

$H \rightarrow b\bar{b}$ in VBF with an extra central photon

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*based on E. Gabrielli, F. Maltoni, B. Mele,
M. Moretti, F. P. and R. Pittau*

Nucl. Phys. **B781** (2007) 64, [hep-ph/0702119](#)

- Relevance of a measurement of the $Hb\bar{b}$ Yukawa coupling (low Higgs mass range)
- $t\bar{t}H(\rightarrow b\bar{b})$ very challenging according to latest ATLAS and CMS simulations
- $H(\rightarrow b\bar{b})$ in VBF was studied some years ago at parton level. But subsequent “pessimistic” indications from complete simulations
- **Proposal: $H(\rightarrow b\bar{b})$ plus an additional γ in VBF mode**
 - Features of radiation patterns in signal and backg \Rightarrow **good S/\sqrt{B}** , balancing the drop of signal events w.r.t. the signal without γ
 - Parton level study of signal and background (irreducible and reducible) with “optimized cuts”
 - With no available data we have done **very conservative** background estimates
 - The significance could be improved considering showering effects and jet veto strategies
- Summary

$H \rightarrow b\bar{b}$ in VBF

The VBF production mode has been studied at parton level with ALPGEN in

M.L. Mangano, M. Moretti, F. P., R. Pittau and A.D. Polosa, Phys. Lett. B556 (2003) 50

- Typical signature: central $b\bar{b}$ pair + pair of jets in the fwd and bckwd rapidity region
- Main backgrounds:
 - QCD $b\bar{b}jj$ production
 - QCD four jets production (with two light jets mistagged as b jets)
 - QCD $Z(\rightarrow b\bar{b})jj$
 - QCD $W/Z(\rightarrow jj)b\bar{b}$
 - QCD $t\bar{t} \rightarrow b\bar{b} + \text{jets}$
 - QCD multiple overlapping events (especially at high luminosity)

Event selection (typical VBF)

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

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

- selection a) $2.5 < |\eta_j| < 5$, $\eta_{j_1} \eta_{j_2} < 0$, $\Delta R_{bb} < 2$
- 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

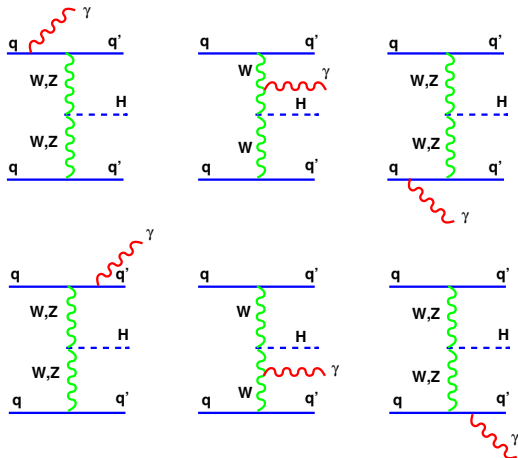
Main results of that study

- Good S/\sqrt{B} significances (at parton level) with 600 fb^{-1} of integrated luminosity (at the level of about 5σ for $m_H < 130 \text{ GeV}$)
- But...
 - S/B of the order of 0.5%
 - trigger problems
 - no leptons to trigger on
 - large QCD 4-jet cross sections also with large p_T thresholds (60 GeV) \Rightarrow potential problems for registering all relevant events on tape without losing signal
- Subsequent results with full detector simulation gave more pessimistic results

Adding a γ would seem hopeless

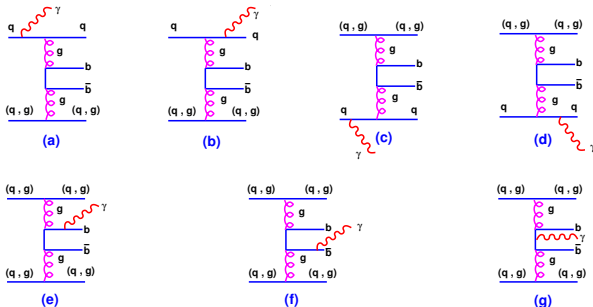
- Naively signal and background expected to drop by a factor of the order of α ($S/\sqrt{B} \rightarrow \sqrt{\alpha} S/\sqrt{B}$)
- But a detailed analysis reveals some interesting features. . .
- Key observation:
 - Signal composed of both Charged Current (CC, with W boson exchange) and Neutral Current (NC, with Z boson exchange)
 - Backgrounds (after VBF-like event selection) composed essentially of NC contributions (including also gluon exchange)
- Moreover
 - The presence of an additional photon can give an additional handle for trigger
 - It seems worth to be explored in detail. . . as we don't have other simple channels for the study of $Hb\bar{b}$ coupling

