ΔMs interplay with B-anomalies

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Luca Di Luzio

In collaboration with Matthew Kirk and Alexander Lenz $arXiv:1712.06572 + work in progress$

Outline

- $1. \Delta M_s$ in the SM [theoretical uncertainties]
	- Hadronic Matrix Element
	- $\bullet\,$ V_{cb} dependence
- 2. Impact on B-anomalies
	- Neutral currents [Z', LQ]
	- Model building directions

ΔMs in the SM

L. Di Luzio (IPPP, Durham) - ΔMs interplay with B-anomalies 02/14

$F(A \cup B \cup C)$ is the transition between B **B** B are prediction (ingredients is denoted by *M^s* SM prediction [ingredients] The mass of the mass of the mass of the mass eigenstates of the mass eigenstates of the mass eigenstates of the \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} cussion because of the distribution of the distribution of the distribution of the exact of the exact of the e size of the hadronic contributions (see e.g. [24–30]). Esti-*M^s* ⌘ *^M^s* T calculation of the box diagrams in T

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operator arises

tsVtb. The CKM elements are the only place in Eq. (2)

well until recently. The most recent FLAG average of lattice results for the non-perturbative matrix for the nonelements points, however, in the direction of a small discrepancy in this observable. Using up-to-SM prediction [ingredients] **B** B are prediction (ingredients is denoted by *M^s* \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} cussion because of the distribution of the distribution of the distribution of the exact of the exact of the e size of the hadronic contributions (see e.g. [24–30]). Esti-*M^s* ⌘ *^M^s* T calculation of the box diagrams in T The mass of the mass of the mass of the mass eigenstates of the mass eigenstates of the mass eigenstates of the

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size of the hadronic contributions (see e.g. [24–30]). Esti-

***** Inami-Lim function $S_0(x_t = \bar{m}_t^2(\bar{m}_t)/M_W^2) \approx 2.368$ [Inami, Lin \bigstar lnami-l or [66]. Taking, however, the most recent lattice inputs, with the G ($-2(1)111$), $-2(0)111$ M **ICLIOH** $\mathcal{D}_0(x_t = m_t(m_t)/M_W) \approx 2.508$ [Indini, Limit Linos (1701)] performal $S_0 (x_t = \bar{m}_t^2(\bar{m}_t)/M_{W}^2) \approx 2.368$ [Ina mediately leads to tree-level contributions to *Bs*-mixing, \blacktriangleright IIIdHI-LIIII RICLOH \varnothing $(\vartheta_t - m_t(m_t)/m_W)$

[Inami, Lim PTR65 (1981)] SM value for *M^s* lm P

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[Buras, Jamin, Weisz NPB347 (1990)] discussion of the theoretical uncertainties. $\hat{\eta}_B \approx 0.8379$ [Buras, Jamin, Weisz NPB347 (1990)]

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The calculation of the box diagrams in Fig. 1 gives the

tive contributions to *Bs*-mixing. The new value for the

SM prediction [ingredients] Luca Di Luzio,1, ⇤ Matthew Kirk,1, *†* and Alexander Lenz1, *‡* ¹*Institute for Particle Physics Phenomenology, Department of Physics, Durham University, DH1 3LE, Durham, United Kingdom* well until recently. The most recent FLAG average of lattice results for the non-perturbative matrix for the nonelements points, however, in the direction of a small discrepancy in this observable. Using up-todate inputs from standard sources such as PDG, FLAG and one of the two leading CKM fitting $F(A \cup B \cup C)$ is the transition between B **B** B are prediction (ingredients is denoted by *M^s* ¹². \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} cussion because of the distribution of the distribution of the distribution of the exact of the exact of the e size of the hadronic contributions (see e.g. [24–30]). Esti-*M^s* ⌘ *^M^s* T calculation of the box diagrams in T The mass of the mass of the mass of the mass eigenstates of the mass eigenstates of the mass eigenstates of the

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 Imi -l im function $S_0(r_i = \bar{m}_i^2(\bar{m}_i)/M_{\rm irr}^2) \approx 2.368$ ario Lorrente $p_{0} = \bar{m}^{2}(\bar{m}_{1})/M_{\text{int}}^{2} \approx 2.368$ \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} ***** Inami-Lim function $S_0(x_t = \bar{m}_t^2(\bar{m}_t)/M_W^2) \approx 2.368$ \bigstar lnami-l or [66]. Taking, however, the most recent lattice inputs, westime G $\begin{pmatrix} -2 & -1 & 1 & 1 & 1 \end{pmatrix}$ M **ICLION** $\mathcal{D}_0(x_t = m_t(m_t)/M_W) \approx 2.508$ p function $S_0 (x_t = \bar{m}_t^2(\bar{m}_t)/M_{W}^2) \approx 2.368$ mediately leads to tree-level contributions to *Bs*-mixing, \blacktriangleright IIIdHI-LIIII RICLOH \varnothing $(\vartheta_t - m_t(m_t)/m_W)$

- $\hat{\eta}_B \approx 0.8379$ *i*ve NLO QCD corrections $\hat{\eta}_B \approx 0.8379$ D corrections $\hat{\eta}_B$ $\overline{}$ ≈ 0.837 *B*(*µ*)*,* (6) tive NI O OCD corrections $\hat{n}_P \approx 0.8379$ have so far shown no discrepancies from the Standard Standar \star Perturbative NLO QCD corrections $\hat{\eta}_B \approx 0.8379$ \hat{w} NIM \cap \cap consections \hat{w} \sim 0.9270 S and S value for the mass of M \approx 0.0010 ★ Perturbative NLO QCD corrections $\hat{\eta}_B \approx 0.8379$ In the SM calculation of *M^s*
- The hadronic matrix element of this operator is operator in this operator is operator is operator in this operator is adronic matrix element (Lattice / HQET Sum R *S*0(*x^t* = ¯*m*² We also indicated the renormalisation scale dependence of the bag parameter; in our analysis we take *µ* = $\frac{1}{\sqrt{2}}$ (SM), while we have an intriguing list of deviation of deviation of deviation of deviation $\frac{1}{\sqrt{2}}$ t firative constructions and the term t for t flavour t flavour t flavour t \star Hadroi * Hadronic matrix element (Lattice / HQET Sum Rules) Andreas Kronfeld, Ai

[See talks by referred in Andreas Kronfeld, Aida El-Khadra,)
Thomas Mannel Thomas Raubl \ldots is 1.8 \ldots is 1.8 \ldots is 1.8 \ldots is 1.8 \ldots . considerably above the measurement. In this paper we a, $\frac{1}{2}$ by the non-perturbative on $\frac{1}{2}$ INDITERE THE LITNICE Γ and by one of the Thomas Mannel, Thomas Rauh] ables. In particular *^b* ! *^s*`⁺` transitions seem to be d II. *Bs*-MIXING IN THE SM *v v v v t the corrections are the only place in Eq. (3) [See talks by* Andreas Kronfeld, Aida El-Khadra, ity one finds only one contributing CKM structure *^t* = *^Q* = ¯*s*↵*µ*(1 5)*b*↵ ⇥ *^s*¯*^µ*(1 5)*b .* (4) Thomas Mannel, Thomas Rauh]

groups (CKMfitter) – see Appendix C and Appendix D and Appendix D and Appendix D and Appendix D and Appendix D

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\langle B_s^0 | Q | \bar{B}_s^0 \rangle = \frac{8}{3} M_{B_s}^2 f_{B_s}^2 B(\mu) \qquad Q = \left[\bar{s} \gamma_\mu (1 - \gamma_5) b \right] \left[\bar{s} \gamma^\mu (1 - \gamma_5) b \right]
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 \hat{p} $D = n \hat{D}$ (Dbat reperpendization scale and schame independent) are and sending independently renormalization scale and scheme independent) $\hspace{0.1mm}$ $\hat{\eta}_B B \equiv \eta_B \hat{B}$ renorma ↵*s*(*µ*) $-$ u $$ n scal<mark>(</mark> $\hat{\eta}_B B \equiv \eta_B \hat{B}$ (Bhat renormalization scale and scheme independent) III. *Bs*-MIXING BEYOND THE SM a negative, beyond the SM (BSM) contribution to *C*⁹ *M^s* ⌘ *^M^s* In the SM calculation of *M* ¹² one four quark *B* = 2 λ \mathcal{L}_c are corrections are corrections are compressed in the compressed in the corrections are compressed in the compression of \mathcal{L}_c ^h*Q*i⌘h*B*⁰ *^s [|]Q|B*¯⁰ SC *M*² *^B^s f* ² *B*(*µ*)*,* (5)

ables. In particular *^b* ! *^s*`⁺` transitions seem to be

operator arises

with the Fermi constant *G^F* , the masses of the *W* boson,

tsVtb. The CKM elements are the only place in Eq. (2)

and the bag parameter is used in the bag parameter is used in the literature (e.g. by α

size of the hadronic contributions (see e.g. [24–30]). Esti-

The calculation of the box diagrams in Fig. 1 gives the

tive contributions to *Bs*-mixing. The new value for the

SM prediction [ingredients] Ingredients i well until recently. The most recent FLAG average of lattice results for the non-perturbative matrix for the nonelements points, however, in the direction of a small discrepancy in this observable. Using up-todate inputs from standard sources such as PDG, FLAG and one of the two leading CKM fitting $F(A \cup B \cup C)$ is the transition between B **B** B are prediction (ingredients is denoted by *M^s* \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} \int_{0}^{1} cussion because of the distribution of the distribution of the distribution of the exact of the exact of the e size of the hadronic contributions (see e.g. [24–30]). Esti-*M^s* ⌘ *^M^s* T calculation of the box diagrams in T The mass of the mass of the mass of the mass eigenstates of the mass eigenstates of the mass eigenstates of the $\overline{}$

