Theory Questions for the Higgs Sector

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HCP Kyoto, 11/2012

Where Higgs and BSM physics stand

Back to data-driven theory? [Shifman 1210.0004]

– we (you) have discovered a ‘Higgs’

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$\Rightarrow$ experimentalists talk, theorists listen [speaker quietly leaving the stage]

Immediate questions

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3. What can we expect in the future?

- WBF analyses still weak
- VH and $t\bar{t}H$ missing
- self coupling not accessible?

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- except Higgs production in gluon fusion
- except Higgs decay to photons
- except g_{WWH} might mean $HW^{\mu\nu}W_{\mu\nu}$
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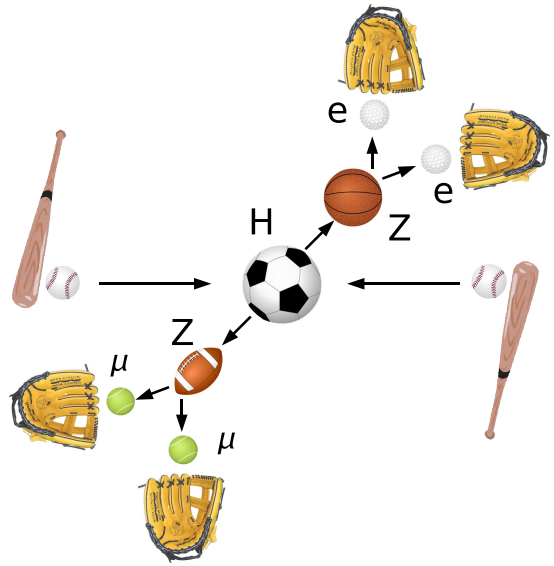
$\Rightarrow$ analyze Higgs kinematics [in as many channels as possible]



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Model independent angles

- first step: Higgs polar angle for spin-0 vs spin-2 [Alves; Choi etal]

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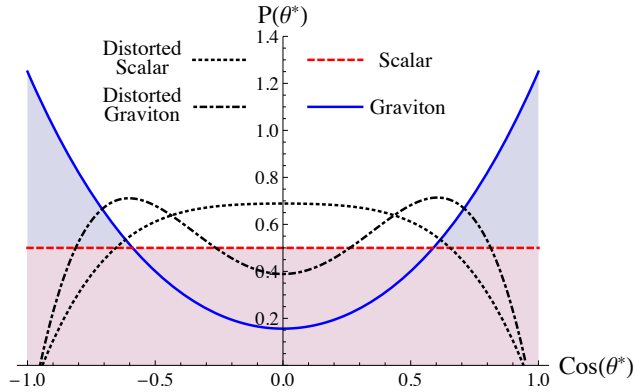

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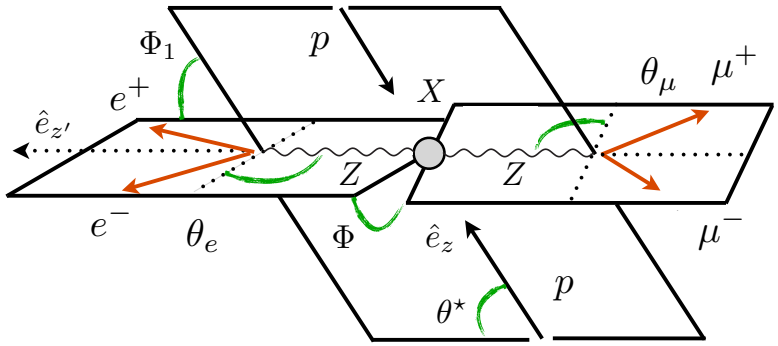

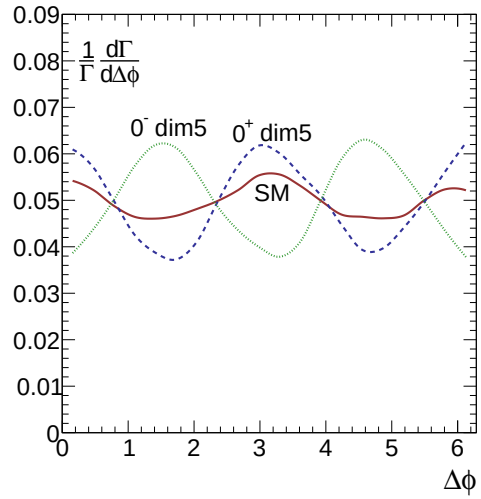

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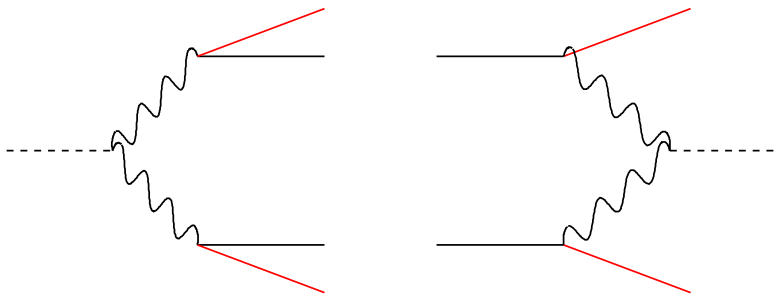

