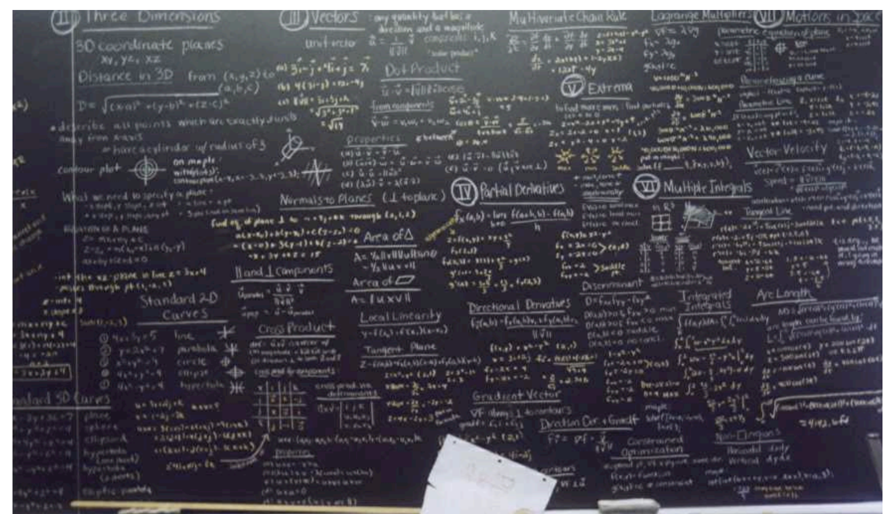
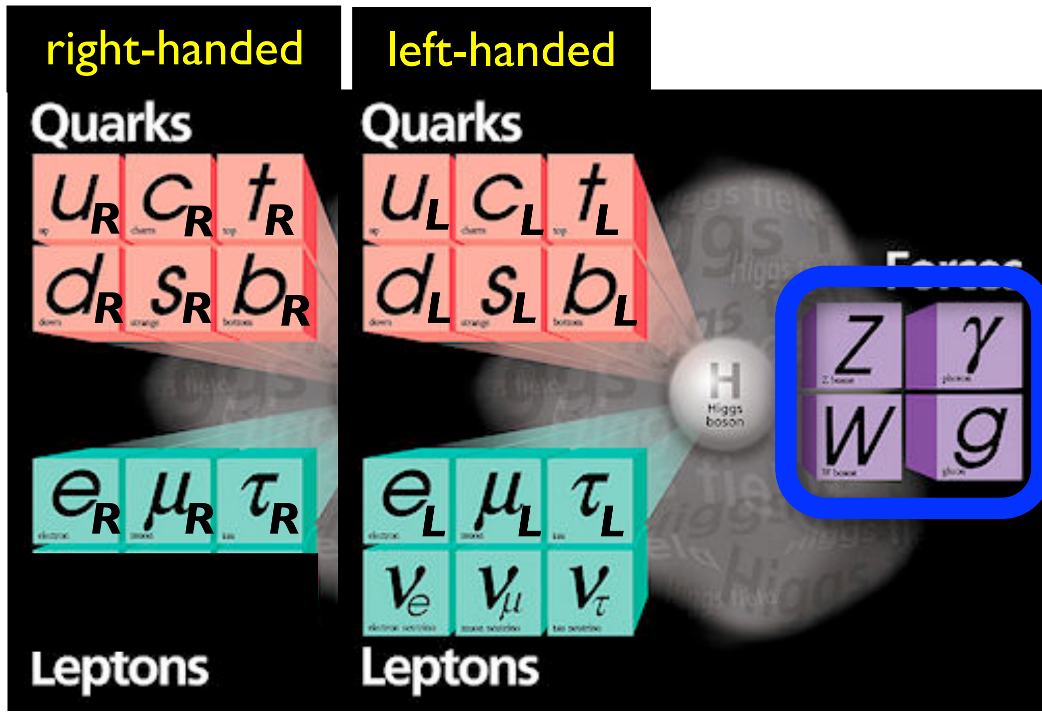
Implications of LHC Data to New Physics

Alex Pomarol (Univ. Autonoma Barcelona)

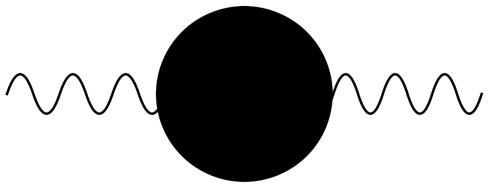
vs





right-handed
left-handed
Quarks
Quarks
Leptons
Leptons
Forces
Higgs boson

Effects on the gauge-boson propagators



$$\equiv \Pi_{ij}(q^2)$$

nicely parametrized in terms of 4 quantities (for the EW sector):

$$\hat{T} = \frac{g^2}{M_W^2}\left[\Pi_{W_3}(0) - \Pi_{W+}(0)\right]$$

$$\hat{S} = g^2\ \Pi'_{W_3B}(0)$$

$$W = \frac{g^2 M_W^2}{2}\ \Pi''_{W_3}(0)$$

$$Y = \frac{g'^2 M_W^2}{2}\ \Pi''_{B}(0)$$

Peskin, Takeushi
Barbieri, AP, Rattazzi, Strumia

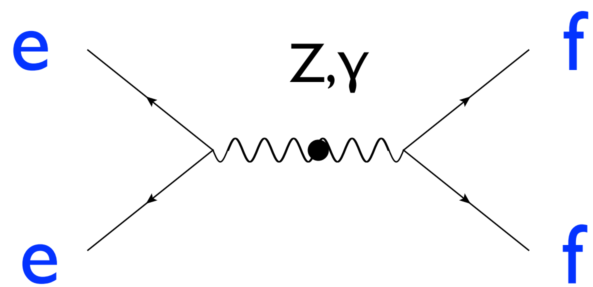
1) Transverse part of gauge bosons:

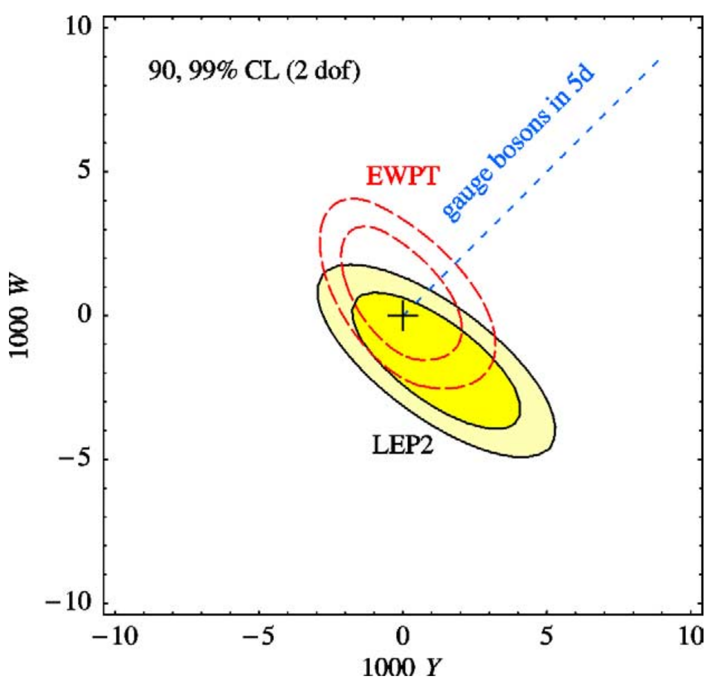
$$Y \leftrightarrow (\partial_\rho B_{\mu\nu})^2 \frac{1}{\Lambda^2}$$

$$W \leftrightarrow (D_\rho W_{\mu\nu})^2 \frac{1}{\Lambda^2}$$

} effects p^2/Λ^2

Thanks to LEP2:





bounds at the per mille level:
gauge bosons look like
elementary up to $\Lambda \gtrsim 3$ TeV!

(from Tevatron similar but
weaker bounds for the gluon)

1) Transverse part of gauge bosons:

$$\left.\begin{array}{l} Y \leftrightarrow (\partial_\rho B_{\mu\nu})^2 \dfrac{1}{\Lambda^2} \\[2ex] W \leftrightarrow (D_\rho W_{\mu\nu})^2 \dfrac{1}{\Lambda^2} \end{array}\right\} \text{effects } p^2/\Lambda^2$$

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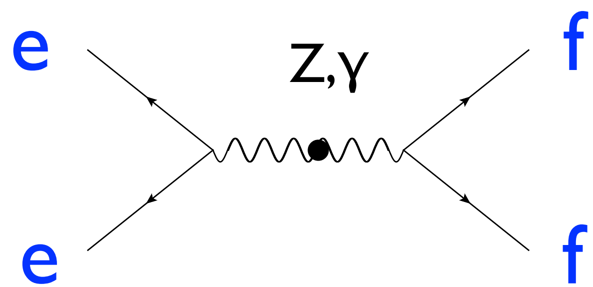

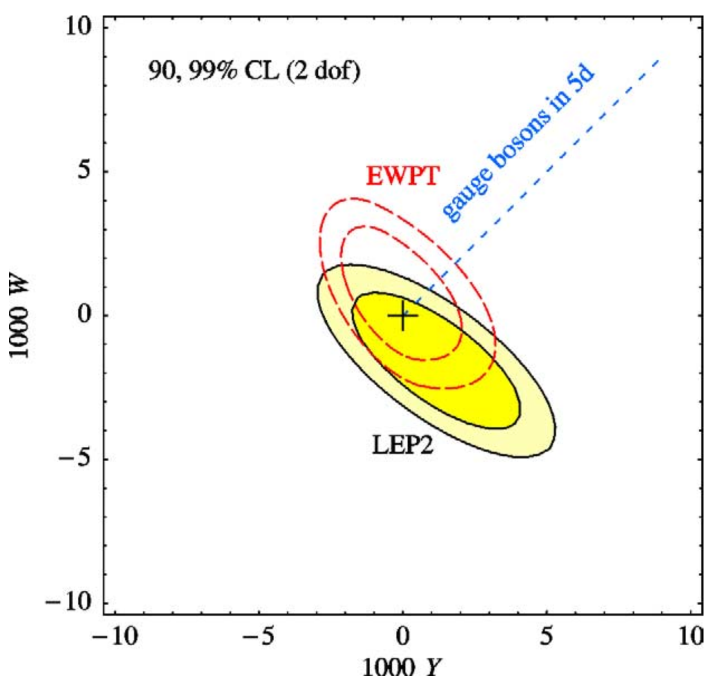

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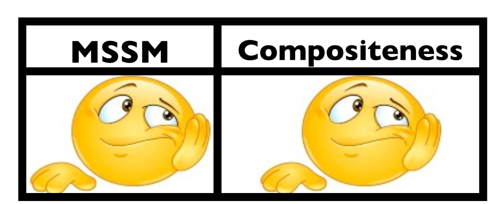
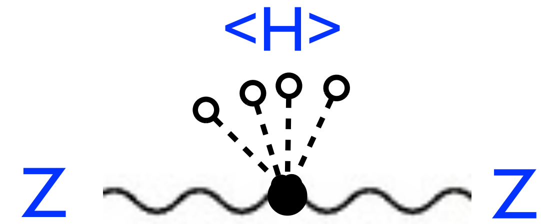


2) EW symmetry breaking effects:

➜ information on the EWSB sector

a) $\widehat{T} \leftrightarrow (H^\dagger \overleftrightarrow{D}_\mu H)^2 \frac{1}{\Lambda^2}$

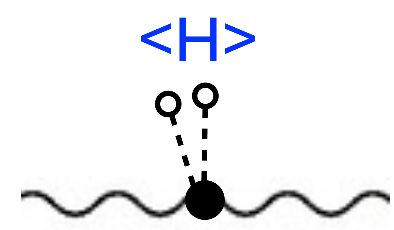
➥ Contribute to the Z-mass:



Equivalent to ρ-1: Contribution to $M_W^2 - M_Z^2 \cos^2\theta_W$

b) $\widehat{S} \leftrightarrow H^\dagger W_{\mu\nu} H\, B_{\mu\nu} \frac{1}{\Lambda^2}$

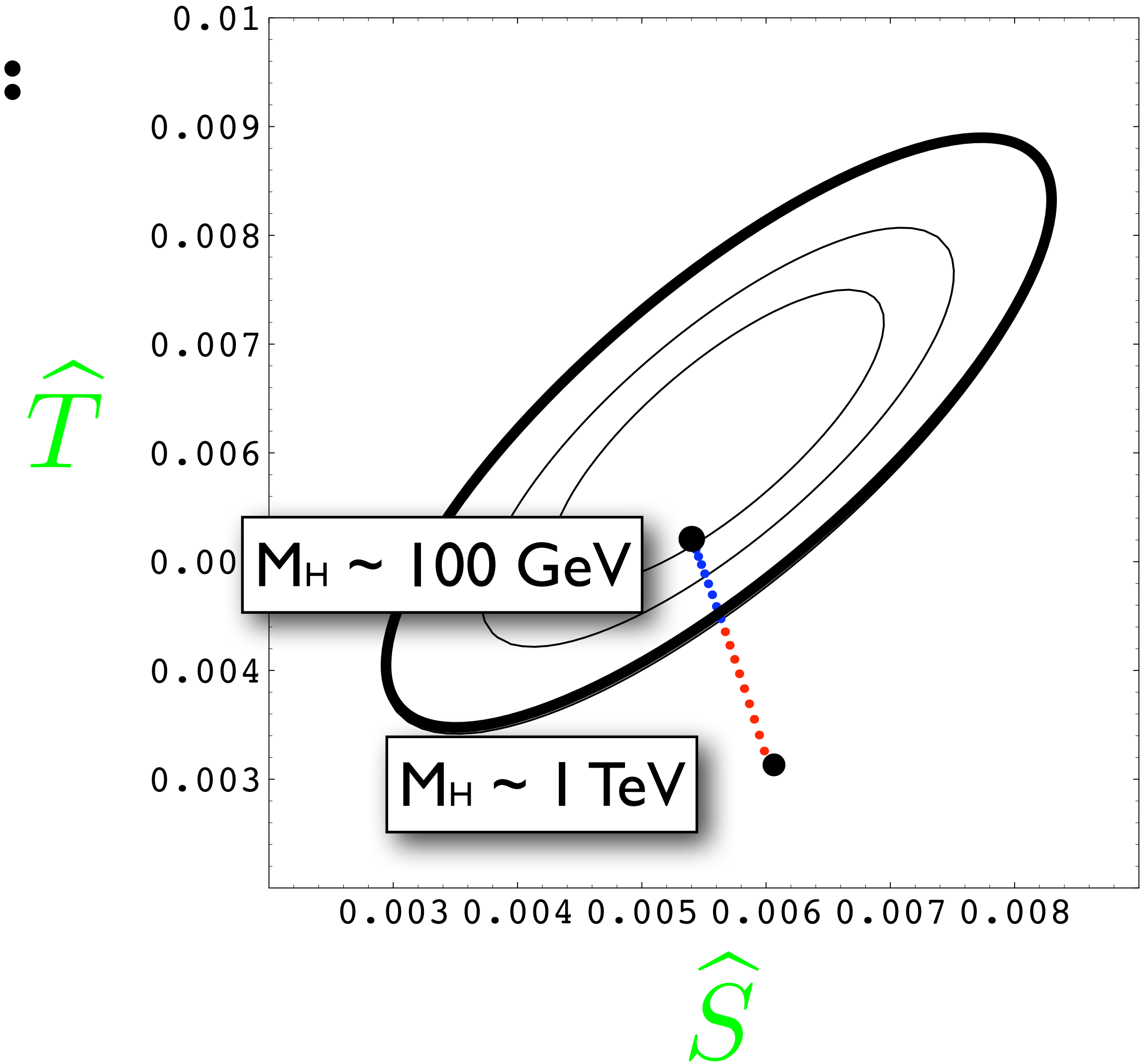
➥ W-B kinetic mixing:



