Enhancing $B_s \to e^+ e^-$ to an Observable Level

Gilberto Tetlalmatzi-Xolocotzi

Based on:

M. Black, A. Plascencia and GTX, 2208.08995 [hep-ph]

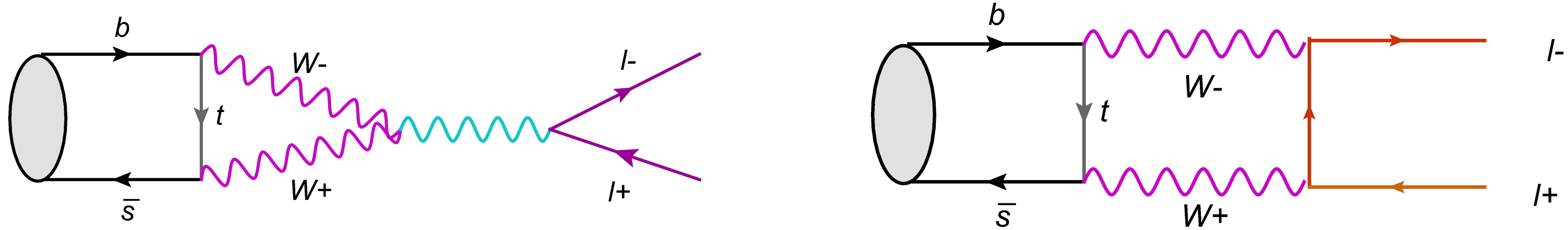
CPPS, Theoretische Physik 1,
Universität Siegen,

Université Paris-Saclay, CNRS/IN2P3,
IJCLab,

B_s meson rare decays properties

In the SM the processes $B_s \rightarrow l^+ \, l^-$ are induced via loops

$$l = e\,,\mu\,,\tau$$



They are extremely clean: all the non-perturbative information is encoded in the decay constant of the initial *B* meson which is known with a precision of 1%.

$$f_{Bs} = 230.3 \pm 1.3\ MeV$$

B_s meson rare decays properties

Helicity suppression

$$\bar{\mathcal{B}}r(B_s \to \ell^+\ell^-)_{\rm SM} = \frac{1}{1-y_s}\frac{G_F^2\alpha^2}{16\pi^3}\tau_{B_s}|V_{ts}V_{tb}^*|^2 f_{B_s}^2 M_{B_s} m_\ell^2 \sqrt{1-4\frac{m_\ell^2}{M_{B_s}^2}}|C_{10}^{\rm SM}|^2$$

The decay probability of $B_s \to l^+ l^-$ is proportional to the square of the mass of the lepton in the final state m_l^2

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$m_\tau = 1.776 \;\; GeV$

$$\bar{\mathcal{B}}r(B_s \to \tau^+\tau^-)_{\rm SM} = (7.52 \pm 0.20) \times 10^{-7}$$

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$m_\tau = 1.776 \ GeV$ $\quad$ $\bar{\mathcal{B}}r(B_s \to \tau^+\tau^-)_{\rm SM} = (7.52 \pm 0.20) \times 10^{-7}$

$m_\mu = 0.105 \ GeV$ $\quad$ $\bar{\mathcal{B}}r(B_s \to \mu^+\mu^-)_{\rm SM} = (3.55 \pm 0.10) \times 10^{-9}$

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$m_e = 0.5 \times 10^{-3}\ GeV$ $\bar{\mathcal{B}}r(B_s \to e^+e^-)_{\rm SM} = (8.30 \pm 0.22) \times 10^{-14}$

B_s meson rare decays properties

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Experimental Status

From a weighted average including measurements from LHCb, ATLAS and CMS:

$$\bar{\mathcal{B}}r(B_s \to \mu^+\mu^-)_{\rm Exp} = (3.39 \pm 0.29) \times 10^{-9}$$

which is in agreement with the SM result

$$\bar{\mathcal{B}}r(B_s \to \mu^+\mu^-)_{\rm SM} = (3.55 \pm 0.10) \times 10^{-9}$$

For pairs of τ leptons in the final state

$$\bar{\mathcal{B}}r(B_s \to \tau^+\tau^-) < 6.8 \times 10^{-3}$$

LHCb [hep-ex/1703.02508]

$$\bar{\mathcal{B}}r(B_s \to \tau^+\tau^-)_{\rm SM} = (7.52 \pm 0.20) \times 10^{-7}$$

Experimental Status

Updated bound from LHCb $\bar{\mathcal{B}}r(B_s \to e^+e^-) < 9.4 \times 10^{-9}$

LHCb [hep-ex/2003.03999]

$$\bar{\mathcal{B}}r(B_s \to e^+e^-)_{\rm SM} = (8.30 \pm 0.22) \times 10^{-14}$$

5 Orders of magnitude gap between the experimental bound and the SM

The SM value is out of reach of current or foreseeable experiments

Any near future observation of $B_s \to e^+ e^-$ would be an unambiguous signal of NEW PHYSICS

Effective theory treatment

$$\mathcal{H}_{\text{eff}} = -\frac{G_F V_{tb} V_{ts}^* \alpha}{\sqrt{2}\pi} \left[C_{10}^{\ell\ell} O_{10}^{\ell\ell} + C_S^{\ell\ell} O_S^{\ell\ell} + C_P^{\ell\ell} O_P^{\ell\ell} + + C_{10'}^{\ell\ell} O_{10'}^{\ell\ell} + C_{S'}^{\ell\ell} O_{S'}^{\ell\ell} + C_{P'}^{\ell\ell} O_{P'}^{\ell\ell} \right] + \text{h.c.}$$

In the SM the only $\mathcal{O}_{10}^{\ell\ell} = (\bar{s}\gamma_\mu P_L b)\left(\bar{\ell}\gamma^\mu \gamma_5 \ell\right)$ contributes

