Who ordered that ?

Shahram Vatani
with Giacomo Cacciapaglia and Aldo Deandra
Arxiv=Next Week !

Quick Look On The SM

Quick Look On The SM

Gauge :

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

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↓

Fermions :

Up, Down, Electron, Neutrino

« Family »

Quick Look On The SM

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ElectroWeak Symmetry Breaking :

$$H$$

Quick Look On The SM

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Fermi Theory + Mass

Quick Look On The SM

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Fermions :

Up, Down, Electron, Neutrino
« Family »

ElectroWeak Symmetry Breaking :

$$H$$

↓

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

« Family »

x 3 = Flavor

Construction based on Gauge Principle

Quick Look On The SM

Only aspect that does not derive from Gauge Principle

Fermions :

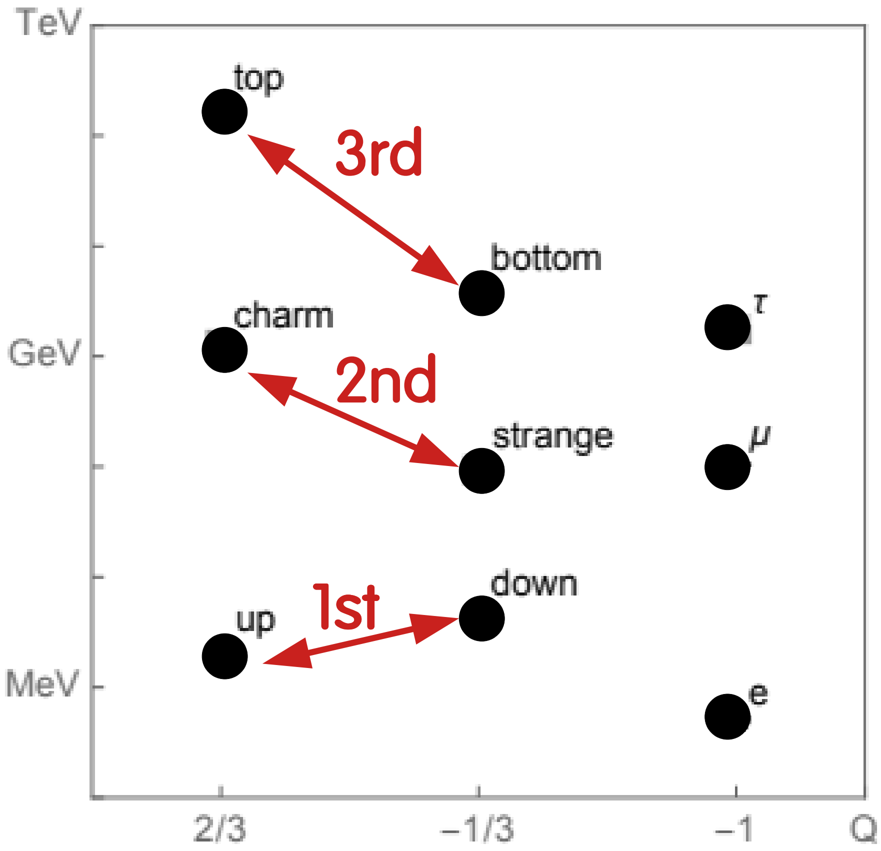
Up, Down, Electron, Neutrino

« Family »

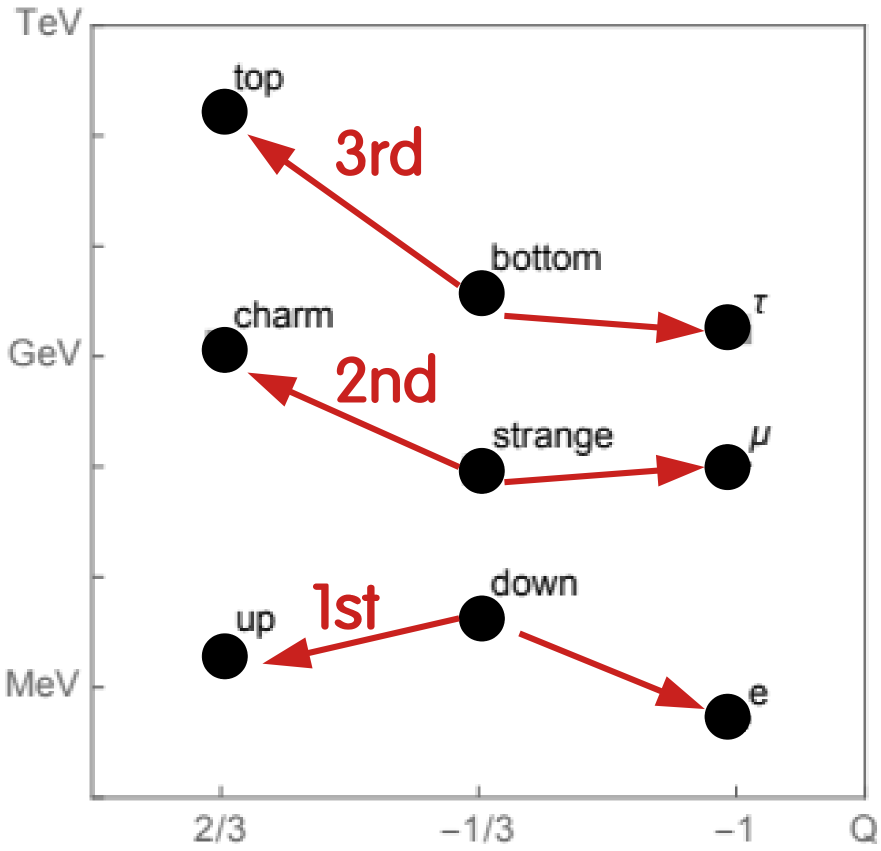
x 3 = Flavor

Construction based on Gauge Principle

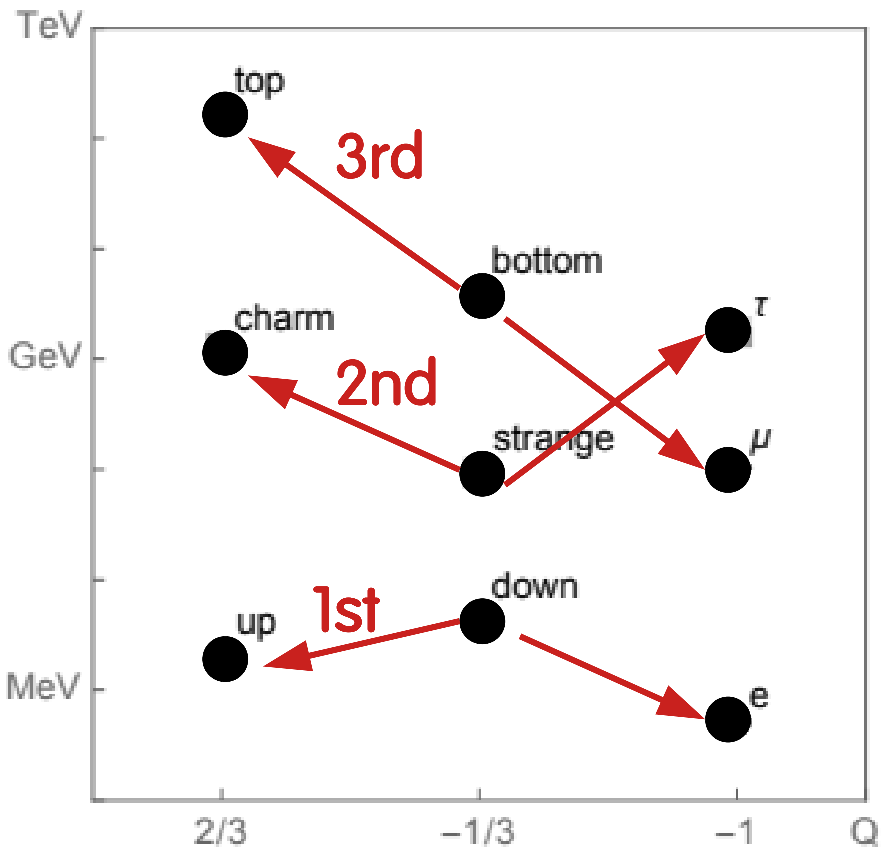
SM Family Assignment



SM Family Assignment



New Family Assignment ?



