Spontaneous Flavor Violation and the 2HDM

Based on arXiv:1811.00017 and 190X.XXXX

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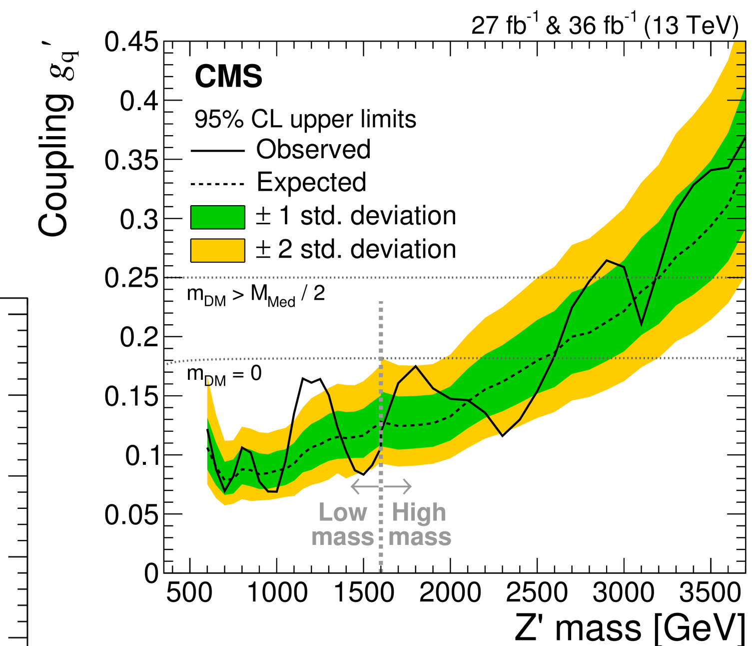
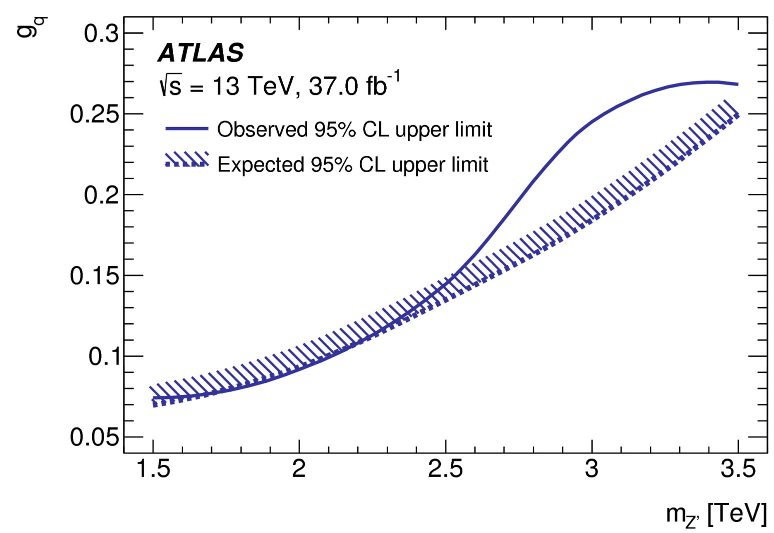
The Search for New Physics

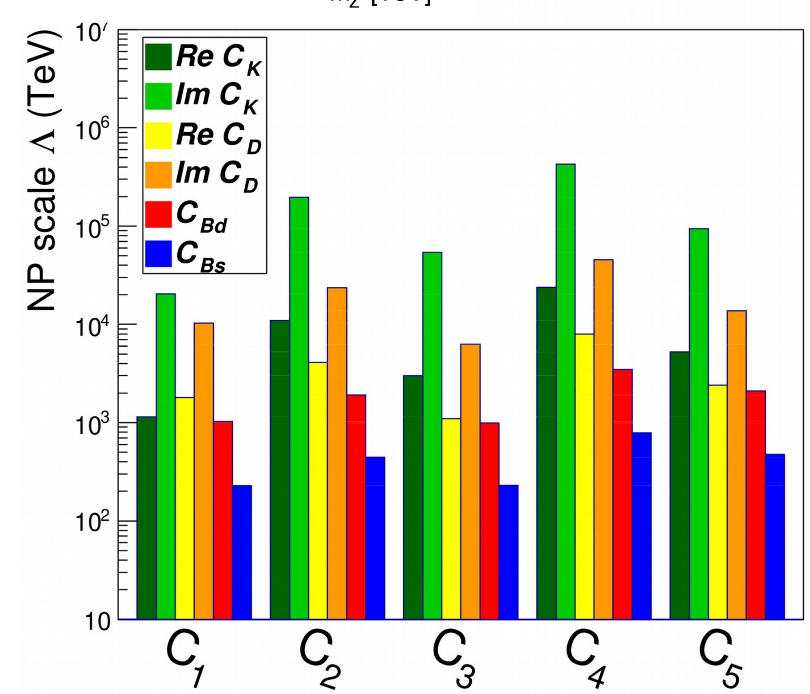
- The LHC has a broad, active program searching for new physics (NP) at the TeV scale

- Great time to examine our assumptions about how NP couples to the Standard Model

- Flavor violation bounds are already probing ~ 100s TeV scale. How do we reconcile this disparity?







Luca Silvestrini, UTFit

Avoiding Flavor Bounds Requires Assumptions

FCNCs in SM suppressed by Yukawa & CKM factors

$$Y^u = \mathrm{diag}(y_u^{\mathrm{SM}}, y_c^{\mathrm{SM}}, y_t^{\mathrm{SM}})$$

$$Y^d = \mathrm{diag}(y_d^{\mathrm{SM}}, y_s^{\mathrm{SM}}, y_b^{\mathrm{SM}})$$

$$y^u_{\mathrm{SM}} = (V^T Y^u)_{ij}, \quad y^d_{\mathrm{SM}} = Y^d$$

For *flavored* new physics, simplest assumption is *Minimal Flavor Violation*

$$\lambda^{d\dagger}_{2,ij}\, Q_i\, \bar{d}_j\, H_2^c, \quad \xi_{ij}\, (d_i^\dagger\, i\bar{\sigma}^\mu\, d_j)\, Z'_\mu$$

In a 2HDM MFV implies: $\lambda^u_{2,ij} \propto y^u_{\mathrm{SM}}, \quad \lambda^d_{2,ij} \propto y^d_{\mathrm{SM}}$

$$y^u_{\mathrm{SM}} = \begin{pmatrix} 10^{-5} & 10^{-3} & 10^{-2} \\ 10^{-6} & 10^{-3} & 10^{-2} \\ 10^{-8} & 10^{-4} & 1 \end{pmatrix}$$

This implicitly assumes NP couples mainly to *third generation* quarks!

