New Physics Models or On the Rare Occasions When Naturalness Meets Flavor

Gilad Perez

Weizmann Inst.

Flavorful Ways to New Physics

KHYS Young Scientists Workshop Flavorful Ways to New Physics

1

The Standard Model (SM) & Flavor Phys.

• *^B*-factories+LHC have an experimental (exp') support that the CKM picture described nature (up to possibly small corrections):

Talk by: Krizan

- Based on several exp' observation (started in 64 many came in the last 10 years or so).
- CP violation (CPV) in the Kaon and *B* system \Rightarrow within the SM correlated => consistent with SM. Talk by: Buras
- Flavor conversion \Rightarrow precision data confirmed the SM.
- New bounds on CPV in the *D* mixing also confirms SM picture.

Talk by: Gersabeck

This implies: severe bounds on non-SM phys. / does it exist?

Is this the end of the story?

Baryogenesis => SM cannot be the only source of CPV.

(otherwise, rapid proton-antip-protons annihilation of yield baryon asym' of $\leq 10^{-18}$)

Almost any SM extension give new sources of flavor & CPV.

Integrating out new physics (NP) => di. 6 Ops.: $(\bar{d}_i d_j)^2 / \Lambda_{NP}^2$

 $\Lambda_{NP} \gtrsim 10^4 \textrm{TeV}$ Precision measurements \Rightarrow $\Lambda_{NP} \gtrsim 10^4 \text{TeV} \gg M_W$

Flavor NP hierarchy "problem" (puzzle not a problem, see later)

What are the problems of the Standard Model* (SM), before & during the LHC era?

 $*$ Let's set quantum gravity aside for simplicity \dots

What are the problems of the Standard Model* (SM), before & during the LHC era?

What kind of new phys. might be motivated during the LHC era?

Reminder: sym' structure of SM quark flavor sector

Talk by: Buras

Int' basis, the gauge part is trivial:

$$
\overline{q}_i^I \not\!\!D q_j^I \delta^{ij}, \quad q \in Q, U, D \longrightarrow q_i \to U_{ij}^{(3 \times 3)} q_j
$$
\nglobal sym': $U(3)_Q \times U(3)_U \times U(3)_D$

Yukawa sector is interesting: The quark Yukawa interactions are given by

$$
-\mathcal{L}_{\text{Yukawa}}^{\text{quarks}} = Y_{ij}^d \overline{Q_{Li}} \phi D_{Rj}^I + Y_{ij}^u \overline{Q_{Li}} \widetilde{\phi} U_{Rj}^I + \text{h.c.}.
$$

global sym': $U(1)_D^3 \times U(1)_U^3 \rightarrow U(1)_B$

Flavor puzzle vs. problem, tuning vs fine tuning **O** ⇥*x* ²³*,*¹³ = .
.. <u>tuni</u> ng vs f $\overline{}$ ne t <u>unin:</u> \mathbf{g}

Flavor puzzle: parameters are small and hierarchical. *y*2 *t,b* nal 1 nd)
 hier $\overline{1}$ \mathbf{r} *<u>u*</u> and hierarchical.

c,s t,b ⇥

Is the flavor sector finely tuned? (quantum unstable?) *^c*23*,*¹³ ⁼ *^O*(⇥²*,*³)

k **theoft's-technical-naturalness: a parameter is natural if** when it's vanishing a new non-anomalous sym' is obtained.

Light masses are protected by residual $U(2)_D \times U(2)_U$ sym'. Mixing angles are protected by $U(1)_Q^3$ sym'.

 μ (2) μ mothing unnatural) *YD*⇥0 \int ¹ $\overline{\text{atur}}$ ⇥8 Flavor puzzles => matter of tuning (nothing unnatural) Higgs mass => fine tuning (unnatural)!

The LHC is a very limited telescope but this is the best we have …

Hierarchy see-saw With NP new flavor problem might arise

Standard Model up to some $\Lambda_{UV}^2 \gg 1 \,\mathrm{TeV}$

$\mathsf{NP},$ model indep': $\Delta F = 2 \text{ status}$

Isidori, Nir & GP, Ann. Rev. Nucl. Part. Sci. (10)

However little is known on tFCNC

Operator Bounds on ⇥ in TeV (*cij* = 1) Bounds on *cij* (⇥ = 1 TeV) Observables Re Im Re Im (¯*sL^µdL*)² ⁹*.*⁸ ¹⁰² ¹*.*⁶ ¹⁰⁴ ⁹*.*⁰ ¹⁰⁷ ³*.*⁴ ¹⁰⁹ *mK*; ⇥*^K* (¯*s^R ^dL*)(¯*sLdR*) ¹*.*⁸ ¹⁰⁴ ³*.*² ¹⁰⁵ ⁶*.*⁹ ¹⁰⁹ ²*.*⁶ ¹⁰¹¹ *mK*; ⇥*^K* (¯*cL^µuL*)² ¹*.*² ¹⁰³ ²*.*⁹ ¹⁰³ ⁵*.*⁶ ¹⁰⁷ ¹*.*⁰ ¹⁰⁷ *mD*; *[|]q/p|,* ⇧*^D* (¯*c^R ^uL*)(¯*cLuR*) ⁶*.*² ¹⁰³ ¹*.*⁵ ¹⁰⁴ ⁵*.*⁷ ¹⁰⁸ ¹*.*¹ ¹⁰⁸ *mD*; *[|]q/p|,* ⇧*^D* (¯*bL^µdL*)² ⁵*.*¹ ¹⁰² ⁹*.*³ ¹⁰² ³*.*³ ¹⁰⁶ ¹*.*⁰ ¹⁰⁶ *m^B^d* ;*SK^S* (¯*b^R ^dL*)(¯*bLdR*) ¹*.*⁹ ¹⁰³ ³*.*⁶ ¹⁰³ ⁵*.*⁶ ¹⁰⁷ ¹*.*⁷ ¹⁰⁷ *m^B^d* ;*SK^S* (¯*bL^µsL*)² ¹*.*¹ ¹⁰² ⁷*.*⁶ ¹⁰⁵ *m^B^s* (¯*b^R ^sL*)(¯*bLsR*) ³*.*⁷ ¹⁰² ¹*.*³ ¹⁰⁵ *m^B^s* TABLE I: Bounds on representative dimension-six *F* = 2 operators. Bounds on ⇥ are quoted assuming an

t

An experimental natural irony …

Our most precise probes are made of light quarks; our initial states are made of light quarks and gluons. However, natural phys. is about Higgs, top & massive gauge fields.

(¯*c^R ^uL*)(¯*cLuR*) ⁶*.*² ¹⁰³ ¹*.*⁵ ¹⁰⁴ ⁵*.*⁷ ¹⁰⁸ ¹*.*¹ ¹⁰⁸ *mD*; *[|]q/p|,* ⇧*^D* (¯*bL^µdL*)² ⁵*.*¹ ¹⁰² ⁹*.*³ ¹⁰² ³*.*³ ¹⁰⁶ ¹*.*⁰ ¹⁰⁶ *m^B^d* ;*SK^S* (¯*b^R ^dL*)(¯*bLdR*) ¹*.*⁹ ¹⁰³ ³*.*⁶ ¹⁰³ ⁵*.*⁶ ¹⁰⁷ ¹*.*⁷ ¹⁰⁷ *m^B^d* ;*SK^S* (¯*bL^µsL*)² ¹*.*¹ ¹⁰² ⁷*.*⁶ ¹⁰⁵ *m^B^s* (¯*b^R ^sL*)(¯*bLsR*) ³*.*⁷ ¹⁰² ¹*.*³ ¹⁰⁵ *m^B^s* TABLE I: Bounds on representative dimension-six *F* = 2 operators. Bounds on ⇥ are quoted assuming an

^d⌅*QVd,*(3.7) where ⌅*^Q* is a diagonal real matrix, and *V^d* is a unitary matrix which parametrizes the misalignment of the operator (3.6) with the down mass basis. The experimental constraints that are most relevant to our study come from *K*⁰–*K*⁰ and*D*⁰–*D*⁰ mixing, which is the first two generation quarks. When studying new physics e μ ignoring the third generation is often a good approximation to the physics at hand. In when the third generation does play a role, our two generation and analysis is applicable as the two generation and analysis is applicable as applicable as long as the two generation and as in the two generation and as the are no strong cancellations with contributions related to the third generation. In a two generation framework, *V* depends on a single mixing angle (the Cabibbo angle ⇤*c*), while *V^d* depends on a

 $s: \Rightarrow \Lambda_s \lesssim 2 \times 10^4$ TeV

 $\sim 10^{-32}$

- $c: \Rightarrow \Lambda_c \leq 2 \times 10^3 \,\text{TeV}$
- $b: \Rightarrow \Lambda_b \lesssim 4 \times 10^2$ TeV

It would raise two questions:

לשאלת הקבוע הקוסמולוגי. ננסה להבין בקצרה בעיה זו, כפי פיזיקה של חלקיקים מתוארת על–ידי תורת שדות, שמשלבת

המצופה מהתיקונים הקוונטיים, כך ששתי התרומות האסטרונומיות סכמטית, אם כן, הכוונון העדין של הקבוע הקוסמולוגי נראה כך:

 \blacklozenge Ho $^{(1)}$ virial set then precise distance $^{(2)}$ \geq 1 and $^{(3)}$ problem $^{(4)}$ \geq $^{(5)}$ \geq $^{(6)}$ \geq $^{(7)}$ \geq $^{(8)}$ \geq $^{(9)}$ \geq $^{(10)}$ \geq $^{(11)}$ \geq $^{(12)}$ \geq $^{(13)}$ \geq $^{$ בעיית הקבוע הקוסמולוגי כמו שכבר ציינו, הכוונון העדין קשור גם לנושא הכוח החלש וגם (ii) Why perturbations not destabilize the system? \leq Fine tuning pro $\bf{Se\,} than \ \ 1:100$

15

 \overline{a}

Top partners & LHC Searches

Naturalness => new colored partners, potentially within the LHC reach.

Top partners & naturalness

Naturalness => new colored partners, potentially within the LHC reach.

thus accessible at high energy measurements! Info' not related to flavor conversion or CP violation,

Everything degenerate *R,* \blacksquare Everything degenerate \blacksquare Splitter \blacksquare \blacksquare *u*˜*R, c*˜*^R* enerate de (˜*c, s*˜)*L, c*˜*R, s*˜*^R* Everything degenerate E acc Everything degenerate \overline{r} Everything Everything S erate degeneration of the control. Everything degenerate l Everything degenerate $\begin{array}{ccc} & & & \sqrt{\text{max.}^{u_R,v_{\hat{c}_R}}}\ \text{Split, but MFV!} \end{array}$

Everything degenerate

Split, but MFV !

Everything degenerate

Split, but MFV !

(˜*c, s*˜)*L, c*˜*R, s*˜*^R*

 $Split, but \, MFV$! Split, but $\overline{\mathsf{M}}$ we define Split, but MFV ! *u*˜*R, c*˜*^R* \mathbf{S} $\begin{array}{c} \mathbf{w}_R, \ \mathbf{c}_R \ \mathbf{S} \end{array}$ Split, but MFV ! Split, but MFV ! ˜)*L,* (˜*c,s*˜)*^L* $\overline{}$ but $\overline{}$ Split, but MFV ! but MFV !

