

# **Heavy neutral MSSM *higgses* at the Photon Collider**

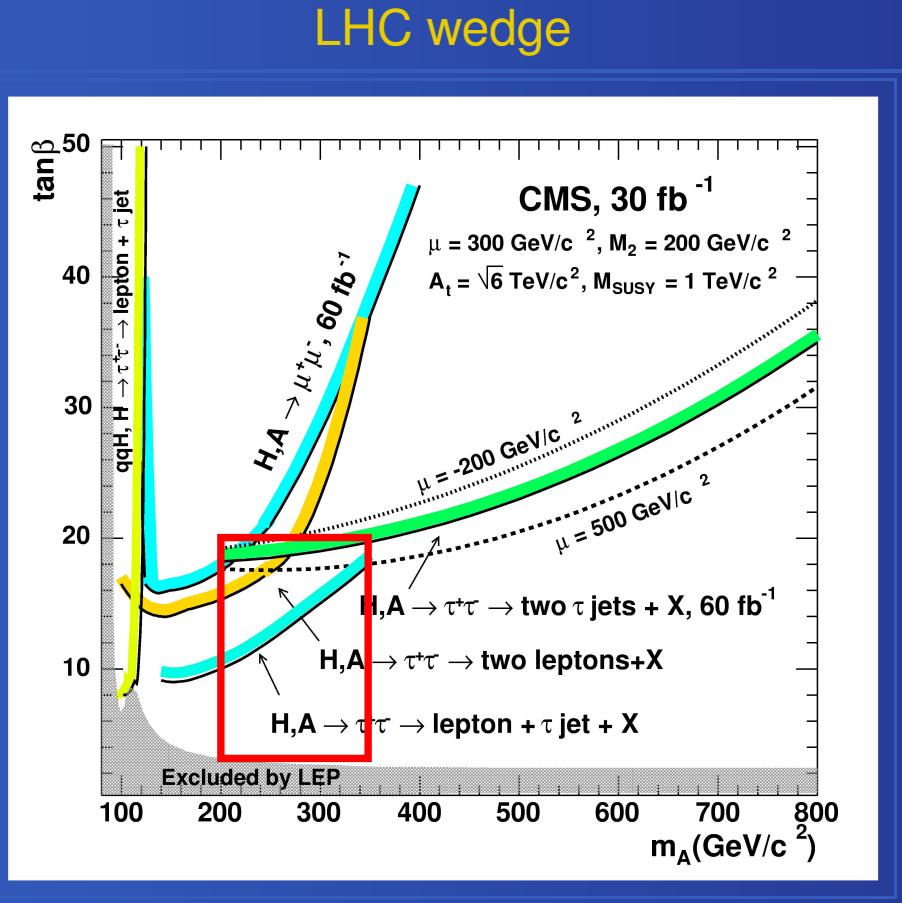
**- a comparison of two analyses**

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# Introduction



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

Two analyses  
with MSSM parameter set:

$$M_A = 300 \text{ GeV}$$
$$\tan \beta = 7, M_2 = \mu = 200 \text{ GeV}$$

MKSZ  
M. Mühlleitner, M. Krämer, M. Spira,  
P. Zerwas, Phys. Lett. B 508 (2001) 311.

$$S/B \approx 36$$
$$(300 \pm 3 \text{ GeV})$$

NŻK  
P. Nieżurawski, A.F. Żarnecki, M. Krawczyk,  
Acta Phys. Pol. B 37 (2006) 1187.

$$S/B \approx 2$$
$$(300 \pm 5 \text{ GeV}, \text{if only } \gamma\gamma \rightarrow b\bar{b}(g) \text{ background taken into account})$$



# MKSZ analysis overview

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

- Compton spectrum  
 $E_L = 1.29 \text{ eV} \Rightarrow$  for  $M_A = 300 \text{ GeV}$  optimal  $E_e = 200 \text{ GeV}$
- NLO calculation for signal and background:
  - full resummation of Sudakov and non-Sudakov logarithms
  - NLO- $\alpha_s$  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  $> 20^\circ$ .
- $N_{jets} = 2$
- Angular cut only for  $b$ :  $|\cos \theta_b| < 0.5$
- Only events in the window  $M_A \pm 3 \text{ GeV}$  taken into account

# MKSZ: Results

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

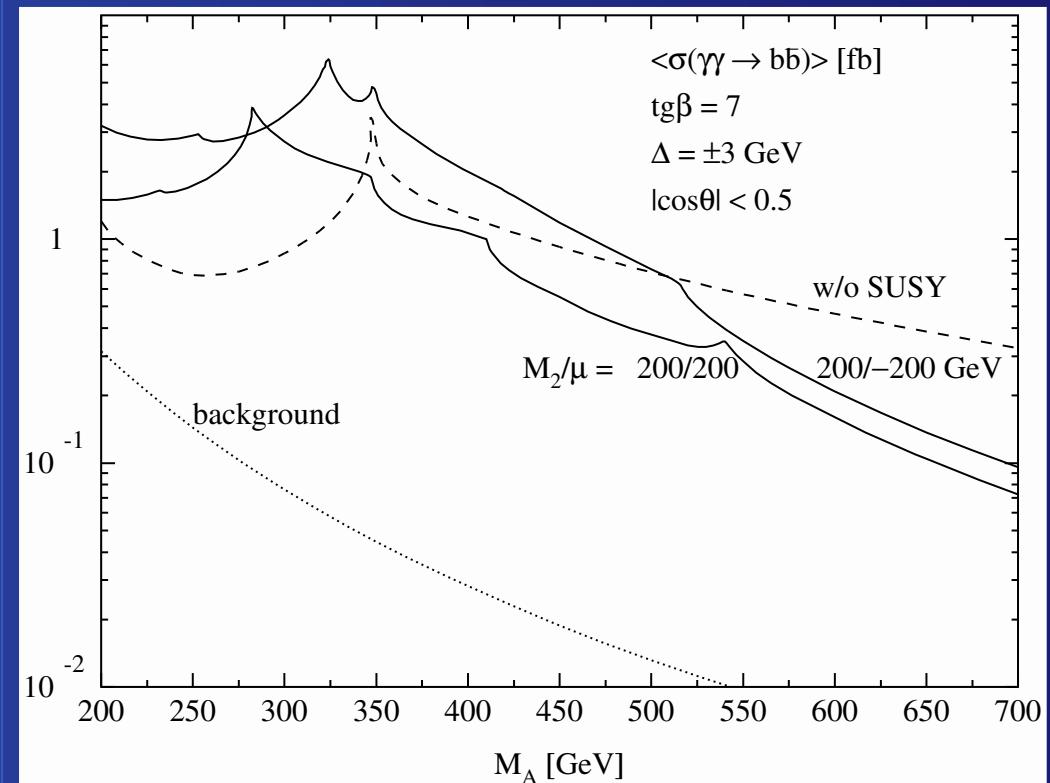
Results for  $M_A = 200\text{-}700 \text{ GeV}$

Considered MSSM parameter sets

$\mu$ [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  $M_A = 200\text{-}700 \text{ GeV}$   
and for  $\tan \beta = 7$



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

# N $\dot{Z}$ K analysis overview

N $\dot{Z}$ K analysis of  $\sigma(\gamma\gamma \rightarrow A, H \rightarrow b\bar{b})$  measurement:

