SEARCH FOR $e \to \tau$ LFV AT THE ELECTRON-ION COLLIDER (EIC)

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OUTLINE

- Review of present LFV limits
- Introduction to leptoquarks
- EIC probe of leptoquark $e \to \tau$
- Comparison of EIC with $\tau \to e\gamma$ limits
- Concluding remarks

OVERVIEW OF LFV SEARCHES

- Present & future limits for LFV processes:

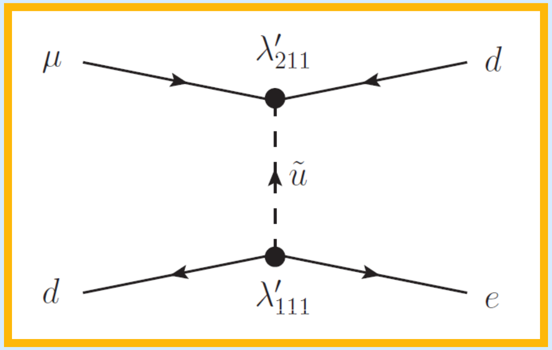
Process	Experiment	Limit $(90\% \; C.L.)$	Year
$\mu \to e\gamma$	MEGA	$Br < 1.2 \times 10^{-11}$	2002
$\mu + Au \to e + Au$	SINDRUM II	$\Gamma_{conv}/\Gamma_{capt} < 7.0 \times 10^{-13}$	2006
$\mu \to 3e$	SINDRUM	$Br < 1.0 \times 10^{-12}$	1988
$\tau \to e\gamma$	BaBar	$Br < 3.3 \times 10^{-8}$	2010
$\tau \to \mu\gamma$	BaBar	$Br < 6.8 \times 10^{-8}$	2005
$\tau \to 3e$	BELLE	$Br < 3.6 \times 10^{-8}$	2008
$\mu + N \to e + N$	Mu2e	$\Gamma_{conv}/\Gamma_{capt} < 6.0 \times 10^{-17}$	2017?
$\mu \to e\gamma$	MEG	$Br \lesssim 10^{-13}$	2011?
$\tau \to e\gamma$	Super-B	$Br \lesssim 10^{-9}$	$>$ 2020?

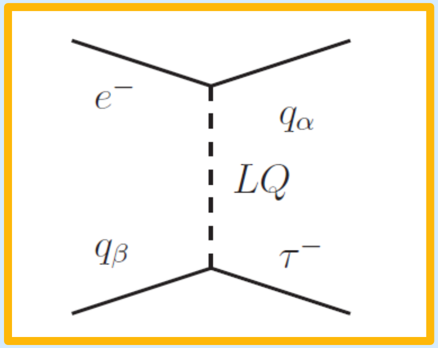
QUESTIONS FOR EIC LFV SEARCH

- The EIC is a proposed high energy, high luminosity electron-proton/ion collider
- Is a search for $e \to \tau$ at the EIC feasible given present limits?
  - What sort of cross sections can be expected and what integrated luminosities are needed?
- Would EIC limits on $e \to \tau$ be competitive with present and future limits from other LFV processes?
  - EIC and Super-B are roughly the same time scale, so $\tau \to e\gamma$ limits are important
  - Present limits on $\mu \to e$ and $\mu \to e\gamma$ are already orders of magnitude stronger than $\tau \to e\gamma$ limits and will continue to improve

WHY LEPTOQUARKS?

- Deep inelastic $e + p \to \tau + X$ at the EIC can be described by a four-fermion operator
- Four-fermion operator arises in RPV SUSY and leptoquark models when integrating out massive propagators
  - Expected to give larger cross sections than other operators (tree level process, no loop or α suppression)





- Use leptoquarks for an initial analysis of $e \to \tau$
  - Direct comparison with limits from HERA

