FIRST GLIMPSES OF A NEW SCALAR'S FACE

LEARNING ABOUT THE ~~EW~~ SCALAR

ULB, 26/10/12

J.R.Espinosa
ICREA, IFAE
Barcelona

1. DISCOVERY and plenty of DATA!
2. $M_h \sim 125$ GeV ➔ Implications for Stability
3. Is it the SM Scalar? ➔ Search channels
4. BSM Hopes ➔ Deviations from SM couplings
   ➔ Nonzero invisible width

Work based on collaborations with:

- **Stability**

J. Elias-Miró, G.F. Giudice, G. Isidori, A. Riotto, A. Strumia + H.M. Lee + G. Degrassi, S. Di Vita

[hep-ph/1112.3022], [hep-ph/1203.0237], [hep-ph/1205.6497]

- **Global Fits to Higgs Data**

C. Grojean, M. Muhlleitner, M. Trott

[hep-ph/1202.3697], [hep-ph/1205.6790], [hep-ph/1207.1717]

For recent related work see :

- **Stability**

M. Holthausen, K.S. Lim, M. Lindner [hep-ph/1112.2415]

F. Bezrukov, M.Y. Kalmykov, B.A. Kniehl, M. Shaposhnikov [hep-ph/1205.2893]

- **Global Fits to Higgs Data**

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]

+...

DISCLAIMER

Credit should go to

F. Englert and R. Brout, *Broken symmetry and the mass of gauge vector mesons*, Phys. Rev. Lett. **13** (1964) 321.

P. W. Higgs, *Broken symmetries and the masses of gauge bosons*, Phys. Rev. Lett. 13 (1964) 508.

P. W. Higgs, *Broken symmetries, massless particles and gauge fields*, Phys. Lett. **12** (1964) 132.

and then

G. S. Guralnik, C. R. Hagen and T. W. B. Kibble, *Global conservation laws and massless particles*, Phys. Rev. Lett. **13** (1964) 585.

DISCLAIMER

Although it would've been fairer to call this scalar the Brout-Englert-Higgs boson I will follow standard practice and call it simply Higgs boson many times.

DISCLAIMER

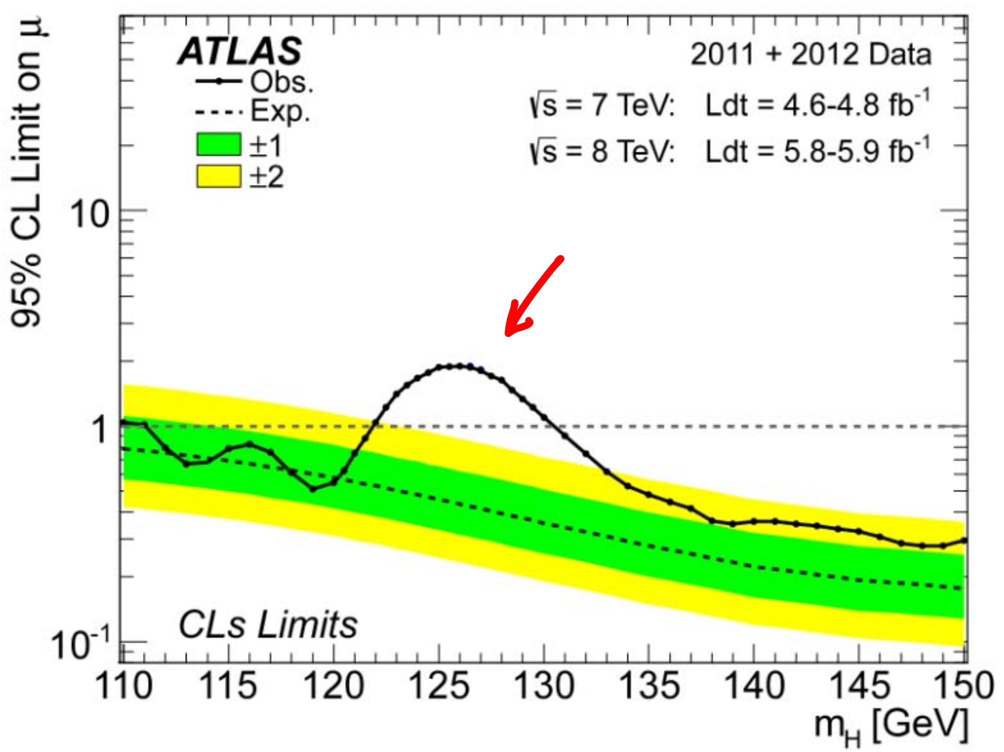
Although it would've been fairer to call this scalar the Brout-Englert-Higgs boson I will follow standard practice and call it simply Higgs boson many times. You could imagine this is just the acronym for

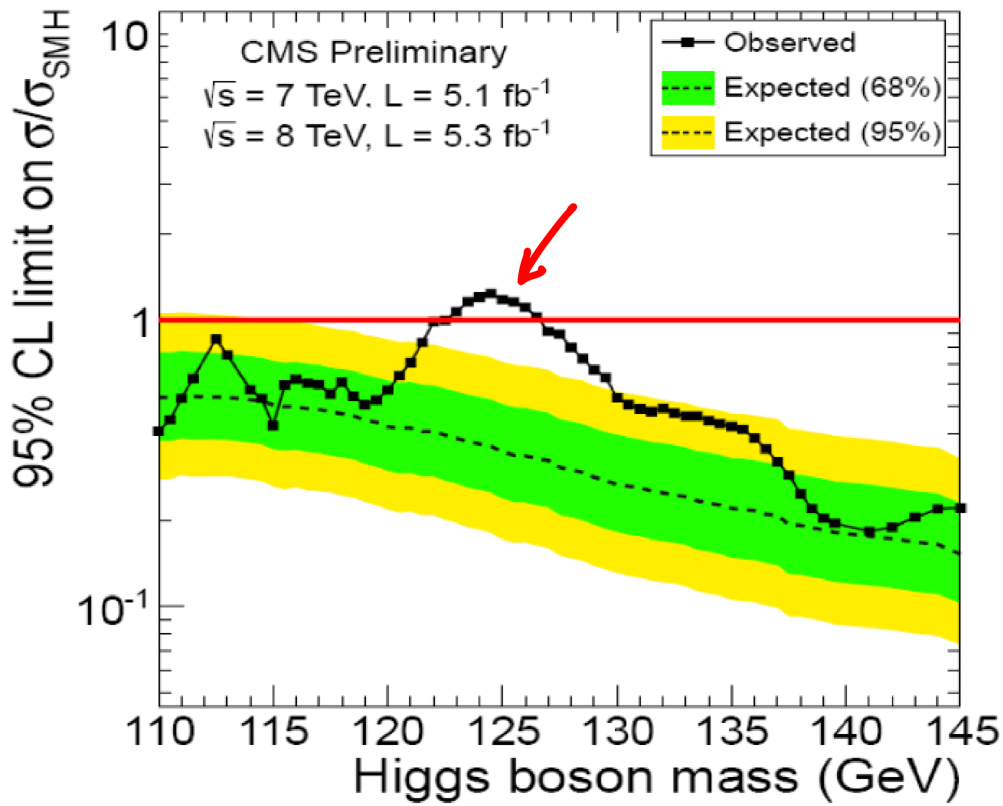
Highly
Interesting
Gluon-
Generated
Scalar

①

DATA !

SIGNAL EXCESS IN 95 % C.L. EXCLUSION LIMITS



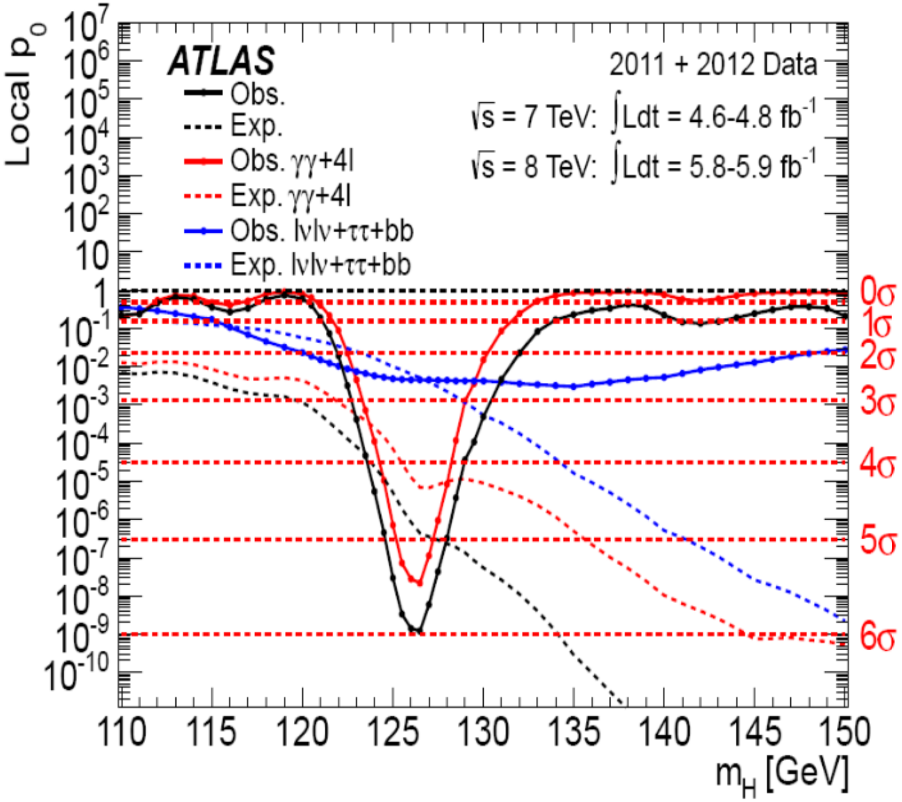


$m_h \sim 126.5$ GeV

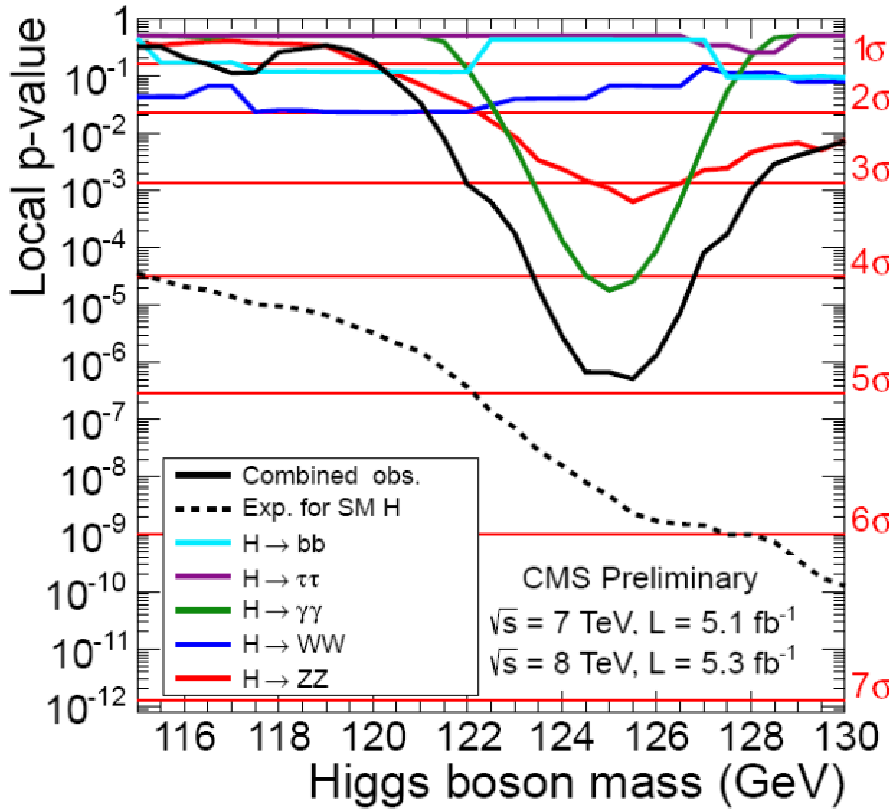
$m_h \sim 125$ GeV

DISCOVERY!

SIGNAL EXCESS ≈ 5σ - 6σ



$m_h \sim 126.5$ GeV



$m_h \sim 125$ GeV

② $M_H \sim 125$ GeV. Implications for Stability

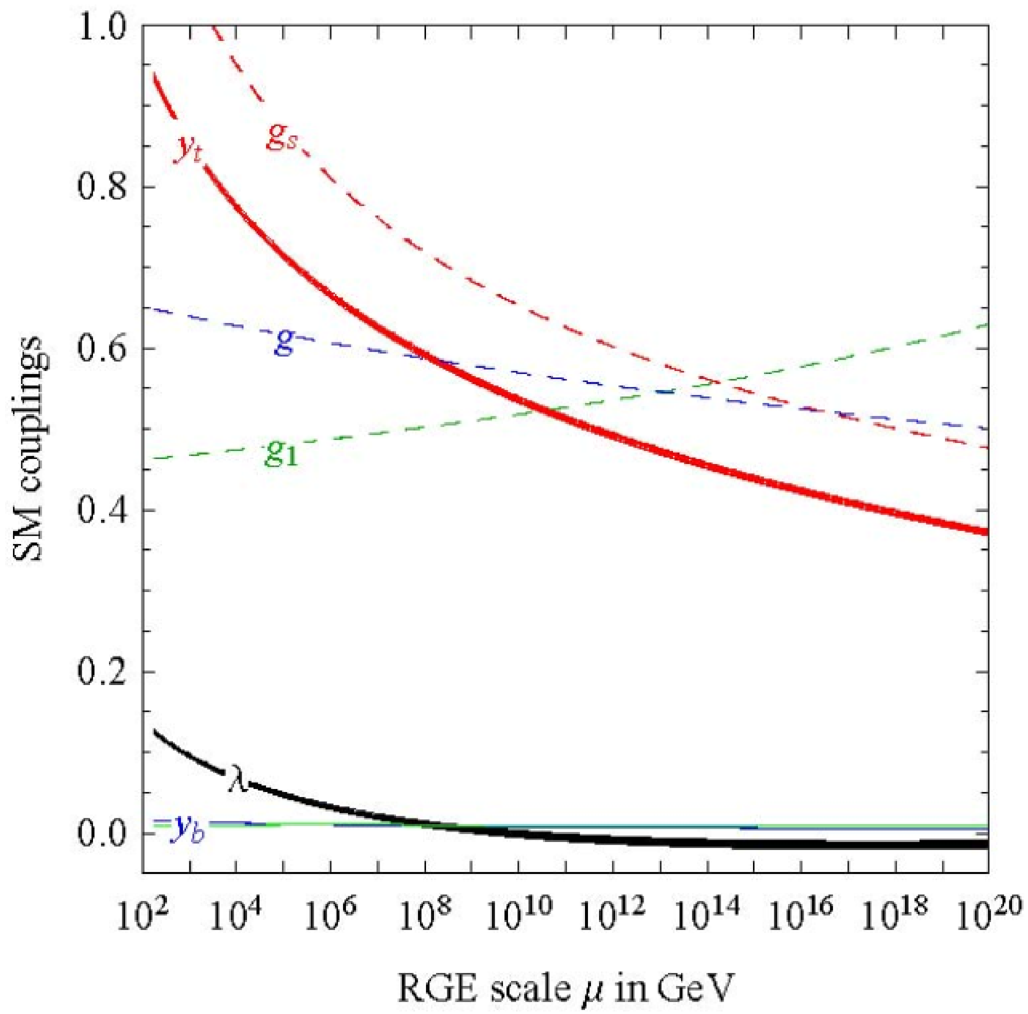
Assume scalar has SM props. and no BSM Physics

All SM parameters known

$M_h \Rightarrow \lambda(EW)$

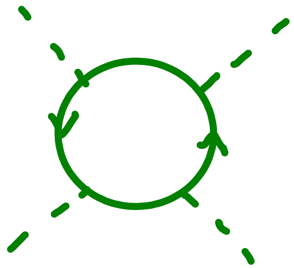
Forgetting naturalness, can the pure SM be valid up to M_{Pl}?

Weakly coupled up to M_{Pl}



VACUUM INSTABILITY

$$\frac{d\lambda}{d\ln Q} \sim -\frac{h_t^4}{16\pi^2}$$

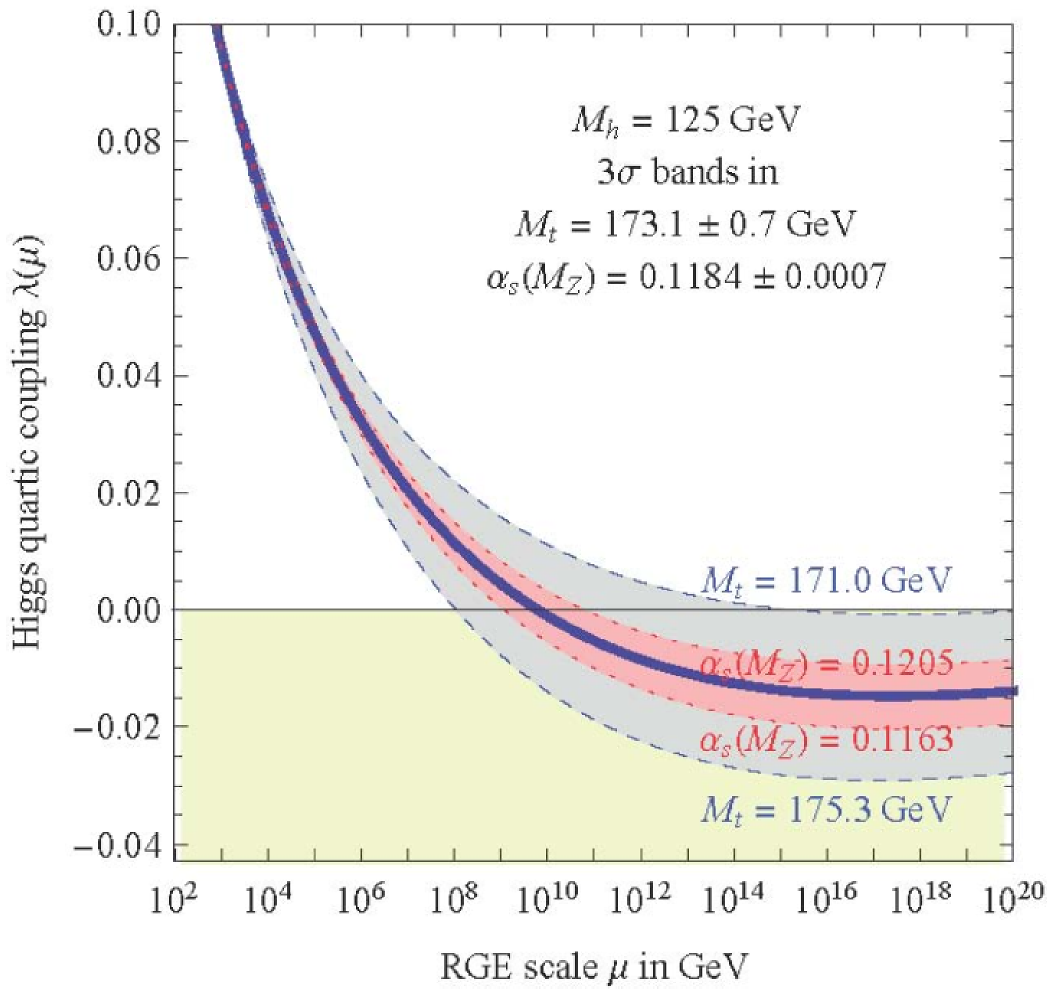


$\lambda < 0$ at $\Lambda_I \sim 10^{10}$ GeV

⇓

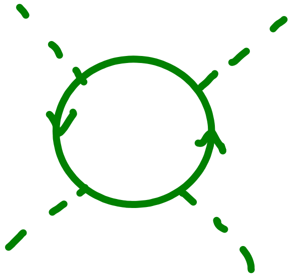
Higgs potential instability

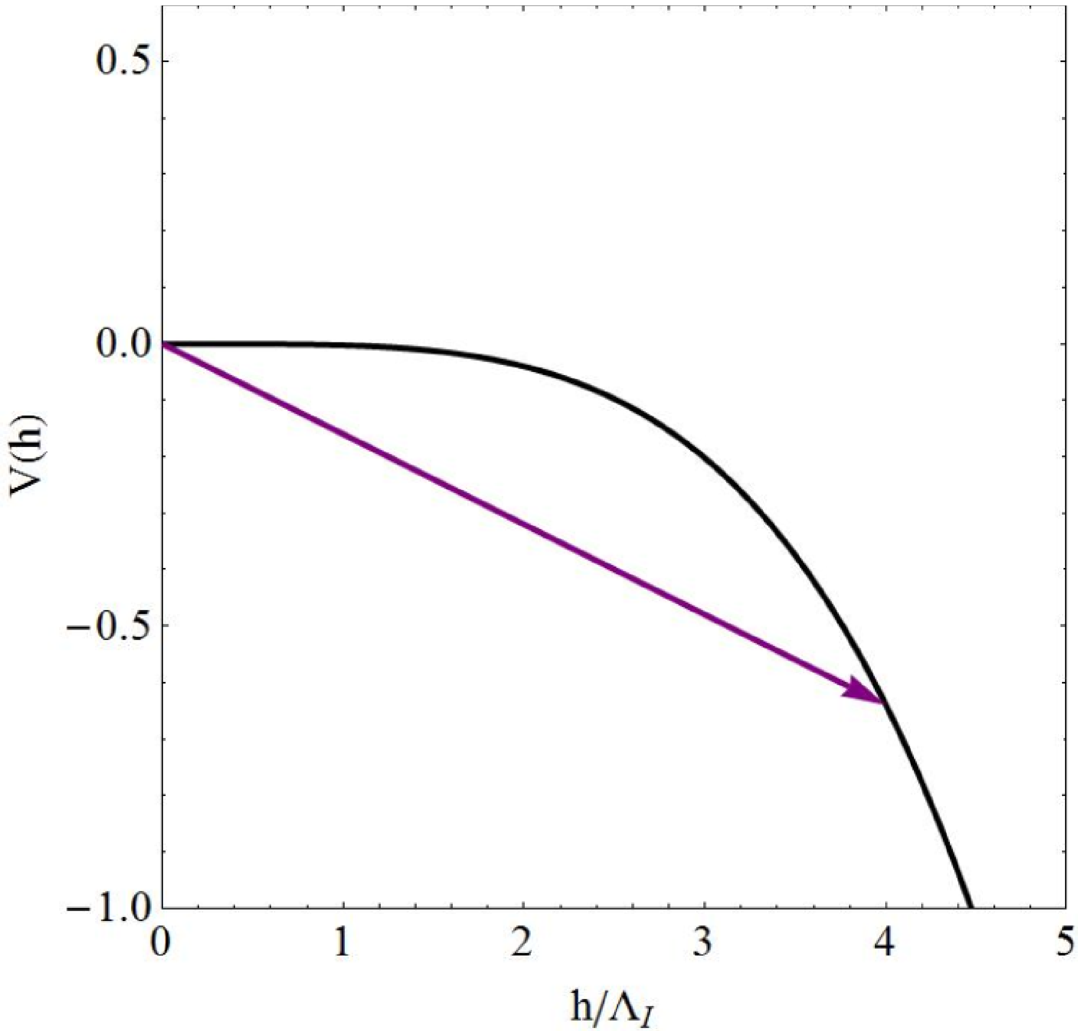
$$V(\phi \gg M_t) \simeq \frac{1}{4}\lambda(Q \simeq \phi)\phi^4$$