Alignment Suppresses FCNCs

This is clear when we look in a particular basis:

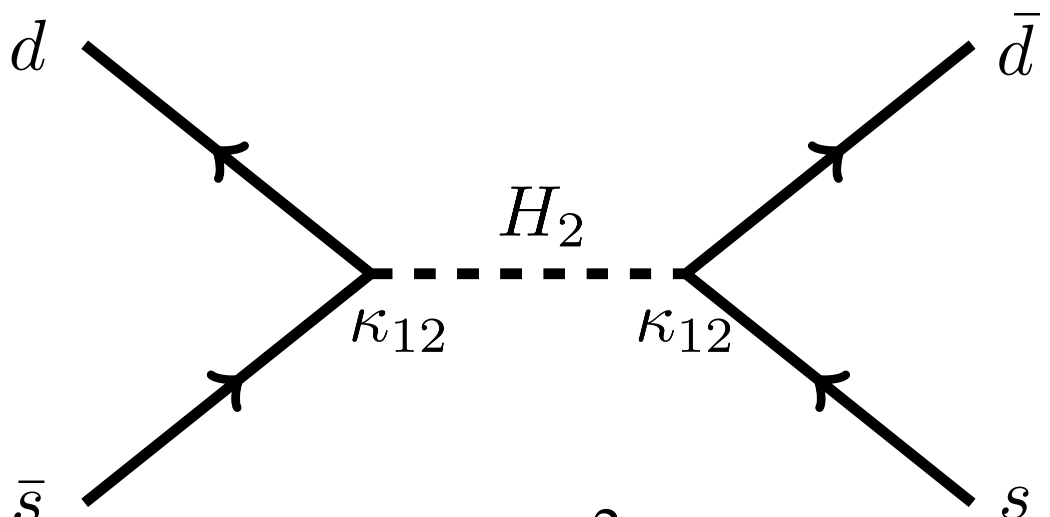
$$\mathscr{L} \supset -V_{ij}^T Y^u Q_i H \bar{u}_j + Y^d Q_i H^c \bar{d}_j + K^d Q_i H_2^c \bar{d}_j$$

$$Y^u = \mathrm{diag}(y_u^{\mathrm{SM}}, y_c^{\mathrm{SM}}, y_t^{\mathrm{SM}})$$

$$Y^d = \mathrm{diag}(y_d^{\mathrm{SM}}, y_s^{\mathrm{SM}}, y_b^{\mathrm{SM}})$$

$$K^d = \mathrm{diag}(\kappa_d, \kappa_s, \kappa_b)$$

Couplings to new physics can be arbitrarily large, without introducing FCNCs



$$\propto \kappa_{12}^2 = 0$$

But demanding alignment without a UV completion is very ad hoc

Spontaneous Flavor Violation

A UV Completion for Flavor Alignment

$$\mathcal{L} \supset -V_{ij}^T Y^u \, Q_i \, H \, \bar{u}_j + Y^d \, Q_i \, H^c \, \bar{d}_j + K^d \, Q_i \, H_2^c \, \bar{d}_j$$

Flavor Violation
"in the up sector"

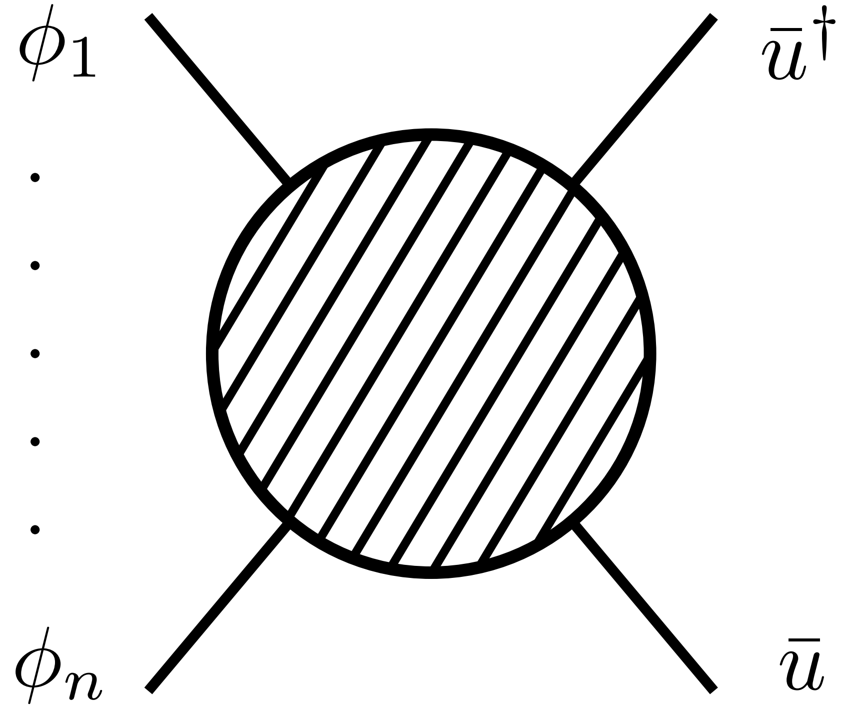
Idea: ***All*** quark family number & CP breaking via renormalization of *either* right-handed up- *or* down-type quarks

$$\mathcal{L} \supset i Z_{ij}^u \, \bar{u}_i^\dagger \, \bar{\sigma}^\mu D_\mu \bar{u}_j + i \bar{d}_i^\dagger \, \bar{\sigma}^\mu D_\mu \bar{d}_i + i \bar{Q}_i^\dagger \, \bar{\sigma}^\mu D_\mu \bar{Q}_i +$$

$\Longrightarrow$ Couplings to the other sector remain *aligned*

A UV Completion for Flavor Alignment

Mixing with
Spontaneously Broken
Flavor Vacuum



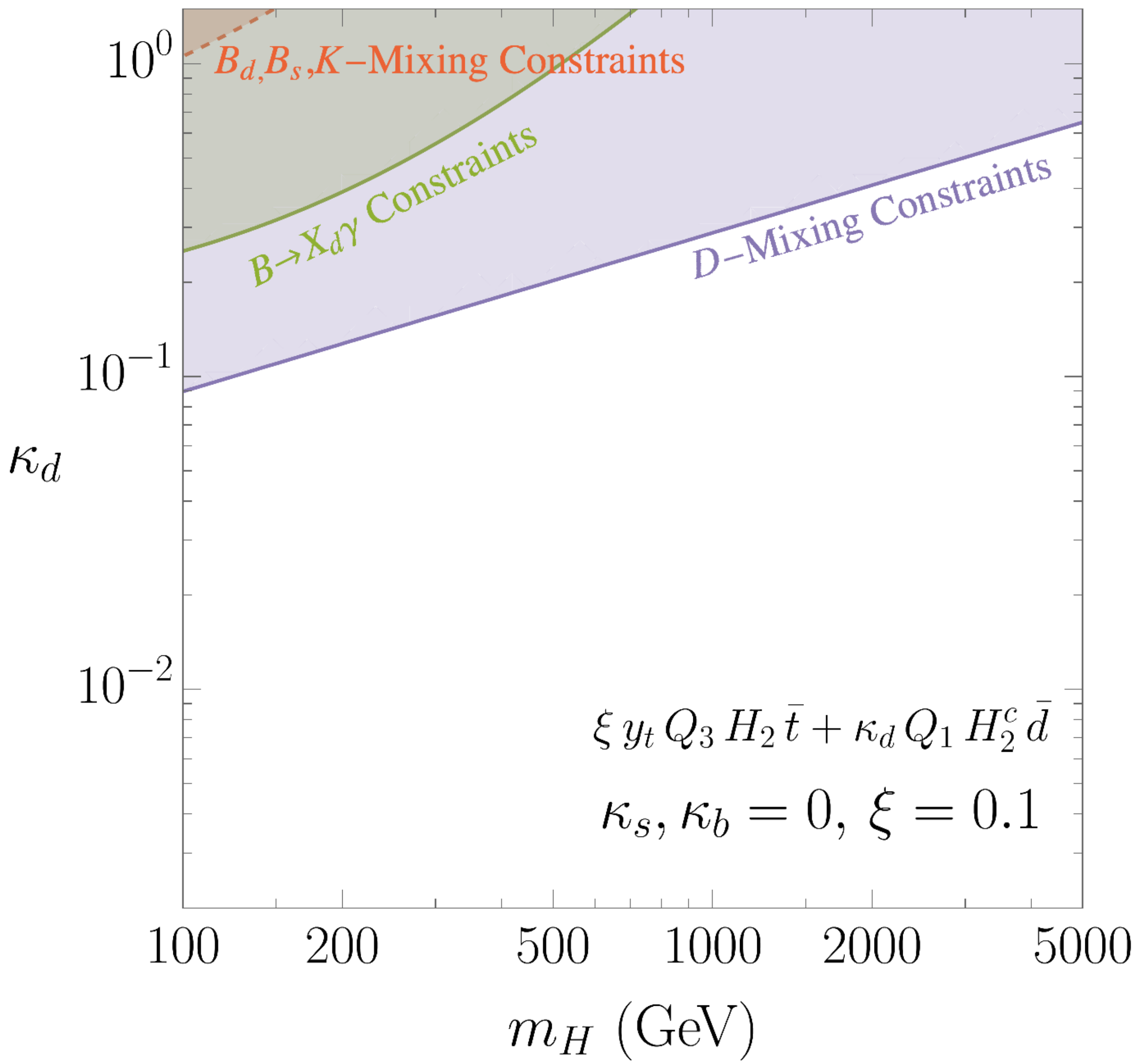
$$\Longrightarrow \quad iZ^u_{ij}\,\bar{u}^\dagger_i\bar{\sigma}^\mu D_\mu\bar{u}_j$$

