Final results for the SM Higgs-boson production in channel $\gamma\gamma \to h \to b\bar{b}$ at the Photon Collider

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Overview

Analysis of $\sigma(\gamma\gamma \to h \to b\bar{b})$ measurement

LCWS'04 Paris:

- NLO QCD background $\gamma\gamma \to Q\bar{Q}(g)$ $\quad (Q = c, b)$
- realistic $\gamma\gamma$-spectra
- b-tagging
- overlaying events $\gamma\gamma \to hadrons$ (OE)
- crossing angle
- primary vertex distribution

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

Overview

Analysis of $\sigma(\gamma\gamma \to h \to b\bar{b})$ measurement

NEW:

- $\gamma\gamma \to W^+W^-$ background contribution (polarized cross section)
- $\gamma\gamma \to q\bar{q}$ ($q = u, d, s$) background contribution (unpolarized cross section)
- $\gamma\gamma \to \tau^+\tau^-$ background contribution
- $\gamma\gamma \to hadrons$ (resolved) as a separate background contribution
- Full optimization of cuts
- Estimates of systematic uncertainties

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

Tools

Photon-photon spectrum: CompAZ

Signal: Hdecay, Pythia

Background:

- NLO $\gamma\gamma \to Q\bar{Q}(g)$ for $Q = c, b$ (G. Jikia)
- $\gamma\gamma \to W^+W^-$ (Pythia + polarized cross section)
- $\gamma\gamma \to q\bar{q}$ for $q = u, d, s$ (Pythia, unpolarized cross section)
- $\gamma\gamma \to \tau^+\tau^-$ (Pythia).

Overlaying events $\gamma\gamma \to hadrons$ (Pythia) with realistic $\gamma\gamma$-luminosity spectrum (V. Telnov)

Parton Shower (not for $Q\bar{Q}(g)$): Pythia

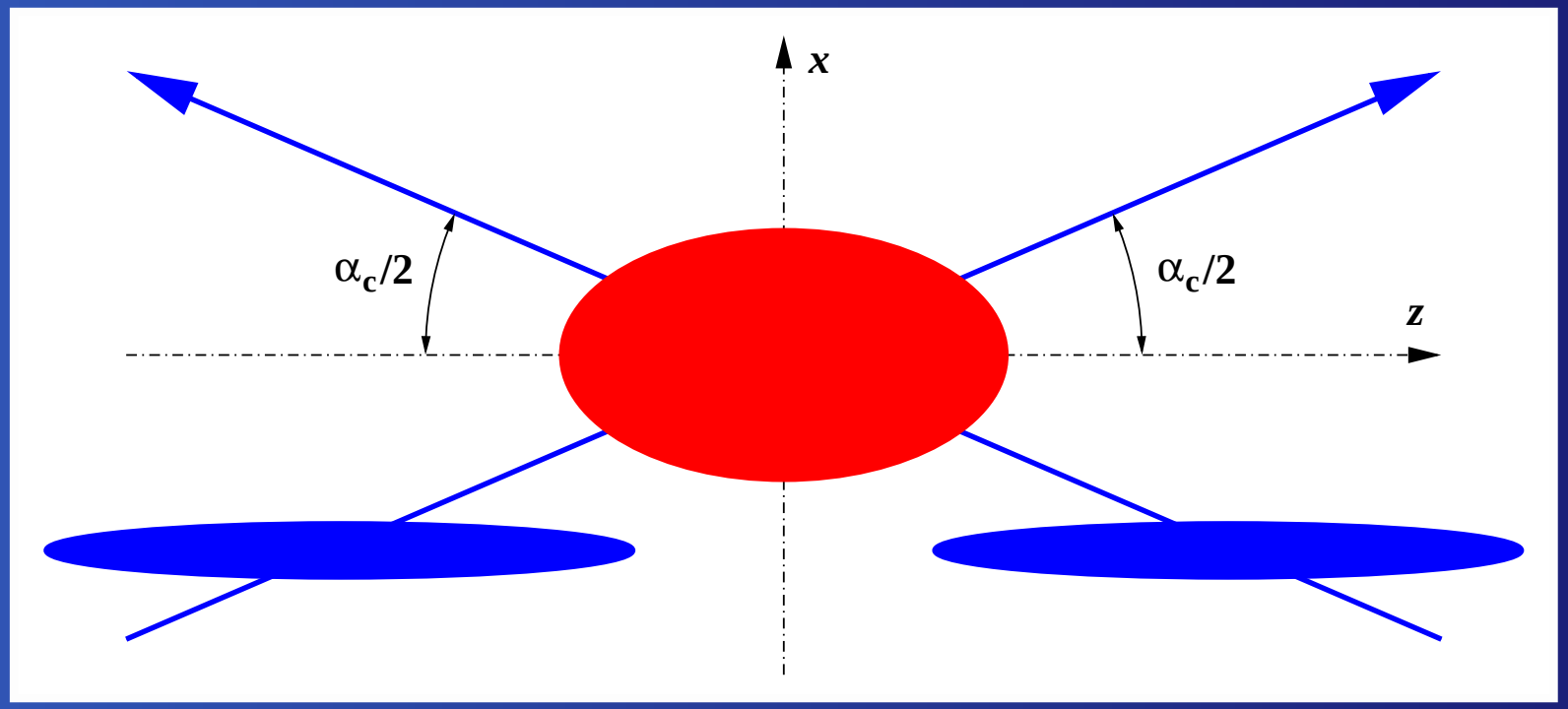
Fragmentation: Pythia (Lund)

Detector performance: Simdet 4.01

Crab-wise crossing of beams

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

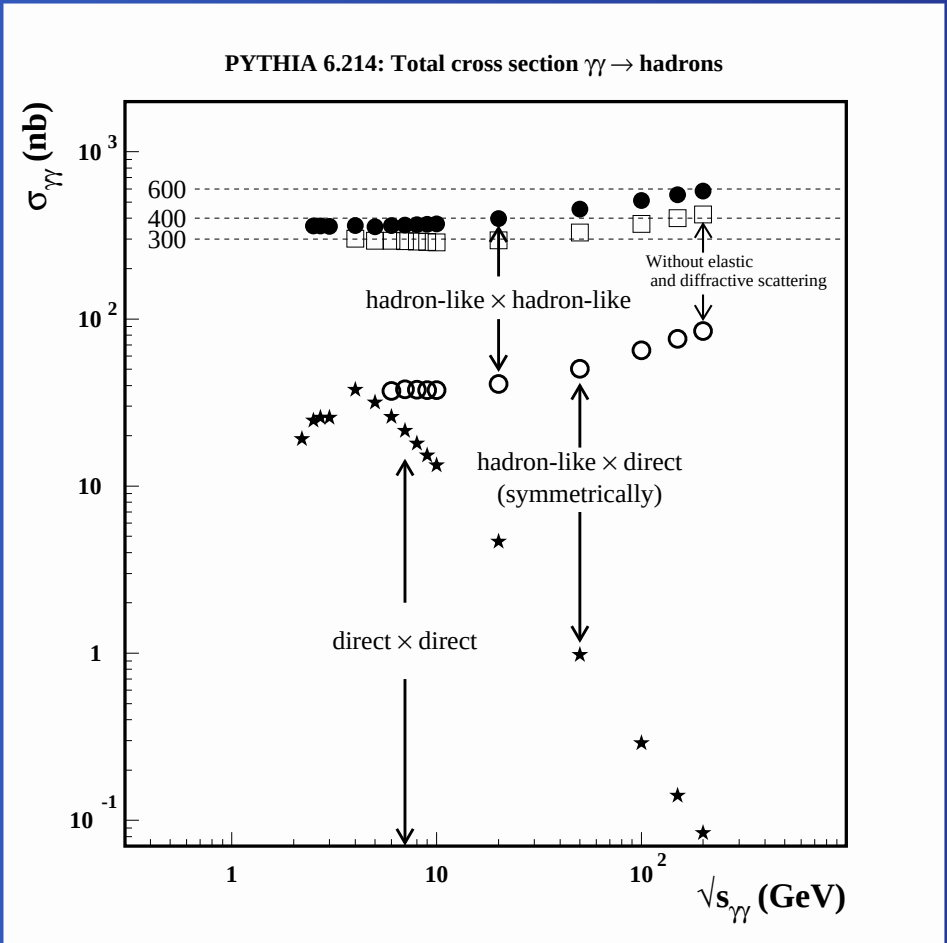
Bunch:	$\sigma_x = 140$ nm	$\sigma_y = 15$ nm	$\sigma_z = 0.3$ mm
Primary vertex:	$\sigma'_x = 3.6\ \mu$m	$\sigma'_y = 11$ nm	$\sigma'_z = 0.2$ mm