VACUUM INSTABILITY

$$\frac{d\lambda}{d\ln Q} \sim -\frac{h_t^4}{16\pi^2}$$





$\lambda < 0$ at $\Lambda_I \sim 10^{10}$ GeV

⇓

Higgs potential instability

$$V(\phi \gg M_t) \simeq \frac{1}{4}\lambda(Q \simeq \phi)\,\phi^4$$

LIFE IN A METASTABLE VACUUM

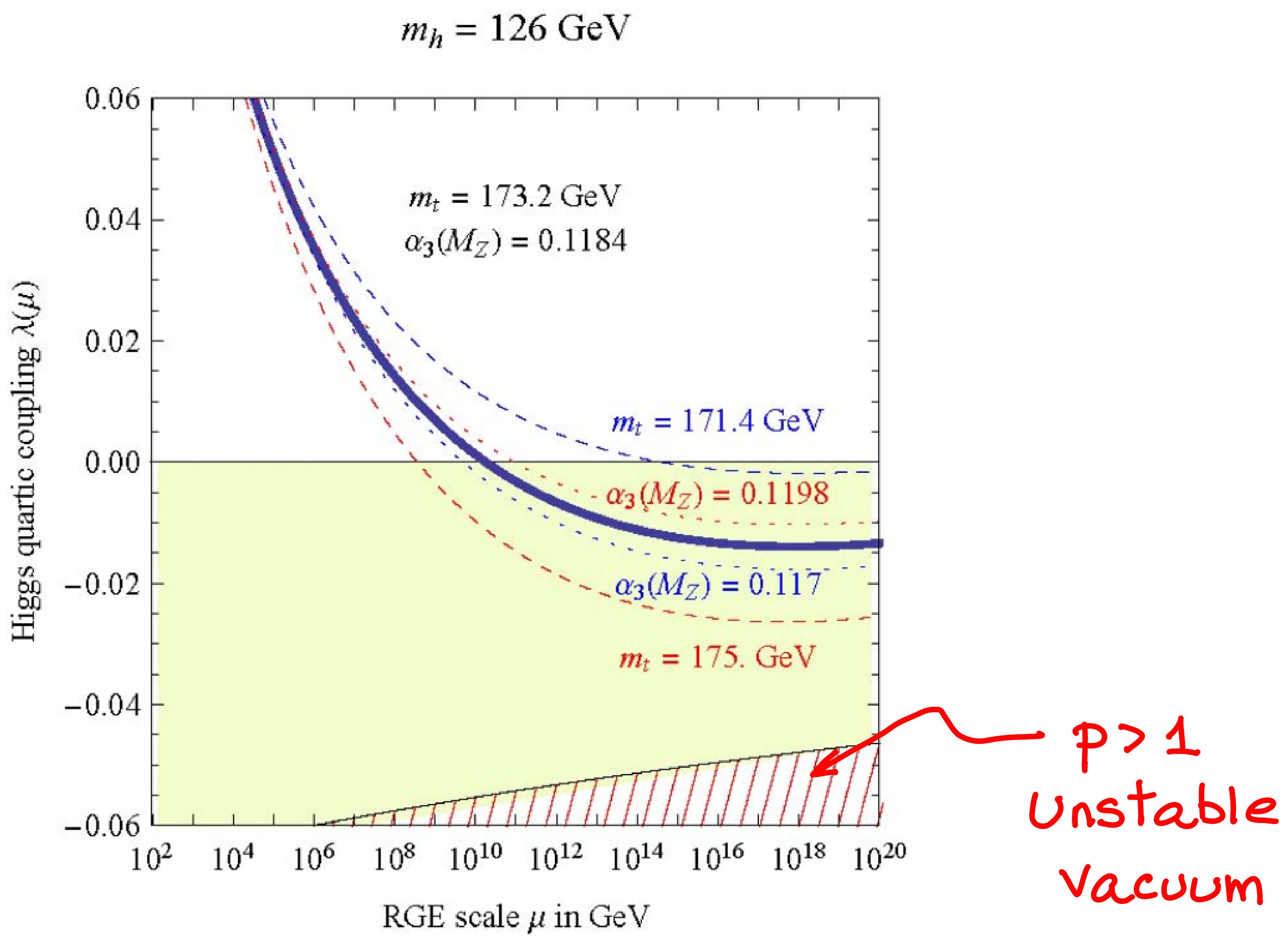
$$p = \text{Decay prob.} = \underbrace{\frac{\text{Decay rate}}{\Delta t \cdot \Delta V}}_{h^4 e^{-S_4}} \tau_U^4 \qquad \text{with } \tau_U^4 \sim \left(e^{140}/M_{Pl}\right)^4$$

$$h^4 e^{-S_4} \sim h^4 \exp\left(-\frac{8\pi^2}{3|\lambda(h)|}\right) \sim h^4 \exp\left[-\frac{2600}{|\lambda|/0.01}\right]$$

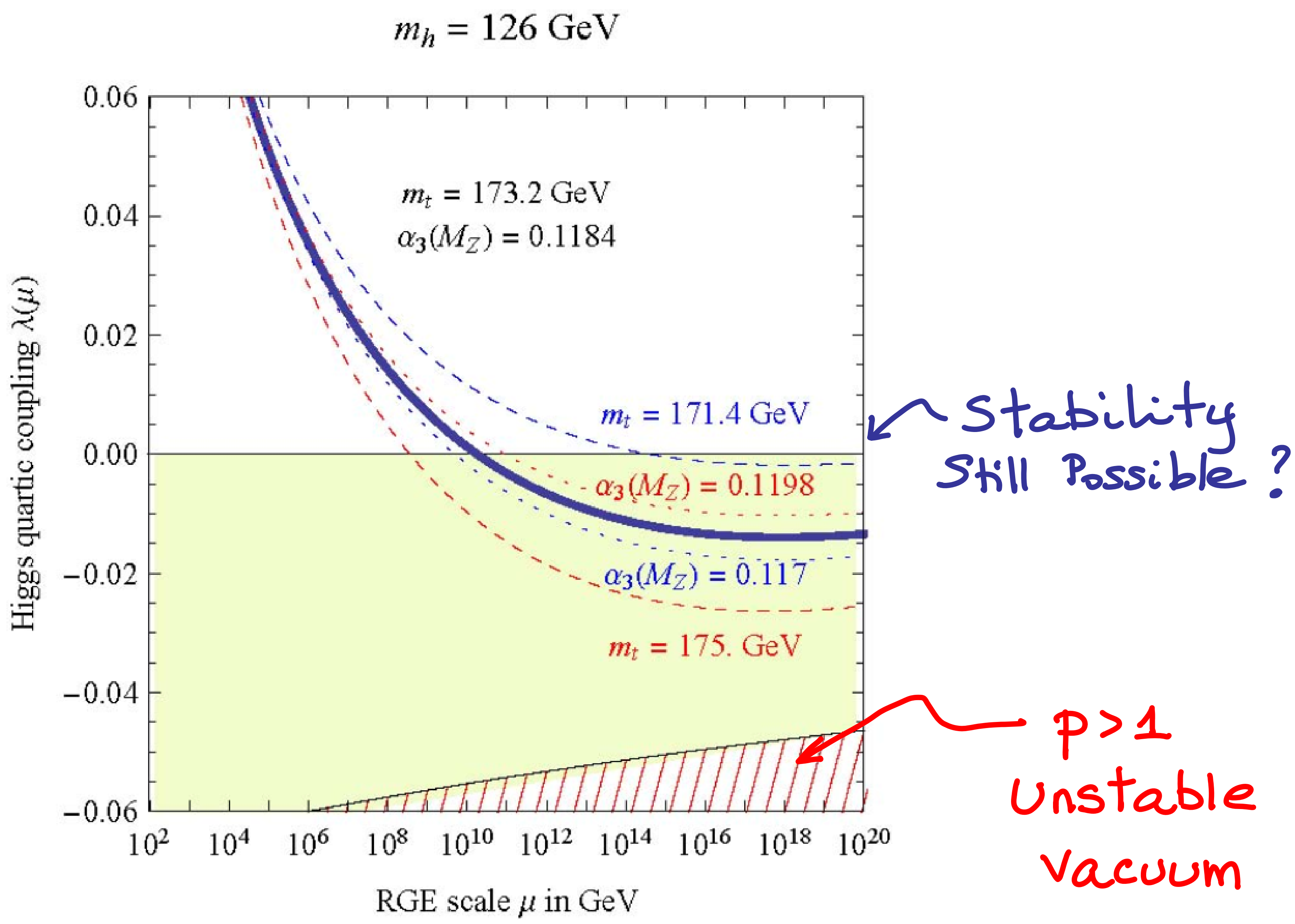
easily wins over τ_U^4

$p \lll 1$: Lifetime of EW vacuum much longer than τ_U

LIFE IN A METASTABLE VACUUM



LIFE IN A METASTABLE VACUUM



NNLO STABILITY BOUND

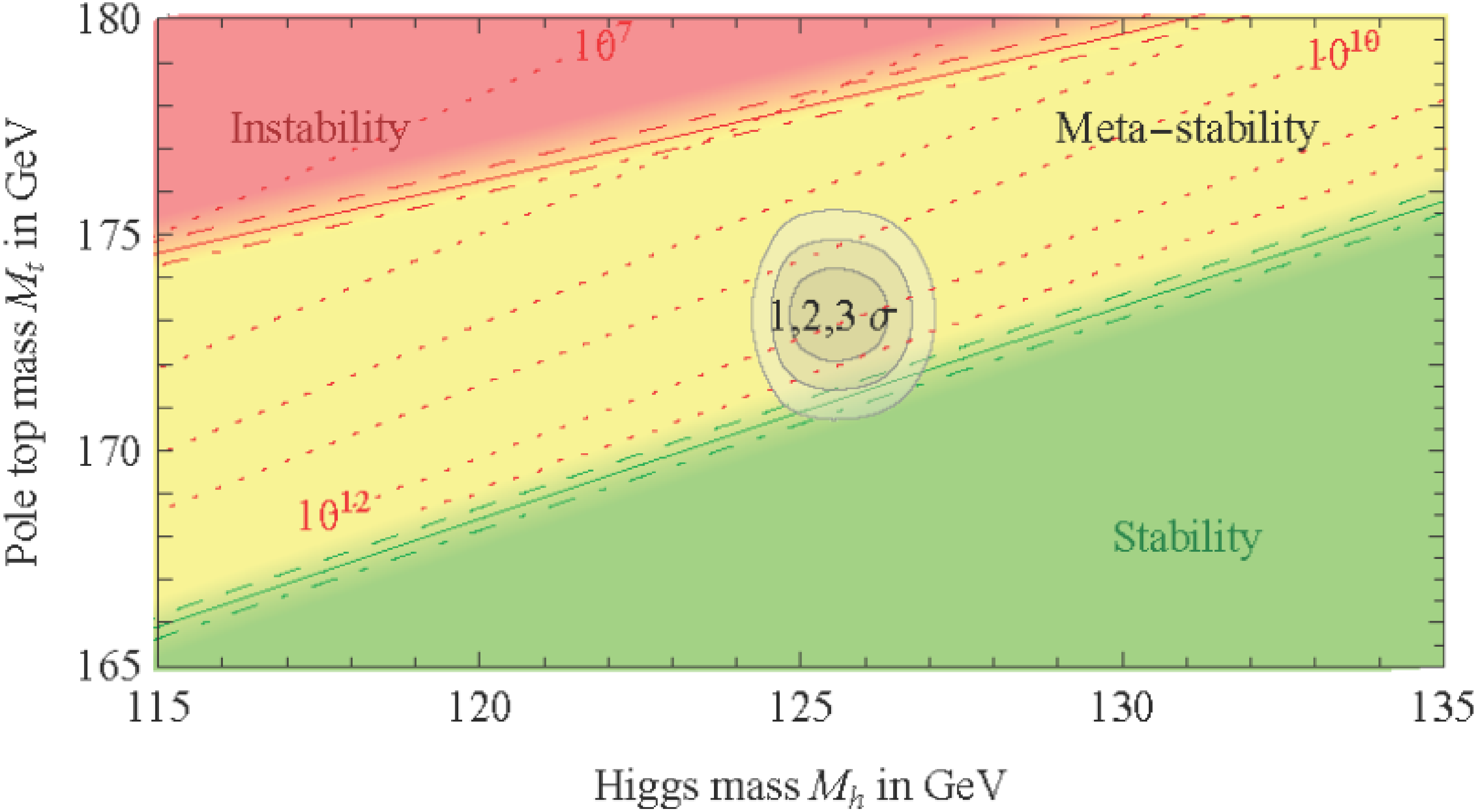
For stability up to M_{Pl} :

$$M_h\,[\mathrm{GeV}] > 129.4 + 1.4\left(\frac{M_t\,(\mathrm{GeV}) - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{th}$$

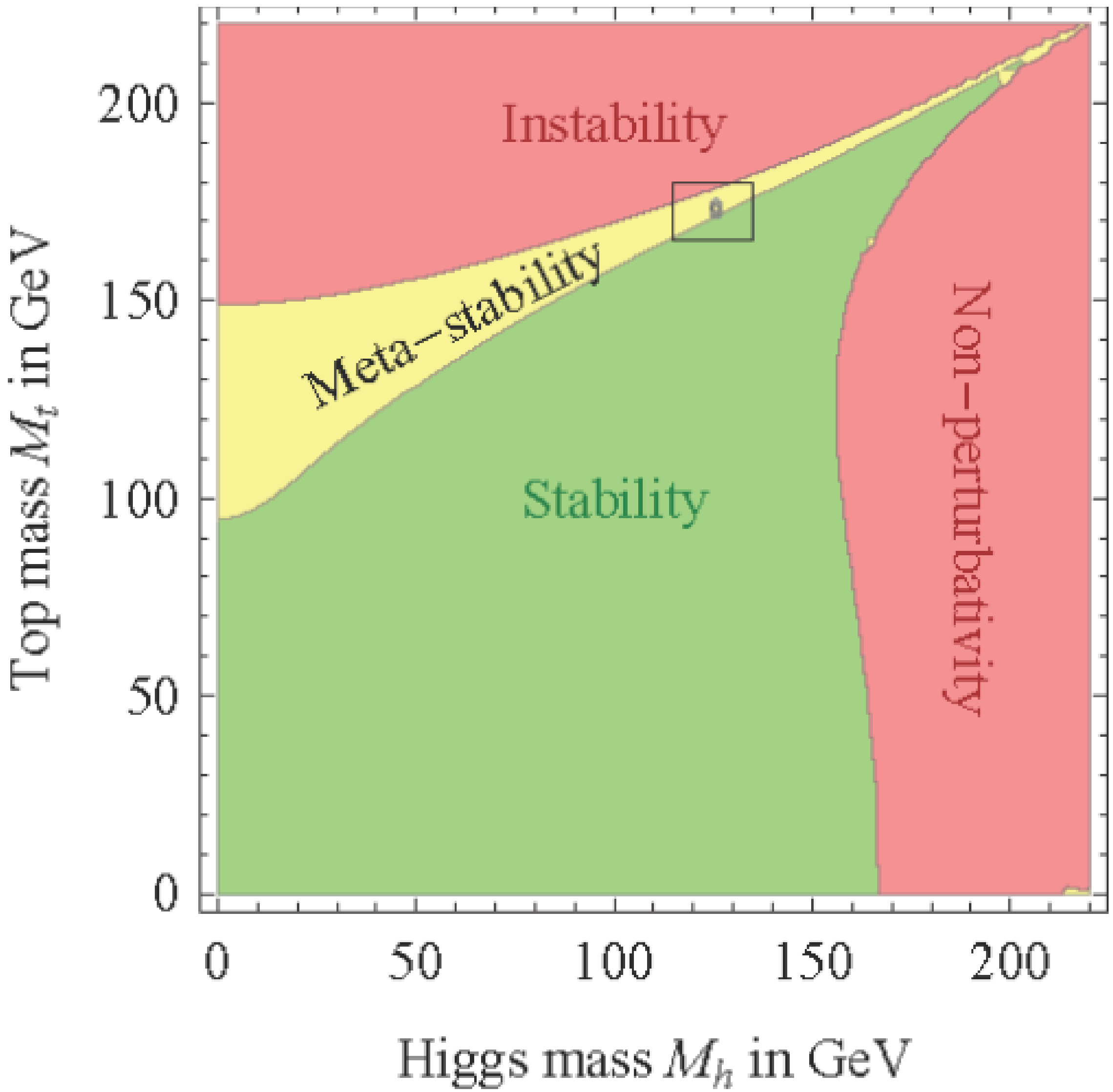
State-of-the-art NNLO calculation:

- 2-loop V_{eff} (Ford, Jack, Jones [hep-ph/0111190])
- 3-loop RGEs (..., Chetyrkin, Zoller [hep-ph/1205.2892])
- 2-loop matching in $\lambda \leftrightarrow M_h^2$; $h_t \leftrightarrow M_t$ (..., Shaposhnikov et al [hep-ph/1205.2893], , Degrassi et al [hep-ph/1205.6497])

LIVING AT THE EDGE



LIVING AT THE EDGE

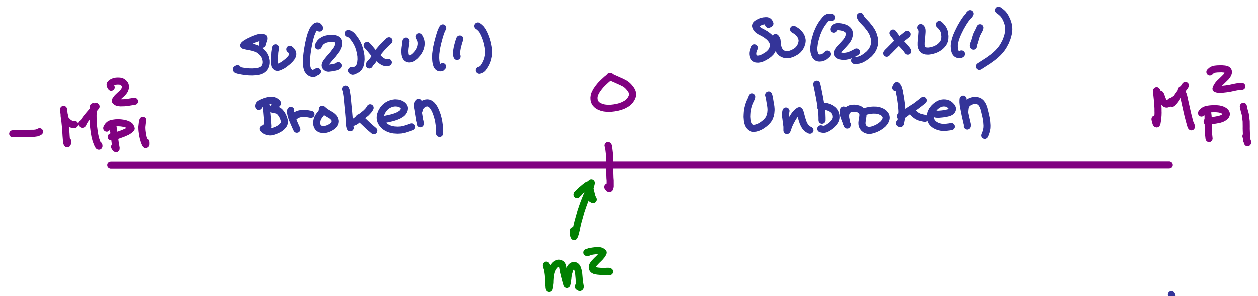


NEW KNOWLEDGE BRINGS NEW QUESTIONS

- Why do we live near the critical boundary for stability?

$$\lambda(M_{Pl}) \simeq 0$$

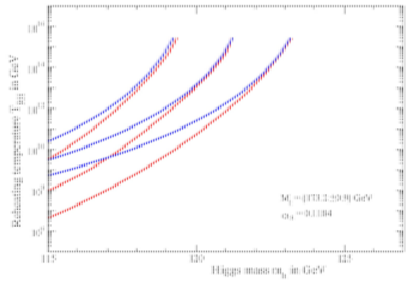
- Is this related to our living near the phase boundary $m^2/M_{Pl}^2 \simeq 0$?



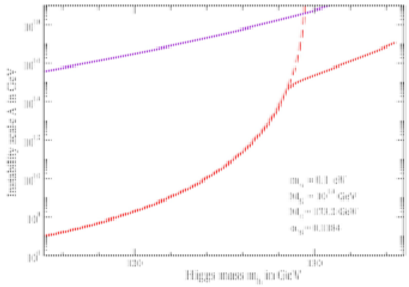
- Is the EW scale determined by Planck scale physics?
- Or is this just a coincidence? BSM...

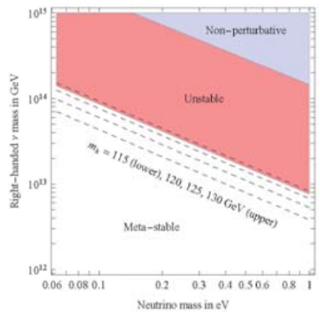
OTHER IMPLICATIONS NOT DISCUSSED

- Cosmology:
  Bound on T_{RH}; inflation,...

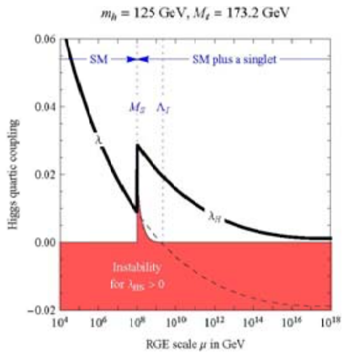


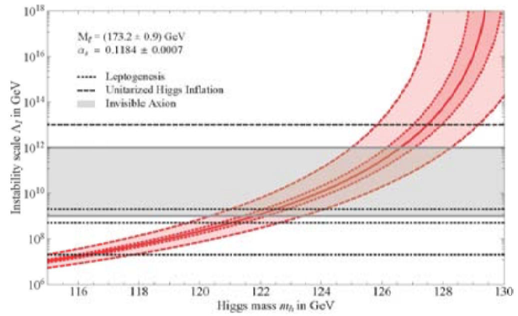
- See-saw neutrinos:
  Bound on $M_{\nu R}$





- Singlet fix of instability
  (from see-saw; axion;
  Higgs inflation,...)





③ IS IT THE SM HIGGS?

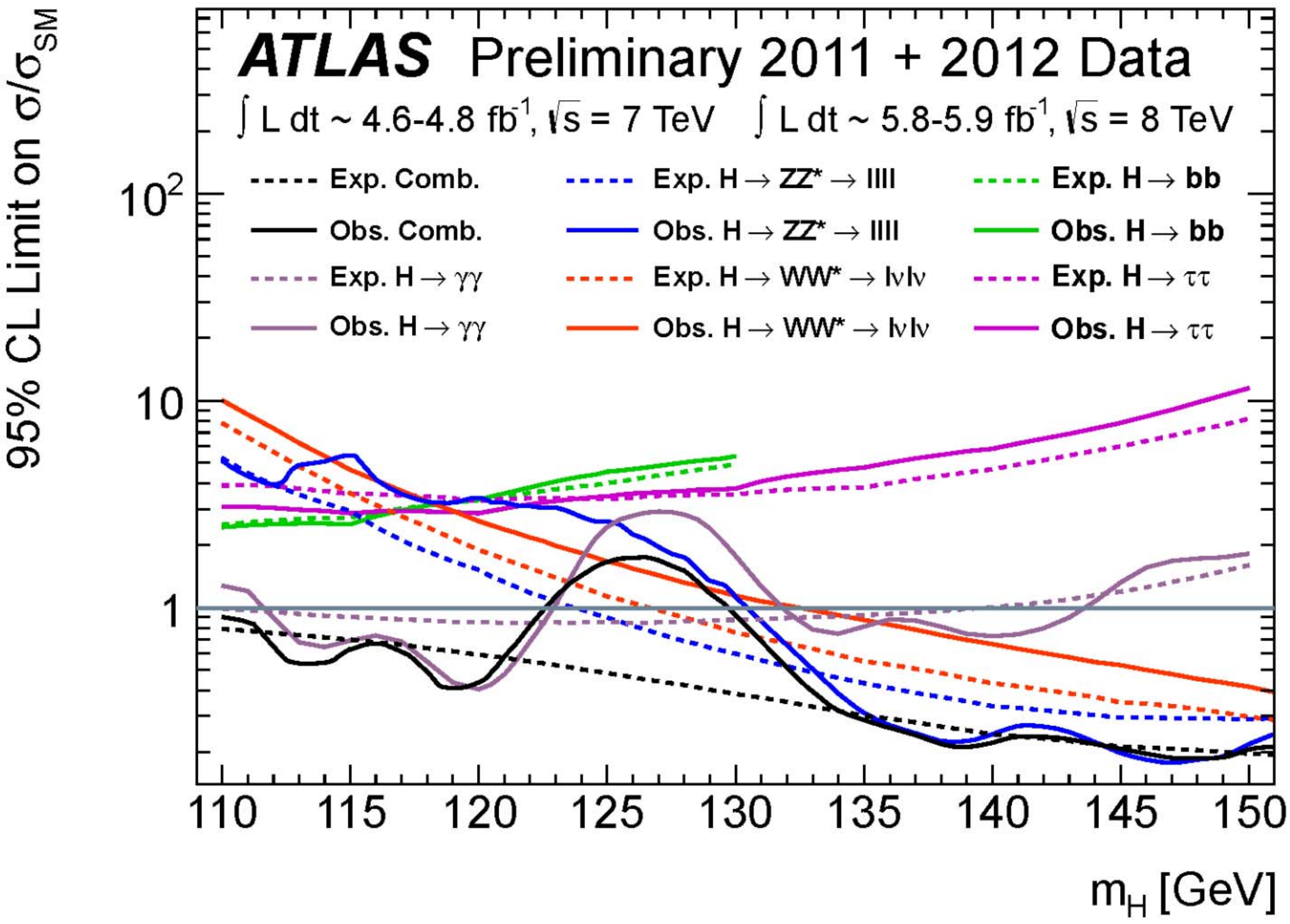
SM Higgs sector is the less tested and more problematic