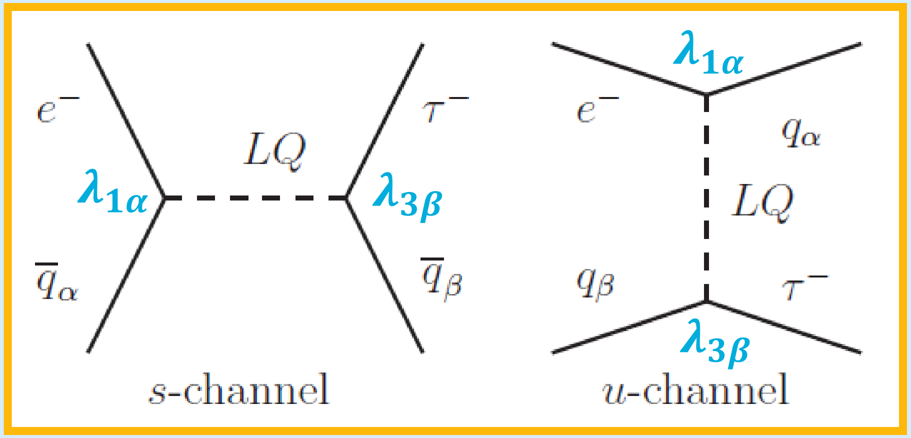
BRW LEPTOQUARK FRAMEWORK

- Leptoquarks (LQs) couple leptons and quarks
- LQs come in many different types:
  - Spin: 0 (scalar) or 1 (vector)
  - Fermion number: $|F| = |3B + L| = 0,\ 2$
  - $SU(2)_L$ representation: singlet, doublet, triplet
  - Chirality: L- or R-handed couplings
- Buchmuller-Ruckl-Wyler (BRW) parameterization catalogs all possible types
  - SM gauge invariant renormalizable Lagrangian gives interactions between LQs and fermions
- 14 LQs in all, assuming L- and R-handed couplings are independent

CROSS SECTION

- High mass approximation: $s \ll M_{LQ}^2$

$$\sigma_{scalar}^{F=0} = \frac{s}{32\pi}\left[\frac{\lambda_{1\alpha}\lambda_{3\beta}}{M_{LQ}^2}\right]^2 \left\{\int dxdy\,\frac{1}{2}x\bar{q}_\alpha(x,xs) + \int dxdy\,\frac{(1-y)^2}{2}xq_\beta(x,-u)\right\}$$



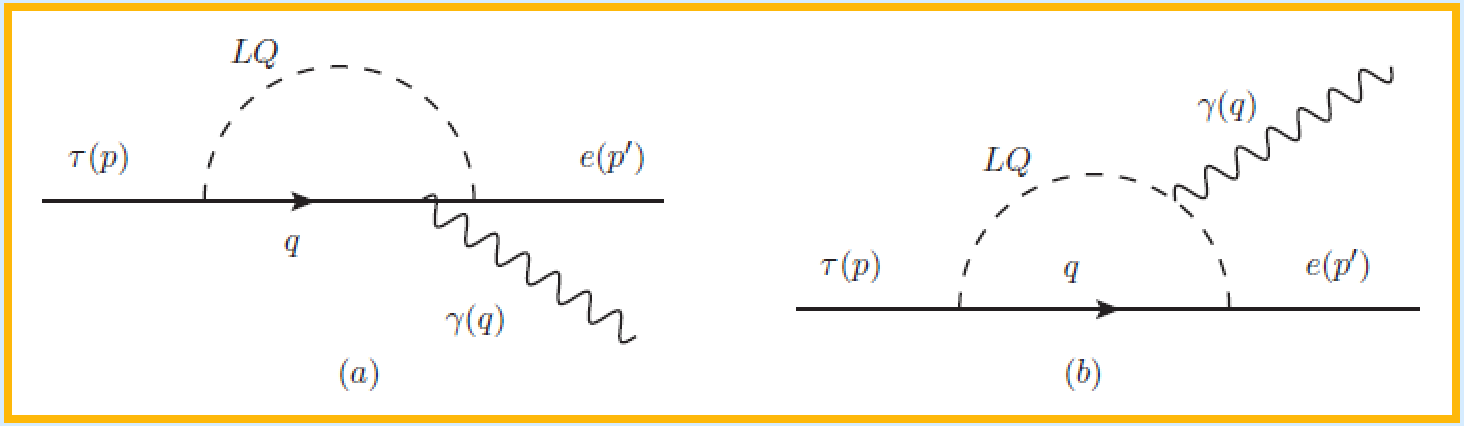
- ZEUS and H1 experiments set limits on these ratios $\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2$ (limits are also taken from various other rare process searches)