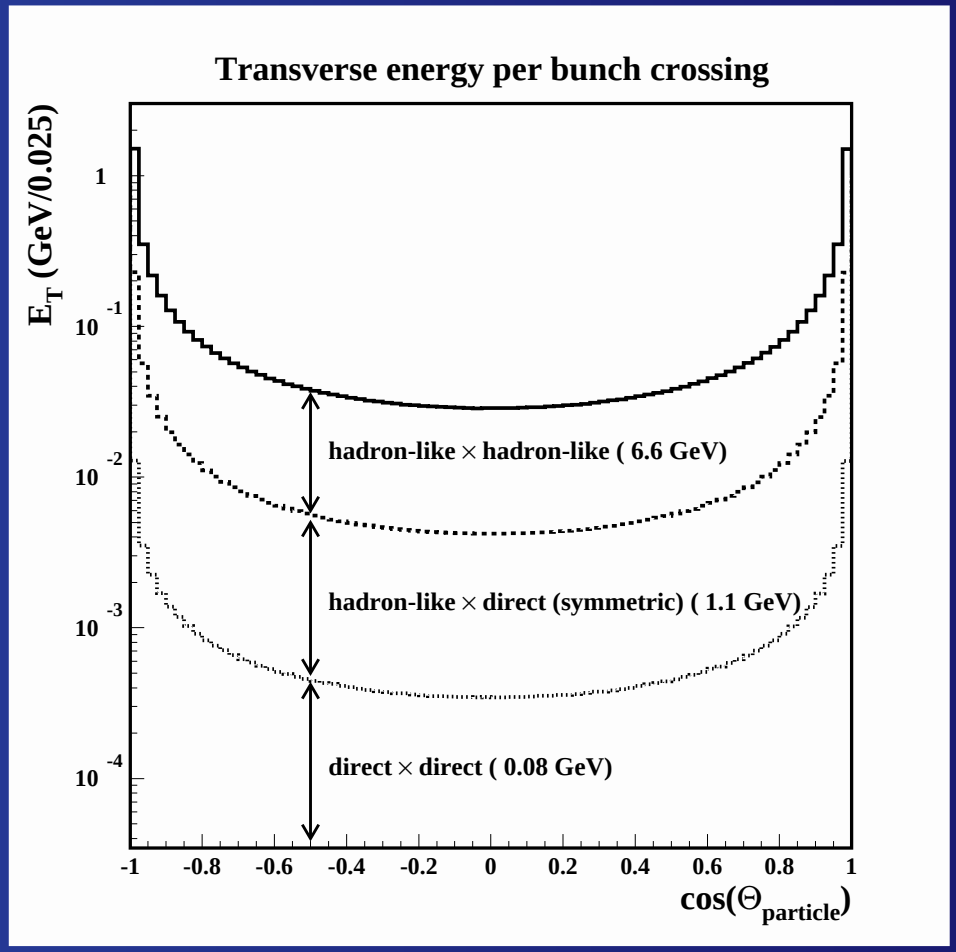
$$\alpha_c = 34 \text{ mrad}$$

$\gamma\gamma \to hadrons$ events

Cross sections



Angular E_T-flow per bunch crossing.

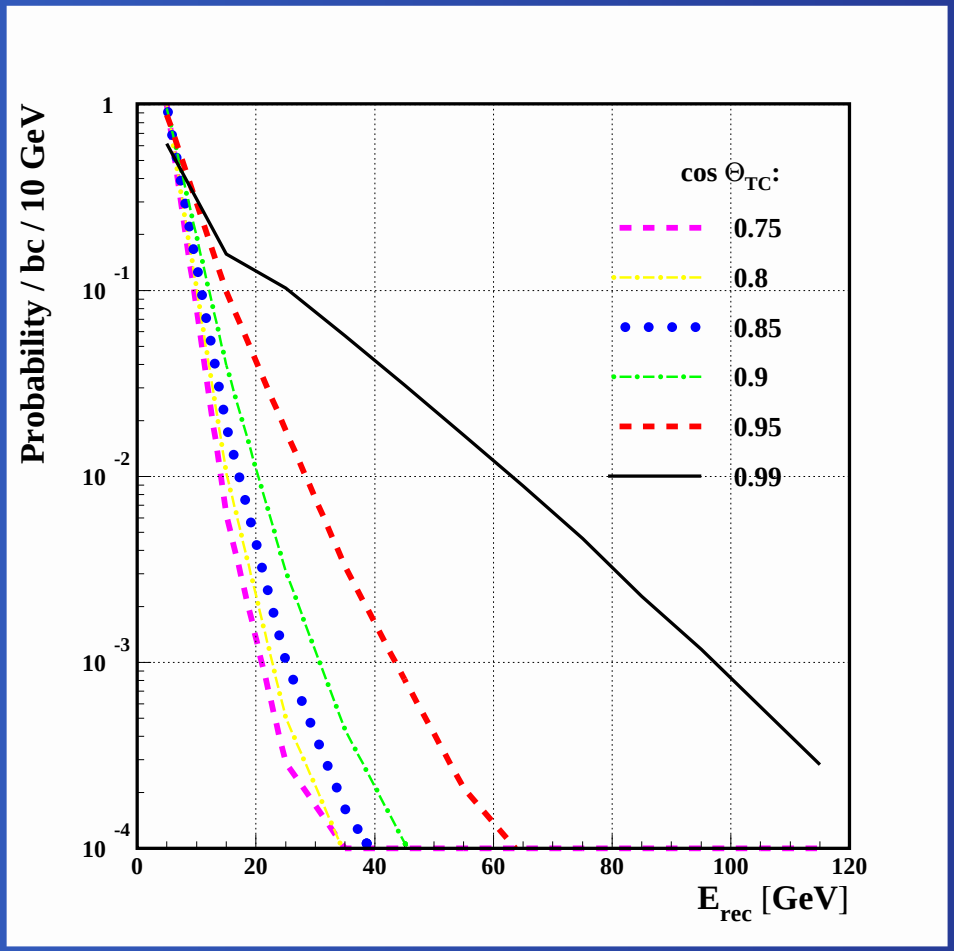


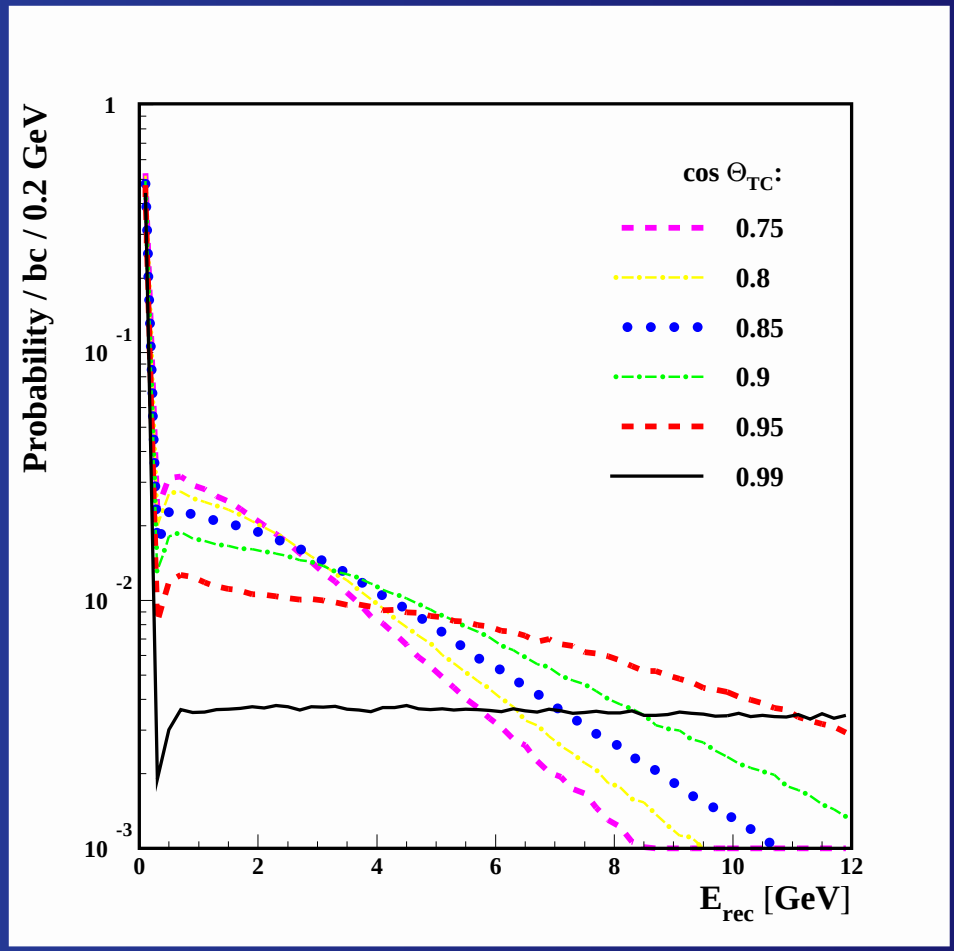
Generation for $\sqrt{s_{ee}} = 210.5$ GeV.

