Is The Muon A Third Family Lepton ?

Shahram Vatani

with Giacomo Cacciapaglia and Aldo Deandra

arXiv:2212.08691

Quick Look On The SM

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Gauge :

$$SU(3)_c \times SU(2) \times U(1)_Y$$

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Up, Down, Electron, Neutrino

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$$H$$

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Fermi Theory + Mass

Construction based on Gauge Principle

Quick Look On The SM

Muon

Strange

Fermions :

Up, Down, Electron, Neutrino

« Family »

Charm

Tau

Construction based on Gauge Principle

Quick Look On The SM

Fermions :

Up, Down, Electron, Neutrino

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x 3 = Flavor

Construction based on Gauge Principle

Quick Look On The SM

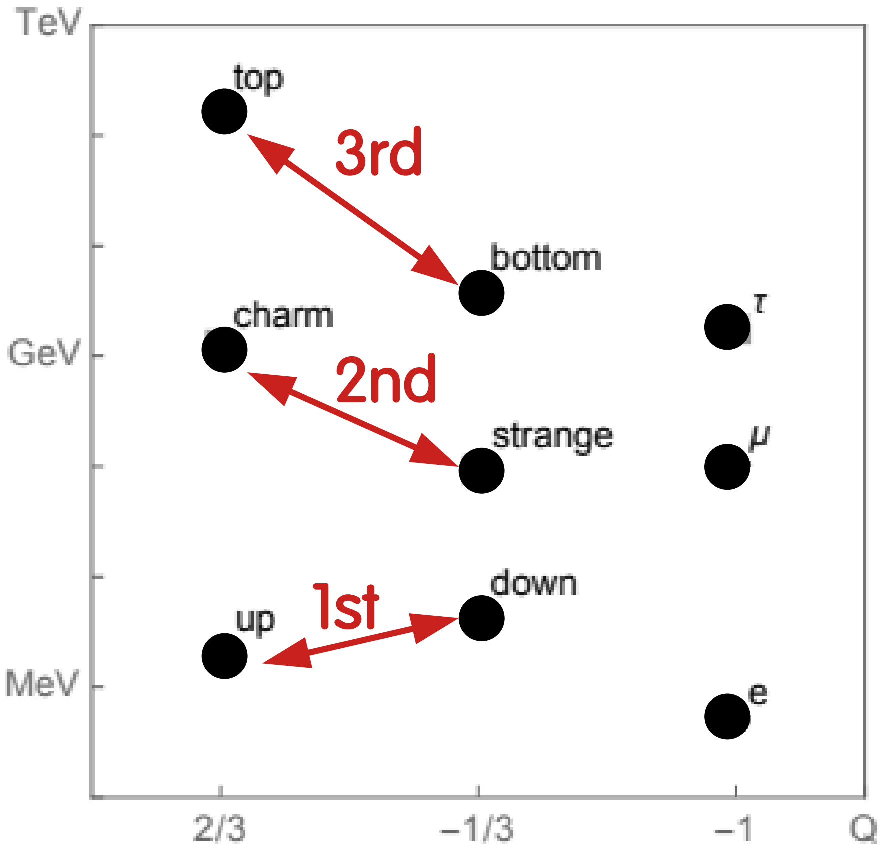
Only aspect that does not derive from Gauge Principle

Fermions :
Up, Down, Electron, Neutrino
« Family »

x 3 = Flavor

Construction based on Gauge Principle

SM Family Assignment



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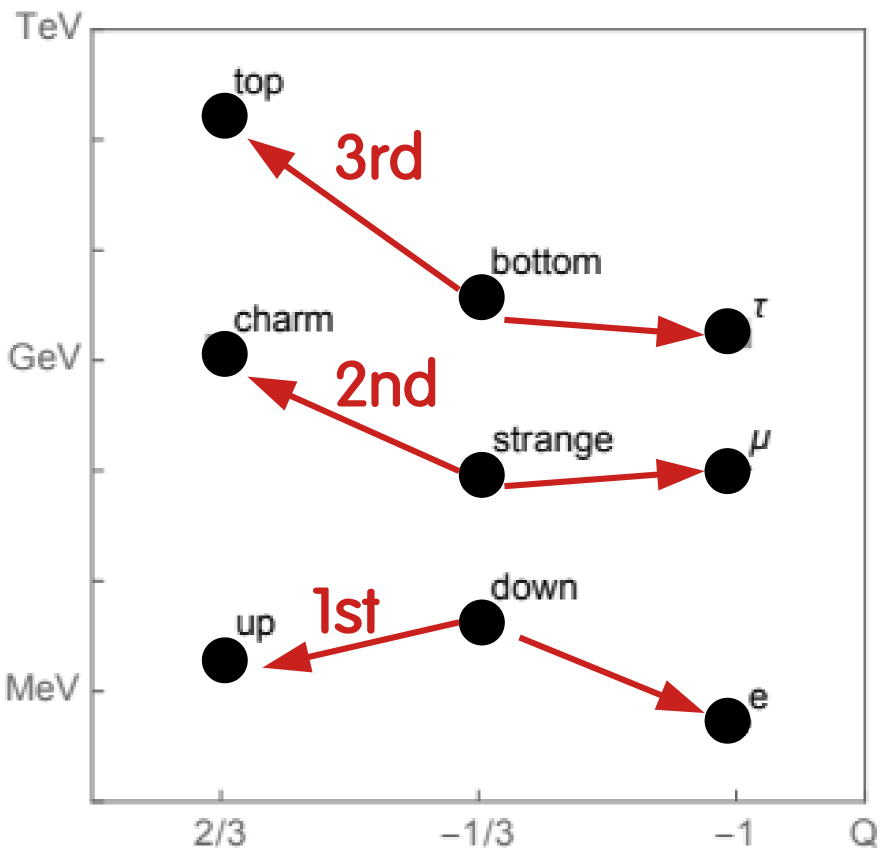
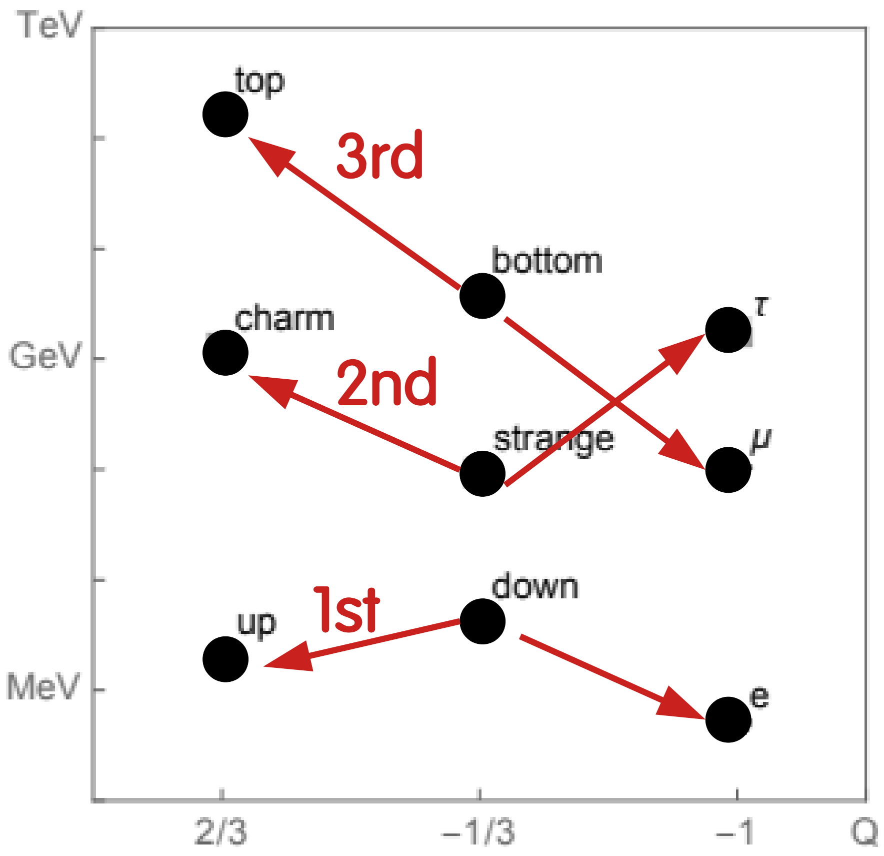


New Family Assignment ?



