First Glimpses at Higgs' face?

LHC search strategies

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Chiral Lagrangian for a light Higgs

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \ldots$$

$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \ldots\right)$$

$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \ldots\right)$$

$$+ \frac{g^2}{16\pi^2}\left(c_{WW}\, W^+_{\mu\nu}W^-_{\mu\nu} + c_{ZZ}\, Z^2_{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma_{\mu\nu}\right)\frac{h}{v} + \ldots$$

$$+ \frac{g^2}{16\pi^2}\left[\gamma^2_{\mu\nu}\left(c_{\gamma\gamma}\frac{h}{v} + \ldots\right) + G^2_{\mu\nu}\left(c_{gg}\frac{h}{v} + c_{2gg}\frac{h^2}{v^2}\ldots\right)\right]$$

$$+ \frac{g^2}{16\pi^2}\left[\frac{c_{hhgg}}{\Lambda^2}G^2_{\mu\nu}\frac{(\partial_\rho h)^2}{v^2} + \frac{c'_{hhgg}}{\Lambda^2}G_{\mu\rho}G_{\rho\nu}\frac{\partial_\mu h\partial_\nu h}{v^2} + \ldots\right]$$

$$+ \ldots$$

SM

$$a = b = c = d_3 = d_4 = 1$$

$$c_{2\psi} = c_{WW} = c_{ZZ} = c_{Z\gamma} = c_{\gamma\gamma} = \ldots = 0$$

A few (reasonable) assumptions:

- ☑ spin-0 & CP-even
  - ↖ $\gamma\gamma$ ↖ WW & ZZ
- ☑ custodial symmetry
  - ↖ EWPD
- ☑ no Higgs FCNC
  - ↖ Flavor

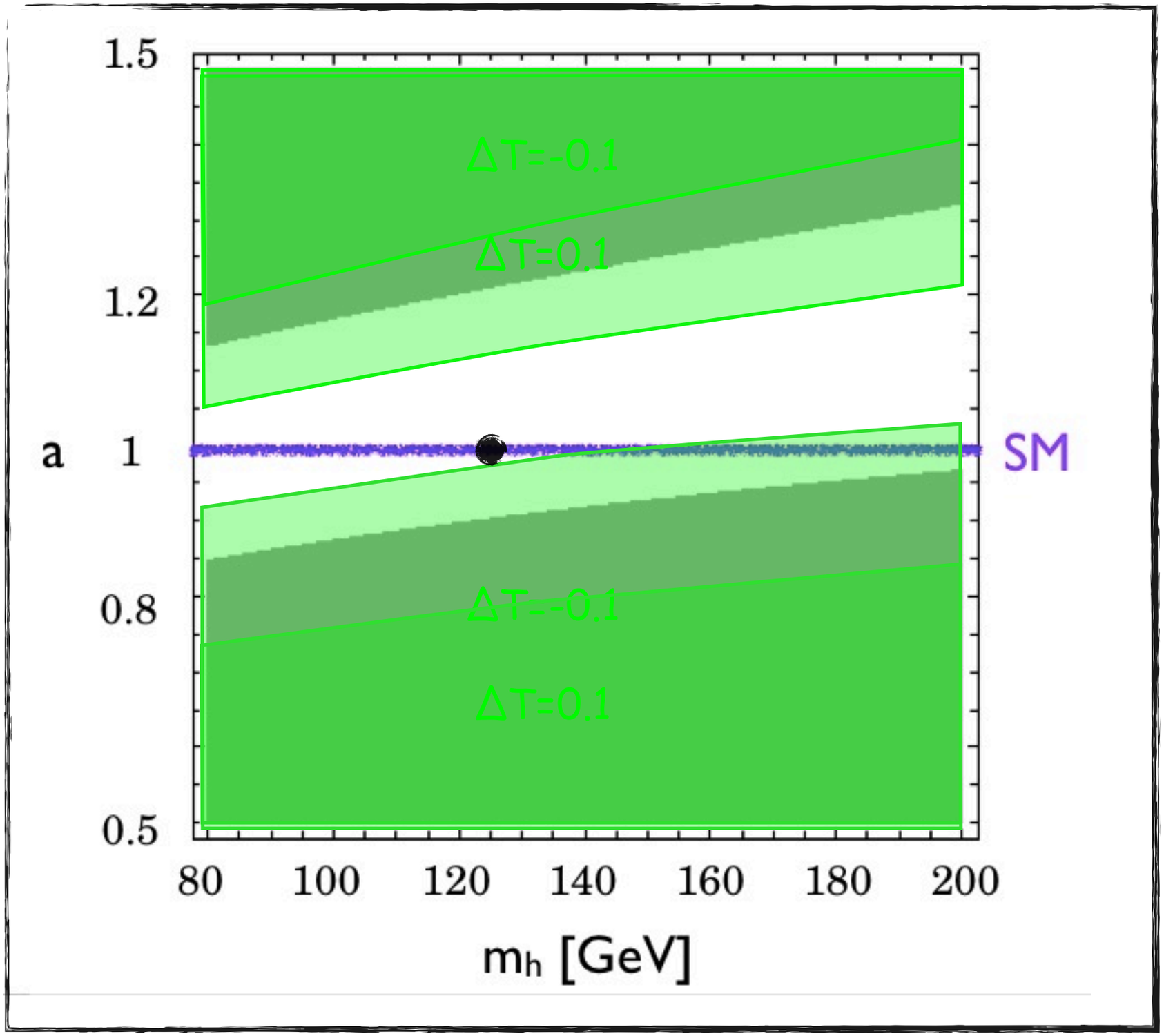
Contino, Grojean, Moretti, Piccinini, Rattazzi '10 Azatov, Contino, Galloway '12

EW data constraints on 'a'

EW fit with SM degrees of freedom + Higgs-like scalar

- EW data require less than 15-20% deviations in the couplings of the Higgs to gauge bosons
- EW data don't constraint the other Higgs couplings

note:
additional UV contributions to S and T can modify the preferred values of couplings



SILH Effective Lagrangian

Giudice, Grojean, Pomarol, Rattazzi '07

At the moment, we don't need to know what the Higgs is made of

⇛ chiral Lagrangian for the composite Higgs ⇚

Genuine strong operators (sensitive to the scale f)

$$\frac{c_H}{2f^2}\left(\partial^\mu |H|^2\right)^2$$

$$\cancel{\frac{c_T}{2f^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)^2}$$

custodial breaking

$$\frac{c_y y_f}{f^2}|H|^2 \bar{f}_L H f_R + \text{h.c.}$$

$$\frac{c_6 \lambda}{f^2}|H|^6$$

Form factor operators (sensitive to the scale m_ρ)

$$\frac{i c_W}{2m_\rho^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)(D^\nu W_{\mu\nu})^i$$

$$\frac{i c_B}{2m_\rho^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)(\partial^\nu B_{\mu\nu})$$

$$\frac{i c_{HW}}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu}$$

$$\frac{i c_{HB}}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$$

minimal coupling: $h \to \gamma Z$

loop-suppressed strong dynamics

$$\frac{c_\gamma}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}\frac{g^2}{g_\rho^2} H^\dagger H B_{\mu\nu} B^{\mu\nu}$$

$$\frac{c_g}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}\frac{y_t^2}{g_\rho^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}$$

Goldstone sym.

