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EWSB Working Group Theory Summary Talk

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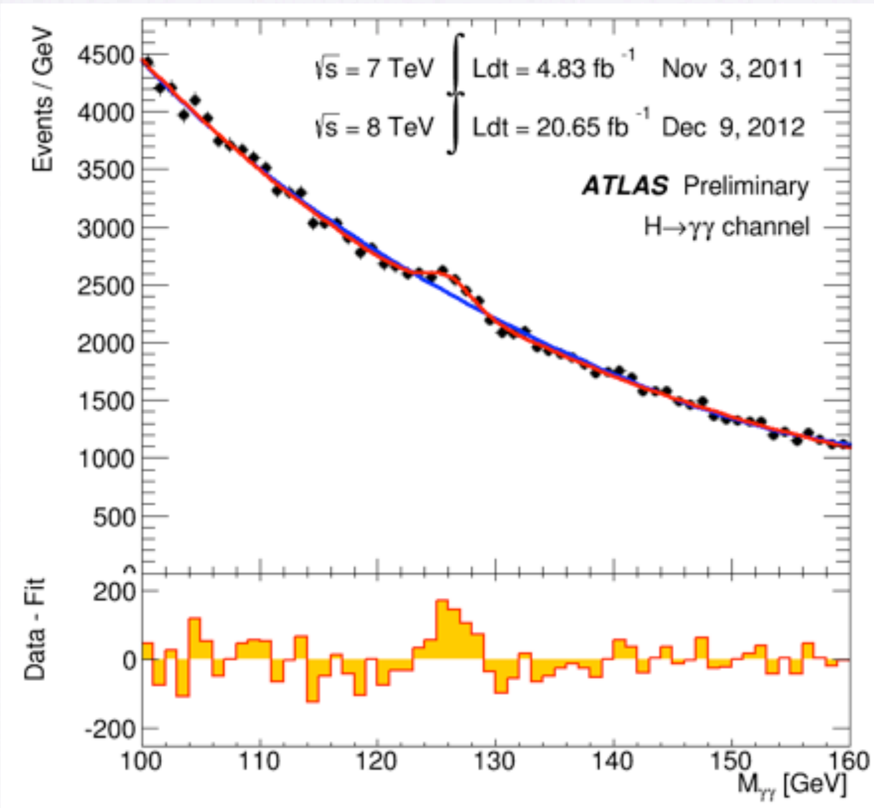
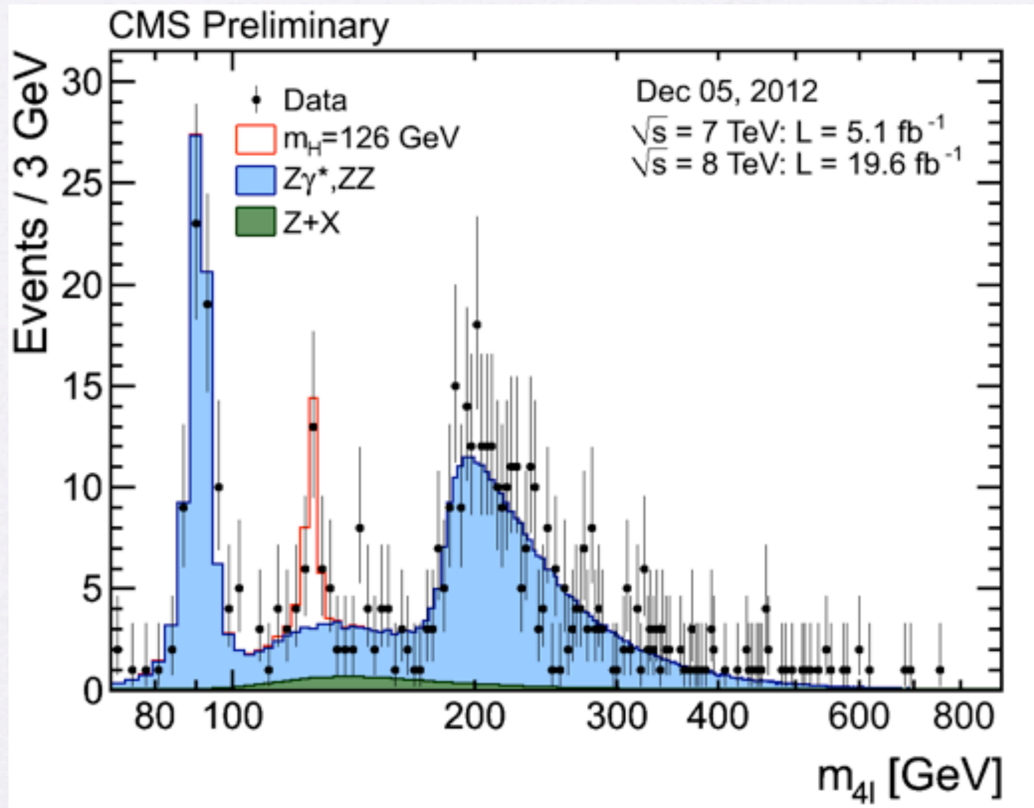
ICTP SAIFR International Centre for Theoretical Physics South American Institute for Fundamental Research

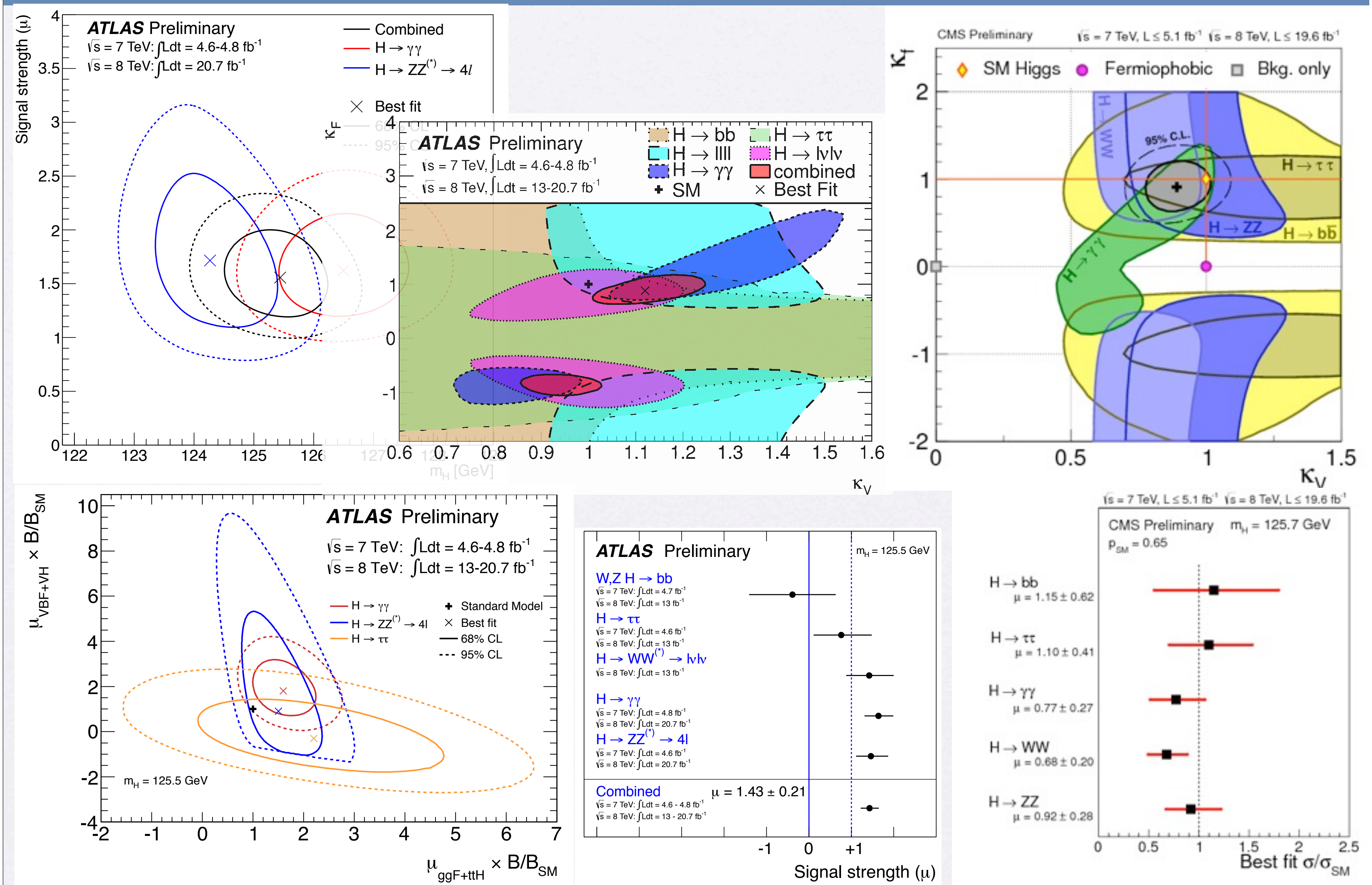
unesp UNIVERSIDADE ESTADUAL PAULISTA "JÚLIO DE MESQUITA FILHO"