θ_{TC}

Reconstructed energy per bc

$\gamma\gamma \to hadrons$

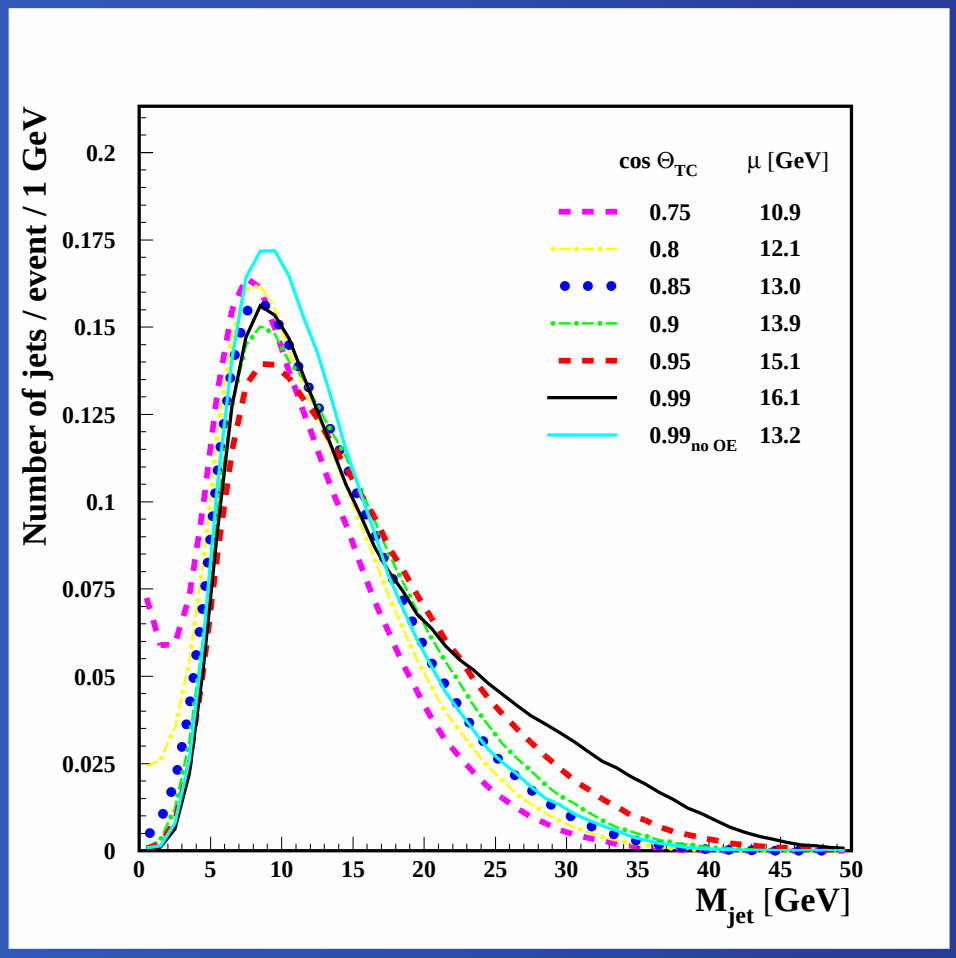




$\sqrt{s_{ee}} = 210.5$ GeV; $N_{OE}/\text{bc} \approx 1$

θ_{TC}

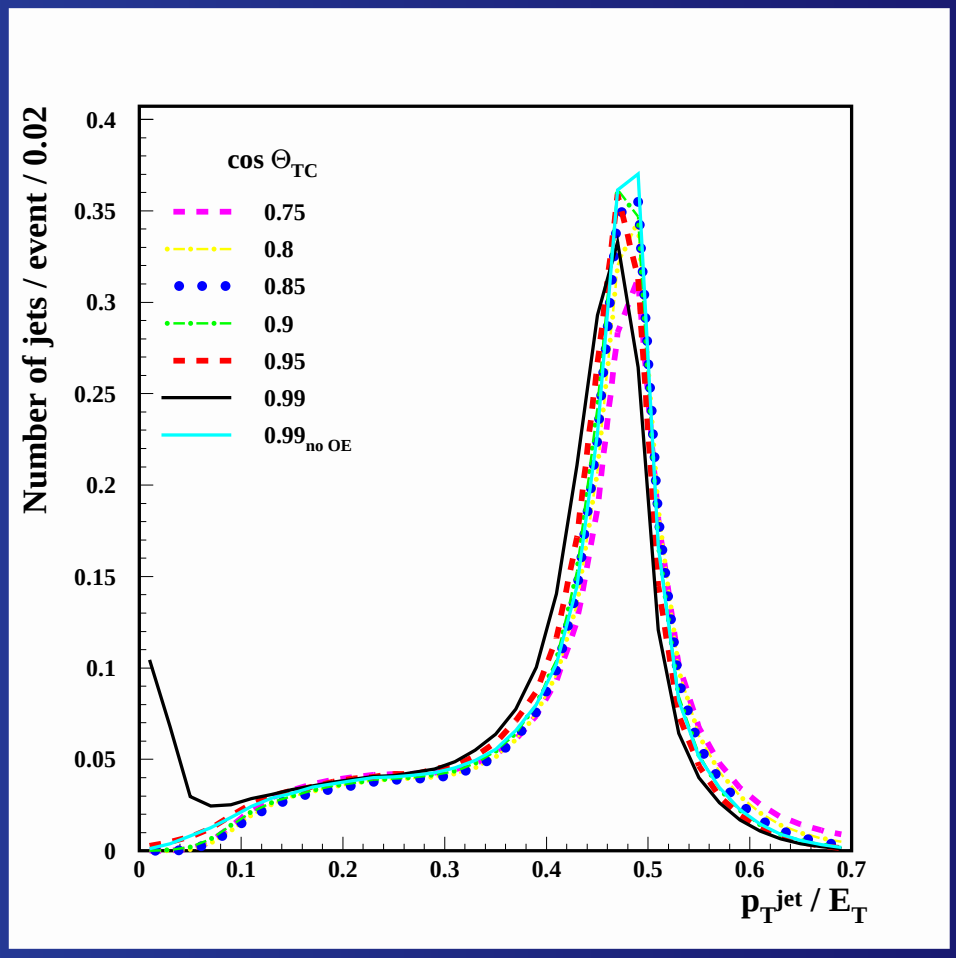
$\gamma\gamma \to h \to b\bar{b}$ ($M_h = 120$ GeV)



M_{jet}

$\sqrt{s_{ee}} = 210.5$ GeV

$\gamma\gamma \to h \to b\bar{b}$ ($M_h = 120$ GeV)

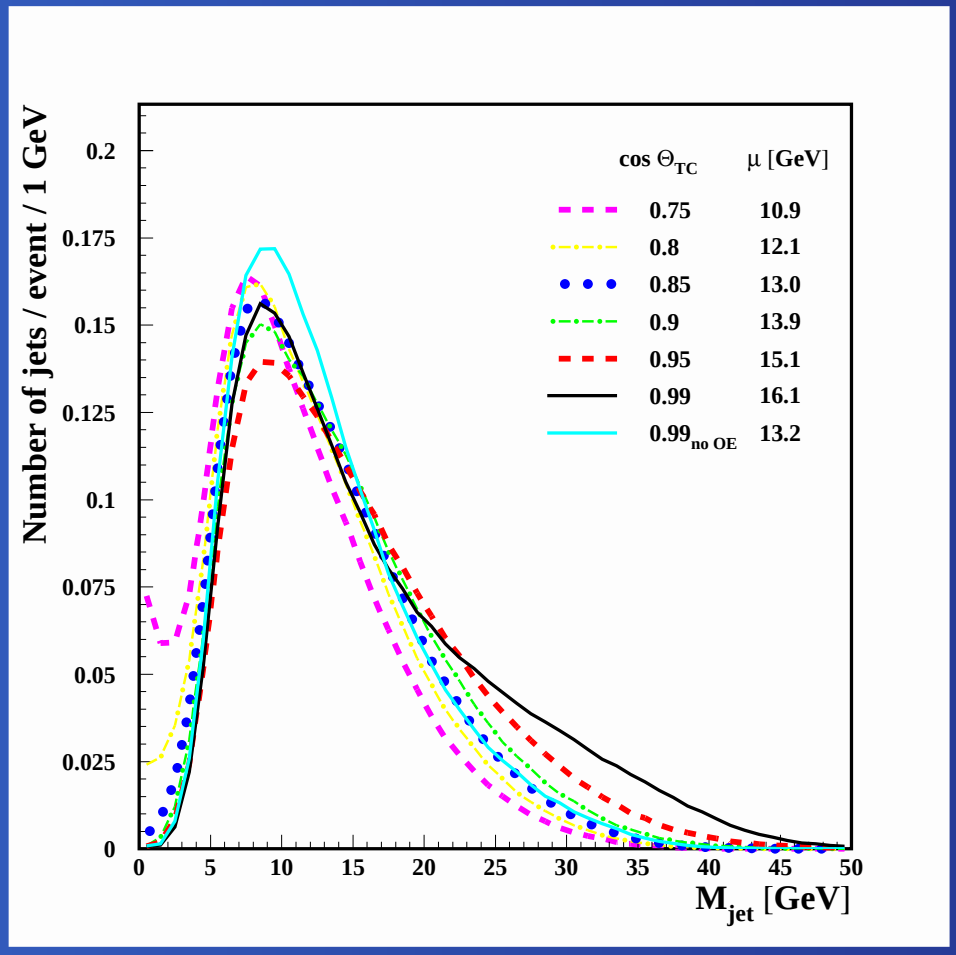


p_T^{jet}/E_T

$\sqrt{s_{ee}} = 210.5$ GeV

θ_{TC}

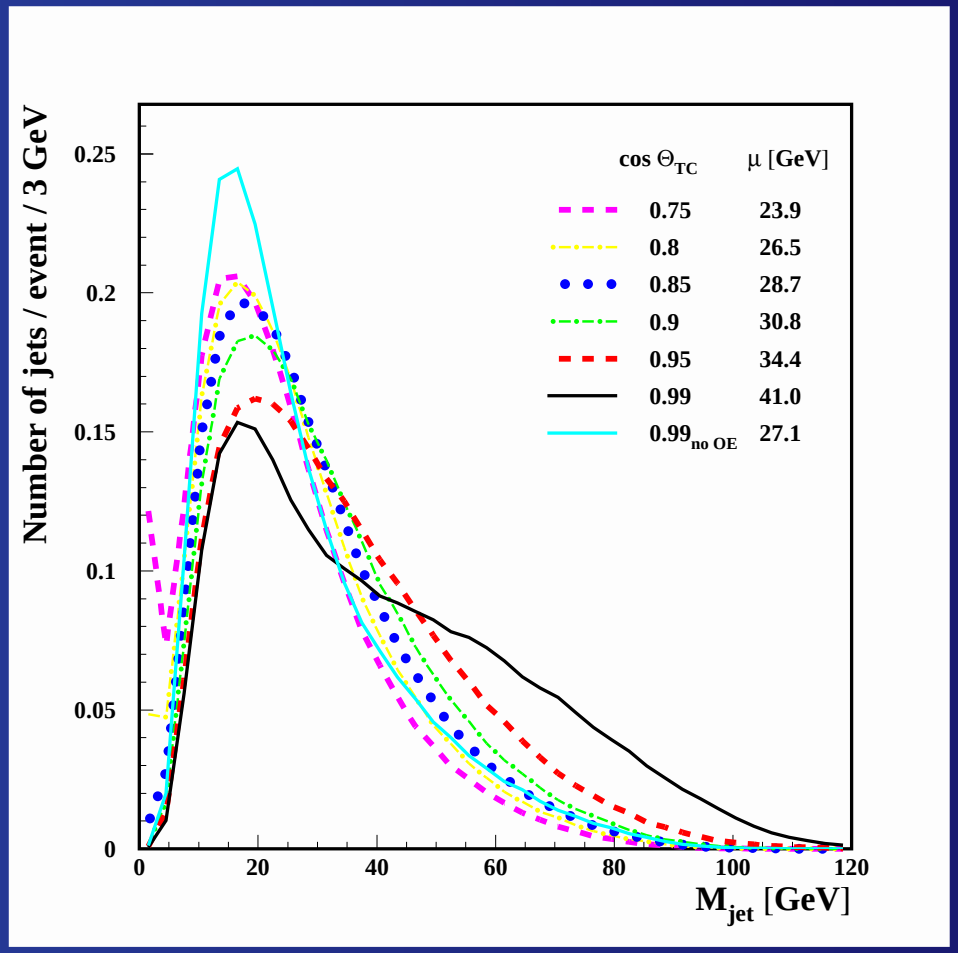
$\gamma\gamma \to h \to b\bar{b}$ ($M_h = 120$ GeV)