NP Vector operator → $\mathcal{O}_{10'}^{\ell\ell} = (\bar{s}\gamma_\mu P_R b)\left(\bar{\ell}\gamma^\mu \gamma_5 \ell\right)$

NP Scalar operators → $\mathcal{O}_S^{\ell\ell} = m_b\,(\bar{s} P_R b)\left(\bar{\ell}\ell\right)$ $\mathcal{O}_{S'}^{\ell\ell} = m_b\,(\bar{s} P_L b)\left(\bar{\ell}\ell\right)$

NP Pseudoscalar operators →

$\mathcal{O}_P^{\ell\ell} = m_b\,(\bar{s} P_R b)\left(\bar{\ell}\gamma^5 \ell\right)$

$\mathcal{O}_{P'}^{\ell\ell} = m_b\,(\bar{s} P_L b)\left(\bar{\ell}\gamma^5 \ell\right)$

Enhancements on $B_s \rightarrow e^+ e^-$

In the presence of pseudoscalar and scalar particles

$$\bar{\mathcal{B}}r(B_s \to \ell^+\ell^-) = \bar{\mathcal{B}}r(B_s \to \ell^+\ell^-)_{\mathrm{SM}} \times \left[|P_{\ell\ell}|^2 + \frac{1-y_s}{1+y_s} |S_{\ell\ell}|^2 \right]$$

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$$P_{\ell\ell} \equiv \frac{C_{10}^{\ell\ell} - C_{10'}^{\ell\ell}}{C_{10}^{\rm SM}} + \frac{M_{B_s}^2}{2m_\ell}\left(\frac{m_b}{m_b+m_s}\right)\left[\frac{C_P^{\ell\ell} - C_{P'}^{\ell\ell}}{C_{10}^{\rm SM}}\right]$$

$$S_{\ell\ell} \equiv \sqrt{1 - 4\frac{m_\ell^2}{M_{B_s}^2}}\,\frac{M_{B_s}^2}{2m_\ell}\left(\frac{m_b}{m_b+m_s}\right)\left[\frac{C_S^{\ell\ell} - C_{S'}^{\ell\ell}}{C_{10}^{\rm SM}}\right]$$

Enhancements on $B_s \to e^+ e^-$

In the presence of pseudoscalar and scalar particles

$$\bar{Br}(B_s \to \ell^+\ell^-) = \bar{Br}(B_s \to \ell^+\ell^-)_{\rm SM} \times \left[|P_{\ell\ell}|^2 + \frac{1-y_s}{1+y_s}|S_{\ell\ell}|^2\right]$$

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For electrons and muons the factor m_ℓ enhances the NP effects

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R. Fleischer, R. Jaarsma, GTX [1703.10160]

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R. Fleischer, R. Jaarsma, GTX [1703.10160]

For electrons the enhancement effect is maximal.

For the effect to take place the Wilson coefficients should not be proportional to the mass of the final state lepton.

The THDM and $B_s \to e^+ e^-$

The Type III THDM

$$-\mathcal{L} \supset \bar{Q}_L \left(Y_1^u \widetilde{H}_1 + Y_2^u \widetilde{H}_2\right) u_R + \bar{Q}_L \left(Y_1^d H_1 + Y_2^d H_2\right) d_R$$
$$+ \bar{\ell}_L \left(Y_1^e H_1 + Y_2^e H_2\right) e_R + \text{h.c.}\,,$$

The two doublets are coupled to quarks and leptons

$$H_1^T = (H_1^+, (v_1 + H_1^0 + iA_1^0)/\sqrt{2})$$

$$\widetilde{H}_1 = i\sigma_2 H_1^*$$

Rotation to the physics basis →

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix}$$

$$\begin{pmatrix} G \\ A \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} A_1^0 \\ A_2^0 \end{pmatrix}$$

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SM Higgs → h

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NP neutral scalars

SM Higgs

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The THDM and $B_s \to e^+ e^-$

The relevant interactions are then

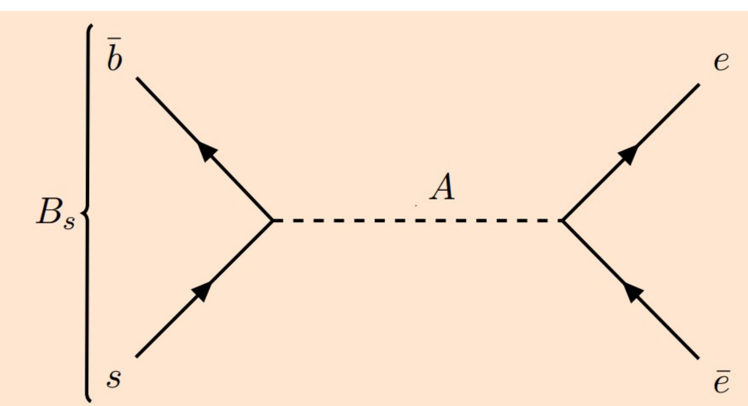
$$-\mathcal{L} \supset y_{ee}\, \bar{e}eH + y_{bs}\, \bar{b}sH - i\, y_{ee}\, \bar{e}\gamma^5 eA - i\, y_{bs}\, \bar{b}\gamma^5 sA$$

leading to the following Wilson coefficients

$$C_S^{ee} = \frac{y_{ee}y_{bs}}{M_H^2}\left(\frac{\sqrt{2}\pi}{m_b G_F V_{tb}V_{ts}^*\alpha}\right), \qquad C_{S'}^{ee} = C_S^{ee},$$

$$C_P^{ee} = -\frac{y_{ee}y_{bs}}{M_A^2}\left(\frac{\sqrt{2}\pi}{m_b G_F V_{tb}V_{ts}^*\alpha}\right), \qquad C_{P'}^{ee} = -C_P^{ee},$$

