Higgs pair production in the bbWW channel

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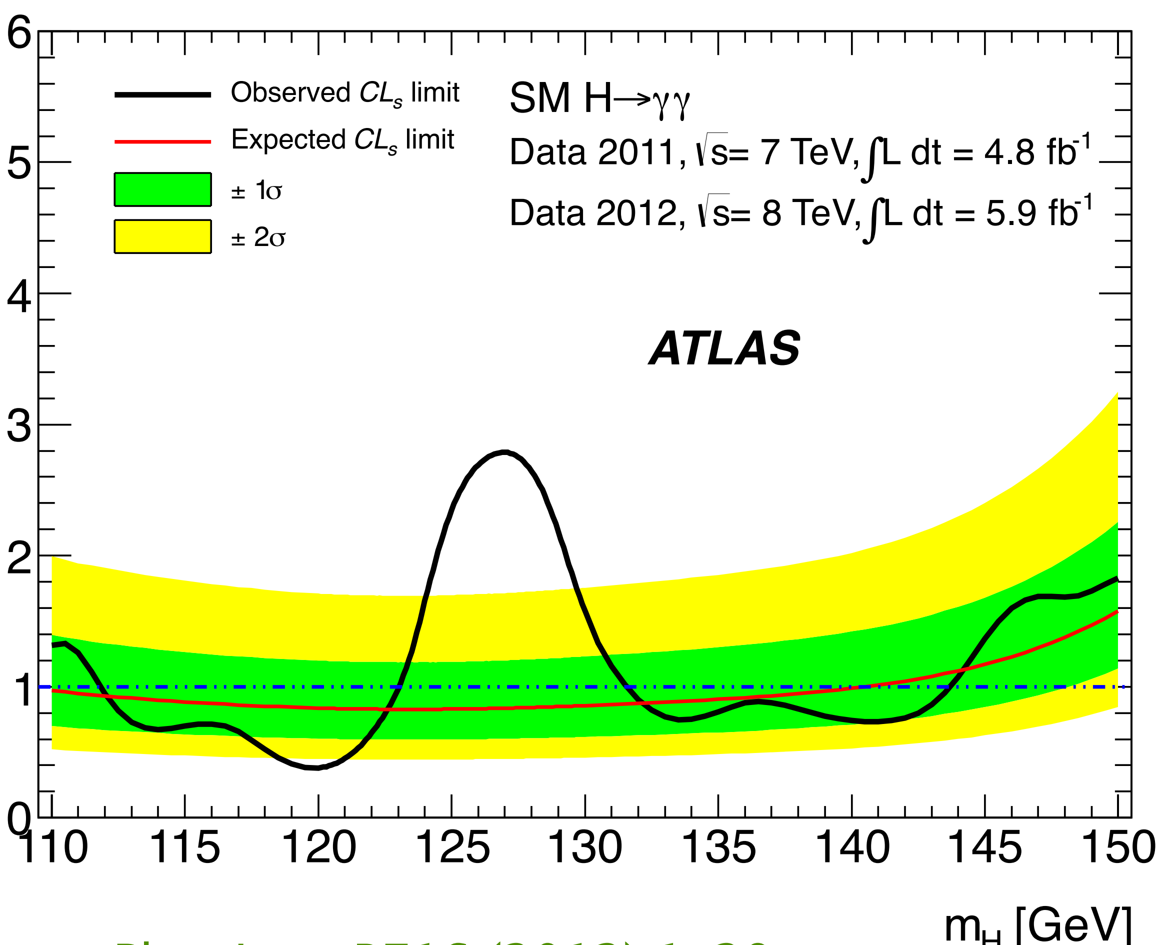
Andreas Papaefstathiou, Li Lin Yang, JZ (arXiv: 1209.1489)

LHC PhenoNet Mid-Term Meeting, 17th Sep 2012.

