

Flavor Physics at the LHC

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03/06/2014, New York

What are the unique capabilities of LHC for flavor studies? (energy, luminosity)

Which observables are most promising? (Higgs, top, CPV in charm & Bs, rare decays with di-leptons)

What have we learned already? (implications for SM hierarchy, flavor, DM puzzles, hints of NP?)

Disclamer: personal selection of topics

Introduction

SM phenomenologically very successful theory

Strong theoretical arguments to consider it as effective theory $\mathcal{L}_{\nu SM} = \left[\mathcal{L}_{\text{gauge}}(A_a, \psi_i) \right] + D_{\mu} \phi^{\dagger} D^{\mu} \phi - V_{\text{eff}}(\phi, A_a, \psi_i)$ $V_{\text{eff}} = -\mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2 + \left(Y^{ij} \psi^i_L \psi^j_R \phi + \frac{y^{ij}}{\Lambda} \right)$ $\frac{\partial \int \psi^i_l T}{\partial \sum_l \psi^j_l} \phi^T \phi + \ldots$ **Unification** of interactions EW scale EVV SCale Corigin of flavor

Need to understand/constrain size of additional terms in series³

Introduction changing transitions among SM quarks mediated by new heavy degrees of freedom

SM phenomenologically very successful theory with masses **masses of allaced by a lagrangian and descri**bed by a lagrangian \mathbf{A} the new particle thresholds but above the Euclide of Photography \mathcal{C}

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Unique LHC probes of flavor

Top quark - heaviest point-like particle known to exist

 \Rightarrow O(1) coupling to the Higgs $y_t \equiv \sqrt{2}m_t/v_{\rm EW} \simeq 1$

 \Rightarrow Profound effects on EW and flavor physics

Higgs boson interactions with fermions of special interest

 \Rightarrow probe existence of new flavor dynamics not too far above the electroweak scale

 \Rightarrow suppressed contributions to low energy observables lead to weak indirect constraints

BSM modifications of Yukawa sector

 $\mathcal{Q}_Y^{(6)} \sim Y'_{ij} \psi_L^i \psi_R^j \phi(\phi^\dagger \phi)$

Giudice, Lebedev, 0804.1753 Agashe, Contino, 0906.1542 Goudelis, Lebedev, Park, 1111.1715 Arhrib, Cheng, Kong, 1208.4669 Alonso et al., 1212.3307 Dery et al., 1302.3229, 1304.6727

...

In EW vacuum: $\mathcal{L}_Y = -m_i \psi_L^i \psi_R^i - \bar{Y}_{ij} (\psi_L^i \psi_R^j) h + \text{h.c.} + \dots$

Generally present if more than one source of fermion masses

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10

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Simplest model examples:

(1) THDM III $\mathcal{L}_{\text{THDMIII}} \ni -Y_{ij}^{(1)} \psi_L^i \psi_R^j \phi^{(1)} - Y_{ij}^{(2)} \psi_L^i \psi_R^j \phi^{(2)} + \text{h.c.}$ \rightarrow \mathcal{L}_Y + couplings to heavier Higgs bosons

c.f. Davidson & Greiner, 1001.0434

(2) Partial compositeness
$$
\mathcal{L}_{\text{PC}} \ni -y_{ij}D_L^i S_R^j \phi - \bar{y}_{ij}D_R^i S_L^j \phi
$$

\n(*D*,*S* - vector-like fermionic
\ndoublets, singlets)
\n
$$
-m_D^{ij}D_R^i \psi_L^j - m_S^{ij}S_L^i \psi_R^j + \text{h.c.}
$$
\n
$$
-\mathcal{L}_Y + \text{couplings of heavier fermions}
$$

c.f. Delaunay, Grojean & Perez, [1303.5701](http://arXiv.org/abs/arXiv:1303.5701)

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Stability of fermionic mass hierarchies:

$$
|\bar{Y}_{ij}\bar{Y}_{ji}|\lesssim \frac{m_im_j}{v^2}_{\text{Cheng & Sher.}}
$$

Phys.Rev. D35, 3484 (1987)

New neutral currents

- flavor diagonal (LHC)
- flavor violating (flavor factories, LHC)

+ FDMs if CPV

Brod, Haisch & Zupan, 1310.1385 Gorban & Haisch, 1404.4873

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Are Higgs couplings to light flavors SM-like?

Current Higgs data exhibit poor sensitivity to first two generation quark Yukawas Fajfer, Greljo, J.F.K. & Mustac, 1304.4219 Delaunay, Golling, Perez & Soreq, 1310.7029

 \Rightarrow in production

1 loop contributions to *gg*→*h* suppressed by small loop function

$$
A_{1/2} \sim r_q \log r_q \,, \quad r_q \equiv (m_q/m_h)^2 \ll 1
$$

direct *qq*→*h* suppressed by small parton luminosity functions

 $\mathcal{L}_{u\bar{u}}(m_h)/\mathcal{L}_{g} (m_h) \sim 4\%$ (2%) @ 7 TeV(14 TeV) LHC

 \Rightarrow in decay:

need to compete against dominant *h*→*bb* mode

$$
|\bar{Y}_{qq}|^2 \simeq 10^{-3} \Gamma_{h \to q\bar{q}} / \Gamma_h^{\rm SM} \qquad \bar{Y}_{bb}^{\rm SM} \equiv \frac{m_b}{v} \simeq 0.02
$$

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⇒ Global fit to LHC Higgs signal strenghts

Admir Greljo private communication see also talk by Y. Soreq

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Within SM effective *Yi≠j* extremely suppressed (GIM+CKM/*m*ν & chirality)

Constraints on first two generation *Yi≠^j* dominated by precision low energy observables energy constraints on \mathcal{L}_{P}

Greljo, J.F.K. & Kopp, 1404.1278

Two complementary production processes (in case of *thu*) 2

Can be disentangled using Higgs rapidity & total event and *pp* [→] [(*^t* [→] *^W*⁺*b*)(*^t* ¯[→] *hq*¯)*,*(*^t* ¯[→] *^W*−¯*b*)(*^t* [→] *hq*)] (right) through flavor violating top-Higgs interactions \sim Can be disentangled using Higgs rapidity & total event violating top-Higgs couplings as a function of the hadronic center of mass energy and normalized to the 4 iyyə rapıully & tulai t

Greljo, J.F.K. & Kopp, 1404.1278

Several competitive signatures

Multileptons

 $h \to ZZ^* \to \ell \ell jj, h \to ZZ^* \to \ell \ell \nu \nu,$ $h \to WW^* \to \ell \ell \nu \nu$, $h \to \tau \tau$.