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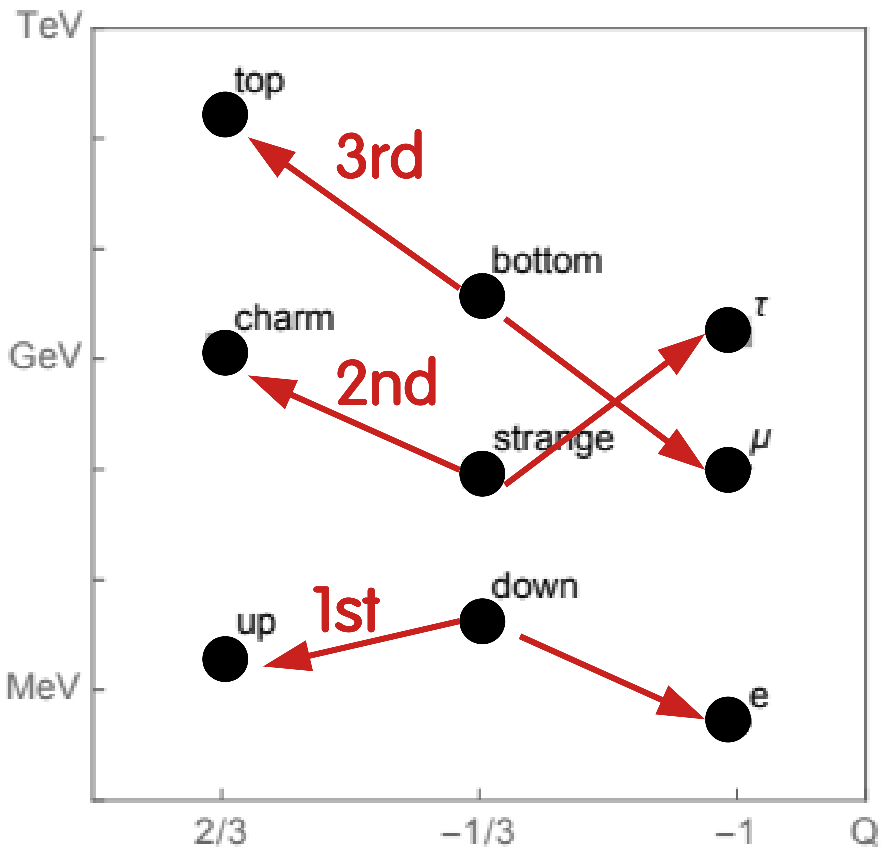

- Relevant in BSM :

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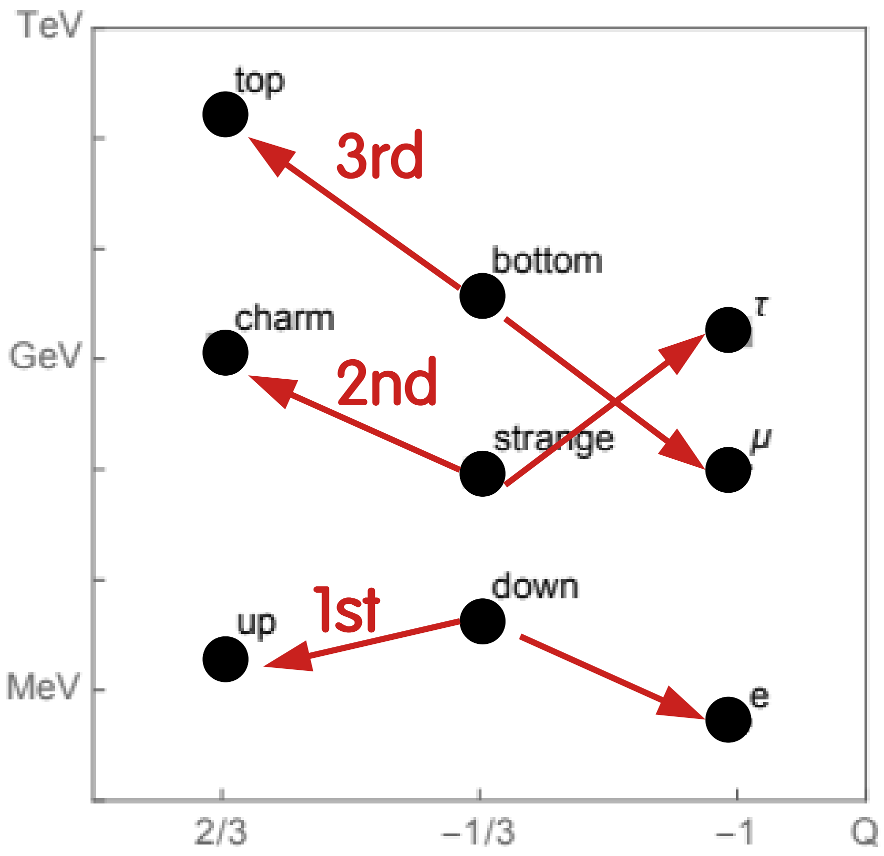

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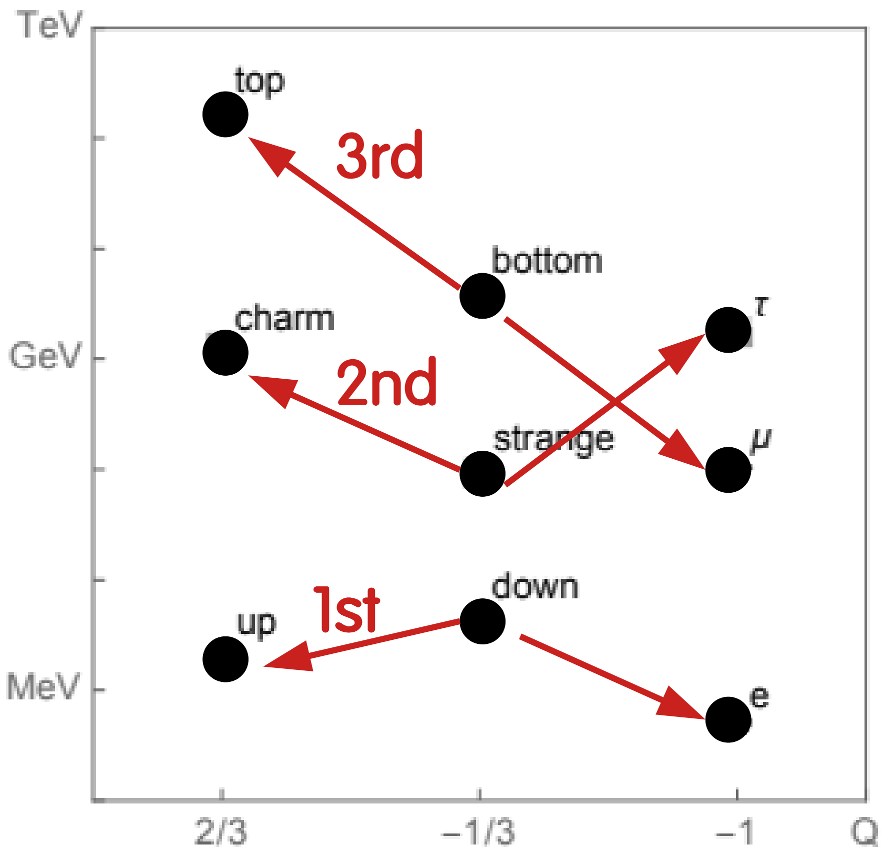

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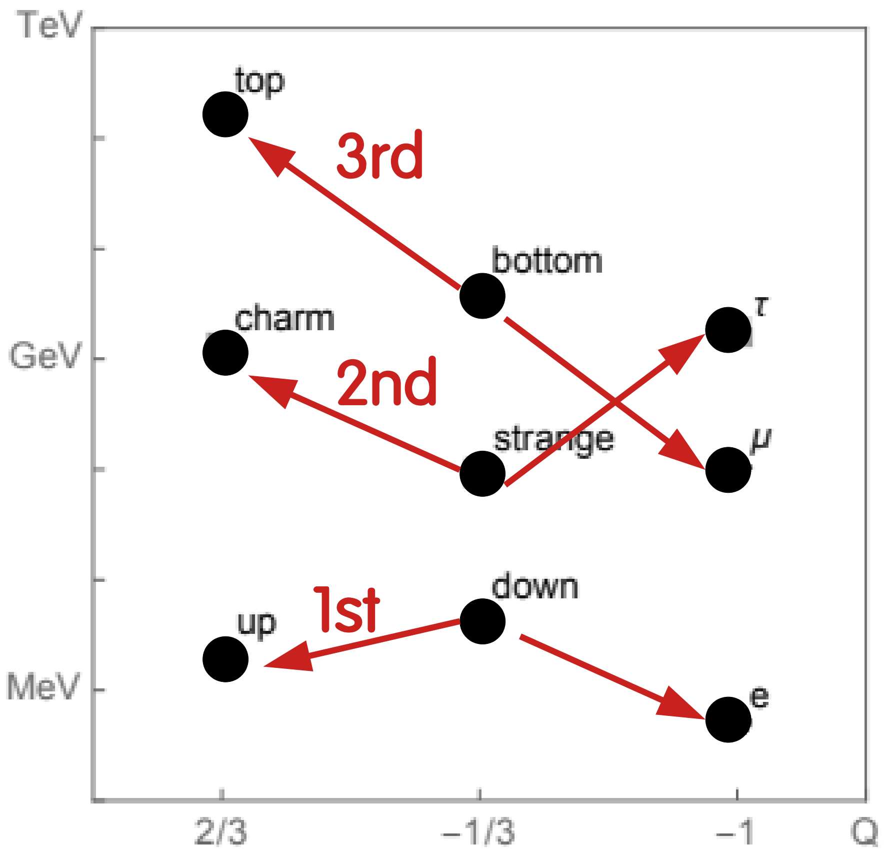
$$\begin{pmatrix} \text{Quark} \\ \text{Lepton} \end{pmatrix} \Leftrightarrow \text{New Physics}$$

New Family Assignment ?