Resonance at ~125 GeV

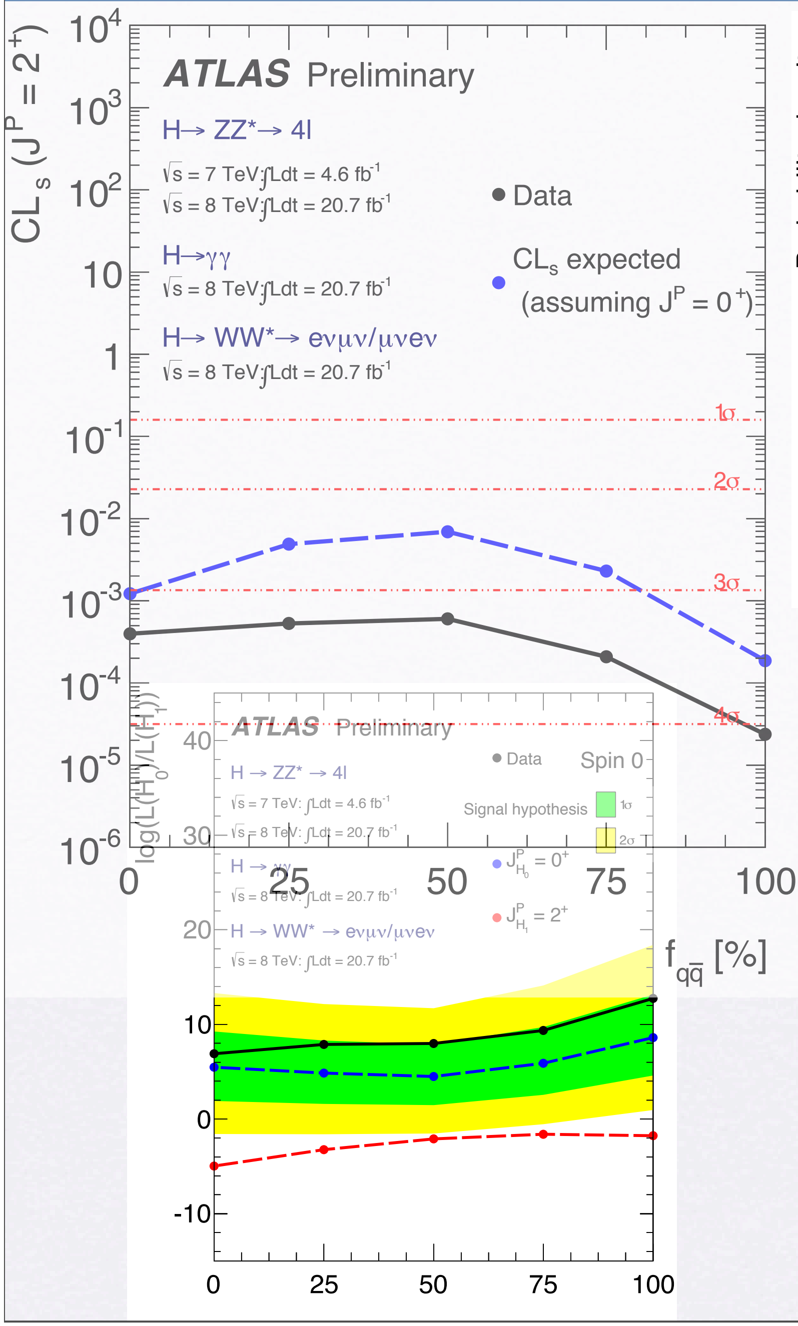


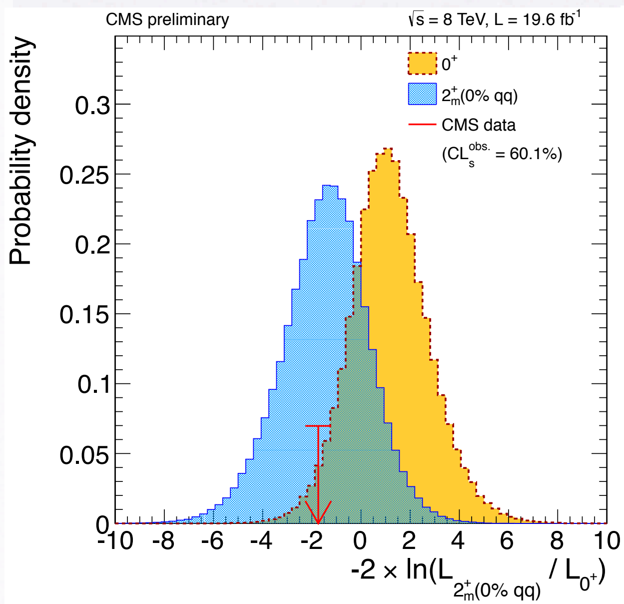


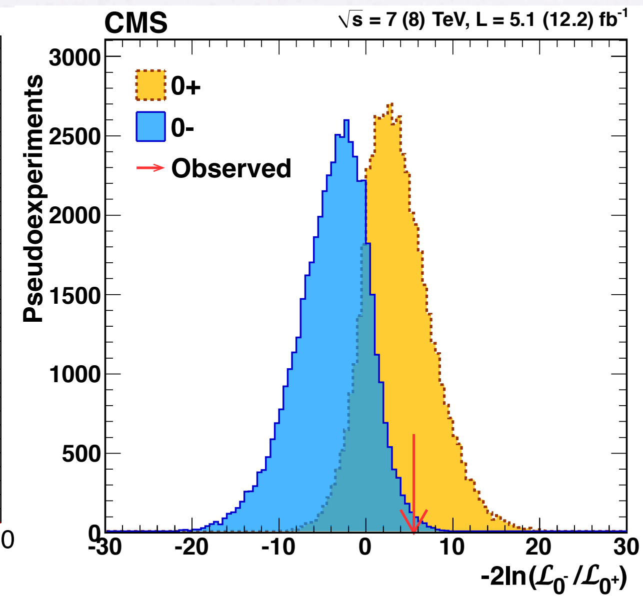
Signal Strengths

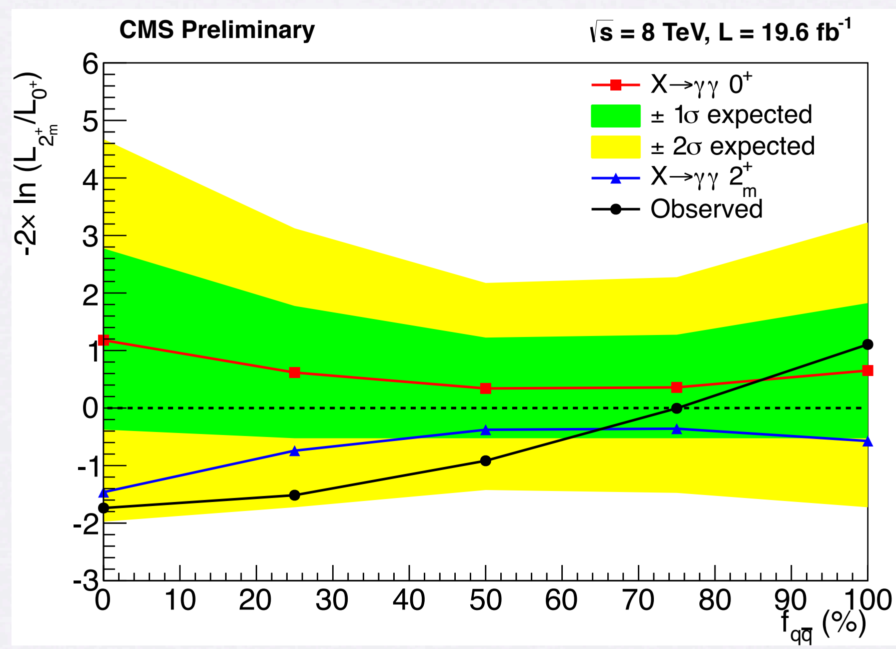


Spin Measurements









The Gauge Sector of the SM

SM gauge interactions obey SU(2) x U(1) relations ...

