Heavy MSSM Higgs Production at a $\gamma\gamma$ Collider: Luminosity and Other Issues.

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- **Heavy Higgs Bosons**

In general, the inclusion of the many non-linear effects incorporated in the CAIN Monte Carlo has a very big impact on strategies and abilities to extract signals.

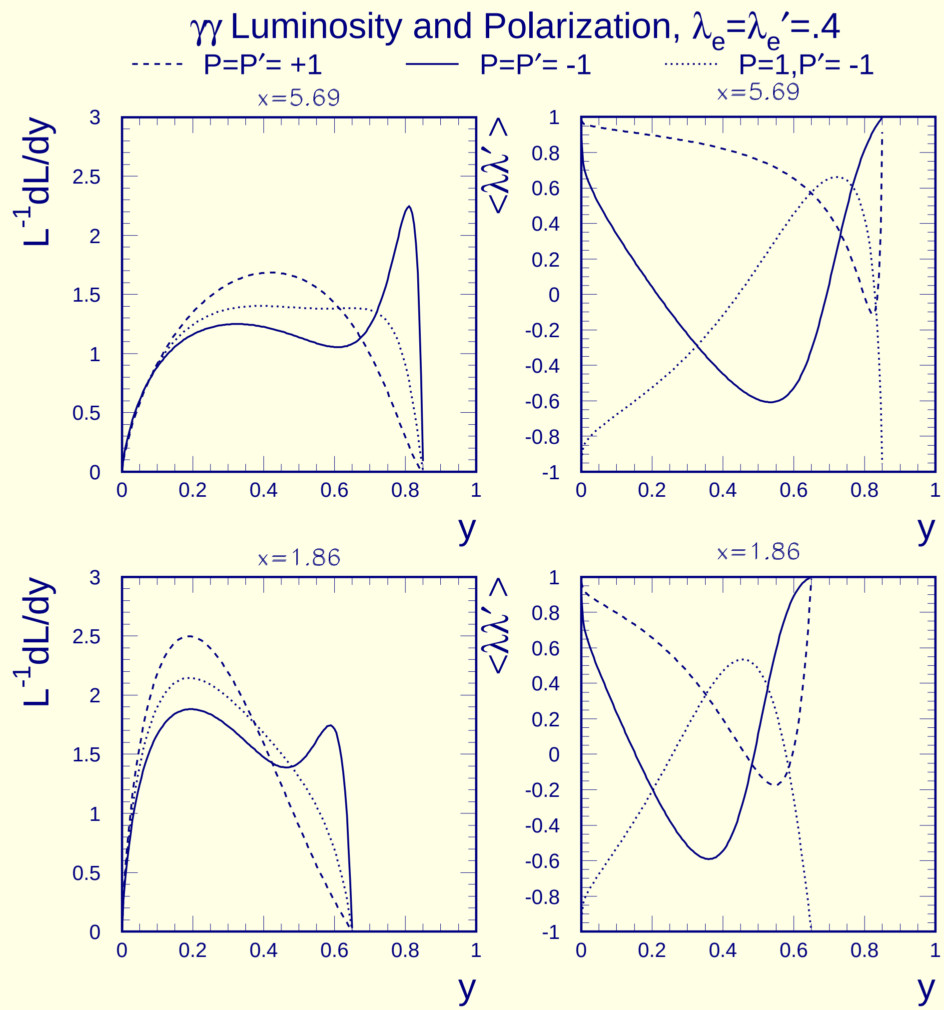
It is also important to recognize that the laser will not have an adjustable wavelength. We have adopted the LLNL standard of 1 micron.

This implies that the famous parameter $x \simeq \frac{4E_{\rm beam}\omega_{\rm laser}}{m^2c^4}$ will vary according to the machine energy (which in turn is determined by physics, e.g. Higgs, issues).

For example, at $\sqrt{s} = 206~{\rm GeV}$, $x \simeq 1.86$, while at another extreme we have considered of $\sqrt{s} = 630~{\rm GeV}$, $x \simeq 5.69$.

Another issue is what degree of electron (and positron?) polarization can be achieved. For Higgs physics (and many other types of physics) the highest achievable level will be critical. Advice from above: use $\lambda_e = 0.4$ (80% pol.).