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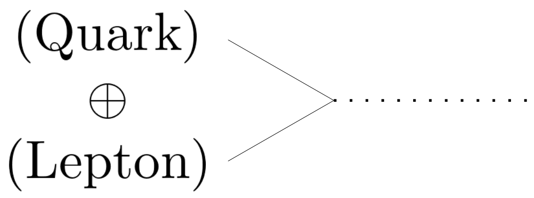

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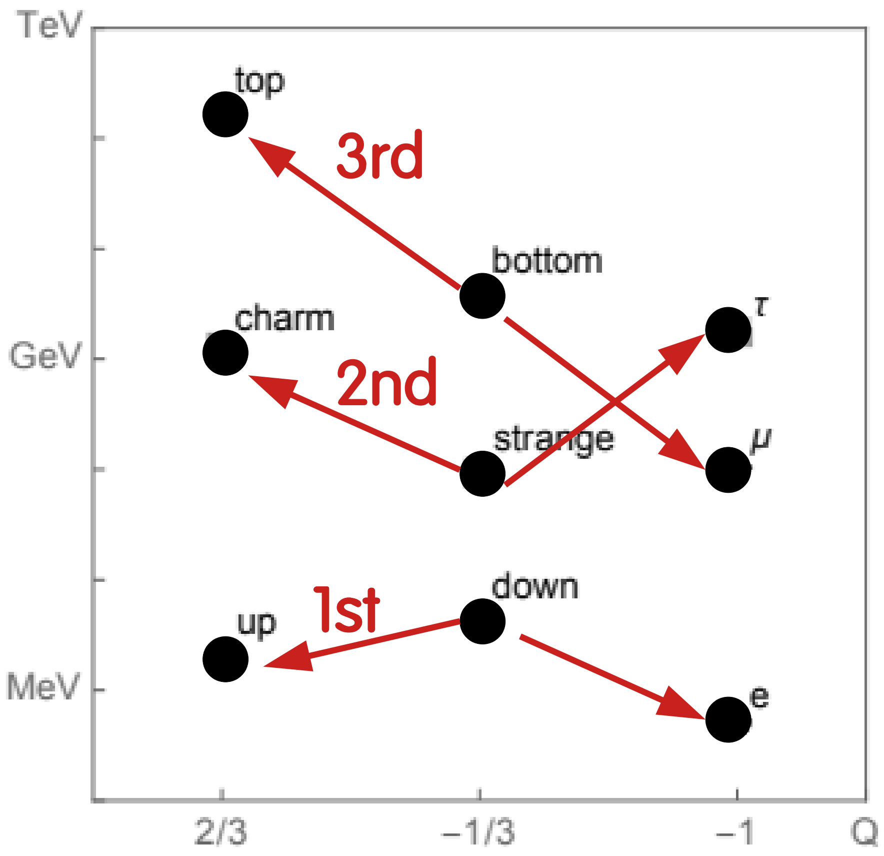

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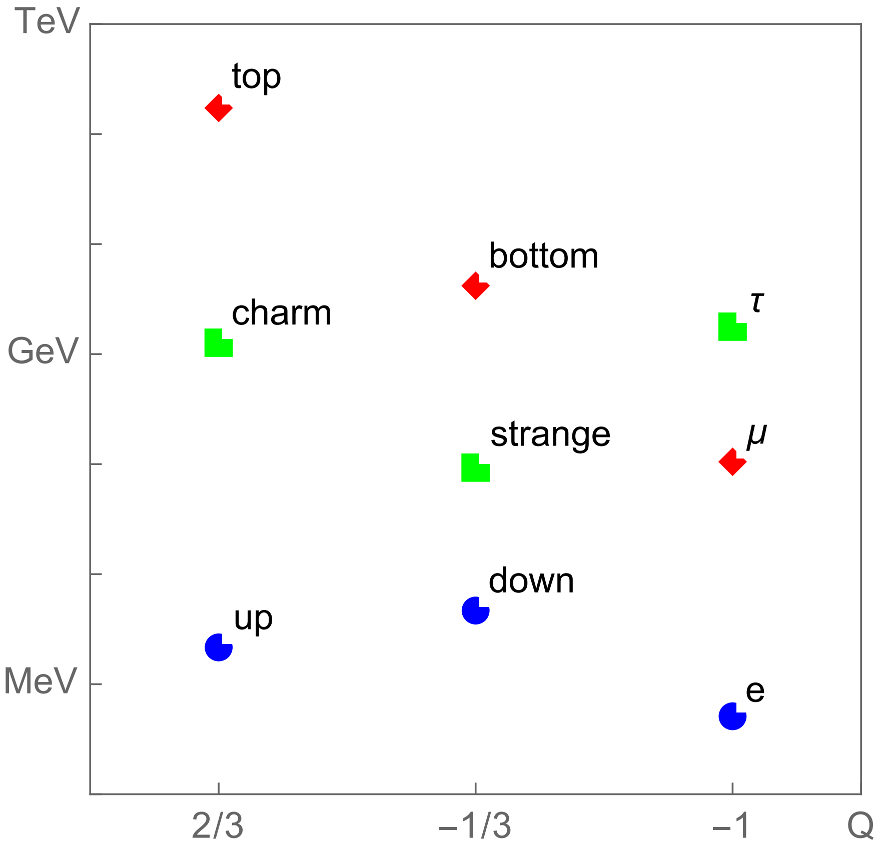
$$\begin{matrix}(\text{Quark})\\ \oplus \\ (\text{Lepton})\end{matrix} \cdots\cdots\cdots$$

- A new mass structure :
  New origin for Yukawa pattern

- 1) Loop Model for Masses

- 2) B Anomalies

New Family Assignment ?



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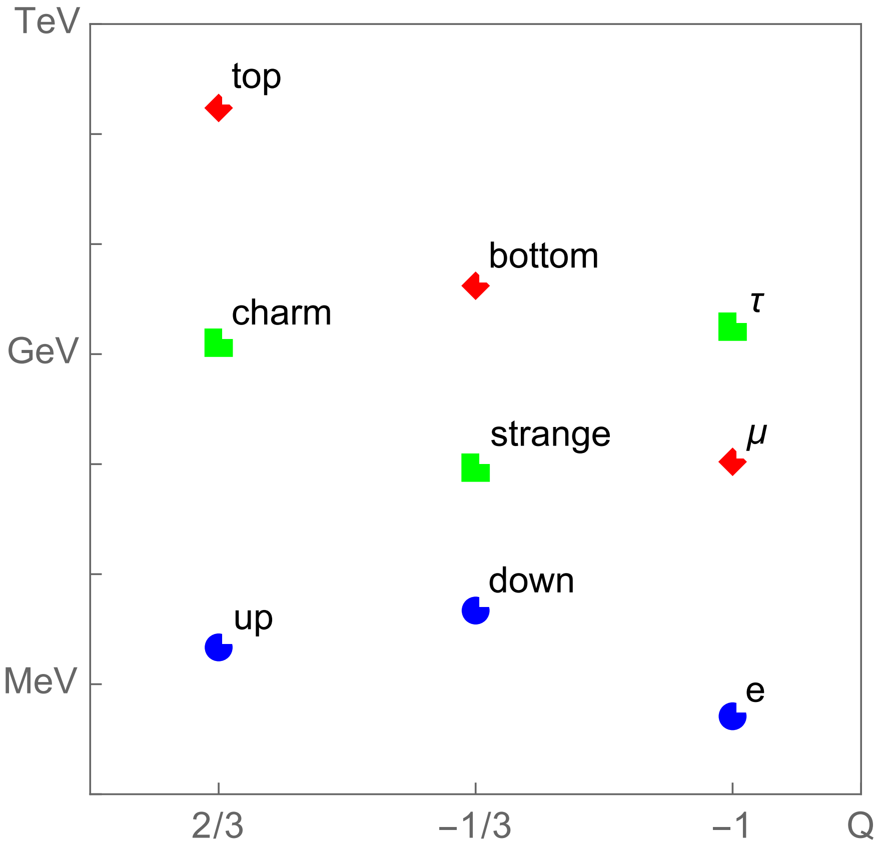