In our model



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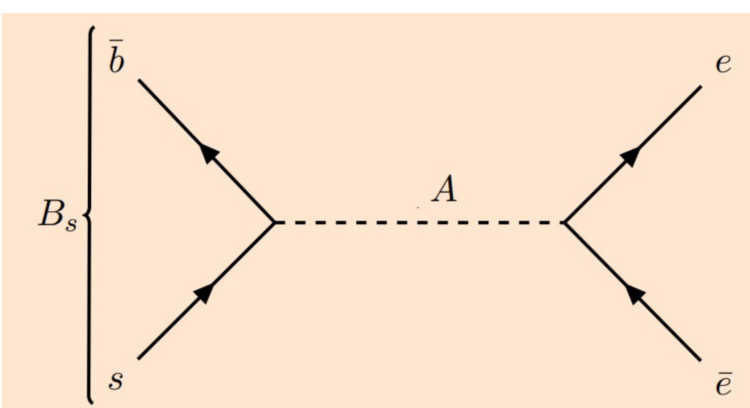


No contribution from *H* to the branching fraction

Phenomenological constraints

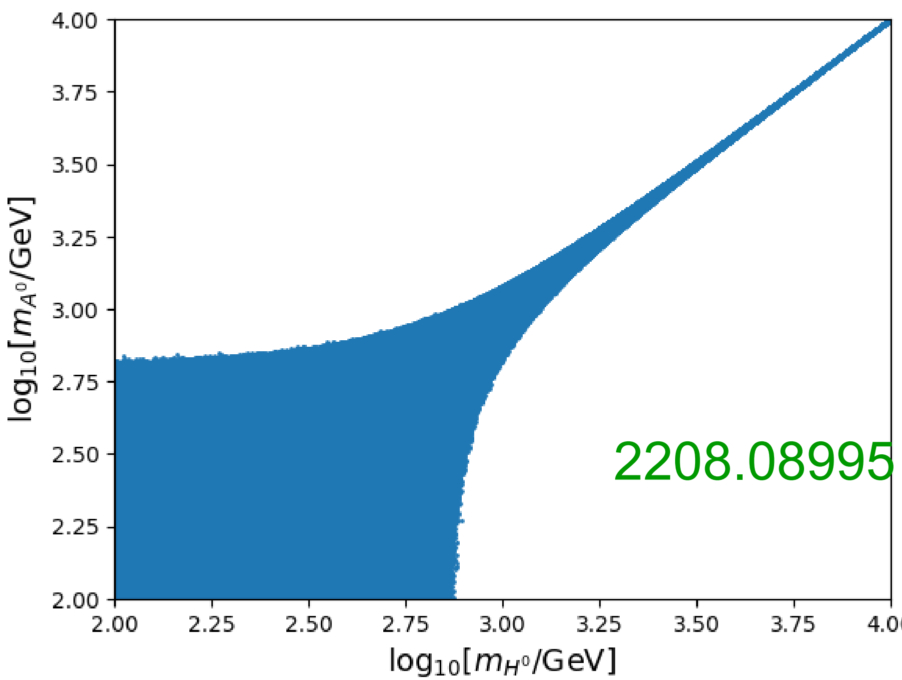
Scalar potential

$$
\begin{aligned}
V(H_1, H_2) = m_{11}^2 H_1^\dagger H_1 + m_{22}^2 H_2^\dagger H_2 - m_{12}^2 \left[\left(H_1^\dagger H_2\right) + \text{h.c.}\right] \\
+ \frac{\lambda_1}{2}\left(H_1^\dagger H_1\right)^2 + \frac{\lambda_2}{2}\left(H_2^\dagger H_2\right)^2 + \lambda_3 \left(H_1^\dagger H_1\right)\left(H_2^\dagger H_2\right) + \lambda_4 \left(H_1^\dagger H_2\right)\left(H_2^\dagger H_1\right) \\
+ \left[\frac{\lambda_5}{2}\left(H_1^\dagger H_2\right)^2 + \lambda_6 \left(H_1^\dagger H_1\right)\left(H_1^\dagger H_2\right) + \lambda_7 \left(H_2^\dagger H_2\right)\left(H_1^\dagger H_2\right) + \text{h.c.}\right].
\end{aligned}
$$

Mass constraints

From perturbativity and vacuum stability

$$
\begin{aligned}
0 < \lambda_{1,2} &< 4 \\
-\sqrt{\lambda_1 \lambda_2} < \lambda_3 &< 4 \\
-4 < \lambda_{4,5,6,7} &< 4
\end{aligned}
$$



