The NMSSM with F-theory unified boundary conditions

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A history of tension

Fine Tuning

$m_h \approx 125 - 126$ GeV

SUSY : $\mathrm{m_h} \leq 130$ GeV

μ problem

It is supersymmetric.

Order of SUSY-breaking soft terms

.

A history of tension

NMSSM

Maniatis, Ellwanger, Hugonie, Teixeira (2010)

$$W_{\rm NMSSM} \;=\; W_{\rm Yuk} \;+\; \lambda S H_u H_d \;+\; \frac{\kappa}{3} S^3$$

$$V_{soft}^S \;= m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 + \left(\lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3 + h.c.\right)$$

$$m_h^2 \;\simeq\; m_Z^2 \cos^2 2\beta \;+\; \lambda^2 v^2 \sin^2 2\beta \;+\; \delta(m_h^2)$$

A history of tension

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$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \delta(m_h^2)$$

UNIVERSALITY

A history of love

- SU(5) unified theory
- Origin of SUSY-breaking
- Universality

Modulus dominance SUSY-breaking in F-theory SU(5) GUTs

L.A., Cerdeño, Ibañez (2008–2012)

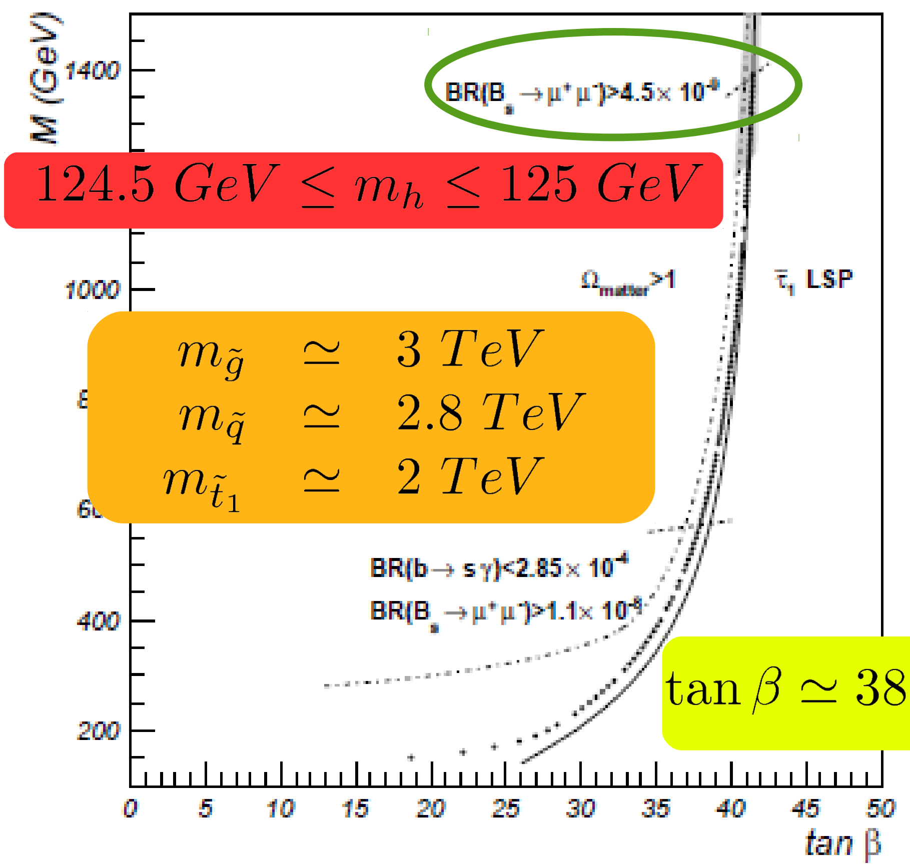
$$
\begin{aligned}
m_{\tilde{f}}^2 &= \tfrac{1}{2}|M|^2 \\
m_H^2 &= \tfrac{1}{2}|M|^2(1-\tfrac{3}{2}\rho_H) \\
A &= -\tfrac{1}{2}M(3-\rho_H) \\
B &= -M(1-\rho_H)
\end{aligned}
$$

A possible history of love

- SU(5) unified theory
- Origin of SUSY-breaking
- Universality

Modulus dominance SUSY-breaking in F-theory SU(5) GUTs

L.A., Cerdeño, Ibañez (2008–2012)



$124.5\ GeV \leq m_h \leq 125\ GeV$

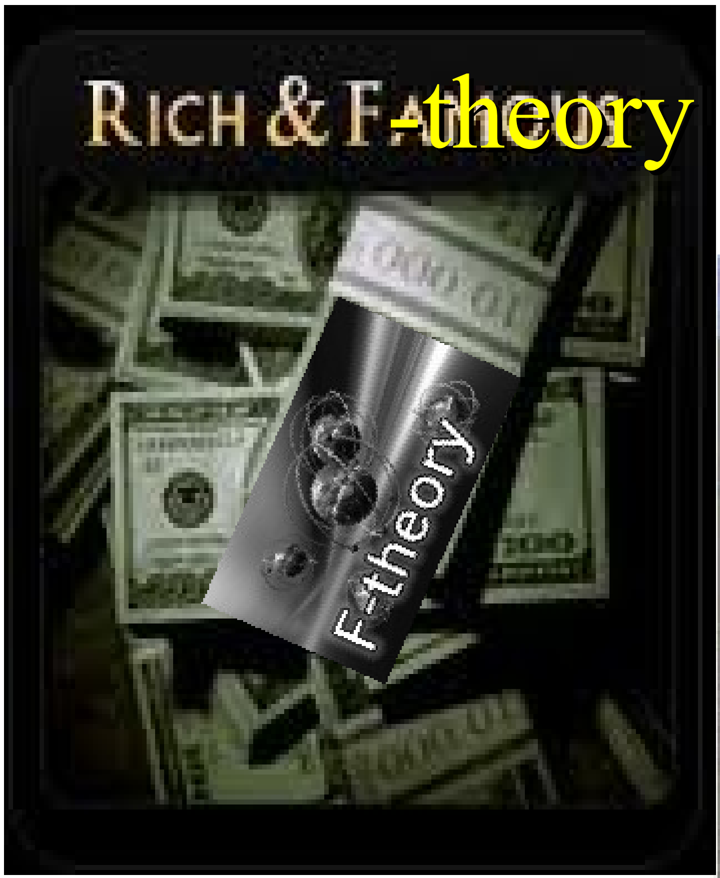
$$m_{\tilde{g}} \simeq 3\ TeV$$
$$m_{\tilde{q}} \simeq 2.8\ TeV$$
$$m_{\tilde{t}_1} \simeq 2\ TeV$$

$\tan\beta \simeq 38 - 41$

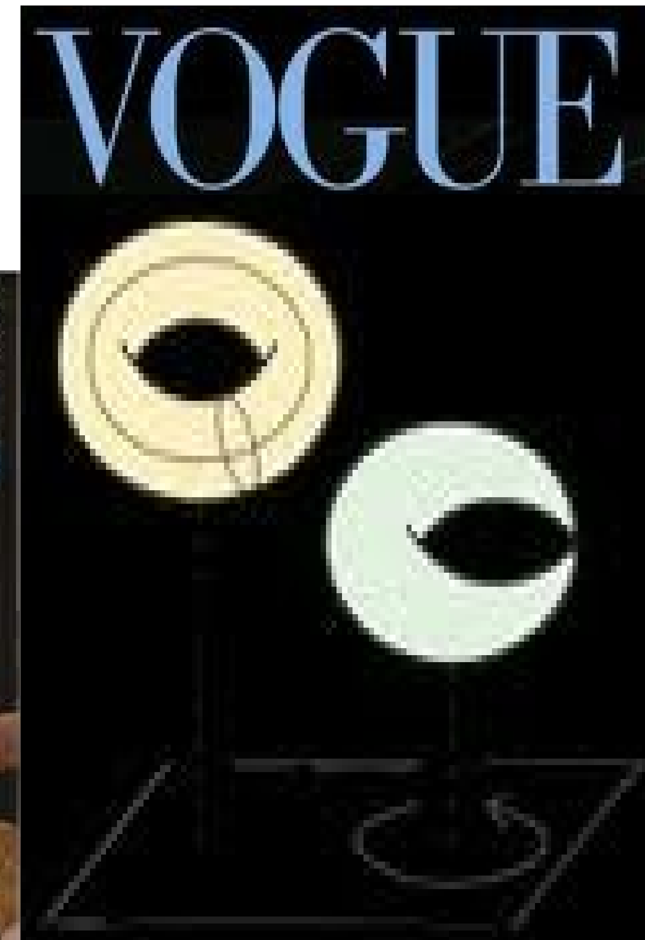
VERY PREDICTIVE !!

Modulus dominated CNMSSM ??

F-theory


RICH & F
-theory
F-theory


WHERE TO RETIRE
SURPRISE! RUST BELT TAX HAVENS
Seagate Eyes A New Market
Health Care Fraud's Real Toll
The Best Retail Stocks
-theory
How A Poor Boy From London Became Diamond Merchant To The World's Super Wealthy
King of Bling


VOGUE

F-theory

- SL(2,Z) in Type IIB

F1-string

$SL(2,\mathbf{R})$

D1-brane

$$\tau \rightarrow \frac{a\tau + b}{c\tau + d}, \qquad \begin{pmatrix} B_2 \\ C_2 \end{pmatrix} \rightarrow \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} B_2 \\ C_2 \end{pmatrix}$$

$$\tau = C_0 + ie^{-\phi} = C_0 + \frac{i}{g_s}$$

Schwarz (1996)

F-theory crash course

- SL(2,Z) in Type IIB

F1-string

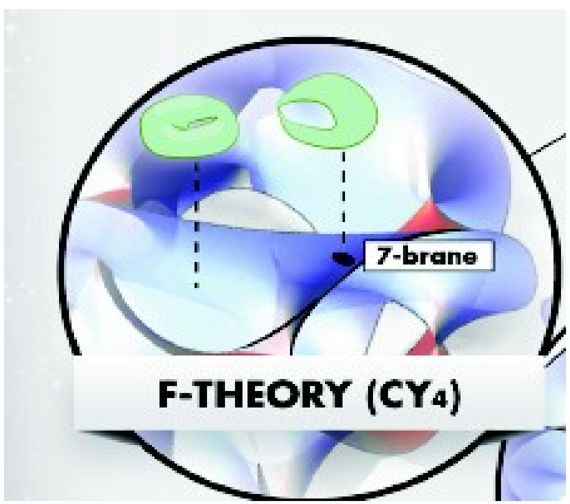
(p,q)-string

$\tau = R_2/R_1 e^{i\theta}$ τ axio-dilaton

Vafa (1996), Morrison, Vafa (1996)

