Buried/Charming Higgs

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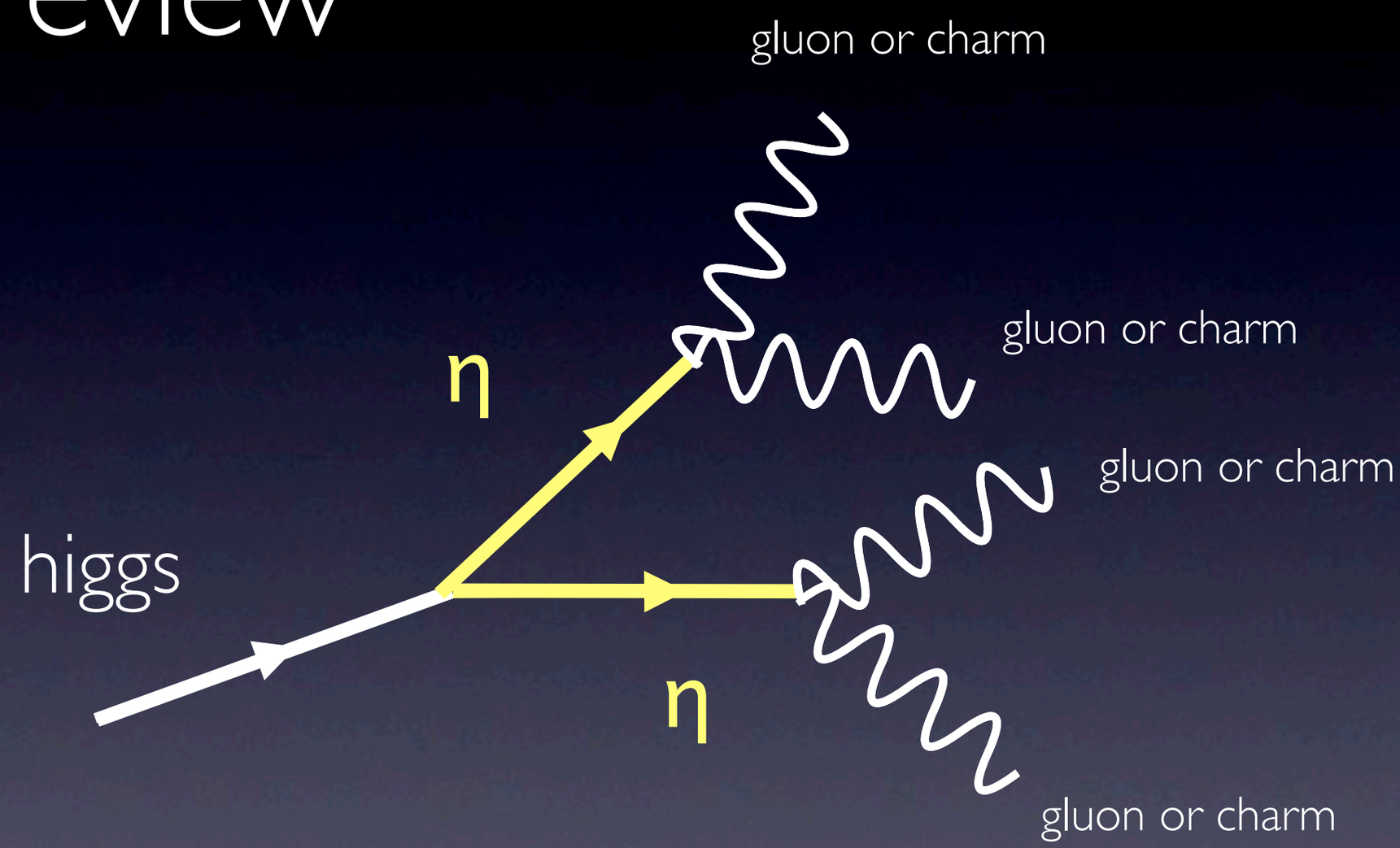
(CERN)

International Workshop on Linear Colliders
(ECFA-CLIC-ILC Joint Meeting)
20/10/2010 Geneva

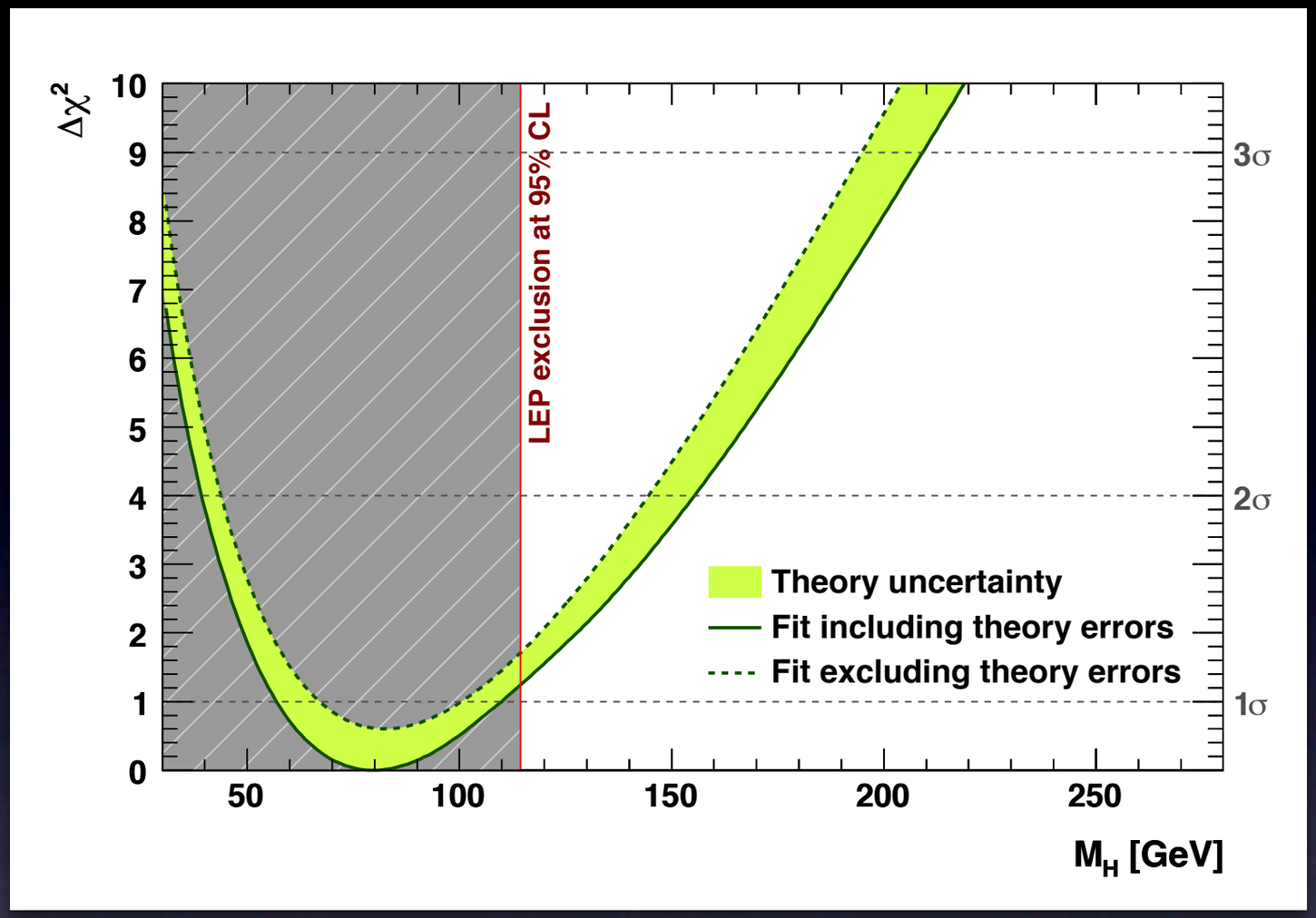
Preview



h → 4 gluon or h → 4 charm

Higgs @ LEP

Gfitter '08



o Indirect tests suggest light scalar < 158 GeV (95%cl)

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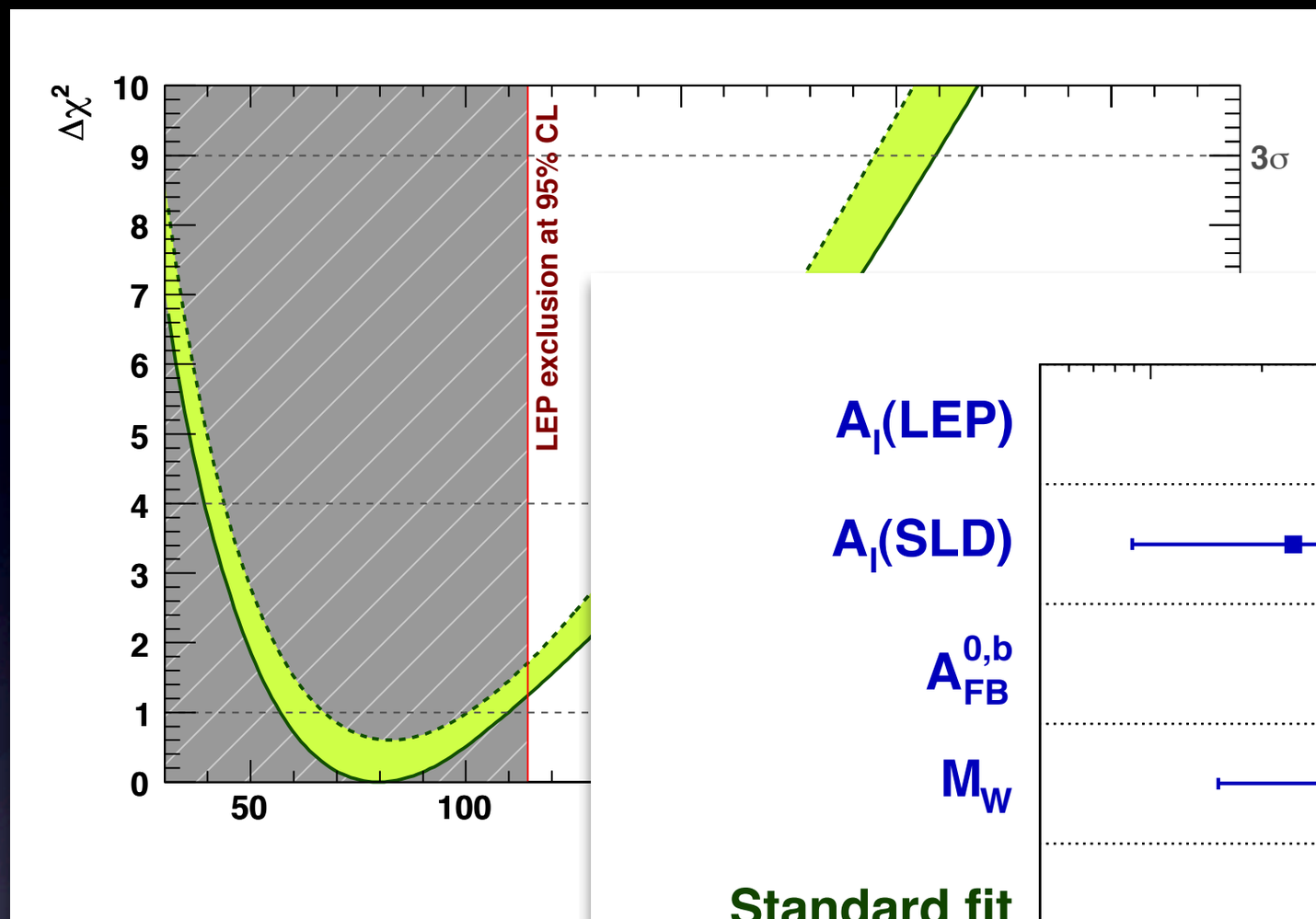

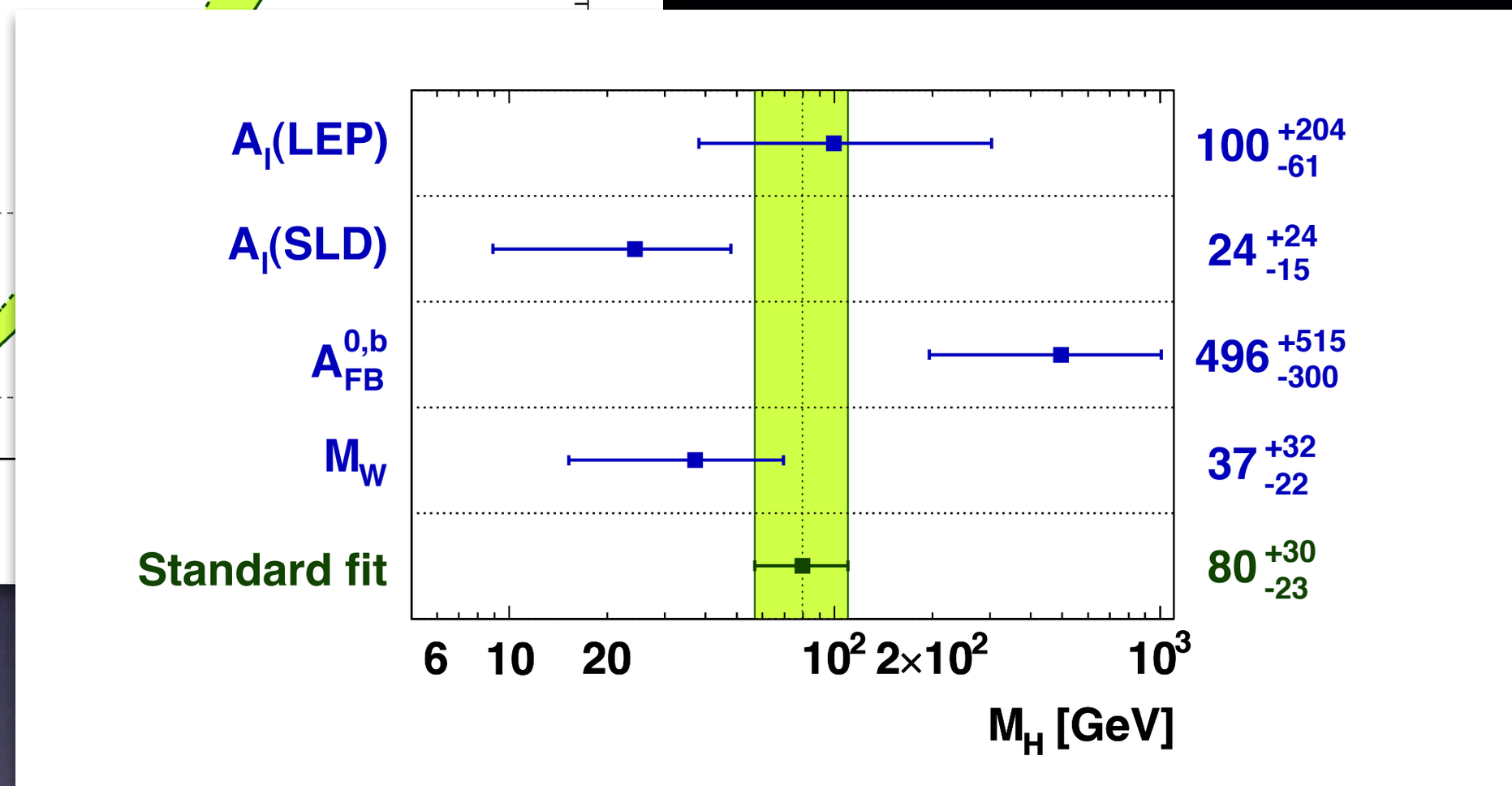

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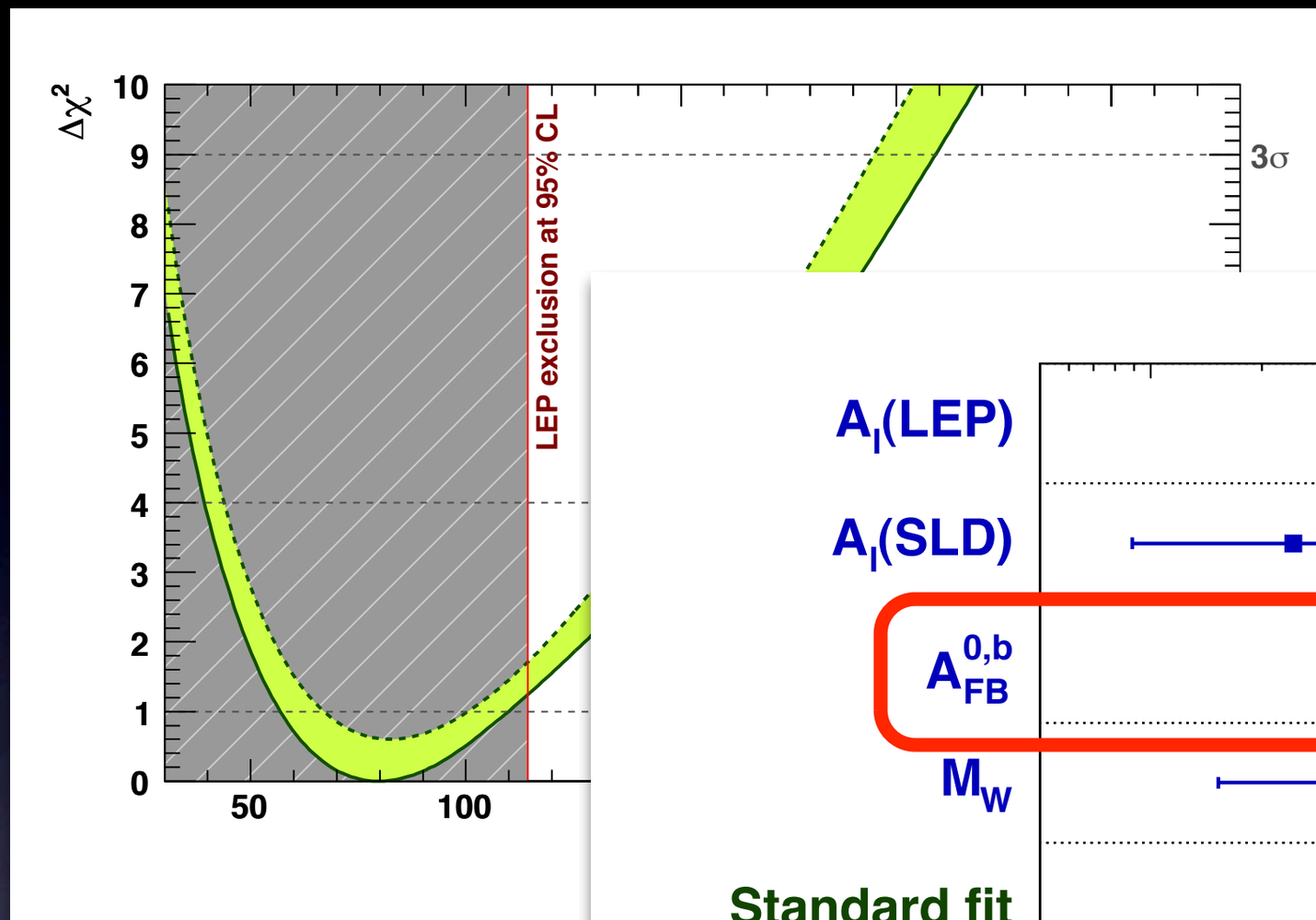

