MSSM *higgses* at the Photon Collider

- the puzzle *36=2* resolved

A detective story

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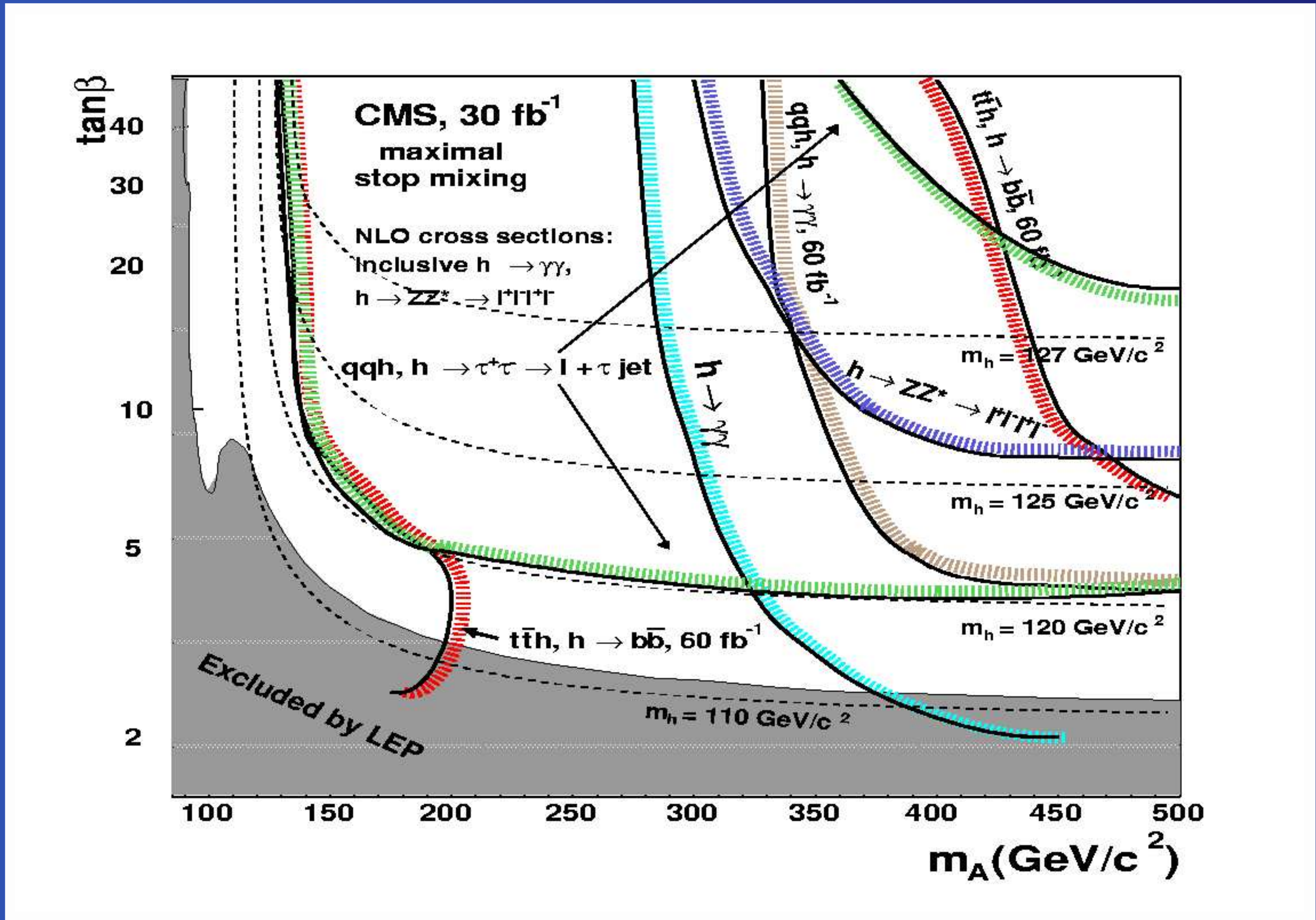
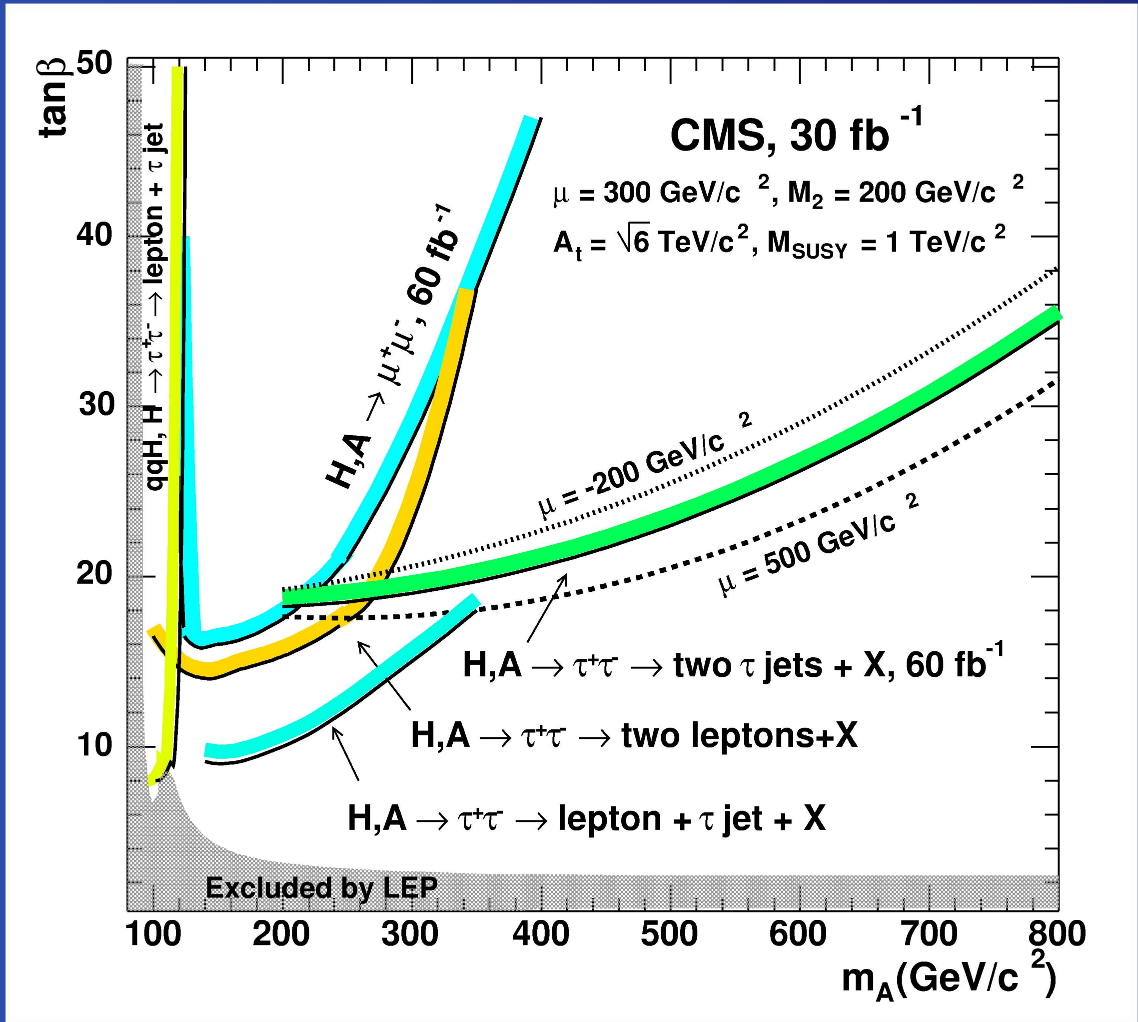
MSSM *higgses* at LHC: h



