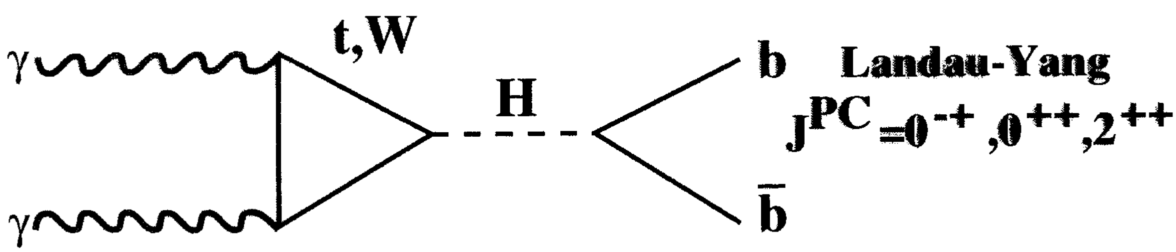
Higgs Production at a Compton Collider

Sitges Workshop

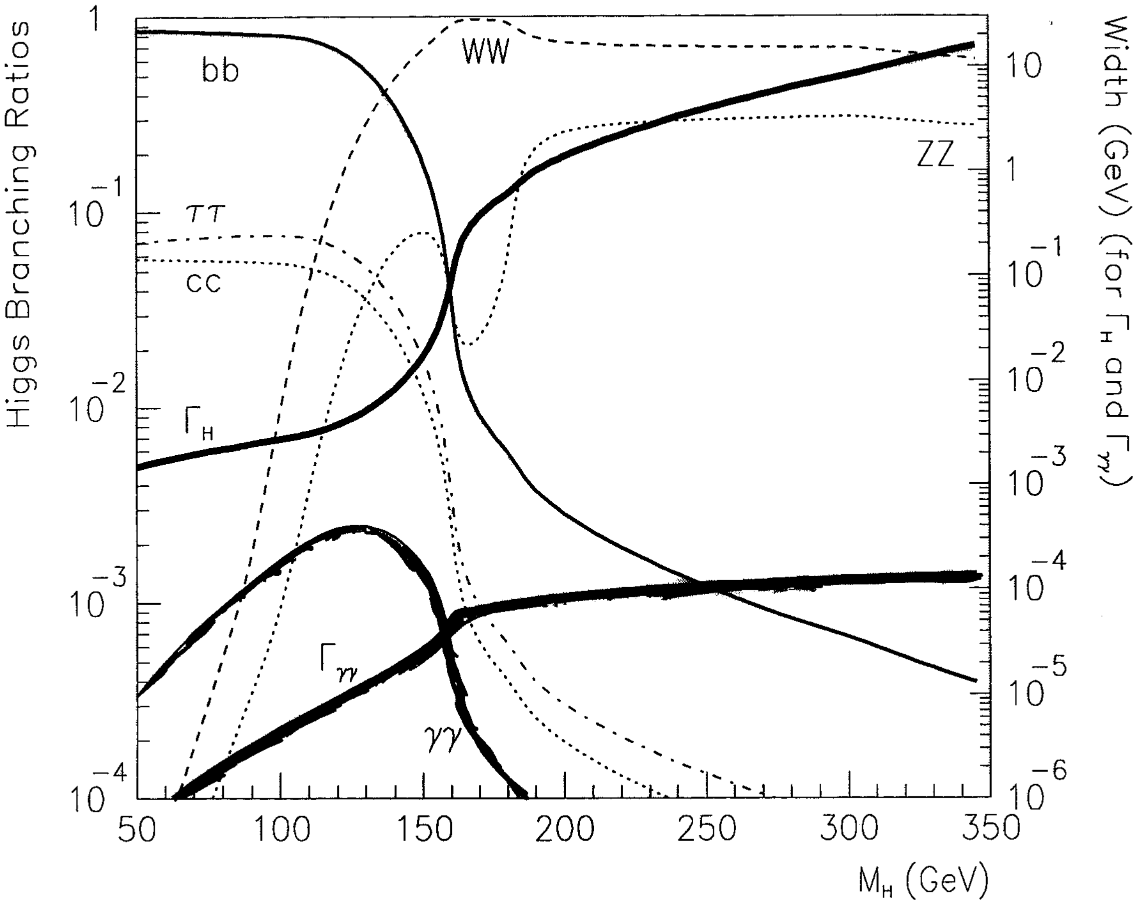
1. May 1999

Georgi Jikia, Stefan Söldner-Rembold
Universität Freiburg



1. Massive charged particles in loop give access to new physics at higher scales
2. Best way to measure total width for higgs masses around 120 GeV in a model independent way?
3. Main background are 'non-resonant' $\gamma\gamma \to b\bar{b}$ and $\gamma\gamma \to c\bar{c}$ processes

[redacted] *Some of the SM branching ratios of the Higgs as a function of the Higgs mass calculated with a top mass of 175 GeV. Also shown (thick lines) are the total width and the $\gamma\gamma$ width.*



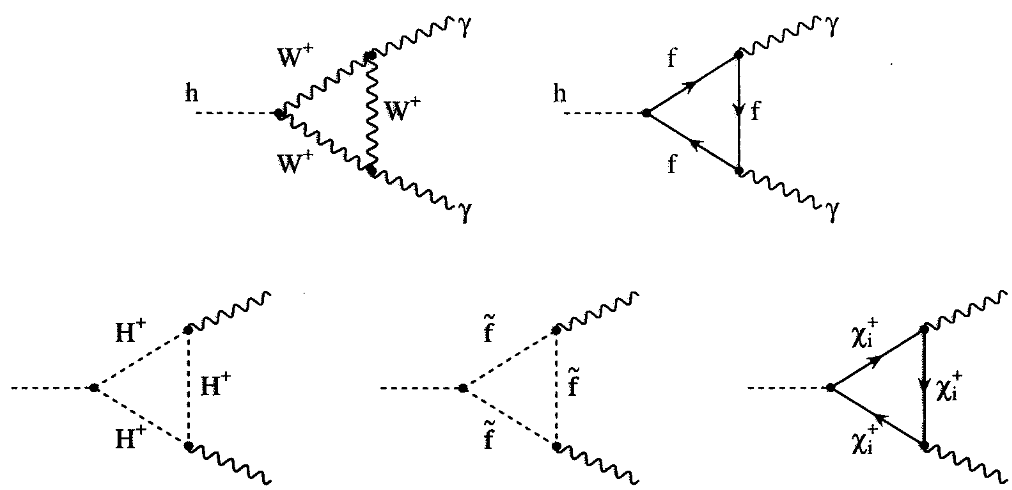
$\Gamma(H\to 2\gamma)$ – a one-loop induced quantity, so that any charged heavy particles which obtain their masses from electroweak symmetry breaking contribute in the loop.

