Is It a/the Higgs?

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Outline

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Discovery of a new boson

Joseph Incandela Fabiola Gianotti

July 4, 2012:

Discovery of a NEW BOSON
of mass about 125 GeV
decaying to $\gamma\gamma$ and ZZ^*.

5.9 sigma

5.0 sigma

Discovery details

- $H \to \gamma\gamma$ ... 4.5 sigma
- $H \to ZZ \to \ell\ell\ell\ell$ ... 3.4 sigma
- $H \to W^+W^- \to e\nu\mu\nu$

$$M^{\mathrm{ATLAS}} = 126.0 \pm 0.4(\mathrm{stat.}) \pm 0.4(\mathrm{sys.})\ \mathrm{GeV}$$

- $H \to \gamma\gamma$ ... 4.1 sigma
- $H \to ZZ \to \ell\ell\ell\ell$ ... 3.1 sigma
- $H \to W^+W^- \to \ell\nu\ell\nu$
- $H \to \tau\tau$
- $H \to bb$

$$M^{\mathrm{CMS}} = 125.3 \pm 0.4(\mathrm{stat.}) \pm 0.5(\mathrm{sys.})\ \mathrm{GeV}$$

Discovery details: ATLAS

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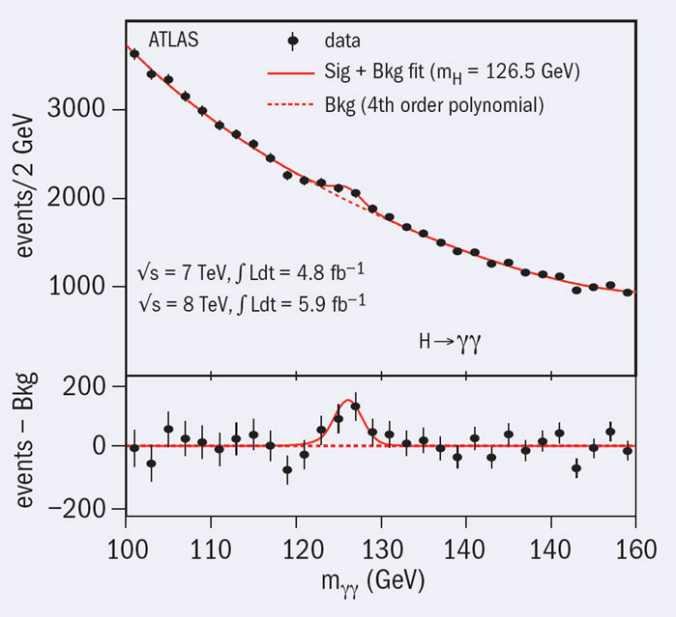

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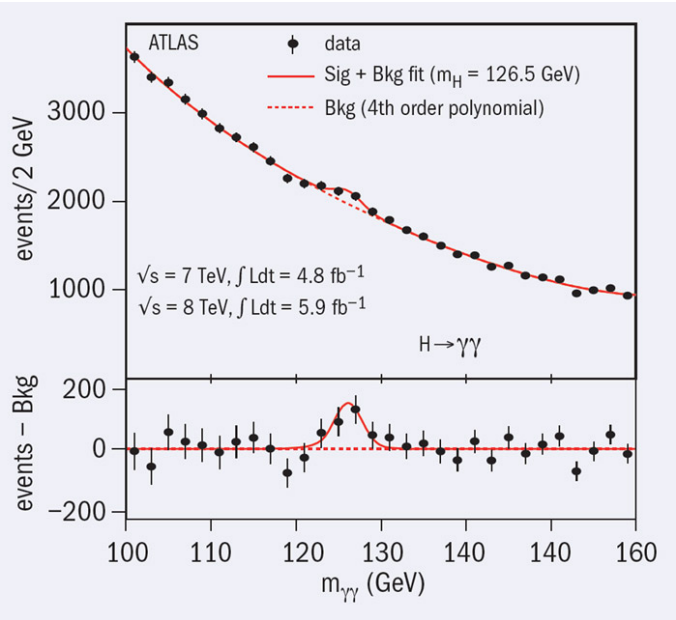

