Global Fits for Rare B decays

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Marie Skłodowska-Curie Actions

Outline

- ☐ $b \to s\ell\ell$: Model-Independent Fits to NP [6']
  - + Looking ahead (R_K and more) [3']
- ☐ $b \to s\ell\ell$: Fits to hadronic contributions [6']
  - + Prospects [3']

NP fits to $b \to s\ell\ell$

A legacy of LHC Run 1

HEP 1,963 records found 1 - 250 jump to record: 1

1. **The LHCb Detector at the LHC**
(2633) LHCb Collaboration (A.Augusto Alves, Jr. (Rio de Janeiro, CBPF) *et al.*). 2008. 217 pp.
Published in **JINST 3 (2008) S08005**
DOI: 10.1088/1748-0221/3/08/S08005
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server
Detailed record - Cited by 2633 records 1000+

2. **Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays**
(774) LHCb Collaboration (Roel Aaij (NIKHEF, Amsterdam) *et al.*). Jun 25, 2014. 10 pp.
Published in **Phys.Rev.Lett. 113 (2014) 151601**
CERN-PH-EP-2014-140, LHCB-PAPER-2014-024
DOI: 10.1103/PhysRevLett.113.151601
e-Print: arXiv:1406.6482 [hep-ex] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service
Detailed record - Cited by 774 records 500+

3. **Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays**
(683) LHCb Collaboration (Roel Aaij (CERN) *et al.*). Jul 13, 2015. 15 pp.
Published in **Phys.Rev.Lett. 115 (2015) 072001**
CERN-PH-EP-2015-153, LHCB-PAPER-2015-029
DOI: 10.1103/PhysRevLett.115.072001
e-Print: arXiv:1507.03414 [hep-ex] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service; Interactions.org article; Link to BBC News article; Link to Symmetry Magazine article; Link to Discovery.c
Detailed record - Cited by 683 records 500+

4. **Measurement of the ratio of branching fractions $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)$**
(550) LHCb Collaboration (Roel Aaij (CERN) *et al.*). Jun 29, 2015. 10 pp.
Published in **Phys.Rev.Lett. 115 (2015) no.11, 111803**, Erratum: **Phys.Rev.Lett. 115 (2015) no.15, 159901**
CERN-PH-EP-2015-150, LHCB-PAPER-2015-025
DOI: 10.1103/PhysRevLett.115.159901, 10.1103/PhysRevLett.115.111803
e-Print: arXiv:1506.08614 [hep-ex] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service; Link to livescience article; Link to Scientific American article
Detailed record - Cited by 550 records 500+

5. **LHCb Detector Performance**
(506) LHCb Collaboration (Roel Aaij (NIKHEF, Amsterdam) *et al.*). Dec 19, 2014. 73 pp.
Published in **Int.J.Mod.Phys. A30 (2015) no.07, 1530022**
LHCB-DP-2014-002, CERN-PH-EP-2014-290
DOI: 10.1142/S0217751X15300227
e-Print: arXiv:1412.6352 [hep-ex] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service
Detailed record - Cited by 506 records 500+

6. **Measurement of Form-Factor-Independent Observables in the Decay $B^0 \to K^{*0}\mu^+\mu^-$**
(503) LHCb Collaboration (R Aaij (NIKHEF, Amsterdam) *et al.*). Aug 7, 2013. 8 pp.
Published in **Phys.Rev.Lett. 111 (2013) 191801**
LHCB-PAPER-2013-037, CERN-PH-EP-2013-146
DOI: 10.1103/PhysRevLett.111.191801
e-Print: arXiv:1308.1707 [hep-ex] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service
Detailed record - Cited by 503 records 500+

$b \to s\ell\ell$ Observables – Total ~ 174

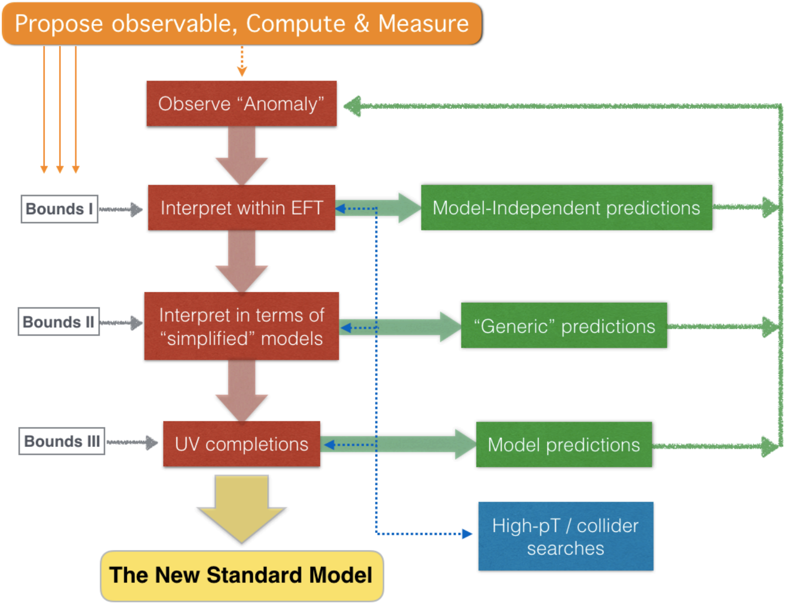
$B_s \to \mu^+\mu^-$	$B \to X_s\mu^+\mu^-$	$B \to K^*\gamma$	$B \to X_s\gamma$
$B \to K\mu\mu$	$B \to K^*\mu\mu$	$B_s \to \Phi\mu\mu$	$\Lambda_b \to \Lambda\mu\mu$
BRs	AOs	Low q^2	Large q^2
R_K	R_{K^*}	LFU	LFUV
LHCb	Belle/BaBar	ATLAS	CMS

