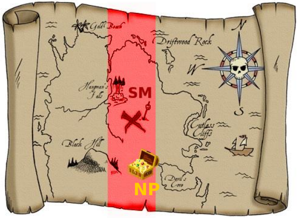
Theory overview of $B_{s,d} \to \mu^+\mu^-$ decays



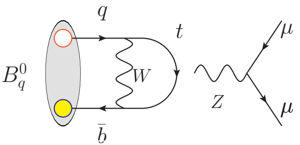
Rob Knegjens

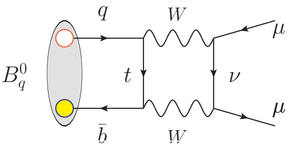
DIS 2014

Warsaw, 28 April - 2 May 2014

IAS TUM Institute for Advanced Study

$B_{d,s} \to \mu^+\mu^-$: promising probes of New Physics





$q = \{d, s\}$

Very suppressed in Standard Model:

- driven by electroweak loops (FCNCs)
- helicity suppressed

Two muon final state: **theoretically clean**

Effective theory description

$$\mathcal{H}_{\text{eff}} = -\frac{G_F\,\alpha}{\sqrt{2}\pi} V_{tb} V_{tq}^* \sum_i^{\{10,S,P\}} \left(\boldsymbol{C_i}\, \boldsymbol{\mathcal{O}_i} + \boldsymbol{C_i'}\, \boldsymbol{\mathcal{O}_i'} \right)$$

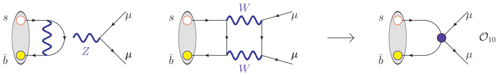
$$\boldsymbol{\mathcal{O}_{10}} = (\bar{q}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu\gamma_5\mu)$$
$$\boldsymbol{\mathcal{O}_S} = (\bar{q}P_R b)(\bar{\mu}\mu)$$
$$\boldsymbol{\mathcal{O}_P} = (\bar{q}P_R b)(\bar{\mu}\gamma_5\mu)$$
$$(P_L \leftrightarrow P_R \text{ for } \mathcal{O}')$$

Hadronic physics

$$\langle 0|\bar{q}\gamma_\mu\gamma_5 b|\overline{B}{}_q^0(p)\rangle = i p_\mu \boldsymbol{f_{B_q}}$$
$$\langle 0|\bar{q}\gamma_5 b|\overline{B}{}_q^0\rangle = -i\frac{M_{B_q}^2}{m_b + m_q} \boldsymbol{f_{B_q}}$$

$$\mathrm{BR}(B_q \to \mu^+\mu^-) = \frac{G_F^2\alpha^2 M_{B_q}}{4\pi^3}\sqrt{1 - 4\frac{m_\mu^2}{M_{B_q}^2}}\,|V_{tb}V_{tq}^*|^2 \tau_{B_q} \boldsymbol{f_{B_q}^2}$$
$$\times\; m_\mu^2 \left[\left| (\boldsymbol{C_{10}} - \boldsymbol{C_{10}'}) + \frac{m_{B_q}}{2m_\mu}(\boldsymbol{C_P} - \boldsymbol{C_P'}) \right|^2 + \left| \frac{m_{B_q}}{2m_\mu}(\boldsymbol{C_S} - \boldsymbol{C_S'}) \right|^2 \right]$$

Standard Model:
$\mathcal{O}_{10}$ dominant

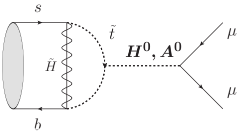


Particularly sensitive to (pseudo)scalar operators!

The MSSM with large tan β

$$H_1,\ H_2 \quad \xrightarrow{\text{SSB}} \quad h^0,\ H^0,\ A^0,\ H^\pm$$

$$\tan\beta \equiv \frac{v_u}{v_d}$$



For $\tan\beta \gg 1$
extra Higgses can decouple:
$M_h \ll M_{A^0} \approx M_{H^0} \approx M_{H^\pm}$

$$C_S \simeq -C_P \propto \frac{\tan^3\beta}{M_{A^0}^2}\frac{\mu A_t}{M_{\tilde{t}_L}^2}$$

Choudhury, Gaur;
hep-ph/9810307

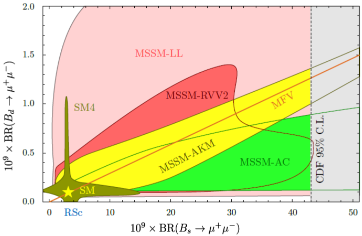
Large enhancements possible!

