# MadMax

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## tracking regions of significance
-an automated approach-

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

# motivation

given a signal model:

- observable ?
- at which level of significance?
- where? (complex final state)

MadMax gets them

from blogspot.com

# outline

regions of significance

hypothesis testing
optimality

getting our hands dirty

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

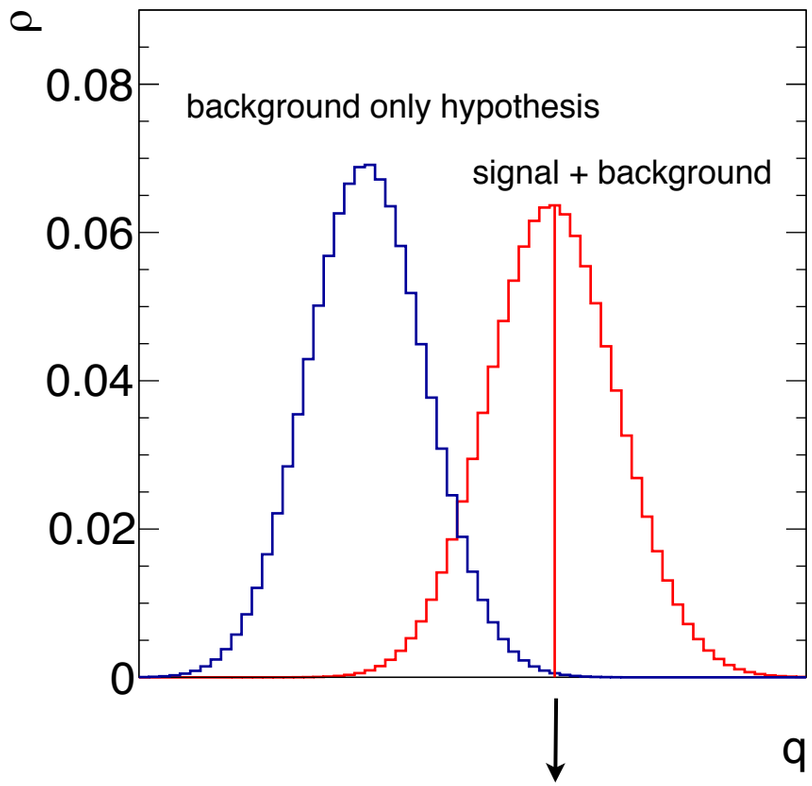
further developments

detector effects
processes

# hypothesis testing

**Neyman-Pearson:** „The log-likelihood ratio q is the most powerful hypothesis test“

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




$$\mathrm{CL}_b(q) = \int_q^\infty dq' \rho_b(q')$$

**gaussian significance *Z***

$$\mathrm{CL}_b\left(q^*_{s+b}\right) = \frac{1}{2}\left(1 - \mathrm{erf}\left(\frac{Z}{\sqrt{2}}\right)\right)$$

# regions of significance

## phase space parametrization

no interference/factorize

MadEvent

MadGraph

$$q(x) = -s + \sum_{j=1}^{n} \log\left(1 + \frac{s f_s(x_j)}{b f_b(x_j)}\right) \xrightarrow{MC} q(\vec{r}) = -\sigma_{\mathrm{tot},s}\mathcal{L} + \log\left(1 + \frac{d\sigma_s(\vec{r})}{d\sigma_b(\vec{r})}\right)$$

event likelihood

single-event probability

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

LEPStat4LHC
[Kyle Cranmer]

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

**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)

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

weight of phase space cell

chose from propagator structure

drops out

pdf implicit in ME

hadron collider  same ME  add initial states

# 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

$$\sum_{d\in\{n_s,n_b\}} \sum_{n_d} \Delta x_{n_d} \frac{|\mathcal{M}_d(x_{n_d})|^2}{\sum_{d'\in\{n_s,n_b\}} |\mathcal{M}_{d'}(x_{n_d})|^2} \begin{pmatrix} \left|\sum_{d''\in n_{s_1}} \mathcal{M}_{d''}(x_{n_d})\right|^2 \\ \vdots \\ \left|\sum_{d''\in n_{b_1}} \mathcal{M}_{d''}(x_{n_d})\right|^2 \\ \vdots \end{pmatrix}$$

