Rare B decays: The Terminator for New Physics?

Joaquim Matias
Universitat Autònoma de Barcelona

In collaboration: S. Descotes, F. Mescia, J. Virto, M. Ramon

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PLAN of the TALK

- I. Methodology to obtain Rare B decay constraints in the space of correlations between Wilson Coefficients.
- II. Angular distribution of $B \to K^*(\to K\pi)l^+l^-$.
- III. Isospin asymmetry of $B \to K^*\mu^+\mu^-$

Pre-LHCb Time (From Tim)

- $B \to \tau\nu$ & CKM fit (BaBar & Belle)
- $B_s \to \mu^+\mu^-$ (CDF excess)
- ϕ_s (CDF and D0 hints of large value)
- A_{fs} (D0 evidence)
- $A_{CP}(B \to K\pi)$ puzzle (BaBar and Belle)
- $A_{FB}(B \to K^*\mu^+\mu^-)$ (BaBar, Belle & CDF hints)
- $A_I(B \to K^{(*)}\mu^+\mu^-)$ (BaBar, Belle & CDF hints)

Post-Moriond 2012 Time: LHCb time

- $B \to \tau\nu$ & CKM fit (BaBar & Belle)
- $B_s \to \mu^+\mu^-$ (CDF excess) consistent with SM
- ϕ_s (CDF and D0 hints of large value) consistent with SM
- A_{fs} (D0 evidence)
- $A_{CP}(B \to K\pi)$ puzzle (BaBar and Belle)
- $A_{FB}(B \to K^*\mu^+\mu^-)$ (BaBar, Belle & CDF hints) consistent SM
- $A_I(B \to K^{(*)}\mu^+\mu^-)$ (BaBar, Belle & CDF hints) end of seminar

Conclusion: "New Physics will be extremely subtle"

- Model Building: **The Era of "Order of Magnitude" NP in Flavour (and check only $B \to X_s \gamma$) is gone**
- Flavour Physicists: Redefine **strategies to Focus when possible on Precise and Clean Observables.**

What type of New Physics (by category not by model) to look for?

- isospin violating • right handed currents • new scalars/tensors
- CP violating NP (Wilson coefficients) in decay.

Experimentalists: Where (which processes) to look for?

- penguin dominated (controlled IR div) and specific WC info.
- d/u spectator different processes (isospin) and d/s (U-spin)
- q^2-observables (enhanced kin.): angular distribution
- F_L (less clean, many low values unexplained, interesting)

For Rare B decays: UT $\to$ Wilson Coefficient planes.

Rare decays constraints:

from UT to WC correlations

Rare decays constraints: from UT to WC correlations

Discussion on constraints on WC from radiative and leptonic B decays should be addressed in a given framework, specific scenarios & observables

S. Descotes, D. Ghosh, JM., M. Ramon, hep-ph/1104.3342

- Framework: NP in C_7, C_9, C_{10} and $C_{7'}, C_{9'}, C_{10'}$ [chirally-flipped operators $\gamma_5 \to -\gamma_5$] as a real shift in the Wilson coefficients
- Scenarios (from the more specific to the more general)
  - A : NP in 7,7' only
  - B : NP in 7,7', 9,10 only
  - C : NP in 7,7',9,10,9',10' only
- Classes within a Framework
  - I: observables sensitive only to 7,7'
  - II: observables sensitive only to 7,7',9,9',10,10'
  - III: observables sensitive to 7,7',9,9',10,10' and more

Operator Basis

The effective Hamiltonian describing the $b \to s l^+ l^-$ transition

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} [\mathbf{C_i}(\mu)\mathcal{O}_\mathbf{i}(\mu) + \mathbf{C'_i}(\mu)\mathcal{O}'_\mathbf{i}(\mu)],$$

$\mathbf{C}_\mathbf{i}^{(\prime)}(\mu)$ are Wilson coefficients and $\mathcal{O}_\mathbf{i}^{(\prime)}(\mu)$ are local operators.

We concentrate on *Electromagnetic dipole+ semileptonic operators:*

$$\mathcal{O}_\mathbf{7} = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu}, \quad \mathcal{O}_\mathbf{9} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l),$$
$$\mathcal{O}_\mathbf{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l),$$

where $P_{L,R} = (1 \mp \gamma_5)/2$ and **primed counterpart operators**

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Observables

Limited sensitivity to hadronic inputs, or strong impact on analysis

- Class-I
  - $\mathcal{B}(B \to X_s\gamma)$ with $E_\gamma > 1.6\,\mathrm{GeV}$ [Misiak, Steinhauser, Haisch]
  - exclusive time-dependent CP asymmetry $S_{K^*\gamma}$
  - isospin asymmetry $A_I(B \to K^*\gamma)$ [Beneke, Feldman, Seidel] [Kagan, Neubert, Feldman, J.M.]
- Class-II
  - Integrated transverse asym. $\tilde{A}_{\mathrm{T}}^2$ in $B \to K^* l^+ l^-$ over low-q^2 region [Kruger and J.M.]
- Class-III
  - $\mathcal{B}(B \to X_s l^+ l^-)$ [Bobeth et al., Huber, Lunghi et al.]
  - Integrated $\tilde{F}_{\mathrm{L}}$ and $\tilde{A}_{\mathrm{FB}}$ in $B \to K^* l^+ l^-$ [1-6 GeV^2] [Beneke, Feldman]

For each observable

- Simple numerical parametrisation as $\delta C_i = C_i(\mu_b) - C_i^{SM}(\mu_b)$
- More statistically significant treatment of constraints.
- Uncertainties ΔX_{th} from SM analysis.

Class-I observables: inclusive $\mathcal{B}(\bar{B} \to X_s\gamma)$

Class-I : only depending on $C_7, C_{7'}$, related to radiative decays
[Misiak, Gambino, Steinhauser. . .]

$$\begin{aligned}
\mathcal{B}(\bar{B} \to X_s\gamma)^{exp}_{E_\gamma>1.6\,\mathrm{GeV}} &= (3.55 \pm 0.24 \pm 0.09) \times 10^{-4} \\
\mathcal{B}(\bar{B} \to X_s\gamma)^{th}_{E_\gamma>1.6\,\mathrm{GeV}} &= \Big[a_{(0,0)} + a_{(7,7)}\left[(\delta C_7)^2 + (\delta C_{7'})^2\right] + \\
&\quad + a_{(0,7)}\,\delta C_7 + a_{(0,7')}\,\delta C_{7'}\Big] \times 10^{-4} \\
\mathcal{B}(\bar{B} \to X_s\gamma)^{SM}_{E_\gamma>1.6\,\mathrm{GeV}} &= (3.15 \pm 0.23) \times 10^{-4}
\end{aligned}$$

- SM value $[a_{(0,0)}]$ expressed as

$$\mathcal{B}(B \to X_s\gamma)^{SM}_{E_\gamma>E_0} = \mathcal{B}(B \to X_c e\bar{\nu}) \left|\frac{V^*_{ts}V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{\mathrm{em}}}{\pi}[P(E_0)+N(E_0)]$$

$$P(E_0) = \sum_{i,j=1\ldots 8} C_i^{\mathrm{eff}}(\mu)C_j^{\mathrm{eff}*}(\mu)K_{ij}(E_0,\mu)$$

- numerical a's reproducing [Misiak, Steinhauser, Haisch]

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Class-I observables: isospin asymmetry in $B \to K^*\gamma$

$$A_I(B \to K^*\gamma) = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

- NLO QCDF: isospin asymmetry from nonfactorisable contributions: spectator quark emits the photon
- thus no change once chirally-flipped operators included, apart from normalisation to isospin-averaged branching ratio
- Strong discriminator of the sign of C_7 [Descotes, D. Ghosh, JM, M. Ramon 2011]. Excellent agreement SM-experiment

$$\begin{aligned} A_I(B \to K^*\gamma)^{exp} &= 0.052 \pm 0.026 \\ A_I(B \to K^*\gamma)^{th} &= c \times \frac{\sum_k d_k(\delta C_7)^k}{\sum_{k,l} e_{k,l}(\delta C_7)^k(\delta C_{7'})^l} \pm \delta c\,. \\ A_I(B \to K^*\gamma)^{SM} &= 0.041 \pm 0.025\,(\mathrm{updates\ Feldman\&JM'03}) \end{aligned}$$

- c, d, e determined numerically.