Minimal Flavour Violation relation:

$$\frac{\mathrm{BR}(B_s \to \mu^+\mu^-)}{\mathrm{BR}(B_d \to \mu^+\mu^-)} \simeq \left|\frac{V_{ts}}{V_{tb}}\right|^2 \frac{f_{B_s}^2}{f_{B_d}^2}\frac{\tau_{B_s}}{\tau_{B_d}}$$

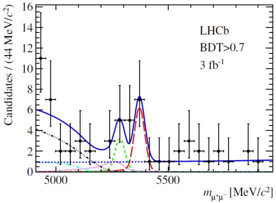
$$\approx 32$$

(and models with $U(2)^3$ symmetry)



Straub;
1012.3893

Experimental progress from the LHC



LHCb + CMS combined: 1307.5024, 1307.5025

$$\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9} \quad (> 5\sigma)$$

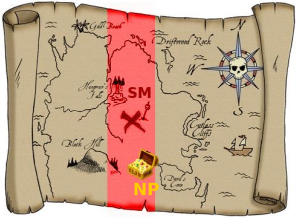
$$\overline{\mathrm{BR}}(B_d \to \mu^+\mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10} \quad (< 3\sigma)$$

SM predictions (pre-LHC):

$$\mathrm{BR}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (3.6 \pm 0.4) \times 10^{-9}$$

$$\mathrm{BR}(B_d \to \mu^+\mu^-)_{\mathrm{SM}} = (1.1 \pm 0.1) \times 10^{-10}$$

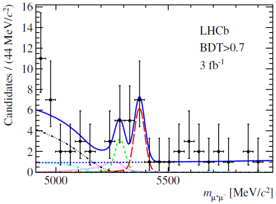
Buras; 0910.1032



No smoking gun signal of New Physics

Can we identify smallish New Physics?

Experimental progress from the LHC



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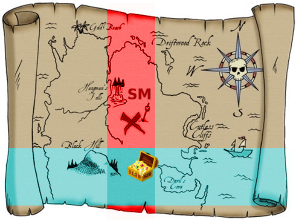
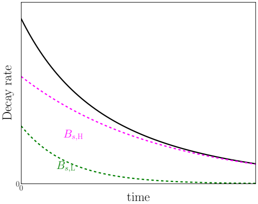
Buras; 0910.1032



No smoking gun signal of New Physics

Can we identify smallish New Physics?

Branching ratio definitions



Experiments integrate the untagged rate over time:

$$\overline{\mathrm{BR}}(B_q \to f) \equiv \frac{1}{2}\int dt \left[\Gamma(B_{q,\mathrm{H}} \to f)\, e^{-\Gamma^q_{\mathrm{H}} t} + \Gamma(B_{q,\mathrm{L}} \to f)\, e^{-\Gamma^q_{\mathrm{L}} t}\right] = \frac{1}{2}\left[\frac{\Gamma(B_{q,\mathrm{H}} \to f)}{\Gamma^q_{\mathrm{H}}} + \frac{\Gamma(B_{q,\mathrm{L}} \to f)}{\Gamma^q_{\mathrm{L}}}\right]$$

Whereas theory calculation in flavour basis:

$$\mathrm{BR}(B_q \to f) \equiv \frac{\frac{1}{2}\left(\Gamma(B^0_q \to f) + \Gamma(\bar{B}^0_q \to f)\right)}{\frac{1}{2}\left(\Gamma^q_{\mathrm{H}} + \Gamma^q_{\mathrm{L}}\right)} = \frac{1}{2}\left[\frac{\Gamma(B_{s,\mathrm{H}} \to f)}{\frac{1}{2}\left(\Gamma^q_{\mathrm{H}} + \Gamma^q_{\mathrm{L}}\right)} + \frac{\Gamma(B_{s,\mathrm{L}} \to f)}{\frac{1}{2}\left(\Gamma^q_{\mathrm{H}} + \Gamma^q_{\mathrm{L}}\right)}\right]$$

$\boldsymbol{y_s = \frac{\Gamma^s_{\mathrm{L}} - \Gamma^s_{\mathrm{H}}}{\Gamma^s_{\mathrm{L}} + \Gamma^s_{\mathrm{H}}}} = 0.075 \pm 0.012$ (1304.2600) $\therefore$ need a **dictionary**:

$$\boxed{\overline{\mathrm{BR}}(B_s \to f) = \mathrm{BR}(B_s \to f)\left[\frac{1 + y_s\, \mathcal{A}^f_{\Delta\Gamma}}{1 - y_s^2}\right]} \qquad \mathcal{A}^f_{\Delta\Gamma} = \frac{\Gamma(B_{s,\mathrm{H}} \to f) - \Gamma(B_{s,\mathrm{L}} \to f)}{\Gamma(B_{s,\mathrm{H}} \to f) + \Gamma(B_{s,\mathrm{L}} \to f)}$$

