EXCLUDING ELECTROWEAK BARYOGENESIS IN THE MSSM

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Based on
D. Curtin, P. Jaiswal, PM 1203.2932

WE HAVE A HIGGS!

WHAT DO WE DO WITH IT?

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- Come up with what its mass means?

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  - Passé... done last December!

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  - Do you hear the ambulance coming???

WHAT DO WE DO WITH IT?

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- Fit it to death?
  - Follow the crowd at all???
- Explain small discrepancies?
  - Do you hear the ambulance coming???
- Invert the problem and see if there were any predictions for BSM Higgs phenomenology BEFORE the LHC found what they did...

WHAT ELSE IS A HIGGS AND A LITTLE BSM GOOD FOR? EWBG!

BARYOGENESIS

$$2.6 \times 10^{-10} < \eta \equiv \frac{n_b - n_{\bar{b}}}{s} < 6.2 \times 10^{-10}$$

- Many ideas out there
  - Leptogenesis
  - Affleck-Dine
  - Tying Dark Matter and Baryon Asymmetry
  - Simpler possibility, do it without "new" high scale physics

BARYOGENESIS

$$2.6 \times 10^{-10} < \eta \equiv \frac{n_b - n_{\bar{b}}}{s} < 6.2 \times 10^{-10}$$

- Sakharov conditions
  - B violation **(already in SM: Sphalerons)**
  - CP violation **(already in SM: obvious...)**
  - departure from thermal equilibrium **(already in SM: EW phase transition)**

Electroweak Baryogenesis!

FACTORIZED EWBG

Out of Eq. Caclulation

Straightforward

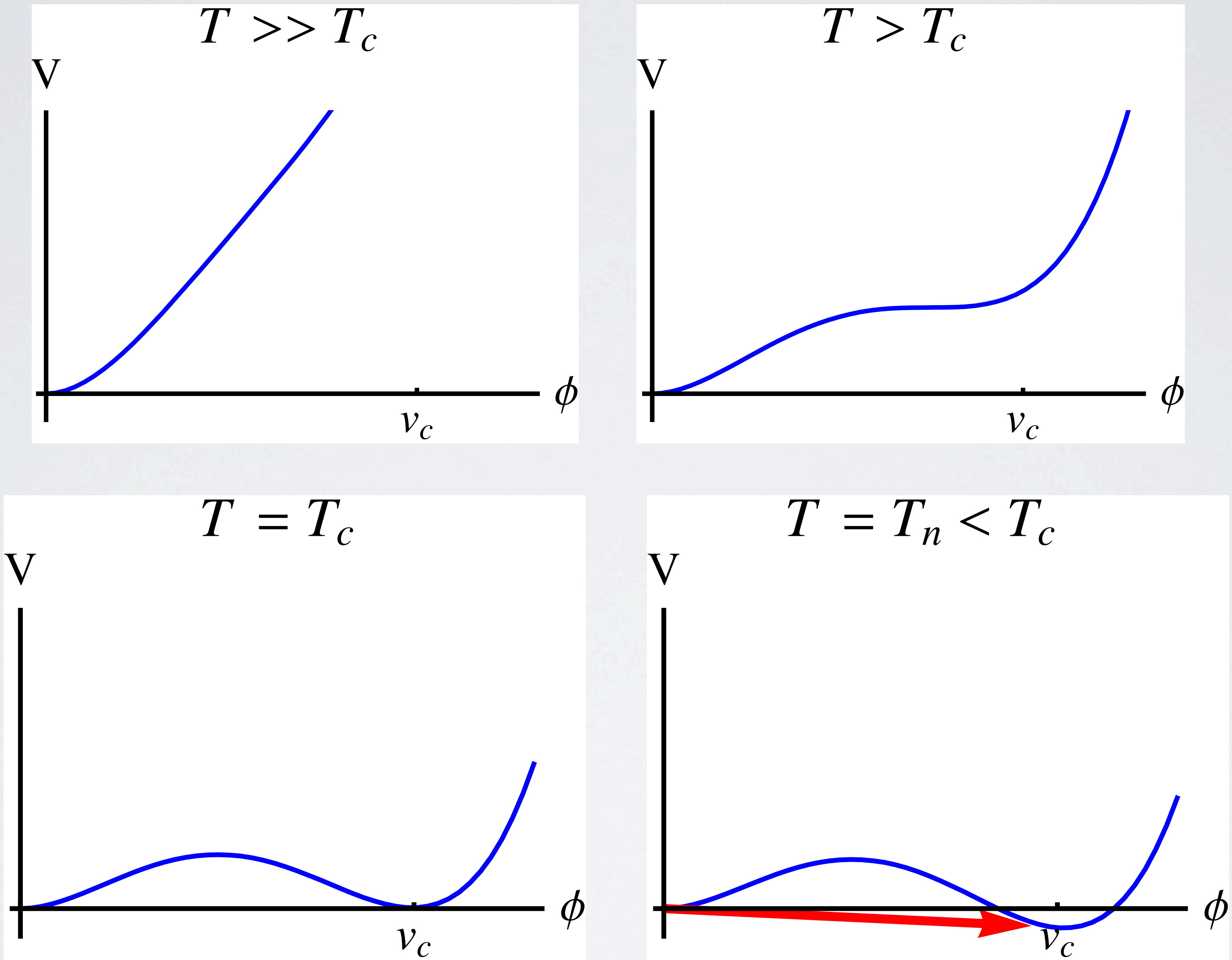
$$\frac{\langle \phi(T_c) \rangle}{T_c} \gtrsim 1$$

Baryon Asymmetry Calculation

Hard...

tunneling,
quantum transport,
hydronamics

NEED TO UNDERSTAND V(T)



FACTORIZED EWBG IN SM

$$\Delta V^{\rm bos}(\phi,T) = \sum_i n_i \left\{ \frac{m_i^2(\phi)}{24} T^2 - \frac{T}{12\pi}\left[m_i^2(\phi) + \Pi_i(T)\right]^{3/2} - \frac{m_i^4(\phi)}{64\pi^2}\log\frac{m_i^2(\phi)}{A_B T^2} \right\}$$

$$\Delta V^{\rm fer}(\phi,T) = \sum_i n_i \left\{ \frac{m_i^2(\phi)}{48} T^2 + \frac{m_i^4(\phi)}{64\pi^2}\log\frac{m_i^2(\phi)}{A_F T^2} \right\}$$

1-loop thermal potential

$$V(\phi,T) = D(T^2 - T_0^2)\phi^2 - ET\phi^3 + \frac{\lambda(T)}{4}\phi^4$$

$$\frac{\phi(T_c)}{T_c} = \frac{2ET_c}{\lambda(T_c)} \simeq \frac{4Ev^2}{m_h^2}$$

$$\frac{\langle\phi(T_c)\rangle}{T_c} \gtrsim 1 \qquad m_h \lesssim \sqrt{\frac{4E}{1.3}} \sim 42\ \mathrm{GeV}$$

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$$V(\phi,T)=D(T^2-T_0^2)\phi^2-ET\phi^3+\frac{\lambda(T)}{4}\phi^4$$

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NOPE!

EWBG MSSM

- New sources of CP violation (was too small in SM)
- New contributions to Higgs potential!

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only from T dependent piece Tm^3

$$\frac{v}{T_c} \sim \frac{cubic}{quartic}$$

$$\begin{aligned} m^2_{\tilde{t}_R} &= m^2_{Q_3} + h_t^2 \phi_u^2 + \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\frac{g^2+g'^2}{2}(\phi_u^2 - \phi_d^2) \\ m^2_{\tilde{t}_L} &= m^2_{U_3} + h_t^2 \phi_u^2 + \left(\frac{2}{3}\sin^2\theta_W\right)\frac{g^2+g'^2}{2}(\phi_u^2 - \phi_d^2) \\ m^2_X &= h_t(A_t\phi_u - \mu\phi_d) \end{aligned}$$

LIGHT STOP SCENARIO

$$m^2_{\tilde{t}_{1,2}}(\phi) = \frac{m^2_{\tilde{t}_L}(\phi) + m^2_{\tilde{t}_R}(\phi)}{2} \pm \sqrt{\left(\frac{m^2_{\tilde{t}_L}(\phi) - m^2_{\tilde{t}_R}(\phi)}{2}\right)^2 + \left[m^2_X(\phi)\right]^2}$$

$$m^2_{Q_3,U_3} \to m^2_{Q_3,U_3} + \Pi$$

Thermal Mass

$$\Pi \sim g^2 T^2$$

Want the largest contribution to the cubic, so the biggest "bare" higgs contribution

LIGHT STOP SCENARIO

- Cancellation between soft mass and thermal mass can give a large cubic

  - Achieving a strong phase transition and avoiding color-breaking requires a mostly right-handed light stop with $m_{\tilde{t}_1} < m_t$ and $A_t \lesssim m_Q/2$. [8, 16, 17].
  - The mostly left-handed stop should be heavier than $\sim$ TeV to satisfy the LEP Higgs mass bound (for a SM-like Higgs) and avoid large corrections to the ρ-parameter.
  - The gluino should be heavier than $\sim 500\,\mathrm{GeV}$ to decouple it from the plasma, otherwise its large contribution to the stop thermal masses would make it even more difficult to achieve the needed cancellation $m_{U_3}^2 \sim -\Pi_{t_R}$.

LSS IN LIGHT OF LHC HIGGS

$$123\,\mathrm{GeV} \leq m_h \leq 128\,\mathrm{GeV}$$

$$\downarrow$$

$$m_{\tilde{t}_R} = 80 - 115\,\mathrm{GeV} \quad , \qquad m_{\tilde{t}_L} \gtrsim 10^3\,\mathrm{TeV} \quad , \qquad \tan\beta \approx 5 - 15$$

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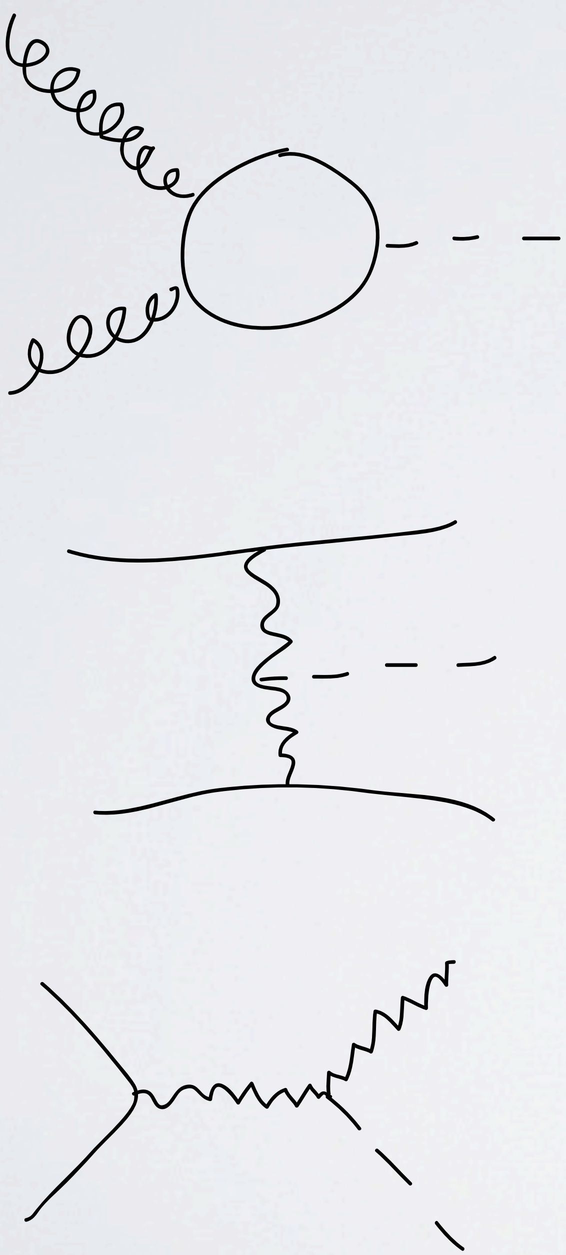
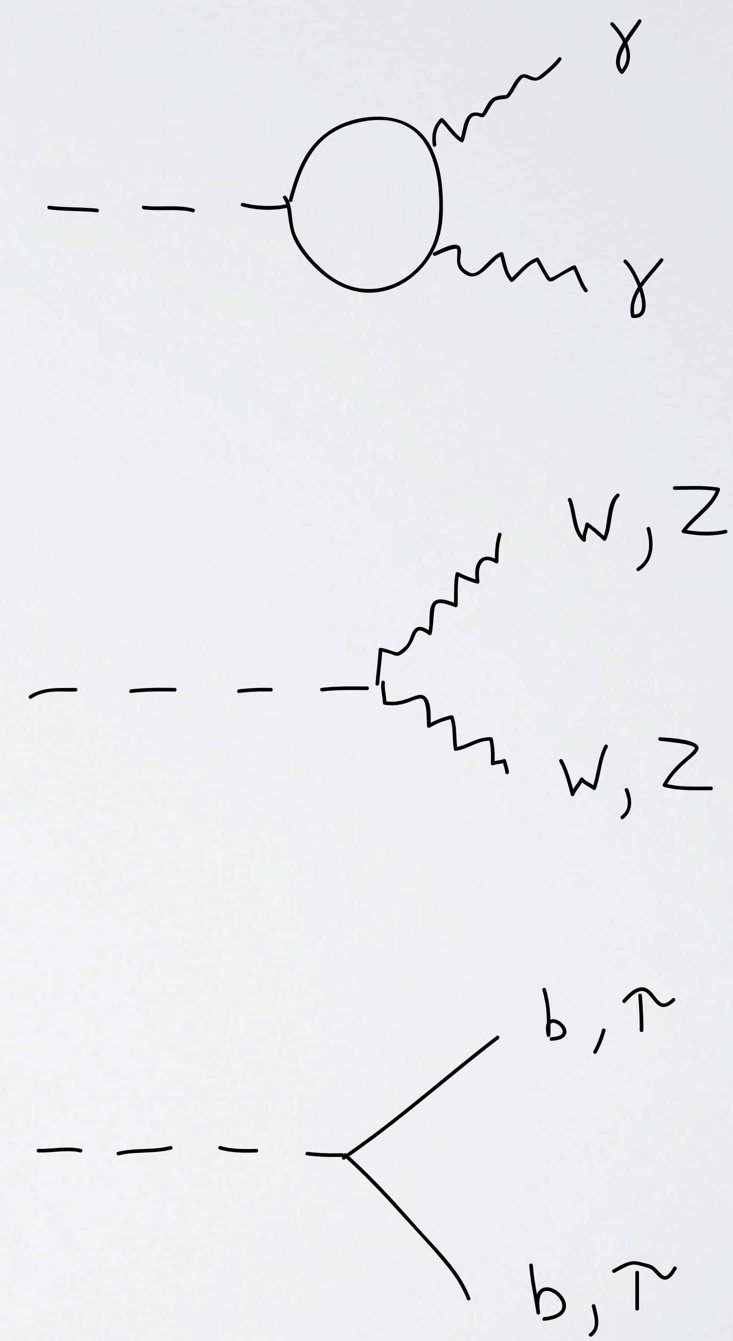
Yikes, crazy starting point, but let's see what happens...

