The Higgs TDR Chapter

Status Report to the ECFA-DESY Workshop

M. Battaglia, K. Desch,
A. Djouadi, E. Gross, B. Kniehl

Theory Motivations

The Higgs Profile Determination

Study of Higgs Bosons in Extended Models

Comparison with LHC

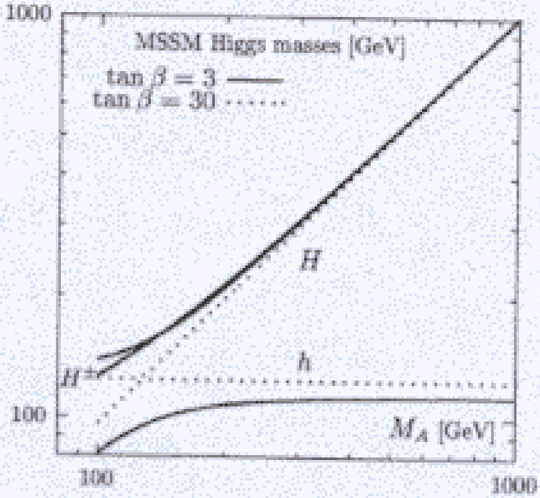
2.1.2 Higgs Bosons in SM Extensions

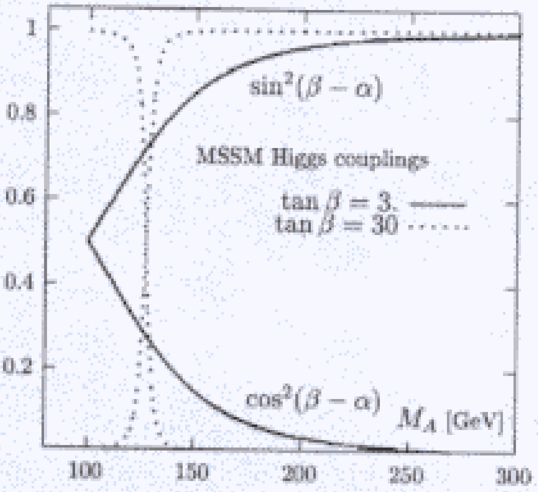
- Several SM extensions introduce additional Higgs doublets:

    1. 2HDM
    2. MSSM
    3. non minimal SUSY

- Supersymmetry relationships among the model parameters, hierarchical structure for the Higgs boson masses ($M_h < M_Z$, $M_A < M_H$ and $M_W < M_{H^\pm}$) partly broken by radiative corrections.
- lightest MSSM h^0 mass ≤ 130 GeV/c^2.
- couplings to fermions and gauge bosons

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi dd}$	$g_{\Phi VV}$
h	$\cos\alpha / \sin\beta \to 1$	$-\sin\alpha / \cos\beta \to 1$	$\sin(\beta-\alpha) \to 1$
H	$\sin\alpha / \sin\beta \to 1/\tan\beta$	$\cos\alpha / \cos\beta \to \tan\beta$	$\cos(\beta-\alpha) \to 0$
A	$1/\tan\beta$	$\tan\beta$	0





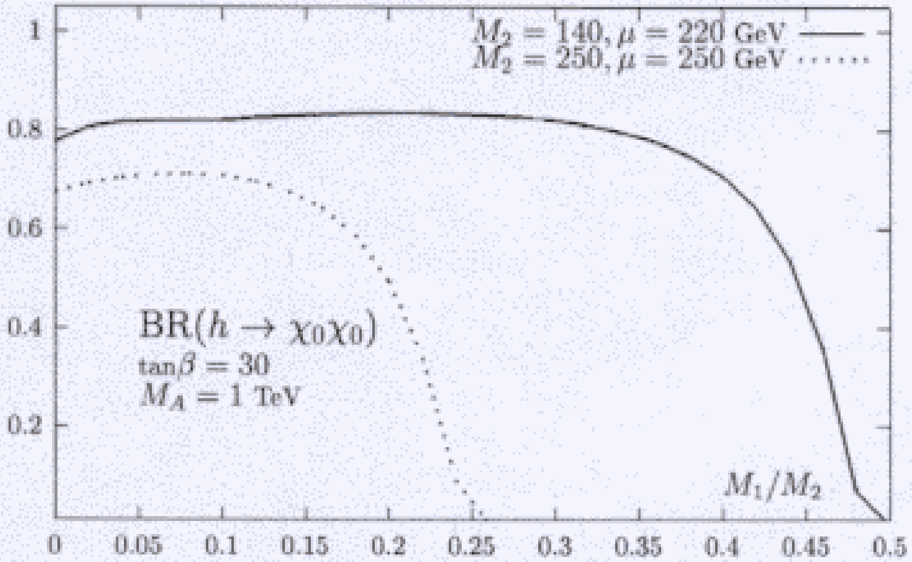
- complementarity of cross sections Higgsstrahlung and Higgs pair production:

$$\sigma_{2HDM}(e^+e^- \to Z + h/H) = \sin^2 / \cos^2(\beta - \alpha)\sigma_{SM}$$

$$\sigma_{2HDM}(e^+e^- \to A + h/H) = \cos^2 / \sin^2(\beta - \alpha)\bar{\lambda}\sigma_{SM}$$

- Mass limits in general SUSY

- Invisible Higgs decays



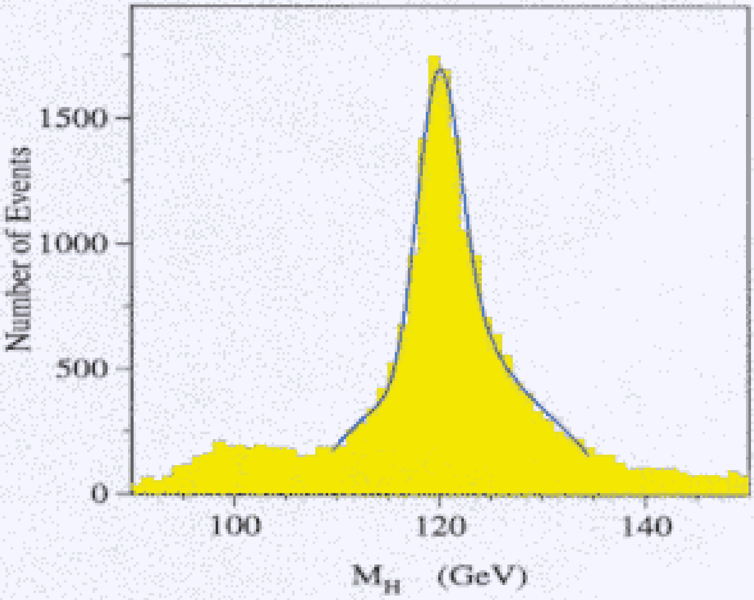
2.1.3 Mass measurement

- Higgs mass M_H not predicted by the theory, it is of great importance to obtain its accurate experimental determination. **Once M_H is fixed, the profile of the Higgs particle is uniquely determined in SM.**

- In theories with extra Higgs doublets, the measurement of the masses is still important to predict their production and decay properties as a function of the remaining model parameters.

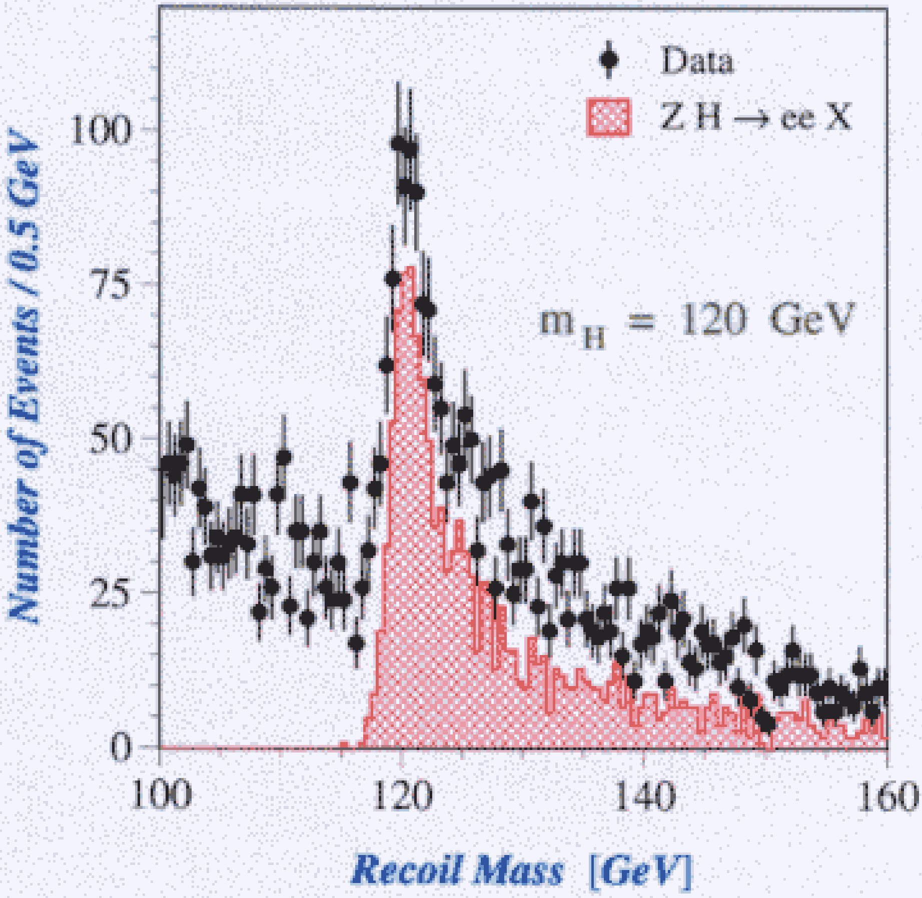
- At the linear collider, the Higgs mass can be best measured by exploiting the kinematical characteristics of the Higgsstrahlung production process $e^+e^- \to Z^* \to HZ^0$

  1. **four jet channel** $q\bar{q}b\bar{b}$: Higgs is reconstructed through its decay in $b\bar{b}$ and the Z^0 in a $q\bar{q}$ pair. The Higgs mass determination relies on a kinematical 5-C fit imposing energy and momentum conservation and the mass of the jet pair closest to the Z^0 mass to correspond to the M_Z.