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Many new physics models that explain the intriguing anomalies in the *b*-quark flavour sector are pers in versigation in the Library. And I
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Library of a model in the particles in the particle in the *beva* in the library in the *box* in the *box mew* in see Lenz. Nierste hep-ph/0612167 Artuso, Borissov, Lenz 1511.09466] [For a review see Lenz, Nierste hep-ph/0612167
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\begin{array}{ccc}\n\mathbf{w} & \mathbf{s} & \mathbf{b} & \mathbf{t}.\mathbf{c},\mathbf{u} \\
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★ Inami-Lim function $S_0(x_t = \bar{m}_t^2(\bar{m}_t)/M_W^2) \approx 2.368$ on the *Z*⁰ mass approaches dangerously close to the energy scales already probed by the LHC. We \bigstar lnami-l or [66]. Taking, however, the most recent lattice inputs, westime G $\begin{pmatrix} -2 & -1 & 1 & 1 & 1 \end{pmatrix}$ M **ICLION** $\mathcal{D}_0(x_t = m_t(m_t)/M_W) \approx 2.508$ p function $S_0 (x_t = \bar{m}_t^2(\bar{m}_t)/M_{W}^2) \approx 2.368$ mediately leads to tree-level contributions to *Bs*-mixing, \blacktriangleright IIIdHI-LIIII RICLOH \varnothing $(\vartheta_t - m_t(m_t)/m_W)$ groups to determine *M*SM leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound

- five NII O OCD corrections $\hat{n}_B \approx 0.8379$ $h(x)$ so far shown no discrepancies from the Standard $h(x)$ \star Perturbative NLO QCD corrections $\hat{\eta}_B \approx 0.8379$ $V = V \cup V$ $V = V \cup V$ equivalents are the only place in V \hat{w} NIM \cap \cap consections \hat{w} \sim 0.9270 S and S value for the mass of M \approx 0.0010 \star P_6 finally identify some model building directions in order to alleviate the tension with *Bs*-mixing.
- t (Lattice / HQET Sum \sim motion element (Lattice / \Box tions between the theory for flattice theory for flavour $\frac{1}{2}$ ★ Hadronic matrix element (Lattice / HQET Su * Hadronic matrix element (Lattice / HQET Sum Rules) 1-loop diagrams given in Fig. 1 is denoted by the Inami-

̣ CKM elements ables. In particular *^b* ! *^s*`⁺` transitions seem to be in tension with the SM expectations: branching ratios \mathcal{L} and \mathcal{L} ratios \mathcal{L} ratios \mathcal{L} ratios \mathcal{L} ratios \mathcal{L} and \mathcal{L} ratios \mathcal{L} ratios \mathcal{L} ratios \mathcal{L} ratios \mathcal{L} ratio investigate the drastic consequences of this new theory \star CKM e Lim function [67] *S*0(*x^t* = (¯*mt*(¯*mt*))²*/M*² in particular the new average provided by the Flavour Lattice Averaging Group (FLAG) one gets a SM value \mathbf{C}

$$
\lambda_t \equiv V_{ts}^* V_{tb} \qquad \qquad V_{us} \quad V_{cb} \quad |V_{ub}/V_{cb}| \quad \gamma_{\text{CKM}}
$$

bs =

4

^p2*GFM*²

size of the hadronic contributions (see e.g. [24–30]). Esti-

W (*NOL Necessarily tr* in terms of 4 inputs, assuming CKM unitarity
(not pecessarily true in presence of NIP) (not necessarily true in presence of NP) investigate the drastic consequences of this new theory a negative, beyond the SM (BSM) contribution to *C*⁹ \overline{a} (not necessarily true in presence of NP) prediction. In Section II we review the SM prediction of factor ˆ⌘*^B* ⇡ 0*.*83798, they have been calculated by [69]. *CLL* \cdot *Q ts* !2

VtbV ⇤

operator arises

tsVtb. The CKM elements are the only place in Eq. (2)

The calculation of the box diagrams in Fig. 1 gives the

tive contributions to *Bs*-mixing. The new value for the

Hadronic matrix element [Lattice]

[November 2017 web-update of Flavour Lattice Averaging Group (FLAG) 1607.00299]

S. Aoki et al., Review of lattice results concerning low-energy particle physics, 1607.00299

⊙ PDG averages of decay constant f_{B0} and f_{B_s} [2] are used to obtain these values.

 $\mathcal{L}_\mathcal{B}$ at $\mathcal{L}_\mathcal{B}$ at $\mathcal{L}_\mathcal{B}$ at $\mathcal{L}_\mathcal{B}$ by multiplying the 2-loop factor 1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521.1.521

\Box Poggia averages of decay constant f † Reported f ² ^BB at µ = m^b is converted to RGI by multiplying the 2-loop factor 1.517. \Box Tuuri vincluded in the r $T_{\rm obs}$ status of lattice-decay computations for \sim breaking ratio, using and the summarized ensembles with light density relations, in the summarized in the summariz $\frac{1}{2}$ and $\frac{1}{2}$ \pm pois constant fbotain ϵ Γ Γ Γ \times Θ is converted to Γ . The 2-loop Γ UTIX CICITIONS E [∗] This result uses an old determination of r¹ = 0.321(5) fm from Ref. [28] that has since been superseded. One constraint to kill them all? Luca Di Luzio,1, ⇤ Matthew Kirk,1, *†* and Alexander Lenz1, *‡ Durham University, DH1 3LE, Durham, United Kingdom* Hadronic matrix element [Lattice]

[November 2017 web-update of Flavour Lattice Averaging Group (FLAG) 1607.00299] ¹*Institute for Particle Physics Phenomenology, Department of Physics, D*-update of Flavour Lattice Averaging Group (FLAG) T607.00277] \sim 1/07 002001 $\left(\bigcup_{i=1}^n \{1, 0, 0, 1\} \right)$ in the discrepancy in this observable. Using up-to-[November 2017 web-update of Flavour Lattice Averaging Group (FLAG) 1607.00299]

$$
\left(f_{B_s}\sqrt{\hat{B}_{B_s}}\right)^{\text{FLAG17}} = 274(8) \text{ MeV} \qquad (f_{B_s})^{\text{FLAG16}} \left(\sqrt{\hat{B}_{B_s}}\right)^{\text{FLAG17}} = 265(10) \text{ MeV}^*
$$

HMC [33] algorithm. There are three choices of lattice spacing, 0.048, 0.065 and 0.075 fm, in the combination (does not include updated from the calcula $\frac{1}{2}$ $\frac{1}{2}$ *Naive combination (does not include updated FNAL/MILC calculation of decay constant)

L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies 04/14

 \sim was in perfect agreement with experiment, see e.g. \sim

^t (¯*mt*)*/M*²

*S*0(*x^t* = ¯*m*²

(↵*s*) 0*.*1% 0*.*1% 0*.*4% 2*.*0% *MIC matrix element II.* (*|Vub/Vcb|*) *<* 0*.*1% 0*.*1% 0*.*2% 0*.*5% on the size of the allowed BSM e↵ects on *Bs*-mixing. For a t II attıcel ve s *M*Exp Hadronic matrix element [Lattice]

• FLAG17 + V_{cb} treatment (see next slide) implies a 1.8 σ discrepancy P 6*.*2% 14*.*8% 14*.*0% 34*.*6%

 $\Delta M_s^{\text{SM}} > \Delta M_s^{\text{exp}} = (17.757 \pm 0.021) \text{ ps}^{-1}$ [HFLAV (CDF + LHCb) 1612.07233] $\overline{166}$ $\overline{1612}$ $\overline{072222}$ SM contribution. If > 0, which is often the case in many BSM $\Delta M_s^{\rm SM} > \Delta M_s^{\rm exp} = (17.757 \pm 0.021) \,\, \mathrm{ps}^{-1}$ [HFLAV (CDF + LHCb) 1612.07233]

p *B*ˆ and the corresponding SM prediction for *Ms*. relative error of 5.8%. The uncertainty in the CKM elements [LDL, Kirk, Lenz 1712.06572]

^LNP

B=² ⁼ 4*GF*

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profil
profil

VtbV⇤

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*M*SM

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CLL

(↵*s*) 0*.*1% 0*.*1% 0*.*4% 2*.*0% *MIC matrix element II.* (*|Vub/Vcb|*) *<* 0*.*1% 0*.*1% 0*.*2% 0*.*5% on the size of the allowed BSM e↵ects on *Bs*-mixing. For a t II attıcel ve s *M*Exp Hadronic matrix element [Lattice]

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^LNP

B=² ⁼ 4*GF*

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★ Lattice updates crucial to settle the issue ! gates a detailed settle the issue. Frucial to settle the issue!

