# Non-leptonic anomaly in $B \to Dh$?


**Ardbeg**
**22.6.2023**
**Alexander Lenz**

EST^D 1815

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# Outline

1) **Overview**
2) Revisiting Exp
3) Revisiting the SM
4) Revisiting BSM
5) Some more BSM tests
6) A decisive test

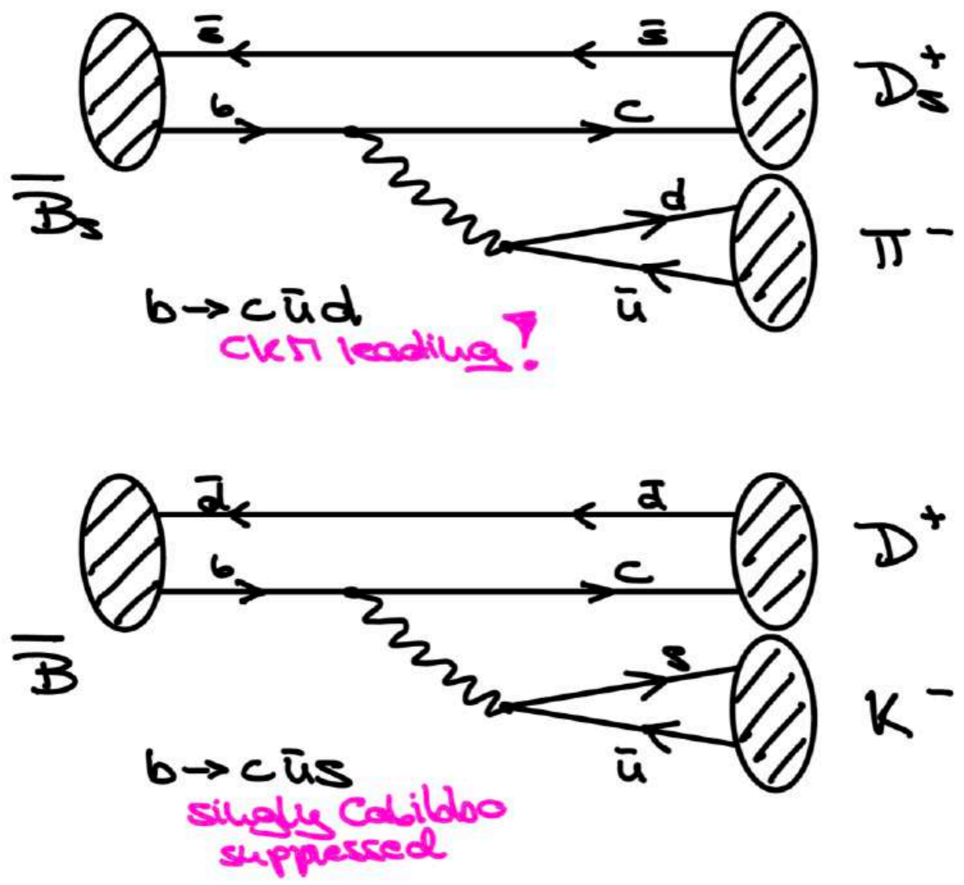

# Non-leptonic decays

**3 $\sigma$ to 7 $\sigma$ deviation of experiment from QCDf predictions with standard error estimates**

e.g. Huber, Kränkl, Li 1606.02888; Bordone, Gubernari, Huber, Jung, van Dyk 2007.10338; Cai, Deng, Li, Yang 2103.04138; …

**N. Skidmore**

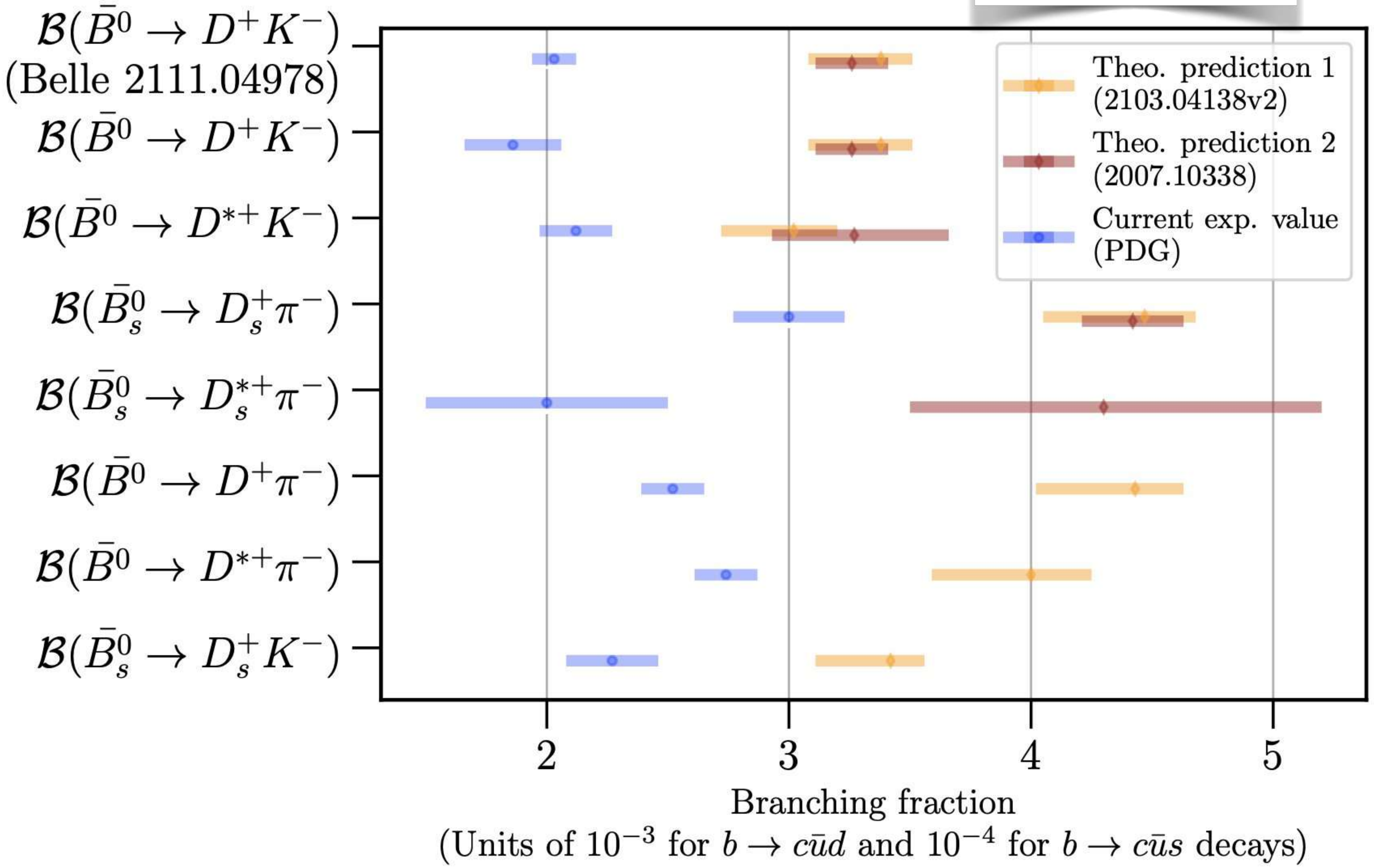
## Colour-allowed Tree-level Decays




- CKM leading decays
- The are no annihilation, penguins,…
- QCDf should work at its best!

Beneke, Buchalla, Neubert, Sachrajda 1999…

$$\langle D_q^{(*)+} L^- | \mathcal{Q}_i | \bar B_q^0 \rangle = \sum_j F_j^{\bar B_q \to D_q^{(*)}}(M_L^2) \times \int_0^1 du\, T_{ij}(u)\phi_L(u) + \mathcal{O}\left(\frac{\Lambda_{QCD}}{m_b}\right)$$



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# Non-leptonic decays


## What could go wrong?

**Alexander Lenz**
@alexlenz42

According to the new Belle measurement in 2111.04978, the decay barB_d to D+ K- is around 7 sigma of the QCD factorisation prediction in 2007.10338. Where is this discrepancy rooted?

| | |
|---|---|
| **QCD factorisation** | **90.9%** |
| New Physics | 9.1% |
| Experiment | 0% |

33 votes · Final results

9:47 AM · Nov 10, 2021 · Twitter Web App

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- **Huber, Kränkl** 1606.02888
- **Bordone, Gubernari, Huber, Jung, vanDyk** 2007.10338
- **Iguro, Kitahara** 2008.01086
- **Cai, Deng, Li, Yang** 2103.04138
- **Bordone, Greljo,Maryocca** 2103.10332
- **Beneke, Böer, Finauro, Vos** 2107.03819

Similar for $B_s \to D_s^{\mp} K^{\pm}$

- **Fleischer, Malami** 2110.04240, 2109.04950

## In the SM the determination of $\gamma$ is super precise

### The ultimate theoretical error on $\gamma$ from $B \to DK$ decays

Joachim Brod[1,*] and Jure Zupan[1,†]

[1]Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221,USA

Abstract

The angle $\gamma$ of the standard CKM unitarity triangle can be determined from $B \to DK$ decays with a very small irreducible theoretical error, which is only due to second-order electroweak corrections. We study these contributions and estimate that their impact on the $\gamma$ determination is to introduce a shift $|\delta\gamma| \lesssim \mathcal{O}(10^{-7})$, well below any present or planned future experiment.