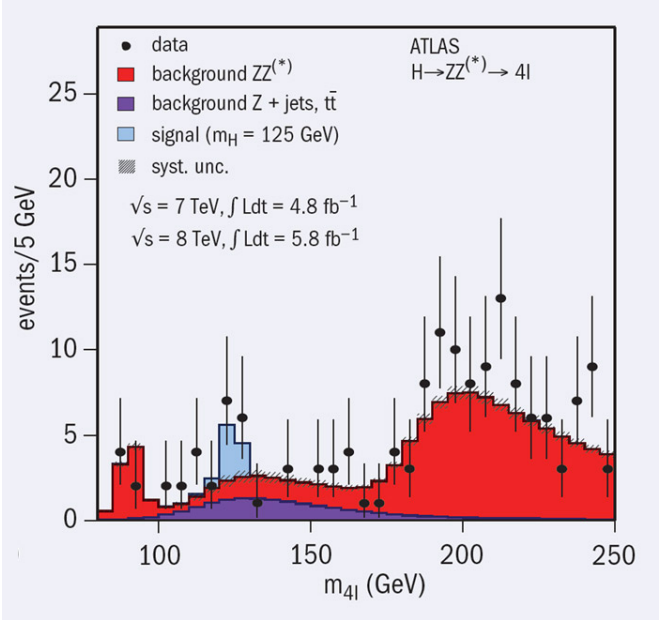

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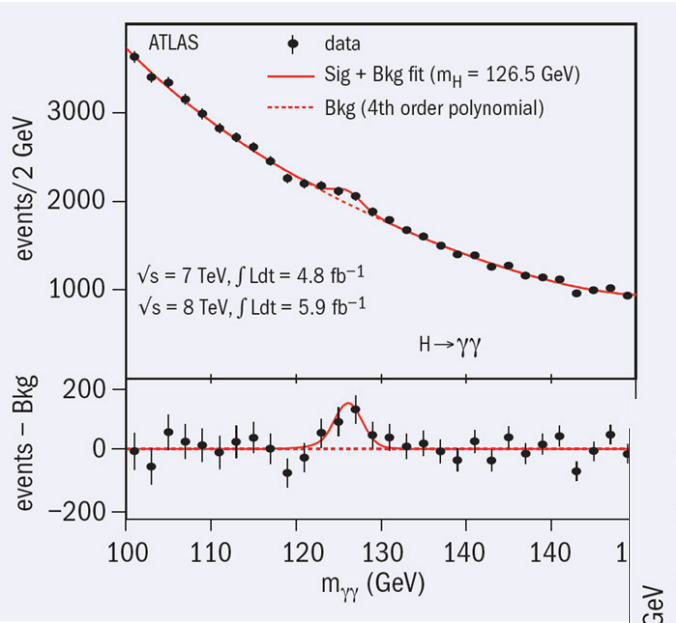

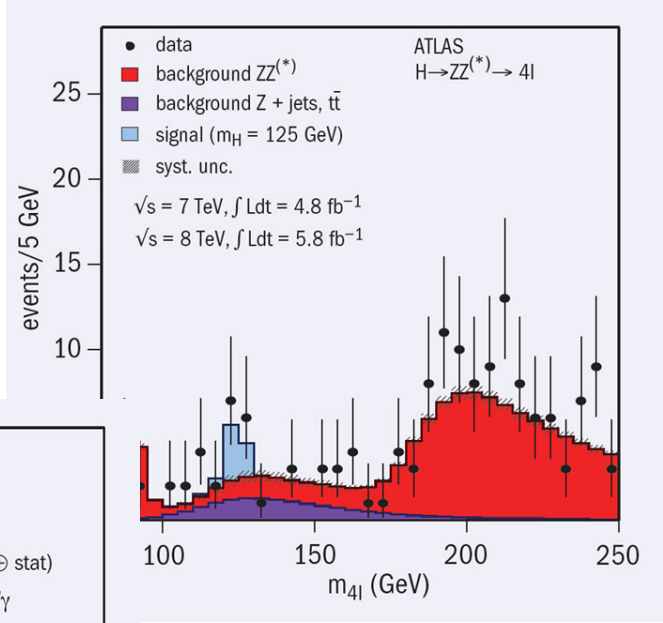

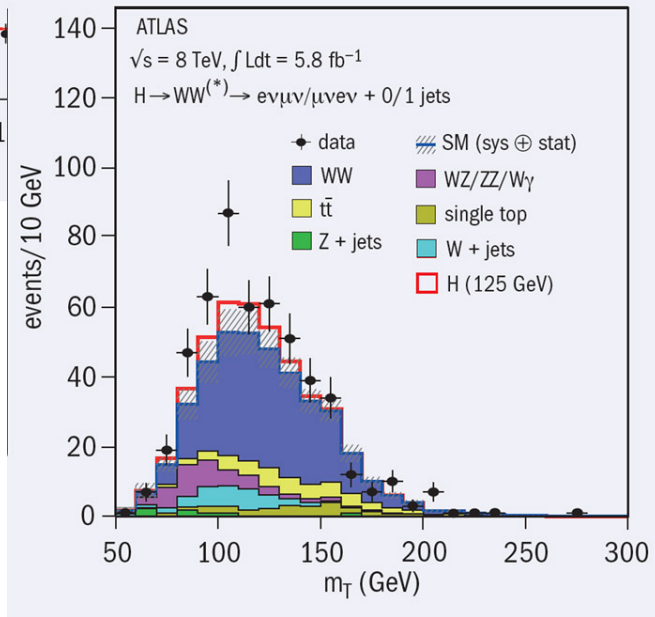

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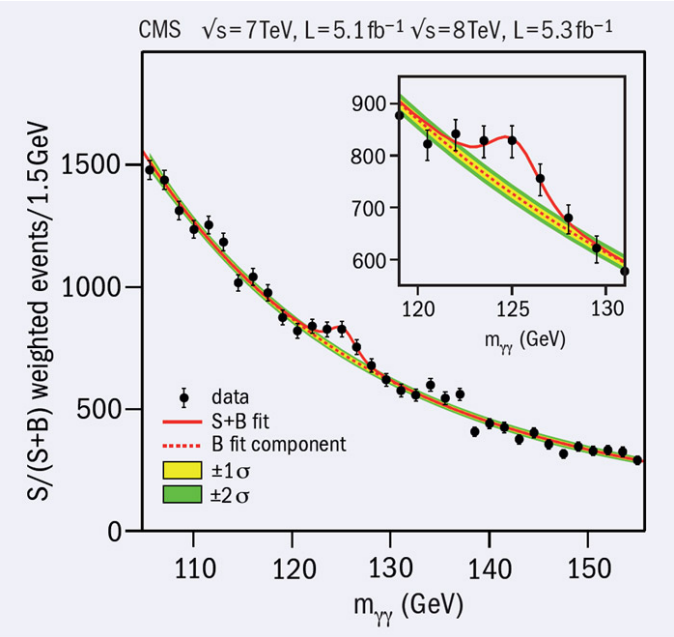

