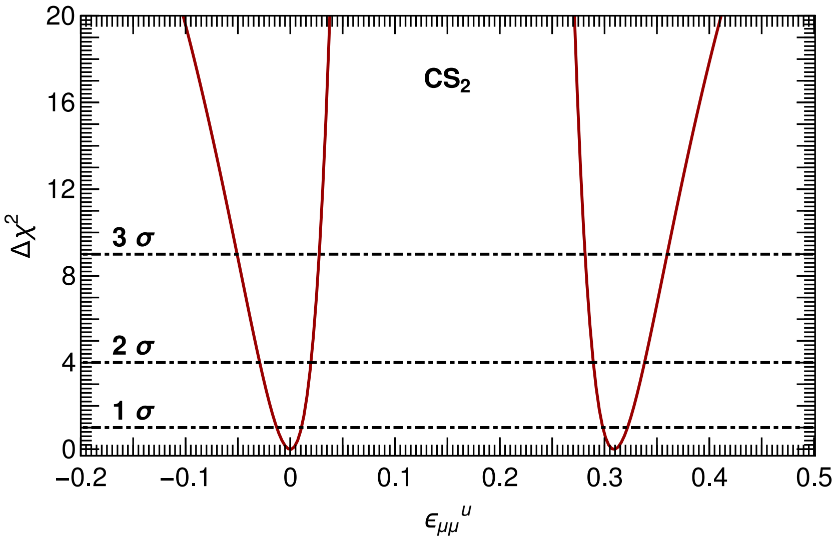
C and F determined with a 3% accuracy

Neutrino NSI

$$\mathcal{L}_{\text{NSI}} \sim G_F \bar{\nu}_a \gamma_\mu (1-\gamma_5)\nu_b \, q\gamma^\mu \epsilon^q_{ab} q$$

Initial state flavor, ν_μ: Only $\epsilon_{\mu b}$ parameters are testable

D.A. et al. arXiv:2103.10857



Region I: Deviations are small, $\epsilon^u_{\mu\mu} \to 0$

Region II: NSI exceeds SM by ~ 2

$\Rightarrow$ Destructive interference

ν**BDX-DRIFT CS$_2$** (7-years)		**COHERENT CsI** (1-year)	
$\epsilon^u_{\mu\mu}$	$[-0.013, 0.011] \oplus [0.30, 0.32]$	$\epsilon^u_{\mu\mu}$	$[-0.06, 0.03] \oplus [0.37, 0.44]$
$\epsilon^u_{e\mu}$	$[-0.064, 0.064]$	$\epsilon^u_{e\mu}$	$[-0.13, 0.13]$

Final remarks

Conclusions

✍ CEvNS offers a rich neutrino program, complementarity with CEvNS related agendas: ν-cleus, CONUS, CONNIE, DM detectors, COHERENT (SNS), νBDX-DRIFT...

✍ SM measurements include: Weak mixing angle at different low-energy scales neutron density distributions for Na, Ge, C, F, S, Pb

✍ BSM searches include: Neutrino NSI, NGI and light vector and scalar mediators, NMM

✍ νBDX-DRIFT combined with a high-energy neutrino beam (e.g. LBNF) is suitable for CEvNS measurements in

CS_2, CF_4, $C_8H_{20}Pb$...

Directionality improves background rejection