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& + \left[\frac{\lambda_5}{2}\left(H_1^\dagger H_2\right)^2 + \lambda_6\left(H_1^\dagger H_1\right)\left(H_1^\dagger H_2\right) + \lambda_7\left(H_2^\dagger H_2\right)\left(H_1^\dagger H_2\right) + \text{h.c.}\right].
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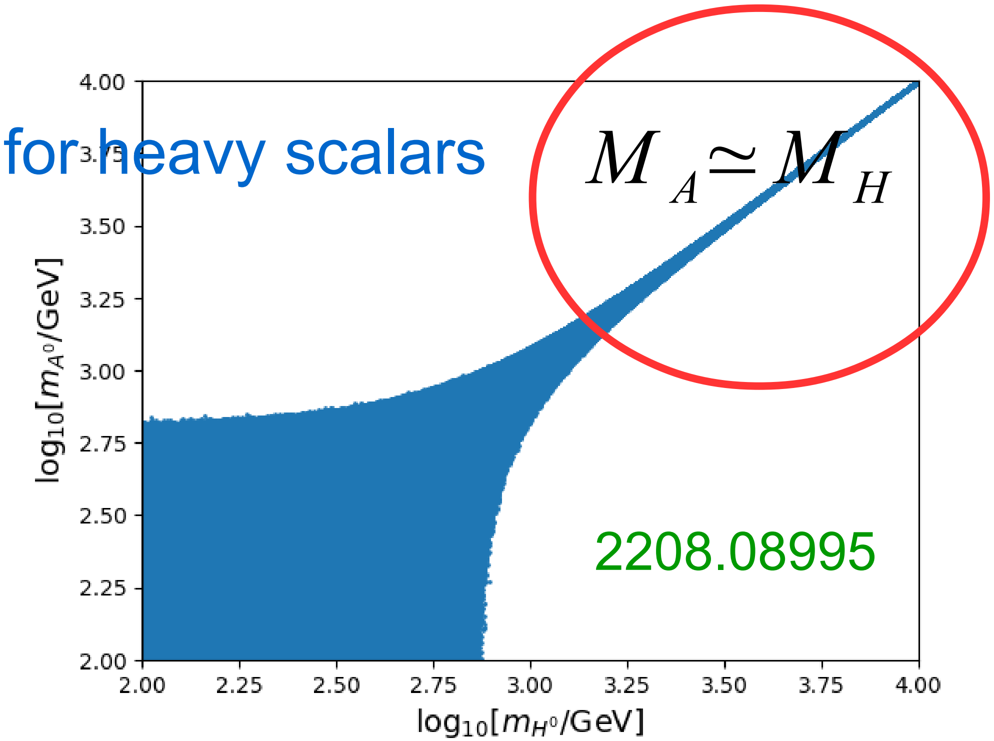
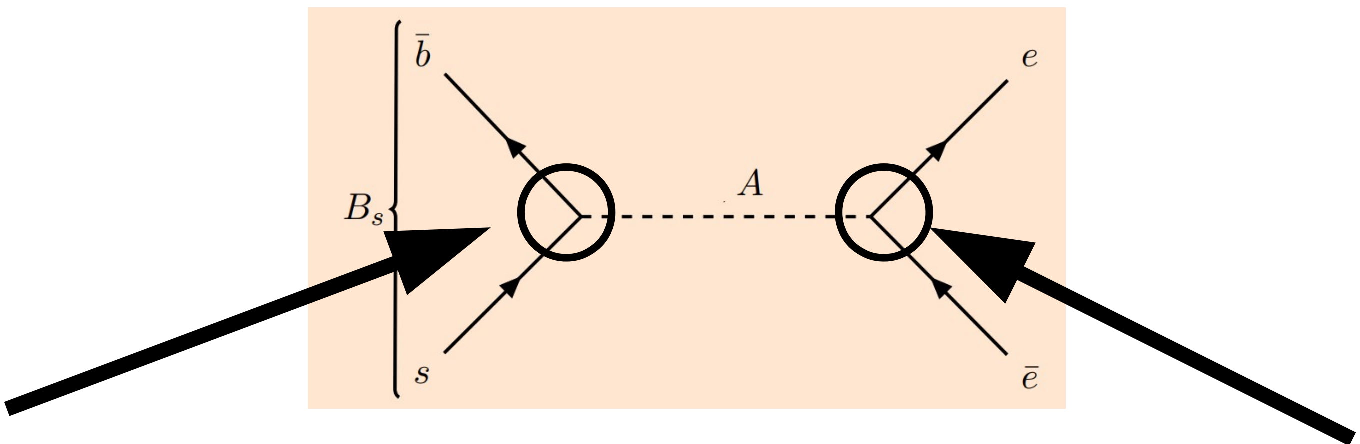
$$

for heavy scalars



Phenomenological constraints

The possible size of the NP couplings to quarks and leptons has to be determined



y_{bs} y_{ee}

Constraints on the leptonic coupling y_{ee}

From e+e- $\longrightarrow$ e+e- scattering

Constraints derived from $\longrightarrow$ LEP electroweak working group [hep-ex/0612034]

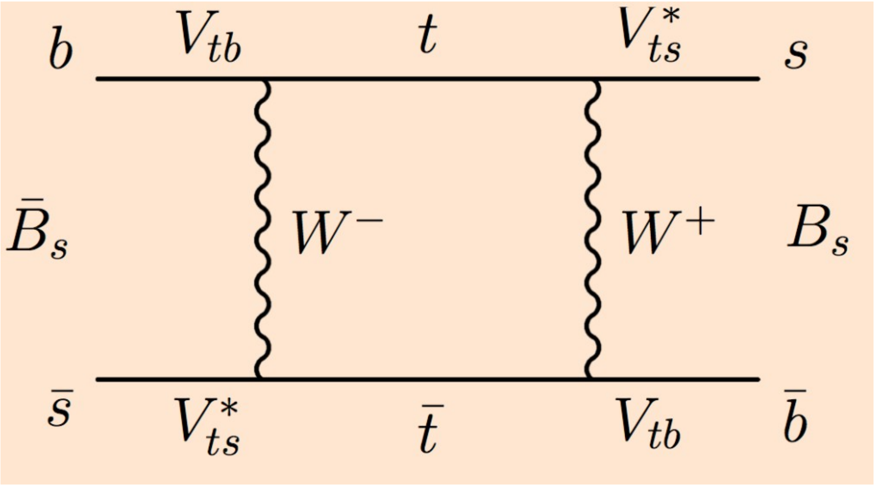
$$\frac{y_{ee}^2}{M_H^2} + \frac{y_{ee}^2}{M_A^2} < \frac{1}{(4\ \mathrm{TeV})^2}$$