K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, N. Tuning, Phys.Rev.D 86 (2012)

$\boldsymbol{\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = +1}$: $\mathrm{BR}(B_s \to \mu^+\mu^-) \to \overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)$ **(↑ 8%)**

K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, A. Pellegrino, N. Tuning, Phys.Rev.Lett 109 (2012)

Perturbative corrections in SM

Perturbative loop corrections in SM

$$C_{10}^{\rm SM} = \frac{-1}{\sin^2\theta_W}\left[Y_0(x_t) + \frac{\alpha_s}{4\pi} Y_1^s(x_t) + \frac{\alpha_e}{4\pi} Y_1^e(x_t) + \left(\frac{\alpha_s}{4\pi}\right)^2 Y_2^s(x_t) + \ldots\right]$$

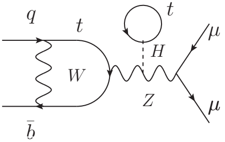
$$x_t = \frac{M_t^2}{M_W^2}$$

NLO QCD: Misiak, Urban; hep-ph/9901278, Buchalla, Buras; hep-ph/9901288

NLO EW in large m_t limit: Buchalla, Buras; hep-ph/9707243

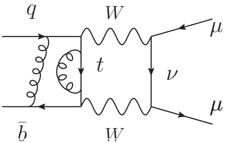
Recent progress:

NLO Electroweak



Bobeth, Gorbahn, Stamou; 1311.1348

NNLO QCD



Hermann, Misiak, Steinhauser; 1311.1347

(see talk of Mikolaj Misiak)

Branching ratio error budgets

$$\overline{\mathrm{BR}}(B_q \to \mu^+\mu^-) = \frac{G_F^4 M_W^4 M_{B_q} m_\mu^2}{2\pi^5} \sqrt{1 - 4\frac{m_\mu^2}{M_{B_q}^2}} |\tilde{C}_{10}^{\mathrm{SM}}(\mu_b)|^2 \frac{\tau_{B_q}}{1-y_q} f_{B_q}^2 |V_{tb} V_{tq}^*|^2$$

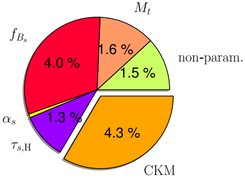
$$\tilde{C}_{10}^{\mathrm{SM}}(\mu_b) = 0.4690 \left[\frac{M_t}{173.1\,\mathrm{GeV}}\right]^{1.53} \left[\frac{\alpha_s(M_Z)}{0.1184}\right]^{-0.09}$$

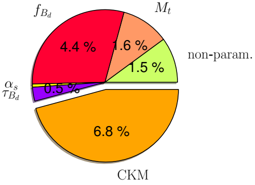
C.Bobeth,M.Gorbahn,T.Hermann,M.Misiak,E.Stamou,M.Steinhauser; 1311.0903

Lattice getting very precise:

$$f_{B_s} = 227.7 \pm 4.5 \text{ MeV}$$
$$f_{B_d} = 190.5 \pm 4.2 \text{ MeV}$$

(FLAG 2013)





Summed in quadrature: **6.4%**

$$\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (\mathbf{3.65 \pm 0.23}) \times \mathbf{10^{-9}}$$

Summed in quadrature: **8.5%**

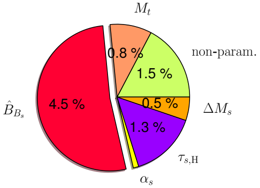
$$\overline{\mathrm{BR}}(B_d \to \mu^+\mu^-)_{\mathrm{SM}} = (\mathbf{1.06 \pm 0.09}) \times \mathbf{10^{-10}}$$

Alternative error budgets

$$\Delta M_q = \frac{G_F^2 M_W^2}{6\pi^2} \eta_B M_{B_q} \hat{B}_{B_q} \boldsymbol{f_{B_q}^2} |\boldsymbol{V_{tb}^* V_{tq}}|^2 S(x_t)$$

