MSSM Higgs Bosons at a $\gamma\gamma$ Collider

Margarete M. Mühlleitner, Univ. de Montpellier

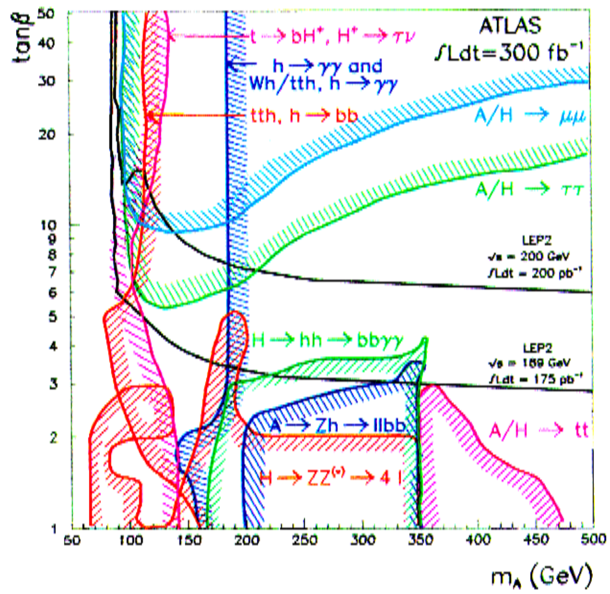
in collaboration with: M. Krämer, M. Spira, P.M. Zerwas

Outline

- Motivation
- $b\bar{b}$ final state
- Separation of H, A
- $\tilde{\chi}_i^+\tilde{\chi}_j^-$, $\tilde{\chi}_i^0\tilde{\chi}_j^0$ final states
- Conclusions

Why heavy MSSM Higgs boson production at $\gamma\gamma$ colliders?

- Search for H, A at the LHC:



Higgs particles H, A with masses $M_{H/A} \gtrsim 200$ GeV, $6 \lesssim \tan\beta \lesssim 15$

might escape discovery at the LHC.

Discovery of H, A important $\leadsto$ disentangle the MSSM from the SM

Light scalar Higgs boson h SM-like in this parameter region.

- At e^+e^- linear colliders: production of H, A with masses

$$M_{H/A} \lesssim 0.5\sqrt{s_{ee}}$$

- Alternative: Search for H, A at future $\gamma\gamma$ colliders

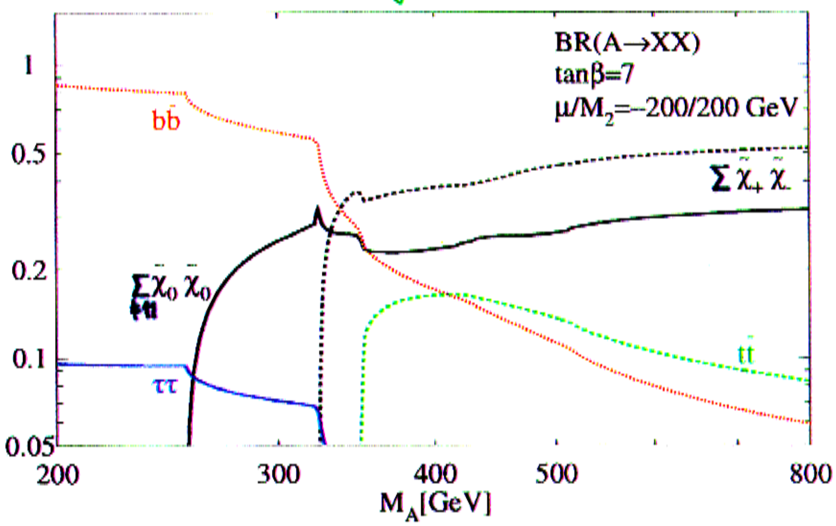
  high luminosity ($\int \mathcal{L} = 300\ fb^{-1}$ in 2 years)

