SIMBA: Theoretical Basics

Bahman Dehnadi

Deutsches Elektronen-Synchrotron

The SIMBA collaboration
Florian Bernlochner, Heiko Lacker, Zoltan Ligeti, Iain Stewart, Kerstin Tackmann, Frank Tackmann

SIMBA collaboration meeting, Nov 12th 2019, Hamburg, Germany
Theory overview
Effective weak interaction at low energies

\[ B \rightarrow X_s \gamma \]

100 GeV

5 GeV

\[ b_R \rightarrow c, t \quad \gamma \quad s_L \]

\[ Q \]

\[ \times C_7 \]
Precise measurement of $b \rightarrow s\gamma$ rate at low scale gives access to possible new physics contributions at high energies.

$B \rightarrow X_s \gamma$

Indirect search for new physics

$Q$

100 GeV

$5$ GeV

$\times (C_7 + C_7^{NP})$
$B \to X_s \gamma$

- $b \to s\gamma$ transition rate: $\frac{d\Gamma}{dE_\gamma} = |C_7|^2 \delta(E_\gamma - m_b/2)$
$B \rightarrow X_S \gamma$

- $b \rightarrow s \gamma$ transition rate: \(\frac{d\Gamma}{dE_\gamma} = |C_7|^2 \delta(E_\gamma - m_b/2)\)

- $E_\gamma$ spectrum determined by nonpert. B distribution (shape function)
\( B \rightarrow X_s \gamma \)

- \( b \rightarrow s\gamma \) transition rate: \( \frac{d\Gamma}{dE_{\gamma}} = |C_7|^2 \delta(E_{\gamma} - m_b/2) \)
- \( E_{\gamma} \) spectrum determined by nonperturbative B distribution (shape function)
- Tail and far-tail is mostly perturbative
$B \rightarrow X_s \gamma$

- $b \rightarrow s\gamma$ transition rate: $\frac{d\Gamma}{dE_\gamma} = |C_7|^2 \delta(E_\gamma - m_b/2)$
- $E_\gamma$ spectrum determined by nonperturbative $B$-meson distribution (shape function)
- Tail and far-tail is mostly perturbative
- $\Upsilon(4S)$ boost and exp. resolution further smears it all out
$B \rightarrow X_s \gamma$

- $b \rightarrow s\gamma$ transition rate: $d\Gamma/dE_\gamma = |C_7|^2 \delta(E_\gamma - m_b/2)$
- $E_\gamma$ spectrum determined by nonperturbative B-meson distribution (shape function)
- Tail and far-tail is mostly perturbative
- $\Upsilon(4S)$ boost and exp. resolution further smears it all out
- Most experimental sensitivity comes from peak region at higher $E_\gamma$
$B \rightarrow X_S \gamma$

- $b \rightarrow s\gamma$ transition rate: $\frac{d\Gamma}{dE_\gamma} = |C_7|^2 \delta(E_\gamma - m_b/2)$
- $E_\gamma$ spectrum determined by nonperturbative B-meson distribution (shape function)
- Tail and far-tail is mostly perturbative
- $\Upsilon(4S)$ boost and exp. resolution further smears it all out
- Most experimental sensitivity comes from peak region at higher $E_\gamma$

Ready for global fit to inclusive $B \rightarrow X_S \gamma$ measurements
What to do next?
Theory Uncertainty

Residual scale dependencies are used to assign a perturbative uncertainty

\[ B \rightarrow X_s \gamma \]
Scales are not physical parameters with an uncertainty that can be propagated, they simply specify a particular perturbative scheme.

Scale variation does not provide any insight into the correlation in the spectrum!
Unknown corrections at higher orders are the actual sources of perturbative theory uncertainty

\[ c_0 + \alpha_s(\mu) \left[ c_1 + \alpha_s(\mu) c_2 \right] + \mathcal{O}(\alpha_s^3) \]
Basic Idea: treat them as theory nuisance parameters

- Encode correct correlations
- Can be propagated straightforwardly
- Can be consistently included in a fit and constrained by data

Unknown corrections at higher orders are the actual sources of perturbative theory uncertainty

\[ c_0 + \alpha_s(\mu) \left[ c_1 + \alpha_s(\mu) \left[ c_2 + \alpha_s(\mu) c_3 \right] \right] + \mathcal{O}(\alpha_s^4) \]
Unknown corrections at higher orders are the actual sources of perturbative theory uncertainty

\[ c_0 + \alpha_s(\mu) \left[ c_1 + \alpha_s(\mu) \left[ c_2 + \alpha_s(\mu) c_3 \right] \right] + \mathcal{O}(\alpha_s^4) \]

**Basic Idea:** treat them as **theory nuisance parameters**

- Encode correct correlations
- Can be propagated straightforwardly
- Can be consistently included in a fit and constrained by data

**Task:** Implement the full next order in terms of unknown parameters

 *(work in progress)*
Similar theoretical framework for $B \rightarrow X_u \ell \bar{\nu}$

- $B \rightarrow X_u \ell \bar{\nu}$ is a 3-body problem → extended phase space
- Sub-leading corrections (and shape functions) play crucial role

$B \rightarrow X_s \gamma :$ absorb all the sub-leading shape functions into the leading shape function

$$\hat{F}_s(k) = \hat{F}(k) + \frac{1}{m_b} \left[ \hat{F}_1(k) + \hat{F}_2(k) - \hat{F}_3(k) + \hat{F}_4(k) \right]$$

$B \rightarrow X_u \ell \bar{\nu} :$ account for a more complicated linear combination of the sub-leading shape functions (more involved kinematic dependence)

- Nonperturbative shape functions are universal functions
Similar theoretical framework for $B \rightarrow X_u \ell \bar{\nu}$

- $B \rightarrow X_u \ell \bar{\nu}$ is a 3-body problem → extended phase space
- Sub-leading corrections (and shape functions) play crucial role

\[ \hat{F}_s(k) = \hat{F}(k) + \frac{1}{m_b} [\hat{F}_1(k) + \hat{F}_2(k) - \hat{F}_3(k) + \hat{F}_4(k)] \]

- $B \rightarrow X_u \ell \bar{\nu}$: account for a more complicated linear combination of the sub-leading shape functions (more involved kinematic dependence)

- Nonperturbative shape functions are universal functions

✓ The aim:

- Global $B \rightarrow X_u \ell \bar{\nu} + B \rightarrow X_s \gamma$ fit using also Belle II measurements
- Simultaneously determine $|V_{tb}V_{ts}^*C_7^{incl}|$, $|V_{ub}|$, $m_b$
Summary and Outlook

- EFT for weak interactions at low energies (e.g. inclusive B meson decay rates)
- Global fit to inclusive $B \rightarrow X_s \gamma$ measurements [current status]
- Theoretical developments [work in progress]
  - Better control on theoretical uncertainties with nuisance parameters
  - Provide a more efficient implementation for theory (C++ program)
  - Fine-tune the theoretical framework for $B \rightarrow X_u \ell \bar{\nu}$
  - Global $B \rightarrow X_s \gamma + B \rightarrow X_u \ell \bar{\nu}$ fit using also Belle II measurements

Thank you for your attention!