$$\frac{\Gamma(H\to 2\gamma)\Big|_{\substack{M_L = 300\,GeV \\ M_U = M_D = 500\,GeV}}}{\Gamma(H\to 2\gamma)\Big|_{SM}} = 0.2 \div 10$$

★ $h, H, A \to 2\gamma$ in MSSM

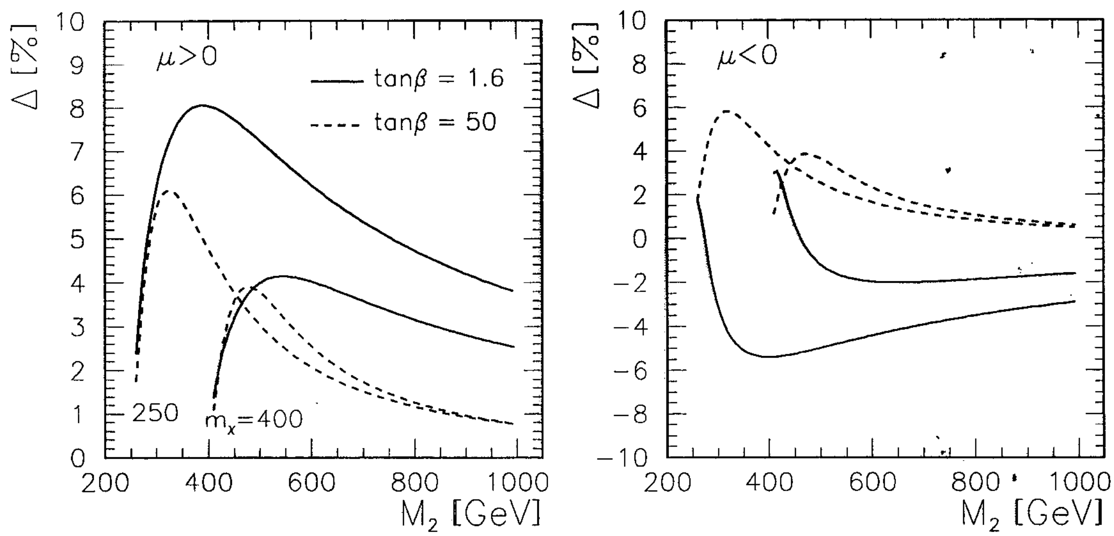
$h, H, A, H^{\pm}$

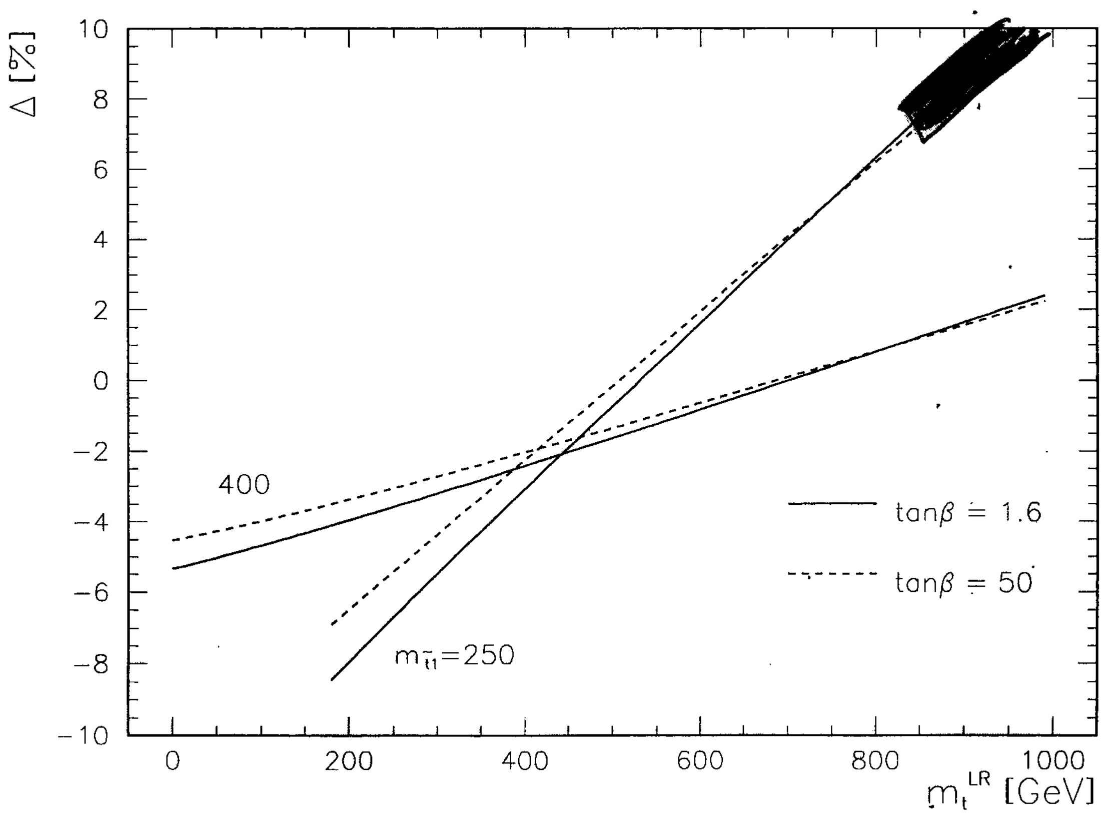
$$m_h^2 \lesssim M_Z^2 \cos^2 2\beta + \frac{3g^2 m_t^4}{8\pi^2 M_W^2} \log\frac{m_{\tilde t}^2}{m_t^2} \lesssim 130\,\mathrm{GeV}$$



A. Djouadi, V. Driesen, W. Hollik, J.I. Illana '96

★ The deviations of the $\Gamma(h \to \gamma\gamma)$ due to the chargino and top squark loops.