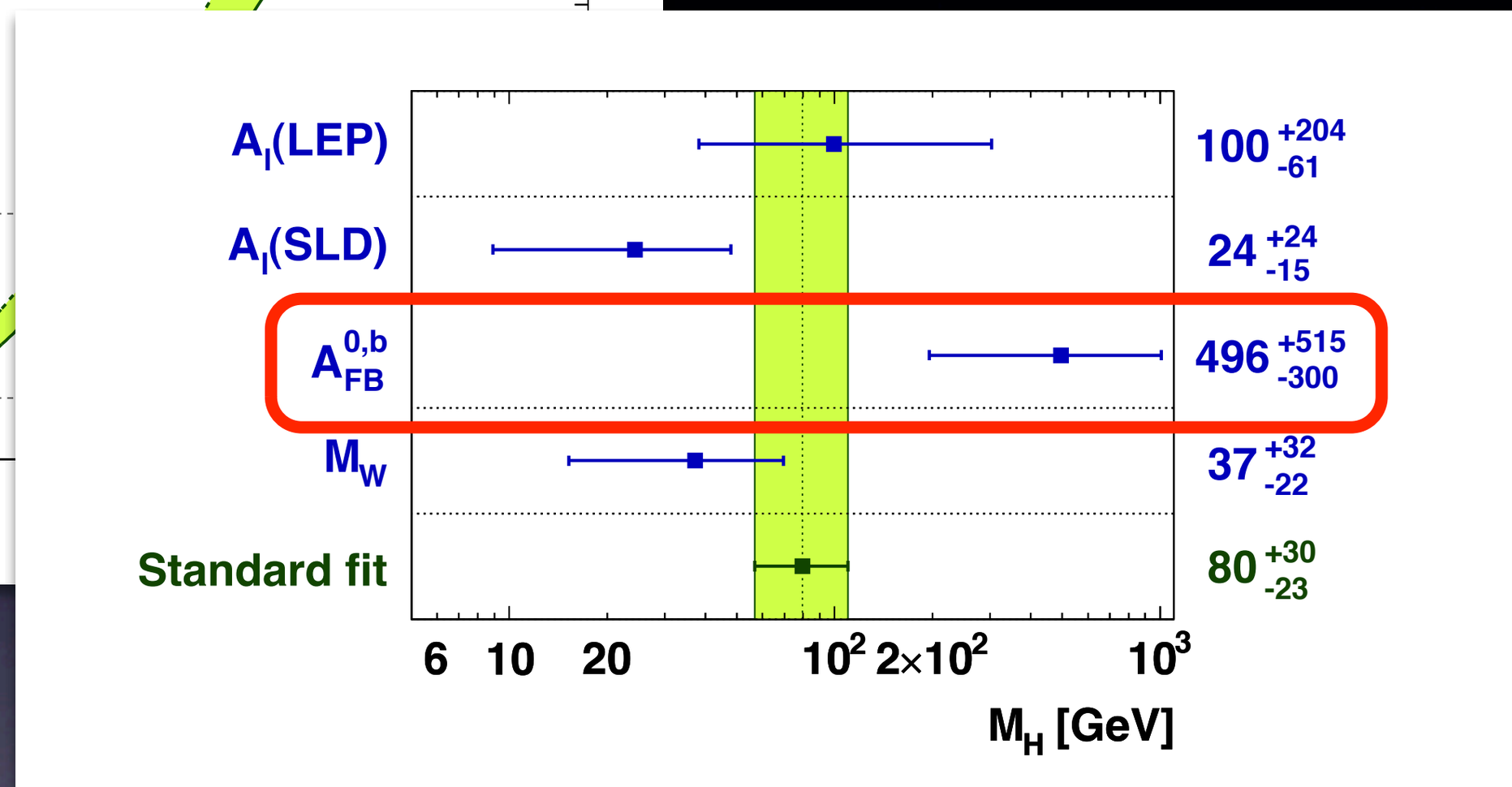

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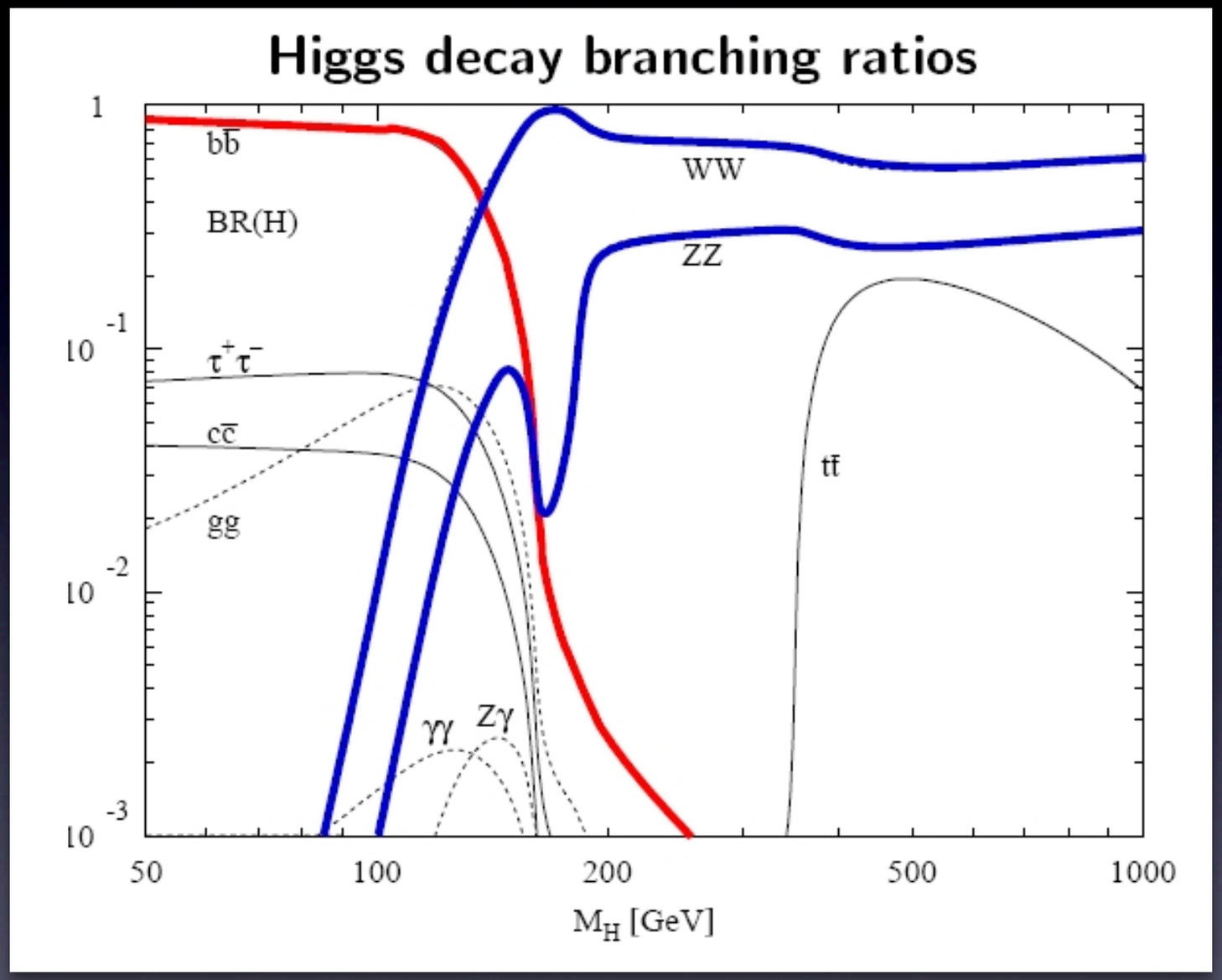
Chanowitz, 0806.0890

- without A^b_{FB}, $m_H = 55^{+32}_{-21}$ GeV , better χ^2

Standard Higgs decays



- Coupling ~ mass, decays into heaviest available
- A light Higgs dominantly decays to $h \to bb$

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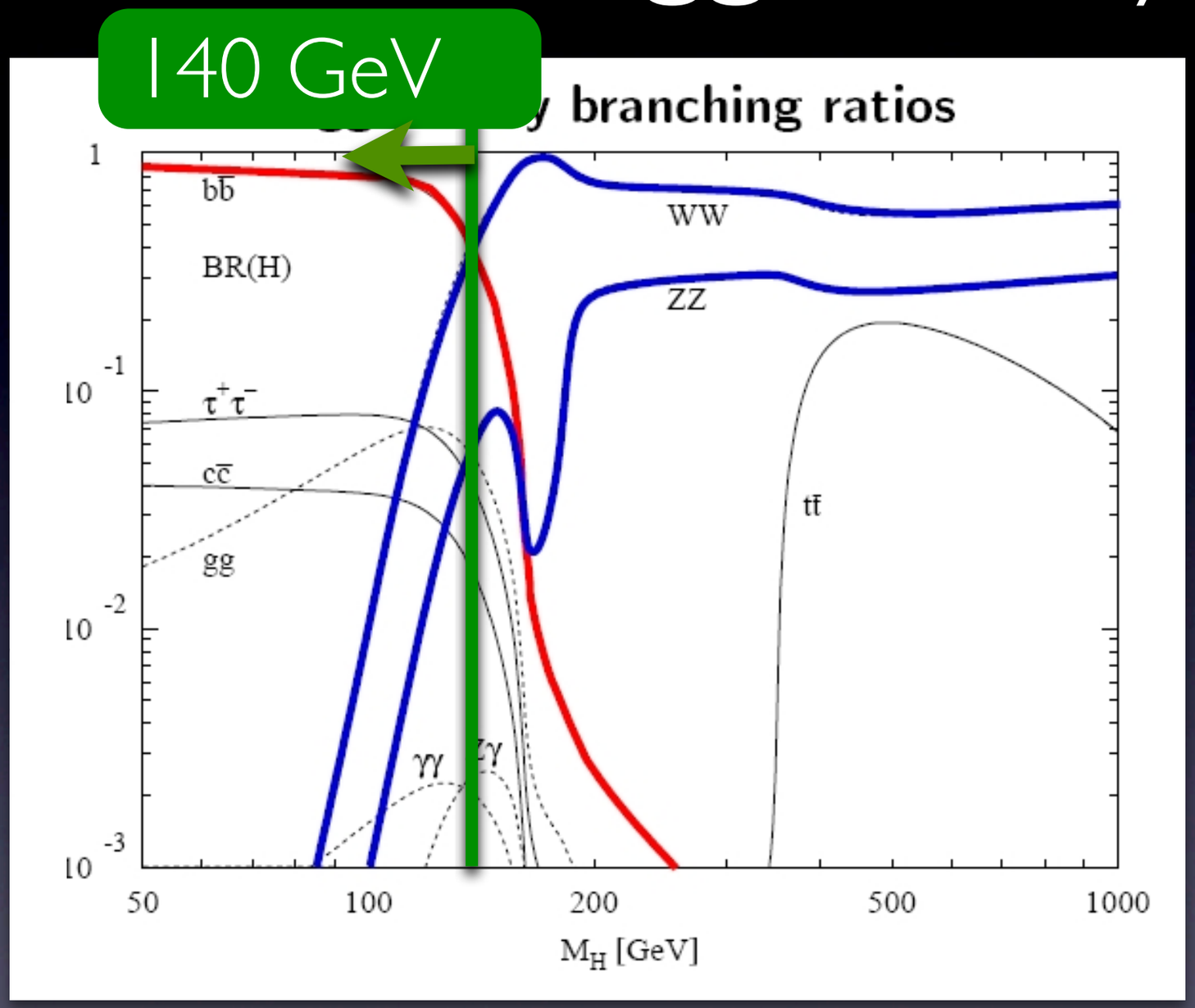

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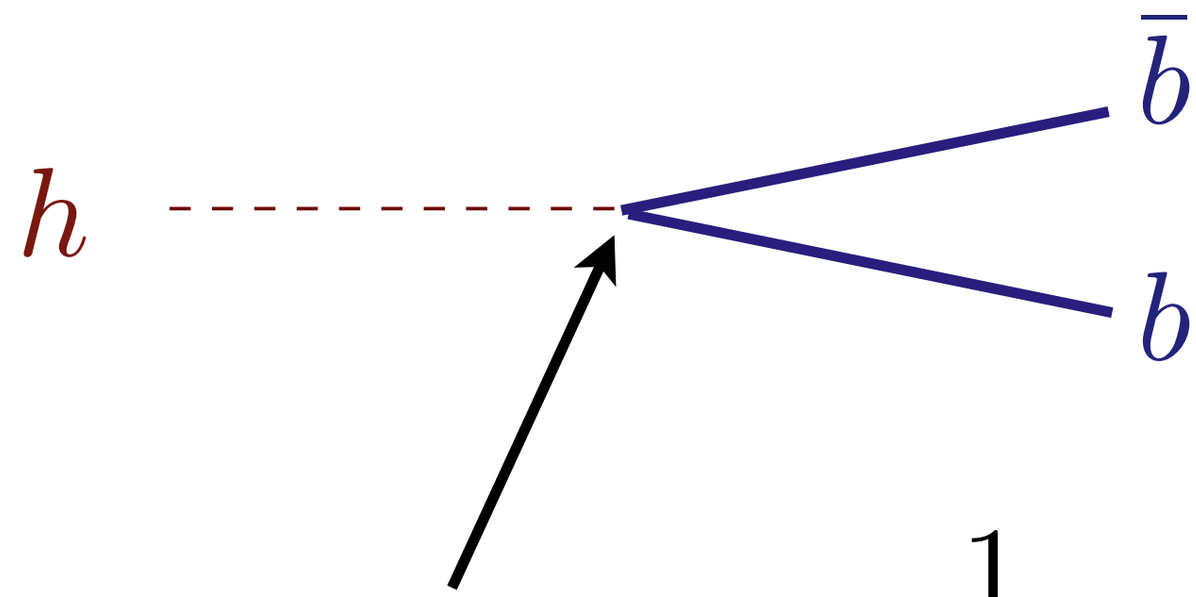
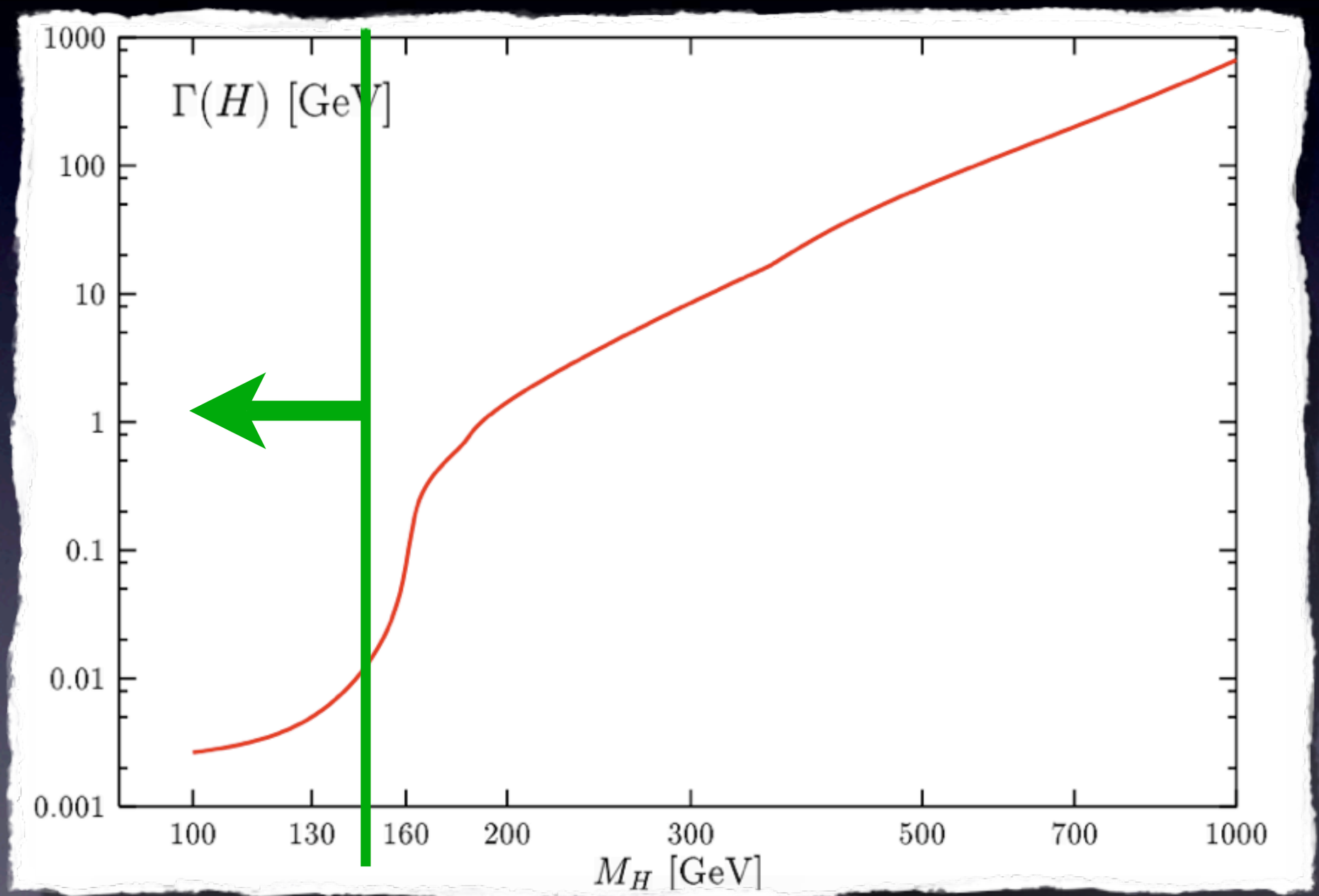
Light Higgs' Small Width