Both charged and neutral current contributions



Irreducible Background $b\bar{b}\gamma jj$

With typical VBF cuts (mainly a threshold on m_{jj} above M_Z , the main contributions come from **only NC** subprocesses)



- **Gluons do not couple to photons**
- γ radiation from separate fermionic current forms separate gauge invariant classes of diagrams

Large angle radiation suppression for NC

- The VBF cuts force the quarks to be in the fwd/bckwd region
- For NC the interference between radiation from in- and out-going legs is destructive for photon angles outside the cone given by the quark legs (angular ordering)
- \Rightarrow the bulk of QED radiation is collinear to the in-/out-going quarks and is cut away if we require a central photon (see later)
- \Rightarrow most of the contribution to the background is expected to come from final state b radiation, even if it is expected to be suppressed due to the $-1/3$ electric charge of b
- In the signal we expect the Z exchange contributions to be suppressed with respect to the W one. This would allow the separation of WWH and ZZH contributions
- the above semi-quantitative arguments have been tested with an explicit calculation (exact LO by means of ALPGEN and MADEVENT, with conservative scale choice)

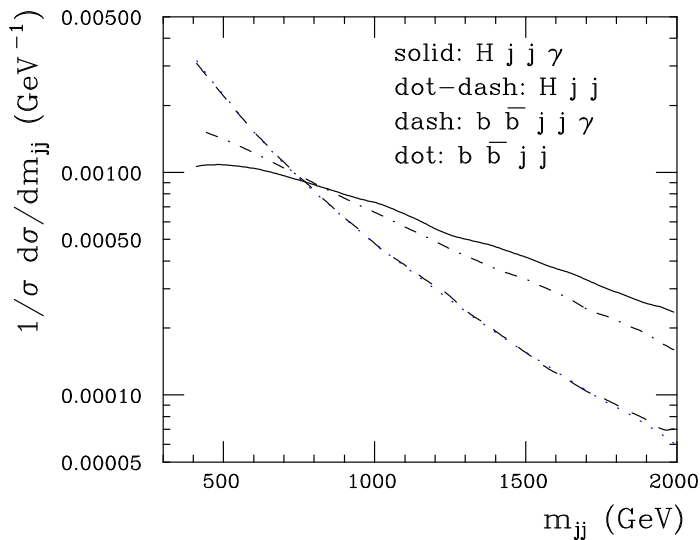
Basic cuts

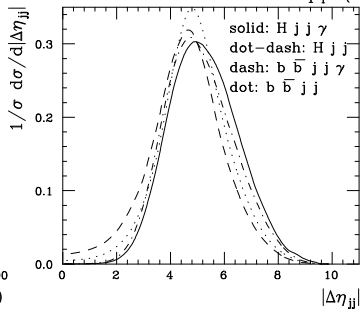
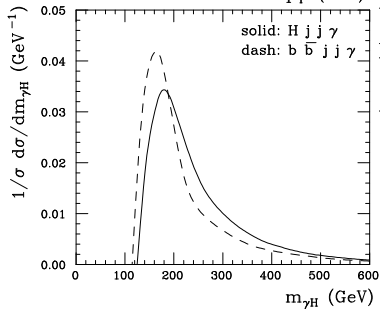
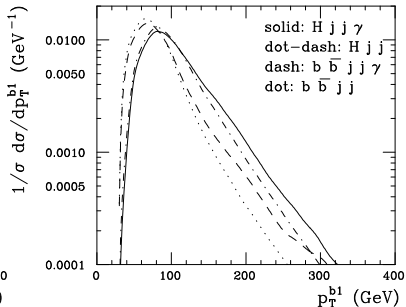
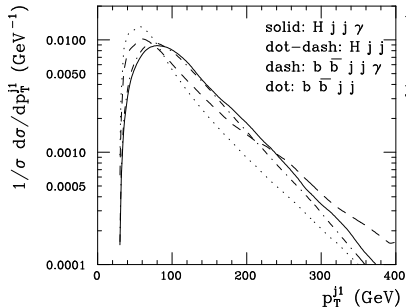