$m_{\tilde{t}_1} \lesssim 300$ GeV, $m_t^{LR} > 1$ TeV $\Rightarrow$ $\Delta \gtrsim 10\%$

Luminosity spectrum

polarized photon energy spectra taken from

I.F. Ginzburg et al, NIM 219 (1984) 10, eq. (12)

$$x = \frac{2E_e\omega_0}{m_e^2} = 4.8$$

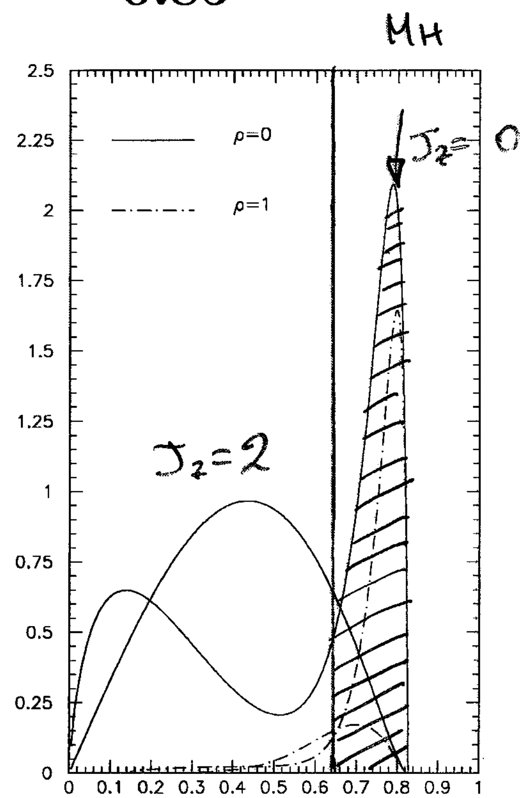
$$\omega_{\max} = 0.83E_e$$

$$z = W_{\gamma\gamma}/2E_e$$

$$z_{\text{peak}} = 0.79$$

100 % polarized laser and 85 % polarized e$^{\pm}$ beam

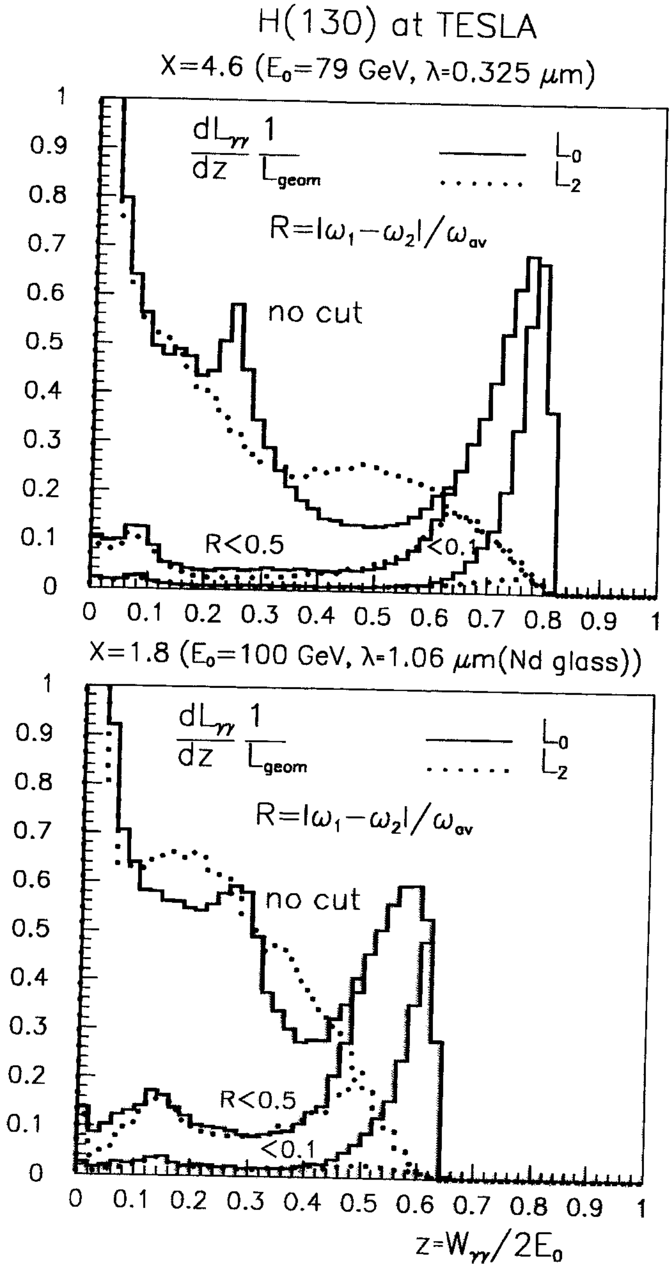
with $2\lambda_e^{1,2}\lambda_\gamma^{1,2} = -0.85$



$\mathcal{L}_{\gamma\gamma}(z>0.65) = \frac{1}{5}\mathcal{L}_{e^+e^-}$

$\sqrt{s_{e^+e^-}} = 150$ GeV, $M_H = 120$ GeV

Telnov:



$J_z = 0$ **dominates peak**

exact results depend on luminosity spectrum

The Higgs signal

$$\sigma(\gamma\gamma \to \mathrm{H} \to \mathrm{b\bar{b}}) = 16\pi \frac{\Gamma(\mathrm{H} \to \gamma\gamma)\Gamma(\mathrm{H} \to \mathrm{b\bar{b}})}{(\mathrm{s}_{\gamma\gamma} - \mathrm{m_H^2})^2 - \mathrm{m_H^2}\Gamma_\mathrm{H}^2} \mathrm{L}_{\gamma\gamma}(\mathrm{J_z} = 0)$$

Widths and branching ratios are calculated using HDECAY (A.Djouadi, J.Kalinowski, M.Spira, 1998)

Main backgrounds:

$\gamma\gamma \to$ b$\bar{\text{b}}$ and $\gamma\gamma \to$ c$\bar{\text{c}}$ with $J_z = 0, 2$

Important:

$$\mathcal{M}_{++}^{\mathrm{born}}(\lambda_q) \propto \frac{m_q}{\sqrt{s_{\gamma\gamma}}} \quad (J_z = 0)$$

But $J_z = 0$ suppression not valid for $\gamma\gamma \to \bar{\mathrm{q}}\mathrm{qg}$

Only direct processes are studied, since $x_\gamma \approx 1$

Resolved cross-section small ??? (currently studied with PYTHIA, problem: possible overlap between LO resolved and NLO direct cross-section)

Analysis

- SIMDET plus analysis code provided by R.Hawkings
- Jet finding with a clustering algorithm for events with $n_{\rm par} > 6$

  about 80 % di-jet events, 20 % three-jet
- Calculated thrust angle $\theta_{\rm T}$
- No b-tagging available

  Assume event ($n_{\rm jet} = 2$) tagging efficiencies of

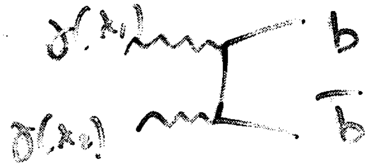
  $\left.\begin{array}{l}\text{70 \% for b-events}\\ \text{3.5 \% for c-events}\end{array}\right\}$ factor 20

