# Andriy Badin

# $B_s$ mixing: Standard Model and Beyond

Based on: Andriy Badin, Fabrizzio Gabbiani and Alexey A. Petrov:
"Lifetime difference in $B_s$ mixing: Standard Model and beyond"
Phys. Lett. B 653 (2007) 230-240

# Outline

- $B_S$ mixing in standard model with subleading $1/m^2$ corrections included.
- Contribution from generic $\Delta B=1$ New Physics models.
- Examples of New Physics models.

Experimental Results:

$$\Delta\Gamma/\Gamma = 0.121 \pm 0.083/0.090$$ PDG

$$\Delta\Gamma/\Gamma = 0.104 \pm 0.076/0.084$$ HFAG

The width difference between heavy and light states is given by:

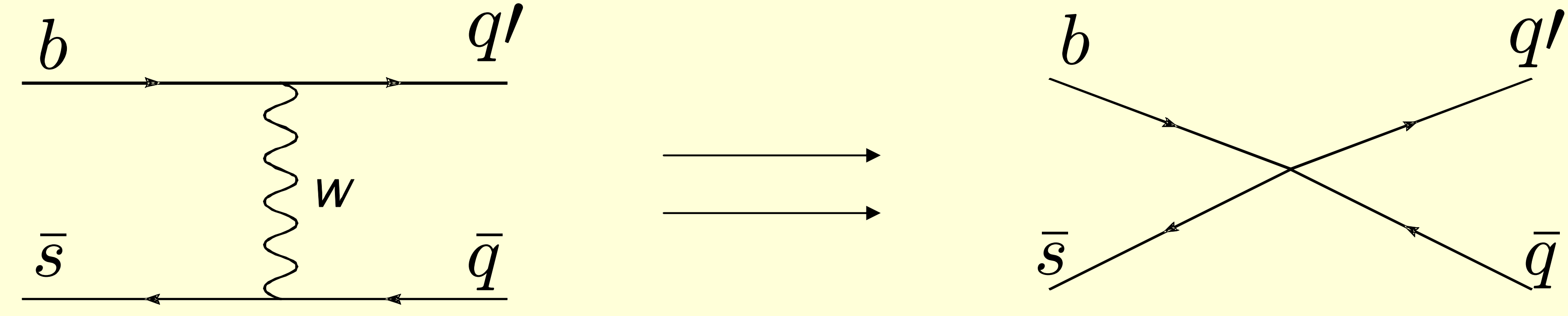
$$\Delta\Gamma_{B_s} = \Gamma_L - \Gamma_H = -2\Gamma_{12} = -2\Gamma_{12} = -2\Gamma_{21}$$

Where $\Gamma_{ij}$ are the elements of the decay-width matrix,

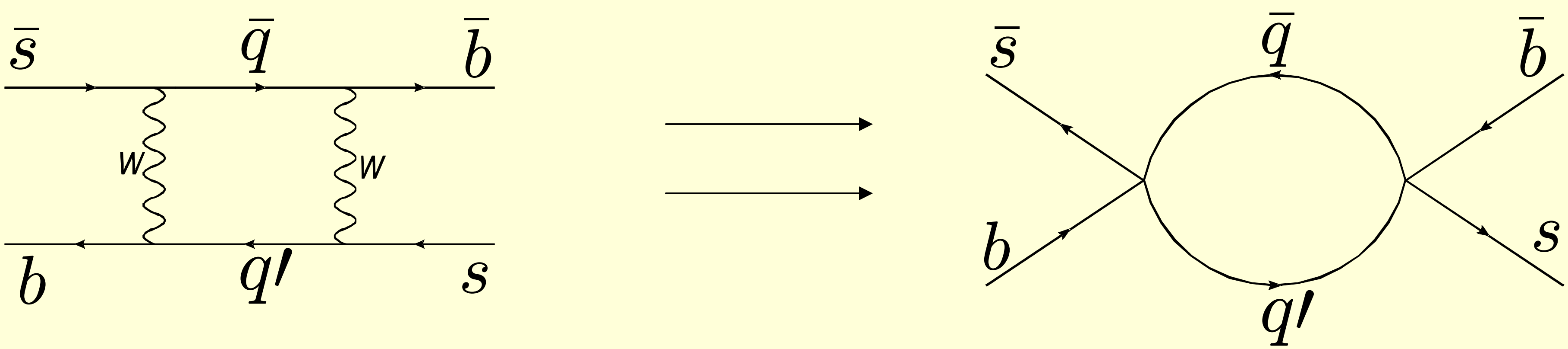
$$i, j = 1, 2, \quad |1\rangle = |B_s\rangle, |2\rangle = |\bar{B}_s\rangle$$

$$\Gamma_{12} = \frac{1}{2M_{B_s}} \langle \overline{B_s} | T | B_s \rangle \qquad T = \mathrm{Im}\, i \int d^4x \mathrm{T}\left(H_{eff}(x) H_{eff}(0)\right)$$