with branching ratios 2*.*4%, 6*.*2%, 0*.*41%, 0*.*1% and 0*.*03%, respectively [18]. Single top + Higgs $t \rightarrow b \ell^+ \nu$

three or more is more is a fact of data at *a* \sim 19.5 fbc. Data at *S* and *S* TeV. Data are binned in the set of data and into a set of data at \sim 100 mm set of data and into a set of data and into a set of data and $\overline{}$ Mo Higgs $\overline{}$ top–moon In this section, we recast a recent CMS search for anomalous production of final states with ▼ Many Higgs decay modes **booked** in the boosted **X** No Higgs/top reconstruction

CMS-PAS-HIG-13-034, CMS arXiv:1404.5801; CMS-SUS-13-002 exclusive categories according to the missing transverse energy *Emp*

the 126 GeV Higgs boson decays to four less with up to four leftons with up to $h \to WW^* \to \ell\ell\nu\nu, h \to \tau\tau,$ $h \to b\overline{b}, h \to gg, h \to \tau\overline{\tau}, h \to c\overline{c}$ production can thus yield up to five leptons, so that multipleptons, so that multiplepton searches can be expected to find the expected to \mathcal{C} 5 $t \rightarrow b u \overline{d}$

 $t \to b \ell^+ \nu$ and the five leptons of the top-Higgs interaction searches can be expected to find to fi No. Higgs than recent untion $\|\cdot\|$ V Largest rate

> **Example 10 V Many Higgs decay modes Example 1 In the boosted regime, can** *^T* , the scalar sum of the transverse momenta of all the jets *H^T* , the existence of *b*-tagged jets, and the presence *^T* , the scalar employ jet substructure methods ¹⁵

modified HEPTopTagger of Plehn et al., 0910.5472, 1006.2833

Higgs tagging: Butterworth et al., 0802.2470 Cacciari, Salam & Soyez, 1111.6097

Greljo, J.F.K. & Kopp, 1404.1278

Improving the LHC reach

 \Rightarrow Limits on $B(t\rightarrow h\mu) \times 1.5$ better than on $B(t\rightarrow h\alpha)$ $\frac{1}{\sqrt{2}}$ function search, a vector boson plus Higgs search and an analysis of $\frac{1}{\sqrt{2}}$ \Rightarrow Limits on *B*(*t*→*hu*) x 1.5 better than on *B*(*t*→*hc*)

 \Rightarrow Future LHC searches could test $|y_{tq}| \sim 0.1$

Greljo, J.F.K. & Kopp, 1404.1278

Discrimination between thc & thu couplings

Possible even without explicit Higgs reconstruction (like in multilepton searches)

In *h*→*WW**→*ll*νν use leptons closest in rapidity as proxy for η*^h*

Probing the invisible through flavor violation *at LHC*

Are there only SM particles at low-energy?

Experimentally:

- Even very light states could be missed if very weakly interacting,
- There is dark matter in the Universe; it could be relatively light.

Theoretically: Plenty of models predict new light particles

- Pseudo-Goldstone scalars (axion, familon,...),
- U(1) vectors (string, ED,...),
- Hidden sectors & messengers (SUSY, mirror worlds,...)
- Many others: millicharged fermions, dilaton, majoron, neutralino, sterile neutrino, gravitino,...

Invisibles Pair Production at Hadron Colliders (FCNCs) are generated at the leading perturbative orrain ruduction al riadion Collide Γ Foncialative at the leading perturbative order. They are fully and the support of sir Droduction of Llodron Collic **Invisibles Pair Production at Hadron Collic DIES Pair Prode** to have a highly nontrivial flavor structure. Only small **Invisibles Pair Production at Hadron C** *COIIIDERS* ever. If nothing else, the flavor symmetry is broken already by the SM Yukawas. At least at loop level (and The sum above runs over the sum above runs of the full set of SU(2) gauge runs of SU(2) and SU(2) gauge runs o invariant operators *O^a* that are bilinear in quark fields.

General discussion in terms of EFT with the U.S. to have a highly nontrivial flavor structure. Only small General discussion in terms of EFT For signal and designation ready by the SM Yukawas. At least at loop level (and General discussion in terms of EFT **Starbange and FIFT** ST. E.K. & Zupan, 1107. $ETIII5$ UI LI I amount of flavor violation in the interactions between NP *a I d C i J a j j a j j j j j j* 1*a*

der. They are further suppressed also by the smallness

of the relevant CKM matrix elements. The agreement of

ever. If nothing else, the flavor symmetry is broken al-

J.F.K. & Zupan, 1107.0623

$$
{\cal L}_{\rm int}=\sum_a {C_a\over \Lambda^{n_a}}{\cal O}_a
$$

enough so that we can integrate them out at a large so that we can integrate them out at a large scale scale s
The mouth so that we can integrate them out at a large scale scale scale scale scale scale scale scale scale s

 $\mathcal{N}(\mathcal{M})$ is assumption). We can this assumption $\mathcal{N}(\mathcal{M})$

 $\mathcal{F}_{\mathcal{A}}$ is not charged under that $\mathcal{F}_{\mathcal{A}}$ is not charged under that \mathcal{B} is not charged under the \mathcal{B}

• With B preservation, O_a need to be bilinear in quark fields T preservation, O_a rieed to be billifear in quark fields. \bullet With B σ simplicity Ω is a saturated under the simplicity Γ B Servation, O_{a} rieed to be billine. \bullet With B preset # *J^a ,* ers. We will show that large effects are likely, leading to \bullet virn \bullet preservation, \bullet With B preservation Ω_2 need to be bilinear in quark fields and we do not write down additional tensor operators and we do not write down additional tensor operators and $t_{\rm eff}$ is both loop and $C_{\rm eff}$ suppressed and $C_{\rm eff}$ **discussion as for** *O***4** and *O₄* Decimens *D*_{*R*} **D**_{*L*} *C_{<i>A***}** D_{*L*} D_{*L*}^{*n*}_{*R*} D_{*L*}^{*n*}_{*R*} D_{*L*}^{*n*}_{*A*} D_{*L*}^{*n*}_{*A*} D_{*L*}^{*n*}_{*A*} D_{*L*}^{*n*}_{*A*} D_{*L*}^{*n*}_{*A*} D_{*L*}^{*n*}_{*A*} D_{*L*}

$$
\begin{aligned} \mathcal{O}^{ij}_{1a}=&(\bar{Q}^{i}_{L}\gamma_{\mu}Q^{j}_{L})\mathcal{J}^{\mu}_{a}\,,\\ \mathcal{O}^{ij}_{2a}=&(\bar{u}^{i}_{R}\gamma_{\mu}u^{j}_{R})\mathcal{J}^{\mu}_{a},\qquad \mathcal{O}^{ij}_{3a}=\left(\bar{d}^{i}_{R}\gamma_{\mu}d^{j}_{R}\right)\mathcal{J}^{\mu}_{a}\,,\\ \mathcal{O}^{ij}_{4a}=&\left(\bar{Q}^{i}_{L}Hu^{j}_{R}\right)\mathcal{J}_{a}\,,\qquad \mathcal{O}^{ij}_{5a}=&\left(\bar{Q}^{i}_{L}\tilde{H}d^{j}_{R}\right)\mathcal{J}_{a}\,, \end{aligned}
$$