Phenomenological constraints

Constraints on the quark coupling y_{bs}

Constraints from neutral B meson mixing

Standard Model + **New Physics**



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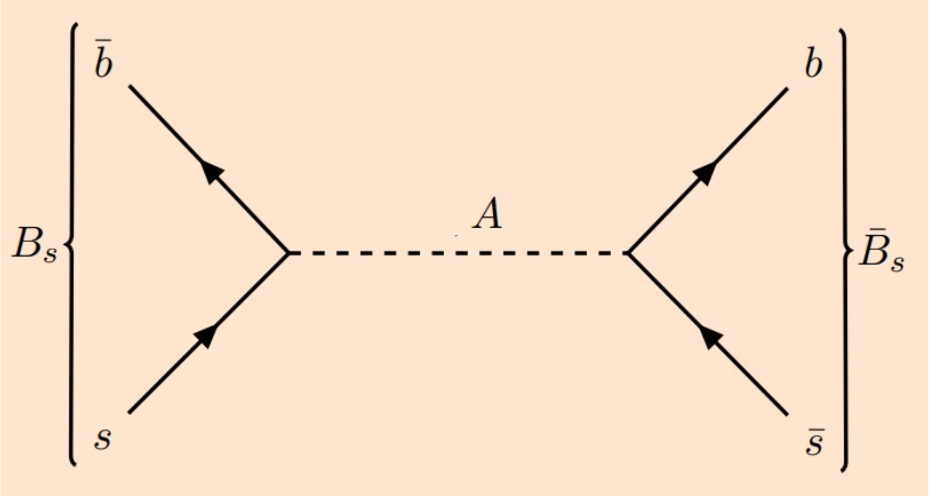


$$\Delta M_s^{\rm SM} = 17.49 \pm 0.64\,{\rm ps}^{-1}$$

$$\Delta M_s^{\rm Exp} = 17.765 \pm 0.006\,{\rm ps}^{-1}$$

Phenomenological constraints

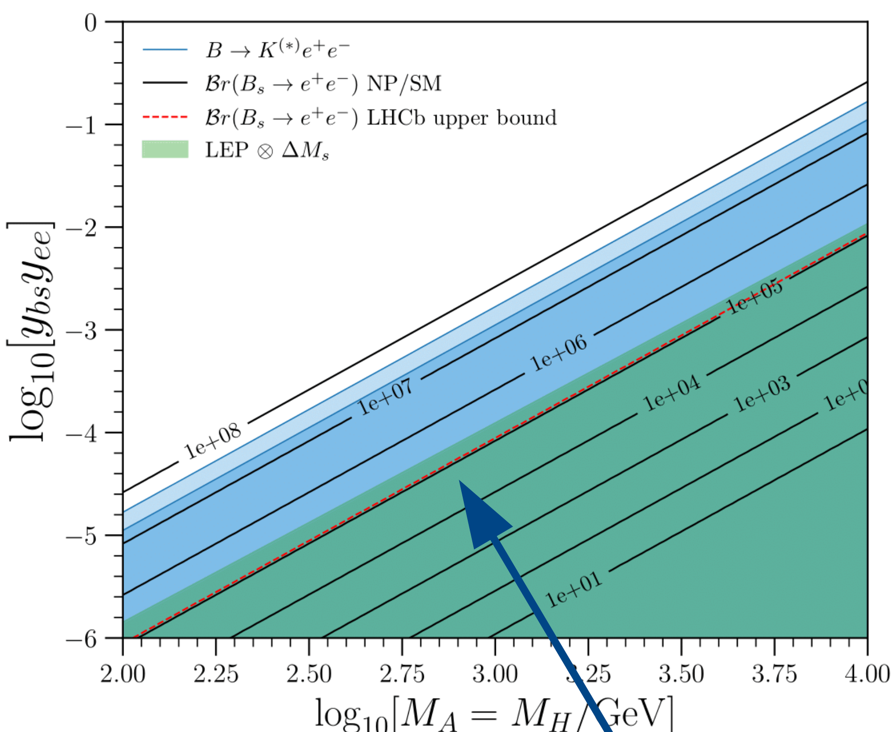
Constraints on the product $y_{ee} y_{bs}$ from $B \to K^{(*)} e^+ e^-$

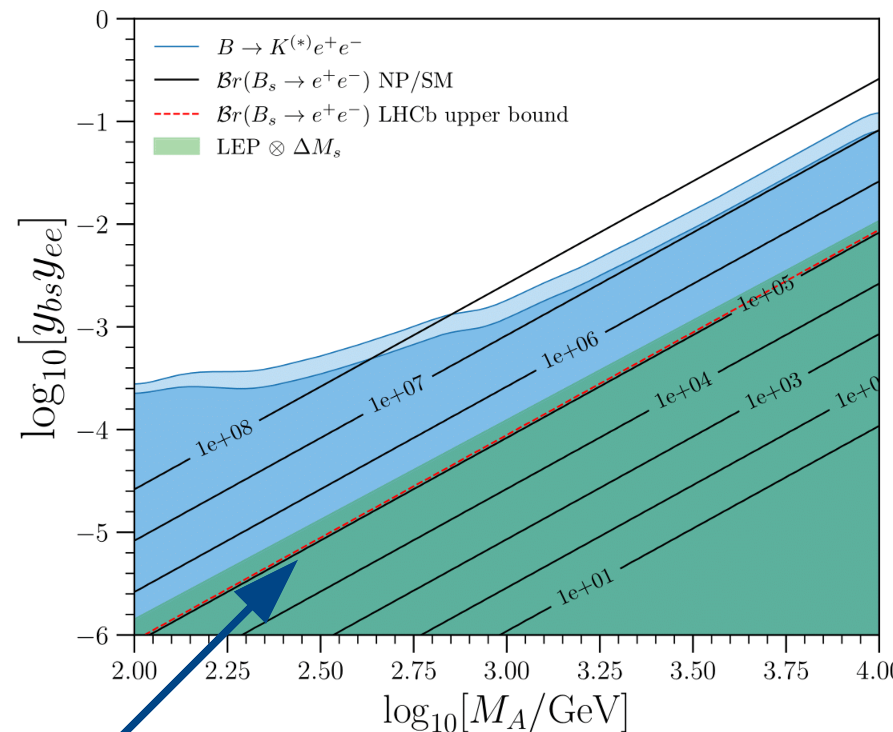
triggered by $b \to s e^+ e^-$ transitions