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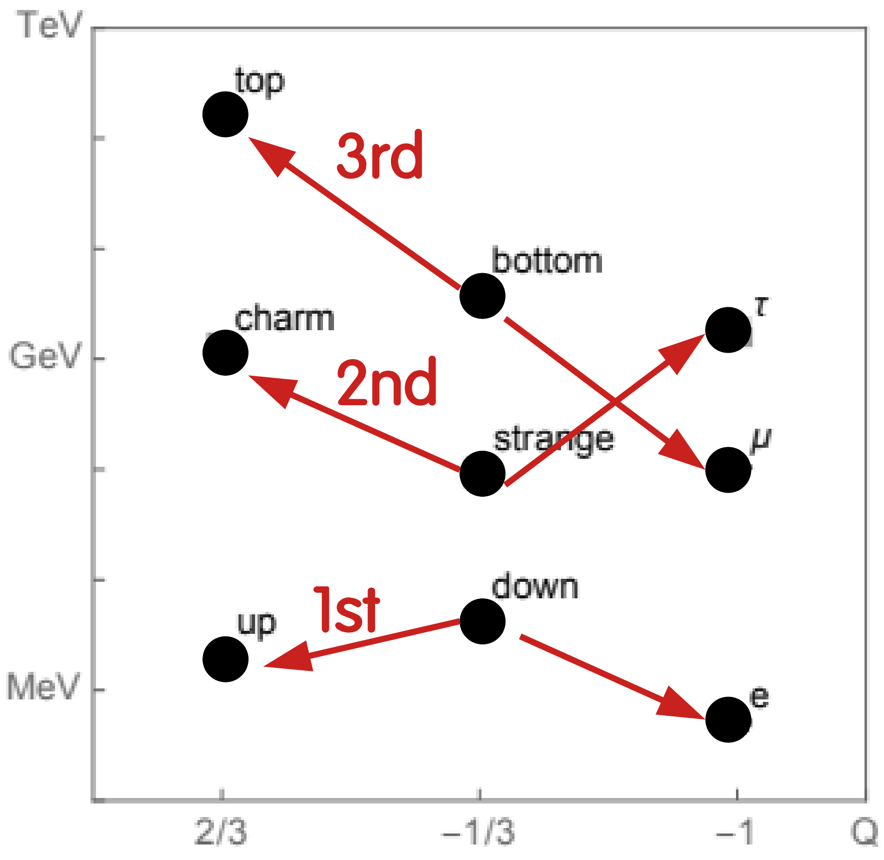
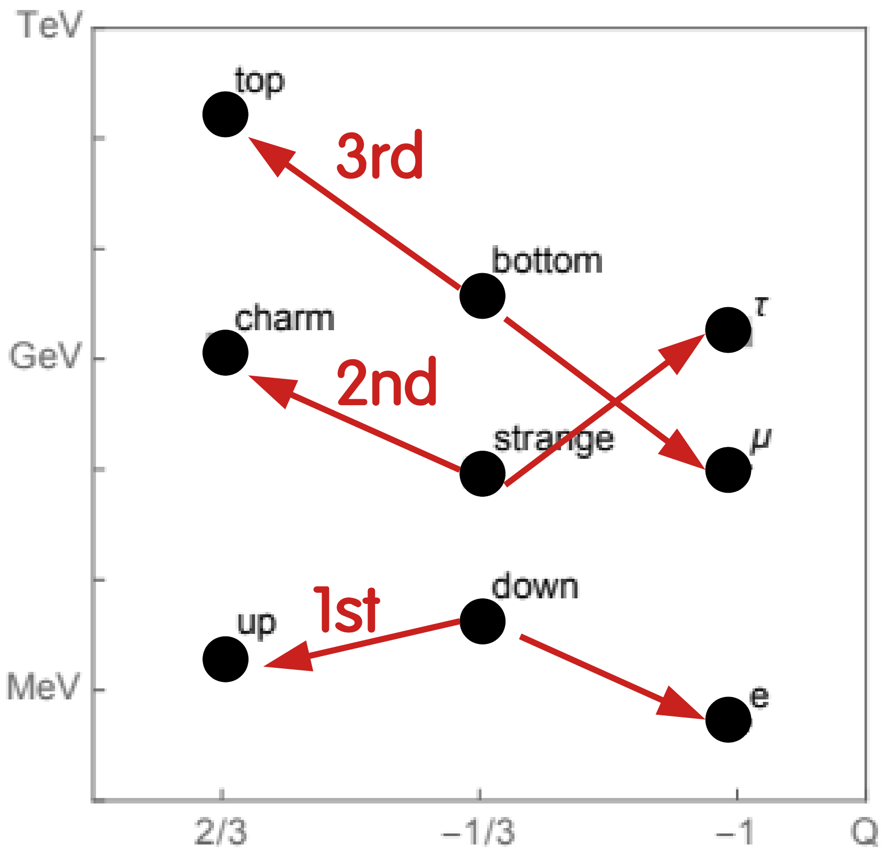


- Relevant in BSM :

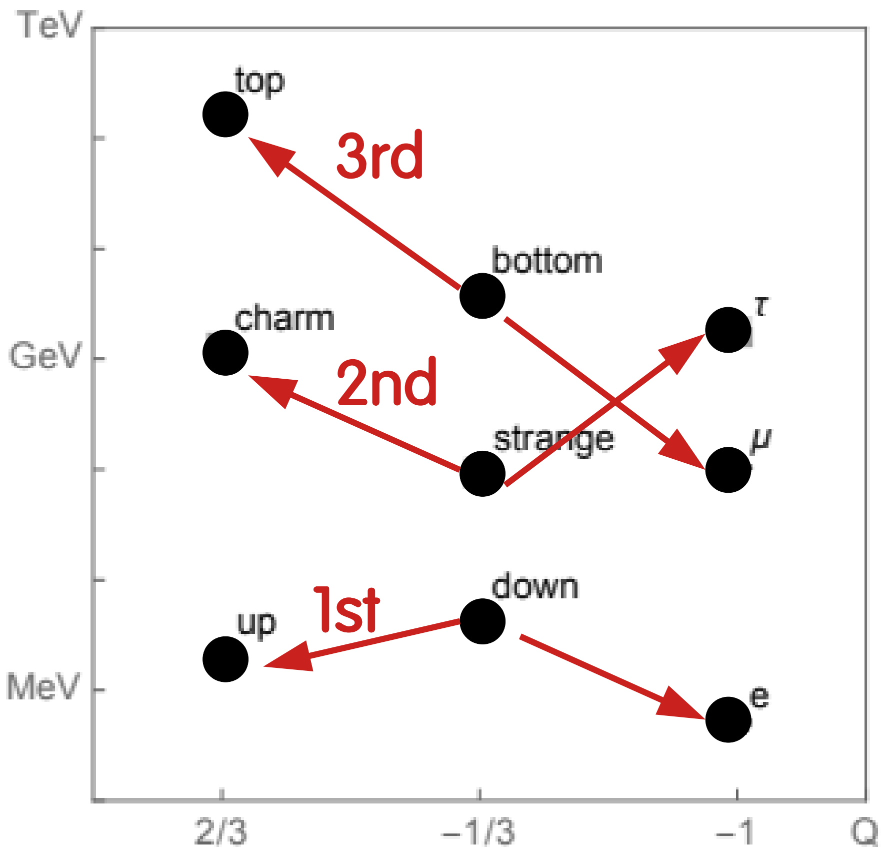
New Family Assignment ?



- Relevant in BSM :

  Pati-Salam Unification

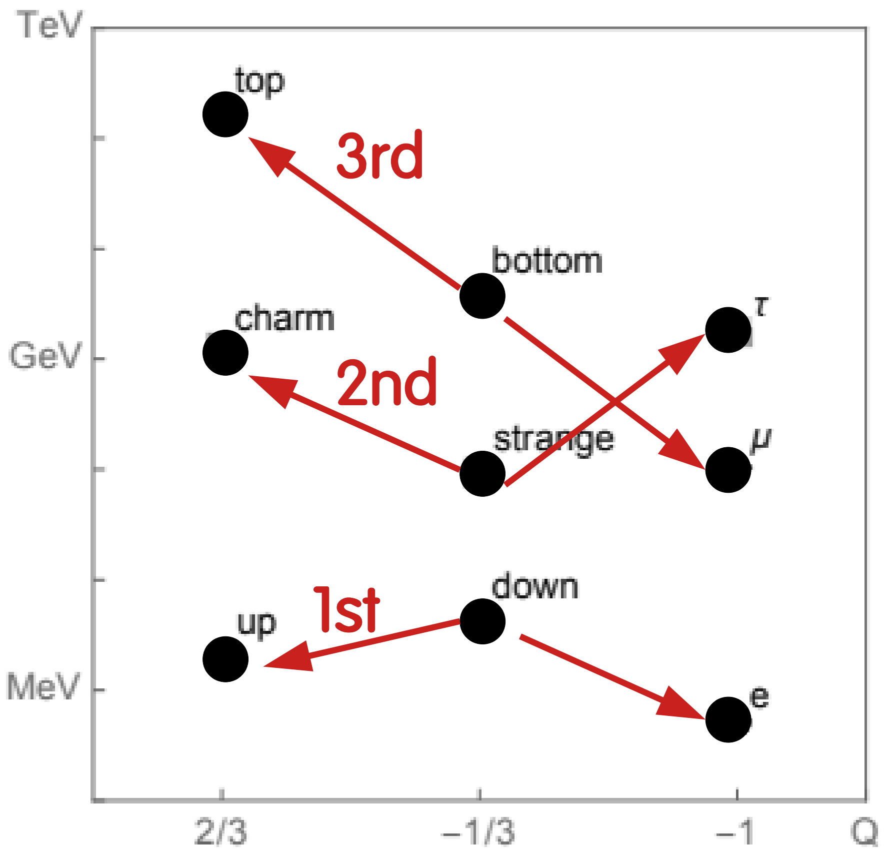
New Family Assignment ?



