GLOBAL FIT TO HIGGS COUPLINGS

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FIRST GLIMPSES AT HIGGS' FACE

GLOBAL FIT TO HIGGS COUPLINGS

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1. "HIGGS" discovery brings plenty of data!
   - ➡ Learn about EWSB
2. Is it the SM Higgs ?
   - ➡ Scrutinize Search channels
3. BSM Hopes
   - ➡ Anomalous Higgs couplings
   - ➡ Special role of $h\gamma\gamma$, hgg
   - ➡ Nonzero invisible width

Work based on collaborations with:

C. Grojean, M. Muhlleitner, M. Trott
[hep-ph/1202.3697], [1205.6790], [1207.1717]

For related hep-ph work see:

D. Carmi, A. Falkowski, E. Kuflik, T. Volansky [1202.3144][1206.4201]
+ J. Zupan [1207.1718]

A. Azatov, R. Contino, J. Galloway [1202.3415][1206.3171]

P. Giardino, K. Kannike, M. Raidal, A. Strumia [1203.4254][1207.1347]

J. Ellis, T. You [1204.0464][1207.1693]

M. Klute, R. Lafaye, T. Plehn, M. Rauch, D. Zerwas [1205.2699]

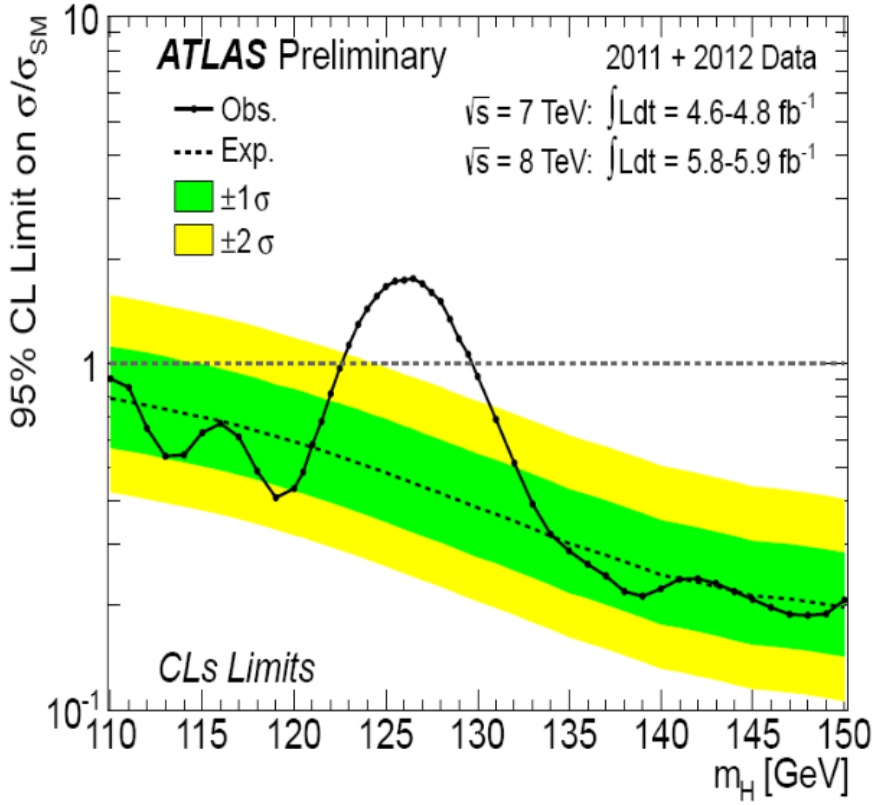
I. Low, J. Lykken, G. Shaughnessy [1207.1093]

T. Corbett, O. Eboli, J. González-Fraile, M.C. González-García [1207.1344]

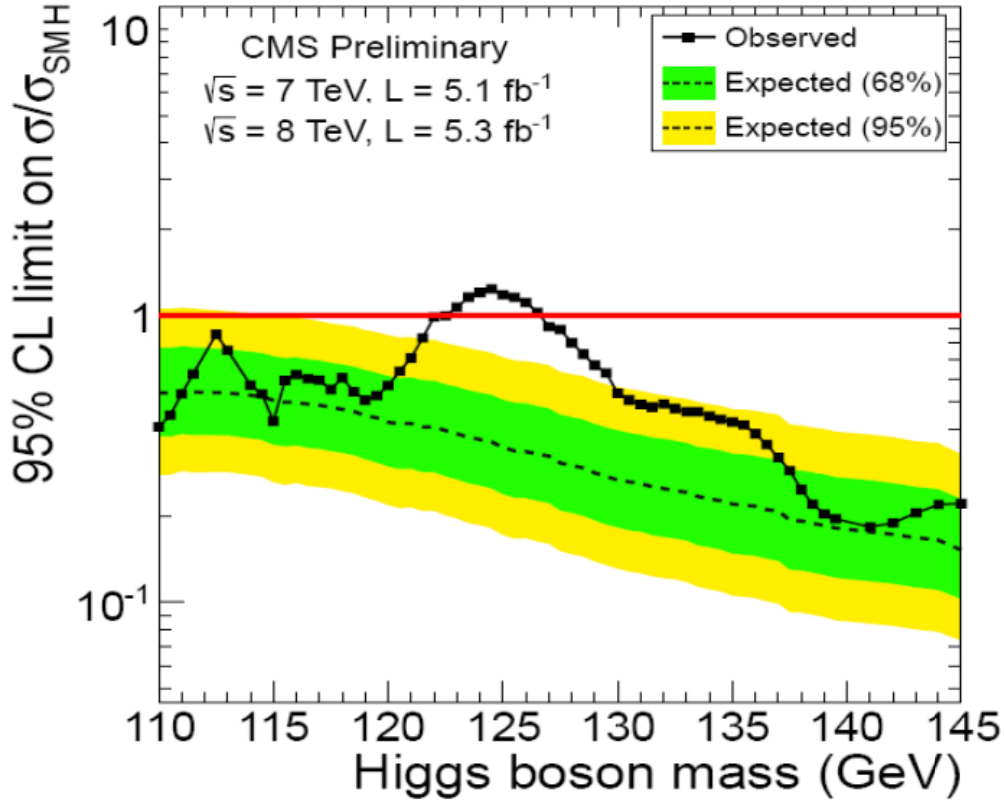
M. Montull, F. Riva [1207.1716]

DATA !

SIGNAL EXCESS IN 95 % C.L. EXCLUSION LIMITS



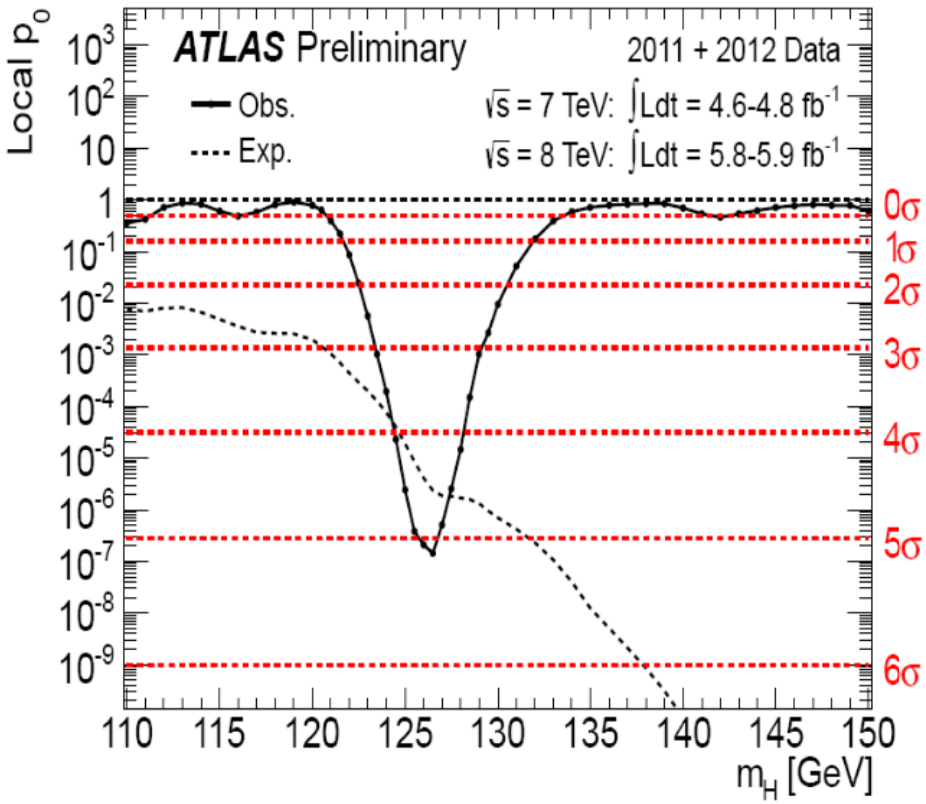
$m_h \sim 126.5$ GeV



$m_h \sim 125$ GeV

DISCOVERY!

SIGNAL EXCESS ≈ 5σ



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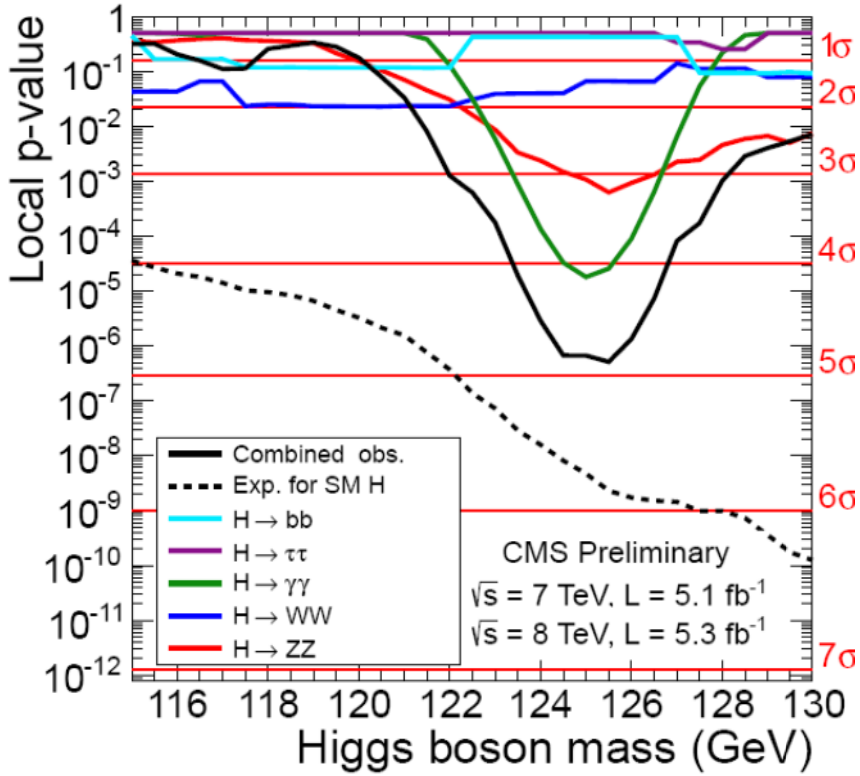


$m_h \sim 125$ GeV

IS IT THE SM HIGGS?

SM Higgs sector is the less tested and more problematic

Affected by hierarchy problem

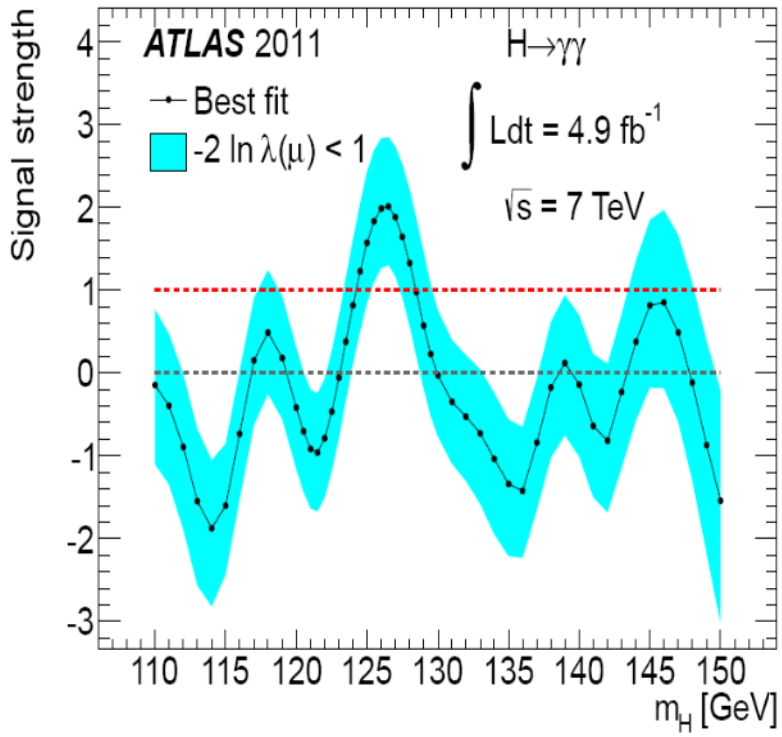
Calls for new physics at the TeV scale

It's very likely that the Higgs will depart from its SM properties

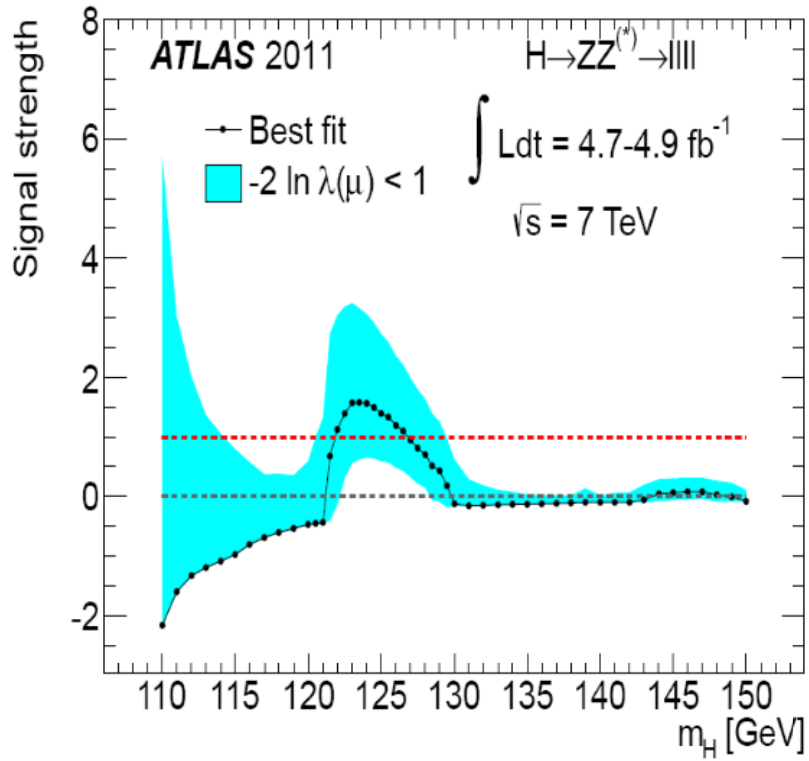
The importance of measuring Higgs couplings cannot be overemphasized

INDIVIDUAL SEARCH CHANNELS

$m_h \sim 125$ GeV : many channels! $\mu = \sigma/\sigma_{SM}$ for ATLAS :



