Rare B decays: The Terminator for New Physics?

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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 $B \rightarrow K^*(\rightarrow K\pi)l^+l^-$.

• III. Isospin asymmetry of $B \rightarrow K^*\mu^+\mu^-$
Pre-LHCb Time (From Tim)

- $B \rightarrow \tau \nu$ & CKM fit (BaBar & Belle)
- $B_s \rightarrow \mu^+ \mu^-$ (CDF excess)
- $\phi_s$ (CDF and D0 hints of large value)
- $A_{fs}$ (D0 evidence)
- $A_{CP}(B \rightarrow K\pi)$ puzzle (BaBar and Belle)
- $A_{FB}(B \rightarrow K^*\mu^+\mu^-)$ (BaBar, Belle & CDF hints)
- $A_{I}(B \rightarrow K^{(*)}\mu^+\mu^-)$ (BaBar, Belle & CDF hints)
• $B \rightarrow \tau \nu$ & CKM fit (BaBar & Belle)
• $B_s \rightarrow \mu^+\mu^-$ (CDF excess) consistent with SM
• $\phi_s$ (CDF and D0 hints of large value) consistent with SM
• $A_{fs}$ (D0 evidence)
• $A_{CP}(B \rightarrow K\pi)$ puzzle (BaBar and Belle)
• $A_{FB}(B \rightarrow K^*\mu^+\mu^-)$ (BaBar, Belle & CDF hints) consistent SM
• $A_{I}(B \rightarrow K^{(*)}\mu^+\mu^-)$ (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 $B \rightarrow X_s\gamma$) 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 $\rightarrow$ Wilson Coefficient planes.
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


- **Framework:** NP in $C_7, C_9, C_{10}$ and $C_7', C_9', C_{10'}$ [chirally-flipped operators $\gamma_5 \rightarrow -\gamma_5$] 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

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

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}}V_{tb}V_{ts}^* \sum_{i=1}^{10} \left[ C_i(\mu) O_i(\mu) + C_i'(\mu) O_i'(\mu) \right],$$

$C_i^{(\prime)}(\mu)$ are Wilson coefficients and $O_i^{(\prime)}(\mu)$ are local operators.

We concentrate on \textit{Electromagnetic dipole+ semileptonic operators}:

$$O_7 = \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu}, \quad O_9 = \frac{e^2}{16\pi^2} (\bar{s} \gamma_{\mu} P_L b) (l \gamma^\mu l),$$

$$O_{10} = \frac{e^2}{16\pi^2} (\bar{s} \gamma_{\mu} P_L b) (l \gamma^\mu \gamma_5 l),$$

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

$$O_7' = \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_L b) F^{\mu\nu}, \quad O_9' = \frac{e^2}{16\pi^2} (\bar{s} \gamma_{\mu} P_R b) (l \gamma^\mu l),$$

$$O_{10}' = \frac{e^2}{16\pi^2} (\bar{s} \gamma_{\mu} P_R b) (l \gamma^\mu \gamma_5 l),$$
Limited sensitivity to hadronic inputs, or strong impact on analysis

- **Class-I**
  - $\mathcal{B}(B \rightarrow X_s \gamma)$ with $E_{\gamma} > 1.6$ GeV [Misiak, Steinhauser, Haisch]
  - exclusive time-dependent CP asymmetry $S_{K^*\gamma}$
  - isospin asymmetry $A_I(B \rightarrow K^*\gamma)$ [Beneke, Feldman, Seidel]

- **Class-II**
  - Integrated transverse asym. $\tilde{A}_T^2$ in $B \rightarrow K^* l^+ l^-$ over low-$q^2$ region [Kruger and J.M.]