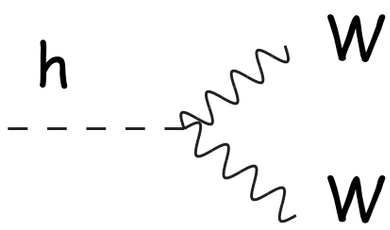
2 parameter Higgs physics @ LHC$_{2011\text{-}2012}$

$$\frac{c_H}{2f^2}\left(\partial^\mu |H|^2\right)^2$$

$$\xi = v^2/f^2$$

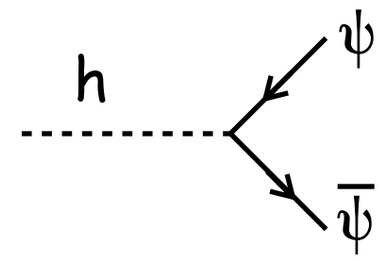
$$\frac{c_y y_\psi}{f^2}|H|^2\bar{\psi}_L H \psi_R$$

Controls the hWW, hZZ couplings



$$a\, g^{SM}_{hVV}$$

Controls the hψψ couplings



$$c\, g^{SM}_{h\psi\psi}$$

Explicit (and calculable) models built in AdS$_5$ spacetimes

Agashe, Contino, Pomarol '04

Contino, Da Rold, Pomarol '06

MCHM5

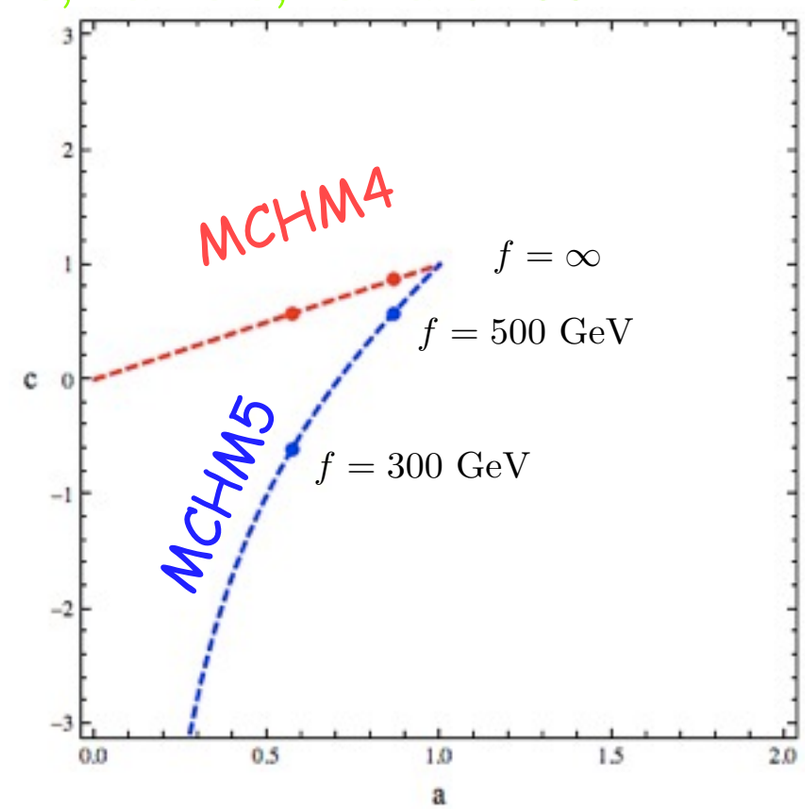
$$a = \sqrt{1-\xi} \qquad c = \frac{1-2\xi}{\sqrt{1-\xi}}$$

MCHM4

$$a = \sqrt{1-\xi} \qquad c = \sqrt{1-\xi}$$

disfavored by EW data (Zbb)

SM is recovered
as a limit when
the compositeness scale
is well above weak scale



2 parameter Higgs physics @ LHC$_{2011\text{-}2012}$

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$$\xi = v^2/f^2$$

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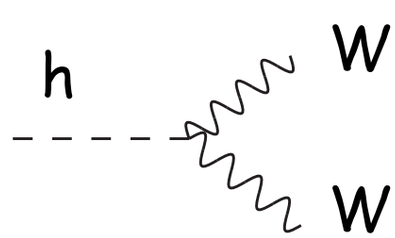
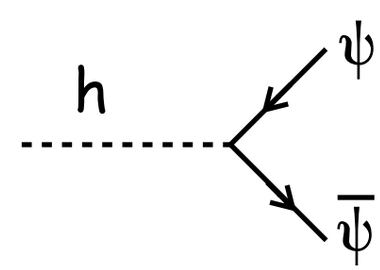


$$a\, g_{hVV}^{SM}$$

$$a = 1 - c_H\, \xi/2$$

Controls the hψψ couplings

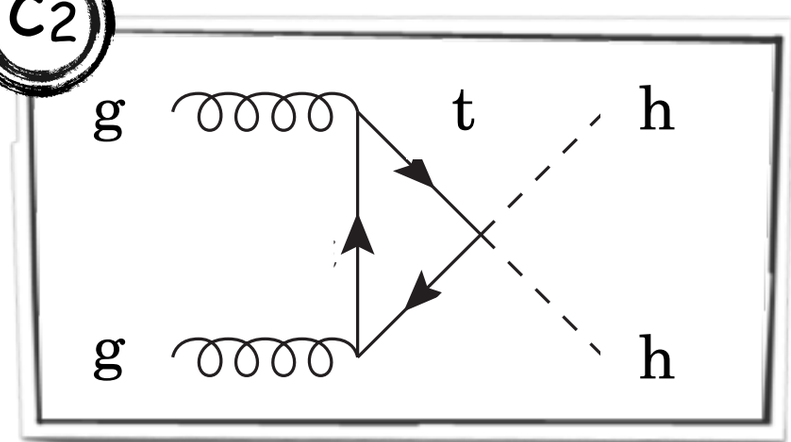


$$c\, g_{h\psi\psi}^{SM}$$

$$c = 1 - (c_H + 2c_y)\, \xi/2$$

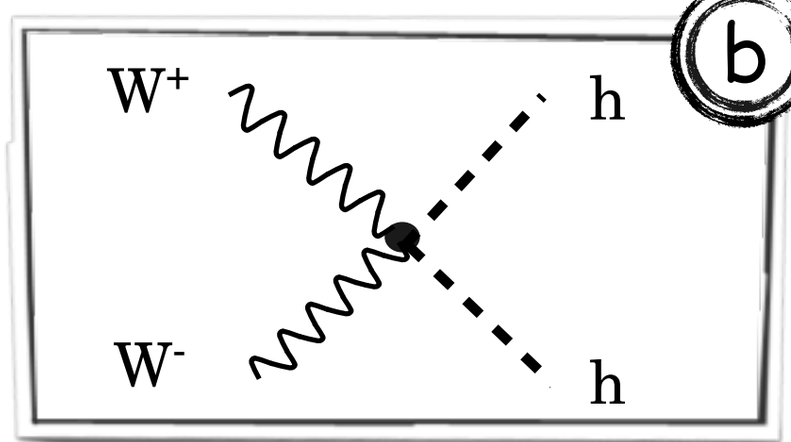
other couplings are very interesting as they are directly testing non-linearities/strong interactions of the Higgs

c_2



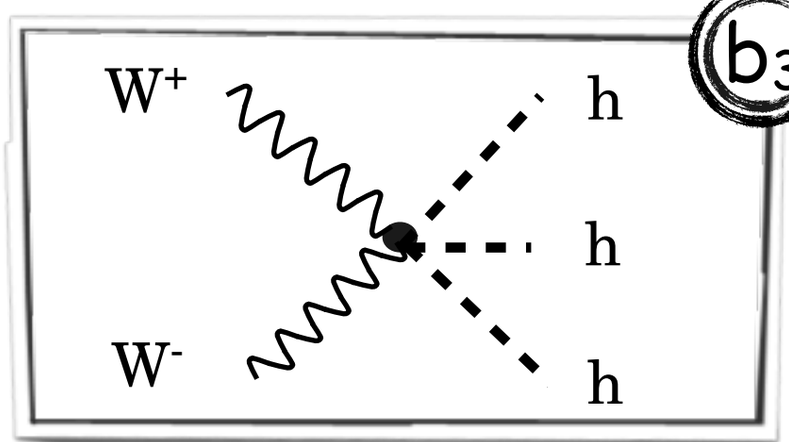
Grôber, Mûhlleitner '10
Contino et al '12
Gillioz et al '12

b



Contino, Grojean,
Moretti, Piccinini, Rattazzi '10

b_3



Contino, Grojean, Pappadopoulo,
Rattazzi, Thamm 'to appear

but they are not on agenda of the current LHC run

2 parameter Higgs physics @ LHC$_{2011\text{-}2012}$

- Higgs couplings modified w.r.t. SM but same kinematics

  (particular to single Higgs process - with more than one Higgs, sensitive to derivative couplings)