- 1st ~ MeV

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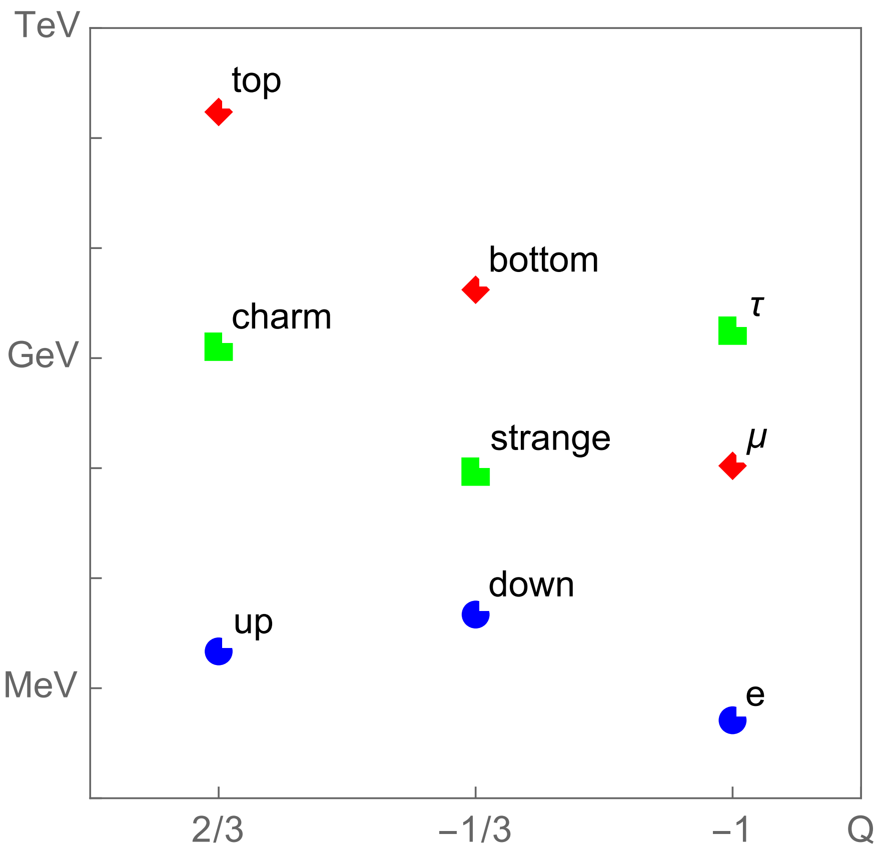

- 1st ~ MeV
- 2nd ~ GeV

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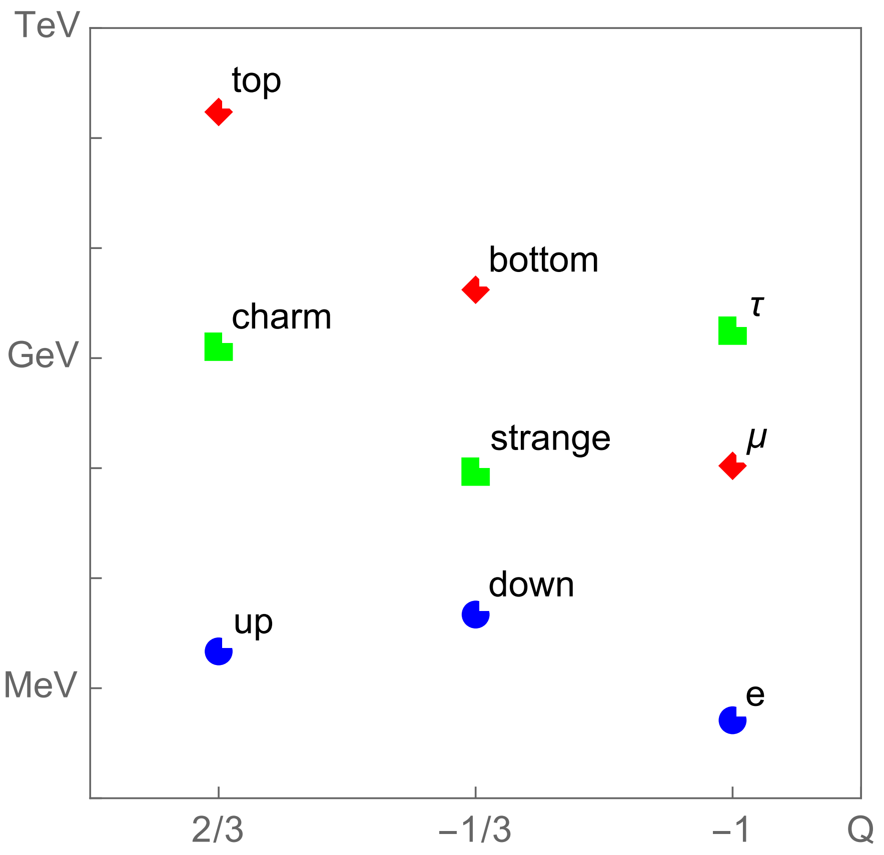

- 1st ~ MeV
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- 3rd with specific pattern :

$$X_{\mathrm{tb}} = \frac{m_{\mathrm{t}}}{m_{\mathrm{b}}} = 41.31^{+0.31}_{-0.21}$$

$$X_{\mathrm{b}\mu} = \frac{m_{\mathrm{b}}}{m_{\mu}} = 39.56^{+0.28}_{-0.19}$$

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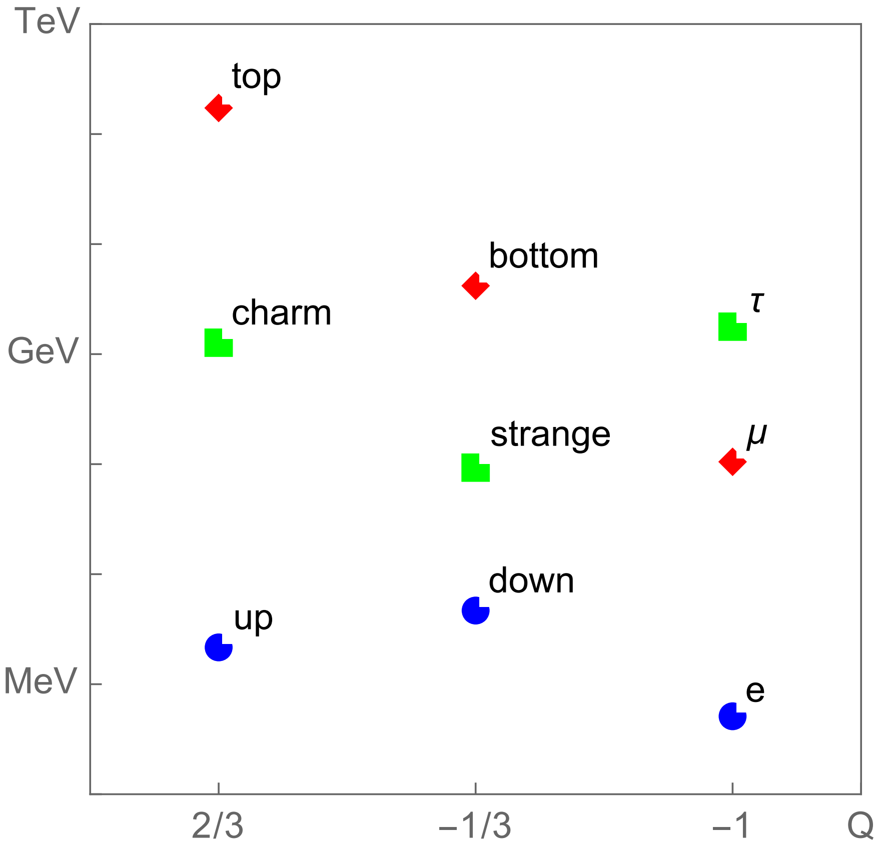

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$$\frac{X_{\mathrm{b}\mu}}{X_{\mathrm{tb}}} = 0.958^{+0.014}_{-0.009}$$

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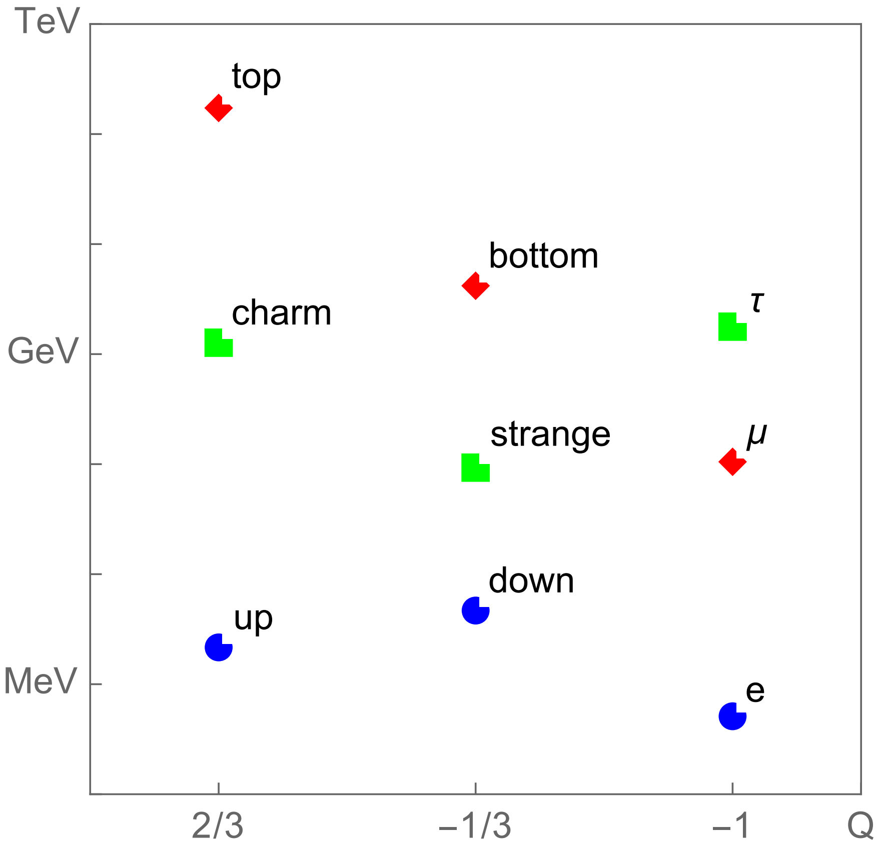