## If there are BSM effects in non-leptonic decays, the determination of $\gamma$ can be modified by $\mathcal{O}(5^\circ)$

PHYSICAL REVIEW D **92,** 033002 (2015)

### New physics effects in tree-level decays and the precision in the determination of the quark mixing angle $\gamma$

Joachim Brod
PRISMA Cluster of Excellence and Mainz Institute for Theoretical Physics, Johannes Gutenberg University, 55099 Mainz, Germany

Alexander Lenz, Gilberto Tetlalmatzi-Xolocotzi, and Martin Wiebusch
Institute for Particle Physics Phenomenology, Department of Physics, Durham University, South Road, Durham DH1 3LE, United Kingdom

**update**
**AL, Tetlalmatzi-Xolocotzi**
**1912.07621**


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# Non-leptonic decays


PHYSICAL REVIEW D **107,** 012003 (2023)

## BELLE, 2207.00134v2

**Measurements of the branching fractions $\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^-)$ and $\mathcal{B}(\bar{B}^0 \to D^{*+}K^-)$ and tests of QCD factorization**

$$Br(\bar{B} \to D^{*+}\pi^-) = (2.62 \pm 0.02 \pm 0.09) \cdot 10^{-3}$$

$$Br(\bar{B} \to D^{*+}K^-) = (2.22 \pm 0.06 \pm 0.08) \cdot 10^{-4}$$

$$\Gamma(\bar{B}^0 \to D^{*+}h^-) = 6\pi^2\tau_B|V_{uq}|^2 f_h^2 X_h |a_1(q^2)|^2 \times d\Gamma(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu})/dq^2|_{q^2=m_h^2},$$

$$|a_1(\pi)| = 0.884 \pm 0.004 \pm 0.003 \pm 0.016$$

$$|a_1(K)| = 0.913 \pm 0.019 \pm 0.008 \pm 0.013$$

PHYSICAL REVIEW D **105,** 012003 (2022)

## 2111.04978

**Study of $\bar{B}^0 \to D^+h^-$ $(h = K/\pi)$ decays at Belle**

$$Br(\bar{B} \to D^+\pi^-) = (2.48 \pm 0.01 \pm 0.09 \pm 0.04) \cdot 10^{-3}$$

$$Br(\bar{B} \to D^+K^-) = (2.48 \pm 0.01 \pm 0.09 \pm 0.04) \cdot 10^{-3}$$

PHYSICAL REVIEW D **104,** 032005 (2021)

## 2103.06810

**Precise measurement of the $f_s/f_d$ ratio of fragmentation fractions and of $B_s^0$ decay branching fractions**

R. Aaij *et al.*[*]
(LHCb Collaboration)

$$Br(B_s \to D_s^-\pi^+) = (3.20 \pm 0.10 \pm 0.16) \cdot 10^{-3}$$

$$Br(B_s \to D_s^-K^+) = (2.41 \pm 0.05 \pm 0.06 \pm 0.14) \cdot 10^{-4}$$


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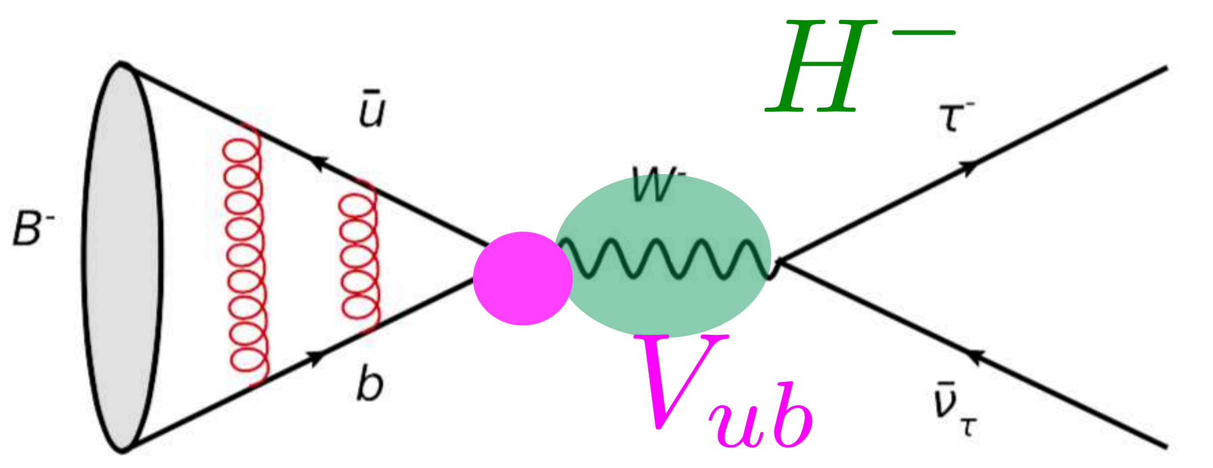
# Outline

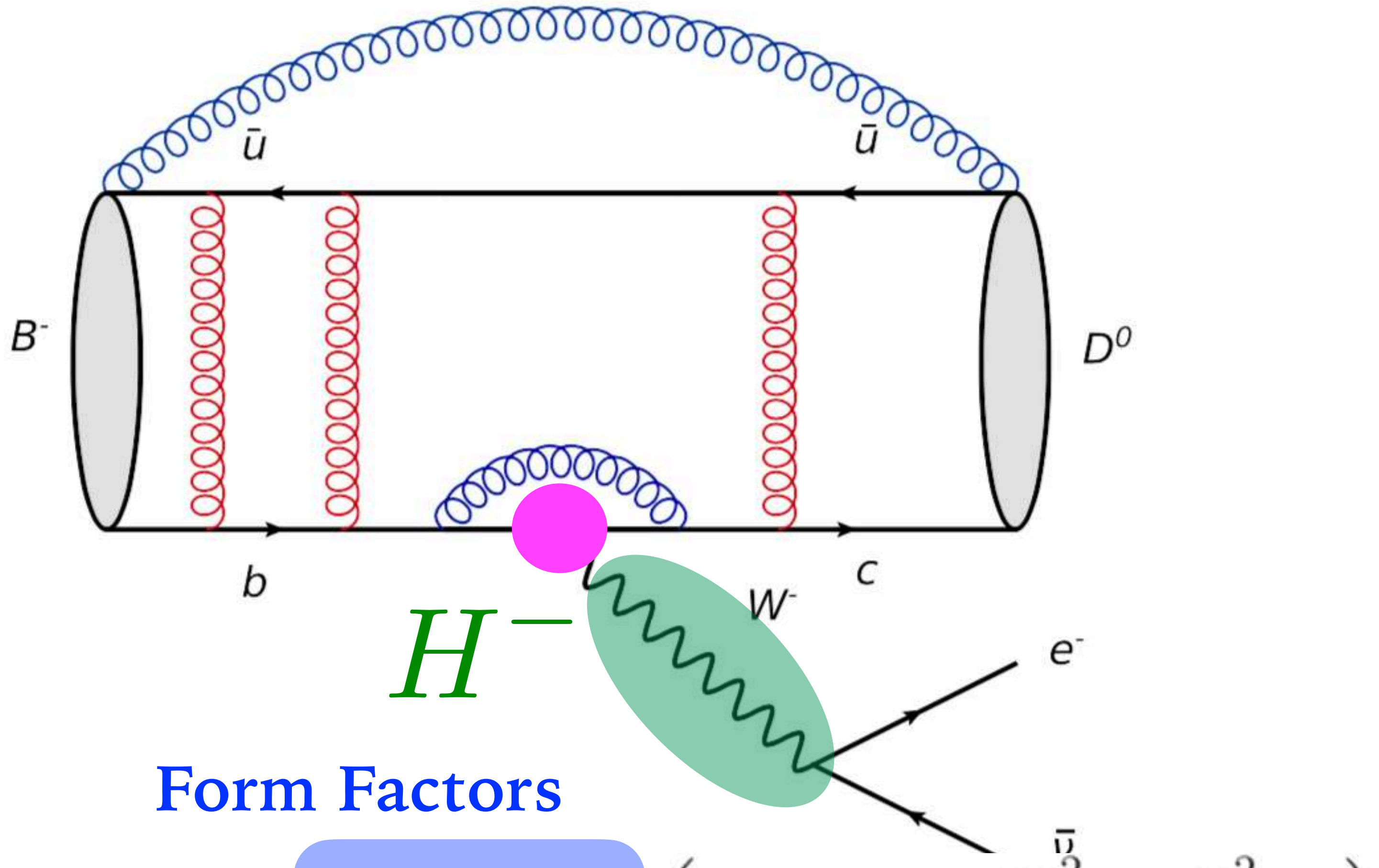
- Leptonic Decays




Decay constant

$$\langle 0|\bar{b}\gamma^\mu\gamma_5 u|B_q(p)\rangle = i f_{B_q} p^\mu$$

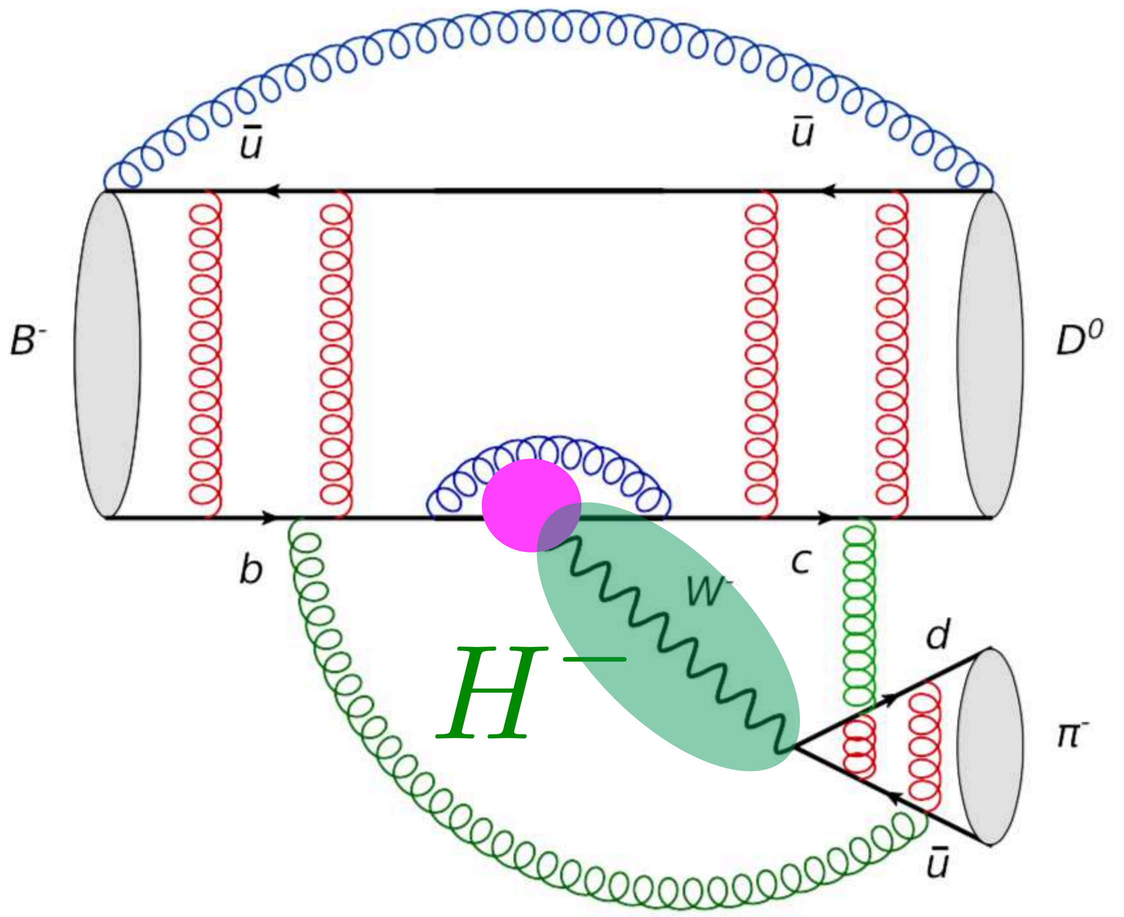
- Semileptonic Decays




Form Factors

$$\langle D^0(p_D)|\bar{c}\gamma_\mu b|B^-(p_B)\rangle = f_+^{B^-\to D^0}(q^2)\left(p_B^\mu + p_D^\mu - \frac{m_B^2 - m_D^2}{q^2}q^\mu\right)$$