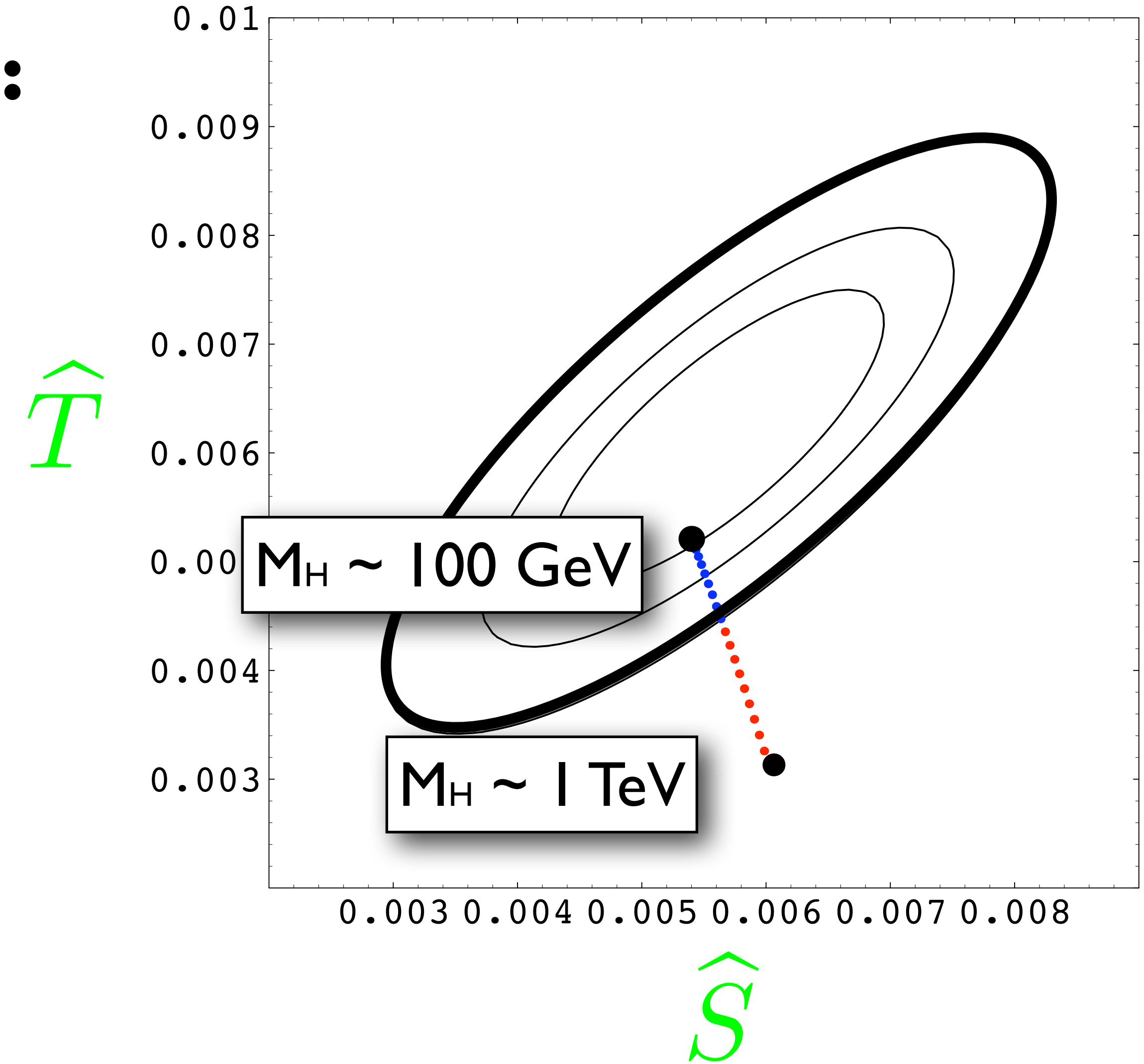
W_μ B_μ

Higgs contribute at the loop level to both

LEP1+Tevatron:



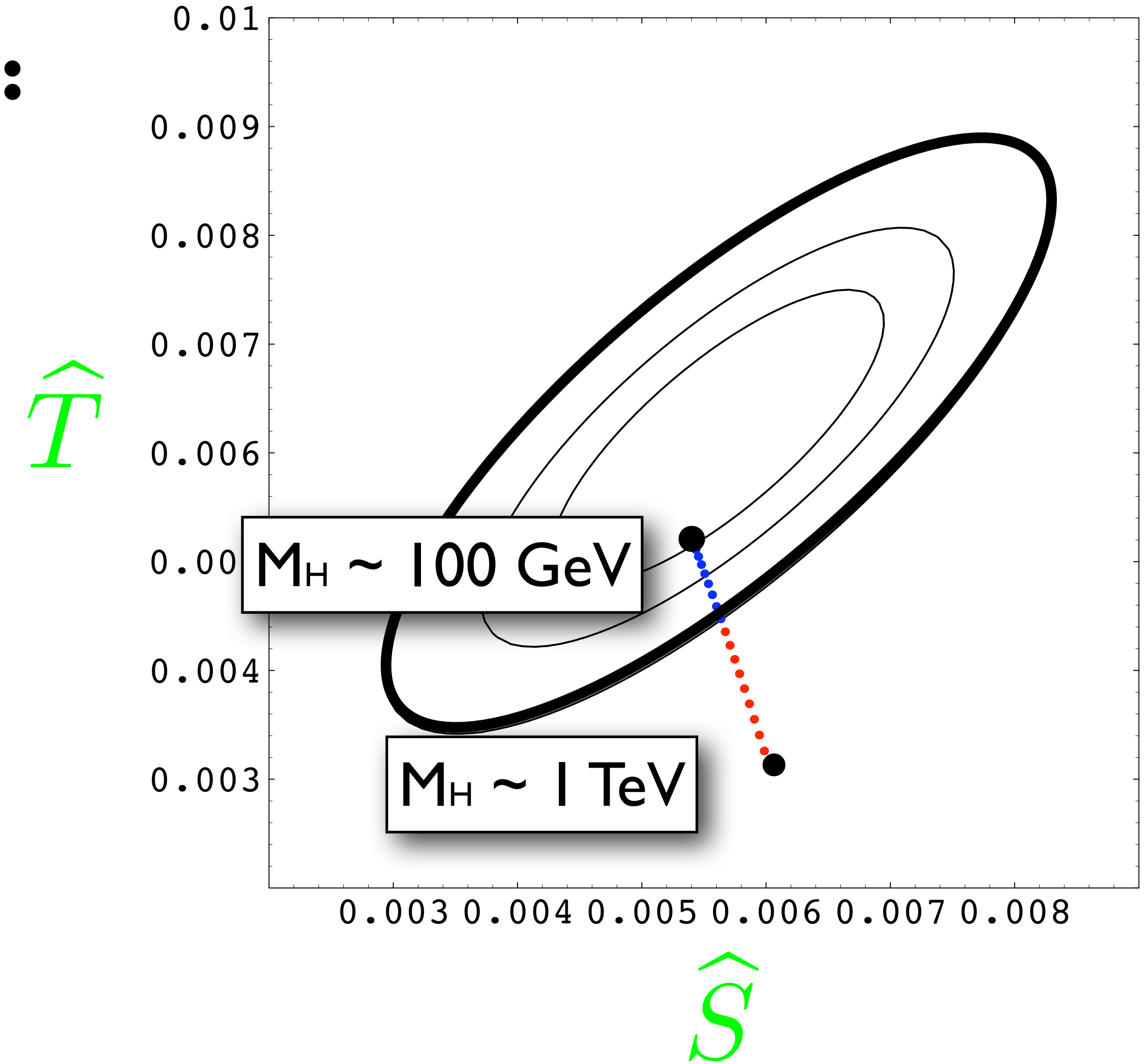
LEP1+Tevatron:



☛ To keep $M_W^2 \approx M_Z^2 \cos^2\theta_W$ a "custodial" symmetry must be present in the EWSB sector

☛ A light Higgs is preferred

LEP1+Tevatron:

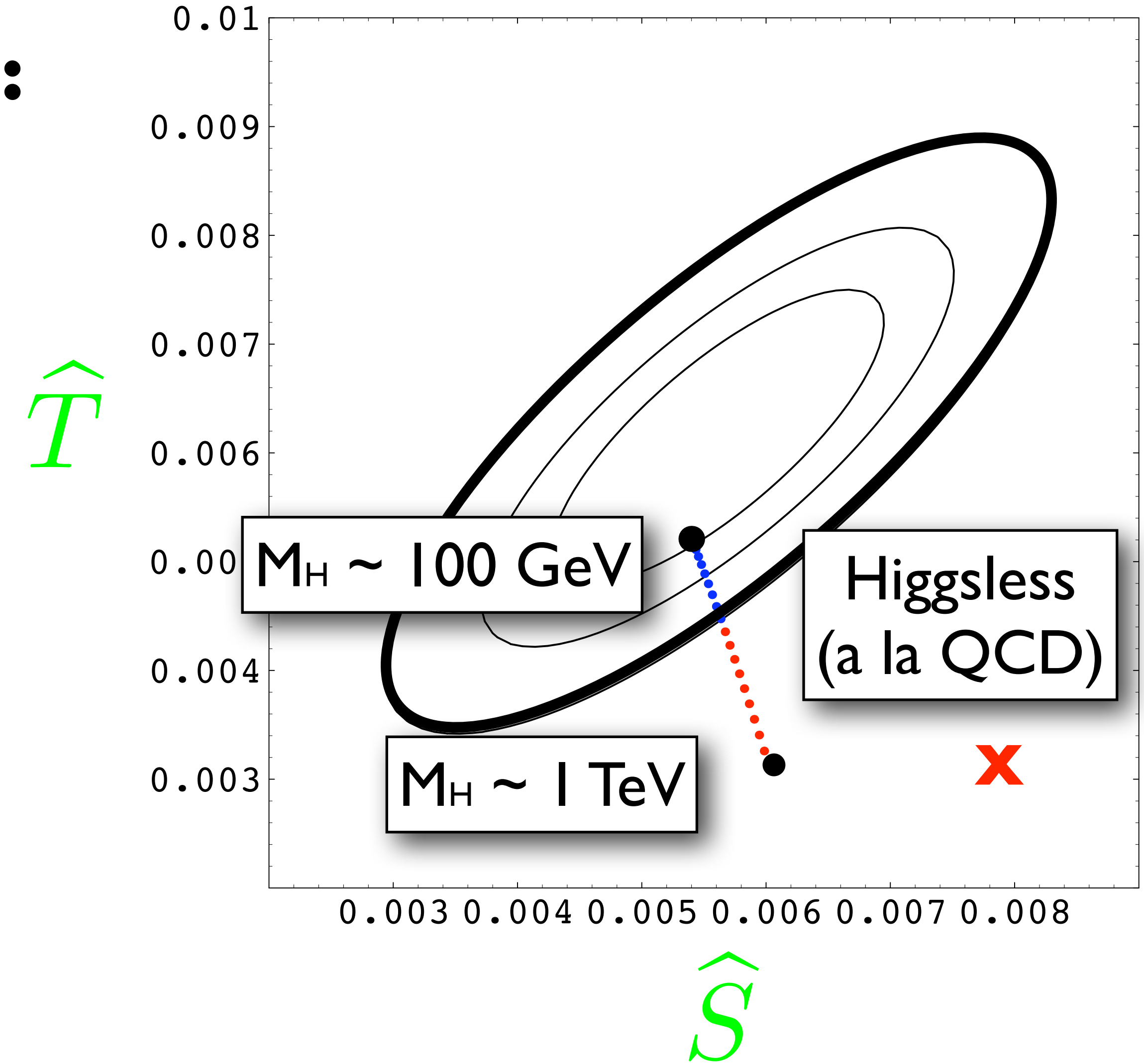


MSSM	Compositeness
	

☛ To keep $M_W^2 \approx M_Z^2 \cos^2\theta_W$ a "custodial" symmetry must be present in the EWSB sector ✓

☛ A light Higgs is preferred ✓

LEP1+Tevatron:

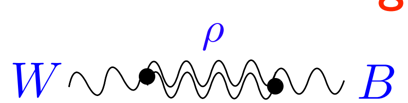


MSSM	Compositeness
	

☛ To keep $M_W^2 \approx M_Z^2 \cos^2\theta_W$ a "custodial" symmetry must be ✓

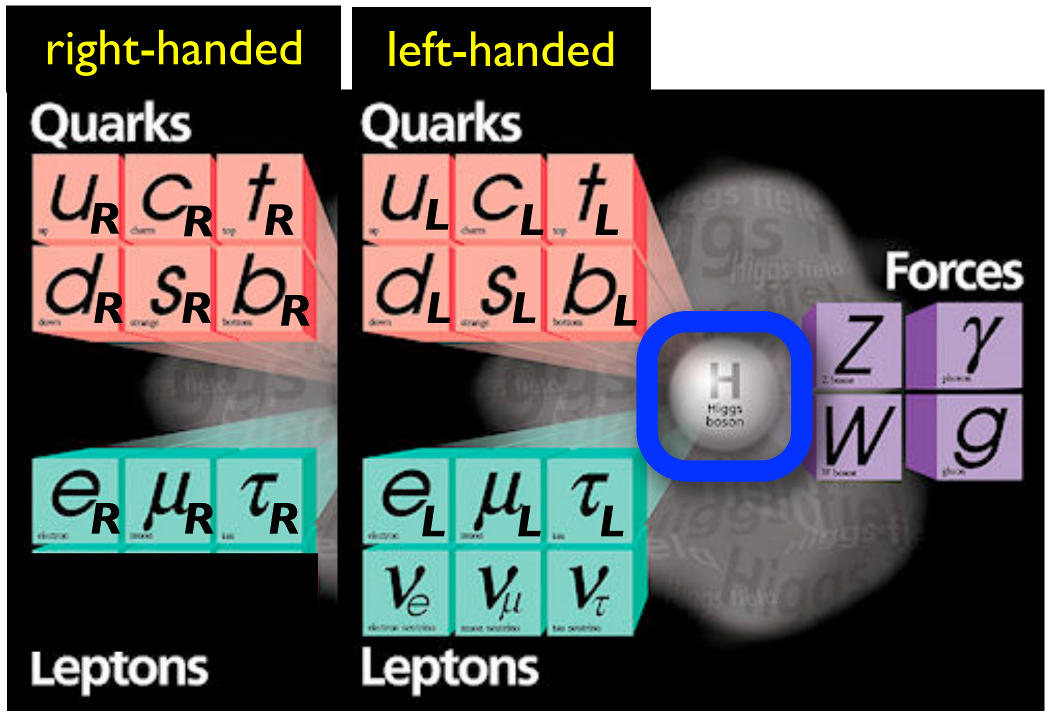
In **composite Higgs models**:

spin-one resonances can give tree-level contribution to S:



$M_\rho \gtrsim$ 3 TeV when 1 TeV expected

➥ Certain tuning in the models are needed (<10-20%)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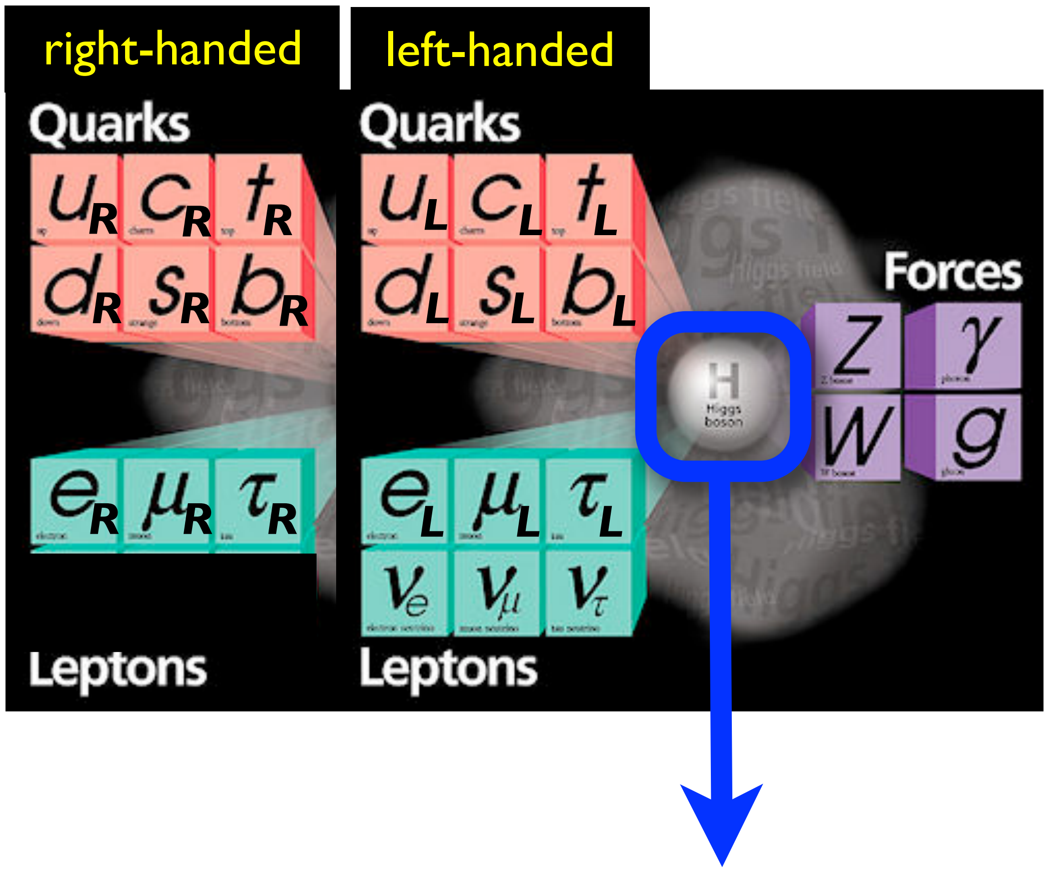
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No more...