*M*SM

 $t_n = t_n$ and $t_n = t_n$. When finally $\frac{1}{2}$ and the same calculation $\frac{1}{2}$ \blacksquare L. Di Luzio (IPPP, Durnam) - ΔIV_s interplay with B-ai $\mathsf{values} \leftarrow \mathsf{true} \leftarrow \mathsf{$ put parameters and the error budget is given in Appendix A α , Duriality - Δ is fitted play with D-anomalies 12 L. Di Luzio (IPPP, Durham) - ΔMs interplay with B-anomalies 04/14

s¯*L*µ*bL*

CLL

V_{cb} dependence account loop-mediated processes, where potentially NP can arise. Taking only tree-level inputs, they find:¹⁰ perturbative parameter, resulting in values around 2012 and 2012 and 2012 and 2012 and 2012 and 2012 and 2012 ps1 ps1 for the mass discussion of the mass discussion of the mass discussion of the mass discussion of the ma than experiment. An independent confirmation of these

• V_{cb} is the second most important ingredient for SM prediction in that direction has been done by the HQET sum rule for SM prediction \mathcal{I}

c 0 03918 **−** 0 03918 **±** 0 03918 **±** 0 03918 **±** 0 03918 **±** 0 03918 **±** 0 03918 **±** 0 03918 **±** *i* we use CKP fitter value α (consistent with inclusive determination) $\left(\frac{1}{2} + \frac{1}{2} + \frac$ \mathbf{u} inclusive determination) p we use CKMfitter value* (consistent with inclusive determination)

V ^B!*D*⇤

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\Delta M_s^{\text{SM}, 2017} = (20.01 \pm 1.25) \text{ ps}^{-1}
$$

$$
[\Delta M_s^{\text{SM}, 2017 \text{ (tree)}} = (19.9 \pm 1.5) \text{ ps}^{-1}]
$$

*Includes loop-mediated observables (potentially affected by NP) [5] J. T. Wei *et al.* (Belle), Phys. Rev. Lett. 103, 171801 NP), and the phase state NP are stated in the phase state NP . \mathcal{L} F. Beau is the dynamics of \mathcal{L}

i Luzio (inni, Durilalii) - **A**ni_s initerpiay with b-anoma (2009) , archives (2009) L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies 05/14

Impact on B-anomalies

L. Di Luzio (IPPP, Durham) - ΔMs interplay with B-anomalies 06/14

ΔM_s vs. new physics (NP) input as well as the values of the CKM elements. We \bigcup vs. nove the averages \bigcap IS VS. HEW PHYSICS (IV $\mathcal{L}_{\mathcal{A}}$, see Appendix C and Appendix C and Appendix D and Appen

 \bullet As an <u>example</u> le • As an example let's assume:

sometimes and the UPU correctly v-I. NP in purely V-A $\Delta B = 2$ operator (same matrix element as in the SM)

 P , no NI T 2. no NP pollution in the extraction of CKM elements

$$
\Delta M_s^{\rm Exp} = 2 \left| M_{12}^{\rm SM} + M_{12}^{\rm NP} \right| = \Delta M_s^{\rm SM} \left| 1 + \frac{M_{12}^{\rm NP}}{M_{12}^{\rm SM}} \right|
$$

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ΔM_s vs. new physics (NP) input as well as the values of the CKM elements. We $\bigcup_{x \in \mathcal{X}} \mathbb{E}[x]$ IS VS. HEW PHYSICS (IV $\mathcal{L}_{\mathcal{A}}$, see Appendix C and Appendix C and Appendix D and Appen mass die rence with the prediction in the prediction in the SM plus NP: the SM plus NP: the SM plus NP: the SM ľ $\overline{1}$ *M*NP 12 parametrised in terms of a decay constant *f^B^s* and a bag SM prediction depends strongly on the non-perturbative N downed as N $\mathbf v$ provided that $\mathbf v$ The parameter *B*ˆ has the advantage of being renormali-**A**MS VS. HEW PHYSICS (1 A commonly used SM prediction of *M^s* was given by ΔV is vs. Hew physics (INF) 8 *M*² *^B^s f* ² *B^s B*(*µ*)*,* (11) $\mathbf{u} = \mathbf{u} + \mathbf$ nity (FLAG) and by one of the two leading CKM fitting \mathcal{C} , \mathcal{C} , \mathcal{C} and \mathcal{C} and \mathcal{C} and \mathcal{C}

 \bullet As an <u>example</u> le • As an example let's assume: • As an example let's as For this equation we will use in the SM part the CKM $\sigma^{+'}$ ² 222 *M*, *s* $\frac{1}{2}$ 2011 **b** 2011 **p** 2013 **c** 2014 **d** 2014 \bullet As an example let's assume: of the bag parameter; in our analysis we take *µ* =

*M*Exp

sometimes and the UPU correctly v- $I₁ NID in purely λ $AP = 2$ operator (corresponding element or$ I. NP in purely V-A $\Delta B = 2$ operator (same matrix element as in the SM) III. *Bs*-MIXING BEYOND THE SM Fig. INP in purely V-A $\Delta B \equiv 2$ operator (same matrix element as in the SPI) 12 could in general in general \overline{a} III. *Bs*-MIXING BEYOND THE SM

 P , no NI T me extraction of CKP elements a are not mean the extraction in the extraction chiral fermion Γ . In the following, we will the following, 2. no NP pollution in the extraction of CKM elements \mathcal{S} di \mathcal{S} die \mathcal{S} die \mathcal{S} die \mathcal{S} corrections for the \mathcal{S} 2. no INP pollution in the extraction o To determine the allowed space for NP e $\frac{1}{2}$ $\overline{2}$ no 2. no NP pollution in the extraction of CKM elements T o determine the allowed space for N

$$
\Delta M_s^{\rm Exp} = 2 \left| M_{12}^{\rm SM} + M_{12}^{\rm NP} \right| = \Delta M_s^{\rm SM} \left| 1 + \frac{M_{12}^{\rm NP}}{M_{12}^{\rm SM}} \right|
$$

$$
\frac{\Delta M_s^{\text{Exp}}}{\Delta M_s^{\text{SM}}} = \left| 1 + \frac{\kappa}{\Lambda_{\text{NP}}^2} \right| \qquad \qquad \frac{\Lambda_{\text{NP}}^{2017}}{\Lambda_{\text{NP}}^{2015}} = \sqrt{\frac{\frac{\Delta M_s^{\text{Exp}}}{(\Delta M_s^{\text{SM}} - 2\delta \Delta M_s^{\text{SM}})^{2015} - 1}{\frac{\Delta M_s^{\text{Exp}}}{(\Delta M_s^{\text{SM}} - 2\delta \Delta M_s^{\text{SM}})^{2017} - 1}} \simeq 5 \qquad (2 \text{ \text{bound})}
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^s 2*M*SM

^s)²⁰¹⁵ ¹

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 \sum_{i} $\Delta M_s^{\rm Exp} = (17.757 \pm 0.12)$ $\Delta M_s^{\rm SM,\,2015} = (18.3 \pm 2.7)\,\,\text{ps}^{-1}$ [Artuso, Borissov, Lenz 1511.09466] SM prediction from Eqs. (12)–(13) to Eq. (15) can have **a** $\frac{1}{25}$ **ps** $\frac{1}{25}$ **increases [LDL, Kirk, Lenz 1712.06572]** $\frac{1}{\pi}$ FUELAY (CDE LIUCL) KIO 070001 *M*Exp \sim , \sim . \sim . \sim dierence using only tree-level inputs for the $\mathcal{O}(\mathbf{r},\mathbf{r})$ other hand, if the tension between the SM prediction and *V* (CDE + LHCb) L412 072331 $\sum_{i=1}^{n}$ $\Delta M_s^{\text{SM},\,2017} = (20.01 \pm 1.25) \, \text{ ps}^{-1}$ *[LD* $\Delta M_e^{\rm Exp} = (17.757 \pm 0.021)~{\rm~ps}^{-1}$. The av (CDE + LHCb) 1612.072331 $A = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}$ of the improvement of SM prediction from Eqs. (12)–(13) to Eq. (15) can have *Bs*-mixing. For a generic NP model we can parametrise plings and the SM contribution. If *>* 0, which is often ΔM_s $= (18.3 \pm 2.1)$ ps [Artuso, Borissov, Lenz 1511.09466] ered in the literature, and since *M*SM ¹ A more conservative determination of the SM value of the mass $2 \frac{1}{2}$ vuuut $\Delta M_s^{\rm{Exp}} = (17.757 \pm 0.021)~{\rm~ps}^{-1}$ $\,$ [HFLAV (CDF + LHCb) 1612.07233] α div α is tree-level in puts for the CKM parameters for the CKM parameters for the CKM parameters for the CKM parameters α [Artuso, Borissov, Lenz 1511.09466]

\overline{I} \overline{N} $\overline{$ \blacksquare L. DI LUZIO (IPPF, DUMI $\overline{\mathsf{with}}$ $\overline{\mathsf{R}}$ سمان
س A typical example where *>* 0 is that of a purely LH y with B-anomalies from the exchange \sim *^s* = (17*.*⁷⁵⁷ *[±]* ⁰*.*021) ps¹ *.* (14) \mathcal{L} 2016 Fermilab (MILC presented a new calculation \mathcal{L} ¹ A more conservative determination of the SM value of the mass L . Di Luzio (IPPP, Durham) - ΔM_s interplay with .
ممالك diles L. Di Luzio (IPPP, Durham) - ΔMs interplay with B-anomalies 07/14

"B-anomalies"