 \bullet coupling to suitable dark sector currents, i.e. · coupling to suitable dark sector currents, i.e. energy (MET). A *t* + */E^T* final state is an experimentally we assume that DM is odd under an exact *Z*2. For For instance, the cross section for *t* + */E^T* can be orders • coupling to suitable dark sector currents, i.e. $\frac{1}{2}$. Decrease the control it of $\frac{1}{2}$ $\frac{1}{2}$ *<i>B* dark sector currents, i.e. ing to *n^a* = 2 for *O*1*a,...,*3*^a* in Eq. (1), while for *O*4*a,*5*^a* we

energy (MET). A *t* + */E^T* final state is an experimentally $\bar{\chi} = \bar{\chi} \gamma^\mu \{1, \gamma_5\} \chi \qquad \mathcal{J}_{S,P} = \bar{\chi} \{1, \gamma_5\} \chi \qquad \qquad \mathcal{J} = \chi^\dagger \chi, \, \mathcal{J}^\mu = \chi^\dagger \chi, \, \mathcal{J}^\$ (contractions of Lorentz tensors *^J ^µ*^ν $\overline{\Omega}$ and which the same discussion as for *O*4*a,*5*^a* will apply. Here *QL, uR, d^R* are indices, *H* is the SM Higgs doublet (with *H*˜ = *i*σ2*H*∗), τ^{μ} $\sigma_{V,A}$ $\overline{\sigma}$ *a O₄a C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} *C*_{*l*} $\mathcal{J}_{V,A}^{\mu} = \bar{\chi} \gamma^{\mu} \{1, \gamma_5\} \chi \quad \mathcal{J}_{S,P} = \bar{\chi} \{1, \gamma_5\} \chi \quad \mathcal{J} = \chi^{\dagger} \chi, \, \mathcal{J}^{\mu} = \chi^{\dagger} \partial^{\mu} \chi$ handed up- and down- quarks, *i, j* are the generational $\mathcal{J}^\mu_{V,}$ *^JS,P* = ¯χ*{*1*,* ^γ5*}*χ, (for Majorana fermion *^J ^µ ^V* = 0), leading to *n^a* = 2 for *O*1*a,...,*3*^a* in Eq. (1), while for *O*4*a,*5*^a* we Fermionic Scalar *V,A* = ¯χγ*^µ{*1*,* ^γ5*}*χ, $\mathcal{J}_{S,P} = \bar{\chi} \{1, \gamma_5\} \chi$ $\qquad \mathcal{J} = \chi^{\dagger} \chi, \, \mathcal{J}^{\mu} = \chi^{\dagger} \partial^{\mu} \chi$ ing to *n^a* = 2 for *O*1*a,...,*3*^a* in Eq. (1), while for *O*4*a,*5*^a* we \overline{a} \overline{b} \overline{c} $\overline{$ that *n^a* = 2 for all operators in (2). that *n^a* = 2 for all operators in (2).

10 One can component of this program is the search of this program is the search of this program is the search of the search of this program is the search of the s on at Hadron Colliders and W **12 icalies in the LHC via some unitermediate** ar
Ari
Ari Invisibles Pair Production at Hadron Colliders

Flavor universal contributions $(C^{ij} \sim \delta^{ij})$ $\mathcal{C}^{\mathcal{S}}$ $\mathcal{C}^{\mathcal{S}}$ 1σ ii coiated in international-state radiation of a state radiation of a state radiation of a standard model para- 16 times 16 $(19 - 0^{y})$

→ mono[jet, *γ*, *Z*, *W*] constraints using initial state radiation for tagging ϵ inq initial state radiation for tagging ²¹ repurposed to study the cases where *X* is a *W* [8] or *Z*

 $\overline{3}$ to add some sensitivity to the monometric to the monometric to the monometric $\overline{2}$

 $\mathcal{L}_{\mathcal{A}}$ diate state. As the final state $\mathcal{L}_{\mathcal{A}}$ are invisible to final state $\mathcal{L}_{\mathcal{A}}$

 $\overline{\mathcal{C}}$ s-section [cm 10^{-37} 10^{-36} $\longrightarrow 10^{-36}$ \overline{C}

Flavor Bounds **and** *s* The last two are bounded by searches for the *b* → *s*νν¯ *Br*(*^B* [→] *^K*∗νν¯) *<* ⁸*.*0×10−⁵ [6] and *Br*(*K*⁺ [→] ^π⁺νν¯) =

Can flavor violating interactions be competitive? 14 TeV LHC was estimated in Ref. [2] to be *^O*(10−4) for or violating intera There are contributions to *^Bd,s* [−]*B*¯*d,s* and *^K* [−]*K*¯ mix- $\overline{}$ \mathcal{L} interactions. Such interactions are for \mathcal{L} There are contributions to *^Bd,s* [−]*B*¯*d,s* and *^K* [−]*K*¯ mixing the competitive:

(1*.*73−1*.15 −1.05)* × 10−10 *i*.15 $\frac{1}{2}$. The reach for $\frac{1}{2}$ at $\$

5 discovery with 10 fb−1.
The 10 fb−1.
The 10 fb−1.

• Constraints from ΔF=2 observables $\frac{1}{2}$ coupling though $\frac{1}{2}$ and $\frac{1}{2}$ \sim to the third generation \sim

• effectively no bounds on C_{1a}^{13} $\frac{\gamma^{13}_{1a}}{\Lambda} \lesssim \frac{1}{2~\text{TeV}},$ C_{1a}^{23} $\frac{\gamma_{1a}^{23}}{\Lambda} \lesssim \frac{1}{0.3~\text{TeV}},$ and bounds of similar size for *C*¹³*,*²³ ³*a,*5*a*. The bounds on Fectively no bounds on $C_{2a,4a}^{2a,2a}$ of $\mathcal{O}(2a)$ $C_{2a,4a}^{13,23}$ Example:

through the SM Higgs portal would not lead to flavor via

• Large monotop (t+E_{miss}) signals possible due to chirality flipping operators they are saturated. This indicates that large *t* + */E^T* prosible at LHC and Tevatron. It would be interesting to interest \sim 1. It would be interesting to interest \sim ality ilipping operators Tevatron (LHC) cross sections, following [12, 13]. We they are saturated. This indicates that large *t* + */E^T* pro- $\frac{1}{2}$ $\frac{1}{2}$ see, whether the more constrained (and thus more likely $\frac{1}{2}$