“Anomalies”

- Observables with larger pulls:

Largest pulls	$\langle P_5' \rangle_{[4,6]}$	$\langle P_5' \rangle_{[6,8]}$	$R_K^{[1,6]}$	$R_{K^*}^{[0.045,1.1]}$	$R_{K^*}^{[1.1,6]}$	$\mathcal{B}_{B_s\to\phi\mu^+\mu^-}^{[2,5]}$	$\mathcal{B}_{B_s\to\phi\mu^+\mu^-}^{[5,8]}$
Experiment	-0.30 ± 0.16	-0.51 ± 0.12	$0.745^{+0.097}_{-0.082}$	$0.66^{+0.113}_{-0.074}$	$0.685^{+0.122}_{-0.083}$	0.77 ± 0.14	0.96 ± 0.15
SM prediction	-0.82 ± 0.08	-0.94 ± 0.08	1.00 ± 0.01	0.92 ± 0.02	1.00 ± 0.01	1.55 ± 0.33	1.88 ± 0.39
Pull (σ)	-2.9	-2.9	+2.6	+2.3	+2.6	+2.2	+2.2
Prediction for $\mathcal{C}_{9\mu}^{\rm NP}=-1.1$	-0.50 ± 0.11	-0.73 ± 0.12	0.79 ± 0.01	0.90 ± 0.05	0.87 ± 0.08	1.30 ± 0.26	1.51 ± 0.30
Pull (σ)	-1.0	-1.3	+0.4	+1.9	+1.2	+1.8	+1.6

Interpretation Layers



Effective Theory for $b \to s$ Transitions

For $\Lambda_{\rm EW}, \Lambda_{\rm NP} \gg M_B$: General model-indep. parametrization of NP :

$$\mathcal{L}_W = \mathcal{L}_{\rm QCD} + \mathcal{L}_{\rm QED} + \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^\star \sum_i \mathcal{C}_i(\mu)\, \mathcal{O}_i(\mu)$$

$$\mathcal{O}_1 = (\bar{c}\gamma_\mu P_L b)(\bar{s}\gamma^\mu P_L c) \qquad \mathcal{O}_2 = (\bar{c}\gamma_\mu P_L T^a b)(\bar{s}\gamma^\mu P_L T^a c)$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu} \qquad \mathcal{O}_{7'} = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_L b) F^{\mu\nu}$$

$$\mathcal{O}_{9\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \qquad \mathcal{O}_{9'\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)$$

$$\mathcal{O}_{10\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \qquad \mathcal{O}_{10'\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell),$$

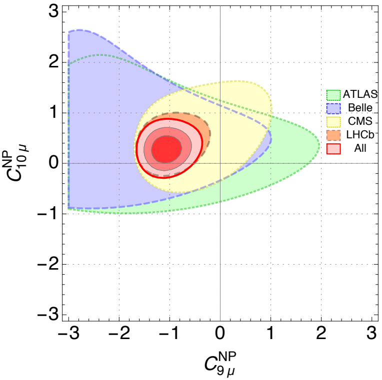
SM contributions to $\mathcal{C}_i(\mu_b)$ known to NNLL Bobeth, Misiak, Urban ’99; Misiak, Steinhauser ’04, Gorbahn, Haisch ’04; Gorbahn, Haisch, Misiak ’05; Czakon, Haisch, Misiak ’06

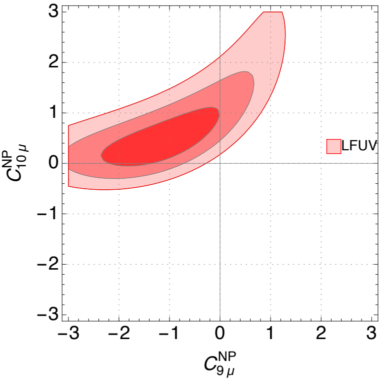
$\mathcal{C}_{7\rm eff}^{\rm SM} = -0.3,\ \mathcal{C}_9^{\rm SM} = 4.1,\ \mathcal{C}_{10}^{\rm SM} = -4.3,\ \mathcal{C}_1^{\rm SM} = 1.1,\ \mathcal{C}_2^{\rm SM} = -0.4,\ \mathcal{C}_{\rm rest}^{\rm SM} \lesssim 10^{-2}$

Global Fits to all data

Perform a global fit to 174 observables (or 17 LFUV observables)

