Beauty (th)

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UK Forum "Quarks and Leptons"
Abingdon, UK, November 14-15, 2013

Outline

- Introduction
- Unitarity triangle, $|V_{ub}|$
- B_s (mixing, $B_s \to \mu^+\mu^-$, non-leptonic)
- Electroweak penguin decays
- Summary

Flavour and CP violation in the SM

$SU(3) \times SU(2) \times U(1)_{\mathrm{Y}}$
Field content and gauge charges

$$-y_i^d (\bar{Q}'_L V^\dagger_{CKM})_i \Phi d_{Ri} - y_i^u \bar{Q}'_{Li} \tilde{\Phi} u_{Ri} - y_i^l \bar{L}_i \Phi e_{Ri} + \text{h.c.}$$

Only charged current.
No Higgs FCNC ⇒ little direct impact of Higgs discovery on SM flavour physics.

$$-\frac{f_{ij}}{\Lambda} [(\bar{L}^T \epsilon)_i i\sigma^2 \Phi] \, [\Phi^T i\sigma^2 L_j] + \text{h.c.}$$

$\sin\theta_{13}$ measured ⇒ CPV measurements in neutrino sector possible.

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- What is $y_i^{u,d}$, $V_{\rm CKM}$? Is $V_{\rm CKM}$ complex? Why is $y_i^{u,d}$, $V_{\rm CKM}$ what it is? (Origin of flavour hierarchies)
- Is this all there is? If not, what is it? Why didn't we see it already? (The other flavour problem)
- Baryogenesis? Leptogenesis? Strong CP problem, absence of EDMs.

The gauge hierarchy-flavour problem

SM presumably valid only below some scale Λ

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm dim\,4} - \frac{\Lambda^2}{2}\Phi^\dagger\Phi + \sum_i \frac{1}{\Lambda^2}\,(\bar{q}q\bar{q}q)_i + \ldots$$

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  Sets the electroweak scale.

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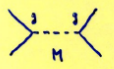
  Electroweak physics requires $\Lambda \leq M_W/g \approx$ few hundred GeV.

- But flavour physics restricts the scale of dimension-6 operators to

$$\Lambda \geq 10^{4-5}\,\text{TeV} \quad (\bar{s}d)(\bar{s}d) \qquad \Lambda \geq 10^3\,\text{TeV} \quad (\bar{b}d)(\bar{b}d)$$



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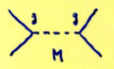

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Difficult to construct natural models.
But the argument may simply be wrong because nature may not care about naturalness ...

Flavour in the LHC Era

LHCb (indirect)

- B_s physics
- Electroweak penguins
- γ from $B \to DK$s
- Charm

LHC ("high-p_T")

- Higgs flavour
- top flavour
- Direct production

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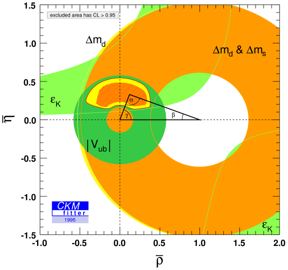
Interplay?

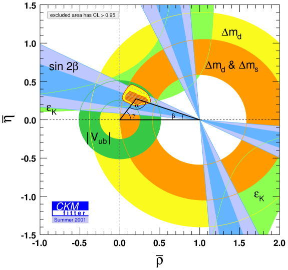
BSM only. Specific models

The Unitarity Triangle

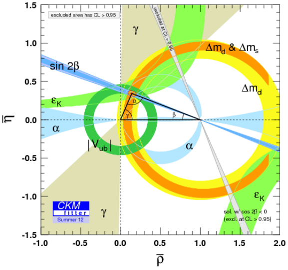
1995 (top discovery)



2001 (B factory turn-on)



2013 (Precision flavour physics)



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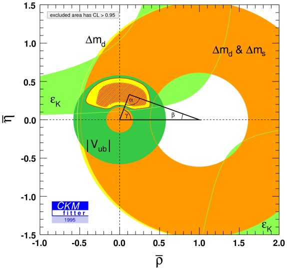

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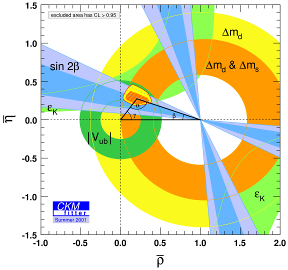

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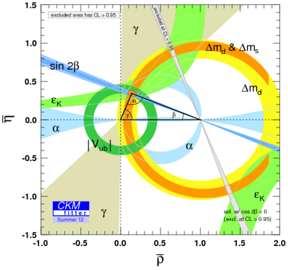

- Anomalies disappeared ($B \to \tau\nu$) or became implausible (Di-muon asymmetry $A_{\rm SL}^s$).
- Never before as consistent and precise → MFV paradigm
- UT triangle fit no longer an adequate representation of all tests of the SM flavour sector.
- Non-standard flavour physics can still be hidden.