 $\frac{1}{2}$ coherent pattern of SM deviations building up since ~ 2012 • A seemingly coherent pattern of SM deviations building up since ~ 2012

Neutral currents elements points, however, in the direction of a small discrepancy in this observable. Using up-todate inputs from standard sources such as PDG, FLAG and one of the two leading CKM fitting on the *Z*⁰ mass approaches dangerously close to the energy scales already probed by the LHC. We finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. $\sum_{n=1}^{\infty}$ a global fit including other observables, which shows a clear preference for non SMS and SMS a

leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound μ current anomalies and ΔV_{ls} $\frac{1}{100000}$ that explains discrepancies in *^B* ! *^K*(⇤) **u** <u>+ board</u> domnound to Served through an daily one \bullet Generic robust connection between neutral current <u>that</u> compositions discrepancies in $\frac{1}{2}$ *n* diversity of the diversity and the diversity of $\frac{1}{2}$ bust connection between neutral current anomalies and Λ M

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a flavour dependent *Z*⁰

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Neutral currents elements points, however, in the direction of a small discrepancy in this observable. Using up-todate inputs from standard sources such as PDG, FLAG and one of the two leading CKM fitting on the *Z*⁰ mass approaches dangerously close to the energy scales already probed by the LHC. We finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. $\sum_{n=1}^{\infty}$ a global fit including other observables, which shows a clear preference for non SMS and SMS a

• Generic robust connection between neutral current anomalies and ΔM_s μ current anomalies and ΔV_{ls} $\frac{1}{100000}$ that explains discrepancies in *^B* ! *^K*(⇤) **u** <u>+ board</u> domnound to Served through an daily one \bullet Generic robust connection between neutral current <u>that</u> compositions discrepancies in $\frac{1}{2}$ *n* diversity of the diversity and the diversity of $\frac{1}{2}$ bust connection between neutral current anomalies and Λ M

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a flavour dependent *Z*⁰

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Neutral cur^{rents} · Z' finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. **Neutral currents** \cdot Z I. INTRODUCTION leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound on the *Z*⁰ mass approaches dangerously close to the energy scales already probed by the LHC. We finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. well until recently. The most recent \mathcal{F}_n recent FLAG average of lattice results for the non-perturbative matrix elements points, however, in this observable. Using up-to-direction of a small discrepancy in this observable. Using up-to-direction of a small discrepancy in this observable. Using up-to-direction of a small discrepancy date inputs from standard sources such as PDG, FLAG and one of the two leading CKM fitting

• Simplified Z' model with purely LH couplings

$$
\mathcal{L}_{Z'} = \tfrac{1}{2} M_{Z'}^2 (Z'_\mu)^2 + \left(\lambda^Q_{ij} \, \bar{d}^i_L \gamma^\mu d^j_L + \lambda^L_{\alpha \beta} \, \bar{\ell}^\alpha_L \gamma^\mu \ell^\beta_L \right) Z'_\mu
$$

[For an anomaly-free UV completion see e.g. Model (SM), while we have an intriguing list of devia-*b* ! *sll* (1) I. INTRODUCTION and and the *Zoox, Han, Yanagida* 1705.03858] ables. In particular *^b* ! *^s*`⁺` transitions seem to be $m_{\rm H}$ and $m_{\rm S}$ contribution are now sufficient to draw various σ n anomaly-free UV completion see e.g. Remarkable finally identify some model building directions in order to alleviate the tension with *Bs*-mixing.

in tension with the SM expectations: branching ratios of hadronic *^b* ! *sµ*⁺*µ* decays [1–3] and the angular distributions for *^B* ! *^K*(⇤) *µ*⁺*µ* decay [2–11] hint at a negative, beyond the SM (BSM) contribution to *C*⁹ [12–23]. The significance of the e↵ect is still under discussion because of the diculty of determining the exact size of the hadronic contributions (see e.g. [24–30]). Estimates of the combined significance of all these deviations range between three and almost six standard deviations. A theoretically much cleaner observable is given by the lepton flavour universality (LFU) ratios *R^K* and *R^K*⇤ [31, 32], where hadronic uncertainties drop out to a very large extent. Here again a sizeable deviation from the SM expectation is found by LHCb [33, 34]. Such an effect might arise for instance from new particles coupling to *bs*¯ and *µ*⁺*µ*, while leaving the *e*⁺*e*-coupling mainly unchanged (see e.g. [35–64] for an arbitrary set of papers investigating *Z*⁰ models). Any new *bs*¯-coupling immediately leads to tree-level contributions to *Bs*-mixing, which is severely constrained by experiment. For quite some time the SM value for the mass di↵erence *M^s* of Figure 1: *Deviations from the SM value R^K* = *R^K*⇤ = 1 *due to the various chiral operators* ously mentioned, a deviation of *R^K*⇤ from *R^K* signals the presence of *C*BSM physics, is not adequate for a careful phenomenological analysis. The same remark remains valid ⌘ [1704.05438] • Deviation from the Standard Model, using only the most cleaner observable gives ⇠ ⁴ where *p* ⇡ 0*.*86 is the polarization fraction [22, 27, 28]. In the chiral-linear limit the expression for *R^K*⇤ simplifies to *R^K*⇤ ' *R^K* 4*p* where 4*p/C*SM *bLµ^L* ⇡ 0*.*40. The formula above clearly shows that, in this approximation, a deviation of *R^K*⇤ from *R^K* signals that *b^R* is involved at the e↵ective operator level with the dominant e↵ect still due to left-handed leptons. As already discussed before, eq. (15) is not suitable for a detailed phenomenological study, and we implement in our numerical code the full expression for *R^K*⇤ [29]. In the left panel of figure 1, we present the di↵erent predictions in the (*RK, R^K*⇤) plane due to turning on the various operators assumed to be generated via new physics in the muon sector. A reduction of the same order in both *R^K* and *R^K*⇤ is possible in the presence of the left-handed operator *C*BSM *^bLµ^L* (red solid line). In order to illustrate the size of the required correction, the arrows correspond to *C*BSM where *p* ⇡ 0*.*86 is the polarization fraction [22, 27, 28]. In the chiral-linear limit the expression for *R^K*⇤ simplifies to where 4*p/C*SM tion of *R^K*⇤ from *R^K* signals that *b^R* is involved at the e↵ective operator level with the dominant e↵ect still due to left-handed leptons. As already discussed before, eq. (15) is not suitable for a detailed phenomenological study, and we implement in our numerical code the full expression for *R^K*⇤ [29]. In the left panel of figure 1, we present the di↵erent predictions in the (*RK, R^K*⇤) plane due to turning on the various operators assumed to be generated via new physics in the muon sector. A reduction of the same order in both *R^K* and *R^K*⇤ is possible in the presence of the left-handed operator *C*BSM correction, the arrows correspond to *C*BSM for *R^K* is *R^K* = *|C^bL*+*RµL^R | |C^bL*+*ReL^R |* This is a clean observable, meaning that it is not a↵ected by large theoretical uncertainties, and its SM prediction is *R^K* = 1. QED corrections give a small departure from unity which, however, does not exceed few percents [26]. However, it has to be noted that new physics which a↵ects di↵erently *µ* and *e* can induce theoretical errors, bringing back the issue of hadronic uncertainties. In the chiral-linear approximation, *R^K* becomes *R^K* ' 1+2 indicating that the dominant e↵ect stems from couplings to left-handed leptons. Any chirality of quarks works, as long as it is not orthogonal to *L* + *R*, namely unless quarks are axial. It is important to notice that the approximation in eq. (13), although capturing the relevant ⁹ ⁼ *C^µ* ¹⁰ ⁼ ⇡ ^p2*GFM*² *^Z*0↵ *Q bs^L µµ VtbV* ⇤ *ts* ! 1 2*M*² *M*² *Z*0 *^L*NP *^Z*⁰ (*Z*⁰ *µ*) ² + ⇣ *Q ij* ¯ *di L^µd^j ^L* + *^L* ↵ ¯`↵ *^L^µ*` *L* ⌘ *Z*0 *µ ,* (3) *Vus Vcb |Vub/Vcb|* CKM (4) 1 ^p2*GFM*² *Z*0 *Q bs VtbV* ⇤ *ts* !2 *,* (5) *B*ˆ*^B^s* ◆FLAG17 = 274(8) MeV (6) *C*BSM *^bLµ^L* (1) *^L ^gµµ L* 1 (31 TeV)² (2) *b* ! *sll* (3) ¹⁰ ⁼ ⇡ ^p2*GFM*² *^Z*0↵ *Q bs^L µµ VtbV* ⇤ *ts* ! *,* (4) *L^µd^j ^L* + *^L* ↵ ¯`↵ *^L^µ*` *L Z*0 *µ ,* [12–23]. The significance of the e↵ect is still under dis-*M*Exp *s ^Q* = [¯*sµ*(1 5)*b*][¯*s^µ*(1 5)*b*] *.* (12) Direct searches for new physics (NP) e↵ects at the LHC have so far shown no discrepancies from the Standard Model (SM), while we have an intriguing list of deviations between experiment and theory for flavour observables. In particular *^b* ! *^s*`⁺` transitions seem to be in tension with the SM expectations: branching ratios of hadronic *^b* ! *sµ*⁺*µ* decays [1–3] and the angular distributions for *^B* ! *^K*(⇤) a negative, beyond the SM (BSM) contribution to *C*⁹ I. INTRODUCTION*^b*!*sµµ* 4*G^F* p2 *VtbV* ⇤ *ts* ↵ 4⇡ *C*BSM *^bLµ^L* [¯*sLµbL*][¯*µL^µµL*] (1) *B*=2 4*G^F* ^p² (*Vtb^V* ⇤ *ts*) ² *CLL bs* [¯*sLµbL*] ² (2) *C*BSM *bLµ^L* ⌘ *^C^µ* ⁹ *^C^µ* ¹⁰ (3) *^RK*(⇤) ⇡ 1 + 2 Re *^C*BSM *bLµ^L C*SM *bLµ^L* ! (4)

neutral *B*_s mentioners, a correction decay of

 $\frac{1}{\sqrt{2}}$

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*B*ˆ*^B^s*

)e **F**ingli

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Neutral currents - Z' finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. *b* ! *sll* (1) I. INTRODUCTION leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound on the *Z*⁰ mass approaches dangerously close to the energy scales already probed by the LHC. We \mathcal{L} ilding directions in order to alleviate the tension with \mathcal{L} on the *Z*⁰ mass approaches dangerously close to the energy scales already probed by the LHC. We finally identify some model building directions in order to alleviate the tension with B

