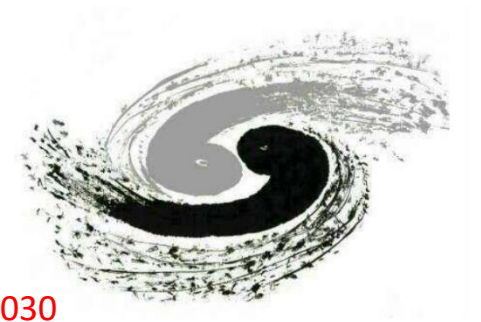# Constraints on neutrino electromagnetic properties from COHERENT elastic neutrino-nucleus scattering

Speaker:

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Based on a work in collaboration with M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, E. Picciau, Y. F. Li, Y. Y. Zhang.

Coherent Elastic Neutrino-Nucleus Scattering

- Predicted in 1974 for $|\vec{q}|R \ll 1$ [Freedman, Physical Review D, 1974, 9(5): 1389]

- Taking into account interactions with both neutrons and protons
  [P.A. Zyla et al., Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)]

$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2 M}{\pi}\left(1 - \frac{MT}{2E_\nu^2}\right)\left[g_V^n N F_N(q^2) + g_V^p Z F_Z(q^2)\right]^2$$

Tree Level $\boxed{g_V^n = -\frac{1}{2} \quad g_V^p = \frac{1}{2} - 2\sin^2\vartheta_W}$

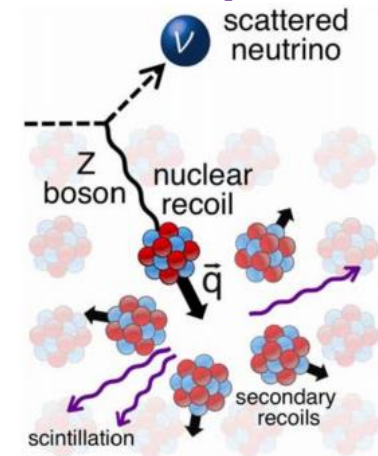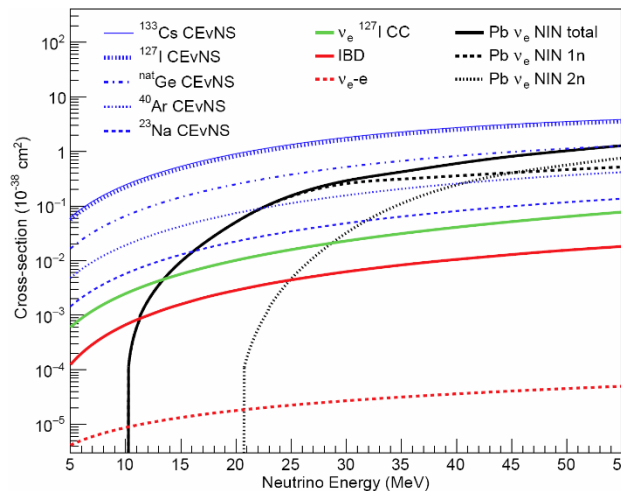**The neutron contribution is dominant!** $\Longrightarrow$ $\frac{d\sigma}{dT} \sim N^2 F_N^2(q^2)$

- The form factors $F_N(|\vec{q}|^2)$ and $F_Z(|\vec{q}|^2)$ describe the loss of coherence for $|\vec{q}|R \gtrsim 1$.

