Higgs at $\gamma\gamma$-Colliders

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Higgs discoveries and studies in a series of $\gamma\gamma$-Colliders

STAGE #1: Assume SM-Higgs (or light h^0) found

→ Then we want to study its properties:

- Mass
- $\Gamma_{\rm tot}$, and $\Gamma(h^0 \to \gamma\gamma)$
- quantum numbers, CP properties
- etc...

⇒ *TEST OF PHYSICS BEYOND THE SM!!!*

→ Propose 1st: $\gamma\gamma$-Collider to be a:

- Higgs-Factory:
  – Single resonance production of h^0
  – Modest initial E_{ee} energy requirements
    $M_{h^0} = 120$ GeV$, E_{ee} \simeq 150$ GeV

STAGE #2: Look for other Higgs ... MSSM-2HDM

⟹ Then want to look for & study the neutral $A^0 \& H^0$ and charged $H^{\pm}$:

- CP $\Leftarrow$ crucial
- Can cover regions *not* accessible to LHC ($\tan\beta \simeq 7, M_{H,A} \geq 200$ GeV)

⟹ Propose 2nd: $\gamma\gamma$-Collider with increased energies:

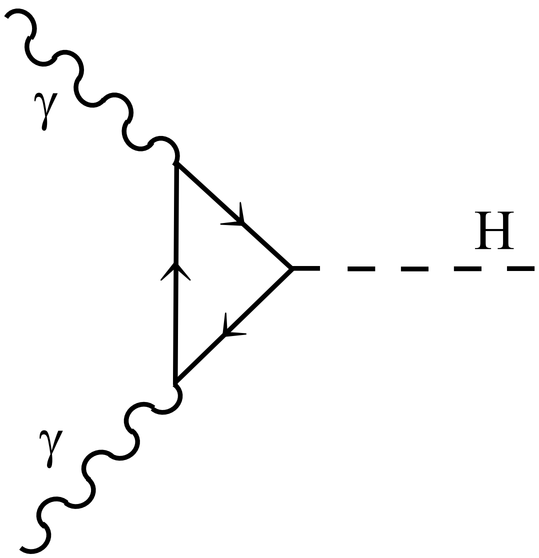
- $E_{ee} \geq 200$ GeV
- γ's with both:

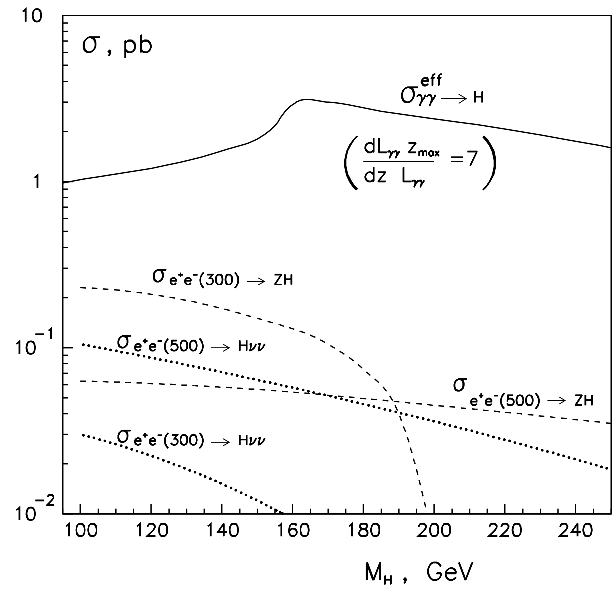
– circular (e^- polarized)

– linear (e^- unpolarized)

polarization becomes crucial !!!

Why $\gamma\gamma$-Colliders ? Physics Reasons





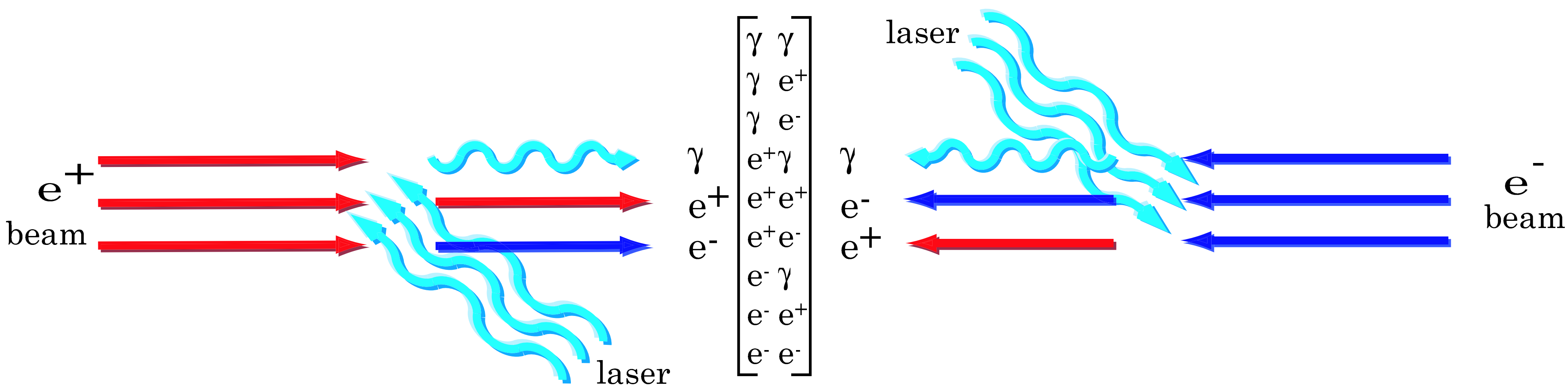
- Can obtain well defined $J = 0, 2$ final states, when starting with circularly polarized γ's
  $\Rightarrow$ important for controlling backgrounds.

- Large cross section
  $\Rightarrow$ Heavy particles in loops!

- Well defined CP-states, when working with linearly polarized γ's
  - $(\gamma_{||} \;\; || \;\; \gamma_{||}) \quad \Rightarrow \quad$ CP-even
  - $(\gamma_{||} \;\; \perp \;\; \gamma_{||}) \quad \Rightarrow \quad$ CP-odd

How can we make a $\gamma\gamma$-Collider?

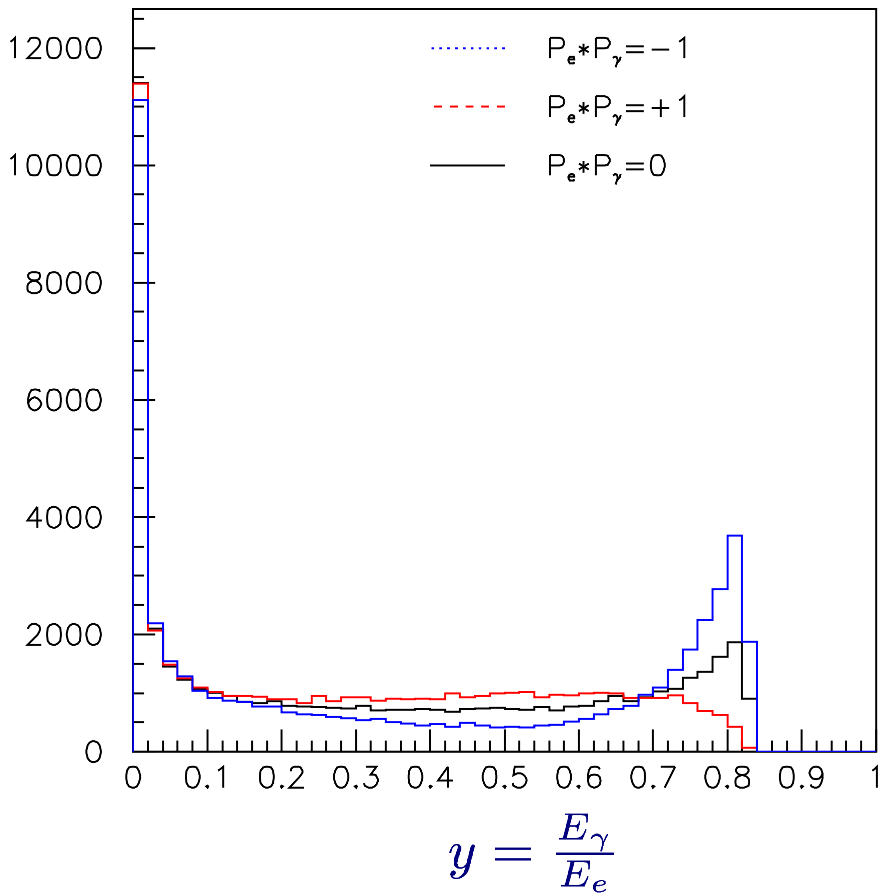
⇒ Comptom Laser Backscattering:

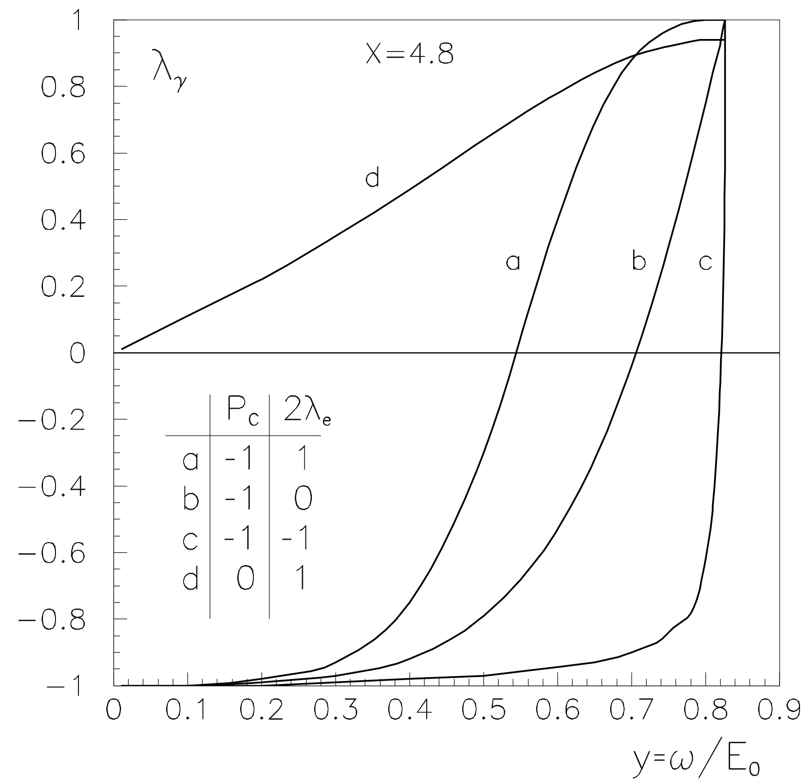


$$E_e + w_o \rightarrow E_{e'} + E_\gamma$$

$$x_{max} = \frac{4E_e w_o}{m_e^2} \qquad E_\gamma = \frac{x}{x+1}E_e \qquad y_{max} = \frac{E_\gamma}{E_e}$$

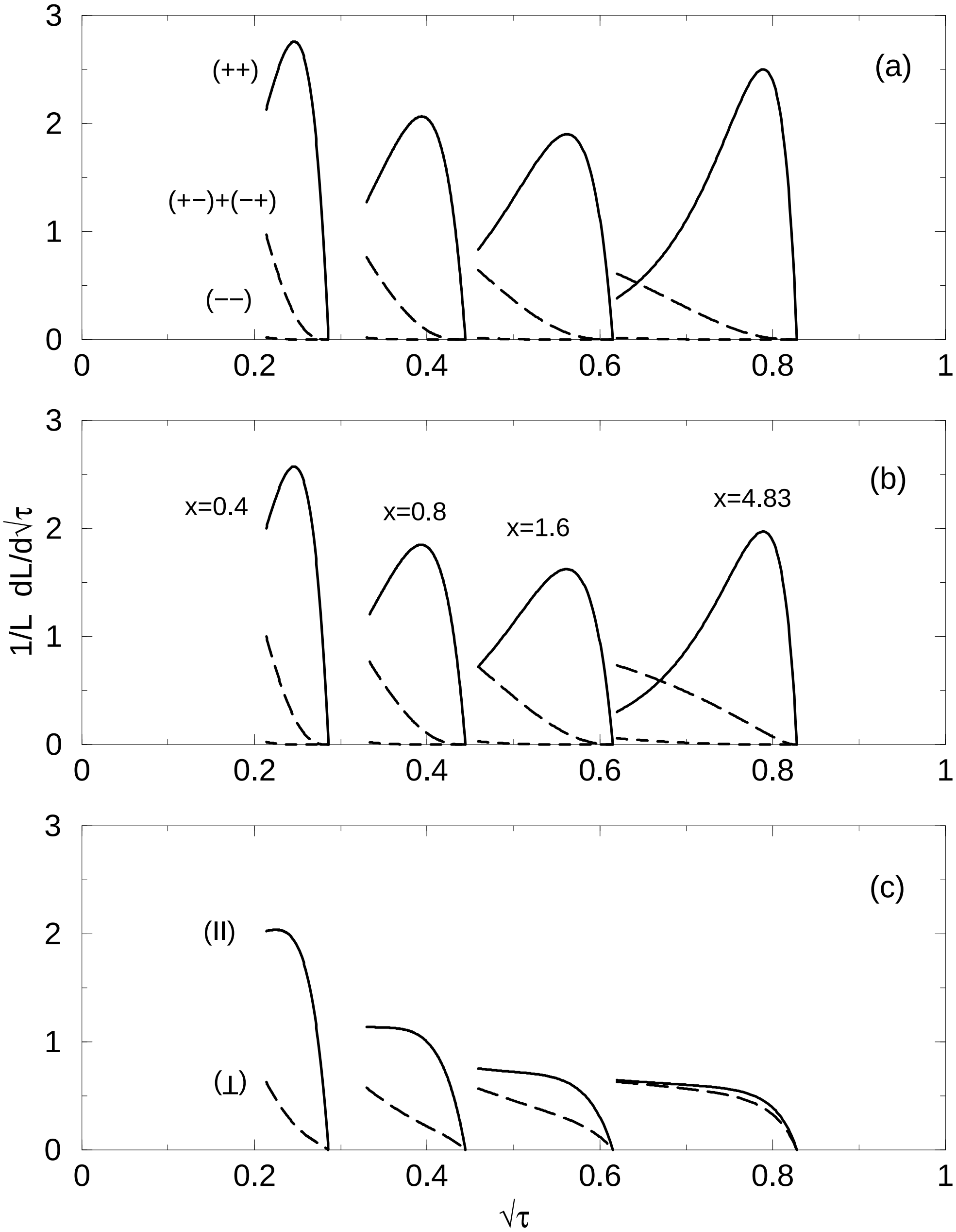
Energy Spectra and Polarization for the produced γ beams?





