ONE-LOOP NEUTRINO MASS IN $SU(5)$[*][◉]

Ilja Doršner

University of Split

PORTOROŽ 2017

New physics at the junction of flavor and collider phenomenology

April 18th, 2017

[*]I. Doršner, S. Fajfer, N. Košnik, arXiv:1701.08322.

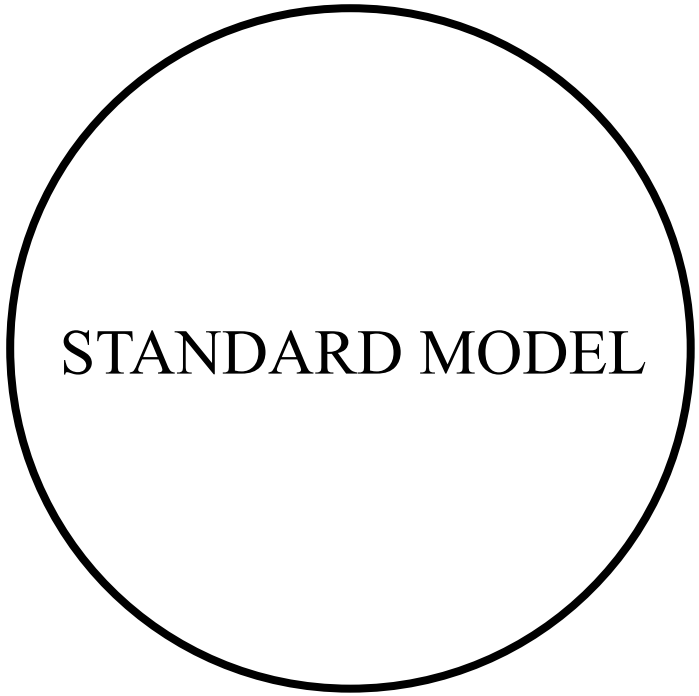
I. Doršner, S. Fajfer, A. Greljo, J.F. Kamenik, N. Košnik, Phys. Rept. 641 (2016).

[◉]Croatian Science Foundation (HRZZ) project # 7118

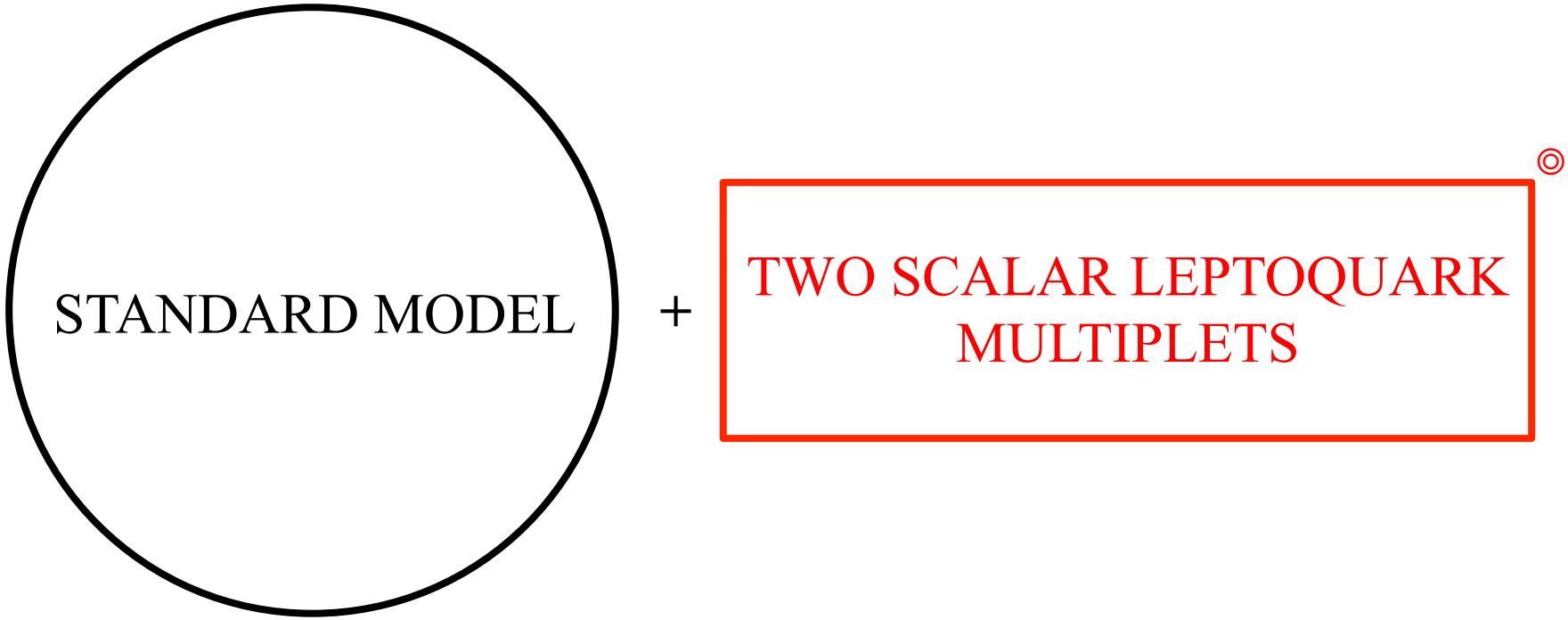
OUTLINE

- **LEPTOQUARK MECHANISMS OF NEUTRINO MASS**
- **ONE-LOOP NEUTRINO MASS MECHANISM IN *SU*(5)**
- **CONCLUSIONS**

ONE-LOOP NEUTRINO MASS MECHANISMS



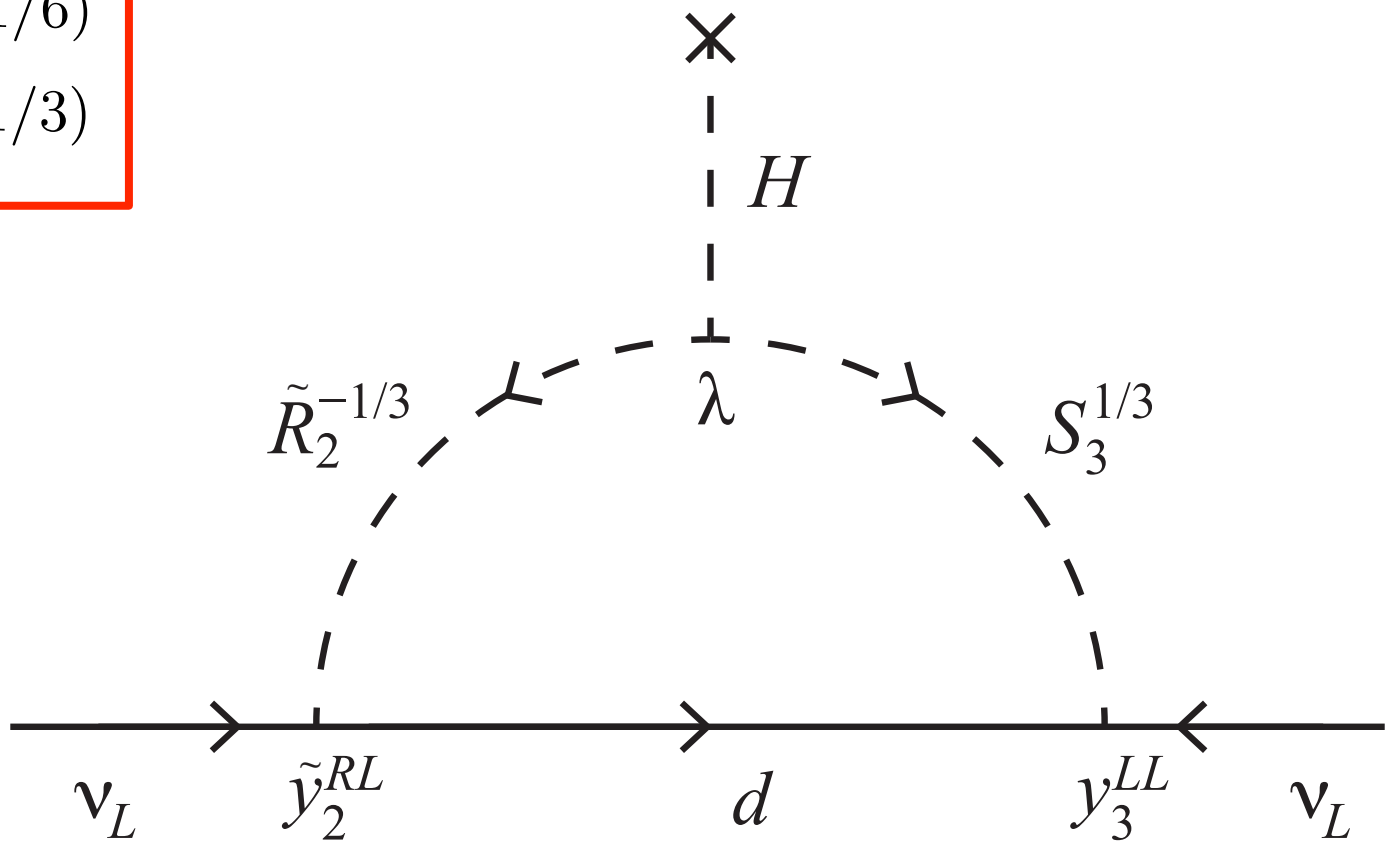
ONE-LOOP NEUTRINO MASS MECHANISMS



◎C.-K. Chua, X.-G. He, W.-Y. P. Hwang, Phys. Lett. B479 (2000).

