Higgs decays to bottoms

Tilman Plehn

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Higgs to bottoms

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$VH, H \to b\bar{b}$

$t\bar{t}H, H \to b\bar{b}$

SUSY $H \to b\bar{b}$

Measuring y_b

Side remark

$VH, H \to b\bar{b}$

$H \to b\bar{b}$ as of 2007 [2/3 of all Higgses at 120 GeV]

– gluon-fusion: killed by QCD background [CMS: $S/B \sim 1/80$]

– WBF H: no trigger, killed by QCD backgrounds [WH, γH might work]

– VH: killed by low rate and NLO background

– $t\bar{t}H$: killed by combinatorics etc

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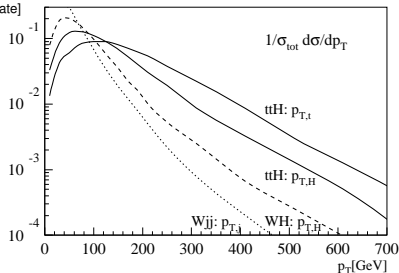## $H \rightarrow b\bar{b}$ as of 2007 [2/3 of all Higgses at 120 GeV]

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Changing everything [Butterworth, Davison, Rubin, Salam; Seymour...]

– S: large m_{bb}, boost-dependent R_{bb}
B: large m_{bb} only for large R_{bb}
S/B: large m_{bb} and small R_{bb}, so boosted Higgs

– fat Higgs jet $R_{bb} \sim 2m_H/p_T < 1$

– $q\bar{q} \rightarrow V_\ell H_b$ viable [$p_T \gtrsim 300$ GeV, few % of rate]

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⇒ non-trivial challenge to jet algorthms

	σ_S/fb	σ_B/fb	$S/\sqrt{B}_{30}$
C/A, $R = 1.2$, MD-F	0.57	0.51	4.4
$k_\perp$, $R = 1.0$, y_{cut}	0.19	0.74	1.2
SISCone, $R = 0.8$	0.49	1.33	2.3

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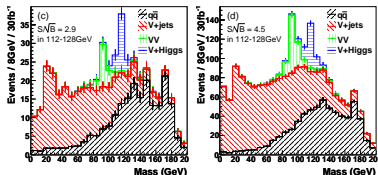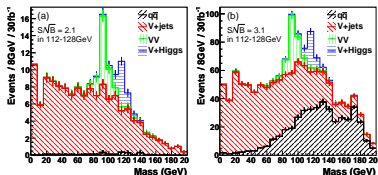SUSY H → b$\bar{b}$

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VH production

– combined channels $V \rightarrow \ell\ell, \nu\nu, \ell\nu$

– NLO rates [bbV notorious, not from data alone]

– Z peak as sanity check

– confirmed to 20% [Piquadio]
  subjet b tag excellent [70%/1%]
  charm rejection challenging
  $m_H \pm 8$ GeV tough

– improvements possible [Soper, Spannowsky]

⇒ crucial for Higgs sector studies

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$t\bar{t}H, H \rightarrow b\bar{b}$

Long death of $t\bar{t}H, H \rightarrow b\bar{b}$ [Cammin & Schumacher, CMS-TDR and Atlas-CSC worse]

– trigger: $t \rightarrow bW^+ \rightarrow b\ell^+\nu$
  reconstruction and rate: $\bar{t} \rightarrow \bar{b}W^- \rightarrow \bar{b}jj$

– continuum background $t\bar{t}b\bar{b}, t\bar{t}jj$ [know at NLO]

– no chance:
  1– combinatorics: m_{bb} from $pp \rightarrow 4b_{tag} \, 2j \, \ell\nu$