ensure $\sigma_{n_{s/b}} = \sum_n d\sigma_{n_{s/b}}$

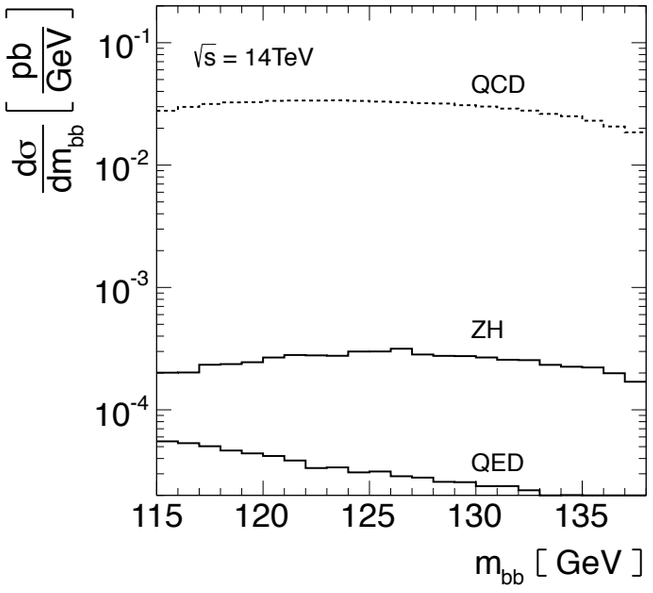
# *ZH* production

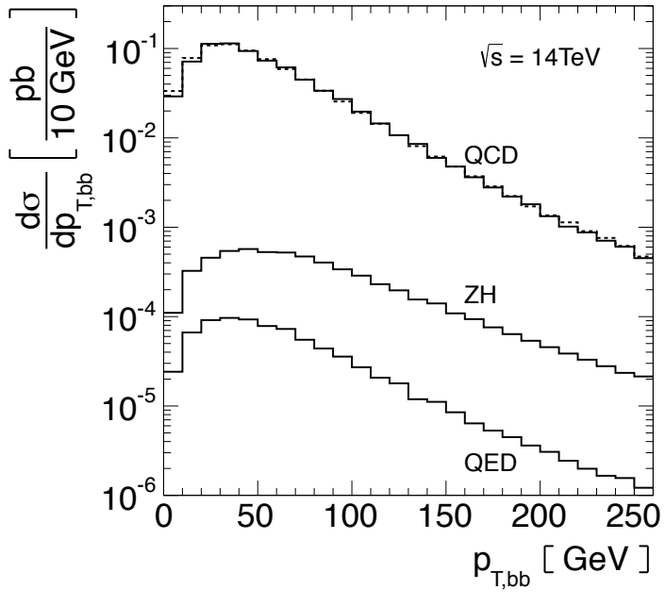
assumptions

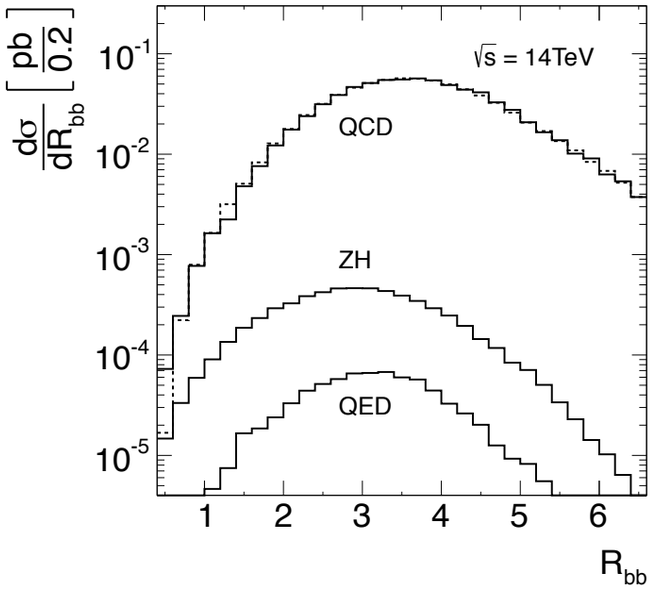
full *Z* reconstruction ($e$, $\mu$)
*H* decay to b-quarks
gaussian smearing in $m_{b\bar{b}}$
only irreducible backgrounds

