Higgs bosons production in association with a photon at LHC

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based on:
E.G, F.Maltoni, B. Mele, M.Moretti, F.Piccinini, R.Pittau, NPB 781 (2007), 64
Higgs productions in association with a central photon

$pp \rightarrow h \ jj + \gamma$ via Vector-Boson-Fusion in the SM

where $h \rightarrow bb(bar)$

allows measurement of $bbH$ and $WWH$ couplings

$pp \rightarrow H/A + \gamma$ in the MSSM at large $\tan(bet)$

where $H/A \rightarrow \tau\tau$

clean probe of $b$-quark density in the proton

allows also measurement of $bbH$ coupling

Conclusions
Higgs boson searches at LHC

- Higgs boson search is one of main tasks of LHC
- range of mass is not predicted, varying from LEP limit of 114.5 GeV up to theoretical upper bound $\Lambda \sim 800$ GeV
- SM precision tests favor a light Higgs boson, with mass below 200 GeV
- discovery of a light Higgs boson is challenging at LHC due to the huge background (bckg) in $b\bar{b}$
- discovery channels of Higgs boson at LHC strongly depend on the actual Higgs mass
Higgs boson production mechanisms

- **Gluon-gluon fusion**, main mechanism in the whole range
  - **X-section of order of O(10) pb** for \( m_H < 200 \text{ GeV} \)

- **Vector boson fusion** is also sizeable

- \( t\bar{t} \) interesting at low Higgs masses
Mass range $[115-130]$ GeV
$H \rightarrow \gamma \gamma$

$H \rightarrow ZZ \rightarrow 4l$ (l=μ,e) golden channel

Mass range $[150-170]$ GeV
$H \rightarrow WW \rightarrow 2l 2\nu$ (l=μ,e) silver channel

for $m(H)=165$ GeV, ~ $1\text{fb}^{-1}$ necessary for Higgs discovery
not a discovery channel, but relevant for measuring the $H_{bb}$ Yukawa coupling at LHC

up to now, more serious studies only for $Ht\bar{t}$

optimized $\sigma$-sections of signal are of the order of $O(10$ fb). $Ht\bar{t}$ has been disfavored by recent CMS analyses
A new promising channel to measure $bbH$ coupling at the LHC

E.G., F. Maltoni, B. Mele, M. Moretti, F. Piccinini, R. Pittau

*Nucl. Phys. B781 (2007), 64*

\[ pp \rightarrow H \gamma + jj \]

same mechanism of $H$ production by Vector Boson Fusion + $\gamma$
signal at partonic level

\[ q q \rightarrow q q H + \gamma \]
main advantages

- trigger on gamma at high pT

- the large gluon component in QCD bckg is idle in radiating a photon

- dynamical effects suppress radiation of central photon with respect to signal

- $O(10\text{fb})$ x-section

- could provide a new independent test of Hbb and HWW couplings
signal cross section $pp \rightarrow H \gamma jj$

minimal set of kinematical cuts

$\Delta R_{i,j} > 0.4 \quad p_T^\gamma \geq 20 \text{ GeV} \quad m_{i,j} > 100 \text{ GeV}$

<table>
<thead>
<tr>
<th>$m_H$ (GeV)</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(H\gamma jj)$ [fb]</td>
<td>67.4</td>
<td>64.0</td>
<td>60.4</td>
<td>56.1</td>
</tr>
<tr>
<td>$\mathcal{BR}(H \rightarrow bb)$</td>
<td>0.770</td>
<td>0.678</td>
<td>0.525</td>
<td>0.341</td>
</tr>
</tbody>
</table>

- Higgs BR to bb(bar)$\rightarrow$HDECAY
- full EW tree-level matrix element to $pp \rightarrow H \gamma jj$ computed with ALPGEN + MADEVENT
- PDF set is CTEQ5L

$$\Delta R_{i,j} = \sqrt{(\Delta_{i,j} \phi)^2 + (\Delta \eta_{i,j})^2}$$
Higgs production in VBF signal (no photon)

The basic partonic process is $qq \rightarrow qq \, H$

Mangano, Moretti, Piccinini, Pittau, Polosa (2003)

$p_T(j) \approx 40 \text{ GeV}$

Characteristic of the signal: $pp \rightarrow H(\rightarrow b\bar{b}) + 2j$

- Two jets with large invariant mass
- Widely separated in rapidity (forward/backward)
- Typical transverse momentum of jets $p_T(j) \sim 40 \text{ GeV}$
- Higgs decay products lying at intermediate rapidity
the signal has large $\times$-section, BUT it is difficult to measure due to the huge QCD background.

