Toward discovery of lepton number violation at collider experiments

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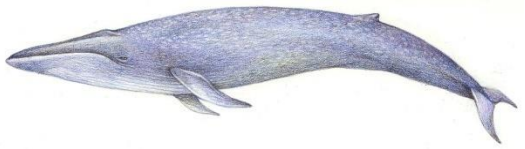
based on ‘M. Kohda, HS, K. Tsumura, PLB718, 1436 (2013)’

Introduction -Neutrino Mass-

Neutrino masses are extremely smaller than other fermion masses.

$$\text{neutrino} \lesssim 1\,\text{eV} \quad \text{electron} = 0.5\,\text{MeV} \quad \text{tau} = 1.8\,\text{GeV} \quad \text{top} = 172\,\text{GeV}$$



$$1\,\text{MeV} \text{ ”}\simeq\text{”} \ 1\,\text{kg}$$

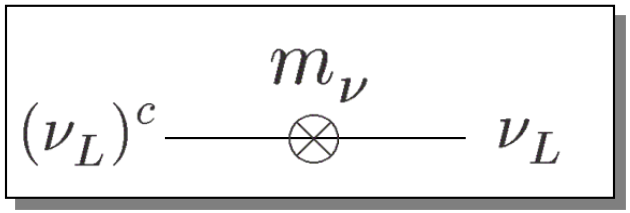
⟶ neutrino-specific mechanism to generate their masses ?

c.f. $m_\nu = y_\nu \dfrac{v_{\rm SM}}{\sqrt{2}} \Rightarrow y_\nu \sim 10^{-12}$ **for** $m_\nu \sim 0.1\,\text{eV}$

“Unnatural”

Neutrino-specific mass term

Majorana : $\dfrac{1}{2} m_\nu \overline{(\nu_L)^c}\, \nu_L$



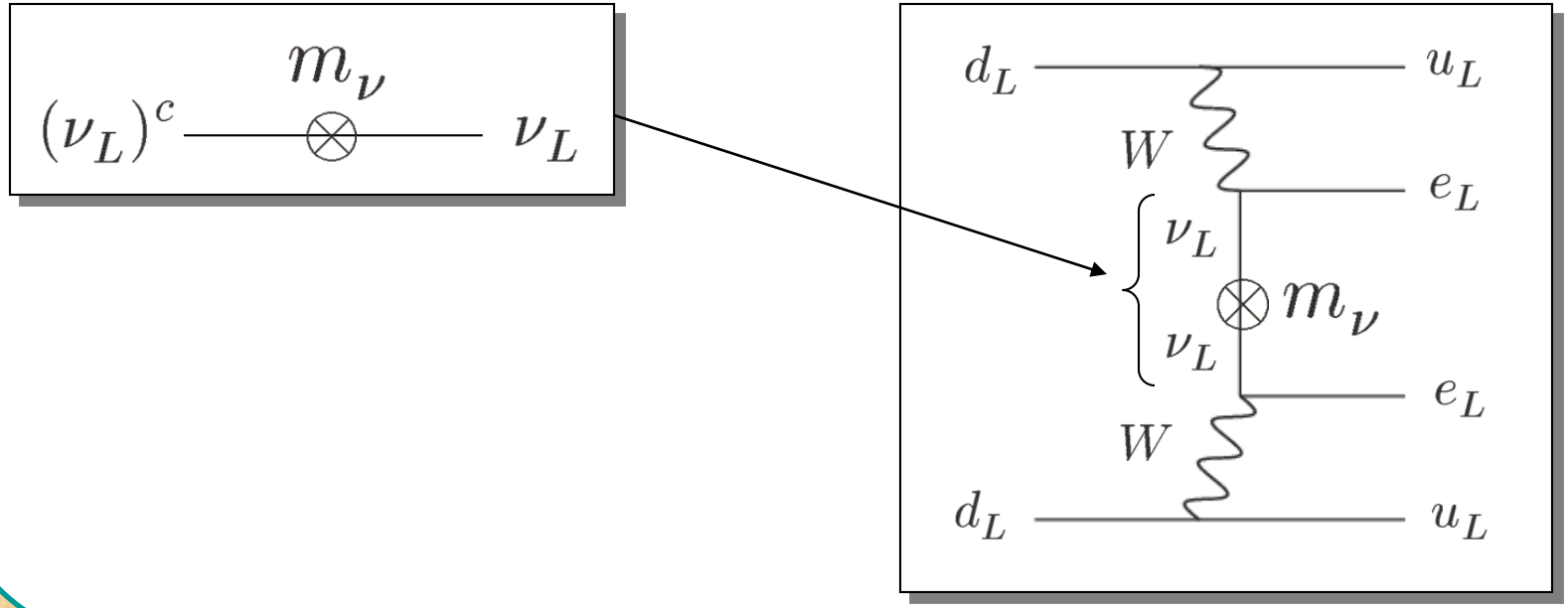
$Q_{EM}: \ 0 + 0 = 0$ **Allowed only for neutrinos**

