$|V_{ub}|$ and $|V_{cb}|$ from Inclusive B Decays

Frank Tackmann

Massachusetts Institute of Technology

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Outline

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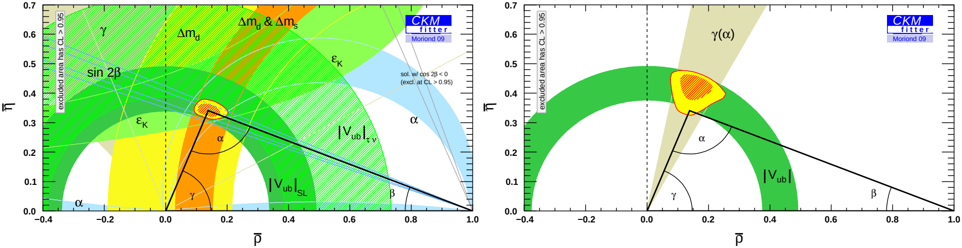
1. Introduction
2. Inclusive $|V_{cb}|$
   - Global Fits
3. Inclusive $|V_{ub}|$
   - Current Status
   - New Developments

Why Care About $|V_{ub}|$ and $|V_{cb}|$?



$|V_{ub}|$ and $|V_{cb}|$ are important ingredients in Unitarity Triangle

- $|V_{ub}|$ dominant uncertainty in side opposite β
  - $\sin 2\beta$ favors small $|V_{ub}| \Rightarrow > 2\sigma$ tension (amplified by $B \to \tau\nu$)
- Constraint from ϵ_K depends on $|V_{cb}|^4$
- Crucial to obtain SM reference UT to compare tree and loop processes

To turn small discrepancies into hints of New Physics, model independent predictions are mandatory

Inclusive vs. Exclusive vs. Leptonic $|V_{ub}|$

Small but persistent systematic difference between inclusive and exclusive

Leptonic: $10^3|V_{ub}|_{B\to\tau\nu} = 5.2 \pm 0.5_{[\mathrm{exp}]} \pm 0.4_{[f_B]}$

Inclusive OPE: $10^3|V_{ub}|_{\mathrm{BLL}} = 4.87 \pm 0.24_{[\mathrm{exp}]} \pm 0.38_{[\mathrm{theory}]}$

Inclusive SCET: $10^3|V_{ub}|_{\mathrm{BLNP}} = 4.32 \pm 0.16_{[\mathrm{exp}]}\,{}^{+0.32}_{-0.27}{}_{[\mathrm{theory}]}$

Exclusive: $10^3|V_{ub}|_{B\to\pi\ell\nu} = 3.38 \pm 0.36_{[\mathrm{exp+lattice}]}$

- Uncertainties in inclusive determinations are underestimated
- Exclusive almost at 10% from improved lattice calculation combined with model independent treatment of $B \to \pi\ell\nu$ form factor [Fermilab/MILC (2008)]

[$\longrightarrow$ see talk by Ruth Van de Water]

Before starting to get excited about a charged Higgs in $B \to \tau\nu$

- Inclusive and exclusive $|V_{ub}|$ have to converge
- Uncertainty on f_B should go down

Inclusive vs. Exclusive $|V_{cb}|$

Looks like $|V_{cb}|$ wants to get some attention as well

Inclusive OPE: $10^3|V_{cb}|_{\text{kinetic}} = 41.48 \pm 0.48_{[\text{exp}]} \pm 0.58_{[\text{theory}]}$

Exclusive: $10^3|V_{cb}|_{B\to D\ell\nu} = 39.1 \pm 1.4_{[\text{exp}]} \pm 0.9_{[\text{lattice}]}$

Exclusive: $10^3|V_{cb}|_{B\to D^*\ell\nu} = 38.3 \pm 0.5_{[\text{exp}]} \pm 1.0_{[\text{lattice}]}$

[$\longrightarrow$ see talk by Christoph Schwanda]

Recent first unquenched lattice calculation of $B \to D^*\ell\nu$ form factor

[Fermilab/MILC (2008)] [$\longrightarrow$ see talk by Ruth Van de Water]