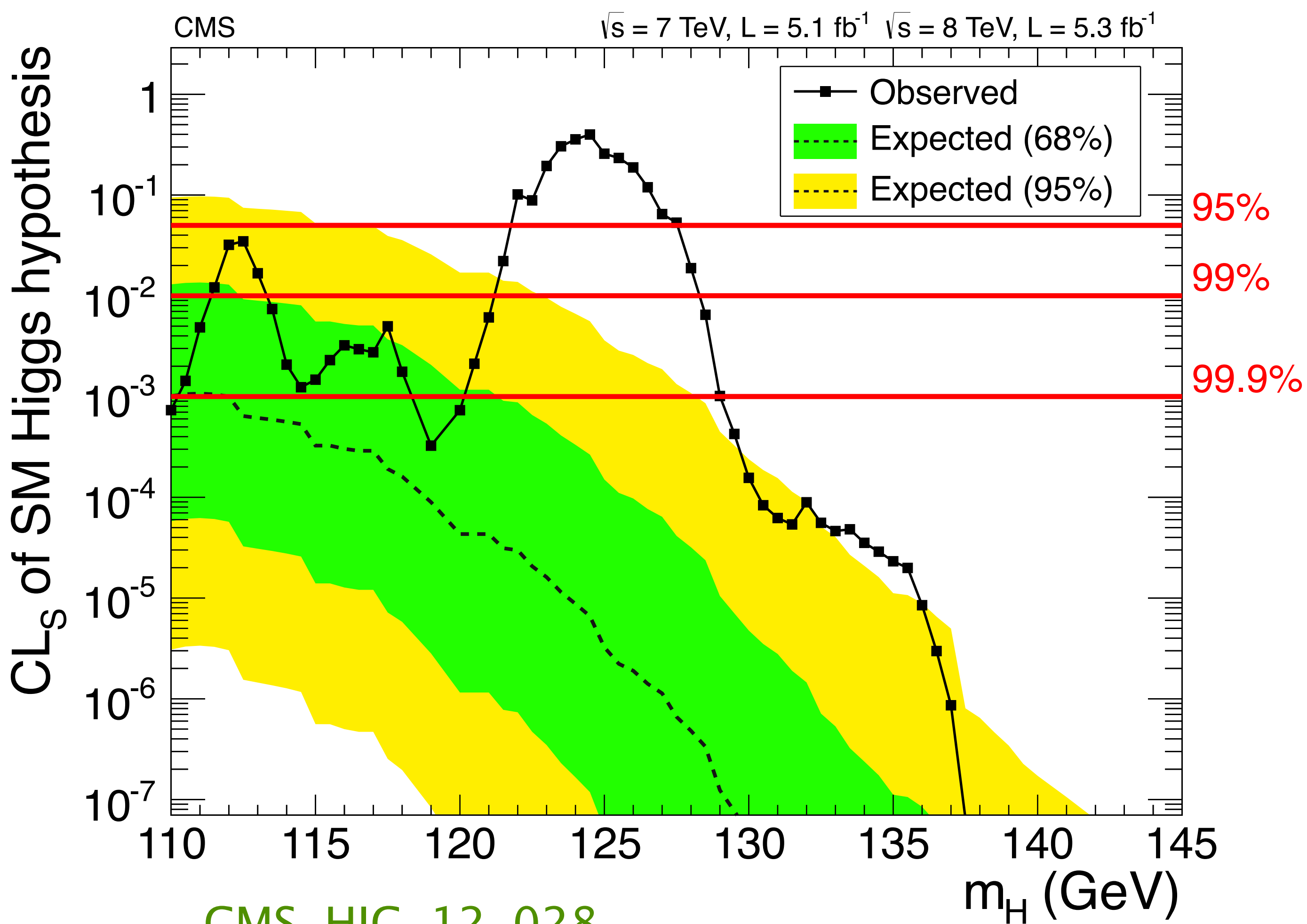
Outline

- Motivation
- Higgs pair production and decays
- Event generation and analysis
- Conclusions

Higgsday



Phys.Lett. B716 (2012) 1–29



CMS–HIG–12–028

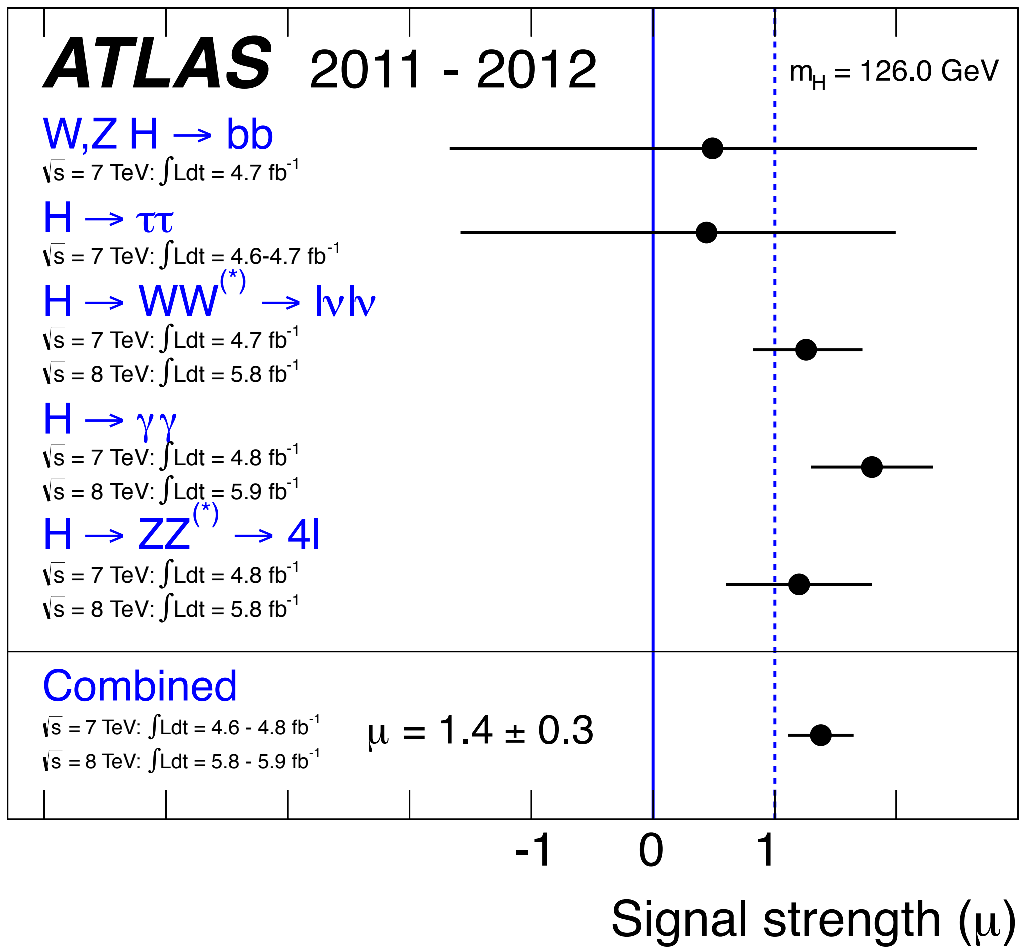
4th July 2012: ATLAS and CMS have observed a new state, with mass ~ 125 GeV.