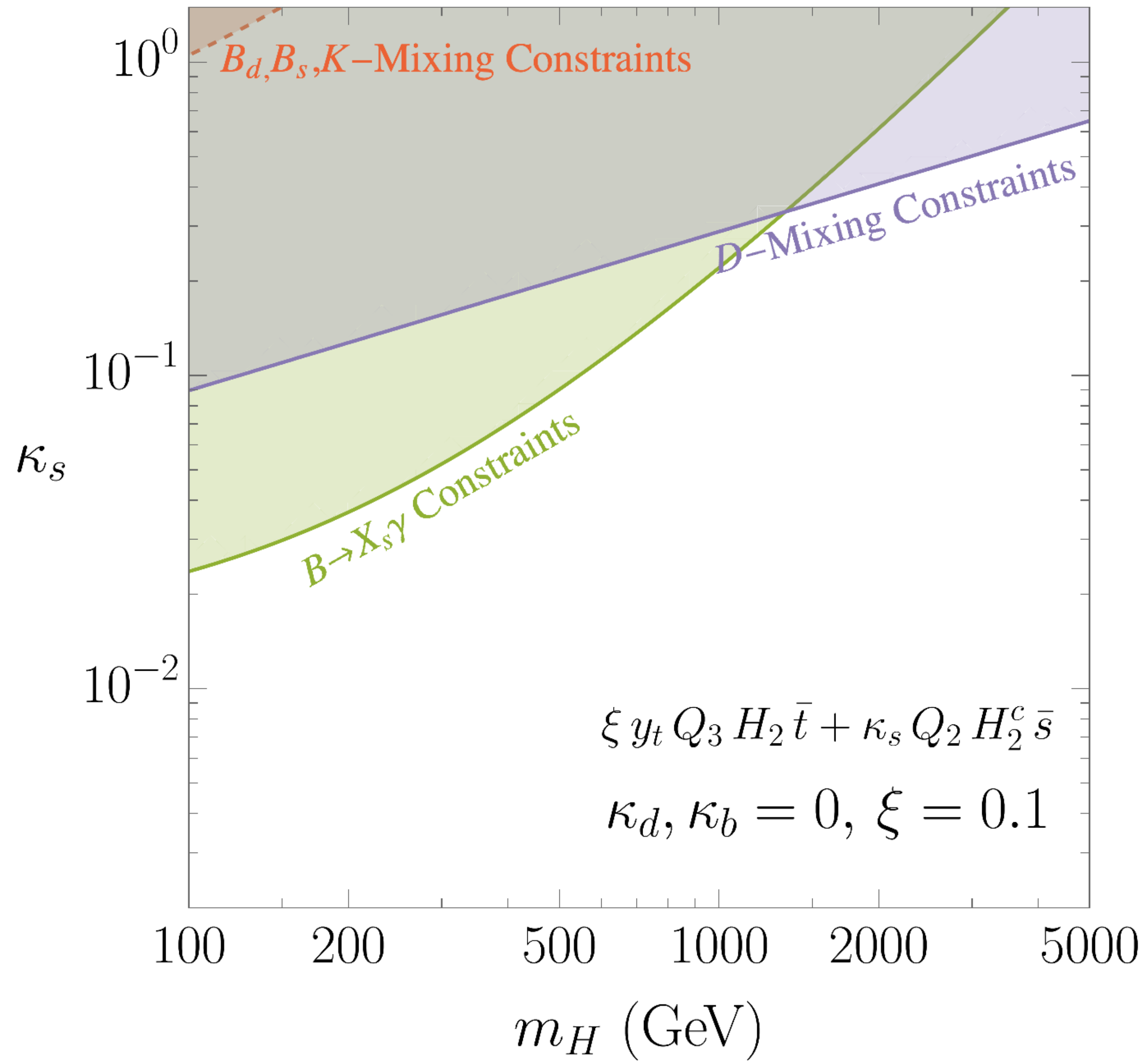
$$\mathcal{L} \supset i Z^u_{ij}\,\bar{u}^\dagger_i\,\bar{\sigma}^\mu D_\mu \bar{u}_j + i\bar{d}^\dagger_i\,\bar{\sigma}^\mu D_\mu \bar{d}_i + i\bar{Q}^\dagger_i\,\bar{\sigma}^\mu D_\mu \bar{Q}_i +$$

