Lectures on BSM and Dark Matter theory (1st class)

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Hadron Collider Physics Summer School

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Overview

Chapter 1: Introduction:
The Standard Model and its open problems

Chapter 2:
- SUSY theories.
Direct & indirect searches of SUSY particles
- Twin Higgs theories.
Direct & indirect searches of the “twin Higgs”

TODAY

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Chapter 3:
* Introduction on Dark Matter
* WIMP Dark Matter; Complementarity of searches

Chapter 4:
* (Light) Dark Matter living in a dark sectors
* Complementarity of accelerator experiments
(high energy vs. high intensity)

TOMORROW

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TOMORROW

Goal: Some basics + overview of what I find exciting about BSM theories + pheno
Disclaimer: not comprehensive!
Please interrupt **to ask questions! We do not have to go through all slides! :)**

Let us start!

Chapter 1: Introduction:
The Standard Model and its open problems

S.Gori

First: what is the Standard Model (SM)?

The SM is

- a remarkably successful description of nature
- a Quantum Field Theory
- based on symmetry principles
- ~minimal
- a model with an enormous predictive power

But we do not understand why it works so well. . .

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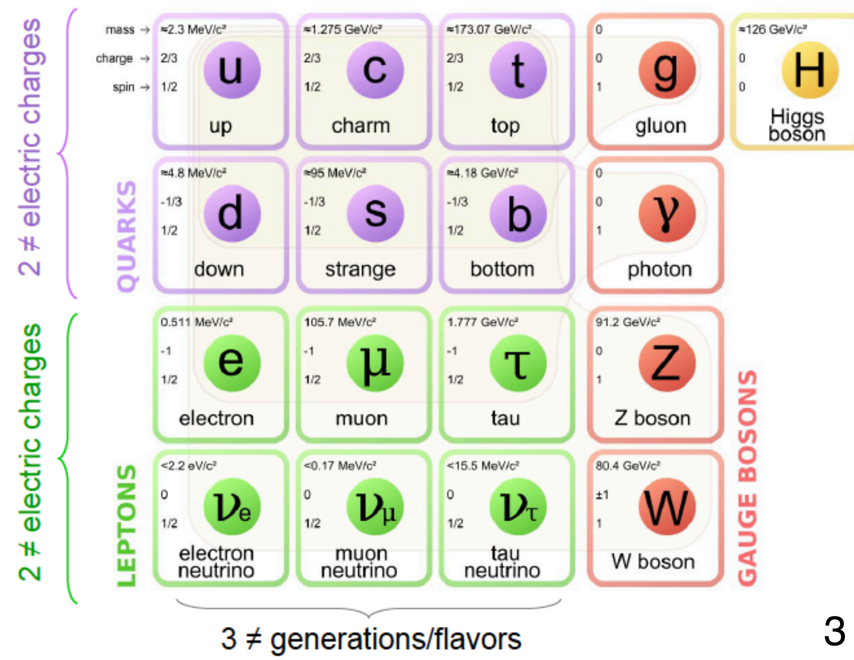
Particle content:



Fundamental principles of the SM

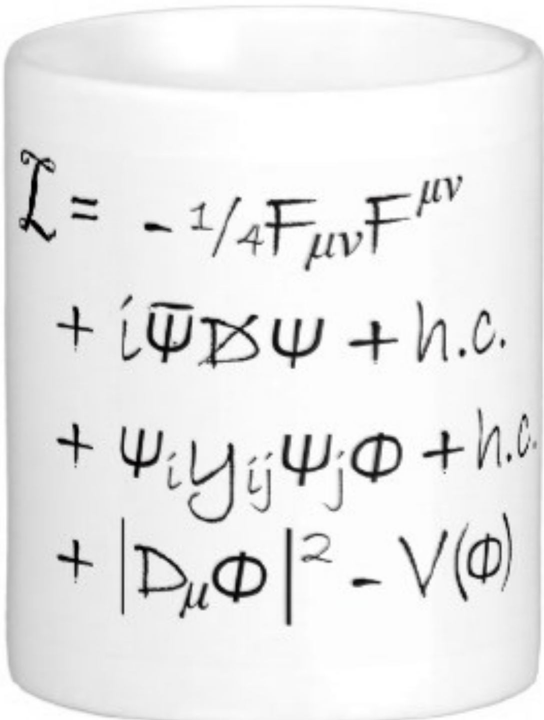
We write down a Lagrangian based on

- minimality: only observed and/or unavoidable objects
- unitarity
- renormalizability: finite predictions for the physical observables
- symmetries

Symmetries:

- Lorentz symmetry
- Gauge symmetries: $SU(3)_C \times SU(2)_L \times U(1)_Y$
- we do not impose global symmetries. They are "accidental": e.g.
  - ✔ $SU(3)^5$ flavor symmetry broken by the Higgs interactions with fermions
  - ✔ Lepton and baryon number
  - ✔ ...

Free parameters of the SM Lagrangian



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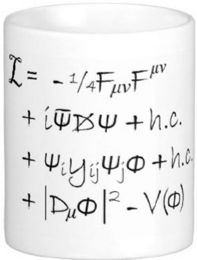


$$-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$
$$i\bar{\Psi}\not{D}\Psi + h.c.$$

- Describes the gauge interactions of quarks and leptons

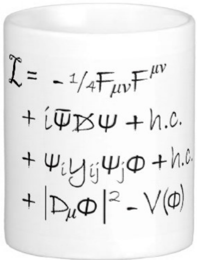
- Parametrized by 3 gauge couplings g_1, g_2, g_3

- Stable with respect to quantum corrections

- Highly symmetric

Gauge sector

Free parameters of the SM Lagrangian



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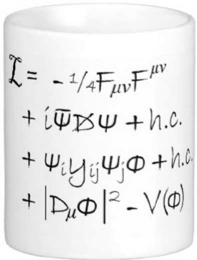
Gauge sector

$$+ |D_\mu \Phi|^2 - V(\Phi)$$

- Breaks electro-weak symmetry and gives mass to the *W* and *Z* bosons
- 2 free parameters: Higgs mass Higgs vev
- Not stable with respect to quantum corrections

Higgs sector

Free parameters of the SM Lagrangian



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Higgs sector

$$+ \Psi_i y_{ij}\Psi_j\Phi + h.c.$$

- Leads to masses and mixings of the quarks and leptons
- 10+10 free parameters in the quark+lepton sector (12 in the lepton sector in case of Majorana masses)
- Stable with respect to quantum corrections

Flavor sector

Open problems/questions for the SM

Let us re-write the SM Lagrangian allowing also for operators up to dimension 6 in the SM fields

$$
\begin{aligned}
\mathcal{L}_{\rm SM} \sim\ & \Lambda^4 - \Lambda_H^2 H^2 + \lambda H^4 \\
+\ & \bar{\psi} \not{D} \psi + (D_\mu H)^2 + (F_{\mu\nu})^2 \\
+\ & F_{\mu\nu}\tilde{F}_{\mu\nu} + Y H \bar{\psi}\psi \\
+\ & \frac{1}{\Lambda}(LH)^2 + \frac{1}{\Lambda^2}\sum_i O_i(\text{dim6})
\end{aligned}
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Cosmological constant problem

$$\left(\frac{\Lambda}{M_{\text{Planck}}}\right)^4 \sim 10^{-120}$$

Hierarchy problem

$$\left(\frac{m_h}{M_{\text{Planck}}}\right)^2 \sim 10^{-36}$$

Vacuum stability problem

see next slide

Flavor puzzle

$$\frac{y_t}{y_u} \sim 10^{-5}$$

Z. Ligeti lectures

New Physics flavor puzzle

Origin of neutrino masses

Strong CP problem

$$\frac{\Theta}{16\pi^2} F_{\mu\nu}\tilde{F}_{\mu\nu}, \quad \Theta \leq 10^{-10}$$

Beyond the Standard Model (BSM) physics?

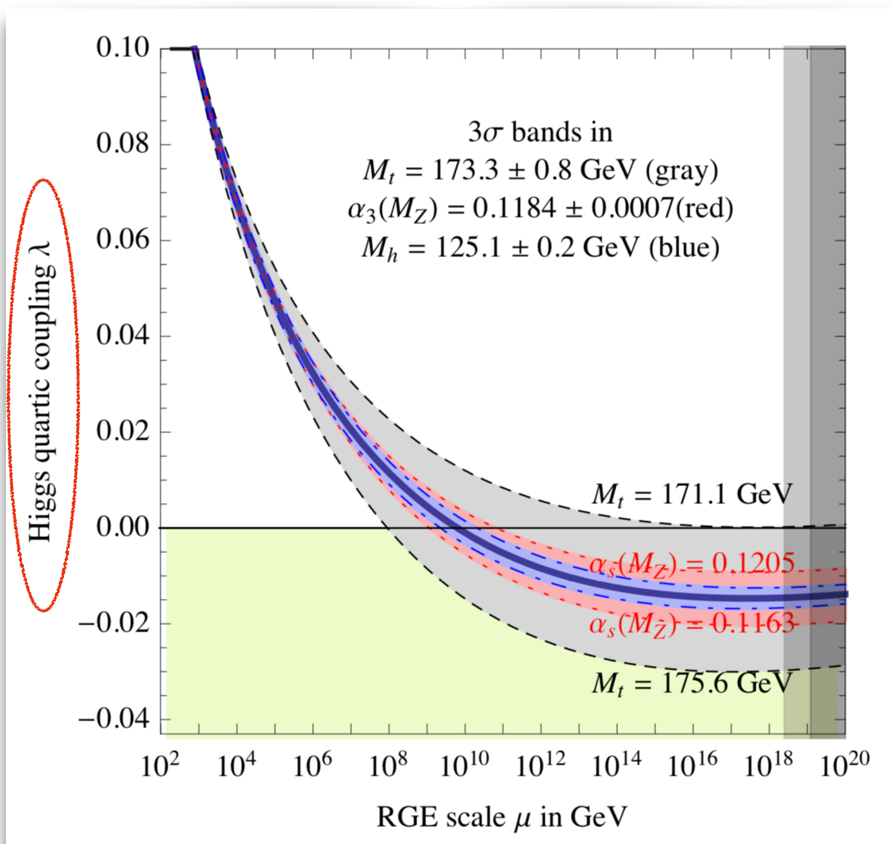
Vacuum stability

Once we fix the two free parameters of the Higgs potential,
we can compute the running of the quartic coupling, λ, as a function of the energy scale

$$V = -\mu^2 |H|^2 + \lambda |H|^4$$

See lectures by H. Logan

Buttazzo et al, 1307.3536



Assuming no New Physics

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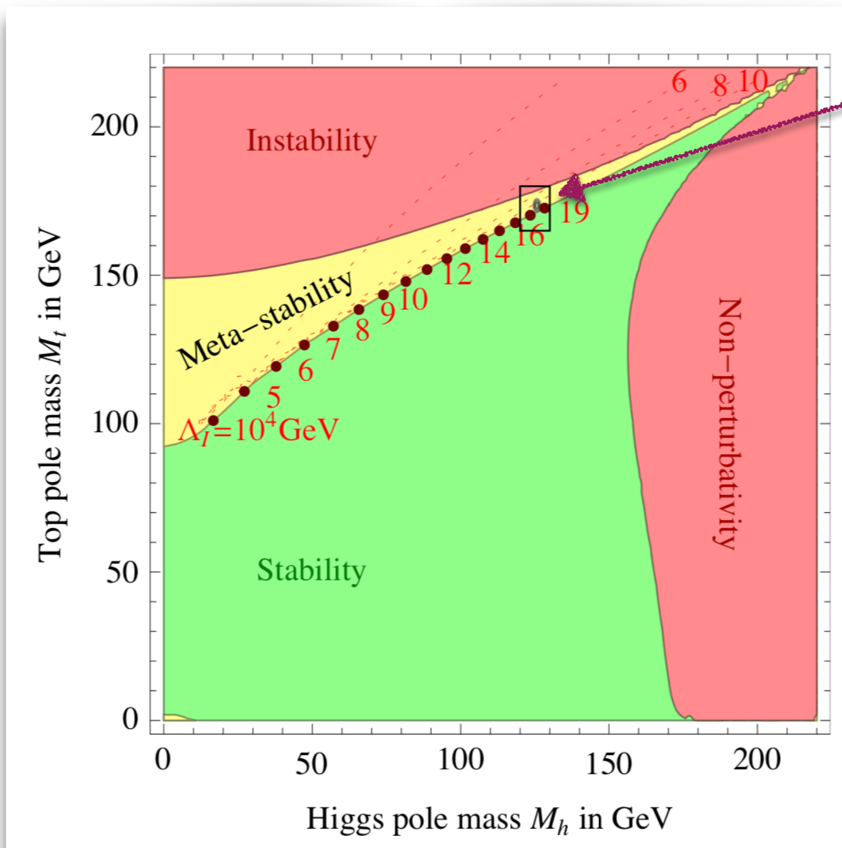
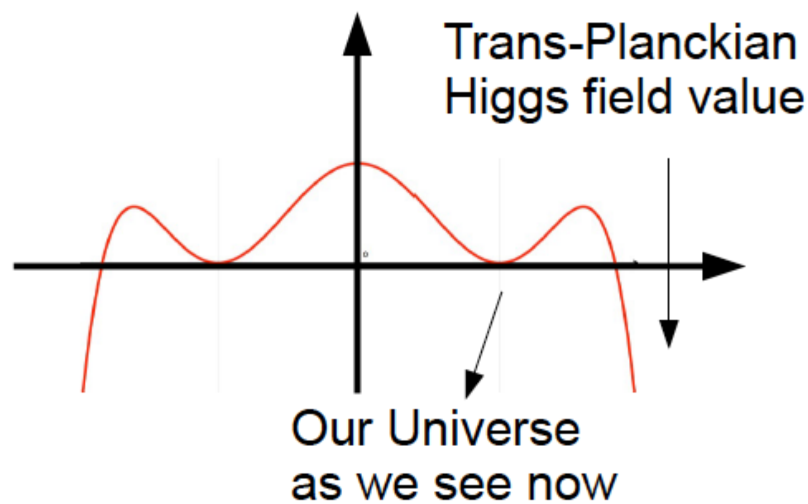


We are here.
Is this a coincidence?