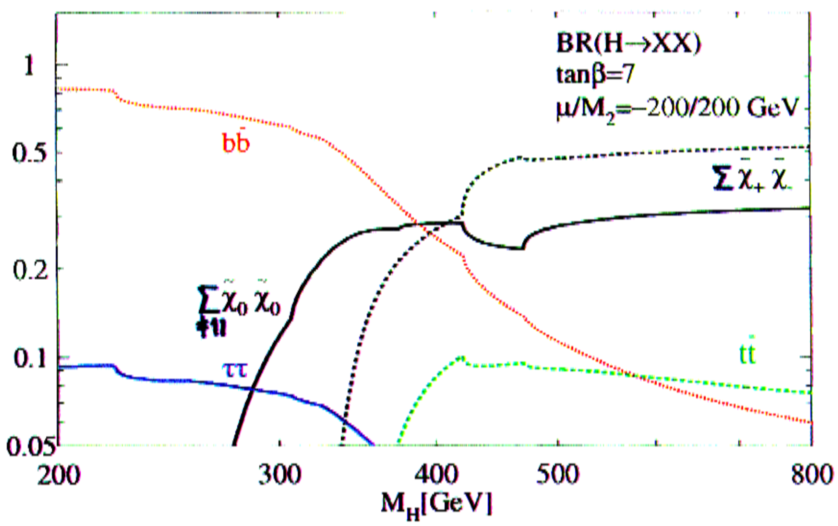
  high energy, high degree of polarization

  H, A can be produced with masses up to

$$M_{H/A} \lesssim 0.8\sqrt{s_{ee}}$$

Investigated Channels



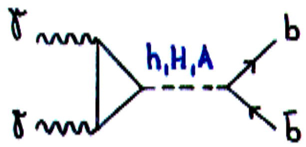


Process $\gamma\gamma \to b\bar{b}$

signal - background - interference

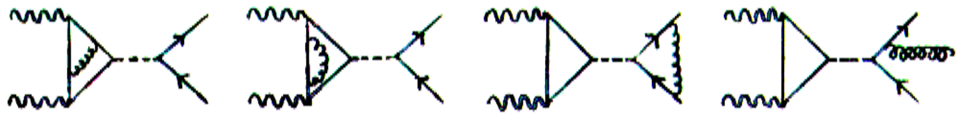
signal process

LO



Spira, Djouadi, Graudenz, Zerwas
Melnikov, Yakovlev
Inoue, ...
Braaten, Leveille
Drees, Hikasa
⋮

NLO



$$\frac{d\sigma_{LO}^{++/--}}{d\cos\theta} = \frac{N_c G_F \alpha^2 \beta m_b^2}{128\pi^3}\left[g_{hbb}^2 \beta^2 |\mathcal{G}_h|^2 + g_{Hbb}^2 \beta^2 |\mathcal{G}_H|^2 + g_{Abb}^2 |\mathcal{G}_A|^2 + 2 g_{hbb} g_{Hbb} \beta^2 \,\mathrm{Re}(\mathcal{G}_h \mathcal{G}_H^*)\right]$$

$$\frac{d\sigma_{LO}^{+-/-+}}{d\cos\theta} = 0$$

$\mathcal{G}_\Phi = \mathcal{A}_\Phi / [1 - m_\Phi^2/s + i m_\Phi \Gamma_\Phi / s]$ $\Phi = h, H, A$; $\mathcal{A}_\Phi$: $\gamma\gamma\Phi$ form factor

$\beta = [1 - 4m_b^2/s]^{1/2}$

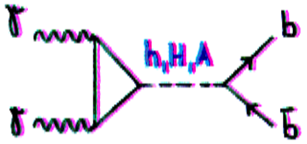
$g_{\Phi bb}$ Yukawa couplings in units of the SM coupling