 $\frac{u_R, c_R}{\tilde{u}}$

 $\sum_{\alpha} u_R$ ⁿ c_R

 $\tilde u_R,$

 u_R

 $\frac{\omega_{R}}{\tilde{v}}$

u˜*R, c*˜*^R*

u˜*R, c*˜*^R*

 $\int_{R_1}^{\infty} E_R^X C_R^X$

d 3 ۴ *L*

d 2 $\overline{)}$ *L*

 \tilde{c}_R

u˜*R, c*˜*^R*

dR, s˜*^R*

dR, s˜*^R*

dR, s˜*^R*

dR, s˜*^R*

 $\frac{1}{2}$

˜

 $\left(\widetilde{q}_2^{\bm{d}}\right)_L$

 \widetilde{d})_r (\widetilde{c}_i)

 $d)$ *L*^{*,* c ₍ i}

 $\widetilde{\mathscr{A}}_L(\widetilde{c}_n)$

˜

(˜*u,* ˜

t i

Split, but MFV !

ATLAS ?? **LHCb** Split, but MFV ! Everything degenerate Split, but MFV ! *d* ˜ Everything degenerate Everything degenerate *u*˜*R, c*˜*^R ^R, s*˜*^R* Everything degenerate Everything degenerate xe^x \overline{a} *^R, s*˜*^R* Splittling degenerate Everything degenerate

enerate
.---enerate_:

Everything degenerate

(˜*c,s*˜)*L, c*˜*R, s*˜*^R*

(˜*c,s*˜)*L, c*˜*R, s*˜*^R*

 $\frac{1}{2}$

˜

R,

Everything degenerate

Everything degenerate

Naturalness & the two top frontiers

Naturalness & the two top frontiers

Outline

♦ Supersymmetry & flavorful naturalness.

♦ Composite pseudo Nambu-Goldstone boson (pNGB) Higgs:

- i. Alignment: non-degenerate composite first two generation;
- ii. Anarchy: importance of top flavor violation & naturalness.

 $($ \bullet See appendix for recent development on Higgs-quarks phys. $)$

♦ Conclusions.

Supersymmetric Flavorful Naturalness & implications of split first two generation squark spectrum

Partner are elusive because of non-trivial flavor physics effects

Supersymmetric (SUSY) Flavourful naturalness

- ♦ Standard model: 3 copies (flavours) of quarks; same holds for new physics. (say supersymmetry)
- ♦ "Hardwired" assumption: top partner (stop) is mass eigenstate.

Dine, Leigh & Kagan, Phys.Rev. D48 (93); Dimopoulos & Giudice (95); Cohen, Kaplan & Nelson (96)

Supersymmetric partners, also come in 3 replicas <=> flavours.

Flavourful naturalness

- ♦ Standard model: 3 copies (flavours) of quarks; same holds for new physics. (say supersymmetry)
- ♦ "Hardwired" assumption: top partner (stor) is mass eigenstate. Dine, Leigh & Kagan, Phys.Rev. D48 (93); Dimopoulos & Giudice (95);

Cohen, Kaplan & Nelson (96) > 1000 citations !

Supersymmetric partners, also come in 3 replicas <=> flavours.

♦ This need not be the case, top-partner => "stop-scharm" admixture.

Flavourful naturalness

- ♦ Standard model: 3 copies (flavours) of quarks; same holds for new physics. (say supersymmetry)
- ♦ "Hardwired" assumption: top partner (stor) is mass eigenstate. Dine, Leigh & Kagan, Phys.Rev. D48 (93); Dimopoulos & Giudice (95);

Cohen, Kaplan & Nelson (96) > 1000 citations ...

Supersymmetric partners, also come in 3 replicas <=> flavours.

♦ This need not be the case, top-partner => "stop-scharm" admixture.

Signatures change, opening the charm front at high energy $\&$ in D-meson CP violation.

What is the impact of stop-flavor-violation on tuning ? (flavored naturalness)

- \bullet Flavor: only $\tilde{t}_R \tilde{u}_R$ or $\tilde{t}_R \tilde{c}_R$ sizable mixing is allowed.
- ♦ Naively sounds crazy ...

Dine, Leigh & Kagan (93); Dimopoulos & Giudice (95).

What is the impact of adding flavor violation on stop searches ? (flavorful naturalness)

 \bullet Flavor: only $\tilde{t}_R - \tilde{u}_R$ or $\tilde{t}_R - \tilde{c}_R$ sizable mixing is allowed.

♦ Naively sounds crazy as worsening the fine tuning problem.

$$
h \cdots \underbrace{\int_{y_t}^{t} y_t \cdots \int_{y_1}^{t} \cdots \int_{y_{i-1}}^{y_i} \tilde{C}_R}_{h} \qquad \qquad \delta m_{Hu}^2 = -\frac{3y_t^2}{8\pi^2} \left(m_{\tilde{t}_L}^2 + \cos^2 \theta_{23}^{RR} m_1^2 + \sin^2 \theta_{23}^{RR} m_2^2 \right)
$$

• However, as you'll see soon the scharm can be light...

 \blacktriangle The $\frac{n}{L}$, f^* \mathbb{R} \longrightarrow $f \circ f^*$ produ \bullet The $"\tilde{t}_R \tilde{t}_R^* " \to t_R t_R^*$ production is suppressed by $\left(\cos \theta_{23}^R\right)^4$. E_R^* ^{*} $\rightarrow t_R t_F^*$ *R* $\left(\cos\theta^R_{23}\right)^4$

contributions from the SM particles by the SM particles by the SM particles μ Potentially: new hole in searches, possibly improve naturalness

PDFs: all 4 flavor "sea" squarks can be rather light

Mahbubani, Papucci, GP, Ruderman & Weiler (12).
30 Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Single squark can be as light as 400-500GeV! LO mixed up-down squark production cross section is multiplied by a K-factor of 1*.*5 (2*.*0).

Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Are non-degenerate first 2-generation squarks consistent with flavor bounds?

Surprisingly: answer is probably yes both from low energy & UV perspectives.

See Galon, GP & Shadmi (13) for microscopic realization, aligned SUSY breaking flavored gauge mediation models.

Yasmin & Gilad Perez <jasgilperez@gmail.com>

Your Holiday Inn Express (R) Reservation Confirmation - SOMMA LOMBARDO, ITALY: 67442015

Holiday Inn Express Reservations <HolidayInnExpress@reservations.ihg.com> Mon, Feb 15, 2010 at 2:35 PM Reply-To: HolidayInnExpress@reservations.ihg.com To: jasgilperez@gmail.com

Thank you for choosing Holiday Inn Express. Here is your reservation information.

32

Sea LH squarks vs. valence LH squarks

Adding flavor constraints (Δm_D) for LH squarks:

Sea LH squarks vs. valence LH squarks

Adding flavor constraints (Δm_D) for LH squarks:

Are non-degenerate first 2-generation squarks consistent with flavor bounds?

♦SUSY flavor & CP violation => misalignment between squark soft masses & standard model (SM) Yukawa matrices.

 \bullet SM: right handed (RH) flavor violated by single source, $Y_d^{\dagger} Y_d$ or $Y_u^{\dagger} Y_u$, => RH SUSY masses are alignable removing RH flavor & CP violation:

♦ SM LH sector consist of 2 flavor breaking sources: $Y_d Y_d^{\dagger} \& Y_u Y_u^{\dagger}$

Make Another Reservation

 $F = F \cup F \cup F$ is diagrams with a model wi

Then, Stab Replace:
Your Priority Club Rewards number applies to this reservation.

Tha charm frantiary recontly $LTCh$ made impressive the suarm from degreer. Fourty Lited mass impressive exception of the measurements of **Progress in CPV** in mixing to the measurements of P α progress in CPV in mixing The Susy left handed flavor channels The charm frontier: recntly LHCb made impressive

f_{dY_d} f_{dY_d} alignment implications; no hope for non-degeneracy, below the TeV scale, some level of degree $\frac{1}{2}$ m-degenera *mQ*˜² + *mQ*˜¹ m_Q *m*₂ **c** SUSY alignment implications: no hope for non-degeneracy? $\mathrm{NP} = \tilde{m}_\mathcal{C}^2$ *Q*

0*.*034 maximal phases

Thank you for choosing Holliday) in Spread Spread with centroid information. The spread of the third generation information. The space of the space of the space of the third generation (Sec. 3.2), the space of the space o 1^{uc} Then k you for choosing Holland applies the second information $c = \frac{\tilde{q}_L^2}{\tilde{q}_L^2}$ $\frac{\tilde{q}_L^2}{\tilde{q}_L^2}$ $\frac{u}{\tilde{q}_L^2}$ the $\frac{u}{\tilde{q}_L^2}$ the second to the second to the second to the second to the second Looks like squark anarchy/alignment is and the singlet description of the single split of the splite splite screenation. With phases, first 2 gen' squark need to have almeste equal masses. Add to Calendar Gig**ure 10:** Diagrams which cause flavor violation in models with arbitrary soft masses.
MR GILAD PEREZ (a)

 $m_{\widetilde{Q}_2} - m_{\widetilde{Q}_1}$

 $m_{\widetilde{Q}_2} + m_{\widetilde{Q}_1}$

 \leq

 $\sqrt{ }$

Mes $m_L²$ has arbitrary off-diagonal entries. If $m_k²$ constrained.

 $\sqrt{0.27}$ vanishing phases $\frac{G_{\text{Mail}}}{\text{Your Holland Puns.} (R) Reservation\text{ Confirmation - SOMM} }$

 $\mu_{\rm AGN}$

Reply-To: HolidayInnExpre To: jasgilperez@gmail.com

 $\frac{1}{2}$

Other Travel Resources

Fig. 5g and eq. (3.72)]. There are similar diagrams with the left-handed slepton mass matrix
 \mathbf{m}_L^2 has arbitrary off-diagrams in \mathbf{G} is \mathbf{M}_{BS} . If \mathbf{m}_{BS}^2 are \mathbf{m}_{BS}^2 is \mathbf{m}_{BS}^2 constrained.
There are also imported the state of the set of these comes in the state of the set of **Additional Guests:** Fig. 5g and eq. (3.72)]. There are similar diagrams if the left-handed slepton mass matrix \mathbf{F} **If** $\mathbf{m}_{\mathbf{k}\alpha}^2 \mathbf{R}_{\mathbf{k}} \mathbf{R}_{\mathbf{k}} \mathbf{R}_{\mathbf{k}} \mathbf{R}_{\mathbf{k}}$ were "random", with all entries of comparable size, then the special chergus to \mathbb{B}^n , $(u_t \to x)$ would be about 5 or 6 orders of contributions of \mathbb{B}^n $\frac{1}{2}$ and tude larger than $\frac{1}{2}$ for Hotel Guest in entital upper limit of 5×10^{-11} , even if the selections are as heavy as 1 TeV. Then fore the form of the slepton mass matrices must be severely MILAN-MALPENSA AIRPORT **HILAN-MALPENSA**
Holiday Inn Express There are also imp or \mathbf{b} and \mathbf{c} and **Helpful Links** Local Maps

Please use your confirmation number to reference your reservation.

