Relating B_s Mixing and $B_s \to \mu^+ \mu^-$ with New Physics

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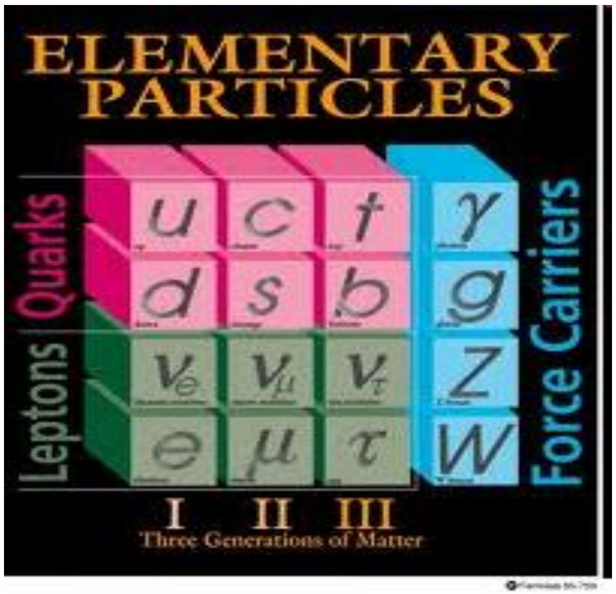
Based on E. Golowich, J. Hewett, S. Pakvasa, A. A. Petrov, G. Yeghiyan, arXiv: 1102.0009 [hep-ph]

1. Introduction/Motivation
2. Results
3. Conclusion

1. **Introduction/Motivation**

The Standard Model of electromagnetic, weak and strong interactions:



- is a consistent theory that describes all the experimental phenomena in particle physics up to a 100 GeV scale.

plus Higgs doublet H
or a physical Higgs state h

1. **Introduction/Motivation**

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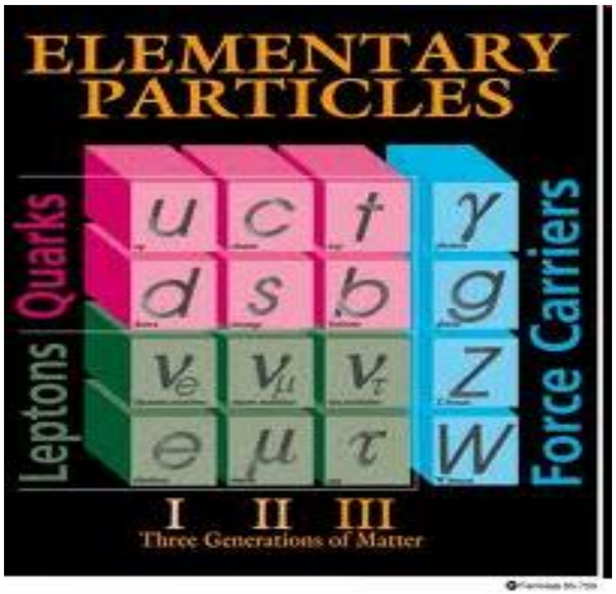

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- is a consistent theory that describes all the experimental phenomena in particle physics up to a 100 GeV scale.

there are several sreasons to believe that the SM should be replaced by a more fundamental theory at energies ~ 100 GeV or larger

$B_s \to \mu^+ \mu^-$ - represents the possibility of low-energy indirect search for new physics (NP) beyond the SM.

B_s $(s\bar{b})$, μ^-, μ^+ - are the SM states, $M_{Bs} = 5.366$ GeV, $m_u = 0.113$ GeV, where should NP come from?