QCD background to Higgs boson production via VBF

A set of $t,u$-channel diagrams

$s$-channel diagrams suppressed by $m(jj) > \text{TeV}$
how the emission of a photon affects the background

one would expect by naive QED rescaling

\[ \frac{S}{\sqrt{B}} \bigg|_{H\gamma jj} \sim \sqrt{\alpha} \left( \frac{S}{\sqrt{B}} \right) \bigg|_{H jj} \]

if so, then there would be no advantage in considering a photon emission

QED naive rescaling holds for inclusive processes but not always when restricted regions of phase space are considered!

requirement of centrality dramatically increases S/B ratio, while signal cross section roughly follows QED naive rescaling
cuts made at partonic level (we considered also partonic shower effects)

optimized sub-set of kinematical cuts enhancing S/B

- \( m(jj) > 800 \text{ GeV} \)
- \( m_H(1-10\%) < m(bb) < m_H(1+10\%) \)
- \( p_T(\gamma) > 20 \text{ GeV} \)

leading contribution to bckg of VVB fusion
<table>
<thead>
<tr>
<th>sub-processes</th>
<th>$\sigma_i$ (pb)</th>
<th>$\sigma_i/\sigma$</th>
<th>$\sigma_i^\gamma$ (fb)</th>
<th>$\sigma_i^\gamma/\sigma^\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$gq \rightarrow b\bar{b} , gg , (\gamma)$</td>
<td>57.2(1)</td>
<td>55.3 %</td>
<td>17.3(1)</td>
<td>51.6 %</td>
</tr>
<tr>
<td>$gg \rightarrow b\bar{b} , gg , (\gamma)$</td>
<td>25.2(1)</td>
<td>24.4 %</td>
<td>3.93(3)</td>
<td>11.7 %</td>
</tr>
<tr>
<td>$qq' \rightarrow b\bar{b} , qq' , (\gamma)$</td>
<td>7.76(3)</td>
<td>7.5 %</td>
<td>4.04(2)</td>
<td>12.1 %</td>
</tr>
<tr>
<td>$qq \rightarrow b\bar{b} , qq , (\gamma)$</td>
<td>6.52(2)</td>
<td>6.3 %</td>
<td>4.49(3)</td>
<td>13.4 %</td>
</tr>
<tr>
<td>$qq' \rightarrow b\bar{b} , q\bar{q}' , (\gamma)$</td>
<td>4.60(2)</td>
<td>4.4 %</td>
<td>2.28(2)</td>
<td>6.8 %</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow b\bar{b} , q\bar{q} , (\gamma)$</td>
<td>2.13(2)</td>
<td>2.1 %</td>
<td>1.21(2)</td>
<td>3.6 %</td>
</tr>
<tr>
<td>$gg \rightarrow b\bar{b} , q\bar{q} , (\gamma)$</td>
<td>0.0332(7)</td>
<td>0.03 %</td>
<td>0.124(3)</td>
<td>0.37 %</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow b\bar{b} , gg , (\gamma)$</td>
<td>0.0137(2)</td>
<td>0.01 %</td>
<td>0.094(2)</td>
<td>0.28 %</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow b\bar{b} , q'\bar{q}' , (\gamma)$</td>
<td>0.000080(3)</td>
<td>0.00007 %</td>
<td>0.00080(8)</td>
<td>0.002 %</td>
</tr>
</tbody>
</table>

$bckg(\gamma) / bckg \sim 1/3000$

$signal(\gamma) / signal \sim 1/100$
bckg is less active by requiring a central photon

dynamical effect: destructive interference for gamma at large angles a) + b) and c) + d)

dominant effect, but suppressed by the b-quark electric charge
what happens if the radiation of a photon from b-coupling is switched off
Radiation of photon from b-coupling is switched off.

