Detecting and Studying Higgs Bosons in Two-Photon Collisions at a Linear Collider

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Collaborators: D. Asner, J. Gronberg
Reference: hep-ph/0110320

Other recent papers on topic:
S. Soldner-Rembold, G. Jikia: hep-ex/0101056
M.M. Muhlleitner, M. Kramer, M. Spira, P.M. Zerwas: hep-ph/0101083

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Outline

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- Naive Luminosities vs. Realistic Luminosities
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- **Naive Luminosities vs. Realistic Luminosities**
- **Light Higgs Bosons**
- **Heavy Higgs Bosons**
- **CP Determination**

- **Employ CAIN Monte Carlo for luminosity — includes many non-linear effects $\Rightarrow$ big impact on strategy.**

- **The laser will not have an adjustable wavelength. We have adopted the LLNL standard of 1 micron.**

- $\Rightarrow x \simeq \frac{4E_{\rm beam}\omega_{\rm laser}}{m^2c^4}$ **will vary according to the machine energy.**

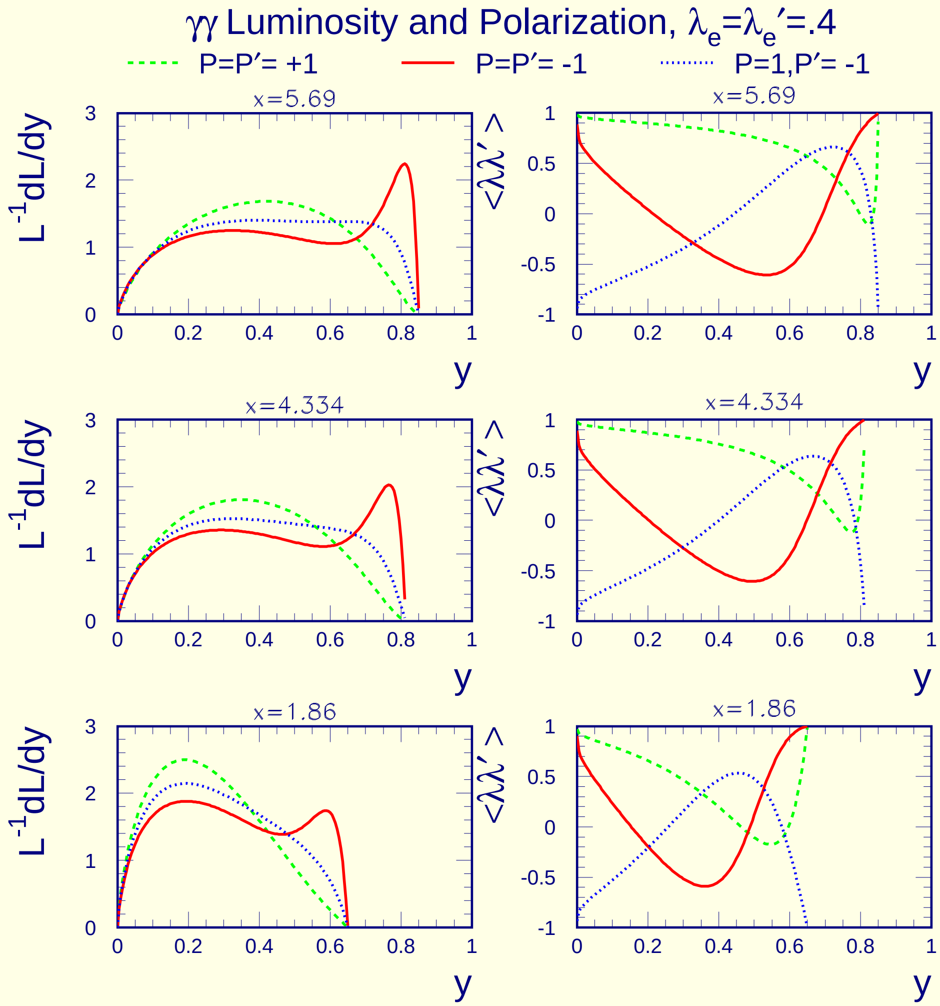
  Tripler option, laser wavelength $=1/3\ \mu$ **is only flexibility, but useful.**

  For $P\lambda_e = P'\lambda'_e < 0$, $\sqrt{s} = 206\ \mathrm{GeV}$, $x \simeq 1.86$ **and** $\sqrt{s} = 160\ \mathrm{GeV}$, $x \simeq 4.33$ **both** $\Rightarrow$ **peak at** $E_{\gamma\gamma} = 120\ \mathrm{GeV}$.

  $\sqrt{s} = 630\ \mathrm{GeV}$, $x \simeq 5.69 \Rightarrow$ **peak at** $500\ \mathrm{GeV}$.

- **Want highest possible** λ_e, λ'_e **for maximal peaking. Current advice: use** $\lambda_e = 0.4$ **(80% pol.).**

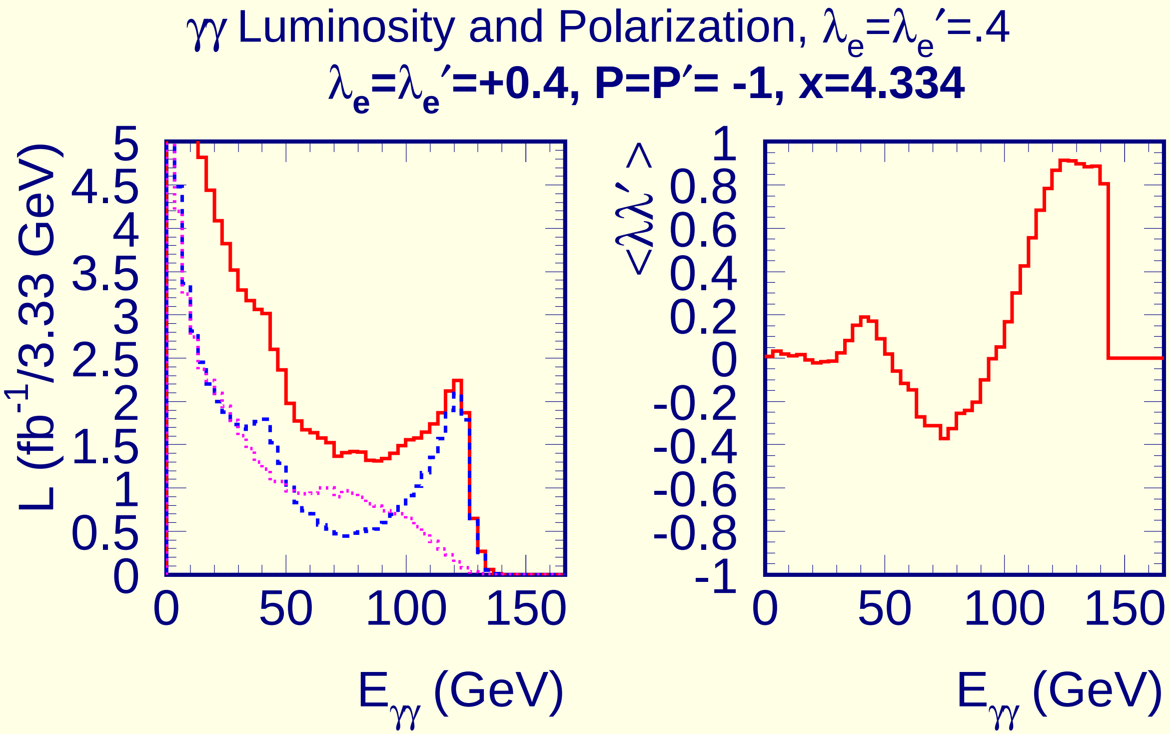
LUMINOSITIES



Naive Luminosity Expectations for $\lambda_e = \lambda_e' = 0.4$ vs. $y = \frac{E_{\gamma\gamma}}{E_{ee}}$.

Note the peak at high y when $P\lambda_e, P'\lambda_e' < 0$. At the peak, $\langle\lambda\lambda'\rangle$ is bigger for bigger λ_e, λ_e'.

Real Life Luminosities



CP-IP sep. = 1mm; $\sqrt{s} = 160$ GeV; flat beam (round → $\times 2$, but not consistent with running parasitic to e^-e^-.

Note: the good peak requires tripler (⇒ 1/3 micron wavelength).

(a) CAIN predictions for the $dL/dE_{\gamma\gamma}$ for circularly polarized [case (II)] photons assuming a 10^7 sec year, $\sqrt{s} = 160$ GeV, 80% electron beam polarization, and a 1.054/3 micron laser wave length, after including beamstrahlung and other effects. The blue (purple) curve shows $dL/dE_{\gamma\gamma}$ for the $J_z = 0$ ($J_z = 2$) two-photon configuration. (b) the corresponding value of $\langle\lambda\lambda'\rangle$.

- $\Delta\mathcal{L}_{\gamma\gamma}$ at $E_{\gamma\gamma} = 120~\mathrm{GeV} \Rightarrow d\mathcal{L}/dE_{\gamma\gamma} \sim 0.66\mathrm{fb}^{-1}/~\mathrm{GeV}$ per 10^7 sec year.

- The corresponding luminosity at TESLA could be as much as a factor of 2 larger due to higher repetition rate and larger charge per bunch.

- To avoid low-$E_{\gamma\gamma}$ tail, need much larger CP-IP separation and/or a high-field sweeping magnet.

- ACFA report considered a CP-IP separation of 1 cm (vs. 1 mm) and a 3 Tesla (vs. 1 Tesla) sweeping magnet.

  Disadvantage: substantially lower value for $d\mathcal{L}/dE_{\gamma\gamma}$ at the peak, at least for the bunch charge, repetition rate and spot size employed.

