Towards a global fit to extract the $B \to X_s\gamma$ decay rate and $|V_{\mathrm{ub}}|$.

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ICHEP Paris, July 2010

SIMBA Collaboration

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Supported by

Bundesministerium
für Bildung
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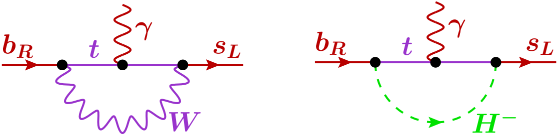
Hints for new physics in the flavour sector

- BSM physics if present in the observed flavour sector is small and enters via loops. $B \to X_s\,\gamma$ decay rate sensitive to BSM physics. Good knowledge of SM theory prediction and measurements needed for a hunt.



SM and MSSM graph for $B \to X_s\,\gamma$.

- Model independent framework that combines all available information into a global fit for the $B \to X_s\,\gamma$ decay rate desirable to constrain BSM.

- Aim of **SIMBA**: provide a global fit that combines all available information on $B \to X_s\,\gamma$, $B \to X_c\,l\,\bar{\nu}$ and $B \to X_u\,l\,\bar{\nu}$ to extract $|V_{\rm ub}|$ and the $B \to X_s\,\gamma$ decay rate.

The shape function: $\widehat{F}(k)$

Ligeti, Stewart, Tackmann (in preparation)

$$\frac{\mathrm{d}\Gamma_{B\to X_s\gamma}}{\mathrm{d}E_\gamma} \propto |C_7^{\mathrm{incl}}|^2 \left(\int \mathrm{d}k\, \Gamma_{77}(E_\gamma, k)\, \widehat{F}(k) + \sum_m \Gamma_m\, \widehat{F}_m(k) \right) + \sum_{i\neq 7} \mathcal{O}(C_7^{\mathrm{incl}} C_i) + \sum_{ij\neq 77} \mathcal{O}(C_i C_j)\,,$$

- The b quark distribution function in the B meson (the shape function) determines shape of $B \to X_s\gamma$ spectrum and contains non-perturbative physics.
- Dominant contributions from $C_{i\neq 7}$ can be absorbed into new Wilson coefficient $C_7^{\mathrm{incl}} = C_7 + \sum_k\ C_k$.
- Residual contributions $\backsim C_{i\neq 7}$ are very small.
- $\widehat{F}_m$: $\frac{1}{m_b}$ corrections from subleading shape functions.

The shape function: $\widehat{F}(k)$

Ligeti, Stewart, Tackmann (in preparation)

$$\frac{\mathrm{d}\Gamma_{B\to X_s\gamma}}{\mathrm{d}E_\gamma} \propto |C_7^{\rm incl}|^2 \left(\int \mathrm{d}k\, \Gamma_{77}(E_\gamma, k)\, \widehat{F}(k) + \sum_m \Gamma_m \widehat{F}_m(k) \right) + \sum_{i\neq 7} \mathcal{O}(C_7^{\rm incl} C_i) + \sum_{ij\neq 77} \mathcal{O}(C_i C_j)\,,$$

- Current analysis of $B \to X_s\gamma$ measurements uses extrapolation to obtain $\mathcal{B}(E_\gamma > 1.6)$ by fixing $\widehat{F}(k)$ to a model function:

  $\mathcal{B}(E_\gamma > 1.6) = (3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$ from HFAG [hep-ex/0603003]

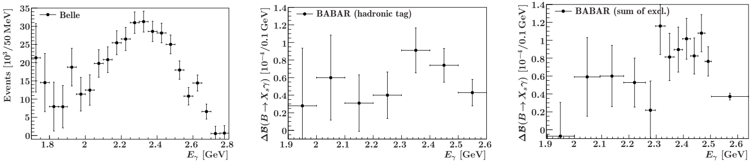
- Can be compared with calculated value at two-loop in the local OPE region:

  $\mathcal{B}(E_\gamma > 1.6) = (3.15 \pm 0.23) \times 10^{-4}$ from Misiak *et al.* [hep-ph/0609232v2]

- Model function introduces model dependencies. Is there a better way?

A new strategy to constrain BSM physics

- Sensitivity to BSM lies in normalization C_7^{incl}.
- **Strategy**: Global fit to all available data on photon energy spectrum to determine both $\widehat{F}(k)$ and C_7^{incl} simultaneously.
- This offers a model independent alternative to extrapolating measurements down to $\mathcal{B}(E_\gamma > 1.6)$.



