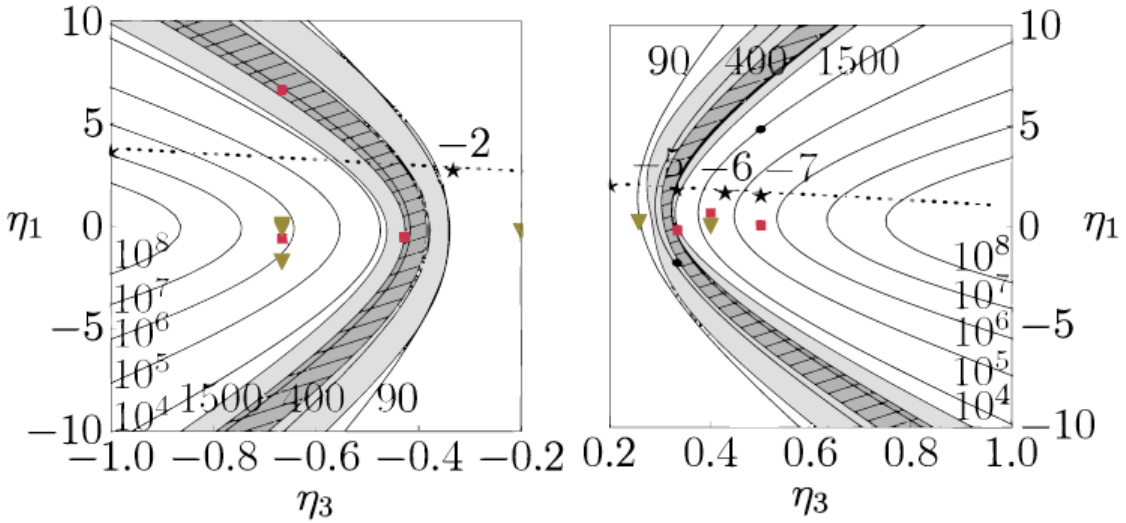
II. Reduced fine tuning : nonuniversal gaugino masses

Reduced fine tuning : nonuniversal gaugino masses

$$16\pi^2 \frac{d}{dt} m_{H_u}^2 = 3\left(2 |y_t|^2 (m_{H_u}^2 + m_{Q_3}^2 + m_{u_3}^2) + 2 |a_t|^2\right) - 6 g_2^2 |M_2|^2 - \frac{6}{5} g_1^2 |M_1|^2$$

New focus point: cancellation between M_3 and M_2 contributions if $|M_2|^2 \simeq |M_3|^2$ at M_{SUSY}



$$M_3 : M_2 : M_1 = \eta_3 : 1 : \eta_1$$

Reduced fine tuning : nonuniversal gaugino masses

$$16\pi^2 \frac{d}{dt} m_{H_u}^2 = 3\left(2 \mid y_t \mid^2 (m_{H_u}^2 + m_{Q_3}^2 + m_{u_3}^2) + 2 \mid a_t \mid^2\right) - 6 g_2^2 \mid M_2 \mid^2 - \frac{6}{5} g_1^2 \mid M_1 \mid^2$$

New focus point: cancellation between M_3 and M_2 contributions if $|M_2|^2 \simeq |M_3|^2$ at M_{SUSY}

Natural ratios? e.g.:

GUT: $SU(5): \ \Phi^N \subset (24 \times 24)_{symm} = 1 + 24 + 75 + 200; \quad SO(10): \ (45 \times 45)_{symm} = 1 + 54 + 210 + 770$

	$\eta_3 : 1 : \eta_1$	$2.7\eta_3 : 1 : 0.5\eta_1$
Representation	$M_3 : M_2 : M_1$ at M_{GUT}	$M_3 : M_2 : M_1$ at M_{EWSB}
1	1:1:1	6:2:1
24	2:(-3):(-1)	12:(-6):(-1)
75	1:3:(-5)	6:6:(-5)
200	1:2:10	6:4:10

String: $(3 + \delta_{GS}) : (-1 + \delta_{GS}) : \left(-\frac{33}{5} + \delta_{GS}\right)$ (OII, also mixed moduli anomaly)

$$M_a = M_s \left[\alpha + b_a g_a^2\right]$$

Phenomenology

- Gaugino mass ratios

$$\frac{M_i(Q)}{M_{1/2}} = \eta_i \frac{\alpha_i(Q)}{\alpha_i(M_X)} \quad \Rightarrow \quad \begin{aligned} \frac{M_1(Q)}{M_2(Q)} &\approx 0.5\eta_1 \\ M_2(Q) &\approx 0.8 M_{1/2} \\ \frac{M_3(Q)}{M_2(Q)} &\approx 2.7\eta_3 \end{aligned}$$

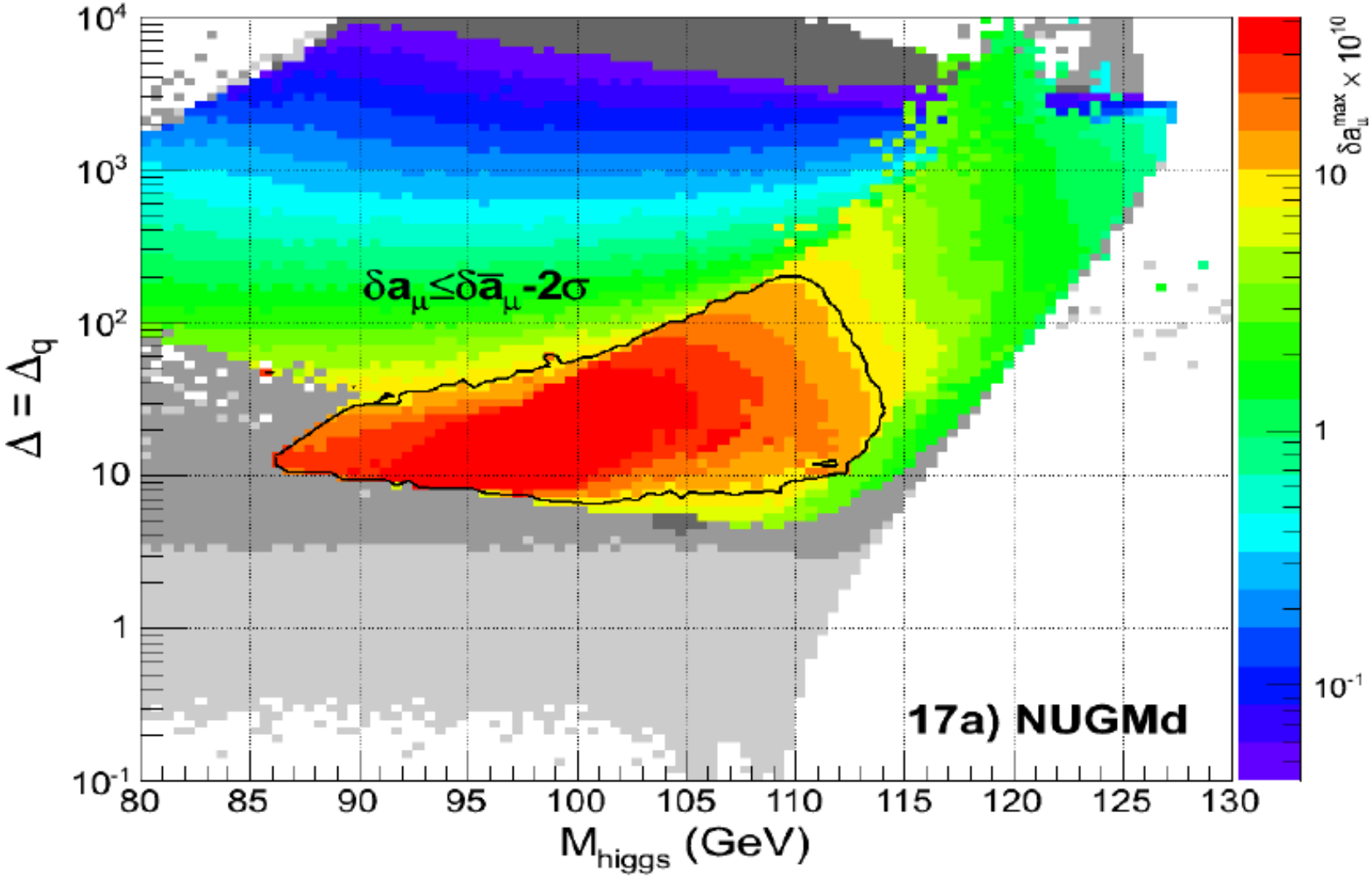
…. gauginos can be very heavy

- Light neutralino and 2 charginos nearly degenerate

$$m_{\chi_2^0} - m_{\chi_1^0} = M_Z^2 \left(\frac{s_W^2}{M_1} + \frac{c_W^2}{M_2} \right) + \mathcal{O}(\frac{M_Z^3}{M_2^2})$$

$$m_{\chi_1^\pm} - m_{\chi_1^0} = \frac{1}{2} M_Z^2 \left(\frac{s_W^2}{M_1} + \frac{c_W^2}{M_2} \right) + \frac{1}{2} M_Z^2 \left(\frac{s_W^2}{M_1} - \frac{c_W^2}{M_2} \right) \epsilon \sin 2\beta + \mathcal{O}(\frac{M_Z^3}{M_2^2})$$

