Heavy H and A MSSM Higgses at PLC

– a comparison of two analyses

Michael Spira (PSI) and Piotr Nieżurawski (Warsaw U.)

In collaboration with

M. Muehlleitner, M. Kraemer,P. Zerwas,

M. Krawczyk and A. F. Żarnecki (Warsaw U.)

Scenario

- MSSM – CP conserving case
- Light SM-like Higgs boson h (< 140 GeV)
- Heavy Higgs bosons H and A

  negligible couplings to W/Z

  masses above 200 GeV

  almost degenerate

  large couplings(at large tan beta) to b (tau)

LHC wedge:
only Higgs boson h discovered at LHC

Experimental study.. Mazumdar talk

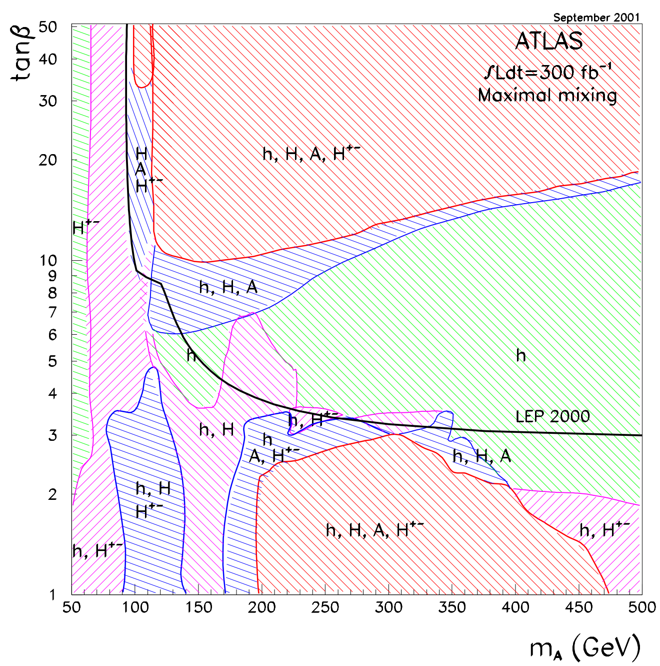
*Muehlleitner et al.. PL B 508 (2001)
Djouadi et al. 2004
Asner et al. PR D67 (2003)
**Nieżurawski et al. hep-ph/0507006

Comparion of * and ** analyses –
background issue: importance of 2jet configuration

$\mathcal{MSSM}$ $\mathcal{H}$iggs $\mathcal{B}$oson $\mathcal{P}$roduction in $\gamma\gamma$ $\mathcal{C}$ollisions

Krämer,MM,Spira,Zerwas, Phys.Lett.B508(2001)311-316

▷ Search for H, A at the **LHC**:



Higgs particles H, A with masses $M_{H/A} \gtrsim 200$ GeV and centered around $\tan\beta \sim 7$ may escape discovery at the LHC

▷ 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**

Ginzburg,Kotkin,Panfil, Serbo,Telnov

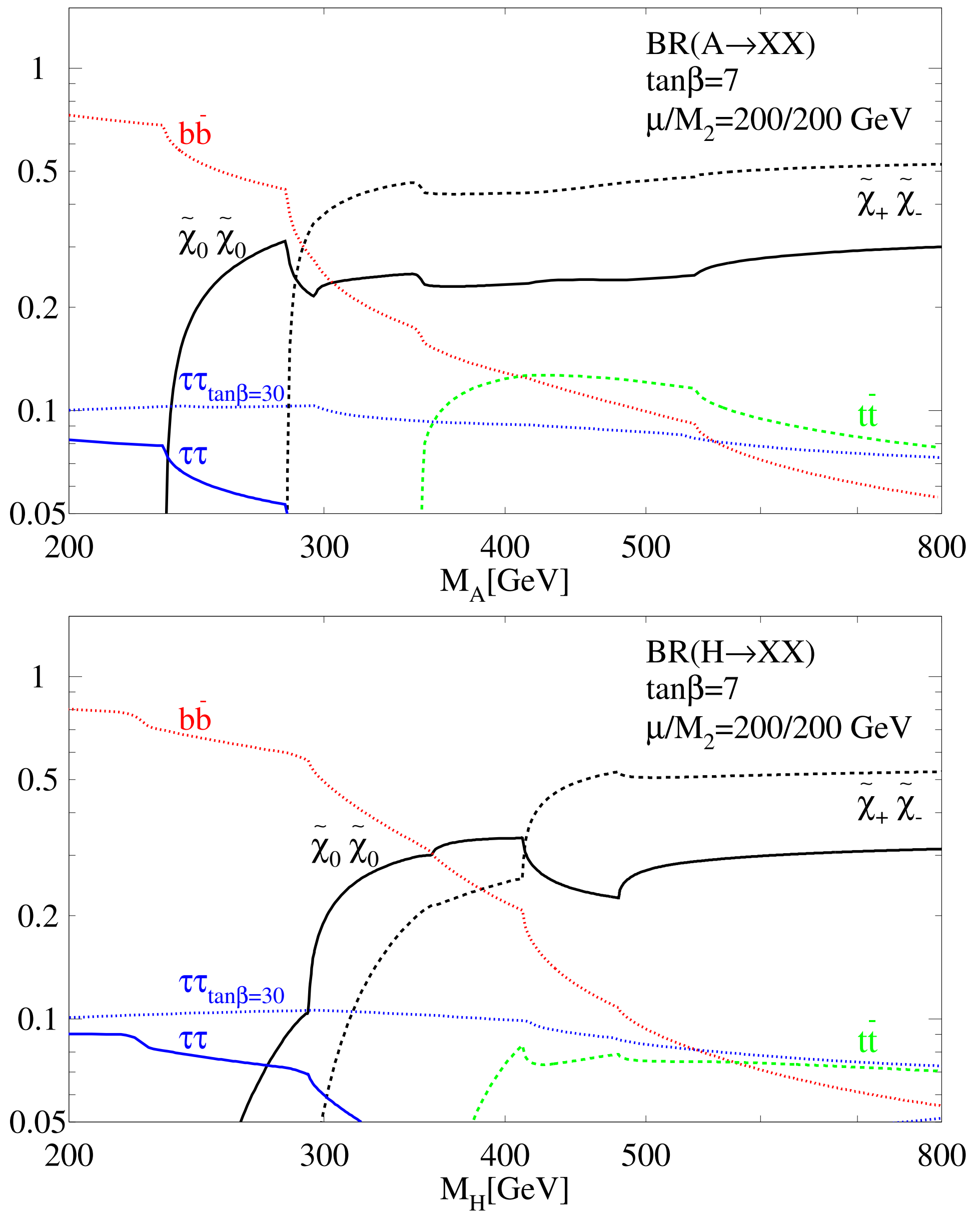
high luminosity ($\int \mathcal{L} = 300$ fb^{-1} in 2 years)

high energy, high degree of polarisation

H, A can be produced with masses up to $M_{H,A} \lesssim 0.8\sqrt{s_{ee}}$

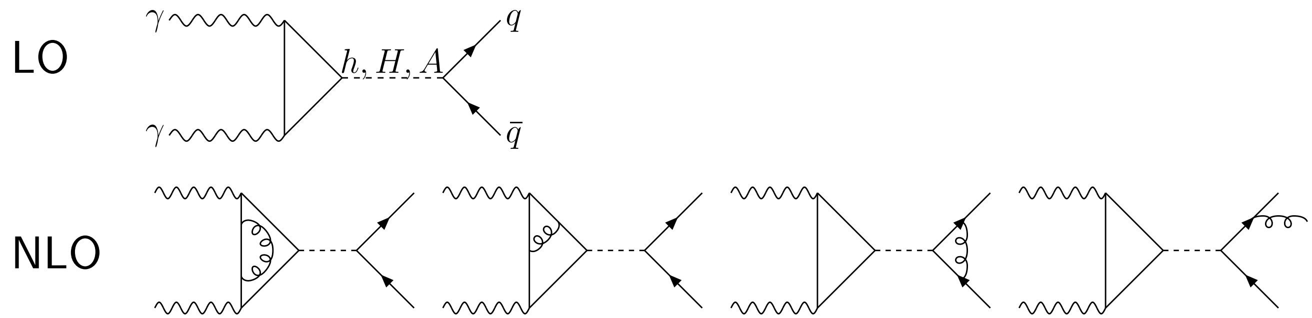
$\mathcal{D}$ecay $\mathcal{M}$odes

HDECAY



$\mathcal{P}$rocess $\gamma\gamma \longrightarrow q\bar{q}$ – signal

Signal process



Spira,Djouadi,Graudenz,Zerwas
Melnikov,Yakovlev
Inoue et al.
Braaten,Leveille
Drees,Hikasa;...