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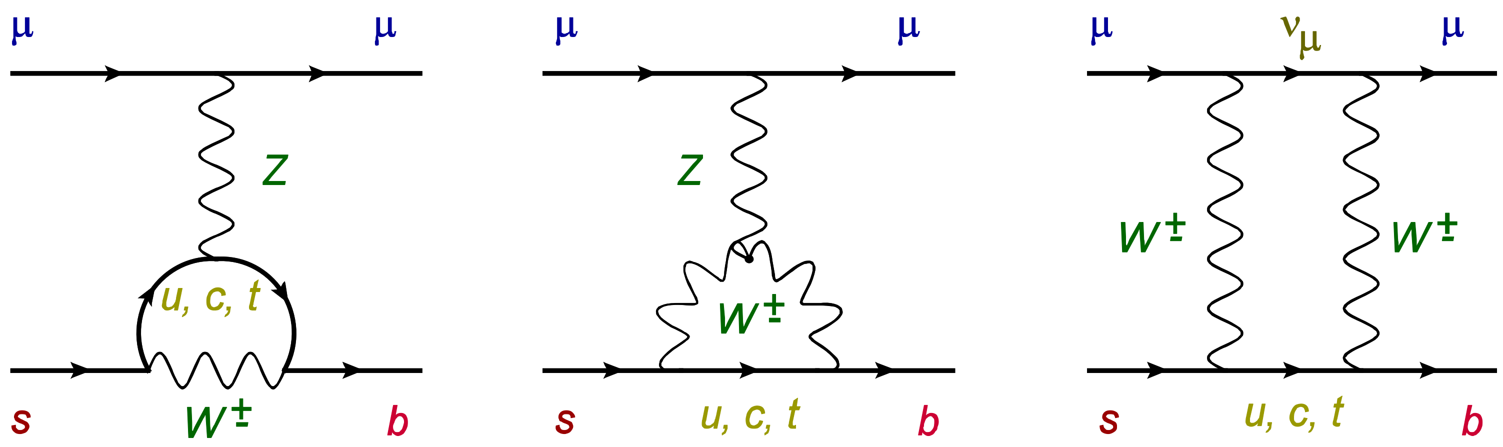
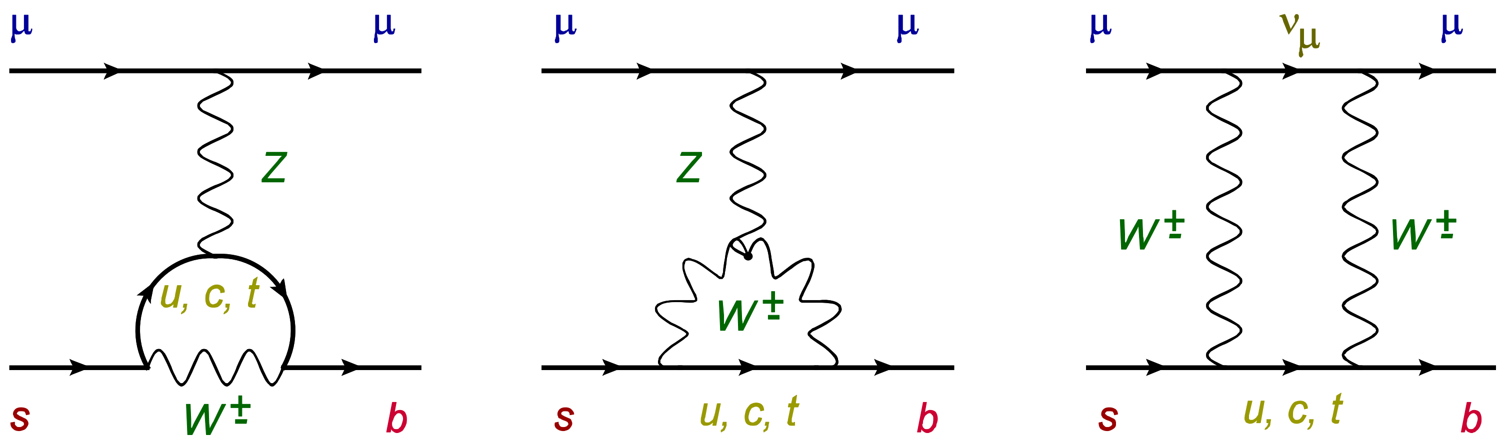
SM diagrams for $B_s \to \mu^+ \mu^-$ to the leading order: **occur due to exchange of heavy W and Z bosons** (M_W = 80 GeV, M_Z = 91 GeV)



NP contribution: diagrams with other heavy (hypothetical) particles

In principle, NP contribution to $B_s \rightarrow \mu^+ \mu^-$ may be greater than that of the SM by orders of magnitude, because….