+ for $|M_1| < \mu$, Bino or Higgsino LSP candidate



2-loop fine tuning in 75 case

Ghilencea, Lee, Park

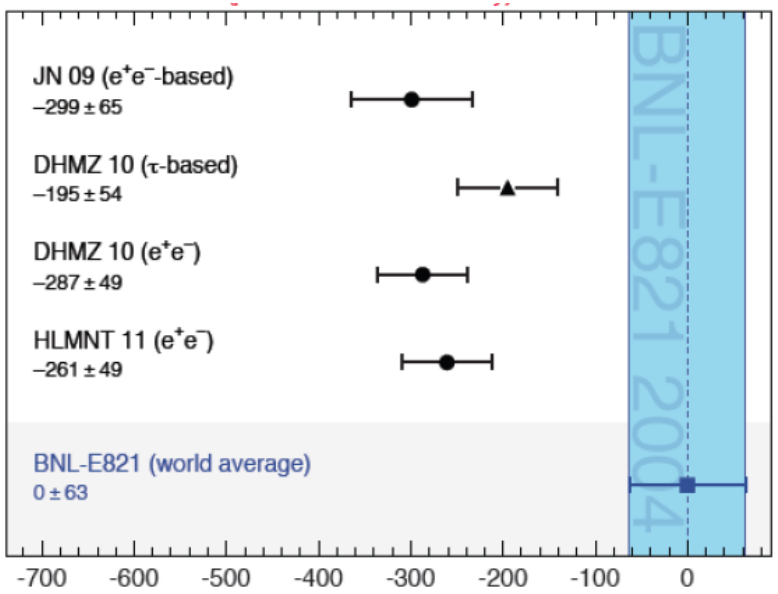
Muon g-2

$$a_\mu^{theory} - a_\mu^{expt} = -(28.7 \pm 8.0) \times 10^{-10}$$

Theory error from hadronic contribution:

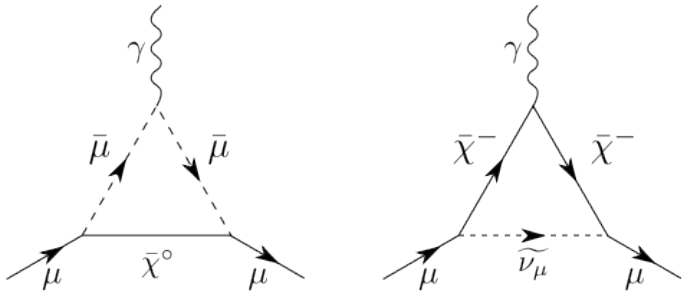
$$\delta a_\mu^{e^+e^-} = 3.6\,\sigma$$

$$\delta a_\mu^{\tau} = 2.4\,\sigma$$



SUSY

$$\delta a_\mu^{SUSY} = -13 \times 10^{-10} \left(\frac{100\,GeV}{M_{SUSY}} \right)^2 \tan\beta$$



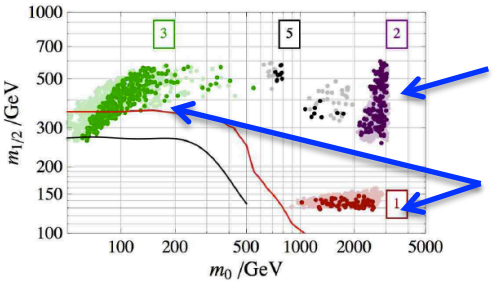
Needs light sleptons – anomaly/mirage spectrum?

Summary (before Higgs discovery)

- Hierarchy problem $\Longrightarrow$ SUSY breaking structure and/or further states

- CMSSM $m_i = M_0 \quad Max\left[\Delta_{EW}, \Delta_{\Omega}\right] = 15(29), \quad m_h = 114(116) \pm 2GeV$

  Complementary DM & LHC searches



(a) $m_h > 111$ GeV

DM $\quad \Delta \le 100 \quad$ Sensitivity $\times (10 - 100)$

LHC $\quad \left(\text{Full region } LHC\ 14TeV\ 10\,fb^{-1}\right)$

(Gauge mediation $\Delta >> 100$)

- NMSSM $\quad$ Reduced $\Delta \Longrightarrow$ GNMSSM $\Longrightarrow Z_{4R}, Z_{8R}$

  SUSY states can be (slightly)heavier

  $m_h \rightarrow 130GeV$

- Gaugino focus point $\quad M_i = \eta_i M_{1/2}$

  Characteristic η_i

  Light $\chi^{0,\pm}$

  $\delta(b \rightarrow s\gamma)$ significant

  $\delta(g-2)$ Small(?)

Summary (after Higgs discovery)

- Hierarchy problem $\Longrightarrow$ SUSY breaking structure and/or further states

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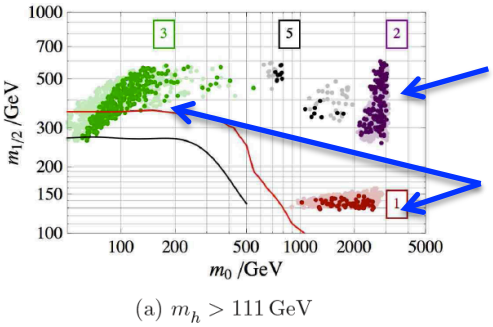

(a) $m_h > 111$ GeV

DM $\quad \Delta \leq 100 \quad$ Sensitivity $\times (10-100)$ (Now achieved!)

LHC $\quad$ (Full region $LHC\ 14TeV\ 10\,fb^{-1}$)

$\Delta_{MSSM} > 300$ for $m_H = 126GeV$

- NMSSM Reduced $\Delta \Longrightarrow$ GNMSSM $\Longrightarrow Z_{4R}, Z_{8R}$

  Further light/invisible Higgs a possibility

- Gaugino focus point

  Mixed anomaly mediation, mirage mediation …

  Light sleptons…g-2!

- Natural SUSY, SPLIT SUSY…

LHC and BSM

(More) solutions to the hierarchy problem

$\Lambda \leq 1 TeV$??

- Composite: e.g. technicolour

LHC and BSM

(More) solutions to the hierarchy problem

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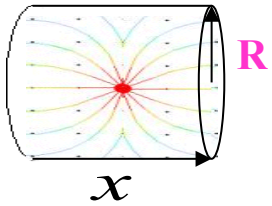
- Composite: e.g. technicolour
- $\Lambda_{fundamental} \simeq 1TeV!$

Xtra dimensions



$$V(r) = \frac{1}{M_*^{2+d} R^d} \frac{m_1 m_2}{r}, \quad D = 4 + d, \quad r \ll R$$

$$M^2_{Planck} = M_*^2 \left(M_* R \right)^d$$

(or warped extra dimensions)

LHC and BSM

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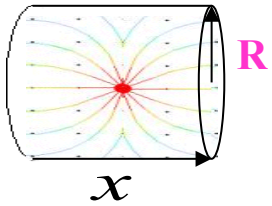

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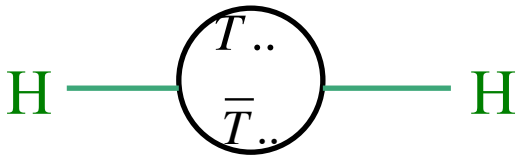
(or warped extra dimensions) c.f. Dudas lectures

- Symmetry protection Nambu - Goldstone



e.g. $SU(3) \rightarrow SU(2)$ $8 \rightarrow 3$ 5 Goldstone modes

$$\begin{pmatrix} . & . & H^{*+} \\ . & . & H^{*0} \\ H^- & H^0 & . \end{pmatrix}$$

Symmetry broken by gauge interactions – pseudo Goldstone bosons

...addresses little hierarchy problem only

....little Higgs

LHC and BSM

(More) solutions to the hierarchy problem

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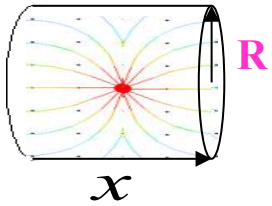

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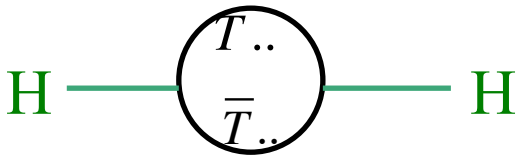

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Symmetry broken by gauge interactions – pseudo Goldstone bosons

...addresses little hierarchy problem only
....little Higgs

- Anthropic e.g split SUSY, no SUSY

Xtra dimensions

Kaluza Klein Decomposition

$$\int d^5x\sqrt{g}\left\{\frac{1}{2}\partial_M\Phi\partial^M\Phi-\frac{1}{2}M^2\Phi^2\right\} = \sum_n\int d^4x\,\frac{1}{2}\left\{\partial_\mu\phi_n\partial^\mu\phi_n-m_n^2\phi_n^2\right\}$$

$$\Phi(x^\mu,y) = \frac{e^{A(y)}}{\sqrt{L}}\sum_n\phi_n(x^\mu)f_n(y)$$

Universal extra dimensions

$$ds^2=\eta_{\mu\nu}dx^\mu dx^\nu-dy^2$$

Flat

$$f_n^{(+,+)} = \begin{cases} 1 & \text{for } n=0 \\ \sqrt{2}\cos m_n y & \text{for } n\neq 0 \end{cases}$$