 $\frac{1}{2}$ (also *b* + *E*_{miss}, but can be due to flavor conserving ops.) charm jet in the final state $\mathbf{1}_{\mathbf{1}_{\mathbf{1}}}$ production, the charm-gluon and up-gluon initial state signal can be picked out from the SM background of the SM background of the SM background of the SM background
The SM background of the S

• reconstruction using $j_{(b)}jj+E_{\rm miss}$, or $j_{(b)}l+E_{\rm miss}$ andrea, Fuks & Maltoni, 1106.6199 (mistagged) jet+invisibly decaying *Z* events. From now $\frac{10}{100}$ circuit a number of $\frac{100}{100}$ $\frac{1}{2}$ and retain $\frac{1}{2}$ assume that $\frac{1}{2}$ Alvarez, Coluccio Leskow, Drobnak & J.F.K., 1310.7600
Agram et al., [1311.6478](http://arXiv.org/abs/arXiv:1311.6478)

Andrea, Fuks & Maltoni, 1106.6199 \mathcal{L}_{S} and set above effect is not specific to estimate its size in a number of ϵ in a number of ϵ in a number of ϵ

Expectations in Models of Flavor MINIMAL FLAVOR VIOLATION. LET US FIRST ASSUME THAT IS NOT US FIRST ASSUME THAT IS NOT US FIRST ASSUME THAT IS NO **Expectations in Ma** $\sum_{i=1}^n \sum_{j=1}^n \sum_{j$ the LHC. B above effect is not F above effect is non- \mathcal{L} and can increase \mathcal{L} and concrete models model

mally flavor violating, i.e. that the flavor is only broken that the flavor is only broken that the flavor is o
The flavor is only broken that the flavor is only broken that the flavor is only broken that the flavor is onl d'Ambrosio et al., hep-ph/0207036

...

 $\frac{M_{\rm{max}}}{M_{\rm{max}}}$

els of flavor the coupling of DM to quarks will depend on

Minimal Flavor Violation **Minimal** \overline{U} violution \overline{U} the Minimal η the zero mode of the mediator. Both large *u^R* − *tR*–DM

mally flavor violating, i.e. that the flavor is only broken that the flavor is only broken the flavor is only broken that the flavor of α

$$
C_{2a} = b_1^{(2a)} + b_2^{(2a)} Y_u^{\dagger} Y_u + b_3^{(2a)} Y_u^{\dagger} Y_d Y_d^{\dagger} Y_u + \cdots,
$$

$$
C_{4a} = (b_1^{(4a)} + b_2^{(4a)} Y_d Y_d^{\dagger} + \cdots) Y_u.
$$

the interactions of the interactions of the mediators \mathcal{M} are mini-field \mathcal{M} are mini-field \mathcal{M}

of flavor. For instance, instance, in warped extra dimensional models with the contract of the contract of the
The contract of the contract o

- For $b_1^a \sim b_2^a \sim b_3^a$ C_{2a} almost flavor diagonal and universal \overline{V} close of flower discreptional was up-*V*₂ σ ³ U_{2a} alitiost liavor diagonal and universal *V*CKM diag(*yd, ys, yb*) and *Y^u* = diag(*yu, yc, yt*). In • For $b_1^a \sim b_2^a \sim b_3^a$ C_{2a} almost flavor diagonal and universal $\mathcal{L}(\mathcal{M})$ is due to spontaneously broken horizontal br Γ tion, while the first two generations are Γ to the first two generations are Γ \bullet For $v_1^2 \sim v_2^2 \sim v_3^2$. U_{2a} all nost havor diagona
- C4a is highly hierarchical, can have large flavor violation if *yb*~1 the following let us assume that *b^a* ¹ [∼] *^b^a* ² [∼] *^b^a* ³ are all of hierarchical, can have large flavor violation if y_b \bullet $\bigcap_{i\in I}$ is highly higrarchies $O4d$ io inging increactions α symmetries are generated that the through the through α κ ittiavo kilgo navoi violation ilg μ • C_{4a} is highly hierarchical, can have large fl

Single invisible + t Production *^q [|]* ! [√]*mimj/v*EW [33]. We note however that in principle larger values are also possible. In fact, the structure of quark Yukawas due to spontaneously broken horizontal symmetries [34]. The quark fields carry

horizontal charges *H*(*uⁱ*

R)*, H*(*dⁱ*

R)*, H*(*Qⁱ*

Corresponds to production of neutral mediators in DM *models d,u* . An assignment of horizontal charges leading to phenomenologically satisfactory quark The horizontal symmetries then also fix the sizes of ˜*yij*

^L) (while *H*1*,*² and *S* do not carry a horizontal charge) so that the *H*¹

• Example: Scalar DM (S) via (heavy h₂) Higgs portal in *THDMIII* state in the model (*h*2) and can be described by the following effective Lagrangian [11], $\mathcal{L}^{\tilde{y}}_{h_2} = \sum$ ij $\sqrt{ }$ $\tilde{y}_{u}^{ij}\bar{u}^{i}P_{R}u^{j}h_{2} + \tilde{y}_{d}^{ij}\bar{d}^{i}P_{R}d^{j}h_{2}$ $\overline{ }$ $+$ h.c. $+$ $\lambda v_{\text{EW}}h_2SS$, :xample: Scalar DM (S) v DIVIIII λ $\int z \, i \, \overline{\partial} \, \overline{\partial} \, \overline{\partial}$ ij

Recently first experimental LHC search using hadronic final states by CMS (CMS-PAS-B2G-12-022) masses and the CKM matrix, is *^H*(*{Q*¹ *L, Q*² *L, Q*³ *^L*; *u*¹ *R, u*² *R, u*³ *^R*; *d*¹ *R, d*² *R, d*³ *^R}*) = *{*3*,* 2*,* 0; −3*,* −1*,* 0; −3*,* −2*,* −2*}* [35] . ¯ thresholds (2*m^S < m^h*² ! ²*mt*), and for ^λ ⁼ *^O*(1) (consistent with obtaining the correct Recently first experimental LHC search using hadronic final states by CMS (CMS-PAS-B) hadronic final states by CMS (CMS-PAS-B2G-12-022) Recently first experimental LHC search using hadronic final states by CMS (CMS-PAS-B2G-12-022)