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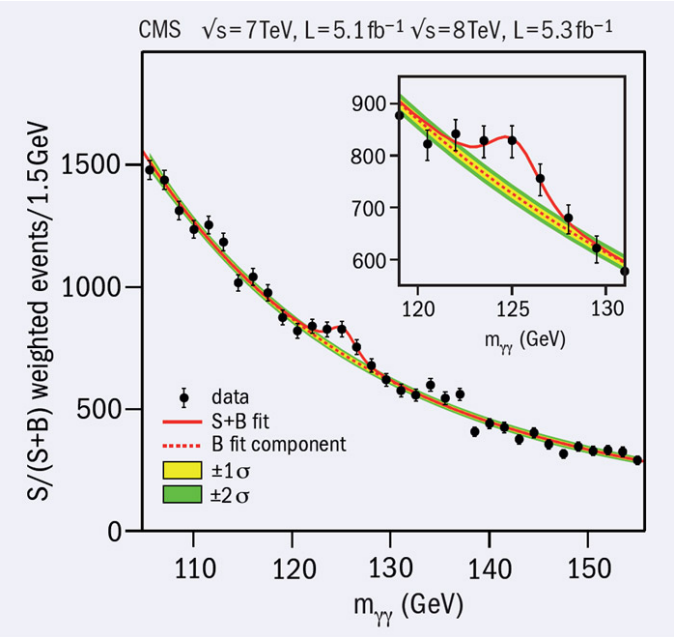
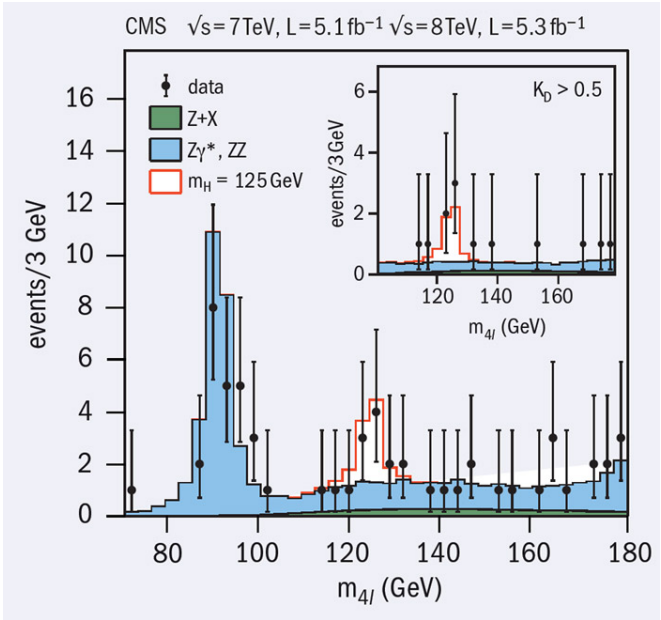
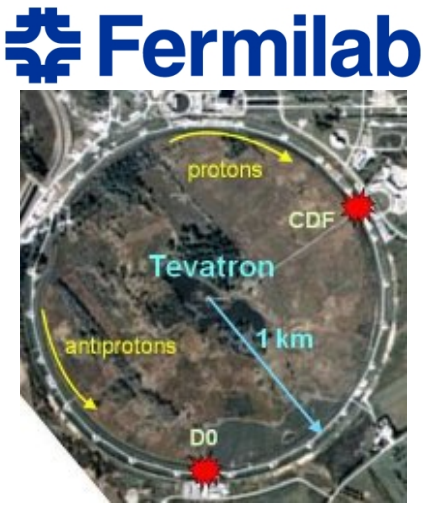
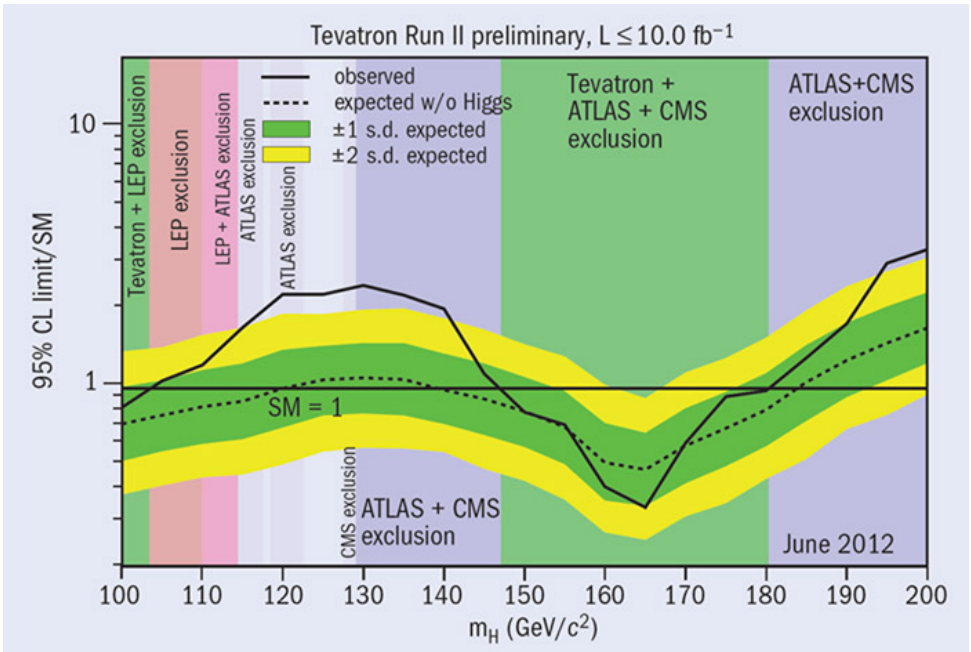




Tevatron contribution





$H \to b\bar{b}$ ... 3.1 sigma excess in $(120, 135)$ GeV

... the most favorable channel if $M^{\rm SM}_{\rm Higgs} \leq 135$ GeV

What we have got ...