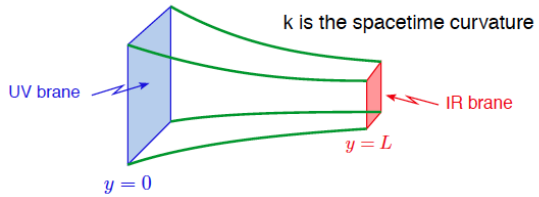
$$m_n^2=M^2+(n/R)^2$$

$$f_n^{(-,-)} = \sqrt{2}\sin m_n y\ ,$$

Warped extra dimensions

$$ds^2=e^{-2ky}\,\eta_{\mu\nu}dx^\mu dx^\nu-dy^2$$

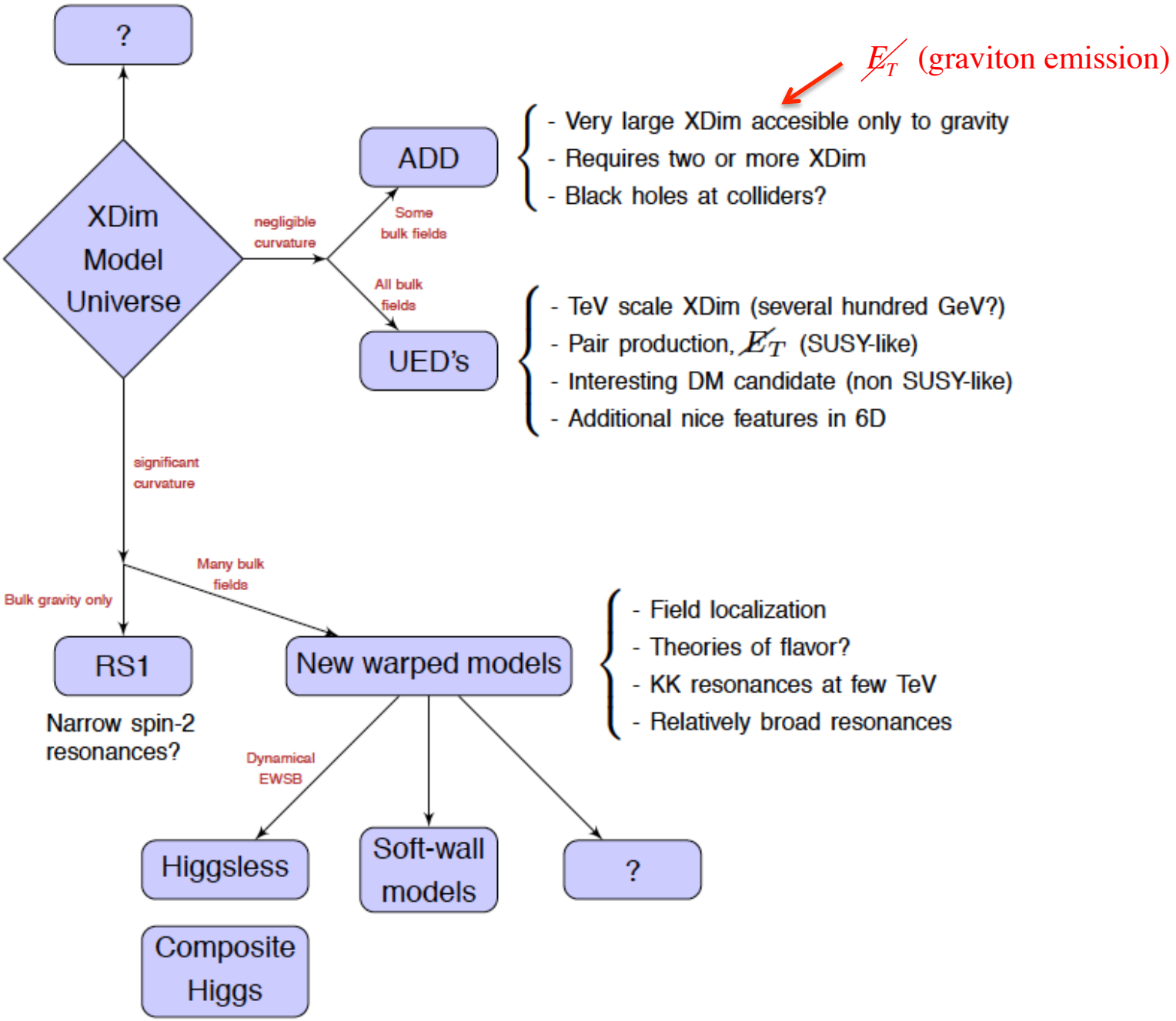
$$f_n = N_n\,e^{ky}\left\{J_\alpha\left(\frac{m_n}{k}e^{ky}\right)+b_n\,Y_\alpha\left(\frac{m_n}{k}e^{ky}\right)\right\}$$



AdS_5

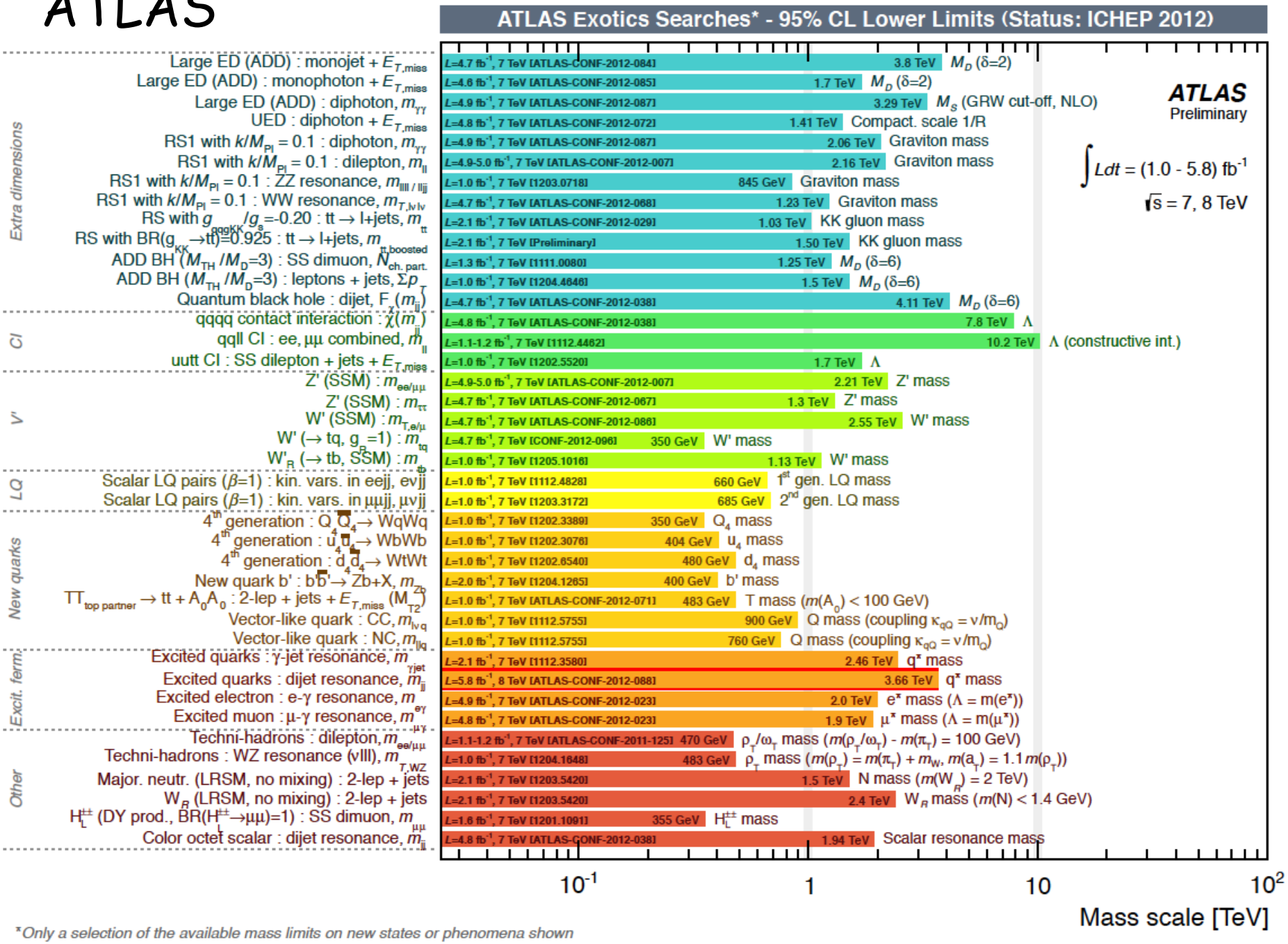
$$m^{(n)}=k\,x_n\,e^{-kL}=O(TeV),\qquad J_1(x_n)=0$$