- **Relevant in BSM :**
  Pati-Salam Unification

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

New Family Assignment ?



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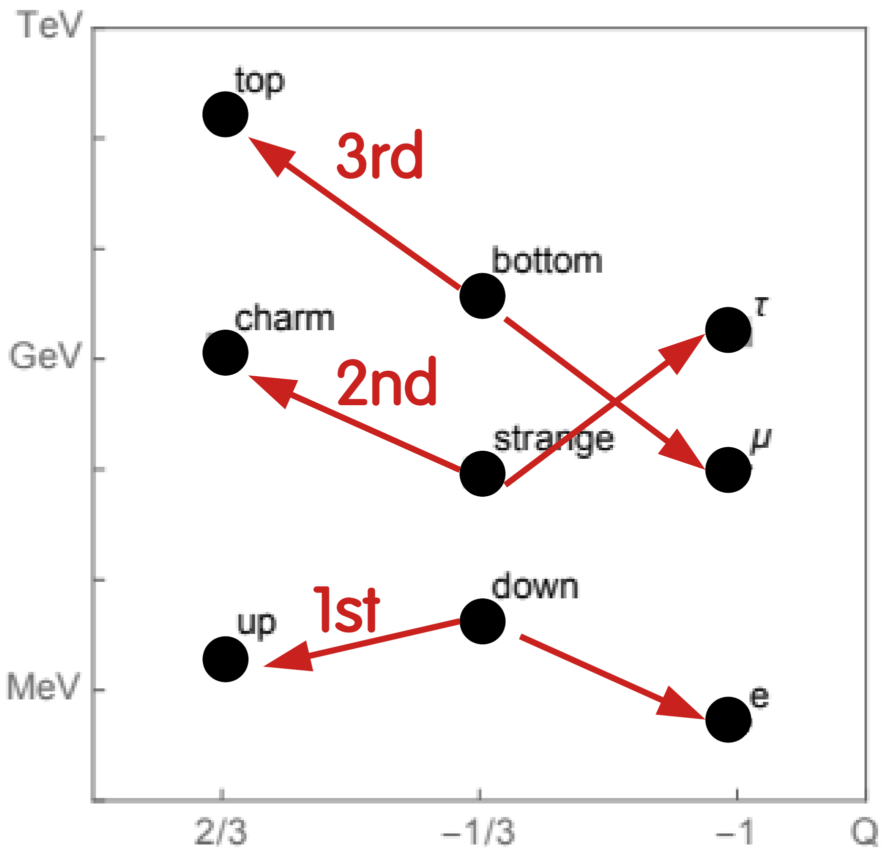
(Quark)
$\oplus$
(Lepton)

New Family Assignment ?



- **Relevant in BSM :**
  Pati-Salam Unification

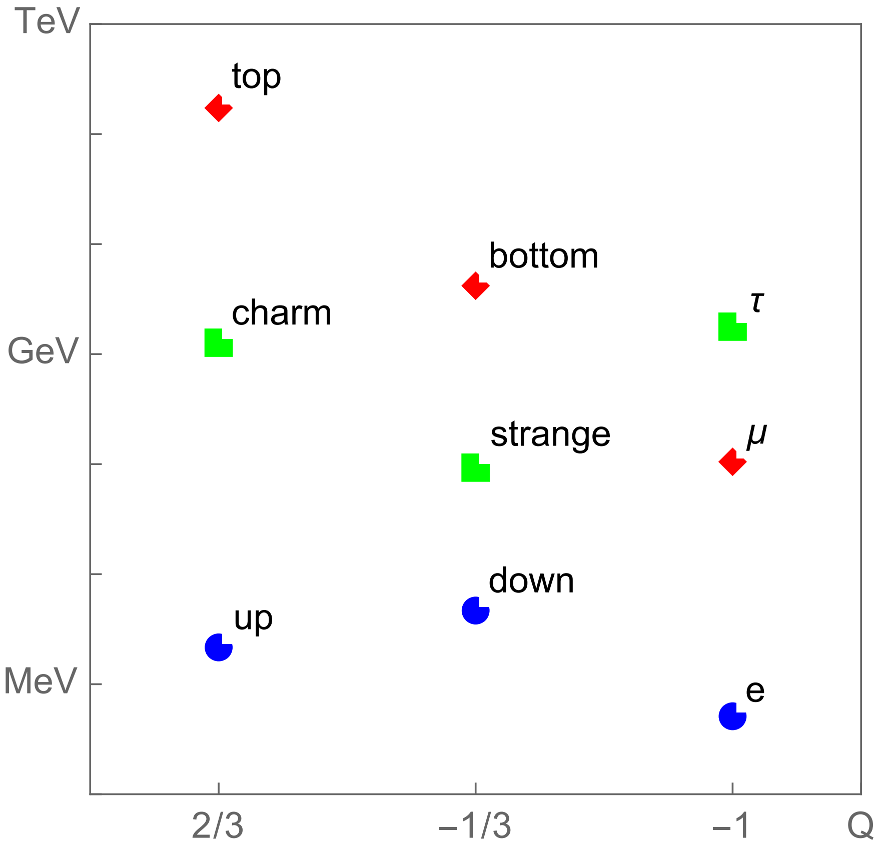
  (Quark) ⊕ (Lepton) ....

- **A new mass structure :**
  New origin for Yukawa pattern

- 1) Loop Model for Masses

- 2) B Anomalies

New Family Assignment ?



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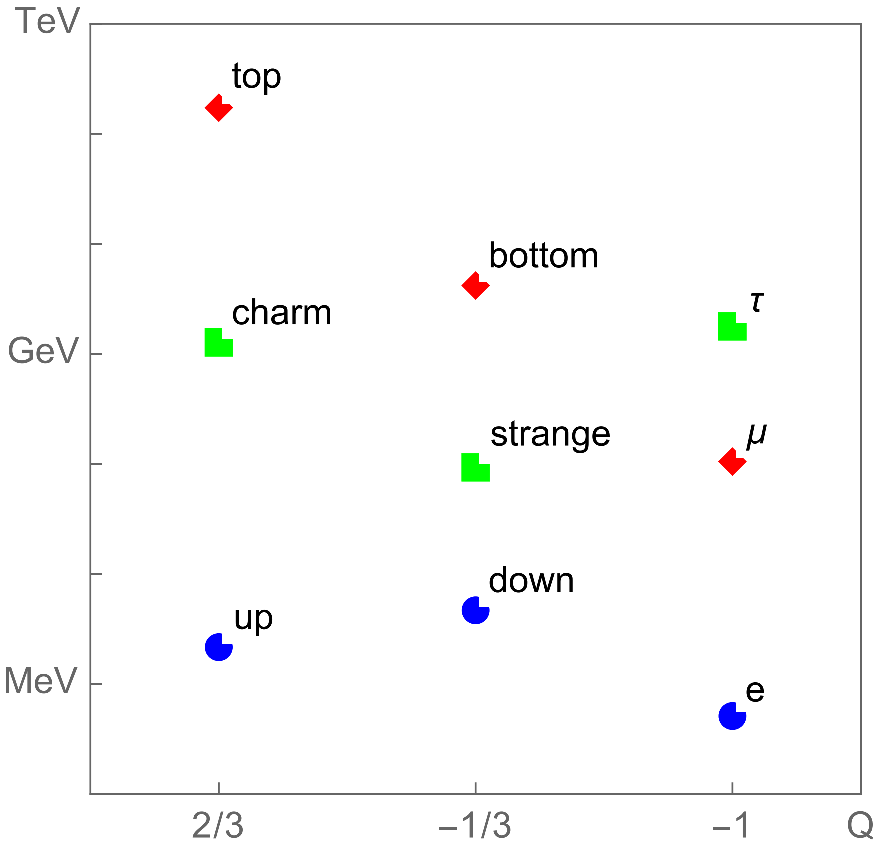
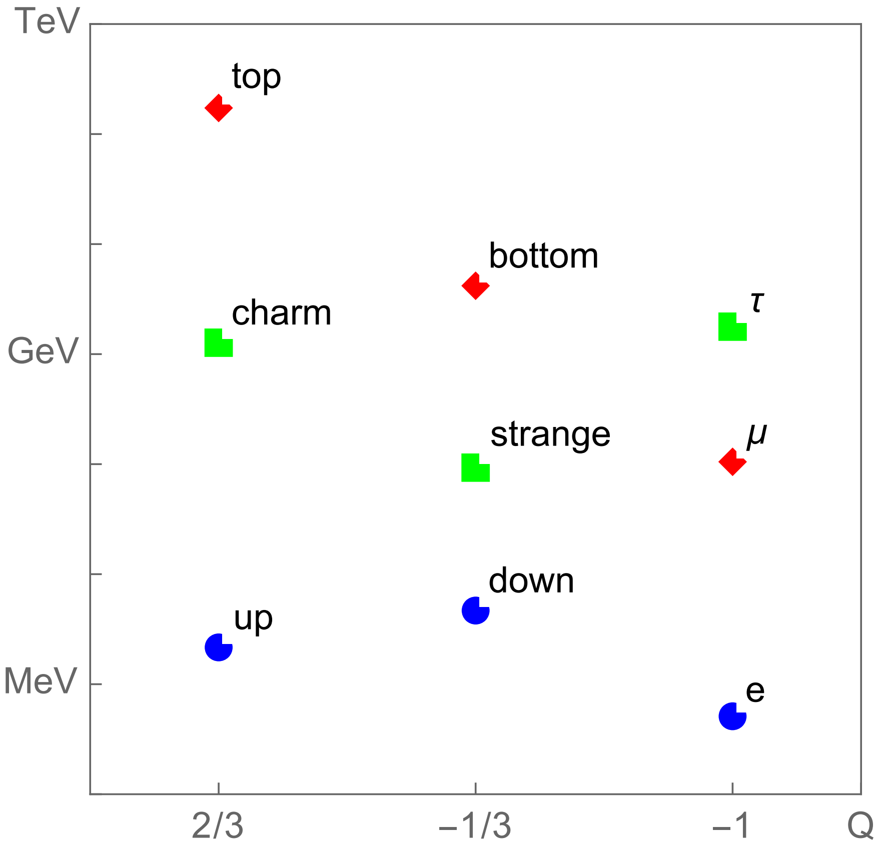