Capdevila, Crivellin, Descotes-Genon, Matias, JV 2017





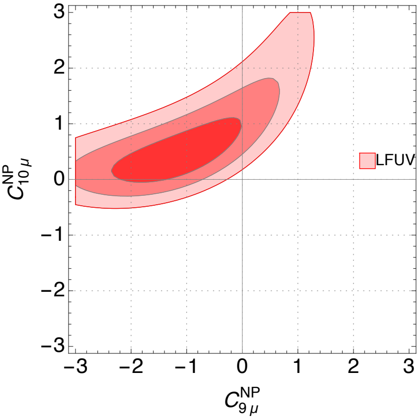
- Observed LFNU consistent with $B \to K^* \mu\mu$ Anomaly

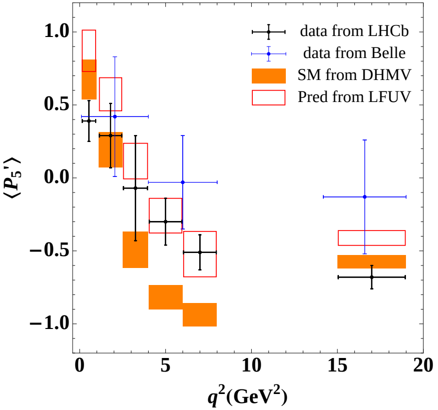
$$\boxed{\mathcal{L}_{NP} \simeq (35\ \mathrm{TeV})^{-2}\ [\bar{s}\,\gamma^{\nu} P_L\, b][\bar{\mu}\,\gamma_{\nu}\,\mu]}$$

Descotes-Genon Matias JV 2013

$P'_5\,(B \to K^\star \mu\mu)$ = *"LFNU Prediction"* (2017)

Capdevila, Crivellin, Descotes-Genon, Matias, JV 2017





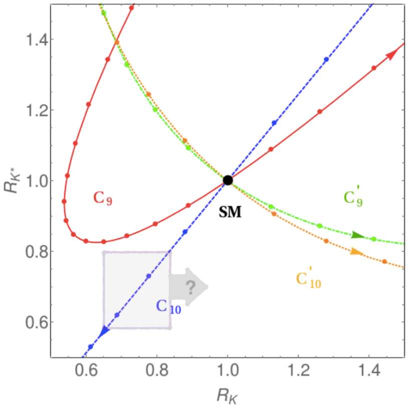
Red: Best fit point from LFNU-only fit

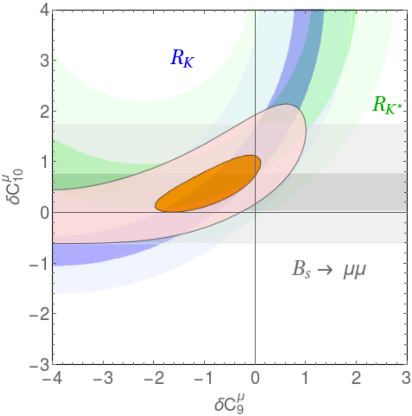
Fit to R_K , $R_{K^\star}$ and $B_s \to \mu^+\mu^-$

- $R_{K(\star)}$ constrain $\simeq (C^{\rm NP}_{i\mu} - C^{\rm NP}_{ie})$. But let's assume NP in μ only...

$$\mathcal{L}^{\rm NP}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\frac{\alpha_{\rm em}}{4\pi}\left\{C^{\rm NP}_{9\mu}\,[\bar{s}\gamma_\nu P_L b][\bar{\mu}\gamma^\nu\mu] + C^{\rm NP}_{10\mu}\,[\bar{s}\gamma_\nu P_L b][\bar{\mu}\gamma^\nu\gamma_5\mu] + \cdots\right\}$$

Li-Sheng Geng *et al* 2017





Looking ahead: R_K and more

Disclaimer: Theorist speculations involved

- $R_K^{2014} = 0.745^{+0.090}_{-0.074} \pm 0.036 \quad \longrightarrow \; 3/\mathrm{fb} \quad (2011\text{-}12)$
- + 2/fb (2015-16) $\longrightarrow$ Out next week?? (not full Run 2)
- + improved selection $\Rightarrow$ 15% more events from Run 1

$$^{+0.090}_{-0.074} \times \sqrt{\frac{3}{3+2\times 2}} \times \sqrt{\frac{1}{1.15}} = {}^{+0.055}_{-0.045}$$

Looking ahead: R_K and more

Disclaimer: Theorist speculations involved

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$$^{+0.090}_{-0.074} \times \sqrt{\frac{3}{3+2\times 2}} \times \sqrt{\frac{1}{1.15}} = \,^{+0.055}_{-0.045}$$