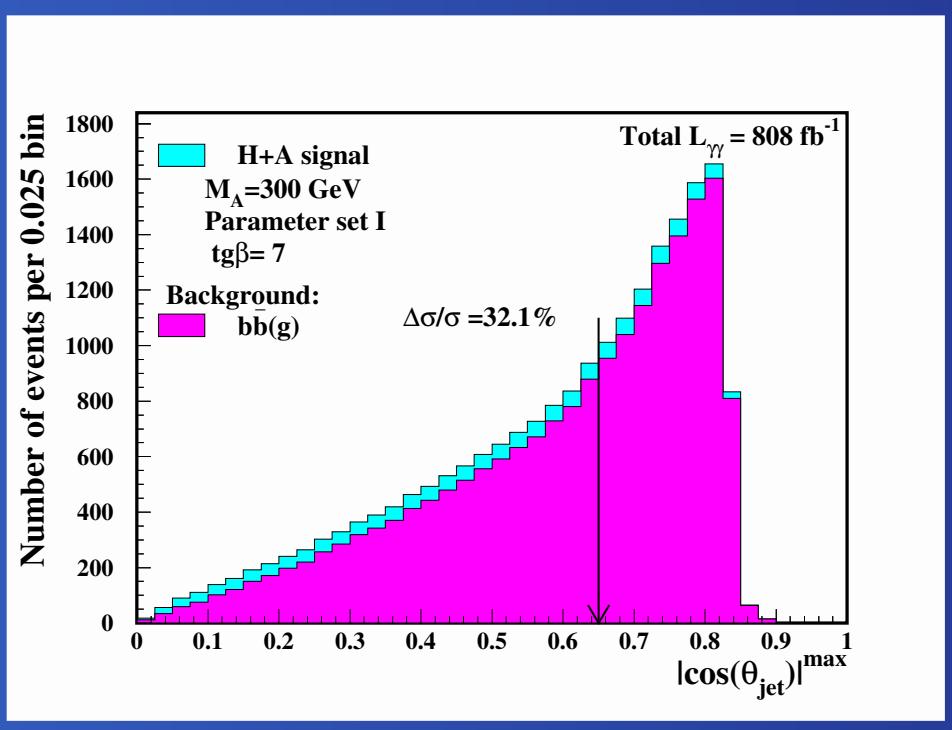
- TESLA-like  $\gamma\gamma$ -spectra (V. Telnov simulations, COMPAZ parametrization)  
 $E_L = 1.17$  eV  $\Rightarrow$  for  $M_A = 300$  GeV optimal  $E_e = 210$  GeV
- Beams crossing angle, primary vertex distribution
- $A$  and  $H$  parameters from HDECAY.  
Generated in resonance approximation with PYTHIA.  
Parton shower  $\rightarrow$  3-jet events.
- NLO QCD background  $\gamma\gamma \rightarrow Q\bar{Q}(g)$  ( $Q=c, b$ ) with program by G. Jikia:
  - resummation of non-Sudakov logarithms up to 4-loop order
  - JADE jet definition,  $y_{cut} = 0.01$
  - LO- $\alpha_s$  with the scale  $\mu^2 = (m_{Tb}^2 + m_{T\bar{b}}^2)/2$
- Other backgrounds:  $\gamma\gamma \rightarrow W^+W^-$ ,  $\gamma\gamma \rightarrow q\bar{q}$  ( $q=u, d, s$ ),  $\gamma\gamma \rightarrow \tau^+\tau^-$
- Overlaying events  $\gamma\gamma \rightarrow$  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:

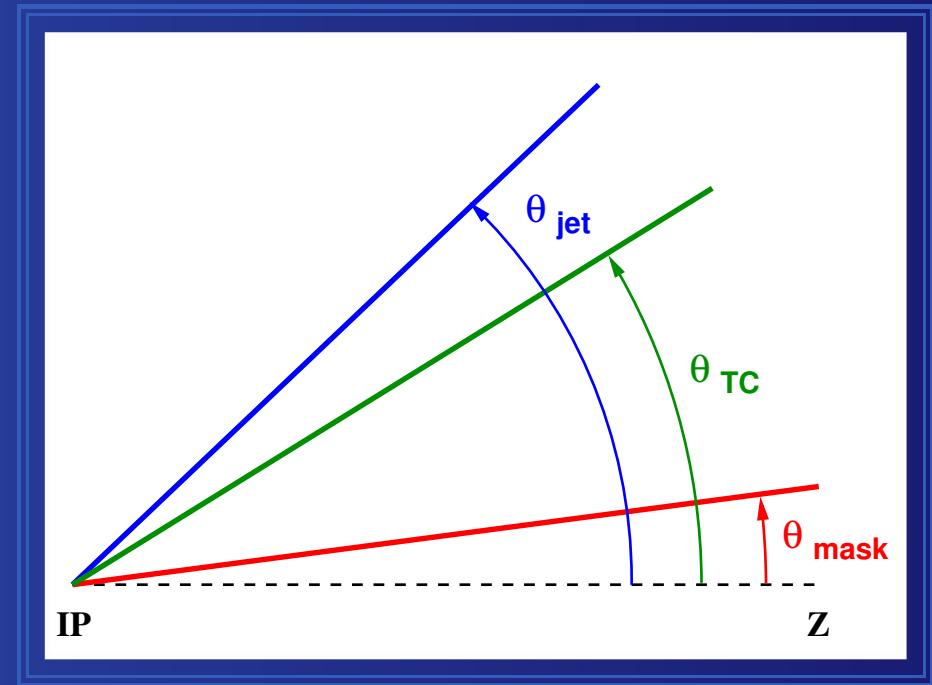
$$\frac{\Delta\sigma(\gamma\gamma \rightarrow A, H \rightarrow b\bar{b})}{\sigma(\gamma\gamma \rightarrow A, H \rightarrow b\bar{b})} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S}$$

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:  $\cos \theta_{TC} = 0.85$

$\gamma\gamma \rightarrow Q\bar{Q}(g)$  suppression

Jets:  $|\cos \theta_{jet}|^{max} = 0.65$



# N $\dot{Z}$ K: 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  $\theta_{TC}$ :  $E_{TC} < 80$  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

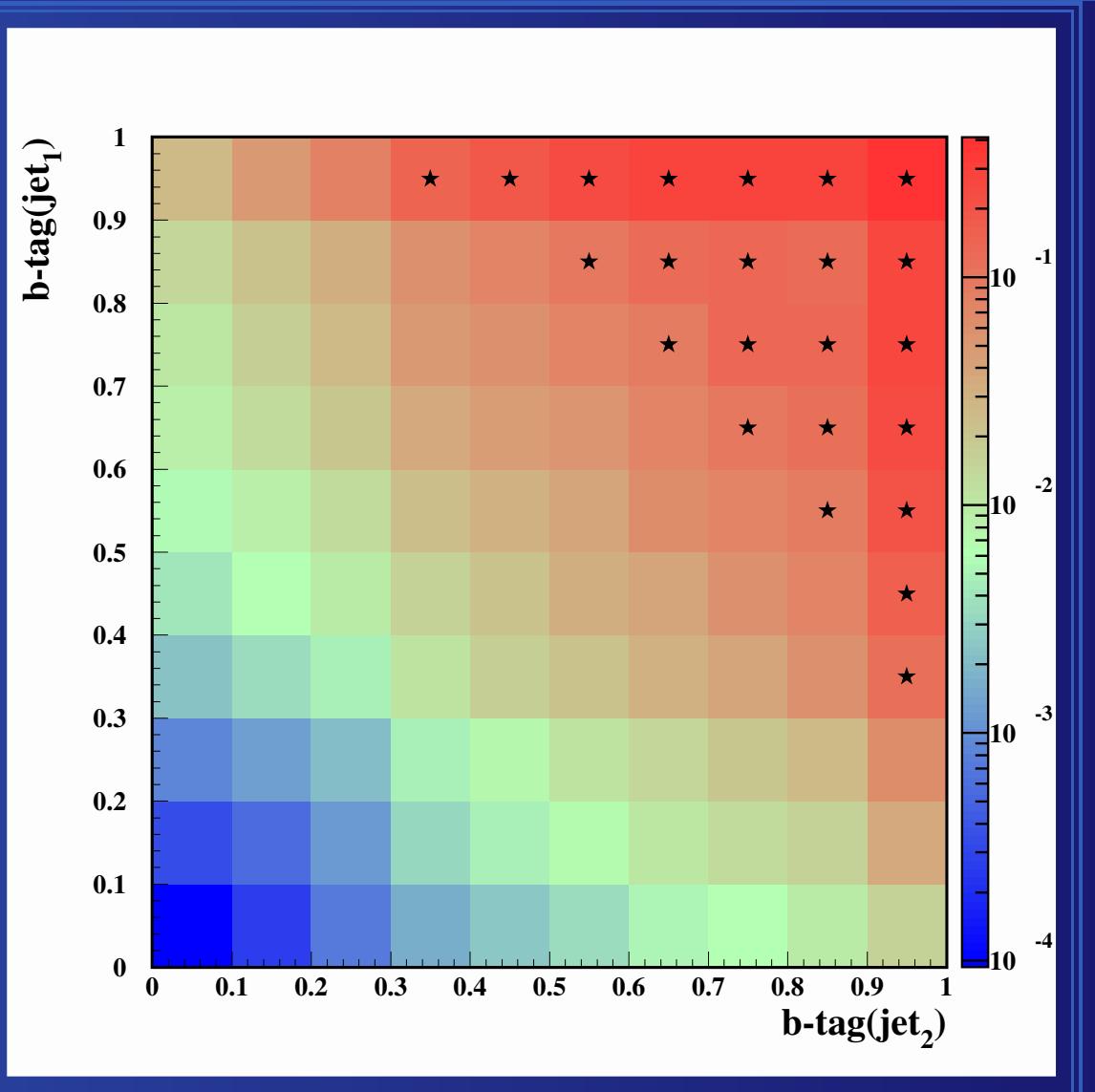
higgs-tagging: a cut on the ratio  
of  $\gamma\gamma \rightarrow A, H \rightarrow b\bar{b}$   
to  $\gamma\gamma \rightarrow b\bar{b}(g), c\bar{c}(g), q\bar{q}$  ( $q = u, d, s$ )  
events