- Non-leptonic Decays




Factorisation

$$\langle D^0\pi^-|\bar{c}\gamma_\mu(1-\gamma_5)b\cdot\bar{u}\gamma^\mu(1-\gamma_5)d|B^-\rangle$$
$$\approx \langle D^0|\bar{c}\gamma_\mu(1-\gamma_5)b|B^-\rangle \cdot \langle\pi^-|\bar{u}\gamma^\mu(1-\gamma_5)d|0\rangle$$

I) Imaginary part of CKM-elements = CP Violation

II) Instead of a W-Boson a charged Higgs particle could be exchanged

**III) QCD effects are crucial! Perturbative QCD corrections**
**Non-perturbative: decay constants, form factors, factorisation**

IV) Determination of SM-Parameter

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# Non-leptonic decays


**Two-body non-leptonic heavy-to-heavy decays at NNLO in QCD factorization** #1

Tobias Huber (Siegen U.), Susanne Kränkl (Siegen U.), Xin-Qiang Li (CCNU, Wuhan, Inst. Part. Phys. and Hua-Zhong Normal U. and Hua-Zhong Normal U., LQLP) (Jun 9, 2016)

Published in: *JHEP* 09 (2016) 112 • e-Print: 1606.02888 [hep-ph]



**A puzzle in $\bar{B}^0_{(s)} \to D^{(*)+}_{(s)}\{\pi^-, K^-\}$ decays and extraction of the $f_s/f_d$ fragmentation fraction** #1

Marzia Bordone (Siegen U.), Nico Gubernari (Munich, Tech. U.), Tobias Huber (Siegen U.), Martin Jung (Turin U. and INFN, Turin), Danny van Dyk (Munich, Tech. U.) (Jul 20, 2020)

Published in: *Eur.Phys.J.C* 80 (2020) 10, 951 • e-Print: 2007.10338 [hep-ph]



$$\langle D_q^{(*)+} L^- | \mathcal{Q}_i | \bar{B}_q^0 \rangle = \sum_j F_j^{\bar{B}_q \to D_q^{(*)}}(M_L^2) \times \int_0^1 du\, T_{ij}(u) \phi_L(u) + \mathcal{O}\left(\frac{\Lambda_{QCD}}{m_b}\right)$$

Eur. Phys. J. C (2020) 80:347
https://doi.org/10.1140/epjc/s10052-020-7850-9
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Theoretical Physics

**Heavy-Quark expansion for $\bar{B}_s \to D_s^{(*)}$ form factors and unitarity bounds beyond the $SU(3)_F$ limit**

Marzia Bordone[1,a], Nico Gubernari[2,b], Danny van Dyk[2,c], Martin Jung[3,d]
[1] Universität Siegen, Walter-Flex Straße 3, 57072 Siegen, Germany
[2] Technische Universität München, James-Franck-Straße 1, 85748 Garching, Germany
[3] Dipartimento di Fisica, Università di Torino & INFN, Sezione di Torino, 10125 Torino, Italy

**NNLO**

**LO in** $\varepsilon \sim \Lambda_{QCD}/E_L \sim \Lambda_{QCD}/m_b$

$$\mathcal{A}(\bar{B}_q^0 \to D_q^+ L^-) = i\frac{G_F}{\sqrt{2}} V_{uq_2}^* V_{cb}\, a_1(D_q^+ L^-) f_L \times F_0^{\bar{B}_q \to D_q}(M_L^2)(M_{B_q}^2 - M_{D_q}^2)$$

| | | |
|---|---|---|
| $F_0^{\bar{B}\to D}(M_K^2)$ | — | $0.672 \pm 0.011$ |
| $F_0^{\bar{B}_s^0\to D_s}(M_\pi^2)$ | — | $0.673 \pm 0.011$ |
| $A_0^{\bar{B}\to D^*}(M_K^2)$ | — | $0.708 \pm 0.038$ |
| $A_0^{\bar{B}_s^0\to D_s^*}(M_\pi^2)$ | — | $0.689 \pm 0.064$ |

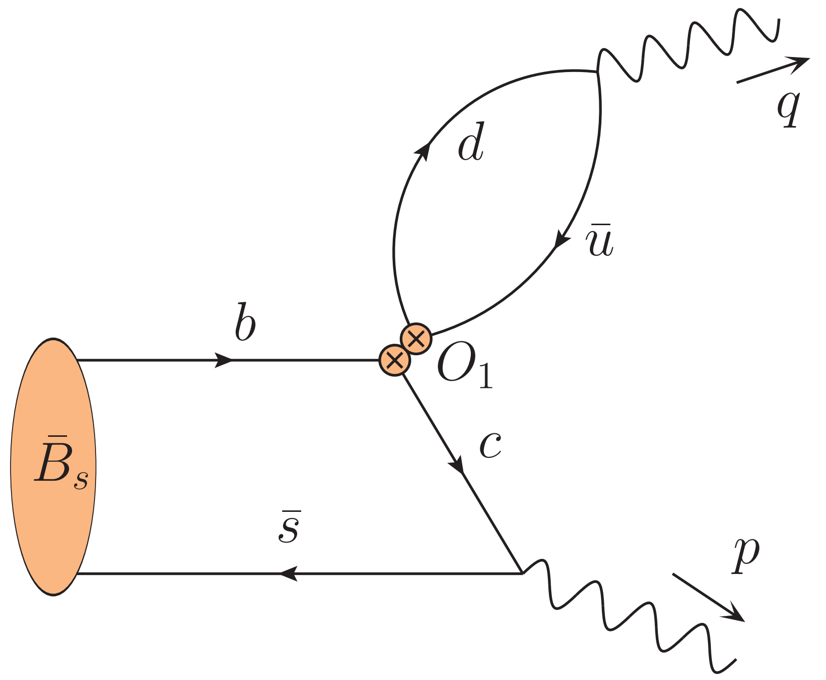
**NLO in $\epsilon$: $\epsilon^1$**

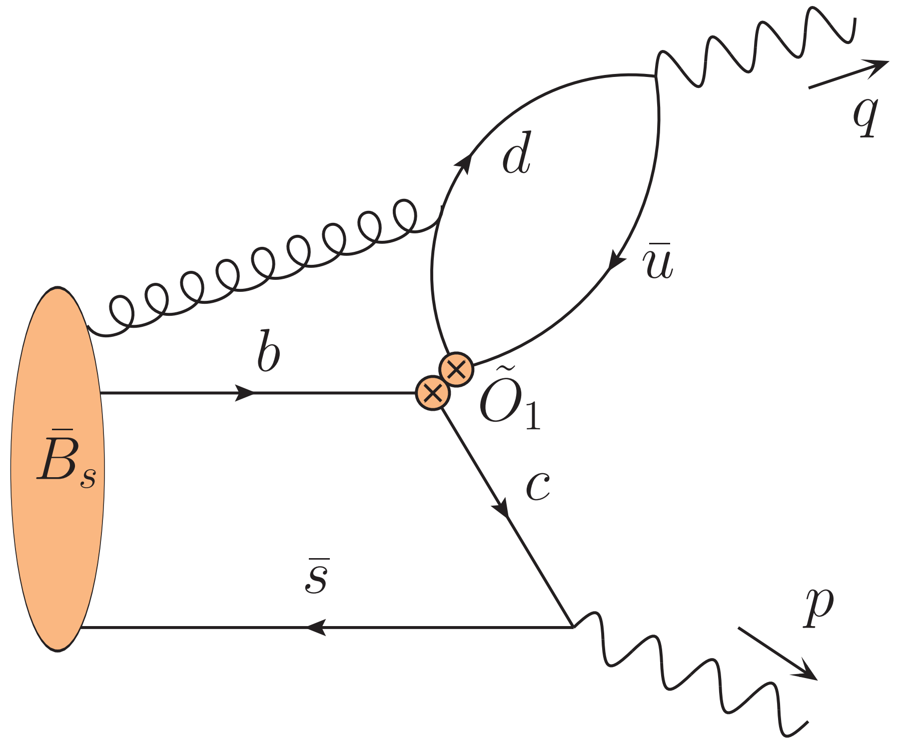
- Higher twist to light meson DA
- Emission of hard-collinear gluon from spectator quark
- Emission of hard-collinear gluon from heavy quark
- Exchange of soft-gluon between B,D-system and light meson

**Bordone, et al: first estimates of power corrections yield very small effect, overall uncertainties are also very small**


# Non-leptonic decays

## New estimates within QCD sum rules (Piscopo, Rusov in progress)




$$F_\mu^{\tilde{O}_1}(p,q) = i^2 \int d^4x \, e^{ip\cdot x} \int d^4y \, e^{iq\cdot y} \, \langle 0|\mathrm{T}\left\{ j_5^D(x), \tilde{O}_1(0), j_\mu^\pi(y) \right\} |\bar{B}_s(p+q)\rangle$$

### Other previous estimates

- [Block, Shifman (1993)]: estimate of soft-gluon effects in $\bar{B}_d^0 \to D^+\pi^-$ decays using the two-point QCD SR
  - ▷ The correlator $\mathcal{A}^\alpha = 2\int d^4x \langle D|\mathrm{T}\{O_T(x), j_\pi^\alpha(0)\}|\bar{B}\rangle e^{iq\cdot x}$
  - ▷ Short-distance OPE and saturation by the pion
  - ▷ An estimate $\dfrac{\mathcal{A}_{\mathrm{NF}}}{\mathcal{A}_{\mathrm{F}}} \sim 0.13$
- [Halperin (1994)]: estimate of soft-gluon effects in $\bar{B}^0 \to D^0\pi^0$ using the two-point QCD SR
- [Cui, Li (2004)]: estimate of soft-gluon effects in $\bar{B}^0 \to D^0\pi^0$ using LCSR with the $\pi$-meson LCDAs



**Indication: non-factorizable contribution larger - uncertainties larger - stay tuned**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# Non-leptonic decays

## New estimates within QCD sum rules (Piscopo, Rusov in progress)

### Bordone et al.:

$$\frac{\mathcal{A}(\bar{B}^0_{(s)} \to D^+_{(s)} L^-)_{\rm NLP}}{\mathcal{A}(\bar{B}^0_{(s)} \to D^+_{(s)} L^-)_{\rm LP}} \simeq -[0.06, 0.6]\%\,,$$

$$\mathrm{Br}(\bar{B}^0 \to D^+ K^-) = (3.26 \pm 0.15) \times 10^{-4}\,,$$
$$\mathrm{Br}(\bar{B}^0_s \to D^+_s \pi^-) = (4.42 \pm 0.21) \times 10^{-3}\,,$$