Wrapping up (before the LHC):

Quite well-measured:

Leptons, left-handed quarks, gauge bosons

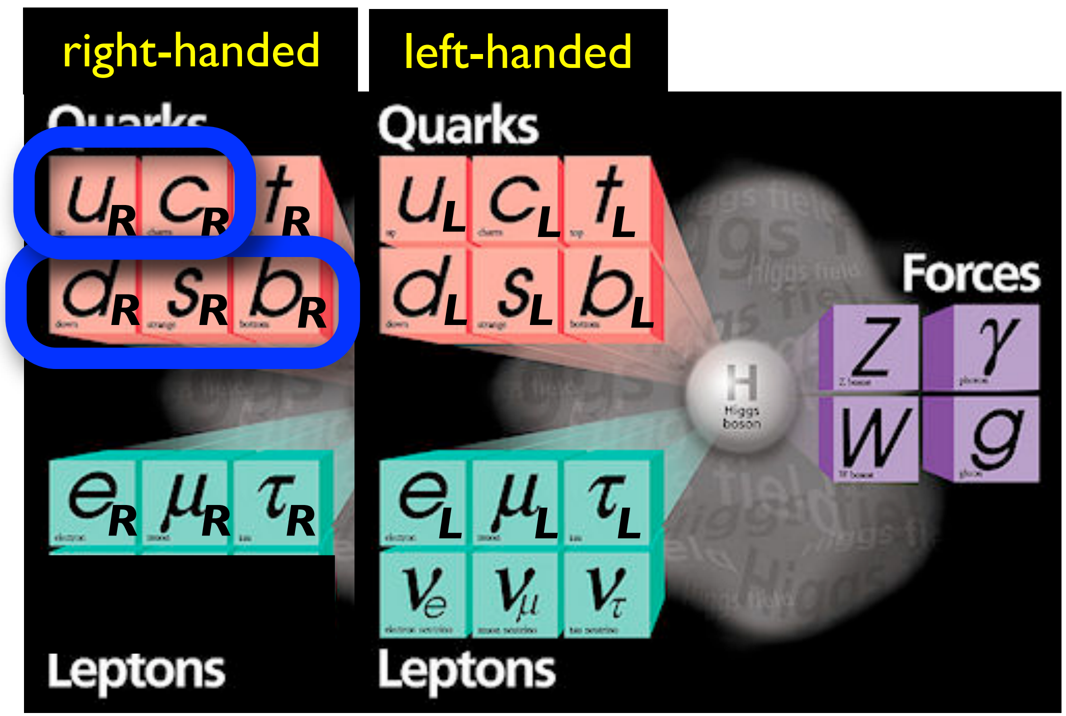
Not very well-measured **(with some hints of BSM)** **:**

Right-handed quark, especially the top

Not at all well-measured:

Higgs

After the LHC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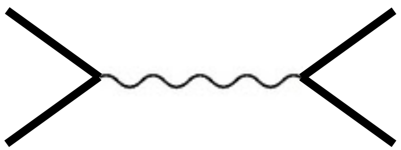
Testing right-handed quark at the LHC

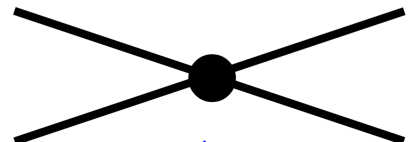
Best test at the LHC: Dijets

$pp \to q\bar{q} \to$ jet+jet affected at high-energy by $\frac{(\bar{u}_R \gamma_\mu u_R)^2}{\Lambda^2}$



$\frac{1}{t}$

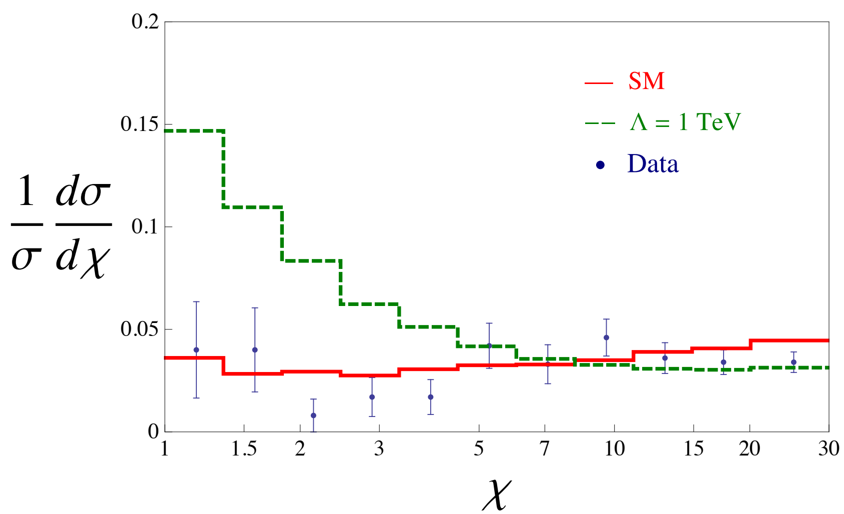
+



$\frac{1}{\Lambda^2}$

➥ large t needed to enhance new-physics effects:

$\hat{t} = -\hat{s}(1 - \cos\theta^*)/2$: Large energies and large scattering angles



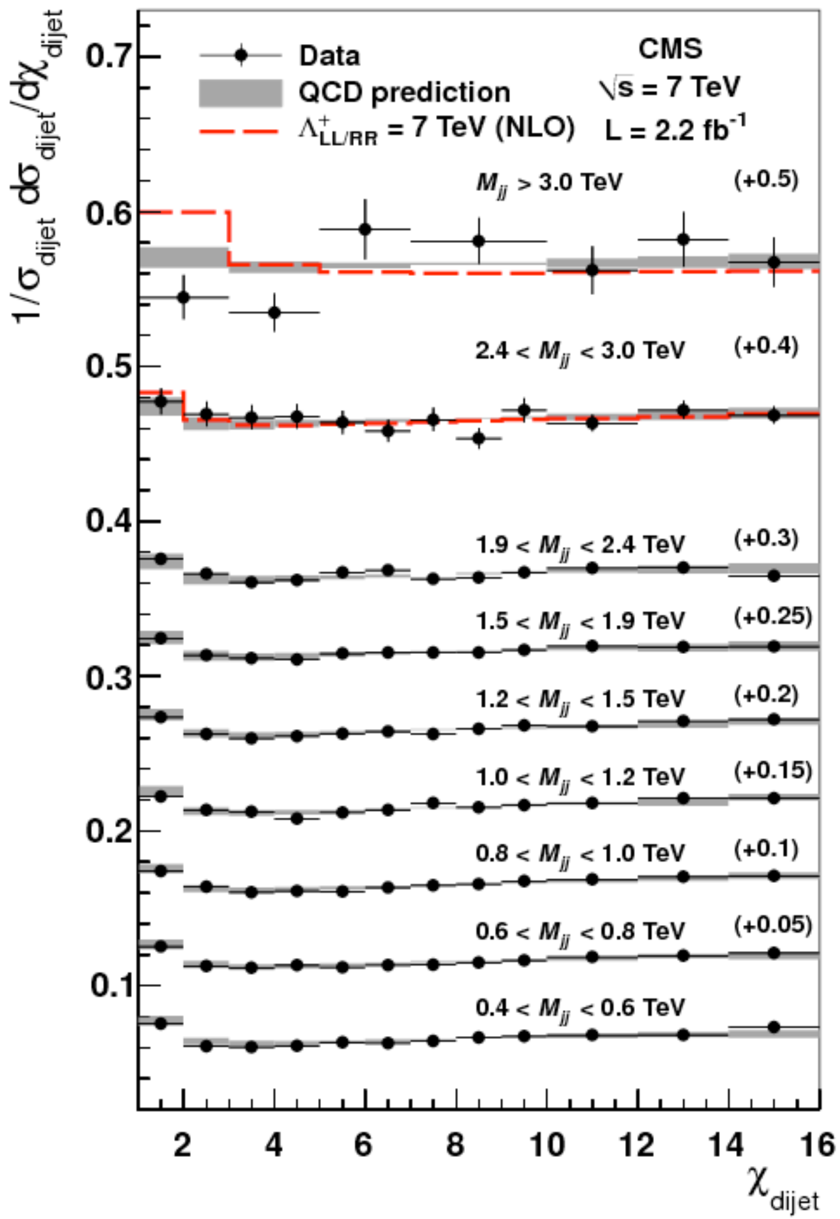
arXiv:1201.6510
using 7 TeV data

$m_{jj} > 2$ TeV

$\chi = (1 + |\cos\theta^*|)/(1 - |\cos\theta^*|)$

$\chi = e^{|y_1 - y_2|}$

LHC recent data



Nothing seen beyond QCD!

Bounds on the scale suppressing four-quark interactions

arXiv:1201.6510
using 7 TeV data

Operator	$\Lambda_-/\sqrt{c_i}$	$\Lambda_+/\sqrt{c_i}$	(TeV)
$\mathcal{O}_{uu}^{(1)}$	4.5	3.0	
$\mathcal{O}_{dd}^{(1)}$	2.4	2.0	
$\mathcal{O}_{ud}^{(1)}$	2.2	2.2	
$\mathcal{O}_{ud}^{(8)}$	1.8	1.3	

bounds as good as for leptons at LEP2

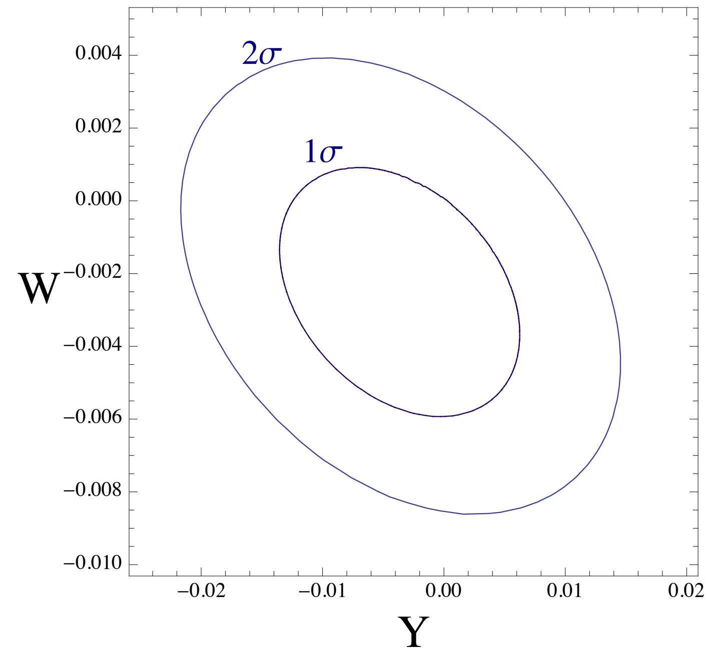
where

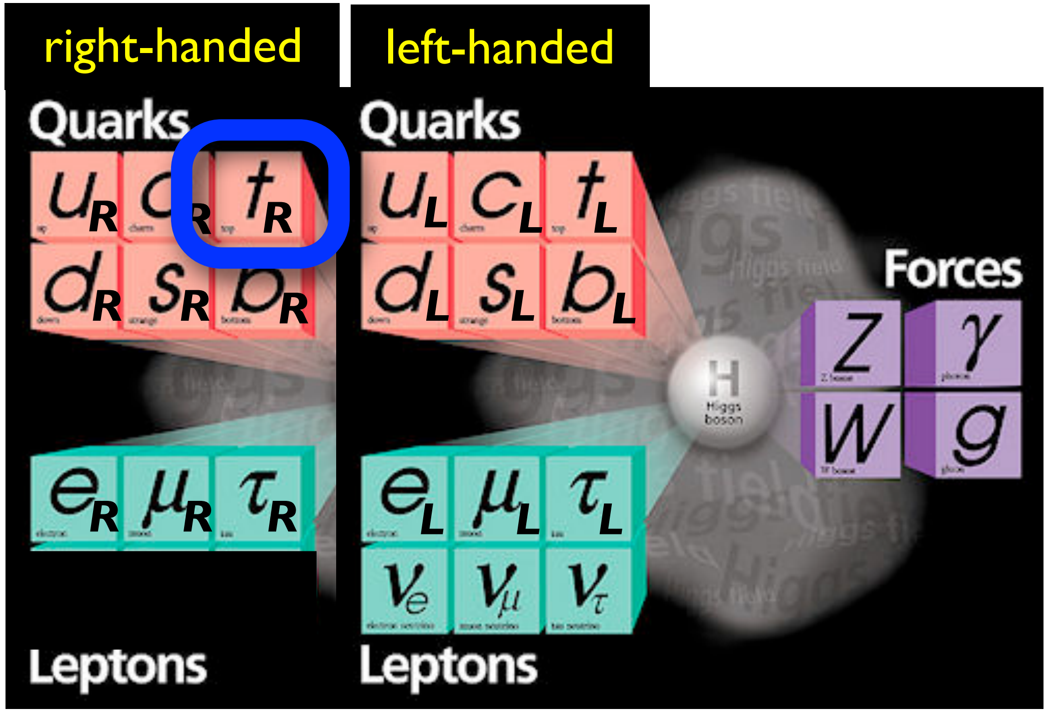
$$\begin{aligned}
\mathcal{O}_{uu}^{(1)} &= (\bar{u}_R\gamma^\mu u_R)(\bar{u}_R\gamma_\mu u_R)\\
\mathcal{O}_{dd}^{(1)} &= (\bar{d}_R\gamma^\mu d_R)(\bar{d}_R\gamma_\mu d_R)\\
\mathcal{O}_{ud}^{(1)} &= (\bar{u}_R\gamma^\mu u_R)(\bar{d}_R\gamma_\mu d_R)\\
\mathcal{O}_{ud}^{(8)} &= (\bar{u}_R\gamma^\mu T^A u_R)(\bar{d}_R\gamma_\mu T^A d_R)
\end{aligned}$$

Recast as a bound on gauge-boson propagator p^2/Λ^2 effects:

$$\frac{-Y}{4m_W^2}(\partial_\rho B_{\mu\nu})^2, \quad \frac{-W}{4m_W^2}(D_\rho W^I_{\mu\nu})^2, \quad \frac{-Z}{4m_W^2}(D_\rho G^A_{\mu\nu})^2$$

$$-9\times 10^{-4} \lesssim Z \lesssim 3\times 10^{-4}$$





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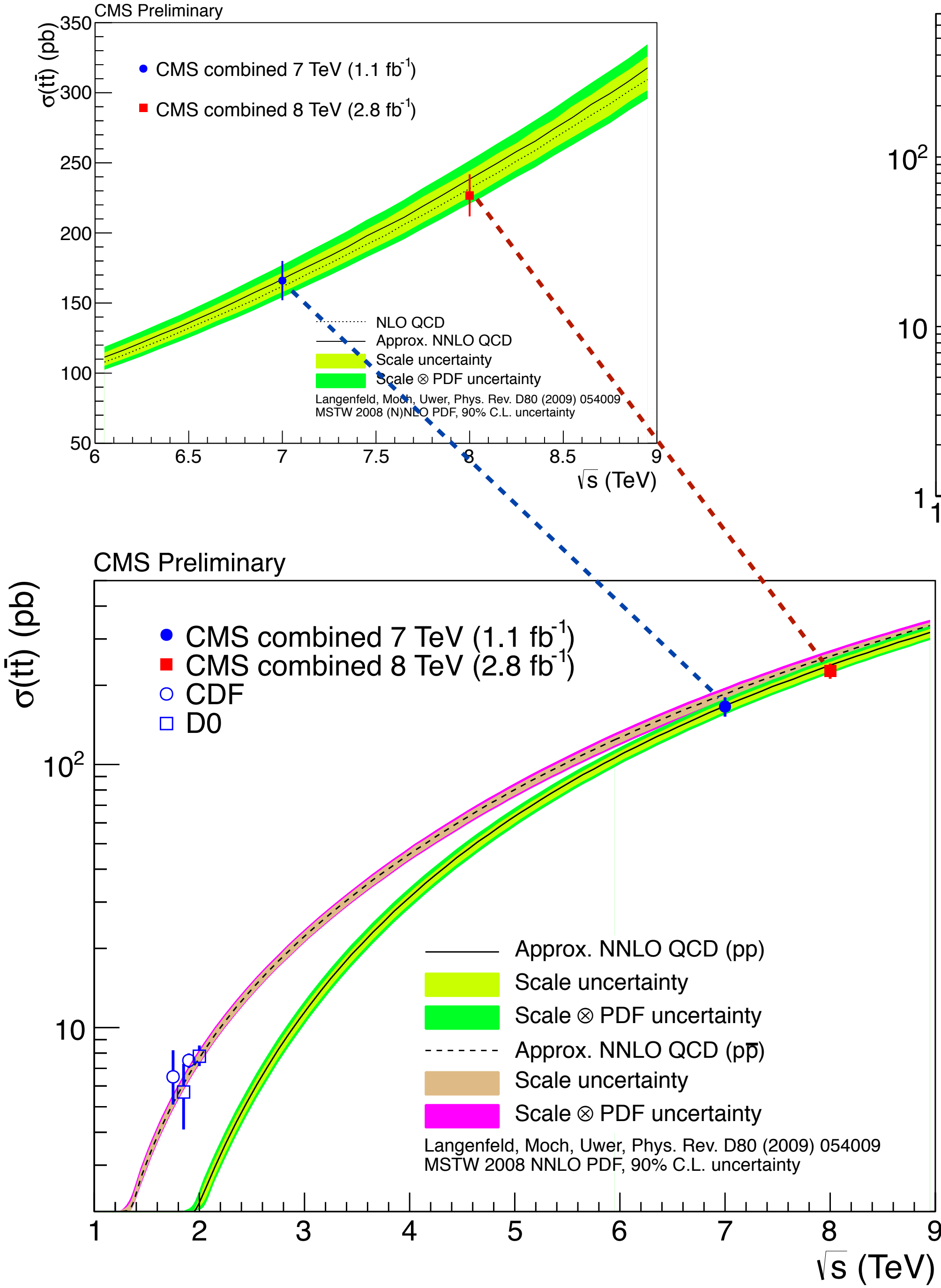
Plenty of new relevant data

