CEνNS as a probe of Z' through kinetic and mass mixing effects

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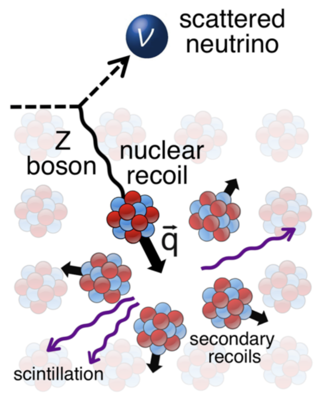
Motivation

Coherent elastic neutrino-nucleus elastic scattering (CEνNS)



Coherent scattering of neutrinos from nuclei [*]

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[*] from Akimov, D., et al. “Observation of coherent elastic neutrino-nucleus scattering.” Science 357.6356 (2017): 1123-1126.

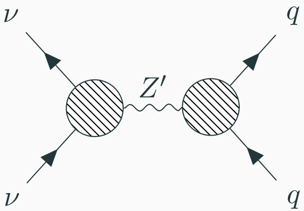
Differential cross section

Differential cross section of $\nu_\beta + N \to \nu_\alpha + N$ as a function of recoil energy E_r:

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 Q_V^2}{2\pi} m_N \left(1 - \left(\frac{m_N E_R}{E_\nu^2}\right) + \left(1 - \frac{E_R}{E_\nu}\right)^2\right) F(q^2)$$

$$Q_V^2 = \left[Z(\frac{1}{2} - 2\sin^2\theta_w) + N(-\frac{1}{2}) + (\mathrm{BSMcharges})\right]^2$$

Mixing with hypercharge gauge group



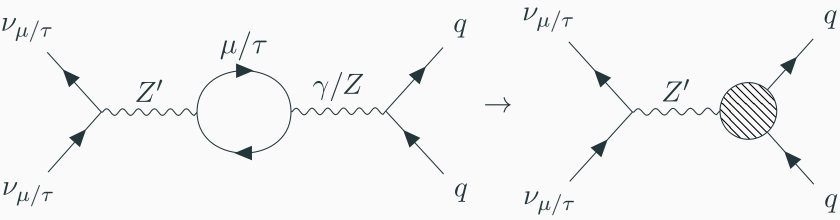
$$L_{\text{gauge}} = -\frac{1}{4}F_a^{\mu\nu}F_{a\mu\nu} - \frac{1}{4}F_b^{\mu\nu}F_{b\mu\nu} - \frac{\epsilon}{2}F_a^{\mu\nu}F_{b\mu\nu}$$

Symmetry breaking

$$\mathcal{L}_{\text{int}} = -\frac{g}{c_w} c_\alpha \left(t_\alpha + \eta s_w\right) \left(\tau_3 - \frac{t_\alpha + \eta / s_w}{t_\alpha + \eta s_w} s_w^2 Q\right) Z'_\mu \bar{f} \gamma^\mu f$$

1. Dark Z boson: $\eta \sim 0$, the interaction coupling becomes: $-\frac{g}{c_w} s_\alpha \left(\tau_3 - s_w^2 Q\right)$
2. Dark hypercharge boson: $s_\alpha \sim 0,\ c_\alpha \sim 1$, the interaction coupling becomes: $\frac{g}{c_w} s_w \epsilon \left(\tau_3 - Q\right) = \epsilon g' Q_Y$

$L_\mu - L_\tau$ model



Effective coupling between quark and Z':

$$\frac{8e^2 g'}{(4\pi)^2}\frac{1}{3}\ln\frac{m_\tau}{m_\mu}$$

Bounds

Existing bounds

1. Fixed target experiment[†]
2. Solar neutrino experiment[‡]
3. Atomic parity violation[§]
4. Neutrino trident production[¶]

[†] Phys. Rev. D38, 3375 (1988), Phys. Rev. Lett. 67, 2942 (1991)

[‡] 1707.09279

[§] Phys. Rev. D85, 115019 (2012)

[¶] Phys. Rev. Lett. 66, 3117 (1991)