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Class-I observables: $B \to K^*\gamma$ CP-asymmetry

[Beneke Feldmann Seidel, Ball and Zwicky]

$$\frac{\Gamma(\bar{B}^0(t)\to\bar{K}^{*0}\gamma)-\Gamma(B^0(t)\to K^{*0}\gamma)}{\Gamma(\bar{B}^0(t)\to\bar{K}^{*0}\gamma)+\Gamma(B^0(t)\to K^{*0}\gamma)} = S_{K^*\gamma}\sin(\Delta m_B t) - C_{K^*\gamma}\cos(\Delta m_B t)$$

- Probe of photon helicity

$$S_{K^*\gamma} = \frac{2\,\mathrm{Im}\left[e^{-2i\beta}\left(\mathcal{A}_L^*\bar{\mathcal{A}}_L + \mathcal{A}_R^*\bar{\mathcal{A}}_R\right)\right]}{|\mathcal{A}_L|^2 + |\mathcal{A}_R|^2 + |\bar{\mathcal{A}}_L|^2 + |\bar{\mathcal{A}}_R|^2}$$

- Computed at NLO in QCD factorisation. At LO,

$$S_{K^*\gamma}^{(\mathrm{LO})} = \frac{-2\left|C_{7'}/C_7\right|}{1+\left|C_{7'}/C_7\right|^2}\sin\left(2\beta - \arg\left(C_7 C_{7'}\right)\right)$$

[Grinstein et al, Bobeth et al]

$$S_{K^*\gamma}^{\mathrm{exp}} = -0.16 \pm 0.22(\mathrm{HFAG})$$

$$S_{K^*\gamma} = f\,{}^{+\delta_f^u}_{-\delta_f^d} + \frac{\sum_{k,l} g_{k,l}(\delta C_7)^k(\delta C_{7\prime})^l}{\sum_{k,l} h_{k,l}(\delta C_7)^k(\delta C_{7\prime})^l}$$

$$S_{K^*\gamma}^{SM} = -0.03 \pm 0.01$$

- f, g, h fitting coefficients

Class-I observables: $B \to K^*\gamma$ CP-asymmetry

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$$\frac{\Gamma(\bar{B}^0(t)\to\bar{K}^{*0}\gamma)-\Gamma(B^0(t)\to K^{*0}\gamma)}{\Gamma(\bar{B}^0(t)\to\bar{K}^{*0}\gamma)+\Gamma(B^0(t)\to K^{*0}\gamma)} = S_{K^*\gamma}\sin(\Delta m_B t) - C_{K^*\gamma}\cos(\Delta m_B t)$$

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Class-II observables: A_T^2 asymmetry

Class-II : depending only on dipole and semileptonic operators

$B \to K^* \ell^+ \ell^-$ asymmetry $A_T^2(q^2) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$, [Kruger and J.M.]

- $A_\perp$ and $A_\parallel$ depend only on $C_{7,7',9,9',10,10'}$ (no tensors/scalars)
- strong potential to discriminate inside C_7' allowed space.

At low q^2, at NLO QCD factorisation $A_T^2(q^2) = A_{\mathrm{T}}^{(2),\,CV}(q^2)^{+\delta_u(q^2)}_{-\delta_d(q^2)}$
with fitting q^2-polynomials for errors δ_u, δ_d and central value

$$A_T^{(2),\,CV}(q^2) = \frac{\sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} k(q^2) F_{(i,j)}(q^2) \delta C_i \delta C_j}{\sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} k(q^2) G_{(i,j)}(q^2) \delta C_i \delta C_j}$$

[$\delta C_0 = 1$ to deal with constant, linear and quadratic terms]

Longer list of new clean class-II observables P_i in part II...

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Longer list of new clean class-II observables P_i in part II...

Class-III observables: $\bar{B} \to X_s \mu^+ \mu^-$

Class-III: depending on dipole and semileptonic operators, but also others (scalar, tensors) $\Longrightarrow$ most of semileptonic observables

- $\bar{B} \to X_s \mu^+ \mu^-$ at low q^2 [1-6 GeV^2]

$$\mathcal{B}(\bar{B} \to X_s \mu^+ \mu^-)^{exp} = (1.60 \pm 0.50) \times 10^{-6}$$
$$\mathcal{B}(B \to X_s \mu^+ \mu^-) = 10^{-7} \times \sum_{i,j=0,7,7',9,9',10,10'} b_{(i,j)} \delta C_i \delta C_j$$
$$\mathcal{B}(\bar{B} \to X_s \mu^+ \mu^-)^{SM} = (1.59 \pm 0.15) \times 10^{-6}$$

  - $\delta C_7, \delta C_9, \delta C_{10}$-only contributions known up to NNLO including e.m. corrections [Bobeth et al, Huber et al]
  - $\delta C_{7'}, \delta C_{9'}, \delta C_{10'}$-only contributions with similar structure $(\gamma_5 \to -\gamma_5)$
  - crossed terms (primed-unprimed) only at LO in α_s, and are suppressed by m_s/m_b [Guetta Nardi]
  - b coefficients determined numerically agreeing with [Huber et al]

Class-III observables: $\tilde{A}_{\mathrm{F}B}$ and $\tilde{F}_L$

$$A_{\mathrm{FB}} = \left(\int_0^1 d(\cos\theta_l)\frac{d^2\Gamma}{dq^2 d\cos\theta_l} - \int_{-1}^0 \dots\right) / \frac{d\Gamma}{dq^2} \qquad F_{\mathrm{L}} = |A_0|^2 / \frac{d\Gamma}{dq^2}$$

The average forward-backward asymmetry $\tilde{A}_{\mathrm{F}B}$ (same for $\tilde{F}_L$) is

$$\tilde{A}_{FB} = \int_{1GeV^2}^{6GeV^2} \frac{d\Gamma}{dq^2} A_{\mathrm{FB}}(q^2) dq^2 / \int_{1GeV^2}^{6GeV^2} \frac{d\Gamma}{dq^2}$$

$$\tilde{A}_{FB} = \frac{\int_{1\mathrm{GeV}^2}^{6\mathrm{GeV}^2} \sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} k(q^2) H_{(i,j)}(q^2) \delta C_i \delta C_j dq^2}{\int_{1\mathrm{GeV}^2}^{6\mathrm{GeV}^2} \sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} k(q^2) I_{(i,j)}(q^2) \delta C_i \delta C_j dq^2} {}^{+\tilde{\delta}_u}_{-\tilde{\delta}_d}$$

computed at NLO in QCD factorisation with fitting q^2-polynomials for central value and errors (same for $\tilde{F}_L$)

$$\tilde{A}_{FB}^{SM} = -0.049 \pm 0.046 \qquad \tilde{F}_L^{SM} = 0.721 \pm 0.043$$

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Standard Model values

In the SM, NNLO in MS-bar including electromagnetic corrections [Chetyrkin, Misiak and Münz, Bobeth et al., Huber et al.]

$C_1(\mu_b)$	$C_2(\mu_b)$	$C_3(\mu_b)$	$C_4(\mu_b)$	$C_5(\mu_b)$
-0.263	1.011	-0.006	-0.081	0.000
$C_6(\mu_b)$	$C_7^{\mathrm{eff}}(\mu_b)$	$C_8^{\mathrm{eff}}(\mu_b)$	$C_9(\mu_b)$	$C_{10}(\mu_b)$
0.001	-0.292	-0.166	4.075	-4.308

- High-scale $\mu_0 = 2M_W$ [uncertainty: varied from M_W to $4M_W$]
- Low-scale $\mu_b = 4.8$ GeV [uncertainty: varied from 2.4 to 9.6 GeV]

For the chirally-flipped operators, we have the SM values

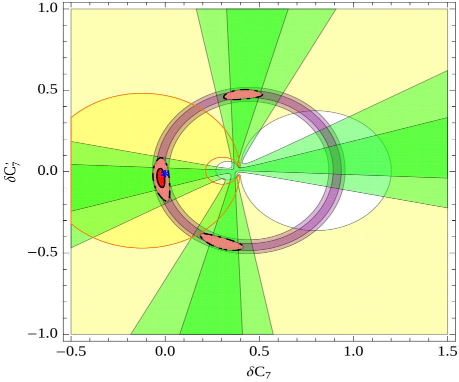
$$C_{7'}^{SM} = \frac{m_s}{m_b} C_7^{SM}, \qquad C_{9',10'}^{SM} = 0$$

Exploring New Physics Constraints

on $C_i^{(\prime)}$:

Scenario A, B and C

$\delta C_7 - \delta C_{7'}$ plane : constraints at 1 and 2 σ



Class I observables (only $O_{7,7'}$)
dark 1σ, light 2σ

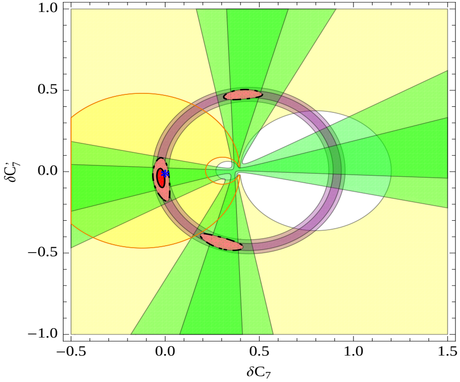
- A_I (yellow)
- $B(B \to X_s\gamma)$ (purple)
- $S_{K^*\gamma}$ (green)

Overlap regions (red dark and light)

- SM region at 1σ solid black countour red dark $(C_7, C_{7'}) \sim (C_7^{SM}, 0)$.
- two non-SM solutions also allowed at 2σ $(C_7, C_{7'}) \simeq (0, \pm 0.4)$ (dashed)

- A_I disfavours flipped-sign solution $(C_7, C_{7'}) = (-C_7^{SM}, 0)$ $\Longrightarrow$Same conclusion as [Gambino, Haisch, Misiak], without using Class-III $B \to X_s \ell^+ \ell^-$
- Flipped sign solution disfavored in Scenario A by $> 2\sigma$.