- mass ~ 125 GeV
- electric charge $= 0$
- color-neutral
- boson
- spin $\neq 1$ (Landau-Yang theorem)
- $g_{hZZ} \sim 100\, g_{h\gamma\gamma}$

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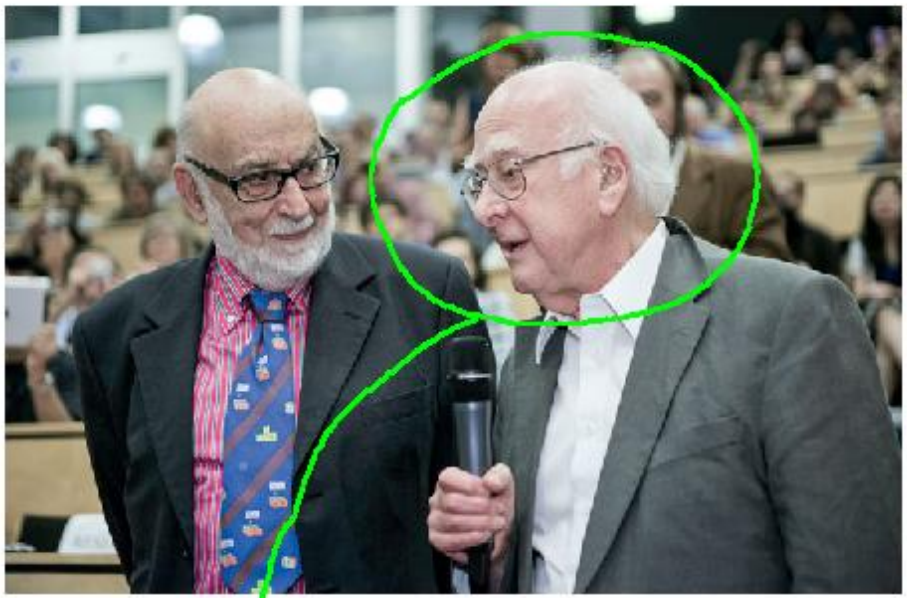

Is the boson related to ESB? (I)

if YES	$\longrightarrow$	a Higgs boson

Electroweak Symmetry Breaking:

- the gauge symmetry $\rightarrow$ interactions
- $m\bar{\psi}\psi$, $m^2 Z_\mu Z^\mu, \ldots$ $\rightarrow$ break the gauge symmetry
- $m \neq 0$ is the experimental fact!
- solution: Spontaneous Symmetry Breaking

... masses to the gauge bosons, at least

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Is the boson related to ESB? (II)

some SSB mechanisms $\longrightarrow$ scalar field(s): Higgs(es)

- Higgs(es) couples to all SSB generated masses
- Higgs cplng $\propto$ SSB mass

the new 125-GeV boson is ...

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- not related $\Longrightarrow$ $g_{hWW} \approx g_{hZZ} \approx g_{h\gamma\gamma}$
- ESB related $\Longrightarrow$ $g_{hWW} \approx g_{hZZ} \gg g_{h\gamma\gamma}$
- fermion masses $\Longrightarrow$ $g_{hff} \sim m_f$

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The SM Higgs

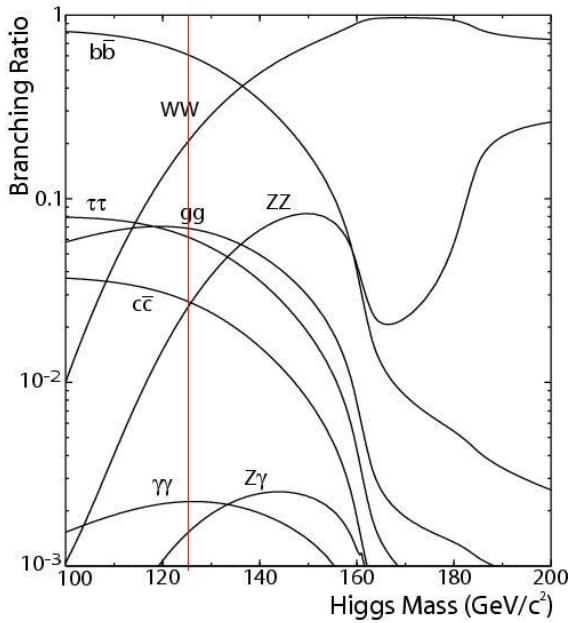
$$\boxed{SM = simplest}$$

- $SU(2)_L$ complex scalar doublet $\rightarrow$ 4 scalar fields
- non-zero vacuum expectation value, $v \approx 250\ \mathrm{GeV}$
- SSB $\rightarrow$ gauge boson & fermion masses
- 3 non-physical fields
- 1 physical field $\rightarrow$ SM Higgs boson
- unknown mass

Profile of 125-GeV SM Higgs

- ☹ very difficult to find
- ☺ large number of decay channels

$$\boxed{\Gamma_{\rm tot} = 4.2 \text{ MeV}}$$



$b\bar{b}$	56%	$\tau\tau$	6.2%	$\gamma\gamma$	0.23%
WW^*	23%	ZZ^*	2.9%	γZ	0.16%
gg	8.5%	$c\bar{c}$	2.8%	$\mu\mu$	0.02%

Is it the 125-GeV SM Higgs?

