$h \to \gamma\gamma$ at a $\gamma\gamma$-Collider

(or, light-by-light scattering via Higgses)

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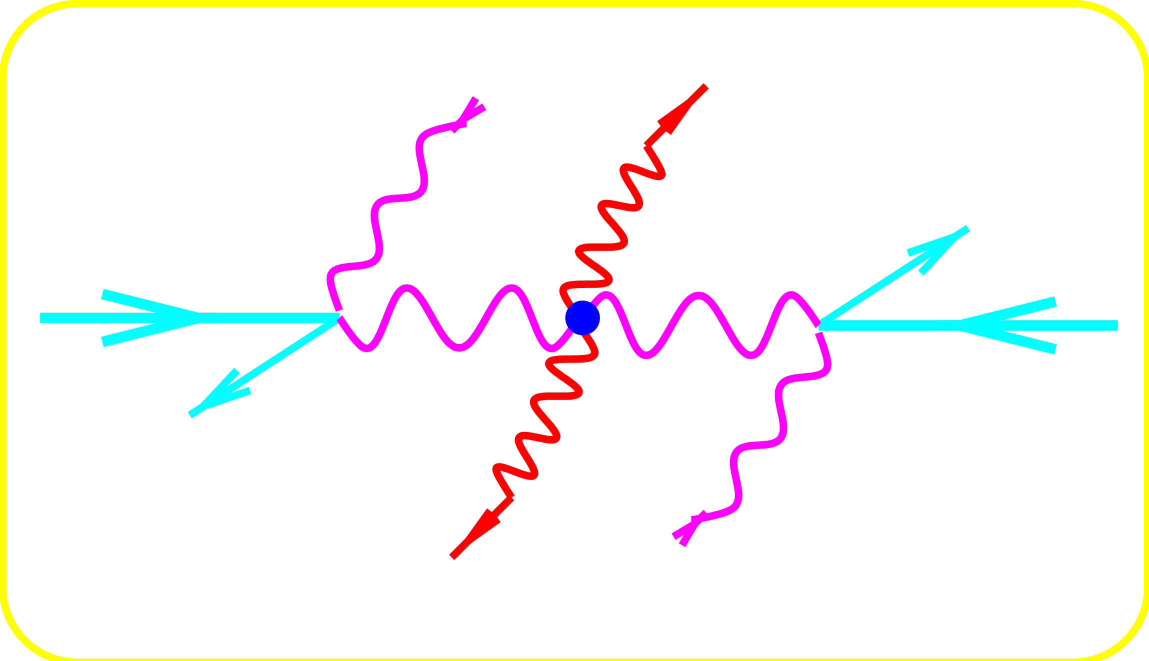