  We have $d\mathcal{L}/dE_{\gamma\gamma} \sim 0.66\mathrm{fb}^{-1}/~\mathrm{GeV}$ per year, as compared to $\sim 0.13\mathrm{fb}^{-1}/~\mathrm{GeV}$ per year for the ACFA report choices.

GENERALITIES

The rate for $\gamma\gamma$ production of any final state X consisting of two jets is given by

$$N(\gamma\gamma \to \widehat{h} \to X) =$$

$$\sum_{\lambda=\pm1,\lambda'=\pm1} \int dz dz' dz_{\theta^*} \frac{d\mathcal{L}_\gamma^{\lambda}(\lambda_e, P, z)}{dz} \frac{d\mathcal{L}_\gamma^{\lambda'}(\lambda_e', P', z')}{dz'} A(z, z', z_{\theta^*}) \times$$

$$\left\{ \frac{1+\lambda\lambda'}{2} \frac{d\sigma_{J_z=0}}{dz_{\theta^*}}(zz's, z_{\theta^*}) + \frac{1-\lambda\lambda'}{2} \frac{d\sigma_{J_z=\pm2}}{dz_{\theta^*}}(zz's, z_{\theta^*}) \right\}. \qquad (1)$$

Higgs Signal:

$$\frac{d\sigma_{J_z=0}}{dz_{\theta^*}}(s', z_{\theta^*}) = \frac{8\pi\Gamma(h \to \gamma\gamma)\Gamma(h \to X)}{(s' - m_h^2)^2 + [\Gamma_h^{\rm tot}]^2 m_h^2}, \qquad (2)$$

Background:

$$\frac{d\sigma_{J_z=0}}{dt'}(s',t',u') = \frac{12\pi\alpha^2 Q_q^4}{s'^2}\frac{m_q^2(s'-2m_q^2)}{\hat{t}^2\hat{u}^2} \ll \tag{3}$$

$$\frac{d\sigma_{J_z=\pm 2}}{dt'}(s',t',u') = \frac{12\pi\alpha^2 Q_q^4}{\hat{s}'^2}\frac{(\hat{t}\hat{u}-m_q^2 s')(\hat{t}^2+\hat{u}^2-2m_q^2 s')}{\hat{t}^2\hat{u}^2} \tag{4}$$

In a common approximation, the dependence of the acceptance and cuts on z and z' is ignored and one writes

$$\sum_{\lambda,\lambda'}\int dz dz' \frac{d\mathcal{L}_\gamma^\lambda(\lambda_e,P,z)}{dz}\frac{d\mathcal{L}_\gamma^{\lambda'}(\lambda_e',P',z')}{dz'}[1,\lambda\lambda']$$

$$= \int dy \frac{d\mathcal{L}_{\gamma\gamma}(\lambda_e,\lambda_e',P,P',y)}{dy}[1,\langle\lambda\lambda'\rangle(y)]\,, \tag{5}$$

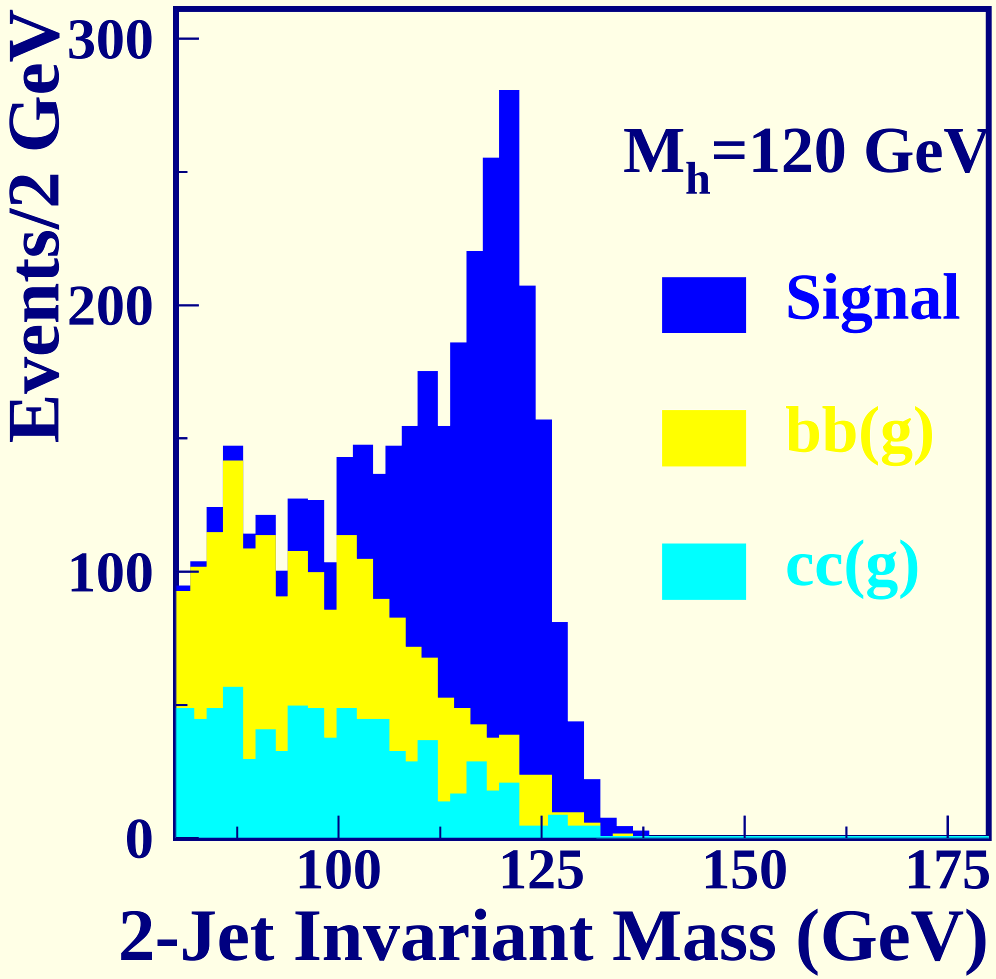
where $y = E_{\gamma\gamma}/\sqrt{s} = \sqrt{s'}/\sqrt{s} = zz'$. In this approximation, one obtains

$$N(\gamma\gamma\to h\to X) = \frac{4\pi^2\Gamma(h\to\gamma\gamma)B(h\to X)(1+\langle\lambda\lambda'\rangle(y))}{\sqrt{s}m_h^2}\frac{d\mathcal{L}_{\gamma\gamma}}{dy}\bigg|_{y=m}$$

$$\equiv I_\sigma(\gamma\gamma \to h \to X) \qquad \left[(1+\langle\lambda\lambda'\rangle)\frac{d\mathcal{L}_{\gamma\gamma}}{dE_{\gamma\gamma}}\right]_{E_{\gamma\gamma}=m_h} \frac{\int_{-1}^{1} dz_{\theta^*} A(z_{\theta^*})}{2},$$

where we have assumed that the resolution, $\Gamma_{\rm res}$, in the final state invariant mass m_X is such that $\Gamma_{\rm res} \gg \Gamma_h^{\rm tot}$ and that $\frac{d\mathcal{L}}{dE_{\gamma\gamma}}$ does not change significantly over an interval of size $\Gamma_h^{\rm tot}$.

THE SM HIGGS BOSON



Higgs signal and background, using tripler, $\sqrt{s} = 160$ GeV, $\epsilon_b = 0.7$, $\epsilon_c = 0.035$, $|\cos\theta^*| < 0.5$.

We find excellent signal; 1 10^7 sec year $\Rightarrow$ 2.9% measurement of $N(\gamma\gamma \to h_{\rm SM} \to b\overline{b})$.

Our analysis is similar, but not identical, to that of Jikia. Both employ JETSET fragmentation, but we employ Durham $y = 0.02$ for defining the two-jet component. Further, we employ the event mixture predicted by PYTHIA (passed through JETSET), the LC Fast Monte Carlo detector simulation within ROOT, which includes calorimeter smearing and detector configuration. The signal is generated using PANDORA plus PYTHIA/JETSET. Cuts:

- Only tracks and showers with $|\cos\theta| < 0.9$ in the laboratory frame are accepted.
- Track momentum $>$ 200 MeV and shower energy $>$ 100 MeV.
- Only (reconstructed) two jet events are retained.
- Require back-to-back in three dimensions: $|p_i^1 + p_i^2| < 12~\mathrm{GeV}$ for $i = x, y, z$.
- $|\cos\theta^*| < 0.5$, θ^* in the $\gamma\gamma$ center of mass.

Note: Since $\langle\lambda\lambda'\rangle$ is not really close to 1, $J_z = \pm 2 \Rightarrow$ dominant background; $\Rightarrow$ fancy radiative corrections not a big effect. They were not included.