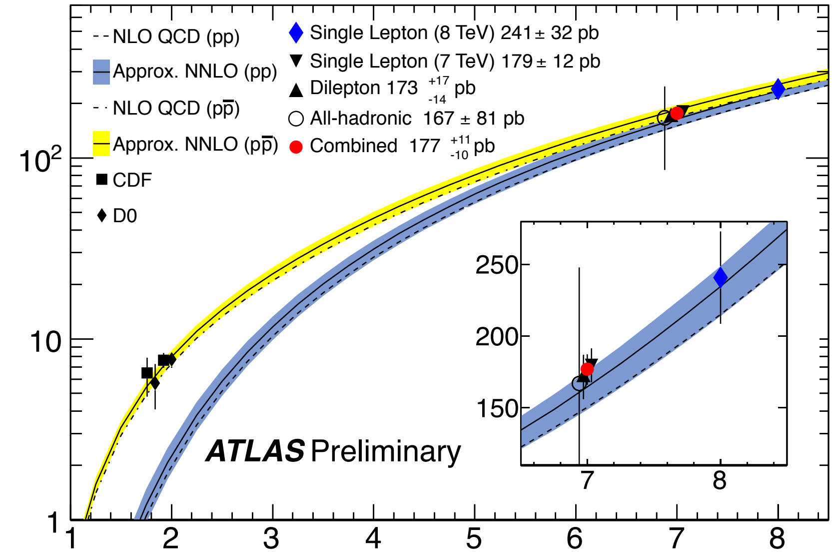
Plenty of new relevant data

Let's first address *possible new physics* in the top FB asymmetry measured at Tevatron:

1) Expecting larger production cross-section, specially at large invariant-mass from new physics

New LHC data: $t\bar{t}$ cross-sections





Excellent agreement with the SM

Differential cross sections

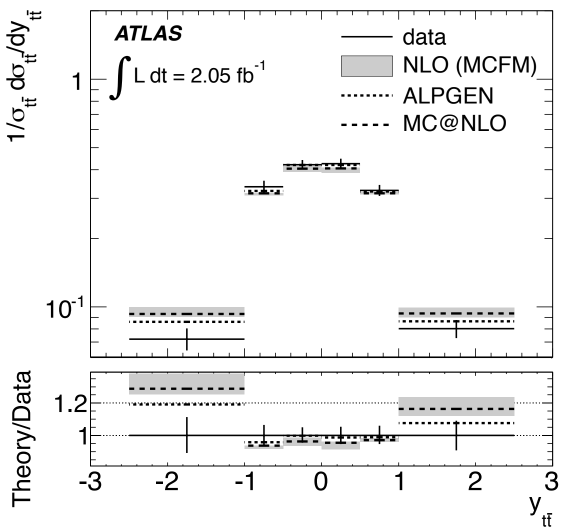
CMS: CMS PAS TOP-12-027 (l+jets)
CMS: CMS PAS TOP-12-028 (dilepton)

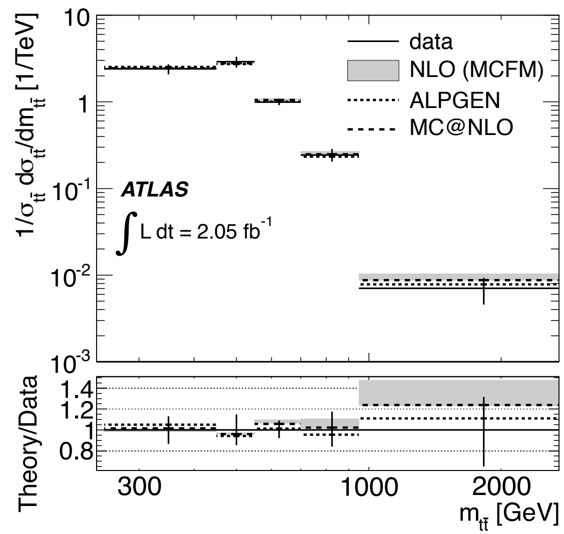
ATLAS: Eur. Pys. J. C (2013) (l+jets)

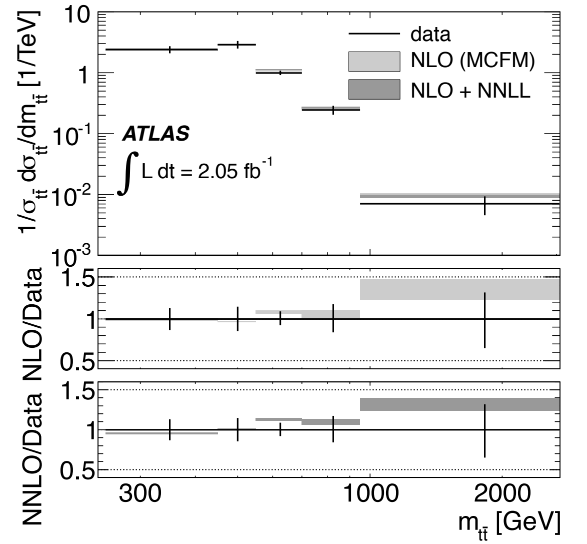
No significant deviation from SM observed

$$\frac{1}{\sigma}\frac{d\sigma(x_i)}{dx_i}$$

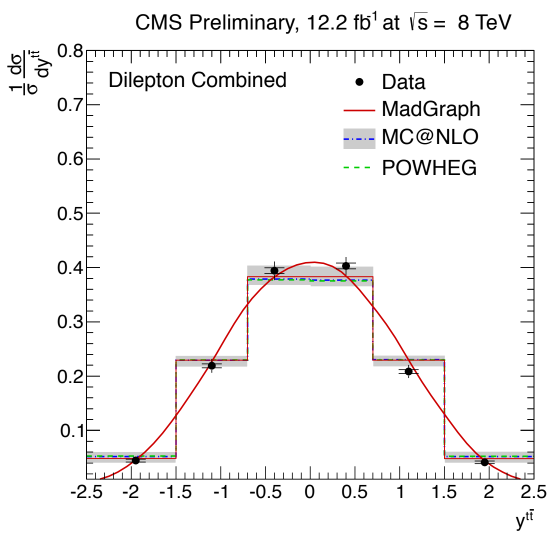
ATLAS

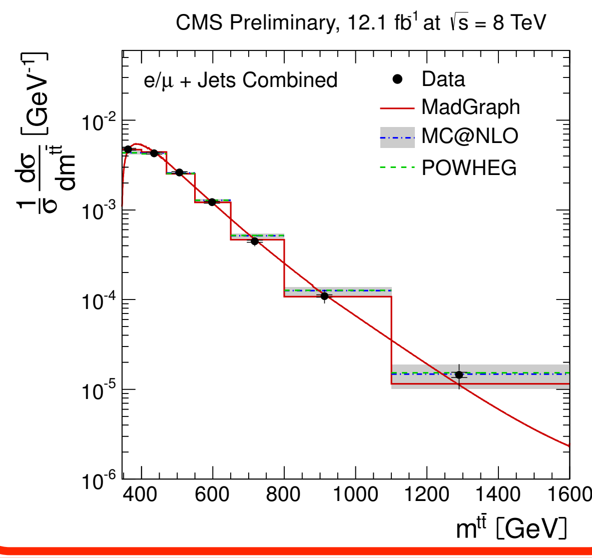


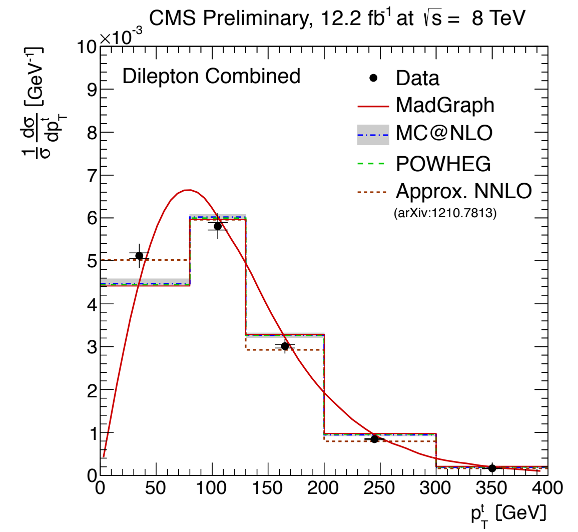




CMS **New**







Plenty of new relevant data

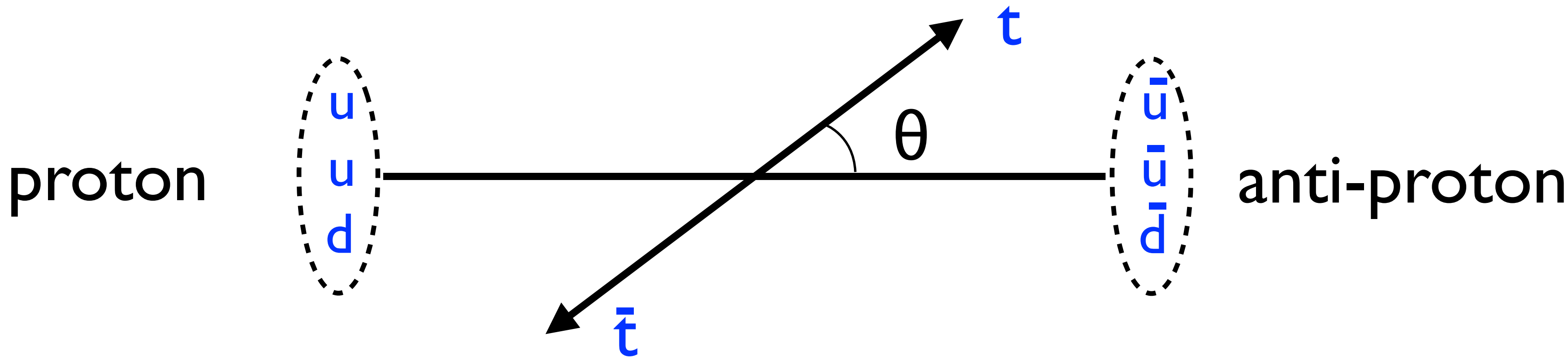
Let's first address *possible new physics* in the top FB asymmetry measured at Tevatron:

1) Expecting larger production cross-section, specially at large invariant-mass from new physics X

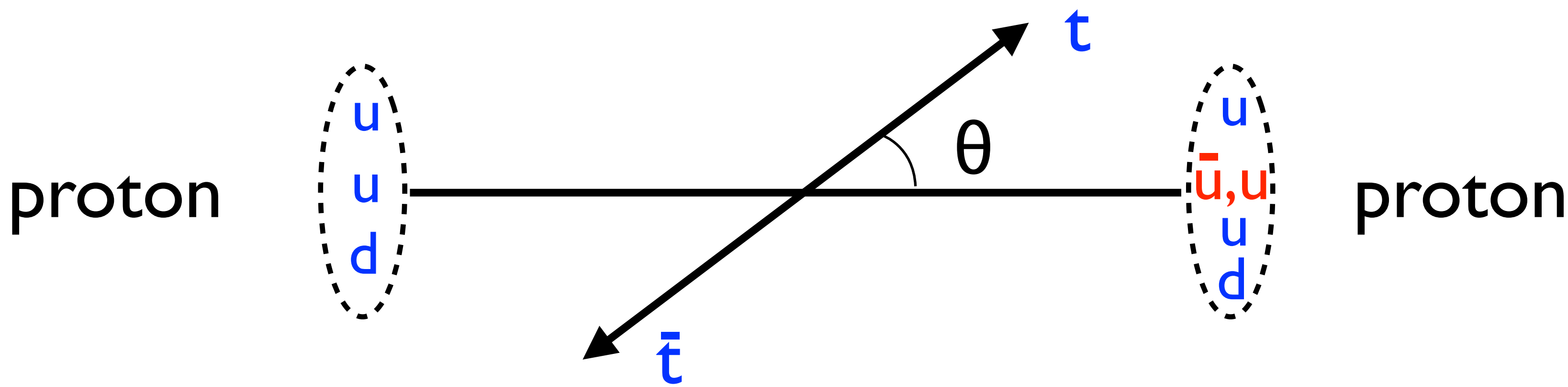
2) Expecting deviations form top asymmetries from new physics

At the LHC, no meaning of the Forward-Backward asymmetry

$p\bar{p}$-collider: ~ known direction of the quark and antiquark:



pp-collider: Symmetric initial state. We must exploit that valence quarks have ~ more momentum than (sea) antiquark



➥ different rapidity distributions

$t\bar{t}$-Charge Asymmetry

At the LHC:

Reconstructing $t\bar{t}$: $\Delta|y| = |y_t| - |y_{\bar{t}}|$

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$t\bar{t}$-Charge Asymmetry

arXiv:1302.6618

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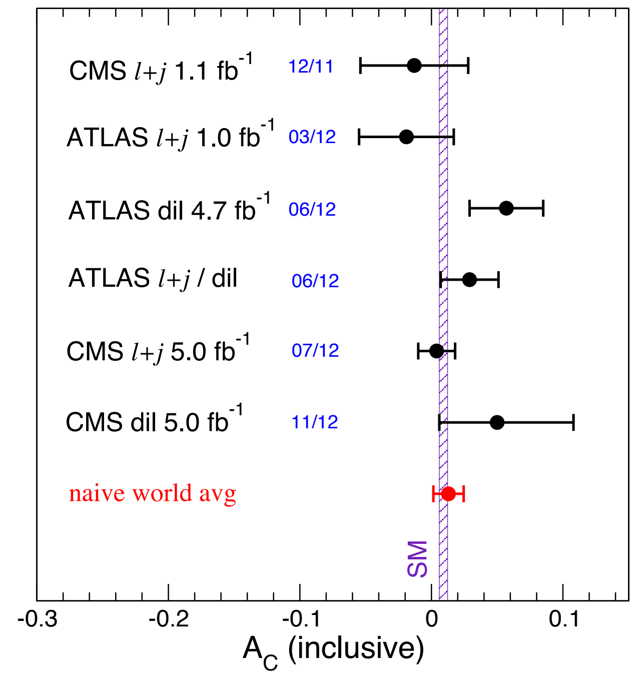

No deviation with respect the SM!

