

Heavy neutral MSSM *higgses* at the Photon Collider

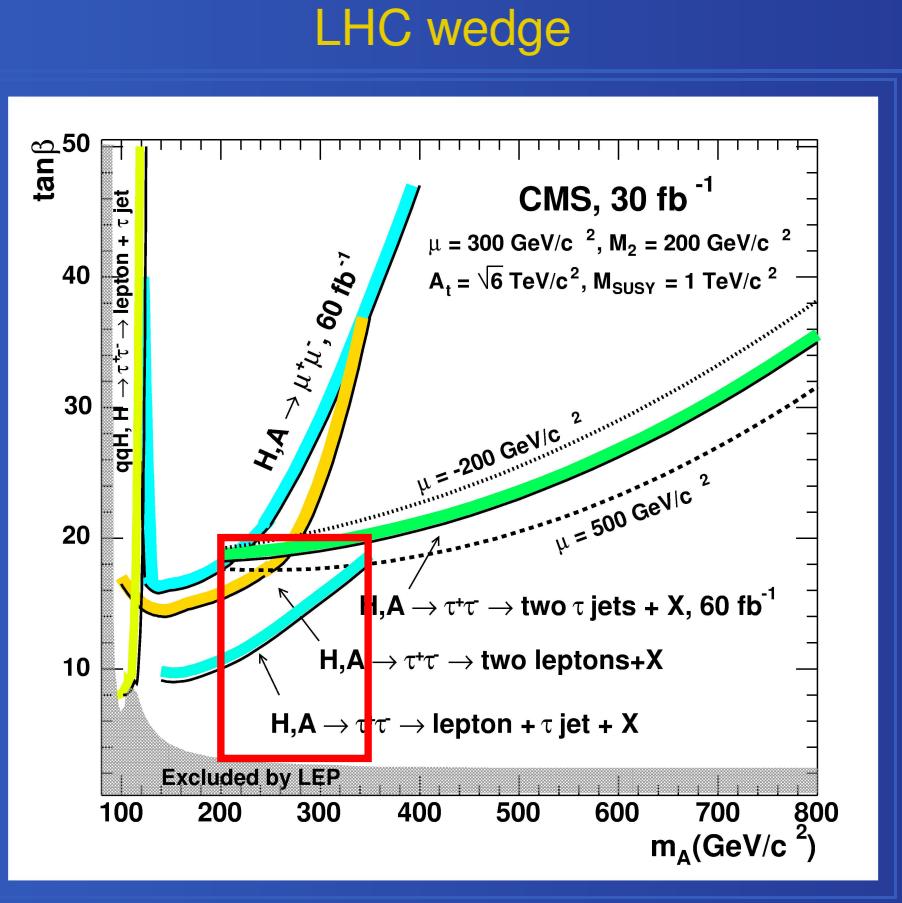
- a comparison of two analyses

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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- 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 $> 20^\circ$.
- $N_{jets} = 2$
- 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

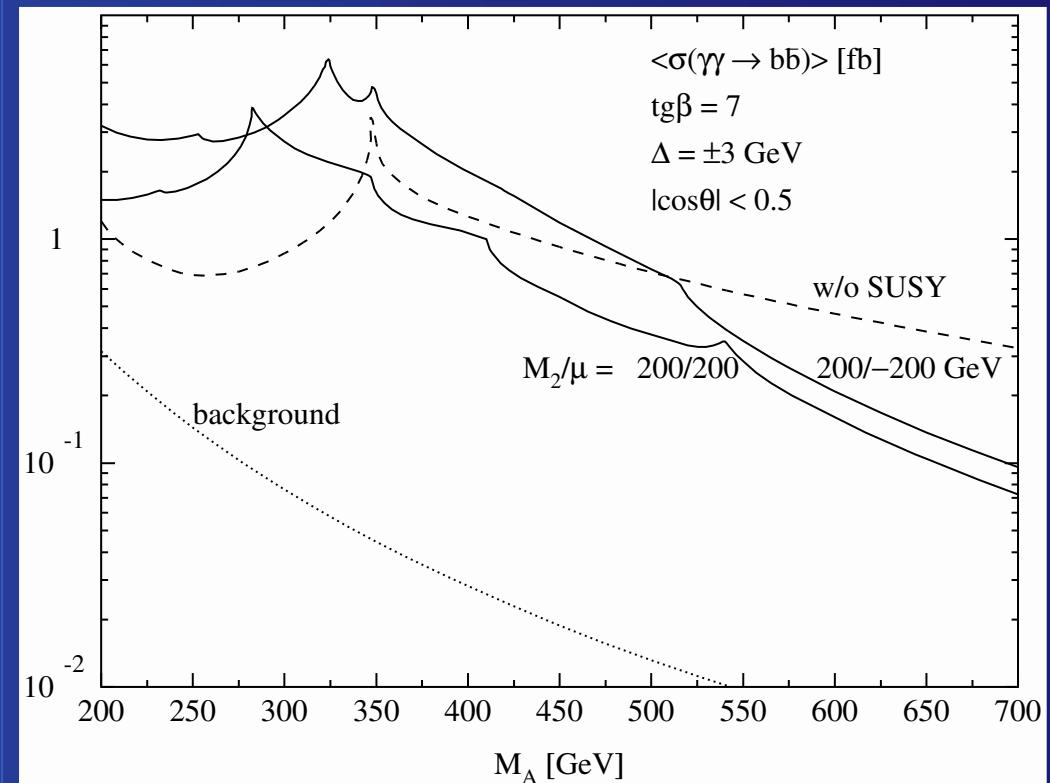
Results for $M_A = 200\text{-}700 \text{ GeV}$

Considered MSSM parameter sets

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 $M_A = 200\text{-}700 \text{ GeV}$
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:

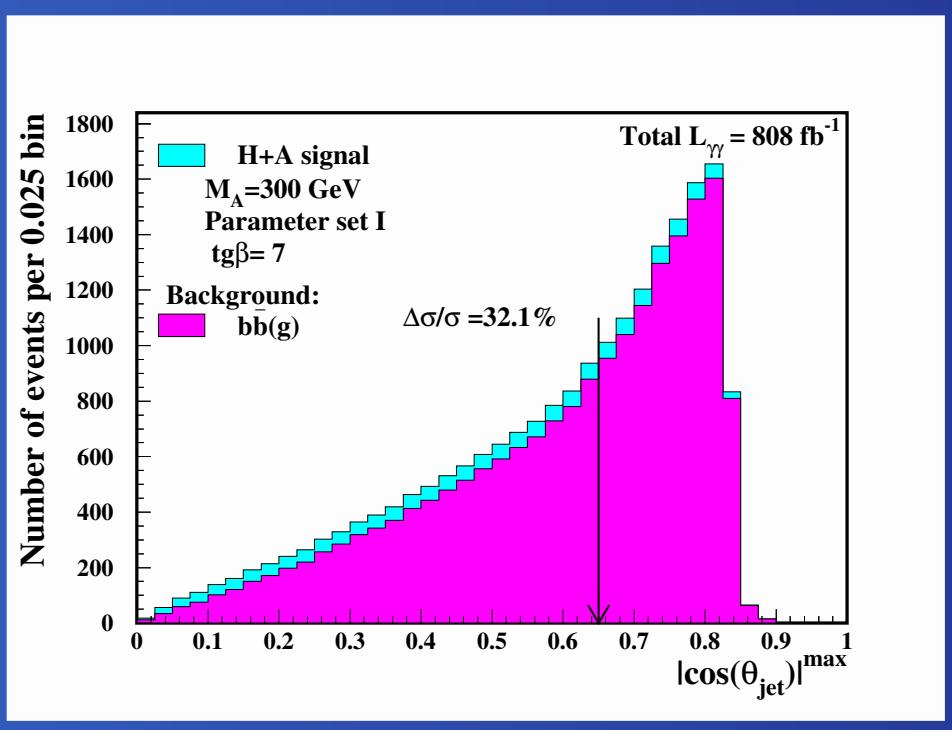
- TESLA-like $\gamma\gamma$ -spectra (V. Telnov simulations, COMPAZ parametrization)
 $E_L = 1.17 \text{ eV} \Rightarrow$ for $M_A = 300 \text{ GeV}$ optimal $E_e = 210 \text{ GeV}$
- Beams crossing angle, primary vertex distribution
- A and H parameters from HDECAY.
Generated in resonance approximation 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- α_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 $\gamma\gamma \rightarrow \text{hadrons}$: 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:

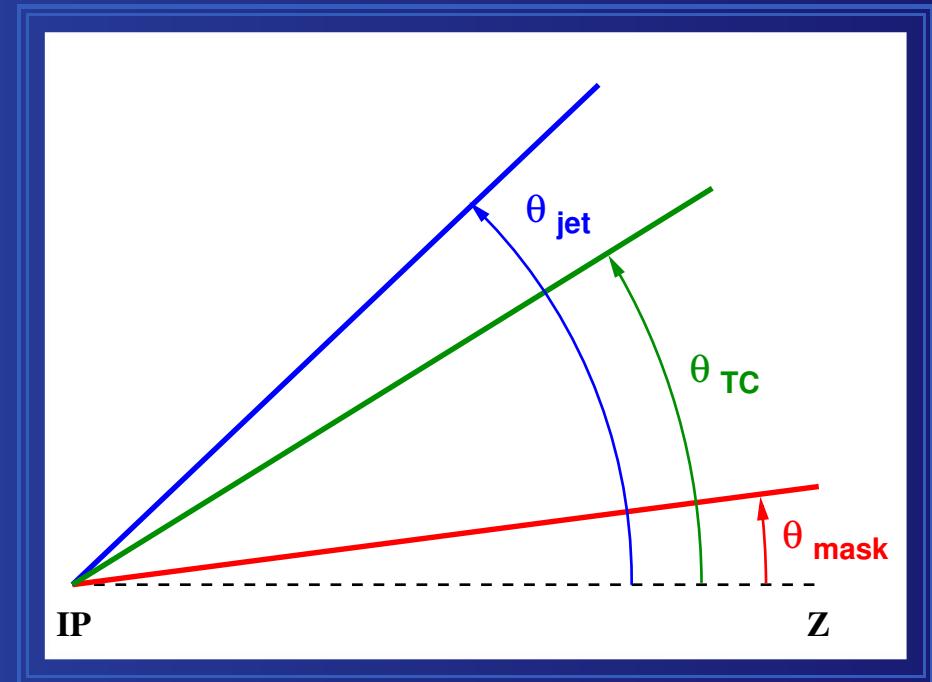
$$\frac{\Delta\sigma(\gamma\gamma \rightarrow A, H \rightarrow b\bar{b})}{\sigma(\gamma\gamma \rightarrow A, H \rightarrow b\bar{b})} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S}$$

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 θ_{TC} : $E_{TC} < 80$ GeV
- for each jet: $N_{trk} \geq 4$
- b -tagging