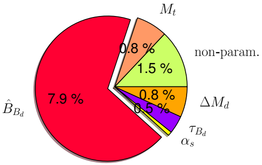
$$\mathrm{BR}(B_q \to \mu^+\mu^-) = \frac{3(G_F^2 M_W m_\mu)^2 \tau_{B_q}}{4\pi^3} \frac{\eta_Y^2 Y^2(x_t)}{\eta_B S(x_t)} \frac{\boldsymbol{\Delta M_q}}{\boldsymbol{\hat{B}_{B_q}}}$$

Buras; hep-ph/0303060



Summed in quadrature: **5.1%**

$\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (\mathbf{3.53 \pm 0.18}) \times \mathbf{10^{-9}}$



Summed in quadrature: **8.8%**

$\overline{\mathrm{BR}}(B_d \to \mu^+\mu^-)_{\mathrm{SM}} = (\mathbf{1.00 \pm 0.09}) \times \mathbf{10^{-10}}$

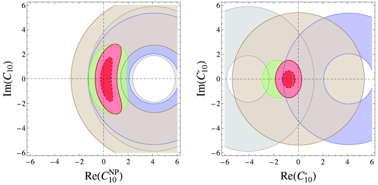
Constraining New Physics with $\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)$

$$\overline{R} \equiv \frac{\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)}{\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)_{\mathrm{SM}}}, \qquad \boxed{\overline{R}_{\mathrm{exp}} = 0.79 \pm 0.20, \qquad \overline{R}_{\mathrm{SM}} = 1}$$

$$\mathrm{BR}(B_s \to \mu^+\mu^-) \propto m_\mu^2 \left[\left| (C_{10} - C'_{10}) + \frac{m_{B_s}}{2m_\mu}(C_P - C'_P) \right|^2 + \left| \frac{m_{B_s}}{2m_\mu}(C_S - C'_S) \right|^2 \right]$$

NP contributions to $C_{10}^{(\prime)}$: Z' models, modified Z couplings, ...

(See for example Buras, Fazio, Girrbach; 1211.1896, Straub; 1302.4651, Guadagnoli, Isidori; 1302.3909)



$B_s \to \mu^+\mu^-$, $B_d \to X_s \ell^+\ell^-$, $B_d \to K\mu^+\mu^-$, $B_d \to K^*\mu^+\mu^-$, 1,2 σ fit

Altmannshofer, Straub; 1206.0273, 1305.5704

Most stringent constraints on $C_{10}^{(\prime)}$ from $B_d \to K^*\mu^+\mu^-$

Recent fit of $b \to s\ell^+\ell^-$ observables:

Beaujean, Bobeth, van Dyk; 1310.2478

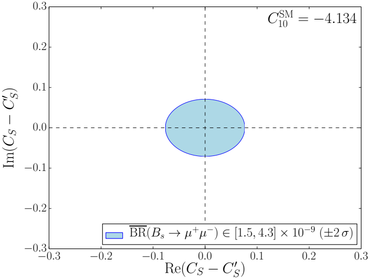
(see talk of Danny van Dyk)

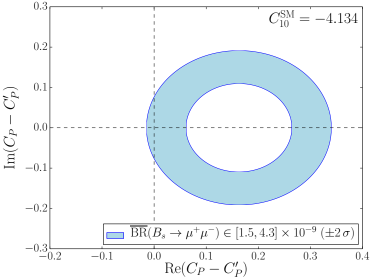
Constraining New Physics with $\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)$

$$\overline{R} \equiv \frac{\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)}{\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)_{\mathrm{SM}}}, \qquad \boxed{\overline{R}_{\exp} = 0.79 \pm 0.20, \qquad \overline{R}_{\mathrm{SM}} = 1}$$

$$\mathrm{BR}(B_s \to \mu^+\mu^-) \propto m_\mu^2 \left[\left| (C_{10} - C'_{10}) + \frac{m_{B_s}}{2m_\mu}(\boldsymbol{C_P} - \boldsymbol{C'_P}) \right|^2 + \left| \frac{m_{B_s}}{2m_\mu}(\boldsymbol{C_S} - \boldsymbol{C'_S}) \right|^2 \right]$$

Best bounds on scalar operators $\boldsymbol{C_S - C'_S}$ and $\boldsymbol{C_P - C'_P}$:



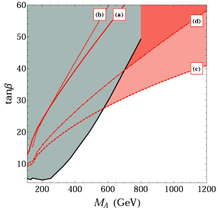


$C_S + C'_S$ and $C_P + C'_P$ to be probed by $B \to K\mu^+\mu^-$

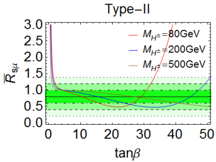
(Becirevic, Kosnik, Mescia, Schneider; 1205.5811)