Effective ΔB = 1 interaction




ΔΓ diagrams




# Both vertices are SM:

$$\frac{G_f}{\sqrt{2}} V_{bq}^{*} V_{qs} \left[ C_1 \left(\overline{b}^i q^j\right)_{V-A} \left(\overline{q}^j s^i\right)_{V-A} + \; C_2 \left(\overline{b}^i q^i\right)_{V-A} \left(\overline{q}^j s^j\right)_{V-A} \right] \left(\overline{b}^i q^j\right)_{V-A} \left(\overline{q}^j s^i\right)_{V-A}$$

## 1/m expansion

$$\Gamma_{21}(B_s) = \frac{1}{2M_{B_s}} \sum_k \langle B_s|\mathcal{T}_k|B_s\rangle = \sum_k \frac{C_k(\mu)}{m_b^k} \langle B_s|\mathcal{O}_k^{\Delta B=2}(\mu)|B_s\rangle$$

$$\Gamma_{21}(B_s) = -\frac{G_F^2 m_b^2}{12\pi(2M_{B_s})} \left(V_{cb}^* V_{cs}\right)^2 \left\{\left[F(z) + P(z)\right]\langle Q\rangle + \left[F_S(z) + P_S(z)\right]\langle Q_S\rangle + \delta_{1/m} + \delta_{1/m^2}\right\}$$

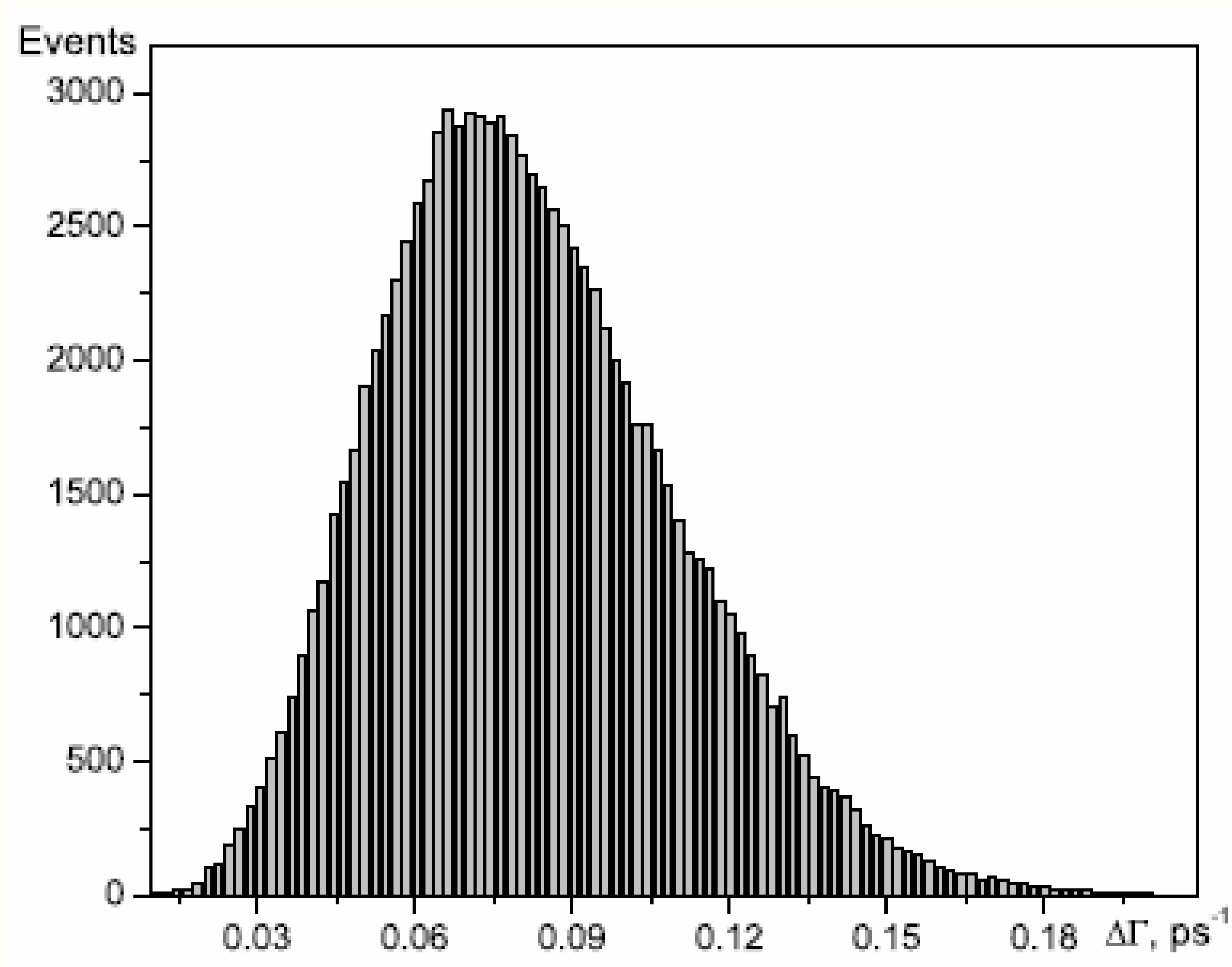
Leading order and corrections O(1/m) were calculated by several groups.
For example:M. Beneke, G. Buchalla, I. Dunietz, Phys. Rev. D 54 (1996) 4419

