# CEvNS with the LBNF beamline and the $\nu$BDX-DRIFT directional detector

Diego Aristizabal

**USM, Chile**

**arXiv:2103.XXXXX**

Bhaskar Dutta (Texas A&M), Doojin Kim (Texas A&M)

Daniel Snowden-Ifft (Occidental College, LA, CA), Louis Strigari (Texas A&M)

daristizabal@uliege.be

daristi@gmail.com

# CE$\nu$NS

CE$\nu$NS occurs when the neutrino energy $E_\nu$ is such that nucleon amplitudes sum up coherently $\Rightarrow$ cross section enhancement

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

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

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

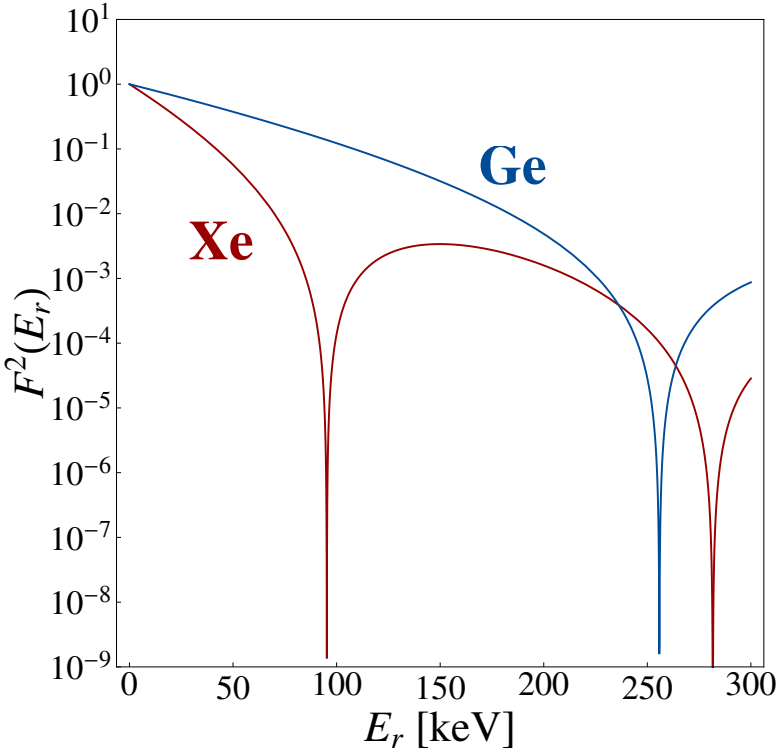


**Freedman, 1974**

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

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

**Helm, 1956**

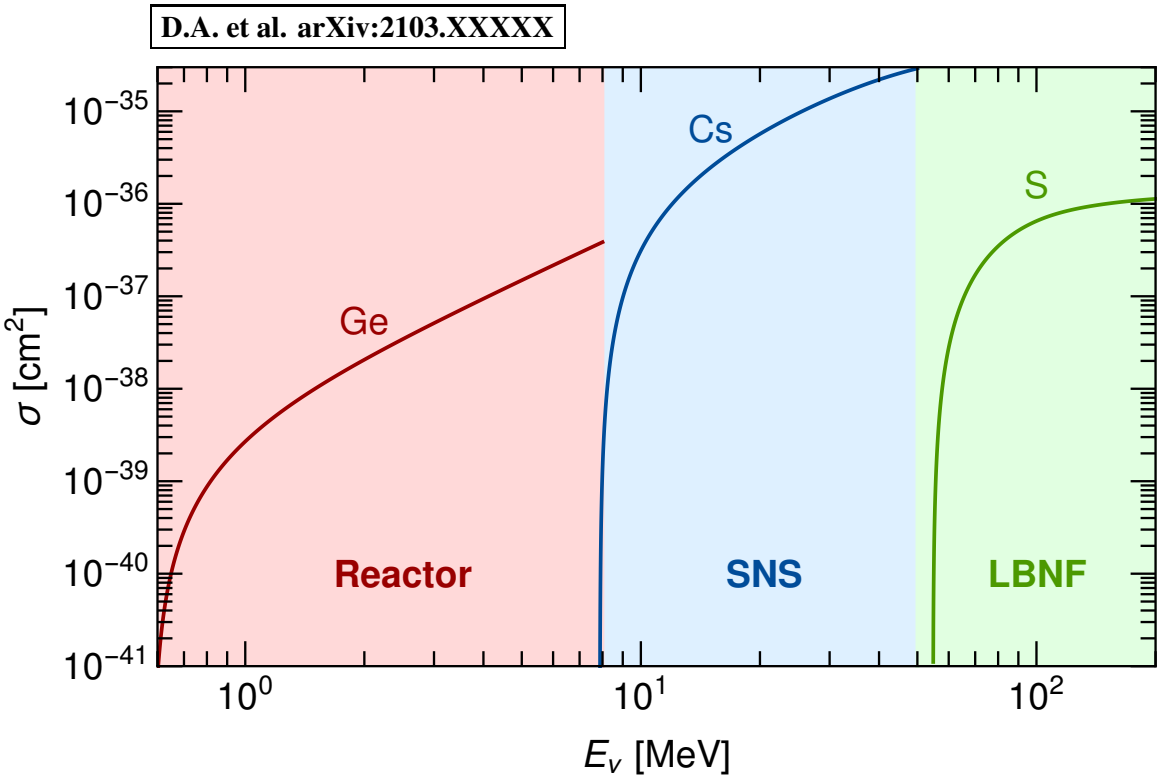


# Neutrino sources and CEvNS “regimes”



“Laboratory” sources: Reactor neutrinos, SNS neutrinos, LBNF (NuMI)

“Astrophysical” sources: Solar, DSNB, Atmospheric, SN burst



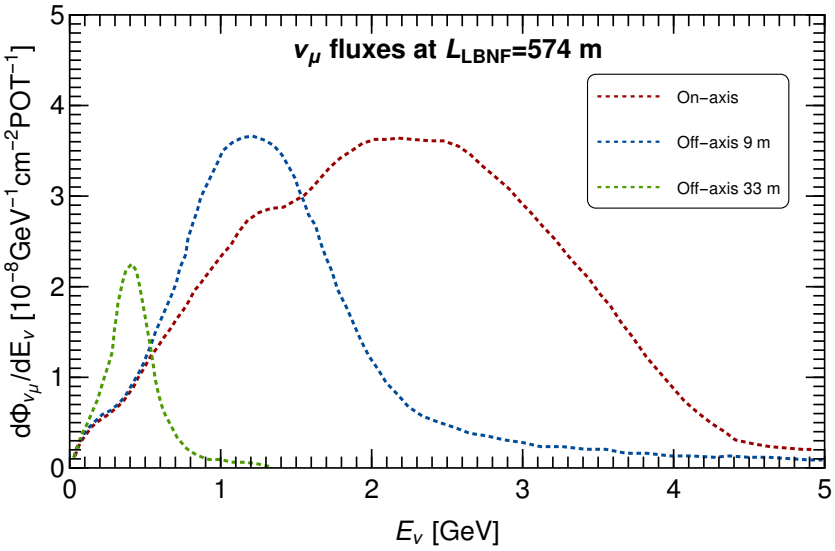

Entering the “high-energy” window requires a substantial amount of $\nu$’s in the low-enery tail