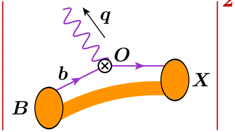
- Exclusive $|V_{cb}|$ is 8% lower than inclusive ($> 2\sigma$ discrepancy)
- Hard to imagine how inclusive $|V_{cb}|$ could go down more than $\sim 0.5\%$

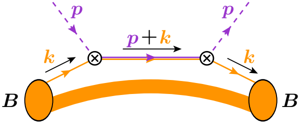
Outline

OPE for Inclusive Decays

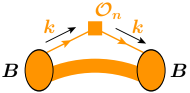
Dependence on final state X drops out when summing over all X

$$\mathrm{d}\Gamma = \sum_X \Big| \quad \Big|^2 = \mathrm{Im}$$





$$= \sum_n \qquad \times$$



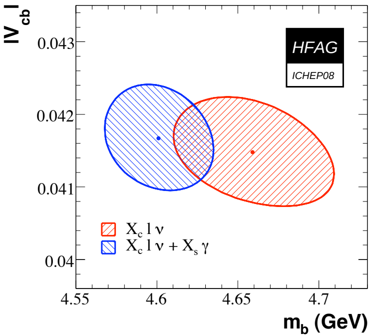
$$= \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 \left[C_0(\alpha_s) 1 + \frac{0}{m_b} + C_1(\alpha_s) \frac{\lambda_1}{m_b^2} + C_2(\alpha_s) \frac{\lambda_2}{m_b^2} + \cdots \right]$$

- LD properties of B meson parametrized by MEs of local operators
  - $\mu_\pi^2 \sim -\lambda_1 \sim \langle k^2 \rangle, \quad \mu_G^2 \sim 3\lambda_2 \sim \langle \sigma_{\mu\nu} G^{\mu\nu} \rangle \sim m_{B^*}^2 - m_B^2$
- SD physics contained in perturbative coefficients $C_n(p)$
  - $C_0(\alpha_s)$ given by perturbative quark decay
  - To get well-behaved α_s series need a SD mass $m_b^{1S}, m_b^{\mathrm{kin}}, \ldots$

Global $|V_{cb}|$ Fits

$|V_{cb}|$ is determined from a combined fit

- $B \to X_c \ell \nu$ partial rates (with cut on E_ℓ)
  - Normalization determines $|V_{cb}|$
- $B \to X_c \ell \nu$ lepton energy and hadronic mass moments
  - Shapes of distributions (moments) determine quark masses $m_{b,c}$ and nonperturbative parameters $\lambda_{1,2}$, ...



Two schemes

- 1S [Bauer et al. (2002, 2004)], kinetic [Benson et al. (2003); Gambino, Uraltsev (2004)]

Current HFAG result in kinetic scheme

[→ see talk by Christoph Schwanda]

$$|V_{cb}| = 41.48 \cdot 10^{-3} \times (1 \pm 1.1\%_{[\text{fit}]} \pm 0.2\%_{[\tau_B]} \pm 1.4\%_{[\text{theory}]})$$

⇒ Limited by theory uncertainty

$B \to X_s\gamma$ Moments and $|V_{cb}|$

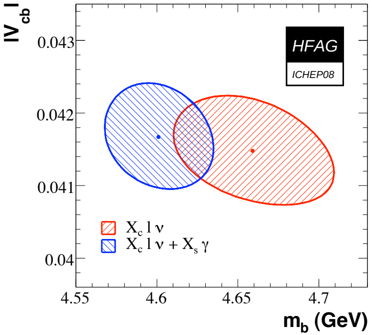
By default fit includes $B \to X_s\gamma$ photon energy moments

Input	$\lvert V_{cb}\rvert$ $[10^{-3}]$	$m_b^{\rm kin}$ [GeV]
$B \to X_c\ell\nu + X_s\gamma$	$41.67 \pm 0.43_{[\rm fit]} \pm \cdots$	4.601 ± 0.034
$B \to X_c\ell\nu$ only	$41.48 \pm 0.47_{[\rm fit]} \pm \cdots$	4.659 ± 0.049

- Application of local OPE to $B \to X_s\gamma$ moments is on much less solid ground than for $B \to X_c\ell\nu$ moments