### Exp.:

$$\mathrm{Br}(B^0 \to D^- K^+) = (2.05 \pm 0.08) \times 10^{-4}\,,$$
$$\mathrm{Br}(B^0_s \to D^-_s \pi^+) = (2.98 \pm 0.14) \times 10^{-3}\,,$$

### Piscopo, Rusov - LCSR only

$$\frac{C_2\langle O_2^d\rangle}{C_1\langle O_1^d\rangle} = 0.051^{+0.059}_{-0.052}\,, \qquad \bar{B}^0_s \to D^+_s \pi^-\,,$$

$$\frac{C_2\langle O_2^s\rangle}{C_1\langle O_1^s\rangle} = 0.039^{+[illegible]}_{-0.034} \qquad \bar{B}^0 \to D^+ K^-\,.$$

$$\mathrm{Br}(\bar{B}^0_s \to D^+_s \pi^-) = (2.14^{+1.89}_{-1.76}) \times 10^{-3}\,,$$
$$\mathrm{Br}(\bar{B}^0 \to D^+ K^-) = (2.03^{+2.06}_{-1.50}) \times 10^{-4}\,,$$

Preliminary


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# Non-leptonic decays


PHYSICAL REVIEW D **102,** 071701(R) (2020)

## 2008.01086

**Implications for new physics from a novel puzzl in $\bar{B}^0_{(s)} \to D^{(*)+}_{(s)} \{\pi^-, K^-\}$ decays**

Syuhei Iguro[1,*] and Teppei Kitahara[2,3,†]

### BSM in $C_1$ and $C_2$

to these processes. In spite of severe bounds from the other flavor observables and the LHC searches, we conclude that a $-10\%$ shift in the $b \to c\bar{u}q$ amplitude is possible by the left-handed $W'$ model. Such a new physics contribution can reduce the tension in the $b \to c\bar{u}q$ processes.

JHEP

PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: *March 15, 2021*
REVISED: *August 31, 2021*
ACCEPTED: *September 30, 2021*
PUBLISHED: *October 28, 2021*

## 2103.04138

**Probing new physics in class-I B-meson decays into heavy-light final states**

**Fang-Min Cai,[1] Wei-Jun Deng,[1] Xin-Qiang Li[2] and Ya-Dong Yang**

*Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, P.R. China*

- **Redo analysis of Bordone at al. + ratio with sl**
- **Extend to 20 BSM operators**

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{cb} V_{uq}^* \Big\{ \sum_i \mathcal{C}_i(\mu)\mathcal{Q}_i(\mu) + \sum_{i,j} \Big[ C_i^{VLL}(\mu)\mathcal{Q}_i^{VLL}(\mu) + C_i^{VLR}(\mu)\mathcal{Q}_i^{VLR}(\mu) + C_j^{SLL}(\mu)\mathcal{Q}_j^{SLL}(\mu) + C_i^{SLR}(\mu)\mathcal{Q}_i^{SLR}(\mu) + (L \leftrightarrow R) \Big] \Big\} + \text{h.c.}\,,$$

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# Non-leptonic decays



JHEP

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RECEIVED: *April 1, 2021*
REVISED: *July 10, 2021*
ACCEPTED: *July 22, 2021*
PUBLISHED: *August 9, 2021*


**2008.01086**

**Exploiting dijet resonance searches for flavor physics**


Marzia Bordone,[a,b] Admir Greljo[c,d] and David Marzocca[e]


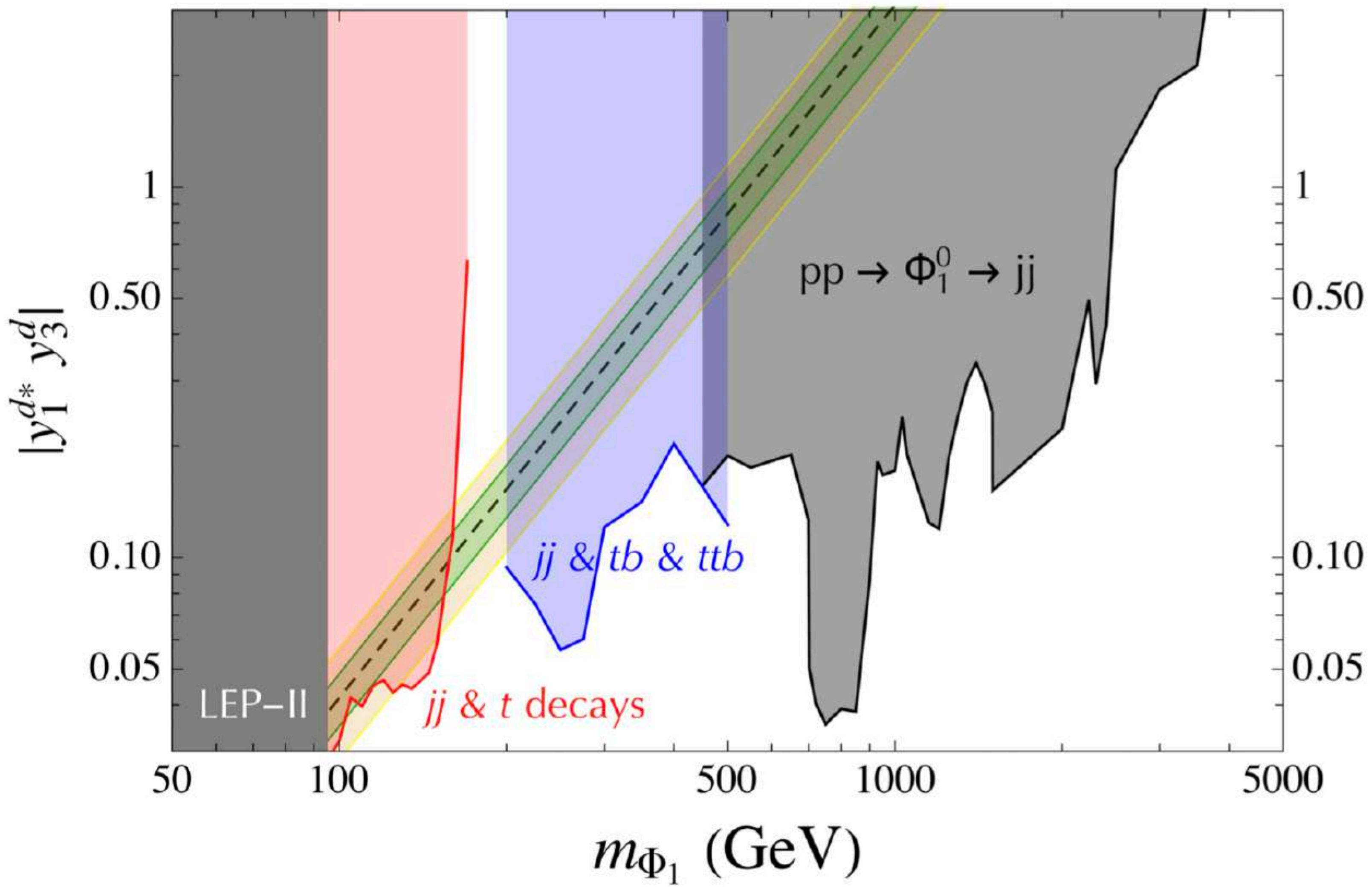


**Figure 7**. The compilation of the high-$p_T$ collider constraints on the $\Phi_1$ model (Benchmark I) together with the best-fit region from non-leptonic $B$ decays. See section 4.2 for details.

## Ongoing re-analysis

**Atkinson, Englert, Kirk, Tetlalmatzi-Xolocotzi**

- **Confirmation of results from Cai et al.**
- **What happens if SM central values and SM uncertainties change?**
- **Include top-observables**

- **"BSM in non-leptonic tree-level decay is excluded by collider constraints" is a very strong conclusion!**
  **Uncertainties due to e.g. recasting?**

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# Non-leptonic decays

Taming New Physics in $b \to c\bar{u}d(s)$ with $\tau(B^+)/\tau(B_d)$ and $a_{sl}^d$

**2211.020724**

Alexander Lenz,[a] Jakob Müller,[a] Maria Laura Piscopo,[a] Aleksey V. Rusov[a]

$$\mathcal{H}_{\rm eff}^{\rm NP}(x) = \frac{4G_F}{\sqrt{2}} V_{cb} V_{ud}^* \sum_{i=1}^{10} \left[ C_i^{\rm NP}\, Q_i(x) + C_i^{\prime \rm NP}\, Q_i'(x) \right] + {\rm h.c.},$$

$$Q_1 = (\bar{c}^i \gamma_\mu P_L\, b^i)(\bar{d}^j \gamma^\mu P_L\, u^j)\,, \qquad Q_2 = (\bar{c}^i \gamma_\mu P_L\, b^j)(\bar{d}^j \gamma^\mu P_L\, u^i)\,,$$

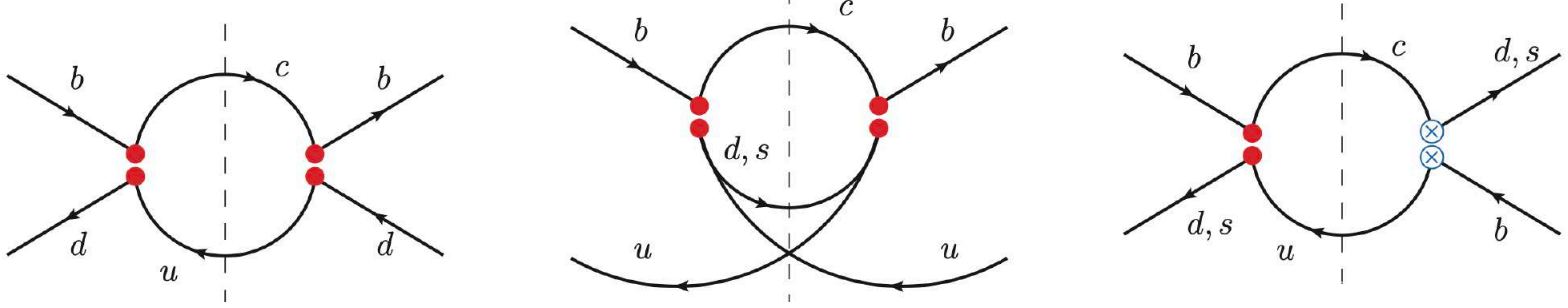
$$Q_3 = (\bar{c}^i \gamma_\mu P_R\, b^i)(\bar{d}^j \gamma^\mu P_L\, u^j)\,, \qquad Q_4 = (\bar{c}^i \gamma_\mu P_R\, b^j)(\bar{d}^j \gamma^\mu P_L\, u^i)\,,$$