THE DOWN-TYPE QUARK LOOPS[©]

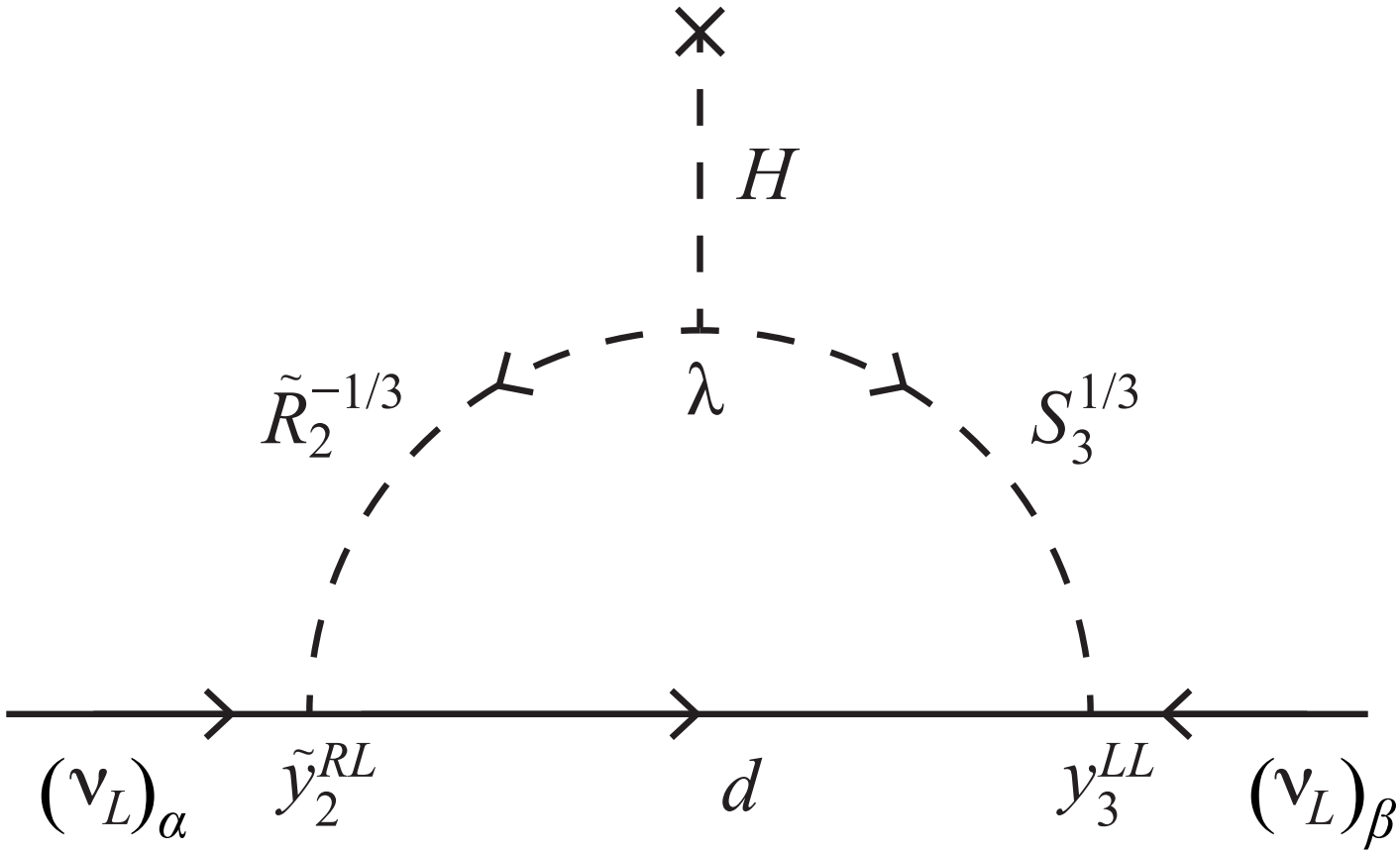
$$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$$
$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$



[©]C.-K. Chua, X.-G. He, W.-Y. P. Hwang, Phys. Lett. B479 (2000).