$|V_{ub}|$ problem

Inclusive $B \to X_u \ell \nu$

$$|V_{ub}| = (4.41 \pm 0.15_{\rm exp}{}^{+0.15}_{-0.17}{}_{\rm th}) \cdot 10^{-3}$$

Kinematic constraints due to charm background.
HQE + resummation.

Exclusive $B \to \pi \ell \nu$

$$|V_{ub}| = (3.23 \pm 0.31) \cdot 10^{-3}$$

Lattice QCD
QCD sum rules
analyticity

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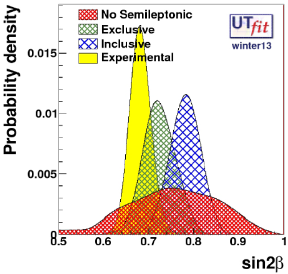

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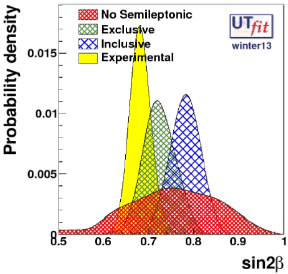
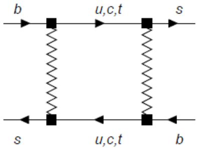


- V_{ub} – $\sin 2\beta$ – ϵ_K connection
- Bet on exclusive ...
- Some two-loop results for inclusive (fully differential (Brucherseifer, Caola, Melnikov, 2012); hard coefficient for resummation (Bonciani, Ferroglia; Asatrian, Greub, Pecjak; MB, Huber, Li; Bell, 2008)) not yet implemented.

B_s lifetime difference and mixing phase

$$i\frac{d}{dt}\begin{pmatrix}|B_s(t)\rangle\\ |\bar{B}_s(t)\rangle\end{pmatrix} = \left(\mathrm{M}^s - \frac{i}{2}\,\Gamma^s\right)\begin{pmatrix}|B_s(t)\rangle\\ |\bar{B}_s(t)\rangle\end{pmatrix}$$



Three observables related to mixing:

- $\Delta m_s/\Gamma_s$ large $\rightarrow$ many oscillations per lifetime

$$M_{12} \propto (V_{ts}^* V_{tb})^2$$

- $\Delta\Gamma_s$ ($|\Gamma_{12}^s|$) relevant. Significant fraction of common final states from $b \to c\bar{c}s$.

$$\frac{\Delta\Gamma}{\Gamma} = (1, \alpha_s) \times 16\pi^2 \frac{\Lambda^3}{m_b^3} + 16\pi^2 \frac{\Lambda^4}{m_b^4} + \ldots \quad \Longrightarrow \quad \Delta\Gamma_s = (0.090 \pm 0.018)\,\mathrm{ps}^{-1}$$

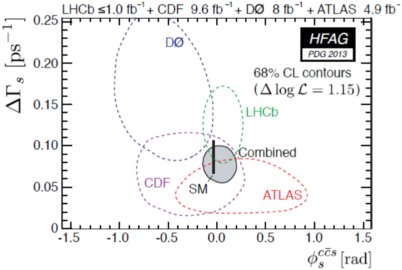
[Lenz-Nierste update, 1102.4274]

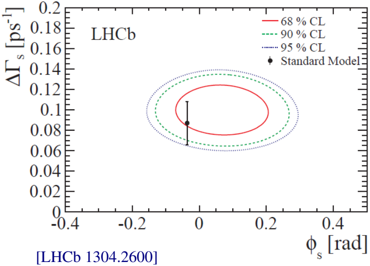
OPE+HQE [MB, Buchalla, Dunietz, 1996; MB et al., 1998] + Lattice

- Phase [MB et al, 1998, 2003; Ciuchini et al., 2003]

$$\phi_s = \arg\left(-\frac{M_{12}^s}{\Gamma_{12}^s}\right) = 0.22^\circ \pm 0.06^\circ \qquad 2\beta_s = 2\arg\left(-V_{tb}^* V_{ts}/(V_{cb}^* V_{cs})\right) = 2.1^\circ \pm 0.1^\circ$$

$\Delta\Gamma_s$ and β_s from $B_s \to J/\psi\phi$ and related





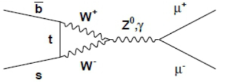
[LHCb 1304.2600]

- Last loophole for large NP in $B_{d,s}$ mixing closed
- HQE and Quark-Hadron Duality works in $b \to c\bar{c}s$.
- No effect large expected in MFV models.
- Generic models would affect B_d mixing more than B_s due to stronger CKM suppression. But quark flavour mixing may be related to lepton neutrino mixing.
- To complete the picture

$$a_{\rm sl} = \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \frac{\Delta\Gamma_s}{\Delta M_s} \tan\Phi_s$$

Anomaly in D0 measurement.

$B_s \to \mu^+\mu^-$



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- SM only C_{10} $\Rightarrow$ helicity suppression
  Sensitive to scalar couplings.