CP DETERMINATION FOR SM HIGGS

For a Higgs boson of pure CP, Higgs cross section $\propto$

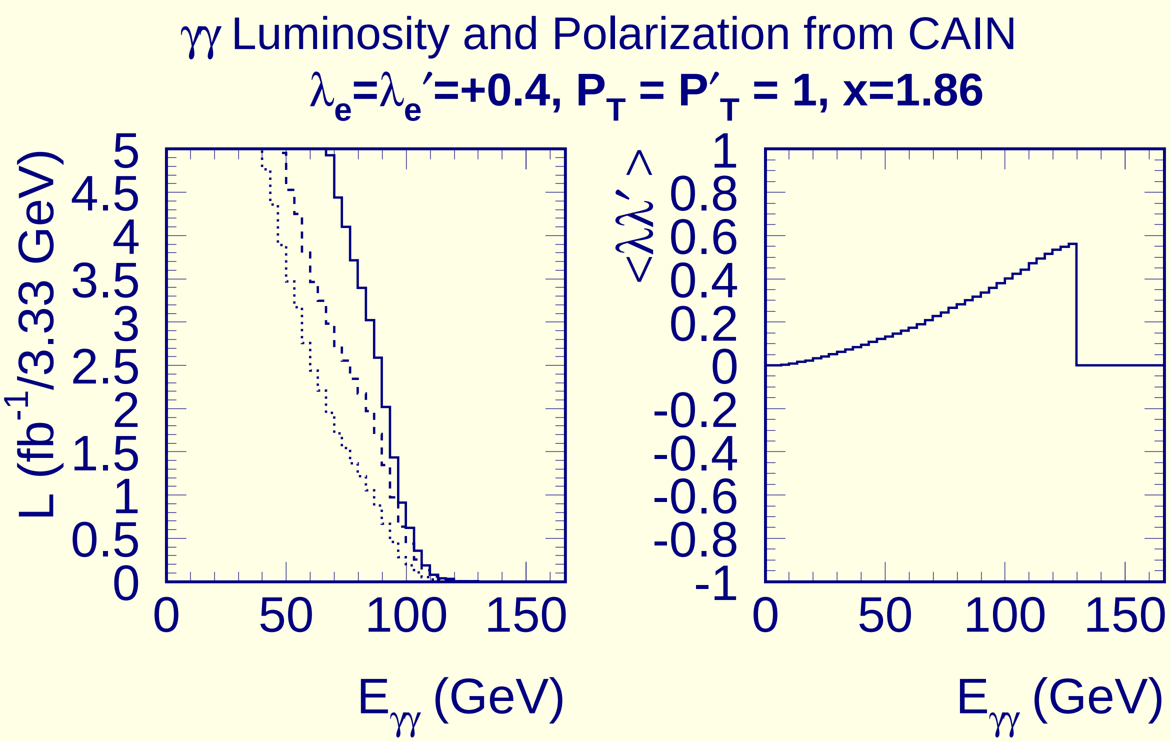
$$\frac{d\mathcal{L}}{dE_{\gamma\gamma}}\left(1+\langle\lambda\lambda'\rangle+\mathcal{CP}\langle\lambda_T\lambda_T'\rangle\cos 2\delta\right) \tag{7}$$

- $\mathcal{CP}=+1$ ($\mathcal{CP}=-1$) for a pure CP-even (CP-odd) Higgs boson.
- δ is the angle between the transverse polarizations of the laser photons.
- asymmetry for parallel vs. perpendicular orientation of the transverse linear polarizations in the absence of background

$$\mathcal{A}\equiv\frac{N_{\parallel}-N_{\perp}}{N_{\parallel}+N_{\perp}}\propto\frac{\mathcal{CP}\langle\lambda_T\lambda_T'\rangle}{1+\langle\lambda\lambda'\rangle}\,, \tag{8}$$

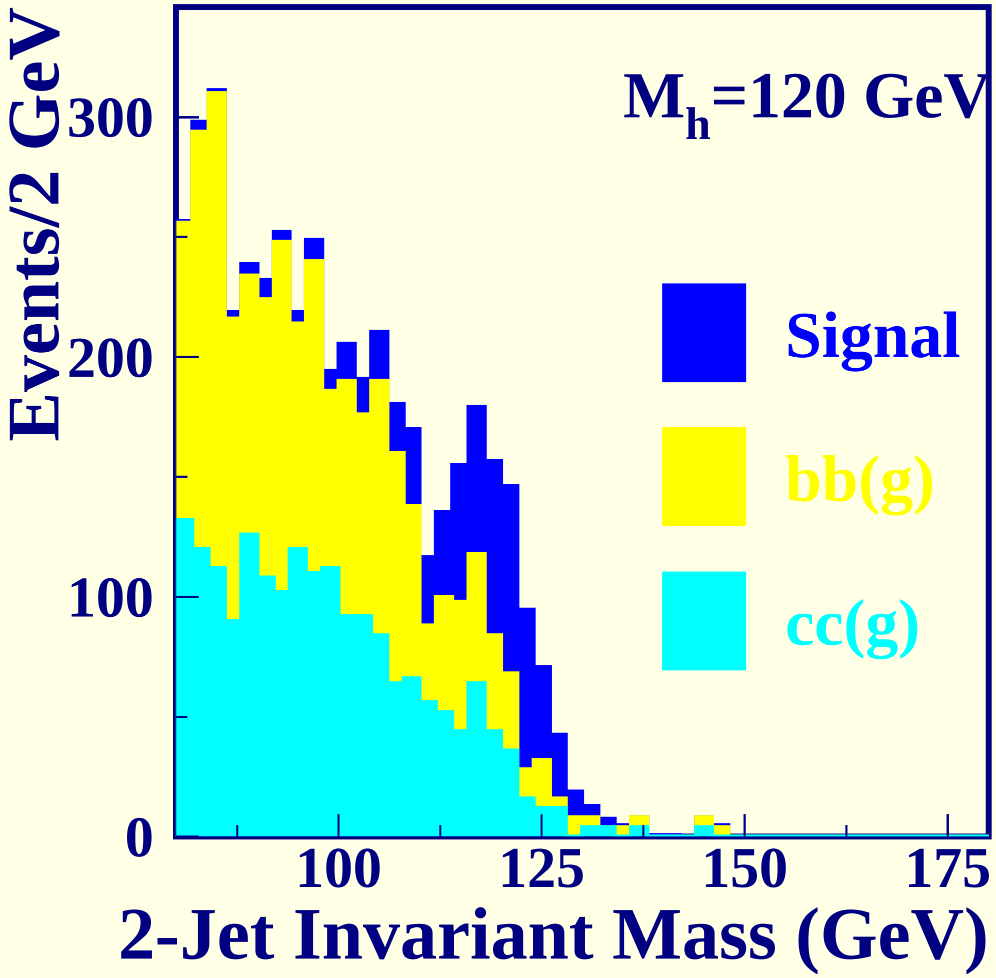
  which is positive (negative) for a CP-even (odd) state.
- The $b\overline{b}(g)$ and $c\overline{c}(g)$ backgrounds result in additional contributions to the $N_{\parallel}+N_{\perp}$ denominator.

Luminosities and $\langle\lambda\lambda'\rangle$ for transverse pol.



CP-IP sep. = 1mm; $\sqrt{s} = 206$ GeV; flat beam 100% transverse laser polarization

(a) CAIN predictions for the $dL/dE_{\gamma\gamma}$ for linearly polarized photons assuming a 10^7 sec year, $\sqrt{s} = 206$ GeV, 80% electron beam polarization, and a 1.054 micron laser wave length. The blue (purple) curve shows $dL/dE_{\gamma\gamma}$ for the $J_z = 0$ ($J_z = 2$) two-photon configuration.
(b) the corresponding value of $\langle\lambda\lambda'\rangle = (L_{J_z=0} - L_{J_z=2})/(L_{J_z=0} + L_{J_z=2})$.
Note: $\langle\lambda_T\lambda'_T\rangle \sim \langle\lambda\lambda'\rangle$ (accidentally) for this setup.



Higgs signal and background for transversely polarized photons, $\sqrt{s} = 206$ GeV, $\epsilon_b = 0.7$, $\epsilon_c = 0.035$, $|\cos\theta^*| < 0.5$.
1/2 yr $\perp$ and 1/2 yr $\|$.

We find good signal; 1 10^7 sec year $\Rightarrow$ 7.9% measurement of $N(\gamma\gamma \to h_{\rm SM} \to b\overline{b})$ and $\delta\mathcal{CP}/\mathcal{CP} \sim 0.11$ check of $\mathcal{CP} = +1$.

The error computation is as follows:

- **We have only 60% linear polarization for the colliding photons for $E_{\gamma\gamma} \sim 120~\mathrm{GeV}$,**

  $\Rightarrow N_{\|} \sim 180[1+(0.6)^2]+220 \sim 465$ and $N_{\perp} \sim 180[1-(0.6)^2]+220 = 335$ (for $\perp$ orientation there is no extra contribution in the case of the CP-even SM Higgs boson).

