# On $b \to s(d)\ell^+\ell^-$ exclusive decays

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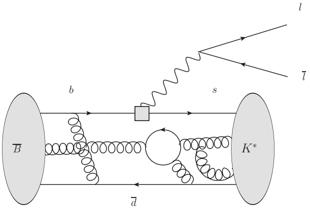
# OUTLINE

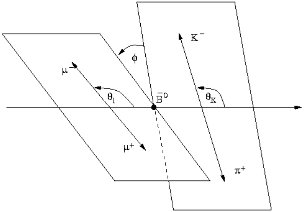
1. $\bar{B} \to \bar{K}^* \ell^+ \ell^-$
   - The low $q^2$ anomalies and interpretations
   - Connecting the theory with the experiment
   - Numerical analyses
   - Superclean observables
2. $SU(2)_L \times U(1)_Y$ constraints on $b \to s(d)\ell^+\ell^-$
   - Electro-weak gauge symmetry constraints on $\mathcal{H}_W$
   - Phenomenological consequences: $B_q \to \ell\ell$
   - Phenomenological consequences: $B \to K\ell\ell$
3. Conclusions

# The $B \to K^* \ell^+ \ell^-$ anomaly




| Expt. | ~# events |
|---|---|
| CDF | 100 PRL106(2011)161801 |
| BaBar | 150 PRD86(2012)032012 |
| Belle | 200 PRL103(2009)171801 |
| CMS | 400 PLB727(2013)77 |
| ATLAS | 500 arXiv:1310.4213 |
| LHCb | 1000 (1 $\text{fb}^{-1}$) JHEP 1308 (2013) 131 |

- **4-body decay**



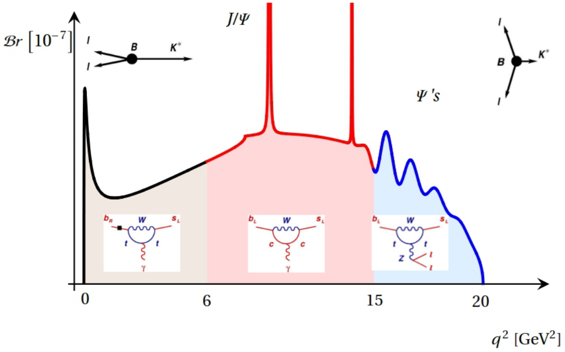

$$\frac{d^{(4)}\Gamma}{dq^2\, d(\cos\theta_l) d(\cos\theta_k) d\phi} = \frac{9}{32\pi}\big(I_1^s \sin^2\theta_k + I_1^c \cos^2\theta_k$$

$$+ \quad (I_2^s \sin^2\theta_k + I_2^c \cos^2\theta_k)\cos 2\theta_l + I_3 \sin^2\theta_k \sin^2\theta_l \cos 2\phi$$

$$+ \quad I_4 \sin 2\theta_k \sin 2\theta_l \cos\phi + I_5 \sin 2\theta_k \sin\theta_l \cos\phi + I_6 \sin^2\theta_k \cos\theta_l$$

$$+ \quad I_7 \sin 2\theta_k \sin\theta_l \sin\phi + I_8 \sin 2\theta_k \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_k \sin^2\theta_l \sin 2\phi\big)$$

Up to $I_i(q^2)$ **12** $q^2$-dependent observables




- **Large-recoil region** (low $q^2$)
  - Heavy to collinear light quark ⇒ QCDf or SCET (power-corrections)
  - Dominant effect of the photon pole
- **Charmonium region**
  - Dominated by long-distance (hadronic) effects
  - Starting at the perturbative $c\bar{c}$ threshold $q^2 \simeq 6-7$ GeV$^2$
- **Low-recoil region** (high $q^2$)
  - Heavy quark EFT + Operator Product Expansion (OPE) (duality violation)
  - Dominated by semileptonic operators

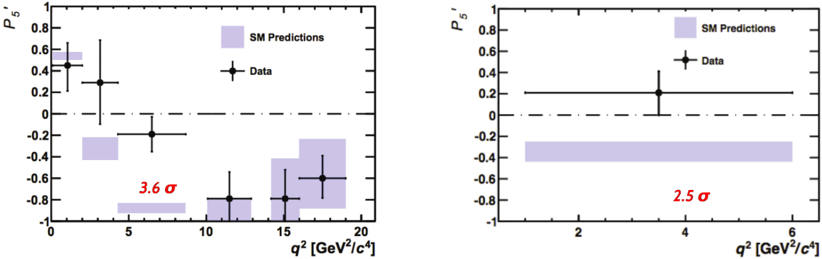
# The $P_5'$ anomaly at low $q^2$ (1 $\text{fb}^{-1}$)