- **Class-III**
  - $\mathcal{B}(B \rightarrow X_s l^+ l^-)$ [Bobeth et al., Huber, Lunghi et al.]
  - Integrated $\tilde{F}_L$ and $\tilde{A}_{FB}$ in $B \rightarrow K^* l^+ l^-$ [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 $\Delta X_{th}$ 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

$[\text{Misiak, Gambino, Steinhauser…}]$

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

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

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

$$P(E_0) = \sum_{i,j=1…8} C_i^{\text{eff}}(\mu) C_j^{\text{eff} \ast}(\mu) K_{ij}(E_0, \mu)$$

- numerical a’s reproducing $[\text{Misiak, Steinhauser, Haisch}]$
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...]

$$\mathcal{B}(\bar{B} \to X_S \gamma)_{E_\gamma > 1.6 \text{ GeV}}^{\text{exp}} = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_S \gamma)_{E_\gamma > 1.6 \text{ GeV}}^{\text{th}} = \left[ a(0,0) + a(7,7) \left( (\delta C_7)^2 + (\delta C'_7)^2 \right) + a(0,7) \delta C_7 + a(0,7') \delta C'_7 \right] \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_S \gamma)_{E_\gamma > 1.6 \text{ GeV}}^{\text{SM}} = (3.15 \pm 0.23) \times 10^{-4}$$

- SM value $[a(0,0)]$ expressed as

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

$$P(E_0) = \sum_{i,j=1...8} C_{i}^{\text{eff}}(\mu) C_{j}^{\text{eff}}(\mu) K_{ij}(E_0, \mu)$$

- numerical $a$’s reproducing [Misiak, Steinhauser, Haisch]
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

$$A_I(B \to K^*\gamma)^{exp} = 0.052 \pm 0.026$$

$$A_I(B \to K^*\gamma)^{th} = c \times \frac{\sum_k d_k (\delta C_7)^k}{\sum_k, l e_k, l (\delta C_7)^k (\delta C_7')^l} \pm \delta c.$$

$$A_I(B \to K^*\gamma)^{SM} = 0.041 \pm 0.025$$ (updates Feldman&JM’03)

- $c, d, e$ determined numerically.
Class-I observables: isospin asymmetry in $B \rightarrow K^*\gamma$

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

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- $c, d, e$ determined numerically.
Class-I observables: $B \rightarrow K^* \gamma$ CP-asymmetry

[Beneke Feldmann Seidel, Ball and Zwicky]

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

- Probe of photon helicity
  \[
  S_{K^* \gamma} = \frac{2 \text{Im} \left[ e^{-2i\beta} (A^*_L \bar{A}_L + A^*_R \bar{A}_R) \right]}{|A_L|^2 + |A_R|^2 + |\bar{A}_L|^2 + |\bar{A}_R|^2}
  \]

- Computed at NLO in QCD factorisation. At LO,
  \[
  S^{(\text{LO})}_{K^* \gamma} = \frac{-2 \left| C'_{7} / C_{7} \right|}{1 + \left| C'_{7} / C_{7} \right|^2} \sin \left( 2\beta - \arg \left( C_{7} C_{7}' \right) \right)
  \]

[Grinstein et al, Bobeth et al]

\[
S_{K^* \gamma}^{\text{exp}} = -0.16 \pm 0.22 (\text{HFAG})
\]

\[
S_{K^* \gamma} = f + \delta^{u}_f - \delta^{d}_f + \frac{\sum_{k,l} g_{k,l} (\delta C_{7})^{k} (\delta C_{7}')^{l}}{\sum_{k,l} h_{k,l} (\delta C_{7})^{k} (\delta C_{7}')^{l}}
\]

\[
S^{\text{SM}}_{K^* \gamma} = -0.03 \pm 0.01
\]

- $f$, $g$, $h$ fitting coefficients
Class-I observables: $B \to K^* \gamma$ CP-asymmetry

[Beneke Feldmann Seidel, Ball and Zwicky]

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

- Probe of photon helicity
  $$S_{K^\ast \gamma} = \frac{2 \Im \left[ e^{-2i\beta} (A^*_L \bar{A}_L + A^*_R \bar{A}_R) \right]}{ |A_L|^2 + |A_R|^2 + |\bar{A}_L|^2 + |\bar{A}_R|^2}$$

- Computed at NLO in QCD factorisation. At LO,
  $$S^{(LO)}_{K^\ast \gamma} = -2 \frac{|C_7'/C_7|}{1 + |C_7'/C_7|^2} \sin (2\beta - \arg(C_7 C_7'))$$

[Grinstein et al, Bobeth et al]

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

$$S_{K^* \gamma} = f^+ + \sum_{k,l} g_{k,l} (\delta C_7)^k (\delta C_7')^l$$

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

- $f, g, h$ fitting coefficients
Class-II observables: $A_T^2$ asymmetry

Class-II: depending only on dipole and semileptonic operators

$B \rightarrow K^* \ell^+ \ell^-$ 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 $C_{7}^\prime$ allowed space.