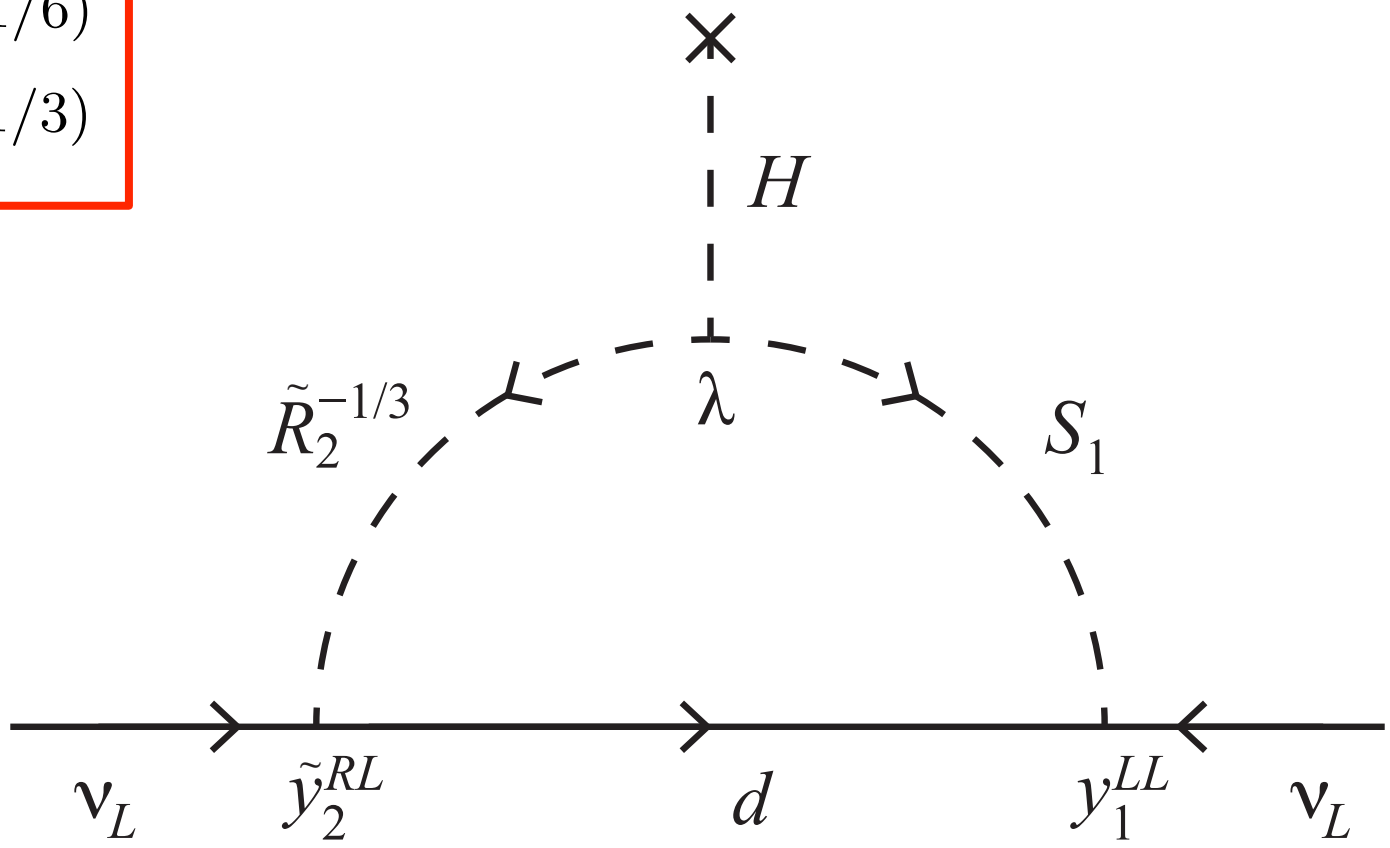
THE DOWN-TYPE QUARK LOOPS

$(m_N)_{\alpha\beta} =$

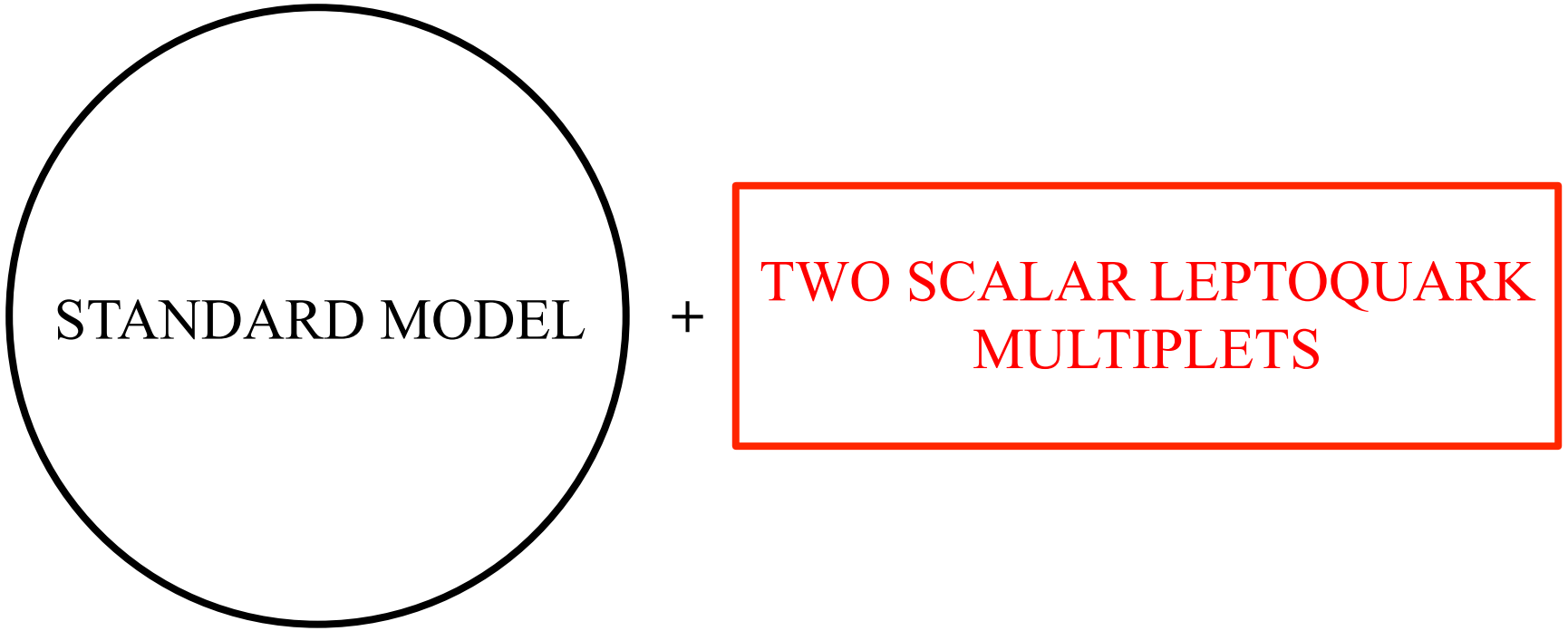


THE DOWN-TYPE QUARK LOOPS

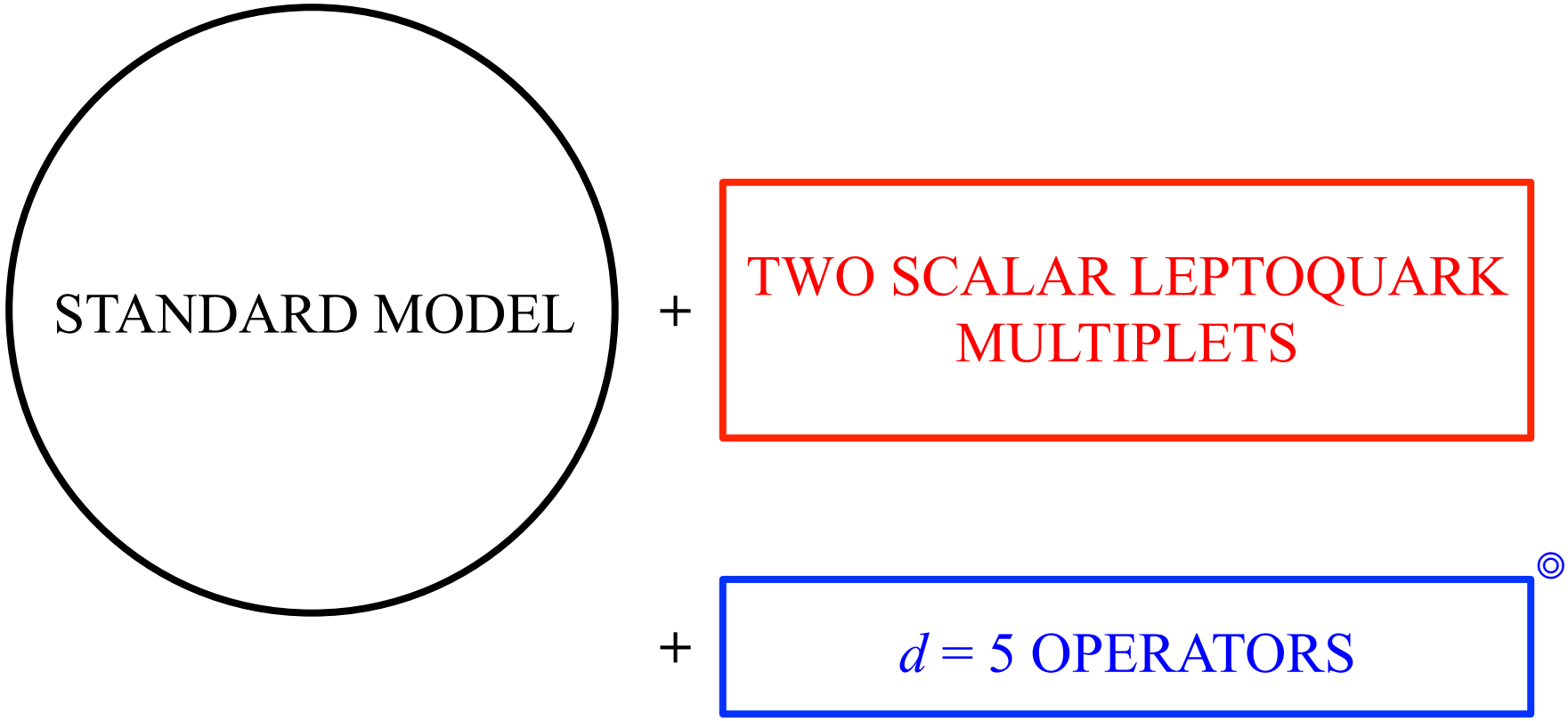
$$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$$
$$S_1 \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)$$



ONE-LOOP NEUTRINO MASS MECHANISMS



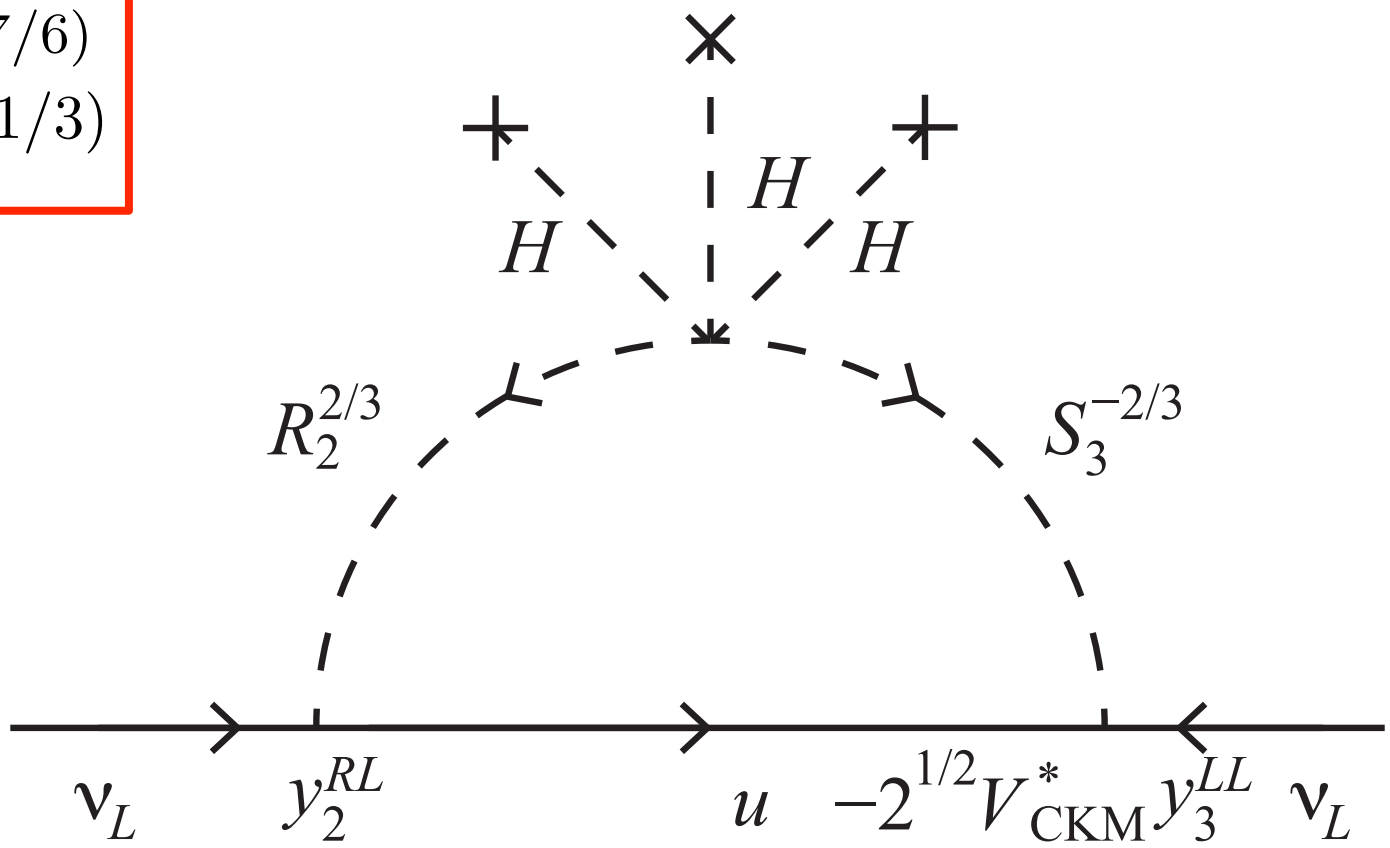
ONE-LOOP NEUTRINO MASS MECHANISMS



◎I. Doršner, S. Fajfer, N. Košnik, arXiv:1701.08322.