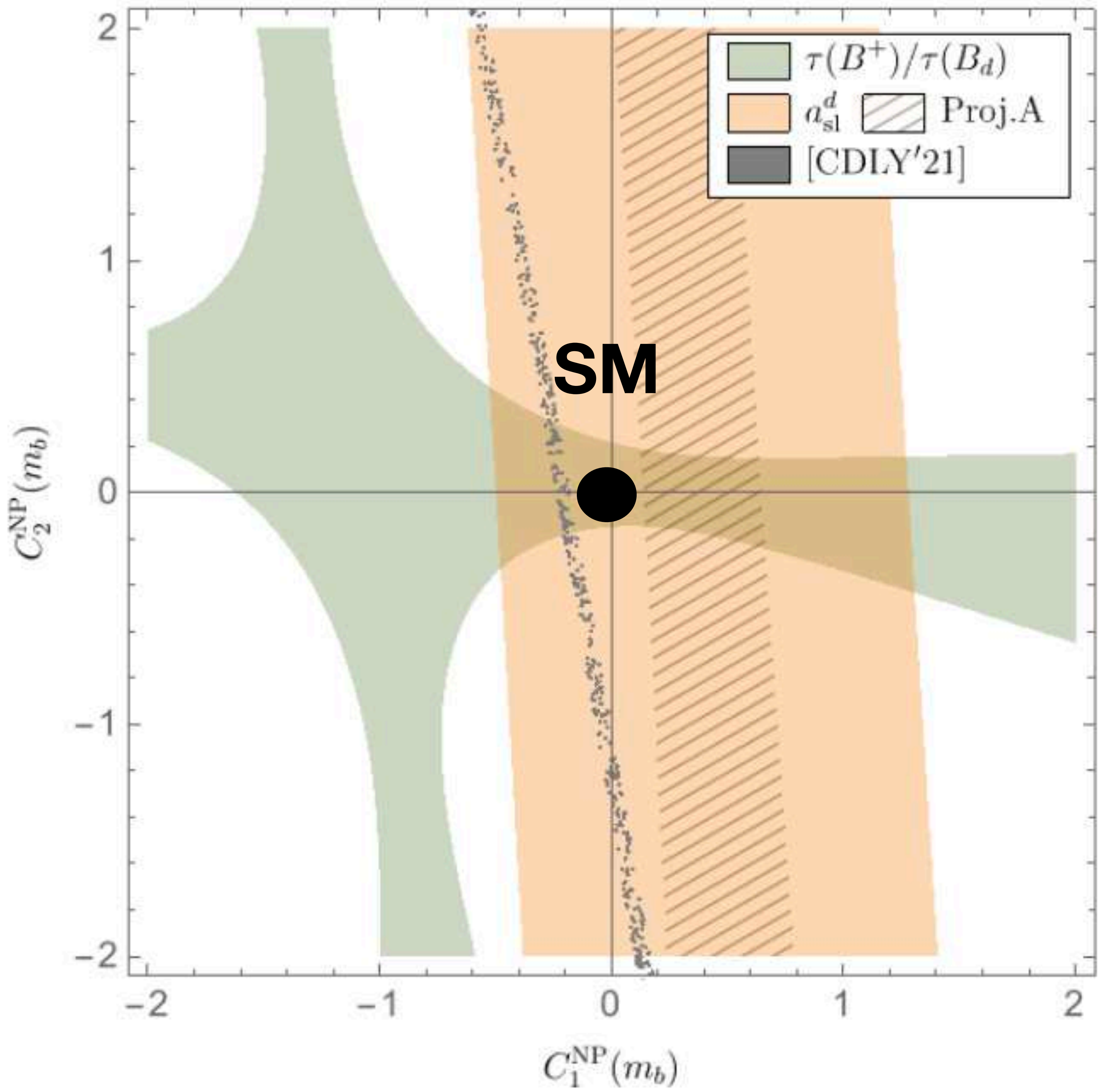
$$Q_5 = (\bar{c}^i P_L\, b^i)(\bar{d}^j P_R\, u^j)\,, \qquad Q_6 = (\bar{c}^i P_L\, b^j)(\bar{d}^j P_R\, u^i)\,,$$

$$Q_7 = (\bar{c}^i P_R\, b^i)(\bar{d}^j P_R\, u^j)\,, \qquad Q_8 = (\bar{c}^i P_R\, b^j)(\bar{d}^j P_R\, u^i)\,,$$

$$Q_9 = (\bar{c}^i \sigma_{\mu\nu} P_R\, b^i)(\bar{d}^j \sigma^{\mu\nu} P_R\, u^j)\,, \qquad Q_{10} = (\bar{c}^i \sigma_{\mu\nu} P_R\, b^j)(\bar{d}^j \sigma^{\mu\nu} P_R\, u^i)\,.$$

**Lifetime** **Lifetime** **Mixing**



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$$Q_1 = (\bar{c}^i \gamma_\mu P_L b^i)(\bar{d}^j \gamma^\mu P_L u^j)\,, \quad Q_2 = (\bar{c}^i \gamma_\mu P_L b^j)(\bar{d}^j \gamma^\mu P_L u^i)\,,$$

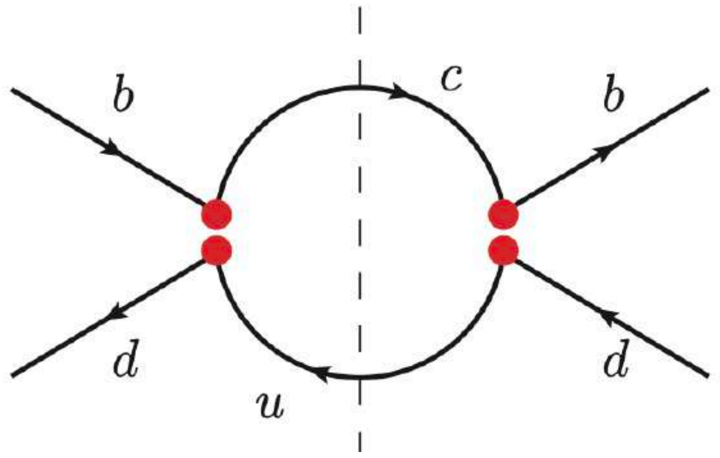
$$Q_3 = (\bar{c}^i \gamma_\mu P_R b^i)(\bar{d}^j \gamma^\mu P_L u^j)\,, \quad Q_4 = (\bar{c}^i \gamma_\mu P_R b^j)(\bar{d}^j \gamma^\mu P_L u^i)\,,$$

$$Q_5 = (\bar{c}^i P_L b^i)(\bar{d}^j P_R u^j)\,, \quad Q_6 = (\bar{c}^i P_L b^j)(\bar{d}^j P_R u^i)\,,$$

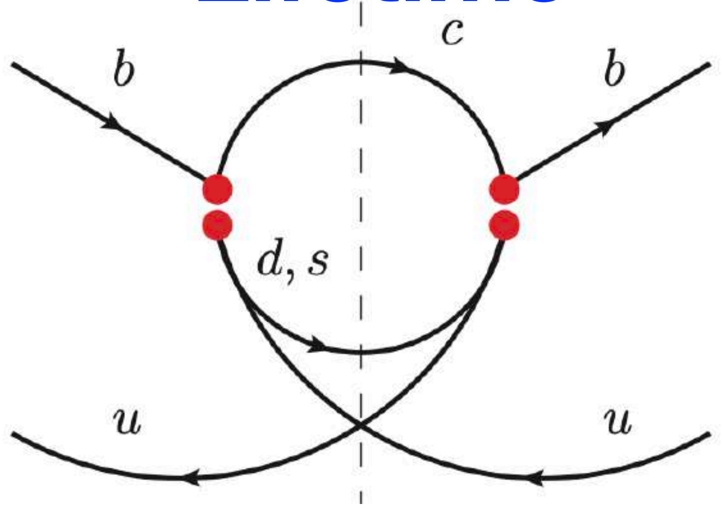
$$Q_7 = (\bar{c}^i P_R b^i)(\bar{d}^j P_R u^j)\,, \quad Q_8 = (\bar{c}^i P_R b^j)(\bar{d}^j P_R u^i)\,,$$

$$Q_9 = (\bar{c}^i \sigma_{\mu\nu} P_R b^i)(\bar{d}^j \sigma^{\mu\nu} P_R u^j)\,, \quad Q_{10} = (\bar{c}^i \sigma_{\mu\nu} P_R b^j)(\bar{d}^j \sigma^{\mu\nu} P_R u^i)\,.$$

