

MadMax

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ZPW 2014

tracking regions of significance
-an automated approach-

with Tilman Plehn and Daniel Wiegand
arXiv: 1311.2591 [hep-ph]
Plehn, Cranmer: Eur. Phys. J. C 51, 415 (2007)

outline

regions of significance

hypothesis testing
optimality

getting our hands dirty

boosted Higgs
theoretical uncertainties
corrections (NLO, jets, ...)

further developments

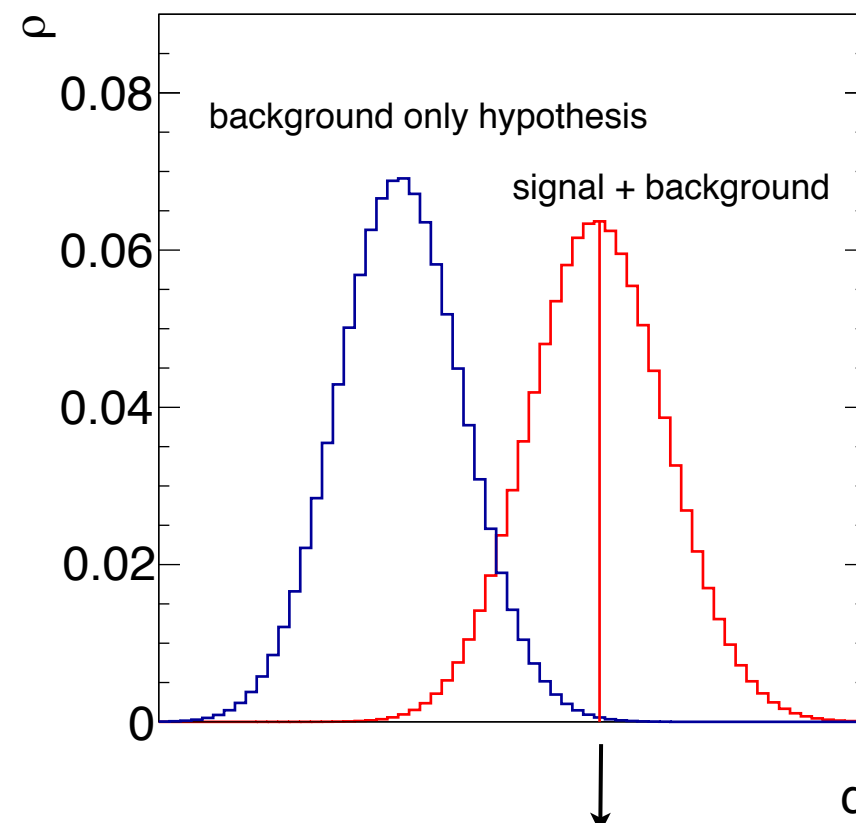
detector effects
processes

hypothesis testing

Neyman-Pearson:

„The log-likelihood ratio q is the most powerful hypothesis test“

$$q(x) = \log \frac{L(x|H_s)}{L(x|H_b)}$$



$$CL_b(q) = \int_q^{\infty} dq' \rho_b(q')$$

gaussian significance Z

$$CL_b(q_{s+b}^*) = \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{Z}{\sqrt{2}} \right) \right)$$

regions of significance

phase space parametrization

no interference/factorize

$$q(x) = -s + \sum_{j=1}^n \log \left(1 + \frac{s f_s(x_j)}{b f_b(x_j)} \right)$$

event likelihood

MadEvent

\xrightarrow{MC}

$$q(\vec{r}) = -\sigma_{\text{tot},s} \mathcal{L} + \log \left(1 + \frac{d\sigma_s(\vec{r})}{d\sigma_b(\vec{r})} \right)$$