$$\kappa^2=\frac{1}{M_*^3}\qquad M_P^2 = M_5^3\int_0^L dy\,e^{-2A(y)}$$



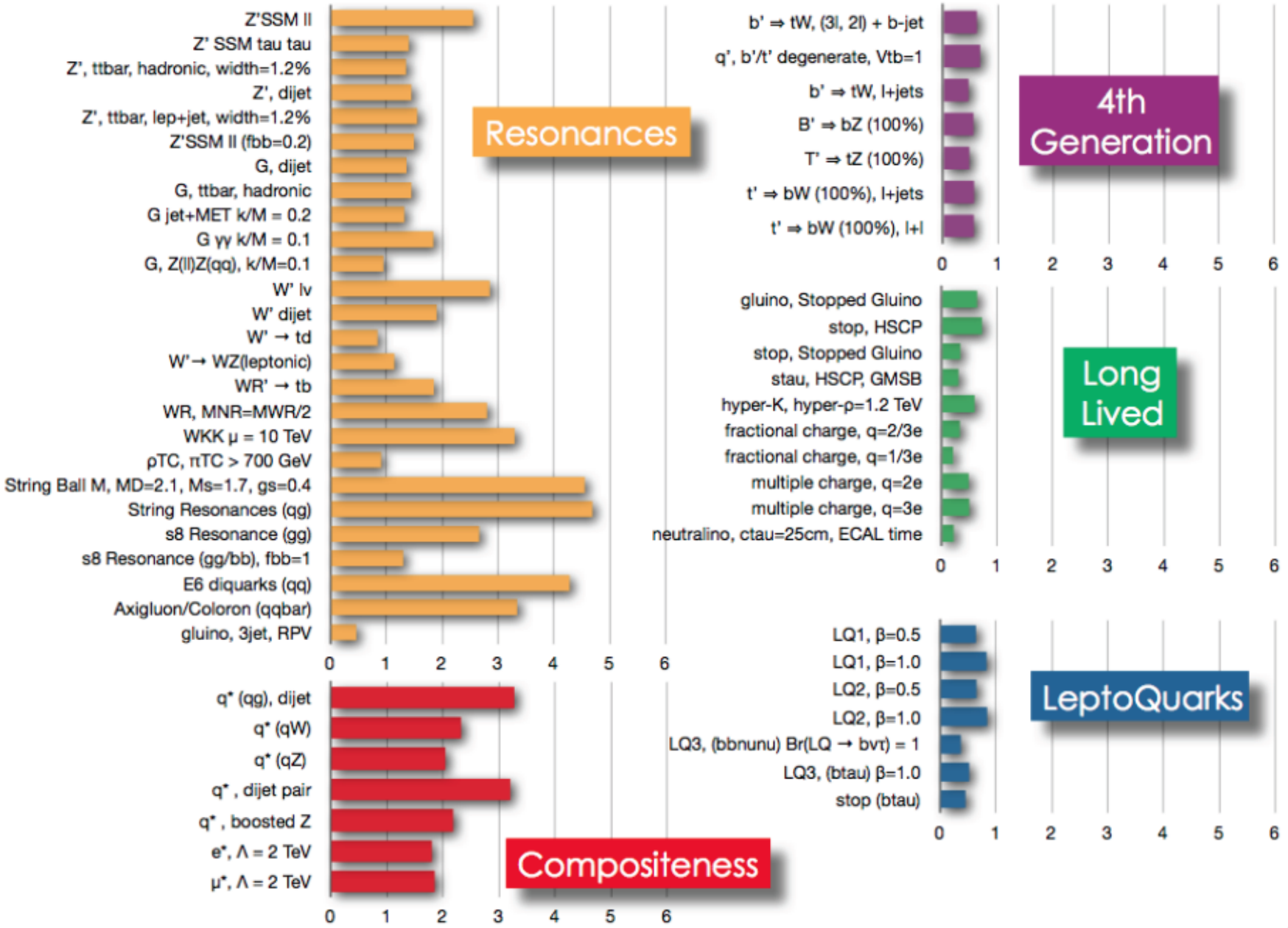
$\not{E}_T$ (graviton emission)