γγ



ZZ

INDIVIDUAL SEARCH CHANNELS

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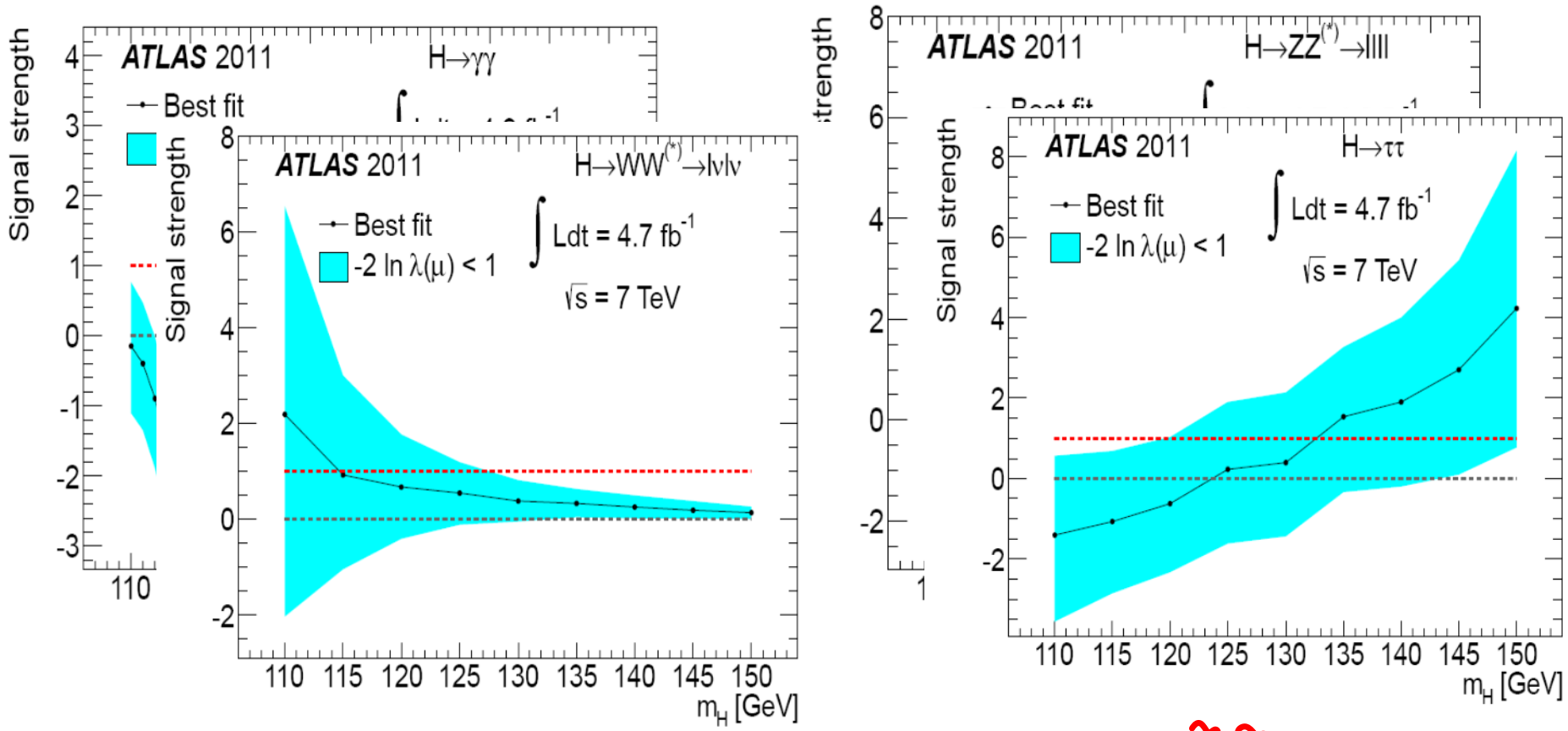

WW

ττ

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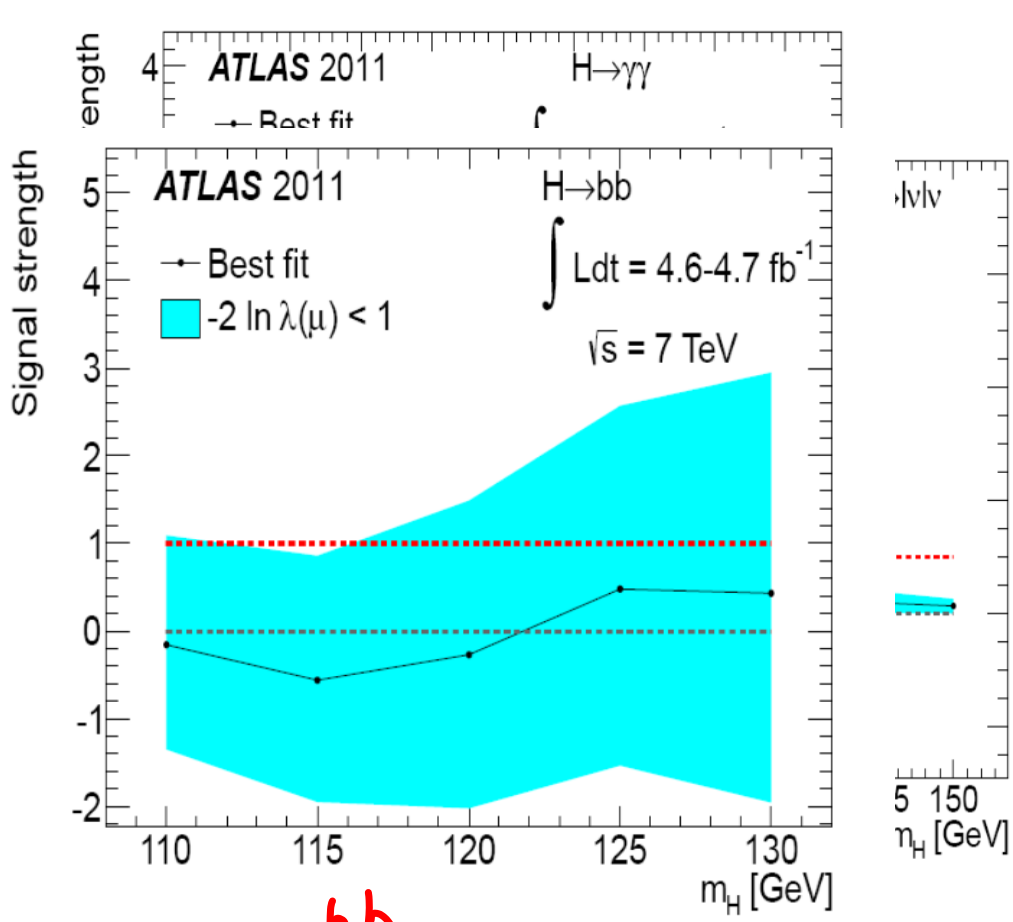
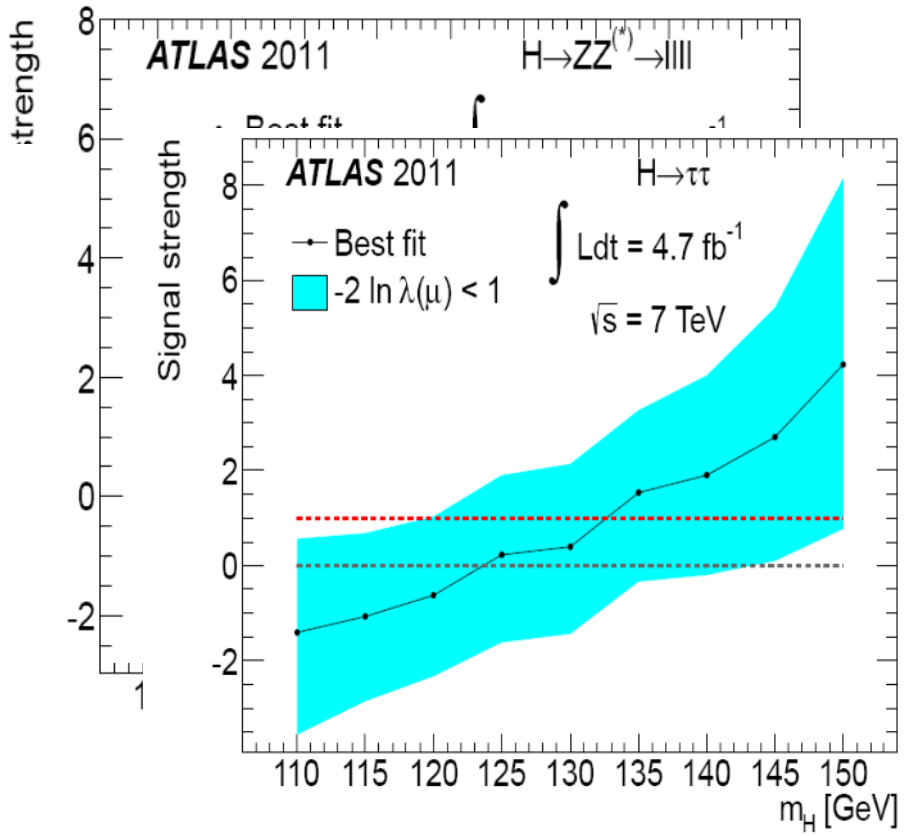


bb

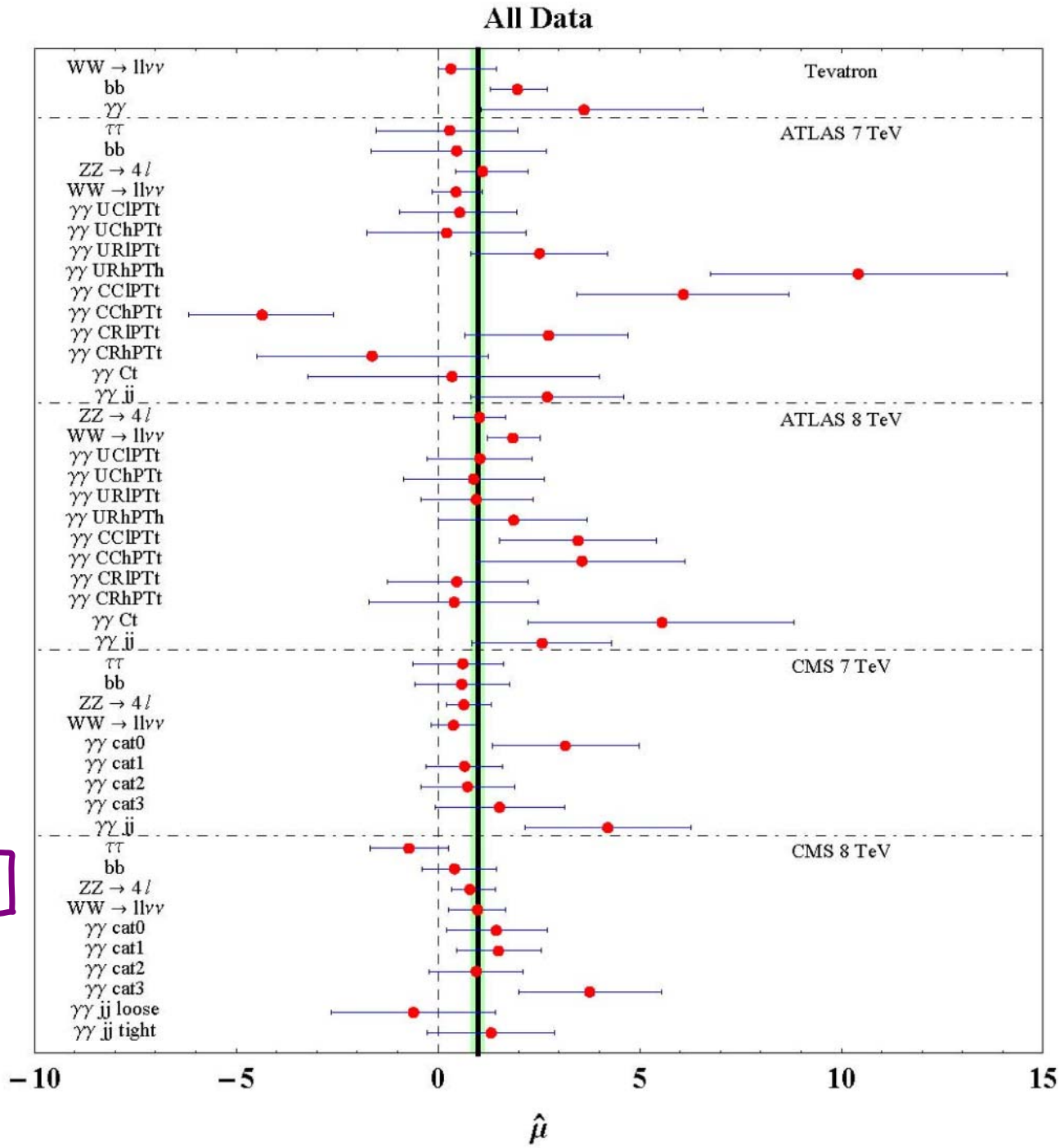


+ Similar data from CMS & Tevatron

DATA USED IN OUR FITS

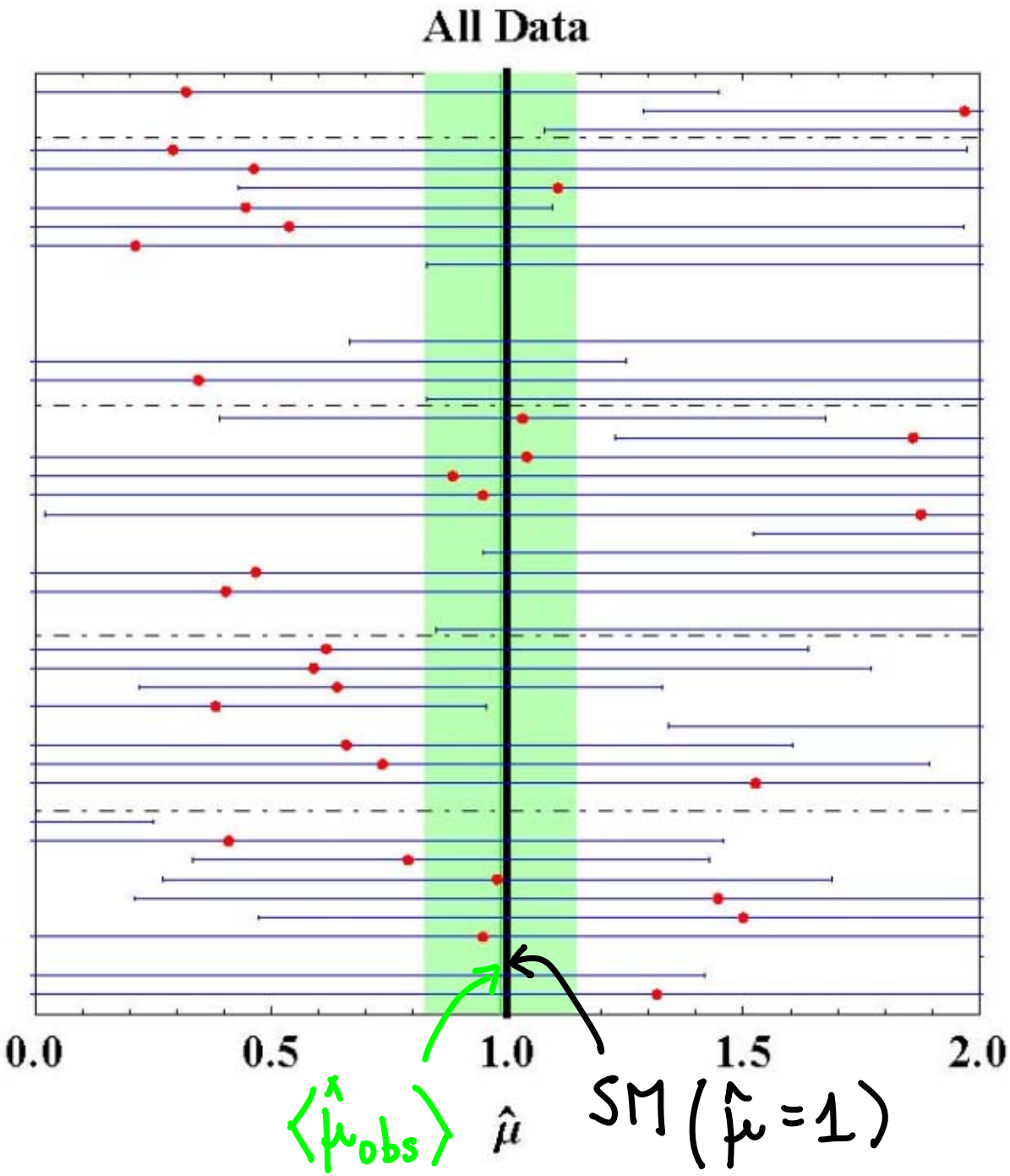
48 channels, including latest WW → 2l2ν from ATLAS @ 8 TeV