If goal is

- to determine $|V_{cb}|$
  - $B \to X_c\ell\nu$ alone is as precise, so no reason to include $B \to X_s\gamma$ here
- to obtain precise m_b as input for $|V_{ub}|$ determination
  - There is a better way to include $B \to X_s\gamma$ data (as I will show)



Theory Status

Rate is a double expansion in α_s and $(\Lambda_{\mathrm{QCD}}/m_b)^n$

$$\mathrm{d}\Gamma = \frac{G_F^2 m_b^5}{192\pi^3}\,|V_{cb}|^2 \left[C_0(\alpha_s) 1 + \frac{0}{m_b} + C_1(\alpha_s)\frac{\lambda_1}{m_b^2} + C_2(\alpha_s)\frac{\lambda_2}{m_b^2} + \cdots \right]$$

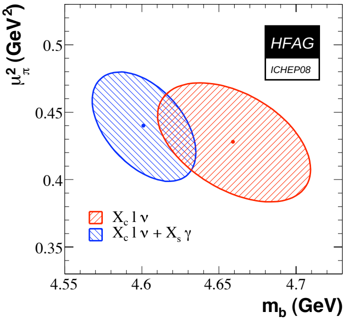
n		α_s^0	α_s^1	$\alpha_s^2\beta_0$	full α_s^2
0		✓	✓	✓	(✓)
2	$\lambda_1 \sim \mu_\pi^2$	✓	(✓)	(×)	
2	$\lambda_2 \sim \mu_G^2$	✓	(×)	×	
3	$\sim 1/m_b^3$	✓	×	×	
4	$\sim 1/m_b^4$	(✓)	×	×	
4	$\sim 1/m_c^2 m_b^3$	(×)	×	×	

- ✓ included in fits
- (✓) known, not yet included
- (×) being calculated
- × not known/needed

- Probably most important missing pieces are $\alpha_s \mu_G^2$ corrections

Existing Theory Improvements

- $\alpha_s \mu_\pi^2$: Expect $\sim 20\%$ shift in value of μ_π^2
  [Becher, Boos, Lunghi (2007)]
  - Likely no effect on $|V_{cb}|$, but will be interesting to see effect on m_b
- full α_s^2 vs. $\alpha_s^2 \beta_0$: Mostly affect total rate
  [Melnikov; Czarnecki, Pak (2008)]
  - Shift $|V_{cb}|$ by -0.5% (kinetic scheme) or -0.3% (1S scheme)



- $1/m_b^4$: Small effect ($\sim 0.25\%$ on total rate) [Dassinger, Turczyk, Mannel (2007)]

Limiting 1.4% theory uncertainty in kinetic scheme fit comes from first fitting for total $\mathcal{B}(B \to X_c \ell \nu)$ and then converting to $|V_{cb}|$

- Was obtained from estimates of now (mostly) known contributions
- With total and differential rates known at same level in expansion should avoid additional step and directly fit for $|V_{cb}|$

Wishlist for Future Fits

$$|V_{cb}| = 41.48 \cdot 10^{-3} \times \left(1 \pm 1.1\%_{[\mathrm{fit}]} \pm 0.2\%_{[\tau_B]} \pm 1.4\%_{[\mathrm{theory}]}\right)$$

Eagerly awaiting updated HFAG fit in the 1S scheme ...

How to gain confidence in $\mathcal{O}(1\%)$ (theory) uncertainties

- Please provide the theory expressions that are actually going into fits
- Compare separate fits at $\mathcal{O}(1, \alpha_s, \alpha_s^2)$
- Keep α_s as free fit parameter?
- How do you feel about adding theory errors in quadrature at 1% level?
  - Separate out fit uncertainties into experimental and theoretical parts
  - Should think carefully about theory correlations
  - If feasible, should also try RFit [CKM Fitter] treatment of theory uncertainties

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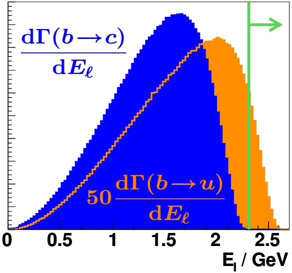
$|V_{ub}|$ from Inclusive $B \to X_u \ell \nu$