(b) a skake va

n exclose %
කී තුණ්ද ඕ

Your Priority Club Rewards number applies to this reservation.

(squark doublets, gluino, 1TeV)

 Blum, Grossman, Nir & GP (09) **LOMBARDO, ITALY: 67442015**

γ

Reservation Information **Your confirmation in more is 6,44201**

Priority Club Rewards:

M
 **Volume Holiday Inn Express (R) Reservation Confirmation - SOMM

Your Holiday Inn Express (R) Reservation Confirmation - SOMM**

Holiday Inn Express Reservations <HolidayInnExpress@reservations.ihg.com> Mon, Feb 15, 2010 at 2:35 PM

Thank you for choosing Holiday Inn Express. Here is your reservation information.

 \tilde{q} 1 *L* K^0 $\tilde{\mathbf{g}}$ \leftarrow $\widetilde{\mathbf{g}}$ $\$

d

s

q˜ 2 $\tilde{q}_c \cdot \tilde{q}_v^2$ 1 *L*

s $q\bar{g}$ $q\bar{g}$ d g g d

s

 \tilde{q} 2 *L*

 ΔM_K xasakhin & Gilad Perez <jasgilperez@gmail.com D , A_Γ^D

Reservation Questions: 180 945 3716

 $u \notin U \cup U \}$

1900⁰⁶⁵³⁷¹⁶ ĝ\$ \$ 0⁰

 $u \leftarrow \frac{4L}{L}$, $\frac{4L}{L} \leftarrow c$

s

 \tilde{q} 2 \tilde{q}_L^1 \tilde{q}_L^2 1 *L*

 \mathfrak{g} of

11

.
L

 $\mathbf \Gamma$

u

 \tilde{q} c \tilde{q}_L^2 \tilde{q}_L^1

 c q_L q_L u g g \overline{I}

s

 \tilde{q} 2 *L*

 $\begin{align} \text{for } A_P^D, A_P^D. \end{align}$

 ϵ_K appearing in the next of $\epsilon_{\text{2s-EM}}$. The version constraints in the state interestion and the interestion of the first two squares in the mass of the first two squares in the state of the state of the state of th ₃₉₋₀₃₃₁.
Haigus from the diagram \overline{K}^0 mixing gets contributions from the diagram in Fig. 12b, among others, if $\mathcal{L}^{\text{MSSM}}_{\text{soft}}$ contains (mass)² terms which may down squarks and the power of the existence of the state and search that the contract of the state of the state and the contract of the state with the state with the state with the state with the vertices in Fig. 12b are all fixed by $\sum_{n=1}^{\infty}$ of strong interaction strength; there are similar diagrams in which the bino and winos are exchanged.⁵⁴ If the squark and gaugino masses are of conservable V or less, on**e ti president is in the proportion of the system** for and entire stay at time of booking. Fully non refundable. Prepayment ϵ_K appearing in the netrostron and ϵ_K appearing in the netrostron and ϵ_K of down-strange squares and the animal and is non refundable. No refunds if cancelled or changed.
The complexy produced in the complexy phases in the complexy of the complexy of the can inclement and the inthe soft parameters.⁵⁵ Constraints come from the soft parameters.⁵⁵ Constraints come from the D^0 , \overline{D}^0 and B^0 , $\overline{B}^{\text{[or every even}}$, $\overline{B}^{\text{[or every even}}$ be exampled; A deposit Required; A deposit for the entire stay is due at time of booking. scalar fields get VEVs, **tervery frontials faster**, trices contribute off-diagonal squark and slepton contains

scalar fields get VEVs. For a dependent trices contribute off-diagonal squark and slepton
(mass)² terms [for example, $\overline{d}a_d\tilde{Q}H_d + c.c. \rightarrow (a_d)_{12}\langle H_d^0\rangle \tilde{s}_L\tilde{d}_R^* + c.c.$, etc.], so their form
is also strongly con $(\text{mass})^2$ terms [for example, $\overline{d\mathbf{a_d}}\widetilde{Q}H_d + \text{c.c.} \rightarrow (\mathbf{a_d})_{12}\langle H_d^0\rangle \widetilde{s}_L \widetilde{d}_R^* + \text{c.c.}$, etc.], so their form is also strongly constrained by flavor-changing neutral current (FCNC) limits. There are is also strongly constrained by flavor-changing neutral current (FCNC) limits. There are other significant constraints on CP-violating phases in the gaugino masses and (scalar)³ soft couplings following from limits on the electric dipole moments of the neutron and electron.⁵⁷

27. In particular, one can suppose that the squark and slepton (mass) matrices are flavor-blind. This means that they should each be proportional to the 3×3 identity All of these potentially dangerous FCNC and CP-violating effects in the MSSM can be All of these potentially dangerous FCNCand CP-violating effects in the MSSM can be evaded if one assumes (or can explain!) that supersymmetry breaking should be suitably evaded if one assumes (or can explain!) that supersymmetry breaking should be suitably "universal". In particular, one can suppose that the squark and slepton $(mass)^2$ matrices are flavor-blind. This means that they should each be proportional to the 3×3 identity

37

Tha charm frantiary recontly $LTCh$ made impressive the suarm from degreer. Fourty Lited mass impressive exception of the measurements of **Progress in CPV** in mixing to the measurements of P α progress in CPV in mixing The Susy left handed flavor channels The charm frontier: recntly LHCb made impressive

 f_{dY_d} f_{dY_d} alignment implications; no hope for non-degeneracy, below the TeV scale, some level of degree $\frac{1}{2}$ m-degenera SUSY alignment implications: no hope for non-degeneracy? $\mathrm{NP} = \tilde{m}_\mathcal{C}^2$ *Q*

Constraining (RH) flavorful naturalness $\overline{}$

Flavored naturalness LHC^{8:} $m_{\tilde{t}} \sim 700 \,\mathrm{GeV}$

 \bullet The relevant parameters to constrain are:

Blanke, Giudice, Paride, GP & Zupan (13)

Define relative tuning measure: $\xi =$ $\tilde{m}_1^2 c^2{+}\tilde{m}_2^2 s^2$ m_0^2 $, \quad (m_0=570\,{\rm GeV})$ $m_{\tilde{t}} \sim 2 \,\textrm{TeV}$

stop,scharm like squark mass, $m_{1,2}$ & $C \equiv \cos \theta_{23}^{RR}$

Flavored naturalness LHC^{8:} $m_{\tilde{t}} \sim 700 \,\mathrm{GeV}$

parameters of displaced tracks and topological properties of **Secondary and terminesis** using multiparameters and the secondary vertices of the secondary

$\frac{1}{2}$ Charm tagging at the LHC ATLAS EPS 2013

As search for stop decay to charm τ heutraling ($t \to c + \gamma$ gging has been employed for the first time at LHC
The solutions of the simulations of the solutions of • In new ATLAS search for stop decay to charm + neutralino $(\tilde{t} \to c + \chi^0)$ charm jet tagging has been employed for the first time at LHC

 $AILAS-CONI$ ATLAS-CONF-2013-068

30 *< p^T <* 200 • charm jets identified by combining "information from the impact parameters of displaced tracks and topological properties of secondary and tertiary decay vertices" using multivariate techniques

> 'medium' operating point: c-tagging efficiency = 20%, \bullet rejection factor of 5 for b jets, 140 for light jets. \ddot{t} is obtained for simulated $\dot{t}\bar{t}$ events for jets with $30 < p_T < 200$, and calibrated with data

Composite light quarks & pseudo-NGB (pNGB) Higgs: Flavor & Naturalness

Delaunay, Grojean & GP (13); Delaunay, Fraille, Flacke, Lee, Panico & GP (13); Azatov, Panico, GP & Soreq (14); Blanke, Delaunay, Martin & GP, in preparation.

Two slides on pNGB Composite H Models Sinces on pryop Composite *II* ribueis terms of the elementary fermions as well as their mixing with the composite resonances. We

possibility consists in directly identifying the latter with chiral SO(5) singlet states of the

 \blacklozenge Structure of minimal composite Higgs model SO(5)/SO(4): n_{min} ial composite Liiggs model ov $\sum_{i=1}^n \sum_{i=1}^n \binom{n}{i}$

Agashe, Contino & Pomarol (05)

2nd slide on pNGB Composite *H* Models & (up) flavor

Anarchy vs. Hierarchy, LHC & Naturalness implications evarious Formation and Suppression of the suppression of the various coupling in the various coupling in the t ρ marshes and not exact we do not expect to flavor changing processes to an interval processes to arise to arise to an interval processes to an interval processes to an interval processes to an interval processes to an

 \bullet UV anarchy => low *E* hierarchy: $y_R^u \ll y_R^c \ll y_R^t$. \bullet UV anarchy \equiv 10w E hierarchy: \Box U_D \mathcal{L} and the strength of the strength of the strength of the strength of the SM fields and the SM fields and

at some level.

$$
y_R^u \ll y_R^c \ll y_R^t
$$

2 gen approx' symmetric *L,R* (*i* = 1*..*3 is a generation index and *L, R*

 $\lambda_L^3 : \lambda_L^2 : \lambda_L^1 \sim 1 : V_{cb} : V_{ub} \sim 1 : 4 \times 10^{-2} : 4 \times 10^{-3}$, $\lambda_{R,u}^{3} : \lambda_{R,u}^{2} : \lambda_{R,u}^{1} \sim 1$: *m^c* $m_t V_{cb}$ $\frac{m_u}{l}$ $\frac{m_u}{m_t V_{ub}} \sim 1:9 \times 10^{-2} : 2 \times 10^{-3},$

 \bullet Toward "composite flavourful naturalness" from RH anarchy low E , (allowed by EW precision tests): Delaunay, Gedalia, Lee, GP & x Ponton 2 (10) Redi & Weiler (11). v roward composite navour iar naturalmes. *zarowed by LYY precision tests).* measurements severely constrain non-SM shifts in the *Z* to *b*¯*b* coupling. This motives us to

$$
y_R^u \lesssim y_R^c \sim y_R^t \sim 1
$$
 split 2 gen'

Delaunay, Fraille, Flacke, Lee, Panico & GP (13); Blanke, Delaunay, Martin & GP, in preparation.

Collider implications for split 2 gen' (similar to SUSY case)

Delaunay, Fraile, Flacke, Lee, Panico & GP (13).

High *p_T* Quark Flavor Phys. at the LHC

♦ Tops & bottom are relatively easy to tag & measure precisely.

♦ As the protons are filled \w first gen' (valence) quarks their coupling to new physics are severely constrained.

Second gen' physics is currently in a blind spot of the LHC; Need to push boundaries to eliminate it.

$Composite t\rightarrow cZ$ $U \rightarrow C Z$

- $\bullet t \rightarrow cZ$ null test of the SM.
- $\bullet t \rightarrow cZ$ in composite models could be large. Agashe GP & Soni (06) **L**_{tc}, **c**_{*l*} + *g***_t_{***l***} + ***g*_{*1*} + *g* \overline{V} C₂ in composite modern could be identity. Agashe of a solid (00)

are the only ones needed for our analysis.