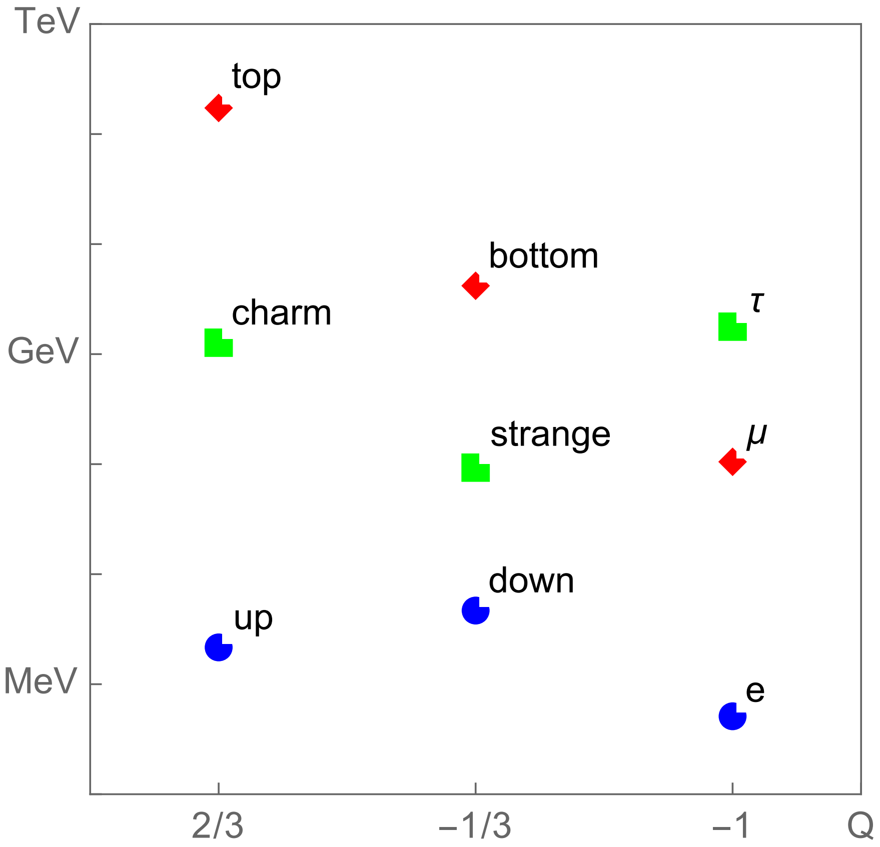
- 1st ~ MeV

New Family Assignment ?



- 1st ~ MeV
- 2nd ~ GeV

New Family Assignment ?



- 1st ~ MeV
- 2nd ~ GeV
- 3rd with specific pattern :

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

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

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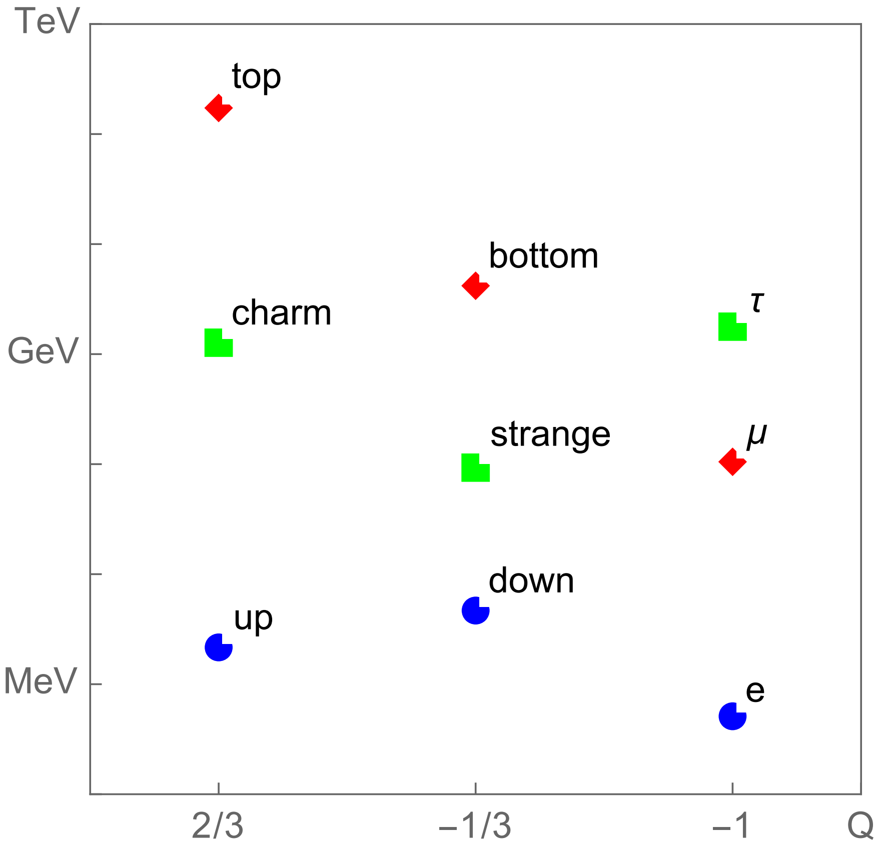

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$$\frac{X_{\mathrm{b}\mu}}{X_{\mathrm{tb}}} = 0.958^{+0.014}_{-0.009}$$

Loop Generation

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$$\phi = (3, 2, 1/6)$$

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$$\begin{aligned}\mathcal{L}_{\text{Yuk}} =& y_t \; \bar{t}_R q_L \; H + \lambda_S \; S \; \Big(c_{qq} \; \bar{q}^c_L q_L + c_{tb} \; \bar{b}^c_R t_R \\ & + c_{ql} \; \bar{q}_L l^c_L + c_{t\mu} \; \bar{t}_R \mu^c_R + c_{b\nu} \; \bar{b}_R \nu^c_R \Big) + \\ & \lambda_\phi \; \phi \; \Big(c_{q\nu} \; \bar{q}_L \nu_R + c_{bl} \; \bar{b}_R l_L \Big) + \text{h.c.}\end{aligned}$$