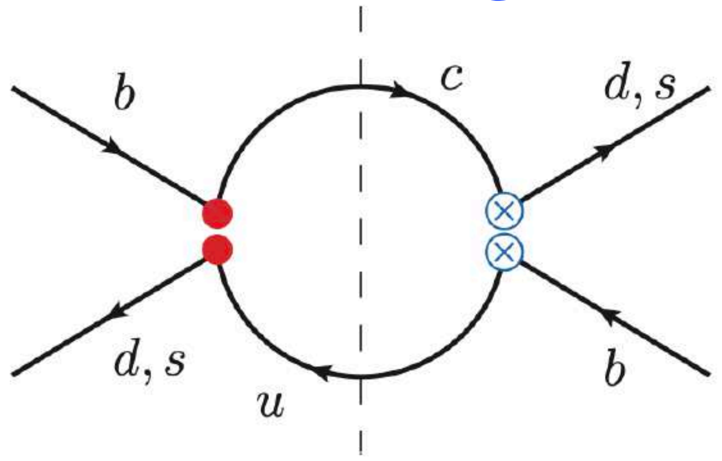
Lifetime

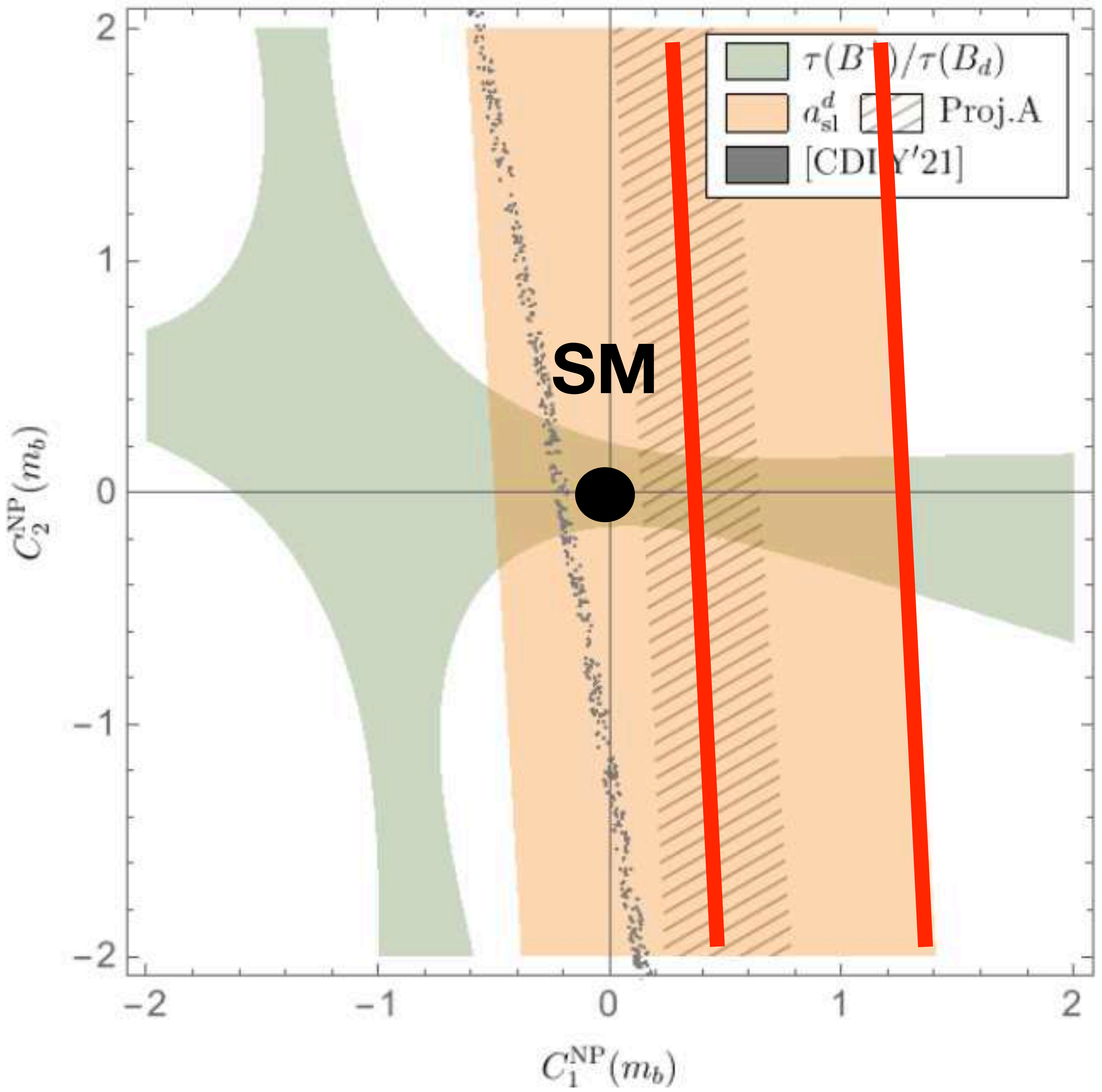



Lifetime




Mixing




Lucia: LHCb Next Week

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Alexander Lenz,[a] Jakob Müller,[a] Maria Laura Piscopo,[a] Aleksey V. Rusov[a]


$$\mathcal{H}_{\rm eff}^{\rm NP}(x) = \frac{4G_F}{\sqrt{2}} V_{cb} V_{ud}^* \sum_{i=1}^{10} \left[ C_i^{\rm NP}\, Q_i(x) + C_i^{\prime\rm NP}\, Q_i^\prime(x) \right] + {\rm h.c.},$$

$$Q_1 = (\bar{c}^i \gamma_\mu P_L\, b^i)(\bar{d}^j \gamma^\mu P_L\, u^j)\,, \qquad Q_2 = (\bar{c}^i \gamma_\mu P_L\, b^j)(\bar{d}^j \gamma^\mu P_L\, u^i)\,,$$

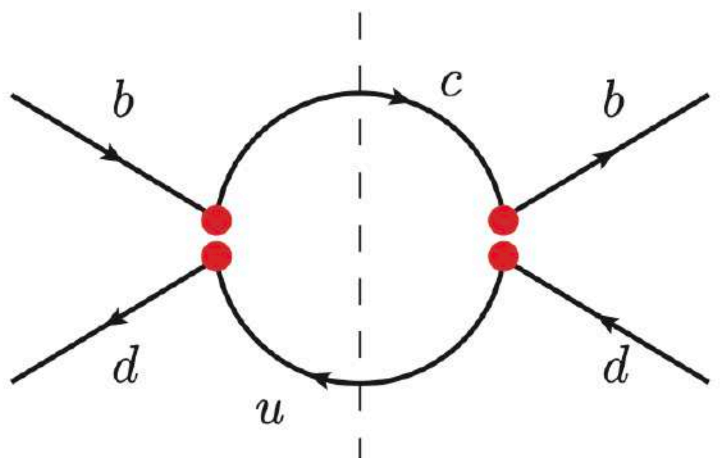
$$Q_3 = (\bar{c}^i \gamma_\mu P_R\, b^i)(\bar{d}^j \gamma^\mu P_L\, u^j)\,, \qquad Q_4 = (\bar{c}^i \gamma_\mu P_R\, b^j)(\bar{d}^j \gamma^\mu P_L\, u^i)\,,$$

$$Q_5 = (\bar{c}^i P_L\, b^i)(\bar{d}^j P_R\, u^j)\,, \qquad Q_6 = (\bar{c}^i P_L\, b^j)(\bar{d}^j P_R\, u^i)\,,$$

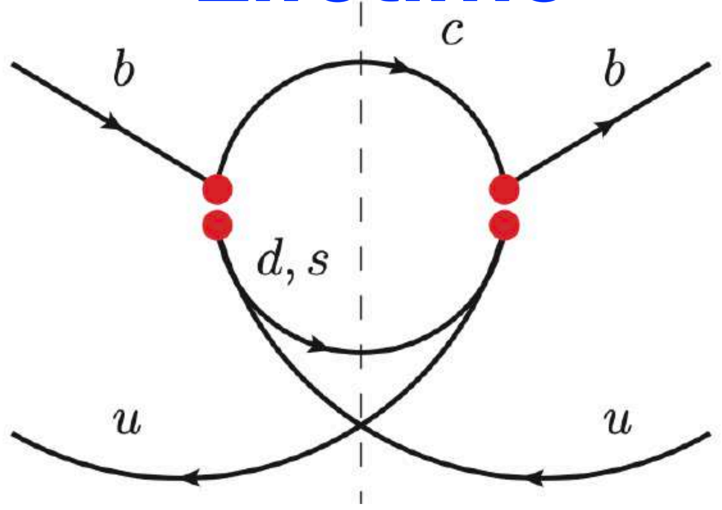
$$Q_7 = (\bar{c}^i P_R\, b^i)(\bar{d}^j P_R\, u^j)\,, \qquad Q_8 = (\bar{c}^i P_R\, b^j)(\bar{d}^j P_R\, u^i)\,,$$

$$Q_9 = (\bar{c}^i \sigma_{\mu\nu} P_R\, b^i)(\bar{d}^j \sigma^{\mu\nu} P_R\, u^j)\,, \qquad Q_{10} = (\bar{c}^i \sigma_{\mu\nu} P_R\, b^j)(\bar{d}^j \sigma^{\mu\nu} P_R\, u^i)\,.$$

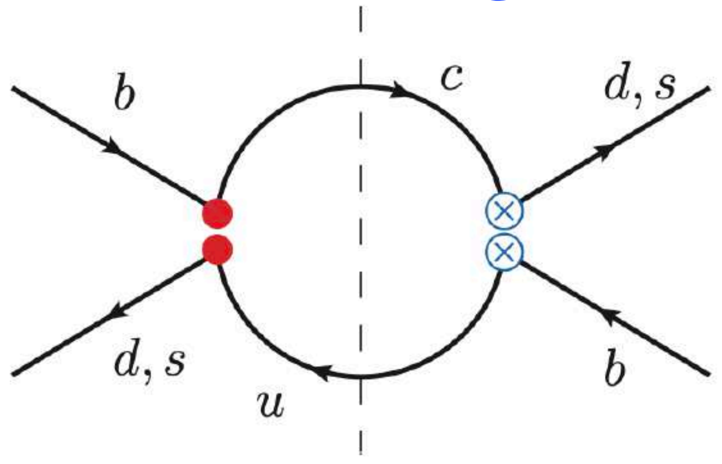
**Lifetime**

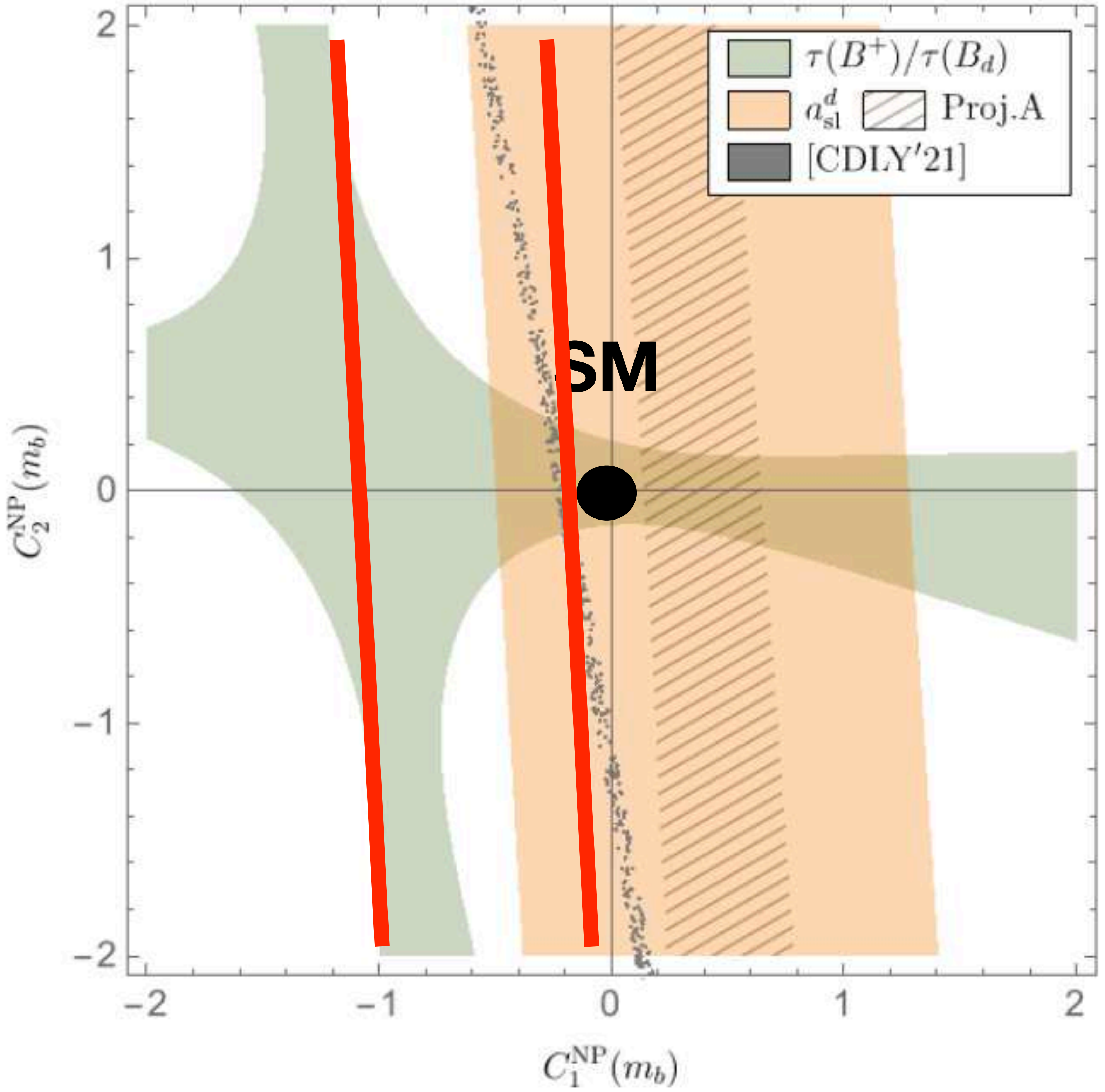



**Lifetime**




**Mixing**




**Lucia: LHCb Next Week**

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# Outline

1) Overview
2) Revisiting Exp
3) Revisiting the SM
4) Revisiting BSM
5) Some more BSM tests
6) **A decisive test**


