

# (Re)interpretation of Flavour Constraints

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(Re)interpreting the results of new physics searches at the LHC  
CERN, December 12, 2016

# Outline

- ⇒ Theoretical framework for  $B$  decays
- ⇒  $B \rightarrow K^* \ell^+ \ell^-$  observables and calculations
- ⇒ Numerical approach
- ⇒ Which data do Flavour factories publish
- ⇒ New Physics searches
- ⇒ What would be the best way to exchange the information?
- ⇒ Questions for discussion

# Theoretical framework for $B$ decays

## A multi-scale problem

- new physics:  $\Lambda_{\text{NP}} \gtrsim \text{TeV}$
- electroweak interactions:  $M_W \sim 80 \text{ GeV}$
- hadronic effects:  $m_b \sim 5 \text{ GeV}$
- QCD interactions:  $\Lambda_{\text{QCD}} \sim 0.2 \text{ GeV}$

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$\Rightarrow$  Effective field theory approach:

separation between low and high energies using Operator Product Expansion

- short distance: Wilson coefficients, computed perturbatively
- long distance: local operators

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left( \sum_{i=1 \dots 10, S, P} (C_i(\mu) \mathcal{O}_i(\mu) + C'_i(\mu) \mathcal{O}'_i(\mu)) \right)$$

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New physics:

- Corrections to the Wilson coefficients:  $C_i \rightarrow C_i + \Delta C_i^{\text{NP}}$
- Additional operators:  $\sum C_j^{\text{NP}} \mathcal{O}_j^{\text{NP}}$

# Operators

$$\mathcal{O}_1 = (\bar{s}\gamma_\mu T^a P_L c)(\bar{c}\gamma^\mu T^a P_L b)$$

$$\mathcal{O}_2 = (\bar{s}\gamma_\mu P_L c)(\bar{c}\gamma^\mu P_L b)$$

$$\mathcal{O}_3 = (\bar{s}\gamma_\mu P_L b)\sum_q(\bar{q}\gamma^\mu q)$$

$$\mathcal{O}_4 = (\bar{s}\gamma_\mu T^a P_L b)\sum_q(\bar{q}\gamma^\mu T^a q)$$

$$\mathcal{O}_5 = (\bar{s}\gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} P_L b)\sum_q(\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q)$$

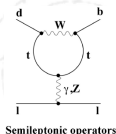
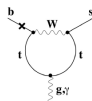
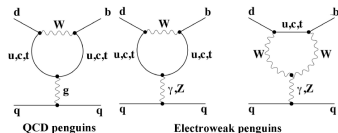
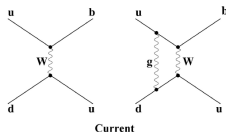
$$\mathcal{O}_6 = (\bar{s}\gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a P_L b)\sum_q(\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q)$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} \left[ \bar{s}\sigma^{\mu\nu}(m_s P_L + m_b P_R)b \right] F_{\mu\nu}$$

$$\mathcal{O}_8 = \frac{g}{16\pi^2} \left[ \bar{s}\sigma^{\mu\nu}(m_s P_L + m_b P_R)T^a b \right] G_{\mu\nu}^a$$

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu b_L)(\bar{l}\gamma_\mu l)$$

$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu b_L)(\bar{l}\gamma_\mu \gamma_5 l)$$



## Two main steps:

- Calculating  $C_i^{eff}(\mu)$  at scale  $\mu \sim M_W$  by requiring matching between the effective and full theories

$$C_i^{eff}(\mu) = C_i^{(0)eff}(\mu) + \frac{\alpha_s(\mu)}{4\pi} C_i^{(1)eff}(\mu) + \dots$$

- Evolving the  $C_i^{eff}(\mu)$  to scale  $\mu \sim m_b$  using the RGE:

$$\mu \frac{d}{d\mu} C_i^{eff}(\mu) = C_j^{eff}(\mu) \gamma_{ji}^{eff}(\mu)$$

driven by the anomalous dimension matrix  $\hat{\gamma}^{eff}(\mu)$

SM contributions to  $C_i(\mu_b)$  are known to NNLO QCD and NLO EW/QED

# Hadronic quantities

To compute the amplitudes:

$$\mathcal{A}(A \rightarrow B) = \langle B | \mathcal{H}_{\text{eff}} | A \rangle = \frac{G_F}{\sqrt{2}} \sum_i \lambda_i C_i(\mu) \langle B | \mathcal{O}_i | A \rangle(\mu)$$

$\langle B | \mathcal{O}_i | A \rangle$ : hadronic matrix element

How to compute matrix elements?