Observable	q^2 bin (GeV^2)	Exp. Avg.	SM Pred.
$10^8 \times \frac{\Delta\mathcal{B}}{\Delta q^2}(B^+ \to K^+ e^+ e^-)$	[1.0,6.0]	3.24 ± 0.65 [37, 38]	3.37 ± 0.56
	[0.1,4.0]	4.70 ± 1.01 [38]	3.40 ± 0.58
	[4.0,8.12]	2.36 ± 0.79 [38]	3.31 ± 0.54
$10^7 \times \frac{\Delta\mathcal{B}}{\Delta q^2}(B^0 \to K^{*0} e^+ e^-)$	[0.003,1.0]	3.09 ± 0.99 [39]	2.10 ± 0.35
$P_4'(B \to K^* e^+ e^-)$	[1.0,6.0]	-0.71 ± 0.40 [40]	-0.34 ± 0.04
	[14.18,19.0]	-0.15 ± 0.41 [40]	-0.63 ± 0.01
$P_5'(B \to K^* e^+ e^-)$	[1.0,6.0]	-0.23 ± 0.41 [40]	-0.42 ± 0.09
	[14.18,19.0]	-0.86 ± 0.34 [40]	-0.63 ± 0.03

Direct sensitivity to the Wilson coefficients $C^{ee}_{S^{(\prime)}, P^{(\prime)}}$

Phenomenological constraints





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It is possible to saturate the current experimental bounds while obeying the known constraints

Generating the NP couplings

Pati-Salam like model

Consider the model introduced in

P. Fileviez-Perez
M.B. Wise
[1307.6213]

based on the symmetry group

$$\mathrm{SU}(4)_C \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_R.$$

SM matter fields (leptons are the 4th color of fermions)

$$F_{QL} = \begin{pmatrix} u_r & u_g & u_b & \nu \\ d_r & d_g & d_b & e \end{pmatrix} \sim (\mathbf{4}, \mathbf{2}, 0),$$

$$F_u = \begin{pmatrix} u_r^c & u_g^c & u_b^c & \nu^c \end{pmatrix} \sim (\bar{\mathbf{4}}, \mathbf{1}, -1/2),$$

$$F_d = \begin{pmatrix} d_r^c & d_g^c & d_b^c & e^c \end{pmatrix} \sim (\bar{\mathbf{4}}, \mathbf{1}, 1/2).$$

This scenario can be considered a low energy limit of the Pati-Salam model

J. C. Pati and
A. Salam
Phys. Rev. D 10, 275

Quarks and leptons are unified at low energy

Generating the NP couplings

The Yukawa sector

$$-\mathcal{L} = \bar{u}_R \left(Y_1^T \widetilde{H}_1 + \frac{1}{2\sqrt{3}} Y_2^T \widetilde{H}_2 \right) Q_L + \bar{N}_R \left(Y_1^T \widetilde{H}_1 - \frac{\sqrt{3}}{2} Y_2^T \widetilde{H}_2 \right) \ell_L$$

$$+ \bar{d}_R \left(Y_3^T H_1^\dagger + \frac{1}{2\sqrt{3}} Y_4^T H_2^\dagger \right) Q_L + \bar{e}_R \left(Y_3^T H_1^\dagger - \frac{\sqrt{3}}{2} Y_4^T H_2^\dagger \right) \ell_L + \text{h.c.}$$

Type III THDM with 4 Yukawa matrices

$$\tilde{Y}^\ell = (\tan\beta - 3\cot\beta) \frac{M^E_{\text{diag}}}{4v} + 3(\tan\beta + \cot\beta) \frac{V_c^T M^D_{\text{diag}} V}{4v},$$

$$\tilde{Y}^d = (3\tan\beta - \cot\beta) \frac{M^D_{\text{diag}}}{4v} + (\tan\beta + \cot\beta) \frac{V_c^* M^E_{\text{diag}} V^\dagger}{4v},$$

↑

Physical matrices

Generating the NP couplings

Rotation matrix

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13} & -c_{12}s_{23} - s_{12}c_{23}s_{13} & c_{23}c_{13} \end{pmatrix}$$

For $\tan\beta \gg 1$ $s_{ij} \to 1$ $s'_{ij} \to 1$

$$\tilde{Y}^{\ell} = \frac{\tan\beta}{4v} \begin{pmatrix} m_e + 3m_b & \varepsilon & \varepsilon \\ \varepsilon & m_\mu + 3m_s & \varepsilon \\ \varepsilon & \varepsilon & m_\tau + 3m_d \end{pmatrix}$$

$y_{ee} \gg y_{\mu\mu}, y_{\tau\tau}$

$$\tilde{Y}^{d} = \frac{\tan\beta}{4v} \begin{pmatrix} 3m_d + m_\tau & \varepsilon & \varepsilon \\ \varepsilon & 3m_s + m_\mu & \varepsilon \\ \varepsilon & \varepsilon & 3m_b + m_e \end{pmatrix}$$