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

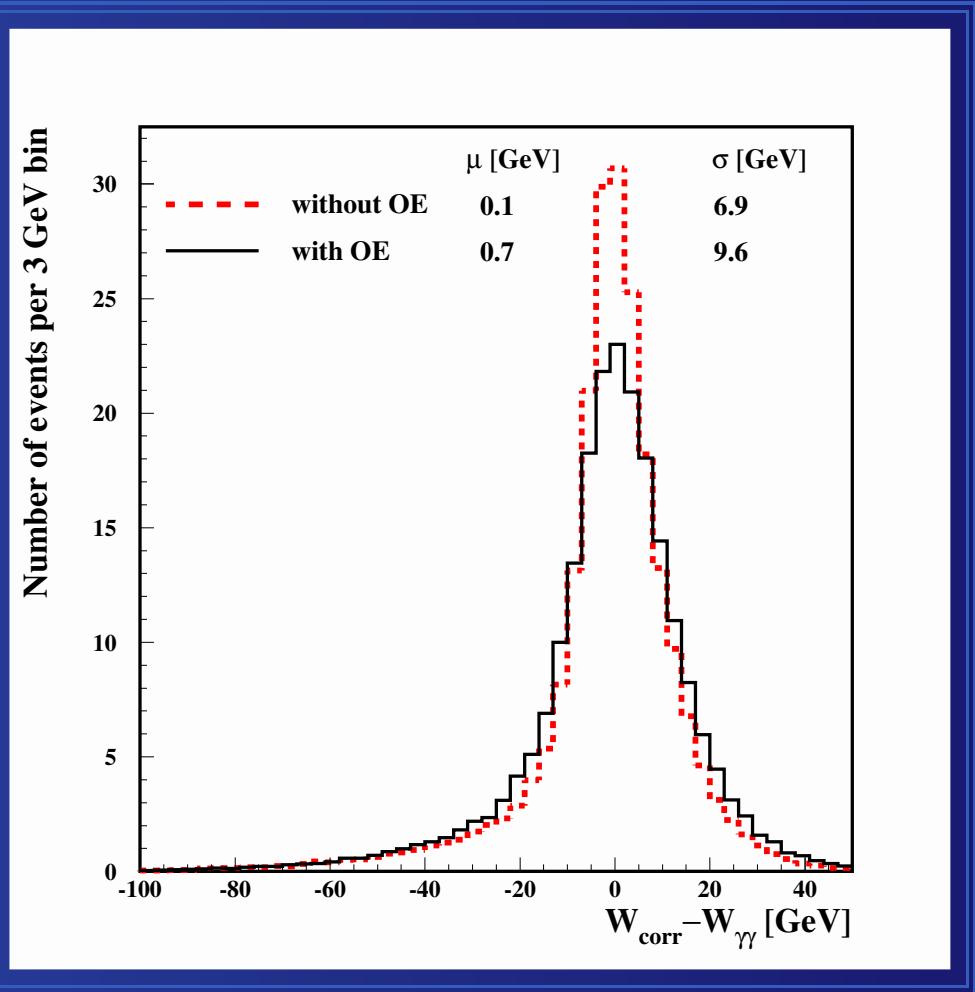
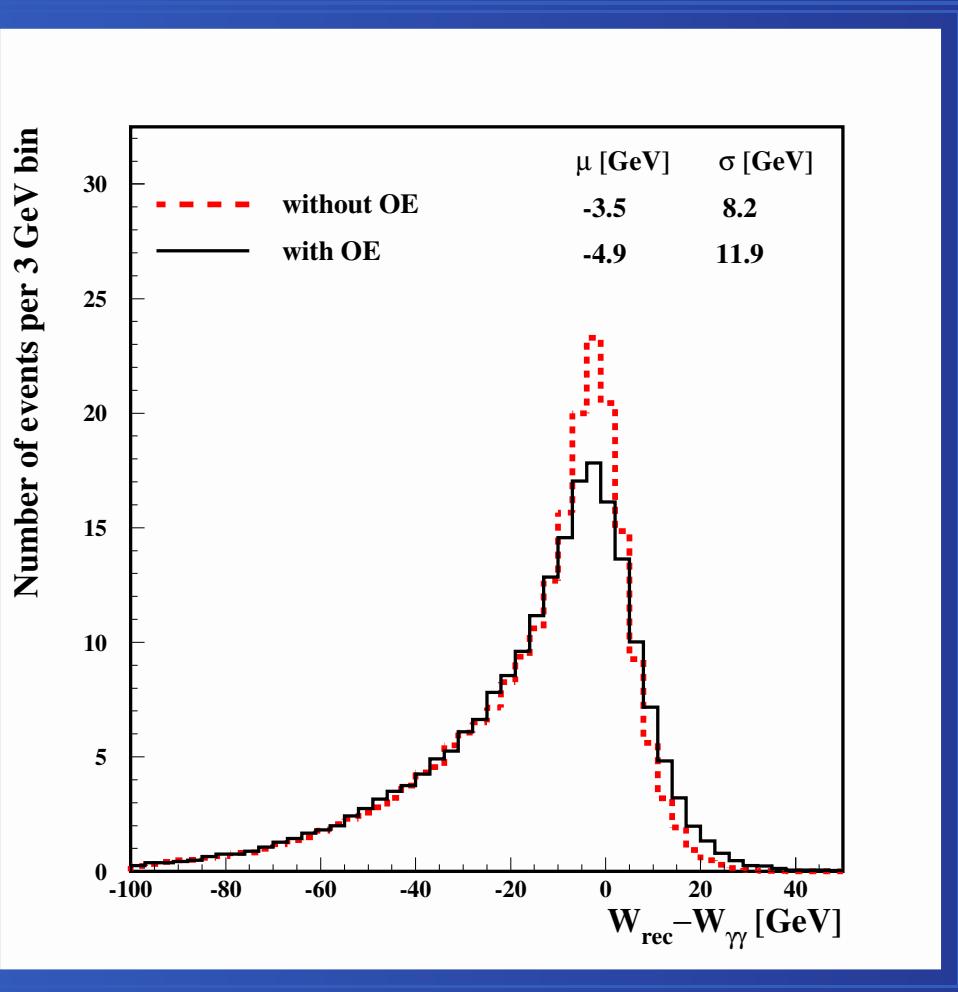
Without OE

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

Tighter cuts are needed  
due to OE contribution



# NŻK: $\gamma\gamma \rightarrow A \rightarrow b\bar{b}$



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

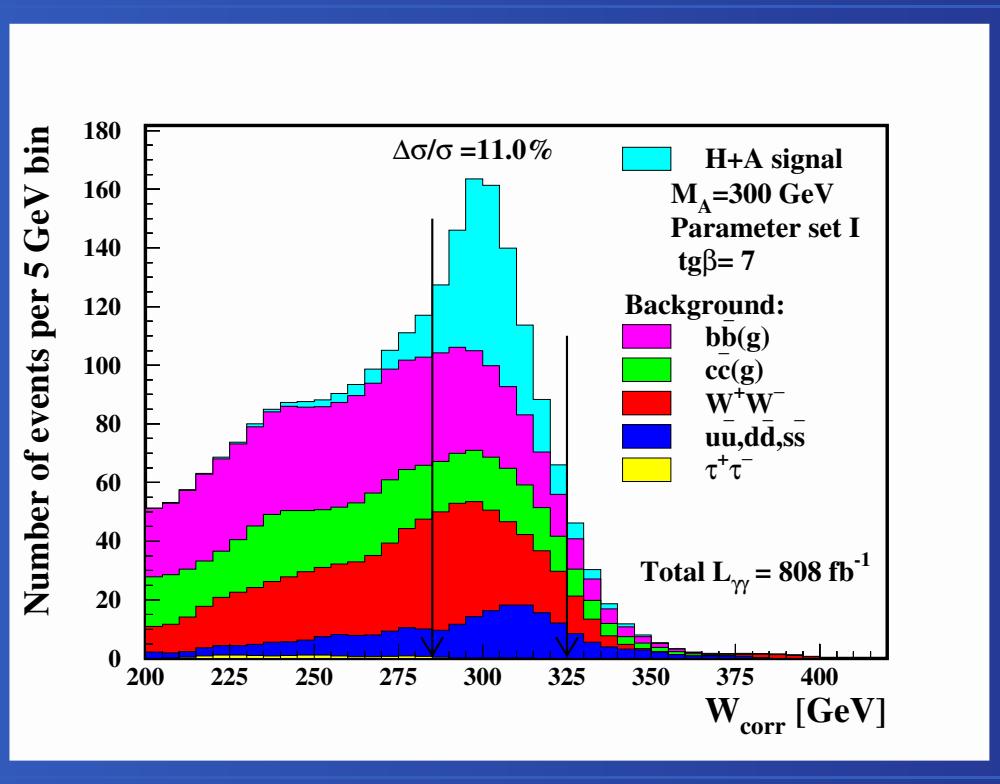
Acta Phys. Pol. B34 177 2003, hep-ph/0208234