$\delta C_7 - \delta C_{7'}$ plane : constraints at 1 and 2 σ



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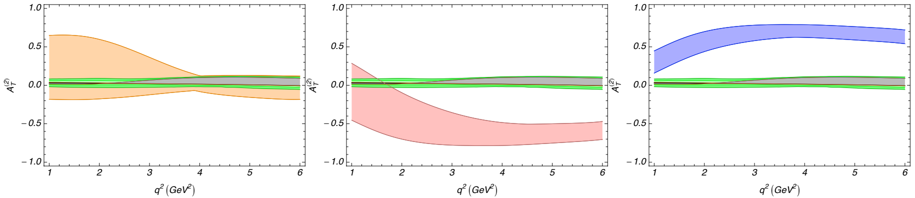
Scenario A ($C_{7,7'}$): prediction for class-II observable A_T^2

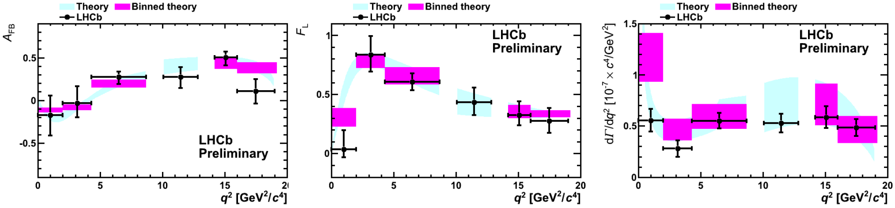


- Mapping of the three black allowed regions under Scenario A ($C_7, C_{7'}$) into A_T^2 only restricted by class-I observables: $B \to X_s\gamma$, A_I, $S_{K^*\gamma}$.
- $A_T^2(q^2)$ for $q^2 = 1\ldots6$ GeV^2 has different shapes for the three regions in ($C_7, C_{7'}$)
  - $(\delta C_7, \delta C_{7'}) \simeq (0,0)$ (left)
  - $(\delta C_7, \delta C_{7'}) \simeq (0.3,-0.4)$ (center)
  - $(\delta C_7, \delta C_{7'}) \simeq (0.3,0.4)$ (right)

Notice that for the two non-SM regions $C_7 \sim 0$. In this case (opposite to $C_7 \sim C_7^{SM}$ case) positive A_T^2 is for $C_7' > 0$ and negative for $C_7' < 0$.

LHCb results EPS11 $\rightarrow$ LHCb Moriond

At EPS11, new results from LHCb on $B_s \to \mu\mu$ and $B \to K^*\ell\ell$



A_{FB} F_L $d\Gamma/dq^2$

Including LHCb in the world average

$$\tilde{A}_{FB} = 0.33^{+0.22}_{-0.24} \to 0.04 \pm 0.12 \to -0.130^{+0.068}_{-0.078}$$

$$\tilde{F}_L = 0.60^{+0.18}_{-0.19} \to 0.60 \pm 0.09 \to 0.622^{+0.059}_{-0.057}$$

What is the impact of LHCb results alone from F_L and A_{FB} ?

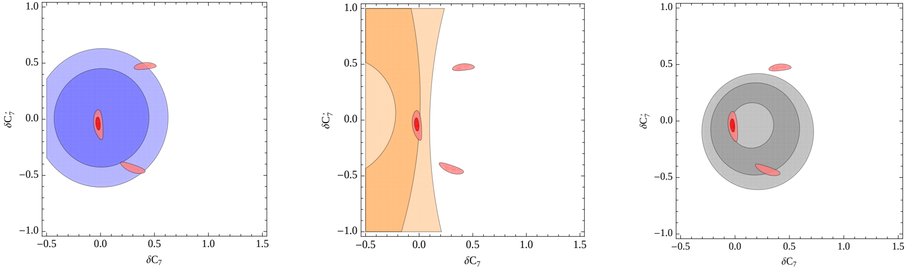
- Still same constraints on $C_7, C_{7'}$ from $b \to s\gamma$
- Different impact for Scenarios A and B

Scenario A ($C_{7,7'}$) : class-III observables (Moriond12) 1-2 σ

Scenario A:

$\Longrightarrow$class-III observables constrain further the shifts $\delta C_7, \delta C_{7'}$

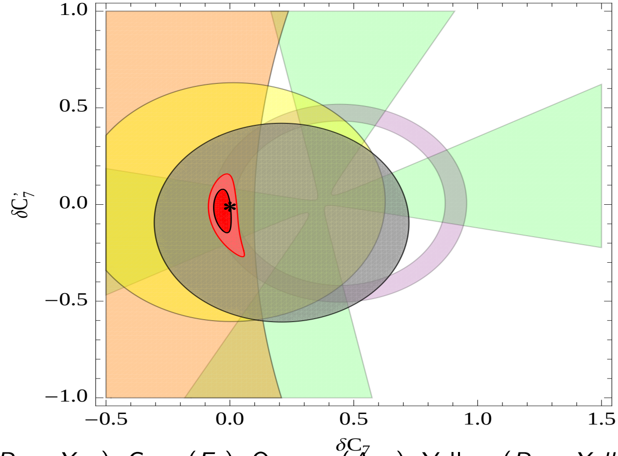
Correlations in $(\delta C_7, \delta C_{7'})$ plane:



$B(B \to X_s \mu^+ \mu^-)$ $\tilde{A}_{FB}$ $\tilde{F}_L$

- $B(B \to X_s \mu^+ \mu^-)$ favors SM-like region (at 1σ) and non-SM regions (at 2σ). All three disfavors flipped sign solution at more than 2 σ.
- $\tilde{A}_{FB}$ selects SM region and $\tilde{F}_L$ favours SM region and the lower non-SM region.

Scenario A: Combined constrain from class I & III observables

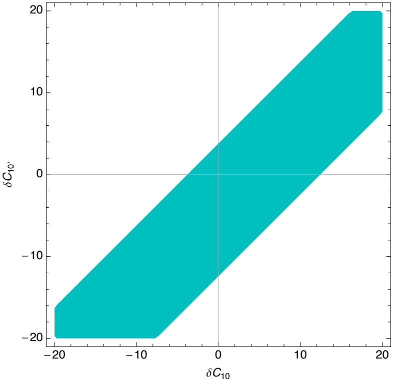


Purple ($B \to X_s\gamma$), Grey (F_L), Orange (A_{FB}), Yellow ($B \to X_s ll$), Green ($S_{K*\gamma}$). All constraints shown here at 2 sigma. Good agreement of all observables with SM region at 1σ. No non-SM region allowed at $< 2\ \sigma$.

Constraint on $C_{10}, C_{10'}$ from $B_s \to \mu^+\mu^-$

$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{16\pi^3} f_{B_s}^2 m_{B_s}\tau_{B_s}|V_{tb}V_{ts}^*|^2 m_\mu^2 \sqrt{1-\frac{4m_\mu^2}{m_{B_s}^2}}|C_{10}-C_{10'}|^2$$

$(\delta C_{10}, \delta C'_{10})$



Using our inputs, we get

$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)^{\rm SM} = (3.44\pm0.32)\cdot 10^{-9}$$

one order of magnitude smaller than 90% CL LHCb exp bound

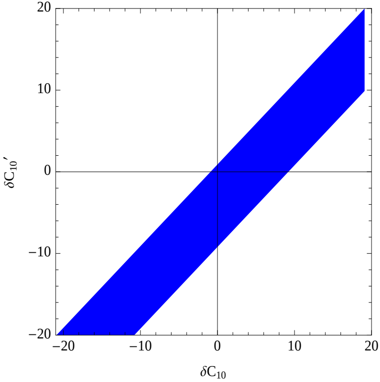
$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)^{\rm exp} < 1.2\cdot 10^{-8}.$$

leading to weak constraints on C_{10} (Scenario B) and $C_{10'}$ (Scenario C)

Constraint on $C_{10}, C_{10'}$ from $B_s \to \mu^+\mu^-$

$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{16\pi^3} f_{B_s}^2 m_{B_s} \tau_{B_s} |V_{tb}V_{ts}^*|^2 m_\mu^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} |C_{10} - C_{10'}|^2$$

$(\delta C_{10}, \delta C'_{10})$



Using our inputs ($f_{Bs} = 227.7\text{MeV}$)

$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)^{\rm SM} = (3.2 \pm 0.3) \cdot 10^{-9}$$

