# Determining $\tan\beta$ in $\tau\tau$ Fusion to SUSY Higgs Bosons at a Photon Collider

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## Methods to determine $\tan\beta$ for large values beyond $\tan\beta = 10$

(a) charginos / neutralinos $\Rightarrow$ $\cos 2\beta$ slope $\sim 1/\tan^3\beta$ insensitive — Choi et al

(b) $\tau$ polarization etc $\Rightarrow$ $\sim 10\%$ — Boos et al

(c) $bbH/A$, $H/A$ widths etc $\Rightarrow$ LHC/$300 fb^{-1}$ : 12 to 4% — Gunion et al

$\Rightarrow$ LC/$2,000 fb^{-1}$ : 5 to 3% at $M_A = 200$GeV

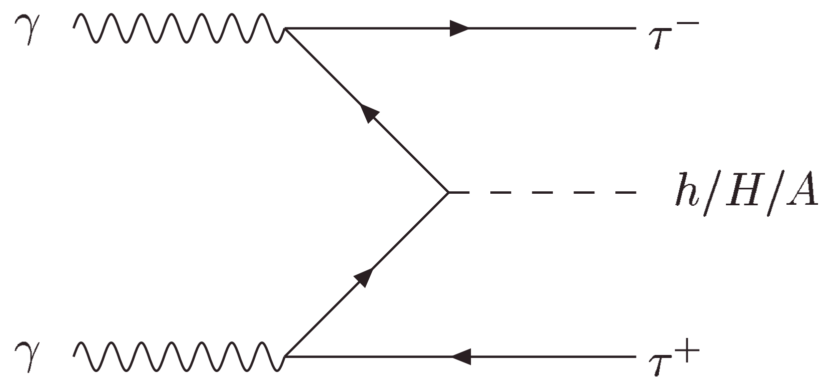
(d) LHC sim $H/A \to \tau\tau$ $\Rightarrow$ $30 fb^{-1}$ $\sim 20\%$ — Kinnunen et al

(e) $\gamma\gamma \to H/A \to b\bar{b}$ $\Rightarrow$ $\sim 4$ to $10\%$ [estimate] — see: Niezurawski et al and Velasco et al

Additional methods strongly required for precision analysis of $\tan\beta$

New method: Tauon fusion of Higgs $h/H/A/$ at $\gamma\gamma$ collider:

$$\gamma\gamma \to (\tau^+\tau^-)(\tau^+\tau^-) \to \tau^+\tau^- + h/H/A$$




couplings: for large $\tan\beta$

$$A\tau\tau = \tan\beta,\ H\tau\tau \simeq \tan\beta \quad \text{for } A, H \ \text{ heavy}$$
$$h\tau\tau \simeq \tan\beta \qquad A \ \text{ light}$$

Higgs decays: $h/H/A \to bb$ at 90% level $\Rightarrow$ SPS1b

SIGNAL: in equivalent-particle approximation

$$\sigma_{\gamma\gamma} \approx 2 \int dx_1 D_{\tau/\gamma}(x_1) \int dx_2 D_{\tau/\gamma}(x_2) \times \hat{\sigma}[\tau\tau \to \Phi; \hat{s} = x_1 x_2 s]$$

fusion coss-section:

$$\hat{\sigma}[\tau\tau \to \Phi; \hat{s}] \approx \frac{\pi m_\tau^2}{2v^2} \tan^2\beta \, \frac{m_\Phi \Gamma_\Phi/\pi}{(\hat{s}-m_\Phi^2)^2 + m_\Phi^2 \Gamma_\Phi^2}$$

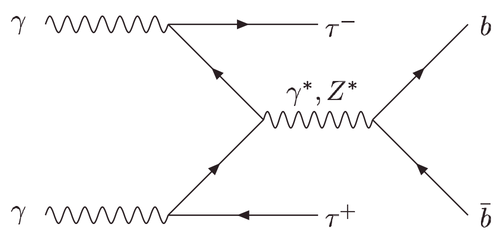
splitting function $\gamma \to \tau$ :

$$D_{\tau/\gamma}(x) = \frac{\alpha}{2\pi}[x^2 + (1-x)^2] \log\left(\frac{m_\Phi^2}{m_\tau^2}\right)$$

