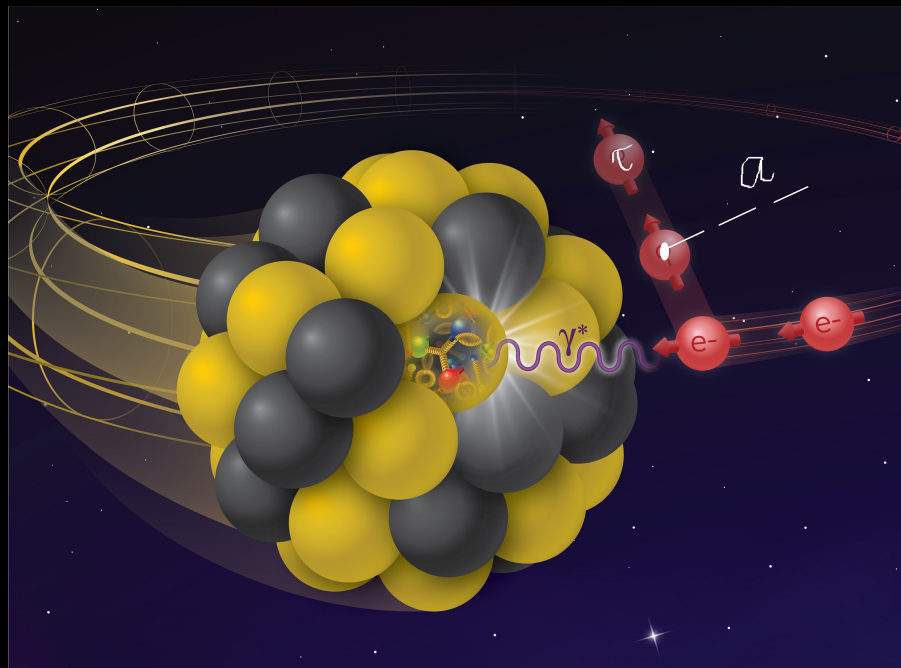


Lepton-Flavor-Violating ALPs at the Electron-Ion Collider: A Golden Opportunity

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Based on: H.D., R. Marcarelli, E. Neil, 2112.04513 [hep-ph]

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Introduction:

- Axion-like-particles (ALPs): well-motivated
 - Goldstone boson products of global symmetry breaking
 - Already observed: pions of QCD from $SU(2)_L \times SU(2)_R$ breaking
 - Relatively light, due to explicit breaking by light quark masses (Pseudo-Goldstone boson)
 - PQ Axions: may resolve strong CP puzzle ($\bar{\theta} \lesssim 10^{-9}$)
 - Show up in other theoretical contexts, e.g. dark matter models
 - Dark sector confinement: dark pion ALPs
- For example, H.D., Giardino, Neil, Rinaldi, 1709.01082

- Often ALP couplings are assumed to be diagonal in flavor
- In general, this need not be the case
- We focus on ALP mediated lepton-flavor-violation (LFV), in particular $e\text{-}\tau$
 - ALPs of GeV scale masses or larger
 - Possible parity violation (PV) effects
 - Prospects for discovery at the planned EIC at BNL

See also: [Gonderinger, Ramsey-Musolf, 1006.5063](#), for leptoquark mediated $e\text{-}\tau$ LFV at the EIC; [Liu, Yan, 2112.02477](#), for probing ALP $\gamma\gamma$ coupling at the EIC

- Advantages of EIC
 - Relatively large $\sqrt{s} \sim 100$ GeV
 - e -beam polarization (probe of PV)
 - Large Z (atomic number) ions: enhanced coherent EM scattering $\propto Z^2$
 - We will choose **gold** ($Z = 79$), as an example

- Important relevant interaction:

$$\mathcal{L}_\ell = \frac{\partial_{\mu a}}{\Lambda} \sum_{\ell\ell'} \bar{\ell} \gamma^\mu (V_{\ell\ell'} + A_{\ell\ell'} \gamma_5) \ell' + h.c. \quad (1)$$

- $V_{\ell\ell'}, A_{\ell\ell'}$ real, CP conserved; PV from $V_{\ell\ell'}$
- To parameterize PV, define

$$\theta_{\ell\ell'} = -\tan^{-1}(V_{\ell\ell'}/A_{\ell\ell'})$$

with $C_{\ell\ell'} = \sqrt{V_{\ell\ell'}^2 + A_{\ell\ell'}^2}$

- Use equations of motion:

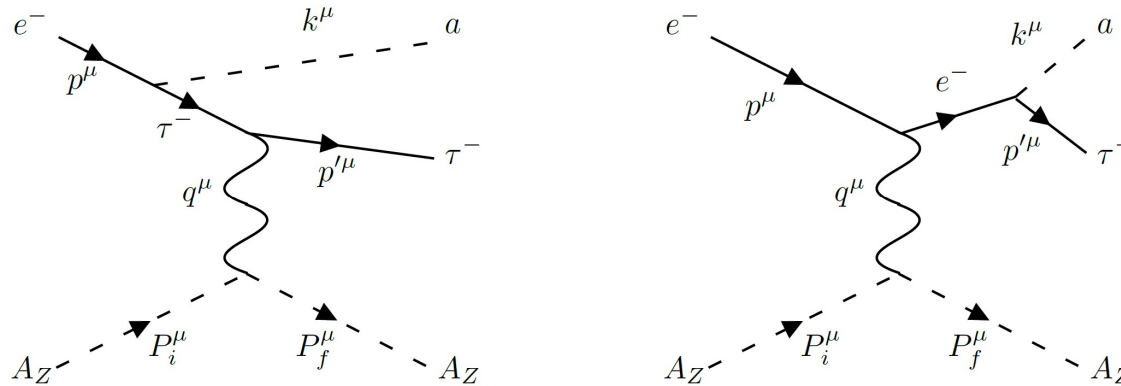
$$\mathcal{L}_\ell = \frac{C_{\ell\ell'}}{\Lambda} a \sum_{\ell\ell'} \bar{\ell} (m^- \sin \theta_{\ell\ell'} - m^+ \cos \theta_{\ell\ell'} \gamma_5) \ell' + h.c., \quad (2)$$

where $m^\pm \equiv m_\ell \pm m_{\ell'}$

- Left-right asymmetry:

$$r_{LR}(\theta_{\tau e}) = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \sin 2\theta_{\tau e}$$

