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Theoretical Aspects of Higgs Physics at the LHC

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1. SM Higgs Production at the LHC
2. Yukawa couplings
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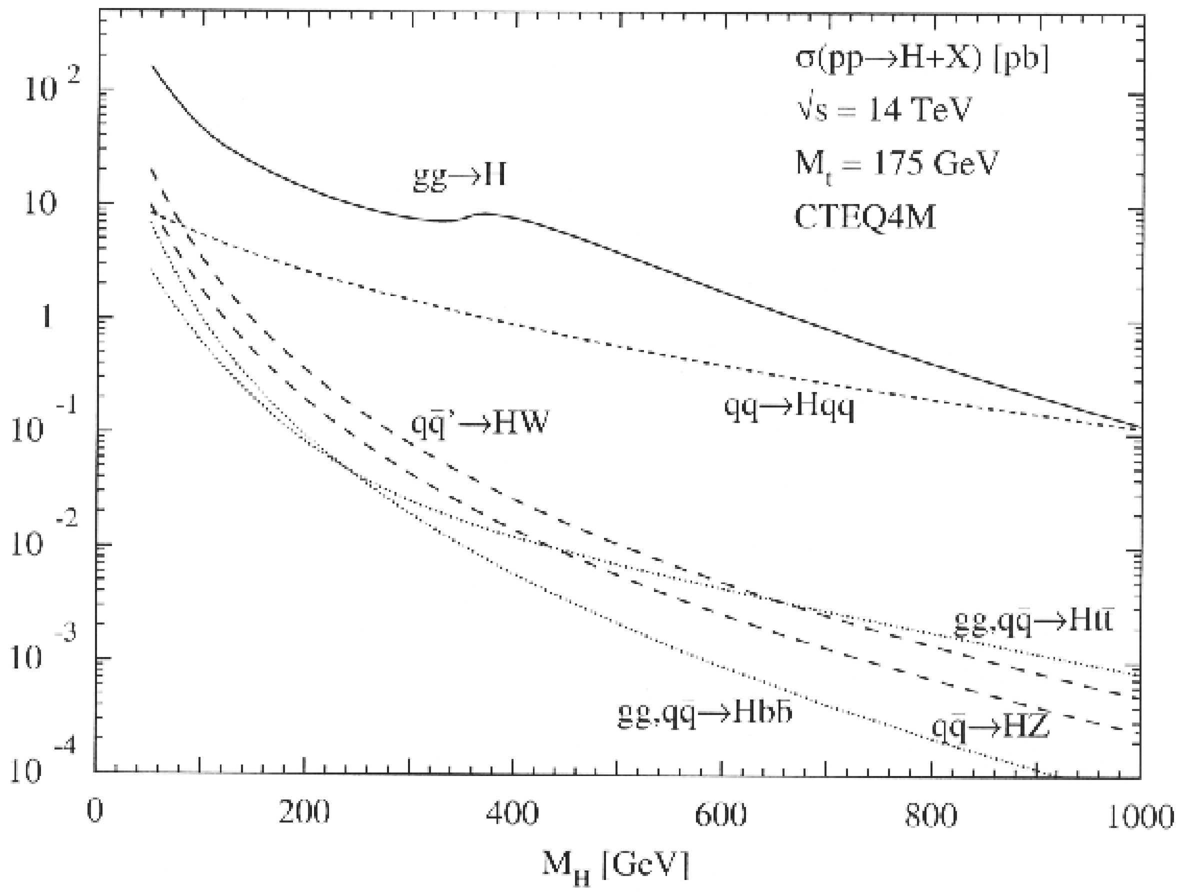
EPSHEP 2003, Aachen, 17-23 July, 2003

Signal cross sections at LHC ($\sqrt{s} = 14$ TeV)



M. Spira, Fortschr. Phys. 46 (1998) 203

- $pp \to H$

  1. NNLO results now avaliable (total cross section in the $m_t \to \infty$ limit)

R.V. Harlander, W.B. Kilgore, *Phys. Rev. Lett.* 88(2002)201801; JHEP 0210 (2002) 017