- Motivation & Assumptions
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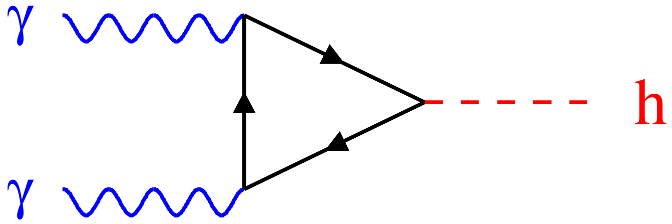
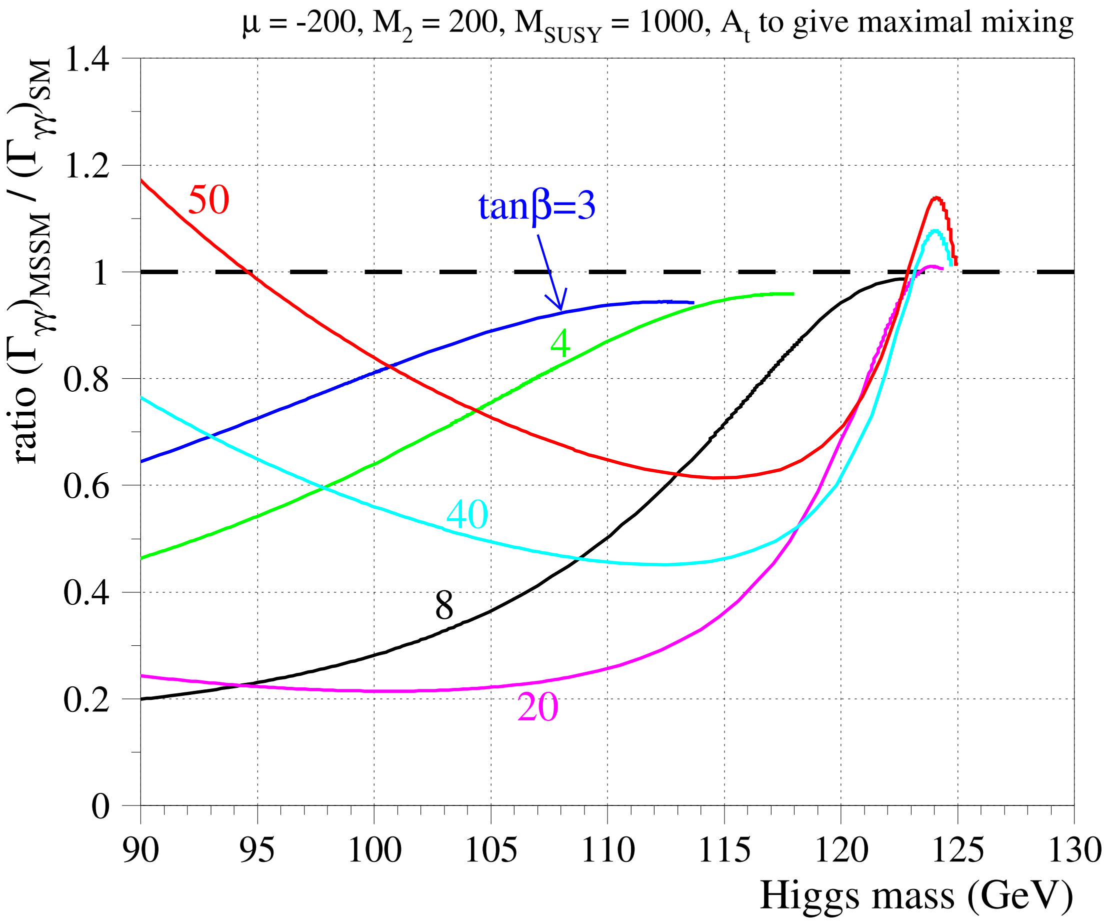
Motivation

The $h - \gamma\gamma$ coupling occurs only through loops, and hence can be very sensitive to New Physics.



A large suppression in the MSSM is possible.

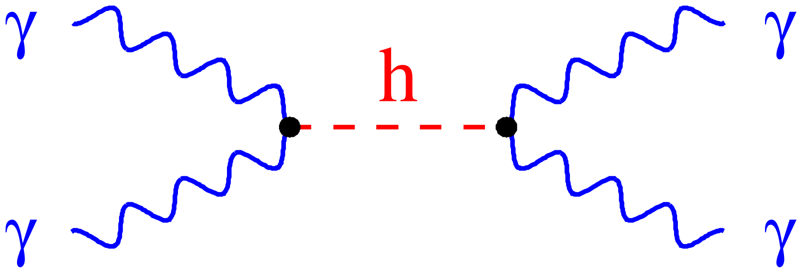


Measurements of $\Gamma_{\gamma\gamma}$ are very important!

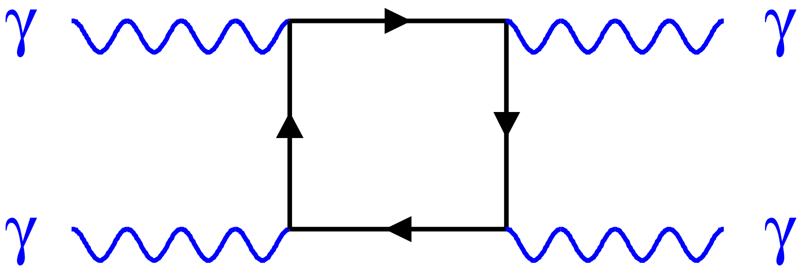
$\gamma\gamma \to \gamma\gamma$

{ Classically, light does not self-scatter – this is due only to quantum effects. }

The signal depends on $h - \gamma\gamma$ triangle both in initial & final state. Heavy, charged particles ($W^{\pm}$, $t\bar{t}$) dominate.



