35 years of $b \to s\ell^+\ell^-$: from Charged Higgses to Leptoquarks and back to the SM

Università di Roma "La Sapienza"
Facoltà di Scienze Matematiche, Fisiche e Naturali
Corso di Laurea in Fisica
A.A. 1987-88

EFFETTI FENOMENOLOGICI DELLO SCAMBIO VIRTUALE

DI BOSONI DI HIGGS CARICHI

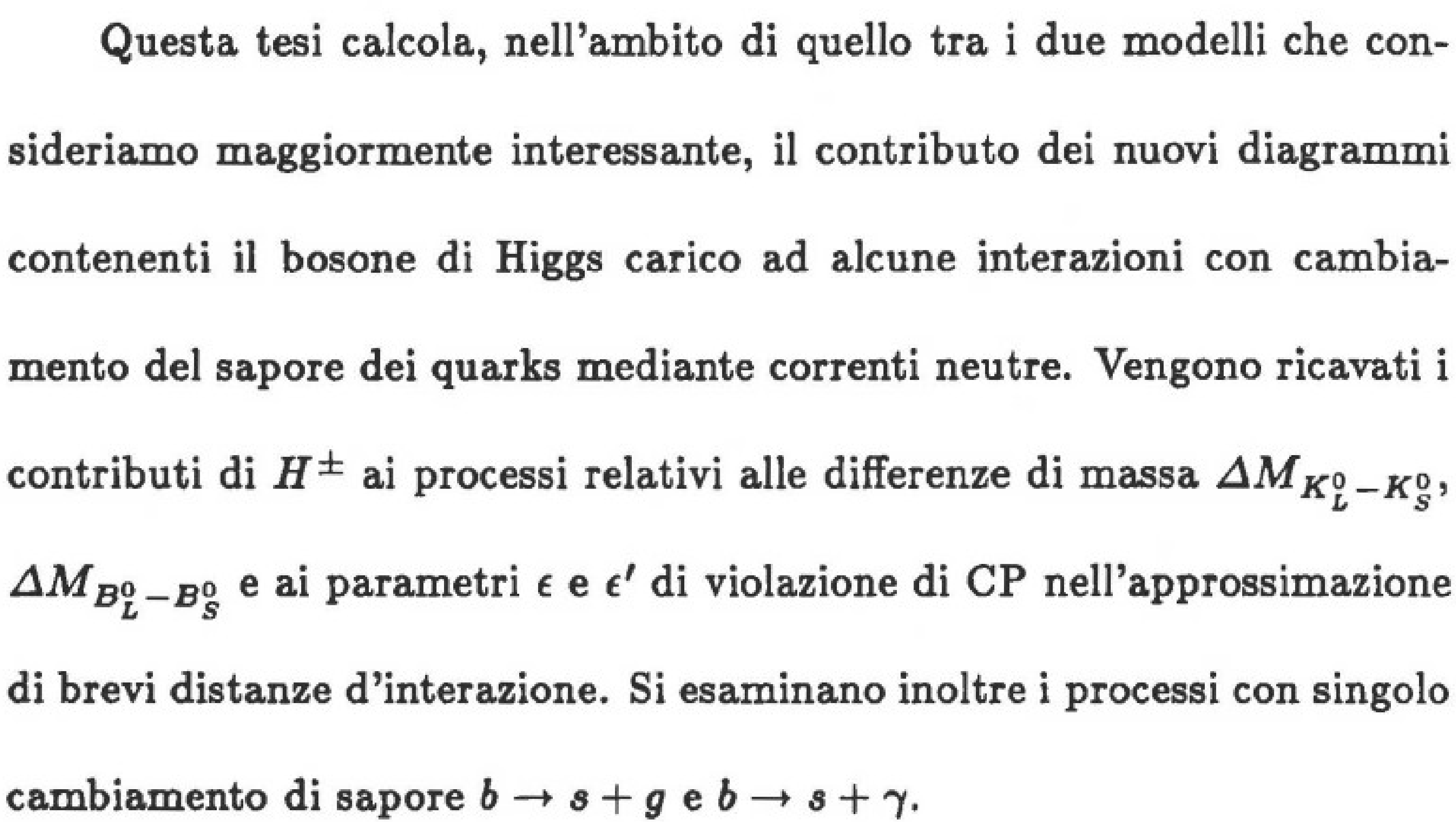
Laureando:

Marco Ciuchini
matr. N52494

PHYSICAL REVIEW D **107**, 055036 (2023)

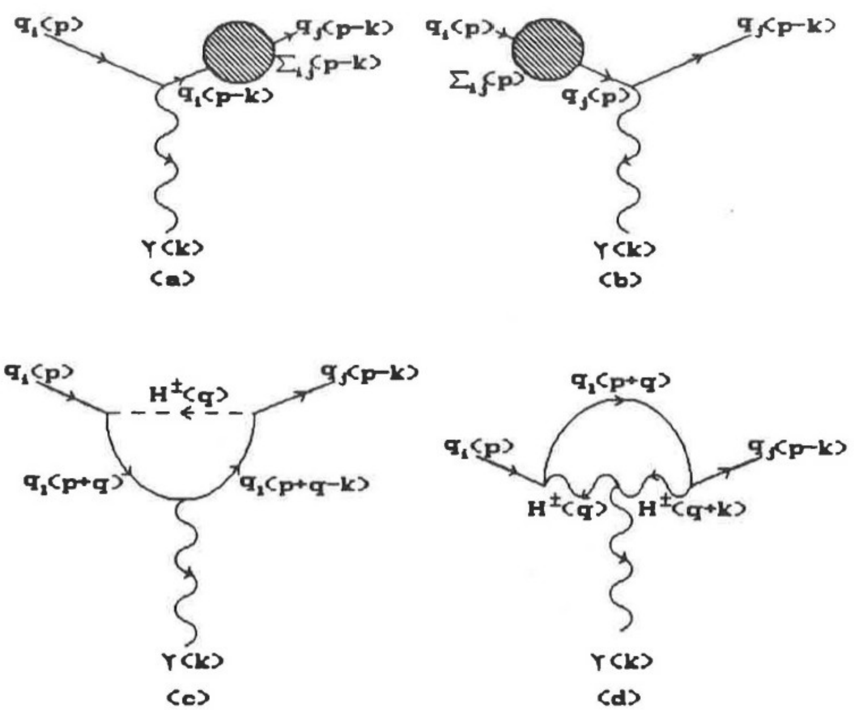
Constraints on lepton universality violation from rare *B* decays

The Early Days



The Early Days

- The full matching of ΔF=2 and of FCNC Z, γ and gluon couplings is computed, and constraints are derived



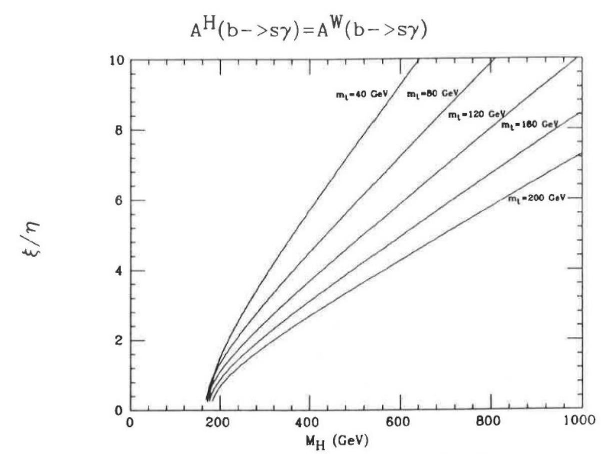


Fig. 4.15 $b \to s\gamma$: le curve che verificano $\frac{H^H_{eff}}{H^W_{eff}} = 1$

The first paper on $b \to s\ell^+\ell^-$

Istituto Nazionale Fisica Nucleare

Sezione SANITA'
Istituto Superiore di Sanita'
Viale Regina Elena 299
I 00161 Roma, Italy

INFN-ISS 89/3

EFFECTS OF THE CHARGED HIGGS BOSON ON THE $b \to sl^+l^-$ DECAY†

M. Ciuchini

INFN - Sezione Sanità
Istituto Superiore di Sanità - Physics Laboratory
Viale Regina Elena, 299. I-00161 Roma (Italy)

Conclusions

The analysis of the rate $\Gamma(b \to sl^+l^-)$ in the $2H$ model defined by the interaction Lagrangian in (1) shows that the considered transition in not particularly sensitive to the charged Higgs boson. On the contrary, due to a cancellation between the standard and Higgs "magnetic" form factors, it is slightly suppressed with respect to the standard model in a quite large region of the parameters space. A significant enhancement of the rate (up to a factor ~ 6 for $r = 4$, large M_t and small M_H) can be obtained by choosing values of the Higgs doublets v.e.v. ratio $\frac{\xi}{\eta} > 1$, i.e. values not allowed in the minimal SUSY extension of the standard model.

- The calculation in the thesis is extended to $b \to s\ell^+\ell^-$

The NLO days

- Then comes Guido with an easy proposal, to be completed in a few weeks: upgrade all this to NLO in QCD
- A few years of two-loop calculations carried out running Schoonship on an Amiga in Bologna followed; I remember the hot summer afternoons in Enrico's office at the first floor, where we absorbed heat until the very last sun ray of the day...

The NLO days

- In the winter of 1994/95, Marco and I went to CERN to work with Guido. We were in Guido's office on a Saturday afternoon, running the code that performed the prediction of ε'/ε at NLO. Disk space was precious, so Marco's work chain was:

  1) edit the source;
  2) compile;
  3) delete auxiliary files;
  4) run.

- As the afternoon went by, Marco became quicker and quicker in typing the corresponding commands

- At some point, typing at supersonic speed, he added an extra space at step 3), turning an `rm *.o` into an `rm * .o`

- The rest of the weekend was happily spent rewriting all the modifications we made in the last few days (fortunately there was a backup copy from the days before our trip to CERN); luckily this happened before Guido was back at work on Monday morning...

From WEINBERG@physics.utexas.edu
To silvestrini@roma1.infn.it
Cc WEINBERG@UTAPHY.PH.UTEXAS.EDU
Subject **query about MSSM**

Reply | Reply All | Forward | Archive | Junk | Delete | More

14/07/98, 17:10

July 14, 1998

Professor L. Silvestrini
by e-mail to silvestrini@roma1.infn.it

Dear Professor Silvestrini

I have been reading some of your recent papers with Masiero on SUSY and CP violation, and have a question about your use of the term "minimal supersymmetric standard model." Many authors refer to the MSSM as a theory containing the minimum number of superfields needed to make the standard model supersymmetric (including 2 Higgs doublets), with interactions of dimension four constrained by supersymmetry, and arbitrary interactions of dimension three or less which break supersymmetry. You seem to mean something much more specific, with only four free parameters beyond those of the standard model. I would like to ask:
(1) What is the reference for this model?
(2) What is its rationale? In particular, why include a universal gaugino mass, and not include a universal mass for squarks and sleptons as a fifth new parameter?

With thanks in advance for any help you can give me with this.

Sincerely,
Steven Weinberg

Antonio: "this is clearly a fake message. Someone is making fun of us. Must be Ciuchini… In any case, DO NOT REPLY."

Antonio a few years later: "there are two classes of people whose emails don't get answered: students, because you think they are irrelevant, and Nobel prizes, since you think it's a joke…

The Charming Penguins Days

- Guido already told you everything about charming penguins; what is relevant for this talk is that for a while, during the B-factories era, we were fighting with (QCD) factorization practitioners who claimed the presence of NP in hadronic $b \to s$ penguins such as $B \to K\pi$, forgetting about corrections to the infinite B mass limit

ICHEP in Amsterdam, 2002

- Being tired of these discussions, we decided it was more fun to find new ways to extract short-distance information by determining hadronic matrix elements from data:

PHYSICAL REVIEW D **74,** 051301(R) (2006)

New bounds on the Cabibbo-Kobayashi-Maskawa matrix from $B \to K\pi\pi$ Dalitz plot analyses

M. Ciuchini,[1] M. Pierini,[2] and L. Silvestrini[3]

[1]*Dipartimento di Fisica, Università di Roma Tre and INFN, Sezione di Roma III, Via della Vasca Navale 84, I-00146 Roma, Italy*
[2]*Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, USA*
[3]*Dipartimento di Fisica, Università di Roma "La Sapienza" and INFN, Sezione di Roma, P.le A. Moro 2, I-00185 Rome, Italy*
(Received 1 February 2006; published 12 September 2006)

We present a new technique to extract information on the unitarity triangle from the study of $B \to K\pi\pi$ Dalitz plots. Using the sensitivity of Dalitz analyses to the absolute values and the phases of decay amplitudes and isospin symmetry, we obtain a new constraint on the elements of the CKM matrix. We discuss in detail the role of electroweak penguin contributions and outline future prospects.