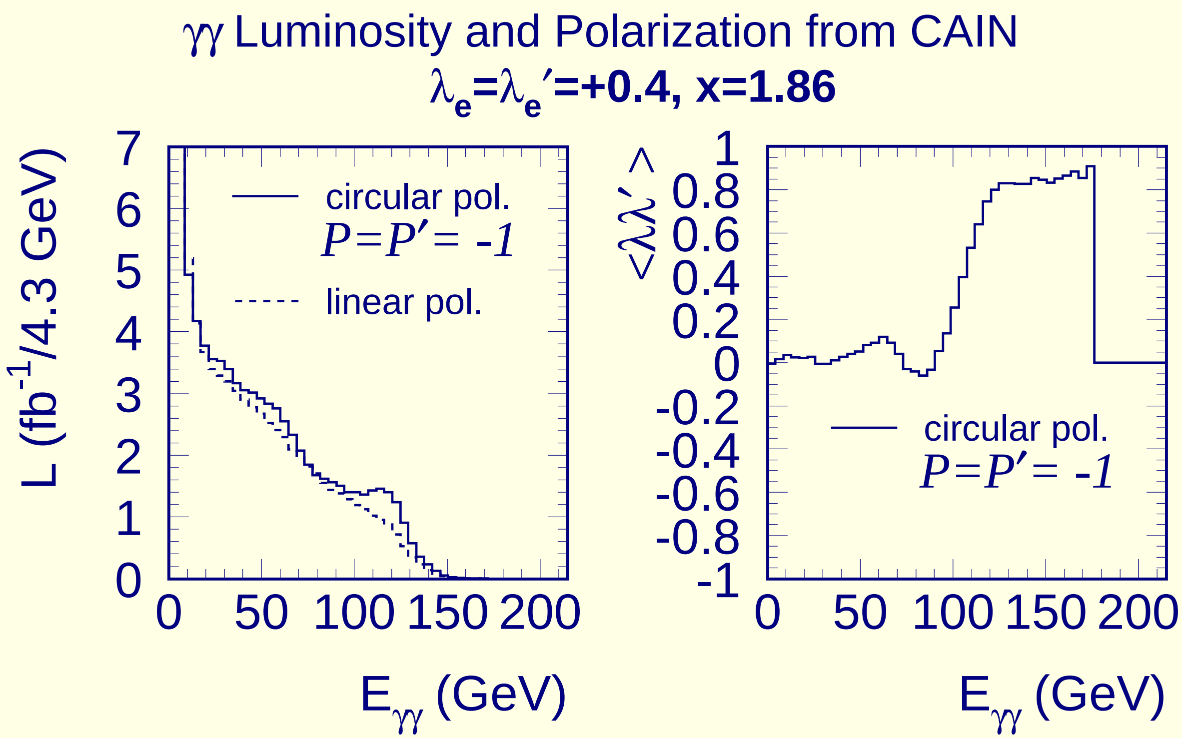
LUMINOSITIES



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 λ_e, λ'_e have same sign that is opposite laser polarizations of same sign, $P = P'$. At the peak, $\langle \lambda\lambda' \rangle$ is large: bigger for bigger λ_e, λ'_e.

Real Life Luminosities



Note: the peak ($\sqrt{s} = 206~\mathrm{GeV}$ for peak at $120~\mathrm{GeV}$) turns into a blip, but $\langle\lambda\lambda'\rangle$ is still large at peak of blip.

(a) CAIN predictions for the $\gamma\gamma$ luminosity distribution for circularly polarized [case (II)] and linearly polarized photons assuming a 10^7 sec year, $\sqrt{s} = 206~\mathrm{GeV}$, 80% electron beam polarization, and a 1.054 micron laser wave length, after including beamstrahlung and other effects. (b) the corresponding value of $\langle\lambda\lambda'\rangle$ for case (II) – circular polarization.

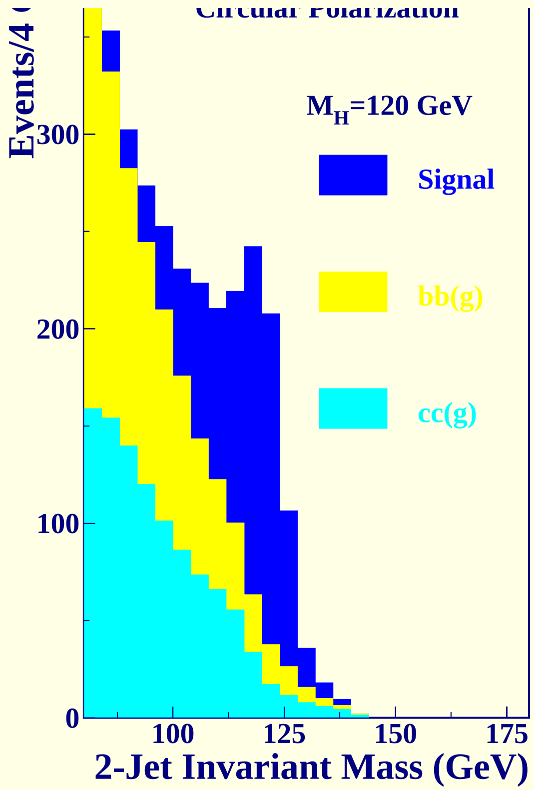
Lots of L at low $E_{\gamma\gamma}$, but with $\langle\lambda\lambda'\rangle \sim 0$.