$$y_b(m_h) \sim \frac{1}{60}$$

$$\Gamma_{h \to b\bar{b}} \sim y_b^2$$

The Higgs Width



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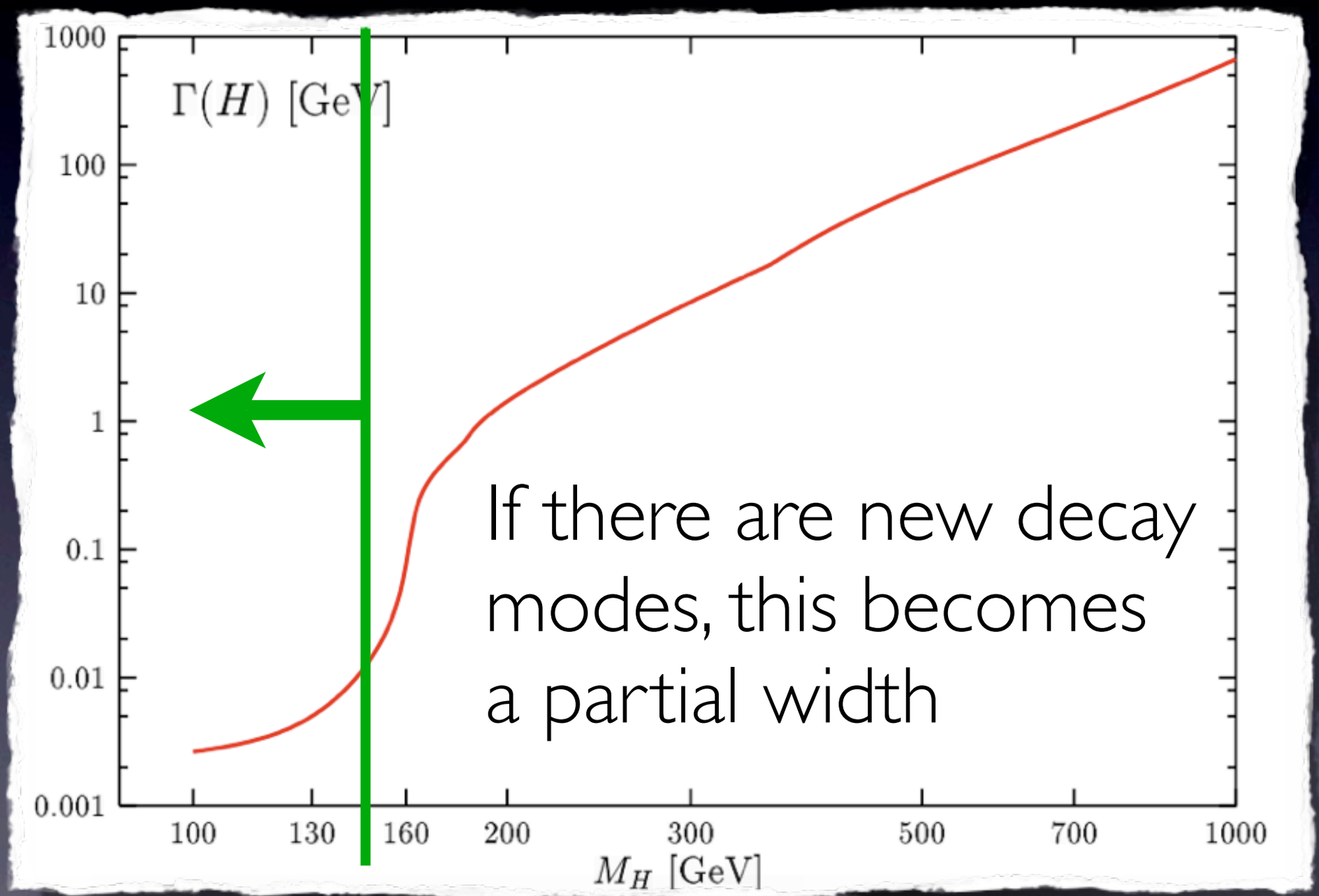
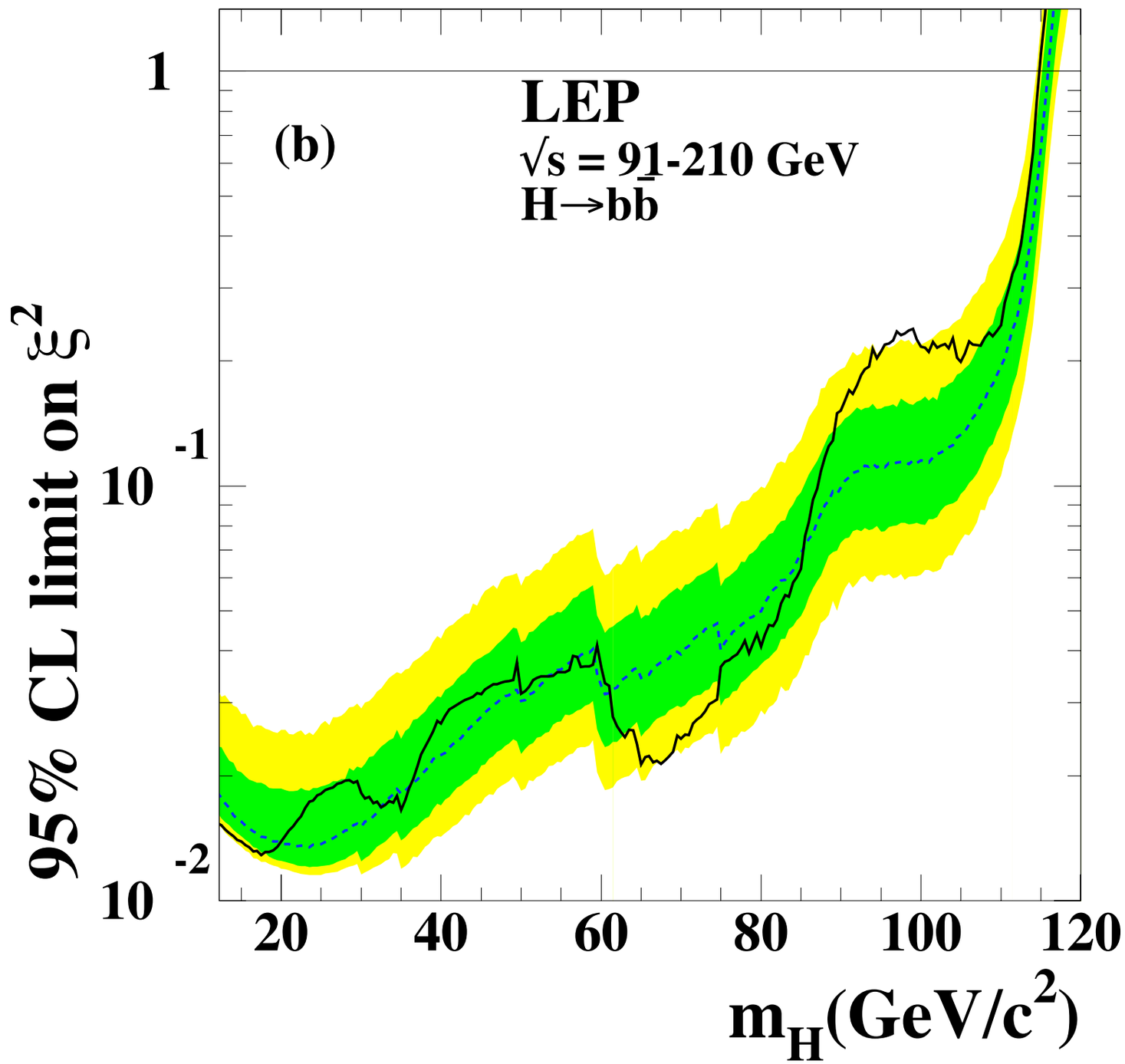
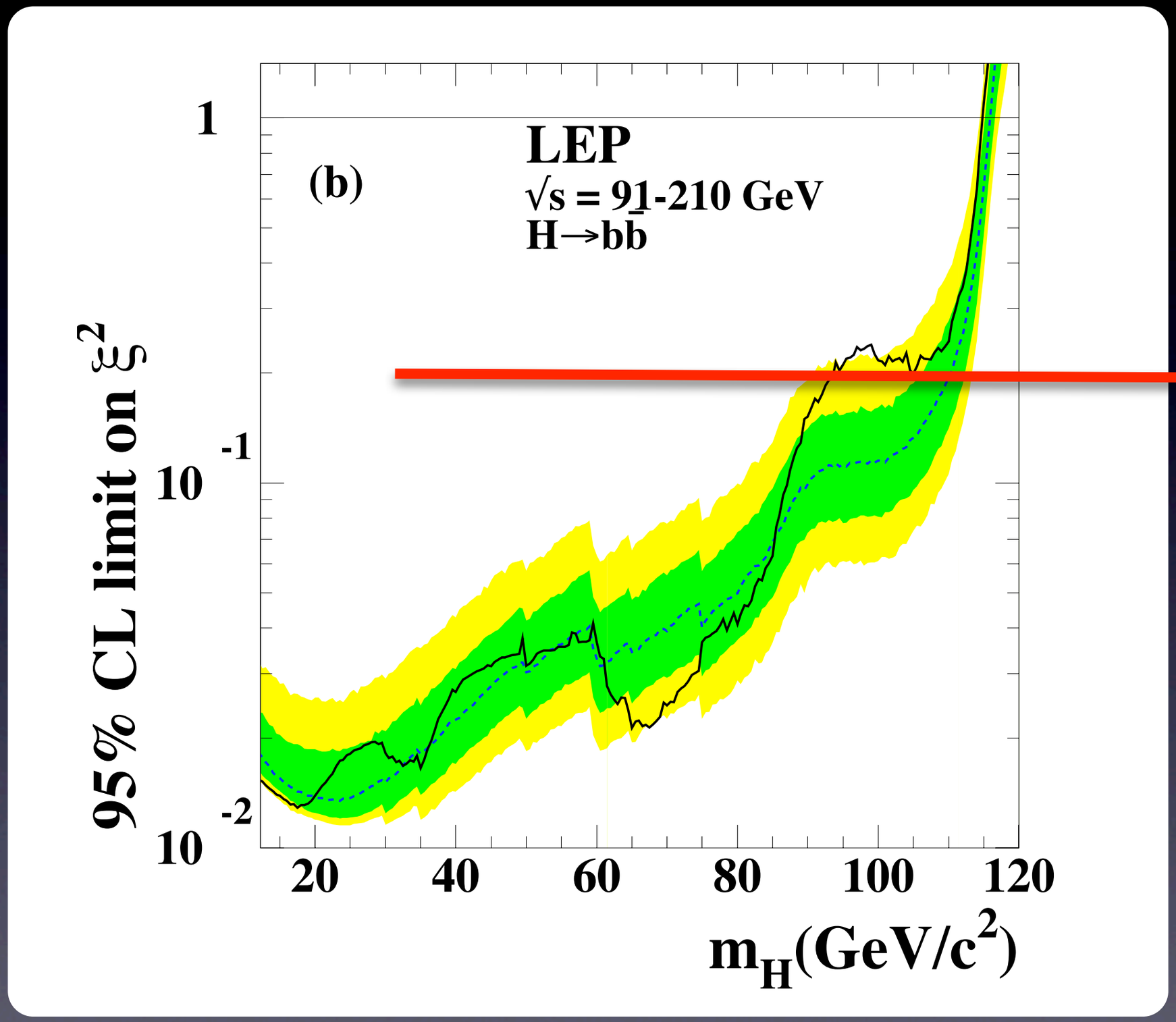


If there are new decay modes, this becomes a partial width

Could we have missed a light Higgs at LEP?

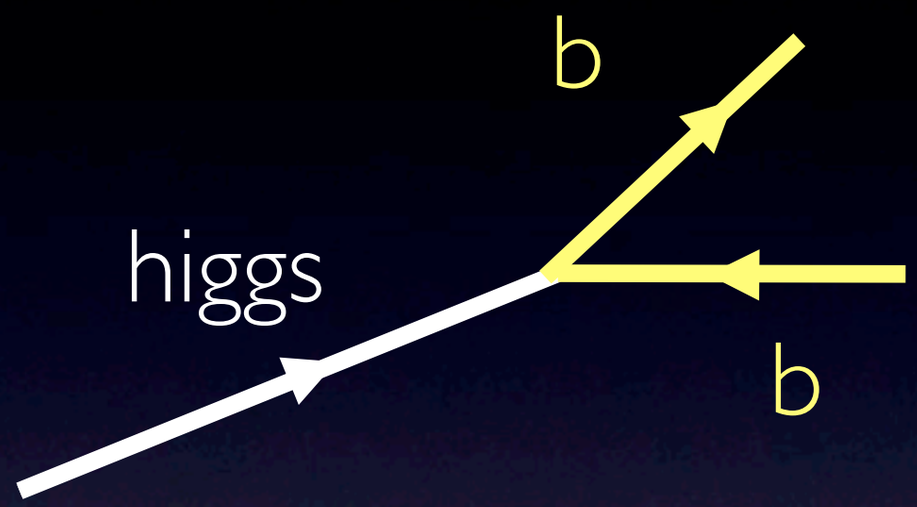

LEP
(b)
√s = 91-210 GeV
H→bb̄
95% CL limit on ξ²
1
10⁻¹
10⁻²
20
40
60
80
100
120
m_H(GeV/c²)



Suppressing SM BR to ~ 20 % is enough

Example: MSSM + singlet η

Dermisek & Gunion '06



VS.

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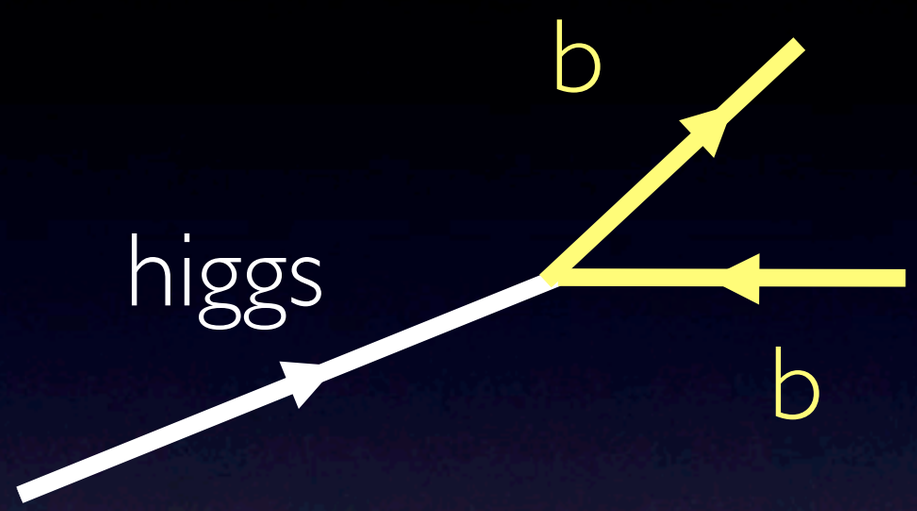

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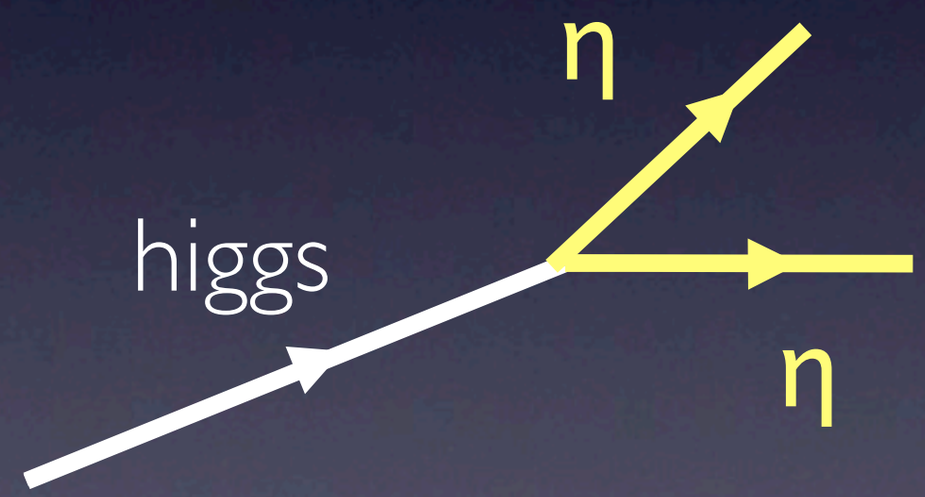

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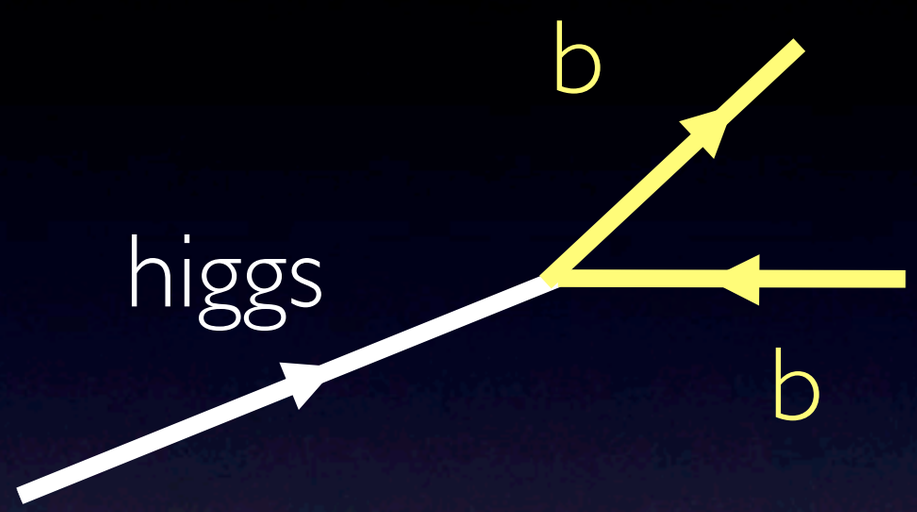

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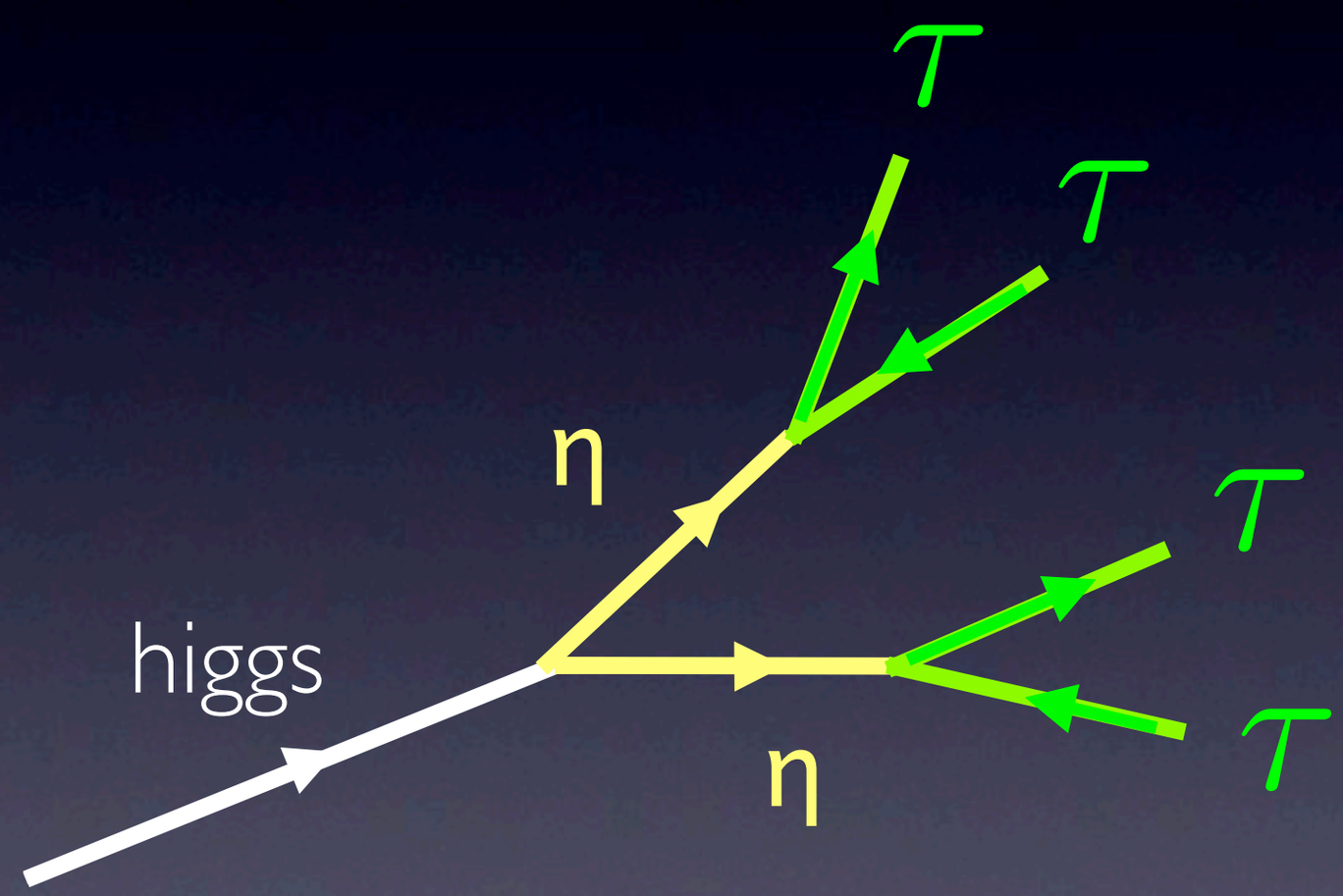

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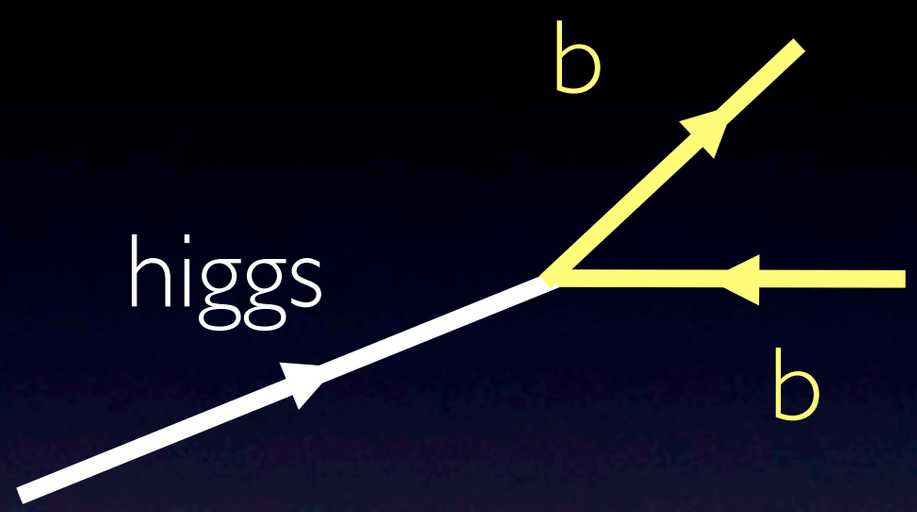

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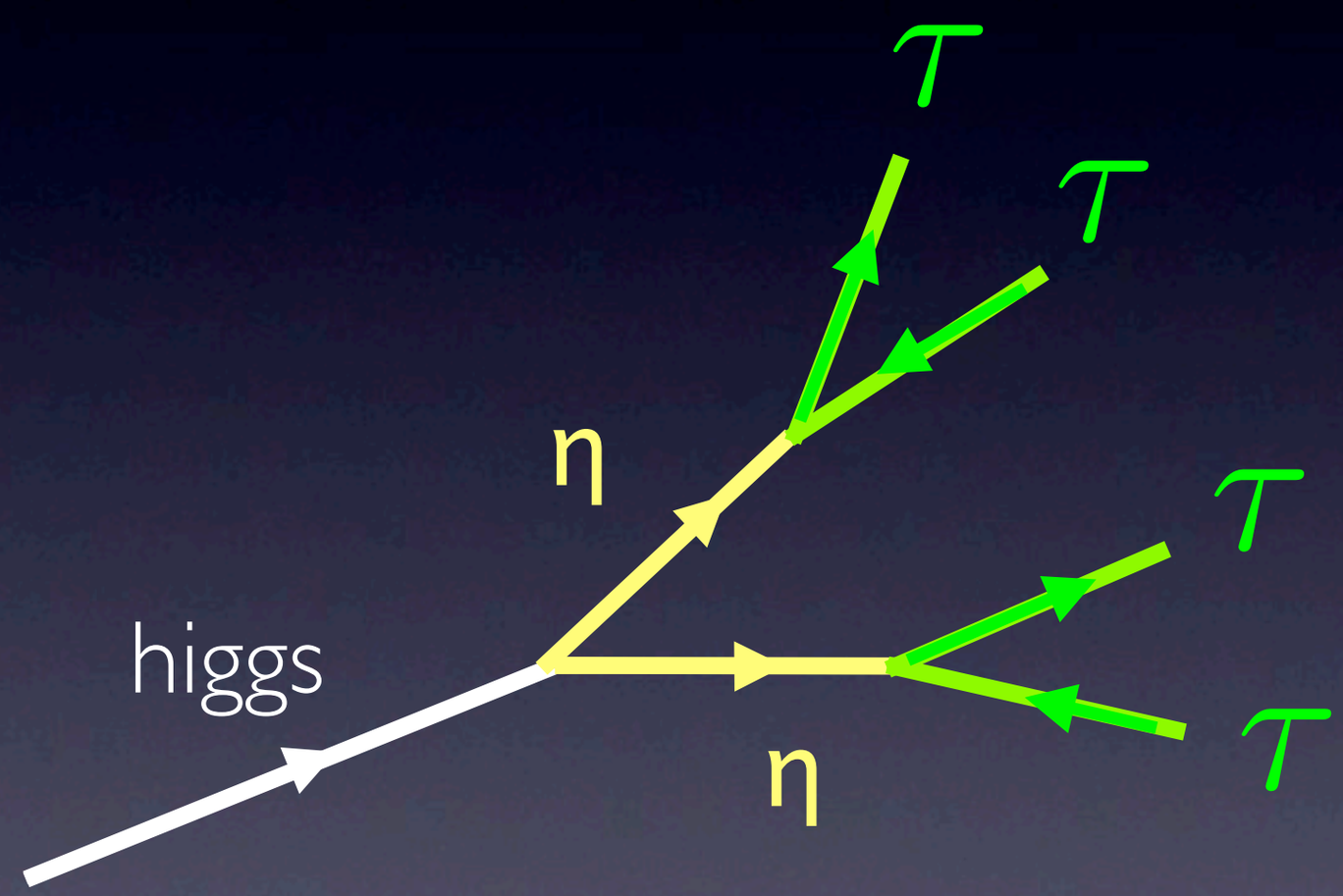

have to assume $m_\eta < 2m_b$

Non-standard Higgs decays

Decay Channel	**Limit**
$h \to b\bar{b}$ or $\tau\bar{\tau}$	115 GeV
$h \to jj$	113 GeV
$h \to WW^*$ or ZZ^*	110 GeV
$h \to \gamma\gamma$	117 GeV
$h \to \not{E}$	114 GeV
$h \to AA \to 4b$	110 GeV
$h \to AA \to 4\tau, 4c, 4g$	86 GeV
$h \to$ anything	82 GeV

Note, constraints on 4 body decays (except 4c and 4g) almost as strong as SM Higgs mass limit.