$$\begin{aligned} p_{\text{T}}^j &\geq 30 \text{ GeV}, \quad p_{\text{T}}^b \geq 30 \text{ GeV}, \quad \Delta R_{ik} \geq 0.7, \\ |\eta_\gamma| &\leq 2.5, \quad |\eta_b| \leq 2.5, \quad |\eta_j| \leq 5, \\ m_{jj} &> 400 \text{ GeV}, \\ m_H(1 - 10\%) &\leq m_{b\bar{b}} \leq m_H(1 + 10\%), \\ 1) \quad p_{\text{T}}^\gamma &\geq 20 \text{ GeV}, \\ 2) \quad p_{\text{T}}^\gamma &\geq 30 \text{ GeV} \end{aligned}$$

Optimized Cuts by looking at distributions ($m_H = 120 \text{ GeV}$)

$$\frac{d\sigma}{dm_{jj}}, \quad \frac{d\sigma}{dp_{\text{T}}^{j1}}, \quad \frac{d\sigma}{dp_{\text{T}}^{b1}}, \quad \frac{d\sigma}{dm_{\gamma H}}, \quad |\Delta\eta_{jj}|$$

The most sensitive distribution





$$m_{jj} \geq 800 \text{ GeV}, \quad p_T^{j1} \geq 60 \text{ GeV}, \quad p_T^{b1} \geq 60 \text{ GeV},$$

$$|\Delta\eta_{jj}| > 4, \quad m_{\gamma H} \geq 160 \text{ GeV}, \quad \Delta R_{\gamma b/\gamma j} \geq 1.2$$

Radiation suppressions for S and B

$$\frac{\sigma^{(N)}(H\gamma jj)}{\sigma^{(N)}(Hjj)} = 0.0016$$

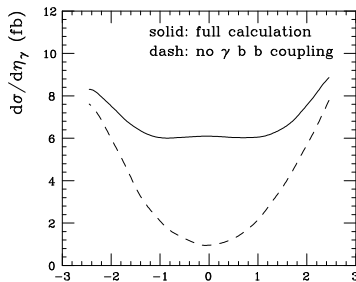
$$\frac{\sigma^{(C)}(H\gamma jj)}{\sigma^{(C)}(Hjj)} = 0.013$$

$$N : qq \rightarrow H(\gamma)qq$$

$$q = (u, d, s, c, \bar{u}, \bar{d}, \bar{s}, \bar{c})$$

$$C : u\bar{c} \rightarrow H(\gamma) d\bar{s}$$

(8 processes)



Results for S and irreducible B

	$p_T^{\gamma, cut}$	$m_H = 120$	$m_H = 130$	$m_H = 140$
$\sigma[H(\rightarrow b\bar{b})\gamma jj]$	20 GeV	3.59(7) fb	2.92(4) fb	1.98(3) fb
	30 GeV	2.62(3) fb	2.10(2) fb	1.50(3) fb
$\sigma[b\bar{b}\gamma jj]$	20 GeV	33.5(1) fb	37.8(2) fb	40.2(1) fb
	30 GeV	25.7(1) fb	27.7(1) fb	28.9(2) fb
$\sigma[H(\rightarrow b\bar{b})jj]$		320(1) fb	254.8(6) fb	167.7(3) fb
$\sigma[b\bar{b}jj]$		103.4(2) pb	102.0(2) pb	98.4(2) pb

Backgrounds decrease by factors of about 3000!