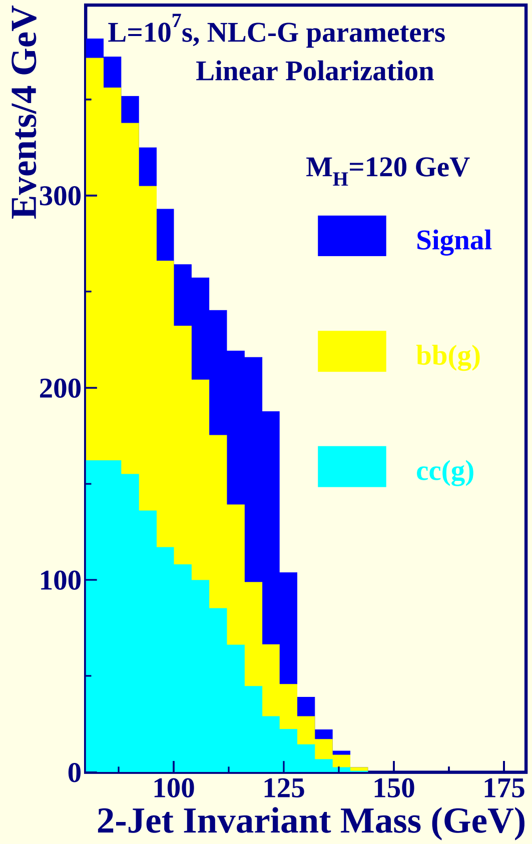
Little L at highest $E_{\gamma\gamma}$ where $\langle\lambda\lambda'\rangle$ is largest.

Can cut away low-$E_{\gamma\gamma}$ tail using cut on $x - x'$ of γ's.

How important is the peak and large $\langle\lambda\lambda'\rangle$?

Circular vs. Linear Polarization, for example





$m_h = 120$ GeV, $\sqrt{s} = 206$ GeV
Circular polarization, peaked spectrum.

$m_h = 120$ GeV, $\sqrt{s} = 206$ GeV,
Linear polarization, falling spectrum.

Note: Looks better if $p_z(b\overline{b}) < 12$ GeV cut applied, but will need to understand p_z shape anyway for reliable result.

THE HEAVY MSSM H^0 and A^0

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 $50\ \mathrm{GeV}$.
  $\Rightarrow$ choose $\sqrt{s}$ and peaked luminosity spectrum with peak near this mass.
- We do not have such constraints. An important question: are there reasonable scenarios for which decoupling ($\cos^2(\beta - \alpha) = 0$) happens essentially independent of m_{A^0} (under investigation).
  $\Rightarrow$ either: (a) scan or (b) run at high energy and use broad spectrum approach.