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

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

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

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

Longer list of new clean class-II observables $P_i$ in part II...
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 $A_T^2(q^2) = A_T^{(2),CV}(q^2) + \delta_u(q^2) - \delta_d(q^2)$

with fitting $q^2$-polynomials for errors $\delta_u, \delta_d$ 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...
Class-III observables: $\bar{B} \rightarrow X_s \mu^+ \mu^-$

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

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

$$
\mathcal{B}(\bar{B} \rightarrow X_s \mu^+ \mu^-)^{\text{exp}} = (1.60 \pm 0.50) \times 10^{-6}
$$

$$
\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-) = 10^{-7} \times \sum_{i,j=0,7,7',9,9',10,10'} b_{(i,j)} \delta C_i \delta C_j
$$

$$
\mathcal{B}(\bar{B} \rightarrow X_s \mu^+ \mu^-)^{\text{SM}} = (1.59 \pm 0.15) \times 10^{-6}
$$

- $\delta C_7, \delta C_9, \delta C_{10}$-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 ($\gamma_5 \rightarrow -\gamma_5$)
- Crossed terms (primed-unprimed) only at LO in $\alpha_s$, and are suppressed by $m_s/m_b$ [Guetta Nardi]
- $b$ coefficients determined numerically agreeing with [Huber et al]

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

$$A_{FB} = \left( \int_0^1 d(\cos\theta_I) \frac{d^2\Gamma}{dq^2 d\cos\theta_I} - \int_{-1}^0 \cdots \right) / \int_{-1}^1 \frac{d\Gamma}{dq^2}$$

$$F_L = |A_0|^2 / \int_{-1}^1 \frac{d\Gamma}{dq^2}$$

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

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

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

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

$$\tilde{A}_{FB}^{SM} = -0.049 \pm 0.046 \quad \tilde{F}_L^{SM} = 0.721 \pm 0.043$$
Class-III observables: $\tilde{A}_{FB}$ and $\tilde{F}_L$

$$A_{FB} = \left( \int_0^1 d(\cos\theta_L) \frac{d^2\Gamma}{dq^2 d\cos\theta_L} - \int_{-1}^0 \ldots \right) / \frac{d\Gamma}{dq^2}$$

$$F_L = |A_0|^2 / \frac{d\Gamma}{dq^2}$$

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

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

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

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

$$\tilde{A}_{FB}^{SM} = -0.049 \pm 0.046 \quad \tilde{F}_{L}^{SM} = 0.721 \pm 0.043$$
In the SM, NNLO in MS-bar including electromagnetic corrections
[Chetyrkin, Misiak and Münz, Bobeth et al., Huber et al.]

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

- High-scale $\mu_0 = 2 M_W$ [uncertainty: varied from $M_W$ to $4 M_W$]
- 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

$$
C_7^{SM} = \frac{m_s}{m_b} C_7^{SM}, \quad C_9^{SM},_1^{SM} = 0
$$
Exploring New Physics Constraints on $C_{ij}^{(')}$:

**Scenario A, B and C**
\[ \delta C_7 - \delta C_7' \text{ plane: constraints at 1 and 2 } \sigma \]

Class I observables (only \(O_7, 7'\))

- **dark** 1\(\sigma\), light 2\(\sigma\)
  - \(A_I\) (yellow)
  - \(B(B \to X_s \gamma)\) (purple)
  - \(S_{K^*\gamma}\) (green)

Overlap regions (red dark and light)

- SM region at 1\(\sigma\) solid black countour red dark
  
  \((C_7, C_7') \sim (C_7^{SM}, 0)\).