However O(1/m) corrections are about 30% of leading contribution. There is a question how well this series converges.

Possible ways to clarify this problem:

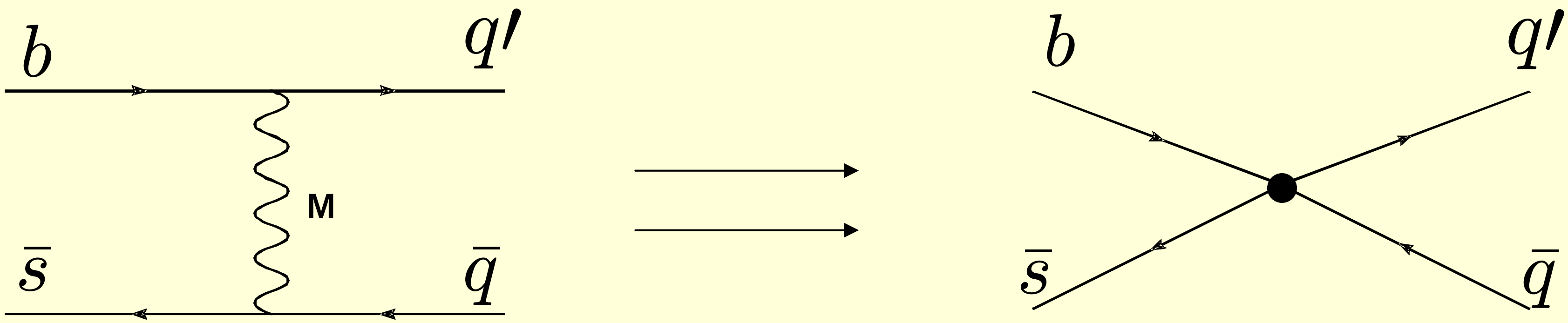
- Redefine basis of operators in such a way that NLO corrections would be small (For example Alexander Lenz, Ulrich Nierste, JHEP 0706:072,2007)
- Compute NNLO corrections directly to see their contribution.

$$\begin{aligned}\Delta\Gamma_{B_s} = \big[&0.0005B + 0.1732B_s + 0.0024B_1 - 0.0237B_2 - 0.0024B_3 - 0.0436B_4 \\ &+ 2\times10^{-5}\alpha_1 + 4\times10^{-5}\alpha_2 + 4\times10^{-5}\alpha_3 + 0.0009\alpha_4 - 0.0007\alpha_5 \\ &+ 0.0002\beta_1 - 0.0002\beta_2 + 6\times10^{-5}\beta_3 - 6\times10^{-5}\beta_4 - 1\times10^{-5}\beta_5 \\ &- 1\times10^{-5}\beta_6 + 1\times10^{-5}\beta_7 + 1\times10^{-5}\beta_8\big]\ (\mathrm{ps}^{-1}).\end{aligned}$$