$\overline{\mathrm{BR}}(B_s \to \mu^+\mu^-)$ constraints on 2HDMs

$$\mathrm{BR}(B_s \to \mu^+\mu^-) \propto m_\mu^2 \left[\left| (C_{10} - C'_{10}) + \frac{m_{B_s}}{2m_\mu}(C_P - C'_P) \right|^2 + \left| \frac{m_{B_s}}{2m_\mu}(C_S - C'_S) \right|^2 \right]$$



Altmannshofer, Carena, Shah, Yu; 1211.1976, 1306.0022



Li, Lu, Pich; 1404.5865

MSSM (Higgsino loop):

$$C_S \simeq -C_P \propto \frac{\tan^3\beta}{M_{A^0}^2} \frac{\mu A_t}{M_{\tilde{t}_L}^2} \quad (\mathrm{MFV})$$

Constructive inteference ($\mu A_t < 0$) more constrained than destructive ($\mu A_t > 0$)

($\tilde{M}_q = 2$ TeV, $\{\mu, A_t\} \sim 1$ TeV)

Type-II 2HDM (non-supersymmetric):

$$C_S \simeq -C_P \propto \frac{\tan^2\beta}{M_{A^0}^2} \quad (\mathrm{MFV})$$

and interferes destructively

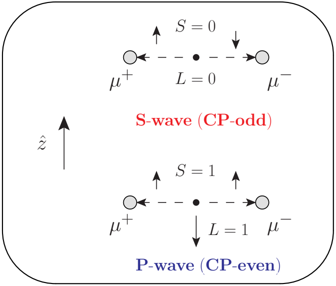
Additional observables desirable!

Decays of the B_s **mass-eigenstates** to two muons

$$\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu\gamma_5\mu)$$
$$\mathcal{O}_{\mathcal{S}} = (\bar{s}P_R b)(\bar{\mu}\mu)$$
$$\mathcal{O}_{\mathcal{P}} = (\bar{s}P_R b)(\bar{\mu}\gamma_5\mu) \qquad (P_L \leftrightarrow P_R \text{ for } \mathcal{O}')$$

$$\boldsymbol{P} \equiv \frac{C_{10}-C'_{10}}{C_{10}^{\rm SM}} + \frac{m_{B_s}}{2\,m_\mu}\left(\frac{C_P-C'_P}{C_{10}^{\rm SM}}\right) \xrightarrow{\rm SM} 1$$

$$\boldsymbol{S} \equiv \sqrt{1-\frac{4\,m_\mu^2}{m_{B_s}^2}}\,\frac{m_{B_s}}{2\,m_\mu}\left(\frac{C_S-C'_S}{C_{10}^{\rm SM}}\right) \xrightarrow{\rm SM} 0$$



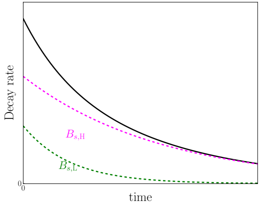
CPV phases cancel in SM:

$$\left|B_{s,\binom{\rm H}{\rm L}}\right\rangle = \frac{1}{\sqrt{2}}\left(|B_s^0\rangle \mp e^{-i\phi_s}|\overline{B}_s^0\rangle\right) \quad \textbf{vs} \quad \langle\mu^+\mu^-|\mathcal{H}_{\rm eff}|\overline{B}_s^0\rangle \propto e^{i\phi_s/2}$$

$$\Gamma(\boldsymbol{B}_{s,\rm L}\to\mu^+\mu^-) \propto |\boldsymbol{P}|^2 \underbrace{\sin^2(\varphi_{\boldsymbol{P}} - \phi_s^{\rm NP}/2)}_{\text{new CP phases}} + \underbrace{|\boldsymbol{S}|^2\cos^2(\varphi_{\boldsymbol{S}} - \phi_s^{\rm NP}/2)}_{\text{scalar operators}}$$

B_s mass-eigenstate rate asymmetry

Probe $\boldsymbol{\Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-)}$ with time-dependent untagged rate:

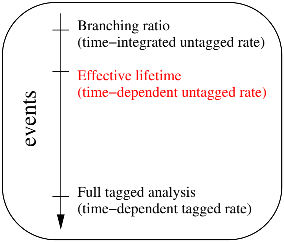


$$\langle \Gamma_{\mu\mu} \rangle \propto e^{-t/\tau_{B_s}} \left\{ \cosh\left(y_s\, t/\tau_{B_s} \right) + \mathcal{A}^{\mu\mu}_{\Delta\Gamma} \sinh\left(y_s\, t/\tau_{B_s} \right) \right\}$$

$$\mathcal{A}^{\mu\mu}_{\Delta\Gamma} \equiv \frac{\Gamma(B_{s,\mathrm{H}} \to \mu^+\mu^-) - \Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-)}{\Gamma(B_{s,\mathrm{H}} \to \mu^+\mu^-) + \Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-)}$$

Single exponential fit $\frac{1}{\tau_{\mathrm{eff}}} e^{-t/\tau_{\mathrm{eff}}}$ gives "effective lifetime":

$$\tau_{\mathrm{eff}} = \frac{\int_0^\infty t\, \langle \Gamma_{\mu\mu} \rangle\, dt}{\int_0^\infty \langle \Gamma_{\mu\mu} \rangle\, dt} = \frac{\tau_{B_s}}{1 - {y_s}^2} \left(\frac{1 + 2\,\mathcal{A}^{\mu\mu}_{\Delta\Gamma}\, y_s + {y_s}^2}{1 + \mathcal{A}^{\mu\mu}_{\Delta\Gamma}\, y_s} \right)$$

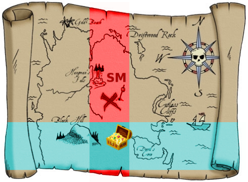


Experimental feasability?

$\sim$ 350 reconst. events expected @LHCb for 50 fb^{-1}

$\Longrightarrow$ $\sim$ 5% uncertainy on effective lifetime

$B_s \to \mu^+\mu^-$ untagged observables



$$\overline{R} = \frac{(1 + y_s\,\mathcal{A}^{\mu\mu}_{\Delta\Gamma})}{1 + y_s}\left(|\boldsymbol{P}|^2 + |\boldsymbol{S}|^2\right)$$

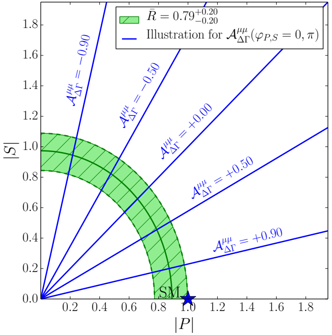
$$\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = \frac{|\boldsymbol{P}|^2 \cos\left(2\varphi_{\boldsymbol{P}} - \phi_s^{\rm NP}\right) - |\boldsymbol{S}|^2 \cos\left(2\varphi_{\boldsymbol{S}} - \phi_s^{\rm NP}\right)}{|\boldsymbol{P}|^2 + |\boldsymbol{S}|^2}$$

K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, A. Pellegrino, N. Tuning, Phys.Rev.Lett 109 (2012)

Solvable scenarios:

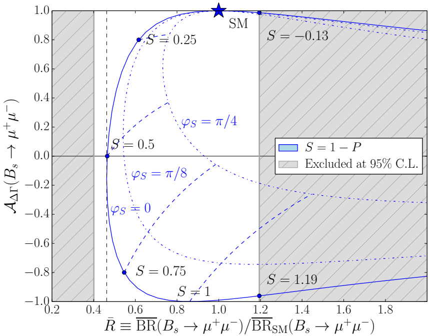
- $|\boldsymbol{P}|$, $\varphi_{\boldsymbol{P}}$ free ($\boldsymbol{S} = 0$)
- $|\boldsymbol{S}|$, $\varphi_{\boldsymbol{S}}$ free ($\boldsymbol{P} = 1$)
- $\boldsymbol{S} = \pm[1 - \boldsymbol{P}]$
- $\varphi_{\boldsymbol{P}} = \varphi_{\boldsymbol{S}} = 0$: $\longrightarrow$

A.J. Buras, R. Fleischer, J. Girrbach, RK; JHEP 1307 (2013) 77



New scalar and pseudoscalar operators on same footing

$\boldsymbol{S = \pm(1 - P)}$ - realised for $\boxed{C_S^{(\prime)} = \pm C_P^{(\prime)}}$ (decoupled 2HDMs)

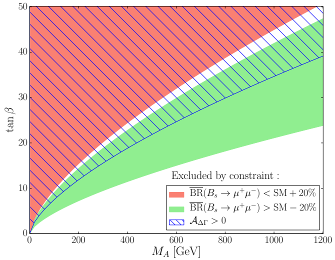


- Full range of $\mathcal{A}_{\Delta\Gamma}^{\mu\mu}$ without CP violating phases
- Lower bound $\overline{R} \geq (1 - y_s)/2$