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

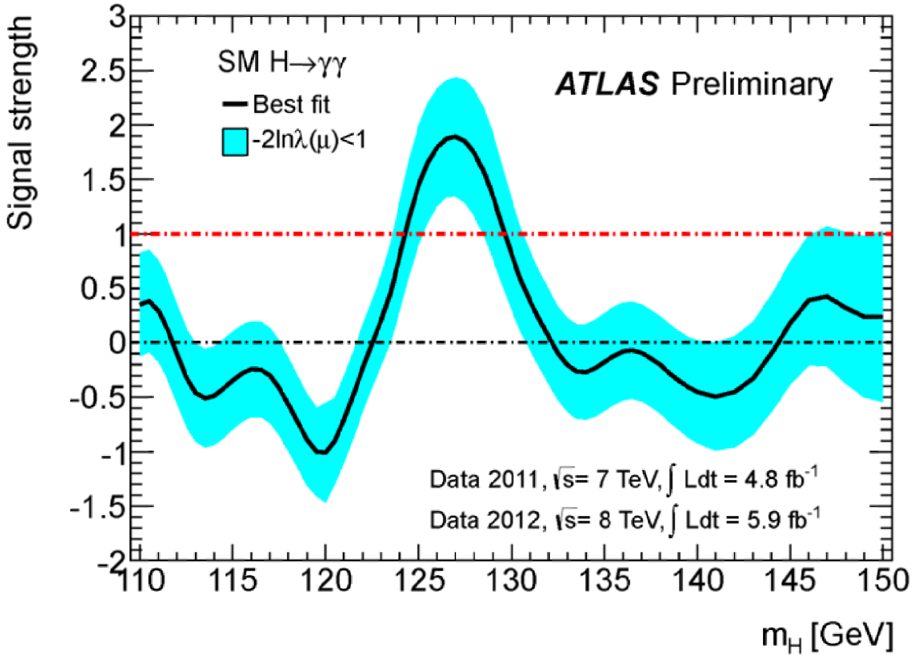
The importance of measuring Higgs couplings cannot be overemphasized

INDIVIDUAL SEARCH CHANNELS

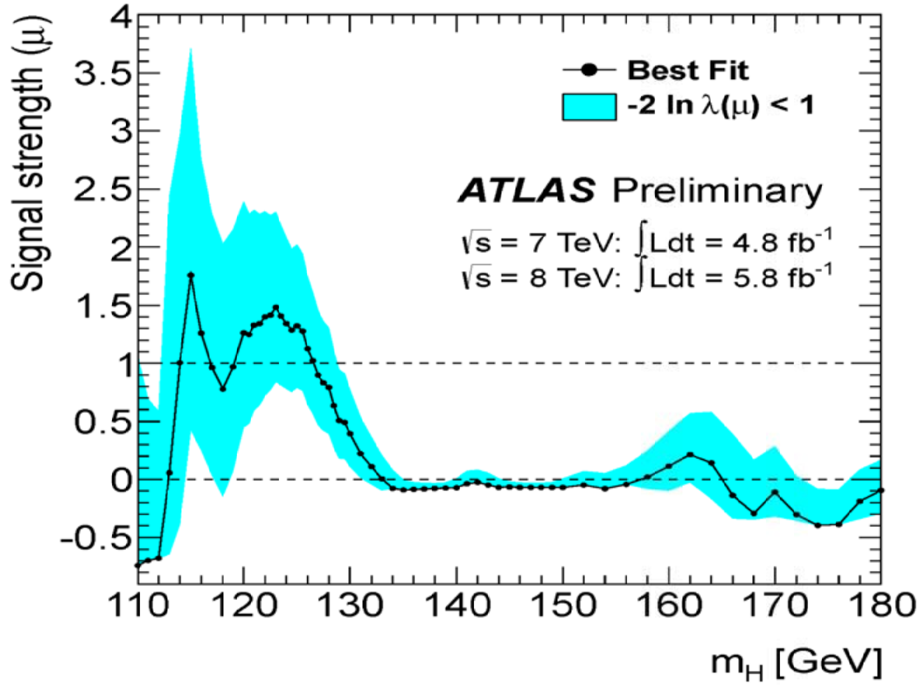


INDIVIDUAL SEARCH CHANNELS

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



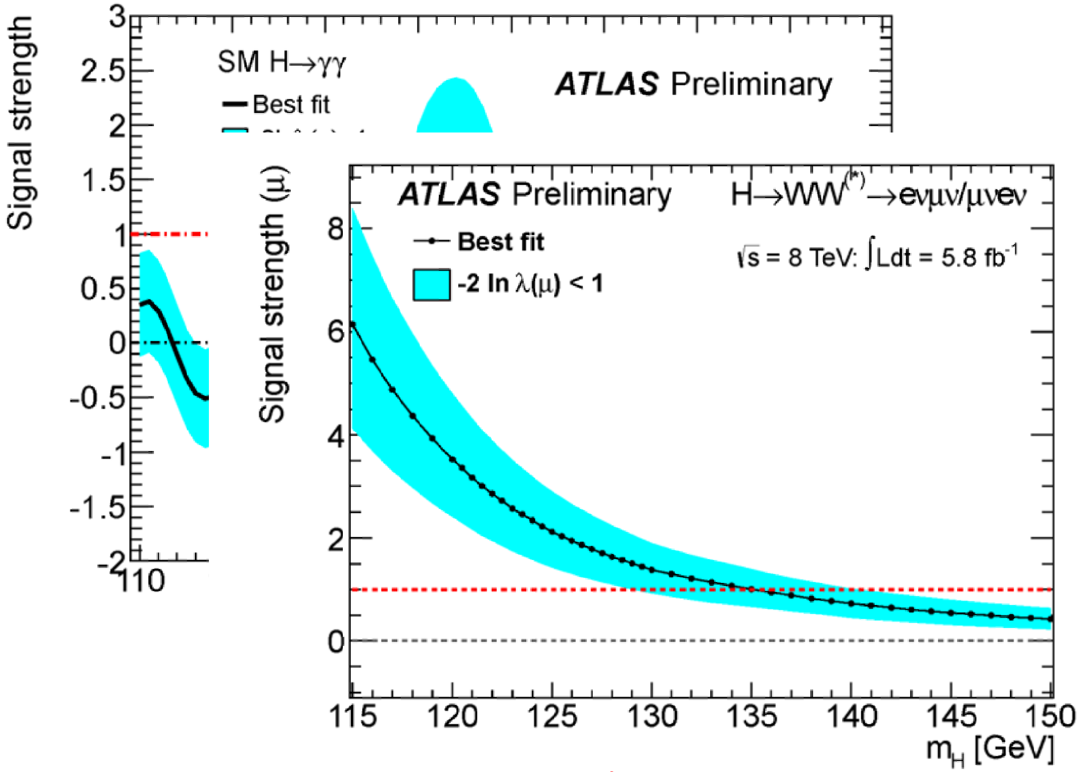
γγ



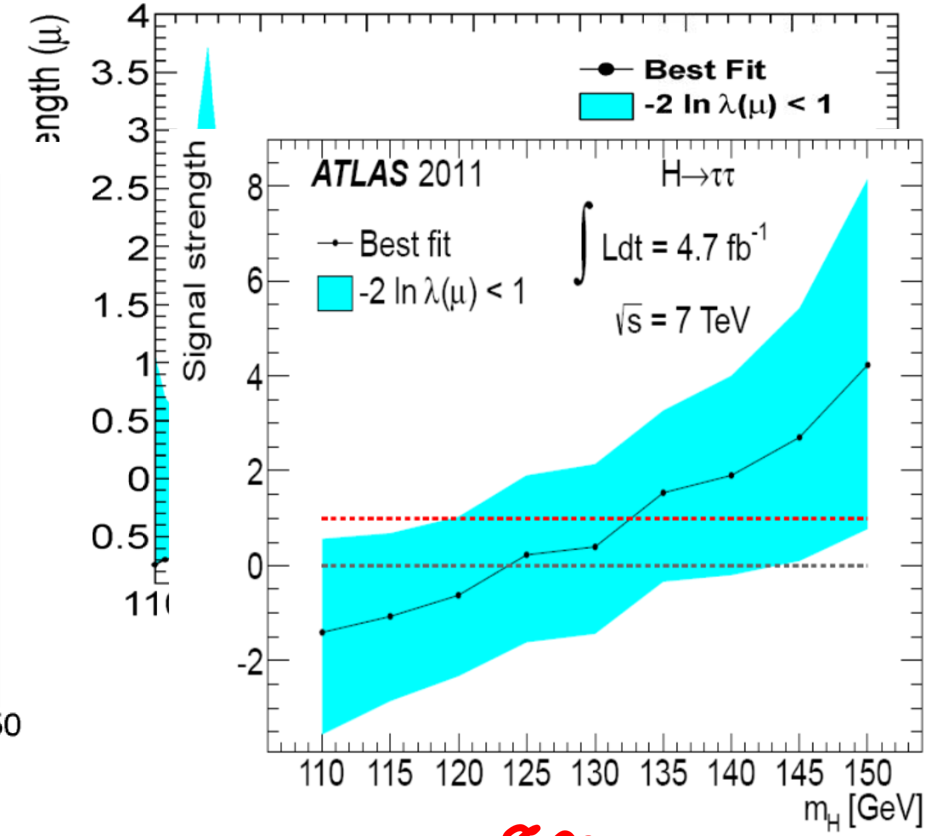
ZZ

INDIVIDUAL SEARCH CHANNELS

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



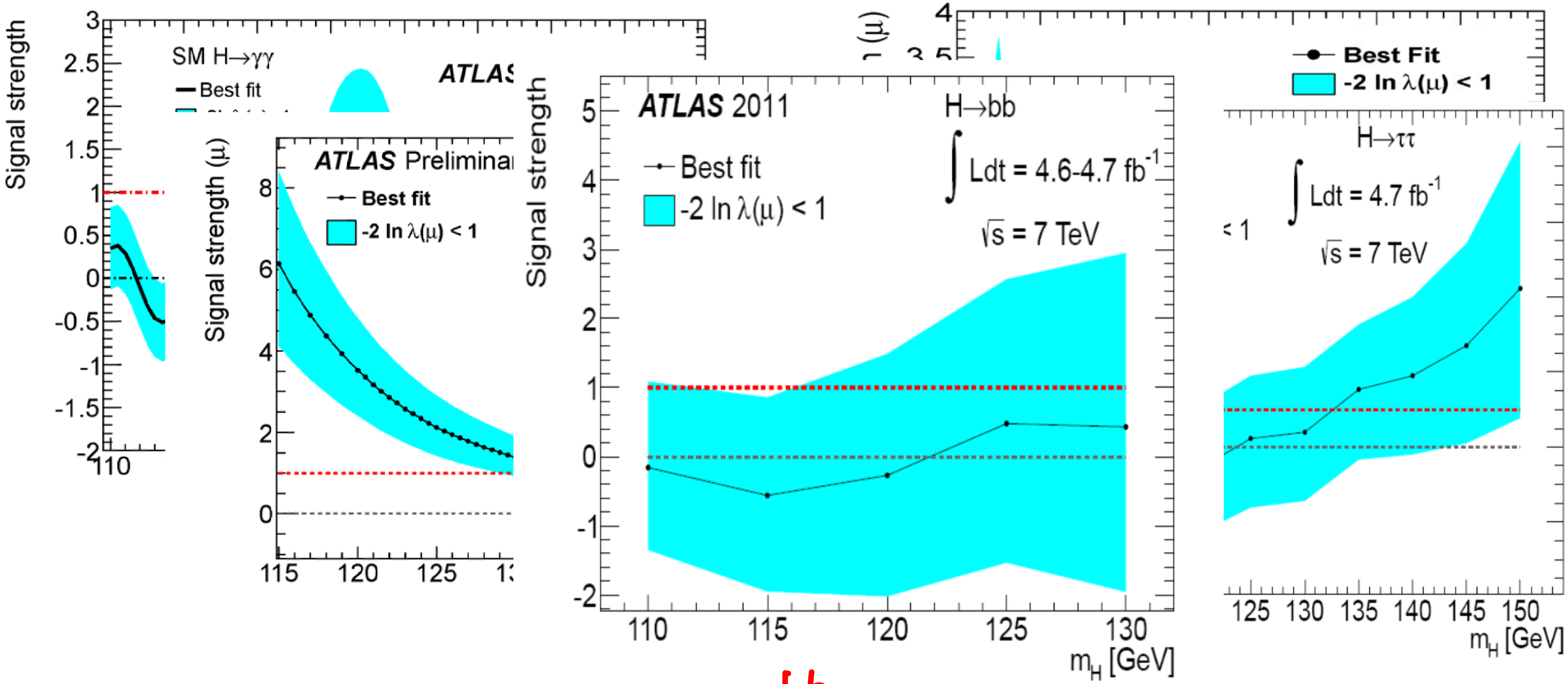
WW



ττ

INDIVIDUAL SEARCH CHANNELS

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



bb

+ Similar data from CMS & Tevatron

95% CL LIMITS & SIGNAL STRENGTHS

From signal yield $n_s = n_{obs} - n_b$ ⇨ Signal strength $\mu = \frac{n_s}{n_s^{SM}}$

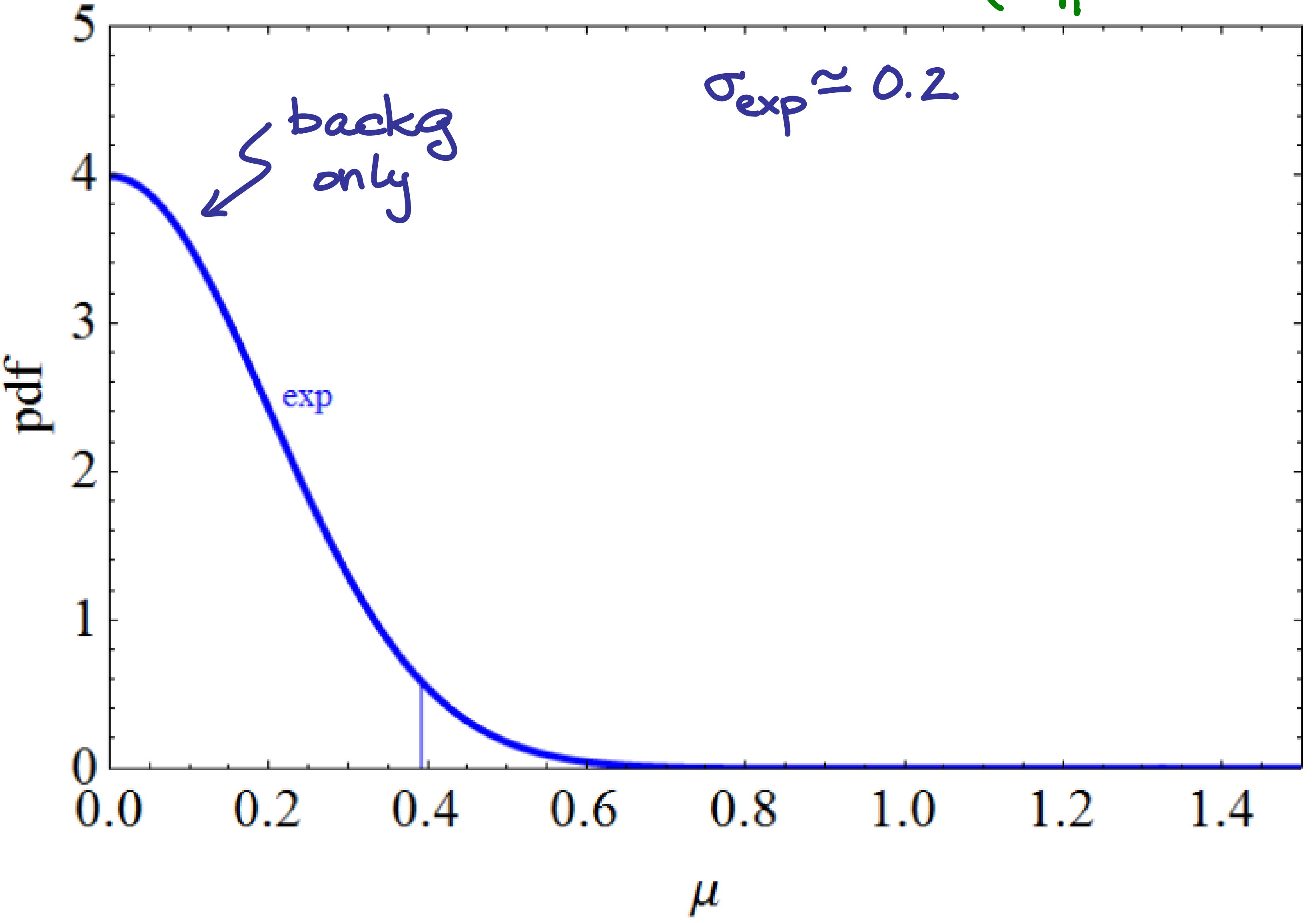
For large # of events μ is distributed as a Gaussian

Backg-only hypothesis ($n_{obs} = n_b$)

$$pdf(\mu) \sim \exp\left(-\frac{\mu^2}{2\sigma^2}\right) \quad \text{with} \quad \sigma \sim \frac{\sqrt{n_b}}{n_s^{SM}}$$

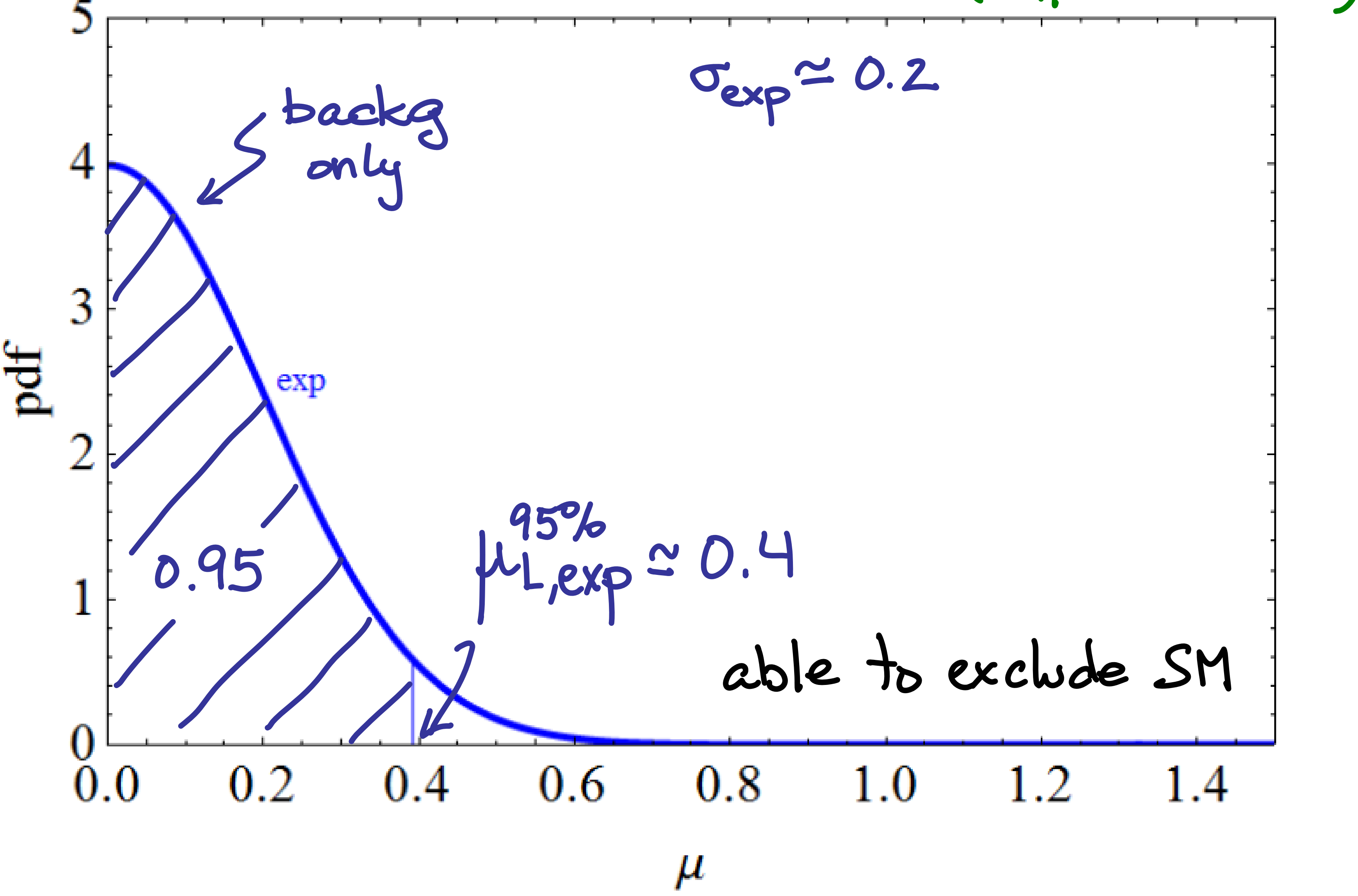
95% CL LIMITS & SIGNAL STRENGTHS

CMS COMBINATION (m_h=125 GeV)



95% CL LIMITS & SIGNAL STRENGTHS

CMS COMBINATION (m_h = 125 GeV)



95% CL LIMITS & SIGNAL STRENGTHS

From signal yield $n_s = n_{obs} - n_b$ ⇨ Signal strength $\mu = \frac{n_s}{n_s^{SM}}$

For large # of events μ is distributed as a Gaussian

Backg-only hypothesis $(n_{obs} = n_b)$

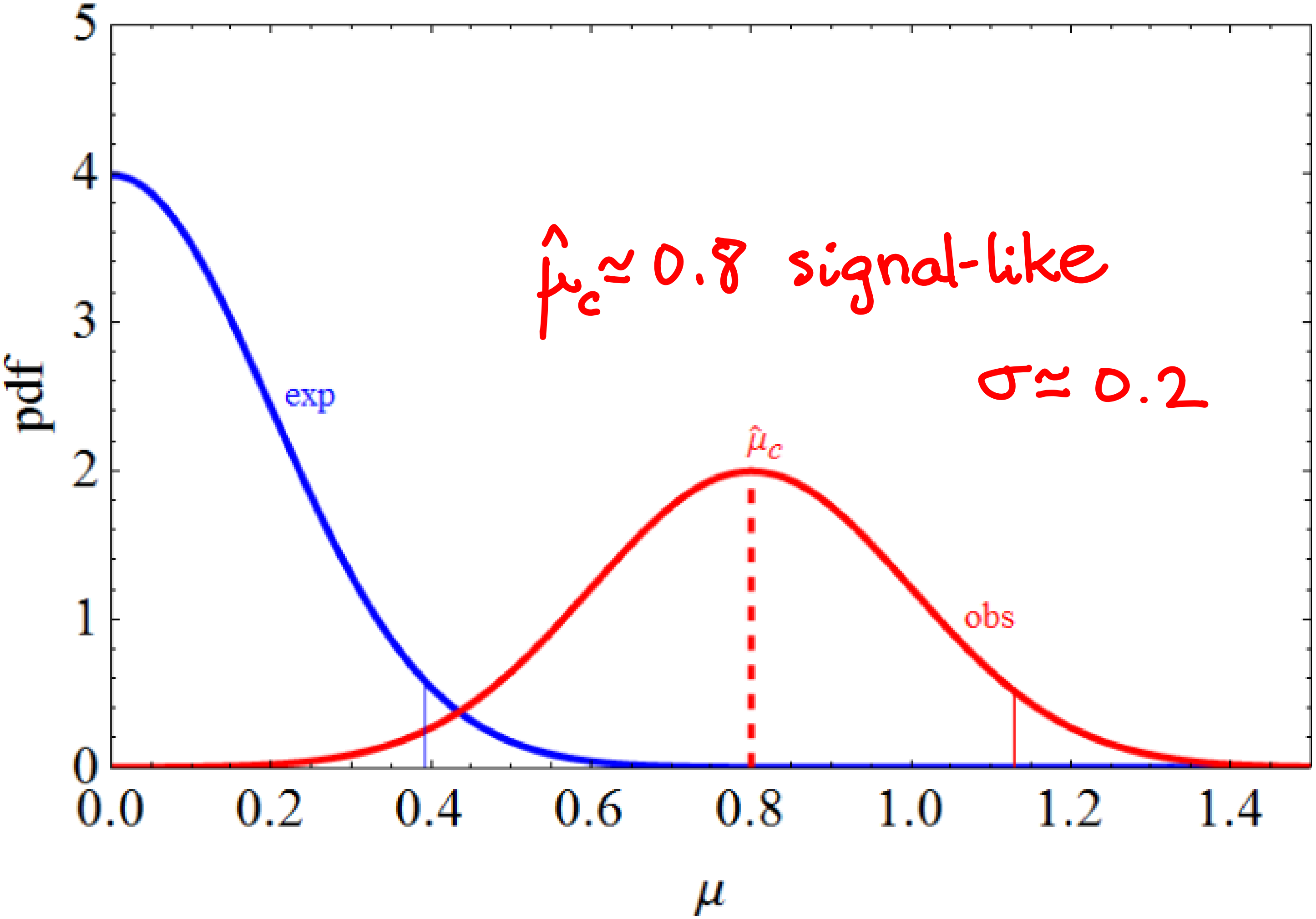
$$\text{pdf}(\mu) \sim \exp\left(-\frac{\mu^2}{2\sigma^2}\right) \quad \text{with} \quad \sigma \sim \frac{\sqrt{n_b}}{n_s^{SM}}$$