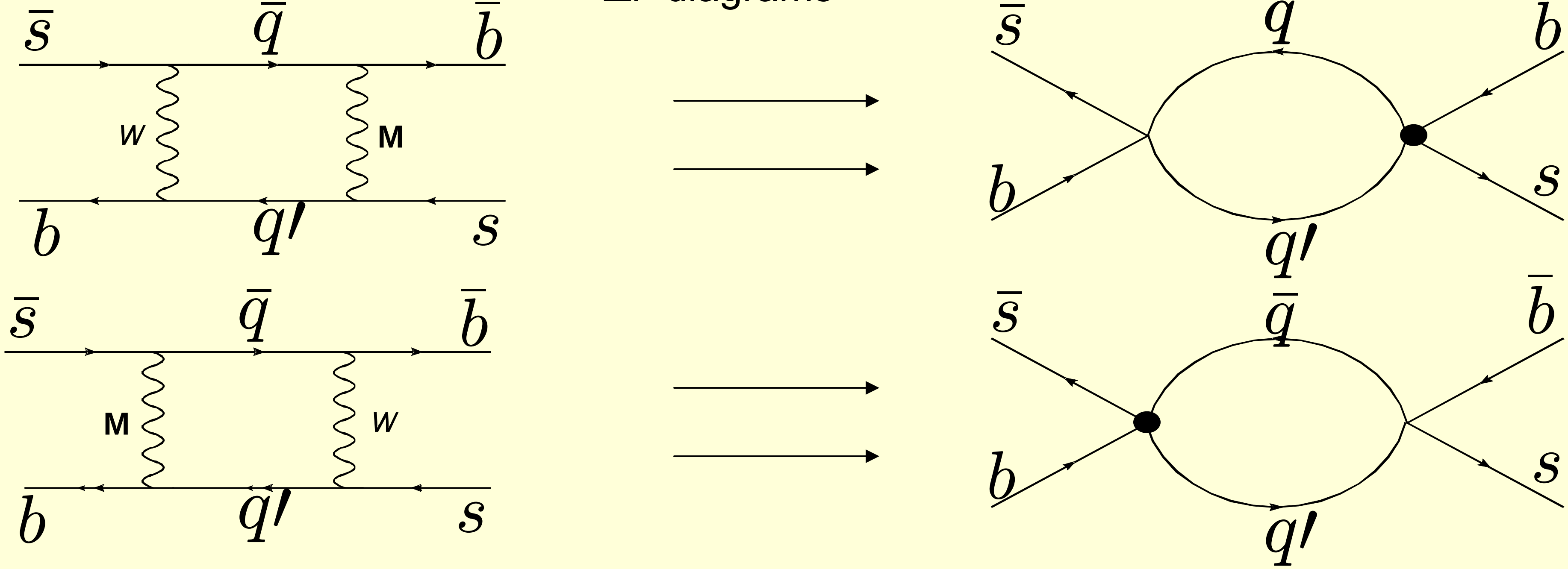



$$\Delta\Gamma_{B_s} = 0.072 + 0.034 - 0.030 ps^{-1} \qquad \frac{\Delta\Gamma_{B_s}}{\Gamma_{B_s}} = 0.104 \pm 0.049$$

## New Physics contribution




## ΔΓ diagrams



# Generic description of New Physics contribution

Eugene Golowich, Sandip Pakvasa, Alexey A. Petrov Phys. Rev. Lett. 98, 181801 (2007)

$$y = \frac{\Delta\Gamma}{\Gamma} = -\frac{4\sqrt{2}G_f}{M_B\Gamma_B}\sum_{q,q'} V^*_{bq}V_{sq'}D_{qq'}\left(K_1\delta_{ik}\delta_{jl} + K_2\delta_{il}\delta_{jk}\right)\sum_{n=1}^{5} I_n\left\langle O_n^{ijkl}\right\rangle$$

$$\left\langle O_1^{ijkl}\right\rangle = \left\langle B_s\left|\bar{b}_k\Gamma_\mu\gamma_\nu\Gamma_2 s_j\bar{b}_l\Gamma_1\gamma^\nu\Gamma^\mu s_i\right|\overline{B_s}\right\rangle;$$

