Higgs Couplings

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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]

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

$gg \to H$
$qq \to qqH$
$gg \to t\bar{t}H$
$qq' \to VH$

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

$H \to ZZ$
$H \to WW$
$H \to b\bar{b}$
$H \to \tau^+\tau^-$
$H \to \gamma\gamma$

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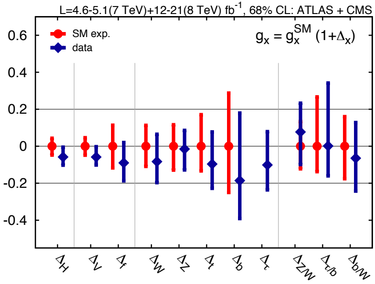
Run I legacy [prelim: Corbett, Goncalves, Gonzelez-Fraile, Rauch,...]

– based on signal and background rates

– ratios and correlations fully included

– 6D, SM-like [Higgs portal to 5%, Oleg's talk]



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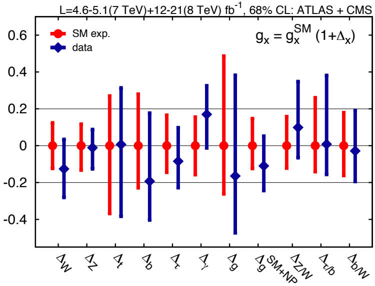

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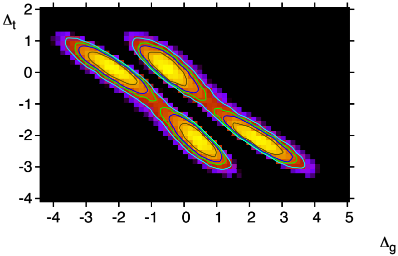

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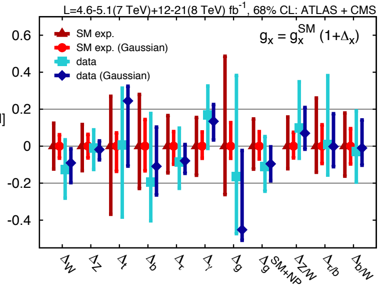

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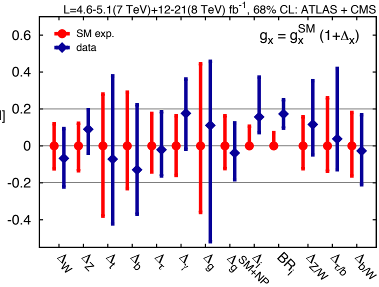

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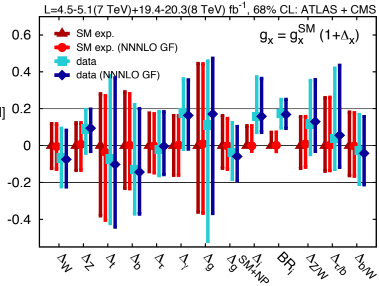

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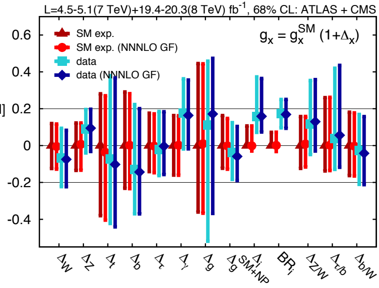
⇒ details matter!



In terms of D6 operators

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

– set of Higgs-gauge operators

$$\mathcal{O}_{GG} = \Phi^\dagger \Phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \qquad \mathcal{O}_{BB} = \cdots$$

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– relevant part after equation of motion, etc

$$\mathcal{L}^{HVV} = - \frac{\alpha_s v}{8\pi} \frac{f_g}{\Lambda^2} \mathcal{O}_{GG} + \frac{f_{BB}}{\Lambda^2} \mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2} \mathcal{O}_{WW} + \frac{f_B}{\Lambda^2} \mathcal{O}_{B} + \frac{f_W}{\Lambda^2} \mathcal{O}_{W} + \frac{f_{\Phi,2}}{\Lambda^2} \mathcal{O}_{\Phi,2}$$

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$$\begin{aligned} \mathcal{L}^{HVV} = {} & g_{Hgg} \; H G^a_{\mu\nu} G^{a\mu\nu} + g_{H\gamma\gamma} \; H A_{\mu\nu} A^{\mu\nu} + g^{(1)}_{HZ\gamma} \; A_{\mu\nu} Z^\mu \partial^\nu H + g^{(2)}_{HZ\gamma} \; H A_{\mu\nu} Z^{\mu\nu} \\ & + g^{(1)}_{HZZ} \; Z_{\mu\nu} Z^\mu \partial^\nu H + g^{(2)}_{HZZ} \; H Z_{\mu\nu} Z^{\mu\nu} + g^{(3)}_{HZZ} \; H Z_\mu Z^\mu \\ & + g^{(1)}_{HWW} \; \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu H + \text{h.c.} \right) + g^{(2)}_{HWW} \; H W^+_{\mu\nu} W^{-\,\mu\nu} + g^{(3)}_{HWW} \; H W^+_\mu W^{-\,\mu} + \cdots \end{aligned}$$