Observed pdf $(n_{obs} = n_b + n_s)$

$$\text{pdf}(\mu) \sim \exp\left(-\frac{(\mu-\hat{\mu})^2}{2\sigma^2}\right) \quad \text{with} \quad \begin{cases} \hat{\mu} = \dfrac{n_{obs} - n_b}{n_s^{SM}} \\ \sigma \sim \dfrac{\sqrt{n_{obs}}}{n_s^{SM}} \end{cases}$$

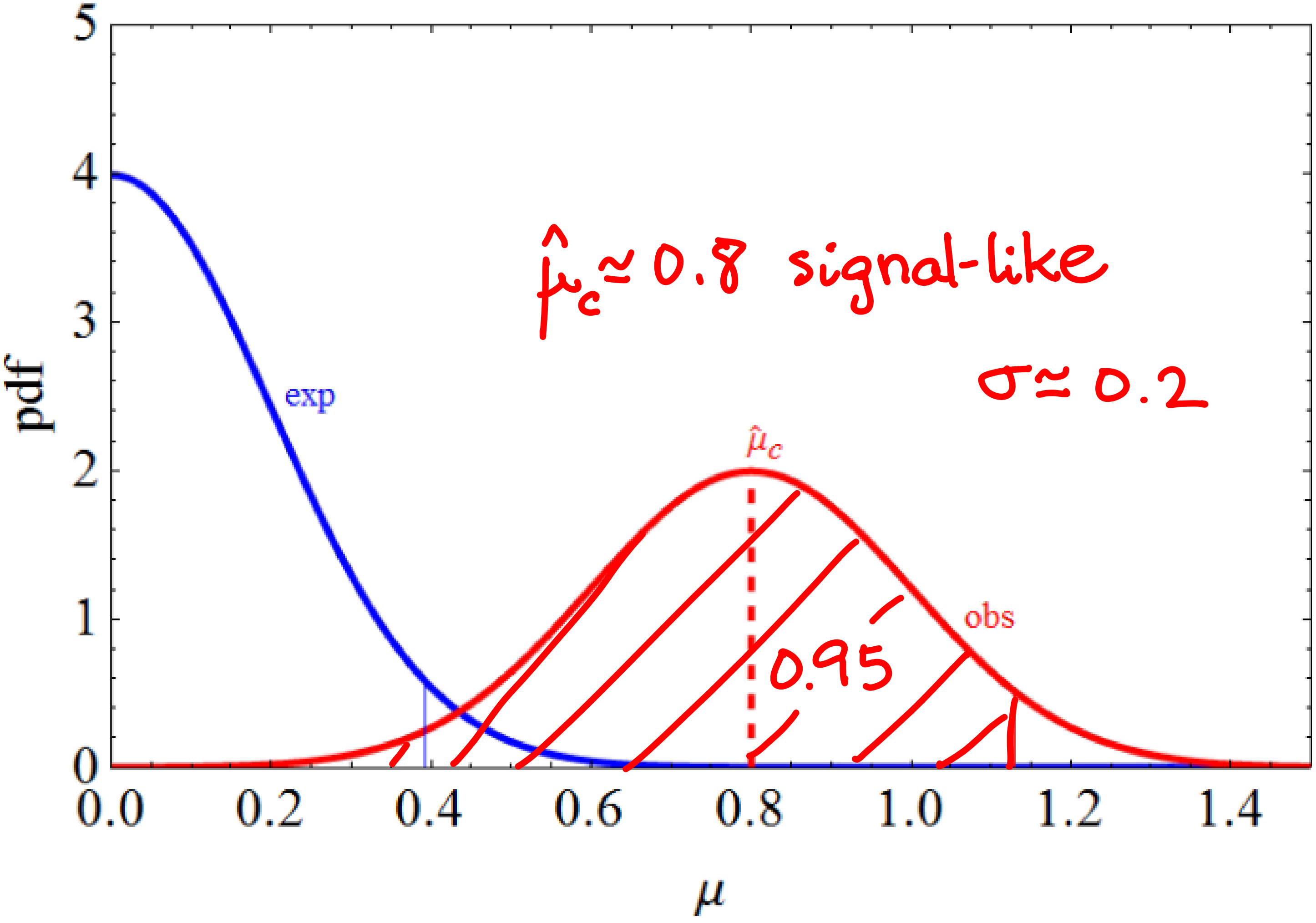
95% CL LIMITS & SIGNAL STRENGTHS

CMS COMBINATION



95% CL LIMITS & SIGNAL STRENGTHS

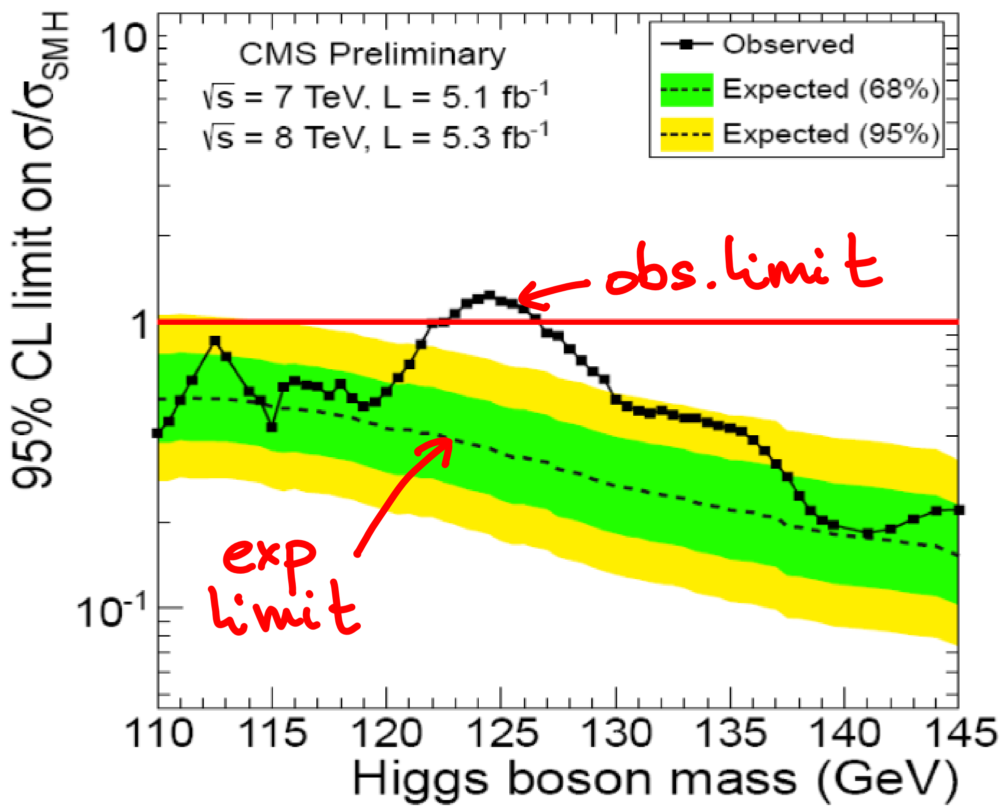
CMS COMBINATION



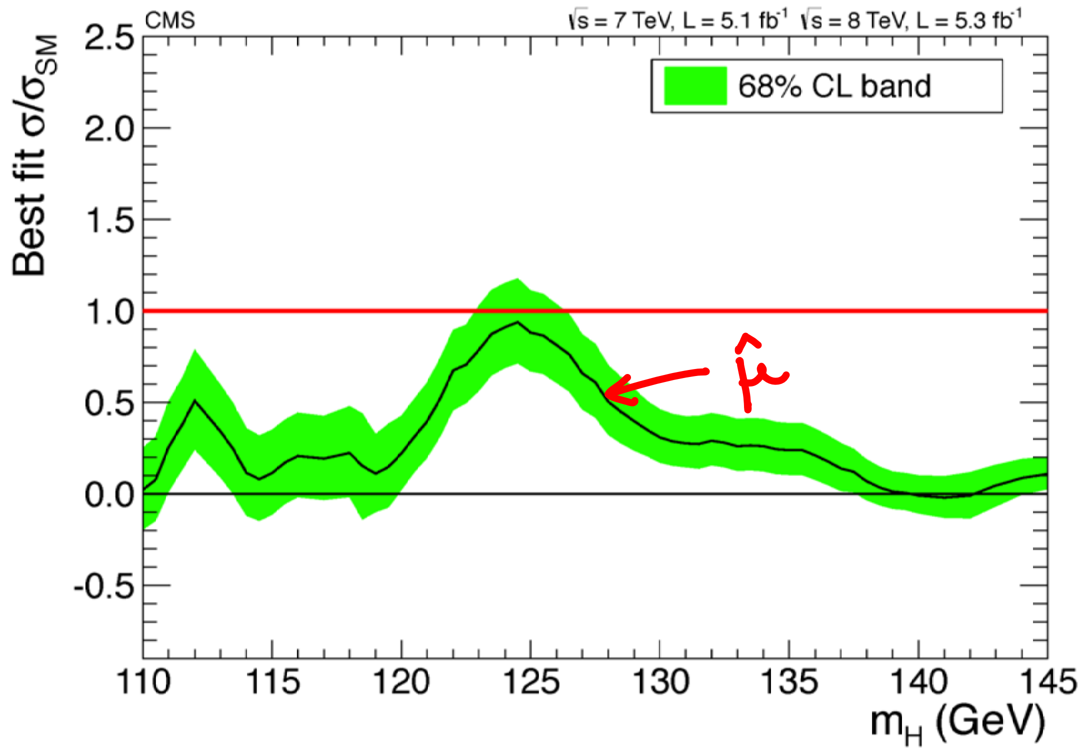
$\mu^{95\%}_{L,obs} \simeq 1.13$

95% CL LIMITS & SIGNAL STRENGTHS

CMS COMBINATION



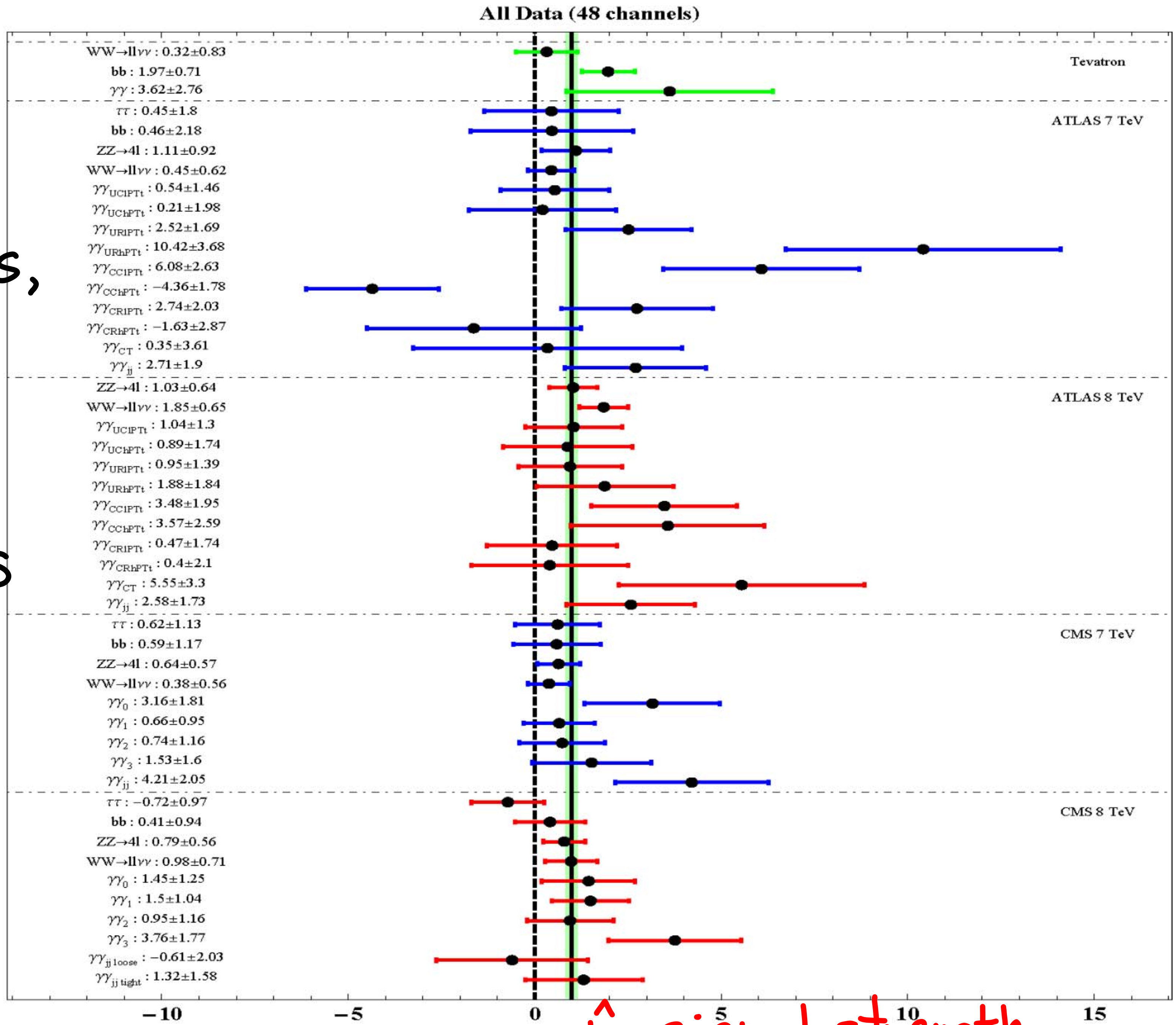
95% CL Limits



$\hat{\mu} \pm \sigma$

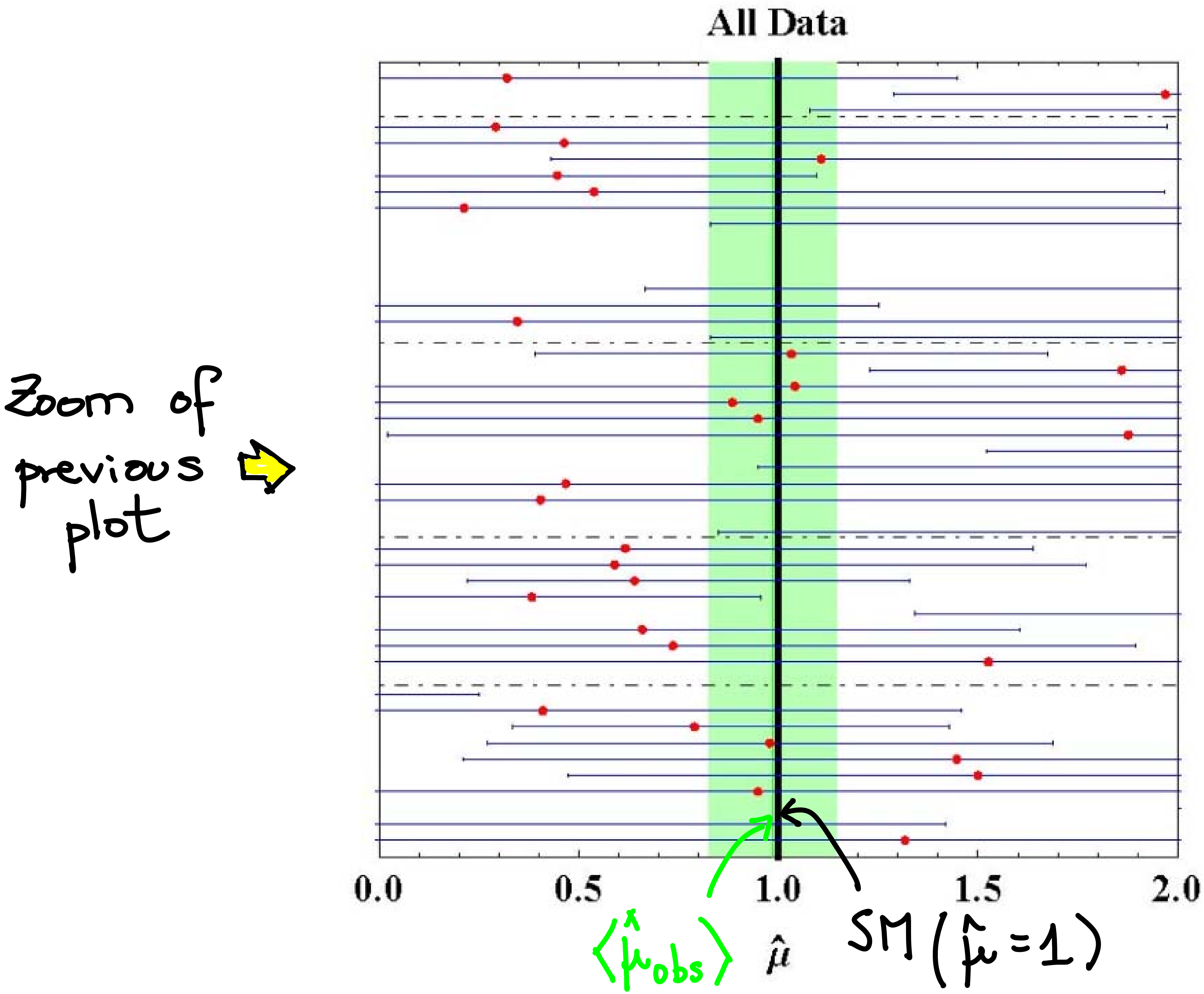
DATA USED IN OUR FITS

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



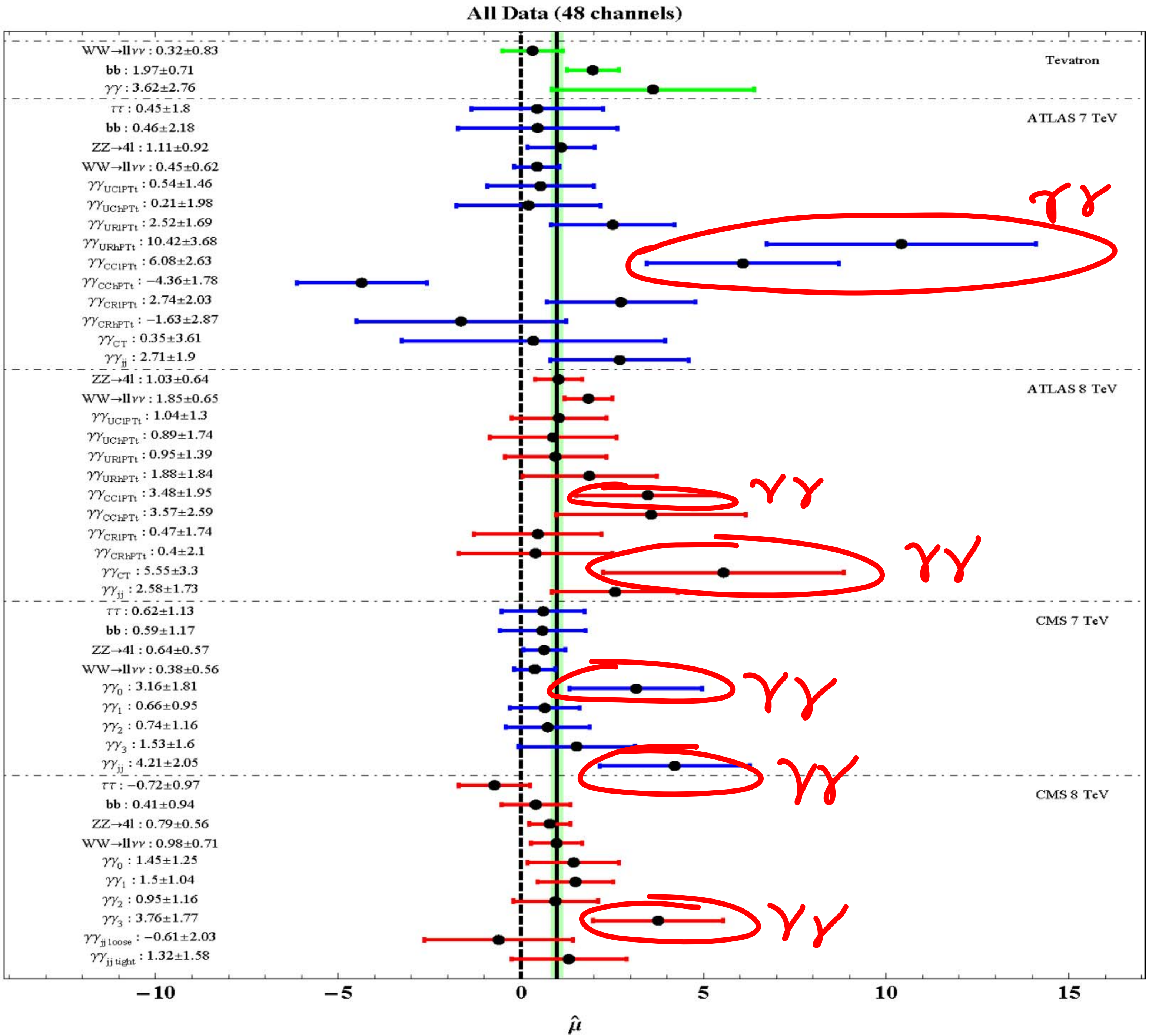
$\hat{\mu}$, signal strength

DATA USED IN OUR FITS

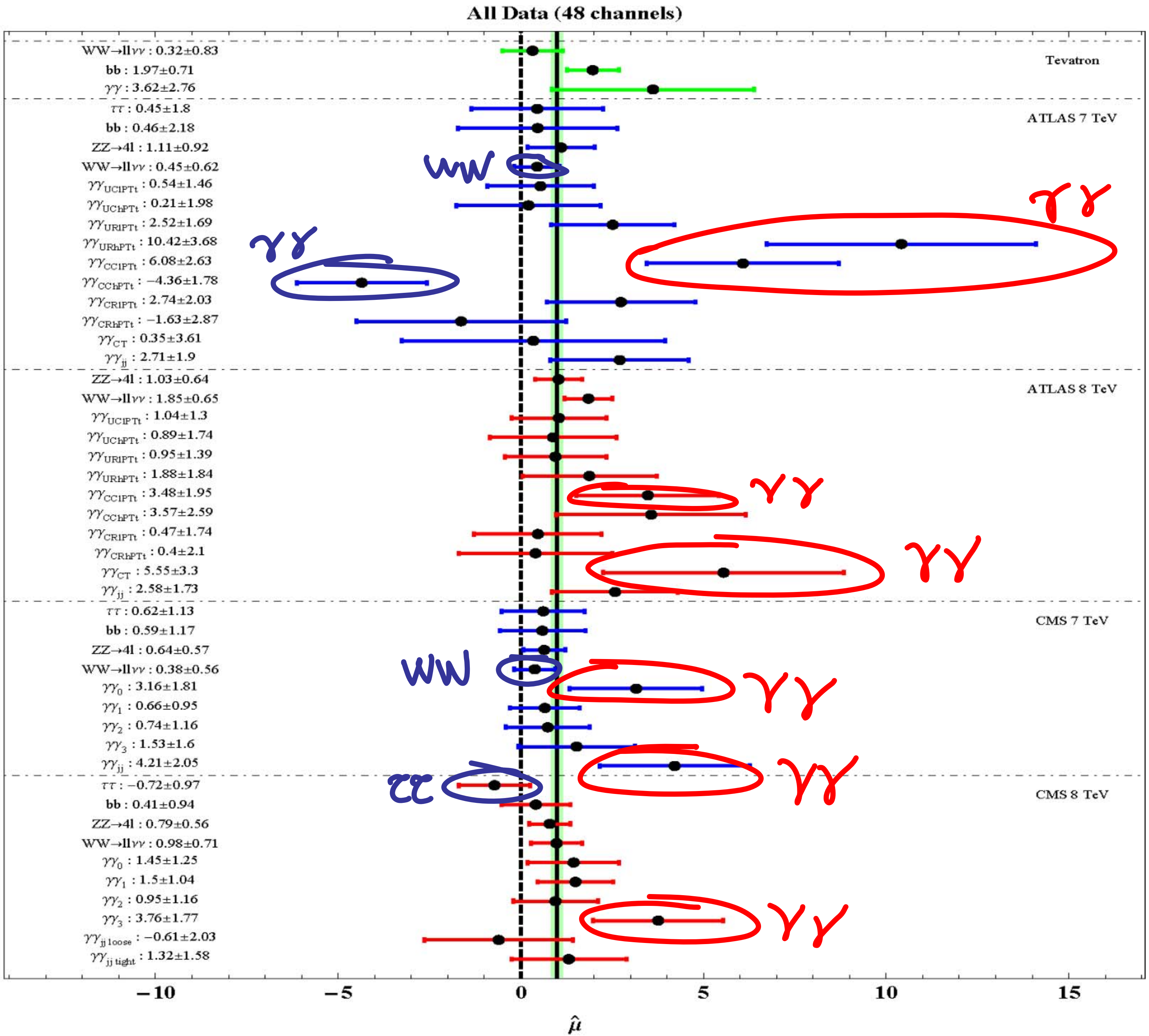


DATA USED IN OUR FITS

Excesses

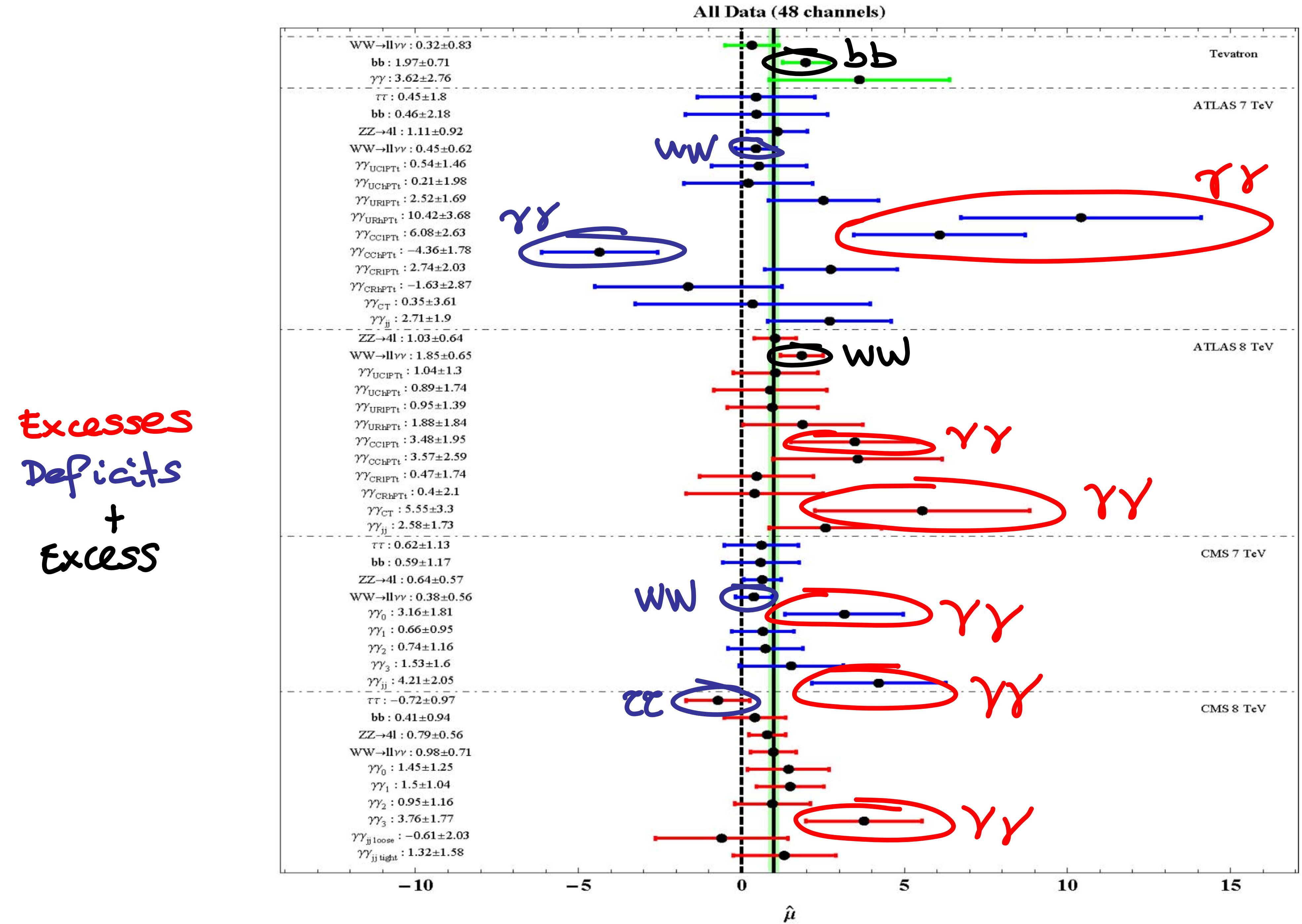


DATA USED IN OUR FITS



Excesses
Deficits

DATA USED IN OUR FITS



(4a) 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

EFFECTIVE LAGRANGIAN APPROACH

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

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

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

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

\+ custodial symmetry

EFFECTIVE LAGRANGIAN APPROACH

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

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

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

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

+ custodial symmetry

+ no tree-level FCNC from h exchange

EFFECTIVE LAGRANGIAN APPROACH

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

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

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

$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \ldots$$

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

+ custodial symmetry

+ no tree-level FCNC from h exchange

First terms in a "chiral lagrangian" with cutoff

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

EFFECTIVE LAGRANGIAN APPROACH

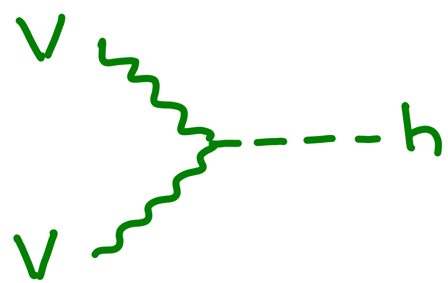
$\mathcal{L}$ valid at $E \sim M_t$.

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

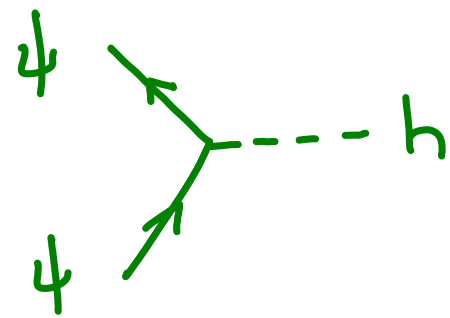
$$\mathcal{L} = \mathcal{L}[h] - \left(M_W^2 W_\mu^+ W^{\mu -} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu\right)\left[1 + 2a\frac{h}{v} + O(h^2)\right]$$

$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \ldots$$

2-parameter extension of the SM with



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



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

$$SM \equiv (a, c) = (1, 1)$$

EFFECTIVE LAGRANGIAN APPROACH

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

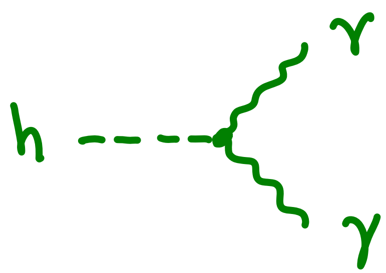