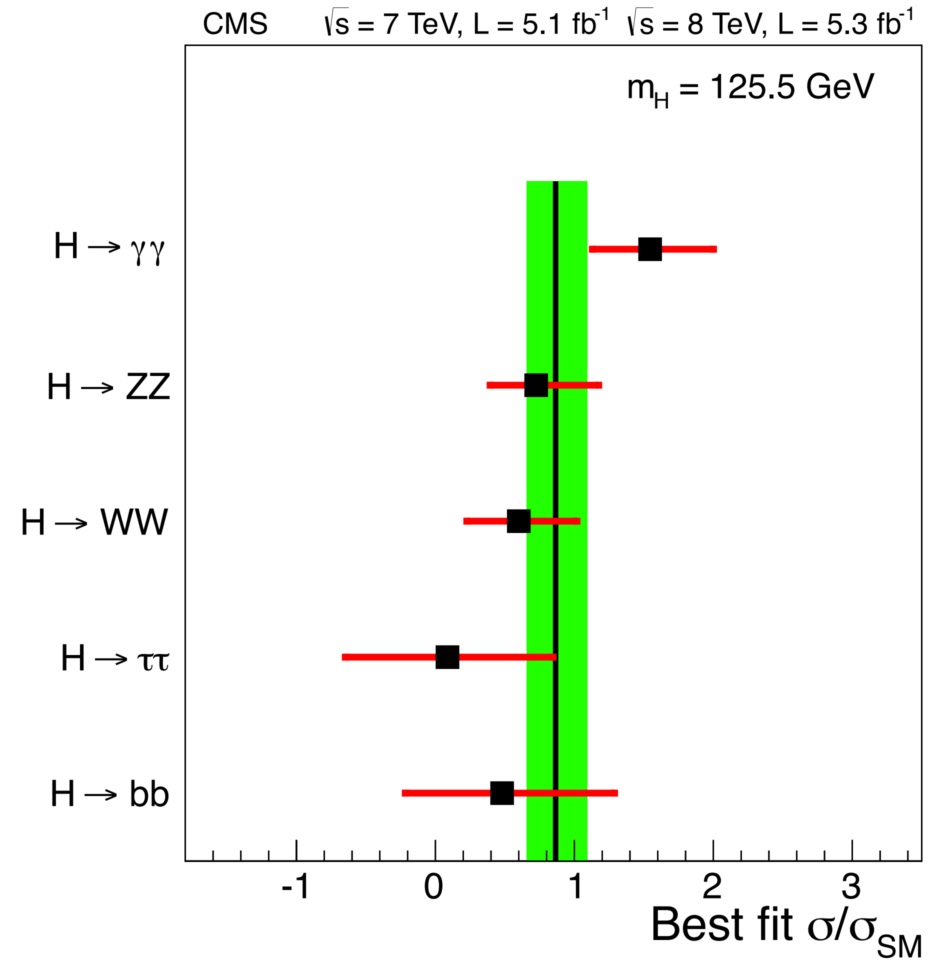
Is it the SM Higgs? ➡ We need to measure its couplings!

Higgs couplings

ATLAS-CONF-2012-127

CMS-HIG-12-020





- Diphoton rate ~ 1.5-2, SM still compatible at 2 sigma.
- Tau, bottoms < SM ?
- Gauge bosons above (below) SM for ATLAS (CMS).

Higgs potential: self couplings

$$V = \frac{1}{2} m_h^2 \ h^2 + \lambda v h^3 + \frac{1}{4} \tilde{\lambda} h^4$$

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7-8 TeV
LHC legacy?

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Maybe being inclusive enough!
(combining several channels)

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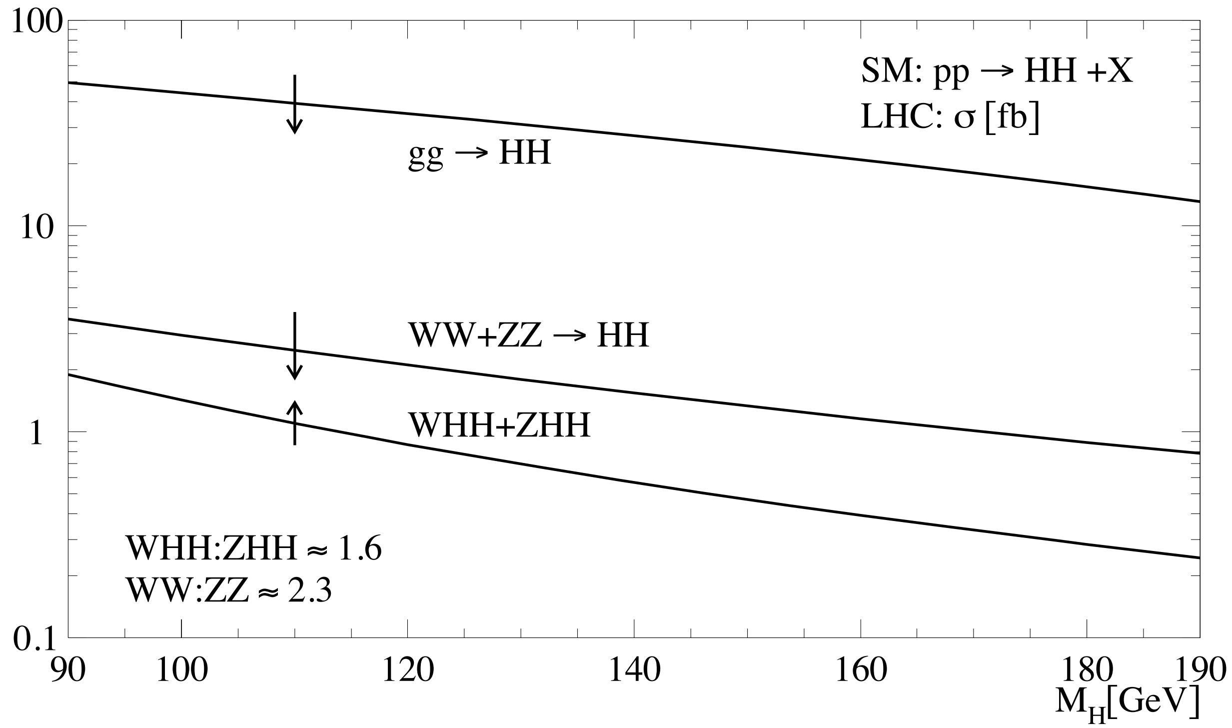
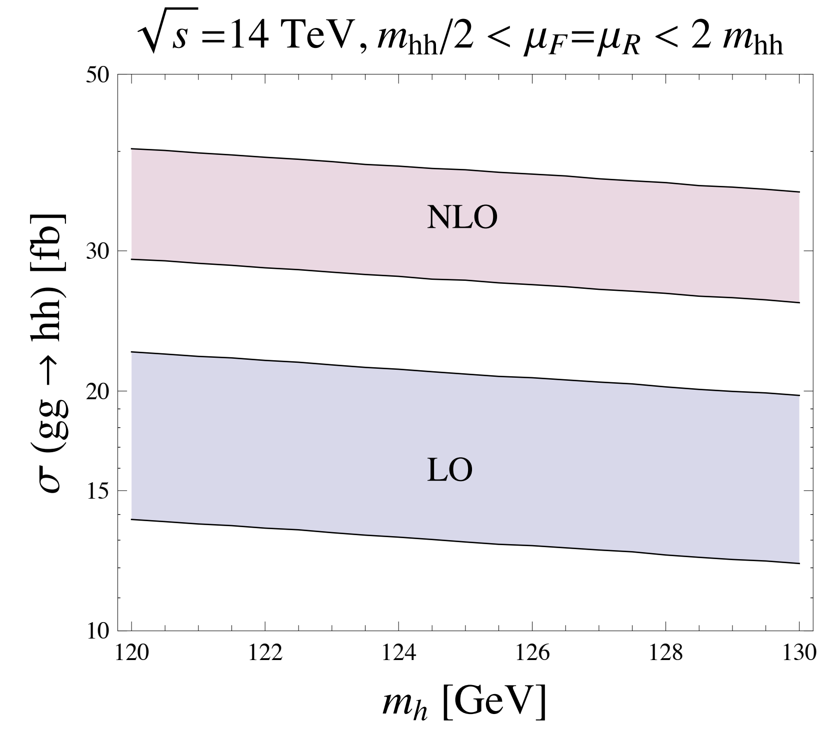
Higgs pairs: production and decay