[see Arnaez, last Wednesday]



DATA USED IN OUR FITS

Zoom of previous plot ⇨



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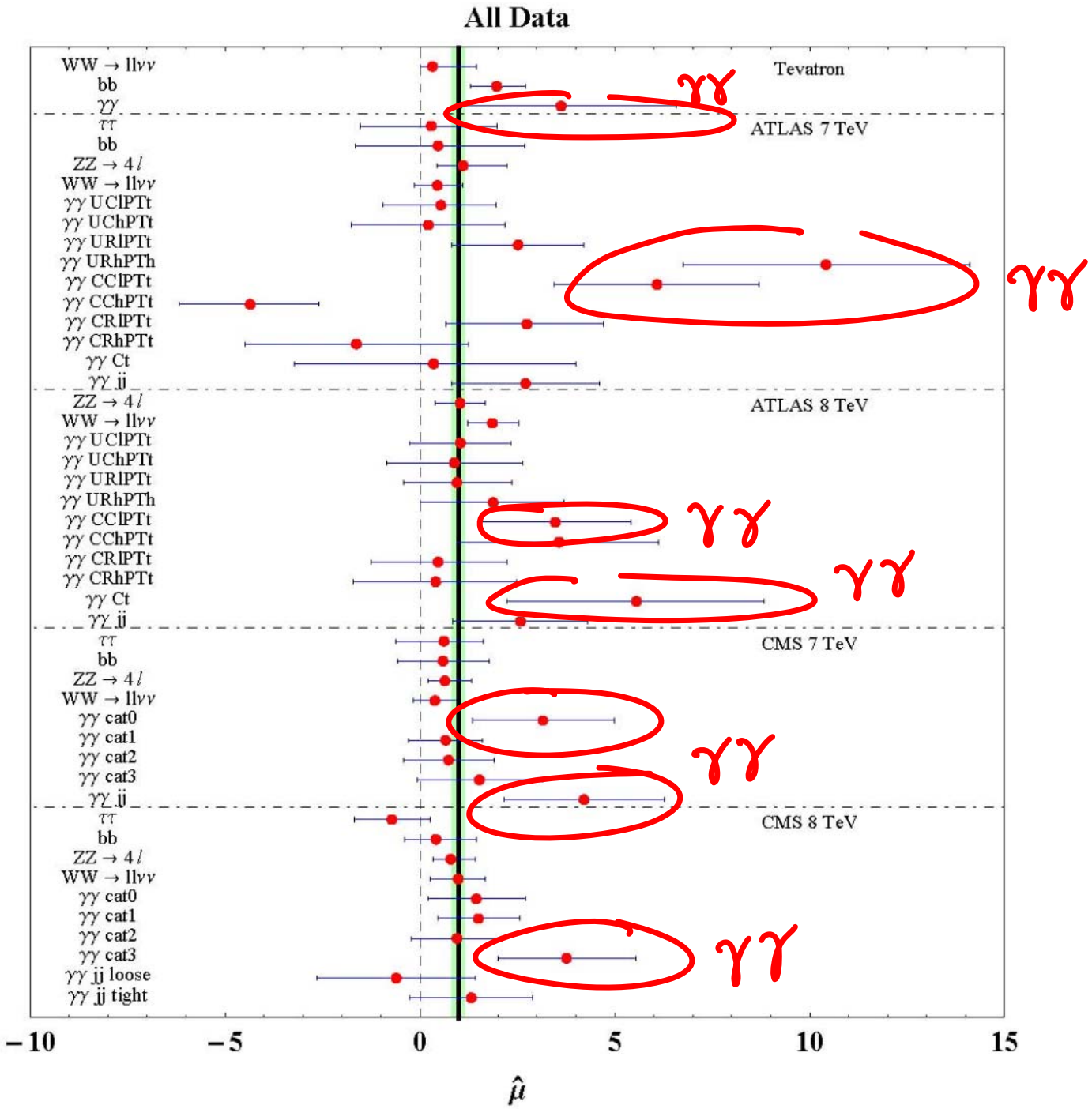

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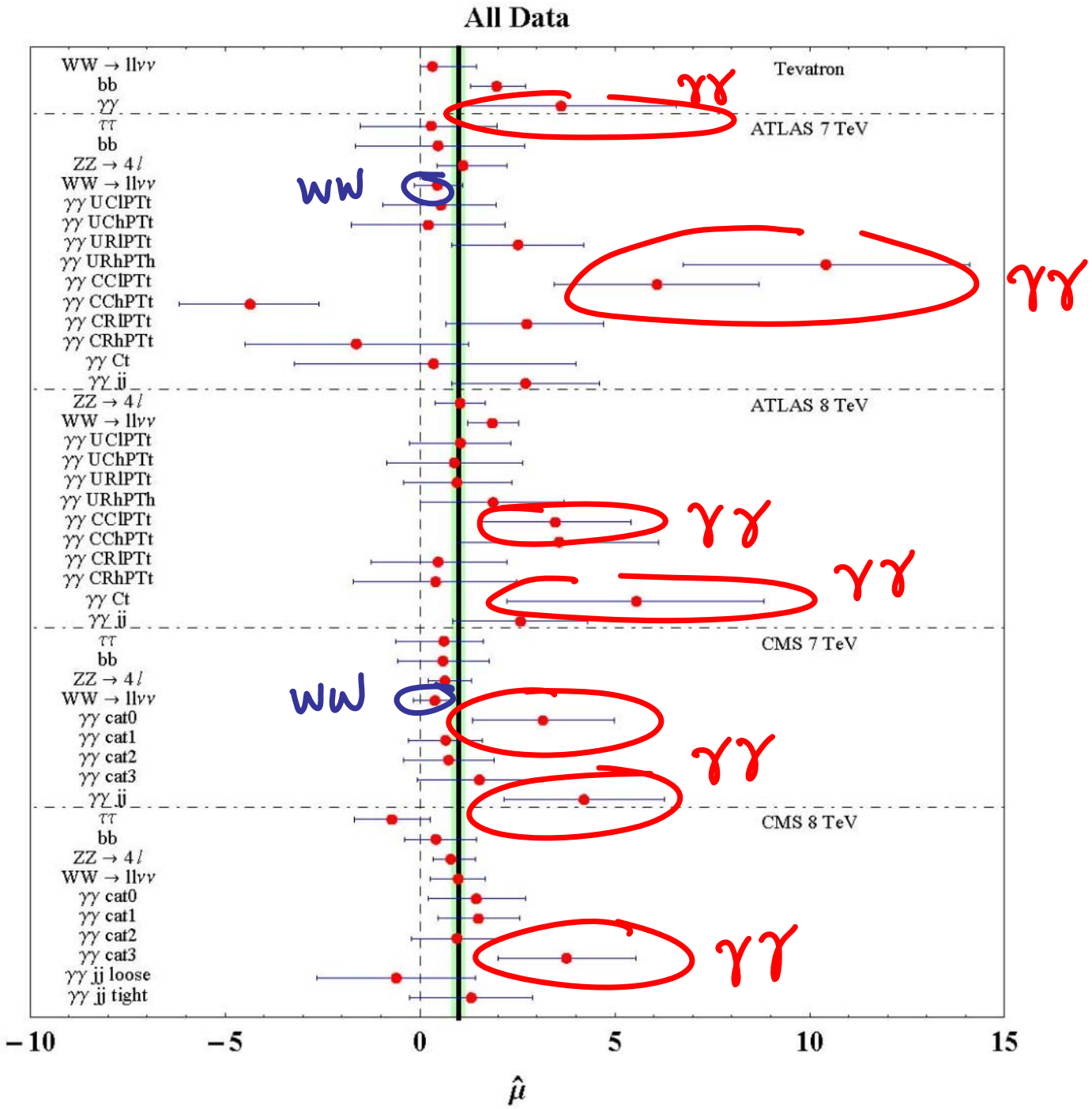

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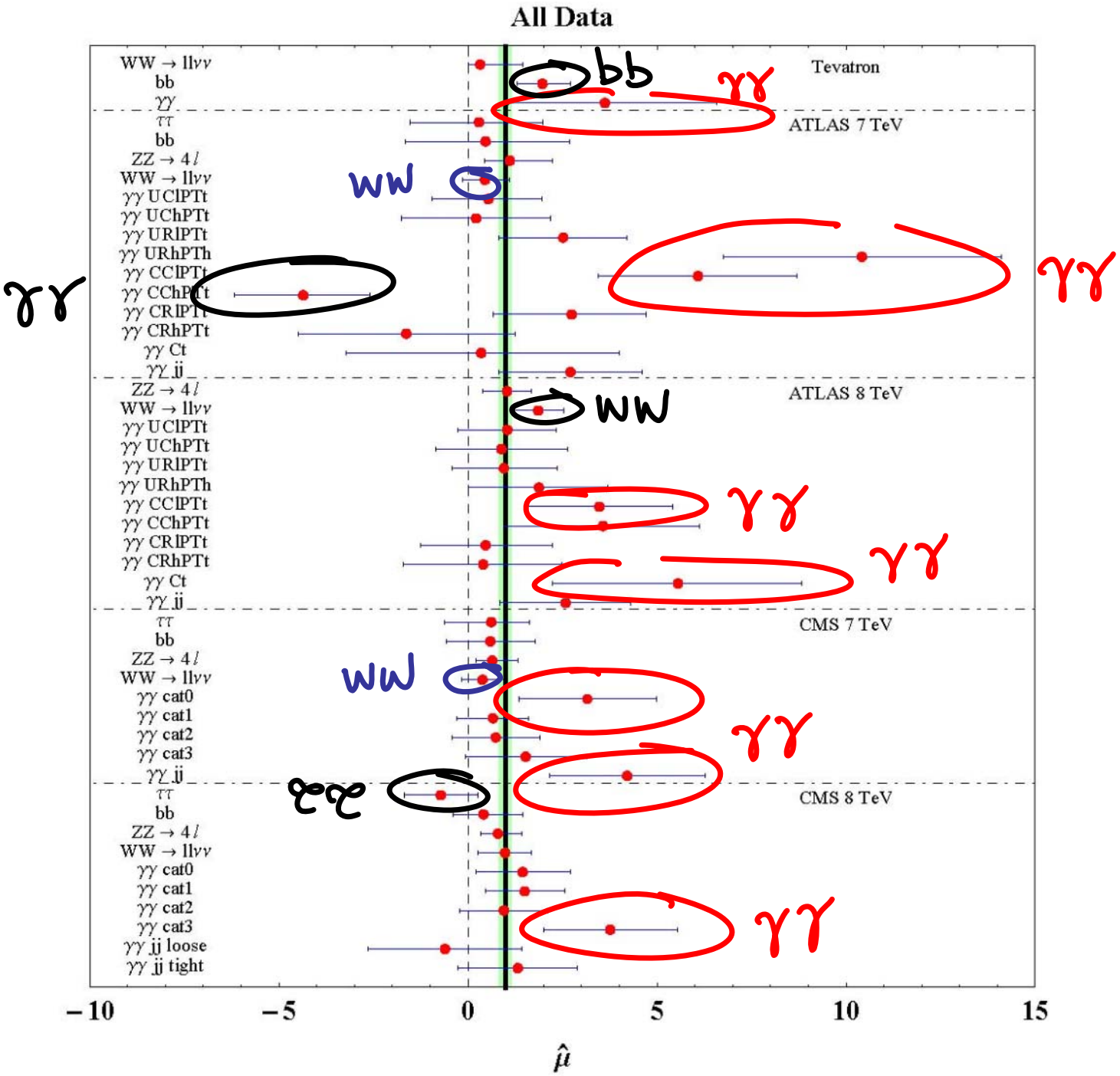

EFFECTIVE LAGRANGIAN APPROACH

$\mathcal{L}$ valid at $E \sim M_t$.

Field content : SM + scalar h (no extra light states)

$$\mathcal{L} = \mathcal{L}[h] - \left(M_W^2 W_\mu^+ W^{\mu -} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu\right)\left[1 + 2a\frac{h}{v} + O(h^2)\right]$$
$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \ldots$$

Contino et al '10 '12

Incorporates $SU(2)_L \times U(1)_Y \to U(1)_{em}$ breaking

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Incorporates $SU(2)_L \times U(1)_Y \to U(1)_{em}$ breaking

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First terms in a "chiral lagrangian" with cutoff

$$\Lambda \gtrsim 4\pi v$$

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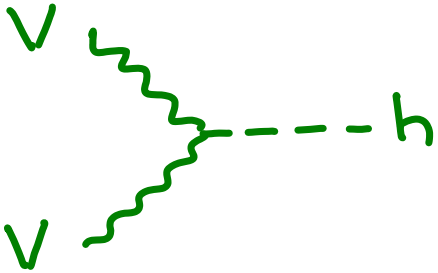
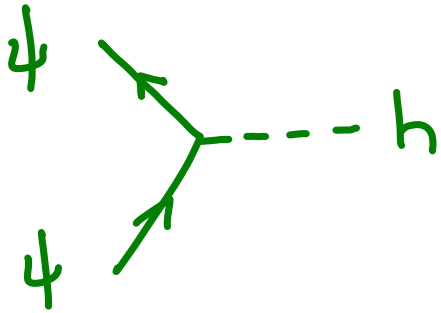
2-parameter extension of the SM with



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



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

$$\text{SM} \equiv (a, c) = (1, 1)$$

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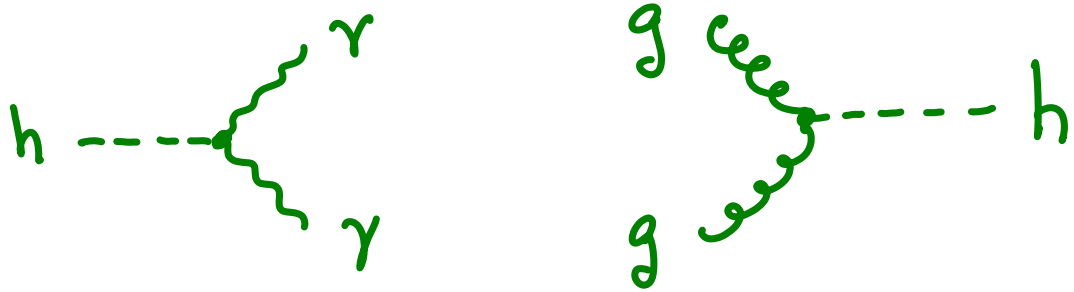
Other operators very relevant for Higgs searches:

$$\frac{g^2}{16\pi^2}\left[c_\gamma A_{\mu\nu} A^{\mu\nu} + c_g G^A_{\mu\nu} G^{A\mu\nu}\right]\frac{h}{v}$$



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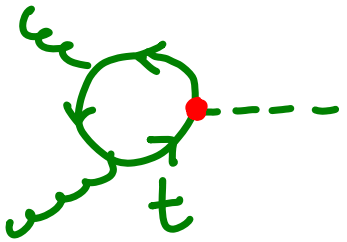
are assumed to come from SM loops only:

$gg \to h$



$\sim c$

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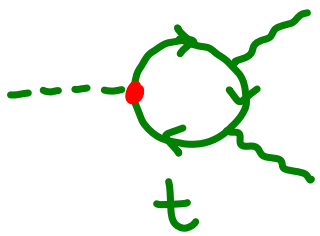
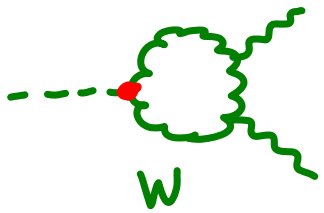
$h \to \gamma\gamma$: 

$\sim c +$ 

$\sim a$

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are assumed to come from SM loops only.

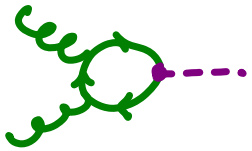
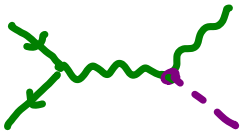
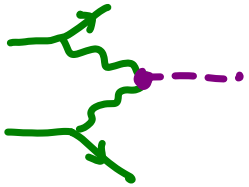
Motivated by composite PNGB Higgs scenarios

Will relax this assumption later on.

