Higgs WG Summary

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On behalf of the Higgs WG conveners

Snowmass 2005
Summary Session
8/27/2005

Outline

- Introduction
  - Organization of the Working Group
  - Charge
  - Introduction to Higgs Physics
- Detector and Machine Needs
- Theory Needs
- γ Collider?
- Outlook and the Future

WG Organization

- Sven Heinemeyer (CERN) : SM, MSSM, detector issues
- Shinya Kanemura (Osaka) : 2HDM and extensions, Non-decoupling effects
- Heather Logan (Carleton) : Higgs couplings, MSSM, Little Higgs
- Alexei Raspereza (DESY) : Experimental, detector and machine issues
- Tim Tait (Argonne) : Exotic and heavy Higgs scenarios

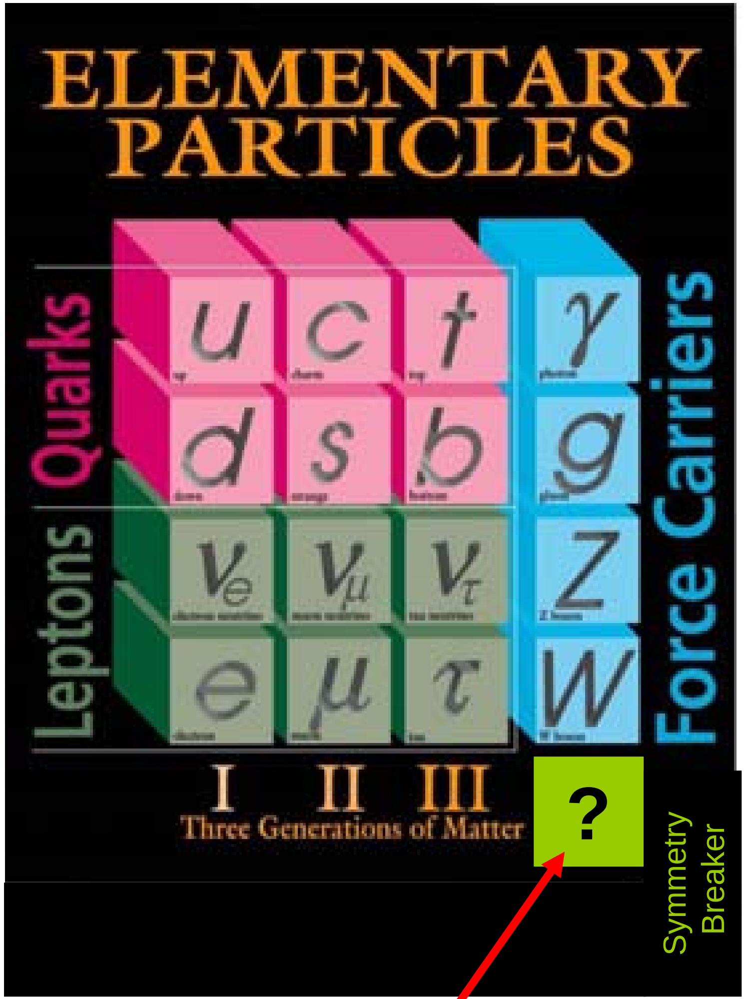
Heartfelt thanks for the hard work from all of my co-conveners!

WG Charges

- What are the most important measurements for Higgs Physics?
- What are new and important recent developments?
- What will ILC add to what is already known from the LHC?
- What are the corresponding detector requirements to allow the corresponding measurements to the appropriate precision?
- What are the theory requirements to allow the corresponding measurements to the appropriate precision?

Introduction to Higgs Physics

- The fact that the electroweak bosons and fermions of the Standard Model have masses is a direct consequence of the electroweak symmetry being **broken**.
- This fact is hugely important to particle physics, but nonetheless the agent of the symmetry breaking is currently **unknown**.
- Until we understand the dynamics responsible for the breaking, the Standard Model itself is **incomplete** and **unverified**.
- The measured masses of the W and Z particles predict that the scale of dynamics of the breaking must be at energy scales of order **100 GeV**.
- The **ILC** is the ideal device to study these energies in enough **detail** and enough **precision** to learn the dynamics of **electroweak symmetry-breaking**.



What goes here?!