Cross sections @ LHC 14 TeV



Djouadi, Kilian, Muhlleitner, Zerwas, Eur. Phys. J. C **10** (1999) 45



A. Papaefstathiou, L. L. Yang, JZ, arXiv 1209.1489

Gluon fusion is dominant over the whole mass range.

Glover, van der Bij, Nucl. Phys. B **309**, 282 (1988); Plehn, Spira and Zerwas, Nucl. Phys. B **479**, 46 (1996), [Erratum-ibid. B **531**, 655 (1998)

Focus in 120-130 GeV: other modes are 10% of GGF.

K-factor ~2 ; scale variation @ LO (NLO) 30 (20) %

Dawson, Dittmaier and Spira, Phys. Rev. D**58**, 115012 (1998)

Cross section computed with HPAIR (http://people.web.psi.ch/spira/hpair/)

Anatomy of the cross section

2 topologies, each with 2 Lorentz structures (1 and 2):

$$\sigma_{LO} = |\alpha_1 C^{(1)}_{tri} + \beta_1 C^{(1)}_{box}|^2 + \gamma_1^2 |C^{(2)}_{box}|^2$$

SM: $\alpha_1 = y_t \lambda$, $\beta_1 = \gamma_1 = y_t^2$

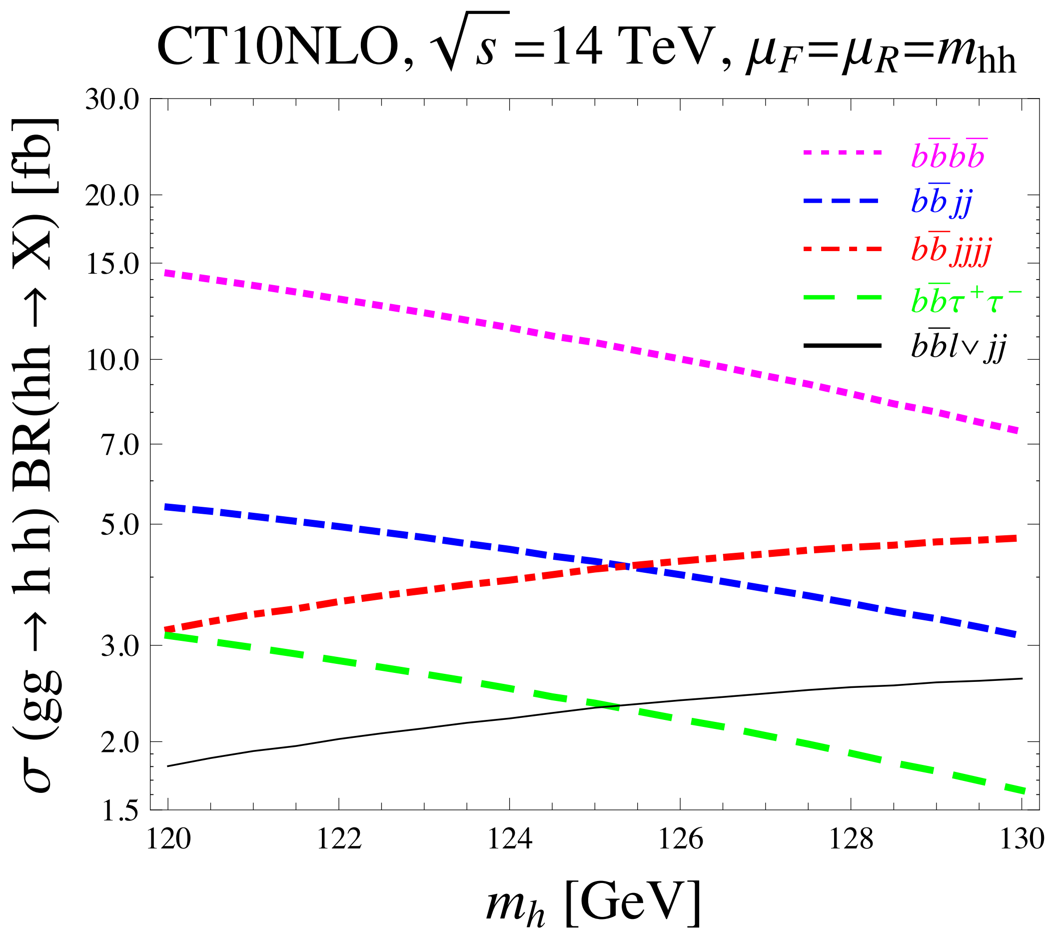
Our fit: $\sigma_{LO}[\text{fb}] = \alpha_1^2 \; 4.73 - \alpha_1\beta_1 \; 22.93 + \beta_1^2 \; 33.89 + \gamma_1^2 \; 0.57.$ $(\text{SM}: \; 16.26)$

$\sigma_{NLO}[\text{fb}] = \alpha_1^2 \; 9.19 - \alpha_1\beta_1 \; 44.30 + \beta_1^2 \; 65.95 + \gamma_1^2 \; 1.17.$ $(\text{SM}: \; 32.01)$

NLO QCD can be reproduced by LO * K-factor (to an accuracy of 1%).