$y_{dd} \simeq y_{bb} \gg y_{ss}$

Generating the NP couplings

$$\mathcal{H}_{\rm eff} \supset -\frac{y_{ee}y_{\mu\tau}}{M_H^2}(\bar\tau\mu)(\bar e e) - \frac{y_{\tau\tau}y_{\mu\tau}}{M_H^2}(\bar\tau\mu)(\bar\tau\tau) + \frac{y_{ee}y_{\mu\tau}}{M_A^2}(\bar\tau\gamma^5\mu)(\bar e\gamma^5 e) + \frac{y_{\tau\tau}y_{\mu\tau}}{M_A^2}(\bar\tau\gamma^5\mu)(\bar\tau\gamma^5\tau)$$

$$\mathcal{O}^{ee}_{LL} = \bar\tau(1-\gamma_5)\mu\ \bar e(1-\gamma_5)e, \qquad \mathcal{O}^{ee}_{RR} = \bar\tau(1+\gamma_5)\mu\ \bar e(1+\gamma_5)e,$$
$$\mathcal{O}^{ee}_{LR} = \bar\tau(1-\gamma_5)\mu\ \bar e(1+\gamma_5)e, \qquad \mathcal{O}^{ee}_{RL} = \bar\tau(1+\gamma_5)\mu\ \bar e(1-\gamma_5)e,$$

$$C^{ee}_{LL} = C^{ee}_{RR} = \frac{y_{ee}y_{\mu\tau}}{4}\left[\frac{1}{M_H^2} - \frac{1}{M_A^2}\right], \qquad C^{ee}_{LR} = C^{ee}_{RL} = \frac{y_{ee}y_{\mu\tau}}{4}\left[\frac{1}{M_H^2} + \frac{1}{M_A^2}\right]$$

the model implies effects on the channels

$\tau^- \to \mu^- e^+ e^-$ $\qquad$ $\tau \to \mu\gamma$

Experimental bounds

$\mathcal{B}r(\tau^- \to \mu^- e^+ e^-) < 1.8 \times 10^{-8}$

Babar [hep-ex/0908.2381]

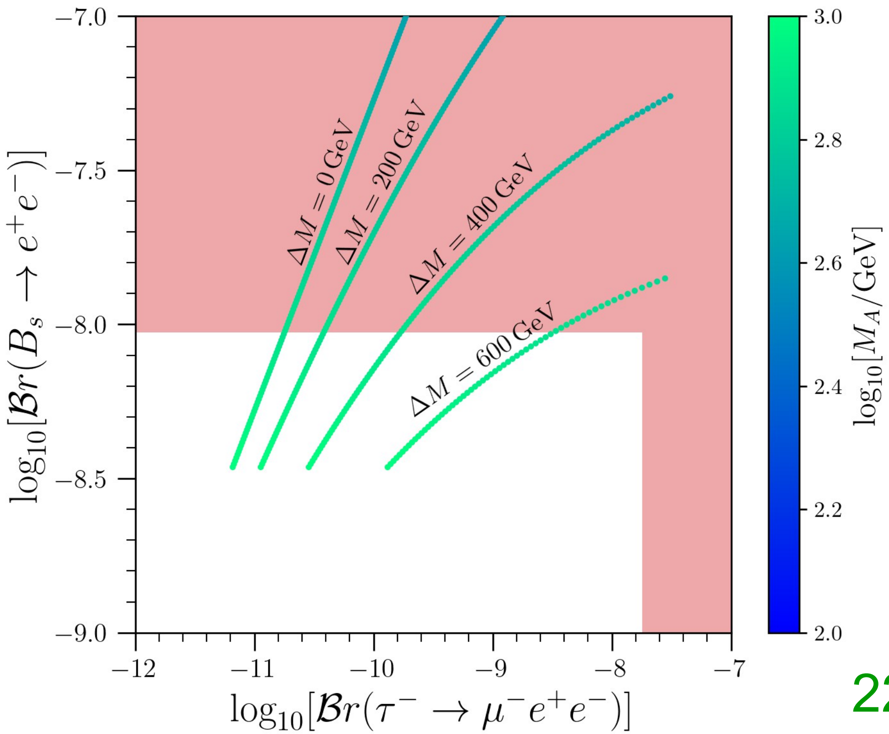
$\mathcal{B}r(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$

Belle [hep-ex/1001.3221]

Generating the NP couplings

Phenomenological correlations

$$\Delta M = M_A - M_H$$



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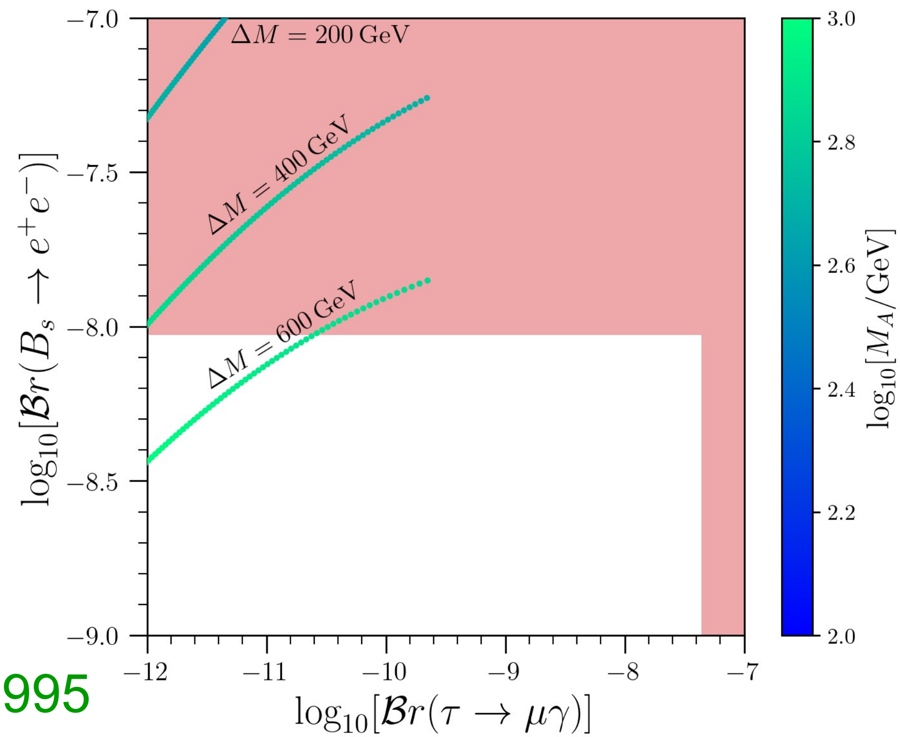

