

Neutrino-Mediated Forces as a Window to New Physics

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UK HEP Forum 2020: Quantum Leaps to the Dark Side,
10th November 2020

For more details see: [arXiv:2004.08328](https://arxiv.org/abs/2004.08328)

A Brief History of Forces

- Newton (1687) and Coulomb (1785)

$$F = G \frac{m_1 m_2}{r^2}, \quad F = k_e \frac{q_1 q_2}{r^2} \quad \Rightarrow \quad V \propto -\frac{1}{r}$$

- QFT: forces the exchange of E and p between interacting particles, carried by a virtual mediator

- Yukawa Interaction: $\mathcal{L} = -g \bar{\psi} \psi \phi$

$$V \propto -g^2 \frac{e^{-m_\phi r}}{r}$$

- Gravity and Fifth Force: How to incorporate gravity? Other long-range forces? Non-standard scaling?

e.g. Axion, dark photon, Z' , dilaton etc.



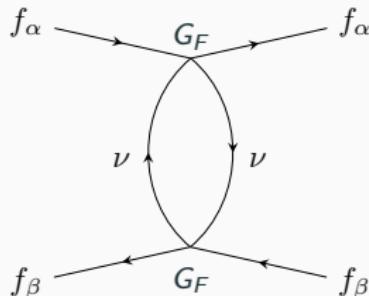
- SM:



Neutrino-Mediated Long-Range Force

- Massless neutrinos

$$V = \frac{G_F'^2}{4\pi^3 r^5}, \quad G_F' = G_F(1 + g_V^\ell)$$

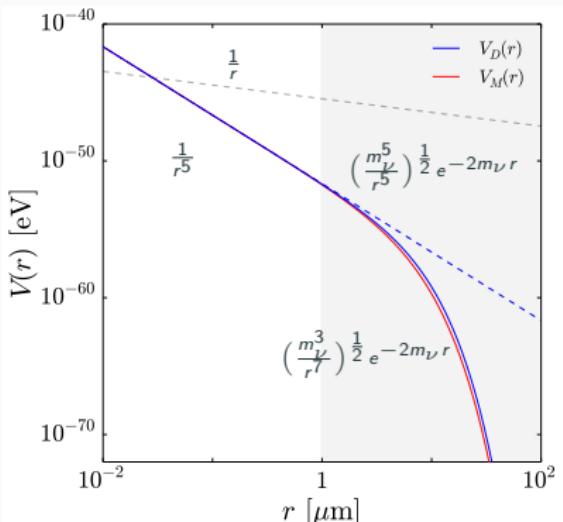


- Massive neutrinos

$$V_D = \frac{G_F'^2 m_\nu^3}{4\pi^3 r^2} K_3(2m_\nu r)$$

$$V_M = \frac{G_F'^2 m_\nu^2}{2\pi^3 r^3} K_2(2m_\nu r)$$

$$\Rightarrow r \sim \frac{1}{2m_\nu} \sim \frac{1}{0.2 \text{ eV}} \sim 1 \text{ } \mu\text{m}$$



Effective Neutrino Interactions and Potentials

- So far only considered SM CC and NC interactions

Effective neutrino interactions:

$$\mathcal{L} = \frac{G_F}{\sqrt{2}} c_{\nu\nu ff} (\bar{\nu} \Gamma \nu) (\bar{f}_\alpha \Gamma' f_\alpha)$$

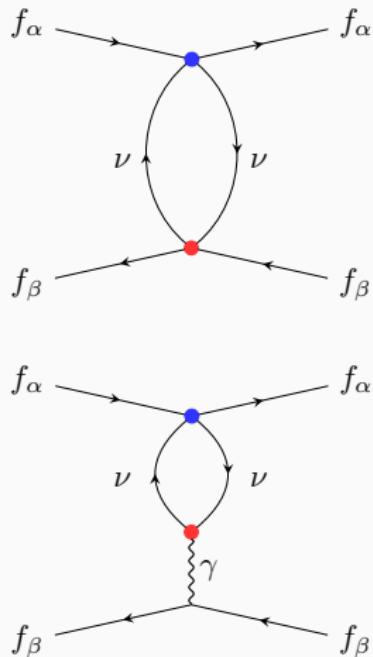
$$\mathcal{L} = c_{\nu\nu\gamma} (\bar{\nu} \Lambda_{\alpha\beta} \nu) F^{\alpha\beta}$$

⇒ Γ, Γ' can be $V \pm A, S, P, T$

⇒ $\Lambda_{\alpha\beta}$ magnetic/electric dipole moment

- Determine distance and spin dependence of non-standard potentials V , e.g.