F-theory crash course

- SL(2,Z) in Type IIB
- Geometric meaning: elliptic fibrations

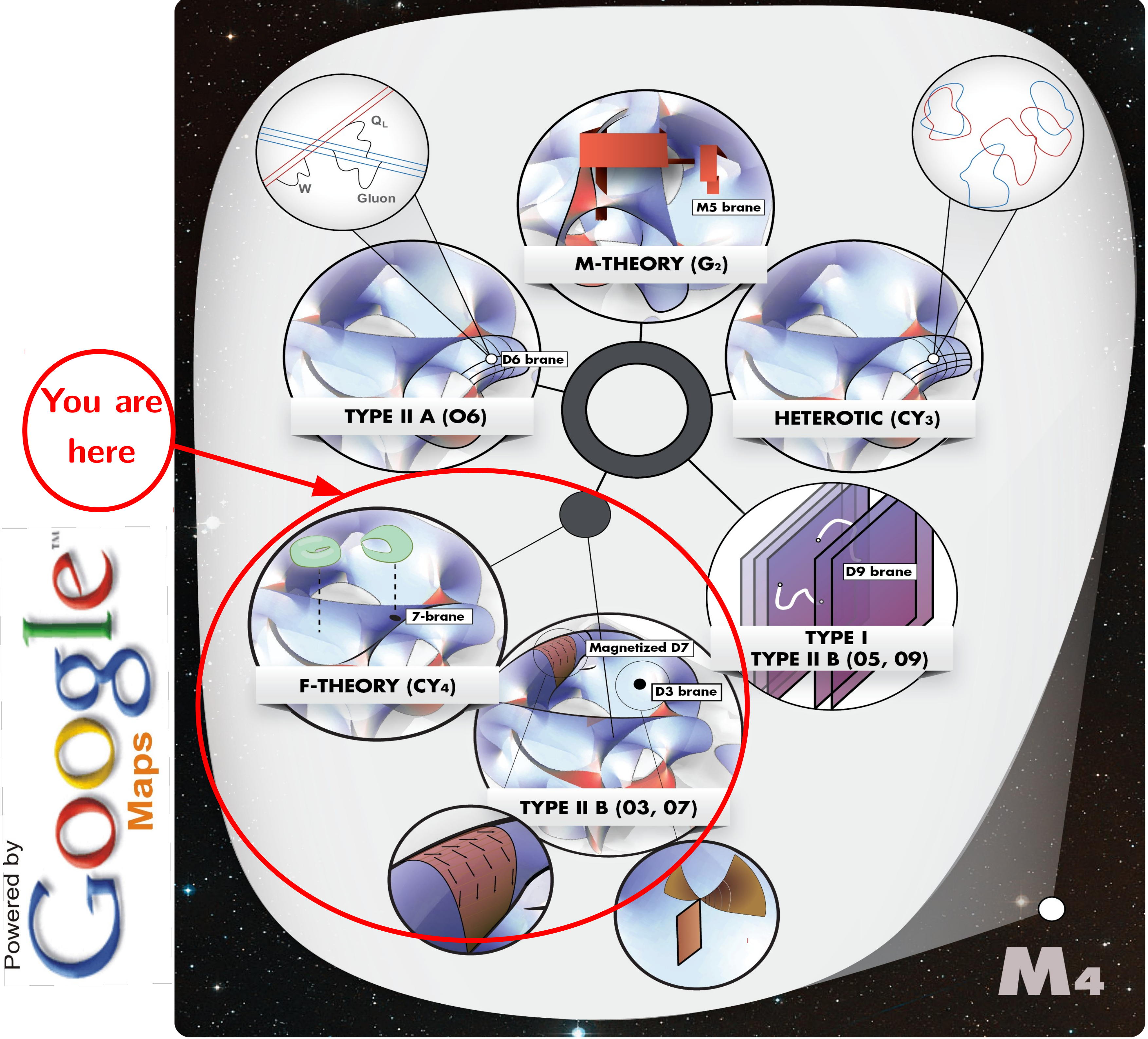


$$\begin{array}{ccc} \mathbf{T}^2 & \rightarrow & \mathrm{CY}_4 \\ & & \downarrow \\ & & \mathcal{B}_3 \end{array}$$

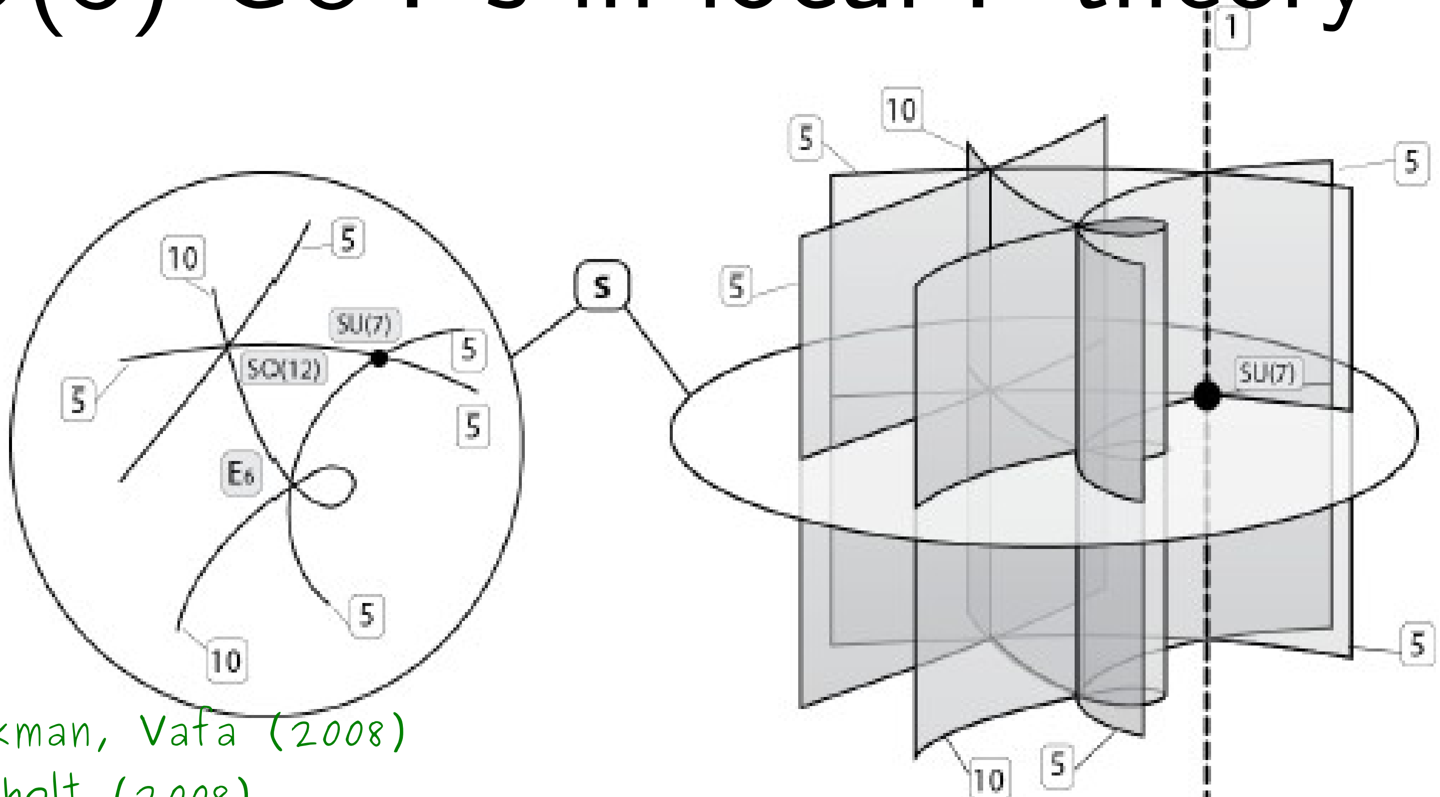
Type IIB with $\tau = \tau(z)$

Beasley, Heckman, Vafa (2008)
Donagi, Wijnholt (2008)

Vafa (1996), Morrison, Vafa (1996)


Q_L
W
Gluon
M5 brane
M-THEORY (G2)
D6 brane
TYPE II A (O6)
HETEROTIC (CY3)
You are here
7-brane
D9 brane
TYPE I
TYPE II B (O5, O9)
F-THEORY (CY4)
Magnetized D7
D3 brane
TYPE II B (O3, O7)
M4
Powered by Google Maps

SU(5) GUT's in local F-theory



Beasley, Heckman, Vafa (2008)

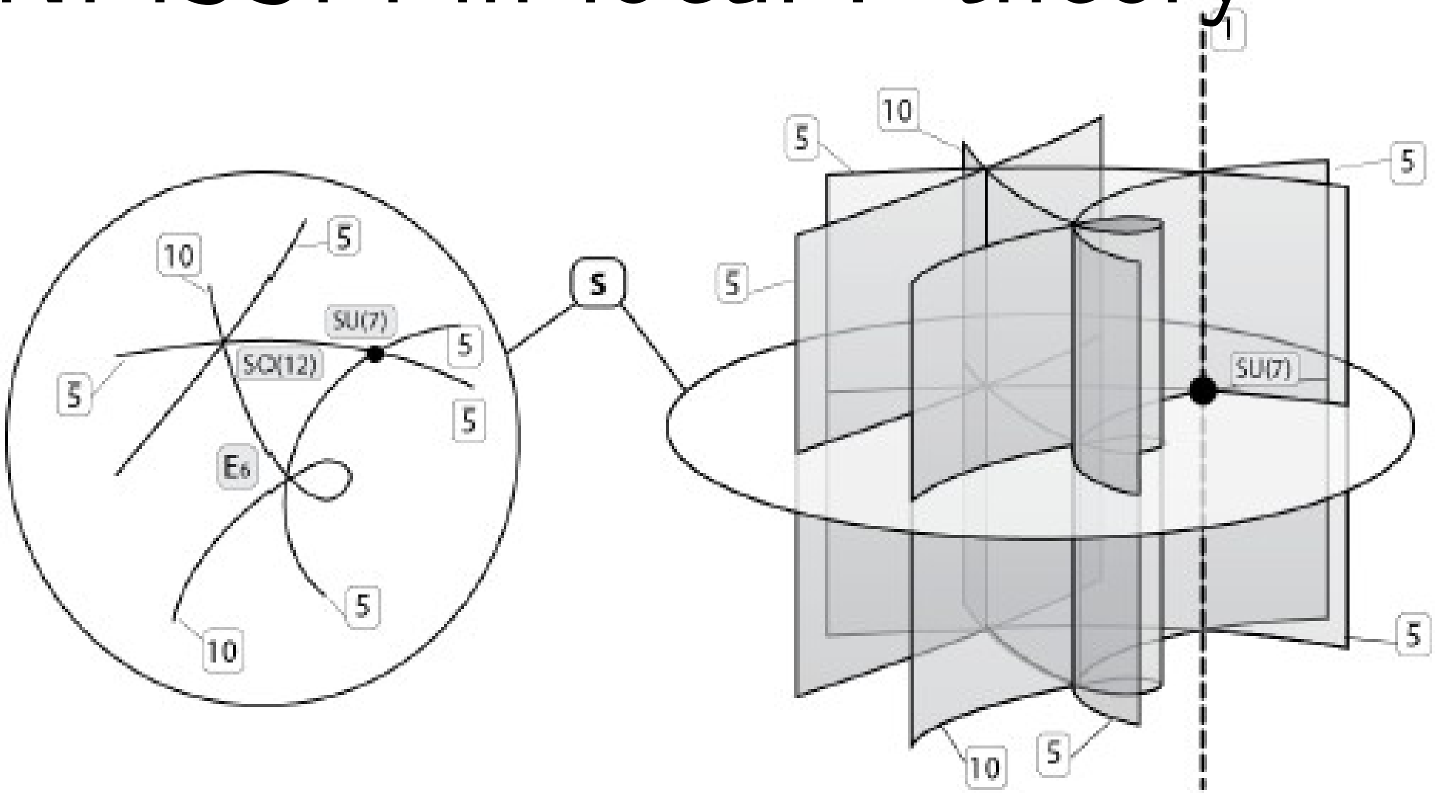
Donagi, Wijnholt (2008)

$$SO(12) \rightarrow SU(5)\times U(1)\times U(1)'$$
$$\mathbf{66} \rightarrow Adjoints + [(\mathbf{10},\ 4,\ 0) + (\bar{\mathbf{5}},\ -2,\ 2) + (\bar{\mathbf{5}},\ -2,\ 2) + c.c.]$$

$$E_6 \rightarrow SU(5)\times U(1)\times U(1)'$$
$$\mathbf{78} \rightarrow Adjoints + [(\mathbf{10},\ -1,\ -3) + (\mathbf{10},\ 4,\ 0) + (\mathbf{5},\ -3,\ 3) + (\mathbf{1},\ 5,\ 3) + c.c.]$$