C. Anastasiou, K. Melnikov, Nucl. Phys. B 646 (2002) 220; hep-ph 0208096

V. Ravindran, J. Smith, W.L. Van Neerven, hep-ph 0302135

leading to an estimate for the error on σ of about 20% mainly due to PDF uncertainties (small x)

2. NNLL resummation matched with fixed order NLO and NNLO

G. Bozzi, S. Catani, D. de Florain, M. Grazzini, hep-ph 0302104

S. Catani, D. de Florain, M. Grazzini, P.Nason, hep-ph 0306211

with comparisono of fixed order results and estimate of the residual QCD uncertainties on differential (Higgs q_t) quantities

- $pp \to ttH$

NLO results now avaliable

W. Beenakker et al., *Phys. Rev. Lett.* 87 (2001) 201805

and independently with good agreement

S. Dawson, C. Jackson, L.H. Orr, L. Reina and D. Wackeroth, hep-ph 0305087

K-factor 0.8 at Tevatron and 1.2 at LHC, with fairly small dependence from μ_F (everything at the parton level)

- VBF (Vector Boson Fusion)

NLO MC (parton level)

T. Figy, C. Oleari, and D. Zeppenfield, hep-ph 0306109

Background

- known at LO + MC showering (ongoing activity to improve the accuracy of the matching) including large jet multiplicities
- a few known at NLO ($\gamma\gamma$, Vjj, Vbb, VV, $gg \to Hjj$)

1. all at partonic level, but VV matched with MC shower (Frixione, Webber)
2. $\gamma\gamma$ partially know also at NNLO (Bern, Dixon and Schmidt)

Higgs couplings

With the assumption that $\Gamma_z/\Gamma_w = z_{SM}$, each channel provides a measurement of the ratio $Z_j^{(i)}$ defined as

$$Z_j^{(i)} = \frac{\Gamma_i \Gamma_j}{\Gamma}$$

$$X_\gamma = \frac{\Gamma_W \Gamma_\gamma}{\Gamma} \qquad \text{from} \qquad qq \to qqH,\ H \to \gamma\gamma$$

$$X_\tau = \frac{\Gamma_W \Gamma_\tau}{\Gamma} \qquad \text{from} \qquad qq \to qqH,\ H \to \tau\tau$$

$$X_W = \frac{\Gamma_W^2}{\Gamma} \qquad \text{from} \qquad qq \to qqH,\ H \to WW^*$$

$$Y_\gamma = \frac{\Gamma_g \Gamma_\gamma}{\Gamma} \qquad \text{from} \qquad gg \to H \to \gamma\gamma$$

$$Y_Z = \frac{\Gamma_g \Gamma_Z}{\Gamma} \qquad \text{from} \qquad gg \to H \to ZZ^*$$

$$Y_W = \frac{\Gamma_g \Gamma_W}{\Gamma} \qquad \text{from} \qquad gg \to H \to WW^*$$

$$T_b = \frac{\Gamma_t \Gamma_b}{\Gamma} \qquad \text{from} \qquad gg \to t\bar{t}H,\ H \to b\bar{b}$$

$$T_W = \frac{\Gamma_t \Gamma_W}{\Gamma} \qquad \text{from} \qquad gg \to t\bar{t}H,\ H \to WW^*$$

$$U_b = \frac{\Gamma_W \Gamma_b}{\Gamma} \qquad \text{from} \qquad q\bar{q} \to WH,\ H \to b\bar{b}$$

D. Zeppenfeld hep-ph/0203123

D. Zeppenfeld et al., Phys. Rev. D62, hep-ph/0002036

$$T_b = \frac{\Gamma_t \Gamma_\tau}{\Gamma} \qquad \text{from} \quad gg \to t\bar{t}H,\ H \to \tau\bar{\tau}$$

A. Belyaev and L. Reina, hep-ph/0205270

$H \to b\bar{b}$ in Weak Boson Fusion

in collaboration with

M.L. Mangano, F. Piccinini, R. Pittau and A.D. Polosa

Up to now the $H \to b\bar{b}$ coupling has been studied in the channels of associate production $Ht\bar{t}$ and HW

Can we add information by exploiting the WBF production mechanism?