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

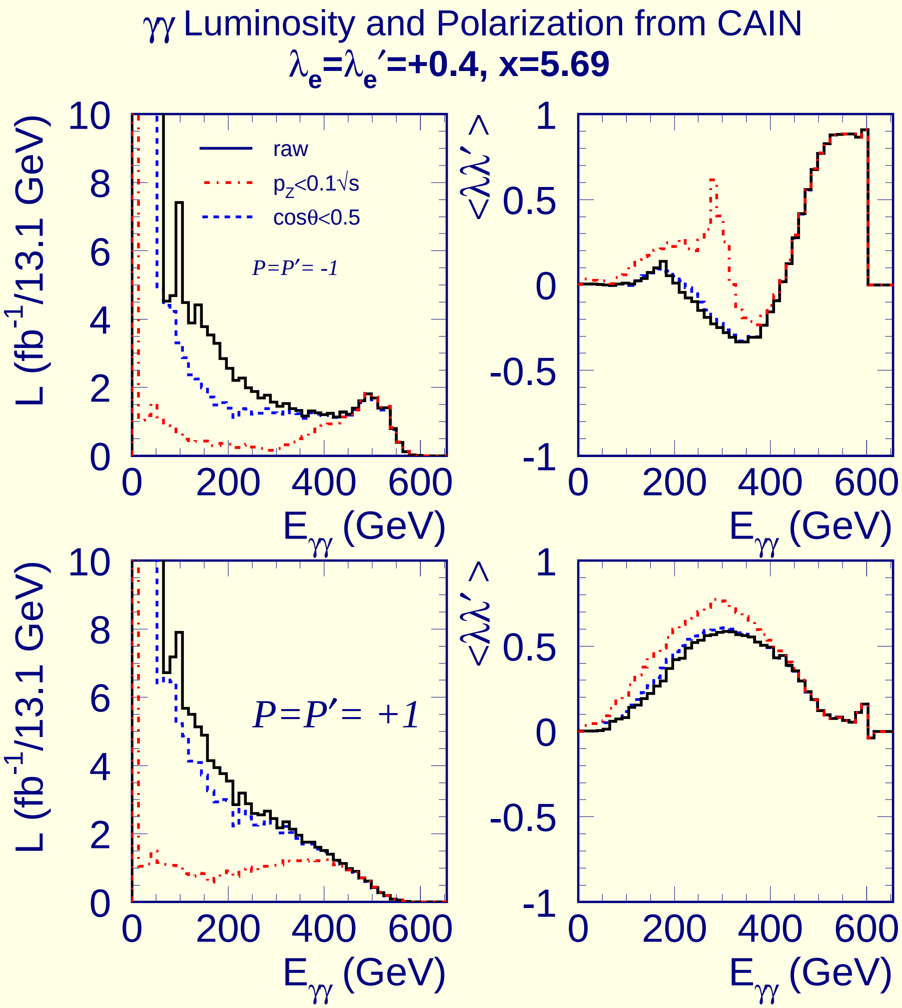
The luminosity peak for $\lambda_e = \lambda'_e = 0.4$ and $P = P' = -1$ is at about $500\ \mathrm{GeV}$

To examine sensitivity for $m_{H^0} \sim m_{A^0}$ on the peak we will look at $m_{A^0} = 500\ \mathrm{GeV}$ with $P = P' = -1$.

- To examine sensitivity for $m_{H^0} \sim m_{A^0}$ far below the peak we will look at $m_{A^0} = 350\ \mathrm{GeV}$ (for which rates are largest).

  Here, it will be much better (but still not good) to use $P = P' = +1$, as we shall see.