Stability condition:
$M_h > (129.6 \pm 1.5)$ GeV

Assuming no New Physics

The hierarchy problem

Let us take a generic theory of scalars, φ, and fermions, ψ:

$$\mathcal{L} = |\partial_\mu \phi|^2 + \bar{\psi} i \not{\partial} \psi - m_f^0 \bar{\psi}\psi - y\phi\bar{\psi}\psi + \mu_0^2 |\phi|^2 - \lambda |\phi|^4$$

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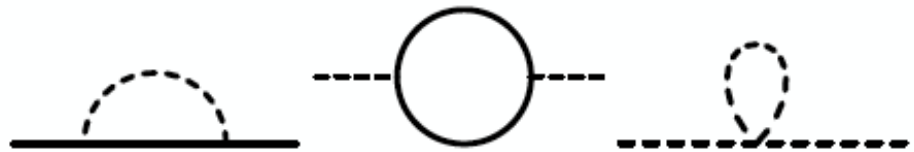

etc.

$$\Delta m_f \sim -\frac{y^2}{16\pi^2} m_f \log\left(\frac{\Lambda}{m_f}\right)$$

$$\Delta\mu^2 \sim \frac{y^2 - \lambda}{16\pi^2} \Lambda^2 + \cdots \qquad \mu^2 = \mu_0^2 + \Delta\mu^2 = \mathcal{O}((100\ \mathrm{GeV})^2)$$

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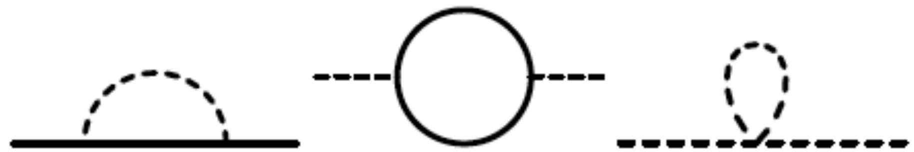

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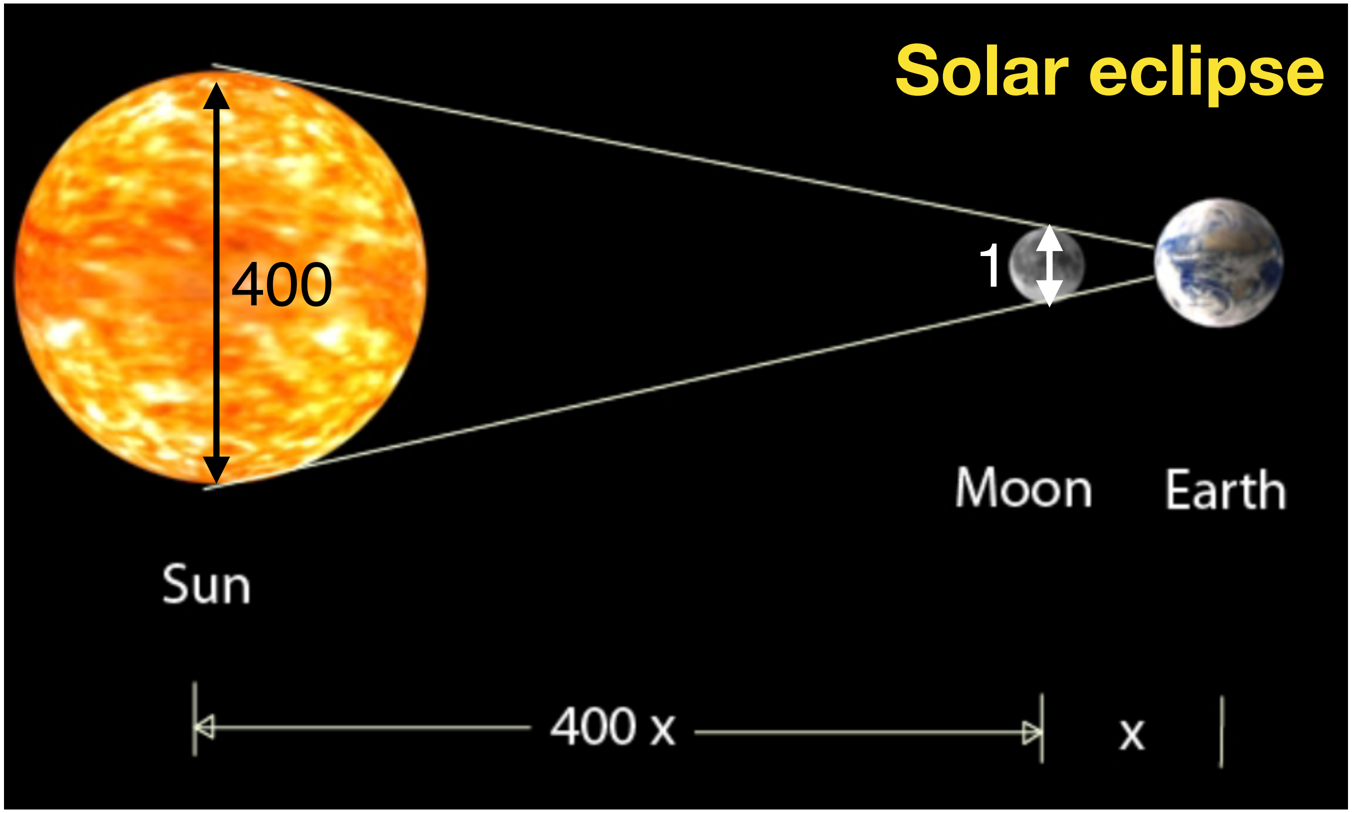
Scalars are very sensitive to the highest scale of the theory

Generically, we would expect some New Physics at the scale

$$\Lambda = \mathcal{O}\left(\frac{4\pi}{g} m_h\right)$$

$m_h \sim 125$ GeV
$M_{Planck} \sim 10^{19}$ GeV

Putting it in perspective…



The distance 1 : 400 should be precise at the **~ 0.05** level

to compare

The precision needed to predict the measured Higgs mass: **0.000000000000000000000000000000001**

Principles to build a "good" BSM theory

- Take a local, lorentz invariant, unitary field theory;
- Preserve gauge invariance ($SU(3) \times SU(2)_L \times U(1)_Y$), anomaly free;
- (Typically) do not introduce too large sources of breaking of the accidental / approximate symmetries of the SM classical Lagrangian

- Not be ruled out by experiments!

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  - baryon and lepton number
  $B_{quark} = 1/3$, $B_{anti\text{-}quark} = -1/3$, $B_{lepton} = 0$ ($L_{lepton} = 1$, $L_{anti\text{-}lepton} = -1$, $L_{quark} = 0$)
  - Individual lepton families
  L_e, L_μ, L_τ (these are broken by neutrino masses in the SM (tiny))
  - Custodial symmetry: $SU(2)_L \times SU(2)_R \to SU(2)_V$ (diagonal)
  (this is broken by hypercharge and Yukawas in the SM)
  - $SU(3)^5$ flavor symmetry (this is broken by the Yukawas in the SM)
- Not be ruled out by experiments!

Addressing the hierarchy problem

Most studied

Supersymmetry

Composite Higgs models or, equivalently, extra-dimensional models

More recently:

Neutral naturalness models (twin Higgs, Chacko et al, 0506256**)**,

Relaxation models (Graham et al, 1504.07551),

Nnaturalness (Arkani-Hamed et al, 1607.06821), ...

Signals at the LHC

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Signals at the LHC

SUSY (basic principle)

Introduce **new scalar degrees of freedom** that are related to the fermions of the SM

$$\Delta\mu^2 \sim \frac{y^2 - \lambda}{16\pi^2}\Lambda^2 + \cdots$$

Cancel the quadratic sensitivity of the Higgs mass to the New Physics scale

Twin Higgs (basic principle)

Introduce **new fermionic degrees of freedom** that are related to the fermions of the SM but **not charged under the SM gauge symmetries**

Cancellation of the quadratic sensitivity is ensured by a **global symmetry** (e.g. SU(4) x Z_2).

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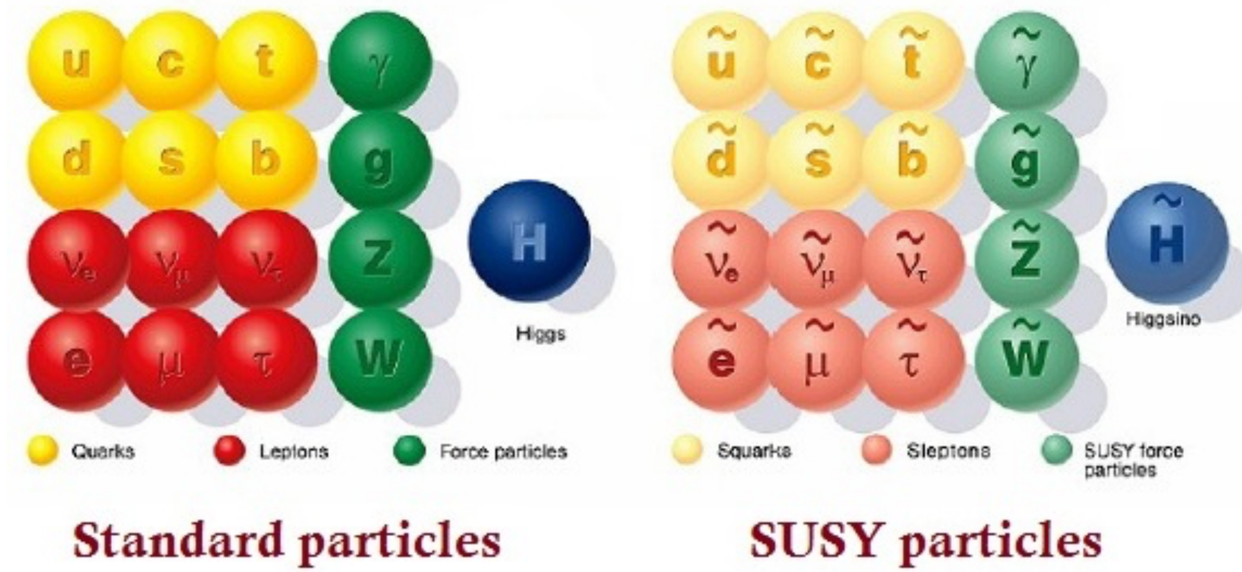
BSM @ the LHC

Supersymmetry

Minimal Supersymmetric Standard Model (MSSM)



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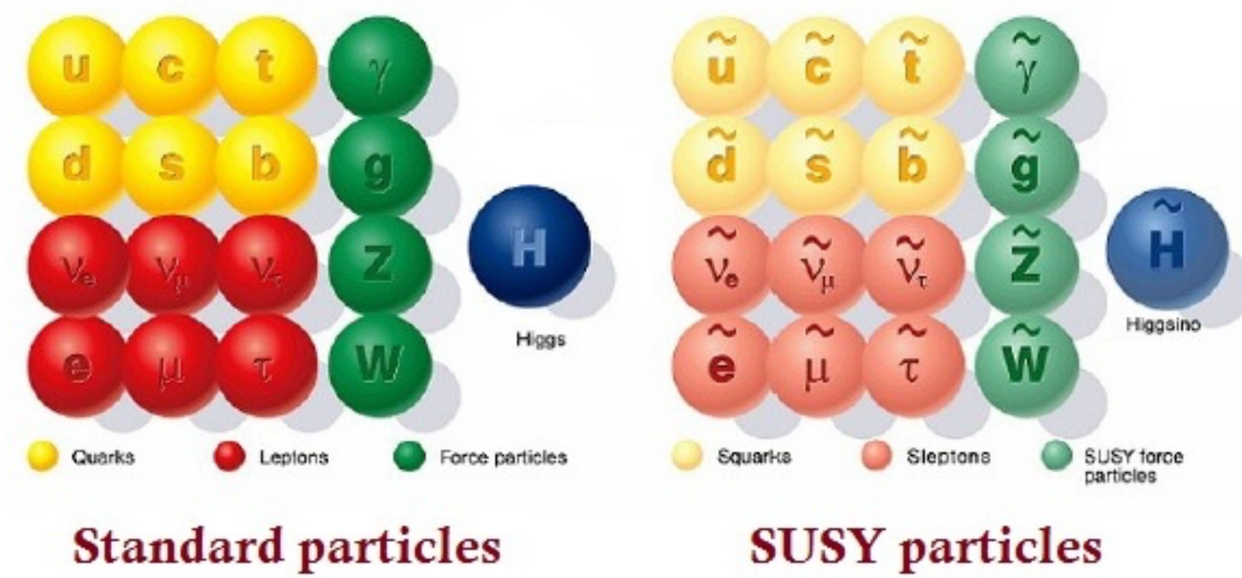

SUSY is broken

(in fact, we know that e.g. the sbottom cannot have the same mass as the bottom quark)

Log sensitivity of the Higgs mass to the New Physics scale:

$$\Delta\mu_h^2 \sim \frac{C^2}{4\pi^2} m_{\rm SUSY}^2 \log\left(\frac{\Lambda}{m_t}\right)$$

TeV-scale SUSY?

Supersymmetry

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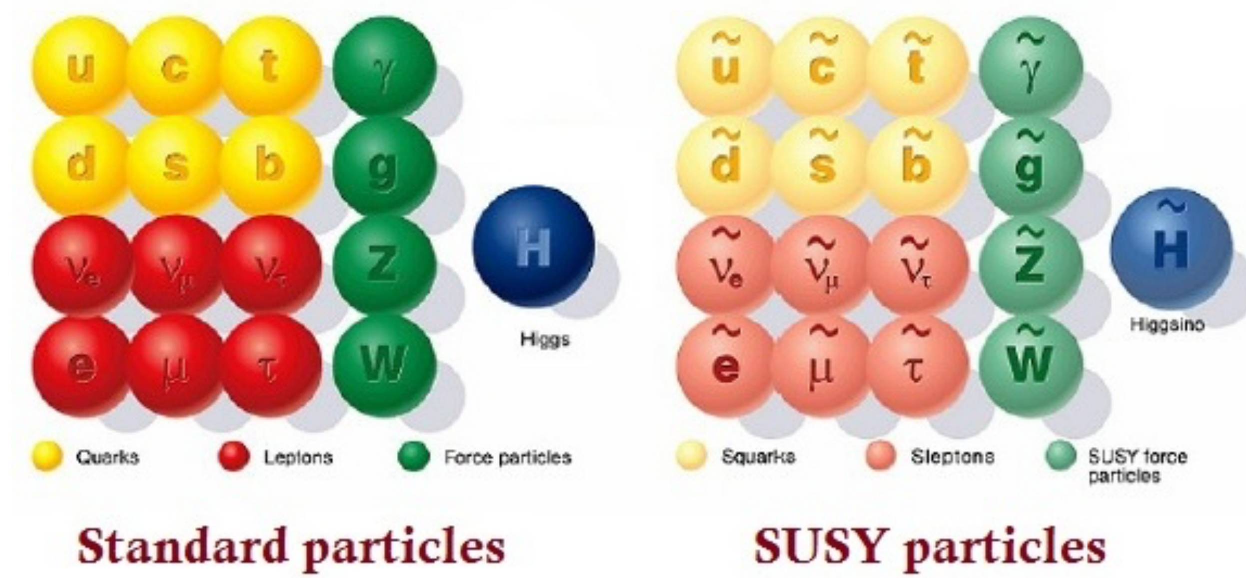

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TeV-scale SUSY?

Additional remarkable properties:

- Gauge coupling unification: if SUSY particles are not too heavy, $g_3 \sim g_2 \sim g_1$ at M_{GUT}
- If we impose R-parity (sparticles with R-parity = -1, SM particles with R-parity = +1), the lightest SUSY particle can be WIMP Dark Matter (see class of tomorrow)

The SUSY mass scale

The “natural spectrum”:

Higgsinos

$$-\frac{m_Z^2}{2} = \mu^2 + m_{H_u}^2 + \cdots \qquad \textbf{(tree level)}$$

The SUSY mass scale

The "natural spectrum":

Gluinos

$$\Delta\mu_h^2 \sim -2\frac{\alpha_s}{\pi^2}\frac{y_t^2}{\pi}|M_3|^2\log^2\left(\frac{\Lambda}{m_t}\right)$$

(2 loops)

Stops
(left handed sbottom)

$$\Delta\mu_h^2 \sim -3\frac{y_t^2}{8\pi^2}\left(m_{Q3}^2 + m_{u3}^2 + |A_t|^2\right)\log\left(\frac{\Lambda}{m_t}\right)$$

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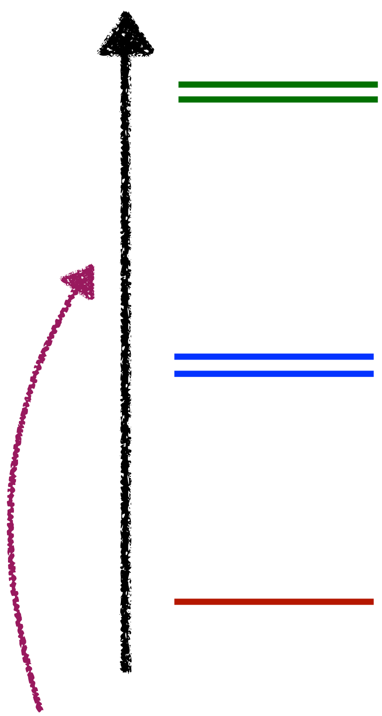
The "natural spectrum":



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(1 loop)

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(tree level)

What is the exact scale?

Said in other words: what is the level of "fine tuning" we are comfortable allowing?

No guaranteed discovery. Exploration of the SUSY paradigm!