Flavor probes of EW and Higgs sectors

 $B_{s,d} \rightarrow \mu_{\mu} + \mu_{\mu}$ A^{A} and A^{A} and B^{A} and B^{A} and ref. B^{A} and $B^{\text{$ **UNETHERE 1\$50 ONT PARSSXIN LOTES). IN INFRED, IT PWRFELASSSUPHYE DISCUSS {4D}/QUTIQ, TSTBERCES LOITE 1881,3D}**
boxtrativis aQL Form txc, bQ= HR\dTF boxt+t bijours bodisme as Rickijani is tva tard -1+Xz fail DF^{7,} as az conservative estimate continuate this conservative correction is the month of this relative continues of the form 100 MeV. $\frac{1}{2}$ $\frac{1}{2}$ bratieng is colifewest in forces) in Thilaen lifewet are sure the set of party, in the religion of the resistance of the common life of the set of the common decoded that the common set of the common set of the common set Sattanive Cstimute ho - indulhant this redstire colicetion is belowblive for $0E^7_{\rm max}$ According to the estimates in the literature (see Ref. [46] and references therein) **By Bandy Britton (1994)** where *^B*(*B^s* [→] *^µ*+*µ*−γ)DE represents the genuine direct-emission branching fraction. Δ bactieng is colifewes sin flutes) in the leads in the waters summed R efle $_s$ [46] μ ari q_L refigue ϵ es flute ϵ asise)

According to the estimates in the literature (see Ref. [46] and references therein)

Theoretically very clean (virtually no long-district and distance contributions) α distribution, in easured by the LIIC experimental distribution, in easured by the LIIC experiment \mathbb{E} distribution, measured by the LHC experiments is the flavor-averaged time-3.2 Connecting the experimental with the theoretical branching ratio In order to obtain a theoretical prediction for the decay rate accessible in experiments, the Last produce to the state into account is the effect of the non-vanishing width difference and the state into account is the effect of the non-vanishing width difference $\mathcal{B}_{d,SM}$ that the account is the enect_ion the non-valushing width difference $\mathcal{B}_{d,SM} = (1.07 \pm 0.10) \times 10^{-1}$, $\mathcal{B}_{d,SM} = \mathcal{B}_{d,SM} = (3.56 \pm 0.18) \times 10^{-1}$ \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} and \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} \mathcal{B}_{at} $\mathcal{B}_{$ $\frac{1}{2}$ ing the experimental with the theoretical branching ratio necting the experimental with the theoretical branching ratio In order to obtain a theoretical prediction for the decay rate accessible in experiments, the to rest point to the compression of the completion of the station of the station of the station of the contract $\frac{72}{10}$; $\frac{1}{2}$, \frac ng the experimental with the theoretical branching ratio ${\rm root}$ t ${\rm tail}$ n at theoretical prediction for the decay rate accessible in experiments, the last point were need to the effect of the contribution of the effect of the ended to the difference in the state of the construction of $\frac{1}{2}$, $\frac{1}{2}$, aninaattiloosratooalipseolootoontosrttiloedoeaayraateaaceessibboenineexpoerinoents,ttiloe
.:Theoperationally vary olangramminturally no long-distance menarchidultions $\rm d$ distribute and the diffect due to $\Delta \Gamma_s \neq 0$ necting the experimental with the theoretical branching ratio In the obtained the decay of the decay of the decay of the decay relationship and the decay of the decay of the it the subset of take into account is the effect of the non-vanishing width difference

Τ*Bs* Τ*Bs* $1.5%$ – 0.7% $\frac{1}{\mathcal{B}}\frac{\partial}{\partial\theta} \mathcal{B}_{S} \longrightarrow \frac{1}{\mathcal{B}}\frac{1}{\mathcal{B}}\frac{\partial}{\partial\theta}\left[\frac{1}{\mathcal{B}}\right]^{2}}$ $\bar{1}$ $\frac{1}{2} \iiint_{0}^{t}$ *dt*([[[*B*͡s(tt)) → ff)]) + [[[*B͡s*(tt)) → ff.
Ut[[F] Bs|]) → f*) + [[*B*s_s(t)] → f)] \overline{a} , \overline{b} ^{*b}</sup>* $\sqrt{25}$ *</sup></sup>* \vert , $\langle \mathcal{B}\hat{\mathcal{B}}\hat{\mathcal{B}}\hat{\mathcal{B}}\hat{\mathcal{B}}\hat{\mathcal{B}}\rangle =\frac{1}{2}$ 1 $\frac{11}{22}$ $\frac{d}{dt}\left(\prod\limits_{i=1}^{n}(\overrightarrow{B}_{i}^{E}(t_{i}^{H}))\rightarrow\rightarrow f_{i}^{E}(t_{i}^{H})\right)+\prod\limits_{i=1}^{n}(\overrightarrow{B}_{i}^{E}(t_{i}^{H}))\rightarrow\rightarrow f_{i}^{E}(t_{i}^{H})$ 0.7% \bullet $\mathcal{B}\left(\mathcal{B}\right)_{s}\rightarrow\mathcal{B}\left(\mathcal{B}\right)_{s}$ 1 $\frac{1}{2} \int_{0}^{t}$ $\frac{d^4f}{dt^4}[\prod_{i=1}^n(\overrightarrow{B_i}(\overrightarrow{t_i})) \rightarrow \rightarrow f]f] + \prod_{i=1}^n(\overrightarrow{B_i}(\overrightarrow{t_i})) \rightarrow \rightarrow f]$ 0.7% $\langle \mathcal{B}(B_s \to f') \rangle_{[t]}^{\gamma_{\lceil t \rceil}} =$ $\overline{\mathbf{1}}$ $\frac{1}{2}$ $dt''\left[\Gamma(B_s(t')) \to f' + \Gamma(B_s(t')) \to f'\right]$

Domptifrant i plaratimet fra depression tipes $\frac{1}{2}$, $\frac{1}{2}$, $\frac{1}{2}$, denotes the decay distribution, assarium continue to the proper time ($\frac{M_t}{2}$) $H_3(t)) \stackrel{\text{de Bryn et al.}}{\longrightarrow} J$ denotes the decay distribution, as saft in a tomofith $\begin{pmatrix} 1.5\% \\ 0 \\ 0 \end{pmatrix}$ *Barti*veigenstateets initial dimed (and correspondingly for B3) he proper time (t'), $B_{\rm s}(t)$) $\stackrel{\text{de} \to}{}$, J,) denotes the decay distribution, as a function of the second M_t . M_t de griss date e tats inititaal Himne (15 mal bette op spoondding) $\overline{}$ $\mathbf{B}(\phi)$ correspondent to the set of the set of ϕ and the component in the ϕ of \mathcal{B}), \mathcal{B} eDonstateant initial timetric uncertainties α avor eigenstate at timitial time (and correspondingly for $\overline{B_s}$). Furthermore one