- Family Symmetry on 1st and 2nd Generations, broken by effective Yukawa (10^{-2} & 10^{-5})
- 3rd generation has tree level yukawa coupling
- Only top-Yukawa is allow (rest by Loop / Froggatt-Nielsen)

Loop Generation

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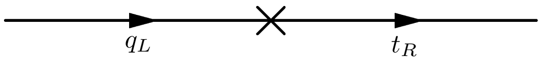

$$m_t = y_t \langle H \rangle$$

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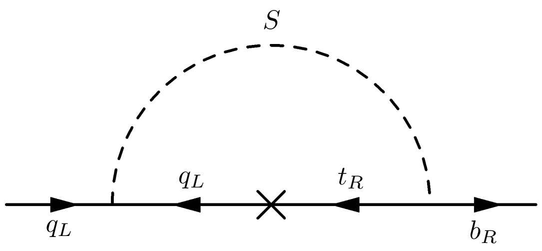

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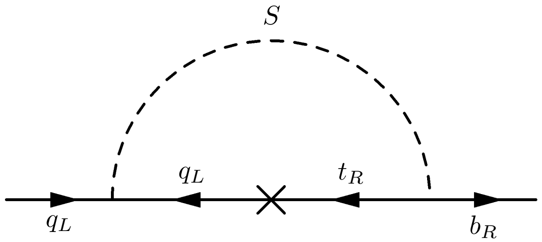

$$\frac{m_b}{m_t} = \frac{\lambda_S{}^2 c_{qq} c_{tb}}{8\pi^2} N_c \ln \frac{\Lambda}{M_S}$$

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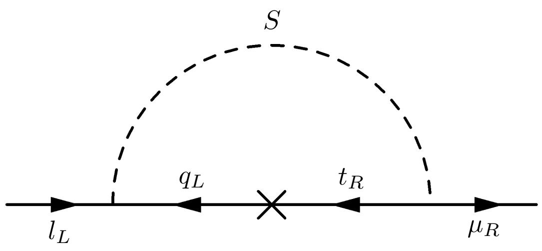

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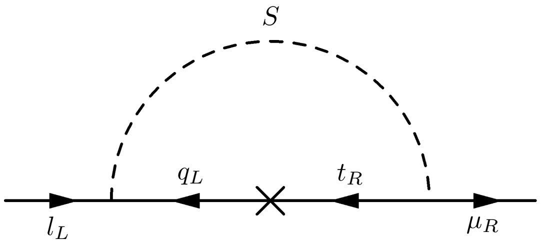

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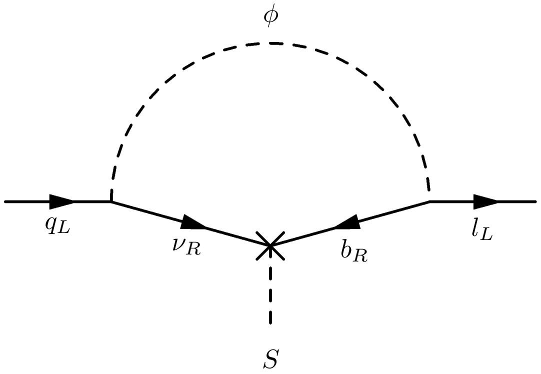

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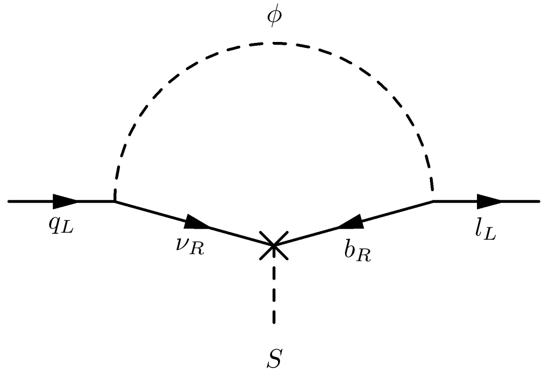

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$$m_\nu = \frac{{m_{\nu,D}}^2}{M_R} \quad m_\nu \cong 1eV \quad , \quad N_R = 3 \quad , \quad \lambda_{\phi/S} = 0.3 \quad , \quad c_{ij} = 1$$

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$$\boxed{M_R = 1.3 \; 10^7 GeV \;\; , \;\; \frac{M_S}{M_\phi} = 1150 \;\; , \;\; \frac{\Lambda}{M_S} = 490}$$

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- If NP couple dominantly to 3rd generation, a sizeable mixing between μ and τ would be required to generate large effects involving $\mu \Rightarrow$ LFV

- LFV is strongly constrained by experiments at levels well beyond the constraints on LFUV

- If the μ is assigned to 3rd generation, anomalies involving μ could be explained without LFV signatures

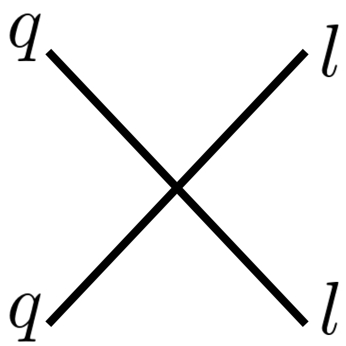
B Anomalies

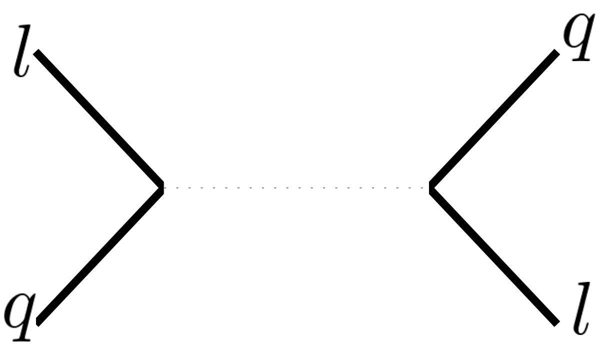
- The LEFT highlight a specific set of 4-Fermion interactions

$$\mathcal{O}_{9(10)} = \frac{\alpha}{4\pi} [\bar{s}\gamma_\mu P_L b] [\bar{\mu}\gamma^\mu(\gamma_5)\mu]$$

How to generate them ?

- New Physics (LeptoQuark)





B Anomalies

B Anomalies

3 SM-like unified families « à la Pati-Salam »

B Anomalies

3 SM-like unified families « à la Pati-Salam »

A	B	C
$\begin{pmatrix}\text{Quark}\\\text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\\text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\\text{Lepton}\end{pmatrix}$

B Anomalies

3 SM-like unified families « à la Pati-Salam »

A		B		C	
$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\Big\vert$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\Big\vert$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	Λ_{UV}