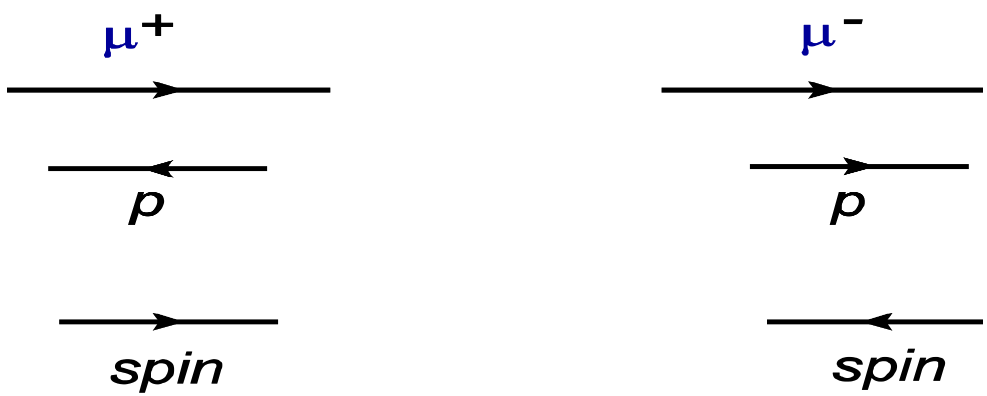


•The SM contribution occurs at one-loop (subleading order in perturbation theory), suppressed by a loop factor, $\alpha/(4 \pi \sin^2\theta_W) = 2.5 \times 10^{-3}$

• Mixing between 2-nd and 3-rd quark generations is suppressed as λ^2 where $\lambda = \sin \theta_C = 0.2259$.

Also, the helicity flip suppression:

•By conservation of spin, muon and antimuon spins must be oppositely directed, or helicity flip operator is needed. Within the SM that would be the muon mass insertion operator, leads to a suppression factor $m_{\mu}/\mathbf{M_B} \sim \mathbf{0.02}$ in the transition amplitude.



Needs $\bar{\mu}_L \ldots \mu_R$ field operator product

The consequence:

$$\mathcal{B}^{(\mathrm{SM})}_{B_s\to\mu^+\mu^-} \simeq 3.3\times 10^{-9}$$

Compare to experimental data:

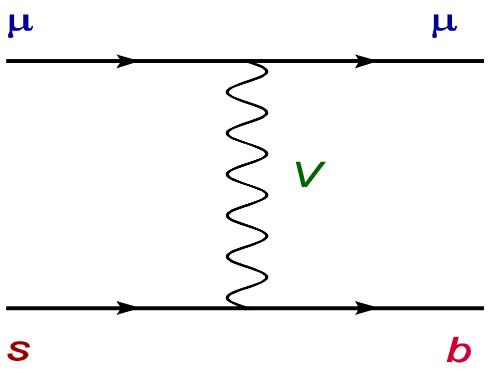
$$\mathcal{B}^{(\mathrm{expt})}_{B_s\to\mu^+\mu^-} < 4.7\times 10^{-8}$$

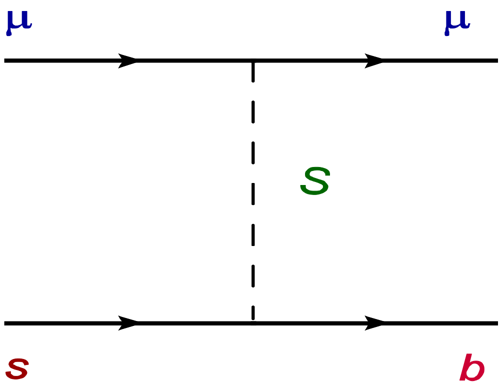
Room for new physics?….