ATLAS



*Only a selection of the available mass limits on new states or phenomena shown

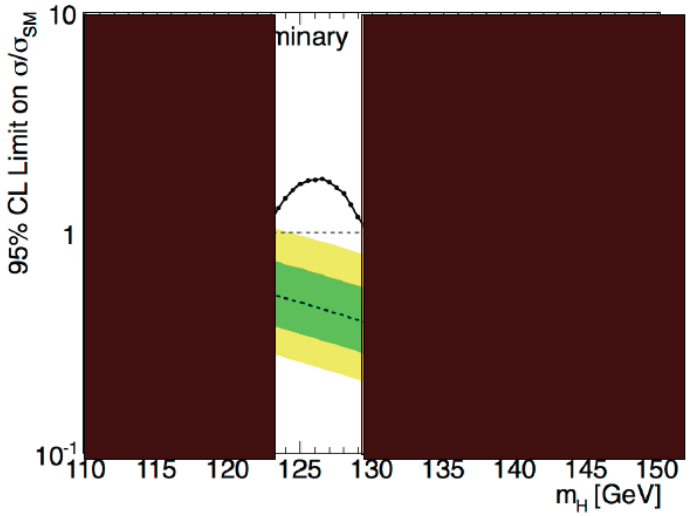
CMS bounds on exotics



LHC and BSM

Higgs discovery and exclusion – LHC July 2012

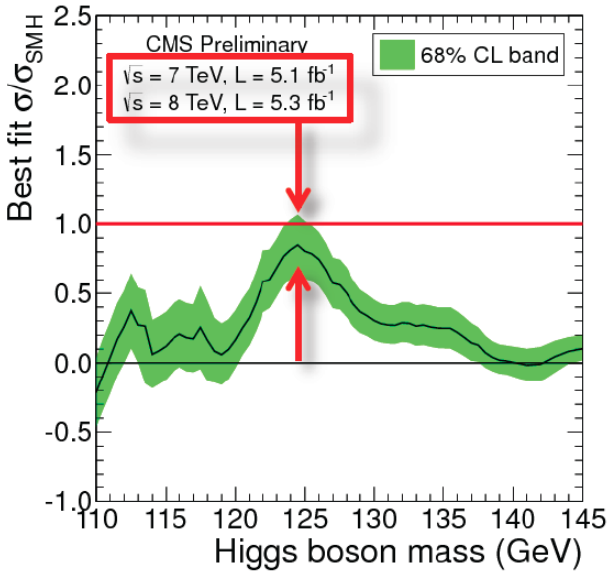
Atlas



Excluded at 95% CL

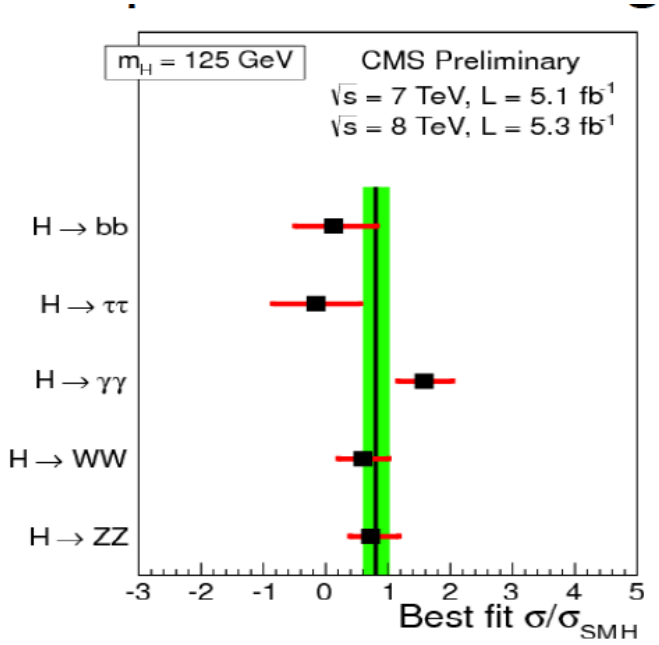
110-122.7 129-557 GeV

CMS

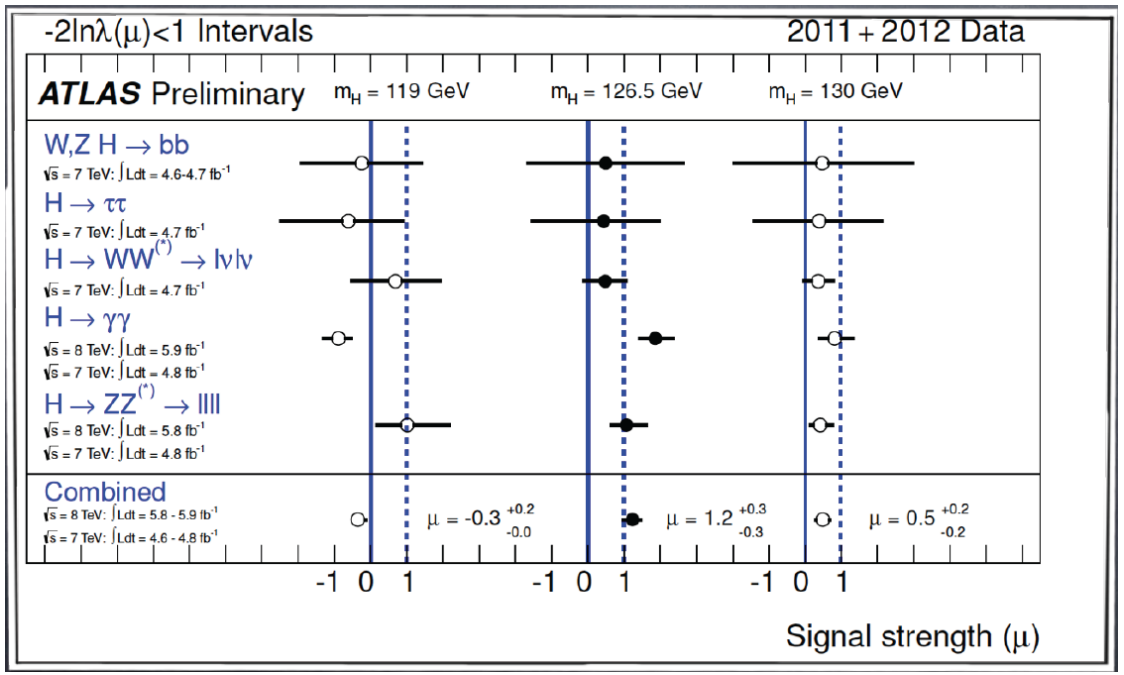


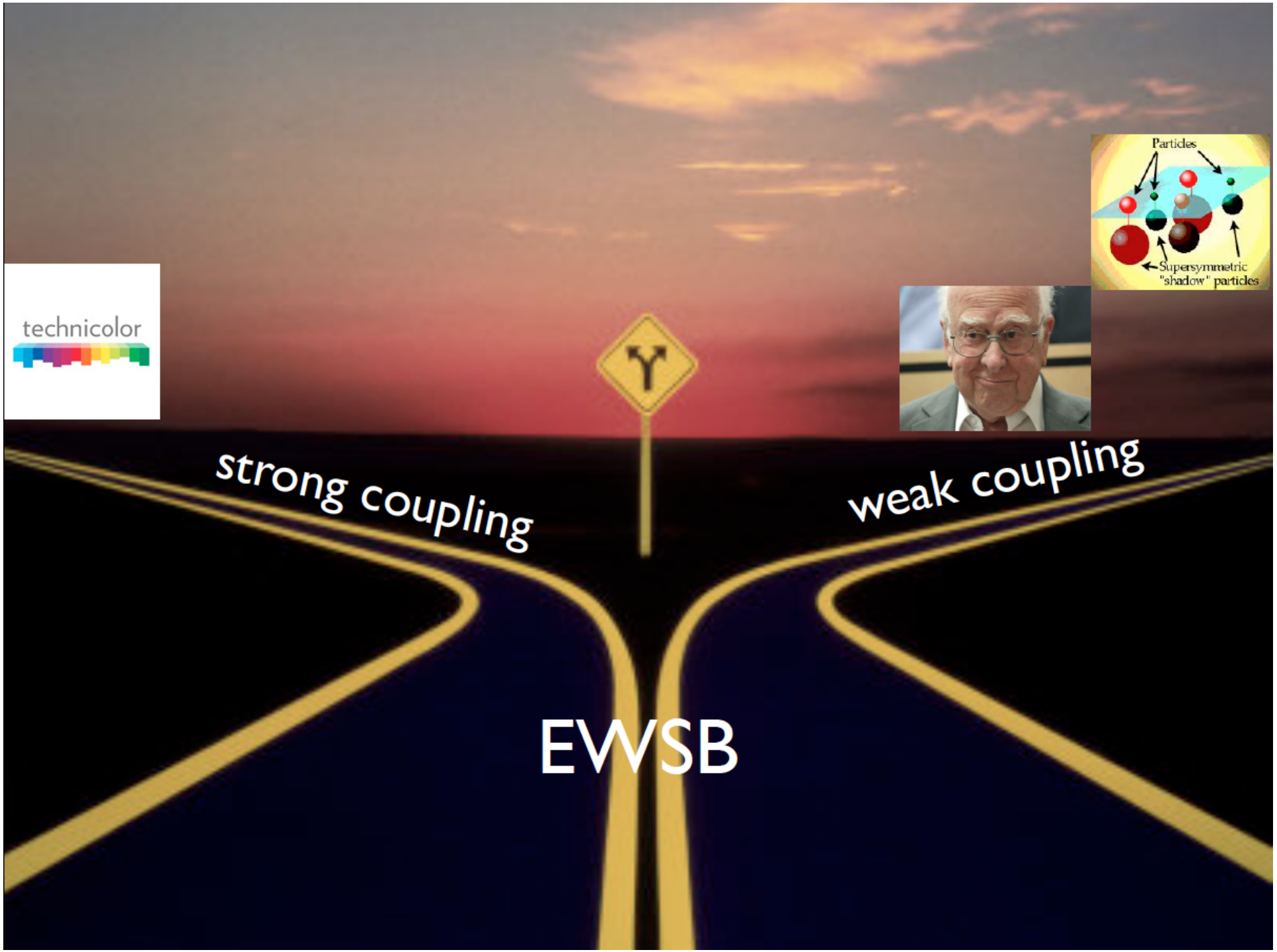
Higgs branching ratios

CMS

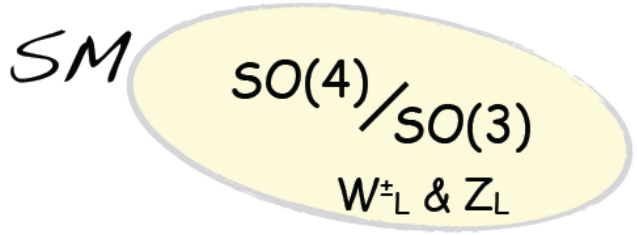


Atlas




technicolor
Particles
Supersymmetric "shadow" particles
strong coupling
weak coupling
EWSB

Effective Field Theory description ... nonlinear $SU(2)_L \times U(1)$



$$\mathbf{H} = (H, \overline{H}) = \begin{pmatrix} h_1 + ih_2 & -h_3 + ih_4 \\ h_3 + ih_4 & h_1 - ih_2 \end{pmatrix}$$

$$= \frac{1}{\sqrt{2}}(h + \mathrm{v})\,\Sigma$$

$$V(H) = -\mu^2 H^\dagger H + \lambda\left(H^\dagger H\right)^2$$

$$SO(4) \sim SU(2)_L \times SU(2)_R$$

$$\Sigma(x) \to U_L \Sigma(x) U_R^\dagger$$

"custodial" symm

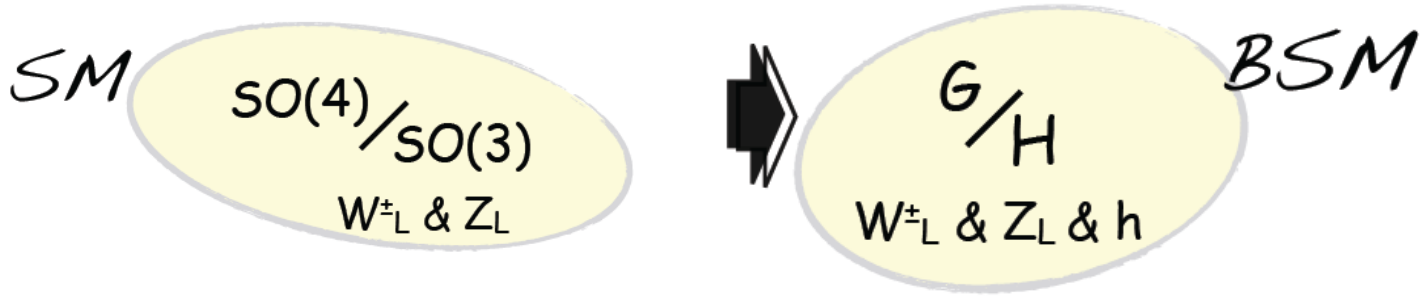
$$\rho \equiv \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = 1$$

$$\Sigma(x) = e^{i\sigma_a \pi^a / \mathrm{v}}$$

$$SO(4) \xrightarrow{\mathrm{v}} SO(3) \qquad W_\mu^\pm, Z$$

$$\pi^a \subset SO(4)/SO(3) \qquad \text{Goldstone bosons}$$

Effective Field Theory description … nonlinear $SU(2)_L \times U(1)$



e.g.

$$SO(5)/SO(4):W,Z,h$$

$$SO(6)/SO(5):W,Z,h,a$$

…

Effective Field Theory description ... nonlinear $SU(2)_L \times U(1)$

General parameterisation of composite models of Higgs:

$$\Sigma(x) = e^{i\sigma_a \pi^a / \mathrm{v}}, \quad h$$

$SM: \quad (h+\mathrm{v})^2$

$$\mathcal{L}_{eff} = \frac{1}{2}(\partial_\mu h)^2 - V(h) + \frac{v^2}{4}\mathrm{Tr}(D_\mu \Sigma^\dagger D^\mu \Sigma)\left[1 + 2\,a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + b_3\,\frac{h^3}{v^3} + \cdots\right],$$

$$-\frac{v}{\sqrt{2}}\,(\bar{u}_L^i \bar{d}_L^i)\,\Sigma\left[1 + c_j\,\frac{h}{v} + c_2\,\frac{h^2}{v^2} + \cdots\right]\begin{pmatrix} y_{ij}^u\, u_R^j \\ y_{ij}^d\, d_R^j \end{pmatrix} + h.c. \cdots,$$

$$(\mathrm{SM}: a = b = (c_j = c) = 1, \quad b_3 = c_2 = \ldots = 0\ )$$

Chiral Lagrangian for a light Higgs @ LHC

Slides from Grojean

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \ldots$$

$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \ldots\right)$$

$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \ldots\right)$$

$$+ \frac{g^2}{16\pi^2}\left(c_{WW}\, W^+_{\mu\nu}W^-_{\mu\nu} + c_{ZZ}\, Z^2_{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma_{\mu\nu}\right)\frac{h}{v} + \ldots$$

$$+ \frac{g^2}{16\pi^2}\left[\gamma^2_{\mu\nu}\left(c_{\gamma\gamma}\frac{h}{v} + \ldots\right) + G^2_{\mu\nu}\left(c_{gg}\frac{h}{v} + c_{2gg}\frac{h^2}{v^2}\cdots\right)\right]$$

$$+ \frac{g^2}{16\pi^2}\left[\frac{c_{hhgg}}{\Lambda^2}G^2_{\mu\nu}\frac{(\partial_\rho h)^2}{v^2} + \frac{c'_{hhgg}}{\Lambda^2}G_{\mu\rho}G_{\rho\nu}\frac{\partial_\mu h\partial_\nu h}{v^2} + \ldots\right]$$

$$+ \ldots$$

SM

$$a = b = c = d_3 = d_4 = 1$$

$$c_{2\psi} = c_{WW} = c_{ZZ} = c_{Z\gamma} = c_{\gamma\gamma} = \ldots = 0$$

A few (reasonable) assumptions:

- ☑ spin-0 & CP-even
  - ↖ $\gamma\gamma$
  - ↖ WW & ZZ
- ☑ custodial symmetry
  - ↖ EWPD
- ☑ no Higgs FCNC
  - ↖ Flavor