PRL **100,** 031802 (2008) PHYSICAL REVIEW LETTERS week ending 25 JANUARY 2008

$B_s \to K^{(*)0}\bar{K}^{(*)0}$ *CP* Asymmetries: Golden Channels for New Physics Searches

M. Ciuchini,[1] M. Pierini,[2] and L. Silvestrini[3]

[1]*Dipartimento di Fisica, Università di Roma Tre and INFN, Sezione di Roma Tre, Via della Vasca Navale 84, I-00146 Roma, Italy*
[2]*Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, USA*
[3]*Dipartimento di Fisica, Università di Roma "La Sapienza" and INFN, Sezione di Roma, Piazzale Aldo Moro 2, I-00185 Rome, Italy*
(Received 23 March 2007; revised manuscript received 22 October 2007; published 22 January 2008)

We point out that time-dependent *CP* asymmetries in $B_s \to K^{*0}\bar{K}^{*0}$ decays probe the presence of new physics in $b \to s$ transitions with an unprecedented theoretical accuracy. We show that, contrary to the case of $B_d \to \phi K_S$, it is possible to obtain a model-independent prediction for the coefficient $S(B_s \to K^{*0}\bar{K}^{*0})$ in the standard model. We give an estimate of the experimental precision achievable with the next generation of B physics experiments. We also discuss how this approach can be extended to the case of $B_s \to \bar{K}^{*0}K^0$, $B_s \to K^{*0}\bar{K}^0$, and $B_s \to K^0\bar{K}^0$ decays and the different experimental challenges for these channels.

CKM 2005, San Diego

In the meantime, people started applying QCD factorization to $b \to s\ell\ell$ decays, forgetting again about power corrections...

… but again we had more interesting things to do than reminding those fans of QCD factorization about charming penguins…

P_5'

- While we were working on the physics of super-B factories, and on the SUSYfit project, the so-called "optimized observables" for $B\to K^{(*)}\ell\ell$ decays were proposed and measured, and of course they deviated from the SM "predictions":

PHYSICAL REVIEW D **88,** 074002 (2013)

Understanding the $B \to K^* \mu^+ \mu^-$ anomaly

Sébastien Descotes-Genon,[1] Joaquim Matias,[2] and Javier Virto[2]

[1]*Laboratoire de Physique Théorique, CNRS/Université Paris-Sud 11 (UMR 8627), 91405 Orsay Cedex, France*
[2]*Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Spain*
(Received 2 August 2013; published 3 October 2013)

We present a global analysis of the $B \to K^*(\to K\pi)\mu^+\mu^-$ decay using the recent LHCb measurements of the primary observables $P_{1,2}$ and $P'_{4,5,6,8}$. Some of them exhibit large deviations with respect to the Standard Model (SM) predictions. We explain the observed pattern of deviations through a large new physics contribution to the Wilson coefficient of the semileptonic operator $\mathcal{O}_9$. This contribution has an opposite sign to the SM one, i.e., reduces the size of this coefficient significantly. A good description of data is achieved by allowing for new physics contributions to the Wilson coefficients $\mathcal{C}_7$ and $\mathcal{C}_9$ only. We find a 4.5σ deviation with respect to the SM prediction, combining the large-recoil $B \to K^*(\to K\pi)\mu^+\mu^-$ observables with other radiative processes. Once low-recoil observables are included the significance gets reduced to 3.9σ. We have tested different sources of systematics, none of them modifying our conclusions significantly. Finally, we propose additional ways of measuring the primary observables through new foldings.

- This forced Marco to go back to his beloved $b\to s\ell\ell$ transitions…

Knowns and unknows in the prediction of $B \to K^*\mu\mu$

Marco Ciuchini

INFN Roma Tre

- Known knowns
- Known unknowns

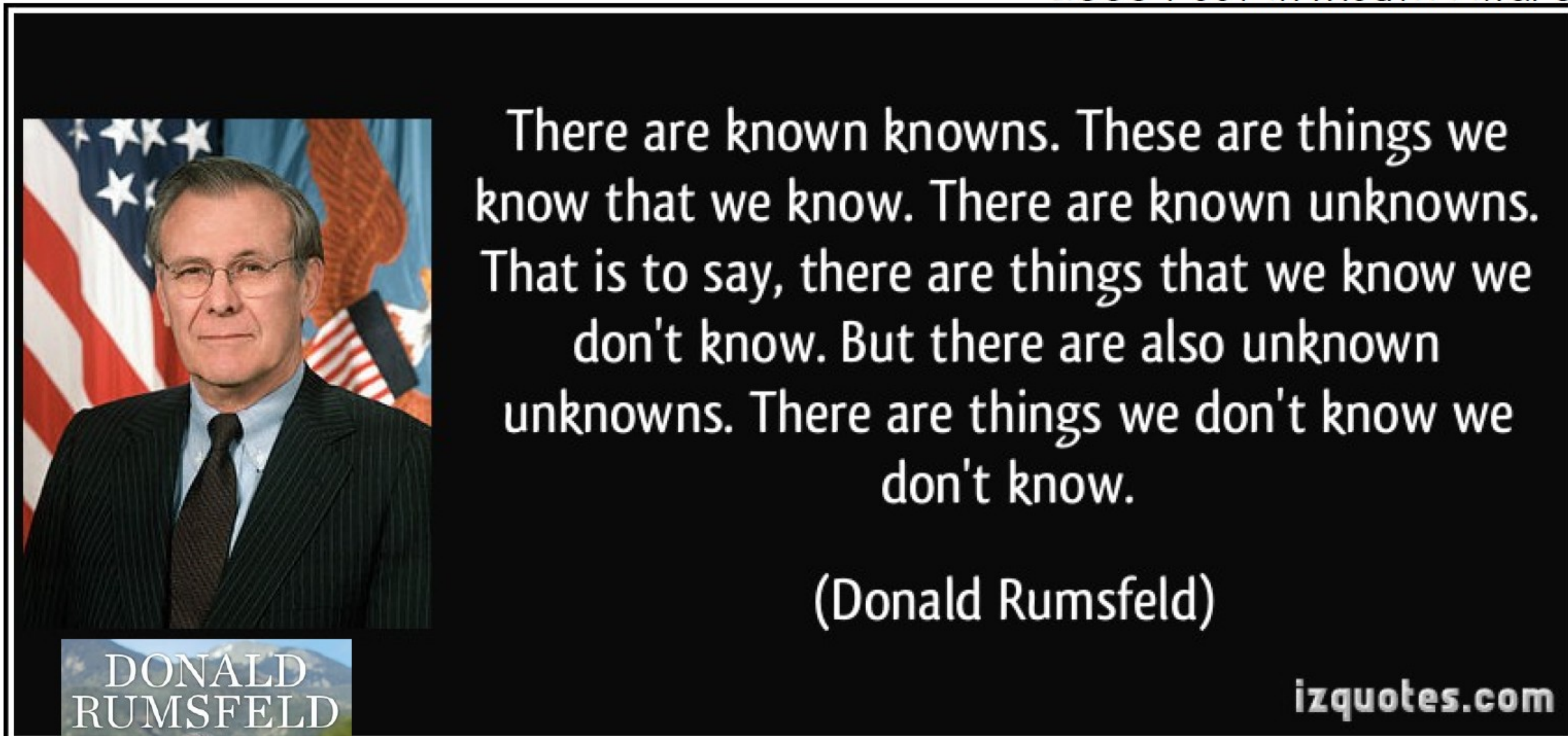
  or perhaps unknown knowns...
- Using data

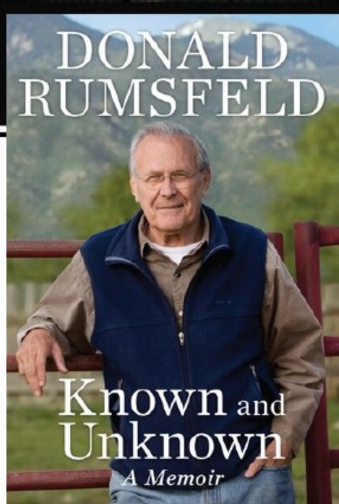
Sixth Workshop on Theory, Phenomenology and Experiments in Flavour Physics - FPCapri2016

11-13 June 2016 *Villa Orlandi, Anacapri, Capri Island, Italy*

Knowns and Unknowns

2003 Foot in Mouth Award





The concept of unknown knowns (thing we know but we prefer to ignore), introduced by later thinkers, may also be relevant for the present discussion

Known knowns in $B \to K^*\mu\mu$ (i)

$$\frac{d^{(4)}\Gamma}{dq^2\, d(\cos\theta_l) d(\cos\theta_k) d\phi} = \frac{9}{32\pi} \Big(I_1^s \sin^2\theta_k + I_1^c \cos^2\theta_k + (I_2^s \sin^2\theta_k + I_2^c \cos^2\theta_k)\cos 2\theta_l$$
$$+ I_3 \sin^2\theta_k \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_k \sin 2\theta_l \cos\phi$$
$$+ I_5 \sin 2\theta_k \sin\theta_l \cos\phi + (I_6^s \sin^2\theta_k + I_6^c \cos^2\theta_K)\cos\theta_l$$
$$+ I_7 \sin 2\theta_k \sin\theta_l \sin\phi + I_8 \sin 2\theta_k \sin 2\theta_l \sin\phi$$
$$+ I_9 \sin^2\theta_k \sin^2\theta_l \sin 2\phi \Big)$$

angular analysis

$$S_i = \left(I_i^{(s,c)} + \bar{I}_i^{(s,c)} \right) / \Gamma'$$
$$\left(2\,\Gamma' \equiv d\Gamma/dq^2 + d\bar{\Gamma}/dq^2 \right)$$

8 CP-AVERAGED OBSERVABLES

$$F_L, A_{FB}, S_{3,4,5,7,8,9}$$

In the helicity amplitude formalism: $(m_\ell \sim 0)$

$$I_1^c = -I_2^c = \frac{F}{2}\left(|H_V^0|^2 + |H_A^0|^2\right),$$
$$I_1^s = 3I_2^s = \frac{3}{8}F\left(|H_V^+|^2 + |H_V^-|^2 + |H_A^+|^2 + |H_A^-|^2\right),$$
$$I_3 = -\frac{F}{2}\mathrm{Re}\left[H_V^+(H_V^-)^* + H_A^+(H_A^-)^*\right],$$
$$I_4 = \frac{F}{4}\mathrm{Re}\left[(H_V^+ + H_V^-)(H_V^0)^* + (H_A^+ + H_A^-)(H_A^0)^*\right],$$
$$I_5 = \frac{F}{4}\mathrm{Re}\left[(H_V^- - H_V^+)(H_A^0)^* + (H_A^- - H_A^+)(H_V^0)^*\right],$$
$$I_6^s = F\mathrm{Re}\left[H_V^-(H_A^-)^* - H_V^+(H_A^+)^*\right],$$
$$I_6^c = 0,$$
$$I_7 = \frac{F}{2}\mathrm{Im}\left[(H_A^+ + H_A^-)(H_V^0)^* + (H_V^+ + H_V^-)(H_A^0)^*\right],$$
$$I_8 = \frac{F}{4}\mathrm{Im}\left[(H_V^- - H_V^+)(H_V^0)^* + (H_A^- - H_A^+)(H_A^0)^*\right],$$
$$I_9 = \frac{F}{4}\mathrm{Im}\left[H_V^+(H_V^-)^* + H_A^+(H_A^-)^*\right].$$

We need to compute few helicity amplitudes:

$$H_{V,A}^{\lambda} \qquad \lambda = 0, \pm$$

Known knowns in B → K*μμ (ii)

$$H_V{}^\lambda = \frac{4iG_F m_B}{\sqrt{2}} \frac{e^2}{16\pi^2} \lambda_t \left\{ C_9^{\rm eff} \tilde{V}_{L\lambda} + \frac{m_B^2}{q^2} \left[\frac{2m_b}{m_B} C_7^{\rm eff} \tilde{T}_{L\lambda} - 16\pi^2 h_\lambda \right] \right\},$$