$$T \simeq |\vec{q}|^2/2M$$
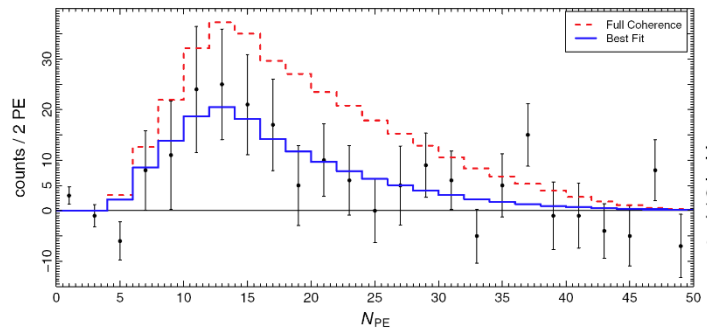$$M \sim 100 \text{ GeV}, \ R \sim 5 \text{ fm}$$
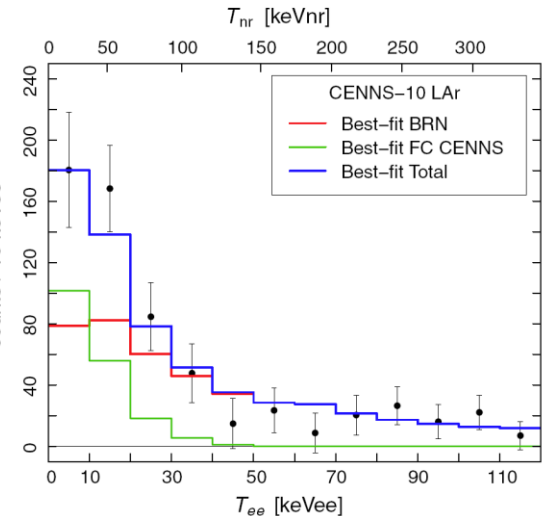$$\rightarrow T \lesssim 10 \text{ keV}$$
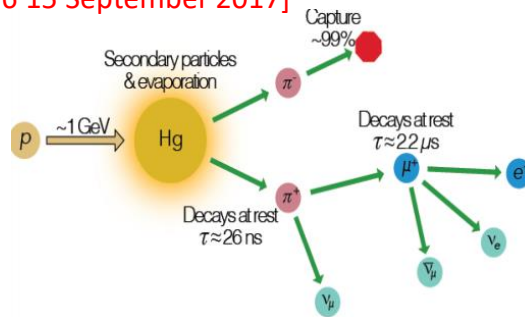
The COHERENT experiment

14.6 kg CsI(2017)

24 kg LAr(2020)

[Akimov et al. *Science* Vol 357, Issue 6356 15 September 2017]
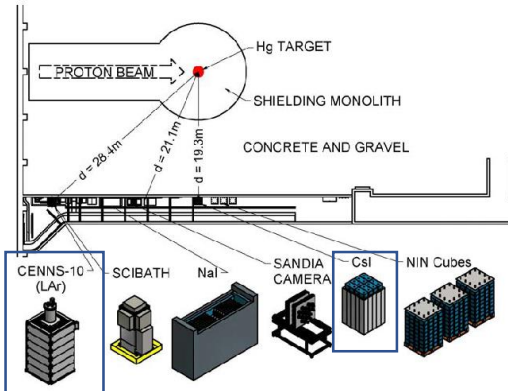
- Prompt monochromatic ν_μ:
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

- Delayed $\bar{\nu}_\mu$ and ν_e :
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

- The COHERENT energy and time information allow us to distinguish the interactions of ν_e, ν_μ and $\bar{\nu}_\mu$

[COHERENT, arXiv:1803.09183, arXiv:2003.10630]

Neutrino electromagnetic properties

- Effective electromagnetic Hamiltonian: [Giunti, Studenikin, RMP 87 (2015) 531, arXiv:1403.6344]

$$\mathcal{H}_{\mathrm{em}}^{(\nu)} = j_\mu^{(\nu)}(x) A^\mu(x) = \sum_{k,j=1}^{N} \bar{\nu}_k(x) \Lambda_\mu^{kj} \nu_j(x) A^\mu(x)$$