$$W_{\text{NMSSM}} = W_{\text{Yuk}} + \lambda S H_u H_d + \frac{\kappa}{3} S^3$$

NMSSM in local F-theory



L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

$$SU(7) \rightarrow SU(5) \times U(1)^2$$

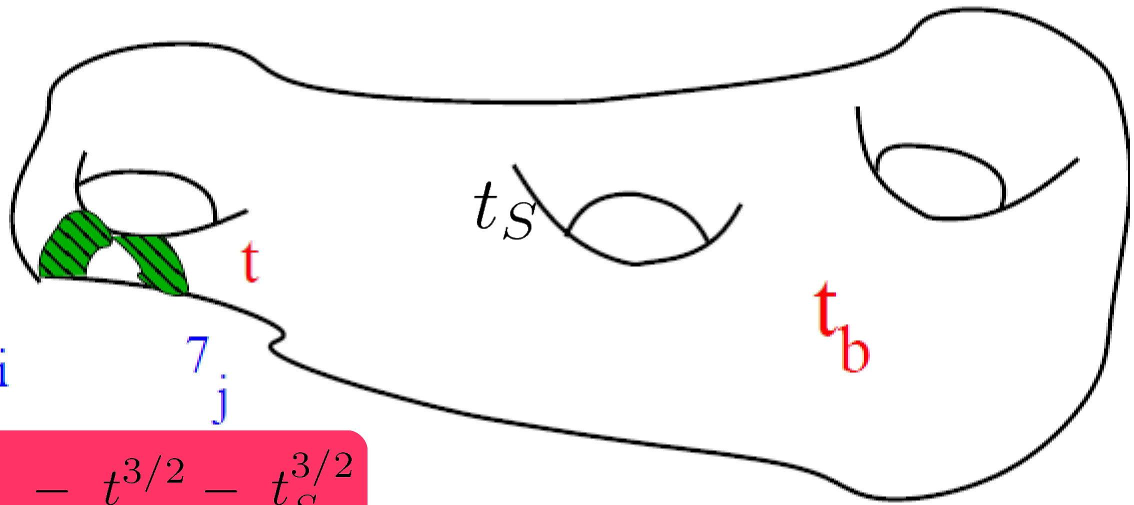
$$\mathbf{48} \rightarrow \mathbf{24} + \mathbf{1}_{(0,0)} + \mathbf{1}_{(0,0)} + [\mathbf{5}_{(0,-1)} + \mathbf{1}_{(-1,1)} + \bar{\mathbf{5}}_{(1,0)} + \text{c.c.}]$$

$$W_{\text{NMSSM}} = W_{\text{Yuk}} + \lambda S H_u H_d + \frac{\kappa}{3} S^3$$

Instantons

T-modulus dominated NMSSM

$t, t_S \ll t_b$



$\mathrm{Vol[CY]} = t_b^{3/2} - t^{3/2} - t_S^{3/2}$

Conlon, Cremades, Quevedo (2007)
L.A., Cerdeño, Ibañez (2008)

- Kähler metrics

$$K_\alpha = \frac{t^{(1-\xi_\alpha)}}{t_b} \quad \Rightarrow \quad K_{\bar{\mathbf{5}},\mathbf{10}} = \frac{t^{1/2}}{t_b}, \qquad K_S = \frac{t_S^{1/2}}{t_b}$$

- Gauge kinetic function

$$f = T$$

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM

- Assuming $F_{t_b} \gg F_t \gg F_{t_S}$ (easily obtained in LVS)

Conlon, Quevedo, Cicoli, Balasubramanian (2005–2011)

- MSSM-like soft terms

$$\rho_H \simeq \alpha_G^{1/2} \simeq 0.2$$

L.A., Cerdeño, Ibañez (2012)

$$\begin{aligned} M &= \frac{F_t}{t} \\ m_H^2 &= \frac{|M|^2}{2}\left(1 - \frac{3}{2}\rho_H\right) \\ m^2_{\bar{\mathbf{5}},\mathbf{10}} &= \frac{|M|^2}{2} \\ A &= -\frac{1}{2}M(3 - \rho_H) \end{aligned}$$

- Singlet-like soft terms

$$A_\lambda = -M\left(1-\rho_H\right), \qquad A_\kappa = m_S^2 = 0$$

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM

- We don't impose the singlet-like boundary conditions
- We have a model with 7 parameters :

$$M \ , \rho_H, \ , \lambda, \ , \kappa, \ , A_\lambda, \ , A_\kappa, \ m_S$$

$\Rightarrow$ $M \ , \rho_H \ , A_\lambda, \ , A_\kappa$; λ ; $tan\beta$

- We perform a large scan using `NMSSMTools,` imposing:

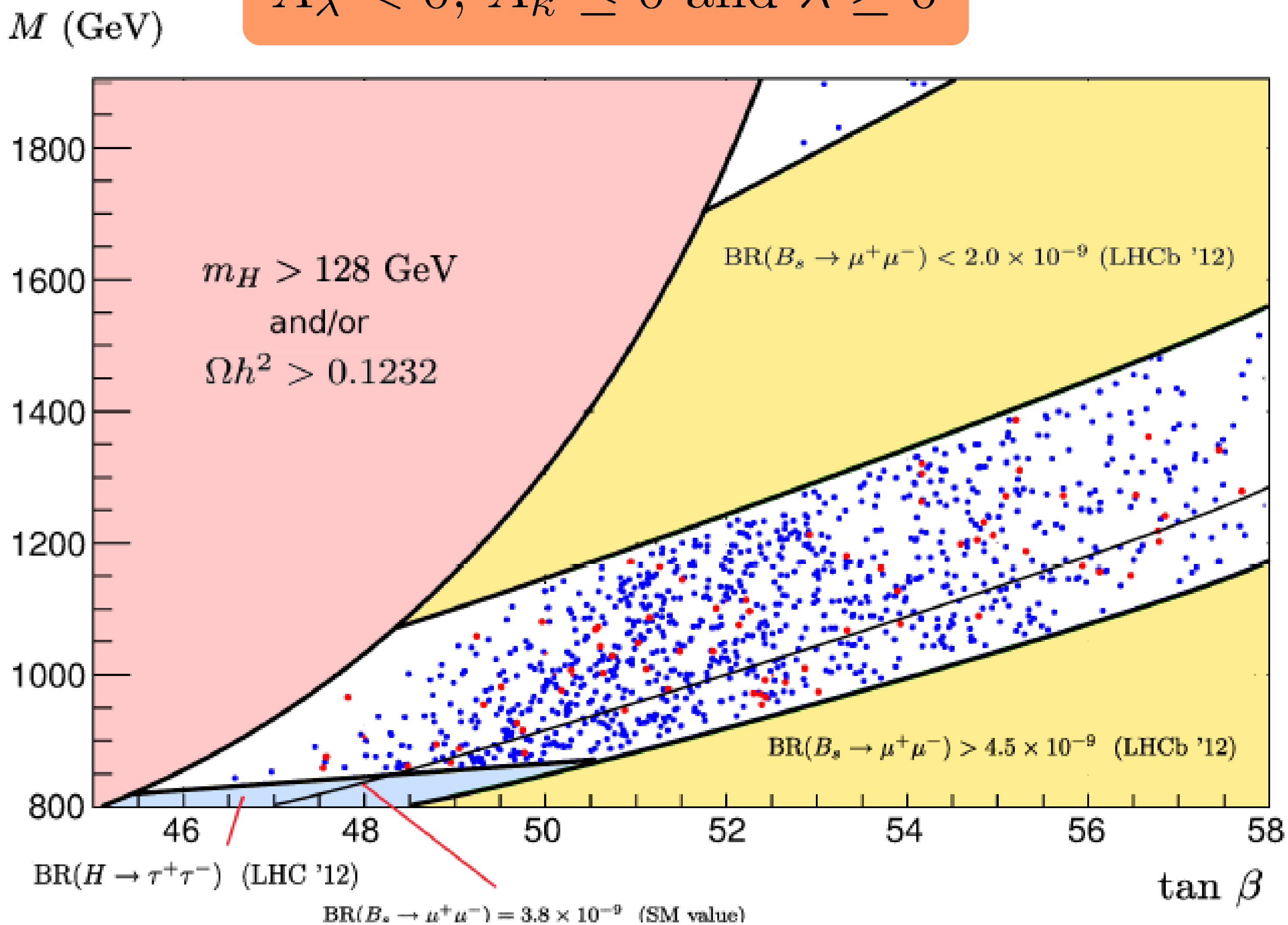
Ellwanger, Gunion, Hugonie (2004)

  - EWSB,
  - Reduced cross sections for Higgs decays (ATLAS and CMS results)
  - Flavor observables (LHCb results)
  - Dark matter relic density using `micrOMEGAS` (WMAP results)

Belanger, Boudejma, Pukhov, Semenov (2011)