- Two non-SM solutions also allowed at 2\(\sigma\) \((C_7, C_7') \sim (0, \pm 0.4)\) (dashed)

- \(A_I\) disfavors flipped-sign solution \((C_7, C_7') = (-C_7^{SM}, 0)\)
  
  \[\Rightarrow\text{Same conclusion as [Gambino, Haisch, Misiak], without using Class-III } B \to X_s \ell^+ \ell^-\]

- Flipped sign solution disfavored in Scenario A by \(> 2\sigma\).
\[ \delta C_7 - \delta C_7', \text{ plane: constraints at 1 and 2 } \sigma \]

Class I observables (only \( O_{7,7'} \))

- **dark** 1\( \sigma \), light 2\( \sigma \)
  - \( A_I \) (yellow)
  - \( B(B \rightarrow X_s\gamma) \) (purple)
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Overlap regions (red dark and light)

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

- \( A_I \) disfavours flipped-sign solution \((C_7, C_7') = (-C_7^{SM}, 0)\)
  \( \implies \) Same conclusion as [Gambino, Haisch, Misiak],
  without using Class-III \( B \rightarrow X_s\ell^+\ell^- \)
- Flipped sign solution disfavored in Scenario A by > 2\( \sigma \).
Scenario A \((C_7, C_7')\): 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 \(q^2 = 1 \ldots 6\) 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 \(C_7' < 0\).
At EPS11, new results from LHCb on $B_s \to \mu\mu$ and $B \to K^*\ell\ell$

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 \((C_7, \bar{C}_7')\): class-III observables (Moriond12) 1-2 \(\sigma\)

Scenario A:

\[
\Rightarrow \text{class-III observables constrain further the shifts } \delta C_7, \delta C_7'.
\]

Correlations in \((\delta C_7, \delta C_7')\) plane:

- \(B(B \rightarrow X_s \mu^+ \mu^-)\)
  - \(B(B \rightarrow X_s \mu^+ \mu^-)\) favors SM-like region (at 1\(\sigma\)) and non-SM regions (at 2\(\sigma\)). All three disfavors flipped sign solution at more than 2 \(\sigma\).

- \(\tilde{A}_{FB}\) 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 ($B \rightarrow X_s \gamma$), Grey ($F_L$), Orange ($\delta A_{FB}$), Yellow ($B \rightarrow X_s ll$), Green ($S_{K^*\gamma}$). All constraints shown here at 2 sigma. Good agreement of all observables with SM region at 1$\sigma$. No non-SM region allowed at < 2 $\sigma$. 
Constraint on $C_{10}$, $C_{10}'$ from $B_s \rightarrow \mu^+ \mu^-$

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

Using our inputs, we get

$$
\mathcal{B}(\bar{B}_s \rightarrow \mu^+ \mu^-)^{SM} = (3.44 \pm 0.32) \cdot 10^{-9}
$$

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

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

leading to weak constraints on $C_{10}$ (Scenario B) and $C_{10}'$ (Scenario C)
Constraint on $C_{10}, C_{10}'$ from $B_s \to \mu^+ \mu^-$

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

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

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

near one order of magnitude smaller than previous exp bound

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

leading to strong constraints on $C_{10}$ (Scenario B) and $C_{10}'$ (Scenario C)
Scenario B \((C_7, C_7', 9, 10)\): class-III constraints in \((\delta C_9, \delta C_{10})\)

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 \(\sigma\) (class-III does no cut)
- Correlation \(\delta C_9, \delta C_{10}\): to be fixed from class-III observables:

\[
\begin{align*}
\text{B}(B \to X_s \mu^+ \mu^-) & \\
\tilde{A}_{FB} & \\
\tilde{F}_L & 
\end{align*}
\]

- Small absolute values of \((C_9, C_{10})\) disfavoured by \(\tilde{F}_L\).
Scenario B: overlap in $\delta C_9 - \delta C_{10}$ plane

- $\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-)$ (green)
- $A_{FB}$ (orange)
- $F_L$ (blue)

Two overlapped region (red)

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

$\implies$ 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.

$\implies$ $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ cuts further in the allowed region.
Scenario B: overlap in $\delta C_9 - \delta C_{10}$ plane

$\rightarrow$ 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.