Field content : SM + scalar h (no extra light states)

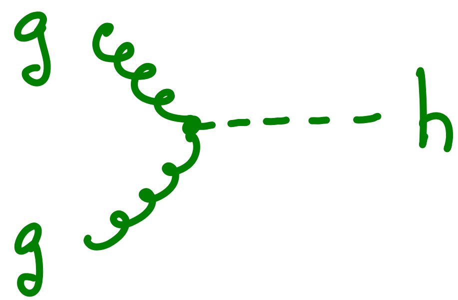
$$\mathcal{L} = \mathcal{L}[h] - \left(M_W^2 W_\mu^+ W^{\mu -} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu\right)\left[1 + 2a\frac{h}{v} + O(h^2)\right]$$

$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \ldots$$

Other operators very relevant for Higgs searches:

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





EFFECTIVE LAGRANGIAN APPROACH

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

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

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

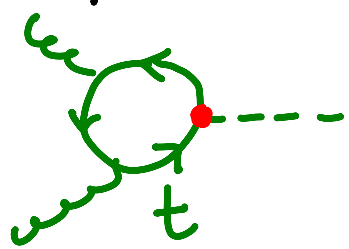
$$- m_{\psi_i}\bar{\psi}_i \psi_i \left[1 + c\,\frac{h}{v} + O(h^2)\right] + \dots$$

Other operators very relevant for Higgs searches:

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

are assumed to come from SM loops only:

$gg \to h$



$\sim c$

EFFECTIVE LAGRANGIAN APPROACH

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

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

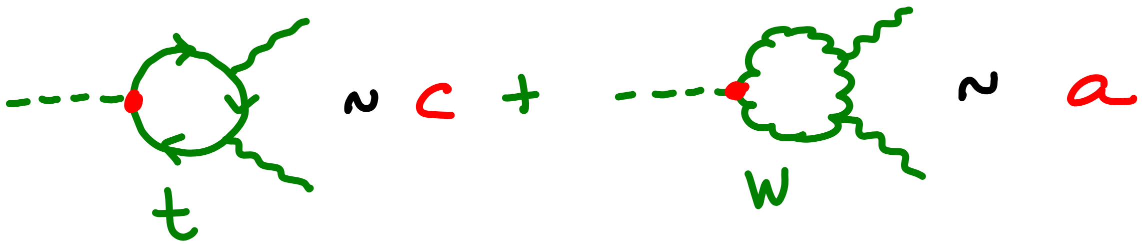
$$\mathcal{L} = \mathcal{L}[h] - \left(M_W^2 W_\mu^+ W^{\mu -} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu\right)\left[1 + 2a\frac{h}{v} + O(h^2)\right]$$
$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \dots$$

Other operators very relevant for Higgs searches:

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

are assumed to come from SM loops only:

$h \to \gamma\gamma$:



EFFECTIVE LAGRANGIAN APPROACH

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

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

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

$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \ldots$$

Other operators very relevant for Higgs searches:

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

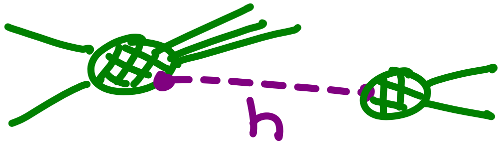
are assumed to come from SM loops only.

Motivated by composite PNGB Higgs scenarios

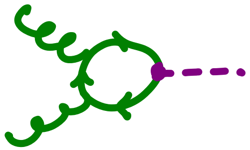
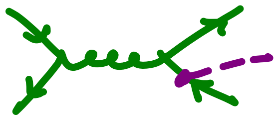
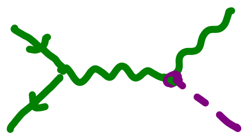
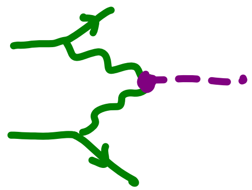
Will relax this assumption later on.

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:

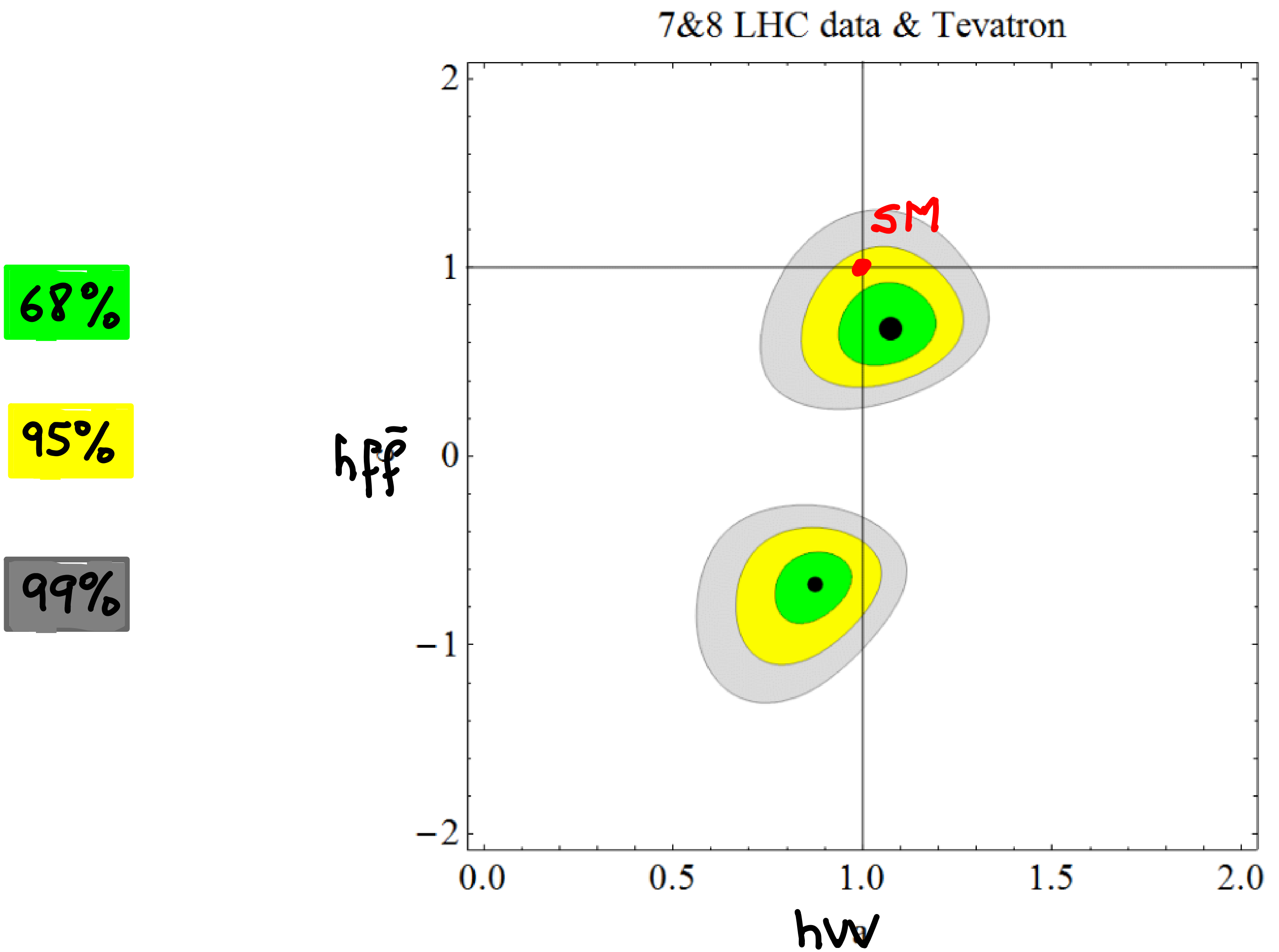
$$\mu_i = \left[\frac{\sigma^{SM(a,c)}_{pp\to h\to X}}{\sigma^{SM}_{pp\to h\to X}}\right]_i = \frac{\sum_{p_i} \epsilon_{p_i}\sigma_{p_i}(a,c)\times BR^{SM(a,c)}_{h\to X}}{\sum_{p_i}\epsilon_{p_i}\sigma_{p_i}\times BR^{SM}_{h\to X}}$$

RATES IN SM(a,c)

- Need to know efficiencies ϵ_{p_i} to properly rescale σ_i
- 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.

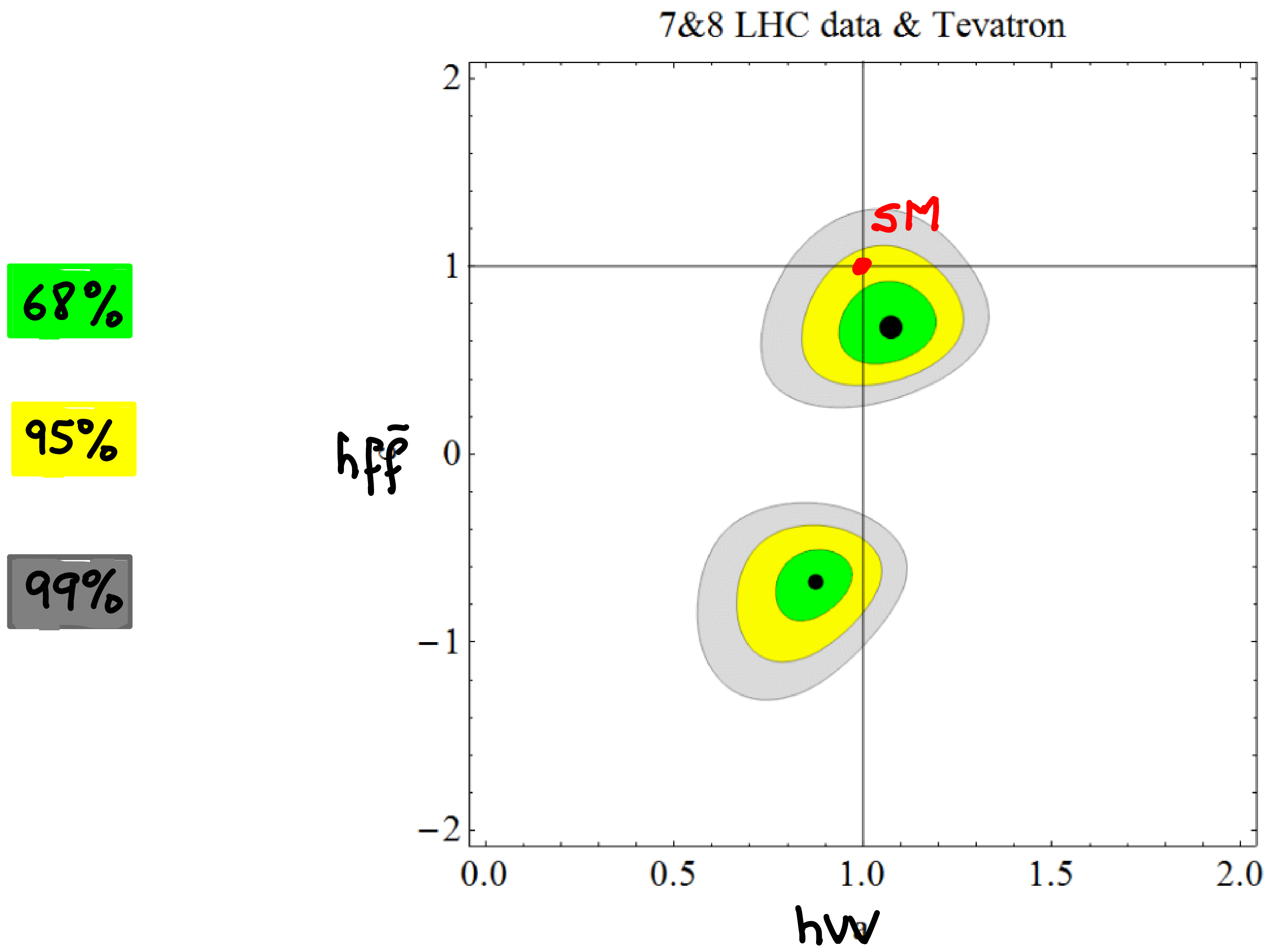
FITS IN SM(a,c)

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



FITS IN SM(a,c)

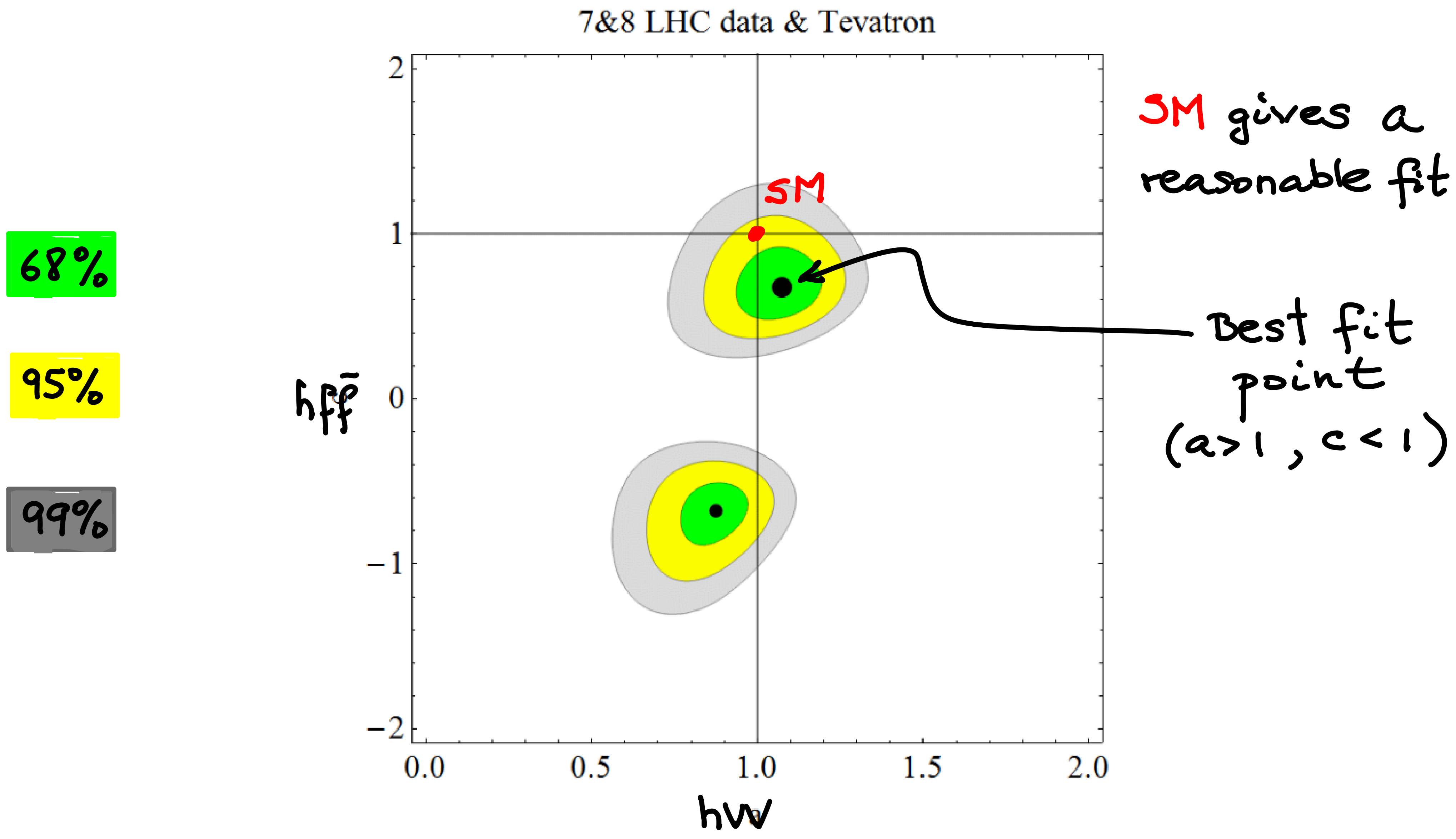
χ^2 fit to $\hat{\mu}_i \pm \sigma_i$ from 48 channels (ATLAS+CMS+Tevatron)



