

Case for boosted Higgs searches

Tilman Plehn

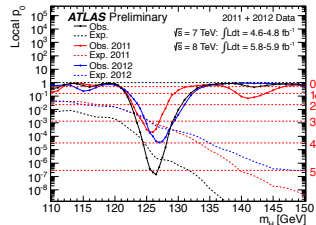
Universität Heidelberg

BOOST, 7/2012

Higgs discovery

Amazing work by ATLAS and CMS

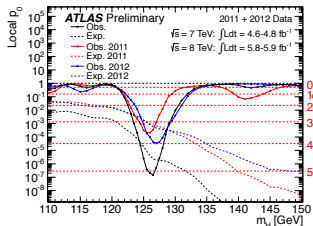
- 'silver channel' $H \rightarrow \gamma\gamma$
local 4.5σ (ATLAS), 4.1σ (CMS)
 - 'golden channel' $H \rightarrow ZZ \rightarrow 4\ell$
local 3.4σ (ATLAS), 3.2σ (CMS)
 - remaining WW and $\tau\tau, bb$
adding little
 - combined 5.0σ (ATLAS), 4.9σ (CMS) [LEE 4.3 σ]
- \Rightarrow resonance at $m_H = 125 - 126$ GeV discovered



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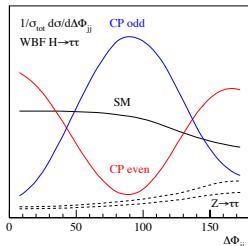
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So, what is this bump?

- psychologically: looked for Higgs, so found a Higgs
 - spin-0 scalar expected [P even?]
 - spin-1 vector unlikely with $V \rightarrow \gamma\gamma$ [Landau-Yang]
 - spin-2 graviton unexpected
 - Albert: need many $H \rightarrow ZZ$ or WBF events!
- 1- quantum numbers needed

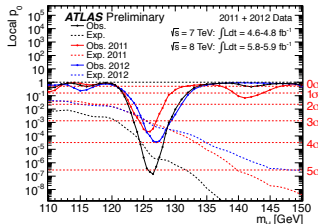
[Lykken et al; Melnikov et al; Hagiwara, Mawatari, TP, Rainwater, Zeppenfeld,...]



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Assume CP-even fundamental scalar

- Standard Model Higgs fine? [Holthausen, Lim, Lindner]
 - Higgs in reasonably decoupling theories all fine?
MSSM-Higgs one example [tons of papers]
hypersphere in $m_{\tilde{t}_{L/R}}, \tan\beta, A_t, \mu, m_A$ predicting little $[x_t^2 / (m_{\tilde{t}_1} m_{\tilde{t}_2}) \gtrsim 1]$
 - strongly interacting light Higgs supposedly fine?
 - Higgs portal fine?
- 2- coupling measurement needed

Higgs couplings

The model

- assume: we see such a scalar narrow resonance
SM-like D4 structures
self coupling out of reach [Baur etal; Englert etal]
- couplings from production & decay combinations?

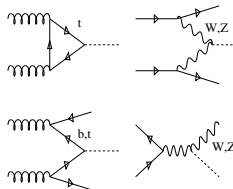
$$\begin{array}{l} gg \rightarrow H \\ qq \rightarrow qqH \\ gg \rightarrow t\bar{t}H \\ qq' \rightarrow VH \end{array}$$

 \longleftrightarrow

$$g_{HXX} = g_{HXX}^{\text{SM}} (1 + \Delta_X)$$

 \longleftrightarrow

$$\begin{array}{l} H \rightarrow ZZ \\ H \rightarrow WW \\ H \rightarrow b\bar{b} \\ H \rightarrow \tau^+\tau^- \\ H \rightarrow \gamma\gamma \end{array}$$



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Why 126 GeV is perfect [Zeppenfeld et al; Dührssen et al; SFitter 2009/2012; Contino et al]

- measurements: $GF : H \rightarrow ZZ, WW, \gamma\gamma$ [2011]
 $WBF : H \rightarrow ZZ, WW, \gamma\gamma, \tau\tau$ [2012]
 $VH : H \rightarrow b\bar{b}$ [2014: BDRS?]
 $t\bar{t}H : H \rightarrow b\bar{b} \dots$ [2015: boosted?]
- parameters: g_{HXX} with $X = W, Z, t, b, \tau, g, \gamma$ [plus Higgs mass]
- correlations: $N_{\text{ev}} \propto \frac{g_p^2 g_d^2}{\Gamma_{\text{tot}}(g_X^2)}$

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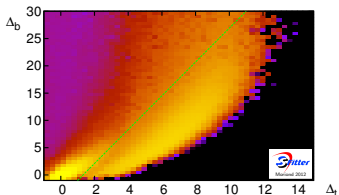
SFitter ansatz [Dührssen, Klute, Lafaye, TP, Rauch, Zerwas]