LSS CHANGES HIGGS PHENOMENOLOGY

Production



Decay



MSSM HIGGS PHENO

$$\Gamma(h \to gg) = \frac{G_\mu \alpha_s^2 m_h^3}{36\sqrt{2}\pi^3} \left| \frac{3}{4} \sum_f A_{1/2}(\tau_f) + \frac{3}{4} \frac{g_{h\tilde{t}_R\tilde{t}_R}}{m_{\tilde{t}_R}^2} A_0(\tau_{\tilde{t}_R}) \right|^2$$

$$\tau_i = m_h^2/4m_i^2$$

$$\Gamma(h \to \gamma\gamma) = \frac{G_\mu \alpha^2 m_h^3}{128\sqrt{2}\pi^3} \left| \sum_f N_c Q_f^2 A_{1/2}(\tau_f) + A_1(\tau_W) \right.$$
$$\left. + \frac{4}{3} \frac{g_{h\tilde{t}_R\tilde{t}_R}}{m_{\tilde{t}_R}^2} A_0(\tau_{\tilde{t}_R}) + \sum_{\chi^+} \frac{2m_W}{m_{\chi^+}} g_{h\chi^+\chi^-} A_{1/2}(\tau_{\chi^+}) \right|^2$$

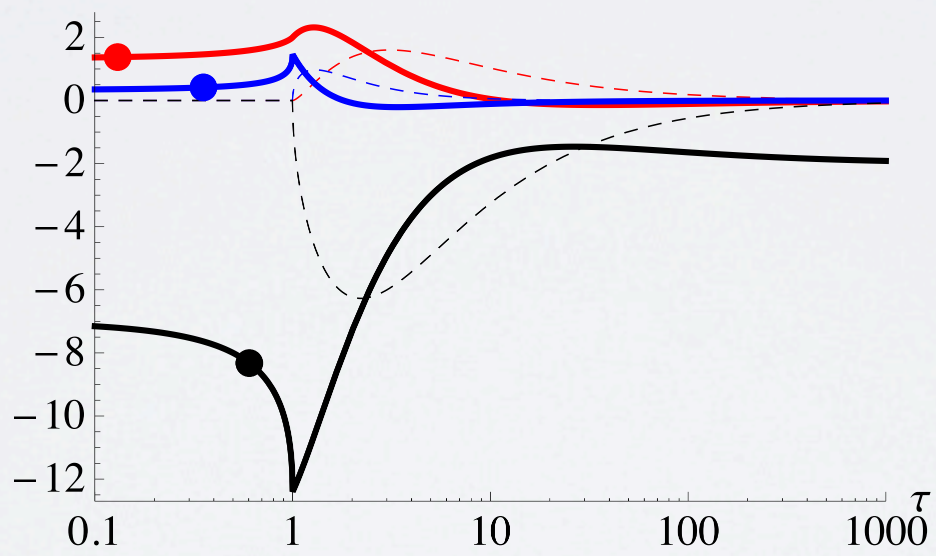
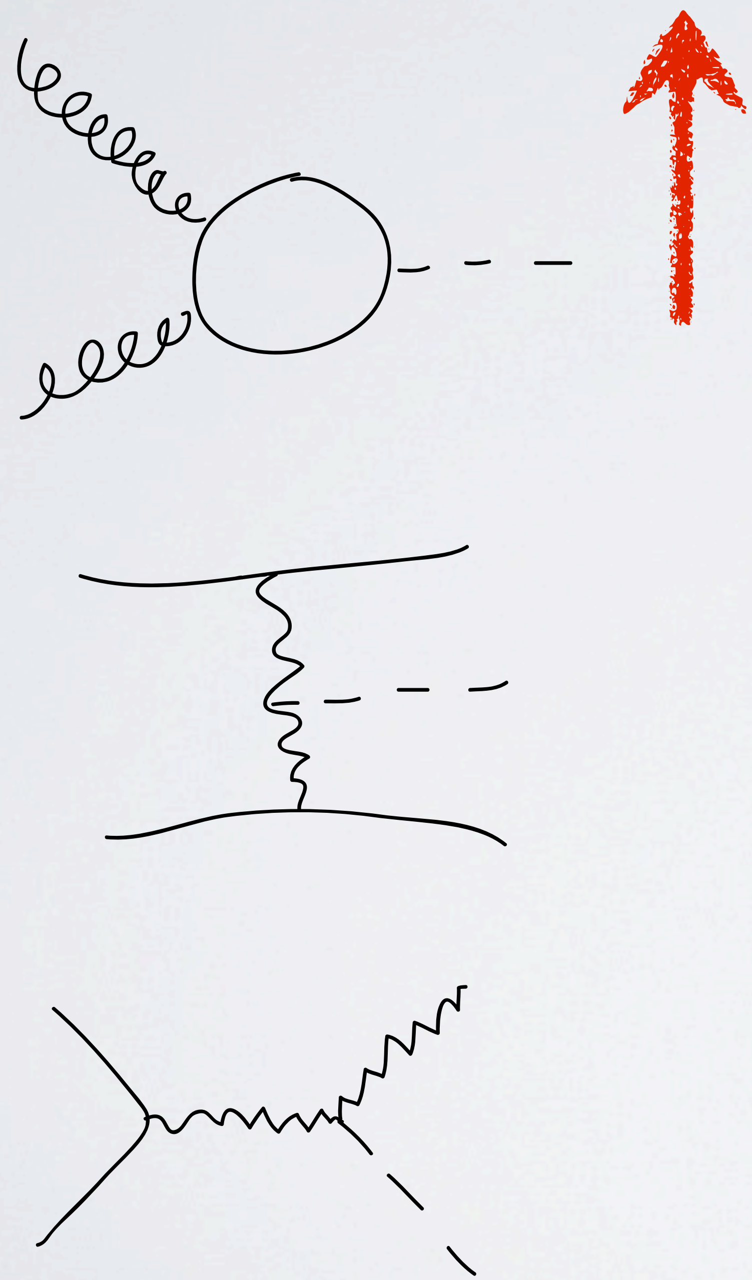


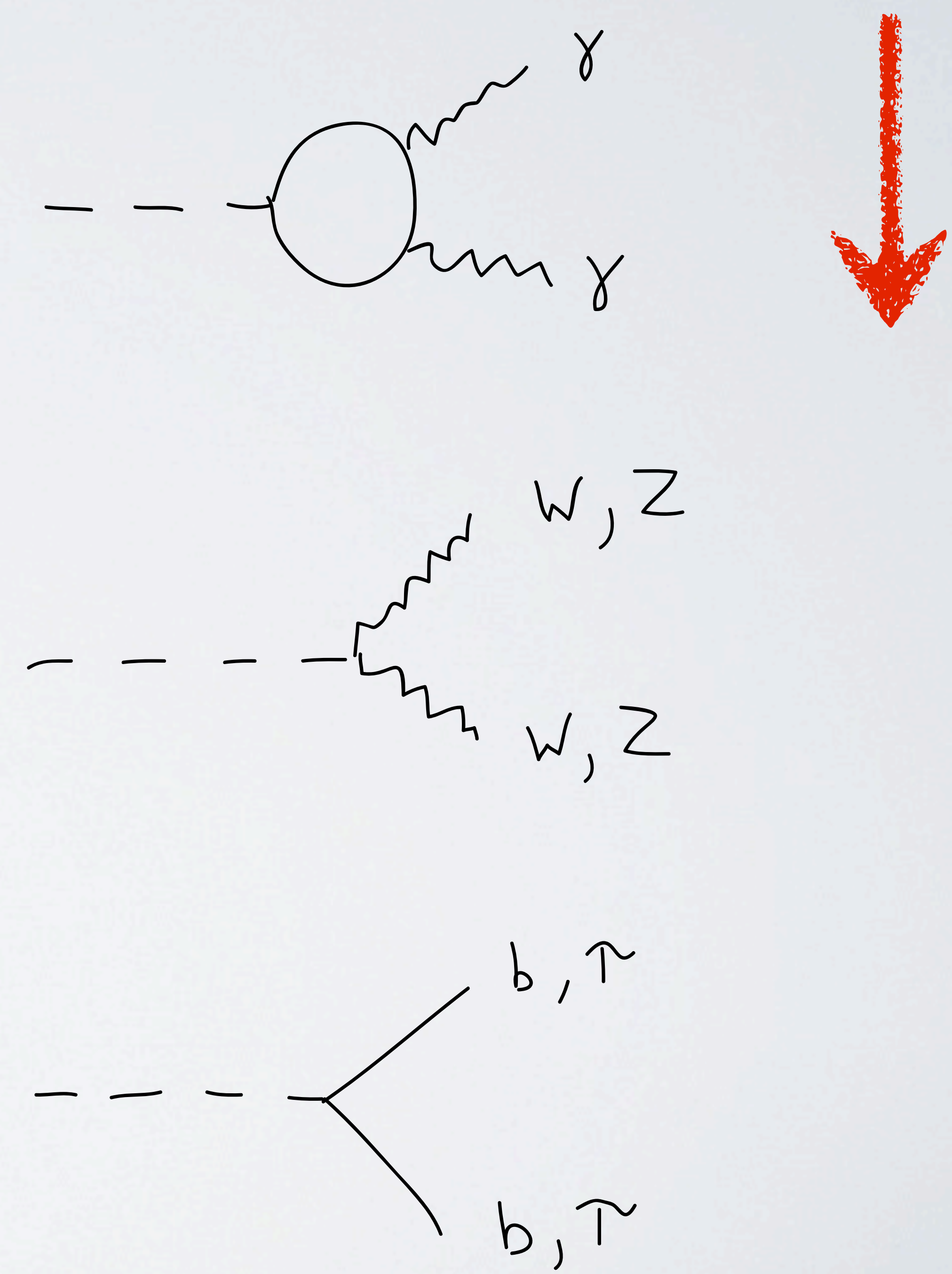
Figure 3: The solid (dashed) curves represent the real (imaginary) part of the functions $A_0(\tau)$ (blue), $A_{1/2}(\tau)$ (red) and $A_1(\tau)$ (black). The blue, red and the black points correspond to a 105 GeV stop, top quark and W boson respectively assuming a Higgs boson of mass 125 GeV.