## acceptance cuts

$p_{T,l} > 10$ GeV $\quad |\eta_l| < 2.5$ $\quad |m_{b\bar{b}} - m_H| < 12$ GeV



# *ZH* production

efficiencies:

$$\mathrm{BR}(H \to b\bar{b}) = 56\%$$

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

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

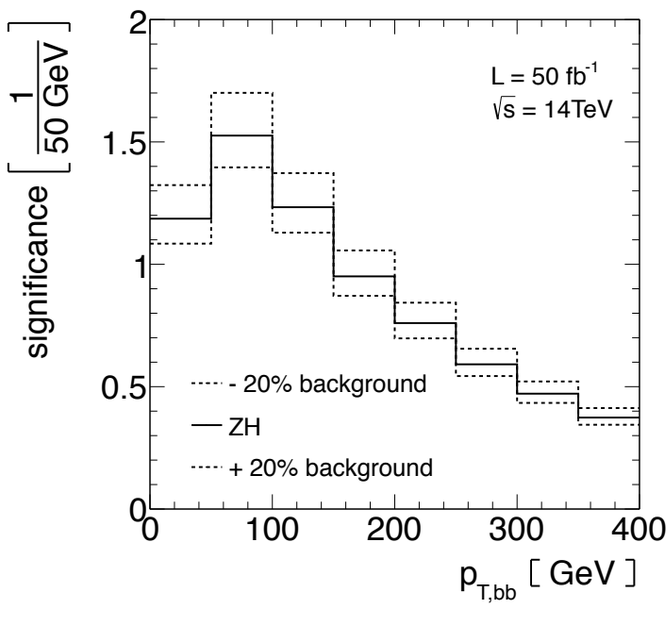
$$\epsilon_{ll} = 60\%$$

correction factors

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

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

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

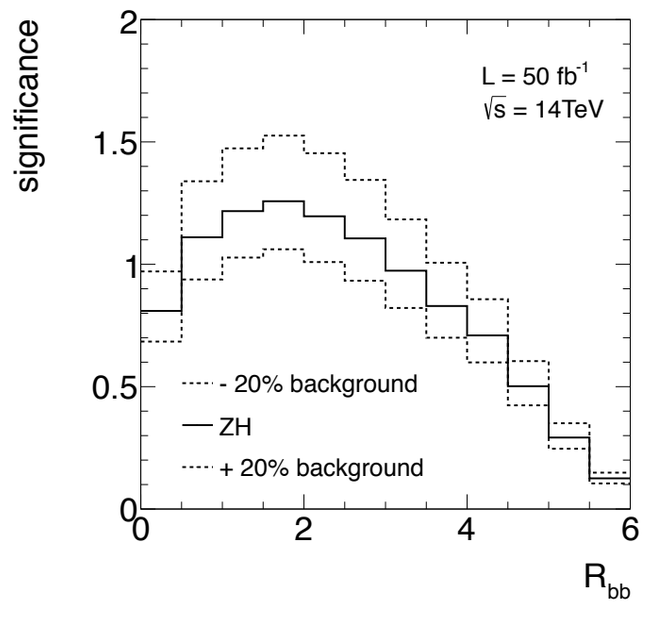