RATES IN SM(a,c)

★ Only h couplings are modified:
Signal rate modified
kinematics unchanged

★ Different production mechanisms change differently.

$\sigma\Big[$  , $\Big] \sim c^2$ $\quad \sigma\Big[$  ,  $\Big] \sim a^2$

★ Expected signal strengths:

$$\mu_i = \left[\frac{\sigma^{SM(a,c)}_{pp\to h\to X}}{\sigma^{SM}_{pp\to h\to X}}\right]_i = \frac{\sum_{p_i} \epsilon_{p_i}\sigma_{p_i}(a,c)\times BR^{SM(a,c)}_{h\to X}}{\sum_{p_i} \epsilon_{p_i}\sigma_{p_i}\times BR^{SM}_{h\to X}}$$

RATES IN SM(a,c)

★ Need to know efficiencies ϵ_{p_i} to properly rescale σ_i

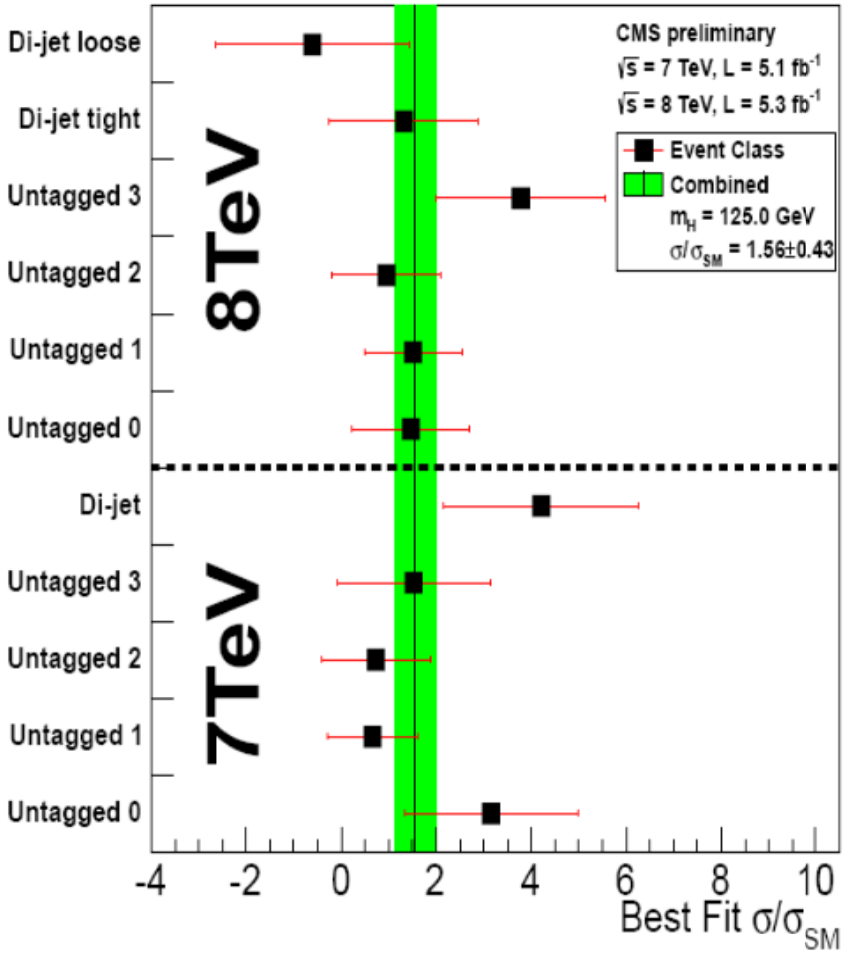
ATLAS $\gamma\gamma$ subcategories

$\sqrt{s}$	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
8 TeV	Inclusive	111.6	88.5	7.4	2.7	1.6	0.5
	Unconverted central, low p_{Tt}	14.4	92.9	4.2	1.7	1.0	0.2
	Unconverted central, high p_{Tt}	2.5	72.5	14.1	6.9	4.2	2.3
	Unconverted rest, low p_{Tt}	31.4	92.5	4.1	2.0	1.1	0.2
	Unconverted rest, high p_{Tt}	5.3	72.1	13.8	7.8	4.6	1.7
	Converted central, low p_{Tt}	9.1	92.8	4.3	1.7	1.0	0.3
	Converted central, high p_{Tt}	1.6	72.7	13.7	7.1	4.1	2.3
	Converted rest, low p_{Tt}	27.3	92.5	4.2	2.0	1.1	0.2
	Converted rest, high p_{Tt}	4.6	70.8	14.4	8.3	4.7	1.7
	Converted transition	13.0	88.8	6.0	3.1	1.8	0.4
	2-jets	2.9	30.4	68.4	0.4	0.2	0.2

Crucial to probe (a,c) dependence of rates

RATES IN SM(a,c)

- ★ Need to know efficiencies ϵ_{p_i} to properly rescale σ_i
- ★ Need to know measured $\hat{\mu}$'s separately at 7,8 TeV



RATES IN SM(a,c)

★ Need to know efficiencies ϵ_{p_i} to properly rescale σ_i

★ Need to know measured $\hat{\mu}$'s separately at 7, 8 TeV

When only $\hat{\mu}_{7+8}$ is available, we used Gaussian combination formulas:

$$\frac{\hat{\mu}_{7+8}}{\sigma_{7+8}^2} = \frac{\hat{\mu}_7}{\sigma_7^2} + \frac{\hat{\mu}_8}{\sigma_8^2} \qquad \frac{1}{\sigma_{7+8}^2} = \frac{1}{\sigma_7^2} + \frac{1}{\sigma_8^2}$$

to get $\hat{\mu}_8 \pm \sigma_8$ from $\hat{\mu}_7 \pm \sigma_7$, $\hat{\mu}_{7+8} \pm \sigma_8$.

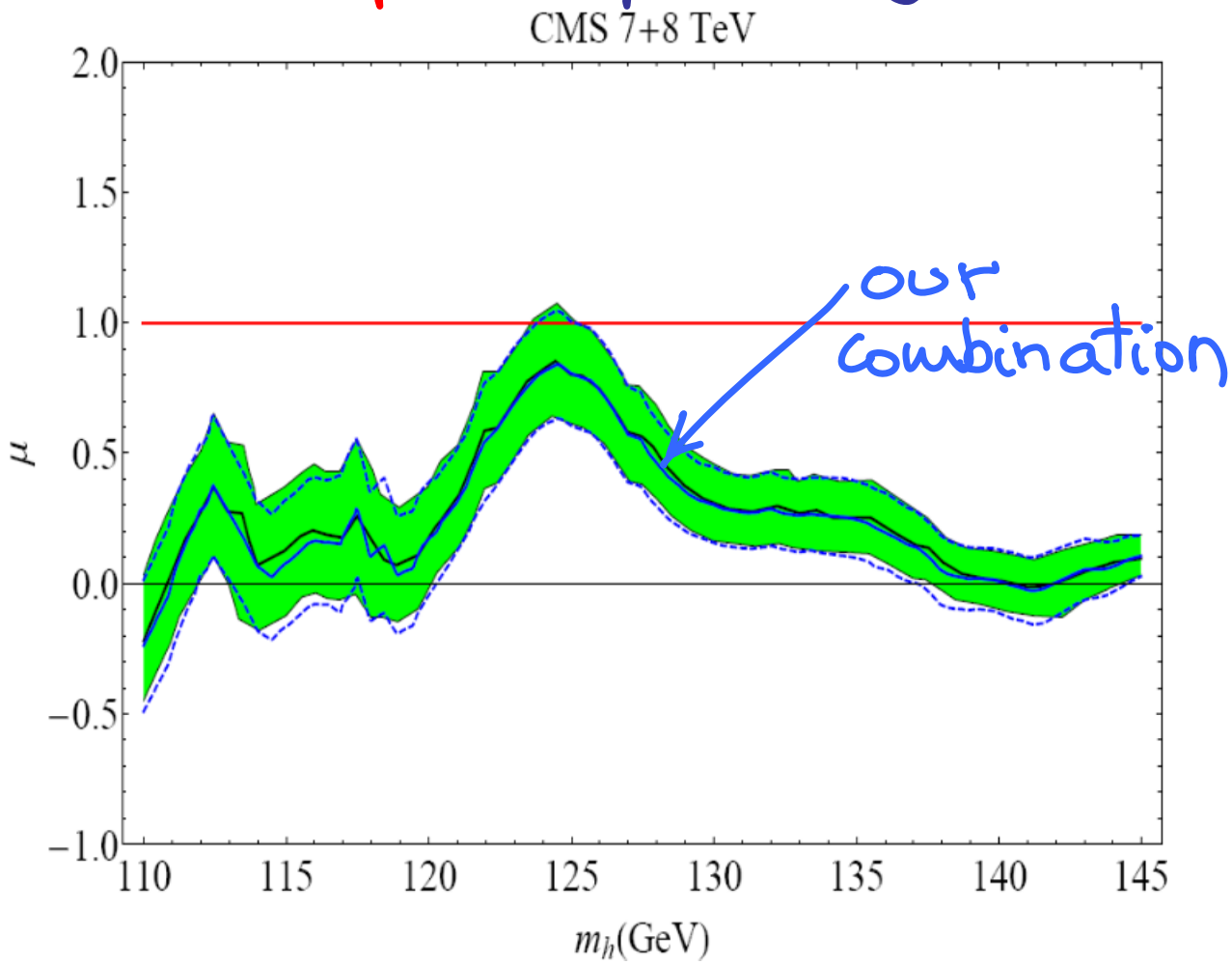
RATES IN SM(a,c)

★ Need to know efficiencies ϵ_{p_i} to properly rescale σ_i

★ Need to know measured $\hat{\mu}$'s separately at 7,8 TeV

We checked this works well :

Official CMS combination at 7+8 TeV



RATES IN SM(a,c)

- Need to know efficiencies ϵ_{p_i} to properly rescale σ_i
- Need to know measured $\hat{\mu}$'s separately at 7, 8 TeV
- Have assumed Gaussian distributed $\hat{\mu}$'s and neglected correlations when combining different channels and/or experiments.

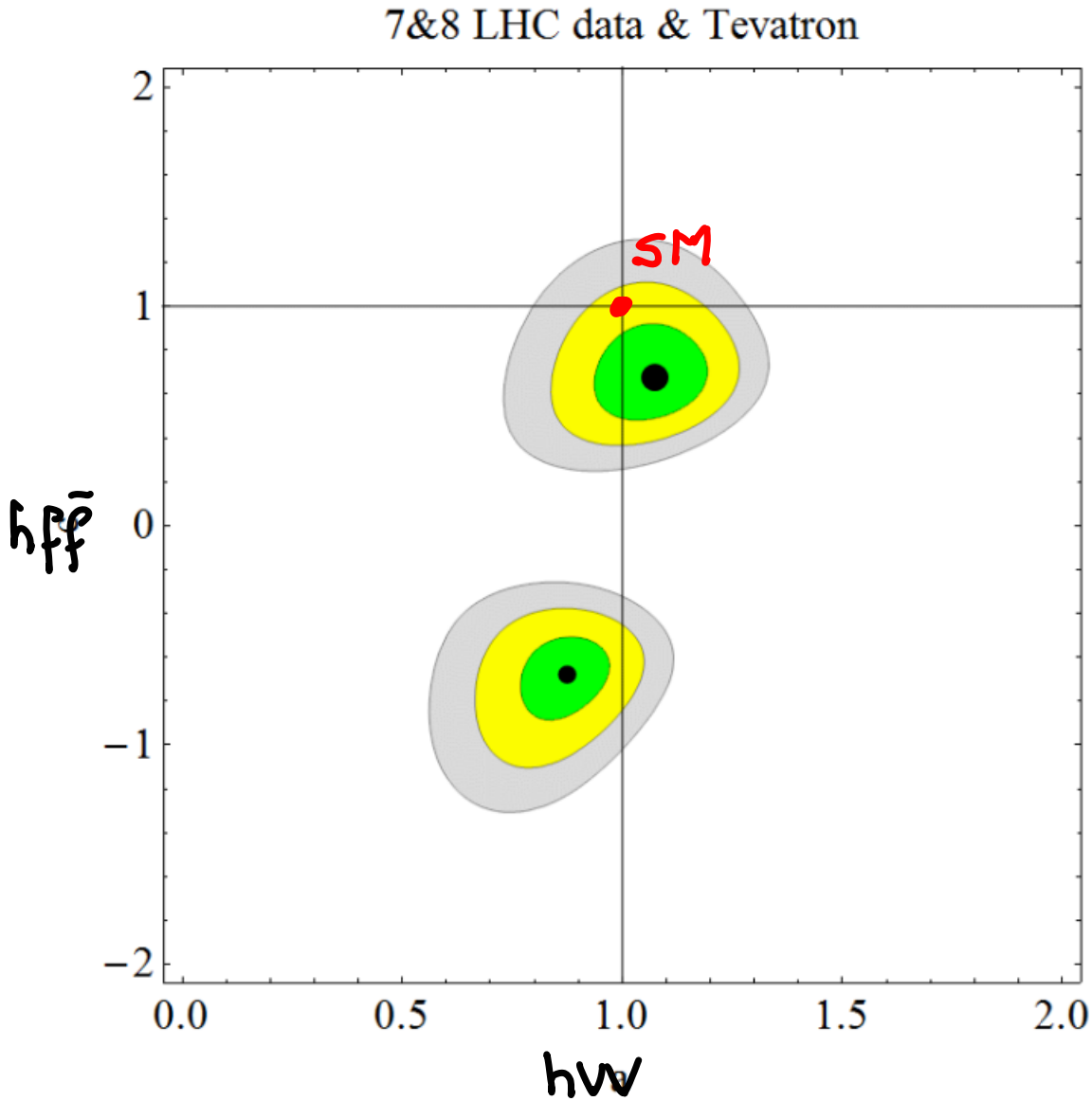
FITS IN SM(a,c)

χ^2 fit to $\hat{\mu}_i \pm \sigma_i$ from 48 channels (ATLAS + CMS + Tevatron)

68%

95%

99%



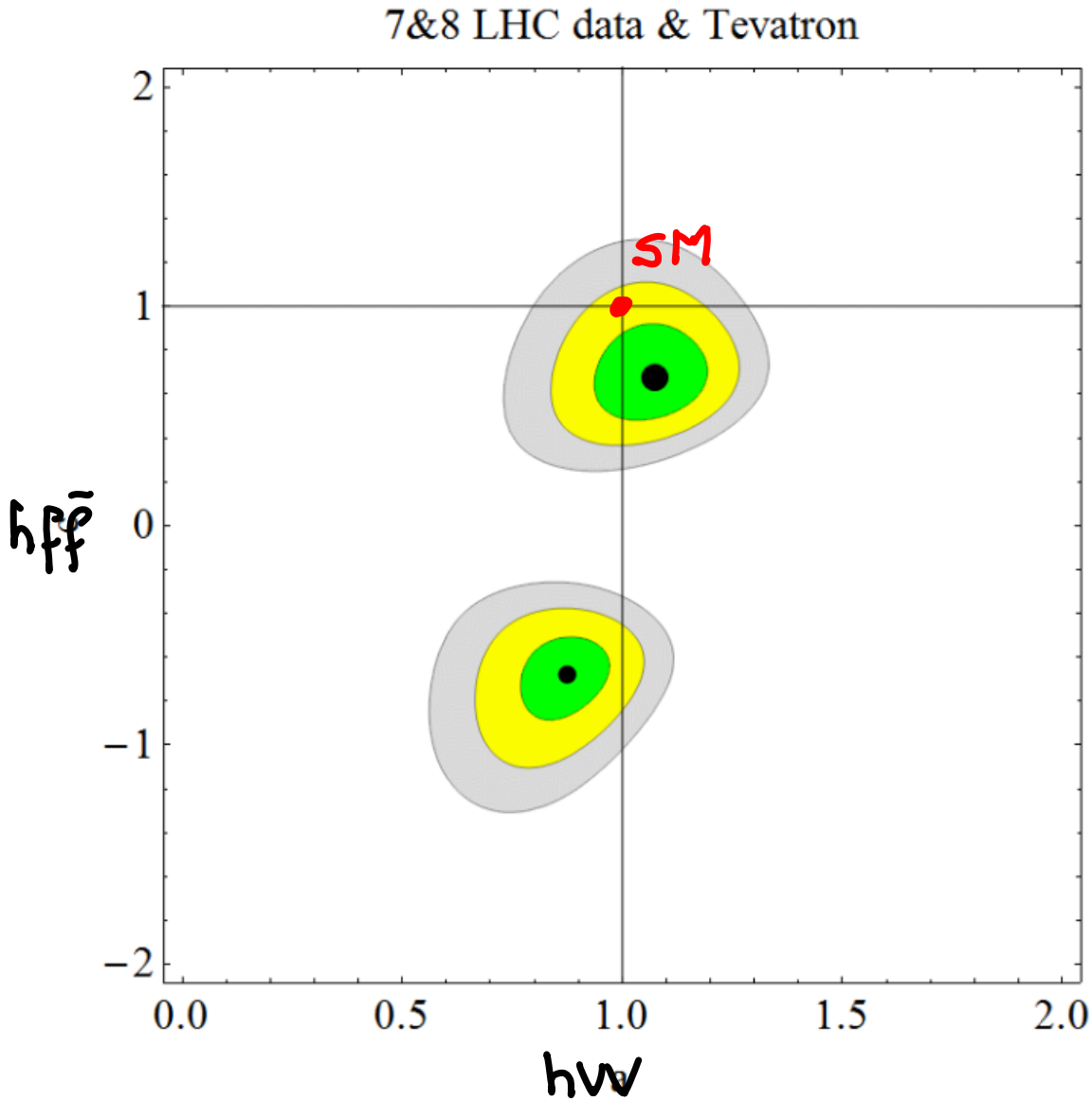
FITS IN SM(a,c)