Since $y_{\mu\mu} \ll y_{ee}$ we can obey the known results for

$\bar{\mathcal{B}}r(B_s \to \mu^+\mu^-)$ within 2 σ

Conclusions

- Scalars and pseudoscalar particles can enhance dramatically the branching fraction $Br\left(B_s \to e^+ e^-\right)$.
- One of the conditions for the enhancement is that the New Physics couplings should not be proportional to m_e
- The type III THDM allows to fulfill this criteria while satisfying the known phenomenological constraints.
- The required conditions can be accomplished within the Low energy limit of the Pati Salam model.

Acknowledgements

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Phenomenological constraints

Relevant Operators

$$\mathcal{O}_V^{\Delta B=2} = \bar{s}_i \gamma^\mu (1-\gamma_5) b_i \; \bar{s}_j \gamma_\mu (1-\gamma_5) b_j, \qquad \mathcal{O}_{LL}^{\Delta B=2} = \bar{s}_i (1-\gamma_5) b_i \; \bar{s}_j (1-\gamma_5) b_j$$

$$\mathcal{O}_{RR}^{\Delta B=2} = \bar{s}_i (1+\gamma_5) b_i \; \bar{s}_j (1+\gamma_5) b_j, \qquad \mathcal{O}_{LR}^{\Delta B=2} = \bar{s}_i (1-\gamma_5) b_i \; \bar{s}_j (1+\gamma_5) b_j$$

Standard Model

$$C_{RR}^{\Delta B=2} = \frac{y_{bs}^2}{4}\left[\frac{1}{m_H^2} - \frac{1}{m_A^2}\right], \qquad C_{RR}^{\Delta B=2} = C_{LL}^{\Delta B=2}, \qquad C_{LR}^{\Delta B=2} = \frac{y_{bs}^2}{2}\left[\frac{1}{m_H^2} + \frac{1}{m_A^2}\right]$$

$$\Delta M_s = 2|M_{12}^s|$$

$$M_{12}^s = \frac{G_F^2}{12\pi^2} \lambda_t^2 M_W^2 S_0(x_t) \hat{\eta}_B f_{B_s}^2 M_{B_s} B_1 + \frac{1}{2M_{B_s}}\left[2C_{RR}^{\Delta B=2}\langle \mathcal{O}_{RR}^{\Delta B=2}\rangle + C_{LR}^{\Delta B=2}\langle \mathcal{O}_{LR}^{\Delta B=2}\rangle\right].$$

The THDM and $B_s \rightarrow e^+ e^-$

Non-diagonal mass matrices

$$m^i = Y_1^i \frac{v_1}{\sqrt{2}} + Y_2^i \frac{v_2}{\sqrt{2}}$$

After transforming to the physical basis for fermions

$$-\mathcal{L} \supset \bar{f}_L^i \left[\frac{M_{\rm diag}^i}{v} h + \left(-\cot\beta \frac{M_{\rm diag}^i}{v} + \frac{\Omega^i}{\sqrt{2} s_\beta} \right) (H \pm iA) \right] f_R^i + \text{h.c.}$$

$$\widetilde{Y}^\ell = -\cot\beta \frac{M_{\rm diag}^E}{v} + \frac{\Omega^\ell}{\sqrt{2} s_\beta} = \begin{pmatrix} y_{ee} & \varepsilon & \varepsilon \\ \varepsilon & y_{\mu\mu} & \varepsilon \\ \varepsilon & \varepsilon & y_{\tau\tau} \end{pmatrix}$$

To enhance decays into pairs of electrons

$$y_{\mu\mu} \ll y_{ee}$$

$$\widetilde{Y}^d = -\cot\beta \frac{M_{\rm diag}^D}{v} + \frac{\Omega^d}{\sqrt{2} s_\beta} = \begin{pmatrix} y_{dd} & \varepsilon & \varepsilon \\ \varepsilon & y_{ss} & y_{bs}/2 \\ \varepsilon & y_{bs}/2 & y_{bb} \end{pmatrix}$$

To avoid sizeable lepton flavour violation, and bounds from kaon-mixing

$$\varepsilon \ll y_{ij}$$

Generating the NP couplings

For the off-diagonal couplings we have

$$\tilde{Y}^d_{sb} = \frac{1}{4v}\left(\tan\beta + \cot\beta\right)\left(m_\mu s'_{23}c_{23} - m_e s_{23}c'_{23}\right),$$

$$\tilde{Y}^d_{bs} = \frac{1}{4v}\left(\tan\beta + \cot\beta\right)\left(m_\mu s_{23}c'_{23} - m_e s'_{23}c_{23}\right),$$

$$\tilde{Y}^\ell_{\mu\tau} = \frac{3}{4v}\left(\tan\beta + \cot\beta\right)\left(m_s s'_{23}c_{23} - m_d s_{23}c'_{23}\right),$$

$$\tilde{Y}^\ell_{\tau\mu} = \frac{3}{4v}\left(\tan\beta + \cot\beta\right)\left(m_s s_{23}c'_{23} - m_d s'_{23}c_{23}\right),$$

where $s_{ij} \to 1$ $s'_{ij} \to 1$ but for s_{23} and s'_{23}

when $s_{23} = s'_{23}$ → $\tilde{Y}^d_{sb} = \tilde{Y}^d_{bs} = y_{bs}/2$, $\tilde{Y}^\ell_{\mu\tau} = \tilde{Y}^\ell_{\tau\mu} = y_{\tau\mu}/2$