... but spectrum of gauge bosons and fermions does not

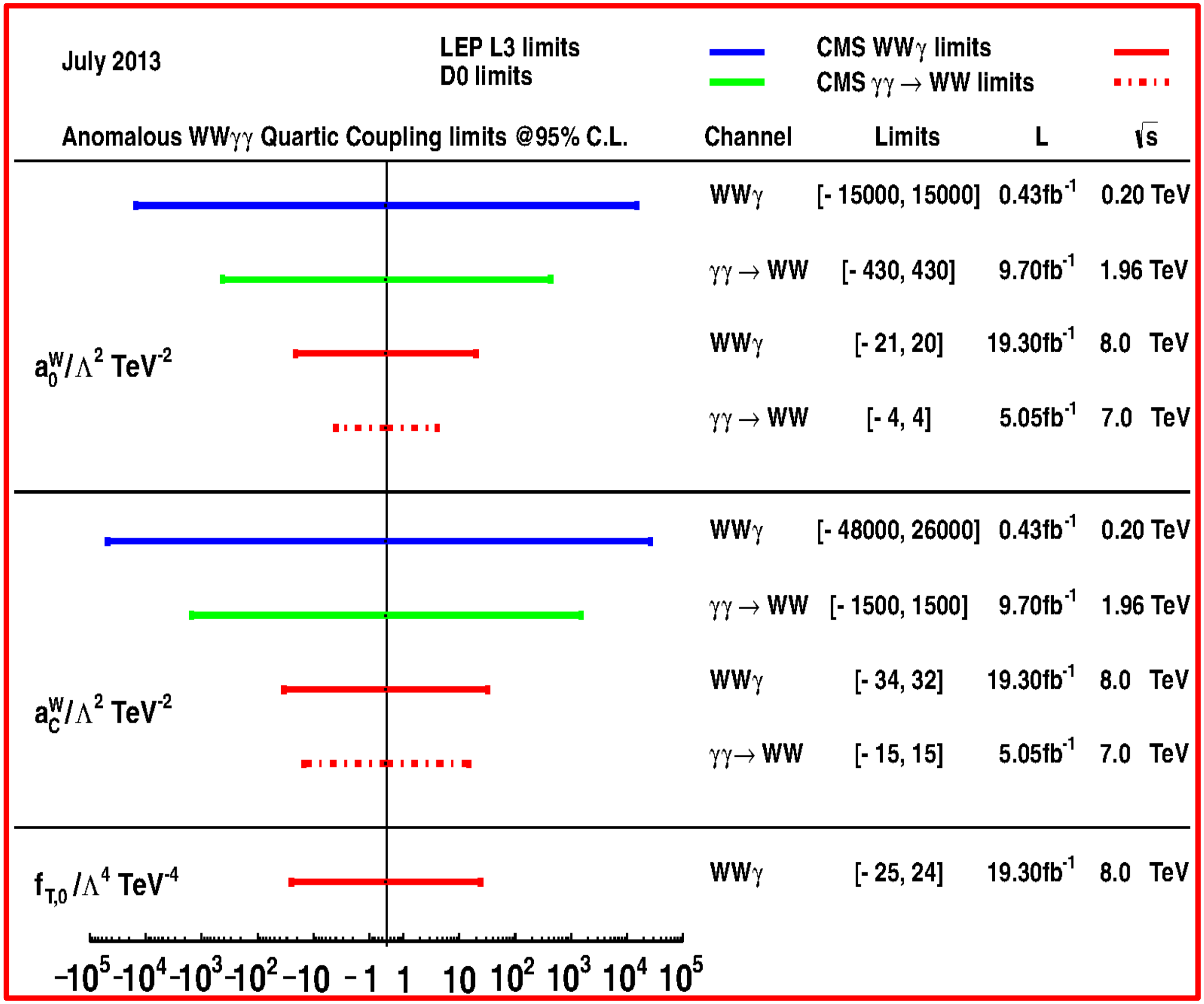
Physics governed by an $\mathbf{SU(2)_L \times U(1)_Y}$ gauge theory

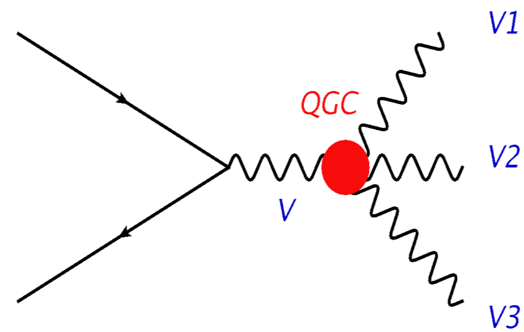
... that is spontaneously broken

- **We have known this since LEP!**
- **Latest LHC results further confirm this picture...**
  (as did the Tevatron)

aQGCs

From Qiang Li's talk





WWγ+WZγ →lνjjγ

$$-25 < f_{T,0}/\Lambda^4 < 24\ \mathrm{TeV}^{-4},$$
$$-12 < \kappa_0^W/\Lambda^2 < 10\ \mathrm{TeV}^{-2},\ \text{and}$$
$$-18 < \kappa_C^W/\Lambda^2 < 17\ \mathrm{TeV}^{-2}.$$

A Light Scalar

Discovery of the Higgs at the LHC:

First example of what could be an elementary scalar!

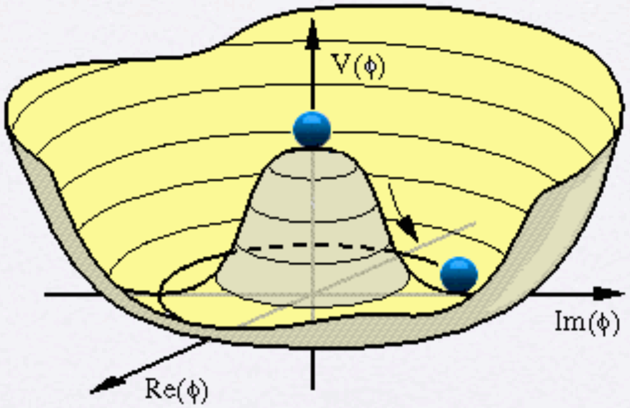
Fluctuations associated with EWSB vev are weakly coupled

An important step towards an understanding of EWSB

Understanding EWSB?

Even if we can confirm this picture:

(i.e. measure the Higgs potential)



Why is the EWS broken? What dynamics is behind this phenomenon?

What is the characteristic scale associated to this BSM physics?

... and is it related to other BSM physics required to understand other open questions such as neutrino masses, flavor structure, DM, matter-antimatter asymmetry...?

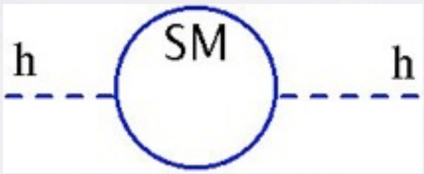
Naturalness

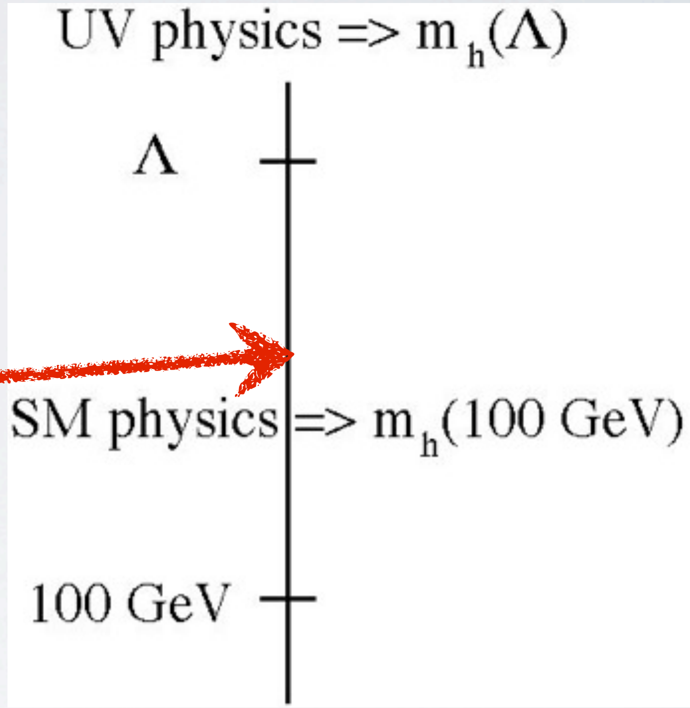
From Gustavo Burdman's talk

Quadratic sensitivity of m_h to t

- Generic in Quantum Field Theory
  It does not depend on there being new heavy particles

$$m_h^2(100\ \mathrm{GeV}) = m_h^2(\Lambda) + \Delta m_h^2$$





All momentum shells above $100\ \mathrm{GeV}$ contribute to quadratic sensitivity of the UV boundary condition !

Search for a (seemingly) weaker version of naturalness

(but most likely with strong hidden assumptions)

Finite Naturalness and new physics

From Alessandro Strumia's talk

Neutrino mass models add extra part

$$M \lesssim \begin{cases} 0.7\ 10^7\,\text{GeV} \times \sqrt[3]{\Delta} & \text{type I see-saw model,} \\ 200\,\text{GeV} \times \sqrt{\Delta} & \text{type II see-saw model,} \\ 940\,\text{GeV} \times \sqrt{\Delta} & \text{type III see-saw model.} \end{cases}$$

Leptogenesis is compatible with FN only in type I.