PRL **111,** 191801 (2013) PHYSICAL REVIEW LETTERS week ending 8 NOVEMBER 2013

**Measurement of Form-Factor-Independent Observables in the Decay $B^0 \to K^{*0}\mu^+\mu^-$**

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

(Received 9 August 2013; published 4 November 2013)



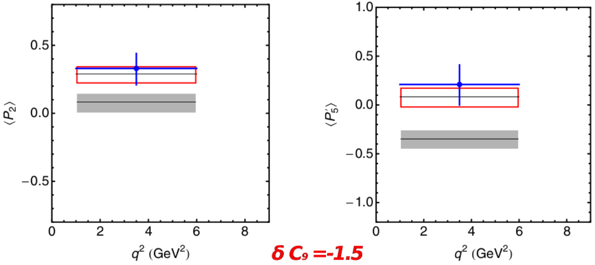

SM predictions from Egede *et al.* JHEP11(2008)032

**There are 2 more $\text{fb}^{-1}$ on tape!!**

# The $P_5'$ anomaly: New Physics?

- It was noted that there is another tension in $P_2$ at low $q^2$
- The discrepancies can be solved by a sizable NPs contribution to $C_9$

Descotes-Genon *et al.* PRD88,074002,hep-ph 1311.3876



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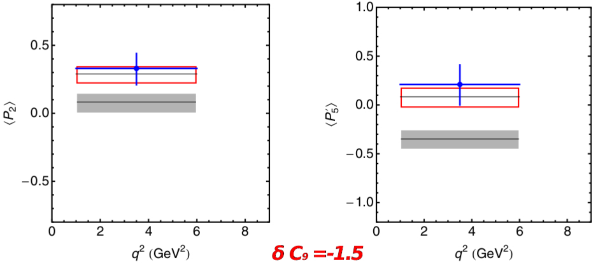



- An independent analysis

  Altmannshofer *et al.* Eur.Phys.J. C73 (2013) 2646

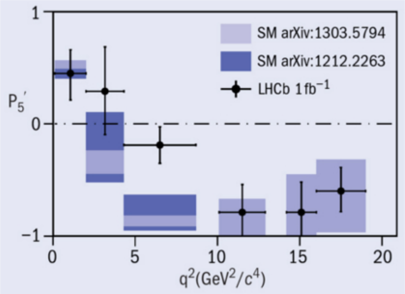
  1. Confirmed the important role of $C_9$ to explain the anomaly
  2. High $q^2$ analysis played an important role in revealing other sources of NPs

# The $P_5'$ anomaly: New Physics?

**CERN COURIER**

Nov 20, 2013

## LHCb and theorists chart a course for discovery




Jäger and JMC, JHEP 1305 (2013) 043

- Larger SM uncertainties in the predictions

**GOAL:** Explain the anomalies largely by *uncertain* hadronic effects?

# The weak Hamiltonian for $b \to s$ transitions

- In the SM we have

$$\mathcal{H}_W = \frac{G_F}{\sqrt{2}} \sum_{p=u,\,c} \lambda_p \left[ C_1 \mathcal{O}_1^p + C_2 \mathcal{O}_2^p + \sum_{i=3,\,10} C_i \mathcal{O}_i \right] ,$$

$$\mathcal{O}_7 = \frac{e}{4\pi^2} \hat{m}_b \, \bar{s}\sigma_{\mu\nu} P_R F^{\mu\nu} b \,,$$

$$\mathcal{O}_1^c = (\bar{c}b)_{V-A}(\bar{s}c)_{V-A} \,, \qquad \mathcal{O}_2^c = (\bar{c}_i b_j)_{V-A}(\bar{s}_j c_i)_{V-A} \,,$$

$$\mathcal{O}_9 = \frac{\alpha_{\rm em}}{2\pi}(\bar{s}b)_{V-A}(\bar{l}l)_V \,, \qquad \mathcal{O}_{10} = \frac{\alpha_{\rm em}}{2\pi}(\bar{s}b)_{V-A}(\bar{l}l)_A$$

Buchalla *el al.*Rev.Mod.Phys.68(1996)1125

- **Info from DOFs at $\Lambda \sim \mathcal{O}(m_W)$ stored in the Wilson coeffs. $C_i(\mu)$'s**

Table : Wilson coefficients of the SM at $\mu = 4.8$ GeV.

| $C_1$ | $C_2$ | $C_7^{\rm eff}$ | $C_9$ | $C_{10}$ |
|---|---|---|---|---|
| -0.144 | 1.060 | -0.305 | 4.24 | -4.312 |