  (based on information from Marco Battaglia)

$$\frac{\sigma(\gamma\gamma \to \mathrm{c\bar{c}})}{\sigma(\gamma\gamma \to \mathrm{b\bar{b}})} > \frac{e_c^4}{e_b^4} = 16$$

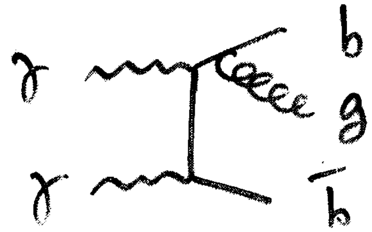
double-tag required to suppress charm

Backgrounds for $\gamma\gamma \to H \to b\bar{b}$

- 

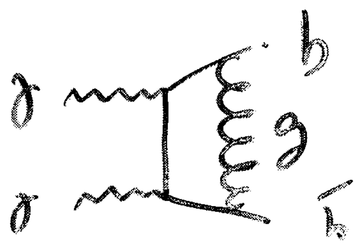
$$\sigma(J_z=0) \sim \frac{m_b^2}{s}$$

Borden, Bauer, Caldwell ('93)

- 

$\sigma_{\gamma\gamma\to b\bar{b}g}(J_z=0)$ is not suppressed

Borden, Khoze, Stirling, Ohnemus ('94)

- 

G.J., Tkabladze ('94, '96)

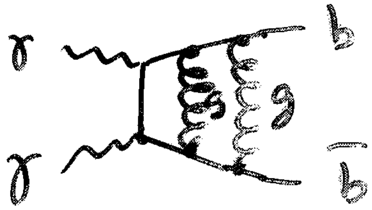
Contogouris, Merebashvili ('95)

(1-loop) $\mathcal{M}_{\gamma\gamma\to b\bar{b}}(J_z=0)$ is not suppressed, but still small

-3

$$\frac{\sigma^{soft+virt}(J_z=0)}{\sigma^{Born}(J_z=0)} = 1 - \frac{2\alpha_s}{\pi}\log^2\frac{s}{m_b^2}$$

$+2.5$

- 

$$+ \frac{121}{108}\frac{\alpha_s^2}{\pi^2}\log^4\frac{s}{m_b^2}$$

Fadin, Khoze, Martin ('97)

Melles, Stirling '98

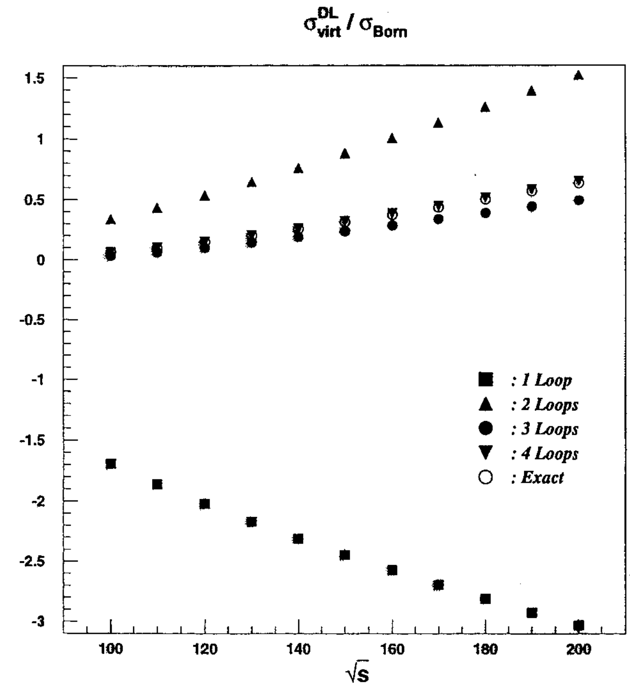


Figure [redacted]: The size of the virtual double logarithmic (DL) contributions relative to the Born cross section through four loops. The 'exact' result (open circles) is given by the all orders resummation according to Eq. (1) and is in very good agreement with the four–loop approximation given in Eq. (2). The huge one and two loop contributions can be seen to lead to physically distorted results.

$$\sigma^{DL}_{\text{virt+soft}} = \sigma_{\text{Born}} \left\{ 1 + \mathcal{F} \;\, {}_2F_2(1,1;2,\tfrac{3}{2};\tfrac{1}{2}\mathcal{F}) + 2\,\mathcal{F} \;\, {}_2F_2(1,1;2,\tfrac{3}{2};\tfrac{C_A}{4C_F}\mathcal{F}) \right\}^2$$
$$\exp\left(\frac{\alpha_s C_F}{\pi} \left[\log\frac{s}{m_q^2}\left(\frac{1}{2} - \log\frac{s}{4k_c^2}\right) + \log\frac{s}{4k_c^2} - 1 + \frac{\pi^2}{3} \right] \right) \tag{1}$$

1-loop 2-loop 3-loop

$$\frac{\sigma^{\text{DL}}_{\text{virt}}}{\sigma_{\text{Born}}} \sim 1 + 6\mathcal{F} + \frac{1}{6}\left(56 + 2\frac{C_A}{C_F}\right)\mathcal{F}^2 + \frac{1}{90}\left(94 + 90\frac{C_A}{C_F} + 2\frac{C_A^2}{C_F^2}\right)\mathcal{F}^3$$
$$+\frac{1}{2520}\left(418 + 140\frac{C_A}{C_F} + 238\frac{C_A^2}{C_F^2} + 3\frac{C_A^3}{C_F^3}\right)\mathcal{F}^4 + \mathcal{O}\left(\mathcal{F}^5\right) \tag{2}$$

4-loop

$$\mathcal{F} = -C_F\frac{\alpha_s}{4\pi}\log^2\frac{m^2}{s} = -0.45 \;@\sqrt{s} = 200\,\text{GeV}$$

$W_{\gamma\gamma} > 100$ GeV

No detector simulation

	$\gamma\gamma \to H \to b\bar{b}$	$\gamma\gamma \to b\bar{b}(g)$			$\gamma\gamma \to c\bar{c}(g)$		
	$J_z = 0$	$J_z = 0$	$J_z = 2$	tot	$J_z = 0$	$J_z = 2$	tot
σ, $\lvert\cos\theta\rvert < 0.95$	0.144 pb	0.174	0.189	0.362	2.28	3.06	5.33
σ, $\lvert\cos\theta\rvert < 0.7$	0.105 pb	0.034	0.065	0.099	0.47	1.03	1.51
# evnts, no b-tag	15700 [redacted]	14900 [redacted]			226000 [redacted]		
# $b\bar{b}$ evnts, b-tag	11000 [redacted]	10400 [redacted]			7910 [redacted]		