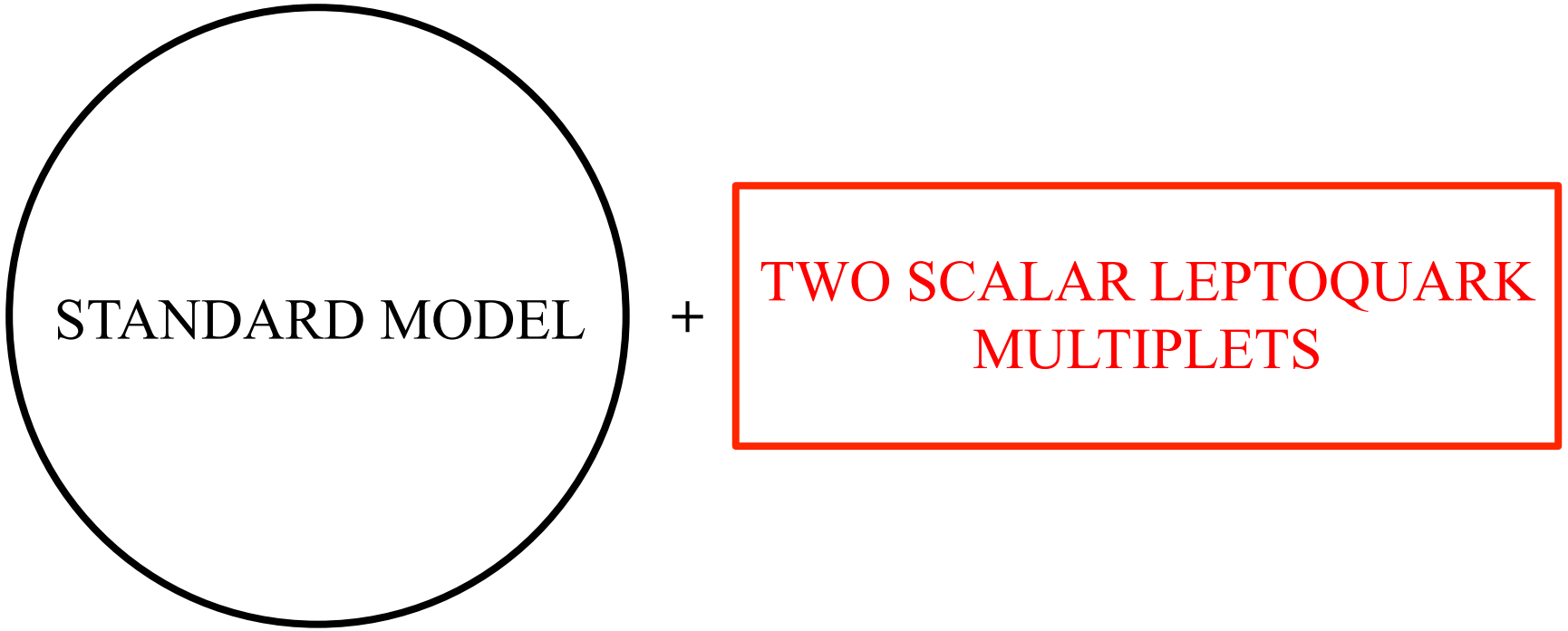
THE UP-TYPE QUARK LOOPS[©]

$$R_2 \equiv (\mathbf{3}, \mathbf{2}, 7/6)$$
$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$

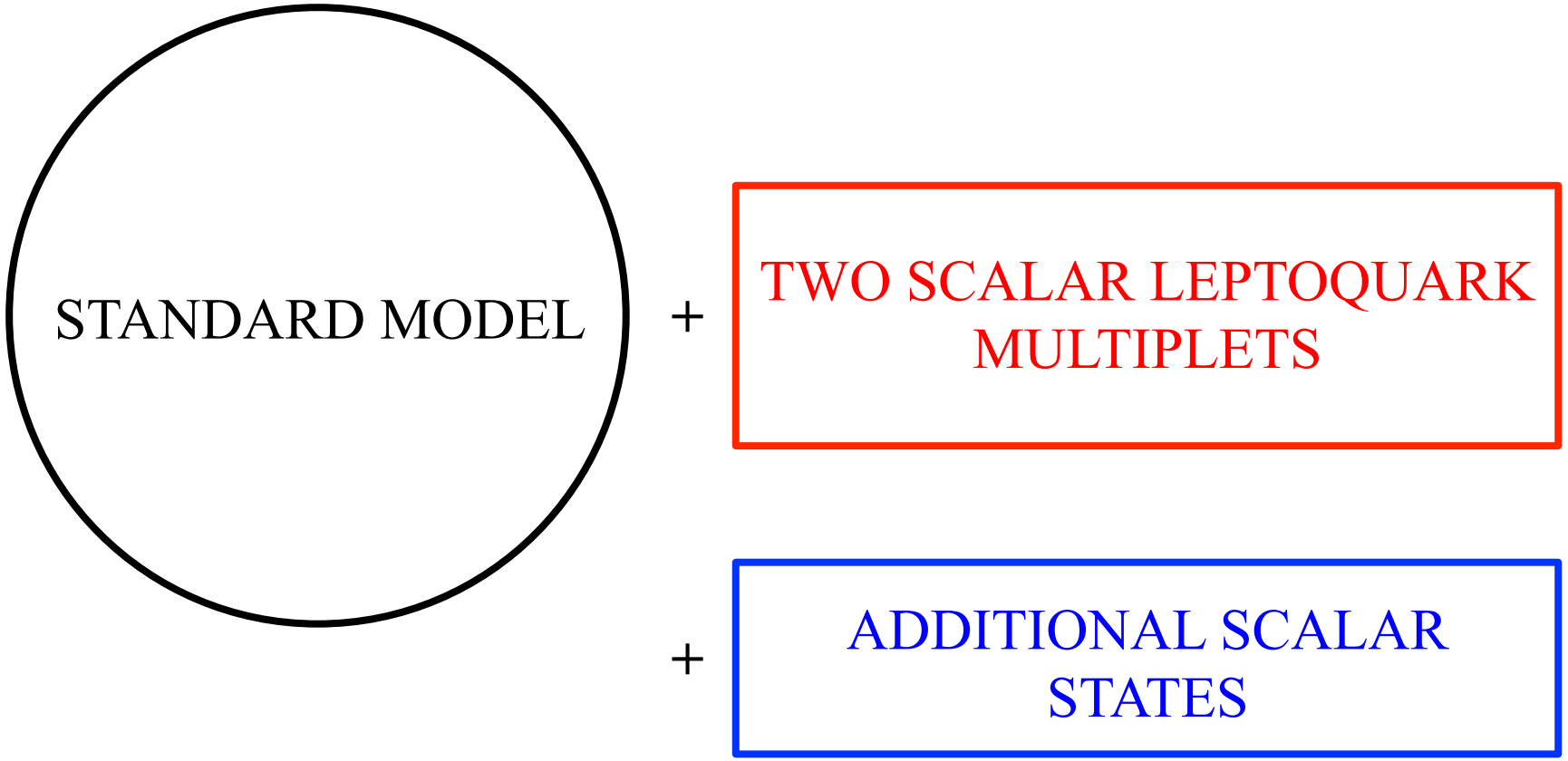


[©]I. Doršner, S. Fajfer, N. Košnik, arXiv:1701.08322.