Mass accuracy $\simeq 50$ MeV$/c^2$ at 120 GeV for 500 fb^{-1}.

2. $\ell^+\ell^- b\bar{b}$ **channel**: Z decays $Z^0 \to e^+e^-$ and $Z^0 \to \mu^+\mu^-$ offer a clean signature in the detector and the lepton momenta are measured with high accuracy in the large tracking volume of the TESLA detector. In order to further improve the resolution of the recoil mass, a vertex constraint is applied in reconstructing the lepton trajectories.

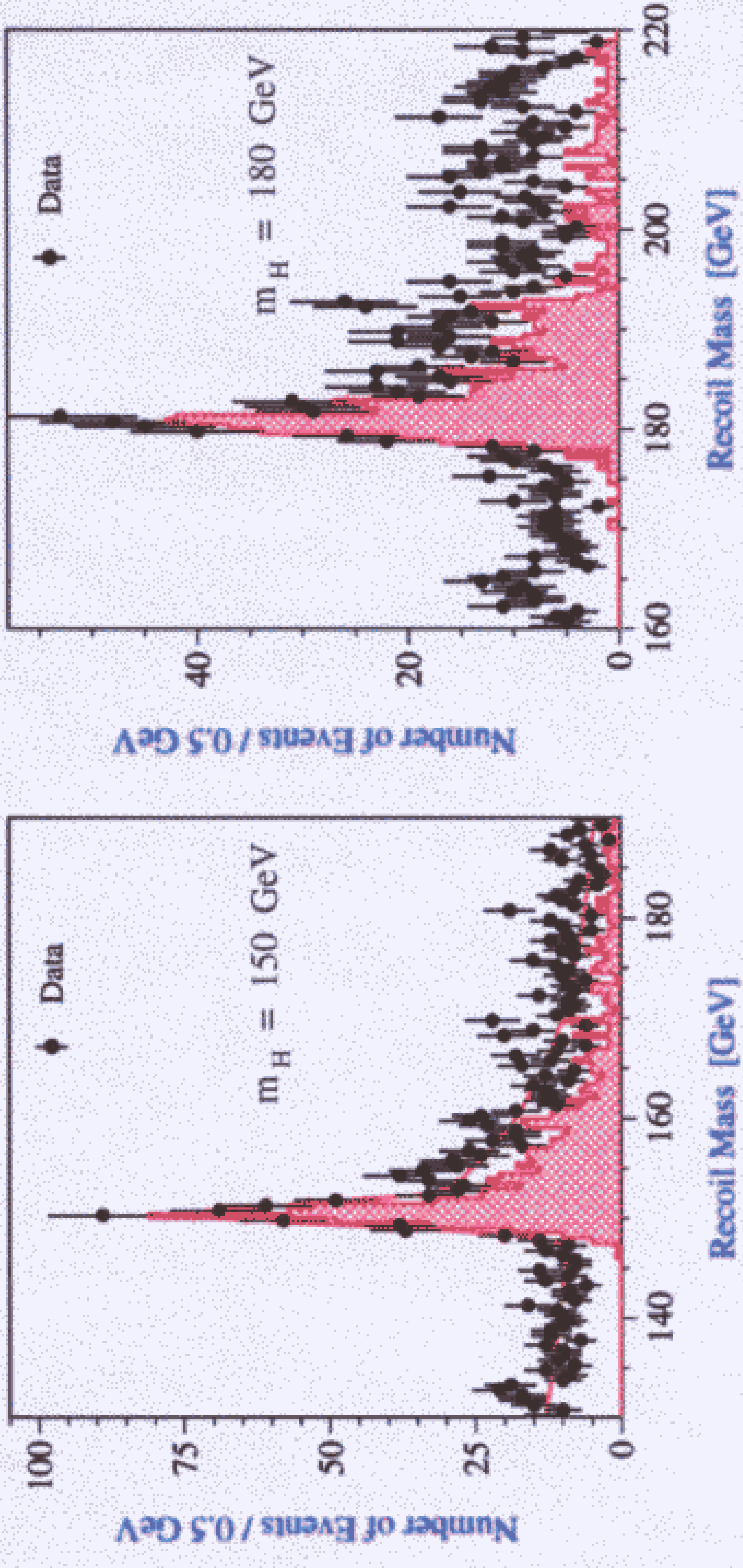


Signal selection efficiencies $\geq 50\%$
Recoil mass resolution = 1.5 GeV/c^2
Mass accuracy $\simeq 70$ MeV/c^2 at 120 GeV for 500 fb^{-1}.

3. $\ell^+\ell^- WW$ **channel**: New results reported:

Recoil Mass

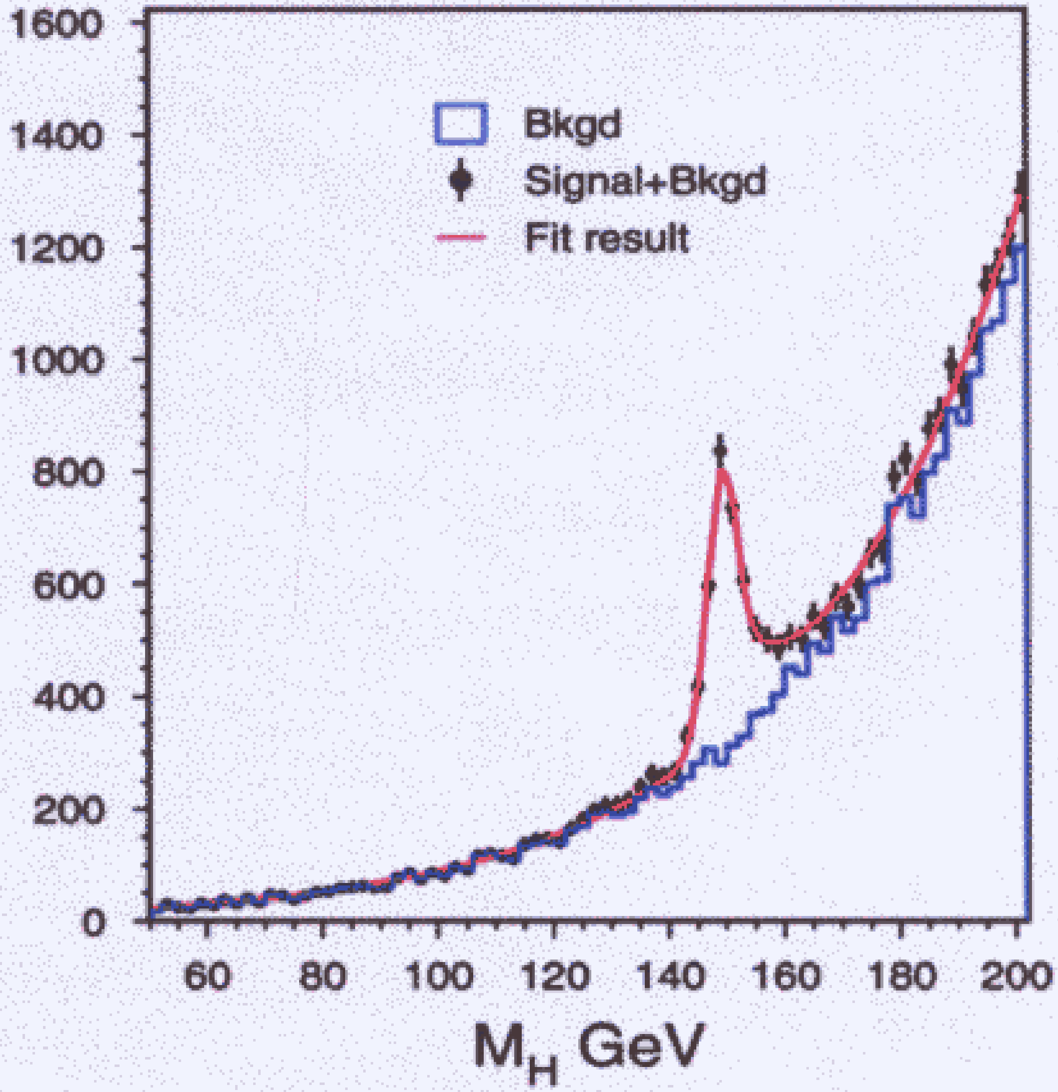
The recoil mass for e^+e^-



Mass fit

$M_H = 150$ GeV :

- 5C fit $(4P + M_Z)$ is performed
- Events are selected if
  $L_{HZ} > 0.5$ and $\chi^2_{5C} > 20$