# Connecting the theory to experiment: The helicity amplitudes

- Helicity amplitudes $\lambda = \pm 1, 0$

$$H_V(\lambda) = -iN\Big\{C_9\,\tilde{V}_{L\lambda} - \frac{m_B^2}{q^2}\Big[\frac{2\,\hat{m}_b}{m_B}C_{7\gamma}\,\tilde{T}_{L\lambda} - 16\pi^2 h_\lambda\Big]\Big\},$$

$$H_A(\lambda) = -iNC_{10}\,\tilde{V}_{L\lambda}, \qquad H_P = iN\frac{2\,m_l\hat{m}_b}{q^2}C_{10}\Big(\tilde{S}_L + \frac{m_s}{m_b}\tilde{S}_R\Big)$$

## $C_9$ is exposed to various hadronic backgrounds

- Hadronic form factors

$$-im_B\,\tilde{V}_{L(R)\lambda}(q^2) = \langle M(\lambda)|\bar{s}\not\epsilon^*(\lambda)P_{L(R)}b|\bar{B}\rangle,$$
$$m_B^2\,\tilde{T}_{L(R)\lambda}(q^2) = \epsilon^{*\mu}(\lambda)q^\nu\langle M(\lambda)|\bar{s}\sigma_{\mu\nu}P_{R(L)}b|\bar{B}\rangle,$$
$$im_B\tilde{S}_{L(R)}(q^2) = \langle M(\lambda=0)|\bar{s}P_{R(L)}b|\bar{B}\rangle.$$

- Form factors in the helicity basis

Bharucha it et al.JHEP 1009 (2010) 090, Jäeger and JMC JHEP1305(2013)043

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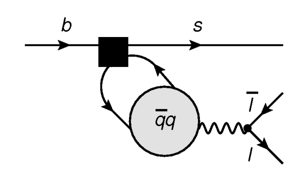
## $C_9$ is exposed to various hadronic backgrounds

- Non-local contribution




$$h_\lambda \propto \int d^4y e^{iq\cdot y}\langle \bar{K}^*|j^{\mathrm{em,had},\mu}(y)\mathcal{H}^{\mathrm{had}}(0)|\bar{B}\rangle\epsilon_\mu^*$$

Especially sensitive to $c\bar{c}$ contributions!

# Form Factors at large recoil

- **Heavy-quark** and **large-recoil** ($K^*$) limit only **2** independent "soft form factors"

$$T_+ = V_+ = 0, \qquad T_- = V_- = \frac{2E}{m_B}\xi_\perp, \qquad T_0 = V_0 = S = \frac{E}{m_{K^*}}\xi_\parallel$$

Dugan *et al.* PLB255(1991)583, Charles *et al.* PRD60(1999)014001

- The observable $P_5'$

$$P_5' = \frac{I_5}{2\sqrt{-I_{2s}I_{2c}}} = \frac{(\mathrm{Re}[(H_V^- - H_V^+)H_A^{0*} + (H_A^- - H_A^+)H_V^{0*}]}{\sqrt{(|H_V^0|^2 + |H_A^0|^2)(|H_V^+|^2 + |H_V^-|^2 + |H_A^+|^2 + |H_A^-|^2)}}$$

- *Rationale* behind $P'$ basis: Ignore in first app. $\alpha_s$ corrections and $h_\lambda$

$$H_V^0 \propto \xi_\parallel, \qquad H_V^- \propto \xi_\perp, \qquad H_V^+ \sim 0$$

$$P_5' \simeq \frac{2E^2}{m_B m_{K^*}} F(q^2, C_{7\gamma}, C_9, C_{10})$$

$F(q^2, C_{7\gamma}, C_9, C_{10})$ hadronic independent at $\mathcal{O}(\alpha_s^0, (\frac{\Lambda}{E})^0)$

$\alpha_s$ corrections can be computed to any order in QCDf or SCET

Beneke *et al.* NPB592(2001)3, NPB685(2004)249, Bauer *et al.* PRD63(2001)114020

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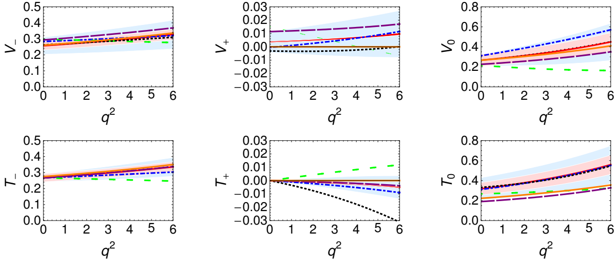
# Agnostic approach to power corrections ($\frac{\Lambda}{E}$)