B Anomalies

3 SM-like unified families « à la Pati-Salam »

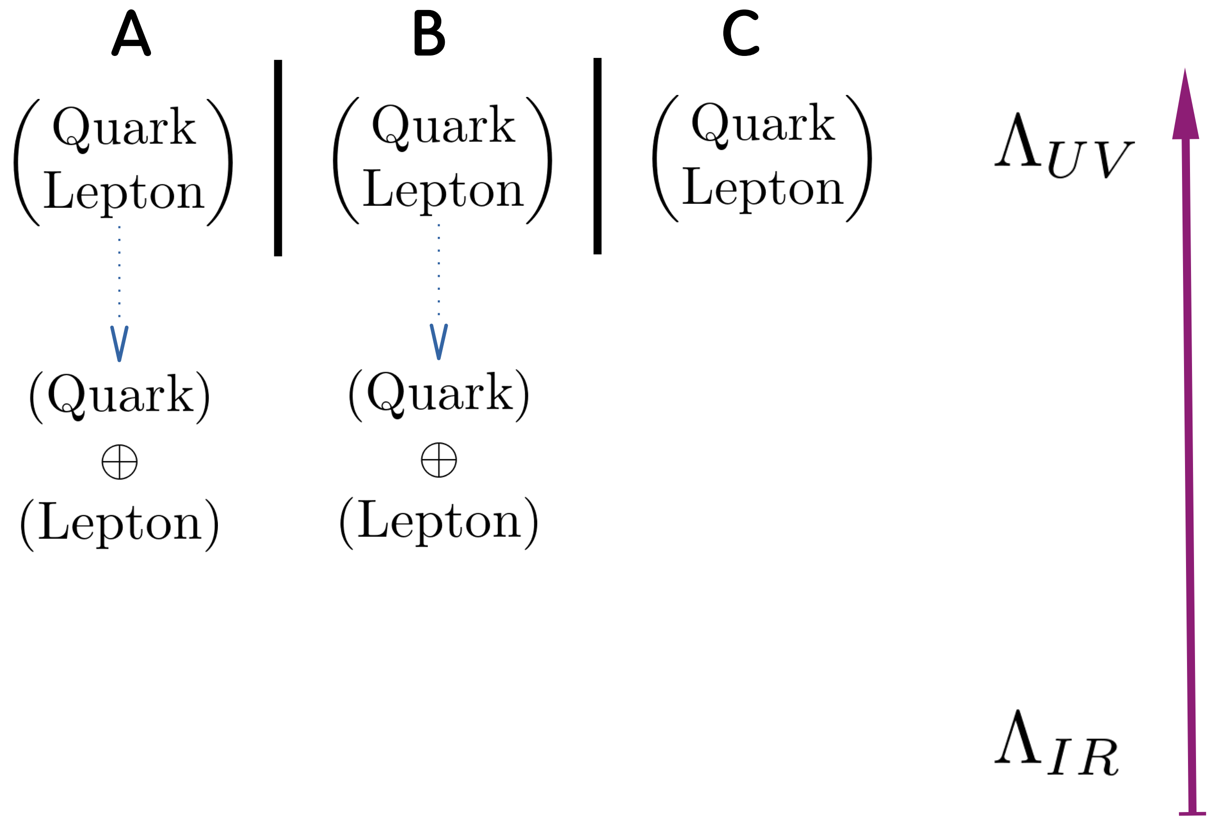
A	B	C
$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$

Λ_{UV}

Λ_{IR}

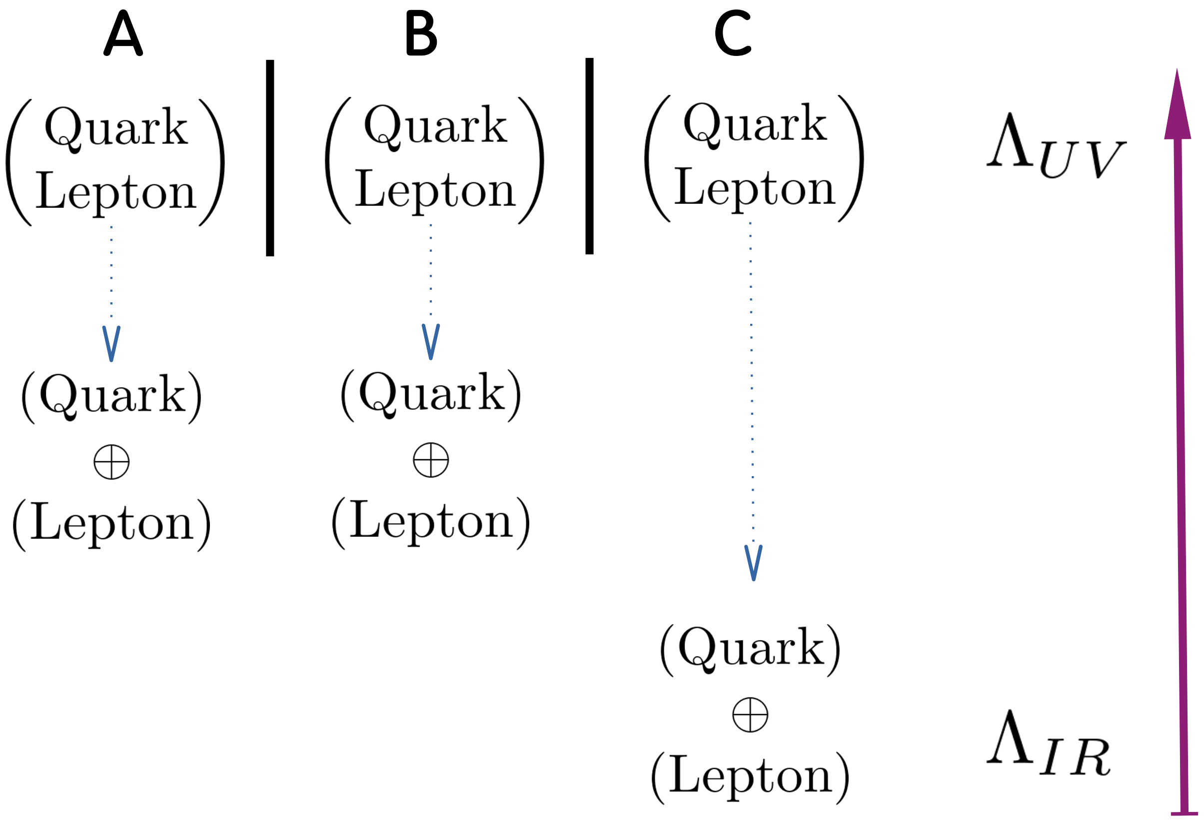
B Anomalies

3 SM-like unified families « à la Pati-Salam »



B Anomalies

3 SM-like unified families « à la Pati-Salam »



B Anomalies

3 SM-like unified families « à la Pati-Salam »

A	B	C
$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$
$\downarrow$	$\downarrow$	$\downarrow$
$(\text{Quark}) \oplus (\text{Lepton})$	$(\text{Quark}) \oplus (\text{Lepton})$	$(\text{Quark}) \oplus (\text{Lepton})$

B Anomalies

3 SM-like unified families « à la Pati-Salam »

A

$$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix} \longrightarrow (\text{Quark}) \oplus (\text{Lepton})$$

B

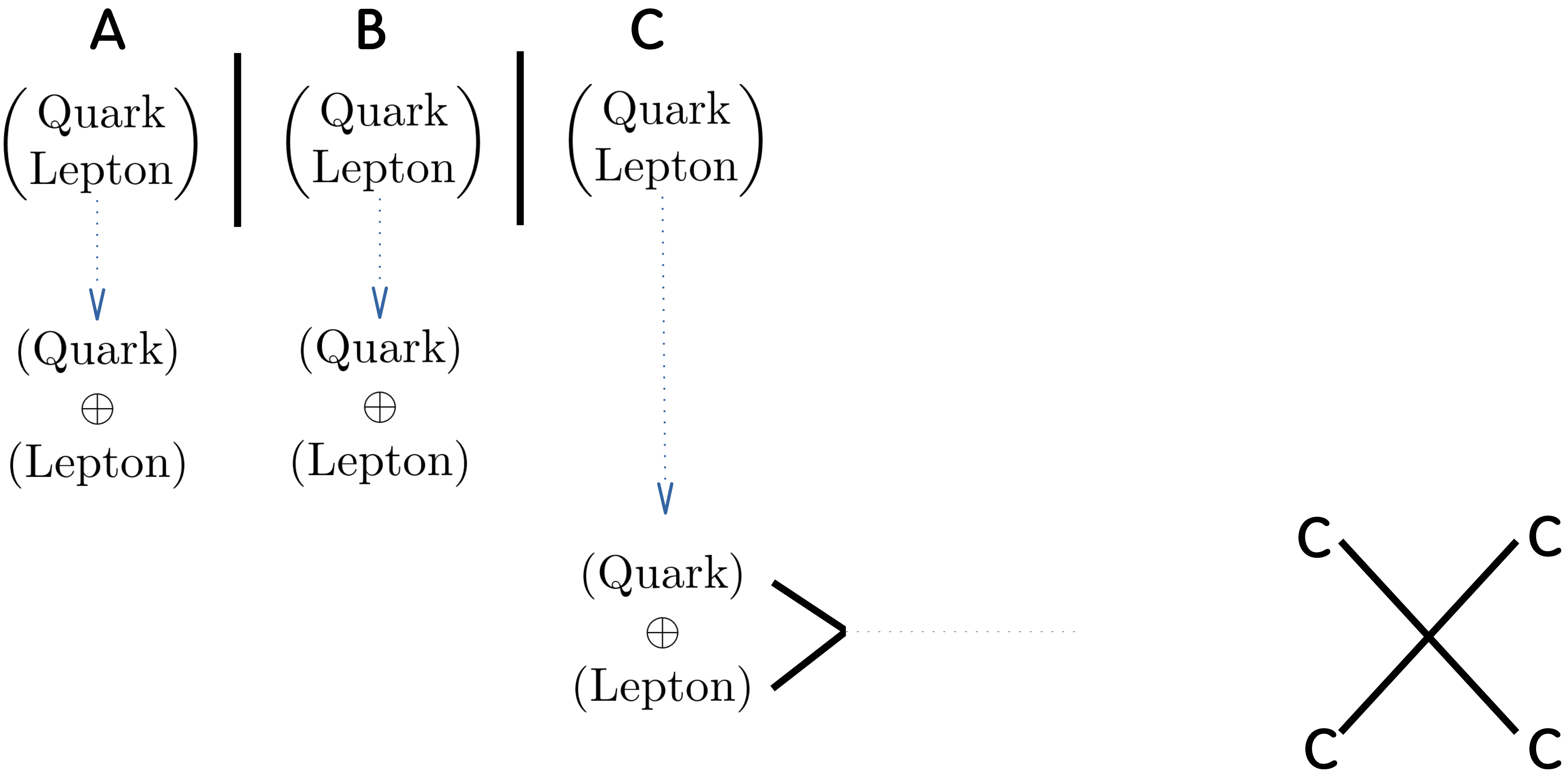
$$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix} \longrightarrow (\text{Quark}) \oplus (\text{Lepton})$$