Signal is fitted with assymetric gaussian

$M_H = 149.76 \pm 0.13$ GeV

$\sigma_l = 3.0$ GeV, $\sigma_r = 3.3$ GeV

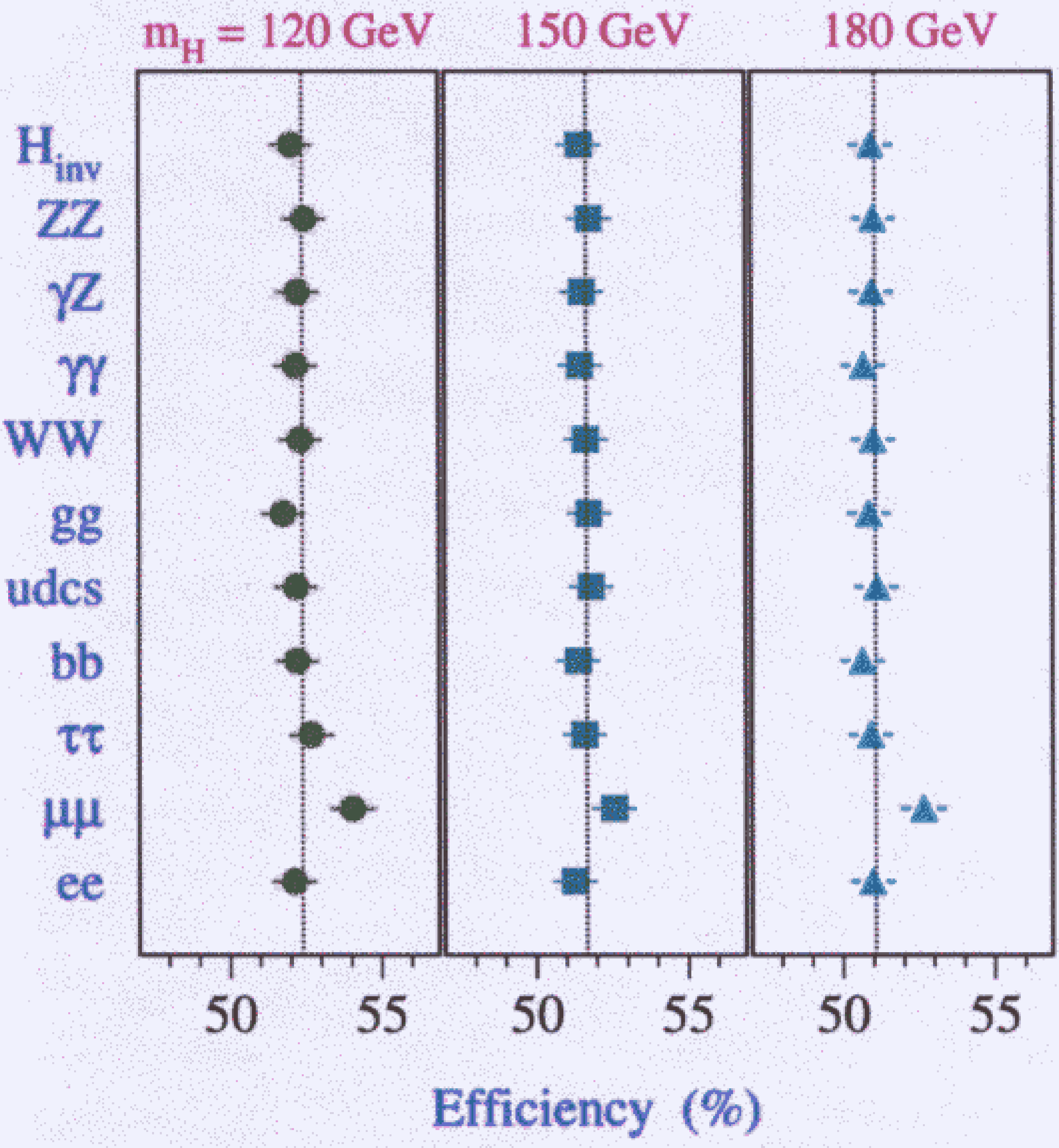
Summary of Higgs Mass Determination Accuracies

M_H (GeV/c^2)	Technique	δM_H (Mev/c^2)
120	$\ell\ell qq$	70
120	$qqbb$	50
120	**Combined**	**40**
150	$qqWW$	130
150	$\ell\ell$ Recoil	90
150	**Combined**	70
180	$\ell\ell$ Recoil	110
180	$qqWW$	160
180	**Combined**	90

- $\gamma\gamma$ collider may provide Higgs mass determination with $1XX$ MeV/c^2 accuracy by resonance scan with sharp edge of the luminosity spectrum.

Efficiency $\mu^+\mu^-$

The efficiency is (almost) independent of the Higgs decay mode



2.1.4 Couplings to Massive Gauge Bosons (W and Z)

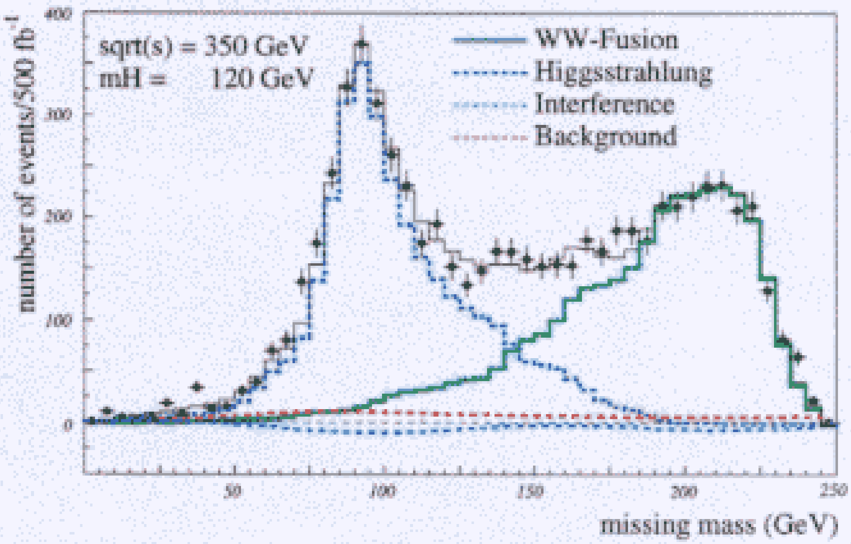
- **Production cross-sections** provide information on the **Higgs couplings to gauge boson** g_{HZZ} **and** g_{HWW}, are needed to **extract the Higgs decay branching fractions from observed decay rates** and provide a determination of Higgs boson total width when matched with the BR($H \to WW^*$)

1. **Higgsstrahlung process** measured by analysis of the mass of the system recoiling against the Z
   - Provides a cross section determination independent on the Higgs decay modes.
   - Statistical accuracy of ± 2.8%, combining the e^+e^- and $\mu^+\mu^-$ channels.
   - Systematics are estimated to be ± 2.5%, mostly due to the uncertainties on the selection efficiencies and on the luminosity spectrum.

The fitted Higgsstrahlung cross sections for different M_H with 500 fb^{-1} at $\sqrt{s} = 350$ GeV. The first error is statistical and the second due to systematics.

m_H (GeV/c^2)	σ_{HZ} (fb) ($\mu\mu$)	σ_{HZ} (fb) (ee)
120	$5.26 \pm 0.18 \pm 0.13$	$5.35 \pm 0.21 \pm 0.13$
150	xxxx $\pm 0.18 \pm 0.11$	xxxx $\pm 0.17 \pm 0.10$
180	xxxx $\pm 0.17 \pm 0.09$	xxxx $\pm 0.15 \pm 0.08$

2. *WW* **fusion** accurately determined in the $b\bar{b}\nu\bar{\nu}$ final state where signal can be be well separated from the corresponding Higgsstrahlung final state exploiting the different spectrum for the $\nu\bar{\nu}$ invariant mass
   - Accuracy from 3% to 16% for Higgs boson masses from 120 GeV/c^2 to 160 GeV/c^2.



   - $\gamma\gamma \rightarrow$ hadrons background overlapped to the $H\nu\bar{\nu}$ event, that may affect the reconstruction and tagging efficiency, can be reduced to a negligible level by a topological tag that profits of long bunch length at TESLA compared to the track extrapolation accuracy.
   - Using beam polarization, the relative contribution of the Higgsstrahlung and *WW* fusion can be varied and systematics arising from the contributions from the two processes and their interference to the fitted spectrum can be consequently reduced.

Exemplification of gain from polarization: $\sigma_{H\nu\bar{\nu}}$ for:

No polarization	80% e^-	80% e^- + 45% e^+

- Accurate determination of the **branching fraction for the decay** $H/h^0 \to WW^*$ can be obtained in the Higgsstrahlung process by analysing semi-leptonic W decays $e^+e^- \to HZ \to \ell\bar{\nu}q\bar{q}q\bar{q}$
  - Large W^+W^- and $t\bar{t}$ backgrounds significantly reduced by imposing the compatibility of the two hadronic jets with Z^0 mass and their recoil system with the Higgs mass.
  - Further background suppression ensured by anti-b tag requirement
  - Residual WW^* background with one off-shell W suppressed by exploiting the possibility to collide right-handed polarized electrons.

Relative accuracy in the determination of a SM Higgs production cross-sections and decay rates into gauge bosons for 500 fb^{-1} at $\sqrt{s} = 350$ GeV

Channel	$M_H = 120$ GeV/c^2	140 GeV/c^2
$\sigma(e^+e^- \to HZ)$	± 0.025	± 0.025
$\sigma(e^+e^- \to WW \to H\nu\bar{\nu})$	± 0.025	± 0.025
$\sigma(e^+e^- \to ZZ \to He^+e^-)$	± 0.xxx	± 0.xxx
BR($H/h^0 \to WW^*$)	± 0.051	± 0.025
BR($H/h^0 \to Z^0Z^0$)		± 0.xxx

2.1.5 Coupling to Photon

- **Higgs production/decay to** $\gamma\gamma$ proceed through **loops** dominated, in SM, by contribution of W **boson** but **sensitive to any particles coupling directly to Higgs,** γ