• Simplified Z' model with purely LH couplings

Fermally-free UV completion see e.g.
 Alonso, Cox, Han, Yanagida 1705.03858] [For an anomaly-tree UV completion see e.g.
Alonso, Cox, Han,Yanagida 1705.03858] ables. In particular *^b* ! *^s*`⁺` transitions seem to be α J
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Anagida | / /∪∪
∩⊐ *VtbV* ⇤

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\mathcal{L}_{Z'} = \frac{1}{2} M_{Z'}^2 (Z'_\mu)^2 + \left(\lambda^Q_{ij} \, \bar{d}^i_L \gamma^\mu d^j_L + \lambda^L_{\alpha \beta} \, \bar{\ell}^\alpha_L \gamma^\mu \ell^\beta_L \right) Z'_\mu
$$

$$
C_{b_L \mu_L}^{\rm BSM} = -\frac{\pi}{\sqrt{2} G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu\mu}^L}{V_{tb} V_{ts}^*} \right)
$$

$$
\mathcal{L}^{\rm NP}_{\Delta B=2} \supset -\frac{4 G_F}{\sqrt{2}} \left(V_{tb} V_{ts}^*\right)^2 C_{bs}^{LL} \left[\bar{s}_L \gamma_\mu b_L\right]^2
$$

$$
C_{bs}^{LL} = \frac{1}{4\sqrt{2}G_F M_{Z'}^2} \left(\frac{\lambda_{bs}^Q}{V_{tb} V_{ts}^*}\right)^2 > 0
$$
\n(assuming real couplings)

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Flaging of the state of the s

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for instance for instance from new particles coupling $f(x)$ (assuming real couplings) $\frac{f(x)}{f(x)}$ $\dim \sigma c$) $\frac{1}{\sqrt{2}}$ *c*eal c

(5)

1

*^Z*⁰ (*Z*⁰

Global view on Z' par. space ∇ har share Dan space

• Simplified Z' model with purely LH couplings (assuming $\lambda_{bs}^Q = \lambda_{bb}^Q V_{ts}$) \mathcal{L} $\mathcal{$ $\sum_{b=1}^n$ $\sum_{s=1}^n$ *Physics Ph_b* $\sum_{s=1}^n$ *_{<i>Physics*} *Physics*,

¹⁰ ⁼ ⇡

Figure 1: The parameter space in the (*gµµ, gbb*) plane compatible with *RK*(⇤) anomalies and Z 10 (IPPP, Durham) - Δ 1 mass interplay with B-anomalies Z 0 mass for the plane, with a unique Z 0 mass Z 0 mass Z d² anomalies *bbVts* (3) L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies 11/14

tions between experiment and theory for flavour observ-

bs^L µµ

Z' at future colliders

- Pessimistic scenario: only bs and mumu couplings fixed by anomaly
- $g_L^{bs} g_L^{\mu\mu}$ $M_{Z^\prime}^2$ = 1 $\frac{1}{(31 \text{ TeV})^2}$
- **S** [Allanach, Gripaios, You, 1710.06363] - Projected sensitivities of di-muons resonance searches

[See also talk by Allanach] *Vus Vcb |Vub/Vcb|* CKM (5)

Z' at future colliders

- Pessimistic scenario: only bs and mumu couplings fixed by anomaly $\frac{g_L^{\text{os}} g_L^{\mu \mu}}{M^2} = \frac{1}{(31 \text{ TeV})^2}$ $g_L^{bs} g_L^{\mu\mu}$
	- Projected sensitivities of di-muons resonance searches *Z [Allanach, Gripaios, You, 1710.06363]*

 \mathbf{z} and the actual limit at low masses the actual limit at low masses, as indicated by the shaded by the

 $M_{Z^\prime}^2$

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 $\frac{1}{(31 \text{ TeV})^2}$

Z' at future colliders

- Pessimistic scenario: only bs and mumu couplings fixed by anomaly $\frac{g_L^{\text{os}} g_L^{\mu \mu}}{M^2} = \frac{1}{(31 \text{ TeV})^2}$ $g_L^{bs} g_L^{\mu\mu}$
	- Projected sensitivities of di-muons resonance searches *<i>Z Allanach, Gripaios, You, 1710.063631*

 \mathbf{z} and the actual limit at low masses the actual limit at low masses, as indicated by the shaded by the

 Γ \blacksquare AM legured streers search and f_{u} the wester \blacksquare \blacksquare \blacksquare \blacksquare Bee also talk by Allanach]
 \blacksquare \blacksquare Bee also talk by Allanach] ΔM_s bound stronger than future colliders?

Vus Vcb |Vub/Vcb| CKM (5) [See also talk by Allanach]

 $M_{Z^\prime}^2$

=

1

 $\frac{1}{(31 \text{ TeV})^2}$

How to fit the ΔM_s "discrepancy" *^Q* = [¯*sµ*(1 5)*b*][¯*s^µ*(1 5)*b*] *.* (10) leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound on the *Z*O mass and *Z*O mass and the *Z*O mass and finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. severely constrained by *Bs*-mixing, for which the Standard Model prediction and experiment agreed W_{max} recently. The most recent FLAG average of Λ eleituv luituits, however, in the discrepancy in the direction of a small discrepancy in the discrepancy in th date inputs from standard sources such as PDG, FLAG and one of the two leading CKM fitting ¹*Institute for Particle Physics Phenomenology, Department of Physics,* Ω \mathcal{L} and \mathcal{L} models in the intriguing and \mathcal{L} **b**
and
 \overline{p} *Z*0 *bsµ* ¯*b* ¯*s µ µ >* diccion or *A* D \sim 7 TeV (1)

well until recently. The most recent Γ

1) Complex couplings
\n
$$
C_{b_L \mu_L}^{\text{BSM}} = -\frac{\pi}{\sqrt{2} G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu\mu}^L}{V_{tb} V_{ts}^*} \right)
$$

1) Complex couplings
\n
$$
C_{b_L\mu_L}^{\text{BSM}} = -\frac{\pi}{\sqrt{2}G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu\mu}^L}{V_{tb} V_{ts}^*} \right)
$$
\n
$$
R_{K^{(*)}} \approx 1 + 2 \text{Re} \left(\frac{C_{b_L\mu_L}^{\text{BSM}}}{C_{b_L\mu_L}^{\text{SM}}} \right)
$$
\nNot strong dependence from Im

CLL v, *in the line*
 b ! *sll* (3) $\mathop{\mathsf{long}}\nolimits$ de = *||* (2) Not strong dependence from Im part (as long as we are in the linear regime) $\overline{\mathbf{r}}$

 $\{12,32\}$, the significance of the e $\{12,32\}$ still under distribution of the e $\{12,42\}$

$\left| \right|$ $\left| \$ mixing if the *Z*⁰ does not couple universally in the gaugelution in order to achieve *CLL bs <* 0 is to allow for complex $\alpha_{1,1}$ $+\alpha$ β_{1} $+\alpha_{2}$ Λ Λ *Z*0 models the could have the could have the consequence of the conse mixing if the *Z*⁰ does not couple universally in the gauge- L_{α_1} , $+_{\alpha_2}$ \hat{L}_+ $+_{\alpha_2}$ \wedge \wedge \wedge \wedge \wedge \wedge ¹*Institute for Particle Physics Phenomenology, Department of Physics,* ¹*Institute for Particle Physics Phenomenology, Department of Physics,* Ω \mathcal{L} and \mathcal{L} models in the intriguing and \mathcal{L} **b**
and
 \overline{p} *Z*0 *bsµ* ¯*b* ¯*s µ µ >* diccion or *A* D \sim 7 TeV (1) I. *^Q* = [¯*sµ*(1 5)*b*][¯*s^µ*(1 5)*b*] *.* (10) leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound on the *Z*O mass and *Z*O mass and the *Z*O mass and How to fit the ΔM_s "discrepancy"

 \bigcup Complex couplings vector leptoquarks arising from a spontaneously broken arising from a spontaneously broken and the spontaneous
The spontaneously broken and the spontaneously broken and the spontaneously broken and the spontaneously broke well until recently. The most recent Γ