$$\frac{d\sigma_{\rm LO}^{++/--}}{d\cos\theta} = \frac{N_c G_F^2 \alpha^2 \beta m_q^2}{128\pi^3}\left[g_{hqq}^2 \beta^2 |\mathcal{G}_h|^2 + g_{Hqq}^2 \beta^2 |\mathcal{G}_H|^2 + g_{Aqq}^2 |\mathcal{G}_A|^2 + 2 g_{hqq} g_{Hqq} \beta^2 {\rm Re}(\mathcal{G}_h \mathcal{G}_H)\right]$$

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

$$\mathcal{G}_\Phi = \mathcal{M}_\Phi/(1 - m_\Phi^2/s + i m_\Phi \Gamma_\Phi/s) \qquad \Phi = h, H, A \qquad \mathcal{M}_\Phi: \ \gamma\gamma\Phi - \text{form factor}$$

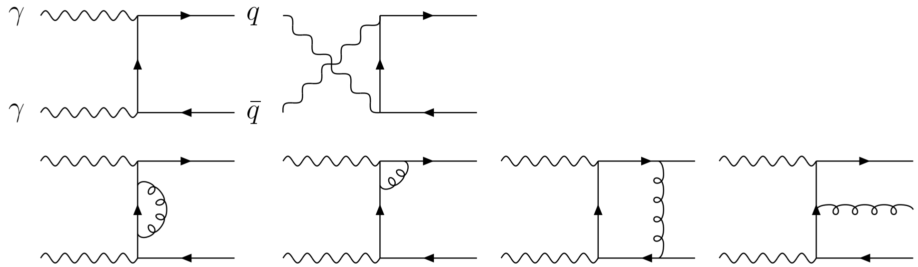
$$\beta = (1 - 4m_q^2/s)^{1/2}$$

$\mathcal{P}$rocess $\gamma\gamma \to q\bar{q}$ – bkg & interference

Background process

LO

NLO



Jikia, Tkabladze
Kamal, Merebashvili, Conogouris

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

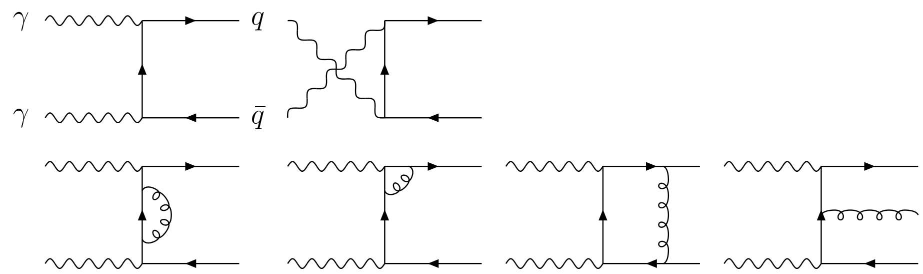
$$\frac{d\sigma_{\rm LO}^{+-/-+}}{d\cos\theta} = \frac{N_c\alpha^2 Q_q^4 4\pi\beta^3}{s}\frac{\sin^2\theta(2-\beta^2\sin^2\theta)}{(1-\beta^2\cos^2\theta)^2}$$

$\mathcal{P}$rocess $\gamma\gamma \to q\bar{q}$ – bkg & interference

Background process

LO

NLO



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

Interference process

$$\frac{d\sigma_{\rm LO}^{++/--}}{d\cos\theta} = \frac{N_c G_F\alpha^2 Q_q^2\beta}{\sqrt{2}\pi}\frac{m_q^2}{s}\frac{1}{1-\beta^2\cos^2\theta}\left[g_{hqq}\beta^2{\rm Re}(\mathcal{G}_h)+g_{Hqq}\beta^2{\rm Re}(\mathcal{G}_H)-g_{Aqq}{\rm Re}(\mathcal{G}_A)\right]$$

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

NLO corrections have been calculated

$\mathcal{P}$rocess $\gamma\gamma \to b\bar{b}$ - technical details

- $b\bar{b}$ final state most promising
- Restriction to 2-jet final states $\rightsquigarrow$ enhance S/B
- Higher order corrections (in 2-jet) are accounted for by resummation — Fadin, Khoze, Martin; Melles, Stirling
- Polarisation of $e^\pm$ and laser beams $\rightsquigarrow$ enhance S/B

  [For leading order with realistic photon spectra see also Gunion et al.]

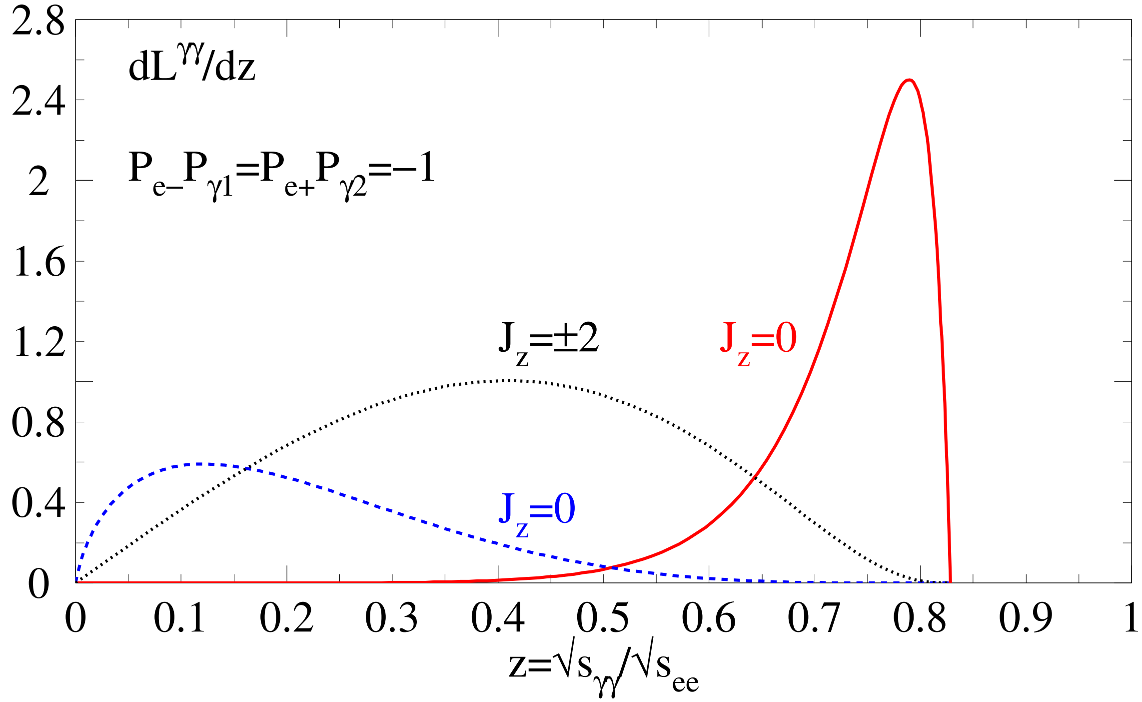
$\gamma\gamma$ luminosity $d\mathcal{L}^{\gamma\gamma}/dz$ — Ginzburg et al., Kühn et al.