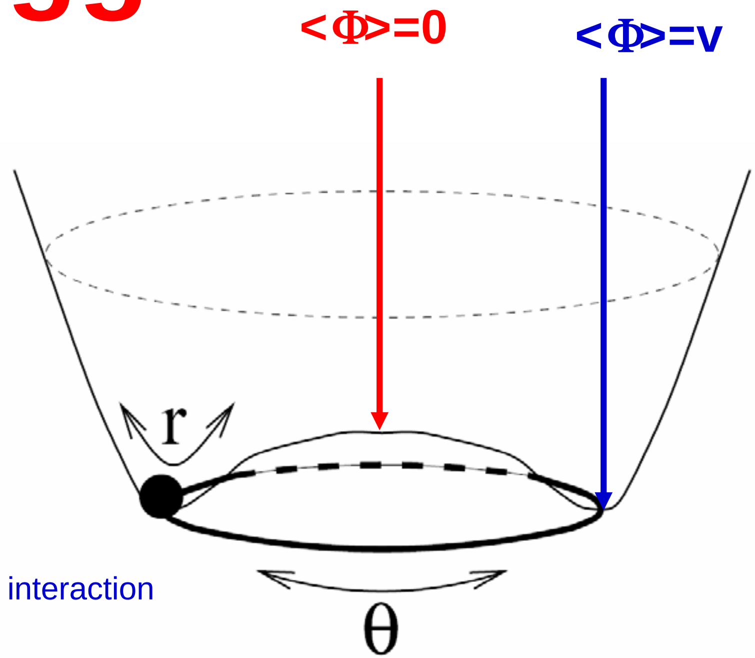
SM Higgs

- The SM accomplishes EWSB through a complex, fundamental scalar field.
- A potential is written down which induces an expectation value in the Higgs, breaking the EW symmetry.
- The potential is characterized by two quantities:

$$V_{Higgs} = -\mu^2 |\Phi|^2 + \lambda |\Phi|^4$$

Higgs “mass” parameter

Higgs “quartic” interaction



- One combination of these quantities is closely related to the W and Z boson masses.
- Some of the entries in the scalar field are “eaten” by the W and Z bosons to serve as their longitudinal polarizations.
- A real scalar field is left over and is the signature of the SM proposal for EWSB.

$$\langle \Phi \rangle = \mathrm{v} = \sqrt{\frac{\mu^2}{2\lambda}}$$

$$M_W^2 = g_W^2 \mathrm{v}^2$$

$$M_h^2 = 2\lambda \mathrm{v}^2$$

Measuring the Higgs mass measures λ, the self-interaction.

Mysteries of EWSB in the SM

“The Standard Model description of electroweak symmetry-breaking is a sham!”
- Michael Peskin

- The SM describes data. Until we see the Higgs, we don’t know if it is correct or not, but we have reasons to believe that it is not the whole story.
- The Higgs potential is unstable with respect to quantum corrections.
- Imagine the one loop correction to the Higgs mass parameter from some heavy particle we haven’t seen yet, i.e.:
  - Stringy states near the Planck scale
  - Grand unified gauge bosons
  - Majorana right-handed neutrinos

$$\frac{g^2}{16\pi^2} M_X^2$$

- Scalars like the Higgs would prefer to have masses near the heaviest particles in the theory. And yet, the Planck scale, GUT scale, and seesaw scale we infer are all much larger than the EW scale. This hierarchy problem motivates much of our belief in new physics at **~ 100 GeV**.

Basic Strategy

- Ultimately, the ILC must discriminate between competing models of electroweak symmetry-breaking.

- In order to do that, we need to understand the mapping between:

Model Space → **Observable Space** → **Detector Space**

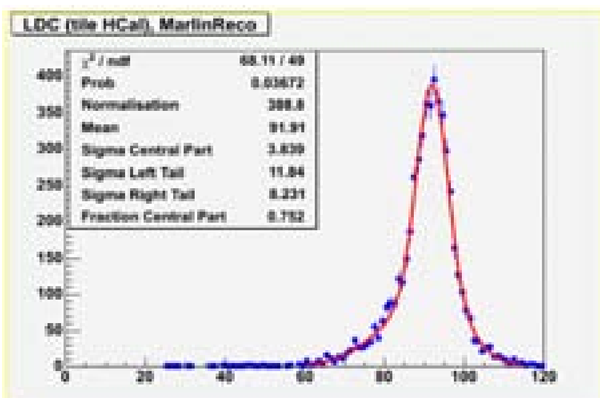
- We also need to understand the geography of both *interesting* model space and *realistic* detector space.