**significance**

$2.7 \pm 0.3\ \sigma$

Higgs tagger

$$p_T \approx 50 - 150\ \mathrm{GeV}$$
$$R_{bb} \approx 2.0$$



# *ttH* production

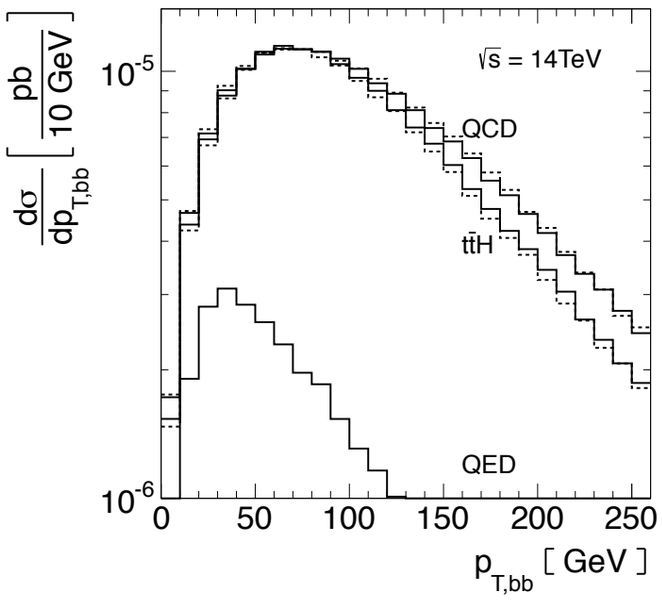
assumptions

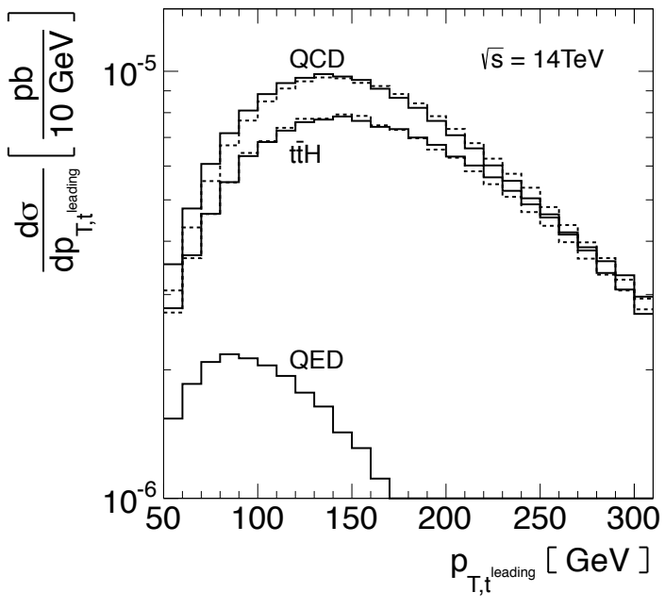
top full reconstructed
*H* decay to b-quarks
gaussian smearing in $m_{b\bar{b}}$
only irreducible backgrounds

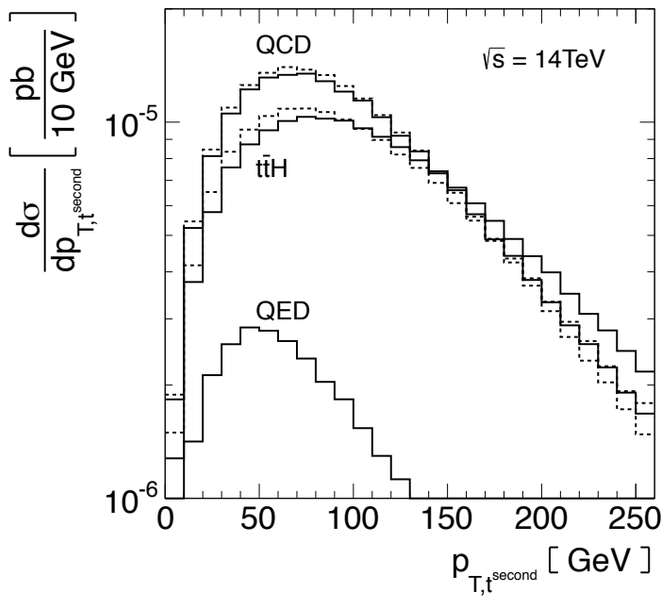
→ top tagger studies (no combinatorics)

## acceptance cuts

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



# *ttH* production

efficiencies:

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

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

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

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

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

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

## correction factors

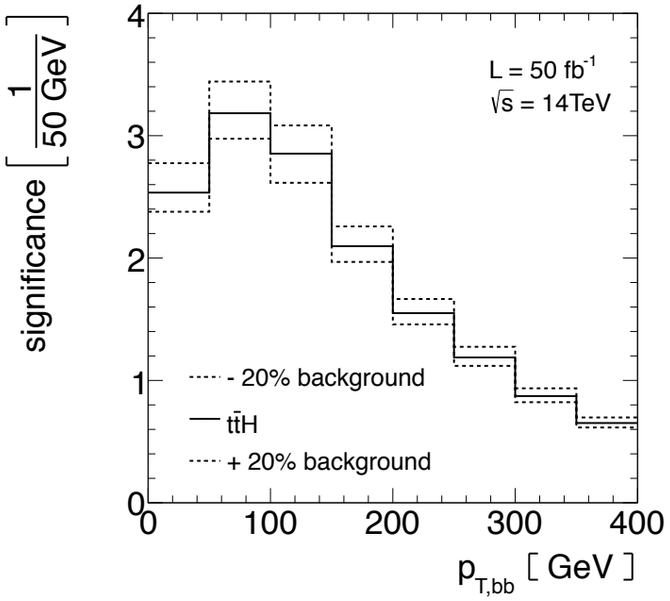
$t\bar{t}H$

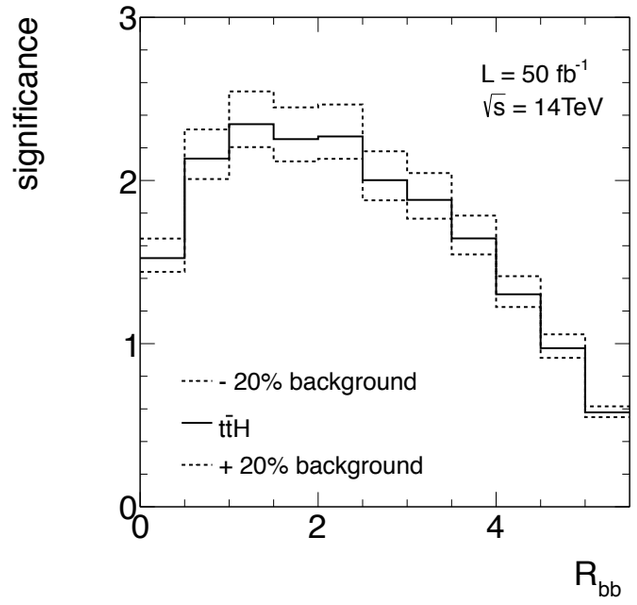
$$\log \frac{d\sigma_{\text{ME+PS}}}{d\sigma_{\text{LO}}} = 0.53 - 2.5 \times 10^{-3} p_{T,b\bar{b}} + 2.0 \times 10^{-5} p_{t,b\bar{b}}^2 - 3.9 \times 10^{-8} p_{t,b\bar{b}}^3$$

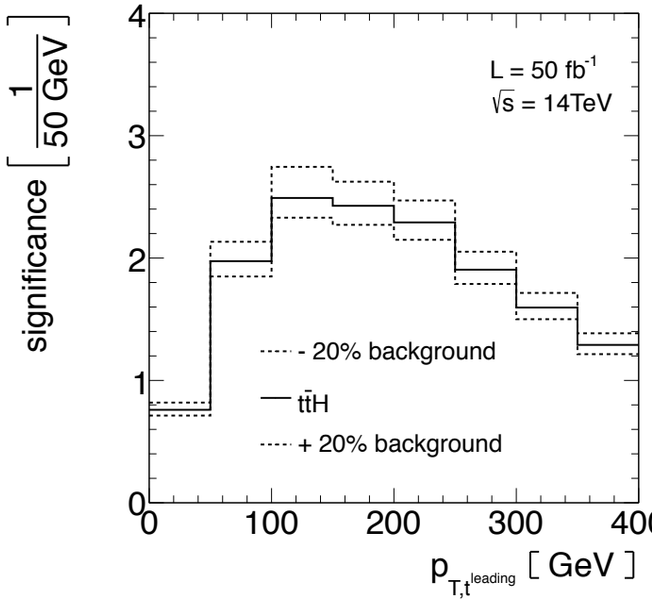
$$\log \frac{d\sigma_{\text{ME+PS}}}{d\sigma_{\text{LO}}} = 0.98 - 6.7 \times 10^{-3} p_{T,b\bar{b}} + 3.8 \times 10^{-5} p_{t,b\bar{b}}^2 - 7.6 \times 10^{-8} p_{t,b\bar{b}}^3$$

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

# *ttH* production




similar Higgs properties as *ZH*
low momentum tops → challenging

**significance**

$5.3 \pm 0.5\ \sigma$

# 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
reducible backgrounds

extra radiation