I) Complex couplings
\n
$$
C_{b_L\mu_L}^{\text{BSM}} = -\frac{\pi}{\sqrt{2}G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu_L}}{V_{tb} V_{ts}^*}\right)
$$
\n
$$
\frac{M_{Z'}^{\text{BSM}}}{M_{12}^{\text{SM+NP}}} = |\Delta| e^{i\phi_{\Delta}} \qquad \frac{\lambda_{s}^Q \lambda_{\mu_L}}{I_{ts}^2} = \frac{1}{2} \left|\frac{\lambda_{0}^Q \lambda_{\mu_L}}{I_{ts}^2}\right|
$$
\n
$$
\frac{\lambda_{0.005}^2}{I_{ts}^2} = \frac{\lambda_{0.0025}^2}{4E_{ts}^2}
$$

$$
C_{b_L \mu_L}^{sum} = -\frac{1}{\sqrt{2}G_F M_{Z'}^2 \alpha} \left(\frac{V_{tb} V}{V_{tb} V}\right)
$$

$$
\frac{M_{12}^{\text{SM+NP}}}{M_{12}^{\text{SM}}} \equiv |\Delta| e^{i\phi_{\Delta}}
$$

compatibly with a plethora of other indirect constraints

1) Complex couplings
\n
$$
C_{b_L \mu_L}^{\text{BSM}} = -\frac{\pi}{\sqrt{2} G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu_L}}{V_{tb} V_{ts}^*} \right)
$$
\n
$$
\frac{M_{12}^{\text{SM+NP}}}{M_{12}^{\text{SM}}} = |\Delta| e^{i \phi_{\Delta}}
$$
\n
$$
\frac{\Delta M_{s}^{\text{Exp}}}{\Delta M_{s}^{\text{SM}}} = |\Delta| = \left| 1 + \frac{C_{bs}^{LL}}{R_{\text{SM}}^{\text{loop}}} \right|
$$

that related to the LFU violating ratios *RD*(⇤) ⌘ *B*(*B* ! \Box Blue ar *A*mix Blue and Red regions have a 10 overlap

 $\{12,32\}$, the significance of the e $\{12,32\}$ still under distribution of the e $\{12,42\}$

Q bs^L

ts !

\overline{a} - L. Di Luzio (IPPP, Durham) - **Δ**i^vi_s interplay (as e.g. those pointed out in those pointed out in the 2 bound in 2 cently reassessed at the EFT level in Ref. [113]. Regard- Γ r, Durnam) - **A**rt_s interplay with b-anomalies *C*_{*x*} Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies 13/14 $\sum_{i=1}^{n}$ B^2 *B*^{B^2} (*B*^{B^2} B^2 B^2 ◆FLAG17

¹*Institute for Particle Physics Phenomenology, Department of Physics,* Ω \mathcal{L} and \mathcal{L} models in the intriguing and \mathcal{L} **b**
and
 \overline{p} *Z*0 *bsµ* ¯*b* ¯*s µ µ >* diccion or *A* D \sim 7 TeV (1) *Z* models the could happen as a consequence of α mixing in the *Howa* to the current basis in the animal similar method of the similar method of the similar method of the similar second be a gauge theory, while scalar-leptoquark couplings to SM second theory, while scalar-leptoquark couplings to SM s \Box fermions and \Box in the \Box couplings (cf. Eq. (23) and Eq. (26) Z^2 models the Z^2 models the Z^2 mixing if the *Z*⁰ does not couple universally in the gauge- $\frac{1}{2}$ $\frac{1}{2}$ mixing in the *Z*₀ does not couple $\left| \right|$ $\left| \$ mixing if the *Z*⁰ does not couple universally in the gauge-I. I. I. I. I. I. I. I. I. I. *^Q* = [¯*sµ*(1 5)*b*][¯*s^µ*(1 5)*b*] *.* (10) leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound on the *Z*O mass and *Z*O mass and the *Z*O mass and How to fit the ΔM_s "discrepancy"

well until recently. The most recent Γ elements points, however, in the direction of a small discrepancy in this observable. Using up-to-1) Complex couplings $v_{\rm{max}}$ observables, that we discuss in turn. In turn. In order turn. In turn. \bigcup Complex couplings fermions couplings \bigcup Complex couplings fermions are in the internal complete going in the set of the set o \bigcup Complex couplings **1) Complex couplings**

1) Complex couplings
\n
$$
C_{b_L \mu_L}^{\text{BSM}} = -\frac{\pi}{\sqrt{2} G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu\mu}^L}{V_{tb} V_{ts}^*} \right)
$$
\n
$$
\frac{M_{12}^{\text{SM+NP}}}{M_{12}^{\text{SM}}} \equiv |\Delta| e^{i\phi_{\Delta}}
$$
\n
$$
\phi_{\Delta} = \text{Arg} \left(1 + \frac{C_{bs}^{LL}}{R_{\text{SM}}^{\text{loop}}} \right)
$$

$$
C_{b_L \mu_L}^{L \to \mu_L} = -\frac{1}{\sqrt{2} G_F M_{Z'}^2 \alpha} \left(\frac{V_{tb} V}{V_{tb} V} \right)
$$

$$
\frac{M_{12}^{\text{SM+NP}}}{M_{12}^{\text{SM}}} \equiv |\Delta| e^{i\phi_{\Delta}}
$$

$$
\phi_{\Delta} = \text{Arg} \left(1 + \frac{C_{bs}^{LL}}{I_{\text{beam}}} \right)
$$

$$
\frac{M_{12}^{\text{SM+NP}}}{M_{12}^{\text{SM}}} \equiv |\Delta| e^{i\phi_{\Delta}}
$$

$$
\phi_{\Delta} = \text{Arg}\left(1 + \frac{C_{bs}^{LL}}{R_{\text{SM}}^{\text{loop}}}\right)
$$

*R*loop

$$
A_{\rm CP}^{\rm mix}(B_s \to J/\psi \phi) = \sin(\phi_\Delta - 2\beta_s)
$$

 $A_{\rm CP}^{\rm mix} = -0.021 \pm 0.031$ [HFLA $\mathbf{C}_{\mathbf{r}}$, and we neglected penguin contributions \mathbf{r} $\beta_s=0.01852\pm0.00032$ [CKMFitter] *bs* ⌘ are displayed in Fig. (4). $A_{\rm CP}^{\rm mix} = -0.021 \pm 0.031$ [HFLAV 1612.07233] are displayed in Fig. (4). The displayed in Fig. (4). The displayed in Fig. (4). The displayed in \mathcal{A} 031 [HFLAV 1612.07233] [116], and we neglected penguin contributions [64]. The [116], and we neglected penguin contributions [64]. The CP = 0*.*021*±*0*.*031 [70], *^s* = 0*.*01852*±*0*.*00032 combined 2 constraints on the Wilson coecient *CLL f*^{*B*}*BsB<i>B***_{***B***}^{***B***}***Bs******BB*_{*B*}*B*_{*B*}*B*_{*B*}^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*}*B*^{*B*} \mathcal{L} β ^z = α $A_{CP}^{\text{mix}} = -0.021 \pm 0.031$ ¹⁰ ⁼ ⇡ *Q i* $\frac{1}{2}$ *di ^L* + *^L* ↵ ¯`↵

<u>limits</u> imaginary part *gbs* = *gbbVts* (8) ⁻ CP violation in mixing <u>limits</u> imaginary part

20 Metation in mixing <u>limits</u> imaginary part mediately leads to tree-level contributions to *Bs*-mixing, **CP** violation in mixing limits imaginal a negative, beyond the SM (BSM) contribution to *C*⁹

 $\{12,32\}$, the significance of the e $\{12,32\}$ still under distribution of the e $\{12,42\}$

$\frac{d}{dx}$ */ Connected to* $R(K^{(*)})$ $\mathrm{Arg}(\lambda_{bs}^Q) \sim \pi/2$ 4*G^F*

Interesting option:

 $\mathcal{F}_{\mathcal{A}}(t)$, combined constraints on the complex Wilson coefficient on the complex Wilson coefficient of \mathcal{A} in UV compete models of vector leptoquark $(R(K^{(*)}) + R(D^{(*)}))$ extra Z'/G' states from *Amix* that can naturally (compatibly with a U(2) spurion analysis) accommodate that ...
⊂⊂ *f^B^s* \overline{t} *B*ˆ*^B^s* $PCCIIIC$ *A* naturally (compatibly with a $U(2)$ spurion analysis) accommodate that Γ for instance for $\Gamma^{(*)}$ instance from new particles coupling from new particles coupling from $\Gamma^{(*)}$ in UV compete models of vector leptoquark $(R(K^*)) + R(D^{(*)}))$ extra Z'/G' states
11/2) spurion analysis) accommodate that *b* models els of vector leptoquark (R(K^(*)) + R(D^(*))) extra Z'/G' states
tibly with a U(2) spurion analysis) accommodate that *,* (4) roquark (K(K<u>V) + K(UV))</u> extra 27 + 3tates
?) spurion analysis) accommodate that ompatibly with a U(2) spurion analysis) accommodate that

[Bordone, Cornella, Fuentes-Martin, Isidori 1805.09328] \mathbf{L} is defined, the contraction of \mathbf{L} distributions for *^B* ! *^K*(⇤) a negative, beyond the SM (BSM) contribution to *C*⁹