→ Model building, Lattice simulations, Light flavour symmetries, Heavy flavour symmetries, ...

→ Describe hadronic matrix elements in terms of **hadronic quantities**

Two types of hadronic quantities:

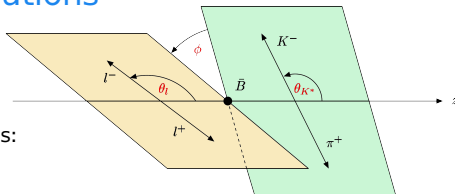
- **Decay constants**: Probability amplitude of hadronising quark pair into a given hadron
- **Form factors**: Transition from a meson to another through flavour change



# $B \rightarrow K^* \ell^+ \ell^-$ – Angular distributions

## Angular distributions

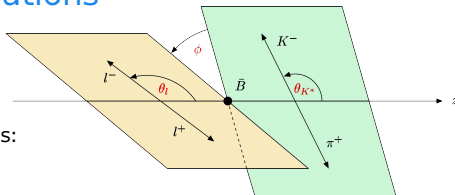
The full angular distribution of the decay  $\bar{B}^0 \rightarrow \bar{K}^{*0} \ell^+ \ell^-$  ( $\bar{K}^{*0} \rightarrow K^- \pi^+$ ) is completely described by four independent kinematic variables:  $q^2$  (dilepton invariant mass squared),  $\theta_\ell$ ,  $\theta_{K^*}$ ,  $\phi$



# $B \rightarrow K^* \ell^+ \ell^-$ – Angular distributions

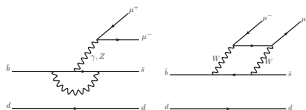
## Angular distributions

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Main operators:

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2} (\bar{s} \gamma^\mu b_L) (\bar{\ell} \gamma_\mu \ell), \quad \mathcal{O}_{10} = \frac{e^2}{(4\pi)^2} (\bar{s} \gamma^\mu b_L) (\bar{\ell} \gamma_\mu \gamma_5 \ell)$$



F. Kruger et al., Phys. Rev. D 61 (2000) 114028;

W. Altmannshofer et al., JHEP 0901 (2009) 019; U. Egede et al., JHEP 1010 (2010) 056

## Differential decay distribution:

$$\frac{d^4 \Gamma}{dq^2 d \cos \theta_\ell d \cos \theta_V d \phi} = \frac{9}{32\pi} J(q^2, \theta_\ell, \theta_V, \phi)$$

$$J(q^2, \theta_\ell, \theta_V, \phi) = \sum_i J_i(q^2) f_i(\theta_\ell, \theta_V, \phi)$$

↘ angular coefficients  $J_{1-9}$

↘ functions of the transversity amplitudes  $A_0, A_{\parallel}, A_{\perp}, A_t,$

and  $A_S$ , Transversity amplitudes: functions of Wilson coefficients and form factors

# $B \rightarrow K^* \ell^+ \ell^-$ – Amplitudes

A closer look to the Effective Hamiltonian:

$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{eff}}^{\text{had}} + \mathcal{H}_{\text{eff}}^{\text{sl}}$$
$$\mathcal{H}_{\text{eff}}^{\text{sl}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[ \sum_{i=7,9,10} C_i^{(\prime)} O_i^{(\prime)} \right]$$

$\langle \bar{K}^* | \mathcal{H}_{\text{eff}}^{\text{sl}} | \bar{B} \rangle$ :  $B \rightarrow K^*$  form factors  $V, A_{0,1,2}, T_{1,2,3}$

Transversity amplitudes:

$$A_{\perp}^{L,R} \simeq N_{\perp} \left\{ (C_9^+ \mp C_{10}^+) \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2} C_7^+ T_1(q^2) \right\}$$

$$A_{\parallel}^{L,R} \simeq N_{\parallel} \left\{ (C_9^- \mp C_{10}^-) \frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2} C_7^- T_2(q^2) \right\}$$

$$A_0^{L,R} \simeq N_0 \left\{ (C_9^- \mp C_{10}^-) [(\dots) A_1(q^2) + (\dots) A_2(q^2)] \right. \\ \left. + 2m_b C_7^- [(\dots) T_2(q^2) + (\dots) T_3(q^2)] \right\}$$

$$A_S = N_S (C_S - C'_S) A_0(q^2)$$

$$(C_i^{\pm} \equiv C_i \pm C'_i)$$

# $B \rightarrow K^* \ell^+ \ell^-$ – Amplitudes

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$$\mathcal{H}_{\text{eff}}^{\text{had}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[ \sum_{i=1\dots 6} C_i O_i + C_8 O_8 \right]$$