The background follows through a box. Light charged particles ($e^{\pm}$) dominate.



- $M_{\gamma\gamma}$: background falls rapidly, signal has a peak
- $\cos\theta_{\gamma}$: BG peaked in forward direction, SG is flat

{ We are ignoring QM interference – for now. }

Assumptions

This study is geared towards a NLC scenario.

- Higgs mass: $m_h = 120$ GeV
- electron energy: $E_e = 80$ GeV
- polarization: $P(e^-) = -0.8$ & $P(\text{laser}) = 1$
- yield: 11,000 Higgses produced in a year

Assume excellent calorimetry (CMS)

$$\frac{\sigma_E}{E} = \sqrt{\frac{0.015}{E} \oplus 0.0045}$$

which amounts to $\sigma_M = 0.42$ GeV.

We consider only a SM Higgs, for which

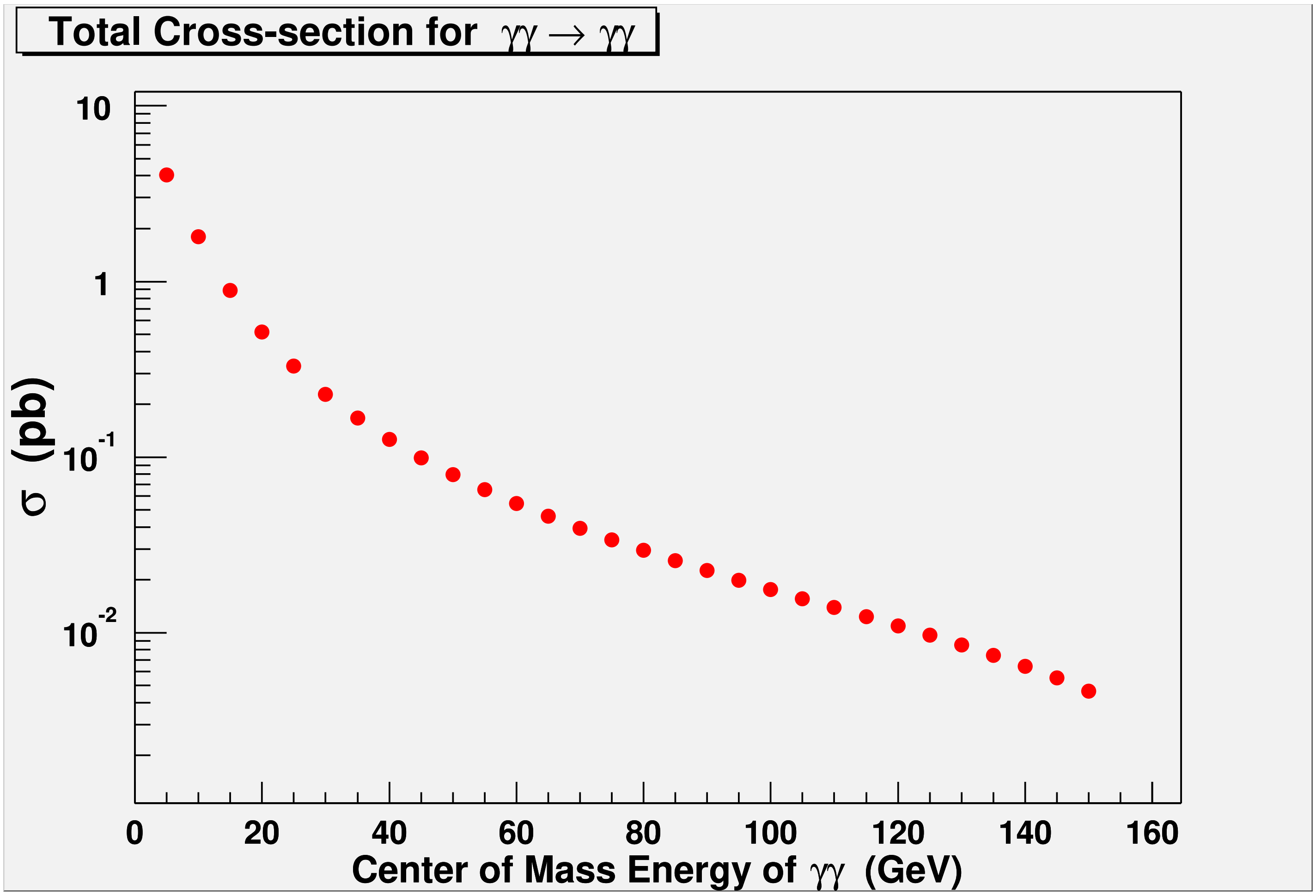
$$BR(h \to \gamma\gamma) = 2.1 \times 10^{-3}.$$