(TeV-scale stops imply ~O(1%) fine tuning)

(Some) pheno of SUSY particles

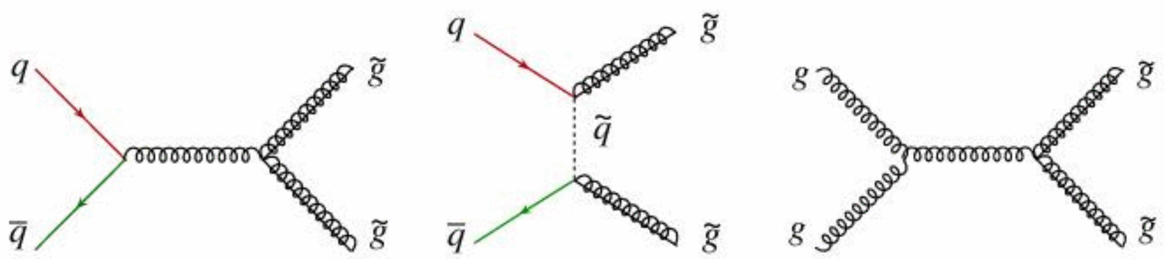
SUSY provides a remarkably rich set of signatures for the LHC

(Some) pheno of SUSY particles

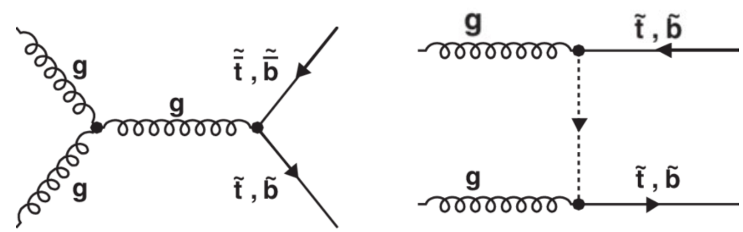
SUSY provides a remarkably rich set of signatures for the LHC

All SUSY particles are charged under the SM gauge symmetries.
That means that SUSY particles will be copiously produced at the LHC

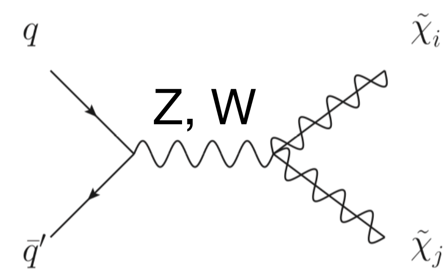
In the case of R-parity conservation:



gluino production (SU(3) interactions)



squark production
(SU(3) interactions)



Chargino and neutralino production
(SU(2) and U(1) interactions)

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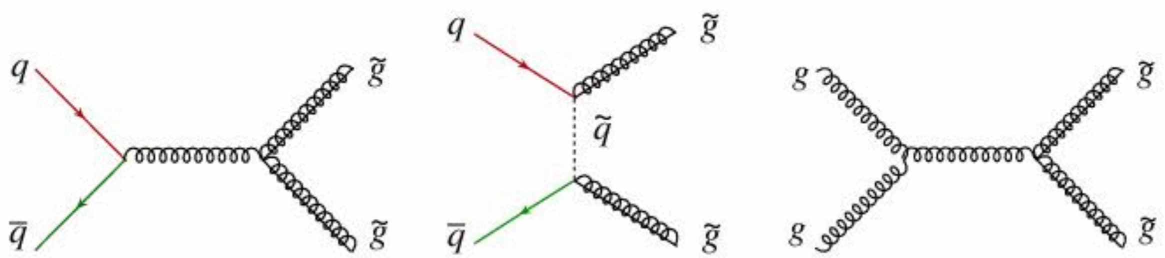

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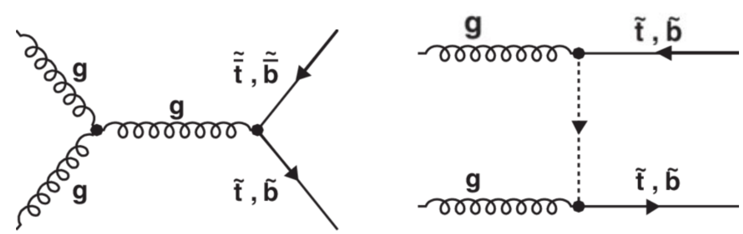

squark production
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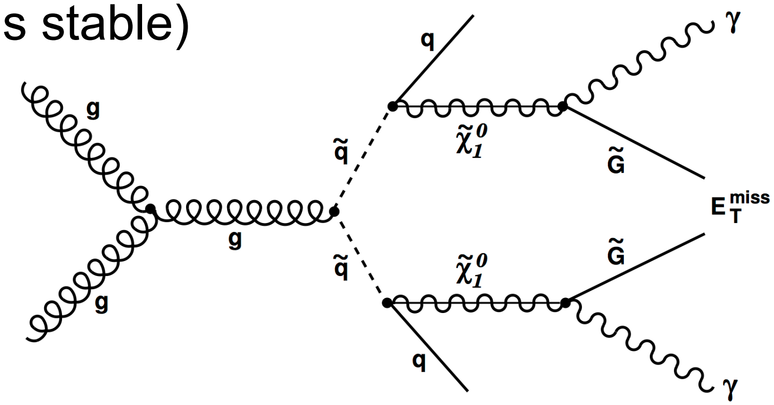
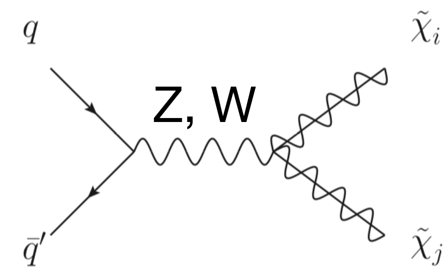
Missing energy-enriched signatures
(MET arises from the lightest SUSY particle that is stable)





Chargino and neutralino production
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(Some) pheno of SUSY particles

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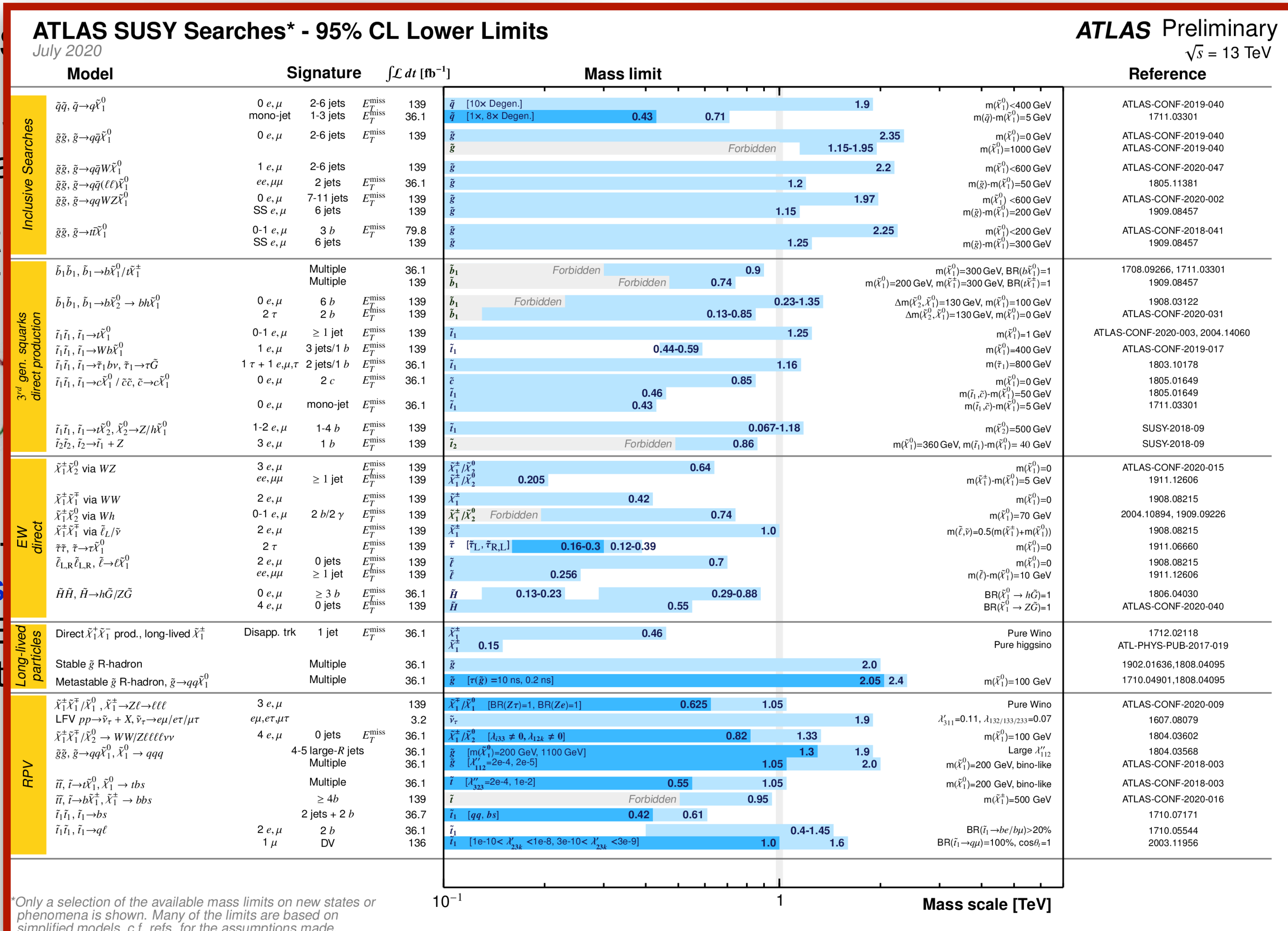

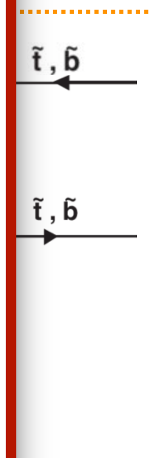

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(Some) pheno of SUSY particles

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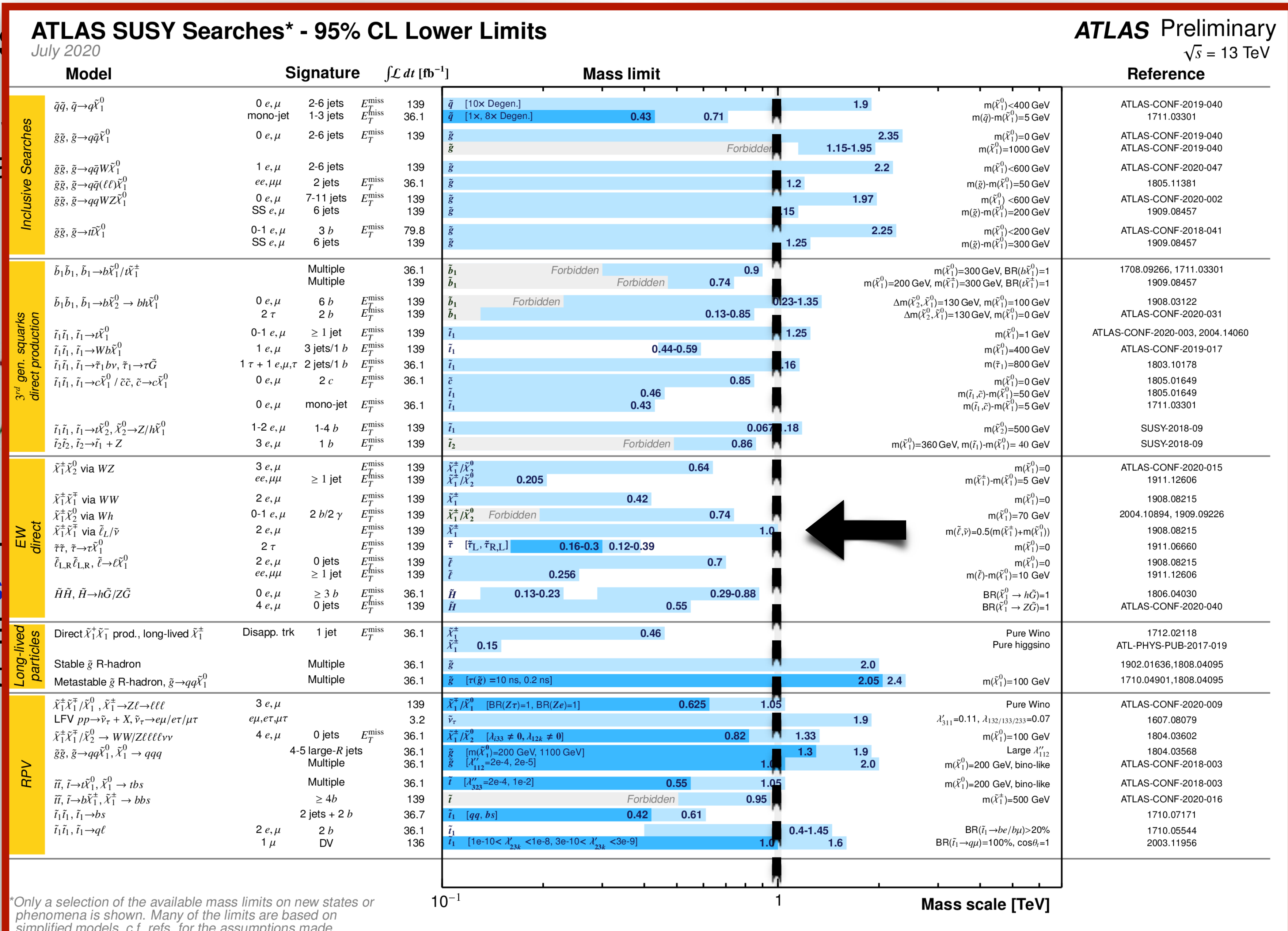

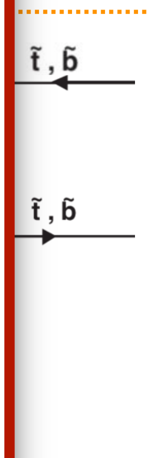

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(Some) pheno of SUSY particles

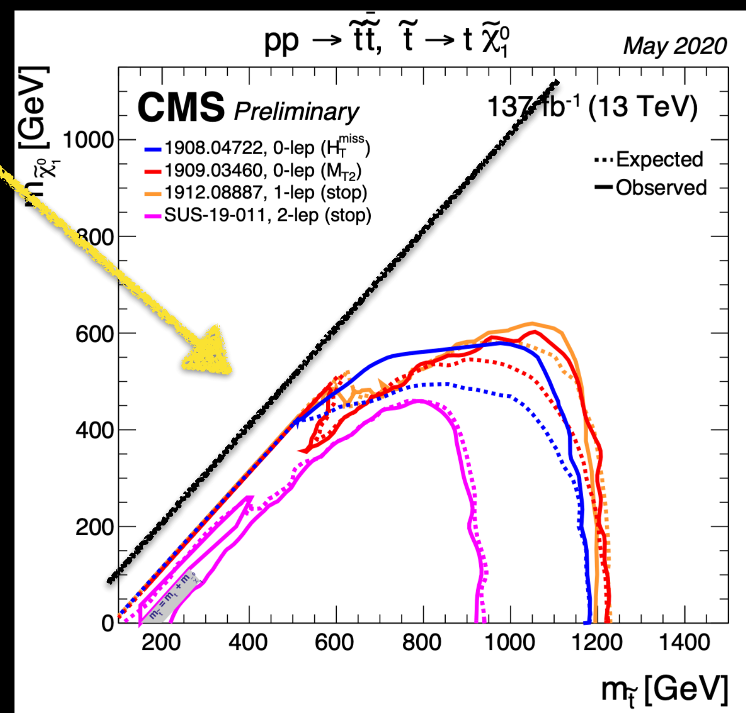
To keep in mind:

There are ways to weaken somewhat these bounds.

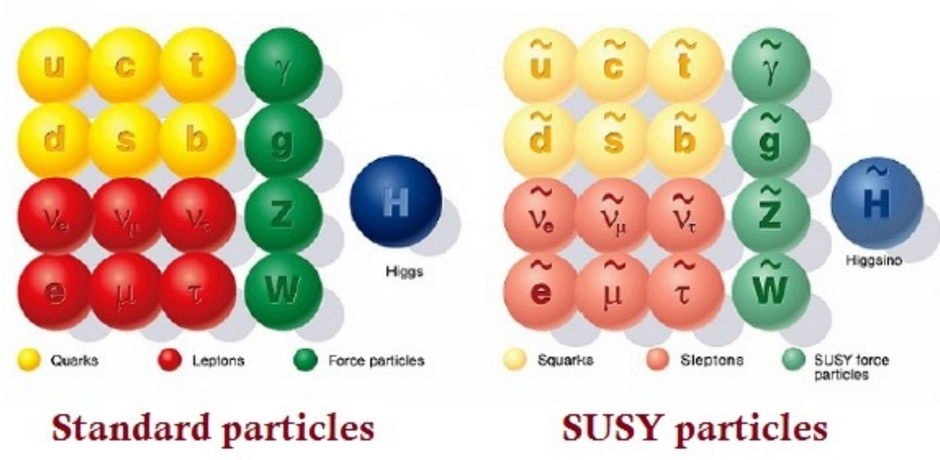
For example,

<u>We can reduce the amount of missing energy</u>

- introducing some (clever) R-parity violating operator;
- using a SUSY dark sector at around the same mass of the SUSY spectrum (stealth SUSY, Fan et al, 1105.5135);
- Squeezing the SUSY spectrum or raising the lightest SUSY mass.



SUSY predicts a second Higgs doublet!