¹*M*¹

₩

We can now construct the structures that contribute to the *Ztc* and *Zuc* interactions and

$$
BR(t \to cZ) \simeq 3.5 \times (g_{tc,R}^2, g_{tc,L}^2) \approx \left(\frac{g}{2c_W}\right)^2 \left(\left(\frac{m_c}{m_t V_{cb}}\right)^2, V_{cb}^2 \right) \frac{v^4}{M_*} \times \left(\frac{y_{L,R}}{M_*}\right)^4
$$

$$
\sim (8.5, 1.8) \times 10^{-6} \left(\frac{500 \,\text{GeV}}{M_*}\right)^4 \times \left(\frac{y_{L,R}}{M_*}\right)^4
$$

 \overline{M} essen (i) \overline{H} even energhy. I II equating is suppressed • Lesson (i) flavor anarchy: LH coupling is suppressed. generate the operators in Eq. (2). First of all we consider the coupling involving the left-handed *M*1*M*4?

where α is the cosine the cosine the Weinberg angle (YS: ask about α) and α as a α as α

violation of our theory as explained above. We have also use *M*⇤ to describe the scale that

controls the "microscopic" scale of our e \sim microscopic theory. We can learn several interesting things theory. We can learn several interesting things the things of our experiments of the things the things of things the \blacklozenge Lesson (ii) strong dependence on level of top compositeness. SM fields. The mass basis is defined via the basis in which the spurion *ALL* ⌘ *m*SM

Composite natural t → cZ ✓*mcm^t* mposi[.] \overline{a} *M*⇤ λ fural $t \rightarrow c$

 $\bullet t \rightarrow cZ$ null test of the SM. \bullet *t* $\rightarrow cZ$ null test of the SM.

For the left-handed coupling instead we get

 $\bullet t \rightarrow cZ$ in composite models could be large. $\overline{}$ Z *m* composite models c *^f ^Vcb* ⇠ ⁷ ⇥ ¹⁰⁴

Agashe GP & Soni (06)

 $\cdot t \rightarrow cZ$ in custodial composite models could be small.

Agashe, Contino, Da Rold & Pomarol (06) *R. Notice that the explicit results in Eqashe, Continued with the explicit results in Eqashe, Continued with the explicit results in* R

 $\rightarrow t \rightarrow cZ$ in natural custodial composite models should be large. From the above results we can derive the following estimate for the branching fraction

As both LH & RH tops needs to be composite, Azatov, Panico GP & Soreq (14)

$$
BR(t \to cZ) \sim 10^{-5} \left(\frac{700}{M_*}\right)^4 \cdot \frac{1}{\frac{1}{\lambda_L}} \cdot \frac{1}{\frac{1}{\lambda_L}} \cdot \frac{1}{\frac{1}{\lambda_L}} \cdot \frac{1}{\frac{1}{\lambda_R}} \cdot \frac{1}{\frac{1}{\lambda_L}} \cdot \frac{1}{\frac{1}{\lambda_L}} \cdot \frac{1}{\frac{1}{\lambda_R}} \cdot \frac{1}{\lambda_R}} \cdot \frac{1}{\lambda_R} \
$$

 α in the presence of light composite resonances is not far from the current experimental composite resonances is not far from the current experimental composite resonances is not far from the current experimental compo One extra prediction tops should be KH polar Figure 1: Schematic structure of the diagrams contributing to the flavor violating *Z* couplings η s should be κ H polarized single the elementary fields while the elementary fields while the elementary fields while the elementary fields which η \bullet One extra prediction tops should be RH polarized.

and currently not probe the probe probe probe A zatov, Par Azatov, Panico, GP & Soreq (14) 48

Lessons from *t*→*cZ,* anarchy in relation with naturalness

• Anarchy \iff generic misalignment between $y's \& M's$. \overline{a} *L*) ² 2(*y^t R*) *M*1*M†* ¹ *M*4*M†* 4 \leq x deperic misalignment hetween $u' \in \ell_X M'$ where $\mathcal{L}_{\mathbf{r}}$ is the cut o $\mathcal{L}_{\mathbf{r}}$ and in the second line the second line the approximation of $\mathcal{L}_{\mathbf{r}}$ \sim generation generation forward y s α in straightforward

L,R c,u α is a second and the generation of α is α in the generation is also $\alpha_{L,R}$ \approx *N^c* $16\pi^2$ $\left[(y_L^t)^2 - 2(y_R^t)^2 \right] \left(M_{1_1}^2 + \Delta M_1^2 s_{1L}^2 - M_{4_1}^2 - \Delta M_4^2 s_{4L}^2 \right]$ $\left[(y_L^t)^2 - 2(y_R^t)^2 \right] \left(M_{1_1}^2 + \Delta M_1^2 s_{1L}^2 - M_{4_1}^2 - \Delta M_4^2 s_{4L}^2 \right) \quad \Delta M_1^2 \equiv M_{1_2}^2 - M_{1_1}^2$ ↵ ⇡ *N^c* L,R incouning αa Archer, Azatov & Matsedonski. See also yesterday's talks by: fine tuning $\propto \alpha^{-1}$

 $\sum_{i=1}^{n}$ $\lim_{n \to \infty} \frac{p_i}{p_i} + \sum_{i=1}^{n} \frac{p_i}{p_i}$ \bullet Fine tuning & $t \rightarrow cZ$ within pNGB depends on misalignment the tween flavor breaking sources (& level of charm compositeness). 49 Blanke, Delaunay, Martin & GP, in preparation. between flavor breaking sources (& level of charm compositeness).

, (29)

$BR(t \rightarrow cZ)$ vs. tuning

Azatov, Panico, GP & Soreq (14)

 $\epsilon = 0.3$, $M_* = 700$ GeV, $0 < \theta_V < \pi/4$

The correlation between BR(t $\rightarrow cZ$) and the additional fine-tuning of the model FT_{mixing}/FT_t .

Conclusions

- ♦ Accommodating flavor violation => modifications of the usual estimation of fine tuning as well as phenomenology.
- ♦ SUSY: (i) scharms can be light & buried in LHC data;
	- (ii) stop-scharm mixing might lead to improved naturalness.
- ♦ Composite pNGB-*H*:
	- (i) charm-partners can be light & buried in LHC data;
	- (ii) top-charm partner mixing might lead to improved naturalness;
	- (iii) new anarchic contributions to sizeable $t \rightarrow cZ \&$ fine tuning.
- ♦ Interplay \w CPV in D mixing & *b-s* transition, tested at LHCb.

Combining $K^0 - \overline{K^0}$ mixing and $D^0 - \overline{D^0}$ mixing
to constrain the flavor structure of new physics \mathbf{u} with the simpler two generations case, which is actually very useful in constraints \mathbf{u}

Two generation covariance description <u>rwo generation covariance description</u>

 $X_{\mathcal{Q}}$ is 2x2 Hermitian matrix, can be described as a vector in SU(2) 3D flavor space. naturally interpreted as a vector in three dimensional real space, which applies to *A^d* and *Au*. X_Q is 2x2 Hermitian matrix, can be described as a

$$
|\vec{A}| \equiv \sqrt{\frac{1}{2}\text{tr}(A^2)}, \quad \vec{A} \cdot \vec{B} \equiv \frac{1}{2}\text{tr}(A\,B), \quad \vec{A} \times \vec{B} \equiv -\frac{i}{2}[A,B],
$$

$$
\cos(\theta_{AB}) \equiv \frac{\vec{A} \cdot \vec{B}}{|\vec{A}||\vec{B}|} = \frac{\text{tr}(AB)}{\sqrt{\text{tr}(A^2)\text{tr}(B^2)}}.
$$

The space can be span by using the SM Yukawas (very useful for CPV, see later): by a new physics source. Consider a dimension six *SU*(2)*L*-invariant operator, involving only by using the SMY

$$
\mathcal{A}_u \equiv (Y_u Y_u^\dagger)_{\text{tr}} \ \mathcal{A}_d \equiv (Y_d Y_d^\dagger)_{\text{tr}}
$$

Two generation covariance description, cont' the same space as *A^d* and *Au*. 3 In the down sector for example, the operator for example, the operator above is relevant of \mathbf{A} Iwo generation covariance description, cont^{or}

basis for each sector, with the following unit vector, with the following unit vectors, with the following unit

: The contribution of X_Q to $K^0 - \overline{K^0}$ mixing, Δm_K , given by the solid blue line. In the down mass basis, $\hat{\mathcal{A}}_d$ corresponds to σ_3 , \hat{J} is σ_2 and \hat{J}_d is σ_1 .

 C_{embin} theory. Recently, huge progress has been made in meato constrain the flavor structure of new physics violation in the neutral *D* system [2]: $\overline{K0}$ miving and $\overline{D0}$ $\overline{D0}$ mivin $\sum_{n=0}^{\infty}$ in $\sum_{n=0}^{\infty}$ dia D or D in $\sum_{n=0}^{\infty}$ presented in $[3]$ and obtain the following upper bounds upper bounds upper bounds upper bounds upper bounds up $Combin'$ $\frac{1}{2}$ components the new *I*^{*n*} mixing and D° – *I* $\overline{p^0}$ mixin \overline{p} *,* $\overline{}$ $\frac{1}{2}$ $\Gamma^{2}_{\rm 2}$ and $D^{0} = \overline{D^{0}}$ mixing $\frac{1}{2}$ direction $\frac{1}{2}$ mining without loss of generality, *YDY † ^D* and *Y^U Y †*

 N_{data} that in $\overline{}$ doublet can be simultaneous Notice that:

In this work, we develop the formalism that is nec-

A 2-gen' case, 3 adjoints yield CPV: $J = \text{Tr}$ Projection of X_Q onto \hat{J} is measuring the physical CPV phase. m_{χ} degrees or χ $\left\{ X\left[Y_{D}Y\right] \right\}$ *,* exp = 5*.*⁹ ⇥ ¹⁰⁷ \mathcal{I}_2) exp = 3*.*³ ⇥ ¹⁰⁹ \overline{a} $\sqrt{2}$ exp = 1*.*⁰ ⇥ ¹⁰⁷ $\mathscr{L}_{\theta_{xd}}$ $\longrightarrow \hat{\lambda}$. (σ \overline{L} Δ **c** $\left(\begin{array}{ccc} 1 & 2 & D \\ 1 & 0 & C \end{array} \right)$ \mathbf{r} \mathcal{L}^{max} **s** \hat{i} \hat{j} \hat{k} \hat{k} CPV in ˆ*v*2. The ˆ*v*² parameter is the projection of *X^Q* $\sqrt{\frac{1}{\ln K}}$ without loss of generality, *YDY †* $\sqrt{|z_1^{\mathbf{A}}|}$ $\mathscr{C}(\mathscr{O}_{xd})$ Δ 2 and the up sectors. A *Z*-gen case, \textsf{pints} yield CPV: $J = \text{Tr} \left\{ X \left| Y_D Y_D^\dagger, Y_U Y_U^\dagger \right| \right\}$ that lead to *zsd* and *zcu* have the form $\left\{\begin{array}{c} \hat{J}\left(\sigma_{2}\right) \end{array}\right\}$ vides a source of flavor violation between $\mathcal{E}(\mathcal{X})$ $\longrightarrow \hat{\mathcal{A}}_d(\sigma_3)$ A 2-gen' case, 3 adjoints yield CPV: $J = \text{Tr}\left\{X\right\}$ $\sqrt{ }$ $Y_D Y_D^\dagger, Y_U Y_U^\dagger \bigg] \bigg\}$ = *i*(*y*² *^s ^Y* ² $\left(\int_{a}^{\infty} \int_{a}^{b} f(x) dx \right)$ ¹²(ˆ*v*¹ *iv*ˆ2) \overline{O} *zcu* = ² $\frac{1}{\sqrt{K}}$ \mathscr{D}_{xd}