- experimental/theory errors on signal and backgrounds [RFit]
ATLAS and CMS both included
total width from observed partial widths
 - starting point: exclusive likelihood map
individual coupling: profile likelihood
best fit: Minuit
errors: toy measurements
- ⇒ global and local analysis possible

Global/local 7 TeV analysis

Global view on 7 TeV data [Klute, Lafaye, TP, Rauch, Zerwas]

- is there a SM-like solution?
are there alternative solutions?
- (1) expected 2011: SM central values, measured error bars
- large-coupling solution separable

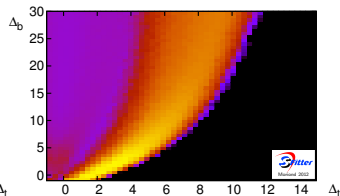
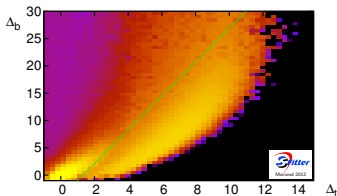


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- (2) measured 2011: measured central values and error bars
 - both solutions overlapping
 - error bars inflated



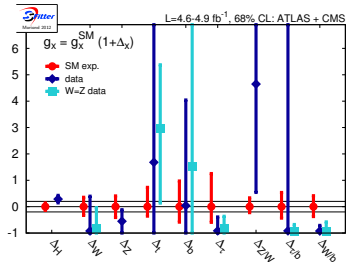
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Local view on 7 TeV data

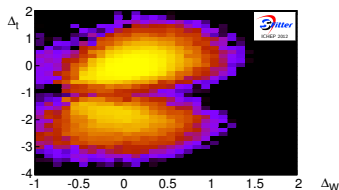
- focus on SM solution where possible
 - five couplings from data
 - $g_W \sim 0$ while g_Z okay
 - g_b and g_t hurt by secondary solution
 - g_τ inconclusive in data
 - poor man's analysis great: $\Delta_j \equiv \Delta_H$
- ⇒ pointing towards Standard Model?



Global/local 8 TeV analysis

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- has g_W improved?
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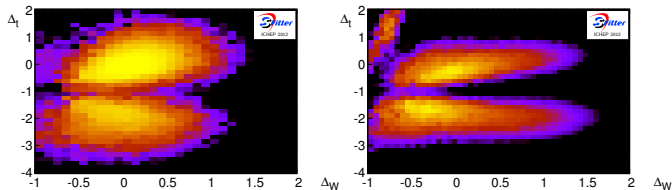
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improved $\Delta_{W,b,t}$ error bars



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Local view on 8 TeV data

– focus on SM solution

– six couplings from data

$g_{W,Z}$ okay

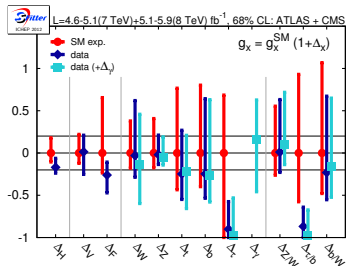
$g_{t,b}$ indirectly

g_τ poor

g_γ possible

– poor man's analyses great: $\Delta_H, \Delta_V, \Delta_f$

⇒ moving towards Standard Model?



Global/local 8 TeV analysis

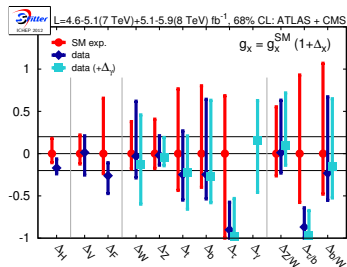
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Testing the Higgs

- six couplings determined [g_{ggH} missing]
- error bars 20 – 50%
- central value $\Delta_\gamma = 0.16$
- all good fits



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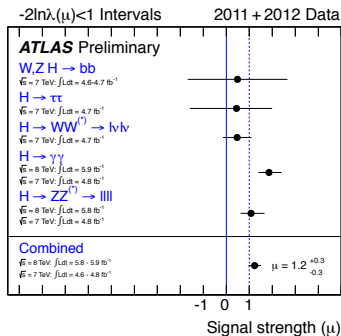
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Testing the Higgs

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 - error bars 20 – 50%
 - central value $\Delta_\gamma = 0.16$
 - all good fits
- ⇒ so what's next?

hypothesis	χ^2_{2012}/dof	solutions
independent Δ_x	27.7/49	3
including Δ_γ	27.3/48	2
two-parameter $\Delta_{V,f}$	29/52	2
form factor Δ_H	??/53	

Bottom Yukawa

Discovery

Higgs couplings

Bottom Yukawa

Top Yukawa

Direct vs indirect measurements

- no $b\bar{b}H$ production observed
 - no $H \rightarrow b\bar{b}$ decay observed [which I trust]
 - information from $\text{BR}(H \rightarrow b\bar{b}) \sim 58\%$ [HDecay]
- ⇒ happiness depending on choices

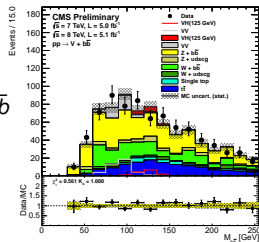
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Best channel $q\bar{q} \rightarrow VH, H \rightarrow b\bar{b}$

