Excluding Electroweak Baryogenesis in the MSSM

Prerit Jaiswal

YITP, Stony Brook University
&
Brookhaven National Lab

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[arXiv:1203.2932] David Curtin, Patrick Meade, PJ

Motivation

- Baryon Asymmetry of the Universe (BAU)
  → *"an unsolved mystery"*
- Many approaches : Leptogenesis, Affleck-Dine Baryogenesis, Electroweak Baryogenesis (EWBG)
- EWBG → weak scale physics

  → direct experimental tests
- LEP limits on SM Higgs mass *inconsistent* with EWBG
- Supersymmetry (MSSM) → Solution to Hierarchy Problem, Gauge Coupling Unification, Dark Matter?
- Can generate sufficient BAU and consistent with collider constraints …... until 2011 LHC data.

Electroweak Baryogenesis

- Sakharov's three conditions :

  → B-violation

  → C/CP-violation

  → Departure from thermal equilibrium

- EWBG :

  → Sphaleron processes

  → Complex phases

  → 1^{st} Order Phase Transition

- EWBG in SM : All three conditions satisfied. However, not enough BAU (weak first order phase transition).

Electroweak Baryogenesis

BAU Computation

First order
Phase Transition

Not so easy!
→ more constraining

Creating BAU

↓

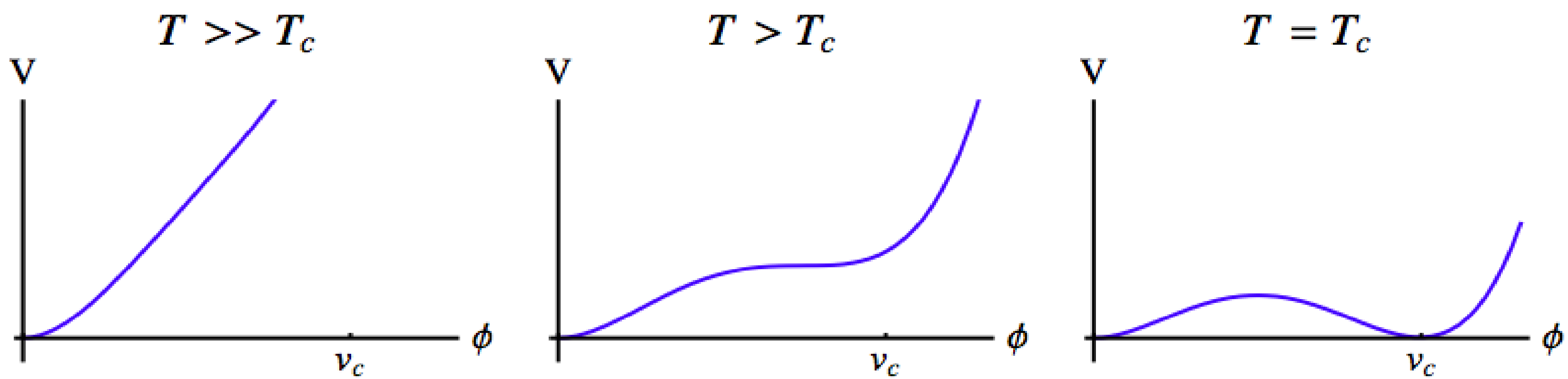
Quantum transport,
hydrodynamic calc.

↓

sources of CP violation :
EDM Constraints

Reasonably easy to satisfy..

First Order Phase Transition



- Sphaleron processes ~ $e^{-v/T}$

  → Inside the bubble wall (broken phase), sphalerons suppressed.

  → Suppression must be strong enough to prevent washout of B generated outside the wall ($v_c/T_c \gtrsim 1$)

- To get first order phase transition, a *cubic term* in φ is required.

  → Strength of phase transition ~ (cubic coeff)/(quartic coeff)

- Thermal QFT → only *bosons* can generate such a term.

First Order Phase Transition

- Form of the cubic term in the thermal potential :

$\rightarrow V \sim T\, m^3(\varphi) \sim c\, T\, \varphi^3$

SM

- Background dependent bosons : W, Z
- Small couplings to φ

$\rightarrow$ small cubic coeff

$\rightarrow$ weak 1st order phase transition

MSSM

- Background dependent bosons : W, Z, Stops
- Large top Yukawa couplings to φ

$\rightarrow$ large cubic coeff

$\rightarrow$ strong 1st order phase transition … but

Thermal Potential in the MSSM

V (cubic) ~ T $m^3(\varphi)$ ~ c T φ^3

where, $m(\varphi)$ are the mass eigenstates.

