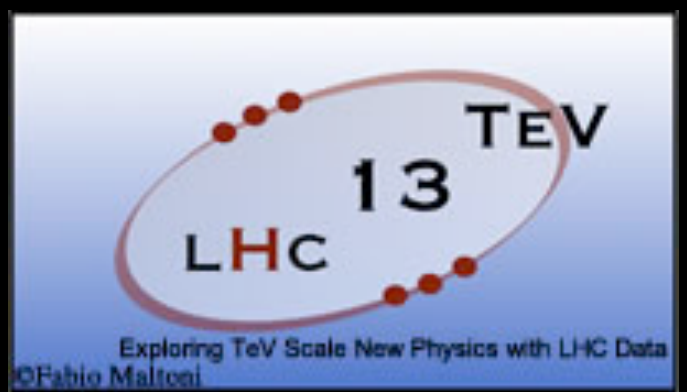
A Flavorful Top-Coloron Model

R. Sekhar Chivukula
Michigan State University



- Extended Color Dynamics
- A Top-Coloron Model
- Flavor Symmetries and Constraints
- Scalars: Same Sign Top Signature
- Flavor Independent Constraints
- Conclusions

KITP July 10, 2013

Extended Color Dynamics

New colored gauge bosons

Classic Axigluon: P.H. Frampton and S.L. Glashow, Phys. Lett. B 190, 157 (1987).

Topgluon: C.T. Hill, Phys. Lett. B 266, 419 (1991).

Flavor-universal Coloron: R.S. Chivukula, A.G. Cohen, & E.H. Simmons, Phys. Lett. B 380, 92 (1996).

Chiral Color with $g_L \neq g_R$: M.V. Martynov and A.D. Smirnov, Mod. Phys. Lett. A 24, 1897 (2009).

New Axigluon: P.H. Frampton, J. Shu, and K. Wang, Phys. Lett. B 683, 294 (2010).

Other color-octet states: (cf. "partial compositeness")

KK gluon: H. Davoudiasl, J.L. Hewett, and T.G. Rizzo, Phys. Rev. D63, 075004 (2001)
B. Lillie, L. Randall, and L.-T. Wang, JHEP 0709, 074 (2007).

Techni-rho: E. Farhi and L. Susskind, Physics Reports 74, 277 (1981).

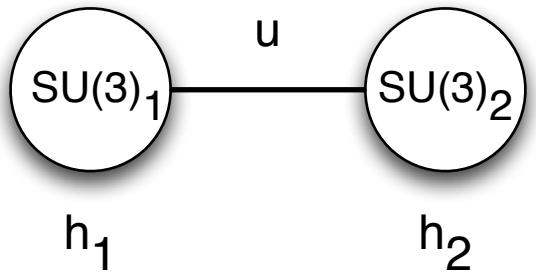
Recent catalog of colored states:

Color sextets, colored scalars, low-scale scale string resonances...

T. Han, I. Lewis, Z. Liu, JHEP 1012, 085 (2010).

Gauge Sector

Coloron Models: Gauge Sector



SU(3)$_1$ x SU(3)$_2$ color sector with $M^2 = \frac{u^2}{4}\begin{pmatrix} h_1^2 & -h_1 h_2 \\ -h_1 h_2 & h_2^2 \end{pmatrix}$

unbroken subgroup: SU(3)$_{1+2}$ = SU(3)$_{QCD}$

$$h_1 = \frac{g_s}{\cos\theta} \qquad h_2 = \frac{g_s}{\sin\theta}$$

gluon state: $G_\mu^A = \cos\theta\, A_{1\mu}^A + \sin\theta\, A_{2\mu}^A$

couples to: $g_S J_G^\mu \equiv g_S(J_1^\mu + J_2^\mu)$

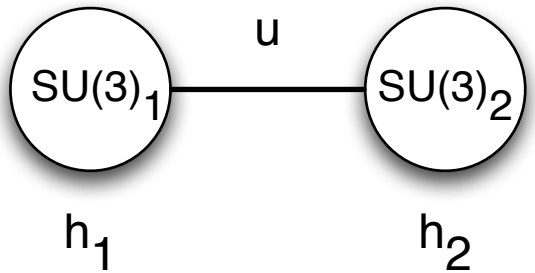
coloron state: $C_\mu^A = -\sin\theta\, A_{1\mu}^A + \cos\theta\, A_{2\mu}^A$ $\qquad M_C = \frac{u}{\sqrt{2}}\sqrt{h_1^2 + h_2^2}$

couples to: $g_S J_C^\mu \equiv g_S(-J_1^\mu \tan\theta + J_2^\mu \cot\theta)$

low-energy current-current interaction: $\mathcal{L}_{FF}^2 = -\frac{g_S^2}{2M_C^2} J_C^\mu J_{C\,\mu}$

Fermions

Coloron Models: Quark Charges



$$g_S J_G^\mu \equiv g_S (J_1^\mu + J_2^\mu)$$

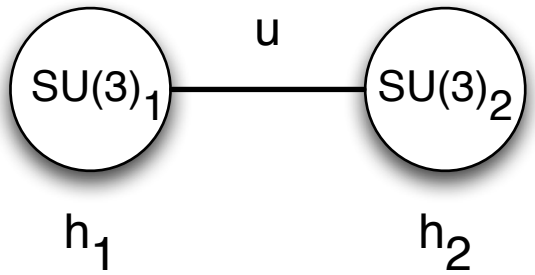
$$g_S J_C^\mu \equiv g_S (-J_1^\mu \tan\theta + J_2^\mu \cot\theta)$$

low-energy current-current interaction: $\mathcal{L}_{FF}^2 = -\frac{g_S^2}{2M_C^2} J_C^\mu J_{C\,\mu}$

Depending on how quarks transform under $SU(3)_1$ x $SU(3)_2$ the presence of colorons may impact

- LHC dijet mass distribution (or angular distribution)
- kinematic distributions of tt or bb final states
- asymmetry in top-quark production: A^t_{FB}
- FCNC processes: $K\bar{K}, D\bar{D}, B\bar{B}$ mixing, $b \to s\gamma$
- precision EW observables: delta-rho, R_b

Coloron Models: Quark Charges



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Patterns of Quark Charges

$SU(3)_1$	$SU(3)_2$	model	pheno.
	$(t,b)_L$ q_L t_R,b_R q_R	**coloron**	dijet
q_R	$(t,b)_L$ q_L t_R,b_R		
t_R,b_R	$(t,b)_L$ q_L q_R		
q_L	$(t,b)_L$ t_R,b_R q_R		
q_L t_R,b_R	$(t,b)_L$ q_R	**new axigluon**	dijet, $A^t_{FB,}$ FCNC
q_L q_R	$(t,b)_L$ t_R,b_R	**topgluon**	dijet, tt, bb, FCNC, $R_{b...}$
t_R,b_R q_R	$(t,b)_L$ q_L	**classic axigluon**	dijet, A^t_{FB}
q_L t_R,b_R q_R	$(t,b)_L$		

(No spectators required)

q = u,d,c,s

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$SU(3)_1$	$SU(3)_2$	model	pheno.
	$(t,b)_L$ q_L t_R,b_R q_R	**coloron**	dijet
q_R	$(t,b)_L$ q_L t_R,b_R		
t_R,b_R	$(t,b)_L$ q_L q_R		
q_L	$(t,b)_L$ t_R,b_R q_R		
q_L t_R,b_R	$(t,b)_L$ q_R	**new axigluon**	dijet, A^t_{FB}, FCNC
q_L q_R	$(t,b)_L$ t_R,b_R	**topgluon**	dijet, tt, bb, FCNC, $R_{b...}$
t_R,b_R q_R	$(t,b)_L$ q_L	**classic axigluon**	dijet, A^t_{FB}
q_L t_R,b_R q_R	$(t,b)_L$		