- We fix $\xi_{\parallel}(0)$ using theoretical predictions

$$\xi_{\perp}(0) = T_1(0) = 0.30(1), \qquad \xi_{\parallel}(0) = \frac{2m_{K^*}}{m_B} A_0(0) = 0.09(2)$$

- Parametrize

$$F^{\rm p.c.,\pm} = \pm a_F \pm b_F \frac{q^2}{m_B^2}$$




- **Light-cone SRs** (Ball&Zwicky'05, Khodjamirian *et al.*'10)
- **QCD SRs** (Colangelo *et al.*'96)
- **Dyson-Schwinger** (Ivanov *et al.*'07)

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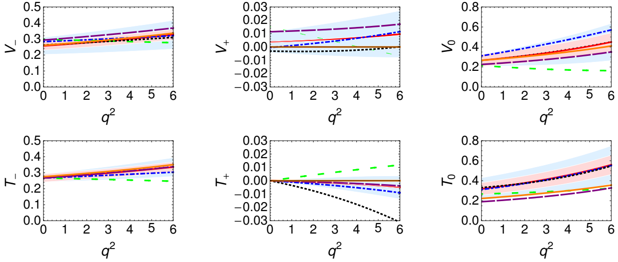
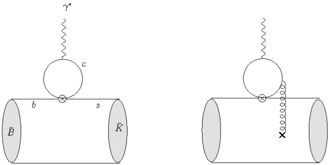



**Consistent with power counting**

Power corrections typically at 5% – 20% level

# Calculation of $h_\lambda$ at low $q^2$

- **QCDf**: Can be computed at leading-power $\Lambda/E$ perturbatively in $\alpha_s$
- Power corrections from charm-loop weighted by large WCs



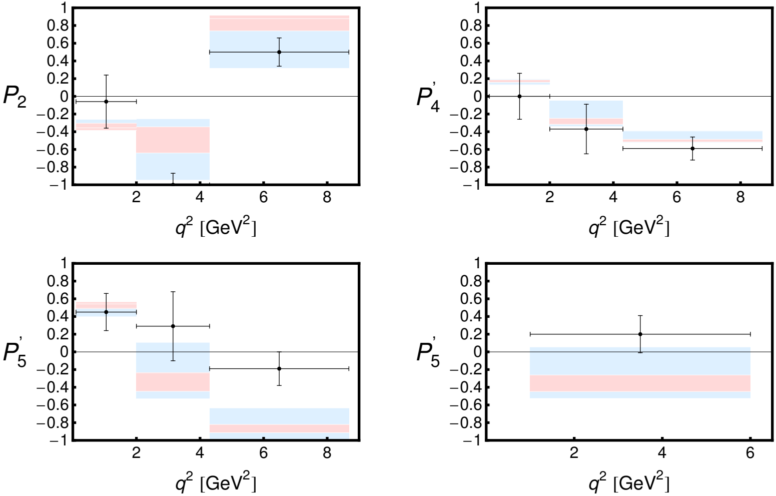

- Estimate of the effects obtained using non-local **LCSRs**
  **One can only trust up to 4-6 GeV$^2$!!**

  Khodjamirian *et al.*JHEP1009(2010)089

- Power corrections from light quarks CKM suppressed but "resonate"

$$a_\mu^{\rm had,\,l-q} \approx \int d^4x\, e^{-iq\cdot x} \sum_{P,P'} \langle 0|j_\mu^{\rm em,\,l-q}(x)|P'\rangle\langle P'(x)|P(0)\rangle\langle K^* P|\, H_W^{\rm had}(0)|B\rangle$$

Non-factorizable contributions to $h_+$ are $\Lambda/m_B$ (Jäger and JMC'12)




Red band: “Scale factor method”* and montecarlo with 66% spread

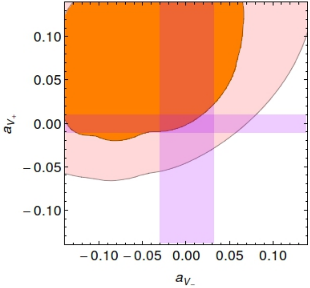
Descotes-Genon *et al.* JHEP05(2013)137

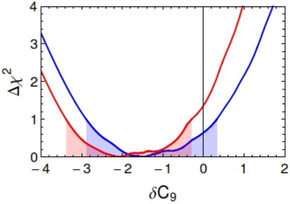
Blue band: This analysis, Montecarlo with **“maximum spread”** (100%)

- **Reminder:** I don’t believe my treatment of charm over 6 GeV$^2$!

# The significance of the low-$q^2$ anomaly in our analysis

- We fit all the $P_i'$ observables in the bin [1,6] GeV$^2$ using the "***R*-Fit method**"




- Marginalized $\chi^2$ and 1-$\sigma$ intervals
  - Red "marginalized" $\chi^2(\delta C_9)$
  - Blue *Idem.* but $a_{V\_} = -0.056$ (-20% p.c.)