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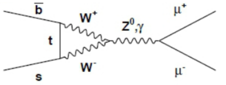

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- Width difference correction [De Bruyn et al., 2012]

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$$\mathrm{BR}(B_s \to f)_{\mathrm{obs}} = \frac{1}{2}\int_0^\infty dt\, \langle \Gamma(B_s(t) \to f) \rangle = \underbrace{\frac{\tau_{B_s}}{2}(R_H^f + R_L^f)}_{\text{theory calculation}} \underbrace{\left[\frac{1 + \mathcal{A}_{\Delta\Gamma}^f y_s}{1 - y_s^2} \right]}_{+10\%\ \text{correction}}$$

$$y_s = \Delta\Gamma_s/(2\Gamma_s) \approx 0.1$$

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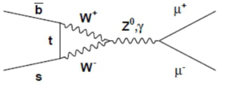

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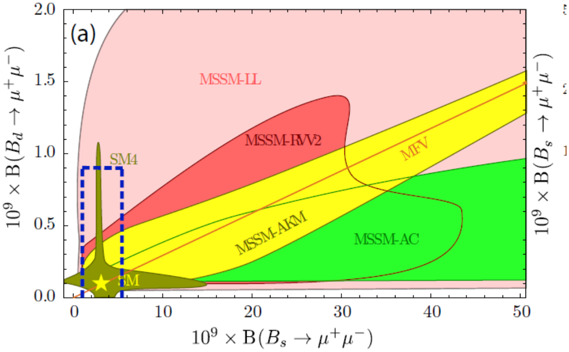
- LHCb + CMS: $(2.9 \pm 0.7) \times 10^{-9}$ vs. Theory [Bobeth et al., 1311.0903]: $(3.65 \pm 0.23) \times 10^{-9}$

$B_s \to \mu^+\mu^-$ model killing

[Straub, 1205.6094]



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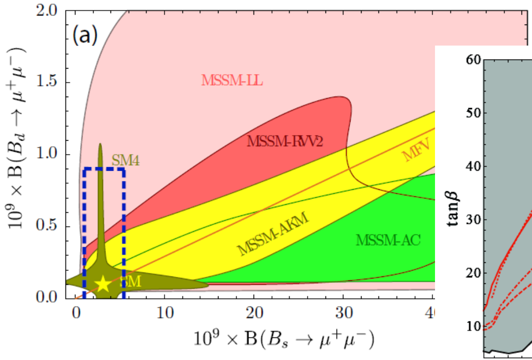
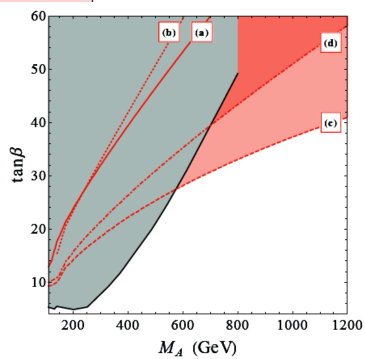


[Altmannshofer, 1306.0022]



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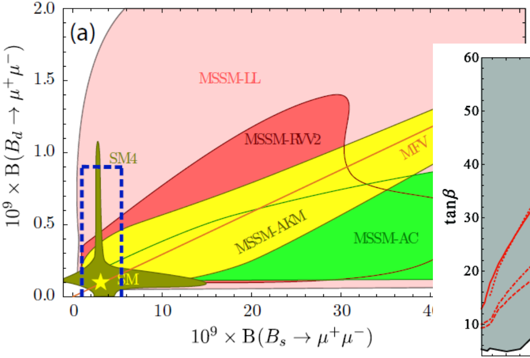

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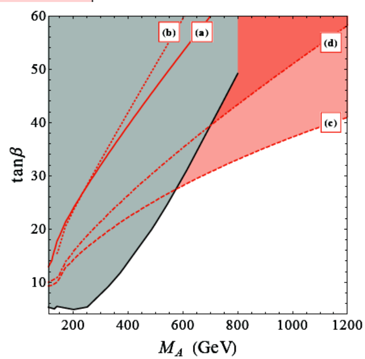
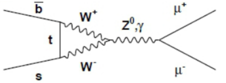


- Scalar FCNC cannot play an important role in non-helicity-suppressed amplitudes.
- Suppression relative to SM possible for pseudoscalar Higgs interfering with SM axial-vector contribution.