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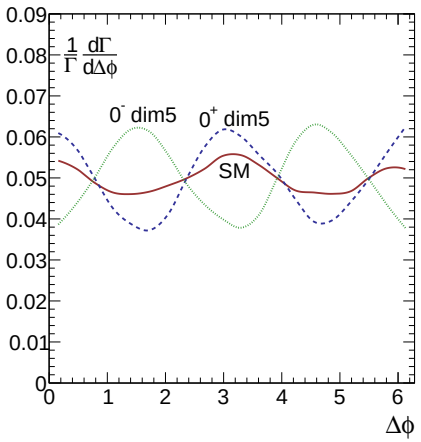

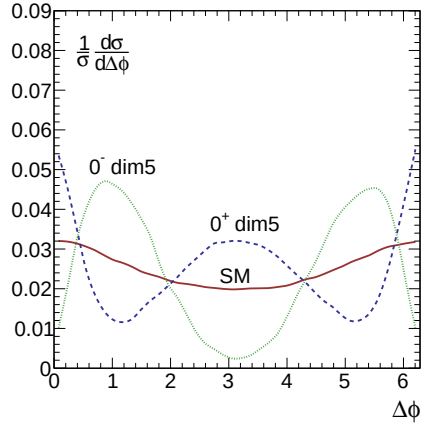

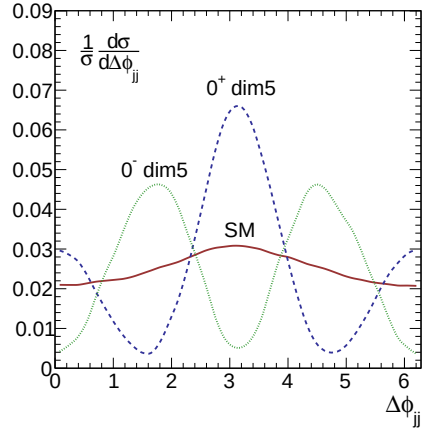

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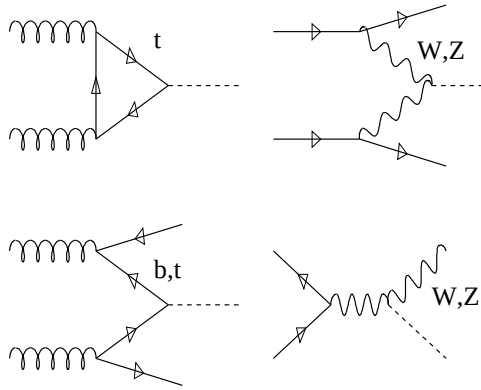
  azimuthal jet angle with same information
- Higgs operators testable in almost all channels [MC: Madgraph, etc]

$\Rightarrow$ will this work?

Couplings



Current model [guessing answer to question One]

- assume: narrow CP-even scalar
  SM-like D4 structures
  SM-induced D6 structures
- couplings from production & decay combinations?

$$\boxed{\begin{aligned} gg &\to H \\ qq &\to qqH \\ gg &\to t\bar{t}H \\ qq' &\to VH \end{aligned}} \quad \longleftrightarrow \quad \boxed{g_{HXX} = g_{HXX}^{\text{SM}} \; (1 + \Delta_X)} \quad \longleftrightarrow \quad \boxed{\begin{aligned} H &\to ZZ \\ H &\to WW \\ H &\to b\bar{b} \\ H &\to \tau^+\tau^- \\ H &\to \gamma\gamma \end{aligned}}$$

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

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

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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 [most general ansatz now]
electroweak corrections still not relevant

– starting point: exclusive likelihood map
individual coupling: profile likelihood
best fit: Minuit
errors: toy measurements

$\Rightarrow$ global and local analysis possible

Global/local analysis

Global view on 8 TeV data [Klute, Lafaye, TP, Rauch, Zerwas; TP & Rauch]

– g_W included post-ICHEP

(1) expected 2012: SM central values, measured error bars

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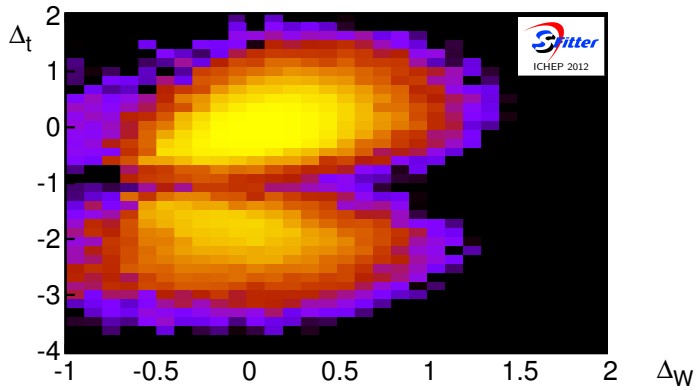