Desirable: BSM models that mitigate the box-triangle interference.

Branching ratios and rates



A. Papaefstathiou, L. L. Yang, JZ (arXiv 1209.1489)

Hadronic decays dominate: semileptonic mode 7.5% @ 125 GeV

Total rate for $gg \to hh \to b\bar{b}W^+W^- \to b\bar{b}l\nu jj$ (before any cuts) 2.34 fb. $(\ell = e, \mu)$

$b\bar{b}\gamma\gamma$ "most promising channel" S=6, B=11 with 600 fb^{-1} Baur, Plehn, Rainwater PRD **69**, 053004

$b\bar{b}\tau^+\tau^-$ best prospects: S=57, B=119 with 600 fb^{-1}. Dolan, Englert, Spannowsky, arXiv: 1206.5001

Event generation and analysis

Event generation

- Signal: MG/ME (private model from R. Frederix)
- PDFs: CTEQ6L1 (LO) and CT10 (NLO)
- Shower and hadronization: HERWIG++
- Jet clustering: FASTJET 3.0.3
- Backgrounds: $t\bar{t}$ (HERWIG++) and W+ jets (ALPGEN) MLM-matched.
- Approx. NNLO rate $t\bar{t}$: 240 pb (uncertainty 10%).

Ahrens, Ferroglia, Neubert, Pecjak, Yang, PLB 703, 135

Process	σ_{initial} (fb)
$hh \to b\bar{b}\ell\nu jj$	2.34
$t\bar{t} \to b\bar{b}\ell\nu jj$	240×10^3
$W(\to \ell\nu)b\bar{b}$+jets	2.17×10^3
$W(\to \ell\nu)$+jets	2.636×10^6
$h(\to \ell\nu jj)$+jets	36.11
$h(\to \ell\nu jj)b\bar{b}$	6.22
$h(\to b\bar{b}) + WW(\to \ell\nu jj)$	0.0252

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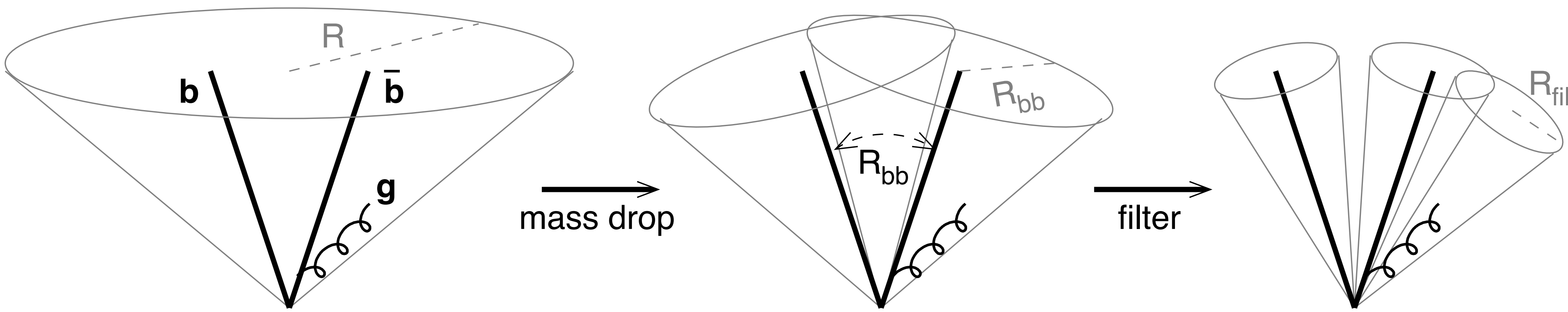
Analysis (I)