Note: Two distinct theories: up- or down-type SFV

Flavor Bounds in an SFV 2HDM

Charged Higgs Contributions to FCNCs arise at loop-level

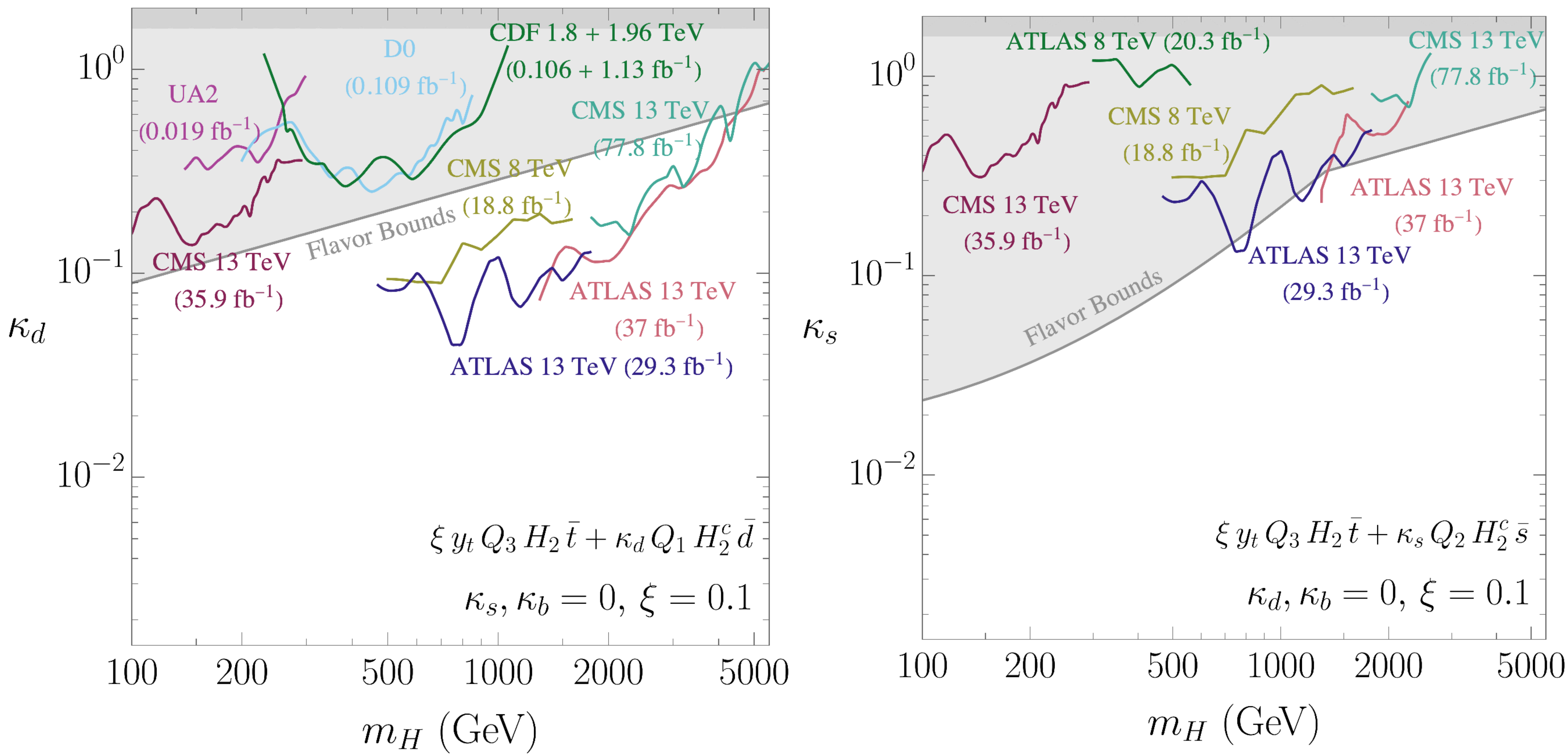




Order ~ 0.1 couplings to first and second generation quarks are allowed for a large range of masses!

Limits from Dijet Searches

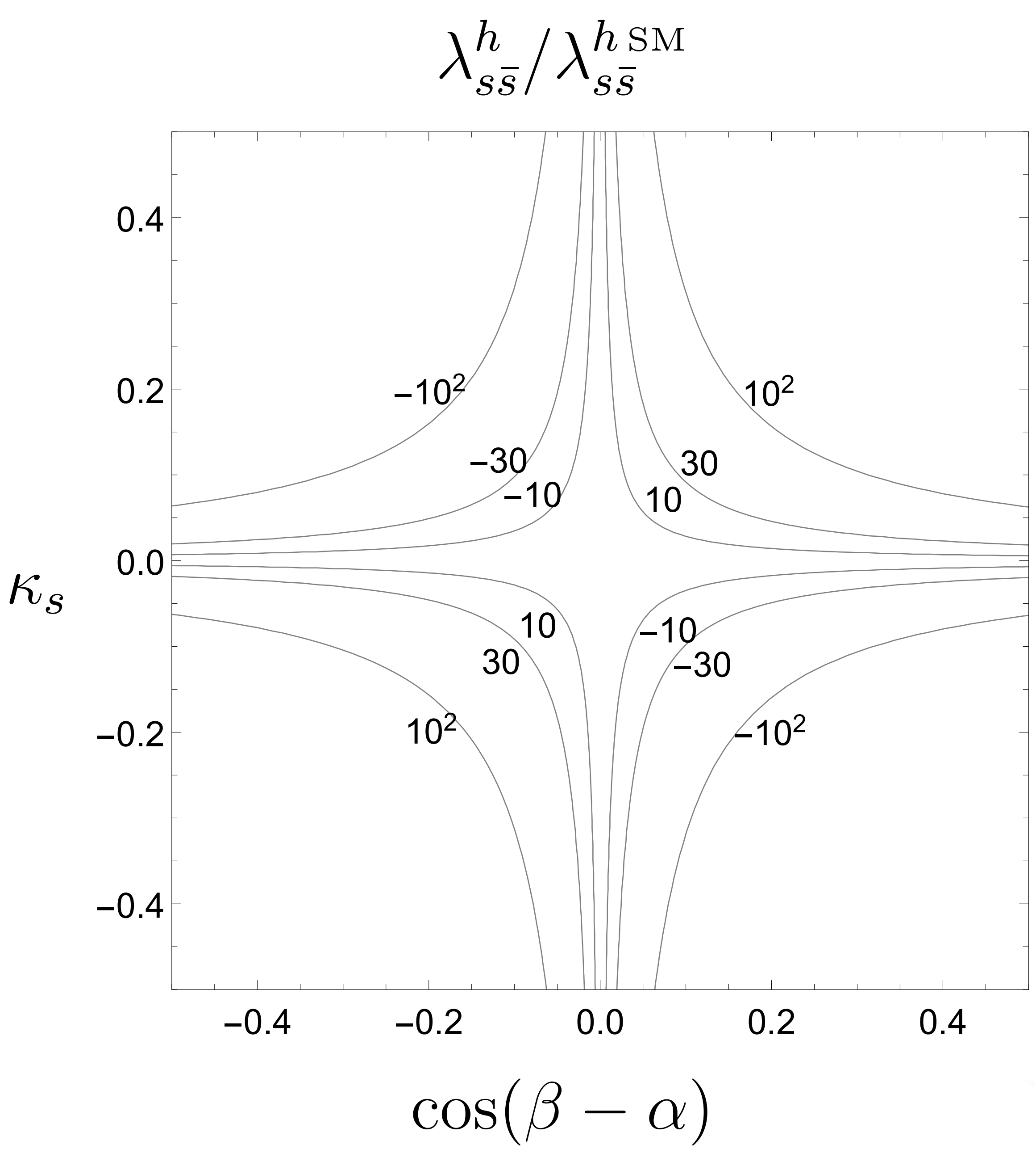
Heavy Higgs Produced in Tree-Level Quark Fusion, Decays to Dijets