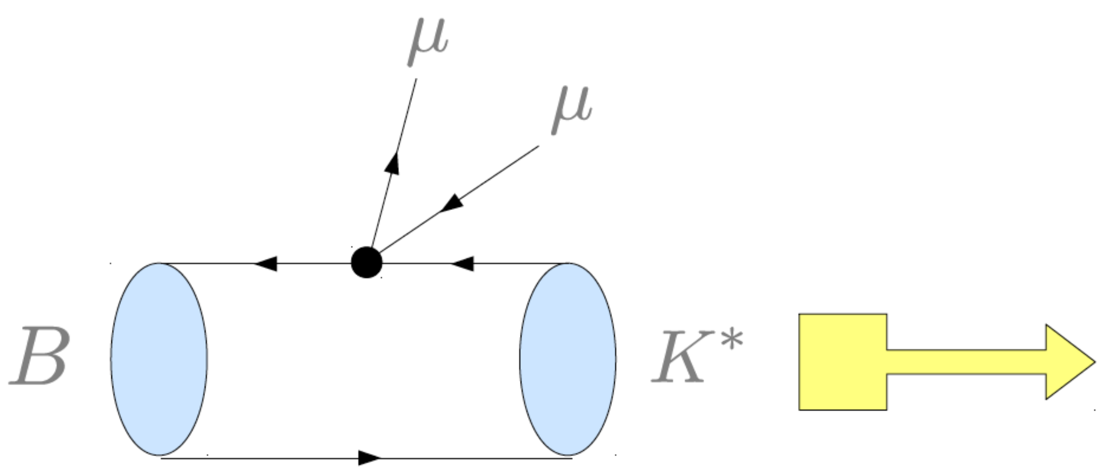
$$H_A{}^\lambda = \frac{4iG_F m_B}{\sqrt{2}} \frac{e^2}{16\pi^2} \lambda_t C_{10} \tilde{V}_{L\lambda}.$$

NNLO Wilson coefficients from the ΔB=1 effective Hamiltonian:

$$\mathcal{H}_{\rm eff}^{\Delta B=1} = \mathcal{H}_{\rm eff}^{sl+\gamma} + \mathcal{H}_{\rm eff}^{had}$$

$$\mathcal{H}_{\rm eff}^{sl+\gamma} = -\frac{4G_F}{\sqrt{2}} \lambda_t \left(C_7 Q_{7\gamma} + C_9 Q_{9V} + C_{10} Q_{10A} \right)$$

$$Q_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma_{\mu\nu} F^{\mu\nu} b_R\,,$$
$$Q_{9V} = \frac{\alpha_e}{4\pi} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)\,,$$
$$Q_{10A} = \frac{\alpha_e}{4\pi} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \gamma^5 \ell)\,.$$



Hadronic matrix elements of quark currents: **FORM FACTORS**

Known unknowns in B → K*μμ

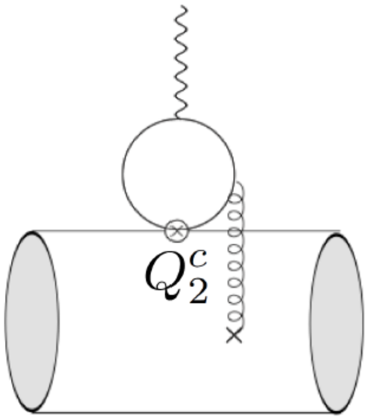
$$H_V{}^\lambda = \frac{4iG_F m_B}{\sqrt{2}} \frac{e^2}{16\pi^2} \lambda_t \left\{ C_9^{\rm eff} \tilde{V}_{L\lambda} + \frac{m_B^2}{q^2} \left[\frac{2m_b}{m_B} C_7^{\rm eff} \tilde{T}_{L\lambda} - 16\pi^2 h_\lambda \right] \right\}$$

$$h_\lambda(q^2) = \frac{\epsilon_\mu^*(\lambda)}{m_B^2} \int d^4x e^{iqx} \langle \bar{K}^* | T\{ j^\mu_{\rm em}(x) \mathcal{H}_{\rm eff}^{\rm had}(0) \} | \bar{B} \rangle$$

Non-factorizable power-suppressed contributions of 4-quark operators to the matrix element

- dominated by

$$Q_1^c = (\bar{s}_L \gamma_\mu T^a c_L)(\bar{c}_L \gamma^\mu T^a b_L),$$
$$Q_2^c = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L),$$



the charm pair can be close to the resonant region

Do we know how to compute them?

In general, no!

Making the unknowns known…

An exploratory study in 2 steps: KMPW, arXiv:1006.4945

1. at $q^2 \ll 4m_c^2$ the c loop is dominated by light-cone dynamics. One can write $\left[\mathcal{H}_\mu^{(B\to K^{(*)})}(p,q)\right]_{nonfact} = 2C_1\langle K^{(*)}(p)|\widetilde{\mathcal{O}}_\mu(q)|B(p+q)\rangle$, where $\widetilde{\mathcal{O}}_\mu(q) = \int d\omega\, I_{\mu\rho\alpha\beta}(q,\omega)\bar{s}_L\gamma^\rho\delta[\omega - \frac{(in_+\mathcal{D})}{2}]\widetilde{G}_{\alpha\beta}b_L$ is a non-local operator representing the first subleading term of an expansion in $\Lambda^2/(4m_c^2-q^2)$, (single soft gluon approximation), whose ME is computed using LCSR

   1 ▶ estimate the hadronic contribution for $q^2 < 1$ GeV^2

   but no hard gluons, no phases, large errors (100%?), …?

2. extend the previous result to all q^2 using a dispersion relation, where the spectral functions are given by the 2 physical poles plus additional effective poles that parametrize the integral over the cut at $q^2 > 4m_D^2$

2 ▶
$$\Delta C_{9,i}^{(c\bar{c})}(q^2) = \frac{r_{1,i}\left(1-\frac{\bar{q}^2}{q^2}\right) + \Delta C_{9,i}^{(c\bar{c})}(\bar{q}^2)\frac{\bar{q}^2}{q^2}}{1 + r_{2,i}\frac{\bar{q}^2-q^2}{m_{J/\psi}^2}}$$

$r_{1,i}$	$r_{2,i}$
$0.10^{+0.02}_{-0.00}$	$1.13^{+0.00}_{-0.01}$
$0.09^{+0.01}_{-0.00}$	$1.12^{+0.00}_{-0.01}$
$0.06^{+0.04}_{-0.10}$	$1.05^{+0.05}_{-0.04}$

but model dependence(?), no pert. gluons and phases, ρ positivity…?

Knowing unknowns using data

MC, Fedele, Franco, Mishima, Paul, Silvestrini, Valli, 1512.07157

1. adopt the following parametrization

$$h_\lambda(q^2) = h_\lambda^{(0)} + q^2 h_\lambda^{(1)} + q^4 h_\lambda^{(2)}$$

$$\begin{aligned} \mathrm{abs}(h_\lambda^{(i)}) &\in [0,\, 2\cdot 10^{-3}] \\ \arg(h_\lambda^{(i)}) &\in [0,\, 2\pi) \end{aligned}$$

2. enforce the helicity amplitude suppression on h_+ Jaeger&Camalich, 1212.2263
3. assume there are no contribution beyond the SM
4. include/exclude the effect of th. constraints on $h_\lambda^{(i)}$:

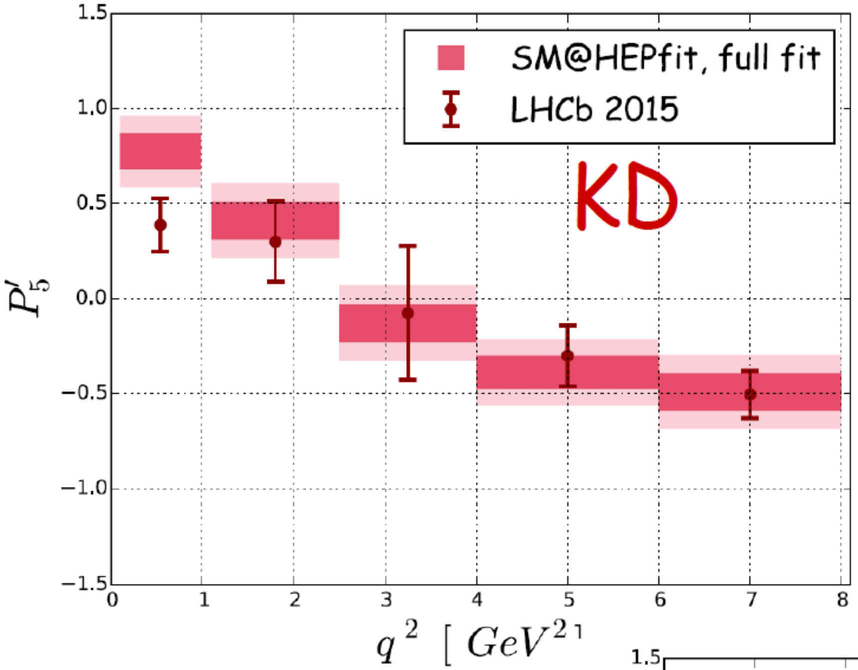
   KMPW: LCSR results at $q^2 \leq 1$ GeV^2 — Khodjamirian, Mannel, Pivovarov, Wang, 1006.4945

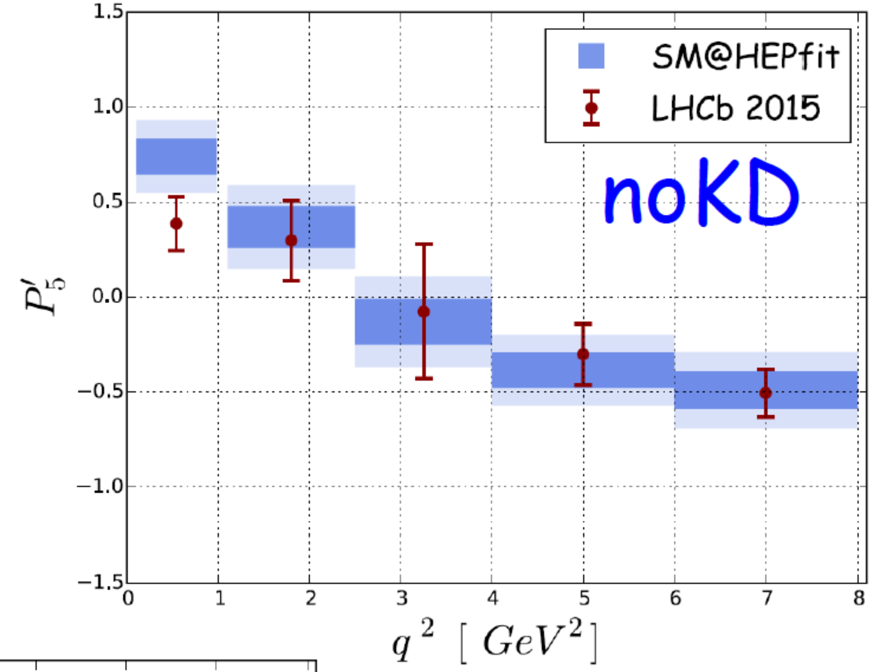
   fullKMPW: LCSR+dispersion relation on the whole q^2 range

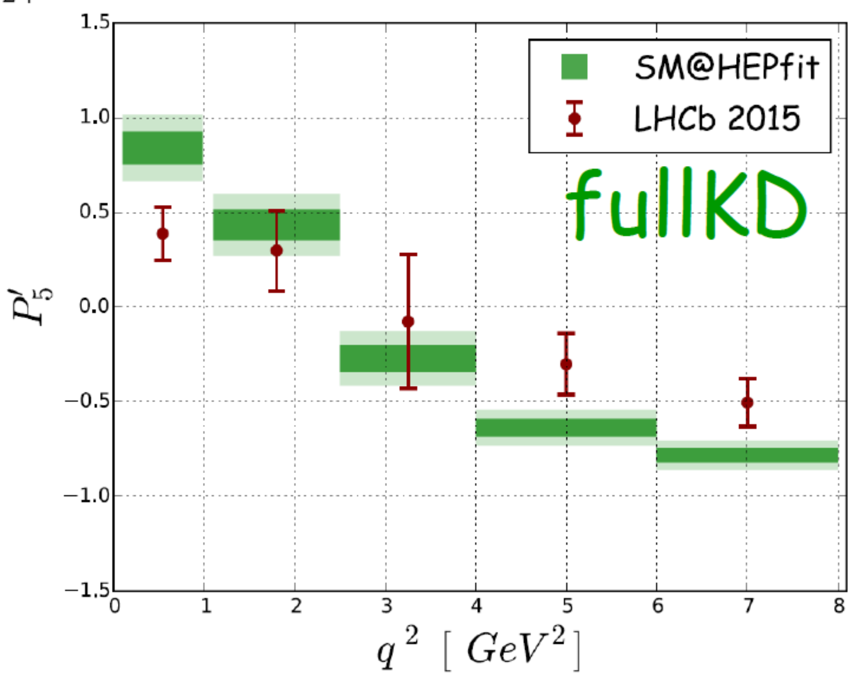
   noKMPW: no KMPW constraints on $h_\lambda^{(i)}$
5. fit the $h_\lambda^{(i)}$ from the LHCb binned angular variables (including correlations) and BRs of $B \to K^*\mu\mu$, $B \to K^*ee$, $B \to K^*\gamma$

HEPfit (using HEPfit - https://hepfit.roma1.infn.it)

The fate of the anomaly







Comparison of the fits

The Bayes factor cannot be computed from the MCMC

Information Criterion

T. Ando, Am. J. Math. and Manag. Sc. 31 (2011), no. 1-2 13

$$\mathrm{IC} = -2\overline{\log L} + 4\sigma^2_{\log L}$$

Results

noKMPW:	IC=72
KMPW:	IC=78
no q^4 terms:	IC=81
fullKMPW:	IC=111

- Towards a calculations...