1. check all the decay channels exist

2. check out their production/decay rates

$$\Downarrow$$

the boson's cplngs

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Decay channel evidence

channel	ATLAS	CMS	Tevatron
$\gamma\gamma$	4.5σ	4.1σ	–
ZZ^*	3.6σ	3.2σ	–
WW^*	2.8σ	1.6σ	–
$b\bar{b}$	–	–	3.1σ
$\tau\tau$	–	deficit?	–

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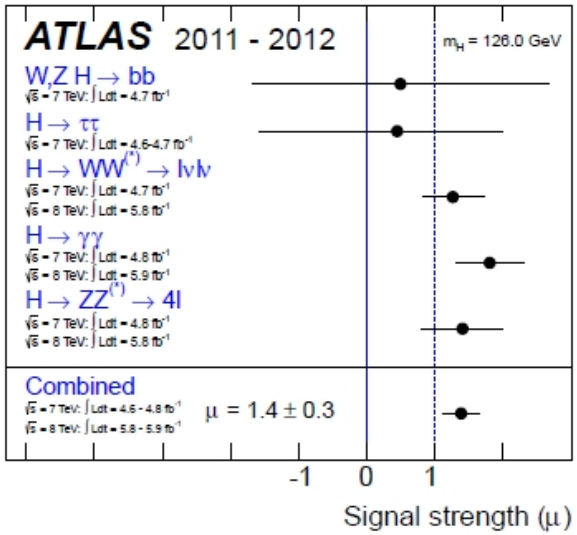
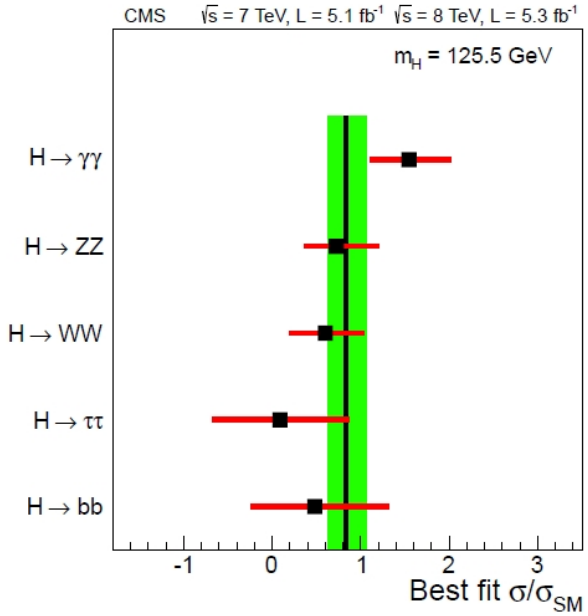
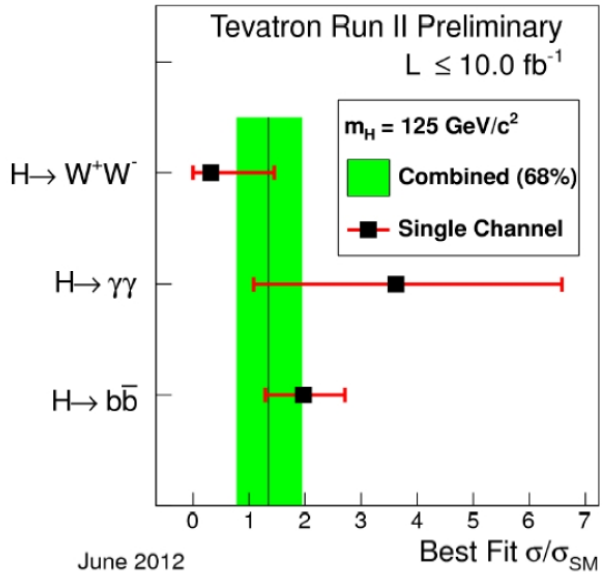
Production/decay rates







relative signal strength:

$$\mu \equiv \frac{(\sigma_{\rm prod} \cdot {\rm BR})_{\rm obs}}{(\sigma_{\rm prod} \cdot {\rm BR})_{\rm SM}}$$

$\mu = 0$ ... no Higgs

$\mu = 1$ ... SM Higgs

Is it the *simplest* Higgs?

- data roughly resembles IT
- we cannot say it is not IT

If **YES**:

the end of the story of the LHC physics

If **NO**:

new particles and new forces

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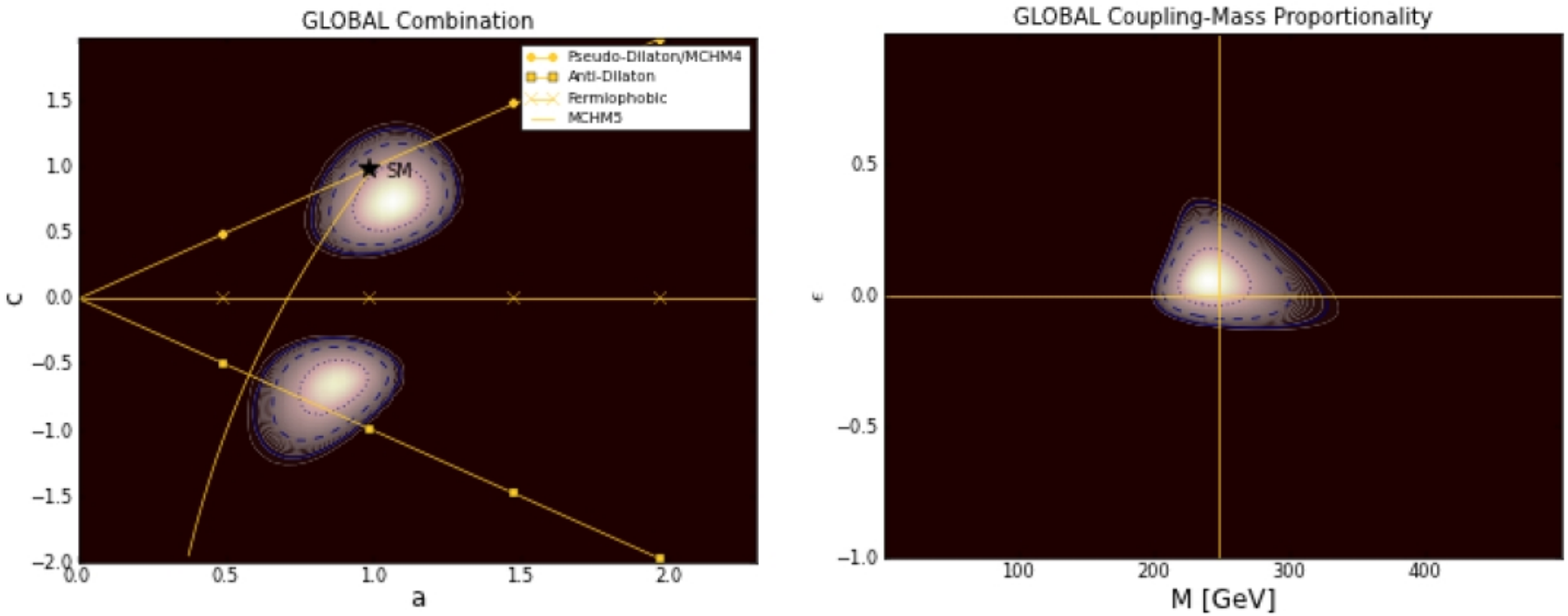
Outline

Casualties and survivors

- SUSY & Technicolor: "organized retreat"
  - unobserved particles & observed boson
- $\exists$ theories w/o Higgs which are not excluded
  - 125-GeV techni-dilaton favored by the LHC data [arXiv:1207.5911, 1208.0546]
- the "Higgs cplngs" discrimination
  - many models $\mu \approx 1$
  - global fit needed – insufficient statistics at the moment
  - LHC troublemakers: $h \to b\bar{b}$, $h \to c\bar{c}$

Casualties and survivors



[J.Ellis, T.You, arXiv:1207.1693]

$$\begin{aligned}\mathcal{L}_{eff} &= \frac{v^2}{4}\mathrm{Tr}\left(D_\mu U D^\mu U^\dagger\right) \times \left[1 + 2a\frac{h}{v} + \ldots\right] \\ &- \frac{v}{\sqrt{2}}\Sigma_f \bar{f}_L \lambda_f f_R \left[1 + c_f \frac{h}{v} + \ldots\right] + h.c.\end{aligned}$$