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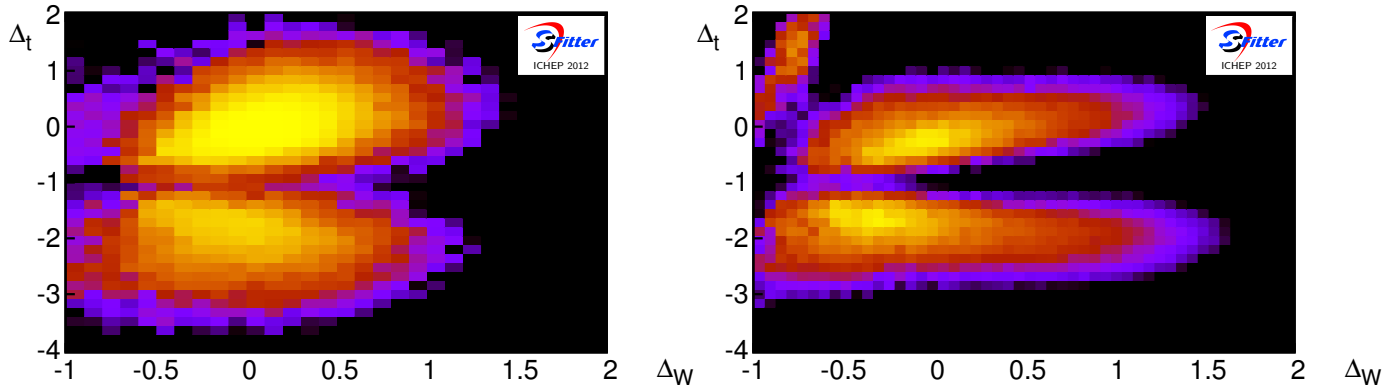
weak third solution with large quark Yukawas



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Local view on 7 TeV data

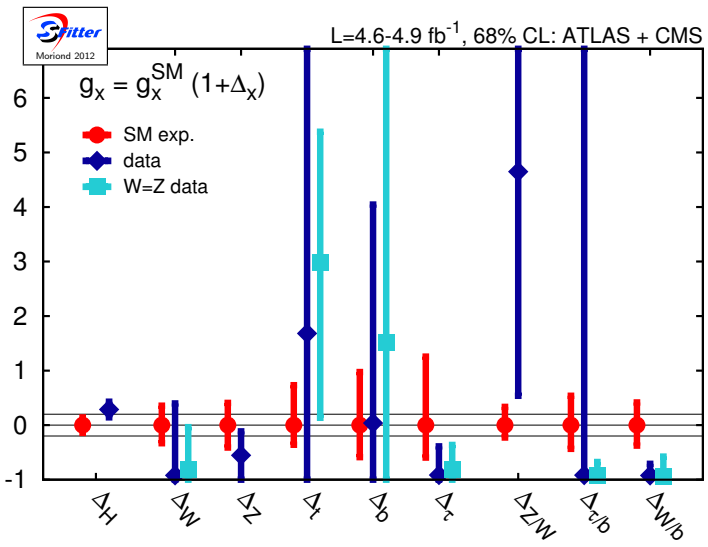
– focus on SM solution where possible

– 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: $\Delta_j \equiv \Delta_H$

$\Rightarrow$ pointing towards Standard Model?



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Local view on 8 TeV data [post-ICHEP]

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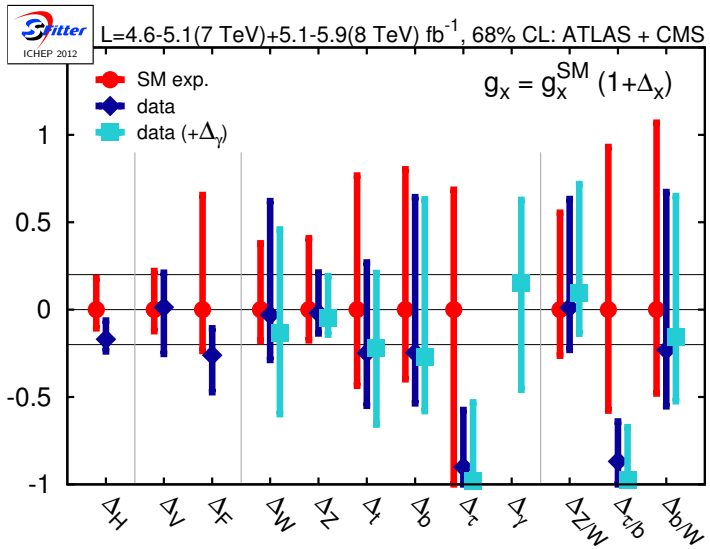
– six couplings from data [errors 20 — 50%]