$$\begin{aligned} \mathcal{A}_\lambda^{(\text{had})} &= -i \frac{e^2}{q^2} \int d^4 x e^{-iq \cdot x} \langle \ell^+ \ell^- | j_\mu^{\text{em, lept}}(x) | 0 \rangle \\ &\quad \times \int d^4 y e^{iq \cdot y} \langle \bar{K}_\lambda^* | T \{ j^{\text{em, had}, \mu}(y) \mathcal{H}_{\text{eff}}^{\text{had}}(0) \} | \bar{B} \rangle \\ &\equiv \frac{e^2}{q^2} \epsilon_\mu L_V^\mu \left[ \underbrace{\text{LO in } \mathcal{O}\left(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}}\right)}_{\text{Non-Fact., QCDf}} + \underbrace{h_\lambda(q^2)}_{\text{power corrections}} \right] \end{aligned}$$

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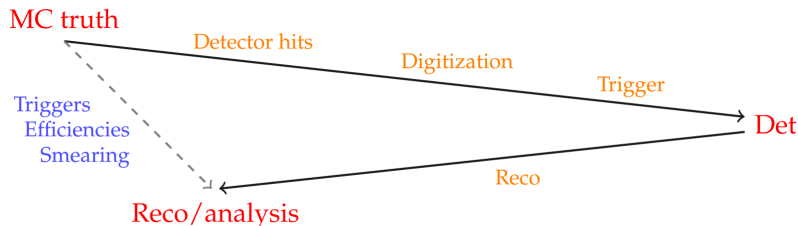
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Anomalies can be explained with 20-50% non-factorisable power corrections at the observable level in the critical bins (Ciuchini et al., 1512.07157)

This corresponds to more than 150% error at the amplitude level for the critical bins!

## Detector effects 1/2

⇒ In Flavour factories because we usually measure the properties of a  $B$  meson decay we can provide the measurements that are corrected for the detector effects!



⇒ The differences that "Reco recovery" doesn't recover are recovered at the analysis stage.

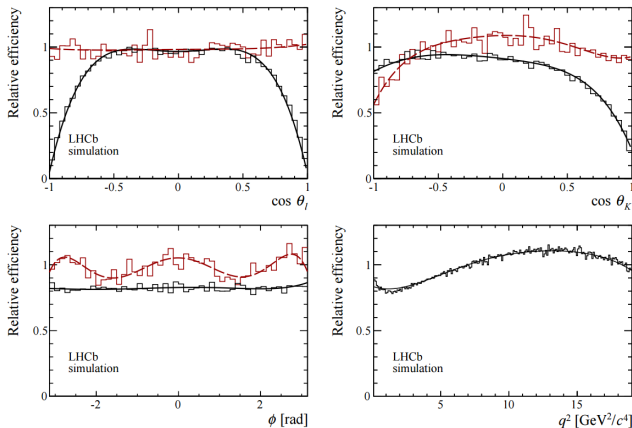
⇒ Some imperfections (usually small), are assigned as systematics!

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Thanks to Andy Buckley for the plot.

# Detector effects 2/2

⇒ For example: measurement of angular coefficients of  $B \rightarrow K^* \mu \mu$ , [arXiv::1512.04442](https://arxiv.org/abs/1512.04442),  
[arXiv::1604.04042](https://arxiv.org/abs/1604.04042)

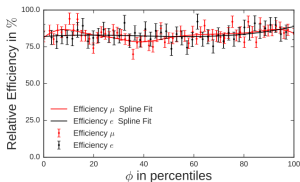


⇒ In Flavour physics we have ways to ensure we control our detector effects.

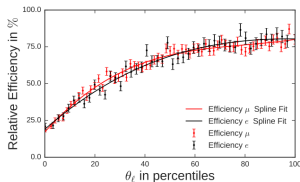


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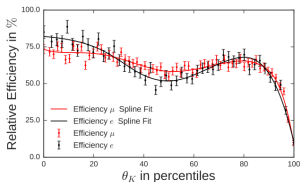
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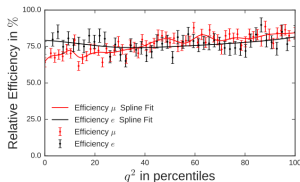
(a) Efficiency in  $\phi$