M_{jet}

$\sqrt{s_{ee}} = 210.5$ GeV

$\gamma\gamma \to A \to b\bar{b}$ ($M_A = 300$ GeV)

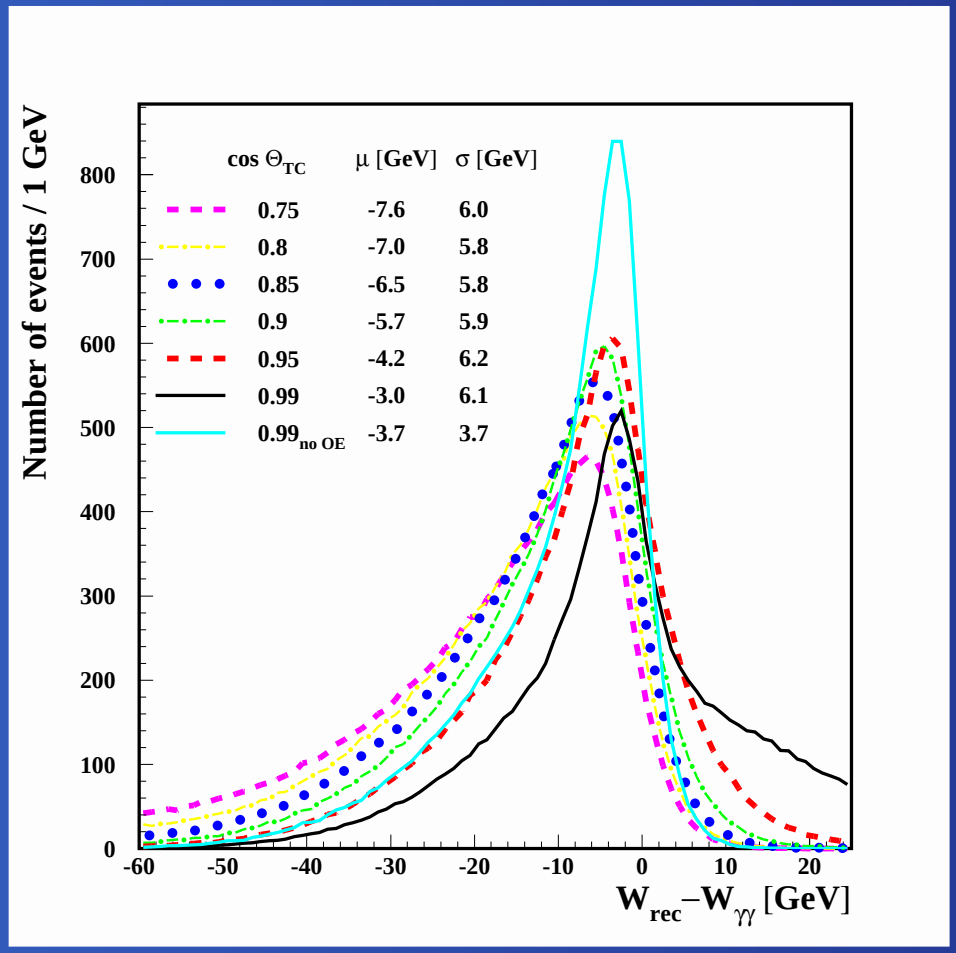


M_{jet}

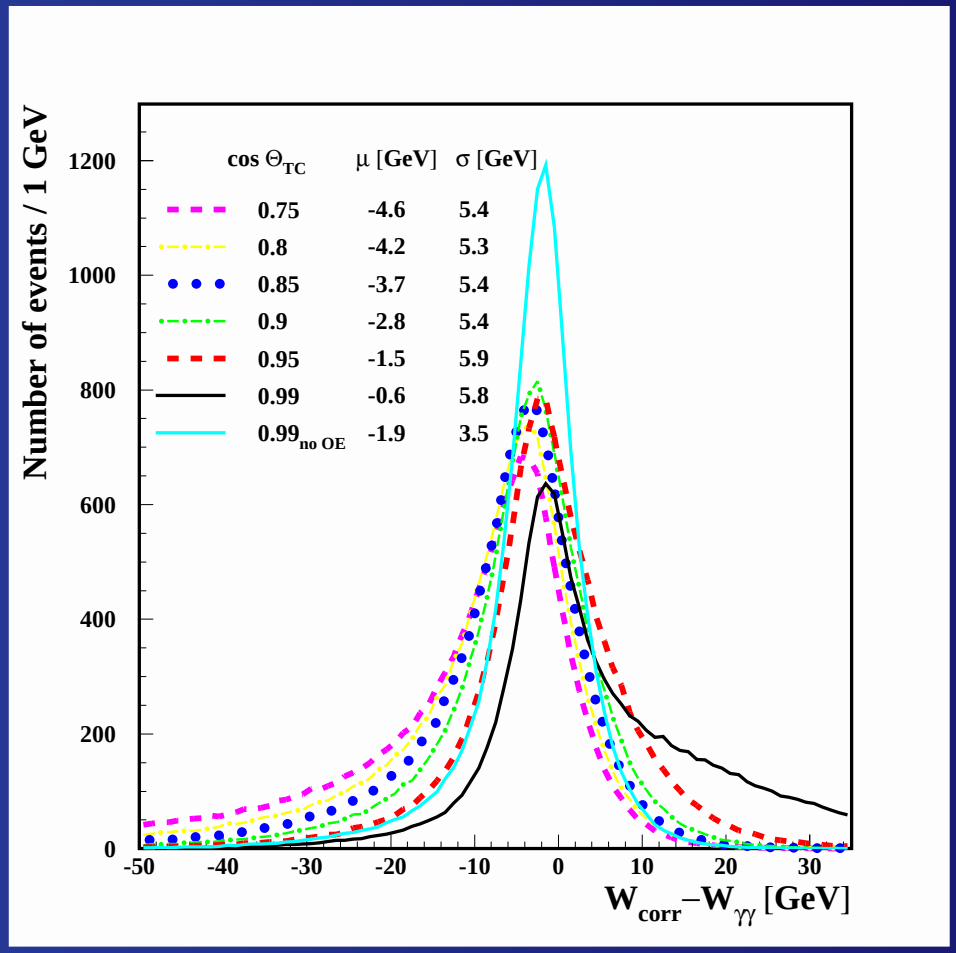
$\sqrt{s_{ee}} = 419$ GeV

θ_{TC}

$\gamma\gamma \to h \to b\bar{b}$ ($M_h = 120$ GeV)



$W_{rec} - W_{\gamma\gamma}$



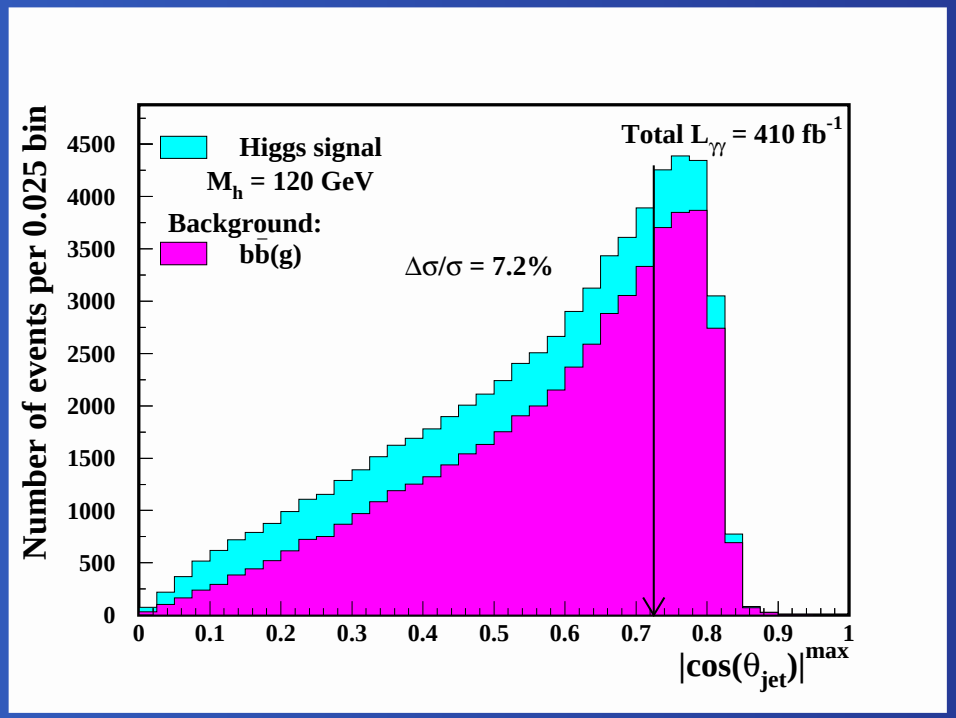
$W_{corr} - W_{\gamma\gamma}$

Cuts

Cuts optimized by minimizing:

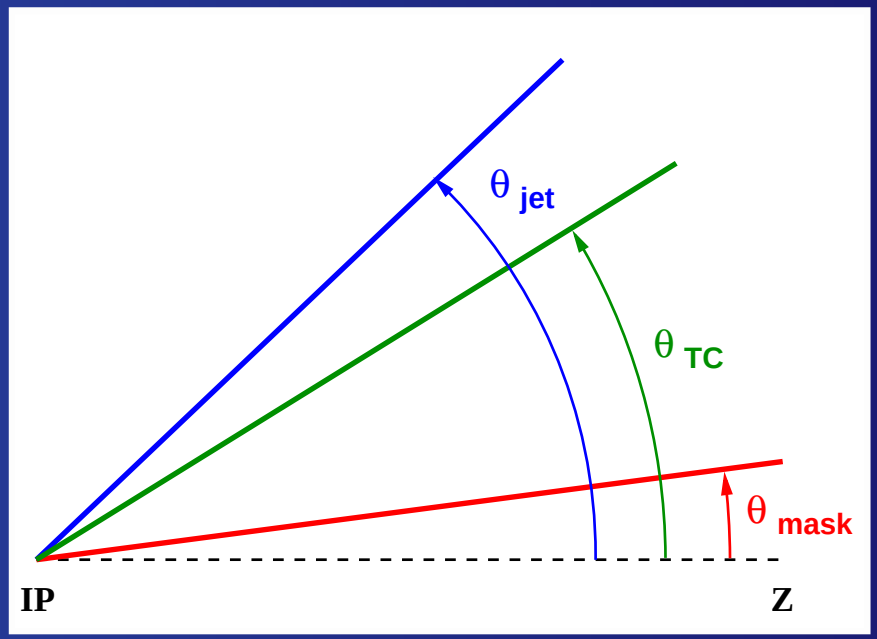
$$\frac{\Delta\sigma(\gamma\gamma \to h \to b\bar{b})}{\sigma(\gamma\gamma \to h \to b\bar{b})} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S},$$