$\rightarrow$ $\text{BR}(B_s \rightarrow \mu^+\mu^-)$ cuts further in the allowed region.
Angular distribution of

\[ B \rightarrow K^* \rightarrow K\pi l^+ l^- : \]

RH currents/new scalars/CPV in WC
The decay $\bar{B}_d \rightarrow \bar{K}^*0(\rightarrow K^- \pi^+)l^+l^-$ with the $K^*0$ on the mass shell is described by $s$ and three angles $\theta_l$, $\theta_K$ and $\phi$

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

- **$q^2 = s$** square of the lepton-pair invariant mass.
- **$\theta_l$** angle between $p_{l^-}$ in $l^+l^-$ rest frame and dilepton’s direction in rest frame of $\bar{B}_d$
- **$\theta_K$** angle between $p_{K^-}$ in the $\bar{K}^*0$ rest frame and direction of the $\bar{K}^*0$ in rest frame of $\bar{B}_d$
- **$\phi$** angle between the planes defined by the two leptons and the $K - \pi$ planes.
The decay $\bar{B}_d \rightarrow \bar{K}^* (\rightarrow K^- \pi^+) l^+ l^-$ with the $K^*$ on the mass shell is described by $s$ and three angles $\theta_l$, $\theta_K$ and $\phi$

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

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 $A_{\perp,\parallel,0}$) is inside the coefficients $J_i$.
- short distance physics $C_i$ is encoded in ($H_{\pm 1,0}$ or $A_{\perp,\parallel,0}$)
\[ J_{1s} = \frac{(2 + \beta^2_{\ell})}{4} \left[ |A_{\perp}|^2 + |A_{\parallel}|^2 + (L \rightarrow R) \right] + \frac{4m^2_{\ell}}{q^2} \text{Re} \left( A_{\perp}^L A_{\perp}^{R*} + A_{\parallel}^L A_{\parallel}^{R*} \right), \]

\[ J_{1c} = |A_0^L|^2 + |A_0^R|^2 + \frac{4m^2_{\ell}}{q^2} \left[ |A_t|^2 + 2\text{Re}(A_0^L A_0^{R*}) \right] + \beta^2_{\ell} |A_S|^2, \]

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

\[ J_3 = \frac{1}{2} \beta^2_{\ell} \left[ |A_{\perp}|^2 - |A_{\parallel}|^2 + (L \rightarrow R) \right], \quad J_4 = \frac{1}{\sqrt{2}} \beta^2_{\ell} \left[ \text{Re}(A_0^L A_0^{L*}) + (L \rightarrow R) \right], \]

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

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

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

\[ J_8 = \frac{1}{\sqrt{2}} \beta^2_{\ell} \left[ \text{Im}(A_0^L A_{\perp}^{L*}) + (L \rightarrow R) \right], \quad J_9 = \beta^2_{\ell} \left[ \text{Im}(A_{\parallel}^L A_{\parallel}^L) + (L \rightarrow R) \right]. \]

**SCALARS:** We have 8 complex amplitudes \((A_{\perp,\parallel,0,(L,R)S,t})\) and 12 experimental inputs

**NO SCALARS:** We have 7 complex amplitudes \((A_{\perp,\parallel,0,(L,R),t})\) and 11 experimental inputs
ZOO of observables in the market:

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

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

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

- Asymmetries with Longitudinal sensitivity: Egede, Hurth, JM, Ramon, Reece (2008) $A^5_T$
- $A^{im}_T$ related to $A^{im}$: Becirevic, Schneider (2011)
Can one extract all the information from the angular distribution in an efficient, systematic and clean way?
Geometrical interpretation of angular distribution ($m_l = 0$)

Define

\[ n_\parallel = (A_\parallel^L, A_\parallel^R^*) \]
\[ n_\perp = (A_\perp^L, -A_\perp^R^*) \]
\[ n_0 = (A_0^L, A_0^R^*) \]

or

\[ m_1 = (H_{+1}^L, H_{-1}^R^*) \]
\[ m_2 = (H_{-1}^L, H_{+1}^R^*) \]
\[ m_3 = (H_0^L, H_0^R^*) \]