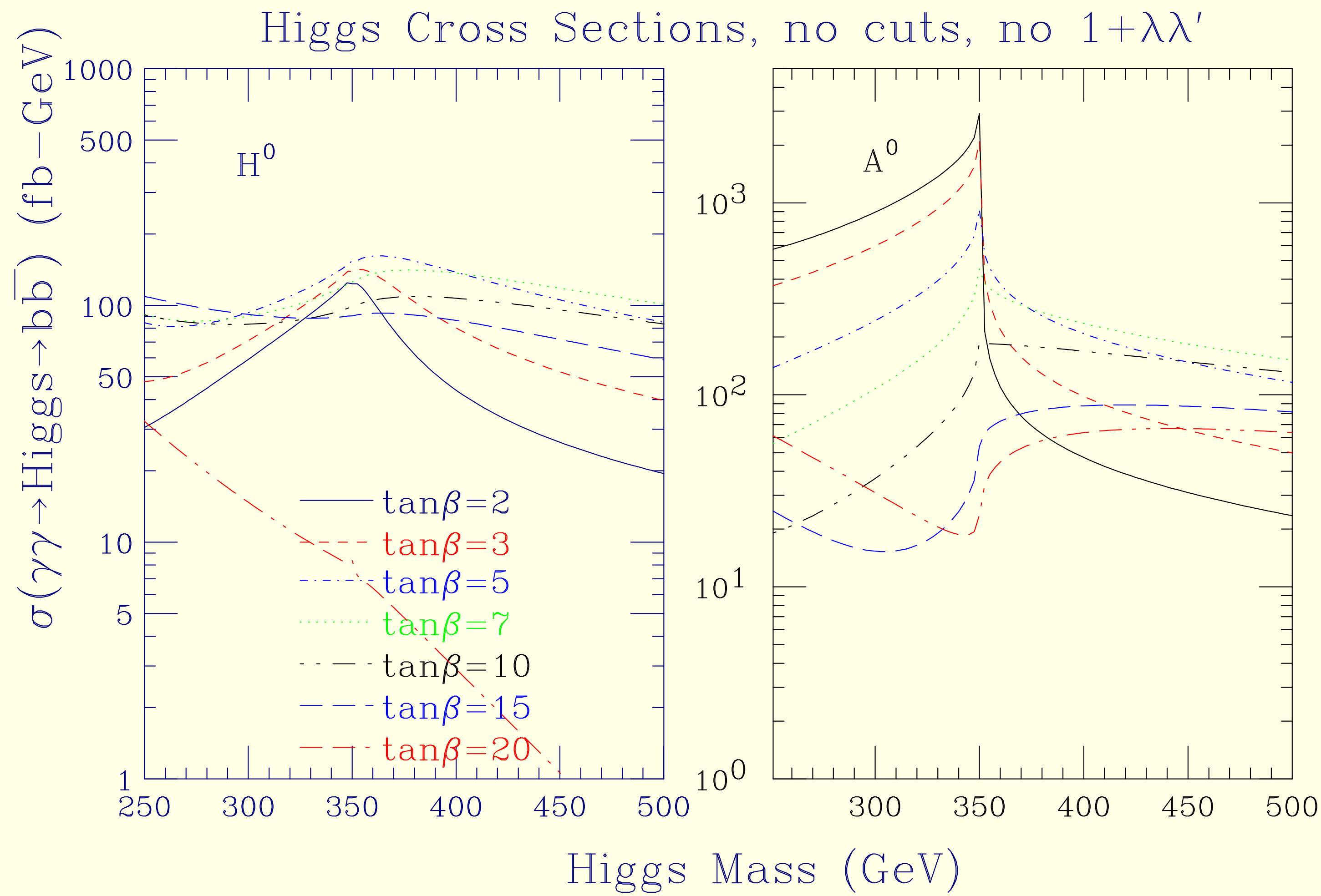
The Luminosity Spectra



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

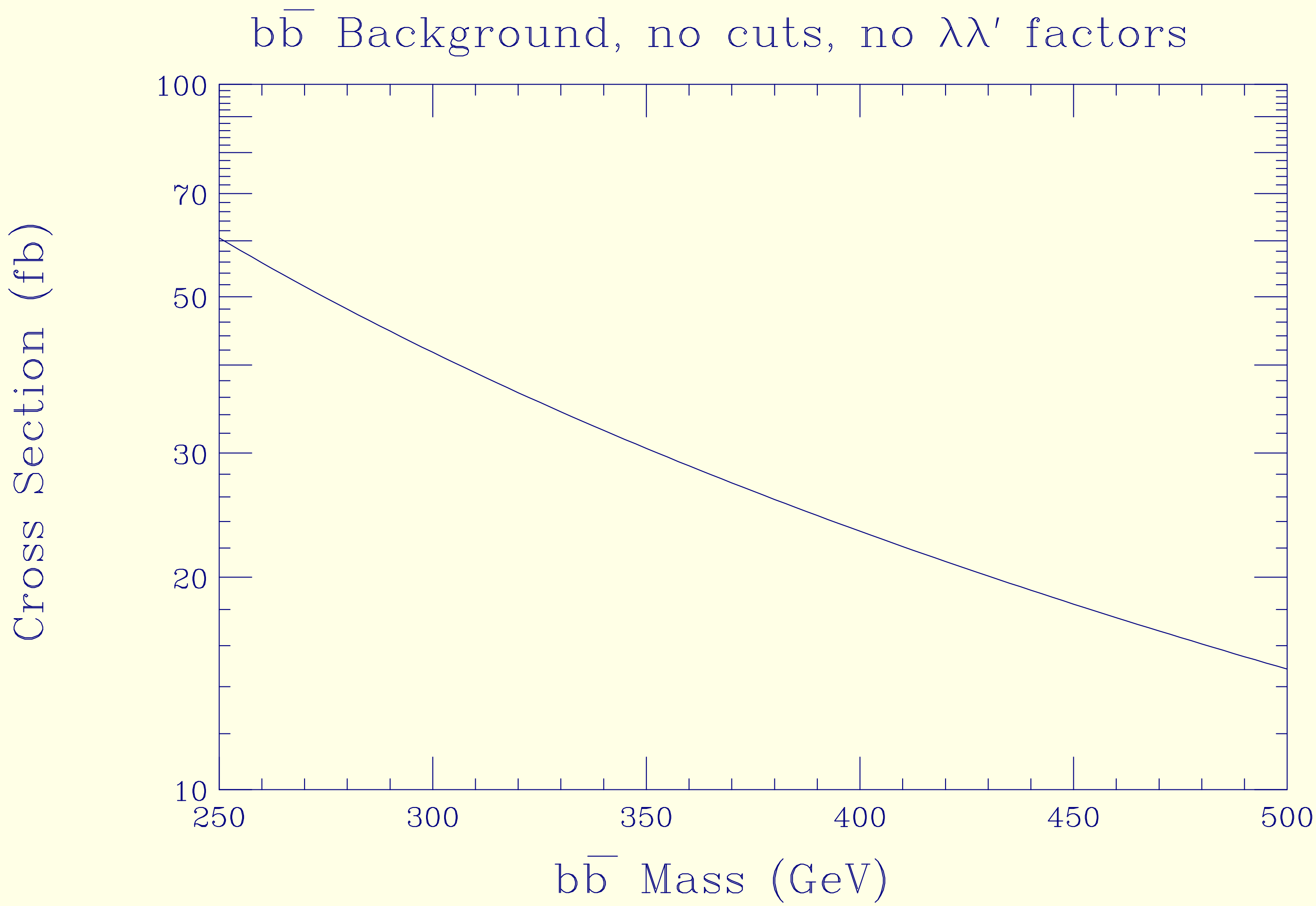
Note: p_z cut would again 'clean up' low-$E_{\gamma\gamma}$ tail.