"P": pol.; $\sqrt{s_{ee}} = 500$ GeV

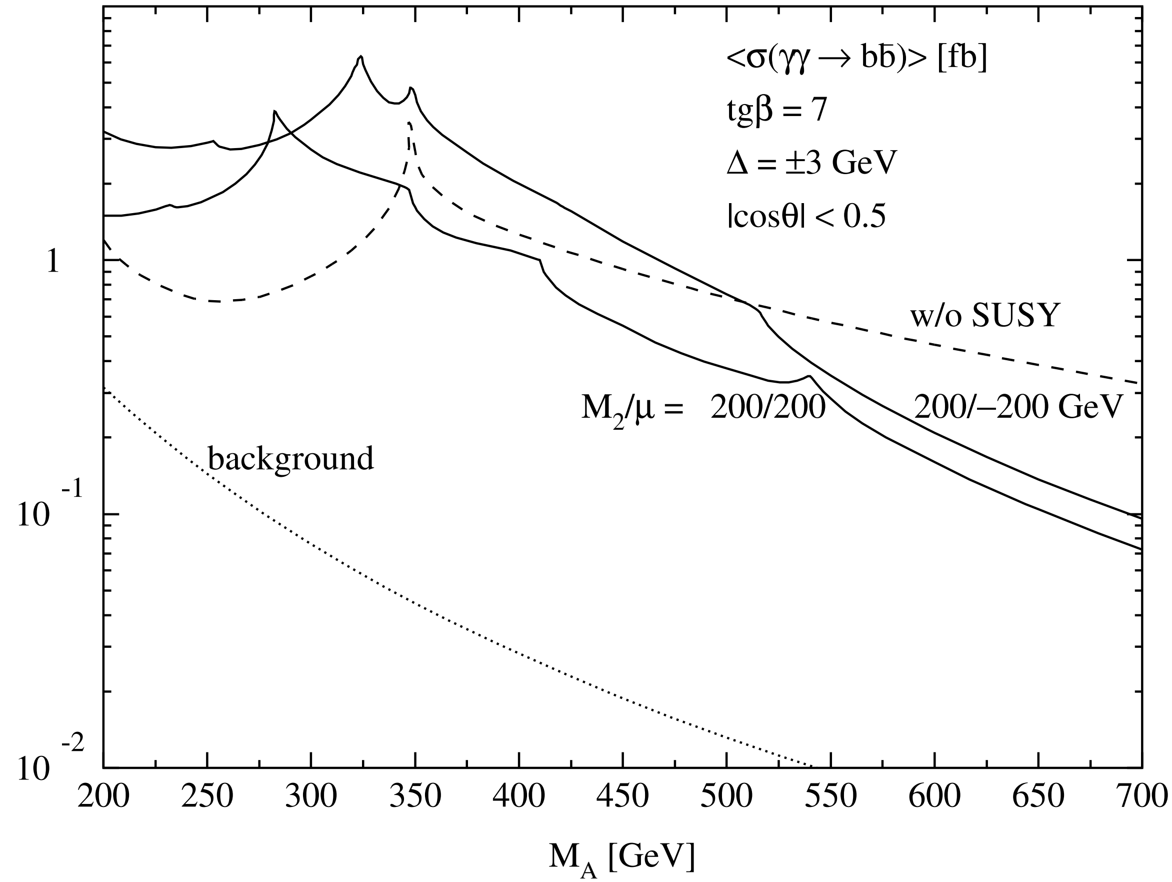
For this helicity combination:

$d\mathcal{L}^{\gamma\gamma}/dz$ max. for $J_z = 0$

peaked towards high energies



$\mathcal{R}$esult $e^+e^- \to \gamma\gamma \to b\bar{b}$



- ▷ Cut in $\cos\theta$ enhances S/B
- ▷ $\sigma_{\text{bkg}} \lesssim 0.3$ fb; $\sigma_{\text{signal}} \gtrsim 0.1$ fb for $M_A \lesssim 600$ GeV
- ▷ Peaks/kinks: behaviour of $\gamma\gamma A$ form factor/BR$(H/A \to b\bar{b})$ at the gaugino/$t\bar{t}$ thresholds

Improved analysis on $\gamma\gamma \rightarrow$ *higgs* $\rightarrow b\bar{b}$

including overlaid events, vertex smearing and crab crossing for SM and MSSM

P. Nieżurawski, A. F. Żarnecki, M. Krawczyk

Faculty of Physics
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$\gamma\gamma \rightarrow$ ***higgs*** $\rightarrow b\bar{b}$

Photon-photon spectrum: CompAZ

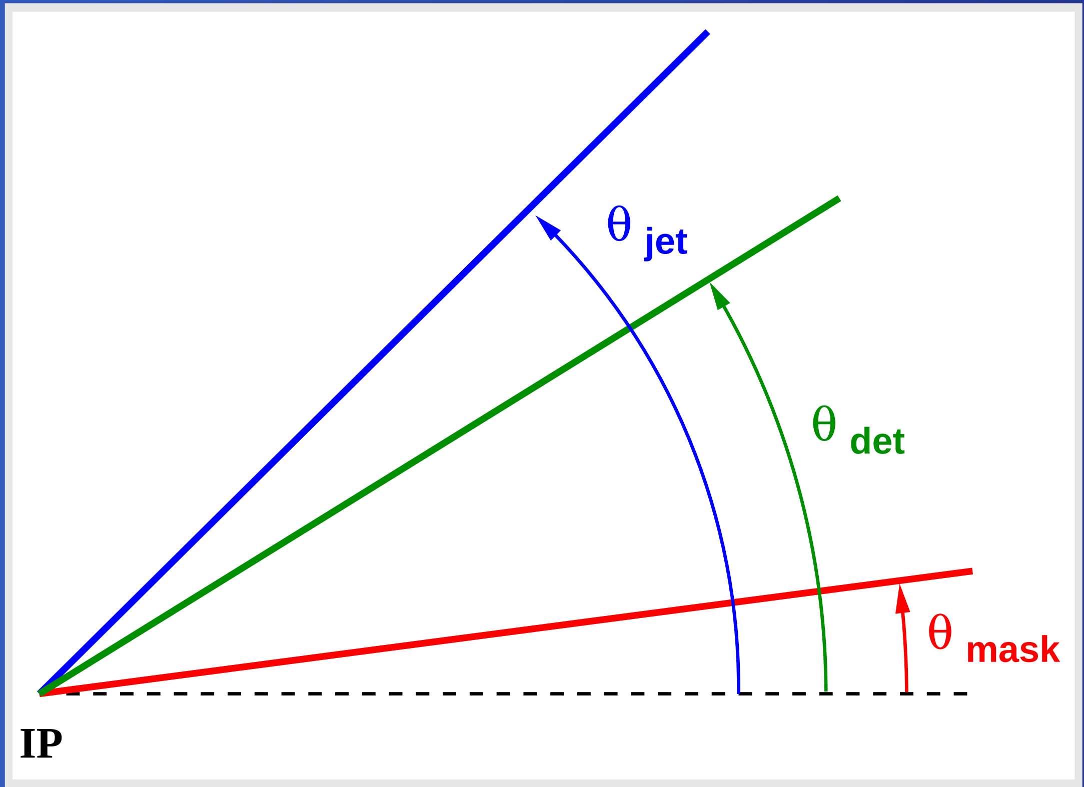
Signal: HDECAY, PYTHIA
Background: NLO $Q\bar{Q}(g)$ (G. Jikia)
Pile-up events $\gamma\gamma \rightarrow$ *hadrons* with realistic $\gamma\gamma$-luminosity spectrum (V. Telnov)
Parton Shower (signal only) : PYTHIA
Fragmentation: PYTHIA (Lund)

Detector performance: SIMDET 4.01
Jets: Durham algorithm with $y_{cut} = 0.02$,
(clusters & tracks below $\theta_{\text{det}} = 555$ mrad are ignored)

Selection of $b\bar{b}$ events for $M_{\text{higgs}} = 120$ (300) GeV:

- ZVTOP-B-Hadron-Tagger by T. Kuhl
- consider only jets with $p_T^{\text{jet}}/E_T > 0.1$ (OE-jets suppression)
- $N_{\text{jets}} = 2, 3$
- $|P_z|/E < 0.12$ (0.07) where $P_z = \sum p_z^{\text{jet}}$ and $E = \sum E^{\text{jet}}$
- $|\cos\theta_{\text{jet}}| < 0.71$ (0.65) for each jet

Angles



2 or 3 jets above
$\theta_{\text{jet}} = 45^\circ$ $(\cos\theta_{\text{jet}} = 0.71)$