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ALEPH/K. Cranmer et al.

arXiv:1003.0705 [hep-ex]

$\to 4\tau$: 107 GeV

ongoing, more later

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The Higgs mass in MSSM

$$
\begin{aligned}
V &= (|\mu|^2 + m_{H_u}^2)|H_u^0|^2 + (|\mu|^2 + m_{H_d}^2)|H_d^0|^2 - (b\, H_u^0 H_d^0 + \text{c.c.}) \\
&\quad + \frac{1}{8}(g^2 + g'^2)(|H_u^0|^2 - |H_d^0|^2)^2.
\end{aligned}
$$

At tree-level: firm upper bound on the lightest of the two CP even Higgs bosons

$$m(h^0) < M_Z$$

Experimentally: $m(h^0) > 114\,\text{GeV}$

Either MSSM is wrong or loop correction large (**75%**).

Tuning in the MSSM

$$m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{\text{stop}}^2}{m_t^2}$$

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$$\frac{m_Z^2}{2} = -|\mu|^2 - \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1} \approx -m_{H_u}^2$$

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$$\delta m_{Hu}^2(\text{loop}) = -\frac{3y_t^2}{8\pi^2} m_{\rm stop}^2 \ln \frac{\Lambda^2}{m_{\rm stop}^2} \approx 600 \cdot \frac{m_Z^2}{2}$$

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Little Hierarchy problem

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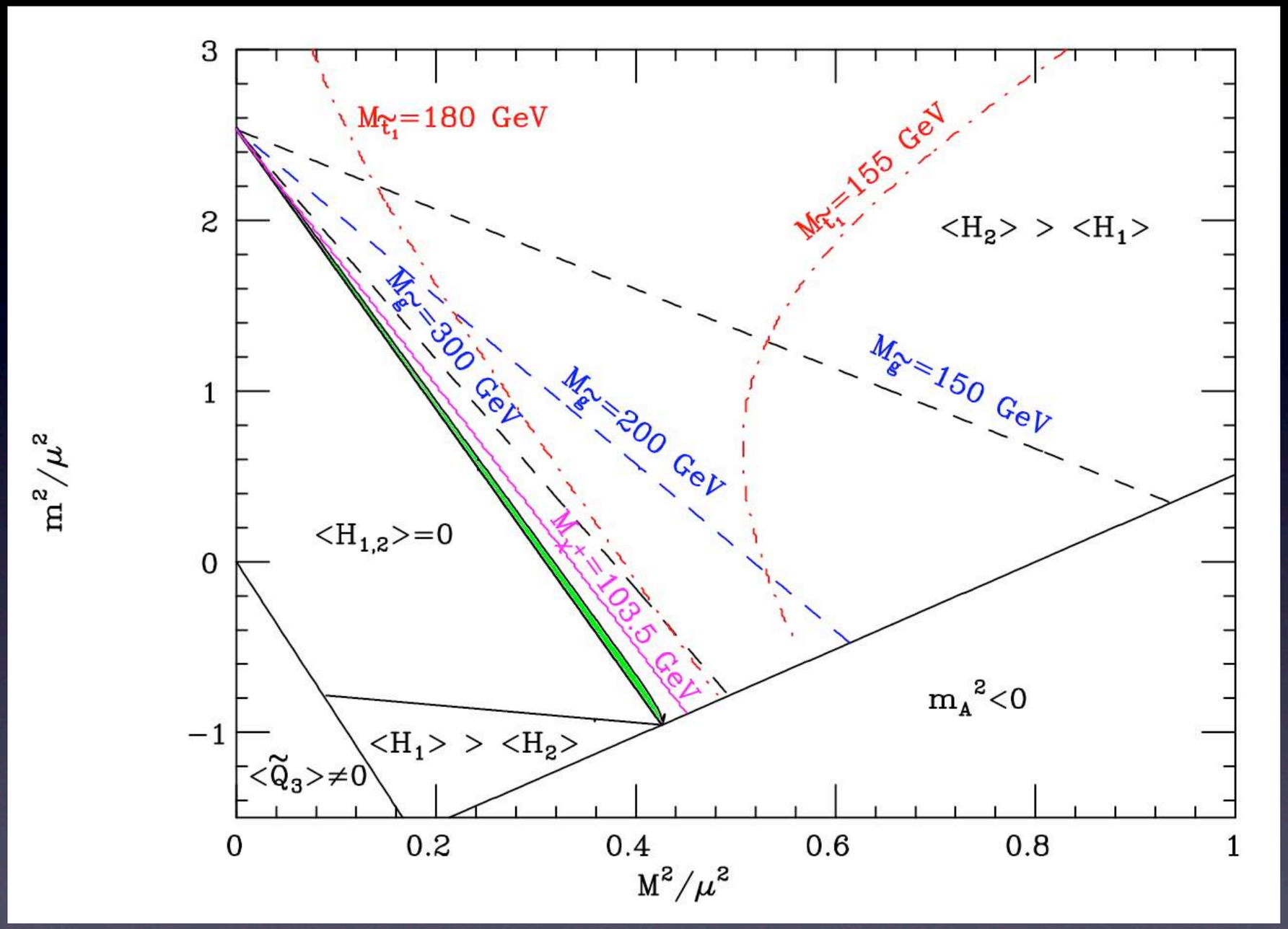
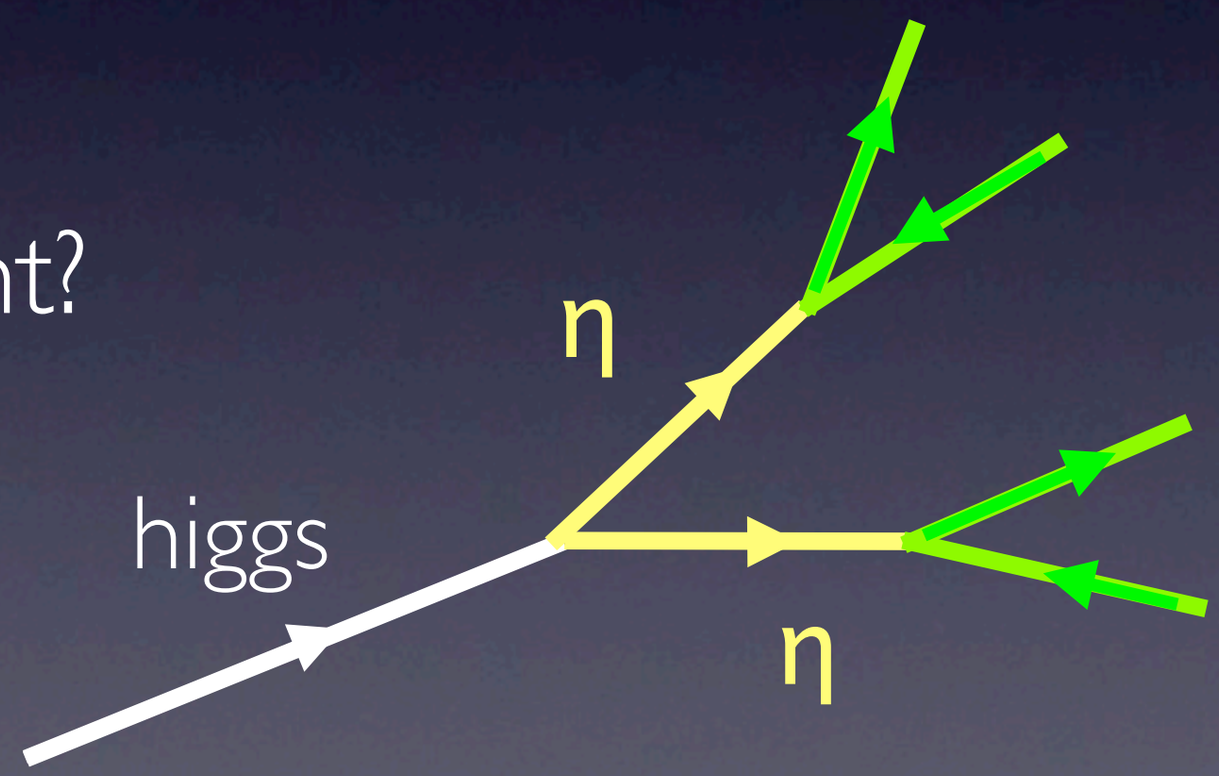
Giudice, Rattazzi '06



Naturalness of the MSSM after LEP2?

Who ordered the η?

Why is the η so light?



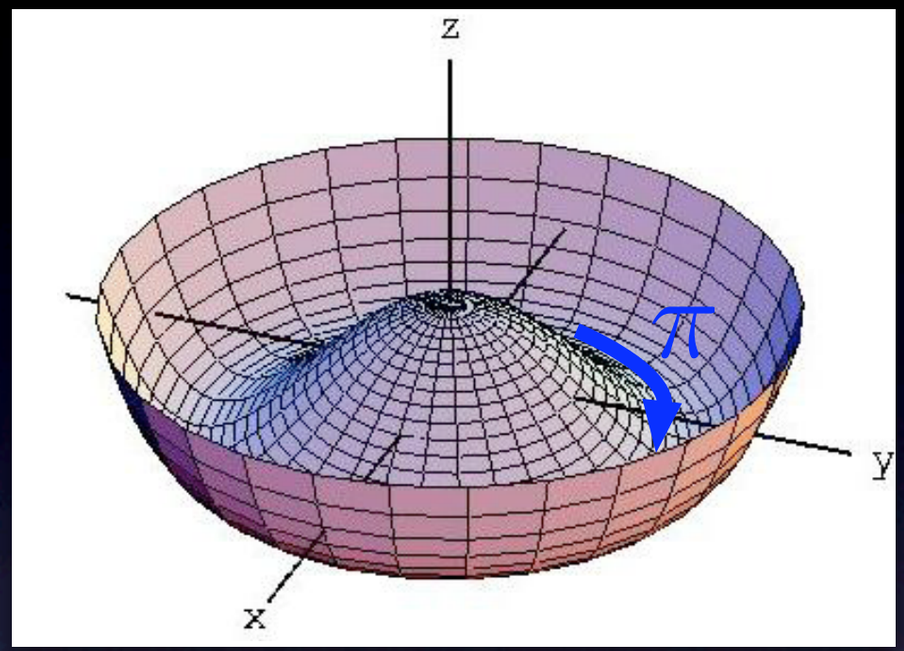
Higgs as a pseudo-Goldstone Boson

Higgs as pGB of SU(3)/SU(2) at $f \approx (2-3) \times v$

8 - 3 $=$ ***5*** broken generators

5 $=$ ***4*** (Higgs doublet) **+** ***1*** (singlet)

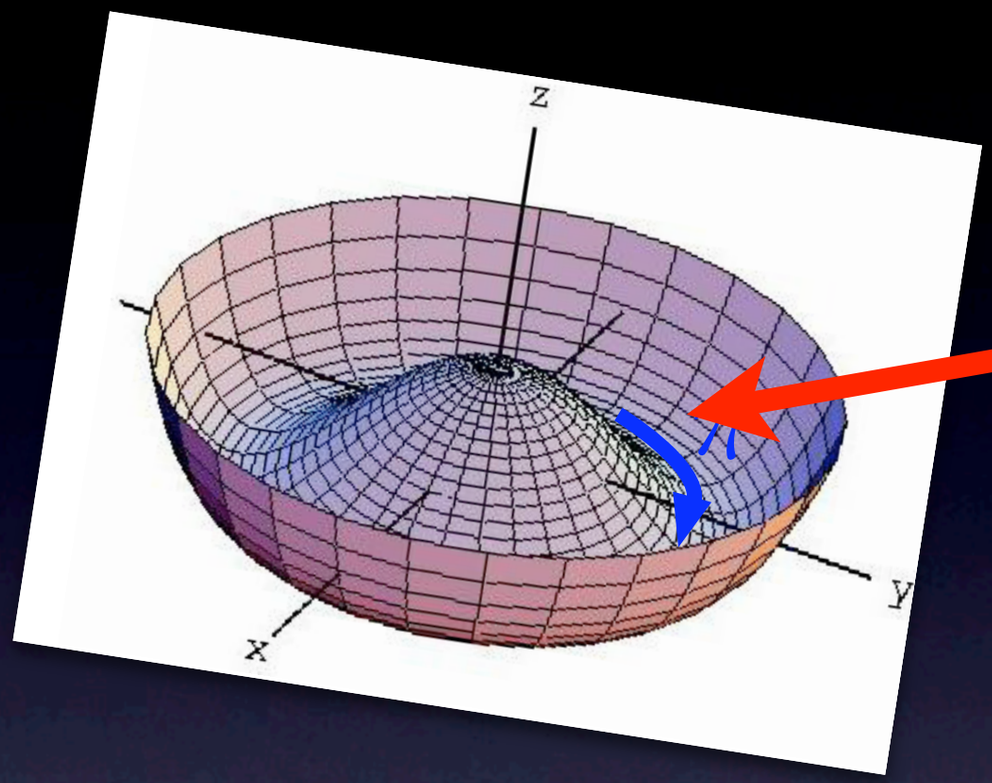
Inspired by QCD



mass protected by global symmetry

$$\pi \to \pi + \alpha$$

Inspired by QCD



Potential tilted:
due to quark masses
and gauging of EM
GB → *pGB*

$$m^2_{\pi^\pm} \approx \frac{\alpha_{em}}{4\pi}\Lambda^2_{QCD}$$

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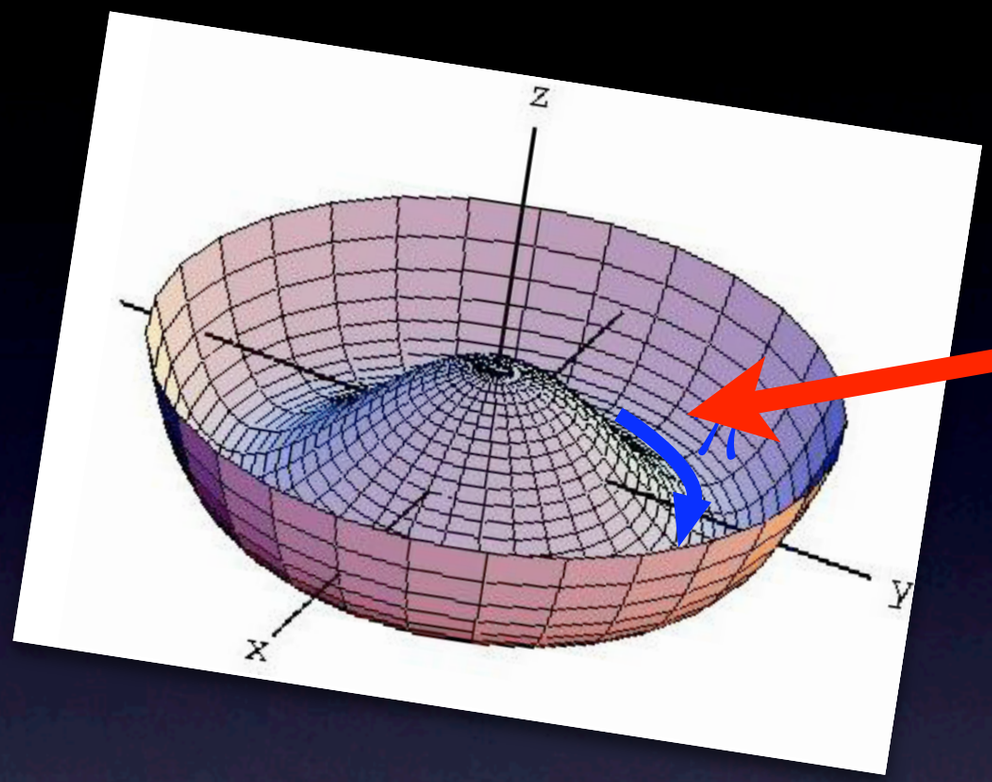

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$$m_{\pi^\pm}^2 \approx \frac{\alpha_{em}}{4\pi}\Lambda_{QCD}^2$$

Translate to EW sector

$$\Lambda_{strong} \sim \frac{4\pi v}{\lambda_t} \sim 1\mathrm{TeV}$$

too low! → collective breaking

pGB's: Higgs + singlet

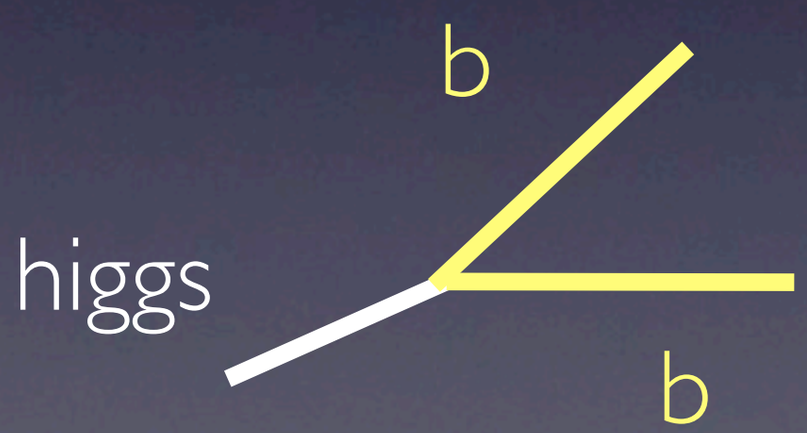
Parameterization of Higgses:
GB of SU(3)→SU(2)

$$\Sigma_{u,d}(\mathbf{3}_{\pm 1/3}) = e^{iT^a G^a} \begin{pmatrix} 0 \\ 0 \\ f_{u,d} \end{pmatrix}, \quad T^a G^a = \frac{1}{f} \begin{pmatrix} 0 & H \\ H^\dagger & \eta \end{pmatrix},$$

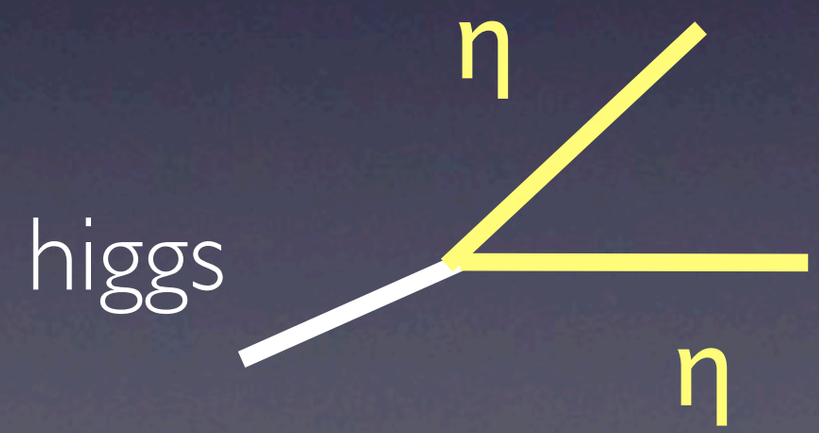
$h \to \eta\eta$ vs. $h \to bb$

Goldstone interaction *fixed by symmetry*

$$\mathcal{L}_{h\eta^2} \approx -h(\partial_\mu \eta)^2 \frac{\tan(\tilde{v}/f)}{\sqrt{2}f}$$



vs.