$L\#: \ 1 + 1 = 2$ **Lepton number violation**

Majorana mass & L#V processes

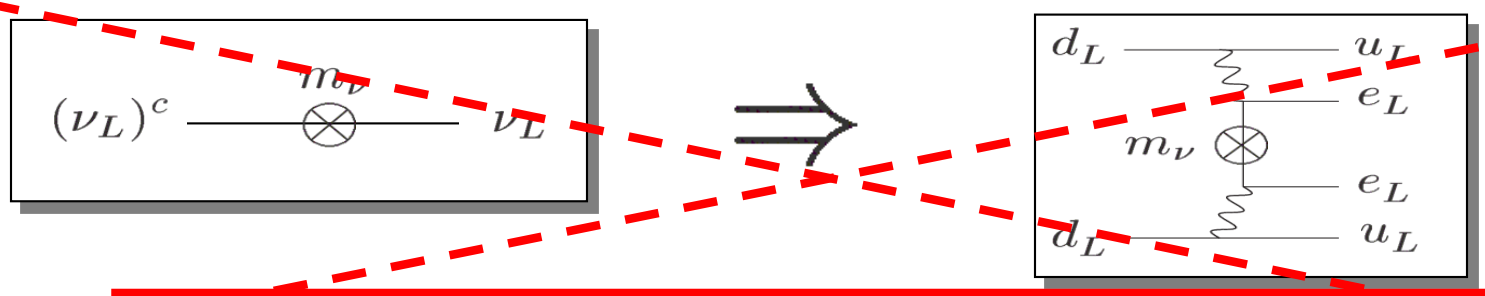
Majorana neutrino (tiny mass) $\Rightarrow$ **L#V process (tiny rate)**

e.g., Neutrinoless double beta decay



Since neutrinos are very light, the process is very rare

Motivation



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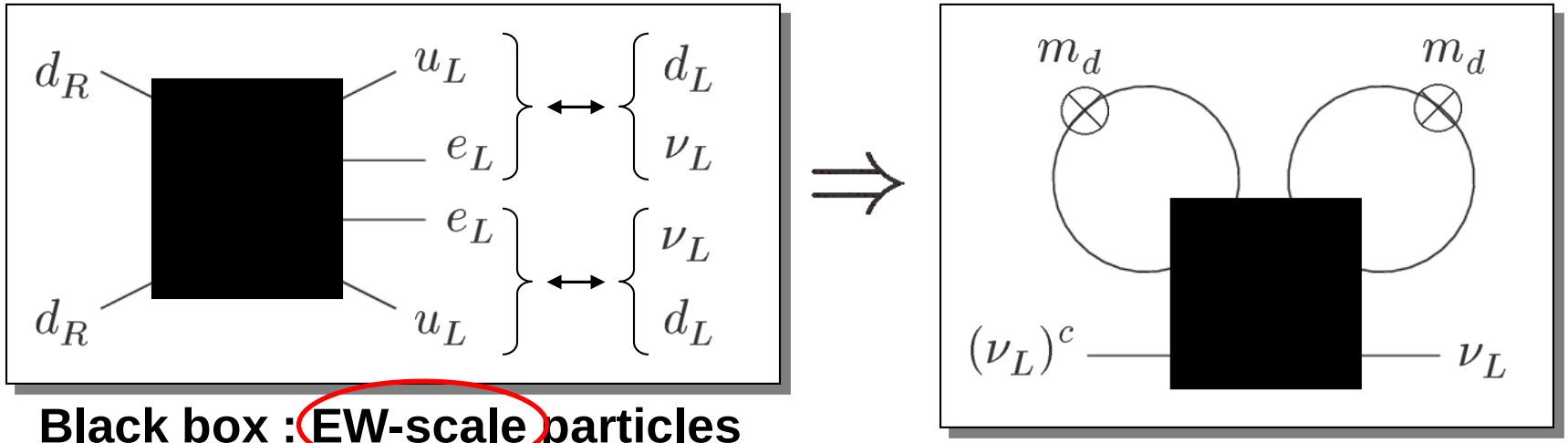