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

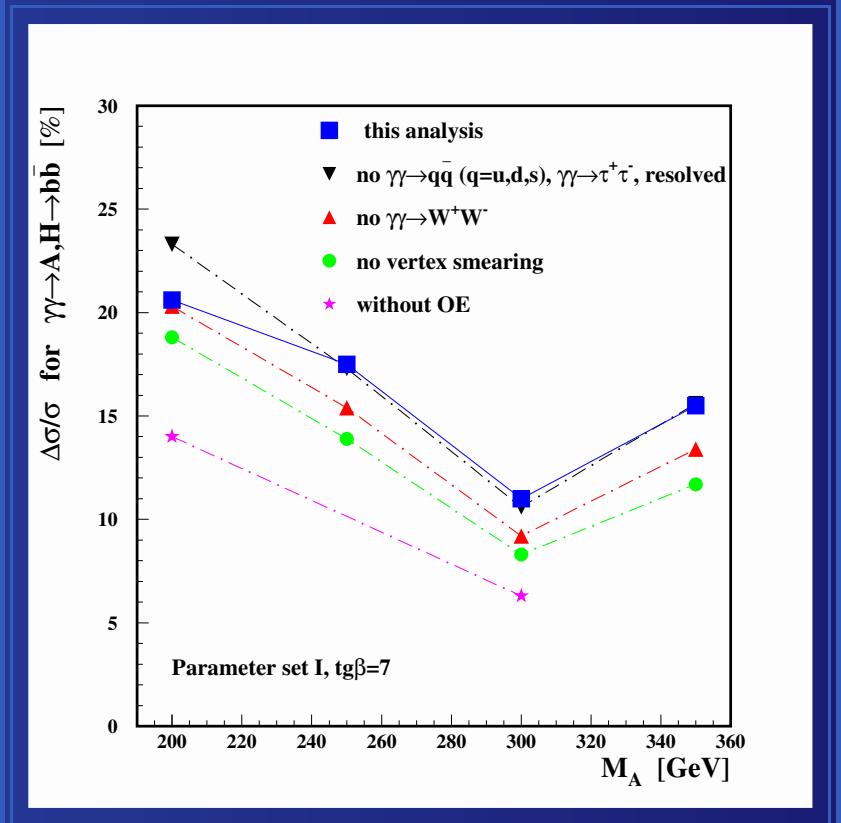
# NŻK: Precision at PLC

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

Results for  $M_A = 300$  GeV



Results for  $M_A = 200-350$  GeV



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

our previous results compared

# NŻK: Precision at PLC

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

Considered four MSSM parameter sets:

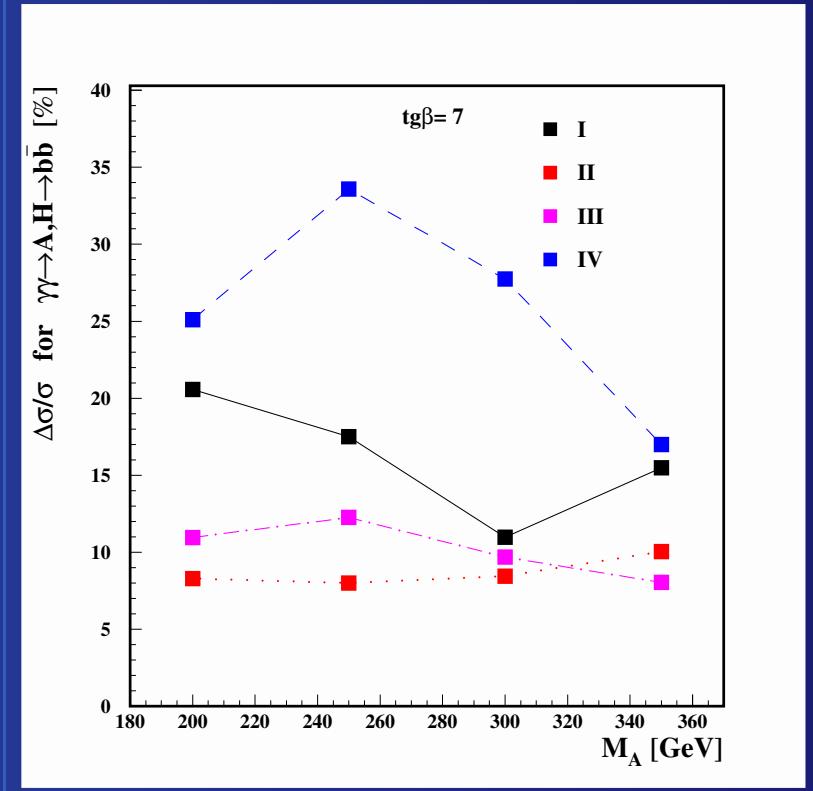
Symbol	$\mu$ [GeV]	$M_2$ [GeV]	$A_{\tilde{f}}$ [GeV]
I	200	200	1500
II	-150	200	1500
III	-200	200	1500
IV	300	200	2450

I and III – following M. Mühlleitner *et al.*  
but 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  $M_A = 200\text{-}350$  GeV



Results for  $M_A = 200, 250, 300, 350$  GeV

Four MSSM scenarios for  $\tan \beta = 3\text{--}20$

# Comparison of both analyses

Comparison only on the parton level

- MSSM parameters chosen:  
 $M_A = 300 \text{ GeV}$ ,  $\tan \beta = 7$ ,  $\mu = M_2 = 200 \text{ GeV}$ ,  
 $A_{\tilde{f}} = 1500 \text{ GeV}$ ,  $M_{\tilde{f}} = 1 \text{ TeV}$
- Flat, normalized luminosity spectrum:  $\sqrt{s_{\gamma\gamma}} = 300 \pm 3 \text{ GeV}$
- 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  $\gamma\gamma \rightarrow b\bar{b}$  BACKGROUND (with JADE):

- With angular cut for both quarks 2-jet and 3-jet parts are of the same order.  
 $\rightarrow N_{jets} = 2, 3$ .  
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  $\gamma\gamma \rightarrow A, H \rightarrow b\bar{b}$  SIGNAL (with JADE):

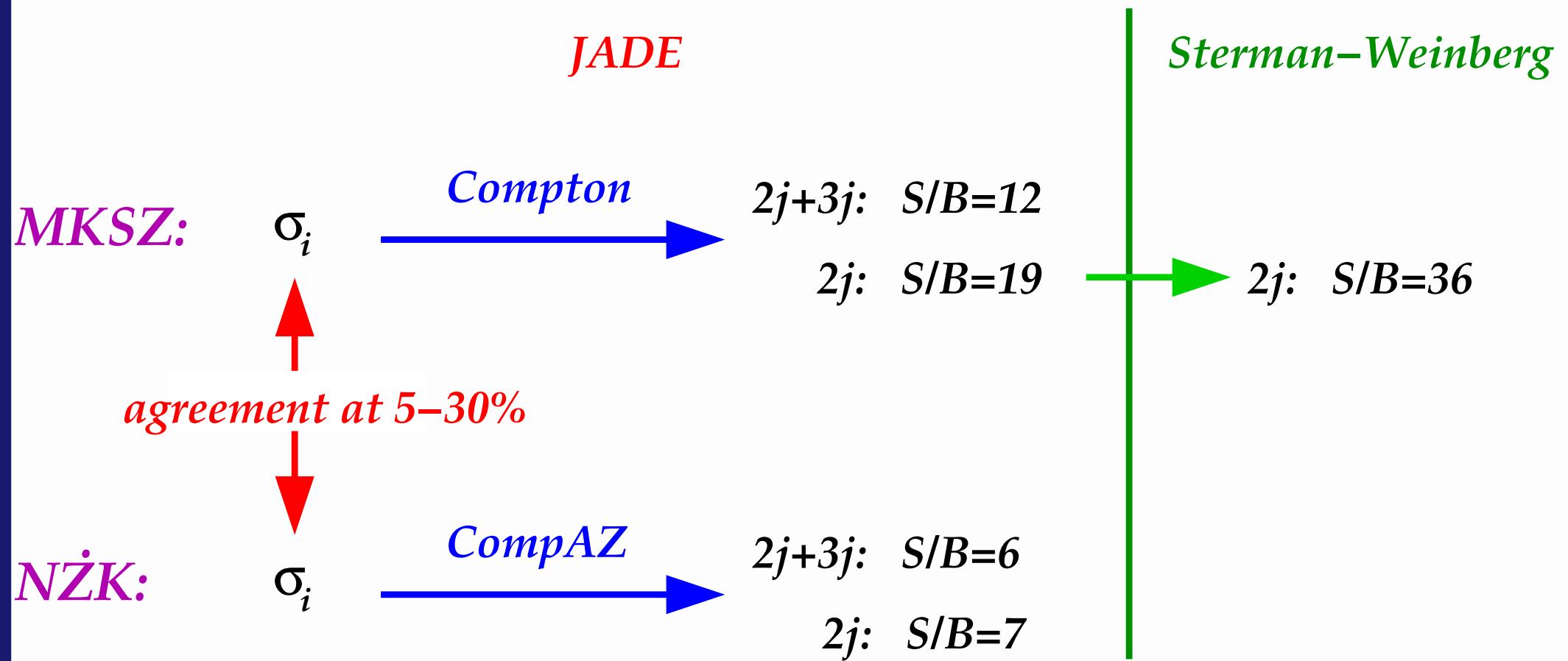
- Both approaches agree within 5% for total cross section,  
and within 30% for 2-jet and 3-jet classes separately.

