$U(1)_{B_3-3L_\mu}$ Gauge Symmetry as the simplest description of $b \to s$ anomalies

Rahul Srivastava
Work Done in Collaboration with
Cesar Bonilla, Tanmoy Modak, José W. F. Valle
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The $b \to s\mu^+\mu^-$ Anomalies

- Several decay modes measured by LHCb show anomalous behavior compared to SM expectation

$$R_K = \frac{B \to K\mu^+\mu^-}{B \to Ke^+e^-}, \qquad R_K^{\rm SM} = 1$$

$$R_K^{\rm expt} = 0.745^{+0.090}_{-0.074}\ (\text{stat}) \pm 0.036\ (\text{syst})\ , \quad 1 \le q^2 \le 6.0\ \text{GeV}^2$$

$$R_K^* = \frac{B \to K^*\mu^+\mu^-}{B \to K^*e^+e^-}, \qquad R_{K^*}^{\rm SM} = 1$$

$$R_{K^*}^{\rm expt} = \begin{cases} 0.660^{+0.110}_{-0.070}\ (\text{stat}) \pm 0.024\ (\text{syst})\ , & 0.045 \le q^2 \le 1.1\ \text{GeV}^2 \\ 0.685^{+0.113}_{-0.069}\ (\text{stat}) \pm 0.047\ (\text{syst})\ , & 1.1 \le q^2 \le 6.0\ \text{GeV}^2 \end{cases}$$

- Anomalies also observed in angular distribution P_5' of $B \to K^*\mu^+\mu^-$
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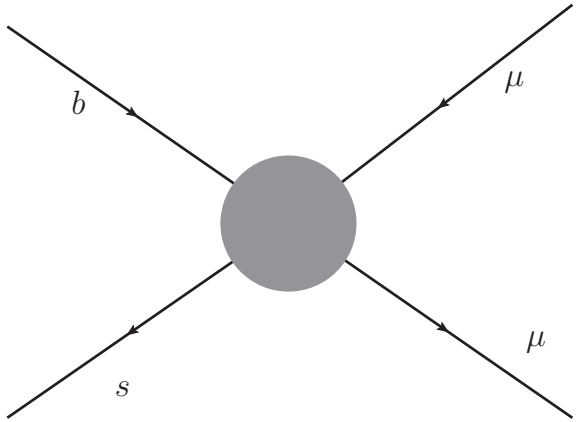

- These transitions can be described by the an effective Hamiltonian,

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}}\frac{e^2}{16\pi^2}V_{tb}V_{ts}^*\sum_i \left(\mathcal{C}_i(\Lambda)O_i(\Lambda) + \mathcal{C}_i'(\Lambda)O_i'(\Lambda)\right)$$

  where $\mathcal{C}_i^{(\prime)} = \mathcal{C}_i^{(\prime)SM} + \mathcal{C}_i^{(\prime)NP}$.
- Relevant operators required to account for the anomalies are of the restricted type,

$$\mathcal{O}_9 = (s\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \ell), \qquad \mathcal{O}_9' = (s\gamma_\alpha P_R b)(\bar{\ell}\gamma^\alpha \ell)$$
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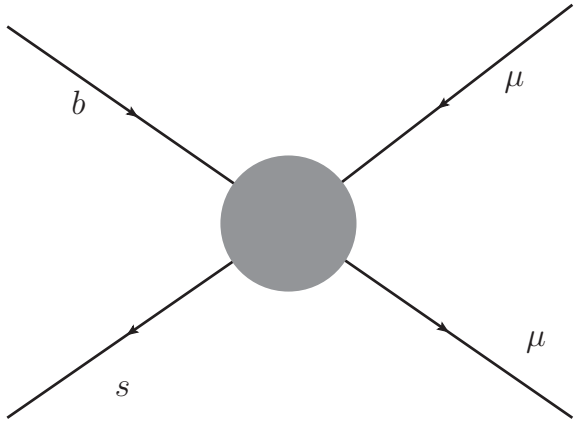