Signal rate proportional to $y_{Hbb} \cdot y_{HVV}$

Typical signature: central $b\bar{b}$ pair + pair of jets in the fwd and backward rapidity region

Main backgrounds:

- QCD $bbjj$ production
- QCD four jets production (with two light jets mistagged as b jets)
- QCD $Z(\to b\bar{b})jj$
- QCD $W/Z(\to jj)b\bar{b}$
- QCD $t\bar{t} \to b\bar{b}+$ jets
- QCD multiple overlapping events (especially at high luminosity)

Parton level study performed by means of the event generator ALPGEN

M.L. Mangano, M. Moretti, F. P., R. Pittau and A.D. Polosa, hep-ph/0206293

Event selection

$$
\begin{aligned}
p_T^b &> 30 \text{ GeV} \\
|\eta_b| &< 2.5 \\
\Delta R_{bb} &> 0.7 \\
|m_{bb} - m_H| &< \delta_m \cdot m_H \\
\epsilon_b &= 0.5
\end{aligned}
$$

$$
\begin{aligned}
p_T^j &> 60 \text{ GeV} \\
|\eta_{j_1} - \eta_{j_2}| &> 4.2 \\
\Delta R_{jj}, \Delta R_{jb} &> 0.7 \\
m_{jj} &> 1000 \text{ GeV} \\
0.01 < \epsilon_{\rm mis} &< 0.05
\end{aligned}
$$

- selection a)

$$2.5 < |\eta_j| < 5, \quad \eta_{j_1}\eta_{j_2} < 0, \quad \Delta R_{bb} < 2$$

- selection b)

$$|\eta_j| < 5$$

The cut $|\eta_{j_1} - \eta_{j_2}| > 4.2$ allows to suppress the "background" due to H + 2 jets QCD production

V. Del Duca et al., Phys. Rev. Lett. 87, 122001 (2001)

Table 1: The sensitivity, for two different values of the factorization/renormalization scale Q^2. The mistagging efficiency of light jets, ϵ_{mis}, is $\epsilon_{mis} = 0.01$. The integrated luminosity is 600 fb^{-1}.

m_H	115 GeV	120 GeV	140 GeV
$(a)\ S/\sqrt{B}$	4.8	4.7	2.2
	4.4	4.3	2.0
$(b)\ S/\sqrt{B}$	8.3	8.0	4.5
	7.5	7.7	4.0

Table 2: The same as Table 3 but with a mistagging efficiency of $\epsilon_{mis} = 0.05$.

m_H	115 GeV	120 GeV	140 GeV
$(a)\ S/\sqrt{B}$	3.9	3.9	1.7
	3.7	3.6	1.6
$(b)\ S/\sqrt{B}$	6.6	6.4	3.5
	6.5	6.2	3.1

Even if $S/\sqrt{B}$ at the level of 5σ, the ratio S/B is only of the order of 0.5%[a]

$\rightarrow$ the background need to be known with accuracy at the 0.1% level. Therefore it should be determined entirely from the data

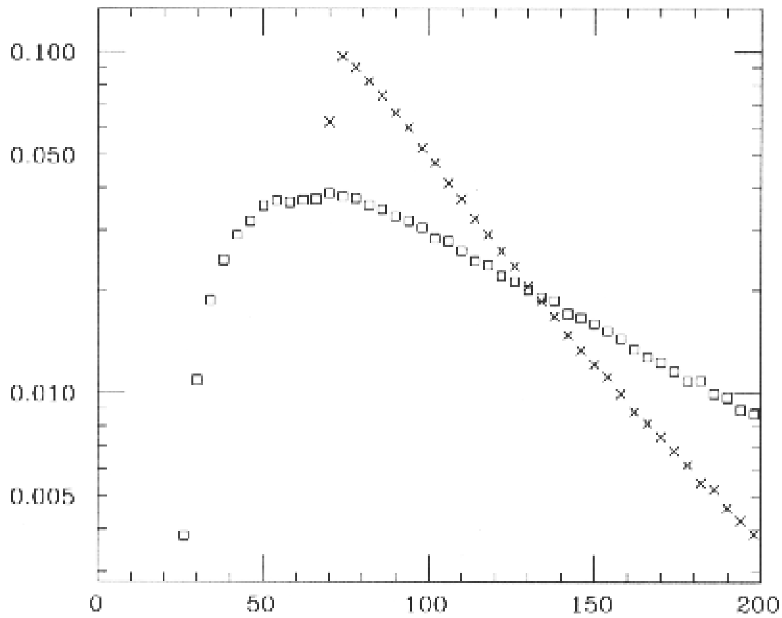
It is important to see the $b\bar{b}$ invariant mass distributions

[a] A increase in S/B can be obtained by exploting rapidity gaps, as suggested in V.A. Khoze et al., hep-ph/0207365. But this would require a full detector simulation.

