color meets flavor

Outlook for theory and BSM investigations

Siegen
25.9.2025
Alexander Lenz

Universität Siegen

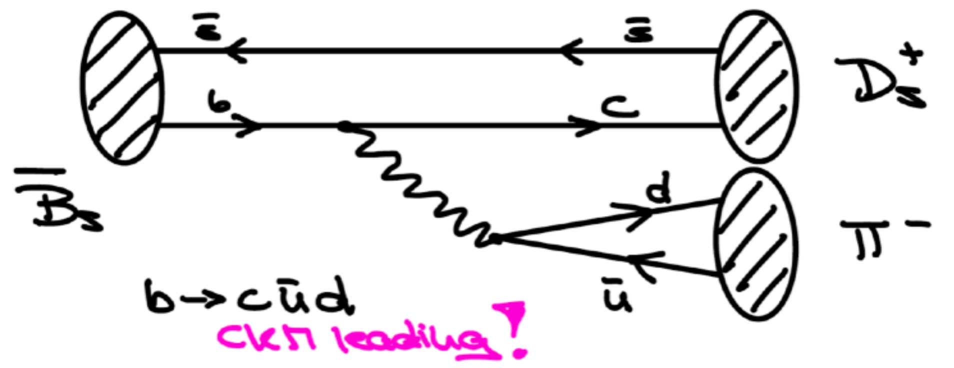
Outline

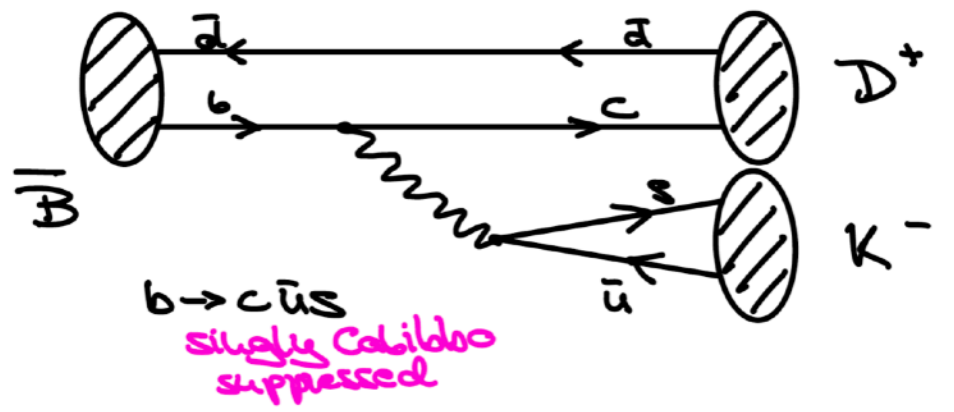
1) **Why BSM effects in tree-level decays?**
2) A decisive test of certain BSM effects in tree-level decays
3) Reminder: extraction of γ_{CKM} in BSM scenarios

Why BSM effects in tree-level decays?

3 σ to 7 σ deviation of experiment from leading power QCDf predictions with standard error estimates

Colour-allowed Tree-level Decays

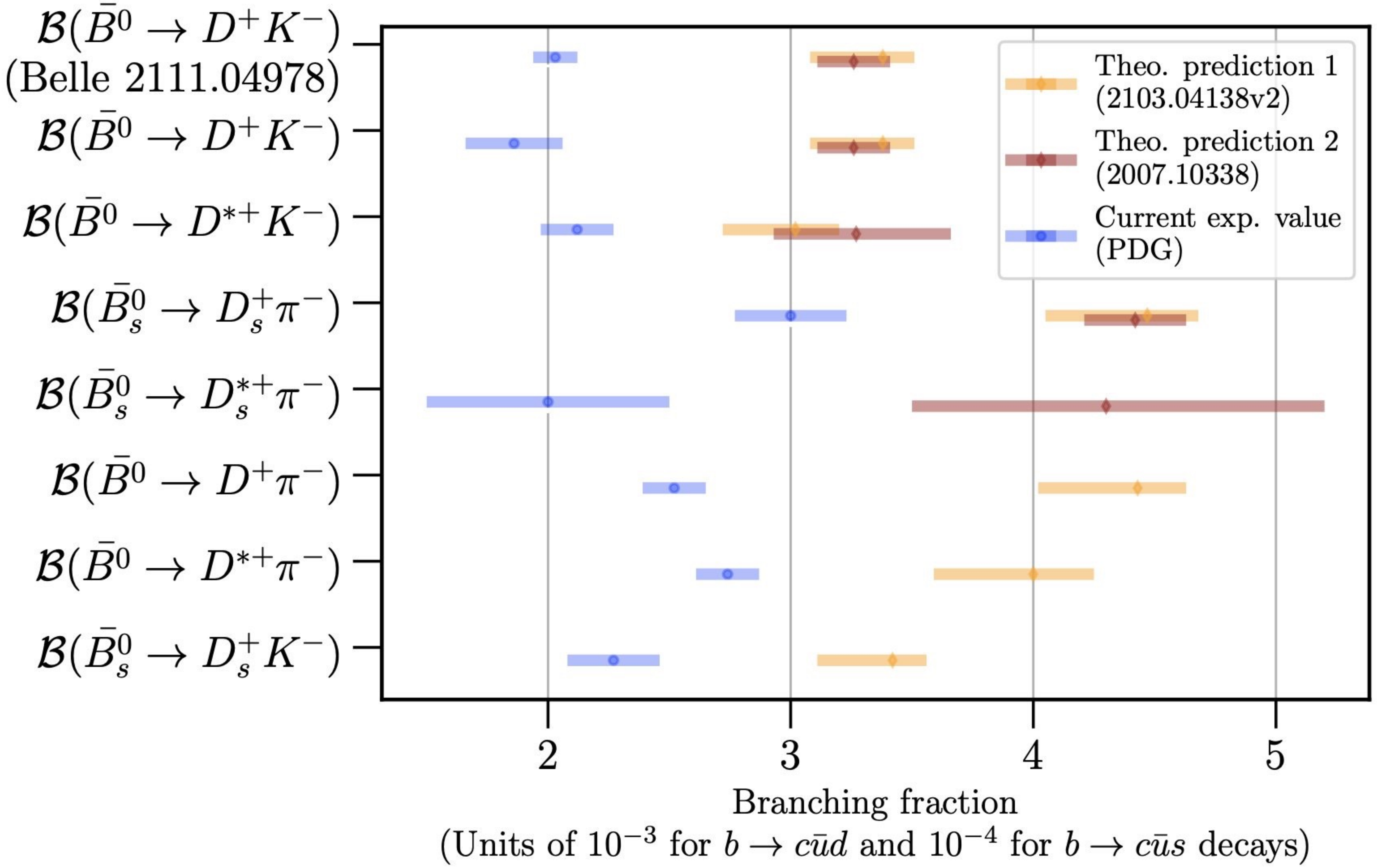




- CKM leading decays
- The are no annihilation, penguins,…
- QCDf should work at its best!

Beneke, Buchalla, Neubert, Sachrajda 1999…

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



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The “favoured” explanation?

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

The “unfavoured” explanation?

3 σ to 7 σ deviation of experiment from leading power QCDf predictions with standard error estimates - confirmed by more recent measurements

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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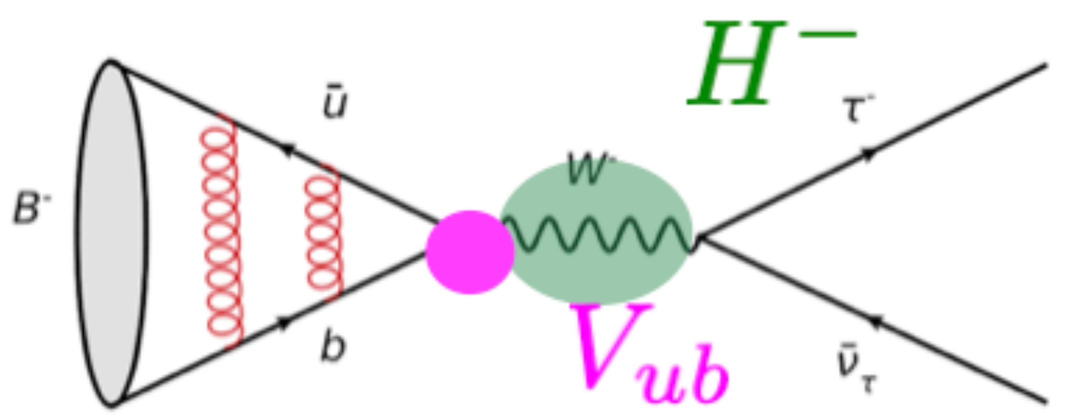
The “favoured” explanation?

color meets flavor

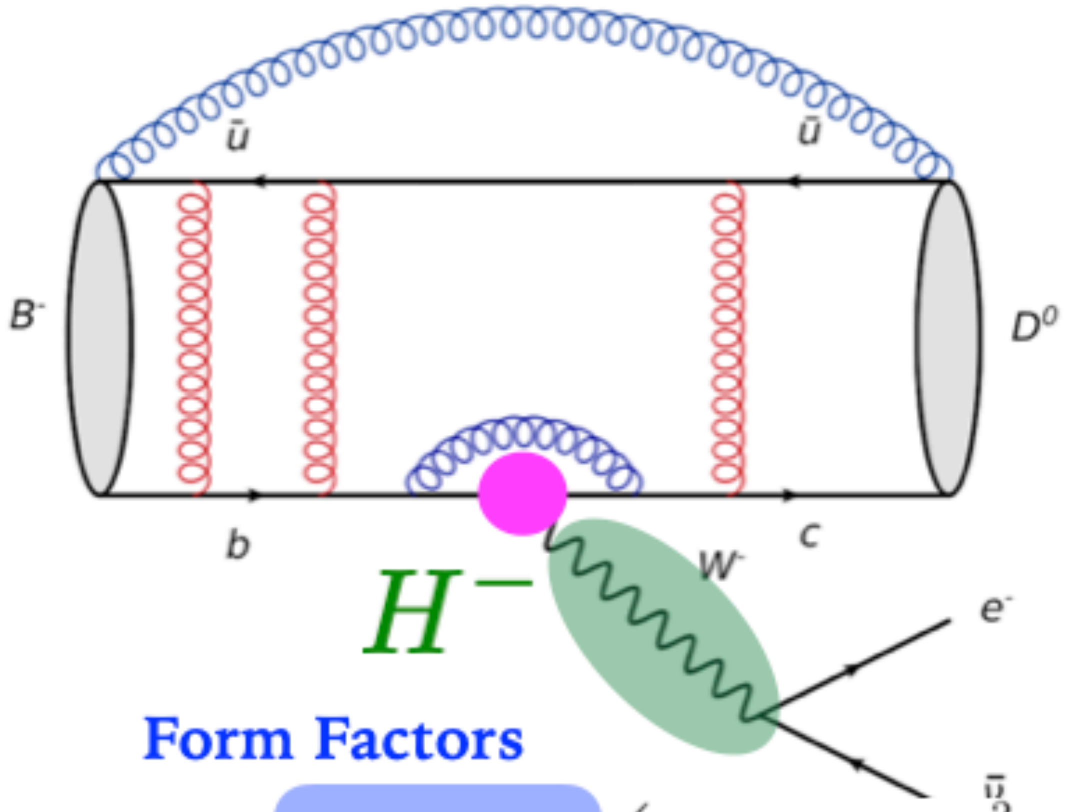
- Leptonic Decays



Decay constant

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

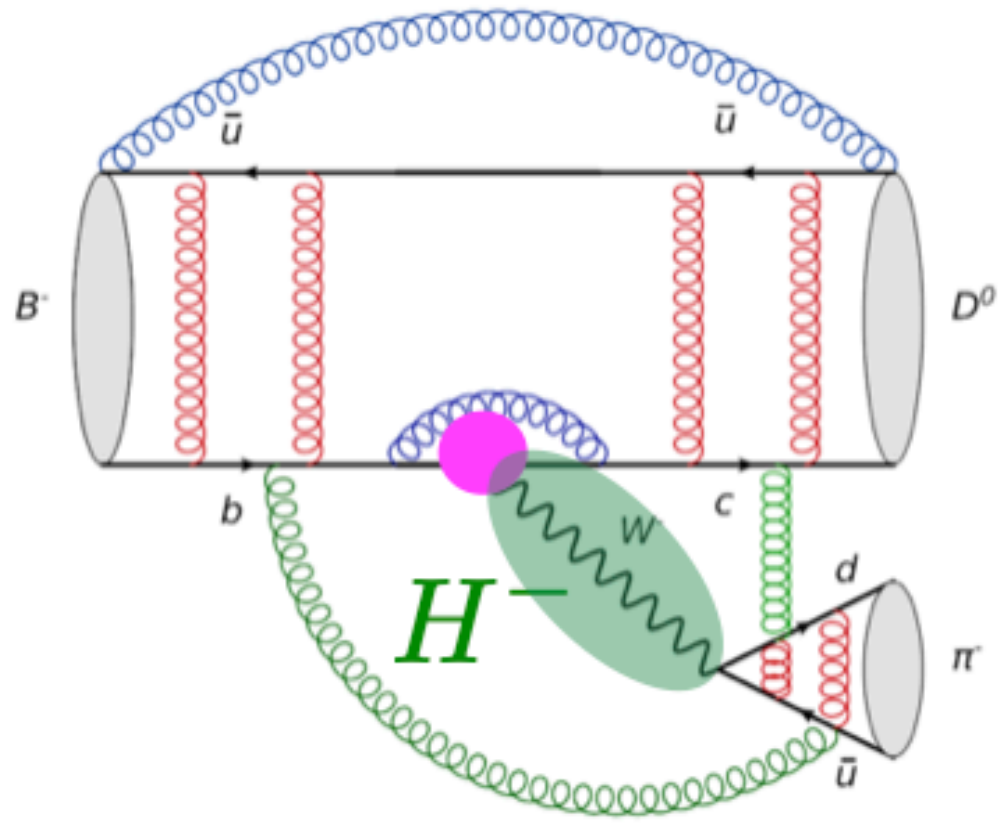
- Semileptonic Decays



Form Factors

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

- Non-leptonic Decays



Factorisation

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

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

The “favoured” explanation?

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]

pdf DOI cite claim reference search 49 citations

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]

pdf DOI cite claim reference search 29 citations

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

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 $\varepsilon \sim \Lambda_{\rm QCD}/E_L \sim \Lambda_{\rm QCD}/m_b$

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

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

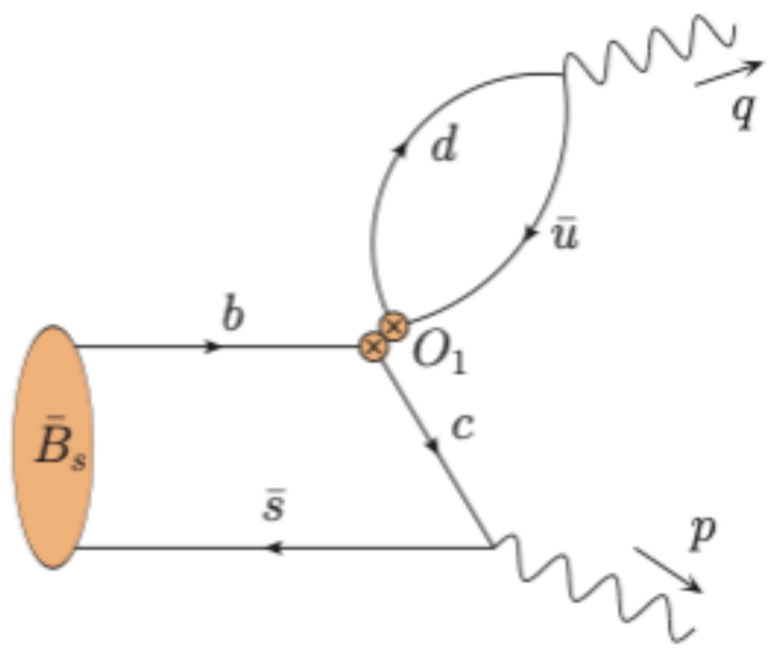
NLO in ϵ: ϵ^1

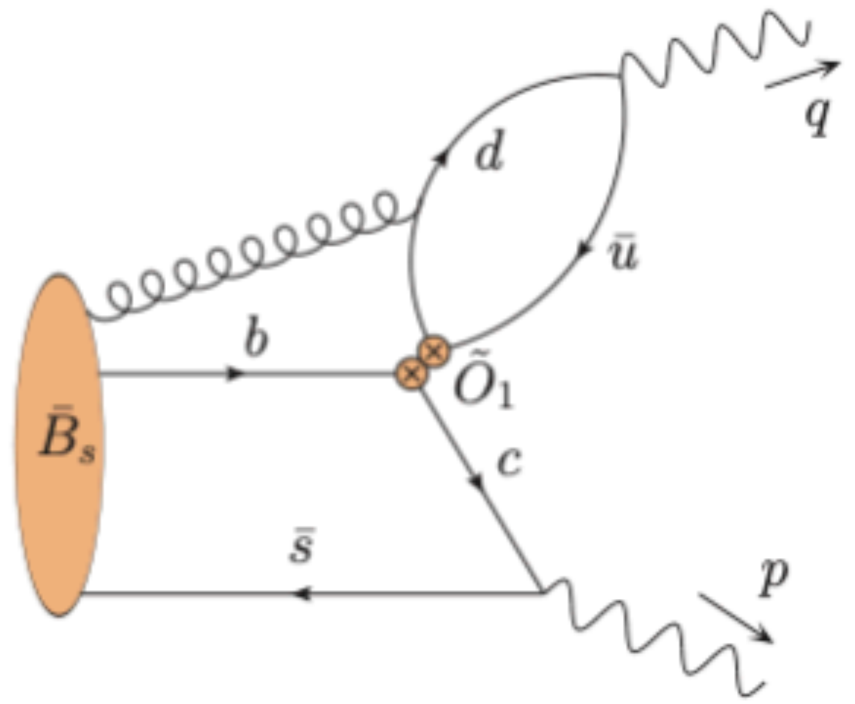
- Higher twist to light meson DA
- Emission of hard-collinear gluon from spectator quark
- Emission of hard-collinear gluon from heavy quark
- Exchange of soft-gluon between B,D-system and light meson

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

The “favoured” explanation?