  "Any reasonable calculation is better than a fit!" – T. Hurth

from Nazila's talk

- Towards a calculations...

  "Any reasonable calculation is better than a fit!" – T. Hurth

from Nazila's talk

- Towards a calculations...

"Any reasonable calculation is better than a fit!" – T. Hurth

solid

from Nazila's talk

NP CLAIMS

- M. Ciuchini

LUV & LEPTOQUARKS

LHC Seminar

Search for new physics with $b \to s\ell^+\ell^-$ decays at LHCb

by Simone Bifani (University of Birmingham (GB))

Tuesday Apr 18, 2017, 11:00 AM → 12:00 PM Europe/Zurich

503/1-001 - Council Chamber (CERN)

Description The family of decays mediated by $b \to s\ell^+\ell^-$ transitions provides a rich laboratory to search for effects of physics beyond the Standard Model. In recent years LHCb has found hints of deviations from theoretical predictions both in the rates and angular distributions of such processes. In addition, hints of lepton flavour non-universality have been seen when comparing $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ decay rates, with the so-called R_K ratio. Similar observables in different decays, such as $R_{K^*} = \mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)/\mathrm{BR}(B^0 \to K^{*0}e^+e^-)$ and others, can also be measured by LHCb, thus providing further avenues to test the effectiveness of lepton flavour universality. The latest results from LHCb in this sector will be presented.

cern_2017_04_18.p... EPLHCseminar18.0... Recording

Organized by M. Mangano, C. Lourenco, G. Unal................. **Refreshments will be served at 10h30**

Webcast There is a live webcast for this event Watch

Reply | Reply All | Forward | Archive | Junk | Delete | More

From Marco Ciuchini <marco.ciuchini@roma3.infn.it>

To 'Ayan Paul' <apaul2@alumni.nd.edu>, 'Luca Silvestrini' <luca.silvestrini@roma1.infn.it> MORE 18/04/17, 19:18

Subject **R: paperi pronta**

Printing now, comments tomorrow!
Ciao. Marco

Da: Ayan Paul [mailto:apaul2@alumni.nd.edu]
Inviato: martedì 18 aprile 2017 13:43
A: Marco Ciuchini <marco.ciuchini@roma3.infn.it>; Luca Silvestrini <luca.silvestrini@roma1.infn.it>; Enrico Franco <enrico.franco@roma1.infn.it>; Mauro Valli <mauro.valli@roma1.infn.it>; Marco Fedele <marco.fedele@uniroma1.it>; Antonio Coutinho <coutinho@fis.uniroma3.it>
Oggetto: paperi pronta

ciao tutti,

The paper is getting close to ready. I am attaching the draft. The title, abstract and fig 5 & 6 are not final yet. Sec. 3.2 and 4 needs some work. The dotted lines need to be filled with the authors' names. Please take a look at this as soon as possible, and possibly immediately. We have new runs out with the new RK* as presented today morning. Hopefully they will be in soon. As you will notice, the fits already sit on the value presented by LHCb. So the conclusions will mostly remain the same.

We insist on sending this out tonight. We hope you will not object. Thank you.

regards,
M.A.M

Reply | Reply All | Forward | Archive | Junk | Delete | More

From Ayan Paul <apaul2@alumni.nd.edu>

To Mauro Valli <mauro.valli@roma1.infn.it>, Marco Fedele <marco.fedele@uniroma1.it> MORE 19/04/17, 02:18

Subject **Fwd: arXiv New submission -> 1704.05447 in hep-ph from apaul2@alumni.nd.edu**

just to let you know that you published a paper in the arXiv today in case the Trump Administration inquires about it.

I hop you feel proud of 7 sigma deviations!

ciao
Ayan e Mauro

Begin forwarded message:

From: e-prints@arxiv.org
Subject: arXiv New submission -> 1704.05447 in hep-ph from apaul2@alumni.nd.edu
Date: 19 April 2017 at 02:15:42 GMT+2
To: apaul2@alumni.nd.edu
Reply-To: help@arxiv.org

Your submission submit/1866571 has been assigned the permanent arXiv identifier 1704.05447 and is available at:

http://arxiv.org/abs/1704.05447

The paper password for this article is: wj2ph
Please share this with your co-authors. They may use it to claim ownership.

From Marco Ciuchini <marco.ciuchini@roma3.infn.it>

To Ayan Paul <apaul2@alumni.nd.edu>, Mauro Valli <mauro.valli@roma1.infn.it> MORE 19/04/17, 06:59

Subject **Re: Fwd: arXiv New submission -> 1704.05447 in hep-ph from apaul2@alumni.nd.edu**

Is this a joke? I have not even read the paper. Please remove my name from the author list before it appears on arxiv.
Marco

Il 19 aprile 2017 02:18:22 CEST, Ayan Paul <apaul2@alumni.nd.edu> ha scritto:

> just to let you know that you published a paper in the arXiv today in case the Trump Administration inquires about it.
>
> I hop you feel proud of 7 sigma deviations!
>
> ciao
> Ayan e Mauro

From Marco Ciuchini <marco.ciuchini@roma3.infn.it>

To Ayan Paul <apaul2@alumni.nd.edu>, Mauro Valli <mauro.valli@roma1.infn.it> MORE 19/04/17, 07:40

Subject **Re: Fwd: arXiv New submission -> 1704.05447 in hep-ph from apaul2@alumni.nd.edu**

To make things as clear as possible, either the paper is withdrawn today or our collaboration ends today. In any case, remove my name. You seem to ignore the basic rules of scientific collaboration.
M

From Ayan Paul <apaul2@alumni.nd.edu>

To Marco Ciuchini <marco.ciuchini@roma3.infn.it> 19/04/17, 09:47

Cc Mauro Valli <mauro.valli@roma1.infn.it>, Marco Fedele <marco.fedele@uniroma1.it> MORE

Subject **Re: arXiv New submission -> 1704.05447 in hep-ph from apaul2@alumni.nd.edu**

Dear Marco,

My sincere apologies for not realizing that this would be a problem. We were in a rush to put this on the arXiv for reasons which, I admit, are quite unscientific. Since we have had extensive discussions in the past on these topics and the paper is essentially written along those lines, we incorrectly assumed we could include you and then wait for your comments to be incorporated in a v2.

While we would like to have you on this work, if you have objections to it, we will do as you say. It will be nice if you can reconsider your stance and take a look at the work. We will incorporate your comments and suggestions in a v2. Thank you and again, we wouldn't have done this had we known it would become a problem for our collaboration.

regards,
Ayan

LUV & LEPTOQUARKS

On Flavourful Easter eggs for New Physics hunger and Lepton Flavour Universality violation

Marco Ciuchini[a], António M. Coutinho[a], Marco Fedele[b,c], Enrico Franco[c], Ayan Paul[c], Luca Silvestrini[c] and Mauro Valli[c]

[a] *INFN, Sezione di Roma Tre, Via della Vasca Navale 84, I-00146 Roma, Italy*

[b] *Dipartimento di Fisica, Università di Roma "La Sapienza", P.le A. Moro 2, I-00185 Roma, Italy*

[c] *INFN, Sezione di Roma, P.le A. Moro 2, I-00185 Roma, Italy*

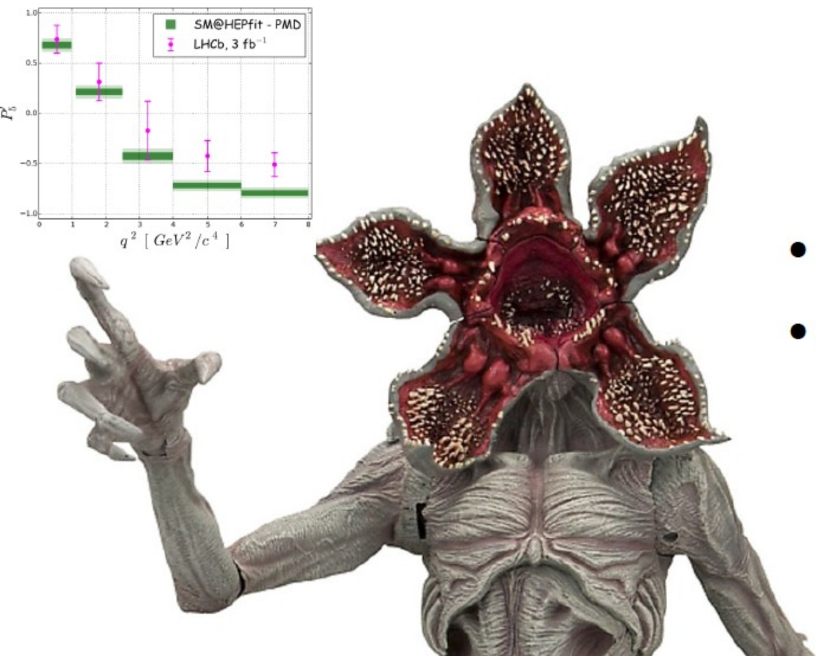
E-mail: marco.fedele@uniroma1.it, ayan.paul@roma1.infn.it, mauro.valli@roma1.infn.it

ABSTRACT: In the world of media, Easter eggs are commonly associated to the internal jokes and/or secret messages usually hidden e.g. in computer gaming and hi-tech software. In this work, we take advantage of this terminology to motivate the search for New Physics Beyond the Standard Model of Particle Physics in the radiative and (semi-)leptonic channels of rare B meson decays. Within the standard approach of effective field theory of weak interactions for $\Delta B = 1$ transitions, we look for possibly unexpected subtle NP effects, aka "flavourful Easter eggs". We perform a Bayesian analysis that takes into account the state-of-the-art of the experimental information concerning these processes, including the suggestive measurements from LHCb of R_K and R_{K^*}, the latter available only very recently. We parametrize NP contributions to $b \to s$ transitions in terms of shifts of Wilson coefficients of the electromagnetic dipole and semileptonic operators, assuming CP-conserving effects, but allowing in general for violation of lepton flavour universality. We show how the optimistic/conservative hadronic estimates can impact quantitatively the size of NP extracted from the fit.