$$\left\langle O_2^{ijkl}\right\rangle = \left\langle B_s\left|\bar{b}_k\Gamma_\mu\hat{p}\Gamma_2 s_j\bar{b}_l\Gamma_1\hat{p}\Gamma^\mu s_i\right|\overline{B_s}\right\rangle;$$

$$\left\langle O_3^{ijkl}\right\rangle = \left\langle B_s\left|\bar{b}_k\Gamma_\mu\Gamma_2 s_j\bar{b}_l\Gamma_1\hat{p}\Gamma^\mu s_i\right|\overline{B_s}\right\rangle;$$

$$\left\langle O_4^{ijkl}\right\rangle = \left\langle B_s\left|\bar{b}_k\Gamma_\mu\hat{p}\Gamma_2 s_j\bar{b}_l\Gamma_1\Gamma^\mu s_i\right|\overline{B_s}\right\rangle;$$

$$\left\langle O_5^{ijkl}\right\rangle = \left\langle B_s\left|\bar{b}_k\Gamma_\mu\Gamma_2 s_j\bar{b}_l\Gamma_1\Gamma^\mu s_i\right|\overline{B_s}\right\rangle;$$

$$I_1(y,z) = -\frac{km_b}{48\pi}\left(1 - 2(y+z) + (y-z)^2\right)$$

$$I_2(y,z) = -\frac{k}{24\pi m_b}\left(1 + (y+z) - 2(y-z)^2\right)$$

$$I_3(y,z) = \frac{k}{8\pi}\sqrt{z}\left(1 + y - z\right)$$

$$I_4(y,z) = -\frac{k}{8\pi}\sqrt{y}\left(1 - y + z\right)$$

$$I_5(y,z) = \frac{km_b}{4\pi}\sqrt{zy}$$

$$k \equiv \frac{m_b}{2}\left(1 - 2(y+z) + (y-z)^2\right)^{1/2};$$

$$y \equiv \left(\frac{m_{q'}}{m_b}\right)^2; \; z \equiv \left(\frac{m_q}{m_b}\right)^2$$

$\Gamma_{1,2}$ and $D_{qq'}$ are parameters of a New Physics model

- Multi Higgs Model

This model contains charged Higgs bosons as parts of the extended Higgs sector and provides new flavor-changing interactions mediated by charged Higgs bosons