New estimates within QCD sum rules





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

Non-factorisable effects in the decays $\bar{B}_s^0 \to D_s^+\pi^-$ and $\bar{B}^0 \to D^+K^-$ from LCSR

Maria Laura Piscopo and Aleksey V. Rusov

Physik Department, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany

E-mail: maria.piscopo@uni-siegen.de, rusov@physik.uni-siegen.de

Abstract: In light of the current discrepancies between the recent predictions based on QCD factorisation (QCDF) and the experimental data for several non-leptonic colour-allowed two-body B-meson decays, we obtain new determinations of the non-factorisable soft-gluon contribution to the decays $\bar{B}_s^0 \to D_s^+\pi^-$ and $\bar{B}^0 \to D^+K^-$, using the framework of light-cone sum rule (LCSR), with a suitable three-point correlation function and B-meson light-cone distribution amplitudes. In particular, we discuss the problem associated with a double light-cone (LC) expansion of the correlator, and motivate future determinations of the three-particle B-meson matrix element with the gluon and the spectator quark aligned along different light-cone directions. Performing a LC-local operator product expansion of the correlation function, we find, for both modes considered, the non-factorisable part of the amplitude to be sizeable and positive, however, with very large systematic uncertainties. Furthermore, we also determine for the first time, using LCSR, the factorisable amplitudes at LO-QCD, and thus the corresponding branching fractions. Our predictions are in agreement with the experimental data and consistent with the results based on QCDF, although again within very large uncertainties. In this respect, we provide a rich outlook for future improvements and investigations.

JHEP10(2023)180

Indication: non-factorizable contribution larger - uncertainties larger - stay tuned

and let’s have fun first

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The “fun” explanation?

color meets flavor

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

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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**

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

The “fun” explanation?

JHEP
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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]

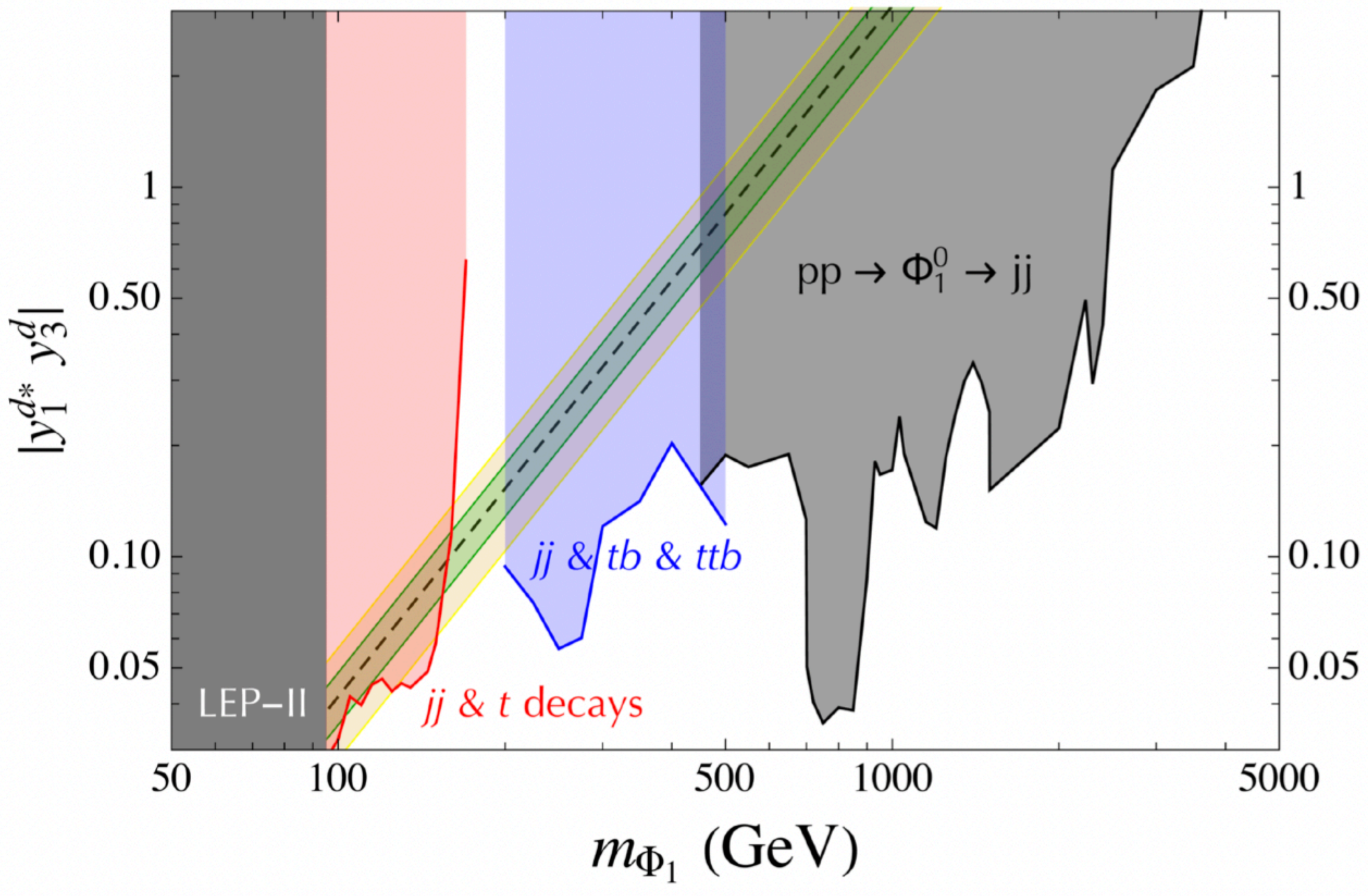


Figure 7. The compilation of the high-p_T collider constraints on the Φ_1 model (Benchmark I) together with the best-fit region from non-leptonic B decays. See section 4.2 for details.

Eur. Phys. J. C (2025) 85:258
https://doi.org/10.1140/epjc/s10052-024-13739-w
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Regular Article - Theoretical Physics

2411.00940

Collider-flavour complementarity from the bottom to the top

Oliver Atkinson[1], Christoph Englert[1,a], Matthew Kirk[2,b], Gilberto Tetlalmatzi-Xolocotzi[3,4,c]

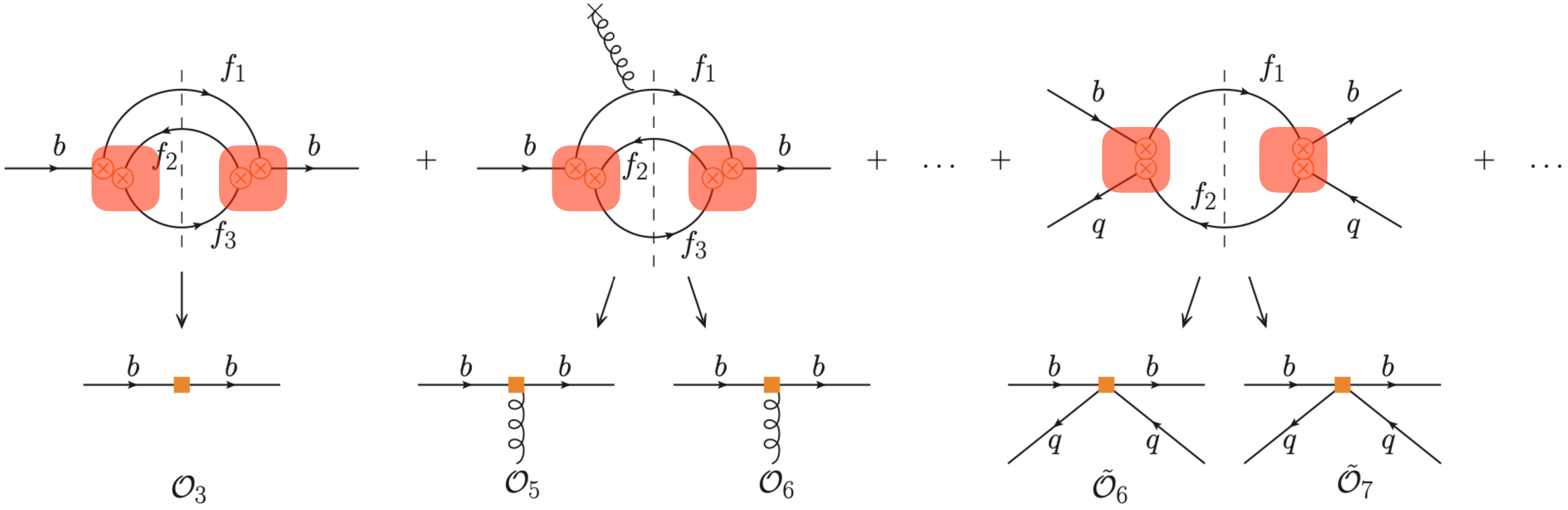
[1] School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK
[2] Institute for Particle Physics Phenomenology, Durham University, Durham DH1 3LE, UK
[3] Physik Department, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany
[4] Universitè Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

BSM effects in non-leptonic B decays cannot be arbitrarily large!

Why BSM effects in tree-level decays?

New tree-level $\Delta B = 1$ operators affect also liftetimes and Γ_{12}

$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \ldots + 16\pi^2 \left(\tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \ldots \right)$$



Why BSM effects in tree-level decays?

Effect on total decay rates

$$\Gamma(\mathscr{B}_q) = \Gamma_3^{\rm SM} \boxed{+ \Gamma_3^{\rm BSM}} + \delta\Gamma(\mathscr{B}_q)^{\rm SM} \boxed{+ \delta\Gamma(\mathscr{B}_q)^{\rm BSM}}$$

Effect on lifetime ratios
$$\frac{\tau(B_1)}{\tau(B_2)} = 1 + \left[\Gamma(B_2) - \Gamma(B_1)\right] \tau(B_1)$$

$$\frac{\tau(B_1)}{\tau(B_2)} = 1 + \left[\underbrace{(\Gamma_3 - \Gamma_3)}_{=0} + \Gamma_5 \underbrace{\left(\frac{\langle \mathcal{O}_5 \rangle_{B_2} - \langle \mathcal{O}_5 \rangle_{B_1}}{m_b^2} \right)}_{\text{isopin/SU(3)}_{\text{F}}\text{breaking}} + \Gamma_6 \underbrace{\left(\frac{\langle \mathcal{O}_6 \rangle_{B_2} - \langle \mathcal{O}_6 \rangle_{B_1}}{m_b^3} \right)}_{\text{isopin/SU(3)}_{\text{F}}\text{breaking}} + \ldots \right] \tau(B_1)$$

$$+16\pi^2 \left[\left(\tilde{\Gamma}_6(B_2) \frac{\langle \tilde{\mathcal{O}}_6 \rangle_{B_2}}{m_b^3} - \tilde{\Gamma}_6(B_1) \frac{\langle \tilde{\mathcal{O}}_6 \rangle_{B_1})}{m_b^3} \right) + \left(\tilde{\Gamma}_7(B_2) \frac{\langle \tilde{\mathcal{O}}_7 \rangle_{B_2}}{m_b^4} - \tilde{\Gamma}_7(B_1) \frac{\langle \tilde{\mathcal{O}}_7 \rangle_{B_1})}{m_b^4} \right) + \ldots \right] \tau(B_1)$$

Why BSM effects in tree-level decays?

Effect on total decay rates

$$\Gamma(\mathscr{B}_q) = \Gamma_3^{\text{SM}} + \Gamma_3^{\text{BSM}} + \delta\Gamma(\mathscr{B}_q)^{\text{SM}} + \delta\Gamma(\mathscr{B}_q)^{\text{BSM}}$$

Effect on lifetime ratios

$$\frac{\tau(B_1)}{\tau(B_2)} = 1 + \left[\Gamma(B_2) - \Gamma(B_1)\right]\tau(B_1)$$

$$\frac{\tau(B_1)}{\tau(B_2)} = 1 + \left[\underbrace{(\Gamma_3 - \Gamma_3)}_{=0} + \Gamma_5 \underbrace{\left(\frac{\langle\mathcal{O}_5\rangle_{B_2} - \langle\mathcal{O}_5\rangle_{B_1}}{m_b^2}\right)}_{\text{isopin/SU(3)}_\text{F}\text{breaking}} + \Gamma_6 \underbrace{\left(\frac{\langle\mathcal{O}_6\rangle_{B_2} - \langle\mathcal{O}_6\rangle_{B_1}}{m_b^3}\right)}_{\text{isopin/SU(3)}_\text{F}\text{breaking}} + \ldots\right]\tau(B_1)$$

$$+16\pi^2\left[\left(\tilde{\Gamma}_6(B_2)\frac{\langle\tilde{\mathcal{O}}_6\rangle_{B_2}}{m_b^3} - \tilde{\Gamma}_6(B_1)\frac{\langle\tilde{\mathcal{O}}_6\rangle_{B_1}}{m_b^3}\right) + \left(\tilde{\Gamma}_7(B_2)\frac{\langle\tilde{\mathcal{O}}_7\rangle_{B_2}}{m_b^4} - \tilde{\Gamma}_7(B_1)\frac{\langle\tilde{\mathcal{O}}_7\rangle_{B_1}}{m_b^4}\right) + \ldots\right]\tau(B_1)$$

BSM effects modify

- **Wilson coefficients** $\Gamma_i, \tilde{\Gamma}_i$
- **Potential new Dirac structures in operators**

Why BSM effects in tree-level decays?

New tree-level $\Delta B = 1$ operators affect also liftetimes and Γ_{12}

$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \ldots + 16\pi^2 \left(\tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \ldots \right)$$

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$\Delta B = 0$ - new Dirac Structures

HQET sum rules for matrix elements of dimension-six four-quark operators for meson lifetimes within and beyond the Standard Model #6

Matthew Black (U. Siegen (main) and U. Edinburgh (main)), Martin Lang (U. Siegen (main)), Alexander Lenz (U. Siegen (main)), Zachary Wüthrich (U. Siegen (main)) (Dec 17, 2024)

Published in: *JHEP* 04 (2025) 081 • e-Print: 2412.13270 [hep-ph]

pdf DOI cite claim reference search 3 citations

Why BSM effects in tree-level decays?

New tree-level $\Delta B = 1$ operators affect also liftetimes and Γ_{12}

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

$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \ldots + 16\pi^2 \left(\tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \ldots \right)$$

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$\Delta B = 0$ - new Dirac Structures

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pdf DOI cite claim reference search 3 citations

$\Delta B = 0$ - new Wilson coefficients

Taming new physics in b → cūd(s) with τ(B$^+$)/τ(B$_d$) and a_{sl}^d #12
Alexander Lenz (Siegen U.), Jakob Müller (Siegen U.), Maria Laura Piscopo (Siegen U.), Aleksey V. Rusov (Siegen U.) (Nov 4, 2022)
Published in: *JHEP* 09 (2023) 028 • e-Print: 2211.02724 [hep-ph]
pdf DOI cite claim reference search 18 citations

Why BSM effects in tree-level decays?

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New tree-level $\Delta B = 1$ operators affect also liftetimes and Γ_{12}

Charming new physics in rare B-decays and mixing
Jaeger, Kirk, Lenz, Leslie
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$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \ldots + 16\pi^2 \left(\tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \ldots \right)$$

$\Delta B = 0$ - new Dirac Structures

HQET sum rules for matrix elements of dimension-six four-quark operators for meson lifetimes within and beyond the Standard Model #6
Matthew Black (U. Siegen (main) and U. Edinburgh (main)), Martin Lang (U. Siegen (main)), Alexander Lenz (U. Siegen (main)), Zachary Wüthrich (U. Siegen (main)) (Dec 17, 2024)
Published in: *JHEP* 04 (2025) 081 • e-Print: 2412.13270 [hep-ph]
pdf DOI cite claim reference search 3 citations

$\Delta B = 0$ - new Wilson coefficients
BSM and SM penguins

Subleading power corrections to the total decay rate of B-mesons within and beyond the Standard Model

Martin Lang,[a] Alexander Lenz,[a] Ali Mohamed,[a] Maria Laura Piscopo,[b,c] Aleksey V. Rusov,[d]

In progress

$\Delta B = 0$ - new Wilson coefficients

Taming new physics in b → cūd(s) with τ(B$^+$)/τ(B$_d$) and a_{sl}^d #12
Alexander Lenz (Siegen U.), Jakob Müller (Siegen U.), Maria Laura Piscopo (Siegen U.), Aleksey V. Rusov (Siegen U.) (Nov 4, 2022)
Published in: *JHEP* 09 (2023) 028 • e-Print: 2211.02724 [hep-ph]
pdf DOI cite claim reference search 18 citations

Why BSM effects in tree-level decays?

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

New tree-level $\Delta B = 1$ operators affect also liftetimes and Γ_{12}

$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \ldots + 16\pi^2 \left(\tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \ldots \right)$$

Towards a complete NLO description of the nonleptonic decay rate within the LEFT/WET

Stefan Meiser

based on [Meiser, van Dyk, Virto 2411.09458] and recent work with Angel Picazo and Javier Virto

Institute of Cosmos Sciences (ICCUB), Barcelona

Universität Siegen, 25 September 2025

ICCUB | Institut de Ciències del Cosmos UNIVERSITAT DE BARCELONA | EXCELENCIA MARÍA DE MAEZTU | Studienstiftung des deutschen Volkes

$\Delta B = 0$ - new Dirac Structures

HQET sum rules for matrix elements of dimension-six four-quark operators for meson lifetimes within and beyond the Standard Model #6
Matthew Black (U. Siegen (main) and U. Edinburgh (main)), Martin Lang (U. Siegen (main)), Alexander Lenz (U. Siegen (main)), Zachary Wüthrich (U. Siegen (main)) (Dec 17, 2024)
Published in: *JHEP* 04 (2025) 081 • e-Print: 2412.13270 [hep-ph]
pdf DOI cite claim reference search 3 citations

$\Delta B = 0$ - new Wilson coefficients
BSM and SM penguins

Subleading power corrections to the total decay rate of B-mesons within and beyond the Standard Model

In progress

Martin Lang,[a] Alexander Lenz,[a] Ali Mohamed,[a] Maria Laura Piscopo,[b,c] Aleksey V. Rusov,[d]

$\Delta B = 0$ - new Wilson coefficients

Taming new physics in b → cūd(s) with τ(B$^+$)/τ(B$_d$) and a_{sl}^d #12
Alexander Lenz (Siegen U.), Jakob Müller (Siegen U.), Maria Laura Piscopo (Siegen U.), Aleksey V. Rusov (Siegen U.) (Nov 4, 2022)
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Why BSM effects in tree-level decays?

Is there a connection between mixing and rare decays (anomalies)?