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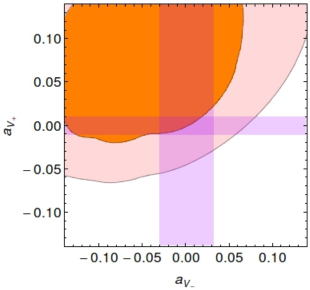


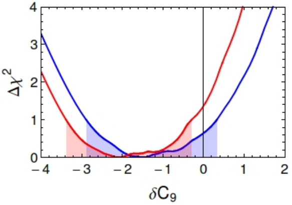


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- The anomaly could be *largely* accommodated in the SM through p.c.'s

$$H_V^- \sim \left\{ C_9 (V_-^{\text{QCDf}} + a_{V\_}) - \frac{m_B^2}{q^2}\left[\frac{2\,\hat{m}_b}{m_B} C_{7\gamma} T_-^{\text{QCD}} - 16\pi^2 h_- \right]\right\}$$

- Charm contribution in $h_\lambda$ could also play a role

Lyon *et al.* arXiv:1406.0566

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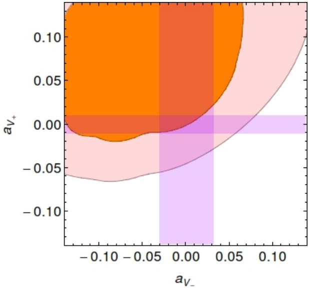


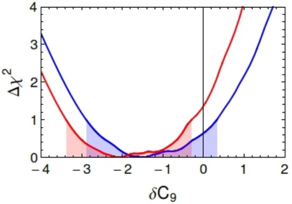


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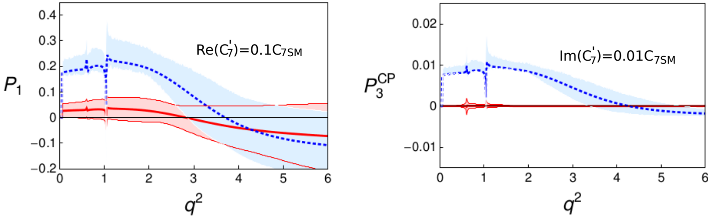
- Similar conclusions were drawn from a bayesian analysis

Beaujean *et al.* arXiv:1310.2478,JHEP1208(2012)030

  - Global analysis of all $b \to s\ell\ell$ data
  - Sizable power corrections (scale-factor method)

# "Superclean" observables and $C_7'$




- The observables $I_3$ and $I_9$ are proportional to

$$I_3 \propto \mathrm{Re}\left(H_+^V H_-^V\right) \propto \mathrm{Re}\left(C_7\, C_7'^*\right), \qquad I_9 \propto \mathrm{Im}\left(H_+^V H_-^V\right) \propto \mathrm{Im}\left(C_7\, C_7'^*\right),$$

## Low hadronic backgrounds:

$T_+ \sim \mathcal{O}(\Lambda/m_b \times q^2/m_b^2)$, $h_+ \sim \mathcal{O}(\Lambda/m_b)$

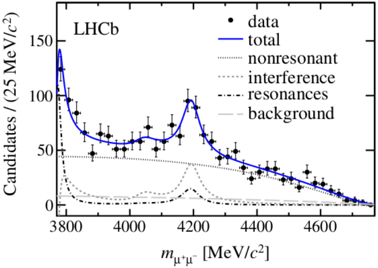
**Hadronic uncertainties cancel in $P_1$ and $P_3^{CP}$ up to $q^2 \sim 1-2$ GeV$^2$** (Jäger and JMC'12)

# What about the high $q^2$ region

- Especially suited for determining $C_9$
- Theoretical approach based on an HQET+OPE (assume small QHDV!)

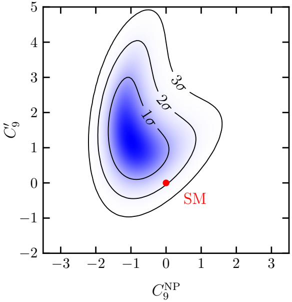
Grinstein *et al.* PRD70(2004)114005, Bobeth *et al.* JHEP1007(2010)098, Beylich *et al* EPJC71(2011)1635

- **However:** Large QHDV?




Kaonic mode

- FFs can be calculated in LQCD!!