- Background processes unaffected

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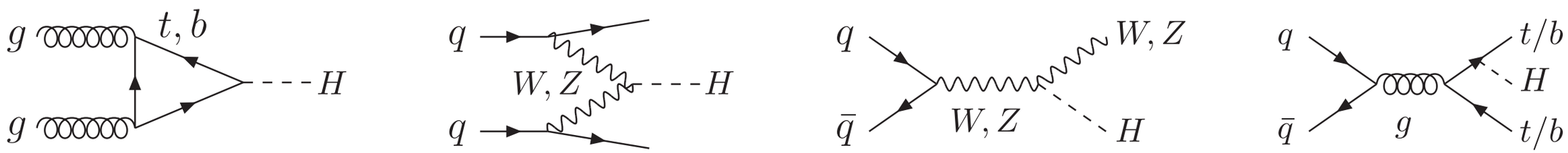
simple rescaling of SM searches



$\frac{\sigma_{NLO}}{\sigma_{NLO}^{SM}}$ c^2 a^2 a^2 c^2

The QCD NLO rescale trivially in the flavor universal limit. Not the EW NLO

$$\Gamma(H \to f\bar{f}) = c^2\, \Gamma^{SM}(H \to f\bar{f})\,,$$
$$\Gamma(H \to VV) = a^2\, \Gamma^{SM}(H \to VV)\,,$$
$$\Gamma(H \to gg) = c^2\, \Gamma^{SM}(H \to gg)\,,$$
$$\Gamma(H \to \gamma\gamma) = \frac{(cI_\gamma + aJ_\gamma)^2}{(I_\gamma + J_\gamma)^2}\Gamma^{SM}(H \to \gamma\gamma)\,,$$

$\simeq (1.26\,a - 0.26\,c)^2$ for m_h=125GeV

2 parameter Higgs physics @ LHC$_{2011\text{-}2012}$

- Higgs couplings modified w.r.t. SM but same kinematics

  (particular to single Higgs process - with more than one Higgs, sensitive to derivative couplings)

distributions are unaffected

the efficiencies are the same as in the SM

(as long as interferences w/ bckgd are negligible)

$$\epsilon_{ji} = \frac{\sigma^{\text{cut}}(j \to h) \times \text{Br}(h \to i)_{|a,c}}{\sigma^{\text{no cut}}(j \to h) \times \text{Br}(h \to i)_{|a,c}} = \frac{\sigma^{\text{cut}}(j \to h) \times \text{Br}(h \to i)_{|\text{SM}}}{\sigma^{\text{no cut}}(j \to h)_{\times} \text{Br}(h \to i)_{|\text{SM}}}$$

simple rescaling of the channel composition

$\sqrt{s}$	Category	Events	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
7 TeV	Inclusive	79.3	87.8	7.3	2.9	1.6	0.4
	Unconverted central, low p_{Tt}	10.4	92.9	4.0	1.8	1.0	0.2
	Unconverted central, high p_{Tt}	1.5	66.5	15.7	9.9	5.7	2.4
	Unconverted rest, low p_{Tt}	21.6	92.8	3.9	2	1.1	0.2
	Unconverted rest, high p_{Tt}	2.7	65.4	16.1	10.8	6.1	1.8
	Converted central, low p_{Tt}	6.7	92.8	4.0	1.9	1.0	0.2
	Converted central, high p_{Tt}	1.0	66.6	15.3	10	5.7	2.5
	Converted rest, low p_{Tt}	21.0	92.8	3.8	2.0	1.1	0.2
	Converted rest, high p_{Tt}	2.7	65.3	16.0	11.0	5.9	1.8
	Converted transition	9.5	89.4	5.2	3.3	1.7	0.3
	2-jets	2.2	22.5	76.7	0.4	0.2	0.1

Model independent χ^2 fit to LHC excess @ "125"

Espinosa, Grojean, Muhlleitner, Trott '12

Atlas 95%CL exclusion

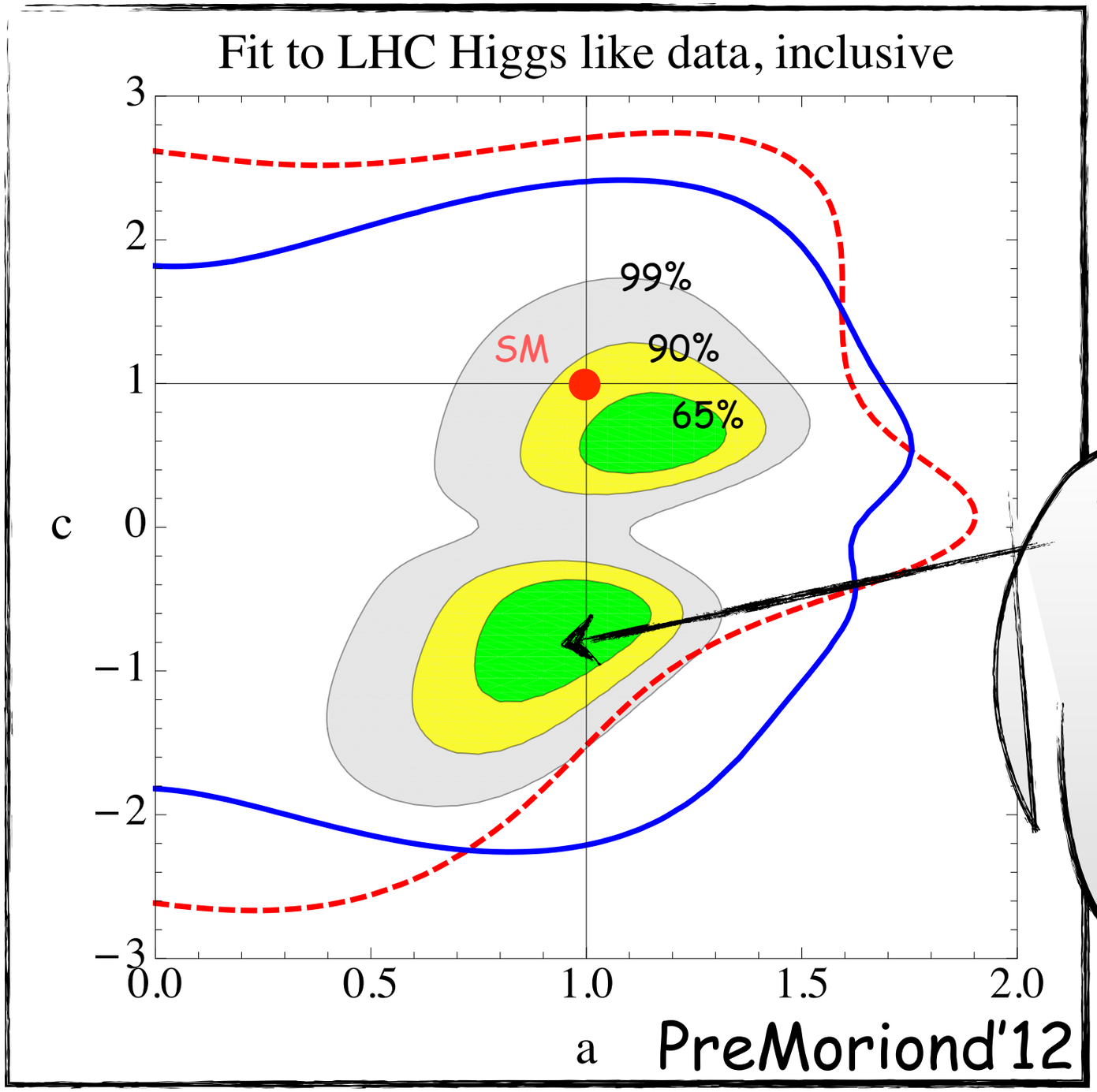
CMS 95%CL exclusion

SM 82%CL away from best fit point

Two minima:

(a,c)=(1.13,0.58)
χ^2=2.86

(a,c)=(0.96,-0.64)
χ^2=1.96



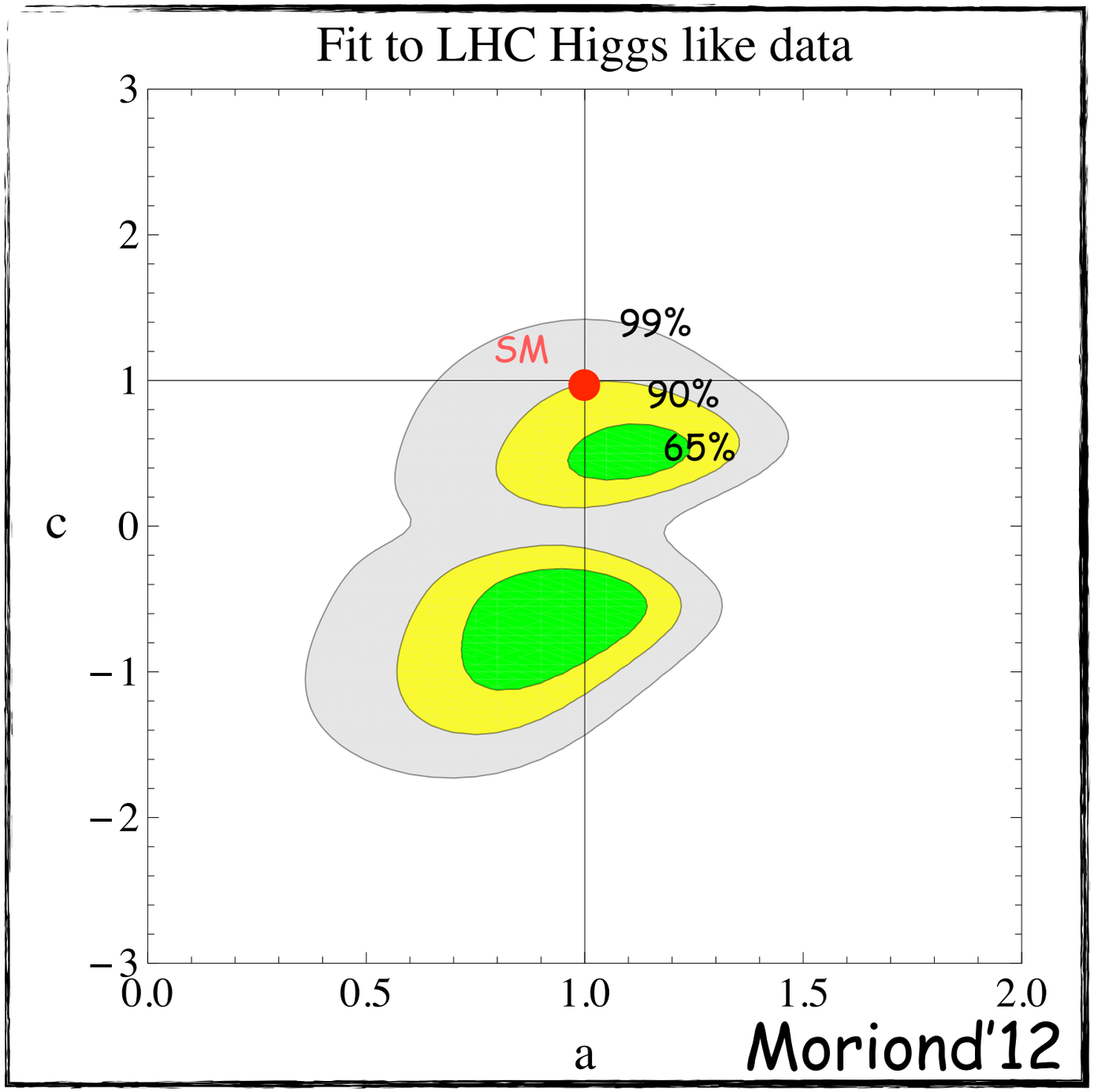
note: a fermiophobic Higgs is disfavored by data (mostly VBF channels)

"disfermiophilia"

the current data prefers "negative" coupling to fermions
≈
positive interference between top and W in $\gamma\gamma$ channel

Model independent χ^2 fit to (Moriond) LHC data

Espinosa, Grojean, Muhlleitner, Trott '12



note: a fermiophobic Higgs is disfavored by data (mostly VBF channels) at 97%CL

SM 88%CL away from best fit point (~2σ)

Two minima:

(a,c)=(1.18,0.55)
χ^2=7.5

(a,c)=(0.99,-0.64)
χ^2=6.3

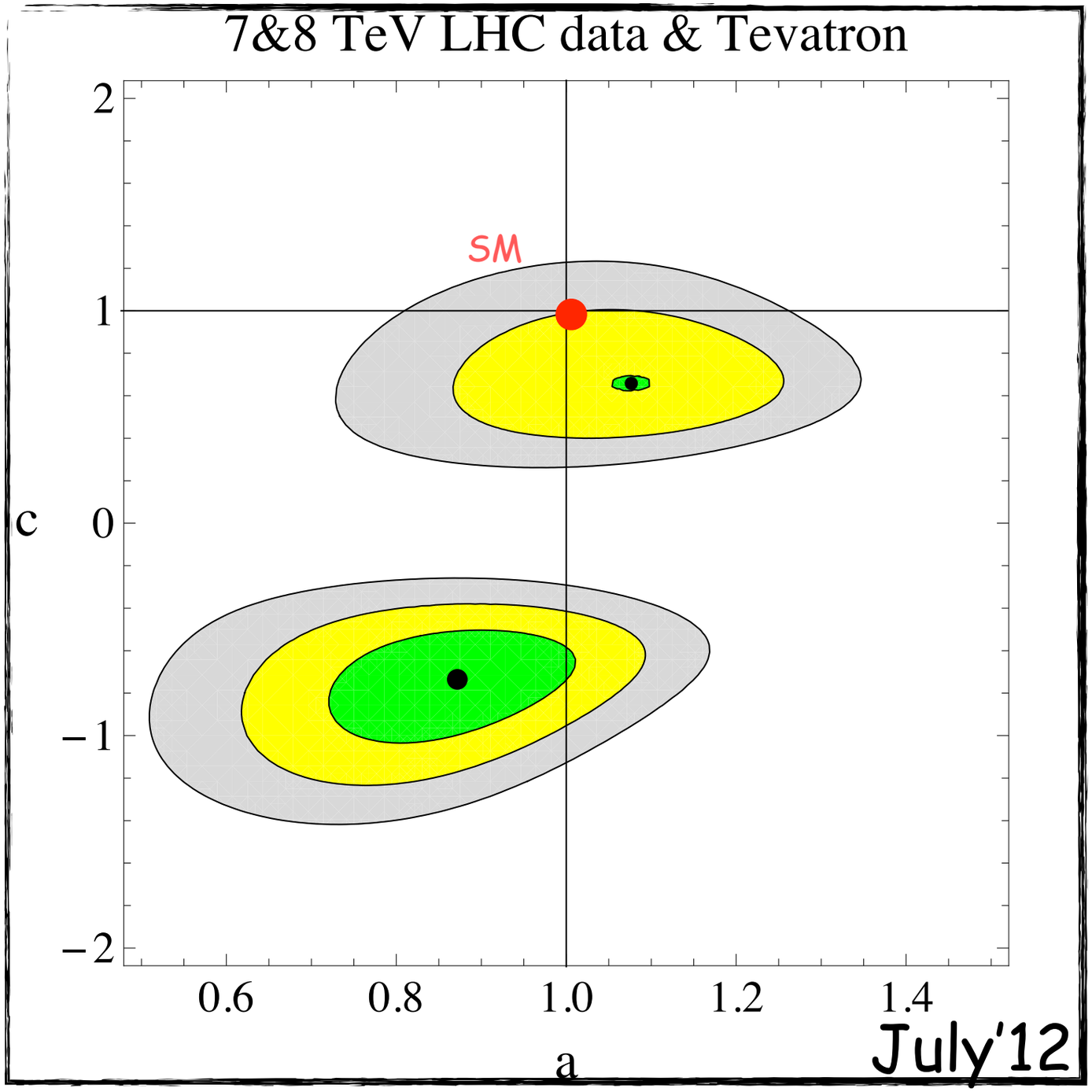
for similar analyses, see also

Azatov, Contino, Galloway '12

Carni, Falkowski, Kuflik, Volansky '12

Model independent χ^2 fit to (July'12) LHC data

Espinosa, Grojean, Muhlleitner, Trott '12



SM 93%CL away from best fit point (~1.8σ)

Two minima:

(a,c)=(0.86,-0.64)
χ^2=41

(a,c)=(1.05,0.63)
χ^2=41.4

note: a fermiophobic Higgs is disfavored by data (mostly VBF channels) at 99.99%CL ie 4σ

Warning

need to rescale independently 7 & 8 data sets

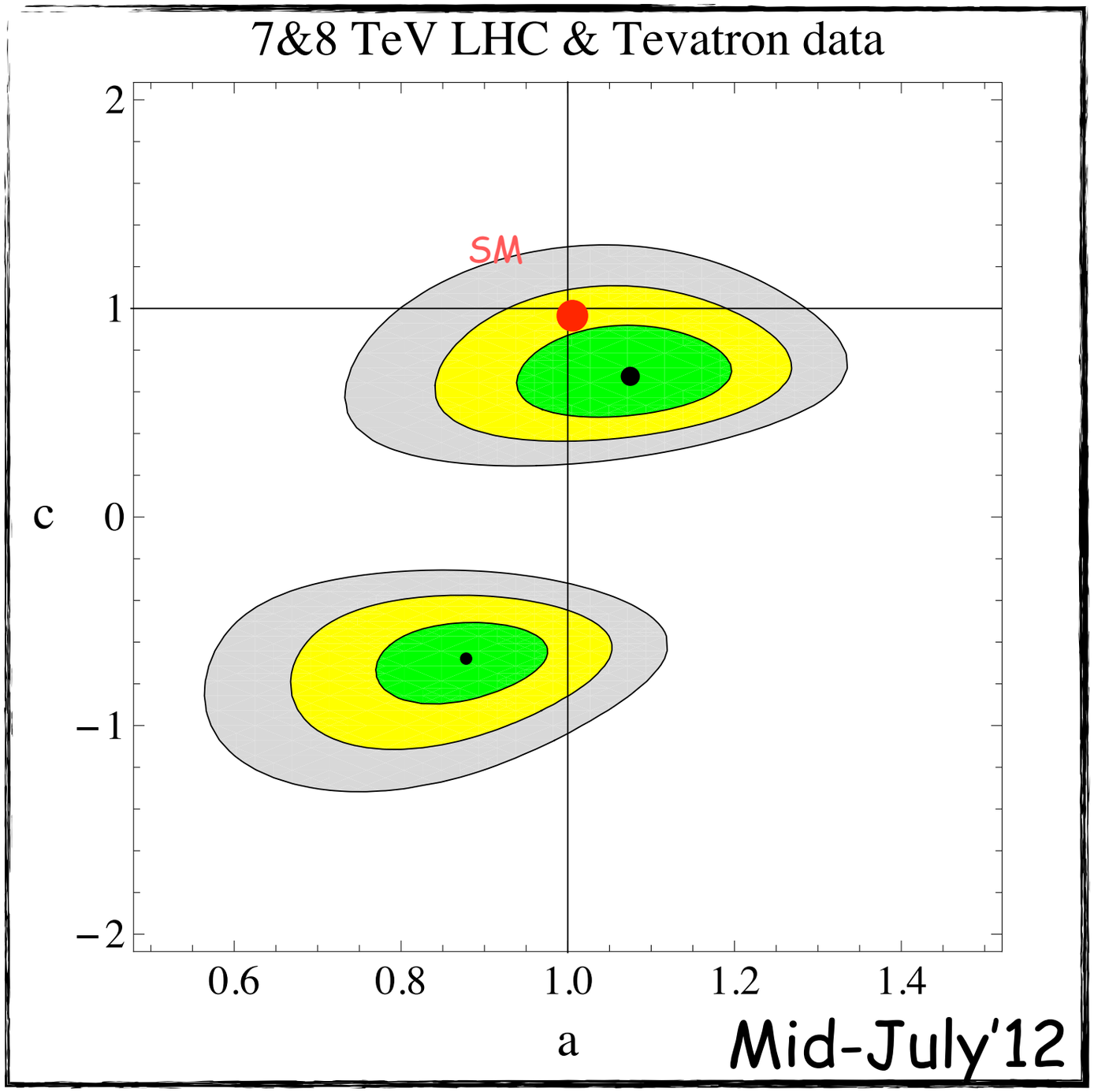
(on July 4th, only 7 and 7+8 combination were available)

for similar analyses, see also

Giardino, Kannike, Raidal, Strumia '12
Carni, Falkowski, Kuflik, Volansky, Zupan '12
Corbet, Eboli, Gonzalez-Fraile, Gonzalez-Garcia '12
Ellis, You '12 Montull, Riva '12