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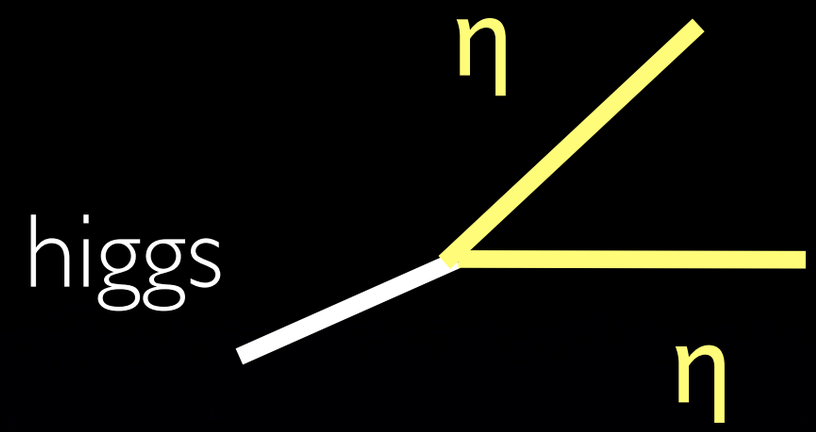

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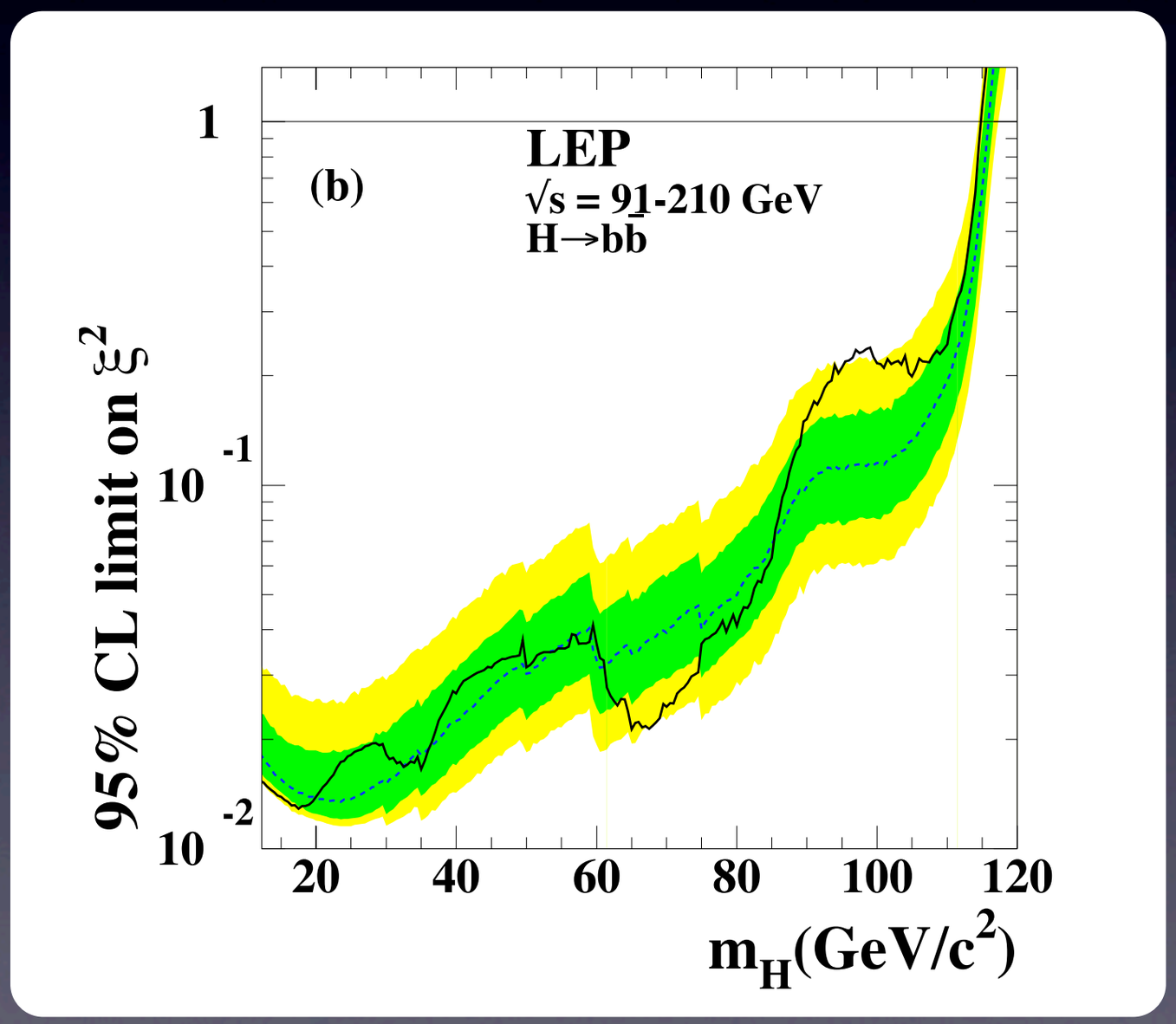

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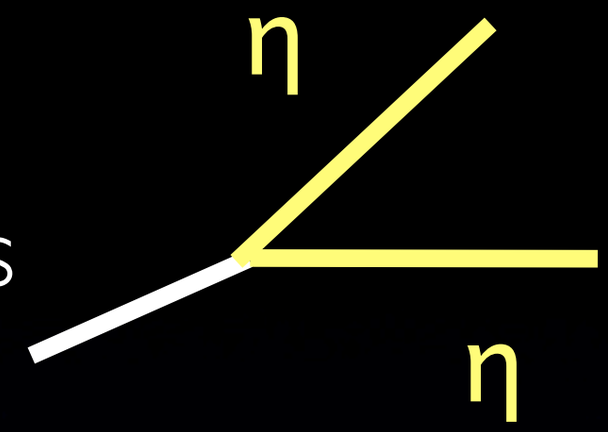
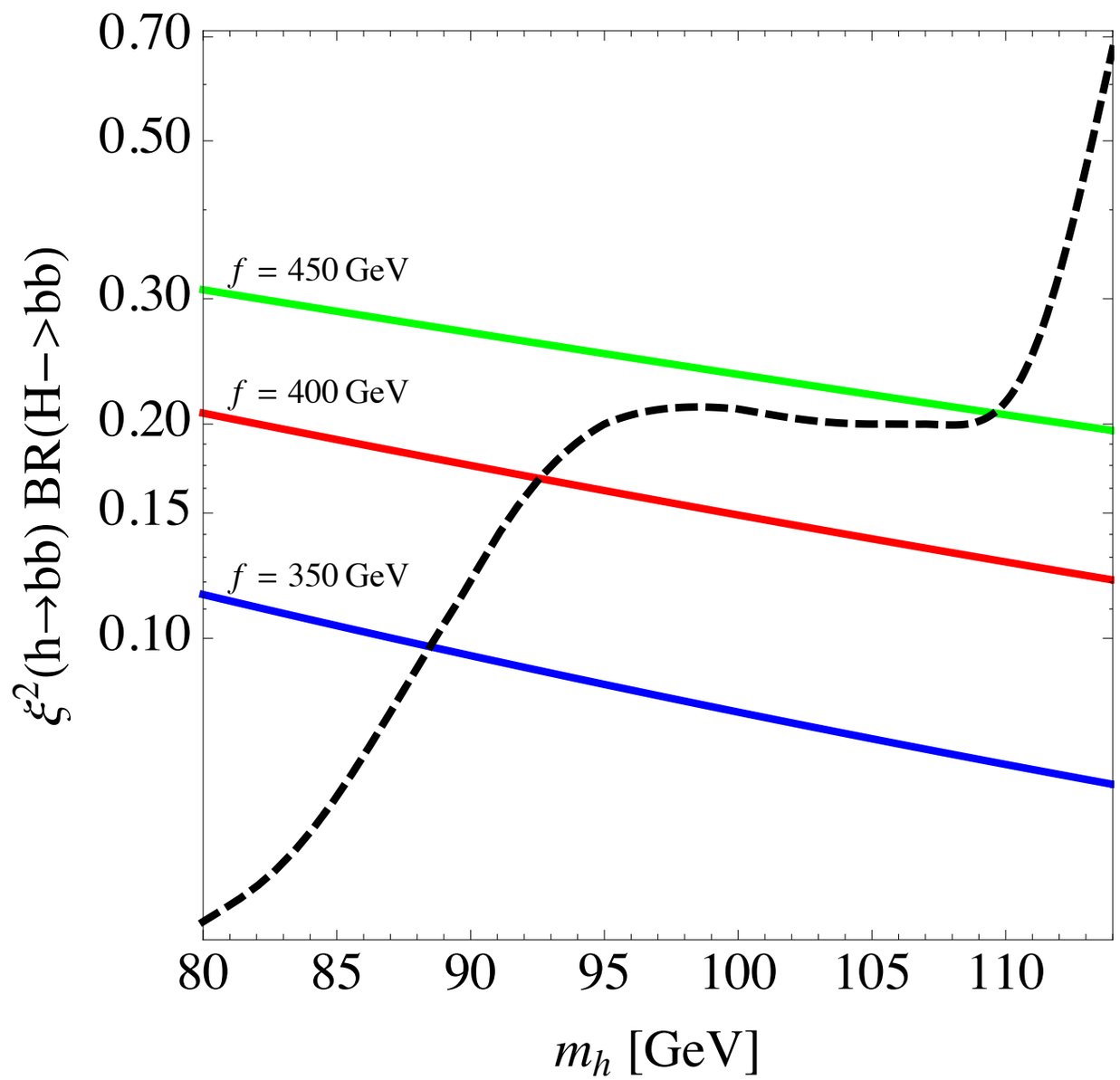
higgs





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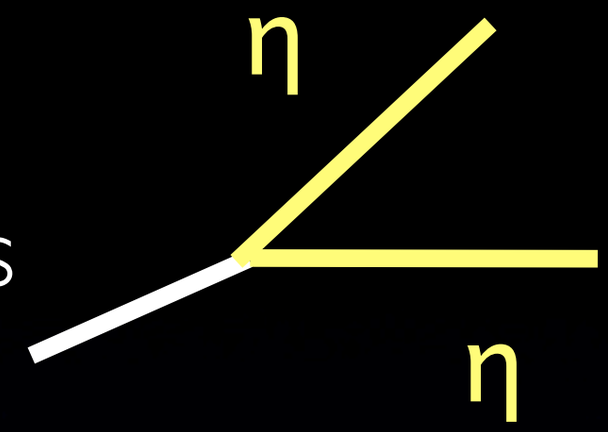

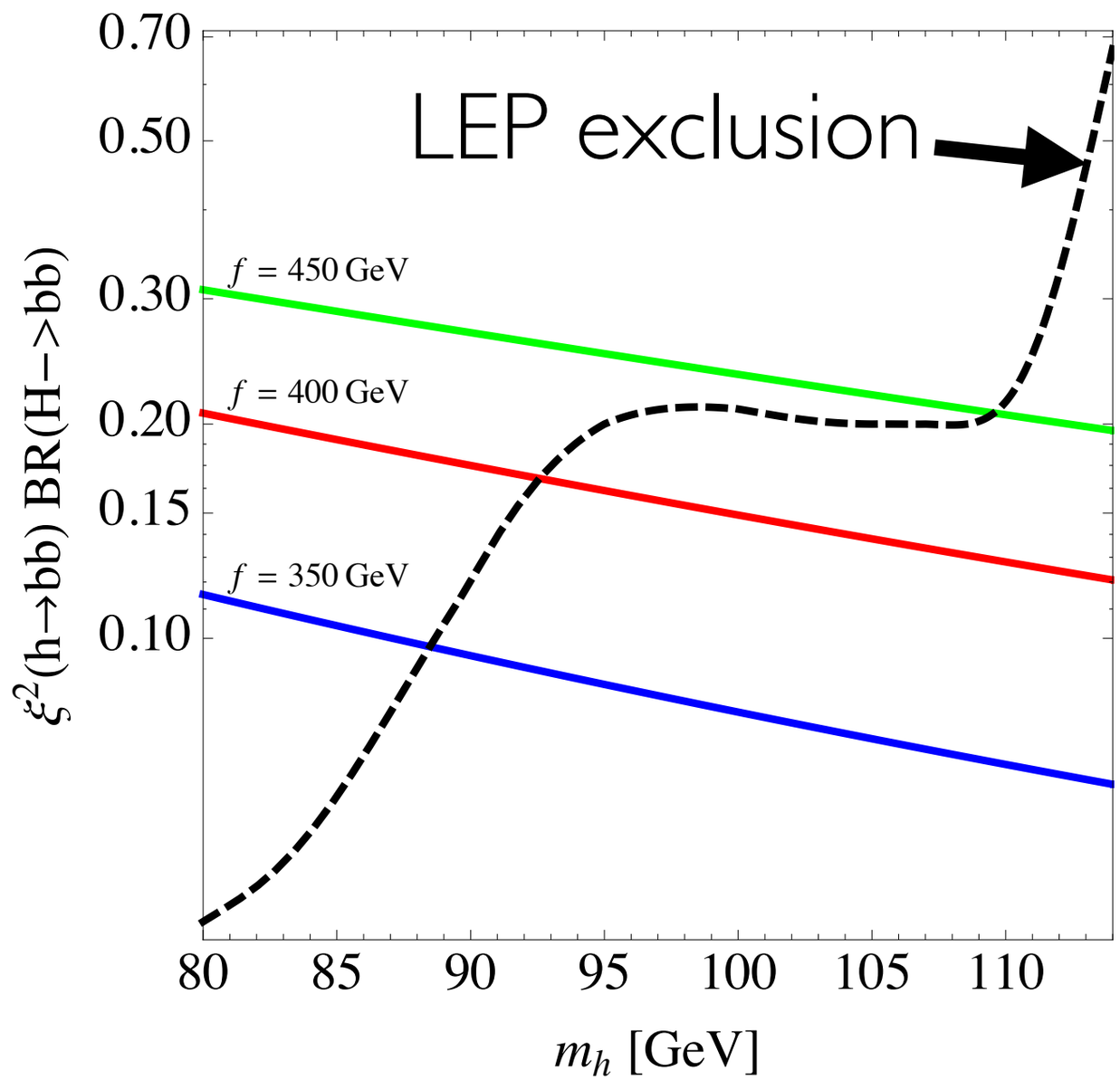

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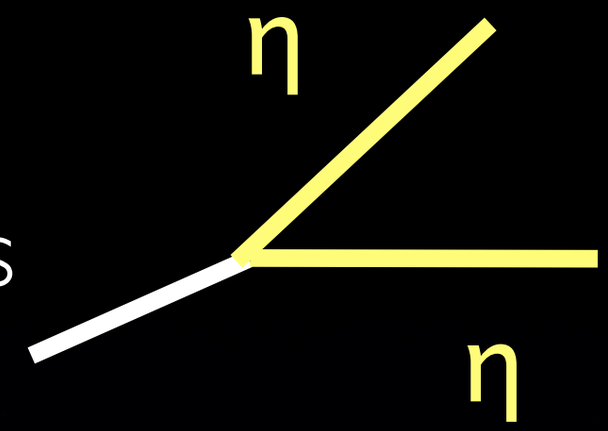

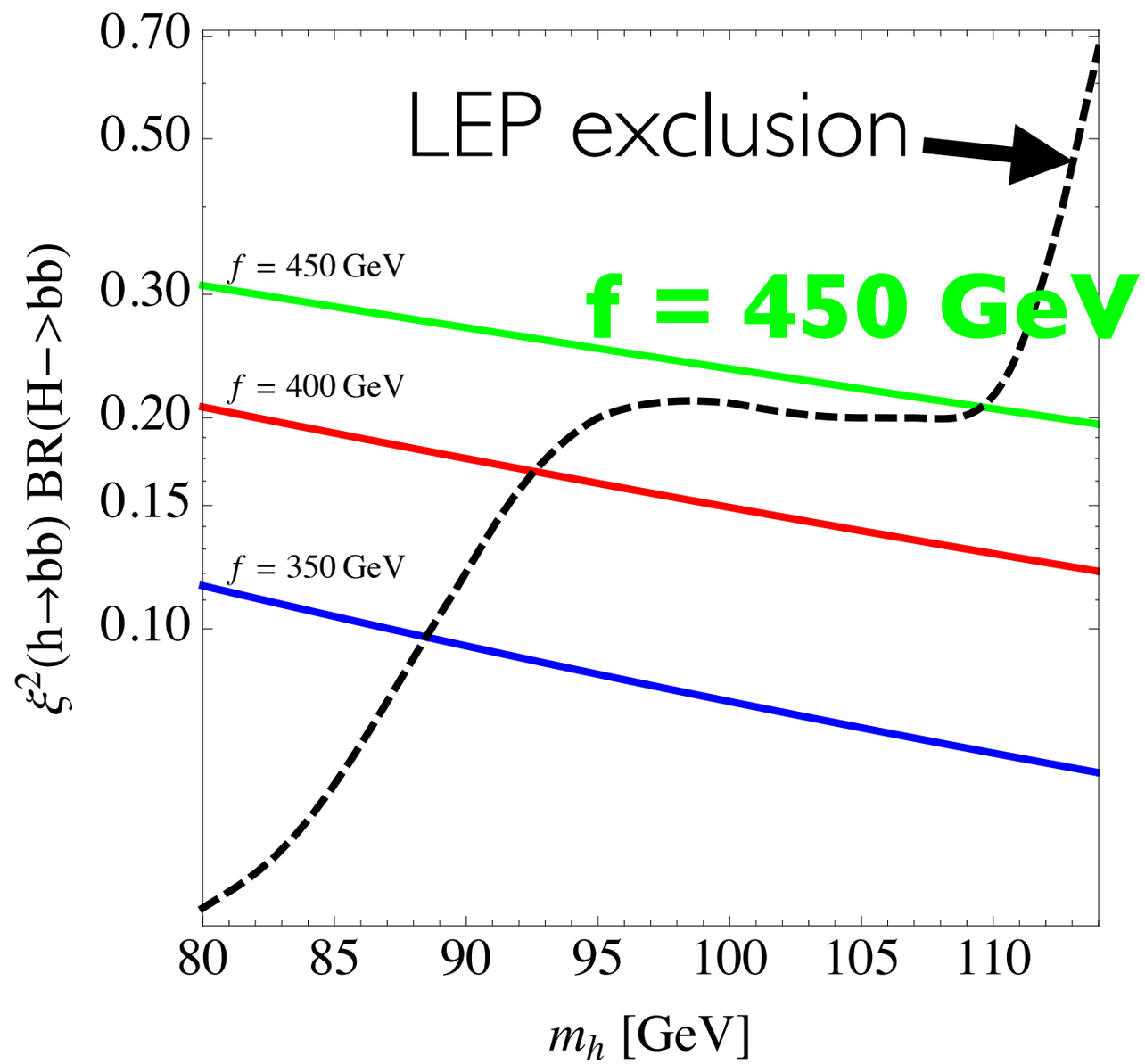

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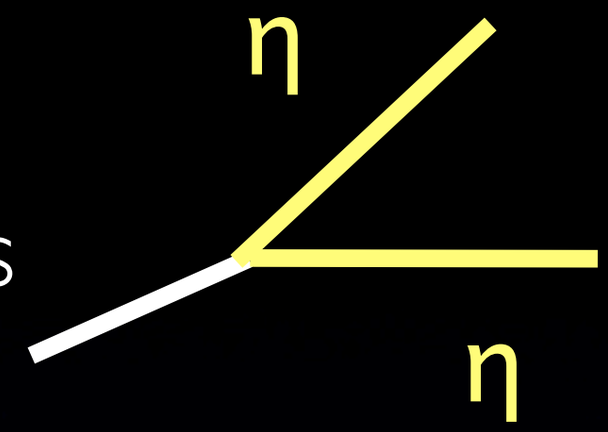