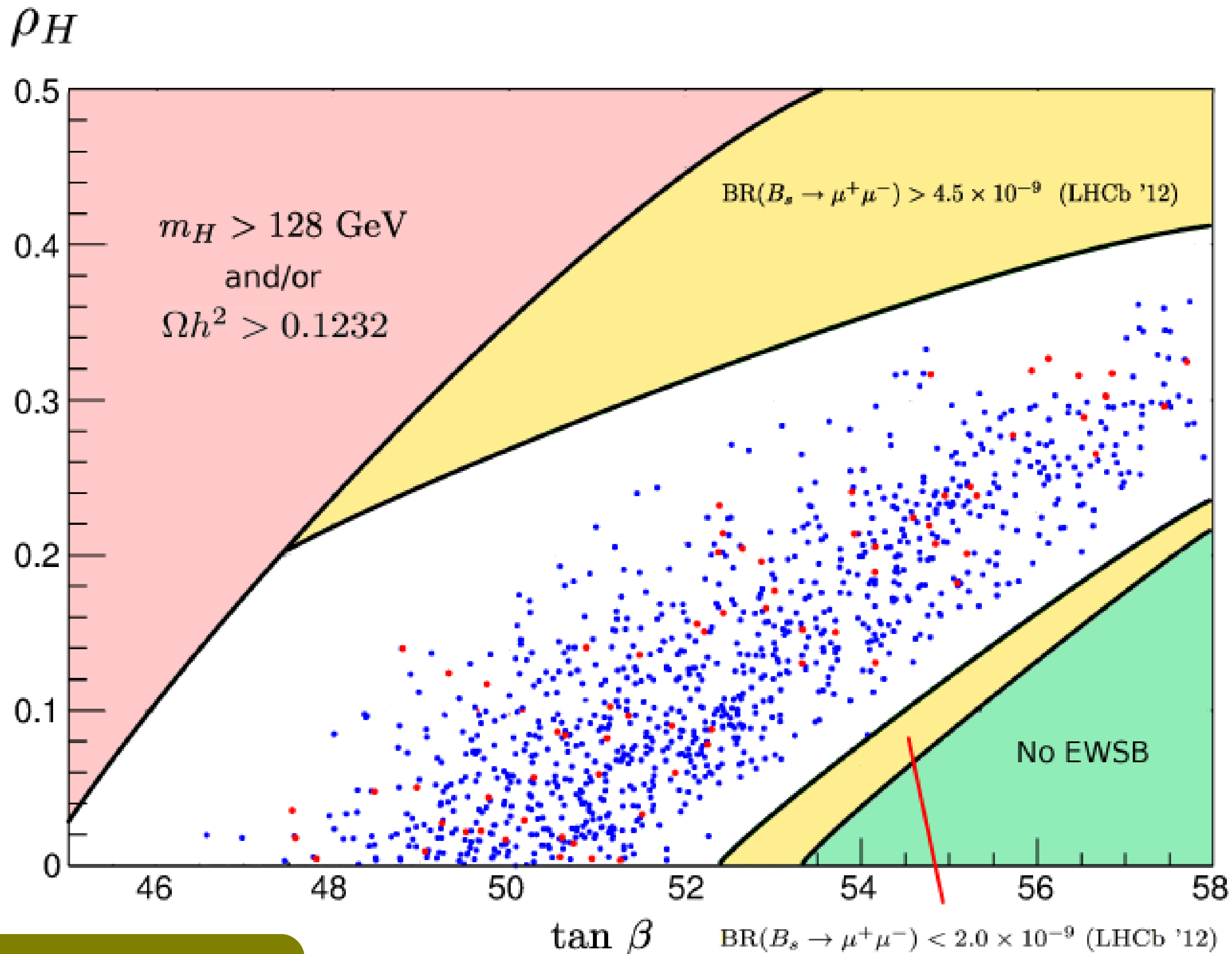
T-modulus dominated NMSSM

$A_\lambda < 0,\ A_\kappa \leq 0$ and $\lambda \geq 0$



L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

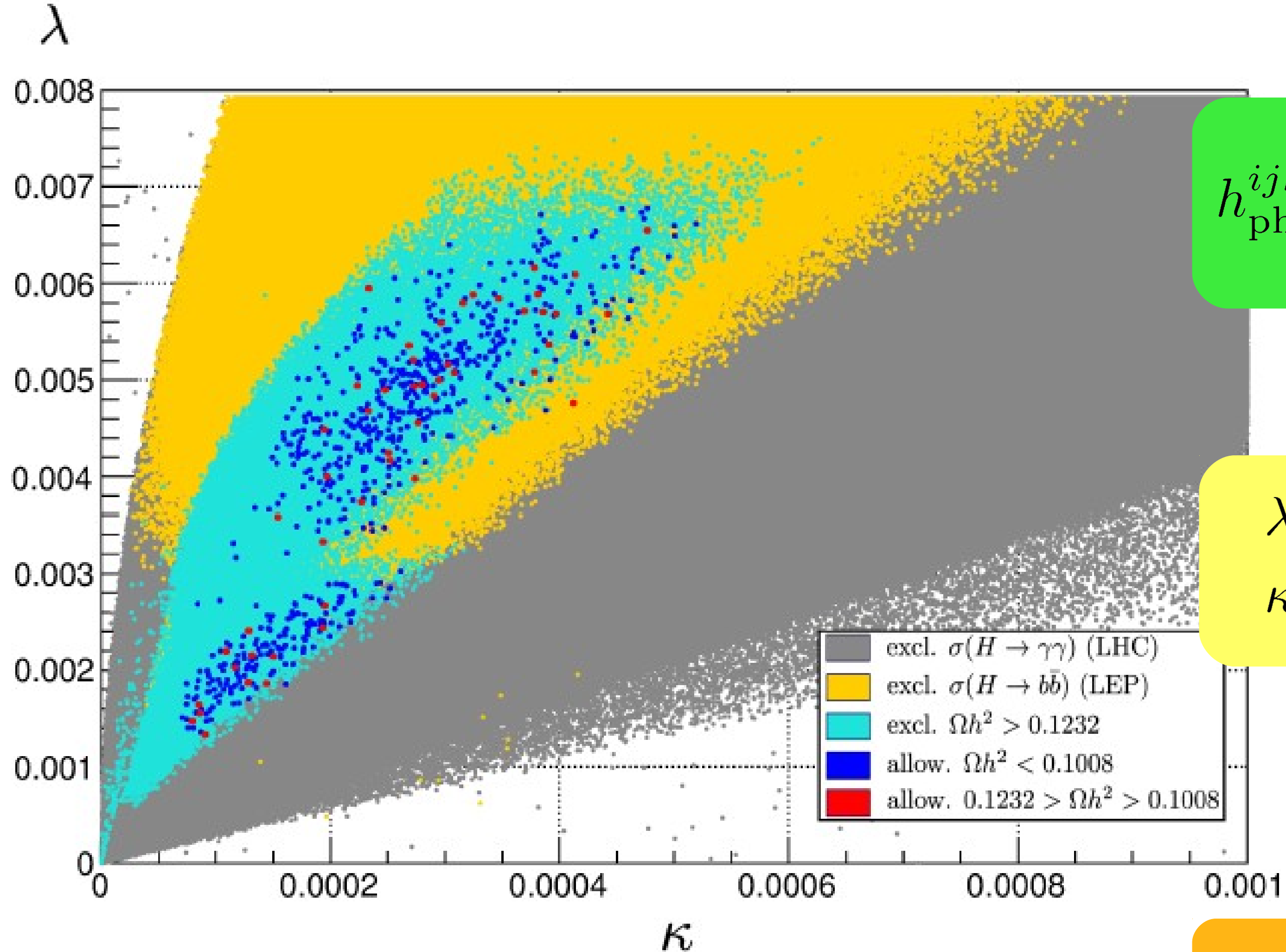
T-modulus dominated NMSSM



$$\rho_H \simeq \alpha_G^{1/2} \simeq 0.2$$

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM



$$h^{ijk}_{\rm phys} = \frac{h_0^{ijk}}{(K_i K_j K_k)^{1/2}} e^{K/2}$$

$$\lambda_{\rm phys} = \lambda_0 \, t^{-1/2} \, t_S^{-1/4}$$
$$\kappa_{\rm phys} = \kappa_0 \, t_S^{-3/4}$$

$$t_S \simeq t = \alpha_G^{-1} \simeq 24$$

$$\lambda_{\rm phys}, \kappa_{\rm phys} \simeq 9 \times 10^{-2} \, \lambda_0, \kappa_0$$

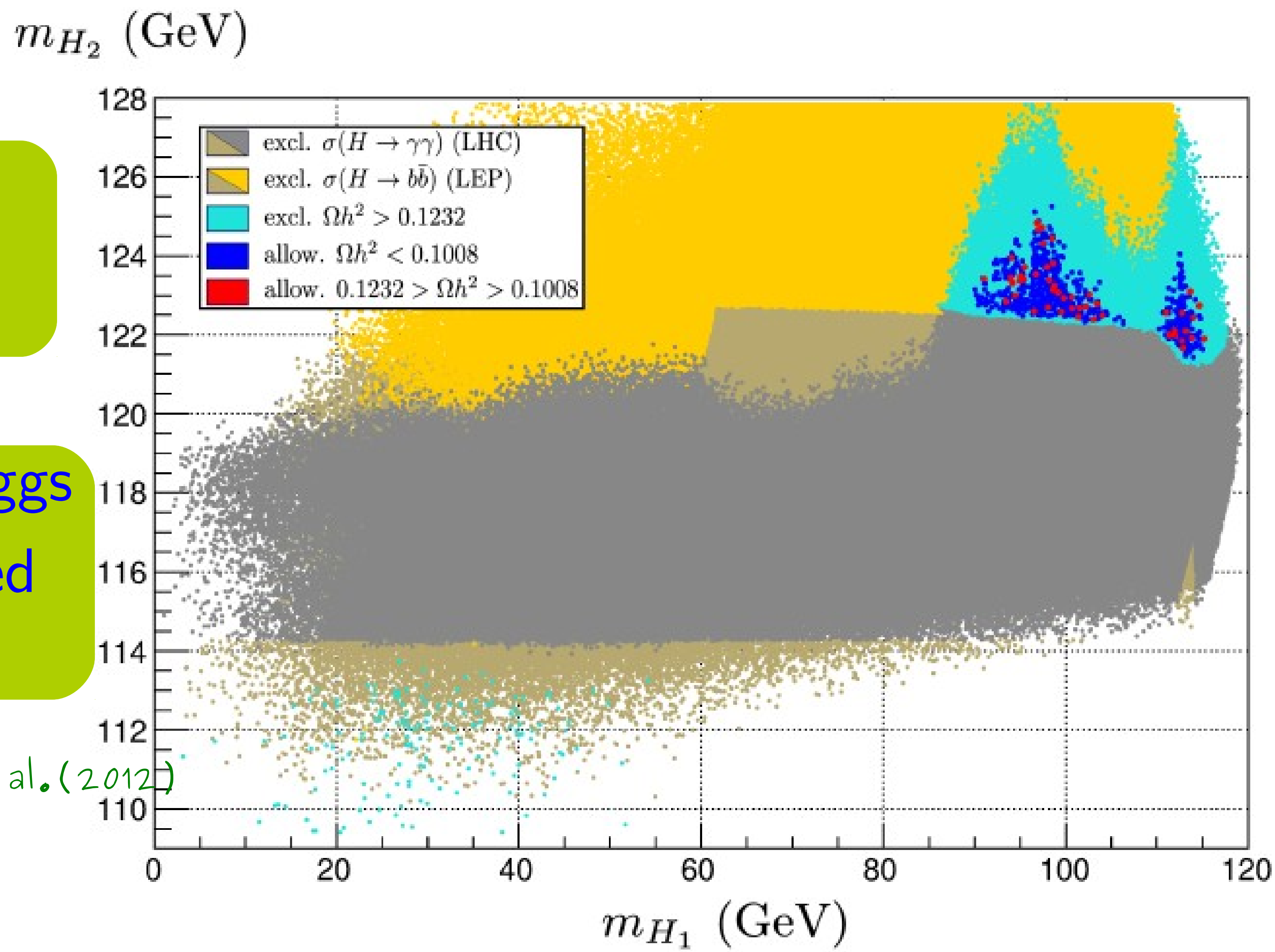
L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM

$m_{H_1} \lesssim 120$

$m_{H_2} \gtrsim 122$

Extra light Higgs fairly decoupled from SM



Also see Belanger et al.(2012)

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

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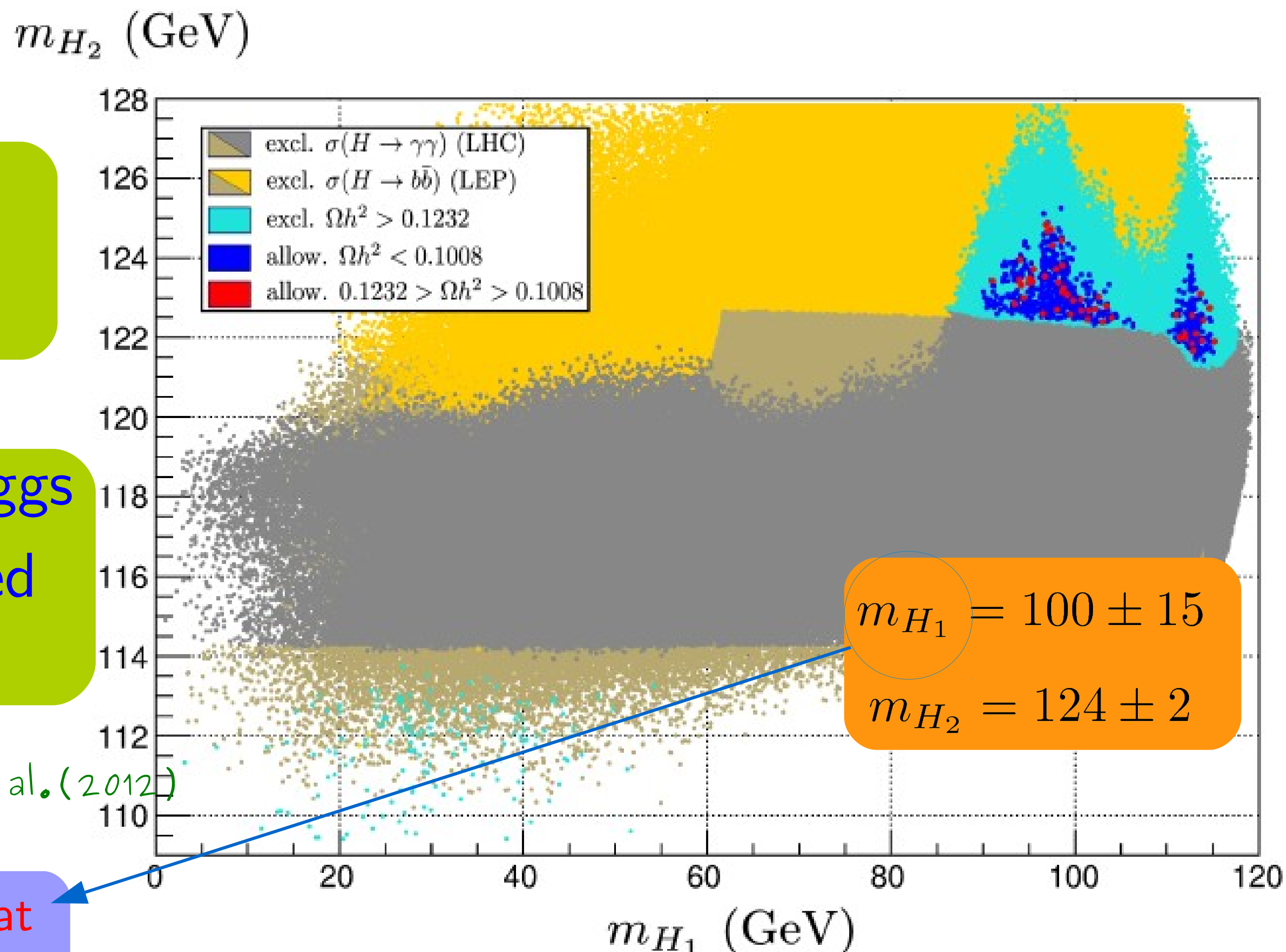