ONE-LOOP NEUTRINO MASS MECHANISMS

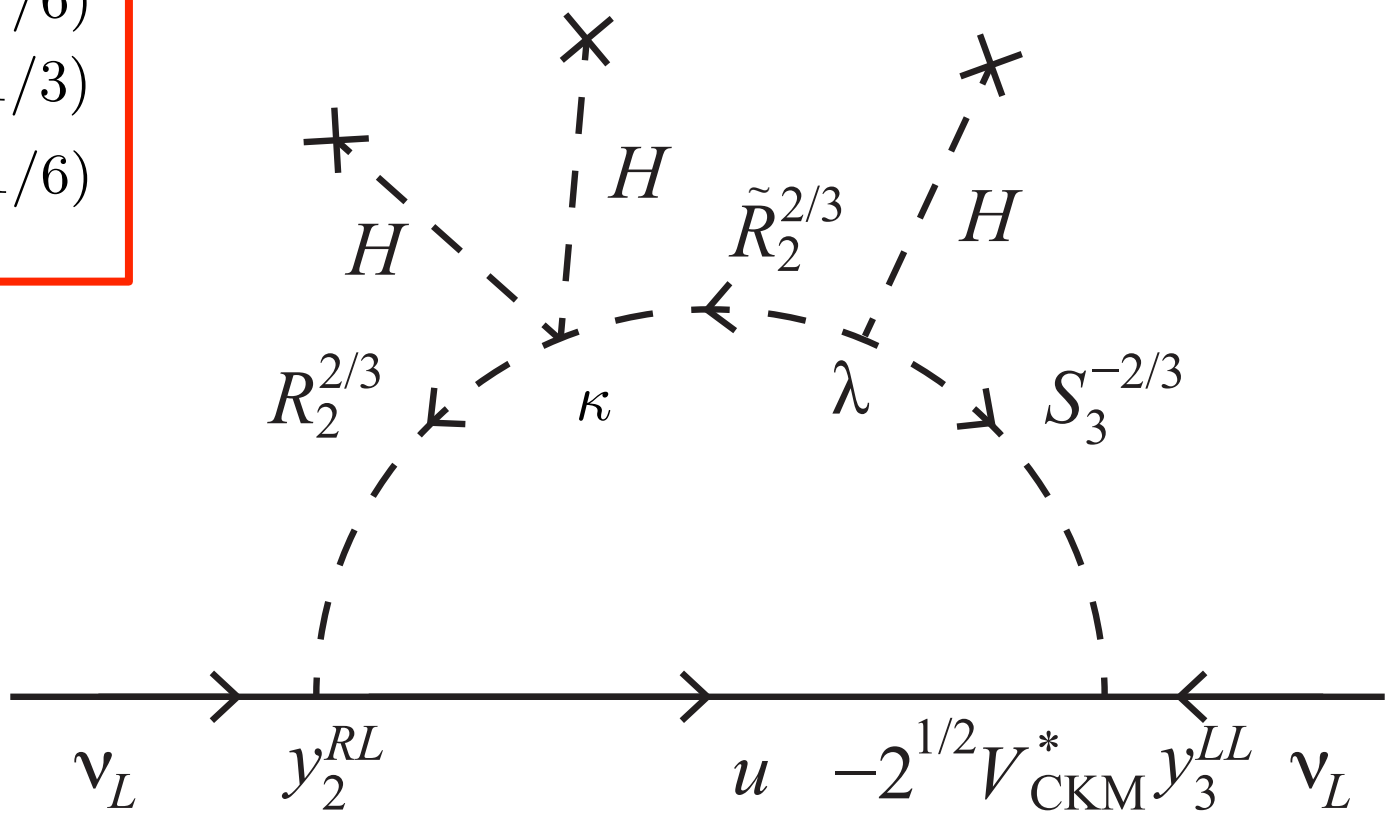


ONE-LOOP NEUTRINO MASS MECHANISMS



THE UP-TYPE QUARK LOOPS ©

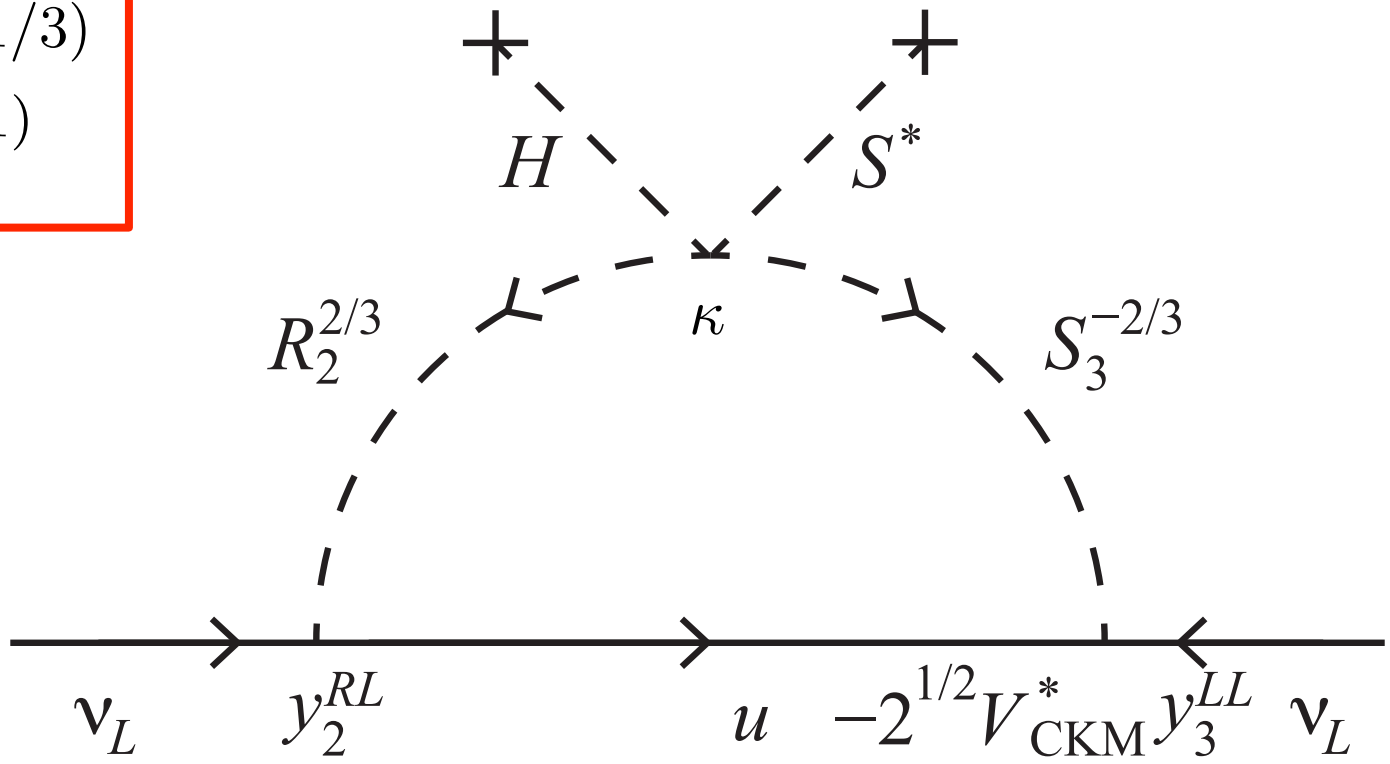
$$R_2 \equiv (\mathbf{3}, \mathbf{2}, 7/6)$$
$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$
$$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$$



©D. Aristizabal Sierra, M. Hirsch, and S. G. Kovalenko, Phys. Rev. D77 (2008).

THE UP-TYPE QUARK LOOPS ©

$$R_2 \equiv (\mathbf{3}, \mathbf{2}, 7/6)$$
$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$
$$S \equiv (\mathbf{1}, \mathbf{3}, 1)$$



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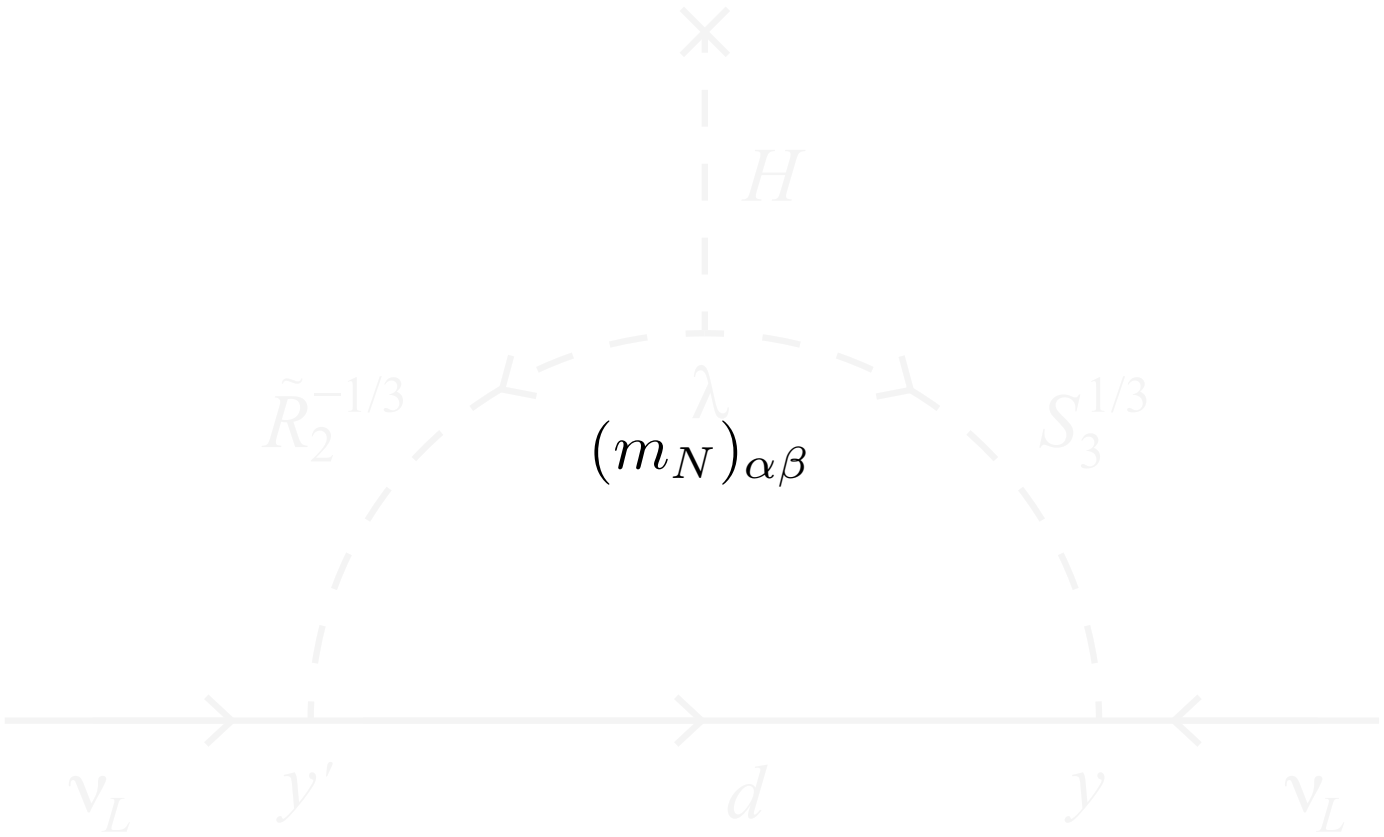
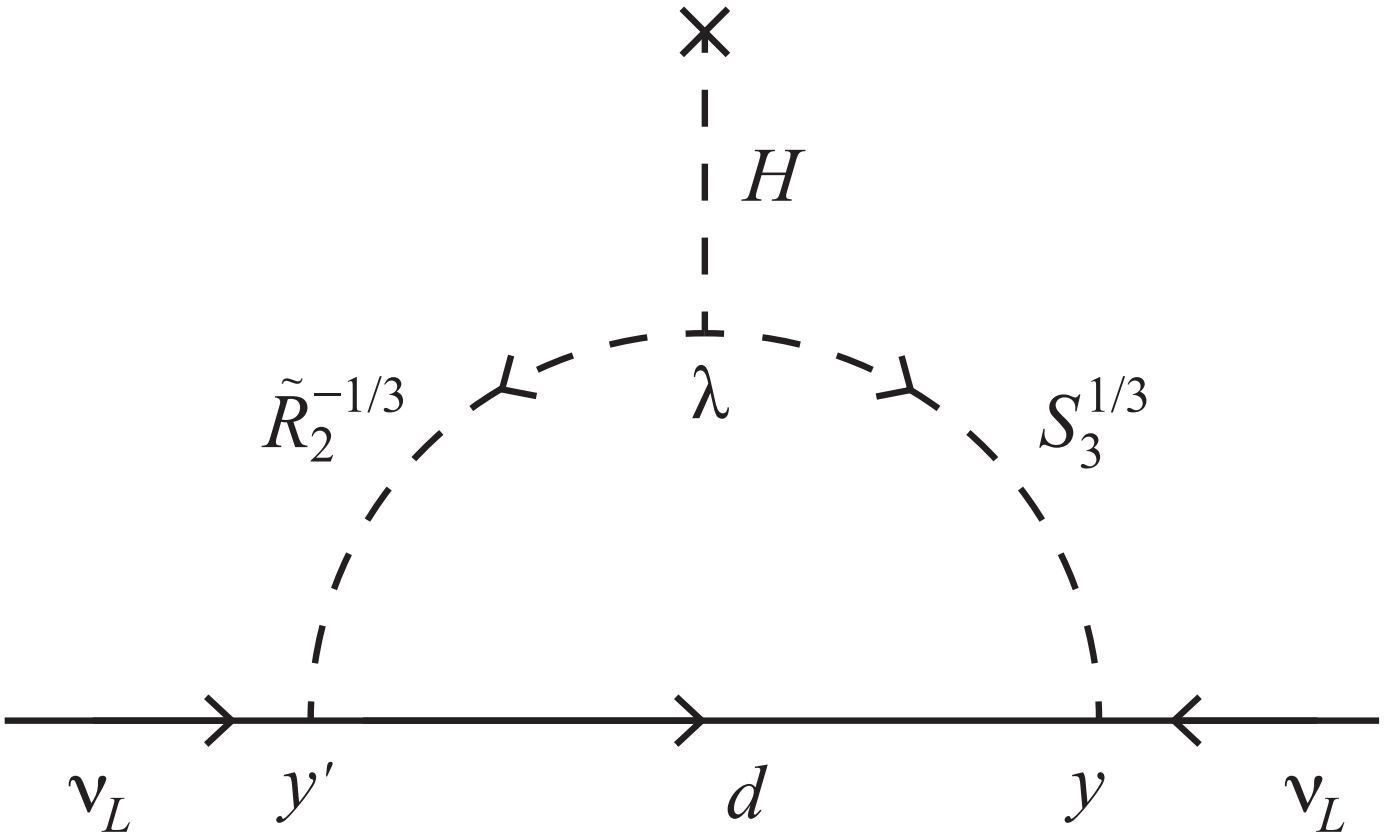
ONE-LOOP NEUTRINO MASS MECHANISMS