Axion and LHC usually are like fish and bicycle because $f_a \gtrsim 10^9\,\text{GeV}$. Axion models can satisfy FN, e.g. KSVZ models employ heavy quarks with mass M

$$M \lesssim \sqrt{\Delta} \times \begin{cases} 0.74\,\text{TeV} & \text{if } \Psi = Q \oplus \bar{Q} \\ 4.5\,\text{TeV} & \text{if } \Psi = U \oplus \bar{U} \\ 9.1\,\text{TeV} & \text{if } \Psi = D \oplus \bar{D} \end{cases}$$

Inflation does not need big scales and anyhow flatness implies small couplings
Absolute gravitational limit on H_I and on any mass [Arvinataki, Dimopoulos..

$$\delta m^2 \sim \frac{y_t^2 M^6}{M_{\text{Pl}}^4 (4\pi)^6} \qquad \text{so} \qquad M \lesssim \Delta^{1/6} \times 10^{14}\,\text{GeV}$$

Dark Matter: extra scalars/fermions with/without weak gauge interactions.

Strong vs weak dynamics

Existence of weakly coupled light scalar makes makes the naturalness question more pressing

But it does not settle the issue of whether the underlying EWSB dynamics

is weakly coupled (as in SUSY)

or strongly coupled (as in pNGB scenarios)

Or whether the Higgs sector is just the minimal one (i.e. as in the SM)

Strong Dynamics: the Higgs as a pNGB

From Gustavo Burdman's talk

In the analogy with QCD

- Technicolor:

$$\left.\begin{array}{r} h \simeq \sigma \\ m_h \simeq \Lambda \end{array}\right\} \textbf{x}$$

- Higgs is a pNGB: H. Georgi and D. B. Kaplan '80

$$\left.\begin{array}{r} h \sim \pi \\ m_h \ll \Lambda \end{array}\right\}$$ remnant from spontaneous breaking of global symmetry G

Global symmetry protects $m_h \Rightarrow V(h) = 0$

Explicit breaking: from gauge/Yukawa interactions $\Rightarrow m_h \neq 0$

Minimal example

From Enrico Bertuzzo's talk

G	H	N_G	NGBs rep.$[H]$ = rep.$[\mathrm{SU}(2)\times\mathrm{SU}(2)]$
→ SO(5)	SO(4)	4	$\mathbf{4}=(\mathbf{2},\mathbf{2})$
SO(6)	SO(5)	5	$\mathbf{5}=(\mathbf{1},\mathbf{1})+(\mathbf{2},\mathbf{2})$
SO(6)	SO(4) × SO(2)	8	$\mathbf{4_{+2}}+\bar{\mathbf{4}}_{\mathbf{-2}}=2\times(\mathbf{2},\mathbf{2})$
SO(7)	SO(6)	6	$\mathbf{6}=2\times(\mathbf{1},\mathbf{1})+(\mathbf{2},\mathbf{2})$
SO(7)	G_2	7	$\mathbf{7}=(\mathbf{1},\mathbf{3})+(\mathbf{2},\mathbf{2})$
SO(7)	SO(5) × SO(2)	10	$\mathbf{10_0}=(\mathbf{3},\mathbf{1})+(\mathbf{1},\mathbf{3})+(\mathbf{2},\mathbf{2})$
SO(7)	$[\mathrm{SO}(3)]^3$	12	$(\mathbf{2},\mathbf{2},\mathbf{3})=3\times(\mathbf{2},\mathbf{2})$
Sp(6)	Sp(4) × SU(2)	8	$(\mathbf{4},\mathbf{2})=2\times(\mathbf{2},\mathbf{2}),(\mathbf{2},\mathbf{2})+2\times(\mathbf{2},\mathbf{1})$
SU(5)	SU(4) × U(1)	8	$\mathbf{4}_{-5}+\bar{\mathbf{4}}_{\mathbf{+5}}=2\times(\mathbf{2},\mathbf{2})$
SU(5)	SO(5)	14	$\mathbf{14}=(\mathbf{3},\mathbf{3})+(\mathbf{2},\mathbf{2})+(\mathbf{1},\mathbf{1})$

Agashe, Contino, Pomarol 05

… and beyond

From Enrico Bertuzzo's talk

G	H	N_G	NGBs rep.$[H]$ = rep.$[SU(2) \times SU(2)]$
SO(5)	SO(4)	4	$\mathbf{4} = (\mathbf{2}, \mathbf{2})$
SO(6)	SO(5)	5	$\mathbf{5} = (\mathbf{1}, \mathbf{1}) + (\mathbf{2}, \mathbf{2})$
SO(6)	SO(4) × SO(2)	8	$\mathbf{4}_{+\mathbf{2}} + \bar{\mathbf{4}}_{-\mathbf{2}} = 2 \times (\mathbf{2}, \mathbf{2})$
SO(7)	SO(6)	6	$\mathbf{6} = 2 \times (\mathbf{1}, \mathbf{1}) + (\mathbf{2}, \mathbf{2})$
SO(7)	G_2	7	$\mathbf{7} = (\mathbf{1}, \mathbf{3}) + (\mathbf{2}, \mathbf{2})$
SO(7)	SO(5) × SO(2)	10	$\mathbf{10}_\mathbf{0} = (\mathbf{3}, \mathbf{1}) + (\mathbf{1}, \mathbf{3}) + (\mathbf{2}, \mathbf{2})$
SO(7)	$[SO(3)]^3$	12	$(\mathbf{2}, \mathbf{2}, \mathbf{3}) = 3 \times (\mathbf{2}, \mathbf{2})$
Sp(6)	Sp(4) × SU(2)	8	$(\mathbf{4}, \mathbf{2}) = 2 \times (\mathbf{2}, \mathbf{2}), (\mathbf{2}, \mathbf{2}) + 2 \times (\mathbf{2}, \mathbf{1})$
→ SU(5)	SU(4) × (U(1))	8	$\mathbf{4}_{-5} + \bar{\mathbf{4}}_{+\mathbf{5}} = 2 \times (\mathbf{2}, \mathbf{2})$
SU(5)	SO(5)	14	$\mathbf{14} = (\mathbf{3}, \mathbf{3}) + (\mathbf{2}, \mathbf{2}) + (\mathbf{1}, \mathbf{1})$
→ SO(9)	SO(8)	8	$8 = (2,2)_{+1} + (2,2)_{-1}$

Bertuzzo, De Sandes, Ray, Savoy 12

Absence of BSM signals

Assume the worst

and hope for the best

(Non-decoupling effects)

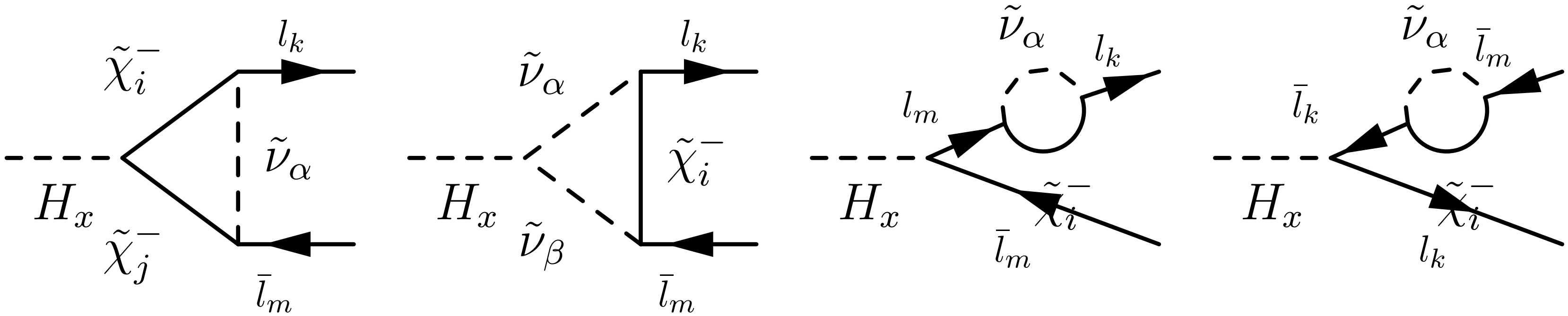
Motivation

Signals of new physics

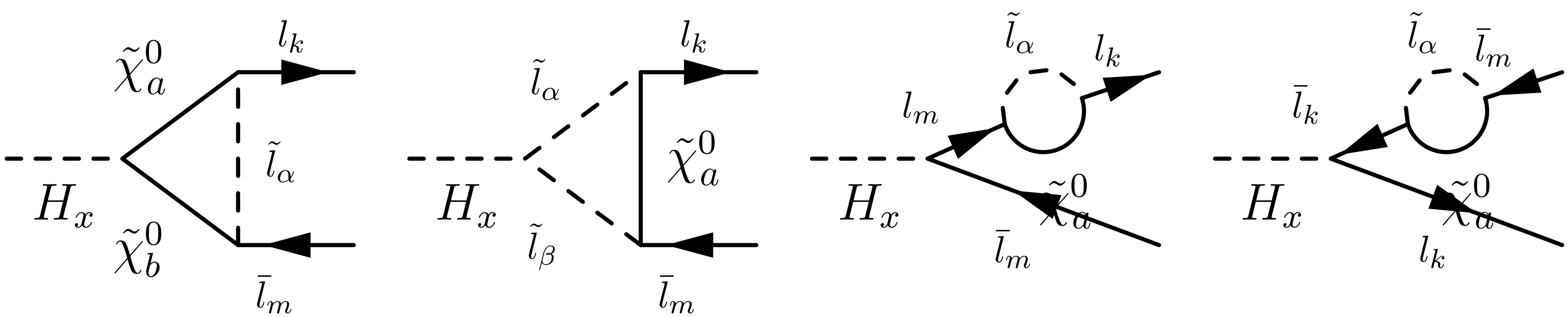
- Some years ago, first signal of BSM physics: LFV in neutrino oscillations.
- Recent discovery of SM-like Higgs boson at the LHC, with $m_{H_{\mathrm{SM}}} \simeq 126$ GeV.
- Absence of results in the direct searches for SUSY (m_{SUSY} into multi-TeV range).
- Indirect SUSY observables with non-decoupling behavior with m_{SUSY}.