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

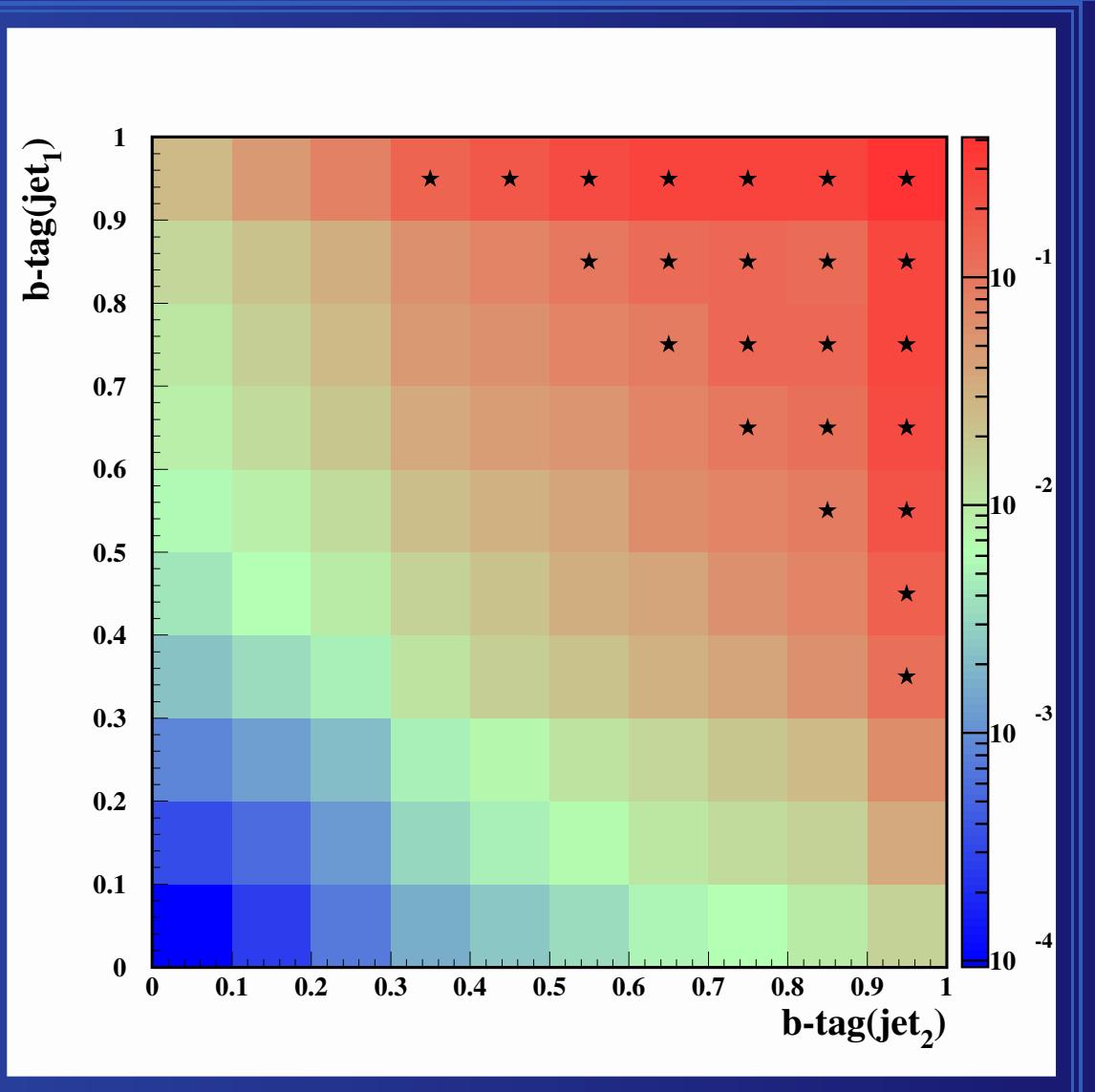
NŻK: *higgs-tagging*

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

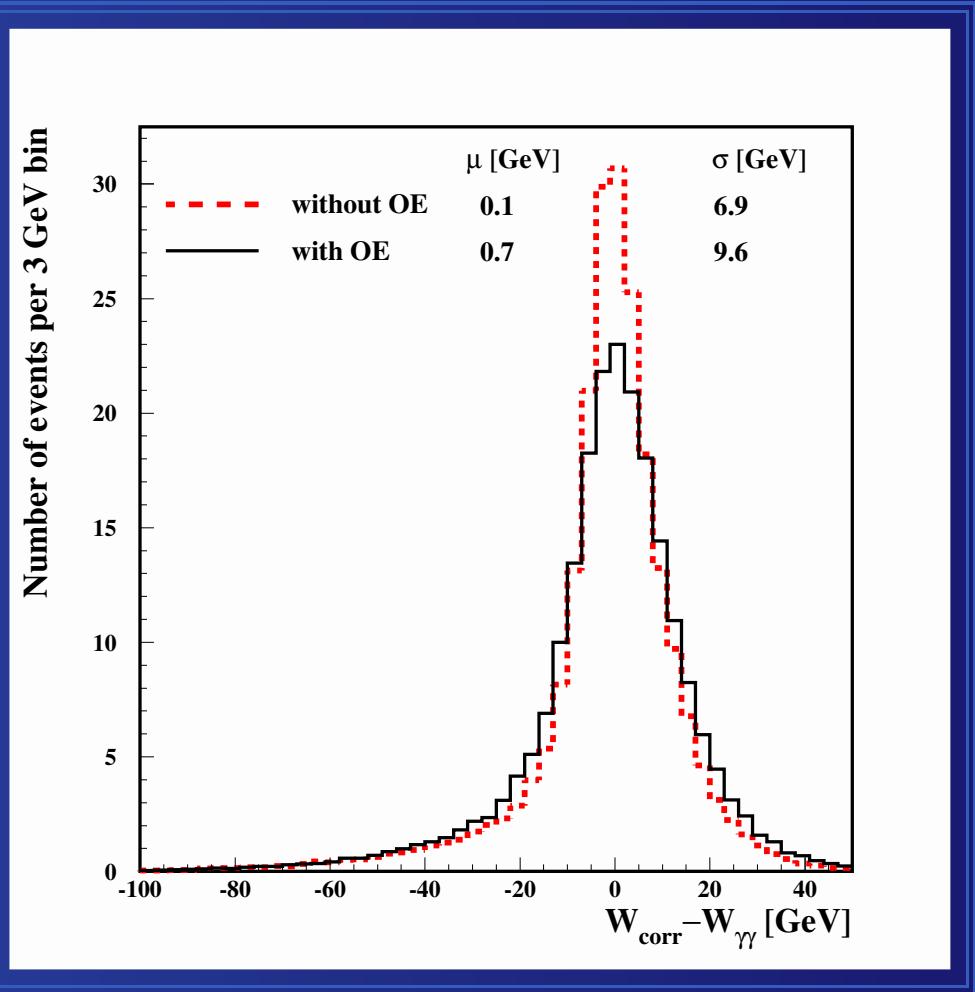
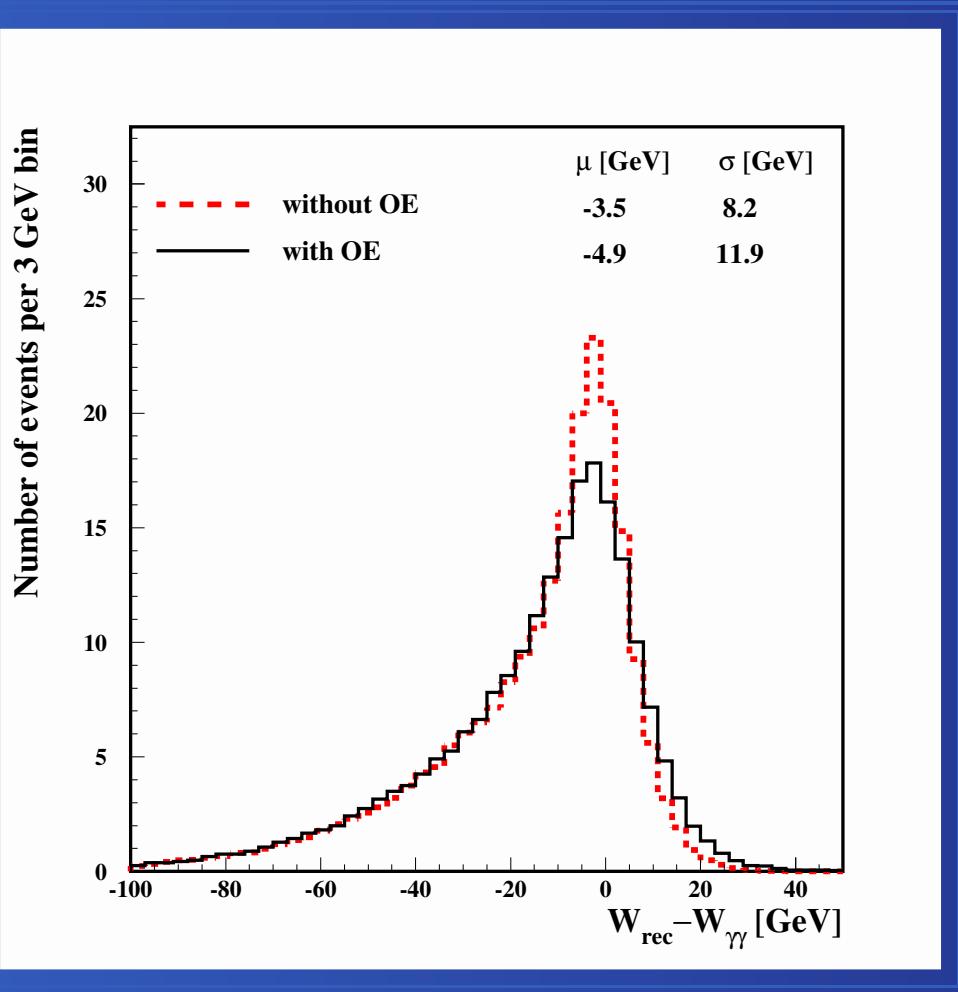
$\Rightarrow \varepsilon_h = 53\%$
 $\varepsilon_{bb} = 47\%$
 $\varepsilon_{cc} = 2.9\%$
 $\varepsilon_{uds} = 0.5\%$

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



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

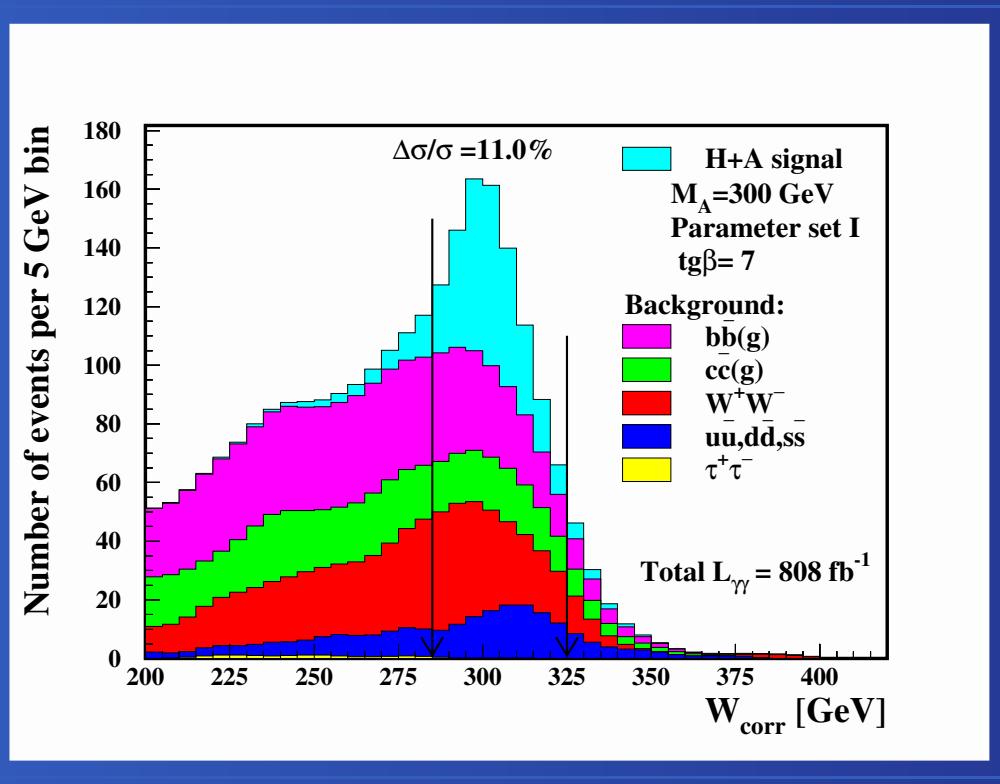
Acta Phys. Pol. B34 177 2003, hep-ph/0208234