Removing huge charm background requires stringent phase space cuts

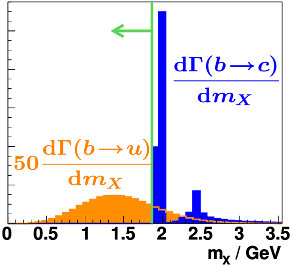
$$\mathcal{B}(B \to X_c \ell \nu)/\mathcal{B}(B \to X_u \ell \nu) \simeq 50$$

- Cuts can drastically enhance perturbative and nonperturbative corrections



Rates become sensitive to b-quark PDFs in B meson

- Determine shape of spectra
- Leading order: Universal shape function (SF) [Neubert (1993); Bigi et al. (1993)]
- $\mathcal{O}(\Lambda_{QCD}/m_b)$: Several more subleading shape functions [Bauer, Luke, Mannel (2001)]
- Need to be extracted from data (like any PDF)



[→ see talk by Elisabetta Barberio for recent measurements and averages]

Regions of Phase Space

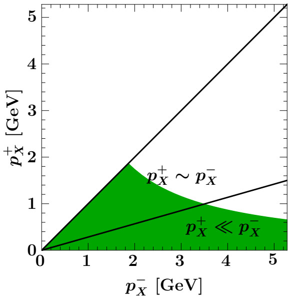
Kinematic variables: $p_X^\pm = E_X \mp |\vec{p}_X|$

Shape function region (SCET region): $p_X^+ \ll p_X^-$

- Leading order in $1/m_b$ requires nonperturbative shape function $S(\omega)$
  [Korchemsky, Sterman (1994); Bauer et al. (2001)]

$$\mathrm{d}\Gamma = H(E_\ell, p_X^\pm) \int \mathrm{d}\omega \, J[p_X^- (p_X^+ - \omega)] S(\omega)$$

- $\mathcal{O}(\alpha_s^2)$ corrections recently completed
  [Becher, Neubert (2005, 2006); Bonciani, Ferroglia; Asatrian et al.; Beneke et al.; Bell (2008)]



Local OPE region: $p_X^+ \sim p_X^-$ (large q^2, small E_ℓ)

- Leading order in $1/m_b$ given by quark decay (as in $B \to X_c \ell \nu$) known to $\mathcal{O}(\alpha_s, \alpha_s^2 \beta_0)$ [De Fazio, Neubert (1999); Gardi, Ridolfi, Gambino (2006)]

Cut on $m_X < m_D$ does not imply $p_X^+ \ll p_X^- \Rightarrow$ depends on both regions

Current Approaches

Current approaches are essentially based on theory for one region and are extrapolated/modeled into other region

	BLNP [Bosch et al. (2004, 2005)]	GGOU [Gambino et al. (2007)]
based on	SCET region	local OPE region
SCET region	$\mathcal{O}(\alpha_s)$ NLL resummation	$\mathcal{O}(\alpha_s, \alpha_s^2\beta_0)$ no resummation
local OPE region	partly $\mathcal{O}(\alpha_s)$, partly model	$\mathcal{O}(\alpha_s, \alpha_s^2\beta_0)$
m_b scheme	tied to SF scheme m_b^{SF}	uses kinetic scheme m_b^{kin}
nonpert. input	LO: universal SF $S(\omega)$ $1/m_b$: 3 subleading SFs	3 LO distribution functions $F_i(k_+, q^2)$

- BLL: local OPE at large q^2 (consistency important cross check) [Bauer, Ligeti, Luke (2000, 2001)]
- DGE: Fixed perturbative model for SF (from renormalon resummation) [Andersen, Gardi (2006, 2008)]

Non-Experimental Uncertainties

Theoretical uncertainties

- Unknown higher orders in α_s, $1/m_b$ expansions
- Weak annihilation (open question $\Rightarrow$ separate data into B^+ and B^0)