$g_{W,Z}$ fine
$g_{t,b}$ indirectly
g_τ poor
g_γ now possible



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– all hypotheses great: $\Delta_H, \Delta_V, \Delta_f, \ldots$

$\Rightarrow$ moving towards Standard Model?

hypothesis	χ^2_{2012}/dof	sol's
Standard Model	43.3/54	
form factor Δ_H	32.2/53	1
two-parameter $\Delta_{V,f}$	29.0/52	2
independent Δ_x	27.7/49	3
including Δ_γ	27.3/48	2

More on couplings

Anomalous Higgs couplings [Hagiwara etal; Corbett, Eboli, Gonzales-Fraile, Gonzales-Garcia]

– anomalous couplings from D6 operators f_j [index '2' for $W_{\mu\nu} W^{\mu\nu}$]

$$g_{Hgg} = -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} \qquad g_{H\gamma\gamma} = -\frac{gM_W}{\Lambda^2}\frac{s^2(f_{BB}+f_{WW}-f_{BW})}{2}$$

$$g^{(1)}_{HZ\gamma} = \frac{gM_W}{\Lambda^2}\frac{s(f_W-f_B)}{2c} \qquad g^{(2)}_{HZ\gamma} = \frac{gM_W}{\Lambda^2}\frac{s[2s^2 f_{BB}-2c^2 f_{WW}+(c^2-s^2)f_{BW}]}{2c}$$

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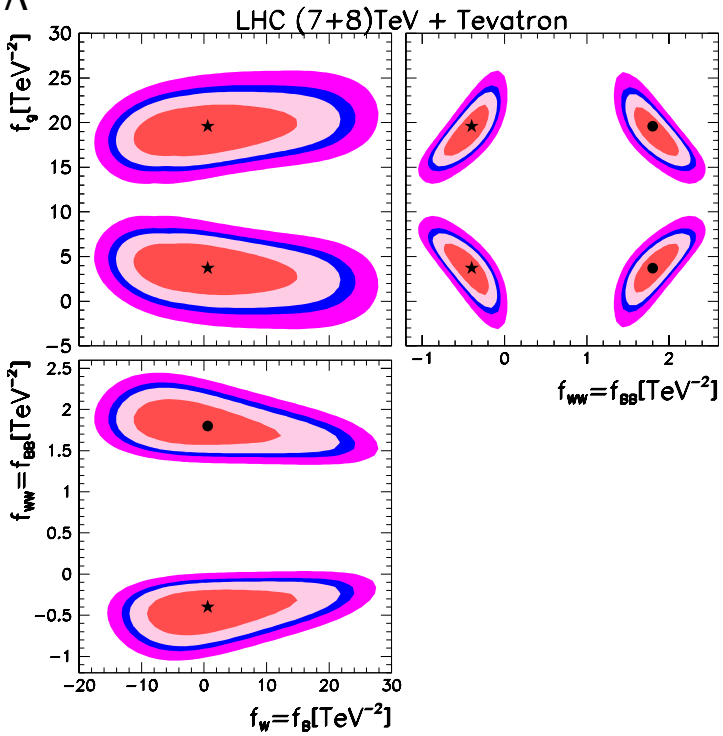
– asume $f_W = f_B$ [otherwise no convergence]
fit f_{gg}, f_{WW}, f_{BB}
observe usual sign-flip degeneracy
compare to $\Delta\kappa$ and Λ in g_{WWV}



Future: top Yukawa

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

- crucial to understand Higgs sector [details later]
- trigger: $t \to bW^+ \to b\ell^+\nu$
  reconstruction and rate: $\bar{t} \to \bar{b}W^- \to \bar{b}jj$
- continuum background $t\bar{t}b\bar{b}$, $t\bar{t}jj$ [weighted by b-tag]

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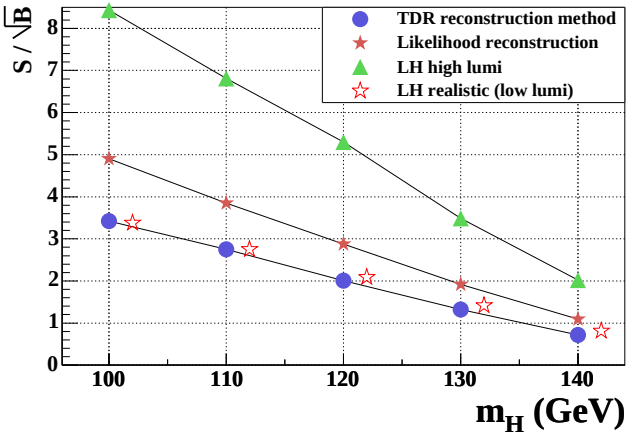
- not a chance:
  1– combinatorics: m_H in $pp \to 4b_{tag}\ 2j\ \ell\nu$
  2– kinematics: peak-on-peak
  3– systematics: $S/B \sim 1/9$