- **For these numbers, $\mathcal{A} = 130/800 \sim 0.16$. The error in $\mathcal{A}$ is $\delta\mathcal{A} = \sqrt{N_{\|}N_{\perp}/N^3} \sim 0.017$ ($N \equiv N_{\|} + N_{\perp}$), yielding $\frac{\delta\mathcal{A}}{\mathcal{A}} = \frac{\delta\mathcal{CP}}{\mathcal{CP}} \sim 0.11$.**

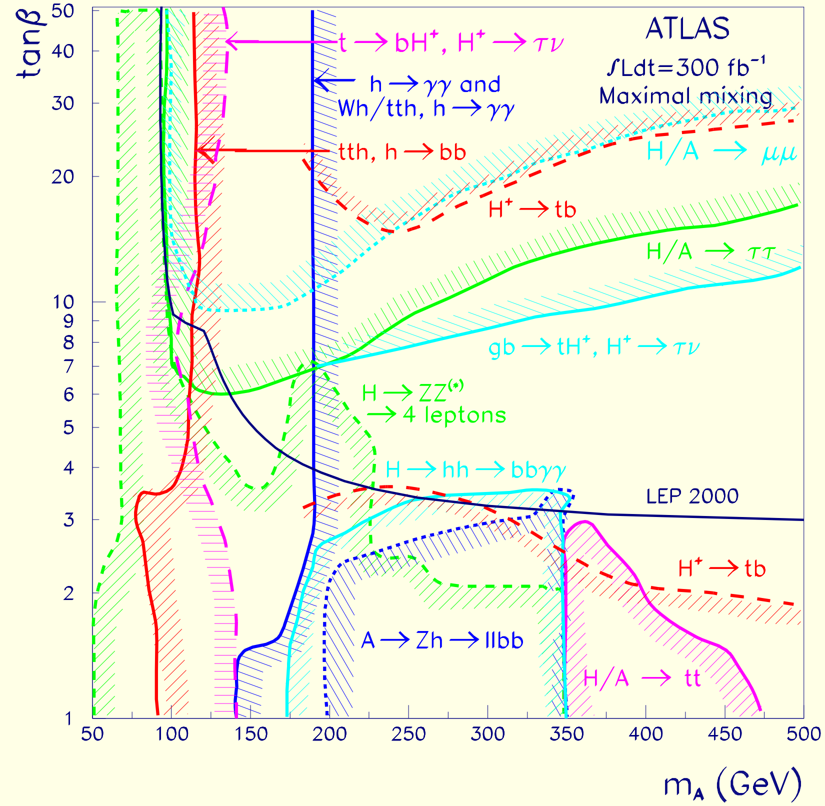
THE HEAVY MSSM H^0 and A^0

- Imagine SUSY has been discovered so we would expect that the two doublet MSSM Higgs sector must be present (or some extension thereof).

- It is very possible that only the h^0 of the MSSM will be discovered in normal LC e^+e^- collisions and LHC operation.
  - $\sqrt{s}$ at the LC is $< m_{A^0} + m_{H^0} \sim 2m_{A^0}$ and $< 2m_{H^\pm} \sim 2m_{A^0}$, so the pair processes are kinematically forbidden.
  - $m_{A^0} \gtrsim \sqrt{s} - 2m_{A^0}$ so that $WW \to A^0A^0, H^0H^0$ at LC is kinematically forbidden or event rate suppressed.
  - The $[m_{A^0}, \tan\beta]$ values are such that the LHC cannot find the $H^0, A^0, H^\pm$.

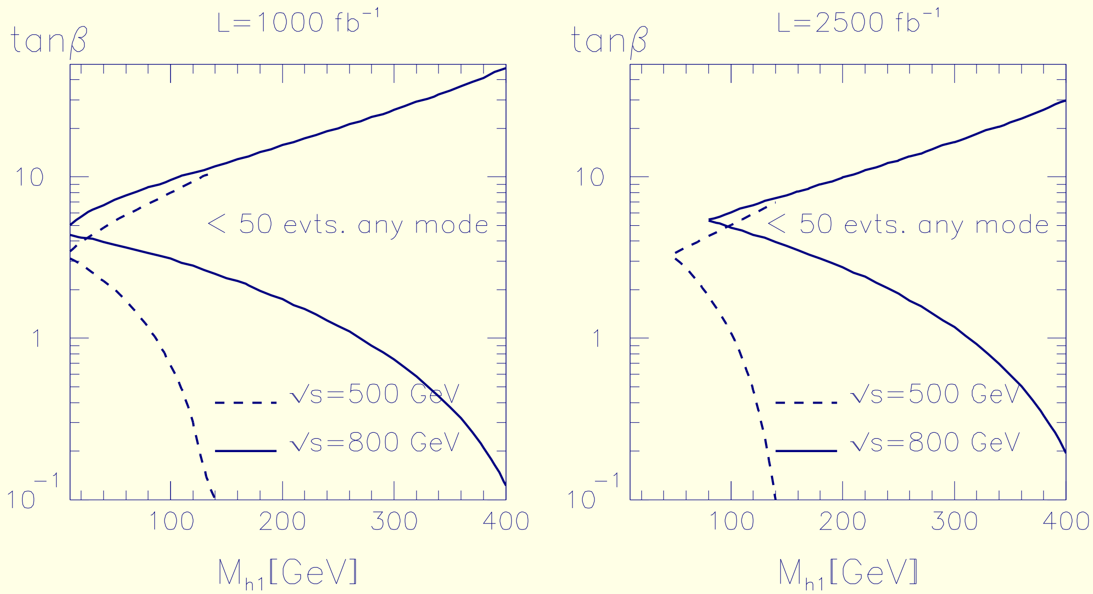
- $\Rightarrow \gamma\gamma$ collisions would give the best chance for H^0, A^0 detection

There is a region starting at $m_{A^0} \sim 200$ GeV at $\tan\beta \sim 6$, widening to $2.5 < \tan\beta < 15$ at $m_{A^0} = 500$ GeV for which the LHC cannot directly observe any of the heavy MSSM Higgs bosons.



5σ discovery contours for MSSM Higgs boson detection in various channels are shown in the $[m_{A^0}, \tan\beta]$ parameter plane, assuming maximal mixing and an integrated luminosity of $L = 300\mathrm{fb}^{-1}$ for the ATLAS detector. This figure is preliminary.

This wedge is not covered at the LC.
In fact, the LC wedge for $t\bar{t}+H^0,A^0$ and $b\bar{b}+H^0,A^0$ is even larger.
Further, $e^+e^- \to ZH^0H^0$ and $e^+e^- \to ZA^0A^0$ only cover up to $m_{A^0} = 150$ GeV ($m_{A^0} = 250$ GeV) at $\sqrt{s} = 500$ GeV ($\sqrt{s} = 800$ GeV) using 20 events in $L = 1$ ab^{-1}.



For $\sqrt{s} = 500$ GeV (dashes) and $\sqrt{s} = 800$ GeV (solid) the maximum and minimum $\tan\beta$ values between which $t\bar{t}h$ and $b\bar{b}h$ final states both have fewer than 50 events for decoupled h (a) $L = 1000\mathrm{fb}^{-1}$ or (b) $L = 2500\mathrm{fb}^{-1}$.

There are two scenarios:

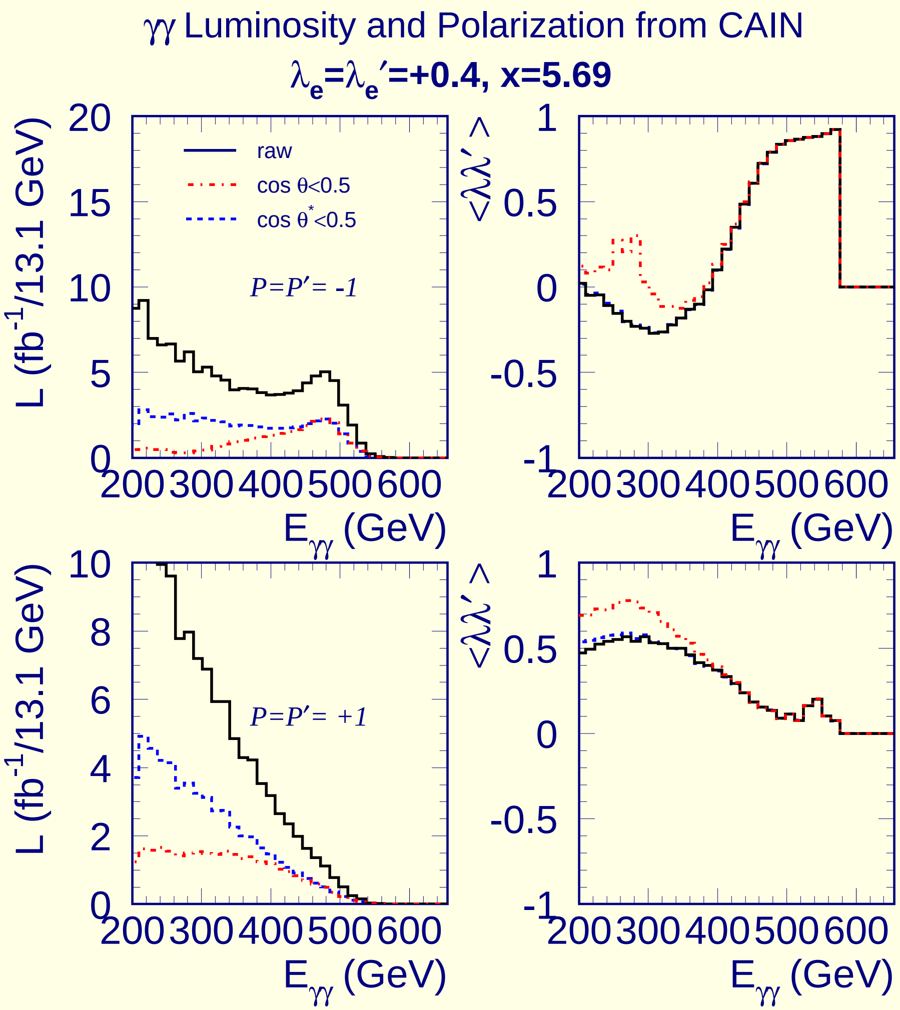
- **We have some constraints from precision h^0 measurements ($e.g.$ from $\Gamma(h^0 \to b\bar{b})$) that determine $m_{H^0} \sim m_{A^0}$ within 50 GeV.**
  $\Rightarrow$ choose $\sqrt{s}$ and peaked luminosity spectrum with peak near this mass.
- **We do not have such constraints. In particular: are there reasonable scenarios for which decoupling ($\cos^2(\beta - \alpha) = 0$) happens essentially independent of m_{A^0} (Yes!).**
  No deviation seen $\Rightarrow$ (a) scan or (b) run at high energy and use broad spectrum approach. To cover interesting region, must do both.

We shall examine what happens if we operate at $\sqrt{s} = 630$ GeV ($\to$ $x = 5.69$ for 1 micron laser wavelength).