- Stop mass eigenstates :

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

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

- Complications due to :

→ non-linear φ dependence

→ Thermal masses : $\Pi_{t_L},\ \Pi_{\tilde{t}_R} \sim g^2T^2$

EWBG in MSSM

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

- Require $m^2_{U_3} \sim -\Pi_{t_R}$ and small mixing.

  → maximize cubic term

  → avoid color-breaking

  $m_{\tilde{t}_1} < m_t$ and $A_t \lesssim m_Q/2$ (*light right-handed stop*)

- *Heavy left-handed stops* > TeV

  (ρ parameter and LEP Higgs mass constraints)

$$m_h^2 = m_Z^2 c_{2\beta}^2 + \frac{3m_t^4}{4\pi^2 v^2}\left(\log\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right)$$

EWBG in MSSM

Light Stop Scenario

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

M. Carena, G. Nardini, M. Quiros and C. E. M. Wagner, Nucl. Phys. B **812**, 243 (2009) [arXiv:0809.3760 [hep-ph]].

The Fingerprint of EWBG

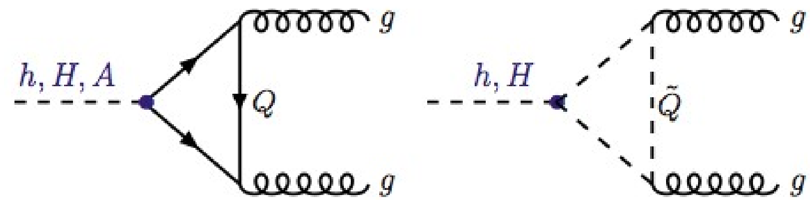
- Direct searches for stops model dependent

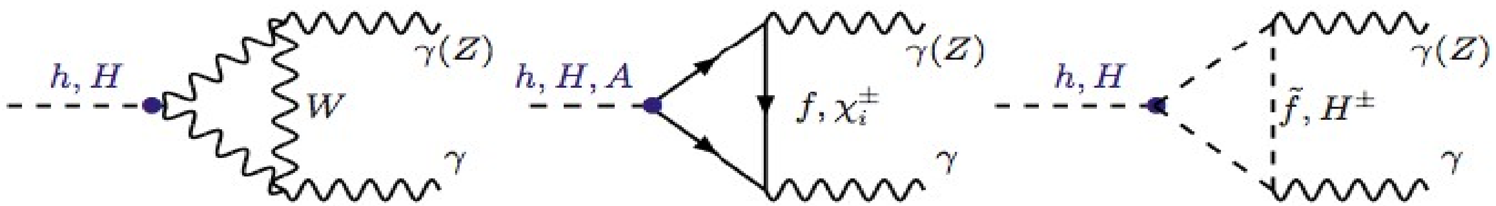
  → easy to evade e.g. displaced vertex

- *Fingerprint of EWBG* : Effect of light stops on Higgs phenomenology through loops : correlations between Higgs production and decay channels