For example:



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

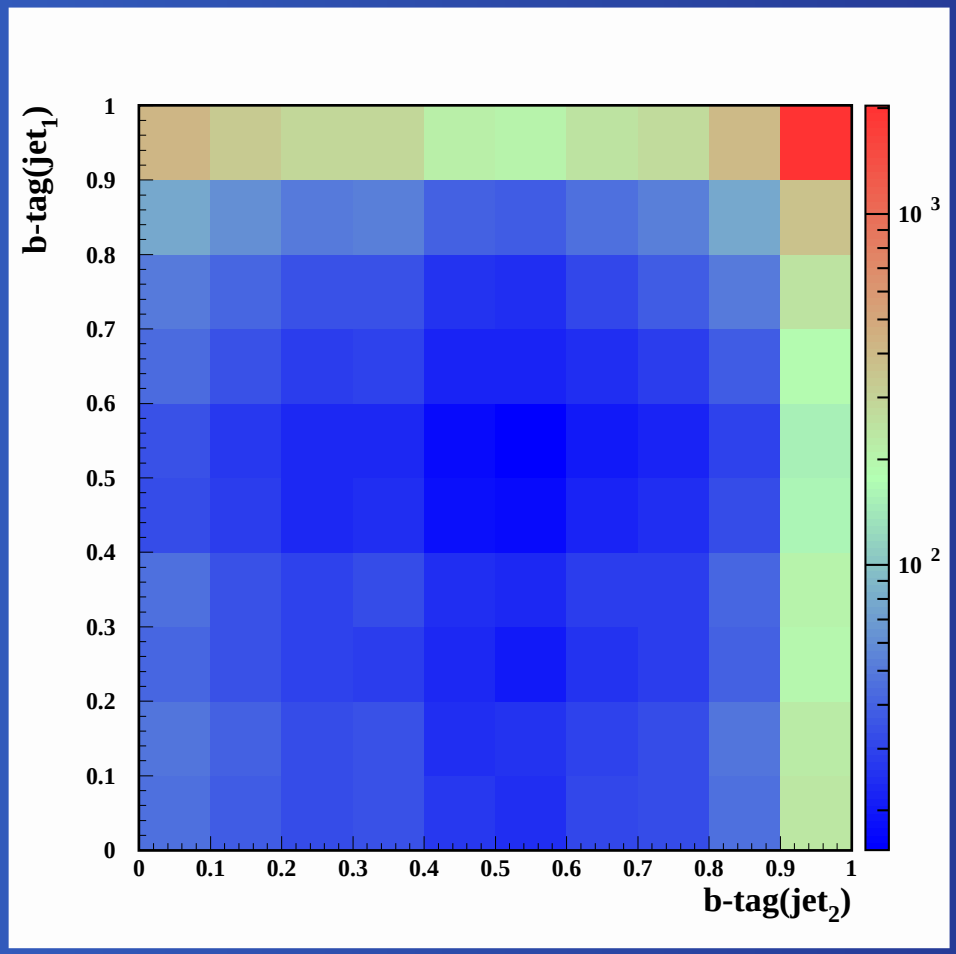
Tracks & clusters: $\cos\theta_{TC} = 0.85$

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

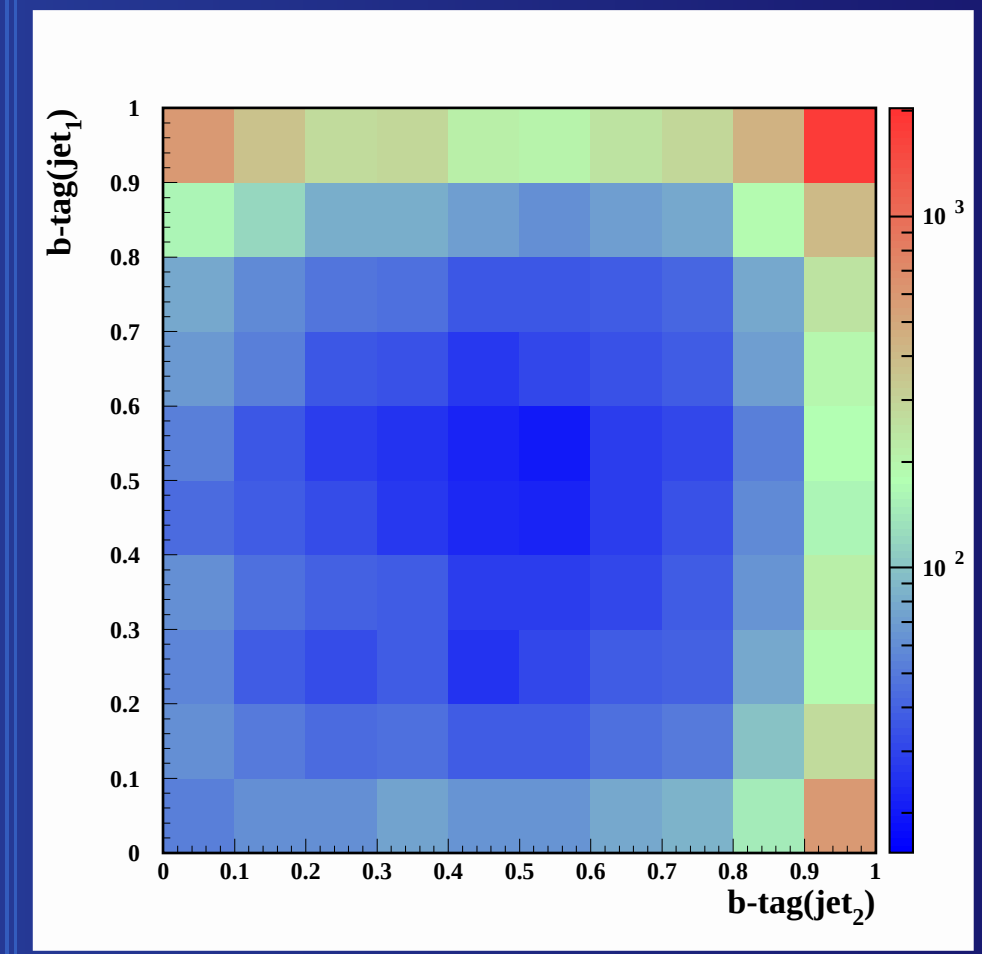
Jets: $|\cos\theta_{jet}|^{\max} = 0.725$