The luminosity peak for $\lambda_e = \lambda'_e = 0.4$ and $P = P' = -1$ is at about 500 GeV with good $\langle\lambda\lambda'\rangle$ and $\mathcal{L}$ down to 450 GeV.

For $P = P' = +1$, get broad spectrum sensitivity in region of $m_{A^0} \sim 350 - 400$ GeV.

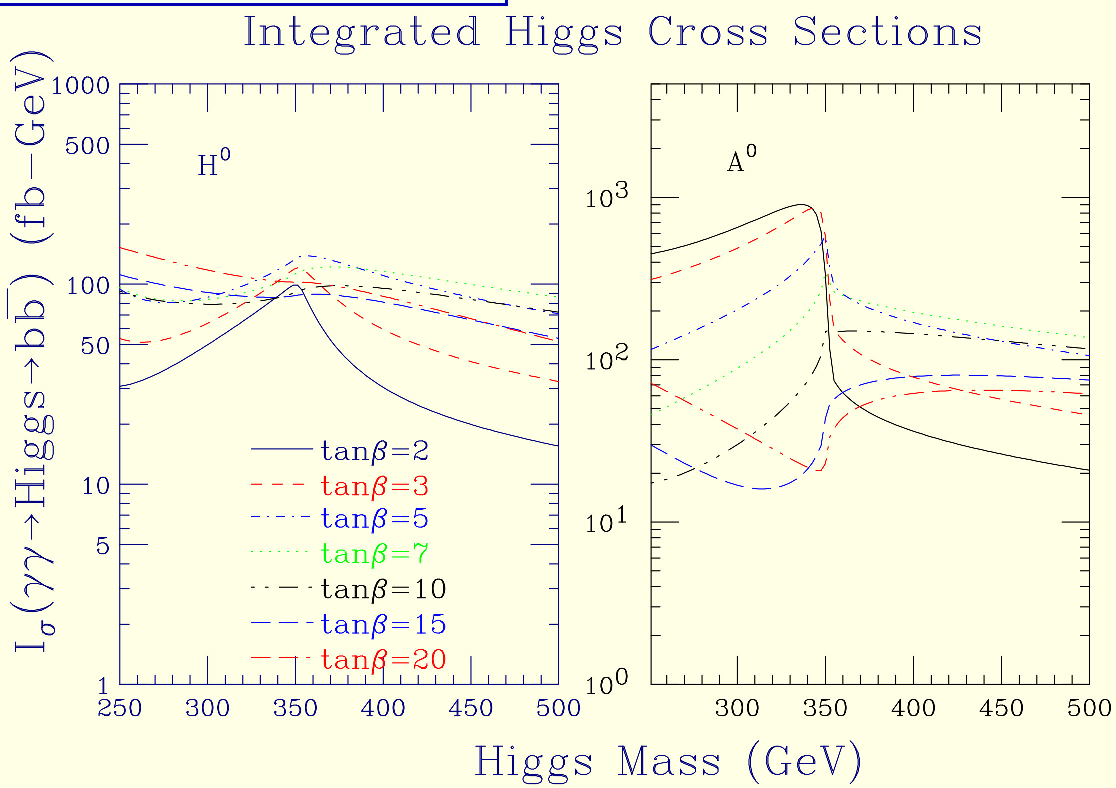
The Luminosity Spectra



Note: p_z **cut be used to 'clean up' low-**$E_{\gamma\gamma}$ **tail.**

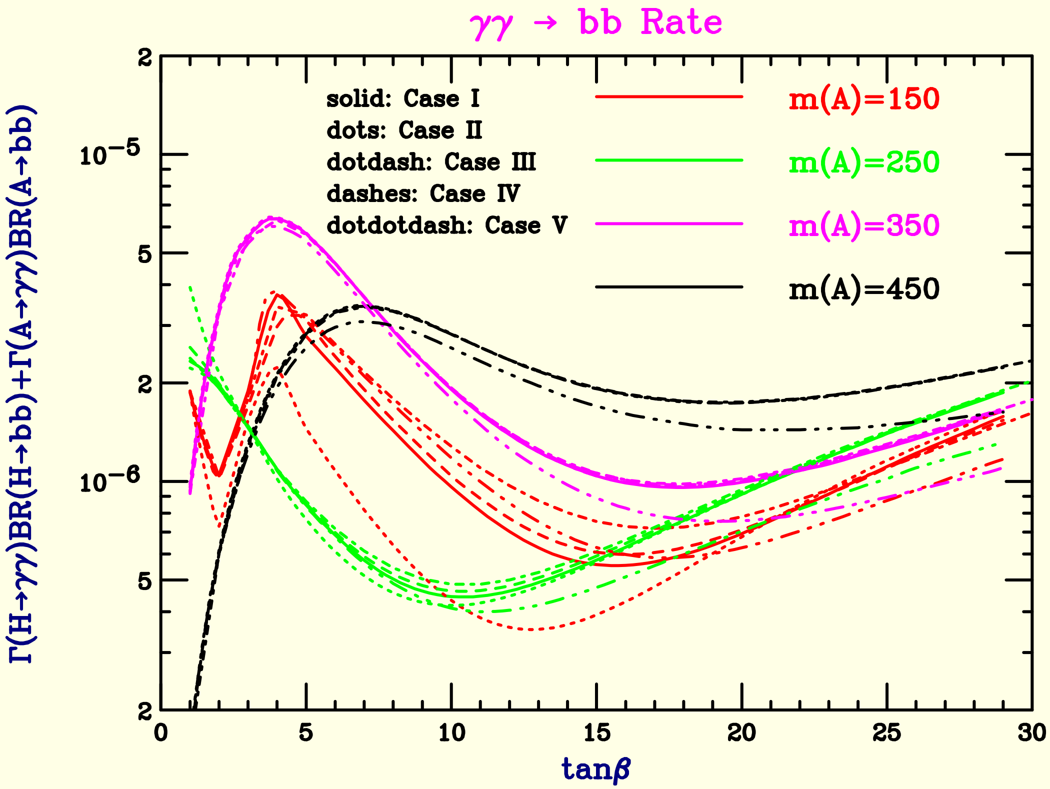
Luminosity and $\langle\lambda\lambda'\rangle$ **expectations for** $\lambda_e = \lambda'_e = 0.4$ **vs.** $E_{\gamma\gamma}$ **for** $P = P' = -1$ **and** $P = P' = +1$**.**

Basic Signal Cross Sections



Cross section ($\mathrm{fb}-\ \mathrm{GeV}$ units) to be multiplied by efficiencies, $1+\langle\boldsymbol{\lambda\lambda'}\rangle$ and $\left[\frac{dL}{dE_{\gamma\gamma}}\right]_{E_{\gamma\gamma}=m_{A^0}}$.

Model Dependence of Cross Sections



I: max-mix, $m_{\rm SUSY} = \mu = 1$ TeV, no Δ_b.
II: max-mix, $m_{\rm SUSY} = -\mu = 1$ TeV, no Δ_b.
III: no-mix, $m_{\rm SUSY} = \mu = 1$ TeV, no Δ_b.
IV: max-mix, $m_{\rm SUSY} = 1$ TeV, $\mu = 0$, no Δ_b
V: max-mix, $m_{\rm SUSY} = \mu = 1$ TeV, w. Δ_b

Model indep. except for large-μ, large-$\tan\beta$ SUSY loop corrections to $b\overline{b}$ coupling.
Even these corrections mainly affect the h^0 and not the H^0, A^0.
Note: Dip in $\sum\Gamma(\gamma\gamma)B(b\overline{b})$ at $\tan\beta \sim 15-20 \Rightarrow$ signals will improve above the LHC wedge region.

Note: Since our $\langle\lambda\lambda'\rangle$ is never really close to 1, $\sigma_{J_z=2} \sim 2\langle\sigma\rangle$ is always dominant.

Note: Our background is actually computed using Pythia (with full λ and λ' dependence built in (thanks to Mrenna)).

Initial and final state radiation is thus built in, which also mimics loss of $1 - \langle\lambda\lambda'\rangle$ suppression should we have been closer to the $\langle\lambda\lambda'\rangle \sim 1$ situation.

Same cuts as for SM Higgs.

Typical: $\epsilon_{\rm cuts} \sim 0.35 - 0.4$.