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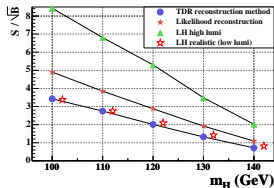 2– kinematics: peak-on-peak
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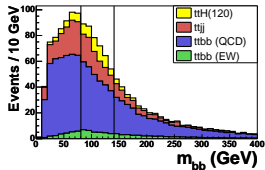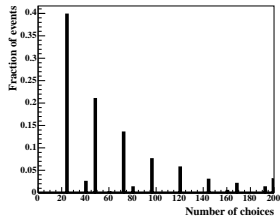2– kinematics: peak-on-peak
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New analysis

– tagged (boosted) top and Higgs
trigger on lepton

– add'l continuum b tag [remove 'Higgs' as $t_\ell \rightarrow b$ plus QCD]

– side bin in continuum $t\bar{t}b\bar{b}$

per 1 fb^{-1}	signal	$t\bar{t}Z$	$t\bar{t}b\bar{b}$	$t\bar{t}$+jets
events after acceptance	24.1	6.9	191	4160
events with one top tag	10.2	2.9	70.4	1457
events with $m_{bb} = 110 - 130$ GeV	2.9	0.44	12.6	116
corresponding to subjet pairings	3.2	0.47	13.8	121
subjet pairings two b tags	1.0	0.08	2.3	1.4
including a third b tag	0.48	0.03	1.09	0.06

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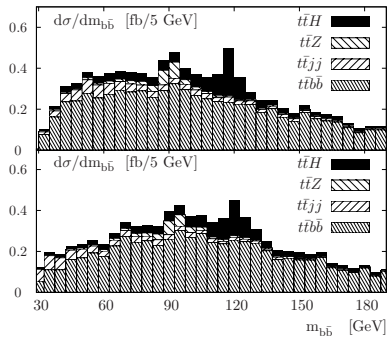SUSY $H \rightarrow b\bar{b}$

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m_H	S	S/B	$S/\sqrt{B}$
115	57	1/2.1	5.2 (5.7)
120	48	1/2.4	4.5 (5.1)
130	29	1/3.6	2.9 (3.0)

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Higgs tag in $t\bar{t}H$ [TP, Salam, Spannowsky]

– uncluster one-by-one: $j \rightarrow j_1 + j_2$
1– unbalanced $m_{j_1} > 0.8 m_j$ means QCD; discard j_2
2– soft $m_{j_1} < 30$ GeV means QCD; keep j_1

– double b tag [possibly add balance criterion]
three leading $J = p_{T,1} p_{T,2} (\Delta R_{12})^4$ vs m_{bb}^{filt}
no mass constraint — side bin

– jets everywhere; underlying event and pileup deadly
filter reconstruction jets [Butterworth–Salam]
decay plus one add'l jet at $R_{\text{filt}} \sim R_{jj}/2$
reconstruct masses w/ QCD jet

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Standard Model top tag [TP, Salam, Spannowsky, Takeuchi]

- known for heavy resonances [Johns Hopkins, Stony Brook, Princeton, Washington, Atlas]
- only way to test fat-jet methods
- start like Higgs tagger [R=1.5]
  kinematic selection [filtered]
  $m_t^{\text{rec}} = 150...200$ GeV
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  helicity angle large [learn from single tops]
- no side bands to check

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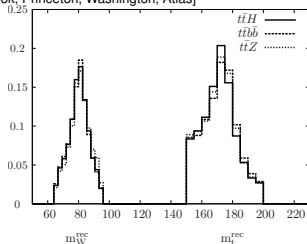## Standard Model top tag [TP, Salam, Spannowsky, Takeuchi]

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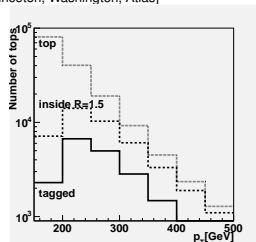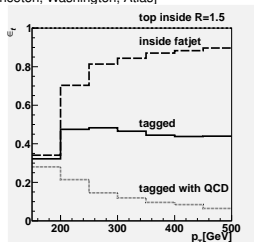SUSY $H \rightarrow b\bar{b}$

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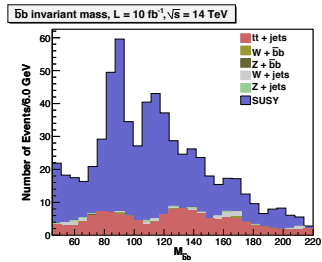
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## Higgs in cascade decays   [Kribs, Martin, Roy, Spannowsky]

– idea: find Higgs in cascade decays   [Cambridge]
– BSM sample after missing energy or hard γ cut
– Higgs tag over the remaining event
– side bin analysis in m_{bb}
– more to follow...