Contino, Grojean, Moretti, Piccinini, Rattazzi '10

Azatov, Contino, Galloway '12

Chiral Lagrangian for a light Higgs @ LHC

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$$+ \frac{g^2}{16\pi^2}\left[\gamma^2_{\mu\nu}\left(c_{\gamma\gamma}\frac{h}{v} + \dots\right) + G^2_{\mu\nu}\left(c_{gg}\frac{h}{v} + c_{2gg}\frac{h^2}{v^2}\dots\right)\right]$$

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$$+ \dots$$

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Contino, Grojean, Moretti, Piccinini, Rattazzi '10

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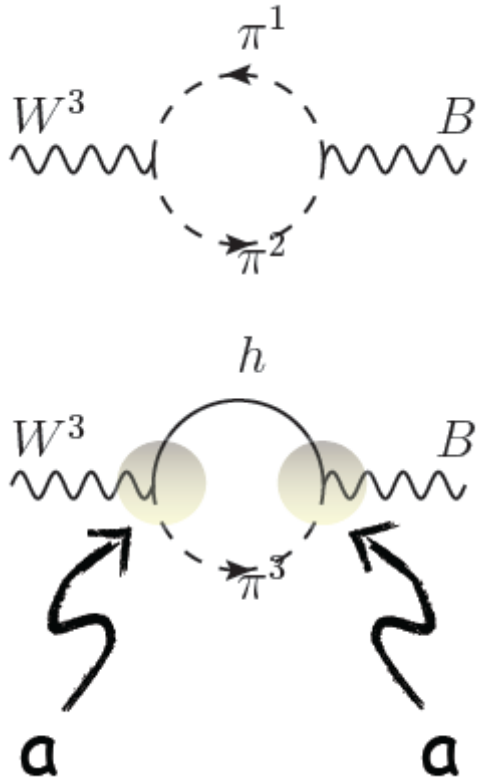
Electroweak precision tests

$$\alpha S \equiv -4e^2 \frac{d}{dq^2}\Delta_3\left(q^2\right)\Big|_{q^2=0} \qquad \alpha T = \frac{e^2}{s^2 c^2 m_Z^2}$$

$$\Delta S \approx \frac{-(1-a^2)}{6\pi} \log\left(\frac{m_h}{\Lambda}\right)$$

$$\Delta T \approx \frac{3(1-a^2)}{8\pi \cos^2\theta_W} \log\left(\frac{m_h}{\Lambda}\right)$$



Chiral Lagrangian for a light Higgs @ LHC

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \dots$$

$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \dots\right)$$

$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \dots\right)$$

$$+ \frac{g^2}{16\pi^2}\left(c_{WW}\, W^+_{\mu\nu}W^-_{\mu\nu} + c_{ZZ}\, Z^2_{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma_{\mu\nu}\right)\frac{h}{v} + \dots$$

$$+ \frac{g^2}{16\pi^2}\left[\gamma^2_{\mu\nu}\left(c_{\gamma\gamma}\frac{h}{v} + \dots\right) + G^2_{\mu\nu}\left(c_{gg}\frac{h}{v} + c_{2gg}\frac{h^2}{v^2}\dots\right)\right]$$

$$+ \frac{g^2}{16\pi^2}\left[\frac{c_{hhgg}}{\Lambda^2}G^2_{\mu\nu}\frac{(\partial_\rho h)^2}{v^2} + \frac{c'_{hhgg}}{\Lambda^2}G_{\mu\rho}G_{\rho\nu}\frac{\partial_\mu h\partial_\nu h}{v^2} + \dots\right]$$

$$+ \dots$$

SM

$$a = b = c = d_3 = d_4 = 1$$

$$c_{2\psi} = c_{WW} = c_{ZZ} = c_{Z\gamma} = c_{\gamma\gamma} = \dots = 0$$

A few (reasonable) assumptions:

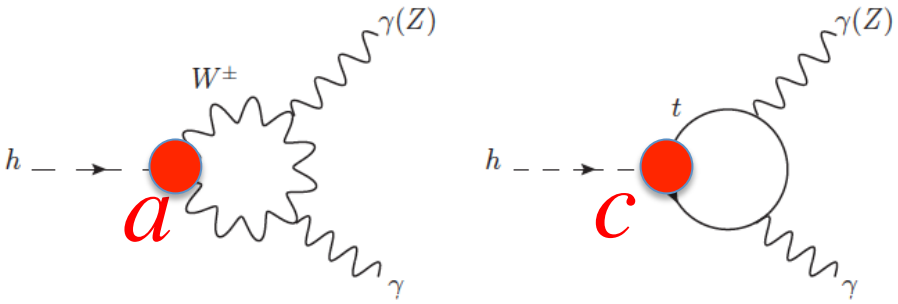
- ☑ spin-0 & CP-even
  - ↖ $\gamma\gamma$
  - ↖ WW & ZZ
- ☑ custodial symmetry
  - ↖ EWPD
- ☑ no Higgs FCNC
  - ↖ Flavor

Contino, Grojean, Moretti, Piccinini, Rattazzi '10

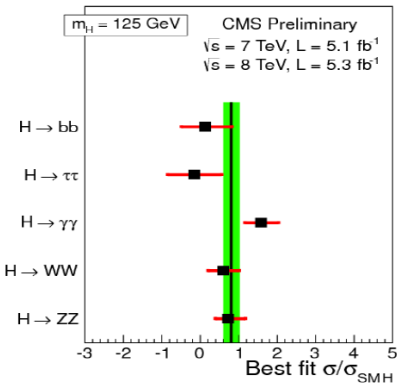
Azatov, Contino, Galloway '12

Higgs signal strength data

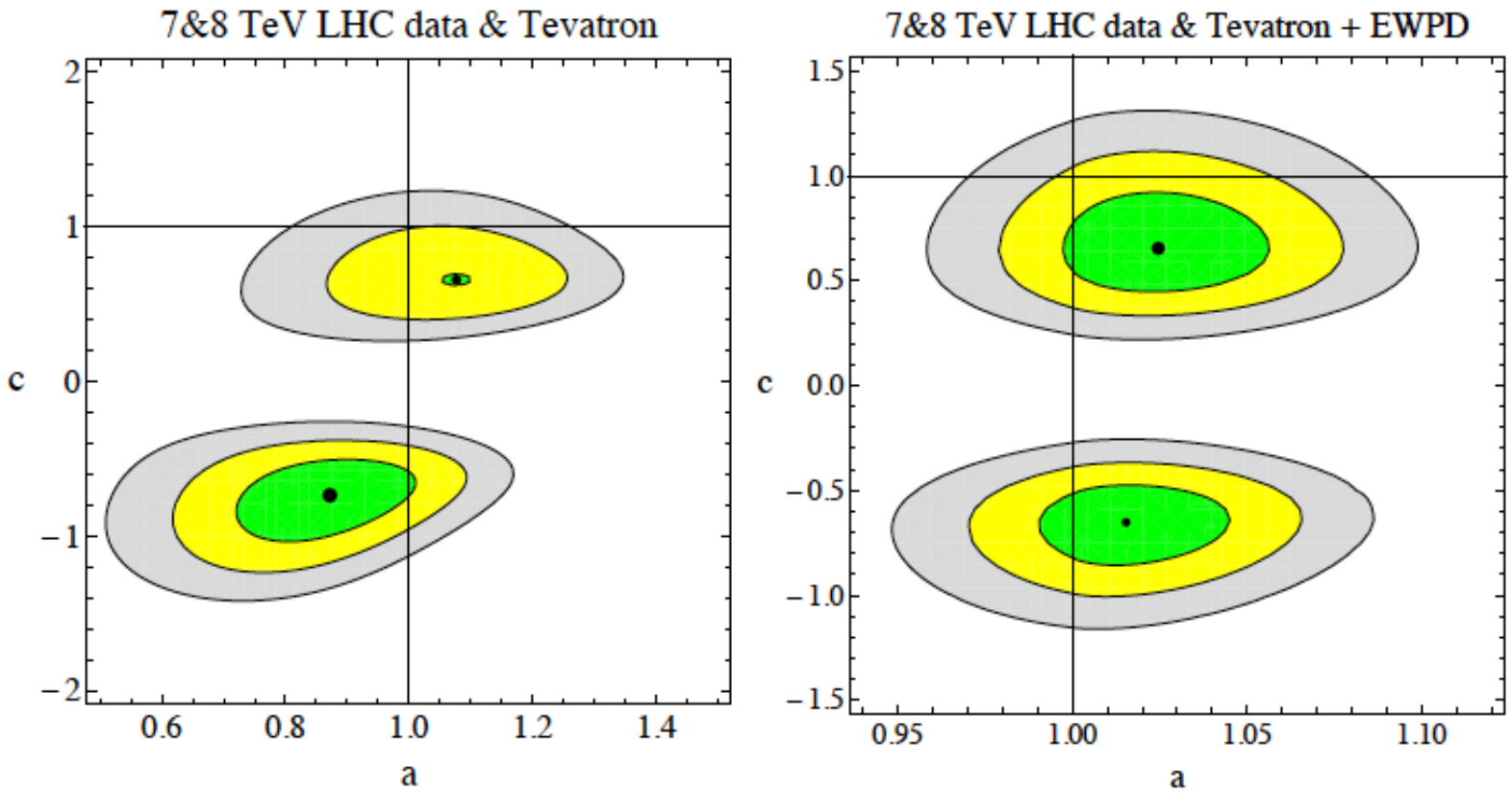
$$\mu_i = \frac{[\sum_j \sigma_{j\to h} \times \mathrm{Br}(h \to i)]_{observed}}{[\sum_j \sigma_{j\to h} \times \mathrm{Br}(h \to i)]_{SM}}$$



Interference term $\propto -a\,c$



c negative?