**LBNF provides that!**

# LBNF neutrino beamline low-energy tail



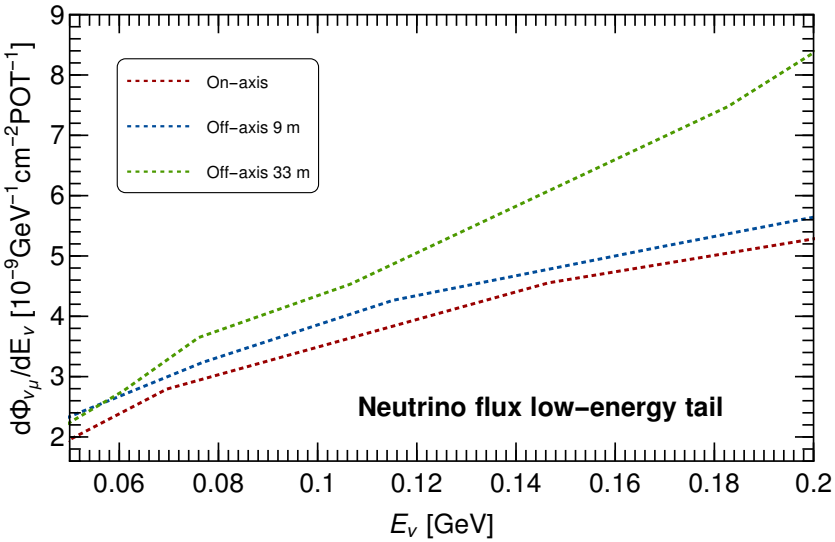
**arXiv:2002.03005**




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$^2$

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

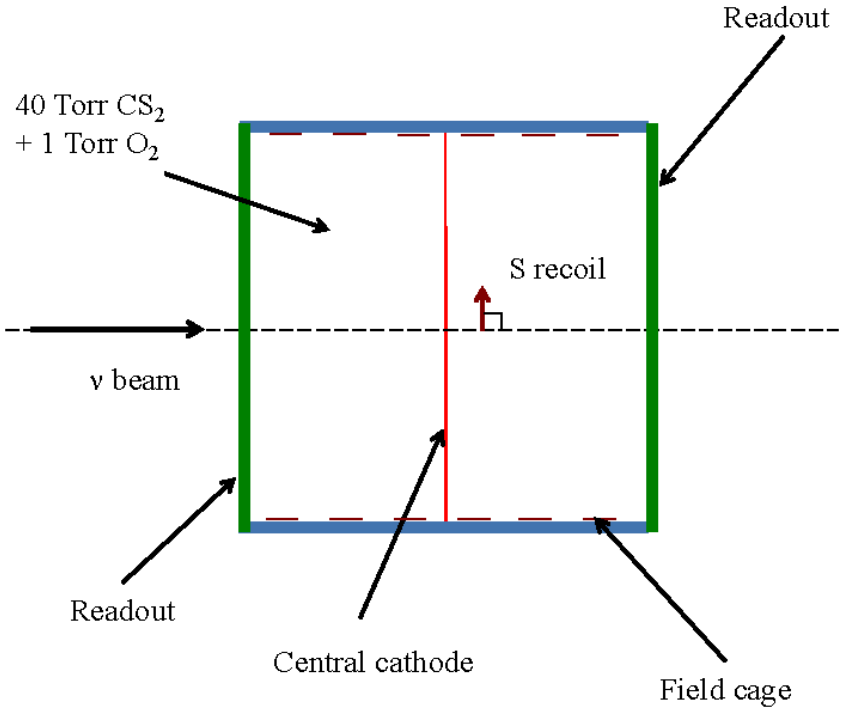
**Sizable number of events!**

# $\nu$BDX-DRIFT: Basics



➪ 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)

# Physics program



The combination of the LBNF neutrino beamline and the $\nu$BDX-DRIFT defines a neutrino program

**CEvNS measurements**

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

... Complementary to CONUS (Ge), CONNIE (Si), COHERENT (Ar, CsI, NaI)

**SM measurements**

Measurements of $\sin^2\theta_W$ at a new energy scale

... Complementary to DUNE measurements in electron channel

Measurements of neutron distributions in e.g. C, S, F, Pb...

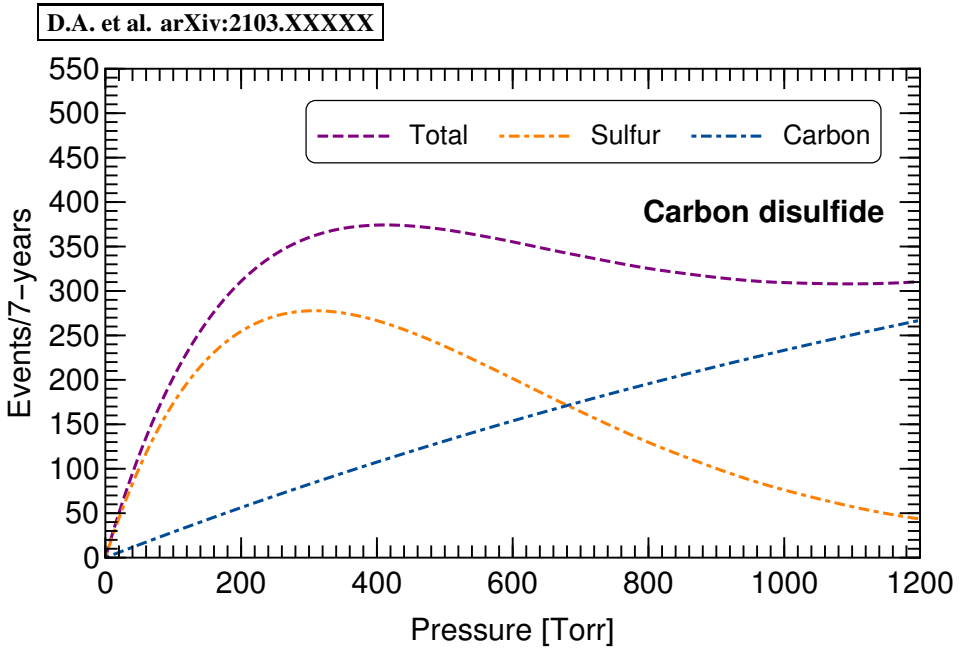
**BSM searches**

Neutrino NSI, NGI, Dark neutrino interactions...