χ^2 fit to $\hat{\mu}_i \pm \sigma_i$ from 48 channels (ATLAS + CMS + Tevatron)

68%

95%

99%



SM gives a reasonable fit

FITS IN SM(a,c)

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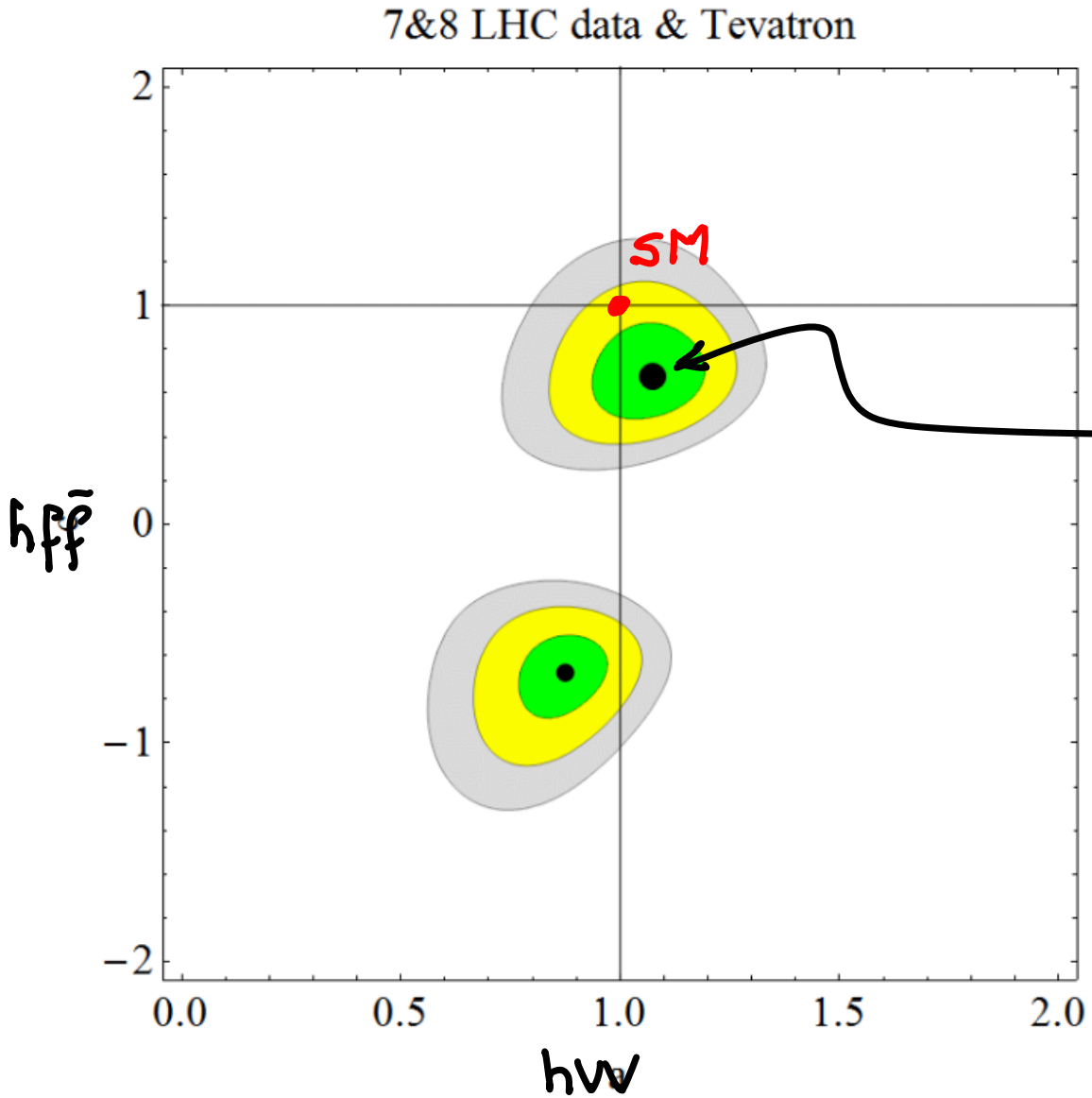


SM gives a reasonable fit

Best fit point ($a>1$, $c<1$)

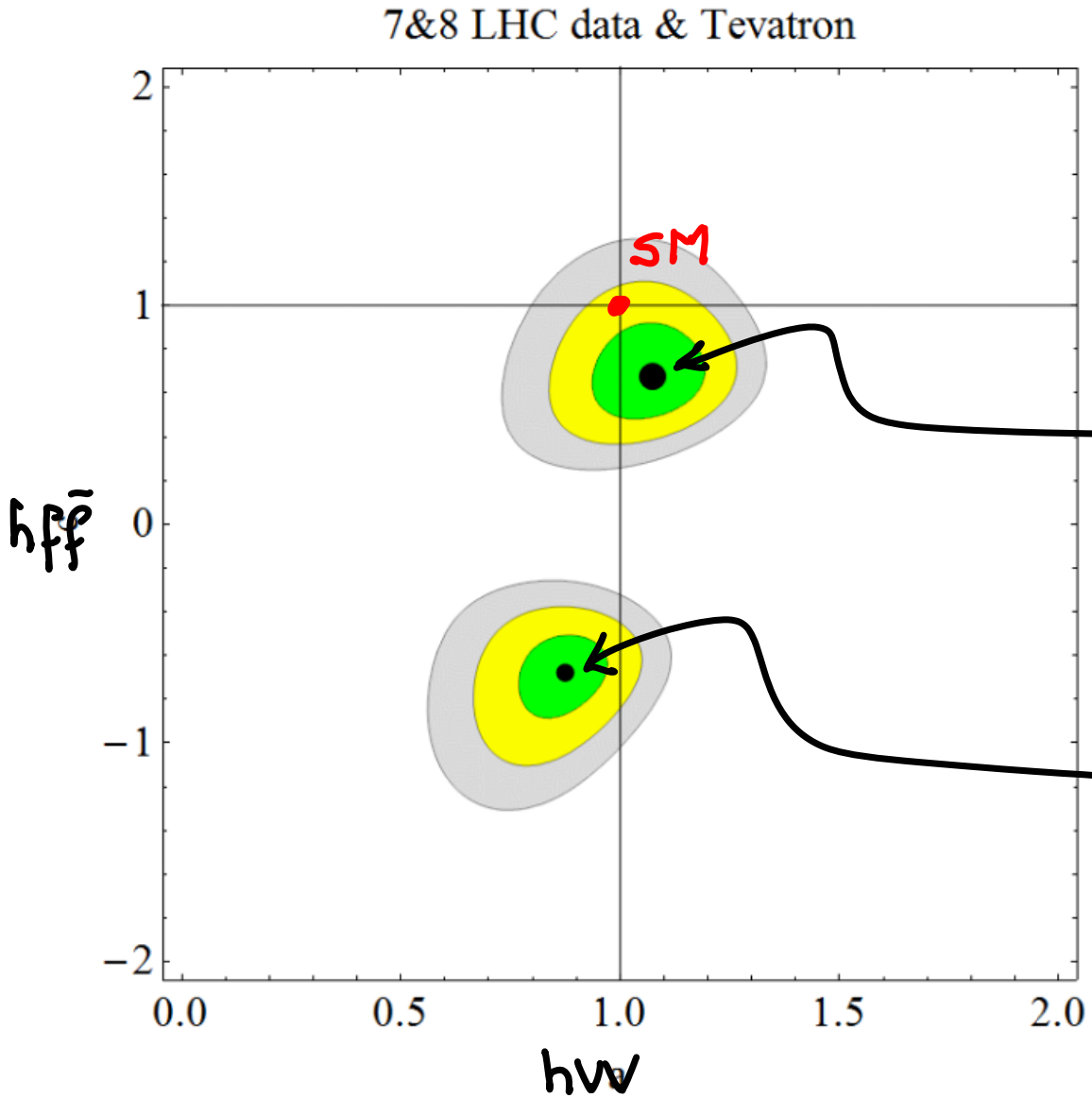
FITS IN SM(a,c)

χ^2 fit to $\hat{\mu}_i \pm \sigma_i$ from 48 channels (ATLAS + CMS + Tevatron)

68%

95%

99%

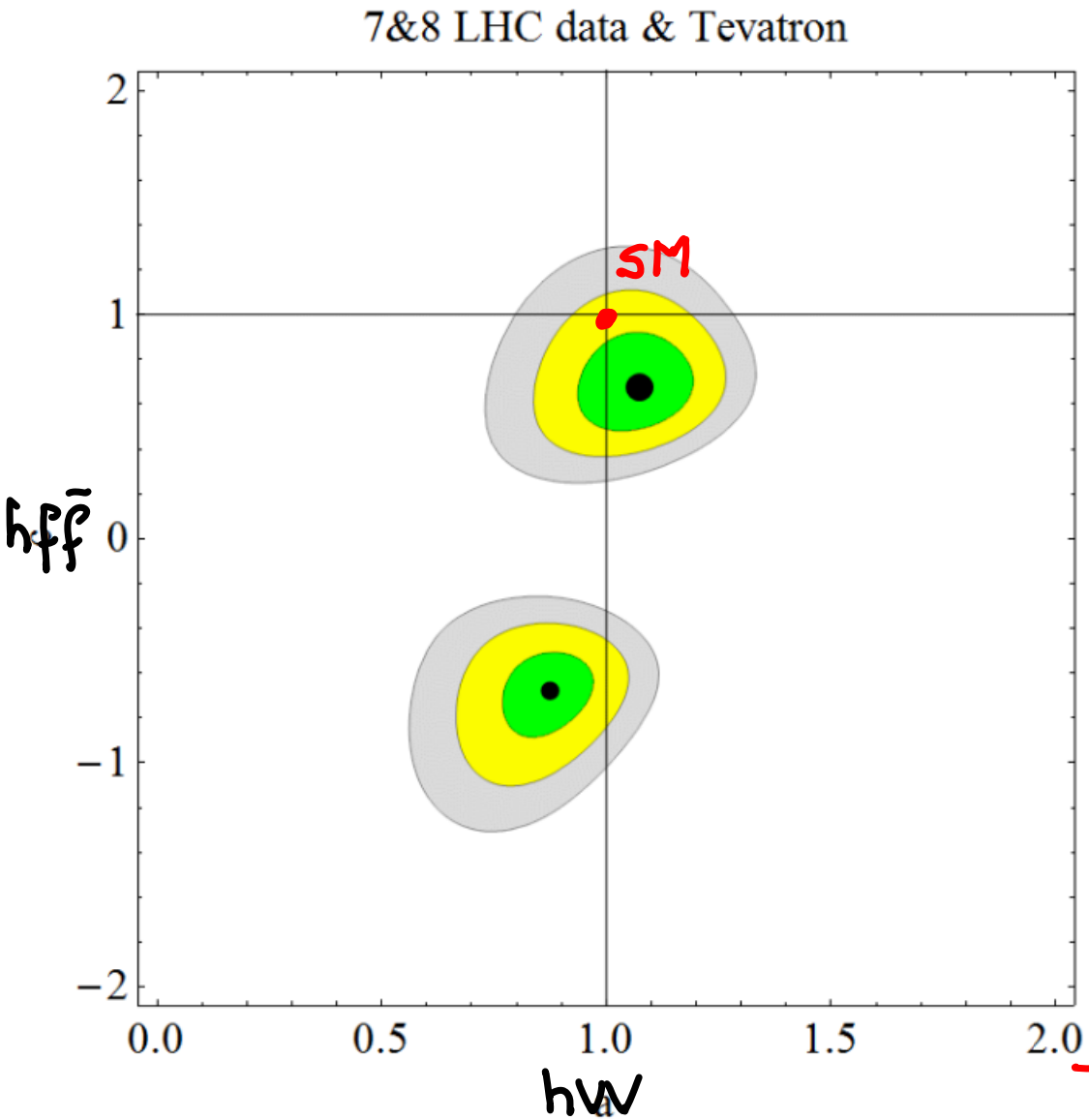


SM gives a reasonable fit

Best fit point ($a>1$, $c<1$)

Nearly deg. second χ^2_{min} ($a<1$, $c<0$, $|c|<1$)

FITS IN SM(a,c)



How to improve SM's fit:

$|c|<1 \Rightarrow BR_{b\bar{b}} \downarrow$ ~20%

$\Downarrow$

$BR_{\gamma\gamma} \uparrow\uparrow$ x2-3

$BR_{WW} \uparrow$

compensating $\sigma_{gg} \downarrow$ ~50%

Two solutions due to approx.

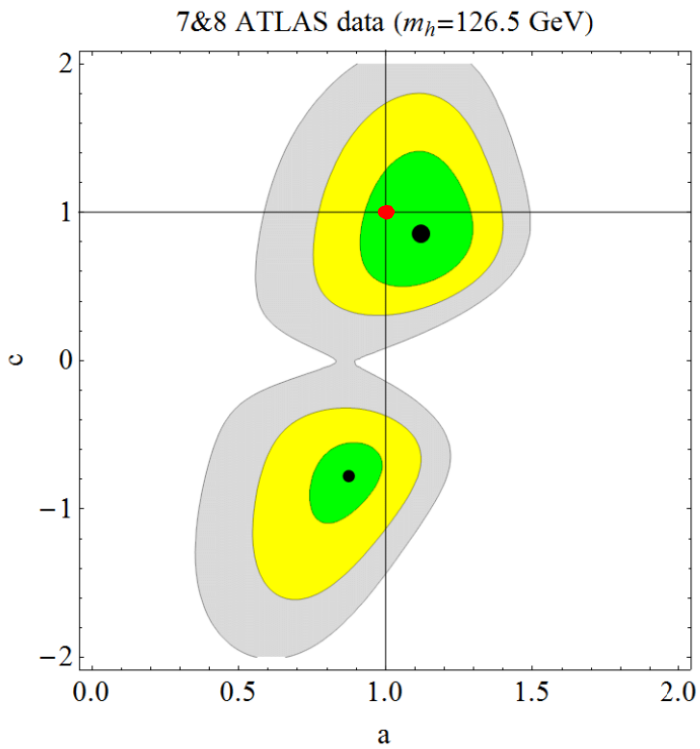
$a \leftrightarrow -a$ $c \leftrightarrow -c$ sym.