Dependence on the initial polarization of e^- and laser

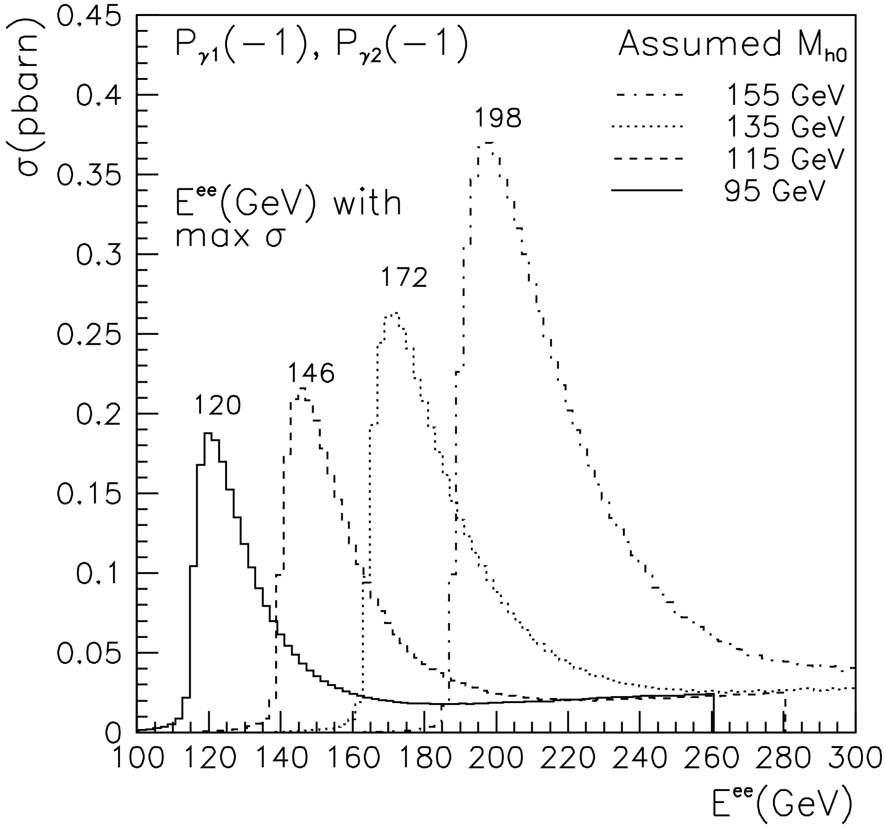
Luminosities to be expected in $\gamma\gamma$

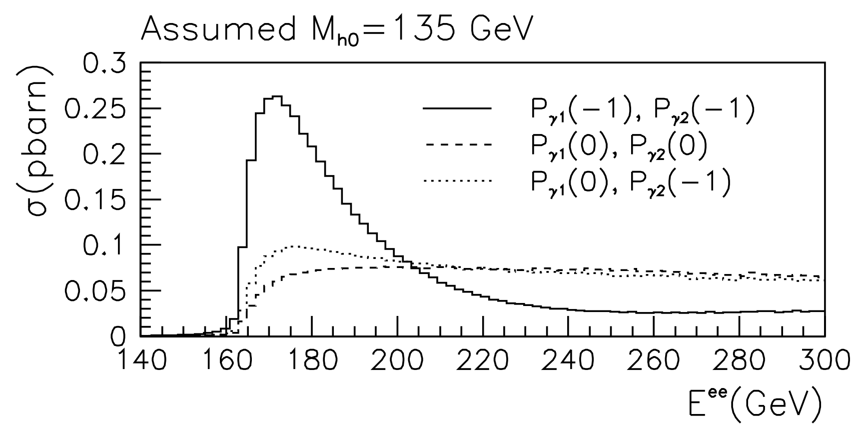


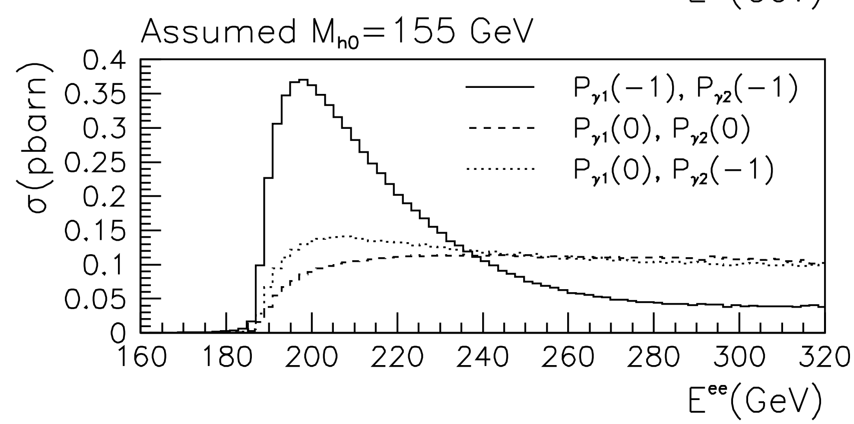
- $\sqrt{\tau} = E_{\gamma\gamma}/E_{e^+e^-}$, L=luminosity
- (a) assumes 100% polarization of e^-,
  $\pm$ stands for helicity of photons
- (b) assumes 80% polarization of e^-
- (c) assumes 0% polarization of e^-;
  need small x to have one of the polarization orientations dominating

$\gamma\gamma$ as a Higgs factory... e^- beam tuning

- Example. Assume 100% polarized electrons used:

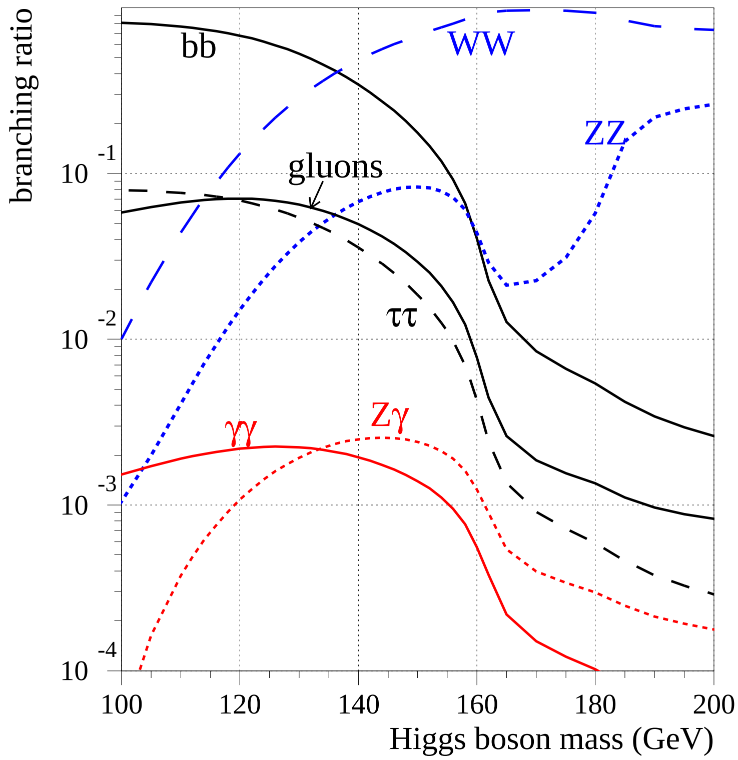




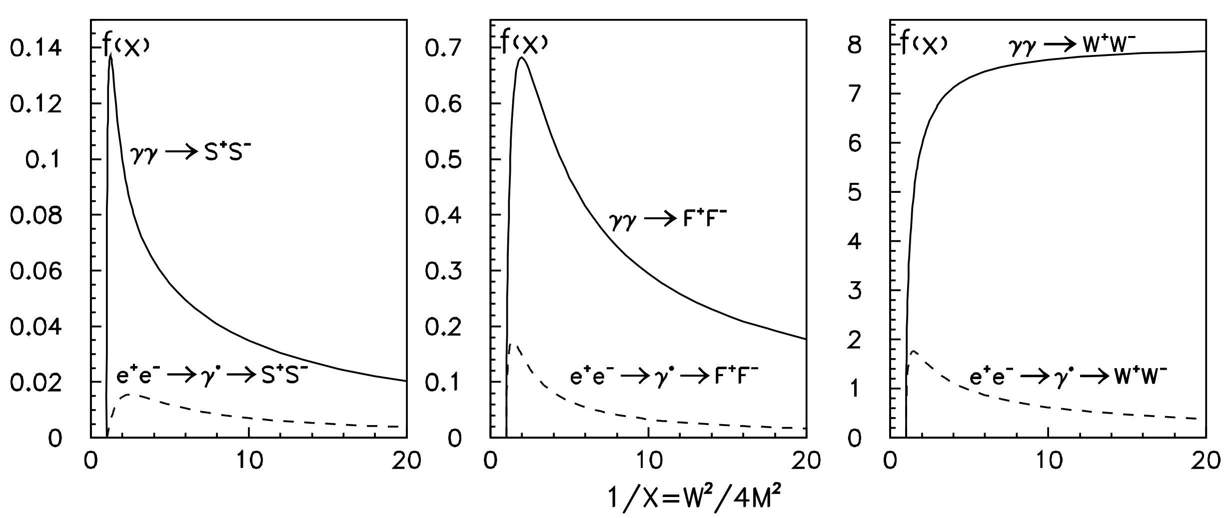


Things to keep in mind in Higgs selection

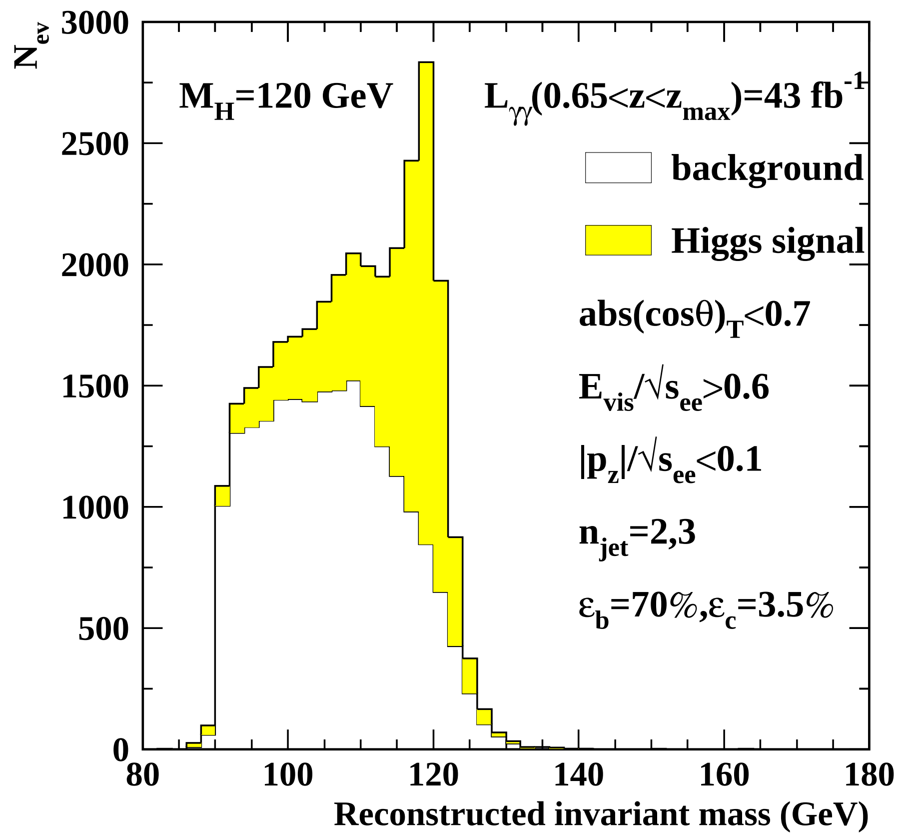
Obviously, the search mode depends on its mass....



$\gamma\gamma$ is not only efficient in producing Higgs...



Selection for 120 GeV SM-Higgs ($h^0 \to b\bar{b}$)

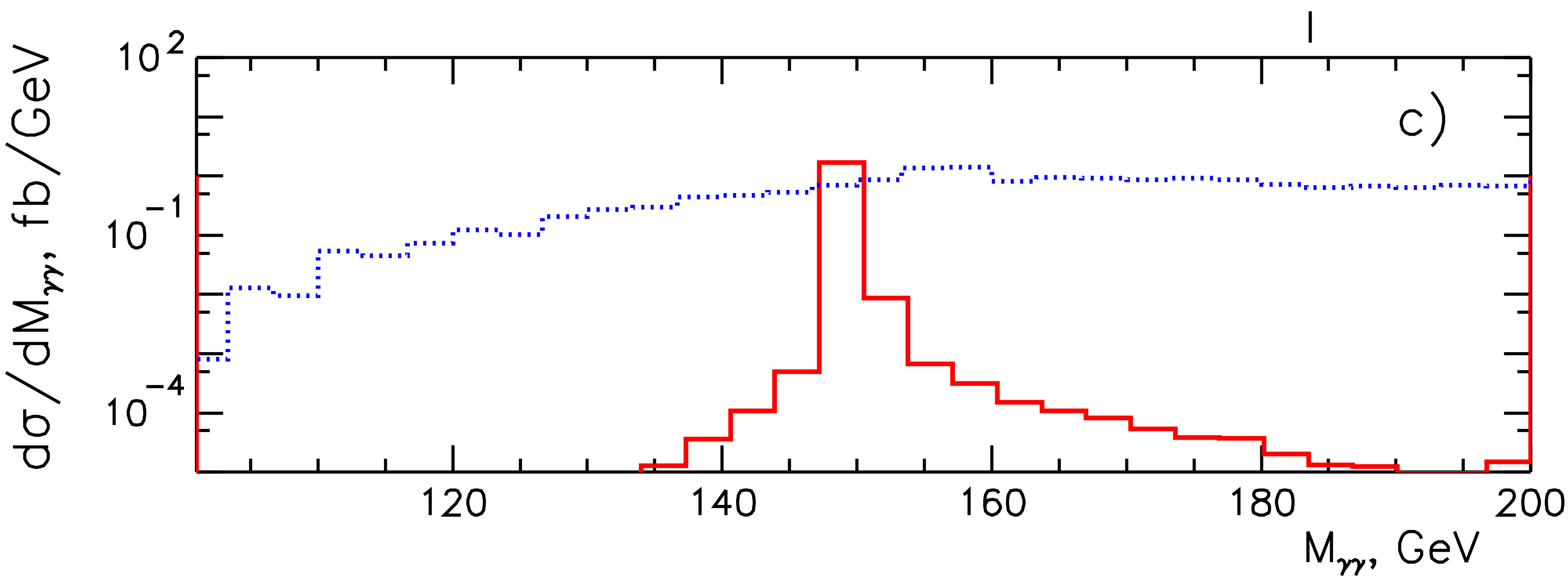


signal = two b-quark jets background = continuum b production

- photons of the same helicity ⇒ suppress continuum $b\bar{b}$
- this does not suppress the $b\bar{b}g$ final state!

It is *still* possible to isolate a good signal for the Higgs: hep-ph/0101056

Selection for 150 GeV SM-Higgs ($h^0 \to W^+W^-$)