h

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

MSSM *higgses* at LHC: $A,\ H$



A, H

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

MSSM *higgses* at ILC: A, H

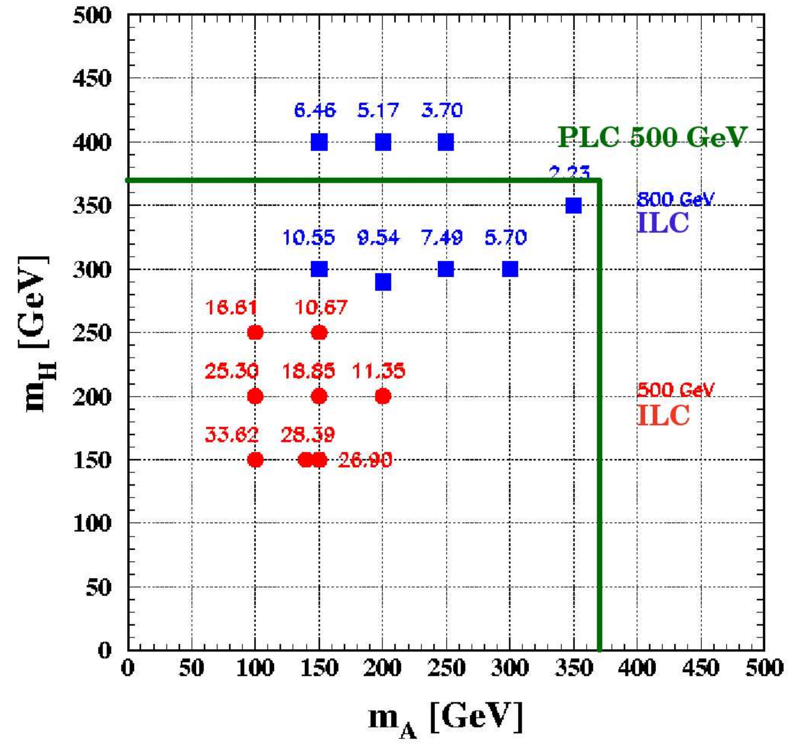


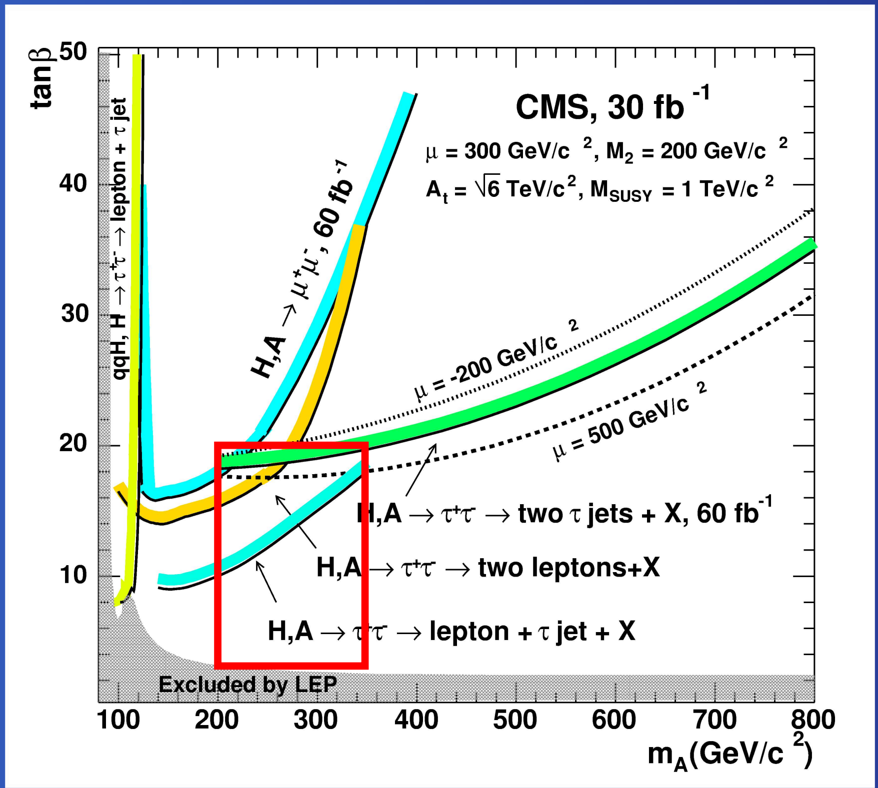
Figure 5.1: *Higgs boson mass grid for different mass hypotheses* (m_{H},m_{A}) *considered in the study for* $\sqrt{s} = 500$ *GeV (round red points) and 800 GeV (square blue points). The numbers indicate cross sections for* $\mathrm{e^+e^-} \to \mathrm{HA}$ *in fb.*

A, H

From: Tatsiana's Klimkovich thesis, 2005

Introduction

LHC wedge



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

Two analyses
with MSSM parameter set:
$M_A =$ 300 GeV
$\tan\beta = 7,\ M_2 = \mu =$ 200 GeV

MKSZ
M. Mühlleitner, M. Krämer, M. Spira,
P. Zerwas, Phys. Lett. B 508 (2001) 311.
$S/B \approx 36$
(300 ± 3 GeV)

NŻK
P. Nieżurawski, A.F. Żarnecki, M. Krawczyk,
Acta Phys. Pol. B 37 (2006) 1187.
$S/B \approx 2$
(300 ± 5 GeV, only $\gamma\gamma \to b\bar{b}(g)$ background)

MKSZ analysis overview

MKSZ analysis of $\gamma\gamma \to A, H \to b\bar{b}$, $\gamma\gamma \to b\bar{b}$ processes:

- Compton spectrum

  $E_L = 1.29$ eV $\Rightarrow$ for $M_A =$ 300 GeV optimal $E_e = 200$ GeV
- NLO calculation for signal and background:
  - full resummation of Sudakov and non-Sudakov logarithms
  - NLO-α_s with the scale $\mu^2 = s_{\gamma\gamma}$
- Interference between signal and background taken into account
- NLO QCD corrections of the interference terms to quark final states including the resummation of the large (non-)Sudakov logarithms calculated
- 3-jet events defined by the Sterman–Weinberg criterion:

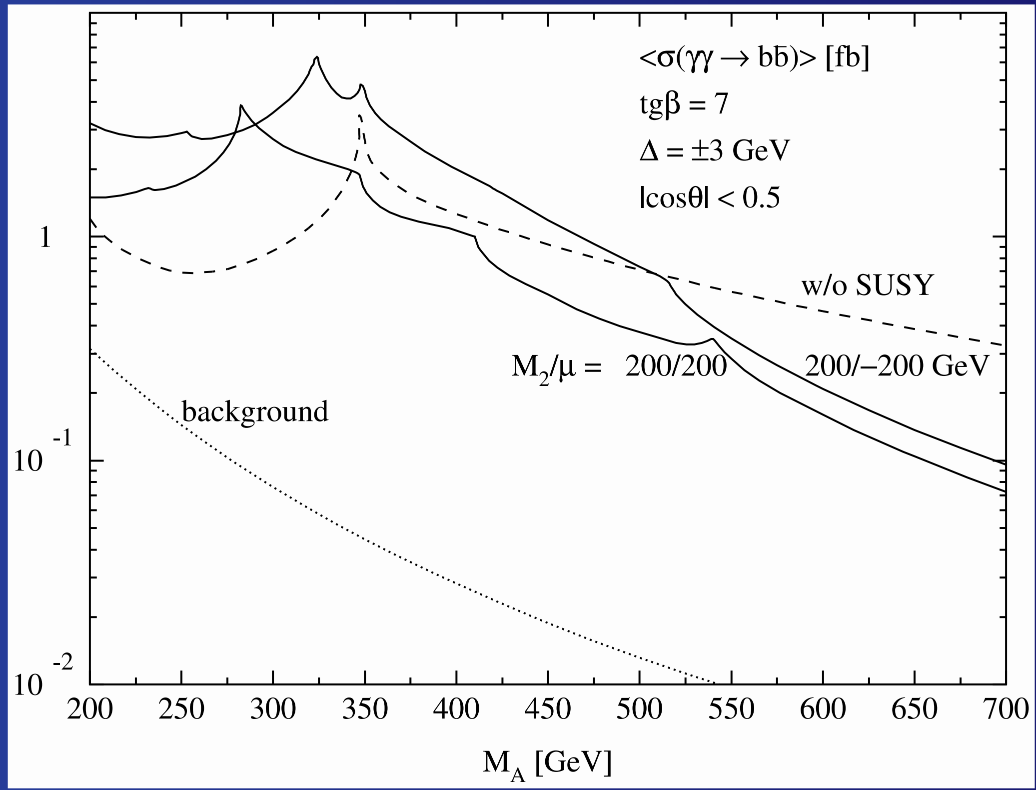
  Energy of the radiated gluon > 10% $\sqrt{s_{\gamma\gamma}}$

  and the angles between all three final partons > 20°.
- $N_{jets} = 2$
- Angular cut only for b: $|\cos\theta_b| < 0.5$
- Only events in the window $M_A \pm 3$ GeV taken into account

MKSZ: Results

Cross sections of $\gamma\gamma \to A, H \to b\bar{b}$ and $\gamma\gamma \to b\bar{b}$ processes

Results for $M_A =$ 200-700 GeV



Considered MSSM parameter sets

μ [GeV]	M_2 [GeV]	$A_{\tilde{f}}$ [GeV]
200	200	0
-200	200	0

Also the limit of vanishing SUSY-particle contributions considered.

Results for $M_A =$ 200-700 GeV and for $\tan\beta = 7$

Average cross sections in the invariant mass window ± 3 GeV.
$M_A =$ 300 GeV, $\mu =$ 200 GeV $\Rightarrow S/B \approx 36$

NŻK analysis overview

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

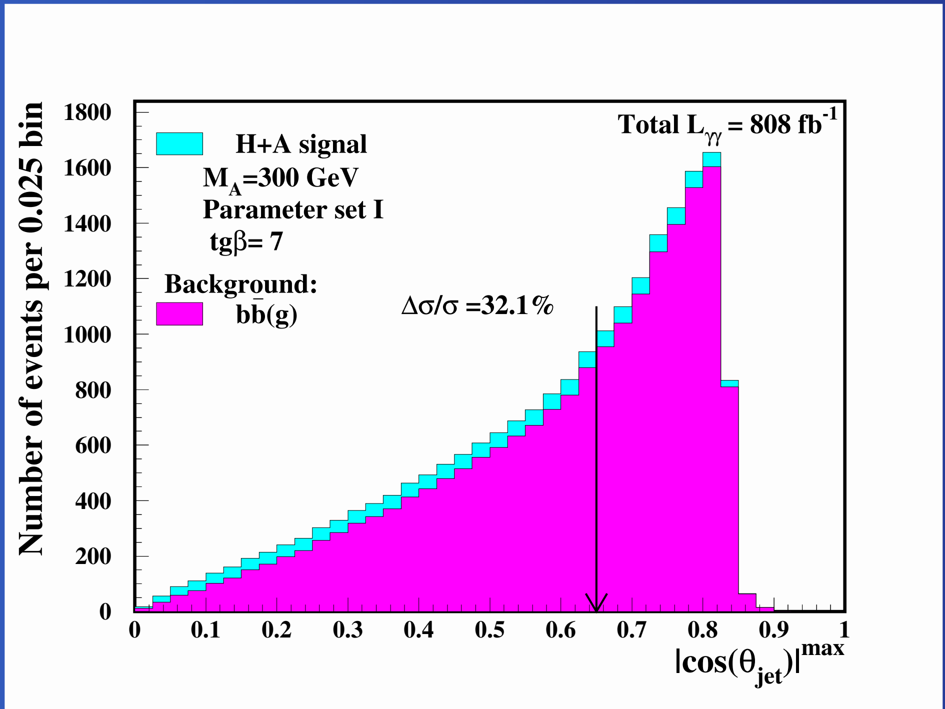
- TESLA-like $\gamma\gamma$-spectra (V. Telnov simulations, CompAZ parametrization)
  $E_L = 1.17$ eV $\Rightarrow$ for $M_A =$ 300 GeV optimal $E_e = 210$ GeV
- Beams crossing angle, primary vertex distribution
- A and H parameters from HDecay.
  Generated in resonance approximation with Pythia.
  Parton shower $\to$ 3-jet events.
- NLO QCD background $\gamma\gamma \to Q\bar{Q}(g)$ $(Q = c, b)$ with program by G. Jikia:
  - resummation of non-Sudakov logarithms up to 4-loop order
  - JADE jet definition
  - LO-α_s with the scale $\mu^2 = (m_{Tb}^2 + m_{T\bar{b}}^2)/2$
- 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 2 OE per bunch crossing
- b-tagging algorithm (package ZvTop-B-Hadron-Tagger by T. Kuhl)
- Detector simulation (Simdet)
- Full optimization of cuts

NŻK: Cuts

Cuts optimized by minimizing:

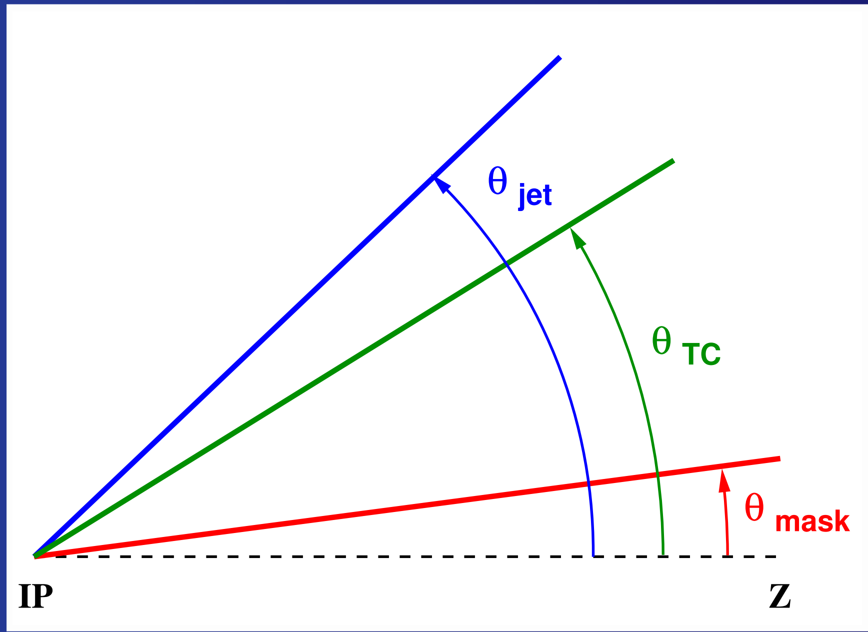
$$\frac{\Delta\sigma(\gamma\gamma \to A, H \to b\bar{b})}{\sigma(\gamma\gamma \to A, H \to b\bar{b})} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S}$$

For example, for $M_A = 300$ GeV:



Maximal value of $|\cos\theta_{jet}|$ over all jets in the event

All angular cuts



Detector mask
Particles on Pythia level: $\cos\theta_{mask} \approx 0.99$

OE suppression
Tracks & clusters: $\cos\theta_{TC} = 0.85$

$\gamma\gamma \to Q\bar{Q}(g)$ suppression
Jets: $|\cos\theta_{jet}|^{\max} = 0.65$

NŻK: Reconstruction & Selection

Selection of $b\bar{b}$ events for $M_A = 300$ GeV:

- OE suppression: clusters & tracks with $|\cos\theta_i| > \cos\theta_{TC} = 0.85$ ignored
- $W_{rec} > 1.2\, W_{\gamma\gamma}^{\min}$

  Jets: Durham algorithm, $y_{cut} = 0.02$
- $N_{jets} = 2, 3$
- for each jet: $|\cos\theta_{jet}| < 0.65$
- $|P_z|/E < 0.06$

Rejection of W^+W^- events:

- for each jet: $M_{jet} < 65$ GeV
- energy below θ_{TC}: $E_{TC} < 80$ GeV
- for each jet: $N_{trk} \geq 4$

- b-tagging

Correction for crossing angle: jets boosted with $\beta = -\sin(\alpha_c/2)$

NŻK: *higgs*-tagging

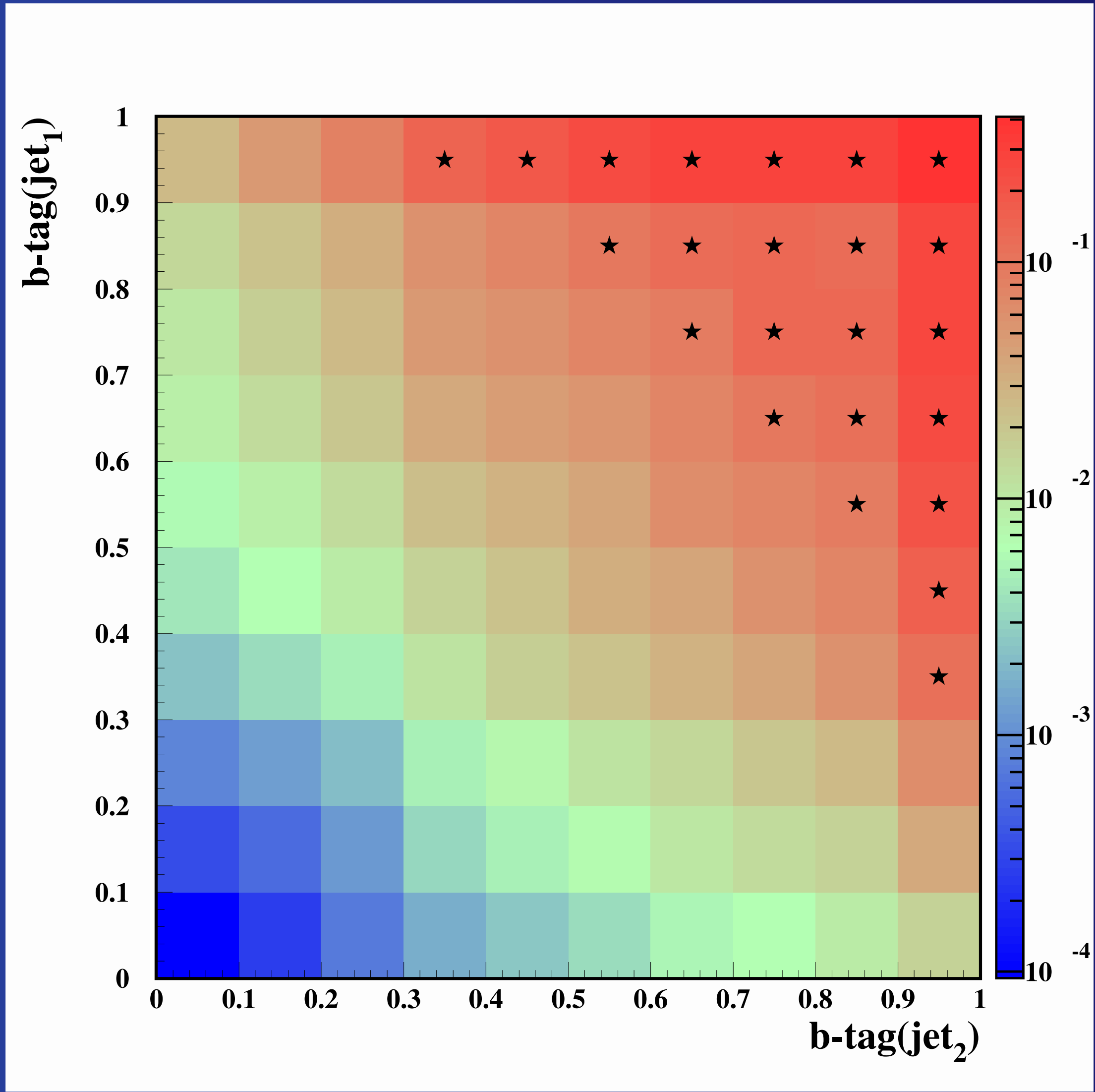
higgs-tagging: a cut on the ratio of $\gamma\gamma \to A, H \to b\bar{b}$ to $\gamma\gamma \to b\bar{b}(g), c\bar{c}(g), q\bar{q}$ $(q = u, d, s)$ events

$\Rightarrow \varepsilon_h = 53\%$
$\varepsilon_{bb} = 47\%$
$\varepsilon_{cc} = 2.9\%$
$\varepsilon_{uds} = 0.5\%$