L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies 13/14 $\sum_{i=1}^{n}$ **B** B and ΔM_s interplay with B-anomalies and the surface of the M₃/14 ◆FLAG17 $\frac{1}{\sqrt{1}}$ 4 ^p2*GFM*² 5 (164) *<u>A</u> ∆ in* Δ M_s inter lay with

How to fit the
$$
\Delta M_s
$$
 "discrepancy"

groups to determine *M*SM

$$
C_{b_L \mu_L}^{\text{BSM}} = -\frac{\pi}{\sqrt{2} G_F M_{Z'}^2 \alpha} \left(\frac{\lambda_{bs}^Q \lambda_{\mu\mu}^L}{V_{tb} V_{ts}^*} \right)
$$
 0.4 $\begin{bmatrix} \Delta M_s 1 - 2\sigma \\ \sigma \\ \sigma \end{bmatrix}$

Meed new phases close to maximal *L* \overline{M} *M*² e I new phases close to maxi

not directly connected to $R(K^{(*)})$

combined 2 constraints on the Wilson coecient *CLL*

*M*Exp

 $\{12,32\}$, the significance of the e $\{12,32\}$ still under distribution of the e $\{12,42\}$

*Durham University, DH1 3LE, Durham, United Kingdom M*SM $0.01\,$ $\frac{1}{2}$ \mathcal{L} 1 $\int (\lambda_{23}^Q)^2 (\bar{s}_L \gamma_\mu b_L)^2 + (\lambda_{23}^d)^2 (\bar{s}_R \gamma_\mu b_R)^2$ $\overline{1}$ $\mathcal{L}_{Z'}^{\text{eff}} \supset -\frac{1}{2M_{Z\tau}^2} \left[(\lambda_{23}^Q)^2 \left(\bar{s}_L \gamma_\mu b_L \right)^2 + (\lambda_{23}^d)^2 \left(\bar{s}_R \gamma_\mu b_R \right)^2 \right]$) $\mathcal{L}_{Z'}^{\text{eff}} \supset -\frac{1}{2M_{Z'}^2} \left[(\lambda_{23}^Q)^2 (\bar{s}_L \gamma_\mu b_L)^2 + (\lambda_{23}^d)^2 (\bar{s}_R \gamma_\mu b_L) \right]$

 \setminus

 $\sqrt{2}$

*Z*0 *µ*

1) Complex couplings
\n2) RH currents contamination
\n
$$
\mathcal{L}_{Z'} \supset \frac{1}{2} M_{Z'}^2 (Z'_\mu)^2 + \left(\lambda_{ij}^Q \bar{d}_L^i \gamma^\mu d_L^j + \lambda_{ij}^d \bar{d}_R^i \gamma^\mu d_L^j \right)
$$
\n
$$
\mathcal{L}_{Z'}^{\text{eff}} \supset -\frac{1}{2M_{Z'}^2} \left[(\lambda_{23}^Q)^2 (\bar{s}_L \gamma_\mu b_L)^2 + (\lambda_{23}^d)^2 (\bar{s}_R \gamma^\mu b_R) + \text{h.c.} \right]
$$

 ${\cal L}_{Z'} \supset \frac{1}{2} M_{Z'}^2 (Z'_\mu)^2 + \left(\lambda^Q_{ij} \, \bar{d}^i_L \gamma^\mu d^j_L + \lambda^d_{ij} \, \bar{d}^i_R \gamma^\mu d^j_R \right)$

 $\mathcal{L}_{Z^\prime} \supset \frac{1}{2} M_{Z^\prime}^2 (Z^\prime_\mu)^2 + \left(\lambda^Q_{ij} \, \bar{d}^i_L \gamma^\mu d^j_L + \lambda^d_{ij} \, \bar{d}^i_R \gamma^\mu d^j_R \right) Z^\prime_\mu$

 $\mathcal{L}_{Z'} \supset \frac{1}{2} M_{Z'}^2 (Z'_\mu)^2 + \left(\lambda_{ii}^Q \, \bar{d}_L^i \gamma^\mu d^2 \right)$

 $\begin{pmatrix} 1 \\ 2 \end{pmatrix}$

C
anomalies. $\vec{q}^i_{L'}$
 $\gamma_\mu l$ finally identify μ _i μ _i leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound ϵ couplings finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. 1) Complex couplings $\bigg)$ $\bigg)$ $\bigg)$ $\frac{d}{b}$ s (2) $= 5$ \bigwedge^{\prime} $V \qquad \lambda^L_{\mu\mu} = 1$ I. INTRODUCTION $M_{Z'}=5 \text{ TeV} \qquad \lambda^L_{\mu\mu}=1$ Ite contamination 2) RH currents contamination 0.03 \mathcal{L}_f is reducing containmanon $\overline{}$ *µ*¹*Institute for Particle Physics Phenomenology, Department of Physics, M^Z*⁰ = 5 TeV (8) \mathbb{R}^2 $b \rightarrow sll$

0.02

 -0.01

 -0.02

 $-0.03 -$

 \prec *d*

\mathbf{f} is some model building directions in order to alleviate the tension with \mathbf{f} C
x
component and standard Model prediction and experiment agreement and experiment and experiment agreed predict
discontinuity and experiment and experiment and experiment and experiment and experiment and experiment agre n_{max} elements points, however, in the direction of a small discrepancy in this observable. Using up-to d auto tit the ANM sdiscrepancy s **Solution and a sexual service parametermine space of the allowed parameters** d_{max} in puts from standard sources such as PDG, FLAG and one of the two leading Ω **IOW TO TIT THE AIM, discrepancy** How to fit the **ΔM**_s "discrepancy"

L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies 13/14 *L*IU (IF F , D urha Z IO (IPPF, Durnam) - ΔV Is interplay with B-and 4*G^F a***_L** *is**litter* **play with** *D* **and**

\mathbf{f} is some model building directions in order to alleviate the tension with \mathbf{f} C
x
component and standard Model prediction and experiment agreement and experiment and experiment agreed predict
discontinuity and experiment and experiment and experiment and experiment and experiment and experiment agre n_{max} **C**
anomalies. elements points, however, in the direction of a small discrepancy in this observable. Using up-to d auto tit the ANM sdiscrepancy s **Solution and a sexual service parametermine space of the allowed parameters** leptoquark models explaining the *B*-anomalies. Remarkably, in the former case the upper bound d_{max} in puts from standard sources such as PDG, FLAG and one of the two leading Ω **IOW TO TIT THE AIM, discrepancy** How to fit the **ΔM**_s "discrepancy"

 ϵ couplings $\begin{pmatrix} 1 \\ 2 \end{pmatrix}$ 1) Complex couplings finally identify some model building directions in order to alleviate the tension with *Bs*-mixing.

 \mathcal{L}_f is reducing containmanon 2) RH currents contamination I. INTRODUCTION

1) Complex couplings
\n2) RH currents contamination
\n
$$
\mathcal{L}_{Z'} \supset \frac{1}{2} M_{Z'}^2 (Z'_{\mu})^2 + \left(\lambda_{ij}^Q \bar{d}_L^i \gamma^{\mu} d_L^j + \lambda_{ij}^d \bar{d}_R^i \gamma^{\mu} d_R^j \right) Z'_{\mu}
$$
\n
$$
\mathcal{L}_{Z'}^{\text{eff}} \supset -\frac{1}{2M_{Z'}^2} \left[(\lambda_{23}^Q)^2 (\bar{s}_L \gamma_{\mu} b_L)^2 + (\lambda_{23}^d)^2 (\bar{s}_R \gamma_{\mu} b_R)^2 + (2\lambda_{23}^Q \lambda_{23}^d (\bar{s}_L \gamma_{\mu} b_L)(\bar{s}_R \gamma_{\mu} b_R)) + \text{h.c.} \right]
$$
\nLR operator can have any sign and gets RG enhanced

LR operator can have any sign
and gets RG enhanced and gets RG enhanced

> However RH quark currents worsen the fit of neutral current anomalies

- $1. \Delta M_s$ is a powerful test of the SM
- 2. If new physics in $b \rightarrow s \ell \ell$ natural to expect a deviation in ΔM_s

Looking forward for Lattice / HQET-SR updates !