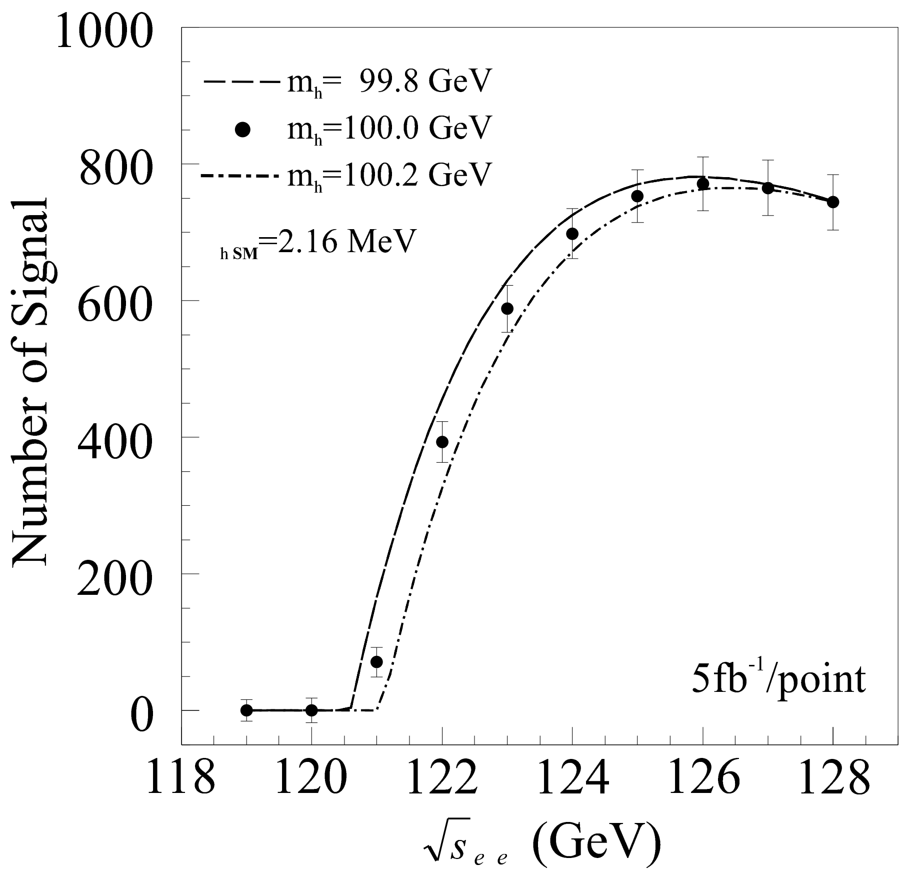
Huge continuum production of W^+W^- makes this exceptionally difficult: $\sigma(\gamma\gamma \to WW) \sim 81$ pb

Nonetheless, a measurement for < 160 GeV looks quite feasible. Boos et al. hep-ph/9801359

Mass measurement of the Higgs (Scan)

Take advantage of the sharp edge of the photon spectrum to pin down the Higgs mass.

$\Longrightarrow \Delta m_h = 100$ MeV for 50 fb^{-1}



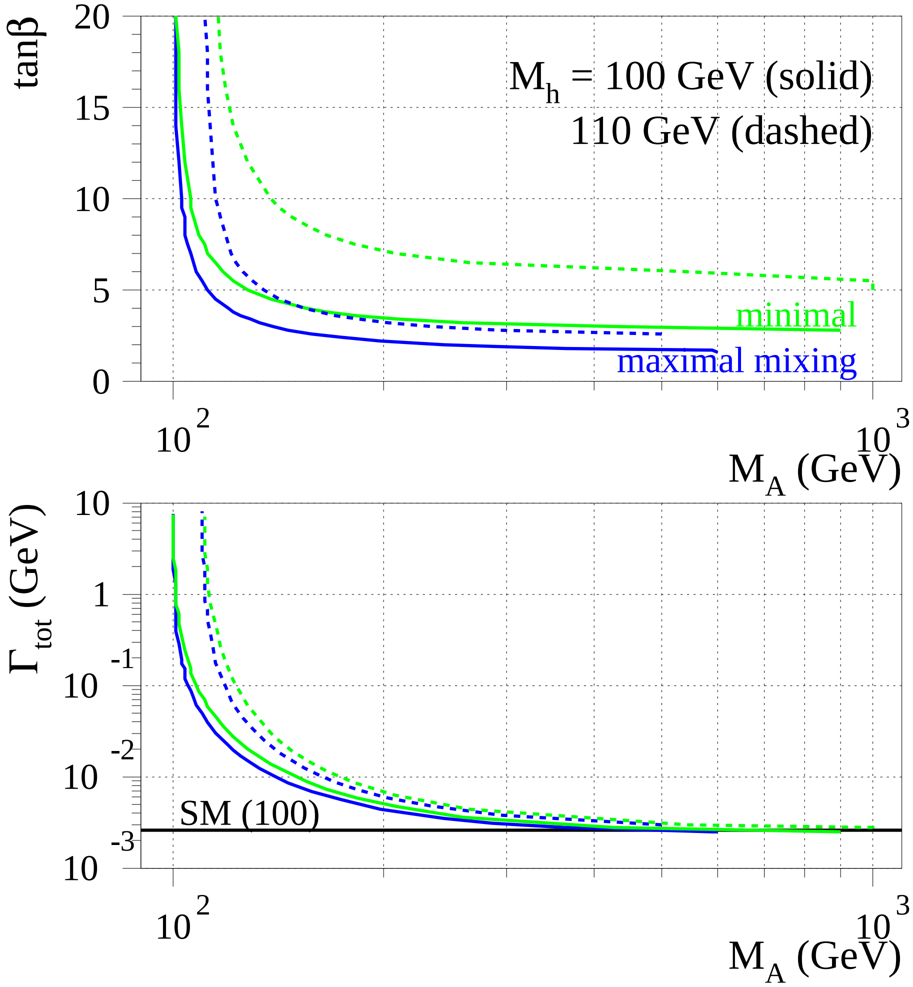
The same data would give $\frac{\Delta\Gamma_{tot}}{\Gamma_{tot}} = 6\%$.

Ohgaki, hep-ph/0002083

What we learn from M_{h^0}?

As an example, a measurement of the mass limits $\tan\beta$ and m_A.

Effect due to stop mixing possiblities.



Another measurement, constraining m_A is Γ_{tot} ! M. Schmitt, $\gamma\gamma$WS2001.

How to get Widths, Γ_{tot} & $\Gamma_{\gamma\gamma}$?

The mass peak when $M_h^0 = 120$ GeV, gives a 2% measure of

$$\{\ \Gamma(h^0 \to \gamma\gamma) \times BR(h^0 \to \gamma\gamma)\}$$

after 40 fb^{-1}.

Taking $BR(h^0 \to \gamma\gamma)$ and $BR(h^0 \to b\bar{b})$ from elsewhere,

$$\Gamma_{tot} = \frac{\{\Gamma_{\gamma\gamma} \times BR(h^0 \to b\bar{b})\}}{\{BR(h^0 \to \gamma\gamma)\{\times\{BR(h^0 \to b\bar{b})\}}$$