**Partial cross sections**

<table>
<thead>
<tr>
<th>sub-processes</th>
<th>$\sigma_i^\gamma$[no b rad] (fb)</th>
<th>$\sigma_i^\gamma$[no b rad]/$\sigma^\gamma$[no b rad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$gq \rightarrow b\bar{b} gq\gamma$</td>
<td>8.19(6)</td>
<td>47.8 %</td>
</tr>
<tr>
<td>$gg \rightarrow b\bar{b} gg\gamma$</td>
<td>0</td>
<td>0 %</td>
</tr>
<tr>
<td>$qq' \rightarrow b\bar{b} qq'\gamma$</td>
<td>2.80(2)</td>
<td>16.4 %</td>
</tr>
<tr>
<td>$qq \rightarrow b\bar{b} qq\gamma$</td>
<td>3.49(3)</td>
<td>20.4 %</td>
</tr>
<tr>
<td>$q\bar{q}' \rightarrow b\bar{b} q\bar{q}'\gamma$</td>
<td>1.57(2)</td>
<td>9.2 %</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow b\bar{b} q\bar{q}\gamma$</td>
<td>0.87(1)</td>
<td>5.1 %</td>
</tr>
<tr>
<td>$gg \rightarrow b\bar{b} q\bar{q}\gamma$</td>
<td>0.10(2)</td>
<td>0.6%</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow b\bar{b} gg\gamma$</td>
<td>0.096(2)</td>
<td>0.6 %</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow b\bar{q} q'\bar{q}'\gamma$</td>
<td>0.0009(1)</td>
<td>0.005 %</td>
</tr>
</tbody>
</table>
SIGNAL
no destructive interference at large angle, due to the charged gauge boson

different angular photon distribution with respect to bckg
VBF is sensitive to both WWH and ZZH

requiring a central photon in VBF increases sensitivity to WWH
suppresses contaminations from $g^* g^* \rightarrow H$
induced by loop of top

basic kinematical cuts (see next slide)

- with $p_t > 20$ GeV $\rightarrow$ reduction factor of $8 \times 10^{-4}$
for $\sigma (H \gamma jj)$ with respect to $\sigma (H jj)$
(induced by $g^* g^* \rightarrow H$)

- cross section $\sim 0.21$ fb (negligible!)
basic cuts

\[ p_T^j \geq 30 \text{ GeV}, \quad p_T^b \geq 30 \text{ GeV}, \quad \Delta R_{ik} \geq 0.7, \]

\[ |\eta_\gamma| \leq 2.5, \quad |\eta_b| \leq 2.5, \quad |\eta_j| \leq 5, \]

\[ m_{jj} > 400 \text{ GeV}, \quad m_H(1 - 10\%) \leq m_{b\bar{b}} \leq m_H(1 + 10\%) \]

1) \[ p_T^\gamma \geq 20 \text{ GeV}, \]

2) \[ p_T^\gamma \geq 30 \text{ GeV}, \]

\[ \frac{d\sigma}{dm_{jj}}, \quad \frac{d\sigma}{dp_T^j}, \quad \frac{d\sigma}{dp_T^b}, \quad \frac{d\sigma}{dm_{\gamma H}}, \quad \frac{d\sigma}{|\Delta \eta_{jj}|}. \]
crucial distribution \( m(j,j) \)
→ optimized cuts follow:

\[ m_{jj} \geq 800 \text{ GeV}, \quad p_{T}^{j1} \geq 60 \text{ GeV}, \quad p_{T}^{b1} \geq 60 \text{ GeV}, \]
\[ |\Delta \eta_{jj}| > 4, \quad m_{\gamma H} \geq 160 \text{ GeV}, \quad \Delta R_{\gamma b/\gamma j} \geq 1.2, \]

\[
N(B) = L \sigma_B \varepsilon(b) \varepsilon(b) \\
N(S) = L \sigma_S \text{BR} \varepsilon(b) \varepsilon(b) \varepsilon(bb)
\]

\[ \text{signf} = \frac{N(S)}{\sqrt{N(B)}} \]

we used

\[ L = 100 \text{ fb}^{-1} \]
\[ \varepsilon(b) = 60\% \rightarrow \text{eff. b-tag} \]
\[ \varepsilon(bb) = 70\% \rightarrow \text{due to ( +/-10 \%) bb mass resolution} \]
**pp → H γ + jj : optimized cross sections**

