Constraining New Physics in $b \to s$ with ~~WilsonFitter~~

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2nd Meeting SUSY/BSM Fit WG, DESY Hamburg
November 22nd, 2010

Constraining New Physics in $b \to s$ with EOS

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on behalf of the EOS WG

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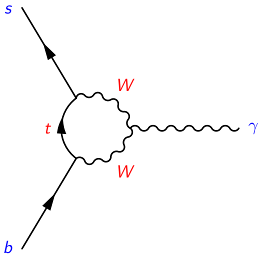
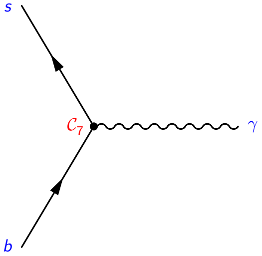
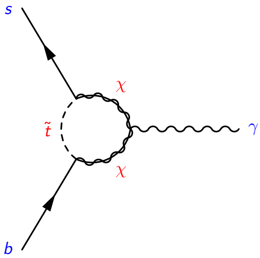
http://project.het.physik.tu-dortmund.de/eos/

New Physics Contributions to FCNCs

- $b \to s$ transitions mediated by Flavor Changing Neutral Currents
- New Physics contributions can enter via extended particle content
- probe for new physics indirectly by studying loop dominated processes







Model Independent Analysis

$b \to s$ Hamiltonian

$$\mathcal{H}^{\rm eff} = -\frac{4G_{\rm F}}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i(\mu) \mathcal{O}_i(\mu)$$

SM basis (dominant operators for $b \to s\ell^+\ell^-$):

$$\mathcal{O}_7 \propto [\bar{s}\sigma_{\mu\nu} P_R b] F^{\mu\nu} \qquad \mathcal{O}_{9(10)} \propto [\bar{s}\gamma_\mu P_L b][\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$

- calculate long distance physics via $\langle \ldots | \mathcal{O}_i(\mu = m_b) | \ldots \rangle$
- treat $\mathcal{C}_i(\mu = m_b)$ as free parameters, $i = (7), 9, 10$
- search for best-fit solutions in the $\mathcal{C}_i$ parameter space
- $|\mathcal{C}_7|$ constrained by existing $\mathcal{B}(b \to s\gamma)$ data: $|\mathcal{C}_7| \simeq |\mathcal{C}_7^{\rm SM}|$
- fit $\mathcal{C}_{9,10}$ from existing $B \to K^*\ell^+\ell^-$ and $B \to X_s\ell^+\ell^-$ data

Long Distance Physics – Observables

each $\Delta B = 1$ observable is $P \equiv P(\mathcal{C}_i)$

Exclusive

- $B \to K^*\ell^+\ell^-$: $\mathcal{B}, A_{\rm FB}, F_{\rm L}, A_{\rm T}^{(i)}$ at NLO α_s
  $1\,\mathrm{GeV}^2 \le q^2 \le 6\,\mathrm{GeV}^2$
  M. Beneke et al '01 and '04
- $B \to K^*\ell^+\ell^-$: $\mathcal{B}, A_{\rm FB}, F_{\rm L}, H_{\rm T}^{(i)}$ at NLO in α_s
  $14\,\mathrm{GeV}^2 \le q^2 \le q^2_{\rm max}$
  B. Grinstein, D. Pirjol '04
  C. Bobeth, G. Hiller, DvD '10

Inclusive

- $B \to X_s\ell^+\ell^-$: $\mathcal{B}$ at NNLO, $1/m_b$ and log-enh. EM corr.
  $1\,\mathrm{GeV}^2 \le q^2 \le 6\,\mathrm{GeV}^2$
  T. Huber et al '05
- $B \to X_s\gamma$: $\mathcal{B}$ NNLO in the SM
  NP contr. only at LO
  $E_\gamma \ge 1.6\,\mathrm{GeV}$
  M. Misiak et al '06

CP asymm. $(B \to K^*\ell^+\ell^-)$ in preparation

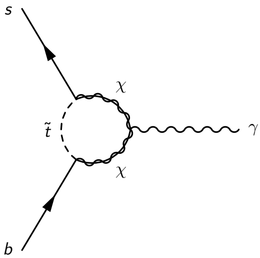
Short Distance Physics – Wilson Coefficients