(No spectators required)

q = u,d,c,s

A Flavorful Top-Coloron Model

R.S.C., Elizabeth Simmons, N. Vignaroli
arXiv:1302.1069

Flavorful Top-Coloron Model

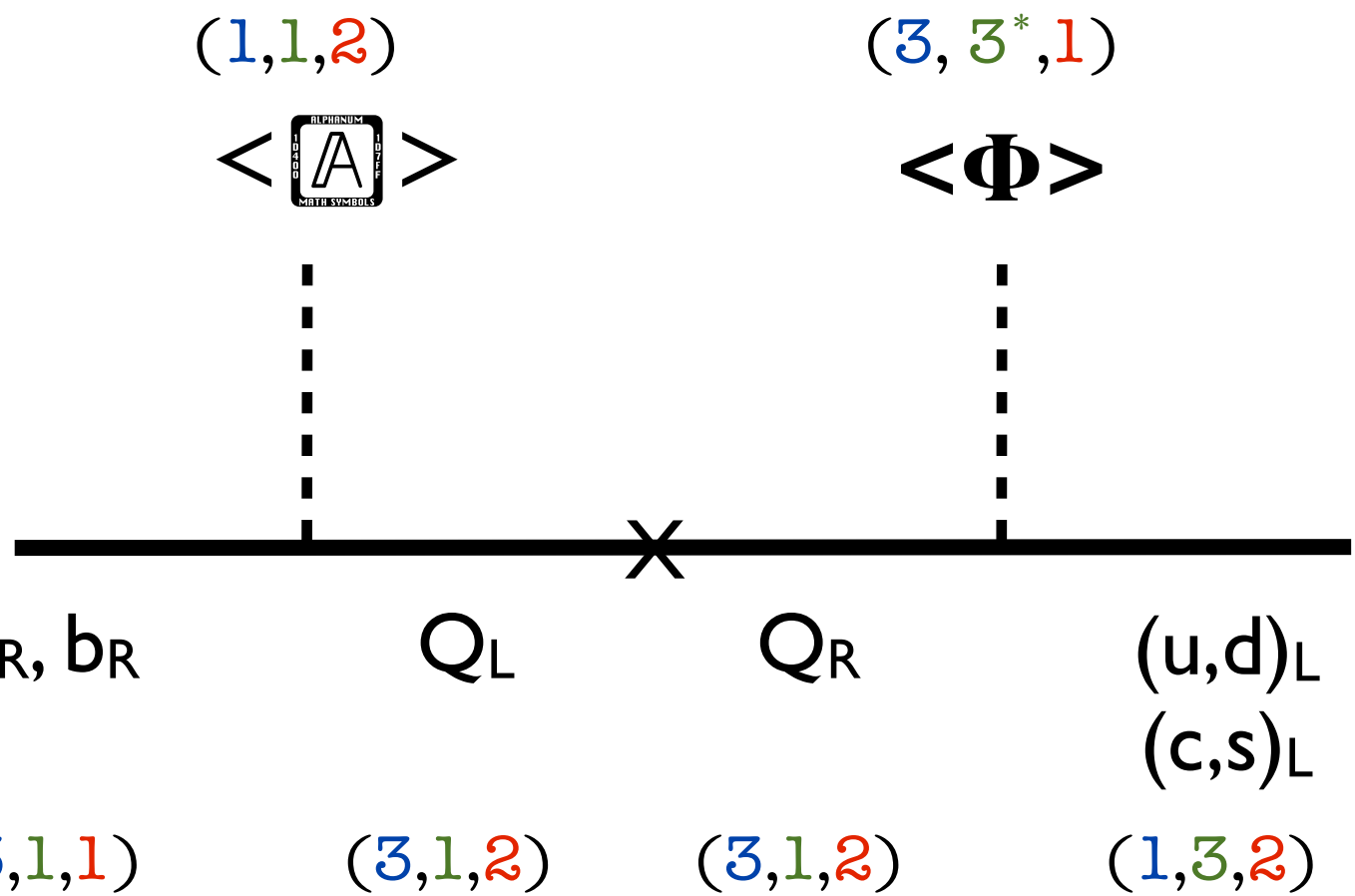
particles		$SU(3)_1$	$SU(3)_2$	$SU(2)_W$
3rd generation quarks	$(t,b)_L$	3	1	**2**
	t_R, b_R	3	1	1
light quarks	$(u,d)_L \quad (c,s)_L$	1	3	2
	$u_R, d_R \quad c_R, s_R$	1	3	1
vector quarks	Q_L, Q_R	3	1	**2**
light scalar		1	1	**2**
heavy scalar	Φ	3	3*	1

Next to minimal flavor symmetry:

$$U(2)_{\vec{\psi}_L} \times U(2)_{\vec{u}_R} \times U(2)_{\vec{d}_R} \times U(2)_{\vec{\mathcal{Q}}_L} \times U(1)_{t_R} \times U(1)_{b_R} \times U(1)_{Q_R}$$

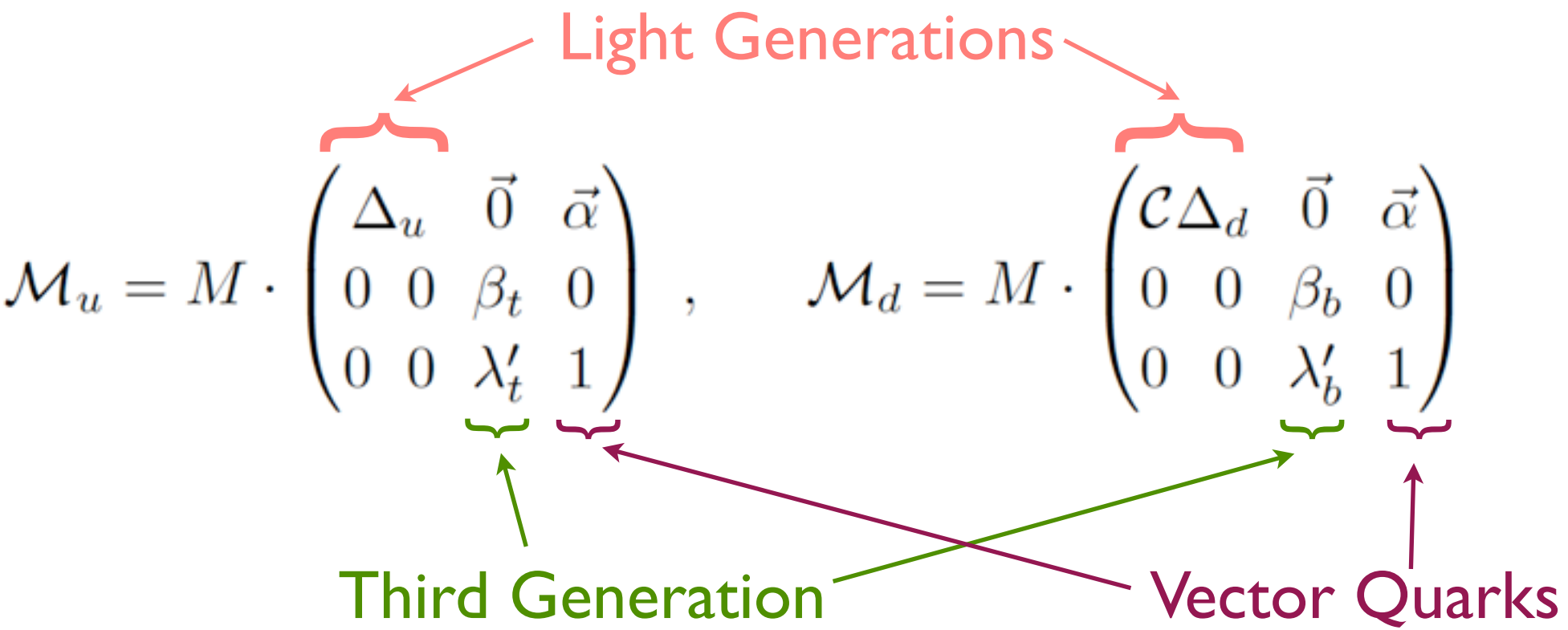
Generational Mixing

$SU(3)_1 \times SU(3)_2 \times SU(2)_W$



Mixing to third generation occurs indirectly, through mixing with vector quarks.