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

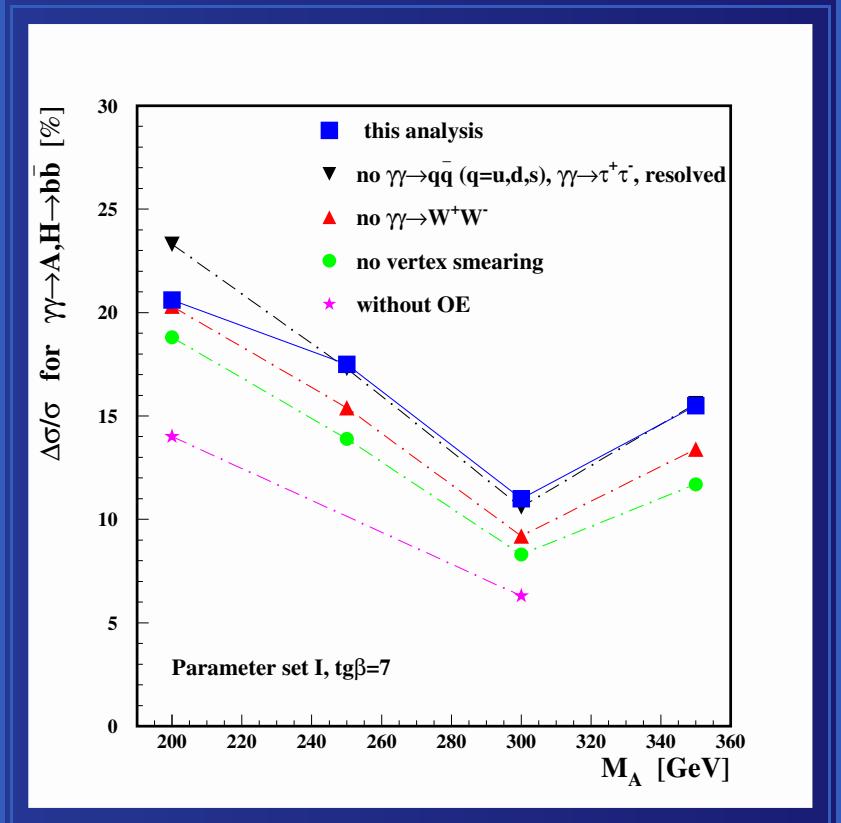
NŻK: Precision at PLC

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 ± 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:

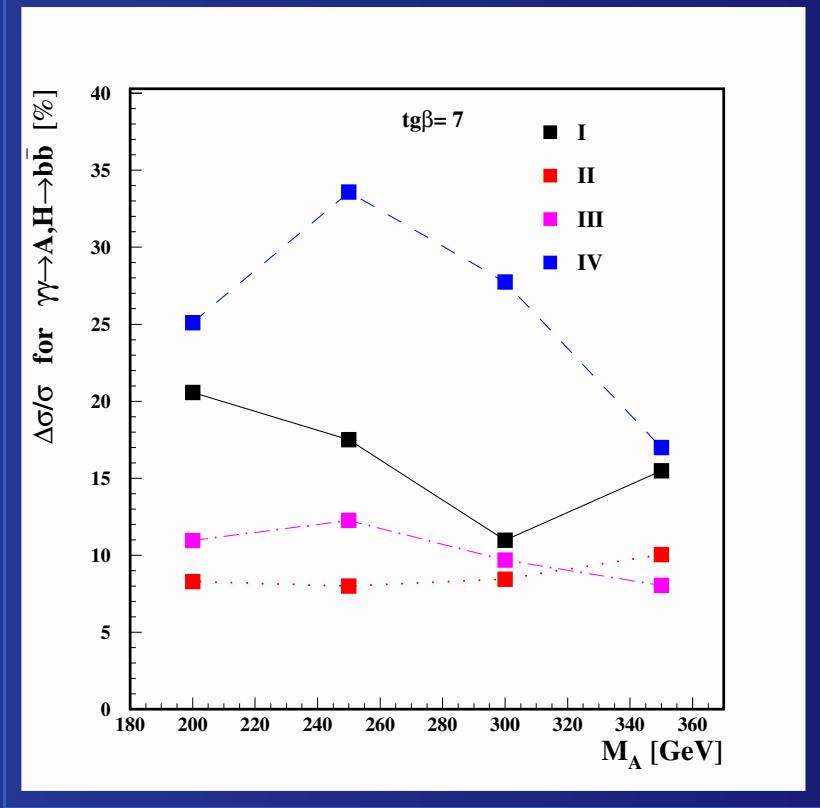
Symbol	μ [GeV]	M_2 [GeV]	$A_{\tilde{f}}$ [GeV]
I	200	200	1500
II	-150	200	1500
III	-200	200	1500
IV	300	200	2450

I and III – following M. Mühlleitner *et al.*
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):

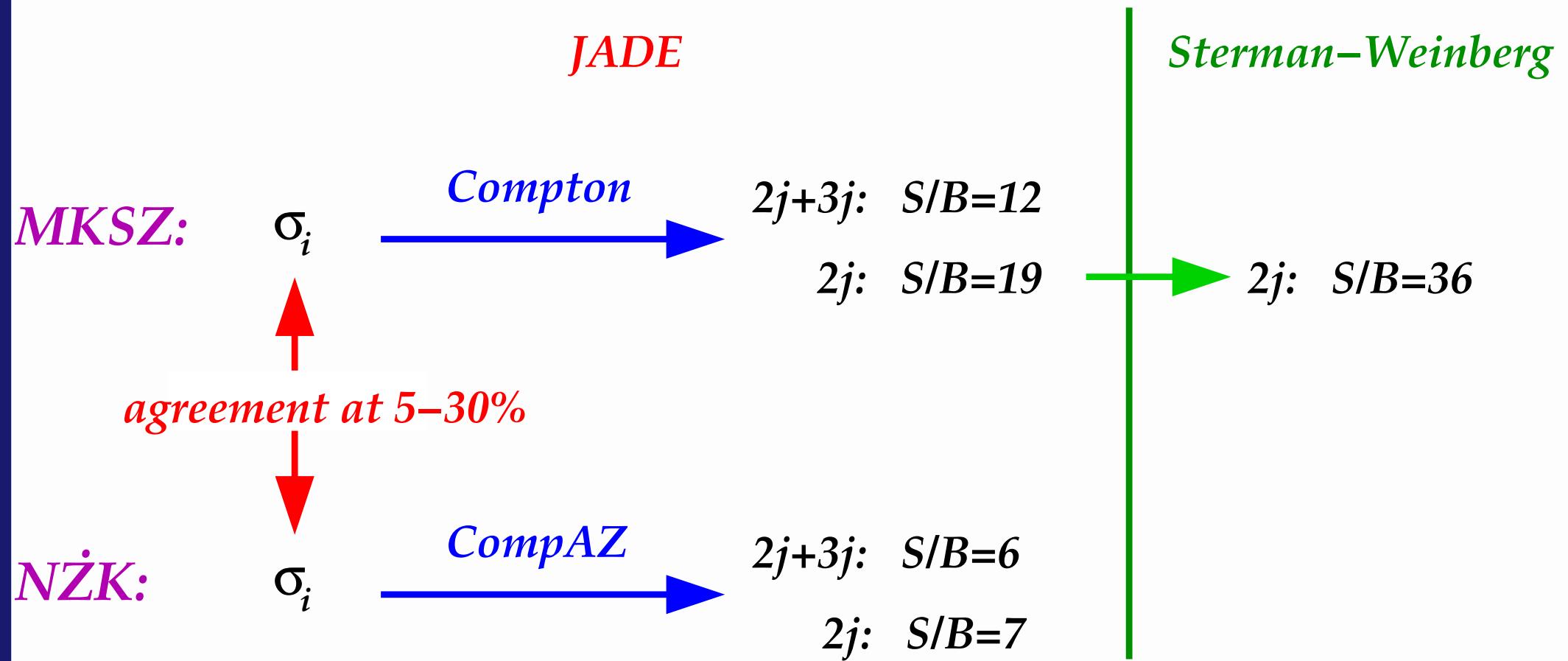
- Both approaches agree within 5% for total cross section,
and within 30% for 2-jet and 3-jet classes separately.