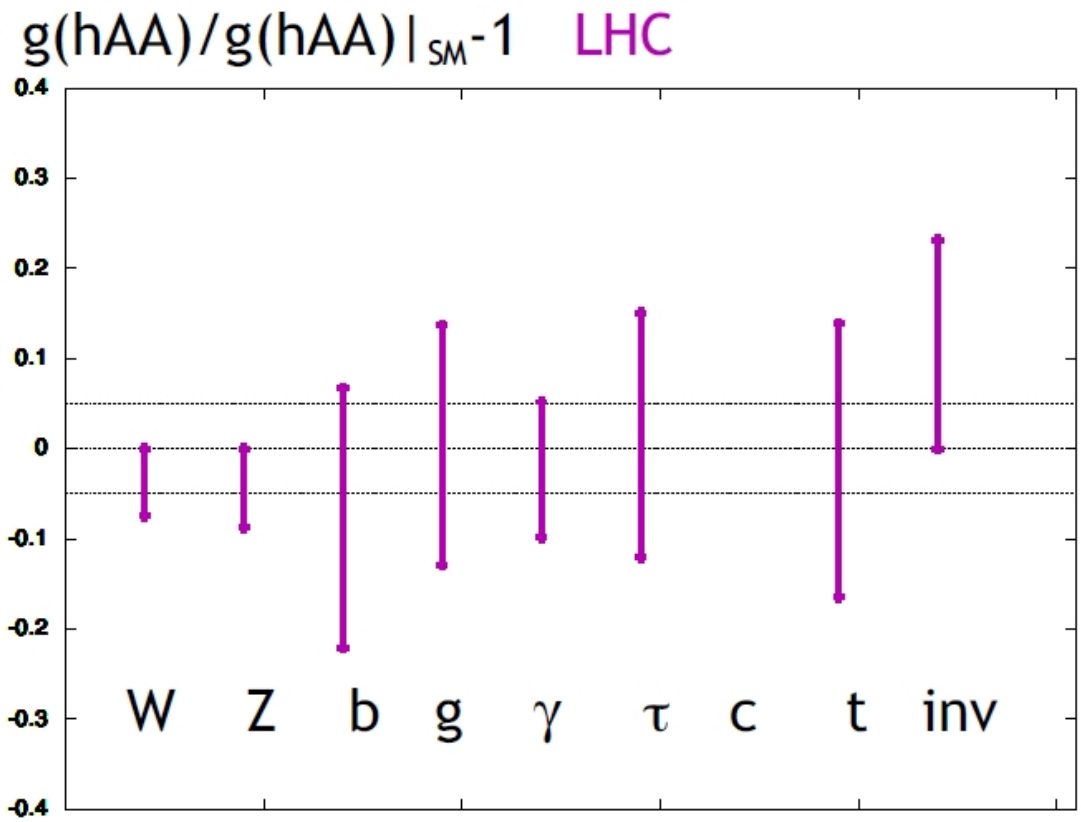
"Higgs cplng" theory predictions

theory	cplng	correction	notes
SUSY	$h\tau\tau$	$10\% \left(\frac{400\ \text{GeV}}{m_A}\right)^2$	(1)
SUSY(large β)	$hb\bar{b}$	$\text{corr}(h\tau\tau) + (1 \leftrightarrow 3)\%$	–
composite Higgs	$hf\bar{f}$	$(3 \leftrightarrow 9)\% \left(\frac{1\ \text{TeV}}{f}\right)^2$	(2)
Little Higgs	hgg	$(5 \leftrightarrow 9)\%$	–
	$h\gamma\gamma$	$(5 \leftrightarrow 6)\%$	–

(1) m_A ... the mass of a heavy A^0 Higgs boson

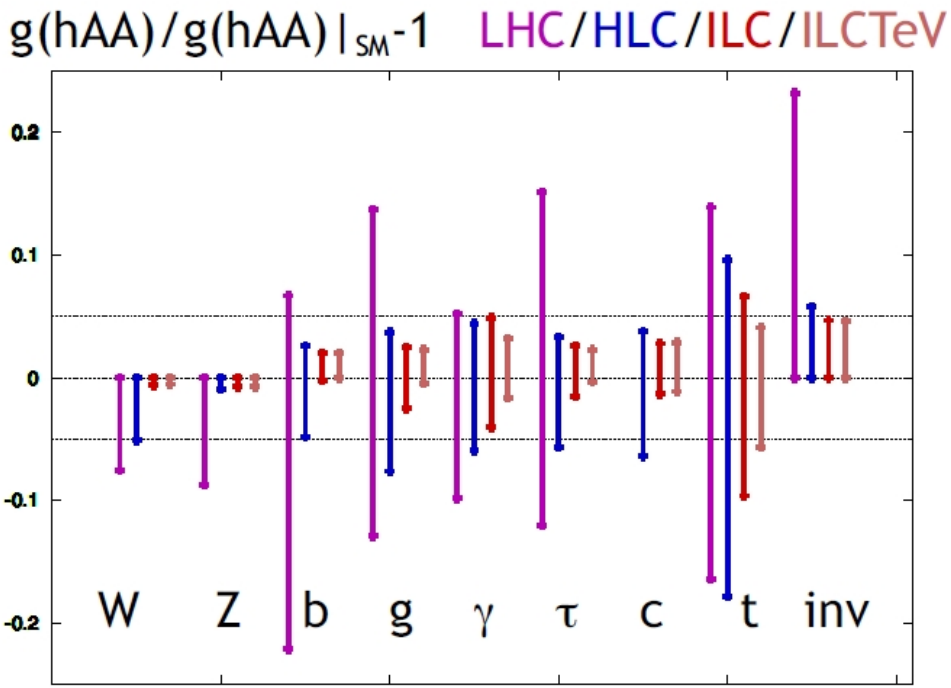
(2) f ... the Goldstone boson decay constant

Accuracy estimates for LHC (14 TeV, 300 fb^{-1})



[M.E.Peskin, arXiv:1207.2516]

Accuracy estimates for future colliders



[M.E.Peskin, arXiv:1207.2516]

LHC 14 TeV, 300 fb^{-1}

HLC 250 GeV, 250 fb^{-1}

ILC 500 GeV, 500 fb^{-1}

ILCTeV 1 TeV, 1 ab^{-1}

Complementary input

- find new particles/resonances
  - good understanding of SM – bkgd
  - good understanding of NP – signal
  - new triggers
- 125-GeV SM Higgs $\Rightarrow$ Hierarchy problem
  - new theoretical ideas

Outline

Top-BESS model

- effective Lagrangian:

  non-linear sigma model + new $SU(2)$ vector resonance triplet

  global symmetry:

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(2)_{HLS} \overset{SSB}{\longrightarrow} SU(2)_{L+R} \times U(1)_{B-L}$$

  local symmetry:

$$\underset{g}{SU(2)_L} \times \underset{g'}{U(1)_Y} \times \underset{g''}{SU(2)_{HLS}} \overset{SSB}{\longrightarrow} \underset{e}{U(1)_{em}}$$

- BESS: R. Casalbuoni *et al*, PL**B155**,95(1985); NP**B282**,235(1987)
- top-BESS: M.G., J.Juráň, I.Melo, PR**D84**,035013(2011)

  special role of top quark in ESB: $m_t \approx v/\sqrt{2}$

Top-BESS fermion sector

fermion sector (SM fermions):

$$\mathcal{L}_f^{tBESS} = \underbrace{\mathcal{L}_f^{SM}(W,B)}_{\text{mixing induced Vff cplngs}} + \underbrace{\mathcal{L}_{(t,b)}^{BSM}(W,B,V)}_{\text{direct chiral cplngs}} + \underbrace{\mathcal{L}_{(t,b)}^{BSM'}(W,B)}_{\text{new W/B cplngs}}$$