<table>
<thead>
<tr>
<th>$p_T^{\gamma,\text{cut}}$</th>
<th>$m_H = 120$ GeV</th>
<th>$m_H = 130$ GeV</th>
<th>$m_H = 140$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma[H(\rightarrow b\bar{b})\gamma jj]$</td>
<td>20 GeV</td>
<td>3.59(7) fb</td>
<td>2.92(4) fb</td>
</tr>
<tr>
<td></td>
<td>30 GeV</td>
<td>2.62(3) fb</td>
<td>2.10(2) fb</td>
</tr>
<tr>
<td>$\sigma[bb\gamma jj]$</td>
<td>20 GeV</td>
<td>33.5(1) fb</td>
<td>37.8(2) fb</td>
</tr>
<tr>
<td></td>
<td>30 GeV</td>
<td>25.7(1) fb</td>
<td>27.7(1) fb</td>
</tr>
<tr>
<td>$\sigma[H(\rightarrow b\bar{b})jj]$</td>
<td>320(1) fb</td>
<td>254.8(6) fb</td>
<td>167.7(3) fb</td>
</tr>
<tr>
<td>$\sigma[bbjj]$</td>
<td>103.4(2) pb</td>
<td>102.0(2) pb</td>
<td>98.4(2) pb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$p_T^{\gamma,\text{cut}}$</th>
<th>$m_H = 120$ GeV</th>
<th>$m_H = 130$ GeV</th>
<th>$m_H = 140$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S/\sqrt{B}</td>
<td>_{H\gamma jj}$</td>
<td>20 GeV</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>30 GeV</td>
<td>2.2</td>
<td>1.7</td>
</tr>
<tr>
<td>$S/\sqrt{B}</td>
<td>_{H jj}$</td>
<td>3.5</td>
<td>2.8</td>
</tr>
</tbody>
</table>

$L$=100 fb$^{-1}$  
$S/B(\gamma) \sim 1/10$  
$S/B \sim 1/300$
Reducible backgrounds

- \( pp \rightarrow \gamma + 4 \text{ jets} \) where two among the light jets are faked-tagged as \( b \)-jets

- \( pp \rightarrow b \bar{b} + 3 \text{ jets} \) where one of the light jets is misidentified as a photon

- \( pp \rightarrow 5 \text{ jets} \) where one of the light jets is misidentified as a photon and two light jets are faked-tagged as \( b \)-jets
number of events ($m_H=120$ GeV)

<table>
<thead>
<tr>
<th>$pp \rightarrow \gamma H(\rightarrow b\bar{b}) + 2j$</th>
<th>$p_T^\gamma \geq 20$ GeV</th>
<th>$p_T^\gamma \geq 30$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow \gamma b\bar{b} + 2j$</td>
<td>90</td>
<td>66</td>
</tr>
<tr>
<td>$pp \rightarrow \gamma + 4j$</td>
<td>1206</td>
<td>925</td>
</tr>
<tr>
<td>$pp \rightarrow b\bar{b} + 3j$</td>
<td>440</td>
<td>324</td>
</tr>
<tr>
<td>$pp \rightarrow 5j$</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>$S/\sqrt{B}$</td>
<td><strong>2.2</strong></td>
<td><strong>1.8</strong></td>
</tr>
</tbody>
</table>

$\varepsilon_{\text{fake}} \rightarrow$ for mistagging light-jet as a b-jet

$\varepsilon_{\text{fake}} = 1\%$  \quad $\varepsilon_{\gamma j} = 1/5000$ (ATLAS)
Parton shower effects and central jet veto

no color is exchanged in the signal between initial and final fermionic lines

on the contrary, bckg is characterized by the presence of t-channel virtual gluons

more QCD radiation is expected for background

invariant mass and rapidity separation between the tagging jets are expected to decrease in the bckg events with respect to partonic configurations.
algorithms for identification of light tagging jets

the identification of light tagging jets not uniquely defined, due to extra QCD radiation

Alg.1 - highest and second highest pT with $p_T(j_1) > 60 \text{ GeV}$  $p_T(j_2) > 30 \text{ GeV}$