$$(m_N)_{\alpha\beta}$$

ONE-LOOP NEUTRINO MASS MECHANISMS



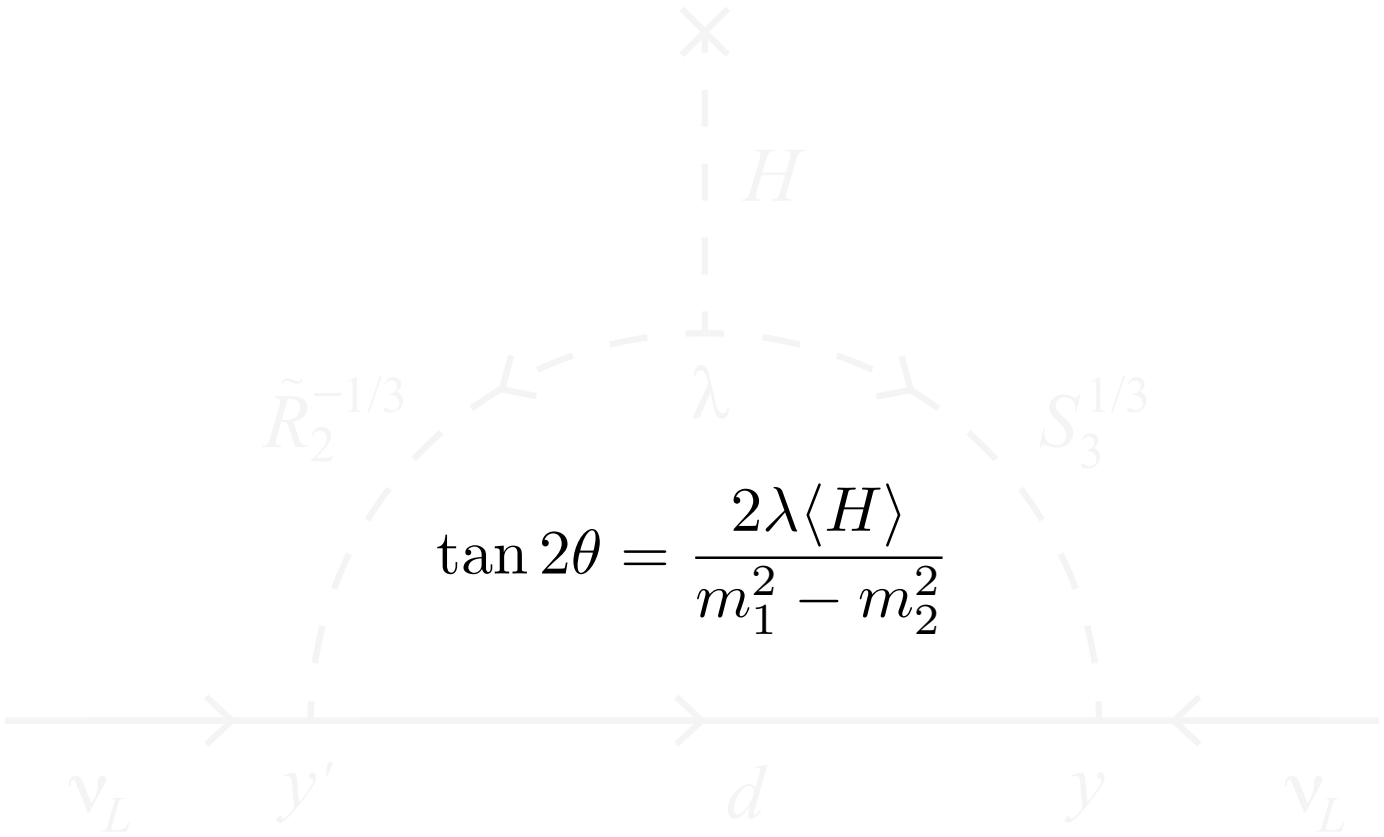
ONE-LOOP NEUTRINO MASS MECHANISMS

$$\left[\begin{array}{cc} \tilde{R}_2^{-1/3\,*} & S_3^{1/3} \end{array}\right] \left[\begin{array}{cc} m_1^2 & \lambda\langle H\rangle \\ \lambda\langle H\rangle & m_2^2 \end{array}\right] \left[\begin{array}{c} \tilde{R}_2^{-1/3\,*} \\ S_3^{1/3} \end{array}\right]^*$$

ONE-LOOP NEUTRINO MASS MECHANISMS

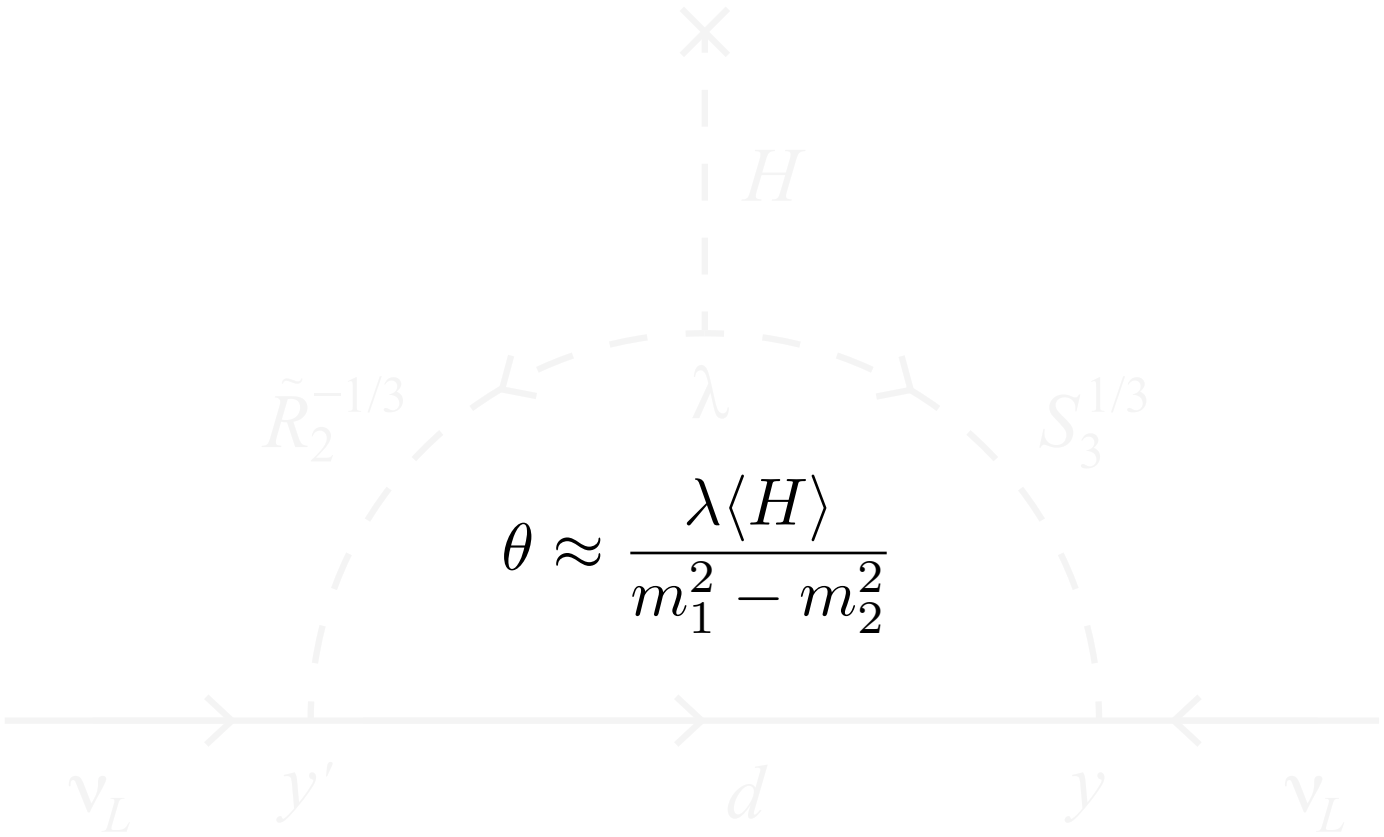
$$\begin{bmatrix} \tilde{R}_2^{-1/3\,*} \\ S_3^{1/3} \end{bmatrix} \rightarrow \begin{bmatrix} c_\theta & s_\theta \\ -s_\theta & c_\theta \end{bmatrix} \begin{bmatrix} \tilde{R}_2^{-1/3\,*} \\ S_3^{1/3} \end{bmatrix} \quad \begin{bmatrix} m_1^2 & \lambda\langle H\rangle \\ \lambda\langle H\rangle & m_2^2 \end{bmatrix} \rightarrow \begin{bmatrix} m^2_{\mathrm{LQ}\,1} & 0 \\ 0 & m^2_{\mathrm{LQ}\,2} \end{bmatrix}$$