$\sim 1/g''$

Vtt ...	$\sim b_{L,R} \cdot g''$
$Vt_L b_L$ ...	$\sim b_L \cdot g''$
$Vb_L b_L$ ...	$\sim b_L \cdot g''$
$Vt_R b_R$ ...	$\sim p\, b_R \cdot g''$
$Vb_R b_R$ ...	$\sim p^2 b_R \cdot g''$

$0 \le p \le 1$

Xtt ...	$\sim \lambda_{L,R} \cdot g_X$
$Xt_L b_L$ ...	$\sim \lambda_L \cdot g_X$
$Xb_L b_L$ ...	$\sim \lambda_L \cdot g_X$
$Xt_R b_R$ ...	$\sim p\, \lambda_R \cdot g_X$
$Xb_R b_R$ ...	$\sim p^2 \lambda_R \cdot g_X$

X=W,B, $g_X = g, g'$

Adding the 125-GeV scalar resonance

top-BESS model:

$$\mathcal{L}_{\rm tBESS} = \mathcal{L}_{\rm GB} + \mathcal{L}_{\rm ESB} + \mathcal{L}_{\rm ferm}$$

+ scalar resonance:

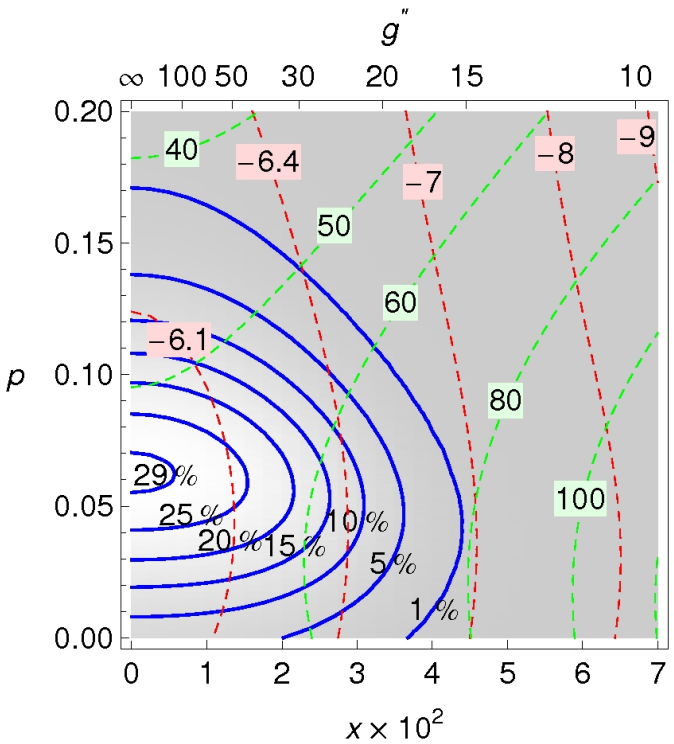
$$\begin{aligned}\mathcal{L}'_{\rm tBESS} \quad = \quad & \mathcal{L}_{\rm tBESS} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2} {M_S}^2 S^2 \\ & + a \frac{v}{2} \mathrm{Tr}(D_\mu U^\dagger D^\mu U) S \\ & - \frac{1}{v} c \left(\bar{\psi}^a_L U M^a_f \psi^a_R + \mathrm{H.c.} \right) S\end{aligned}$$

where

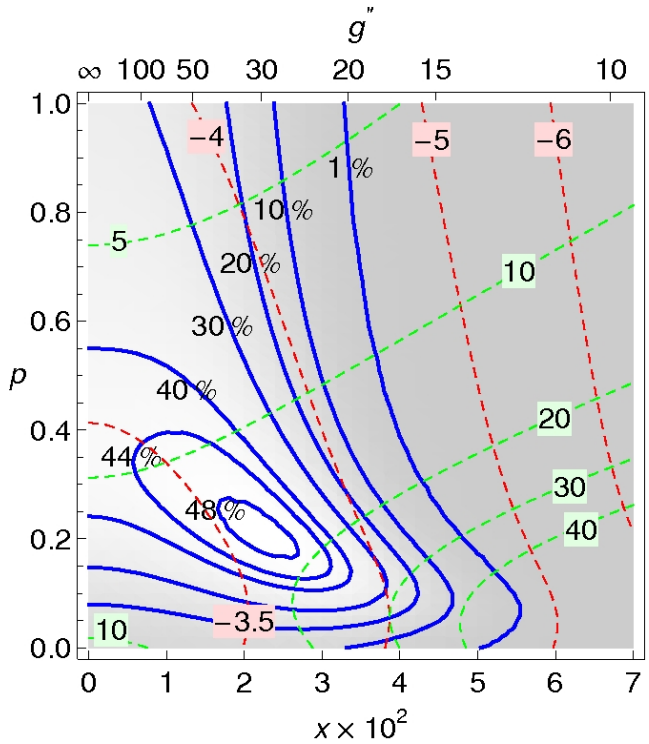
$$D_\mu U = \partial_\mu U + \boldsymbol{W} U - U \boldsymbol{B}^{R3}$$

Low-energy limits

no scalar



125-GeV scalar



Conclusions

- the Higgs era in HEP just has begun!
- all major "players" still in game
- the 2012 LHC data might bring big news or nothing
- new e^+e^- linear collider needed