$B_s \to \mu^+\mu^-$ – Standard candle of electroweak penguin processes



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- Single hadronic parameter: $f_{B_s} = (227.7 \pm 4.5)$ MeV [FLAG, 1310.8555]
- Single short-distance coefficient: $\mathcal{L}_{\text{weak}} \propto C_{10} \times [\bar{s}b]_{V-A}[\bar{\ell}\ell]_A$

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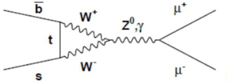

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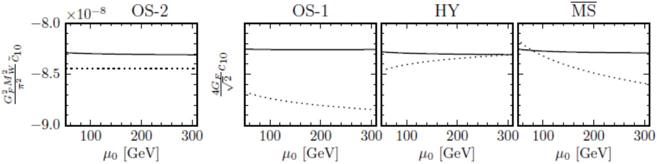
- NEW: 2-loop EW [Bobeth, Gorbahn, Stamou, 1311.1348], 3-loop QCD [Herrmann, Misiak, Steinhauser, 1311.1347]



- Practically eliminates non-par th uncertainty [Bobeth et al., 1311.0903]

$$10^9\,\mathrm{Br}(B_s \to \mu^+\mu^-) = 3.65 \pm 0.06\,(\text{th}) \pm 0.22\,(\text{param's: } f_{B_s}, m_t, |V_{tb}^*V_{ts}|, \tau_{B_s})$$

Hadronic matrix elements

HQE/OPE, lattice, (QCD sum rules)

QCD factorization, (flavour symmetries)

None – pure quantum interference

$\langle 0|\mathcal{O}|B\rangle$

$\langle B|\mathcal{O}|B\rangle$

$\langle M|\mathcal{O}|B\rangle$

$\langle M_1 M_2|\mathcal{O}|B\rangle$

Increasingly difficult

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γ from $B \to DK$ [and related methods] $2\beta_{B_s}$	$B \to \tau\nu_\tau$ $B_s \to \mu^+\mu^-$ $\Delta M_{B_d,B_s}$ $\Delta\Gamma_{B_s}$	$B \to D\tau\nu_\tau$ $\|V_{ub}\|$ $B \to K\nu\bar{\nu}$	$B \to \rho\gamma$ $B \to K^{(*)}\ell\ell$	Direct CP asym $B_s \to \pi K, KK, \ldots$ $B_s \to \pi\pi$ $B_s \to \phi\phi, K^{*0}\bar{K}^{*0}$

→ Increasingly difficult

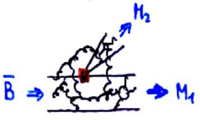
Many new LHCb results

Hadronic matrix elements from QCD factorization

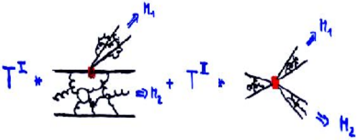
[BBNS, 1999-2003]

Heavy quark limit: $m_b \gg \Lambda_{\rm QCD}$
Large-energy limit: $E_M \approx m_b/2 \gg \Lambda_{\rm QCD}$
Scales: m_b, $\sqrt{m_b \Lambda_{\rm QCD}}$, $\Lambda_{\rm QCD}$, $(M_{\rm EW}, \Lambda_{\rm NP})$

$\mu \approx m_b$



$\mu \approx 1$ GeV



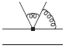
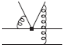
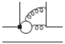
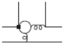
- Reduces $\langle M_1 M_2|\mathcal{O}|B\rangle$ to simpler $\langle M|\mathcal{O}|B\rangle$ (form factors), $\langle 0|\mathcal{O}|B\rangle$, $\langle 0|\mathcal{O}|M\rangle$ (decay constants and distribution amplitudes).
- Calculation from first principles, but limited accuracy by $\Lambda_{\rm QCD}/m_b$ corrections.

Status of NNLO radiative calculations (non-leptonic)

$$\langle M_1 M_2 | C_i O_i | \bar{B} \rangle_{\mathcal{L}_{\rm eff}} = \sum_{\rm terms} C(\mu_h) \times \Big\{ F_{B\to M_1} \times \underbrace{T^{\rm I}(\mu_h,\mu_s)}_{1+\alpha_s+\ldots} \star f_{M_2} \Phi_{M_2}(\mu_s)$$

$$+ f_B \Phi_B(\mu_s) \star \Big[\underbrace{T^{\rm II}(\mu_h,\mu_I)}_{1+\ldots} \star \underbrace{J^{\rm II}(\mu_I,\mu_s)}_{\alpha_s+\ldots} \Big] \star f_{M_1} \Phi_{M_1}(\mu_s) \star f_{M_2} \Phi_{M_2}(\mu_s) \Big\}$$

$$+ 1/m_b\text{-suppressed terms}$$

Status	2-loop vertex corrections (T_i^I)	1-loop spectator scattering (T_i^{II})
Trees	 [GB 07, 09] [Beneke, Huber, Li 09]	 [Beneke, Jäger 05] [Kivel 06] [Pilipp 07]
Penguins	 in progress	 [Beneke, Jäger 06] [Jain, Rothstein, Stewart 07]

from G. Bell [FPCP 2010]

Tree-dominated decays complete at NNLO.
Other non-leptonic and $B \to (M,\gamma)(\gamma, \ell^+\ell^-, \ell\nu)$ at NLO (= partly 2-loop).
No NNLO result yet on direct CP asymmetries: $A_{\rm CP} = [c \times \alpha_s]_{\rm NLO} + \mathcal{O}(\alpha_s^2, \Lambda/m_b)$