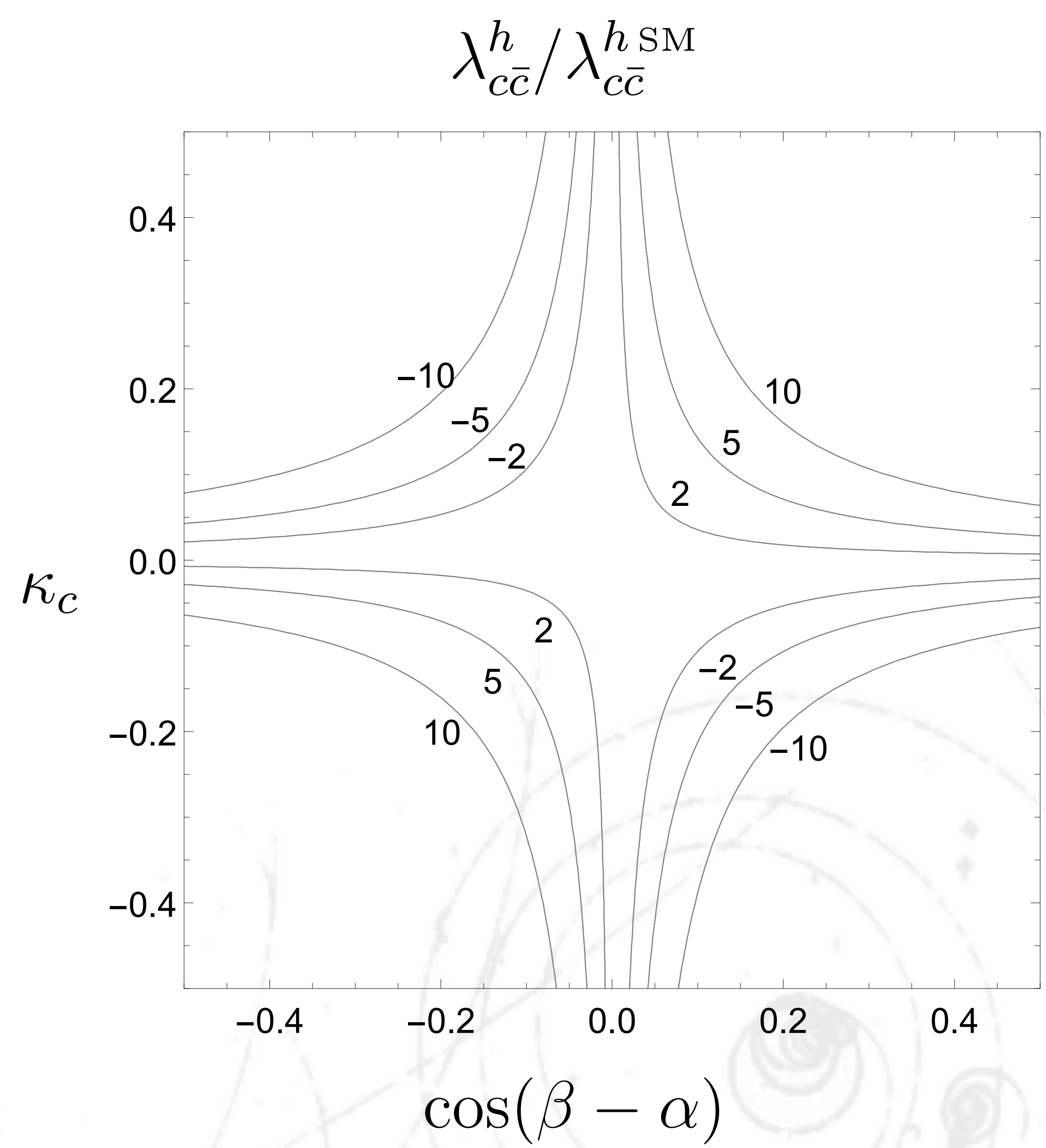
Much of the parameter space is more efficiently probed with colliders — even for O(100 GeV) new Higgses!

Mixing Leads to Enhancement of SM Yukawas

Up-Type SFV



Down-Type SFV



Realistic targets for quark-flavor taggers!

Conclusions

- Flavor assumptions have *drastic* implications for new physics searches and collider phenomenology
- Spontaneous Flavor Violation ensures flavor alignment — allows for large couplings to light quarks
- In the 2HDM, this leads to strong production and enhanced Yukawas
- SFV can be applied to any BSM model!

SMEFT,
MSSM,
Z-primes,
Leptoquarks,
Vector-like quarks,
Axions,
Colored Scalars,
…

Backup

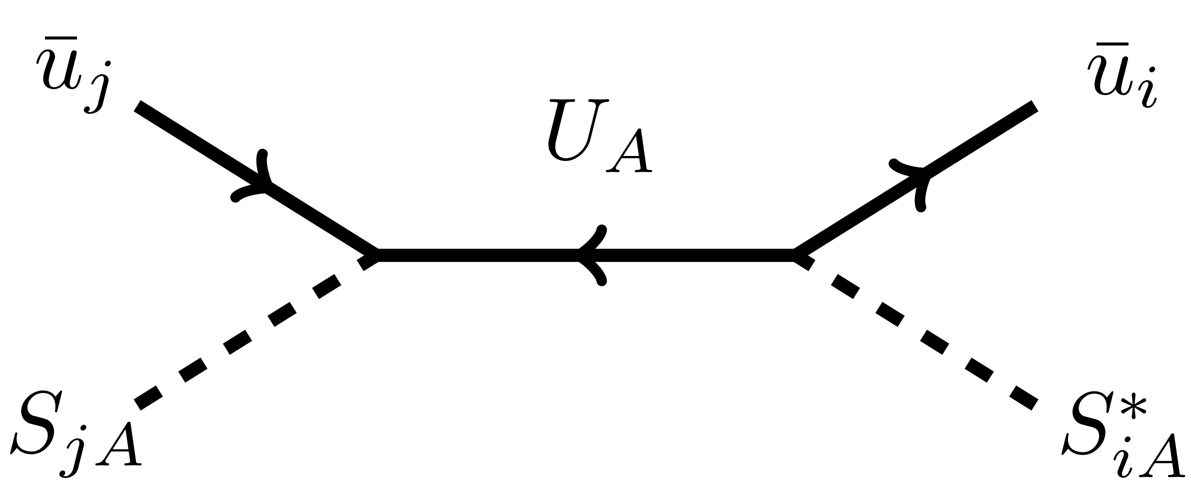
Backup: Details of the UV Completion

$$\mathscr{L} \supset M_{AB}\, U_A\, \bar{U}_B + \xi\, S_{iA}\, \bar{u}_i\, U_A - \left[\eta^u_{ij}\, Q_i\, H\, \bar{u}_j - \eta^d_{ij}\, Q_i\, H^c\, \bar{d}_j + \text{h.c.}\right] + \mathcal{L}_{\text{BSM}}$$

No additional spurions/fields transforming under $U(3)_{\bar{u}}$

Introduce mixing between up-quark and heavy VLQs in a flavor breaking vacuum

	$U(3)_U$	$U(3)_{\bar{U}}$	$U(3)_{\bar{u}}$	$U(1)_B$	$\mathbb{Z}_2$
U	3			$1/3$	-1
$\bar{U}$		3		$-1/3$	-1
S	$\bar{3}$		$\bar{3}$		-1