 $\overline{s} s =$ L
 τ*B^s* $=$ $\frac{1}{2}$ L
–($\frac{2}{\pi}$ $\left[\Gamma_{ss}^{F\mu\nu} + \Gamma_{ss}^{F\mu}\right]$ $y,$ yy _s \equiv $\frac{1}{2}$ *E*
 ss − Γ_{*SS*}
 L
 Σ
 Σ $\frac{11}{5}$ s = 0*.*088 *±* 0*.*014 *,* (26) $\frac{1}{2}$ In good agreement with experiment $\prod_{SS} =$ 1 τ*B^s* = $\tilde{1}$ $\overline{\mathcal{Z}}$ $T_{\!ss} = \frac{1}{\tau_{\rm obs}^4} = \frac{1}{4} \left(\prod_{s,s}^{H}\! H_{\!-\!1}^L \right)$ $\left(\begin{matrix} \lambda\ \end{matrix} \right), \qquad \text{y}$ *y*s= Γ*L ^s* [−] ^Γ*^H s* 2Γ*^s* = 0*.*088 *±* 0*.*014 *,* (26) = 0*.*088 *±* 0*.*014 *,* (26) $\overline{J} = \frac{1}{2}$ (i, \overline{I} i, \overline{I} i, \overline{I} i, \overline{I} i, \overline{I} imentional \overline{I} imentional \overline{I} $\mathbf{1}$ $\stackrel{1}{B\!B\!}_{\!ss}$ = $\mathbf{1}$ $\overline{2}$ * Γ*^H ^s* + Γ*^L s* $\big), ,$ *yy*_s = $\mathop{\hbox{\rm LE}}\limits_{s\overline s}$ *^s* [−] ^Γ*^H s* $\int_{s}^{\overline{L}}2\pi\int_{s}^{\overline{H}}\frac{dt}{s}$ $\Gamma_s =$ 了
内 τ*B^s* 2 = $\bar{\mathcal{Y}}$ $\bigl\langle \Gamma_s^H+\Gamma_s^L\bigr\rangle$ $\int_{0}^{\sqrt{y}}$, $y_s =$ 2Γ*^s* $= 0.088 \pm 0.014$, $\sqrt{26}$

In Good agreement with experiment \sim s the total decay widths of the two mass eigenstates. As discussed in Ref. [14], $\frac{1}{12} \frac{1}{12} \frac{1$ \sim y
Γ s the total decay widths of the two mass eigenstates. As discussed in Ref. \mathcal{L} integraved describbutid his of that ect was the standard as \mathcal{L} *B^s* 4.0# L the total decay widths of the two mass eigenstates. As discussed in R40% for the two mass eigenstates. As discussed in R40% for with Γ*H,L* $t=0$ by integrated distribution is related to the fla \mathcal{B} -averaged \mathcal{C} and $t=0$ by

Figure 112 Figure budgets ftor the two branching Standard Motople beidespt in (980) ((eft) and (1939) (\Rightarrow f) $\partial_t [t] = K^t (t, y, y) \setminus \mathcal{B} (B^t \rightarrow f) \setminus \{t \mapsto 0\} = K^t (t, y, y)$ $\frac{(\cancel{B_5}, \cancel{2}, \cancel{0})}{\cancel{(B_5}, \rightarrow \text{)}}$ *, (24)*
∴off⊚r>+ where the state of the model of a model of a model of t and α is a model of \mathbb{R}^n . Fijgandard Motoolala bajd get spfdød) (tetty) and risbij) ΓΓΩς, 27 124 Γεγγρή θυματος του του του των θρεσμοφή in \Rightarrow $f f)(\theta$ _{*t*}. $\stackrel{\text{D}{d}}{=}$ $\kappa f^f(t; y, y)$ $\stackrel{\text{D}{d}}{=}$ $\beta f^f(x, y, y)$ $\frac{\Gamma(\cancel{B_3}, \cancel{2}, \cancel{0})}{\Gamma(\cancel{B_3}, \cancel{2}, \cancel{0})}$ $\frac{(\mathcal{Q}^2)}{(\mathcal{Q}^2)}$, (\mathcal{Q}^2) re *kt yy* a his a model-and channel-dependent correction factor. Figure 1: Error budgets for the two branching ratio calculations of *B^s* → *µ*⁺*µ*[−] in the 2Γ*^s* Steamdard Motople legisles at spridge lytery and (1639) r \Rightarrow \Rightarrow f f (θ) \rightarrow \Rightarrow f f (θ) \rightarrow \Rightarrow f f \rightarrow f f f f f g g g f $\frac{E_{\mathcal{A}}}{B_{d}}$ (exp) = (10*PD*₁₉1,2) × 10⁻¹⁰
 $\frac{E_{d}}{B_{d}}$ (f(t, $\frac{1}{2}$ (3,6+1*.9*) × 10⁻¹⁰
 $\frac{1}{2}$ (f(t, $\frac{1}{2}$) × 10⁻¹⁰
 $\frac{1}{2}$ (f(t, $\frac{1}{2}$) + 1.9) + 1.2) × 10⁻¹⁰
 $\frac{1}{2}$ (f(t, $\frac{1}{2$ $\frac{(1, 1, 1, 1)}{(2, 1, 1)}$, $(2, 7)$ where kerestime the two budgets for the two budgets for the two budgets for the two band measure of the two budgets for the two band measure of the two budgets for the two band of the two band of two band of the two band o $\langle B \rangle = f \rangle = f(t, y_s)$
 $\langle B \rangle = f(t, y_s)$ $\overrightarrow{B} \rightarrow f$ \overrightarrow{B} \overrightarrow{F} \overrightarrow{B} \overrightarrow{F} $\$ 2Γ*^s* **, Briddee talk and Sprand-Menzemer 14 and 14 an**

 0.8 \overline{a}

 $-2.7%$

FBs FBs

 (26)

|*V*_{tb}^{*W*_s}

 \mathcal{B}

!*V*tb "*V*ts! !*V*tb "*V*ts!

Bs,d → μ*⁺*μ*-Bs,d* → *!⁺!-* $B_{s,d} \Rightarrow M^{+}M^{-}$

Particularly sensitive to FCNC scalar currents and FCNC Z Particularly sensitive to FCNC scalar currents and FCNC Z penguins penguins Particularly sensitive to FCNC scalar currents and FCNC Z penguins

Clean probe of the Yukawa interaction $(\Rightarrow Higgs sector)$ Clean probe of the Yukawa interaction $(\Rightarrow$ Higgs sector)

beyond tree level beyond tree level beyond tree level

Latest results beginning to test possible to test possible *Bd/B^s* enhancement enhancement Latest results beginning to test possible *Bd/Bs*enhancement see talk by Kohal

Nontrivial test of MFV Nontrivial test of MFV. Hurth et al., 0807.5039 Nontrivial test of MFV. NONTrivial t