(b) Efficiency in  $\theta_\ell$



(c) Efficiency in  $\theta_K$

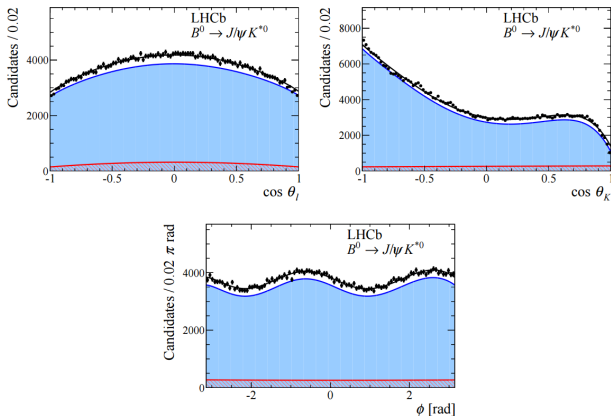


(d) Efficiency in  $q^2$

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# Published data format

- ⇒ There are number of ways the B-factories publish their results.
- ⇒ Most of the time the information to links are on the collaboration web pages:



Belle Journal Publications  
The Belle Collaboration

## Physics Publications

471. "Measurement of the  $\tau$  lepton polarization and  $R(D^*)$  in the decay  $B \rightarrow D^* \tau^+ \nu_\tau$ "  
S.Hosoe, et al. (Belle Collaboration), submitted to PRL  
Belle preprint 2016-14, KEK Preprint 2016-53, [arXiv:1612.08529 \[hep-ex\]](https://arxiv.org/abs/1612.08529)

470. "Search for  $D^0$  decays to invisible final states at Belle"  
Y.Lai, et al. (Belle Collaboration), submitted to PRD  
Belle preprint 2016-13, KEK Preprint 2016-51, [arXiv:1611.09453 \[hep-ex\]](https://arxiv.org/abs/1611.09453)

469. "Search for the  $\theta^0$  Glueball in  $V(1S)$  and  $V(2S)$  decays"  
S.Jin, et al. (Belle Collaboration), submitted to PRD  
Belle preprint 2016-12, KEK Preprint 2016-50, [arXiv:1611.07131 \[hep-ex\]](https://arxiv.org/abs/1611.07131)

468. "Observation of  $D^0 \rightarrow p^+ \gamma$  and search for CP violation in radiative charm decays"  
T.Casse, et al. (Belle Collaboration), submitted to PRL  
Belle preprint 2016-11, KEK Preprint 2016-24, [arXiv:1610.02247 \[hep-ex\]](https://arxiv.org/abs/1610.02247)

467. "Search for a dark vector gauge boson decaying to  $e^+e^-$  using  $q \rightarrow e^+ \gamma$  decays"  
E.Woo, et al. (Belle Collaboration), published in [PRD94, 042001 \(2016 Nov 29\)](https://arxiv.org/abs/1610.04188)  
Belle preprint 2016-10, KEK Preprint 2016-19, [arXiv:1609.05599 \[hep-ex\]](https://arxiv.org/abs/1609.05599)

466. "Measurement of the branching ratio of  $B^0 \rightarrow D^+ \tau^+ \nu_\tau$  relative to  $B^0 \rightarrow D^+ \tau^+ \nu_\tau$  decays with a semileptonic tagging method"  
Y.Sato, T.Iijima, K.Sadametzki, et al. (Belle Collaboration), published in [PRD94, 072007 \(2016 Oct 27\)](https://arxiv.org/abs/1610.04127)  
Belle preprint 2016-08, KEK Preprint 2016-8, [arXiv:1607.07621 \[hep-ex\]](https://arxiv.org/abs/1607.07621)

465. "Study of Excited  $\Sigma_c$  States Decaying Into  $\Sigma_c^0$  and  $\Sigma_c^+$  Baryons"  
J.Yehou, et al. (Belle Collaboration), published in [PRD94, 012011 \(2016 Sep 23\)](https://arxiv.org/abs/1610.01210)  
Belle preprint 2016-07, KEK Preprint 2016-7, [arXiv:1607.07123 \[hep-ex\]](https://arxiv.org/abs/1607.07123)

464. "Measurement of the CKM angle  $\phi_1$  in  $B^0 \rightarrow D^{*0} \mu^+ \mu^-$ ,  $D^0 \rightarrow K_s^0 \mu^+ \mu^-$  decays with time-dependent binned Dalitz plot analysis"  
V.Vorobiev, et al. (Belle Collaboration), published in [PRD94, 012001 \(2016 Sep 01\)](https://arxiv.org/abs/1610.01200)  
Belle preprint 2016-09, KEK Preprint 2016-10, [arXiv:1607.05513 \[hep-ex\]](https://arxiv.org/abs/1607.05513)