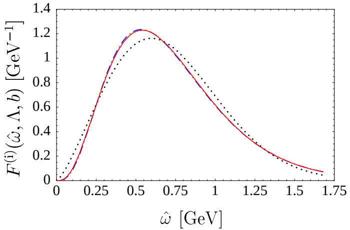
Uncertainties from input parameters

- m_b: Total rate $\sim |V_{ub}|^2 m_b^5$, partial rates with cuts $\sim |V_{ub}|^2 m_b^{\mathcal{O}(10)}$
  - Need precise m_b to get precise $|V_{ub}|$
  - Like to avoid scheme changes ($m_b^{1S} \leftrightarrow m_b^{\mathrm{SF}} \leftrightarrow m_b^{\mathrm{kin}}$)
  - Currently taken from $B \to X_c \ell\nu + X_s\gamma$ global $|V_{cb}|$ fits
- Leading shape/distribution function(s): Observables can depend on
  (a) only 1st moment $\simeq m_b$: total rate, q^2 spectrum
  (b) all moments, i.e. the full shape: p_X^+, large E_ℓ
  (c) something in between: m_X
  - Ideally: Extract from data (e.g. $B \to X_s\gamma$ spectrum)
  - Currently: Modeled with 1st+2nd moment fixed by m_b, μ_π^2

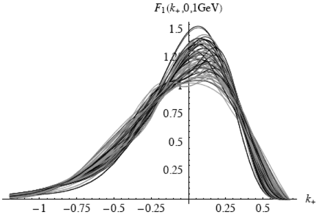
Shape Function Models and Uncertainties

LO SF models for fixed m_b, μ_π^2

BLNP



GGOU



	BLNP		GGOU
$\delta\|V_{ub}\|$(models)	2.2%	? ⟷	1.0%
$\delta\|V_{ub}\|(m_b, \mu_\pi^2)$	5.1%		3.9%

These model/SF uncertainties are an underestimate

- Use precise m_b, μ_π^2 from $|V_{cb}|$ fits but otherwise fixed model functions
- Shape variation should reflect the actual information we have

⇒ Currently, we do not know inclusive $|V_{ub}|$ to better than 10%

Caveats in Measurements

Monte Carlo signal model depends on the shape function

- Corresponding systematic uncertainty is correlated with m_b and SF uncertainty in the theory
- Can become dominant systematic uncertainty if signal shape is needed for background subtraction, e.g. Babar lepton endpoint [PRD 73, 012006 (2006)]

$\mathcal{B}$ with E_ℓ^{cut} [GeV]	$\mathbf{2.0}$	$\mathbf{2.1}$	$\mathbf{2.2}$	$\mathbf{2.3}$
other sys unc. [%]	$\mathbf{8.8}$	$\mathbf{8.6}$	$\mathbf{7.9}$	$\mathbf{6.6}$
SF sys unc. [%]	$\mathbf{6.0 - 13.3}$	$\mathbf{3.5 - 8.6}$	$\mathbf{1.6 - 4.0}$	$\mathbf{0.3 - 0.8}$

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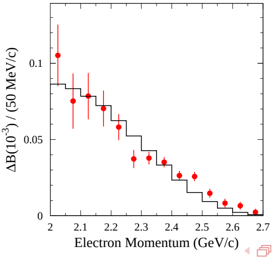
other sys unc. [%]	8.8	8.6	7.9	6.6
SF sys unc. [%]	$6.0 - 13.3$	$3.5 - 8.6$	$1.6 - 4.0$	$0.3 - 0.8$

Lepton-endpoint measurements define signal region with an explicit upper cut $E_\ell^\Upsilon < 2.6\,\mathrm{GeV}$

- Kinematic endpoint in $\Upsilon(4S)$ frame is $E_\ell^\Upsilon < 2.81\,\mathrm{GeV}$
- Rate is clearly nonzero for $E_\ell^\Upsilon > 2.6\,\mathrm{GeV}$
- *Impossible* to calculate on theory side



Strategy Towards Precision $|V_{ub}|$

Precision of inclusive $|V_{ub}|$ depends on

- How well we know m_b and SF and correlation between them
- Ability to (consistently) combine many different measurements
  - Different kinematic cuts: E_ℓ, m_X, q^2, p_X^+
  - Different analysis techniques: hadronic tag, untagged