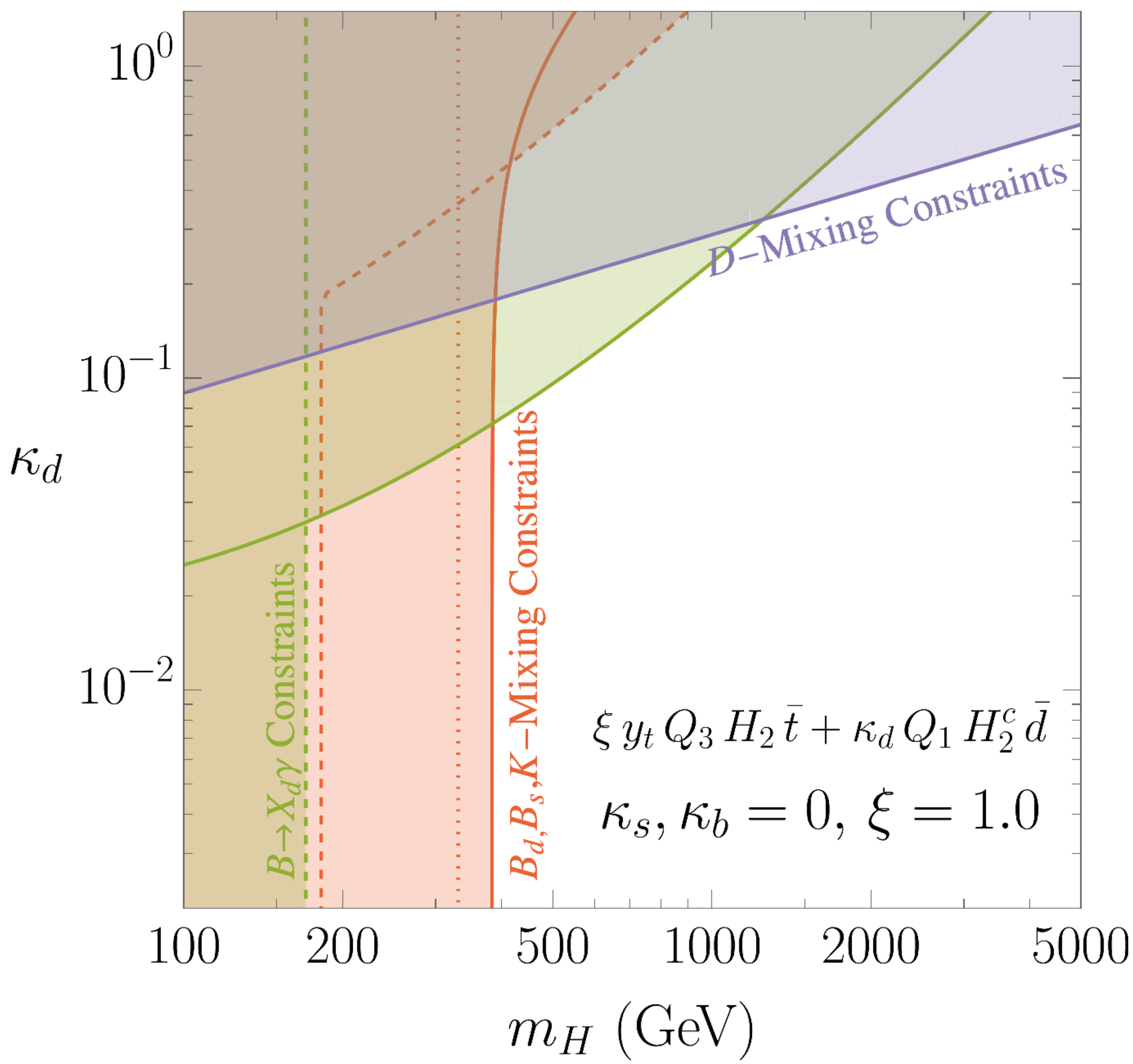


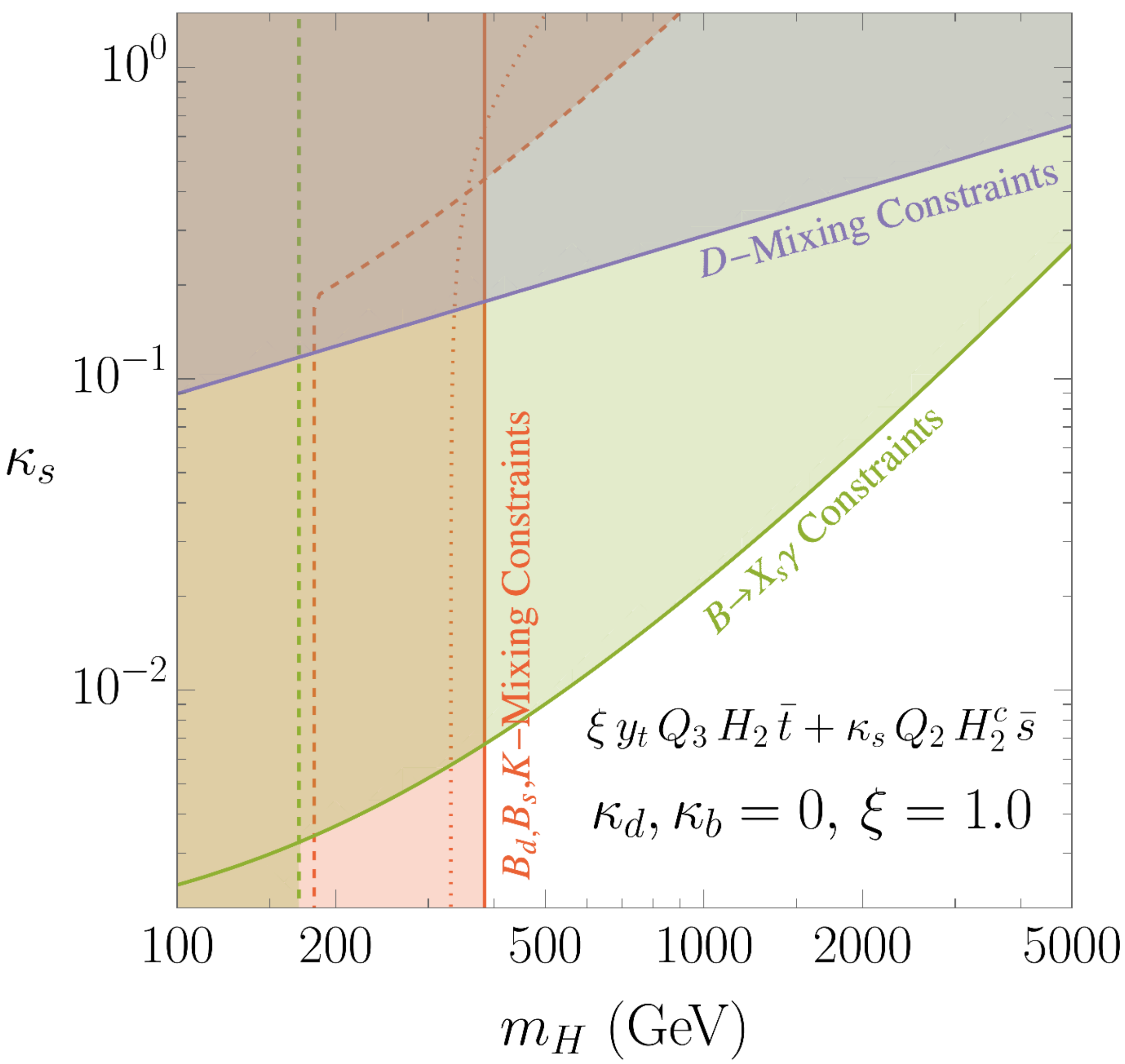
Integrating out heavy quarks leads to wave-function renormalization of the SM up-quarks

$$Z^u_{ij} = \delta_{ij} + \frac{\xi^* \xi}{M^*_A M_A} S^*_{iA} S_{jA}$$

The source of all flavor-breaking!
CKM matrix arises from returning to canonical basis