hgg effective vertex : enhancement

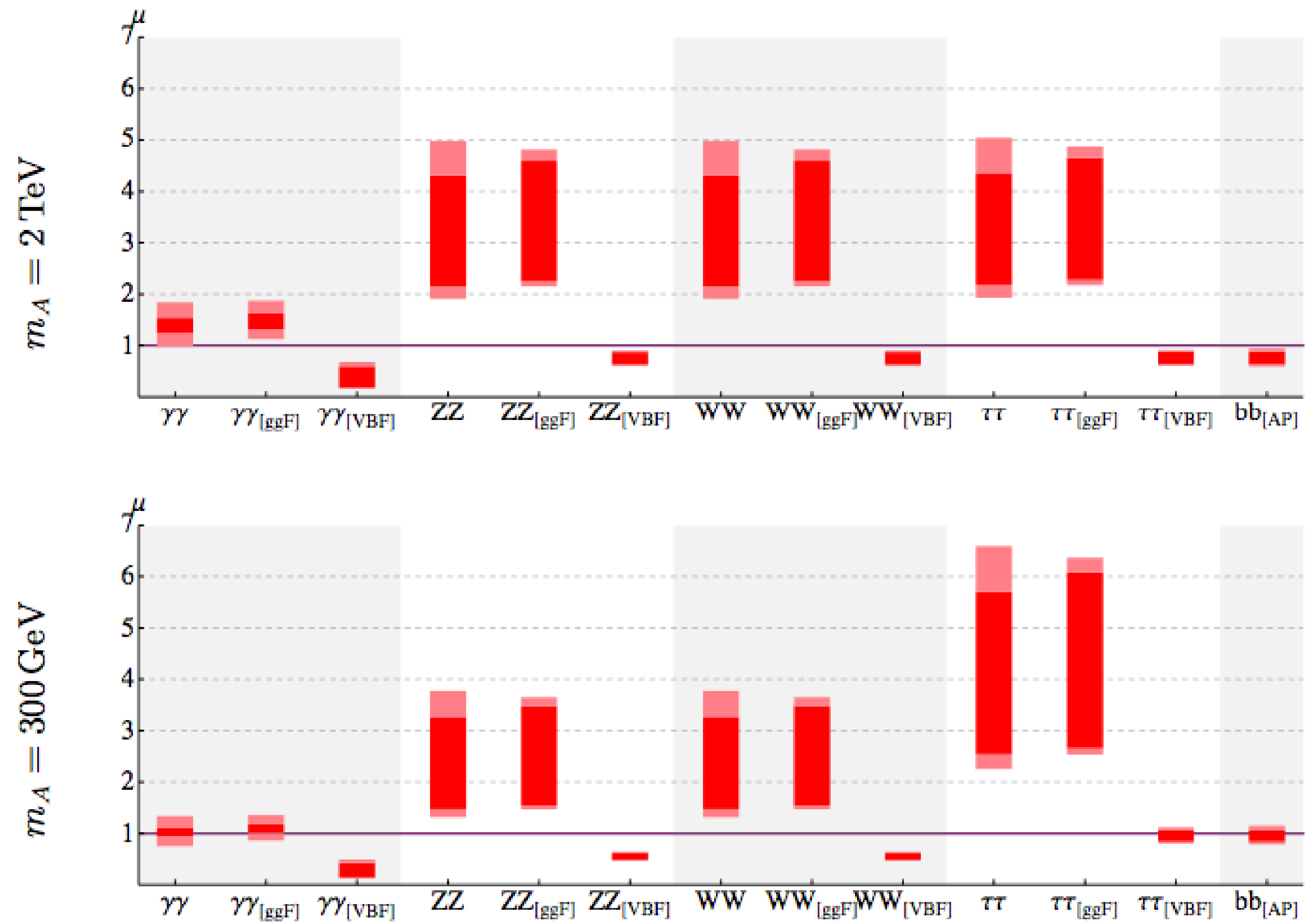
hγγ effective vertex : suppression



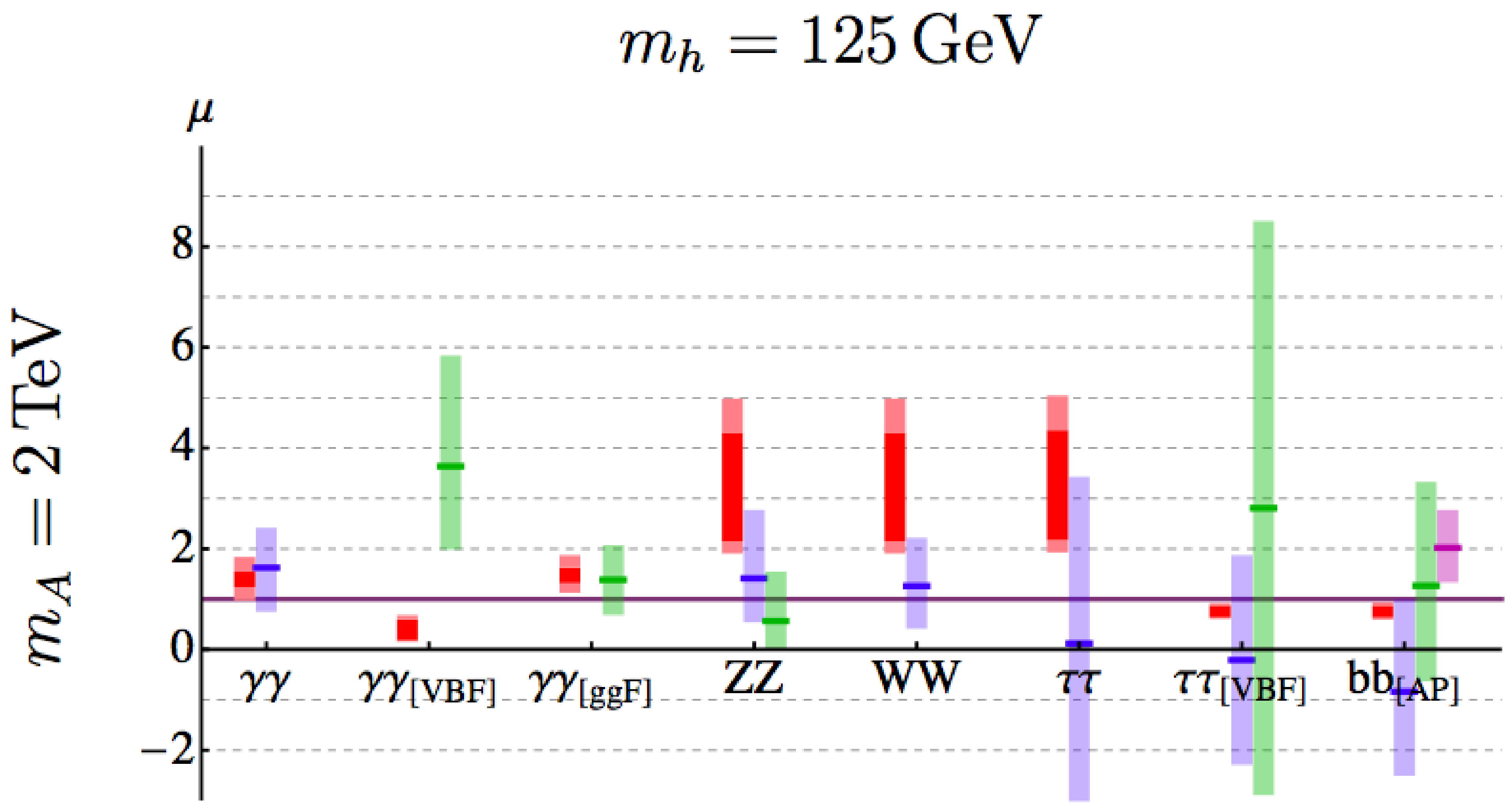


The Fingerprint of EWBG

$m_h = 125\,\text{GeV}$ $m_{\tilde{t}_R} \in (80, 115)\,\text{GeV}$ $\tan\beta \in (5, 15)$