BDRS: Butterworth, Davison, Rubin, Salam, **Phys.Rev.Lett. 100 (2008) 242001**



1- Fat jet (FASTJET) : CA with $R = 1.4,\ p_{Tj} > 40\ \mathrm{GeV}$

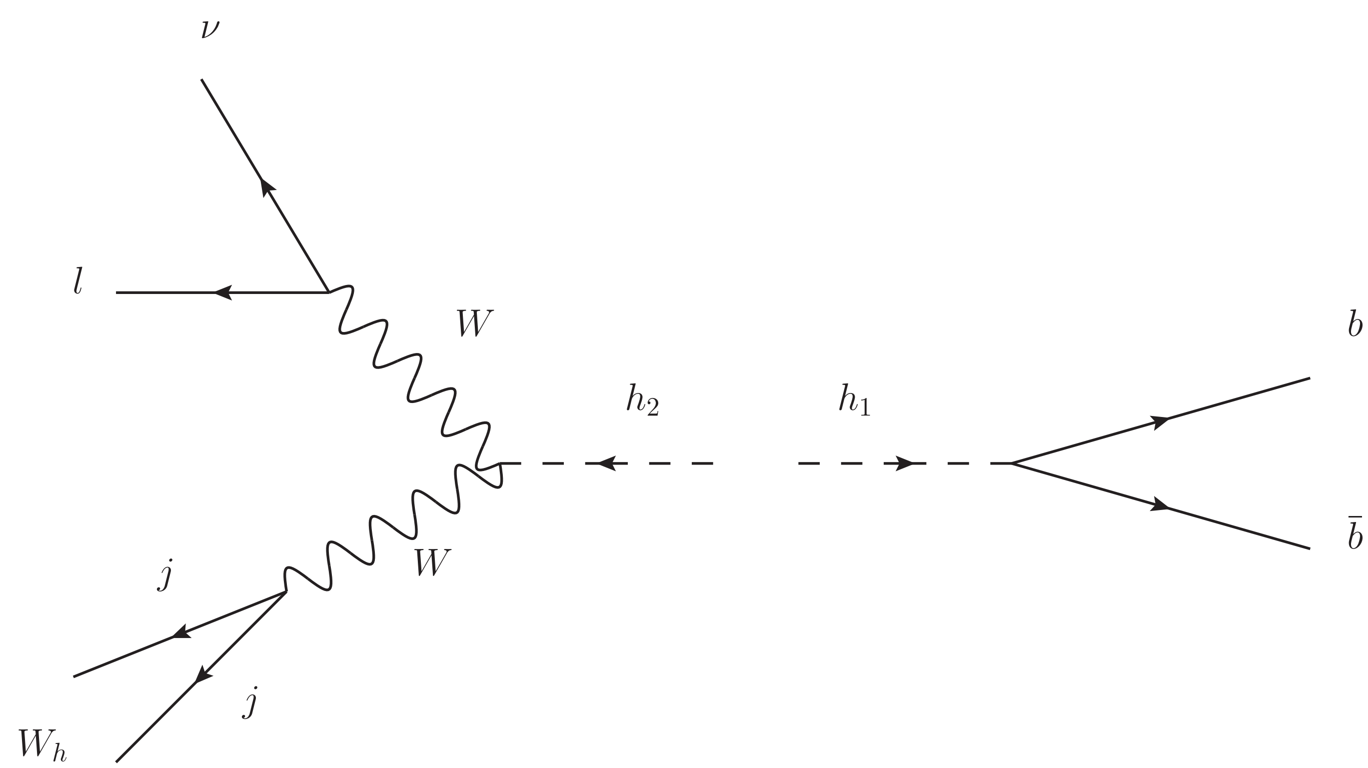
2- Subjets $j_1, j_2\ (m_{j_1} > m_{j_2})$ have to fulfill:

i) $m_{j_i} < \mu m_j$ (mass drop) $(\mu = 0.667)$

ii) $y = \dfrac{\min(p^2_{T,j_1}, p^2_{T,j_2})}{m_j^2} \Delta R^2_{j_1,j_2} > y_{cut}$ $(y_{\mathrm{cut}} > 0.09)$

3- Filtering: recluster with $R_{filt} = \min(0.35, R_{b\bar{b}})$.

Analysis (II)



Basic cuts

Isolated lepton: $p_T^l > 10$ GeV, $|\eta| < 2.5$, $\sum_{R=0.15} p_T^{vis} < 0.1\ p_T^l$

$\not{E}_T > 10$ GeV in $|\eta| < 5.0$

Fat jet with j_1, j_2 b-tagged, $p_T > 180$ GeV: h_1 ($h \to b\bar{b}$)

Fat jet: $p_T > 40$ GeV, $m > 5$ GeV (W_h candidate)