$$\Rightarrow \quad R_K^{2019} = \;^{+0.055}_{-0.045} \pm 0.030$$

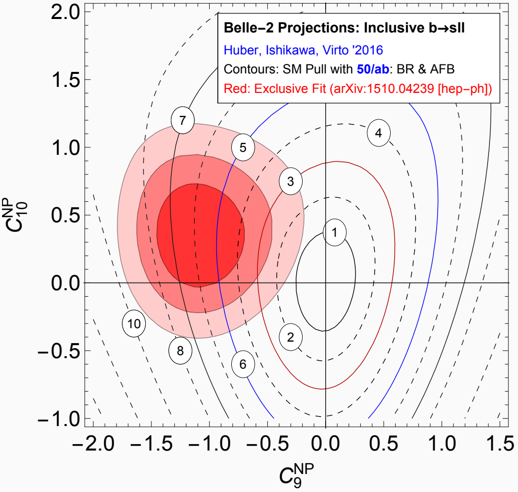
Looking ahead: R_K and more

Disclaimer: Theorist speculations involved

- $R_{K^*}^{2017}$ = 3/fb (2011-12) +2/fb (2015-16) for this fall??
- R_{Kp}, R_ϕ and $R_{K\pi\pi} \sim 2020$
- Also $B \to K^* \mu\mu$ AOs 5/fb update for $\sim$ fall (?)
- $B \to K^* ee$ and $B_s \to \Phi\mu\mu \sim 2020$
- Unbinned analyses for end 2019 or 2020 (see later)

Complementarity with inclusive measurements at Belle-2

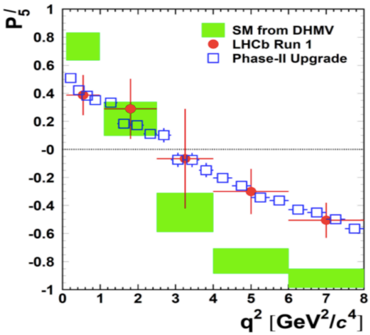
- Belle-II is directly sensitive to the $b \to s$ anomaly with $B \to X_s\, \mu^+ \mu^-$



Huber, Ishikawa, JV, "The Belle II Physics Book"

Prospects from LHCb Phase-2 upgrade

☐ LHC Phase-2 will put experimental errors to negligible levels ($\sim$ 2035)
CERN-LHCC-2017-003, LHCb EoI



☐ Bottleneck is SM uncertainties:
Assuming vanishing exp uncertainties

$\text{Pull}(P_5'^{[2.5,4.0]}) = 3.5\sigma$

$\text{Pull}(P_5'^{[4.0,6.0]}) = 6.5\sigma$

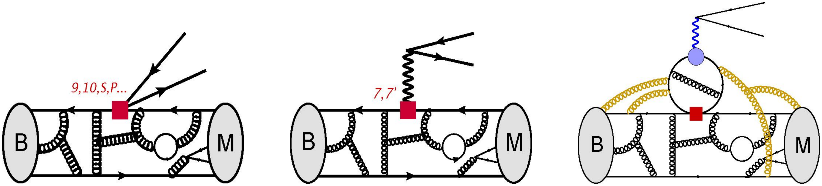
$\text{Pull}(P_5'^{[6.0,8.0]}) = 5.4\sigma$

☐ Good motivation to improve on the theory.

☐ Huge improvement in e^+e^- modes too.

Hadronic (+NP) fits to $b \to s\ell\ell$

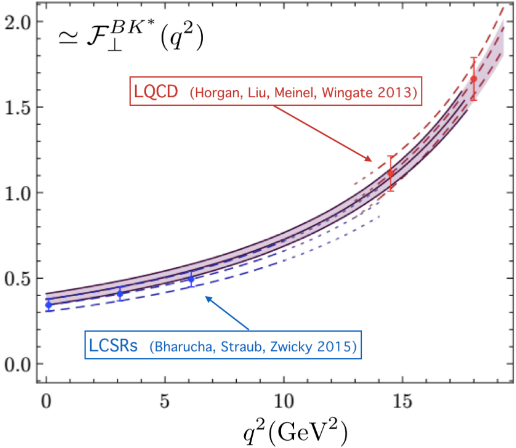
Exclusive Decay Amplitude



$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}_\lambda \left\{ (C_9 \mp C_{10}) \mathcal{F}_\lambda(q^2) + \frac{2 m_b M_B}{q^2} \left[C_7 \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b} \mathcal{H}_\lambda(q^2) \right] \right\}$$

- Local (Form Factors) : $\mathcal{F}_\lambda^{(T)}(q^2) = \langle \bar{M}_\lambda(k) | \, \bar{s} \, \Gamma_\lambda^{(T)} \, b \, | \bar{B}(k+q) \rangle$
- Non-Local : $\mathcal{H}_\lambda(q^2) = i \, \mathcal{P}_\mu^\lambda \int d^4x \, e^{iq\cdot x} \, \langle \bar{M}_\lambda(k) | T\{ \mathcal{J}_{\rm em}^\mu(x), \mathcal{C}_i \, \mathcal{O}_i(0) \} | \bar{B}(q+k) \rangle$

Hadronic Form Factors



q^2**-dependence :**

$\mathcal{F}(q^2) \propto \sum_k \alpha_k z(q^2)^k$

"z-parametrization"

Bourrely, Caprini, Lellouch

"Optimized" observables :

$P_1, P_2, P_5', \ldots$ (a full *basis*)