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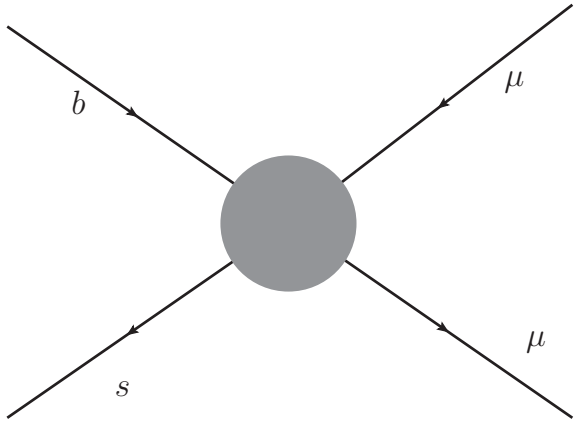

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Global Fits

- Global Fit of Effective Couplings[1]

	All					LFUV				
1D Hyp.	Best fit	1 σ	2 σ	Pull_{SM}	p-value	Best fit	1 σ	2 σ	Pull_{SM}	p-value
$\mathcal{C}_{9\mu}^{\text{NP}}$	-1.10	$[-1.27, -0.92]$	$[-1.43, -0.74]$	5.7	72	-1.76	$[-2.36, -1.23]$	$[-3.04, -0.76]$	3.9	69
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	-0.61	$[-0.73, -0.48]$	$[-0.87, -0.36]$	5.2	61	-0.66	$[-0.84, -0.48]$	$[-1.04, -0.32]$	4.1	78
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}'_{9\mu}$	-1.01	$[-1.18, -0.84]$	$[-1.33, -0.65]$	5.4	66	-1.64	$[-2.12, -1.05]$	$[-2.52, -0.49]$	3.2	31
$\mathcal{C}_{9\mu}^{\text{NP}} = -3\mathcal{C}_{9e}^{\text{NP}}$	-1.06	[-1.23,-0.89]	[-1.39,-0.71]	5.8	74	-1.35	$[-1.82, -0.95]$	$[-2.38, -0.59]$	4.0	71

	All			LFUV		
2D Hyp.	Best fit	Pull_{SM}	p-value	Best fit	Pull_{SM}	p-value
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10\mu}^{\text{NP}})$	(-1.17,0.15)	5.5	74	(-1.13,0.40)	3.7	75
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}'_{7})$	(-1.05,0.02)	5.5	73	(-1.75,-0.04)	3.6	66
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9'\mu})$	(-1.09,0.45)	5.6	75	(-2.11,0.83)	3.7	73
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10'\mu})$	(-1.10,-0.19)	5.6	76	(-2.43,-0.54)	3.9	85
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9e}^{\text{NP}})$	(-0.97,0.50)	5.4	72	(-1.09,0.66)	3.5	65
Hyp. 1	(-1.08,0.33)	5.6	77	(-1.74,0.53)	3.8	77
Hyp. 2	(-1.00, 0.15)	4.9	61	(-1.89,0.27)	3.1	39
Hyp. 3	(-0.65,-0.13)	4.9	61	(0.58,2.53)	3.7	73
Hyp. 4	(-0.65,0.21)	4.8	59	(-0.68,0.28)	3.7	72

TABLE II: Most prominent patterns of New Physics in $b \to s\mu\mu$ with high significances. The last four rows corresponds to hypothesis 1: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\text{NP}} = \mathcal{C}_{10'\mu})$, 2: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\text{NP}} = -\mathcal{C}_{10'\mu})$, 3: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}, \mathcal{C}_{9'\mu} = \mathcal{C}_{10'\mu})$ and 4: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}, \mathcal{C}_{9'\mu} = -\mathcal{C}_{10'\mu})$. The "All" columns include all available data from LHCb, Belle, ATLAS and CMS, whereas the "LFUV" columns are restricted to R_K, R_{K^*} and $Q_{4,5}$ (see text for more detail). The p-values are quoted in % and Pull_{SM} in units of standard deviation.