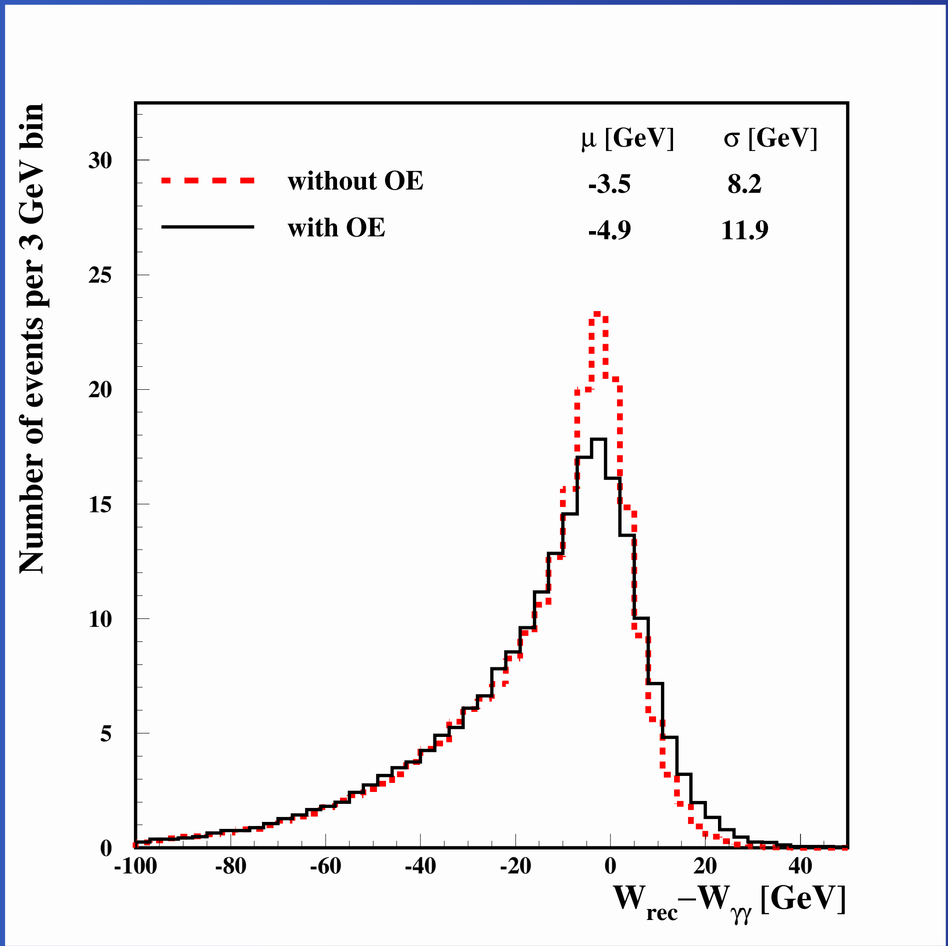
Without OE

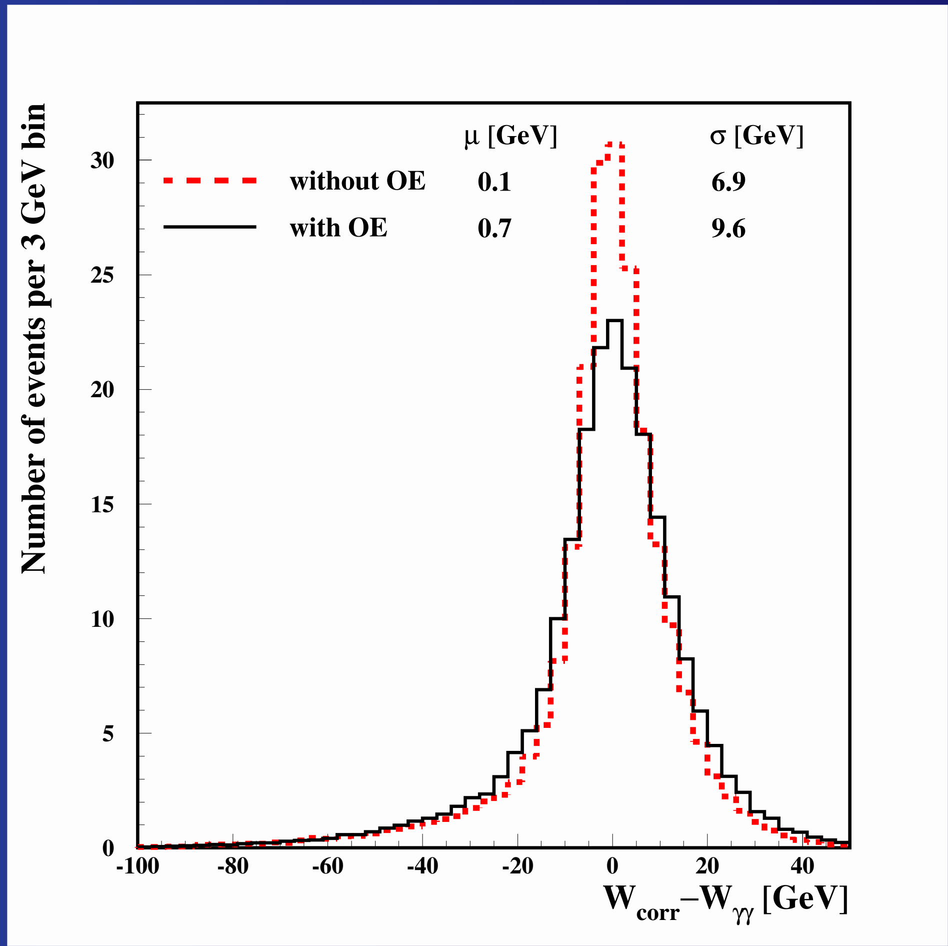
$\Rightarrow \varepsilon_h = 57\%$
$\varepsilon_{bb} = 52\%$
$\varepsilon_{cc} = 1.8\%$
$\varepsilon_{uds} = 0.1\%$

Tighter cuts are needed due to OE contribution



NŻK: $\gamma\gamma \to A \to b\bar{b}$





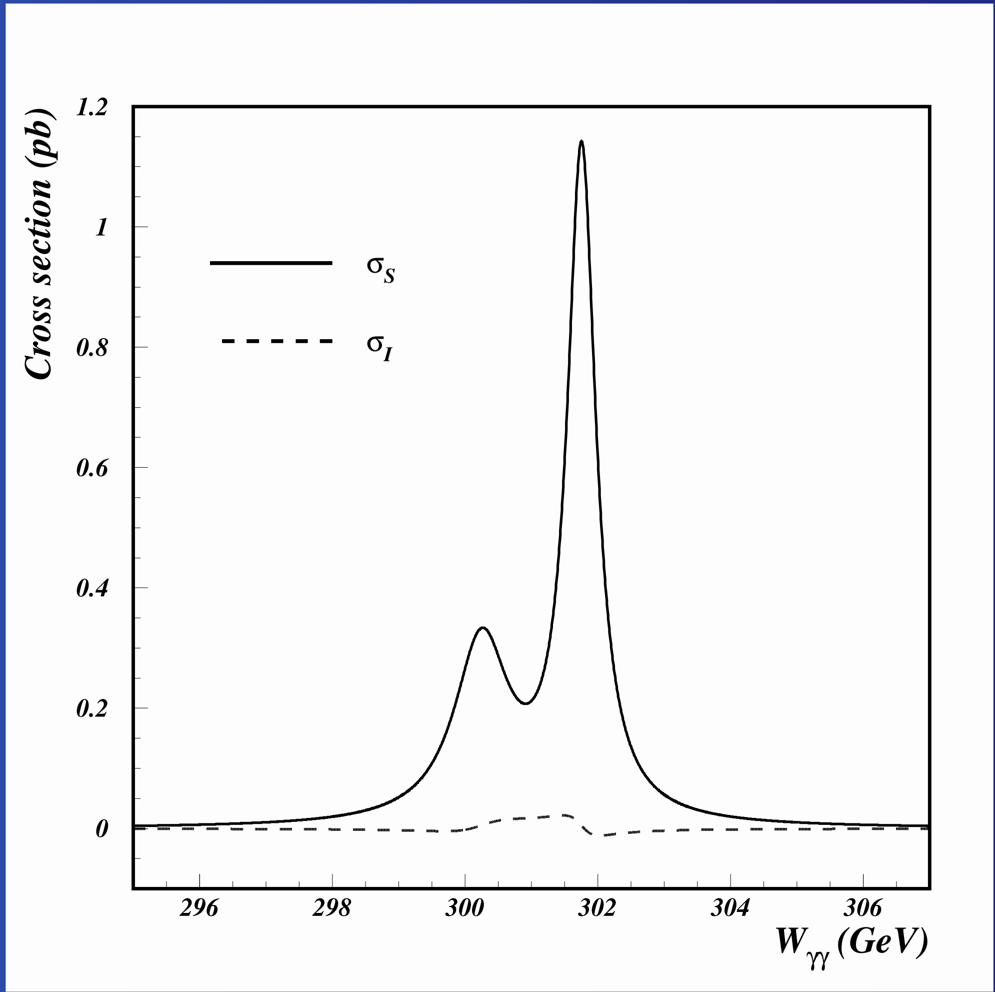
$$W_{\rm corr} \equiv \sqrt{W_{rec}^2 + 2P_T(E+P_T)}$$

Acta Phys. Pol. B34 177 2003, hep-ph/0208234

Gaussian fit from $\mu - 1.3\sigma$ to $\mu + 1.3\sigma$.

NŻK: $\gamma\gamma \to A, H \to b\bar{b}$

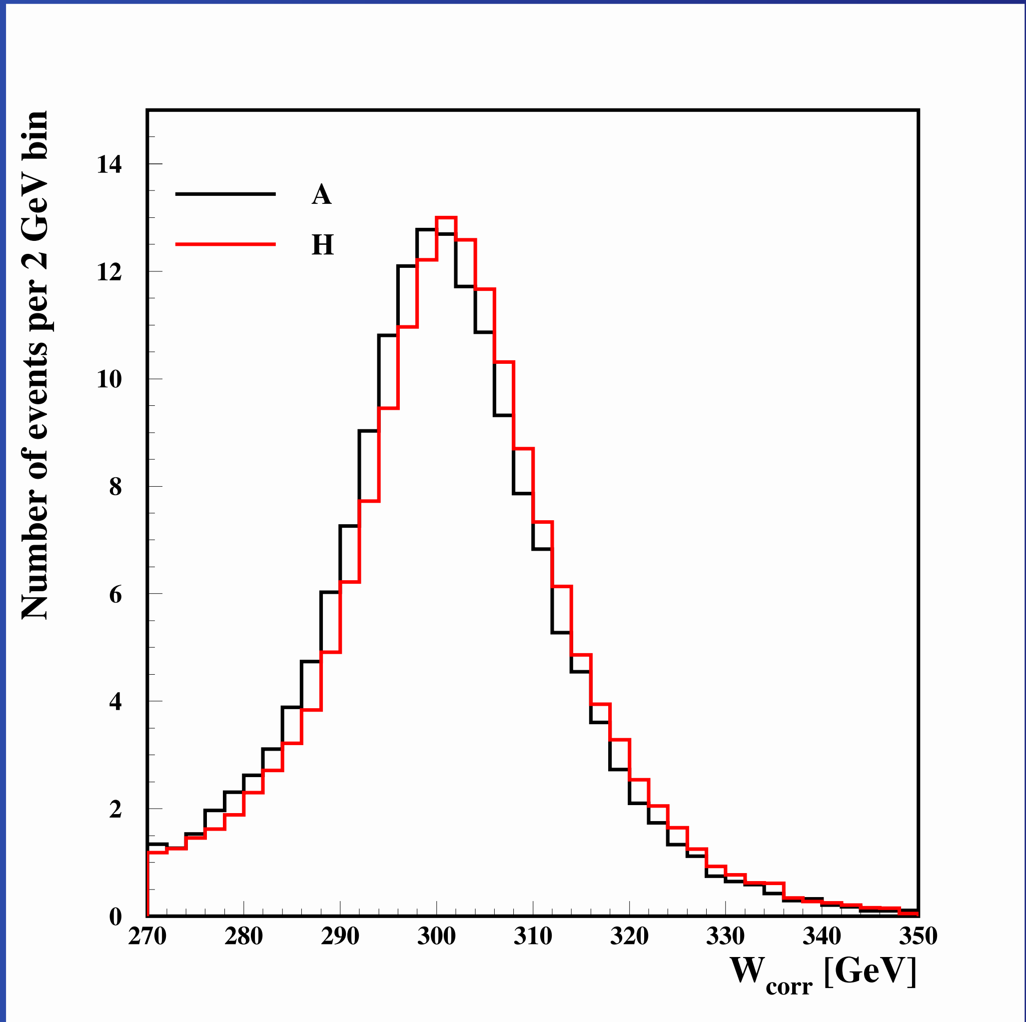
LO cross section for signal and interference term.