Assuming
$$
SU(2)_L
$$
: $\frac{1}{\Lambda_{\rm NP}^2} (\overline{Q_{Li}}(X_Q)_{ij} \gamma_\mu Q_{Lj}) (\overline{Q_{Li}}(X_Q)_{ij} \gamma^\mu Q_{Lj}),$

invariant for our framework: the contract of t
In the contract of the contract

 $\overrightarrow{A_d}$ \rightarrow $\overrightarrow{A_d}$ (σ_3)

*^A*ˆ*Qu,Q^d* ⌘ $\lim\!$ $\hat{\mathbf{a}}$ ľ *,* + b_o $\mathbf{A}^{\mathbf{0}}$ mixi *Ad A* to constrain the flavor structure of new pl α *J* α *L* α *D*^{α} α *M* α *d* α \overline{a} definitions allow for an intervals of the flavor and \overline{a} ombining $K^{\circ} - K^{\circ}$ mixing and $D^{\circ} - D^{\circ}$ i \circ combets

$$
\frac{C_1}{\Lambda_{\rm NP}^2} O_1 = \frac{1}{\Lambda_{\rm NP}^2} \left[\overline{Q}_i(X_Q)_{ij} \gamma_\mu Q_j \right] \left[\overline{Q}_i(X_Q)_{ij} \gamma^\mu Q_j \right],
$$
\n
$$
\left| C_1^{D,K} \right| = \left| X_Q \times \hat{A}_{Q^u, Q^d} \right|^2 \qquad \text{(Sorry } \mathcal{A}_{u,d} \equiv A_{Q^u, Q^d})
$$

Composite light quarks

♦ Custodial sym' for *Z->bb* => allow for composite light

Agashe, Contino, Da Rold & Pomarol (06)

quarks \wo tension with precision tests.

Delaunay, Gedalia, Lee, GP & Ponton x 2 (10) Redi & Weiler (11)

♦ Drastic change to pheno': large production rates, top forward-backward asymmetry, non-standard flavor signals ...

Delaunay, Gedalia, Lee, GP & Ponton x 2 (10) Redi & Weiler (11); Da Rold, Delaunay, Grojean & GP; Redi, Sanz, de Vries & Weiler (13); Atre, Chala & Santiago (13).

(i) LHC implications for non-degenerate first 2-gen' partners.

Delaunay, Fraille, Flacke, Lee, Panico & GP (13)

(ii) non-standard modification to Higgs decays.

Delaunay, Grojean & GP (13); Delaunay, Golling, GP & Soreq (13).

Lesson (i): High p_T Quark Flavor Phys. at the LHC

♦ Tops & bottom are relatively easy to tag & measure precisely.

♦ As the protons are filled \w first gen' (valence) quarks their coupling to new physics are severely constrained.

Second gen' physics is currently in a blind spot of the LHC; push boundaries to eliminate it.

The model & relevant coupligs 2.1 Models with partially composite right-handed up-type quarks We consider a classification computer ^R is the diagonal generator of the SU(2)^R subgroup of SO(4) ≃ SU(2)^L × \blacksquare \blacksquare $\frac{1}{2}$ state, $\frac{1}{2}$ state, $\frac{1}{2}$ state, $\frac{1}{2}$ state, $\frac{1}{2}$ contains 27/6 con and the state with charge α state

.
Giudice, Grojean, Pomarol & Rattazz (07); De Simone, Matsedonskyi, Rattazzi & Wulzer (12); Delaunay, Fraille, Flacke, Lee, Panico & GP (13). L_1 , L_2 and L_3 or the component L_1 is sectoral reading to L_2 and L_3 or L_4 Guidice Groiean Pomarol & Rattazz (07) : De Simone Matsed creates, crefting, remainer or random (37) , D v S internet, relation Giudice, Groiean, Pomarol & Rattazz (07): De Simone, Matsedonskvi, Ratta embedded in a fundamental α

$$
\mathcal{L}_{\text{comp}} = i \ \bar{Q} (D_{\mu} + ie_{\mu}) \gamma^{\mu} Q + i \bar{\tilde{U}} \tilde{\mu} \tilde{U} - M_4 \bar{Q} Q - M_1 \bar{\tilde{U}} \tilde{U} + \left(i c \ \bar{Q}^i \gamma^{\mu} d_{\mu}^i \tilde{U} + \text{h.c.} \right),
$$

$$
\mathcal{L}_{\text{elem}} = i \ \bar{q}_L \tilde{\mu} q_L + i \ \bar{u}_R \tilde{\mu} u_R - y_L f \bar{q}_L^5 U_{gs} \psi_R - y_R f \bar{u}_R^5 U_{gs} \psi_L + \text{h.c.},
$$

$$
\psi = \begin{pmatrix} Q \\ \tilde{U} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} iD - iX_{5/3} \\ D + X_{5/3} \\ iU + iX_{2/3} \\ -U + X_{2/3} \\ \sqrt{2}\tilde{U} \end{pmatrix}.
$$

$$
q_L^5 \equiv \frac{1}{\sqrt{2}} (id_L, d_L, i u_L, -u_L, 0)^T.
$$

 \mathcal{L} then mixes with states of the composite sector through Yukawa interactions, \mathcal{L} $u_R^5 \equiv (0^{}, 0^{}, 0^{}, 0^{}, u_R^{})^T$. \mathbf{r} right-handed as particlets could be realized as particle fermions as particles for \mathbf{r} T . $\frac{1}{2}$

$$
\begin{aligned} e^{1,2}_\mu &= -\cos^2\left(\frac{\bar{h}}{2f}\right)gW^{1,2}_\mu, \quad e^3_\mu &= -\cos^2\left(\frac{\bar{h}}{2f}\right)gW^3_\mu - \sin^2\left(\frac{\bar{h}}{2f}\right)g'B_\mu\,,\\ e^{4,5}_\mu &= -\sin^2\left(\frac{\bar{h}}{2f}\right)gW^{1,2}_\mu, \quad e^6_\mu &= -\cos^2\left(\frac{\bar{h}}{2f}\right)g'B_\mu - \sin^2\left(\frac{\bar{h}}{2f}\right)gW^3_\mu\,,\\ \text{with}\ W^1_\mu &= (W^+_\mu + W^-_\mu)/\sqrt{2}, W^2_\mu &= i(W^+_\mu - W^-_\mu)/\sqrt{2}, W^3_\mu &= c_wZ_\mu + s_wA_\mu\text{ and }B_\mu = c_wA_\mu - s_wZ_\mu, \end{aligned} \qquad\qquad\qquad \begin{aligned} \sum_{\nu=0}^{2} \left(\frac{\bar{h}}{2f}\right)gW^{1,2}_\mu - \sum_{\nu=0}^{2} \left(\frac{\bar{h}}{2f}\right)gW^{1,2}_\mu - \sum_{\nu=0}^{2} \left(\frac{\bar{h}}{2f}\right)g'B^\mu\,, \end{aligned}
$$

 $\frac{1}{2}$ $\mathcal{L} = \mathcal{L}$ while the a_{μ} components read
 $a_{\mu}^{IV1,2}$ a_{μ}^{IV2} a_{μ}^{IV3} a_{μ}^{IV3} while the a_{μ} components read
 $e^{W^{1,2}}$ $e^{lR} = e^{W^3}$ $\sqrt{2}$ while the d_{μ} components read

$$
d_{\mu}^{1,2} = -\sin(\bar{h}/f)\frac{gW_{\mu}^{1,2}}{\sqrt{2}}, \quad d_{\mu}^{3} = \sin(\bar{h}/f)\frac{g'B_{\mu} - gW_{\mu}^{3}}{\sqrt{2}}, \quad d_{\mu}^{4} = \frac{\sqrt{2}}{f}\partial_{\mu}h.
$$

The argument: why composite light flavors lead to significant modifications of pNGB Higgs rates, unlike composite tops

Falkowski (07); Low & Vichi (10); Azatov & Galloway (11)

(i) t-partner contributions cancel due to "Nelson-Barr" structure of mass matrix \Rightarrow easy to see using low energy Higgs theorems (LEHTs). Shifman, Vainshtein, Voloshin & Zakharov (79); Kniehl & Spira (95).

(ii) Repeat ex. using effective field theory (EFT).

(iii) Modified LHC Higgs Physics from composite light quarks.

♦ *t*-partner cancellation via the LEHTs: Falkowski (07); Low & Vichi (10); Azatov & Galloway (11); Gillioz et al. (12). \mathcal{W} where the sum is performed only over states that are more massive than the Higgs. We can the Higgs. We c rence tance e fallowing the LEHTs: Electric can be the cellation of the the LEHTs: Eqs. (7) and (8) we find that there are no net effects on radiative Higgs couplings from the c^g = Q−² ^u ^c^γ ⁼ [−]Re[^Y ^Y˜ [∗]] M˜ ^QM˜^U cos ^θ^q cos ^θ^u ⁺ [|]^Y [|] mor cancollation via tho cos ^θ^q cos ^θ^u ⁺ [|]^Y [|] cos² ^θ^q sin² ^θ^u ⁺ [|]^Y [|] cos² du sin² du sin³ Several comments are in order:

 \mathbb{R}^2 Falkowski (07); Low & Vichi (10);Azatov & Galloway (ki (07); Low & Vichi (10);Azz
.

 (i) Consider a mass matrix of n heavy fermion states, $m_f \gg m_h/2$. where the sum is performed only over states that are more massive than the Higgs. We can then t trix of n heavy fer \overline{a} natrix of n heavy fermion states, $m_f \gg m_h/2$. the low-energy terms (LEHT) μ_1 , μ_2 ν termion states, $m_f \gg m_h/2$. C ensidore prese metuir of places formion states $m =$ Lonsider a mass matrix of n neavy fermion states, $m_f\,$

$$
\sigma_{gg\to h} = \sigma_{gg\to h}^{\rm SM} \left| \sum_i \frac{Y_{ii} v}{M_i} \right|^2; \qquad \sum_i \frac{Y_{ii}}{M_i} = \frac{\partial \log(\det M)}{\partial v}
$$

(ii) "Corollary": a mass matrix for which $\det_{F(0)=0,} \mathcal{M} = F(v/f) \times P(Y, M, f)$ \longrightarrow $\begin{pmatrix} \sigma_{gg \to h} = \sigma_{gg \to h}^{\rm SM} \end{pmatrix}$ $F(0) = 0$, $F(0) = 0,$

$$
\mathsf{ch} \ \det_{F(0) = 0, \atop F(0) = 0, \, \mathsf{d}} \mathcal{H} = F(v/f) \times P(Y, M, f) \quad \Longrightarrow \quad \mathcal{H} = \mathcal{H} \left(\mathcal{H} \mathcal{H} \right) = \mathcal{H} \left(\mathcal{H} \mathcal{H} \right)
$$

where
$$
F(0) = 0
$$
, f is the Higgs decay constant of pNGB models, and Y and M stand\n\nGuillioz et al. (12).