Numerical result (tree amplitudes)

$$
\begin{aligned}
T \equiv a_1(\pi\pi) &= 1.009 + [0.023 + 0.010i]_{\text{NLO}} + [0.026 + 0.028i]_{\text{NNLO}} \\
&\quad - \left[\frac{r_{\text{sp}}}{0.485}\right] \left\{[0.015]_{\text{LOsp}} + [0.037 + 0.029i]_{\text{NLOsp}} + [0.009]_{\text{tw3}}\right\} \\
&= 1.00 + 0.01i \quad \to \quad 0.93 - 0.02i \quad (\text{if } 2 \times r_{\text{sp}})
\end{aligned}
$$

$$
r_{\text{sp}} = \frac{9 f_{M_1} \hat{f}_B}{m_b f_+^{B\pi}(0) \lambda_B}
$$

$$
\begin{aligned}
C \equiv a_2(\pi\pi) &= 0.220 - [0.179 + 0.077i]_{\text{NLO}} - [0.031 + 0.050i]_{\text{NNLO}} \\
&\quad + \left[\frac{r_{\text{sp}}}{0.485}\right] \left\{[0.123]_{\text{LOsp}} + [0.053 + 0.054i]_{\text{NLOsp}} + [0.072]_{\text{tw3}}\right\} \\
&= 0.26 - 0.07i \quad \to \quad 0.51 - 0.02i \quad (\text{if } 2 \times r_{\text{sp}})
\end{aligned}
$$

- The colour-suppressed amplitudes are probably dominated by spectator-scattering. [But $\arg\,(C/T_{\pi\pi}) \lesssim 15^\circ$.]
- Qualitative understanding why colour-suppressed decay modes ($\pi^0\pi^0, \ldots$) are large. Largest uncertainty is input parameter dependence: Allows $|C/T|_{\pi\pi} \approx 0.7$, if λ_B is small.
- Soon to do for LHCb: update of 2003 (NLO) results with NNLO accuracy.

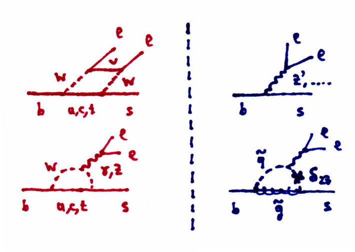
Electroweak penguin decay $B \to K^*(\to K\pi)\ell^+\ell^-$ [and related]

- Sensitive to TeV scale new particles in a cleaner environment than purely hadronic processes.

$$\mathcal{O}_7^{(\prime)} = -\frac{g_{\rm em}\hat{m}_b}{8\pi^2}\,\bar{s}\sigma^{\mu\nu}(1\pm\gamma_5)bF_{\mu\nu}$$

$$\mathcal{O}_{9,10}^{(\prime)} = \frac{\alpha_{\rm em}}{2\pi}\,(\bar{\ell}\ell)_{V,A}\,(\bar{s}b)_{V\pm A}$$

$$\mathcal{O}_{S,P,T}$$



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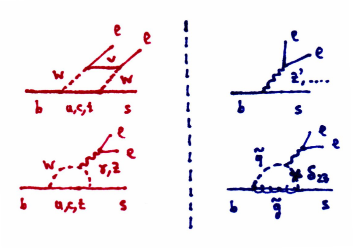
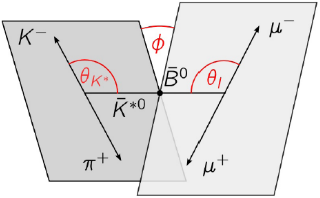


- Powerful diagnostic due to access to different tensor structures and chiralities through kinematic distributions and asymmetries

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

12 (10,8) angular coefficients $I_i(q^2)$ + CP conjugates.



Theory description

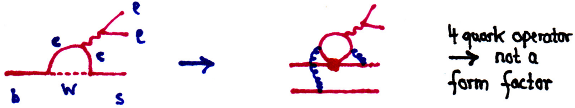
- $B \to K^*$ form factors not enough. Charm loops introduce a "hadronic component" of the virtual photon, as well as resonances.