Charm-loop effects

Marco Ciuchini

INFN ROMA TRE



- charm loops in B decays: a short history
- charm loops in semileptonic B decays
  - Theoretical estimates
  - Phenomenological approach

Towards the Ultimate Precision in Flavour Physics

University of Warwick, 16-18 April 2018

Charm loop in the effective theory

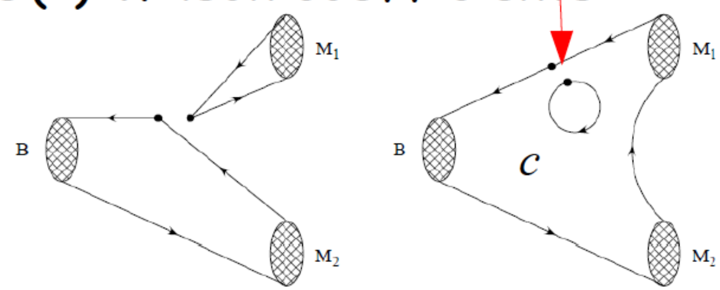
$$\mathcal{H}_{\rm eff}^{\rm had}(\Delta S=1) = \frac{4G_F}{\sqrt{2}}\left\{\lambda_u\left[C_1\left(Q_1^u - Q_1^c\right) + C_2\left(Q_2^u - Q_2^c\right)\right] - \lambda_t\left[C_1 Q_1^c + C_2 Q_2^c + \sum_{i=3}^{6} C_i Q_i + C_8 Q_{8g}\right]\right\}$$

top loops in the SM give rise to penguin operators

- non-perturbative matrix elements of local operators
- α_s suppressed matching conditions, small Wilson coefficients

charm (and up) loops appear as Wick contractions in the MEs

- dominated by the insertion of $Q_{1,2}$, namely $O(1)$ Wilson coefficients
- easily produce intermediate real states, i.e. rescattering, non-local contributions, strong phases, etc.



Taming the charm-loop monster…

2010 → today

Step 1: no new non-perturbative calculation. However an hierarchy among contributions in the helicity basis has been found

Jäger, Camalich, arXiv:1212.2263

$$h_+ \sim \mathcal{O}\left(\frac{\Lambda}{m_b}\right) h_-$$

Step 2: recent attempts to gain more control over the q^2 dependence improving the dispersion relation approach

1. new phenomenological model using resonance data over the full dimuon spectrum
   Blake, Egede, Owen, Pomery, Petridis, arXiv:1709.03921, **see next talk**
2. replace the dispersion relation with a z-expansion of h_λ, constraining the coefficients using analiticity and
   Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305
   1. resonant $B \to \Psi^{(n)} K^*$ data (masses and amplitudes)
   2. LCSR + QCDF theoretical results at small/negative q^2

c-loop from analyticity

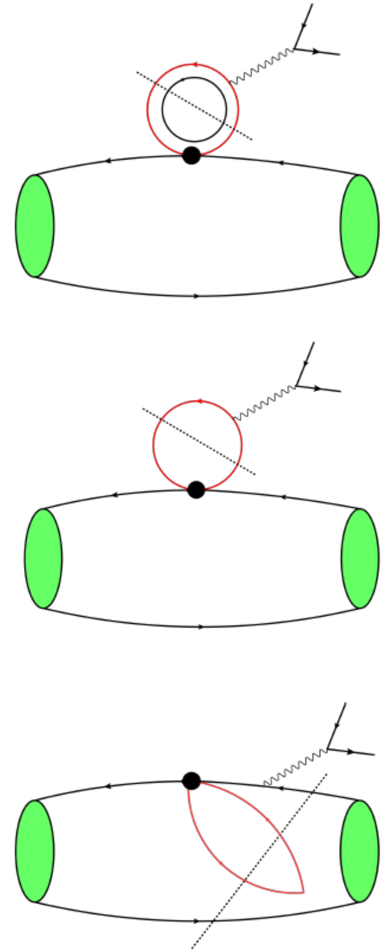
Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305

Features:

- get rid of DD branch cut modeling by mapping it at the boundary of the expansion region
- exploits the ψ(') resonance data to constrain the expansion

Open issues:

- strong phases related to the DD_s cut in p^2 are taken from LCSR and QCDF calculations. Are they reliable?



k	0	1	2
$\mathrm{Re}[\alpha_k^{(\perp)}]$	-0.06 ± 0.21	-6.77 ± 0.27	18.96 ± 0.59
$\mathrm{Re}[\alpha_k^{(\parallel)}]$	-0.35 ± 0.62	-3.13 ± 0.41	12.20 ± 1.34
$\mathrm{Re}[\alpha_k^{(0)}]$	0.05 ± 1.52	17.26 ± 1.64	–
$\mathrm{Im}[\alpha_k^{(\perp)}]$	-0.21 ± 2.25	1.17 ± 3.58	-0.08 ± 2.24
$\mathrm{Im}[\alpha_k^{(\parallel)}]$	-0.04 ± 3.67	-2.14 ± 2.46	6.03 ± 2.50
$\mathrm{Im}[\alpha_k^{(0)}]$	-0.05 ± 4.99	4.29 ± 3.14	–

- z expansion: no sign of convergence for the typical values $|z|\sim 0.2$-0.4
  NB: z expansion of FF at much smaller values

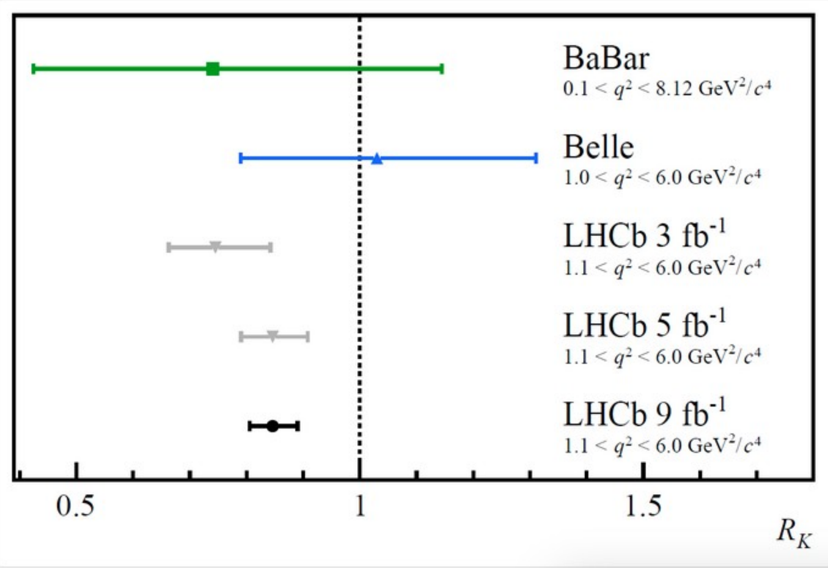
LUV & LEPTOQUARKS

Stronger hints of a violation of lepton universality?

23 March 2021: $R_K = 0.846^{+0.044}_{-0.041}$

Today at the Rencontres de Moriond EW conference and CERN seminar, the LHCb Collaboration presented an updated measurement of the ratio R_K. This tests an important principle of the Standard Model of particle physics known as "lepton universality", which says the three charged leptons (electrons, muons and taus) behave identically, apart from effects due to their different masses. An LHCb paper submitted for publication today **presents evidence** suggesting that lepton universality may be violated in beauty-quark decays, with a statistical significance of 3.1 σ (standard deviations).

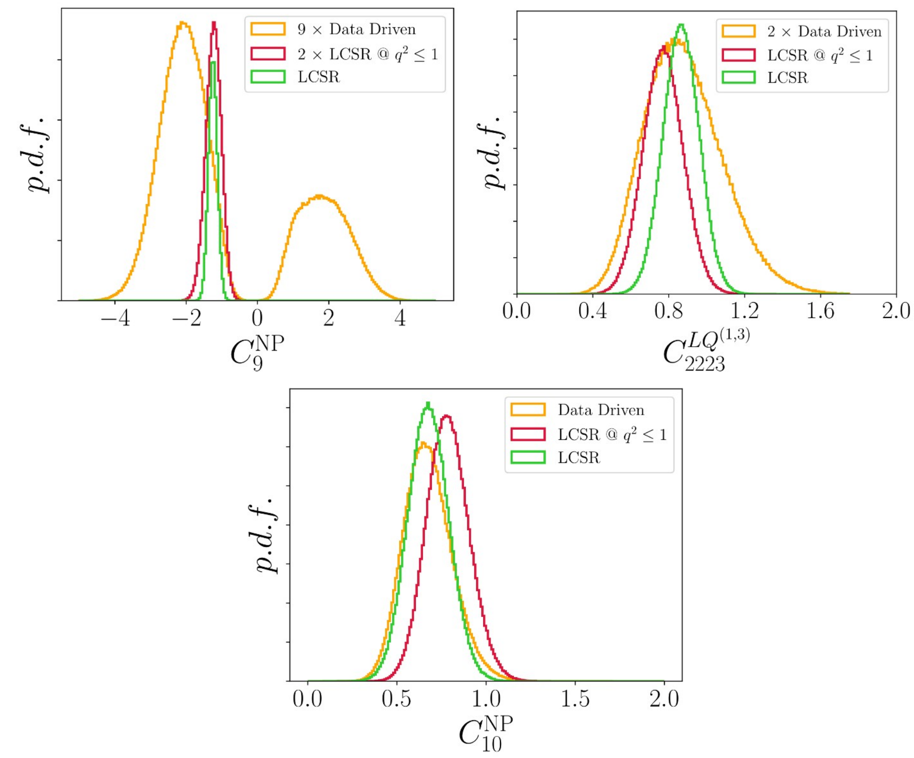
Evidence is the term often used in the community when a measurement has a significance of **more than three σ** ; **observation** is typically reserved for results with **more than five σ**.



The ratio R_K describes how often a B^+ meson decays to a charged kaon and either a positive and a negatively charge muon ($K^+\mu^+\mu^-$) or a positron-electron pair ($K^+e^+e^-$). These decays are extremely rare, occurring at a rate of only one in two million B^+ meson decays. The decays involve the transformation of a beauty quark into a strange quark ($b \to s$), a process that is highly suppressed in the Standard Model and can be affected by the existence of new particles, which could have masses too high to be produced directly even at the Large Hadron Collider.

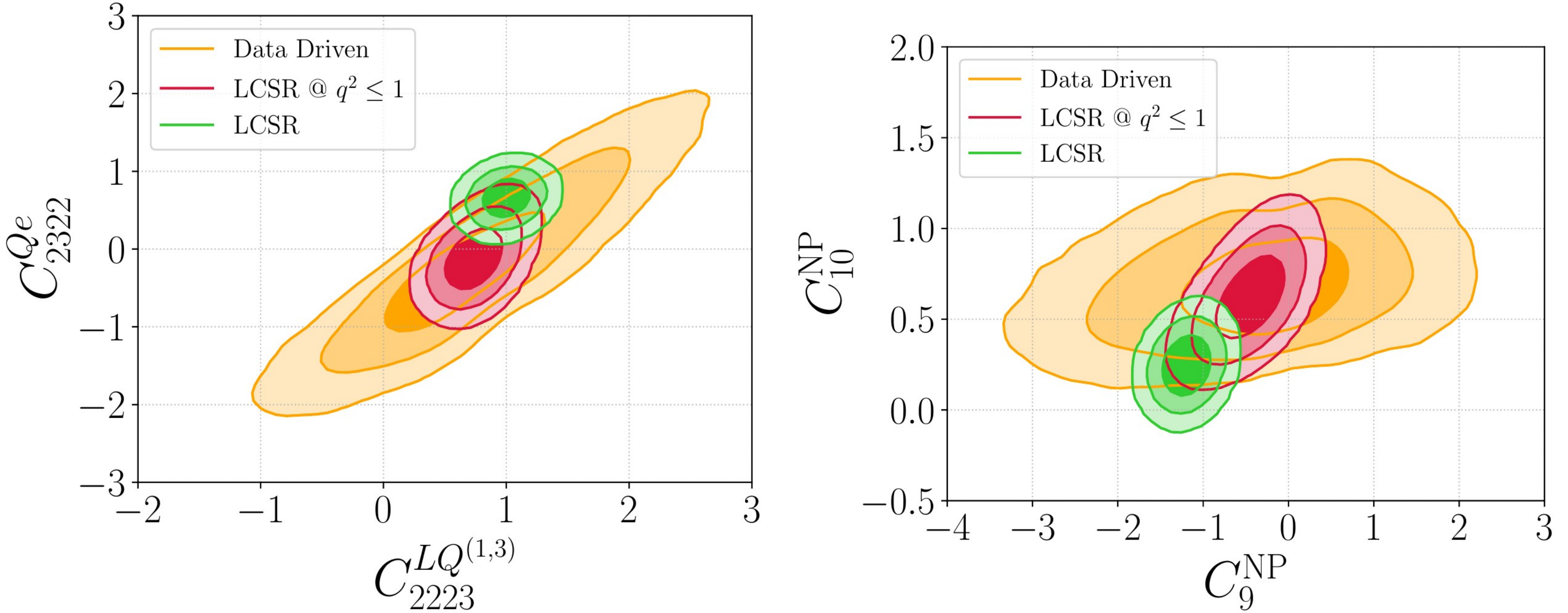
The analysis is performed in the range $1.1<q^2<6.0$ GeV^2, where q^2 is the invariant mass of the $\mu^+\mu^-$ or e^+e^- pair. The value of R_K is measured to be **$0.846^{+0.044}_{-0.041}$**, and is shown in the figure to the left as a black point with error bars. This differs from the Standard Model prediction by **3.1σ**, is the most precise measurement to date; it is consistent with and supersedes previous LHCb R_K results, also shown on the plot as grey points with error bars. Measurements by the BaBar and Belle collaborations are also shown.