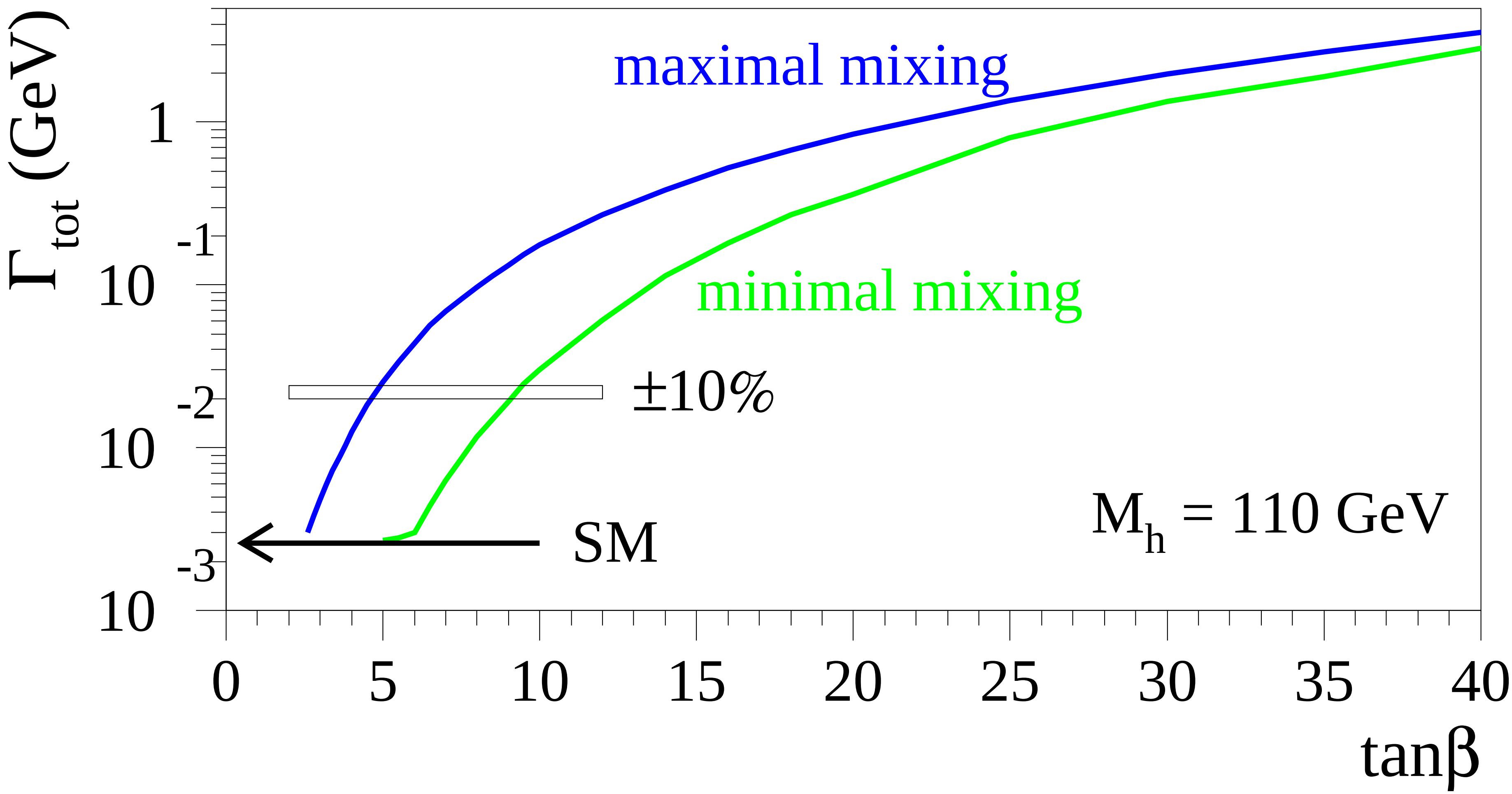
measured to 10–15%. (Melles, Ohgaki: similar conclusions)

This is often proposed as *the* way to get Γ_{tot}.

This would be a model-independent result.
Snowmass 1996, Gunion et al. hep-ph/9703330

(NB: For other possibilitues, see Ohgaki's scan method...)

What we learn from Total Width, Γ_{tot}?

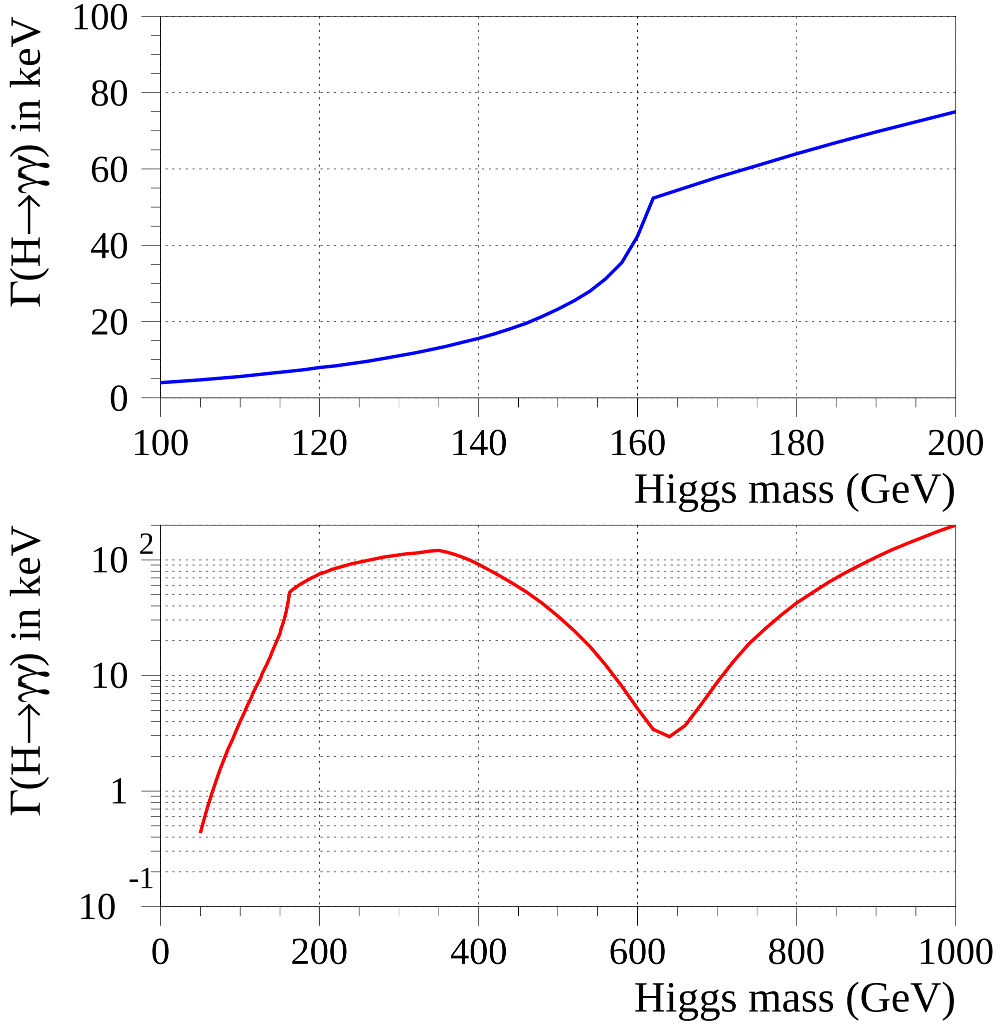


⇒ key for SUSY...

Higgs $\gamma\gamma$ Partial Width, $\Gamma_{\gamma\gamma}$

(More clues for SUSY...)

$\Rightarrow$ $\Gamma_{\gamma\gamma}$ is a strong function of M_{h^0}:



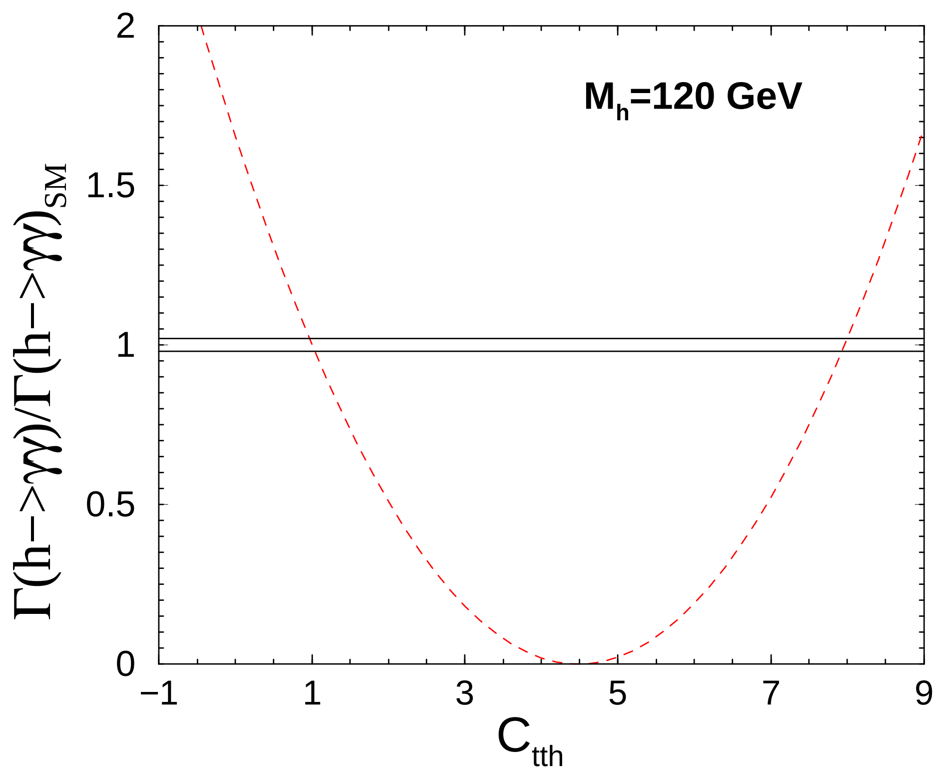
The main contributions come from W and t. Unfortunately, they interfere destructively.