Model independent χ^2 fit to (July'12) LHC data

Espinosa, Grojean, Muhlleitner, Trott '12

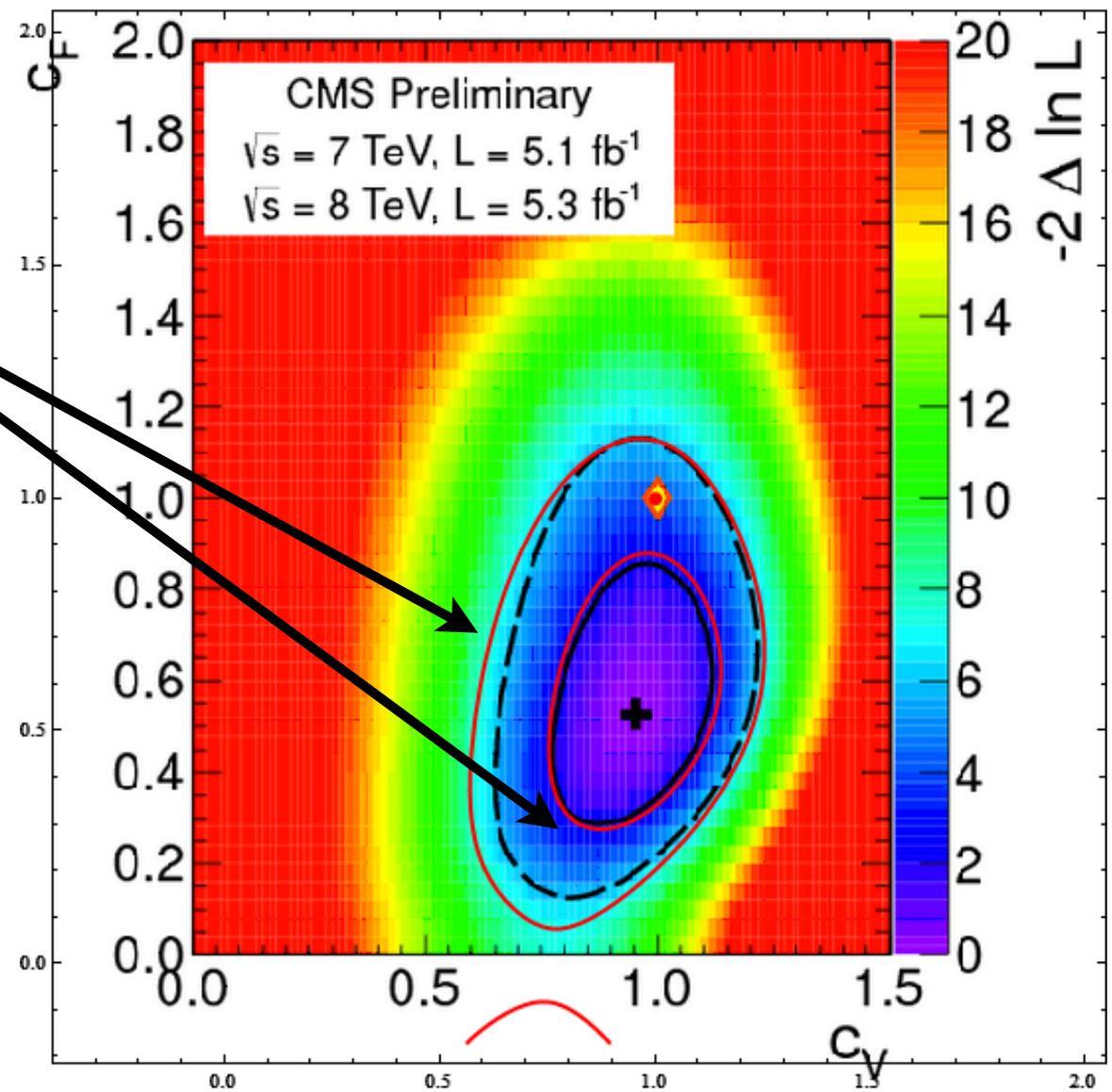


with the latest WW ATLAS channel, the dysfermiophilia region is now longer the best fit region and the SM is slightly better of

Comparison with CMS "official" fit

CMS imposed a prior c > 0
(it doesn't affect χ^2, but it modifies $\Delta\chi^2$)

Our contours

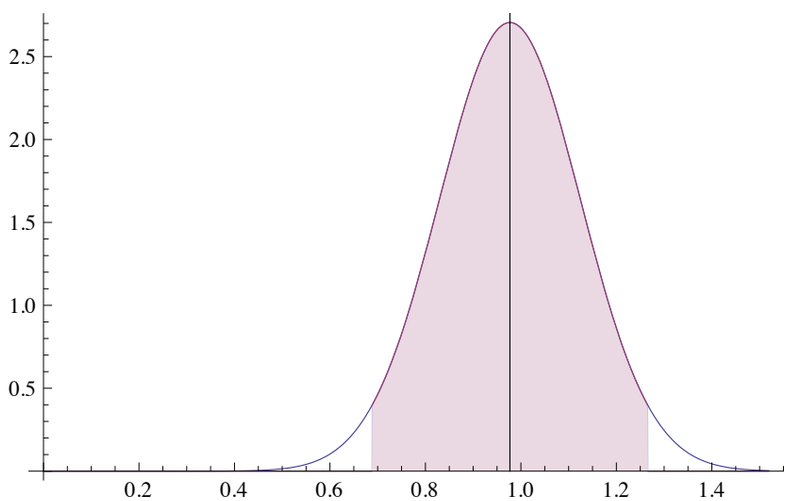


Excluding some (a,c) points

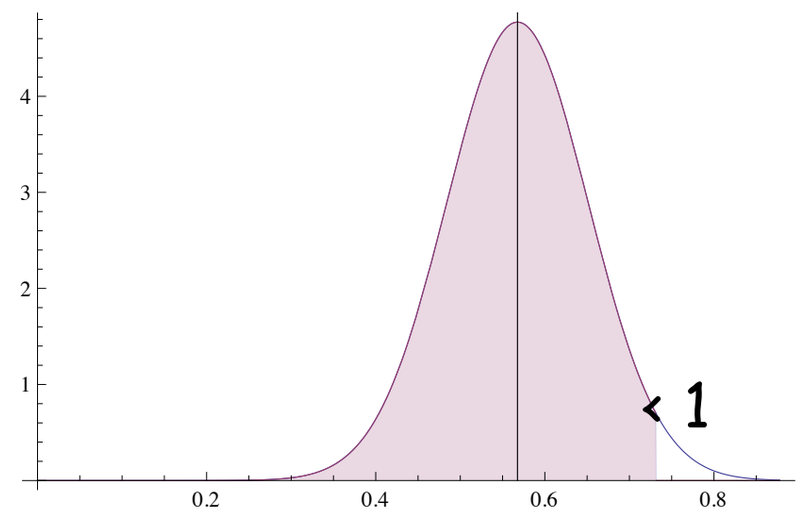
Espinosa, Grojean, Muhlleitner, Trott '12

determine the 95% CL allowed values of the signal strength

Combined SM likelihood

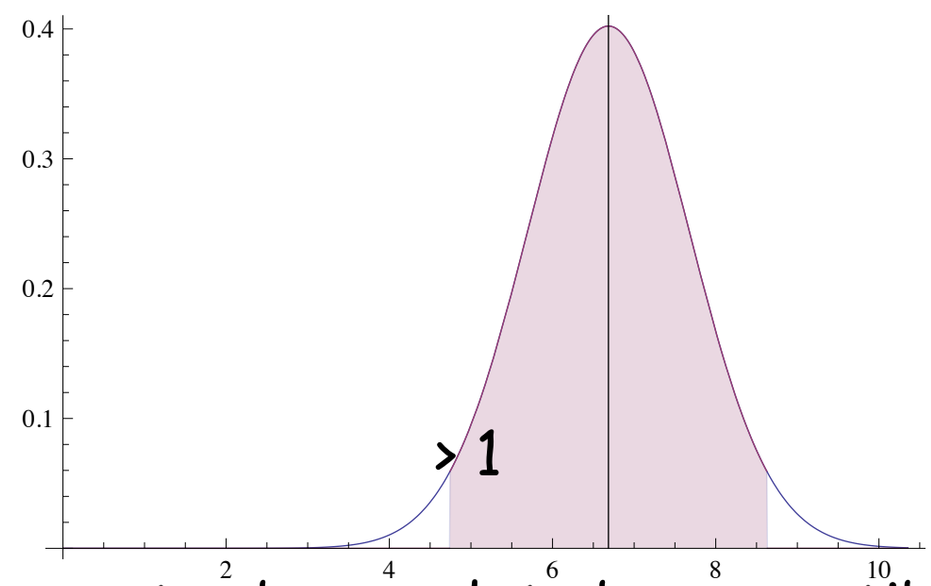


Comb. likelihood for (a,c)=(1.5,1.0)



two few events observed to be compatible with (a,c)

Comb. likelihood for (a,c)=(0.5,0.2)