ONE-DIMENSIONAL NP SCENARIOS



- Dramatic effect of charming penguins on the C_9^{NP} scenario
- Moderate effect on C^{LQ}, small effect on C_{10}^{NP}
- Using $IC=-2\langle\log\mathscr{L}\rangle+4\sigma^2_{\log\mathscr{L}}$, C_9^{NP} is largely preferred using LCSR + analyticity, while C^{LQ} and C_{10}^{NP} are preferred with more conservative assumptions

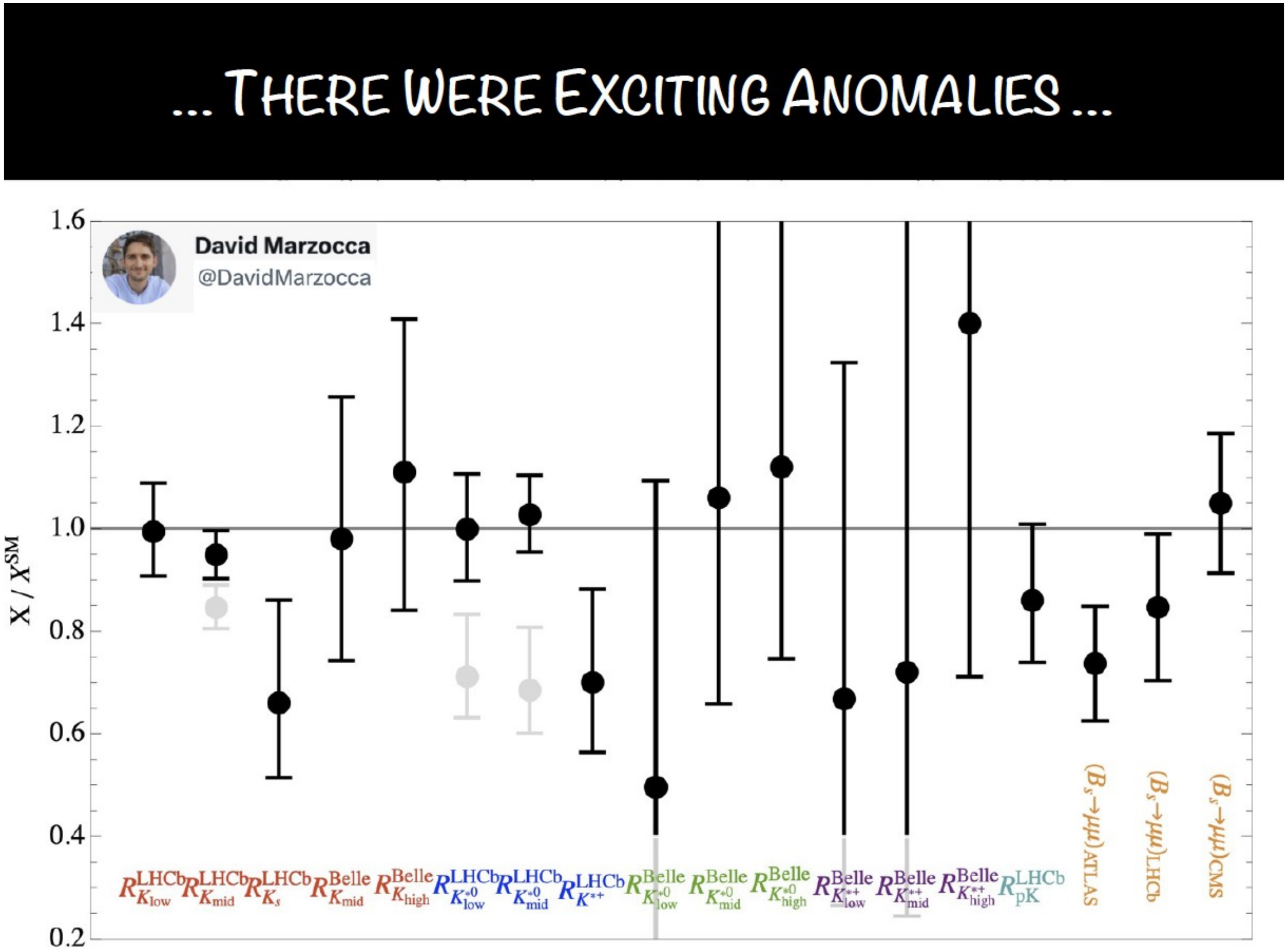
TWO-DIMENSIONAL NP SCENARIOS



Inference on NP coefficients depends on assumptions on charming penguins.

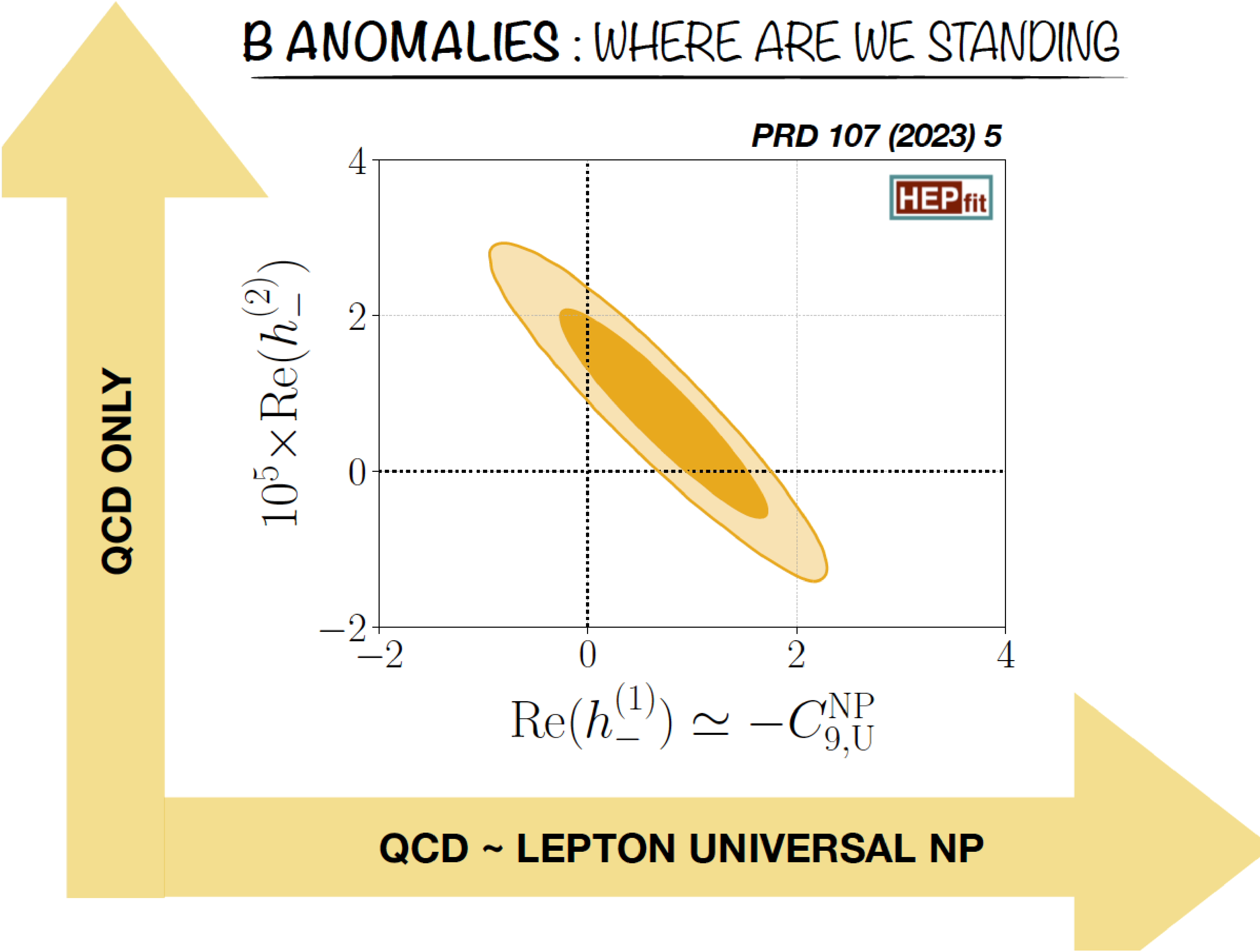
In Data Driven fit, ΔIC similar to 1D C^{LQ} and C_{10}^{NP} scenarios.

LUV went away...



M. Valli @BFA24

B ANOMALIES : WHERE ARE WE STANDING



M. Valli @BFA24

...but the new physics hunger didn't...

PHYSICAL REVIEW LETTERS **132,** 131801 (2024)

Amplitude Analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ Decay

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

(Received 15 December 2023; accepted 26 January 2024; published 28 March 2024)

An amplitude analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay is presented using a dataset corresponding to an integrated luminosity of 4.7 fb^{-1} of pp collision data collected with the LHCb experiment. For the first time, the coefficients associated to short-distance physics effects, sensitive to processes beyond the standard model, are extracted directly from the data through a q^2-unbinned amplitude analysis, where q^2 is the $\mu^+\mu^-$ invariant mass squared. Long-distance contributions, which originate from nonfactorizable QCD processes, are systematically investigated, and the most accurate assessment to date of their impact on the physical observables is obtained. The pattern of measured corrections to the short-distance couplings is found to be consistent with previous analyses of b- to s-quark transitions, with the largest discrepancy from the standard model predictions found to be at the level of 1.8 standard deviations. The global significance of the observed differences in the decay is 1.4 standard deviations.

The LHCb Miracle

- If you are clever enough, and you ask the right people, you can determine separately two things that have the same quantum numbers and are undistinguishable: C_9 and the long-distance contribution...

We are very grateful to Nico Gubernari, Méril Reboud, Danny van Dyk, and Javier Virto for the many helpful discussions. We express our gratitude to our colleagues in

Special Instructions

This ZIP file contains the Supplemetal Material for the publication LHCb-PAPER-2023-032.