$b\bar{b}$-tagging

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



$\gamma\gamma \to b\bar{b}(g)$

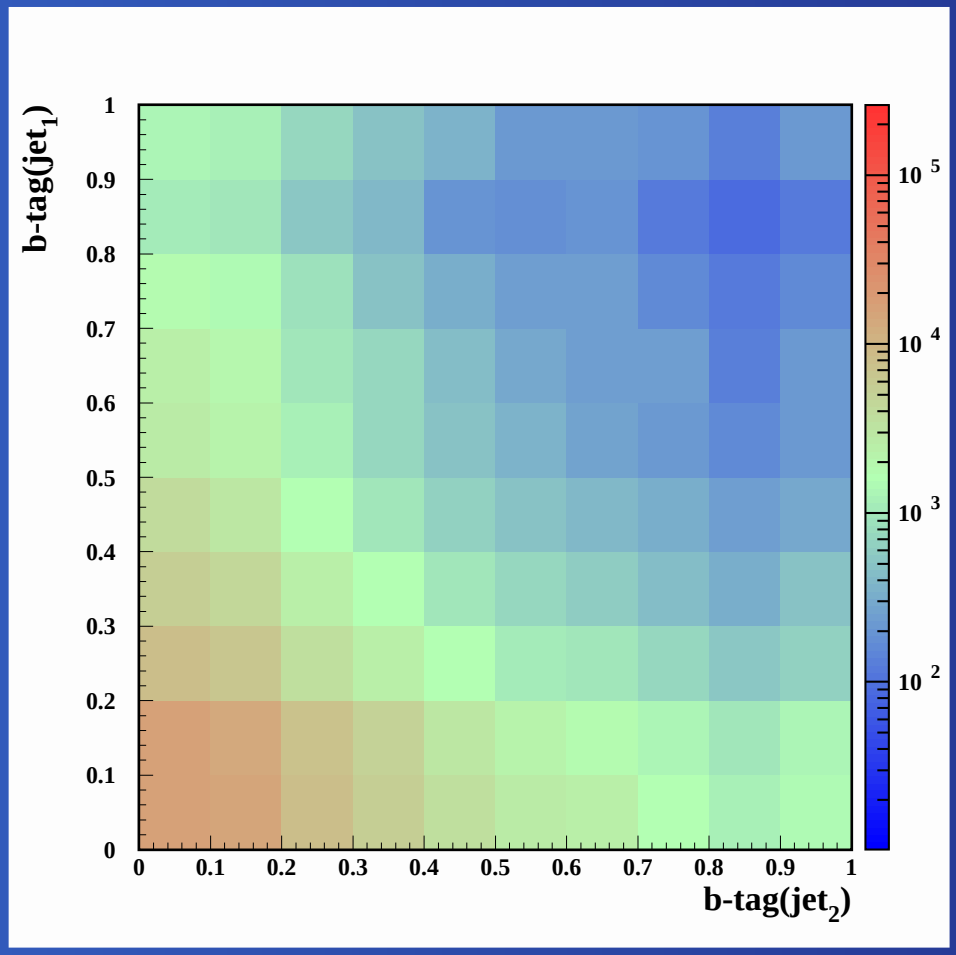


$J_z = 0$ suppressed for $b\bar{b}$

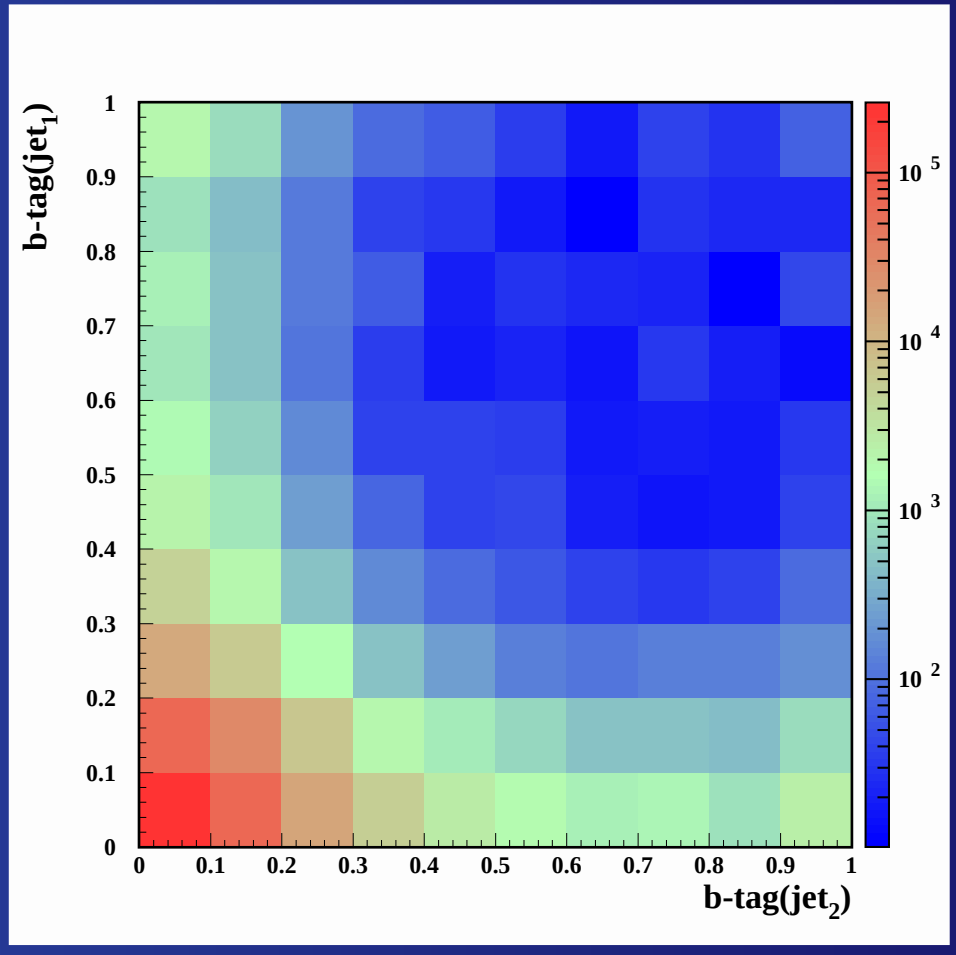
$\Rightarrow$ hard g-jet with low b-tag

$b\bar{b}$-tagging

$\gamma\gamma \to c\bar{c}(g)$



$\gamma\gamma \to q\bar{q}$ $(q = u, d, s)$



Significant fraction mistagged
$\Rightarrow$ double b-tag

higgs-tagging at $M_h = 120$ GeV

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

$\Rightarrow \varepsilon_h = 58\%$

$\varepsilon_{bb} = 50\%$

$\varepsilon_{cc} = 2.2\%$

$\varepsilon_{uds} = 0.16\%$

Without OE

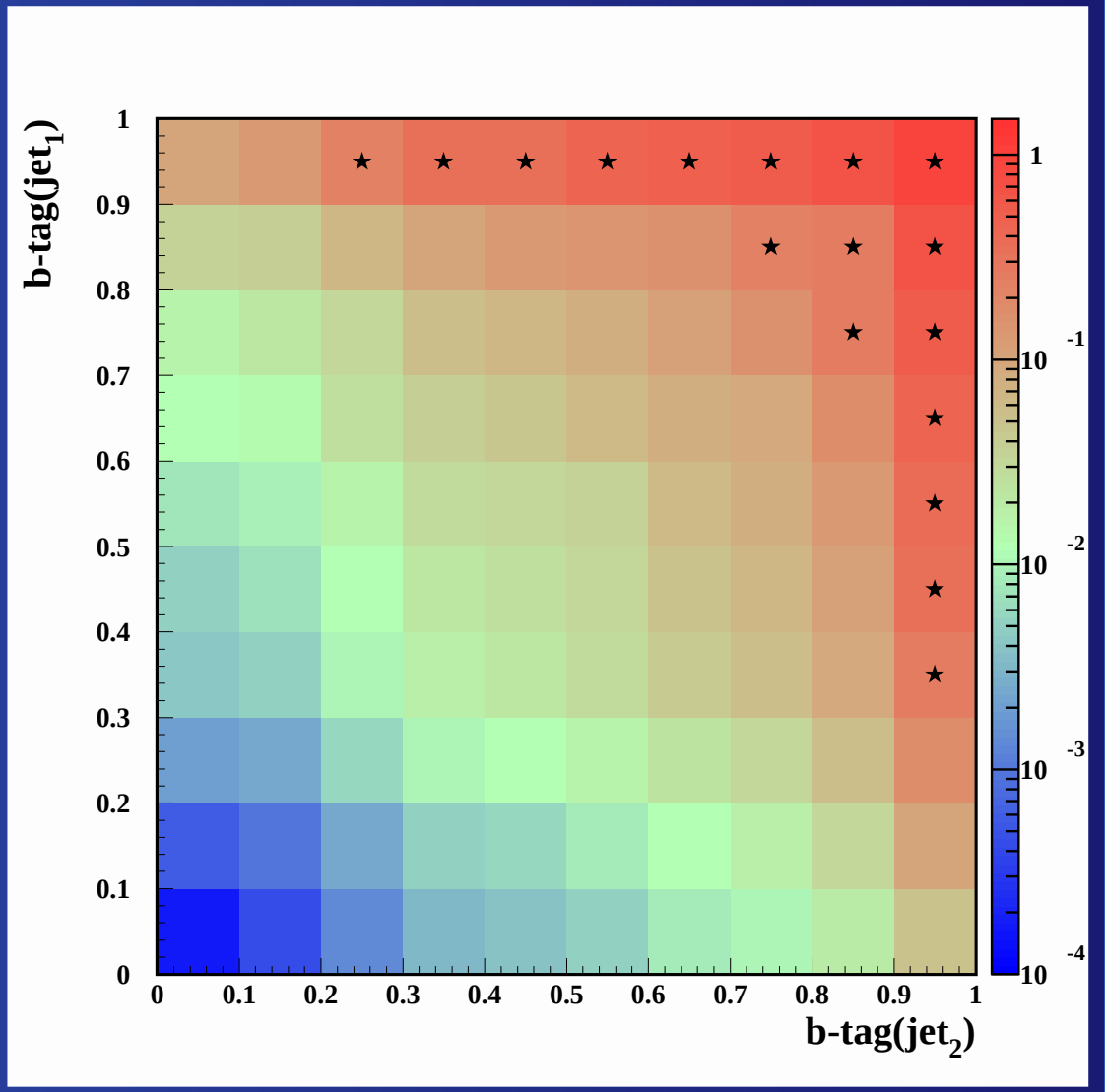
$\Rightarrow \varepsilon_h = 71\%$

$\varepsilon_{bb} = 64\%$

$\varepsilon_{cc} = 2.9\%$

$\varepsilon_{uds} = 0.11\%$

Tighter cuts are needed due to OE contribution



Reconstruction & Selection

Selection of $b\bar{b}$ events for $M_h = 120$ 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: $|\cos\theta_{jet}| < 0.725$
- $|P_z|/E < 0.1$

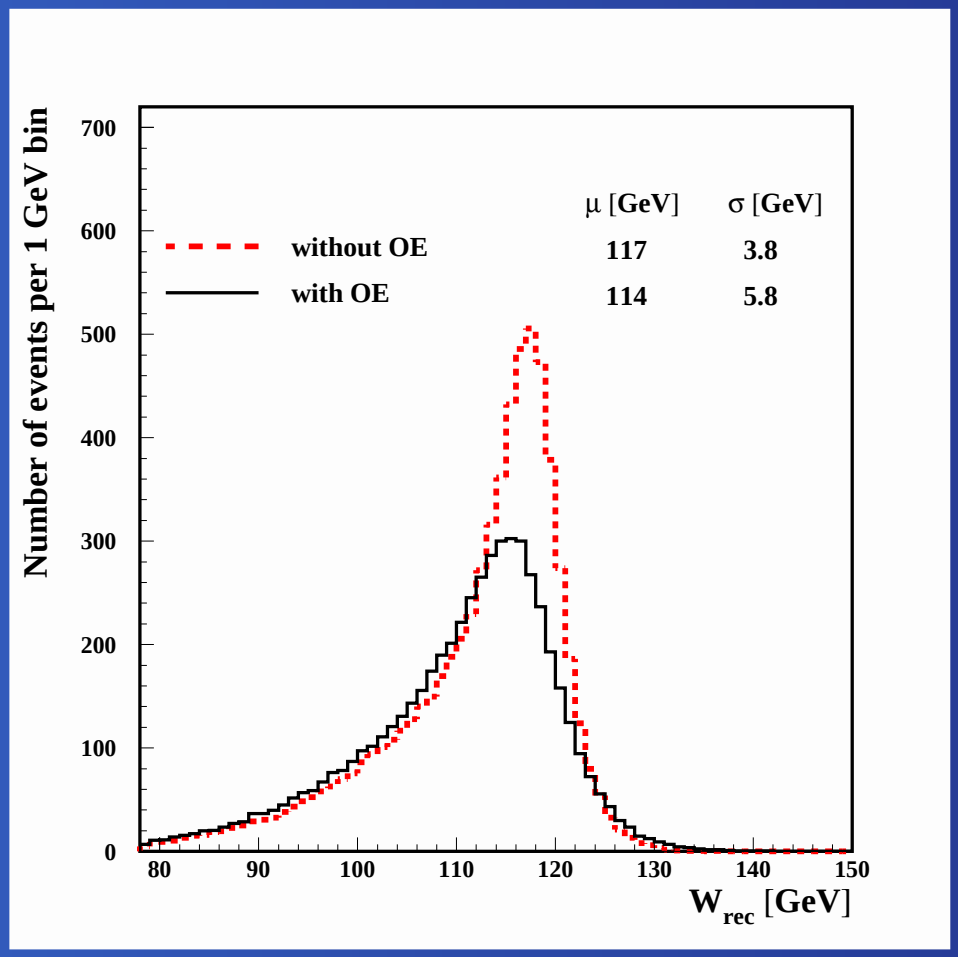
Rejection of W^+W^- events (for $M_h = 150, 160$ GeV):