Backup: Additional Flavor Bounds





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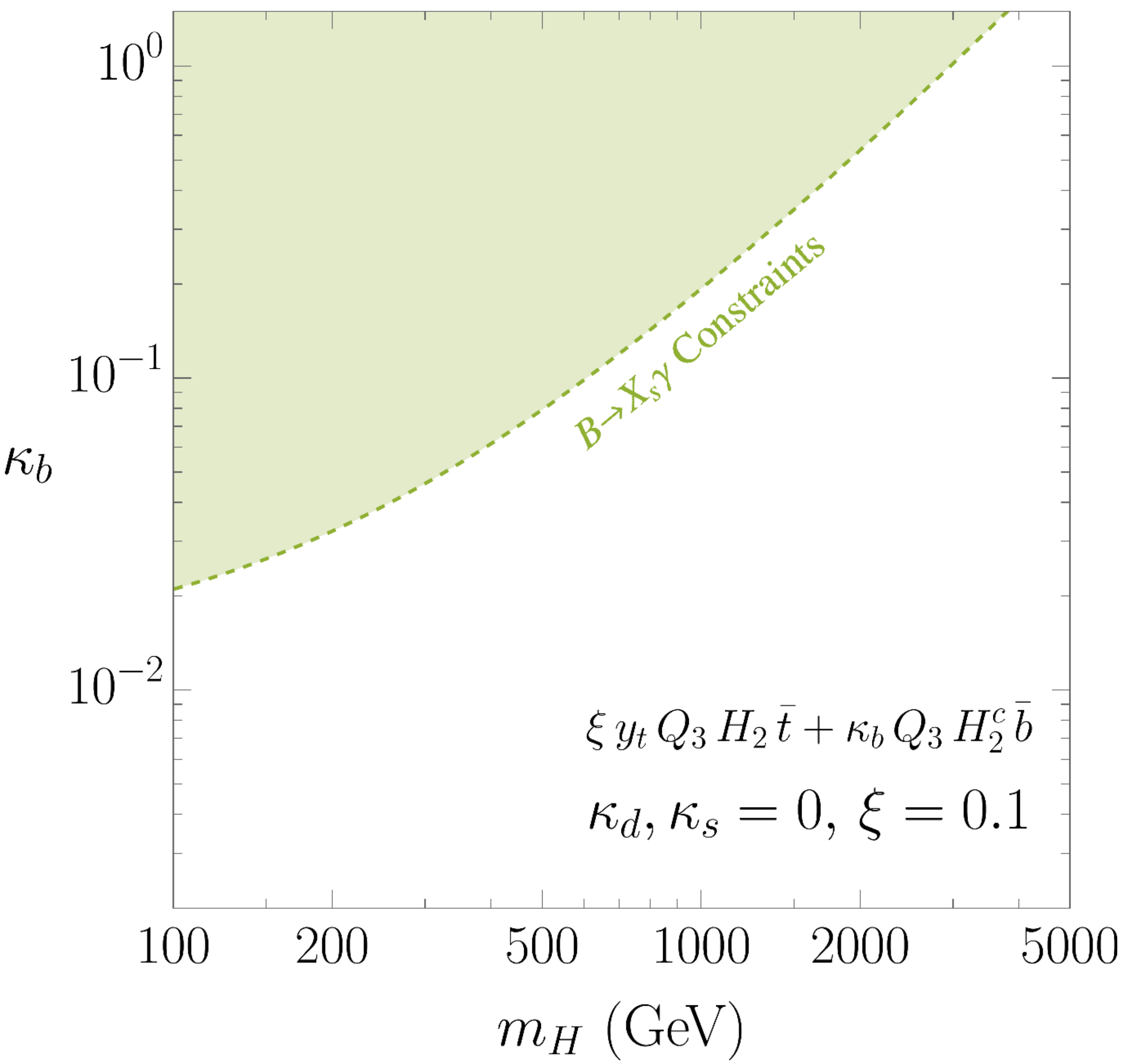
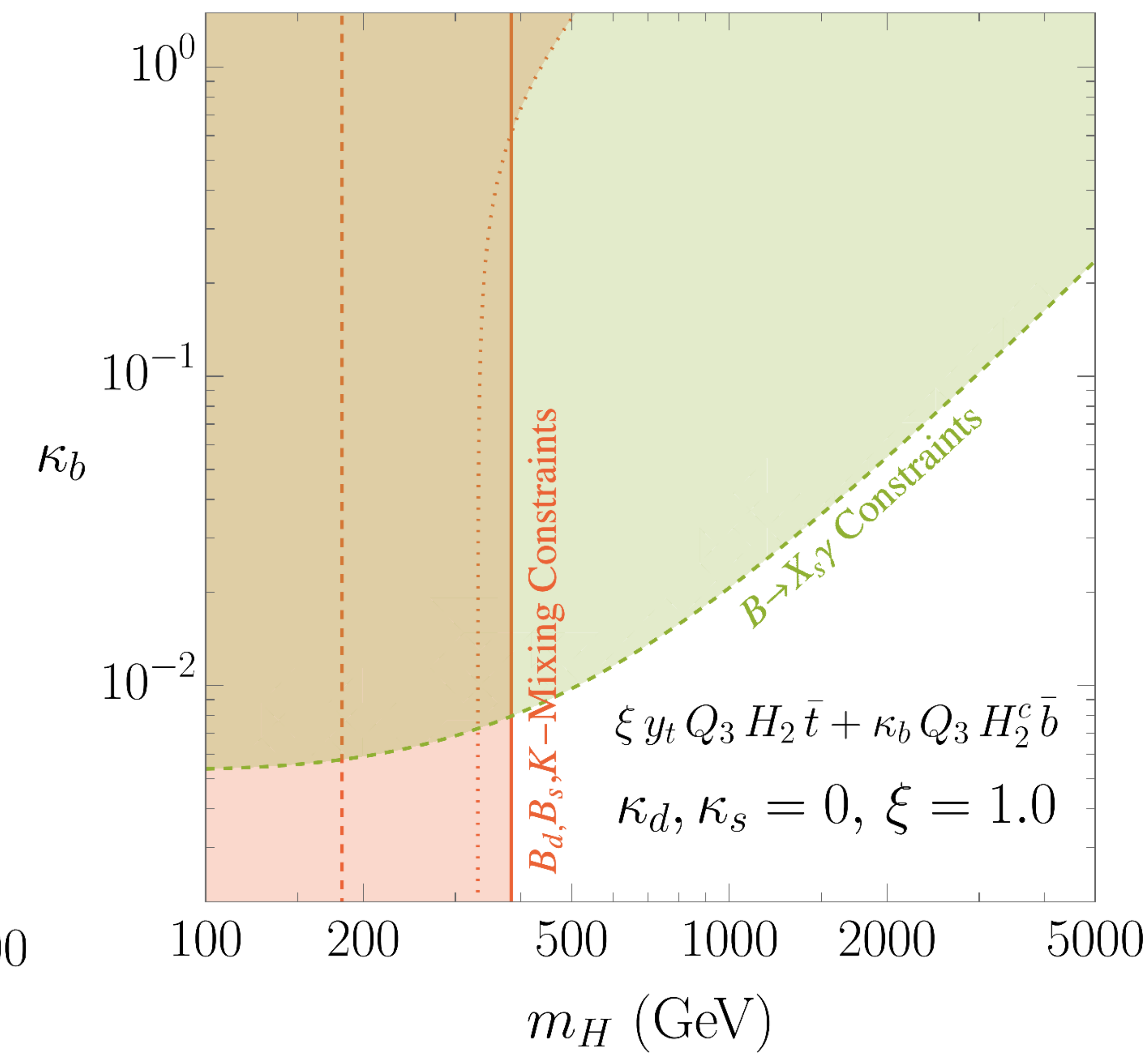