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

Consider NP in tree-level $b \to c\bar{c}s$ transitions with general Dirac structures

$$\mathcal{H}_{\mathrm{eff}}^{c\bar{c}} = \frac{4G_F}{\sqrt{2}} V_{cs}^* V_{cb} \sum_{i=1}^{10} (C_i^c Q_i^c + C_i^{c\prime} Q_i^{c\prime})$$

$$Q_1^c = (\bar{c}_L^i \gamma_\mu b_L^j)(\bar{s}_L^j \gamma^\mu c_L^i), \qquad Q_2^c = (\bar{c}_L^i \gamma_\mu b_L^i)(\bar{s}_L^j \gamma^\mu c_L^j),$$
$$Q_3^c = (\bar{c}_R^i b_L^j)(\bar{s}_L^j c_R^i), \qquad Q_4^c = (\bar{c}_R^i b_L^i)(\bar{s}_L^j c_R^j). \quad (2)$$

This affects both rare decays and lifetimes:

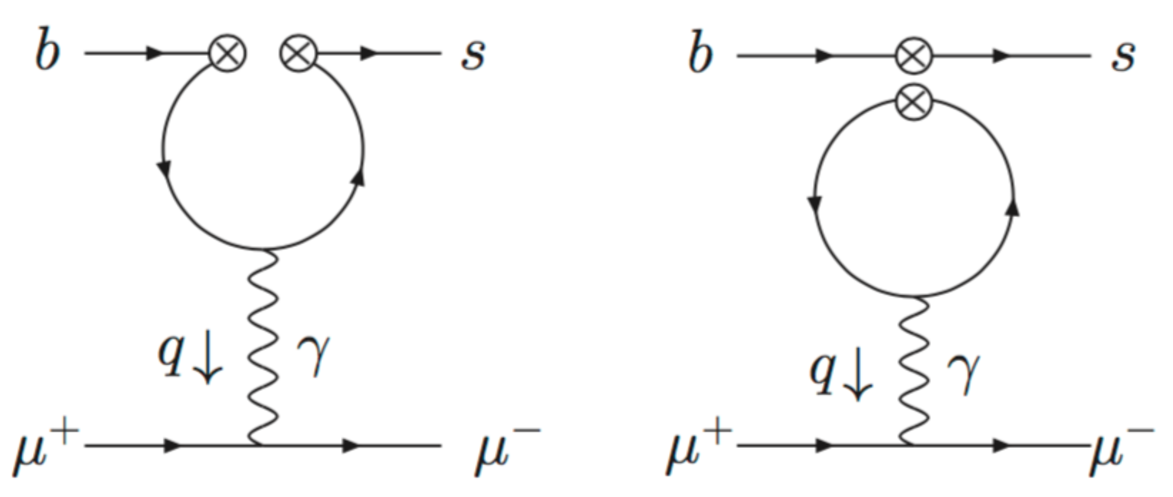

FIG. 1. Leading Feynman diagrams for CBSM contributions to rare and semileptonic decays. With our choice of Fierz-ordering, only the diagram on the left is relevant.

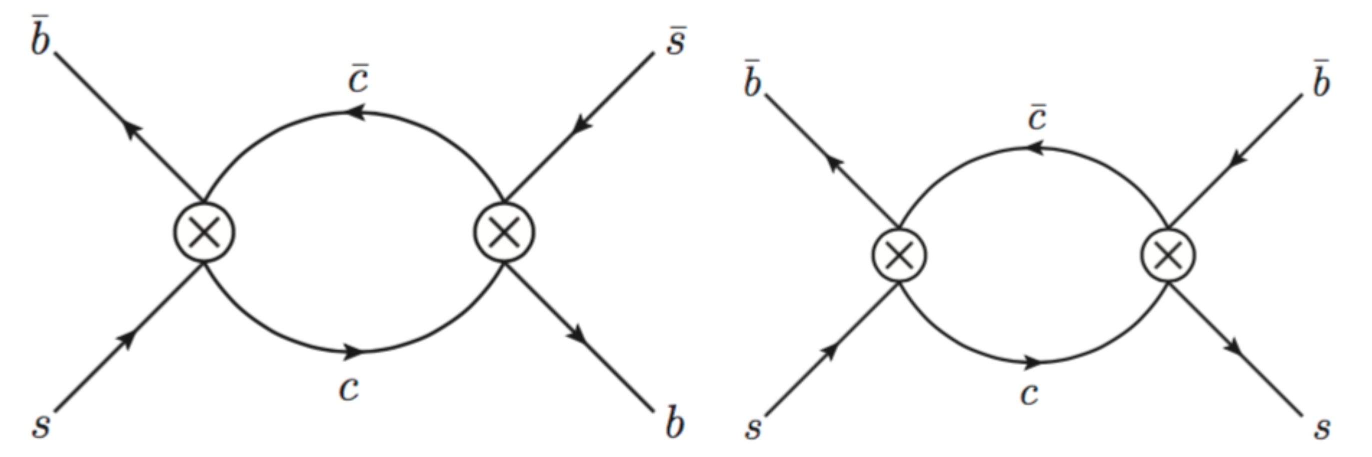

FIG. 2. Leading Feynman diagrams for CBSM contributions to the width difference $\Delta\Gamma_s$ (left) and the lifetime ratio $\tau(B_s)/\tau(B_d)$ (right).

q^2-dependent BSM contributions to rare decays possible!

These ideas were disfavoured for quite some time, since they predicted $R_K \approx 1$

Why BSM effects in tree-level decays?

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- Decay rate difference of B_d Mesons $\Delta\Gamma_d$, can be enhanced by more than 100% due to BSM effects in tree-level decays
- inspired by D0 Dimuon asymmetry $A_{\mu\mu} = C_d a^d_{sl} + C_s a^s_{sl} + C_\Gamma \Delta\Gamma_d$
- inspired the ATLAS measurement of $\Delta\Gamma_d$

On new physics in
Bobeth, Haisch, AL, Pecjak, Tetlalmatzi-Xolocotzi
JHEP 1406 (2014) 040

The New York Times

A New Clue to Explain Existence

Share full article 161

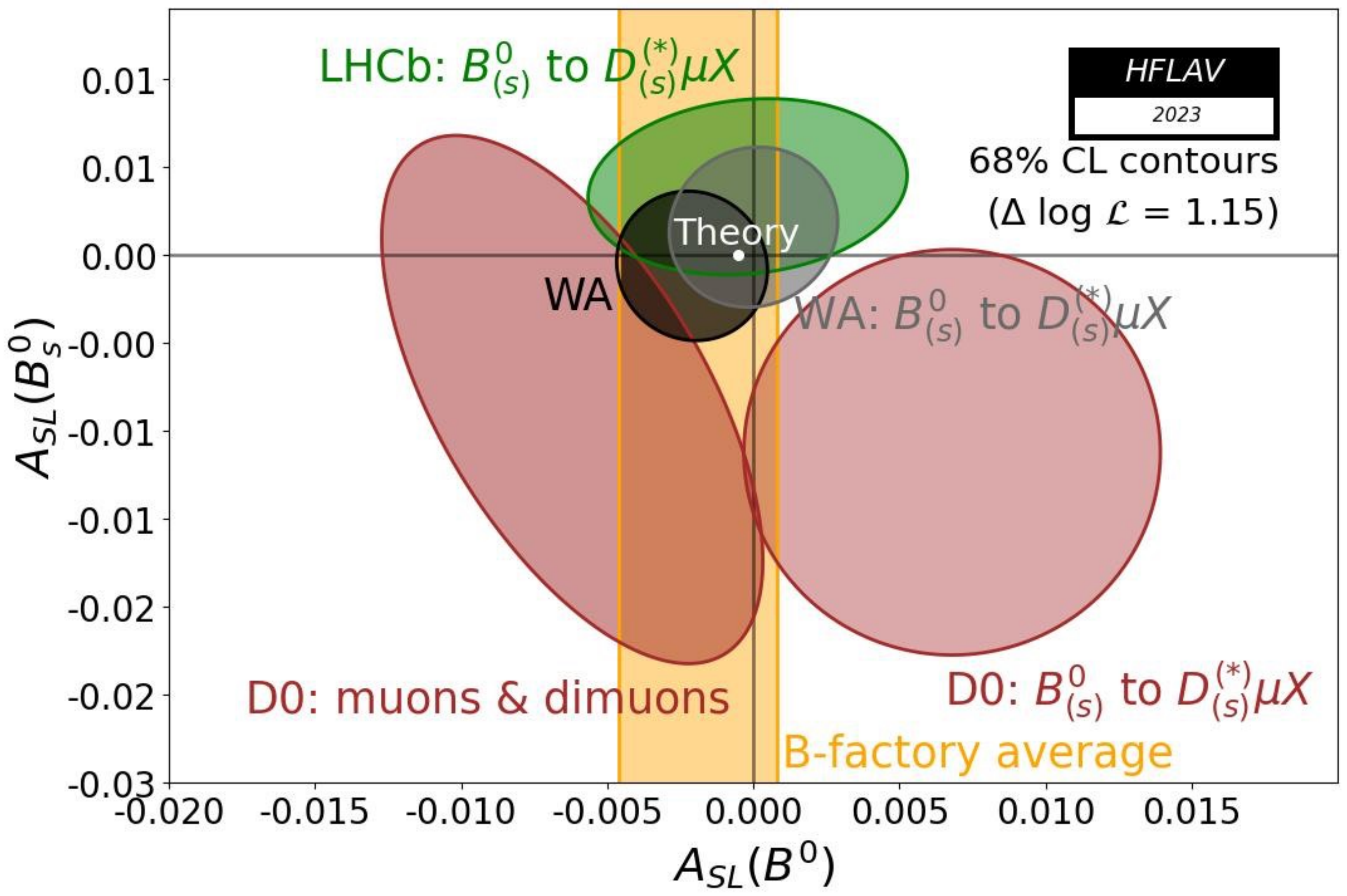
By Dennis Overbye
May 17, 2010

Physicists at the Fermi National Accelerator Laboratory are reporting that they have discovered a new clue that could help unravel one of the biggest mysteries of cosmology: why the universe is composed of matter and not its evil-twin opposite, antimatter. If confirmed, the finding portends fundamental discoveries at the new Large Hadron Collider outside Geneva, as well as a possible explanation for our own existence.

In a mathematically perfect universe, we would be less than dead; we would never have existed. According to the basic precepts of Einsteinian relativity and quantum mechanics, equal amounts of matter and antimatter should have been created in the Big Bang and then immediately annihilated each other in a blaze of lethal energy, leaving a big fat goose egg with which to make stars, galaxies and us. And yet we exist, and physicists (among others) would dearly like to know why.

Sifting data from collisions of protons and antiprotons at Fermilab's Tevatron, which until last winter was the most powerful particle accelerator in the world, the team, known as the DZero collaboration, found that the fireballs produced pairs of the particles known as muons, which are sort of fat electrons, slightly more often than they produced pairs of anti-muons. So the miniature universe inside the accelerator went from being neutral to being about 1 percent more matter than antimatter.

"This result may provide an important input for explaining the matter dominance in our universe," Guennadi Borissov, a co-leader of the study from Lancaster University, in England, said in a talk Friday at Fermilab, in Batavia, Ill. Over the weekend, word spread quickly among physicists. Maria Spiropulu of CERN and the California Institute of Technology called the results "very impressive and inexplicable."



Outline

1) Why BSM effects in tree-level decays?
2) **A decisive test of certain BSM effects in tree-level decays**
3) Reminder: extraction of γ_{CKM} in BSM scenarios

A decisive test

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

2111.04478

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

Tim Gershon
Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

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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

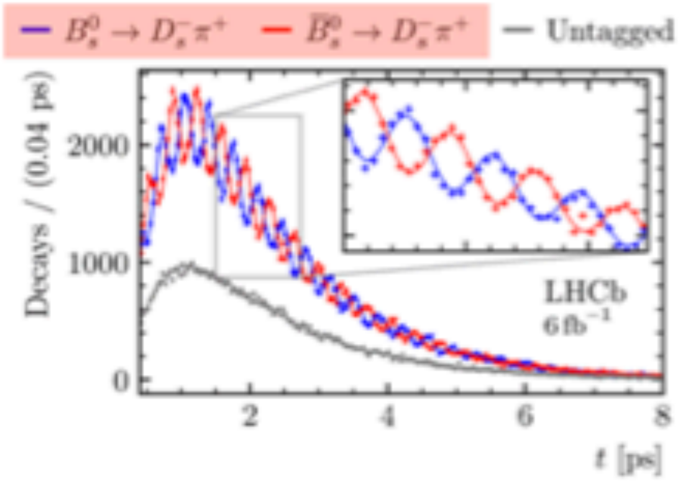
$$a_{sl}^{s,\mathrm{Exp}} = (60 \pm 280) \cdot 10^{-5},$$
$$a_{sl}^{d,\mathrm{Exp}} = (-21 \pm 17) \cdot 10^{-4}.$$

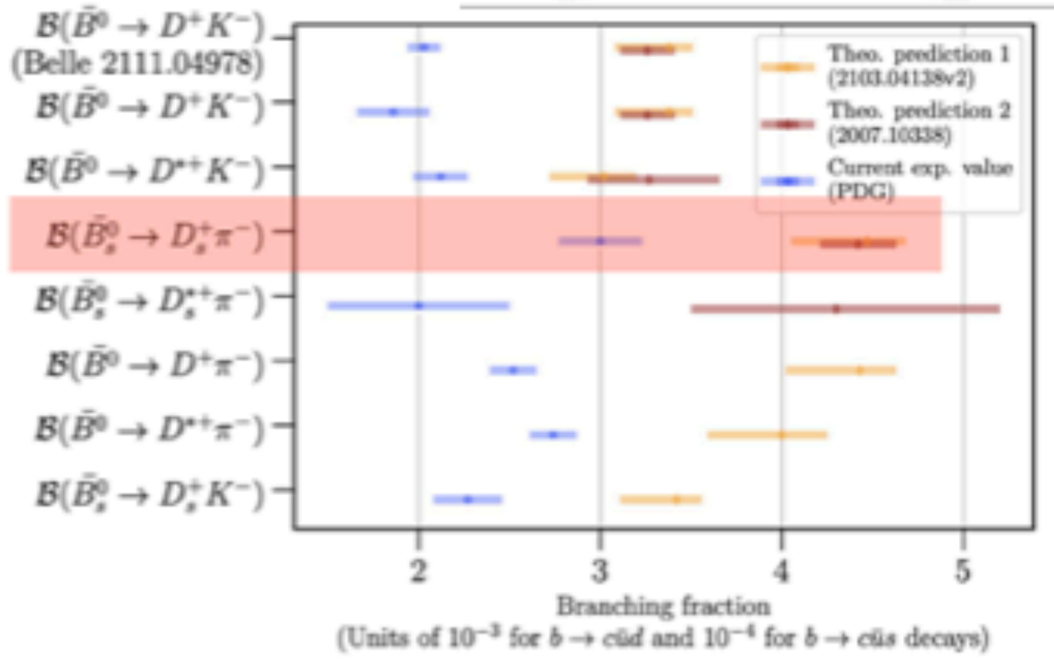
HFLAV 1970?

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





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

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

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

- Derive CP asymmetry

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

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

Constrained by semi-leptonic Measurements

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

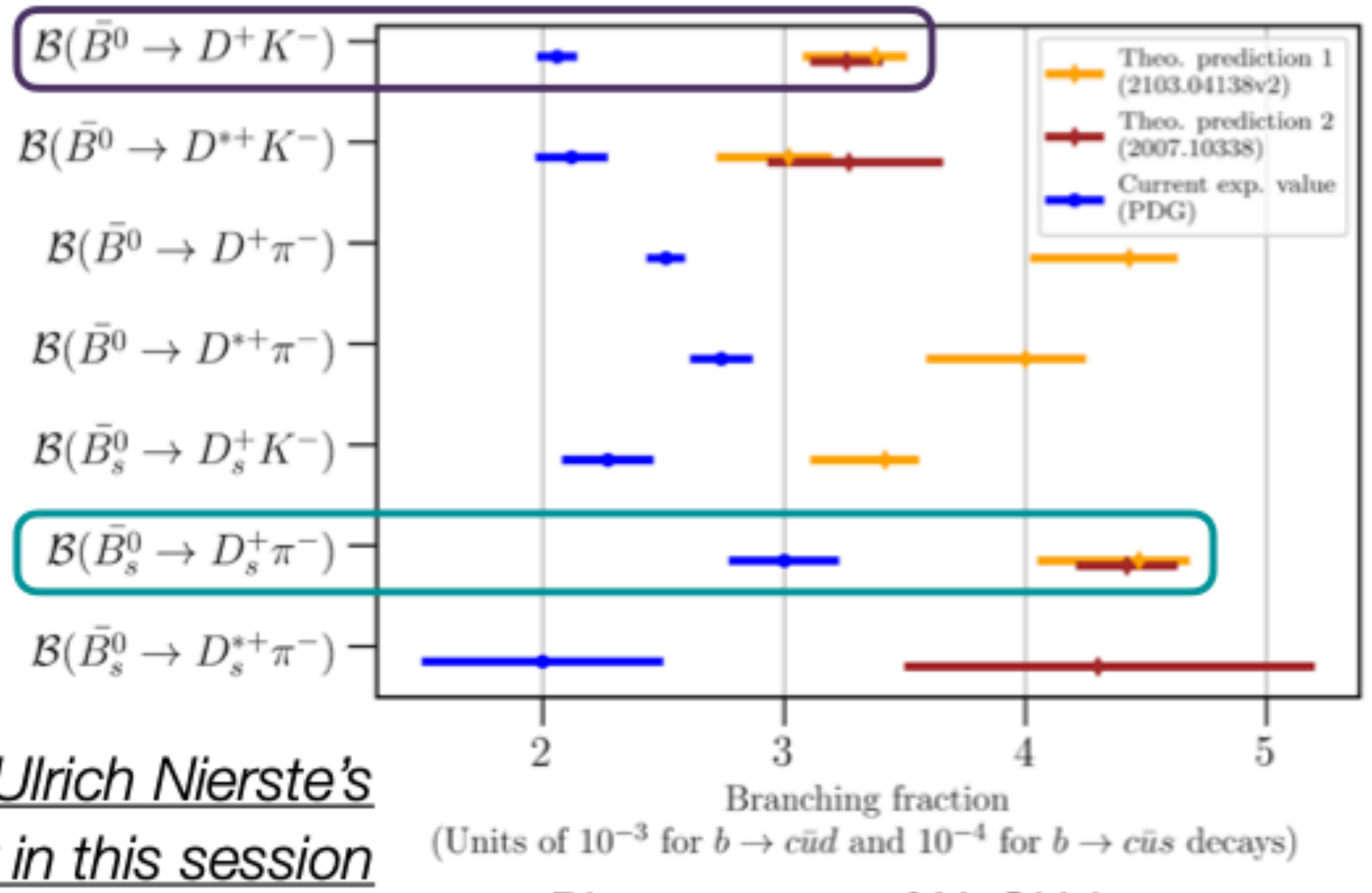
HFLAV 1970?