Standard Model

$(a, c) = (1, 1)$ is $\sim 2\,\sigma$ (C.L. of 0.95)

Bad news for the Higgs impostors

- dilaton with f~1TeV: a=v/f~0.25 will require new (light) dof to get back to the EW ellipses

$h \to \gamma\,\gamma$ enhancement in the MSSM

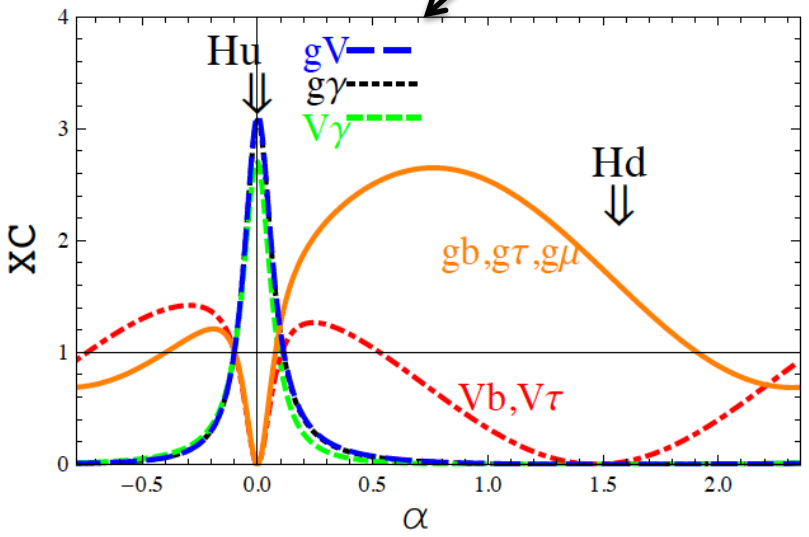
$h \to \gamma\,\gamma$ enhancement in the MSSM

$$\frac{h}{\sqrt{2}} = c_\alpha H_u^0 - s_\alpha H_d^0$$

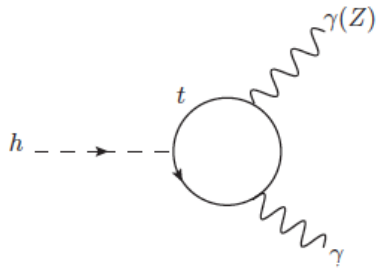
$\alpha \simeq 0$ fine tuned

$\left(M_H^2\right)_{12} = -(m_A^2 + M_Z^2)\sin\beta\cos\beta + \text{Loop}_{12} = 0$

$g\gamma \equiv gg \to \gamma\gamma$ *etc*

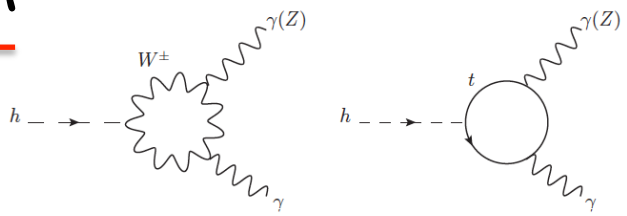


	$\sigma_h/\sigma_{h_{\rm SM}}$	FT($\alpha=0$)	($\alpha=0.06$)	CMS[2]	ATLAS[1]	Tevatron[11]
$VV \to \tau\tau$	$V\tau$	0	0.60			
$q\bar{q} \to Vb\bar{b}$	qb	0	0.60	$1.2^{+2.1}_{-1.9}$	$-0.8^{+1.8}_{-1.7}$	2.0±0.7
$gg \to \tau^-\tau^+$	$g\tau$	0	0.74	$0.63^{+1.00}_{-1.28}$	0.0±1.7	
$gg \to \gamma\gamma$	$g\gamma$	3.1	1.9	1.62±0.68	$1.6^{+0.8}_{-0.7}$	$3.4^{+3.1}_{-2.4}$
$gg \to WW^*$	gW	3.1	2.0	0.40±0.55	0.20±0.62	$0.0^{+1.0}_{-0.0}$
$gg \to ZZ^*$	gZ	3.1	2.0	$0.58^{+0.94}_{-0.58}$	$1.4^{+1.3}_{-0.8}$	
$VV \to \gamma\gamma$	$V\gamma$	2.7	1.6	$3.8^{+2.4}_{-1.8}$[2]		



$h \to \gamma\,\gamma$ enhancement in the MSSM

See Djouadi review



...

New heavy particle contributions:

$$\mathcal{L}_{\gamma\gamma} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \sum_i \frac{b_i e^2}{16\pi^2} \log \frac{\Lambda^2}{m_i^2} + \cdots$$

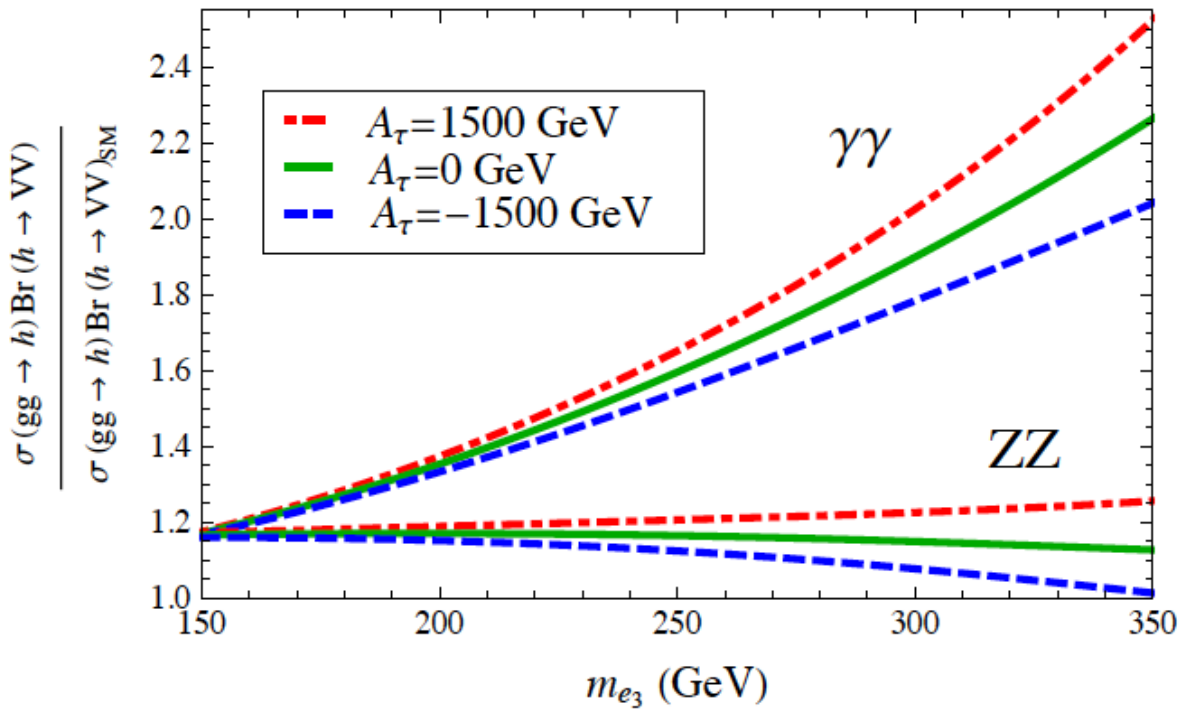
$$\begin{cases} b_{1/2} = \frac{4}{3} N_{c,f} Q_f^2 & \text{for a Dirac fermion ,} \\ b_1 = -7 & \text{for the } W \text{ boson ,} \\ b_0 = \frac{1}{3} N_{c,S} Q_S^2 & \text{for a charged scalar .} \end{cases}$$

Carena et al

SUSY: light $\tilde{\tau}$ $\qquad (LEP : m_{\tilde{l}} > 100 GeV)$

$$A_{\gamma\gamma}^{SM} + \Delta A_{\gamma\gamma} \propto -13 - \frac{m_{\tilde{\tau}_2^2}}{6 m_{\tilde{\tau}_1^2}} \left(1 - \frac{m_{\tilde{\tau}_1^2}}{m_{\tilde{\tau}_2^2}} \right)$$

(a)

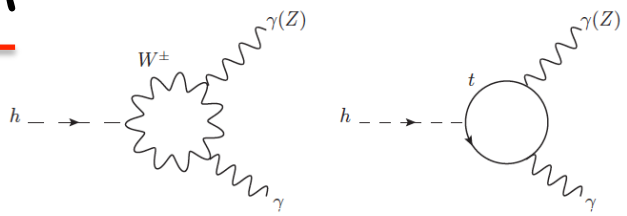


Ratio of the $\sigma(gg \to h) \times$ BR$(h \to VV)$ to its SM value, for both $V = \gamma$ and $V = Z$ as a function of $m_{e_3} = m_{L_3}$, for $\tan\beta = 60$ varying μ such that $m_{\tilde{\tau}_1} = 90$ GeV for different values of A_τ. The Higgs mass varies with m_{e_3}, but remains ~ 125 GeV. *(a)*: $m_A = 1.5$ TeV, $A_t = 2$ TeV, $m_{Q_3} = 2.5$ TeV, $m_{u_3} = 100$ GeV leading to $m_{\tilde{t}_1} \sim 140$ GeV. *(b)*:

Carena et al

$h \to \gamma\,\gamma$ enhancement in the MSSM

See Djouadi review



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anomaly/mirage..?

requires $\quad \tan\beta \sim 60, \quad \mu \geq 300 GeV, \quad m_{\tilde{\tau}} \sim 100 GeV$

maximally mixed stau, heavy higgsinos, LSP light Bino

With slepton universality – g-2 SUSY correction plausibly correct!