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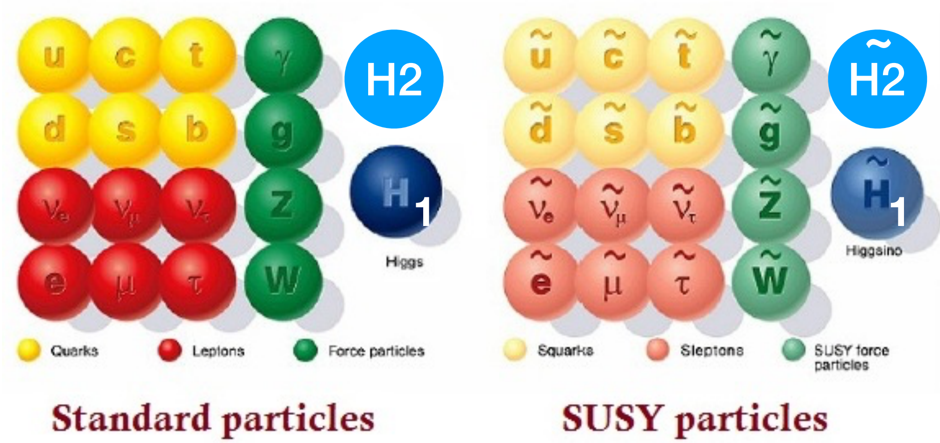

The Higgs Lagrangian is
the Lagrangian of a particular
Two-Higgs-Doublet-Model (2HDM):

H_1 and H_2 Higgs doublets.
They both break electroweak symmetry

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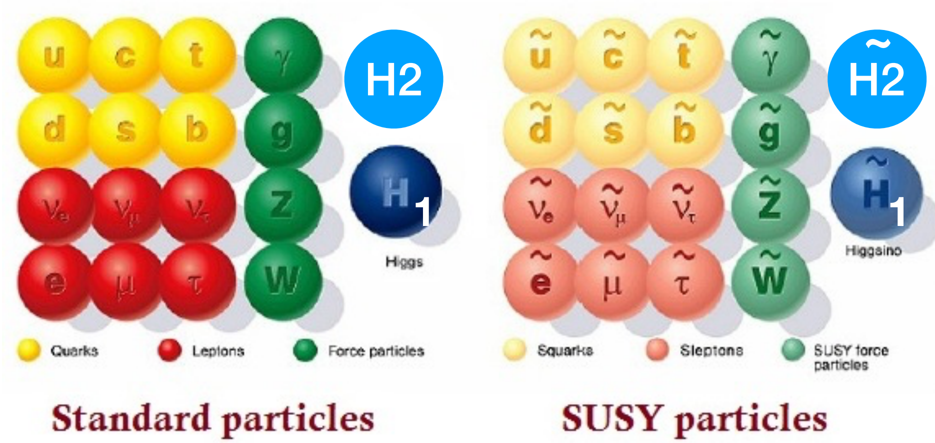

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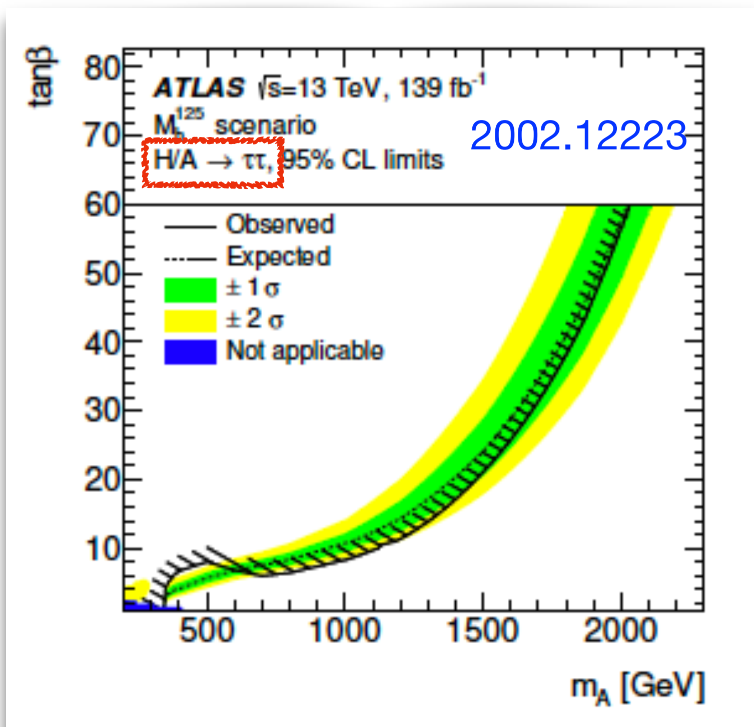
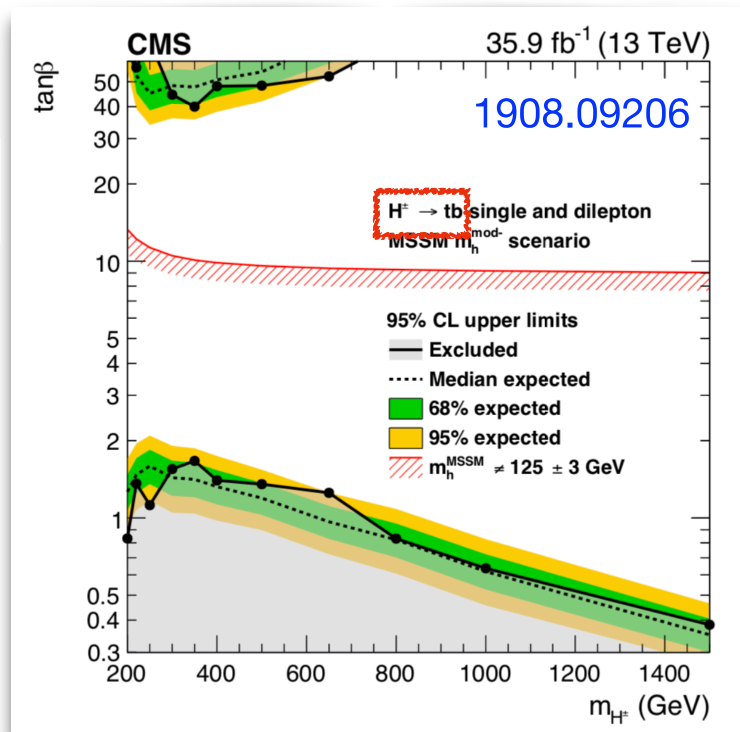
They both break electroweak symmetry

Several searches for new Higgs bosons at the LHC



$$\tan\beta \equiv \frac{v_2}{v_1}$$



Beyond direct searches: The Higgs precision program

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→ towards a precision program to assess the nature of the Higgs boson that we have discovered

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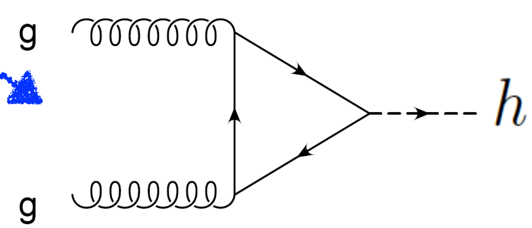

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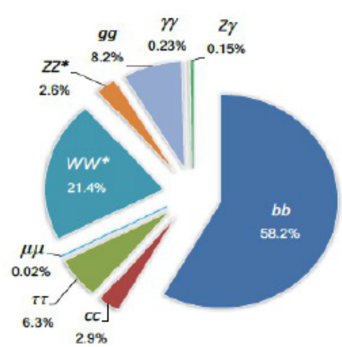


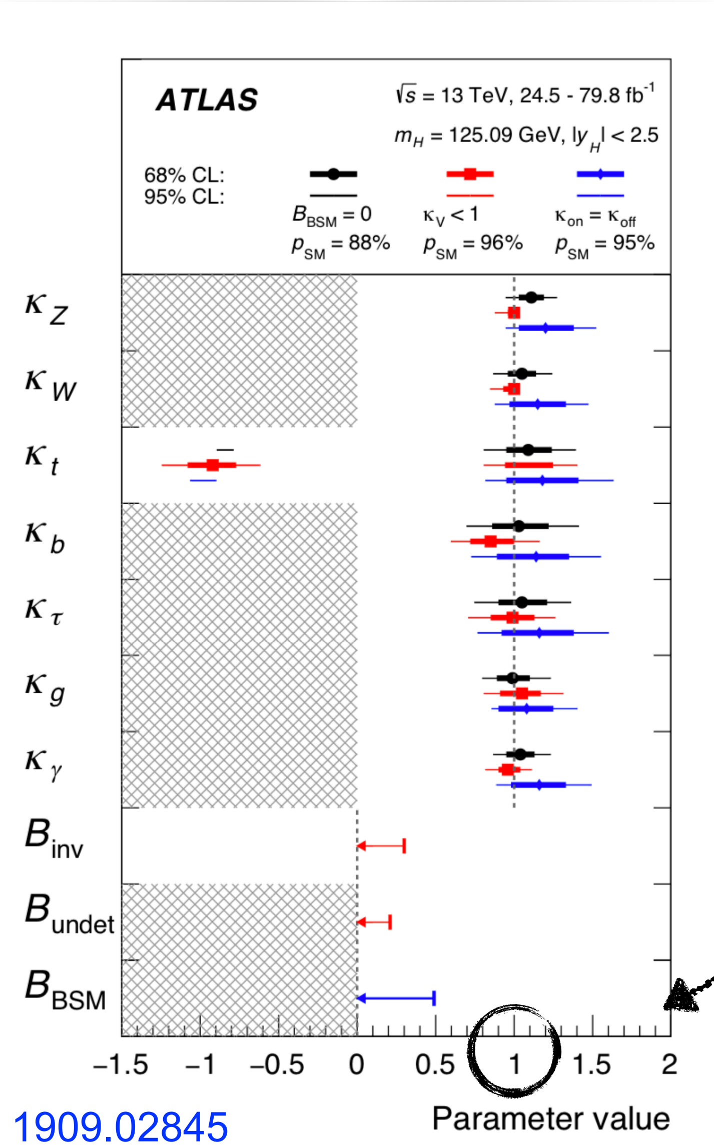
— computed to high precision

— "reduced couplings" to be extracted

We need to make some assumption.
e.g. $\Gamma^{\rm tot}_{\rm theory} = \Gamma^{\rm tot}_{\rm SM}(\kappa_i)$

Status & prospects for the Higgs measurements

The “kappa framework”



SM prediction

See lectures by C. Paus

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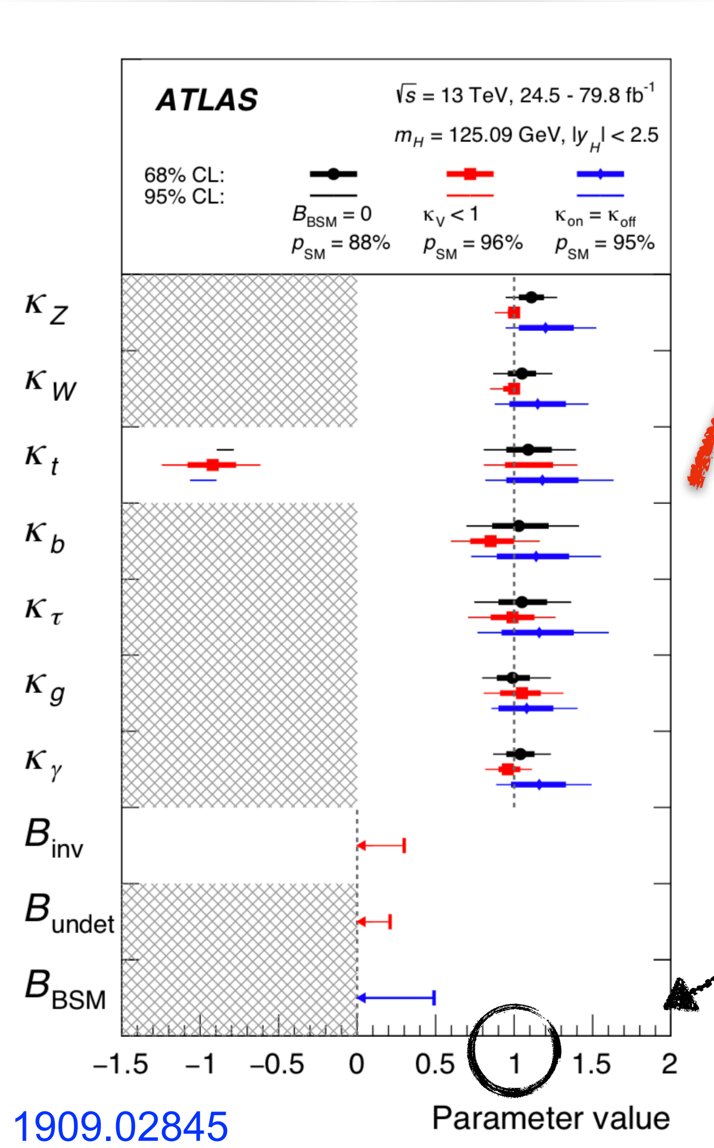
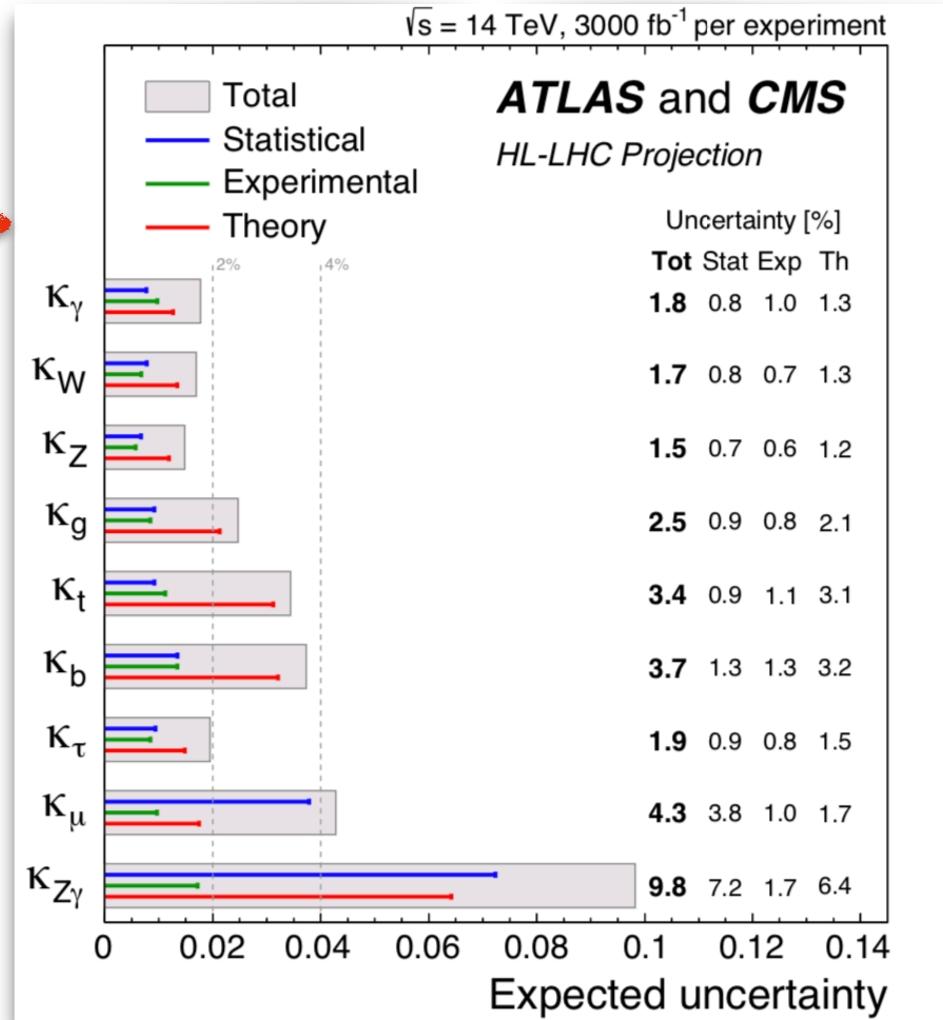


SM prediction

Cepeda, SG, Kado, Ilten, Riva et al., 1902.00134



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Implications on the heavy Higgs bosons

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In particular, the coupling with massive gauge bosons:

$$\boxed{\kappa_V = \sin(\beta - \alpha)}$$

(normalized coupling to the SM value)

Measured to be close to 1

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos(\alpha-\beta) & \sin(\alpha-\beta) \\ -\sin(\alpha-\beta) & \cos(\alpha-\beta) \end{pmatrix} \begin{pmatrix} \Phi_v \\ \Phi_H \end{pmatrix}$$

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Generically, we have an upper bound on the value of $|x|$ with $\alpha = \beta - \pi/2 + x$