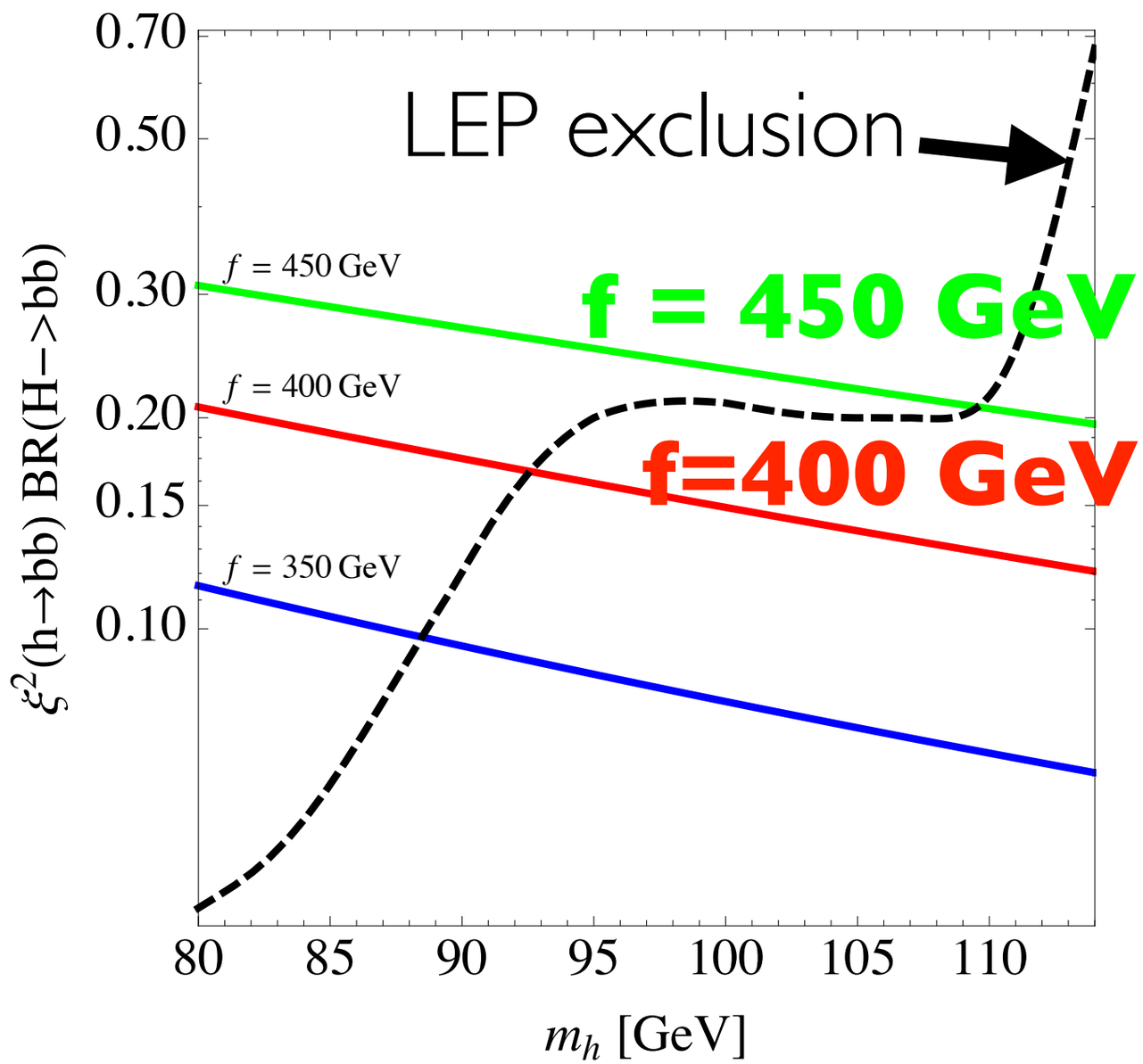

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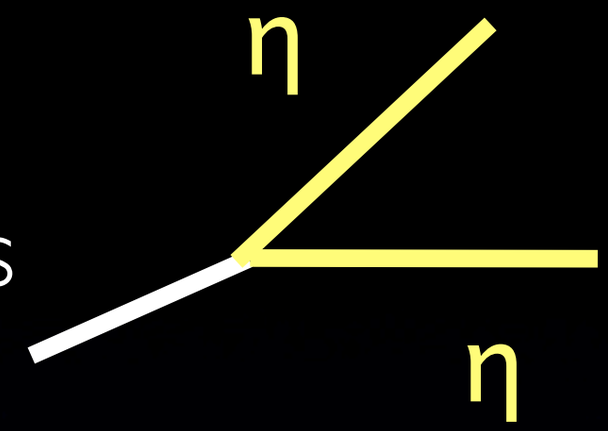

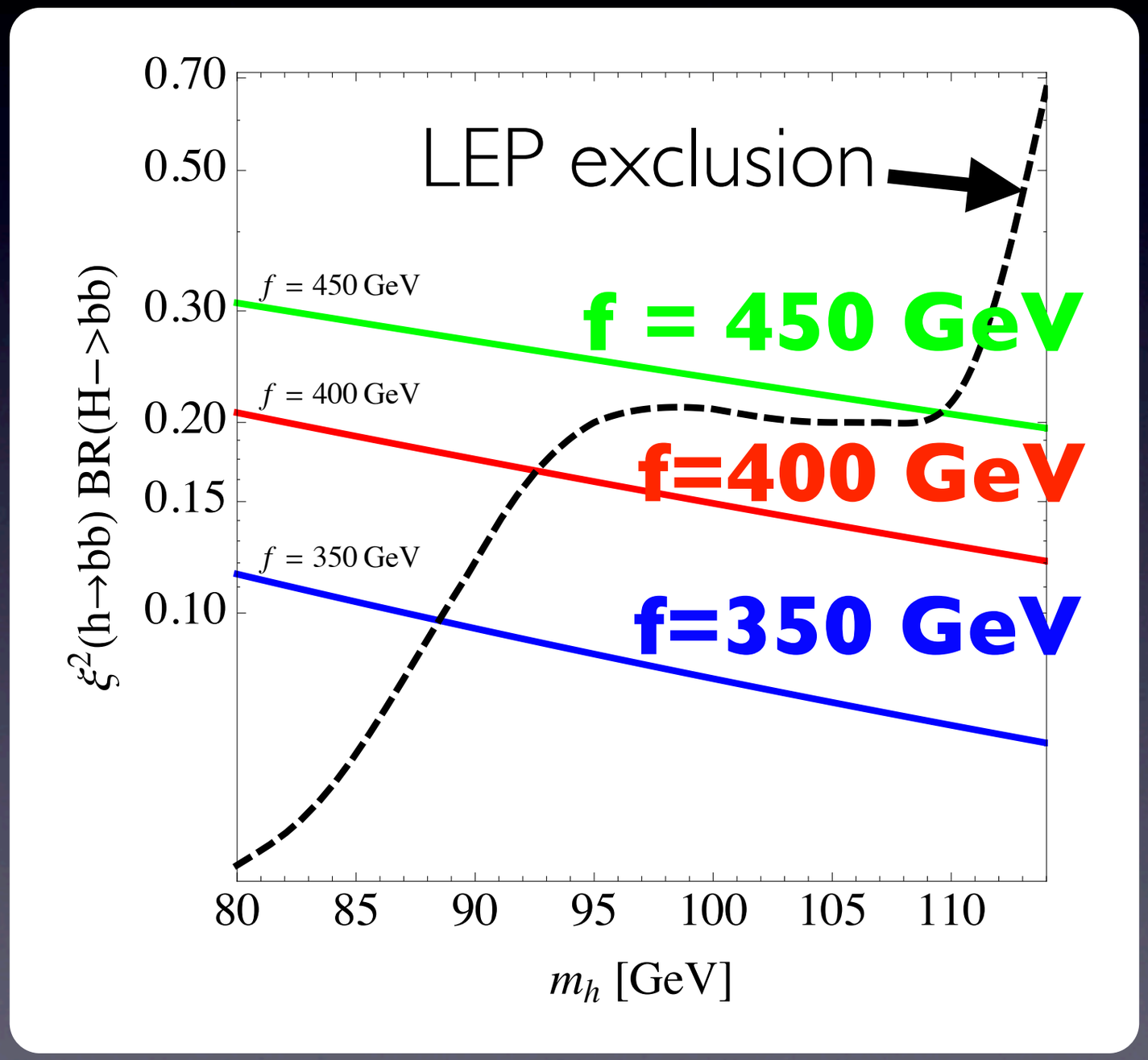

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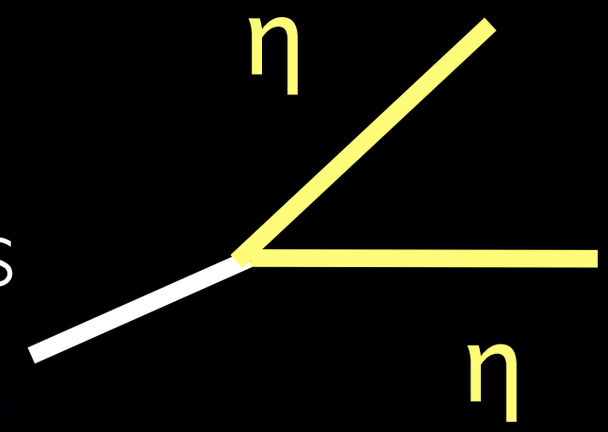
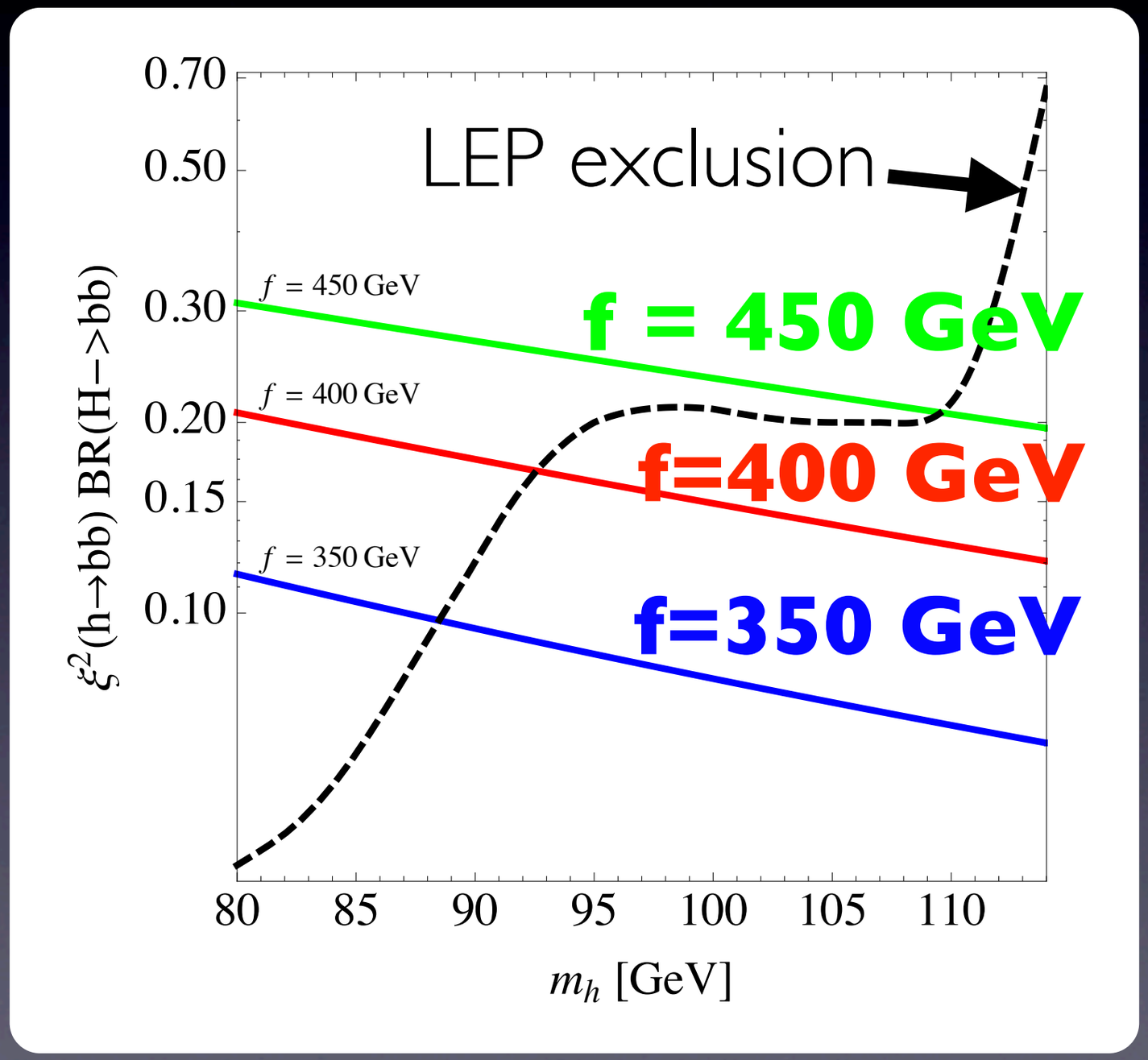




$f \leq 400$ GeV

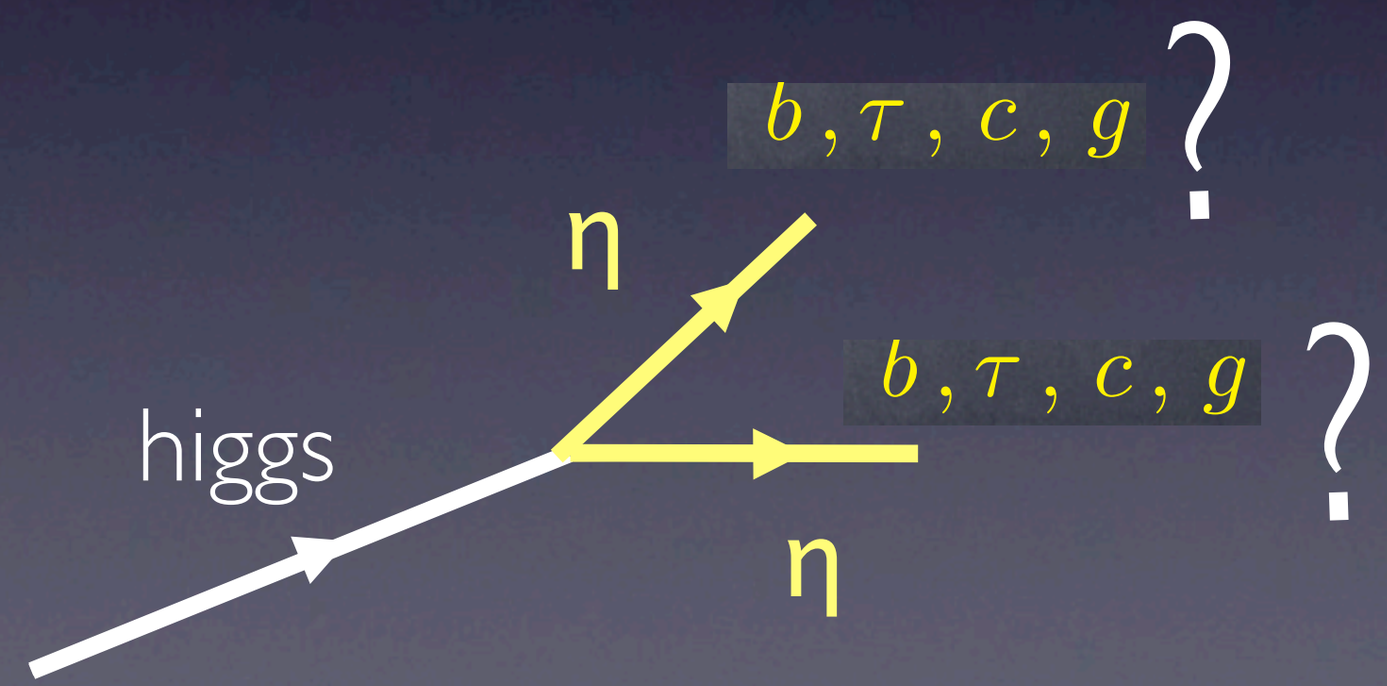
So far...

- Found pGB Higgs model
- Higgs + singlet η, Higgs decays mostly into η.

  Higgs and η mass? LEP?
- What happens to singlet ?

$m_h = ?$

$m_\eta = ?$



So far...

- Found pGB Higgs model
- Higgs + singlet η, Higgs decays mostly into η.

  Higg

- Wha

Need concrete model !
Matter embedding, dynamics, …
1) Supersymmetric theory
2) Composite Higgs (talks by
→Rattazzi, Sundrum, Grojean)

$m_h = ?$

, g ?

, c, g ?

Higgs

η

Susy embedding: theoretical virtues

Susy embedding: theoretical virtues

- Quartic (D-terms) for doublet only $m_\eta \ll m_{h^0}$
- Quadratic term protected, finite & no tuning

Simplest super-Little Higgs

Easiest SUSY embedding of LH is "simplest little Higgs"

Kaplan, Schmaltz '03; Schmaltz '04

Extend $SU(2)_W \times U(1)_Y$ to $SU(3)_W \times U(1)_X$

Higgs doublets become SU(3) triplets

$$H_{u,d} \to \mathcal{H}_{u,d} = (H_{u,d}, S_{u,d}) = 3, \bar{3}$$

and receive cloned partners $\Phi_{u,d} = 3, \bar{3}$

F-Term respects $SU(3)_1 \times SU(3)_2$ symmetry

$$\mathcal{W} = \mathcal{W}_\Phi + \mathcal{W}_\mathcal{H}$$

Higgs potential

Both f/F and v/f radiatively generated through bottom-top loops in Coleman-Weinberg.
Triplet potential

$$m_{\mathcal{H}_u}^2 \approx -\frac{3y_2^2 \sin^2\beta}{2\pi^2} M_{\rm soft}^2 \log(\Lambda/M_T)$$

$$\lambda_{\mathcal{H}_u} \approx \frac{3y_2^4 \sin^4\beta}{8\pi^2} \log((M_{\rm soft}^2 + M_T^2)/M_T^2)$$

$(m_{Hu})^2$ finite !

$$\Delta m^2 \approx -\frac{3m_t^2}{8\pi^2 v_{EW}^2}\left[M_T^2 \log\frac{M_{\rm soft}^2+M_T^2}{M_T^2} + M_{\rm soft}^2 \log\frac{M_{\rm soft}^2+M_T^2}{M_{\rm soft}^2}\right]$$

physical $(m_{Higgs})^2$

$$m_h^2 = \left(1-\frac{v_{EW}^2}{f^2}\right)\left\{m_Z^2\cos^2(2\beta) + \frac{3m_t^4}{4\pi^2 v_{EW}^2}\left[\log\left(\frac{M_{\rm soft}^2 M_T^2}{m_t^2(M_{\rm soft}^2+M_T^2)}\right) -2\frac{M_{\rm soft}^2}{M_T^2}\log\left(\frac{M_{\rm soft}^2+M_T^2}{M_{\rm soft}^2}\right)\right]\right\}$$

