

Higgs Couplings

Tilman Plehn

Rates

Operators

Distributions

Higgs Couplings

Tilman Plehn

Universität Heidelberg

Portoroz, April 2015

Couplings from LHC rates

Standard Model operators [SFitter: Dührssen, Klute, Lafaye, TP, Rauch, Zerwas]

- assume: narrow CP-even scalar

Standard Model operators [leading and making sense]

$$\begin{aligned} \mathcal{L} = & \mathcal{L}_{\text{SM}} - \Delta_W g m_W H W^\mu W_\mu - \Delta_Z \frac{g}{2} m_Z H Z^\mu Z_\mu - \sum_{\tau,b,t} \Delta_f \frac{m_f}{v} H (\bar{t}_R t_L + \text{h.c.}) \\ & + \Delta_g \frac{\alpha_s}{12\pi} \frac{H}{v} G_{\mu\nu} G^{\mu\nu} + \Delta_\gamma F_A^{(\infty)} \frac{H}{v} A_{\mu\nu} A^{\mu\nu} + \text{invisible} \end{aligned}$$

$$\begin{aligned} gg &\rightarrow H \\ qq &\rightarrow qqH \\ gg &\rightarrow ttH \\ qq' &\rightarrow VH \end{aligned}$$

\longleftrightarrow

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

\longleftrightarrow

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

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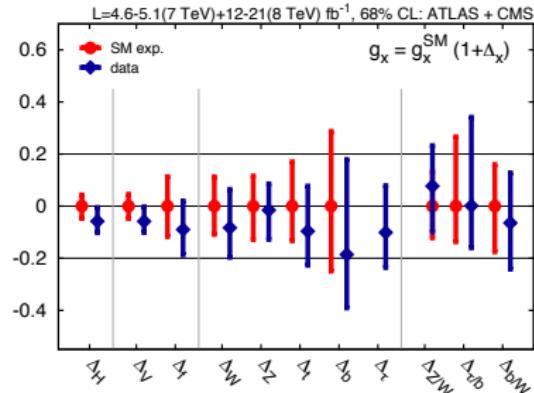
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Run I legacy [prelim: Corbett, Goncalves, Gonzalez-Fraile, Rauch,...]

- based on signal and background rates
- ratios and correlations fully included
- 5D, SM-like [Higgs portal to 5%, Oleg's talk]