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

A decisive test

The $b \to c\bar{u}q$ anomaly

- Tensions between BF measurements/predictions (*see right*), dubbed the $b \to c\bar{u}q$ anomaly [arXiv:2007.10338]
- Could arise from unaccounted for QCD effects; could also arise from New Physics (NP)
- Test by considering CP asymmetry: generic NP amplitude could contribute a direct asymmetry in the flavour specific modes ($B^0 \to D^- K^+$, $B_s^0 \to D_s^- \pi^+$)



Plot courtesy of N. Skidmore

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

More in *Ulrich Nierste's talk later in this session*

- To increase statistical power: measure untagged, time-integrated CP asymmetry:

More to come? See *Phillip Böer's talk from Monday*

$$\left\langle A_{\rm untagged}^q \right\rangle = A_{\rm dir.}^q - \frac{a_{\rm fs}^q}{2}\left(1 - \rho_q\right) \quad \text{where} \quad \rho_q = \frac{\Gamma_q^2 - \frac{\Delta\Gamma_q^2}{4}}{\Gamma_q^2 + \Delta M_q^2} \approx \begin{cases} 0.63 \text{ for } \rho_d \\ 0.001 \text{ for } \rho_s \end{cases}$$

- Compare against measurements in semi-leptonic decays: $a_{\rm fs}^q = a_{\rm sl}^q = \begin{cases} (-21 \pm 17) \times 10^{-4} \text{ for } a_{\rm sl}^d \\ (-6 \pm 28) \times 10^{-4} \text{ for } a_{\rm sl}^s \end{cases}$ Eur. Phys. J. C (2021) 81: 226
- Measure in $B_s^0 \to D_s^- \pi^+$ as BF is significantly larger and $\rho_s \ll \rho_d$

Testing the Standard Model with CP-asymmetries in flavour-specific non-leptonic decays, *PRD 105 (2022), 115023*

Outline

1) Why BSM effects in tree-level decays?
2) A decisive test of certain BSM effects in tree-level decays
3) **Reminder: extraction of γ_{CKM} in BSM scenarios**

Reminder:
extraction of γ_{CKM} in BSM scenarios

The amazing cleanliness of gamma is based on assuming no BSM effects in non-leptonic tree-level decays

In view of an ever increasing experimental precision, how well is this assumption justified?

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extraction of $\gamma_{\rm CKM}$ in BSM scenarios

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In view of an ever increasing experimental precision, how well is this assumption justified?

Look at observables, that are reasonably well known in theory and experiment and try to identify the potential space for BSM effects in the Wilson coefficients C_1 and C_2 for non-leptonic tree-level decays

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Simplest, non-trivial approach

$$C_i = C_i^{SM} + \Delta C_i$$

$$\Delta C_i \in \mathbb{C}$$

Model-independent bounds on new physics effects in non-leptonic tree-level decays of B-mesons

Alexander Lenz (Durham U., IPPP), Gilberto Tetlalmatzi-Xolocotzi (Siegen U. and Nikhef, Amsterdam) (Dec 16, 2019)

e-Print: 1912.07621 [hep-ph]

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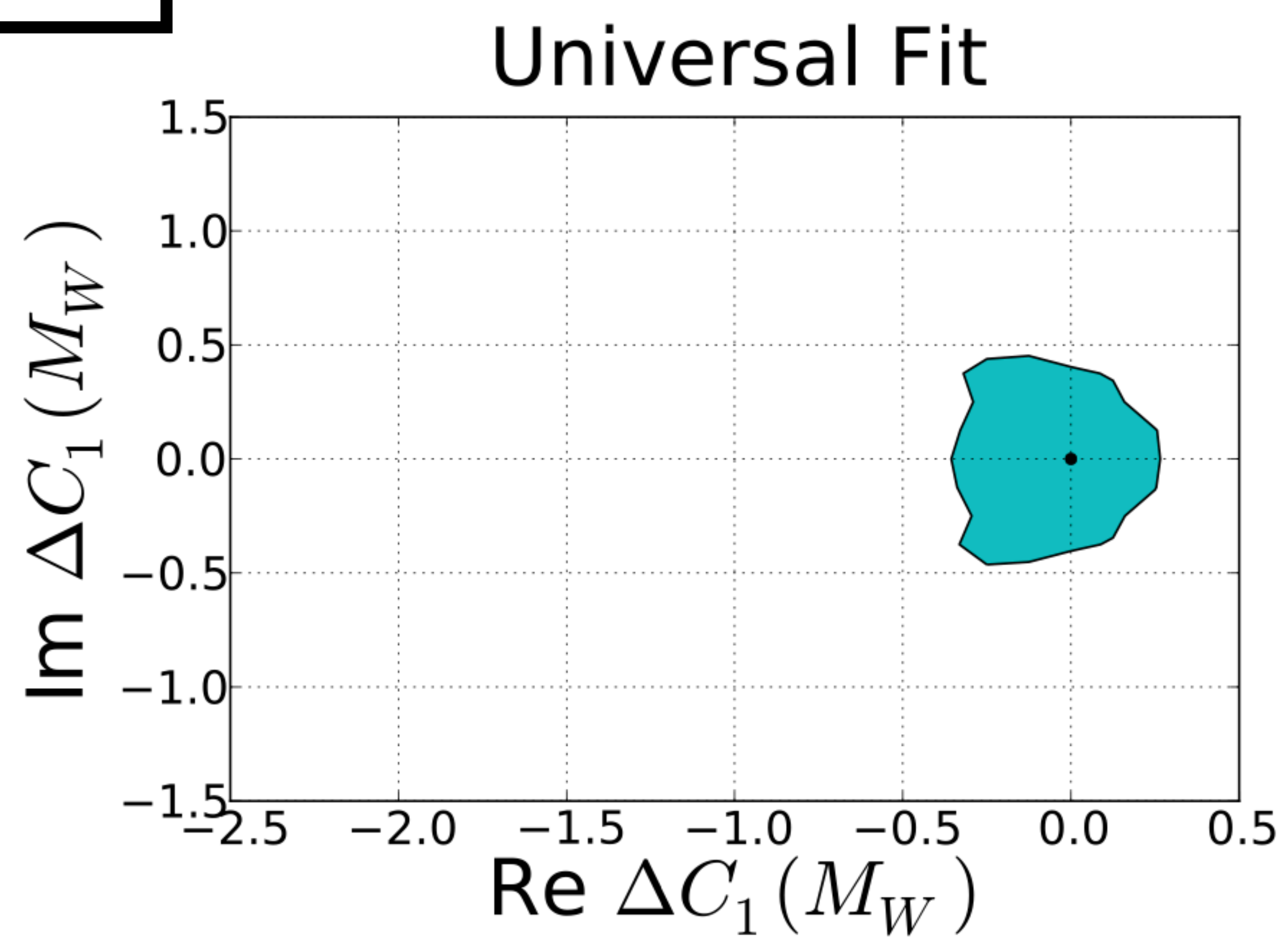

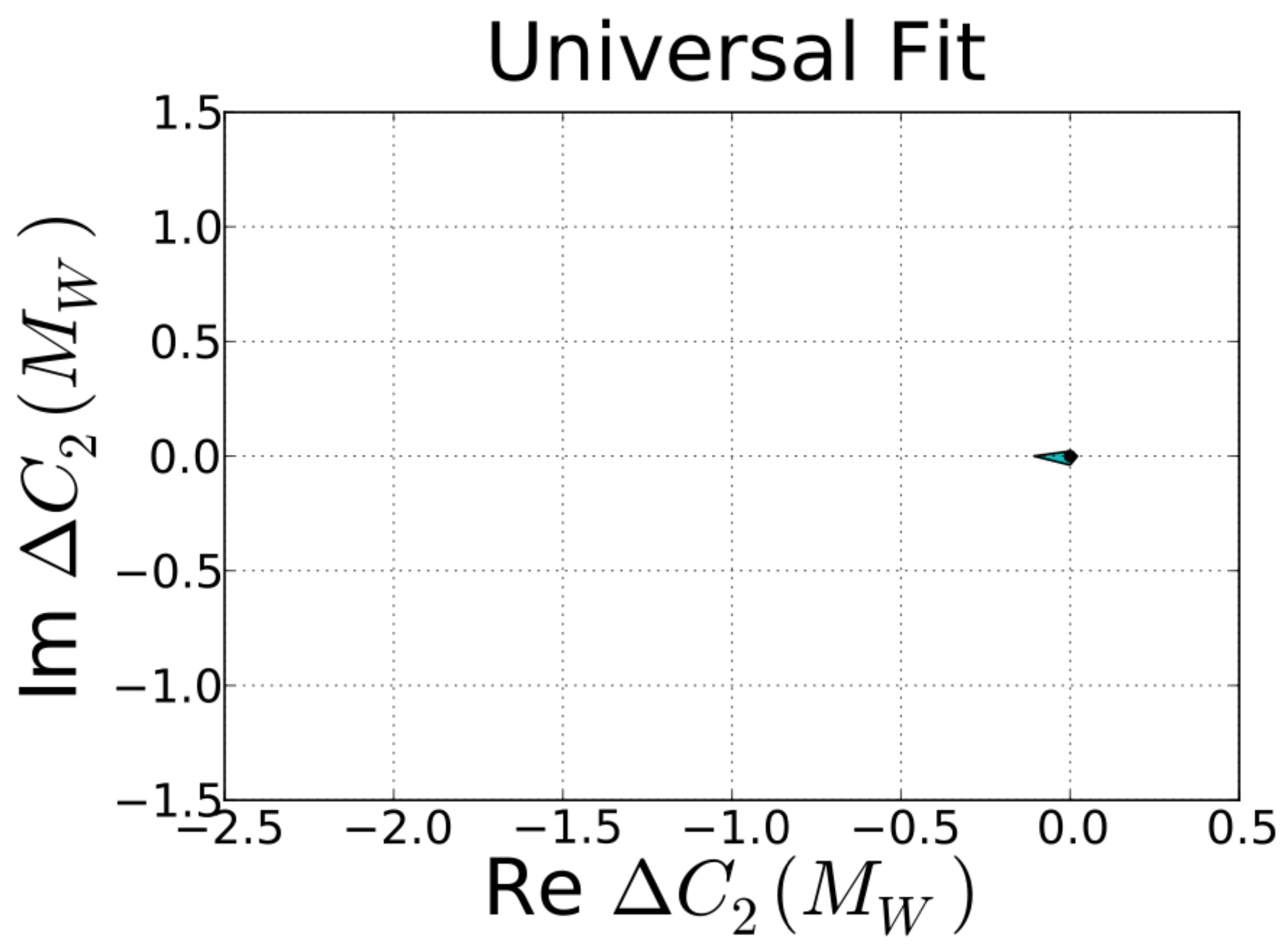

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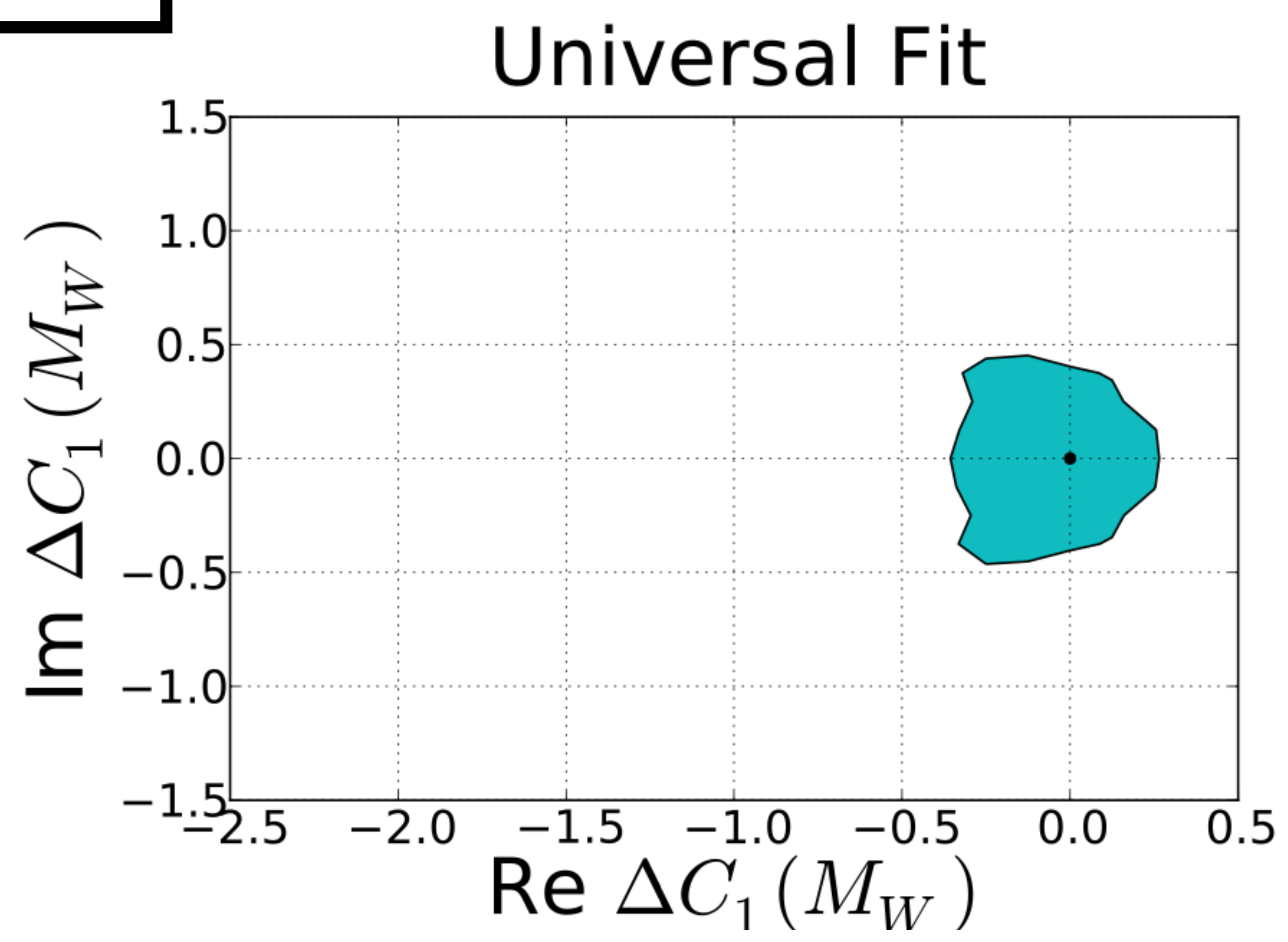
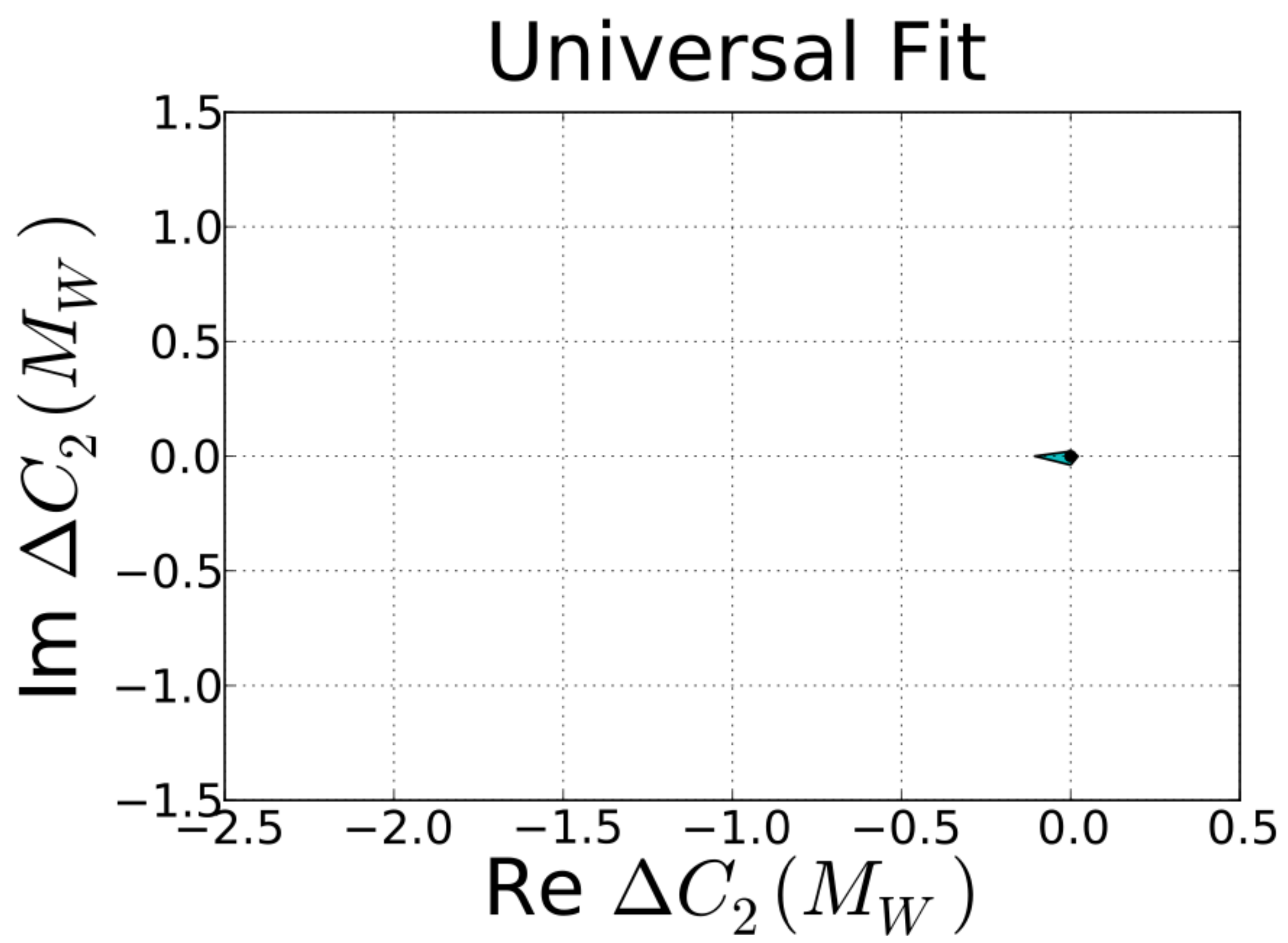




New physics effects in tree-level decays and the precision in the determination of the quark mixing angle γ

Joachim Brod (Mainz U. and U. Mainz, PRISMA), Alexander Lenz (Durham U. and Durham U., IPPP), Gilberto Tetlalmatzi-Xolocotzi (Durham U. and Durham U., IPPP), Martin Wiebusch (Durham U. and Durham U., IPPP) (Dec 3, 2014)