MadGraph

$$\left(1 + \frac{d\sigma_s(\vec{r})}{d\sigma_b(\vec{r})} \right)$$

single-event probability

$$\frac{d\sigma_s}{dq} \quad \& \quad \frac{d\sigma_b}{dq}$$

LEPStat4LHC
[Kyle Cranmer]

$$\rho_b(q) \quad \& \quad \rho_{s+b}(q)$$

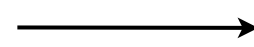
Monte Carlo events:

kinematic cuts

binned plots for any LO observable

include point-wise corrections

full probability distribution



maximum significance

efficient integration

single diagram enhanced method

Maltoni, Stelzer: JHEP **0302**, 027 (2003)

$$\sigma_{\text{tot}} = \sum_n \Delta x_n \left| \sum_d \mathcal{M}_d(x_n) \right|^2 = \sum_d \sum_{n_d} \Delta x_{n_d} \frac{|\mathcal{M}_d(x_{n_d})|^2}{\sum_{d'} |\mathcal{M}_{d'}(x_{n_d})|^2} \left| \sum_{d'} \mathcal{M}_{d'}(x_{n_d}) \right|^2$$

weight of phase space cell ↓ ↓ ↓
chose from propagator structure pdf implicit in ME

hadron collider

same ME

add initial states