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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

$$g_g = \frac{f_{GG} v}{\Lambda^2} \equiv -\frac{\alpha_s}{8\pi} \frac{f_g v}{\Lambda^2} \qquad g_\gamma = -\frac{g^2 v s_\theta^2}{2\Lambda^2} \frac{f_{BB} + f_{WW}}{2}$$

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

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

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

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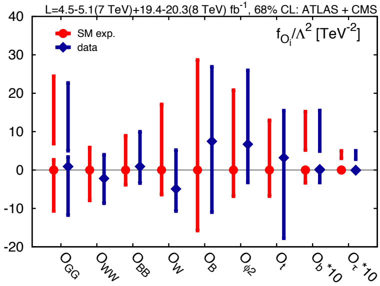
– SFitter rate analysis for $f_{\mathcal{O}}/\Lambda^2$ [exactly as before]

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



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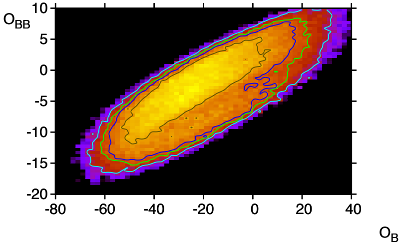

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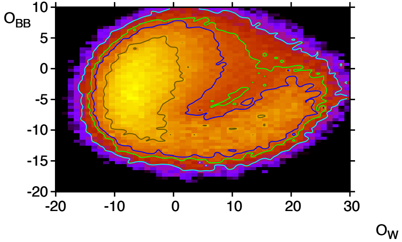
– SFitter rate analysis for $f_{\mathcal{O}}/\Lambda^2$ [exactly as before]

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



In terms of D6 operators

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

– set of Higgs-gauge operators

$$\mathcal{O}_{GG} = \Phi^\dagger \Phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \qquad \mathcal{O}_{BB} = \cdots$$

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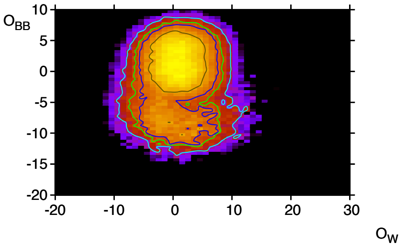
⇒ error analysis challenging

⇒ 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 etal; Azatov etal; Grojean etal; Buschmann etal]

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

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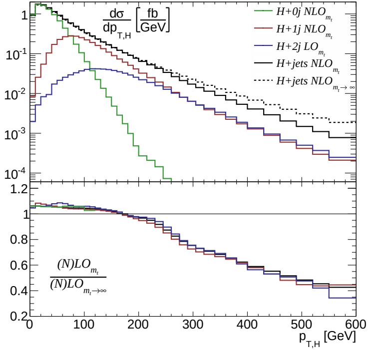
Measuring $\Delta_{t,g}$ from $p_{T,H}$ distributions [Buschm

– simulation: SHERPA-NLO

– sensitive region $p_{T,H} > 250$ GeV
systematic/theory errors potentially bad

– NLO vs top mass orthogonal
jet count vs top mass orthogonal



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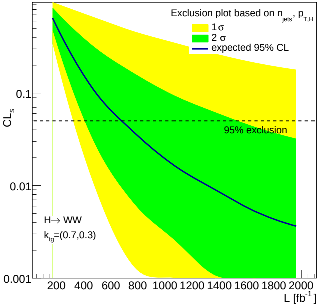
$H \to WW$ analysis
2D likelihood study of $n_{\text{jets}}, p_{T,H}$

$\Rightarrow$ $\Delta_t = -0.3$ to 95% CL with 700 fb^{-1}



Distributions 2

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

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

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

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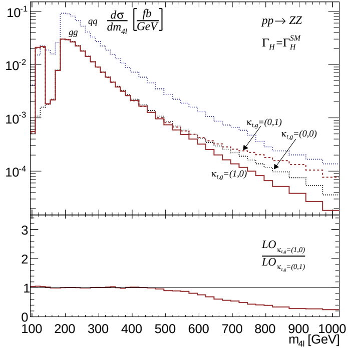

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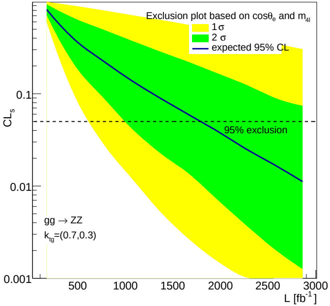

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⇒ $\Delta_t = -0.3$ to 95% CL with 1700 fb^{-1}

⇒ 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

Bundesministerium für Bildung und Forschung