$\sigma(\gamma g \to b\bar{b}) = 6 \cdot 10^{-3}$ pb $\sigma(\gamma g \to c\bar{c}) = 4 \cdot 10^{-2}$ pb

Assuming $b\bar{b}(g)$ tagging efficiency of 70%

$c\bar{c}(g)$ — " — 3.5%

$$\frac{\Delta\Gamma(H\to\gamma\gamma)}{\Gamma(H\to\gamma\gamma)} = \frac{\sqrt{N_{obs}}}{N_{signal}} = 1.6\%$$

$\mathcal{L}_{\gamma\gamma}(0 < z < 0.82) = 150\ fb^{-1}$

$\mathcal{L}_{\gamma\gamma}(0.65 < z < 0.82) = 43\ fb^{-1}$

$\mathcal{L}_{e^+e^-} = 200\ fb^{-1}$

Simulation

Signal:

generate $\mathrm{H} \to \mathrm{b\bar{b}}$

JETSET parton shower to simulate higher order effects (gluon radiation)

JETSET string fragmentation

Background: including QCD 1-loop virtual corrections

Separate generation for two parton ($\mathrm{b\bar{b}}$, $\mathrm{c\bar{c}}$) and three parton final state ($\mathrm{b\bar{b}g}$, $\mathrm{c\bar{c}g}$) using $y_{\mathrm{cut}} = 0.01$

No parton shower

JETSET string fragmentation

$\sqrt{s}_{\mathrm{ee}} = m_{\mathrm{H}}/0.8 = 150$ GeV

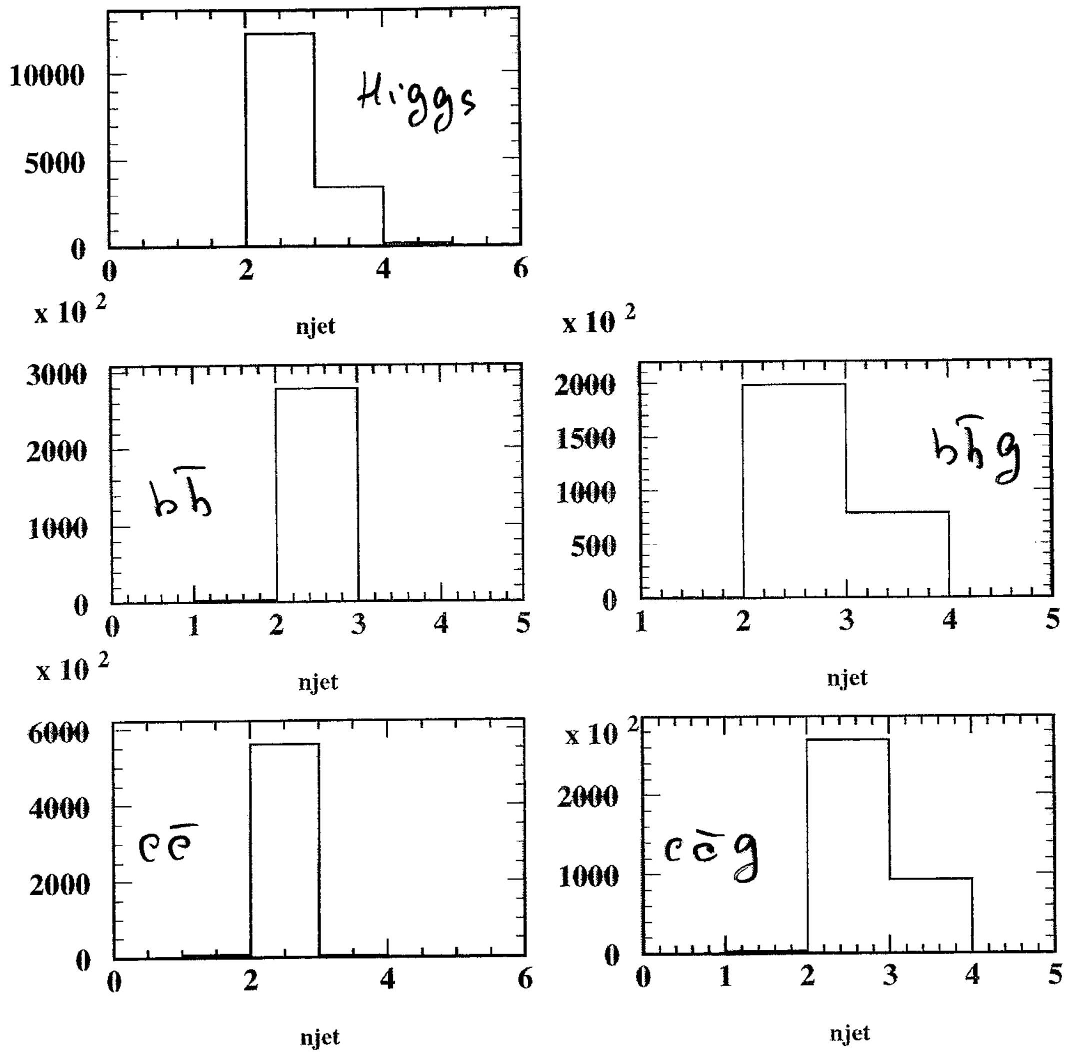
$m_{\mathrm{H}} = 120$ GeV, $m_{\mathrm{b}} = 5$ GeV, $m_{\mathrm{c}} = 1.5$ GeV

Integration / event generation based on BASES/SPRING

process	cross-section	cut
$\gamma\gamma \to \mathrm{H} \to \mathrm{b\bar{b}}$	0.15 pb	
$\gamma\gamma \to \mathrm{b\bar{b}}$	2.68 pb	$W > 60$ GeV
$\gamma\gamma \to \mathrm{b\bar{b}g}$	2.65 pb	$W > 60$ GeV
$\gamma\gamma \to \mathrm{c\bar{c}}$	110.70 pb	$W > 60$ GeV
$\gamma\gamma \to \mathrm{c\bar{c}g}$	70.31 pb	$W > 60$ GeV