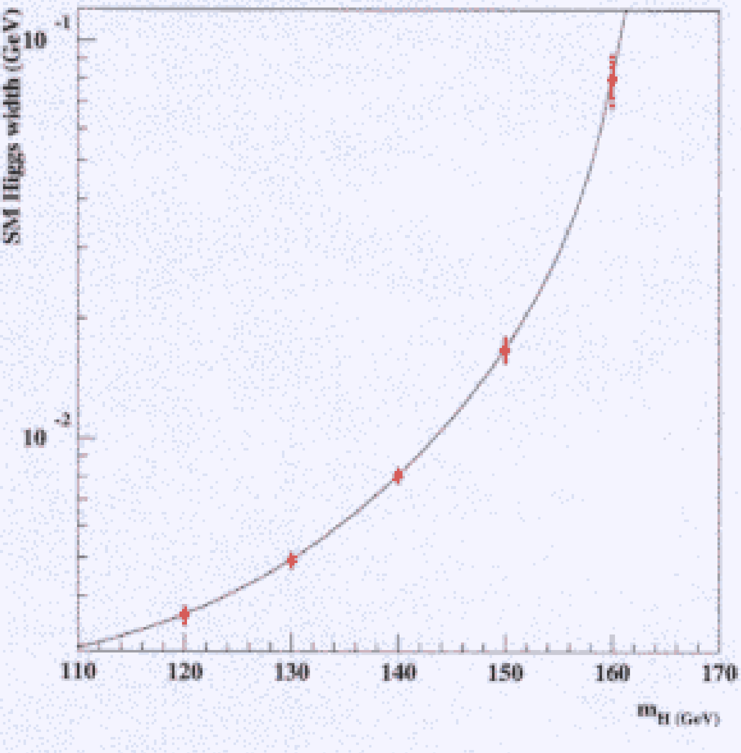
- $\gamma\gamma \rightarrow H$ accessible at $\gamma\gamma$ collider:
    - $\gamma\gamma \rightarrow H \rightarrow b\bar{b}$ accessible but severe $\gamma\gamma \rightarrow c\bar{c}$ background to be rejected by efficient b-tagging (requirements on interaction region and Vertex Tracker).
    - Expected cross section accuracy δ ($\sigma(\gamma\gamma \rightarrow H)) \simeq 1.5\%$ - 5%

- $H \rightarrow \gamma\gamma$: analysed in both $\gamma\gamma\nu\bar{\nu}$ and the $\gamma\gamma$ + jets final states: $\delta(BR(H \rightarrow \gamma\gamma)) \simeq 19\%$ for $M_H = 120$ GeV/c^2 and 500 fb^{-1} at $\sqrt{s}$ = 350 - 500 GeV
- Uncertainty, statistically limited, reduced to 13.5% for 1000 fb^{-1}

2.1.6 Higgs Total Width

- The SM Higgs total width is extremely narrow for light mass values and increases rapidly once the WW^* and ZZ^* decay channels become accessible to reach a value of 1 GeV at the ZZ threshold.
- At the linear collider, Higgs width for masses below 200 GeV is to be obtained indirectly from the **combination of measurements of a Higgs coupling constant with the corresponding decay branching fraction.**

   1. g_{HZZ} through the Higgsstrahlung cross section
   2. g_{HWW} through the WW fusion cross section
   3. $g^{\text{effective}}_{\mathrm{H}\gamma\gamma}$ through $\sigma(\gamma\gamma \to \mathrm{H})$



- Show down to which mass the direct Higgs total width determination becomes feasible / competitive:

2.1.7 Couplings to Fermions and Gluons

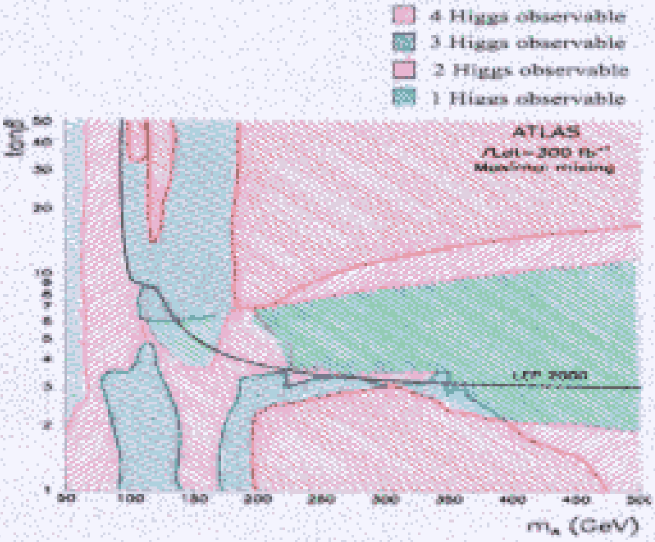
- Accurate determination of the **Higgs couplings to fermions** important as **proof of Higgs mechanism** and to establish the **nature of the Higgs boson**.
- **Higgs decays to** gg **and** $\gamma\gamma$ proceed through **loops** dominated, in SM, by contributions of **top quark** and W **boson** respectively but **sensitive to any particles coupling directly to Higgs,** g **and** γ
- High resolution **Vertex Tracker**, advanced **jet flavour tagging** techniques and the large **statistics available at the** TESLA **collider** move these studies in the domain of **precision measurements**.
    - Hadronic Higgs decay channels: fractions of $b\bar{b}$, $c\bar{c}$ and gg Higgs final states is extracted by a binned maximum likelihood fit to the di-jet flavour tagging probabilities for the Higgs decay candidates
    - $H/h^0 \rightarrow \tau^+\tau^-$: global $\tau\tau$ likelihood is defined by using the response of discriminant variables such as charged multiplicity, jet invariant mass and track impact parameter significance.

Relative accuracy in the determination of Higgs boson decay branching ratios for 500 fb^{-1} at $\sqrt{s} = 350$ GeV

Channel	$M_H = 120$ GeV/c^2	$M_H = 140$ GeV/c^2	$M_H = 160$ GeV/c^2
$H^0/h^0 \rightarrow b\bar{b}$	± 0.027	± 0.027	± 0.0xx
$H^0/h^0 \rightarrow c\bar{c}$	± 0.137	± 0.137	± 0.0xx
$H^0/h^0 \rightarrow gg$	± 0.060	± 0.060	± 0.0xx
$H^0/h^0 \rightarrow \tau^+\tau^-$	± 0.062	± 0.062	± 0.0xx

2.1.13 The Complementarity with the LHC

Number of Higgs Bosons Observable at the LHC



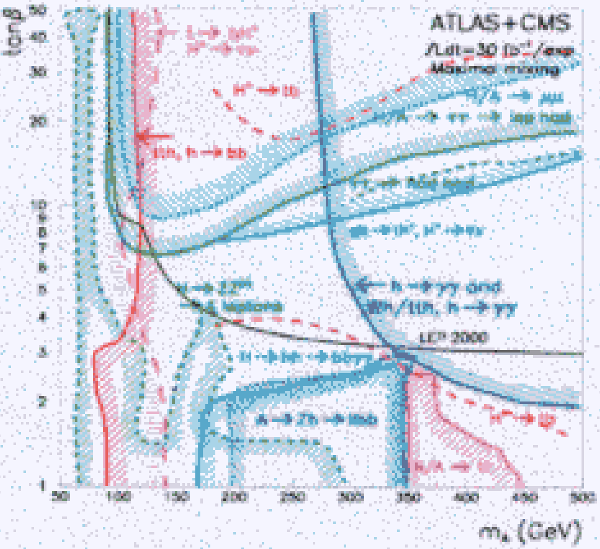
- Beyond its discovery, measurements of the Higgs properties are difficult at the LHC due to limited signal statistics and/or large backgrounds and systematic uncertainties
- While the LHC may provide with some ratios of branching ratios, precision measurements of the absolute branching ratios and couplings remain an experimental program to be addressed at a high luminosity linear collider such as TESLA.
- In summary, the complementarity of TESLA to the LHC in Higgs physics is threefold:

1. The **accuracy of the measurements which are possible at the LHC to be significantly improved**.
2. Accurate **absolute measurements of all relevant Higgs boson couplings** (including the Higgs self coupling) **only possible at TESLA**.
3. Extended Higgs boson scenarios (e.g. invisible Higgs boson decays) can only be seen at TESLA. Therefore the **loopholes of a possible non-discovery at the LHC can be closed at TESLA**.

2.1.14 The Complementarity with the LHC

- Beyond its discovery, measurements of the Higgs properties are difficult at the LHC due to limited signal statistics and/or large backgrounds and systematic uncertainties

MSSM Higgs Bosons Observability at the LHC



- While the LHC may provide with some ratios of branching ratios, precision measurements of the absolute branching ratios and couplings remain an experimental program to be addressed at a high luminosity linear collider such as TESLA.
- In summary, the complementarity of TESLA to the LHC in Higgs physics is threefold:

1. The **accuracy of the measurements which are possible at the LHC to be significantly improved**.
2. Accurate **absolute measurements of all relevant Higgs boson couplings** (including the Higgs self coupling) **only possible at TESLA**.
3. Extended Higgs boson scenarios (e.g. invisible Higgs boson decays) can only be seen at TESLA. Therefore the **loopholes of a possible non-discovery at the LHC can be closed at TESLA**.

Expected signal and background events /100 fb^{-1} for the Higgsstrahlung channel with di-lepton final states $e^+e^- \to Z^0H \to \ell^+\ell^-X$, $(\ell = e,\ \mu)$.

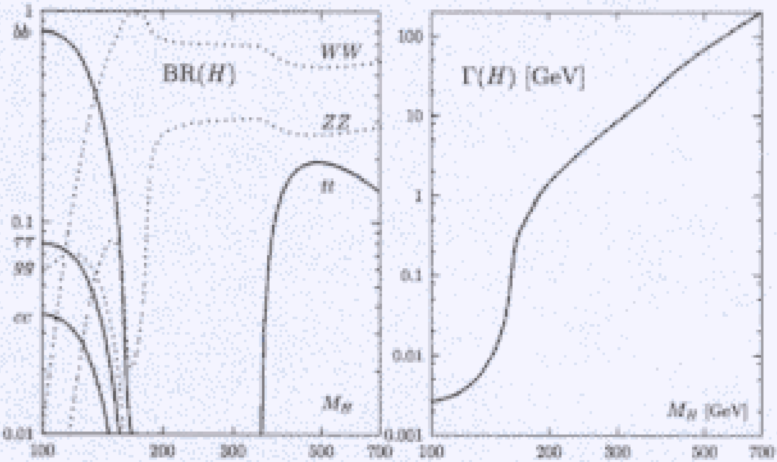
M_H (GeV/c^2)	X	$\sqrt{s} = 350$ GeV	500 GeV	800 GeV
120	$b\bar{b}$	xxx / yyy	xxx / yyy	xxx / yyy
140	$b\bar{b}$	xxx / yyy	xxx / yyy	xxx / yyy
160	WW	xxx / yyy	xxx / yyy	xxx / yyy
180	WW	xxx / yyy	xxx / yyy	xxx / yyy
Max M_H				xxx GeV/c^2