Black box : EW-scale particles

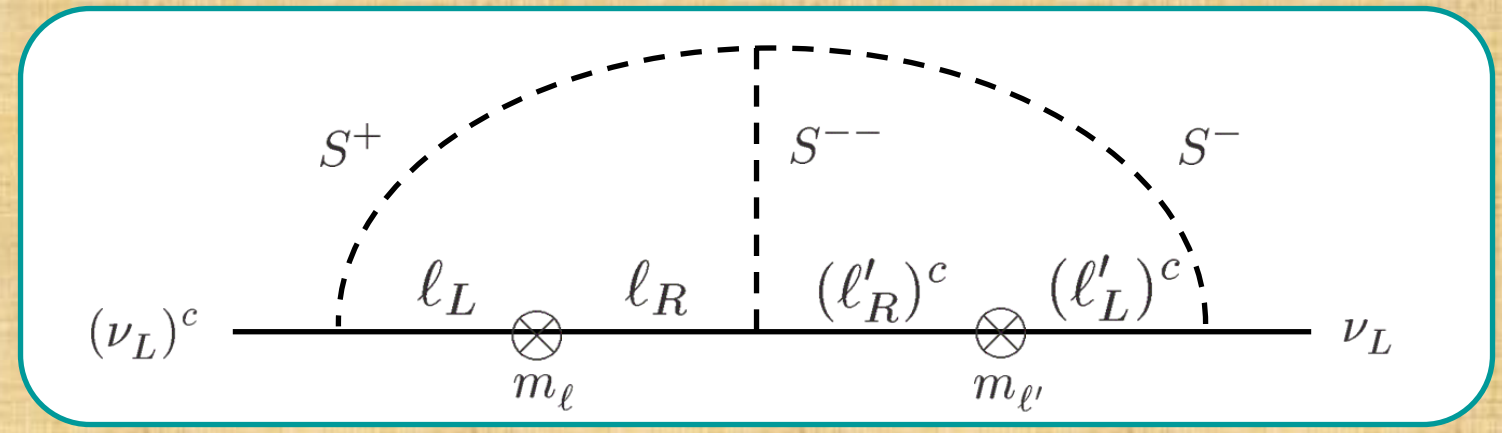
No m_ν

Although neutrinos are very light, the process is NOT very rare

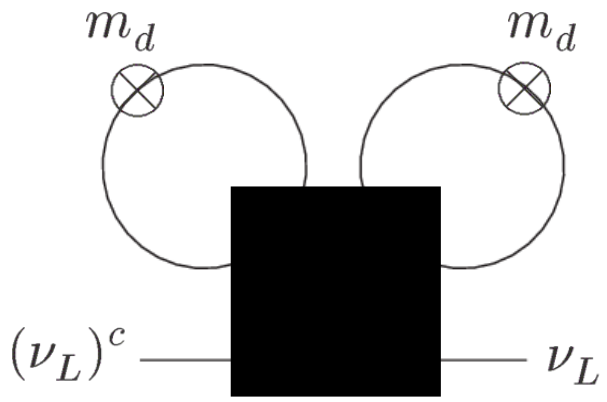
Two-Loop Neutrino Mass

Zee-Babu Model

A. Zee, NPB**264**, 99 (1986)
K.S. Babu, PLB**203**, 132 (1988)



colored version



two colored loops

The Model - colored Zee-Babu Model -

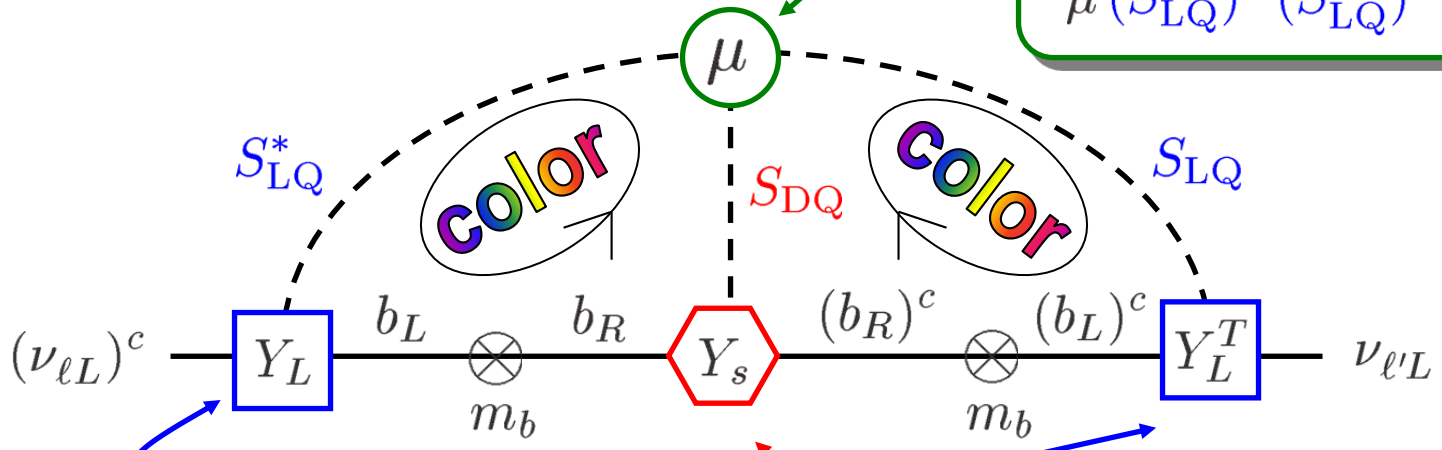
Briefly mentioned in 'K.S. Babu and C.N. Leung, NPB**619**, 667 (2001)'

		$\mathrm{SU}(3)_C$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$B\#$	$L\#$