Mescia, Matias, Ramon, JV, 1202.4266

Descotes-Genon, Matias, Ramon, JV, 1207.2753

Descotes-Genon, Hurth, Matias, JV, 1303.5794

Finite width effects ! : $B \to K^*(\to K\pi)$

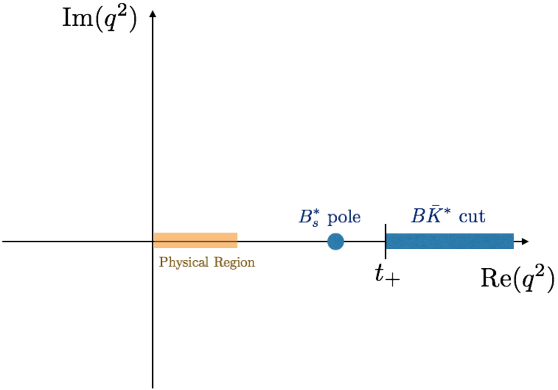
Accessible via LCSRs

Cheng, Khodjamirian, JV, 1701.01633

Cheng, Khodjamirian, JV, 1709.00173

Form Factors : q^2-dependence from analyticity

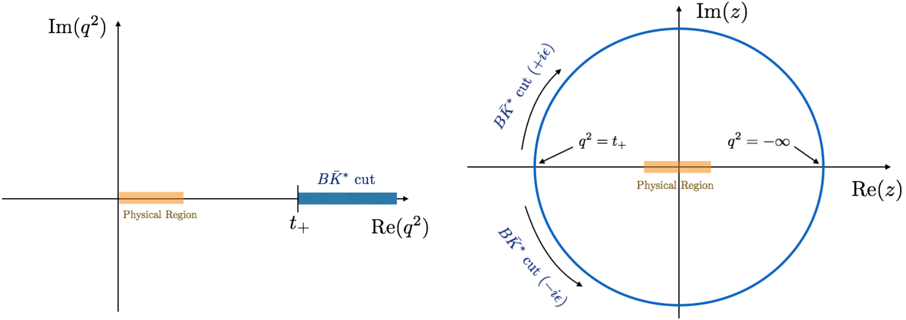
$\mathcal{F}_\lambda^{(T)}(q^2) = \langle \bar{M}_\lambda(k) | \, \bar{s}\, \Gamma_\lambda^{(T)}\, b \, | \bar{B}(k+q) \rangle$: Analytic structure in q^2 :



$\widehat{\mathcal{F}}_\lambda^{(T)}(q^2) \equiv (q^2 - m_{B_s^*}^2)\, \mathcal{F}_\lambda^{(T)}(q^2)$ has no pole, only cut.

Form Factors : q^2-dependence from analyticity

- Conformal mapping : $$z(q^2) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$



- "z-parametrization" : $\widehat{\mathcal{F}}_\lambda^{(T)}(q^2(z))$ is **analytic in** $|z| < 1$

$$\mathcal{F}_\lambda^{(T)}(q^2) = \frac{1}{(q^2 - m^2_{B_s^*})} \sum_k \alpha_k \, z(q^2)^k$$

Bourrely, Caprini, Lellouch

Form Factors : q^2-dependence from analyticity

E.g. $B \to K$ form factors $f_{0,+,T}$ from LQCD $\quad$ $(|z_{\text{phys}}| < 0.15)$

	b_0^+	b_1^+	b_2^+	b_0^0	b_1^0	b_2^0	b_0^T	b_1^T	b_2^T
Mean	0.466	-0.885	-0.213	0.292	0.281	0.150	0.460	-1.089	-1.114
error	0.014	0.128	0.548	0.010	0.125	0.441	0.019	0.236	0.971
b_0^+	1	0.450	0.190	0.857	0.598	0.531	0.752	0.229	0.117
b_1^+		1	0.677	0.708	0.958	0.927	0.227	0.443	0.287
b_2^+			1	0.595	0.770	0.819	-0.023	0.070	0.196
b_0^0				1	0.830	0.766	0.582	0.237	0.192
b_1^0					1	0.973	0.324	0.372	0.272
b_2^0						1	0.268	0.332	0.269
b_0^T							1	0.590	0.515
b_1^T								1	0.897
b_2^T									1

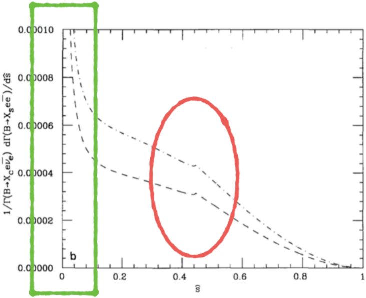
Fermilab-MILC 1509.06235

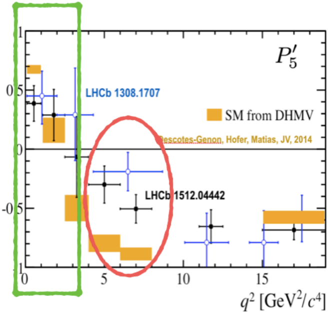
Non-local form factor

- QCD Factorization Beneke, Feldmann, Seidel

$$\mathcal{H}_\lambda(q^2) \sim \Delta C_9^\lambda(q^2)\,\mathcal{F}_\lambda(q^2) + \frac{1}{q^2}\Delta C_7^\lambda(q^2)\,\mathcal{F}_\lambda^T(q^2) + HSS + \mathcal{O}(\Lambda/m_B, \Lambda/E)$$