Hurth et al., 0807.5039

Figure 2: Correlation between the branching ratios of $B_s \to \mu^+ \mu^-$ and B_d in MFV, the SM4 and four SUSY flavour models. The gray area is ruled out in metal contraction between the branching ratios or $D_s \to \mu^+\mu^-$ and $D_d =$ \min wir v, the SM4 and four SOST havour mo

tive couplings of the \overline{Z} boson to down-type quarks 0.00 0.01 0.02 0.03 0.04

 $\frac{\partial^2 f}{\partial x^2}$ from the SM in terms of d out in Refs. [4, 6], there exists a wide class of models where the only relevant Z-boson couplings at zero momentum transfer, defined by the following effective $\frac{1}{2}$ from the SM in $\frac{1}{2}$ $\frac{1}{$ Z-boson couplings at zero momentum transfer, defined by the following effective

$$
\overline{\mathbf{u}}
$$

$$
\mathscr{L}_{\text{eff}}^Z = \frac{g}{c_W} Z_\mu \overline{d}^i \gamma^\mu \left[(g_L^{ij} + \delta g_L^{ij}) P_L + (g_R^{ij} + \delta g_R^{ij}) P_R \right] d^j \tag{3}
$$

Guadagnoli & Isidori 1302.3909 \mathcal{L} *sU*(2)^{*L*} \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} M couplings. In the following we employ state-of-the-art expressions to estimate μ _{ntribut}iawor ¢non) yn iversality→ *ZbbladZ* spyst tilaworiadolati the non-standard effects parameterized by $\delta g_{L}^{ij}g_{L}^{b}$ 0.006 r convenience we recall the leading structure of the $g_{L,R}^{ij}$. The tree-level $\mathbb{S}M$ are $(g_L^{iQ})_{\text{tree}}^{(6)} \cong \frac{c_1 \underline{1}}{2}$ $\frac{L}{2}$ 1 3 $\left\{ \begin{array}{c} \mathcal{S}_{W}^{2} \end{array} \right\}^{ij} Q_{L}^{i} \gamma_{GR}^{\mu} \delta_{\text{free}}^{ij} \frac{1}{\epsilon_{\text{free}}} \right\}^{ij}$ $\tilde{1}$ 3 $\mathscr{L}(\mathscr{G}_{L,R}^{i\neq j})|_{\text{tree}} = 0$. $\sqrt{\mathscr{G}(4)}$ $\sum_{i=1}^{n} R_i$ at the $g_{L,R}^{ii}$ are gauge dependent, but they assume the following simple α -independent $\psi_{tb}^{\text{b}} \psi_{ts}^{\text{min}}$ the limit $m_t \gg m_s$ (or $g \to 0$): $(g_L^{ij})_{1-\text{loop}}^{(ij\&\text{0})} =$ $\frac{m_t^{2^j R}}{16\pi^2 v^2} V_{ti}^* V_{tj}^*$, $m_b |V_{tb}|^2_{\substack{(j \ j) \ (g=0) \ (g=0) \ -\infty}} = 0$ $\frac{d\textrm{enote}}{d}$ where using the latest exp. results $v \approx 246$ GeV. enence we recall to $0.000 \Big\vert \Big\vert \ \mathrm{SM} \big\vert$ -0.002 0.002 0.004 F ixing quality one can compare g flavor (non)universality (*Zbb/Zqq*) vs. flavor violation (*Zbs*) dagnoli & Isidori 1302.3909 \mathcal{L} *SU*(2)^{*L*} \mathcal{L} gauge coupling, \mathcal{L} order \mathcal{L} and \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} and \mathcal{L} \mathcal{L} and \mathcal{L} M couplings. In the following we employ state-of-the-art expressions to estimate μ _{ptribut}iaw@r&negr}Universality→(%Dad_G@Q)^zySt tilaw@rladOlaty r convenience we recall the leading structure of the $g_{L,R}^{ij}$. The tree-level $\mathbb{S}_{\infty}^{\mathbb{N}}$ are $(g_L^{i\mathbf{Q}_{L}^{(6)}})_{\text{free}} \cong \frac{c_1 \underline{1}}{2}$ $\frac{L}{2} \frac{\sqrt{2}}{1}$ 1 3 $\left\{\begin{matrix} S_{W}^{2} \end{matrix}\right\}^{s}$, $\left\{ \begin{matrix} V_{L}^{r} \left\langle \begin{matrix} G_{R}^{r} \end{matrix} \right\rangle_{\rm free}^{r} \end{matrix}\right\}^{s}$ $\mathfrak{1}$ 3 s_{W}^{2} , $(g_{L,R}^{i\neq j})_{\text{tree}}^{i=0} = 0$. $\sqrt{\frac{S}{A}}$ (4) $\sum_{i=1}^{R}$ at the $g_{L,R}^{ii}$ are gauge dependent, but they assume the following simple α -independent $\psi_{tb}^{\text{c}} \psi_{ts}^{\text{min}}$ the limit $m_t \gg m_s$ $\psi_{tb}^{\text{max}} \ll m_s$ $g \to 0$: $(g_L^{ij}|_{1-\text{loop}}^{(b)} =$ $\frac{m_t^{2^j R}}{16\pi^2 v^2} V_{ti}^* V_{tj}^*$, $m_b |V_{tb}|^2_{\left(g^{ij}_R\right)_{1-\text{loop}}^{\left(g=0\right)}} = 0$ $\rho_{\rm{denote}}$ (update using the latest exp. results), $v \approx 246 \text{ GeV}.$ ience we recall the leading structure of the $g_{L,R}^{ij}$. The tree-level \mathbb{R}^N **F***X* \mathbb{R}^N $B_s \rightarrow \mu^+ \mu^-$ (95% C.L. now) $\delta\overline{\mathcal{B}}$ *s* $\overline{\mathcal{B}}$ _s \rightarrow 0.3 \times 10^{-9} *Z* → *b* ¯*b*(*Rb, Ab* 49 95% C.L. $\delta g_L^{bs} = \frac{V_{tb}^0 V_{ts}^{*}}{|V_{ts}|^2} \delta g_L^b$ $\delta g_R^{bs} = \frac{W_s^{\prime\prime} W_b V_{ts}^a}{W_s^2 |V_{ts}|^2} \delta g_R^b$ 0.000 $\frac{1}{100}$ $\partial \Omega^{(6)}_{L} \simeq \frac{c_1 L}{2} (Y_u^1 Y_d^{\dagger})^{ij} \bar{Q}_L^i \gamma^\mu_\theta Q_L^j \phi^\dagger \bar{D}_\mu^1 \phi_L^j$ $\mathcal{Q}_{R}^{(6)} \sim c_{1R}^{2} Y_{d}^{i} (Y_{u} Y_{u}^{\dagger})^{ij} Y_{d}^{j} \bar{d}_{R}^{i} \gamma^{\mu} d_{R}^{j} \phi^{\dagger} \overleftrightarrow{D}_{\mu} \phi^{\dagger}$ $V_{tb}^{\text{OPT}} V_{ts}^*$ *|Vtb|* $\frac{ds}{2}\delta g_L^b$ $\delta g_R^{bs} =$ \hat{m} fW_{b} $\mathit{V}_{ts}^{\text{off}}$ $\binom{m_b|V_{tb}}{P}$ $\frac{t s}{2} \check{\delta} g_R^b$ Fixing flavoring odel one can compare: flavor (non)universality (*Zbb/Zqq*) vs. flavor violation (*Zbs*)