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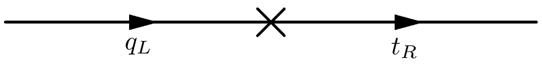

$$m_t = y_t \langle H \rangle$$

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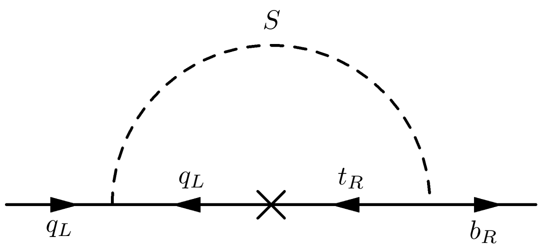

$$\frac{m_b}{m_t} = \frac{{\lambda_S}^2 c_{qq} c_{tb}}{8\pi^2} N_c \ln \frac{\Lambda}{M_S}$$

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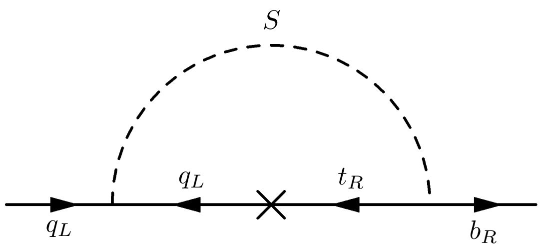

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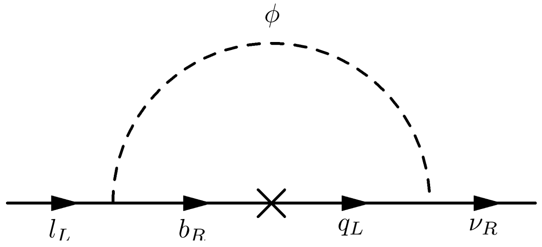

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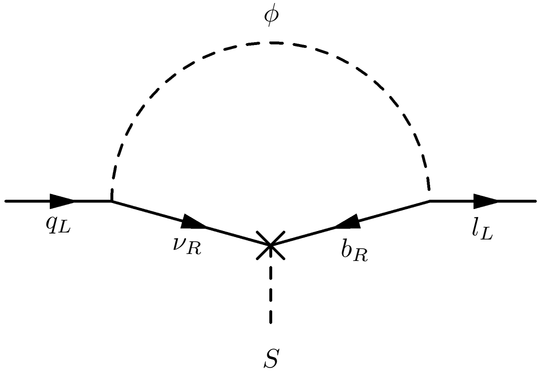

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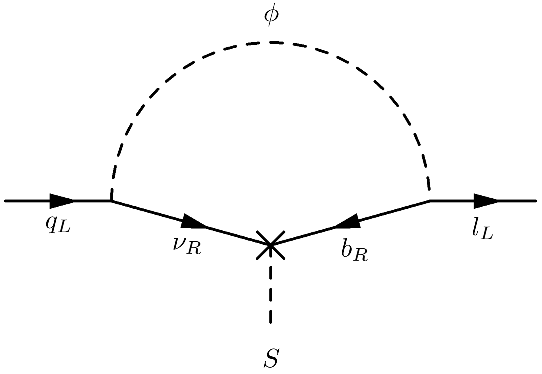

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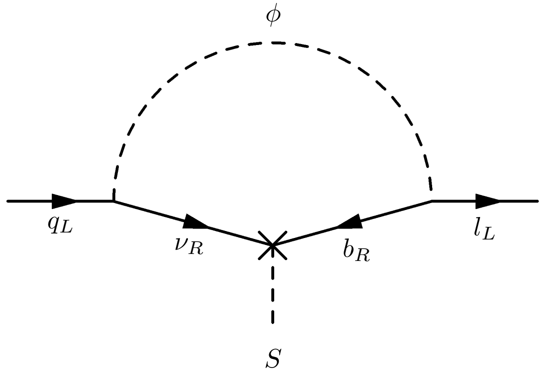

$$c_{ql} = \frac{{\lambda_\phi}^2 c_{q\nu} c_{bl}}{8\pi^2} N_R \ln \frac{\Lambda}{M_\phi}$$

Loop Generation

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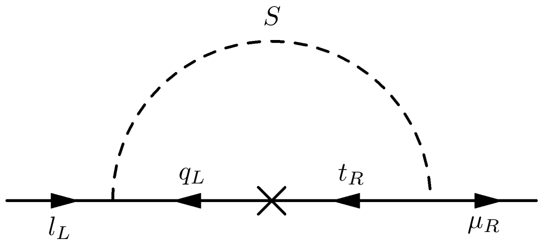

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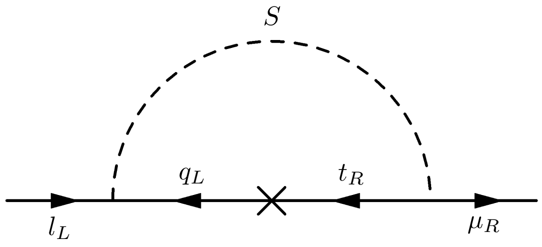

$$\frac{m_\mu}{m_t} = \frac{{\lambda_S}^2 c_{qL} c_{t\mu}}{8\pi^2} N_C \ln \frac{\Lambda}{M_S}$$

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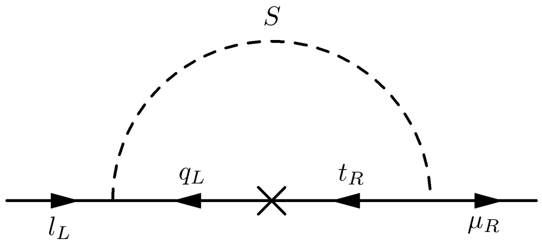

$$\frac{m_\mu}{m_t} = \frac{{\lambda_S}^2 c_{qL} c_{t\mu}}{8\pi^2} N_C \ln \frac{\Lambda}{M_S}$$

$$\frac{m_\mu}{m_b} \cong \frac{m_b}{m_t}$$

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

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$$M_R < M_{S/\phi}$$

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

B Anomalies

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$$R_K = \frac{\mathrm{Br}\left(B^+ \to K^+ \mu^+ \mu^-\right)}{\mathrm{Br}\left(B^+ \to K^+ e^+ e^-\right)} = 0.846^{+0.042}_{0.039}(\mathrm{stat}) K^{+0.013}_{-0.012}(\mathrm{syst})$$

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$$\mathrm{Br}\left(B_s \to \mu^+\mu^-\right)_{Exp} = 3.09^{+0.46+0.15}_{0.430.11} \times 10^{-9}$$

$$\mathrm{Br}\left(B_s \to \mu^+\mu^-\right)_{SM} = 3.65 \pm 0.23 \times 10^{-9}$$

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

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How to generate them ?

B Anomalies

$$R_K = \frac{\mathrm{Br}\left(B^+ \to K^+\mu^+\mu^-\right)}{\mathrm{Br}\left(B^+ \to K^+e^+e^-\right)} = 0.846^{+0.042}_{0.039}(\mathrm{stat})K^{+0.013}_{-0.012}(\mathrm{syst})$$

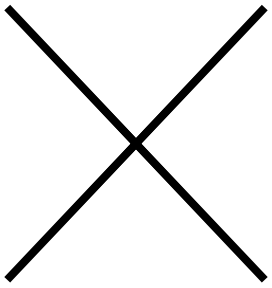
$$\mathrm{Br}\left(B_s \to \mu^+\mu^-\right)_{Exp} = 3.09^{+0.46+0.15}_{0.430.11} \times 10^{-9}$$

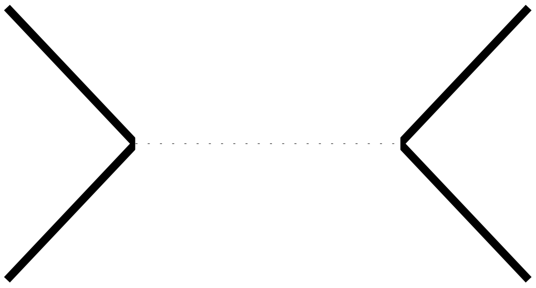
$$\mathrm{Br}\left(B_s \to \mu^+\mu^-\right)_{SM} = 3.65 \pm 0.23 \times 10^{-9}$$

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

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

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

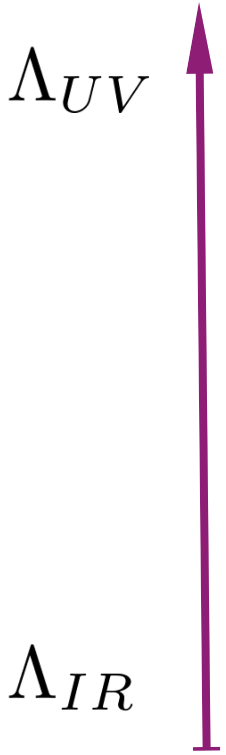
3 SM-like unified families « à la Pati-Salam »