MSSM ALSO CHANGES HIGGS PHENOMENOLOGY

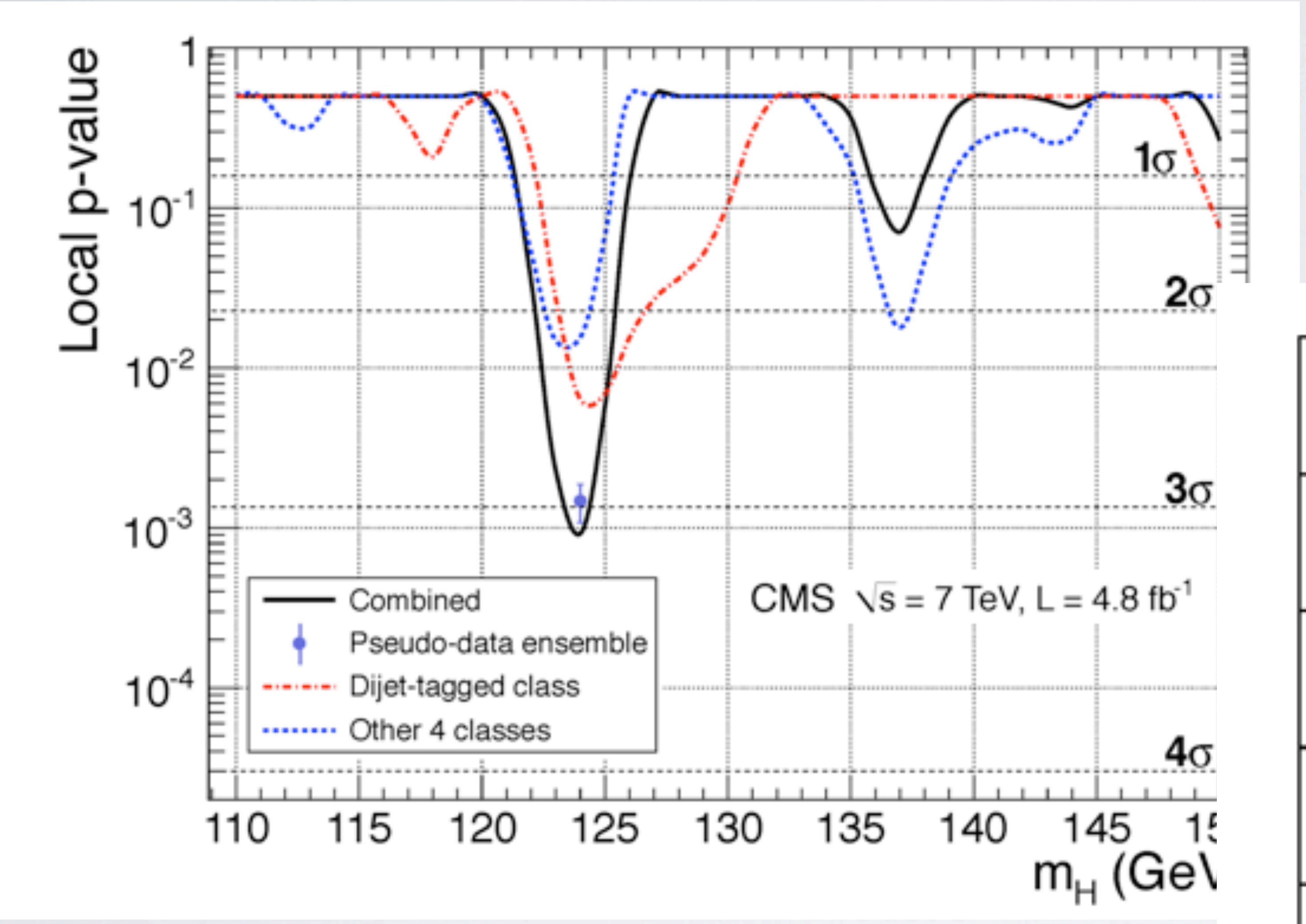
Production

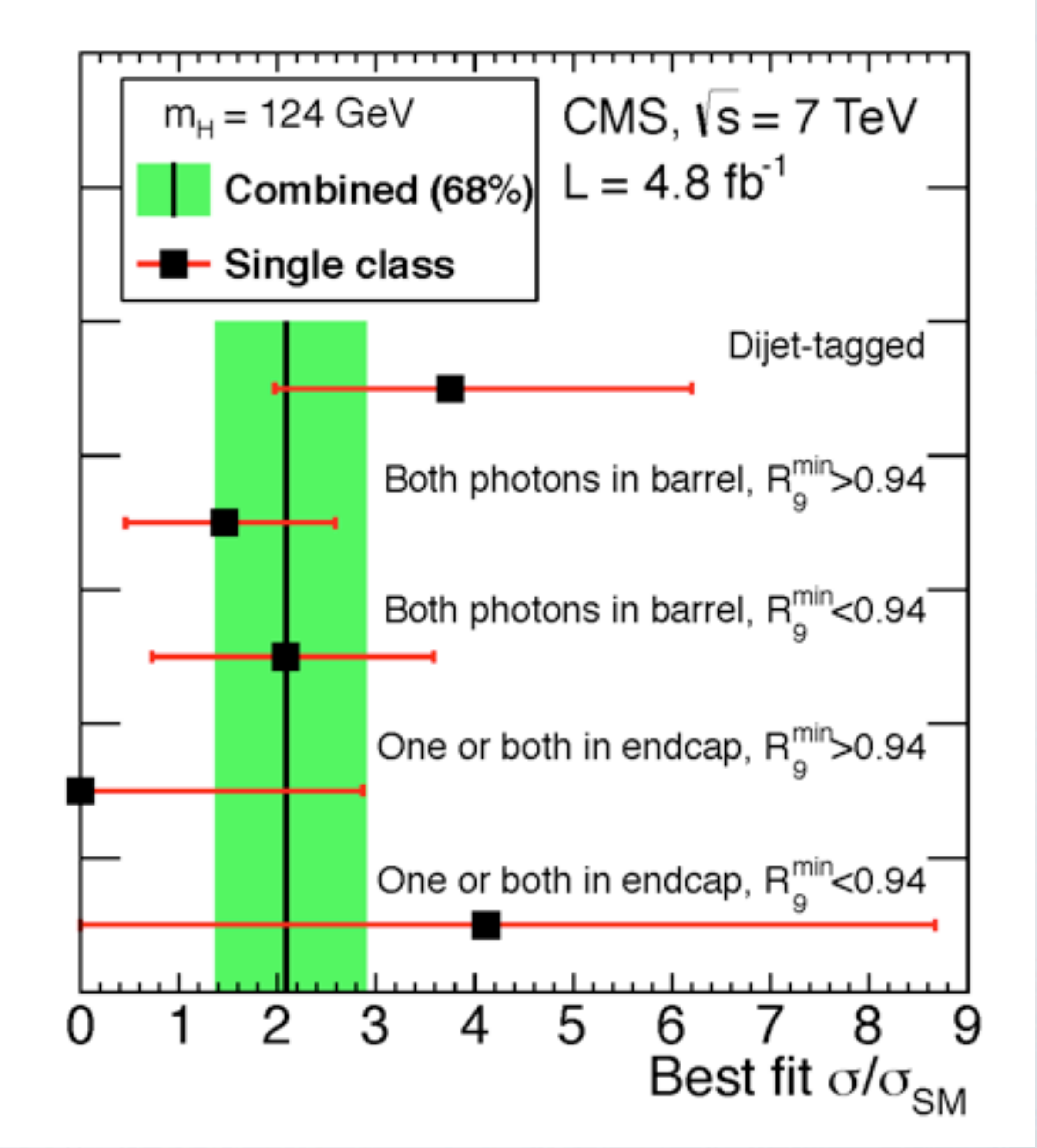


Decay



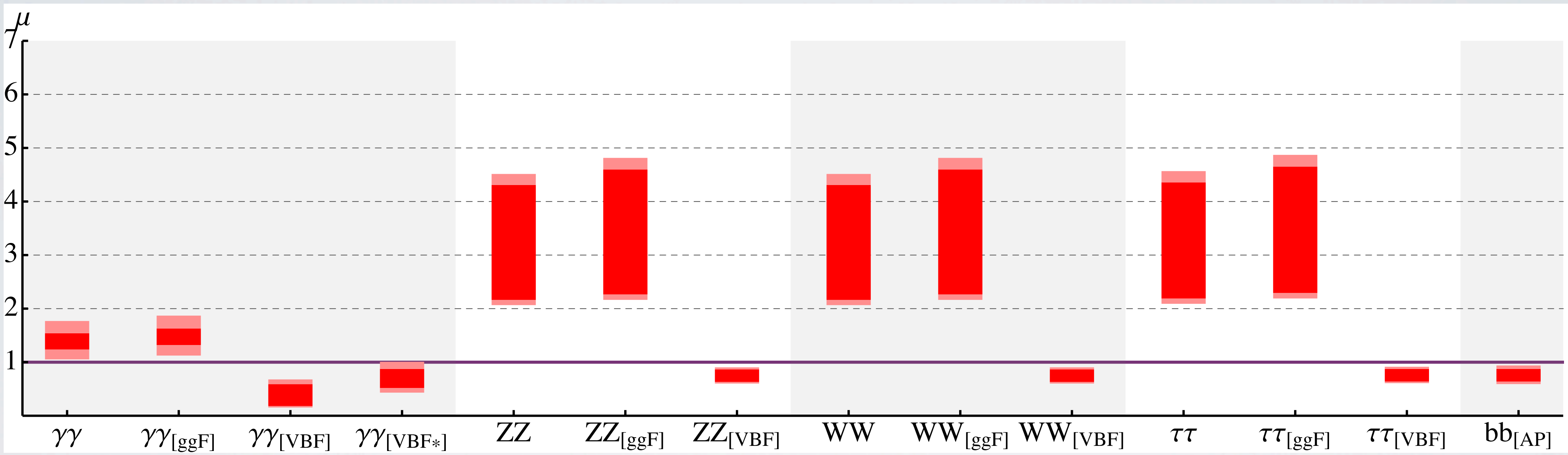
CORRELATION WITH PRODUCTION AND DECAY



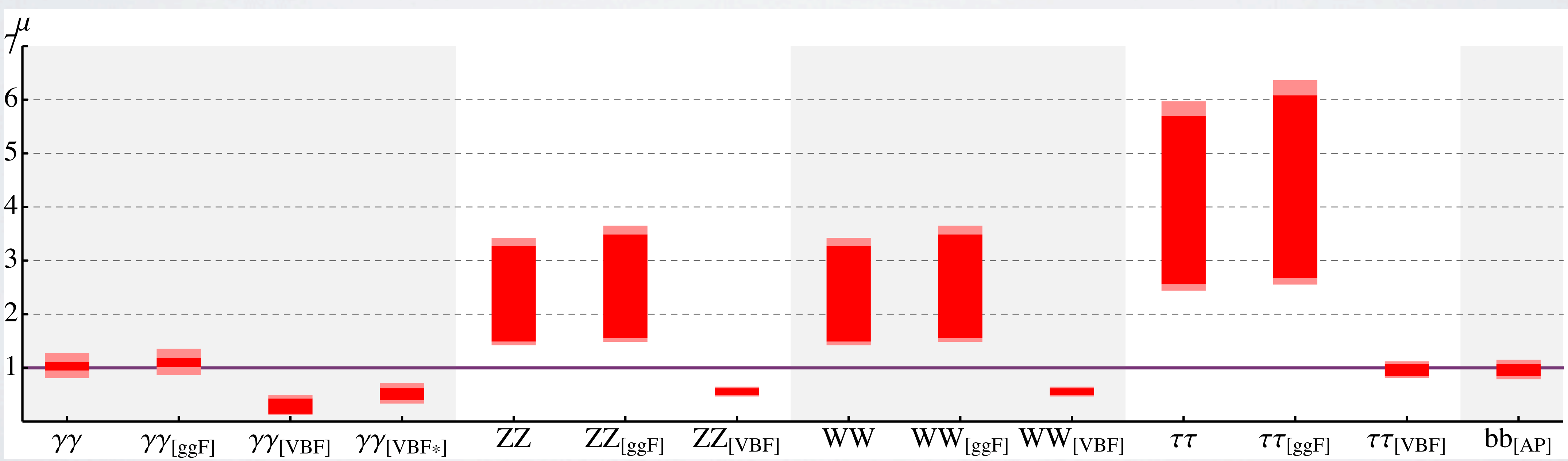


FINGERPRINT OF EWBG!