 σ -physilnclusion of other $b \to s$ **u** δp_L^{ij} meals related to the couplings $\sigma_{0.03}$ 0.04 estly gcould further improve these constraints 34 σ -physilnclusion of other $b \to s$ μ δp_L^{ij} meals related to the couplings δg_R^b $lnclusion of other b \rightarrow s \mu b p_L^{ij}$ meales

ij

ij

OOFBHRP2 2850 % *-* PP ESPRESS *-* **Decays** other *b!sl+l -* ESECASYS

• • much opported information other *b*! Isle charage as Well · progresses sadstate onetheetheorideide Deconstructing b → *s*(γ, l. (1) transitions
Deconstructing b → s(γ, l. (1) transitions
progressessassition anethermeography • much more information in other *b*!*sl+l-* decays as well • progress possible on the theory side

adopted from Altmannshofer @ Snowmass Intensity Frontier Workshop 2013, Argonne

 $B \to K^{*} \ell \ell^+ \ell^-$ anomaly Possible experimental tests:
 $\frac{1}{2}$ • More inclusive observables (integrated over $q^2 = [1, 6]$ GeV²) d by • In ~4! tension with SM estimates (dominated by *P5 '*, also *AFB*, *P2*) *B* → *K*!⁺![−] was found to be well below 1 % of the total hadronic contribution - fine binning could enhance sensitivity to QCD effects *P* Consider high q^2 (low hadronic recoil) region $\frac{q^2}{q}$ $\frac{q^2}{q}$ $\frac{q^2}{q}$ $\frac{q^2}{q}$ $\frac{q^2}{q}$ $\frac{q^2}{q}$ - different theory systematics (HQET OPE) However, some indic • Complementary observables in other modes **Finding Complementary observables** in other modes $\left(\begin{array}{ccc} \mathcal{L} & \mathcal{L} & \mathcal{L} & \mathcal{L} \end{array} \right)$, 1/^mb (estimated) corrections of $\mathcal{L} & \mathcal{L} & \mathcal{$ • Underestimated LD contributions? *Not too close to charm*
Dess sensitive to non-local (resonance) contributions ^{1.2} for the matrix element of Q_{8g} . The operator Q_{8g} still provides a chiral pro and the fermion line entering i^{K*} in Fig. 3 is still "hard-collinear", such i he r *mot too close to charm threshold!* by a power and lattice by a power suppression of a power suppression o Q_{8g} o.4 (Note also that the effect of the soft α $\begin{bmatrix} -0.4 \\ -0.8 \end{bmatrix}$. It is different to see $\begin{bmatrix} -0.8 \\ -0.8 \end{bmatrix}$ is the set of contribution could \mathbf{p} by \mathbf{r} and \mathbf{p} per \mathbf{r} and the double computation operators and the double \mathbf{p} $(B_s \to \phi \ell^+ \ell^-, B \to K \ell^+ \ell^-, B \to X_s \ell^+ \ell^-, \ldots)$ *a*had*,* lq *x x* e^{*x*} *x* + *i*^c × *x* + *i*^c × *x* + *i*^c × *x* + *i*^c i.e. expect reduced rates compared to SM estimates see talk by Serra $B \to K^{*} \ell \ell^{+} \ell^{-}$ anomaly • Consider high q^2 (low hadronic recoil) region - different theory systematics (HQET OPE) ⁰ ¹ ² ³ !0.2 \mathcal{L} **regrate** \overline{z} $\overline{$ g Gev **SU** \sim ְ 0.8 \overline{O} " be sensitivity to QCD effects P_5 $-1.2^L₀$ -0.8 -0.4 $\overline{0}$ 0.4 0.8 1.2 q^2 [GeV²] ontr or assumptions might be violated
ervables in other modes are low-the low-the low-the experimental results for the experimental results for the experimental results for
The experimental results for the experimental results for the experimental results for the experimental results compared to SM Jager & Camalich, 1212.2263 Recent indications? Not too close to charm threshold! However, some indications that some of assumptions might be violated LHCb, 1307.7595

Horgan et al., 1310.3722, 1310.3887 [Horgan et al., 1310.3722, 1310.3887](http://arXiv.org/abs/arXiv:1310.3722)

and are either doubly Cabibbo-suppressed or weighted by the small Wils efficients C_{3-6} . Again, a systematic description exists within QCDF [23], LHCb, 1403.8044 K_{3-6} . Again, a systematic description exists within QCDF [23], - if due to QCD, don't necessarily expect identical effects

Success of SM (CKM paradigm) in describing (quark) flavor phenomena puzzling in light of EW hierarchy problem

Flavor physics intimately connected to Higgs phenomenology - directions just starting to be explored

Top-flavor processes ideal for LHC studies - interesting links to EW hierarchy, flavor, DM puzzles see also Blanke et al., 1302.7232

Puzzling results in rare B decays due to be properly understood

Backup

\bigcup $bles (at$ </u> ohoon Testing flavor through Higgs observables (at LHC)

!*Y*

Within SM effective Y_{i≠j} extremely suppressed (GIM+CKM/ m_v & chirality) $\overline{}$ **Edy**
chirality

Constraints on first two generation *Yi≠^j* dominated by precision flavor observables (both lepton and quark)

Currently LHC already most constraining in *τ-μ*, *τ-e* sectors (recast $\frac{1}{2}$ of $h \rightarrow \tau \tau$

10!³

^e m

!*Y*Μ

$$
B_{s,d} \rightarrow \mu^+\mu^-
$$

Particularly sensitive to FCNC scalar currents and FCNC Z penguins

Clean probe of the Yukawa interaction $(\Rightarrow$ Higgs sector)

beyond tree level

Example: general MSSM

Measurement with σ (BR) ~ 30% provides relevant constraint on such couplings below stability bounds $(|A_{23}A_{33}| < 3m_{\tilde{t}_L}^2)$ for $m_{\tilde{t}_L} < 1 \,\text{TeV}$, $m_{\tilde{t}_R} < 0.5 \,\text{TeV}$

Isidori @ HCP2012, Kyoto Behring et al., 1205.1500 Mahmoudi, Neshatpour & Orloff 1205.1845

 $m_{\tilde{\tau}}^2$

 \tilde{t}_R