

LHC

AND

STRONGLY-INTERACTING EXTENSIONS OF THE SM

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OUTLINE

- 1 A NEW 125 GeV BOSON
- 2 IS IT A HIGGS?
- 3 THEORY AFTER JULY,4
- 4 THE 125-GeV BOSON AND THE TOP-BESS MODEL

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DISCOVERY OF A NEW BOSON

July 4, 2012:



5.9 sigma

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



5.0 sigma

DISCOVERY DETAILS



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

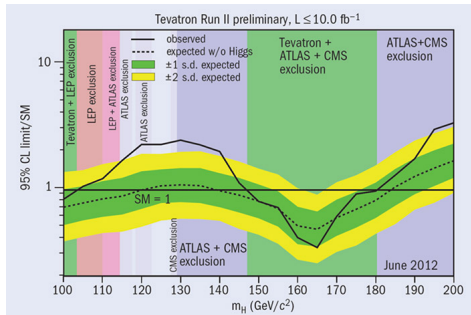
$$M^{\text{ATLAS}} = 126.0 \pm 0.4(\text{stat.}) \pm 0.4(\text{sys.})$$



- $H \rightarrow \gamma\gamma$... 4.1 sigma
- $H \rightarrow ZZ \rightarrow llll$... 3.1 sigma
- $H \rightarrow W^+W^- \rightarrow l\nu l\nu$
- $H \rightarrow \tau\tau$
- $H \rightarrow bb$

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

TEVATRON CONTRIBUTION



... 3.1 sigma excess in (120, 135) GeV

... the most favorable channel if $M_{\text{Higgs}}^{\text{SM}} \leq 135 \text{ GeV}$

WHAT WE KNOW?

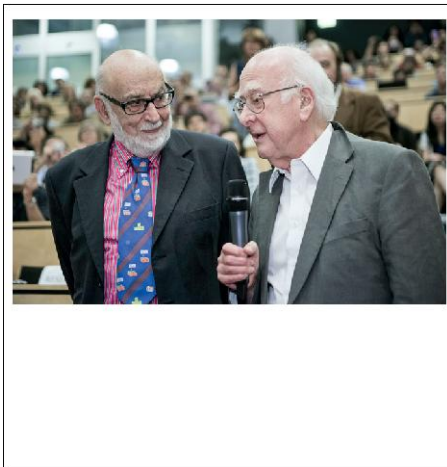
- mass ~ 125 GeV
- electric charge = 0
- color-neutral
- boson
- spin $\neq 1$ (Landau-Yang theorem)
- $g_{hZZ} \sim 100 g_{h\gamma\gamma}$

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IS IT A HIGGS?

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IS THE BOSON RELATED TO ESB?

ESB \longrightarrow masses to W, Z

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

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IS IT THE *simplest* HIGGS?

simplest = SM

- 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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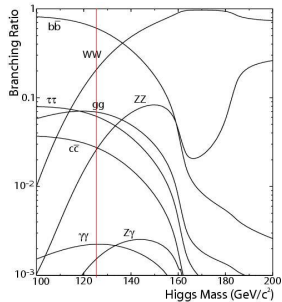
If **NO**:

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PROFILE OF 125-GeV SM HIGGS

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

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



$b\bar{b}$	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



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?	—

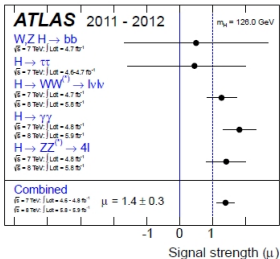
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PRODUCTION/DECAY RATES

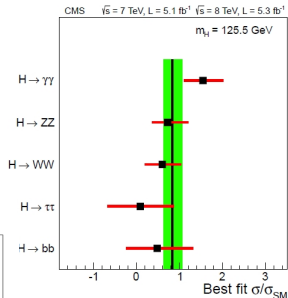
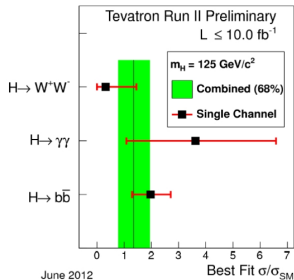


relative signal strength:

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

$\mu = 0$... no Higgs

$\mu = 1$... SM Higgs



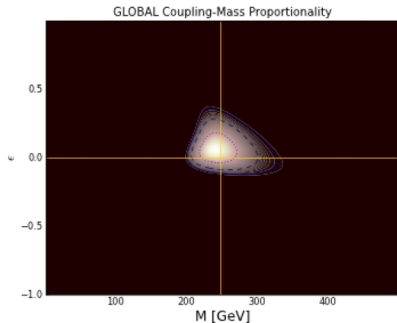
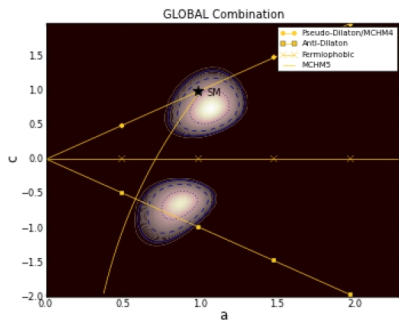
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CASUALTIES AND SURVIVORS

- 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: $h \rightarrow b\bar{b}$, $h \rightarrow c\bar{c}$

CASUALTIES AND SURVIVORS



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

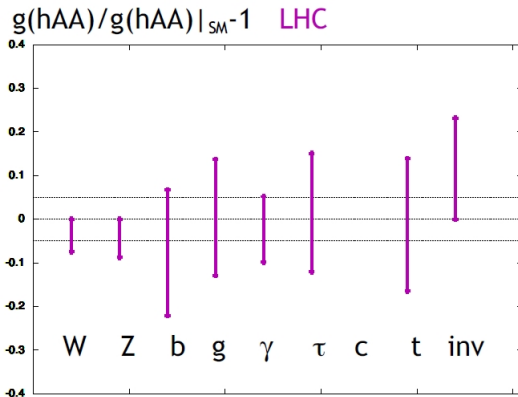
$$\mathcal{L}_{eff} = \frac{v^2}{4} \text{Tr} (D_\mu U D^\mu U^\dagger) \times \left[1 + 2a \frac{h}{v} + \dots \right] - \frac{v}{\sqrt{2}} \Sigma_f \bar{f}_L \lambda_f f_R \left[1 + c_f \frac{h}{v} + \dots \right] + h.c.$$

“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)	$hb\bar{b}$	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

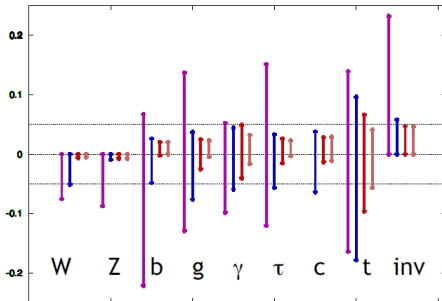
(2) f ... the Goldstone boson decay constant

ACCURACY ESTIMATES FOR LHC (14 TEV, 300 FB⁻¹)

[M.E.Peskin, arXiv:1207.2516]

ACCURACY ESTIMATES FOR FUTURE COLLIDERS

$g(hAA)/g(hAA)|_{SM}-1$ LHC/HLC/ILC/ILCTeV



LHC 14 TeV,
300 fb⁻¹

HLC 250 GeV,
250 fb⁻¹

ILC 500 GeV,
500 fb⁻¹

ILCTeV 1 TeV,
1 ab⁻¹

[M.E.Peskin, arXiv:1207.2516]

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

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TOP-BESS MODEL

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

global symmetry:

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

local symmetry:

$$\begin{array}{ccc} SU(2)_L \times U(1)_Y \times SU(2)_{HLS} & \xrightarrow{SSB} & U(1)_{em} \\ g & g' & g'' & e \end{array}$$

- **BESS**: R. Casalbuoni *et al*, PLB**155**,95(1985); NPB**282**,235(1987)
- **top-BESS**: M.G., J.Juráň, I.Melo, PRD**84**,035013(2011)

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

TOP-BESS FERMION SECTOR

fermion sector (SM fermions):

$$\mathcal{L}_f^{tBESS} = \underbrace{\mathcal{L}_f^{SM}(W, B)} + \underbrace{\mathcal{L}_{(t,b)}^{BSM}(W, B, V)} + \underbrace{\mathcal{L}_{(t,b)}^{BSM'}(W, B)}$$

*mixing induced
Vff cplngs*

$$\sim 1/g''$$

direct chiral cplngs

$$Vt\bar{t} \dots \sim b_{L,R} \cdot g''$$

$$Vt_L b_L \dots \sim b_L \cdot g''$$

$$Vb_L b_L \dots \sim b_L \cdot g''$$

$$Vt_R b_R \dots \sim p b_R \cdot g''$$

$$Vb_R b_R \dots \sim p^2 b_R \cdot g''$$

$$0 \leq p \leq 1$$

new W/B cplngs

$$Xt\bar{t} \dots \sim \lambda_{L,R} \cdot g_X$$

$$Xt_L b_L \dots \sim \lambda_L \cdot g_X$$

$$Xb_L b_L \dots \sim \lambda_L \cdot g_X$$

$$Xt_R b_R \dots \sim p \lambda_R \cdot g_X$$

$$Xb_R b_R \dots \sim p^2 \lambda_R \cdot g_X$$

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

ADDING THE 125-GeV SCALAR RESONANCE

top-BESS model:

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

+ scalar resonance:

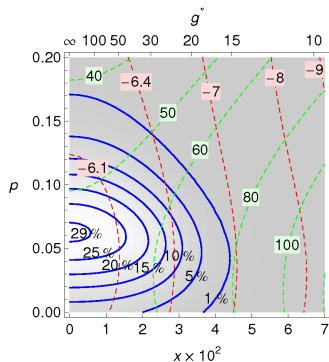
$$\begin{aligned} \mathcal{L}'_{\text{tBESS}} &= \mathcal{L}_{\text{tBESS}} + \frac{1}{2} \partial_\mu S \partial^\mu S - \frac{1}{2} M_S^2 S^2 \\ &\quad + a \frac{v}{2} \text{Tr}(D_\mu U^\dagger D^\mu U) S \\ &\quad - \frac{1}{v} c (\bar{\psi}_L^a U M_f^a \psi_R^a + \text{H.c.}) S \end{aligned}$$

where

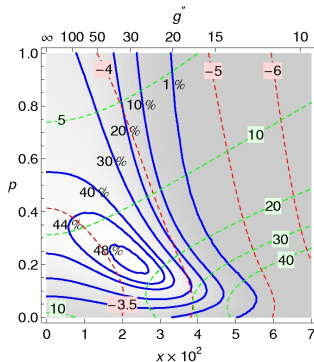
$$D_\mu U = \partial_\mu U + \mathbf{W}U - U\mathbf{B}^{R3}$$

LOW-ENERGY LIMITS

no scalar



125-GeV scalar



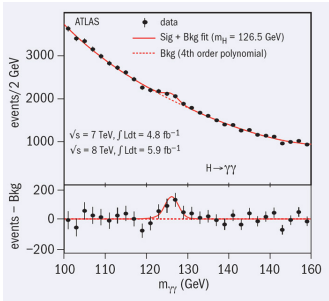
CONCLUSIONS

- 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

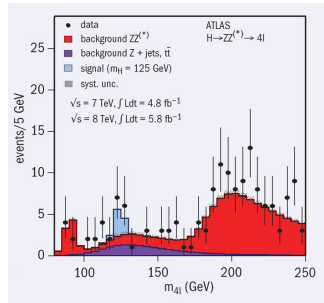
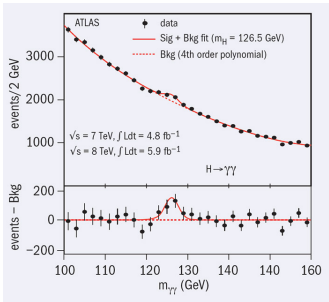
DISCOVERY DETAILS: ATLAS



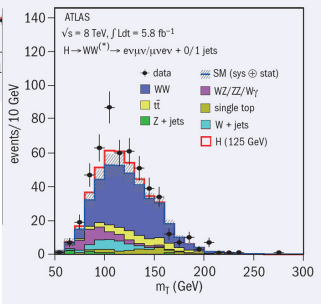
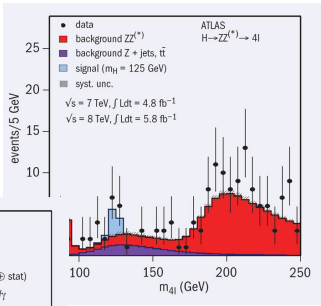
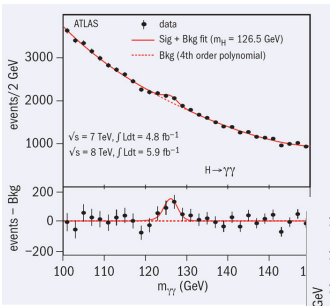
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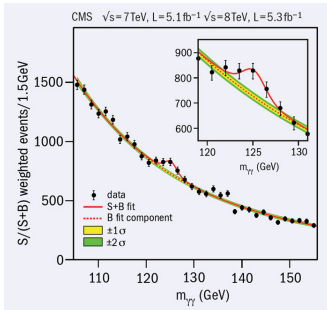
DISCOVERY DETAILS: ATLAS



DISCOVERY DETAILS: CMS



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