$m_A = 2\,\mathrm{TeV}$



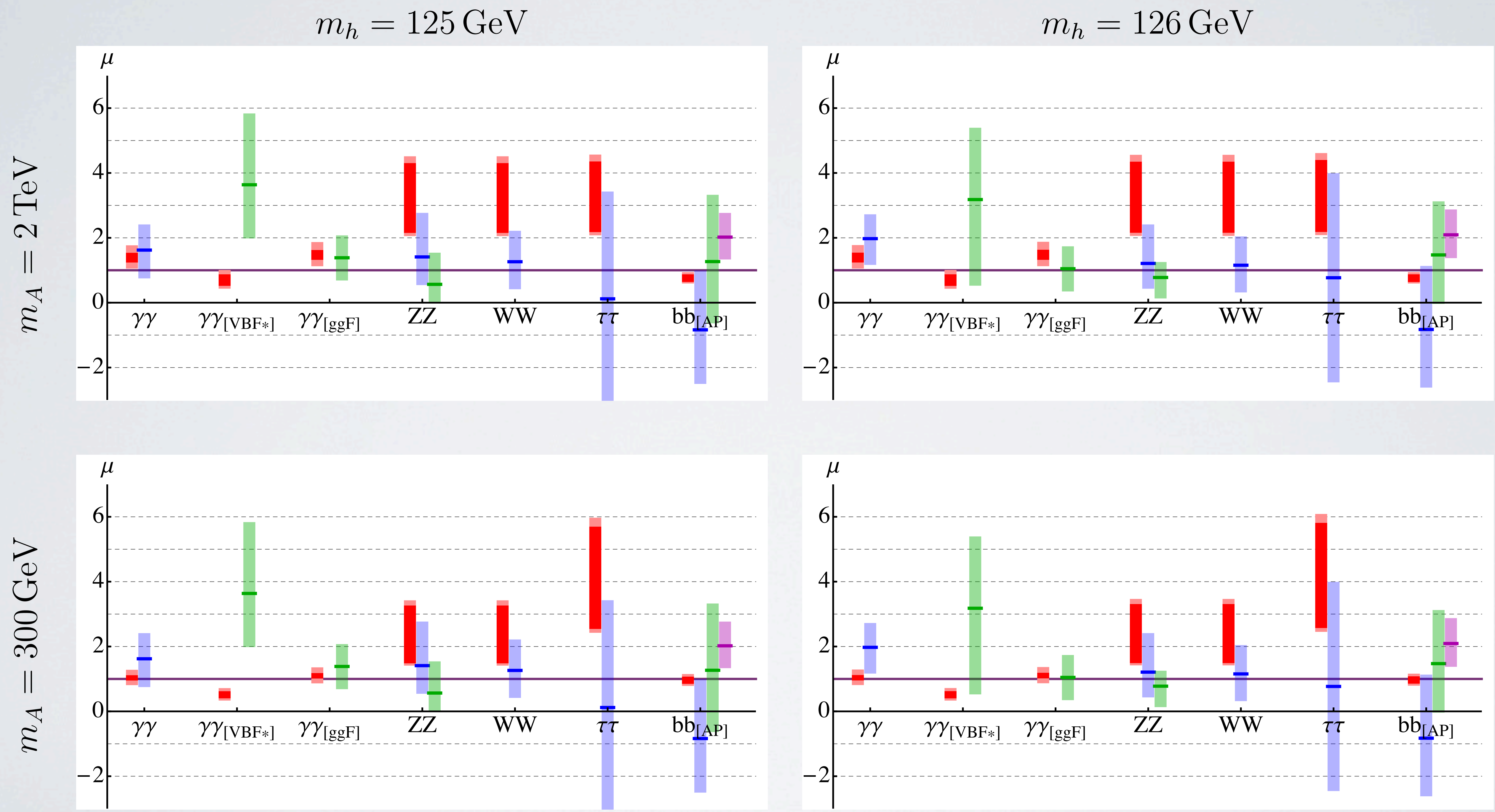
$m_A = 300\,\mathrm{GeV}$



EXPERIMENTAL STATUS (AS OF MORIOND LAST YEAR)

		Production Mode Sensitivity				Signal Strength Bounds	
		ggF	VBF	AP	Inclusive	Source	m_h range (GeV)
$\gamma\gamma$	ATLAS [20]				$\star$	official	(110, 150)
	CMS [23, 59]	$\star$	$\star$			reconstructed† [26]	(120, 128)
ZZ^*	ATLAS [21]				$\star$	official	(110, 150)
	CMS [24]				$\star$	reconstructed† [26]	(120, 128)
WW^*	ATLAS [60]				$\star$	official	(110, 150)
	CMS	$\circ$	$\circ$			—	—
bb	ATLAS [61]			$\star$		official	(110, 130)
	CMS [59, 62]			$\star$		reconstructed† [57]	(110, 130)
	D0 + CDF [63]			$\star$		official	(100, 150)
$\tau\tau$	ATLAS [64]		$\star$		$\star$	reconstructed [57]	(110, 150)
	CMS [65]	$\circ$	$\star$			reconstructed [57]	(110, 150)

EXPERIMENTAL CONSTRAINTS



EXCLUSION AT 125 GEV

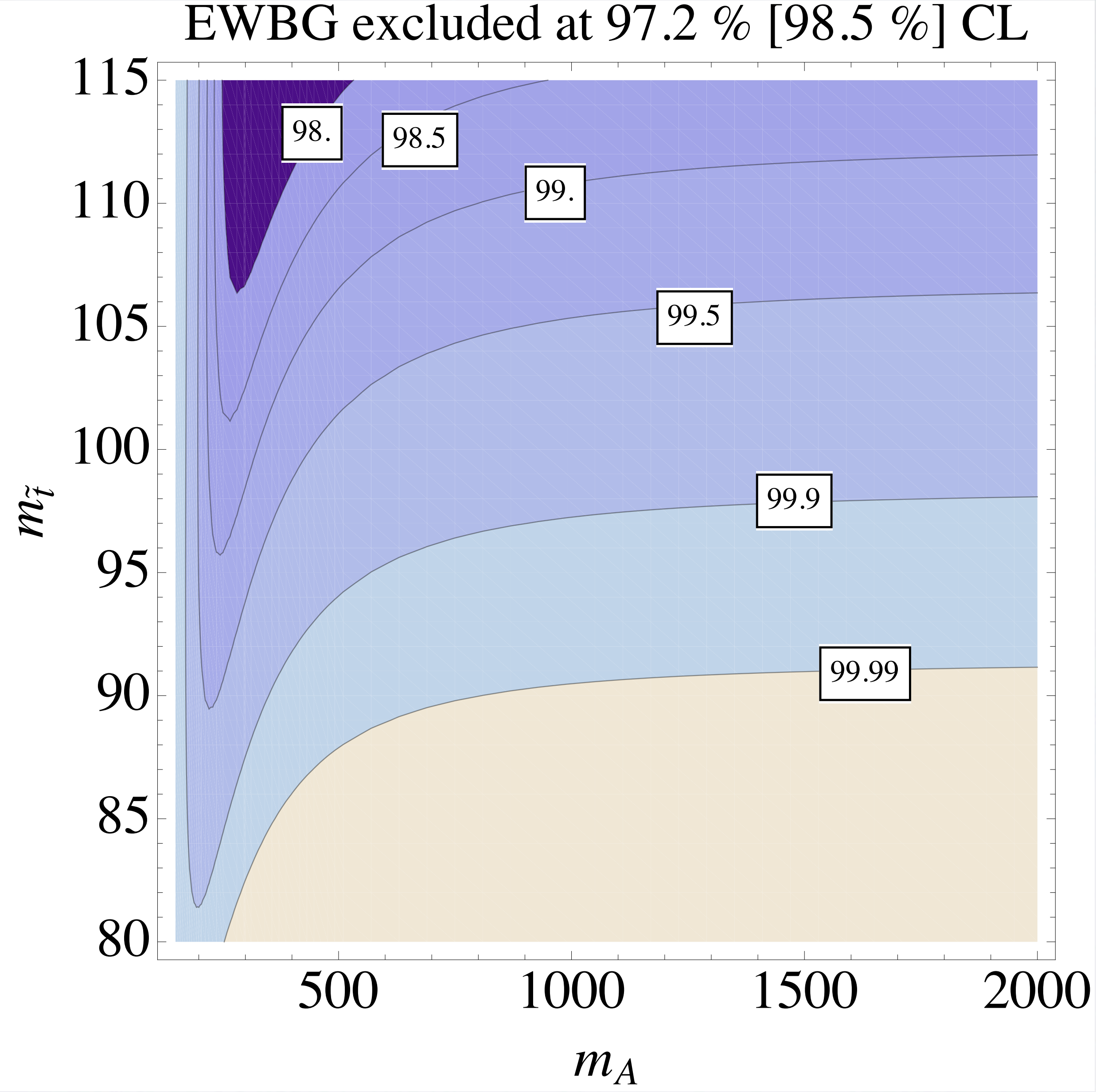
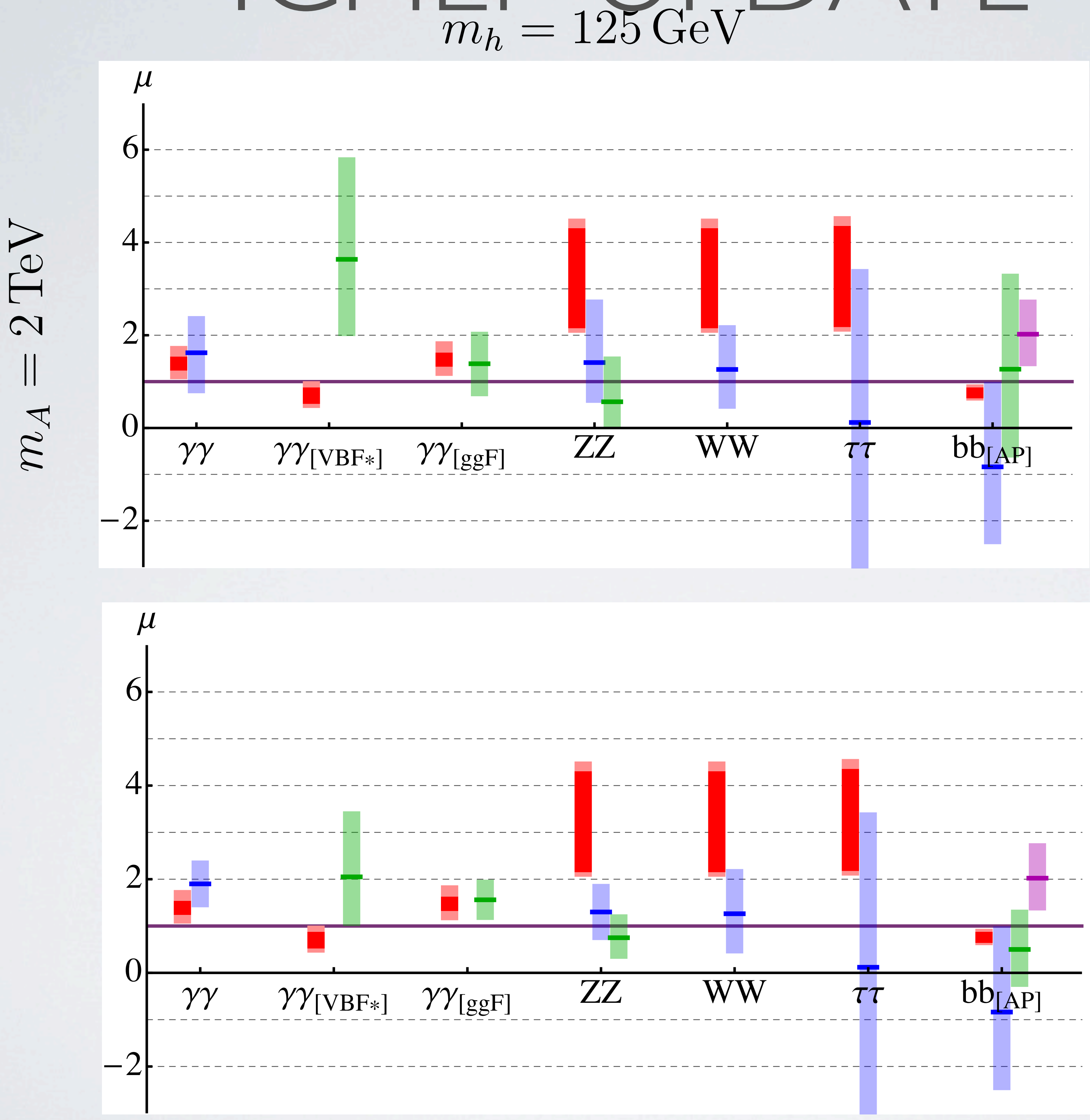


Figure 3: Exclusion plot of EWBG parameter space for $m_h = 125\,\mathrm{GeV}$, obtained by combining the signal strength bounds from the various ATLAS and CMS Higgs searches (not Tevatron) as outlined in Section 5.1. The smallest exclusion at $m_A \approx 300\,\mathrm{GeV}$, $m_{\tilde{t}_R} = 115\,\mathrm{GeV}$ is 97.2%, which increases to 98.5% if we enforce the decoupling limit ($m_A > 1\,\mathrm{TeV}$).