# CEvNS signals

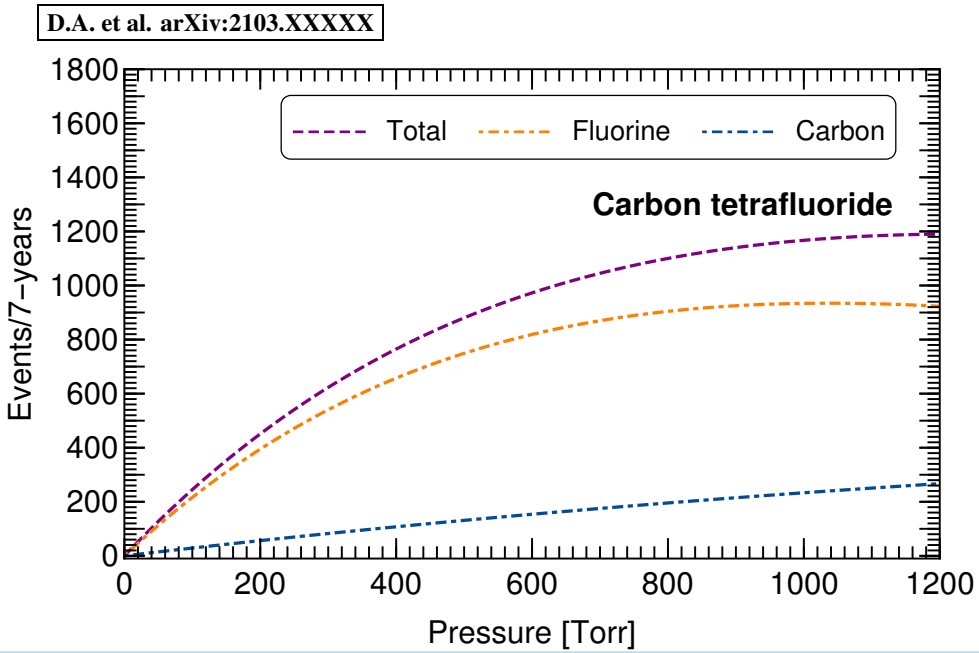
# Signals in $CS_2$ and $CF_4$






Signal peaks at 400 Torr

Expected signal: 370 events




100% filled with $CF_4$

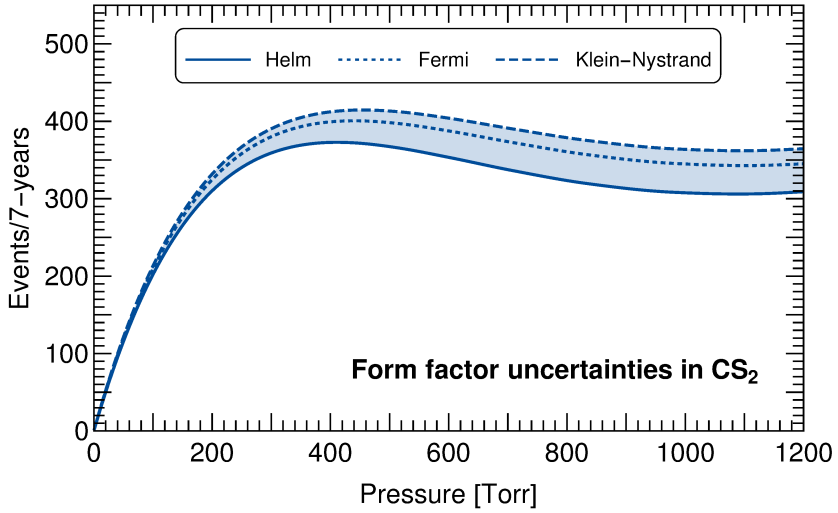
Expected signal: 880 events

# SM and BSM studies

# Neutron density distributions



**D.A. et al. arXiv:2103.XXXXX**

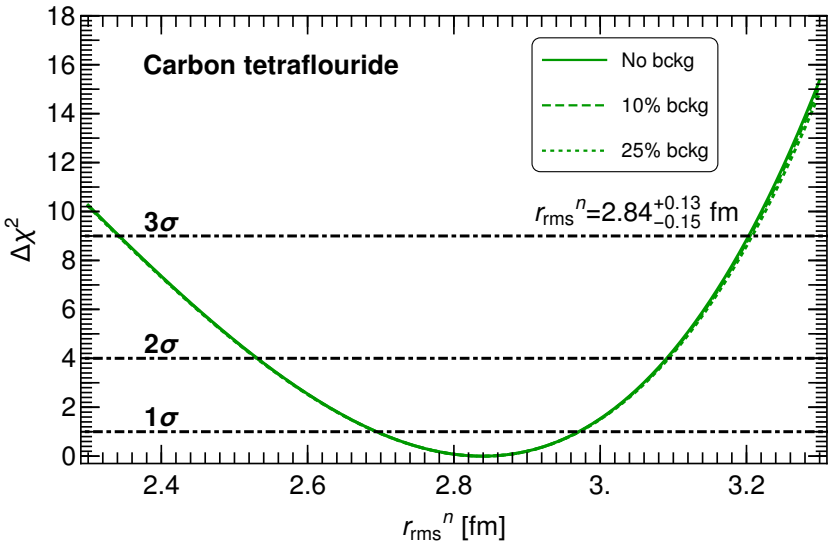



High-energy nature of the flux

⇒ Moderate dependence on the FF

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

**D.A. et al. arXiv:2103.XXXXX**




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

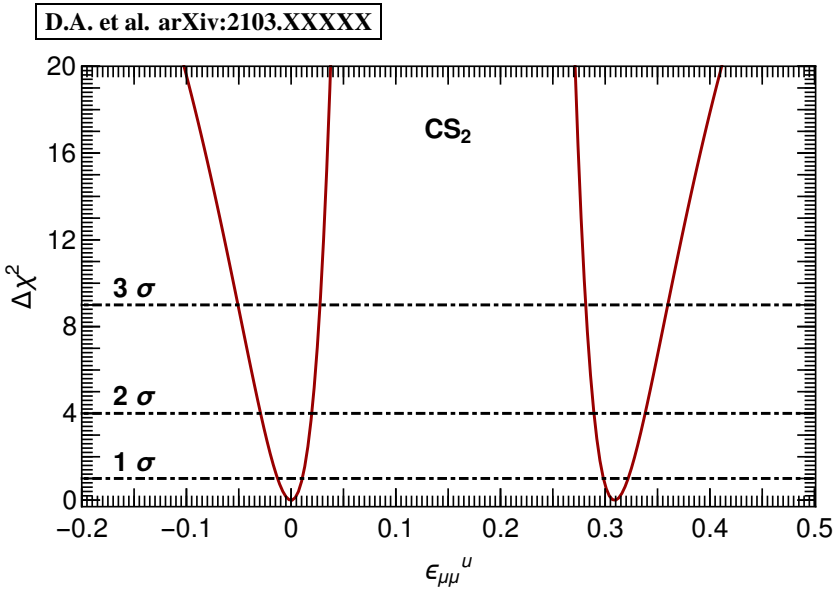
C and F determined with a 3% accuracy

# 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, $\nu_\mu$: Only $\epsilon_{\mu b}$ parameters are testable




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

Region II: NSI exceeds SM by $\sim 2$

$\Rightarrow$ Destructive interference

| **νBDX-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



✍ $\nu$BDX-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

✍ Offers a rich neutrino program, complementary to other CEvNS related agendas: $\nu$-cleus, CONUS, CONNIE, COHERENT (SNS)...

✍ SM measurements include: Weak mixing angle at $\langle Q \rangle \simeq 0.1\,\text{GeV}$ neutron density distributions of C, F, S, Pb with sensitivities of order 3-8%

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

Sensitivities for NSI: $\mathcal{O} \sim 10^{-2}$ couplings can be tested

✍ An agenda for light DM (MeV) is defined as well

$$\pi^0 \to \gamma + \gamma', \; e^* \to e + \gamma'$$

$$\gamma' \to \chi_{\text{DM}} + \chi_{\text{DM}}$$

**Work in progress**