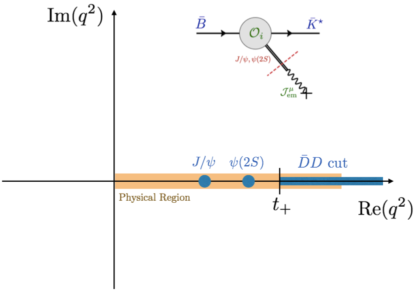
- It is assumed that the charm loop is dominated by short distances

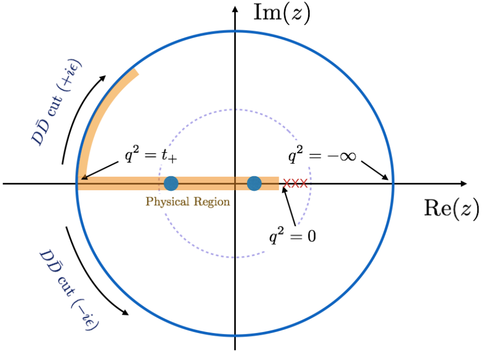




- Kink at $q^2 = 4m_c^2$ symptom of breaking of perturbativity

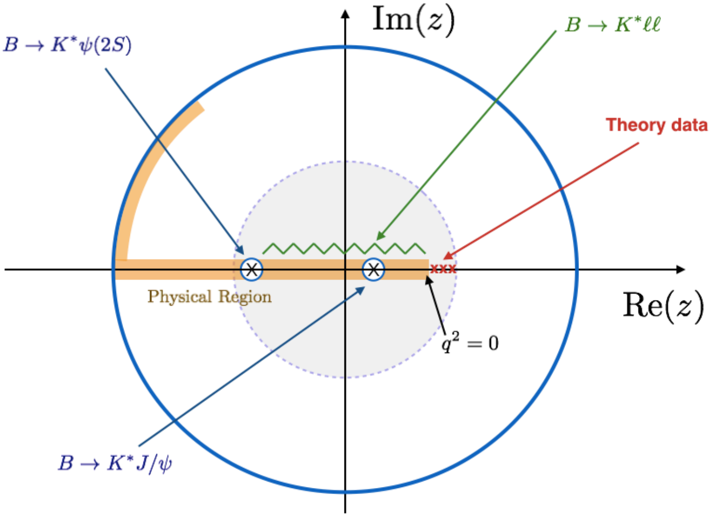
Same strategy as form factors!





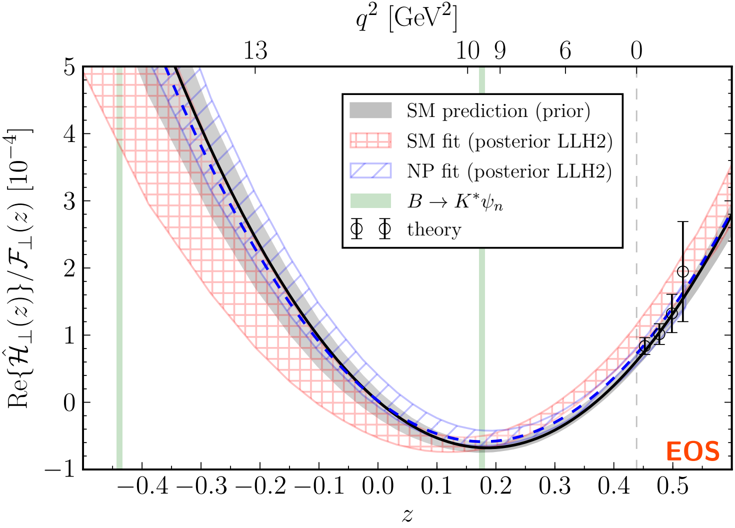
- $\hat{\mathcal{H}}_\lambda(q^2(z)) = (q^2 - M^2_{J/\psi})(q^2 - M^2_{\psi(2S)})\,\mathcal{H}_\lambda(q^2)$ is **analytic in** $|z| < 1$
- Taylor expand $\hat{\mathcal{H}}_\lambda(z)$ around $z = 0$: $\boxed{\hat{\mathcal{H}}_\lambda(z) = \left[\sum_{k=0}^{K} \alpha_k^{(\lambda)} z^k\right] \mathcal{F}_\lambda(z)}$
- Expansion needed for $|z| < 0.52$ $\left(-7\,\mathrm{GeV}^2 \leq q^2 \leq 14\mathrm{GeV}^2 \right)$