ONE-LOOP NEUTRINO MASS MECHANISMS



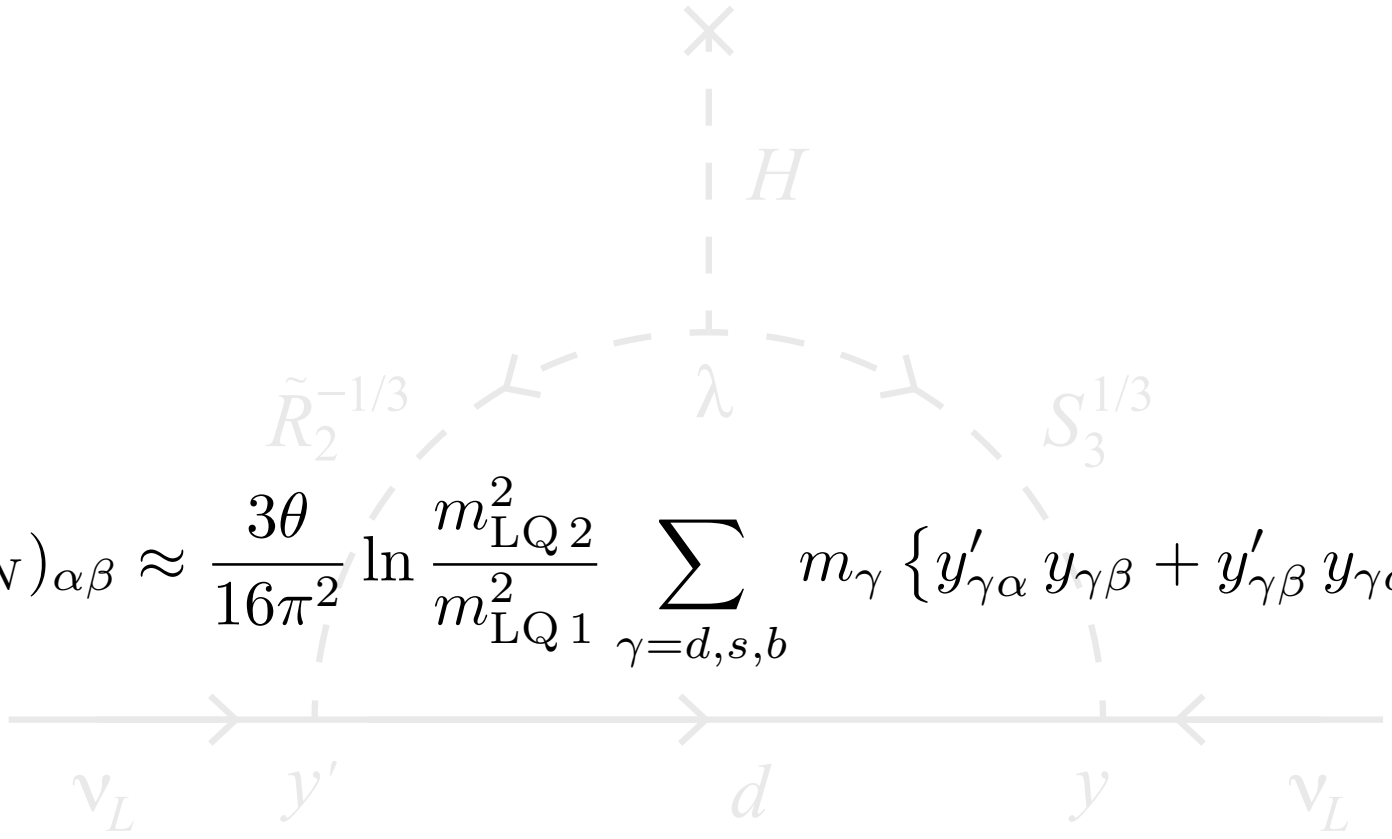
$$\tan 2\theta = \frac{2\lambda\langle H\rangle}{m_1^2 - m_2^2}$$

ONE-LOOP NEUTRINO MASS MECHANISMS



$$\theta \approx \frac{\lambda \langle H \rangle}{m_1^2 - m_2^2}$$

ONE-LOOP NEUTRINO MASS MECHANISMS



$$(m_N)_{\alpha\beta} \approx \frac{3\theta}{16\pi^2} \ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \sum_{\gamma=d,s,b} m_\gamma \left\{ y'_{\gamma\alpha}\, y_{\gamma\beta} + y'_{\gamma\beta}\, y_{\gamma\alpha} \right\}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$ WITH HEAVY LEPTOQUARKS

THE DOWN-TYPE QUARK MASS LOOPS

LQ COMBINATIONS: $\tilde{R}_2 + (S_3 \ \vee \ S_1)$

$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$$

$$S_1 \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)$$

THE DOWN-TYPE QUARK MASS LOOPS

LQ COMBINATIONS: $\tilde{R}_2 + (S_3 \ \vee \ S_1)$

p DECAY LQs: ($S_3, \quad \tilde{R}_2, \quad S_1$)

$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$$

$$S_1 \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)$$

THE UP-TYPE QUARK MASS LOOPS

LQ COMBINATIONS: R_2 + S_3

$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$R_2 \equiv (\mathbf{3}, \mathbf{2}, 7/6)$$

THE UP-TYPE QUARK MASS LOOPS

LQ COMBINATIONS: R_2 + S_3

p DECAY LQs: (S_3)

$$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$

$$R_2 \equiv (\mathbf{3}, \mathbf{2}, 7/6)$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$(m_N)_{\alpha\beta} \approx \frac{3\theta}{16\pi^2} \ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \sum_{\gamma=d,s,b} m_\gamma \left\{ y'_{\gamma\alpha}\, y_{\gamma\beta} + y'_{\gamma\beta}\, y_{\gamma\alpha} \right\}$$

$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$

$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$

$S_1 \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)$

SCALAR LQs	$SU(5)$
$S_3 \equiv (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$	$\overline{\mathbf{45}}$
$\tilde{R}_2 \equiv (\mathbf{3}, \mathbf{2}, 1/6)$	$\mathbf{10}, \mathbf{15}$
$S_1 \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)$	$\overline{\mathbf{5}}, \overline{\mathbf{45}}$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$(m_N)_{\alpha\beta} \approx \frac{3\theta}{16\pi^2} \ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \sum_{\gamma=d,s,b} m_\gamma \left\{ y'_{\gamma\alpha}\, y_{\gamma\beta} + y'_{\gamma\beta}\, y_{\gamma\alpha} \right\}$$

$$m_b \approx 1\,\mathrm{GeV}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$(m_N)_{\alpha\beta} \approx \frac{3\theta}{16\pi^2} \ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \sum_{\gamma=d,s,b} m_\gamma \left\{ y'_{\gamma\alpha}\, y_{\gamma\beta} + y'_{\gamma\beta}\, y_{\gamma\alpha} \right\}$$

$$m_b \approx 1\,\mathrm{GeV}$$

$$\ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \approx 1 \qquad m_{\mathrm{LQ}} \geq 10^{12}\,\mathrm{GeV}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$(m_N)_{\alpha\beta} \approx \frac{3\theta}{16\pi^2} \ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \sum_{\gamma=d,s,b} m_\gamma \left\{ y'_{\gamma\alpha}\, y_{\gamma\beta} + y'_{\gamma\beta}\, y_{\gamma\alpha} \right\}$$

$$m_b \approx 1\,\mathrm{GeV}$$

$$\ln \frac{m^2_{\mathrm{LQ}\,2}}{m^2_{\mathrm{LQ}\,1}} \approx 1 \qquad m_{\mathrm{LQ}} \geq 10^{12}\,\mathrm{GeV}$$

$$\boxed{m_N \approx 10^{-2}\,\theta\, y'\, y\,\mathrm{GeV}}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$m_N \approx 10^{-2}\,\theta\,y'\,y\,\mathrm{GeV}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$m_N \approx 10^{-2}\,\theta\,y'\,y\,\mathrm{GeV}$$

$$\theta \approx \frac{\lambda\langle H\rangle}{m_{\mathrm{LQ}}^2}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$m_N \approx 10^{-2}\,\theta\,y'\,y\,\mathrm{GeV}$$

$$\theta \approx \frac{\lambda\langle H\rangle}{m_{\mathrm{LQ}}^2}$$

$$\kappa\,\mathbf{5}^a\overline{\mathbf{15}}_{bc}\mathbf{45}_a^{cd}\mathbf{24}_d^b$$

SCALAR LQs	$SU(5)$
$S_3 \equiv (\overline{\mathbf{3}},\mathbf{3},1/3)$	$\overline{\mathbf{45}}$
$\tilde{R}_2 \equiv (\mathbf{3},\mathbf{2},1/6)$	$\mathbf{10},\mathbf{15}$
$S_1 \equiv (\overline{\mathbf{3}},\mathbf{1},1/3)$	$\overline{\mathbf{5}},\overline{\mathbf{45}}$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$m_N \approx 10^{-2}\,\theta\,y'\,y\,\mathrm{GeV}$$

$$\theta \approx \frac{\lambda\langle H\rangle}{m_{\mathrm{LQ}}^2}$$

$$\kappa\,\mathbf{5}^a\overline{\mathbf{15}}_{bc}\mathbf{45}_a^{cd}\mathbf{24}_d^b \quad \Rightarrow \quad \lambda \approx \kappa\langle\mathbf{24}\rangle$$

$$\kappa \approx 1 \qquad \langle\mathbf{24}\rangle \approx 10^{16}\,\mathrm{GeV}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$m_N \approx 10^{-2}\,\theta\,y'\,y\,\mathrm{GeV}$$

$$\theta \approx \frac{\lambda\langle H\rangle}{m_{\mathrm{LQ}}^2} \approx \frac{10^{16}\,10^2}{10^{24}} \approx 10^{-6}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$

$$m_N \approx 10^{-2}\,\theta\,y'\,y\,\mathrm{GeV}$$

$$\theta \approx \frac{\lambda\langle H\rangle}{m_{\mathrm{LQ}}^2} \approx \frac{10^{16}\,10^2}{10^{24}} \approx 10^{-6}$$

$$m_N \approx 10\,y'\,y\,\mathrm{eV}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$ WITH HEAVY LEPTOQUARKS

$$10^{12}\,\mathrm{GeV} \leq m_{\mathrm{LQ}} \leq 5 \times 10^{13}\,\mathrm{GeV}$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$ WITH LIGHT LEPTOQUARKS©

©I. Doršner, S. Fajfer, N. Košnik, arXiv:1701.08322.