463. "Energy scan of the  $e^+e^- \rightarrow h_c(nP) \pi^+ \pi^-$  ( $n=1,2$ ) cross sections and evidence for  $\Upsilon(11020)$  decays into charged bottomonium-like states"  
B.Mirak, A.Berard, et al. (Belle Collaboration), published in [PRJ, 111, 142901 \(2016 Sep 29\)](https://arxiv.org/abs/1611.14290)  
Belle preprint 2016-06, KEK Preprint 2016-6, [arXiv:1609.06365 \[hep-ex\]](https://arxiv.org/abs/1609.06365)

462. "Studies of charmed strange baryons in the A D final state at Belle"  
Y.Kato, T.Iijima, et al. (Belle Collaboration), published in [PRD94, 012012 \(2016 August 31\)](https://arxiv.org/abs/1610.04127)  
Belle preprint 2016-05, KEK Preprint 2016-4, [arXiv:1605.09191 \[hep-ex\]](https://arxiv.org/abs/1605.09191)

461. "Search for a massive invisible particle  $X^0$  in  $B^0 \rightarrow e^+ X^0 \mu^-$  and  $B^0 \rightarrow \mu^+ X^0 \mu^-$  decays"  
C.S.Park, Y.-J.Kwon, et al. (Belle Collaboration), published in [PRD94, 012001 \(2016 July 18\)](https://arxiv.org/abs/1610.01200)  
Belle preprint 2016-03, KEK Preprint 2016-2, [arXiv:1605.04410 \[hep-ex\]](https://arxiv.org/abs/1605.04410) [14]



The LHCb Public results



## LHCb publications

(in ascending order)

PUBLICATIONS BY NUMBER

10000

List of papers (total of 346 papers and 14676 citations)

FLAGSHIP TAGS	TITLE	EXPERIMENT NUMBER	JOURNAL	SUBMITTED ON	OPEN
FLAGSHIP TAGS	Observation of the state $\Sigma_c \rightarrow p \bar{K}^0$	PAUS-2005-056	PL	07 Jun 2005	
FLAGSHIP TAGS	Search for resonances in the $\pi^+ \pi^- \pi^0$ invariant mass spectrum in the $B^0 \rightarrow \pi^+ \pi^- \pi^0$ decay	PAUS-2005-047	PL	03 Jun 2005	
FLAGSHIP TAGS	Search for the $\chi_{c0}$ and $\chi_{c1}$ states in $B^0 \rightarrow \pi^+ \pi^- \pi^0$ decays	PAUS-2005-048	PL	23 Jun 2005	
FLAGSHIP TAGS	Search for decays of excited heavy mesons into two photons	PAUS-2005-042	PL	23 Jun 2005	
FLAGSHIP TAGS	Measurements of charm mixing and CP violation using $D^0 \rightarrow A^+ \pi^-$ decays	PAUS-2005-033	PL	18 Nov 2005	
FLAGSHIP TAGS	Measurement of the CKM angle $\phi_1$ from a combination of $D^0$ decays	PAUS-2005-032	PL	08 Nov 2005	
FLAGSHIP TAGS	Measurement of CP asymmetries in $D^0 \rightarrow K^+ K^-$ decays	PAUS-2005-035	PL	08 Nov 2005	
FLAGSHIP TAGS	Observation of the $\psi(3770)$ resonance in $B^0 \rightarrow K^+ K^-$ decays	PAUS-2005-036	PL	08 Nov 2005	
FLAGSHIP TAGS	Measurement of $\text{Br}(B_c \rightarrow H^+ \pi^0 \pi^0)$ and $B^0 \rightarrow \pi^+ \pi^- \pi^0$ production in pp collisions at $\sqrt{s} = 8 \text{ TeV}$	PAUS-2005-038	PL	08 Nov 2005	
FLAGSHIP TAGS	New algorithms for identifying the $B_c^0$ decays using jets and photons	PAUS-2005-039	PL	08 Nov 2005	
FLAGSHIP TAGS	Observation of the decay $B_c^0 \rightarrow \pi^+ \pi^-$ and evidence for $D^0 \rightarrow \pi^+ \pi^-$	PAUS-2005-028	PL	07 Nov 2005	
FLAGSHIP TAGS	Search for the CP-violating decay $B_c^0 \rightarrow \pi^+ \pi^-$ and $D^0 \rightarrow \pi^+ \pi^-$	PAUS-2005-046	PL	12 Nov 2005	