Fit to z-parametrisation

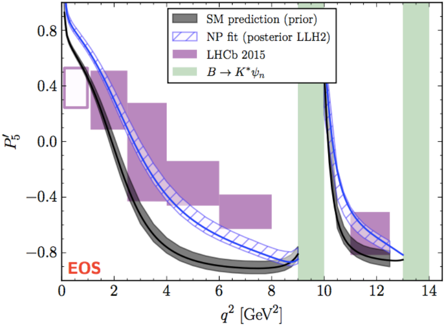


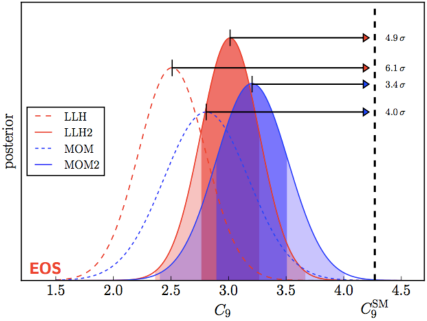
Fit to z-parametrisation

Bobeth, Chrzaszcz, van Dyk, JV, 1707.07305



SM predictions and Fit including $B \to K^* \mu^+ \mu^-$ data and $\mathcal{C}_9^{\mathrm{NP}}$:



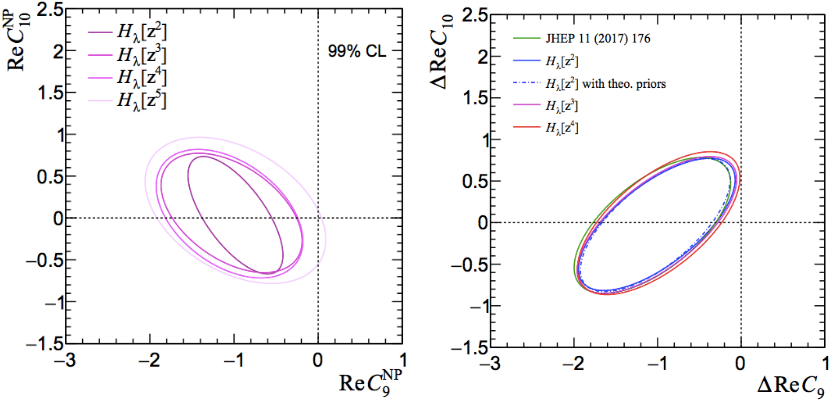


The NP hypothesis with $\mathcal{C}_9^{\mathrm{NP}} \sim -1$ is favored strongly in the global fit

Prospects: LHC Run-2 unbinned fits to z-parametrization

Chrzaszcz, Mauri, Serra, Coutinho, van Dyk 1805.06378

Mauri, Serra, Coutinho 1805.06401

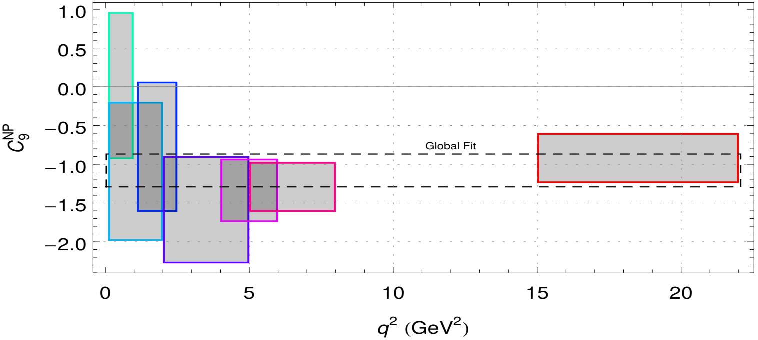


Unbinned fits to $B \to K^* \mu\mu$ (Left) and $B \to K^* \ell\ell$ (Right)

‘A posteriori’ test of non-local effect

☐ Testing the data : q^2-dependence

Descotes-Genon, Hofer, Matias, JV 1510.04239



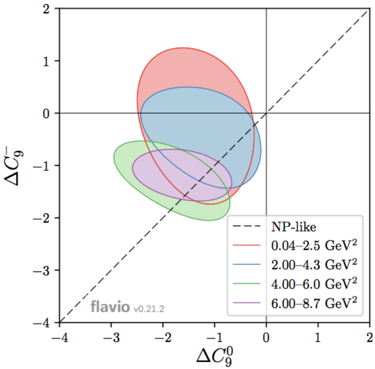
☐ Tiny uncertainites will allow to test hadronic contributions precisely

See also Altmannshofer, Straub 1503.06199, Ciuchini et al 1512.07157, Chobanova et al 1702.02234

‘A posteriori’ test of non-local effect

☐ Testing the data : K^*-helicity dependence

Altmannshofer, Niehoff, Stangl, Straub 1703.09189



☐ Tiny uncertainites will allow to test hadronic contributions precisely

See also Altmannshofer, Straub 1503.06199, Ciuchini et al 1512.07157, Chobanova et al 1702.02234


Thank you

Extra slides

Experimental constraints on z parametrisation $[B \to K^* \ell\ell]$

Bobeth, Chrzaszcz, van Dyk, Virto 2017

Experimental constraints :

- The residues of the poles are given by $B \to K^* \psi_n$:

$$\mathcal{H}_\lambda(q^2 \to M_{\psi_n}^2) \sim \frac{M_{\psi_n} f_{\psi_n}^* \mathcal{A}_\lambda^{\psi_n}}{M_B^2 (q^2 - M_{\psi_n}^2)} + \cdots$$