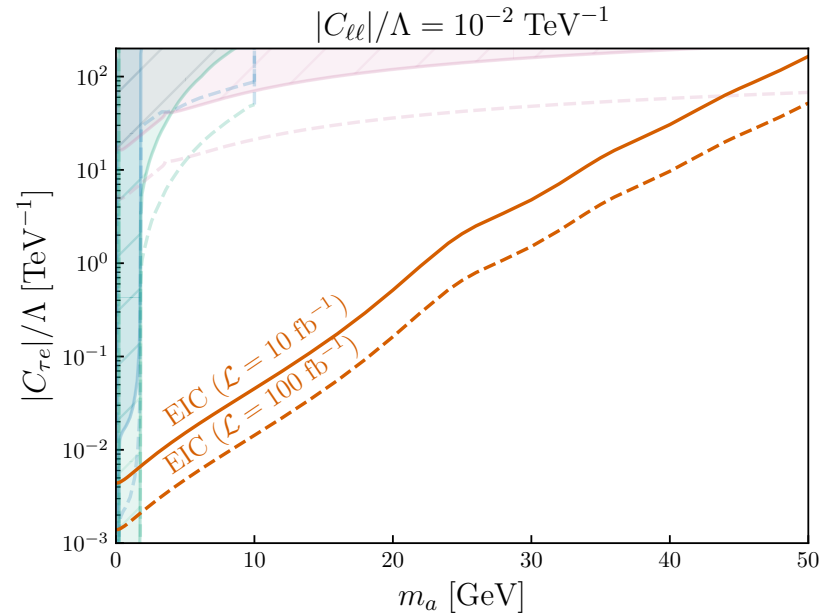
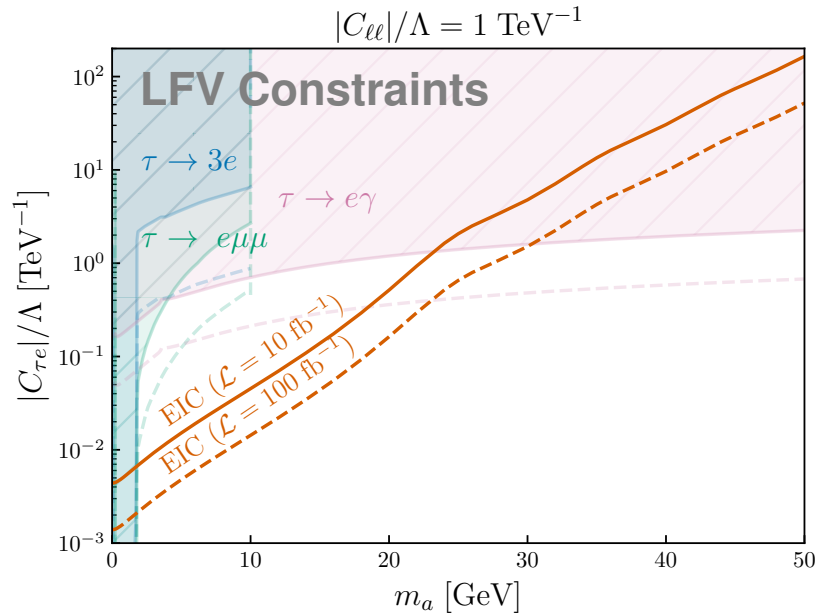
- Two leading diagrams



- At low Q^2 , enhanced coherent scattering $\propto Z^2 \sim 6000$
- Assume ion is a boson: $iV^\mu(q^2, P_i, P_f) = ieZF(q^2)(P_i^\mu + P_f^\mu)$
- Form factor: approximating Fourier transform of the Woods-Saxon distribution

$$F(q^2) = \frac{3}{q^3 R_A^3} (\sin qR_A - qR_A \cos qR_A) \frac{1}{1 + a_0^2 q^2}$$

where $a_0 = 0.79$ fm, $R_A = (1.1 \text{ fm})A^{1/3}$



- Constraints from BABAR (solid) and projections from Belle II (dashed)
- LFV τ -decay bounds (90% CL) from [Cornella, Paradisi, Sumensari, JHEP 01, 158 \(2020\), 1911.06279](#); $\tau \rightarrow e\gamma$ calculated from their formulas
- EIC exclusion limits (90% CL):
 - Assume acceptance \times efficiency $\varepsilon = 1$
 - $a \rightarrow$ leptons inside detector; zero background $\tau^{-\ell^+\ell'}$ final state; e.g. $\ell = \mu, \ell' = e$
 - Sensitivity to $C_{\tau e}$ drops as $\sqrt{\varepsilon}$ (estimates not expected to change significantly)
- For envisioned $\int \mathcal{L} dt$ ([EIC Yellow Report; Abdul Khalek et al., 2103.05419](#)), EIC probes $C_{\tau e}$ well-beyond other projections (right panel: suppressed diagonal couplings)