\nGuillioz et al. (12).

 \mathbf{A} @ *u*
*i*ggs ... Holds for broad class of models, 2-site, composite Higgs ... class of models, 2-site, composite Higgs $\mu_{u} = \frac{w_u - w_u}{w_u}$ that of the SM. The since, composite in 88 \ldots (10) pals 2-eite composite Higgs stand ¹ de for broad class of models 2-site compe $\overline{\text{15}}$ tof broad class of models, $\overline{\text{25}}$ ice, compl

Gillioz et al. (12).
Cancellation of *t*-partners modification of Higgs rates, EFT: Relevant one-looppresenceS. el
 partnersresonancen of t -pa b iancellatic

 \bullet *t*-partners effect Higgs rates in 2 ways in the EFT: u<mark>tes in 2</mark>
ers run in and r
and r $\ddot{\epsilon}$ artners ef
heavy vect $\ddot{}$ H| 2 |

in

(a)

(i) heavy vector-like *t*-partners run in the loop generating $H^{\dagger} H G^{\mu\nu} G_{\mu\nu}$: neavy vector-like *t*-pa the loop generating f $\overline{}$ $\overline{\$ s er
I m par<mark>i</mark> t
il \overline{V} \mathbf{L}

(ii) t -partner mix with the top-like SM fields, modifying their Yukawa: p_i be particle in the virtual criteral components of a fermionic q_i g ϵ ika CM fields madifying thoir Yukowa: μ unce of Filolos, modifying anche fundiva. g and go and ϵ e SM p<mark>p-li</mark>k Diagramat the t -partner m \mathbf{r}

1. integrating out heavy partners: iarti $\overline{1}$ \overline{S}

the

L

$$
\begin{array}{ccccc} & & & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle \\ & & \scriptscriptstyle\langle & \scriptscriptstyle\langle h\rangle & & \end{array}
$$
 . Integrating out heavy partners:
$$
\begin{array}{ccccc} & & \scriptscriptstyle\langle h\rangle & & & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle \\ & & \scriptscriptstyle\langle & \scriptscriptstyle\langle \scriptscriptstyle\frac{1}{2} \end{array} \begin{array}{ccccc} & & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle \\ & & \scriptscriptstyle\langle & \scriptscriptstyle\langle \scriptscriptstyle\frac{1}{2} \end{array} & \begin{array}{ccccc} & & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle & \scriptscriptstyle\langle h\rangle \\ & & \scriptscriptstyle\langle & \scriptscriptstyle\langle \scriptscriptstyle\frac{1}{2} \end{array} & \begin{array}{ccccc} & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle & \scriptscriptstyle\langle h\rangle & \scriptscriptstyle\langle h\rangle \\ & & \scriptscriptstyle\langle & \scriptscriptstyle\langle \scriptscriptstyle\frac{1}{2} \end{array} & \begin{array}{ccccc} & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle & \scriptscriptstyle\langle h\rangle & & \scriptscriptstyle\langle h\rangle & \scriptscript
$$

 α cubetituting into the loop to obtain the amplitude α field is a produced in a position that the temporal that the set of the redundant and the product and the set of 2. substituting into the loop to obtain the amplitude: p of composite fermionic resonances. Single (double) fermionic resonances. Single (double) fermion lines are so field the amplication. stituting into the loop to obtain the amplitude: \blacksquare plitude in the presence of composite fermionic resonances. Single (double) fermion lines are t
t $\frac{1}{2}$ species to $\frac{1}{2}$ 2. substituting into the loop $\ddot{}$ 2. substituting into the loop to obtain the amplitude: amplitude in the presence of composite fermionic resonances. Mass eigenstates are understood

The cancellation of t-partners effects, adding all together

h

h

h

h

Figure 1: Relevant one-loop diagrams contributing to the gluon fusion $\mathbf T$ and gluon fusion among production among production and gluon fusion $\mathbf T$

and can be recast into cy by field redefinitions. Finally, there are custodial breaking operators. Finally, th

Figure 1: Relevant one-loop diagrams contributing to the gluon fusion Higgs production am-

couplings. It receives contributions both from Higgs non-linearities and the presence of vectorlike fermions, while calculations, while calculation by the latter. It will be convenient to introduced by the couplings. It receives contributions both from Higgs non-linearities and the presence of vector-both from Higgs like fermions, while calculations, while calculations, while α introduced by the latter. It will be convenient to introduced by the latter. It will be convenient to introduce the latter. It will be convenient to introd for the Higgs to two photons decay amplitude. =

+

 \blacksquare $t_{\rm eff}$ modify the parameter and how SM $_{\rm eff}$ boson, which are both are bo \bigcap $\mathbf v$ modify the parameter and how SM $_{\text{max}}$ \bullet effects on physical observables. \bullet is a natural operator basis for CHM. c^y parameterizes the modification of the SM Yukawa couplings. It receives contributions both from Higgs non-linearities and the presence of vector-(c) (d) (c) (d) 0

The cancellation of t-partners effects, adding all together

h

h

h

h

h

h

h

Delaunay, Grojean & GP (13).

h

and can be recast into cy by field redefinitions. Finally, there are custodial breaking operators $\mathcal{L}_\mathcal{A}$ and can be recast into cy by field redefinitions. Finally, there are custodial breaking operators. Finally, the state \mathbf{r} like |H† field is realized in as a pNGB. Notice that these two operators are redundant as they do not yield independent O(c) effects on physical observables. $\bullet\bullet$

h

h

h

Delaunay, Grojean & GP (13).

h

h

h

like fermions, while calculations, while calculations, while α introduced by the latter. It will be convenient to introduced by the latter. It will be convenient to introduce the latter. It will be convenient to introd

h

like fermions, while calculations, while calculation by the latter. It will be convenient to introduced by the

Delaunay, Grojean & GP.

h

<u>Sizable corrections for compos</u> **SILADIC CONTECHTONS TOT COMPOT** C izable con physical observables. is a natural operator basis for CHM. cy parameterizes the model of the small structure \sim or composite light quarks! of composite nght quarks. i zable corrections for composite light que izable corrections for composite light qu couplings. It receives contributions both from Higgs non-linearities and the presence of vector- \mathcal{L} (d) \sim (d) \sim (d) \sim **COULD TO COUPOSI** Sizable corrections for composite light quarks!

Figure 1: Relevant one-loop diagrams contributing to the gluon fusion Higgs production am-

Composite light quarks & pseudo Goldstone boson Higgs ^j sums over all Higgs production modes, the most important one being gluon fusion. mposite light quarks & pseudo Goldstone boson Higgs **Hiposite light qual is & pseudo Goldste** and where the above effects are more problems are more problems signal strength μ h_{mean} H_{linear} Higgs signal strengths in the γγ, ZZ[∗] and WW[∗] channels which are best measured at present

the production cross-section times the production times the branching ratio into final states into final states μ

Delaunay, Grojean & GP,. Delaunay, Grojean & GP,.

and where the above effects are more proposition \mathcal{L}_max

 $\mathbf{S}_{\mathbf{D}}$; level of compositeness $\xi = v^2/f^2$, $\epsilon_i \equiv (Y_i v / M_i)^2$, $r = a_{\text{tr}}/Y$, $a_{\text{tr}} = M/f$ $E = \frac{1}{2}$ contributions), which $\frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$. The $\frac{1}{2}$ s_R : level of compositeness $\xi = v^2/f^2$, $\epsilon_i \equiv (Y_i v/M_i)^2$ $r = g_{\Psi}/Y$ $g_{\Psi} \equiv M/f$ function of \mathcal{L} and \mathcal{L} and \mathcal{L} and \mathcal{L} and \mathcal{L} and \mathcal{L} is the RH elementary/composite mixing and we set rise mixing and we set rise mixing and we set rise that we se
In the Mi/(Yif) = 1. We set rise that we set rise to the Mi/(Yif) = 1. We set rise to the Mi/(Yif) = 1. We set

Composite light quarks & pseudo Goldstone boson Higgs ^j sums over all Higgs production modes, the most important one being gluon fusion. mposite light quarks & pseudo Goldstone boson Higgs **Hiposite light qual is & pseudo Goldste** h_{mean} H_{linear} Higgs signal strengths in the γγ, ZZ[∗] and WW[∗] channels which are best measured at present

 $\mathbf{S}_{\mathbf{D}}$; level of compositeness $\xi = v^2/f^2$, $\epsilon_i \equiv (Y_i v / M_i)^2$, $r = a_{\text{tr}}/Y$, $a_{\text{tr}} = M/f$ $E = \frac{1}{2}$ contributions), which $\frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$. The $\frac{1}{2}$ s_R : level of compositeness $\xi = v^2/f^2$, $\epsilon_i \equiv (Y_i v/M_i)^2$ $r = g_{\Psi}/Y$ $g_{\Psi} \equiv M/f$ s_R : level of compositeness $\xi = v^2/f^2$, $\epsilon_i \equiv (Y_i v/M_i)^2$ $r = g_{\Psi}/Y$ $g_{\Psi} \equiv M/f$ function of \mathcal{L} and \mathcal{L} and \mathcal{L} and \mathcal{L} and \mathcal{L} and \mathcal{L} is the RH elementary/composite mixing and we set rise mixing and we set rise mixing and we set rise that we se
In the Mi/(Yif) = 1. We set rise that we set rise to the Mi/(Yif) = 1. We set rise to the Mi/(Yif) = 1. We set

Composite light quarks & pseudo Goldstone boson Higgs ^j sums over all Higgs production modes, the most important one being gluon fusion. mposite light quarks & pseudo Goldstone boson Higgs **Hiposite light qual is & pseudo Goldste** and where the above effects are more problems are more problems signal strength μ leading order through Higgs couplings to gluons and photons. Therefore we focus only on the e boson Higgs i and where the above effects are more pronounced. The Higgs signal strength µⁱ is defined as

shima & Silvestrini; Grojean, Matsedonskyi & Panico $\frac{1}{2}$ and $\frac{1}{2}$ subsequently subject $\frac{1}{2}$, $\frac{1}{2}$ and $\frac{1}{2}$

Composite light quarks & pseudo Goldstone boson Higgs ^j sums over all Higgs production modes, the most important one being gluon fusion. mposite light quarks & pseudo Goldstone boson Higgs **Hiposite light qual is & pseudo Goldste** and where the above effects are more problems are more problems signal strength μ leading order through Higgs couplings to gluons and photons. Therefore we focus only on the e boson Higgs i and where the above effects are more pronounced. The Higgs signal strength µⁱ is defined as

Left handed (LH) SUSY flavorful naturalness

Kats, GP, Stamou, Stolarski & Weiler, in progress.