Broken by $h\gamma\gamma$ amplitude

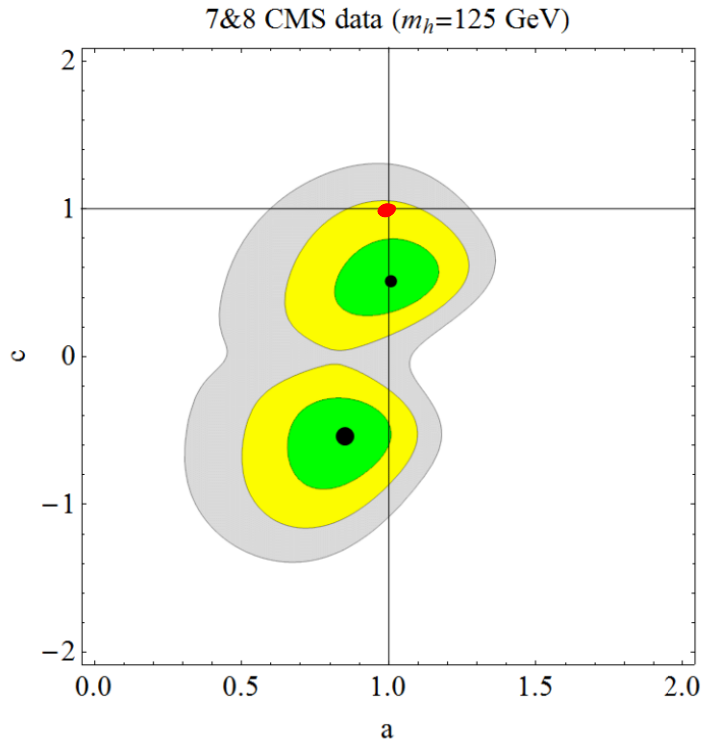
$\sim |1.26a - 0.26c|^2$

$\rightarrow$ Constr. interference for $c<0$

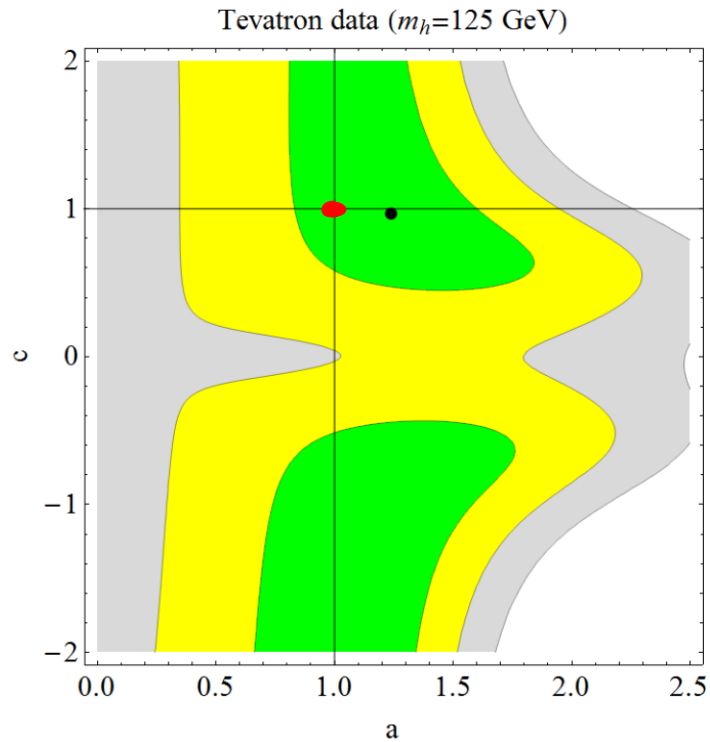
FITS TO SEPARATE EXP.



ATLAS

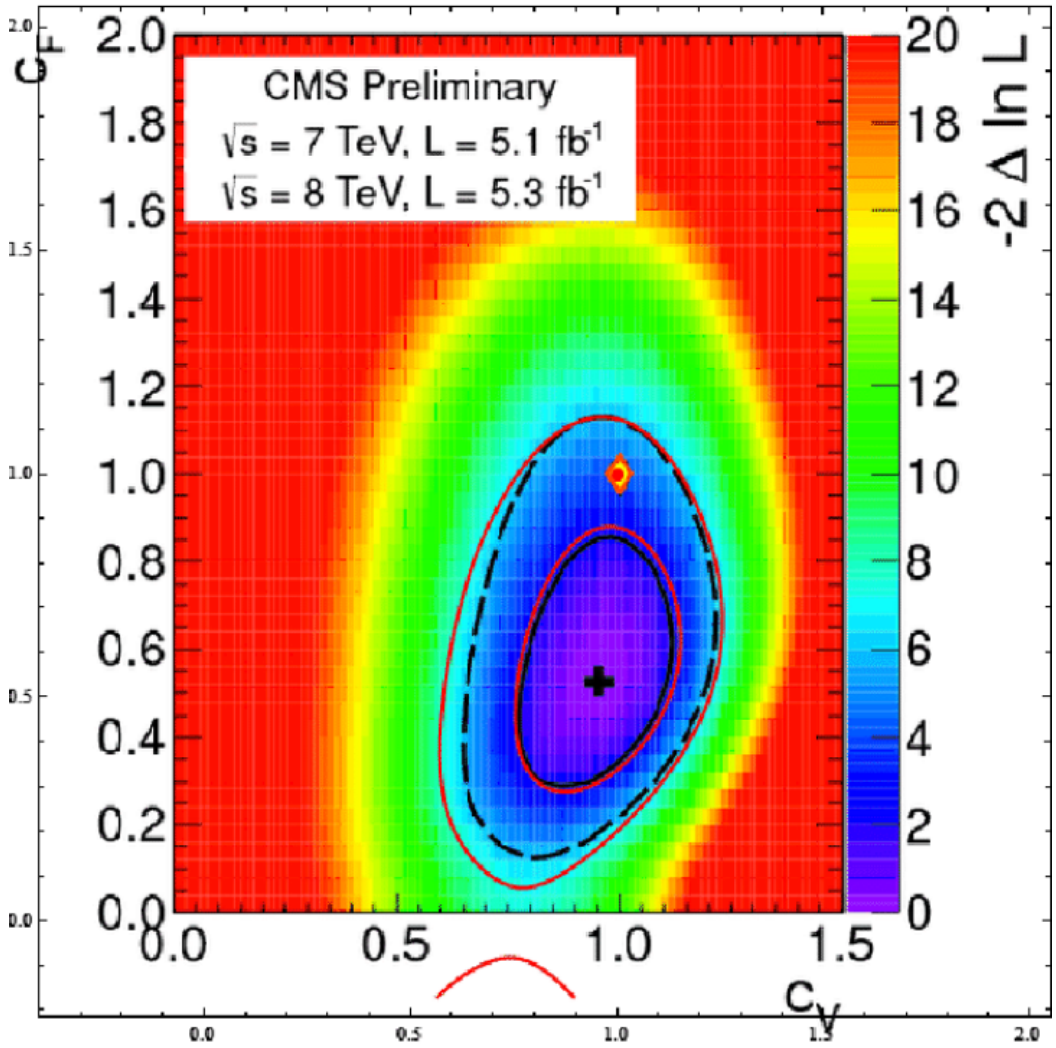


CMS



Tevatron

COMPARISON WITH CMS

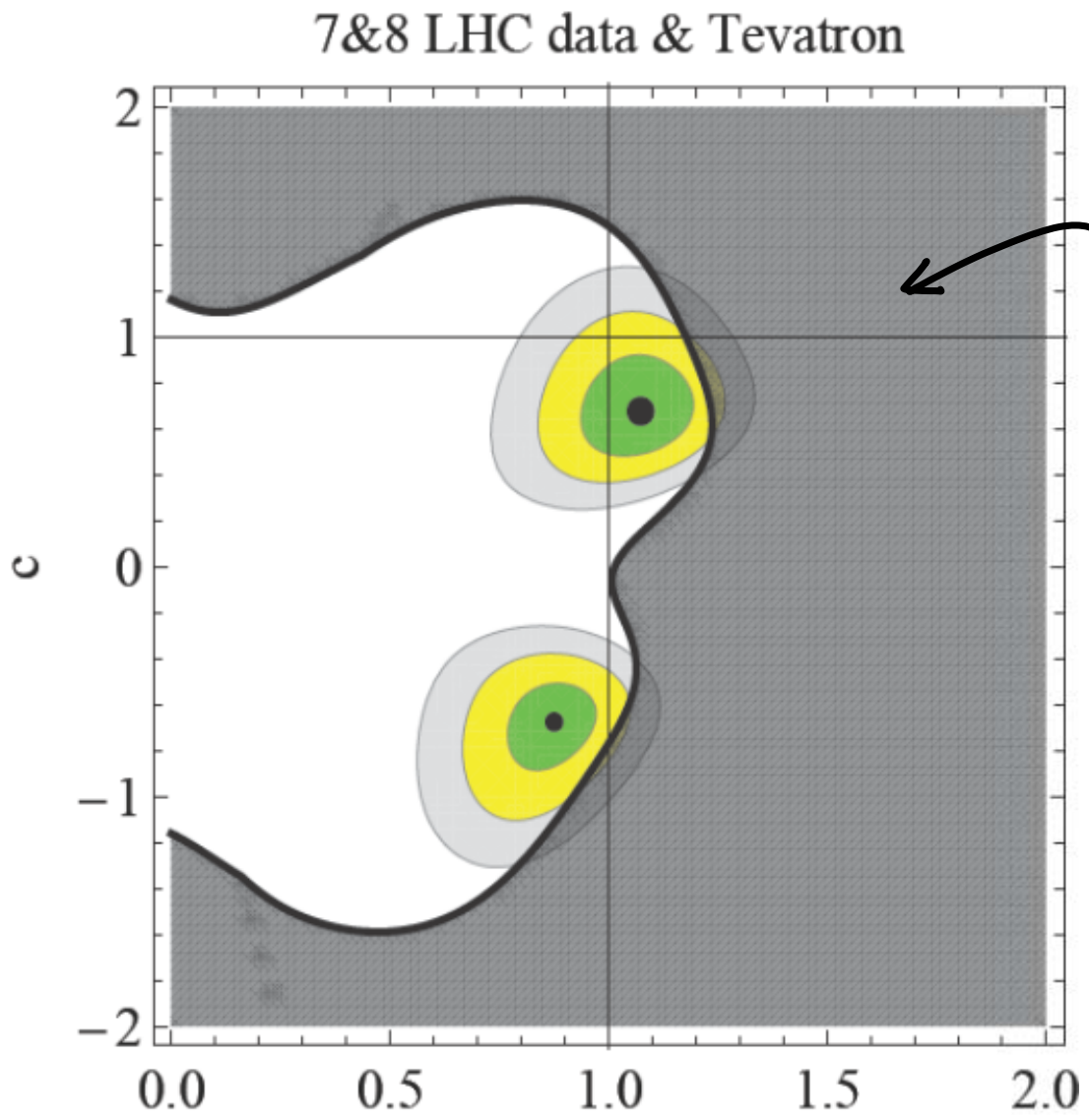


Good agreement

but see Petrucciani's talk this morning

Had to impose prior $c > 0$. (Best fit point for $c < 0$).

EXCLUDING SM (a,c)