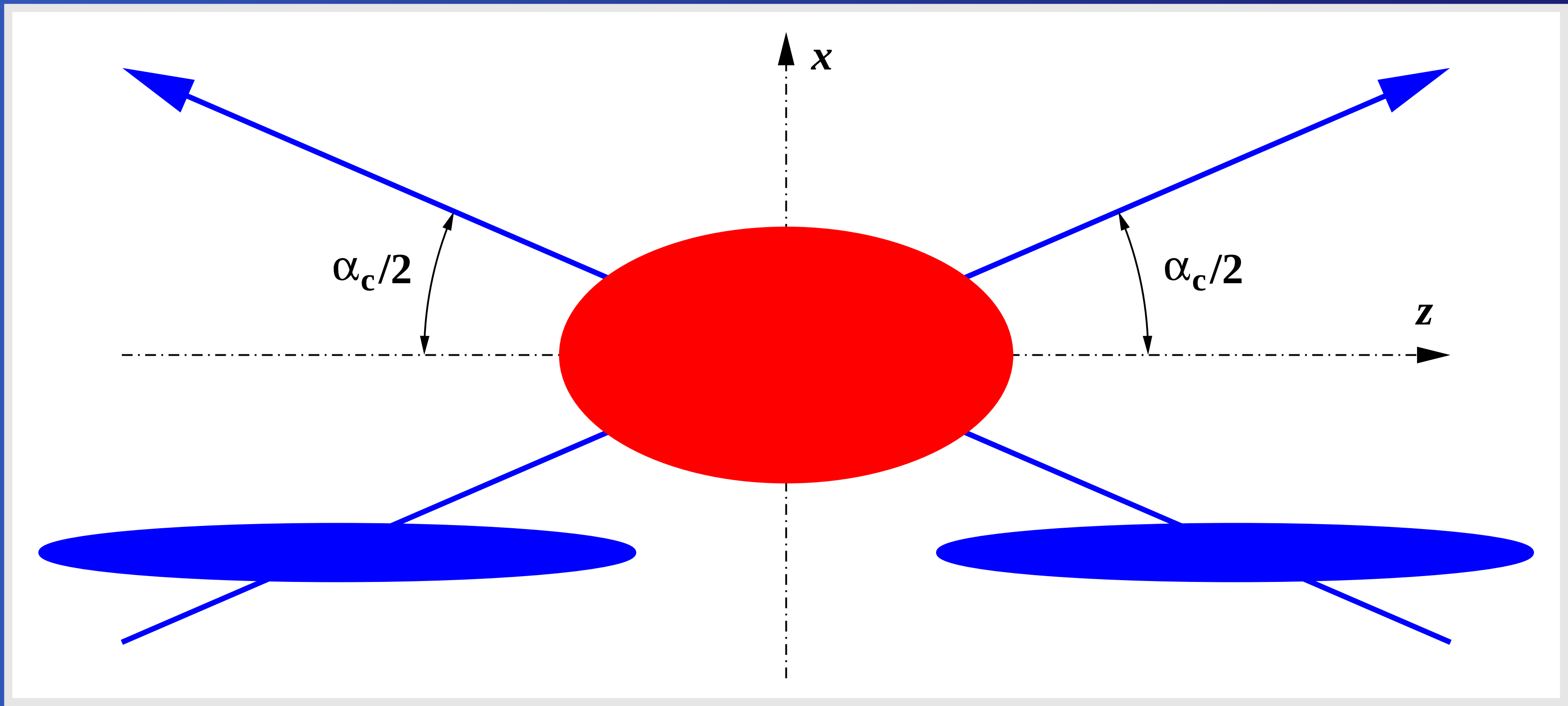
Tracks/clusters ignored below
$\theta_{\text{det}} = 32^\circ$ $(\cos\theta_{\text{det}} = 0.85)$

Remove particles on Pythia level below $\theta_{\text{mask}} = 7.5^\circ$
$(\cos\theta_{\text{mask}} = 0.99)$

Crab-wise crossing of beams

$$\sigma'_x = \sqrt{\tfrac{1}{2}(\sigma_x^2 + \sigma_z^2 \tan^2(\alpha_c/2))} \qquad \sigma'_y = \sigma_y/\sqrt{2} \qquad \sigma'_z = \sigma_z/\sqrt{2}$$

Bunch:	$\sigma_x = 140$ nm	$\sigma_y = 7$ nm	$\sigma_z = 0.3$ mm
Primary vertex:	$\sigma'_x = 3.6\ \mu$m	$\sigma'_y = 5$ nm	$\sigma'_z = 0.2$ mm



$\alpha_c = 34$ mrad

SM, $M_h = 120$ GeV

Corrected reconstructed mass:

$$W_{\rm corr} \equiv \sqrt{W_{rec}^2 + 2P_T(E+P_T)}$$

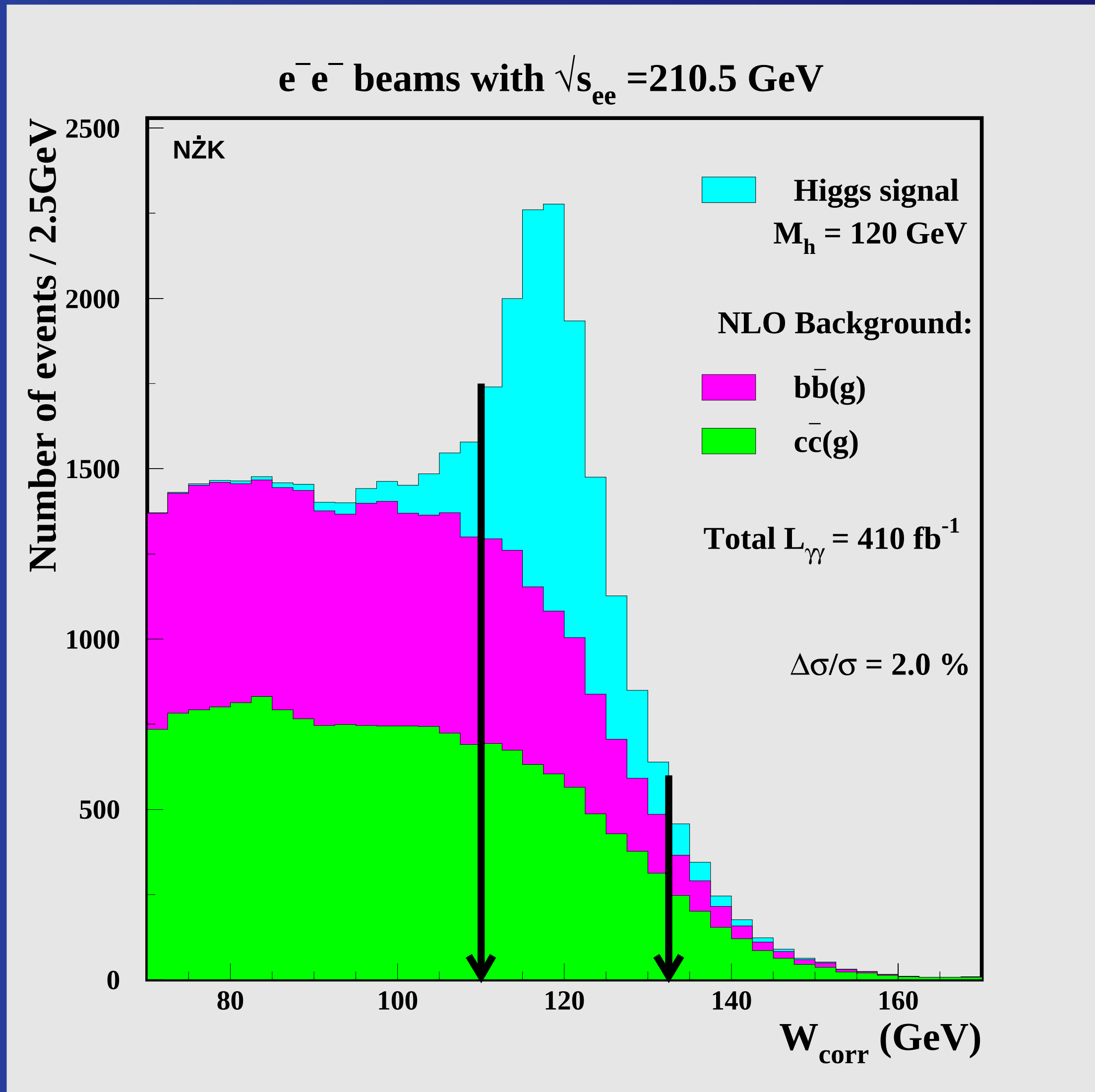
(using only accepted jets)