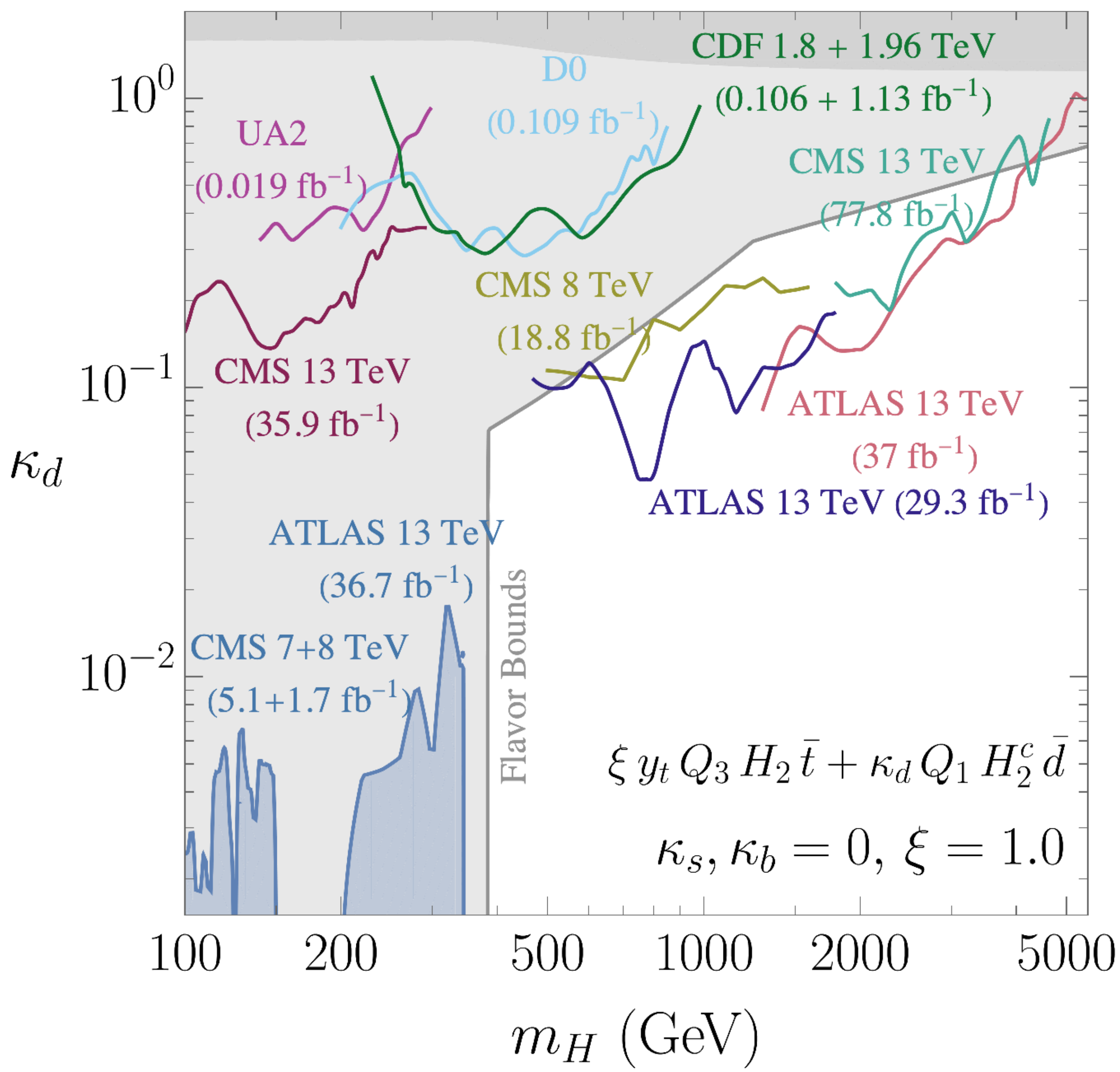
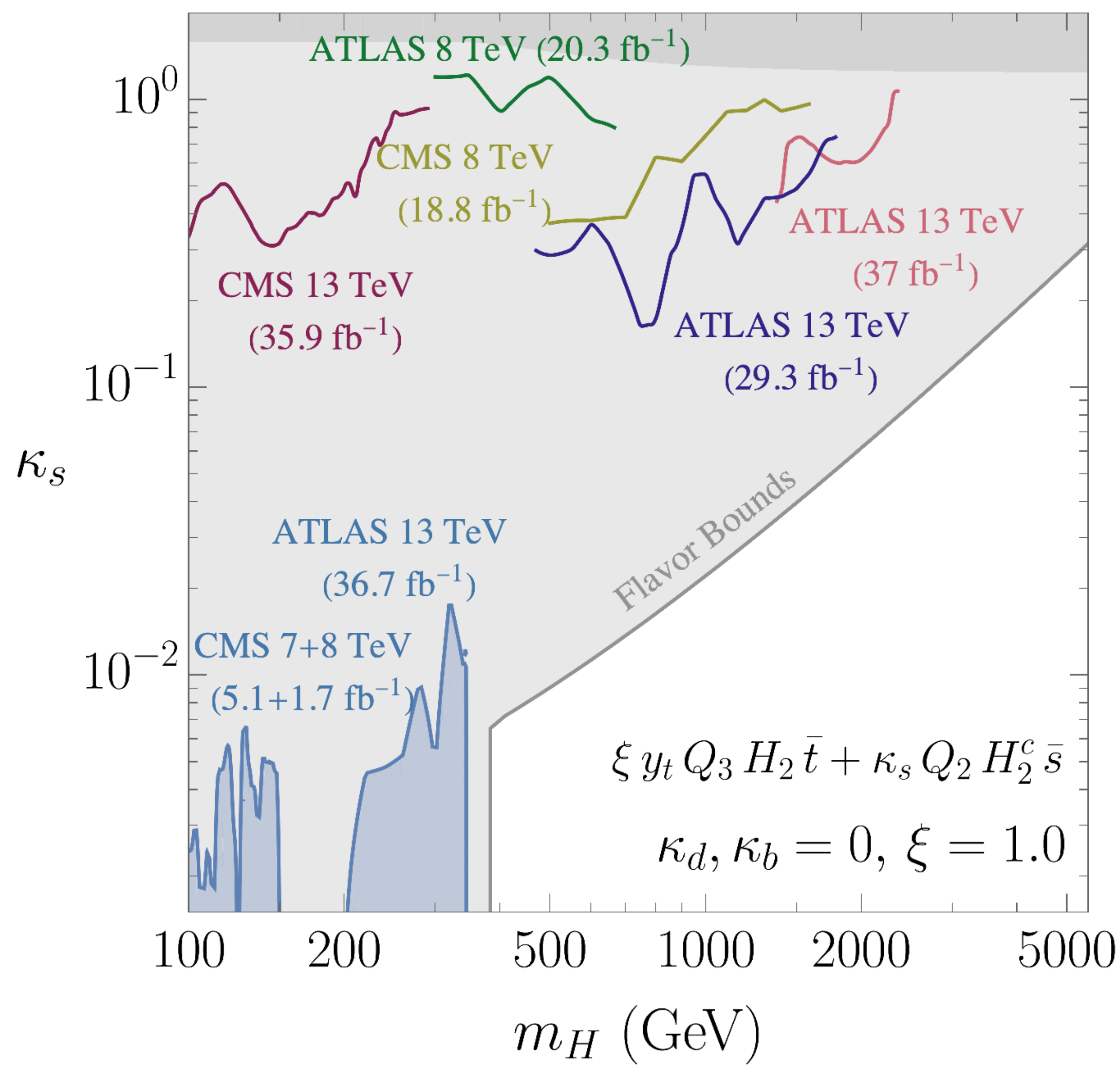




Backup: Additional Collider Bounds





Backup: Additional Collider Bounds