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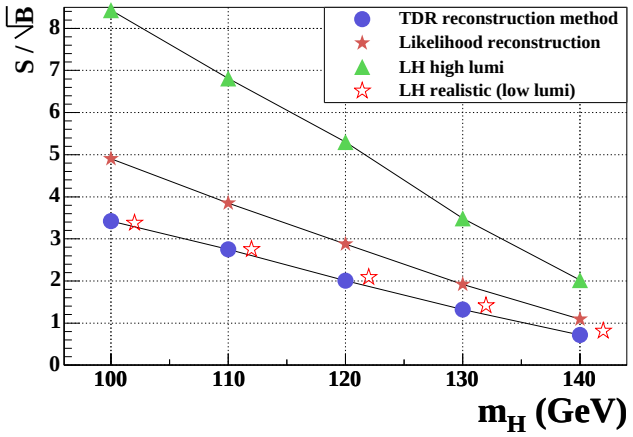

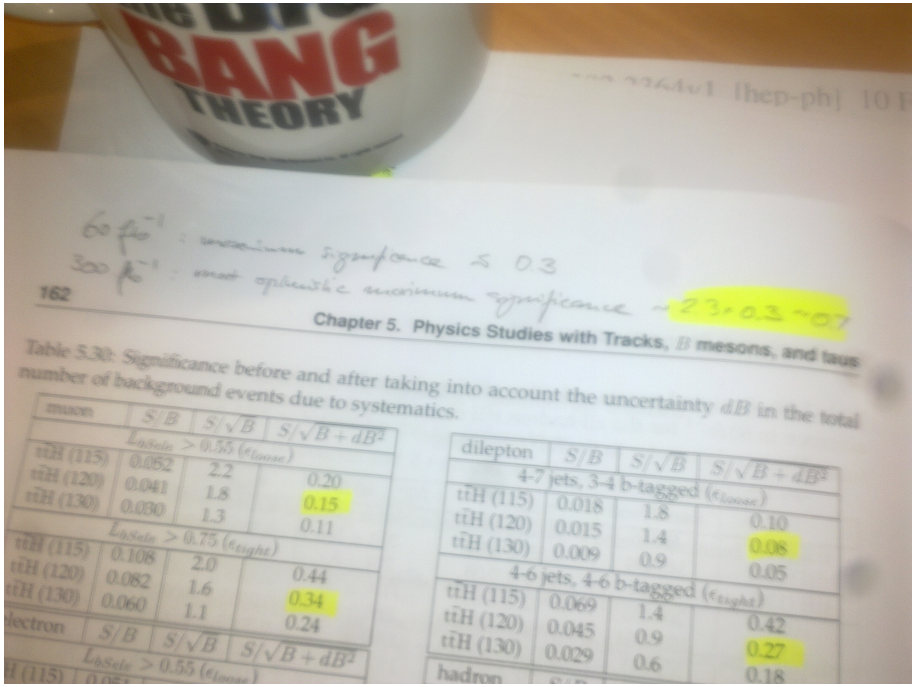

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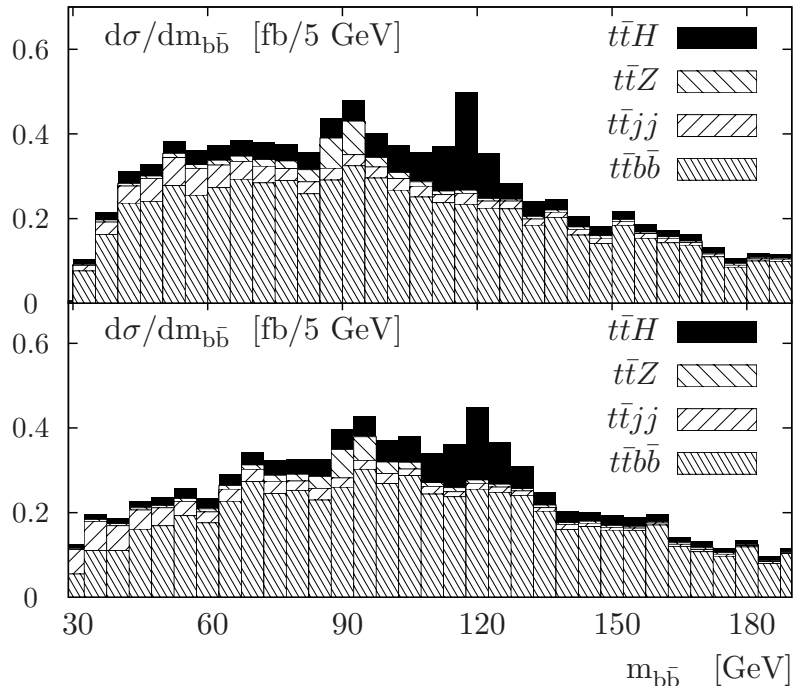
Fat jets analysis [TP, Salam, Spannowsky, Takeuchi]