Couplings from LHC rates

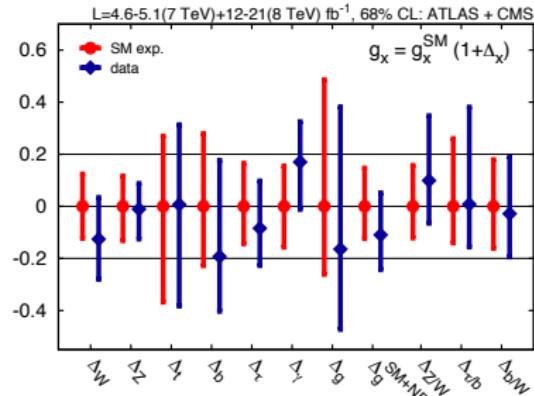
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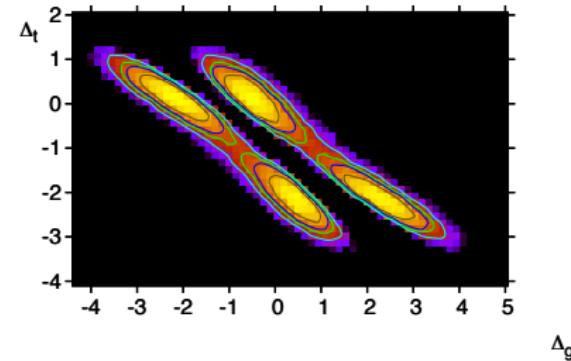
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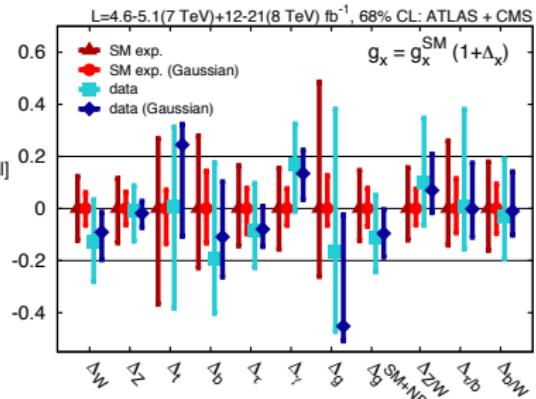
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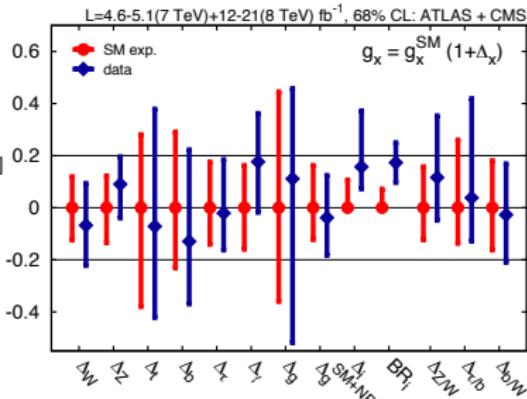
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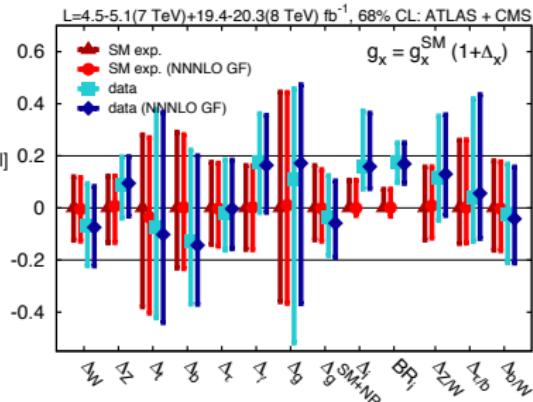
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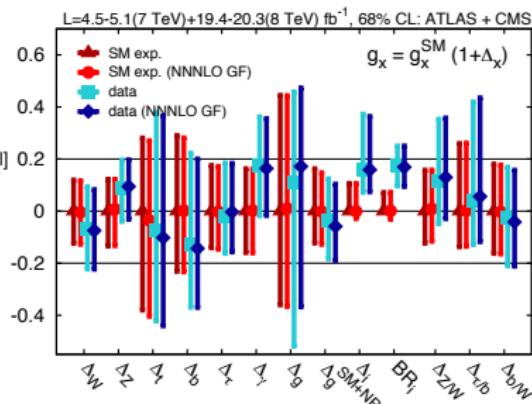
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- ⇒ details matter!



In terms of D6 operators

Higgs sector effective field theory [following Corbett, Eboli, Gonzalez-Fraile, Goncales-Garcia]

- set of Higgs-gauge operators

$$\mathcal{O}_{GG} = \Phi^\dagger \Phi G_{\mu\nu}^a G^{a\mu\nu}$$

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- relevant part after equation of motion, etc

$$\mathcal{L}^{HWV} = - \frac{\alpha_S v}{8\pi} \frac{f_g}{\Lambda^2} \mathcal{O}_{GG} + \frac{f_{BB}}{\Lambda^2} \mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2} \mathcal{O}_{WW} + \frac{f_B}{\Lambda^2} \mathcal{O}_B + \frac{f_W}{\Lambda^2} \mathcal{O}_W + \frac{f_{\Phi,2}}{\Lambda^2} \mathcal{O}_{\Phi,2}$$