First, reduce SF uncertainties by incorporating all available information on it

- Perturbative constraints (perturbative tail and RGE)
- Moment constraints (m_b, λ_1 from $B \to X_c \ell\nu$)
- Shape information from $B \to X_s\gamma$ and $B \to X_u \ell\nu$ spectra

Then repeat success strategy of inclusive $|V_{cb}|$

- Perform global fit to all available data
- Simultaneously determine $|V_{ub}|$ and inputs (m_b, SF)

  [Bernlochner, Lacker, Ligeti, Stewart, FT, K. Tackmann (work in progress)]

New and Improved Approach to Shape Function

[Ligeti, Stewart, FT (2008)]

Start with perturbative constraints on shape function. Derive factorized form

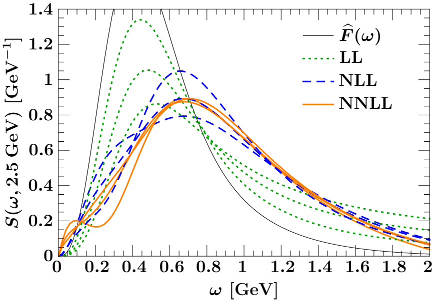
$$S(\omega, \mu_\Lambda) = \int \mathrm{d}k \, \widehat{C}_0(\omega - k, \mu_\Lambda) \, \widehat{F}(k)$$

$\widehat{F}(k)$ purely nonperturbative part

- Determines peak region

$\widehat{C}_0(\omega, \mu_\Lambda)$ perturbative (partonic SF)

- Determines tail consistent with RGE
- Known to $\mathcal{O}(\alpha_s, \alpha_s^2)$
  [Bauer, Manohar (2003); Becher, Neubert (2005)]
- For given $\widehat{F}(k)$ can calculate $S(\omega)$ order by order in α_s, vary μ_Λ to estimate perturbative uncertainty

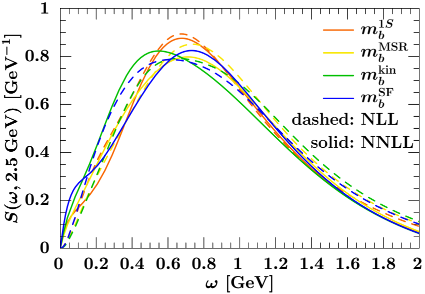


$\mu_\Lambda = (1.0, 1.3, 1.8)$ GeV
+ RGE to $\mu = 2.5$ GeV

Different Short Distance Schemes

$\widehat{C}$ and $\widehat{F}$ defined in generic short distance scheme, can use any m_b scheme!

$$
\begin{aligned}
S(\omega) &= \int \mathrm{d}k\, C_0^{\mathrm{pole}}(\omega - k)\, F^{\mathrm{pole}}(k) \\
&= \int \mathrm{d}k\, C_0^{1S}(\omega - k)\, F^{1S}(k) \\
&= \int \mathrm{d}k\, C_0^{\mathrm{kin}}(\omega - k)\, F^{\mathrm{kin}}(k) \\
&= \int \mathrm{d}k\, C_0^{\mathrm{SF}}(\omega - k)\, F^{\mathrm{SF}}(k) = \ldots
\end{aligned}
$$



Moments of $\widehat{F}(k)$ given by corresponding SD HQE parameters $\widehat{m}_b$, $\widehat{\lambda}_1$, ... (at any order in α_s), e.g.

$$
\int \mathrm{d}k\, k^n\, F^{1S\mathrm{i}}(k) = M_n = \begin{cases} 1 & (n = 0) \\ m_B - m_b^{1S} & (n = 1) \\ -\lambda_1^{\mathrm{i}}/3 + (m_B - m_b^{1S})^2 & (n = 2) \end{cases}
$$

$\Rightarrow$ Can avoid having to switch from different m_b scheme used for $B \to X_c \ell \nu$

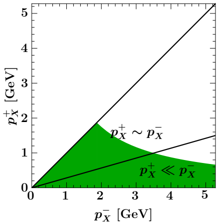
Master Formula

[Ligeti, Stewart, FT (to appear)]