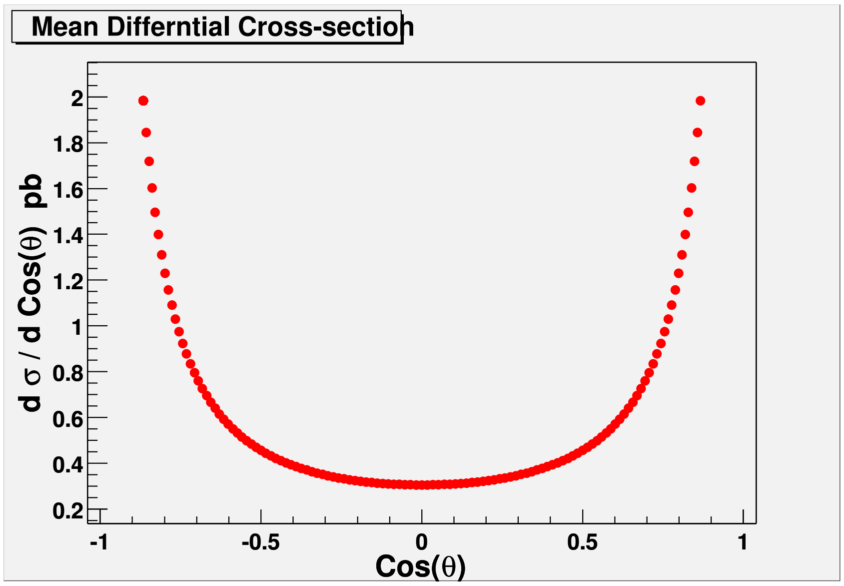
Background

There is no proper event generator for $\gamma\gamma \to \gamma\gamma$.

We wrote an *ad-hoc* generator based on parametrizations for the dependence of the cross section on $\sqrt{s_{\gamma\gamma}}$ and $\cos\theta^*_\gamma$. These dependencies factorize.

Source: SM calculation by Thomas Hahn based on FeynArts and FormCalc (sent by Sven Heinemeyer).





NORMALIZATION:

- We ran PANDORA for the NLC conditions to obtain a signal cross section, $\sigma_{\text{PANDORA}}(h)$.
- We patched in the parametrizations for the background cross section, and ran PANDORA again, to obtain $\sigma_{\text{PANDORA}}(bg)$.
- The number of background events before cuts is