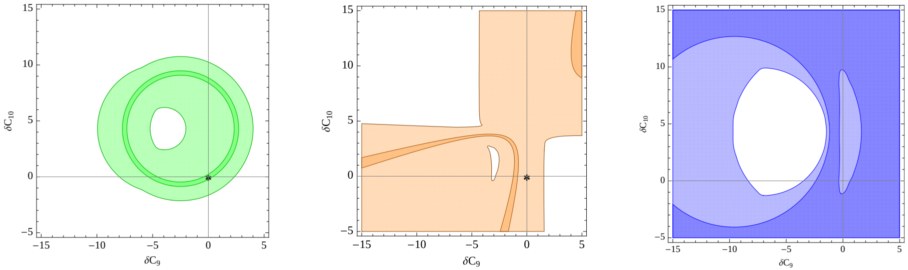
near one order of magnitude smaller than previous exp bound

$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)^{\rm exp} < 4.5 \cdot 10^{-9}.$$

leading to strong constraints on C_{10} (Scenario B) and $C_{10'}$ (Scenario C)

In Scenario B, NP in

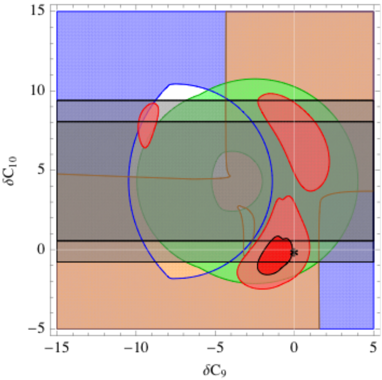
- $C_7, C_{7'}$: same constraints/plot as before from class-I obs., but NOW three red regions allowed at 2 σ (class-III does no cut)
- Correlation $\delta C_9, \delta C_{10}$: to be fixed from class-III observables:



B($B \to X_s \mu^+ \mu^-$) $\tilde{A}_{FB}$ $\tilde{F}_L$

- Small absolute values of (C_9, C_{10}) disfavoured by $\tilde{F}_L$.

Scenario B: overlap in $\delta C_9 - \delta C_{10}$ plane



- $\mathcal{B}(B \to X_s \mu^+ \mu^-)$ (green)
- $A_{\rm FB}$ (orange)
- $F_{\rm L}$ (blue)

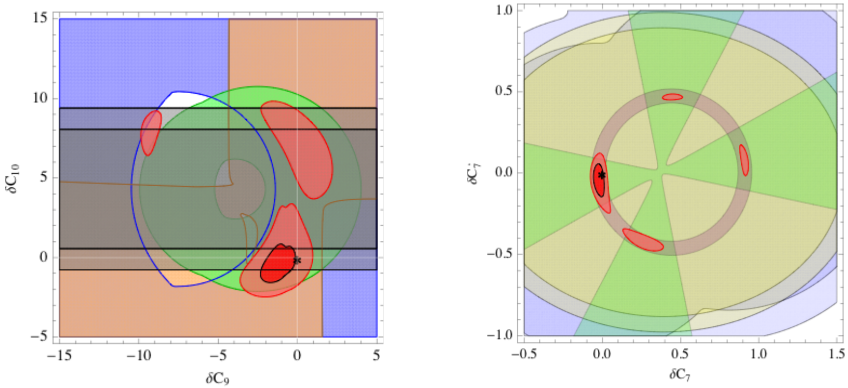
Two overlapped region (red)

- SM region around $(\delta C_9, \delta C_{10}) = (0, 0)$
- non-SM region $(C_9, C_{10}) \simeq (C_9^{SM}, -C_{10}^{SM})$

$\Longrightarrow$Scenario B NP may alter (C_7, C_7') but also (C_9, C_{10}) from their SM values to get a tiny improvement with data and reproduce the experimental values. Non-SM regions allowed at 2 sigma.

$\Longrightarrow \mathrm{BR}(B_s \to \mu^+ \mu^-)$ cuts further in the allowed region.

Scenario B: overlap in $\delta C_9 - \delta C_{10}$ plane



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Angular distribution of $B \to K^*(\to K\pi)l^+l^-$:

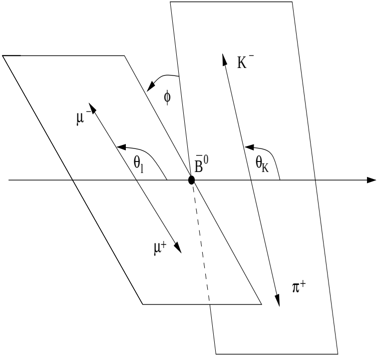
RH currents/new scalars/CPV in WC

Differential decay distributions

The decay $\mathbf{\bar{B}_d} \to \mathbf{\bar{K}^{*0}}(\to \mathbf{K}^-\pi^+)\mathbf{l}^+\mathbf{l}^-$ with the K^{*0} on the mass shell is described by s and three angles $\theta_\mathbf{l}$, $\theta_\mathbf{K}$ and ϕ

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

- $q^2 = s$ square of the lepton-pair invariant mass.
- θ_l angle between $\vec{p_{l^-}}$ in l^+l^- rest frame and dilepton's direction in rest frame of $\bar{B}_d$
- θ_K angle between $\vec{p_{K^-}}$ in the $\bar{K}^{*0}$ rest frame and direction of the $\bar{K}^{*0}$ in rest frame of $\bar{B}_d$
- ϕ angle between the planes defined by the two leptons and the $K - \pi$ planes.



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The differential distribution splits in J_i coefficients:

$$J(q^2, \theta_l, \theta_K, \phi) =$$
$$J_{1s}\sin^2\theta_K + J_{1c}\cos^2\theta_K + (J_{2s}\sin^2\theta_K + J_{2c}\cos^2\theta_K)\cos 2\theta_l + J_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+ J_4\sin 2\theta_K\sin 2\theta_l\cos\phi + J_5\sin 2\theta_K\sin\theta_l\cos\phi + (J_{6s}\sin^2\theta_K + J_{6c}\cos^2\theta_K)\cos\theta_l$$
$$+ J_7\sin 2\theta_K\sin\theta_l\sin\phi + J_8\sin 2\theta_K\sin 2\theta_l\sin\phi + J_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\,.$$

The information on

- the helicity/transversity amplitudes of the K^* ($H_{\pm 1,0}$ or $A_{\perp,\|,0}$) is inside the coefficients J_i.
- short distance physics C_i is encoded in ($H_{\pm 1,0}$ or $A_{\perp,\|,0}$)

$$J_{1s} = \frac{(2+\beta_\ell^2)}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L\to R)\right] + \frac{4m_\ell^2}{q^2}\mathrm{Re}\left(A_\perp^L A_\perp^{R\,*} + A_\parallel^L A_\parallel^{R*}\right),$$

$$J_{1c} = |A_0^L|^2 + |A_0^R|^2 + \frac{4m_\ell^2}{q^2}\left[|A_t|^2 + 2\mathrm{Re}(A_0^L A_0^{R*})\right] + \beta_\ell^2|A_S|^2,$$

$$J_{2s} = \frac{\beta_\ell^2}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L\to R)\right], \quad J_{2c} = -\beta_\ell^2\left[|A_0^L|^2 + (L\to R)\right],$$

$$J_3 = \frac{1}{2}\beta_\ell^2\left[|A_\perp^L|^2 - |A_\parallel^L|^2 + (L\to R)\right], \quad J_4 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Re}(A_0^L A_\parallel^{L\,*}) + (L\to R)\right],$$

$$J_5 = \sqrt{2}\beta_\ell\left[\mathrm{Re}(A_0^L A_\perp^{L\,*}) - (L\to R) - \frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}(A_\parallel^L A_S^* + A_\parallel^R A_S^*)\right],$$

$$J_{6s} = 2\beta_\ell\left[\mathrm{Re}(A_\parallel^L A_\perp^{L\,*}) - (L\to R)\right], \quad J_{6c} = 4\beta_\ell\frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}\left[A_0^L A_S^* + (L\to R)\right],$$

$$J_7 = \sqrt{2}\beta_\ell\left[\mathrm{Im}(A_0^L A_\parallel^{L*}) - (L\to R) + \frac{m_\ell}{\sqrt{q^2}}\mathrm{Im}(A_\perp^L A_S^* + A_\perp^R A_S^*)\right],$$

$$J_8 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Im}(A_0^L A_\perp^{L\,*}) + (L\to R)\right], \quad J_9 = \beta_\ell^2\left[\mathrm{Im}(A_\parallel^{L\,*} A_\perp^L) + (L\to R)\right]$$

SCALARS: We have 8 complex amplitudes ($A_{\perp,||,0,(L,R)S,t}$) and 12 experimental inputs
NO SCALARS: We have 7 complex amplitudes ($A_{\perp,||,0,(L,R)}, t$) and 11 experimental inputs

ZOO of observables in the market:

Observables strongly sensitive to hadronic soft form factors (**SFFD**):

$\mathbf{A_{FB}}$ (forward-backward asymmetry), $\mathbf{F_L}$ (longitudinal polarization fraction), $\mathbf{A_{im}}$ (Egede et al. 2008), $\frac{d\Gamma}{dq^2}$, $\mathbf{J_i}$, $\mathbf{S_i}$ and $\mathbf{A_i}$ (Altmannshofer et al. 2009).