 \bullet Is data on *b*-*s* transitions allows for large $\tilde{q}_3 - \tilde{q}_2$ mixing? $\left(\frac{\delta\tilde{m}_{23}}{200\,\mathrm{GeV}}\right)$ $1200 \,\mathrm{GeV}$ ◆ $1200 \,\mathrm{GeV}$ ◆ LHCb $:S_{\psi\phi} \Rightarrow \sin 2\theta_{23}^{LL} \lesssim 0.9 \times$ ⇥ ⇥ $\tilde{m}_1 + \tilde{m}_2$ \tilde{m}_g $\left(b \rightarrow s\gamma \text{ weaker for } \tan \beta \sim \text{few } \& \tilde{b}_R \sim 3 \,\text{TeV}\right)$ ┥Ӌ $\text{BR}\left(\tilde{b}_L\tilde{b}_L^*,\tilde{t}_L\tilde{t}_L^*\rightarrow b\overline{b},t\overline{t}\right)$ $\left\{ \right.$ $=\cos^4\theta_{23}^{LL}\gtrsim 0.5$

Seems to allow to apply the concept also on the LH sector

Etticiencies Efficiencies, strong mass dependence!

Charming the Higgs

Delaunay, Golling, GP & Soreq (13)

Charming the Higgs subdominant, arises in gluon fundamente della contratta production C narmin through a modified charm-loop contribution. $\mathcal{L}_{\mathcal{A}}$ $\mathsf{F}\mathsf{F}\mathsf{F}\mathsf{F}$ denote the sensitive to be sensitive C couplings to equal u, and u, and u, s, as the latter are already very small in the SM. We thus set ce, $\frac{1}{2}$ in the SM. We thus set ce, $\frac{1}{2}$ in the SM. We thus set ce,

• Currently not much known directly on the charm Yukawa: veal chery not made who we allow in the following. We are left with at most eight \mathcal{N} at most eight independent with \mathcal{N} on the charm fukawa: coversion

fore, there must be a charm Yukawa value for which the

(i) SM - $y_c = m_c/v \sim 0.4 \% \Rightarrow BR(H \rightarrow c\bar{c}) \sim 4\%$, very non-trivial to observe... (*i*) SI 1 - $y_c = m_{c}$, $v = 0.7$ \approx $v = 20$ K(11 \approx CC) δ , very non-trivial to observe...

See also: Bodwin, Petriello, Stoynev & Velasco (13), for charmonia production.

 \blacklozenge However, as $y_b \thicksim 2\%$ & $BR(H\to b\bar b)$ $\thicksim 60\%$, Higgs collider pheno' is susceptible to small perturbation. $\overline{}$ Susceptible to sinal perturbation. \sim 60%. Higgs collider pheno' is \sim 00%, ruggs comuctification is

 \blacklozenge Enlarging charm Yukawa by few leads to dramatic changes, for instance: $\mathcal{S}_{\mathbf{u}}$ is a particle of $\mathcal{S}_{\mathbf{u}}$ particles are assumed by particles are assumed by the articles are assumed by the set of $\mathcal{S}_{\mathbf{u}}$ **• Enlarging charm Yukawa by few leads to dramatic chang** Delaunay, Golling, GP & Soreq (13)

 $\mu_j Q_i H U_j + \frac{\sigma_{ij}}{\Lambda^2} Q_i H U_j (H^{\dagger} H) +$ $\mathcal{L}_0 \;=\; \frac{h}{v}$ $\sqrt{ }$ $c_V\left(2m_W^2W_\mu^+W^{\mu-}+m_Z^2Z_\mu Z^\mu\right)$ − \sum q $c_q m_q \bar{q} q - \sum$ ℓ $c_\ell m_\ell \bar{\ell} \ell \Bigr] \ ,$ $\overline{}$ tively. Asymmetric experimental errors are symmetrized λ simplicity. We consider the most updated set of Higgs updated set of $\Lambda \cong \frac{\sqrt{c_2-1}}{\sqrt{c_2-1}}$ a^u arguments be significantly larger due to $\frac{m}{\lambda}$ and $\frac{v}{\lambda}$

c.

$$
\frac{m}{\sqrt{\lambda}} = \frac{v}{\sqrt{2}} \left(\lambda_{ij}^u + g_{ij}^u \frac{v^2}{2\Lambda^2} \right),
$$

$$
\frac{1}{\sqrt{2}} \left(\lambda_{ij}^u + 3g_{ij}^u \frac{v^2}{2\Lambda^2} \right).
$$

f,i [−] ^µex

$$
\Lambda \simeq \frac{44 \,\text{TeV}}{\sqrt{c_c - 1}}
$$

Charming the Higgs, current status & projections *the!sensitivity to!larger charm coupling in!Higgs data?* weight states a projections by the experimental collaborations, whenever available. current status & projections Van Forte States of projections

Delaunay, Golling, GP & Soreq (13)

next-to-leading order in the QCD coupling and we use the QCD coupling and we use the QCD coupling and we use t

◆ Ball park bounds are from Higgs "invisible" bound: $H_{\rm eff}$ production cross section cross section cross sections and branching ratios of μ

 $BR(H \rightarrow bb)$ is significantly suppressed: $\approx 40\%~(20\%)$ with $c_{gg} > O$ $\sqrt{18 \cdot 10^{-2}}$ (1 $-\left(4.4 - 3.0i\right) \times 10^{-5}c_c\right],$ $\mu \sim 3.0 \times 10^{-3} |c_s|^2 \sigma^{SM}$ \mathfrak{c} and contain \mathfrak{c} if all other "visible" couplings set to SM values: $Br_{inv} \sim 22\%$ @95%CL adding a new physics source of ggh : Br $_{\mathsf{inv}}$ ~< 50% @95%CL - *INV medium)working point* w/&^c =20% efficiency, c_{gg} = c_{gg} only marginal&fraction&of&lost signal&recovered $ED(1, h_0)$ is significantly symmetrical. $BR(H \rightarrow b\bar{b})$ is significantly suppressed: $R_{\rm PPSM}$ $BR_{h\rightarrow b\bar{b}} = \frac{B_{1h\rightarrow b\bar{b}}}{1+(1-(1-1)^2-1)\text{DDSM}}$ \approx 40% (20%) $d_1 + (|c_c| - 1)D\Lambda_h \rightarrow c\bar{c}$ 2 / ² with $\hat{c}_{gg} = c_{gg} + \left[1.3 \times 10^{-2} c_t - (4.0 - 4.3i) \times 10^{-4} c_b\right]$ $,$ $\sigma_{c\bar c\to h} \ \simeq \ 3.0 \times 10^{-3} \, |c_c|^2 \, \sigma_{gg\to h}^{\rm SM},$ Ref. [25]. We however add the following two modifica- $\mathcal{S}_{\mathcal{A}}$ charm loop contribution in the gluon fusion in the gluon fusion cross section in the gluon fusion cross section $BR_{h\rightarrow b\bar{b}} = \frac{BR_{h\rightarrow b\bar{b}}^{\text{SM}}}{1+(\frac{(1-\lambda)^2}{2})^2}$: \overline{c} " 1.3 × 10−2ct − (4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 − 4.0 $\overline{55}$ $\overline{55}$ $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ $b - (4.4 - 3.0i) \times 10^{-5} c_c,$, \mathcal{L} , we include the charm function cross section cross sectio fusion to gluon fusion cross section ratio is evaluated at

$\frac{1}{2}$ assume instead a speculative ε_c =40% c-tagging efficiency: \rightarrow $\mu_{bb+cc} \approx$ 0.9 (0.6) @8TeV $\hat{\theta} = \hat{\theta} \hat{\theta}$, to see the SM limit, can consider \mathcal{E}_c =40% c-tagging efficiency: \blacksquare \triangle actor gg→h, where the charm φ and φ at a gluon function φ $\mathcal{L}_{\mathcal{L}}$ parton distribution functions $\mathcal{L}_{\mathcal{L}}$ The ϵ_c -4070 c-tagging emerging. $(A \cap A)$ order to estimate

parameters of displaced tracks and topological properties of **Secondary and terminesis** using multiparameters and the secondary vertices of the secondary

Charm tagging at the LHC

 $\frac{1}{20}$ As search for stop decay to charm τ heutraling ($t \to c + \gamma$ gging has been employed for the first time at LHC
The solutions of the simulations of the solutions of • In new ATLAS search for stop decay to charm + neutralino $(\tilde{t} \to c + \chi^0)$ charm jet tagging has been employed for the first time at LHC

 $AILAS-CONI$ ATLAS-CONF-2013-068

30 *< p^T <* 200 • charm jets identified by combining "information from the impact parameters of displaced tracks and topological properties of secondary and tertiary decay vertices" using multivariate techniques

> 'medium' operating point: c-tagging efficiency $= 20\%$, \bullet rejection factor of 5 for b jets, 140 for light jets. \ddot{t} is obtained for simulated $\dot{t}\bar{t}$ events for jets with $30 < p_T < 200$, and calibrated with data

An Exclusive Window onto Higgs Yukawa Couplings to light quarks

Bodwin, Petriello, Stoynev & Velasco (13) Kagan, GP, Petriello, Soreq, Stoynev & Zupan (14)

Exclusive path towards Higgs-light quark couplings Exclusive pacific dial symmetry preserved by electroweak symmetry breakwai us Tiiggs-light qualik coup granding in our analysis is in our analysis in our analysis is in our analysis in \mathcal{C} targets. The ATLAS and Collaborations have studysive pach towards i nggs-ngin grangian used in our analysis is **Le** *h*¹¹¹8⁹

v

Exclusive path towards Higgs-light quark couplings
\n• Use the eff. Lagrangian:
$$
\mathcal{L}_{\text{eff}} = -\sum_{q=u,d,s} \bar{\kappa}_q \frac{m_b}{v} \hbar \bar{q}_L q_R - \sum_{q \neq q'} \bar{\kappa}_{qq'} \frac{m_b}{v} \hbar \bar{q}_L q'_R + h.c.
$$
\n
$$
+ \kappa_Z m_Z^2 \frac{h}{v} Z_\mu Z^\mu + 2 \kappa_W m_W^2 \frac{h}{v} W_\mu W^\mu + \kappa_\gamma A_\gamma \frac{\alpha}{\pi} \frac{h}{v} F^{\mu\nu} F_{\mu\nu},
$$

$$
\text{Notice that:}\quad \bar{\kappa}_q = y_q/y^{\rm SM}_b\,,
$$

coupling can also be accessed using can also be accessed using tech-between α

muons at the high-luminosity LHC (HL-LHC) with en-

where in the SM: *h* ! *J/* to probe the flavor-diagonal Higgs coupling

targets. The ATLAS and CMS collaborations have stud-

where in the SM:
$$
\frac{\bar{\kappa}_s = m_s/m_b \simeq 0.020}{\bar{\kappa}_d = m_d/m_b \simeq 1.0 \cdot 10^{-3}}
$$

$$
\frac{\bar{\kappa}_u = m_u/m_b \simeq 4.7 \cdot 10^{-4}}{\kappa_\gamma = \kappa_V = 1}
$$