The total number of Higgs events is then given by (with σ_{H^0,A^0} as plotted):

$$N_{Higgs} = [I_\sigma(H^0) + I_\sigma(A^0)](1 + \langle\lambda\lambda'\rangle)\left(\frac{dL}{dE_{\gamma\gamma}}\right)_{E_{\gamma\gamma}=m_{A^0}} \epsilon_{\rm cuts}\epsilon_b \quad (9)$$

The mass resolution is being studied, but we estimate 1σ width ranging from about 3 GeV at $m_{b\bar b} \sim 250~{\rm GeV}$ to about 6 GeV at $m_{b\bar b} \sim 500~{\rm GeV}$

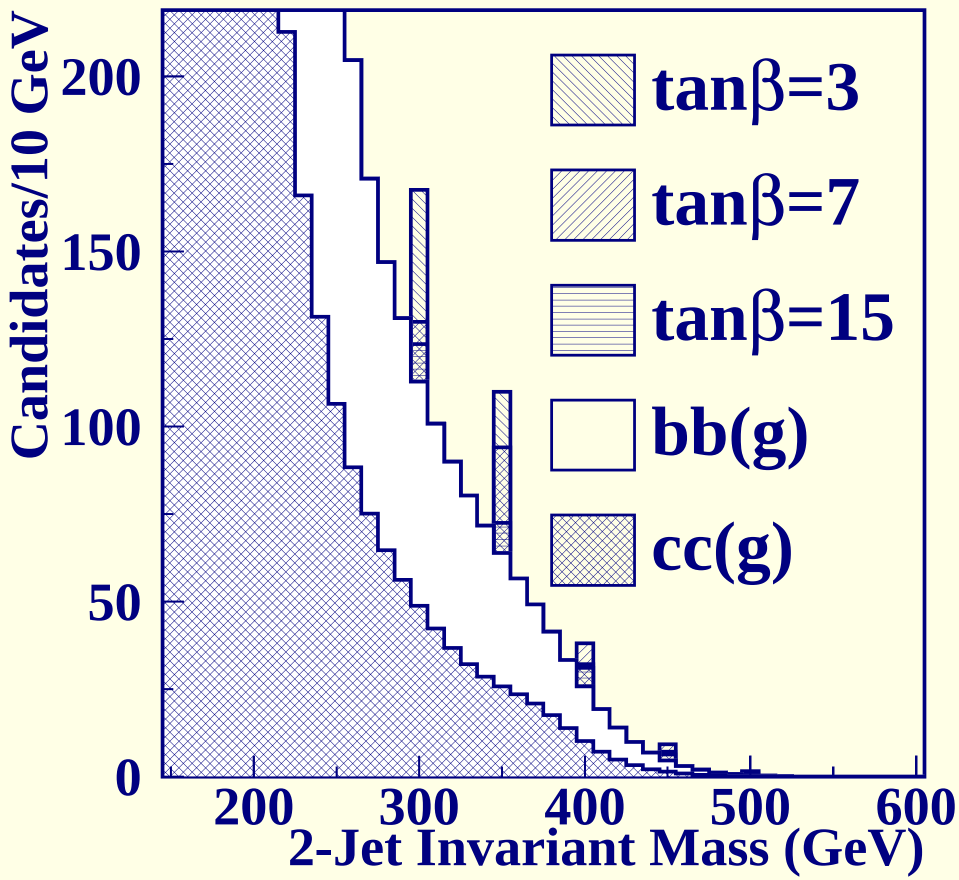
This is similar to TESLA estimates of $30\%\sqrt{m_{b\bar{b}}}$.

Note: Neither analysis includes underlying overlap events, in particular those related to resolved photon processes, but overlapping events should not be a problem at TESLA; NLC?

We will assume that 50% of Higgs events fall into 10 GeV bin, and compute $N_{SD} = S/\sqrt{B}$ for the best bin.

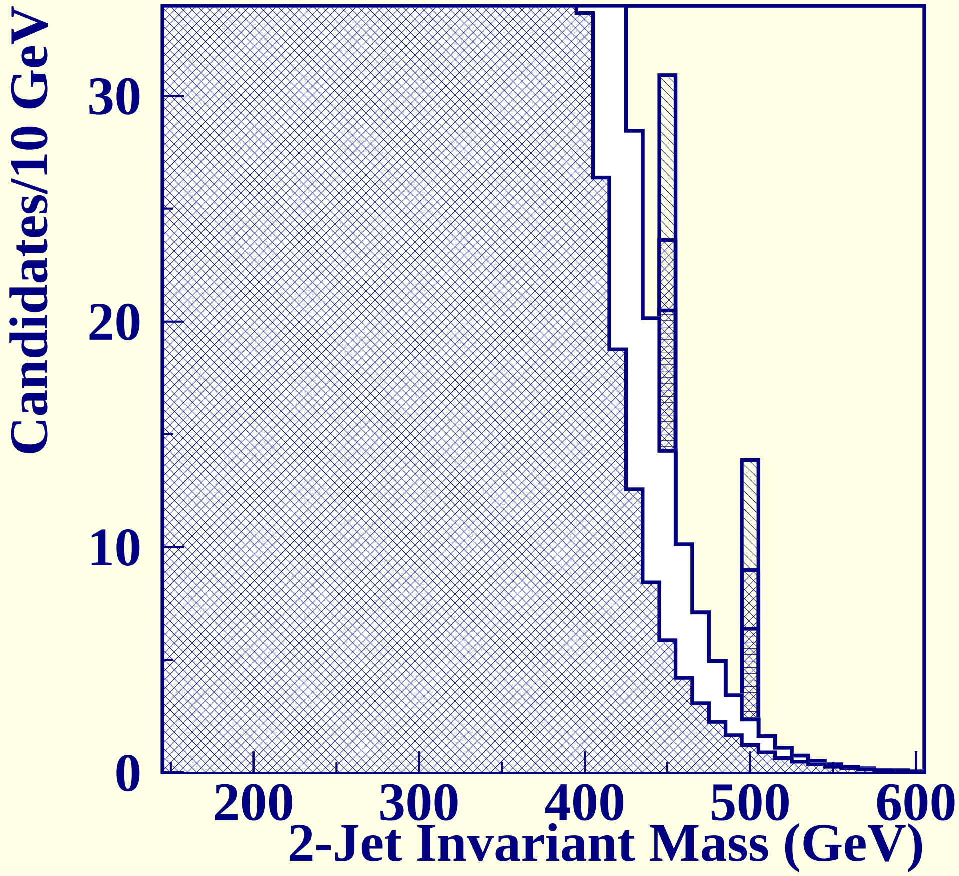
This bin size is meant to roughly account for resolution, (small) mass difference $m_{H^0} - m_{A^0}$, and Higgs widths that start to be of order a few GeV at the higher $\tan\beta$ values in the wedge region.

Results for 1 year of operation in $P = P' = +1$ mode.



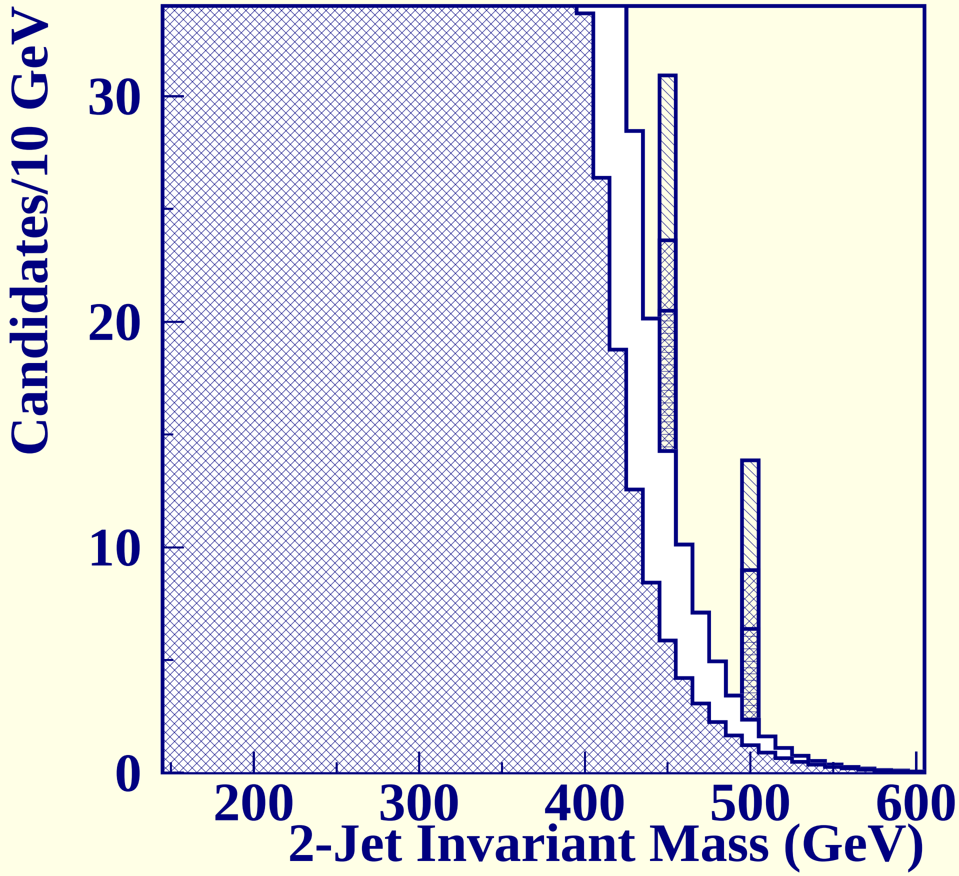
Assume all signal events fall into single 10 GeV $m_{b\bar{b}}$ bin.
$P = P' = +1$ yields reasonably large $\lambda\lambda'$ at $E_{\gamma\gamma} \sim 250 - 400~\mathrm{GeV}$.

The Results for 1 year of operation in $P = P' = -1$ mode



Assume all signal events fall into single 10 GeV $m_{b\bar{b}}$ bin.
$P = P' = -1$ yields luminosity peak at $E_{\gamma\gamma} = 500$ GeV and large $\lambda\lambda'$ there.