What we learn from Partial Width, $\Gamma_{\gamma\gamma}$?

Higgs coupling to mass is an essential prediction in Higgs-theory.

$\Rightarrow$ We need to test it!!!

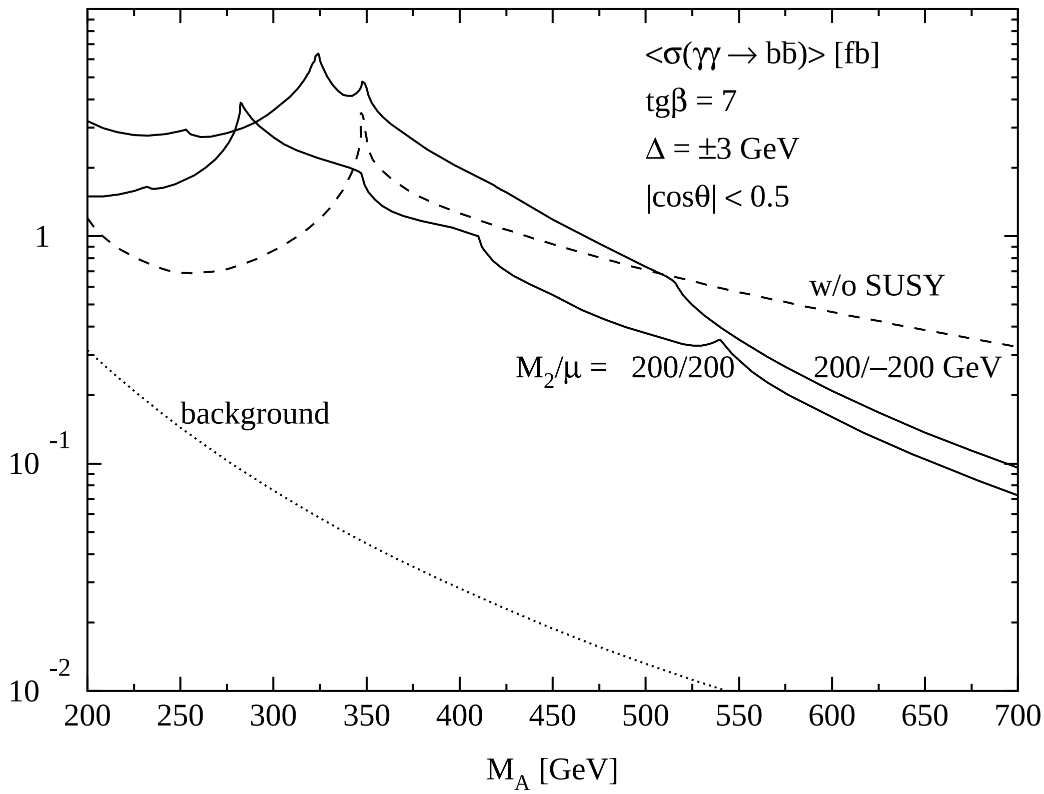
Dawson, $\gamma\gamma$WS2001.



$\gamma\gamma \rightarrow h$ depends on the tth coupling, and a 2% measurement of this cross section results in a 4% constraint on Y_t.

Other Neutral Heavy Higgses

Look at regions at tan β regions that are not accessible to LHC:



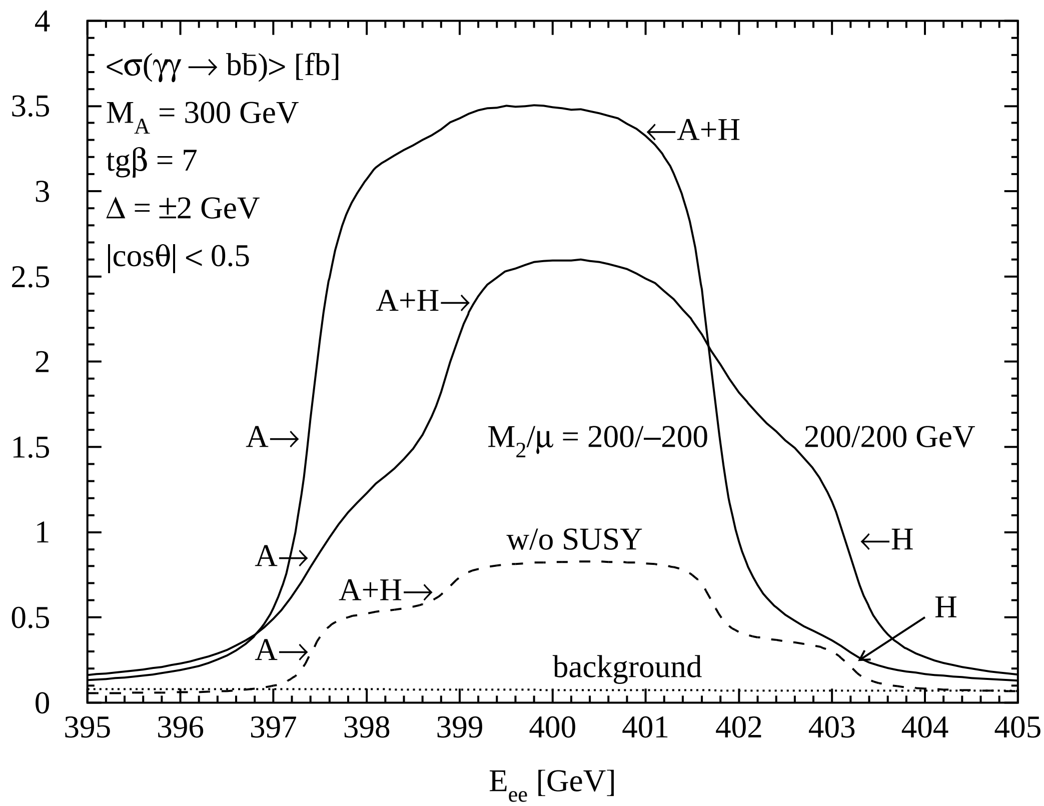
- Cross sections are not too small, and backgrounds are easily managed.
- H and A would be produced singly, the mass range is much greater than in e^+e^- – up to 80% of $\sqrt{s}_{ee}$.
- The $b\bar{b}$ final state confirmed by preliminary event simulations ($\gamma\gamma$WS2001) .

Mühlleitner hep-ph/0101083

What about if $M_A \simeq M_H$

Mühlleitner hep-ph/0101083

In the MSSM, the H and A bosons are very close in mass, test it by scanning:



$h_0, H \Rightarrow$ CP-even
$A \Rightarrow$ CP-odd

This lineshape is sensitive to CP mixing, and changes with different initial states of CP, therefore can turn ON/OFF using lineraly polarized γ's.
M. Schmitt, $\gamma\gamma$WS2001.

CP test in the Higgs Sector

CP Violation is the great enigma of high energy physics.