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

B Anomalies

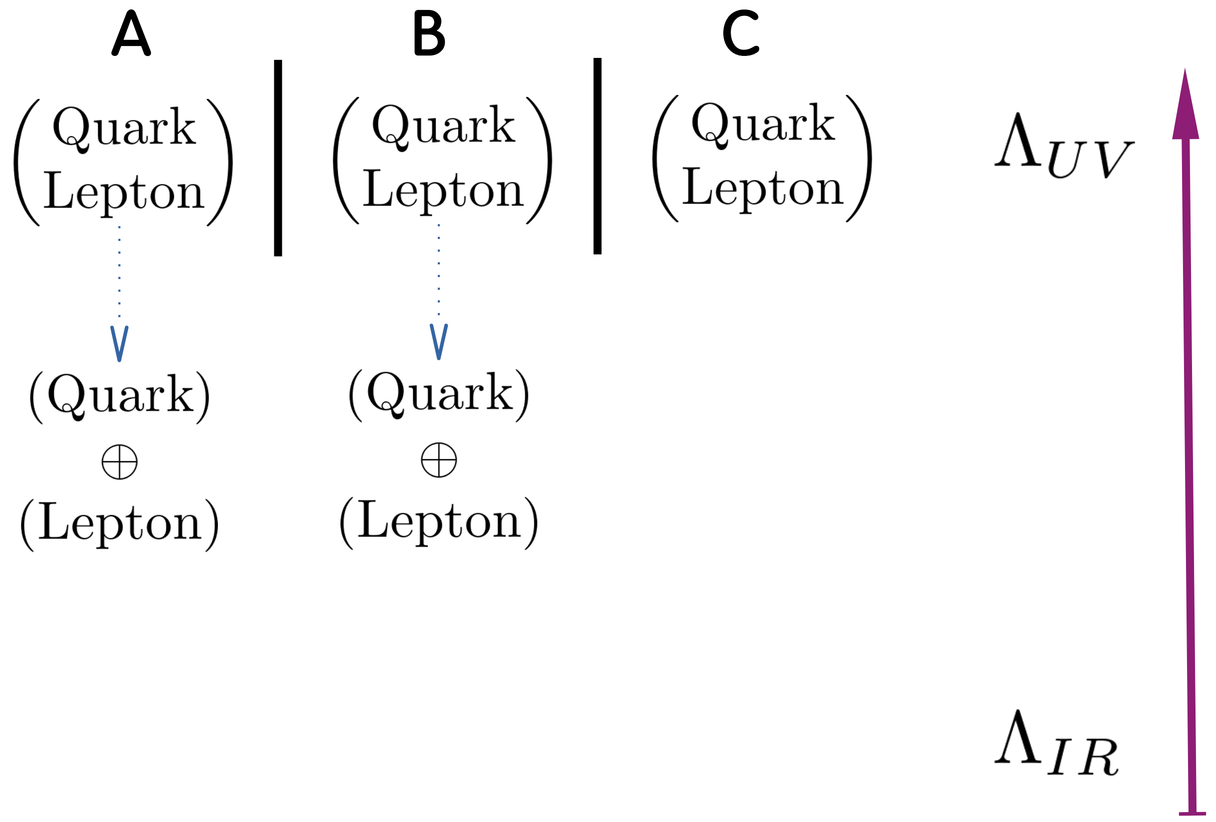
3 SM-like unified families « à la Pati-Salam »

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



B Anomalies

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



B Anomalies

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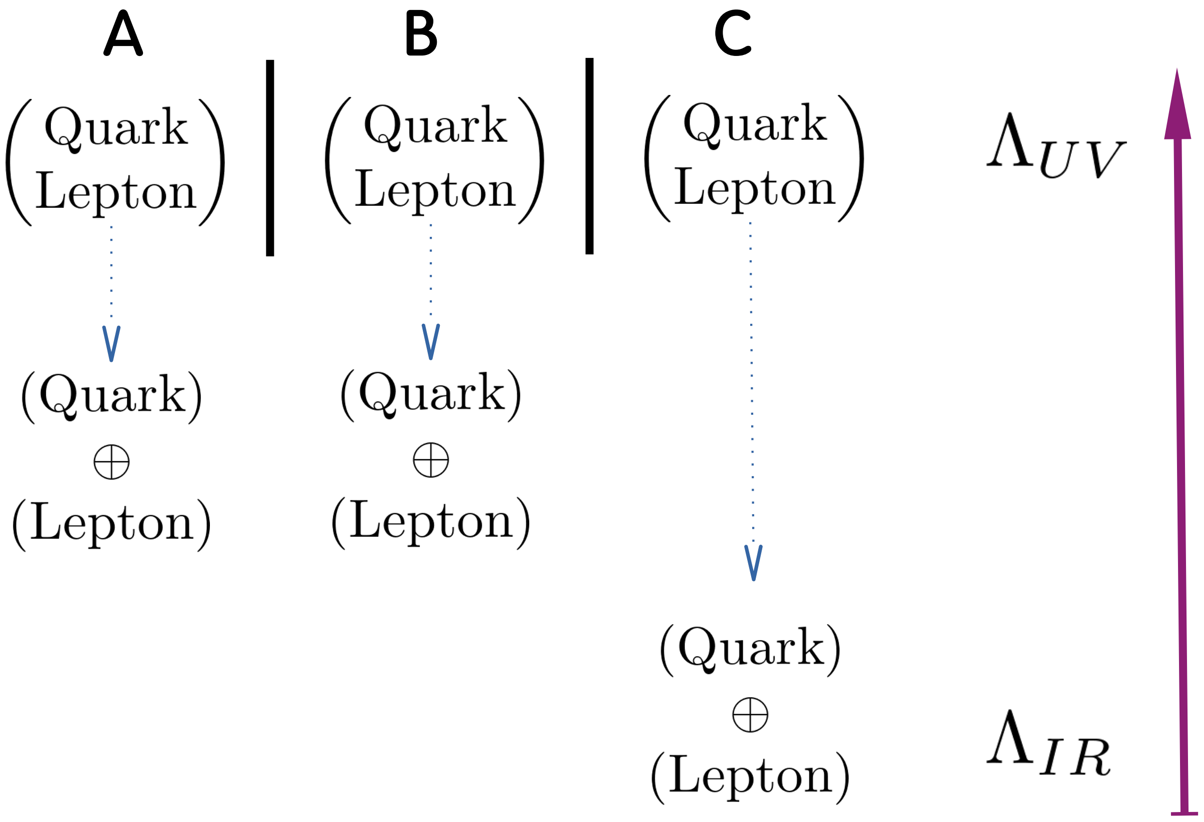


B Anomalies

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

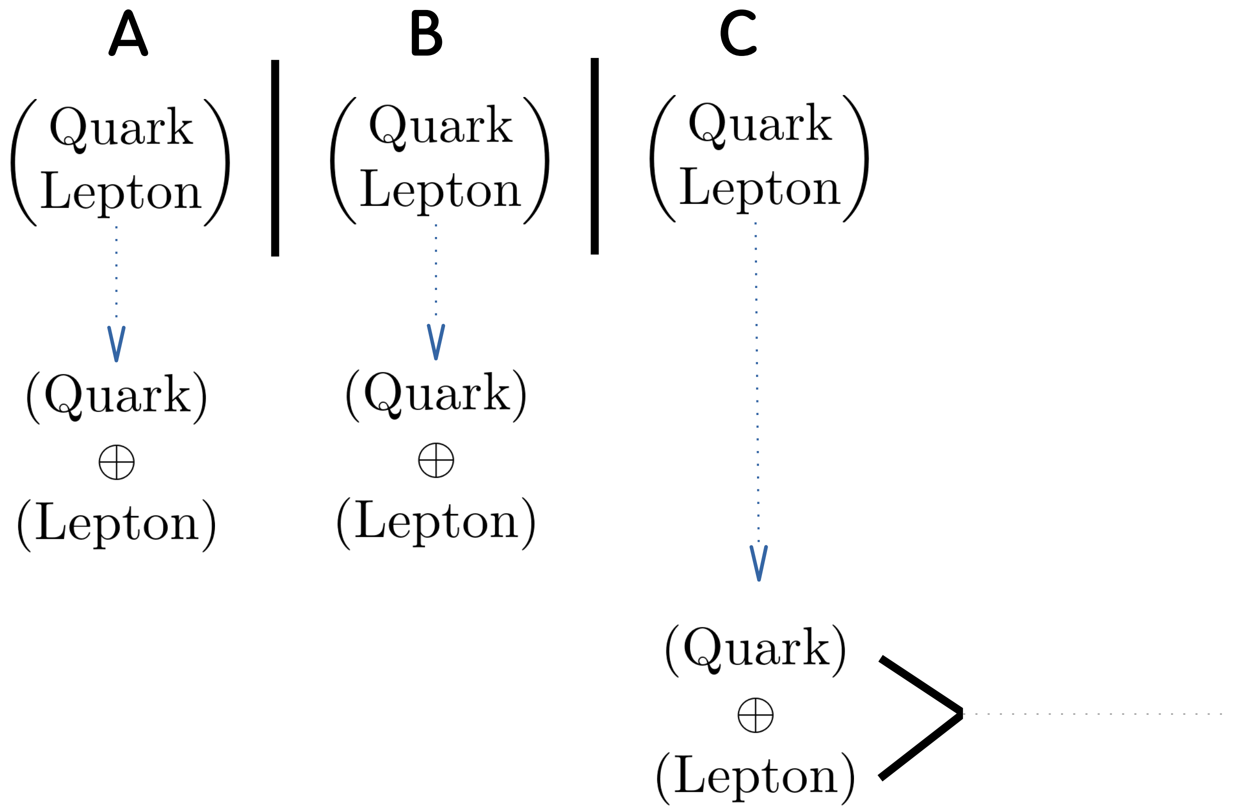
$$\begin{pmatrix} \text{Quark} \\ \text{Lepton} \end{pmatrix} \longrightarrow (\text{Quark}) \oplus (\text{Lepton})$$