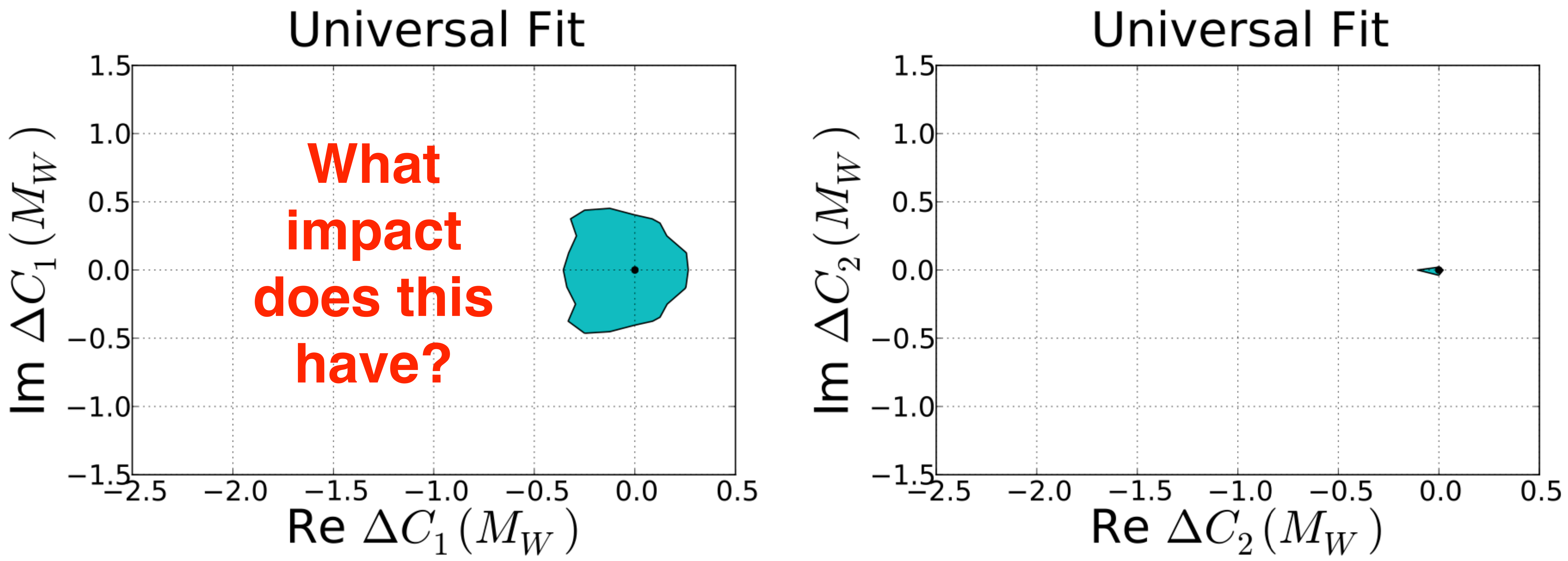
Published in: *Phys.Rev.D* 92 (2015) 3, 033002 • e-Print: 1412.1446 [hep-ph]

On new physics in $\Delta\Gamma_d$ #14

Christoph Bobeth (TUM-IAS, Munich), Ulrich Haisch (Oxford U., Theor. Phys. and CERN), Alexander Lenz (Durham U., IPPP), Ben Pecjak (Durham U., IPPP), Gilberto Tetlalmatzi-Xolocotzi (Durham U., IPPP) (Apr 9, 2014)

Published in: *JHEP* 06 (2014) 040 • e-Print: 1404.2531 [hep-ph]

Reminder:
extraction of γ_{CKM} in BSM scenarios



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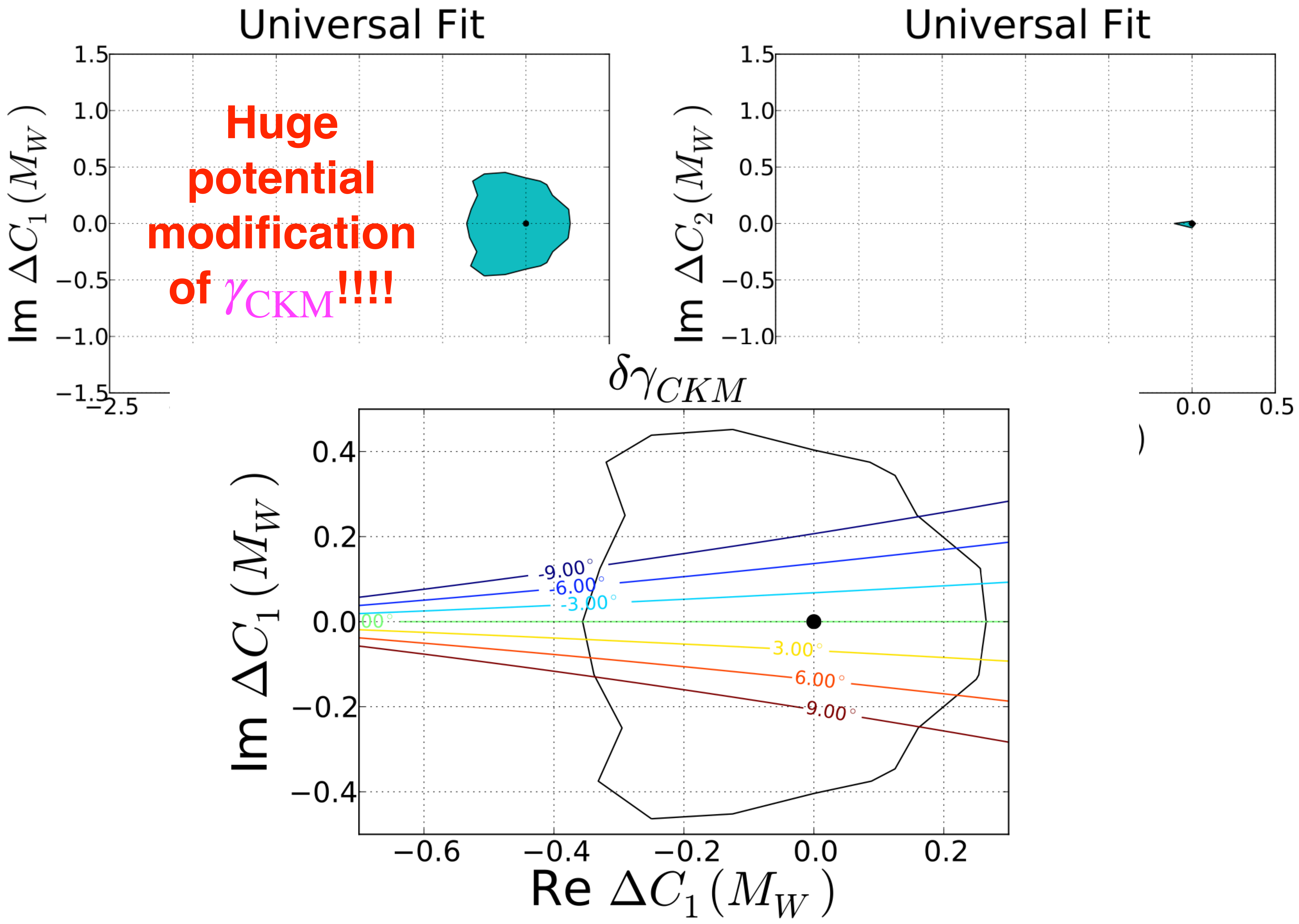

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extraction of γ_{CKM} in BSM scenarios

Notation for the case of BSM effects

$$A(B^- \to D^0 K^-) = \langle D^0 K^- | \mathcal{H}_{\mathrm{eff}}^{\bar{c}us} | B^- \rangle_1 \rightsquigarrow \text{type 1}$$

$$A(B^- \to \bar{D}^0 K^-) = \langle \bar{D}^0 K^- | \mathcal{H}_{\mathrm{eff}}^{\bar{u}cs} | B^- \rangle_2 \rightsquigarrow \text{type 2}$$

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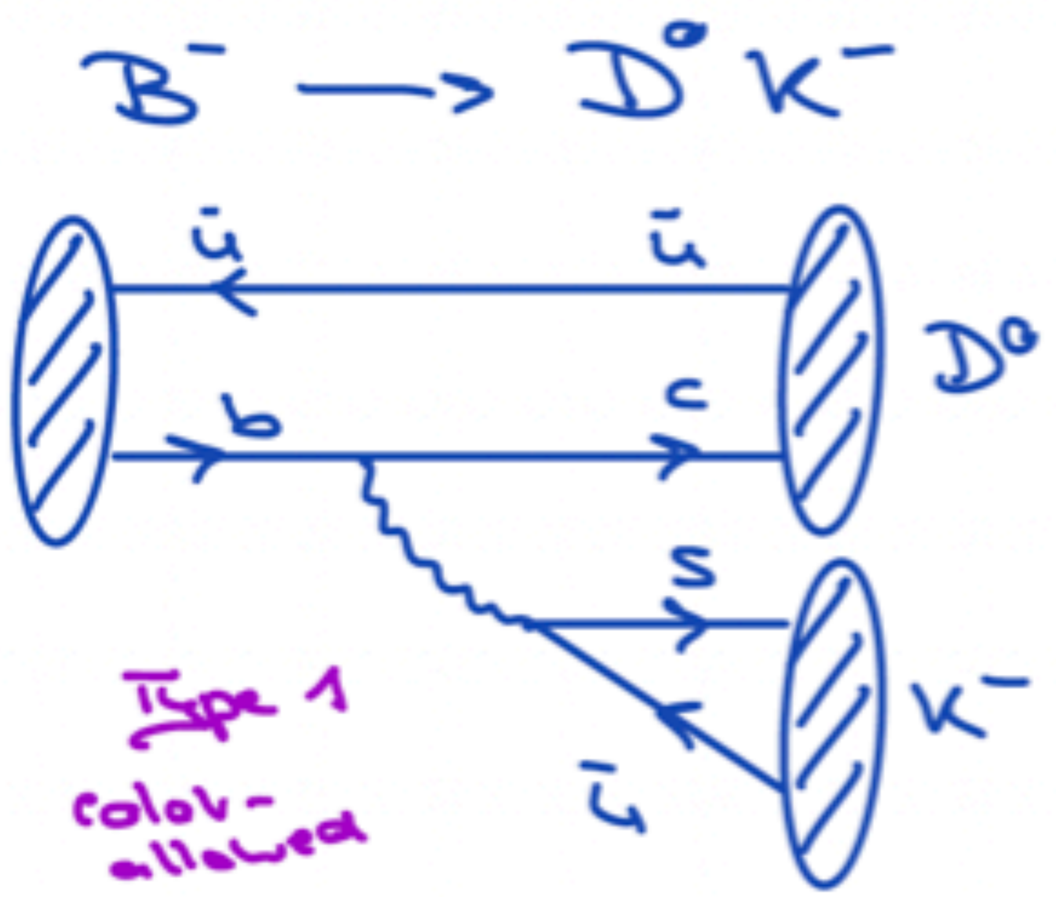

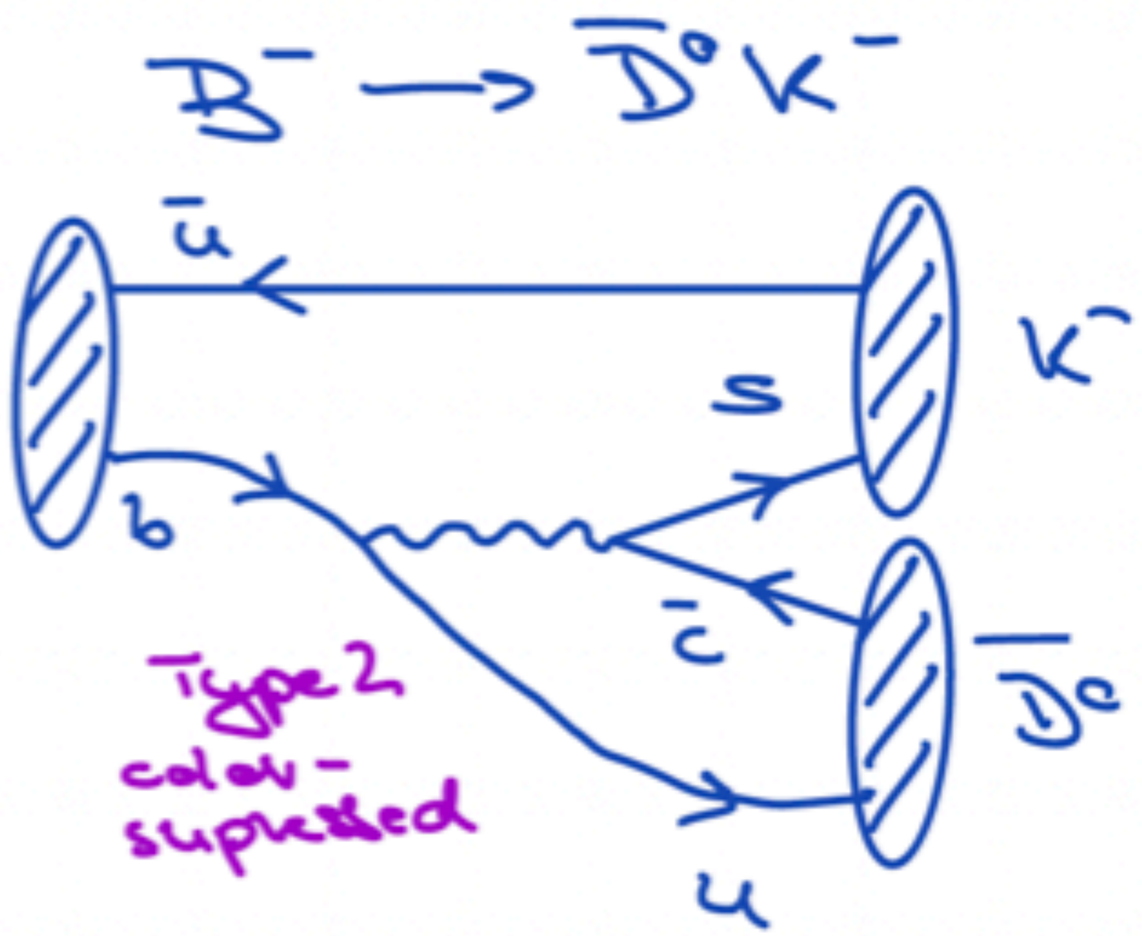

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This implies:

$$\Longrightarrow r_B e^{i(\delta_B - \gamma)} = \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}$$

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Inserting the effective Hamiltonian:

$$r_B e^{i(\delta_B - \gamma)} = \frac{V_{ub} V_{cs}^*}{V_{cb} V_{us}^*} \frac{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2}{\langle D^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1} \frac{C_2 + r A'_2 C_1}{C_2 + r A_1 C_1}$$

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with $r_{A_2}' = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{u}cs} | B^- \rangle_2}{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2}$ $\quad r_{A_1} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{c}us} | B^- \rangle_1}{\langle \bar{D}^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1}$

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This implies:

$$\Rightarrow r_B e^{i(\delta_B - \gamma)} = \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}$$

In the SM:
only weak phase => γ

In the SM: no weak phase=> r_B, δ_B

Inserting the effective Hamiltonian:

$$r_B e^{i(\delta_B - \gamma)} = \boxed{\frac{V_{ub} V_{cs}^*}{V_{cb} V_{us}^*}} \boxed{\frac{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2}{\langle D^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1}} \boxed{\frac{C_2 + r_{A_2'} C_1}{C_2 + r_{A_1} C_1}}$$

with $r_{A_2'} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{u}cs} | B^- \rangle_2}{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2}$ $\qquad r_{A_1} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{c}us} | B^- \rangle_1}{\langle \bar{D}^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1}$

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BSM: additional weak & strong phases possible

=> $\Delta r_B, \Delta\delta_B, \Delta\gamma$

BSM:

weak phase => γ

Inserting the effective Hamiltonian:

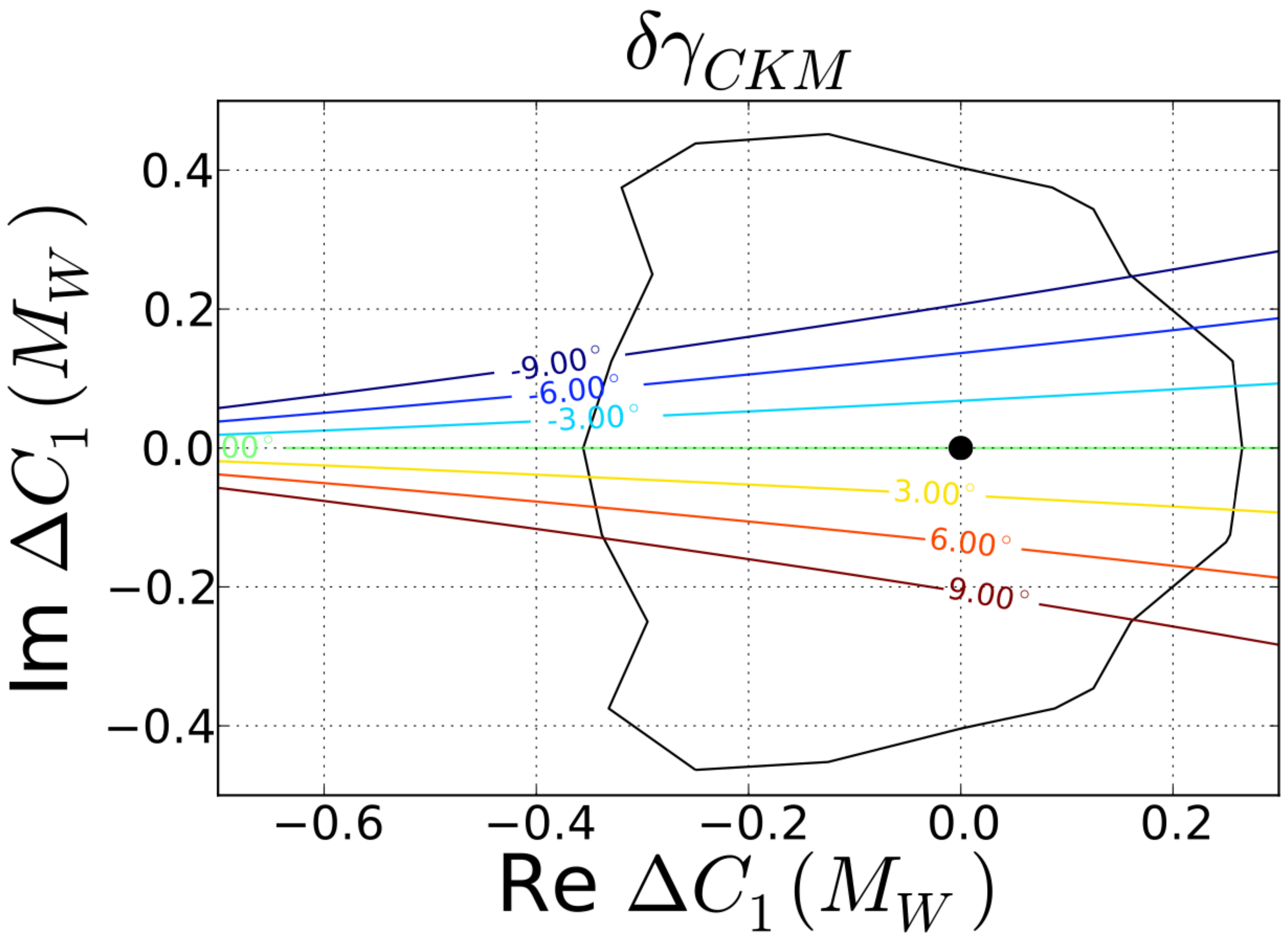
$$r_B e^{i(\delta_B - \gamma)} = \frac{V_{ub} V_{cs}^*}{V_{cb} V_{us}^*} \frac{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2}{\langle D^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1} \frac{C_2 + r_{A_2'} C_1}{C_2 + r_{A_1} C_1}$$

$$\text{with} \quad r_{A_2'} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{u}cs} | B^- \rangle_2}{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2} \qquad r_{A_1} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{c}us} | B^- \rangle_1}{\langle \bar{D}^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1}$$