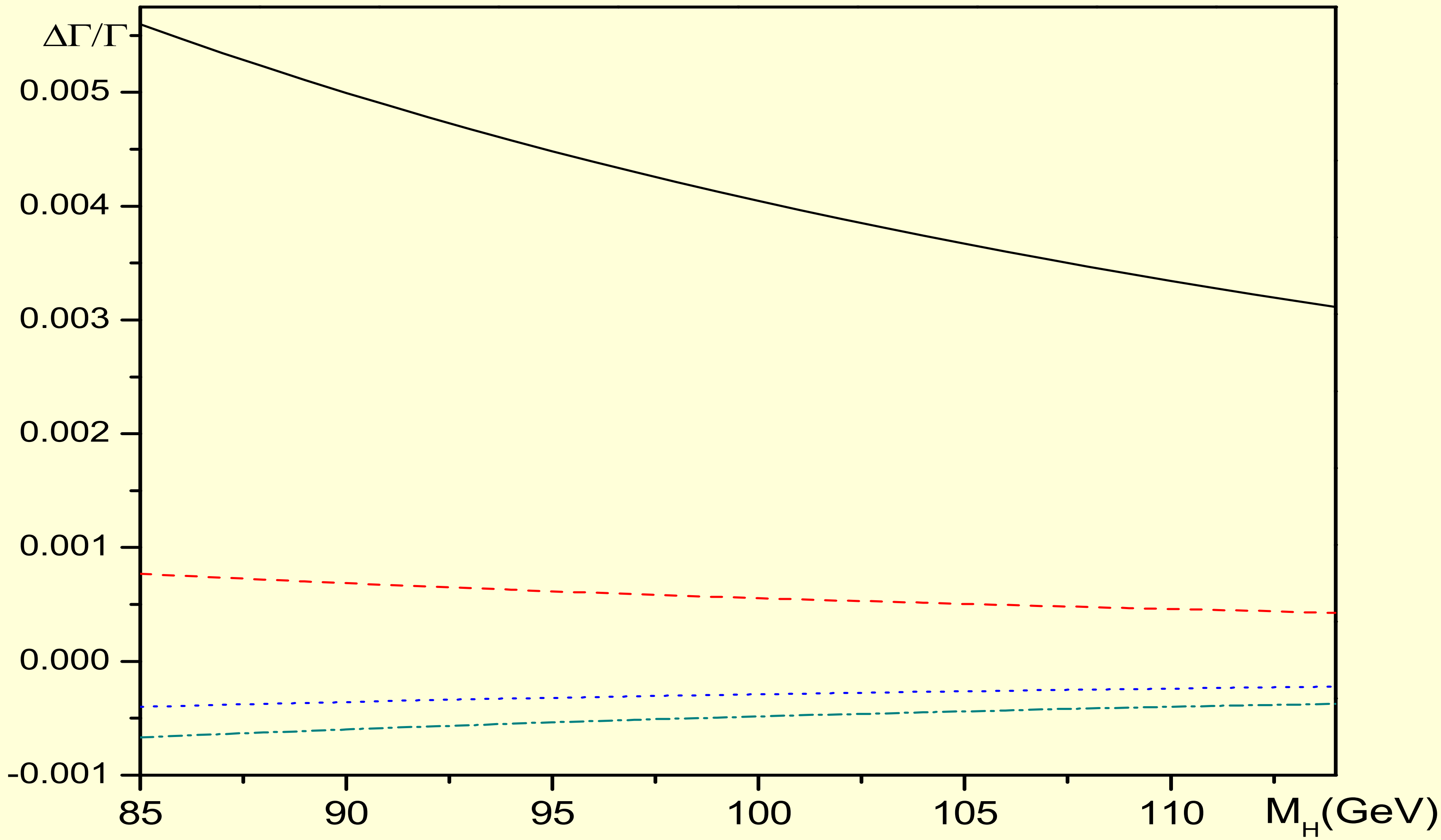
$$\mathcal{H}^{\Delta B=1}_{ChH} = -\frac{\sqrt{2}G_F}{M_H^2}\ \bar{b}_i \overline{\Gamma}_1 q'_i\ \bar{q}_j \overline{\Gamma}_2 s_j$$

where $\overline{\Gamma}_i,\ i = 1, 2$ are

$$\begin{aligned}\overline{\Gamma}_1 &= m_b V^*_{cb} \cot\beta P_L - m_c V^*_{cb} \tan\beta P_R \\ \overline{\Gamma}_2 &= m_s V_{cs} \cot\beta P_R - m_c V_{cs} \tan\beta P_L\end{aligned}$$

For values of $M_H = 85 GeV$ and $\cot\beta = 0.05$ it gives $y_{ChH} \approx 0.006$

Dependence of $y_{ChH}$ on mass of Higgs boson:
solid line - $\tan\beta = 20$,dashed line - $\tan\beta = 10$,
dotted line - $\tan\beta = 5$, dash-dotted line - $\tan\beta = 3$



- Left-Right Symmetric Model

Left–Right Symmetric Model (LRSM) assumes the extended $SU(2)_L x SU(2)_R$ symmetry of the theory, which restores parity at high energies