Horgan *et al.* PRL112(2014)212003

Heated discussions at the moment about the high $q^2$

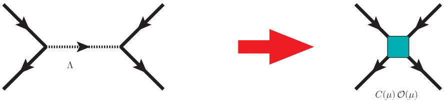
Lyon *et al.*, arXiv:1406.0566

# $SU(2)_L \times U(1)_Y$ and rare $B_q$ decays

R. Alonso, B. Grinstein, JMC, in preparation

# The SM as an EFT

- Assume scale for NPs is at $\Lambda >> v \sim 250$ GeV




- At $E \sim v$ model-independent description of NPs (bottom-up approach)

$$\mathcal{L}_{\rm eft} = \mathcal{L}_{\rm SM} + \sum_i \frac{1}{\Lambda^2} C_i(\mu)\mathcal{O}_i(\mu)$$

Buchmuller *et al.*'86, Grzadkowski *et al.*'10

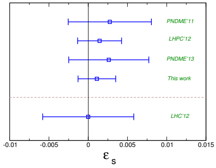
  - $\mathcal{O}_i(\mu)$: $SU(3)_c \times SU(2)_L \times U(1)_Y$-invariant dimension-6 operators built using SM fields
  - $C_i(\mu)$: Wilson coefficients matched at $\Lambda$ with NPs and RGE'd down to $\mu = v$ (Alonso *et al.*'14)

- Same parameterization of NPs at low and high energies:

  e.g. From nuclear and neutron $\beta$-decay

$$\mathcal{L}_{d\to ue\nu} = \mathcal{L}^{\rm SM}_{d\to ue\nu} - \frac{G_F V_{ud}}{\sqrt{2}}\Big[\epsilon_S\ \bar{e}(1-\gamma_5)\nu_e\cdot\bar{u}d - \epsilon_P\bar{e}(1-\gamma_5)\nu_e\cdot\bar{u}\gamma_5 d\Big] + \text{h.c.}$$

Cirigliano *et al.*'09




Gonzalez-Alonso and JMC, PRL112(2014)042501

- Cen Zhang's talk on $t$-quark physics

# Matching $\mathcal{L}_{\rm eft}$ to $\mathcal{H}_W$

- Matching $\mathcal{L}_{\rm eft}$ (Grzadkowski *et al.*'10) to $\mathcal{H}_W$ at $\mu = M_W$ and integrate $W^\pm$, $Z^0$, $h$ out
  - For dipole operators:

$$C_7^{(\prime)} = \frac{8\pi^2}{e y_b \lambda_{ts}} \frac{v^2}{\Lambda^2} \left( c_W C_{dB}^{(\prime)} - s_W C_{dW}^{(\prime)} \right) ,$$

  - For the current-current type of leptonic operators:

$$\begin{aligned}
C_9 &= \frac{4\pi^2}{e^2 \lambda_{ts}} \frac{v^2}{\Lambda^2} \left( C_{qe} + C_{\ell q}^{(1)} - C_{\ell q}^{(3)} - (1 - 4 s_W^2)(C_{Hq}^{(1)} + C_{Hq}^{(3)}) \right) , \\
C_{10} &= \frac{4\pi^2}{e^2 \lambda_{ts}} \frac{v^2}{\Lambda^2} \left( C_{qe} - C_{\ell q}^{(1)} + C_{\ell q}^{(3)} + (C_{Hq}^{(1)} + C_{Hq}^{(3)}) \right) , \\
C_9' &= \frac{4\pi^2}{e^2 \lambda_{ts}} \frac{v^2}{\Lambda^2} \left( C_{ed} + C_{\ell d} - (1 - 4 s_W^2) C_{Hd} \right) , \\
C_{10}' &= \frac{4\pi^2}{e^2 \lambda_{ts}} \frac{v^2}{\Lambda^2} \left( C_{ed} - C_{\ell d} + C_{Hd} \right) .
\end{aligned}$$

- Very rich phenomenological structure but not obvious simplification

# Matching $\mathcal{L}_{\rm eft}$ to $\mathcal{H}_W$

- Matching $\mathcal{L}_{\rm eft}$ (Grzadkowski *et al.*'10) to $\mathcal{H}_W$ at $\mu = M_W$ and integrate $W^\pm$, $Z^0$, $h$ out
  - For the (new-physics) scalar and tensor operators in $\mathcal{H}_W$ ($SU(3)_c \times U(1)_{\rm e.m.}$)

$$\mathcal{O}_S^{(\prime)} = \frac{e^2}{(4\pi)^2}[\bar{s}P_{R(L)}b][\bar{l}l], \qquad \mathcal{O}_P^{(\prime)} = \frac{e^2}{(4\pi)^2}[\bar{s}P_{R(L)}b][\bar{l}\gamma_5 l],$$

$$\mathcal{O}_T = \frac{e^2}{(4\pi)^2}[\bar{s}\sigma_{\mu\nu}b][\bar{l}\sigma^{\mu\nu}l], \qquad \mathcal{O}_{T5} = \frac{e^2}{(4\pi)^2}[\bar{s}\sigma_{\mu\nu}b][\bar{l}\sigma^{\mu\nu}\gamma_5 l].$$