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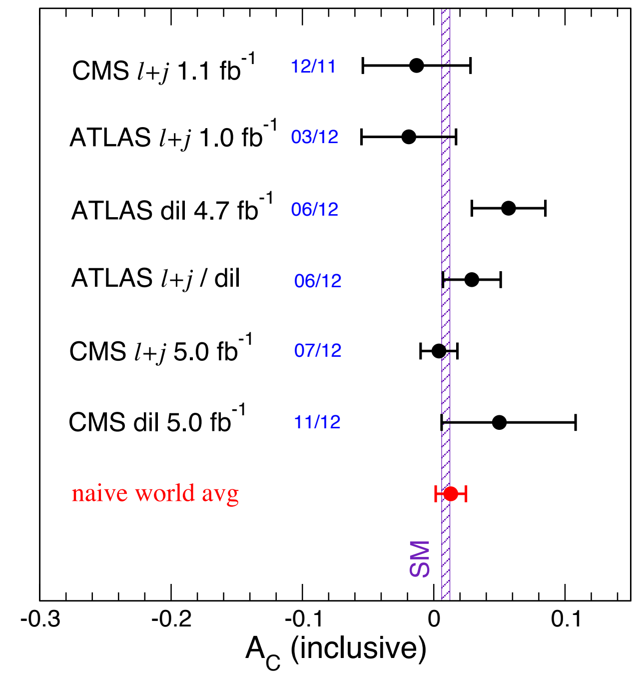
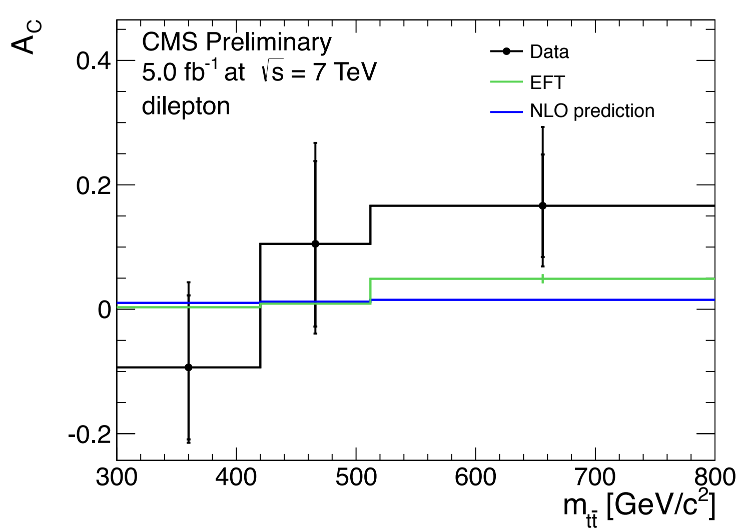
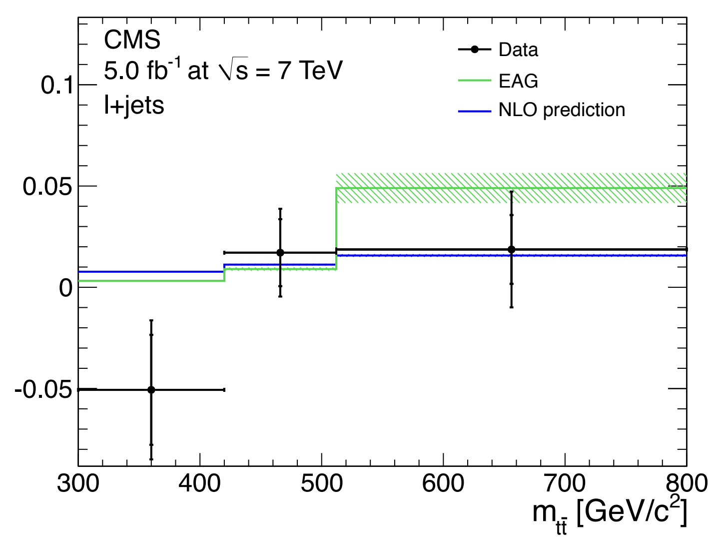






No increase with the invariant mass

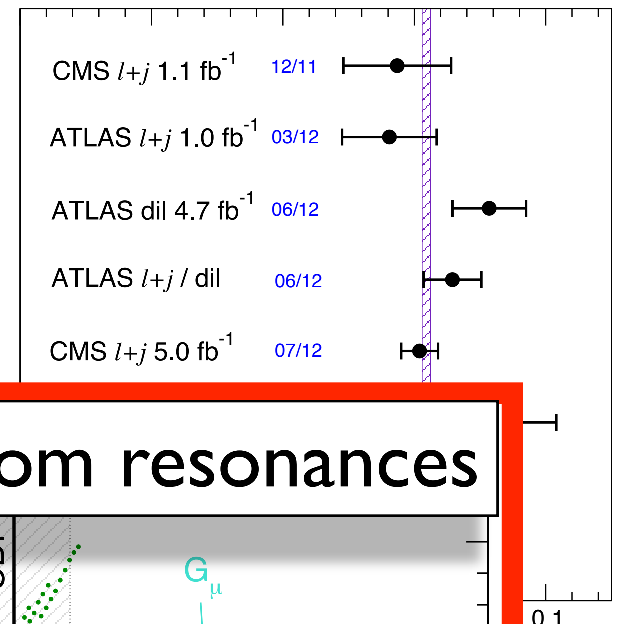
$t\bar{t}$-Charge Asymmetry

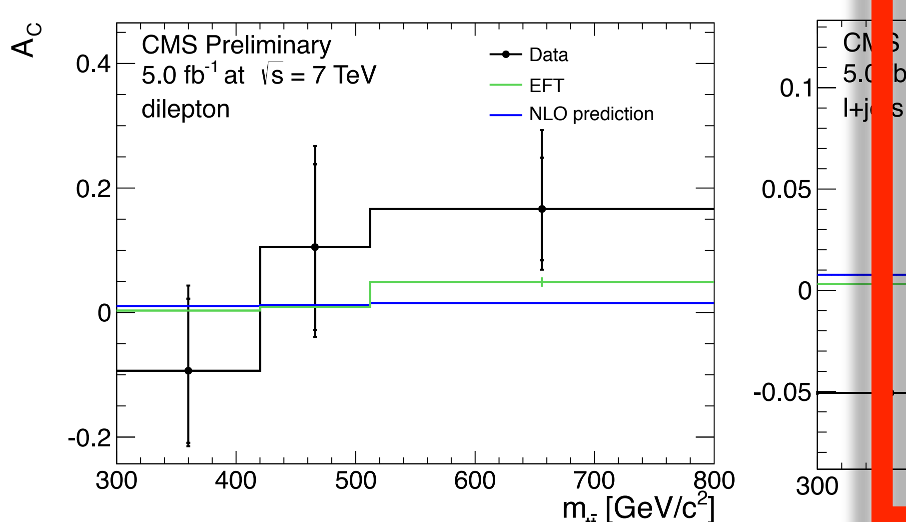
arXiv:1302.6618

At the LHC:

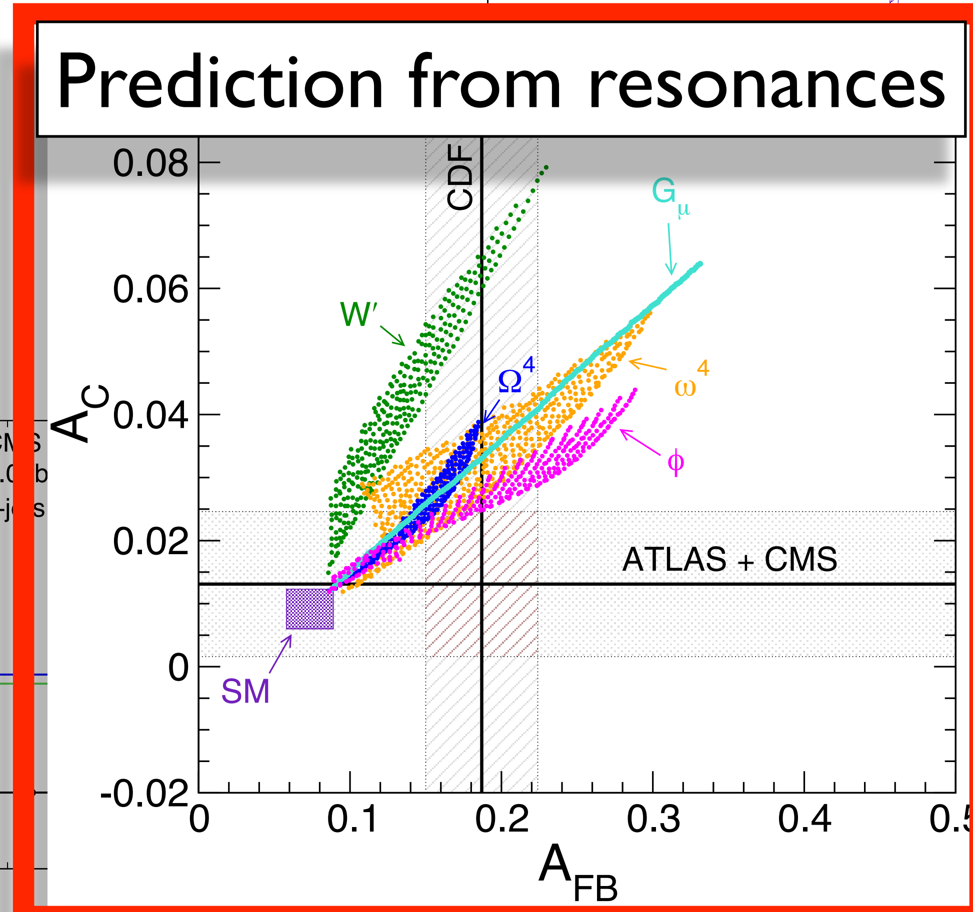
Reconstructing $t\bar{t}$: $\Delta|y| = |y_t| - |y_{\bar{t}}|$

$$A_C = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$$





Prediction from resonances



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Plenty of new relevant data

Let's first address *possible new physics* in the top FB asymmetry measured at Tevatron:

1) Expecting large production cross-section, specially at large invariant-mass from new physics ✗

2) Expecting deviations form top asymmetries from new physics ✗

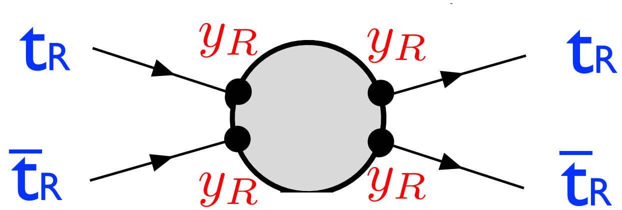
Other new physics expectations

t_R <u>remains</u> as the only quark with possible large BSM effects

Also the only one really motivated by **composite Higgs** models

<u>Main effects:</u>

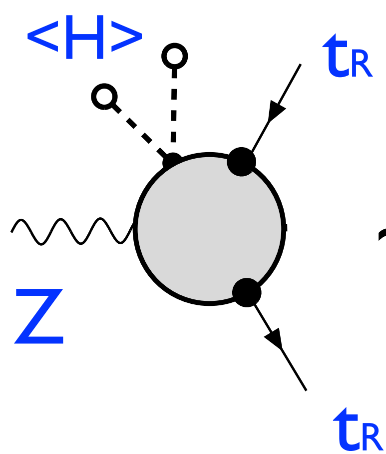
1)



$$\sim \frac{y_R^4}{\Lambda^2}$$

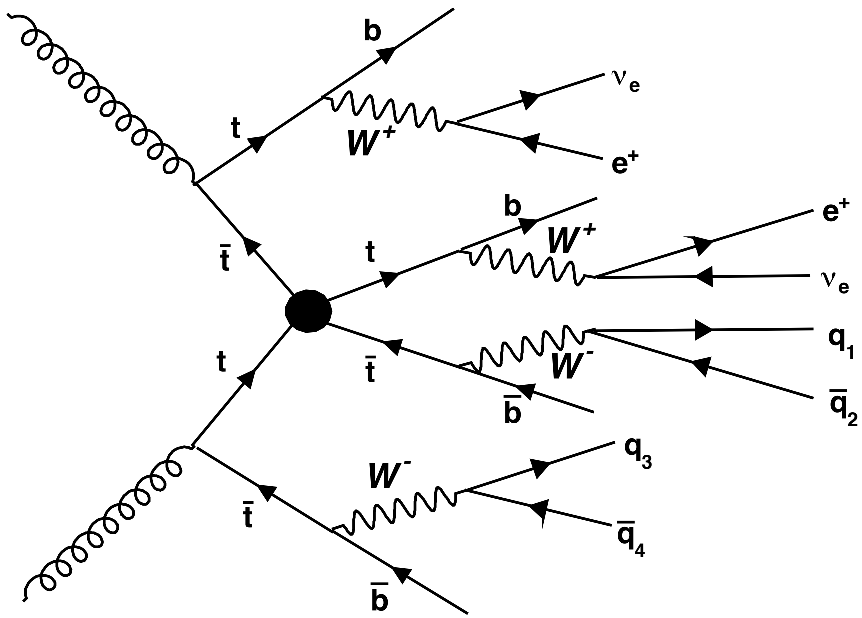
important for $y_R > 1$

2)



$$\sim \frac{y_R^2 v^2}{\Lambda^2}$$

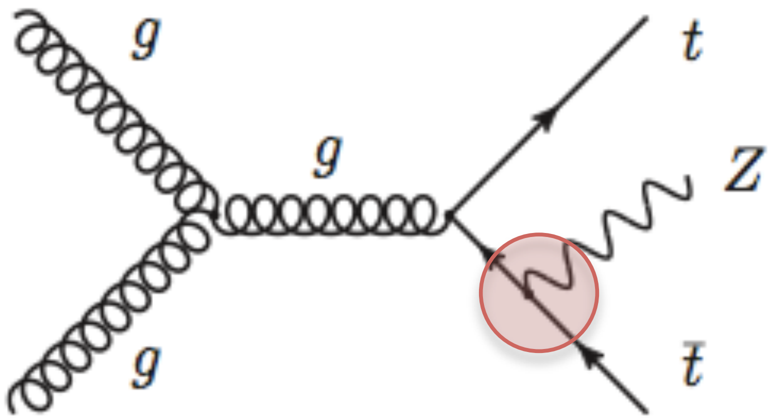
To be seen in 4 top-quark production:

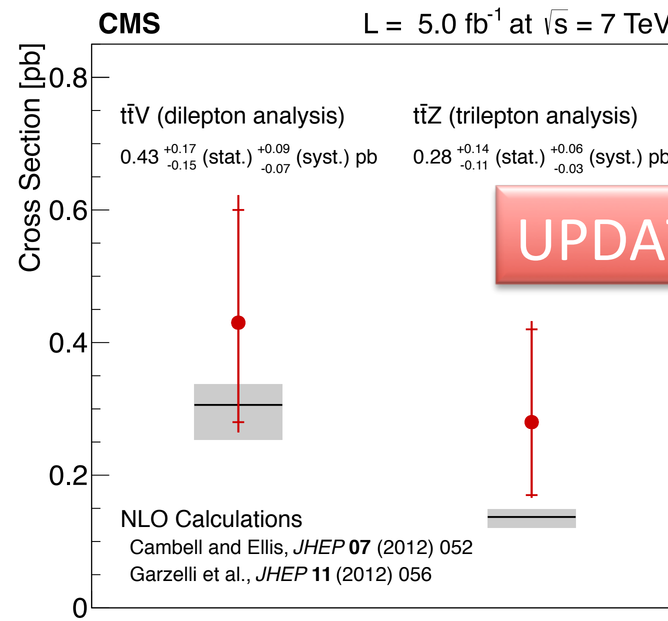


ATLAS-CONF-2012-130: **σ < 61 fb** → $\Lambda \gtrsim 500$ GeV (for $y_R \sim 1$)

PHYSICAL REVIEW D 78, 074026 (2008)

First evidence of ttZ production:



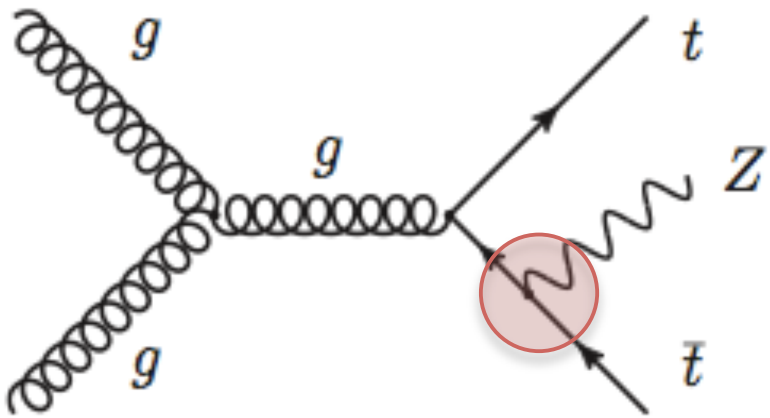


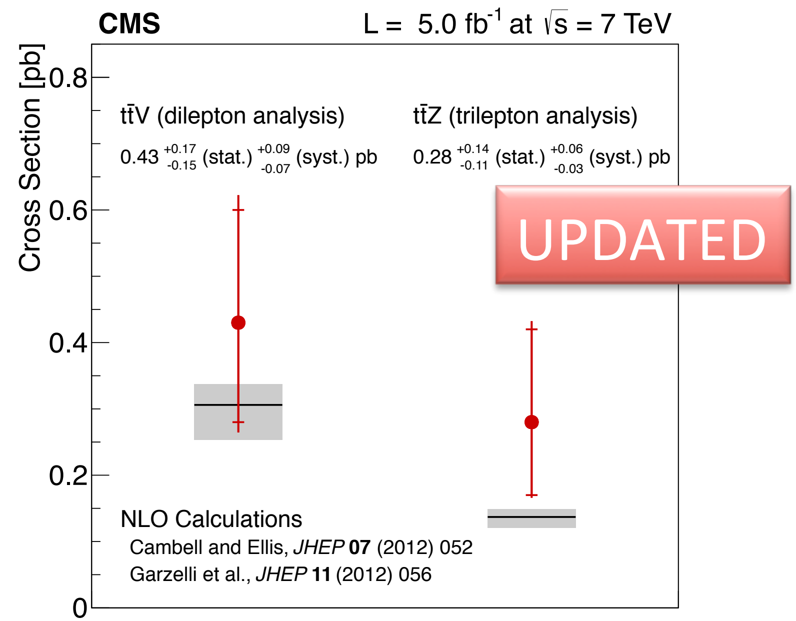
UPDATED

still big errors...