Basic Signal Cross sections



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

Background Cross Section



Spin average cross section (fb units) to be multiplied by efficiencies, corrected for $\lambda\lambda'$ dependence, and integrated over appropriate mass bin: $\int dE_{\gamma\gamma}\frac{dL}{dE_{\gamma\gamma}}\left[\frac{1}{2}(1+\langle\lambda\lambda'\rangle)\sigma_{J_z=0}+\frac{1}{2}(1-\langle\lambda\lambda'\rangle)\sigma_{J_z=2}\right]_{E_{\gamma\gamma}=m_{b\bar{b}}}$.

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.

Efficiencies and Cuts and Procedures

Signal

- For each Higgs mass, m_{A^0}, we generated 1000 Higgs events in Pandora and processed them through root and detector simulation.

- We reconstructed jets using the Durham algorithm with $y < 0.02$.

- We required (at least) two energetic b jets passing through the vertex detector: assumed overall efficiency for tagging the two jets $\epsilon_b = 0.7$.

- We constructed the thrust axis for the two most energetic jets (required to contain a tagged b) in their rest frame and required $\cos\theta^* < 0.5$.

  $dL/dE_{\gamma\gamma}$ and $\langle\lambda\lambda'\rangle$ are very insensitive to this cut $\Rightarrow$ we can simply compute an efficiency $\epsilon_{\rm cuts} =$No. of surviving events (without including ϵ_b) divided by 1000.

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

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

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

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

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

  Note: Neither analysis includes underlying overlap events, in particular those related to resolved photon processes.

Background

- This was generated in context of Pythia (with full $\lambda\lambda'$ dependence as a function of the momentum fractions z and z' of the colliding photons).

- The same jet defining procedures ($y < 0.02$) and cuts, including $\cos\theta^* < 0.5$, as employed for the Higgs signal events were employed.

- $\epsilon_b = 0.7$ was applied to the surviving $b\overline{b}$ background events.

- $\epsilon_c = 0.035$ was applied to the $c\overline{c}$ background events.

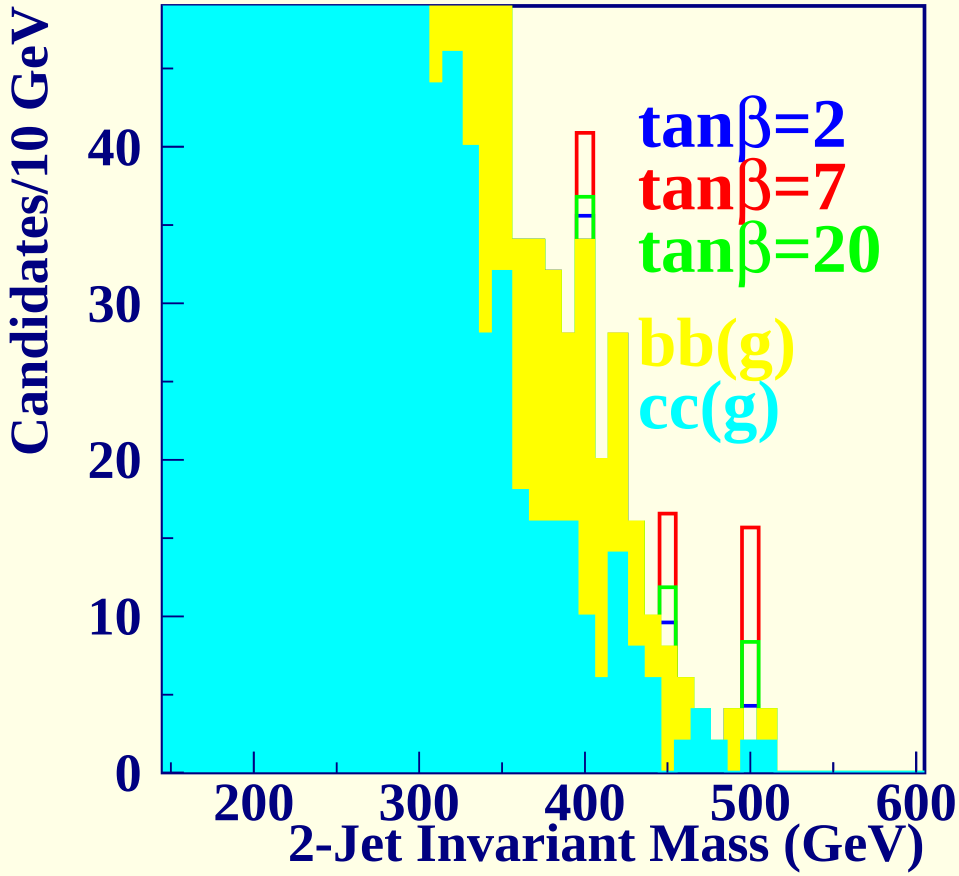
- All was folded with the luminosity distribution as described earlier.