  - imposing e.w. gauge symmetry at $\mu = M_W$ we obtain

$$C_S^l = -C_P^l = \frac{4\pi^2}{e^2\lambda_{ts}}\frac{v^2}{\Lambda^2}C_{\ell edq},$$

$$C_S^{l\prime} = C_P^{l\prime} = \frac{4\pi^2}{e^2\lambda_{ts}}\frac{v^2}{\Lambda^2}C'_{\ell edq},$$

$$C_T = C_{T5} = 0,$$

## LO constraints

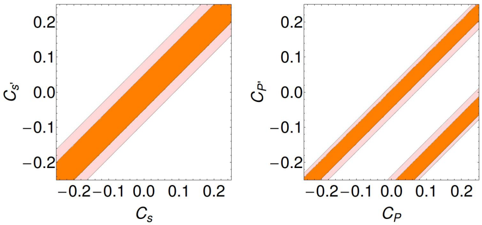
- From **4** scalar operators to only **2**!
- From **2** tensor operators to **none**!

# Phenomenological consequences $B_q \to \ell\ell$

$$\overline{R}_{ql} = \frac{\overline{\mathcal{B}}_{ql}}{\left(\overline{\mathcal{B}}_{ql}\right)_{\rm SM}} = \frac{1 + \mathcal{A}^{ll}_{\Delta\Gamma}\, y_q}{1 + y_q}\left(|S|^2 + |P|^2\right),$$

Steinhauser's talk, De Bruyn *et al.* 109 (2012) 041801

$$S = \sqrt{1 - \frac{4m_l^2}{m_{B_q}^2}}\frac{m_{B_q}^2}{2m_l}\frac{C_S - C_S'}{(m_b + m_q)C_{10}^{\rm SM}}, \qquad P = \frac{C_{10} - C_{10}'}{C_{10}^{\rm SM}} + \frac{m_{B_q}^2}{2m_l}\frac{C_P - C_P'}{(m_b + m_q)C_{10}^{\rm SM}}$$




Data: CMS-PAS-BPH-13-007,LHCb-CONF-2013. Theory: Bobeth *et al.* PRL112(2014)101801

- $B_q \to \ell\ell$ blind to the orthogonal combinations $C_S + C_S'$ and $C_P + C_P'$
  Scalar operators unconstrained!

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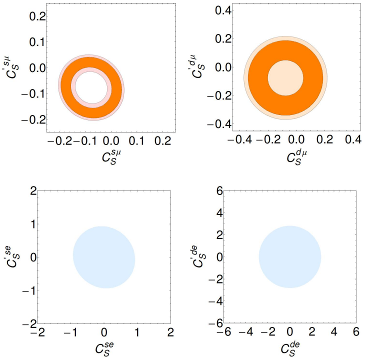



- Radius governed by

$$R = |r_{ql}|\sqrt{\overline{R}_{ql}^{\rm expt}}$$

with $$r_{ql} = \frac{2m_l\,(m_b + m_s)C_{10}^{SM}}{m_{B_q}^2}.$$

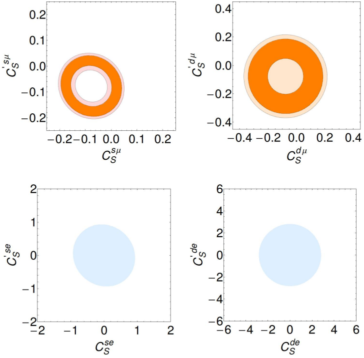
  - $\mu$-mode: Degeneracy radius $R_{min} \sim 0.08$
  - $e$-mode: Degeneracy radius $R_{min} \sim 10^{-3}$

# Phenomenological consequences $B_q \to \ell\ell$

- $\Lambda$ Scale of new physics assuming natural wilson coefficients from $\mathcal{L}_{\rm eft}$ (95%C.L.)

| Channels | $s\mu$ | $d\mu$ | $se$ | $de$ |
|---|---|---|---|---|
| $C_S^{(\prime)}(m_W)$ | 0.1 | 0.15 | 0.6 | 1.5 |
| $\Lambda$ [TeV] | 79 | 130 | 36 | 49 |