- For Higgs particles in the lower part of the intermediate mass range $M_Z \le M_H \le 2M_Z$, the **main decay modes are fermion decays**:

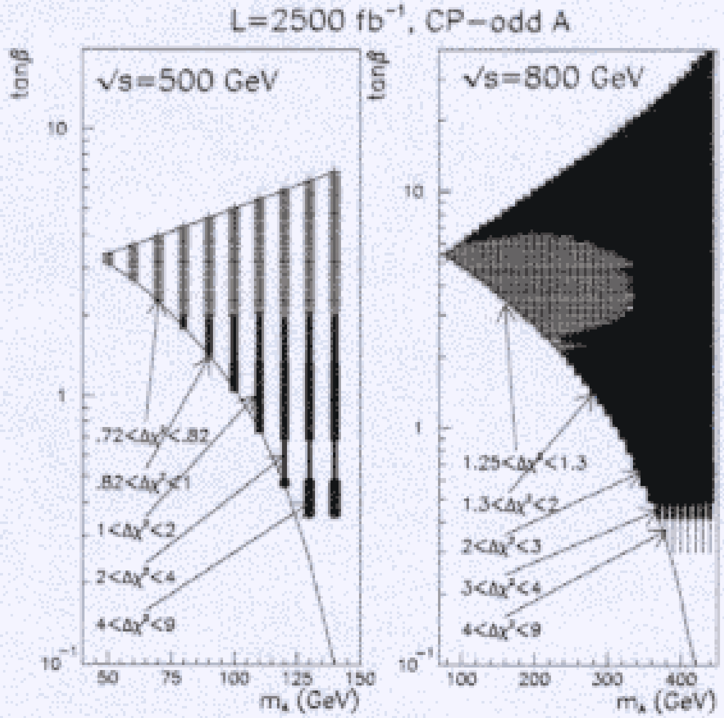
$$\Gamma(H \to f\bar{f}) = \frac{G_F N_C}{4\sqrt{2}\pi} m_f^2(M_H^2) M_H$$

- Above the ZZ threshold, Higgs particles decay almost exclusively into the W/Z **channels**:

$$\Gamma(H \to WW(ZZ)) = 2(1)\frac{\sqrt{2}G_F}{32\pi} M_H^3$$



- For a range of moderate $\tan\beta$ that increases with increasing M_h, the luminosity required for its observation exceeds even that expected at TESLA.



1. Significant improvement in the precision of the electroweak measurements and direct searches at the GigaZ TESLA may clearly exclude (or prefer) the 2HDM no-discovery-wedge fits.
2. Derive possible constraints from $\gamma\gamma \to H$.
3. The problem can be further addressed at a next-to-next generation e^+e^- linear collider.

2.1.13 Non Supersymmetric 2HDM

- In general 2HDM, unconstrained by the requirement of perturbative couplings at a high GUT scale or by the supersymmetric relations between quartic Higgs couplings and gauge couplings, a no-lose theorem cannot be established.

- The h^0, A^0 and $H^\pm$ analyses discussed above are also sensitive to general 2HDM Higgs bosons over a large portion of the parameter space.

- Radiative corrections to H^+H^- pair production can be significant and their model dependence may help discriminating between the SUSY and a non-supersymmetric 2HDM Higgs sector.

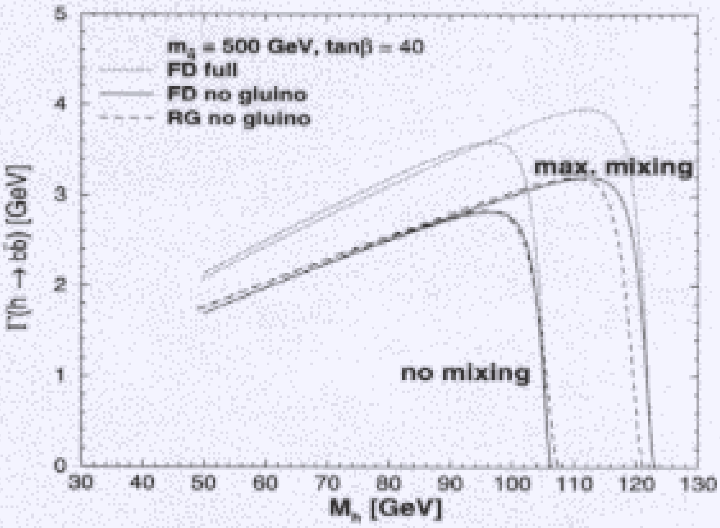
- However, regions of parameter space exist for which all Higgs bosons of the model can escape detection while at the same time the fit to precision electroweak observables is nearly as good as in the SM and Supersymmetry cases

- While for these scenarios require an *ad hoc* choice of the masses and couplings their investigation is interesting to outline the possible open problems and getting hints on how to address them.

- Specific example:
  - Choose Higgs masses so that there is only one h^0 light enough to be produced at TESLA.
  - Suppress ZZh coupling implying $C_h << 1$:

3. **Indirect estimate of the mass** M_{A^0} in the MSSM: accuracy of 70 GeV/c^2 to 100 GeV/c^2 in the mass range 300 $\mathrm{GeV}/c^2 < M_A < 600\ \mathrm{GeV}/c^2$.

4. Additional sources of systematical uncertainties:
   - Corrections to the one-loop MSSM predictions found to be small
   - Corrections coming from the one-loop gluino vertex corrections should also be considered at large $\tan\beta$ and large μ values.

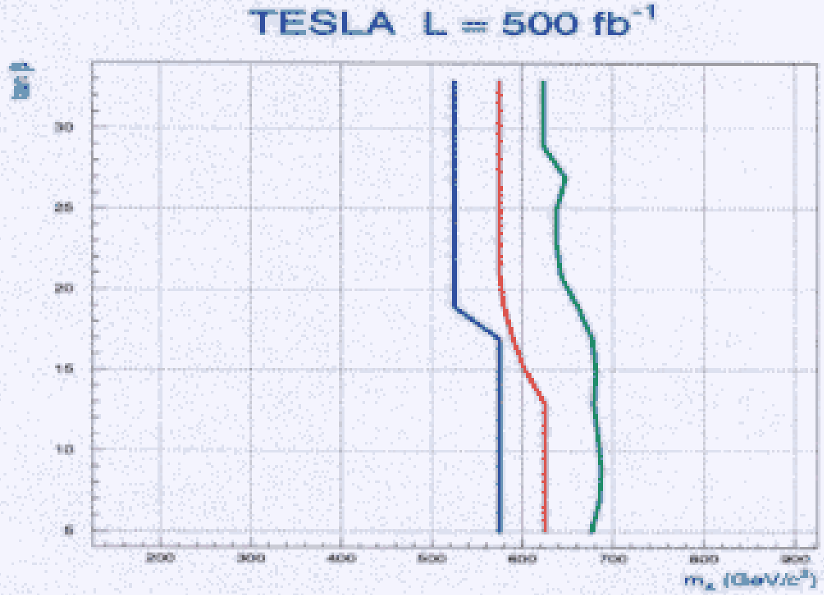


5. If a light Higgs boson is observed and have MSSM-like properties, its associated production with $b\bar{b}$ pairs may be observed and used to **directly determine** $\tan\beta$.

2.1.12 Indirect determination of the SM/MSSM nature of a light Higgs boson and determination of $\tan\beta$

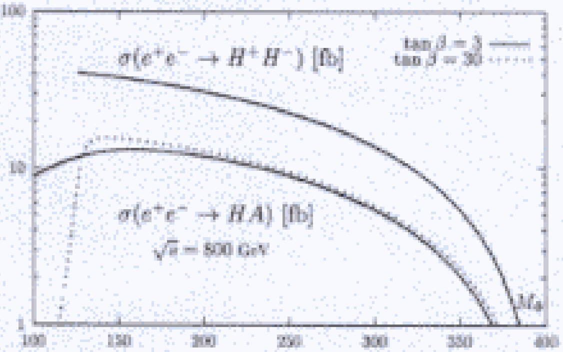
- The discovery of a neutral Higgs boson, with mass in the range $115\ \mathrm{GeV}/c^2 < M_H < 140\ \mathrm{GeV}/c^2$, will raise the question if the observed particle is the **SM Higgs** or the **lightest boson of a SM extension**.
- For a large fraction of the $\tan\beta - M_A$ parameter plane in the MSSM, this neutral boson will be the only Higgs observed at the LHC.
- If the scale M_{SUSY} is high enough, also at TESLA, SUSY will not reveal itself by the production of supersymmetric fermion partners.
- A Higgs generated by a complex multi-doublet model must be **indirectly recognized by a study of its couplings**
  1. HZZ coupling: significantly smaller compared to SM expectation signals the existence of extra Higgs doublets.
  2. Higgs decay branching ratios to tell SM from MSSM Higgs:

$$\Gamma_{b\bar{b}}^{MSSM} \propto \Gamma_{b\bar{b}}^{SM} \frac{\sin^2\alpha}{\cos^2\beta}$$
$$\Gamma_{c\bar{c}}^{MSSM} \propto \Gamma_{c\bar{c}}^{SM} \frac{\cos^2\alpha}{\sin^2\beta}.$$

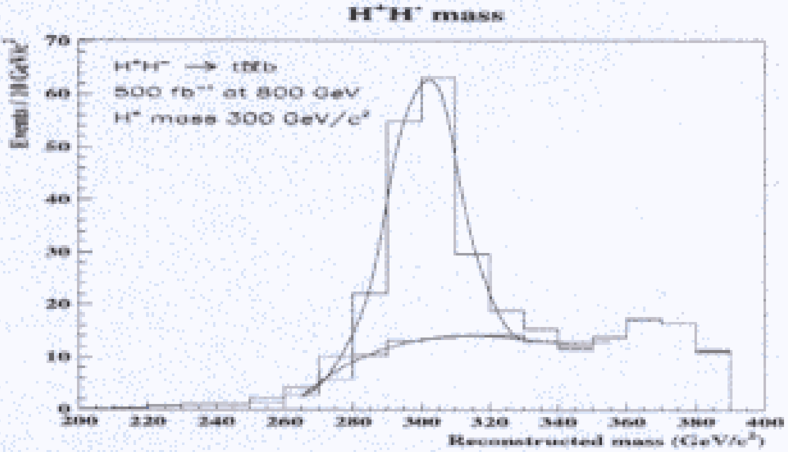


- A most distinctive feature of extended models such as Supersymmetry, or general 2HDM extensions of the SM, is the existence of additional Higgs bosons.