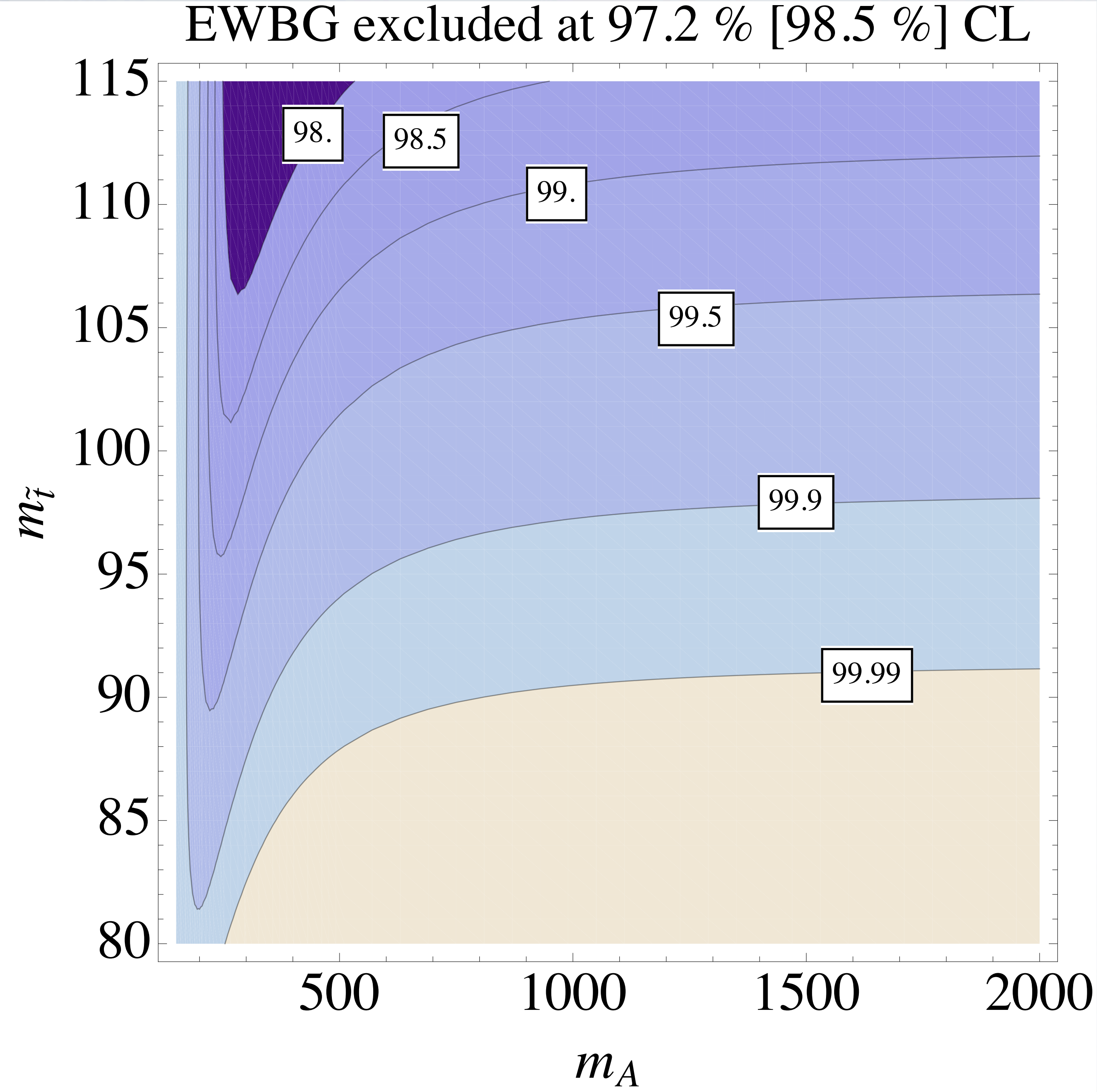
ICHEP UPDATE



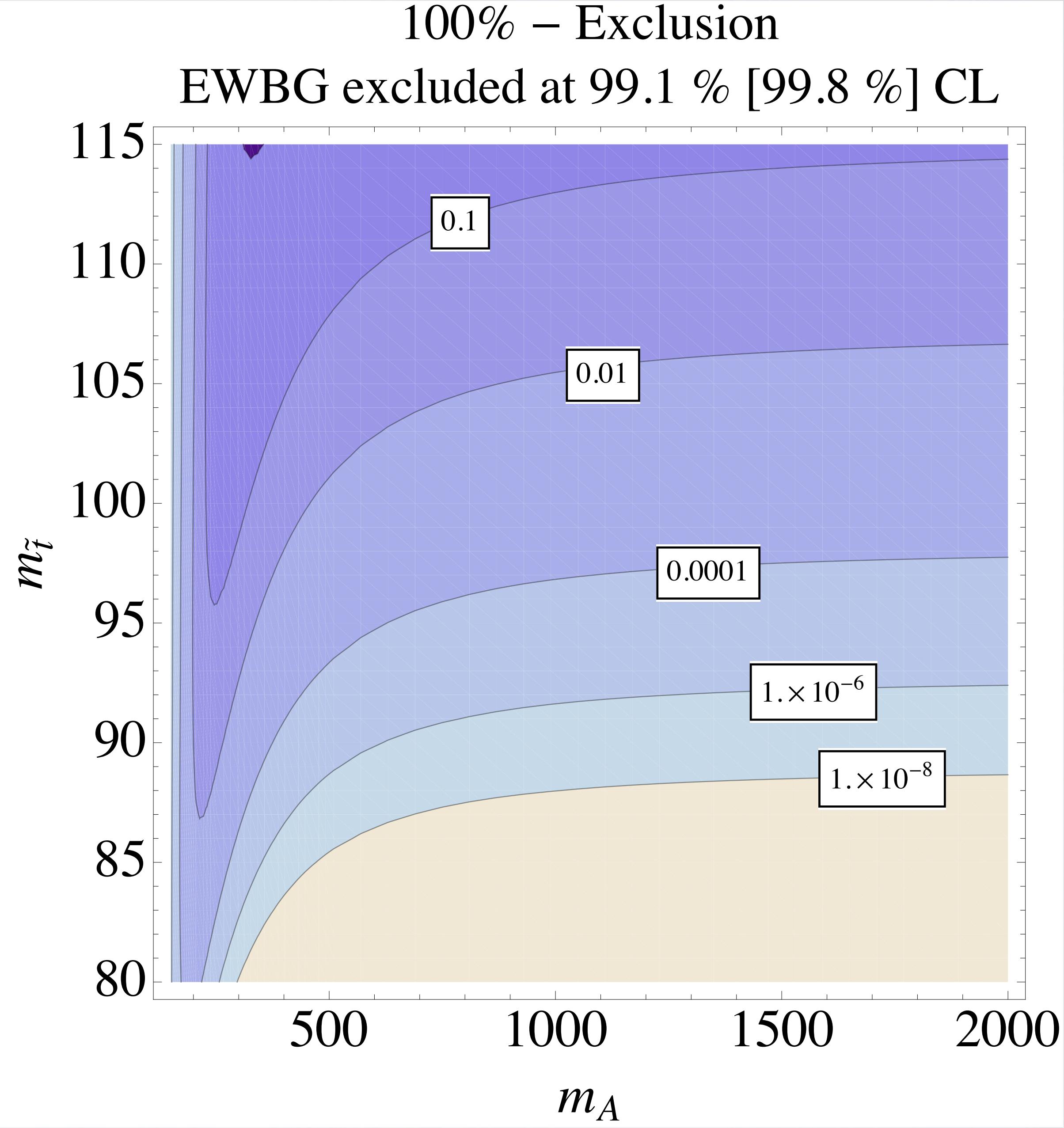
OLD

NEW

EXCLUSION AT 125 GEV

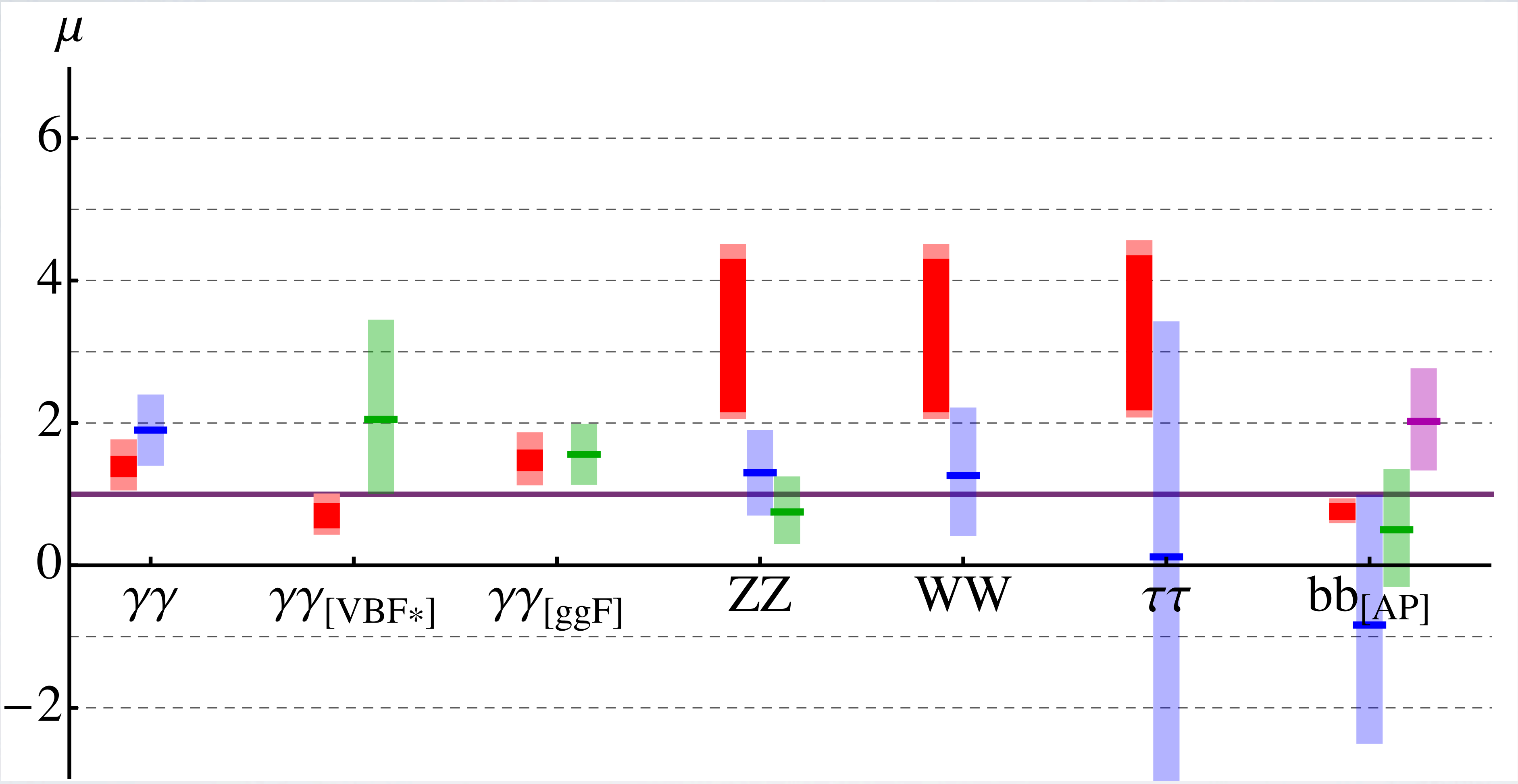


OLD



NEW

ANY WAY OUT??