$b \to s$ Wilson coefficients in the SM as implemented

- matching to SM at NNLO in α_s
- running at NNLO in α_s
- NNLO in α_s & α_e planned for matching and running.
- based on C. Bobeth, P. Gambino, M. Gorbahn, U. Haisch '03

Evaluation in SUSY models:

- e.g. additional chargino/charged higgs loops
- work in progress S. Schacht



Scan Implementations

Method # 1:
implemented + fully tested

- goodness-of-fit scans for all observables
- uses numeric code directly
- expensive: numeric integrations (QCDF, integrated observables)
- needs much computing resources
- example (CPV): 10^7 points take 16 nodes × 8 cores × 1 week

Method # 2:
implemented + caveat emptor

- specialised scans for observable subset
- exploit polynomial structure of observ. in $\mathcal{C}_i$
- determine polynomial of integrated observables
- works even on a laptop (fast!)
- example (CPV): 10^7 points take 1 laptop × 1 core × 40 min

Global Constraints

- use available input on all implemented processes
- calculate goodness-of-fit of measurement $X \pm \sigma$ to prediction $T \pm \Delta^{\pm}$

$$\sigma \cdot \chi = \begin{cases} \min\{T \pm \Delta^{\pm} - X\} & X \notin [T - \Delta^{-},\ T + \Delta^{+}] \\ 0 & \text{otherwise} \end{cases}$$

- sum up χ^2 for all inputs and calculate likelihood:

$$-2 \ln \mathcal{L} = \sum_i \chi_i^2$$

- quite conservative approach

Global Constraints

- scan over components of Wilson coefficients: $c_a = |\mathcal{C}_i|, \arg \mathcal{C}_i$
- marginalise scan with more than two components $< c_a, c_b >$:

$$\mathcal{L}(c_a, c_b, c_c, \dots, c_z) \mapsto \mathcal{L}(c_a, c_b) \equiv \max_{c_c, \dots, c_z} \mathcal{L}$$

- alternatively:

$$\mathcal{L}(c_a, c_b, c_c, \dots, c_z) \mapsto \mathcal{L}(c_a, c_b) \equiv \frac{1}{V} \int_V \mathrm{d}c_c \dots \mathrm{d}c_z \, \mathcal{L}$$

Global Constraints – Inputs

Included:

- $B \to K^* \ell^+ \ell^-$: $\mathcal{B}$ (3 q^2 bins), $A_{\rm FB}$ (3 q^2 bins), $F_{\rm L}$ (1 q^2 bins)
  Source: Belle '09, CDF '10 (preliminary)

- $B \to X_s \ell^+ \ell^-$: $\mathcal{B}$ (1 q^2 bin)
  Source: BaBar '04, Belle '05

- $B \to X_s \gamma$: $\mathcal{B}$ for $E_\gamma > 1.6\, GeV$
  Source: HFAG (March '10)

total of 17 inputs included

Global Constraints – Inputs

Available:

- $B \to K\ell^+\ell^-$: $\mathcal{B}$ and A_{FB} (3 q^2 bins each)
  Source: Belle '09, CDF '10 (preliminary)

total of 12 inputs not yet included

Excluded:

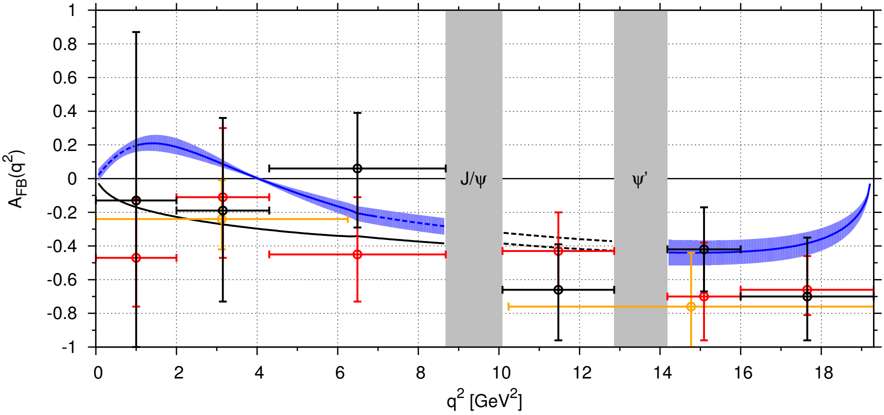
- $B \to K^*\ell^+\ell^-$: $\mathcal{B}$, A_{FB} and F_{L} (2 q^2 bins each)
  BaBar '06/'08 data have unsuitable q^2 binning

total of 6 inputs unusable

Global Constraints – Input Example ($B \to K^*\ell^+\ell^-$)