Extra light Higgs fairly decoupled from SM

$m_{H_1} = 100 \pm 15$

$m_{H_2} = 124 \pm 2$

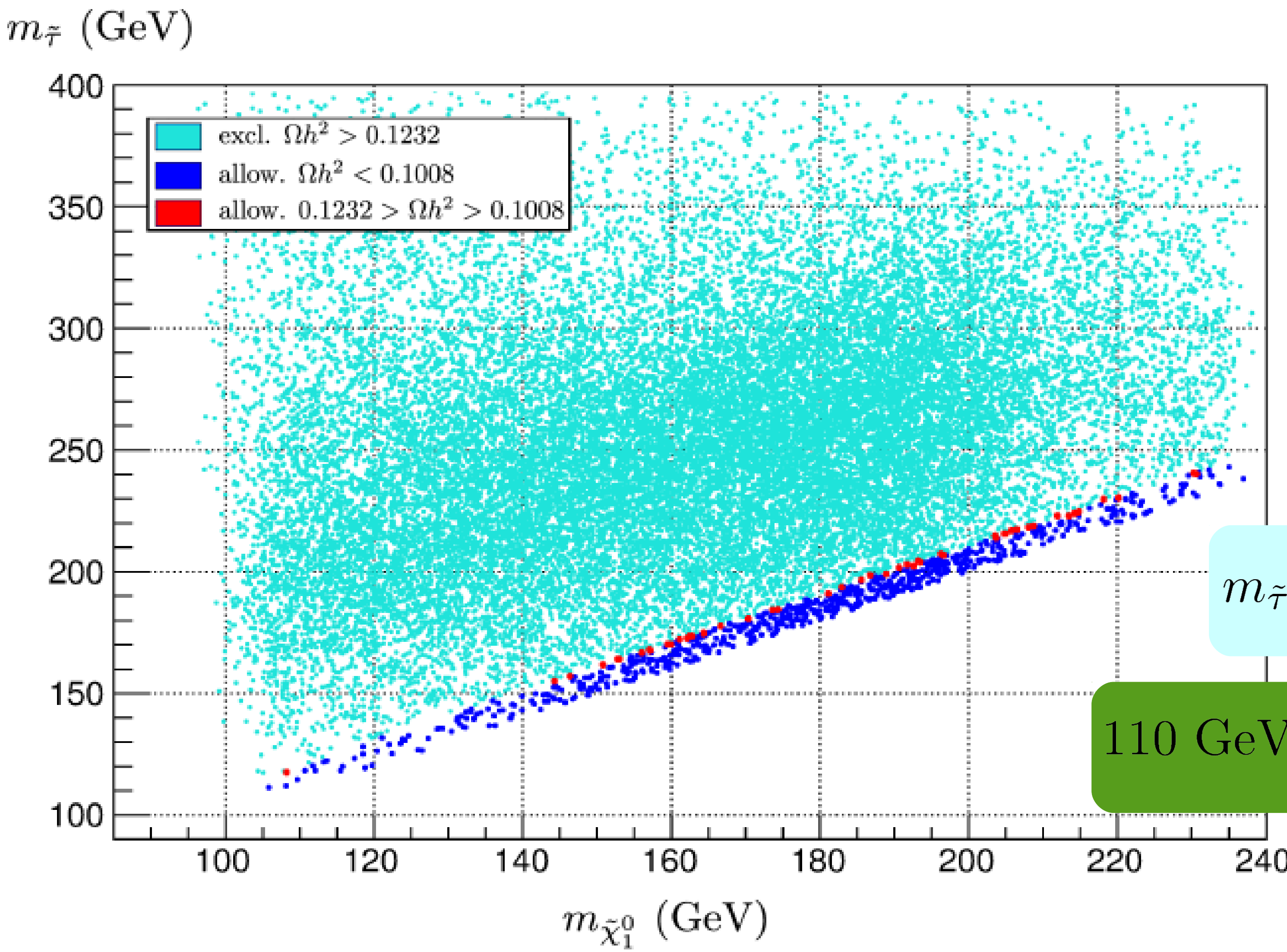
Also see Belanger et al.(2012)

2 sigma excess at LEP

$\mu_{eff} \gtrsim 1$

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM



$m_{\tilde{\chi}_1^0} \approx 2\kappa v_s$

$m_{\tilde{\tau}} - m_{\tilde{\chi}_1^0} \approx 10$ GeV

110 GeV $\lesssim m_{\tilde{\tau}} \lesssim$ 250 GeV

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

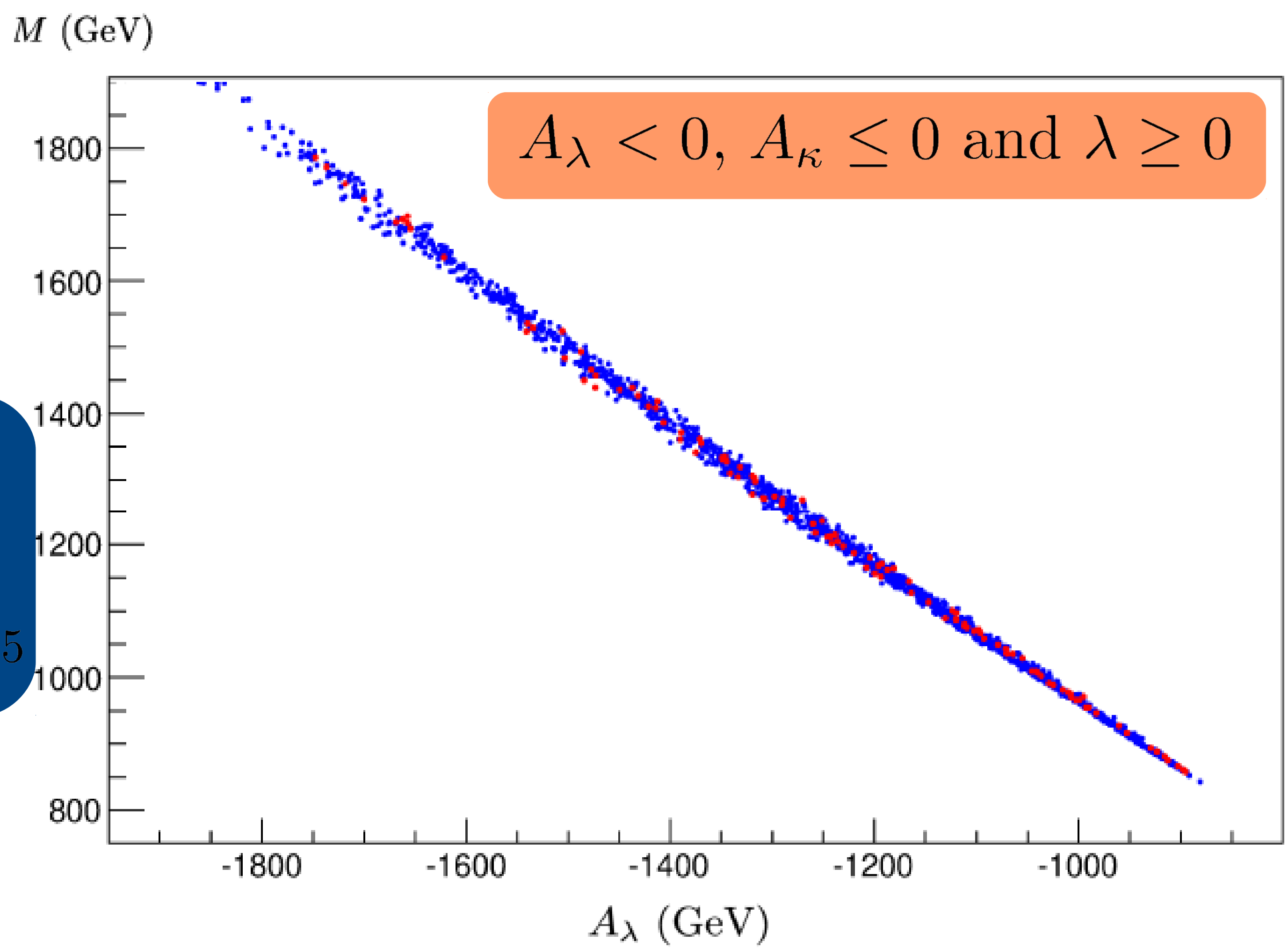
T-modulus dominated NMSSM

$$A_\kappa = m_S^2 = 0$$

$$A_\lambda = -M\,(1-\rho_H)$$

$$(A_\kappa/A) \lesssim 0.3$$

$$-0.015 \lesssim \left(\frac{m_S}{m_{\mathbf{\bar{5},10}}}\right)^2 \lesssim 0.035$$



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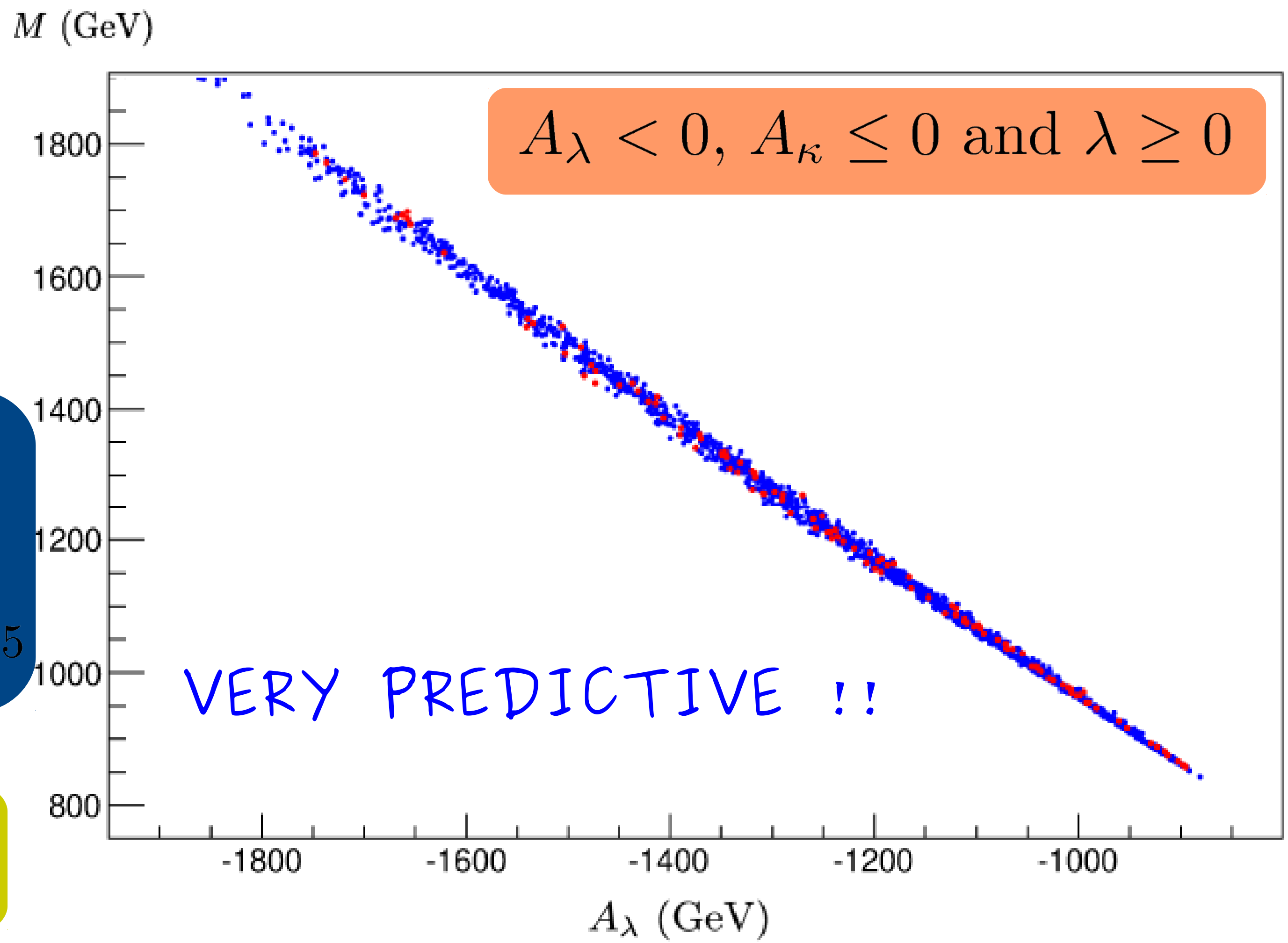
$$M \;, \rho_H \;, A_\lambda, \;, A_\kappa$$