Higgs reconstruction: $(p_l + p_\nu + p_{W_h})^2 = m_h^2$ and $p_\nu^2 = 0$

After the basic cuts

arXiv:0901.0512

Process	σ_{initial} (fb)	$\sigma_{\textbf{basic}}$ (fb)
$hh \to b\bar{b}\ell\nu jj$	2.34	0.134
$t\bar{t} \to b\bar{b}\ell\nu jj$	240×10^3	15.5
$W(\to \ell\nu)b\bar{b}$+jets	2.17×10^3	0.97
$W(\to \ell\nu)$+jets	2.636×10^6	$\mathcal{O}(0.01)$
$h(\to \ell\nu jj)$+jets	36.11	$\mathcal{O}(0.0001)$
$h(\to \ell\nu jj)b\bar{b}$	6.22	$\mathcal{O}(0.001)$
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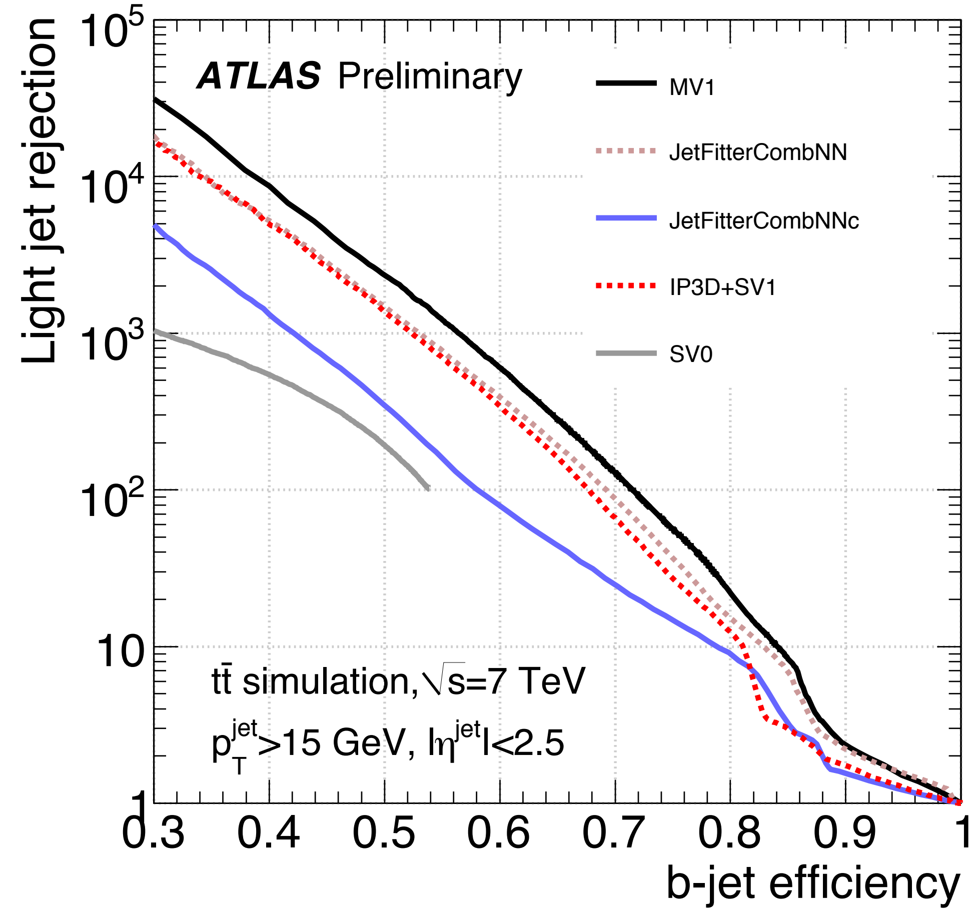
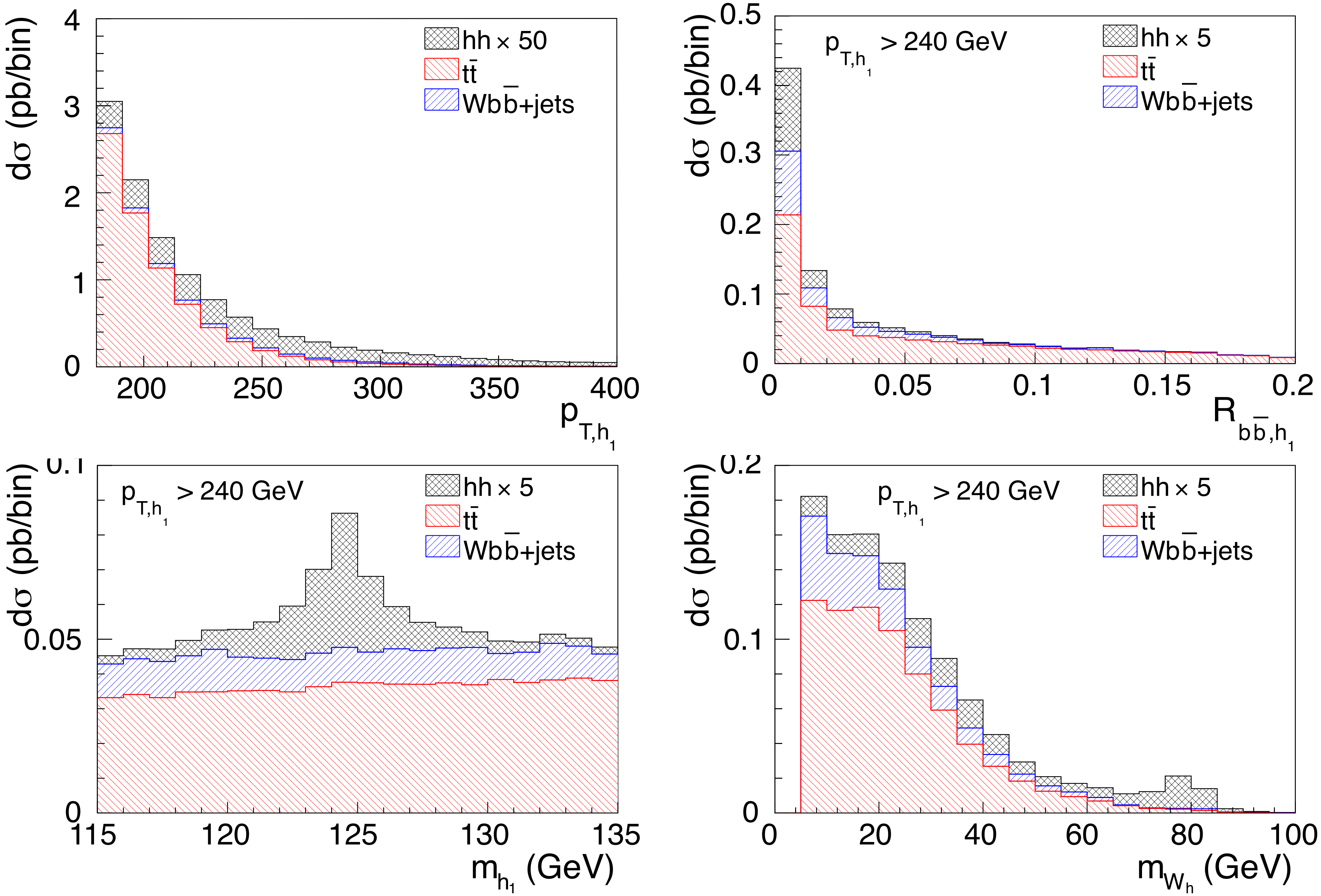


- B-tagging efficiency 70%, light jet rejection 100 (1% $j \to b$).
- Single Higgs and W+light jets backgrounds can be safely neglected.
- Basic cuts keep 5% (signal), 0.05% (wbbj), 0.005% (tt).