[1] Taken from: B. Capdevila et.al; arXiv:1704.05340

UV Completion

- Two simple options
- Add a leptoquark
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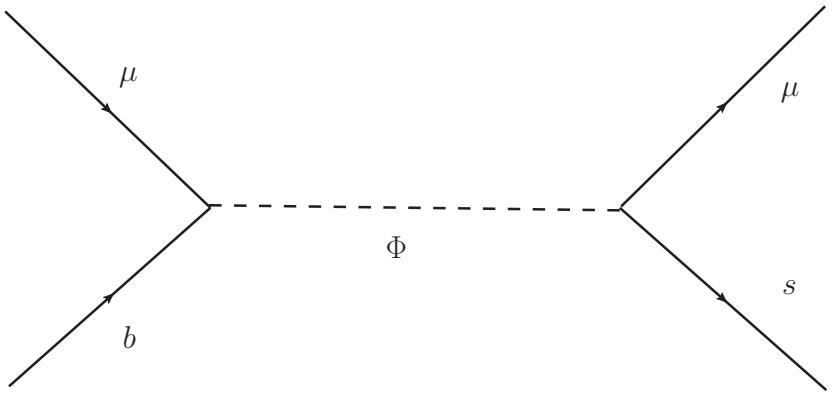

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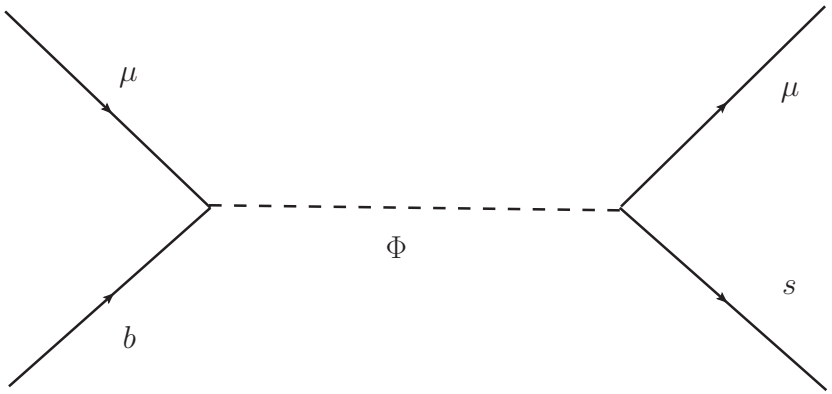

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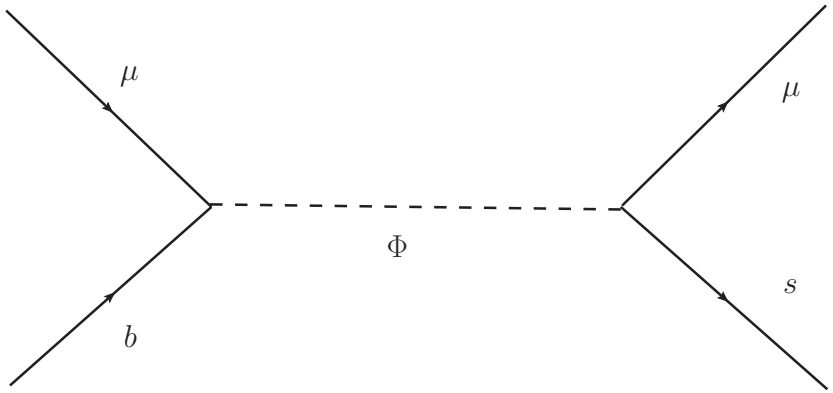