λ $tan\beta$



L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

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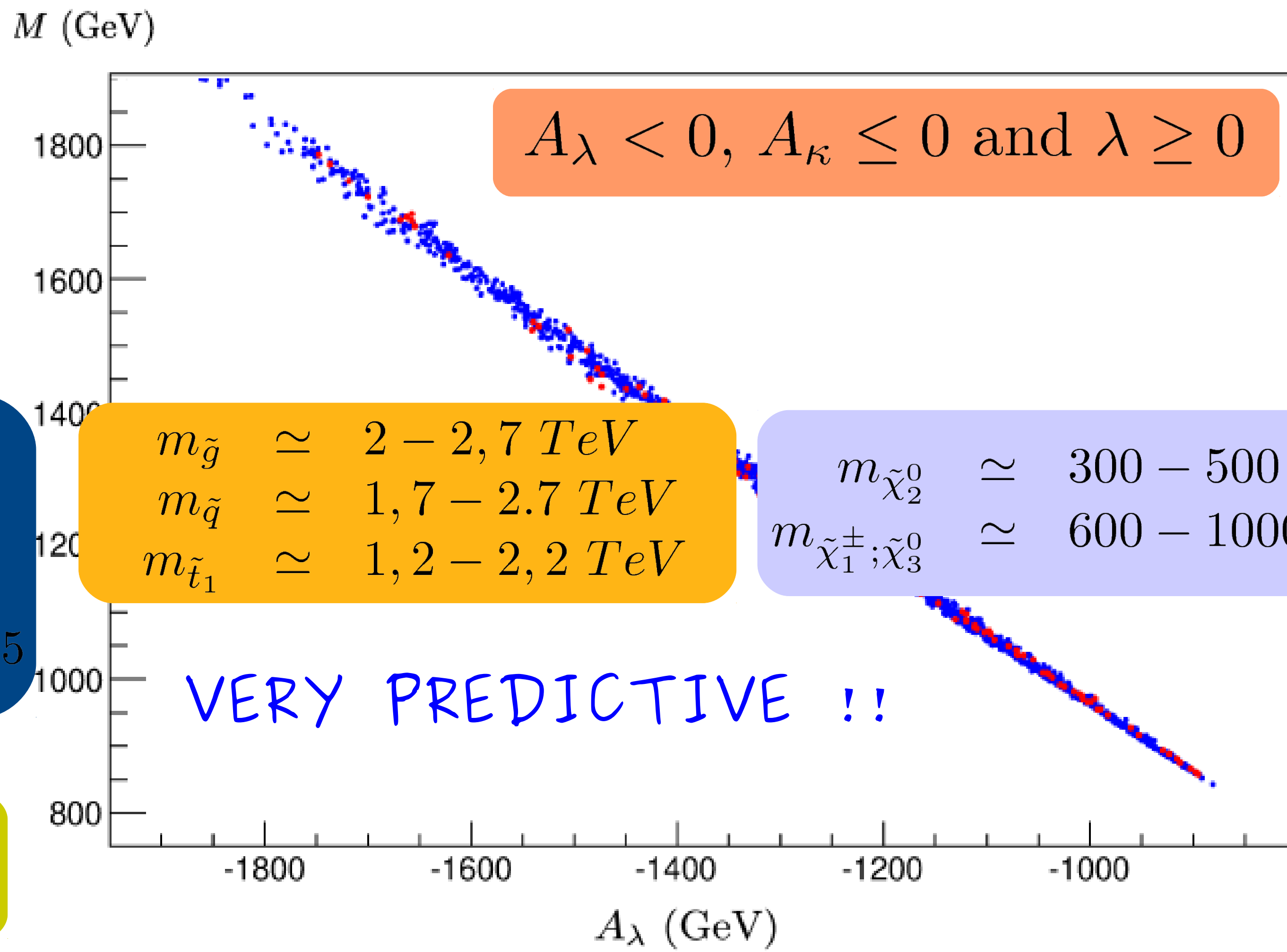
M , ρ_H , A_λ, , A_κ

λ $tan\beta$



$A_\lambda < 0,\ A_\kappa \leq 0$ and $\lambda \geq 0$

$$m_{\tilde{g}} \simeq 2 - 2,7\ TeV$$
$$m_{\tilde{q}} \simeq 1,7 - 2.7\ TeV$$
$$m_{\tilde{t}_1} \simeq 1,2 - 2,2\ TeV$$

$$m_{\tilde{\chi}_2^0} \simeq 300 - 500\ GeV$$
$$m_{\tilde{\chi}_1^\pm;\tilde{\chi}_3^0} \simeq 600 - 1000\ GeV$$

VERY PREDICTIVE !!

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM

$$A_\kappa = m_S^2 = 0$$

$$A_\lambda = -M\,(1-\rho_H)$$

Multitau signals, hard central jets and missing energy

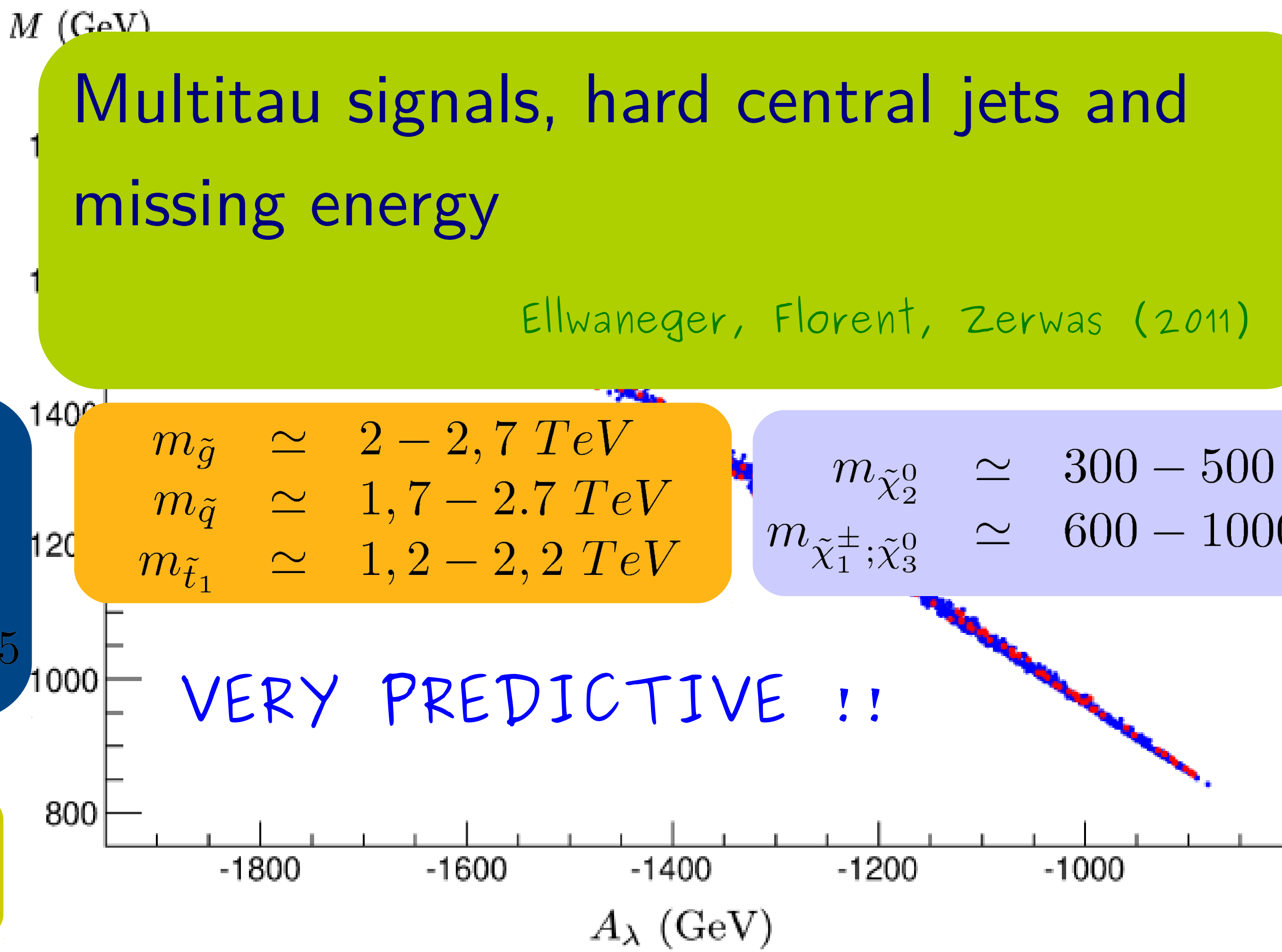
Ellwaneger, Florent, Zerwas (2011)

$$(A_\kappa/A) \lesssim 0.3$$

$$-0.015 \lesssim \left(\frac{m_S}{m_{\mathbf{5},\mathbf{10}}}\right)^2 \lesssim 0.035$$

$$\begin{aligned} m_{\tilde g} &\simeq 2-2,7\ TeV \\ m_{\tilde q} &\simeq 1,7-2.7\ TeV \\ m_{\tilde t_1} &\simeq 1,2-2,2\ TeV \end{aligned}$$

$$\begin{aligned} m_{\tilde\chi_2^0} &\simeq 300-500\ GeV \\ m_{\tilde\chi_1^\pm;\tilde\chi_3^0} &\simeq 600-1000\ GeV \end{aligned}$$



VERY PREDICTIVE !!