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- Higgs couplings to SM particles

$$\begin{aligned} \mathcal{L}^{HVV} = & g_{Hgg} H G_{\mu\nu}^a G^{a\mu\nu} + g_{H\gamma\gamma} H A_{\mu\nu} A^{\mu\nu} + g_{HZ\gamma}^{(1)} A_{\mu\nu} Z^\mu \partial^\nu H + g_{HZ\gamma}^{(2)} H A_{\mu\nu} Z^{\mu\nu} \\ & + g_{HZZ}^{(1)} Z_{\mu\nu} Z^\mu \partial^\nu H + g_{HZZ}^{(2)} H Z_{\mu\nu} Z^{\mu\nu} + g_{HZZ}^{(3)} H Z_\mu Z^\mu \\ & + g_{HWW}^{(1)} (W_{\mu\nu}^+ W^{-\mu} \partial^\nu H + \text{h.c.}) + g_{HWW}^{(2)} H W_{\mu\nu}^+ W^{-\mu\nu} + g_{HWW}^{(3)} H W_\mu^+ W^{-\mu} + \dots \end{aligned}$$

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- plus Yukawa structure $f_{\tau,b,t}$ [Oscar's talk]

- 9 operators for Run I data

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- up to 9 observable Higgs couplings

$$g_g = \frac{f_{GG} v}{\Lambda^2} \equiv -\frac{\alpha_s}{8\pi} \frac{f_g v}{\Lambda^2}$$

$$g_\gamma = -\frac{g^2 v s_\theta^2}{2\Lambda^2} \frac{f_{BB} + f_{WW}}{2}$$

$$g_Z^{(1)} = \frac{g^2 v}{2\Lambda^2} \frac{c_\theta^2 f_W + s_\theta^2 f_B}{2c_\theta^2}$$

$$g_W^{(1)} = \frac{g^2 v}{2\Lambda^2} \frac{f_W}{2}$$

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$$g_W^{(2)} = -\frac{g^2 v}{2\Lambda^2} f_{WW}$$

$$g_Z^{(3)} = M_Z^2 (\sqrt{2} G_F)^{1/2} \left(1 - \frac{v^2}{2\Lambda^2} f_{\Phi,2} \right)$$

$$g_W^{(3)} = M_W^2 (\sqrt{2} G_F)^{1/2} \left(1 - \frac{v^2}{2\Lambda^2} f_{\Phi,2} \right)$$

$$g_f = -\frac{m_f}{v} \left(1 - \frac{v^2}{2\Lambda^2} f_{\Phi,2} \right) + \frac{v^2}{\sqrt{2}\Lambda^2} f_f$$

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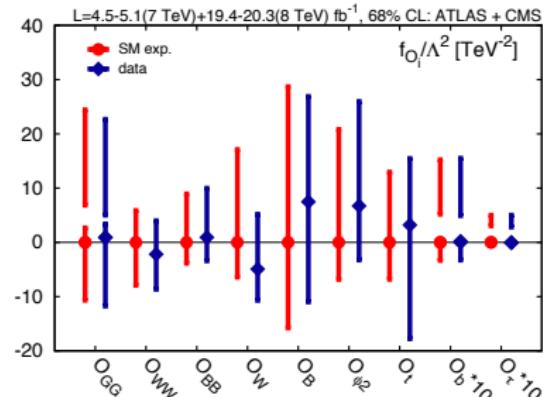
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- not including invisible decays
flat theory errors
read as $10/\text{TeV}^2 = 1/(316 \text{ GeV})^2$
correlations a mess