Correction for crossing angle:

$$p_x \to p_x - \sin(\alpha_c/2)E$$

$$E \to E - \sin(\alpha_c/2)p_x$$

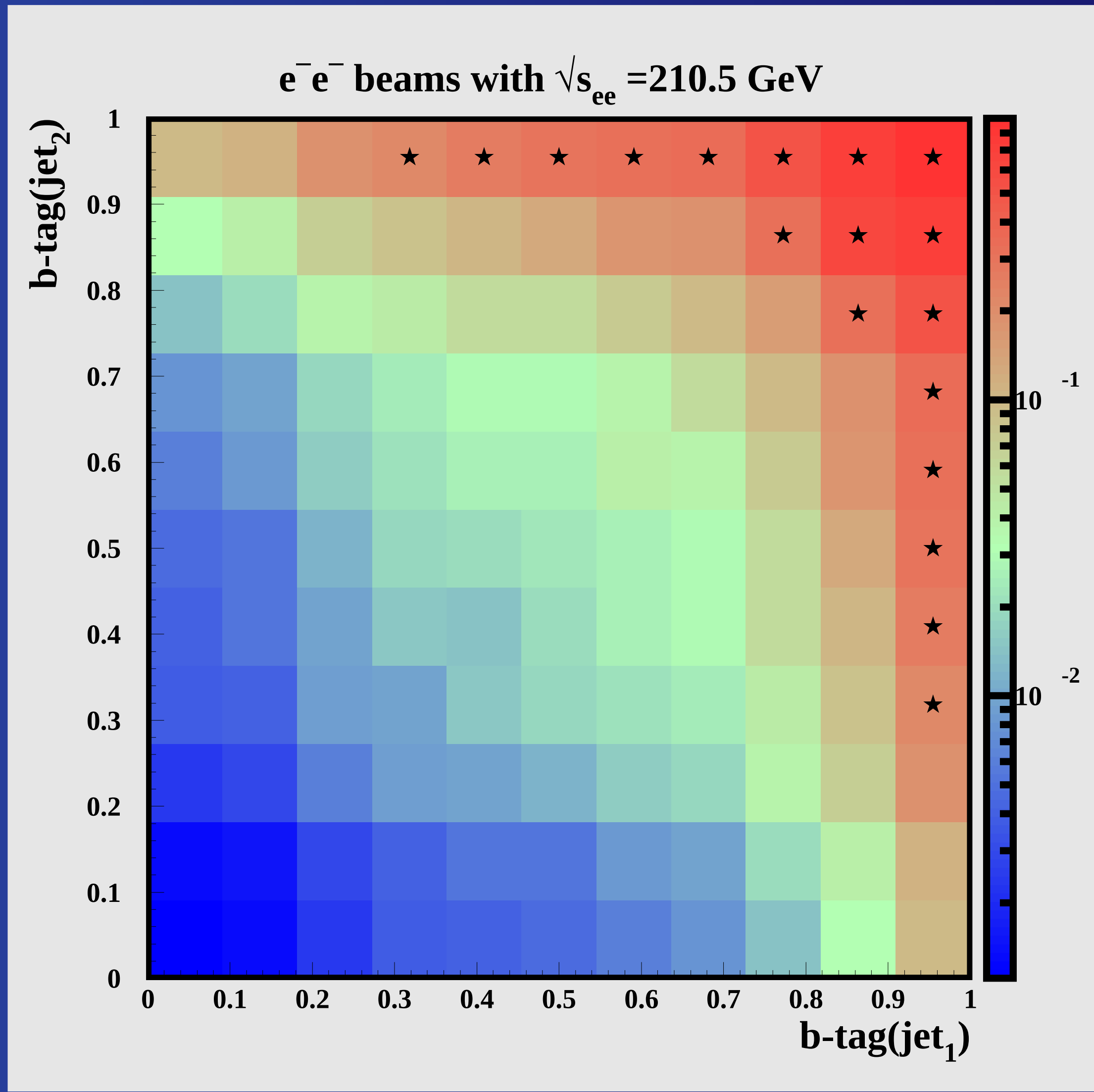
Number of overlaying events: ~ 1 per bc



higgs-tagging at $M_h = 120$ GeV

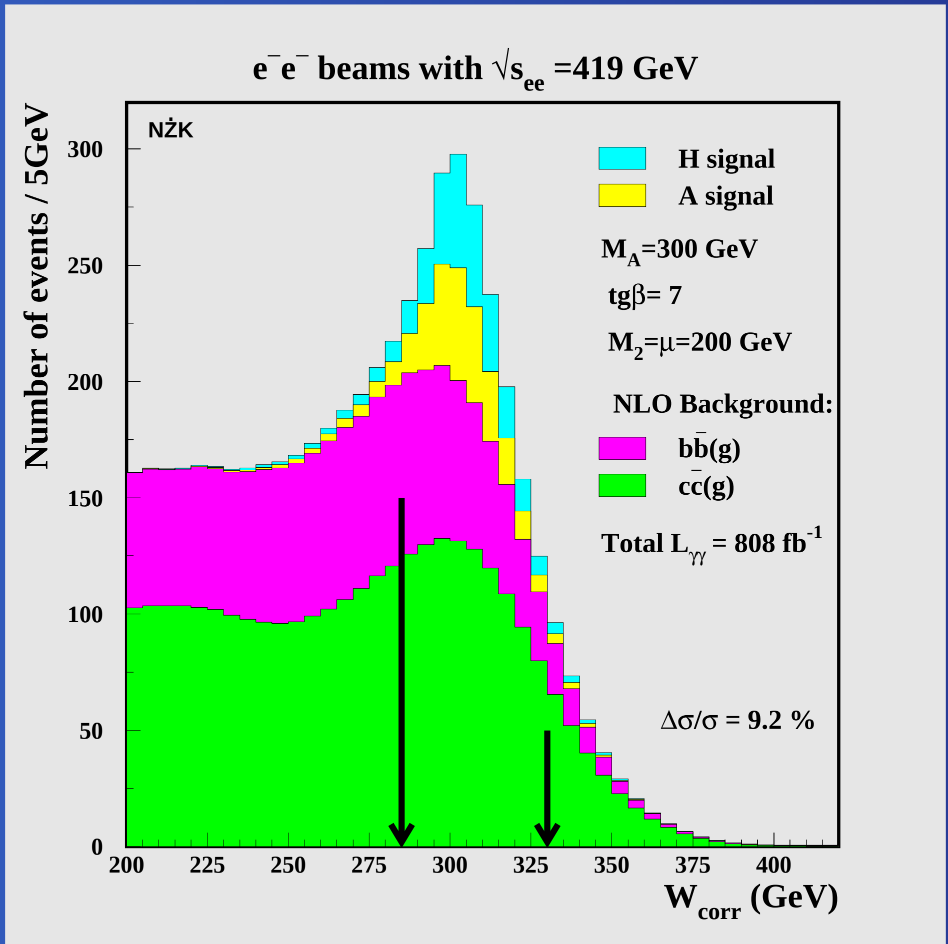
Using *higgs*-tagging:
a cut on the ratio
of $\gamma\gamma \to h \to b\bar{b}$
to $\gamma\gamma \to b\bar{b}(g),\ c\bar{c}(g)$ events

Earlier we used b-tagging:
a cut on the ratio
of $\gamma\gamma \to b\bar{b}(g)$
to $\gamma\gamma \to c\bar{c}(g)$ events

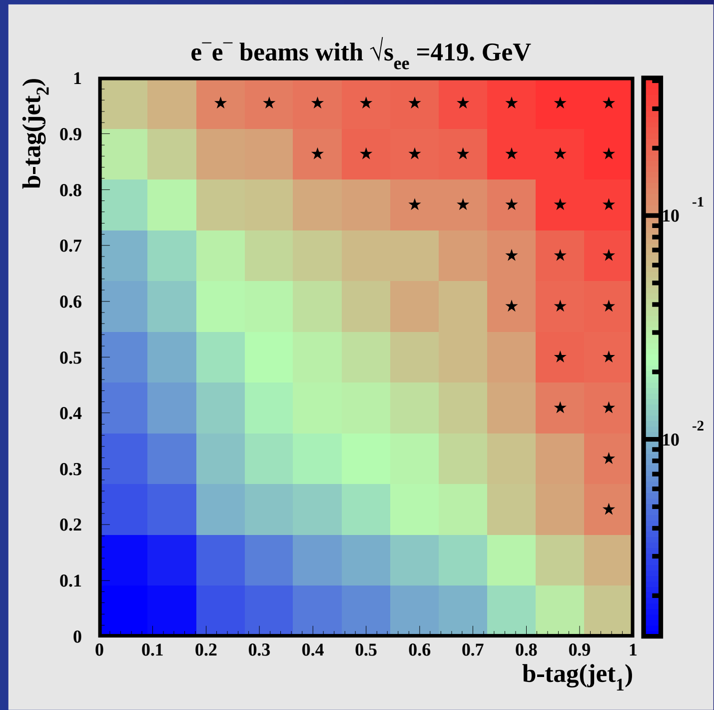


MSSM, $M_A = 300$ GeV

Number of overlaying events: ~ 2 per bc



Optimal *higgs*-tagging



$$\frac{\#\gamma\gamma \to h \to b\bar{b}}{\#\gamma\gamma \to b\bar{b}(g),\ c\bar{c}(g)}$$