- We can use the SM Higgs as a benchmark to help determine the basic needs from the detector. The SM Higgs is somewhat uniquely suited for this task because it typifies the physics we want to do, and is concrete and well-defined.

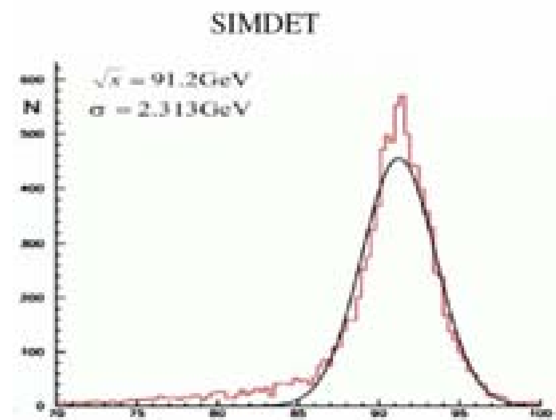
Detector Capability Strategy

- The ILC has entered the phase of detector and machine optimization.

- Most existing studies are based on fast detector simulations. This was fine to establish the physics case of the ILC, but it has some drawbacks:
  - It is difficult to optimize design based on fast simulations.
  - One does not get a realistic understanding of the way the detector design interplays with reconstruction software.
  - We may over- (or under-) estimate the true physics capabilities of the ILC.
- One example can be seen comparing fast to full reconstruction of $Z \rightarrow$ jets.



Presented by
A Raspereza



- An important task before us is to understand this issue, and a first step is to explore how well the fast simulations are doing for key measurements.

Benchmark Studies

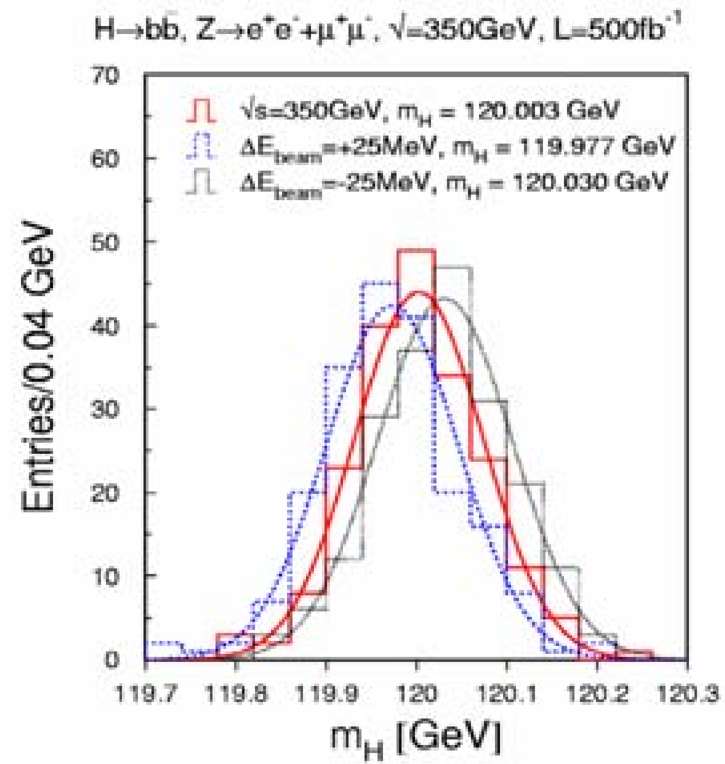
- A few specific Higgs measurements can be used to evaluate the requirements for detector and machine performance in some key areas:
  - Beam energy spread
  - Jet energy resolution
  - Track momentum resolution
  - Jet reconstruction
  - Flavor tagging
  - Vertex reconstruction
- By seeing how specific measurements respond to different design parameters, we get a quantitative measure for the importance of a given design specification.
- New design Proposals can be evaluated for these benchmarks, allowing them to be compared with existing proposals.