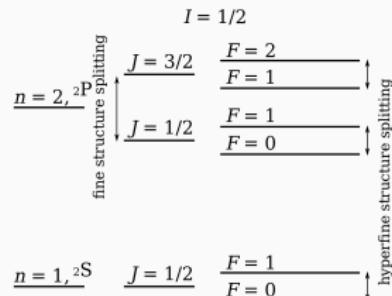
$$V^{V+A} = \frac{G_F'^2 m_\nu^2}{16\pi^3 r^3} \cdot c_{\nu\nu ff}^{V+A}$$



Atomic Spectroscopy

- Shift to atomic energy levels in perturbation theory

$$|\delta E| = \left\langle n^{2S+1} L_J \middle| V \middle| n^{2S+1} L_J \right\rangle$$



- Probes: 1S – 2S and hyperfine splittings of 2-body systems ($e^- e^+$, $e^- \mu^+$, H, D, muonic H, muonic D)

- Compare δE_{th} to δE_{exp} (1-hfs of $e^- \mu^+$)

⇒ Rough bound on $c_{\nu\nu ff}^{V+A}$ and Λ_{NP} :

$$|c_{\nu\nu ff}^{V+A}| \lesssim 3.6 \times 10^2$$

$$\Lambda_{\text{NP}} \gtrsim 10^2 \text{ GeV}$$

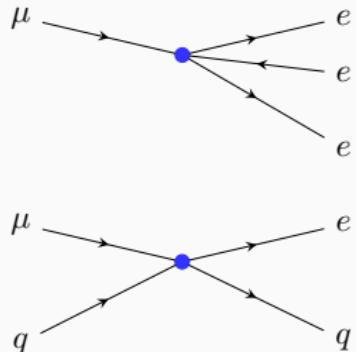


Comparison to cLFV and Future

- Currently most stringent constraints from **cLFV**
 $\mu \rightarrow 3e$ and $\mu N \rightarrow eN$
- However, for atomic-scale probes the EFT is valid down to

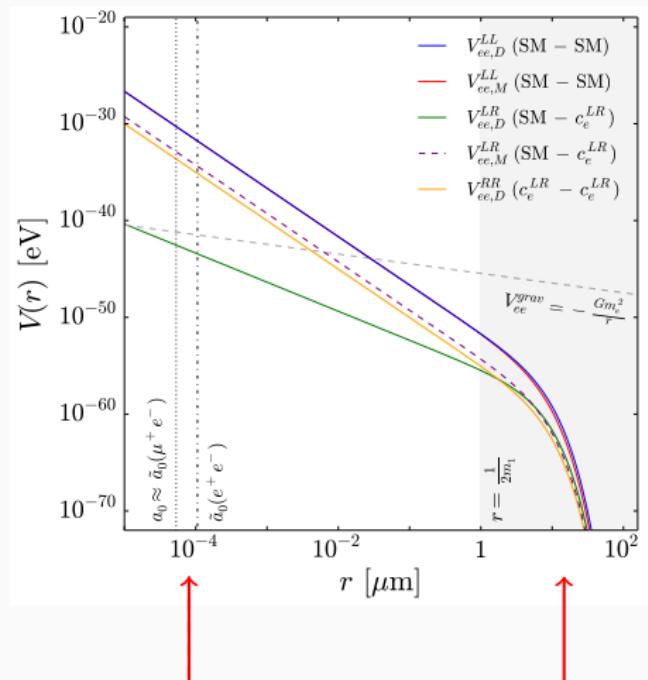
$$\Lambda_{\text{NP}} \gtrsim \alpha m_e \approx 3 \text{ keV}$$

- Improved precision (for $e^- \mu^+$) from
 - ⇒ Rabi oscillation spectroscopy at J-PARC (**MuSEUM**)
 - ⇒ Novel cryogenic and confinient techniques at PSI (**Mu-MASS**) improving on 1999 RAL measurement
- Explosion in quantum technologies around the world makes for an exciting time in the search for new forces



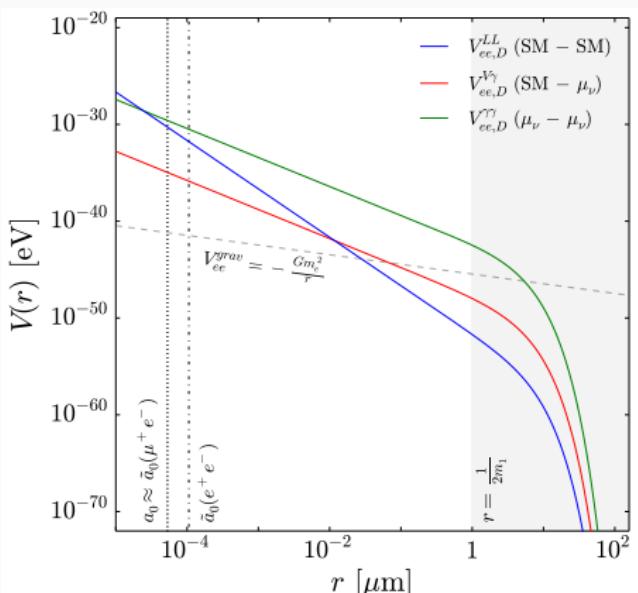
Backup

Non-Standard Potentials



Atomic Spectroscopy

Aggregate coherent weak charge violating WEP
[Segarra, Bernabéu, 2020]



arXiv:2004.08328