SM gives a reasonable fit

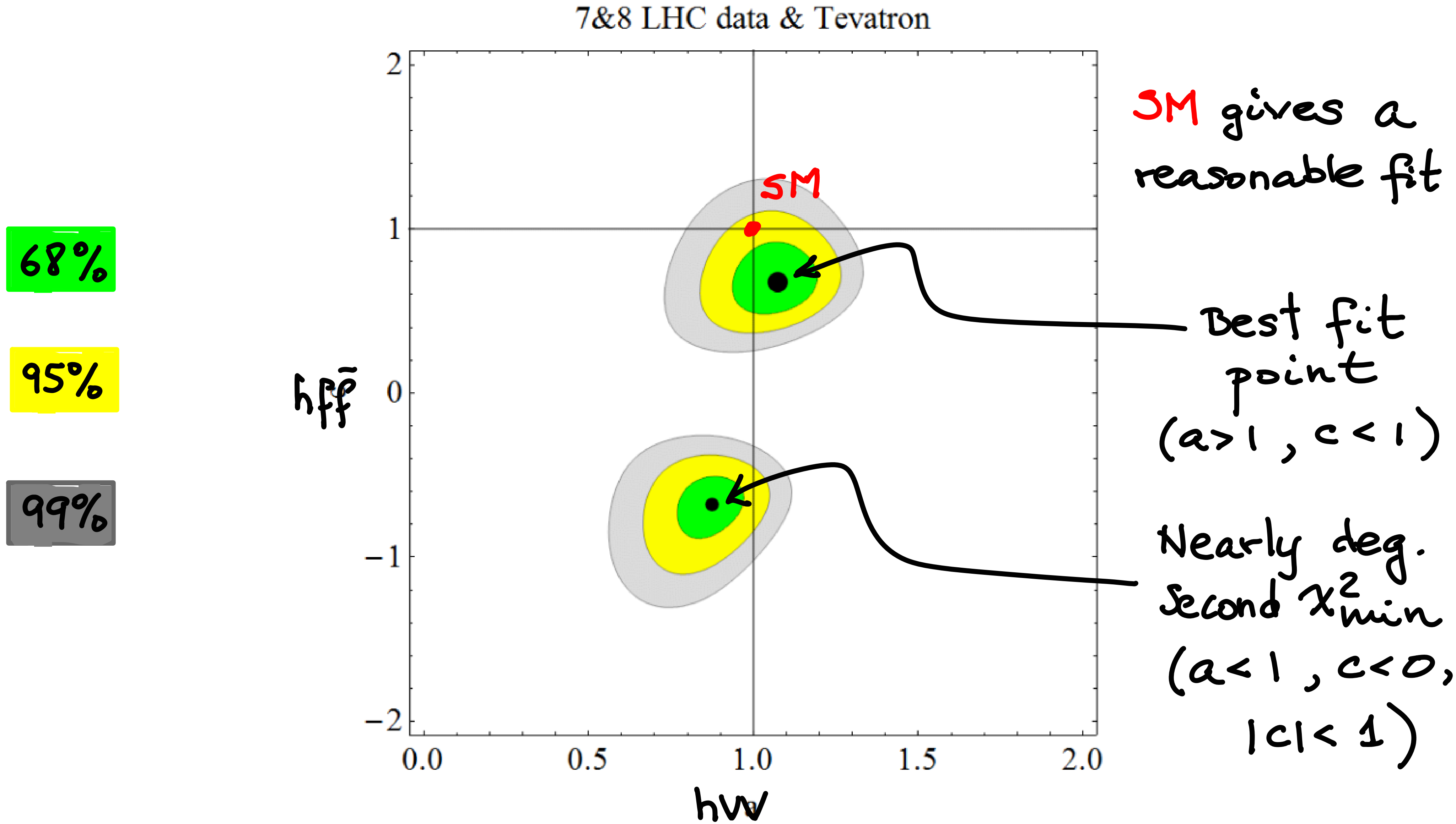
FITS IN SM(a,c)

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



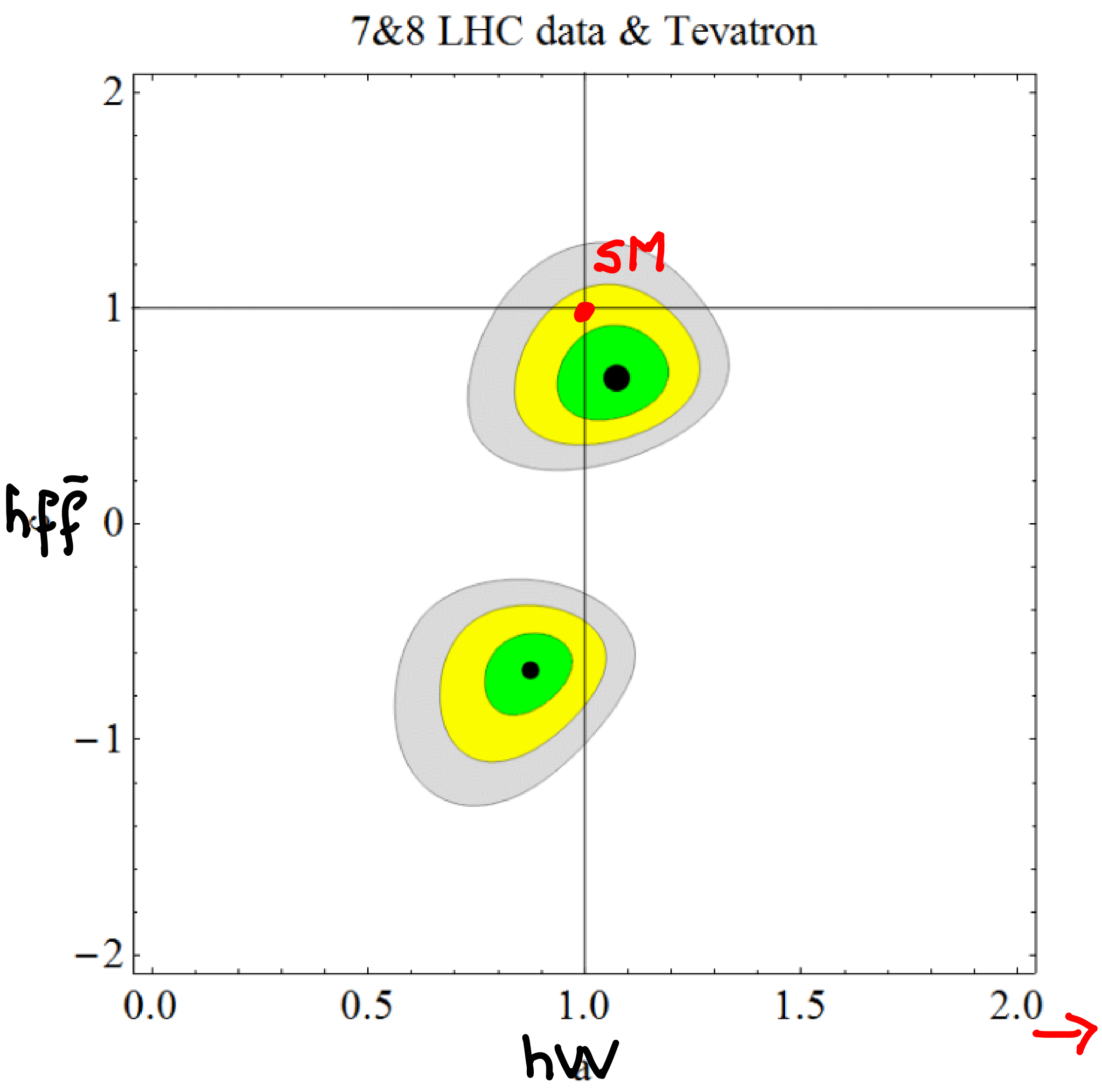
FITS IN SM(a,c)

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



SM gives a reasonable fit

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.

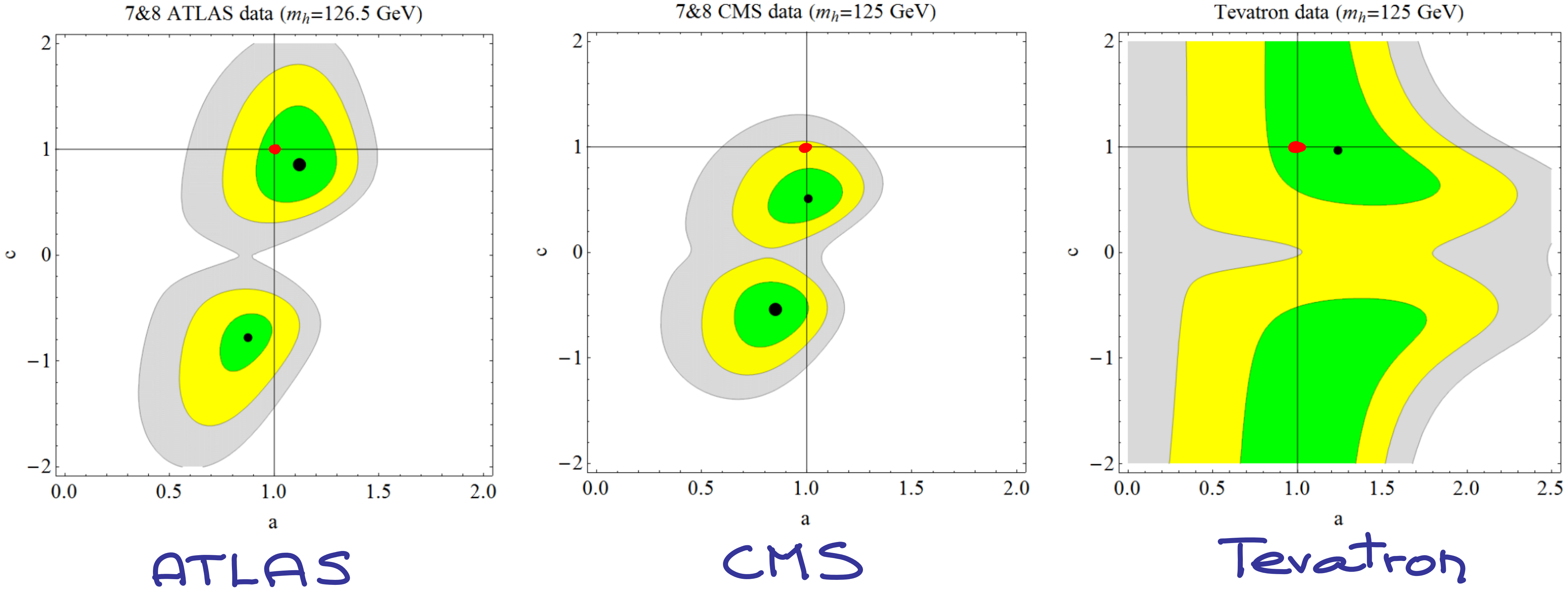
$a\leftrightarrow -a \quad c\leftrightarrow -c$ sym.

Broken by $h\gamma\gamma$ amplitude

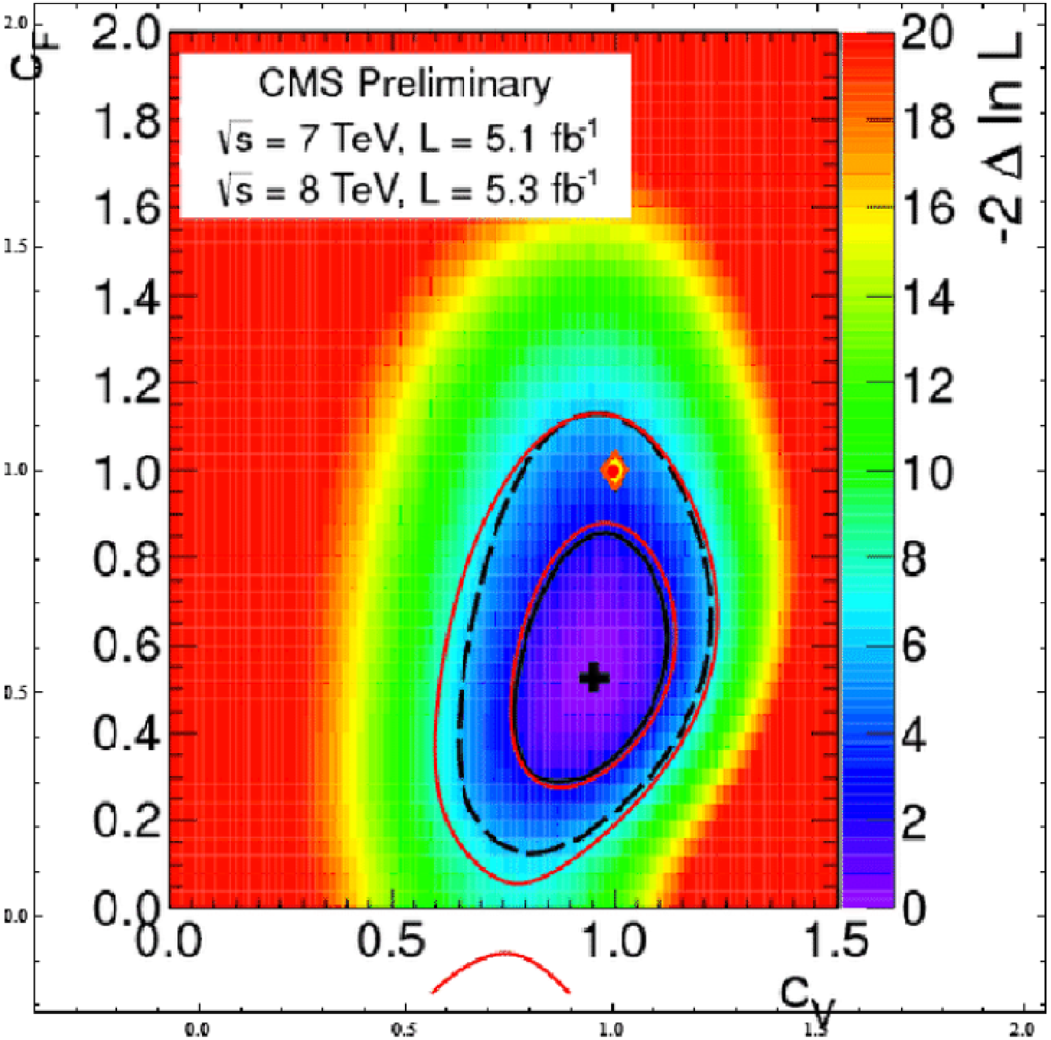
$\sim |1.26\,a - 0.26\,c|^2$

→ Constr. interference for $c<0$

FITS TO SEPARATE EXP.



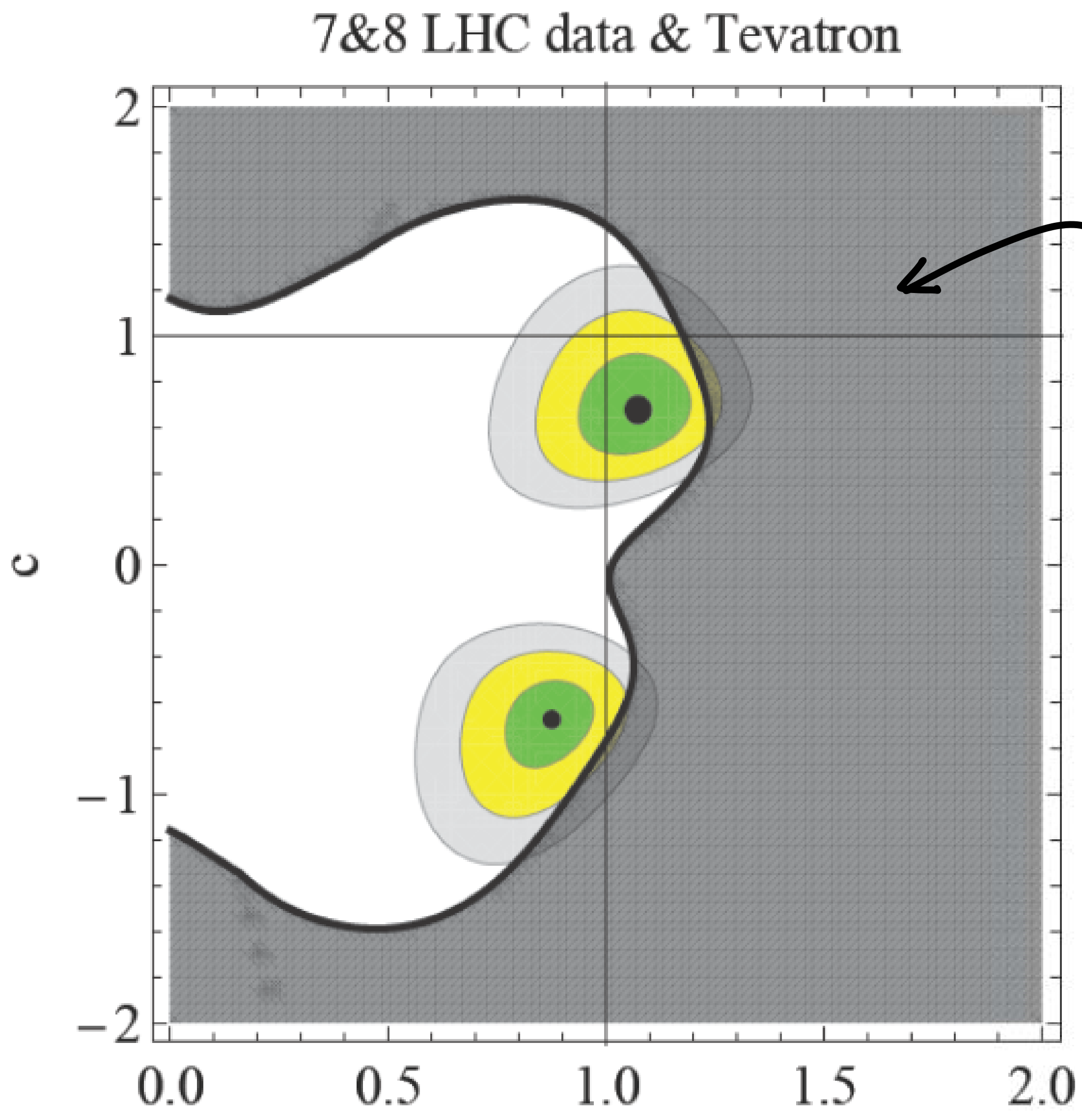
Comparison with CMS



Good agreement

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

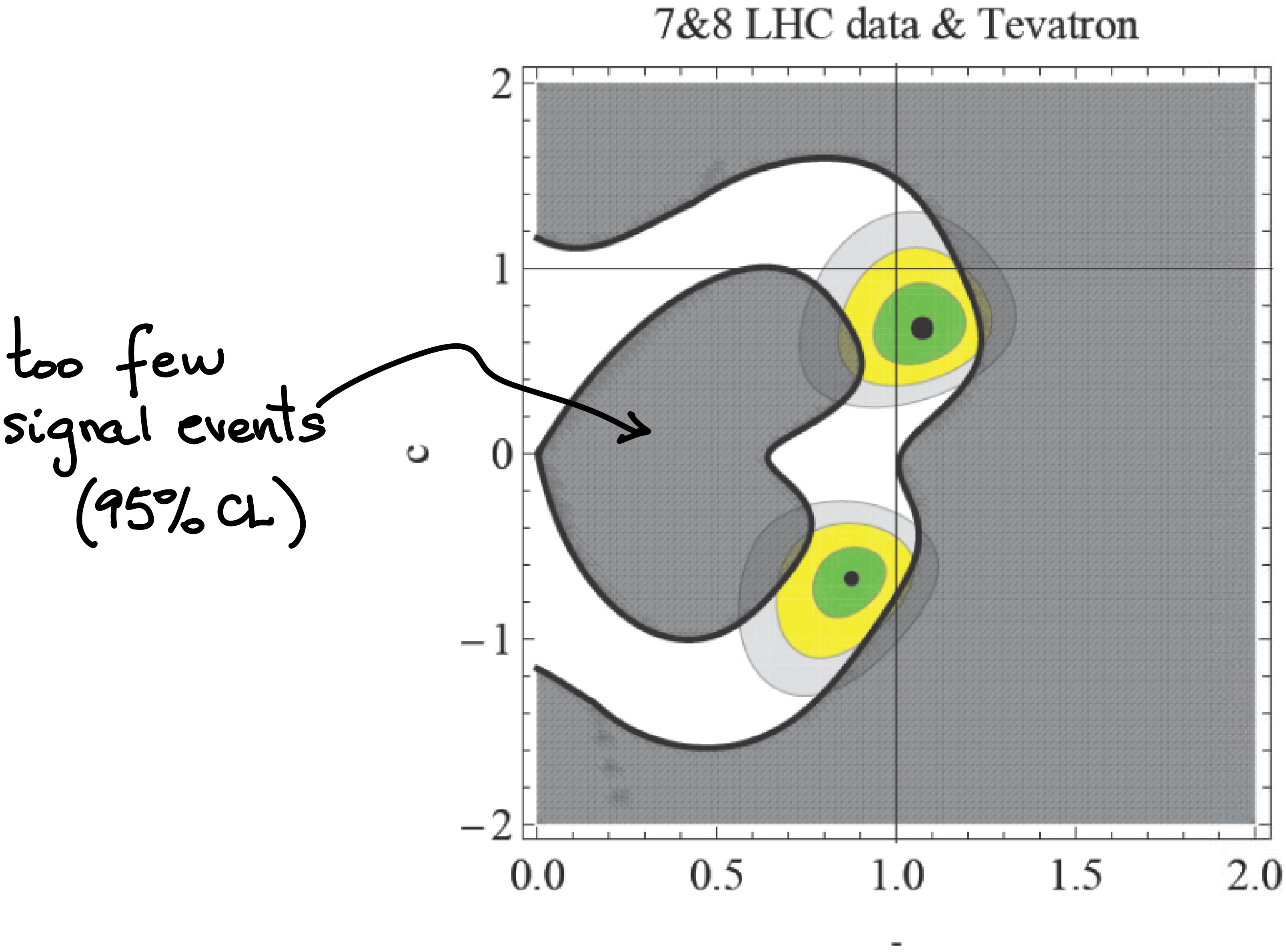
EXCLUDING SM (a,c)



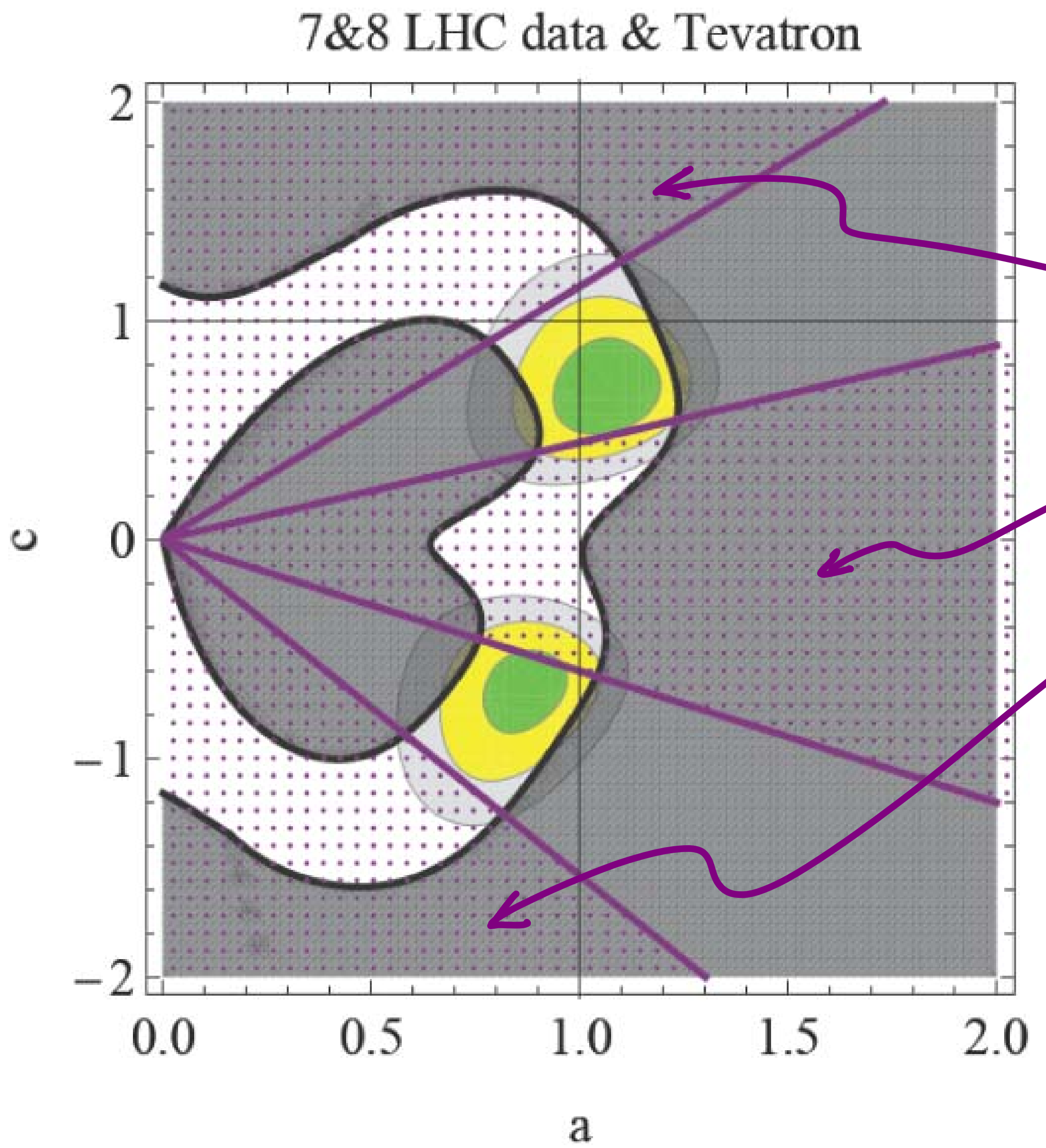
too large signal

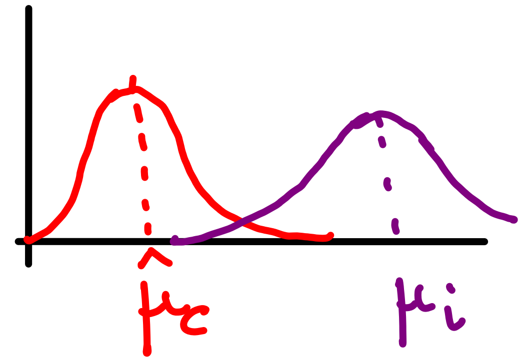
$\hat{\mu}_{exp} > \mu_L^{95\%}$

EXCLUDING SM (a,c)