Interference with $\gamma\gamma \to b\bar{b}$ is less than 1% of the signal even after higher order corrections (M. M. Mühlleitner, hep-ph/0008127)

NŻK: $\gamma\gamma \to A, H \to b\bar{b}$

Reconstructed events



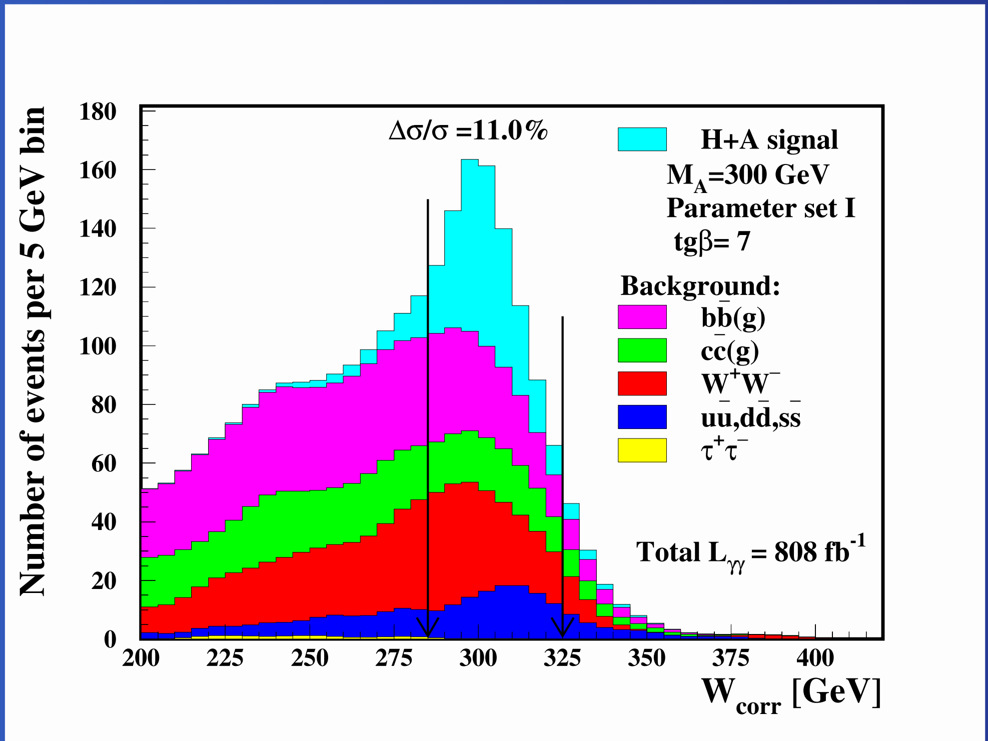
$\tan\beta = 7$

$M_H - M_A \approx 1.5$ GeV

NŻK: Precision at PLC

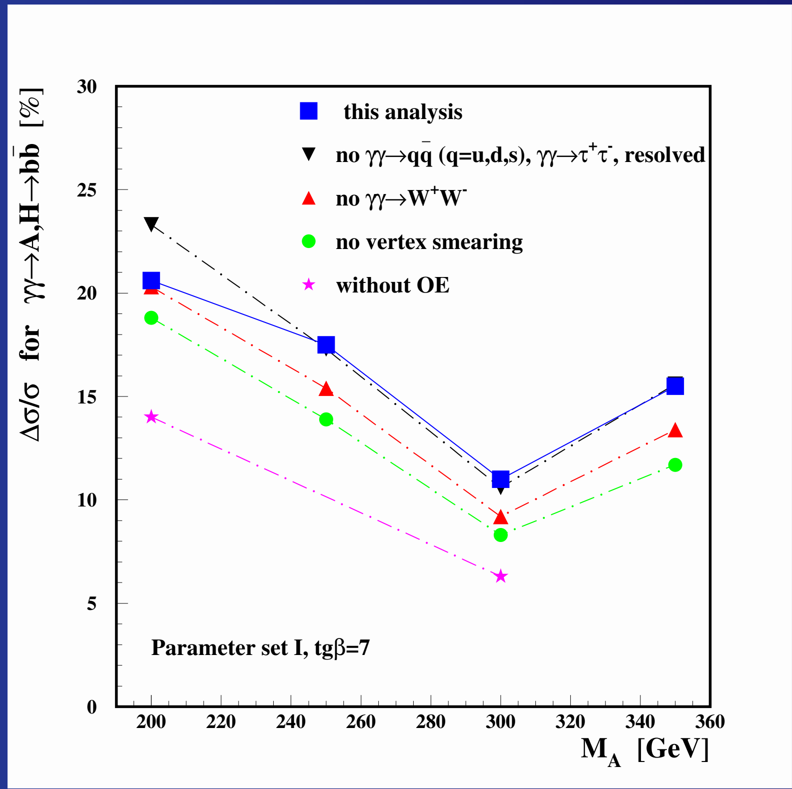
Precision of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ measurement

Results for $M_A = 300$ GeV



Corrected invariant mass distributions.
For 300 ± 5 GeV and with only $\gamma\gamma \to b\bar{b}(g)$ background: $S/B \approx 2$

Results for $M_A =$ 200-350 GeV



our previous results compared

NŻK: Precision at PLC

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

Considered four MSSM parameter sets:

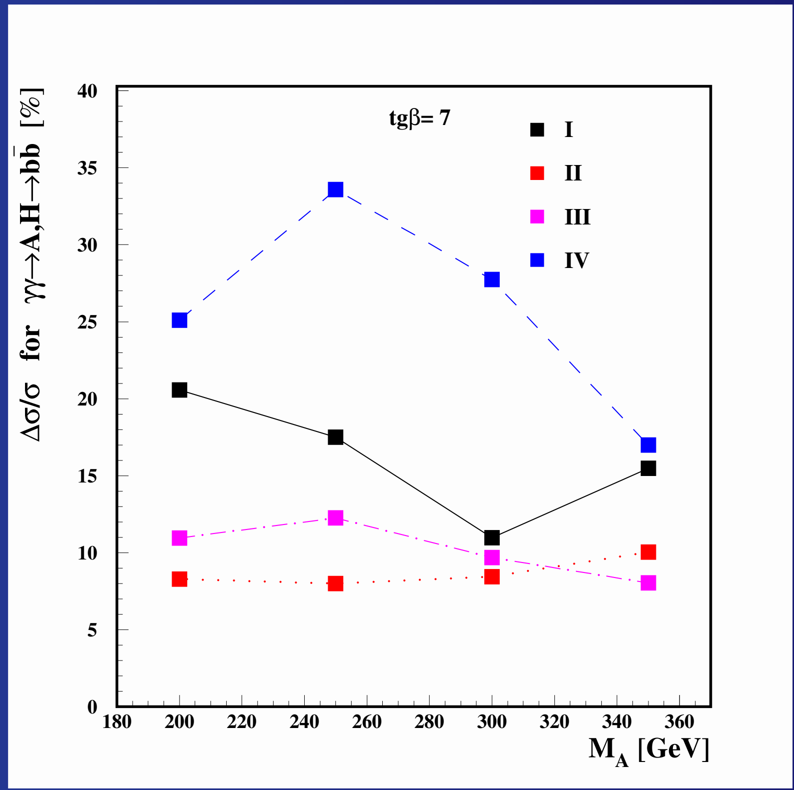
Symbol	μ [GeV]	M_2 [GeV]	$A_{\tilde{f}}$ [GeV]
I	200	200	1500
II	-150	200	1500
III	-200	200	1500
IV	300	200	2450

I and III – following 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

Results for $M_A =$ 200-350 GeV



Results for $M_A =$ 200, 250, 300, 350 GeV
Four MSSM scenarios for $\tan\beta =$ 3–20

Comparison: Setup

Only parton level analysis

- MSSM parameters:
  $M_A = 300$ GeV, $\tan\beta = 7$, $\mu = M_2 = 200$ GeV,
  $A_{\tilde{f}} = 1500$ GeV, $M_{\tilde{f}} = 1$ TeV
- Flat, normalized luminosity spectrum: $\sqrt{s_{\gamma\gamma}} = 300 \pm 3$ GeV
- Angular cut for both quarks: $|\cos\theta_i| < 0.5$ where $i = b, \bar{b}$
- JADE jet definition with $y_{cut} = 0.01$

Comparison: Results

Results for $\gamma\gamma \to b\bar{b}$ background (with JADE):

- With angular cut for both quarks 2-jet and 3-jet parts are of the same order.
  $\to N_{jets} = 2, 3$.
  With cut on one quark the 3-jet part is greater by more than order of magnitude.
- Both approaches agree within 15% for each event class: 2-jet, 3-jet, $J_z = 0$, $|J_z| = 2$.
  The full resummation of Sudakov and non-Sudakov logarithms does not modify the 2-jet numbers too much compared to the 4-loop expansion of the non-Sudakov logarithms.

Results for $\gamma\gamma \to A, H \to b\bar{b}$ signal (with JADE):

- Both approaches agree within 5% for total cross section,
  and within 30% for 2-jet and 3-jet classes separately.

Conclusions

Final conclusions of our comparison:

- If JADE jet definition is used and 2- and 3-jet events are accepted, then the difference is mainly due to different luminosity spectra:
  (L_0/L) used by NŻK = 94% of (L_0/L) used by MKSZ
  (L_2/L) used by NŻK = 5.5 of (L_2/L) used by MKSZ
  $\Rightarrow$ NŻK obtain 2 times lager $b\bar{b}$ background
  After rescaling NŻK obtain S/B around 17% lower than MKSZ.

- Sterman–Weinberg jet definition leads to much higher rate of 2-jet events for signal than for background.
  $\Rightarrow$ 2 times higher S/B ratio for 2-jet events in comparison to results obtained with JADE jet definition

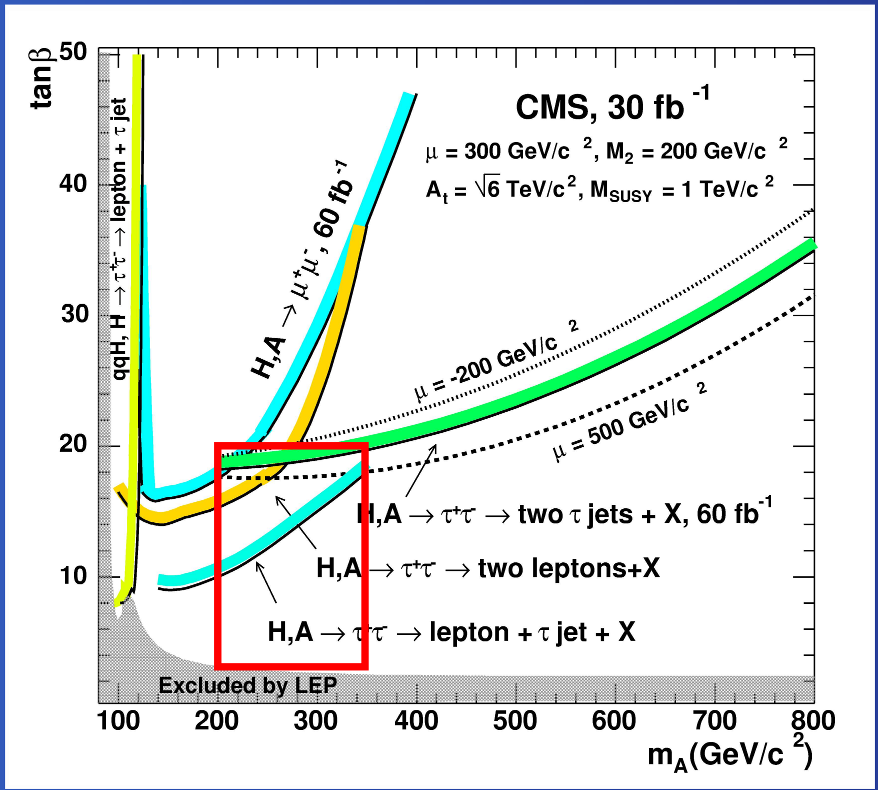
More detailed description: Proceedings of LCWS2006, Bangalore.