# CERN document server



Angular analysis of the  $B^0 \rightarrow K^* \mu^+ \mu^-$  decay using  $3. \text{fb}^{-1}$  of integrated luminosity - Aaij, Roel et al - arXiv:1512.04442

Information Discussion (5) Files

Main file(s):

- JHEP02(2016)104  
version 1 JHEP02(2016)104.pdf [6.46 MiB] 23 Mar 2016, 14:44 Springer Open Access article
- arXiv:1512.04442  
version 2 arXiv:1512.04442.pdf [3.43 MiB] 09 Mar 2016, 00:56  
(see previous)

Additional file(s):

- LHCb-PAPER-2015-051-figures  
version 1 LHCb-PAPER-2015-051-figures.zip [6.5 MiB] 11 Jan 2016, 15:10 Related data file(s)
- LHCb-PAPER-2015-051-supplementary-updated  
version 1 LHCb-PAPER-2015-051-supplementary-updated.zip [33.73 MiB] 17 May 2016, 17:27 Related supplementary data file(s) updated

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# Unification of format

⇒ More and more results are being published on HepData make them "one clic away" to get.

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Angular analysis of the  $B^0 \rightarrow K^{*0} \mu^+ \mu^-$  decay using  $3 \text{ fb}^{-1}$  of integrated luminosity

The LHCb collaboration

Aai, Roel, Abellán Beteta, Carlos, Adro, Bernardo, Adroño, Marco, Afshar, Anthony, Ajlouni, Ziad, Alan, Simon, Albrecht, Johannes, Alonso, Federico, Alexander, Michael

JHEP 1602 (2016) 104, 2016

http://dx.doi.org/10.17132/hepdata.74247

DOI INSPIRE Record HepData

**Abstract (data abstract)**  
 CERN-LHC: An angular analysis of the  $B^0 \rightarrow K^{*0} (\rightarrow K^+ \pi^-) \mu^+ \mu^-$  decay is presented. The dataset corresponds to an integrated luminosity of  $3.0 \text{ fb}^{-1}$  of pp collision data collected at the LHCb experiment. The complete angular information from the decay is used to determine CP-averaged observables and CP asymmetries, taking account of possible contamination from decays with the  $K^{*0}$  system in an S-wave configuration. The angular observables and their correlations are reported in bins of  $q^2$ , the invariant mass squared of the dimuon system. The observables are determined both from an unbinned maximum likelihood fit and by using the principal moments of the angular distribution. In addition, by fitting for  $q^2$ -dependent decay amplitudes in the region  $1.1 < q^2 < 6.0 \text{ GeV}^2/c^2$ , the zero-crossing points of several angular observables are computed. A global fit is performed to the complete set of CP-averaged observables obtained from the maximum

Table 1  
 Data from Appendix A, Table 3  
 10.17132/hepdata.74247.v1.v3  
 CP-averaged angular observables evaluated by the unbinned maximum likelihood fit.

RE	PP → BO + K*(892) + K* P1 → MU + MU + X					
SQRT(S)	7000.0 GeV					
SQRT(S)	8000.0 GeV					
$q^2$ [GeV <sup>2</sup> ]	$F_L$	$S_0$	$S_1$	$S_2$	A <sub>FB</sub>	$S_T$
0.1 - 0.98	0.263 +0.022 stat +0.017 syst	-0.036 +0.063 stat +0.008 syst	0.082 +0.022 stat +0.009 syst	0.17 +0.022 stat +0.018 syst	-0.003 +0.009 stat +0.009 syst	0.015 +0.009 stat +0.004 syst
1.1 - 2.5	0.66 +0.021 stat +0.022 syst	-0.077 +0.035 stat +0.005 syst	-0.077 +0.035 stat +0.005 syst	0.137 +0.022 stat +0.009 syst	-0.191 +0.009 stat +0.012 syst	-0.219 +0.009 stat +0.004 syst
2.5 - 4	0.876 +0.021 stat +0.017 syst	0.035 +0.037 stat +0.007 syst	-0.234 +0.036 stat +0.004 syst	-0.022 +0.021 stat +0.011 syst	-0.118 +0.007 stat +0.007 syst	0.068 +0.007 stat +0.003 syst
4 - 6	0.611 +0.021 stat +0.017 syst	0.035 +0.037 stat +0.007 syst	-0.219 +0.036 stat +0.004 syst	-0.146 +0.021 stat +0.011 syst	0.025 +0.007 stat +0.004 syst	-0.016 +0.007 stat +0.004 syst
6 - 8	0.579 +0.021 stat +0.017 syst	-0.042 +0.033 stat +0.011 syst	-0.296 +0.031 stat +0.002 syst	-0.249 +0.021 stat +0.008 syst	0.152 +0.007 stat +0.008 syst	-0.047 +0.007 stat +0.003 syst
11 - 12.5	0.493 +0.021 stat +0.017 syst	-0.189 +0.033 stat +0.011 syst	-0.283 +0.031 stat +0.002 syst	-0.327 +0.021 stat +0.008 syst	0.318 +0.007 stat +0.008 syst	-0.141 +0.007 stat +0.003 syst