C

$$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix} \longrightarrow (\text{Quark}) \oplus (\text{Lepton})$$

B Anomalies

3 SM-like unified families « à la Pati-Salam »

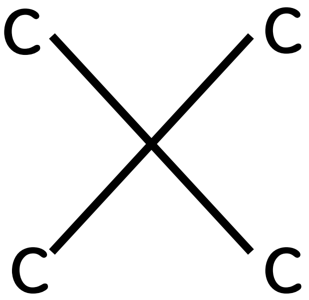


B Anomalies

3 SM-like unified families « à la Pati-Salam »

A	B	C
$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$
$\downarrow$	$\downarrow$	$\downarrow$
$(\text{Quark}) \oplus (\text{Lepton})$	$(\text{Quark}) \oplus (\text{Lepton})$	$(\text{Quark}) \oplus (\text{Lepton})$

$$\Longrightarrow \quad Y \sim \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & \epsilon_3 \\ & & 1 \end{pmatrix}$$

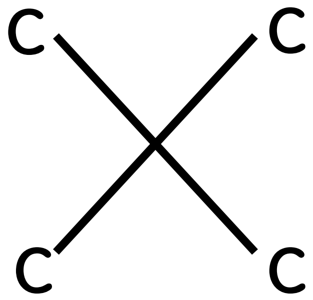


B Anomalies

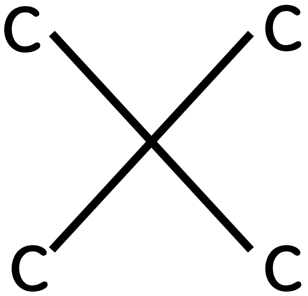
3 SM-like unified families « à la Pati-Salam »

A	B	C
$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$	$\begin{pmatrix}\text{Quark}\\ \text{Lepton}\end{pmatrix}$
$(\text{Quark}) \oplus (\text{Lepton})$	$(\text{Quark}) \oplus (\text{Lepton})$	$(\text{Quark}) \oplus (\text{Lepton})$

$\Longrightarrow$ C $\rightarrow$ B = ϵ_3



B Anomalies



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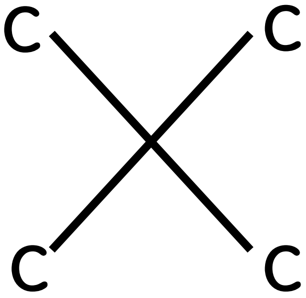
B Anomalies



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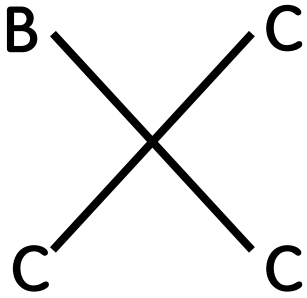
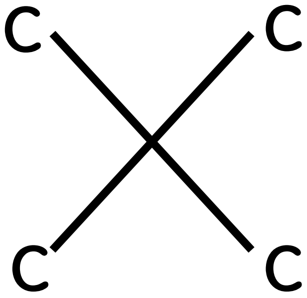
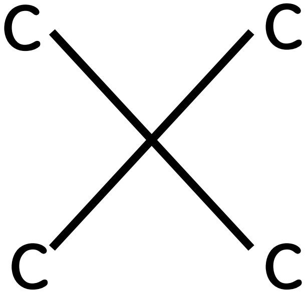


$= \epsilon_3$



B Anomalies



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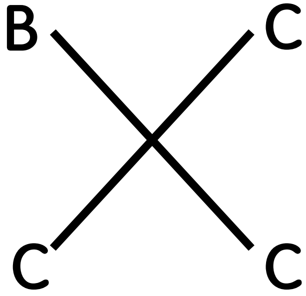
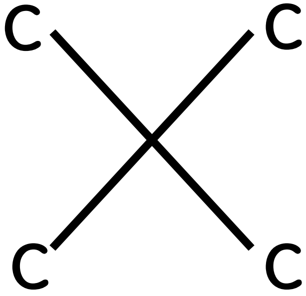
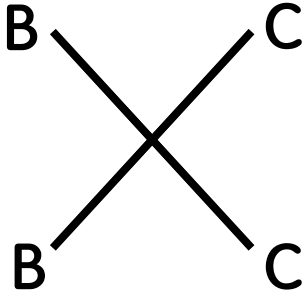
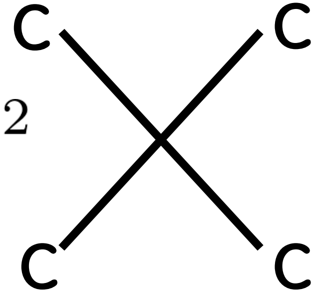


$= \epsilon_3$



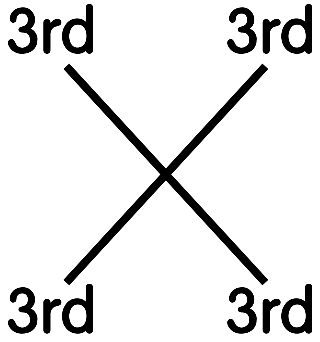


$= {\epsilon_3}^2$



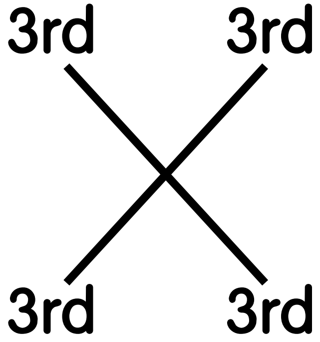
B Anomalies

$$\mathcal{O}_{9(10)} = \frac{\alpha}{4\pi}\,[\bar{s}\gamma_\mu P_L b]\,[\bar{\mu}\gamma^\mu(\gamma_5)\mu] \quad = \quad {\epsilon_3}^3$$



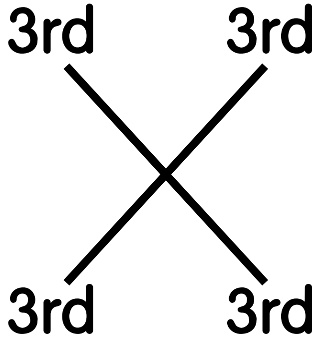
B Anomalies

$$\mathcal{O}_{9(10)} = \frac{\alpha}{4\pi}\,[\bar{s}\gamma_\mu P_L b]\,[\bar{\mu}\gamma^\mu(\gamma_5)\mu] \quad = \quad {\epsilon_3}^3$$



B Anomalies

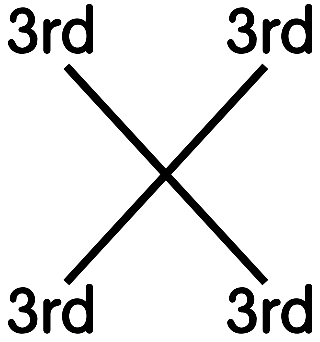
$$\mathcal{O}_{9(10)} = \frac{\alpha}{4\pi} \left[\bar{s}\gamma_\mu P_L b\right] \left[\bar{\mu}\gamma^\mu(\gamma_5)\mu\right] \quad = \quad {\epsilon_3}^3$$



$$Y \sim \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & \epsilon_3 \\ & & 1 \end{pmatrix}$$