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# Non-leptonic decays

PHYSICAL REVIEW D **105,** 115023 (2022)

**2111.04478, see also Fleischer, Vos 1606.06042**

**Testing the Standard Model with *CP* asymmetries in flavor-specific nonleptonic decays**


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- $a_{fs}^q$ is typically measured with semi-leptonic $B_q$ decays
- One could also use the flavour specific $\bar{B}_s \to D_s^+ \pi^-$ decay

$$a_{sl}^{s,\mathrm{Exp}} = \left(60 \pm 280\right) \cdot 10^{-5},$$
$$a_{sl}^{d,\mathrm{Exp}} = \left(-21 \pm 17\right) \cdot 10^{-4}.$$

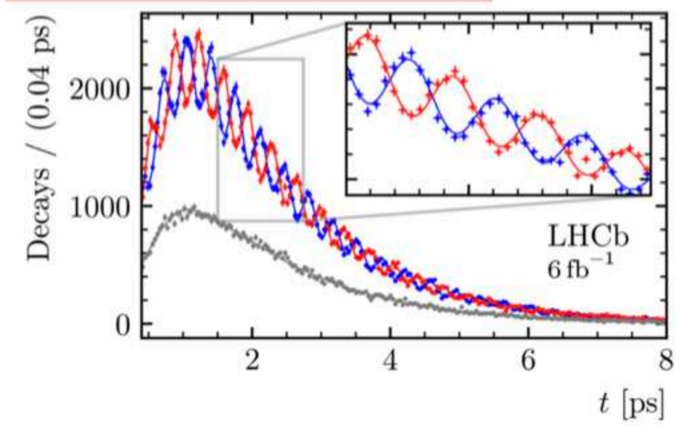
**HFLAV 1970?**

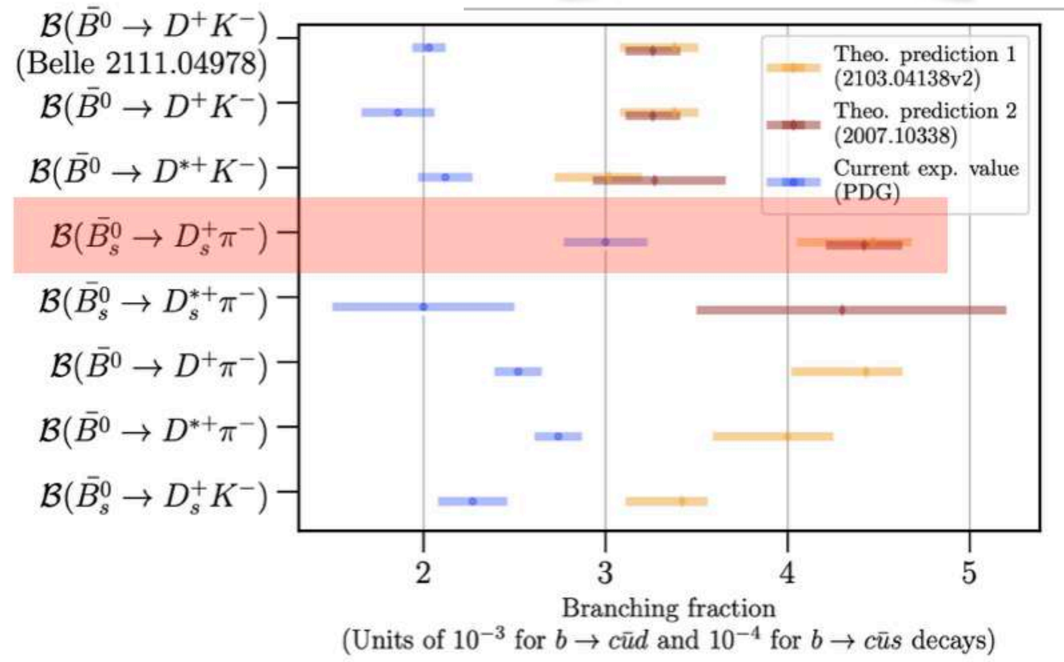
12 April 2021: Fascinating quantum mechanics.

Precise determination of the $B_s^0$–$\bar{B}_s^0$ oscillation frequency.

*"A phenomenon in which quantum mechanics gives a most remarkable prediction" - Richard Feynman*

Today, the LHCb Collaboration submitted a paper for publication that reports a precise determination of the $B_s^0$–$\bar{B}_s^0$ oscillation frequency. This result is presented also today at the joint annual conference of the UK Institute of Physics (IOP), organized by the University of Edinburgh. The $B_s^0$–$\bar{B}_s^0$ oscillation is a spectacular and fascinating feature of quantum mechanics. The strange beauty particle $B^0_s$ composed of a beauty antiquark ($\bar{b}$) bound with a strange quark s turns into its antiparticle partner $\bar{B}_s^0$ composed of a b quark and an s antiquark ($\bar{s}$) about 3 million million times per second ($3*10^{12}$) as seen in the image below.




- Assume: there is new physics in these decays, potentially CP violating

$$\mathcal{A}_f = \left|\mathcal{A}_f^{\mathrm{SM}}\right| e^{i\phi^{\mathrm{SM}}} e^{i\varphi^{\mathrm{SM}}} + \left|\mathcal{A}_f^{\mathrm{BSM}}\right| e^{i\phi^{\mathrm{BSM}}} e^{i\varphi^{\mathrm{BSM}}}$$
$$=: \left|\mathcal{A}_f^{\mathrm{SM}}\right| e^{i\phi^{\mathrm{SM}}} e^{i\varphi^{\mathrm{SM}}} \left(1 + r e^{i\phi} e^{i\varphi}\right),$$

Discrepancy QCDf vs Exp. suggests $r \approx 0.1 - 0.2$

- Derive CP asymmetry

$$\approx 2r \sin\phi \sin\varphi < 0.40$$

$$A_{\mathrm{fs}}^q = \frac{a_{\mathrm{fs}}^q - 2r \sin\phi \sin\varphi + 2a_{\mathrm{fs}}^q r \cos\phi \cos\varphi + a_{\mathrm{fs}}^q r^2}{1 + 2r \cos\phi \cos\varphi + r^2 - 2a_{\mathrm{fs}}^q r \sin\phi \sin\varphi} \approx a_{\mathrm{fs}}^q - A_{\mathrm{dir}}^q$$

Constrained by semi-leptonic Measurements

**Significant exp. deviation of $A_{fs}^q$ from $a_{sl}^q$**
**= unambiguous and theory independent signal for BSM**

$$a_{sl}^{s,\mathrm{Exp}} = \left(60 \pm 280\right) \cdot 10^{-5},$$
$$a_{sl}^{d,\mathrm{Exp}} = \left(-21 \pm 17\right) \cdot 10^{-4}.$$