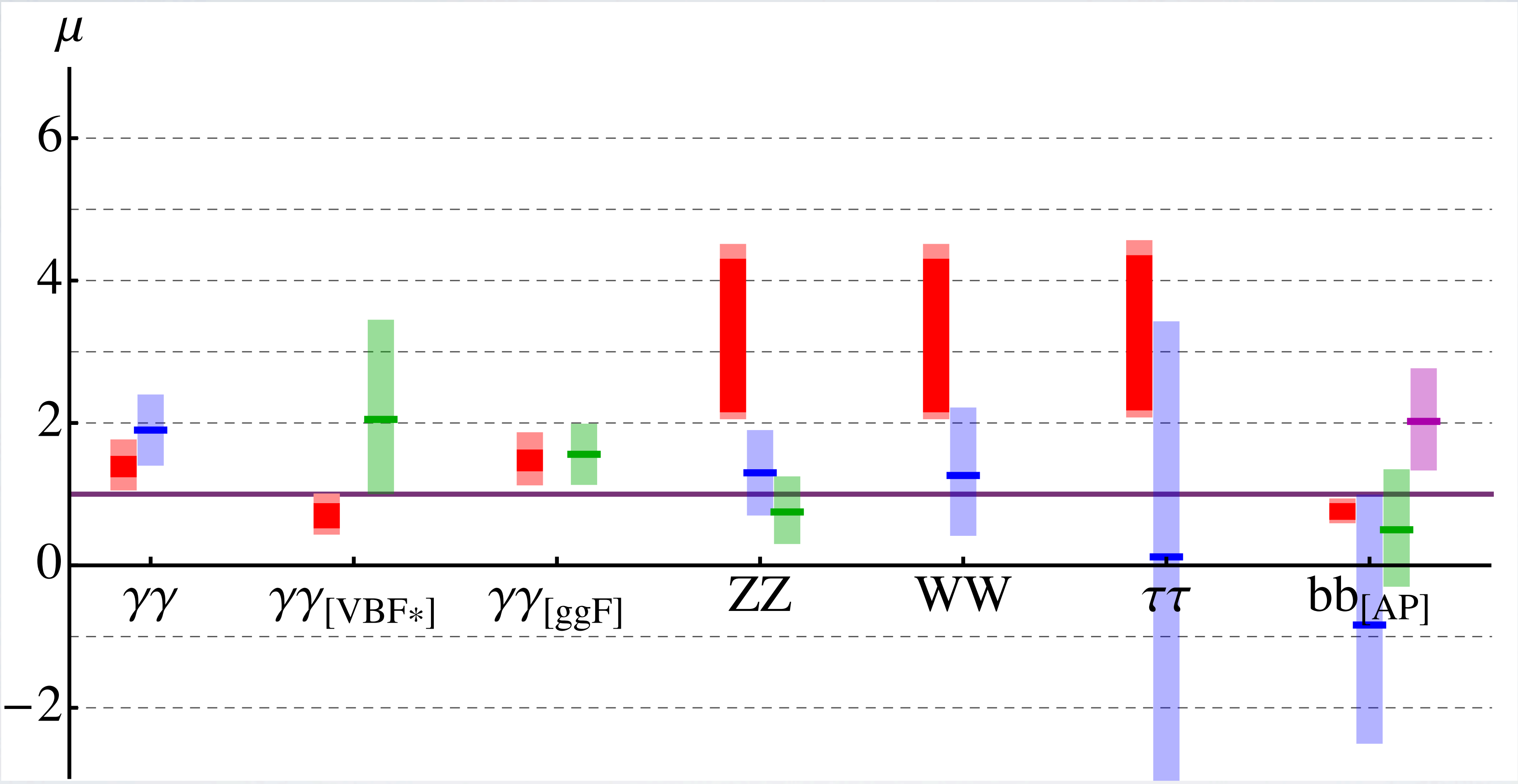


Carena, Quiros, Wagner

Go to $m_{\chi_1^0} < m_h/2$

Jack up $\Gamma(h \to \chi_1^0 \chi_1^0)$

ANY WAY OUT??



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Go to $m_{\chi_1^0} < m_h/2$

Jack up $\Gamma(h \to \chi_1^0 \chi_1^0)$

Really are killed by VBF gammas

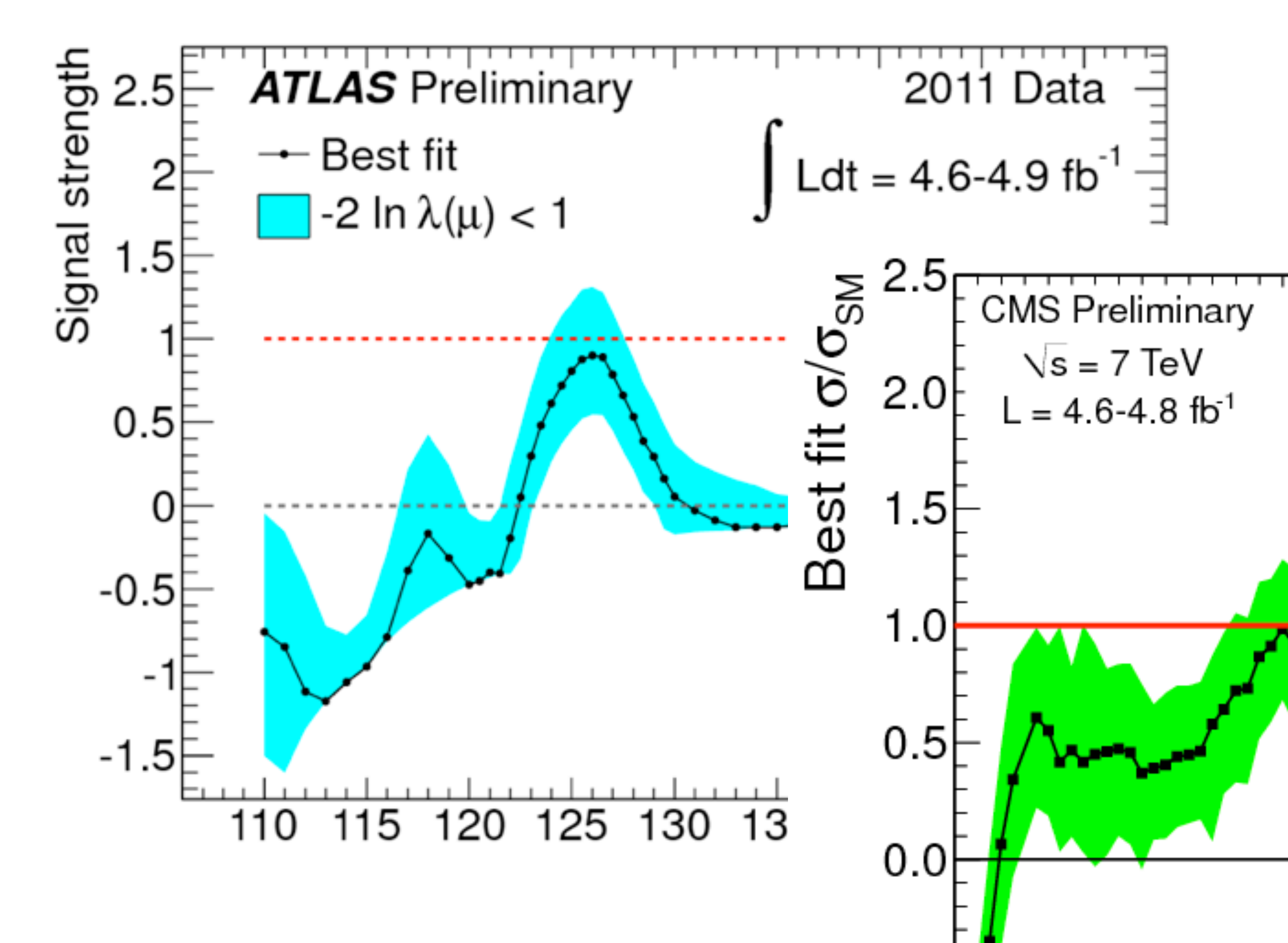
Lose "good fit" to gluon fusion gammas

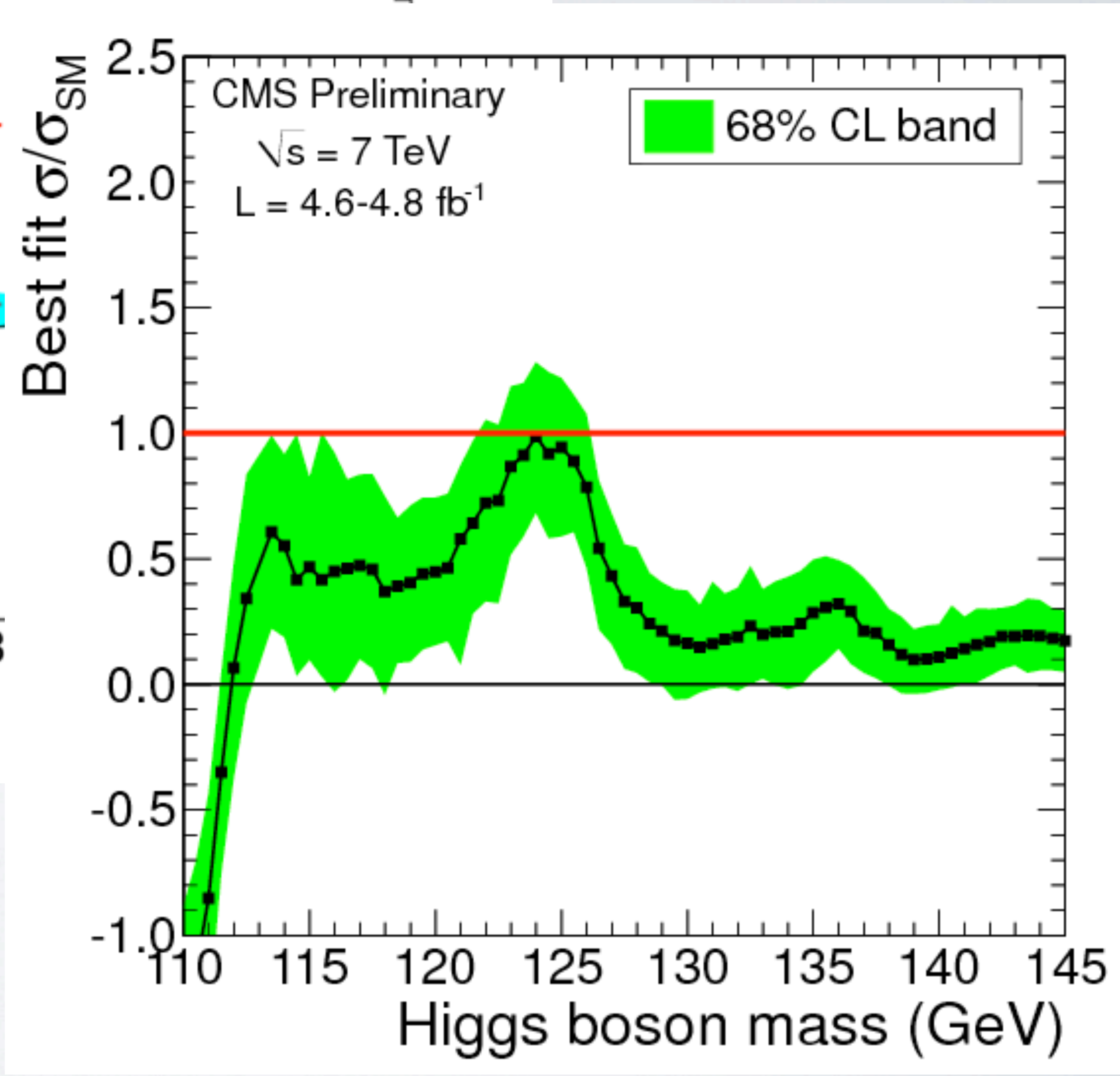
CONCLUSIONS: MSSM EWBG DEAD OR WAITING FOR PLUG TO BE PULLED

- Higgs at 125 means 95% CL exclusion
- Higgs in any of the allowed region excluded at >90% CL
- NMSSM?
- More General Conclusions?