EWBG vs LHC

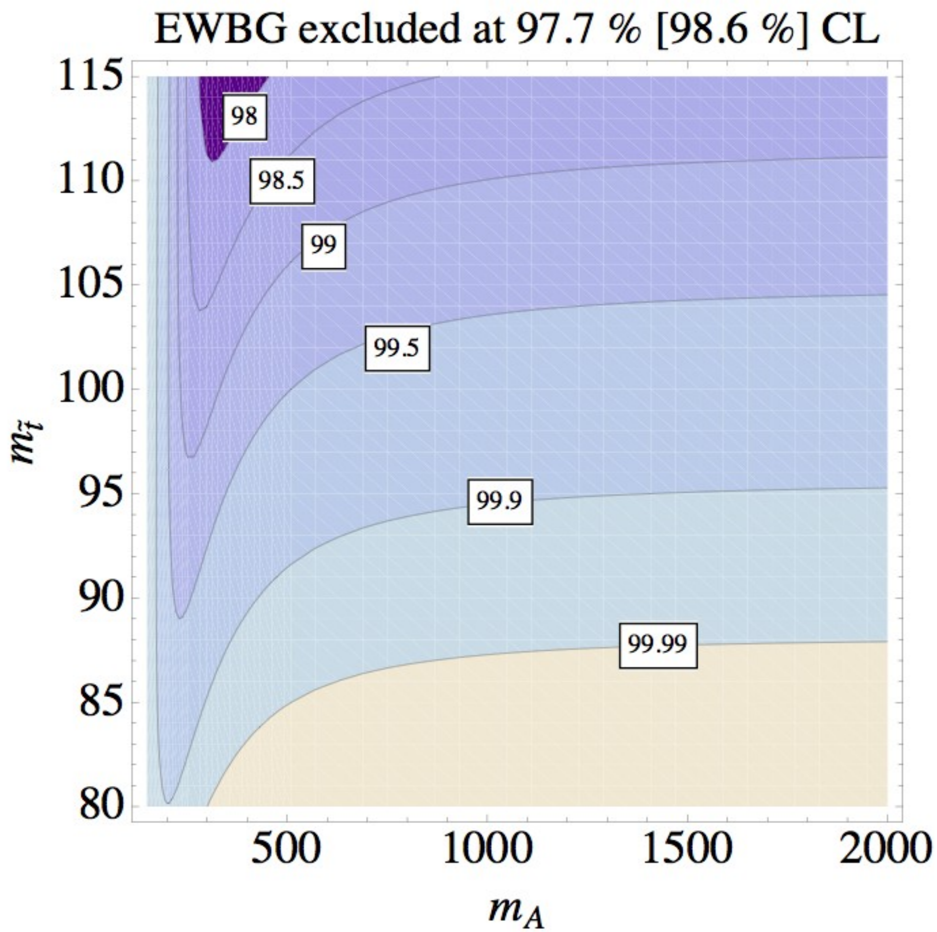


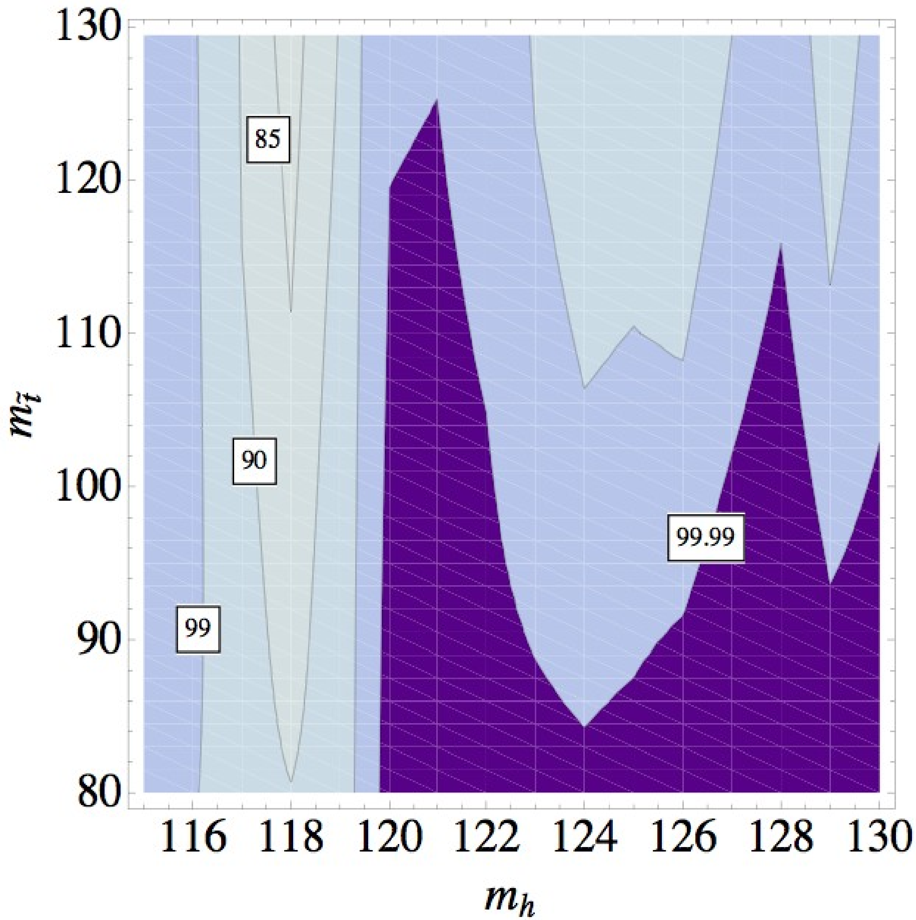
$m_h = 125\,\text{GeV}$
μ
8
6
4
2
0
−2
$m_A = 2\,\text{TeV}$
$\gamma\gamma$
$\gamma\gamma_{[\text{VBF}]}$
$\gamma\gamma_{[\text{ggF}]}$
ZZ
WW
$\tau\tau$
$\tau\tau_{[\text{VBF}]}$
$bb_{[\text{AP}]}$

EWBG vs LHC

$m_h = 125\,\mathrm{GeV}$

decoupling limit $m_A > 1\,\mathrm{TeV}$





Results and Conclusion

- A heavy Higgs (~ 125 GeV) is disfavored by EWBG.
- EWBG prediction : light right-handed stop ($< m_t$)
- Higgs physics : a test of EWBG

  → Production and decay rates modified significantly compared to SM

- Most of the parameter space excluded at 90% CL except

  $m_h \approx 117 - 119\,\mathrm{GeV}$

- $m_h = 125\,\mathrm{GeV}$ Excluded at 95% CL.