Alg.2 - pair of jets with highest invariant mass, $p_T(j_1) > 60 \text{ GeV}$ $p_T(j_2) > 30 \text{ GeV}$
Alg1: $m(j_1, j_2)$
$j_1 =$ highest $p_T$
$j_2 =$ second highest $p_T$

Alg2: $\text{max}[m(j_1, j_2)]$ among all jets

$p_{T1} > 60, \ p_{T2} > 30$
Alg1: 
$\Delta\eta(j_1,j_2)$
$j_1$=highest $p_T$
$j_2$=second highest $p_T$

$pT_1 > 60$, $pT_2 > 30$

Alg2:
$max[\Delta\eta(j_1,j_2)]$ among all jets
jet multiplicity distribution

$p_T$ distribution of the third highest $p_T$ jet
A veto on additional jet activity in the central rapidity region could be very effective in suppressing bckg versus signal. At least a factor 4 improvement is expected for S/B. A more refined analysis will be necessary for quantitative statements.
what if $\gamma \rightarrow W$: $HWjj$  

Rainwater (2001)

- it could help in constraining $\mathbf{b}\mathbf{b}H$ coupling

- however, accurate studies of background and parton shower effects are missing

- relevant cross section is smaller than $H\gamma jj$

with same optimized event selection criteria (with constraints on photon applied to charged lepton)

for $m_H = 120 \text{ GeV}$ and $p_T(\gamma) > 20 \text{ GeV}$ we get

$$\sigma(H\gamma jj) \sim 4.4 \times \sigma(HWjj)$$
Higgs sector in the MSSM

Two complex Higgs boson doublets $HU$ and $HD$

**Spectrum:**
- two CP-even $(h,H)$ and one CP-odd $(A)$ neutral +
- a pair of charged Higgs bosons

**At tree-level,** Higgs sector fully specified by two parameters:
- $\tan\beta = \langle HU \rangle / \langle HD \rangle$
- $mA$ = mass of pseudoscalar $A$.
  *(radiative corrections depend on other SUSY parameters)*

**Light-Higgs boson mass scenario,** naturally predicted in the MSSM
Large $\tan\beta$ scenarios are favored:

- viable dark matter candidate
- large radiative corrections to lightest Higgs boson mass
- large SUSY contributions to $(g-2)\mu$: needed to accommodate the present $3.4\sigma$ deviation
- $H/A$ Yukawa to $b$-quarks enhanced by $\tan\beta$

CDF and D0 collaborations have recently analyzed $pp\rightarrow (H,A,h) \rightarrow \tau\tau$

- no evidence of signal observed;
- only an excess of events in the region $m_H=140-160$ and $\tan\beta>45$ observed;
- limits on $m_A$ and $\tan\beta$ out to be weaker than expected
b-quark fusion process $bb \rightarrow H/A$

- main mechanism for $H/A$ production at large $\tan\beta$

- $bb \rightarrow H/A$ rates comparable with $gg \rightarrow H/A$ rates:
  - in SM is two order of magnitude smaller than gluon fusion

- particularly sensitive to the composition of proton in terms of $b$-quarks

- $b$-quark parton density derived perturbatively from gluon parton density, no direct measurement of it

- no hope in the SM to separate $bb \rightarrow h$ from $gg \rightarrow h$

- in MSSM this is possible for large $\tan\beta$, although a contamination of $gg \rightarrow h$ is unavoidable
if a high-pT photon is required then no contamination from gg fusion

a photon in the final states selects the initial partonic process

large tan\(\beta\) compensates for EM suppression

gg \to H/A + \gamma

vanishes forbidden by C-parity

stable under radiative corrections
the most promising signature is $H/A \rightarrow \tau \tau$

- BR~10% for large tan$\beta$ almost insensitive to $m_H$
- BCKG for $\tau\tau+\gamma$ final states has an EW origin and is well under control
- Tagging tau leptons allows drastic reduction of the BCKG
- Tau-tau signature well studied in SM and MSSM. Very promising for Higgs discovery

Note: the complete tau-tau invariant mass can be fully reconstructed, provided the two taus are not neither back-to-back nor collinear in lab frame (due to undetected neutrinos)

Condition satisfied by requiring a large $p_T$ of the photon
signal cross section in pb versus mA