SM Result for A_{FB}

Exp. Data: BaBar'08, Belle'09, CDF'09



Large Recoil $q^2 \ll m_b^2$

$q^2 \simeq m_b^2$ Low Recoil

C.Bobeth,G.Hiller,DvD '10

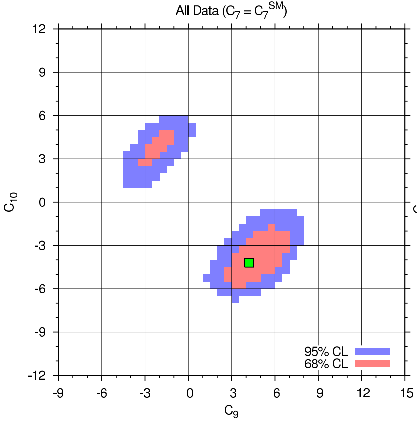
Global Constraints – SM Basis

- fix $|\mathcal{C}_7|$ to best-fit solution from $\mathcal{B}(B \to X_s\gamma)$ ($\simeq |\mathcal{C}_7^{\mathrm{SM}}|$)
- scan 30 points in both $\mathcal{C}_9$ and $\mathcal{C}_{10}$ with 0.5 increment
- scan for both signs $\mathcal{C}_7 = \pm\mathcal{C}_7^{\mathrm{SM}}$
- use SM values of $\mathcal{C}_{1\ldots6}, \mathcal{C}_8$ (less sensitive to NP)

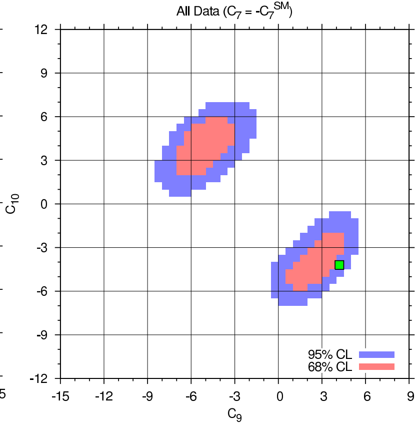
Global Constraints – SM Basis

$\mathcal{C}_9$ vs $\mathcal{C}_{10}$: green square marks the SM

$\mathcal{C}_7 = +\mathcal{C}_7^{\rm SM}$



$\mathcal{C}_7 = -\mathcal{C}_7^{\rm SM}$



C.Bobeth, G.Hiller, DvD '10

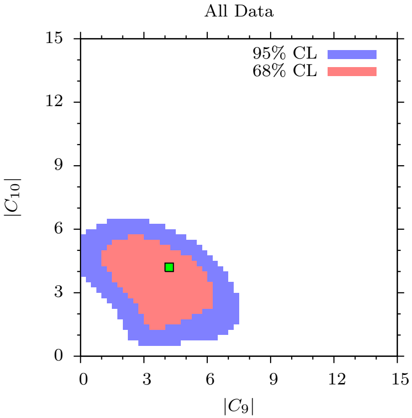
Data Sources: Belle + CDF data of $B \to K^* \ell^+ \ell^-$, BaBar + Belle data of $B \to X_s \ell^+ \ell^-$

Global Constraints – SM Basis + CPV

- fix $|\mathcal{C}_7|$ to best-fit solution from $\mathcal{B}(B \to X_s\gamma)$ ($\simeq |\mathcal{C}_7^{\mathrm{SM}}|$)
- scan 60 points in both $|\mathcal{C}_9|$ and $|\mathcal{C}_{10}|$ with 0.25 increment
- scan 16 points in $\arg \mathcal{C}_7$
- scan 32 points in both $\arg \mathcal{C}_9$ and $\arg \mathcal{C}_{10}$
- use SM values of $\mathcal{C}_{1\ldots6}, \mathcal{C}_8$ (less sensitive to NP)
- marginalize to $\mathcal{L}(|\mathcal{C}_9|, |\mathcal{C}_{10}|)$

Global Constraints – SM Basis + CPV

PRELIMINARY, $|\mathcal{C}_9|$ vs $|\mathcal{C}_{10}|$. Green square marks the SM.