Table 2  
 Data from Appendix A, Table 4  
 10.17132/hepdata.74247.v1.v3  
 CP-asymmetric angular observables evaluated by the unbinned maximum likelihood fit. The first uncertainties are statistical and the second systematic.

Table 3  
 Data from Appendix A, Table 3  
 10.17132/hepdata.74247.v1.v3  
 CP-asymmetric angular observables evaluated by the unbinned maximum likelihood fit. The first uncertainties are statistical and the second systematic.

Table 4  
 Data from Appendix A, Table 4  
 10.17132/hepdata.74247.v1.v4  
 Optimized angular observables evaluated by the unbinned maximum likelihood fit. The first uncertainties are statistical and the second

Visualize

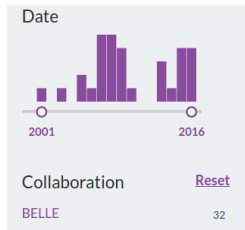
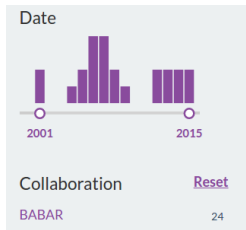
Sum errors Log Scale (X)

Select variables or hide different error bars by clicking on them.

Variables  
 $F_L$  Summed error

# Unification of format

⇒ More and more papers from Flavour community are appearing on HepData.



# This is not the end of the story!!

⇒ Even if experimentalist publish a number there is always a chance that the data might be misinterpreted by theorists.

# This is not the end of the story!!

- ⇒ Even if experimentalist publish a number there is always a chance that the data might be misinterpreted by theorists.
- ⇒ Many times the error gets symmetrized, the correlation neglected, or worse...

## Publish likelihood?

- ⇒ The proposal that I would like to make for discussion is that HepData portal (or similar) would have a possibility that experiments could publish the whole multidim. likelihood function.
- ⇒ In this way we ensure that the function will be used as the experiment intended to.



# GAMBIT: a *second-generation* global fit code

GAMBIT: The **G**lobal **A**nd **M**odular **B**SM **I**nference **T**ool

Overriding principles of GAMBIT: flexibility and modularity

- General enough to allow fast definition of new datasets and theoretical models
- Plug and play scanning, physics and likelihood packages
- Extensive model database – not just small modifications to constrained MSSM (NUHM, etc), and not just SUSY!
- Extensive observable/data libraries (likelihood modules)
- Many statistical options – Bayesian/frequentist, likelihood definitions, scanning algorithms
- A smart and *fast* LHC likelihood calculator
- Massively parallel
- Full open-source code release soon!
- Hear more in Anders Kvellestad tmr!

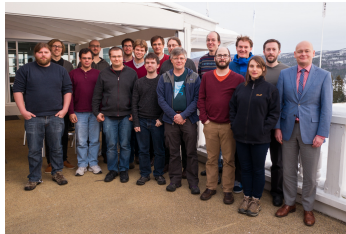
# The GAMBIT Collaboration

30 Members, 16 institutions, 10 countries, 11  
Experiments, 4 major theory codes

ATLAS	A. Buckley, P. Jackson, C. Rogan, M. White,
Flavour exp.	F. Bernlochner, M. Chrzaszcz, N. Serra
Fermi-LAT	J. Conrad, J. Edsjö, G. Martinez P. Scott
CTA	C. Balázs, T. Bringmann, J. Conrad, M. White
HESS	J. Conrad
IceCube	J. Edsjö, P. Scott
AMS-02	A. Putze
CDMS, DM-ICE	L. Hsu
XENON/DARWIN	J. Conrad
Theory	P. Athron, C. Balázs, T. Bringmann, J. Cornell, L. Dal, J. Edsjö, B. Farmer, A. Krislock, A. Kvellestad, M. Pato, F. Mahmoudi, A. Raklev, P. Scott, C. Weniger, M. White