# 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**:  
 $(L_0/L)_{\text{N}\dot{\text{Z}}\text{K}} = 94\% \text{ of } (L_0/L)_{\text{MKSZ}}$   
 $(L_2/L)_{\text{N}\dot{\text{Z}}\text{K}} = 5.5 \text{ of } (L_2/L)_{\text{MKSZ}}$   
⇒ N $\dot{Z}$ K obtain 2 times larger  $b\bar{b}$  background  
After rescaling N $\dot{Z}$ K obtain  $S/B$  around 20% lower than MKSZ.
- Sterman–Weinberg jet definition leads to much higher rate of 2-jet events for signal than for background.  
⇒ 2 times higher  $S/B$  ratio for 2-jet events in comparison to results obtained with JADE jet definition

# Summary of comparison



More detailed description: hep-ph/0612369

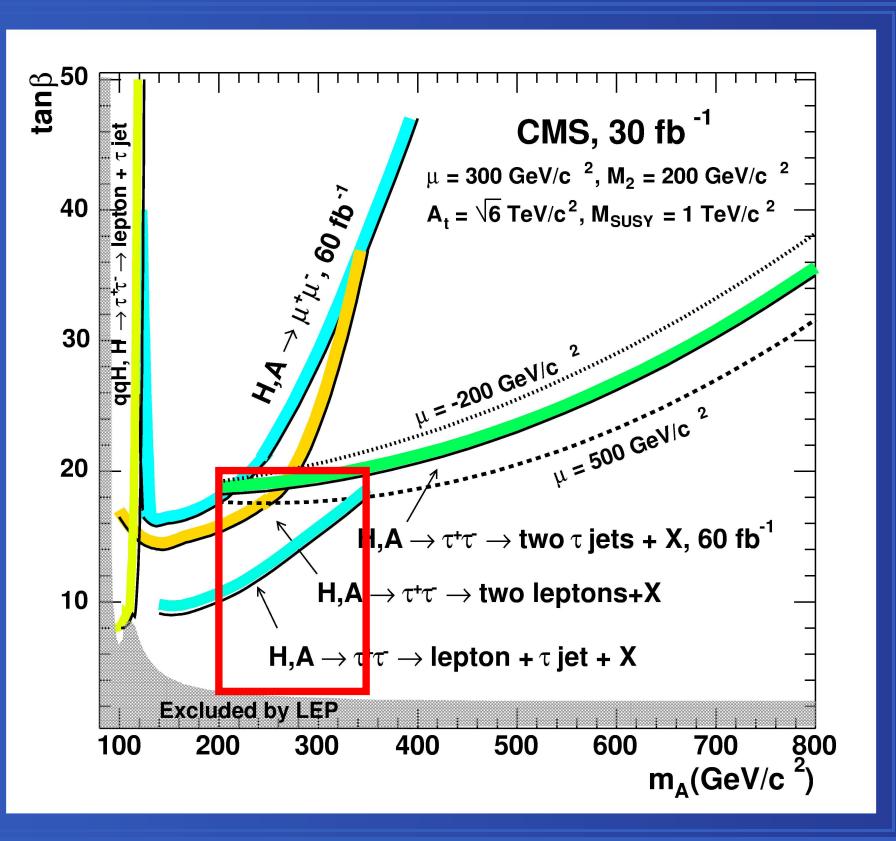
# Backup Slides

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	$\mu$ [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

# Crab-wise crossing of beams

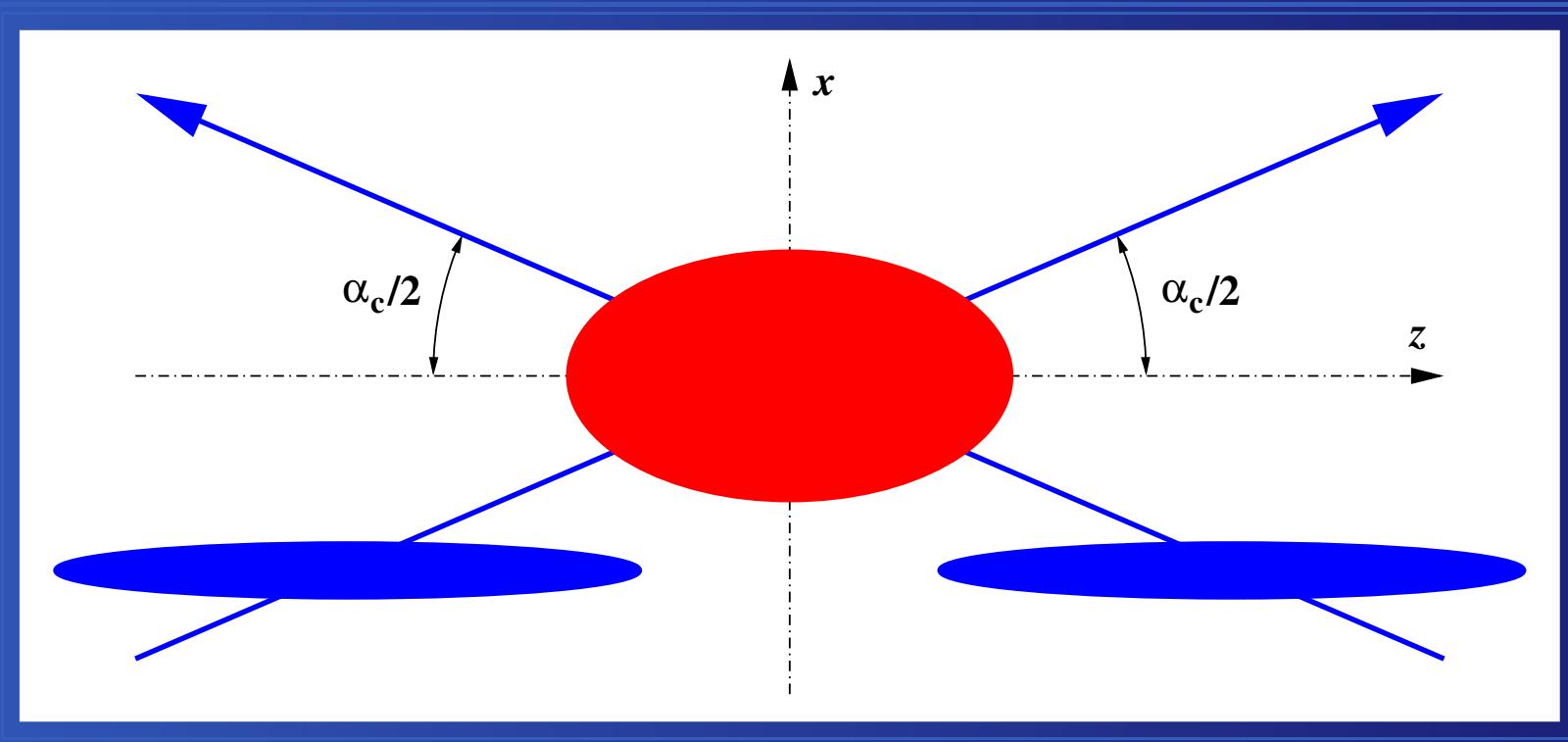
$$\sigma'_x = \sqrt{\frac{1}{2}(\sigma_x^2 + \sigma_z^2 \tan^2(\alpha_c/2))}$$

$$\sigma'_y = \sigma_y / \sqrt{2}$$

$$\sigma'_z = \sigma_z / \sqrt{2}$$

Bunch:  $\sigma_x = 140 \text{ nm}$   $\sigma_y = 15 \text{ nm}$   $\sigma_z = 0.3 \text{ mm}$