L. Di Luzio (IPPP, Durham) - ΔMs interplay with B-anomalies

Input parameters

L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies *^s* , even for real couplings. L. Di Luzio (IPPP, Durh c

Error budget

ETMC13 [133] (262 *[±]* 10) MeV (18*.*³ *[±]* ¹*.*5) ps¹

L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies and the state of the state of

Scalar LQ and hence the constraints are expected to be minded (✏*^a*)*L*↵ *S^a* $\overline{}$ $\overline{\phant$ Many new physics models that explain the intriguing anomalies in the *b*-quark flavour sector are severely constrained by *Bs*-mixing, for which the Standard Model prediction and experiment agreed \forall cardin FL \forall One constraint to kill them all? One constraint to kill them all? Luca Di Luzio,1, ⇤ Matthew Kirk,1, *†* and Alexander Lenz1, *‡* ¹*Institute for Particle Physics Phenomenology, Department of Physics,* and hence the constraints are expected to be milder computed to be milder compared to the *Z*o calar III \sum direct due to the structure of the structure of the structure of the leptoquark cou-

is more direct due to the structure of the structure of the structure of the leptoquark cou- $S_3 \sim (3, 3, 1/3)$ *^S*³ ⇠ (¯3*,* ³*,* ¹*/*3),⁶ with the Lagrangian $S_2 \sim (\bar{3} \; 3 \; 1/3)$ \sim 3 (\sim , \sim , \sim , \sim) • $S_3 \sim (\bar{3}, 3, 1/3)$

^s , allowed for

$$
\mathcal{L}_{S_3} = -M_{S_3}^2 |S_3^a|^2 + y_{i\alpha}^{QL} \overline{Q^c}^i (\epsilon \sigma^a) L^{\alpha} S_3^a
$$

$$
\delta C_9^{\mu} = -\delta C_{10}^{\mu} = \frac{\pi}{\sqrt{2}G_F M_{S_3}^2 \alpha} \left(\frac{y_{32}^{QL} y_{22}^{QL*}}{V_{tb} V_{ts}^*} \right)
$$
\n
$$
C_{bs}^{LL} = \frac{1}{4\sqrt{2}G_F M_{S_3}^2} \frac{5}{64\pi^2} \left(\frac{y_{3\alpha}^{QL} y_{2\alpha}^{QL*}}{V_{tb} V_{ts}^*} \right)^2
$$
\n
$$
\frac{1.5}{68} \frac{1}{8} \frac{1.5}{10}
$$
\n
$$
\frac{5}{8} \frac{1.5}{10}
$$
\n
$$
\frac{5}{8} \frac{1.5}{10}
$$

onnection is "more direct" (compared to \angle), but bounds are weaker is "more direct" (compared t Connection is "more direct" (compared to \overline{a} one rather expects *yQL* (compared to 7)
Vertical model of the UP λ \mathcal{L} bounds are weaker induced at \mathcal{L}

Q

bs^L

µµ ts !

^RK(⇤) ⇡ 1 + 2 Re *^C*BSM

¹⁰ ⁼ ⇡

l
H

*Z*0

*M*Exp

fermions are in general complex even before going in the

ables. In particular *^b* ! *^s*`⁺` transitions seem to be

in tension with the SM expectations: branching ratios

L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies $\mathcal{S}^{(1)}$ is can use the results of global fits which apply the results which apply the results which apply the results which applies D ı Luzıo (IPPP, Durha $(1, 1)$. $(1, 2)$. On the other hand, in flavour models predict-. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies μ ₁₁ μ ¹ is filter play with D a $F \cap$ i Luzio (IPPP Durbam) – Λ M, internlav with B-anomalies for mediation that explains discrepancies in *^B* ! *^K*(⇤) *µ*⁺*µ* decays as compared to SM predictions. The diagram F Figure 1. Few mann of the two trees-level possibilities for F and F and F and F $F(x) = \sum_{n=1}^{\infty} F(x)$ in Feynman diagrams of the two trees-level possibilities for $F(x)$ *C*_{*z*} *C*_{*z*} *C*_{*z*} *C*_{*z*} *C*_{*s*} interplay with B-anomalies *,* (3) *CLL bs* = \overline{D} i Luzio (IPPP \overline{D} urham) - $\overline{\Lambda}M$, internlay with B-anomalies *3. Combined RK*(⇤) *and RD*(⇤) *explanations* D i Luzio (IPPP, Durham) - Δ i $^{\prime\prime}$ i_s interplay with B-anomalies

Charged currents $\bigcap_{\mathfrak{p} \text{ prime}} \mathfrak{p}$ \overline{C} elements points, however, in the direction of a small discrepancy in this observable. Using up-toarded currents such as PDG, FLAG and one of the two leading \sim groups to determine *M*SM *^s* , we find a severe reduction of the allowed parameter space of *Z*⁰ and finally identify some model building directions in order to alleviate the tension with *Bs*-mixing. I. INTRODUCTION rante construction to kill the maintaining them allows the main to kill the main α

• Connection between $R(D^{(*)})$ and ΔM_s in presence of an $SU(2)_L$ triplet op. $P(N^*)$ and M in prosonso of an α and Λ M_c in presence of α (*f^B^s*) riplet op. *g*_{*g*} *g*_{*u*} *g*_{*y*} *g*_{*u*} on Λ ⁰ mass approaches dengtherously close to the energy scales and Λ *z*¹ is in presence or an oo \angle _/_L a spice op. ¹*Institute for Particle Physics Phenomenology, Department of Physics, Durham University, DH1 3LE, Durham, United Kingdom*

cussion because of the diculty of determining the exact

4

^p2*GFM*²

‡ alexander.lenz@durham.ac.uk

mates of the combined significance of all these deviations $\mathcal{O}(\mathcal{C})$

Vus Vcb |Vub/Vcb| CKM (4)

‡ alexander.lenz@durham.ac.uk

⇤*^R^K* = 31 TeV (44)

4

^p2*GFM*²

VtbV ⇤

\Box diagrams to the e \Box very closely that of the *W* contribution in the SM (see e.g. App. B.1 in [6]). Focussing for concreteness on the case of *Bs*-mixing (analogous expressions hold for *B^d* and *K*-mixing Vector LQ [UV complete] *FLIV* (1 *x*↵)(1 *x*) ✓7*x*↵*x* ⁴ ¹ ◆

• FCNC @ I-loop under control [LDL, Fue

after replacing the down-quark flavours in the e \sim 1000,000,000,000 \sim $\text{C}_1 \text{C}_1$ and C_2 and C_3 currently C_3 currents). (LDL, Fuentes-Martin, Greljo, Nardecchia, Renner 1808.00942) 1 Grelio, Nar $C($

and keeping only the leading order in *xi*, I get

⁷ and the experimental measurement from [67]. We

Y^d (7)

$$
\begin{aligned}\n\ell_{\alpha} &\stackrel{\mathcal{E}_{\alpha}}{\longrightarrow} \mathcal{H}_{\text{eff}}^{\text{NP}} = -\frac{g_4^4}{128\pi^2 m_U^2} \left(\bar{b}_L \gamma^{\mu} s_L \right) \left(\bar{b}_L \gamma_{\mu} s_L \right) \sum_{\alpha, \beta} \lambda_{\alpha} \lambda_{\beta} F(x_{\alpha}, x_{\beta}) \\
&\geq U \\
&\geq U \\
\ell_{\alpha} &\bar{b}\n\end{aligned}
$$
\n
$$
\lambda_{\alpha} = (\mathcal{V}^{\dagger})_{\alpha b}^* \mathcal{V}_{\alpha s}^{\dagger} \qquad x_{\alpha} = m_{\alpha}^2 / M_U^2
$$

Ladratic divergencies + GIM-like suppression *C*

2 GIM-like suppression σ chouse cancellation of quadratic divergencies σ on *^F*(*x*↵*, x*) = ¹ $rac{1}{2}$ rac 1 2*x* + $\overline{}$ $\big)$ 1 <u>C</u> \sum α $\lambda_{\alpha} = 0$ ensures cancellation of quadratic divergencies + GIM-like suppression (1 *x*↵)(1 *x*) proves cancellation of quadratic divergencies + CIM like suppression down-aligned flavour of the Gilbre structure). The First suppression

q (6) $\frac{1}{2}$ (6) $\frac{$

these factors for a 600 GeV for vector-like quark mass are [36]

these factors for a 600 GeV for vector-like quark mass are [36]

P α (4) = 0 (2) = 0 (4) = lenton partners welcomed I $x_{\alpha} + x_{\beta} + \ldots$ **Fight lepton partners w** partners welcor *x*2 log *x M*SM *s* where the SM loop function, including RG e α ects from the top mass scale, reads scale, reads scale, reads scale, reads scale, α $F(x_\alpha, x_\beta) \simeq X + x_\alpha + x_\beta + \ldots$ (1) the light lepton partners welcomed ! $\sqrt{1 + x + x_0}$ **c** $\frac{1}{2}$ **c** $\frac{1}{2}$ ind the lepton partners we formed additional mass suppression proportional to *M*² *L/M*² *^U* with respect to the naive dimensional

), and for di↵erent values of *ML*. The experimental limit on *CLL*

$$
C_{bs}^{LL} \sim \Delta R_{D^{(*)}}^2 M_U^2
$$
\n
$$
C_{bs}^{LL} \sim \Delta R_{D^{(*)}}^2 M_L^2
$$
\nin absence of GIM protection

SU(4) (8) *Y^d* (6) *Y^d* (7) I ay with B-anomalies Eq. (8) with Eq. (8) with Eq. (8) we get zio (IPPP, Durham) - **A**l^vi_s interplay with B-anomalies L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies

using the SM determination in $\mathcal{P}_{\mathcal{A}}$ and $\mathcal{P}_{\mathcal{A}}$ are substituting the SM determination in $\mathcal{P}_{\mathcal{A}}$

these factors for a 600 GeV for a 600 GeV for vector-like σ 600 GeV for vector-like σ (36) σ

these factors for a 600 GeV for a 600 GeV for vector-like σ 600 GeV for vector-like σ (36) σ

rice or oir *P*(*D*(

pt
arde Vector LQ [UV complete]

• FCNC@ I-loop under control

en
Reni (9)

9.00 [LDL, Fuentes-Martin, Greljo, Nardecchia, Renner [1808.00942](http://arxiv.org/abs/arXiv:1808.00942)]

² P, I *F*(*x*↵*, x*) ' 1 + *x*↵ + *x* + *...* (8) L. Di Luzio (IPPP, Durham) - ΔM_s interplay with B-anomalies