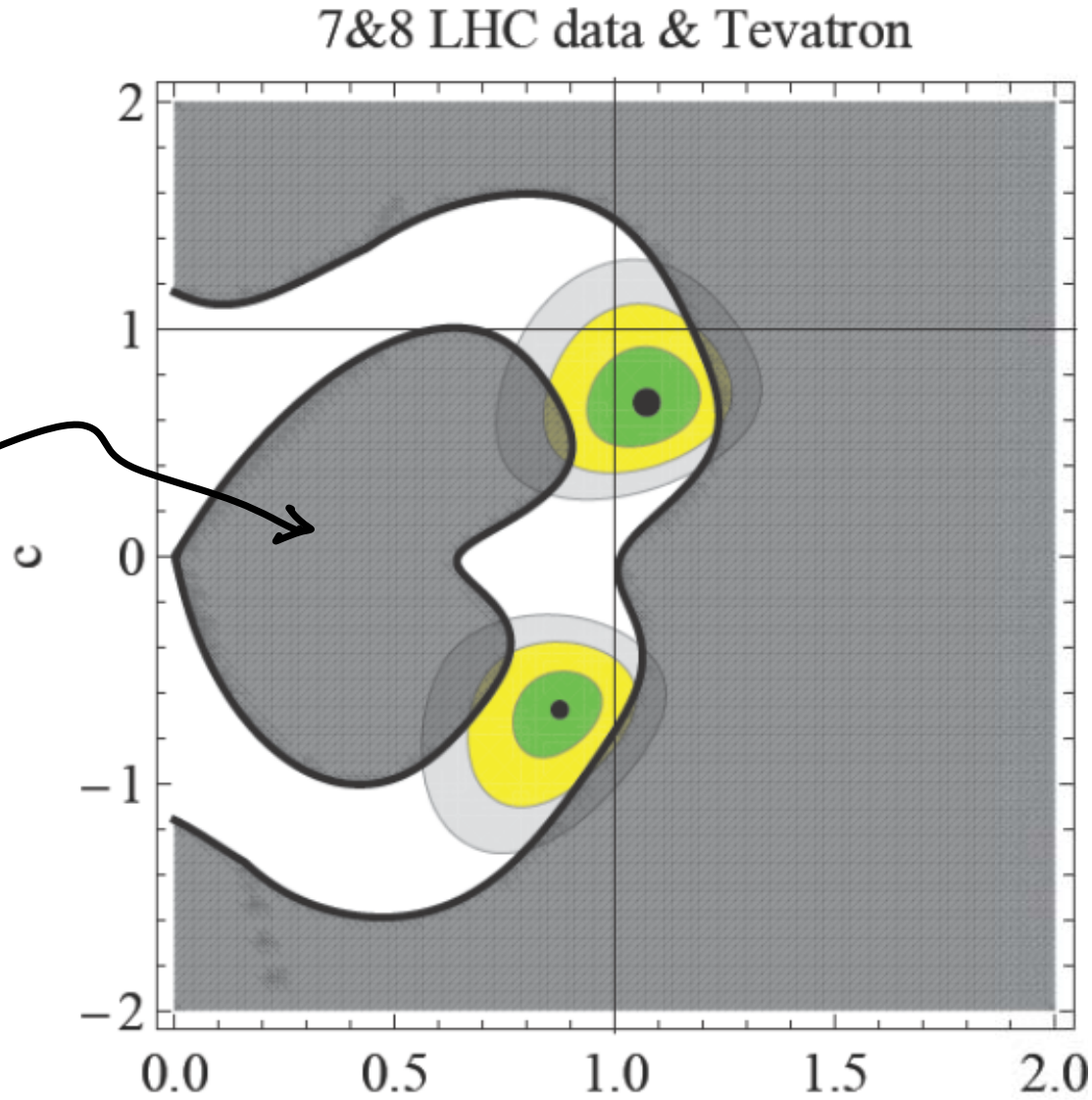


too large signal

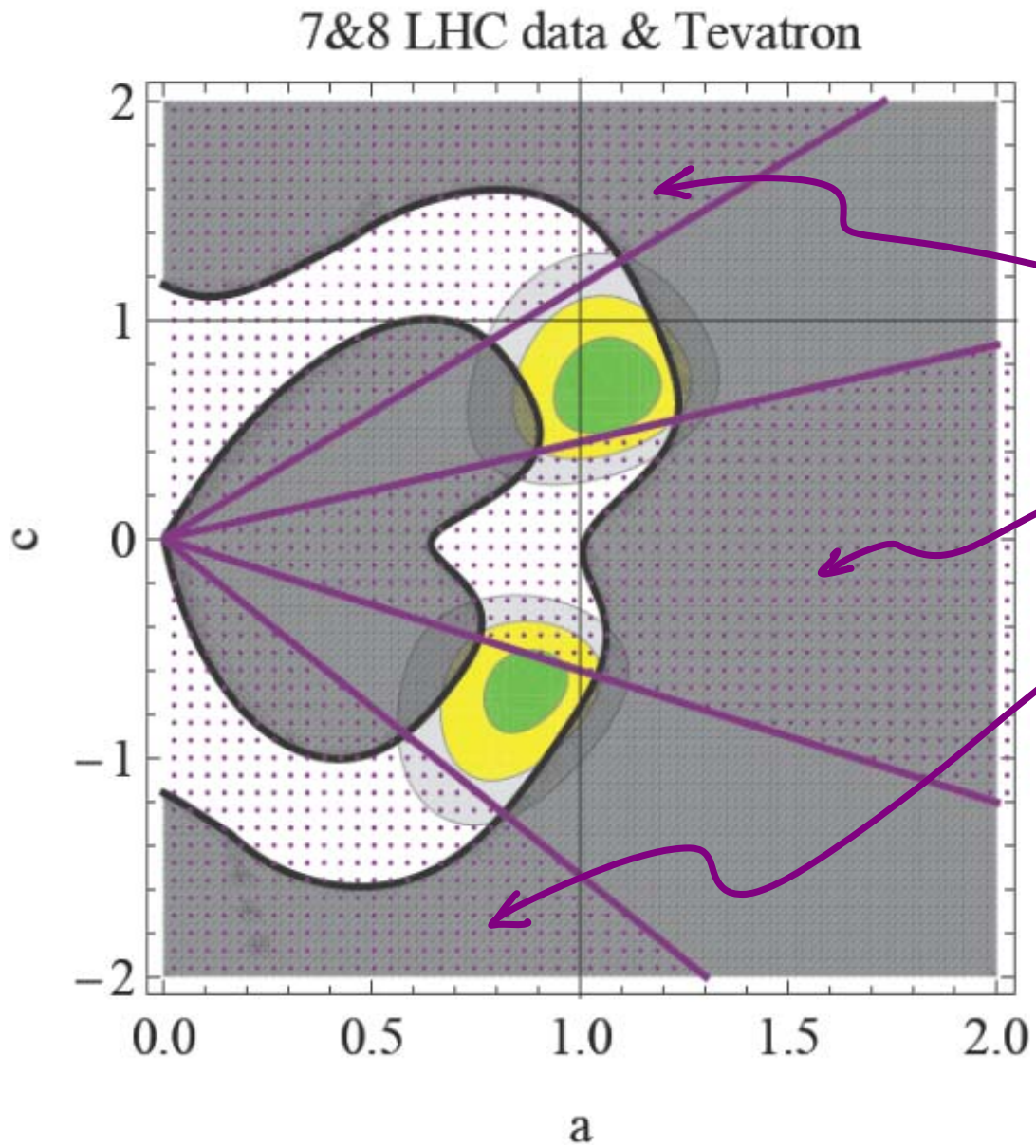
$\hat{\mu}_{exp} > \mu_L^{95\%}$

EXCLUDING SM (a,c)

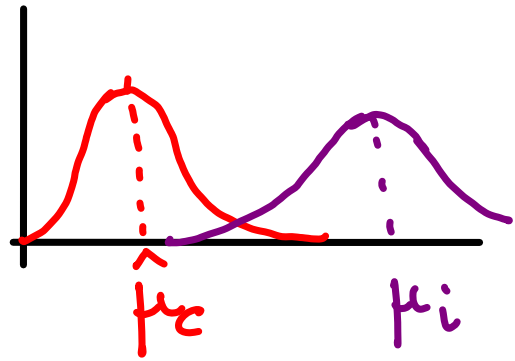
too few signal events (95% CL)



EXCLUDING SM (a,c)



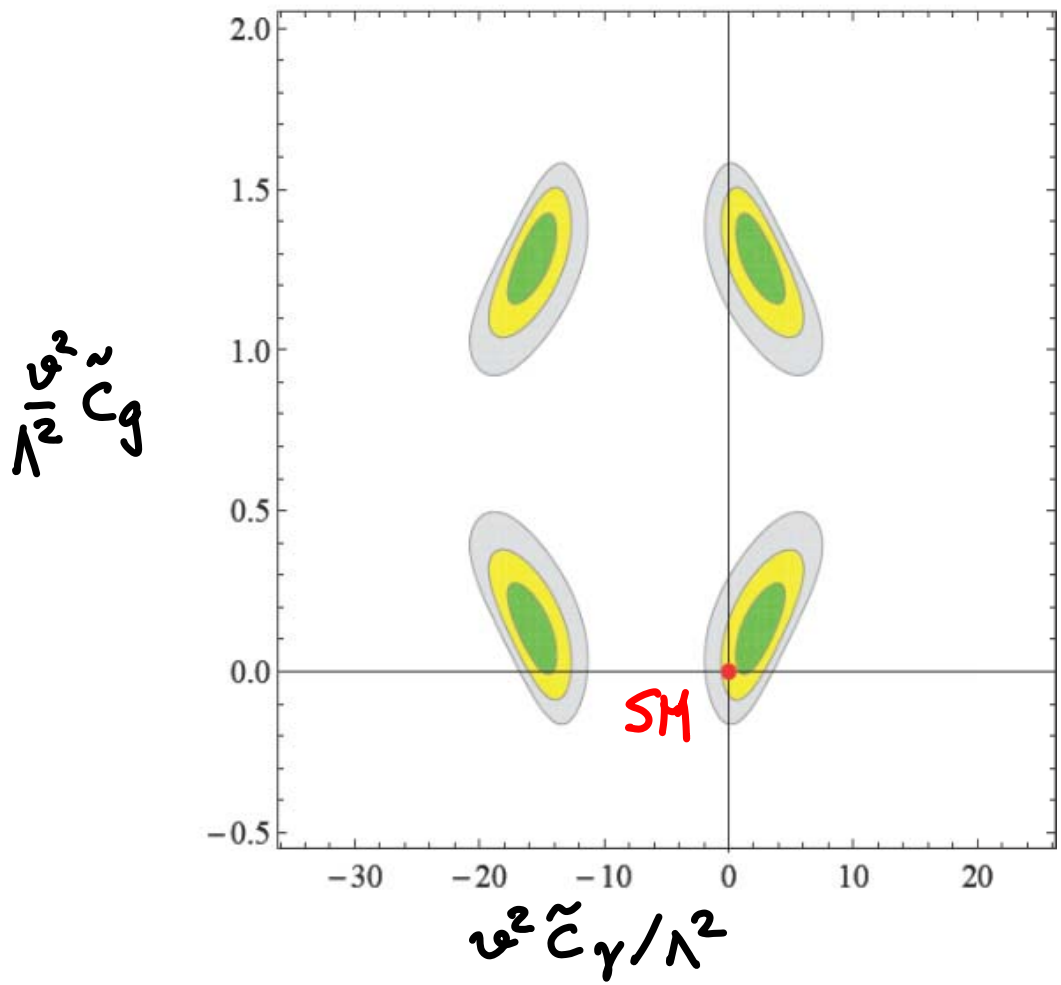
Too much tension in some channels



BSM EFFECTS IN $h\gamma\gamma$, hgg

Take $a=c=1$, add $\frac{-1}{32\pi^2}\left[e^2\tilde{c}_\gamma F_{\mu\nu}F^{\mu\nu} + g_s^2\tilde{c}_g G^A_{\mu\nu}G^{A\mu\nu}\right]\frac{H^\dagger H}{\Lambda^2}$

e.g. from loops of heavy charged particles $\Rightarrow$ SM $(\tilde{c}_\gamma, \tilde{c}_g)$



Model-independent result:

Map particular models to this plane

BSM EFFECTS IN $h\gamma\gamma$, hgg

Take $a=c=1$, add $\frac{-1}{32\pi^2}\left[e^2\tilde{c}_\gamma F_{\mu\nu}F^{\mu\nu} + g_s^2\tilde{c}_g G^A_{\mu\nu}G^{A\mu\nu}\right]\frac{H^\dagger H}{\Lambda^2}$

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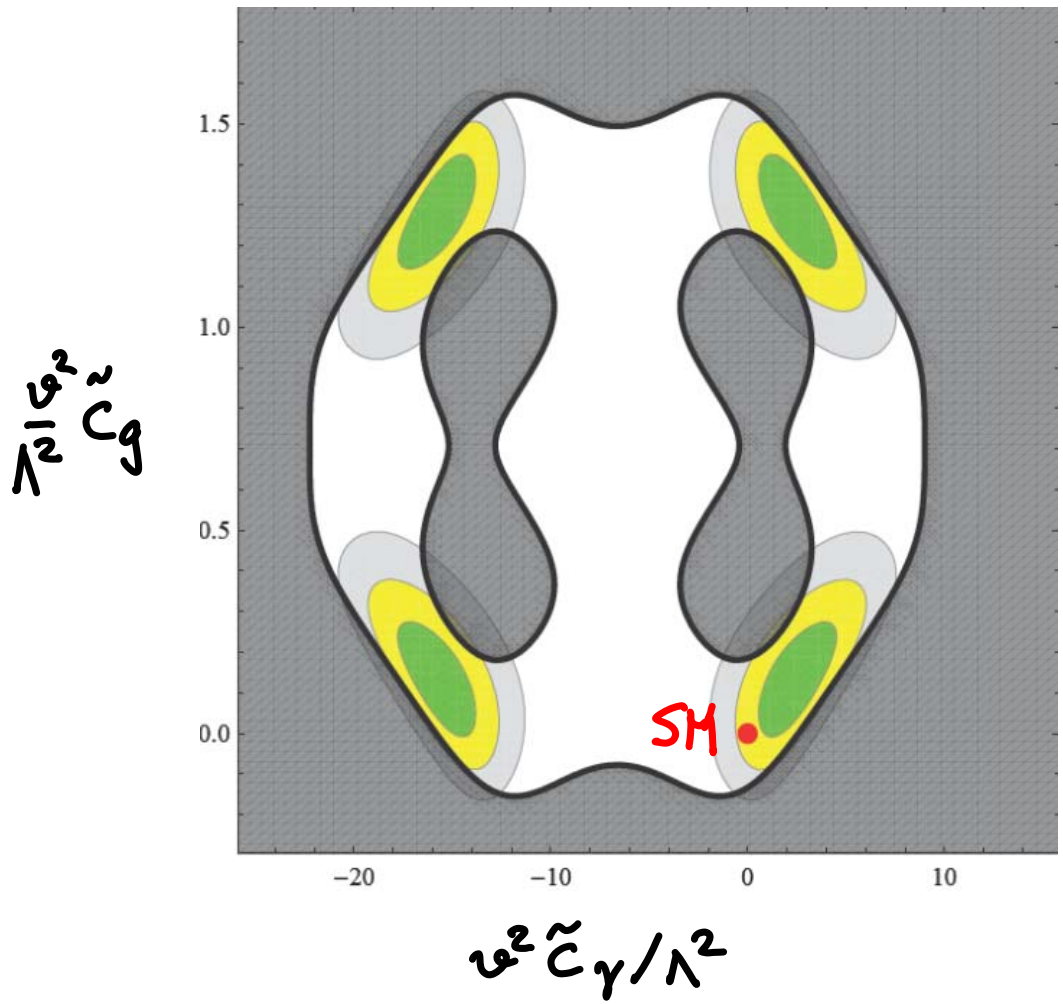
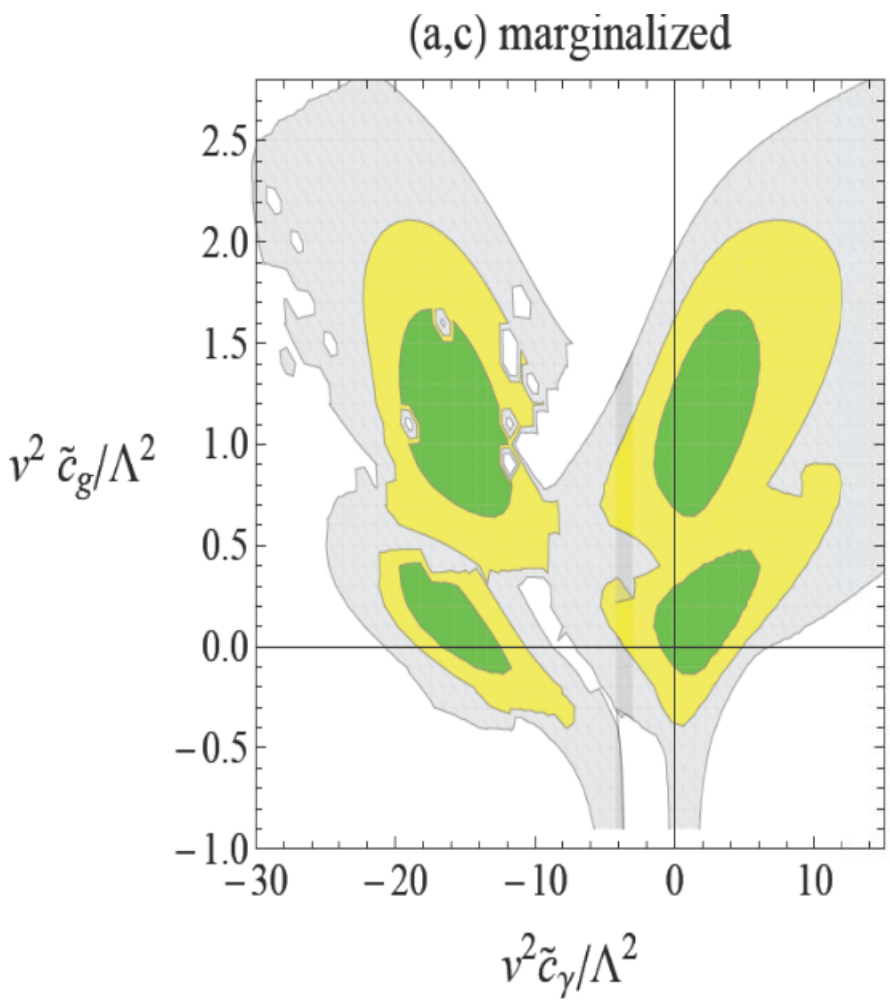


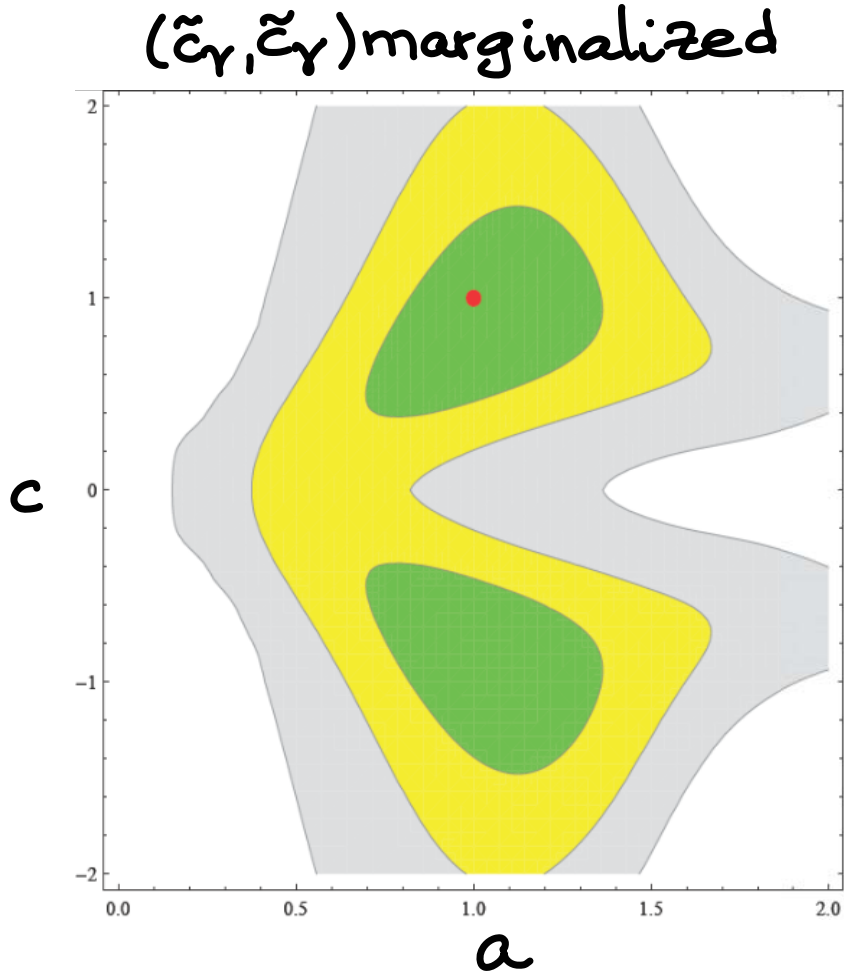
Model-independent result:

Map particular models to this plane

ANOMALOUS h COUPLINGS $(a,c) \neq (1,1)$

OR LOOP INDUCED EFFECTS $(\tilde{c}_g, \tilde{c}_\gamma) \neq (0,0)$?