Lepton flavor violating Higgs decay (LFVHD) rates induced by SUSY at one loop: may be sizeable even at very heavy $m_{\mathrm{SUSY}} \simeq \mathcal{O}(5\ \mathrm{TeV})$.

One-loop LFV SUSY-induced Higgs decay diagrams

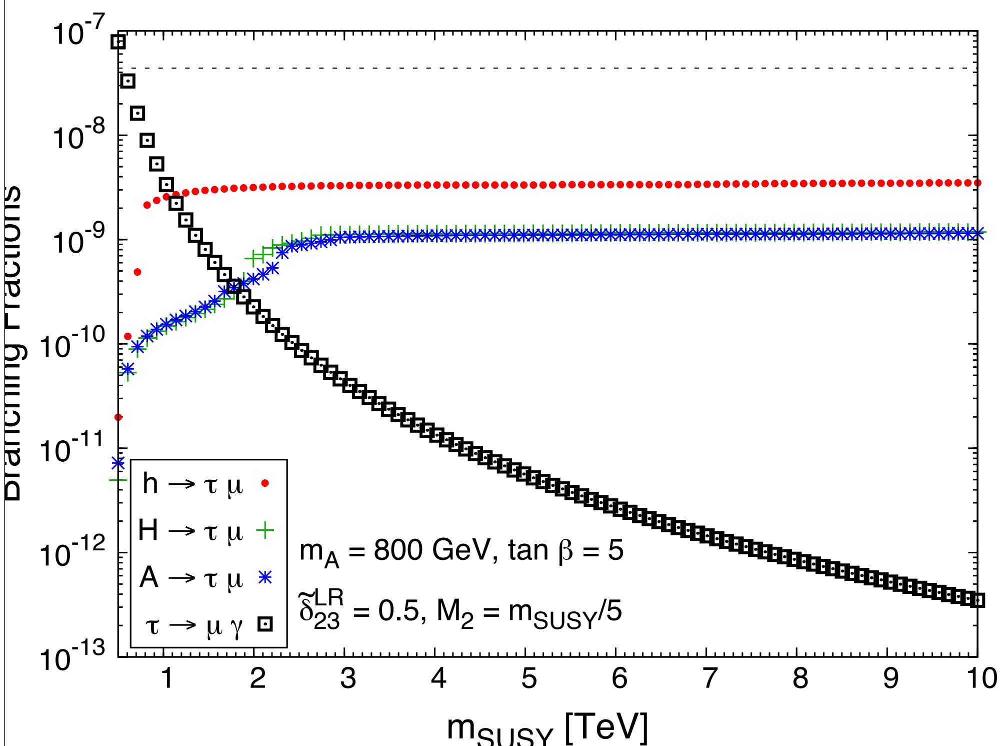


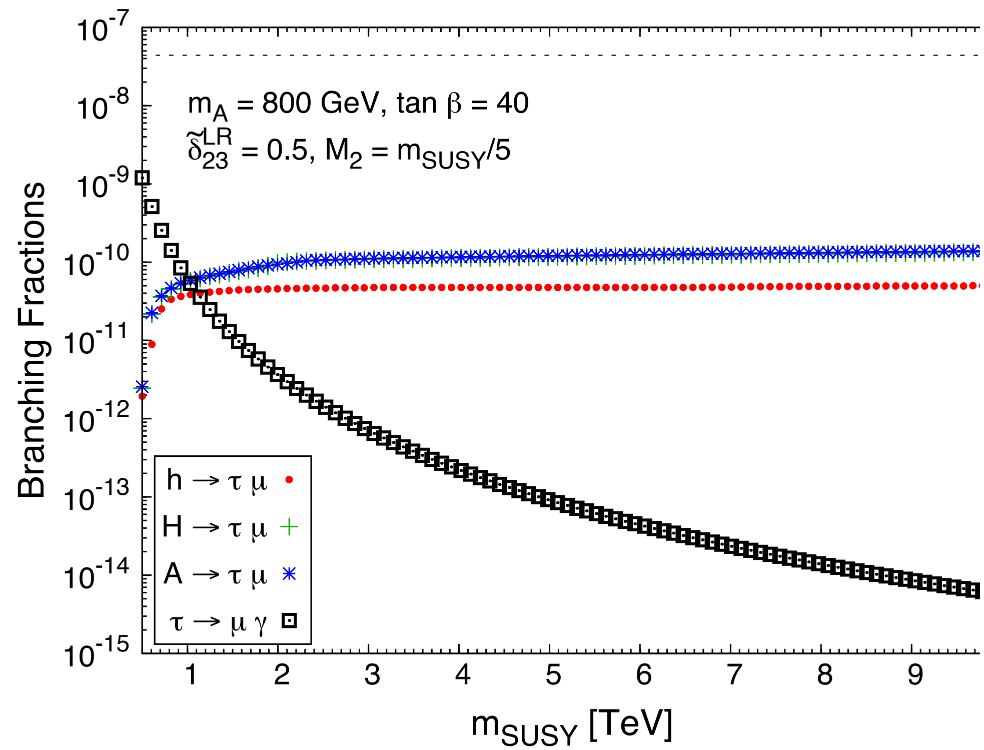
(1) (2) (3) (4)



(5) (6) (7) (8)

LFV rates as functions of $m_{\rm SUSY}$ ($\tilde{\delta}_{23}^{LR} = 0.5$)





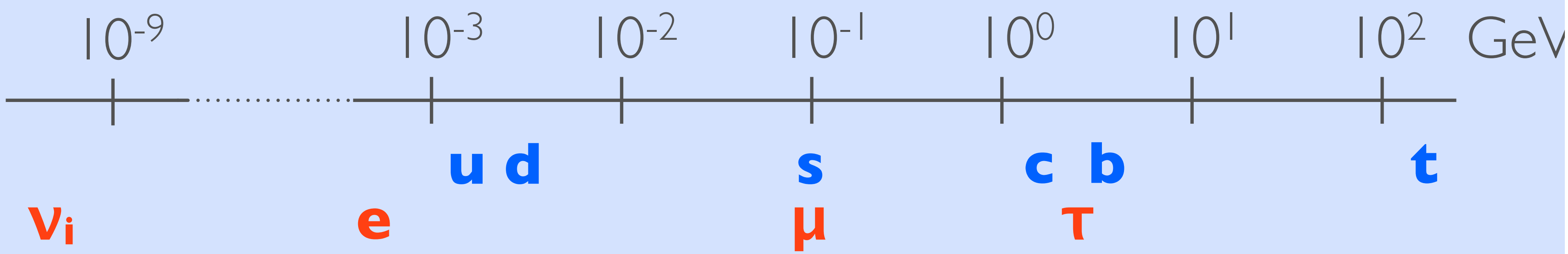
- LFVHD rates tend to a constant as $m_{\rm SUSY}$ grows.
- Strong decoupling behavior of BR$(\tau \to \mu\gamma) \sim 1/m_{\rm SUSY}^4$.
- $\Gamma(H, A \to \tau\mu)$ approximately constant with $\tan\beta$.
- BR$(h, H, A \to \tau\mu) \sim (\tan\beta)^{-2}$ for $\tan\beta \geq 10$.

Connections to flavor?