Reminder:
extraction of $\gamma_{\rm CKM}$ in BSM scenarios

If C_1 and C_2 can get new weak BSM phases, then the extracted of $\gamma_{\rm CKM}$ changes as

$$\gamma \longrightarrow \gamma + (rA_1 - rA'_2)\,\frac{\mathrm{Im}\,\Delta C_1}{C_2}$$



with $rA'_2 = \dfrac{\langle \bar{D}^0 K^- | Q_1^{\bar{u}cs} | B^- \rangle_2}{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle_2}$

$rA_1 = \dfrac{\langle \bar{D}^0 K^- | Q_1^{\bar{c}us} | B^- \rangle_1}{\langle \bar{D}^0 K^- | Q_2^{\bar{c}us} | B^- \rangle_1}$

Reminder:
extraction of γ_{CKM} in BSM scenarios

Status so far:

- Only very, very naive estimates for r_{A_1} and r'_{A_2}

(colour counting $r_{A_1} \approx \mathcal{O}(1)$, $r'_{A_2} \approx \mathcal{O}(N_c)$, naive factorisation $r_{A_1} \approx \mathcal{O}(0.4)$, annihilation reduces r'_{A_2}we used $r_{A_1} - r'_{A_2} \approx 0.6$)

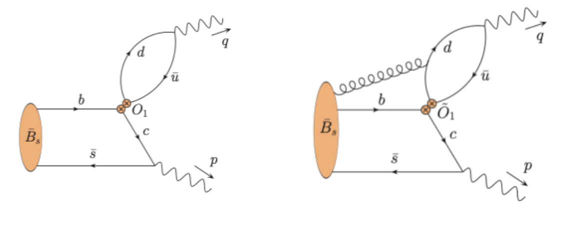
-

Reminder:

extraction of $\gamma_{\rm CKM}$ in BSM scenarios

Status so far:

New estimates within QCD sum rules



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

Non-factorisable effects in the decays $\bar{B}_s^0 \to D_s^+\pi^-$ and $\bar{B}^0 \to D^+K^-$ from LCSR

Maria Laura Piscopo and Aleksey V. Rusov
Physik Department, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany
E-mail: maria.piscopo@uni-siegen.de, rusov@physik.uni-siegen.de

Abstract: In light of the current discrepancies between the recent predictions based on QCD factorisation (QCDF) and the experimental data for several non-leptonic colour-allowed two-body B-meson decays, we obtain new determinations of the non-factorisable soft-gluon contribution to the decays $\bar{B}_s^0 \to D_s^+\pi^-$ and $\bar{B}^0 \to D^+K^-$, using the framework of light-cone sum rule (LCSR), with a suitable three-point correlation function and B-meson light-cone distribution amplitudes. In particular, we discuss the problem associated with a double light-cone (LC) expansion of the correlator, and motivate future determinations of the three-particle B-meson matrix element with the gluon and the spectator quark aligned along different light-cone directions. Performing a LC-local operator product expansion of the correlation function, we find, for both modes considered, the non-factorisable part of the amplitude to be sizeable and positive, however, with very large systematic uncertainties. Furthermore, we also determine for the first time, using LCSR, the factorisable amplitudes at LO-QCD, and thus the corresponding branching fractions. Our predictions are in agreement with the experimental data and consistent with the results based on QCDF, although again within very large uncertainties. In this respect, we provide a rich outlook for future improvements and investigations.

JHEP10(2023)180

Indication: non-factorizable contribution larger - uncertainties larger - stay tuned

- Only very, very naive estimates for r_{A_1} and r'_{A_2} $\longrightarrow$ missing

  (colour counting $r_{A_1} \approx \mathcal{O}(1)$, $r'_{A_2} \approx \mathcal{O}(N_c)$, naive factorisation $r_{A_1} \approx \mathcal{O}(0.4)$, annihilation reduces r'_{A_2} we used $r_{A_1} - r'_{A_2} \approx 0.6$)

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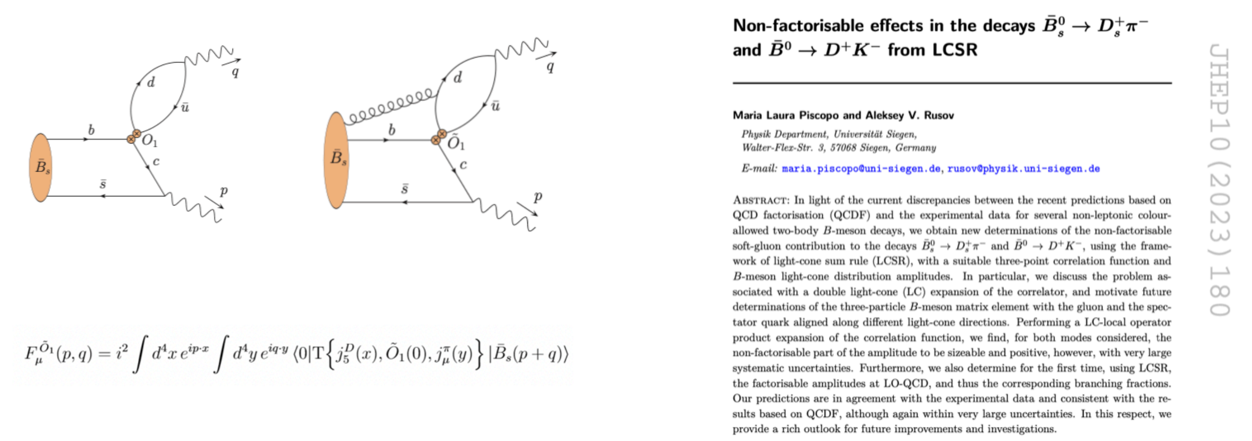

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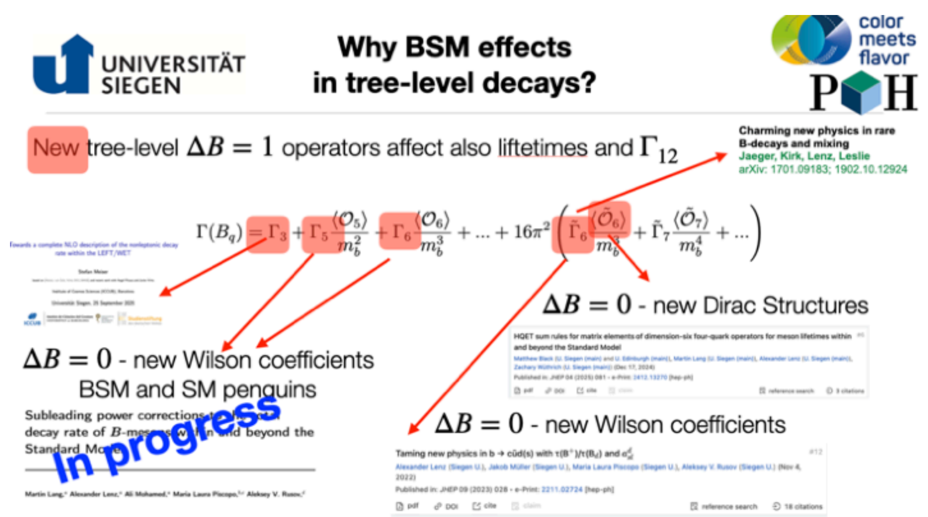
- Only systematic studies of BSM effects in C_1 and C_2, but only partly for new Dirac structures



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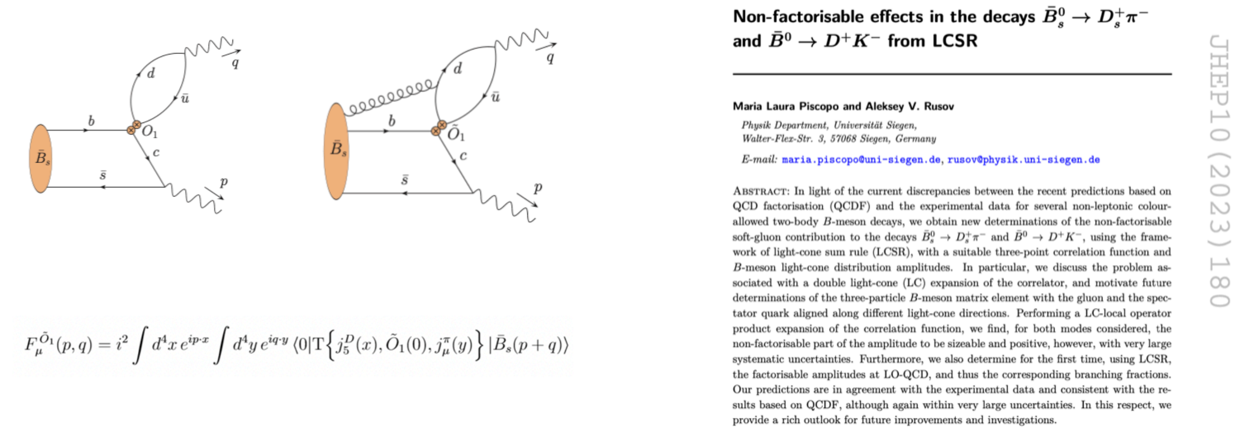

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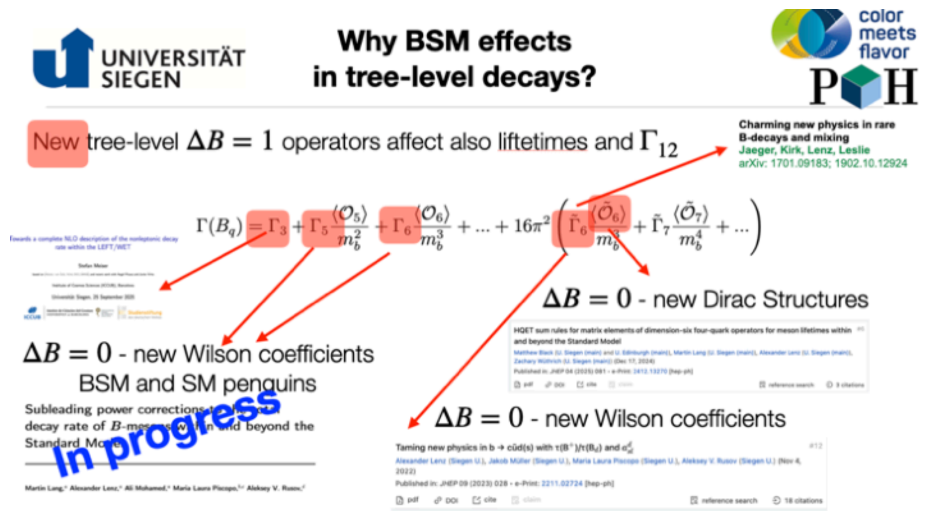

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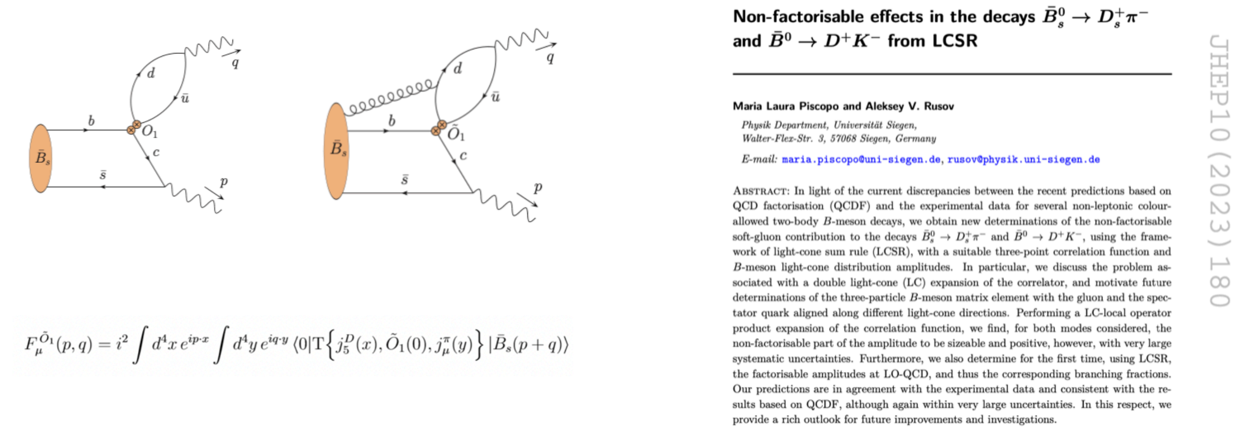

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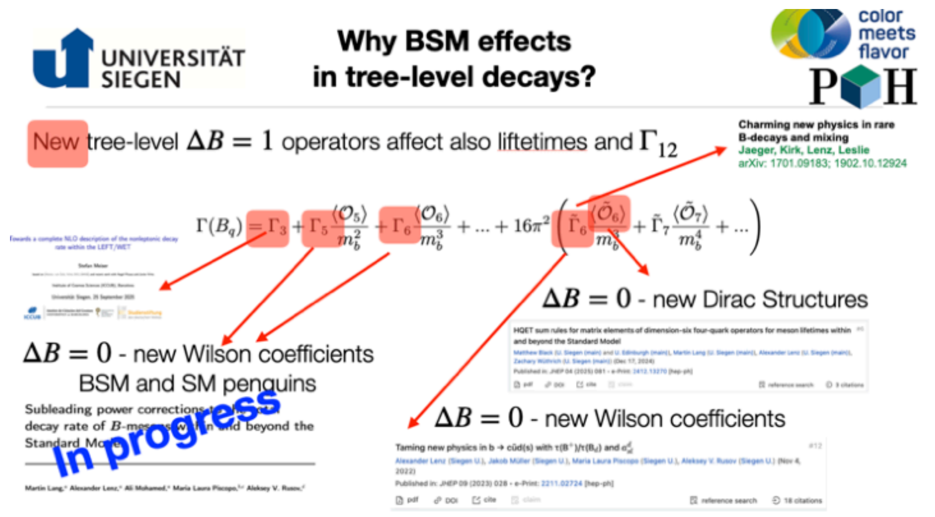

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Most ignored theory result of our workshop

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extraction of γ_{CKM} in BSM scenarios

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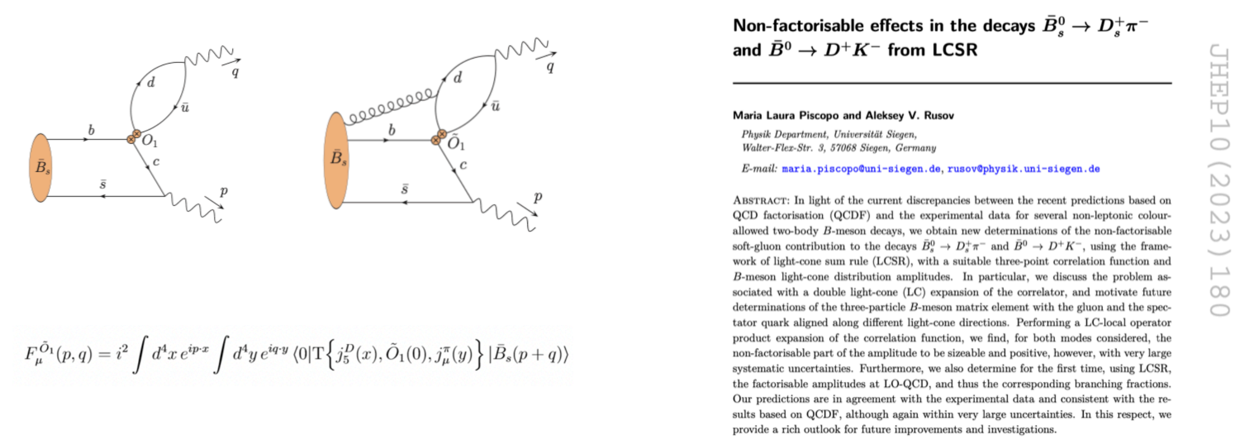

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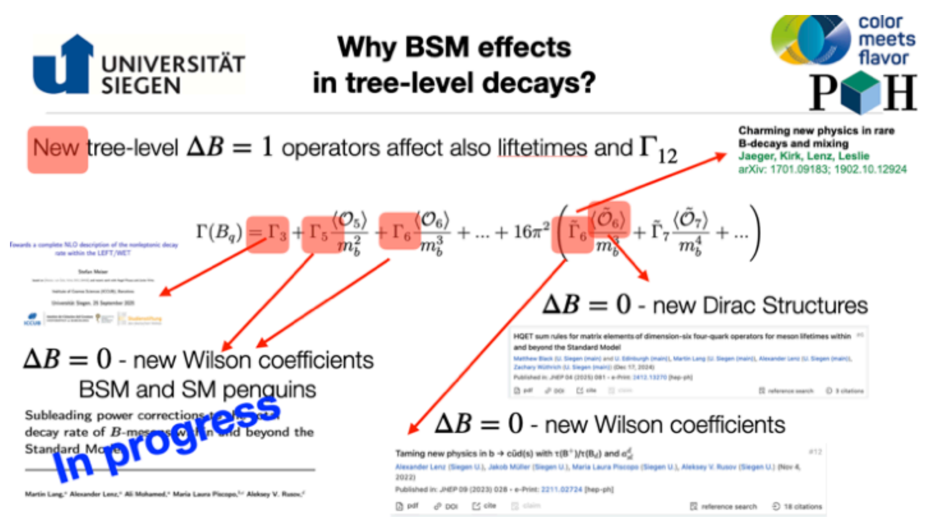