May it happen that due to NP contribution
$B(\mathbf{B_s \to \mu^+ \mu^-}) >> B^{SM}(\mathbf{B_s \to \mu^+ \mu^-})$ **?**

Beyond the SM:

• Many SM extensions allow quark Flavor Changing Neutral Currents (FCNC), $B_s \rightarrow \mu^+ \mu^-$ may occur at the tree level.





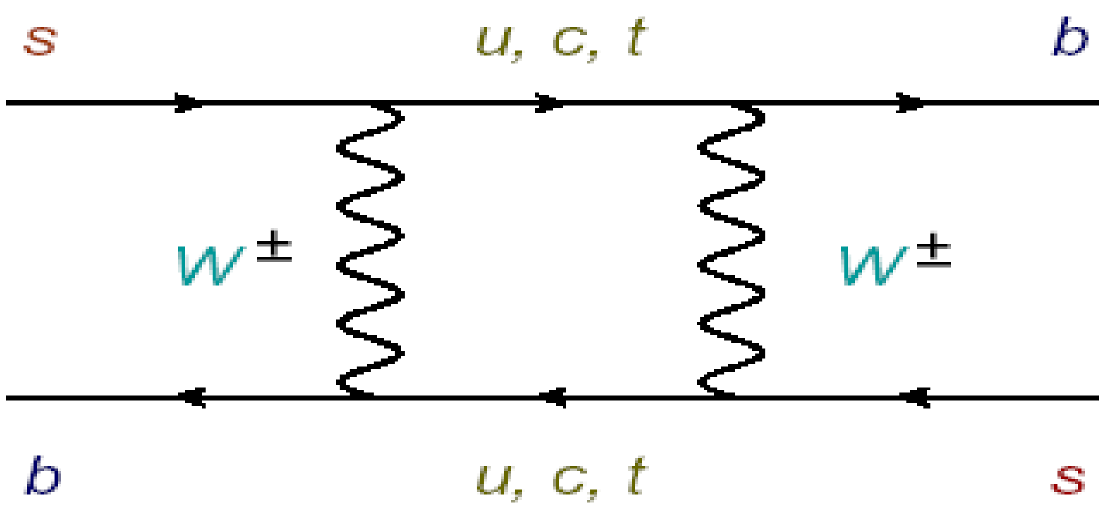
•Within many SM extensions mixing between quark generations is not suppressed.

• Within many SM extensions we get scalar or pseudoscalar operators with helicity flip.

In other words, NP contribution to $B_s \rightarrow \mu^+ \mu^-$ may exceed the SM contribution by orders of magnitude. Detecting $B_s \rightarrow \mu^+ \mu^-$ at a rate exceeding the SM one would manifest a signal for New Physics!

There is however a process with similar features but a slight (and essential) difference: $B_s - \bar{B}_s$ oscillations (mixing) – one of the manifestations of mater-to-antimatter oscillations in the Nature.

Within the SM occurs via the "box" diagrams



Brief description of the oscillation formalism:

$$\mathrm{i}\,\frac{\partial}{\partial t}\begin{pmatrix} B_s(t) \\ \overline{B}_s(t) \end{pmatrix} = \left(M - \frac{\mathrm{i}}{2}\Gamma \right) \begin{pmatrix} B_s(t) \\ \overline{B}_s(t) \end{pmatrix}$$

The oscillation is parameterized by off-diagonal elements: $M_{12} = M_{21}^*$ and $\Gamma_{12} = \Gamma_{21}^*$ that are related to the transition amplitude.