Structure functions used: CTEQ6L1 with factorization scale = mA/2

Tevatron x-section = 2.5 fb, for pT>20 GeV, mA=150, tgβ=50
analysis of tau-tau signature

\[ pp \rightarrow H/A \rightarrow \tau \tau \gamma \]

main irreducible BCKG is due to tau-pair production via gamma or Z off-shell

also: \( pp \rightarrow WW \gamma \) with \( W \rightarrow \tau \nu \)

negligible: \( \times \)-sec \( \sim 14 \text{fb} \) for \( p_T > 30 \text{ GeV} \)

only the resonant \( H/A \rightarrow \tau \tau \) production associated to a high \( p_T \) photon can disentangle the initial \( bb \) partonic state

the spurious signal coming from channel

\( bb \rightarrow H/A \rightarrow \tau^* \tau \rightarrow \tau \tau \gamma, \) photon radiated by a tau, must be also kept under control
Large SUSY radiative corrections on b-Yukawa factorizes, residual dependence is small.

In MSSM, $m_A \sim m_H$ (at large $\tan\beta$) gives a factor 2 of enhancement in the cross-section.

Assumed tau-pair efficiency = 0.2 comes from:

- $\tau \rightarrow \ell \nu_\tau \nu_\ell$ (35%)
- $\tau \rightarrow h\nu$ (50%)

ID efficiency = 90% for $\tau \rightarrow \ell \nu_\tau \nu_\ell$ and 25% for $\tau \rightarrow h\nu$. Double hadronic decays contribute with 0.016 to 0.2.
optimized set of cuts to avoid non-resonant production

- $p_T^\gamma > 30, 30, 40, 50$ GeV, for $m_A = 150, 200, 300, 500$ GeV,
- $0.9 m_A < m_{\tau\tau} < 1.1 m_A$ on the $\tau\tau$ invariant mass;
- $p_T^{\tau^\pm} > 20$ GeV, $|\eta_\gamma| < 2.5$, $|\eta_{\tau^\pm}| < 2.5$
- $\Delta R_{\gamma\tau^\pm} > 0.7$, $\Delta R_{\tau\tau} > 0.7$, $\Delta \phi_{\tau\tau} < 2.9$.

suppress the kin. configurations where photon is collinear to one of taus: allows tau-tau mass reconstruction

$\Delta \phi_{\tau\tau} < 2.9$ quite effective at larger masses
after applying all cuts one gets substantial purity of the signal $bb \rightarrow H/A \gamma$

$\gamma$–radiation off b’s: 83% (66%) of observed rate for $mA=150$ (500) GeV at $\tan\beta=50$
Signal $x$-section and corresponding significance $S$

<table>
<thead>
<tr>
<th>$\tan \beta$</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_A$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>5.58</td>
<td>7.3</td>
<td>12.5</td>
<td>13</td>
</tr>
<tr>
<td>200</td>
<td>3.00</td>
<td>5.3</td>
<td>6.81</td>
<td>9.5</td>
</tr>
<tr>
<td>300</td>
<td>0.727</td>
<td>2.4</td>
<td>1.67</td>
<td>4.5</td>
</tr>
<tr>
<td>500</td>
<td>0.0981</td>
<td>0.72</td>
<td>0.238</td>
<td>1.5</td>
</tr>
</tbody>
</table>

$$S = \frac{n(S)}{\sqrt{n(S) + n(B)}}$$

- sensitivity to PDF $\sim O(20\%)$

- $L=100/fb$, $\varepsilon(\tau\tau)=0.2$

- only irreducible bckg
Conclusions

- The request of an associated high-\textit{p}_T photon in the Higgs boson production offers great advantages (trigger efficiency improved).

- **SM** \( pp \rightarrow H \gamma + jj \)
  - With a light Higgs boson decaying in \( H \rightarrow bb \), can help in constraining both Hbb and HWW couplings (\( L=100 \text{ /fb} \)).

- **MSSM** \( pp \rightarrow H/A + \gamma \)
  - With \( H/A \rightarrow \tau \tau \), can provide a clean probe of the b-quark density in the proton at large \( \tan \beta \) (\( L=100 \text{ /fb up to } mA=500 \)).