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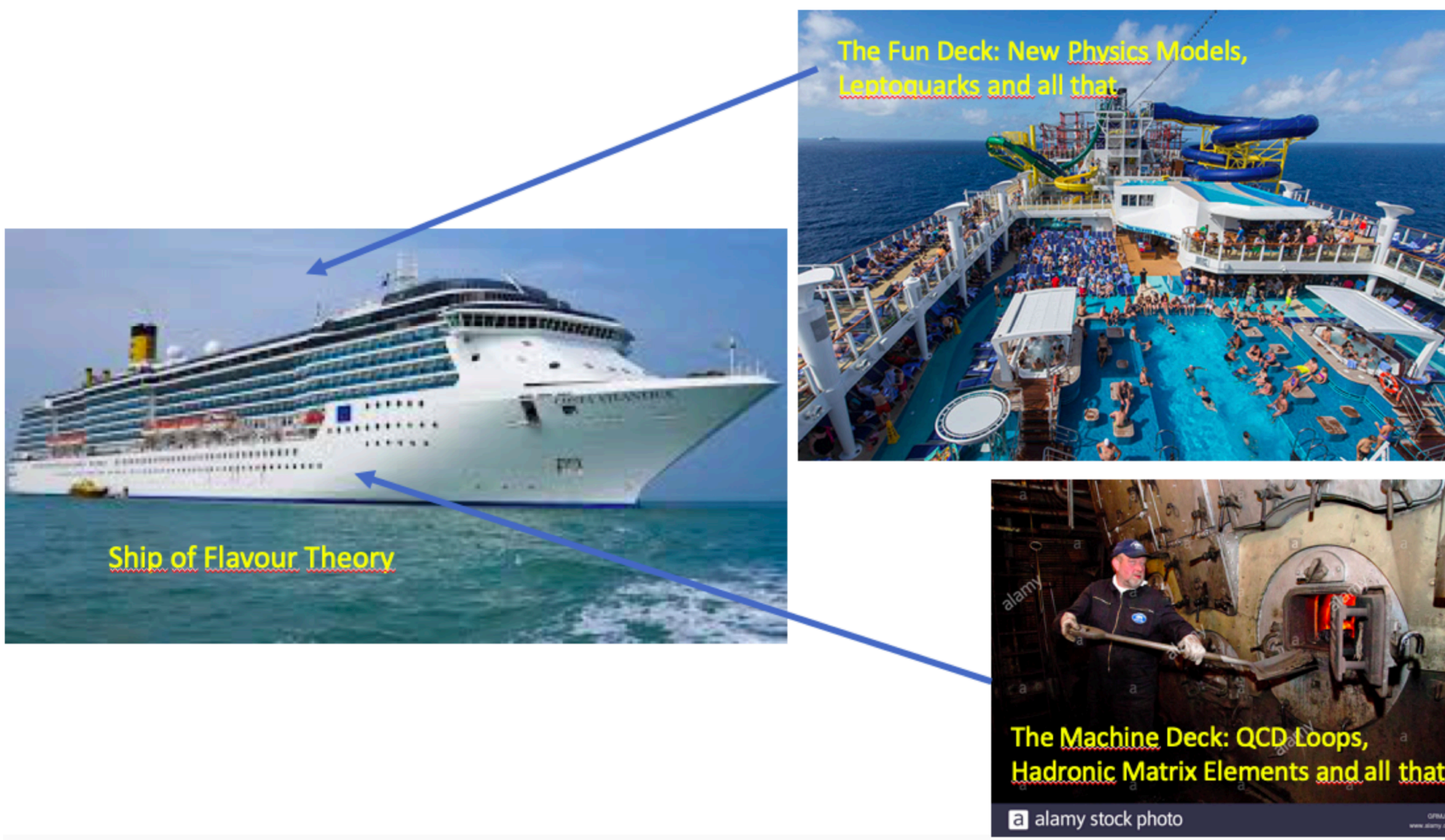
Total decay rates of B mesons at NNLO-QCD #5

Manuel Egner (KIT, Karlsruhe, TTP), Matteo Fael (U. Padua, Dept. Phys. Astron. and INFN, Padua), Alexander Lenz (Siegen U.), Maria Laura Piscopo (Siegen U. and Nikhef, Amsterdam and Vrije U., Amsterdam), Aleksey V. Rusov (Siegen U. and Munich, Tech. U.) et al. (Dec 18, 2024)

Published in: *JHEP* 04 (2025) 106 • e-Print: 2412.14035 [hep-ph]

$$\Gamma(B^+) = 0.587^{+0.025}_{-0.035}\ \mathrm{ps}^{-1},\ \Gamma(B_d) = 0.636^{+0.028}_{-0.037}\ \mathrm{ps}^{-1},\ \Gamma(B_s) = 0.628^{+0.027}_{-0.035}\ \mathrm{ps}^{-1}$$

Conclusion


The Fun Deck: New Physics Models,
Leptoquarks and all that
Ship of Flavour Theory
The Machine Deck: QCD Loops,
Hadronic Matrix Elements and all that
alamy stock photo

Conclusion

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

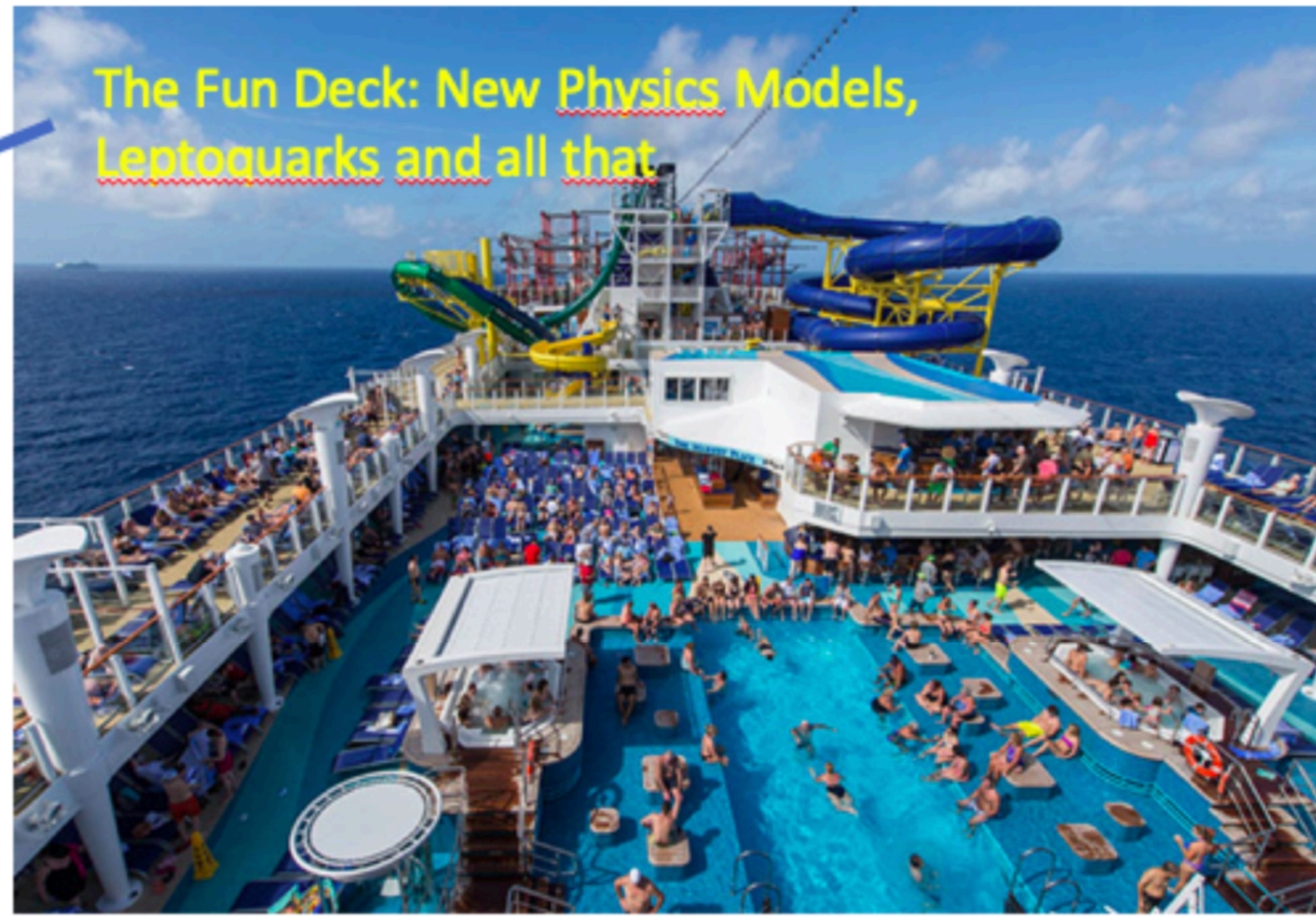
Conclusion

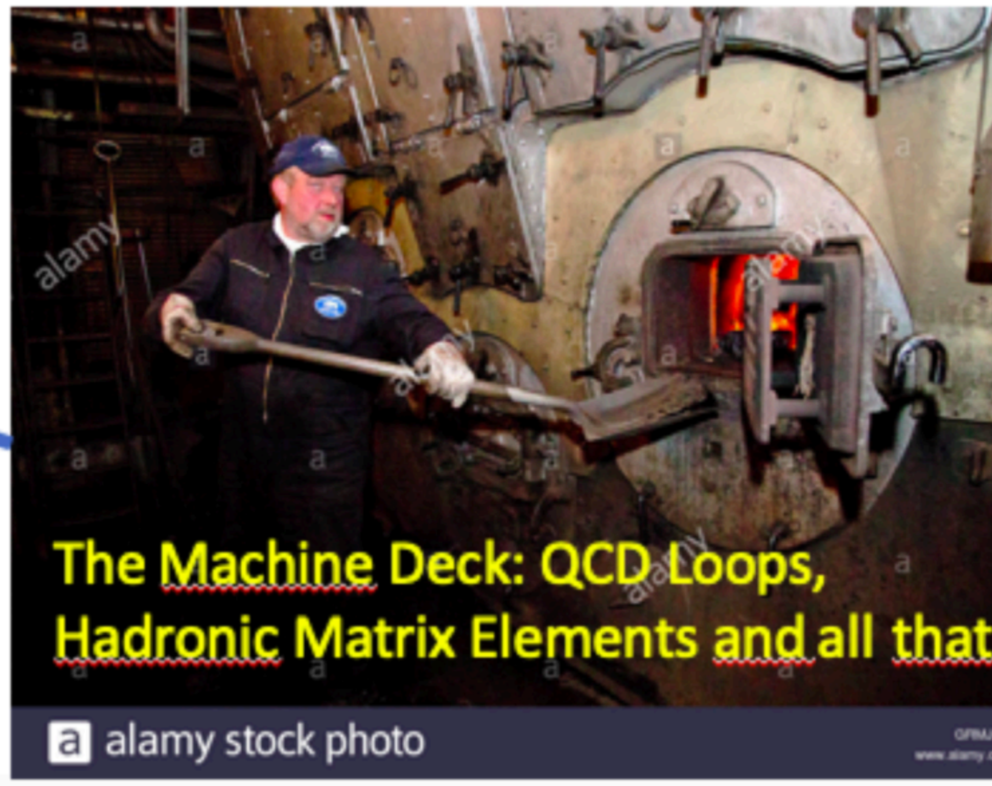
- We must still understand QCD better - also for the fun deck => put more efforts into the machine deck or the ship will get stuck or drift away!

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

Conclusion

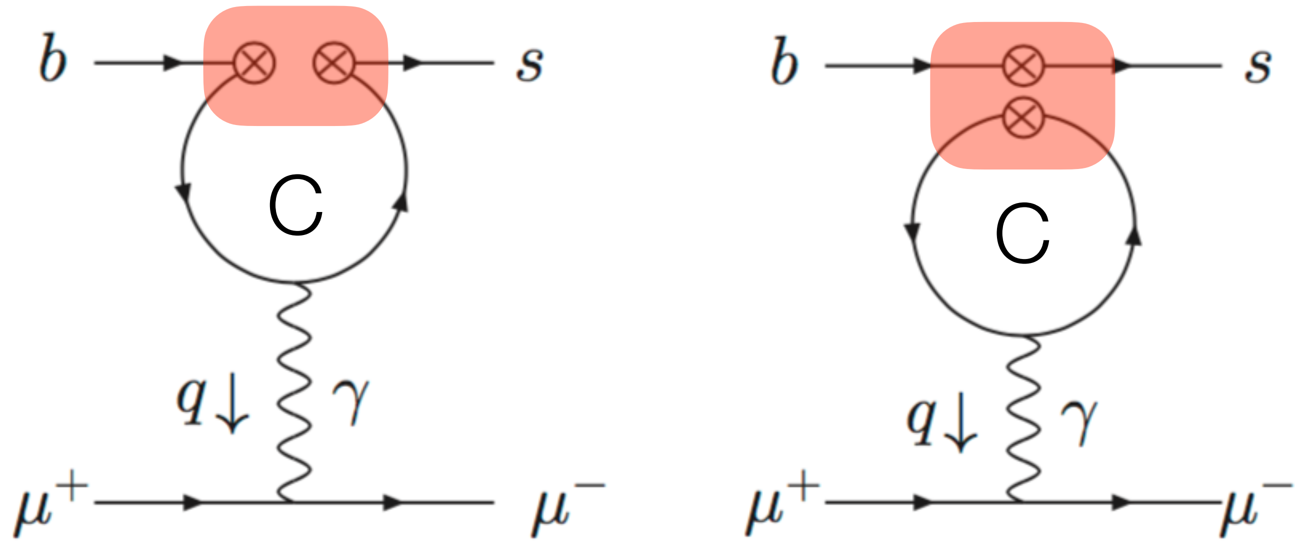
- We must still understand QCD better - also for the fun deck => put more efforts into the machine deck or the ship will get stuck or drift away!





- 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

Outline

1) Why BSM effects in tree-level decays?
2) A decisive test of certain BSM effects in tree-level decays
3) **Reminder: extraction of $\gamma_{\rm CKM}$ in the SM**
4) Reminder: extraction of $\gamma_{\rm CKM}$ in BSM scenarios

Reminder:
extraction of γ_{CKM} in the SM

Amazing cleanliness of the extraction of γ_{CKM} within the SM:
1 part per million

The ultimate theoretical error on γ from $B \to DK$ decays
Joachim Brod (Cincinnati U.), Jure Zupan (Cincinnati U.) (Aug 26, 2013)
Published in: *JHEP* 01 (2014) 051 • e-Print: 1308.5663 [hep-ph]

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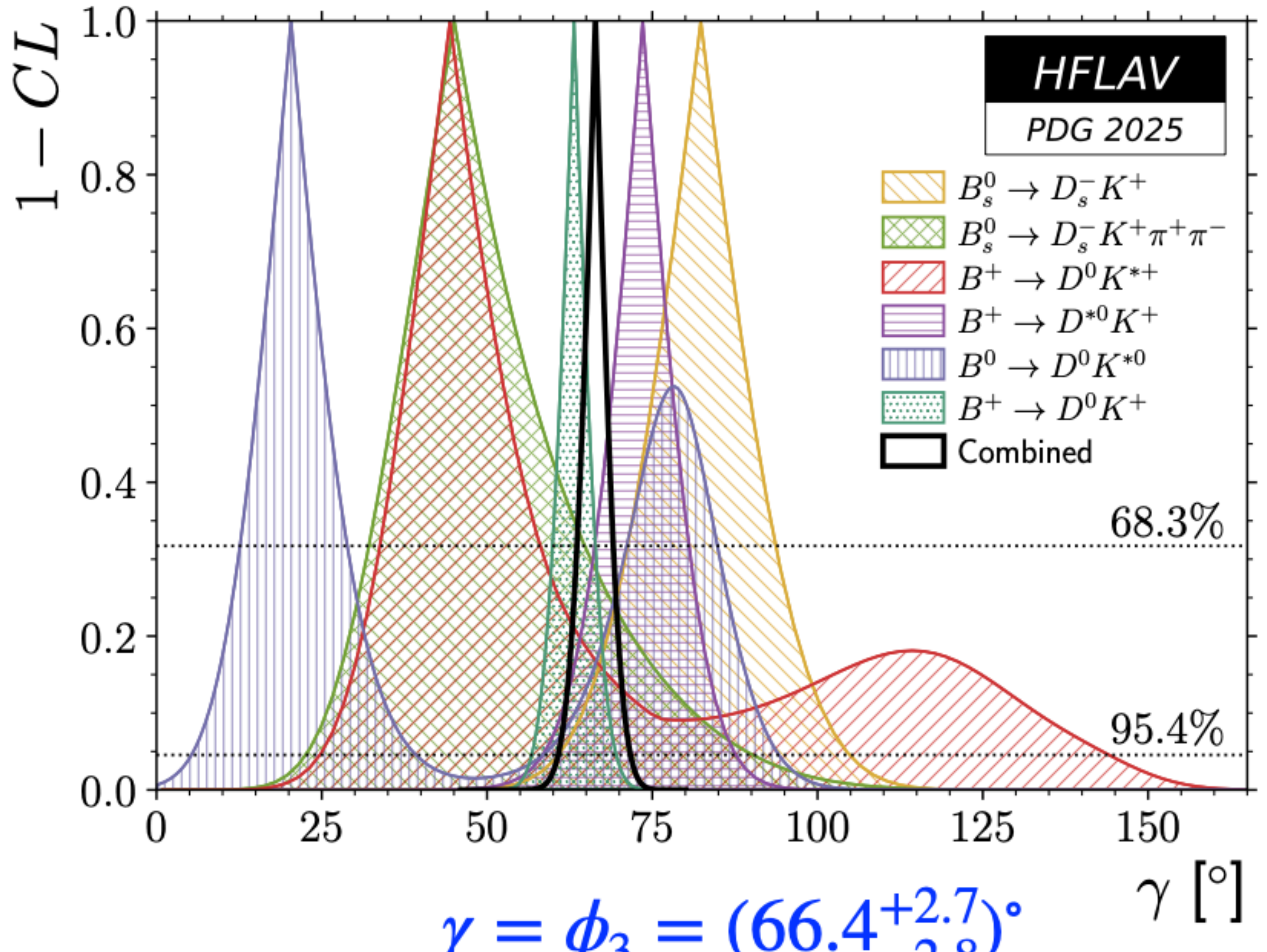
CKM angle γ

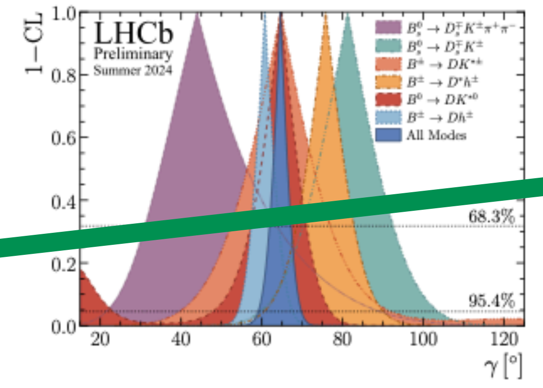
$\to$ A. Lupato in parallel sessions
$\to$ S. Zhang in parallel sessions

- CKM angle γ from interferences between $b \to c$ and $b \to u$ transitions
- Benefit from large statistics using tree-dominated processes
- Complementary methods, dependent on combinations of favoured and suppressed B and D decays
- Multi-body D decays are used in combination with input on strong phases from independent measurements (BESIII, CLEO3)
- Combination of LHCb measurements of the CKM angle γ and charm mixing parameters