Separation $S = \widehat{C} \otimes \widehat{F}$ allows to consistently connect

SCET region: $p_X^+ \ll p_X^-$

Local OPE region: $p_X^+ \sim p_X^-$



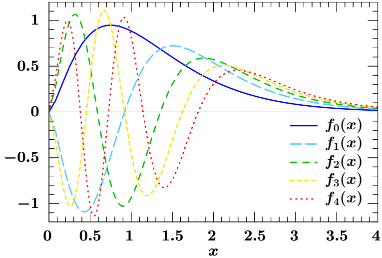
$$\mathrm{d}\Gamma = |V_{ub}|^2 K(E_\ell, p_X^-, p_X^+) \int \mathrm{d}k\, \widehat{W}_{\mathrm{pert}}(p_X^-, p_X^+, k)\, \widehat{F}(k)$$

- Combines optimal descriptions for different phase space regions
- Smooth transition between correct fixed-order result in local OPE region and RGE improved result in SCET region
- Not the case in any previous approach!

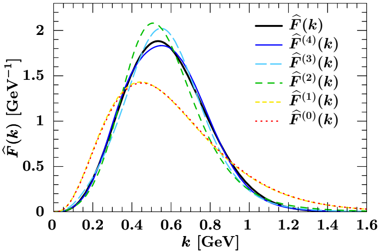
Next: Determine nonperturbative input function $\widehat{F}(k)$

Designer Orthonormal Basis Functions

Basis



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



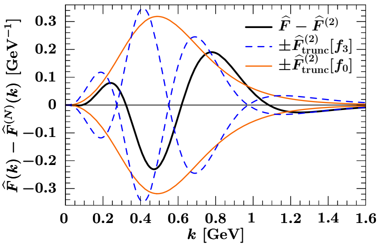
Design suitable orthonormal basis for $\widehat{F}(k)$ (formally model independent)

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

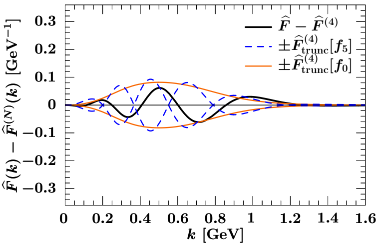
- Builds an orthonormal basis on top of any given model function
- Keep terms up to $n \le N$ as required by precision of data
- Experimental uncertainties and correlations can be properly captured by uncertainties and correlations in basis coefficients c_n

Estimating Residual Model Dependence

Truncation error at $N = 2$



Truncation error at $N = 4$



Truncating series at $n \leq N$ introduces residual dependence on basis model

- Overall size of truncation error scales with $1 - \sum_{n=0}^{N} c_n^2$
- Can test expansion by varying N and underlying basis model
- Choose final N so that truncation error is small compared to experimental uncertainties in coefficients

$\Rightarrow$ Allows for systematic, fully data driven SF uncertainties

Setup for Global $|V_{ub}|$ Fit

Use expansion $\widehat{F}(k) = \left[\sum_n c_n f_n(k)\right]^2$ in master formula and moments

$$\mathrm{d}\Gamma = |V_{ub}|^2 \sum_{n,m} c_n c_m K(E_\ell, p_X^\pm) \int \mathrm{d}k\, \widehat{W}_{\mathrm{pert}}(p_X^\pm, k) f_n(k) f_m(k)$$

$$M_j(m_b^{1S}, \lambda_1^{\mathrm{i}}) = \sum_{n,m} c_n c_m \int \mathrm{d}k\, k^j\, f_n(k) f_m(k)$$

Perform combined fit (similar to $|V_{cb}|$)

- $B \to X_u \ell\nu$ partial rates
  - Normalization determines $|V_{ub}|$
- $B \to X_s\gamma$ and $B \to X_u \ell\nu$ spectra
  - Shapes of distributions constrain $\widehat{F}(k)$ through basis coefficients c_n
- Known moments of $\widehat{F}(k)$
  - Consistently combines existing constraints on m_b^{1S}, λ_1^{i} (from $B \to X_c \ell\nu$ or anywhere else) with $B \to X_u \ell\nu$ and $B \to X_s\gamma$ data