First direct measurements of top-Z coupling.

First evidence of ttZ production:





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First direct measurements of top-Z coupling.

Also flavor-changing decays:

$$BR(t \to cZ) = 2 \times 10^{-4} \, (\xi c_R)^2 \left(\frac{\theta_{tc}}{V_{cb}} \right)^2$$

$\xi = (v/\Lambda)^2$ for $y_R \sim 1$

JHEP06(2007)045

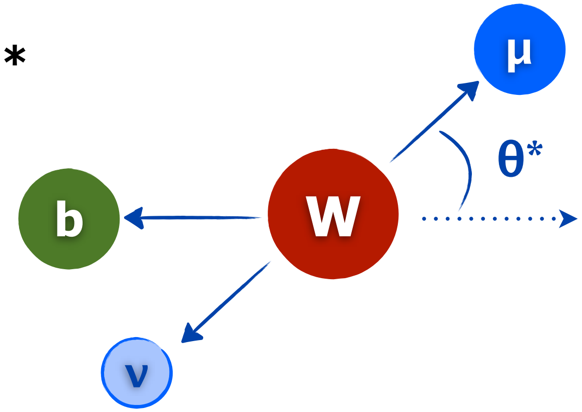
CMS bound: $BR(t \to Zq) < 0.21\%$

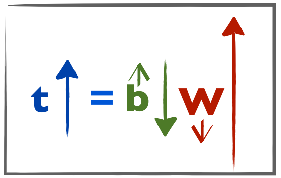
arXiv:1208.0957

W helicity in top decays

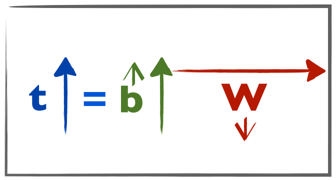
V-A SM nature of the tWb coupling can be probed using θ*

- compute cosθ* to measure contributions from different helicities
- $F_{0/L/R}$ relative contributions for SM are well known
- Different relative contrib. can indicate new physics
  - in SM only $V_L \neq 0$ and $g_R = g_L = V_R = 0$

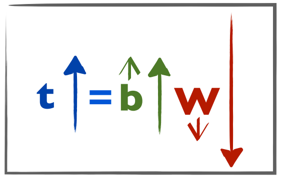




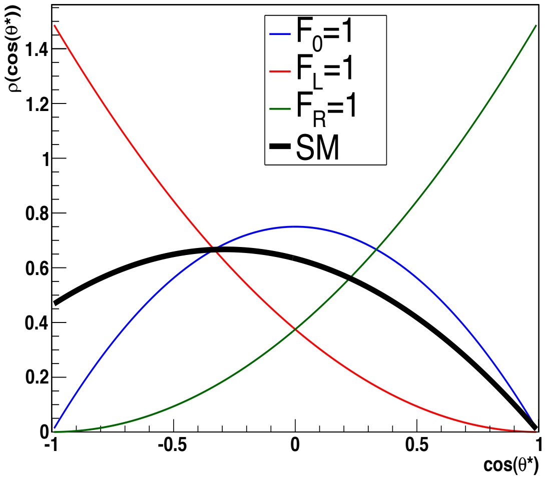
F_L [SM≈0.311]



F_0 [SM≈0.687]



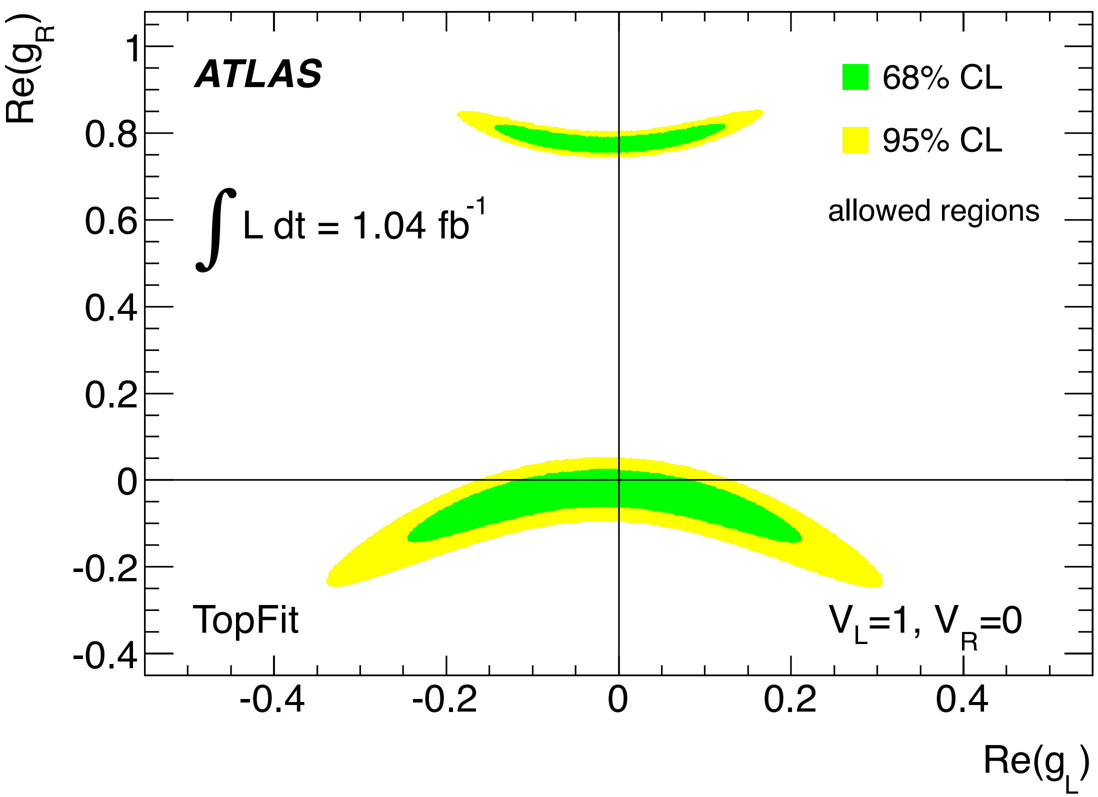
F_R [SM≈0.001]

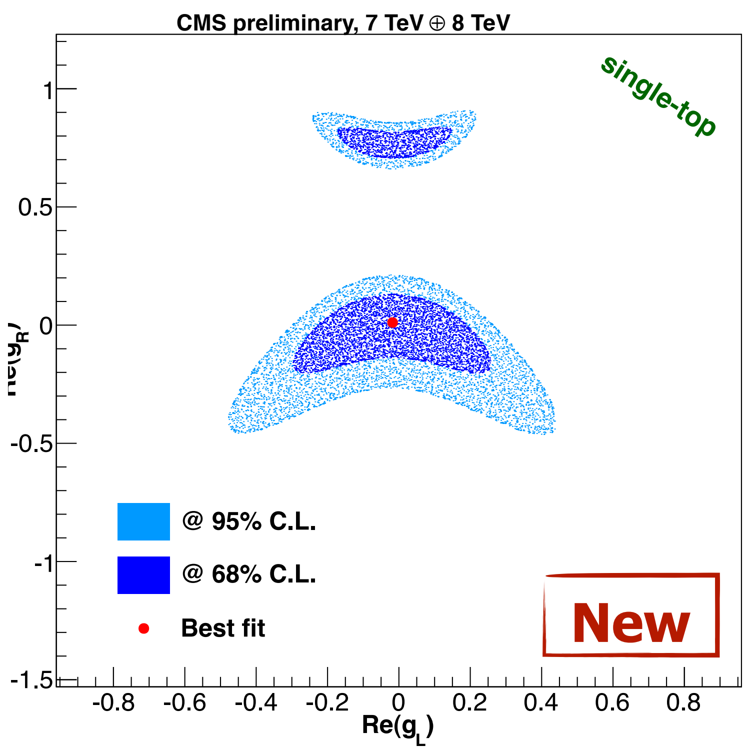


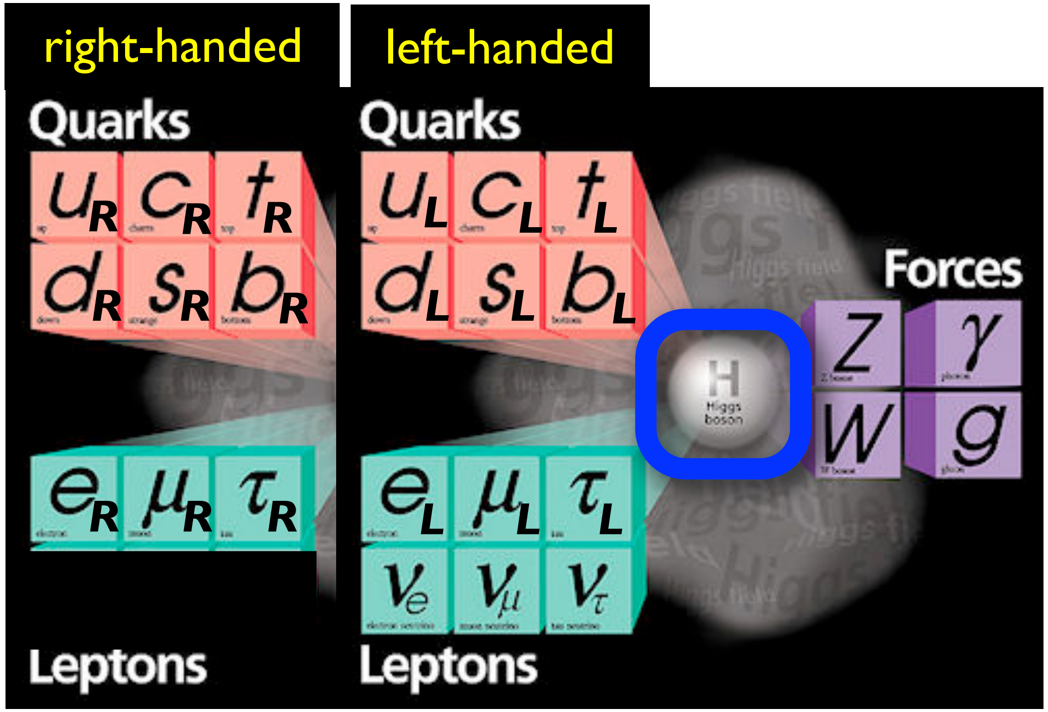
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)F_0 + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R$$

New constraints on top dipole moments:

$$-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_\nu}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_\mu^-$$

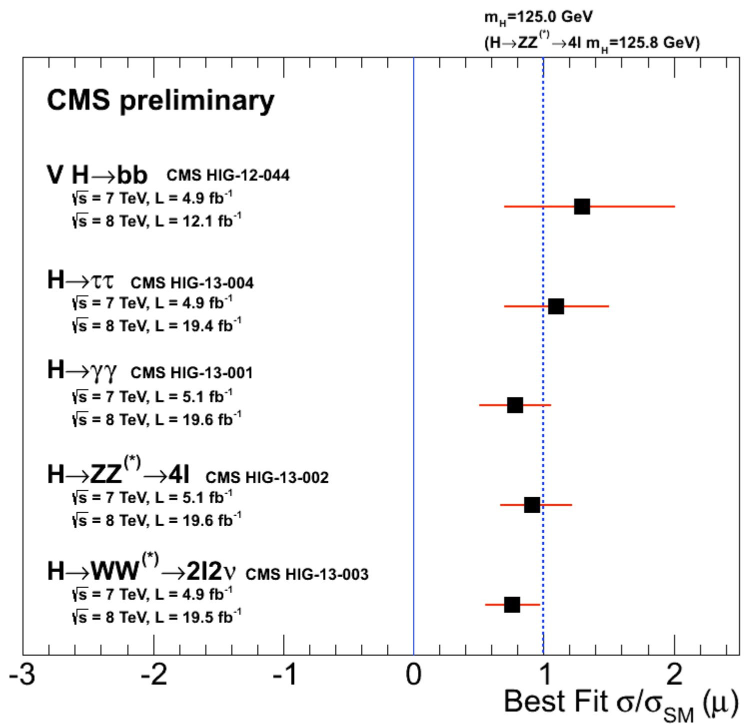


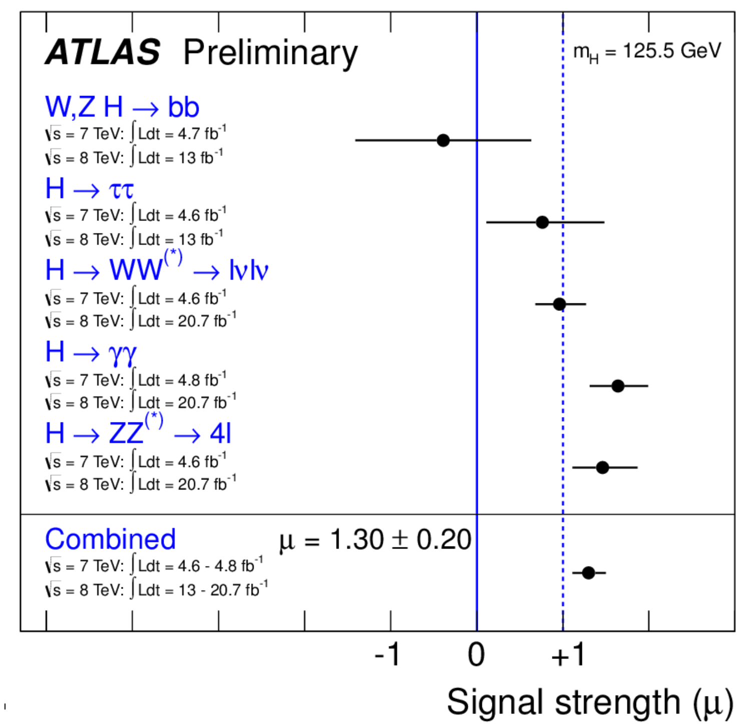



right-handed
left-handed
Quarks
u_R c_R t_R
d_R s_R b_R
e_R μ_R τ_R
Leptons
Quarks
u_L c_L t_L
d_L s_L b_L
e_L μ_L τ_L
ν_e ν_μ ν_τ
Leptons
H
Higgs boson
Forces
Z γ
W g

The 4th of July of 2012 marked
a new milestone in particle physics

A Higgs-like state has been discovered





with no significant deviations from a SM Higgs!

What the Higgs mass

$$\mathbf{m_H \approx 125\ GeV}$$

tells us?

What the Higgs mass

$$\mathbf{m_H \approx 125\ GeV}$$

tells us?