$\bar{b}b$ invariant mass, L = 10 fb^{-1}, $\sqrt{s}$ = 14 TeV

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Higgs sector

Higgs-sector analysis [Zeppenfeld, Kinnunen, Nikitenko, Richter-Was; Dührssen et al.]

– optimistic LHC scenario: everything working and good data

– Higgs vs. scalars? SM vs MSSM? doublet vs. general Higgs?

– light Higgs: 10 main channels ($\sigma \times BR$)

– measurements: $GF : H \rightarrow ZZ, WW, \gamma\gamma$
$\quad\quad\quad\quad\quad\quad WBF : H \rightarrow ZZ, WW, \gamma\gamma, \tau\tau$
$\quad\quad\quad\quad\quad\quad VH : H \rightarrow b\bar{b}$ [Butterworth, Davison, Rubin, Salam]
$\quad\quad\quad\quad\quad\quad t\bar{t}H : H \rightarrow \gamma\gamma, WW, (b\bar{b})...$

– parameters: couplings $W, Z, t, b, \tau, g, \gamma$ [plus m_H]

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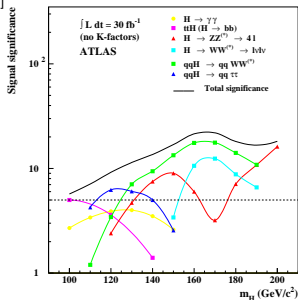
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Total width and g_{bbH}

– degeneracy $\sigma\, BR \propto (g_p^2/\sqrt{\Gamma_H})\ (g_d^2/\sqrt{\Gamma_H}) \equiv C > 0$

– bad scaling
$$C = \lim_{g^2 \to 0} \frac{g^4}{\Gamma_H} = \lim_{g^2 \to 0} \frac{g^4}{g^2(\Gamma_{vis}/g^2) + \Gamma_x} = 0$$

   means constraint: $\sum \Gamma_i(g^2) < \Gamma_H \to \Gamma_H|_{min}$

– $WW \to WW$ unitarity: $g_{WWH} \lesssim g_{WWH}^{SM} \to \Gamma_H|_{max}$

– for now $\Gamma_H = \sum_{obs} \Gamma_j$, so $H \to b\bar{b}$ crucial

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Errors

Sources of uncertainty

- statistical error: Poisson
  systematic error: Gaussian, if measured
  theory error: not Gaussian

- LHC rate 10% off: no problem
  LHC rate 30% off: no problem
  LHC rate 300% off: Standard Model wrong
  means theory likelihood flat centrally and zero far away

- profile likelihood construction: RFit [CKMFitter]

$$-2 \log \mathcal{L} = \chi^2 = \vec{\chi}_d^T \, C^{-1} \, \vec{\chi}_d$$

$$\chi_{d,i} = \begin{cases} 0 & |d_i - \bar{d}_i| < \sigma_i^{(\text{theo})} \\ \dfrac{|d_i - \bar{d}_i| - \sigma_i^{(\text{theo})}}{\sigma_i^{(\text{exp})}} & |d_i - \bar{d}_i| > \sigma_i^{(\text{theo})} \end{cases},$$

- measuring ratios
  useless if statistics dominated
  theory errors — same initial states
  systematic errors — same final states
  ???