SFFI observables (at LO soft form factors cancels exactly):

$\mathbf{A_T^2}$ Transverse asymmetry: Krueger-J.M (2005) $\mathbf{A_T^3}$ and $\mathbf{A_T^4}$ Asymmetries with Longitudinal sensitivity: Egede, Hurth, JM, Ramon, Reece (2008) $\mathbf{A_T^5}$ Second Transverse asymmetry: Egede, Hurth, JM, Ramon, Reece (2010) $\mathbf{A_T^{re}}$ related to A_T^5: Becirevic, Schneider (2011) $\mathbf{A_T^{im}}$ related to A^{im}: Becirevic, Schneider (2011)

Can one extract **all** the information from the angular distribution in an **efficient**, systematic and **clean** way?

Define

$$n_\parallel = (A_\parallel^L, A_\parallel^{R*}) \qquad m_1 = (H_{+1}^L, H_{-1}^{R}{}^*)$$

$$n_\perp = (A_\perp^L, -A_\perp^{R*}) \qquad \text{or} \qquad m_2 = (H_{-1}^L, H_{+1}^{R}{}^*)$$

$$n_0 = (A_0^L, A_0^{R*}) \qquad m_3 = (H_0^L, H_0^{R*})$$

Spin amplitudes — Helicity amplitudes

All physical information of the distribution encoded in 3 moduli + 3 relative angles (complex) - 1 constraint (**third relation)**.

$$|n_\parallel|^2 = \frac{2}{3}J_{1s} - J_3\,, \qquad |n_\perp|^2 = \frac{2}{3}J_{1s} + J_3\,, \qquad |n_0|^2 = J_{1c}$$

$$n_\perp^\dagger n_\parallel = \frac{J_{6s}}{2} - iJ_9\,, \qquad n_0^\dagger n_\parallel = \sqrt{2}J_4 - i\frac{J_7}{\sqrt{2}}\,, \qquad n_0^\dagger n_\perp = \frac{J_5}{\sqrt{2}} - i\sqrt{2}J_8$$

Those are the building blocks of any observable (only 8 independent)

Constraint:

$$\left|(n_{\|}^{\dagger}\, n_{\perp})|n_0|^2 - (n_{\|}^{\dagger}\, n_0)(n_0^{\dagger}\, n_{\perp})\right|^2 = (|n_0|^2|n_{\|}|^2 - |n_0^{\dagger}\, n_{\|}|^2)(|n_0|^2|n_{\perp}|^2 - |n_0^{\dagger}\, n_{\perp}|^2)$$

This translates into an experimental test between J_i:

$$-\mathbf{J_{2c}} = 6\frac{(2\mathbf{J_{1s}}+3\mathbf{J_3})\left(4\mathbf{J_4^2}+\mathbf{J_7^2}\right)+(2\mathbf{J_{1s}}-3\mathbf{J_3})\left(\mathbf{J_5^2}+4\mathbf{J_8^2}\right)}{16\mathbf{J_{1s}^2}-9\left(4\mathbf{J_3^2}+\mathbf{J_{6s}^2}+4\mathbf{J_9^2}\right)} - 36\frac{\mathbf{J_{6s}}(\mathbf{J_4}\mathbf{J_5}+\mathbf{J_7}\mathbf{J_8})+\mathbf{J_9}(\mathbf{J_5}\mathbf{J_7}-4\mathbf{J_4}\mathbf{J_8})}{16\mathbf{J_{1s}^2}-9\left(4\mathbf{J_3^2}+\mathbf{J_{6s}^2}+4\mathbf{J_9^2}\right)} \equiv \mathbf{f}$$

A second way of showing this is to count degrees of freedom and symmetries of the distribution.

Counting d.o.f. : Primary Observables

Experimental (J_i) $\leftrightarrow$ theoretical (A_i) degrees of freedom

$$\mathbf{n_J} - \mathbf{n_d} = \mathbf{2n_A} - \mathbf{n_s}$$

- $\mathbf{n_J}$: # coefficients of differential distribution: J_i
- $\mathbf{n_d}$: # relations between J_i
- $\mathbf{n_A}$: # spin amplitudes
- $\mathbf{n_s}$: # symmetries of the distribution

Case: **Massless leptons with no scalars:**

$\mathbf{n_J = 11}$, $\mathbf{n_d = 3}$ ($J_{1s} = 3J_{2s}$, $J_{1c} = -J_{2c}$ and the **third relation**),

$\mathbf{n_A = 6}$ (spin amplitudes), $\mathbf{n_s = 4}$ **symmetries**.

Independent experimental inputs: 11-3=**8**=9 b.b.-1 constraint

The most general case (massive leptons + scalars) is presented in J.M, F. Mescia, M.Ramon, J.Virto'12.

U. Egede, T. Hurth, J.M, M. Ramon, W. Reece '10

Table: The dependencies between the coefficients in the differential distribution and the symmetries between the amplitudes in several cases.

Case	**Coefficients**	**Dependencies**	**Amplitudes**	**Symmetries**
$m_\ell = 0,\ A_S = 0$	11	3	6	4
$m_\ell = 0$	11	2	7	5
$m_\ell > 0,\ A_S = 0$	11	1	7	4
$m_\ell > 0$	12	0	8	4

All symmetries (massive with scalars) are known and described in J.M, F. Mescia, M.Ramon, J.Virto'12.

Is there a systematic way of extracting the maximally clean information from Angular Distributions?

or

Is there a basis of OBSERVABLES that covers all the information?

$$O = \left\{ \frac{d\Gamma}{dq^2}, A_{FB}, P_1, P_2, P_3, P_4, P_5, P_6 \right\}$$

- **SFFD Observables**: A_{FB} (or F_L) and $\frac{d\Gamma}{dq^2}$
- **Basis of Clean (SFFI) Observables**:

$$P_1 = \frac{|n_\perp|^2 - |n_\||^2}{|n_\perp|^2 + |n_\|}|^2} = \frac{J_3}{2J_{2s}} \qquad P_4 = \frac{\mathrm{Re}(n_0^\dagger n_\|)}{\sqrt{|n_\||^2|n_0|^2}} = \frac{\sqrt{2}J_4}{\sqrt{-J_{2c}(2J_{2s} - J_3)}}$$

$$P_2 = \frac{\mathrm{Re}(n_\perp^\dagger n_\|)}{|n_\perp|^2 + |n_\||^2} = \frac{J_{6s}}{8J_{2s}} \qquad P_5 = \frac{\mathrm{Re}(n_0^\dagger n_\perp)}{\sqrt{|n_\perp|^2|n_0|^2}} = \frac{J_5}{\sqrt{-2J_{2c}(2J_{2s} + J_3)}}$$

$$P_3 = \frac{\mathrm{Im}(n_\perp^\dagger n_\|)}{|n_\perp|^2 + |n_\||^2} = \frac{-J_9}{4J_{2s}} \qquad P_6 = \frac{\mathrm{Im}(n_0^\dagger n_\|)}{\sqrt{|n_\||^2|n_0|^2}} = \frac{-J_7}{\sqrt{-2J_{2c}(2J_{2s} - J_3)}}$$

- $P_i = 1..6$ form a basis for all clean observables.
- Two dirty + $P_{i=1..6}$ can generate any observable.
- If $J_{6c} \sim 0$ (no scalars) $P_{1,2,3,4,6}$ and P_5 fit $C_{7,7',9,10,9',10'}$.

Examples (clean ones in the clean basis):

$$
\begin{aligned}
A_T^{(2)} &= P_1 \qquad A_T^{(re)} = 2P_2 \\
A_T^{(im)} &= -2P_3 \qquad A_T^5 = \sqrt{\frac{1 - P_1^2 - 4P_2^2 - 4P_3^2}{4}} \\
A_T^3 &= f_1(P_i) \qquad A_T^4 = f_2(P_i)
\end{aligned}
$$

Examples of SFFD ones ($m_\ell = 0$):

$$
A_{im} = -F_T P_3 \qquad A_{FB} = -\frac{3}{2} F_T P_2 \qquad F_L = 1 + \frac{2A_{FB}}{3P_2}
$$

For the same reason better use $P_1 = A_T^2$ (FFI) than S_3 (FFD).

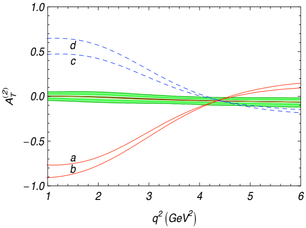
Why $A_T^2 = P_1$ is better than A_{FB}? Why $A_{FB}|_{SM} \not\Rightarrow A_T^2|_{SM}$?