Exclusive path towards Higgs-light quark couplings Exclusive pacific dial symmetry preserved by electroweak symmetry breakwai us Tiiggs-light qualik coup $\frac{V}{2}$ grangian used in our analysis is in our analysis is in our analysis in \mathcal{C} targets. The ATLAS and Collaborations have studysive pach towards i nggs-ngin grangian used in our analysis is *M***d** in Couplings ¯*q*

Use the eff. Lagrangian: targets. The ATLAS and CMS collaborations have stud- \bullet Use the eff. Lagrangian: $\mathcal{L}_{\text{eff}} = \sum \overline{\kappa}_q$ *q*=*u,d,s m^b* $\frac{m_b}{v}h\bar{q}_Lq_R - \sum_{\pi\neq\pi'}\bar{\kappa}_{qq'}$ $q \neq q'$ *m^b v* $h\bar{q}_Lq_R' + h.c.$ $+ \kappa_Z m_Z^2$ *h v* $Z_\mu Z^\mu + 2\kappa_W m_W^2$ *h v* $K_Z m_Z^2 \frac{\mu}{r} Z_\mu Z^\mu + 2 \kappa_W m_W^2 \frac{\mu}{r} W_\mu W^\mu$ $m = 1$ muons at the high-luminosity LHC (Here λ HC) with λ and λ with λ constructs m_b . **the Higgs coupling coupling** $L_{\text{eff}} = -\sum_{q=u,d,s} \kappa_q \frac{1}{v} n q_L q_R - \sum_{q \neq q'} \kappa_{qq'} \frac{1}{v} n q_L q_R$ $\displaystyle q{=}u$, $d,$ \overline{v} couplings to light \overline{v} *q*=*u,d,s v* Kagan, GP, Petriello, Soreq, Stoynev & Zupan (14)*h <i><i>z* \overline{A} \overline{B} \overline{C} \overline{D} $\overline{D$ $+ \ \kappa_\gamma A_\gamma$ α π *h v* $F^{\mu\nu}F_{\mu\nu}$, $rac{20}{\pi}$
se

$$
\text{Notice that:}\quad \bar{\kappa}_q = y_q/y^{\rm SM}_b\,,
$$

 $\left| \frac{1 - \sqrt{1 + \frac{1}{2}}}{\sqrt{1 + \frac{1}{2}}}\right|$

where generically: *h* ! *J/* to probe the flavor-diagonal Higgs coupling

¯*qq*⁰ = ¯⇤ *^q*0*^q* and *V,,q* are real because of the assumed ere generically: $\|\bar{\kappa}_u\| < 0.98$, $\|\bar{\kappa}_d\| < 0.93$, $\|\bar{\kappa}_s\| < 0.70$ to the SM *b*-quark Yukawa coupling for later convenience. varying only one at the time (95%CL) $\vert \bar{\mathbf{r}} \vert$ / 2 $\vert \bar{\mathbf{r}} \vert$ / 2 $\vert \bar{\mathbf{r}} \vert$ / 3 $\vert \bar{\mathbf{r}} \vert$ / 2 $\vert \bar{\mathbf{r}} \vert$ / 3 $\vert \bar{\mathbf{r}} \vert$ / 2 $\vert \bar{\mathbf{r}} \vert$ / 2 $\vert \bar{\mathbf{r}} \vert$ $\frac{|V \circ a|}{|V \circ a|}$ \leq 2.10 $\frac{1}{|V \circ a|}$ \leq 2.12 $\frac{|V \circ a|}{|V \circ a|}$ varying all couplings (95%CL) and ¯*^s* ⁼ *^ms/m^b* ' ⁰*.*020, ¯*^d* ⁼ *^md/m^b* ' ¹*.*⁰ *·* ¹⁰³ , $\left| \left| \bar{\kappa}_{qq'} \right| < 0.6(1) \right| \, \left| \text{for } q, q' \in u, d, s, c, b \text{ and } q \neq 0 \right|$ \overline{a} $\ln 1 \times 1.2$ $\ln 1 \times 1.4$ $\vert n_u \vert \sim 1.5$, $\vert n_d \vert \sim 1.4$, $\frac{1}{2}$ *k*u_p mg an coapmigo (2070 $|\bar{\kappa}_s| < 0.70$ $\frac{1}{\sqrt{2}}$ are flavor-conserving. The SM loop function $\frac{1}{\sqrt{2}}$ $\%$ CL) $|\bar{\kappa}| < 1.4$ $|\kappa_s|$ < 1.4 ¯*^u* ⁼ *^mu/m^b* ' ⁴*.*⁷ *·* ¹⁰⁴. The quark masses are evalud, s, c, b and $q \neq q'$ varying all couplings (95%CL)

 $\left\lceil \frac{N}{2} \right\rceil$

ated at *µ* = *m^h* using NNLO running in the MS scheme same for the flavor violating case

(FCNC non-robust bound: $|\bar\kappa_{bs}| < 8\cdot 10^{-2}$ Harnik, Kopp & Zupan; Blankenburg, Ellis, Isidori, (12)

Exclusive path towards Higgs-light quark couplings Exclusive pacific dial symmetry preserved by electroweak symmetry breakwai us Tiiggs-light qualik coup targets. The ATLAS and Collaborations have studysive pach towards i nggs-ngin grangian used in our analysis is

External The main idea

Adding off-diagonal: $h \to \bar{B}^{0*}\gamma$, $h \to \bar{B}^{0*}\gamma$, $h \to K^{0*}\gamma$, $h \to D^{0*}\gamma$

Kagan, GP, Petriello, Soreq, Stoynev & Zupan (14)

 \Box *|* **0**.6 (1)*, commetary one.* \Box . **bear** ? = 6*.*84(72), using the inputs from [27] and fixing ♦ Let us understand them one by one.

$\mathsf{Ex}\colon h \to \phi\gamma$, direct contribution $\mu = \psi / \mu$ ulicu contuivu an o↵-shellness *^Q*² ⇠ *^O*(*m*² mode considered here allows direct access to the flavor- $\mathsf{Lx} : h \to \phi \gamma$, direct contribution

 \blacklozenge The resulting sensitivity:

$$
\frac{\text{BR}_{h\to\phi\gamma}}{\text{BR}_{h\to b\bar{b}}}=\frac{\kappa_\gamma\big[(3.0\pm0.13)\kappa_\gamma-0.78\bar{\kappa}_s\big]\cdot10^{-6}}{0.57\bar{\kappa}_b^2},
$$

for 1st generation: Similar holds

$$
\begin{aligned} \text{Similar holds} \\ \text{for 1st generation:} \\ \frac{\text{BR}_{h \rightarrow \rho \gamma}}{\text{BR}_{h \rightarrow b \bar{b}}} = \frac{\kappa_{\gamma} \left[(1.9 \pm 0.15) \kappa_{\gamma} - 0.24 \bar{\kappa}_{u} - 0.12 \bar{\kappa}_{d} \right] \cdot 10^{-5}}{0.57 \bar{\kappa}_{b}^2}, \\ \frac{\text{BR}_{h \rightarrow \omega \gamma}}{\text{BR}_{h \rightarrow b \bar{b}}} = \frac{\kappa_{\gamma} \left[(1.6 \pm 0.17) \kappa_{\gamma} - 0.59 \bar{\kappa}_{u} - 0.29 \bar{\kappa}_{d} \right] \cdot 10^{-6}}{0.57 \bar{\kappa}_{b}^2}, \end{aligned}
$$

(11)

Experimental sensitivity function of the contract \mathbf{r} and \mathbf{r} are contract to the contract of the contract o **PROSPECTS**

Kagan, GP, Petriello, Soreq, Stoynev & Zupan (14)

- focus on $h \rightarrow \phi \gamma$, use **Pythia 8.1**
	- main decay modes: $\phi \to K^+ K^-(49\%)$, $K_L K_S(34\%)$, $\pi^+ \pi^- \pi^0(15\%)$
	- for $pp \rightarrow h \rightarrow \phi \gamma$ at 14TeV LHC in 70 to 75% cases the kaons/pions and the prompt photon have $|\eta| < 2.4$
		- within the minimal fiducial volume of the ATLAS and CMS experiments
	- adopt the geometrical acceptance factor $Ag = 0.75$
		- do not include other efficiency or trigger factors
- assume $\kappa_{\gamma} = 1$, negligible background, 3σ reach

two detectors

wo detectors

one detector

one detector

no theory error

Future experiments **PROSPEQTS**

- only a few events expected at e^+e^- colliders
	- ILC, ILC with luminosity upgrade, CLIC
	- probably too small for observation of $h \to \phi \gamma$
- \approx 30 events expected at FCC-ee (TLEP)
	- too small to probe a deviation from the SM prediction
- $h \rightarrow \phi \gamma$ measurements unique to future hadron machines

Thoughts about experimental strategy

- for $h \to \phi \gamma$ decay most promising $\phi \to K^+ K^-$
	- near collinearity of the photon and the *φ*-jet in the transverse plane
	- jet sub-structure information
		- two close high- p_T tracks in a narrow cone
	- di-track invariant mass distribution assuming kaons
		- 1.5% (better than 15 MeV) resolution (CMS)
- can probably be used to significantly cut on the background
	- on jet+*γ* QCD backgrounds

• on
$$
h \rightarrow \phi \gamma + n\pi^{\circ}
$$
, $\eta^{(')}(\rightarrow neutr.) \gamma$

• dedicated trigger probably required to enhance the reach

Thoughts about experimental strategy

- $h \rightarrow \rho^{\circ} \gamma$ mode
	- $Br(\rho^{\circ} \to \pi^+\pi^-) \sim 100\%$
	- relatively clean mode, similar to $\phi \rightarrow K^+ K^-$ decay
- $h \rightarrow \omega \gamma$ mode
	- $Br(\omega \rightarrow \pi^+ \pi^- \pi^{\circ}) \sim 89\%$
	- harder to trigger on
	- hard-to-identify *π°* smears the observable quantities
	- a detailed experimental study required

Flavor violating couplings

Kagan, GP, Petriello, Soreq, Stoynev & Zupan (14)

• FV modes
$$
h \to \bar{B}_s^{0*} \gamma
$$
, $h \to \bar{B}^{0*} \gamma$, $h \to \bar{K}^{0*} \gamma$, $h \to D^{0*} \gamma$

- can probe *κ̄ bs,sb, κ̄ bd,db, κ̄ sd,ds* and *κ̄ cu,uc*
- $h \to \bar{K}^{0*} \gamma$ similar expr. as $h \to \phi \gamma$
	- but only direct amplitude
- for $\bar{\kappa}_{ds} \sim O(1) \Rightarrow Br(h \to \bar{K}^{0*}\gamma) \sim O(10^{-8})$
	- not observable at planned future colliders

$$
\frac{BR_{h\to \bar{B}_s^{*0}\gamma}}{BR_{h\to b\bar{b}}} = \frac{(2.1 \pm 1.0) \cdot 10^{-7}}{0.57\bar{\kappa}_b^2} \frac{|\bar{\kappa}_{bs}|^2 + |\bar{\kappa}_{sb}|^2}{2},
$$