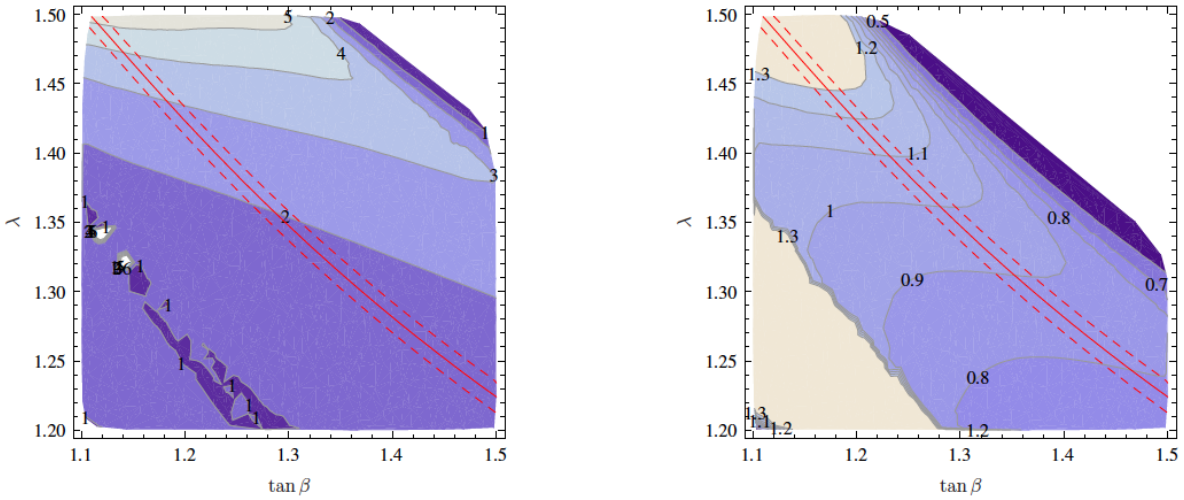
Giudice et al

$h \to \gamma\,\gamma$ enhancement in the GNMSSM (λNMSSM)

New interaction allows sizeable correction at small tanβ:

$$W = \lambda S H_u H_d \quad \Rightarrow V \supset \lambda^2 \left| H_u H_d \right|^2$$

$$g_{hH^+H^-} = \frac{i}{4}\Big\{ v\cos\beta\left[2(\lambda^2 - g_2^2) + (g_1^2 + g_2^2 - 2\lambda^2)\cos 2\beta\right] Z_1^h$$
$$- v\sin\beta\left[2(g_2^2 - \lambda^2) + (g_1^2 + g_2^2 - 2\lambda^2)\cos 2\beta\right] Z_2^h$$
$$- 4\lambda\left[v_s\lambda + \sqrt{2}\mu + (\tfrac{1}{\sqrt{2}}(A_\lambda + \mu_s) + v_s\kappa)\sin 2\beta\right] Z_3^h \Big\}$$

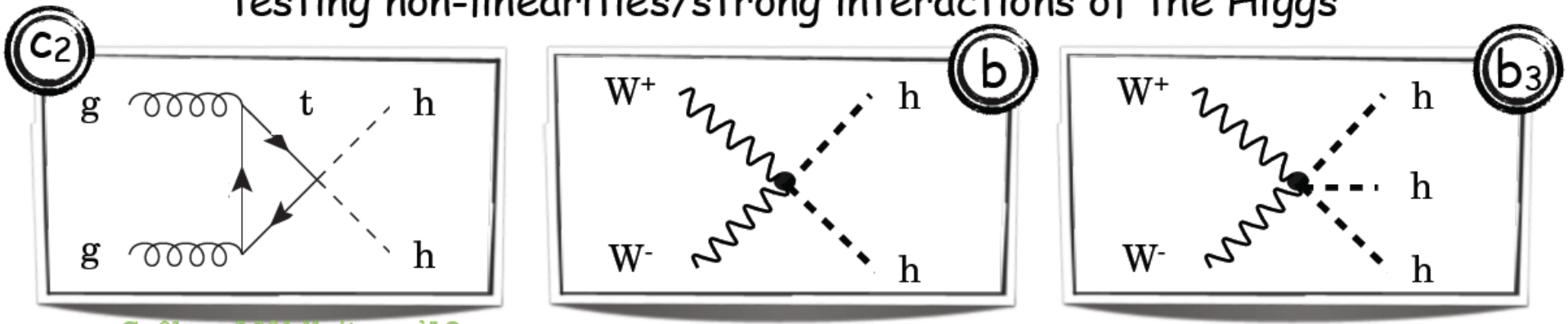


Higgsino (and chargino) enhancement in large λ limit

Schmidt-Hoberg, Staub

Future tests of compositeness:

other couplings are very interesting as they are directly testing non-linearities/strong interactions of the Higgs



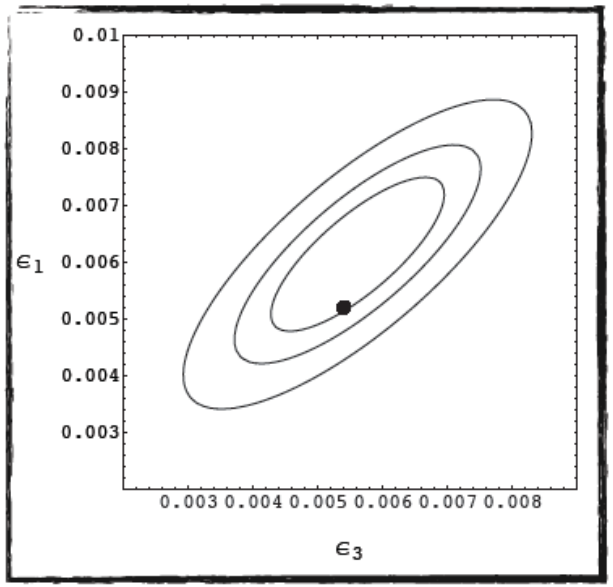
Grôber, Mühlleitner '10
Contino et al '12
Gillioz et al '12

Contino, Grojean,
Moretti, Piccinini, Rattazzi '10

Contino, Grojean, Pappadopoulo,
Rattazzi, Thamm 'to appear

but they are not on agenda of the current LHC run

A tension between LHC and EW data?



EW fit strongly suggests custodial symmetry

$$\Sigma = e^{i\sigma^a \pi^a / v}$$

Goldstone of $SU(2)_L \times SU(2)_R / SU(2)_V$

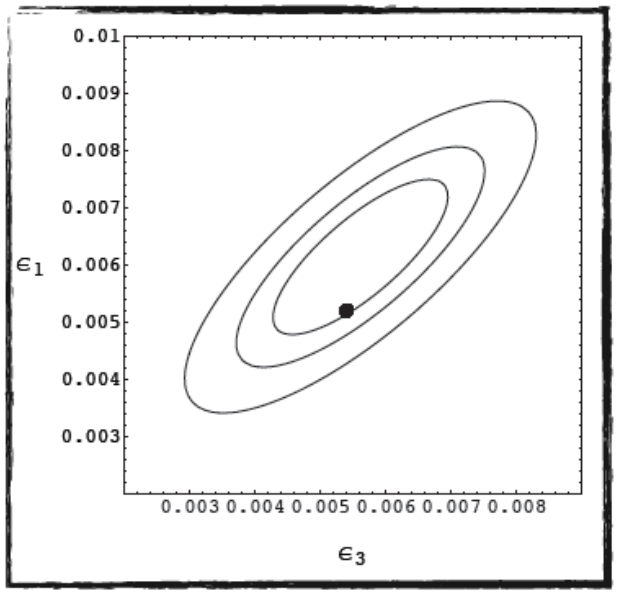
$$\frac{v^2}{4} \mathrm{Tr}\left(D_\mu \Sigma^\dagger D^\mu \Sigma\right) \Rightarrow \rho = 1 \text{ ie } \epsilon_1 = \hat{T} = 0$$

✓

also $\Rightarrow \quad \mu_{ZZ} = \mu_{WW}$

$$\left(\mu_i = \frac{\sum_j \mathcal{A}_{ji}\, \sigma(j \to h) \times \mathrm{Br}(h \to i)}{\sum_j \mathcal{A}_{ji}\, \sigma(j \to h) \times \mathrm{Br}(h \to i)\,|_{\mathrm{SM}}} \right)$$

A tension between LHC and EW data?



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✓

also $\Rightarrow$ $\mu_{ZZ} = \mu_{WW}$ ✗

but

Channel [Exp]	$\mu_{119.5}$ $(\mu^L_{119.5})$	μ_{124} (μ^L_{124})	μ_{125} (μ^L_{125})
$pp \to Z\,Z^\star \to \ell^+\,\ell^-\,\ell^+\,\ell^-$ [ATLAS]	$-0.5^{+0.5??}$ (5.1)	$1.6^{+1.4}_{-0.8}$ (4.7)	$1.4^{+1.3}_{-0.8}$ (4.1)
$pp \to W\,W^\star \to \ell^+\,\nu\,\ell^-\,\bar{\nu}$ [ATLAS]	$0.0^{+1.2}_{-1.3}$ (2.4)	$0.1^{+0.7}_{-0.7}$ (1.6)	$0.1^{+0.7}_{-0.6}$ (1.4)