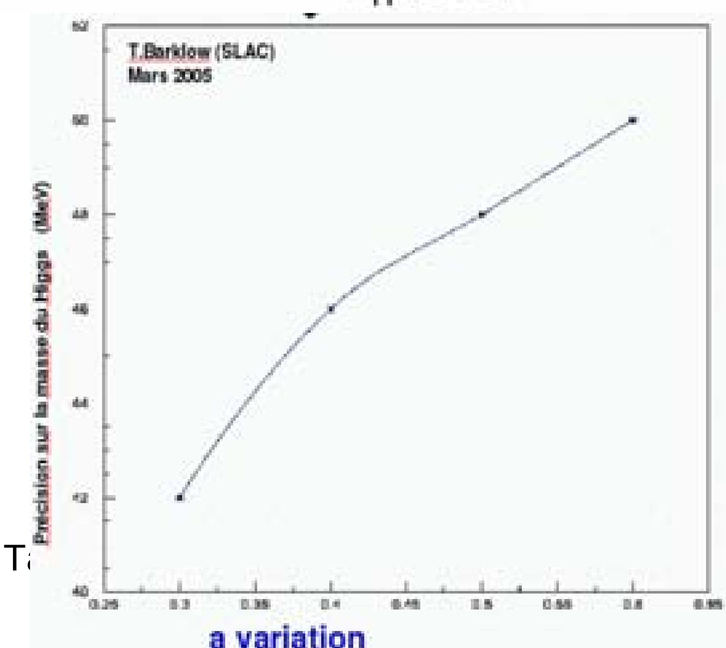
Examples

- An example is the reconstruction of the Higgs mass in HZ events.
- This measurement illustrates both the need for control over spread in the beam energy, as well as jet energy resolution:

$$\Delta E_J = a \times \sqrt{E_J} \oplus b \times E_J + c$$

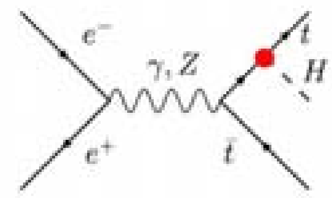
- Other measurements discussed include
  - HZ, with $H \rightarrow WW$,
  - HZ, with $H \rightarrow cc$,
  - HHZ production.