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Higgs couplings

SFitter analysis [Dührssen, Lafaye, TP, Rauch, Zerwas]

– all couplings varied around SM values $g_{HXX} = g_{HXX}^{SM} (1 + \delta_{HXX})$
  $\delta_{HXX} \sim -2$ means sign flip   [$g_{HWW} > 0$ fixed]

– need assumption about loop-induced couplings $g_{ggH}, g_{\gamma\gamma H}$ [Ian's talk]

– likelihood map and local errors from SFitter

– experimental/theory errors on signal and backgrounds   [do not ask theorists!]

luminosity measurement	5 %
detector efficiency	2 %
lepton reconstruction efficiency	2 %
photon reconstruction efficiency	2 %
WBF tag-jets / jet-veto efficiency	5 %
b-tagging efficiency	3 %
τ-tagging efficiency (hadronic decay)	3 %
lepton isolation efficiency ($H \rightarrow 4\ell$)	3 %

σ (gluon fusion)	13 %
σ (weak boson fusion)	7 %
σ (VH-associated)	7 %
σ ($t\bar{t}$-associated)	13 %

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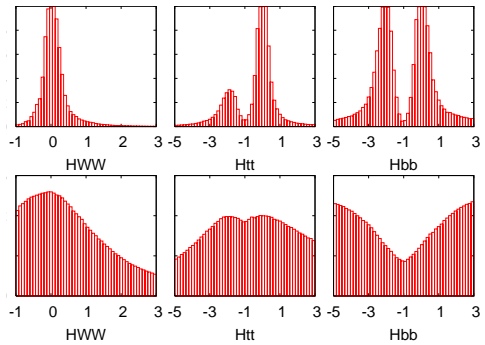
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- error bars for Standard Model hypothesis [smeared data point, 30fb^{-1}]

coupling	without eff. couplings			including eff. couplings		
	σ_{symm}	σ_{neg}	σ_{pos}	σ_{symm}	σ_{neg}	σ_{pos}
δ_{WWH}	± 0.23	$- 0.21$	$+ 0.26$	± 0.24	$- 0.21$	$+ 0.27$
δ_{ZZH}	± 0.50	$- 0.74$	$+ 0.30$	± 0.44	$- 0.65$	$+ 0.24$
$\delta_{t\bar{t}H}$	± 0.41	$- 0.37$	$+ 0.45$	± 0.53	$- 0.65$	$+ 0.43$
$\delta_{b\bar{b}H}$	± 0.45	$- 0.33$	$+ 0.56$	± 0.44	$- 0.30$	$+ 0.59$
$\delta_{\tau\bar{\tau}H}$	± 0.33	$- 0.21$	$+ 0.46$	± 0.31	$- 0.19$	$+ 0.46$
$\delta_{\gamma\gamma H}$	—	—	—	± 0.31	$- 0.30$	$+ 0.33$
δ_{ggH}	—	—	—	± 0.61	$- 0.59$	$+ 0.62$
m_H	± 0.26	$- 0.26$	$+ 0.26$	± 0.25	$- 0.26$	$+ 0.25$
m_b	± 0.071	$- 0.071$	$+ 0.071$	± 0.071	$- 0.071$	$+ 0.072$
m_t	± 1.00	$- 1.03$	$+ 0.98$	± 0.99	$- 1.00$	$+ 0.98$

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VH, $H \to b\bar{b}$
$t\bar{t}H$, $H \to b\bar{b}$
SUSY $H \to b\bar{b}$
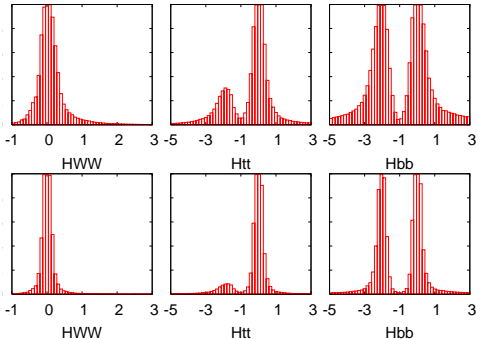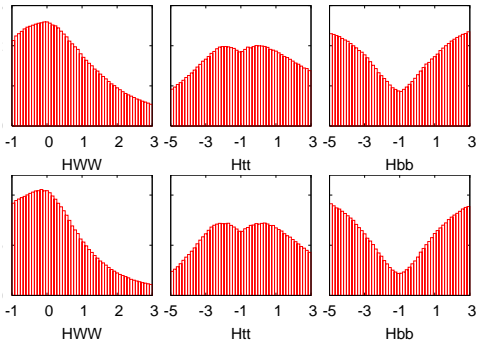
Measuring y_b