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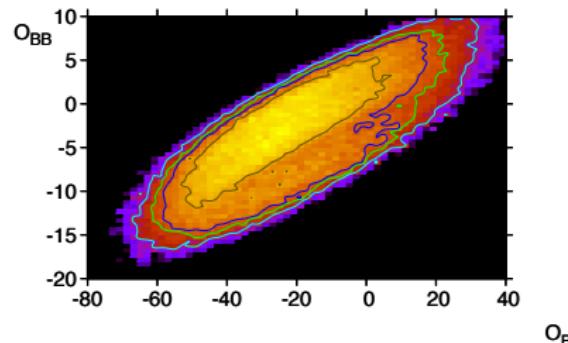
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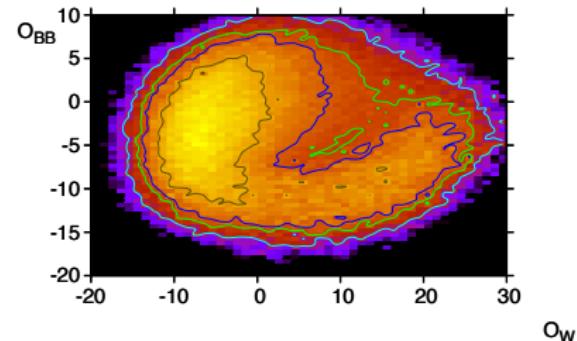
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$$\mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu (\Phi^\dagger \Phi) \partial_\mu (\Phi^\dagger \Phi)$$

$$\mathcal{O}_{\Phi,3} = \frac{1}{3} (\Phi^\dagger \Phi)^3$$

$$\mathcal{O}_{\Phi,4} = (D_\mu \Phi)^\dagger (D^\mu \Phi) (\Phi^\dagger \Phi)$$

- SFitter rate analysis for $f_{\mathcal{O}}/\Lambda^2$ [exactly as before]

- not including invisible decays

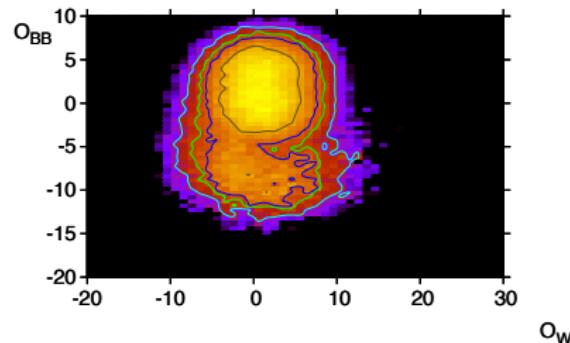
flat theory errors

read as $10/\text{TeV}^2 = 1/(316 \text{ GeV})^2$

correlations a mess

⇒ error analysis challenging

⇒ **distributions the key**



Distributions 1

Top–Higgs–gluon Lagrangian [Ellis, Hinchliffe, Soldate, v d Bij; Baur & Glover]

- test ggH vertex structure [to keep production rate]

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \left(\Delta_t g_{ggH} + \Delta_g \frac{\alpha_s}{12\pi} \right) \frac{H}{v} G_{\mu\nu} G^{\mu\nu}$$

- high- p_T logarithms from 1,2 jets [Banfi et al; Azatov et al; Grojean et al; Buschmann et al]

$$|\mathcal{M}_{Hj(j)}|^2 \sim \frac{m_t^4}{p_T^4} \log^4 \frac{p_T^2}{m_t^2}$$

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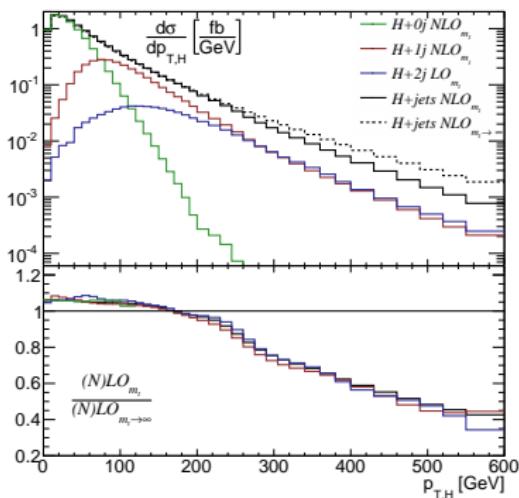
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Measuring $\Delta_{t,g}$ from $p_{T,H}$ distributions [Buschm]