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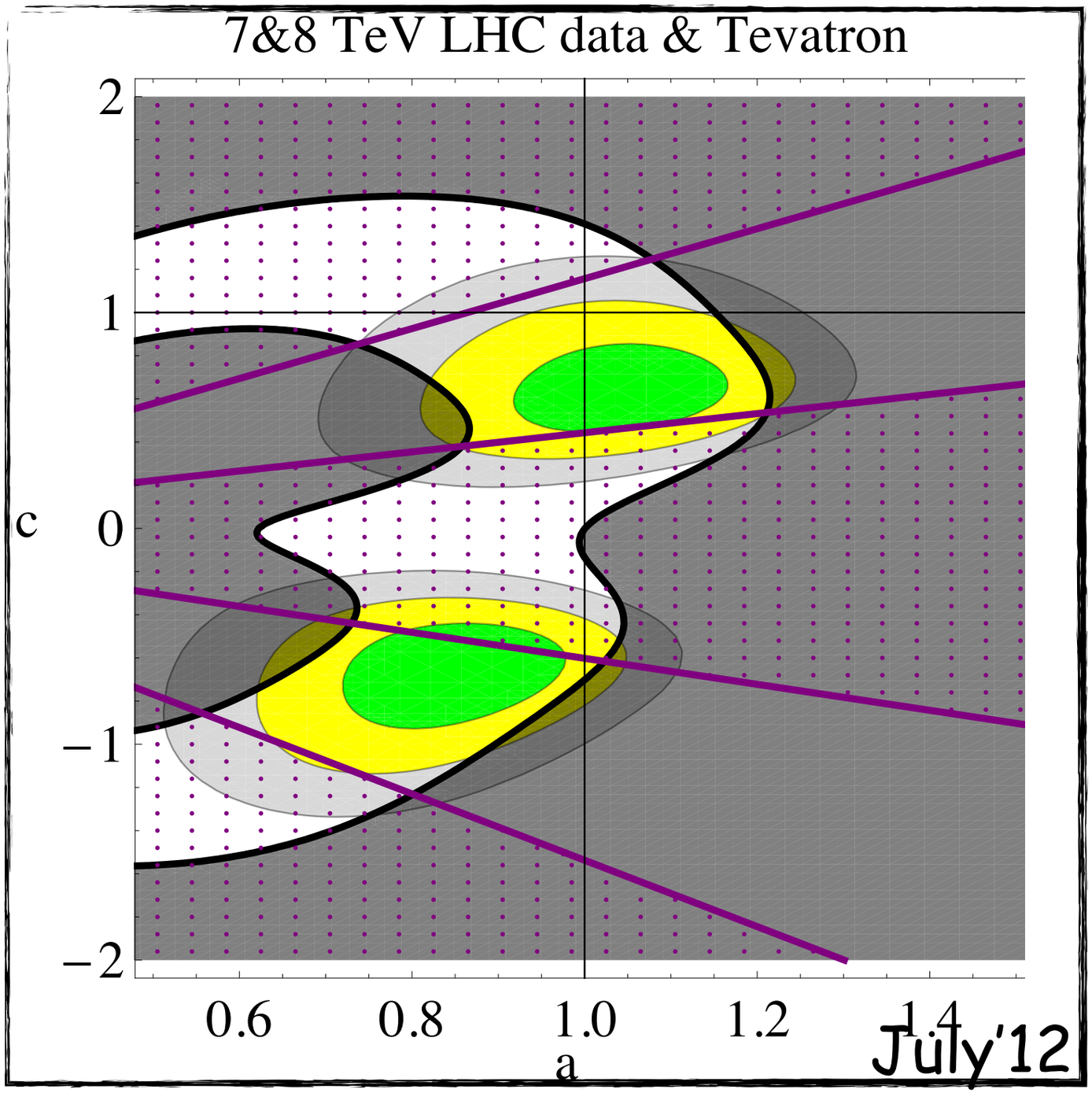
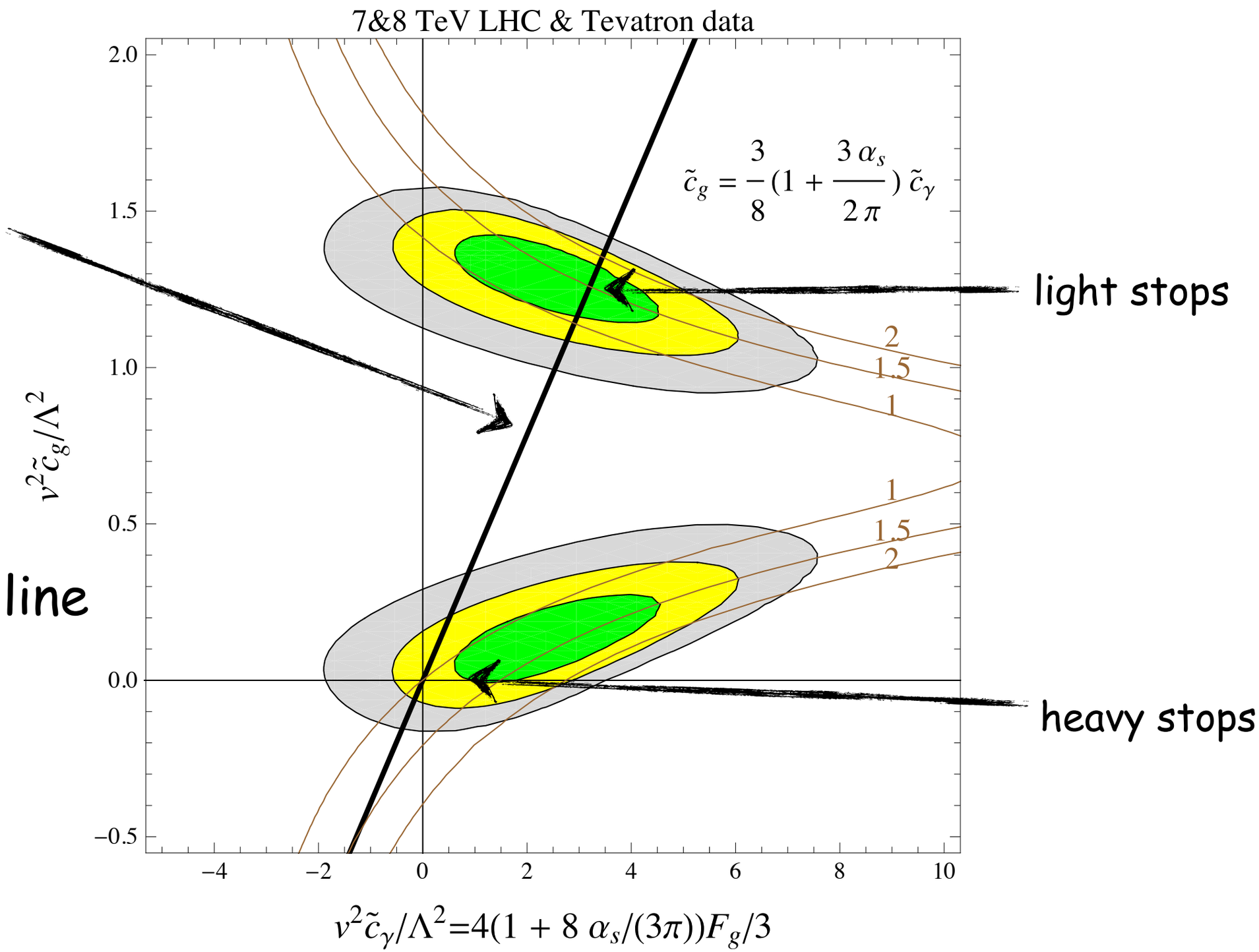