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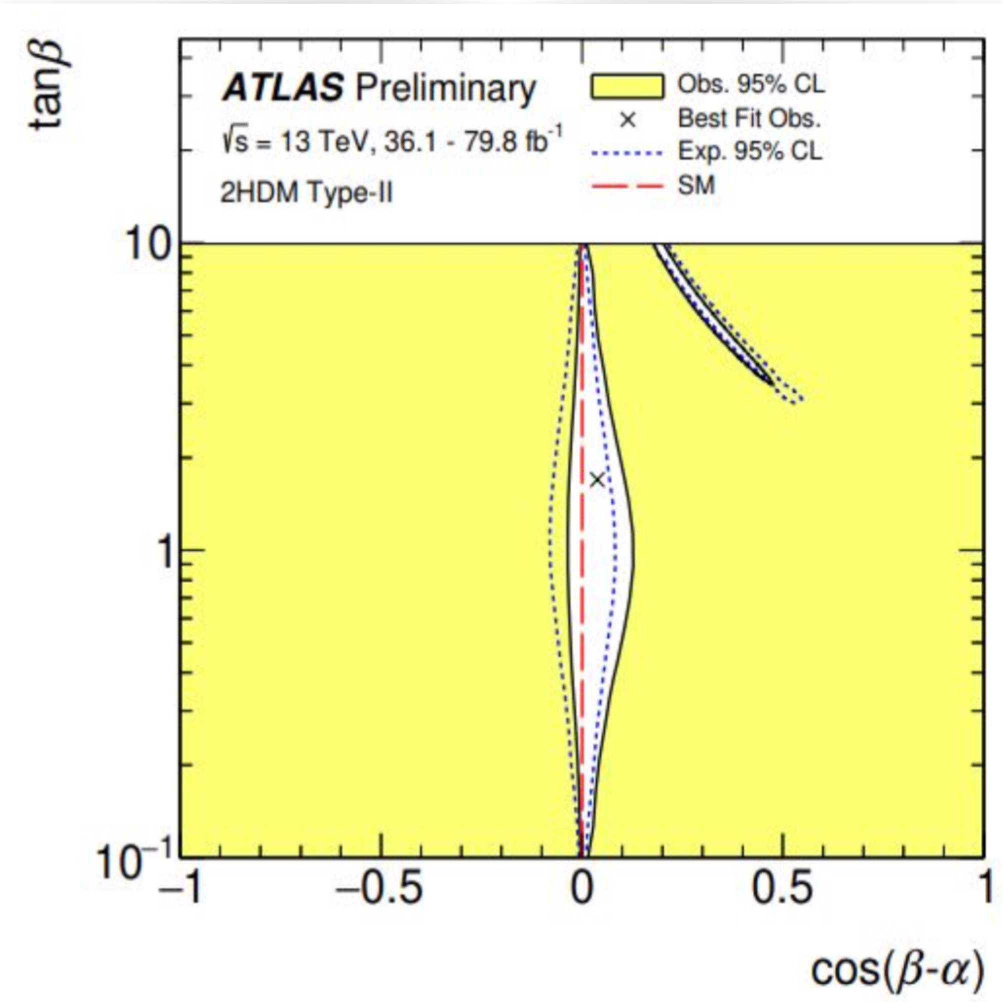
Bound on the mixing angle

Putting all measurements together…



1909.02845

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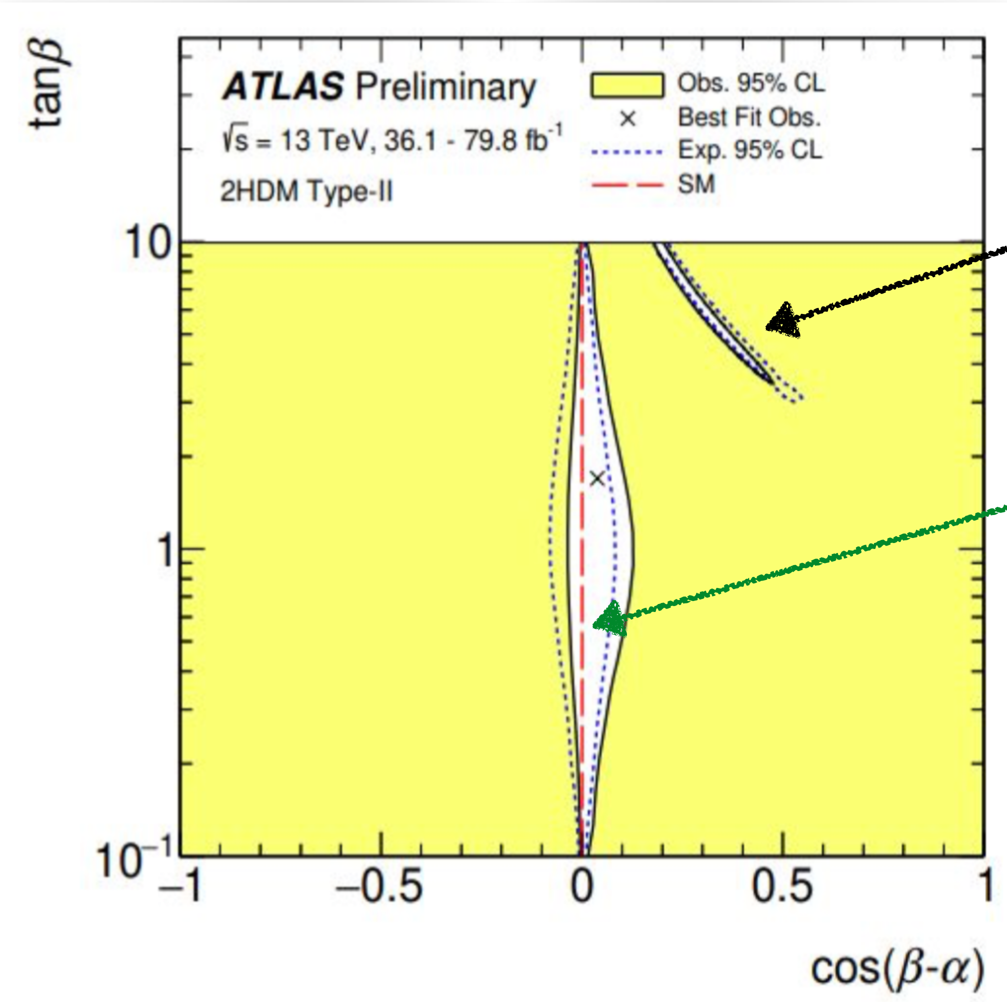
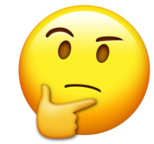


1909.02845

What is this additional region?



Alignment (or decoupling) limit

$$\sin(\beta-\alpha)=1$$

In this limit, the 125 GeV Higgs has the same properties as in the SM

Why 2 names? (alignment/decoupling)

$$\alpha=\beta-\pi/2+O(\lambda_i v^2/M_A^2)$$

What do we learn on the new H bosons?

So far we have considered the couplings of the 125 GeV Higgs boson

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The couplings of the heavy Higgs bosons are related:

→ Upper bound on the coupling of the heavy Higgses with gauge bosons:

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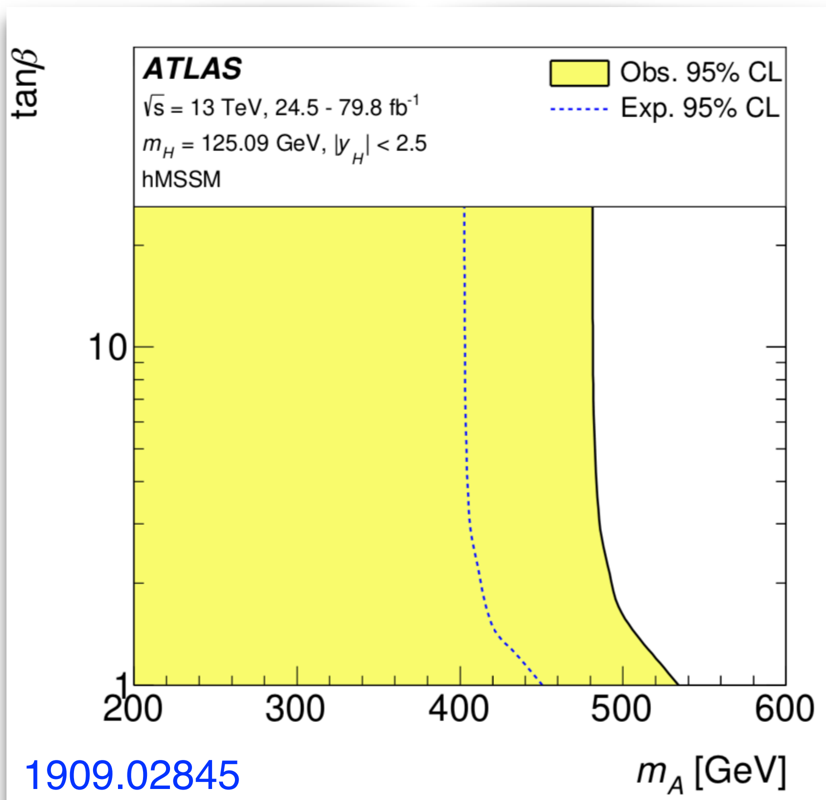

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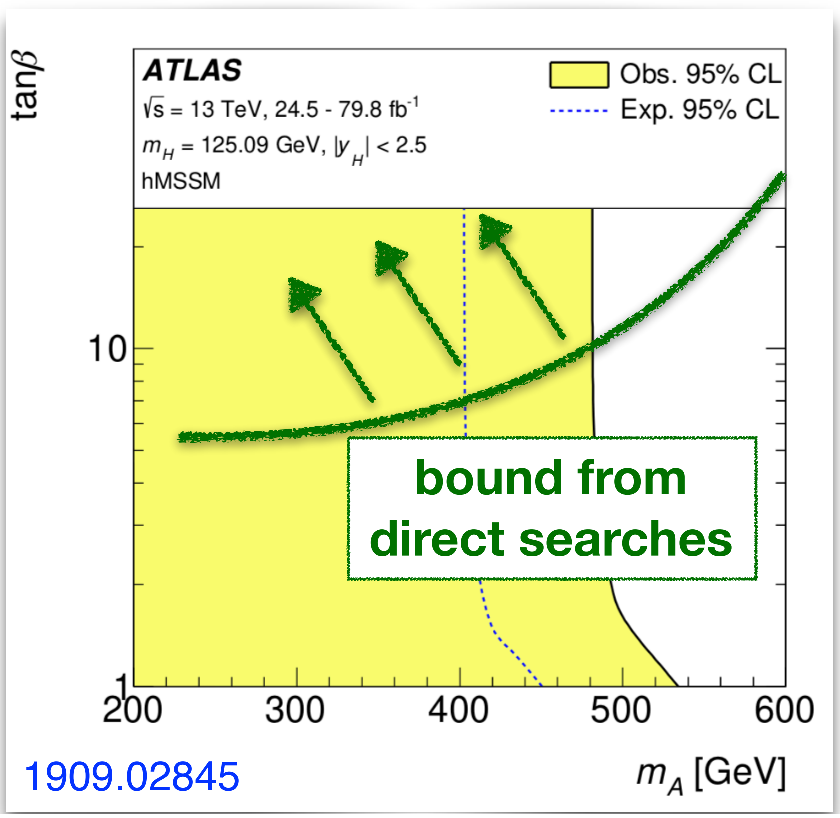

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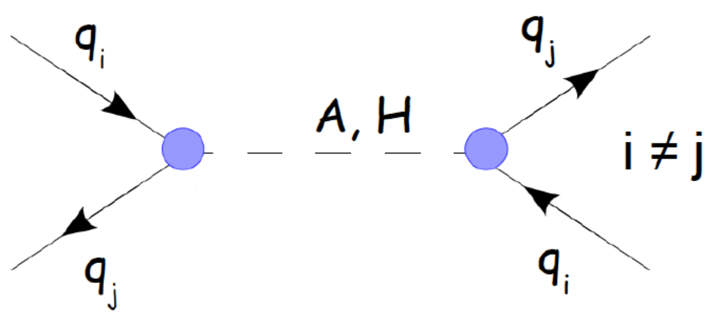
Heavy Higgs impact on flavor physics

- In all generality, we can write

$$\mathcal{H}_Y^{\rm gen} = \bar{Q}_L X_{d1} D_R H_1 + \bar{Q}_L X_{u1} U_R H_1^c + \bar{Q}_L X_{d2} D_R H_2^c + \bar{Q}_L X_{u2} U_R H_2 + {\rm h.c.}$$

(H_1, H_2 with hypercharge ±1/2)

If X_{d1}, X_{u1}, X_{d2}, X_{u2} are generic 3*3 matrices in flavor space:
Flavor changing neutral currents (FCNCs) at the tree-level!



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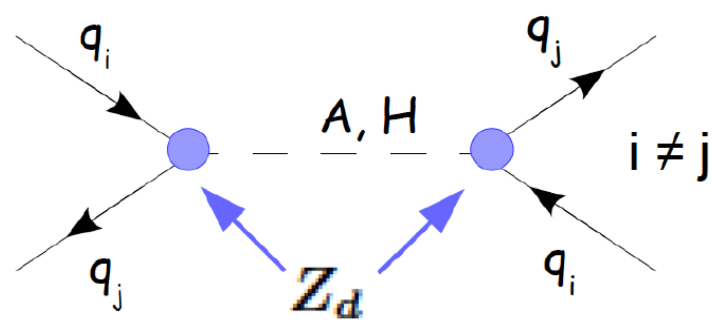

* How to see this?

Step 1: go to the "Higgs basis"

$$\begin{pmatrix} \Phi_v \\ \Phi_H \end{pmatrix} = \begin{pmatrix} c_\beta & s_\beta \\ -s_\beta & c_\beta \end{pmatrix} \begin{pmatrix} H_1 \\ H_2^c \end{pmatrix}$$

$$\tan\beta \equiv \frac{v_2}{v_1} \qquad \langle \Phi_v^\dagger \Phi_v \rangle = v^2/2, \quad \langle \Phi_H^\dagger \Phi_H \rangle = 0$$

Step 2: write the Lagrangian in this basis

$$\mathcal{H}_Y^{\rm gen} = \bar{Q}_L \left[\frac{\sqrt{2}}{v} M_d \Phi_v + Z_d \Phi_H \right] D_R + \text{h.c.}$$

with

$$\left.\begin{aligned} Z_d &= \cos\beta X_{d2} - \sin\beta X_{d1} \\ M_d &= \frac{v}{\sqrt{2}} (\cos\beta X_{d1} + \sin\beta X_{d2}) \end{aligned}\right\} \text{Not proportional!}$$

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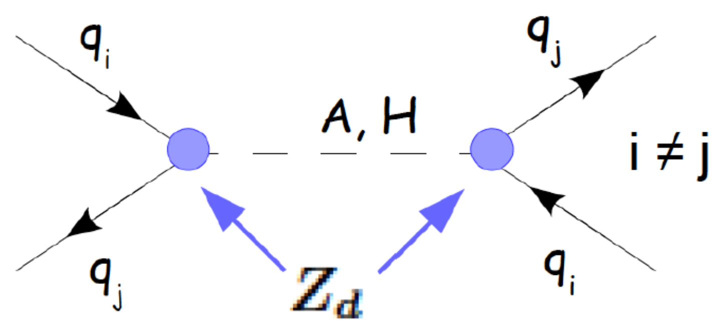

- Result: 2HDMs with a generic flavor structure have

Very stringent bounds from low energy flavor measurements!

e.g. the H, A Higgs bosons should have a mass ≥ **O(10^4 TeV)**,
to agree with measurements of Kaon mixings

SUSY has a “clever” Yukawa Lagrangian

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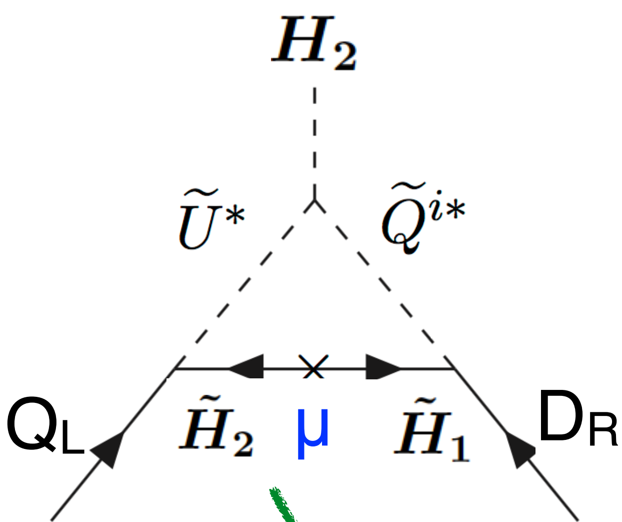