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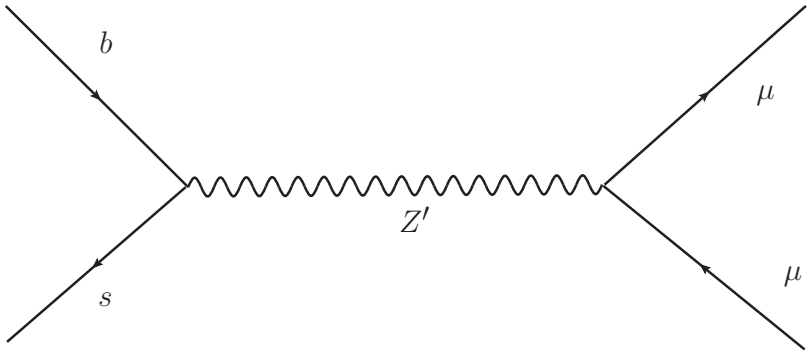

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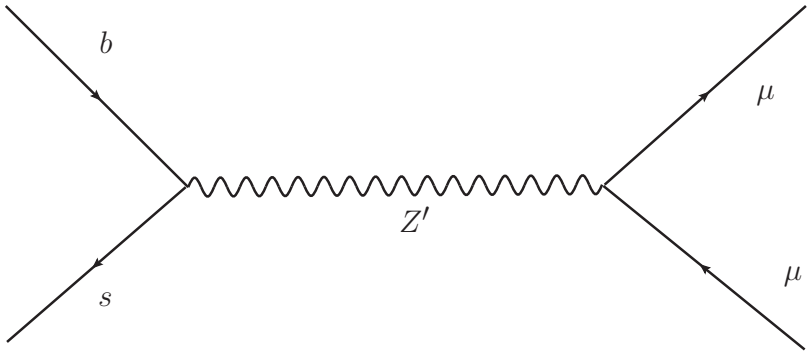

- The Z' boson should satisfy following criterion
  - Violate Lepton Flavor Universality: Must not couple democratically all charged lepton, in particular to e and μ
  - FCNC in quark sector: Should induce FCNC in $b \to s$ transitions
  - No dangerous FCNC: Should not induce large FCNC in highly constrained processes like $\mu \to 3e$ or in K systems e.g. $K^0 - \bar{K}^0$ oscillations
  - Should be consistent with other flavor, precision and collider constraints

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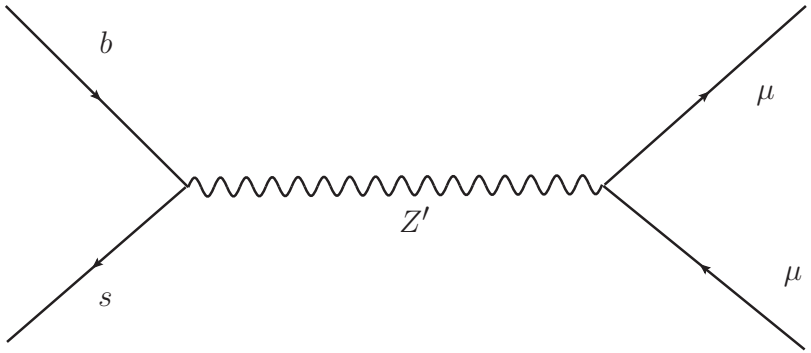

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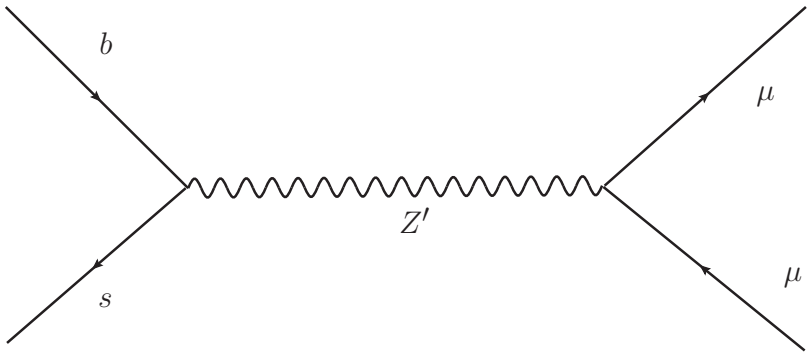