**HFLAV 1970?**

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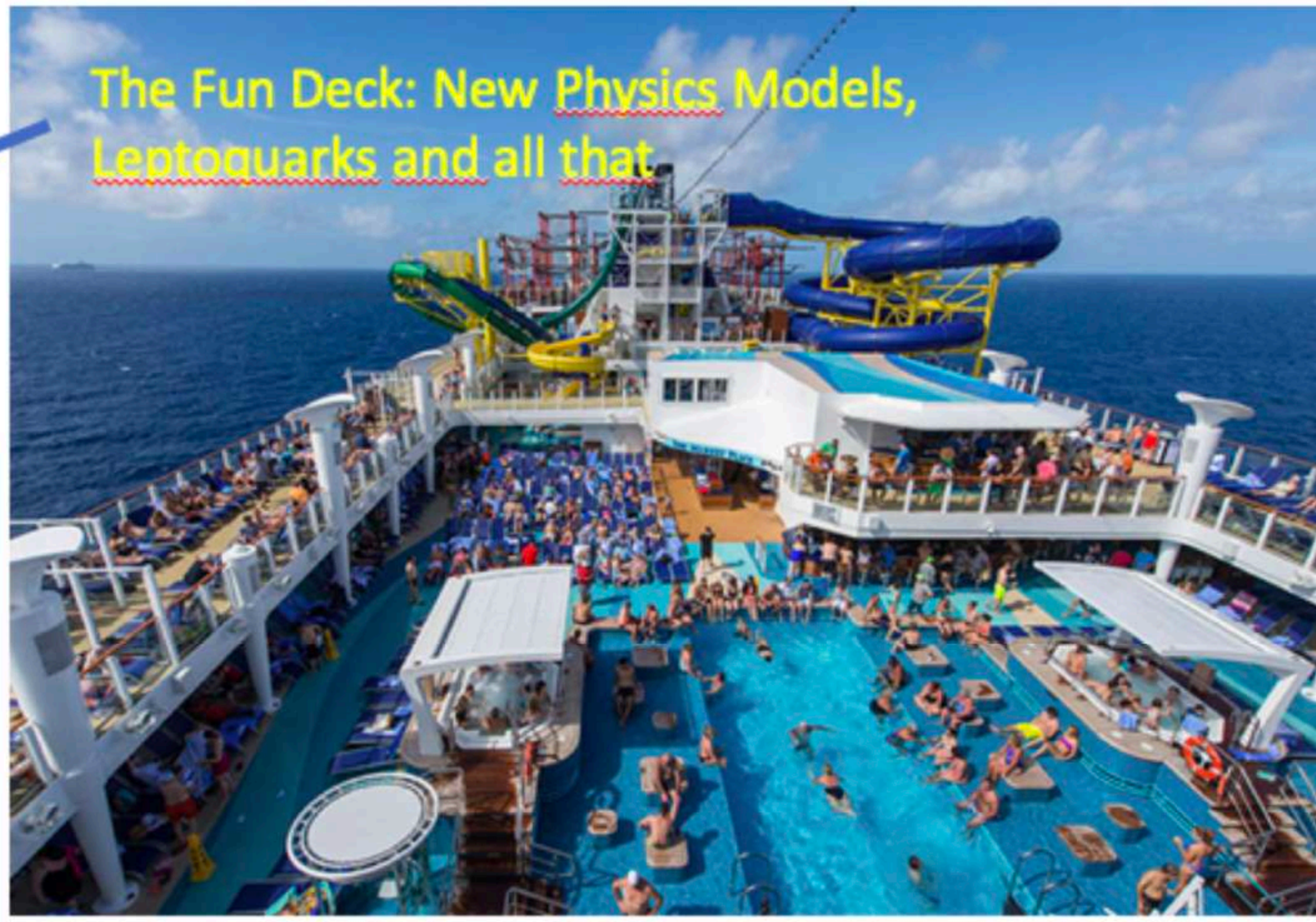
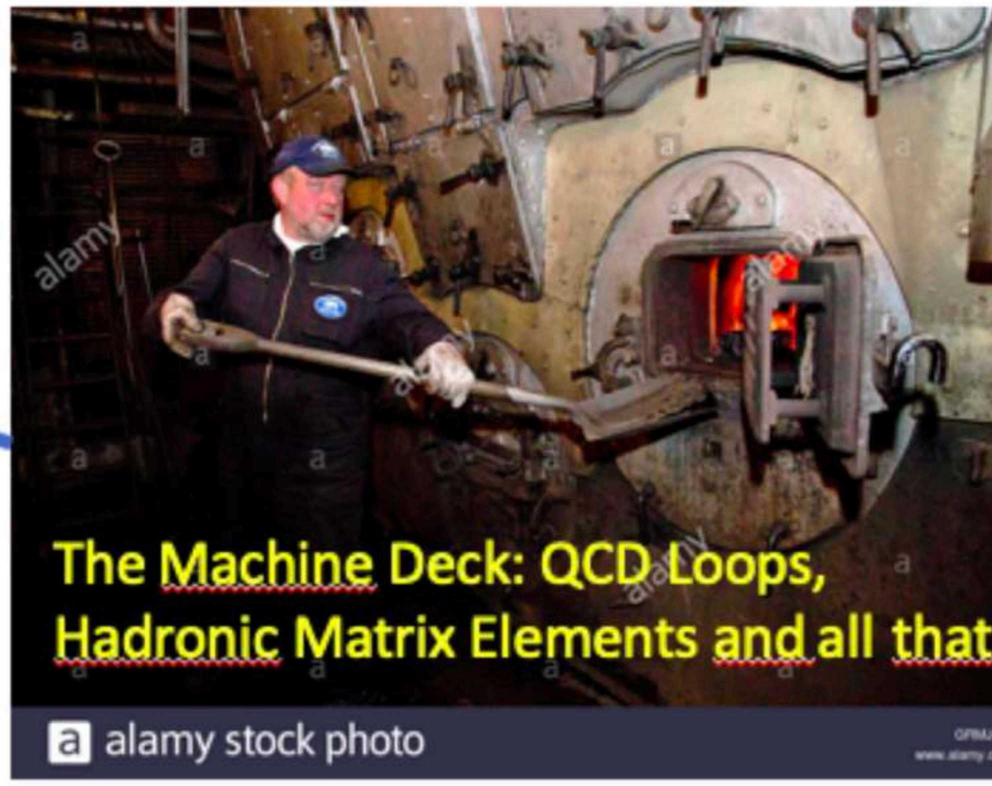
# Conclusion

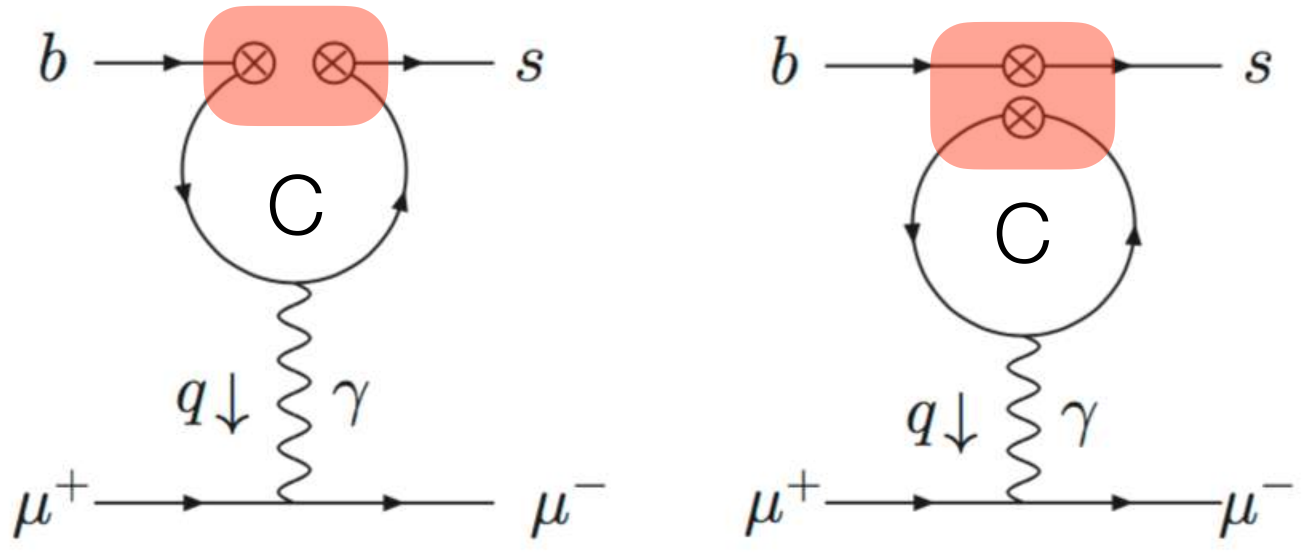

- We must still understand QCD better
  => put more efforts into the machine deck or the ship will get stuck or drift away!




- Still room for BSM effects in non-leptonic tree-level decays with interesting opportunities
  => Enjoy the f(s)un deck


- Since $R_K$ is gone, a $b \to c\bar{c}s$ BSM explanation of e.g. $B_s \to \phi ll$ might be more interesting again




**Charming new physics in rare B-decays and mixing**
**Jaeger, Kirk, Lenz, Leslie**
arXiv: 1701.09183; 1902.10.12924

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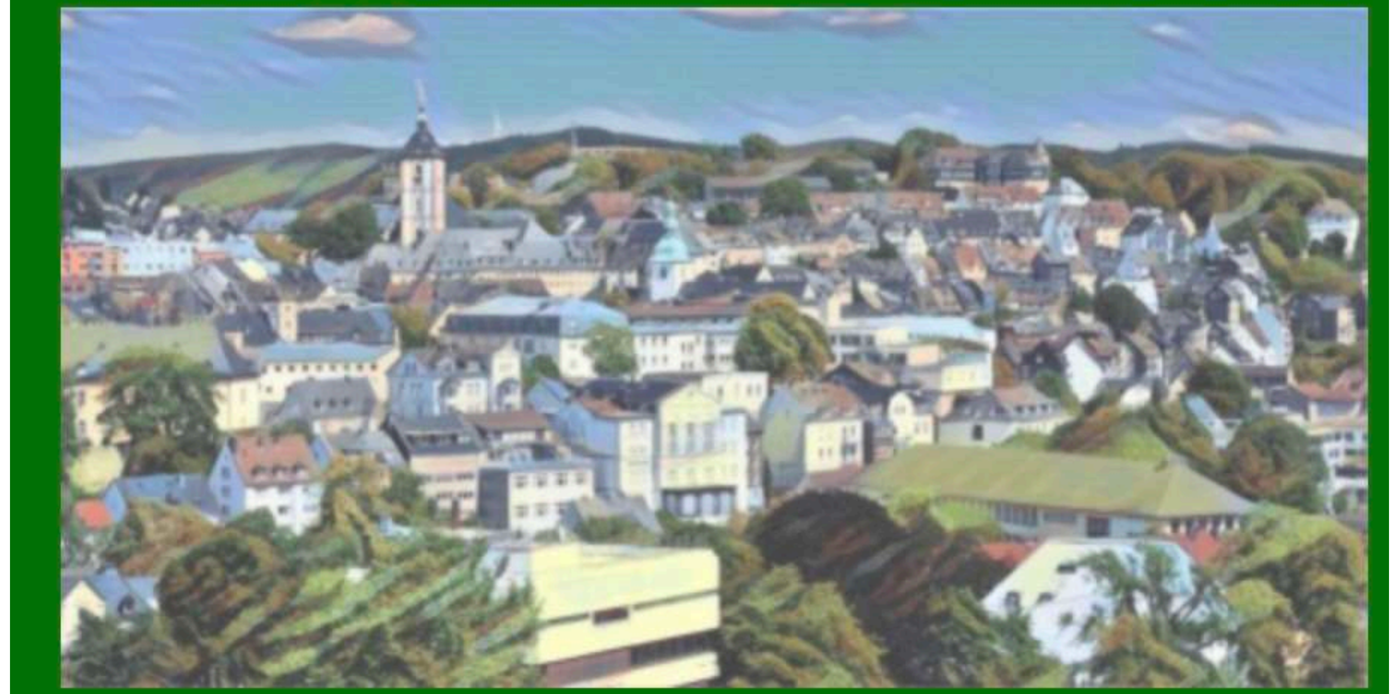
SUBATOMIC HEROES

11th International Workshop on Charm Physics (CHARM 2023)



Jul 17 – 21, 2023
Hörsaalzentrum Unteres Schloss
Europe/Berlin timezone

## Beyond the Flavour Anomalies

1.-3.4.2020
IPPP, Durham University, UK

Topics:

- Global fits for $b \to sll$ anomalies
- Experimental challenges for future measurements
- Connections to $R_D$, $R_{D^*}$, ....
- Connections to $b \to dll$
- Connections to $b \to s\nu\nu$, $b \to s\tau\tau$
- Connections to $g-2$, $B$-mixing, CPV,...
- Connections to high-$q^2$ physics
- BSM models to explain anomalies
- Hadronic corrections

Local Organising Committee:
- Maria Laura Piscopo
- Christos Vlahos
- Alexander Lenz

Organising Committee:
- Martin Bauer (IPPP)
- Alexander Lenz (IPPP)
- Michael McCann (Imperial)
- Mitesh Patel (Imperial)
- Kostas Petridis (Bristol)
- Michael Spannowsky (IPPP)

**5th edition in April 2024 in Siegen**


# The end