Partial differential $B \to X_s\,\gamma$ decay rate, as measured by Belle and BaBar from

[arXiv.0907.1384,0711.4889,hep-ex/0508004].

Basis expansion of $\widehat{F}(k)$

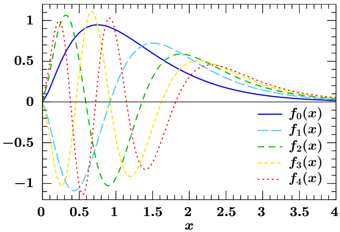
Ligeti, Stewart, $\widehat{F}$ Tackmann [arXiv:0807.1926]

Model dependent method: $\Rightarrow$ $\widehat{F}(k)$ model function.

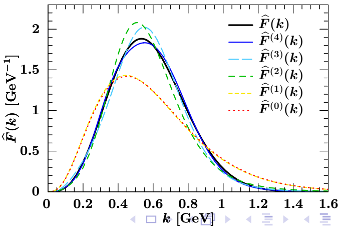
Model indep. method: $\Rightarrow$ Use basis expansion of model function and fit coefficients to measurement true shape of $\widehat{F}(k)$.

$$\widehat{F}(\lambda x) = \frac{1}{\lambda}\left(\sum_{n=0}^{\infty} c_n f_n(x)\right)^2, \qquad s.t. \qquad \int \mathrm{d}k\, \widehat{F}(k) = \sum_{n=0}^{\infty} c_n^2 = 1\,.$$

Functional basis



Expansion of Gaussian $\widehat{F}(k)$



Benefits and residual model dependencies

Benefits:

→ Minimizes model dependency.

→ Measurement determines precision, e.g. by including terms up to a specific order N.

→ Experimental uncertainties and correlations are captured in the basis coefficients c_n.

Truncating expansion at N terms introduces residual model dependencies from the chosen function basis:

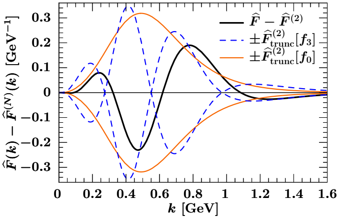
→ Overall size of truncation error scales with $1 - \sum_{n=0}^{N} c_n^2$.

→ Convergence of expansion can be studied by varying basis of expansion and order N of truncation.

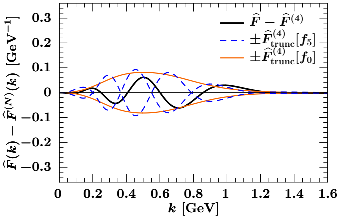
Truncation uncertainty

→ The truncation order N should be fixed s.t. the uncertainty due to the envelope generated by the truncation is small with respect to the experimental uncertainties of the fitted coefficients.

Truncation error at $N = 2$



Truncation error at $N = 4$



⇒ **Allows experimental driven estimation of shape function with uncertainties on reliable footing.**

Calculation and global fit

- Used theory for the fits is at NNLL/NNLO and includes $\frac{1}{m_b}$ corrections.
- It is straightforward to include constraints from $B \to X_c\, l\, \bar{\nu}$ and $B \to X_u\, l\, \bar{\nu}$ into the framework.
- Residual contributions from terms $\backsim \mathcal{O}(C_7^{\text{incl}} C_i)_{i\neq 7}$ and $\backsim \mathcal{O}(C_i C_j)_{ij\neq 77}$ are very small in our fit range and are neglected for now.

Disclaimer

→ Results are work in progress, numbers subject to change.

→ No theoretical uncertainties included yet.

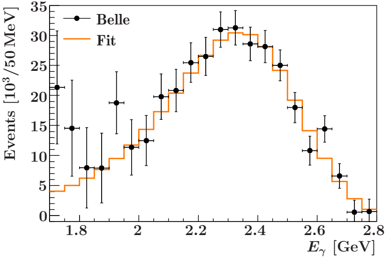
Fit Result for $B \to X_s \gamma$ spectra

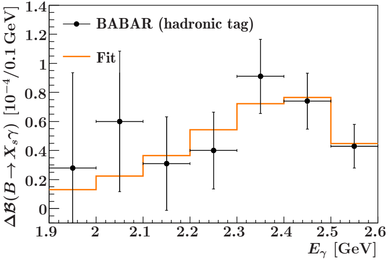
Fit for 5 coefficients and C_7^{incl}:

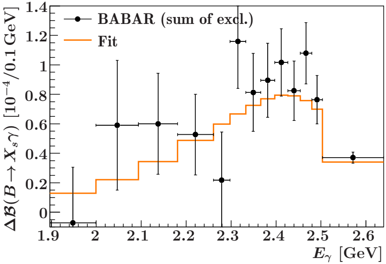
- χ^2 fit including experimental correlations

  $\to \chi^2/\text{dof} = 27.75/37$

- Fits validated with pseudo experiments

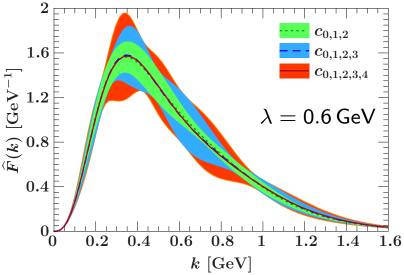






Fit Results for $\widehat{F}(k)$

$\widehat{F}(k)$ with different number of coefficients consistent and converging

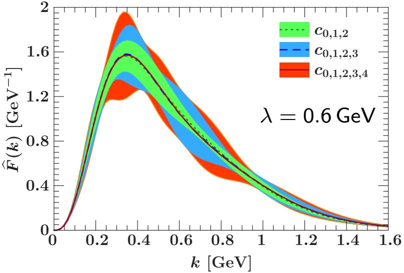


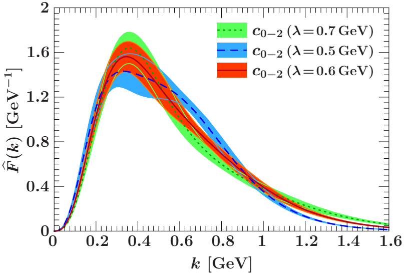
Fit Results for $\widehat{F}(k)$

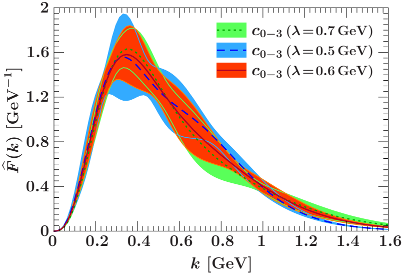
$\widehat{F}(k)$ with different number of coefficients consistent and converging

Different bases help to determine truncation error

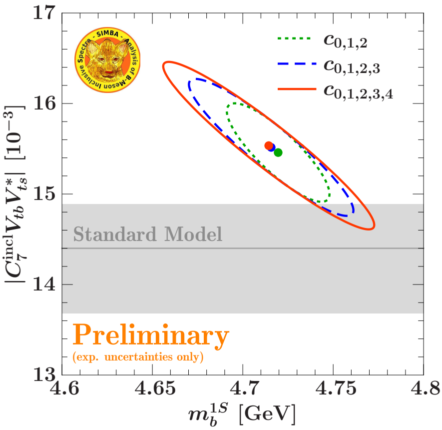
Here: need 4 coefficients for consistency between bases







Fit Result for $C_7^{\rm incl}\,|V_{tb}\,V_{ts}^*|$



- The extracted central value of $C_7^{\rm incl}\,|V_{tb}\,V_{ts}^*|$ is somewhat higher than SM prediction.
- This is consistent by comparing HFAG with Misiak *et al.*
- Too few coefficients (=fixed model) underestimate uncertainties.
- $C_7^{\rm incl\ SM} = 0.354^{+3.2\%}_{-3.5\%}$

  $|V_{tb}\,V_{ts}^*| = 40.68^{+0.9\%}_{-3.6\%} \times 10^{-3}$

Summary and Outlook

Summary:

$\rightarrow$ We showed the first fit results from **SIMBA** for the $B \rightarrow X_s \gamma$ differential rate, the nonpert. shape function, and $C_7^{\text{incl}} |V_{\text{tb}} V_{\text{ts}}^*|$ within a model independent framework.

$\rightarrow$ Simultaneously determined m_b^{1S} from $B \rightarrow X_s \gamma$ data.

Outlook:

$\rightarrow$ Include moment constraints of the shape function from $B \rightarrow X_c l \bar{\nu}$ and the $B \rightarrow X_u l \bar{\nu}$ decay rate to combine all information for a fit on $|V_{\text{ub}}|$.

$\rightarrow$ Include theory uncertainties into the fit procedure.