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

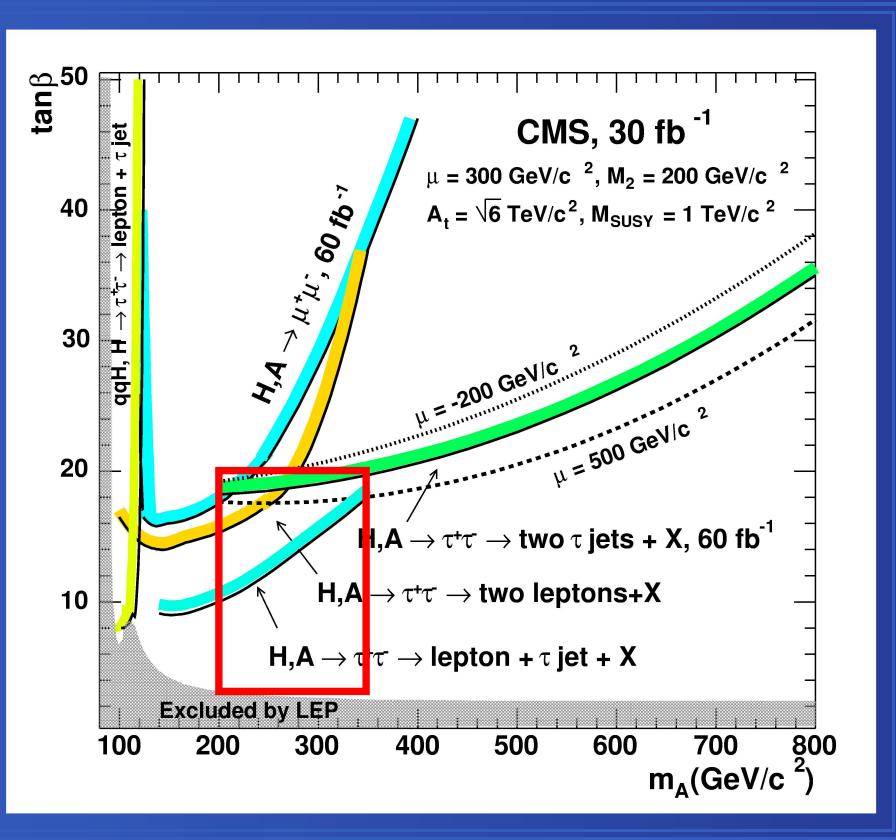
Backup Slides

Backup Slides



Introduction

LHC wedge



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(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

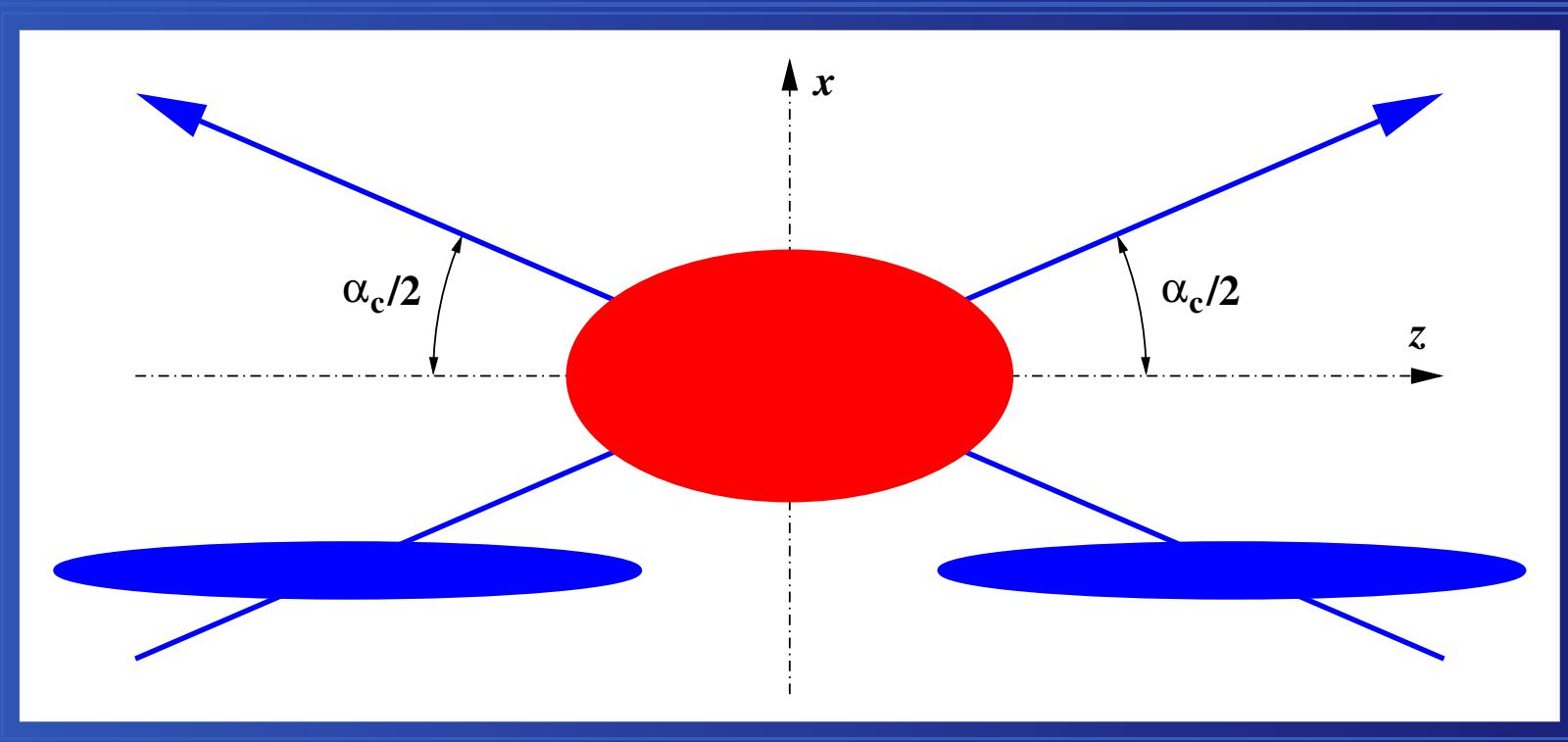
$$\sigma'_x = \sqrt{\frac{1}{2}(\sigma_x^2 + \sigma_z^2 \tan^2(\alpha_c/2))}$$