C

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

B Anomalies

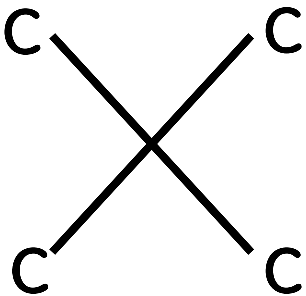
3 SM-like unified families « à la Pati-Salam »



B Anomalies

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

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



B Anomalies

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

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

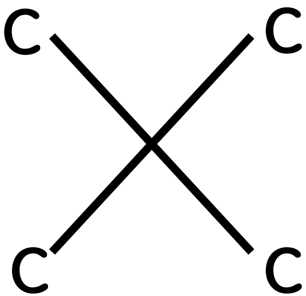
$$\Longrightarrow \quad Y \sim \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & \epsilon_3 \\ & & 1 \end{pmatrix}$$

B Anomalies

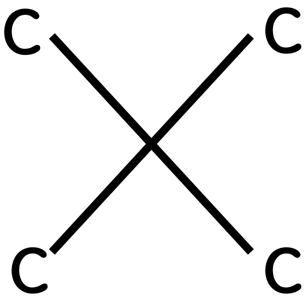
3 SM-like unified families « à la Pati-Salam »

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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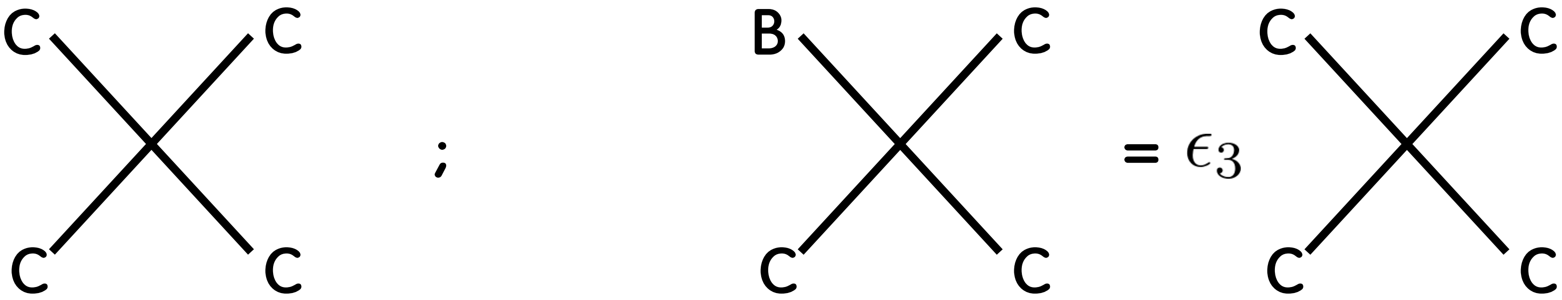
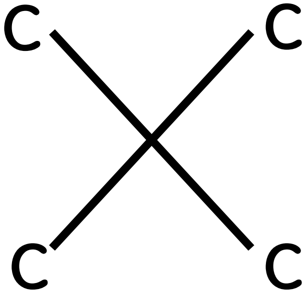
B Anomalies



B Anomalies



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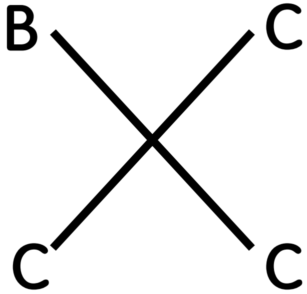
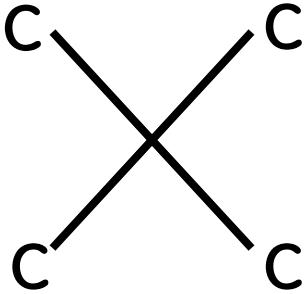
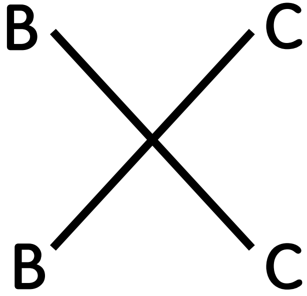
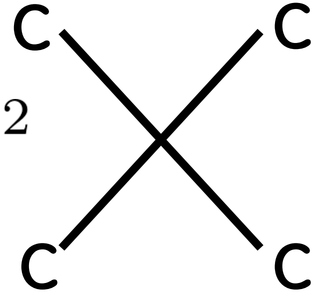


$= \epsilon_3$



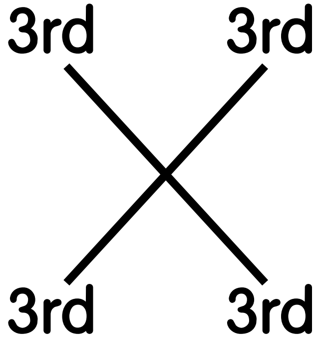


$= {\epsilon_3}^2$



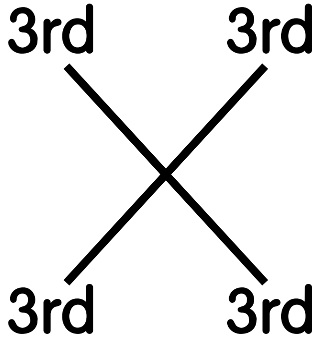
B Anomalies

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



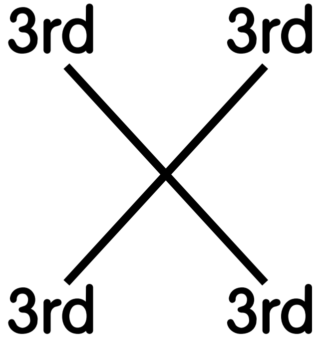
B Anomalies

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



B Anomalies

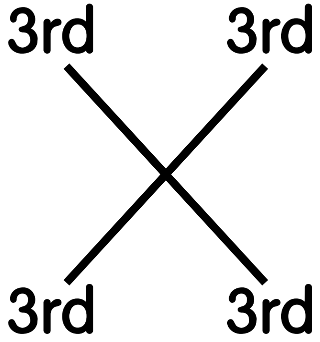
$$\mathcal{O}_{9(10)} = \frac{\alpha}{4\pi}\left[\bar{s}\gamma_\mu P_L b\right]\left[\bar{\mu}\gamma^\mu(\gamma_5)\mu\right] \quad = \quad {\epsilon_3}^3$$