M , ρ_H , A_λ, , A_κ

λ

$tan\beta$

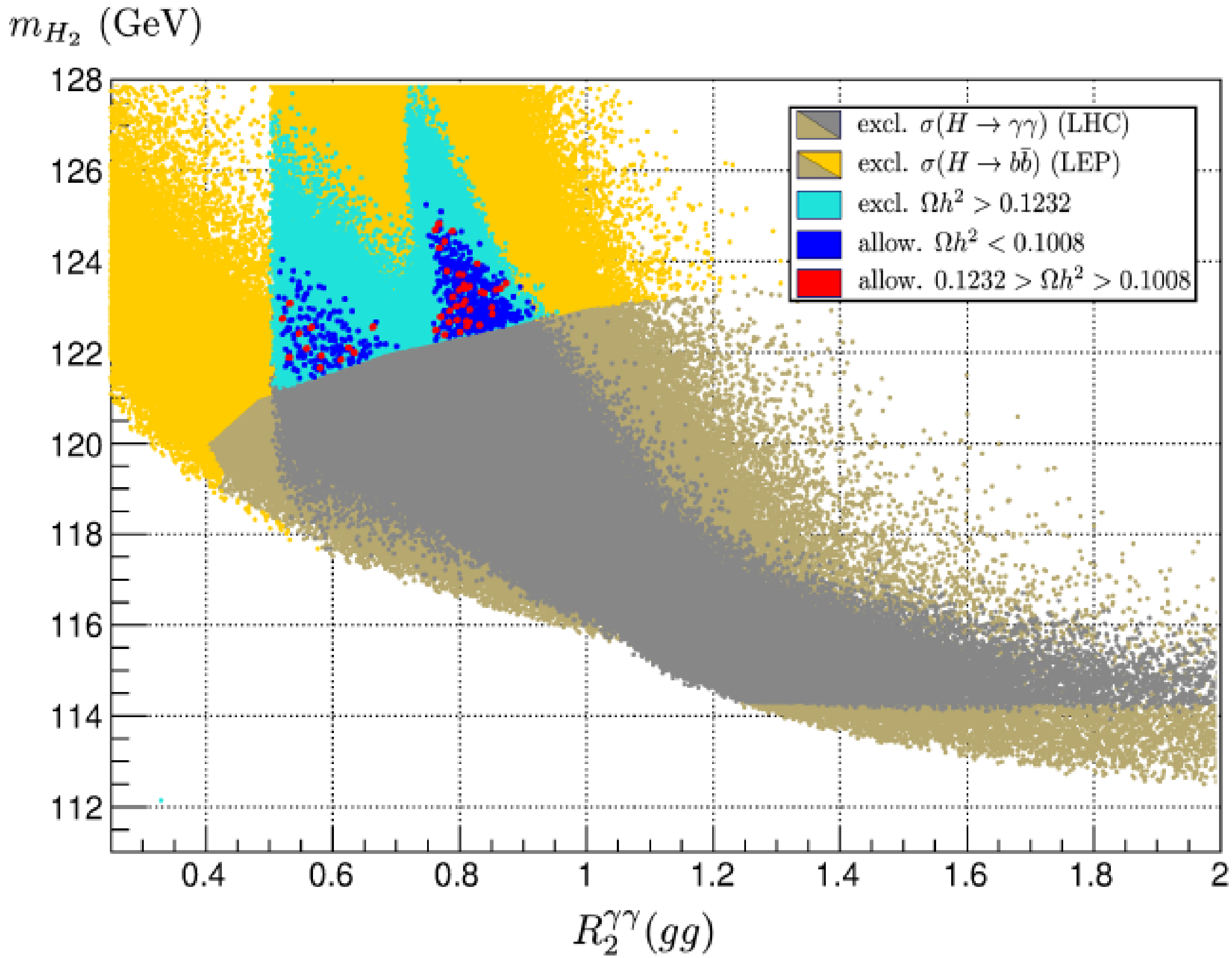
L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

Conclusions

- We have analyzed a constrained version of the NMSSM with boundary conditions obtained from the assumption of modulus dominance SUSY breaking in F-theory SU(5) GUT's.
- Requiring EWSB, Dark Matter, Flavor observables, LEP and LHC limits we have a very predictive model
  - Small λ and κ parameters ($\leqslant$ 0,1)
  - Large tan β .
  - Singlet dominant $m_{H1} = 100\ GeV$ (LEP excess) and $m_{H2} = 125\ GeV$
  - B $\rightarrow \mu\ \mu$ satisfies LHCb results and even below the SM value.
  - Dark matter is the neutralino (singlino). Correct relic density thanks to coannihilation with NLSP (stau).
  - Detectable at LHC.

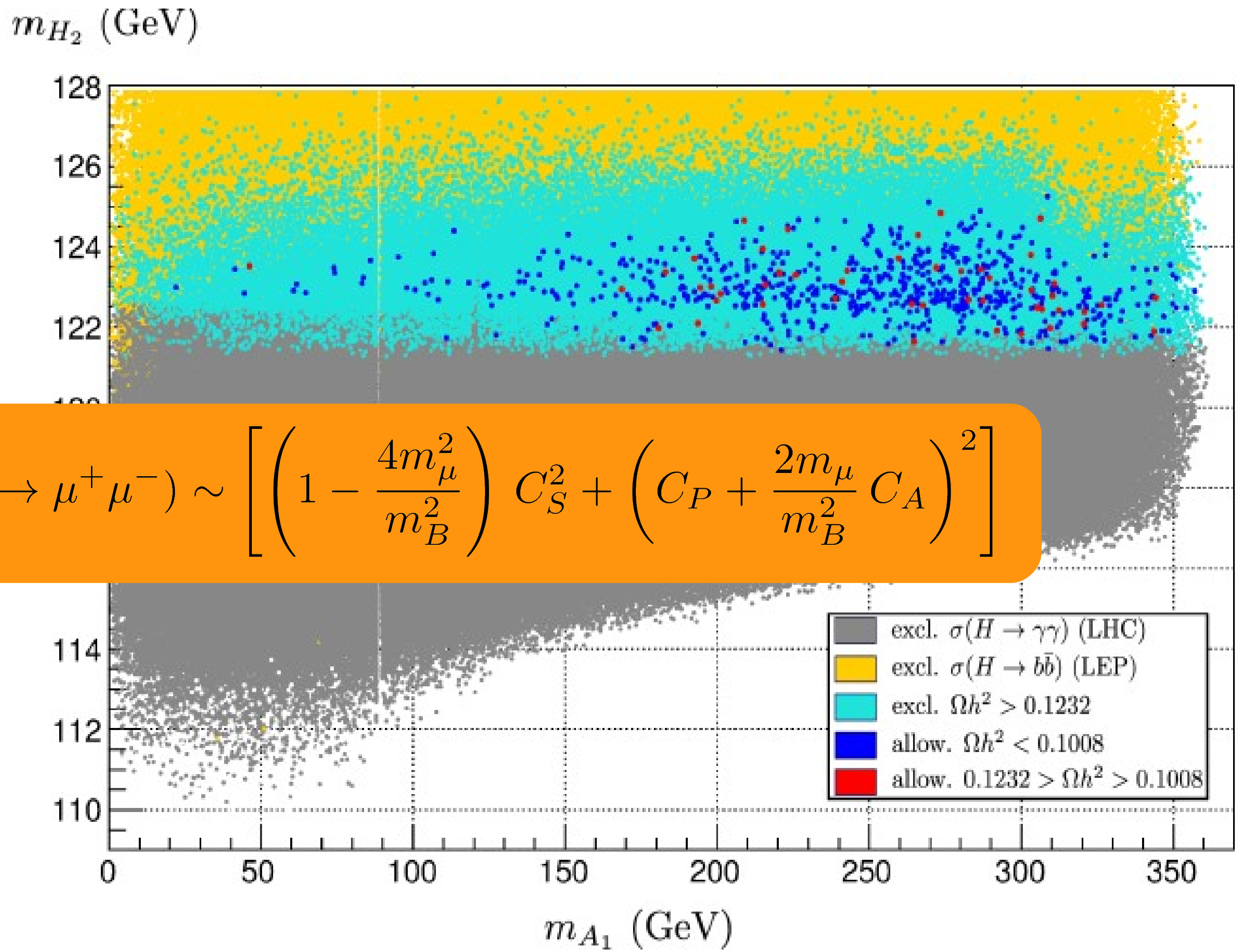
Backup slides

T-modulus dominated NMSSM



L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM



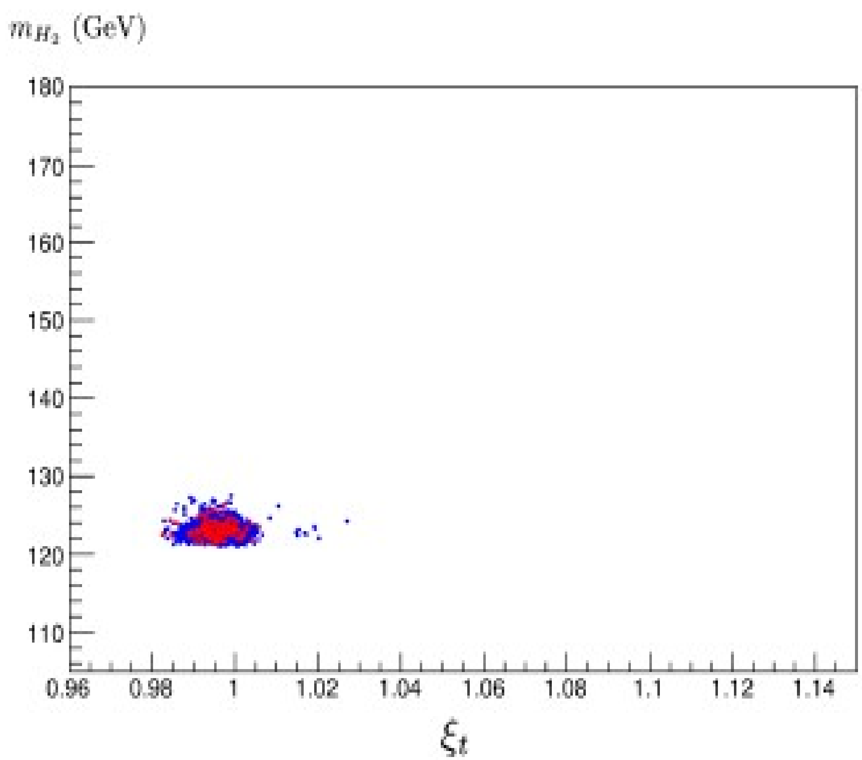
$$\mathrm{BR}(B_s \to \mu^+\mu^-) \sim \left[\left(1 - \frac{4m_\mu^2}{m_B^2}\right) C_S^2 + \left(C_P + \frac{2m_\mu}{m_B^2}\, C_A\right)^2\right]$$

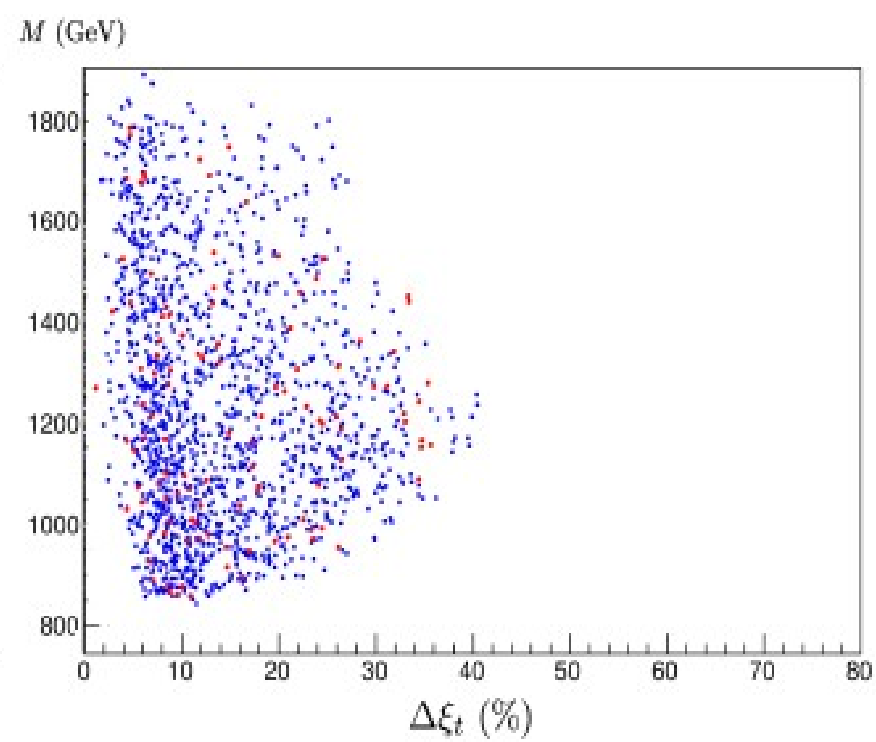
L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM

$$K_S = \frac{t_S^{1/2}\, t^{1-\xi_t}}{t_b}$$

$$\begin{aligned} A_\lambda &= -M(2-\xi_t-\rho_H) \\ A_\kappa &= -3M(1-\xi_t) \\ m_S^2 &= |M|^2(1-\xi_t) \end{aligned}$$