HFLAV



$\gamma = \phi_3 = (66.4^{+2.7}_{-2.8})^\circ$



$\gamma = (64.6 \pm 2.8)^\circ$

LHCb-CONF-2024-004

$\to$ A. Bertolin in parallel sessions

F. Blanc, CKM 15/09/2025

CKMfitter (similar results UTfit)

γ [deg] (meas. not in the fit)	66.29 [+0.72 -1.86]

A few degrees discrepancy possible

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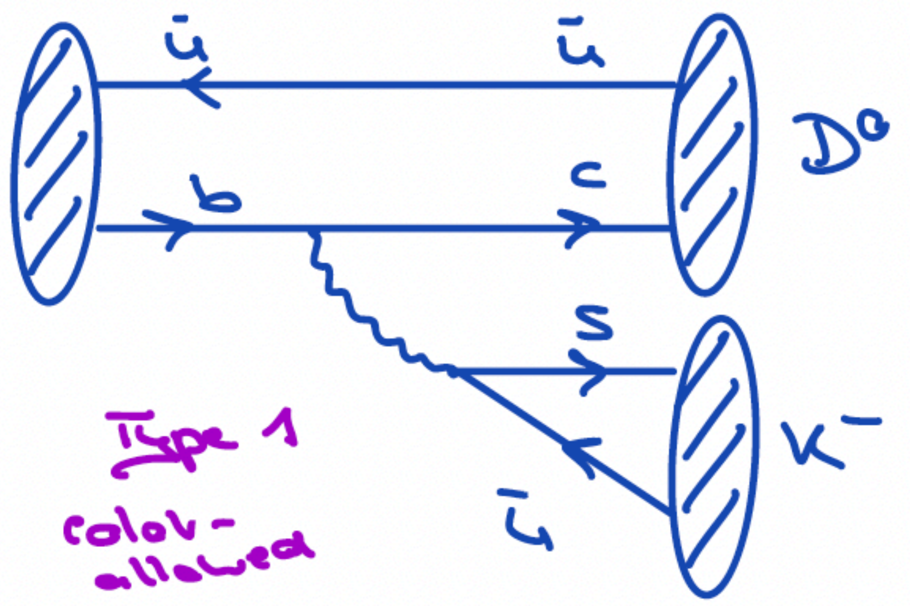
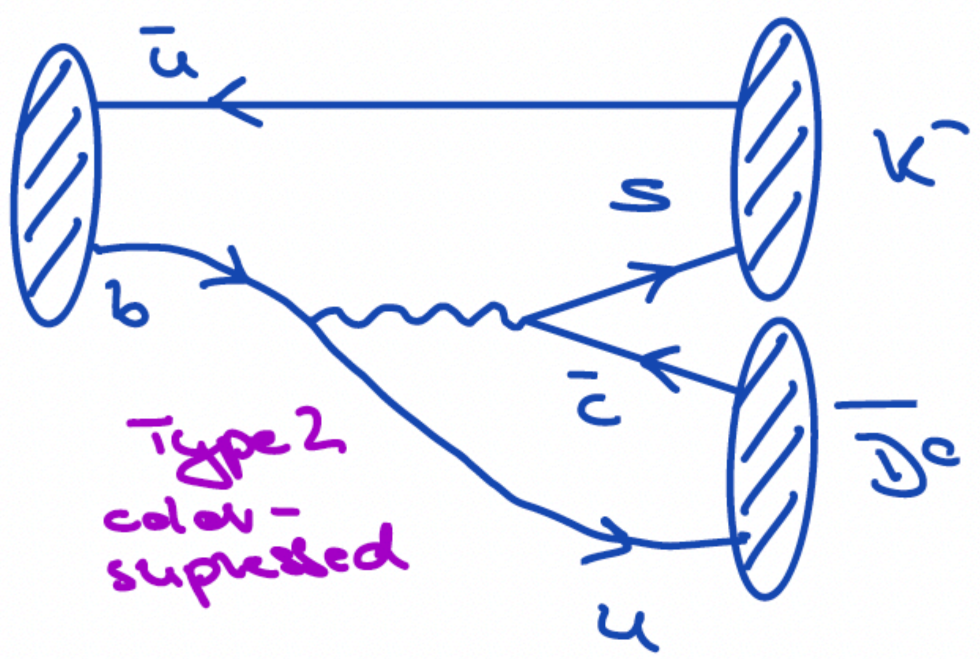
Extraction of γ from $B^\pm \to DK^\pm$:

$B^- \to D^0 K^-$ $\qquad$ $B^- \to \bar{D}^0 K^-$





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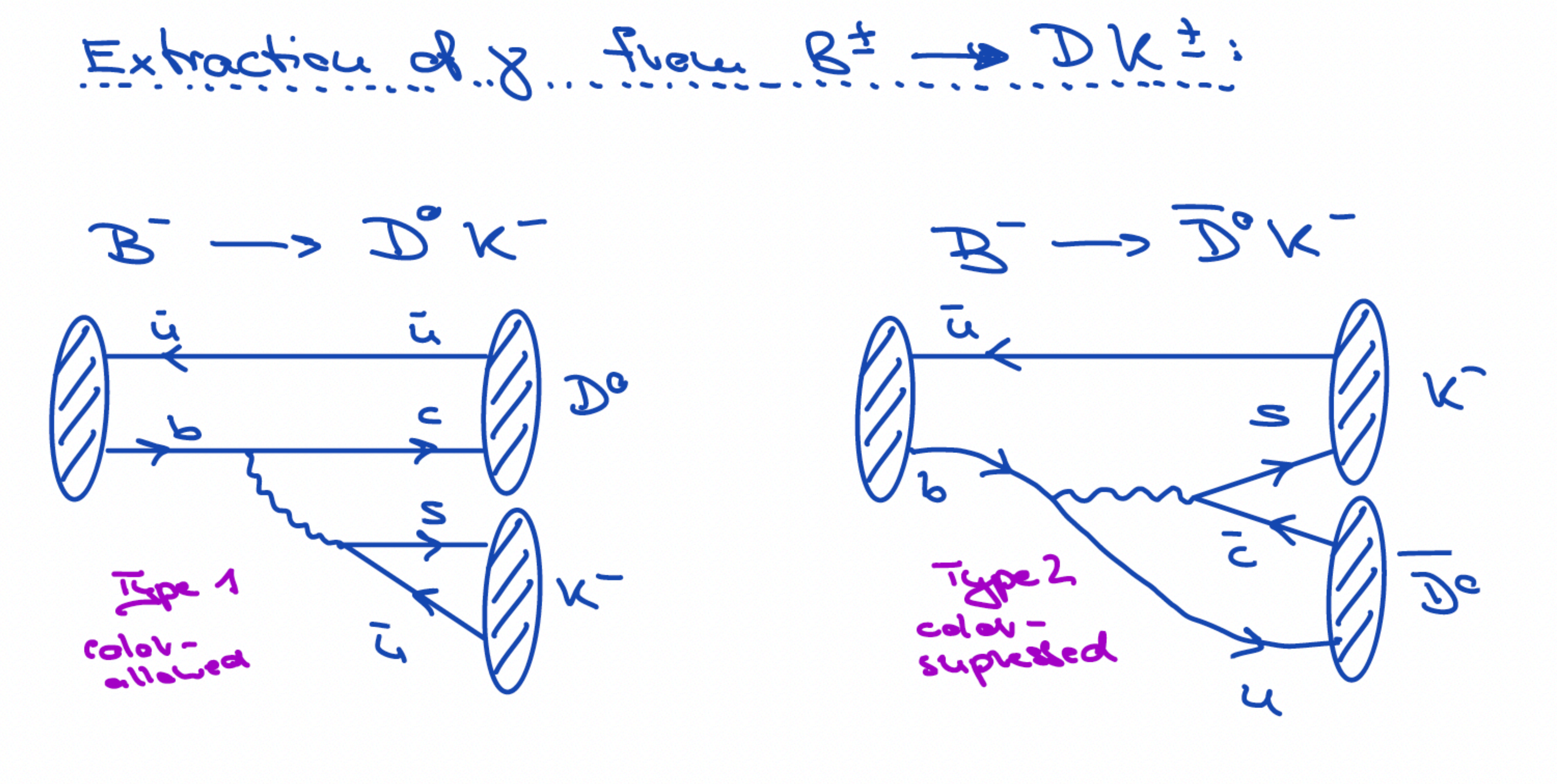

Note:
- A B^- can both decay into a $D^0$and a $\bar{D}^0$ meson
- The first possibility is colour-allowed, the second colour-suppressed

Reminder:
extraction of $\gamma_{\rm CKM}$ in the SM

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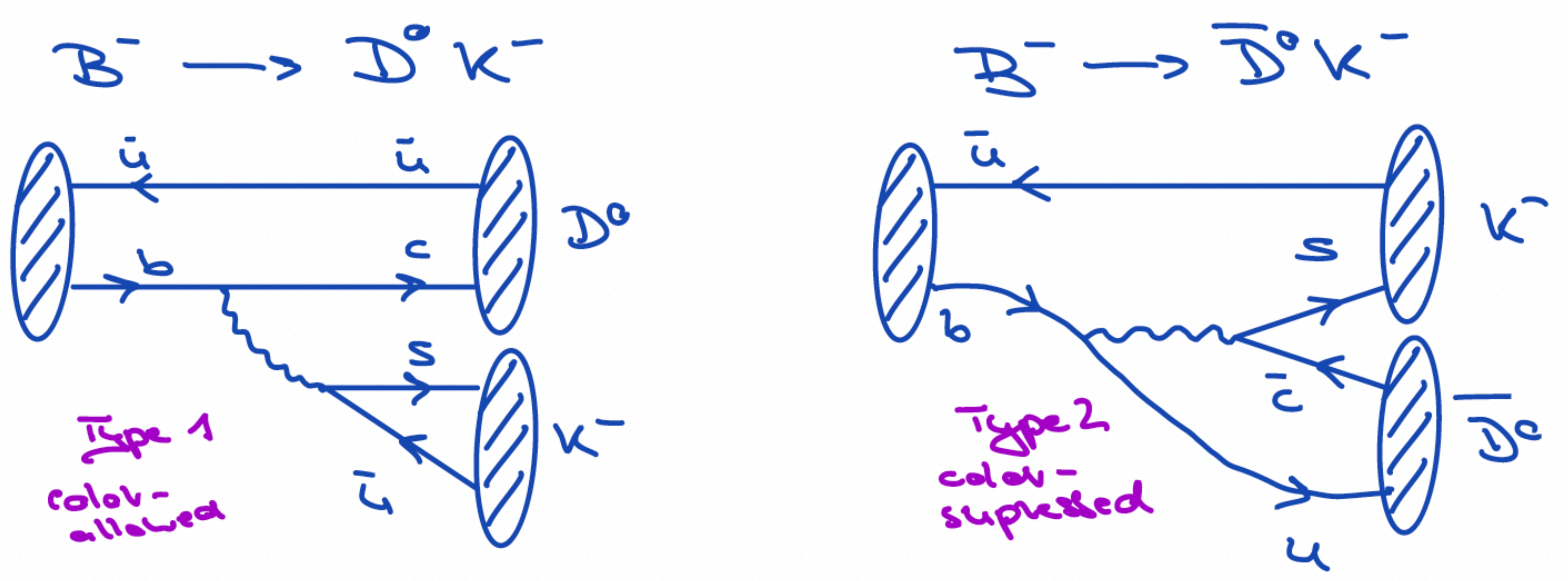

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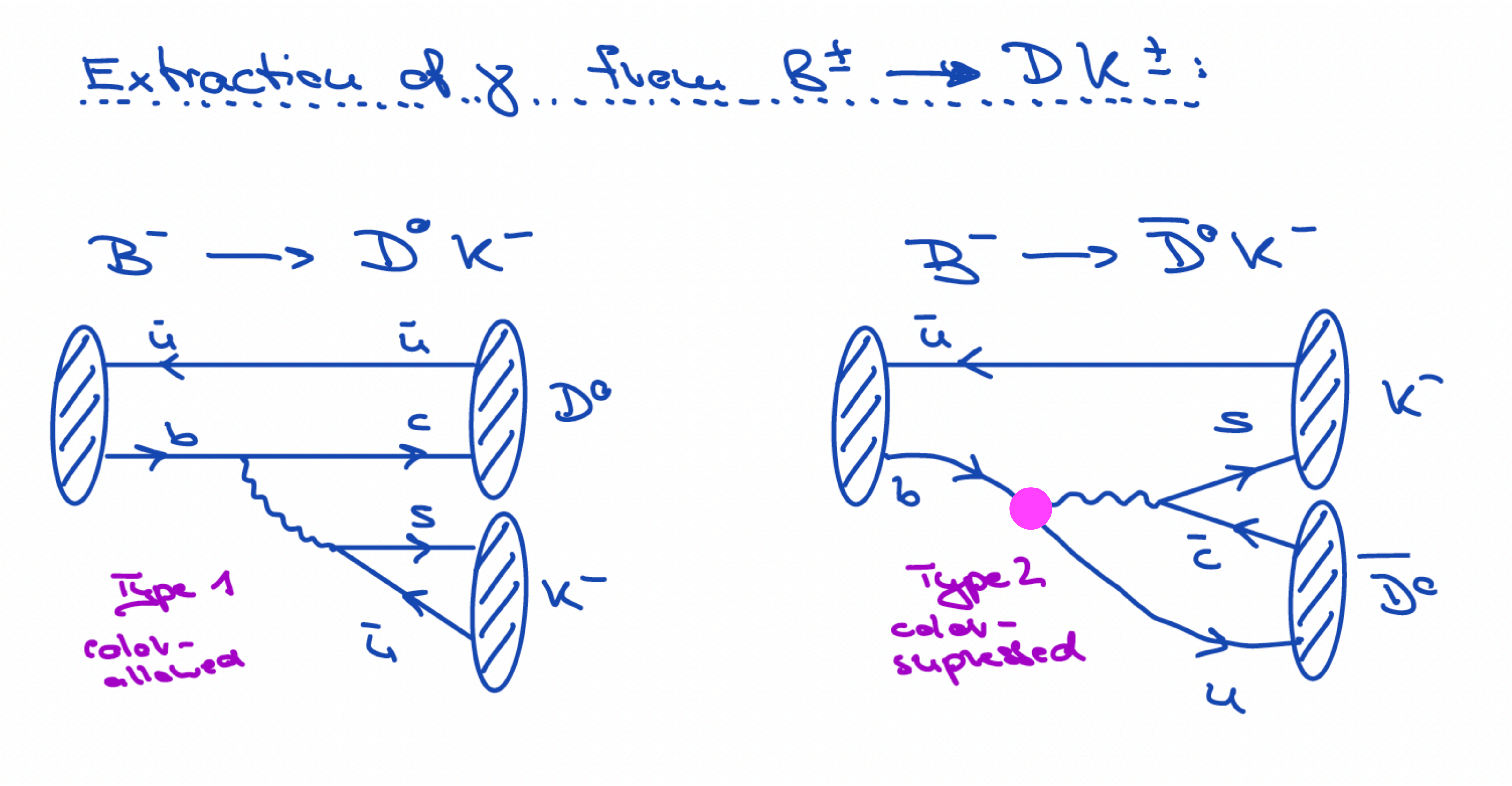

Note:

- A B^- can both decay into a $D^0$and a $\bar{D}^0$ meson
- The first possibility is colour-allowed, the second colour-suppressed
- there are no penguins possible
- The only significant weak phase in these diagrams is γ_{CKM} in the suppressed decay - stemming from V_{ub}

Reminder:
extraction of γ_{CKM} in the SM

Within the SM $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$ decays

(as well as $B^+ \to \bar{D}^0 K^+$ and $B^+ \to D^0 K^+$)

are described with the effective Hamiltonian:

$$\mathcal{H}_{eff}^{\bar{u}_1 u_2 d_1} = \frac{G_F}{\sqrt{2}} V_{u_1 b} V_{u_2 d_1}^* \left[C_1 Q_1^{\bar{u}_1 u_2 d_1} + C_2 Q_2^{u_1 \bar{u}_2 d_1} \right]$$

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With the colour re-arranged
and the colour-allowed tree-level operators

$$Q_1^{\bar{u}_1 u_2 d_1} = (\bar{u}_1^\alpha b^\beta)_{V-A} (\bar{d}_1^\beta u_2^\alpha)_{V-A}$$
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Consider: final states f_D into which both the D^0 and the $\bar{D}^0$ can decay, e.g. $\pi^+\pi^-$ and K^+K^-

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Reminder: extraction of γ_{CKM} in the SM

color meets flavor

P H

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We can write generally - without knowing the values of $A_1, \delta_1, A_2, \delta_2$

$$\mathcal{A}(B^- \to D^0 K^- \to f_D K) =: A_1 e^{i\delta_1} \qquad \mathcal{A}(B^- \to \bar{D}^0 K^- \to f_D K) =: A_2 e^{i(\delta_2 - \gamma)}$$

Reminder:
extraction of γ_{CKM} in the SM

Therefore we get for the amplitude $B^- \to f_D K^-$ two contributions
(one from intermediate D^0 and one from $\bar{D}^0$)

$$\mathcal{A}(B^- \to f_D K^-) = A_1 e^{i\delta_1} + A_2 e^{i(\delta_2 - \gamma)}$$

$$= A_1 e^{i\delta_1}\left[1 + \underbrace{\frac{A_2}{A_1}}_{=: r_B} e^{i\overbrace{(\delta_2 - \delta_1}^{}} {}^{-\gamma)}\right]$$

Reminder:
extraction of $\gamma_{\rm CKM}$ in the SM

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$$= A_1 e^{i\delta_1}\left[1 + \underbrace{\frac{A_2}{A_1}}_{=: r_B} e^{i\overbrace{(\delta_2-\delta_1}^{}-\gamma)}\right]$$

$=: r_B$ $\quad =: \delta_B$

Similarly we get for the amplitude $B^+ \to f_D K^+$

$$\mathcal{A}(B^+ \to f_D K^+) = A_1 e^{i\delta_1}\left[1 + r_B\, e^{i(\delta_B + \gamma)}\right]$$

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Reminder:
extraction of γ_{CKM} in the SM

color meets flavor

Therefore we get for the amplitude $B^- \to f_D K^-$ two contributions
(one from intermediate D^0 and one from $\bar{D}^0$)

$$\mathcal{A}(B^- \to f_D K^-) = A_1 e^{i\delta_1} + A_2 e^{i(\delta_2 - \gamma)}$$
$$= A_1 e^{i\delta_1}\left[1 + \underbrace{\frac{A_2}{A_1}}_{=: r_B} e^{i(\underbrace{\delta_2 - \delta_1}_{=: \delta_B} - \gamma)}\right]$$

Similarly we get for the amplitude $B^+ \to f_D K^+$

$$\mathcal{A}(B^+ \to f_D K^+) = A_1 e^{i\delta_1}\left[1 + r_B e^{i(\delta_B + \gamma)}\right]$$

These two expressions allow the precise extraction of γ_{CKM} from experimental data