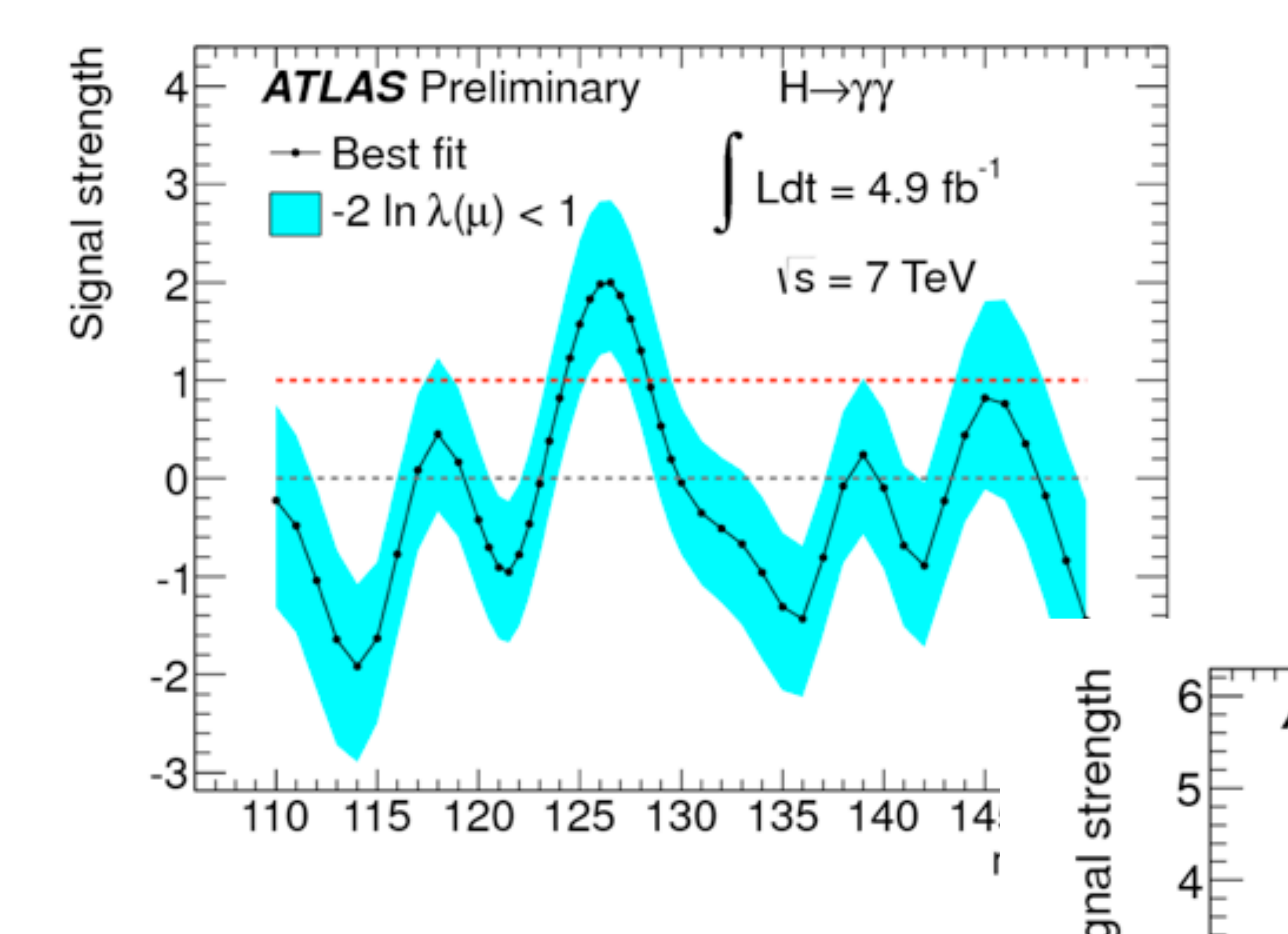
EXTRA SLIDES

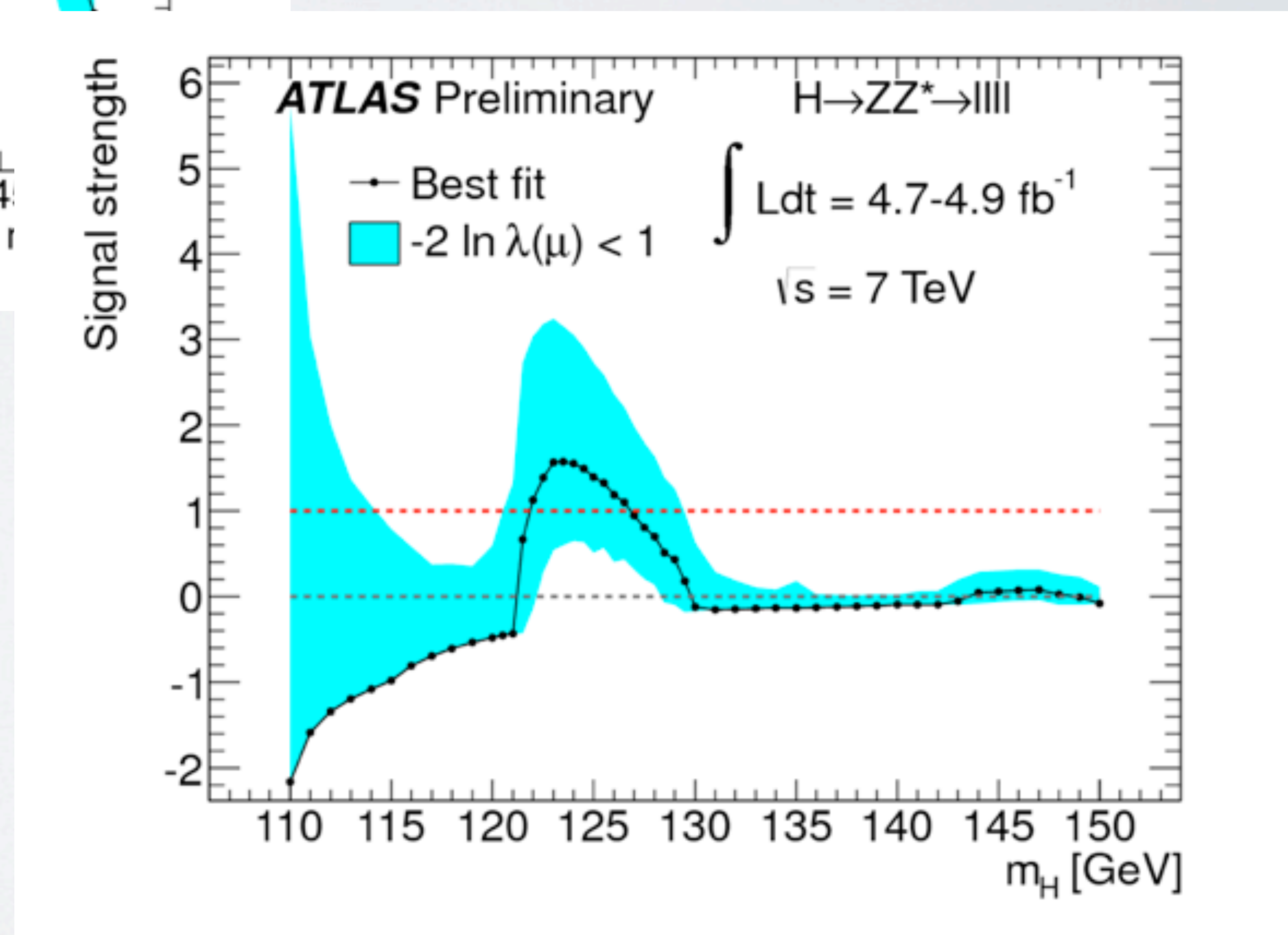
OBSERVATION?





NOT ALL CHANNELS EQUALLY OBSERVED YET...





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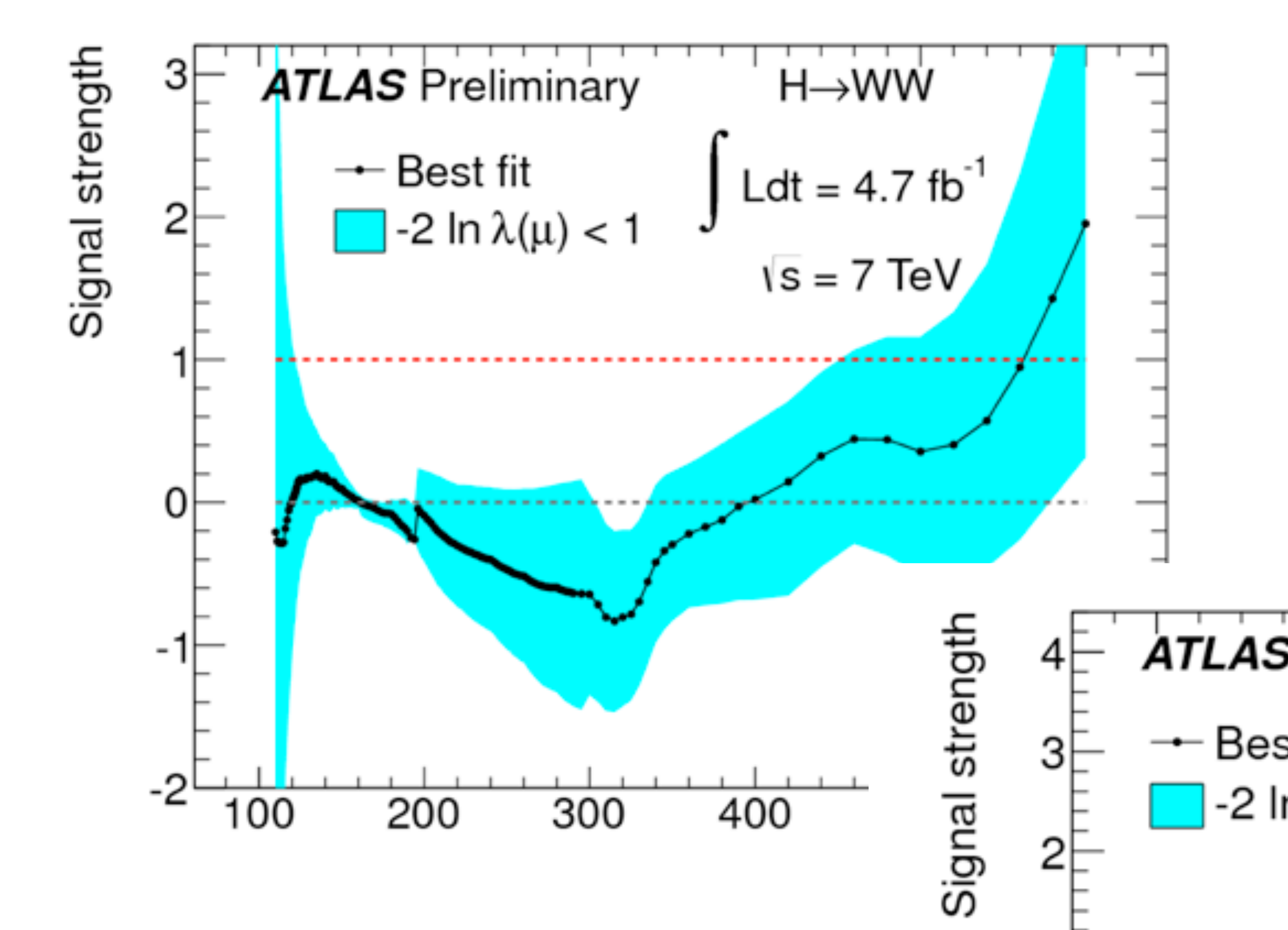

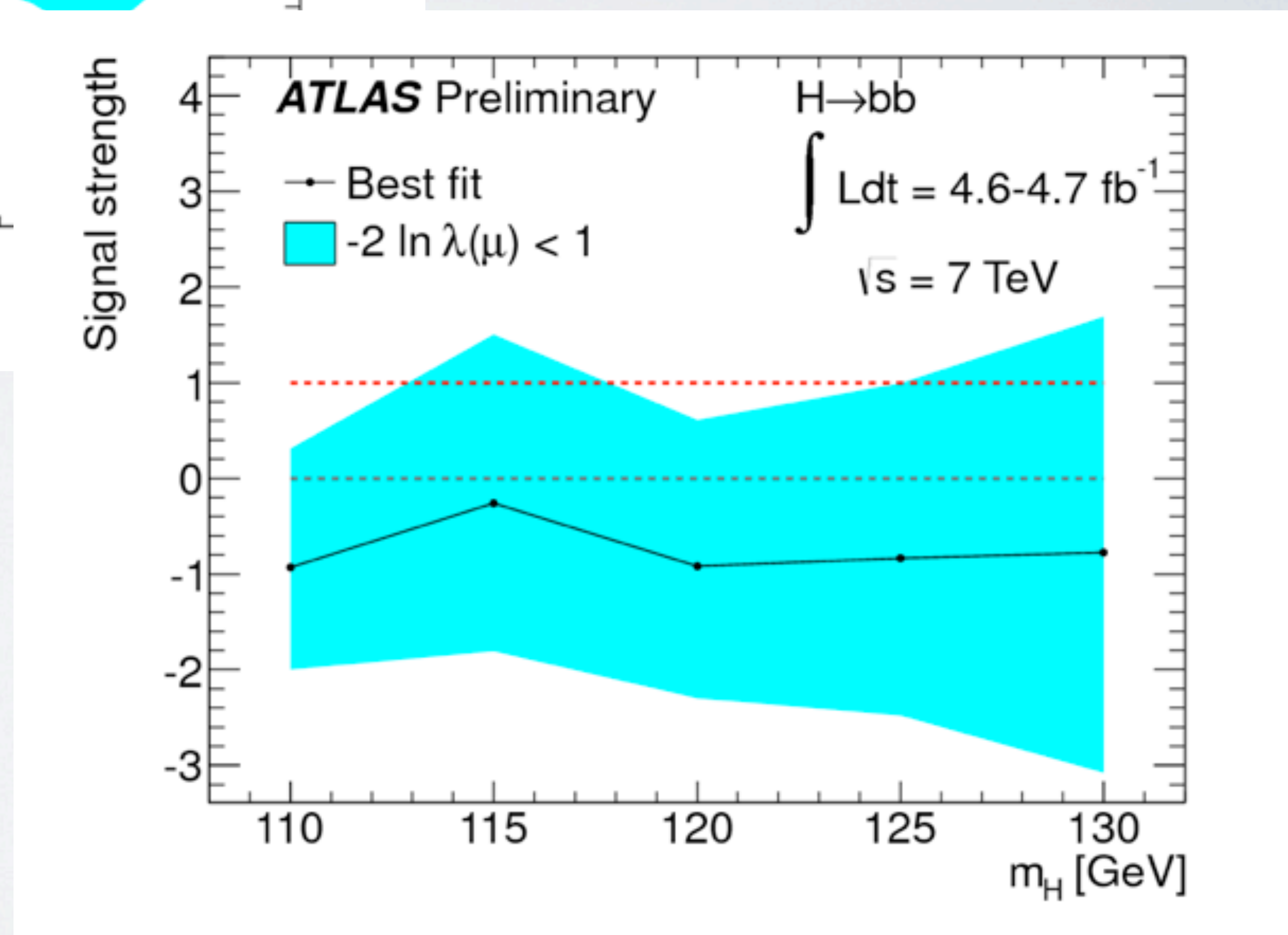

MAY NOT BE GOOD FOR YOU BUT...