Backup Slides

Backup Slides

Introduction

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]
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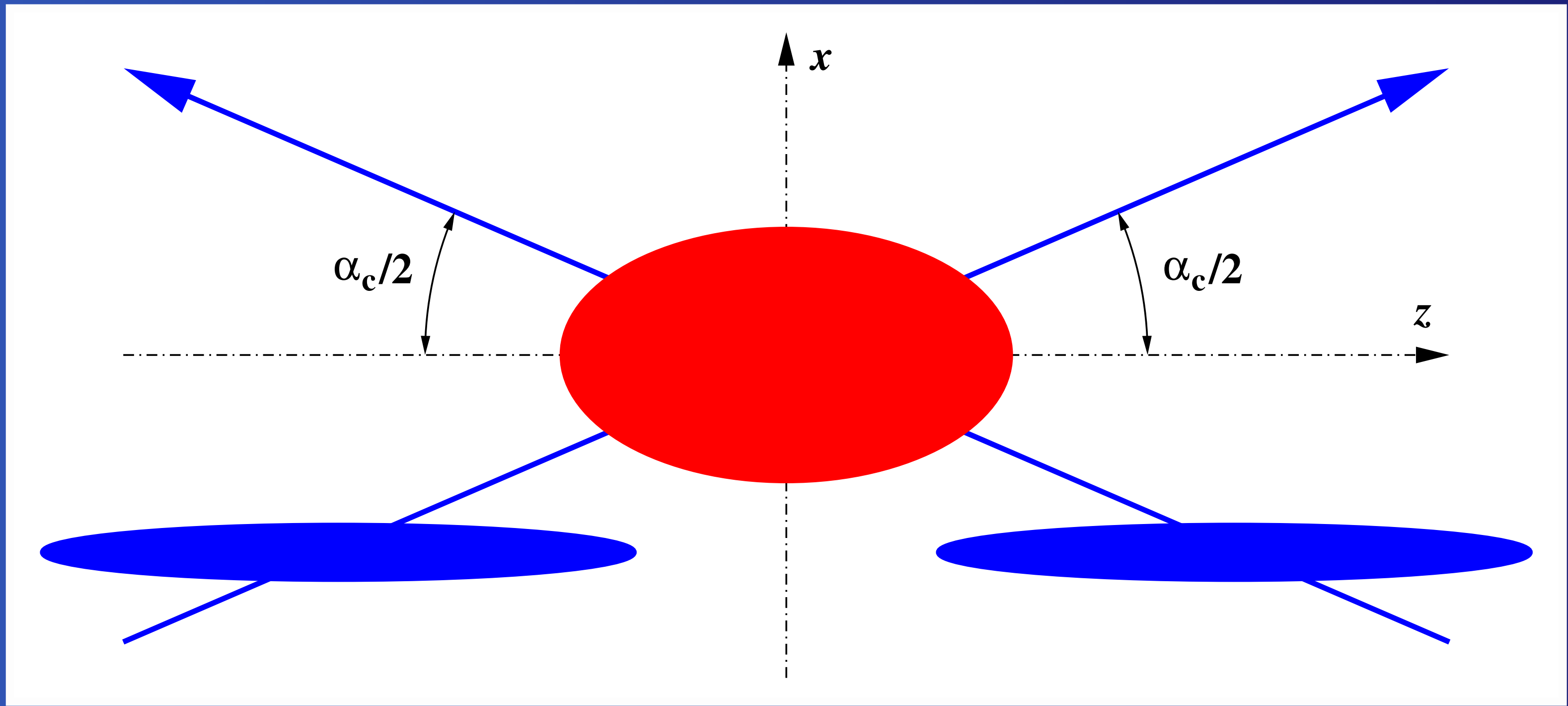
I and III – following M. Mühlleitner *et al.*
with higher $A_{\tilde{f}}$ to have M_h above 114 GeV
II – an intermediate scenario

IV – as in CMS NOTE 2003/033

Crab-wise crossing of beams

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

Bunch:	$\sigma_x = 140$ nm	$\sigma_y = 15$ nm	$\sigma_z = 0.3$ mm
Primary vertex:	$\sigma'_x = 3.6\ \mu$m	$\sigma'_y = 11$ nm	$\sigma'_z = 0.2$ mm

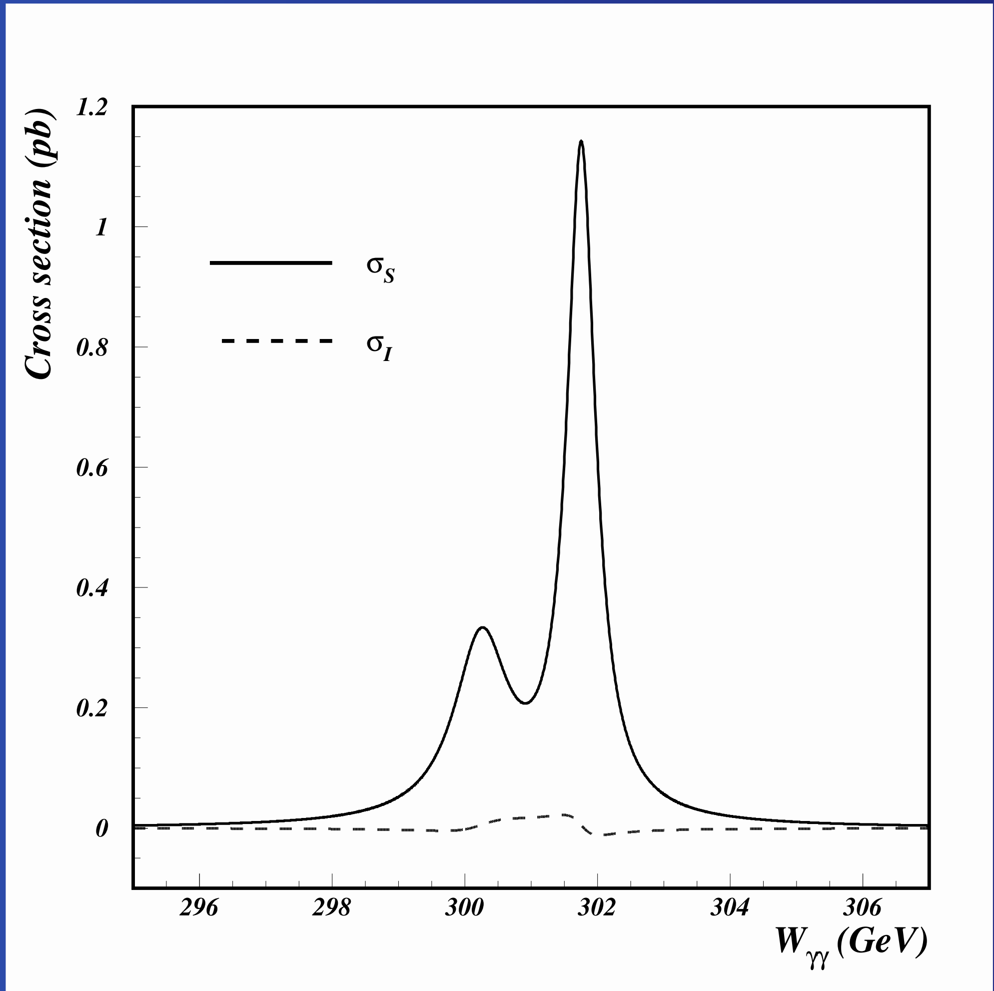


$\alpha_c = 34$ mrad

Primary vertex distribution + $\gamma\gamma \to hadrons$ OE = possible flavour mistagging

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

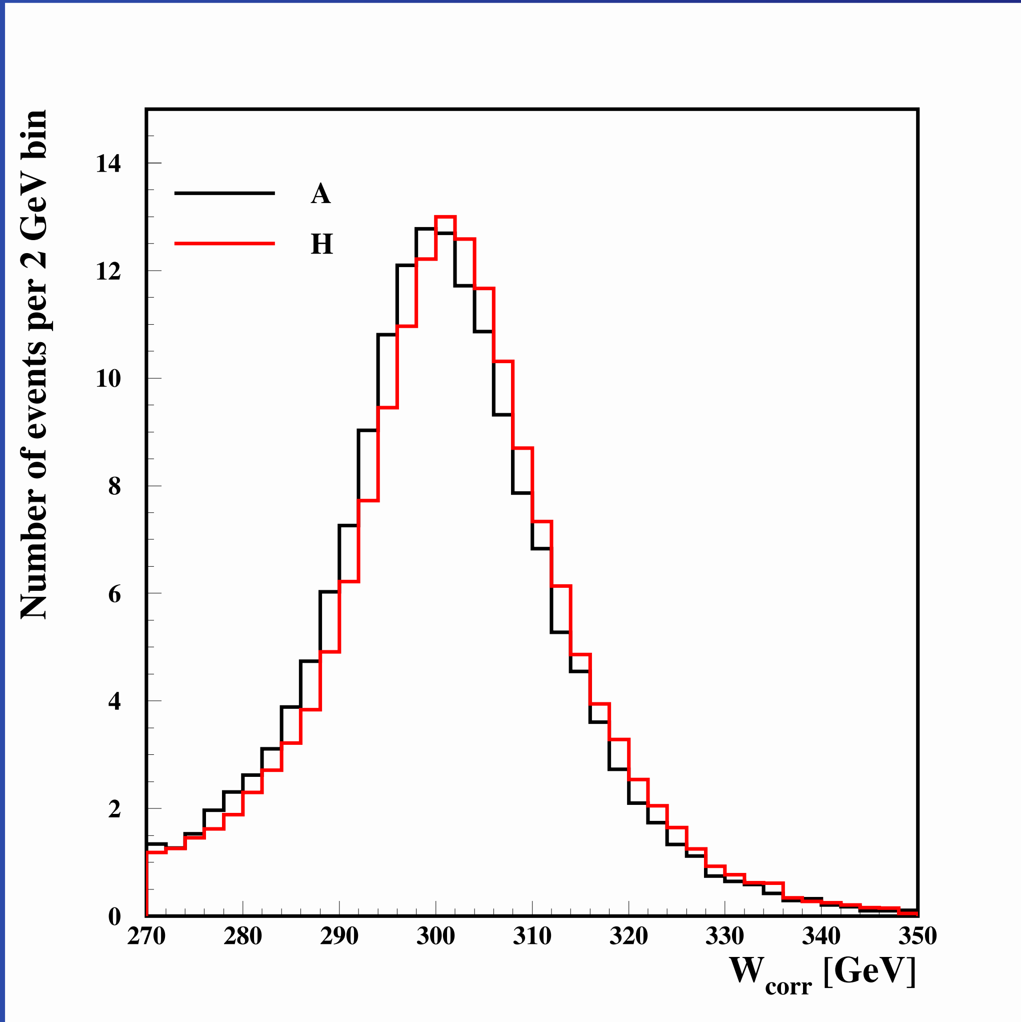
LO cross section for signal and interference term.