ONE-LOOP ν MASSES IN $SU(5)$ WITH LIGHT LQs

A POSSIBLE $SU(5)$ SET-UP:

$\mathbf{5}$
THE STANDARD MODEL SYMMETRY BREAKING
CHARGED FERMION MASSES

$\mathbf{15}$
$\tilde{R}_2$
UNIFICATION
TYPE II SEE-SAW ν MASSES

$\mathbf{45}$
S_3
THE STANDARD MODEL SYMMETRY BREAKING
CHARGED LEPTON & DOWN-TYPE QUARK MASSES

•H. Georgi, S. L. Glashow, Phys. Rev. Lett. 32 (1974). ⊙I. Doršner, P. Fileviez Perez, Nucl. Phys. B723 (2005). ◆H. Georgi, C. Jarlskog., Phys. Lett. B86 (1979).

ONE-LOOP ν MASSES IN $SU(5)$

$\mathbf{5}$	$\mathbf{15}$ $\tilde{R}_2$	$\mathbf{45}$ S_3
$x_{ij}\mathbf{10}_i\overline{\mathbf{5}}_j\overline{\mathbf{5}}$	$y'_{ij}\overline{\mathbf{5}}_i\overline{\mathbf{5}}_j\mathbf{15}$	$y_{ij}\mathbf{10}_i\overline{\mathbf{5}}_j\overline{\mathbf{45}}$
$x'_{ij}\mathbf{10}_i\mathbf{10}_j\mathbf{5}$		

$\mathbf{10}_i$ & $\overline{\mathbf{5}}_i$ $(i = 1, 2, 3)$ COMPRISE THE STANDARD MODEL FERMIONS

ONE-LOOP ν MASSES IN $SU(5)$

$\mathbf{5}$	$\mathbf{15}$	$\mathbf{45}$
	$\tilde{R}_2$	S_3
$x_{ij}\mathbf{10}_i\overline{\mathbf{5}}_j\overline{\mathbf{5}}$	$y'_{ij}\overline{\mathbf{5}}_i\overline{\mathbf{5}}_j\mathbf{15}$	$y_{ij}\mathbf{10}_i\overline{\mathbf{5}}_j\overline{\mathbf{45}}$ ◎
$x'_{ij}\mathbf{10}_i\mathbf{10}_j\mathbf{5}$		

◎I. Doršner, S. Fajfer, N. Košnik, Phys. Rev. D 86, 015013 (2012).

p DECAY THROUGH THE LQ MIXING

Q	**5**	**15**	**45**	
1/3	S_1	$\tilde{R}_2^{-1/3\,*}$	$S_3^{1/3}$	S_1
2/3		$\tilde{R}_2^{2/3}$	$R_2^{2/3}$	$S_3^{2/3}$
4/3			$S_3^{4/3}$	$\tilde{S}_1$
5/3				$R_2^{5/3}$

p DECAY THROUGH THE LQ MIXING

$$\begin{bmatrix} S_1 & S_1 & \tilde{R}_2^{-1/3\,*} & S_3^{1/3} \end{bmatrix} \begin{bmatrix} & & & \\ & & & \\ & & 4\times 4 & \\ & & & \\ & & & \end{bmatrix} \begin{bmatrix} S_1 \\ \\ S_1 \\ \\ \tilde{R}_2^{-1/3\,*} \\ \\ S_3^{1/3} \end{bmatrix}^{*}$$

p DECAY THROUGH THE LQ MIXING

$$\begin{bmatrix} S_1 & S_1 & \tilde{R}_2^{-1/3\,*} & S_3^{1/3} \end{bmatrix} \begin{bmatrix} & & 0 & 0 \\ & & 0 & 0 \\ 0 & 0 & & \\ 0 & 0 & & \end{bmatrix} \begin{bmatrix} S_1 \\ S_1 \\ \tilde{R}_2^{-1/3\,*} \\ S_3^{1/3} \end{bmatrix}^*$$

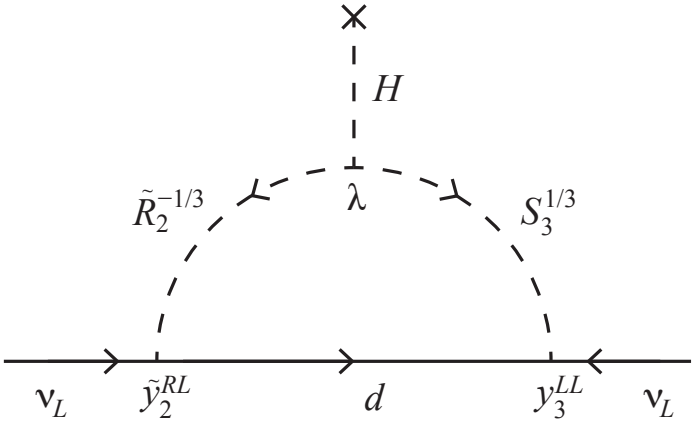
p DECAY THROUGH THE LQ MIXING

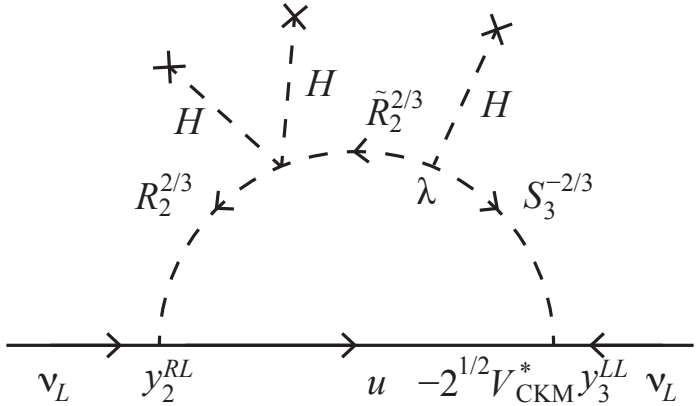
Q	**5**	**15**	**45**	
1/3	S_1	$\tilde{R}_2^{-1/3\,*}$	$S_3^{1/3}$	S_1
2/3		$\tilde{R}_2^{2/3}$	$R_2^{2/3}$	$S_3^{2/3}$
4/3			$S_3^{4/3}$	$\tilde{S}_1$
5/3				$R_2^{5/3}$

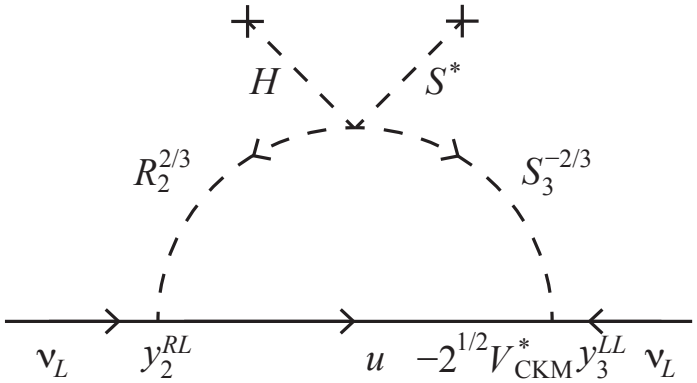
p DECAY THROUGH THE LQ MIXING

$$\begin{bmatrix} S_3^{4/3} & \tilde{S}_1 \end{bmatrix} \begin{bmatrix} & 0 \\ 0 & \end{bmatrix} \begin{bmatrix} S_3^{4/3} \\ \tilde{S}_1 \end{bmatrix}^*$$

ONE-LOOP ν MASS MECHANISMS IN $SU(5)$ WITH LIGHT LEPTOQUARKS







CONCLUSIONS

SU(5) CAN ACCOMMODATE WITH EASE THE ONE-LOOP NEUTRINO MASS MECHANISM THAT IS BASED ON THE LEPTOQUARK MULTIPLET MEDIATION AND MIXING.

THE USE OF *SU*(5) CAN INCREASE PREDICTIVITY OF THE SET-UP. THIS COULD ESPECIALLY BE REFLECTED IN THE DECAY PATTERNS OF THE RELEVANT LEPTOQUARK MULTIPLETS.

CONCLUSIONS

IN THE HEAVY LEPTOQUARK REGIME THE VIABILITY WINDOW FOR THE LEPTOQUARK MASSES AND COUPLINGS TO THE MATTER IS EXTREMELY NARROW.

THE LIGHT LEPTOQUARK LIMIT CAN ALSO BE ACCOMMODATED. IN THAT REGIME THERE CAN BE AN INTERPLAY BETWEEN THE DOWN-TYPE AND THE UP-TYPE QUARK LOOPS.

THANK YOU

dorsner@fesb.hr