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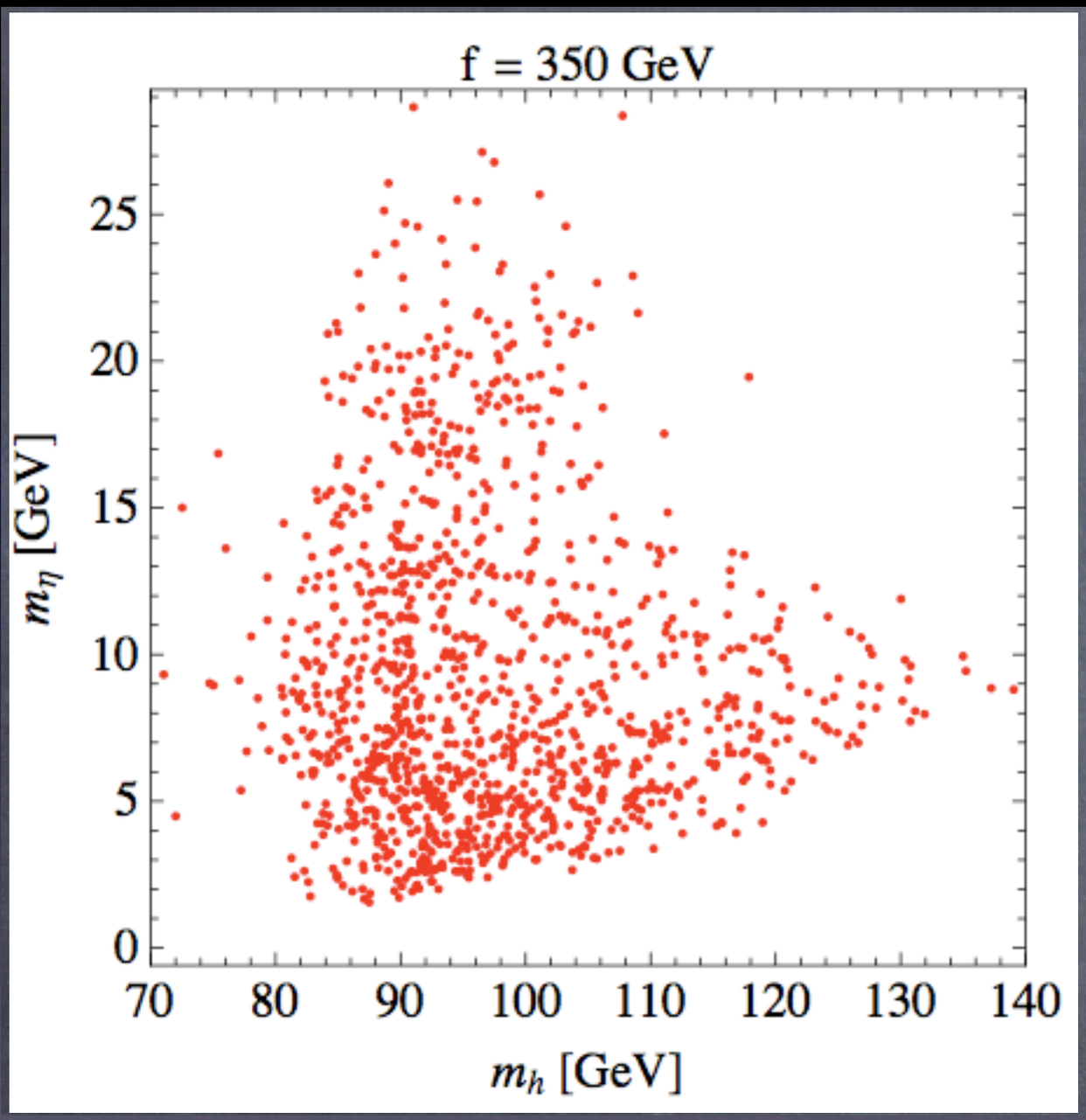
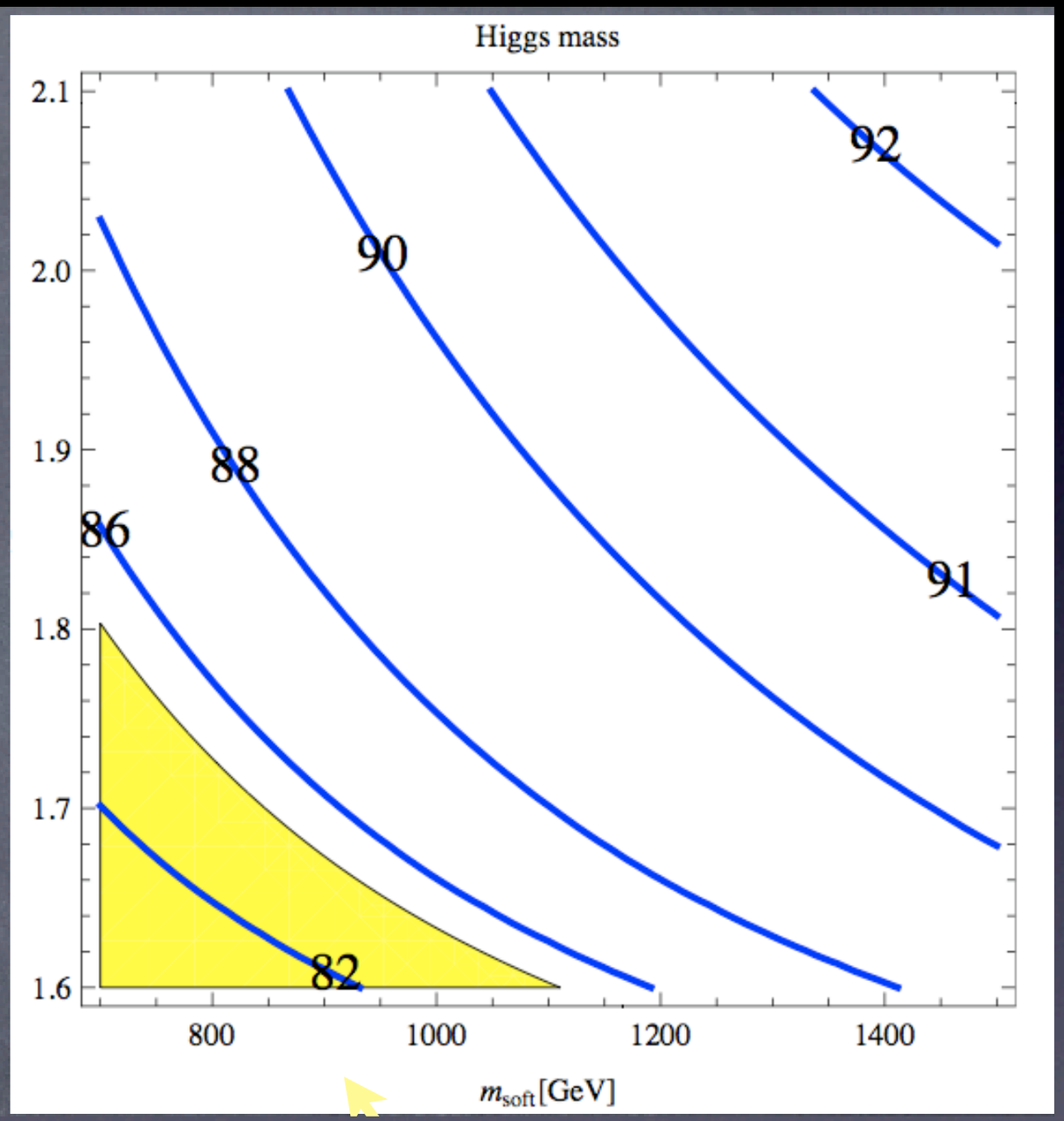

f = 350 GeV
25
20
15
10
5
0
70
80
90
100
110
120
130
140
m_η [GeV]
m_h [GeV]


Higgs mass
2.1
2.0
1.9
1.8
1.7
1.6
800
1000
1200
1400
92
90
88
86
91
82
$m_{\rm soft}$[GeV]

Eta fermion coupling

η in 3rd component of Higgs triplet

SM fermions mostly in 1,2 component of Quark triplet

→ Coupling $i(\bar{f}\gamma_5 f)\eta \sim$ (mixing with heavy partner)

	non-flipped	flipped
	Buried	Charming
Top	$\tilde{y}_t \sim \frac{m_t^3}{\sqrt{2}v_{EW}^2 f} \sim 0.2$	$\tilde{y}_t \sim \frac{m_t}{\sqrt{2}f} \sim 0.2$
Charm	$\tilde{y}_c \sim \frac{m_c^3}{\sqrt{2}v_{EW}^2 f} \sim 10^{-9}$	$\tilde{y}_c \sim \frac{m_c}{\sqrt{2}f} \sim 10^{-3}$
B	$\tilde{y}_b \sim \frac{m_b m_t^2}{\sqrt{2}v_{EW}^2 f} \sim 10^{-2}$	$\tilde{y}_b \sim \frac{m_b^3}{\mu_V^2 f} \sim 10^{-12}$
Tau	$\tilde{y}_\tau \sim \frac{m_\tau^3 f}{\sqrt{2}f v_{EW}^2} \sim 10^{-8}$	$\tilde{y}_\tau \sim \frac{m_\tau^3 f}{\sqrt{2}f v_{EW}^2} \sim 10^{-8}$

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$m_{eta} < 2m_b$

Eta fermion coupling

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SM fermions mostly in 1,2 component of Quark triplet

→ Coupling $i(\bar{f}\gamma_5 f)\eta \sim$ (mixing with heavy partner)

Extra suppression

$$\tilde{y}_b \sim \frac{m_b}{f} \times \frac{m_b^2}{\mu_V^2}$$

	non-flipped	flipped
	Buried	Charming
Top	~~$\tilde{y}_t \sim \frac{m_t^3}{\sqrt{2}v_{EW}^2 f} \sim 0.2$~~	~~$\tilde{y}_t \sim \frac{m_t}{\sqrt{2}f} \sim 0.2$~~
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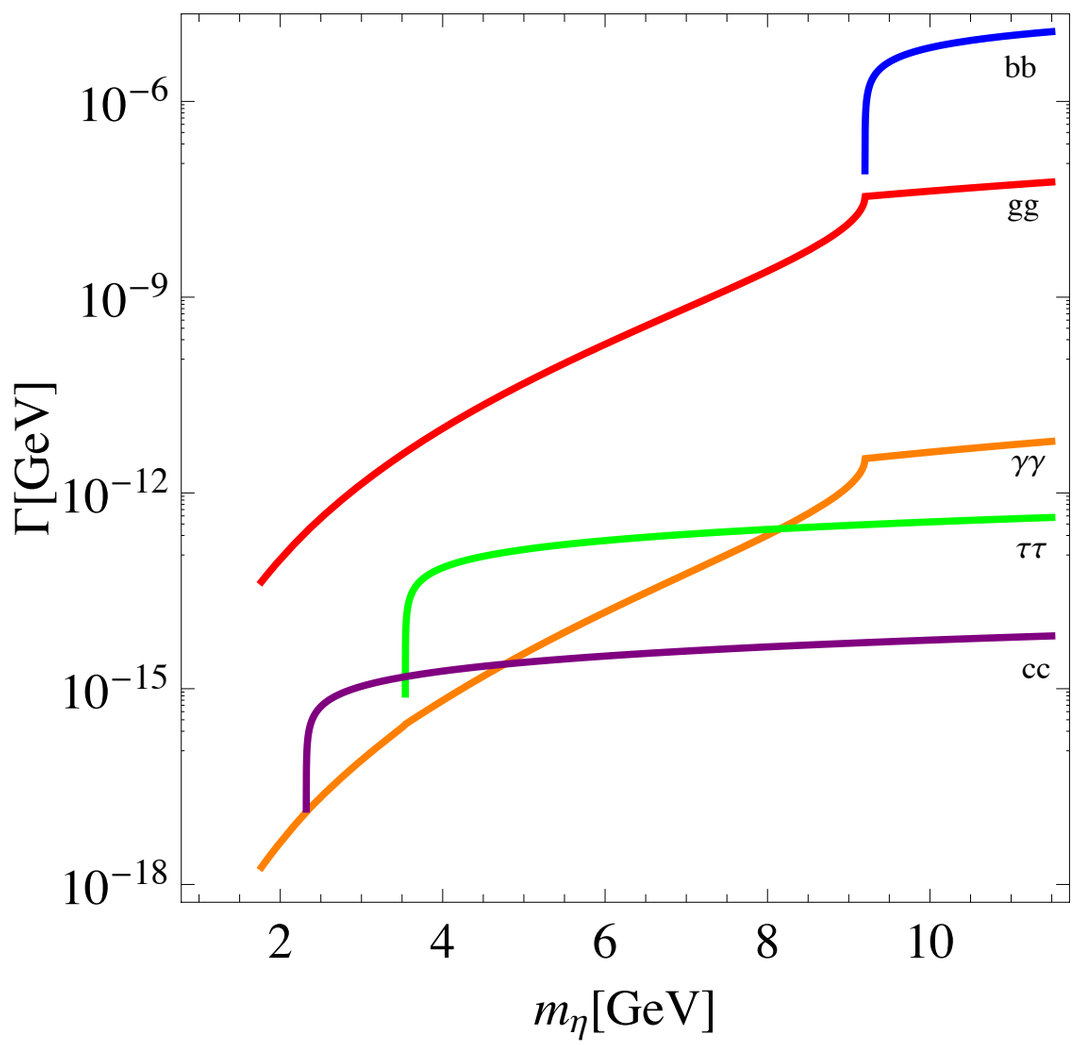
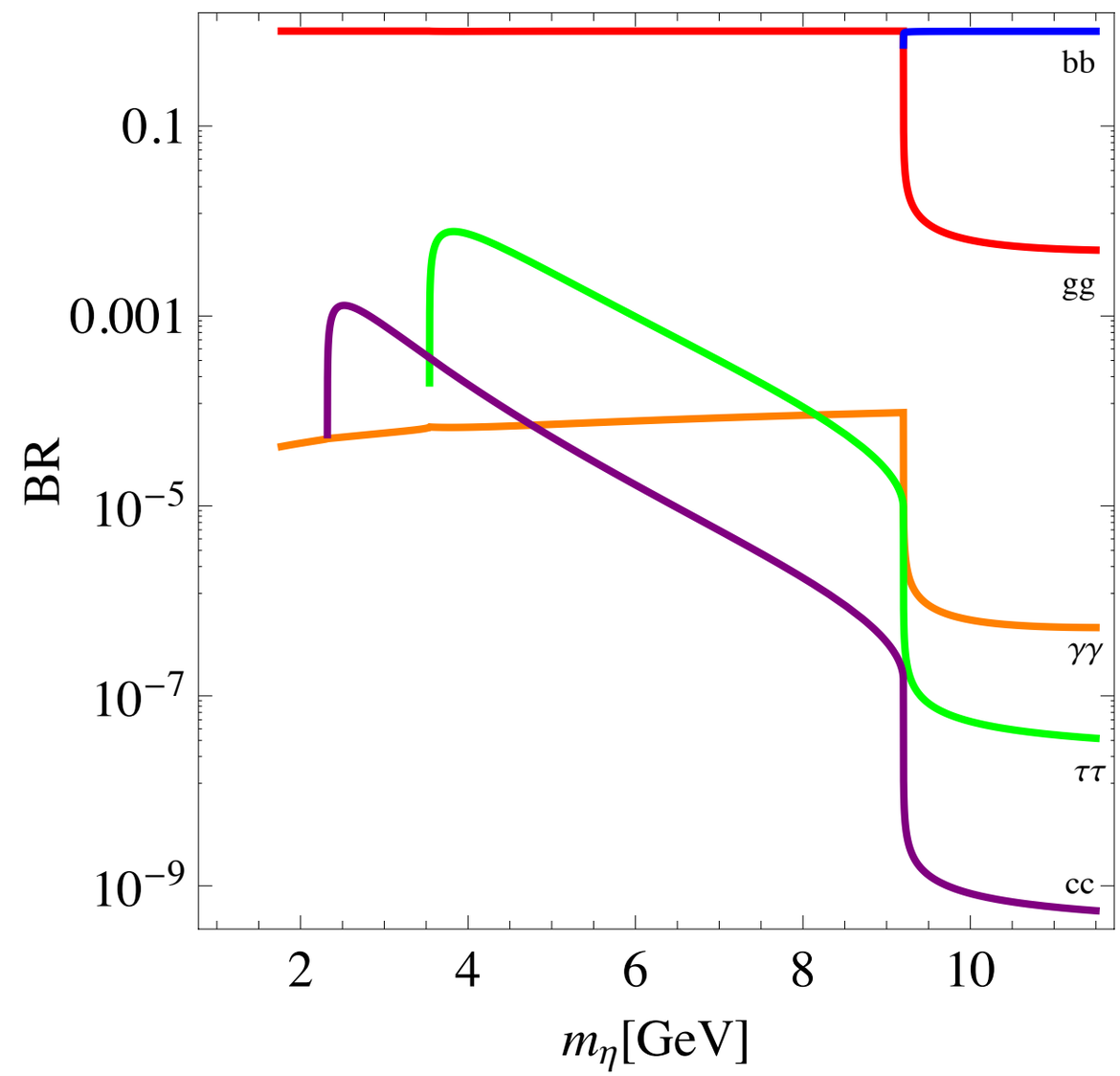
$m_{eta} < 2m_b$