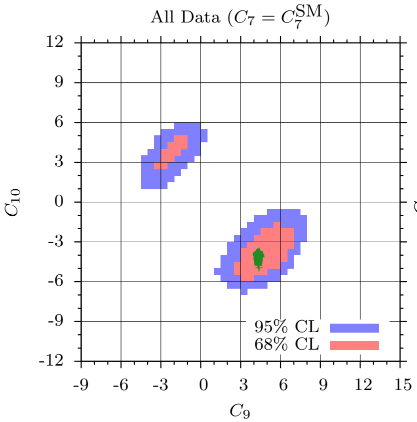
C.Bobeth, G.Hiller, DvD (in preparation)

Data sources: Belle + CDF data of $B \to K^*\ell^+\ell^-$, BaBar + Belle data of $B \to X_s\ell^+\ell^-$

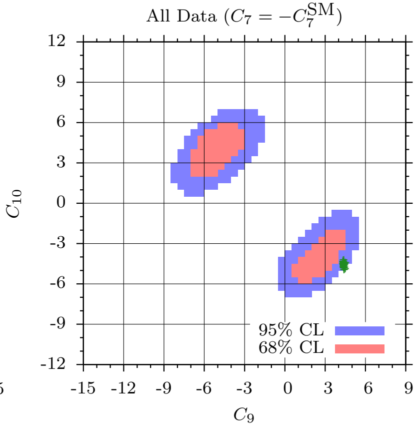
Global Constraints – Comparison MSSM+MFV

VERY PRELIMINARY, $\mathcal{C}_9$ vs $\mathcal{C}_{10}$, MSSM (charged higgs + charginos) in green

$\mathcal{C}_7 = +\mathcal{C}_7^{\rm SM}$



$\mathcal{C}_7 = -\mathcal{C}_7^{\rm SM}$



C.Gross, G.Hiller, S.Schacht (in preparation)

Summary and Outlook

EOS is ...

- a generator/evaluator for several B flavor observables
- capable of constraining New Physics with existing data

We plan to ...

- fully implement $B \to X_s \gamma$ at NNLO (not started yet)
- implement $B \to K\ell^+\ell^-$ (work in progress)
- broaden the operator basis to helicity-flipped, scalar and/or tensor operators (not started yet)

Proper release planned for 2011
(However, sources are already available on the web)

http://project.het.physik.tu-dortmund.de/eos/

Literature

- $B \to K^* \ell^+ \ell^-$ NLO calculation at Large Recoil (M.Beneke, T.Feldmann, D.Seidel '01 and '04): `arxiv:hep-ph/0106067` and `arxiv:hep-ph/0412400`
- $B \to K^* \ell^+ \ell^-$ Low Recoil observables and model independent analysis (C.Bobeth, G.Hiller, DvD '10): `arxiv:1006.5013 [hep-ph]`
- $B \to X_s \ell^+ \ell^-$ NNLO branching ratio (C.Bobeth, P.Gambino, M.Gorbahn, U.Haisch '03): `arxiv:hep-ph/0312090`
- $B \to X_s \ell^+ \ell^-$ NNLO branching ratio (T.Huber, E.Lunghi, M.Misiak, D.Wyler '05): `arxiv:hep-ph/0512066`
- $B \to X_s \gamma$ NNLO branching ratio (M.Misiak et al '06): `arxiv:hep-ph/0609232`

Outline

EOS Implementation

- written in `C++-0x` (GCC version $\geq$ 4.4)
- mostly self-contained, only one external dependency (GNU Scientific Library)
- multi-threaded calculations
- memoisation of expensive calculations
- extensive testing framework (Unit Tests), covering physics and utilities alike

Operators beyond the SM

(pseudo)scalar operators:

$$\mathcal{O}_{S(P)} \propto [\bar{s} P_R b][\bar{\ell}\ell]$$

(pseudo)tensor operators:

$$\mathcal{O}_{T(T5)} \propto [\bar{s}\sigma_{\mu\nu} b][\bar{\ell}\sigma^{\mu\nu}(\gamma_5)\ell]$$

helicity-flipped basis (dominant operators for $b \to s\ell^+\ell^-$):

$$\mathcal{O}'_7 \propto [\bar{s}\sigma_{\mu\nu} P_L b] F^{\mu\nu} \qquad \mathcal{O}'_{9(10)} \propto [\bar{s}\gamma_\mu P_R b][\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$