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

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

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

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

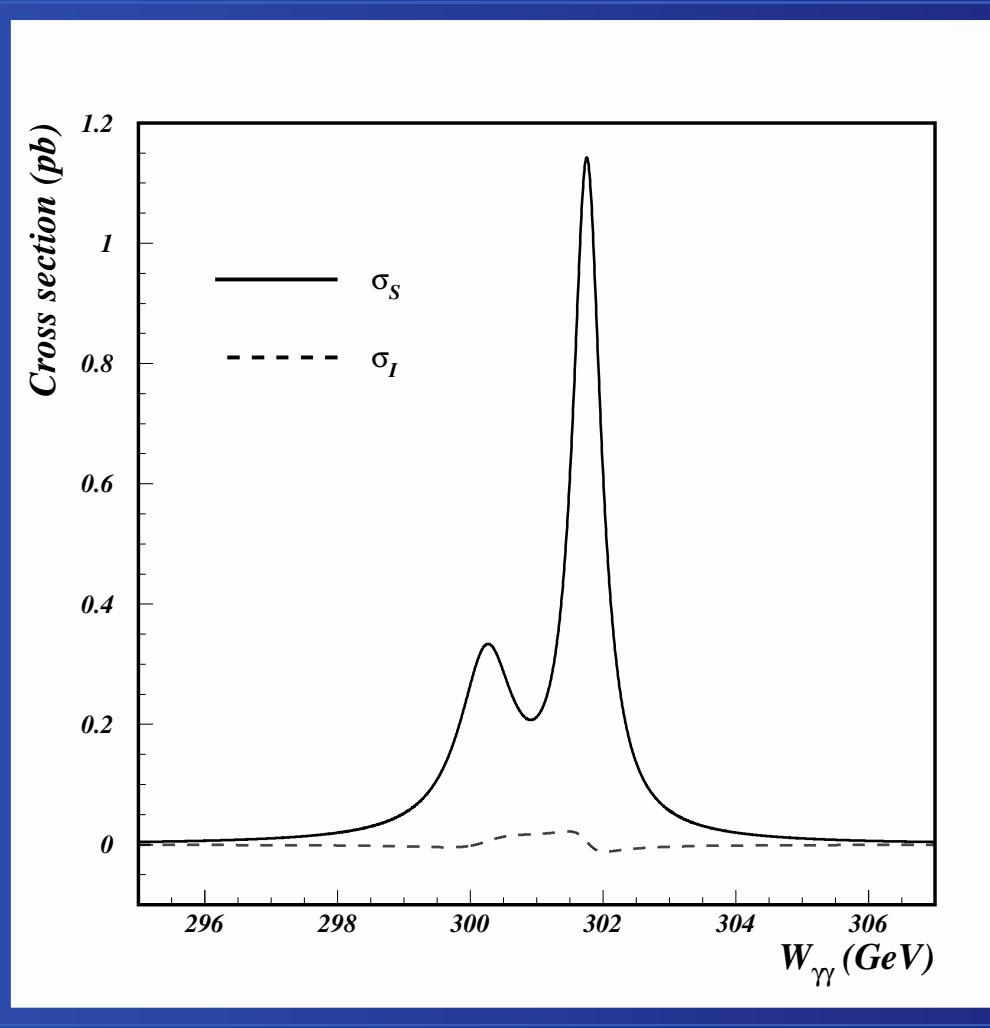


$$\alpha_c = 34 \text{ mrad}$$

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

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

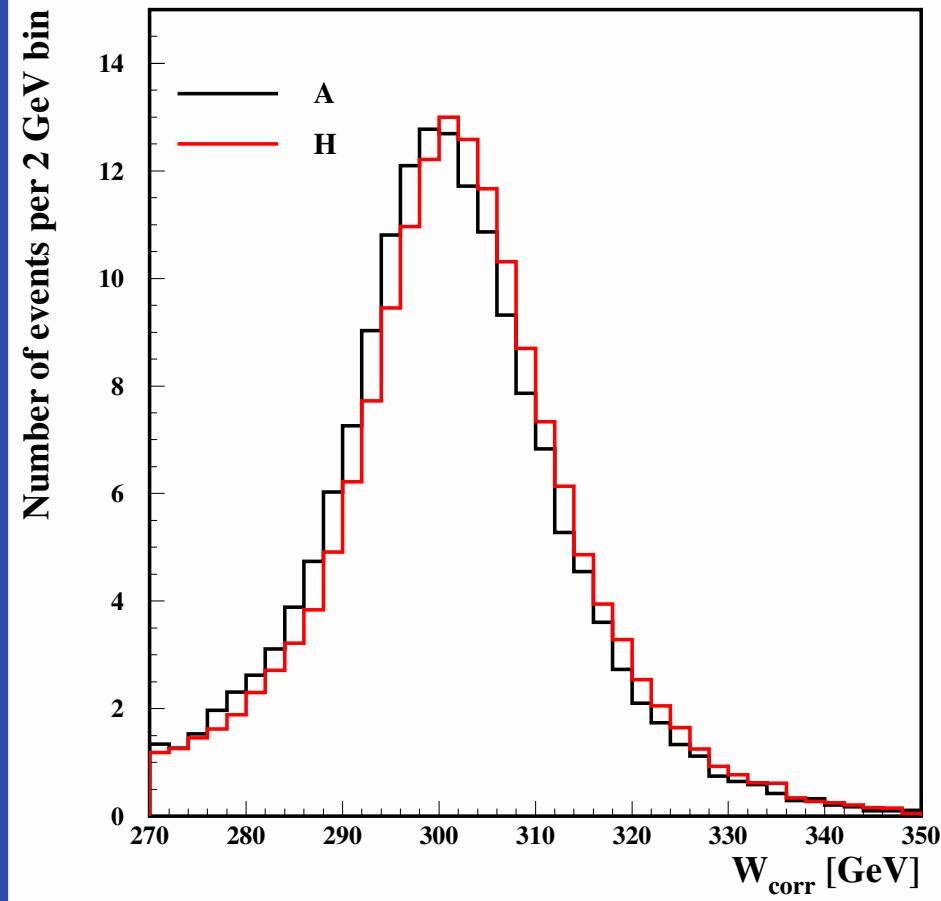
LO cross section for signal and interference term.



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

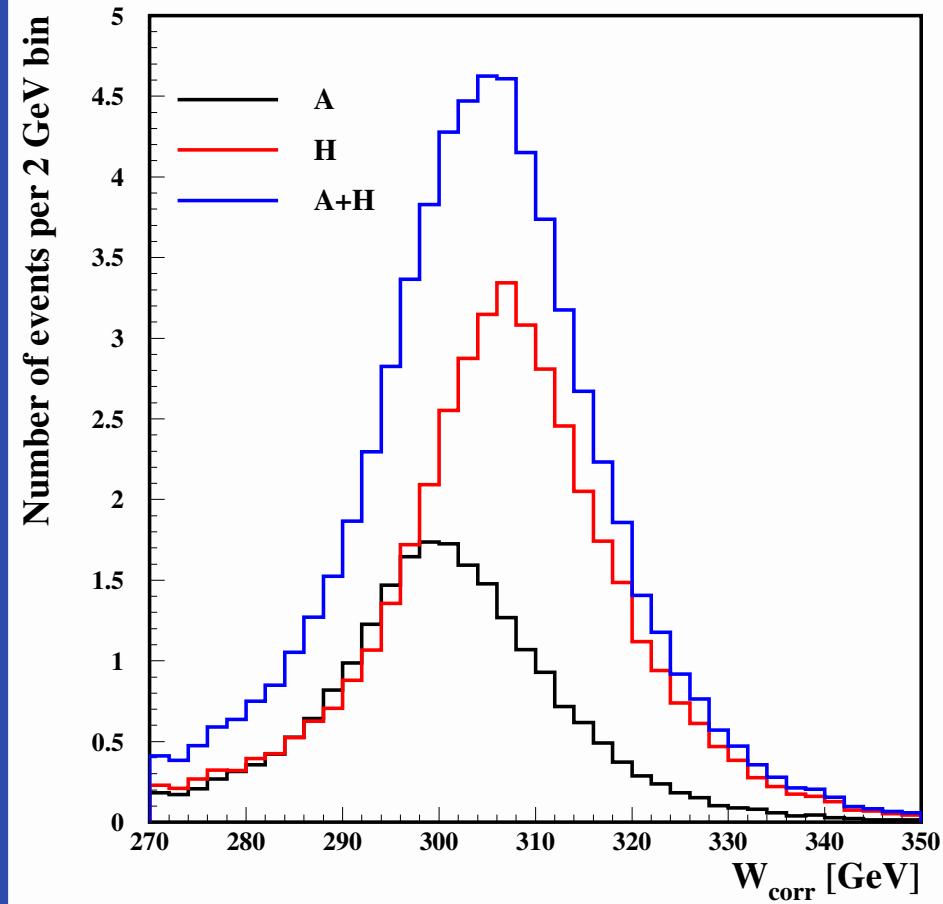


$$\begin{aligned} \tan \beta &= 7 \\ M_H - M_A &\approx 1.5 \text{ GeV} \end{aligned}$$