EXCLUDING SM (a,c)

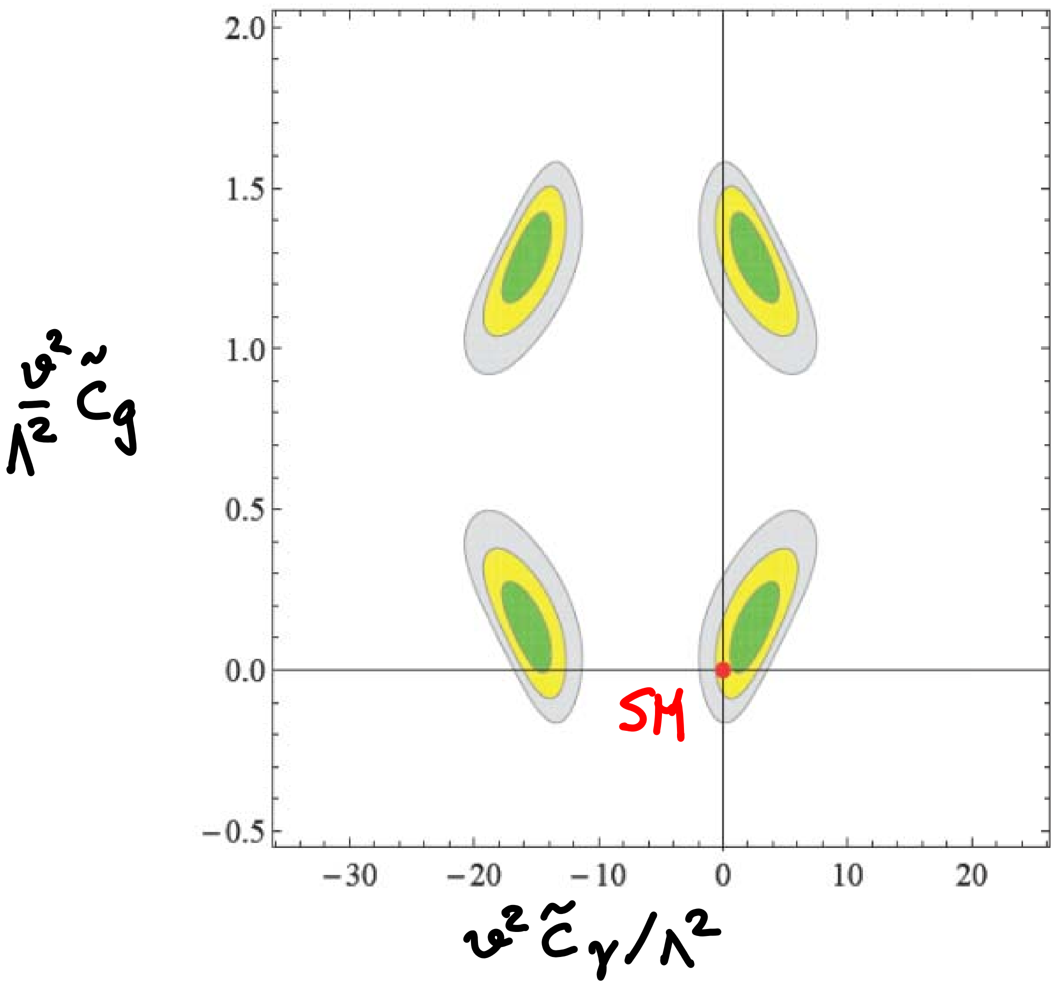




BSM EFFECTS IN $h\gamma\gamma$, hgg

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 ⇨ SM $(\tilde{c}_\gamma, \tilde{c}_g)$



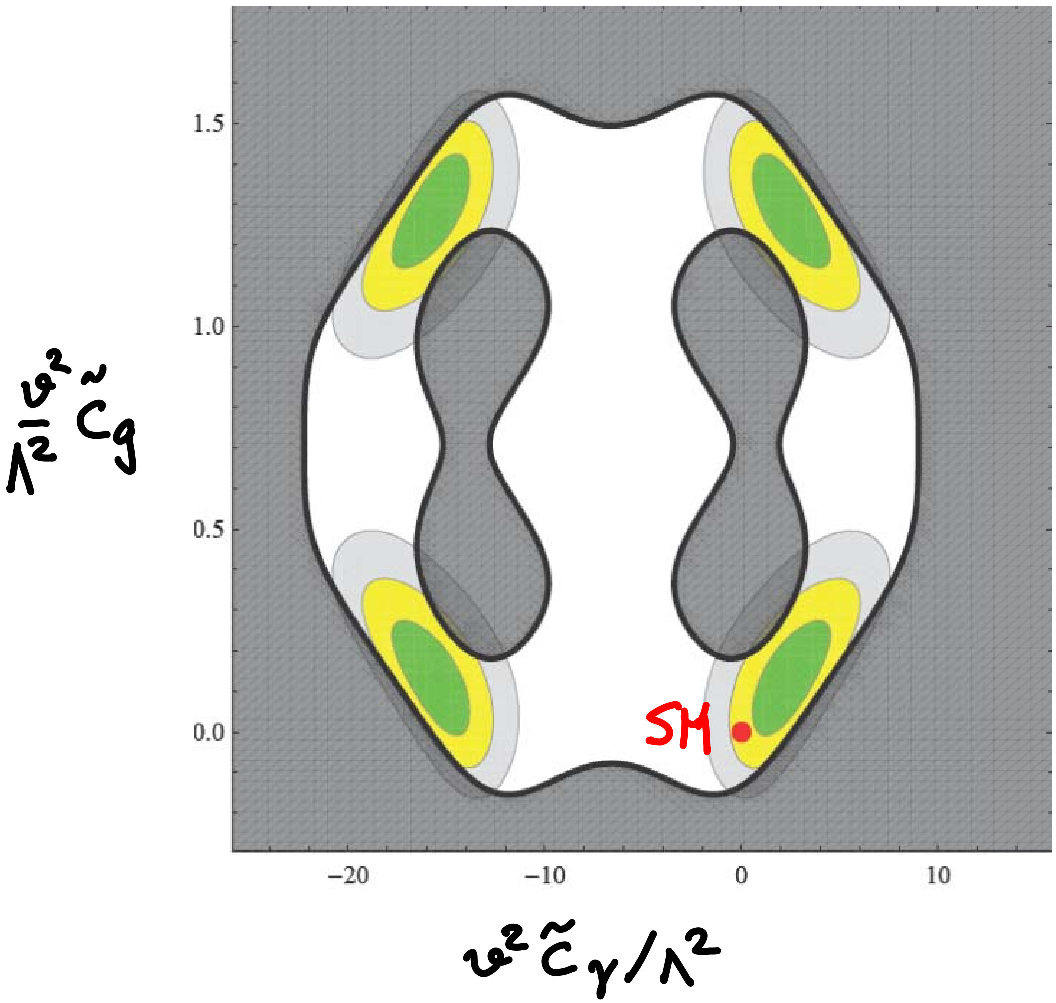
Model-independent result:

Map particular models to this plane

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

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

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



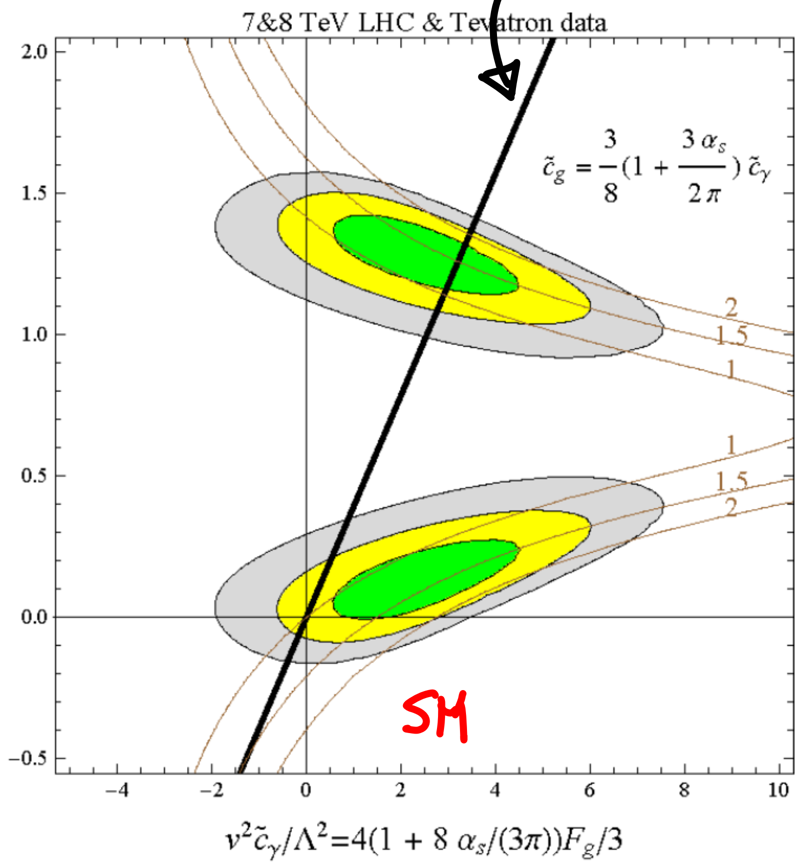
Model-independent result:

Map particular models to this plane

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

Example: Stop, which gives $\tilde{c}_\gamma = 2 N_c Q_{\tilde{t}}^2 \tilde{c}_g$

stop line

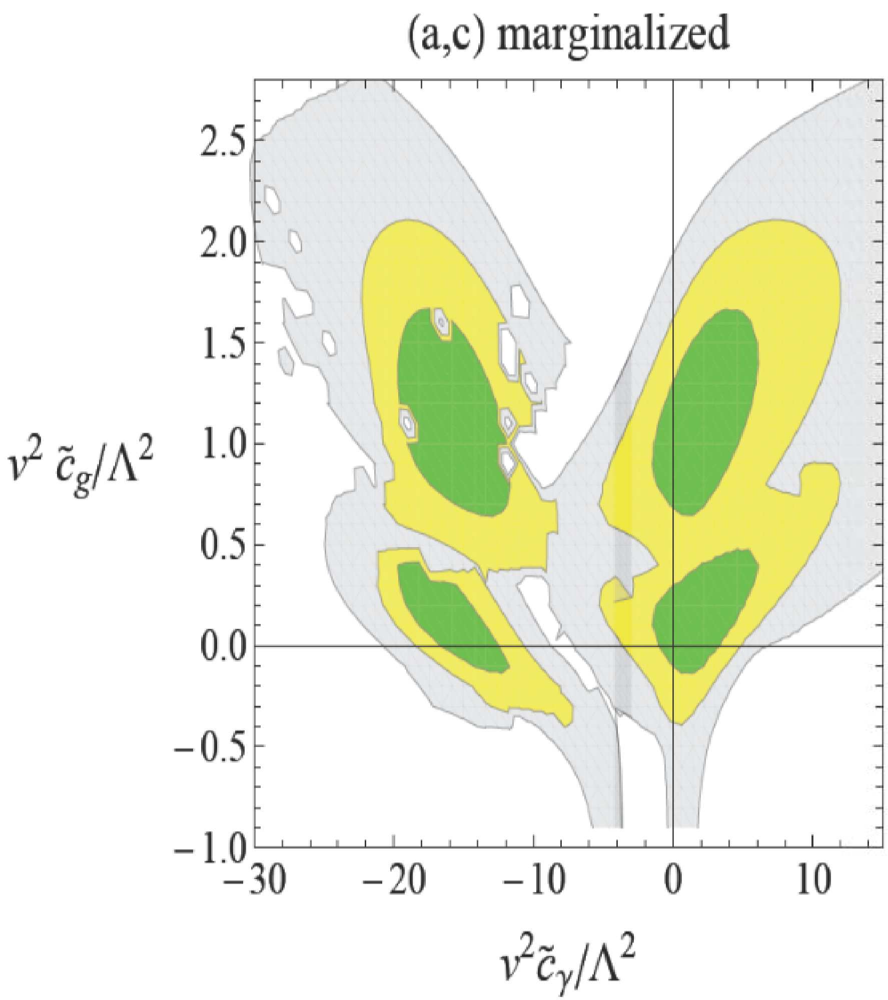


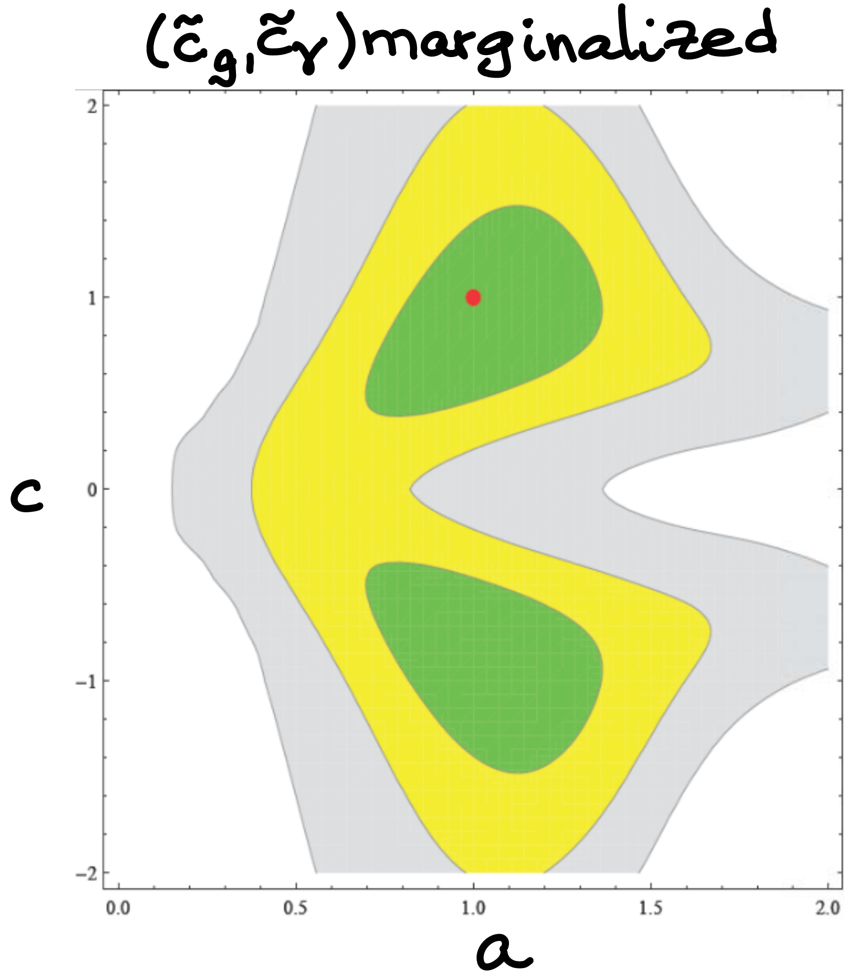
$\frac{v^2}{\Lambda^2}\tilde{c}_g$

$v^2\tilde{c}_\gamma/\Lambda^2$

See JRE, Grojean, Sanz, Trott '12

ANOMALOUS h COUPLINGS $(a,c) \neq (1,1)$
OR LOOP INDUCED EFFECTS $(\tilde{c}_g, \tilde{c}_\gamma) \neq (0,0)$?





Need more data !

(4b) HIGGS INVISIBLE WIDTH ?

$h \to XX$ for light (SM singlet) X (Higgs portal, DM, ...)

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

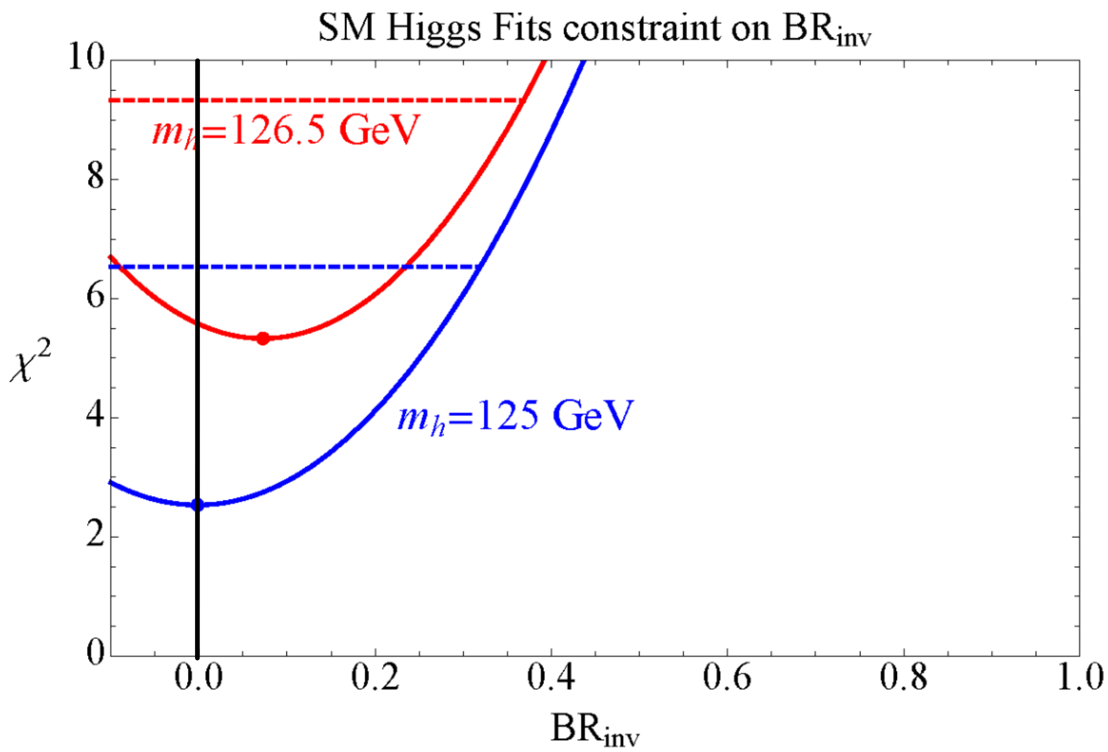
χ^2 fit to combined $\hat{\mu}_c \pm \sigma_c$

χ^2_{min} at $BR_{inv} = (0.0, 0.08)$

SM with $BR_{inv} = 0$ OK

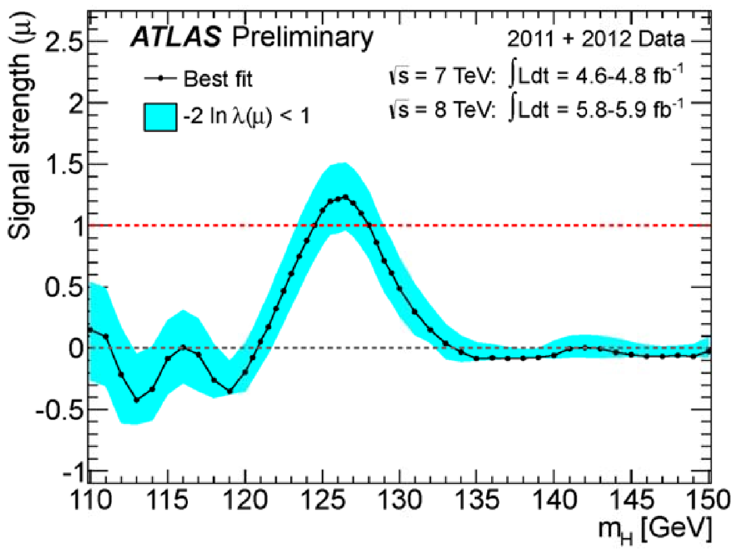
Still there is room for

large BR_{inv} ($\lesssim 0.35$ @ 95% CL)

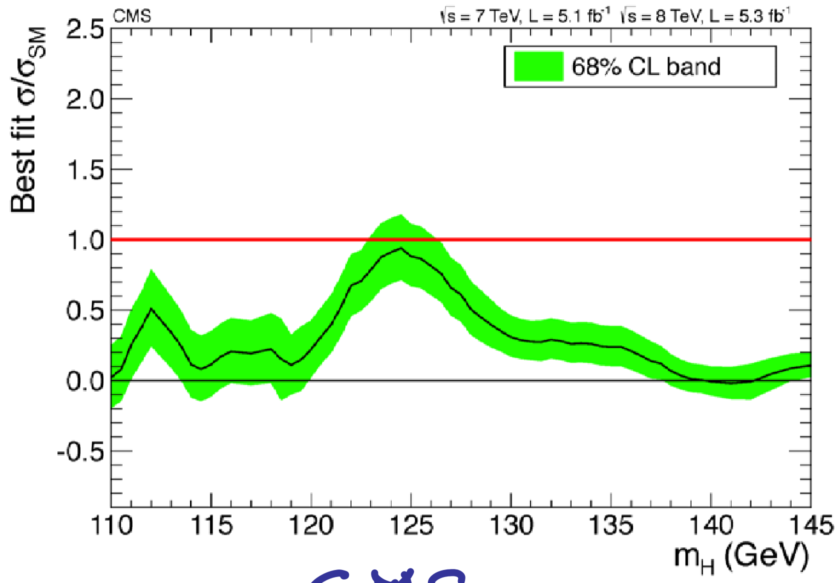


HIGGS INVISIBLE WIDTH ?