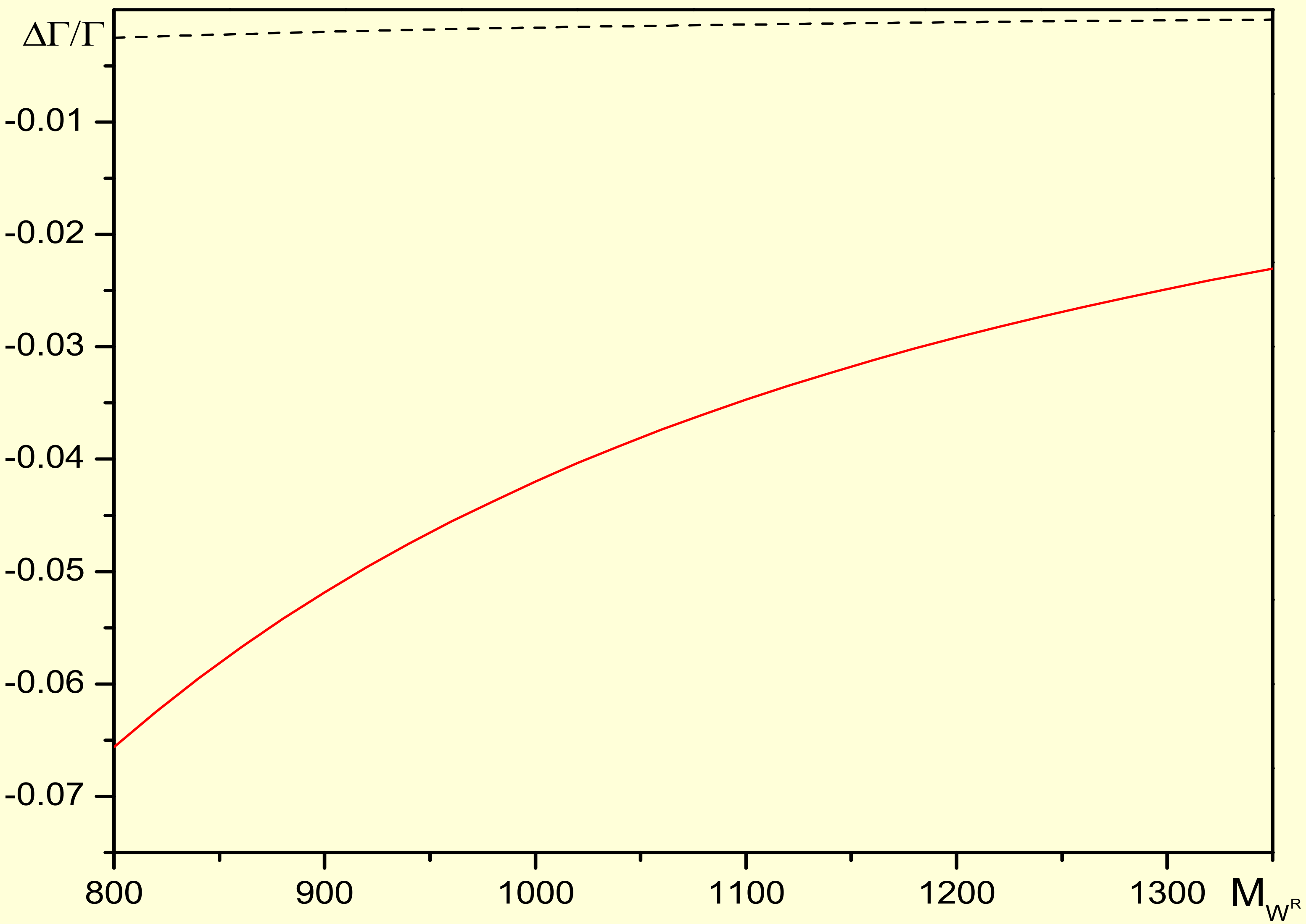
$$\overline{\Gamma}_{1,2} = \gamma^\mu P_R$$