- require tagged top and Higgs
  trigger on lepton
  only continuum $t\bar{t}b\bar{b}$ left [with sidebands]



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Fat jets analysis [TP, Salam, Spannowsky, Takeuchi]

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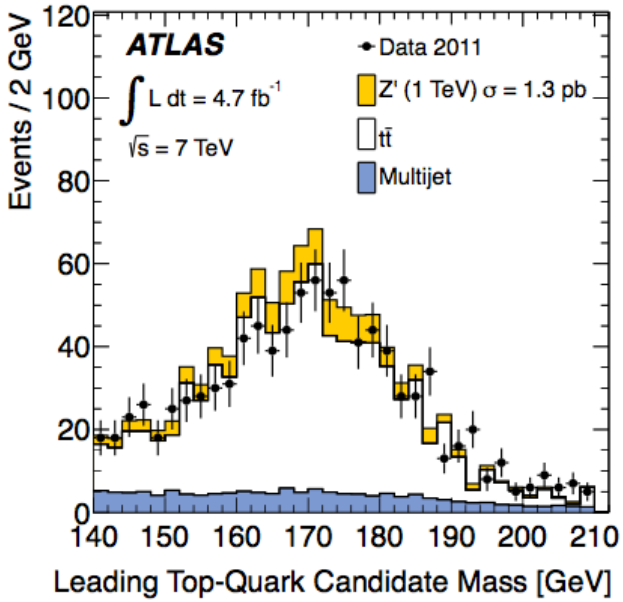
- top tagger working [Atlas-Heidelberg, talk yesterday]

$\Rightarrow$ can we do it?



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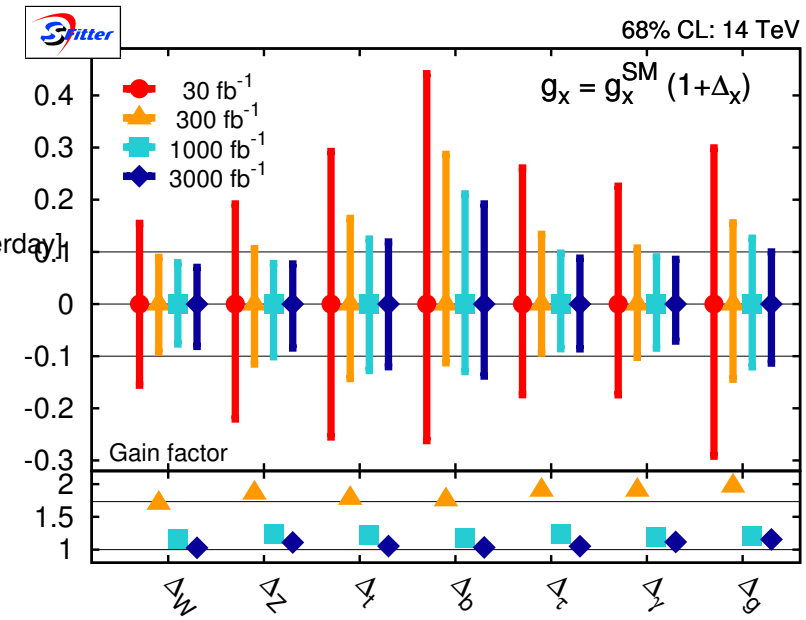

Weak scale theory

D6 operators

- SM: non-decoupling chiral fermions $g_{Hgg} \sim \alpha_s/(12\pi v)$
- new particle with charge Q and SU(3) Casimir $C(R)$ [Reece]

$$R_\gamma = \frac{g_{H\gamma\gamma}}{g^{\text{SM}}_{H\gamma\gamma}} = \left[1 + 0.28\xi \left(1 \mp \sqrt{R_g}\right)\right]^2, \qquad \xi = \frac{3Q^2}{C_2(R)}$$