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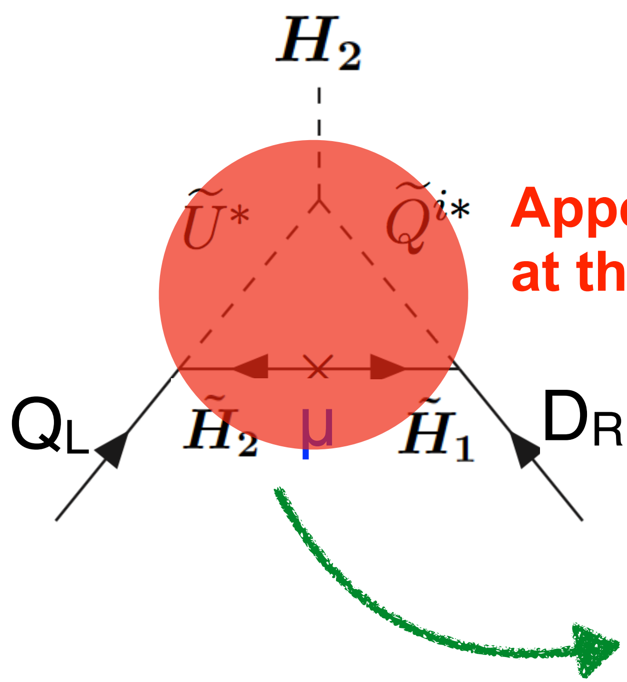
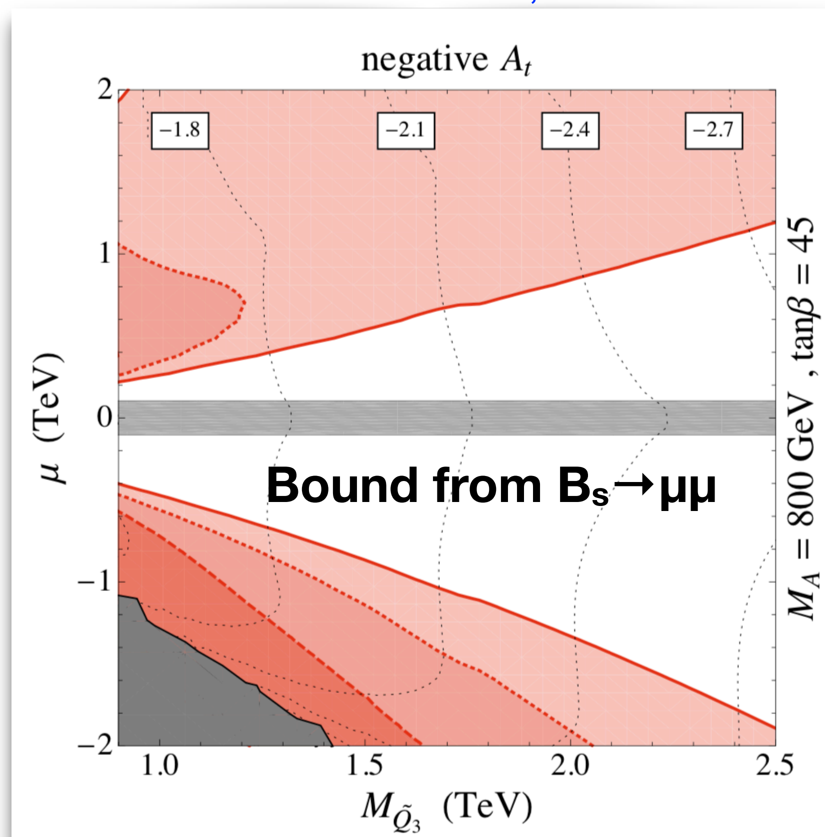


Appearance of FCNCs at the one loop level

$\bar{Q}_L X_{d2} D_R H_2^c$

Altmannshofer et al., 1211.1976



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Twin Higgs models & the hierarchy problem

SM$_A$ x SM$_B$ x Z$_2$

Global symmetry of the scalar potential (e.g. SU(4))

→ The SM Higgs is a (massless) Nambu-Goldstone boson

$$H = \begin{pmatrix} H_A \\ H_B \end{pmatrix}$$

~SM Higgs doublet

Twin Higgs doublet

$$V(H) = -m^2 H^\dagger H + \lambda (H^\dagger H)^2$$

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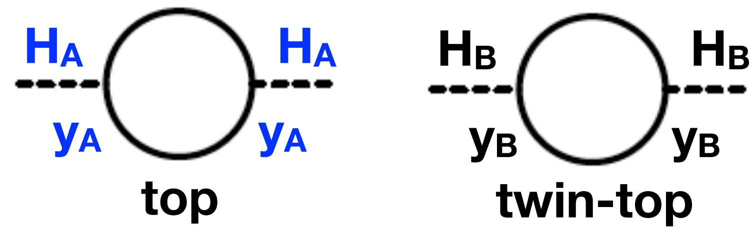

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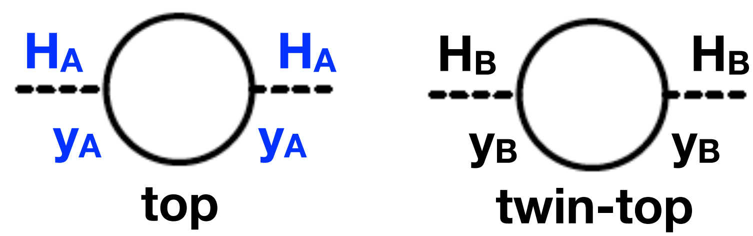

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SU(4) and Z_2 are (softly) broken:

$v_A \neq v_B$

$(f^2 \equiv v_A^2 + v_B^2 \gg 246\ \mathrm{GeV})$

Loop corrections to mass are SU(4) symmetric

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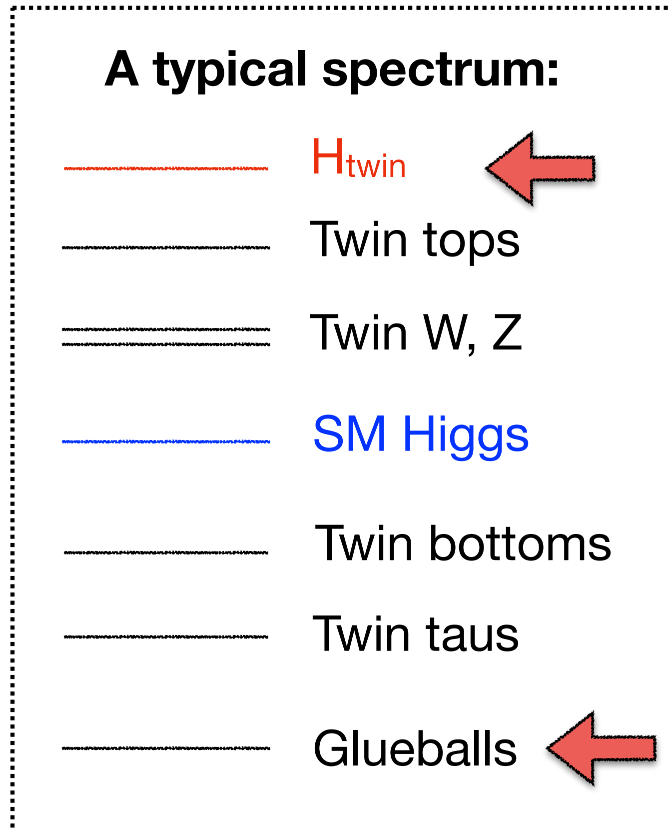
Phenomenology of the twin Higgs



Phenomenology of the twin Higgs

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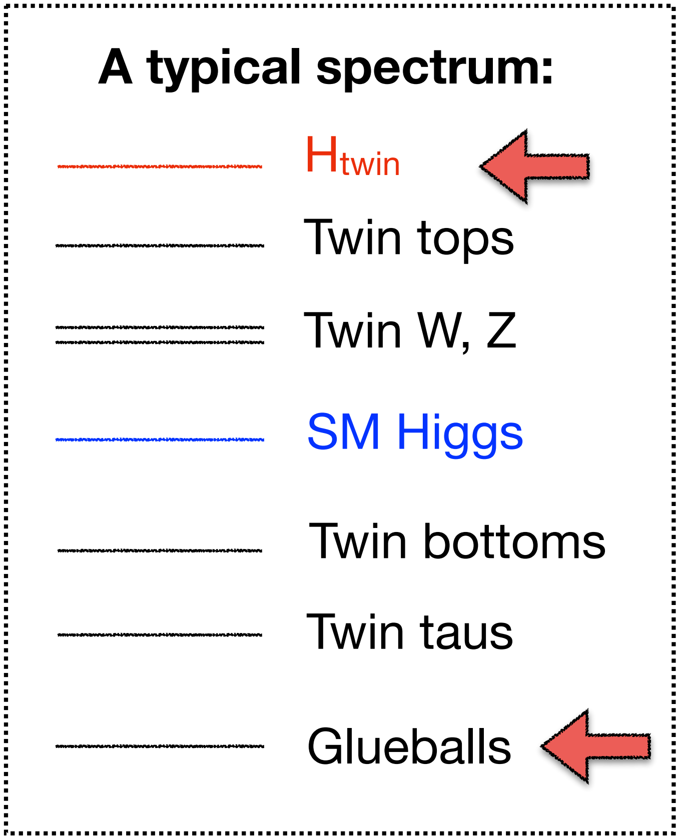
The twin Higgs will mix with the 125 GeV Higgs with a mixing angle ~ v^2/f^2

Because of this mixing, it can be produced as a SM Higgs boson (reduced rates!)



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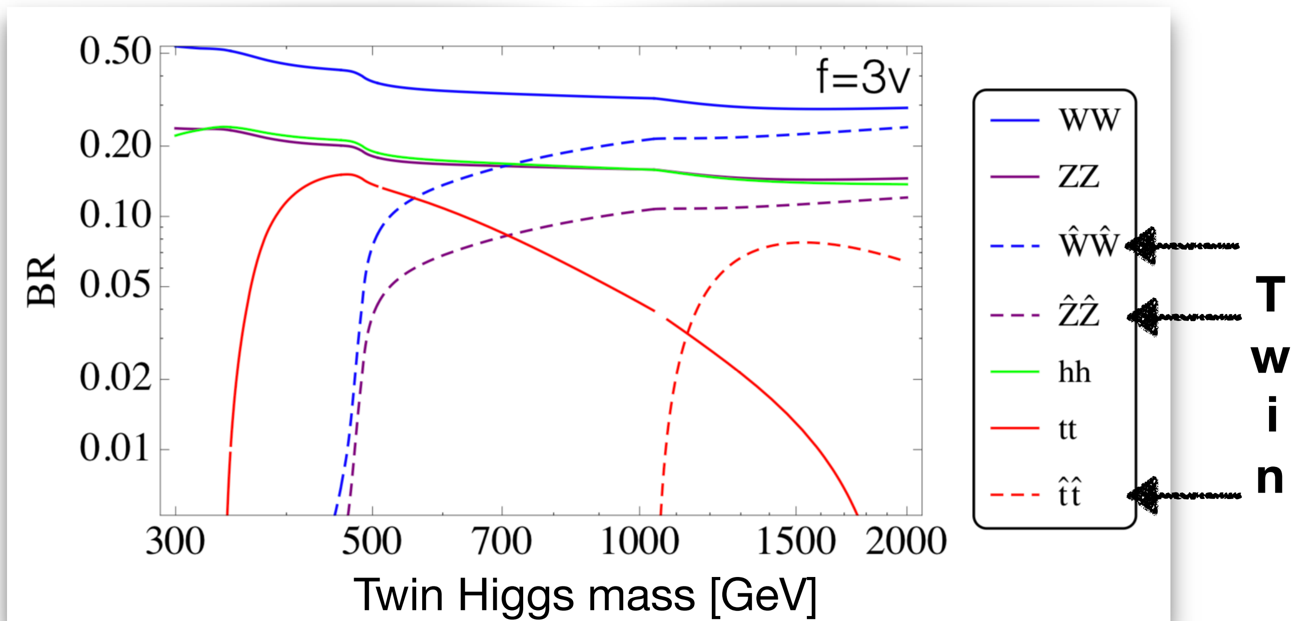
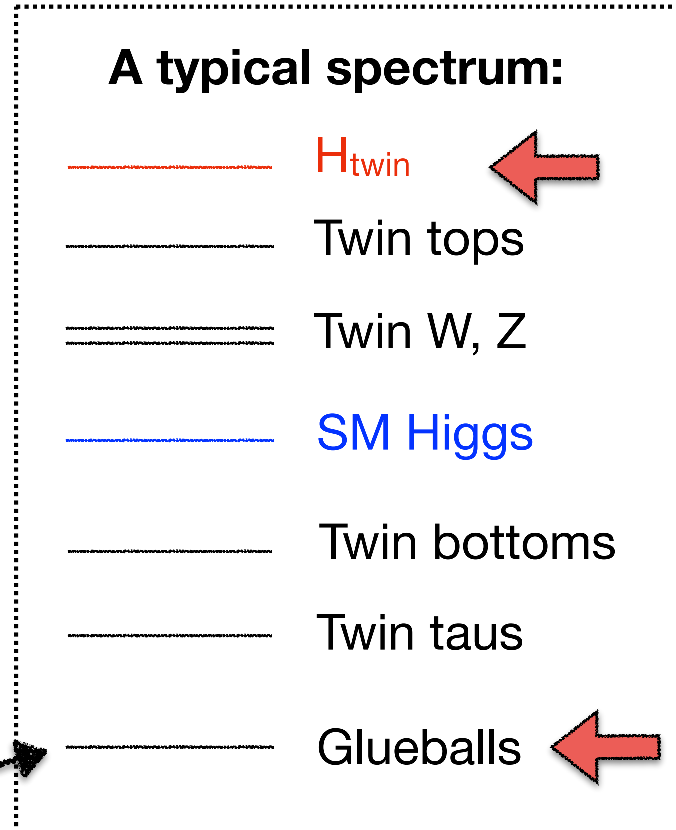
2. **Decay of the twin Higgs**

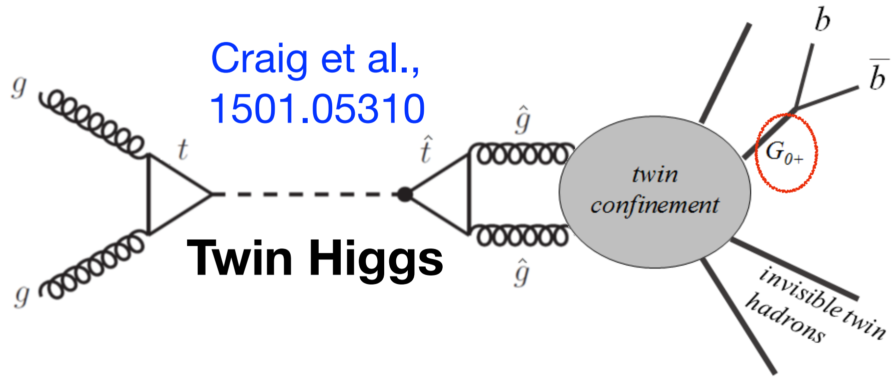


N.Craig



Twin particles undertake cascade decays to (typically) long lived glue-balls

Long-lived signatures from twin Higgs decays



Craig et al., 1501.05310

Glue-ball.
0^{++} mixes with the 125 GeV Higgs and decays typically displaced.