- Vertex function:

$$\Lambda_\mu(q) = \left(\gamma_\mu - q_\mu \slashed{q}/q^2\right)\left[F_Q(q^2) + F_A(q^2)q^2\gamma_5\right] - i\sigma_{\mu\nu}q^\nu\left[F_M(q^2) + iF_E(q^2)\gamma_5\right]$$

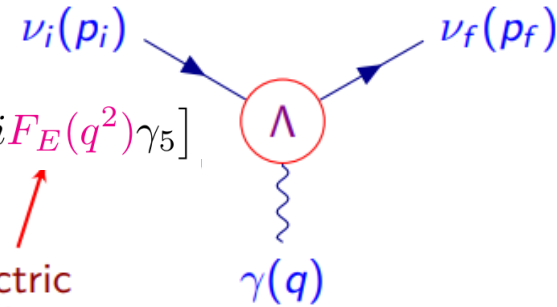Lorentz-invariant form factors: charge   anapole   magnetic   electric

$q^2 = 0 \implies$ $\mathbb{q}$ a μ ε

$$F_Q(q^2) = F_Q(0) + q^2 \frac{dF_Q(q^2)}{dq^2}\Big|_{q^2=0} + \cdots = q_\nu + \frac{q^2}{6}\langle r_\nu^2\rangle \cdots$$

In the Standard Model: $F_Q(q^2) \approx \dfrac{q^2}{6}\langle r_\nu^2\rangle$

Beyond the Standard Model: $F_Q(q^2) \approx q_\nu$

$$\frac{d\sigma_{\nu_\ell\text{-}\mathcal{N}}}{dT}(E,T) = \frac{G_{\mathrm{F}}^2 M}{\pi}\left(1 - \frac{MT}{2E^2}\right)\left\{\left[\left(g_V^p - \tilde{Q}_{\ell\ell}\right)ZF_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right]^2 + Z^2 F_Z^2(|\vec{q}|^2)\sum_{\ell'\neq\ell}|\tilde{Q}_{\ell'\ell}|^2\right\}$$

$$\frac{d\sigma_{\nu_\ell\text{-}\mathcal{N}}^{\mathrm{mag}}}{dT_{\mathrm{nr}}}(E,T_{\mathrm{nr}}) = \frac{\pi\alpha^2}{m_e^2}\left(\frac{1}{T_{\mathrm{nr}}} - \frac{1}{E}\right)Z^2 F_Z^2(|\vec{q}|^2)\left|\frac{\mu_{\nu_\ell}}{\mu_{\mathrm{B}}}\right|^2$$