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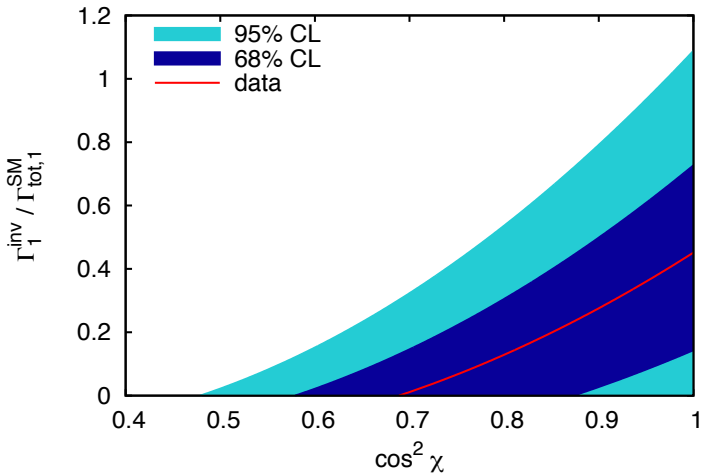
Higgs portal [e.g. Englert, Plehn, Rauch, Zerwas, Zerwas]

- renormalizable mixing $\mathcal{L} \sim (S^\dagger S)\,(H^\dagger H)$
- form-factor correction to SM Higgs [cos χ] plus invisible decays

$\Rightarrow$ invisible Higgs possible?



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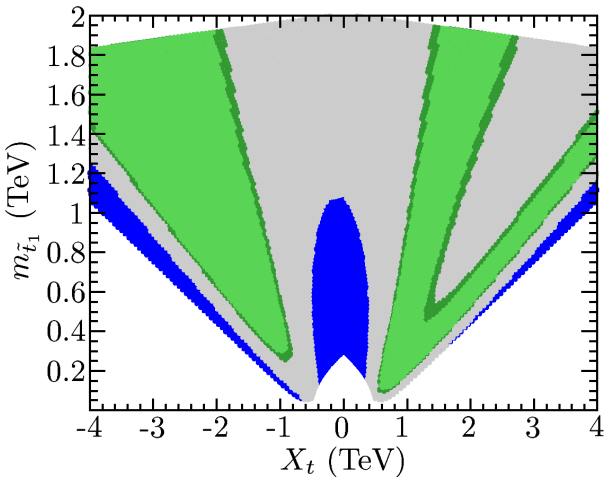
Supersymmetry

- MSSM Higgs mass the best-predicted LHC observable? [Hahn etal + Stal]
- stop mass/mixing crucial [$m_A = 1$ TeV, $\tan\beta = 20$]



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More general [Gupta, Rzehak, Wells]

- modelling Higgs coupling deviations
- deviations allowed by other constraints

	ΔhVV	$\Delta h\bar{t}t$	$\Delta h\bar{b}b$
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	$< 1\%$	3%	$10\%^{(\text{large } \tan\beta)}$, $100\%^{(\text{small } \tan\beta)}$

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- correlation of Δ_τ and heavy Higgs states

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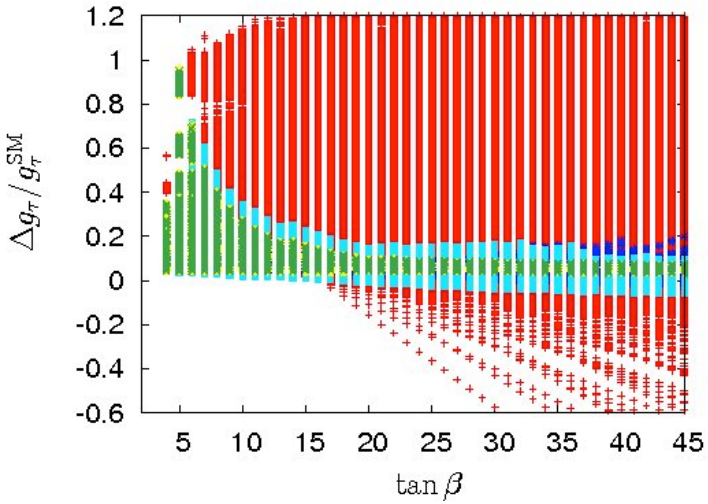

High scale theory

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High-scale effects

- Higgs mass related to self coupling: $m_H = v\sqrt{2\lambda}$
  top mass related to Yukawa: $y_t = \sqrt{2} m_t / v$