Need more data

HIGGS INVISIBLE WIDTH ?

$h \to XX$ for light (SM singlet) X

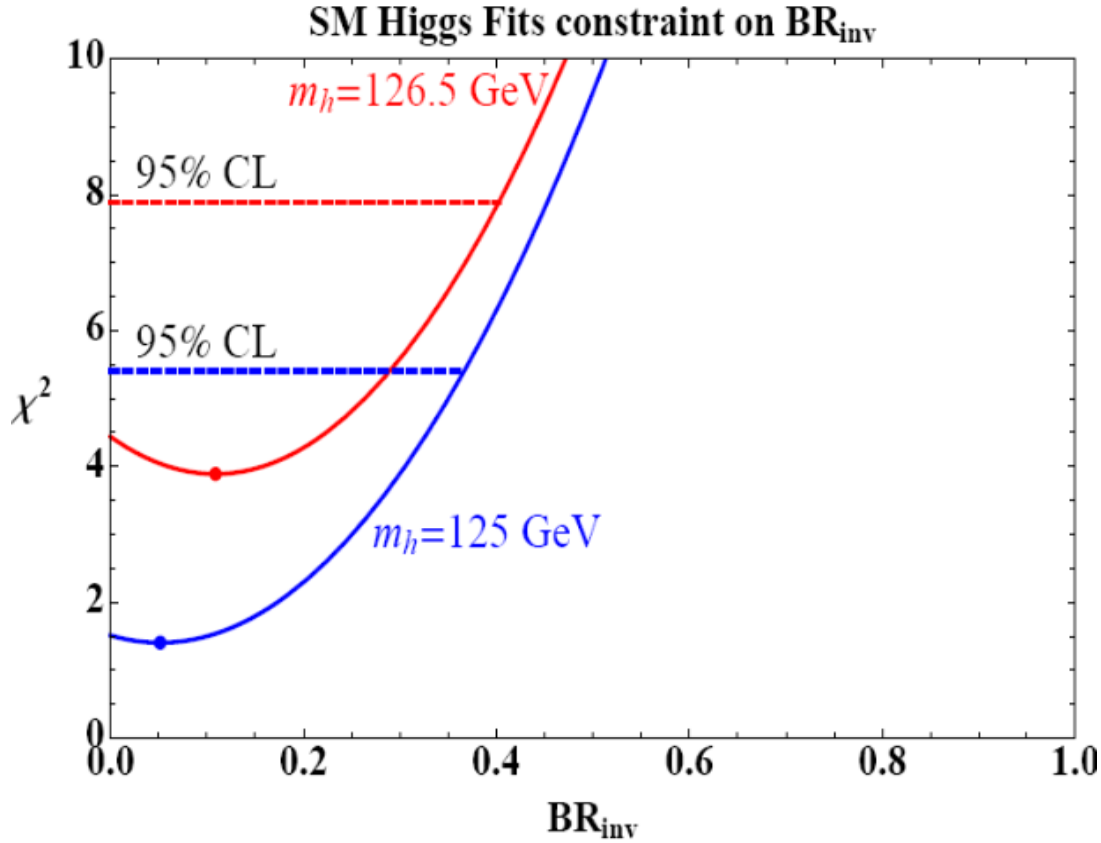
Universal reduction of $Br_j = \dfrac{\Gamma(h \to j)}{\Gamma_{SM} + \Gamma_{inv}} = (1 - BR_{inv})\, Br_j^{SM}$

χ^2 fit to combined $\hat{\mu}_c \pm \sigma_c$

χ^2_{min} at $BR_{inv} = (0.05, 0.12)$

SM with $BR_{inv} = 0$ OK

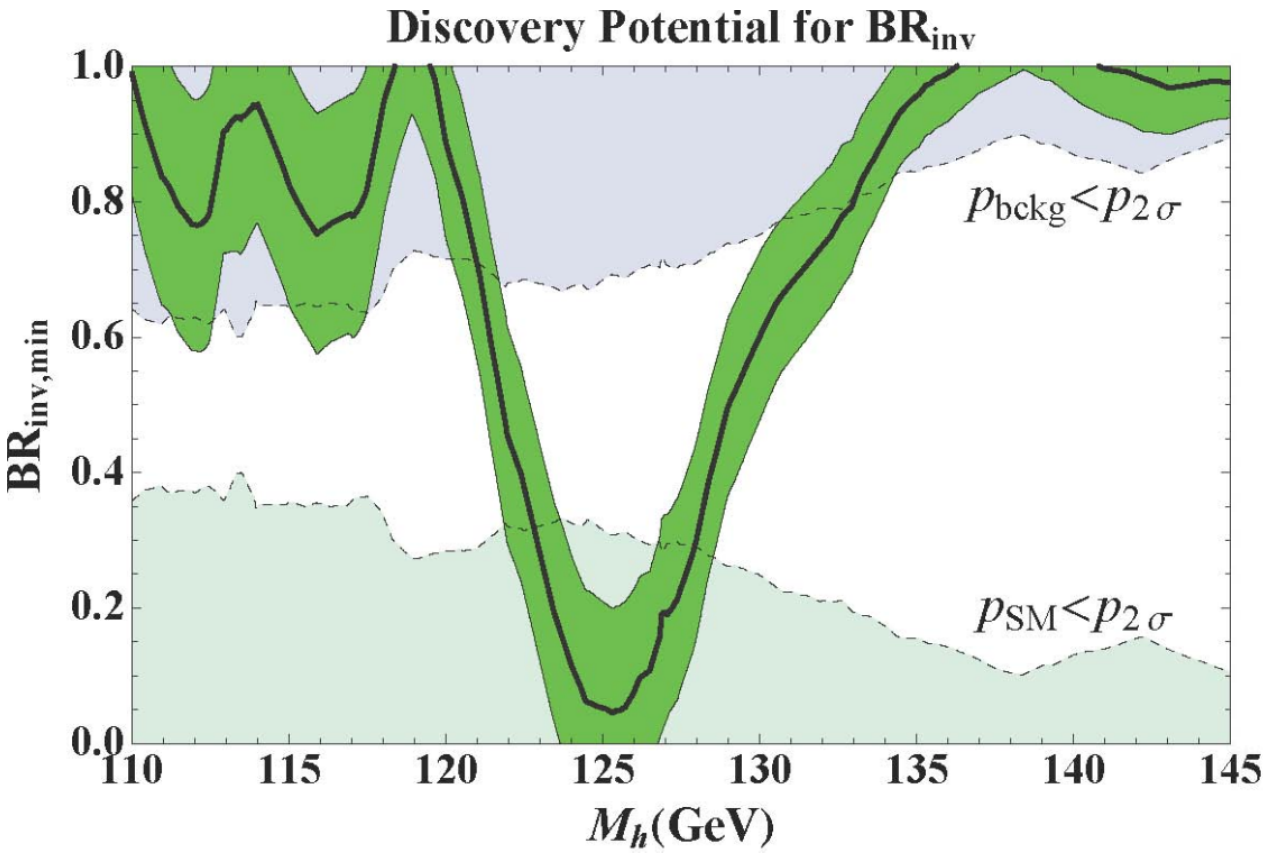
Still there is room for sizable BR_{inv} ($\lesssim 0.4$ @ 95% CL)



HIGGS INVISIBLE WIDTH ?

Current situation as a function of m_h

$BR_{inv} = 1 - \hat{\mu}_c$



No strong conclusion possible

CONCLUSIONS

We finally have data to explore the physics of electroweak symmetry breaking!

★ Deviations of Higgs properties from the SM are a must of natural BSM: extremely important measurements.

★ Couplings compatible with SM

Some interesting deviations ($\gamma\gamma$), not statistically signif (yet?)

Hint of new particle(s) through loop effect?

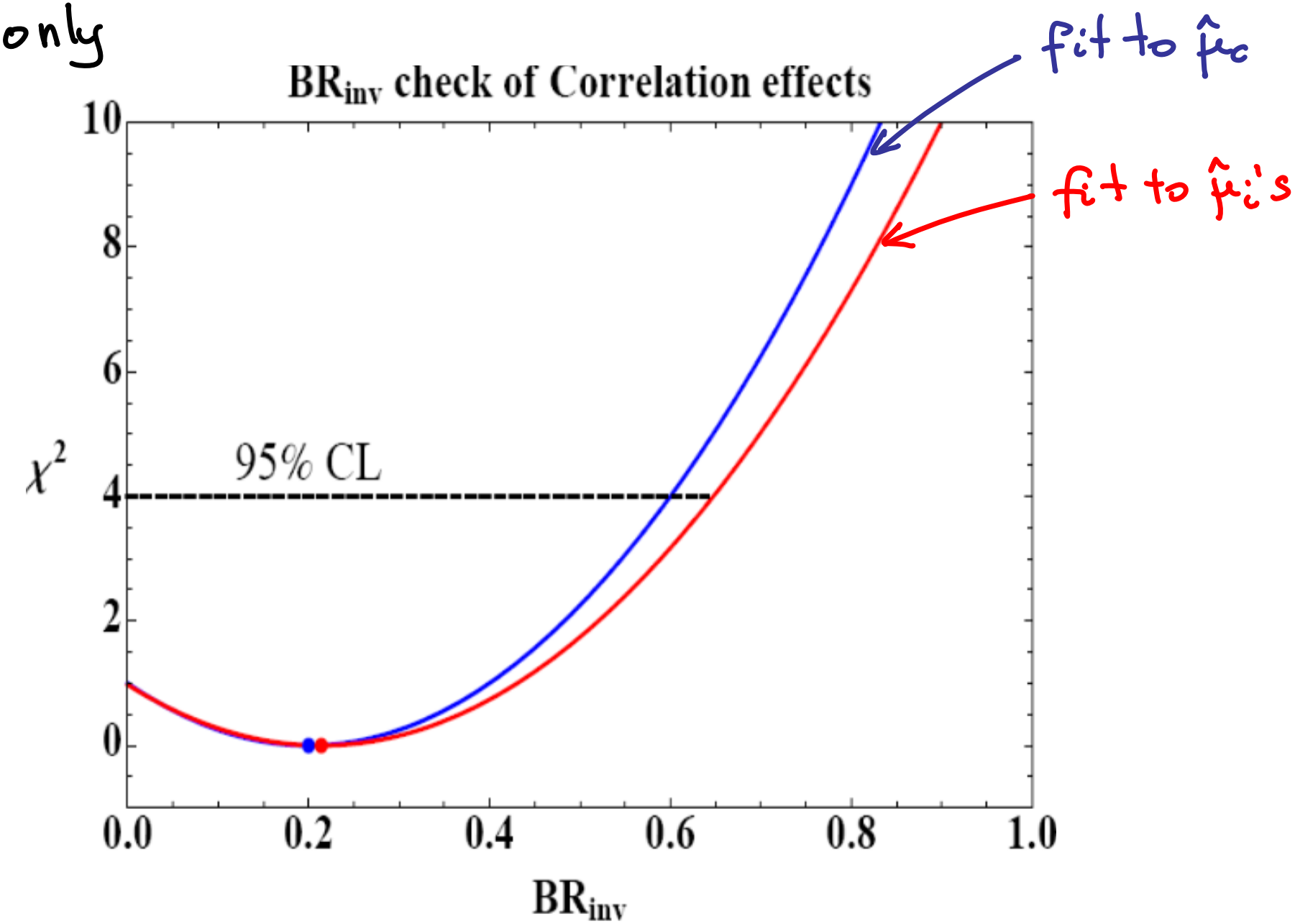
★ Plenty of room for nonzero BR_{inv} (DM?)

$BR_{min} \sim 0.05 \pm 0.32$, Compatible with SM

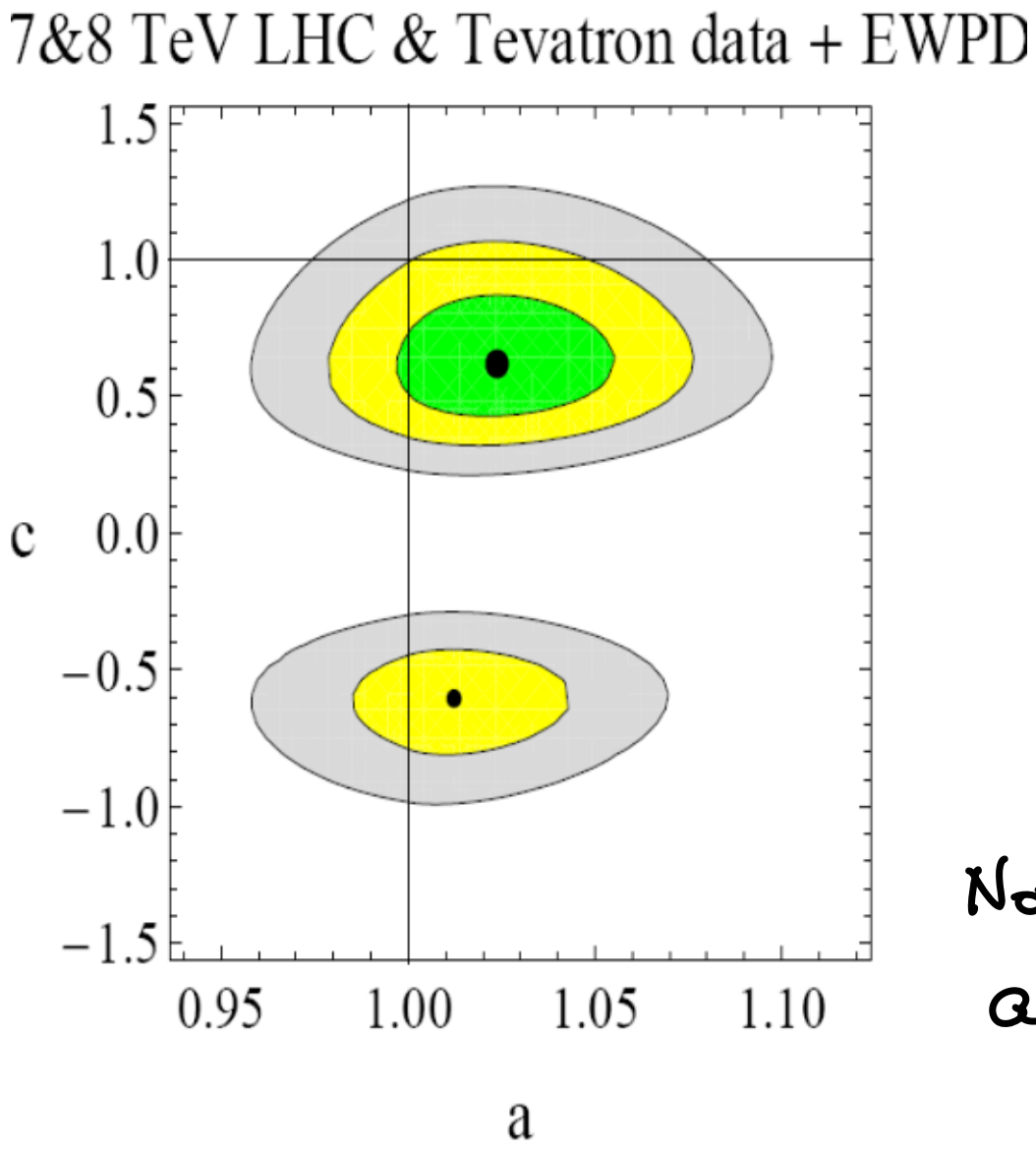
EXCITING TIMES AHEAD!

XCHECK OF CORR. EFFECTS

CMS data only



ADDING EWPT



Notice squeezed a interval!

$a \sim 1$