Scalar Leptoquark	S_{LQ}	$\underline{\mathbf{3}}$	$\underline{\mathbf{1}}$	$-1/3$	$1/3$	1
Scalar Diquark	S_{DQ}	$\underline{\mathbf{6}}$	$\underline{\mathbf{1}}$	$-2/3$	$2/3$	0

Two-loop neutrino mass

soft L#V term (no B#V)

$$\mu\,(S^{\alpha}_{\mathrm{LQ}})^{*}\,(S^{\beta}_{\mathrm{LQ}})^{*}\,S^{\alpha\beta}_{\mathrm{DQ}}$$



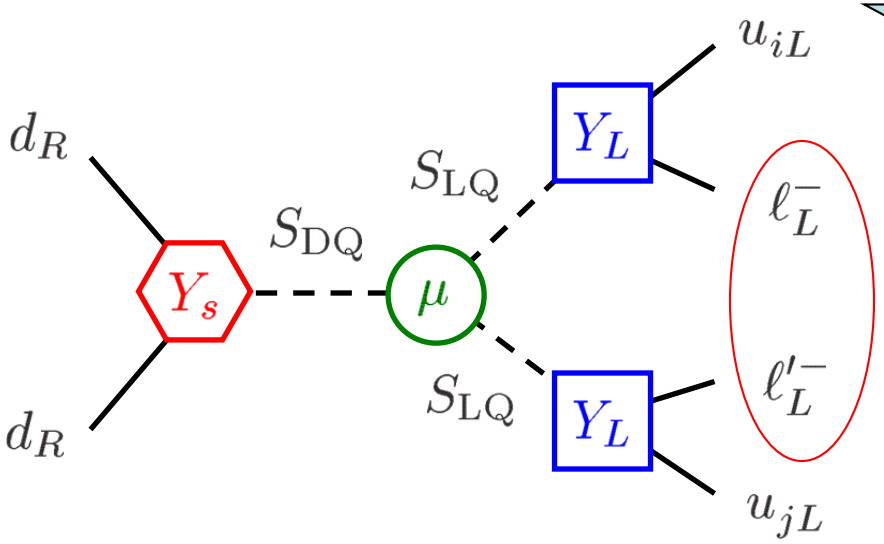
$$(Y_L)_{\ell i}\left[\overline{L^{c}_{\ell}}\,i\,\sigma_2\,Q^{\alpha}_{i}\,(S^{\alpha}_{\mathrm{LQ}})^{*}\right]+\cdots$$