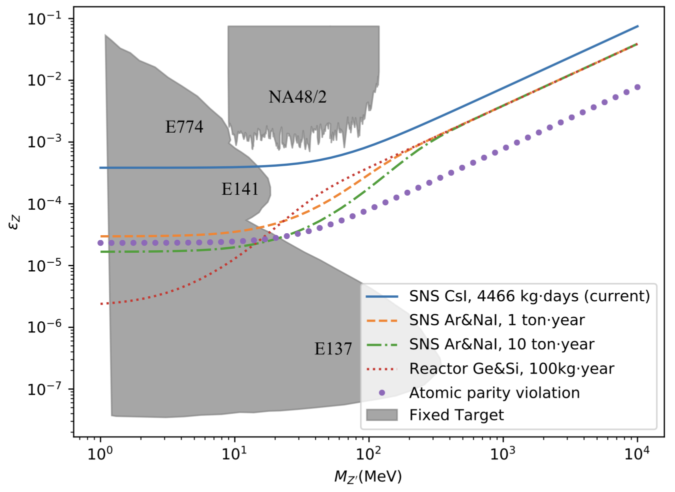
Analyzing tools

$$\chi^2 = \sum_{\text{bins,detectors}} \frac{\left(N_{exp} - (1+\beta)\, N_{pred}\right)^2}{N_{bg} + N_{exp}} + \left(\frac{\beta}{\sigma_\beta}\right)^2$$

Name	Detector	Source	Exposure	Threshold
Current (COHERENT)	CsI	SNS (20m)	4466 kg.days	4.25 keV
Future (reactor)	Ge	1GW reactor (20m)	10^5 kg.days	100 eV
	Si	1GW reactor (20m)	10^5 kg.days	100 eV
Future (accelerator)	NaI	SNS (20m)	1 or 10 ton.year	2 keV
	Ar	SNS (20m)	1 or 10 ton.year	30 keV

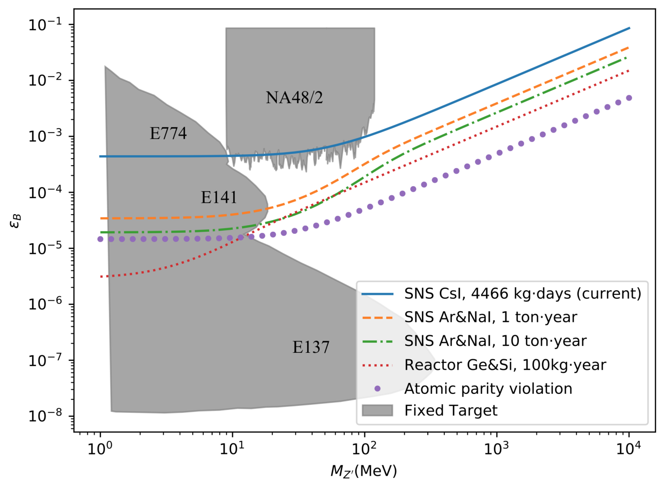
Experimental configurations used in this analysis

Current bounds and future projection for dark Z



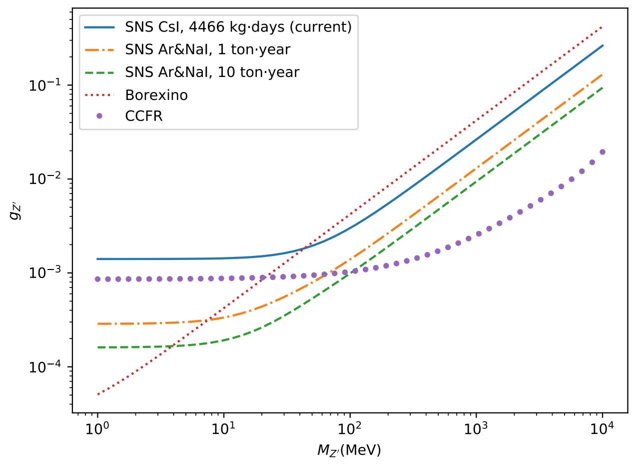
The current and future bounds on the mixing ϵ_Z in the dark Z case are plotted as a function of the Z' mass $M_{Z'}$.

Current bounds and future projection for dark hypercharge



The current and future bounds on the mixing ϵ_B in the dark hypercharge case are plotted as a function of the Z' mass $M_{Z'}$.

Current bounds and future projection for $L_\mu - L_\tau$



The current and future bounds on the coupling $g_{Z'}$ in the L_μ-L_τ model are plotted as a function of the Z' mass $M_{Z'}$.

Conclusion

Conclusion

- The capability of CEνNS to probe light $U(1)$ gauge boson though mixing effect is complementary to fixed target experiments and competitive to atomic parity violation experiments.
- CEνNS dominates Brexino and CCFR in $L_\mu - L_\tau$ scenario where mixing is generated through fermion loop.