$$D_{qq'} = V_{cb}^{*(R)} V_{cs}^{(R)} \frac{G_F^{(R)}}{\sqrt{2}}$$

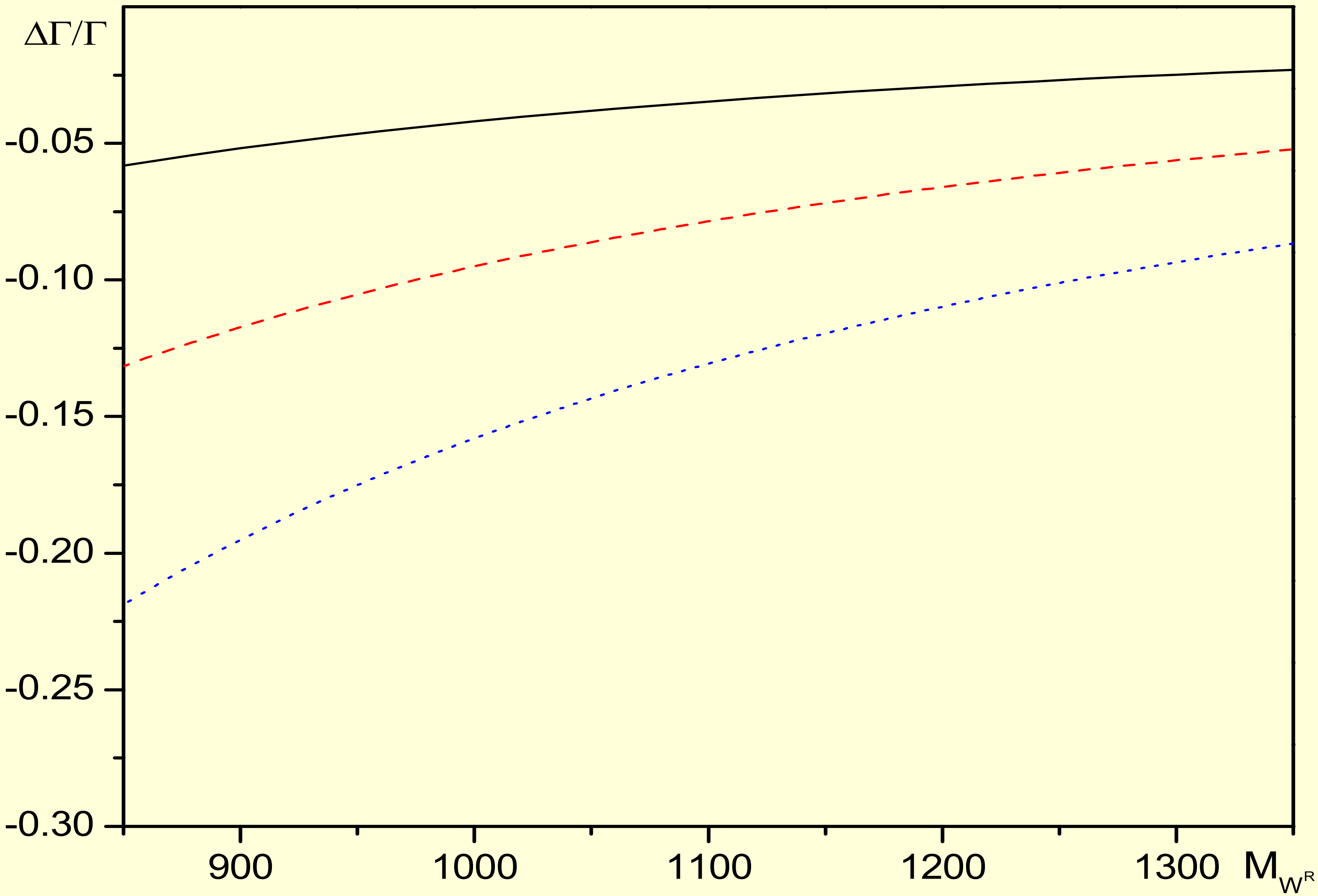
here $\frac{G_F^{(R)}}{\sqrt{2}} = g_R^2 / 8 M_{W^(R)}^2$ and for future calculations we take $g_L = k g_R$

One of possible realizations of such scenario which gives the biggest numerical value of $y_{LR}$ is a "Non-manifest LR" ($V_{ij}^{(R)} \approx 1$) with $M_{W^{(R)}} = 1\ TeV$ value of $y_{LR} \approx -0.04$ was obtained. In case of "manifest LR" (($V_{ij}^{(R)} = V_{ij}$)) contribution from this model is less.

Dependence of $y_{LR}$ on mass of $W^{(R)}$ boson. Solid line "Non manifest" case, dashed - "manifest"



Dependence of $\Delta\Gamma/\Gamma$ on $M_W^{(R)}$ in non-manifest LRSM. Solid line: $\kappa = 1$ dashed line: $\kappa = 1.5$, dotted line: $\kappa = 2$.



# Conclusions

- *The most precise theoretical prediction for Bs lifetime difference obtained. Corrections of the order of $1/m_b^2$ included and appeared to be small. Results are in good agreement with available experimental data*
- *We considered the most general four-fermion effective Hamiltonian, which can be generated by any reasonable extension of the Standard Model and derived its contribution to $\Gamma_{Bs}$*
- *Several models considered:*
  - *Multi Higgs Model can increase lifetime difference. Contribution from this model of NP is rather small. y = 0.006, compare to SM – y=0.10*
  - *Contribution from Left-Right Symmetric Model is rather large and negative :y= -0.04, compare to SM y = 0.10. Studies of mixing help to put constraints onto parameters of this model.*