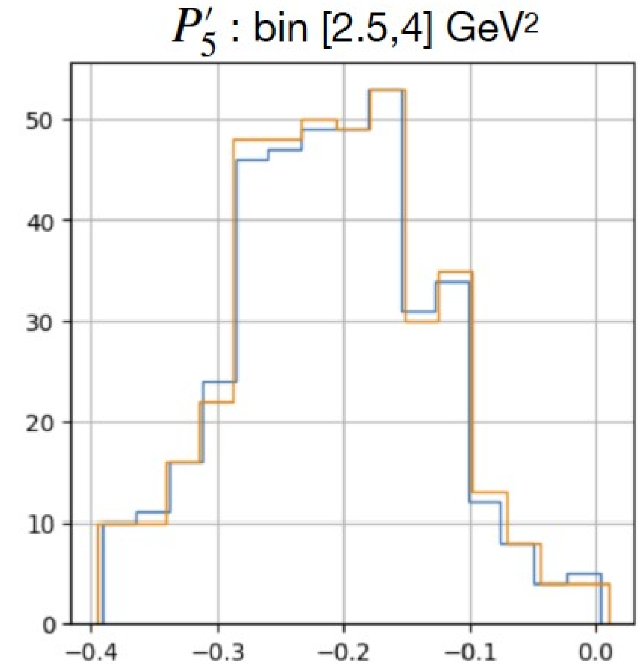
The files are:

coefficients{}.json : - the fit results in form of a bootstrapped set of fit parameters

core/ : - a directory with the implementation of the signal amplitude model employed in the analysis

main.py : - main script with some instruction and examples on how to use the package

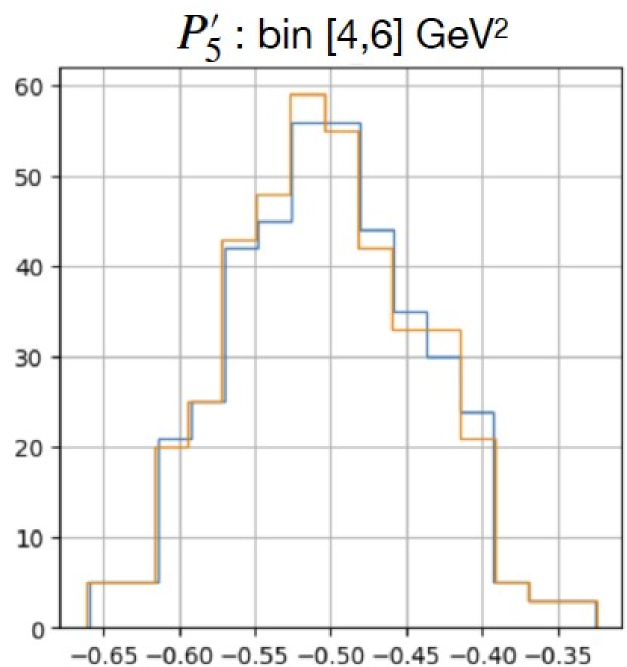
LHCb-PAPER-2023-032-Supplemental-Material.zip

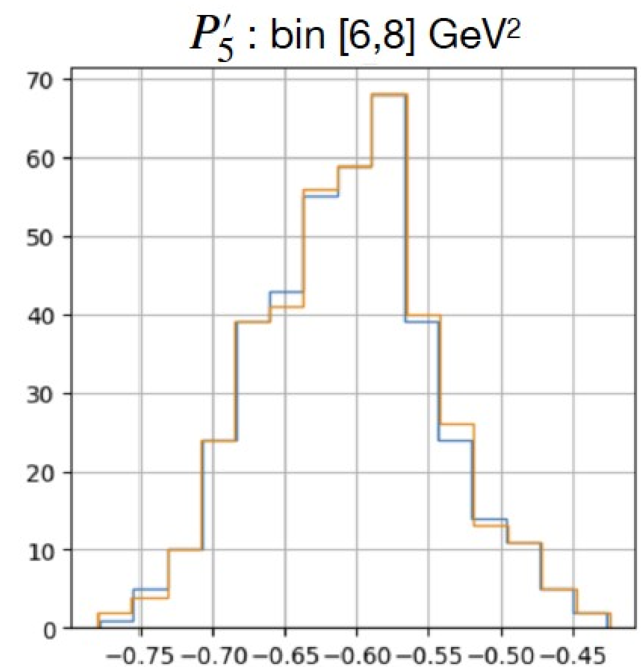


HEPfit

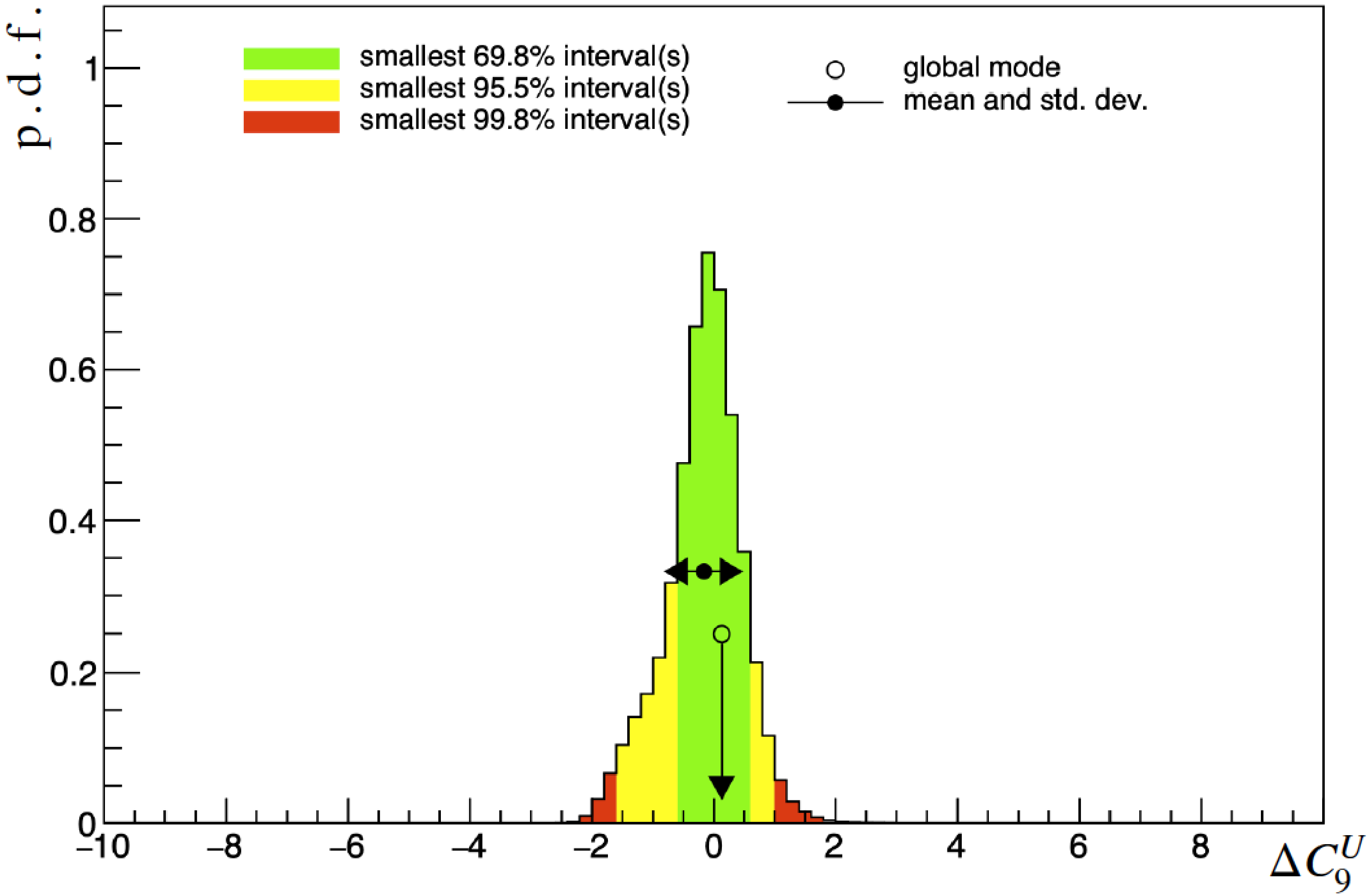
LHCb bootstrap

VERY GOOD AGREEMENT ACROSS ALL OBSERVABLES, INCLUDLING NARROW $c\bar{c}$





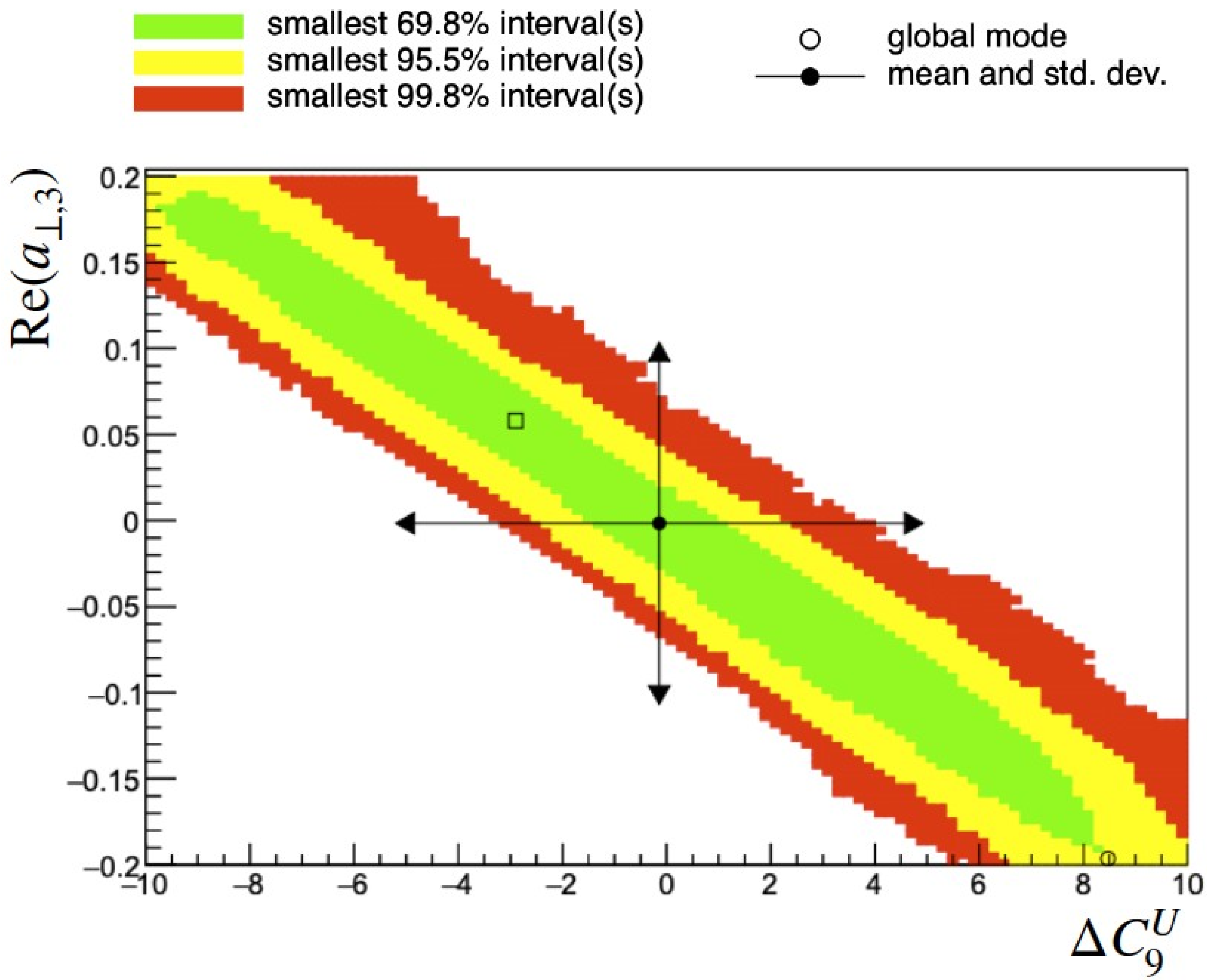
HEPfit MCMC results



BAYESIAN INFORMATION CRITERION PENALIZES ADDITION OF UNIVERSAL ΔC_9.