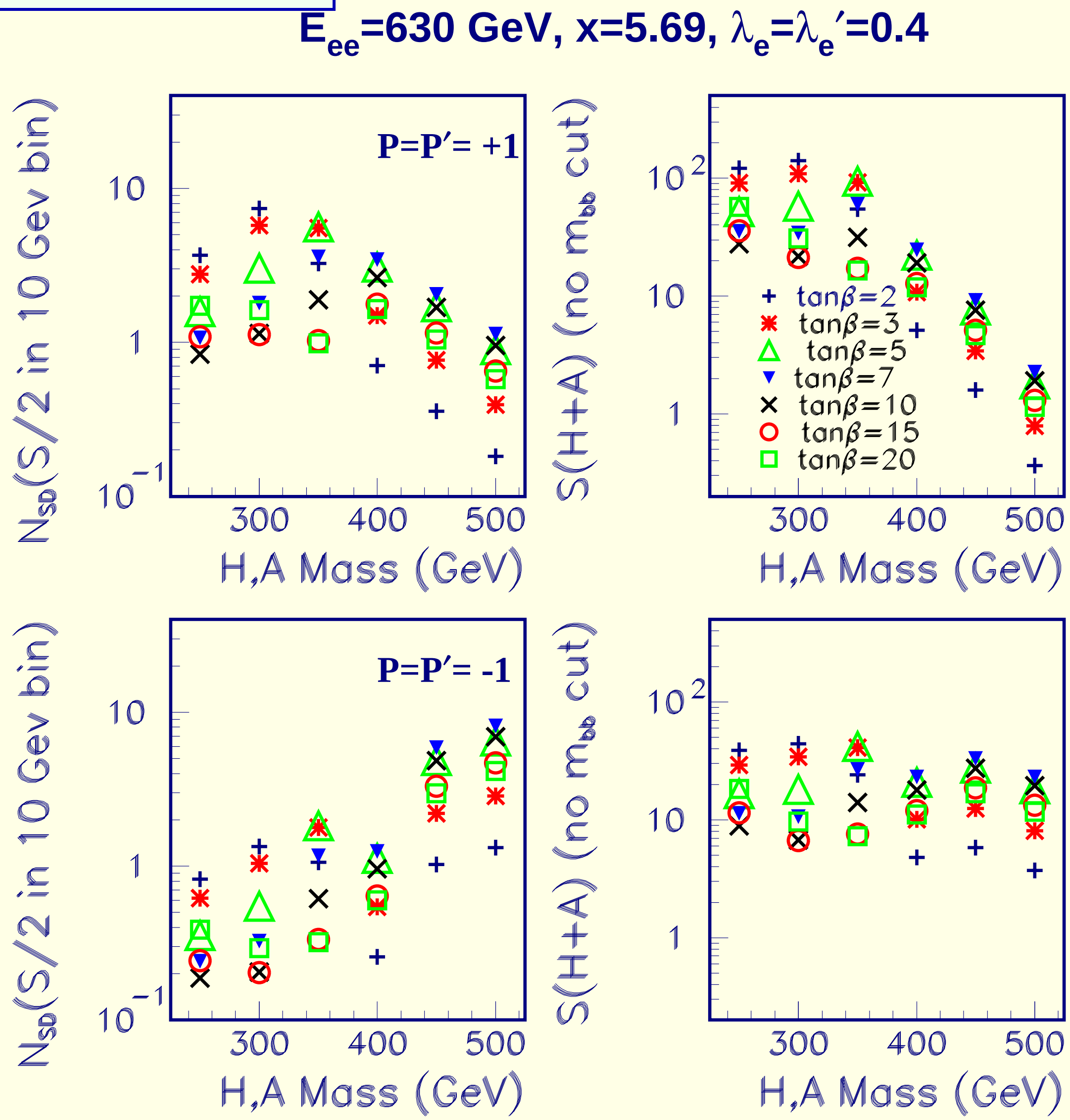
The Results for 1 year of operation in $P = P' = -1$ mode



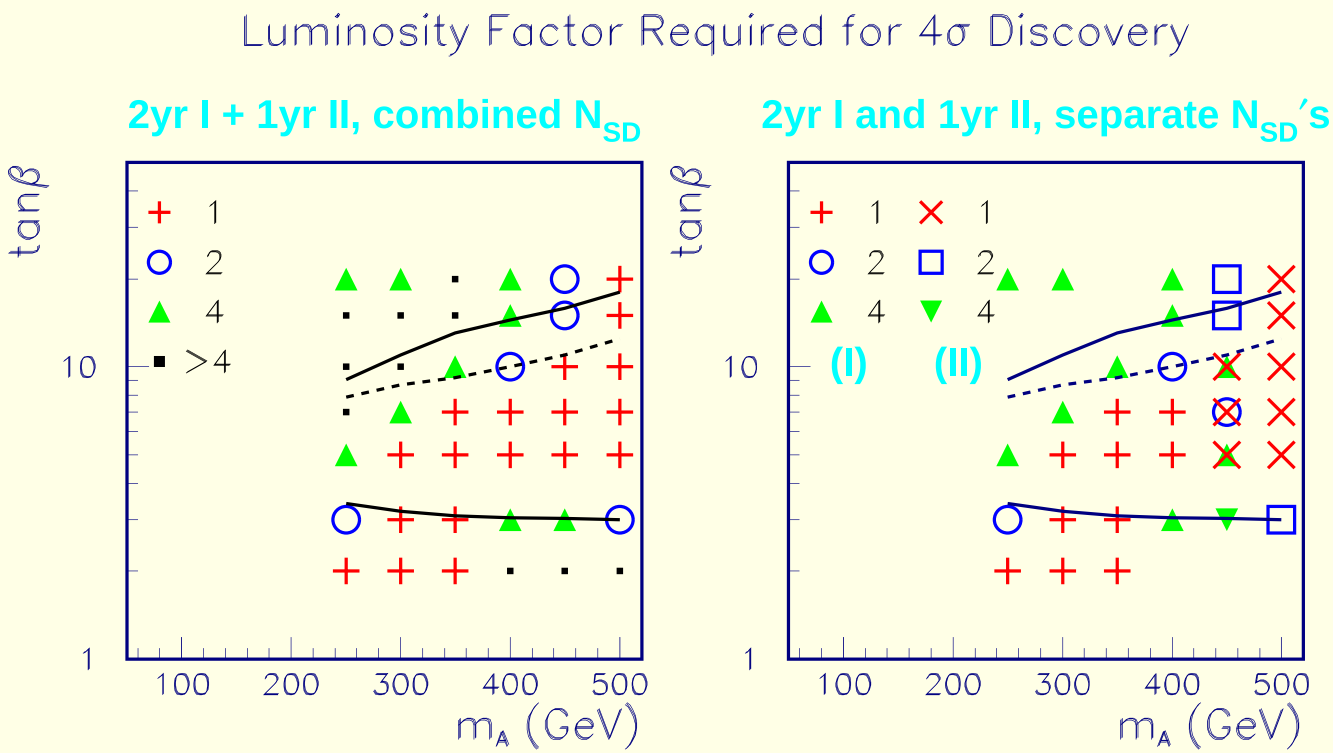
Assume all signal events fall into single $10\ \mathrm{GeV}\ m_{b\bar{b}}$ bin.
$P = P' = -1$ yields luminosity peak at $E_{\gamma\gamma} = 500\ \mathrm{GeV}$ and large $\lambda\lambda'$ there.

$\sqrt{s} = 630$ GeV fixed energy approach

Assume 2 year of NLC operation in $P = P' = +1$ mode and 1 year in $P = P' = -1$ mode. Assume that 1/2 of signal events fall into a single 10 GeV bin centered on $m_{A^0} \sim m_{H^0}$.
$\Rightarrow$ some reasonable signals at intermediate masses for $P = P' = +1$.
$\Rightarrow$ some reasonable signals at highest mass for $P = P' = -1$.

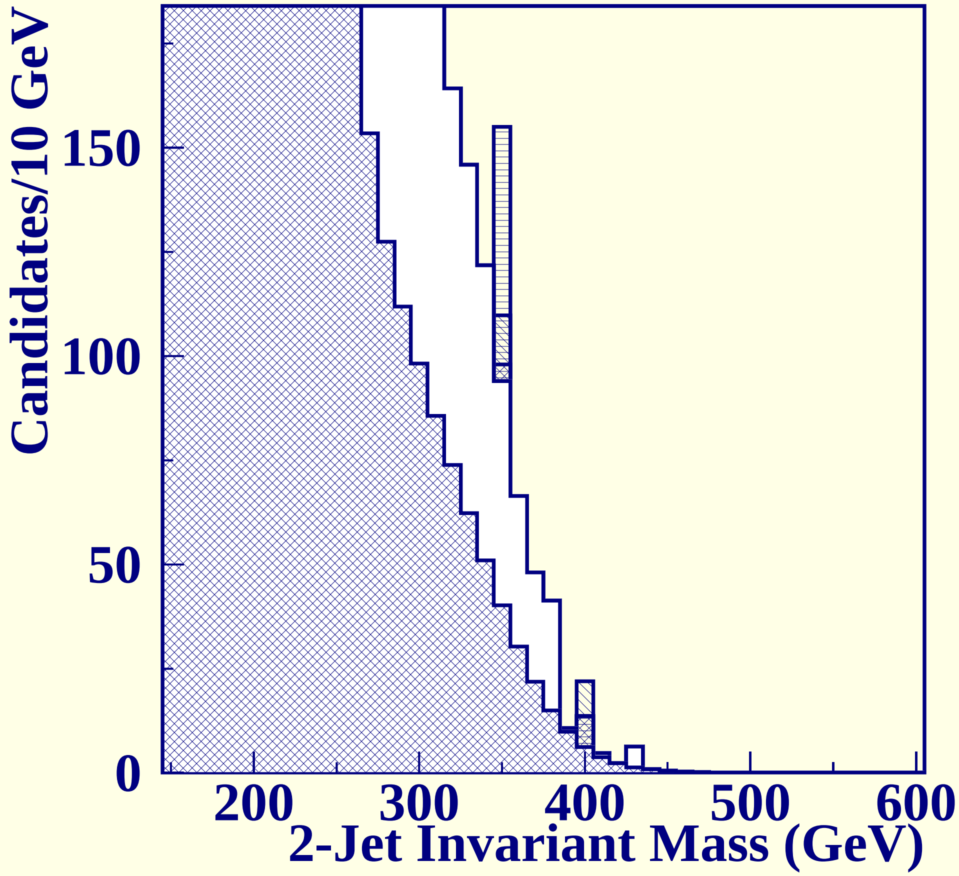


The Wedge Results: peaked + broad spectrum running.