Conclusions

- High precision for SM & MSSM higgses can be achieved despite $\gamma\gamma \to$ *hadrons* pile-up events and primary vertex distribution.
- Cut on p_T^{jet}/E_T discriminates OE jets, remaining after θ_{det} cut.
- Optimal cuts per mass point: $|P_z|/E$, $\cos\theta_{\mathrm{jet}}$.
- *higgs*-tagging: cut on the ratio of $\gamma\gamma \to h \to b\bar{b}$ to $\gamma\gamma \to b\bar{b}(g)$, $c\bar{c}(g)$ events (region in the plane $\text{btag}_1 \otimes \text{btag}_2$)
- Precision of 2% for $\Gamma(h \to \gamma\gamma)\mathrm{Br}(h \to b\bar{b})$ at $M_h =$ 120 GeV.

Plans:

- Background $\gamma\gamma \to WW$
- MSSM: parameters space scan

New results for the MSSM Higgs-bosons production in $\gamma\gamma \to higgs \to b\bar{b}$ at the Photon Collider

Abstract 632

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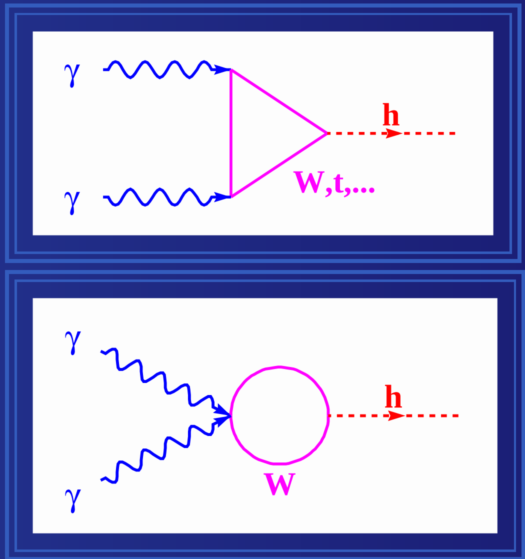
Loop coupling $h\gamma\gamma$:

- Higgs-bosons can be produced as s-channel resonances
- Non-decoupling $\Rightarrow$ tests of models
- The best machine for this measurement: Photon Collider

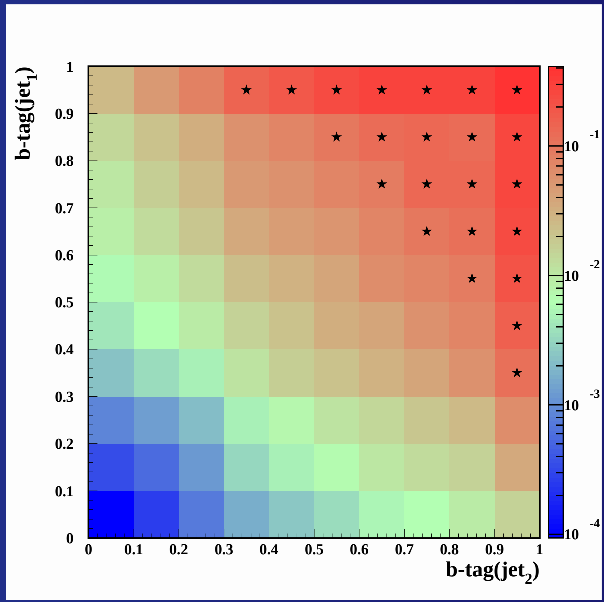


Beyond SM: $H^{\pm}, \chi^{\pm}, \tilde{q}, \tilde{l} \ldots$

Introduction

Our analysis of $\sigma(\gamma\gamma \to h \to b\bar{b})$ and $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ measurement:

- Realistic $\gamma\gamma$-spectra (TESLA-like)
- Beams crossing angle, primary vertex distribution
- NLO QCD background $\gamma\gamma \to Q\bar{Q}(g)$ $(Q = c, b)$
- Other backgrounds: $\gamma\gamma \to W^+W^-$, $\gamma\gamma \to q\bar{q}$ $(q = u, d, s)$, $\gamma\gamma \to \tau^+\tau^-$
- Overlaying events $\gamma\gamma \to hadrons$: about 1–2 OE per bunch crossing
- b-tagging (*e.g.* for $M_A = 300$ GeV: $\varepsilon_h = 53\%$, $\varepsilon_{bb} = 47\%$, $\varepsilon_{cc} = 2.9\%$, $\varepsilon_{uds} = 0.5\%$)
- Realistic detector simulation (SIMDET)
- Full optimization of cuts

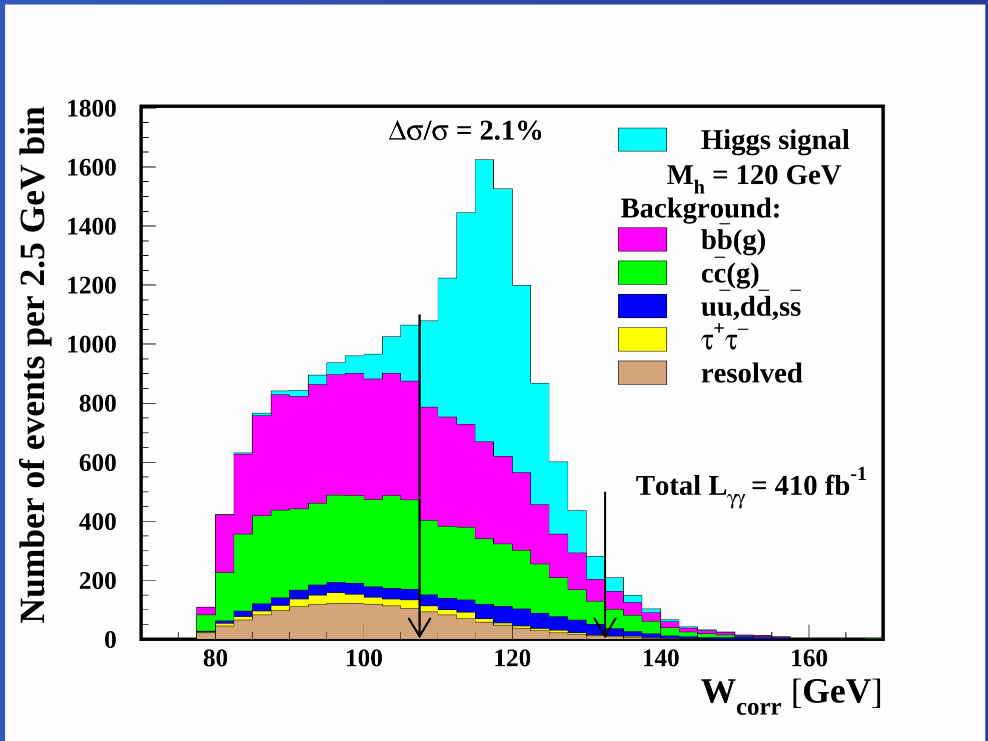


⇒ results for SM with $M_h = 120, 130, 140, 150, 160$ GeV

⇒ results for MSSM with $M_A = 200, 250, 300, 350$ GeV
four MSSM scenarios for $\tan\beta = 3$–20.