Primary vertex:  $\sigma'_x = 3.6 \mu\text{m}$   $\sigma'_y = 11 \text{ nm}$   $\sigma'_z = 0.2 \text{ mm}$

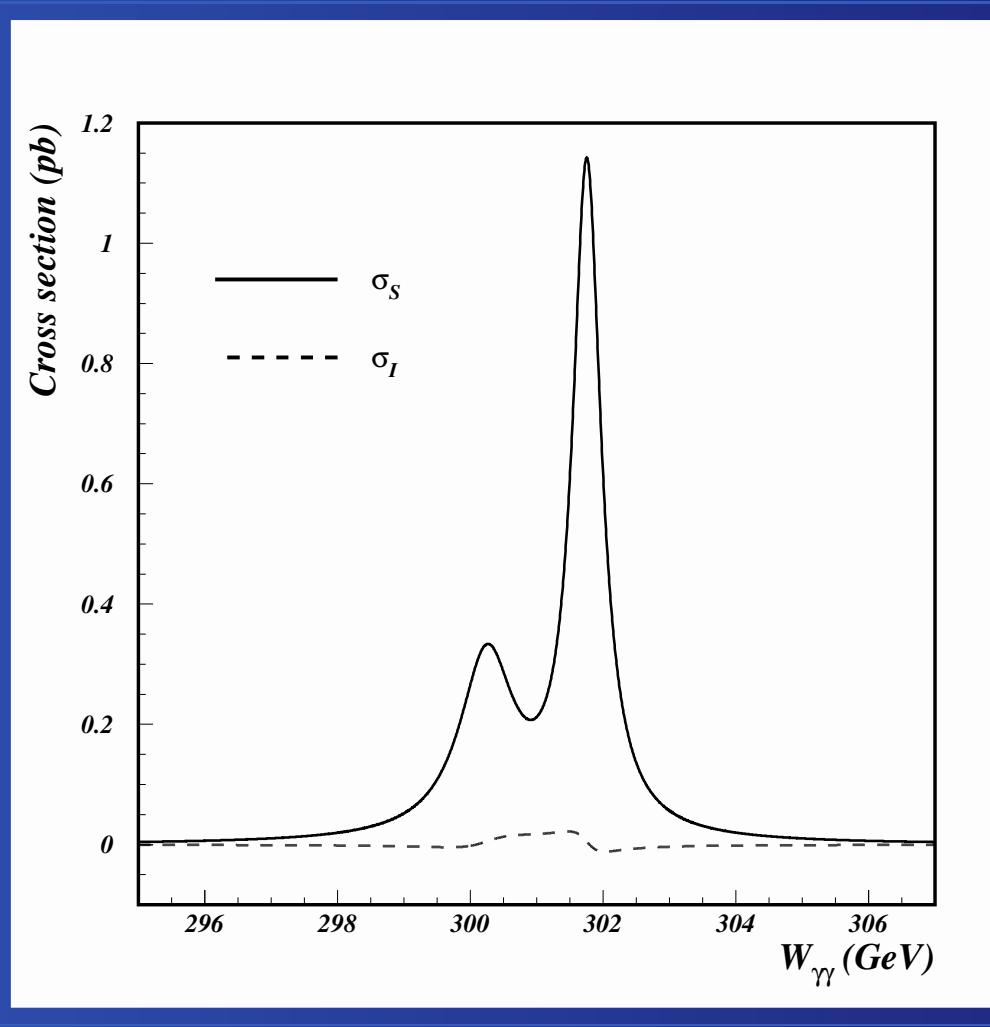


$$\alpha_c = 34 \text{ mrad}$$

Primary vertex distribution +  $\gamma\gamma \rightarrow \text{hadrons}$  OE = possible flavour mistagging

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

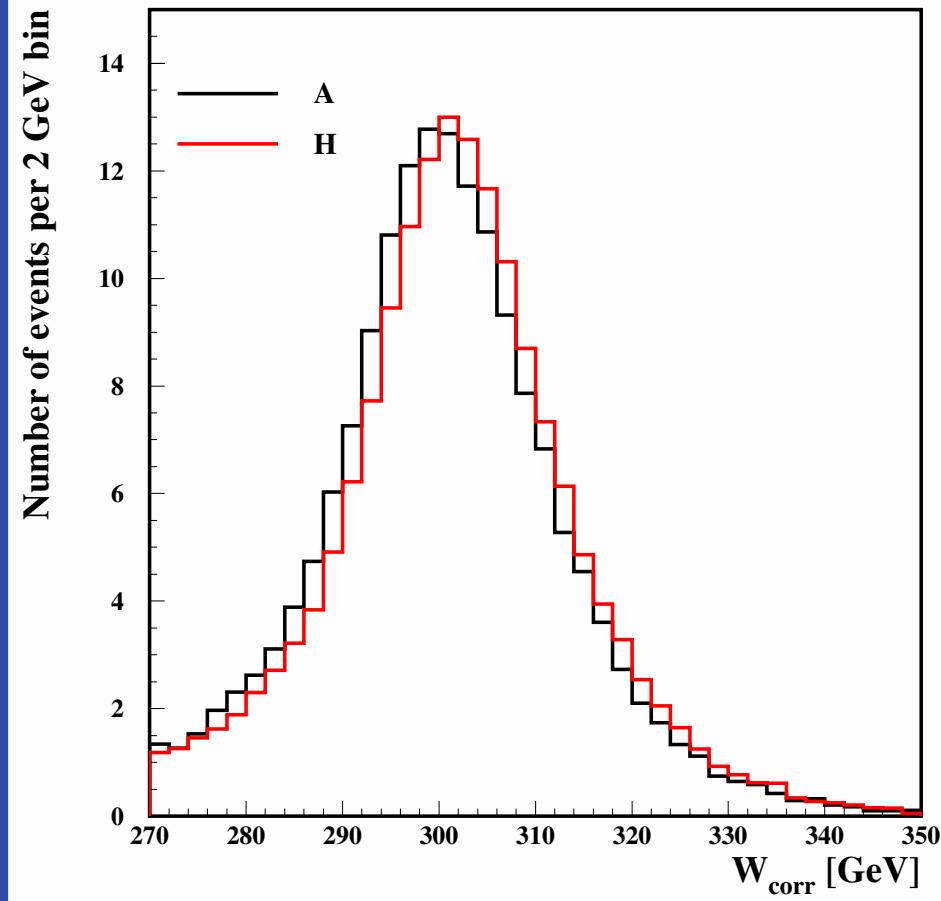
LO cross section for signal and interference term.



Interference with  $\gamma\gamma \rightarrow b\bar{b}$  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

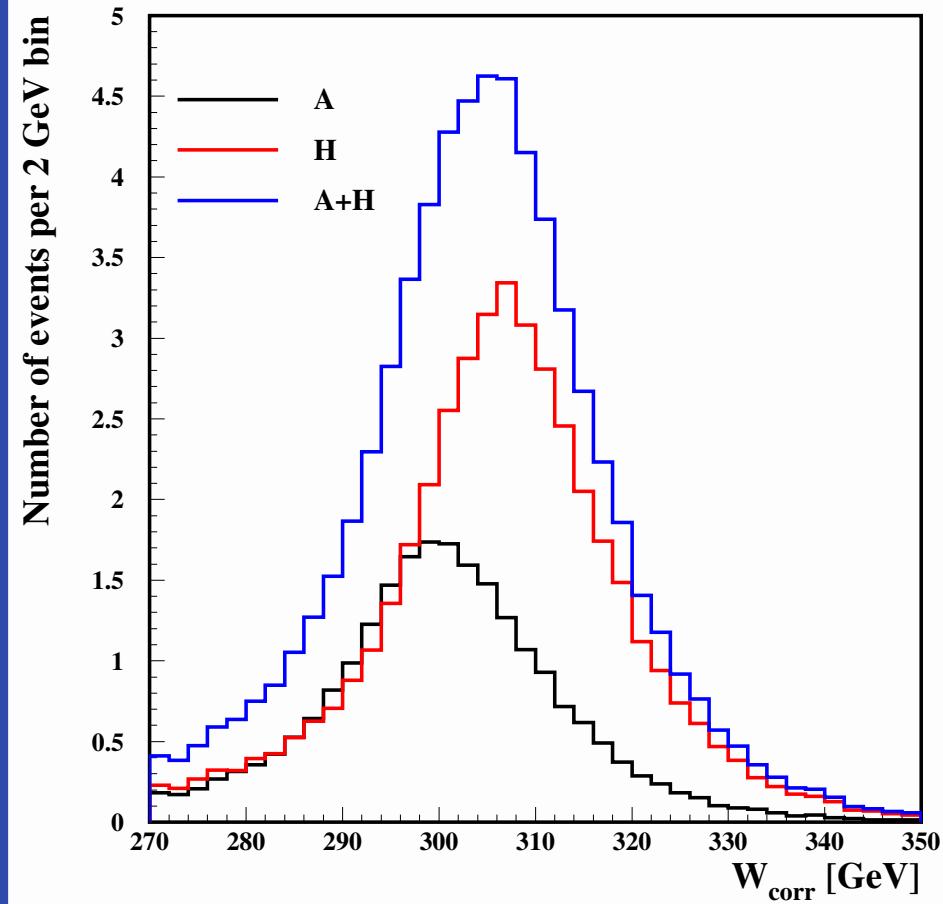


$$\begin{aligned} \tan \beta &= 7 \\ M_H - M_A &\approx 1.5 \text{ GeV} \end{aligned}$$