Signature: $H_T \rightarrow$ >= 2 displaced

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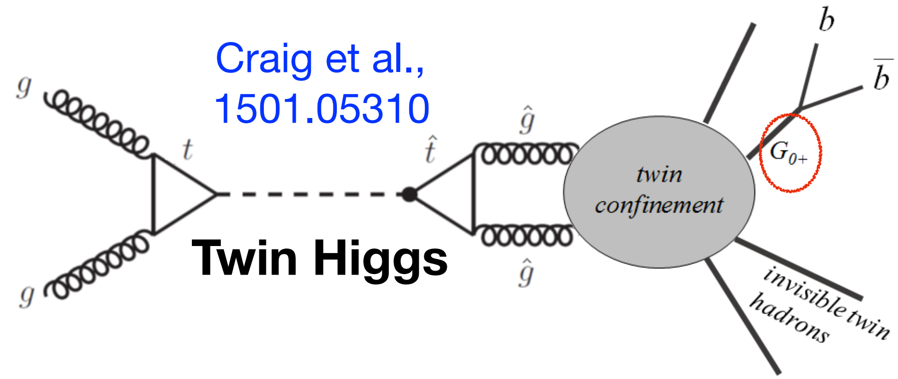
Craig et al., 1501.05310



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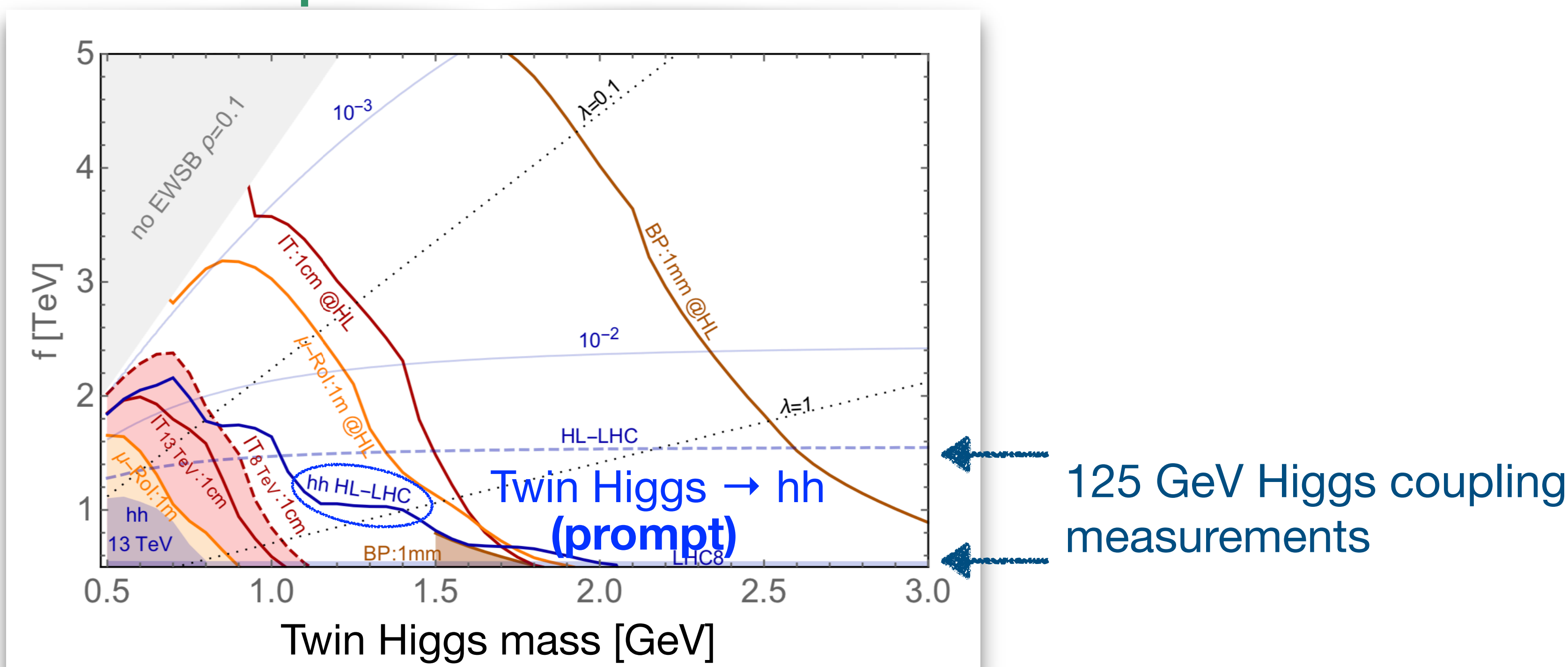
O^{++} mixes with the 125 GeV Higgs and decays typically displaced.

Signature: $H_T \rightarrow$ >= 2 displaced

Prospects for the HL-LHC



Alipour-Fard, Craig, SG, Koren, Redigolo, 1812.09315

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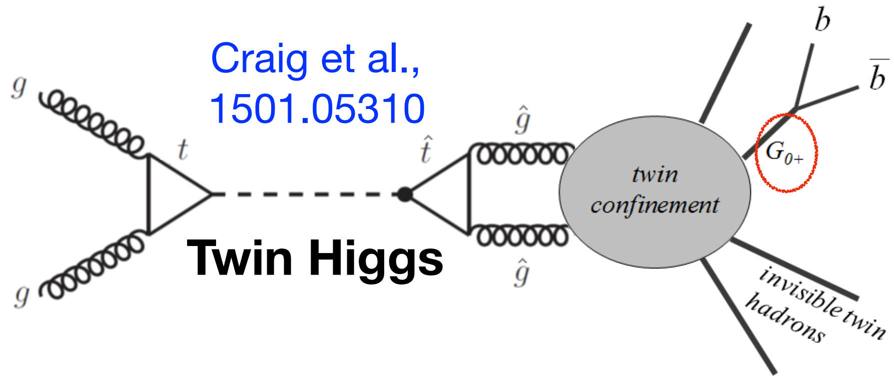

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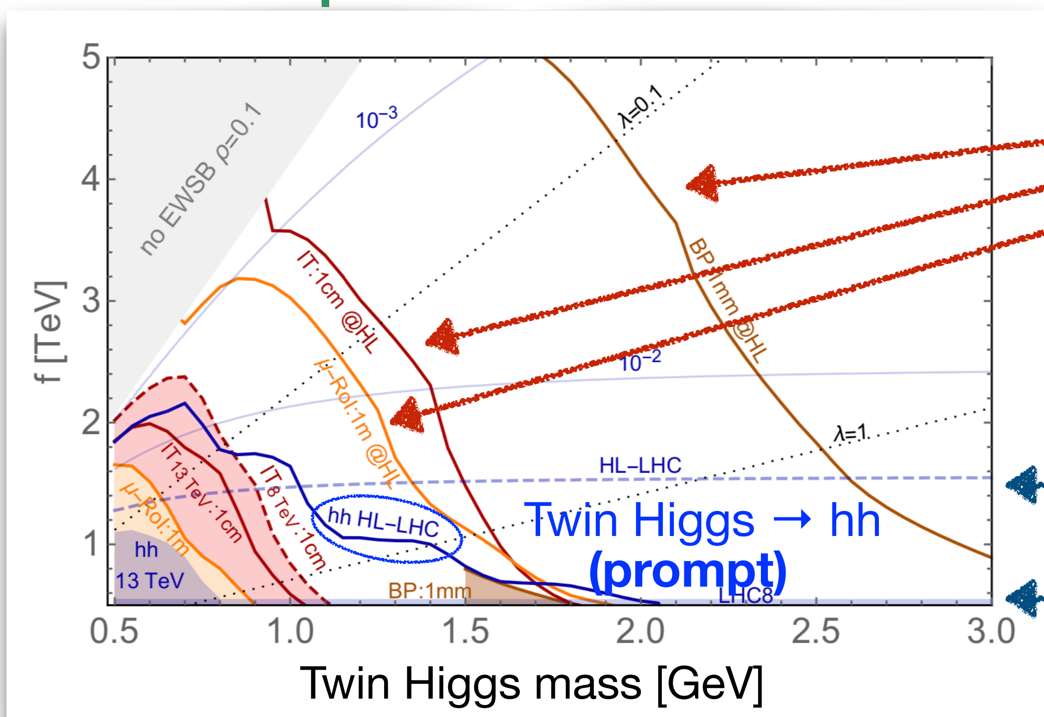

Alipour-Fard, Craig, SG, Koren, Redigolo, 1812.09315

Twin Higgs → glue-balls:
(long lived)

CMS inner tracker analysis;
CMS beam pipe analysis;
ATLAS muon spectrometer analysis

The relative strength depends on other parameters of the theory

125 GeV Higgs coupling measurements

Effects on the 125 GeV Higgs pheno

The 125 GeV Higgs will mix with the twin Higgs with a mixing angle ~ v^2/f^2

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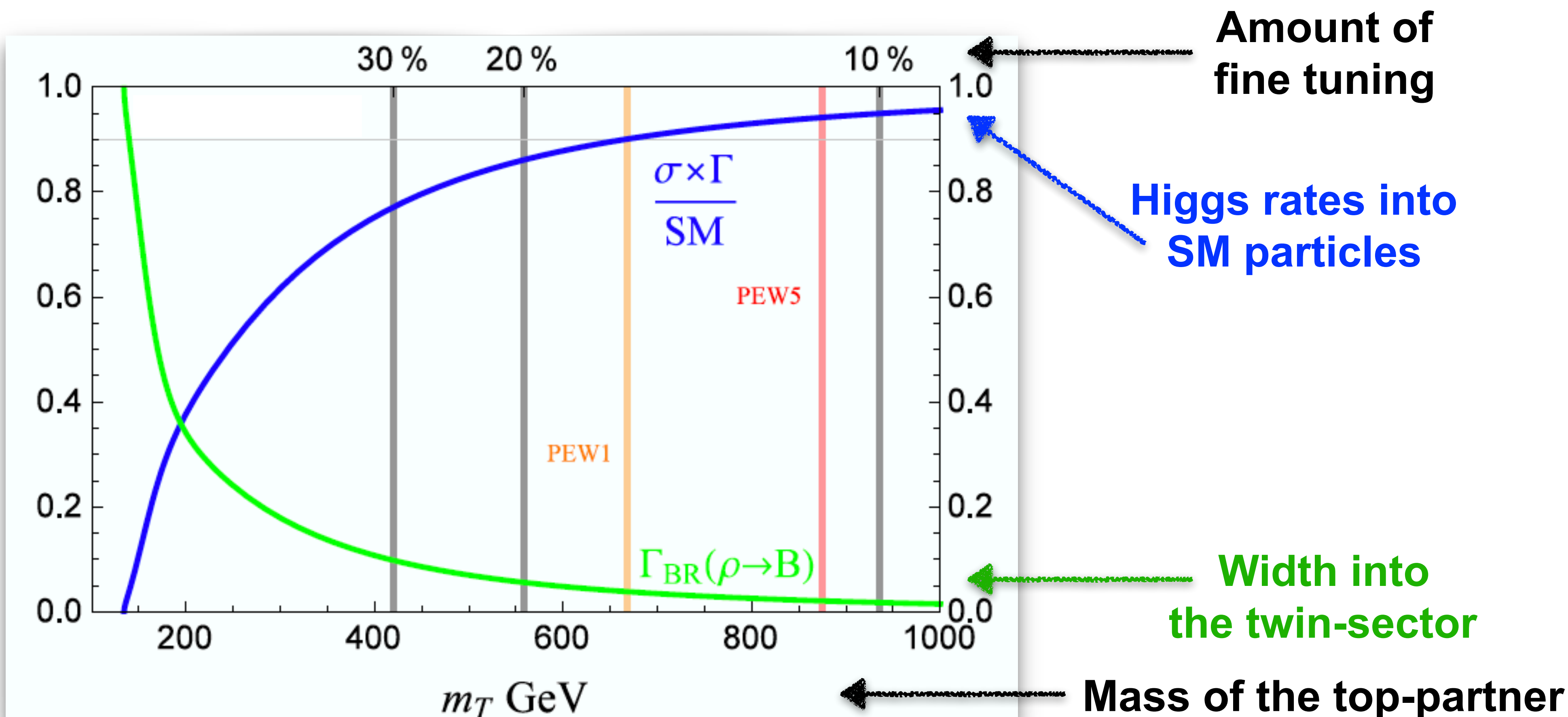


Burdman et al, 1411.3310

Outlook: What have we learned?

The Standard Model is a remarkable theory

however

it does not answer several fundamental questions

Supersymmetry

Hierarchy problem:
Scalar partners of the SM fermions

Direct searches (sparticles + Higgses)

Interplay with precision measurements (Higgs & flavor)

Twin Higgs

Hierarchy problem:
Global symmetry between the SM and the twin sectors

Direct searches of the twin Higgs (displaced signatures!)

Interplay with precision measurements (Higgs)

T-parameter and custodial symmetry (1)

- Why is the T parameter interesting? hep-ph/0410370
- Let us define the symmetry $SU(2)_L \times SU(2)_R$ an additional SU(2)

The usual gauge symmetry

- Let us write the SM Lagrangian in terms of $SU(2)_L \times SU(2)_R$ invariant objects
  - ✓ The Higgs is now in a bi-doublet representation:

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \tilde{\phi} & \phi \end{pmatrix} \quad \text{with} \quad \phi = \begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix} = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \quad \tilde{\phi} \equiv \epsilon\phi^* = \begin{pmatrix} \phi^{0*} \\ -\phi^- \end{pmatrix}$$

  - ✓ The Higgs Lagrangian is given by

$$\boldsymbol{\Phi} \to e^{i\omega_L^i \sigma_i/2} \boldsymbol{\Phi} e^{i\omega_R^j \sigma_j/2}$$

$$\mathcal{L}_{Higgs} = \mathrm{Tr} D^\mu \Phi^\dagger D_\mu \Phi - \mu^2 \mathrm{Tr}\left[\Phi^\dagger \Phi\right] + \lambda \mathrm{Tr}\left[\Phi^\dagger \Phi\right]^2$$

  - ✓ Electroweak symmetry breaking

$$\langle \Phi \rangle = \frac{1}{2} \begin{pmatrix} v & 0 \\ 0 & v \end{pmatrix}$$

$SU(2)_L \times SU(2)_R \to SU(2)_D$ (custodial symmetry)

  - ✓ We can demonstrate that the hypercharge interaction and the Yukawa couplings break the custodial symmetry

T-parameter and custodial symmetry (2)

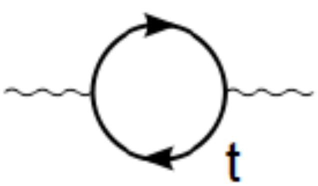
- Why is the T parameter interesting?
- Going back to our definition of the T parameter:

$$\mathcal{L}_{vac-pol} = -\frac{1}{2}W_\mu^3\Pi_{33}(q^2)W_\mu^3 - \frac{1}{2}B_\mu\Pi_{00}(q^2)B_\mu - W_\mu^3\Pi_{30}(q^2)B_\mu - W_\mu^+\Pi_{WW}(q^2)W_\mu^-$$

$$\hat{T} \equiv \frac{\Pi_{33}(0) - \Pi_{WW}(0)}{m_W^2} = \rho - 1$$

$W_\mu^i\ (i = 1, 2, 3)$
is triplet of $SU(2)_L$,
singlet of $SU(2)_R$
$\Rightarrow$ triplet of $SU(2)_D$

- In any theory with custodial symmetry, the T parameter is = 0
- In the SM, the top Yukawa is strongly breaking the custodial symmetry



$$\hat{T} \sim \frac{3G_F m_t^2}{8\sqrt{2}\pi^2} + \cdots$$

Heavy Higgs boson couplings

A bound on x gives also information about the heavy Higgs couplings with fermions (Note: everything is at the tree-level!)

	$y_{\rm 2HDM}/y_{\rm SM}$	Type-II K	Alignment limit:
125 GeV Higgs	hVV	$s_{\beta-\alpha}$	1
	hQu	$s_{\beta-\alpha}+c_{\beta-\alpha}/t_\beta$	1
	hQd	$s_{\beta-\alpha}-t_\beta c_{\beta-\alpha}$	1
	hLe	$s_{\beta-\alpha}-t_\beta c_{\beta-\alpha}$	1
Heavy scalar	HVV	$c_{\beta-\alpha}$	0
	HQu	$c_{\beta-\alpha}-s_{\beta-\alpha}/t_\beta$	$1/t_\beta$
	HQd	$c_{\beta-\alpha}+t_\beta s_{\beta-\alpha}$	t_β
	HLe	$c_{\beta-\alpha}+t_\beta s_{\beta-\alpha}$	t_β
Heavy pseudo-scalar	AVV	0	0
	AQu	$1/t_\beta$	$1/t_\beta$
	AQd	t_β	t_β
	ALe	t_β	t_β

Note the flavor universality!

$$y_{Q^i} = K \times m_{Q^i}/v$$

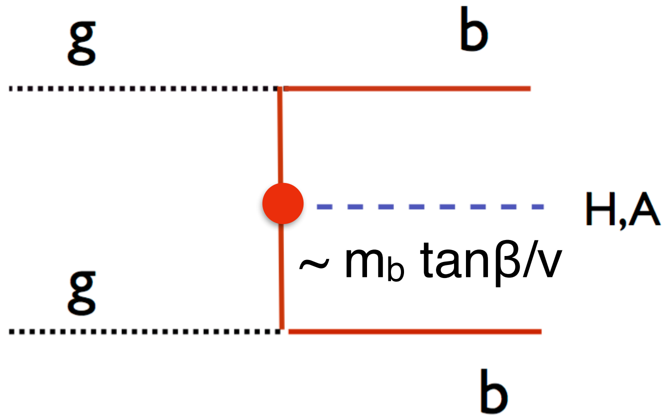
independent on i

The pheno of the additional Higgs is determined by β and their mass

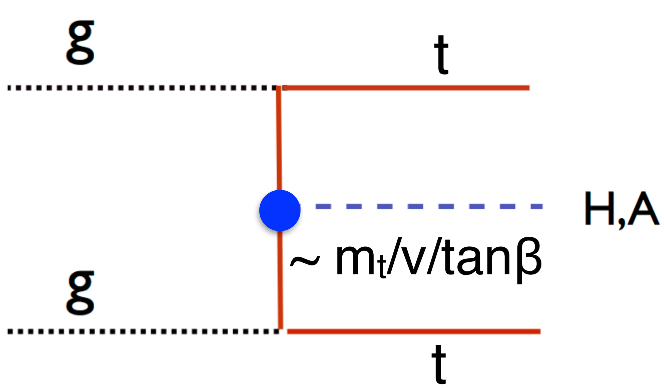
How to produce these H bosons at the LHC?