no angular cut

Jet multiplicity

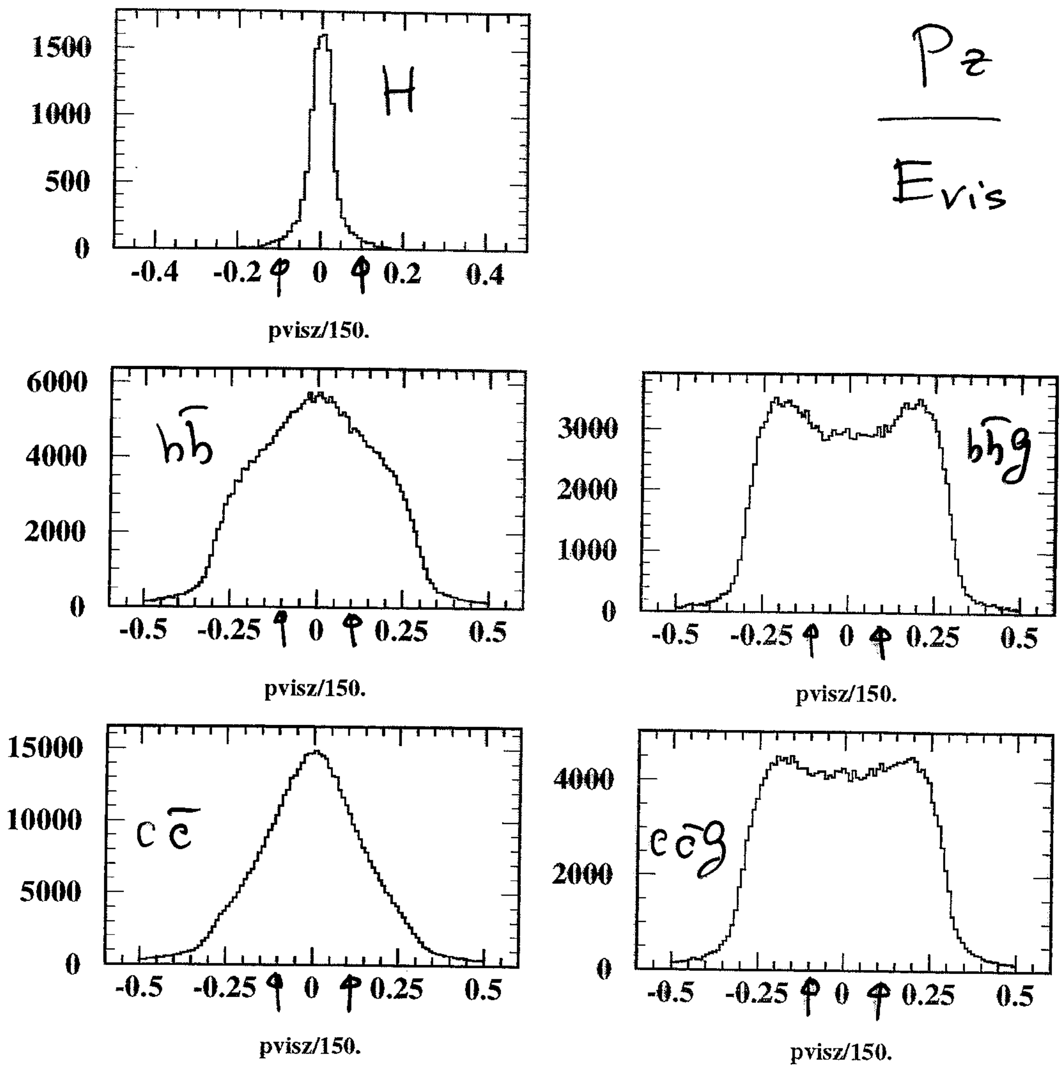


Jet reconstruction with Durham algorithm and

$y_{\rm cut} = 0.02$

3-jet events in Higgs signal from Parton Shower

3-jet events in background from NLO (real) corrections



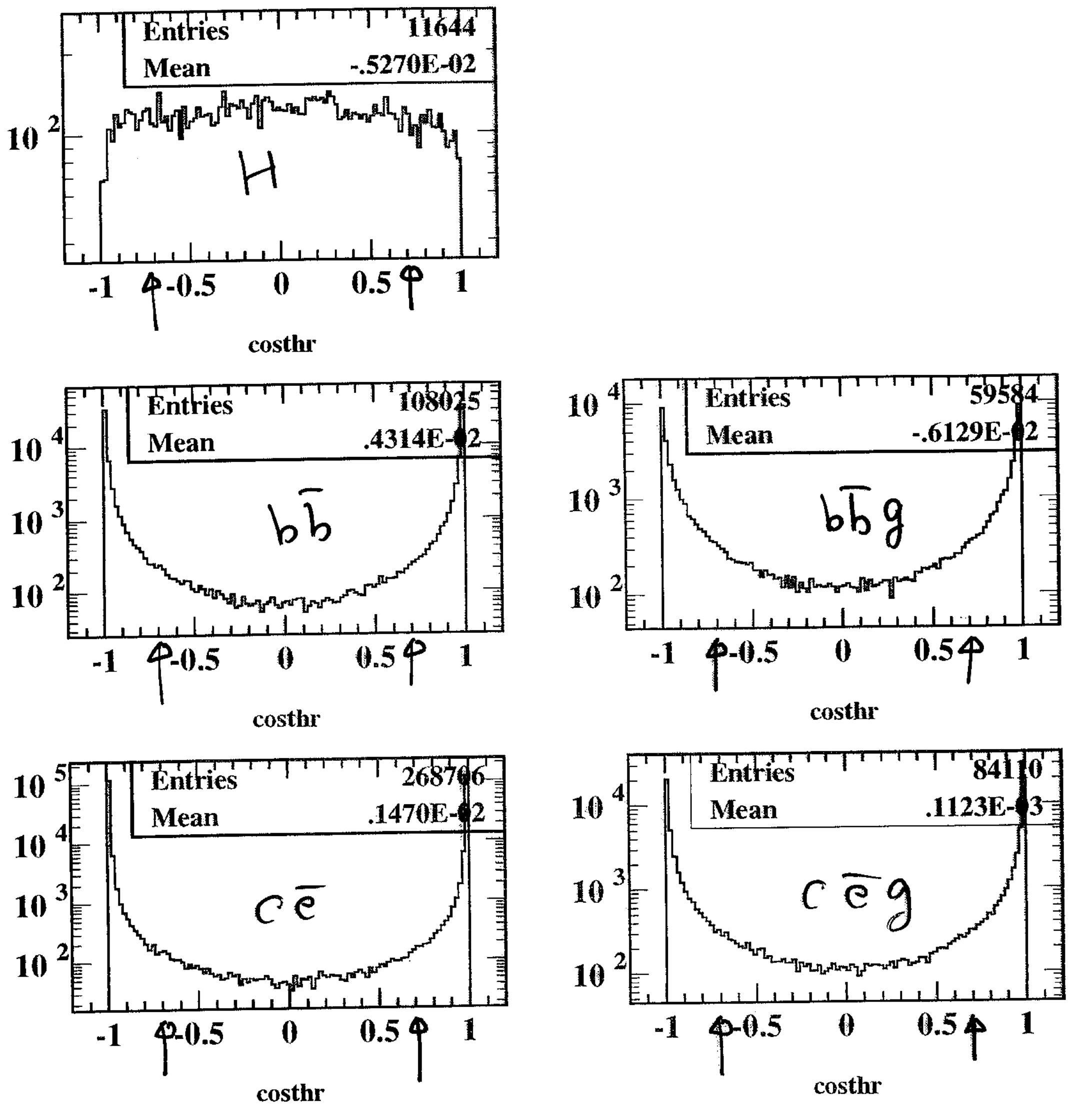
$$\frac{P_z}{E_{vis}}$$

Reconstruction using all detector objects (clusters/tracks)