Taming the background



Our cuts

$p_{T,h_1} > 240$ GeV

$R_{b\bar{b}h_1} < 0.06$

$m_{h_1} \in [120 - 130]$ GeV

$m_{W_h} > 65$ GeV

S=4.5, B=2.4

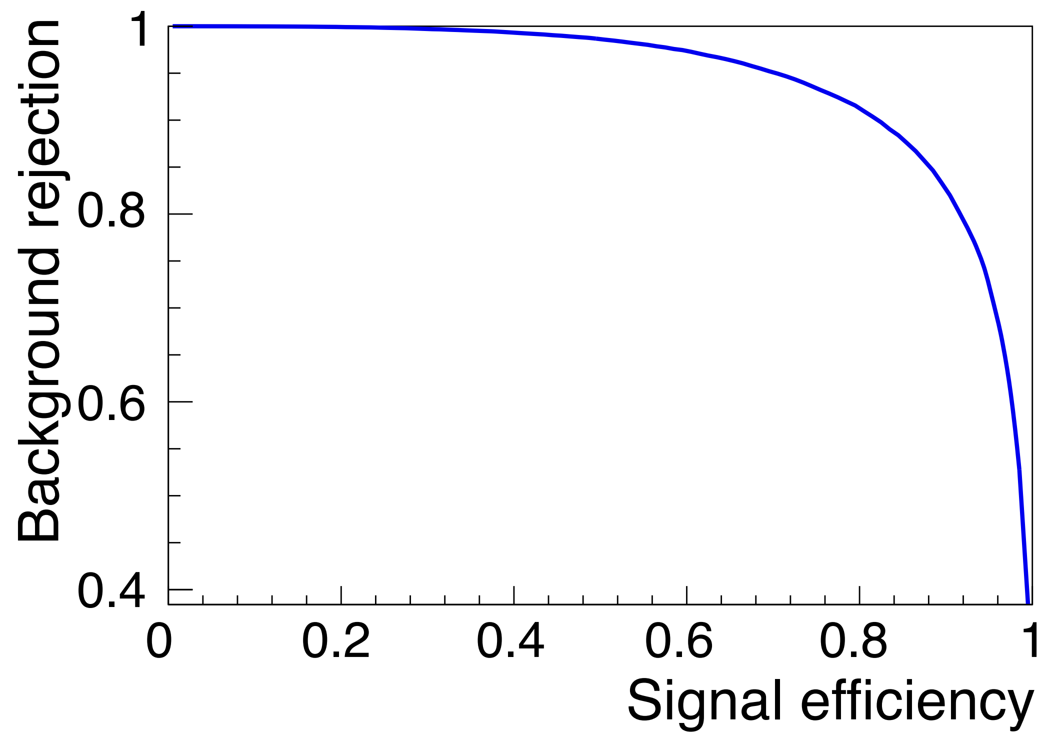
$\sigma = 2.2$

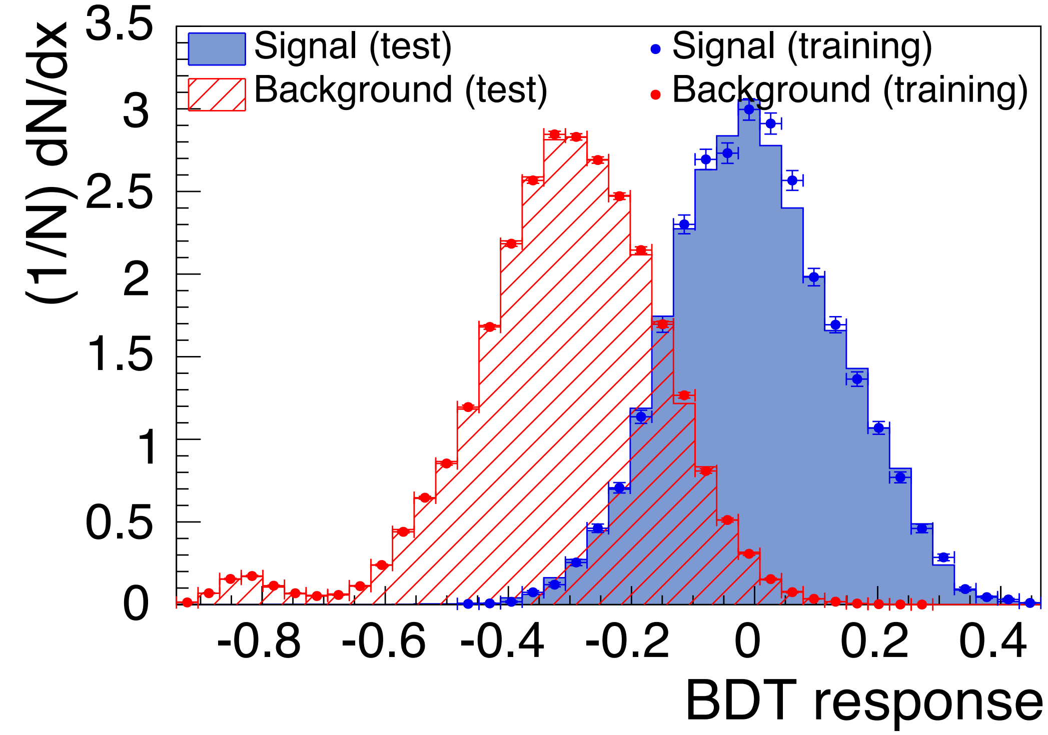
Further improvement ($S \approx 4,\ B \approx 1,\ \sigma = 2.5$) requires cutting on several more variables.

This calls for a multivariate analysis: BDT (Boosted Decision Tree).

↘ TMVA ROOT package

BDT output





- Input variables: from last slide we have $p_{T,h_1},\ R_{b\bar{b}h_1},\ m_{h_1},\ m_{W_h}.$

  we add a few more: $p_{T,h_2},\ p_{T,W_h},\ p_{T,h_1h_2},\ R_{h_1,W_h},\ M_{T,\ell\nu},\ \Delta\phi_{\ell,\nu},\ \Delta\phi_{W_l,W_h}.$

- BDT output: $\mathrm{S} \approx 9,\ \mathrm{B} \approx 5,\ \sigma = 3.1$

- Underlying event on signal does not affect the result.

- Including $W \to \tau\nu_\tau\ (\epsilon_\tau = 0.7)$, we obtain $\sigma =$ 3.6 (3.0) using BDT (cut-based).

Conclusions

- We have studied the 14 TeV LHC reach of $gg \to hh \to b\bar{b}W^+W^- \to b\bar{b}l\nu jj$.
- This channel was discarded in previous studies due to large $t\bar{t}$ background.
- We exploit jet substructure techniques (BDRS) to enhance the sensitivity.
- Initial S/B ~ 10^{-5}, 'basic cuts' bring down to 10^{-2}.
- After 'basic cuts' no single "background killer": multivariate analysis.
- Significance of 3.6 (3.0) with 600 fb^{-1} using a BDT (cut-based) analysis.

  (compare to 1.6 in $b\bar{b}\gamma\gamma$ and 4.85 in $b\bar{b}\tau^+\tau^-$.)
- Further improvements might be obtained combining channels (future work).