Generational Mixing



Weak Mixing ⇒ Cabbibo Matrix, $\mathcal{C}$, and

$$V_{ub} = \alpha_1 d = \alpha_1 \left(\frac{\lambda'_t}{\beta_t} - \frac{\lambda'_b}{\beta_b} \right) = A\lambda^3(\rho - i\eta) = 0.00131 - i0.00334$$

$$V_{cb} = \alpha_2 d = \alpha_2 \left(\frac{\lambda'_t}{\beta_t} - \frac{\lambda'_b}{\beta_b} \right) = A\lambda^2 = 0.0415 \ ,$$

$$d = \mathcal{O}(1)$$
$$\alpha_1 = \mathcal{O}(\lambda^3)$$
$$\alpha_2 = \mathcal{O}(\lambda^2)$$

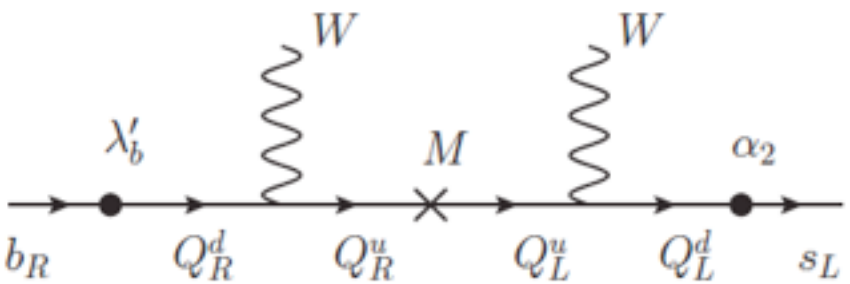
Constraints from Flavor Physics

R.S.C., Elizabeth Simmons, N. Vignaroli
arXiv:1302.1069

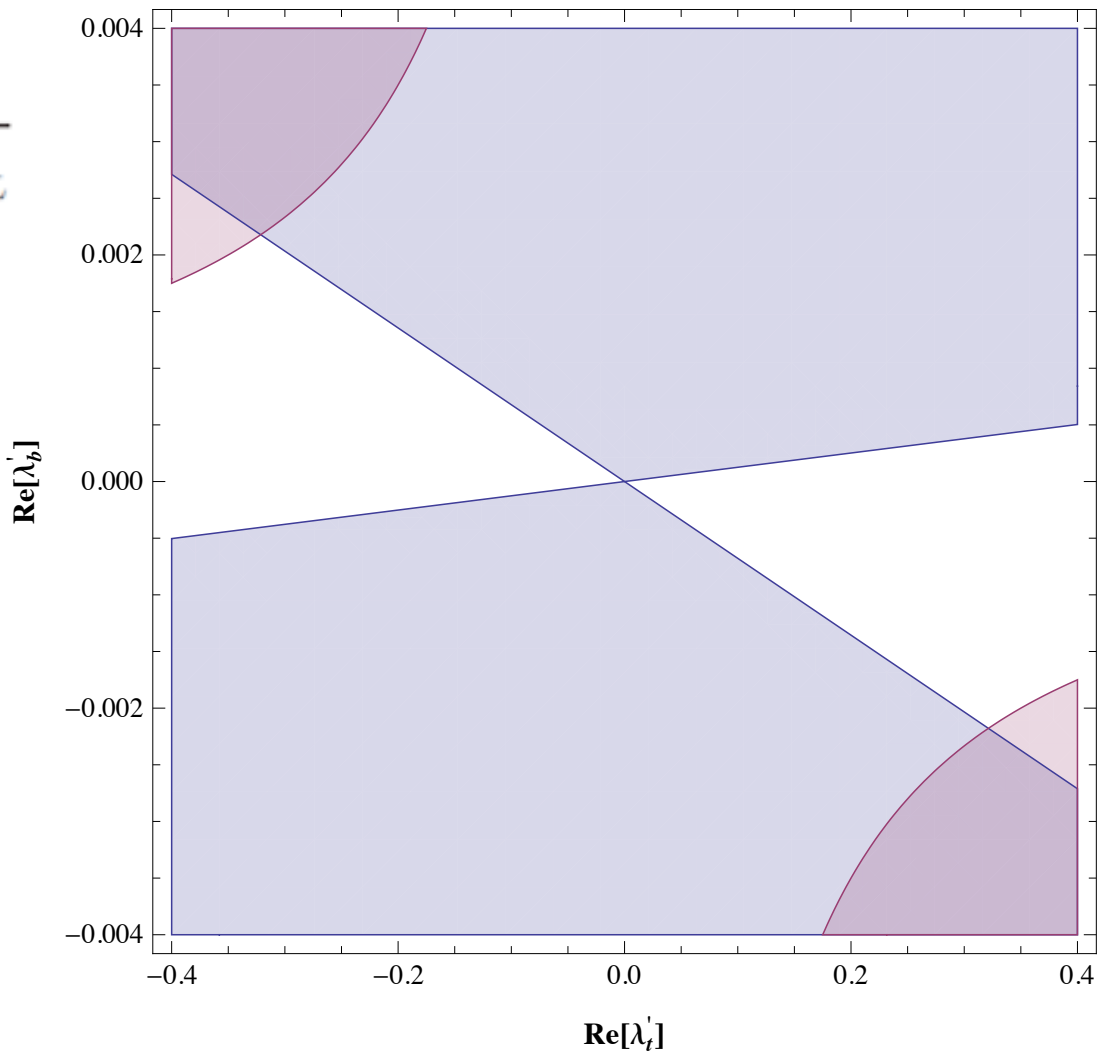
FCNC in Top-Coloron Model

- Mixing among ordinary and heavy vector quarks also leads to flavor-changing b-quark decays: $b \to s\gamma$
- Coloron exchange yields KK, DD, and BB mixing
  - quark charges under strong gauge groups are non-universal
  - the top and bottom mass eigenstate quarks are admixtures of ordinary and heavy vector gauge eigenstate quarks