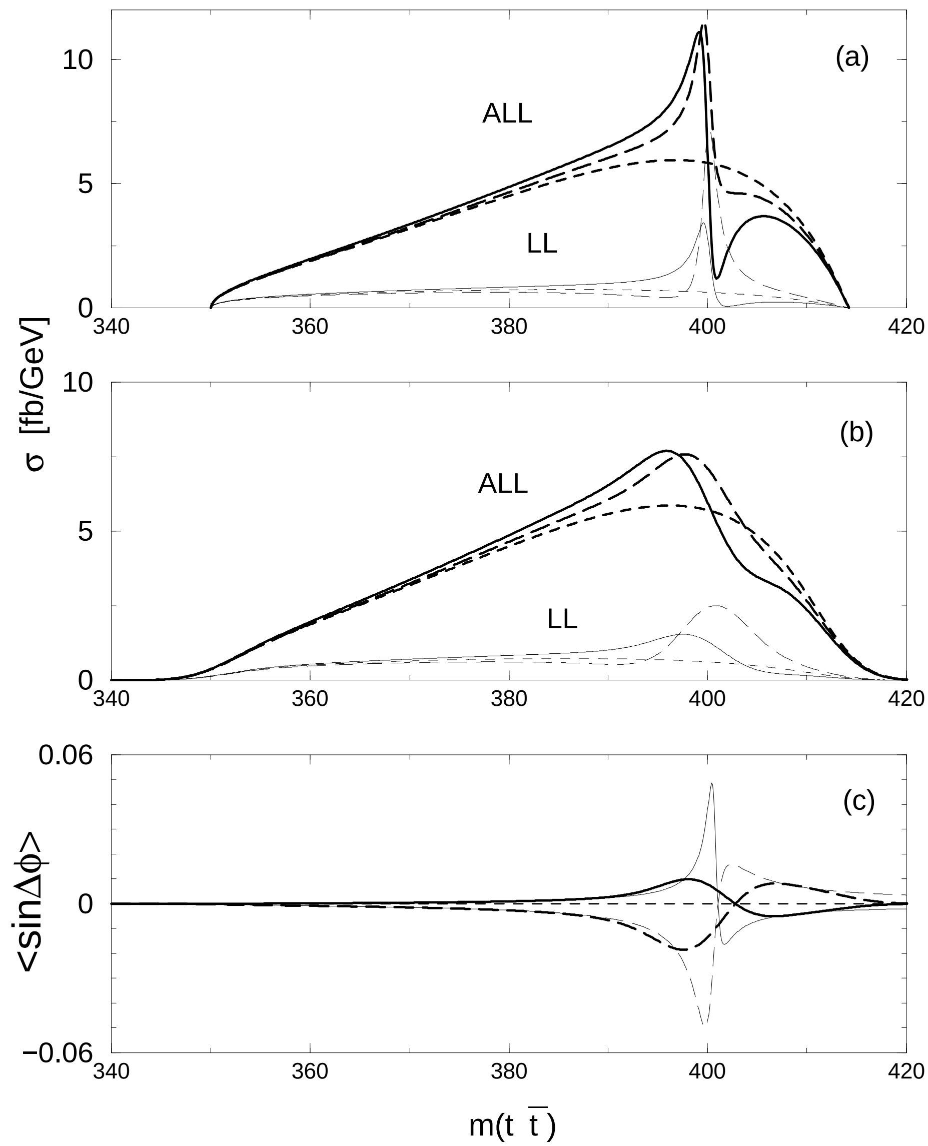
In the MSSM, CP violation in the Higgs sector comes through radiative corrections, with stop loops playing the main role. This effective CPV can be large, and has a major impact on the phenomenology.

The best place to study CP violation in the Higgs sector is at a $\gamma\gamma$-collider – in fact, this is a unique capability of the $\gamma\gamma$-collider.

The technique exploits linear polarization of photon beams. These define a CP-even or CP-odd state depending on whether the polarization vectors are parallel or perpendicular.

CP test using $t\bar{t}$ decays

$\gamma\gamma \to t\bar{t}$: Exploit the interference between continuum and resonant higgs production, assume mass of 400 GeV.



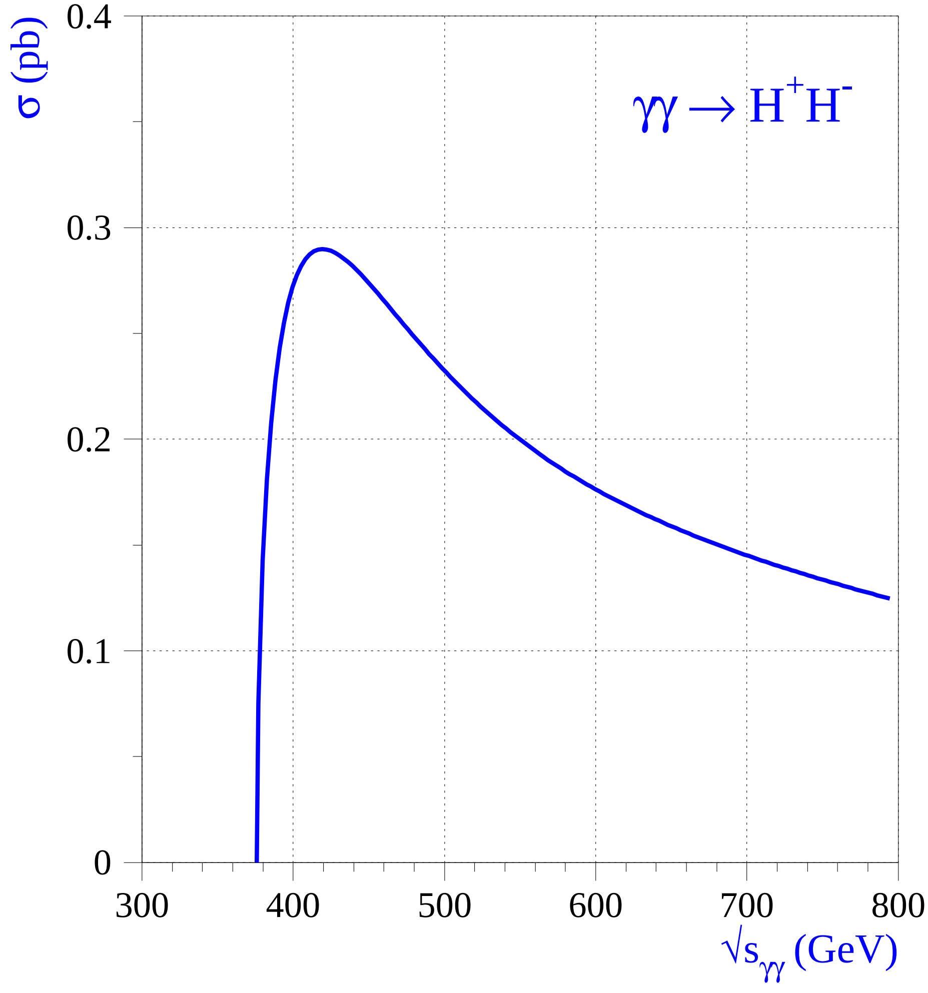
- solid CP-odd
- long-dashed CP-even
- short-dashed QED prediction

Hagiwara, Asakawa hep-ph/0011360

Charged Higgs, $H^{\pm}$

Cross sections are 10× those in an e^+e^- machine.

Furthermore, the sharp turn-on could allow a good measurement of the mass.



CompHEP, hep-ph/9908288

Conclusion

Most of the physics need it to understand the EW sector can be done in a series of $\gamma\gamma$-colliders ... Starting with a 'low' energy Higgs-Factory!

Three areas in which the $\gamma\gamma$-colliders would play a **crucial role** and even **unique role**:

1. Extraction of CP quantum numbers.
   The use of polarized photon beams is an extremely powerful physics tool which is unavailable at electron and proton machines.
2. Production of heavier Higgs states.
   The $\gamma\gamma$-triangle is more robust that the tree-level couplings of Higgs to vector bosons.
3. $\Gamma_{\gamma\gamma}$, the two-photon partial width.
   This will give a simple and powerful tool to study Yukawa coplings through the tth coupling.

other important possibilities not discussed in this talk:

- probing extra dimensions in $\gamma\gamma \to W^+W^-$
- anomalous coupling
- $\tilde{q}$ and $\tilde{g}$ searches & measurements
- and, much more...