Spin amplitudes

\[ |n_{\parallel}|^2 = \frac{2}{3} J_{1s} - J_3, \quad |n_{\perp}|^2 = \frac{2}{3} J_{1s} + J_3, \quad |n_0|^2 = J_{1c} \]
\[ n_\perp^\dagger n_{\parallel} = \frac{J_{6s}}{2} - iJ_9, \quad n_0^\dagger n_{\parallel} = \sqrt{2}J_4 - i\frac{J_7}{\sqrt{2}}, \quad n_0^\dagger n_{\perp} = \frac{J_5}{\sqrt{2}} - i\sqrt{2}J_8 \]

Helicity amplitudes

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

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

\[
\left| (n_1 \uparrow n_\perp) |n_0|^2 - (n_1 \uparrow n_0)(n_0 \uparrow n_\perp) \right|^2 = (|n_0|^2 |n_\parallel|^2 - |n_0 \uparrow n_\parallel|^2)(|n_0|^2 |n_\perp|^2 - |n_0 \uparrow n_\perp|^2)
\]

This translates into an experimental test between \( J_i \):

\[
-J_{2c} = 6 \left( 2J_{1s} + 3J_3 \right) \left( 4J_4^2 + J_7^2 \right) + \left( 2J_{1s} - 3J_3 \right) \left( J_5^2 + 4J_8^2 \right) \frac{16J_1^2 - 9 \left( 4J_3^2 + J_{6s}^2 + 4J_9^2 \right)}{16J_1^2 - 9 \left( 4J_3^2 + J_{6s}^2 + 4J_9^2 \right)}
- 36 \frac{J_{6s}(J_4J_5 + J_7J_8) + J_9(J_5J_7 - 4J_4J_8)}{16J_1^2 - 9 \left( 4J_3^2 + J_{6s}^2 + 4J_9^2 \right)} \equiv f
\]

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 \text{theoretical \((A_i)\)}\) degrees of freedom

\[ n_J - n_d = 2n_A - n_s \]

- \(n_J\) : \# coefficients of differential distribution: \(J_i\)
- \(n_d\) : \# relations between \(J_i\)
- \(n_A\) : \# spin amplitudes
- \(n_s\) : \# symmetries of the distribution

Case: \underline{Massless leptons with no scalars}:

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

\(n_A = 6\) (spin amplitudes), \(n_s = 4\) 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.
Table: The dependencies between the coefficients in the differential distribution and the symmetries between the amplitudes in several cases.

<table>
<thead>
<tr>
<th>Case</th>
<th>Coefficients</th>
<th>Dependencies</th>
<th>Amplitudes</th>
<th>Symmetries</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_\ell = 0, A_S = 0$</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>$m_\ell = 0$</td>
<td>11</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>$m_\ell &gt; 0, A_S = 0$</td>
<td>11</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>$m_\ell &gt; 0$</td>
<td>12</td>
<td>0</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>

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:

\[
\begin{align*}
P_1 &= \frac{|n_\perp|^2 - |n_\parallel|^2}{|n_\perp|^2 + |n_\parallel|^2} = \frac{J_3}{2J_{2s}} \quad & P_4 &= \frac{\text{Re}(n_0^\dagger n_\parallel)}{\sqrt{|n_\parallel|^2 |n_0|^2}} = \frac{\sqrt{2}J_4}{\sqrt{-J_{2c}(2J_{2s} - J_3)}} \\
P_2 &= \frac{\text{Re}(n_\perp^\dagger n_\parallel)}{|n_\perp|^2 + |n_\parallel|^2} = \frac{J_{6s}}{8J_{2s}} \quad & P_5 &= \frac{\text{Re}(n_0^\dagger n_\perp)}{\sqrt{|n_\perp|^2 |n_0|^2}} = \frac{J_5}{\sqrt{-2J_{2c}(2J_{2s} + J_3)}} \\
P_3 &= \frac{\text{Im}(n_\perp^\dagger n_\parallel)}{|n_\perp|^2 + |n_\parallel|^2} = -\frac{J_9}{4J_{2s}} \quad & P_6 &= \frac{\text{Im}(n_0^\dagger n_\parallel)}{\sqrt{|n_\parallel|^2 |n_0|^2}} = \frac{-J_7}{\sqrt{-2J_{2c}(2J_{2s} - J_3)}}
\end{align*}
\]
\( P_i = 1..6 \) 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):