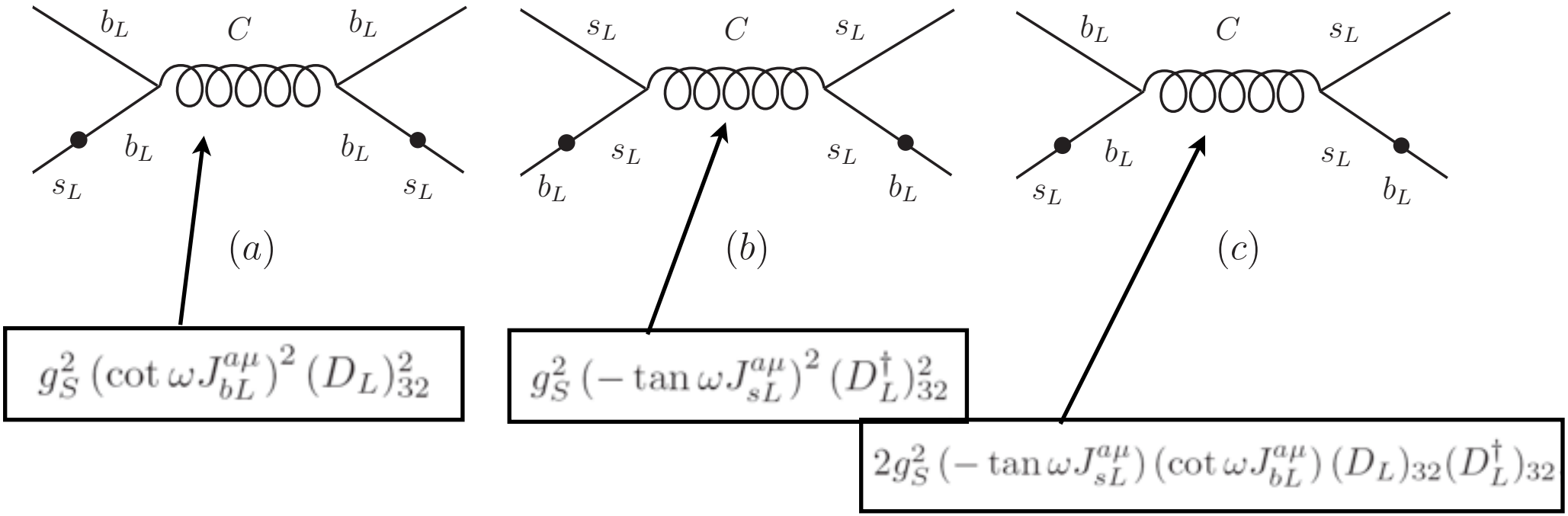
Constraints: b→sγ



Mixing with right-handed electroweak doublets enhances contributions to b→sγ

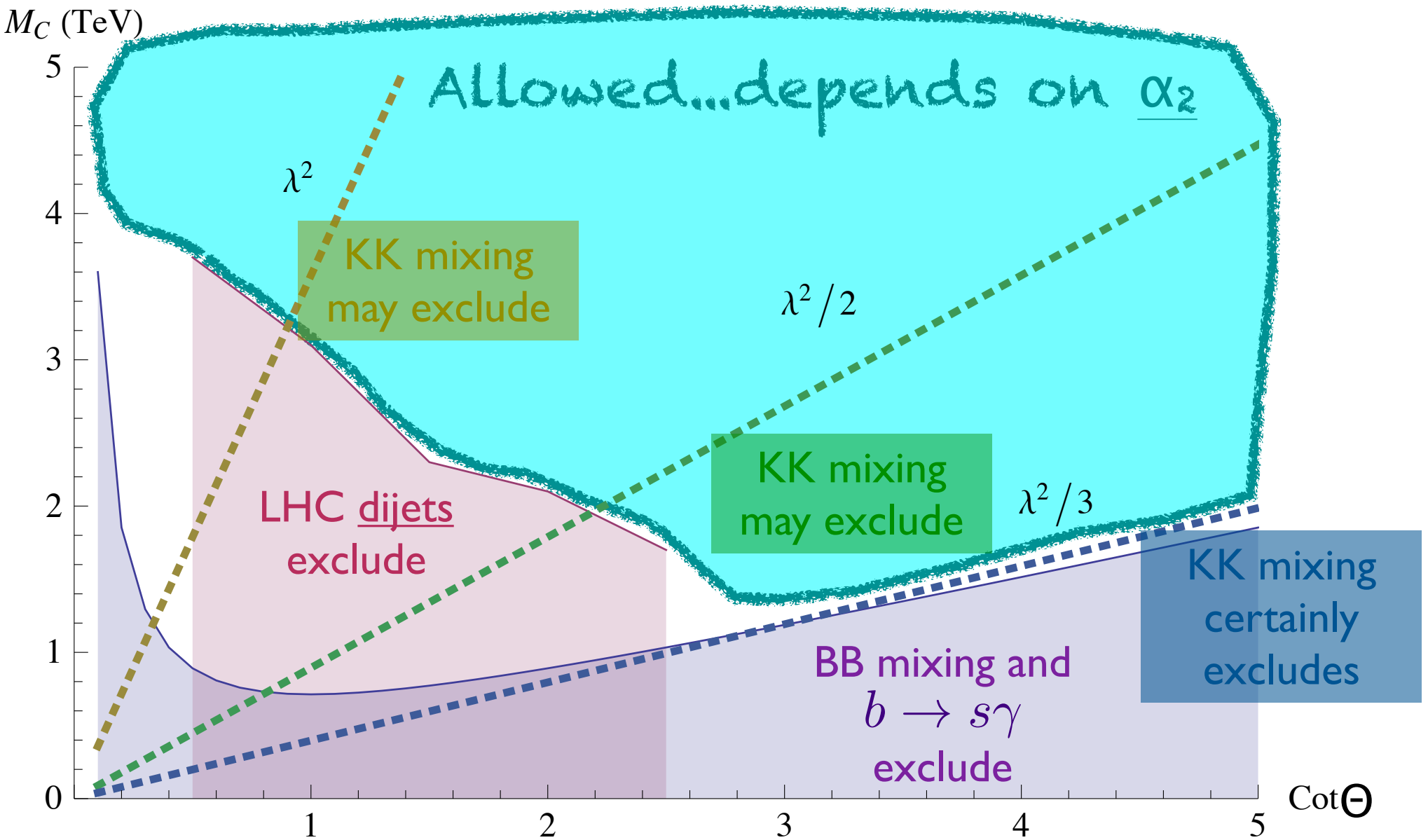


Constraints: B-Bbar Mixing



Flavor-changing Effects from Coloron Exchange:
interplay between mixing and coupling strengths

Flavor Limits on Top-Coloron Model



R.S. Chivukula, EHS, N. Vignaroli (2013)

Scalar Bosons

R.S.C., Elizabeth Simmons, N. Vignaroli
arXiv:1306.2248
Bogdan Dobrescu and Yang Bai
arXiv:1012.5814

Colored Scalars and Their Potential

Most general renormalizable $(3,\overline{3})$ potential:

$$V(\Phi) = -m_\Phi^2 \mathrm{Tr}(\Phi\Phi^\dagger) - \mu(\det\Phi + \mathrm{H.c.}) + \frac{\xi}{2}\left[\mathrm{Tr}(\Phi\Phi^\dagger)\right]^2 + \frac{k}{2}\mathrm{Tr}(\Phi\Phi^\dagger\Phi\Phi^\dagger)$$

For an appropriate range of parameters:

vev

singlet fields

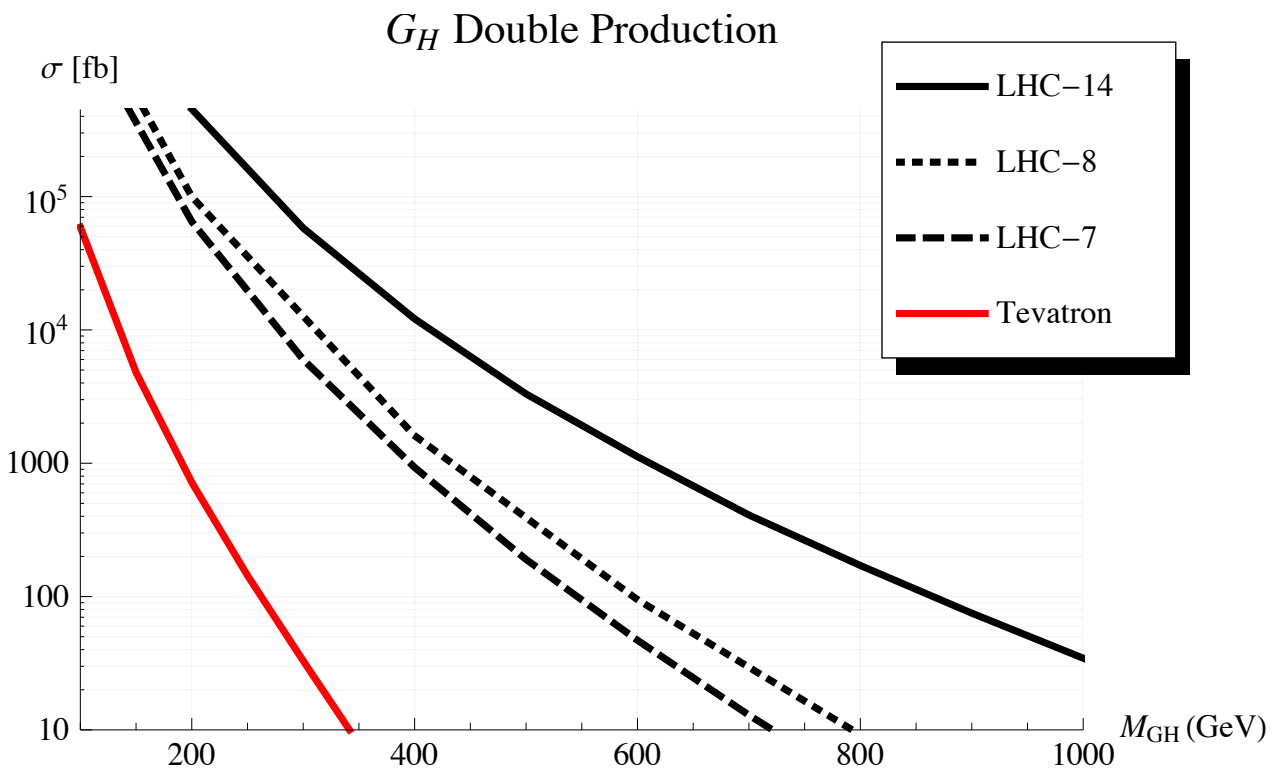
eaten by colorons

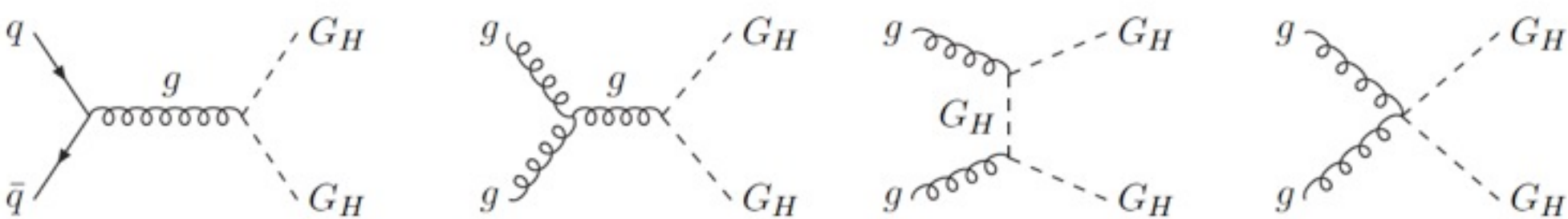
$$\Phi = u + \frac{1}{\sqrt{6}}\left(\phi_R + i\phi_I\right) + \left(G_H^a + iG_G^a\right)T^a$$

Color Octet Scalars

Quark couplings fixed from above!

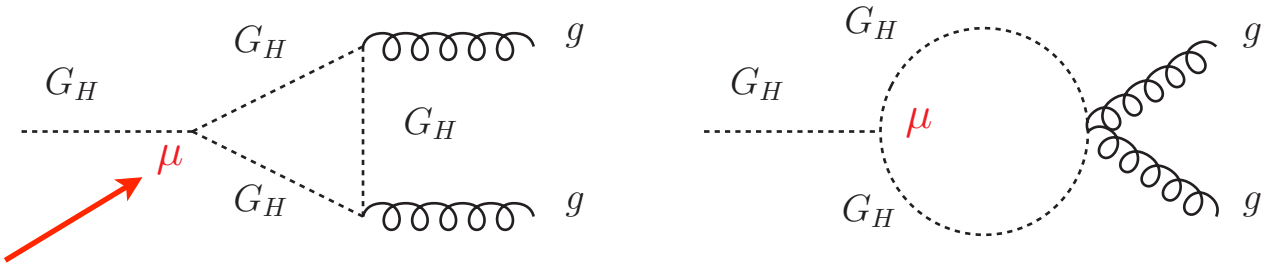
Octet Scalar Production





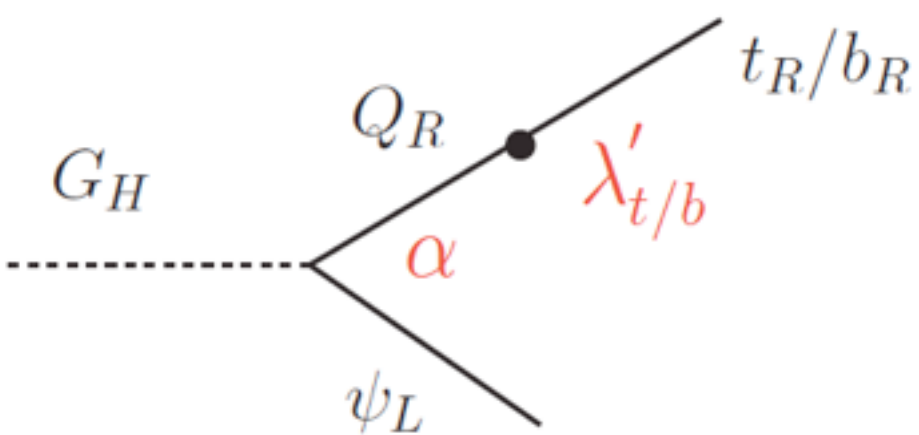
Octet Scalar Decay

Dijets:

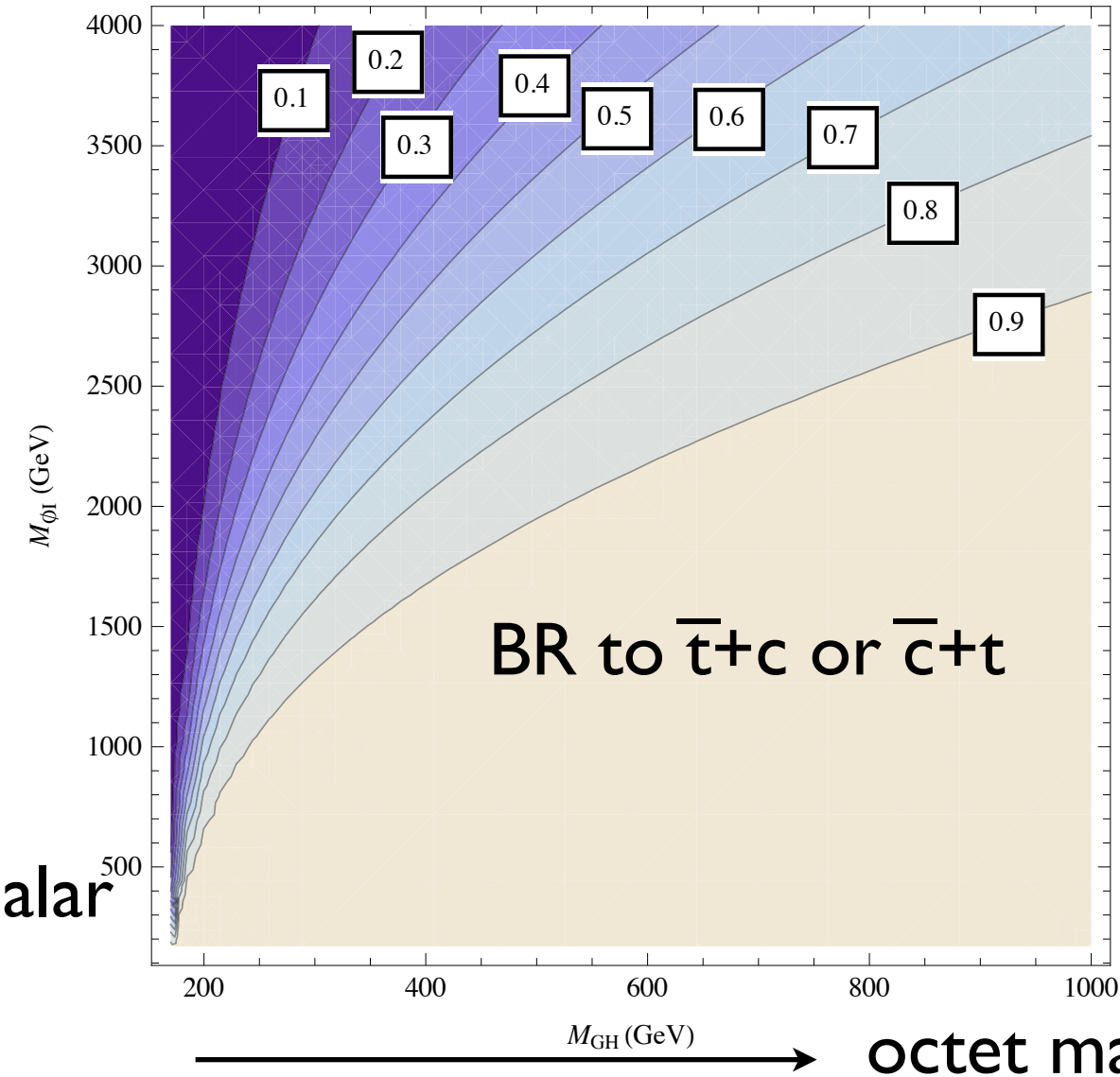


μ related to singlet pseudoscalar mass

$\bar{c}_L t_R + \bar{t}_R c_L$:



Top + Charm Often Very Large!