The mass eigenstates (heavy and light) are

$| B_H > = p\,| B_s > - \; q\,| B_s >$, $| B_L > = p\,| B_s > + \; q\,| B_s >$

where $$\left(\frac{q}{p}\right)^2 = \frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}$$

The eigenstates mass and width difference are

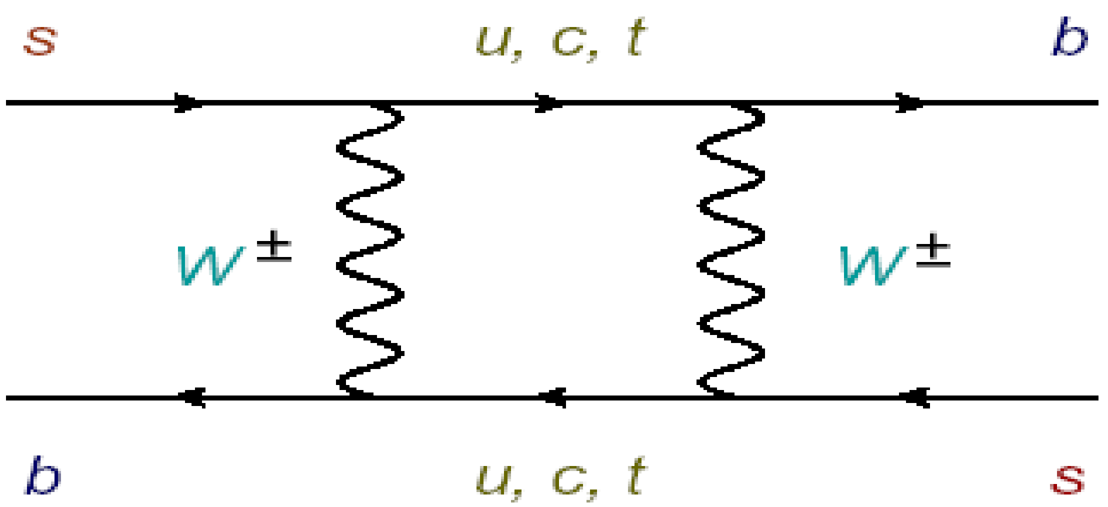
$$\Delta M \simeq 2|M_{12}| \qquad \Delta\Gamma \simeq 2|\Gamma_{12}|\cos\Phi \qquad \Phi = \arg(-M_{12}/\Gamma_{12})$$

Mass and width difference are the physical quantities used to describe meson-antimeson oscillations.

Similarly to $\mathbf{B_s \to \mu^+ \mu^-}$:

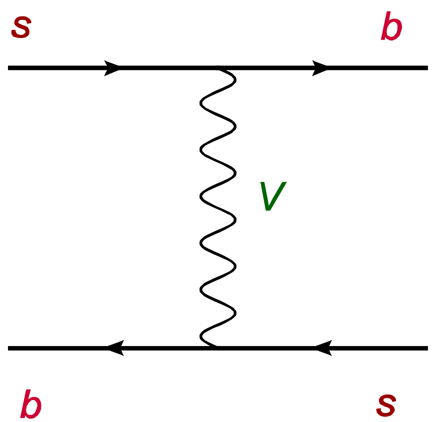
• The SM contribution to B_s mixing occurs at one-loop, is suppressed by a loop factor;

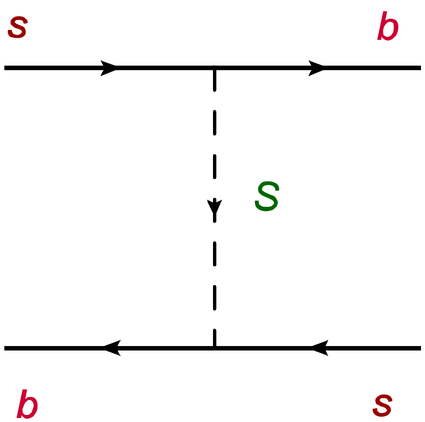
• is suppressed as λ^4, where $\lambda = \sin\theta_C = 0.2259$.