- Angular analyses Belle, Babar, LHCb determine :

$$|r_\perp^{\psi_n}|,\ |r_\parallel^{\psi_n}|,\ |r_0^{\psi_n}|,\ \arg\{r_\perp^{\psi_n} r_0^{\psi_n *}\},\ \arg\{r_\parallel^{\psi_n} r_0^{\psi_n *}\},$$

where $$r_\lambda^{\psi_n} \equiv \operatorname*{Res}_{q^2 \to M_{\psi_n}^2} \frac{\mathcal{H}_\lambda(q^2)}{\mathcal{F}_\lambda(q^2)} \sim \frac{M_{\psi_n} f_{\psi_n}^* \mathcal{A}_\lambda^{\psi_n}}{M_B^2\, \mathcal{F}_\lambda(M_{\psi_n}^2)}$$

- We produce correlated pseudo-observables from a fit (5+5).

Prior Fit to z parametrisation $[B \to K^* \ell\ell]$

Bobeth, Chrzaszcz, van Dyk, Virto 2017

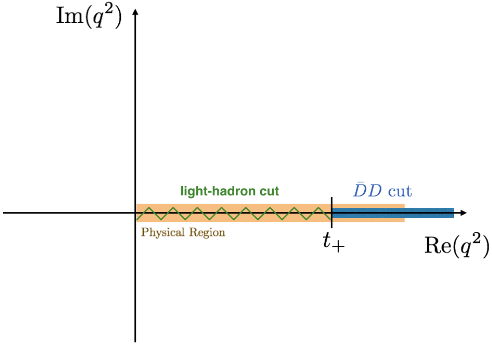
(Prior) Fit to Experimental and theoretical pseudo-observables :

k	0	1	2
$\mathrm{Re}[\alpha_k^{(\perp)}]$	-0.06 ± 0.21	-6.77 ± 0.27	18.96 ± 0.59
$\mathrm{Re}[\alpha_k^{(\|)}]$	-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
$\mathrm{Im}[\alpha_k^{(\|)}]$	-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	–

Table 1: Mean values and standard deviations (in units of 10^{-4}) of the prior PDF for the parameters $\alpha_k^{(\lambda)}$.

Light-hadron cut

The non-local ME of $O^c_{1,2}$ also contains a cut at low q^2 from intermediate "light-hadron" states:



$$\mathrm{Disc}[\mathcal{H}_\lambda(q^2 > t_+)] \sim \sum_X \langle 0|j_{\mathrm{em}}|X_{cc}^{1^{--}}\rangle\langle X_{cc}^{1^{--}} K^*|(\bar{s}c)(\bar{c}b)|\bar{B}\rangle$$

$$\mathrm{Disc}[\mathcal{H}_\lambda(0 < q^2 < t_+)] \sim \sum_X \langle 0|j_{\mathrm{em}}|X^{1^{--}}\rangle\langle X^{1^{--}} K^*|(\bar{s}c)(\bar{c}b)|\bar{B}\rangle$$

Light-hadron cut

⋆ Support for $\langle X^{1^{--}} K^* | (\bar{s}c)(\bar{c}b) | \bar{B} \rangle \ll \langle X_{cc}^{1^{--}} K^* | (\bar{s}c)(\bar{c}b) | \bar{B} \rangle$:

▶ OZI rule.

▶ $\mathcal{B}(B \to K^{(*)}\omega) \approx 2$ - $5 \cdot 10^{-6}$ (in agr. with QCDF from $[\bar{s}q][\bar{q}b]$)

$\Rightarrow \langle K^*\omega | (\bar{s}c)(\bar{c}b) | \bar{B} \rangle \lesssim \underbrace{C_q/C_c}_{few\,\%} \langle K^*\omega | (\bar{s}q)(\bar{q}b) | \bar{B} \rangle$

▶ Same argument for $\mathcal{B}(B \to K^{(*)}\phi)$

▶ In absence of OZI, the natural size of these BRs is 10^{-3} not 10^{-6} :

$\mathcal{B}(B \to KJ/\psi) = 9 \times 10^{-4}$ $\quad \mathcal{B}(B \to K^*J/\psi) = 1.3 \times 10^{-3}$
$\mathcal{B}(B \to K[D^*\bar{D}]) = 6 \times 10^{-3}$ $\quad \mathcal{B}(B \to K[D^*\bar{D}^*]) = 8 \times 10^{-3}$
$\mathcal{B}(B \to K[D\bar{D}]) = 5 \times 10^{-4}$

▶ Note also the **total** BR: $\mathcal{B}(B \to K^{(*)}[\bar{K}K]) \sim 10^{-5} \ll 10^{-3}$

▶ Test: $\mathcal{B}(B \to K^{(*)}X^{1^{--}}(\text{high mass})) \ll 10^{-3}$

Light-hadron cut

Conclusion: OZI $\to$ Two order of magnitude suppression.

- But CKM- and penguin-suppressed light-quark loops are there.
- Not OZI suppressed.
- Must be constrained if precision is sought (but rough estimate might suffice).
- Can do dispersive analysis Khodjamirian, Mannel, Wang 2012 ...
- Could use $b \to d$ analogues. (measure, please)