Process $\gamma\gamma \to b\bar{b}$

signal – background – interference

signal process

LO



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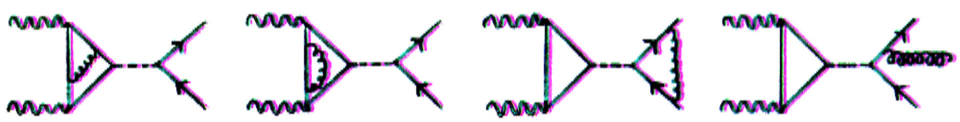
NLO



$$\frac{d\sigma_{LO}^{++/--}}{d\cos\Theta} = \frac{N_c G_F \alpha^2 \beta m_b^2}{128\pi^3}\left[g_{hbb}^2 \beta^2 \left|\mathcal{Y}^{\varphi}_{h}\right|^2 + g_{Hbb}^2 \beta^2 \left|\mathcal{Y}^{\varphi}_{H}\right|^2 + g_{Abb}^2 \left|\mathcal{Y}^{\varphi}_{A}\right|^2 + 2 g_{hbb} g_{Hbb} \beta^2 \,\mathrm{Re}\left(\mathcal{Y}^{\varphi}_{h} \mathcal{Y}^{\varphi}_{H}\right)\right]$$

$$\frac{d\sigma_{LO}^{+-/-+}}{d\cos\Theta} = 0$$

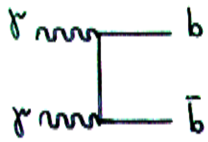
$\mathcal{Y}^{\varphi}_{\Phi} = \mathcal{A}_{\Phi} / [1 - m_{\Phi}^2/s + i m_{\Phi}\Gamma_{\Phi}/s]$ $\Phi = h, H, A$; $\mathcal{A}_{\Phi}$: $\gamma\gamma\Phi$ form factor

$\beta = [1 - 4m_b^2/s]^{1/2}$

$g_{\Phi bb}$ Yukawa couplings in units of the SM coupling

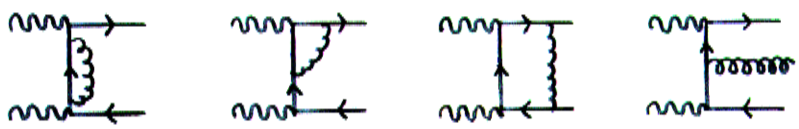
background process

LO



Jikia, Tkabladze
Kamal, Merebashvili, Contogouris

NLO



$$\frac{d\sigma_{LO}^{++/--}}{d\cos\theta} = \frac{N_c \alpha^2 Q_b^4 16\pi\beta(1+\beta^2)}{s} \frac{m_b^2}{s} \frac{1}{(1-\beta^2\cos^2\theta)^2}$$

$$\frac{d\sigma_{LO}^{+-/-+}}{d\cos\theta} = \frac{N_c \alpha^2 Q_b^4 4\pi\beta^3}{s} \frac{\sin^2\theta(2-\beta^2\sin^2\theta)}{(1-\beta^2\cos^2\theta)^2}$$

interference process

$$\frac{d\sigma_{LO}^{++/--}}{d\cos\theta} = -\frac{N_c G_F \alpha^2 Q_b^2 \beta}{\sqrt{2}\pi} \frac{m_b^2}{s} \frac{1}{1-\beta^2\cos^2\theta}\left[g_{hbb}\beta^2 Re(\varphi_h) + g_{Hbb}\beta^2 Re(\varphi_H) - g_{Abb} Re(\varphi_A)\right]$$

$$\frac{d\sigma_{LO}^{+-/-+}}{d\cos\theta} = 0$$

NLO corrections have been calculated

Cross section: $\gamma\gamma \to b\bar{b}$

- At LO: $J_z=0$ background process is suppressed by m_b^2/s due to helicity-flipped states
- At NLO: $J_z=0$ suppression is removed because of non-helicity-flipped states in the 3-jet final state