Interference with $\gamma\gamma \to b\bar{b}$ is less than 1% of the signal even after higher order corrections (M. M. Mühlleitner, hep-ph/0008127)

$\gamma\gamma \rightarrow A, H \rightarrow b\bar{b}$

Reconstructed events

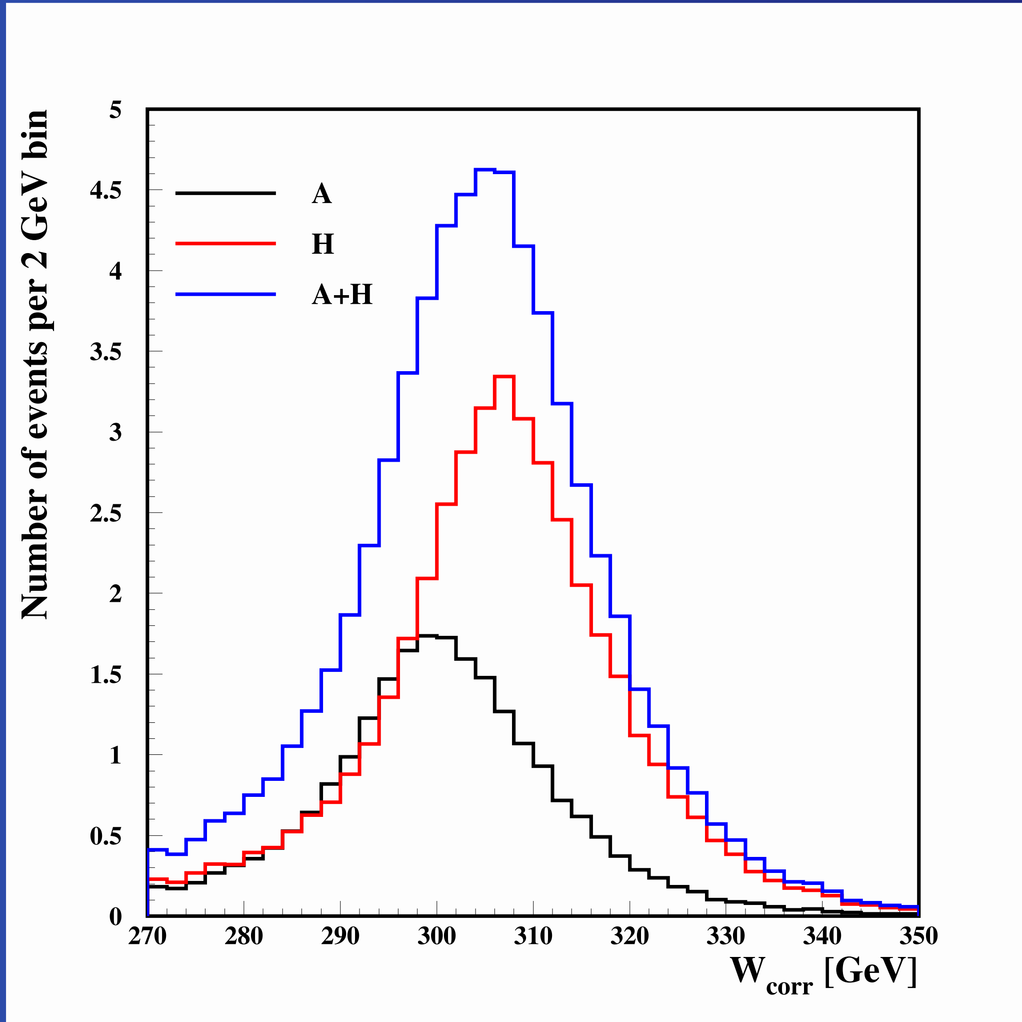


$\tan\beta = 7$

$M_H - M_A \approx 1.5$ GeV

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

Reconstructed events

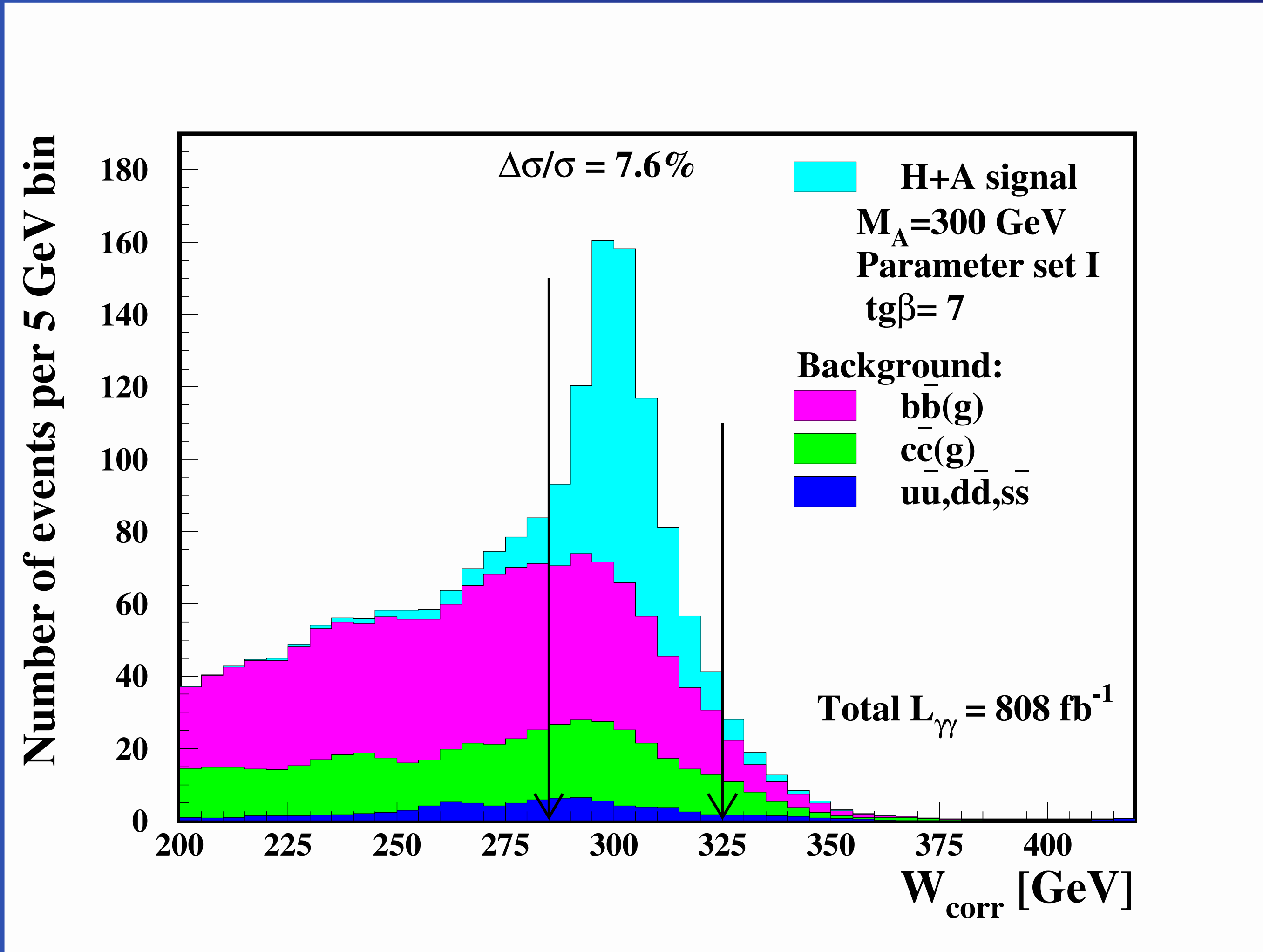


$\tan\beta = 3$

$M_H - M_A \approx 6.8$ GeV

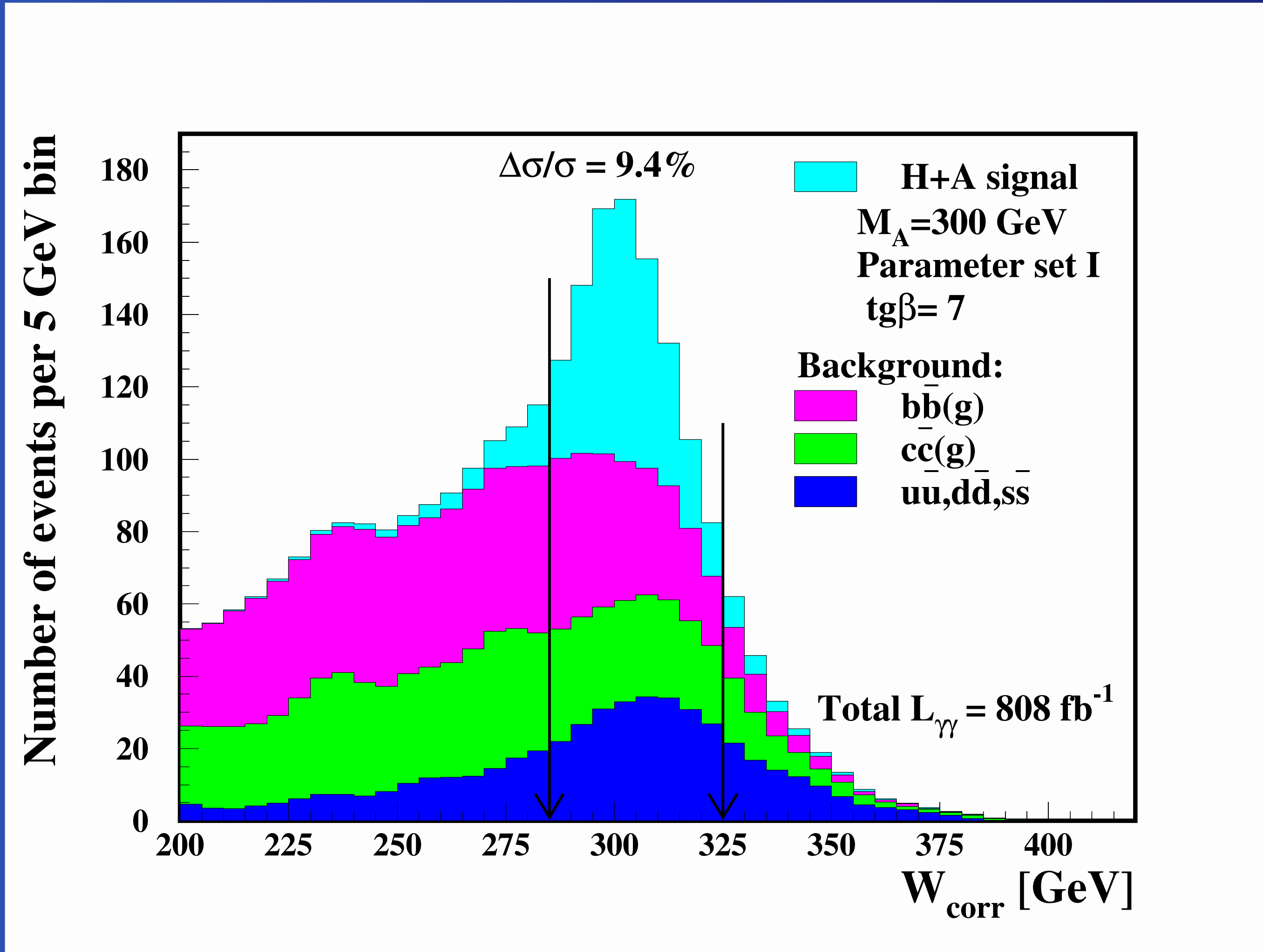
$M_A = 300$ GeV

Without OE, without $\gamma\gamma \to W^+W^-$