	$p_T^{\gamma, cut}$	$m_H = 120$	$m_H = 130$	$m_H = 140$
$S/\sqrt{B} _{H\gamma jj}$	20 GeV	2.6	2.0	1.3
$S/\sqrt{B} _{H\gamma jj}$	30 GeV	2.2	1.7	1.2
$S/\sqrt{B} _{Hjj}$		3.5	2.8	1.9

$$L = 100 \text{ fb}^{-1}, \epsilon_b = 0.6$$

Considering also reducible backgrounds

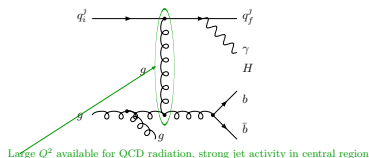
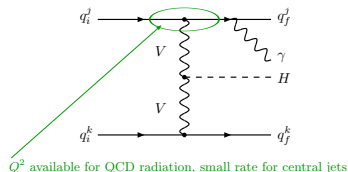
- $pp \rightarrow \gamma + 4 \text{ jets}$
- $pp \rightarrow b\bar{b} + 3 \text{ jets}$
- $pp \rightarrow 5 \text{ jets}$

$$m_H = 120 \text{ GeV}$$

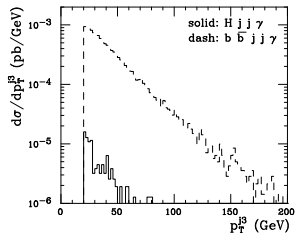
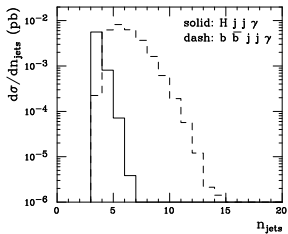
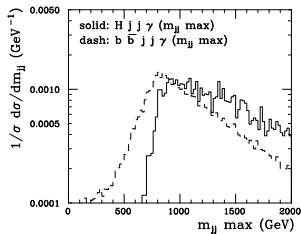
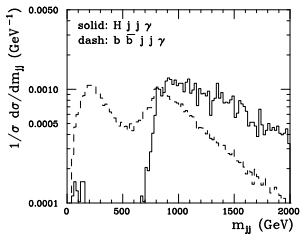
	$p_T^\gamma \geq 20 \text{ GeV}$	$p_T^\gamma \geq 30 \text{ GeV}$
$\sigma(pp \rightarrow \gamma + 4j)$	2.27(2) pb	1.72(4) pb
$\sigma(pp \rightarrow b\bar{b} + 3j)$	61.1(3) pb	45.1(2) pb
$\sigma(pp \rightarrow 5j)$	2.40(1) nb	1.83(1) nb
S/\sqrt{B}	2.2	1.8

$$\epsilon_{\text{fake}} = 0.01, \epsilon_{\gamma j} = 1/5000$$

Shower effect and jet veto



We tried to analyze these features by showering with Herwig two samples of unweighted events. A more solid approach would require a matching procedure to reduce the dependence on partonic cuts. To reduce edge effects we shifted the m_{jj} partonic invariant mass cut to 1 TeV with events generated with $m_{jj} > 800$ GeV



- After showering, only about 50% of the background events satisfy both the requirements for the tagging jets as leading p_T jets and the $m_{jj} > 1$ TeV requirement, while the effect is confined at the 7% level for the signal
- In addition to the above, a substantial fraction of the background events (about 50%) contain at least a third jets with η between the tagging jets and $p_T \geq 20 - 30$ GeV, while only 2% of the signal events contain this additional radiation
- Showering and jet veto seem to allow for a substantial gain in statistical significance

Summary

- preliminary parton level studies show that $\gamma H(\rightarrow b\bar{b})$ VBF production could be promising, despite the drop in signal cross section (bckg cross sections decrease by about a factor of 3000!). It would allow also to separate HWW and HZZ contributions
- With optimized cuts statistical significances of more than 2σ at parton level for $m_H = 120$ GeV and 100 fb^{-1}
- Shower effects and jet veto strategies should improve substantially the above significance
- The correctness of the above picture should be tested with a complete experimental simulation
- Most urgent: solid trigger strategy study