$\Rightarrow$ Restriction to 2-jet topology which is dominated by the helicity-flipped states
$\Rightarrow$ most of the background is cut away

[2-jet event: $E_g^{min} = 0.1\sqrt{s_{\gamma\gamma}}$, $\alpha_{min} = 10°$]

- In the 2-jet topology higher order corrections due to large double logarithms (DL) $\alpha_s^n \log^{2n} \frac{m_b^2}{s}$ become important for $J_z=0$
- Higher order corrections are accounted for by the resummation of the large DL's $\rightsquigarrow$ form factors $\mathcal{F}_g, \mathcal{F}_q$ Fadin, Khoze, Martin Melles, Stirling

$\Rightarrow$ Resummed cross sections:

$$\sigma_R^{signal} = \sigma_{LO}^{signal}\,\mathcal{F}_g$$
$$\sigma_R^{interf} = \sigma_{LO}^{interf}\,\mathcal{F}_g\mathcal{F}_q$$
$$\sigma_R^{bkg} = \sigma_{LO}^{bkg}\,\mathcal{F}_g\mathcal{F}_q^2$$

Cross section $\gamma\gamma \to b\bar{b}$: Full NLO result + resummation of higher orders in the 2-jet topology

Polarization

- polarized electron/positron and laser beams ⇝ suppress the helicity modes of the background process that are not compatible with the signal

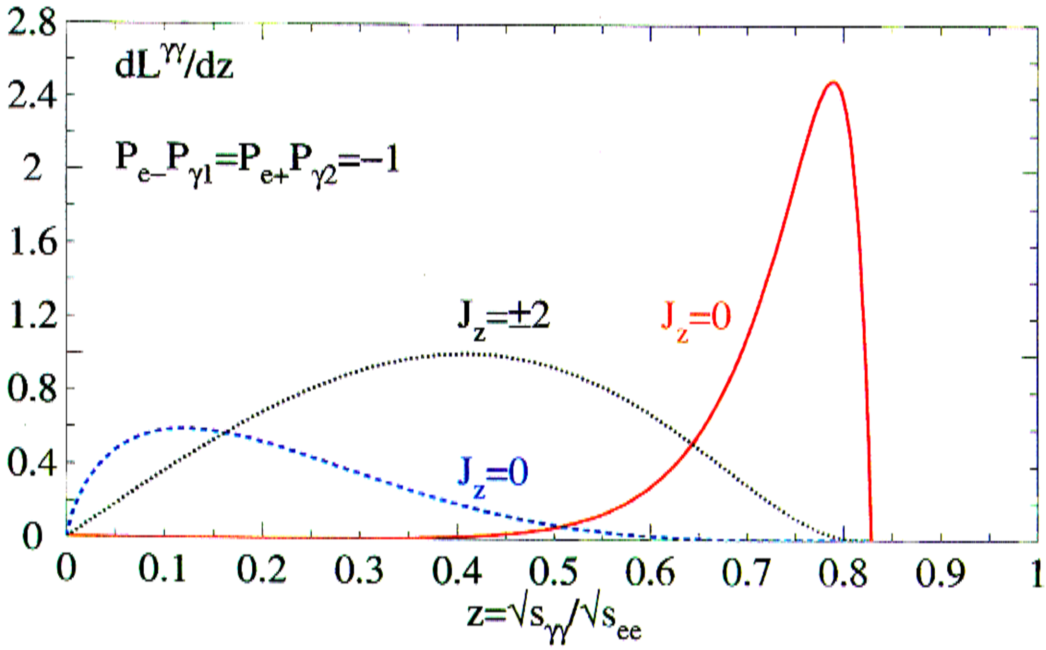
  ⇒ enhance the signal to background ratio