$\gamma\gamma$ cross section [narrow-width approximation]:

$$\sigma_{\gamma\gamma} \approx \frac{\pi m_\tau^2}{2v^2 s} \tan^2\beta \times 2 \int_\tau^1 \frac{dx}{x} D_{\tau/\gamma}(x) D_{\tau/\gamma}(\tau/x) \quad \text{with} \quad \tau = M_\Phi^2/s$$

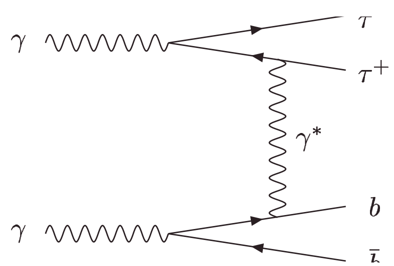
BKGDs: annihilation: $\tau^+\tau^- \rightarrow b\bar{b}$ and $b\bar{b} \rightarrow \tau^+\tau^-$ via $\gamma, Z$:




suppressed $\sim g^2$, except: $M_{bb} \sim M_Z$

$M_{\tau\tau} \sim M_Z$

diffractive: $\gamma\gamma \rightarrow (\tau\tau)(bb)$:




suppr. by event topology: $\tau\tau$ small inv mass / same direction

$bb$ ditto / close to $\gamma$ axes

ANALYSIS:

signal: including Higgs-bremsstrahlung off external legs

$\gamma\gamma \to \tau\tau + h/H/A[\to bb]$

bkgds: all non-Higgs 4-particle final states in $\gamma\gamma \to (\tau\tau)(bb)$

calculated by means of CompHEP

cuts: $M_{bb} = M_\Phi \pm \Delta$ with $\Delta = max[\Gamma_\Phi/2, \Delta_{ex}] \to \Delta_{ex} = 0.05 \times M_\Phi$

$\tau$ polar angle $\geq$ 130 mrad [shielding: dead mask]

$\tau$ energy $\geq$ 5 GeV

$\tau^+$ and $\tau^-$ in opposite directions along beam axis

efficiencies: $\epsilon_{bb} \sim 0.7$ and $\epsilon_{\tau\tau} \sim 0.5 \to \epsilon \sim 0.35$

RESULTS: $E_{e^-e^-} = 800/500$ GeV $\Rightarrow$ $E_{\gamma\gamma} = 600/400$ GeV
$\mathcal{L} = 200/100\ \text{fb}^{-1}$