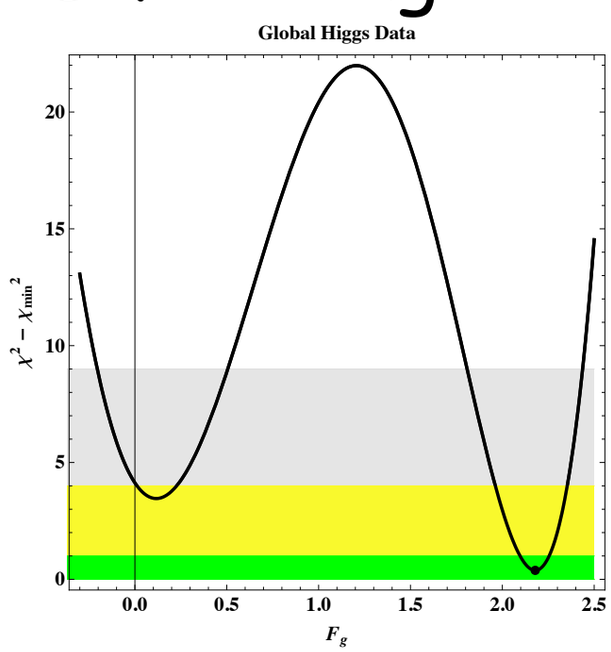
Testing direct contributions to gg and $\gamma\gamma$

Espinosa, Grojean, Sanz, Trott '12

Relation among higher dimensional operators redicted by NSUSY

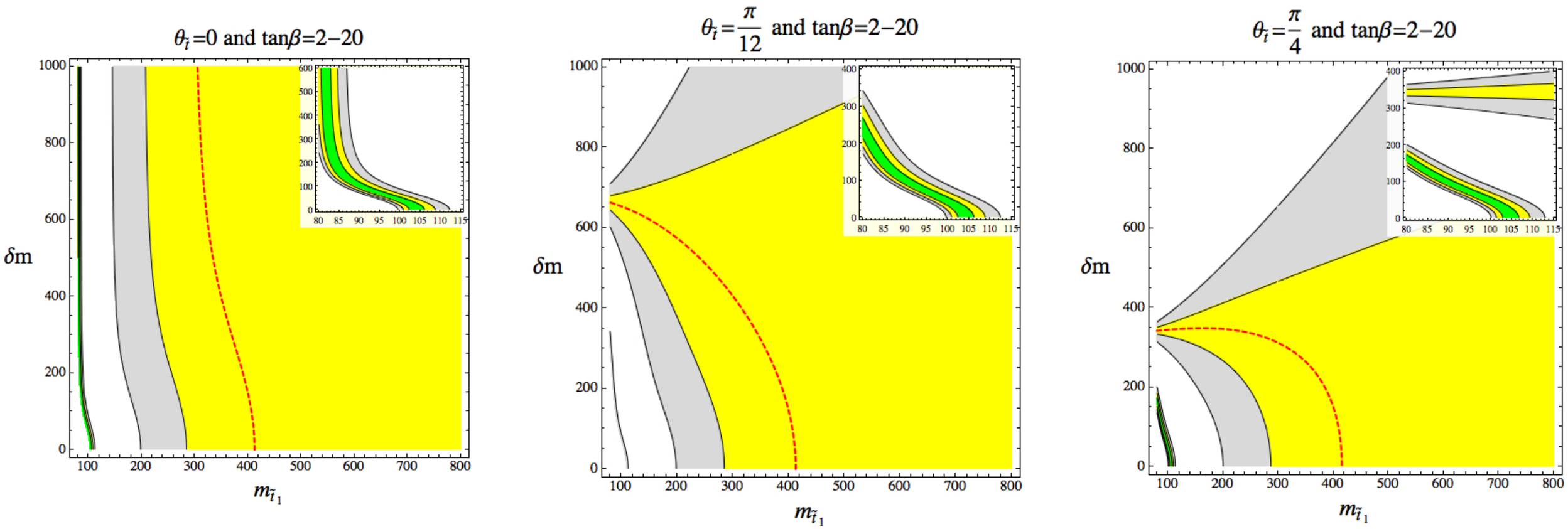


1D fit along the line



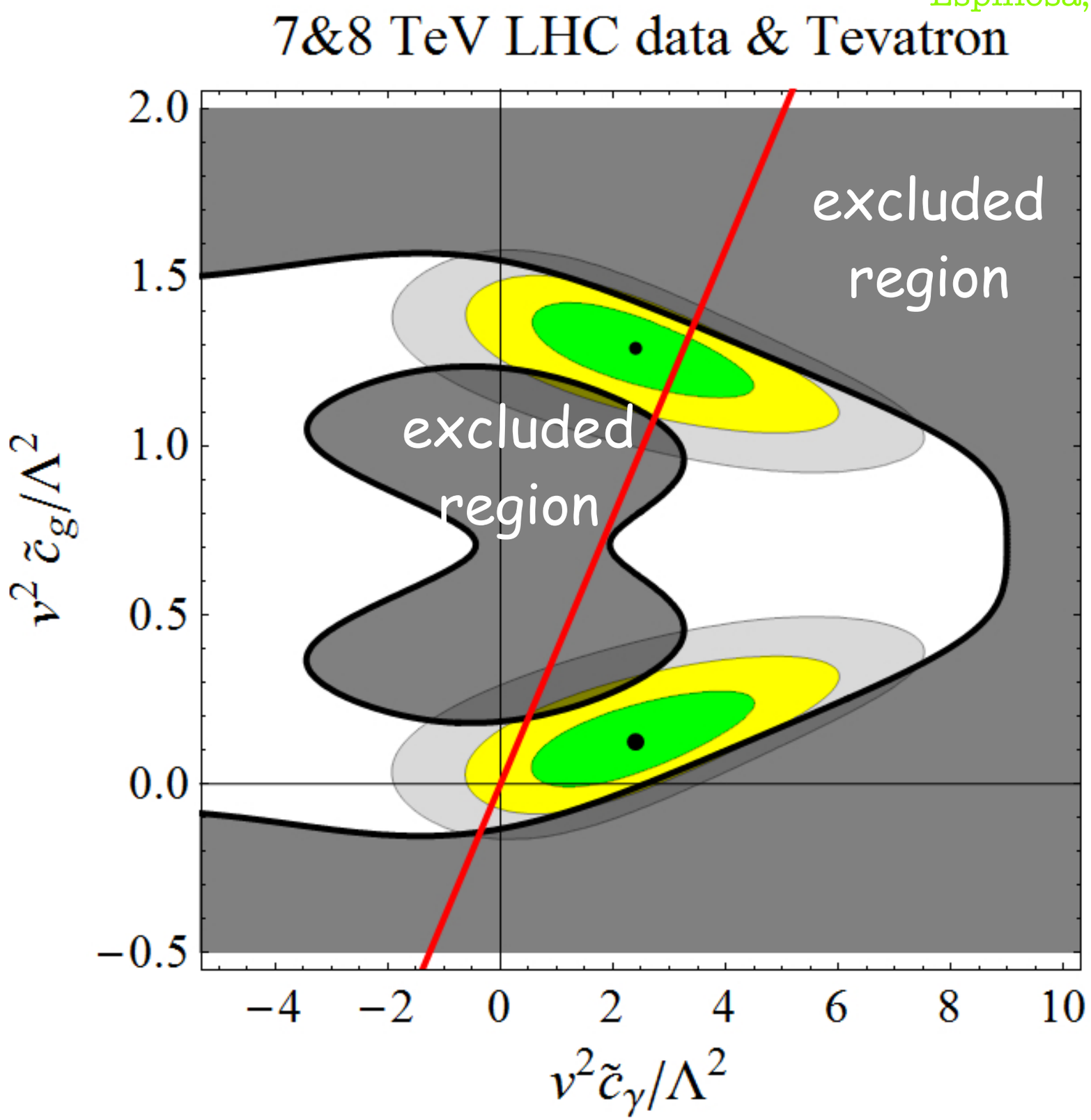
Projection onto stop mass plane

Espinosa, Grojean, Sanz, Trott '12



Stop mass constraints from Higgs

Espinosa, Grojean, Sanz, Trott '12



Stop mass constraints from global fit

Espinosa, Grojean, Sanz, Trott '12

BR($B_s \to X_s\gamma$) prefer degenate stops ⊃ kills the low stop mass region

then Higgs data put a lower bound of the stop mass