- Amplitude has two components

$$\langle K^*\ell\ell|H_{\rm eff}|B\rangle = \underbrace{\sum_i a_i(C^{(\prime)}_{7,9,10},\ldots)\,F_i^{B\to K^*}}_{} + \underbrace{\frac{ie^2}{q^2}\langle\ell\ell|\bar{l}\gamma_\mu l|0\rangle\int d^4x\,e^{iq\cdot x}\,\langle K^*|T(j^\mu_{\rm em}(x)H^{\rm had}_{\rm eff}(0)|B\rangle}_{}$$

Electroweak penguins;
local;
sensitive to new physics

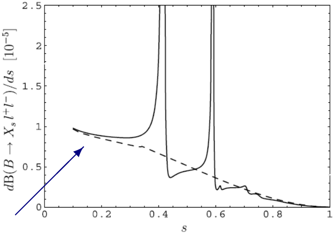
QCD;
non-local;
NP constrained by non-leptonics;
photon pole, charmonium resonances



Lepton invariant mass spectrum and theoretical approaches

- QCD factorization for $q^2 \leq 6\,\mathrm{GeV}^2$ [MB, Feldmann, Seidel, 2001; 2004]

$$\langle \ell\ell K^* | \mathcal{O}_i | \bar{B} \rangle = C_i \xi + \Phi_B \otimes T_i \otimes \Phi_{K^*} + \mathcal{O}(\Lambda/m_b)$$



QCD factorization

Fig. 2 Differential $B \to X_s l^+ l^-$ branching fraction as a function of $s = q^2/m_b^2 \equiv m_{l^+l^-}^2/m_b^2$, including the effect of charm resonances in

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- OPE and HQE for $q^2 \geq 15\,\mathrm{GeV}^2$ [Grinstein, Pirjol, 2004; Beylich et al., 2011]

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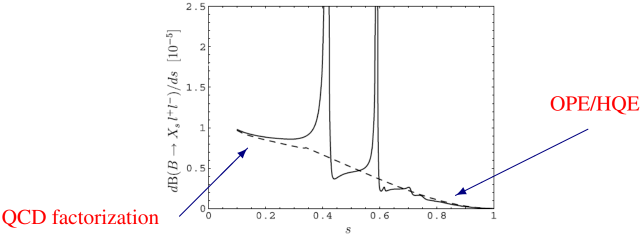
Power corrections and duality violation (integrated) estimated below 2%.



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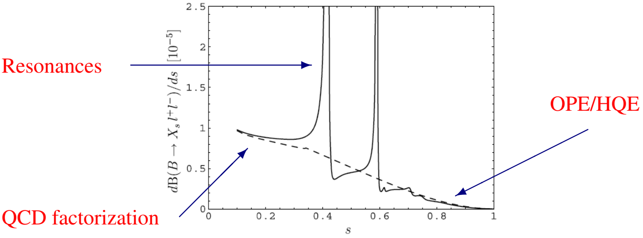
- Charmonium resonance region e.g. [Khodjamirian et al., 2010, 2012]. No quark-hadron duality in this region [MB, Buchalla, Neubert, Sachrajda, 2009]



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Form factors and "effective Wilson coefficients"

- Key point at large recoil: only two independent form factors due to helicity and parity conservation of the strong interaction – up to calculable α_s corrections [Charles et al., 1998, MB, Feldmann, 2000], e.g.,

$$\langle K^*(\lambda = \pm 1)|\bar{s}P_{R/L}\Gamma b|\bar{B}\rangle \quad \Rightarrow \quad \xi_\perp(q^2)$$

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- Double differential distribution with "effective Wilson coefficients"

$$\frac{d^2\Gamma}{dq^2 d\cos\theta} = \frac{G_F^2|V_{ts}^* V_{tb}|^2}{128\pi^3} M_B^3\, \lambda(q^2, m_{K^*}^2)^3 \left(\frac{\alpha_{\rm em}}{4\pi}\right)^2 \times \left[(1+\cos^2\theta)\,\frac{2q^2}{M_B^2}\,\xi_\perp(q^2)^2 \left(|\mathcal{C}_{9,\perp}(q^2)|^2 + C_{10}^2\right)\right.$$
$$\left. + (1-\cos^2\theta)\left(\frac{E\,\xi_\parallel(q^2)}{m_{K^*}}\right)^2 \left(|\mathcal{C}_{9,\parallel}(q^2)|^2 + C_{10}^2\,\Delta_\parallel(q^2)^2\right) - \cos\theta\,\frac{8q^2}{M_B^2}\,\xi_\perp(q^2)^2\,{\rm Re}(\mathcal{C}_{9,\perp}(q^2))\,C_{10}\right]$$

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$$\mathcal{C}_{9,\perp}(q^2) \equiv C_9 + \frac{2m_b M_B}{q^2}\,\frac{\mathcal{T}_\perp(q^2)}{\xi_\perp(q^2)} = C_9 + Y(q^2) + \frac{2m_b M_B}{q^2}\,C_7^{\rm eff} + \ldots$$

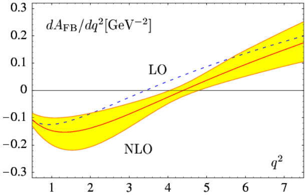
$$\mathcal{C}_{9,\parallel}(q^2) \equiv C_9 - \frac{2m_b}{M_B}\,\frac{\mathcal{T}_\parallel(q^2)}{\xi_\parallel(q^2)} = C_9 + Y(q^2) + \frac{2m_b}{M_B}\,C_7^{\rm eff} - e_q\,\frac{4M_B}{m_b}\,(\bar{C}_3 + 3\bar{C}_4)$$
$$\times \frac{\pi^2}{N_c}\,\frac{f_B f_{K^*}}{M_B(E/m_{K^*})\xi_\parallel(q^2)} \int d\omega\,\frac{M_B\Phi_{B,-}(\omega)}{M_B\omega - q^2 - i\epsilon} + \ldots$$