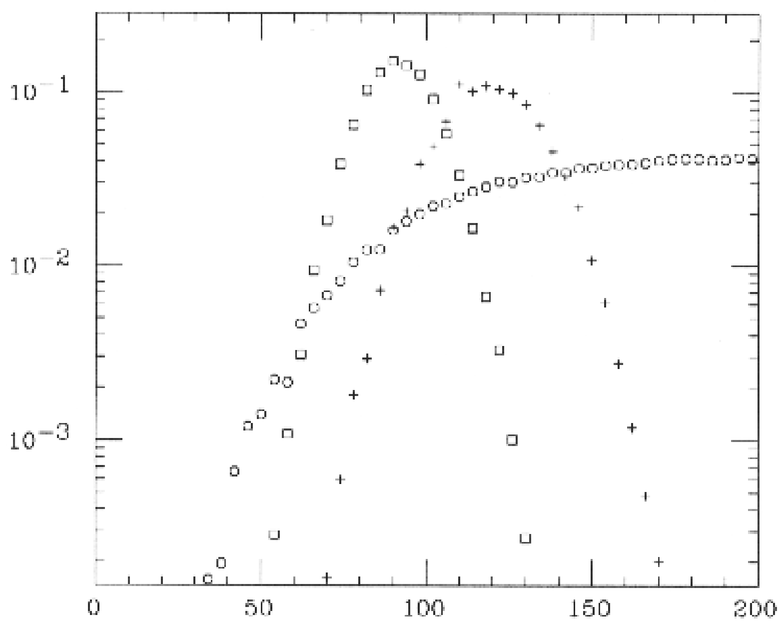
Table 3: The statistical significance in b-quark Yukawa coupling in the configurations (a) and (b), $\delta y/y = \sqrt{B}/2S$, assuming the knowledge of the HWW coupling. High luminosity case 60 fb^{-1}. Here $\epsilon_{\rm mis} = 0.01$.

m_H	115 GeV	120 GeV	140 GeV
$(a)\ \delta\Gamma_{bb}/\Gamma_{bb}$	0.33	0.35	0.71
$(a)\ \delta y_{Hbb}/y_{Hbb}$	0.58	0.51	0.56
$(b)\ \delta\Gamma_{bb}/\Gamma_{bb}$	0.2	0.19	0.37
$(b)\ \delta y_{Hbb}/y_{Hbb}$	0.36	0.30	0.29

The results rely also on the assumption of $SU(2)$ invariance to relate the contributions from the HWW and HZZ couplings, which can not be experimentally disentagled in the WBF mechanism



The shape of m_{bb} (GeV) for the most sizeable backgrounds: QCD $b\bar{b}jj$ (squares) and multiple scattering events (crosses)



The shape of m_{bb} (GeV) assuming a gaussian smearing of 12% in the signal (crosses), the Zjj background (squares) and the $t\bar{t}$ reducible background (circles)

Conclusions

- The measurments of y_b in the channel Hjj (forward jets, VBF) looks promising (for a definite assesment full detector simulation required)
- Combining $qq \to qq(H \to b\bar{b})$ with $qq \to qq(H \to \tau^+\tau^-)$ allows a model independent determination of

$$\Gamma(H \to b\bar{b})/\Gamma(H \to \tau^+\tau^-)$$

  to be confronted with what obtained in $t\bar{t}H$ production
- Comparing $qq \to qq(H \to b\bar{b})$ with the associated $W(H \to b\bar{b})$ production, another test of the SU(2) relation between HWW and HZZ couplings for low Higgs masses could be obtained