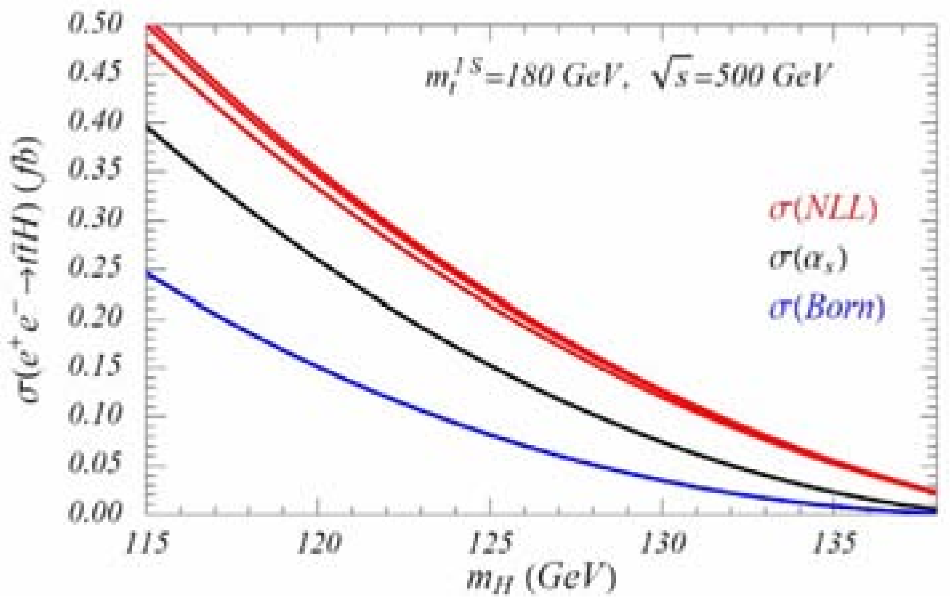




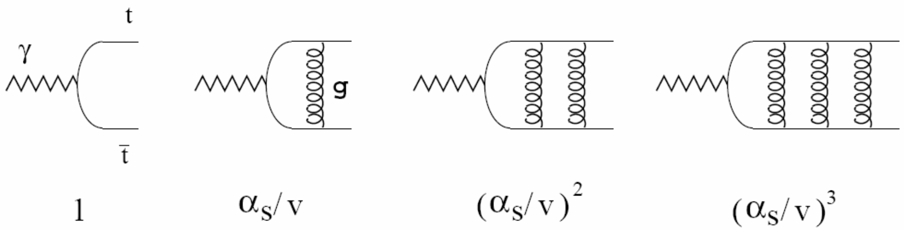
Precise Theoretical Predictions

- Our ability to measure something can be limited by the theoretical tools we have available to make predictions.
- The amazing experimental precision offered by the ILC demands equally precise theory to interpret and analyze the data.
- Measurements at the per cent level typically are sensitive enough to higher order corrections from QCD, EW
- We had a very effective illustration of this point during this meeting. A Hoang presented a new NLL computation of t t H production.
- The threshold corrections when the tops are non-relativistic are quite large, and result in a huge enhancement of the signal.
- Already, this drastically changes our picture of how well ILC at 500 GeV can measure the top Yukawa coupling!





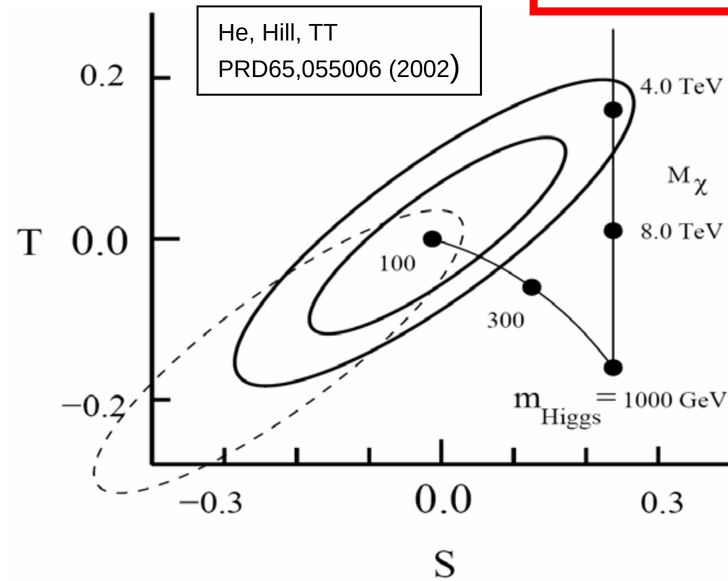
A Hoang, C Farrell PRD72, 014007 (2005)

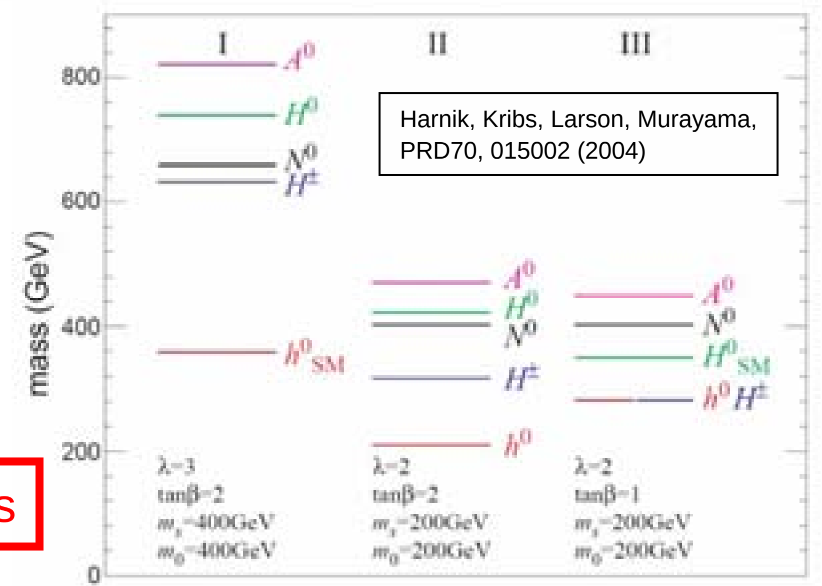


Exotic Scenarios

- SM and MSSM are good benchmark theories, but we must be ready for alternatives. Both favor small m_H.
- However, the EW fit is an indirect determination of m_H, and may be modified by new physics we don't know how to include in the fit.
- Assumptions that make the MSSM minimal are precisely the choice of Higgs sector. Is minimal reasonable?
- We need a compilation of theories beyond the (MS)SM and the deviations they induce in Higgs measurements at the ILC.
- We **must** extend the benchmark measurements to larger Higgs masses!