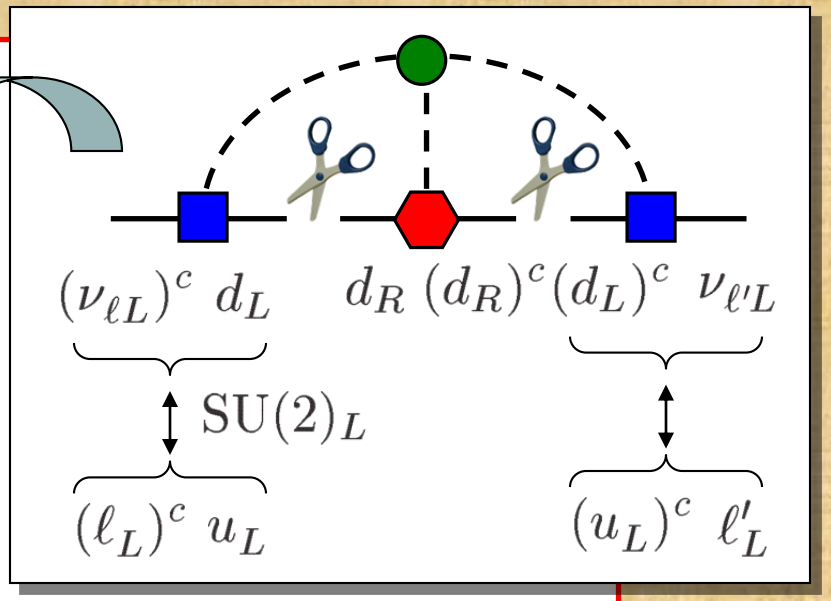
$$(Y_s)_{ij}\left[\overline{(d^{\alpha}_{iR})^{c}}\,d^{\beta}_{jR}\,(S^{\alpha\beta}_{\mathrm{DQ}})^{*}\right]$$

$$Y_s = Y_s^T$$

L#V Process at the LHC

$pp \to \ell^- \ell'^- jj$ **without missing**





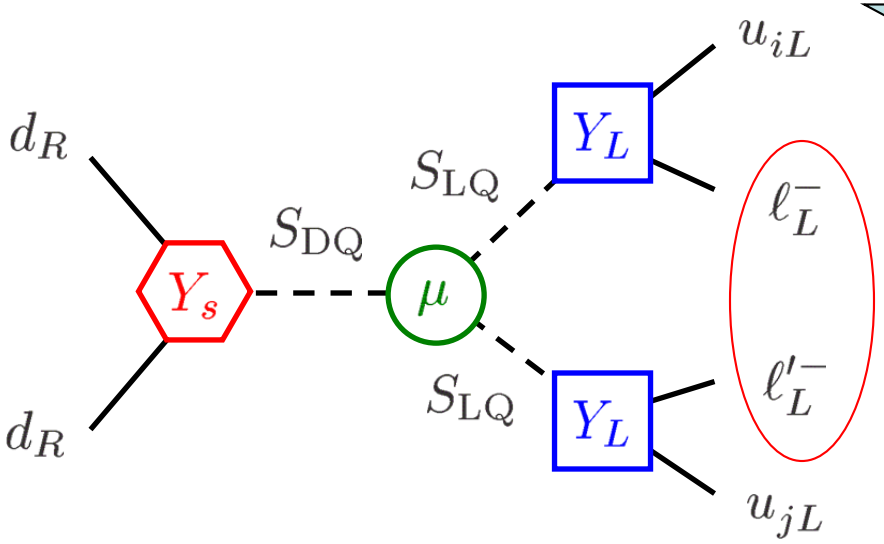
No missing energy $\Rightarrow$ **No missing L#** $(\nu, \overline{\nu}, \mathrm{DM}, \mathrm{etc.})$