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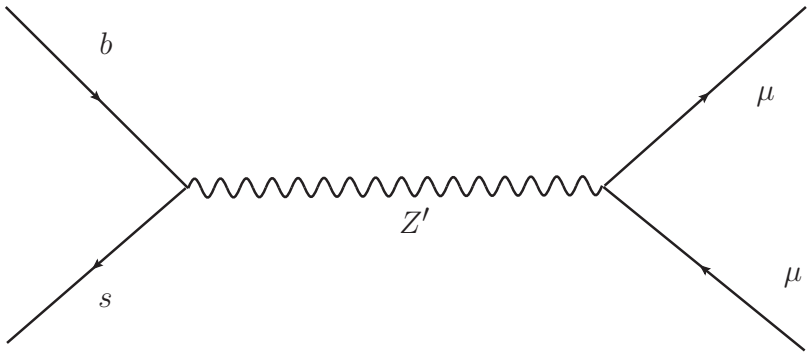

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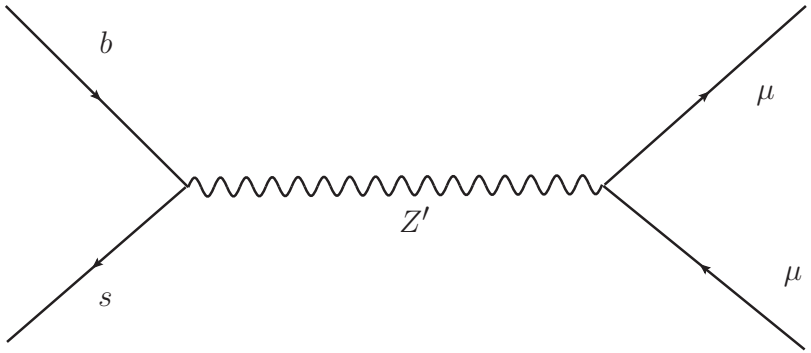

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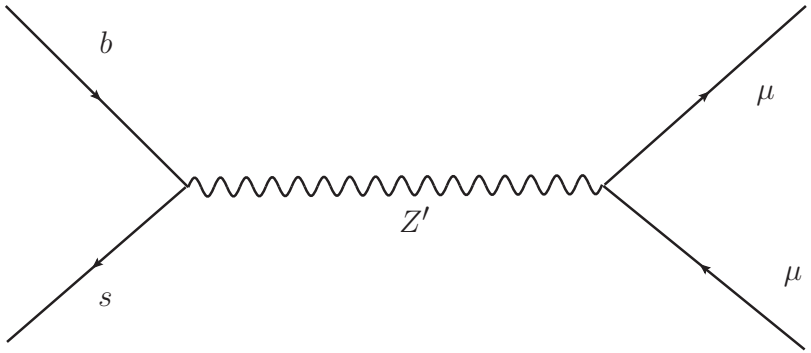

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Gauged $B - L$ Symmetry

- $B - L$ is the simplest symmetry one can think of.
- Under $B - L$:
  - All Quarks (left+right) $\sim \frac{1}{3}$
  - All Leptons (left+right) ~ -1
- Anomaly cancellation: Needs addition of right handed neutrinos $\nu_{i,R};\ i = 1, 2, 3$
- Two solutions:
  - $\nu_{i,R} \sim -1$: Know since antiquity
  - $\nu_{i,R} \sim (-4, -4, +5)$: Recently discussed[2]
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[2] E.Ma, R.Srivastava; arxiv:1411.5042; E. Ma, N. Pollard, R. Srivastava, M. Zakeri; arxiv:1507.03943