Other Comments on Analysis

- Track to shower matching should be performed to avoid double counting electromagneti energy (improves resolution).
- Including resolved photon backgrounds/overlapping events will worsen mass resolution.
- Will it turn out to be helpful to correct for neutrinos?

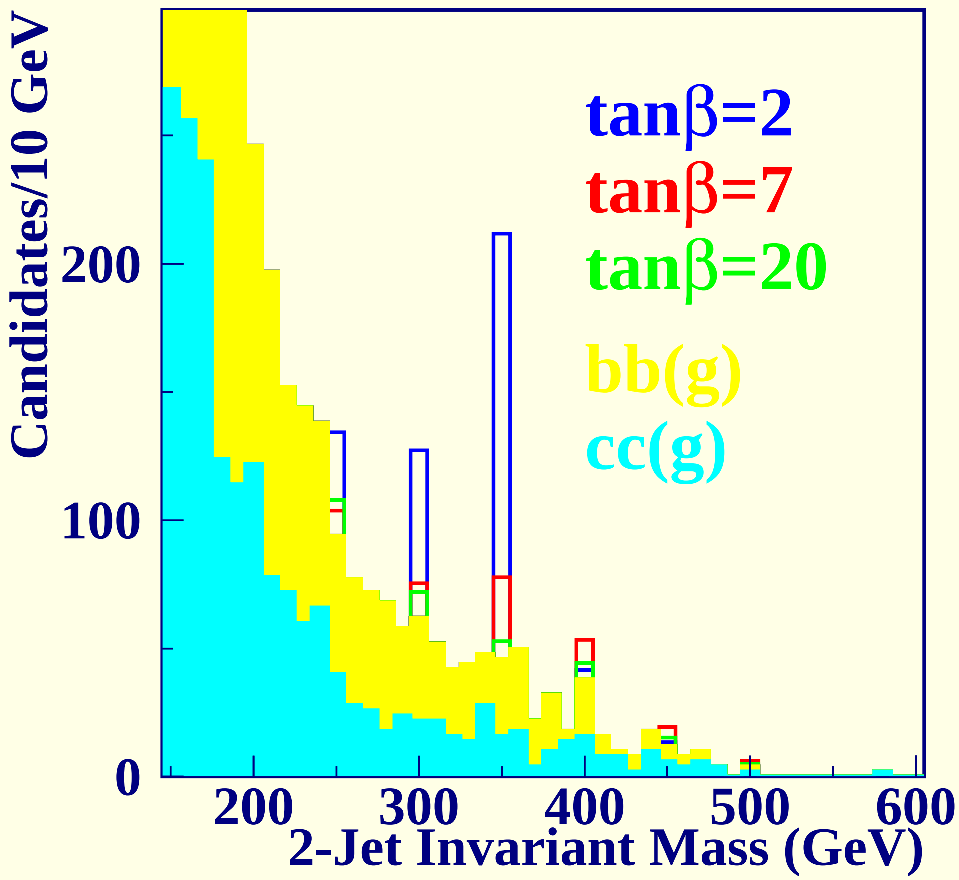
  The best technique would probably be to remove events with significant missing transverse momentum.

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.

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 $E_{\gamma\gamma} \sim 250 - 400$ GeV.

Note: Understanding the exact background shape will be critical.

⇒ Very probable that p_z cut should not be relied on to clean up the appearance of the signal, but rather should be considered a tool in understanding and modeling this shape.