1. $H^\pm$:



   - $e^+e^- \to H^+H^- \to t\bar{b}\bar{t}b$ process studied for $M_{H^\pm} = 300$ GeV$/c^2$ at $\sqrt{s} = 800$ GeV.
   - 8 jet final state with 4 b-quark jets allows to reduce the backgrounds to small level using b tagging and the intermediate t and W mass constraints.
   - Combinatorial background due to jet-jet pairing in signal events can be resolved using jet flavour tagging information: $\delta M = 1$ GeV$/c^2$ and $\delta(\sigma \times BR) \simeq 10\%$



2. H^0, A^0: to be added

2.1.11 Study of SUSY Higgs Bosons

- If Supersymmetry exists in nature, a major goal of TESLA will be that of measuring its Higgs sector to determine the underlying SUSY-breaking mechanism

- In order to match the anticipated experimental precision, highly **accurate predictions** of $m_h, \sigma_{Zh}, \sigma_{Ah}, \Gamma(h \to \ldots), \mathrm{BR}(h \to \ldots)$ are required and progresses have recently been made in the theoretical predictions

- In the most general supersymmetric model, supersymmetry constrains the quartic Higgs couplings. The key sum rule is $\sum_h C_h^2 M_h^2 \leq m_B^2$

- A $\sqrt{s} = 500$ GeV linear collider with $L > 200$ fb^{-1} will produce enough of the light hs that a ZX signal will be seen even if there are many hs separated by less than the experimental resolution, each decaying to a variety of decay modes.

- Study of the lightest neutral MSSM Higgs boson h^0 to follow closely that of the SM-like H^0

- sensitivity to $h^0 \to$ invisible MSSM (w/o gaugino mass unification), stealth Higgs scenario, Xtra dimensions: to be added

2.1.10 Higgs self potential

- **Establish the Higgs mechanism** experimentally in an unambiguous way through the reconstruction of the Higgs self–energy potential.

- Determination of the trilinear self–couplings probed in the production of pairs of neutral Higgs boson
- Most interesting process: double Higgsstrahlung $e^+e^- \rightarrow HHZ$
- Four and six fermion background and tiny signal cross section make this analysis a genuine experimental challenge.
- Profit of characteristics signature with four b jets and a Z^0, reconstructed either in its leptonic or hadronic decay modes, and of the excellent tagging and reconstruction capabilities of the TESLA detector

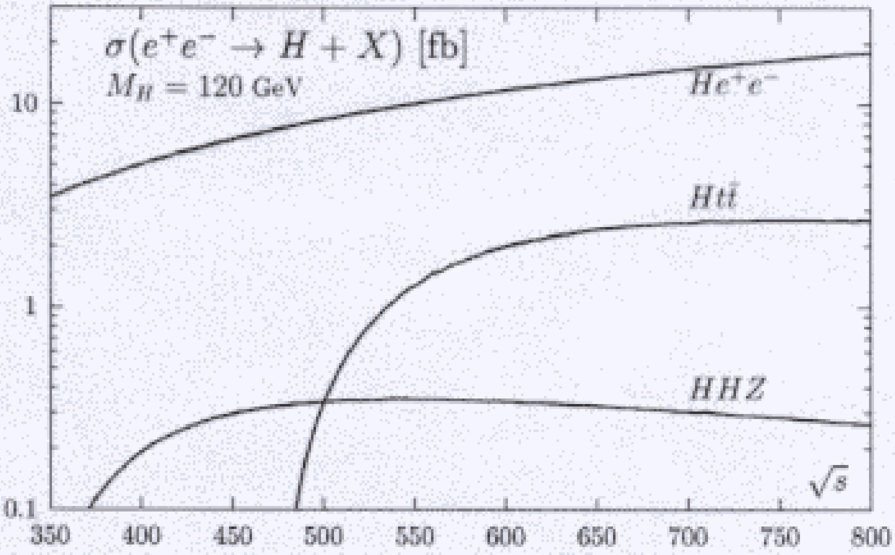
The number of reconstructed signal and background events for the hadronic and leptonic channels and their combination in the double Higgsstrahlung analysis for 500 fb^{-1} at $\sqrt{s} = 500$ GeV.

M_H	120	130	140
HHZ	29.	24.	18.
$\epsilon(HHZ)$ (%)	15.7	16.5	14.7
W^+W^-	25.	25.	23.
$Z\gamma$	12.	14.	10.
ZZ	0.	0.	0.
WWZ	0.	0.	0.
ZZZ	.9	.9	.8
HZ	0.	0.	0.
Total Bkg	38.	41.	34.
$S/\sqrt{B}$	4.7	3.8	3.1

- With 1000 fb^{-1}: 60 signal, 80 bkg evts.

2.1.8 Higgs radiation off top quark

- Higgs Yukawa coupling to the top quark, which is the largest coupling in the SM ($g^2_{t\bar{t}H} \simeq 0.5$ to be compared with $g^2_{b\bar{b}H} \simeq 4 \times 10^{-4}$), directly accessible in $e^+e^- \to t\bar{t}H$



- Experimental accuracy on the determination of top Yukawa coupling has been studied for $\sqrt{s} = 800$ GeV and $L = 1000$ fb^{-1} in both semileptonic and fully hadronic channels.

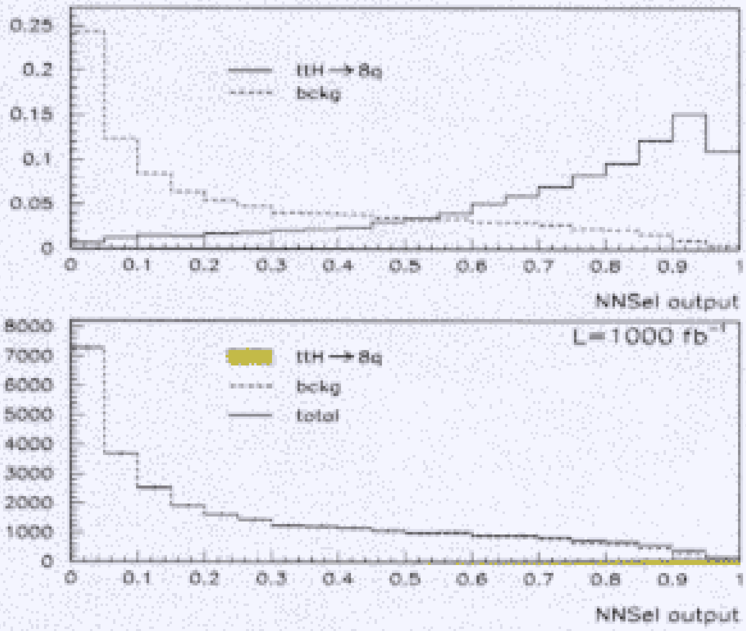
- Efficiency loss from failures of the jet-clustering and of the b-tagging due to hard gluon radiation and large multiplicities.

- Adopt highly efficient pre-selection criteria and a Neural Network trained to separate the signal from remaining backgrounds.

- Essential to ensure a very good knowledge of bkg cross section and response to discriminating variable

Statistical and systematic uncertainties in the top-Higgs Yukawa coupling for an integrated luminosity of 1000 fb^{-1}.

	ϵ (%)	S/B	$\delta_{\text{stat.}}$ (%)	$\delta_{\text{syst.}}$ (%)	$\delta_{\text{tot.}}$ (%)
Semileptonic					
After Preselection	54.1	0.03	11.5	63.1	64.1
Fit to NNSel (50 bins)	54.1	0.03	4.4	9.1	10.1
NNSel>0.9 (optimal cut)	27.1	0.51	5.1	3.8	6.3
Hadronic					
After Preselection	77.1	0.03	9.8	83.5	83.5
Fit to NNSel (50 bins)	77.1	0.03	4.2	13.7	14.3
NNSel>0.95 (optimal cut)	8.5	0.90	7.3	3.0	7.9



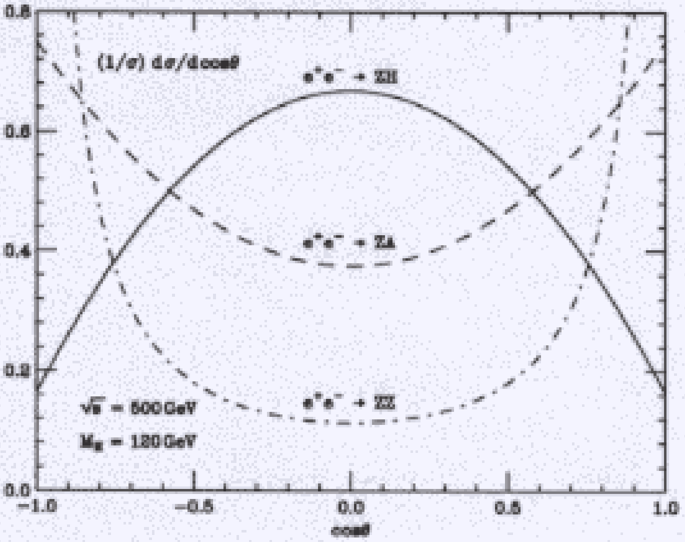
For 1000 fb^{-1} the uncertainty in the top-Higgs Yukawa coupling is ± 4.2% (stat), becoming ± 5.5% (stat+syst) by assuming a 5% uncertainty in the overall background normalization.