RH window: separate N_{SD}'s for 2 yr type-I and 1 yr type-II operation.
LH window: combined N_{SD}'s.
Solid lines = LHC H^0, A^0 wedge.
Above dashed line = LHC $H^\pm$ discovery (then know $\sqrt{s}$ for $m_{A^0} \sim m_{H^\pm}$).
Pair production covers up to $m_{A^0} \gtrsim 300$ GeV.

$\boxed{\text{The Results}}$ for 1 year $P = P' = -1$ (peaked) mode, $\sqrt{s} = 535$ GeV.

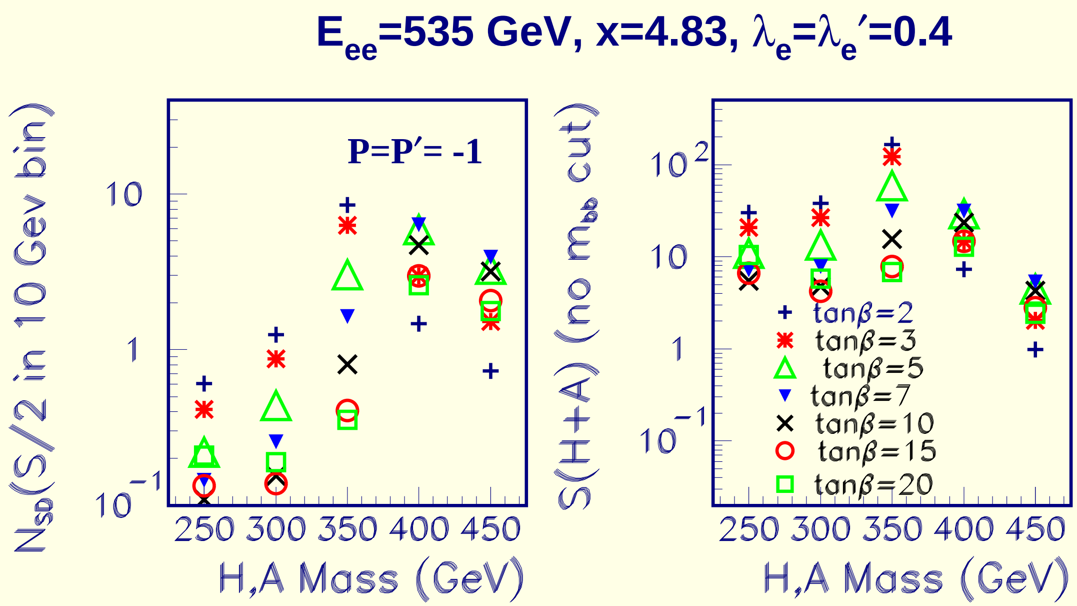


Assume all signal events fall into single 10 GeV $m_{b\bar{b}}$ bin.
$P = P' = -1$ yields luminosity peak at $E_{\gamma\gamma} = 400$ GeV for $\sqrt{s} = 535$ GeV and large $\lambda\lambda'$ there.

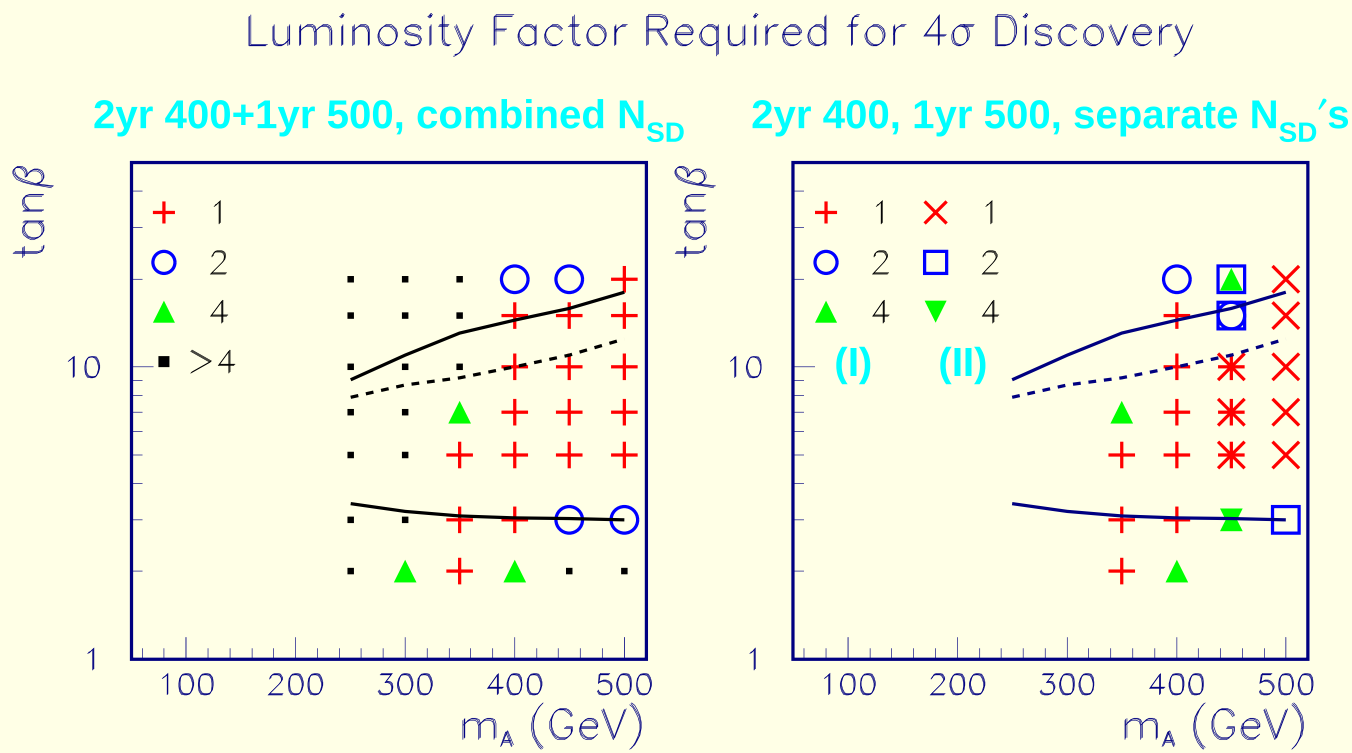
$\sqrt{s} = 535$ GeV peaked spectrum results

For 1 year of NLC operation in $P = P' = -1$ mode at $\sqrt{s} = 535$ GeV (i.e. peak at $E_{\gamma\gamma} = 400$ GeV). Assume that 1/2 of signal events fall into a single 10 GeV bin centered on $m_{A^0} \sim m_{H^0}$.

$\Rightarrow$ some reasonable signals for $m_{A^0} \sim 350$ GeV $- 400$ GeV. Below 350 GeV is covered by pair production at $\sqrt{s} = 630$ GeV.



The Wedge Results: two $\sqrt{s}$ values with peaked spectrum



RH window: separate N_{SD}'s for 2 yr $\sqrt{s} = 535$ GeV and 1 yr $\sqrt{s} = 630$ GeV type-II operation.
LH window: combined N_{SD}'s.

CONCLUSIONS

Excellent precision is achievable for $h_{\rm SM}$ (SM) and h^0 (MSSM) $b\overline{b}$ final state rate.

Extract $\Gamma(\to \gamma\gamma)$ by dividing out measured ($1-2\%$ precision using $e^+e^- \to Z^* \to Zh$) $B(\to b\overline{b})$.

A very decent $\mathcal{CP}$ measurement of the $h_{\rm SM}$ or h^0 will be possible.

Very important to verify H^0, A^0 mass resolutions assumed; work on this is in progress, but there is general agreement that earlier assumptions are not unreasonable.

Resolved photon process backgrounds still need study for NLC. TESLA bunch spacing $\Rightarrow$ no problem there.

NLC yearly luminosities assumed above are about a factor of 2 smaller at the peak than TESLA values.

Also get a factor of 2 increase using round beams at NLC.

$\Rightarrow$ good wedge coverage.

Note: the NLC $\langle\lambda\lambda'\rangle$ is employed here is smaller at the peak because of $\lambda_e = 0.4$ vs. $\lambda_e = 0.45$ assumed in TESLA analysis and because the non-linear etc. stuff in CAIN causes some dilution.

$\Rightarrow$ going to TESLA assumptions of no dilution and higher λ_e would reduce background by perhaps as much as a factor of 2.

$\Rightarrow$ another 40% improvement in $S/\sqrt{B}$.

Some of the weaker low-$\tan\beta$ signals could be enhanced by using the $A^0, H^0 \to t\bar{t}$, $H^0 \to h^0h^0$ and $A^0 \to Zh^0$ final states.

With large $N_{\rm SD}$ for signal, CP studies/separation of the heavy Higgs bosons become possible.

$\Rightarrow$ Clearly, $\gamma\gamma$ collisions will be a very powerful probe of heavy Higgs bosons.

There are general 2HDM models in which the only light Higgs boson is a A^0 (all other Higgs bosons can be heavier than $800~{\rm GeV} - 1~{\rm TeV}$).

Such models can be consistent with precision electroweak data.

A light A^0 can explain (part of) a_μ.

$\gamma\gamma$ collisions (using peaked + broad approach) can discover such an A^0 in about 40% of the wedge region for which it cannot be discovered at the LC or LHC.