EIC SENSITIVITY

- Ratios $\boldsymbol{\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2}$ are the quantities of interest
- Suppose $\sqrt{s} = 90\ GeV$ and $1000\ fb^{-1}$ integrated luminosity
  - $\Rightarrow$ probe $e \rightarrow \tau$ cross sections $\sigma \gtrsim 0.001\ fb$ (order 1 events)
- $\sigma = 0.001\ fb$ corresponds to the smallest value of $\boldsymbol{\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2}$ to which the EIC would be sensitive in principle
  - These values are generally $\sim 1 - 2$ orders of magnitude smaller than ZEUS/H1 limits
  - Exact decrease depends on type of LQ, quark generations (α, β)
- The EIC surpasses HERA limits because of the larger luminosity
- How do potential EIC limits on $\boldsymbol{\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2}$ compare with limits on those same ratios from $\tau \rightarrow e\gamma$?

LEPTOQUARK LOOPS

- $\tau \to e\gamma$ decay via leptoquark loops:



- These diagrams are proportional to $\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2$ with $\alpha = \beta$
  - $\tau \to e\gamma$ limits are only relevant for these "quark flavor-diagonal" cases

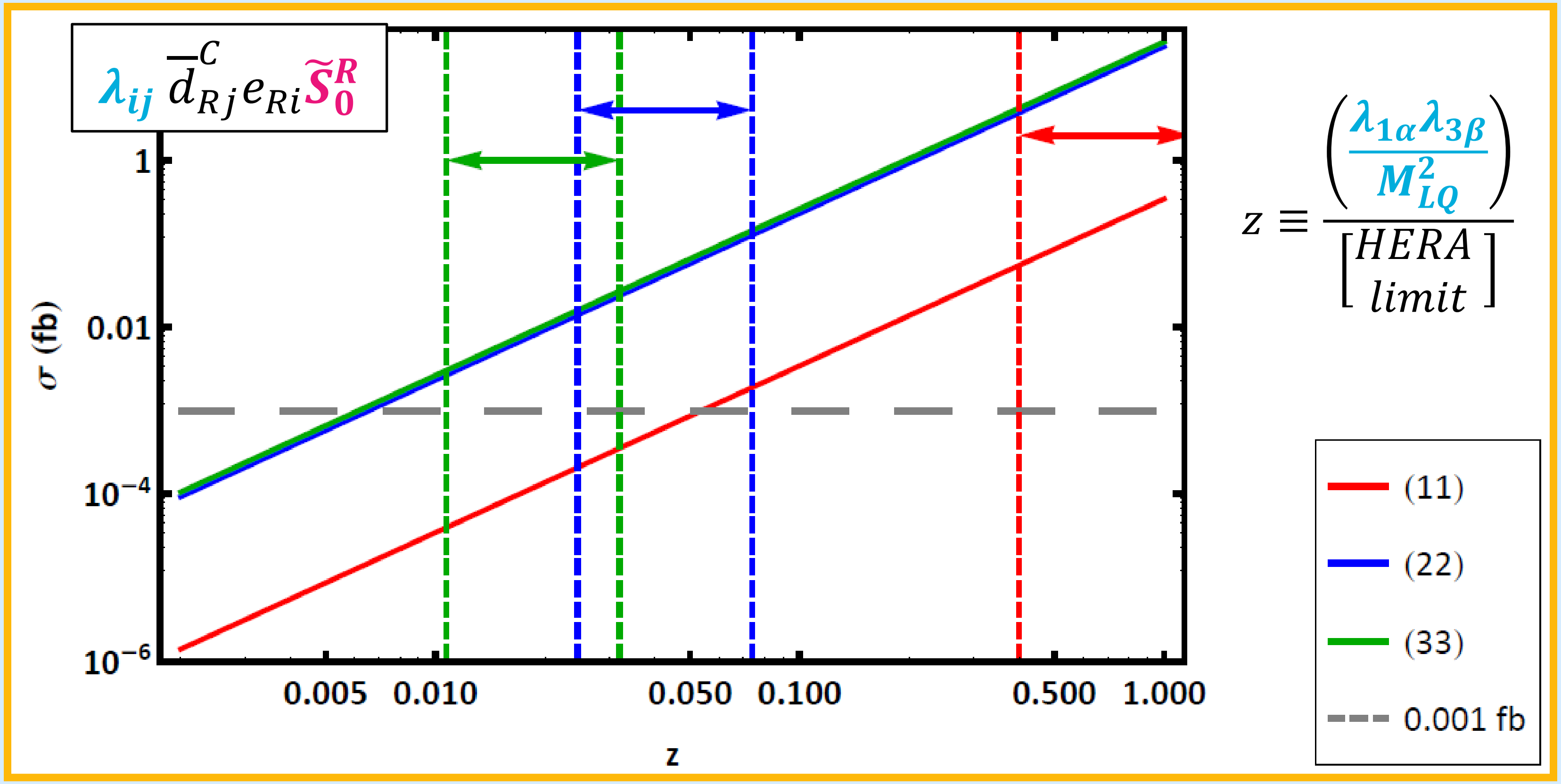
LOOP CALCULATIONS

$$R(\tau \to e\gamma) \equiv \frac{\Gamma(\tau \to e\gamma)}{\Gamma(\tau \to e\bar{\nu}_e \nu_\tau)} = \frac{48\pi^3 \alpha_{EM}}{G_F^2}\left(\left|A_2^L\right|^2 + \left|A_2^R\right|^2\right) \leq 1.85 \times 10^{-7}$$

- $A_2^{L,R}$ are the magnetic moment operator coefficients in the general form for the $\tau \to e\gamma^*$ amplitude
- Calculate $A_2^{L,R}$ coefficients in the limit $m_e, m_\tau \to 0$, $m_q/M_{LQ} \ll 1$ and extract limits on $\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2$
  - Actually obtain a range of possible upper bounds on $\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2$ from $\tau \to e\gamma$ because of a sum over the quark generations