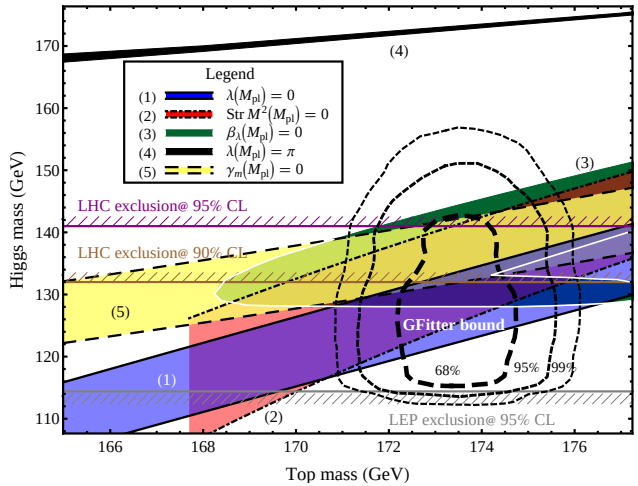
$$\frac{d\,\lambda}{d\,\log Q^2} = \frac{1}{16\pi^2}\left[12\lambda^2 + 6\lambda y_t^2 - 3y_t^4 - \frac{3}{2}\lambda\left(3g_2^2 + g_1^2\right) + \frac{3}{16}\left(2g_2^4 + (g_2^2 + g_1^2)^2\right)\right]$$

- IR fixed point for λ/y_t^2 fixing m_H^2/m_t^2 [with gravity: Shaposhnikov, Wetterich]

$$m_H = 126.3 + \frac{m_t - 171.2}{2.1} \times 4.1 - \frac{\alpha_s - 0.1176}{0.002} \times 1.5$$

- Planck-scale conditions [Holthausen, Lim, Lindner]

$\Rightarrow$ Higgs and top strongly linked



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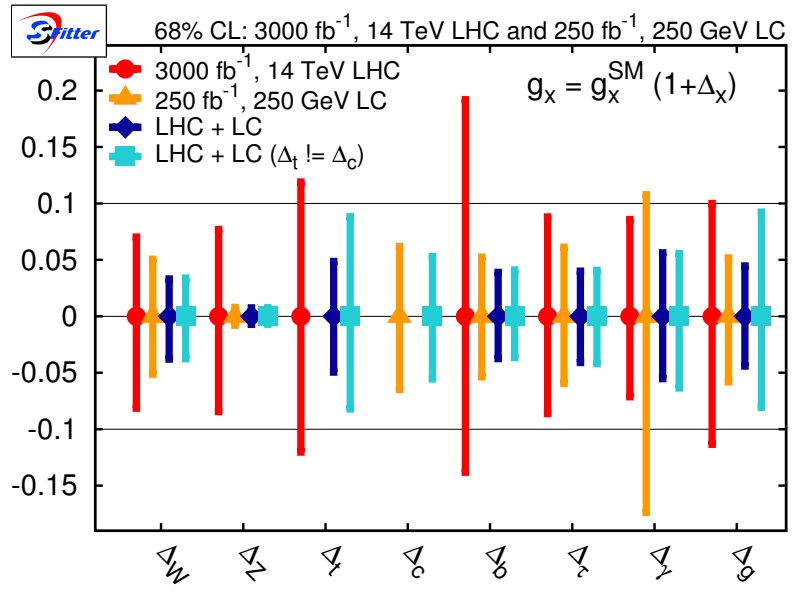

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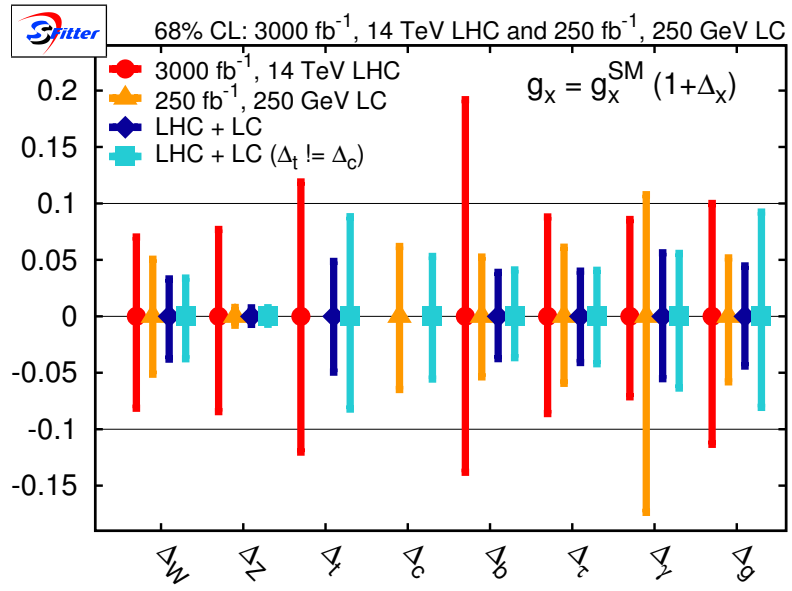

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Towards 14 TeV

- no $b\bar{b}H$ production observed
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Best channel $q\bar{q} \to VH, H \to b\bar{b}$

- let me comment on CMS analysis
- focus on boosted regime $p_{T,V} \gtrsim 120$ GeV
  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 work and are understood]
  no side bands with any S/B

$\Rightarrow$ how will this ever work?

[my hopes rest on BDRS and jet substructure]