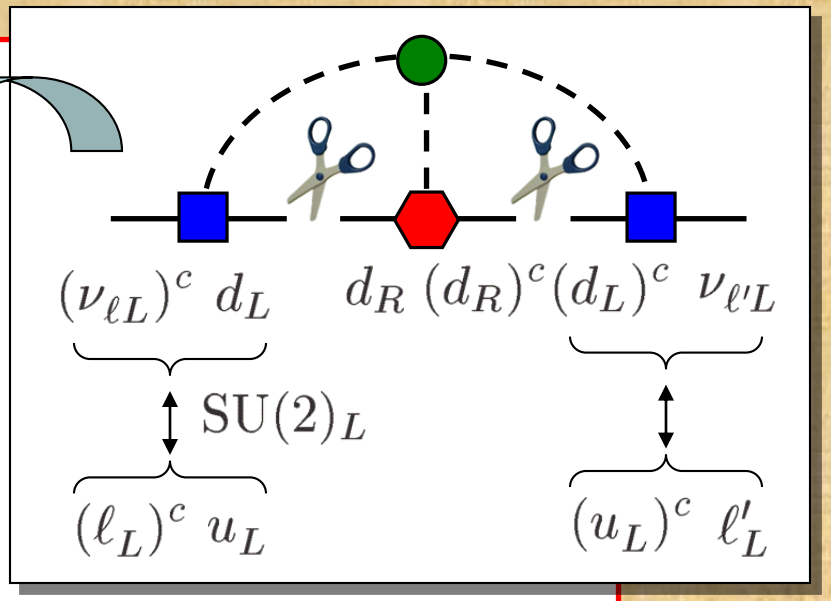
$\Rightarrow$ **Definite total L# of final states**

$\Downarrow$

Evidence for L#V

$pp \to \ell^- \ell'^- jj$ **without missing**





L#V $\Rightarrow$ **No SM process in principle**

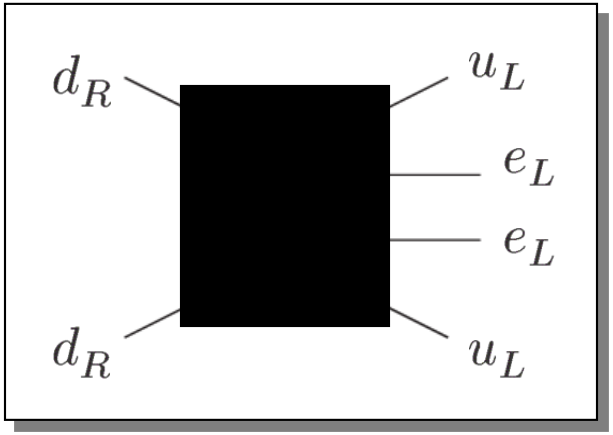
Hard ℓ_L^- $(\sim$ TeV$)$ $\Rightarrow$ **No mimic event in SM**

$\Downarrow$

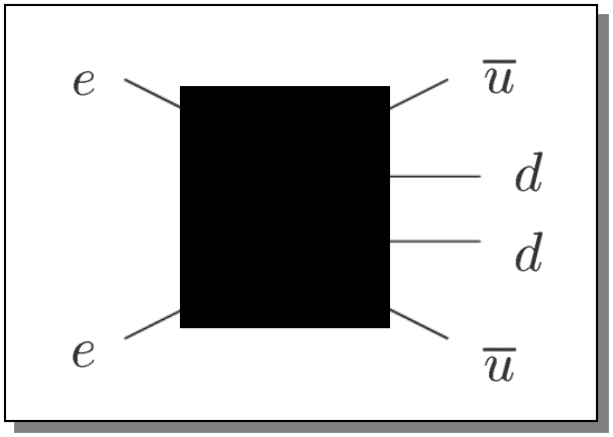
Clear evidence for L#V

@ILC ?

@ LHC



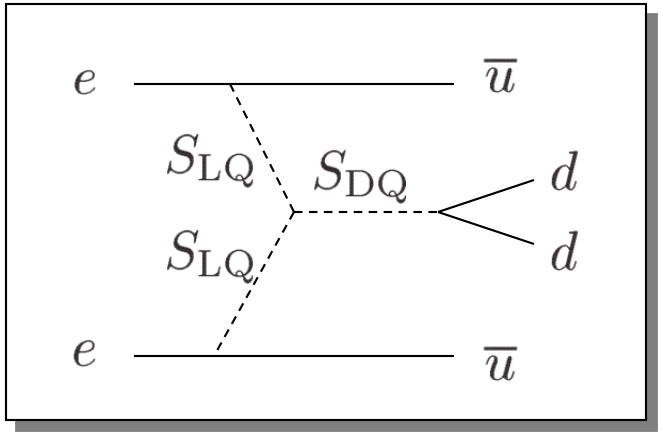
@ ILC



$e^- e^-$ option

ee -> 4j @ ILC ?