Eta decays - buried Higgs



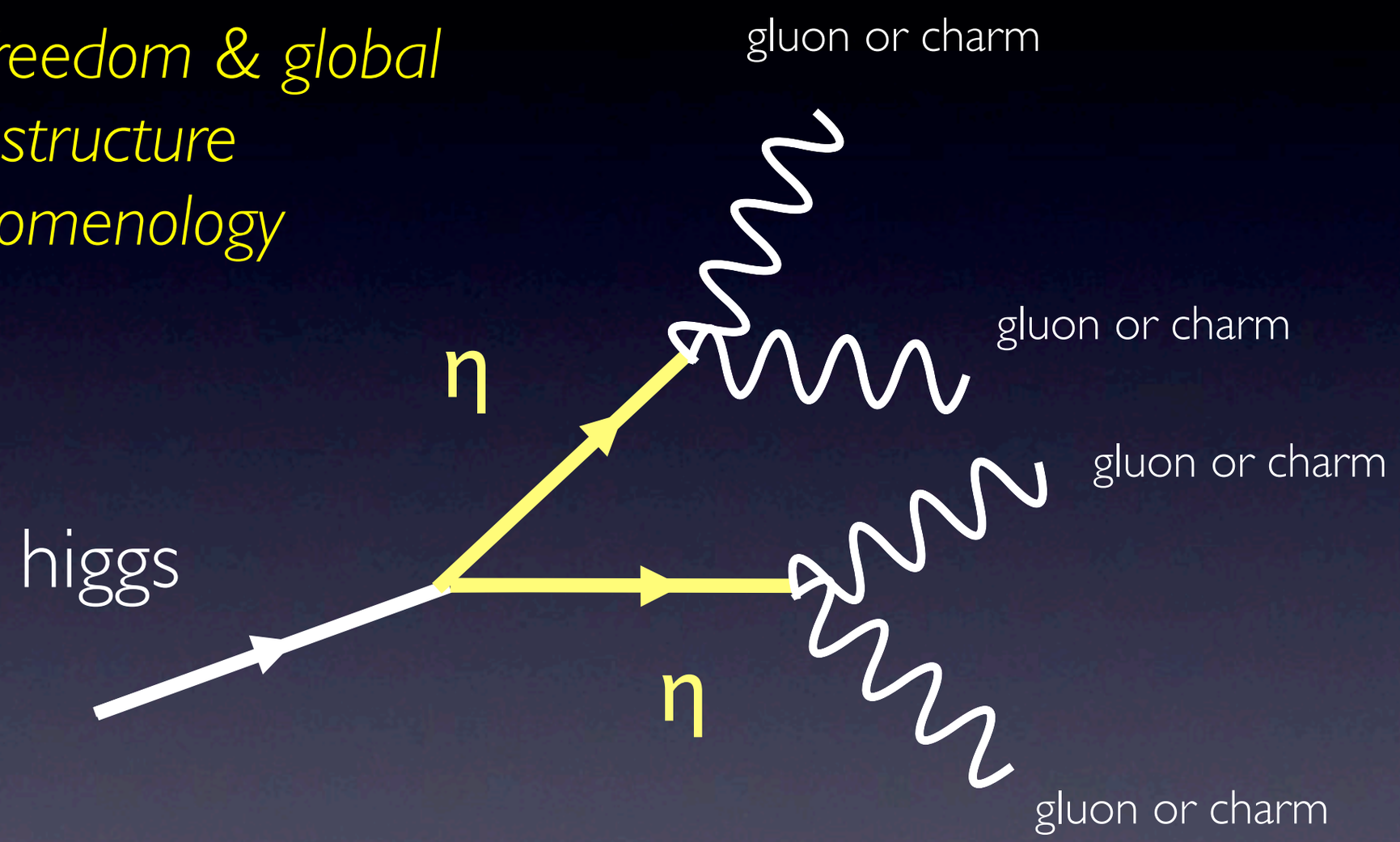


$$\Gamma_{\eta\to gg} = (N_c^2 - 1)\frac{|\kappa^g|^2}{\pi} m_\eta^3$$

Susy pGB: surprising result

Bellazini, Csaki, Falkowski, AW

Anomaly freedom & global symmetry structure fixes phenomenology



h → 4 gluon or h → 4 charm

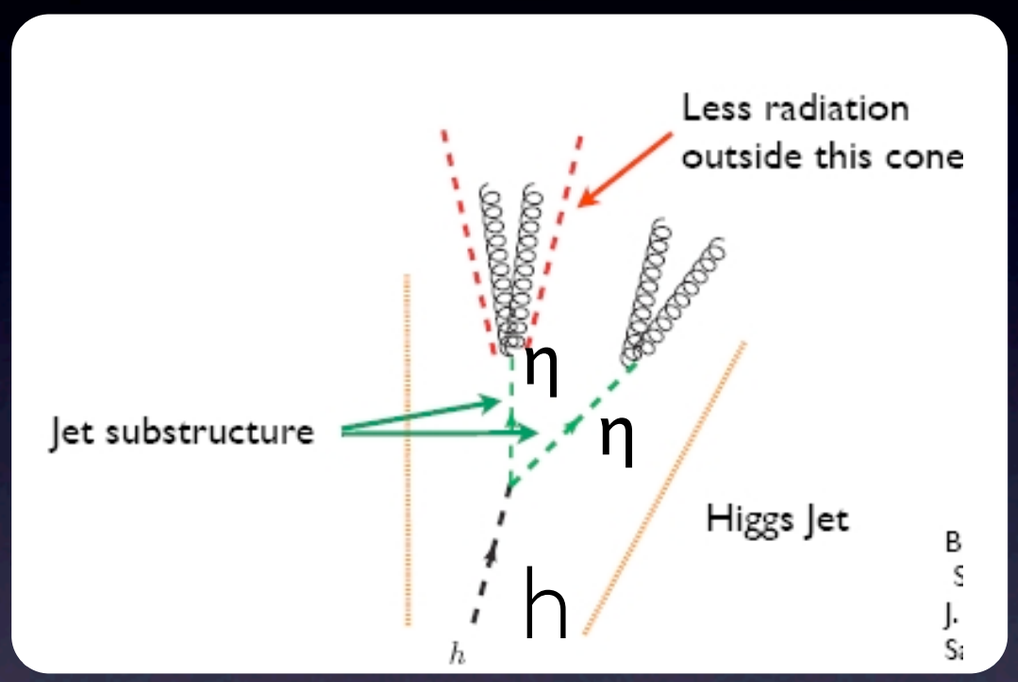
LHC Signals

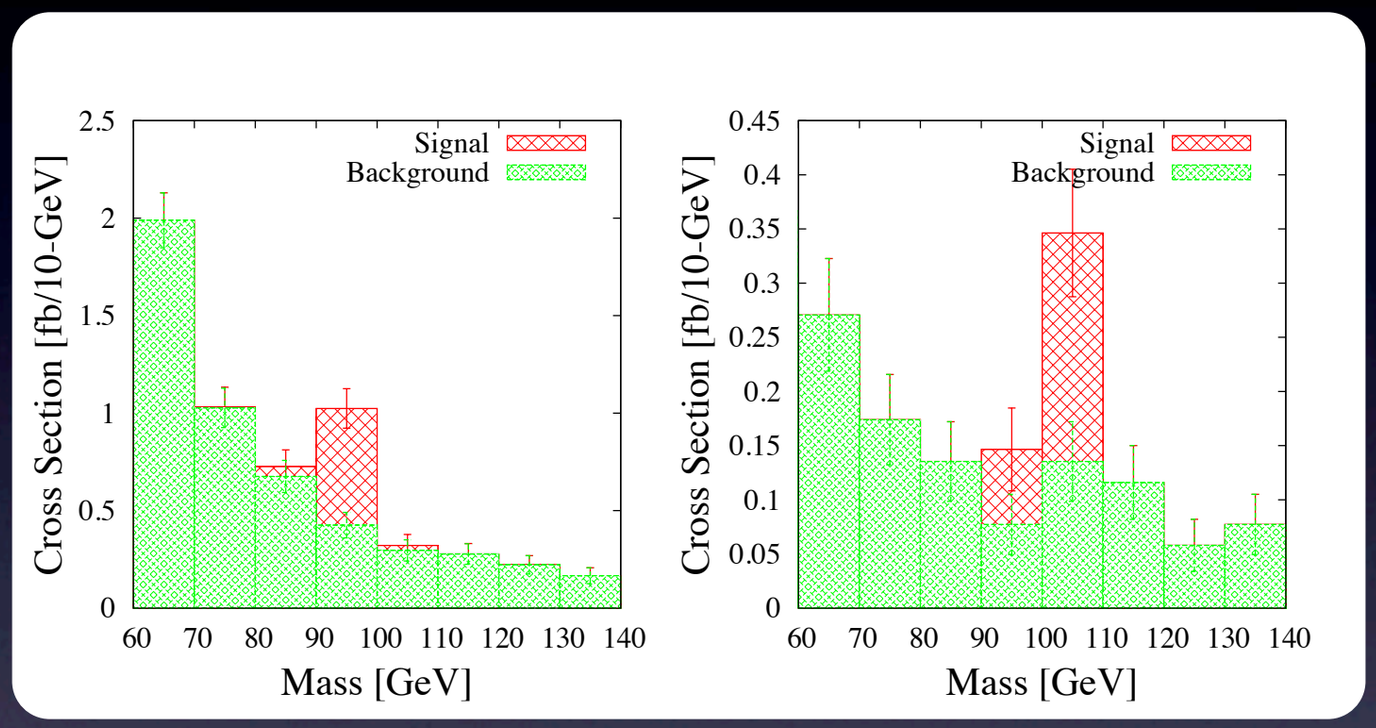
1) How are we going to see the Higgs?
2) Higgs Impostor

Using Jet-substructure to unbury the Higgs

Jet substructure: ttH

Falkowski,et al.





		$m_h = 80$ GeV	$m_h = 100$ GeV	$m_h = 120$ GeV
$pp \to hW$	$S/\sqrt{B}$	6.6 (4.8)	7.8 (5.7)	7.0 (6.9)
	S/B	0.34 (0.067)	0.90 (0.11)	0.80 (0.24)
$pp \to ht\bar{t}$	$S/\sqrt{B}$	6.1 (5.9)	6.1 (5.7)	7.1 (7.1)
	S/B	1.1 (0.97)	1.3 (1.1)	2.5 (2.5)

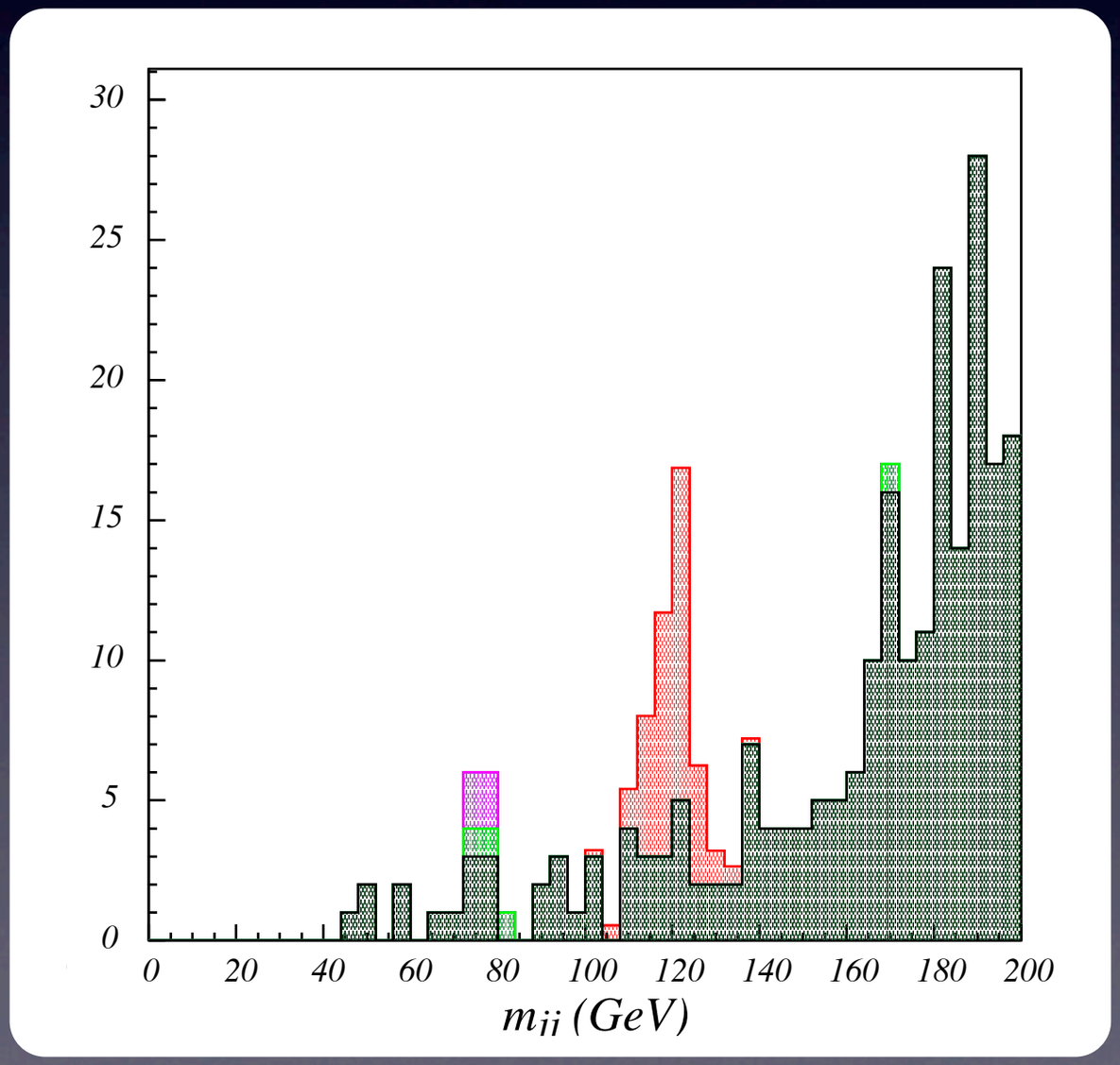
Can unbury the buried Higgs.

(S/B for 100 1/fb)

Jet Substructure II: hW→eνjj

Chen, Nojiri, Sreethawong

shown here: $m_\eta = 4GeV$ ($m_\eta = 8GeV$ slightly harder)



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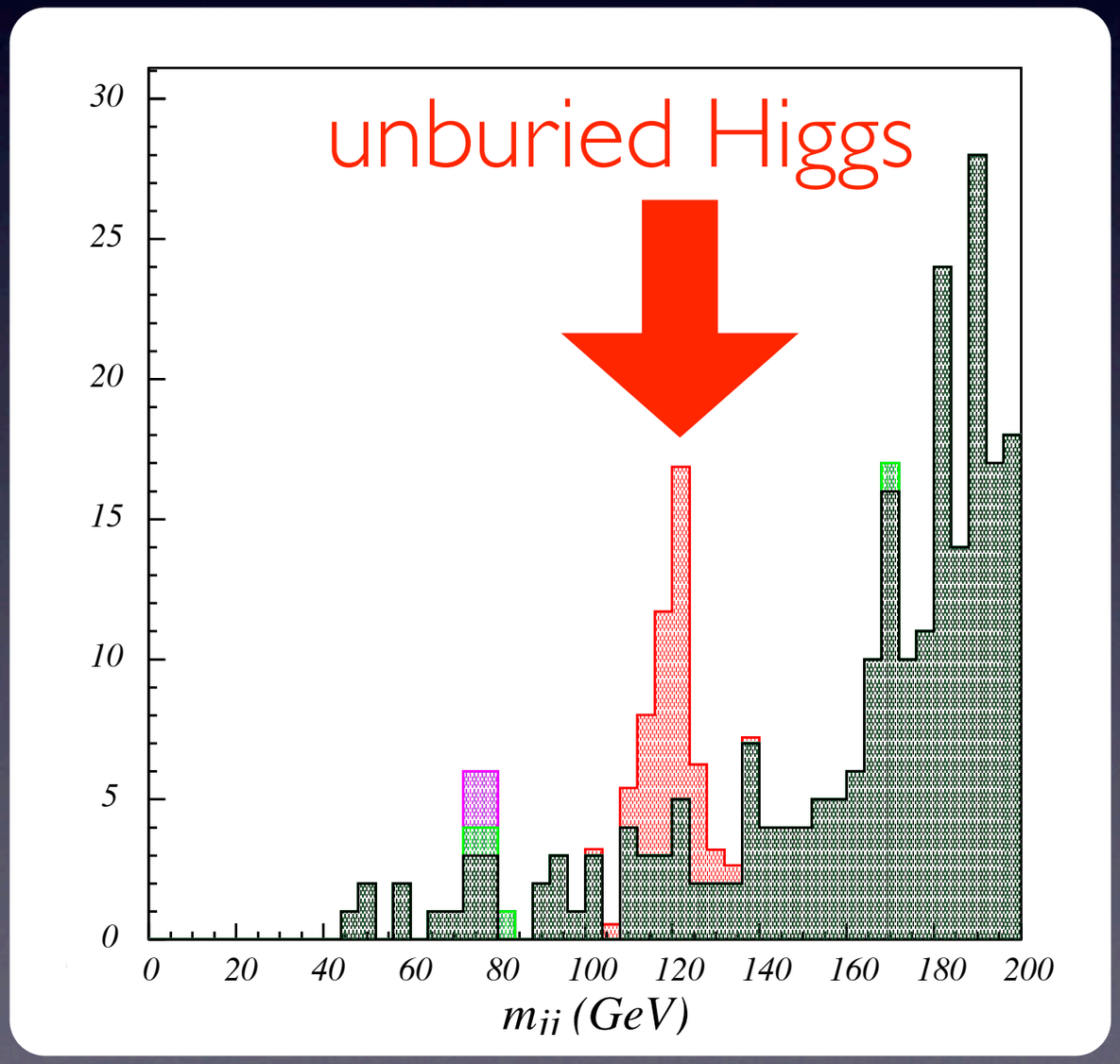

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Chen, Nojiri, Sreethawong

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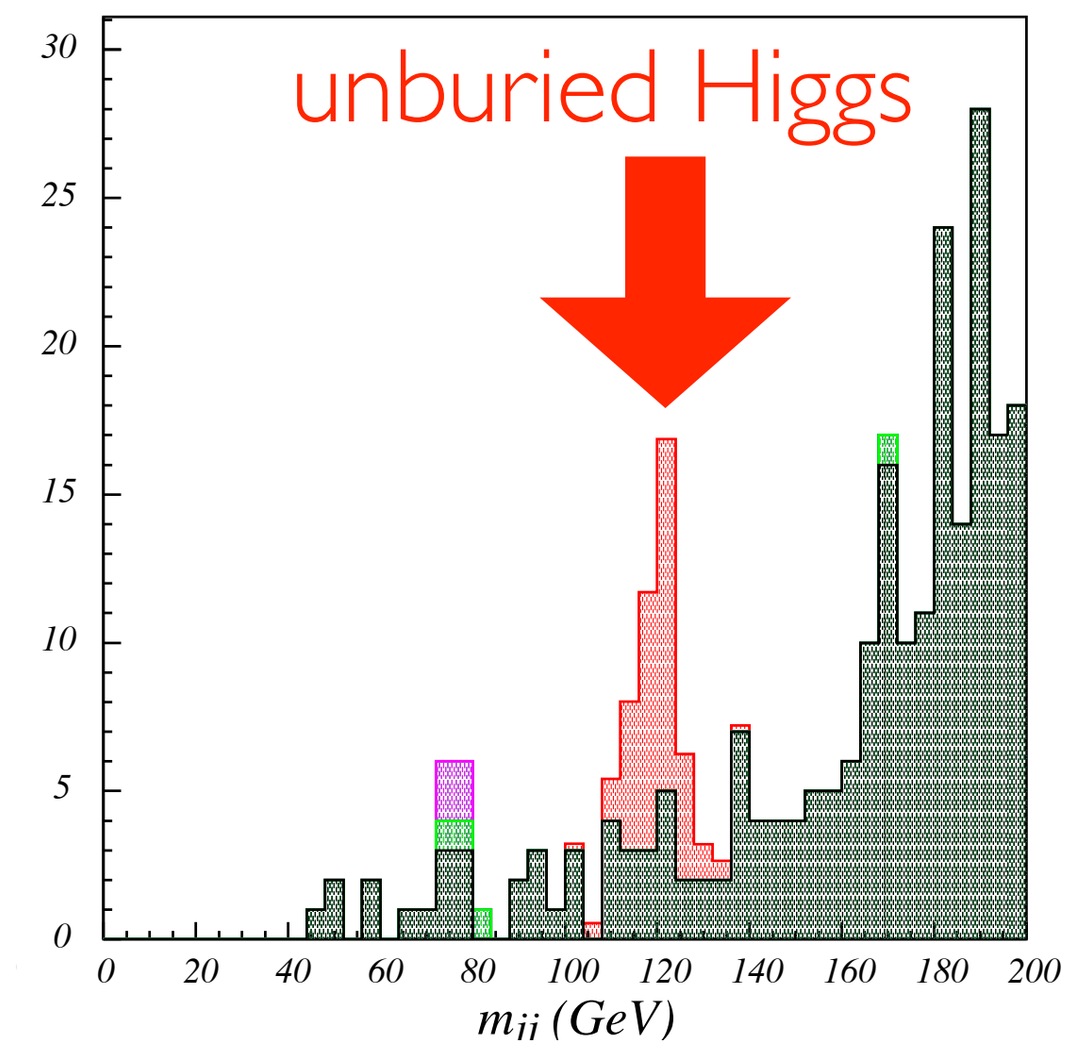
Jet algorithm	σ_S (fb)	$S/\sqrt{B}$
CA	1.13	7.09
KT	0.97	7.03

Table 4: Signal cross section and statistical significance after all cuts in the dijet invariant mass window 110 GeV $\leq m_{jj} \leq$ 130 GeV for $\mathcal{L} = 30$ fb^{-1} at the LHC.



Higgs Impostor

Higgs Impostor

Bellazini, Csaki, Falkowski, AW

$$\mathcal{H}_u \approx (f + r/\sqrt{2}) \begin{pmatrix} 0 \\ \sin((\tilde{v} + h/f)) \\ \cos((\tilde{v} + h/f)) \end{pmatrix}$$

$$m_r^2 \approx 4\lambda_{\mathcal{H}} f^2 \sim 350 \text{ GeV}$$

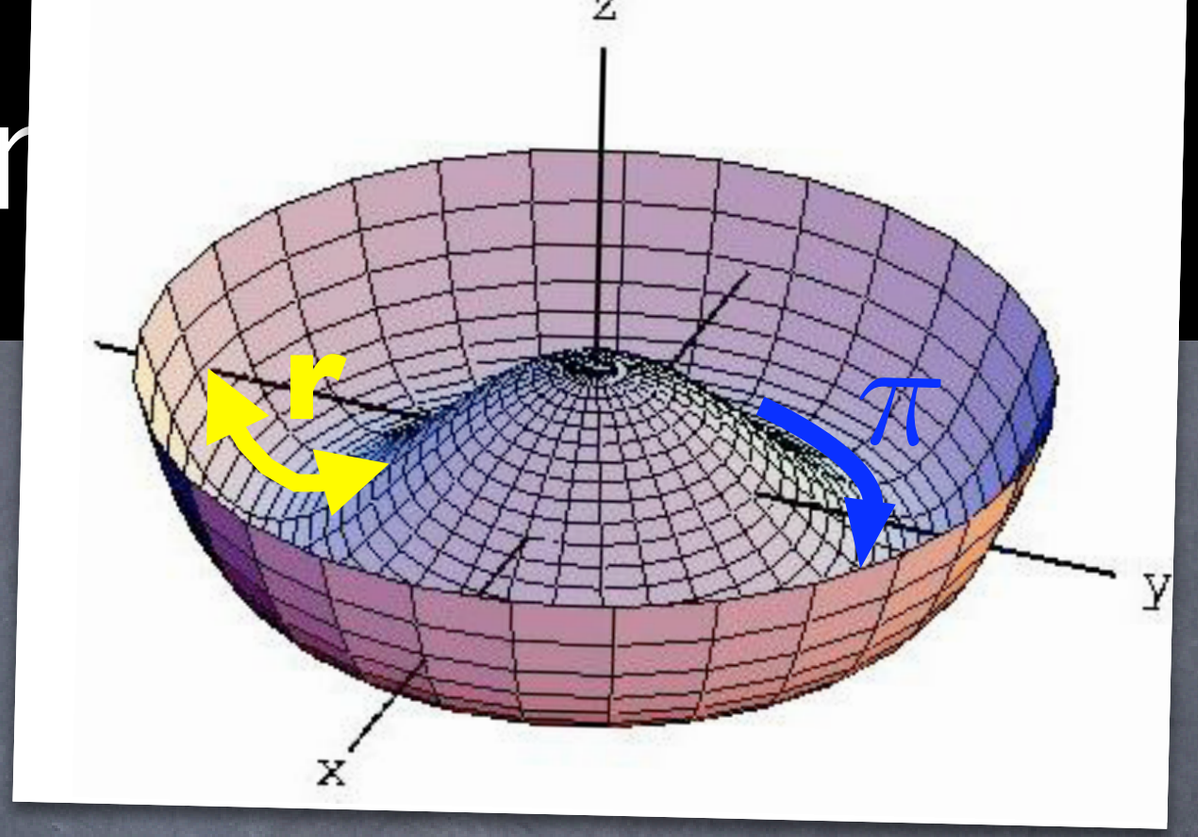
It Couples like the Higgs but suppressed

$$g_{rVV} = g_{hVV}^{SM} \times (v_{EW}/f) \approx \frac{1}{2} \times g_{hVV}^{SM}$$

easily visible @ LHC: $gg \to r \to ZZ \to 4l$

Higgs In

Bellazini, Csaki, Falkowski, AW



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easily visible @ LHC: $gg \to r \to ZZ \to 4l$

Meanwhile, the analysis of ALEPH data is ongoing…

Summary

- The Higgs search is *'at risk'* because the Higgs width is very sensitive to new light unseen physics.

- Higgs can be below SM LEP bound (90 GeV)
- Higgs buried in QCD background (subjets & detailed LEP analysis in progress)
- Higgs impostor predicted