+recently joined: T. Gonzales, J. McKay, R. Ruiz, R. Trotta

-recently retired: A. Saavedra, C. Savage



# Global Analysis with Gambit

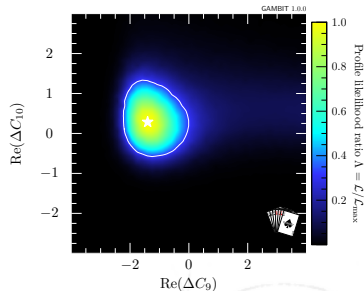
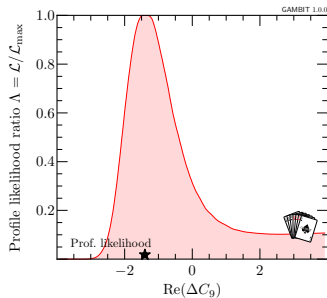
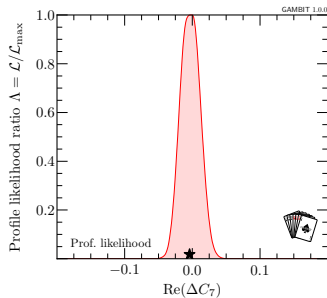
- Wilson coefficients and  $b \rightarrow s\ell^+\ell^-$  observables implemented in **SuperIso**
- **SuperIso**: public code for calculating flavour physics observables
- **SuperIso** interfaced into **GAMBIT** through the flavour physics module **FlavBit**

Mahmoudi, CPC 178 (2008) 745; CPC 180 (2009) 1579, CPC 180 (2009) 1718  
available from <http://superiso.in2p3.fr/>

**GAMBIT**: The Global And Modular BSM Inference Tool  
Web page: <http://gambit.hepforge.org/>

- **FlavBit** determines the likelihoods by comparing the theoretical evaluations and the experimental results taking into account the experimental and theoretical correlations.

# Global Analysis with Gambit - Results



- ⇒ Tension if  $\Delta C_9$  observed!
- ⇒ Other coefficients within SM predictions.
- ⇒  $C_{10}$  still has a big uncertainty.

# Conclusions

- ⇒ Flavour physics is a powerful tool to constrain NP models!
- ⇒ Measurements are becoming more complex!
- ⇒ Ability to publish the full multidim. likelihoods soon will be needed!
- ⇒ **GAMBIT** is the new player for fitting Flavour observables and will be made public soon.
- ⇒  $3-4\sigma$  deviations are present and Run2 data should clear the picture where it's NP or not.



# $B \rightarrow K^* \mu^+ \mu^-$ – Optimized observables

$$\begin{aligned}\langle P_1 \rangle_{\text{bin}} &= \frac{1}{2} \frac{\int_{\text{bin}} dq^2 [J_3 + \bar{J}_3]}{\int_{\text{bin}} dq^2 [J_{2s} + \bar{J}_{2s}]} & \langle P_2 \rangle_{\text{bin}} &= \frac{1}{8} \frac{\int_{\text{bin}} dq^2 [J_{6s} + \bar{J}_{6s}]}{\int_{\text{bin}} dq^2 [J_{2s} + \bar{J}_{2s}]} \\ \langle P'_4 \rangle_{\text{bin}} &= \frac{1}{\mathcal{N}'_{\text{bin}}} \int_{\text{bin}} dq^2 [J_4 + \bar{J}_4] & \langle P'_5 \rangle_{\text{bin}} &= \frac{1}{2\mathcal{N}'_{\text{bin}}} \int_{\text{bin}} dq^2 [J_5 + \bar{J}_5] \\ \langle P'_6 \rangle_{\text{bin}} &= \frac{-1}{2\mathcal{N}'_{\text{bin}}} \int_{\text{bin}} dq^2 [J_7 + \bar{J}_7] & \langle P'_8 \rangle_{\text{bin}} &= \frac{-1}{\mathcal{N}'_{\text{bin}}} \int_{\text{bin}} dq^2 [J_8 + \bar{J}_8]\end{aligned}$$

with

$$\mathcal{N}'_{\text{bin}} = \sqrt{-\int_{\text{bin}} dq^2 [J_{2s} + \bar{J}_{2s}] \int_{\text{bin}} dq^2 [J_{2c} + \bar{J}_{2c}]}$$

+ CP violating clean observables and other combinations

U. Egede et al., JHEP 0811 (2008) 032, JHEP 1010 (2010) 056

J. Matias et al., JHEP 1204 (2012) 104

S. Descotes-Genon et al., JHEP 1305 (2013) 137

# Numerical approach