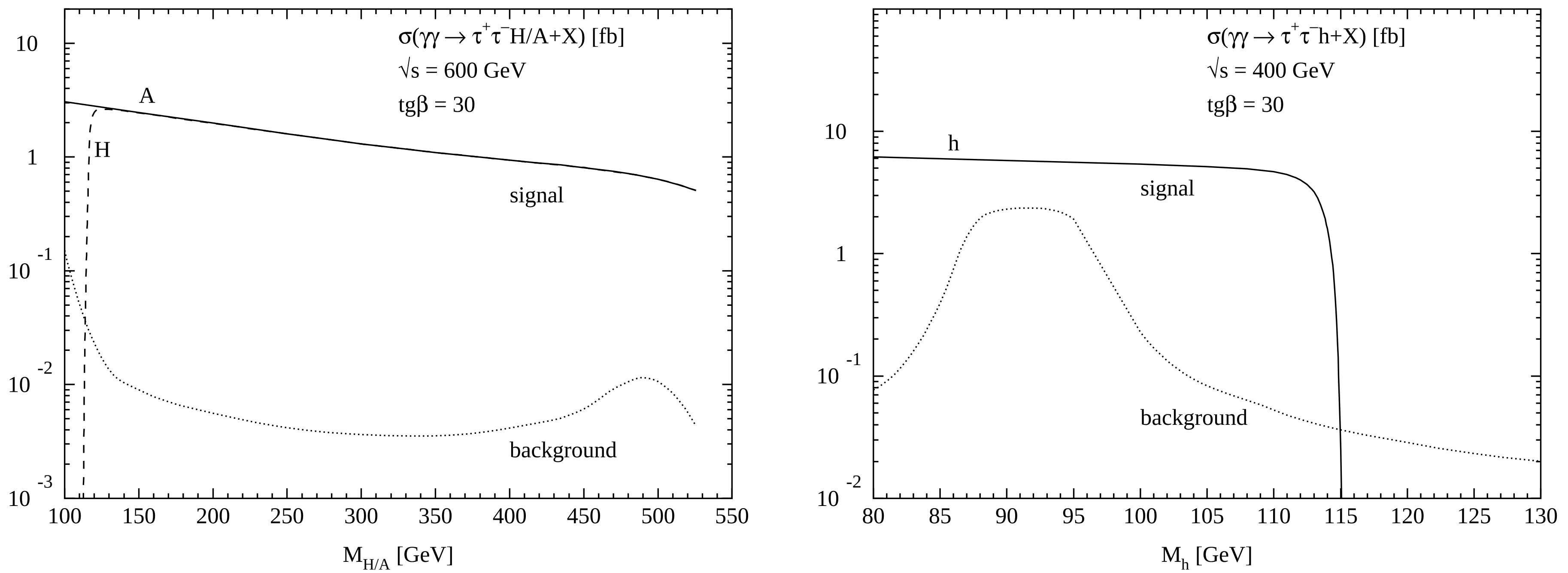
(a) Cross sections $h/H/A$: for $\tan\beta = 10$ to 50

$\sigma(H/A) = 3$ to 1 fb for $M_{A/H} = 100$ to 500 GeV at $\tan\beta = 30$

$\sigma(h) = 5$ fb for $M_h = 110$ GeV at $\tan\beta = 30$

(b) Errors $\Leftarrow$ matching and improving on alternative methods:

| | $E_{\gamma\gamma} = 400$ GeV, $\mathcal{L} = 100\ \text{fb}^{-1}$ | | | $E_{\gamma\gamma} = 600$ GeV, $\mathcal{L} = 200\ \text{fb}^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|---|
| $M_{\text{Higgs}}$ [GeV] | $A \oplus h$ 100 | $A \oplus H$ 200 | 300 | $A \oplus h$ 100 | $A \oplus H$ 200 | 300 | 400 | 500 |
| $\tan\beta$ | I | II | III | IV | V | VI | VII | VIII |
| 10 | 8.4% | 10.7% | 13.9% | 8.0% | 9.0% | 11.2% | 13.2% | 16.5% |
| 30 | 2.6% | 3.5% | 4.6% | 2.4% | 3.0% | 3.7% | 4.4% | 5.3% |
| 50 | 1.5% | 2.1% | 2.7% | 1.5% | 1.8% | 2.2% | 2.6% | 3.2% |



σ(γγ → τ+τ− H/A+X) [fb]
√s = 600 GeV
tgβ = 30
A
H
signal
background
10
1
10 -1
10 -2
10 -3
100
150
200
250
300
350
400
450
500
550
M_{H/A} [GeV]
σ(γγ → τ+τ− h+X) [fb]
√s = 400 GeV
tgβ = 30
h
signal
background
10
1
10 -1
10 -2
80
85
90
95
100
105
110
115
120
125
130
M_h [GeV]

## SUMMARY:

$$\Delta \tan\beta \simeq 0.9 \text{ to } 1.3 \text{ uniform in } \tan\beta$$
$$\text{for all } M_A \text{ up to kin. limit}$$

Results are encouraging enough to start experimental simulations including detector effects, overlaying events, optimized cuts, etc.