From Gero von Gersdorff's talk

✗ The flavor structure of the SM is very peculiar

✗ Strong hierarchy in the masses of the SM fermions:



✗ The quark mixing is pretty much the identity:

$$V_{\mathrm{CKM}} = \begin{pmatrix} 0.97427 \pm 0.00015 & 0.22534 \pm 0.00065 & 0.00351^{+0.00015}_{-0.00014} \\ 0.22520 \pm 0.00065 & 0.97344 \pm 0.00016 & 0.0412^{+0.0011}_{-0.0005} \\ 0.00867^{+0.00029}_{-0.00031} & 0.0404^{+0.0011}_{-0.0005} & 0.999146^{+0.000021}_{-0.000046} \end{pmatrix}$$

HORIZONTAL SYMMETRIES

✗ Horizontal symmetries put quarks in representations of some Abelian or non-Abelian symmetry which consequently is spontaneously broken at a scale somewhat lower than the UV scale.

✗ Generates small order parameter that controls the size of Yukawa couplings

✗ Simplest model: A single U(1) symmetry

Froggatt + Nielsen '79

$$\mathcal{L}_f = H\left(\hat{Y}^u_{ij}\bar{q}_i u_j \left[\frac{\chi}{\Lambda}\right]^{X_{\bar{q}_i}+X_{u_j}} + \hat{Y}^d_{ij}\bar{q}_i d_j \left[\frac{\chi}{\Lambda}\right]^{X_{\bar{q}_i}+X_{d_j}}\right) \qquad X_\chi = -1$$

O(1) bare Yukawas $\hat{Y}^u_{ij}$

$$\epsilon = \frac{\langle\chi\rangle}{\Lambda} \longrightarrow Y^u_{ij} \sim \epsilon^{X_{\bar{q}_i}+X_{u_j}}$$

From Gero von Gersdorff's talk

PROBLEMS OF U(1) MODELS

✗ What does this imply for supersymmetry ?

✗ A general problem of U(1) models is that the suppressions tend to cancel out in the soft terms:

$$K \supset |X|^2 \; c_{ij} \; \epsilon^{|X_i - X_j|} \; \bar{Q}_i Q_i$$

✗ Not so small off-diagonal terms

✗ Diagonal terms completely unsuppressed: uncontrolled splitting

✗ Bounds on first two generation squarks > 100 TeV
(Note: this is also inconsistent with light stops because RG evolution will typically drive those tachyonic)

Arkani Hamed et al '97

✗ Still many parameters

From Gero von Gersdorff's talk

From Gero von Gersdorff's talk

U(2) MODELS

✗ U(2) models make some striking predictions for quark data

$$|V_{us}| \approx \sqrt{m_d/m_s}\ , \quad |V_{ub}/V_{cb}| \approx \sqrt{m_u/m_c}\ , \quad |V_{td}/V_{ts}| \approx \sqrt{m_d/m_s}$$

✓ ✗ ✓

✗ At leading order in the $\epsilon_\chi,\ \epsilon_\phi$ expansion, but no O(1) numbers!!

$$\sqrt{m_d/m_s} = 0.22 \pm 0.02\ , \qquad \sqrt{m_u/m_c} = 0.046 \pm 0.008\ ,$$

$$|V_{us}| = 0.2253 \pm 0.0007\ , \quad |V_{ub}/V_{cb}| = 0.085 \pm 0.004\ , \quad |V_{td}/V_{ts}| = 0.22 \pm 0.01$$

✗ The reason of this discrepancy turns out to be the fact that b_R is a total flavor singlet ($X_{b_R} = 0$) which leads to a strong RH hierarchy in the down sector:

$$\cancel{Y^d_{i1} \ll Y^d_{i2} \ll Y^d_{i3}} \quad \xrightarrow{\text{Fit prefers}} \quad Y^d_{i1} \sim Y^d_{i2} \sim Y^d_{i3}$$

THE SU(2) X U(1) MODEL

✗ Giving up RH down hierarchy ⇒ correction to the exact relations

$$|V_{td}/V_{ts}| \approx |\sqrt{m_d/m_s} + e^{i\beta'}\Delta\, t_d|\sqrt{c_d}$$

$$|V_{ub}/V_{cb}| \approx |\sqrt{m_u/m_c} + e^{i\beta}\Delta\, t_d\sqrt{c_d}|$$

$$|V_{us}| \approx \sqrt{m_d/m_s}\sqrt{c_d}$$

$$\Delta = \frac{\sqrt{m_s m_d}}{|V_{cb}|m_b} \approx 0.09$$

$$t_d = \tan\theta_d = \frac{Y^d_{32}}{Y^d_{33}}$$

Roberts et al '01
Dudas et al '13

✗ The exact relations get corrected by the RH down 23 angle

✗ Fit requires $t_d \approx 0.5$

✗ SUSY: RH sbottom must be heavy!

$$V^d_R = \begin{pmatrix} 1 & \cdot & \cdot \\ \cdot & c_d & s_d \\ \cdot & -s_d & c_d \end{pmatrix}$$

Only the two stops can remain truly light

⇒ Spectrum of Natural SUSY

And to the neutrino sector?

The proposal

From Ana Machado's talk

- We assume that the scalar sector also has three families, once there is no limit on the SM scalar sector.
- And we, also, assume that the symmetry governing the scalar sector is the S3 symmetry.

S_3

arXiv:1003.3552v2

Discrete symmetries are related to flavor physics.

The flavor symmetries are introduced to control Yukawa couplings

The quark masses and mixing angles have been discussed in the standpoint of the flavor symmetries.

The discovery of neutrino masses and the neutrino mixing has stimulated the work of the flavor symmetries.

From Ana Machado's talk

From Ana Machado's talk

The Model

SM x S_3

$$Q_L \sim 1 \quad ; \quad u_R \sim 1 \quad ; \quad d_R \sim 1$$
$$L \sim 1 \quad ; \quad l_R \sim 1 \quad ; \quad N_R \sim 1$$

$$S = \frac{1}{\sqrt{3}}(H_1 + H_2 + H_3) \sim \mathbf{1},$$

The SM Higgs

$$D \equiv (D_1, D_2) = \left[\frac{1}{\sqrt{6}}(2H_1 - H_2 - H_3), \frac{1}{\sqrt{2}}(H_2 - H_3)\right] \sim \mathbf{2}.$$

Possible DM?

Non-minimal SUSY models

(Dirac gauginos, R-symmetries)

From Carla Biggio's talk

The recently discovered scalar particle ⤳ H and the neutrino ν have the

same gauge quantum numbers:

$$L = \begin{pmatrix} \nu \\ l_L^- \end{pmatrix} = (1,2)_{1/2} \qquad\qquad H = \begin{pmatrix} h^0 \\ h^- \end{pmatrix} = (1,2)_{1/2}$$

can they be one the superpartner of the other?

The Higgsinoless MSSM: conseq.

From Carla Biggio's talk

1. $$Y_u = y_u \frac{F}{M\Lambda}$$

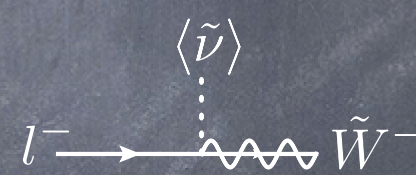
Λ effectiv

M ~~SUSY~~ mediation scale

$$Y_u \sim 1 \Rightarrow \Lambda \sim y_u \frac{F}{M} \qquad m_{\tilde{q}} \sim \frac{F}{M} \lesssim \text{TeV} \Rightarrow \boxed{\Lambda \lesssim 4\pi \text{TeV}}$$

Low scale ~~SUSY~~

2. After EWSB winos mix with leptons



g_{Zll} modified $\Rightarrow$ $$M_{\tilde{W}} \gtrsim \begin{cases} 2.5\,\text{TeV} & l_L^- = e_L \\ 2\,\text{TeV} & l_L^- = \mu_L \\ 1.8\,\text{TeV} & l_L^- = \tau_L \end{cases} \Rightarrow \boxed{\frac{F}{M} \sim \text{TeV}}$$

(From universality constraints: $M_{\tilde{B}} \gtrsim 500$ GeV)

A natural spectrum

- $$m^2_{Q,U} \simeq (400\ \mathrm{GeV})^2 \left[\left(\frac{M_{\tilde{g}}}{2\ \mathrm{TeV}}\right)^2 \ln \frac{M^2_{\Phi_{\tilde{g}}}}{M^2_{\tilde{g}}} + (0.15, 0.3) \left(\frac{\Lambda}{2\ \mathrm{TeV}}\right)^2 \right]$$

  naturally "light" 3rd gen. squarks

- $$m_H^2 \simeq -(100\ \mathrm{GeV})^2 \quad \Bigg[4.3 \left(\frac{m_Q}{600\ \mathrm{GeV}}\right)^2 \frac{\ln \frac{\Lambda}{m_Q}}{\ln 5} - 3.2 \left(\frac{M_{\tilde{W}}}{2\ \mathrm{TeV}}\right)^2 \ln \frac{M^2_{\Phi_{\tilde{W}}}}{M^2_{\tilde{W}}} - \left(\frac{\delta\lambda}{0.015}\right) \left(\frac{\Lambda}{2\ \mathrm{TeV}}\right)^2$$