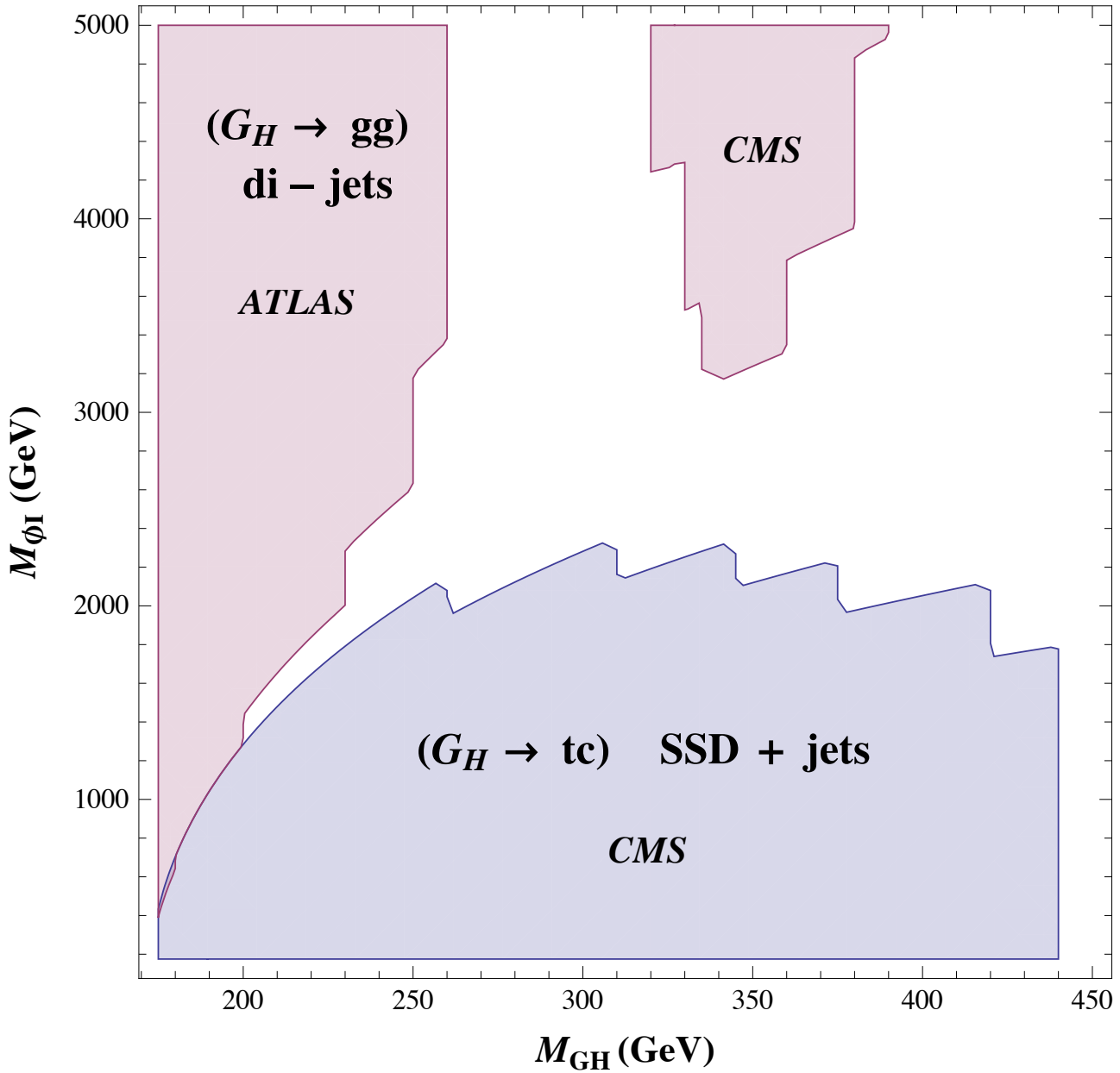


pseudo-scalar mass

octet mass

Octet pair production can lead to same-sign tops (dileptons)!

Experimental Constraints



Singlet mass dependence from behavior of BRs

References: CMS PAS SUS-12-029
ATLAS arXiv:1210.4826
CMS arXiv:1302.0531

Flavor-Universal Constraints On Scalars

R.S.C., Arsham Farzinnia, Jing Ren,
and Elizabeth Simmons
arXiv:1307.xxxx

Scalar Potential: Higgs and Mixing

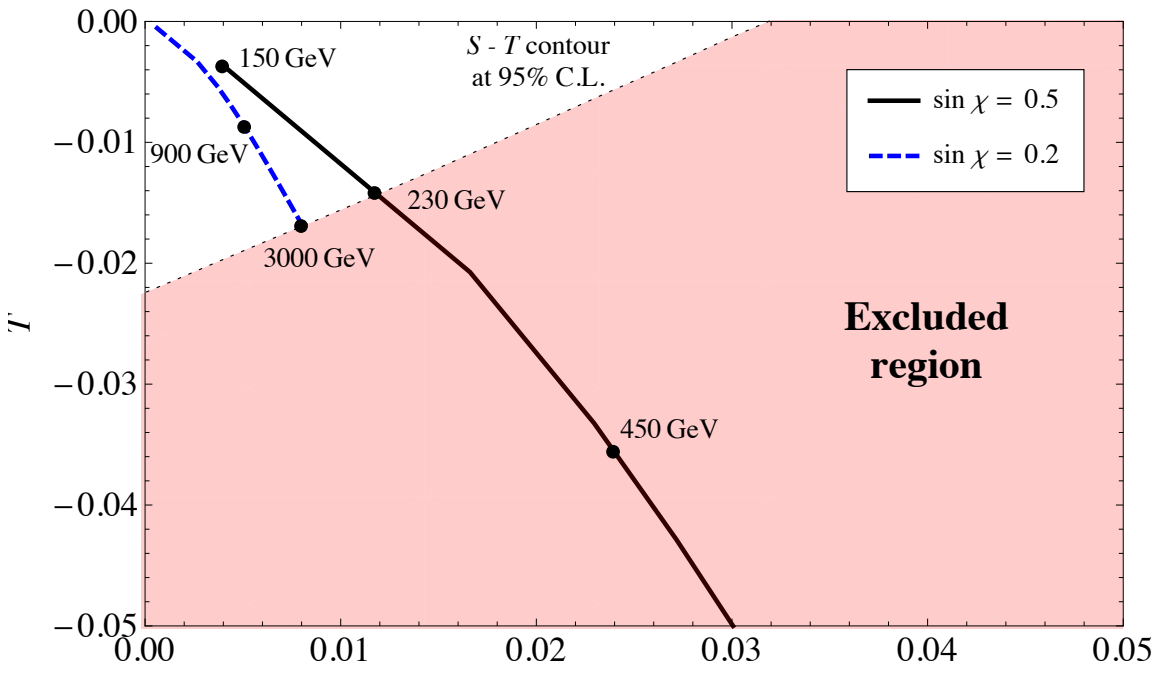
Scalar potential includes Higgs boson as well:

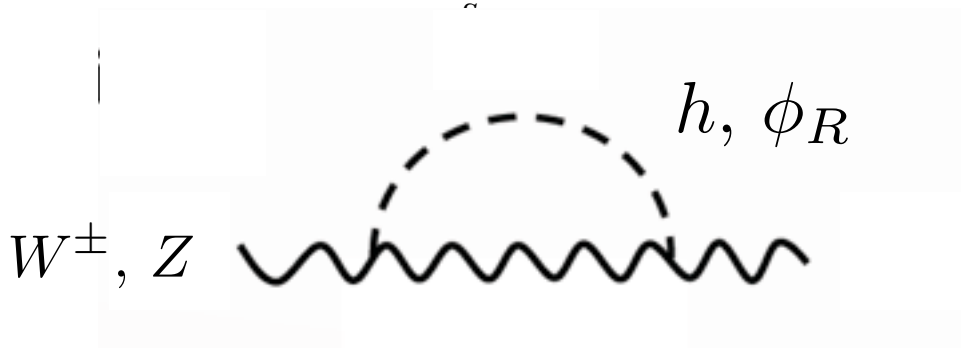
$$V(\phi,\Phi) \subset \frac{\lambda_h}{6}\left(\phi^\dagger\phi - \frac{v_h^2}{2}\right)^2 + \lambda_m\left(\phi^\dagger\phi - \frac{v_h^2}{2}\right)\left(\mathrm{Tr}\left[\Phi^\dagger\Phi\right] - \frac{v_s^2}{2}\right)$$