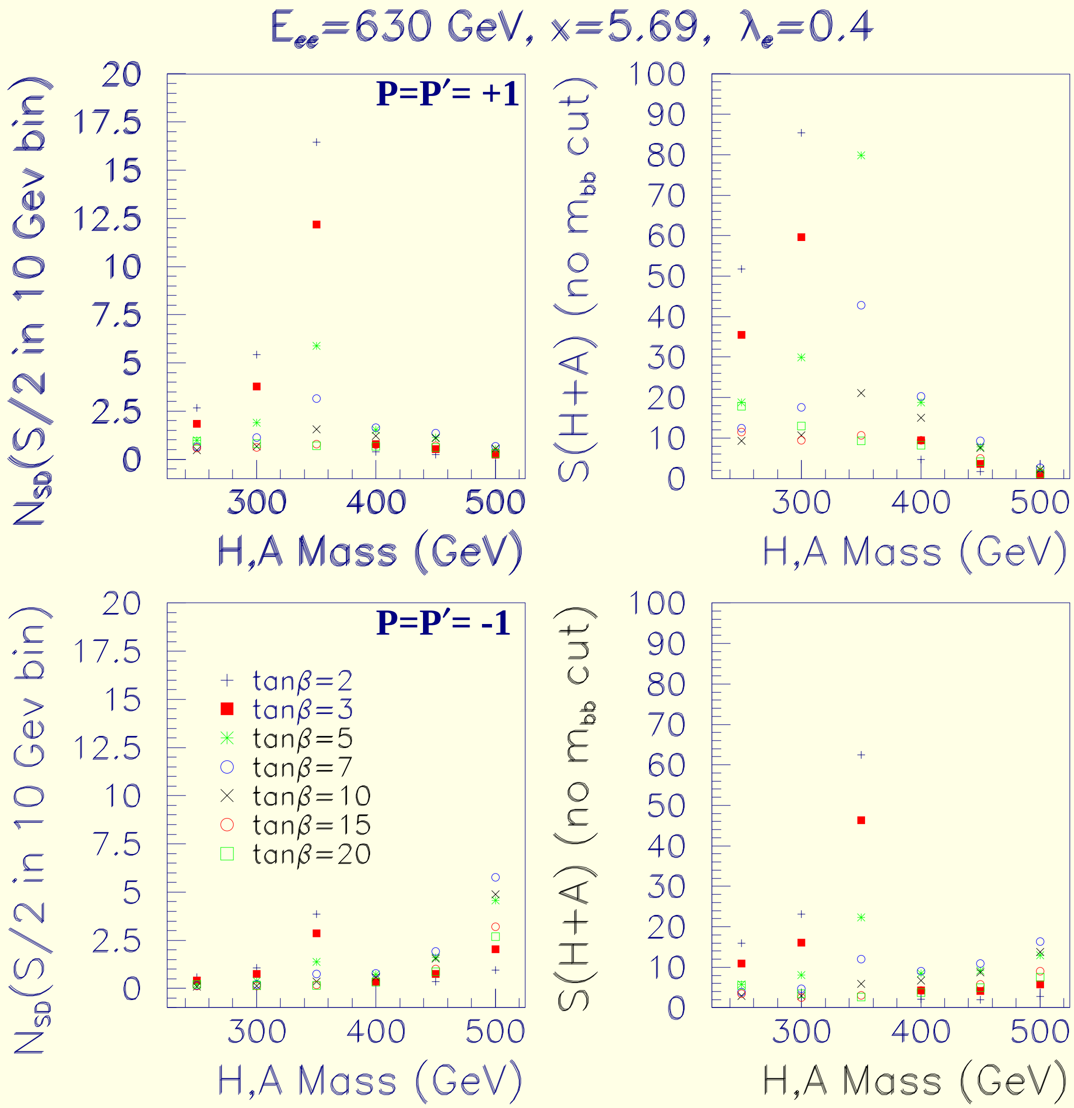
More conservative approach

Assume 1 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 $P = P' = -1$.



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- Hot off the press: New flat beam design increases NLC luminosities by factor of at least 2 $\Rightarrow$ increase in $N_{\rm SD}$'s shown by $\sim 40\%$.
- $\langle\lambda\lambda'\rangle$ 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 $S/\sqrt{B}$.

- **Thus, there is a chance we could gain A factor of $\sim \mathbf{2}$ improvement in $\boldsymbol{N_{SD}}$.**
  $\Rightarrow N_{\rm SD} > 5$ in about 30% of the $\tan\beta, m_{A^0}$ cases using the conservative $S/2$ per 10 GeV approach and about 50% of the cases if resolution sufficient to contain nearly all of the S events in a 10 GeV bin.
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- **With large $\boldsymbol{N}_{\rm SD}$ for signal, CP studies/separation of the heavy Higgs bosons become possible.**
  Estimates for CP analysis will be performed once we have finalized the signal analyis. Must use linearly polarized beams and corresponding luminosities.