Longitudinal missing momentum component

$p_z/\sqrt{s}_{ee}$

$n_{jet} = 2$



$n_{\rm jet} = 2$

$|p_{\rm z}|/\sqrt{s}_{\rm ee} < 0.1$

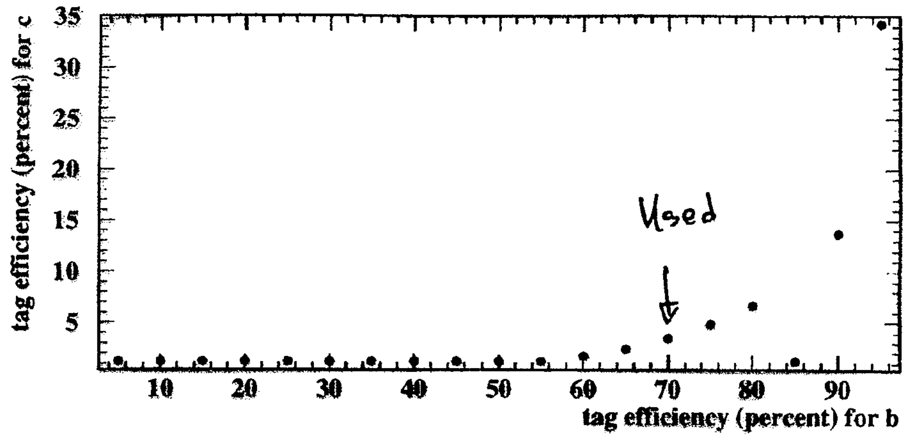
Higgs: isotropic decay

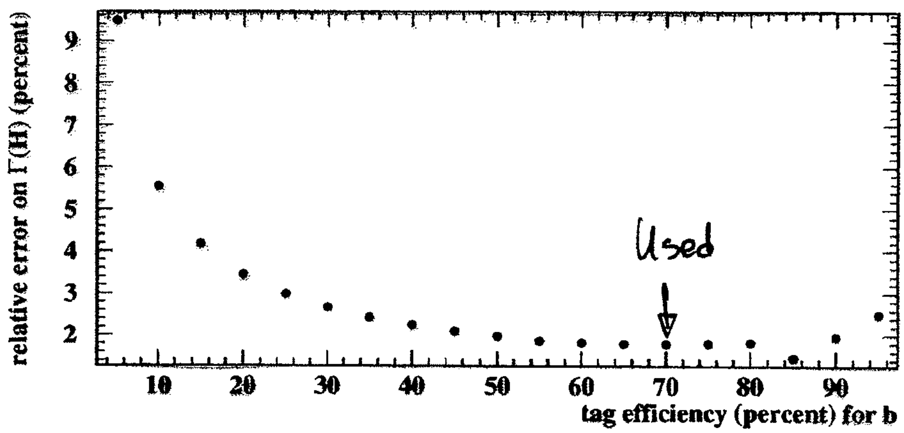
LO t-channel quark exchange ($\gamma\gamma \to \bar{\rm q}{\rm q}$):