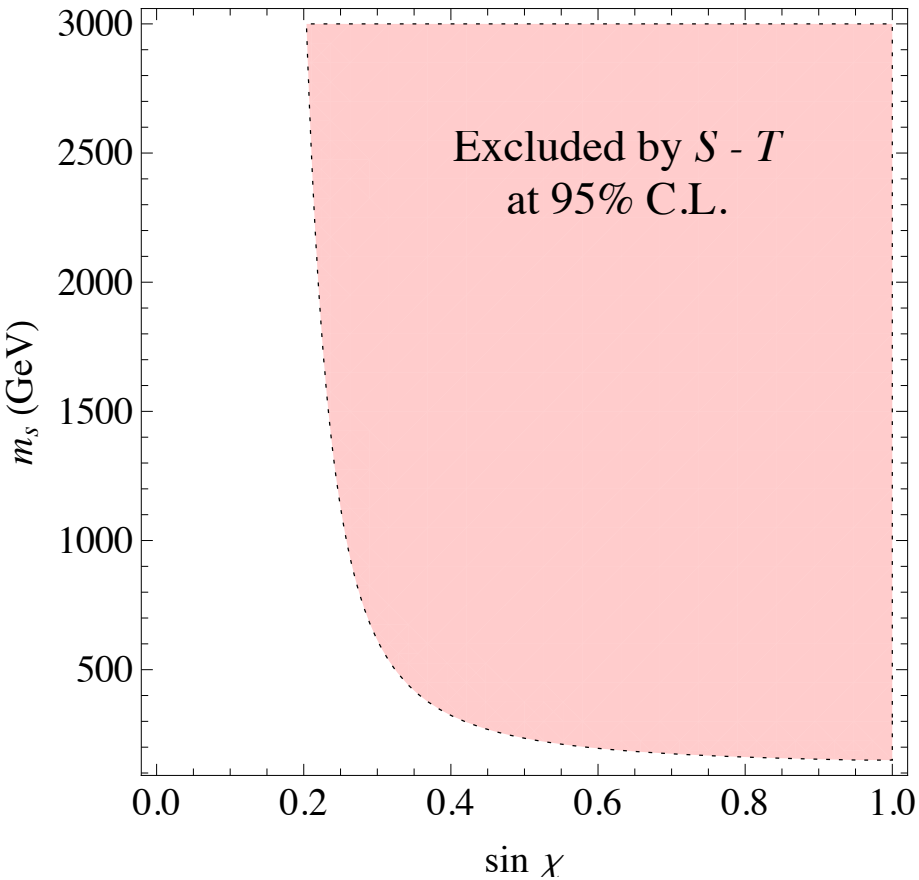
"Higgs portal" coupling: mixing between electroweak and color sectors

$$h = \cos\chi\, h_0 - \sin\chi\, \phi_{0R}$$

Precision Electroweak Constraints



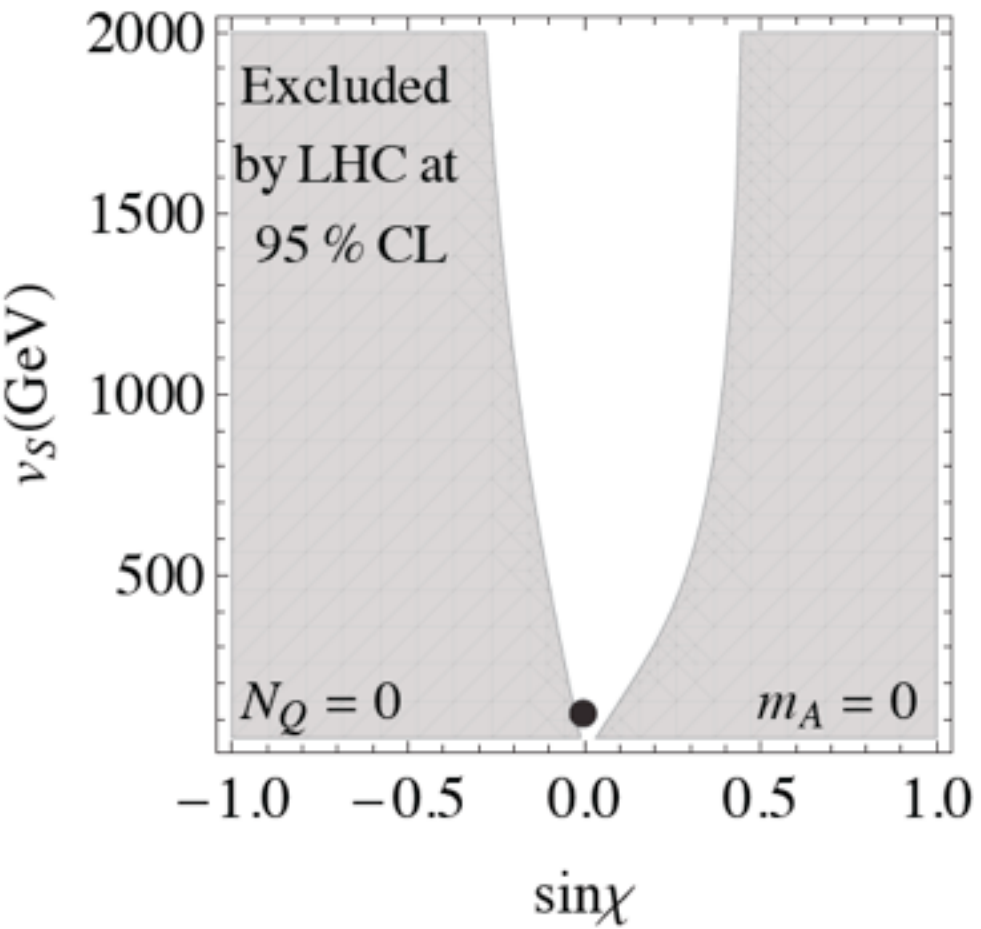


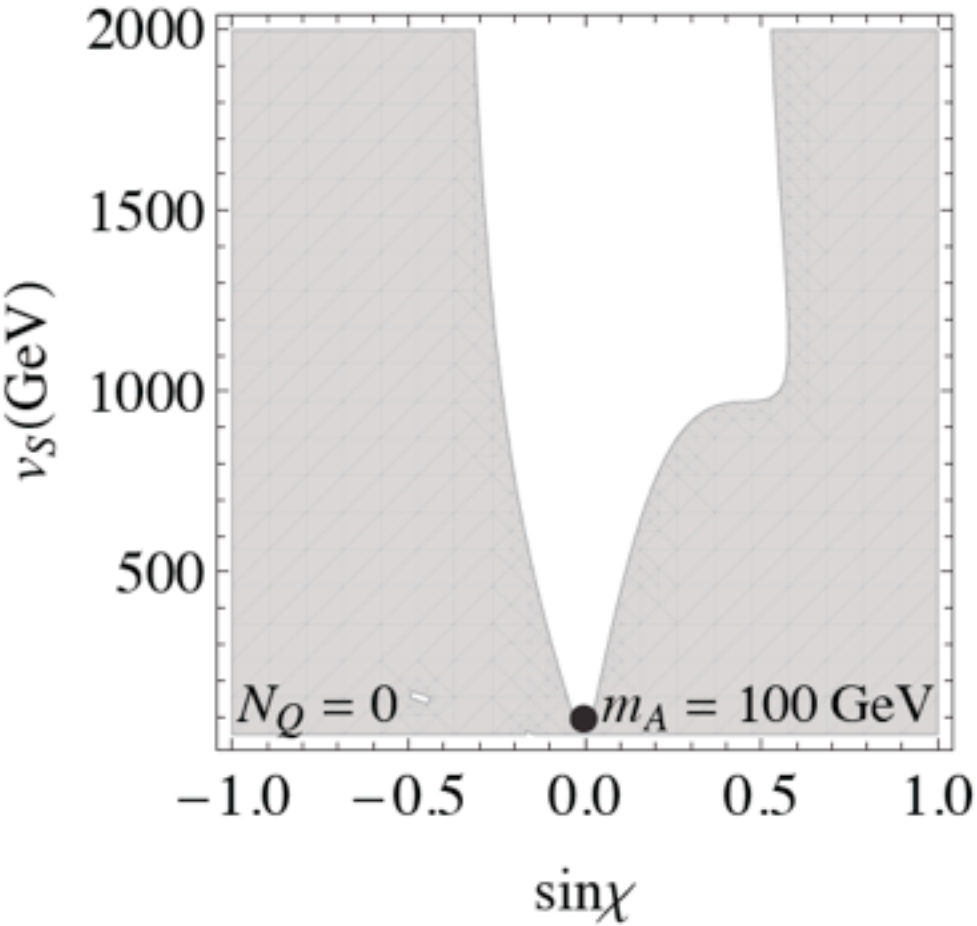


S-T contours from Gfitter, arXiv:1209.2716

Constraints from Higgs Observation

Coloron and colored scalar contributions to production...