E.g. MSSM with large $\tan\beta$

$$C_S \simeq -C_P \propto \frac{\tan^3\beta}{M_A^2}\frac{\mu A_t}{M_{\tilde{t}_L}^2} \quad \text{(MFV)}$$

Loose bound on $\mathcal{A}_{\Delta\Gamma}$ can rule out "large $\tan\beta$" allowed regions:

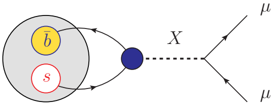


Example of destructive interference scenario

Generic models in the $\overline{R}$-$\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$ parameter space

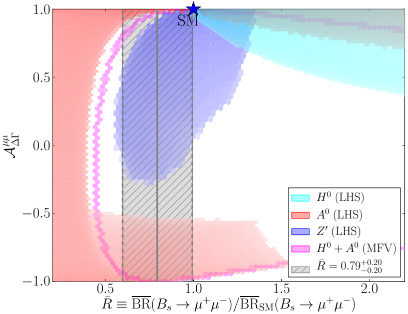
$$X \in \{ \quad Z', \quad H^0, \quad A^0, \quad H^0 + A^0 \quad \},$$

$$M_X = 1\,\mathrm{TeV}$$



- B_s mixing (ΔM_s, ϕ_s) constrains quark couplings
- Lepton couplings left free (no CPV)
- Z' includes combined $b \to s\ell\ell$ constraints on C_{10}

W.Altmannshofer, D.Straub; 1206.0273

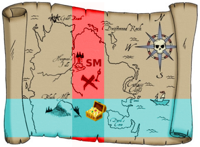


A.J. Buras, R. Fleischer, J. Girrbach, RK, JHEP 1307 (2013) 77

A.J. Buras, F. De Fazio, J. Girrbach, RK, M. Nagai, JHEP 1306 (2013) 111

Summary

- LHC branching ratio measurements reveal no smoking gun signal of NP
- Sensitivity to smallish NP demands precision in theory predictions
- Good progress: NLO EW, NNLO QCD, precise decay constants from lattice
- Effective lifetime of $B_s \to \mu^+\mu^-$ complements branching ratio for identifying NP
- $B_d \to \mu^+\mu^-$ could still surprise us!

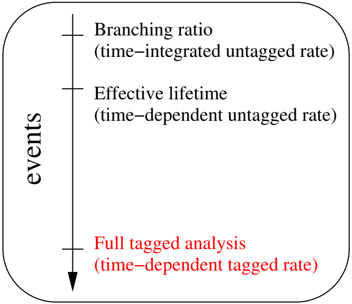


Backup slides

$B_s \to \mu^+\mu^-$ tagged analysis

Eventually also tagged measurement:

$$\frac{\Gamma(B_s^0(t) \to \mu^+\mu^-) - \Gamma(\bar{B}_s^0(t) \to \mu^+\mu^-)}{\Gamma(B_s^0(t) \to \mu^+\mu^-) + \Gamma(\bar{B}_s^0(t) \to \mu^+\mu^-)} = \frac{\boldsymbol{\mathcal{S}_{\mu\mu}} \sin(\Delta M_s t)}{\cosh(y_s t/\tau_{B_s}) + \boldsymbol{\mathcal{A}^{\mu\mu}_{\Delta\Gamma}} \sinh(y_s t/\tau_{B_s})}.$$



- $\mathcal{S}_{\mu\mu}$ **indepedent** if scalar operators:

$$|\boldsymbol{\mathcal{A}^{\mu\mu}_{\Delta\Gamma}}|^2 + |\boldsymbol{\mathcal{S}_{\mu\mu}}|^2 = 1 - \left[\frac{2|P||S|\cos(\varphi_P - \varphi_S)}{|P|^2 + |S|^2}\right]^2$$

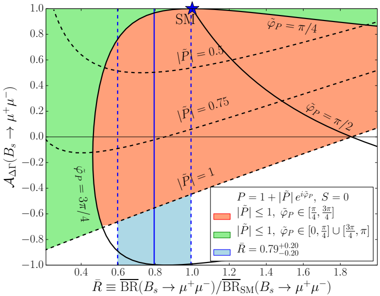
- $\mathcal{S}_{\mu\mu}$ sensitive to small CP phases:

$$\boldsymbol{\mathcal{S}_{\mu\mu}} = \frac{|P|^2 \sin(2\varphi_P - \phi_s^{\rm NP}) - |S|^2 \sin(2\varphi_S - \phi_s^{\rm NP})}{|P|^2 + |S|^2}$$