Light state:

If it has to do with EWSB: $\mathbf{m_H^2 = \lambda v^2}$

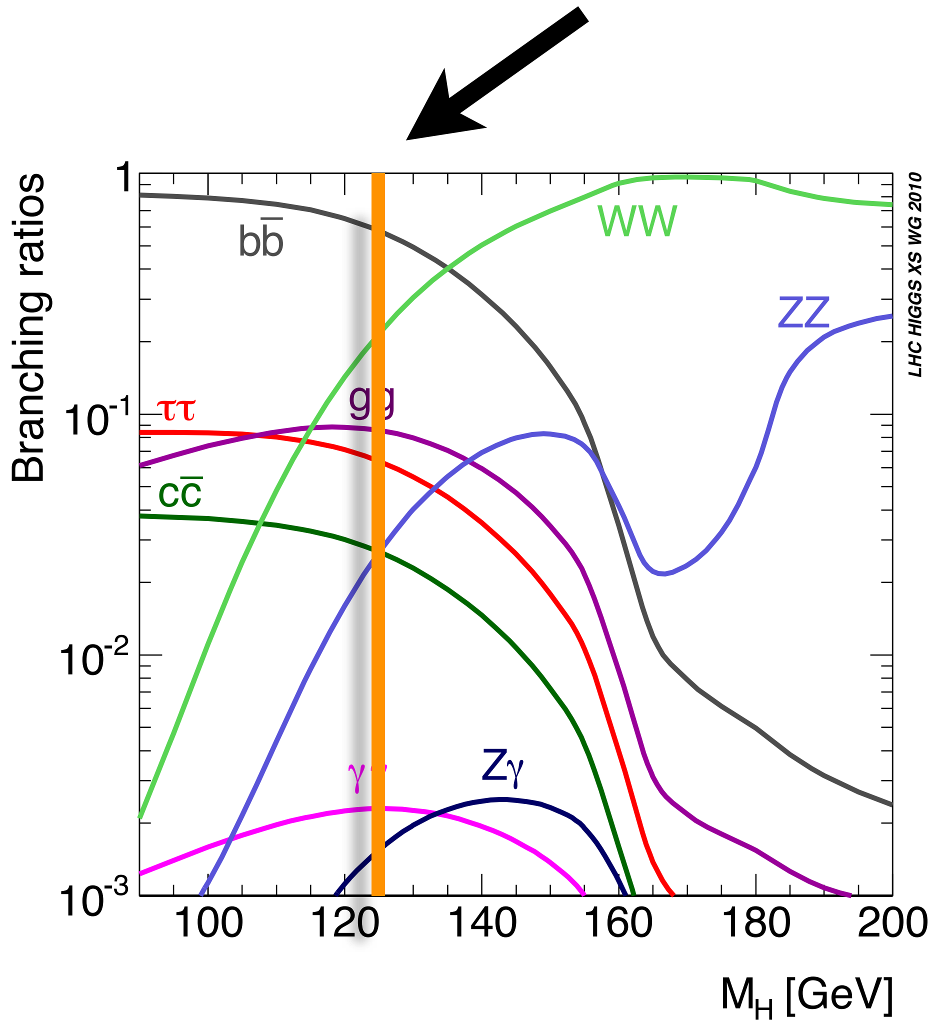
~ 0.26 (perturbative coupling)

Origin of the EWSB potential → a weakly-coupled theory

Excellent for experimentalists:

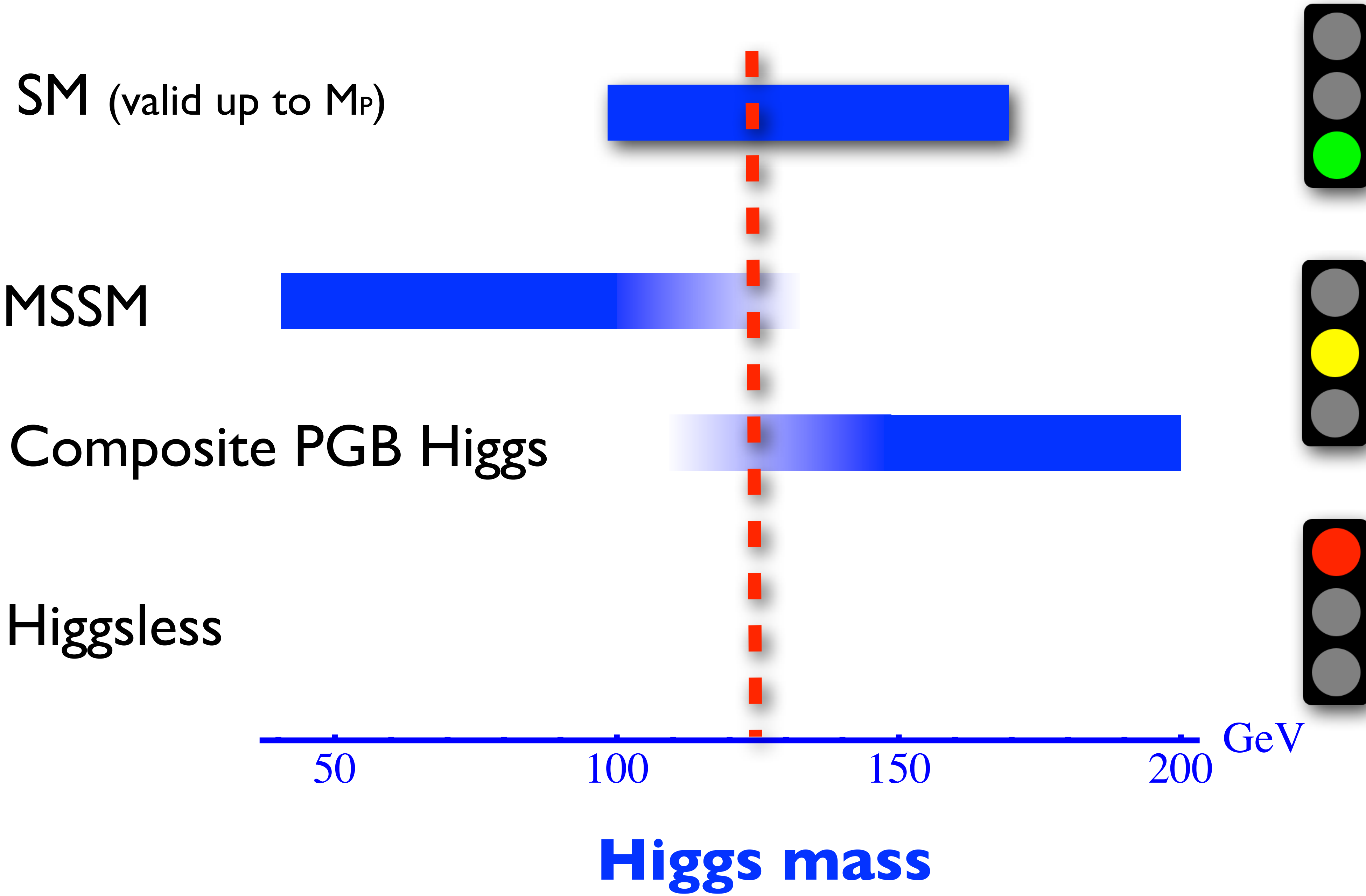
Fabiola Gianotti: "***Nature has been kind to us...***"

Most of decay modes visible: $\mathbf{m_H \approx 125\ GeV}$



For theorist...

Rough Higgs-mass range predictions

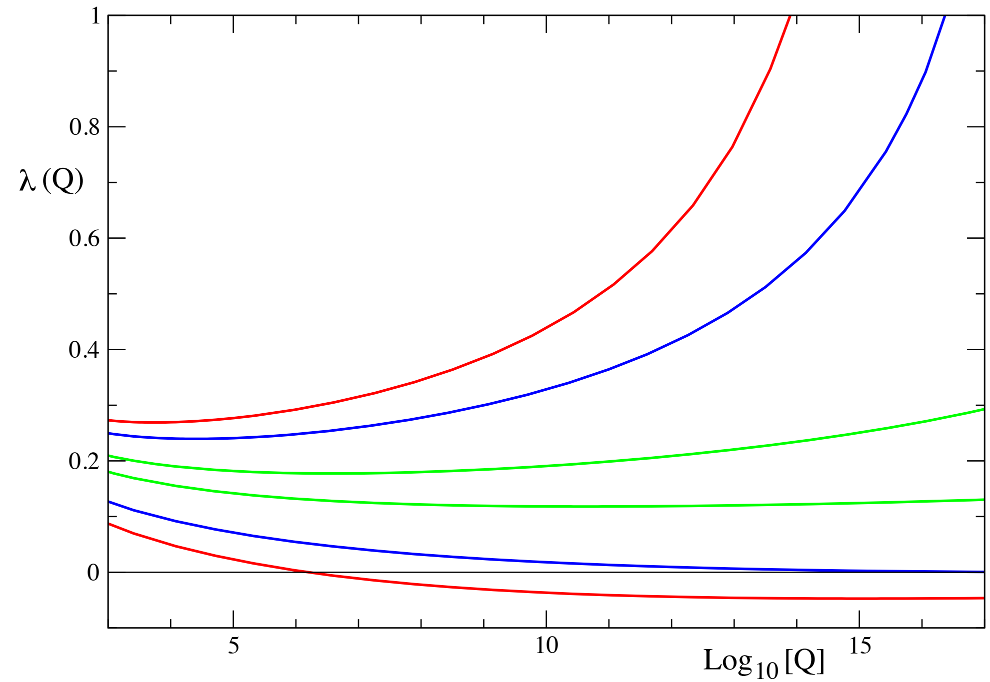


125 GeV SM Higgs

In the SM:

$$m_H^2 = \lambda v^2$$

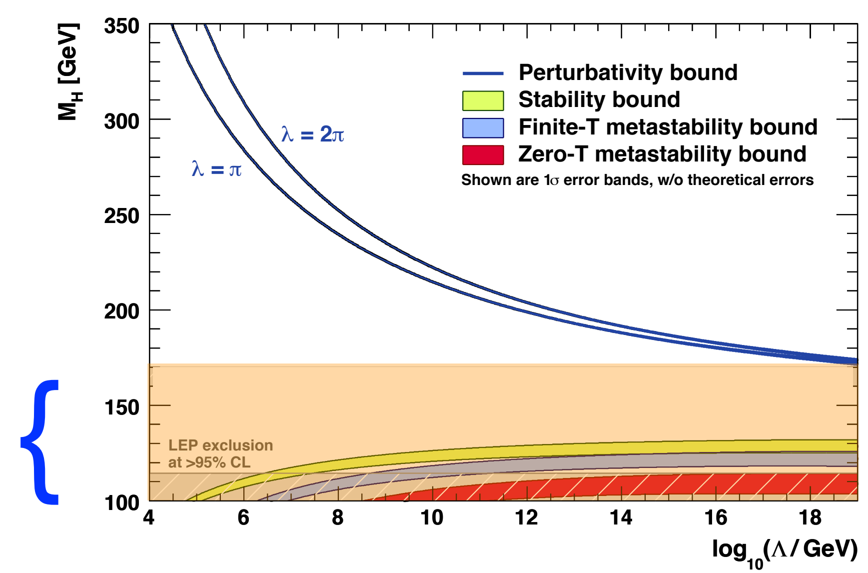
Evolves with the energy



Demanding λ not too large (keep perturbativity),
not too negative that destabilizes the Higgs potential:

from Phys.Lett. B679 (2009) 369

Only a small window
in the Higgs mass
makes the SM consistent
all the way to the Planck scale



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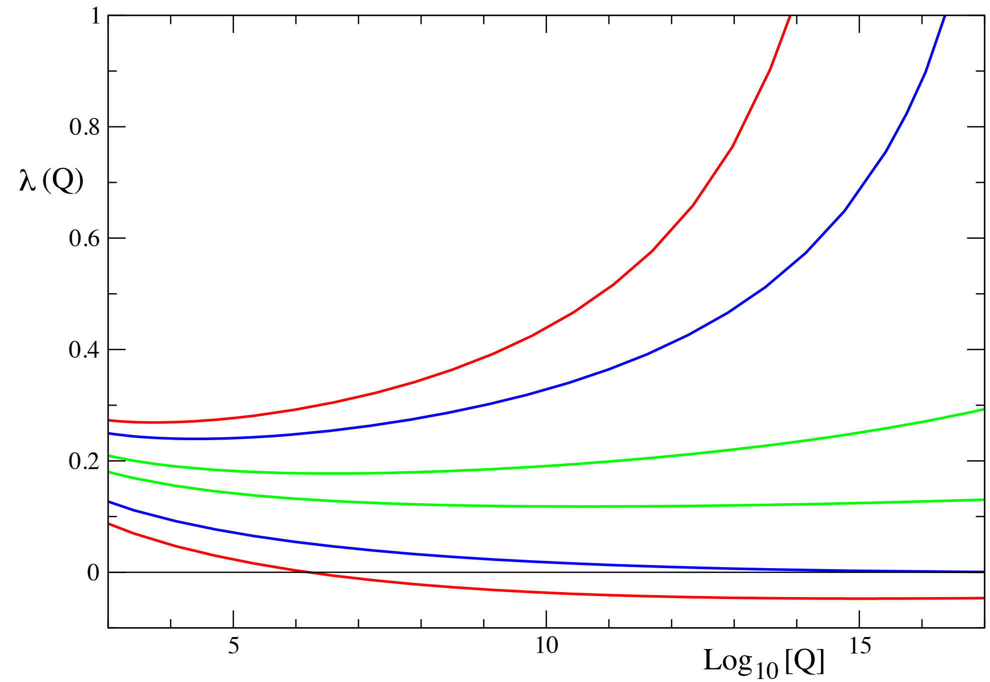

Demanding λ not too large (keep perturbativity),
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from Phys.Lett. B679 (2009) 369

A 125 GeV Higgs is
in this window!

Only a small window
in the Higgs mass
makes the SM consistent
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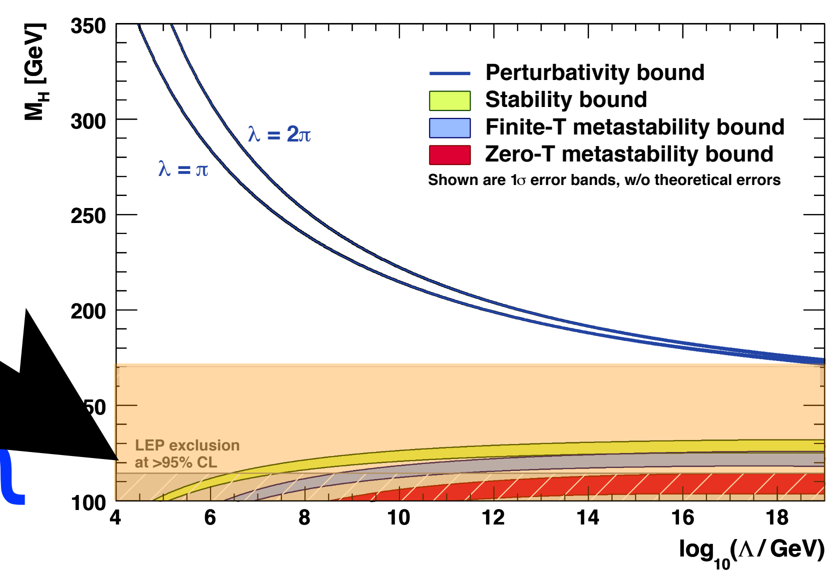

125 GeV MSSM Higgs

In the MSSM:

$$\mathbf{M_h^2 \leq M_Z^2 + \Delta m^2}$$

➥ susy breaking term
(at one-loop)

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$$\mathbf{M_h^2 \leq M_Z^2 + \Delta m^2}$$