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

Reconstructed events

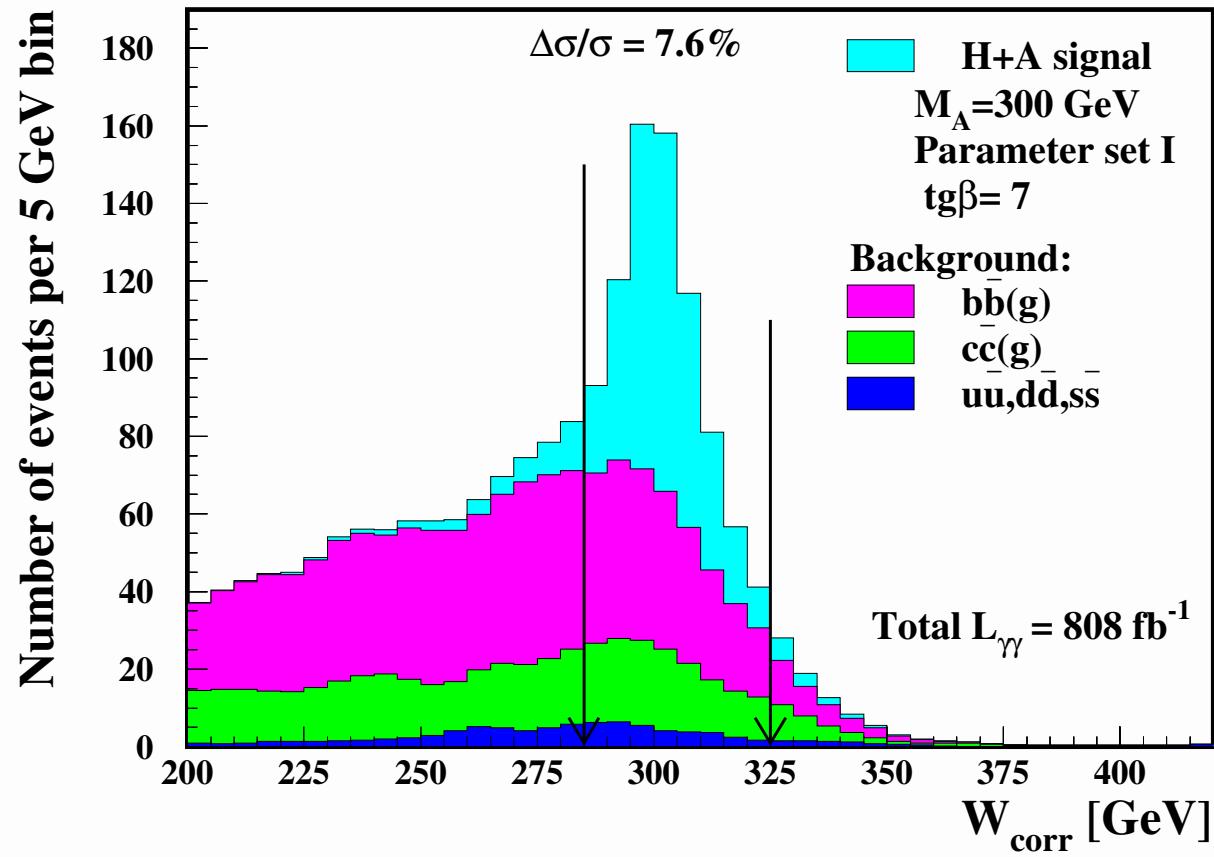


$$\begin{aligned} \tan \beta &= 3 \\ M_H - M_A &\approx 6.8 \text{ GeV} \end{aligned}$$