ALL RESULTS

- Dashed lines are $\tau \to e\gamma$ upper bounds



$$z \equiv \frac{\left(\frac{\lambda_{1\alpha}\lambda_{3\beta}}{M_{LQ}^2}\right)}{\left[\begin{array}{c}HERA\\ limit\end{array}\right]}$$

EIC VS. $\tau \rightarrow e\gamma$

- Generally, where $\tau \rightarrow e\gamma$ limits apply:
  - With $1000\ fb^{-1}$, EIC can probe beyond the current $\tau \rightarrow e\gamma$ limits for all three generations
- Suppose Super-B factories improve the $\tau \rightarrow e\gamma$ branching fraction limit by an order of magnitude: $Br(\tau \rightarrow e\gamma) \sim 10^{-9}$
  - Limits on the ratios $\boldsymbol{\lambda_{1\alpha}\lambda_{3\alpha}/M_{LQ}^2}$ decrease by a factor of $\sqrt{10}$
  - The EIC is still competitive
- Additionally the EIC has two advantages over $\tau \rightarrow e\gamma$ searches
  - $e \rightarrow \tau$ can probe leptoquarks which evade $\tau \rightarrow e\gamma$ limit ($\boldsymbol{\tilde{S}_{1/2}^{L}}$) because of a cancellation of electric charges in the $\boldsymbol{A_2}$ coefficients at first order in m_q^2/M_{LQ}^2
  - Like HERA, EIC could set limits on $\boldsymbol{\lambda_{1\alpha}\lambda_{3\beta}/M_{LQ}^2}$ for all α, β but $\tau \rightarrow e\gamma$ is restricted to quark flavor-diagonal cases $\alpha = \beta$

LEPTOQUARKS AND BEYOND

- Feasibility of an EIC search for $e \rightarrow \tau$ in a leptoquark framework is worth further study
  - An initial analysis of backgrounds, cuts, and tau identification efficiency has been done by members of the EIC collaboration at Brookhaven led by Abhay Deshpande
- Can the EIC probe LFV arising from other non-leptoquark models?
  - If $e \rightarrow \tau$ events are observed at the EIC, can they be used to discriminate between various models of LFV?
- How can the LHC probe leptoquarks with more complicated flavor structure? (current work)

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THE END

Many thanks!