Similarly to $\mathbf{B_s} \rightarrow \mu^+ \mu^-$:

• Many SM extensions allow quark Flavor Changing Neutral Currents (FCNC), $\mathbf{B_s}$ mixing may occur at the tree level.





• Within many SM extensions mixing between quark generations is not suppressed.

Having a large NP contribution to $\mathbf{B_s} \rightarrow \mu^+ \mu^-$ we would in general also have a large NP contribution to $\mathbf{B_s}$ mixing – these two processes are correlated!

Essential difference is the experimental data

$\mathcal{B}^{(\mathrm{expt})}_{B_s\to\mu^+\mu^-} < 4.7\times 10^{-8}$ $\mathcal{B}^{(\mathrm{SM})}_{B_s\to\mu^+\mu^-} \simeq 3.3\times 10^{-9}$ Room for new physics?

The SM predictions for B_s mixing is in agreement with the experiment, e.g. for the mass difference,

$$\Delta M^{(\mathrm{expt})}_{B_s} = (117.0\pm 0.8)\times 10^{-13}\ \mathrm{GeV} \qquad \Delta M^{(\mathrm{SM})}_{B_s} = \left(117.1^{+17.2}_{-16.4}\right)\times 10^{-13}\ \mathrm{GeV}$$

The NP contribution to ΔM_{Bs} is constrained:

$$|\Delta M^{(\mathrm{NP})}_{B_s}| \leq 17.3\times 10^{-13}\ \mathrm{GeV}$$

Leads to severe constraints on the relevant NP parameters

Because of the correlations between two processes, these constraints on the NP parameters imply also severe constraints on the $B_s \to \mu^+ \mu^-$ branching ratio.

2. Results

Within many SM extensions the NP contribution to **$B_s \to \mu^+ \mu^-$** turns to be much less than the SM contribution, against what would be expected

Models with Z' boson (extra gauge boson in addition to those within the SM), FCNC's are allowed with the exchange of Z':