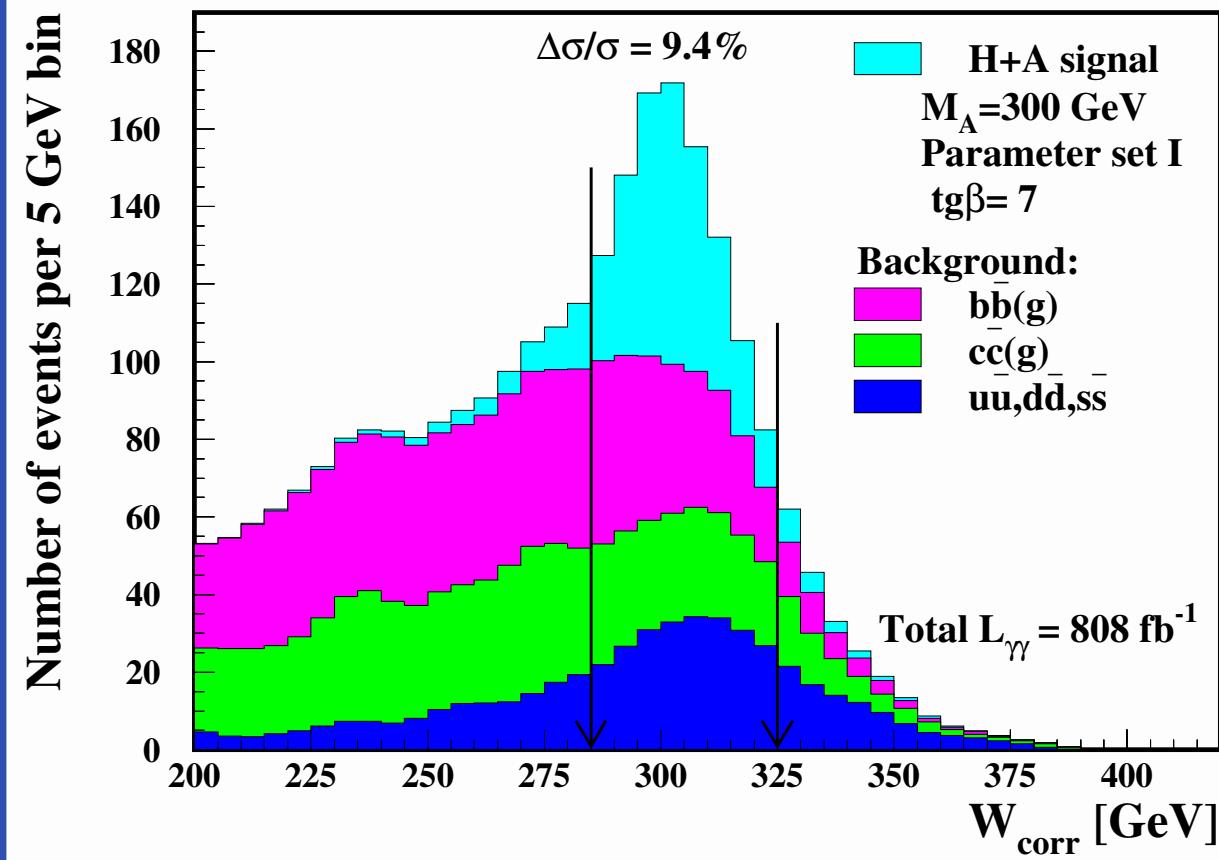
$$M_A = 300 \text{ GeV}$$

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



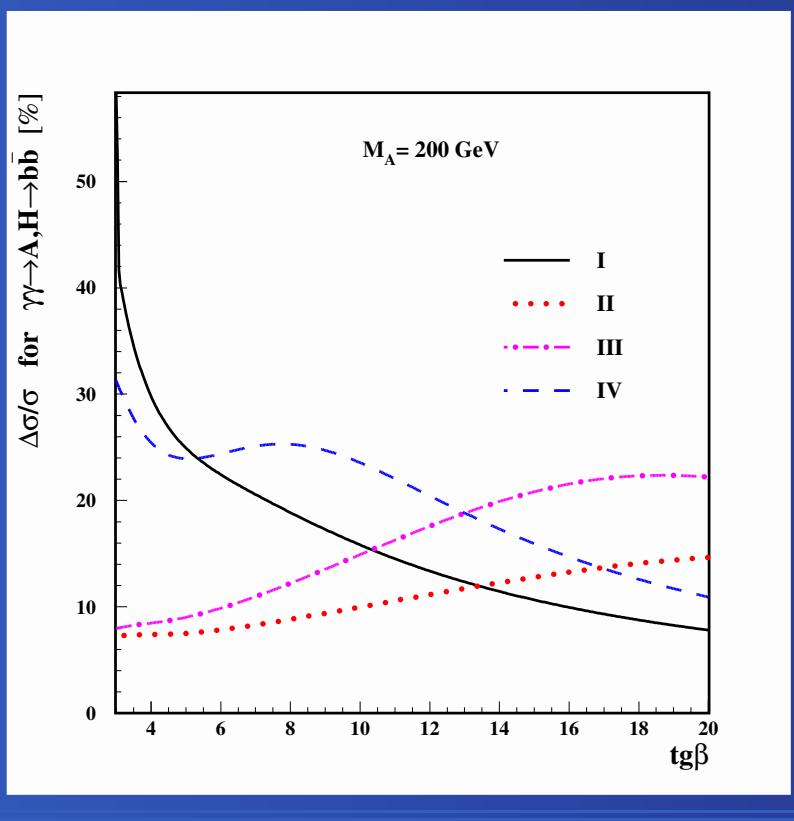
# $M_A = 300 \text{ GeV}$

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

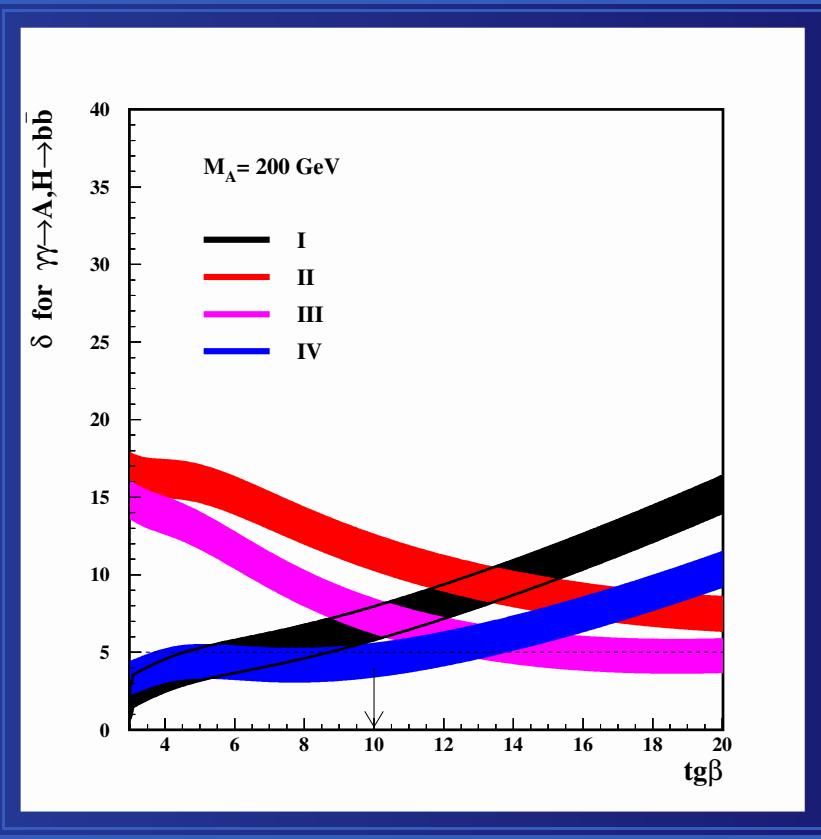


# Precision & Significance

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



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



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

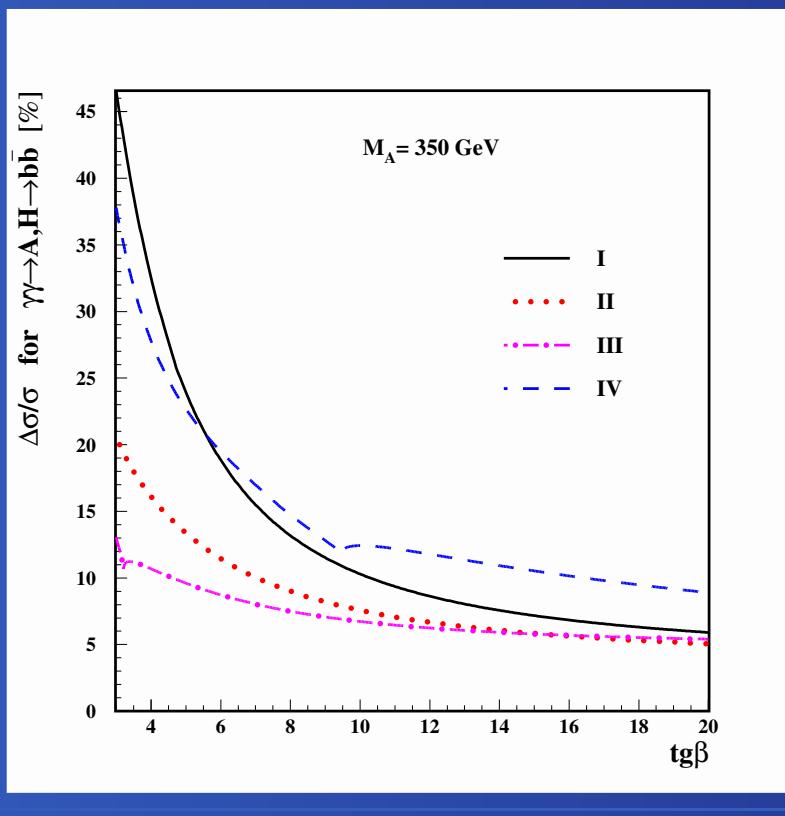
$$\delta = \frac{\mu_S}{\sqrt{\mu_B}} \pm \sqrt{1 + \frac{\mu_S}{\mu_B}}$$

Arrow – lower limit at LHC

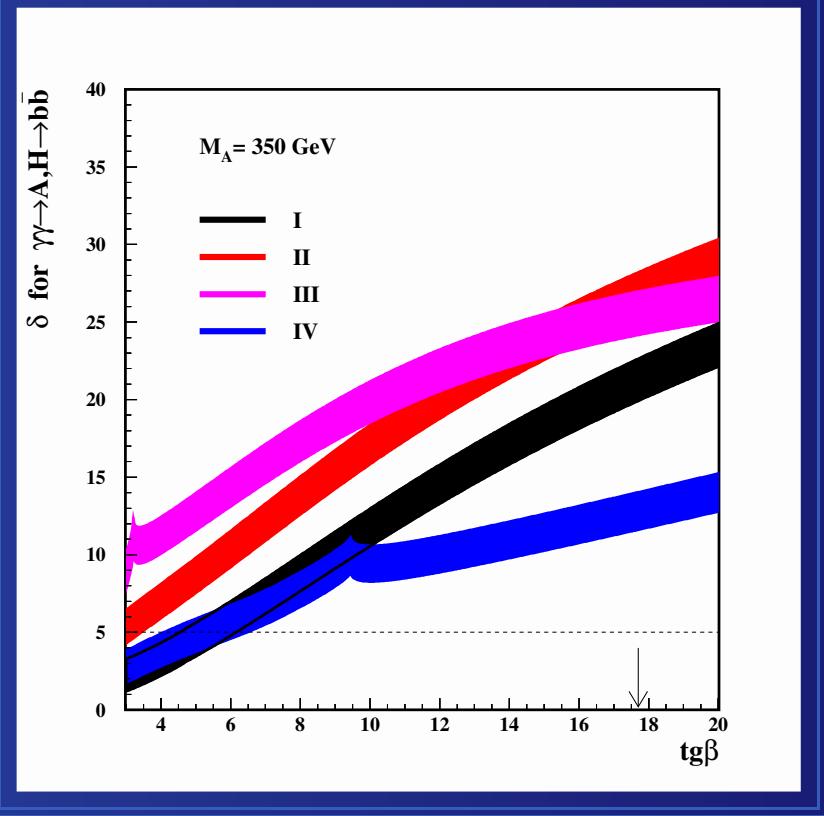


# Precision & Significance

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



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



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

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

Arrow – lower limit at LHC