Example 1 (LQ + DQ)



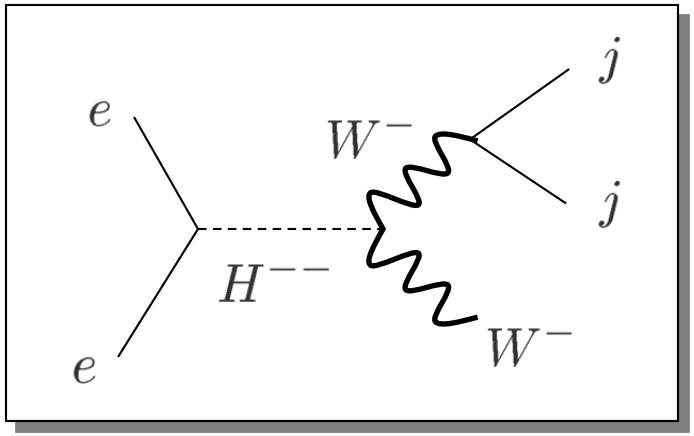
Problems: **Light DQ and LQ ?**

Couples dominantly with 3rd generation quarks?

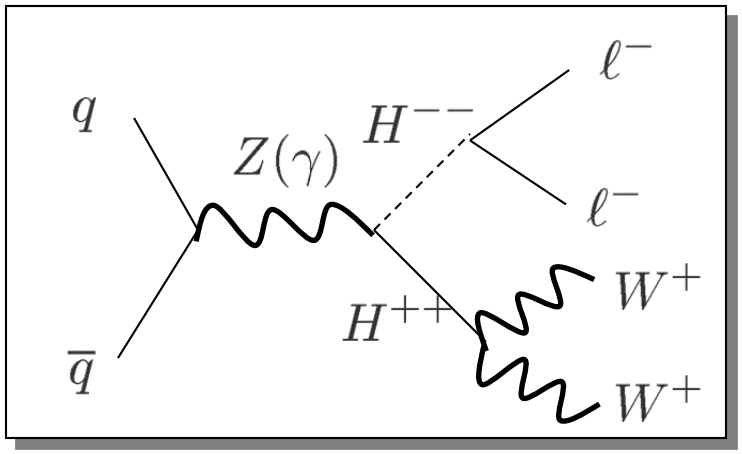
Too small neutrino mass? (subleading contribution?)

ee -> 4j @ ILC ?

Example 2 (SU(2) triplet)

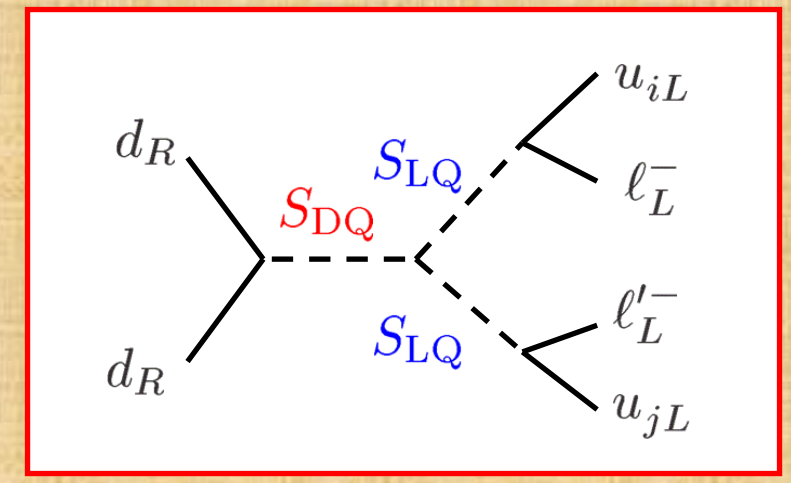


Problems: vs LHC ?



Summary

L#V process at the LHC



L#V process at the ILC