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[2] E.Ma, R.Srivastava; arxiv:1411.5042; E. Ma, N. Pollard, R. Srivastava, M. Zakeri; arxiv:1507.03943

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What Kind of Z' Boson

$U(1)_X$ Symmetry + Vector Quarks + Vector Leptons

- Don't charge SM particles under the new $U(1)_X$ i.e. All SM particles ~ 0 under $U(1)_X$
- Add Vector Quarks + Vector Leptons transforming nontrivially under $U(1)_X$
- Can achieve desired Z' properties by mixing of the vector fermions with SM fermions[3]
- Can have other interesting implications like Dark Matter stability[4]

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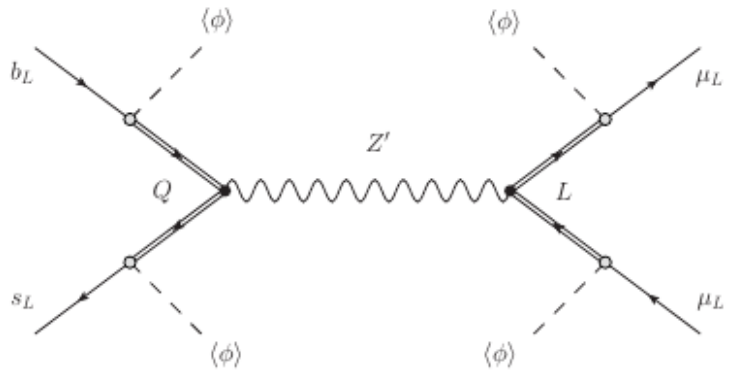

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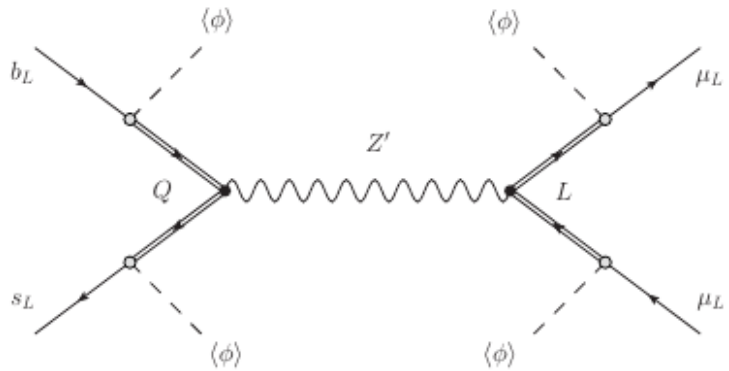

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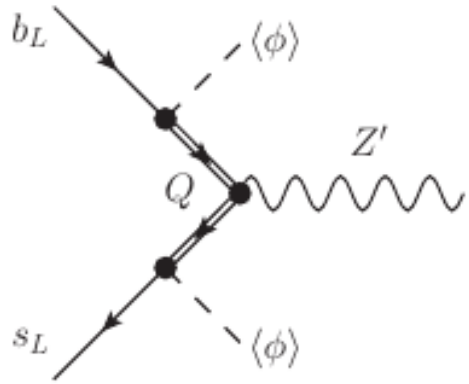

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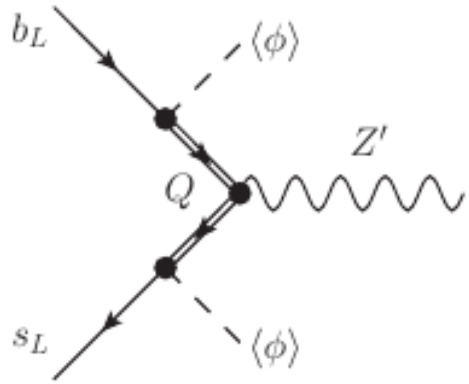

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