event generation

chose due to pdf weight

reweigh phase space point

$$\Delta x_{n_d} \rightarrow \frac{\Delta x_{n_d}}{f_{i_1/p} \times f_{i_2/p}(x_{n_d}, \mu_f^2)}$$

efficient integration

modified single diagram enhanced method

parallel integration of $\begin{pmatrix} q \\ \sigma_s \\ \sigma_b \end{pmatrix}$

n_s signal processes

n_b background processes

$$\sum_{d \in \{n_s, n_b\}} \sum_{n_d} \Delta x_{n_d} \frac{|\mathcal{M}_d(x_{n_d})|^2}{\sum_{d' \in \{n_s, n_b\}} |\mathcal{M}_{d'}(x_{n_d})|^2}$$

$$\begin{pmatrix} \left| \sum_{d'' \in n_{s1}} \mathcal{M}_{d''}(x_{n_d}) \right|^2 \\ \vdots \\ \left| \sum_{d'' \in n_{b1}} \mathcal{M}_{d''}(x_{n_d}) \right|^2 \\ \vdots \end{pmatrix}$$

ensure $\sigma_{n_s/b} = \sum_n d\sigma_{n_s/b}$

ZH production

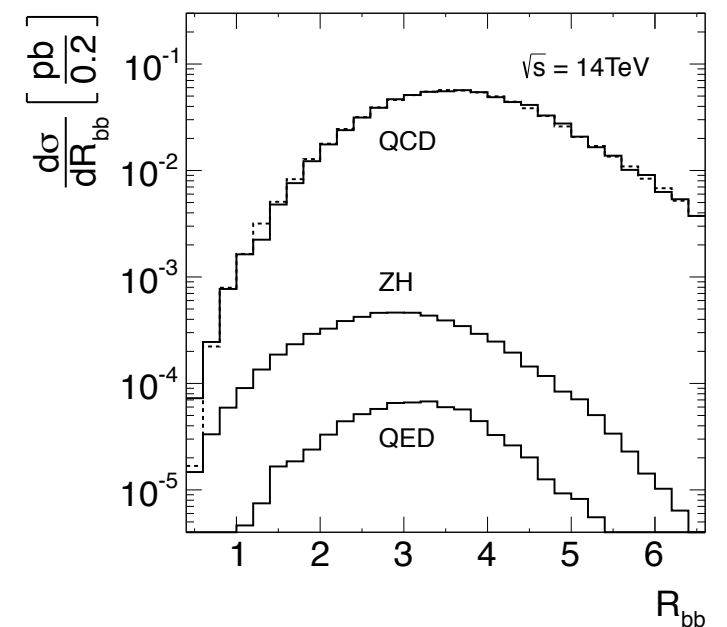
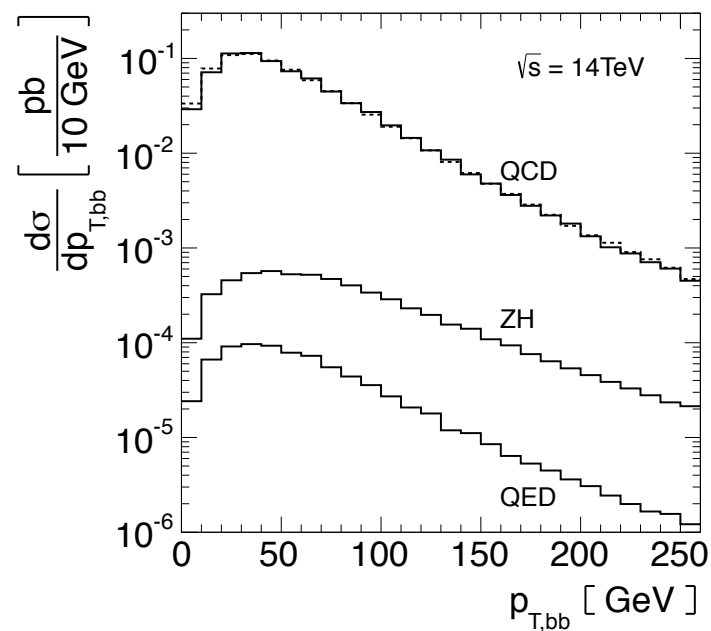
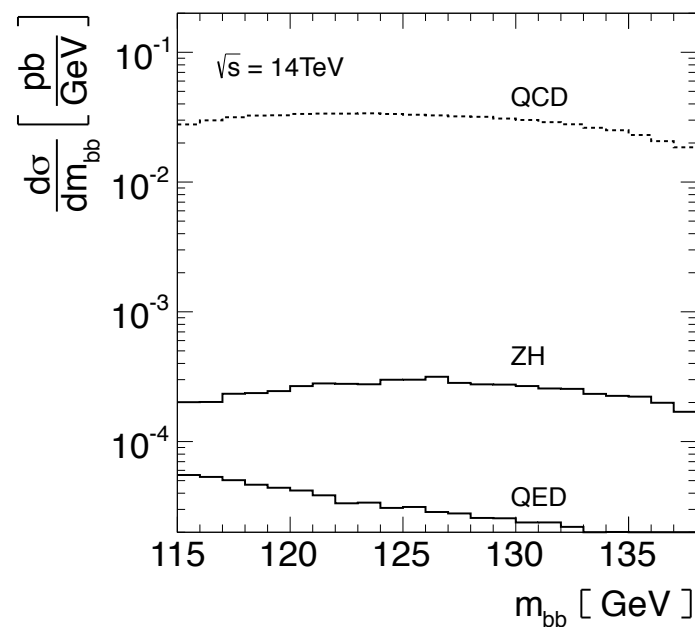
assumptions