L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

T-modulus dominated NMSSM

Point	$\tilde{g}$	$\tilde{Q}_{R,L}$	$\tilde{t}_{1,2}$	$\tilde{b}_{1,2}$	$\tilde{L}_{R,L}$	$\tilde{\tau}_{1,2}$	$\tilde{\chi}_i^0$	$\tilde{\chi}_i^+$	m_{H_i}	m_{A_i}	m_{H^+}
P_1	1921	1758 1827	1263 1558	1481 1583	684 827	230 719	213 367; 696 1238; 1243	696 1244	103 172.4 1016	321 1016	1019
P_2	1983	1814 1886	1302 1601	1521 1626	708 855	175 735	164 381; 721 1274; 1279	721 1279	98.1 173.4 1036	220 1036	1040
P_3	2716	1989 2069	1434 1749	1673 1778	782 944	199 807	189 423; 800 1394; 1400	800 1400	96.9 174.8 1131	273 1131	1134
P_4	2236	2042 2125	1499 1802	1718 1827	804 971	197 831	186 436; 824 1440; 1444	824 1445	97.4 174.3 1095	266 1094	1098
P_5	2289	2091 2175	1527 1841	1762 1868	825 996	216 851	205 447; 845 1471; 1475	845 1476	97.4 174.7 1148	306 1148	1151
P_6	2585	2358 2455	1728 2064	1986 2095	939 1133	178 955	167 513; 967 1653; 1657	967 1657	98.5 174.4 1274	223 1274	1277
P_7	2663	2428 2528	1809 2134	2046 2161	970 1169	204 990	193 530; 999 1712; 1716	999 1716	93.9 173.4 1227	287 1227	1230
P_8	2769	2525 2629	1862 2207	2127 2238	1011 1219	164 1023	153 554; 1043 1770; 1774	1043 1774	97.9 173.7 1330	192 1329	1332

L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

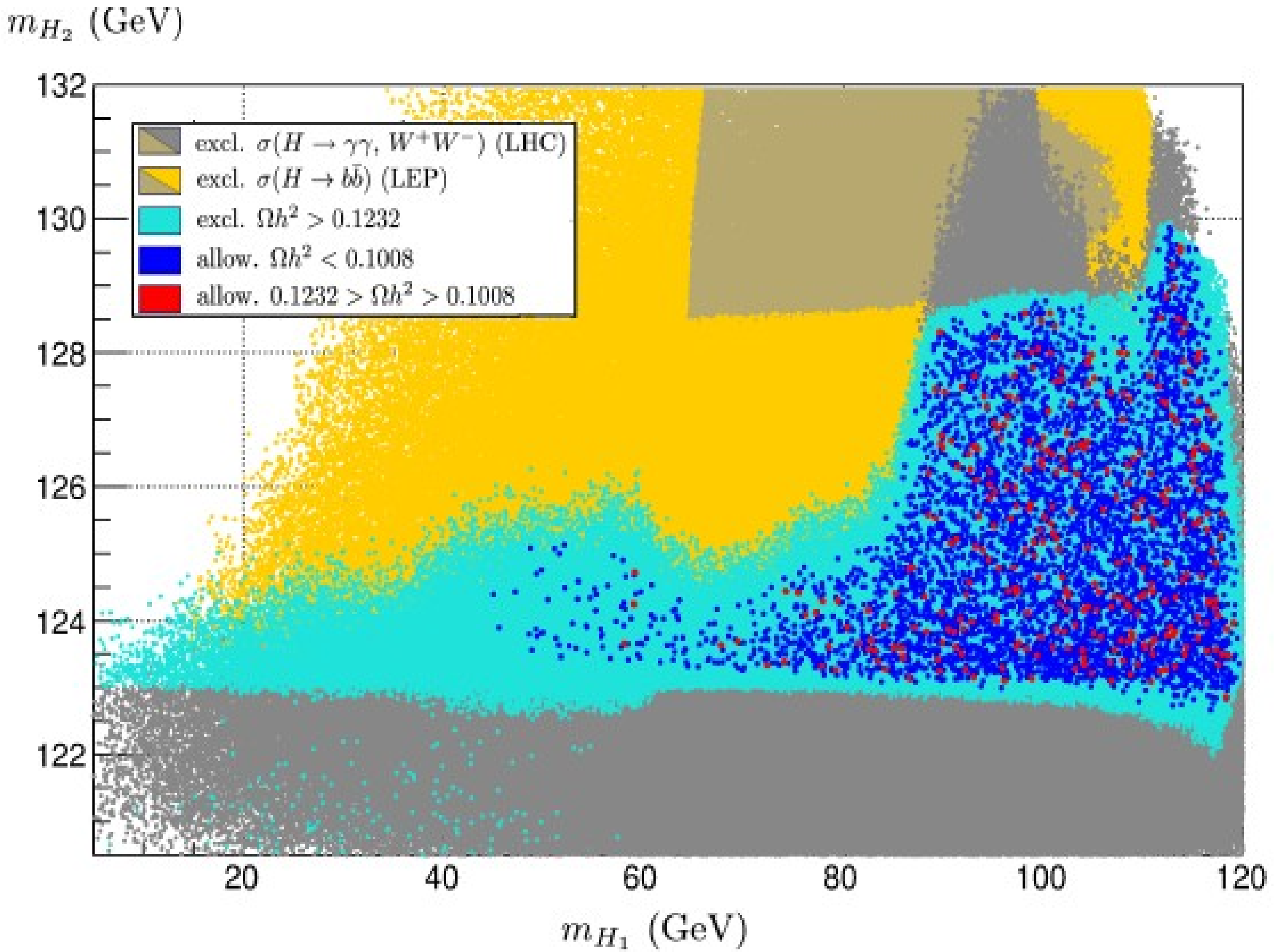
T-modulus dominated NMSSM

Point	M	$\tan\beta$	ρ_H	λ^{GUT}	κ^{GUT}	A_λ^{GUT}	A_κ^{GUT}	m_S^{GUT}
P_1	858.2	47.5	0.035	$5.2\cdot 10^{-3}$	$4.1\cdot 10^{-4}$	-895.4	-319.2	105.9
P_2	888.0	49.0	0.0092	$6.5\cdot 10^{-3}$	$3.8\cdot 10^{-4}$	-922.9	-195.6	50.0
P_3	981.4	49.5	0.021	$6.7\cdot 10^{-3}$	$4.1\cdot 10^{-4}$	-1015.7	-262.2	82.9
P_4	1009.9	52.9	0.195	$6.4\cdot 10^{-3}$	$3.7\cdot 10^{-4}$	-1045.7	-252.7	78.5
P_5	1036.0	51.5	0.135	$6.3\cdot 10^{-3}$	$3.9\cdot 10^{-4}$	-1070.3	-303.1	99.9
P_6	1180.5	53.3	0.030	$5.5\cdot 10^{-3}$	$2.5\cdot 10^{-4}$	-1204.2	-198.2	50.6
P_7	1218.5	56.8	0.30	$5.7\cdot 10^{-3}$	$2.8\cdot 10^{-4}$	-1257.9	-281.6	91.9
P_8	1271.0	55.1	0.182	$5.1\cdot 10^{-3}$	$1.9\cdot 10^{-4}$	-1290.0	-160.5	22.7

Point	λ^{SUSY}	κ^{SUSY}	A_λ^{SUSY}	A_κ^{SUSY}	m_S^{SUSY}	μ_{eff}
P_1	$4.8\cdot 10^{-3}$	$4.1\cdot 10^{-4}$	-107.0	-319.1	105.8	1243
P_2	$5.9\cdot 10^{-3}$	$3.8\cdot 10^{-4}$	-84.3	-195.5	49.9	1280
P_3	$6.1\cdot 10^{-3}$	$4.1\cdot 10^{-4}$	-97.2	-262.2	82.8	1401
P_4	$5.7\cdot 10^{-3}$	$3.7\cdot 10^{-4}$	-98.9	-252.6	78.4	1447
P_5	$5.7\cdot 10^{-3}$	$4.0\cdot 10^{-4}$	-107.3	-303	99.9	1478
P_6	$4.9\cdot 10^{-3}$	$2.5\cdot 10^{-4}$	-91.0	-198.2	50.5	1662
P_7	$4.9\cdot 10^{-3}$	$2.8\cdot 10^{-4}$	-107.3	-281.5	91.9	1723
P_8	$4.5\cdot 10^{-3}$	$1.9\cdot 10^{-4}$	-86.0	-160.5	22.5	1780

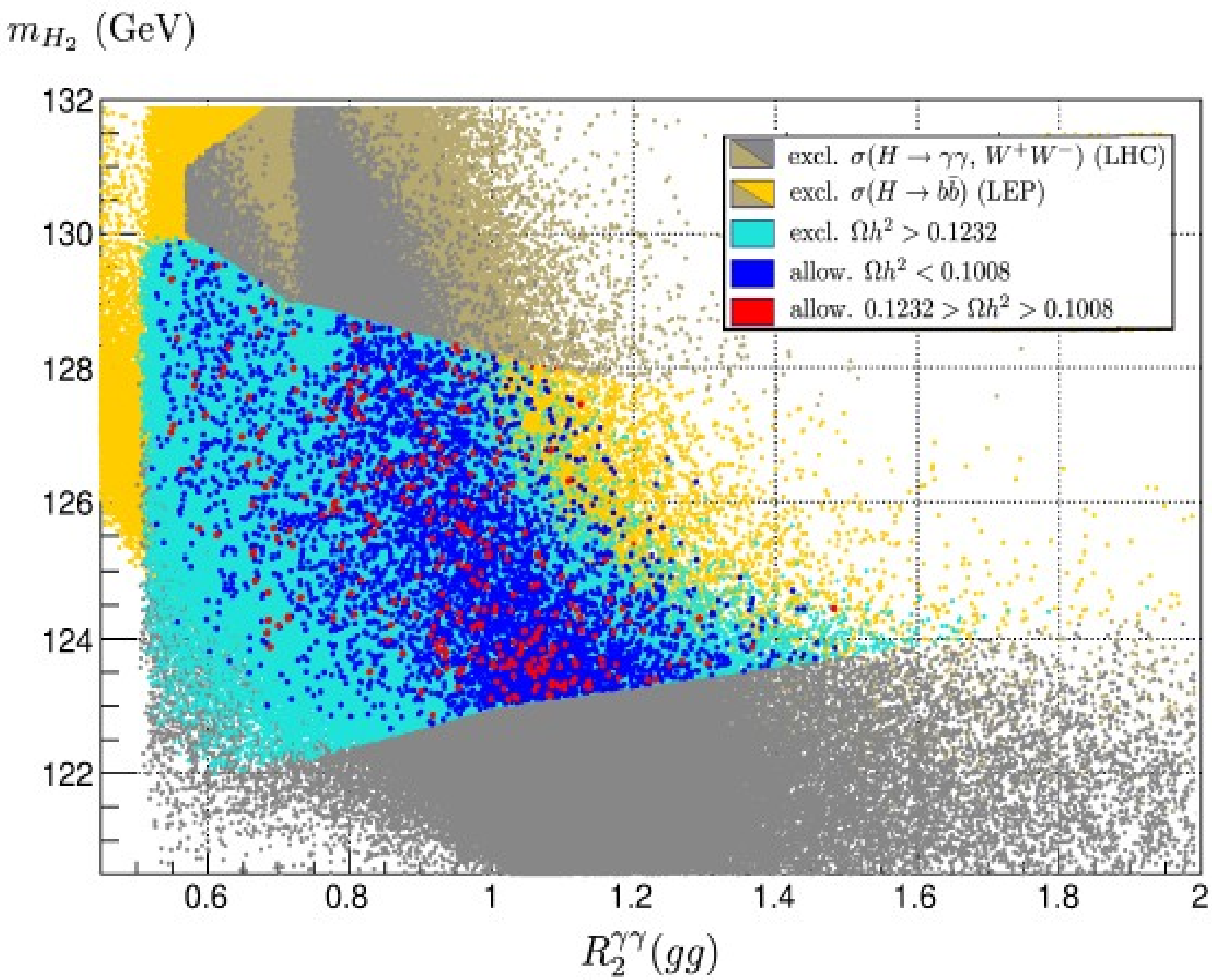
L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

1-loop



L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)

1-loop



L.A., Camara, Cerdeño, Ibañez, Valenzuela (2012)