Definition

Kruger,J.M. '05

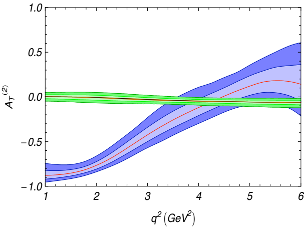
$$A_T^2 = \frac{|A_\perp|^2 - |A_\|{}|^2}{|A_\perp|^2 + |A_\|{}|^2} = -2\frac{\mathrm{Re}H_+^* H_-}{|H_+|^2 + |H_-|^2}$$

- Physics: Deviation from SM LH structure: $A_T^2\Big|_{SM} \sim 0$ (from $A_\perp = -A_\|$).
- Absence of impact of RH currents in A_{FB} does not prevent a large A_T^2.
- Domain: Low-Region $1 \leq q^2 \leq 6\ \mathrm{GeV}^2$ (High region, see G. Hiller et al.)



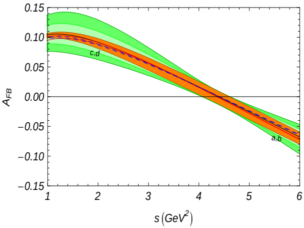
Susy [Lunghi, J.M. '07]

Λ/m_b: light(dark) green $\pm5\%$ ($\pm10\%$)



Exp. sens. susy ($10\mathrm{fb}^{-1}$)

light(dark) blue 1σ (2σ)



A_{FB} + RH currents

(Egede et al. 08)

Other sensitivities of A_T^2: CPV in $O_7 - O_7'$ and O_{10}'

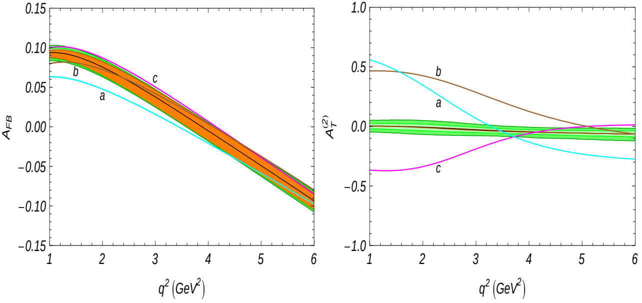
- A_T^2: CP violating phase (O_7') sensitivity BETTER than CP violating observables

A_{FB}: **Mild** sensitivity to C_7' mod+phase A_T^2: **Strong** sensitivity to C_7' mod+phase

$$\mathrm{Num}(A_{FB}) \sim \frac{2m_b M_B}{q^2} C_7^{eff} + C_9 + \frac{2m_b M_B}{q^2} |C_7^{NP}| \cos \phi_7^{NP}$$

$$\mathrm{Num}(A_T^2) = \frac{4m_b M_B}{q^2} \left[\left(\frac{2m_b M_B}{q^2} C_7^{eff} + C_9 \right) |C_7'| \cos \phi_7' + \frac{2m_b M_B}{q^2} |C_7'||C_7^{NP}| \cos(\phi_7' - \phi_7^{NP}) \right]$$

- If only O_{10}' turned on A_T^2 has a different and characteristic q^2-dependence for O_{10}' than for O_7: no zero and maximal deviation around the AFB zero.



$C_7^{NP} e^{i\phi_7^{NP}}$	$C_7' e^{i\phi_7'}$
$0.26 e^{-i\frac{7\pi}{16}}$	$0.2 e^{i\pi}$ (a)
$0.07 e^{i\frac{3\pi}{5}}$	$0.3 e^{i\frac{3\pi}{5}}$ (b)
$0.03 e^{i\pi}$	0.07 (c)

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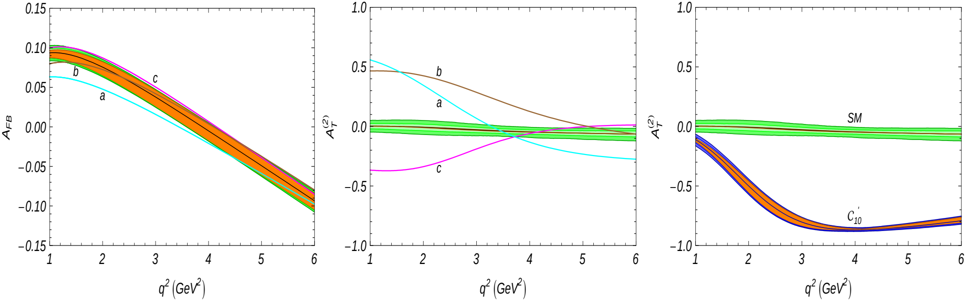


Measuring A_T^2

- Projection fits on each angle:

$$\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi}\left(1+\frac{1}{2}(1-F_{\rm L})\mathbf{A_T^{(2)}}\cos 2\phi + A_{\rm im}\sin 2\phi\right),$$

$$\frac{d\Gamma'}{d\theta_l} = \Gamma'\left(\frac{3}{4}F_{\rm L}\sin^2\theta_l + \frac{3}{8}(1-F_{\rm L})(1+\cos^2\theta_l) + A_{\rm FB}\cos\theta_l\right)\sin\theta_l\,,$$

$$\frac{d\Gamma'}{d\theta_K} = \frac{3\Gamma'}{4}\sin\theta_K\left(2F_{\rm L}\cos^2\theta_K + (1-F_{\rm L})\sin^2\theta_K\right),\quad \Gamma' = d\Gamma/dq^2$$

Time schedule: during the first run ($1-2fb^{-1}$ enough).

- From full angular analysis with small bins, only two coefficients are necessary:

$$A_T^2 = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2} = \frac{\mathbf{J_3}}{2\mathbf{J_{2s}}}\text{but indeed } < A_T^2 >_{bin_i} = \frac{\int_{bin_i} F_T A_T^2 \Gamma'}{\int_{bin_i} F_T \Gamma'}$$

Measuring A_T^2

- Projection fits on each angle in the **new variables**:

$$\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi}\left(1+\frac{1}{2}F_T\mathbf{P_1}\cos 2\phi - F_T\mathbf{P_3}\sin 2\phi\right),$$

$$\frac{d\Gamma'}{d\theta_l} = \Gamma'\sin\theta_l\left(\frac{3}{16}(3-F_L)+\frac{3}{2}F_T\mathbf{P_2}\cos\theta_l - \frac{3}{16}(2-3F_T)\cos 2\theta_l\right)$$

$$\frac{d\Gamma'}{d\theta_K} = \frac{3\Gamma'}{2}\sin\theta_K\left(F_L\cos^2\theta_K+\frac{1}{2}F_T\sin^2\theta_K\right), \quad \Gamma' = d\Gamma/dq^2$$

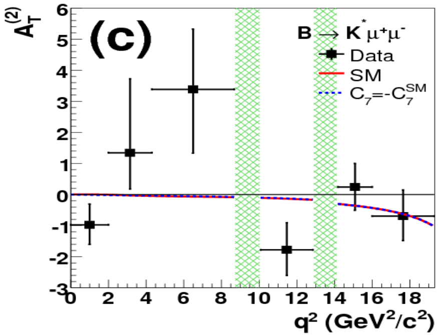
or if preferred $A_{\rm FB} = -3F_T\mathbf{P_2}/2$.

- The full generalization of uniangular distributions for massive leptons and scalars in JM, F. Mescia, M. Ramon, J. Virto'12.

- Also complete expressions of all J_i's in terms of P_i.

CDF measurement of A_T^2

Finally, a first measurement from CDF has come out...



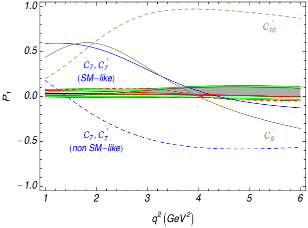
arXiv:1108.0695 [hep-ex] (more precision soon) and LHCb...

HOWEVER, it was obtained assuming zero isospin breaking between $B^0 \to K^{*0} ll$ and $B^+ \to K^{*+} ll$.