\[
A_T^{(2)} = P_1 \quad A_T^{(re)} = 2P_2 \\
A_T^{(im)} = -2P_3 \\
A_T^3 = f_1(P_i) \quad A_T^4 = f_2(P_i)
\]

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

\[
A_{im} = -F_T P_3 \quad A_{FB} = -\frac{3}{2} F_T P_2 \quad F_L = 1 + \frac{2A_{FB}}{3P_2}
\]

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 $A_{FB}|_{SM} \neq A_T^2|_{SM}$?

**Definition**

$$A_T^2 = \frac{|A_{\perp}|^2 - |A_{\parallel}|^2}{|A_{\perp}|^2 + |A_{\parallel}|^2} = -2 \frac{\text{Re}H^*_+ H_-}{|H_+|^2 + |H_-|^2}$$

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

**Susy [Lunghi, J.M. '07]**

$\Lambda/m_b$: light (dark) green $\pm 5\%$ ($\pm 10\%$)

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

light (dark) blue $1\sigma$ ($2\sigma$)

$A_{FB} +$ 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

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

  \[
  \text{Num}(A_T^2) = \frac{4m_b M_B}{q^2} \left[ (\frac{2m_b M_B}{q^2} C_7^{\text{eff}} + C_9) |C'_7| \cos \phi_7' + \frac{2m_b M_B}{q^2} |C'_7||C_7^{NP}| \cos(\phi_7' - \phi_7^{NP}) \right]
  \]

- 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.

\[
\begin{align*}
C_7^{NP} e^{i\phi_7^{NP}} & \quad C'_7 e^{i\phi_7'} \\
0.26 e^{-i\frac{7\pi}{16}} & \quad 0.2 e^{i\pi} (a) \\
0.07 e^{i\frac{3\pi}{5}} & \quad 0.3 e^{i\frac{3\pi}{5}} (b) \\
0.03 e^{i\pi} & \quad 0.07 (c)
\end{align*}
\]
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

\[
\text{Num}(A_{FB}) \sim \frac{2m_bM_B}{q^2} C_7^{\text{eff}} + C_9 + \frac{2m_bM_B}{q^2} |C_{7NP}| \cos \phi_{7NP} \\
\text{Num}(A_T^2) = \frac{4mbM_B}{q^2} \left[ \left( \frac{2mbM_B}{q^2} C_7^{\text{eff}} + C_9 \right) |C'_7| \cos \phi' + \frac{2mbM_B}{q^2} |C'_7||C_{7NP}| \cos (\phi'_7 - \phi_{7NP}') \right]
\]

- 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.
• Projection fits on each angle:

\[
\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi} \left(1 + \frac{1}{2}(1 - F_L)A_T^{(2)} \cos 2\phi + A_{im} \sin 2\phi\right),
\]

\[
\frac{d\Gamma'}{d\theta_l} = \Gamma' \left(\frac{3}{4} F_L \sin^2 \theta_l + \frac{3}{8} (1 - F_L)(1 + \cos^2 \theta_l) + A_{FB} \cos \theta_l\right) \sin \theta_l,
\]

\[
\frac{d\Gamma'}{d\theta_K} = \frac{3\Gamma'}{4} \sin \theta_K \left(2F_L \cos^2 \theta_K + (1 - F_L) \sin^2 \theta_K\right), \quad \Gamma' = \frac{d\Gamma}{dq^2}
\]

Time schedule: during the first run (1 − 2 fb⁻¹ enough).