- simulation: SHERPA-NLO
- sensitive region $p_{T,H} > 250$ GeV
systematic/theory errors potentially bad
- NLO vs top mass orthogonal
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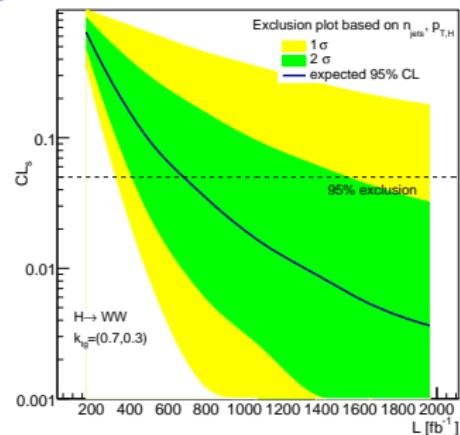
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jet count vs top mass orthogonal
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 $H \rightarrow WW$ analysis
2D likelihood study of $n_{\text{jets}}, p_{T,H}$

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Distributions 2

Not-model-independent width measurements [Kauer & Passarino; Caola & Melnikov; Ellis & Williams]

- peak cross section vs off-shell interference in $H \rightarrow ZZ$

$$\sigma_{\text{peak}} \sim \frac{g_g^2 g_Z^2}{(s - m^2)^2 + m^2 \Gamma^2} = \frac{g_g^2 g_Z^2}{m^2 \Gamma^2} \quad \sigma_{\text{off}}(g_g g_Z) \sim \sigma_{\text{cont}} - \frac{A_{\text{int}} g_g g_Z}{s - m^2} + \frac{A_H g_g^2 g_Z^2}{(s - m^2)^2}$$

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$$\mathcal{M}_{gg \rightarrow ZZ} \sim \pm \frac{m_t^2}{m_Z^2} \log^2 \frac{m_{4\ell}^2}{m_t^2}$$

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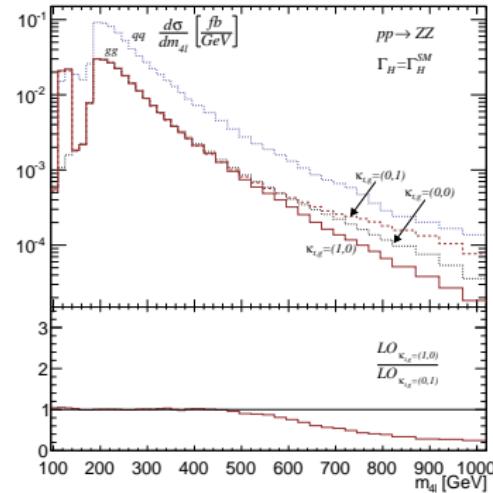
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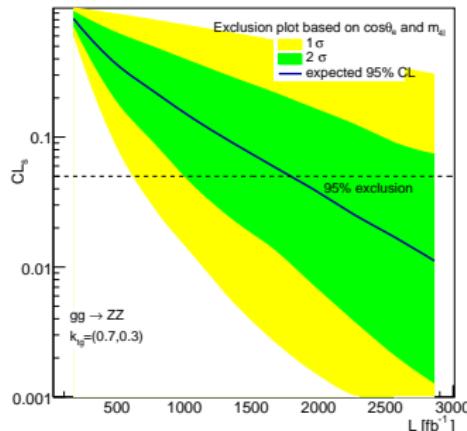
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 $\Rightarrow \Delta_t = -0.3$ to 95% CL with 1700 fb^{-1}
- not great compared to SFitter analysis...

What we learned from Run I

Higgs property tests

- (SFitter) coupling analysis worked/work great [but no anomalies I like]
- hypothesis tests necessary
- extension to D6 operators challenging
- distributions to be included

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

Higgs Couplings

Tilman Plehn

Rates

Operators

Distributions