  EWSB can occur naturally

- other sparticles: at least as heavier as the above

From Carla Biggio's talk

Pheno: stops and sbottoms

No A-terms $\Rightarrow$ prediction: $m_{\tilde{b}_L}^2 = m_{\tilde{t}_L}^2 - m_t^2 + m_b^2$

Decay	Interaction
$\tilde{t}_L \to b_R \bar{l}_L^-$	$Y_d\, HQD\|_{\theta^2}$
$\tilde{t}_L \to t_R \bar{\nu}_L$	$\frac{1}{\Lambda^2}\|H\|^2\|Q\|^2\|_{\theta^4}$
$\tilde{t}_L \to t_L \tilde{G}$	$\frac{m_t^2 - m_{\tilde{t}_L}^2}{F}\, \tilde{t}_L^* \tilde{G}\, t_L$
$\tilde{b}_L \to b_R \bar{\nu}_L$	$Y_d\, QHD\|_{\theta^2}$
$\tilde{b}_L \to b_L \tilde{G}$	$\frac{m_b^2 - m_{\tilde{b}_L}^2}{F}\, \tilde{b}_L^* \tilde{G}\, b_L$

Decay	Interaction
$\tilde{t}_R \to t_L \nu_L$	$\frac{1}{\Lambda^2}\|H\|^2\|U\|^2\|_{\theta^4}$
$\tilde{t}_R \to t_R \bar{\tilde{G}}$	$\frac{m_t^2 - m_{\tilde{t}_R}^2}{F}\, \tilde{t}_R^* \bar{\tilde{G}}\, \bar{t}_L$
$\tilde{b}_R \to b_L \nu_L$	$Y_d\, QHD\|_{\theta^2}$
$\tilde{b}_R \to t_L l_L^-$	$Y_d\, QHD\|_{\theta^2}$
$\tilde{b}_R \to b_R \bar{\tilde{G}}$	$\frac{m_b^2 - m_{\tilde{b}_R}^2}{F}\, \tilde{b}_R^* \bar{\tilde{G}}\, \bar{b}_L$

Only jets + MET

Both jets + MET
and leptoquark decays

From Carla Biggio's talk

Pheno: 1st and 2nd gen. squarks

From Carla Biggio's talk

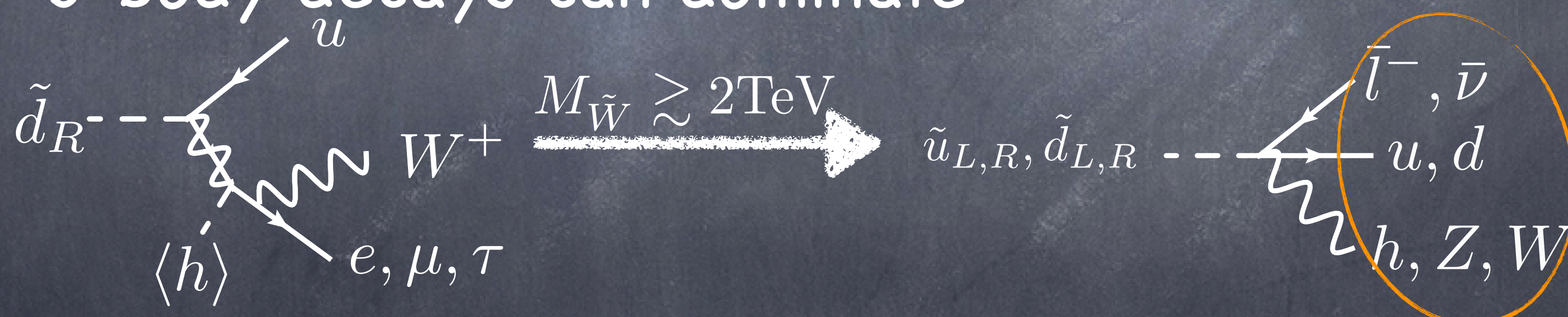
- light gravitino (and F≈TeV²)

  $\tilde{q} \to q\tilde{G} \rightsquigarrow$ jets + MET   m>830GeV

- heavy gravitino (or F>>TeV²)

  2-body decays suppressed by small Yukawas

  $\Rightarrow$ 3-body decays can dominate

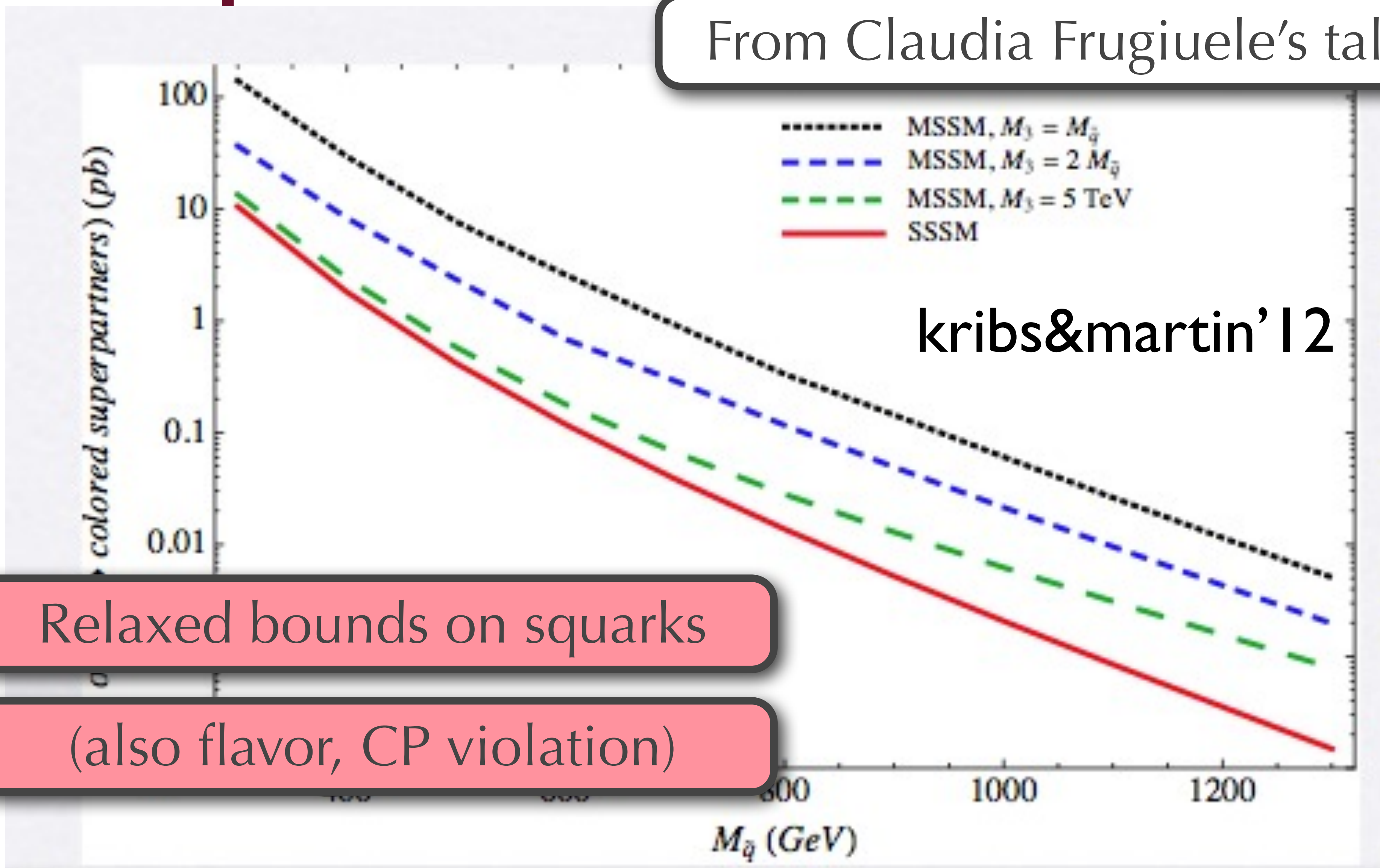


jet (no b-jets) + W/Z + MET/lepton   ← Look for them!!!

More general implications

Supersoft is supersafe!