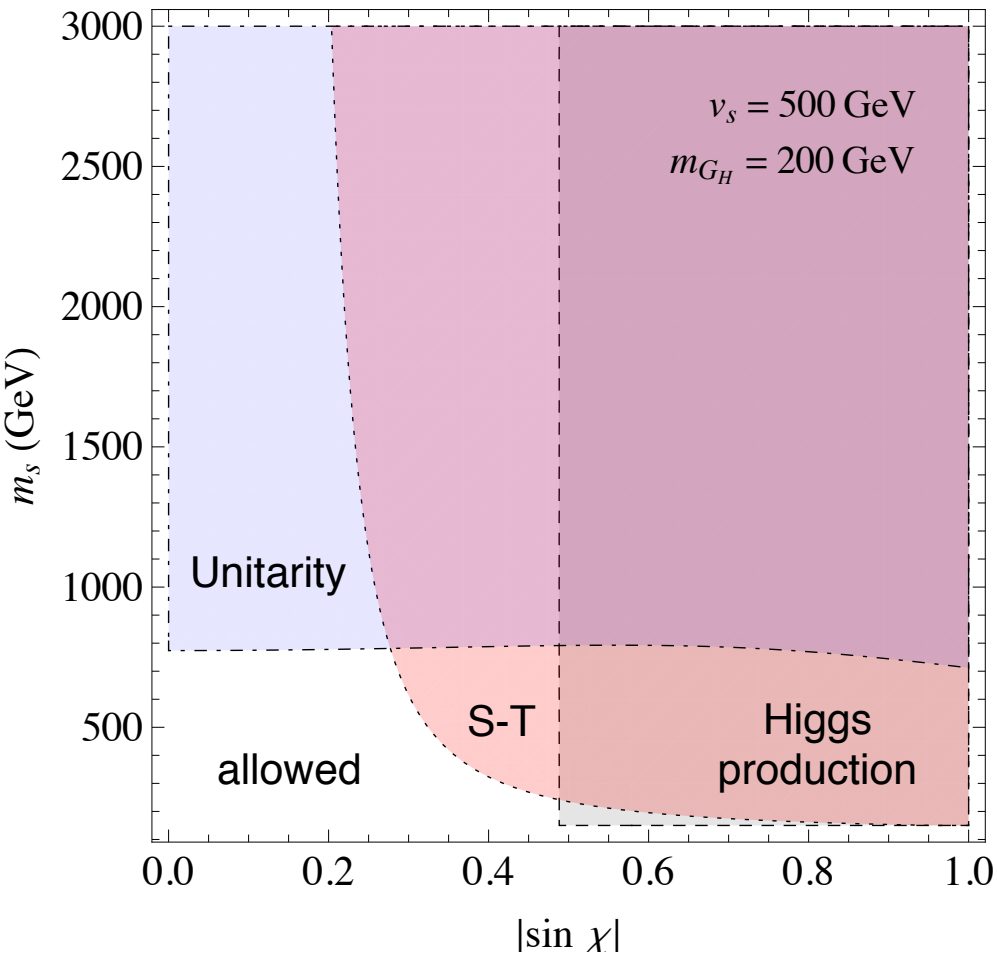


$h \to \phi_I \phi_I$ allowed

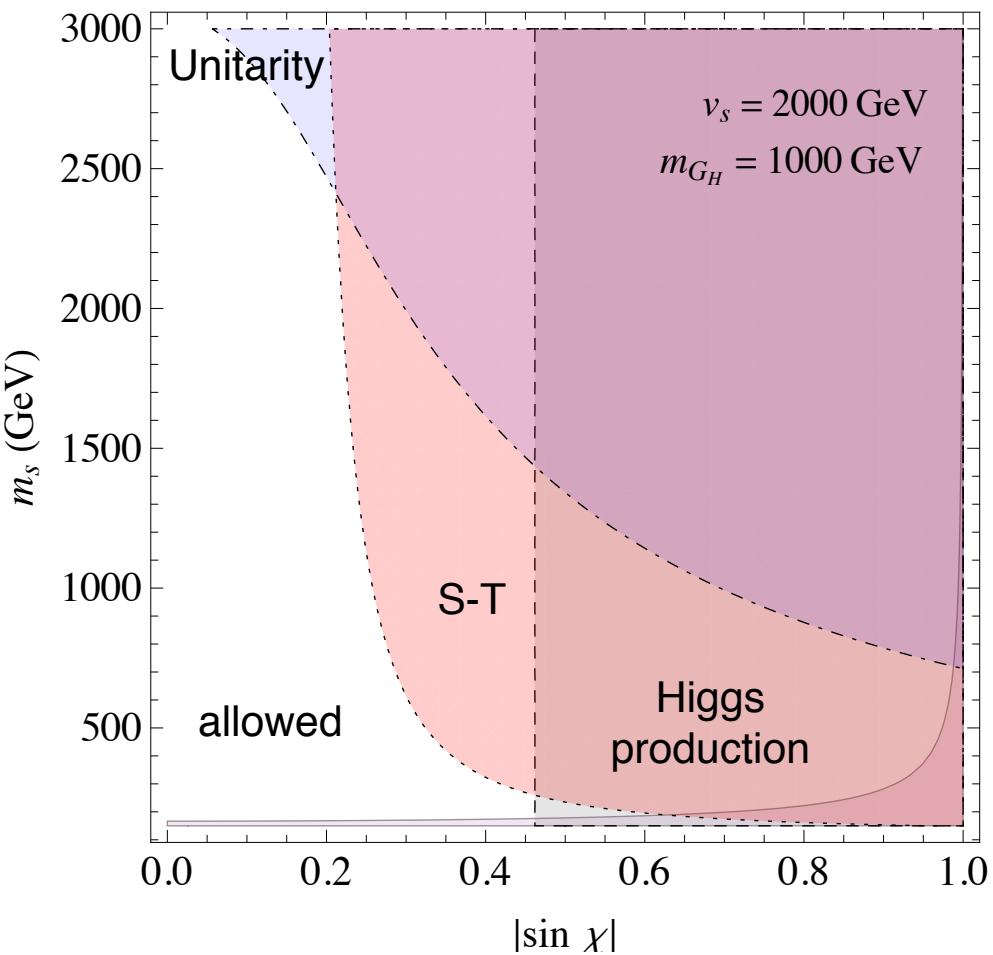
CMS-PAS-HIG-13-005
ATLAS-CONF-2013-034
Yao, Moriond EW 2013

Illustration of Combined Results

u=500 GeV
m_{GH}= 200 GeV



u=2000 GeV
m_{GH}= 1000 GeV



Illustrates interplay of different constraints ...
and of direct and indirect bounds

Conclusions

Conclusions

Many models predict extended strong interactions

Is this extended dynamics flavor-universal or not?

- Introduced a flavorful top-coloron model
- Constraints from FCNCs favor NMFV.
- Same-sign tops, and therefore dileptons, an interesting signature for new colored scalars.

Additional effects of extended strong interactions?

- Color symmetry breaking sector can mix with EWSB
- Constraints on Higgs mixing and from observed properties of Higgs boson