SM summary

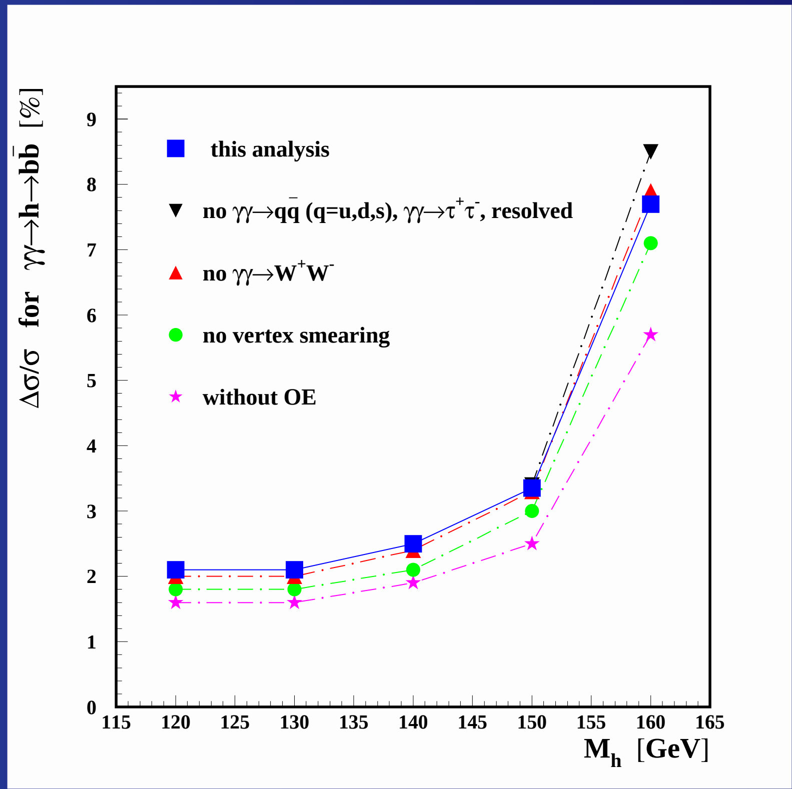
Results for $M_h = 120$ GeV



Corrected invariant mass distributions

$$W_{\rm corr} \equiv \sqrt{W_{rec}^2 + 2P_T(E+P_T)}$$

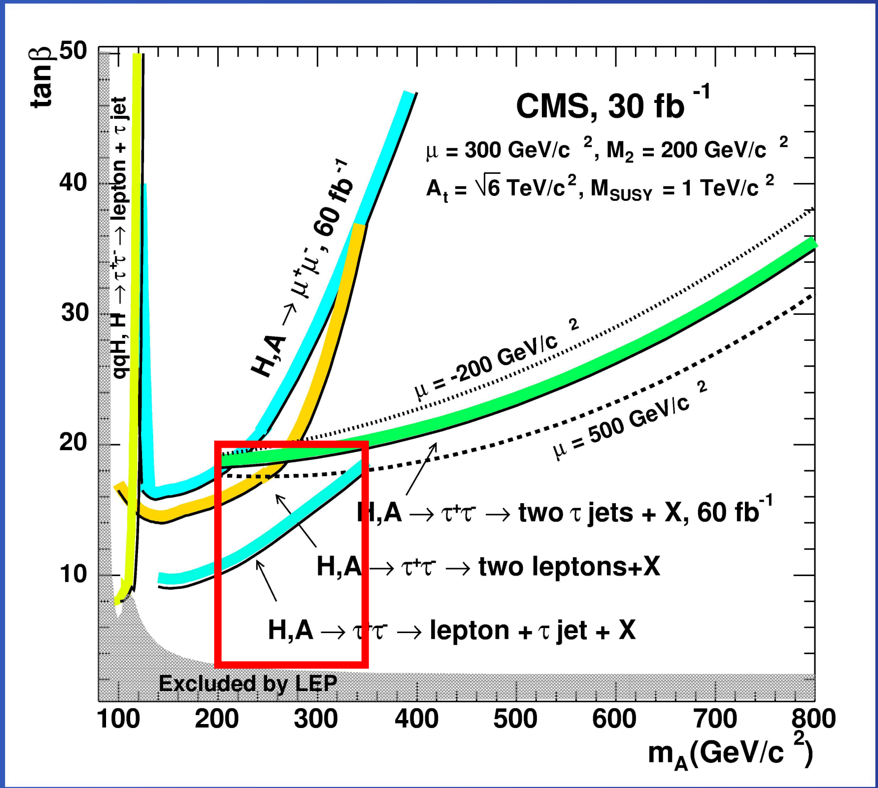
Results for $M_h = 120$-160 GeV



For $M_h = 150$, 160 GeV additional cuts to reduce $\gamma\gamma \to W^+W^-$

MSSM: LHC wedge at PLC

LHC wedge



From: CMS NOTE 2003/033
(the same results as in newer CMS CR 2004/058)

We consider four MSSM parameter sets:

Symbol	μ [GeV]	M_2 [GeV]	$A_{\tilde{f}}$ [GeV]
I	200	200	1500
II	-150	200	1500
III	-200	200	1500
IV	300	200	2450

I and III – as in M. Mühlleitner *et al.*
with higher $A_{\tilde{f}}$ to have M_h above 114 GeV

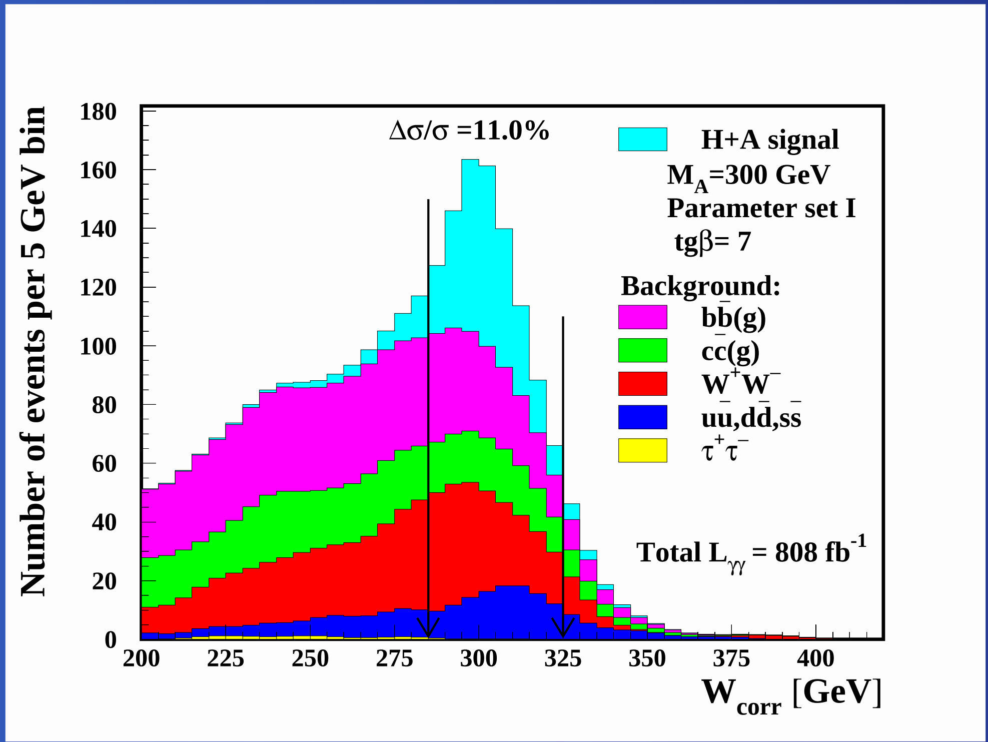
II – an intermediate scenario

IV – as in CMS NOTE 2003/033

MSSM: Precision at PLC

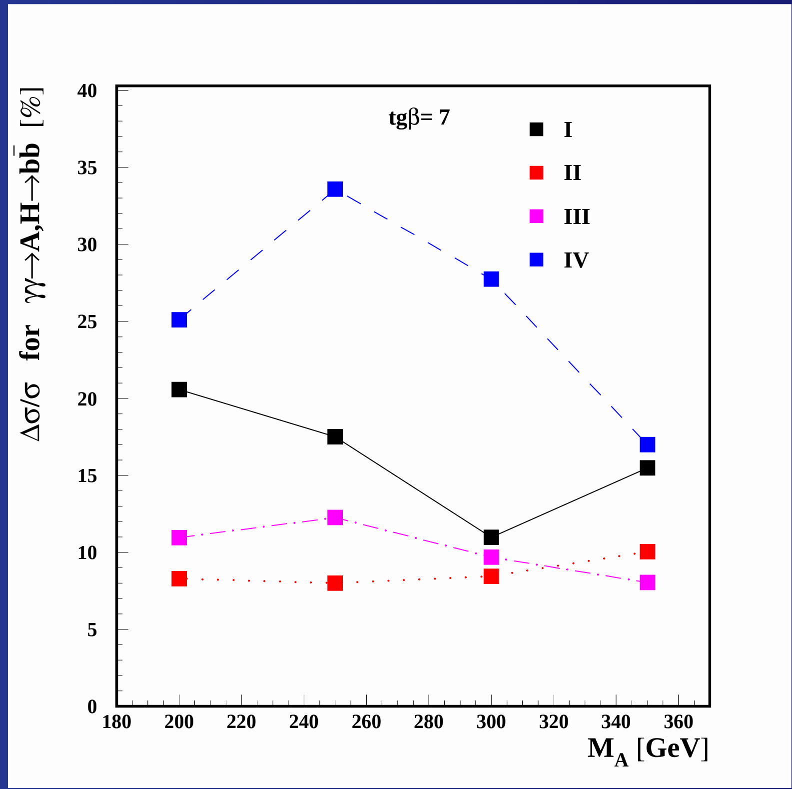
Precision of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ mesurement