From Claudia Frugiuele's talk

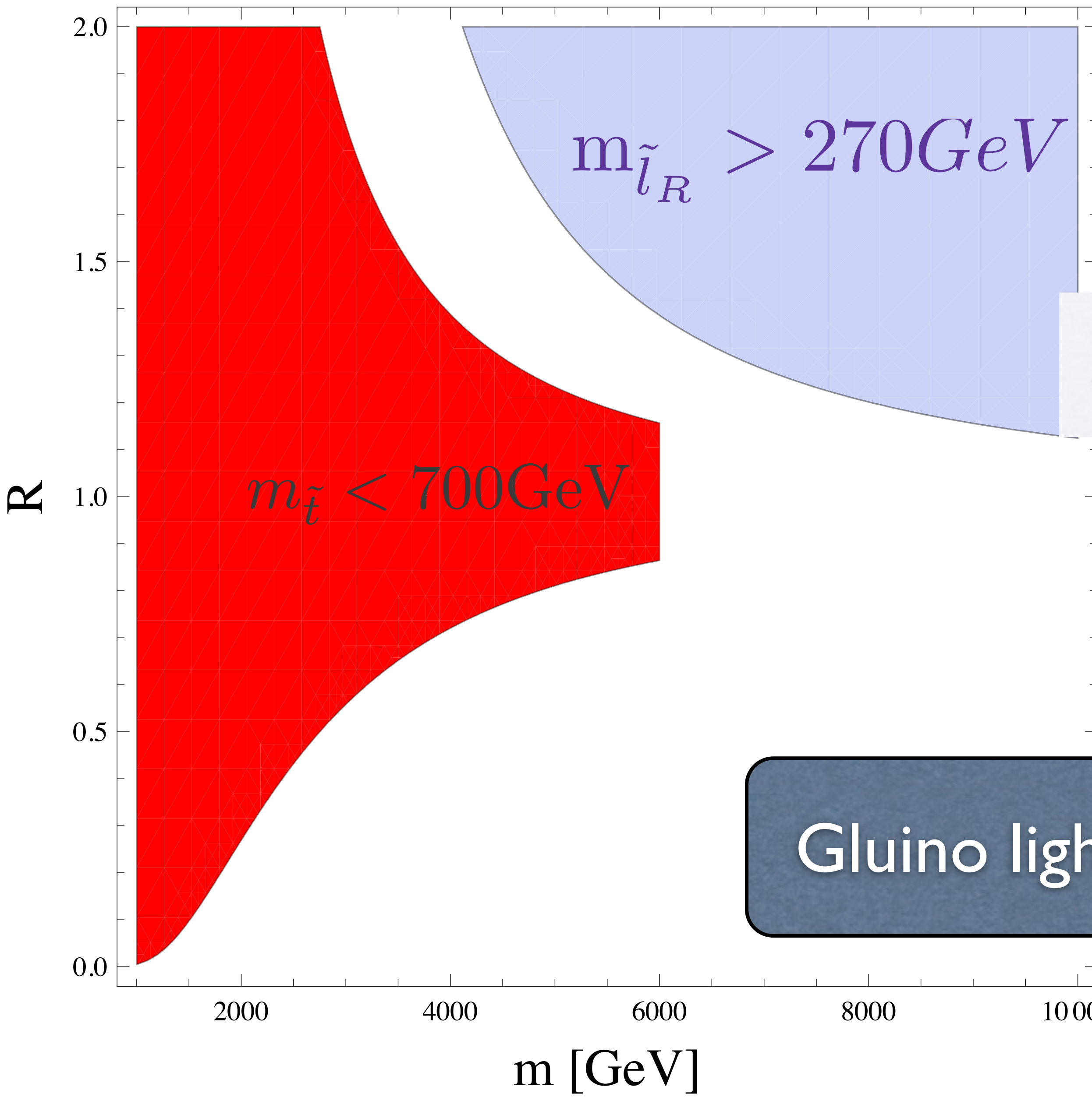


kribs&martin'12

Relaxed bounds on squarks

(also flavor, CP violation)

1st & 2nd generation bounds lowered, 600-700 GeV



finite squarks masses

$$m_{\tilde{q}}^2 \sim \frac{M_{\tilde{g}}^2}{5^2} \log R_g$$

Gluino lighter than bino

From Claudia Frugiuele's talk

A 125 GeV Higgs

See Claudia's talk

How to accommodate observed Higgs mass?

- Tree-level mixing: m_h^{tree} lower than in the MSSM
- No A-terms: harder for stops to contribute (tension with naturalness)
- Scenario contains additional degrees of freedom (triplet, singlet)

  $\longrightarrow$ can contribute to the Higgs mass (but constrained by EWPT)
- Perhaps direct couplings to the SUSY breaking sector?

  (as in Carla's proposal)

(Preliminary) conclusions

From Claudia Frugiuele's talk

- generically it seems to be more challenging to get 126 GeV within this framework than it is in the MSSM, but maybe some interesting windows are still open!

Improvement of naturalness in models with Dirac gauginos not straightforward

Still this framework offers many interesting directions to explore (flavor, RPV..)

Theoretical Issues

Dynamical supersoft model

From Yuri Shirman's talk

- s-confining SQCD

	$SU(5)$	$SU(6)$	$SU(6)$	$U(1)_B$	$U(1)_R$
Q	$\square$	$\square$	$\mathbf{1}$	1	$\frac{1}{6}$
$\overline{Q}$	$\overline{\square}$	$\mathbf{1}$	$\overline{\square}$	-1	$\frac{1}{6}$

- Low energy dofs

	$SU(6)$	$SU(6)$	$U(1)_B$	$U(1)_R$
$\tilde{M}$	$\overline{\square}$	$\square$	0	$\frac{1}{3}$
B	$\square$	$\mathbf{1}$	5	$\frac{5}{6}$
$\overline{B}$	$\mathbf{1}$	$\overline{\square}$	-5	$\frac{5}{6}$

- $SU(5)_D$ subgroup of global symmetry identified with SM

$$\tilde{M} = \begin{pmatrix} M & N \\ \overline{N} & X \end{pmatrix}, \; B = \begin{pmatrix} \phi \\ \psi \end{pmatrix}, \; \bar{B} = \begin{pmatrix} \overline{\phi} \\ \overline{\psi} \end{pmatrix}$$

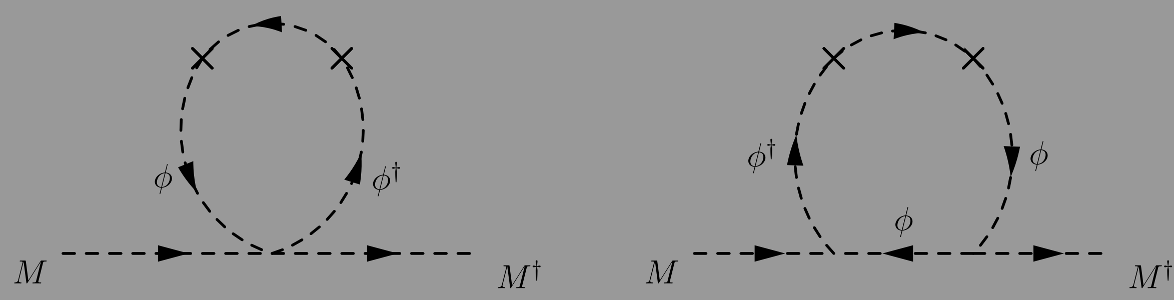
- $U(1)_B$ gauged, acquires D-term

Operator Analysis and Toy Models: Model 1

- $U(1)$ with a D-term and heavy charged messengers

$$W = \bar{\phi}\mathcal{M}\phi + m_\phi \bar{\phi}\phi$$

- Explicit calculation demonstrates the cancellation of the diagrams contributing to $m^2_{\mathcal{M}}$



$$y^2 \int dp^2 p^2 \left[\frac{1}{(p^2 - m_\phi^2)^3} - \frac{3m_\phi^2}{(p^2 - m_\phi^2)^4} \right]$$

- Only second diagram exists for $\mathcal{M}^2$ term
- No cancellation between ϕ and $\bar{\phi}$ contributions
- Non-zero result at $\mathcal{O}(D^4)$

From Yuri Shirman's talk

Operator Analysis and Toy Models: Model 2

- Generate D-term through vevs of charged fields ψ and $\overline{\psi}$

$$W = \bar{\phi}\mathcal{M}\phi + m_\phi \bar{\phi}\phi\,, \qquad D \sim \mathcal{O}\left(|\psi|^2 - |\overline{\psi}|^2\right)$$

- New allowed operator

$$\int d^4\theta \sum_i \frac{\psi_i^\dagger e^{q_i V}\psi_i}{m_\phi^2}\mathcal{M}^\dagger\mathcal{M}$$

- Not generated at one loop. Is it generated at higher order?
- Treat $\mathcal{M}$ as a spurion: renormalizes ψ kinetic terms.
  - At one loop Z_ψ factorizes into a sum of holomorphic and anti-holomorphic terms, $\log M + \log \mathcal{M}^\dagger$
  - No such factorization at higher orders: Z_ψ must depend on $\log \mathcal{M}^\dagger \log M$
- At higher loop orders supersoft is never supersoft.

From Yuri Shirman's talk

Summary

• The Higgs discovery: a very impressive triumph of theoretical/experimental physics

• But lack of any deviations of the SM is disconcerting...

... will we have to accept (in practice) an incomplete understanding of EWSB?

• The conclusion that the EWSB sector is not (completely) natural would be a strong one...

learn what the experimental results imply through the study of ``non-standard" scenarios

Look forward to further analysis from the LHC collaborations...

... and to the 14 TeV LHC run!