- polarized cross section for the process $e^+e^- \to \gamma\gamma \to b\bar{b}$:

$$\sigma(e^+e^- \to \gamma\gamma \to b\bar{b}) = \int_{z_{min}}^{z_{max}} dz \sum_{J_z = 0,0,\pm 2} \frac{d\mathcal{L}^{\gamma\gamma}(J_z)}{dz} \, \hat{\sigma}^{J_z}(\gamma\gamma \to b\bar{b};\, s_{\gamma\gamma} = z^2 s_{ee})$$

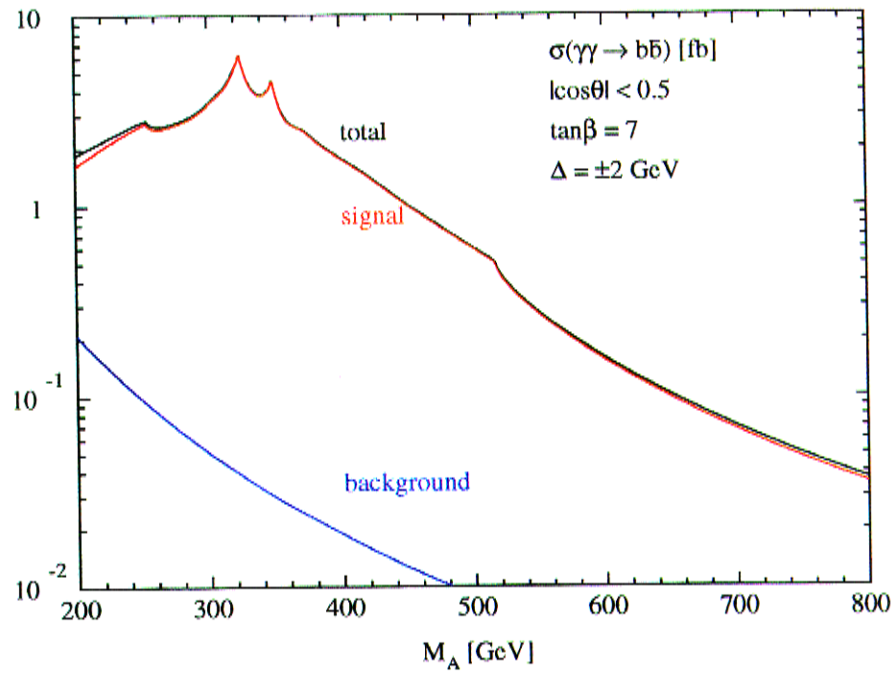
Ginzburg et al.
Kühn et al.

$\gamma\gamma$ luminosity $d\mathcal{L}^{\gamma\gamma}/dz$ "P" polarization; $\sqrt{s_{ee}} = 500$ GeV