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

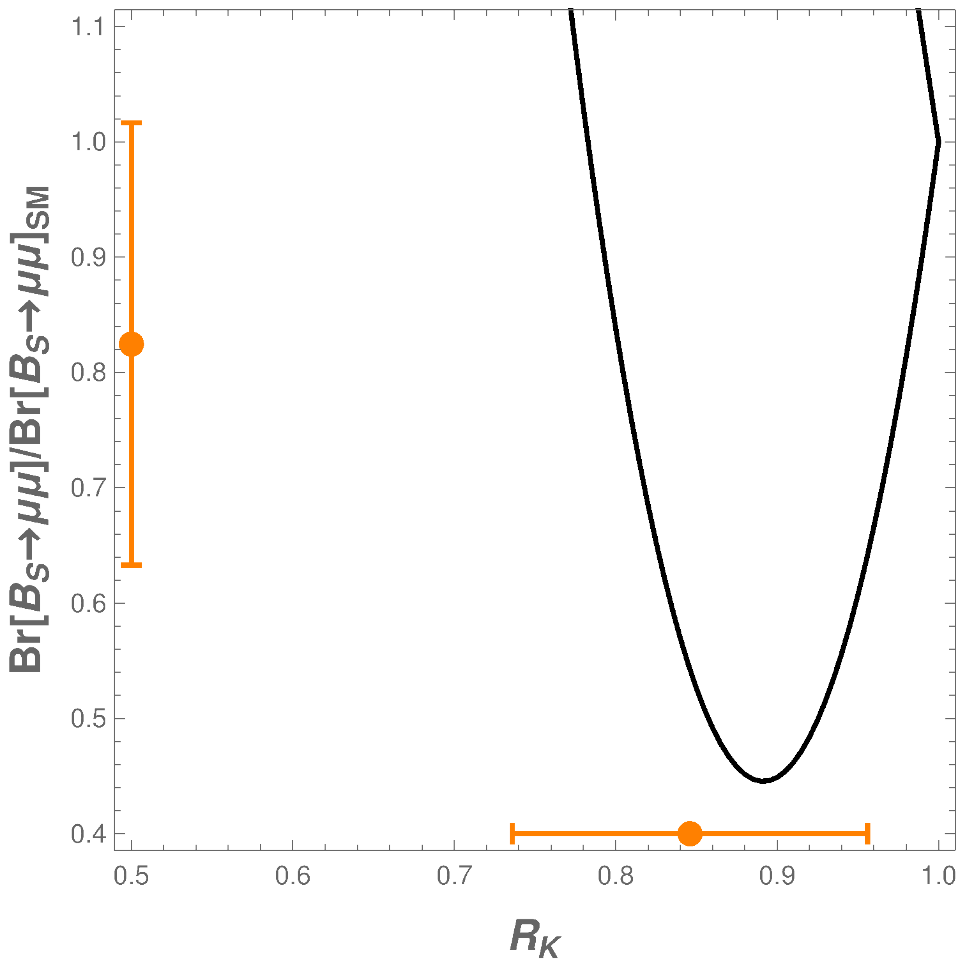
B Anomalies

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



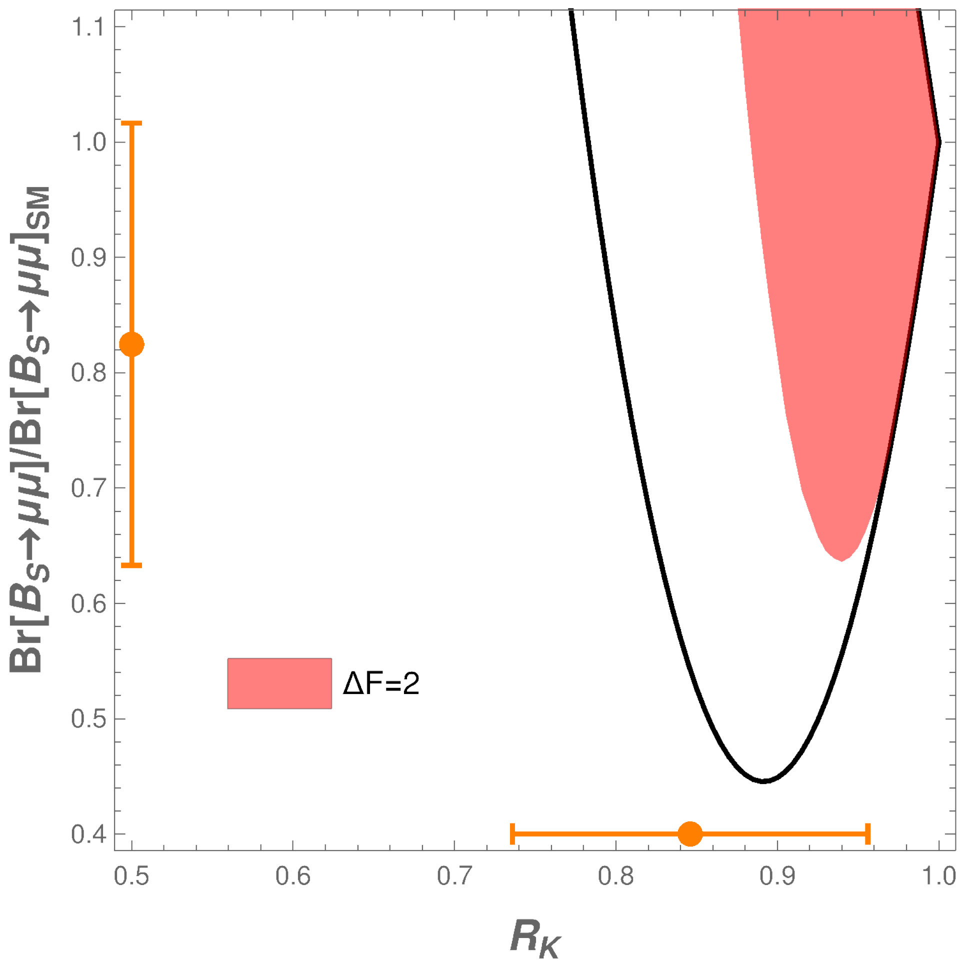
$$Y \sim \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & \epsilon_3 \\ & & 1 \end{pmatrix} \implies \begin{pmatrix} \epsilon_1 & & \\ & \epsilon_2 & 1 \\ & & \epsilon_3 \end{pmatrix}$$

Results

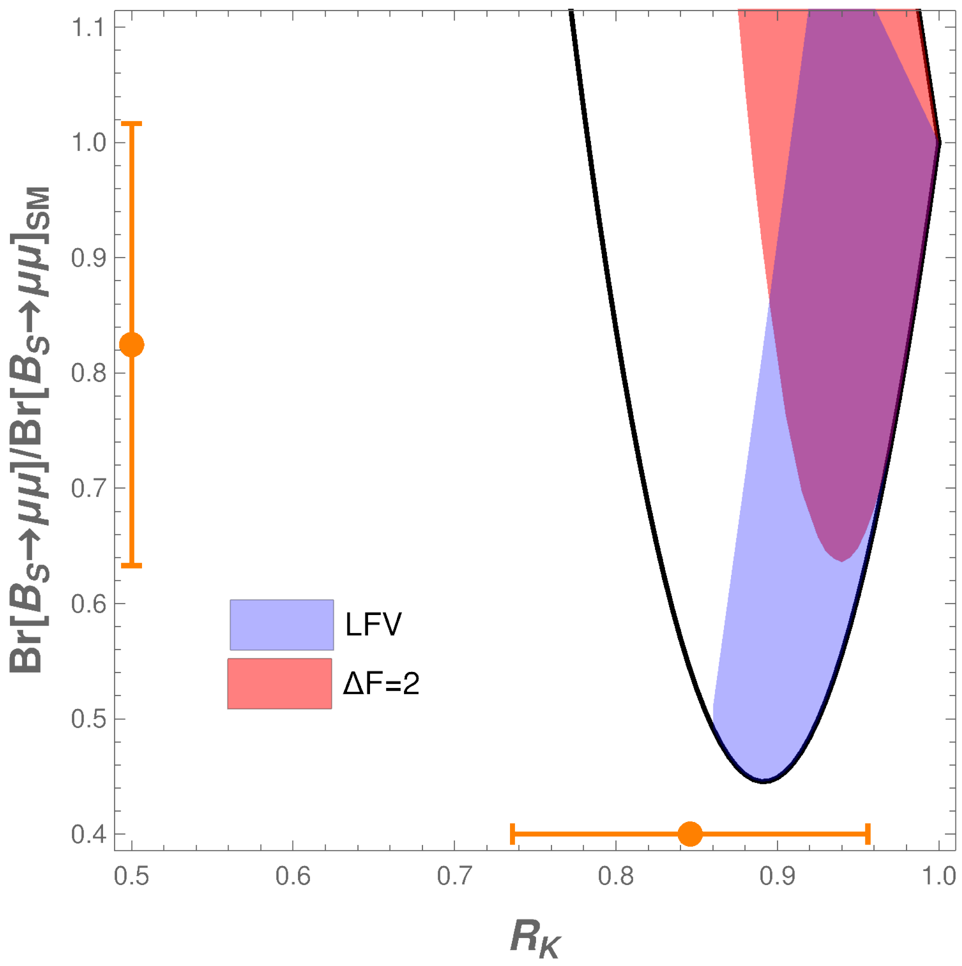


1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
$Br[B_S \to \mu\mu]/Br[B_S \to \mu\mu]_{SM}$
0.5
0.6
0.7
0.8
0.9
1.0
R_K

Results



Results



1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Br[B_S→μμ]/Br[B_S→μμ]$_{SM}$
0.5
0.6
0.7
0.8
0.9
1.0
R_K
LFV
ΔF=2

Thank You !