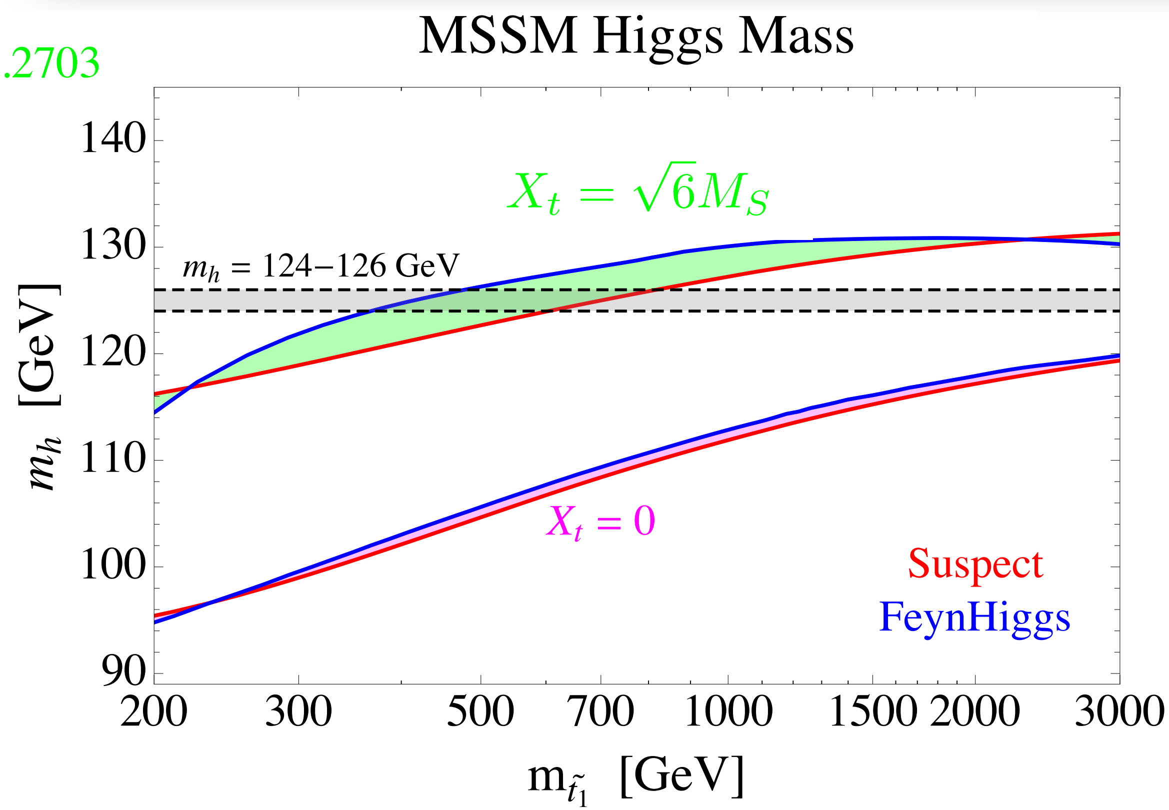
susy breaking term
(at one-loop)

$$\mathbf{(125\ GeV)^2} \qquad \mathbf{(91\ GeV)^2} \qquad \mathbf{(86\ GeV)^2}$$

both have similar size:
Non-small Susy breaking effects

$$m_h^2 = m_Z^2 c_{2\beta}^2 + \frac{3m_t^4}{4\pi^2 v^2}\left(\log\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right)$$

arXiv:1112.2703



$$\tan\beta = \frac{\langle H_u \rangle}{\langle H_d \rangle}$$

$$M_S \equiv \left(m_{\tilde{t}_1} m_{\tilde{t}_2}\right)^{1/2}$$

$$X_t \equiv A_t - \mu \cot\beta$$

Implications: Large tanβ, large stop masses or trilinears

Implications in particular models of susy-breaking

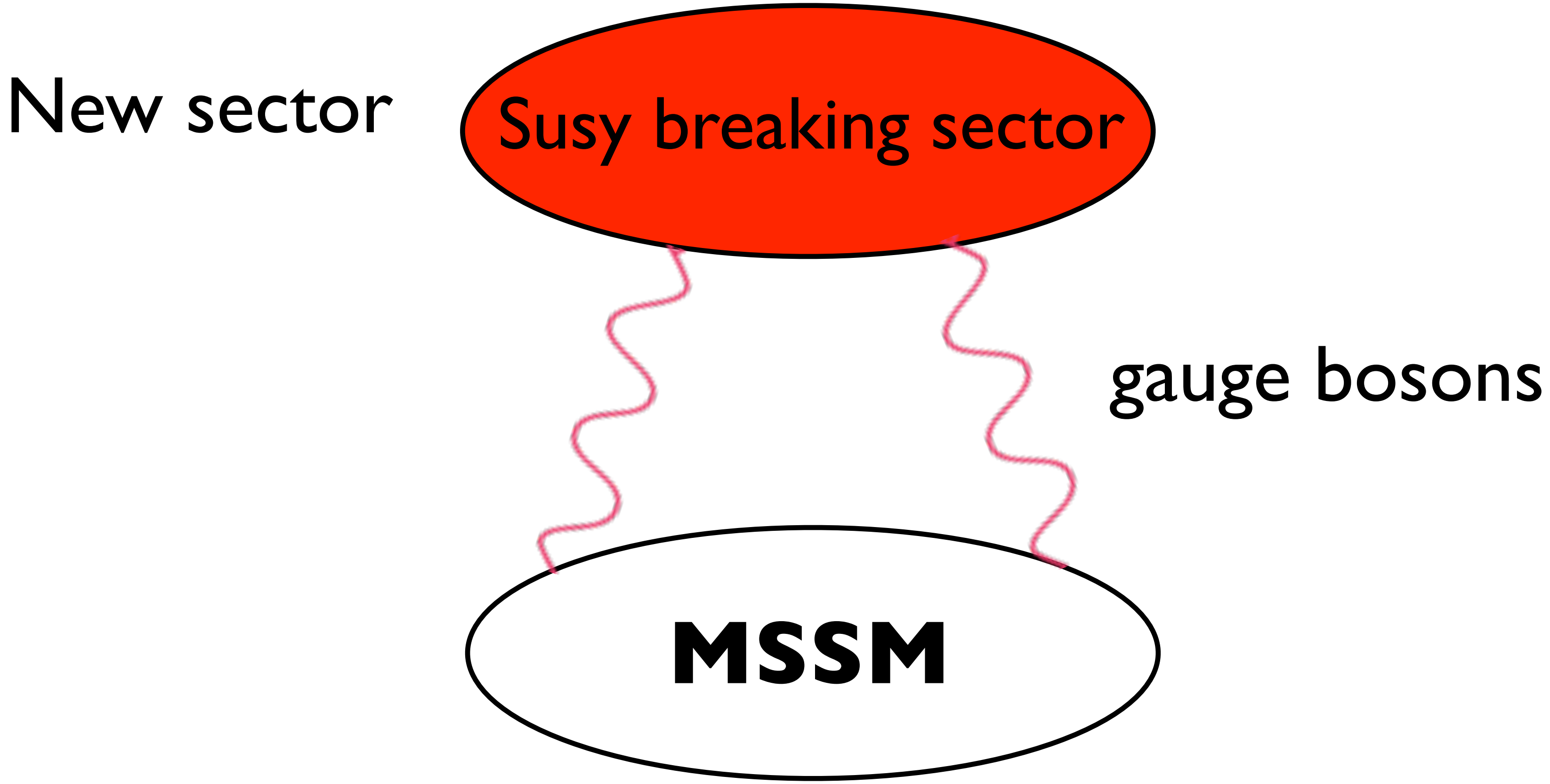
Soft terms must be generated in a **clever** way
(family-symmetric)

Most interesting possibilities:

1) Low-scale susy breaking: **Gauge mediation**

2) High-scale susy breaking:
Gravity/Moduli/Extra-dim mediation

I) Gauge mediation



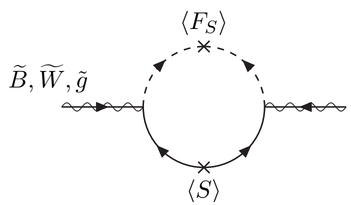
Gauge interactions are "flavor blind":

Universal masses for squarks/sleptons with equal charges

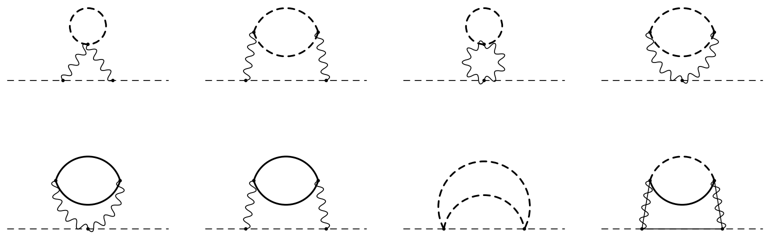
In minimal models trilinears are not generated

(only via RG-evolution)

Very predictive (in the minimal case).
Just calculate loops:



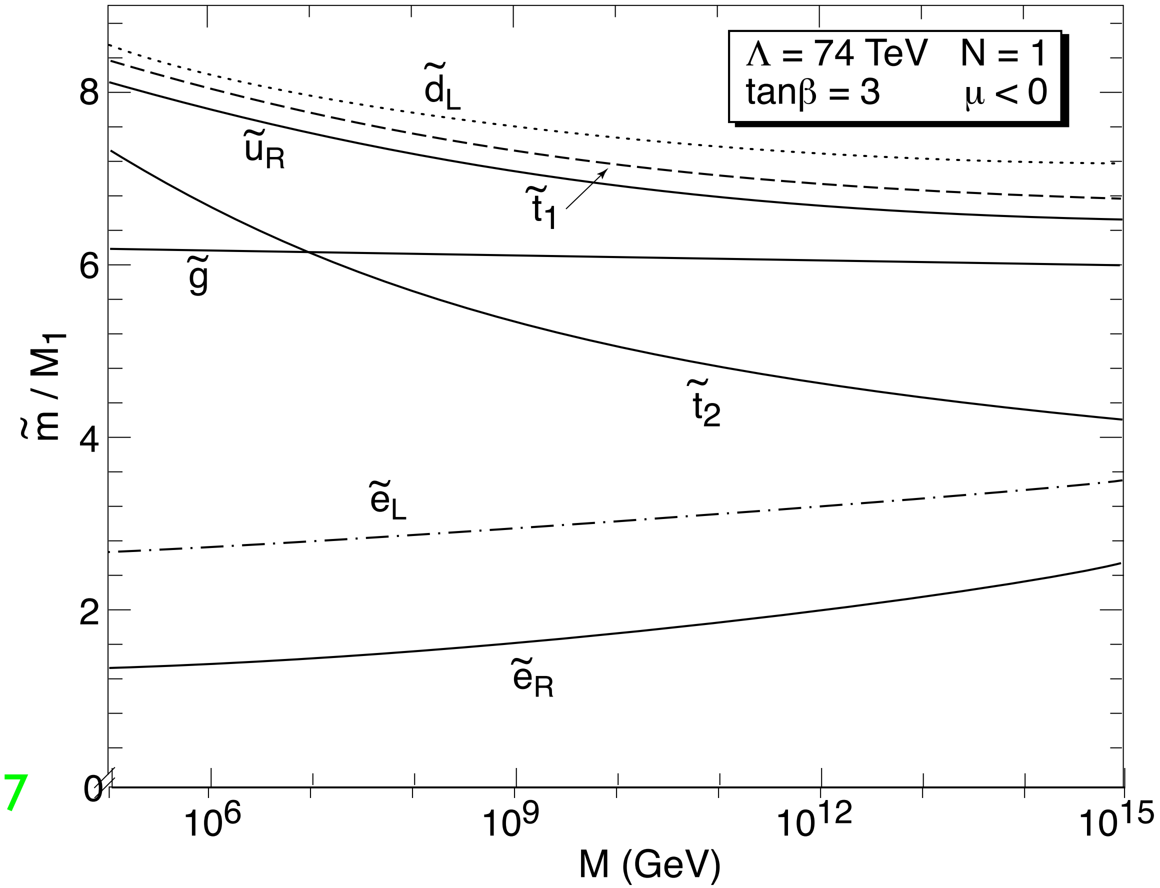
gaugino masses



scalar masses

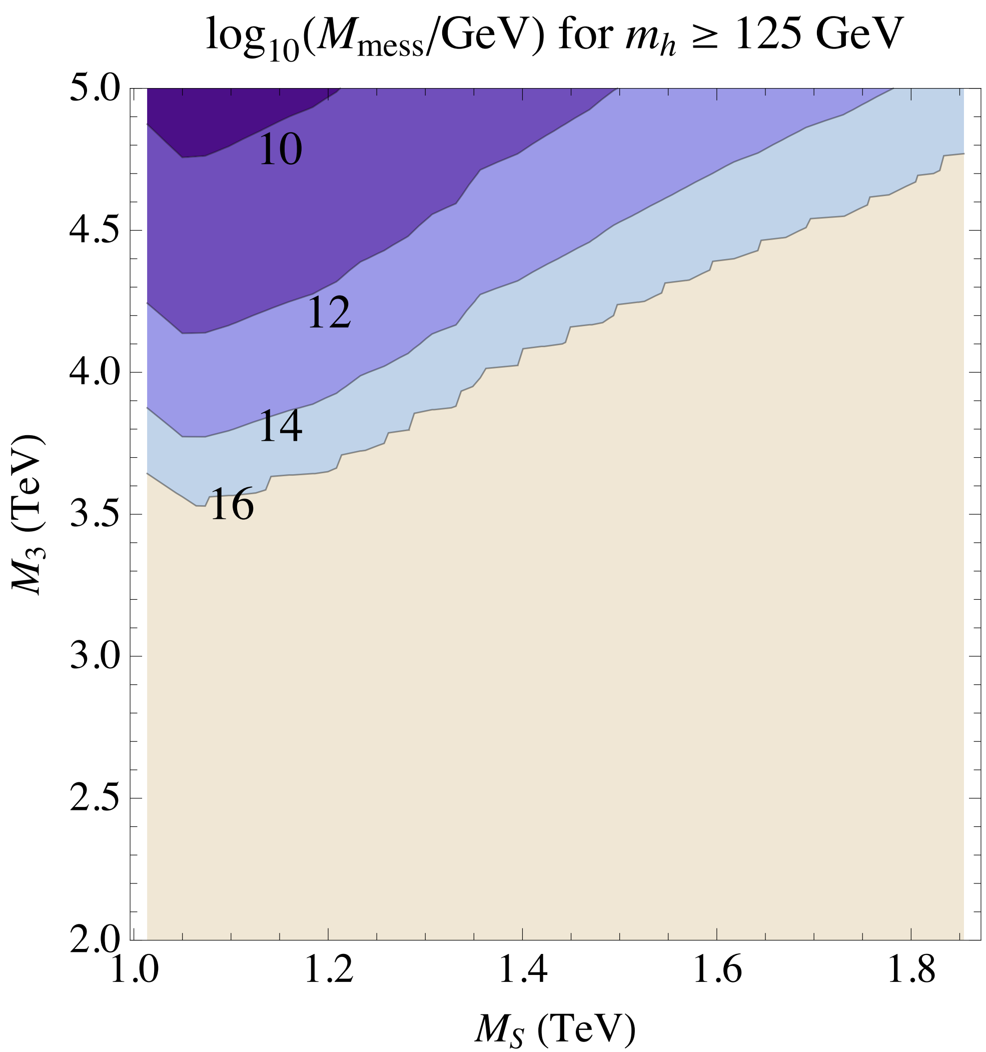
Depends on 4 parameters:

1) μ-term: Higgsino mass
2) Bμ-term: Higgs mixing mass
3) Susy-breaking scale: F
4) Scale where the soft-terms are induced: M



Giudice,Rattazzi 97

GMSB:

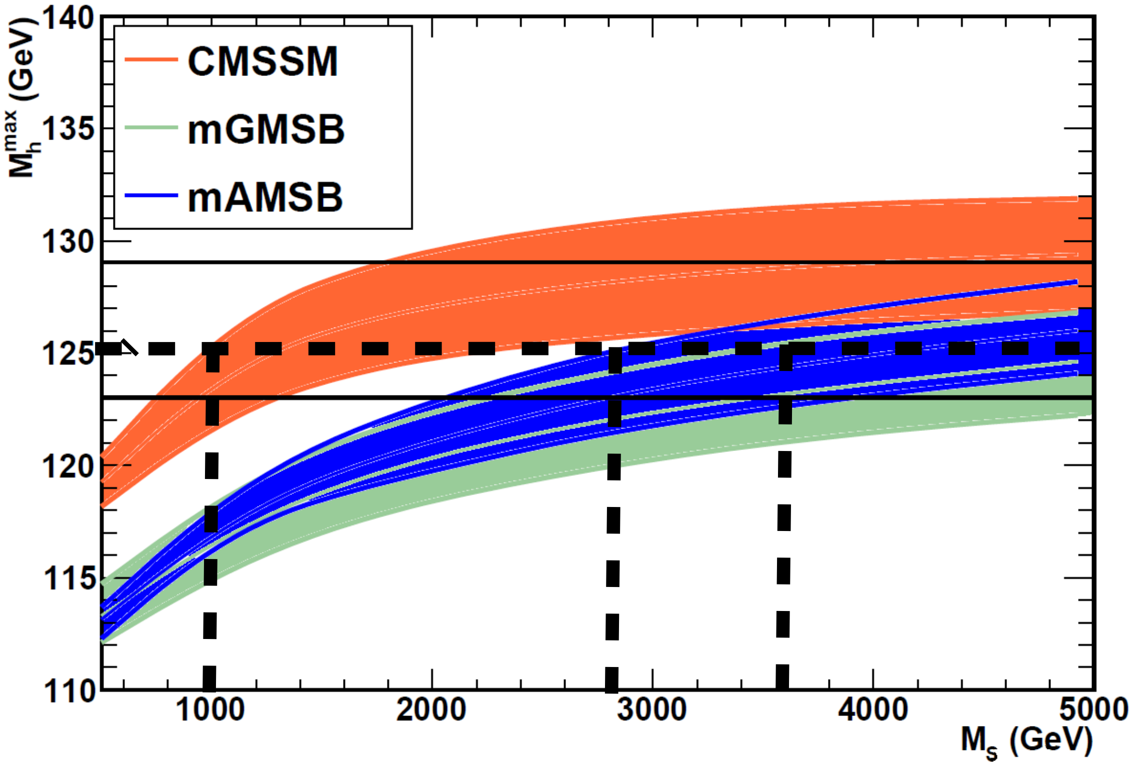


arXiv:1112.3068

gaugino mass

➥ obviates LHC searches!

Higgs mass in particular models of susy breaking:



from arXiv:1207.1348

This implies that most superpartners are beyond present LHC searches!