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

Reconstructed events

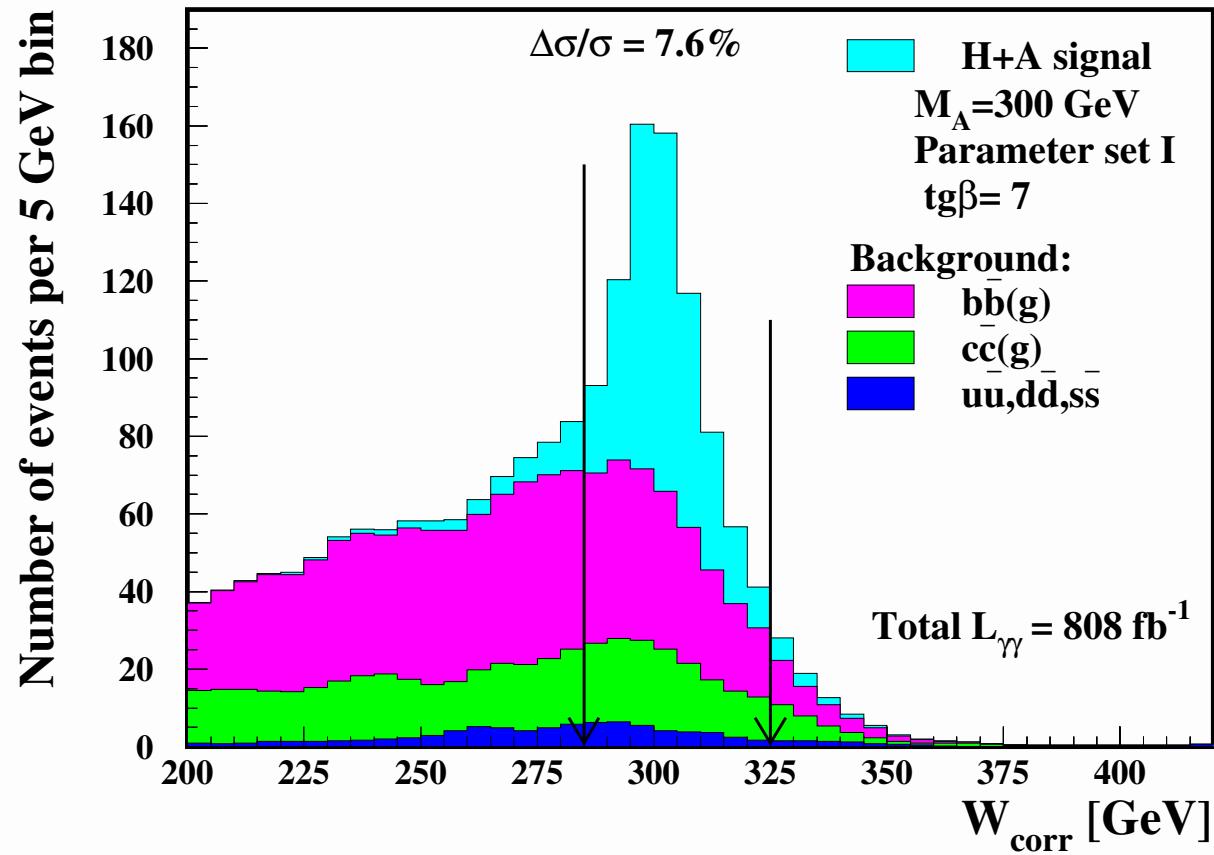


$$\begin{aligned} \tan \beta &= 3 \\ M_H - M_A &\approx 6.8 \text{ GeV} \end{aligned}$$