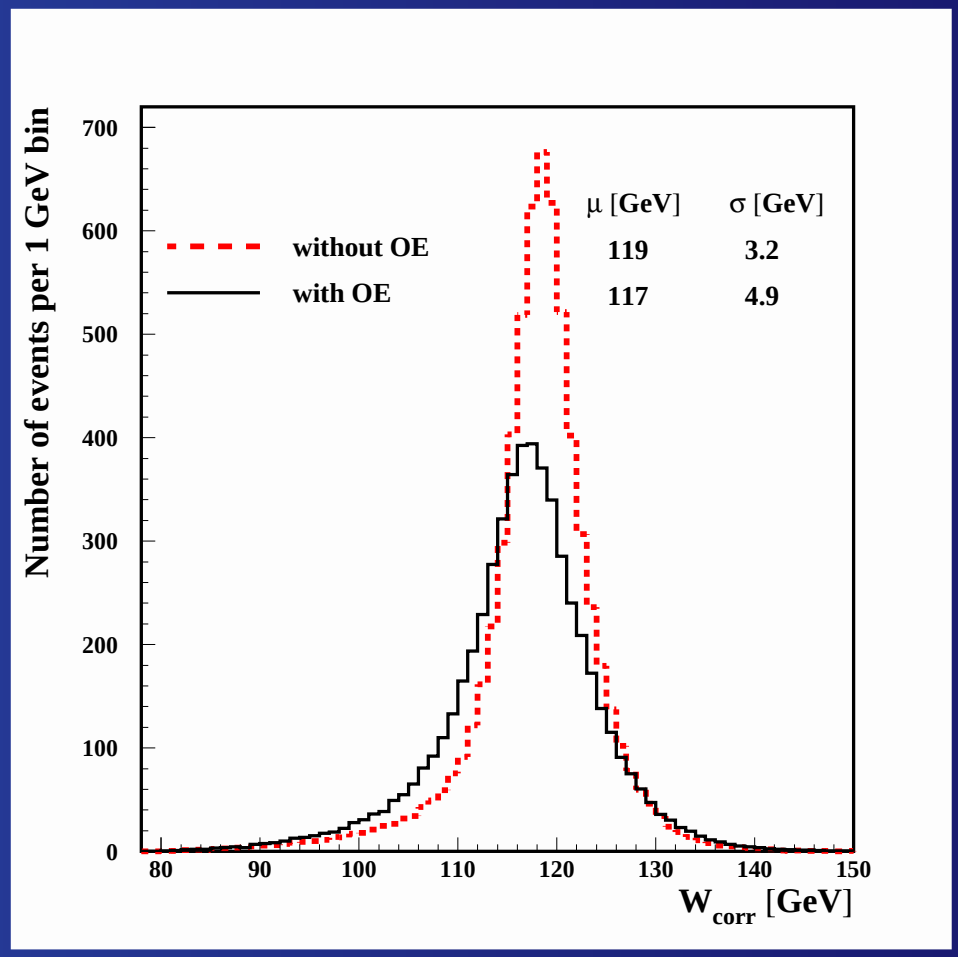
- for each jet: $M_{jet} < 70$ GeV
- energy below θ_{TC}: $E_{TC} < 90$ GeV
- for each jet: $N_{trk} \geq 4$

b-tagging: ZVTOP-B-HADRON-TAGGER (T. Kuhl)

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

SM, $M_h = 120$ GeV





Without OE: 6450 events
With OE : 5530 events

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

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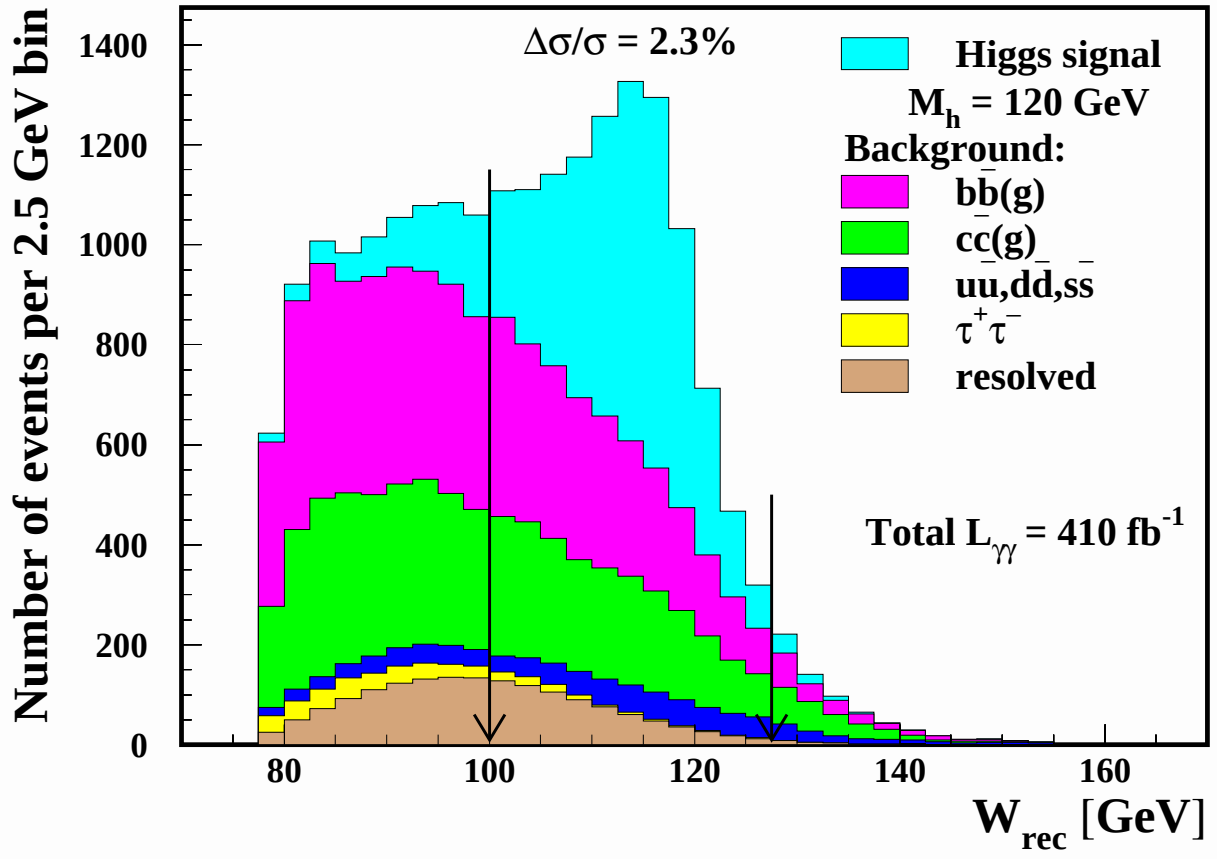
Gaussian fit from $\mu - 1.3\sigma$ to $\mu + 1.3\sigma$.