Results for M_A = 300 GeV



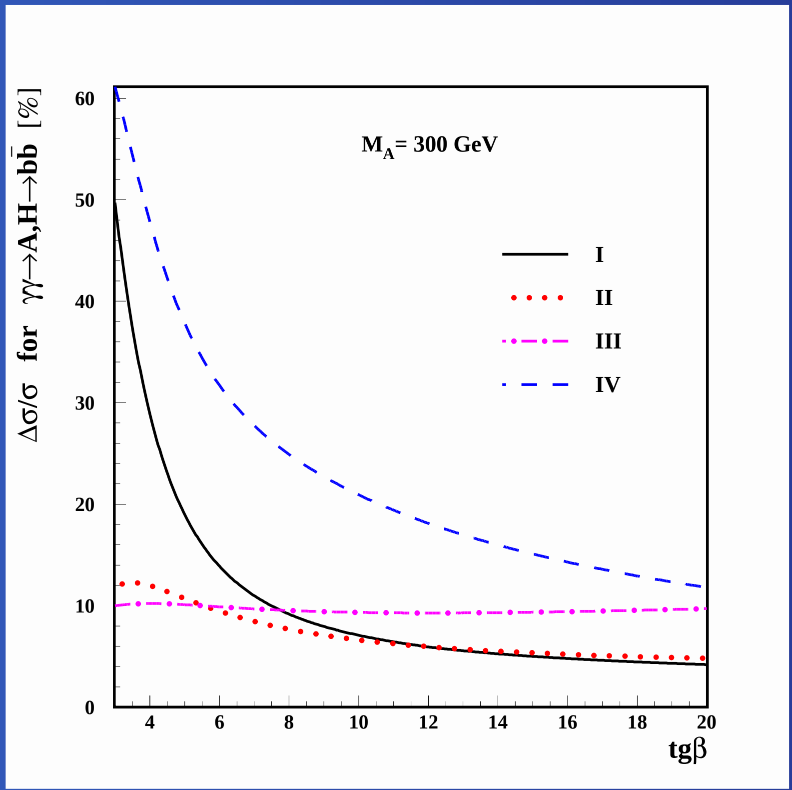
Corrected invariant mass distributions

Results for M_A = 200-350 GeV

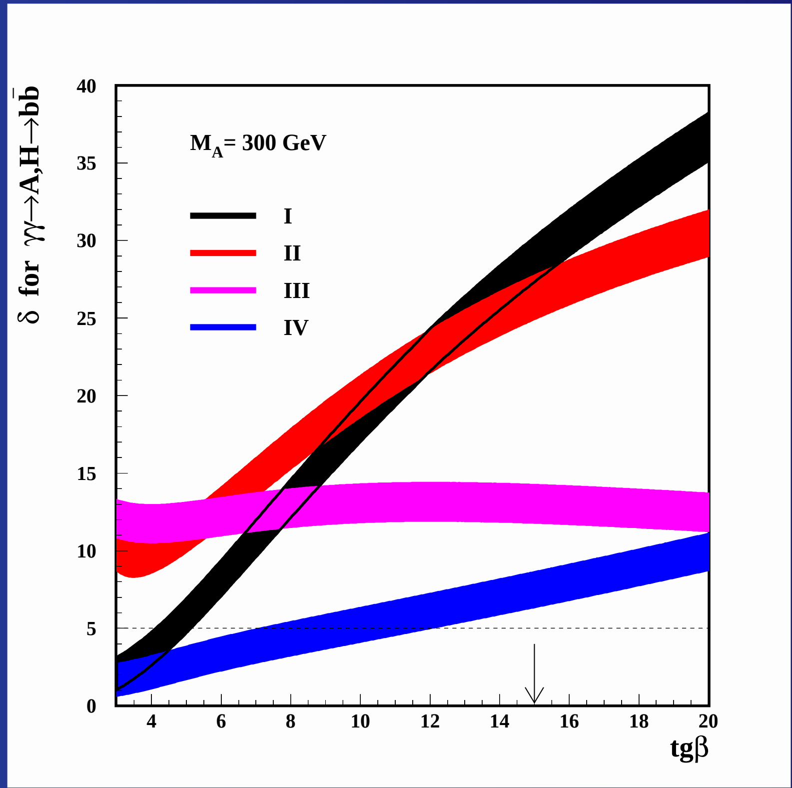


Precision & Significance

$\Delta\sigma(\gamma\gamma \to A, H \to b\bar{b})/\sigma(\gamma\gamma \to A, H \to b\bar{b})$



Significance for $\gamma\gamma \to A, H \to b\bar{b}$



$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S}$$

$$\delta = \frac{\mu_S}{\sqrt{\mu_B}} \pm \sqrt{1 + \frac{\mu_S}{\mu_B}}$$

Arrow – lower limit at LHC

Conclusions

- All relevant theoretical and experimental aspects taken into account.
- SM
  High precision for measurement of the SM Higgs boson despite large effects due to $\gamma\gamma \to hadrons$ overlaying events.

  Statistical precision of 2% for $\Gamma(h \to \gamma\gamma)\mathrm{BR}(h \to b\bar{b})$ at $M_h = 120$ GeV.
  Systematic uncertainty about 2%.
- MSSM
  LHC wedge $\Rightarrow$ four MSSM parameter sets, $\tan\beta = 3$–20 considered

  Precision 11–21% for $M_A = 200$–350 GeV, $\tan\beta = 7$ (set I, after one year)

  For $M_A \gtrsim 300$ GeV the Photon Collider can discover MSSM Higgs bosons below $\tan\beta = 15$ (LHC limit)

$\Rightarrow$ The Photon Collider is a very promising machine

Two analyses

- MKSZ

-dsigma_NLO from Kamel ..

one-particle inclusive

-cut on theta for b |cos|<.5

-Sterman-Weinberg jets

e_g>0.1E_tot, theta_ij>20^o

-scale mu2=s

-resummation of (non)Sudakov logs

- NKZ

-dsigma_NLO from Jikia..(two-body incl)

-cut on theta for b and b bar

|cos|<.7

-Jade (Durham) jets s_ij=(p_i+p_j)2>y_cut s

-mu2=av transverse mass

of b and b bar

-resummation of non-Sudakov logs up to a_s^4

Results for J_z=0: Michael Spira notes'18 Feb 06

Sterman–Weinberg ($\varepsilon > 0.1\sqrt{s}$, $\vartheta_{ij} > 20^\circ$)	JADE ($y_{cut} = 0.01$)
$\sigma_{2j}^{(b,\bar{b})} \sim 1.1$ fb	$\sigma_{2j}^{(b,\bar{b})} \sim 1.6$ fb
$\sigma_{3j}^{(b,\bar{b})} \sim 4.1$ fb	$\sigma_{3j}^{(b,\bar{b})} \sim 4.0$ fb
$\sigma_{2j}^{(b)} \sim 1.1$ fb	$\sigma_{2j}^{(b)} \sim 1.8$ fb
$\sigma_{3j}^{(b)} \sim 28$ fb	$\sigma_{3j}^{(b)} \sim 27$ fb

CONCLUSIONS

- cut on ϑ_b only: $\sigma_{3j} \gg \sigma_{2j}$
- cuts on ϑ_b and $\vartheta_{\bar{b}}$: $\sigma_{3j} \sim \sigma_{2j}$

  $\Longrightarrow$ y_{cut} not too important
- (non-)Sudakov resummation moderate effect

  $\Longleftarrow$ not source of discrepancies

SIGNAL: Work in progress...