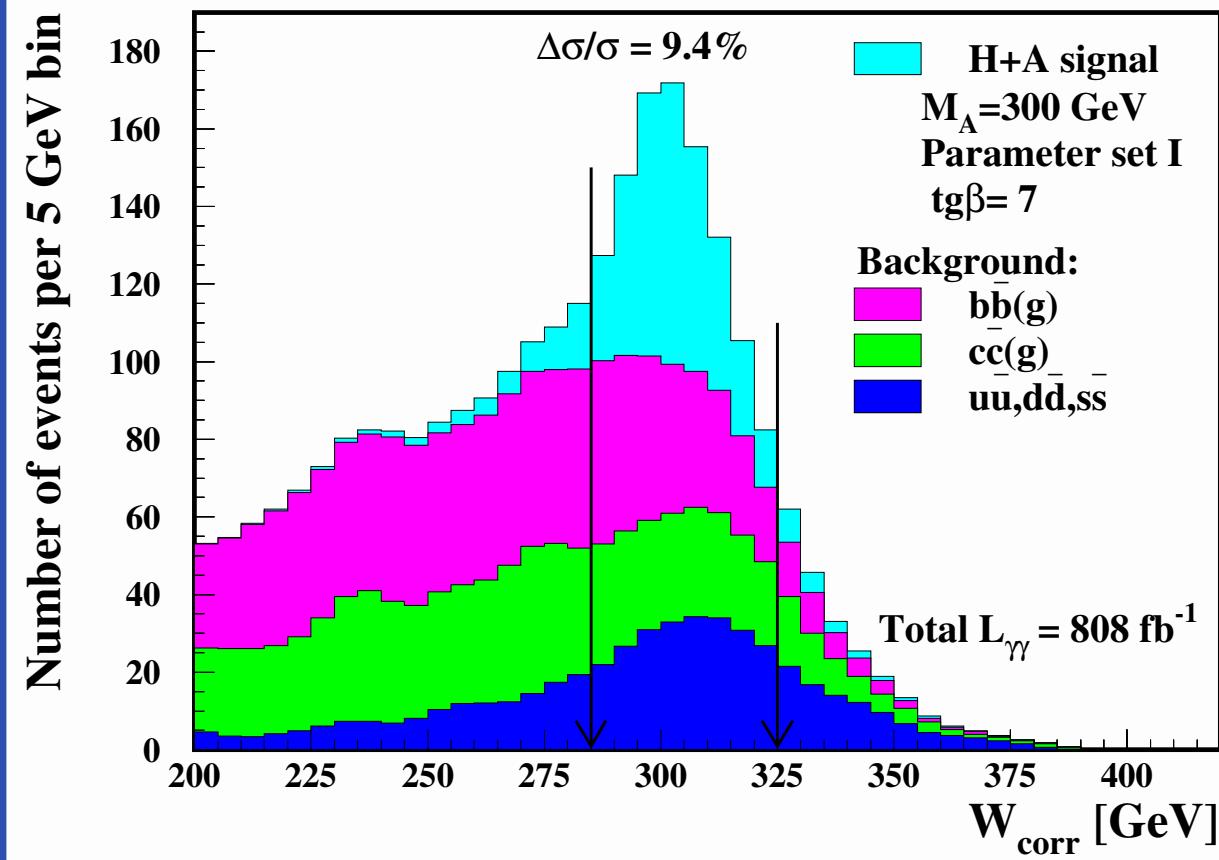
$$M_A = 300 \text{ GeV}$$

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



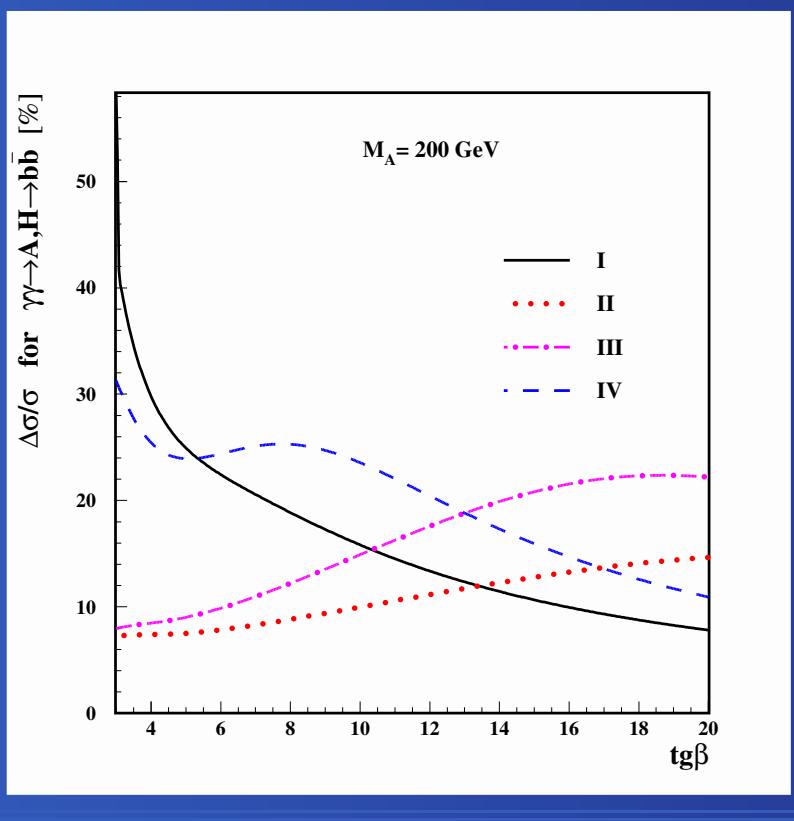
$M_A = 300 \text{ GeV}$

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

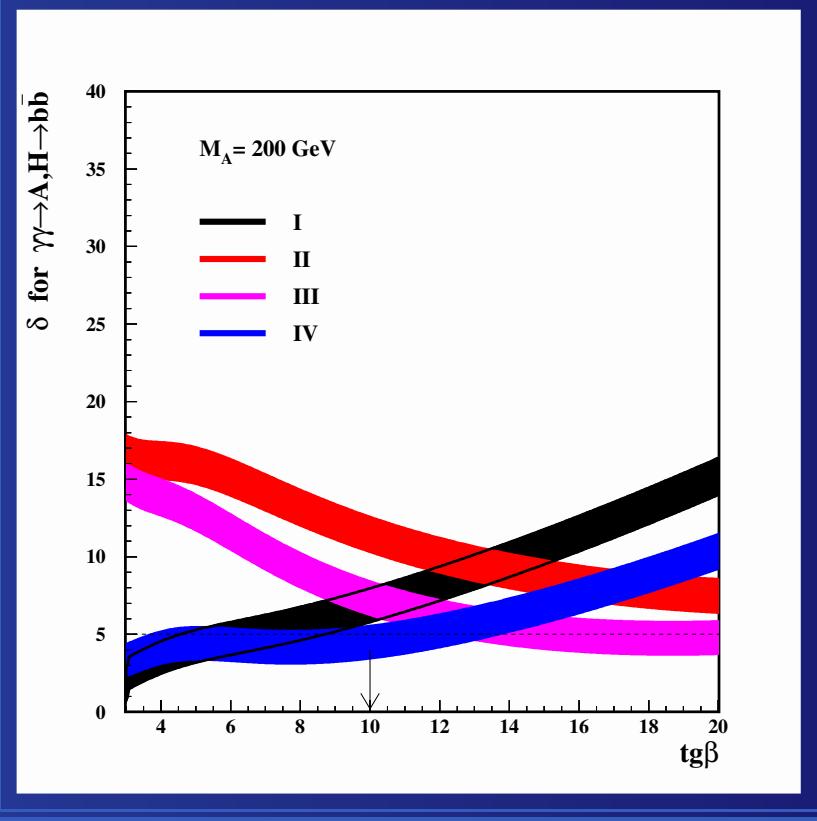


Precision & Significance

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



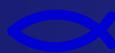
Significance for $\gamma\gamma \rightarrow A, H \rightarrow b\bar{b}$



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

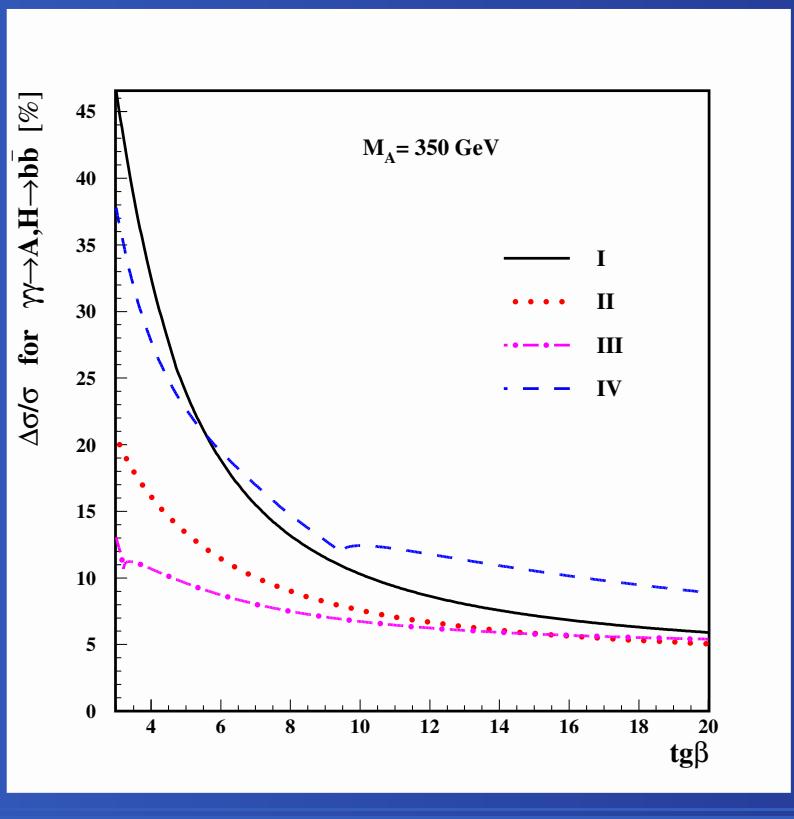
$$\delta = \frac{\mu_S}{\sqrt{\mu_B}} \pm \sqrt{1 + \frac{\mu_S}{\mu_B}}$$

Arrow – lower limit at LHC

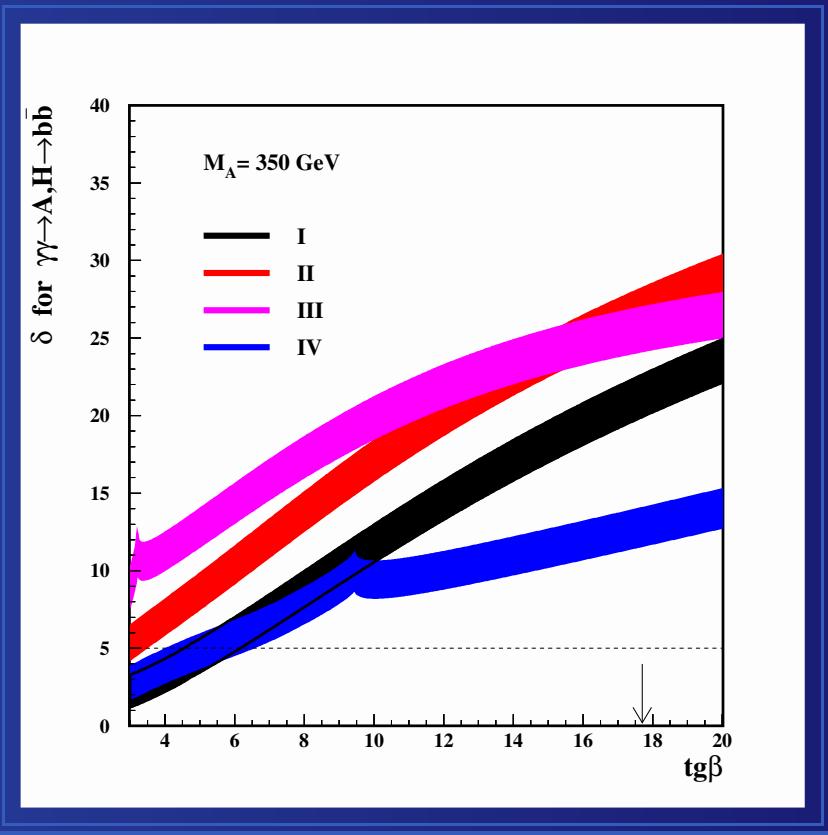


Precision & Significance

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



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