B Anomalies

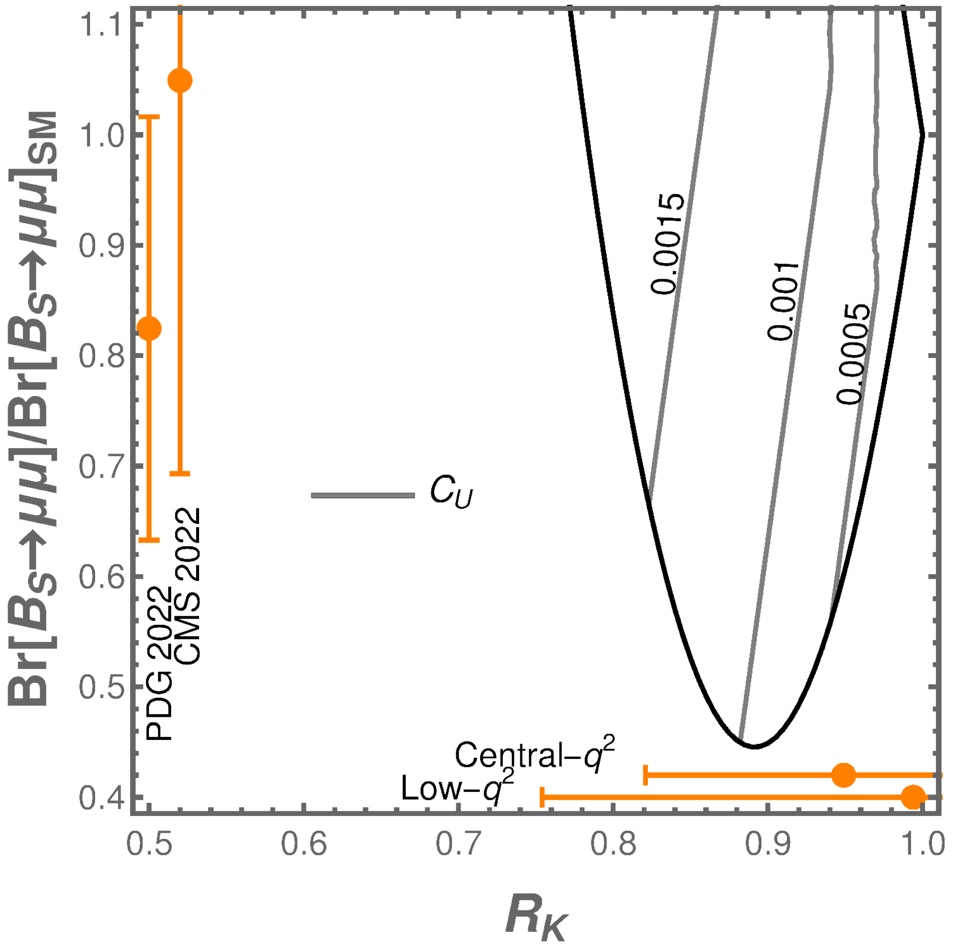
$$\mathcal{O}_{9(10)} = \frac{\alpha}{4\pi}\left[\bar{s}\gamma_\mu P_L b\right]\left[\bar{\mu}\gamma^\mu(\gamma_5)\mu\right] \quad = \quad {\epsilon_3}^3$$



$$Y \sim \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & \epsilon_3 \\ & & 1 \end{pmatrix} \implies \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & 1 \\ & & \epsilon_3 \end{pmatrix}$$

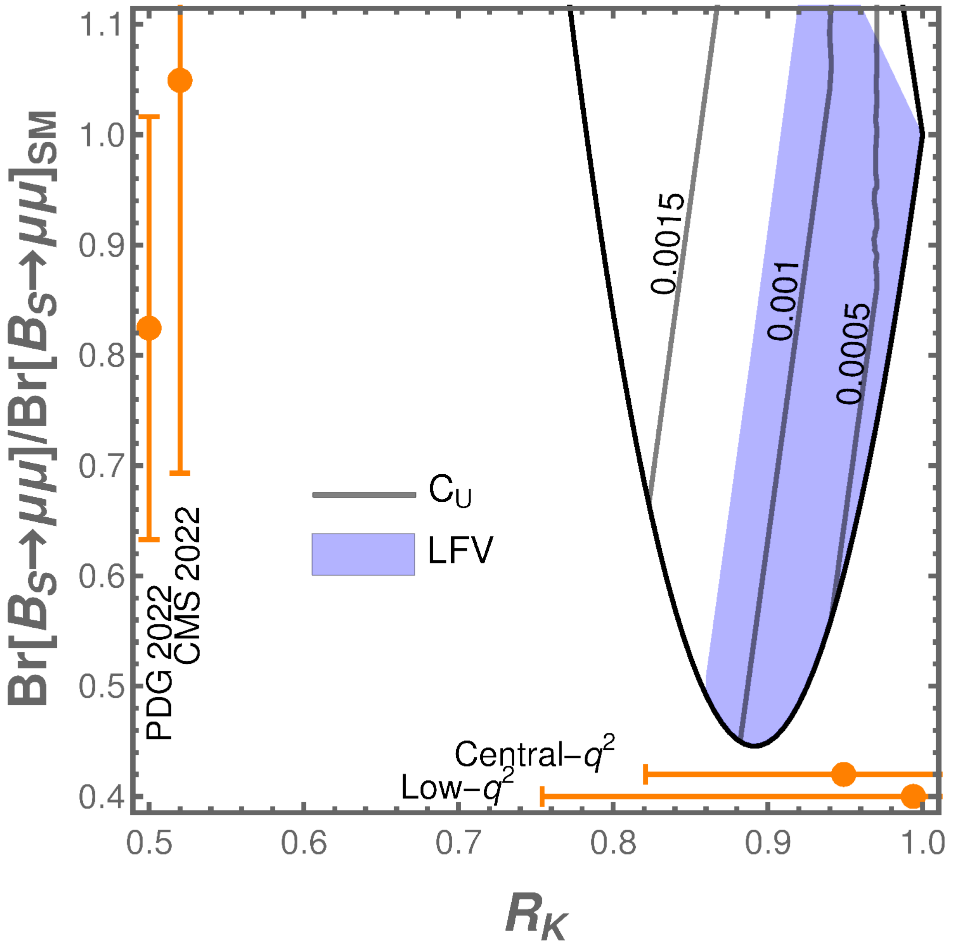
Results

Results



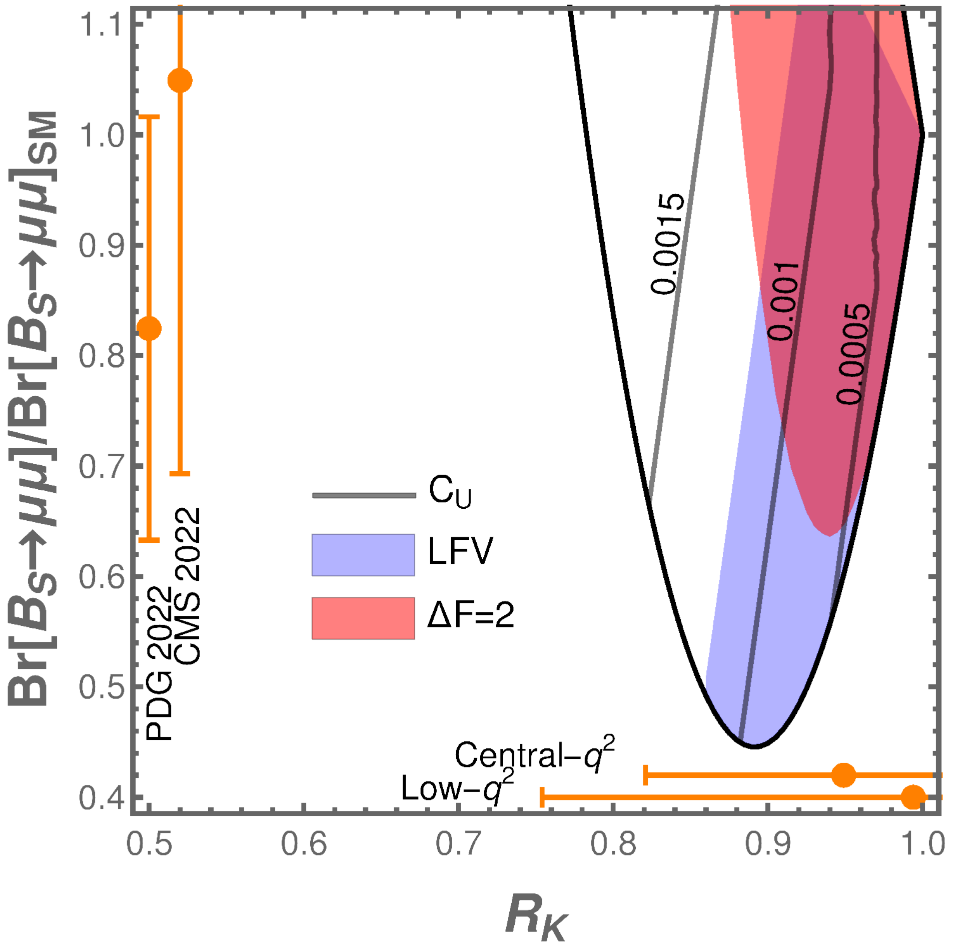
Br[$B_S \to \mu\mu$]/Br[$B_S \to \mu\mu$]$_{SM}$
R_K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0015
0.001
0.0005
C_U
PDG 2022
CMS 2022
Central-q^2
Low-q^2

Results



$\mathrm{Br}[B_S \to \mu\mu]/\mathrm{Br}[B_S \to \mu\mu]_{\mathrm{SM}}$
R_K
PDG 2022
CMS 2022
Central-q^2
Low-q^2
C_U
LFV
0.0015
0.001
0.0005

Results



C_U
LFV
ΔF=2
0.0015
0.001
0.0005
PDG 2022
CMS 2022
Central-q^2
Low-q^2
Br[$B_S \to \mu\mu$]/Br[$B_S \to \mu\mu$]$_{SM}$
R_K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Thank You !