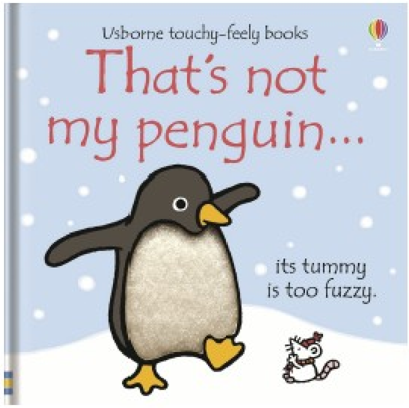
M. Valli @BFA24

HEPfit MCMC results

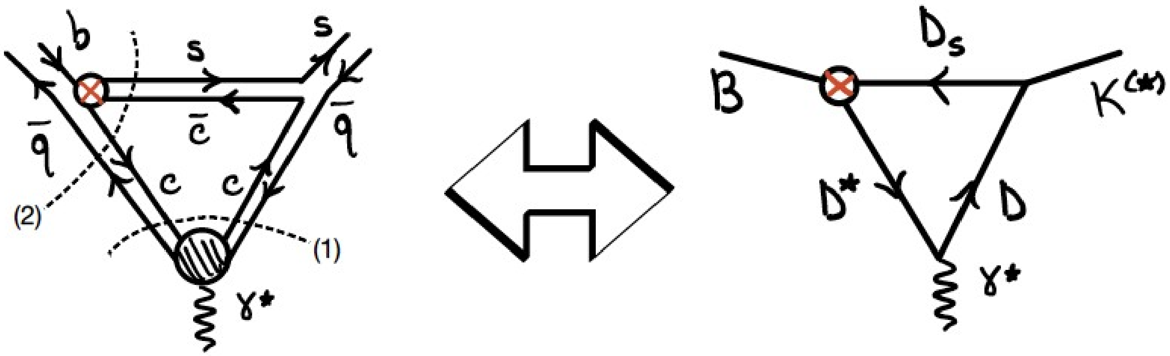


EXPANDING @ NEXT ORDER — INCLUDING $\mathcal{O}(z^3)$ — AFFECTS INFERENCE OF ΔC_9^U

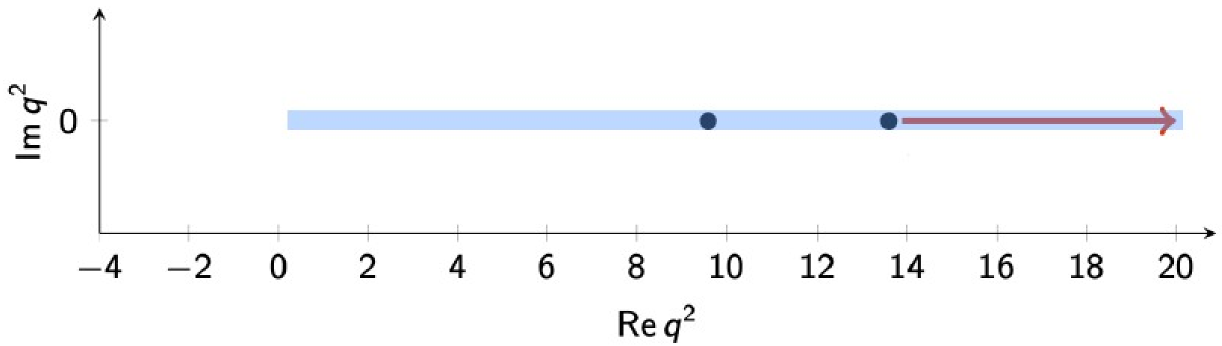
M. Valli @BFA24

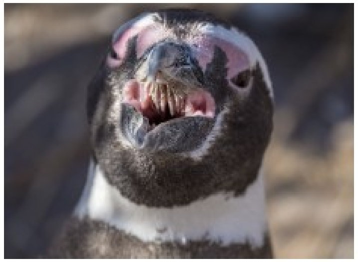


ANSWER TO (A): CHARMING PENGUINS



Rescattering from intermediate on-shell hadronic states.
These effects NOT captured by any analytic cut solely in q^2.





Analyticity <—> mapping into unit circle as done in ***EPJC* 78 (2018) 6**
only if B invariant mass would not allow for cut (2) (instead, it does!).

Triangles, triangles

- While smart people as Silvano and Melikhov had known for a long time the problems of QCDSR estimates of charming penguins, and the intricacies of anomalous thresholds, the rest of the community ignored the problem for quite a while...
- Fortunately, after ~10y, and just in time for Marco's birthday, people started taking rescattering seriously...

Anomalous thresholds: where do they come from?

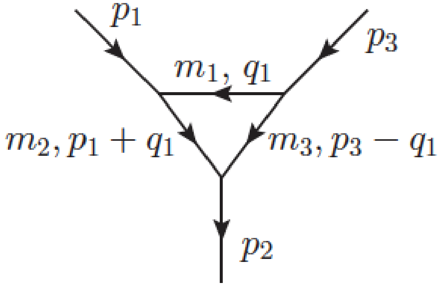
- **Landau equations**: singularities of general loop integral

$$\int \prod_{\ell=1}^{L} \frac{d^4 q_\ell}{(2\pi)^4} \prod_{i=1}^{n} \frac{i}{k_i^2 - m_i^2 + i\epsilon} \quad \text{singular when} \quad \begin{cases} \lambda_i (k_i^2 - m_i^2) = 0 & \text{for all } i = 1, \ldots, n \\ \sum_{i=1}^{n} \lambda_i k_i \cdot \frac{\partial k_i}{\partial q_\ell} = 0 & \ell = 1, \ldots, L \end{cases}$$

$\hookrightarrow$ "leading singularity" $\Leftrightarrow$ all $\lambda_i \neq 0$

- **Triangle diagram**: $L = 1$, $n = 3$, Landau equations become

$$\lambda_i (k_i^2 - m_i^2) = 0 \qquad \sum_{i=1}^{3} \lambda_i k_i = 0$$



  - **Normal thresholds**: e.g., $\lambda_3 = 0 \Rightarrow p_1^2 = (m_1 \pm m_2)^2$

    [zeros of $\lambda(p_1^2, m_1^2, m_2^2)$, $\lambda(a, b, c) = a^2 + b^2 + c^2 - 2(ab + ac + bc)$]

  - **Anomalous threshold**: all $\lambda_i \neq 0$

    $\hookrightarrow p_2^2 = s_\pm \equiv p_1^2 \frac{m_1^2 + m_3^2}{2m_1^2} + p_3^2 \frac{m_1^2 + m_2^2}{2m_1^2} - \frac{p_1^2 p_3^2}{2m_1^2} - \frac{(m_1^2 - m_2^2)(m_1^2 - m_3^2)}{2m_1^2} \pm \frac{1}{2m_1^2} \sqrt{\lambda(p_1^2, m_1^2, m_2^2) \lambda(p_3^2, m_1^2, m_3^2)}$

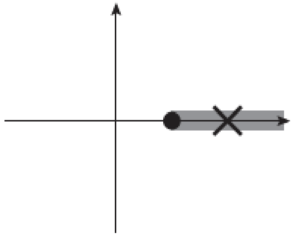
Anomalous thresholds: deformation of the integration contour

- Anomalous branch point on first sheet (can be either s_+ or s_-) requires **deformation of the integration contour**

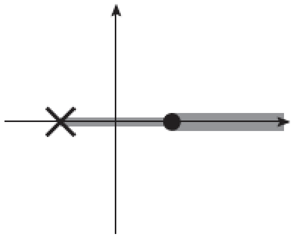
$$s_x = x\left(m_2 + m_3\right)^2 + (1 - x)s_\pm$$

- Three cases:

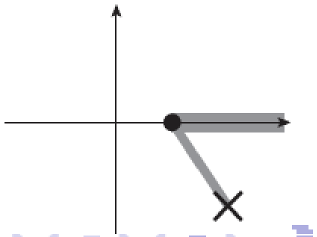
1. $s_\pm$ on normal cut
   $\hookrightarrow$ analytic continuation of normal discontinuity



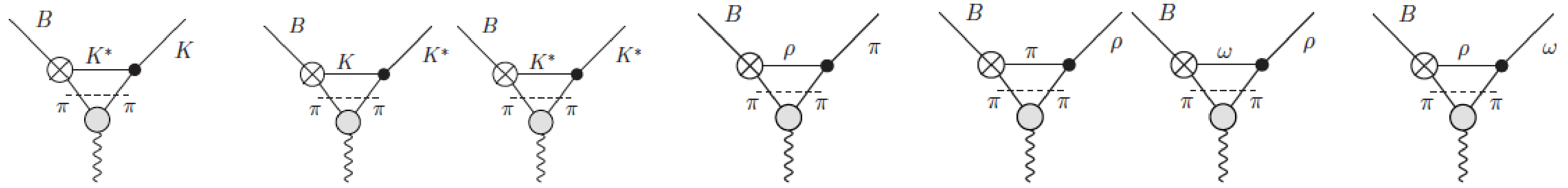
2. $s_\pm$ on negative real axis
   $\hookrightarrow$ integration deformed along real axis

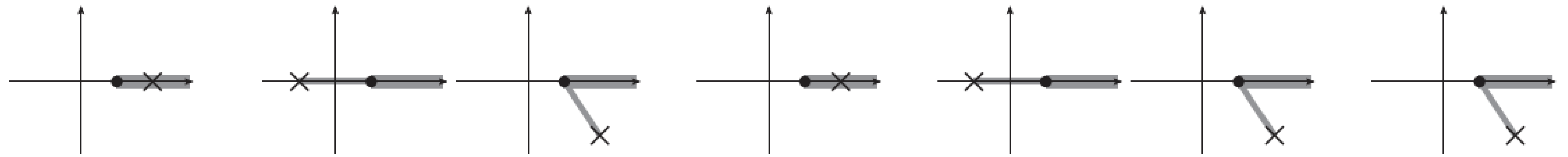


3. $s_\pm$ in complex plane
   $\hookrightarrow$ integration deformed into complex plane



Anomalous thresholds for $B \to (P, V)\gamma^*$: list of processes



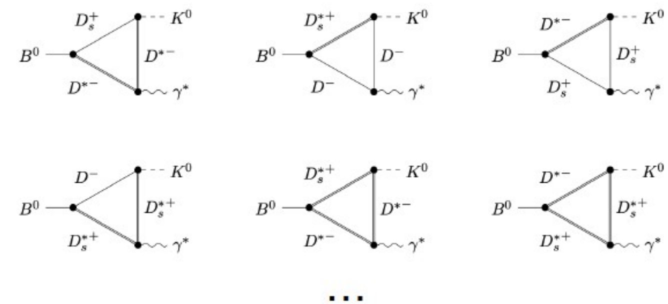


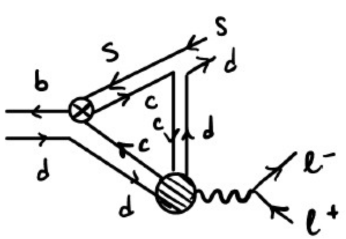
$B \to K\gamma^*$	$B \to K^*\gamma^*$	$B \to \pi\gamma^*$	$B \to \rho\gamma^*$	$B \to \omega\gamma^*$
$s_+ = 18.6\,\text{GeV}^2$	-57.8 $0.5 - 4.2i$	26.4	-859.3 $0.7 - 4.8i$	$0.2 - 4.9i$
$\text{Br}[B \to K^*\pi]$	$\text{Br}[B \to K^{(*)}\pi]$	$\text{Br}[B \to \rho\pi]$	$\text{Br}[B \to \pi\pi, \pi\omega]$	$\text{Br}[B \to \rho\pi]$
$\text{Br}[B \to K\pi\pi]$	$\text{Br}[B \to K^*\pi\pi]$	$\text{Br}[B \to 3\pi]$	$\text{Br}[B \to \rho\pi\pi]$	$\text{Br}[B \to \omega\pi\pi]$

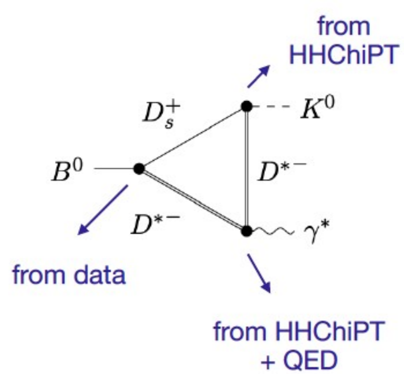
- $s_{\text{thr}} = 4M_\pi^2 = 0.08\,\text{GeV}^2$
- The branching fractions in the last line assume $\pi\pi$ in a P-wave.
- Consider K^*, ρ, ω narrow for now (could integrate over spectral functions).
- To disentangle helicity amplitudes, not only branching ratios, but polarization fractions are required.

Charm rescattering in $B \to K\bar{\ell}\ell$

- We cannot exclude a sizable long-distance contribution with a reduced q^2- or λ- dependence which would mimic a short-distance effect.
- For this reason, we tried to estimate the rescattering contribution from the leading two-body intermediate state $D_s D^*$ and $D_s^* D$.







- We estimate this diagram using data on $B \to DD^*$ and Heavy Hadron Chiral Perturbation Theory (valid for soft kaons).
- Our result is most reliable close to the q^2 end-point (small kaon momentum), and satisfies constraints from gauge invariance.
- The absorptive part is finite and “exact” (no approximations) at the end-point.

CONCLUSIONS

- After 35 years, the processes Marco studied in his thesis are still crucial for indirect NP searches
- $b \to s\ell\ell$ transitions call for a theoretical breakthrough, but fortunately, while Marco is busy in the INFN cockpit, the roman lattice group is working hard on this
- In the meantime unfortunately I'm destroying all the nice HEPfit code written by Marco, so maybe at some point it would be useful to have Marco back to the Github repository…
- Hopefully within another 35 years the charming penguins problem will be fully solved, and we will know if NP is hiding there or not!

Tantissimi auguri Marco,
e grazie di tutto!!