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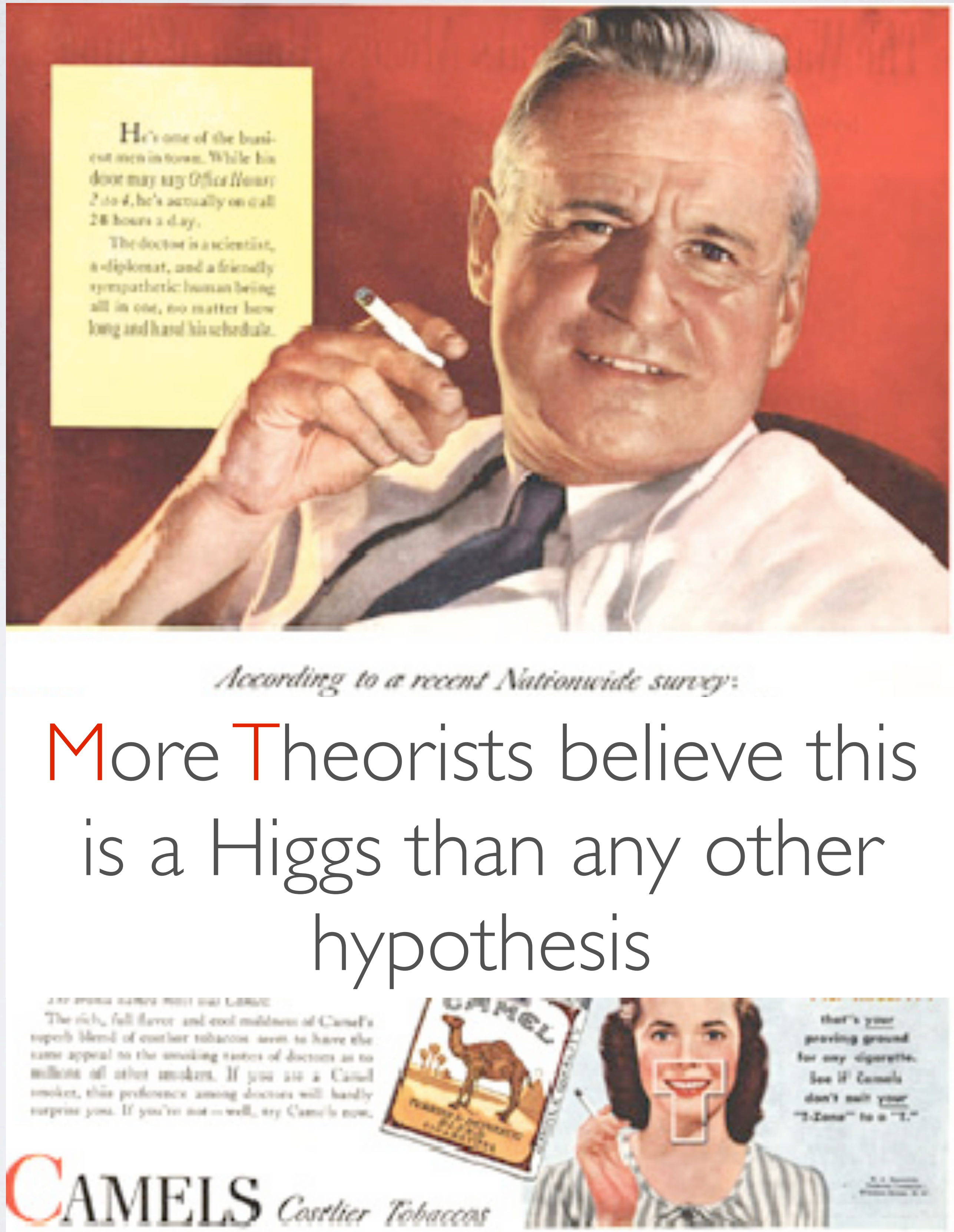
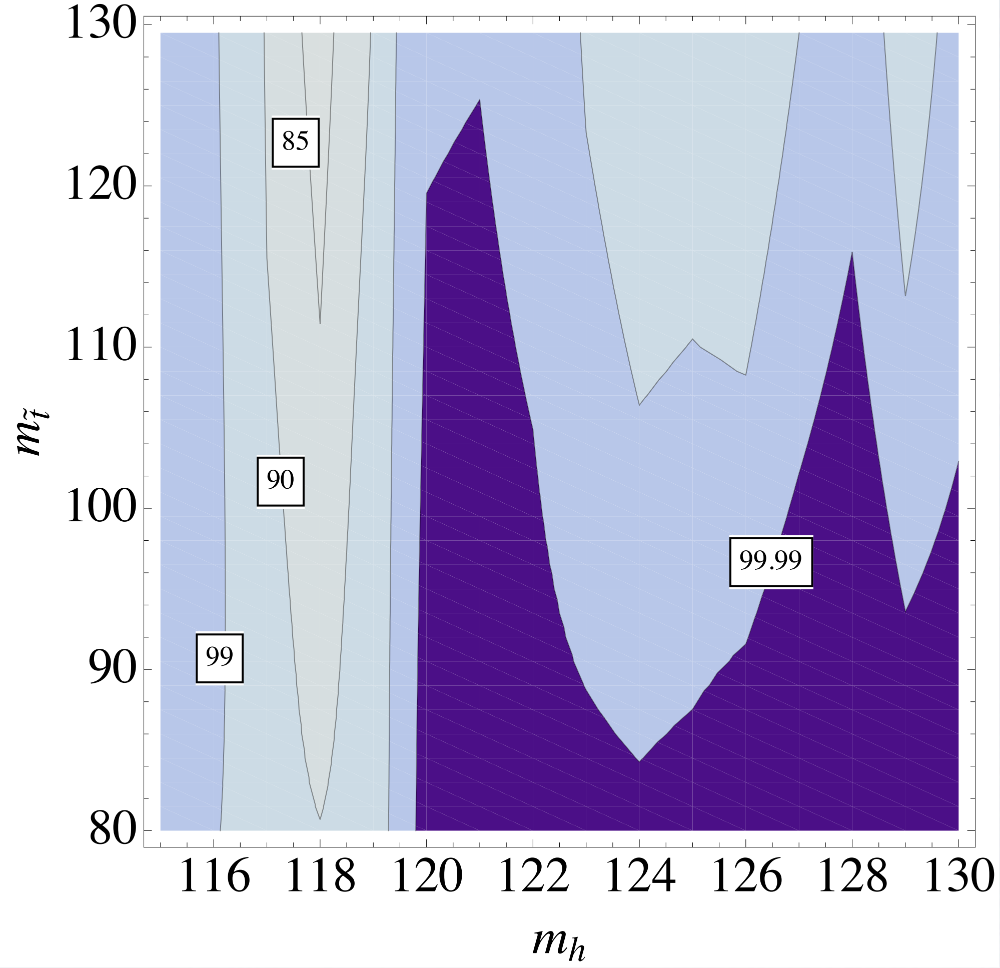
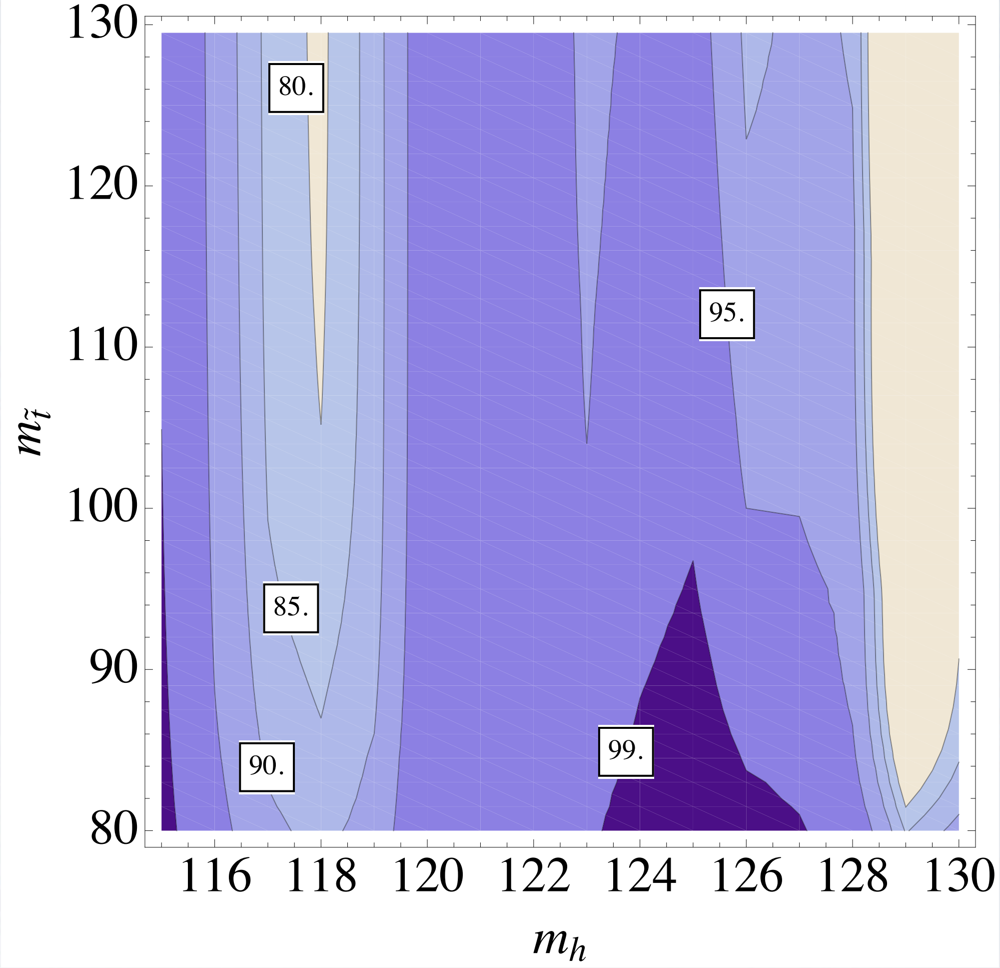


EXCLUSION NOT AT 125



(a) Decoupling Limit



(b) $150\,\text{GeV} < m_A < 2\,\text{TeV}$

Figure 4: Exclusion of a more general Light Stop Scenario in the $(m_h, m_{\tilde{t}_R})$ plane. As before, $\tilde{t}_L$ is taken to be very heavy, while m_A and $\tan\beta$ were varied in the range $(150, 2000)$ GeV and $(5, 15)$. This exclusion plot was created via the same method as Fig. 3, using both ATLAS and CMS data but not the Tevatron bb bound. For each point in the $(m_h, m_{\tilde{t}_R})$ plane we minimize exclusion with respect to theory error, $\tan\beta$ dependence and m_A dependence. The decoupling limit $m_A > 1\,\text{TeV}$ is enforced in (a), while (b) allows the whole range of m_A.