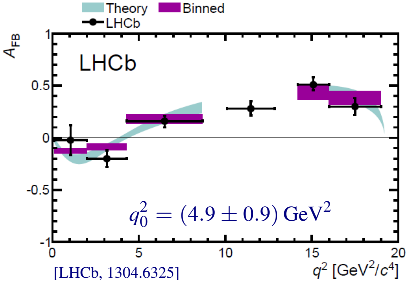
$$\mathcal{T}_a = \xi_a\left(C_a^{(0)} + \frac{\alpha_s C_F}{4\pi}\,C_a^{(1)}\right) + \frac{\pi^2}{N_c}\,\frac{f_B f_{K^*,a}}{M_B}\,\Xi_a \sum_\pm \int \frac{d\omega}{\omega}\,\Phi_{B,\pm}(\omega) \int_0^1 du\,\Phi_{K^*,a}(u)\,T_{a,\pm}(u,\omega)$$

Forward backward asymmetry zero: $\mathrm{Re}(\mathcal{C}_{9,\perp}(q_0^2)) = 0$

- Zero arises if C_9 and C_7 have different sign.
  Almost free from hadronic uncertainties (protected from form factor uncertainty)
  [Burdman, 1997; Ali et al, 1999; MB, Feldmann, Seidel, 2001,2004]

$$q_0^2[K^{*0}] = 4.36^{+0.33}_{-0.31}\,\mathrm{GeV}^2 \qquad q_0^2[K^{*+}] = 4.15 \pm 0.27\,\mathrm{GeV}^2$$ [MB, Feldmann, Seidel, 2004]





[LHCb, 1304.6325]

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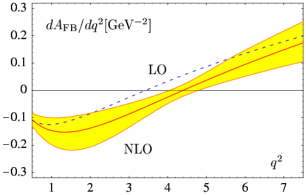
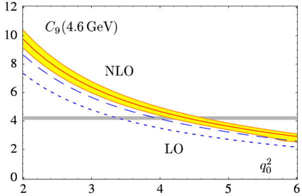
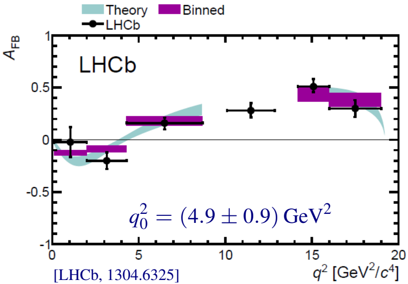






[LHCb, 1304.6325]

$$C_9 = -\frac{2M_B m_b}{q_0^2}\,C_7^{\mathrm{eff}} - \mathrm{Re}\,Y(q_0^2) + \text{known NLO correction}$$

Full angular analysis

- $A_{FB}(q^2)$ is protected from form factor uncertainty only at one point. Can do much better, when angular amplitudes $I_i(q^2)$ are measured. [Egede et al. 2008, 2009, 2010; Altmannshofer et al. 2008; Bobeth et al. 2008; Bobeth, Hiller, van Dyk, 2010, 2011; Matias et al., 2012; Beaujean et al., 2012; Descotes-Genon et al., 2012; Jäger, Camalich, 2012]

- Basic idea: Construct (most) I_i such that

$$I_i(q^2) \propto |\xi_\perp(q^2)|^2 \quad \text{or} \quad |\xi_\|(q^2)|^2 \quad \text{or} \quad \xi_\perp(q^2)\xi_\|(q^2)$$

and take ratios such that form factors cancel. "Theoretically clean" for all q^2.

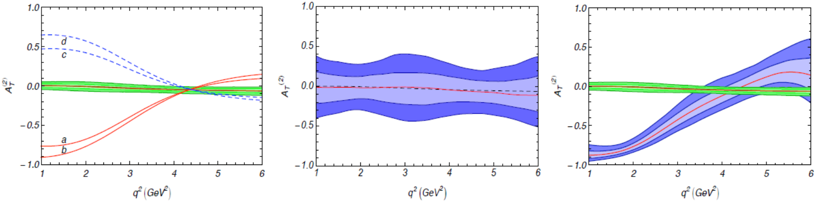
$$P_i(q^2) = a_i(q^2) + \frac{\alpha_s}{\xi_a(q^2)} \times \text{spectator scattering} + O\left(\frac{\Lambda}{m_b}\right)$$

- Example: Transversity amplitude is protected for all q^2.

$$A_T^{(2)}(q^2) = \frac{|A_\perp|^2 - |A_\||^2}{|A_\perp|^2 + |A_\||^2}$$

Full angular analysis

[Figure from Egede et al., 2008]