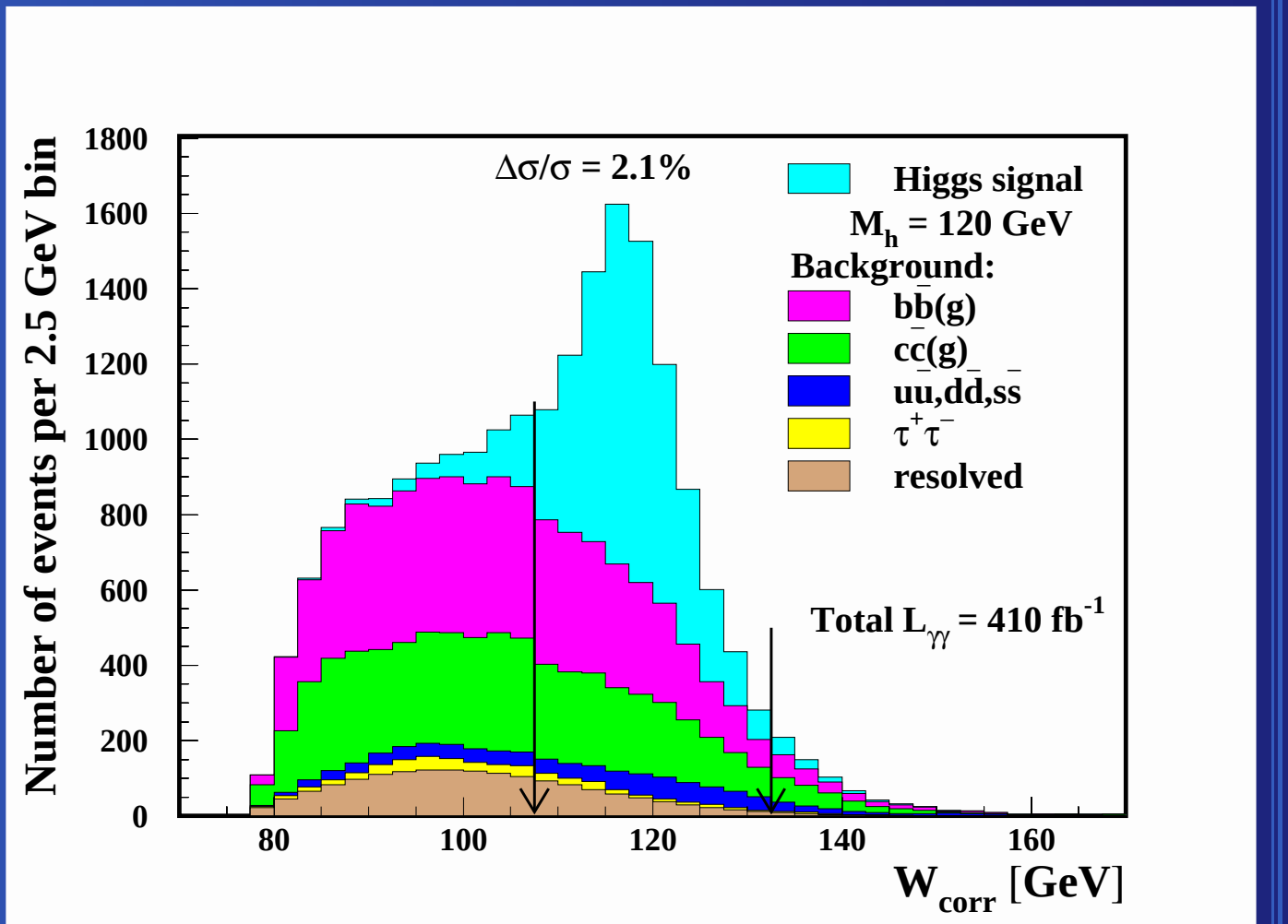
SM, $M_h = 120$ GeV

Final results

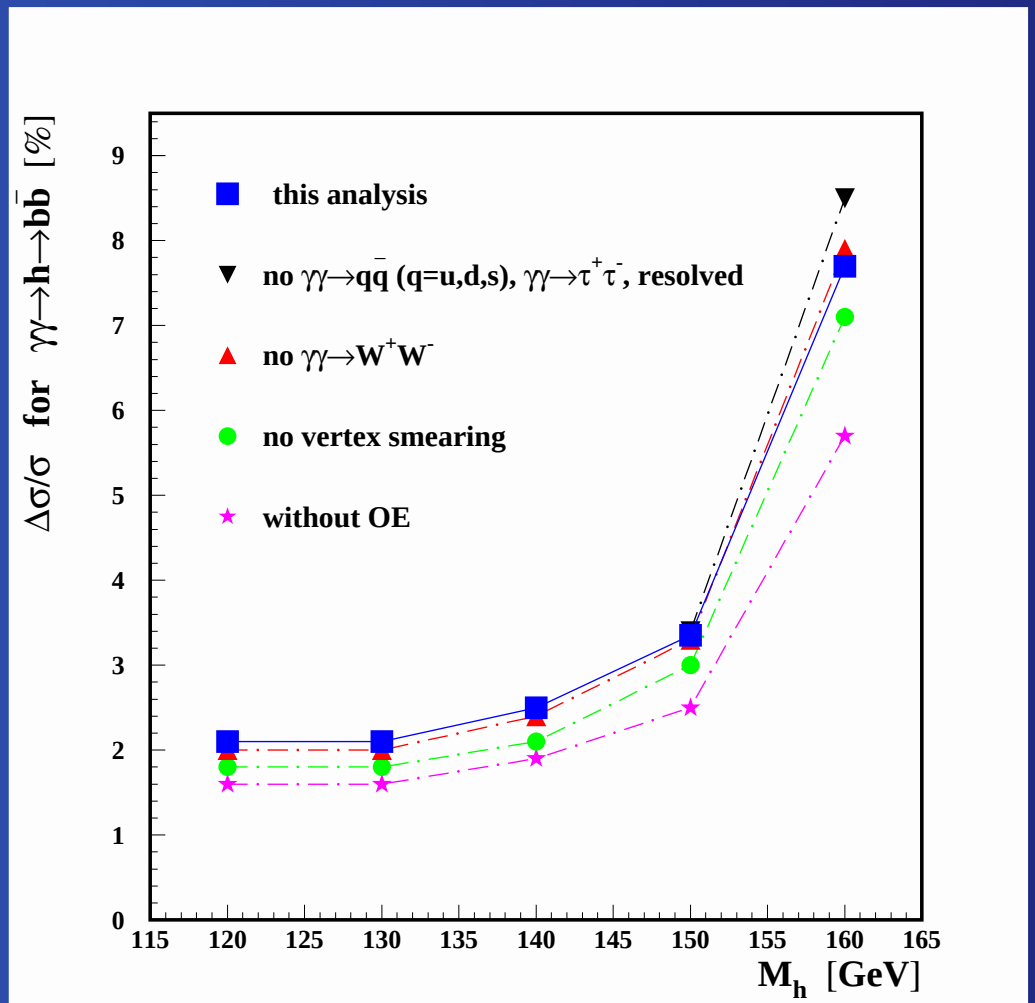


SM, $M_h = 120$ GeV

Final results



SM summary

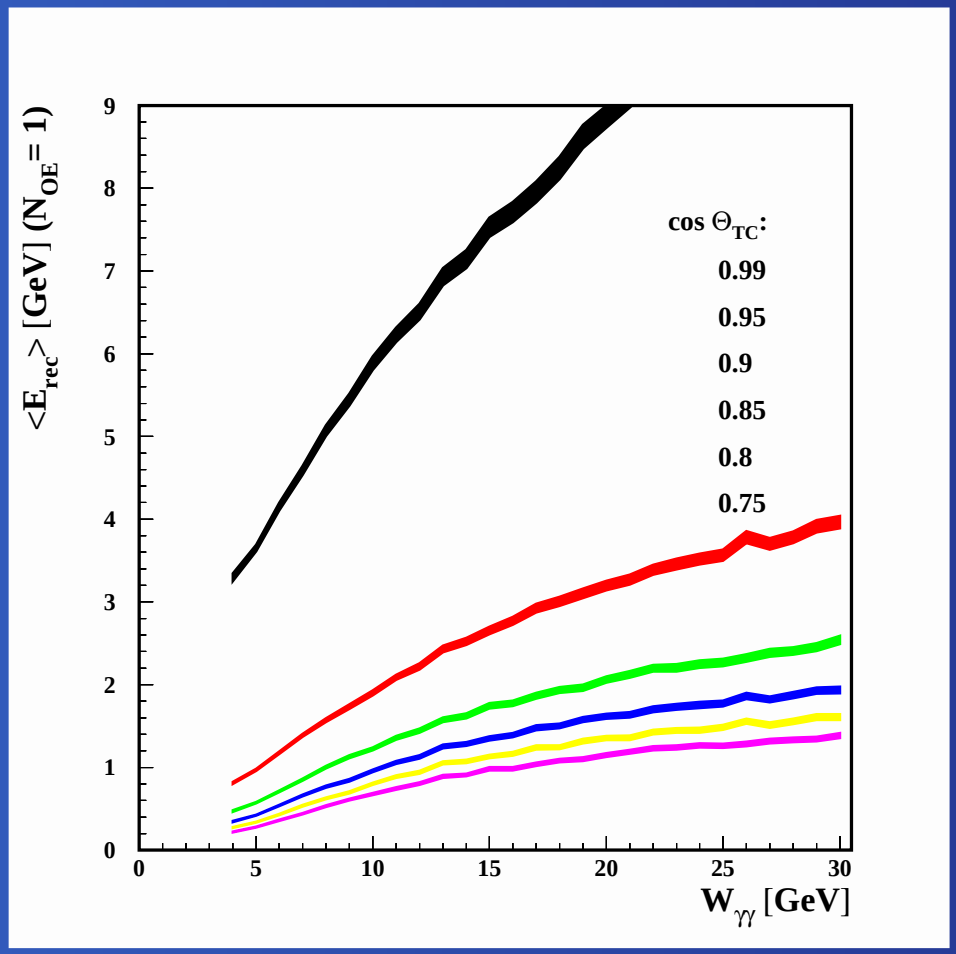


For $M_h = 150$, 160 GeV additional cuts to reduce $\gamma\gamma \to W^+W^-$.

$W_{\gamma\gamma} < 4$ GeV

Influence of $\gamma\gamma \to hadrons$ events with $W_{\gamma\gamma} < 4$ GeV

$< E_{rec} >$ per $\gamma\gamma \to hadrons$ event vs. $W_{\gamma\gamma}$



$\gamma\gamma \to hadrons$ events with $W_{\gamma\gamma} < 4$ GeV would add on average $E \sim 0.1$ GeV per bc if $\theta_{TC} \approx 0.85$.

$\sqrt{s_{ee}} = 210$ GeV.

Systematic uncertainties

Influence of higher order corrections checked (PS applied for $\gamma\gamma \to Q\bar{Q}(g)$): $\Delta\sigma/\sigma$ stable.
Influence of $\gamma\gamma \to hadrons$ with $W_{\gamma\gamma} < 4$ GeV: $\mathcal{O}(0.1)$ GeV per bc.

Background:
$1/2$ year run with lower beam energies
$\Rightarrow$ 3000 background events in mass window (2%)

Luminosity ($J_z = 0$): about 1% (V. Makarenko, K. Mönig, T. Shishkina, hep-ph/0306135)

Constrained maximum likelihood fit: 2.0% stat., 1.8% syst.

b-tagging (and other) efficiency:

- one year at $\sqrt{s_{ee}} = 419$ GeV $\Rightarrow$ 26000 $\gamma\gamma \to ZZ$ events, 5000 $Z \to b\bar{b} \Rightarrow$ 1.4%
- 3 months e^+e^- at $\sqrt{s_{ee}} = M_Z$ with the same detector: $\ll 1\%$!!!

Conclusions

- All important theoretical and experimental aspects of the measurement taken into account.
- Optimal cuts per mass point.
- *higgs*-tagging: cut on the ratio of $\gamma\gamma \to h \to b\bar{b}$ to $\gamma\gamma \to b\bar{b}(g)$, $c\bar{c}(g)$, $q\bar{q}$ ($q = u, d, s$) events.
- High precision for measurement of the SM Higgs boson despite $\gamma\gamma \to hadrons$ 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%.