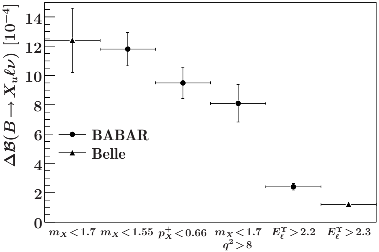
Proof-of-Concept

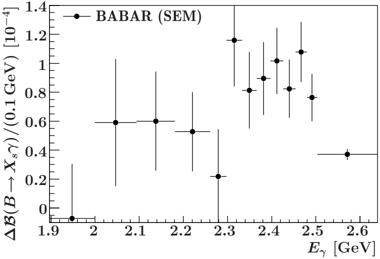
[Bernlochner, Lacker, Ligeti, Stewart, FT, K. Tackmann (work in progress)]

As proof-of-concept, fit to

- $B \to X_u \ell \nu$ hadronic tag
  - BABAR: $m_X, m_X - q^2, p_X^+$
  - Belle: m_X
- $B \to X_u \ell \nu$ lepton endpoint
  - BABAR: $E_\ell^\Upsilon > 2.2\,\mathrm{GeV}$
  - Belle: $E_\ell^\Upsilon > 2.3\,\mathrm{GeV}$
- $B \to X_s \gamma$ spectra
  - Babar sum over exclusive modes
  - Babar hadronic tag (not shown)
- m_b^{1S}, λ_1 from $B \to X_c \ell \nu$
  - Belle fit in 1S scheme

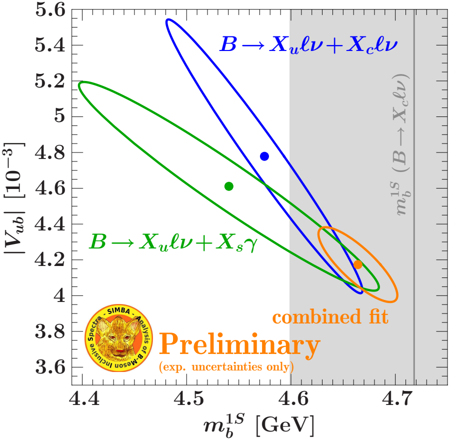
$$m_b^{1S} = (4.72 \pm 0.12)\,\mathrm{GeV}$$
$$\lambda_1 = (-0.31 \pm 0.09)\,\mathrm{GeV}^2$$

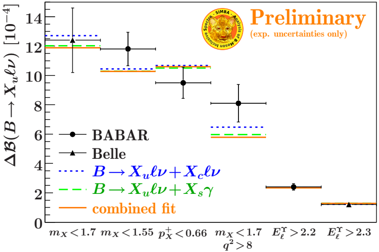


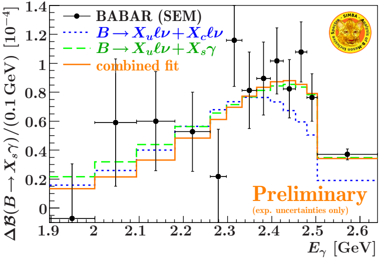


Proof-of-Concept

[Bernlochner, Lacker, Ligeti, Stewart, FT, K. Tackmann (work in progress)]







- Wrong E_γ spectrum without $B \to X_s\gamma$
- Significant improvement from combining $B \to X_s\gamma$ and $B \to X_c\ell\nu$

(Caution: Fits do not include theory uncertainties yet)

Conclusions

Tensions between inclusive and exclusive determinations

- Somewhat disturbing for $|V_{cb}|$
- For $|V_{ub}|$ remains to be seen with improved analyses

Inclusive $|V_{cb}|$ from global fits between $1\% - 2\%$

- Already theory limited, pushing theory below 1% very hard
- Need to be careful how to treat theory uncertainties at $\mathcal{O}(1\%)$ level

$\Rightarrow$ Some theory improvements still possible, will increase confidence

Inclusive $|V_{ub}|$

- Improved treatment of SF and multiple phase space regions
- Work in progress towards combining all information into global fit similar to $|V_{cb}|$
- Will provide more rigorous uncertainties and test of theory
- Key to precision inclusive $|V_{ub}|$ from Super Flavor Factory

SIMBA - Analysis of B-Meson Inclusive Spectra