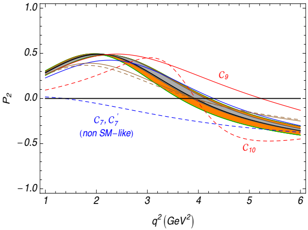
Sensitivities of $P_{1,2,3,4,5,6}$ and massive $M_{1,2}$

P_i: $\delta C_7, \delta C_7', \delta C_9, \delta C_{10}, \delta C_9', \delta C_{10}'$

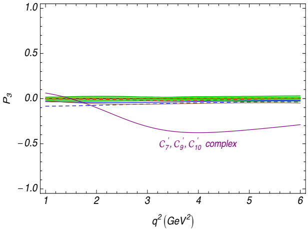
$P_1 = A_T^2,\ C_{7,7',9',10'}$



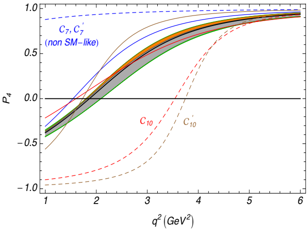
P_2 (Re) $C_{7,7',9,10}$



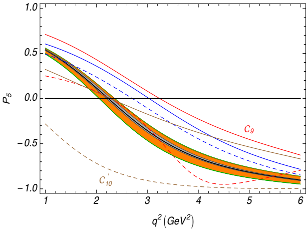
P_3 (Im) Complex $C_{i'}$



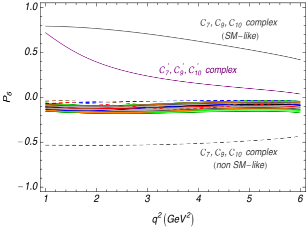
P_4 (Re) $C_{7,7',10,10'}$



P_5 (Re), scalar $C_{9,10'}$



P_6 (Im) Complex $C_{i,i'}$



Massive observables: $B \to K^*(\to K\pi)\tau^+\tau^-$

Massive case ($B \to K^*(\to K\pi)\tau^+\tau^-$) previous observables are trivially generalized with some prefactors (β_ℓ) in $P_{i=1...6}$.
Two new specific observables comes out:

$$M_1 = \frac{4m_\ell^2}{q^2\beta_\ell^2}\frac{\mathrm{Re}\left(A_\perp^L A_\perp^{R*} + A_\parallel^L A_\parallel^{R*}\right)}{[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L \to R)]} = \frac{J_{1s} - J_{2s}\frac{(2+\beta_\ell^2)}{\beta_\ell^2}}{4J_{2s}}$$

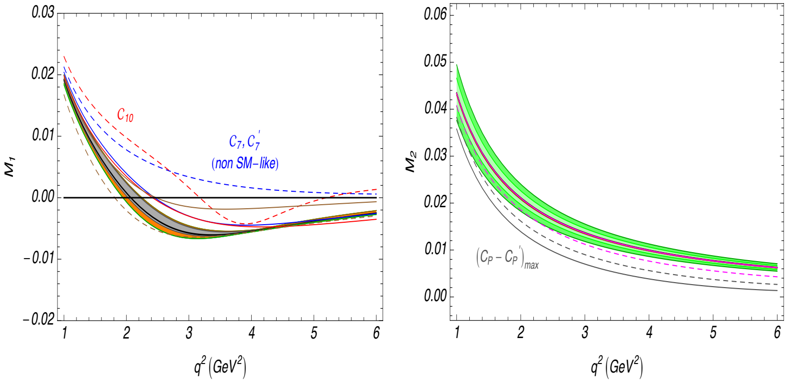
$$M_2 = \frac{4m_\ell^2}{q^2}\frac{\left[|A_t|^2 + 2\mathrm{Re}(A_0^L A_0^{R*})\right]}{|A_0^L|^2 + |A_0^R|^2} = -\beta_\ell^2\frac{J_{1c} + J_{2c}\frac{1}{\beta_\ell^2}}{J_{2c}}$$

Independent experimental inputs = 11-1 =**10**. Basis:

$$O = \left\{\frac{d\Gamma}{dq^2}, A_{FB}, P_1, P_2, P_3, P_4, P_5, P_6, M_1, M_2\right\}$$

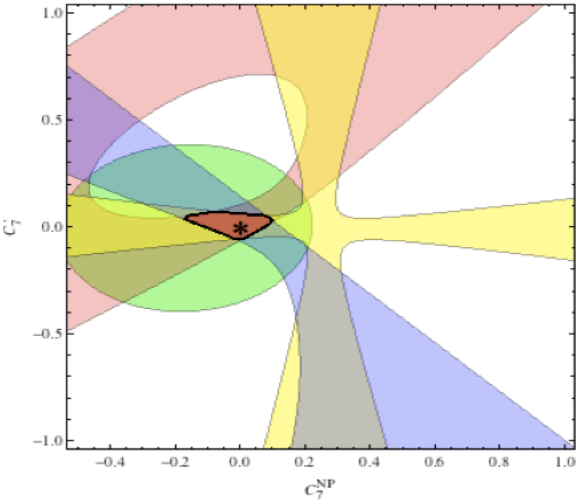
Sensitivities of massive observables $M_{1,2}$

In the case of muons we find for M_1^μ (left) and M_2^μ (right) [scalar]:



- M_1 exhibits some sensitivity to $C_{7,7'}$ and C_{10} even if very mild.
- M_2 is the only observable sensitive to Pseudoscalars.

In the not too far future we can expect to see this type of constraints from P_1 (yellow), P_2 (green), P_4 (red), P_5 (blue).



* SM solution.

Isospin violation

$A_I(B \to K^* ll)$:

Isospin Asymmetry

Definition: [Feldmann,J.M '03]

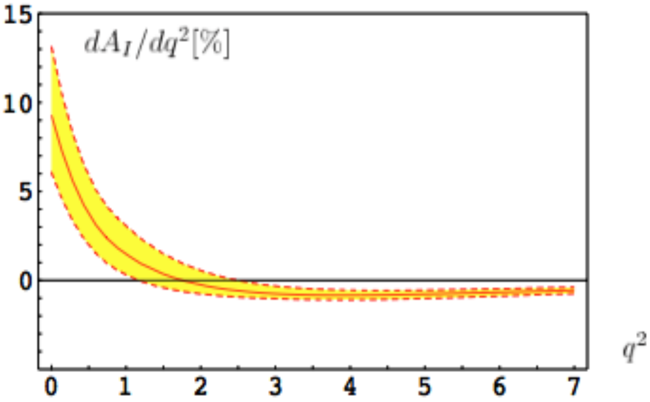
$$\frac{dA_I}{dq^2} \equiv \frac{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/dq^2 - d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/dq^2}{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/dq^2 + d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/dq^2} .$$

- Description for invariant mass of the lepton pair small:

$$1 \leq q^2 \leq 6 \quad \mathrm{GeV}^2$$

- Systematic theoretical description using QCD factorization in the heavy quark limit.
- Sensitivity to NP via **spectator quark** in exclusive modes $\neq$ inclusive counterparts in the short-distance dynamics.

For increasing values of q2 the isospin-asymmetry decreases, and its central value becomes slightly negative above $q^2 = 2$ GeV^2 and stays basically at a constant value of about -1%.



Non-factorizable (NF) graphs where a γ is radiated from spectator quark in **annihilation** or **spectator-scattering** diagrams.

- Contributions sensitive to the charge of the spectator quark.

  $$\mathcal{C}_9^{\perp}(q^2) = [1+b_q^{\perp}(q^2)]\mathcal{C}_9^{(0)\perp}(q^2), \quad \mathcal{C}_9^{\parallel}(q^2) = [1+b_q^{\parallel}(q^2)]\mathcal{C}_9^{(0)\parallel}(q^2)$$

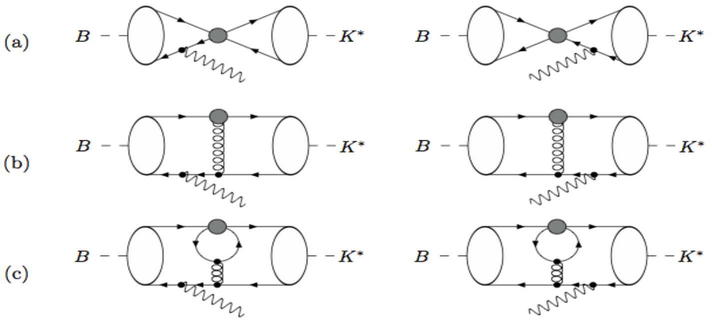
  The functions $b_q^{\perp,\parallel}(q^2)$ parametrize NF effects from photon radiation from spectator quark.

  $$\frac{dA_I}{dq^2}[B \to K^* l^+ l^-] = \mathrm{Re}(b_d^{\perp} - b_u^{\perp}) \times f(\mathcal{C}_9^{\perp}, \mathcal{C}_9^{\parallel}, \mathcal{C}_{10}, b_{d,u}^{\perp,\parallel}, \xi_{\perp,\parallel})$$

- NF independent of the spectator quark drops out. It vanishes in naive factorization. NF effects tiny.
- In the limit $q^2 \to 0$ (photon pole in $C_9^{\perp}$ dominates) and we recover KN:

  $$A_I[B \to K^* \gamma] = \mathrm{Re}[b_d^{\perp}(0) - b_u^{\perp}(0)]$$

  For q^2 large longitudinal polarization dominates.
- Calculation requires to model IR divergences that are the main source of uncertainty.