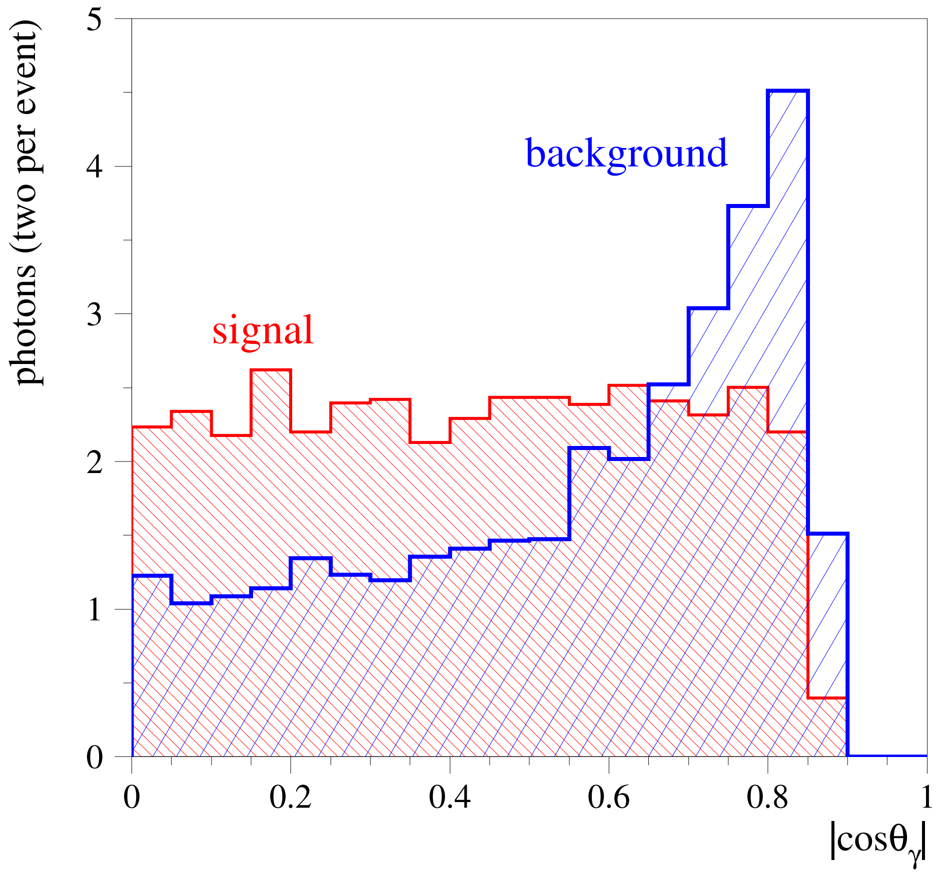
$$N(bg) = \frac{\sigma_{\text{PANDORA}}(bg)}{\sigma_{\text{PANDORA}}(h)} \times N(h)$$

  where $N(h) = 11,000$.
- yields: (for $M_{\gamma\gamma} > 96$ GeV)

$$N(h) = 23 \qquad \text{and} \qquad N(bg) = 149.$$

Analysis Cuts

The only analysis cut is on $\cos\theta_\gamma$.



This plot is normalized to one NLC year.

We choose the cut on $|\cos\theta_\gamma|$ which gives the best measurement of the signal:

$$\text{minimize}: \qquad F = \frac{\sigma_S}{S}$$

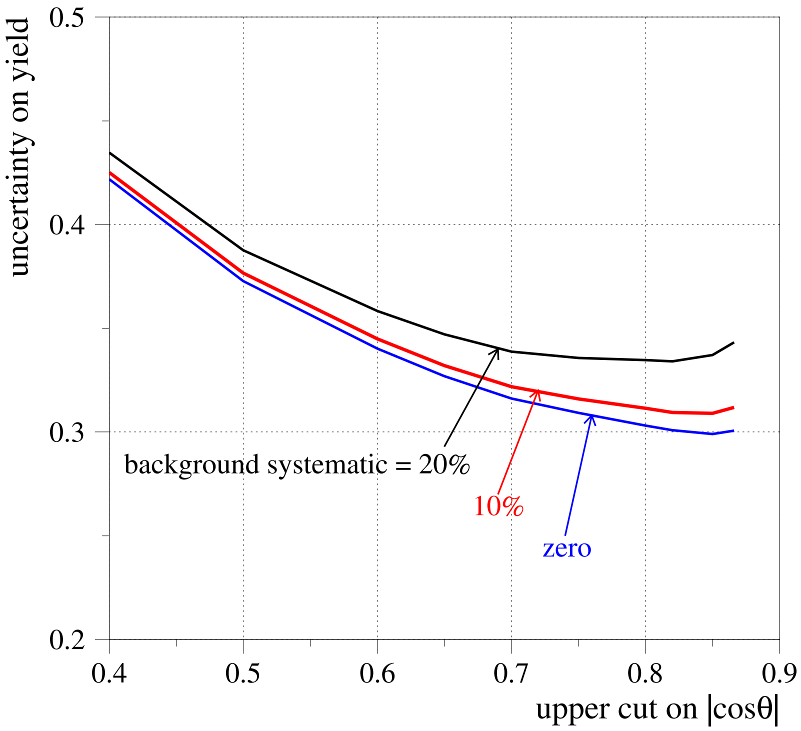
where S is the expected signal (in the SM).