$\dfrac{\sqrt{2}\pi\alpha}{3G_{\mathrm{F}}}\langle r_{\nu_{\ell\ell'}}^2\rangle$ $\dfrac{2\sqrt{2}\pi\alpha}{G_{\mathrm{F}}q^2}q_{\nu_{\ell\ell'}}$
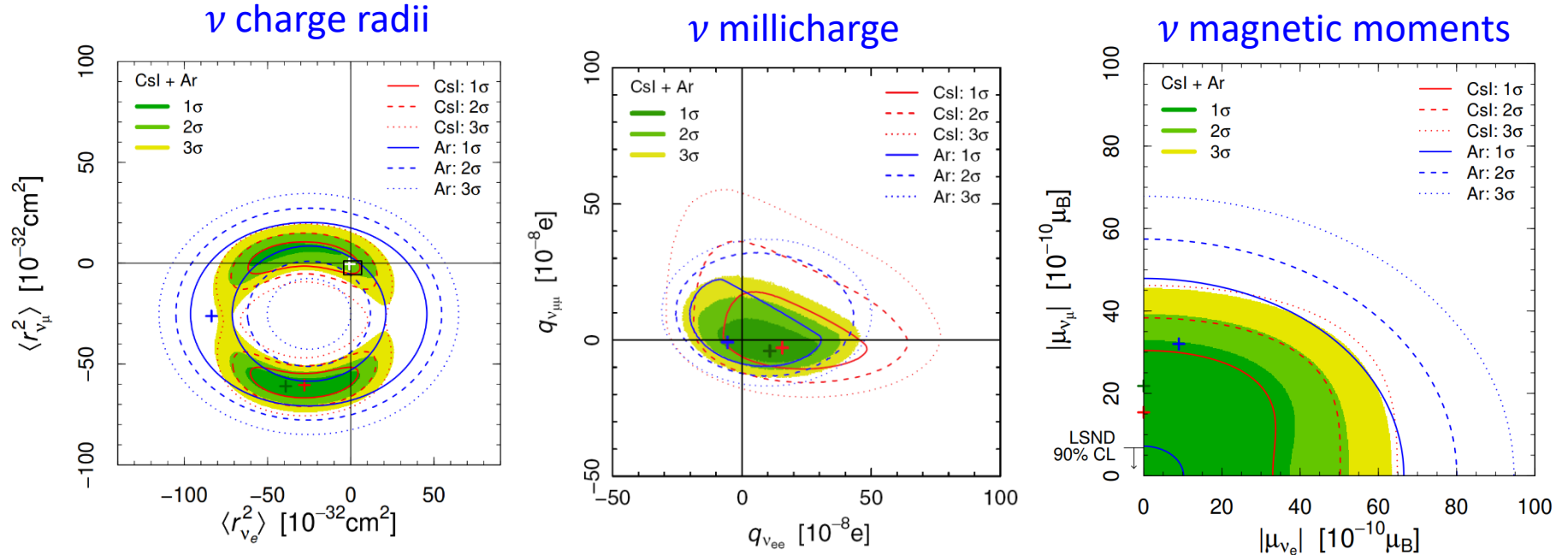
ν magnetic moments ν charge radii ν millicharge

Fit of COHERENT data: neutrino electromagnetic properties

[M. Cadeddu et al. *Phys.Rev.D* 102 (2020) 1, 015030)]

- constraints on the neutrino charge radii:

$$-78 < \langle r_{\nu_e}^2 \rangle < 22, -71 < \langle r_{\nu_\mu}^2 \rangle < 17 \quad [10^{-32} \text{cm}^2].$$

- constraints on the neutrino millicharge:

$$-20 < q_{\nu_e} < 42, -12 < q_{\nu_\mu} < 20 \quad [10^{-8}e].$$

- constraints on the effective neutrino magnetic moment:

$$|\mu_{\nu_e}| < 56, |\mu_{\nu_\mu}| < 41 \quad [10^{-10}\mu_B].$$

- Improvement of the only existing laboratory bound of $q_{\nu_{\mu\mu}}$.

- Muon neutrino magnetic moment only about five times larger than the best current laboratory limit.

Summary

- CEνNS: unique process to explore the neutrino electromagnetic properties.
- The combined fit of the COHERENT CsI and Ar: improvement of constraints on neutrino electromagnetic properties.
- CEνNS: a new way to explore the nuclear and neutrino physics
  - Electroweak precision tests:
    - M. Cadeddu et al. *Phys.Rev.D* 101 (2020) 3, 033004
    - O. Tomalak et al. *JHEP* 02 (2021) 097
  - NSI:
    - B. Dutta et al. *JHEP* 09 (2020) 106
    - C. Giunti, *Phys.Rev.D* 101 (2020) 3, 035039
  - light vector mediators(talk by Emmanuele)
    - O.G. Miranda et al. *JHEP* 05 (2020) 130
    - M. Cadeddu et al. *JHEP* 01 (2021) 116
  - Nuclear structure:
    - M. Cadeddu et al. Phys.Rev.Lett.120.072501
    - M. Cadeddu et al. arXiv: 2102.06153
    - D. K. Papoulias, *Phys.Rev.D* 102 (2020) 113004
    - P. Coloma et al. *JHEP* 08 (2020) 08, 030
  - …

Thanks