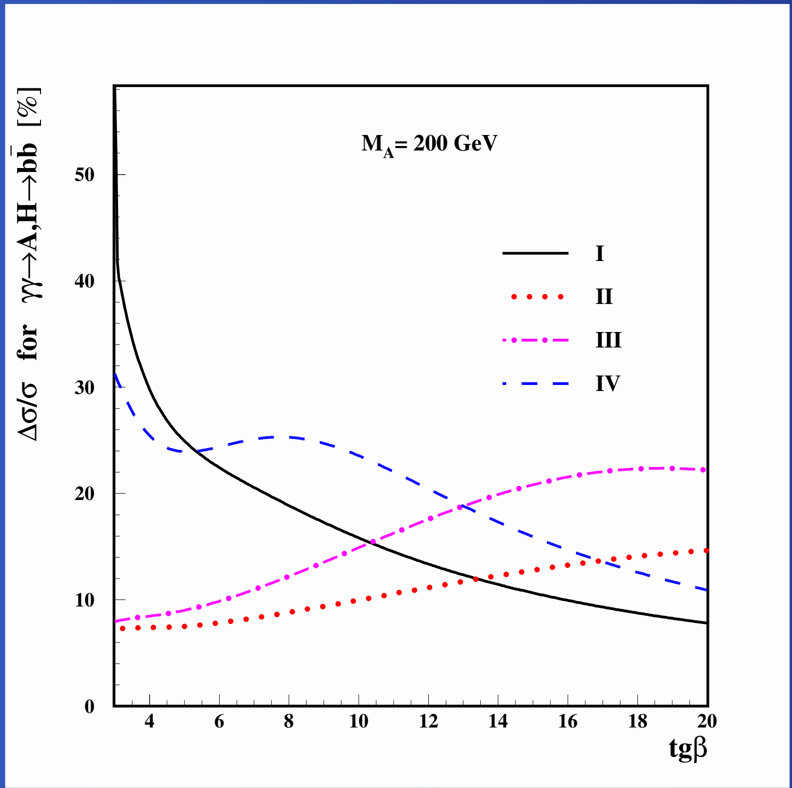
$M_A = 300$ GeV

With OE, without $\gamma\gamma \to W^+W^-$

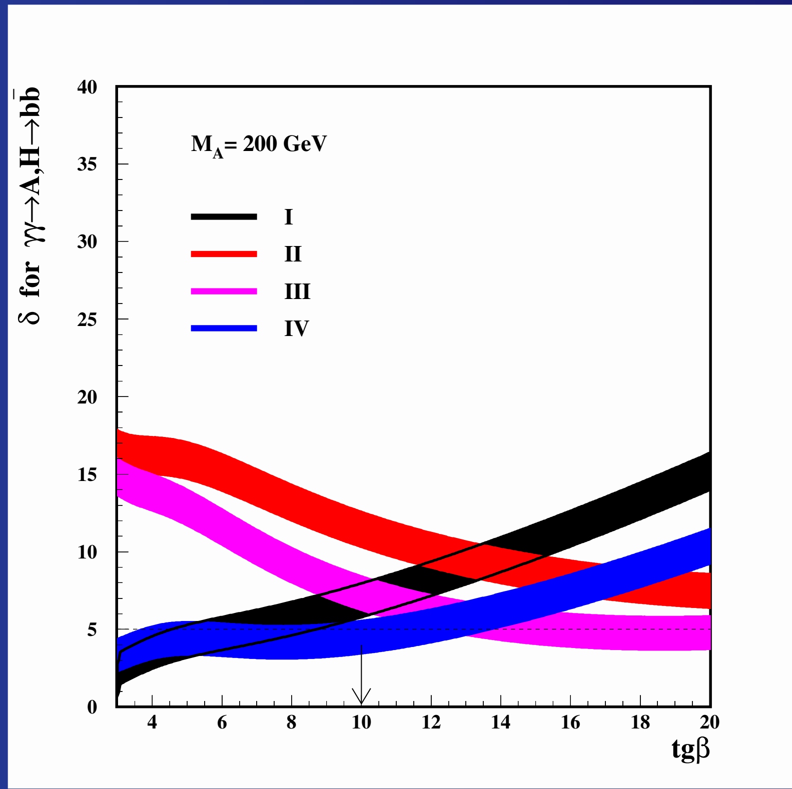


Precision & Significance

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



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



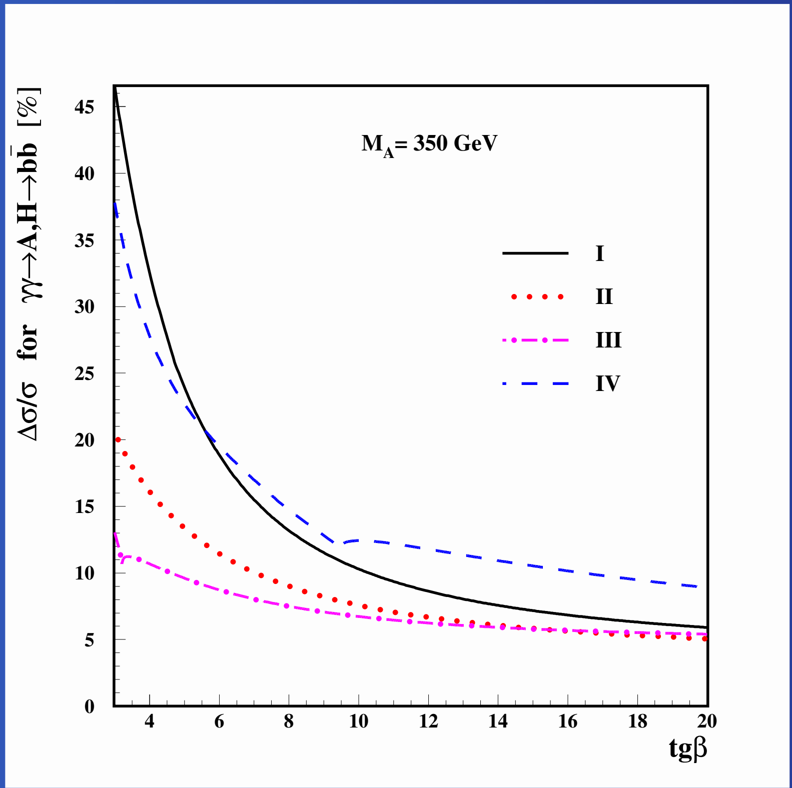
$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S}$$

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

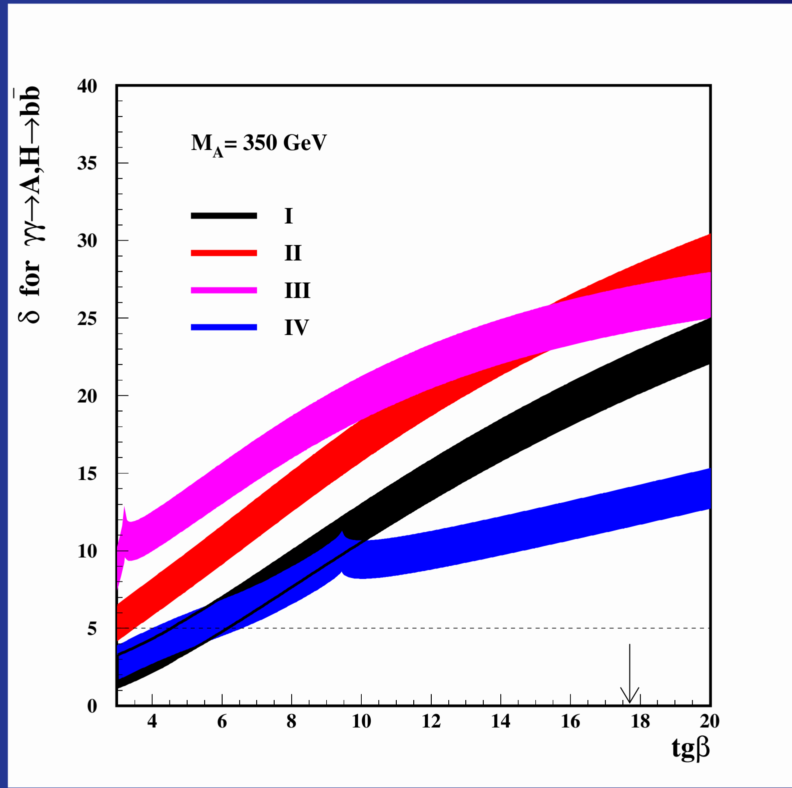
Arrow – lower limit at LHC

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