- CMS analysis available after ICHEP
- focus on boosted regime $p_{T,V} \gtrsim 120$ GeV
- b -tagging e.g. with 50%, 6%, 0.15%
- $\Delta m_{bb}/m_{bb} \sim 10\%$
- fudge factor Data/MC = $1.91 \pm 0.14 \pm 0.31$ for $Wb\bar{b}$
- data-estimated background $\Delta\sigma/\sigma \sim 10\%$
- 12 observables in BDT [most of them understood]
- no side bands with any S/B



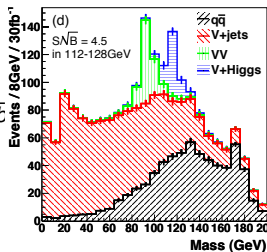
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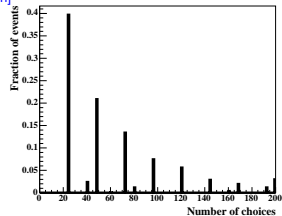
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- ⇒ I rest my case



Top Yukawa

Direct measurement $t\bar{t}H, H \rightarrow b\bar{b}$ [Atlas-Bonn: Jochen Cammin]

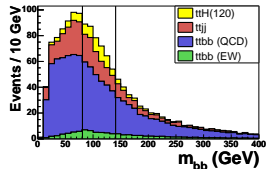
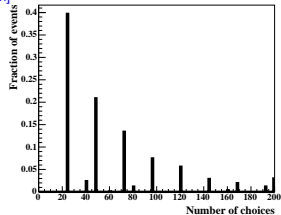
- trigger: $t \rightarrow bW^+ \rightarrow b\ell^+\nu$
reconstruction and rate: $\bar{t} \rightarrow \bar{b}W^- \rightarrow \bar{b}jj$
- continuum background $t\bar{t}b\bar{b}, t\bar{t}jj$ [weighted by b-tag]
- no chance:
 - 1– combinatorics: m_{bb} from $pp \rightarrow 4b_{tag} 2j \ell\nu$



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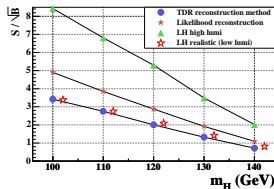
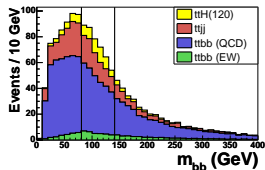
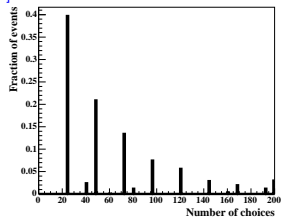
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Fat jets analysis [TP, Salam, Spannowsky]

- require tagged top and Higgs trigger on lepton
- remove 'Higgs' as $t_\ell \rightarrow b$ plus QCD
3rd b tag in continuum
only continuum $t\bar{t}b\bar{b}$ left

Top Yukawa

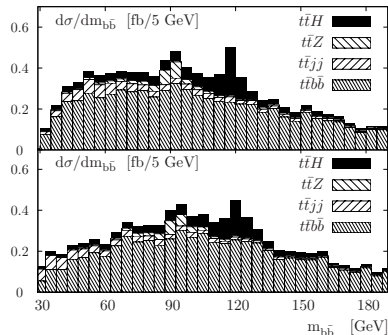
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- ⇒ **side band etc missing in CMS note**

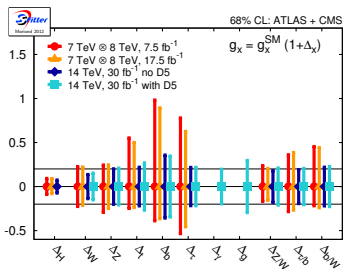
[not a single non-ANN plot in there]



Full set of couplings

2012, 2014, etc

- specially Higgs:
dark side of the Higgs portal?
new states in effective couplings?
- 2012: meaningful WBF measurements
 g_W and g_τ accessible
- 2014: $t\bar{t}H$ and $H \rightarrow b\bar{b}$ measurements
 g_g and g_γ fully accessible



Why the Yukawas are important

- bottom Yukawa most of the Higgs width
- top Yukawa key to new physics
- ILC might not measure g_{tH} (soon)
- Higgs self coupling at LHC requiring g_{ttH}
- ...

Outlook

Higgs@LHC

- discovery in successful bump hunt
 - many open questions

 - first constraint on induced couplings
 - naive guesstimate misleading

 - Yukawa couplings not directly probed
 - classical analyses not promising
- ⇒ **boosted searches the next major step**

For HEPTopTagger progress watch Michael, Gregor, Sebastian

Much of this work was funded by the BMBF Theorie-Verbund which is ideal for hard and relevant LHC work



Higgs Searches

Tilman Plehn

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Higgs couplings

Bottom Yukawa

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