Side remark

Higgs couplings

One-dimensional distributions to check....

1– noisy environment preferring profile likelihoods [no effective couplings, 30 fb^{-1}]

Higgs to bottoms

Tilman Plehn

VH, H → b̄b
t̄tH, H → b̄b
SUSY *H → b̄b*

Measuring *y_b*

Side remark

Higgs couplings

One-dimensional distributions to check....

1– noisy environment preferring profile likelihoods [no effective couplings, 30 fb^{-1}]

2– higher luminosity quantitatively different [no effective couplings, 30 vs 300 fb^{-1}]

Higgs to bottoms

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VH, $H \rightarrow b\bar{b}$

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Measuring y_b

Side remark

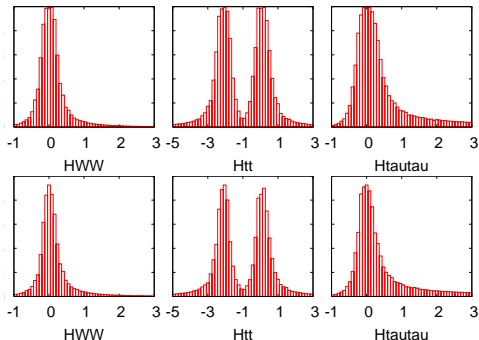# Higgs couplings

One-dimensional distributions to check....

1– noisy environment preferring profile likelihoods   [no effective couplings, 30 fb^{-1}]

2– higher luminosity quantitatively different   [no effective couplings, 30 vs 300 fb^{-1}]

3– but not saving Bayesian statistics   [no effective couplings, 300 fb^{-1}]

Higgs to bottoms

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Higgs couplings

One-dimensional distributions to check....

1– noisy environment preferring profile likelihoods [no effective couplings, 30 fb^{-1}]

2– higher luminosity quantitatively different [no effective couplings, 30 vs 300 fb^{-1}]

3– but not saving Bayesian statistics [no effective couplings, 300 fb^{-1}]

4– theory errors not dominant for 30 fb^{-1} [with effective couplings, 30 fb^{-1}]

$\Rightarrow$ profile likelihood promising for 30 fb^{-1}, errors a mess
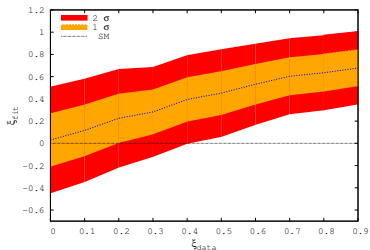
Higgs to bottoms

Tilman Plehn

$VH, H \longrightarrow b\bar{b}$

$t\bar{t}H, H \longrightarrow b\bar{b}$

SUSY $H \longrightarrow b\bar{b}$

Measuring y_b

Side remark

Side remark: scaling Higgs couplings

Strongly interacting Higgs at LHC [Espinosa, Grojean, Mühlleitner]

– looking like fundamental Higgs

– couplings scaled, e.g. $g^2 \rightarrow g^2(1 - \xi)$

– equivalent to Higgs portal scenarios

– technically easy with SFitter [Diploma thesis: SFitter + Bock]

– for 120 GeV Higgs: $\Delta\xi \sim 0.2$ for 30 fb^{-1}

Outlook

Trying to understand Higgs@LHC

– Higgs still an exciting field

– decay to bottoms observable

– parameter analysis the goal

– bottoms in the initial state by Sally...