2.1.9 Quantum Numbers of the Higgs Boson

- Spin, parity, and charge-conjugation quantum numbers J^{PC} of Higgs bosons can be determined at the linear collider in a model-independent way.

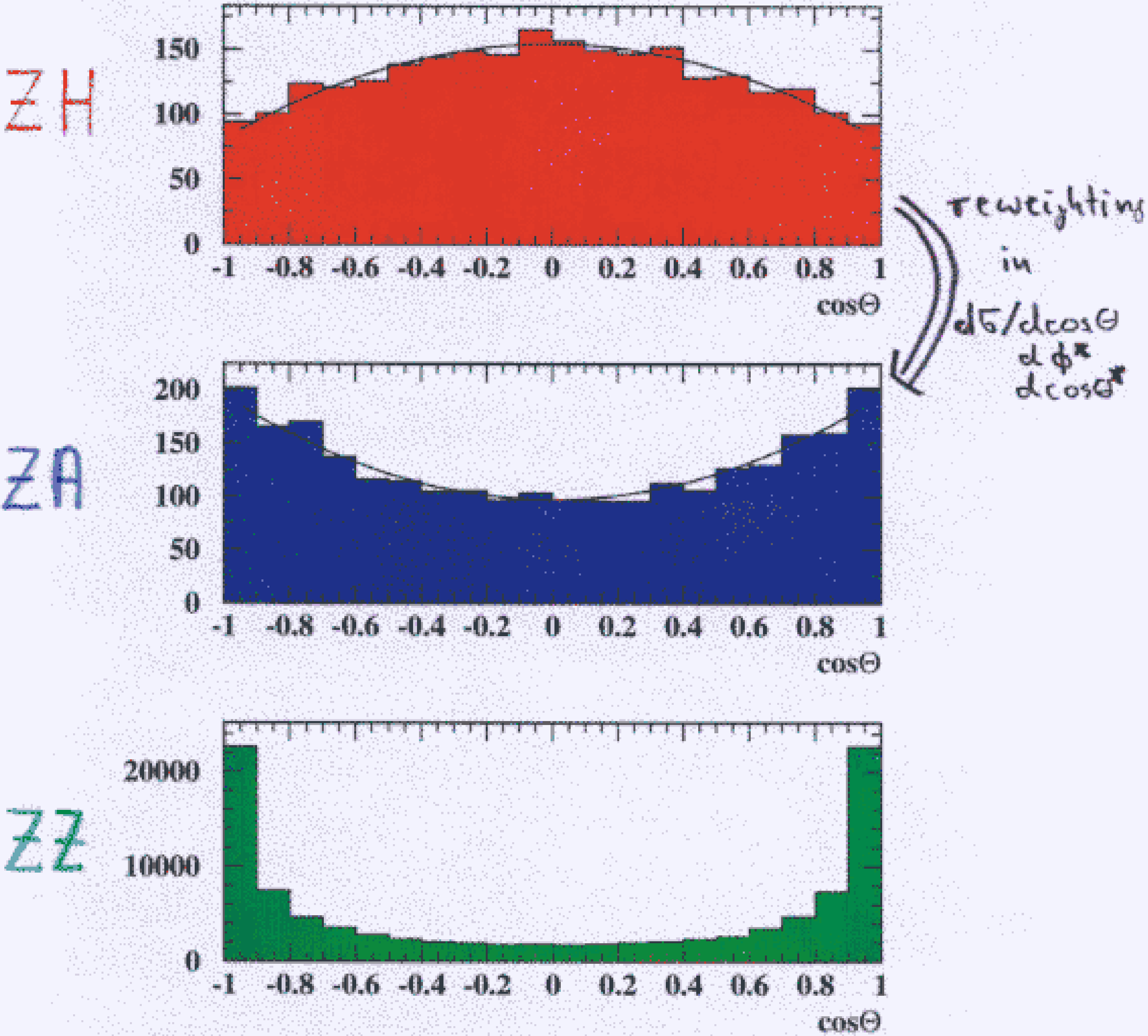
  - **Observation of Higgs production at the photon collider** or the $H \to \gamma\gamma$ **decay** rules out $J = 1$ and sets C to be positive.

  - **Angular dependence of $e^+e^- \to ZH$ cross-section** allows to determine J and P and to distinguish the SM Higgs boson from a CP-odd 0^{-+} state A, or a CP-violating mixture of the two.



  - The angular distribution of the $Z \to f\bar{f}$ decay products in the Higgsstrahlung process allows also to distinguish a CP-even Higgs boson from a CP-odd one or a spin-one boson.

$\cos\Theta_Z$ distribution at generator level



Selection

1) 2 isolated μ, $\sphericalangle_{iso} = 10°$, $E_\mu > 15\,\mathrm{GeV}$, perfect μ ID

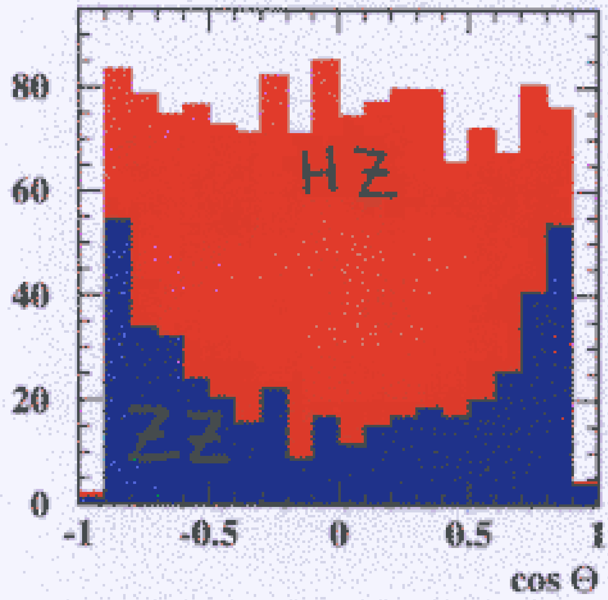
2) $|M_{\mu\mu} - M_Z| < 5\,\mathrm{GeV}$ 3) $|M_{Rec} - M_H| < 5\,\mathrm{GeV}$

4) $|P^z_{\mu 1} + P^z_{\mu 2}| < 125\,\mathrm{GeV}$ 5) $E_\gamma < 40\,\mathrm{GeV}$

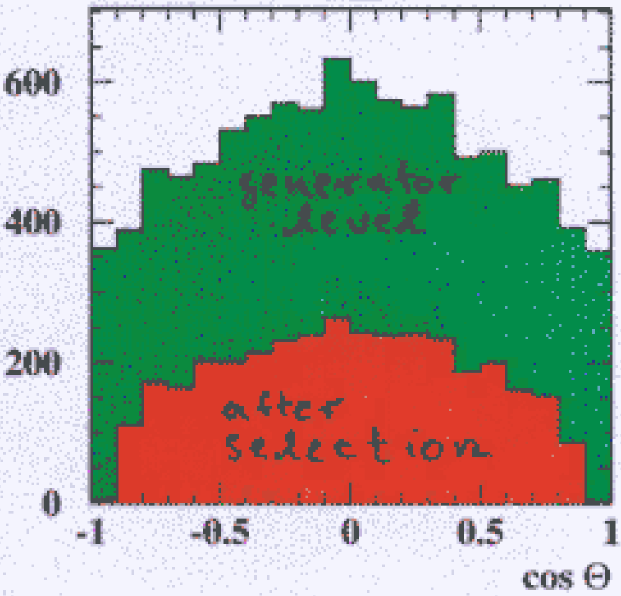
$\varepsilon = 35.5\% \mathrel{\hat{=}} N_{HZ} = 923$ evt