full Z reconstruction (e, μ)
H decay to b-quarks
gaussian smearing in $m_{b\bar{b}}$
only irreducible backgrounds

acceptance cuts

$$p_{T,l} > 10 \text{ GeV} \quad |\eta_l| < 2.5$$

$$|m_{b\bar{b}} - m_H| < 12 \text{ GeV}$$



ZH production

efficiencies:

$$\text{BR}(H \rightarrow b\bar{b}) = 56\%$$

$$\epsilon_{\text{signal}}^{\text{gauss}} = 68\%$$

two: $\epsilon_b^{\text{tag}} = 60\%$

$$\epsilon_{ll} = 60\%$$

correction factors

$$\log \frac{d\sigma_{\text{ME+PS}}}{d\sigma_{\text{LO}}} = 0.65 + 1.1 \times 10^{-3} p_{T,b\bar{b}} + 4.0 \times 10^{-6} p_{t,b\bar{b}}^2$$

$Zb\bar{b}_{\text{QCD}}$

$$k_{\text{signal}} = 1.3$$

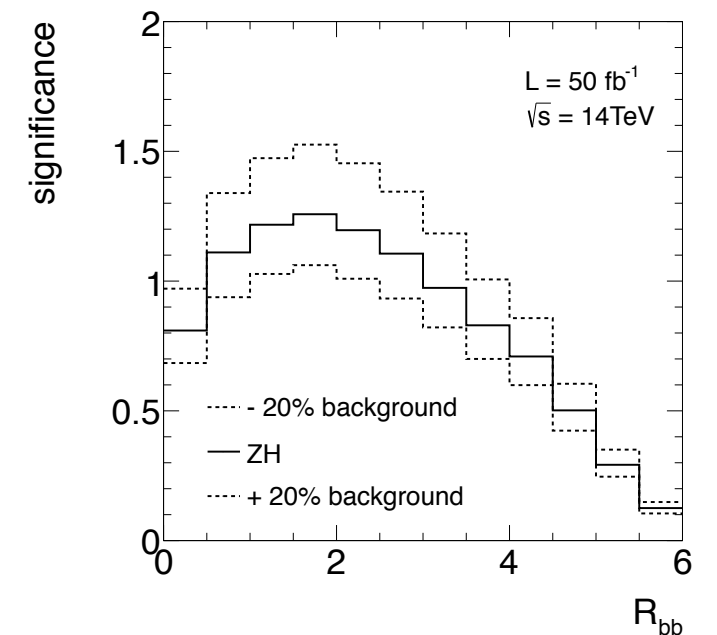
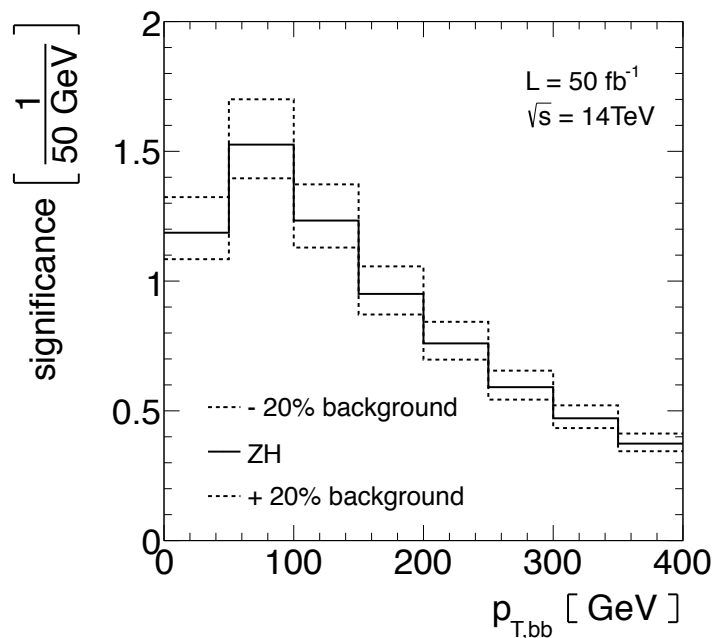
significance

$$2.7 \pm 0.3 \sigma$$

Higgs tagger

$$p_T \approx 50 - 150 \text{ GeV}$$

$$R_{bb} \approx 2.0$$



ttH production

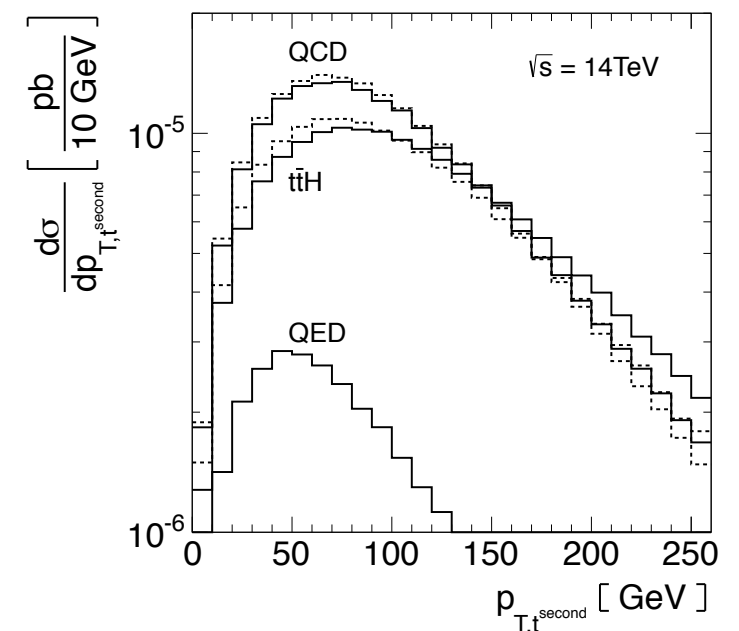
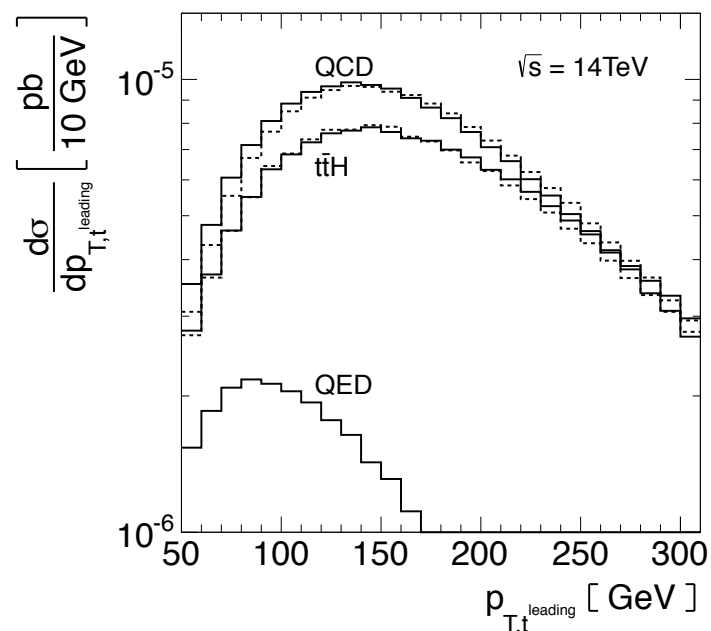
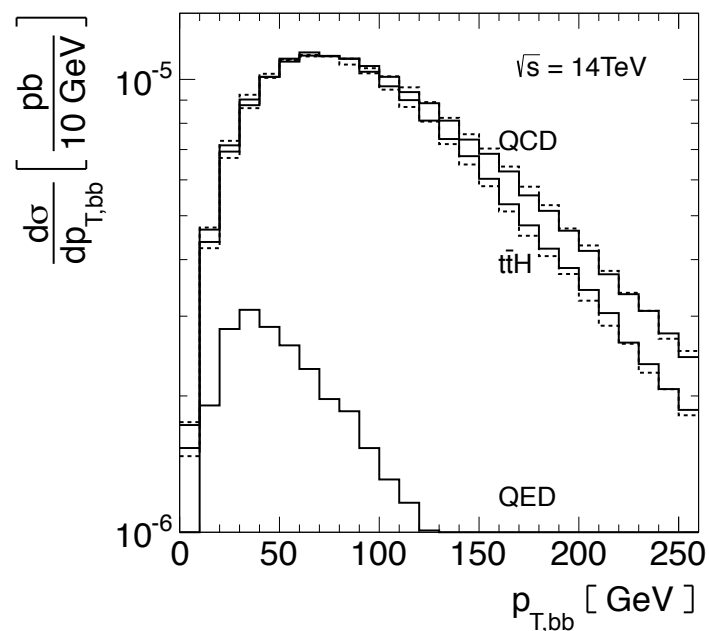
assumptions