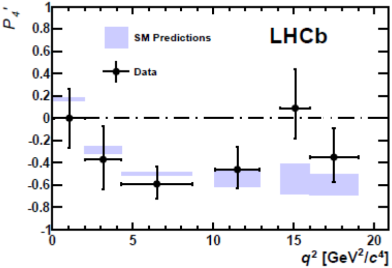
Theoretical error including Λ/m_b and SUSY scenarios (1 TeV masses)

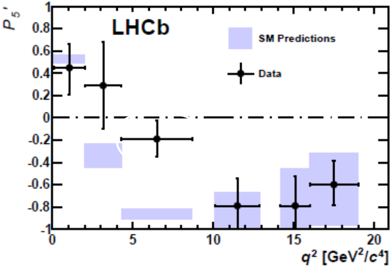
Experimental sensitivity, 10 fb^{-1} at LHCb.

Experimental sensitivity for SUSY scenario b.

- Unique flavour laboratory: The set of all angular observables allows one to determine magnitude, phase and chirality of the magnetic penguin and electroweak penguin coefficients. [Example: $A_T^{(2)}(q^2)$ is negligible in the SM, and proportional to $C_7^{(\prime)}$ BSM.]
- Starts being measured at LHCb [1308.1707]
- Primary application of factorization to LHCb physics.

First results ... [LHCb, 1308.1707]





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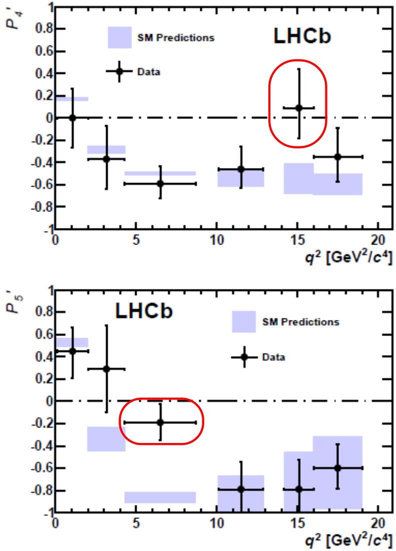

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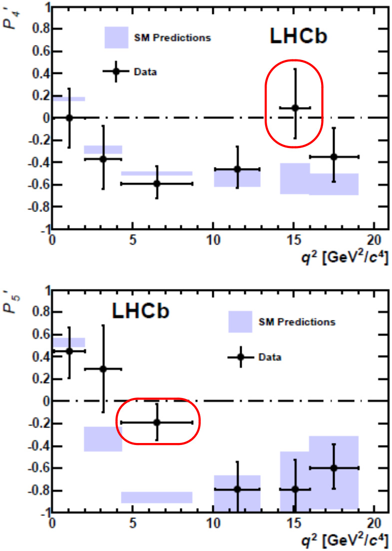

- Theoretical fits of Wilson coefficients [Descotes-Genon, Matias, Virto, 1307.5683; Altmannshofer, Straub, 1308.1501; Horgan et al., 1310.3887; Beaujean, Bobeth, van Dyk, 1310.2478

  $$\Delta C_9 \approx -1.5\ldots-1, \Delta C_{10} \approx 0 \quad \text{SM}$$

  $$\Delta C_9 \approx -1, \Delta(C_9 + C_9') \approx 0,$$
  $$\Delta C_{10}^{(\prime)} \approx 0 \quad \text{SM}'$$

- Requires somewhat ungeneric models: leptophilic $SU(3)_L \times U(1)_X$ [Gauld, Goertz, Haisch, 1310.1082], scalar operators from top color [Datta et al., 1310.1937], ...

- Theoretical uncertainty estimate ($1/m_b$ corrections)? [e.g. Jäger, Camalich, 2012]

- ... or rather a statistical fluctuation.

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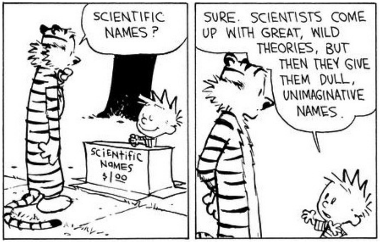
"There is a theory in physics that explains, at the deepest level, nearly all of the phenomena that rule our daily lives [...] It surpasses in precision, in universality, in its range of applicability from the very small to the astronomically large, every scientific theory that has ever existed. This theory bears the unassuming name 'The Standard Model of Elementary Particles' [...] It deserves to be better known, and it deserves a better name. I call it 'The Theory of Almost Everything'."

(Robert Oerter, The Theory of Almost Everything: The Standard Model, the Unsung Triumph of Modern Physics, 2006)



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- Precision matters: "clean" observables and good theoretical methods important for beauty physics at LHCb and SuperBelle
- Even if there is no new fundamental physics (yet) there is lots of fascinating physics