Top Seesaw

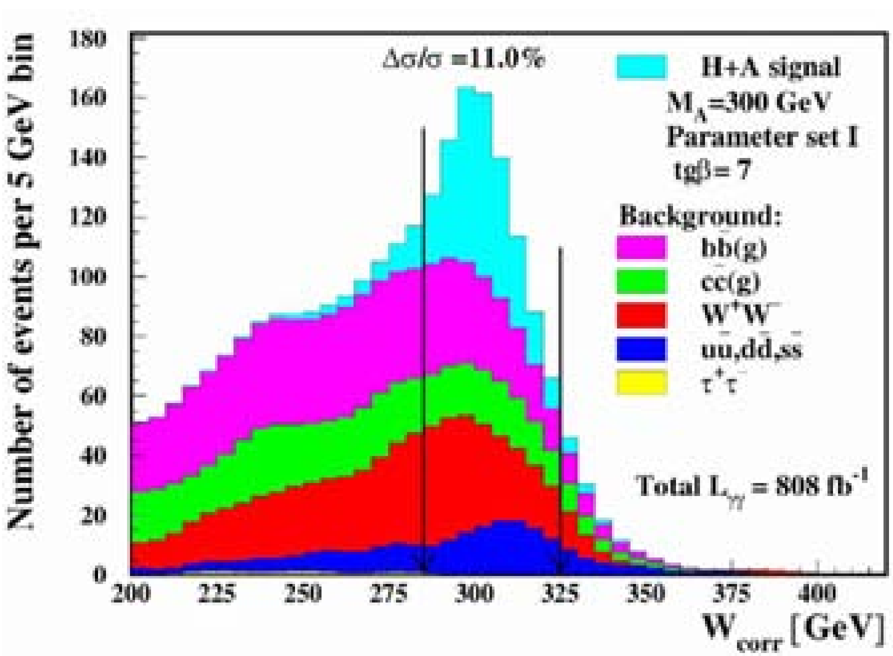


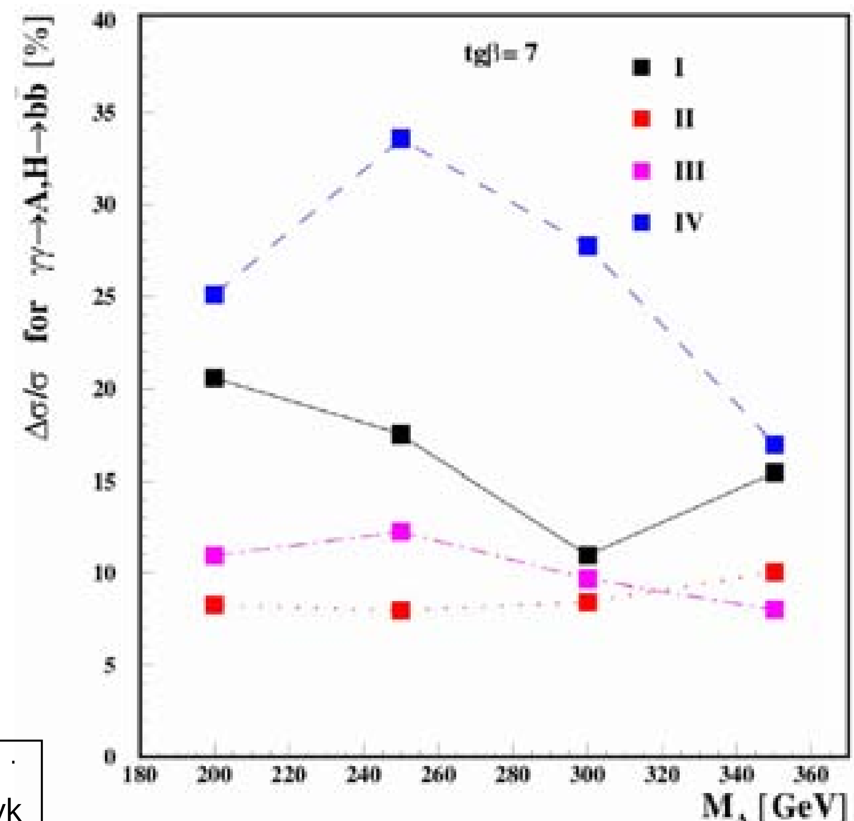


SUSY Fat Higgs

γ Collider?