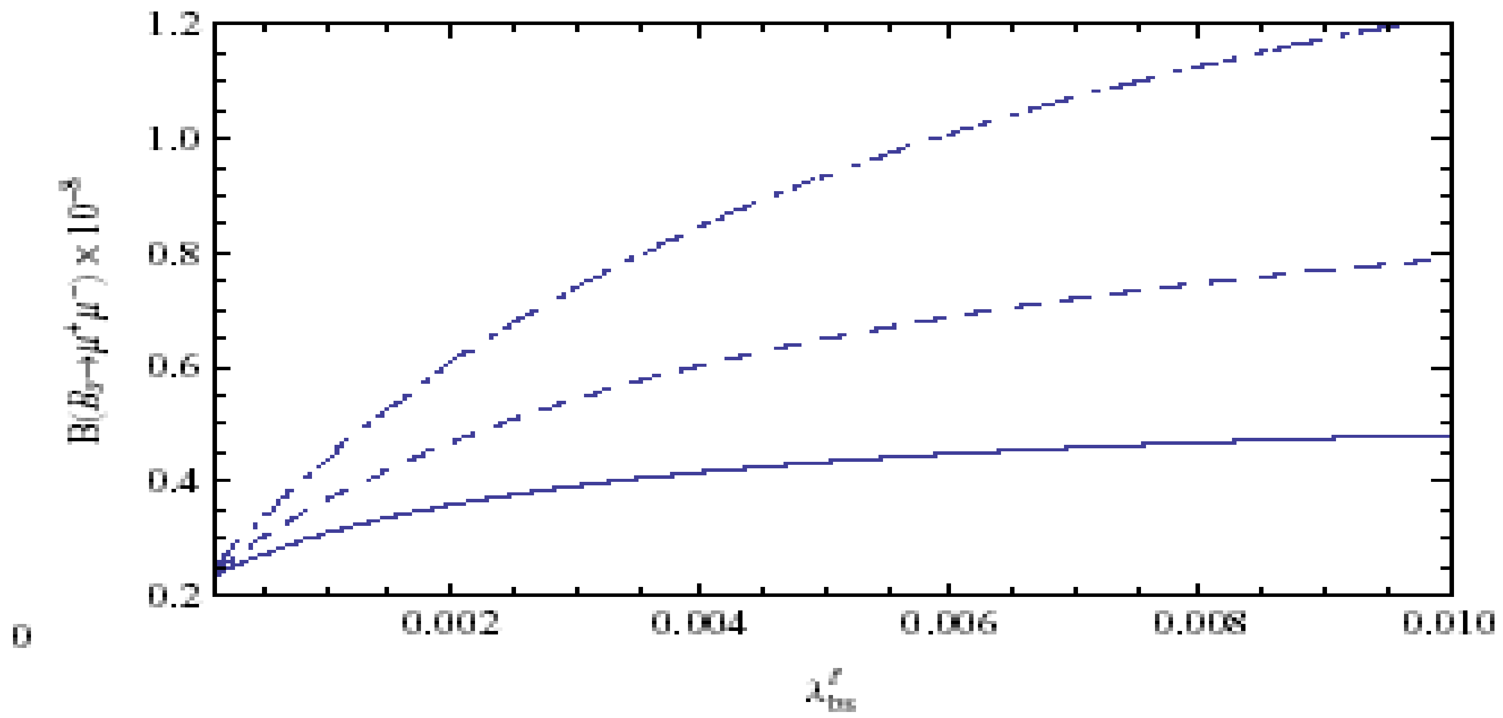
$$\frac{g^2_{Z' s\bar{b}}}{M^2_{Z'}} = \frac{3|\Delta M_{B_s}^{(\mathrm{NP})}|}{M_{B_s} f^2_{B_s} B_{B_s} r_1(m_b, M_{Z'})} \leq 2.47 \times 10^{-11}\ \mathrm{GeV}^{-2}$$

$$\mathcal{B}^{(Z')}_{B_s \to \mu^+\mu^-} \leq 0.25 \times 10^{-9} \cdot \left(\frac{1\ \mathrm{TeV}}{M_{Z'}}\right)^2$$

Family symmetry models: same charge quarks/leptons are gauge SU(3) triplets → SU(2) doublets – FCNC interactions with exchange of non-Abelian gauge bosons:

$$\mathcal{B}^{(\mathrm{FS})}_{B_s \to \mu^+\mu^-} \leq 0.5 \times 10^{-12}$$

Of course, we are not always so successful, often the bounds are functions of some NP parameter, and in some corners of the parameter space, $B^{NP}(\mathbf{B_s \to \mu^+ \mu^-})$ may be large enough, e.g. in 4 generation models.



In some models (e.g. RPV SUSY or FCNC Higgs models), B_s mixing and $\mathbf{B_s \to \mu^+ \mu^-}$ may depend on different combinations of NP couplings and masses, there may be no correlations between these two processes.

In these models bound on $B^{NP}(\mathbf{B_s \to \mu^+ \mu^-})$ is derived within simplified scenarios only.

Conclusions

- **We studied possible correlations between the NP contribution to $B_s - \bar{B}_s$ mixing and $B_s \to \mu^+ \mu^-$ decay.**

- **The SM predictions for B_s mixing are in a decent agreement with the experimental data – the NP contribution must be constrained and the relevant NP parameters must be constrained.**

- **In many SM extensions the constraints on the NP parameters lead to severe constraints on the $B^{NP}(B_s \to \mu^+ \mu^-)$ – no new physics can be seen in this decay.**