- RGE of QCD+EW+Yukawas (Alonso *et al.*'14) has been applied

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# Phenomenological consequences: $B \to K\ell\ell$

$$F_T = \frac{2\sqrt{\lambda}\,\beta_l}{M_B + M_K}\,\frac{f_T(q^2)}{f_+(q^2)}\,C_T^l\,, \qquad F_{T5} = \frac{2\sqrt{\lambda}\,\beta_l}{M_B+M_K}\,\frac{f_T(q^2)}{f_+(q^2)}\,C_{T5}^l,$$

Bobeth *et al.*, JHEP 0712 (2007) 040

- Absence of tensor Wilson coefficients simplifies analyses
- $B \to K\ell\ell$ sensitive to $C_S + C_S'$ and $C_P + C_P'$
  - Scalar contributions to the decay rate are unconstrained
  - Using constraints they are already constrained from $B_q \to \ell\ell$
- Let's take the ratio

$$R_K \equiv \frac{\mathrm{Br}\left(B^+ \to K^+\mu^+\mu^-\right)}{\mathrm{Br}\left(B^+ \to K^+e^+e^-\right)} = 0.745^{+0.090}_{-0.074}(\mathrm{stat}) \pm 0.036(\mathrm{syst})$$

arXiv:1406.6482

  - In the SM we have $R_K = 1.0003(1)$
  - At 95% C.L. the scalar operators can only account for

$$R_K \in [0.982, 1.007]$$

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**The effect should come from $\mathcal{O}_{9,10}^{(\prime)}$**

E.g. For $\delta C_9^{\mu} = -1$ $\delta C_9^e = 0$ we obtain $R_K \simeq 0.79$

# Conclusions

- **$B \to K^* \ell\ell$ decay is a very rich probe of $b \to s$ FCNCs**
- There is a $\sim$4-$\sigma$ tension between 1 fb$^{-1}$ data and some SM predictions
  - New physics mechanisms invoquing $C_9$ can solve the anomaly
- We adopt the $R$-fit philosophy for the treatment of hadronic uncertainties
  - Our **predictions** reasonably agree with the SM
  - Alternative explanation within the SM in terms of power corrections
- **How do we make progress?**
  - More data (2 fb$^{-1}$ on tape) and more finely binned!
  - Better knowledge on power corrections LCSRs or within EFT?
- There are the Super-clean observables to access $C_7'$
- **$SU(2)_L \times U(1)_Y$ constraints on $b \to s(d)\ell^+\ell^-$**
- Benchmark to parameterise new physics in rare $b \to s(d)$ decays
- Same parameterisation of low and high energy new physics
- Important consequences in pheno.

# Obtention of error bands and comparison

- A standard method for modelling power corrections

  Egede *et al.* JHEP 1010 (2010) 056

  Introduce a scale factor $\zeta_i$ per amplitude, e.g.

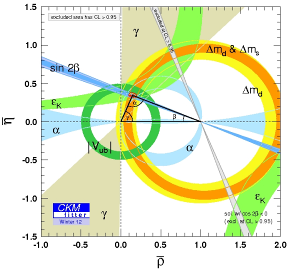
$$H_V(\lambda) \mapsto \zeta_{i,\lambda}\left\{C_9\,\tilde{V}_{L\lambda} - \frac{m_B^2}{q^2}\left[\frac{2\,\hat{m}_b}{m_B}C_{7\gamma}\,\tilde{T}_{L\lambda} - 16\pi^2 h_\lambda\right]\right\}$$

- Run a Montecarlo over $\zeta_i$ and other uncertainties and quote 67% interval (th. 1-$\sigma$)
- Add $\sigma_{\rm th}$ and $\sigma_{\rm expt}$ in quadratures and perform conventional $\chi^2$ analysis

**Two possible issues**

1. $\zeta_i$ can miss interference between power corrections in FFs or $h_\lambda$
2. Is the treatment of theoretical error as experimental adequate?

# Obtention of error bands and comparison




**We use the *R*fit method**

Method employed by **CKMfitter** for treating hadronic uncertainties

Höcker *et al.* EPJC21(2001)225

$$\chi^2(\vec{y}_{\rm ew},\vec{y}_{\rm QCD}) = \left(\frac{x_{{\rm exp},i} - x_{{\rm th},i}(\vec{y}_{\rm ew},\vec{y}_{\rm QCD})}{\sigma_{\rm exp}}\right)^2, \quad \text{if} \quad y_{QCD,i} \in [\bar{y}_i - \sigma_i, \bar{y}_i + \sigma_i] \quad \forall i$$

$$\chi^2(\vec{y}_{\rm ew},\vec{y}_{\rm QCD}) = \infty, \quad \text{otherwise}$$

- Minimize $\chi^2$ scanning $\vec{y}_{\rm QCD}$ by Montecarlo using flat PDFs
- **Our error intervals:** maximum spread of results resulting from Montecarlos