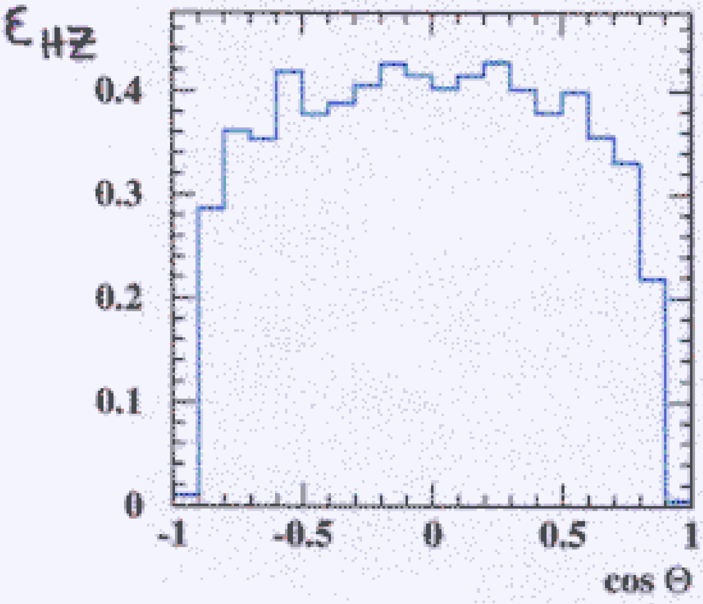
BG: ZZ: 454 evt $\mu\mu$: 0 evt

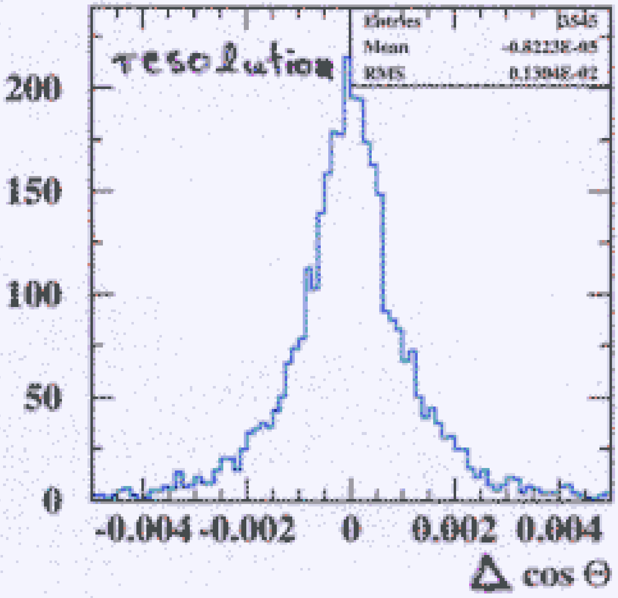
after selection



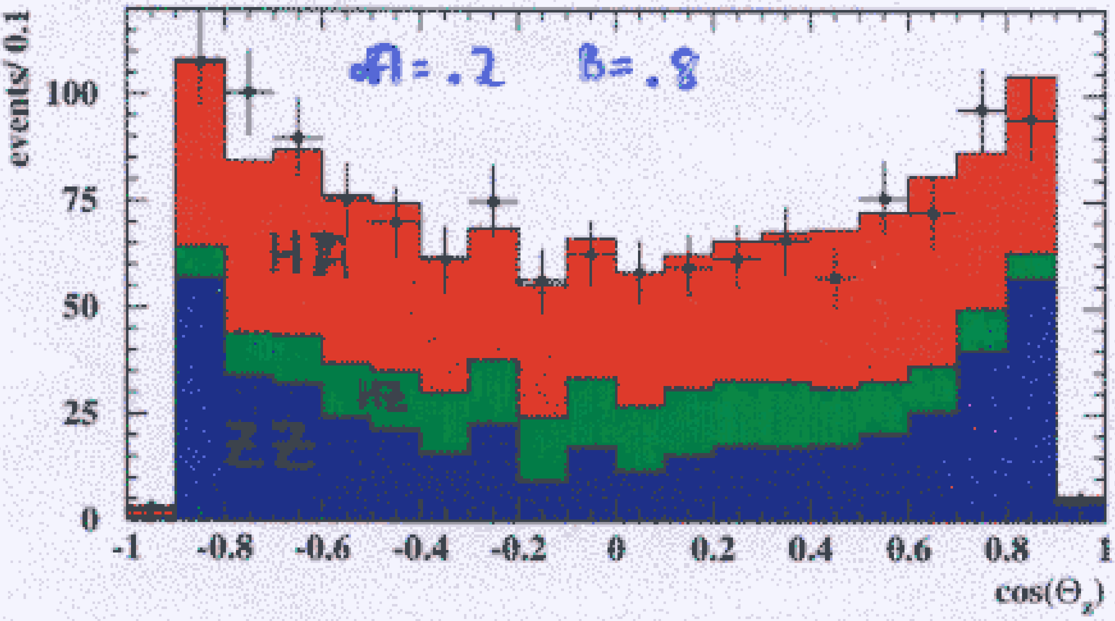
HZ







Fit Results



no int.

no σ_{tot}

i) only shape, no interference, no σ_{tot}

A	B	ΔA	ΔB
1.0	.0	.12	.13
1.0	.3	.13	.14
1.0	.6	.14	.15
.5	.5	.12	.12
.2	.8	.12	.13
.0	1.0	.12	.14
.2	.2	.10	.11
.7	.3	.13	.14

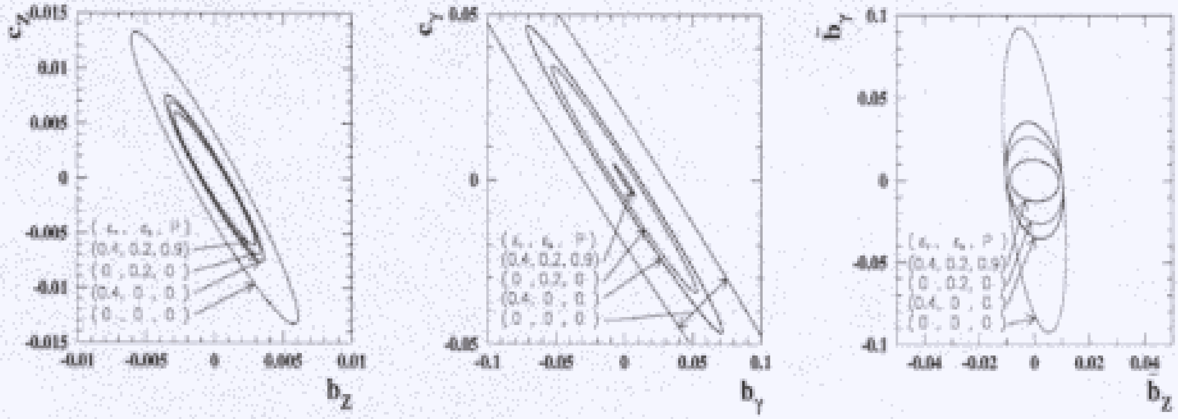
ii) including interference, σ_{tot} (A, B)

A	B	ΔA	ΔB	A	B	ΔA	ΔB
1.0	0.	.02	.003	.5	.3	.51	0.07
1.0	0.3	.08	.02	.5	1.0	.22	0.005
1.0	0.6	.11	.02	.0	1.0	.02	0.006
.5	0.1	.45	.18	.0	.4	.06	0.006

- Anomalous Higgs couplings: high luminosity, such as that provided by TESLA, efficient b and τ identification, electron and positron beam polarisation will enable to determine, deviations from the standard couplings from the angular distribution of $e^+e^- \to Z\Phi \to (f\bar{f})\,\Phi$.

Accuracy on general $ZZ\Phi$ and $Z\gamma\Phi$ couplings from optimal observable analysis.

ϵ_τ	—	0.5	—	—	—	0.5
ϵ_b	—	—	0.6	—	—	0.6
$\lvert P_{e^-}\rvert$	—	—	—	0.8	0.8	0.8
$\lvert P_{e^+}\rvert$	—	—	—	—	0.6(4)	0.6
$\mathrm{Re}\,(b_Z)$	0.00055	0.00038	0.00029	0.00028	0.00023	0.00022
$\mathrm{Re}\,(c_Z)$	0.00065	0.00037	0.00017	0.00014	0.00011	0.00011
$\mathrm{Re}\ (b_\gamma)$	0.01232	0.00665	0.00205	0.00052	0.00036	0.00034
$\mathrm{Re}\ (c_\gamma)$	0.00542	0.00292	0.00090	0.00011	0.00008	0.00007
$\mathrm{Re}\,(\tilde{b}_Z)$	0.00104	0.00099	0.00097	0.00095	0.00078	0.00052
$\mathrm{Re}\,(\tilde{b}_\gamma)$	0.00618	0.00334	0.00105	0.00145	0.00101	0.00063
0.01055	0.00570	0.00176	0.00070	0.00049	0.00046	
0.00206	0.00126	0.00077	0.00070	0.00057	0.00054	
0.00521	0.00281	0.00087	0.00032	0.00022	0.00022	
0.00101	0.00061	0.00035	0.00032	0.00026	0.00026	



- Main **production mechanism of the SM Higgs** in e^+e^- collisions:

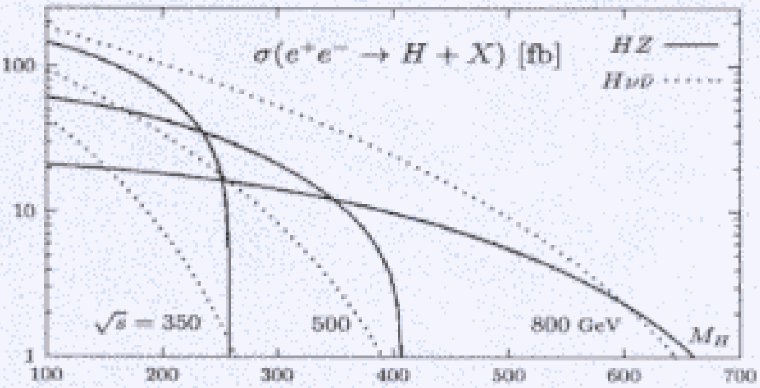
  1. Higgsstrahlung process, $e^+e^- \to (Z^*) \to ZH$: cross section scales as $1/s$ dominates at low energies

  $$\sigma(e^+e^- \to ZH) = \frac{G_F^2 M_Z^4}{96\pi s}(v_e^2 + a_e^2))\,\lambda^{\frac{1}{2}}\frac{\lambda + 12M_Z^2/s}{(1 - M_Z^2/s)^2}$$

  2. WW fusion mechanism, $e^+e^- \to \nu\bar{\nu}(W^*W^*) \to \nu\bar{\nu}H$: cross section rising $\propto \log(s/M_H^2)$ dominates at high energies.

  $$\sigma(e^+e^- \to \bar{\nu}_e\nu_e H) \to \frac{G_F^3 M_W^4}{4\sqrt{2}\pi^3}\left[\left(1 + \frac{M_H^2}{s}\right)\log\frac{s}{M_H^2} - 2\left(1 - \frac{M_H^2}{s}\right)\right]$$

  3. ZZ fusion mechanism, $e^+e^- \to e^+e^-H$: cross section competitive at high energy, possibly attractive process for e^-e^- option.



- With $\int\mathcal{L} \sim 500$ fb^{-1}, $\sim$ 75.000 Higgs bosons produced in one to two years of running for $M_H \sim 130$ GeV.

- The HZ production, with $Z \to \ell^+\ell^-$, offers a very distinctive signature ensuring the **observation of the SM Higgs up to the production kinematical limit at TESLA**.

ECFA-DESY Workshop
DESY, September 2000
Higgs WG and Plenary Meeting

Chapter 2

ELECTROWEAK SYMMETRY BREAKING

2.1 HIGGS MECHANISM

- Higgs mechanism is one of the building blocks of the present picture of electroweak interactions, addressing the fundamental question on the origin of mass.
- If a Higgs boson is found at **LEP2**, Tevatron or the LHC, the **accurate study of its production and decay properties in order to establish the Higgs mechanism as the mechanism of electroweak symmetry breaking will represent a central theme of the TESLA physics programme.**
- Otherwise TESLA will probe Higgs sector of exotic models.

2.1.1 The Standard Model

- Only unknown parameter in SM Higgs sector is the **Higgs mass**