top full reconstructed
H decay to *b*-quarks
gaussian smearing in $m_{b\bar{b}}$
only irreducible backgrounds

→ top tagger studies
(no combinatorics)

acceptance cuts

$$|m_{b\bar{b}} - m_H| < 12 \text{ GeV}$$



ttH production

efficiencies:

$$\epsilon_{\text{irr.}}^{\text{survive}} = 10\%$$

$$\text{BR}(t \rightarrow \text{had.}) = 68\%$$

$$\text{BR}(H \rightarrow b\bar{b}) = 56\%$$

$$\epsilon_{\text{signal}}^{\text{gauss}} = 68\%$$

$$\text{four: } \epsilon_b^{\text{tag}} = 60\%$$

$$\text{two: } \epsilon_t^{\text{tag}} = 33\%$$

correction factors

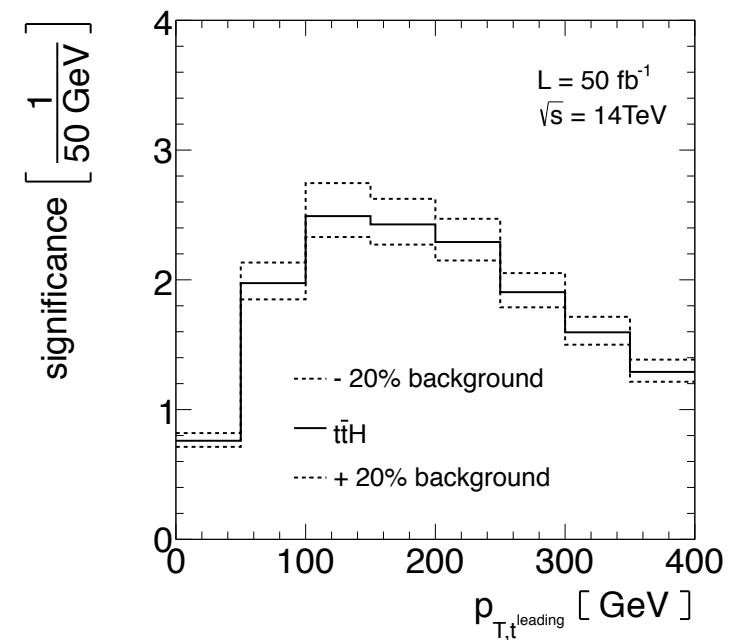
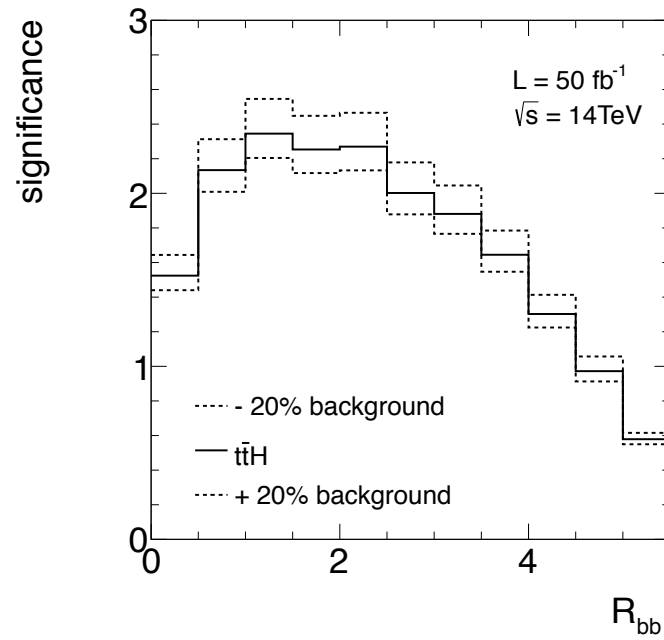
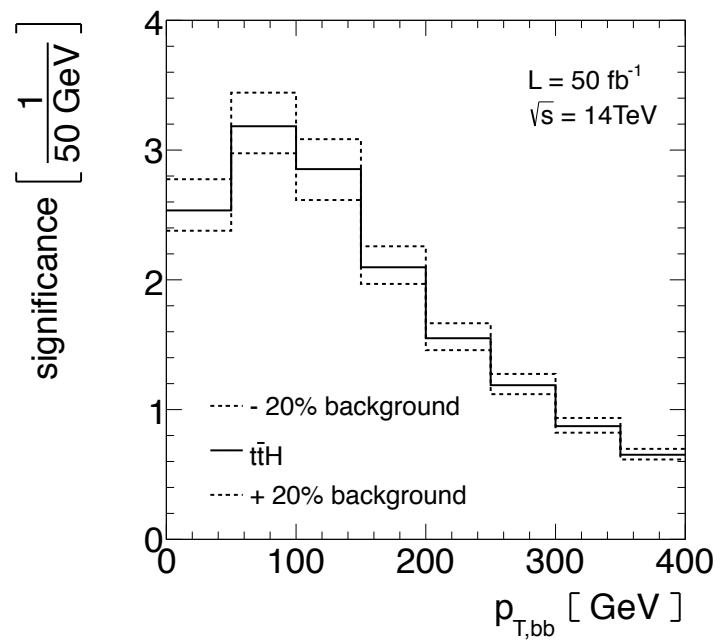
t \bar{t} H

$$\log \frac{d\sigma_{\text{ME+PS}}}{d\sigma_{\text{LO}}} = 0.53 - 2.5 \times 10^{-3} p_{T,b\bar{b}} + 2.0 \times 10^{-5} p_{t,b\bar{b}}^2 - 3.9 \times 10^{-8} p_{t,b\bar{b}}^3$$

$$\log \frac{d\sigma_{\text{ME+PS}}}{d\sigma_{\text{LO}}} = 0.98 - 6.7 \times 10^{-3} p_{T,b\bar{b}} + 3.8 \times 10^{-5} p_{t,b\bar{b}}^2 - 7.6 \times 10^{-8} p_{t,b\bar{b}}^3$$

t \bar{t} b \bar{b} _{QCD}

$t\bar{t}H$ production



significance
 $5.3 \pm 0.5 \sigma$

similar Higgs properties as ZH
low momentum tops \rightarrow challenging

conclusions

automated tool
fully differential
all kinds of models (MG5)
→ highly flexible & fast

maximum significance
(detectability)
→ guide Higgs taggers
→ confront top tagging

efficiencies
correction factors
play around with shapes

transfer functions
fixed coupling
reducible backgrounds

extra radiation