(a) Annihilation topologies with operators $\mathcal{O}_{1-6}$, (b) Hard spectator interaction involving the gluonic penguin operator $\mathcal{O}_8$, (c) Hard spectator interaction involving the operators $\mathcal{O}_{1-6}$. [T. Feldmann, J.M '02]

Main New Physics sensitivities of isospin asymmetry:

- The penguin operators O_{3-6} (dominant annihilation contribution) give the main effect to the isospin asymmetry in $B \to K^* \gamma$ and $B \to K^* l^+ l^-$ together with C_7 (its sign) and partially $C_{9,10}$.
  - $a_6^{(0)} = (\bar{C}_6 + \bar{C}_5/3)$ main impact at small values of q^2
  - $a_4^{(0)} = (\bar{C}_4 + \bar{C}_3/3)$ main impact at larger values of q^2
  - Sign of C_7^{eff} determines the half plain and has a large impact at $q^2 = 0$ on $A_I(B \to K^* \gamma)$.
  - The semi-leptonic operators $O_{9,10}$ are relevant for $B \to K^* l^+ l^-$ at not too small values of q_2.

Main constraints:

- on QCD-penguin operators: non-leptonic B decays, life-time differences of B mesons, kaon decays.
- main constraint on semileptonic $C_{9,10}$ from A_{FB}. A change of sign in C_{10} or C_7 flips A_{FB}.

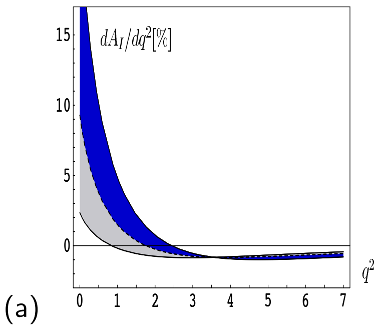
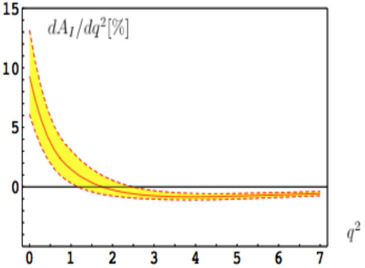
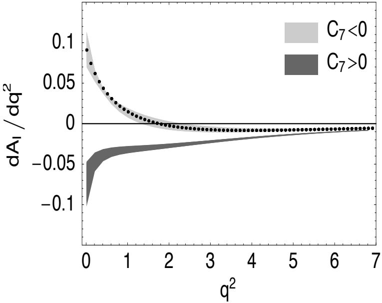


Figure: The isospin asymmetry dA_I/dq^2 for the decay $B \to K^* \ell^+ \ell^-$ as a function of q^2. (a) The combination $a_6^{(0)} = (\bar{C}_6 + \bar{C}_5/3)$ in the function $K_1^{\perp(a)}$ is varied within a factor of two around its SM value (dark band = larger values, light band = smaller values). (b) The same for the combination $a_4^{(0)} = (\bar{C}_4 + \bar{C}_3/3)$ in the functions $K_1^{\|(a)}$ and $K_2^{\perp(a)}$.

MSSM (All susy particles are taken as heavy (about 1 TeV), except for charginos, sneutrinos, the light (mostly right-handed) stop, and charged Higgs fields. Flavor diagonal mass matrix in down sector. Regime for $\tan\beta = 2 - 40$). Impact on δC_7 and δC_8.





SM [Feldmann,J.M '03] MSSM

Even if the flipped sign solution for C_7 is disfavored in some scenarios (see [S. Descotes et al. '11]) shows the difficulty to get -0.5! and also $A_I(B \to K^*\gamma)$

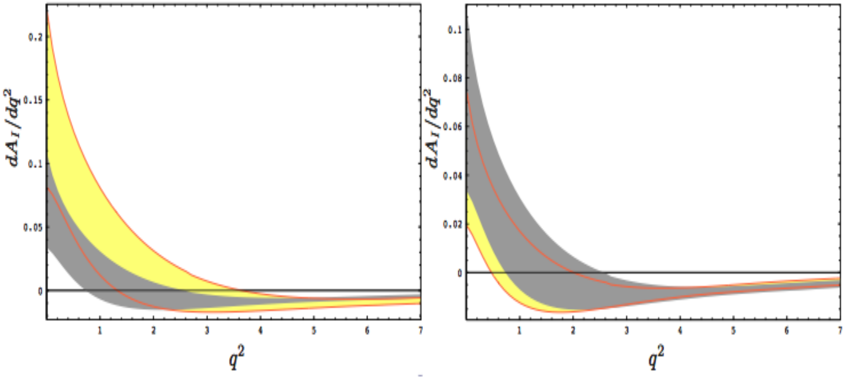
Other possibilities: NP contributions to the QCD-penguin operators C_3, C_4, C_5 and C_6. In particular, we focus on the generic NP case in which

$$C_3^{NP} = C_5^{NP} = -\frac{1}{N_c} C_4^{NP} = -\frac{1}{N_c} C_6^{NP} \equiv \delta C$$

This arises in models of susy when gluino-squark dominates and in some models of extra dimensions.

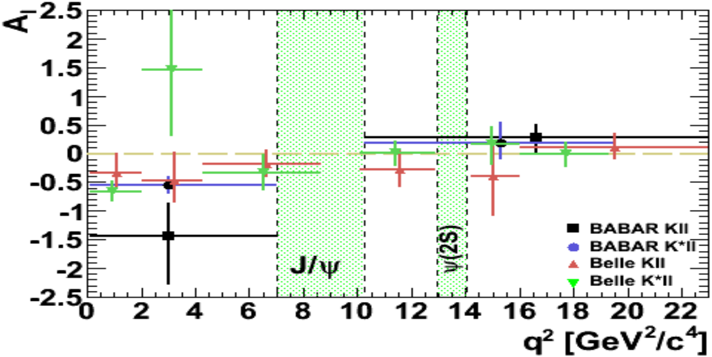
- Most important experimental bounds on the NP contributions to QCD-penguin operators from branching ratios like $B \to \phi K^0$, $B^+ \to \phi K^+$, $B^+ \to \pi^+ K^0$, etc. We compute these branching ratios in NLO QCD-factorization, in order to put bounds on δC.
- It turns out that by far the most important constraint comes from $B^+ \to \pi^+ K^0$.

The bounds considering the large hadronic uncertainties are in a range $-0.003 \leq \delta C \leq 0.012$:



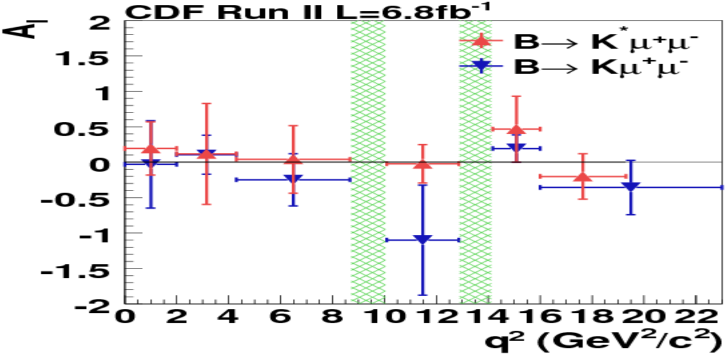
Left plot corresponds to $\delta C = 0.012$ and right plot $\delta C = -0.003$. Negative δC preferred but still very far away from Babar data.

Babar/Belle measurement:



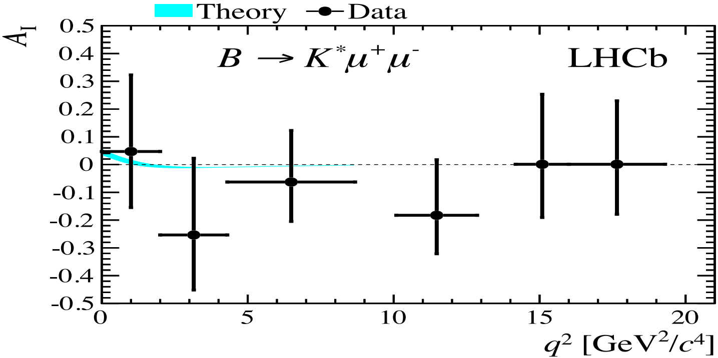
Babar finds 3.9σ, Belle is consistent with Babar for two of the bins. Above J/ψ Babar and Belle are consistent with SM.

CDF measurement PRL107, 201802 (2011) :



LHCb may give the last word on this. IS there a large isospin breaking or not?

LHCb measurement



Life is hard... but not yet the last word.

Conclusions

- Rare B decays phenomenology will play (is playing) a central role in slicing parameter space of models: Better to start taking into account **ALL constraints** coming from rare B decays (message for model building)
- Unitarity Triangle plane will be **complemented** by Wilson Coefficient correlations planes
- Concerning $\mathbf{B} \to \mathbf{K}^*(\to \mathbf{K}\pi)\mu^+\mu^-$ observables P_i **stay tuned** in the following years, since they will play a central role in signaling/constraining new New Physics regions.