$d\sigma/d\cos\theta^* \propto 1/(1-\cos^2\theta^*)$

NLO corrections increase the peaks

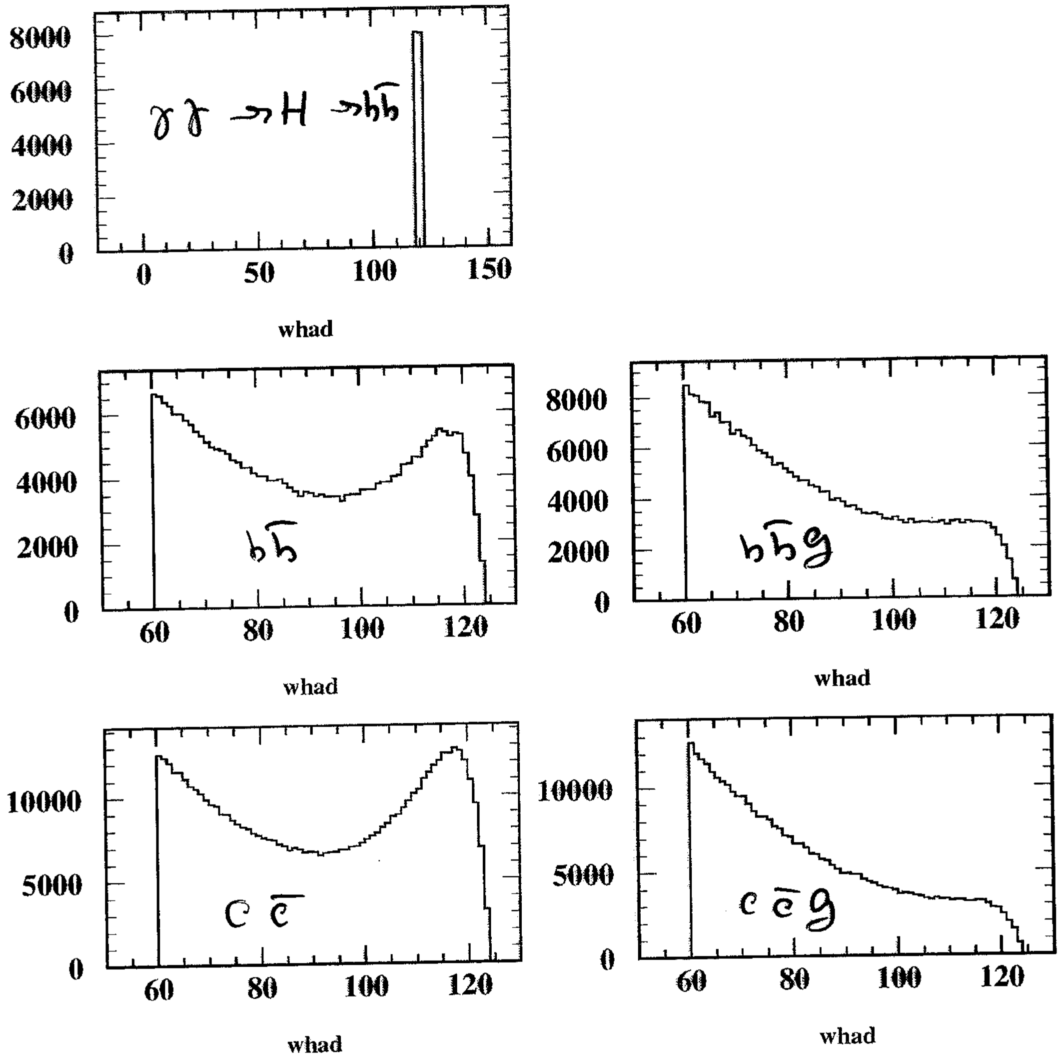
B tagging parametrisation





Using parametrisation by Marco Battaglia

Generated $\gamma\gamma$ cms energy (Whad)

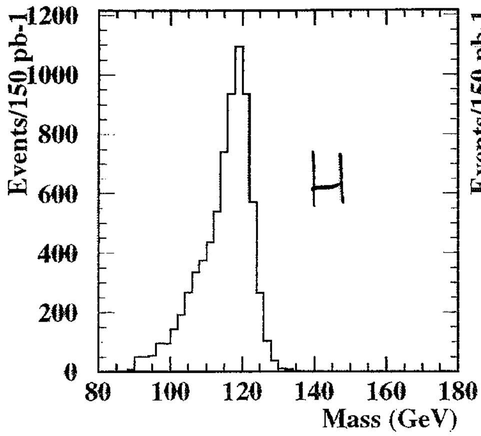


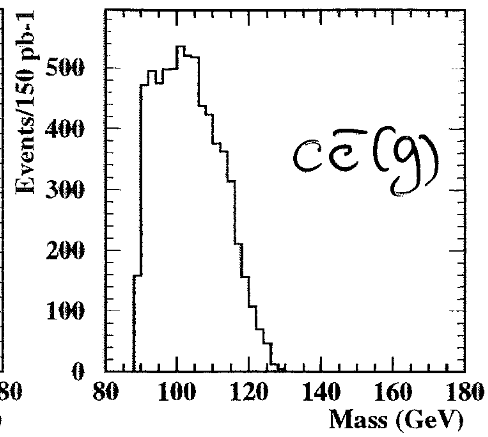
$$L_{\gamma\gamma} = 150\ \mathrm{fb}^{-1} \text{ for } 0 < z < 0.83$$

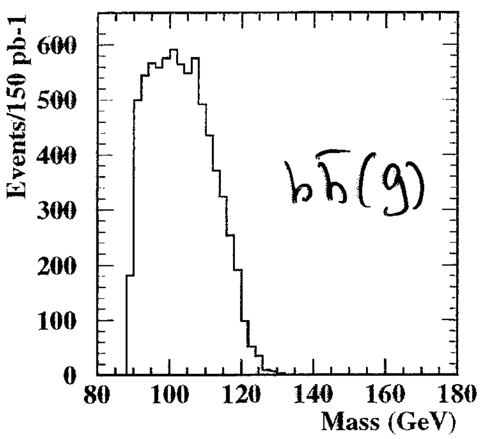
$$L_{\gamma\gamma} = 43\ \mathrm{fb}^{-1} \text{ for } z > 0.65$$

$$L_{ee} \approx 210\ \mathrm{fb}^{-1}$$

Mass distribution







Signal efficiency

35% – 40%

Cuts:

$n_{\text{jet}} = 2$ **(suppresses background at the peak !)**

$|\cos\theta_{\mathrm{T}}| < 0.7$

$|p_{\mathrm{z}}|/E_{\text{vis}} < 0.1$

$p_{\mathrm{T}} < 15$ **GeV**

$E_{\text{vis}}/\sqrt{s}_{\text{ee}} > 0.6$

$\gamma\gamma$ Collider as an Option at JLC, March 1997
Watanabe et al.

$M_H = 120$ GeV

$\sqrt{s_{e^+e^-}} = 150$ GeV

	$\sigma(\lvert\cos\theta\rvert < 0.95)$, pb	Events, $10\,fb^{-1}$
Signal		
$\gamma\gamma \to H \to b\bar{b}$	0.508	5080
Backgrounds ($\sqrt{s} > 75$ GeV)		
$\gamma\gamma \to b\bar{b}(g)$	0.727	7270
$\gamma\gamma \to c\bar{c}(g)$	15.1	151000

Number of events by the topological vertexing method
(Tagging eff. b-jet: 0.7, c-jet: 0.007)

Number of expected events within $100\,GeV < M_{jj} < 126\,GeV$	Double tag	Single tag
$H \to b\bar{b}$	832	1545
$\gamma\gamma \to b\bar{b}(g)$	121	223
$\gamma\gamma \to c\bar{c}(g)$	0.3	101
S / B	$832/121 = 6.9$	$1545/325 = 4.7$
Stat. accuracy	$\boxed{3.7\%}$	$\boxed{2.8\%}$

Assuming

$$\frac{\Delta\Gamma(H\to\gamma\gamma)}{\Gamma(H\to\gamma\gamma)} = \frac{\sqrt{N_{obs}}}{N_{obs}-N_{BG}} \simeq \underline{2\%}$$

$$\frac{\Delta BR(H\to b\bar{b})}{BR(H\to b\bar{b})} = 5\%$$

$$\frac{\Delta BR(H\to\gamma\gamma)}{BR(H\to\gamma\gamma)} = 13\%$$

the error on the total width will be

$$\boxed{\frac{\Delta\Gamma_{tot}}{\Gamma_{tot}} \simeq 14\%}$$

Compare to $\underline{\frac{\Delta\Gamma_{tot}}{\Delta\Gamma} \simeq 5\%}$ from LC value

+ BR($H\to WW^*$)

Possibility to measure $\Gamma(H\to gg)$ to higher accuracy using LHC measurements ?

$$\sigma(gg\to H\to\gamma\gamma) \simeq \frac{\Gamma(H\to gg)\,\Gamma(H\to\gamma\gamma)}{\Gamma_{tot}}$$

SUMMARY

- Measurements of $\Gamma(H \to 2\gamma)$ to 2% statistical accuracy seem to be possible

- Systematic errors:
  - ~ luminosity spectrum
  - ~ background shape
  - ~ detector, b-tagging
  - ~ ΔM_H

- Further optimization possible