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

\[
A_T^2 = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2} = \frac{J_3}{2J_{2s}} \text{ but indeed } < A_T^2 >_{bin} = \frac{\int_{bin} F_T A_T^2 \Gamma'}{\int_{bin} F_T \Gamma'}
\]
• Projection fits on each angle in the **new variables**:

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

\[
\frac{d\Gamma'}{d\theta_I} = \Gamma' \sin \theta_I \left( \frac{3}{16} (3 - F_L) + \frac{3}{2} F_T P_2 \cos \theta_I - \frac{3}{16} (2 - 3F_T) \cos 2\theta_I \right)
\]

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

or if preferred \( A_{FB} = -3F_T P_2/2 \).

• 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...

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig-cdf}
\caption{CDF measurement of $A_T^2$}
\end{figure}

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

arXiv:1108.0695 [hep-ex] (more precision soon)
and LHCb...
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 ($\beta_\ell$) in $P_{i=1...6}$.

Two new specific observables comes out:

$$M_1 = \frac{4m^2_\ell}{q^2\beta^2_\ell} \frac{\text{Re} \left( A^L A^{R*}_L + A^L A^{R*}_R \right)}{\left| A^L_L \right|^2 + \left| A^L_R \right|^2 + (L \to R)} = \frac{J_{1s} - J_{2s} \frac{(2+\beta^2_\ell)}{\beta^2_\ell} }{4J_{2s}}$$

$$M_2 = \frac{4m^2_\ell}{q^2} \frac{\left| A_t \right|^2 + 2\text{Re}(A^L_0 A^{R*}_0)}{\left| A^L_0 \right|^2 + \left| A^R_0 \right|^2} = -\beta^2_\ell \frac{J_{1c} + J_{2c} \frac{1}{\beta^2_\ell}}{J_{2c}}$$

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 $M_{1 \mu}$ (left) and $M_{2 \mu}$ (right) [scalar]:

- $M_1$ exhibits some sensitivity to $C_7, C_7'$ 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

\[ A_{I}(B \rightarrow K^{*}ll) : \]
Isospin Asymmetry

Definition:

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

- Description for invariant mass of the lepton pair small:
  \[1 \leq q^2 \leq 6 \text{ GeV}^2\]

- Systematic theoretical description using QCD factorization in the heavy quark limit.

- Sensitivity to NP via **spectator quark** in exclusive modes ≠ inclusive counterparts in the short-distance dynamics.
For increasing values of $q^2$ 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 $\gamma$ is radiated from spectator quark in \textbf{annihilation} or \textbf{spectator-scattering} diagrams.

- Contributions sensitive to the charge of the spectator quark.

\[
C_9^\perp(q^2) = [1 + b_\perp(q^2)]C_9^{(0)\perp}(q^2), \quad C_9^\parallel(q^2) = [1 + b_\parallel(q^2)]C_9^{(0)\parallel}(q^2)
\]

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

\[
\frac{dA_I}{dq^2}[B \rightarrow K^* l^+ l^-] = \text{Re}(b_d^\perp - b_u^\perp) \times f(C_9^\perp, C_9^\parallel, C_{10}, b_d^\perp, b_u^\parallel, \xi^\perp, \xi^\parallel)
\]

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

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

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 $O_{1-6}$, (b) Hard spectator interaction involving the gluonic penguin operator $O_8$, (c) Hard spectator interaction involving the operators $O_{1-6}$. [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 $C_{7}^{\text{eff}}$ 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 $A_{FB}$.

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Rare B decays: The Terminator for New Physics?
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 $K_1^{\parallel(a)}$ and $K_2^{\perp(a)}$. 

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Rare B decays: The Terminator for New Physics?
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 \( \delta C_7 \) and \( \delta C_8 \). 

![Graph of \( dA_I/dq^2 \) vs \( q^2 \)]

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 \( A_I(B \rightarrow K^*\gamma) \)
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 $\delta C$.

- 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 $\delta C$ preferred but still very far away from Babar data.
Babar/Belle measurement:

Babar finds $3.9\sigma$, Belle is consistent with Babar for two of the bins. Above $J/\psi$ Babar and Belle are consistent with SM.
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 $B \rightarrow K^*(\rightarrow K\pi)\mu^+\mu^-$ observables $P_i$ **stay tuned** in the following years, since they will play a central role in signaling/constraining new New Physics regions.