Define a mass window (*e.g.*, $118 < M_{\gamma\gamma} < 122$ GeV) inside which we observe $N = S + B$ events. We subtract the expected background B which we know to a certain precision p_B. Then,

$$F = \frac{\sqrt{S + B + (p_B \cdot B)^2}}{S}$$

where S and B decrease as the cut on $|\cos\theta_\gamma|$ tightens. We verified this figure-of-merit for $p_B = 0$ by fitting example mass distributions.

We consider $p_B = 0$, 10% and 20%.



The best cut is $|\cos\theta_\gamma| < 0.85$.

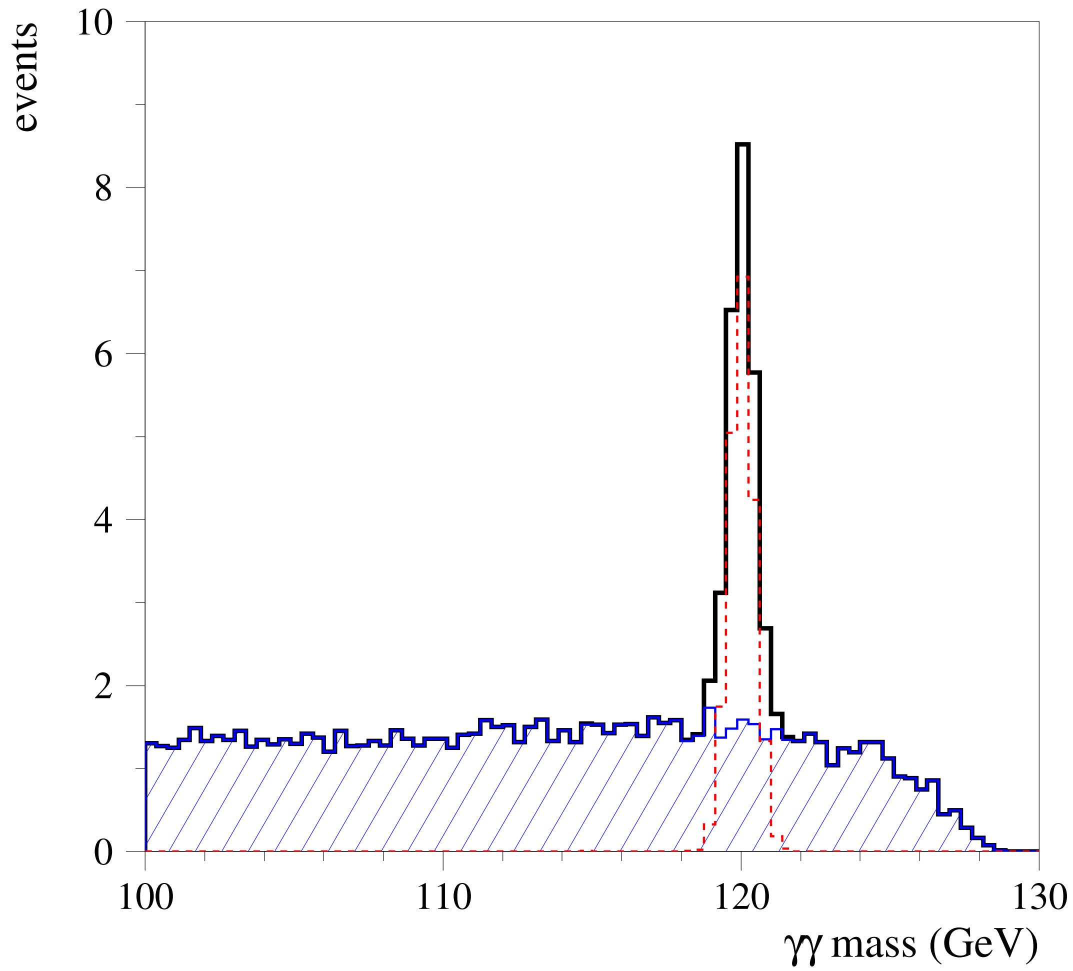
After this cut, the yields inside the mass window are:

$$N(h) = 20 \qquad \text{and} \qquad N(bg) = 16$$

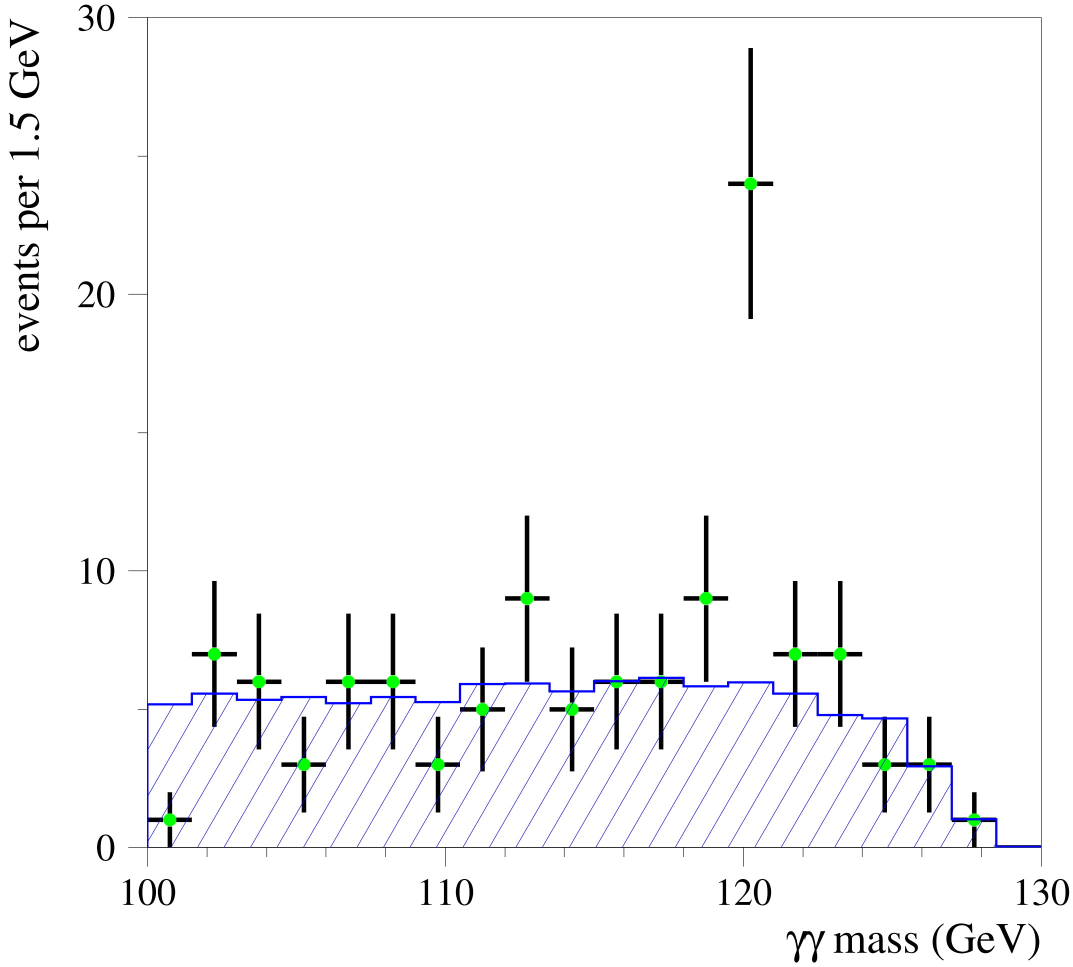
which give $S/B = 1.3$ and $F = 0.31$.

$\Rightarrow$ **the yield will be known to 30%.**

This is the mass distribution based on weighted events:



This is how a real distribution might look:



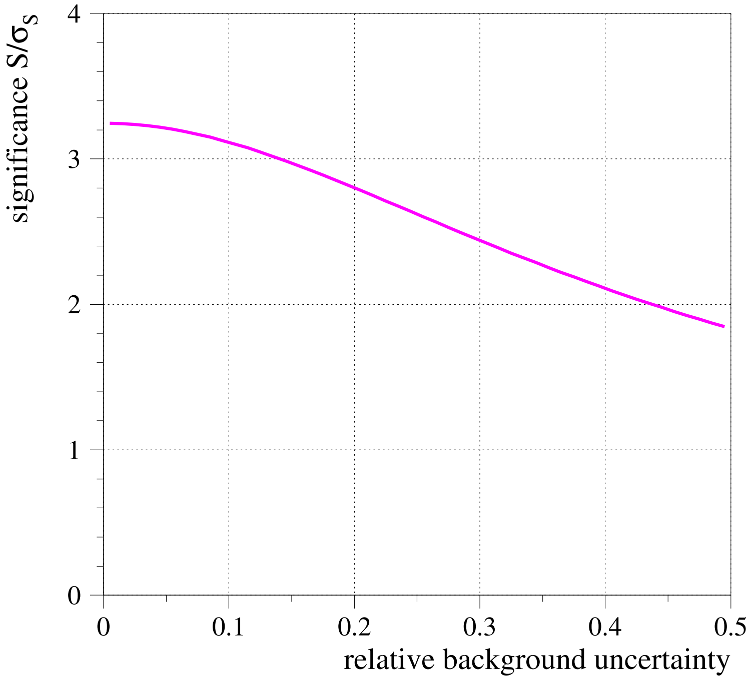
The significance of this peak is about 3σ.

Given the assumed mass resolution of 0.42 GeV, the Higgs mass could be measured to about

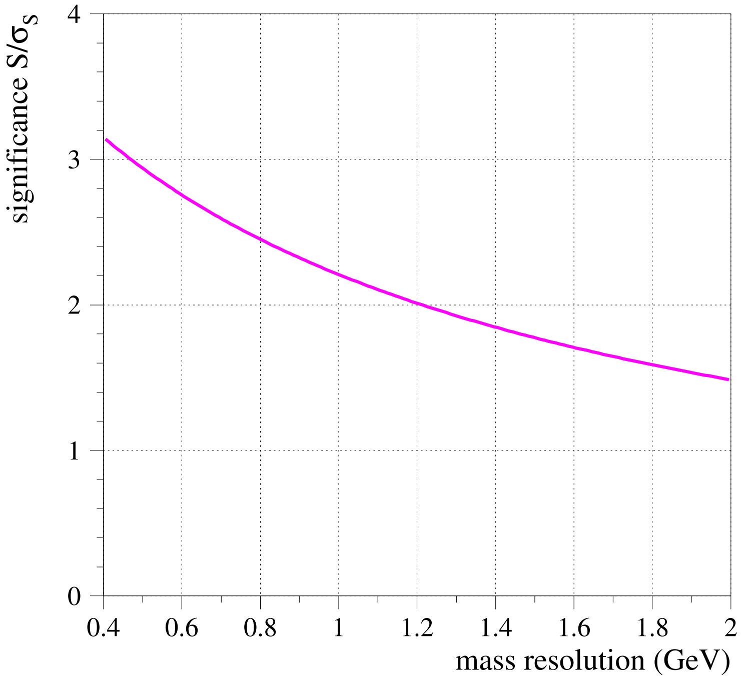
$$\boxed{150 \text{ MeV}}$$

after one year.

We examined how the significance depends on the uncertainty on the background (p_B):



Also, we checked how crucial is the mass resolution:



Extracting Γ_{total}

Aside from a constant of proportionality, the signal here is related to partial and total Higgs widths:

$$S = \kappa \frac{\Gamma_{\gamma\gamma}^2}{\Gamma_{\mathrm{tot}}}.$$

The partial width $\Gamma_{\gamma\gamma}$ can be measured to about 2.2% by combing data from $\gamma\gamma \to h \to b\bar{b}$ and $e^+e^- \to Zh \to Zb\bar{b}$.

As shown, S would be measured to 31% in one year of running, for a Higgs with a SM-like value for $BR(h \to \gamma\gamma)$. Consequently, Γ_{tot} would be extracted in a model-independent way with a precision of 31%.

After three years, this would become 18%.

For three years at a higher-yield machine such as CLICHE and TESLA, it would be 14%.

Summary

A preliminary study of $\gamma\gamma \to h \to \gamma\gamma$ has been completed.

Findings:

1. The background is not negligible, but is managable.
2. For the NLC parameters, one year affords a signal measurement of 31% and a mass measurement of 150 MeV.
3. The dependence of the signal measurement on mass resolution and background uncertainty is not critical.
4. The total width can be extracted at the 30% level.

Caveats and Loopholes:

1. The background cross section calculation needs to be verified.
2. The results are based on the SM. In the MSSM the yield could be significantly reduced.
3. We have ignored QM interference between signal and background.