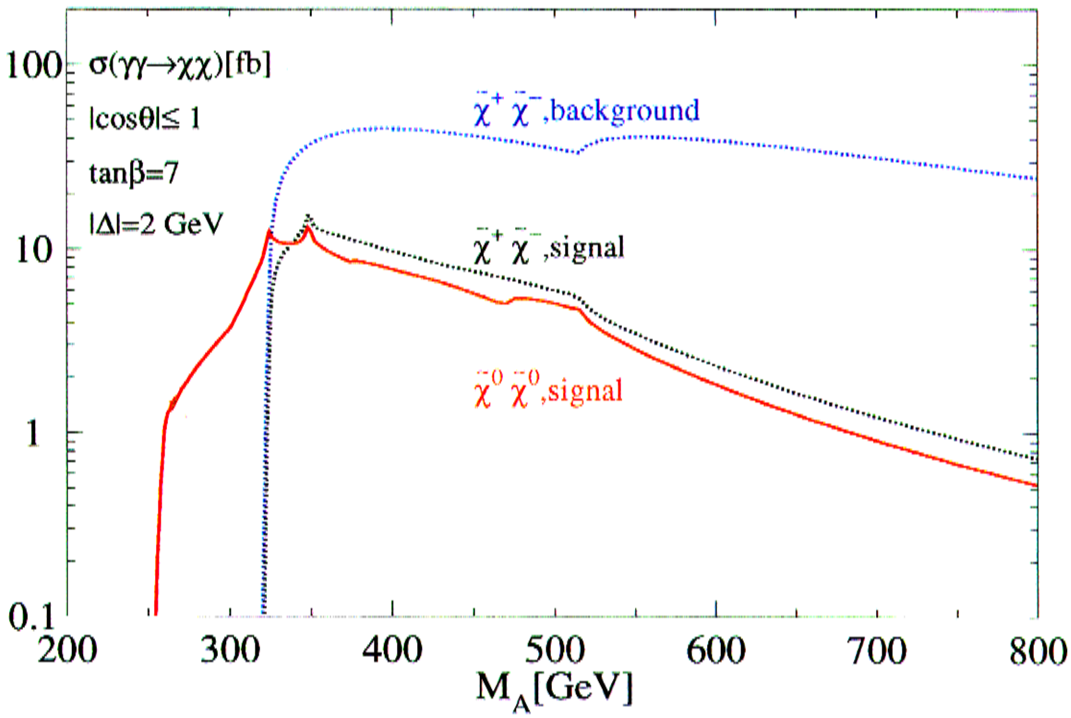
For this helicity combination: $d\mathcal{L}^{\gamma\gamma}/dz$ maximal for $J_z = 0$
peaked towards high energies

$e^+e^- \to \gamma\gamma \to b\bar{b}$ $-\mu = M_2 = 200\,GeV$



- cut in $\cos\theta$ enhances signal to background ratio
- $\sigma_{bkg} \lesssim 0.2$ fb ; $\sigma_{signal} \gtrsim 1$ fb for $M_A \lesssim 450$ GeV
- significance > 5
- peaks and kinks in signal process: behaviour of the $\gamma\gamma A$-form factor and branching fractions into $b\bar{b}$ of H, A at the neutralino, chargino pair production thresholds and at the $t\bar{t}$ threshold

$\gamma\gamma \to \tilde{\chi}_i^+ \tilde{\chi}_j^- / \tilde{\chi}_i^0 \tilde{\chi}_j^0$ $-\mu = M_2 = 200\,\text{GeV}$



- final states summed up except for $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ ($\tilde{\chi}_1^0$ assumed to be the LSP)
- chargino masses large ⇒ cut in cos θ not worthwhile to reduce background
- chargino background $O(50\,\text{fb})$, signal $O(1\ldots10\,\text{fb})$
  ⇒ difficult to extract the signal
- neutralino signal at LO not plagued by background & interference due to neutralinos; above chargino threshold it has to fight against the chargino bkg.

possible decays: $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + W^{\pm *}$, $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + Z^*$ ⇝ due to escaping LSP's and ν's the final states are rather similar

different decay topologies can be exploited to extract the signal

Conclusions

- $e^+e^- \to \gamma\gamma \to b\bar{b}$: Heavy Higgs bosons H, A can be discovered
  $200 \lesssim M_A \lesssim 700$ GeV, moderate and large $\tan\beta$
  crucial: restriction to 2-jet-topology (resummation)
  cut in the scattering angle of the b-quark

- Separation of H, A by a threshold scan; for example:
  $e^+e^- \to \gamma\gamma \to b\bar{b}$: $\tan\beta = 7$, $M_A = 300$ GeV, $M_H = 301.37$ GeV
  $e^+e^- \to \gamma\gamma \to t\bar{t}$: $\tan\beta = 3$, $M_A = 400$ GeV, $M_H = 404.48$ GeV

- Neutralino channel: Different decay topologies of neutralino and chargino cascade decays can be exploited in order to extract the signal

Future $\gamma\gamma$ colliders provide a valuable possibility for the heavy MSSM Higgs boson search at moderate and large $\tan\beta$. The $b\bar{b}$ channel is outstanding.