- A γ collider is an interesting option which has the potential to study Higgs states too massive to be pair-produced in e+e- running.
- Even in the Standard Model, it is a chance to measure the **H-γ-γ** coupling, which is difficult to extract from Higgs decays because it is expected to be very rare.
- If we intend the γ collider option to be taken seriously, we must start planning now in order to decide whether or not it will be incorporated in the upgrade path of the ILC.



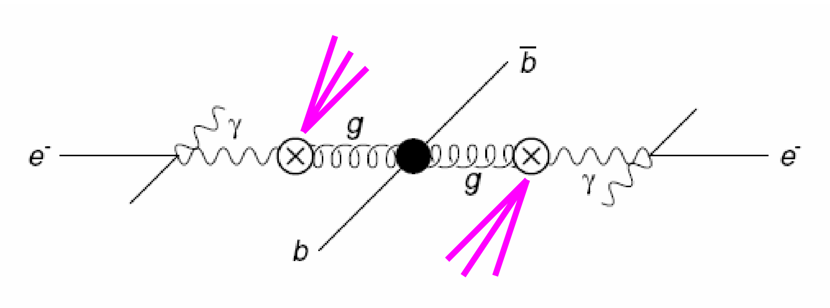


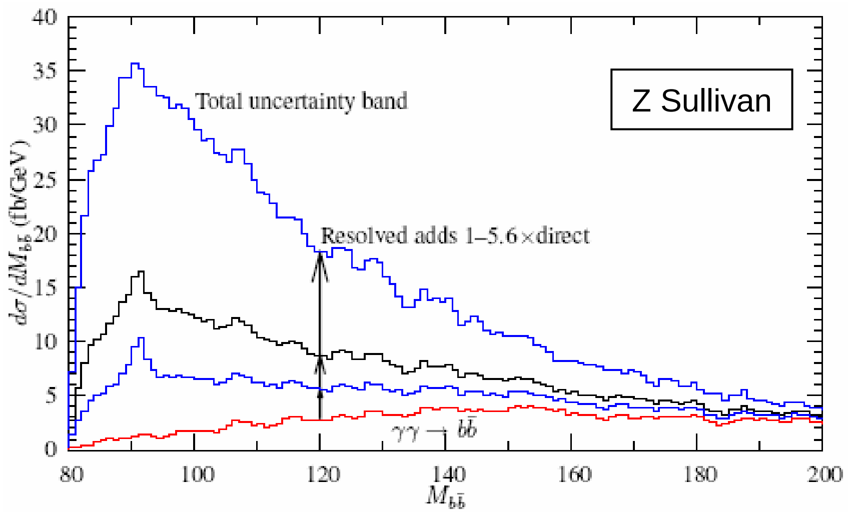
Snowmass, 8/27/05

Presented by J Ciborowski for Niezurawski, Zarnecki, Krawczyk

γ Collider

- However, there is a problem with some of the theory estimates for the backgrounds.
- The “QCD” background of b bbar production has a “resolved” component which depends on the distribution of gluons inside the γ – this PDF is highly uncertain.
- As a result the background estimate is uncertain up to a factor of about **3!.**
- It may be that one could bring this under control by finding the right observable to measure the pdf at a γ collider.
- Or, one might find a way to reduce this background by looking for the extra forward hadronic activity that accompanies the resolved piece and veto’ing it.
- It raises questions that haven’t been seriously considered yet: what will the detectors look like in the forward region at a γ collider? What are the requirements from the relatively high machine backgrounds?
- These issues are vital to define if the γ collider option is to be taken seriously.





Outlook

- We have had a fruitful beginning, with good interplay between theorists and experimentalists. But it is only a beginning.
- For success, we need input from interested people:
  - **Model builders**: What are new and interesting models? What are the parameters that describe them? What are some implications for Higgs? What needs to be done to turn a model idea into concrete information on the particle spectrum, couplings, branching ratios, etc.?
  - **Phenomenologists**: What are new measurements that can test existing models, and what measurements can tell new models apart from one another? How can we improve theoretical predictions to reduce uncertainties in measurements?
  - **Experimentalists/detector experts**: How well can we make these measurements? Can we optimize design to make them better? How can we evaluate realistically our ability to learn about the Higgs and discriminate models?
- In short, regardless of what your area of expertise is, we need **YOU**!