No scalar operators || only new scalar operators

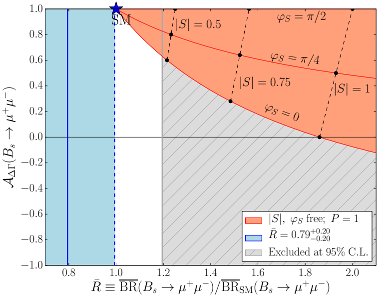
$$\Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-) \propto |P|^2 \underbrace{\sin^2(\varphi_P - \phi_s^{\mathrm{NP}}/2)}_{\text{scenario A}} + \underbrace{|S|^2 \cos^2(\varphi_S - \phi_s^{\mathrm{NP}}/2)}_{\text{scenario B}}$$

Scenario A: $S = 0$



E.g: CMFV, Z' Models, A^0 dominant (2HDM)

Scenario B: $S \neq 0$ ($P = 1$)



E.g: H^0 dominant (2HDM)

Fitting an effective lifetime

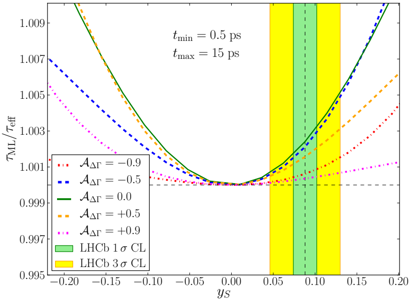
$$f_{\rm true}(t) \equiv \frac{A(t)\,\langle\Gamma(t)\rangle}{\int_0^\infty A(t)\,\langle\Gamma(t)\rangle\,dt}, \qquad f_{\rm fit}(t;\tau) \equiv \frac{A(t)\,e^{-t/\tau}}{\int_0^\infty A(t)\,e^{-t/\tau}\,dt}$$

Minimise : $$-\log L(\tau) = -n\int_0^\infty dt\ f_{\rm true}(t)\log\left[f_{\rm fit}(t;\tau)\right]$$

$$\frac{\int_0^\infty t\,A(t)e^{-t/\tau}\,dt}{\int_0^\infty A(t)e^{-t/\tau}\,dt} = \frac{\int_0^\infty t\,A(t)\langle\Gamma(t)\rangle dt}{\int_0^\infty A(t)\langle\Gamma(t)\rangle dt}$$

Limit that $A(t) = 1$:

$$\tau = \frac{\int_0^\infty t\,\langle\Gamma(t)\rangle dt}{\int_0^\infty \langle\Gamma(t)\rangle dt} \equiv \tau_{\rm eff},$$

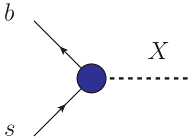


Compatibility with B_s mixing constraints

Consider generic models:

$$X \in \{ \quad \boldsymbol{Z'}, \quad \boldsymbol{H^0}, \quad \boldsymbol{A^0}, \quad \boldsymbol{H^0 + A^0} \quad \},$$

$$M_X = 1\,\mathrm{TeV}$$



$$\mathcal{L}_{\mathsf{FCNC}}(Z') = \left[\Delta_L^{sb}(Z')\,\bar{s}\gamma_\mu P_L b + \Delta_R^{sb}(Z')\,\bar{s}\gamma_\mu P_R b\right] Z'^{\mu}$$

$$\mathcal{L}_{\mathsf{FCNC}}(H) = \left[\Delta_L^{sb}(H)\,\bar{s} P_L b + \Delta_R^{sb}(H)\,\bar{s} P_R b\right] H$$

A.J. Buras, F. De Fazio, J. Girrbach, JHEP 1302 (2013) 116

A.J. Buras, F. De Fazio, J. Girrbach, RK, M. Nagai, JHEP 1306 (2013) 111

Including $\Delta F = 2$ NLO corrections: *A.J. Buras, J. Girrbach, JHEP 1203 (2012) 052*

- Apply B_s mixing constraints:

$$\Delta M_s \in \Delta M_{s,\mathrm{exp}}^{\mathrm{cent.\ val.}} \pm 5\%, \qquad \phi_s \in \phi_{s,\mathrm{exp}}^{\mathrm{cent.\ val.}} \pm 2\,\sigma$$