Indirect evidence. Interpret $\hat{\mu} < 1$ as $\hat{\mu} = 1 - BR_{inv}$

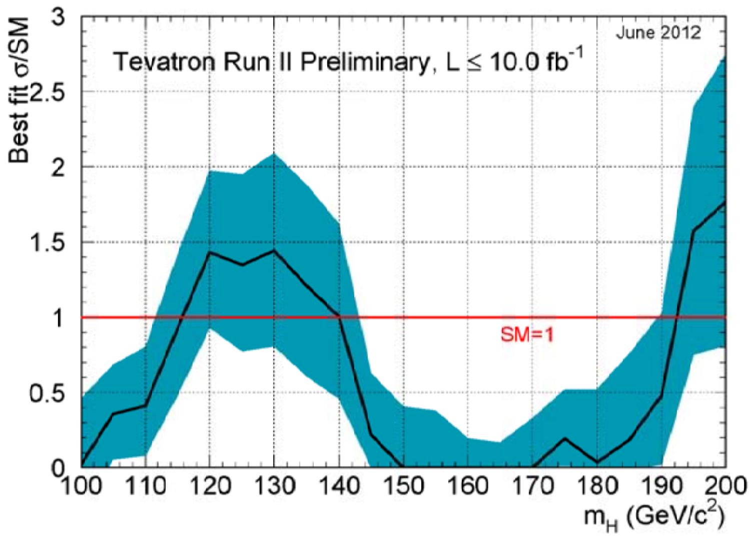


ATLAS



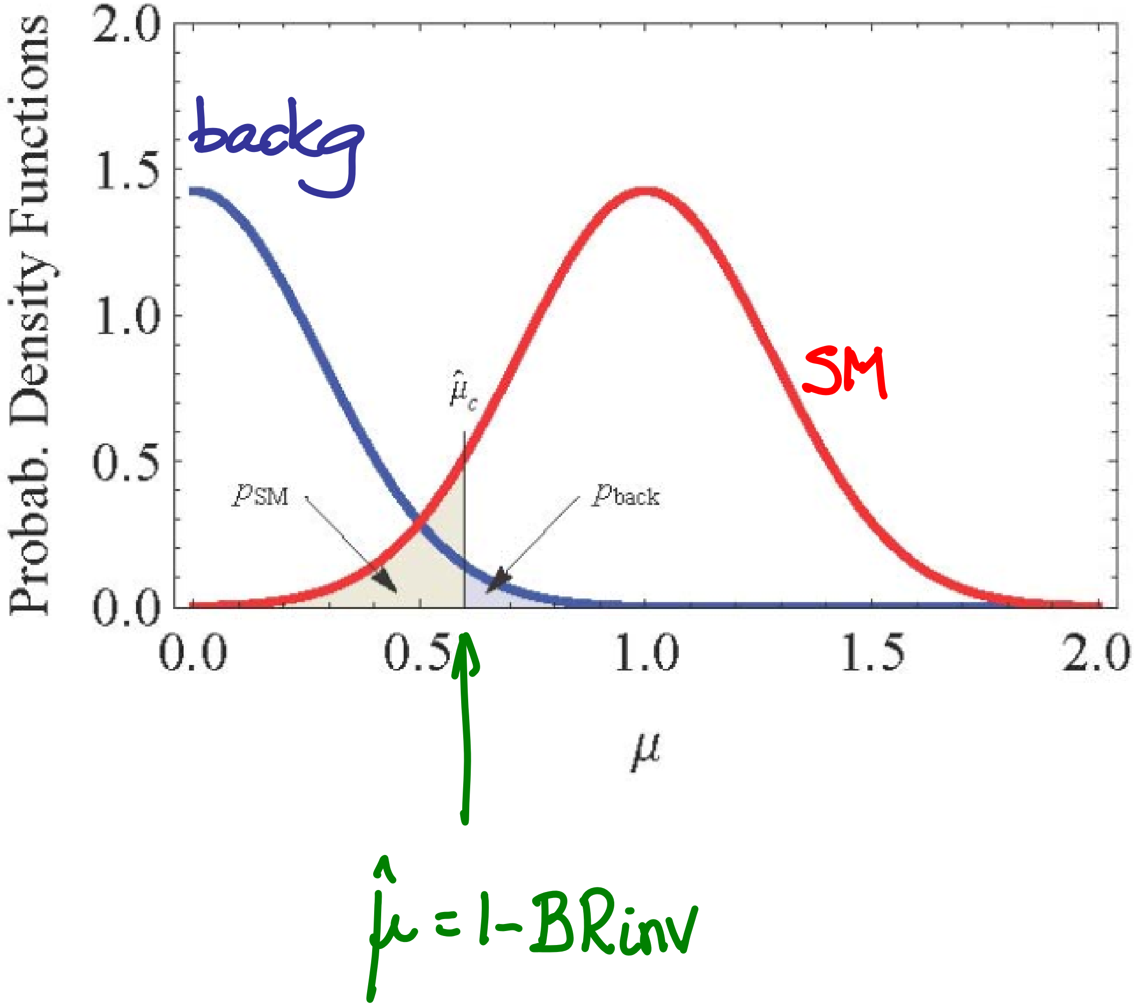
CMS

Tevatron



HIGGS INVISIBLE WIDTH ?

To trust this indirect evidence need $p_{SM}, p_{backg} \ll 1$

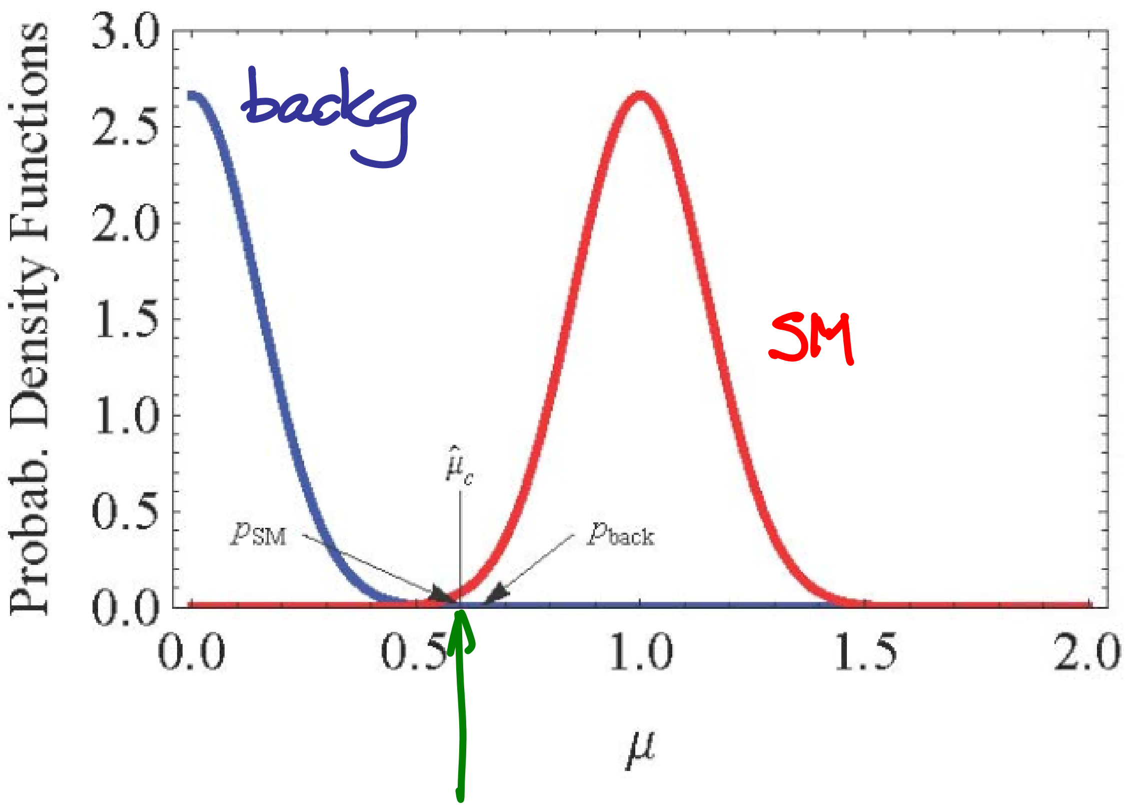


It's crucial to reduce σ

HIGGS INVISIBLE WIDTH ?

To trust this indirect evidence need $p_{SM}, p_{backg} \ll 1$

Must also give small χ^2_{min}



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

It's crucial to reduce σ

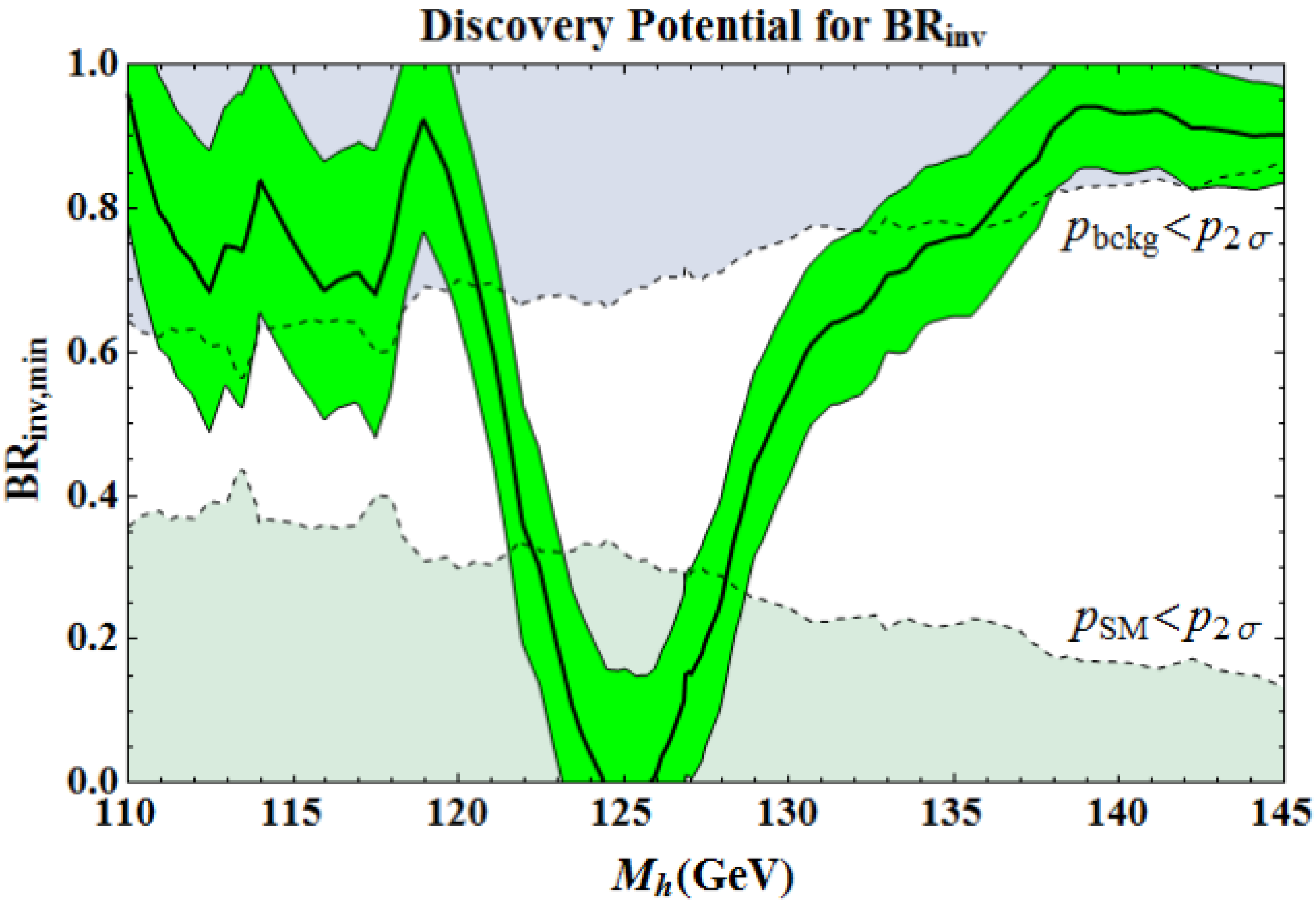
$$\frac{1}{\sigma^2} = \sum_i^{N_{ch}} \frac{1}{\sigma_i^2} \Rightarrow \sigma \sim \frac{\sigma_i}{\sqrt{N_{ch}}}$$

$$\sigma_i \sim \frac{\sqrt{n_{b,i}}}{n_{s,i}^{SM}} \sim \frac{1}{\sqrt{\mathcal{L}}}$$

HIGGS INVISIBLE WIDTH ?

Current situation as a function of m_h

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

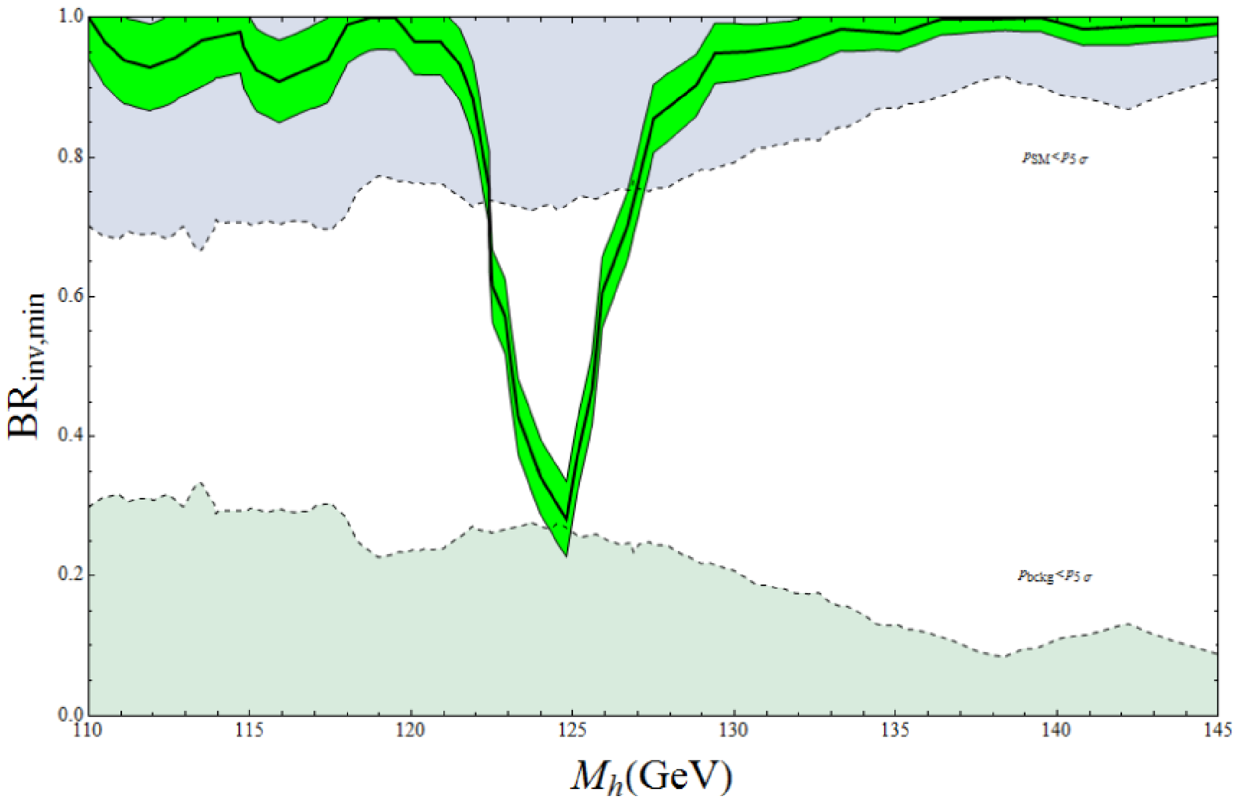


No strong conclusion possible

HIGGS INVISIBLE WIDTH ?

Future situation ($\sigma_c \sim \frac{0.3}{5}$ for $m_h = 124$ GeV)

Hypothetical observed $\hat{\mu}$, of course...

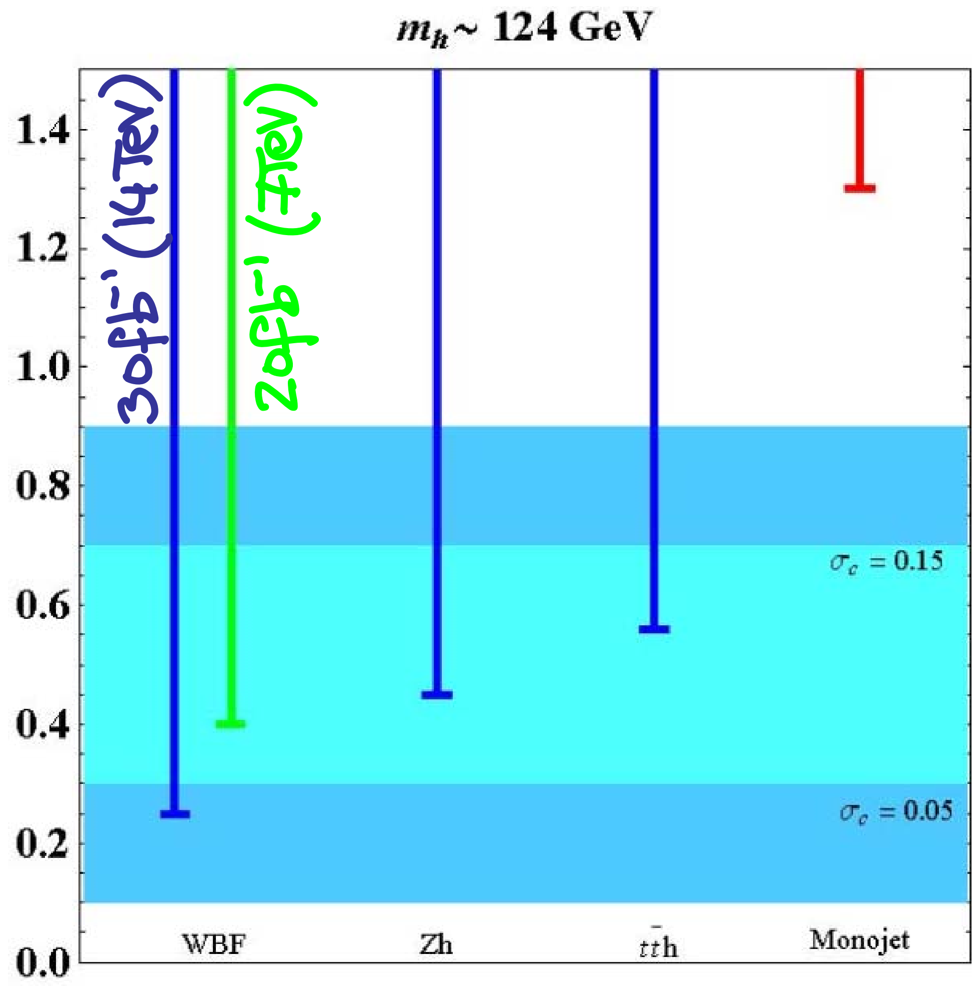


HIGGS INVISIBLE WIDTH ?

How to tell apart $BR_{inv} > 0$ from e.g. $a = c < 1$?

Must validate with direct searches for inv. Higgs decays

$BR_{inv} = \xi$



95% CL reach compared

CONCLUSIONS

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

★ Unstable EW vacuum w/o BSM

Long-lived and intriguinly close to stability boundary

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?)

★ Plenty of room for nonzero BR_{inv}

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

MORE DATA COMING FOR KYOTO ($\sim 20 fb^{-1}$) STAY TUNED!

RATES IN SM(a,c)

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

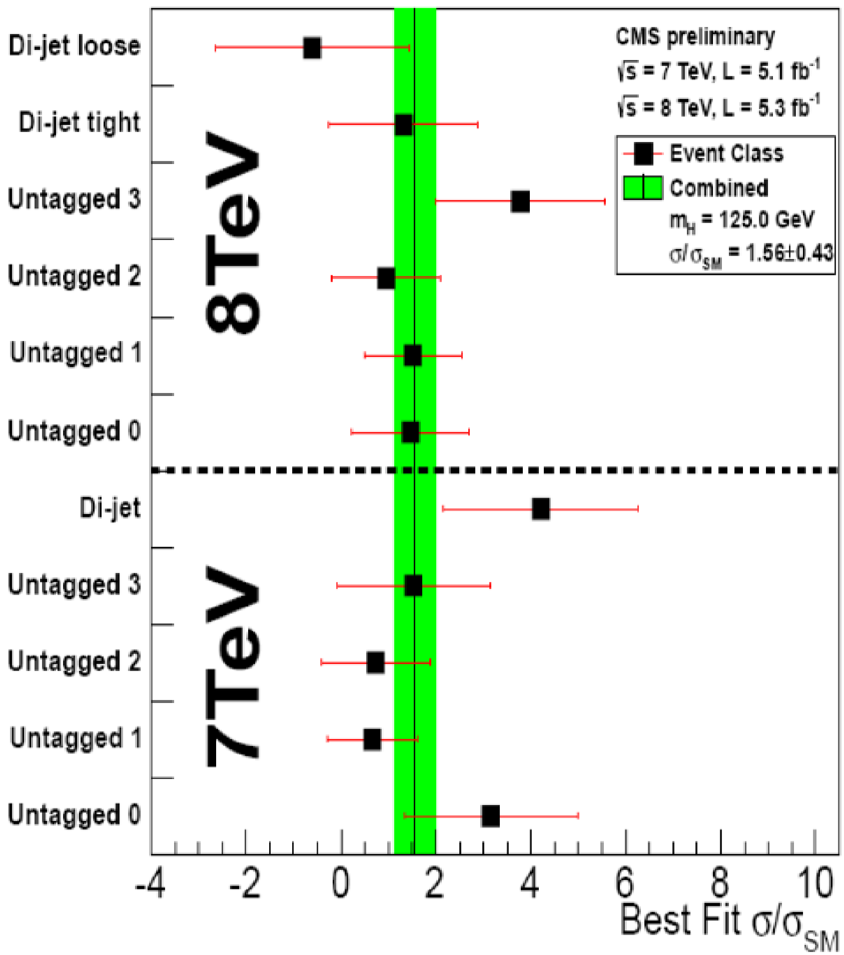
ATLAS $\gamma\gamma$ subcategories

$\sqrt{s}$	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:

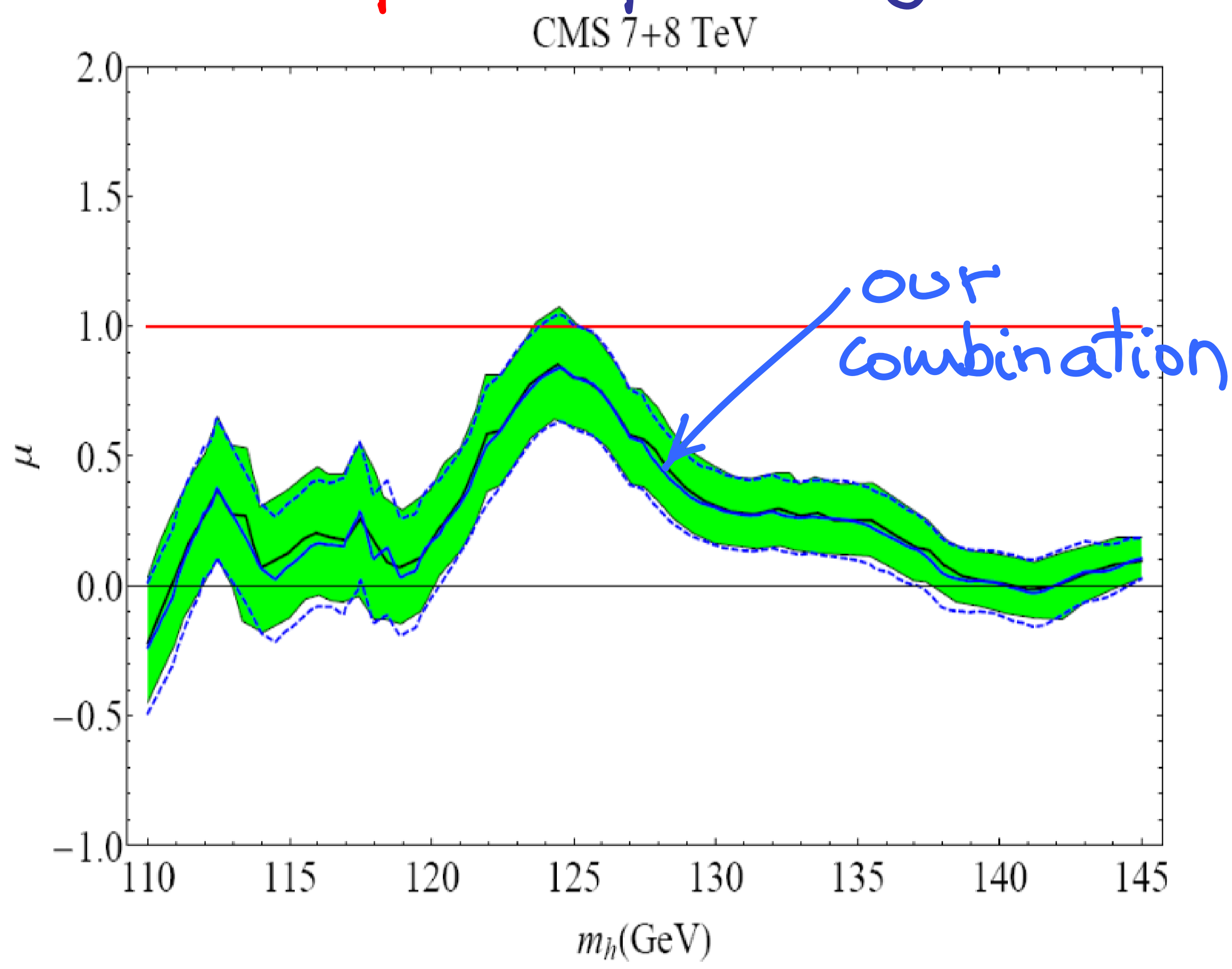
$$\frac{\hat{\mu}_{7+8}}{\sigma_{7+8}^2} = \frac{\hat{\mu}_7}{\sigma_7^2} + \frac{\hat{\mu}_8}{\sigma_8^2} \qquad \frac{1}{\sigma_{7+8}^2} = \frac{1}{\sigma_7^2} + \frac{1}{\sigma_8^2}$$

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 ckecked this works well :



Official CMS combination at 7+8 TeV