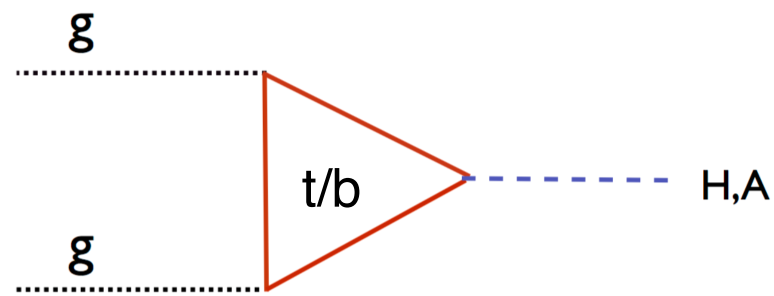
* Neutral Higgs bosons (H,A)

Dominant
at large tanβ:

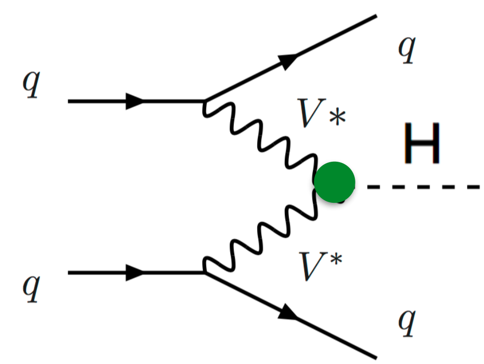


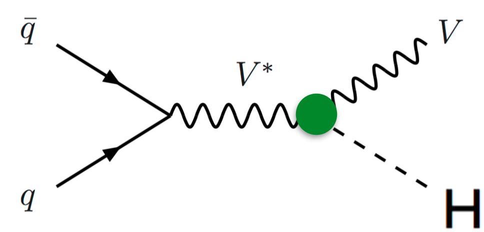
Dominant
at small tanβ:





Suppressed in
the alignment limit:

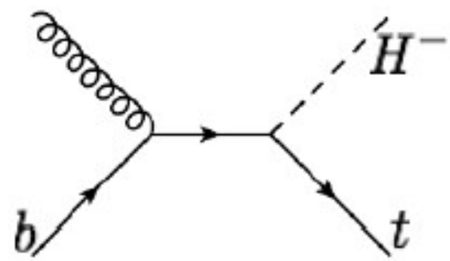




How to produce these H bosons at the LHC?

* Charged Higgs bosons ($H^\pm$)

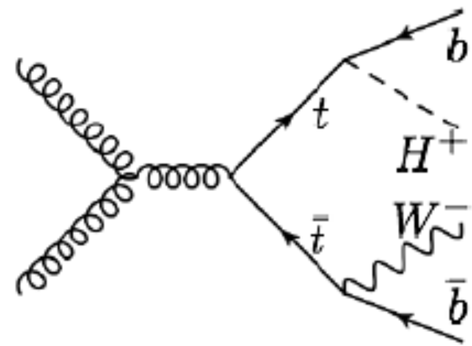
Above the top mass:

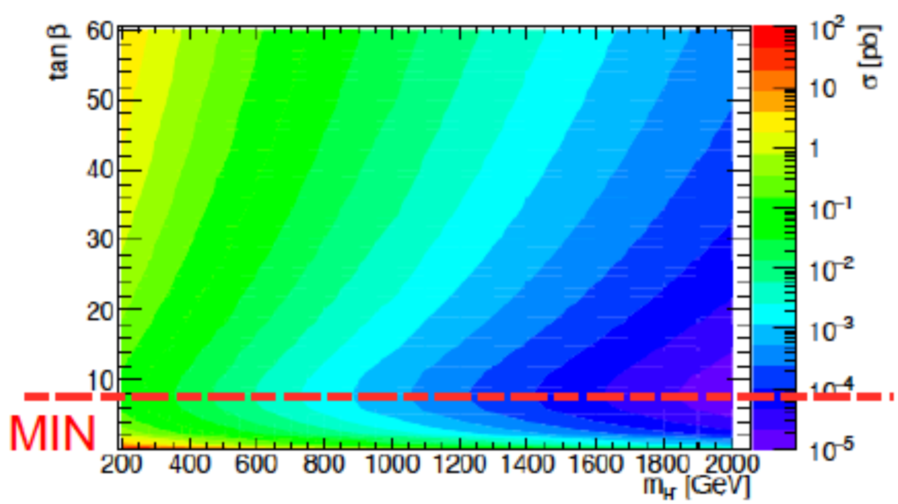


$H^\pm b_R t_L \sim m_b \tan\beta / v$

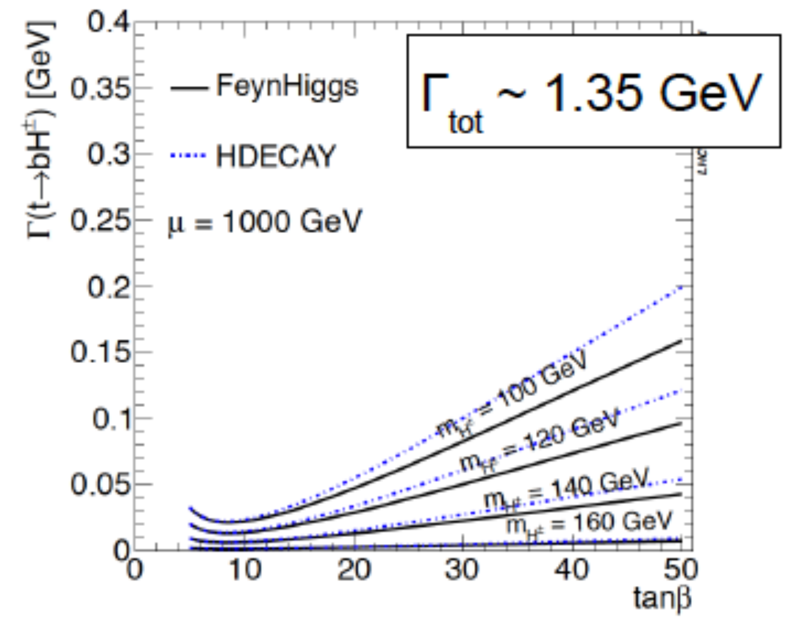
$H^\pm t_R b_L \sim m_t / \tan\beta / v$

Below the top mass:





From the LHCHXSWG YR4, 1610.07922

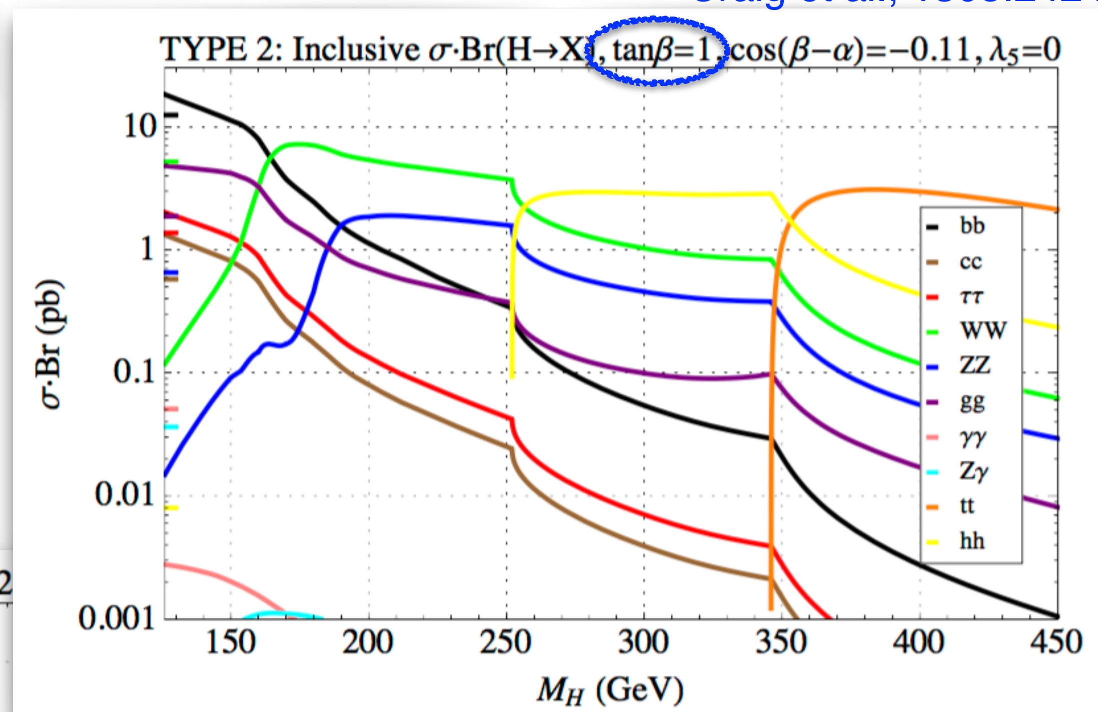


From the LHCHXSWG YR2, 1201.3084

What are the signatures?

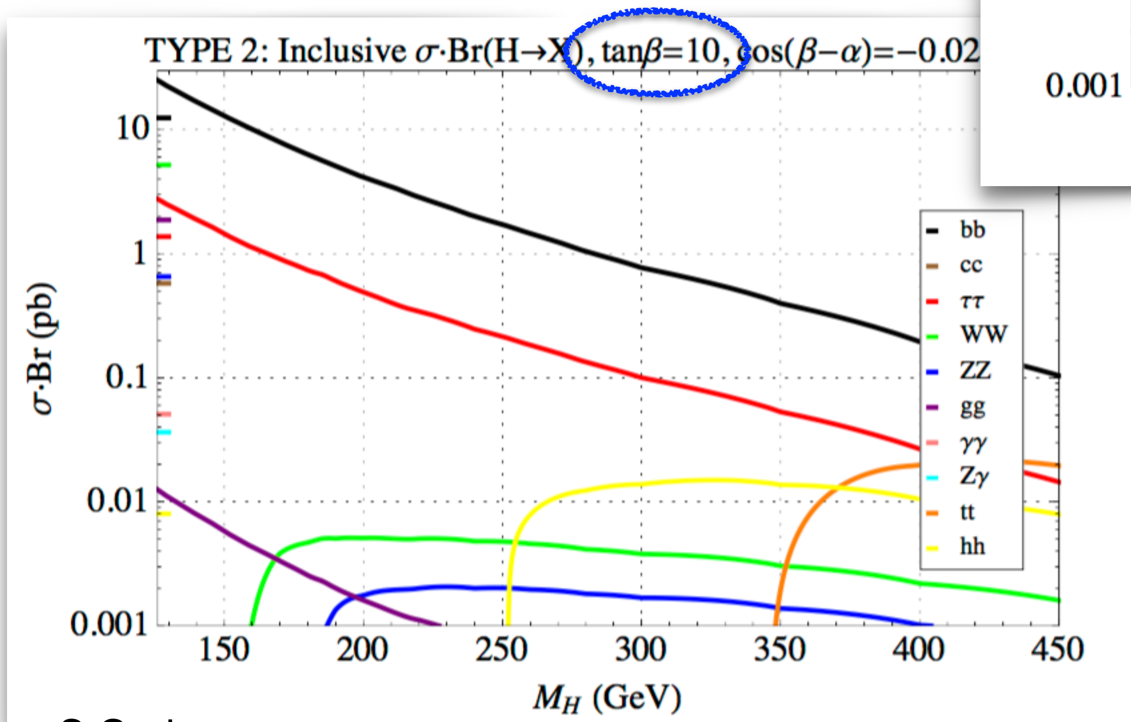
Craig et al., 1305.2424

- Neutral Higgs bosons



Large tanβ:
enhanced couplings with bb, tautau

Alignment limit:
suppressed couplings with hh, WW, ZZ

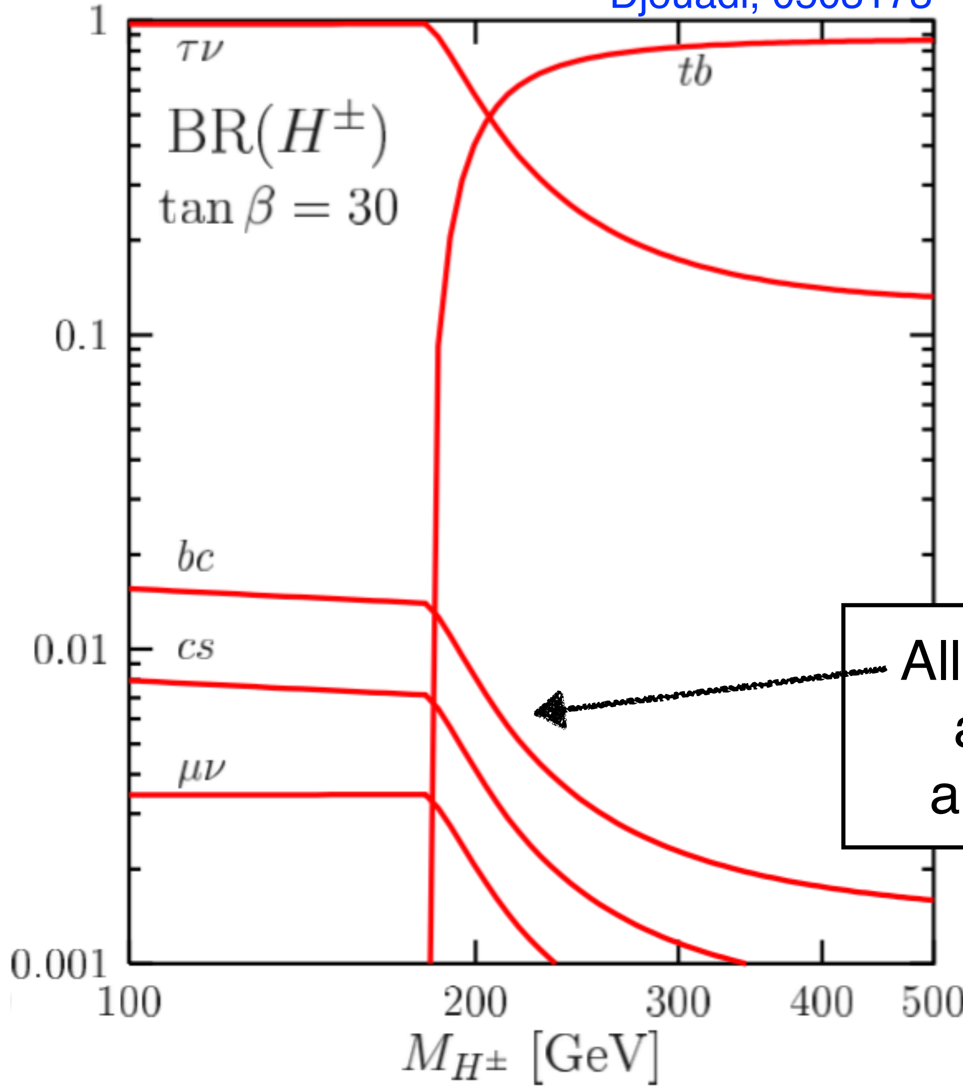


Small tanβ:
enhanced couplings with tt

What are the signatures?

* Charged Higgs bosons

Djouadi, 0503173



All the other decay modes are pretty suppressed above the top threshold