❹ Higgs-physics

- The Higgs-mechanism is the only way we know to give masses to particles in the SM
- Up to now we have no direct evidence for any Higgs-particle
- If the Higgs exists, at least the LHC should have found a particle compatible with it,
- The LC has then to prove that this is really the particle responsible for mass generation

Predictions for the Higgs

Standard Model:

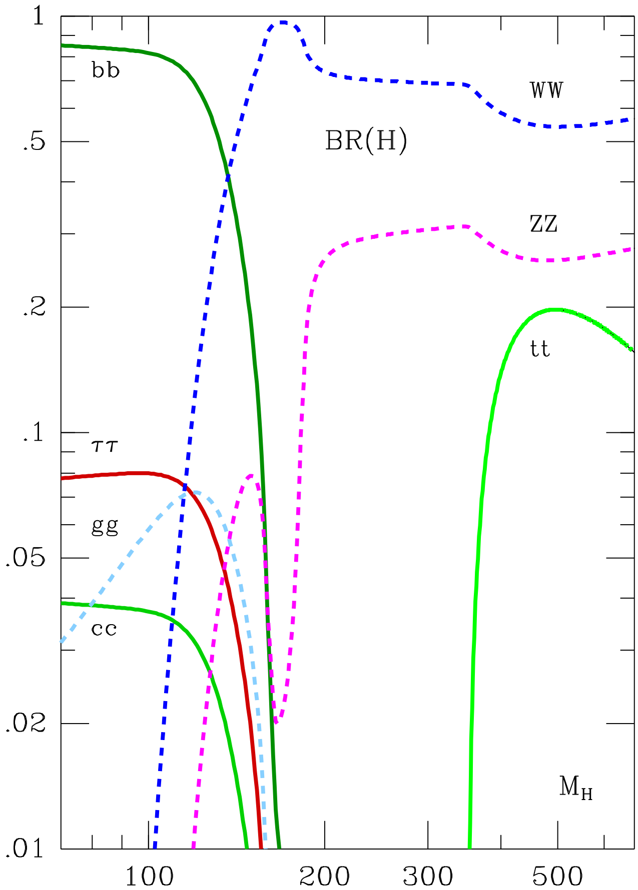
- One complex Higgs doublet $\begin{pmatrix} \Phi^+ \\ \Phi^0 \end{pmatrix}$ with vacuum expectation value $\begin{pmatrix} 0 \\ v \end{pmatrix}$, $v = 246\,\mathrm{GeV}$.
- Higgs potential $V(\Phi) = \lambda(\Phi^*\Phi - v^2/2)^2$
- Higgs mass $m_{\mathrm{H}}^2 = 2\lambda v^2$

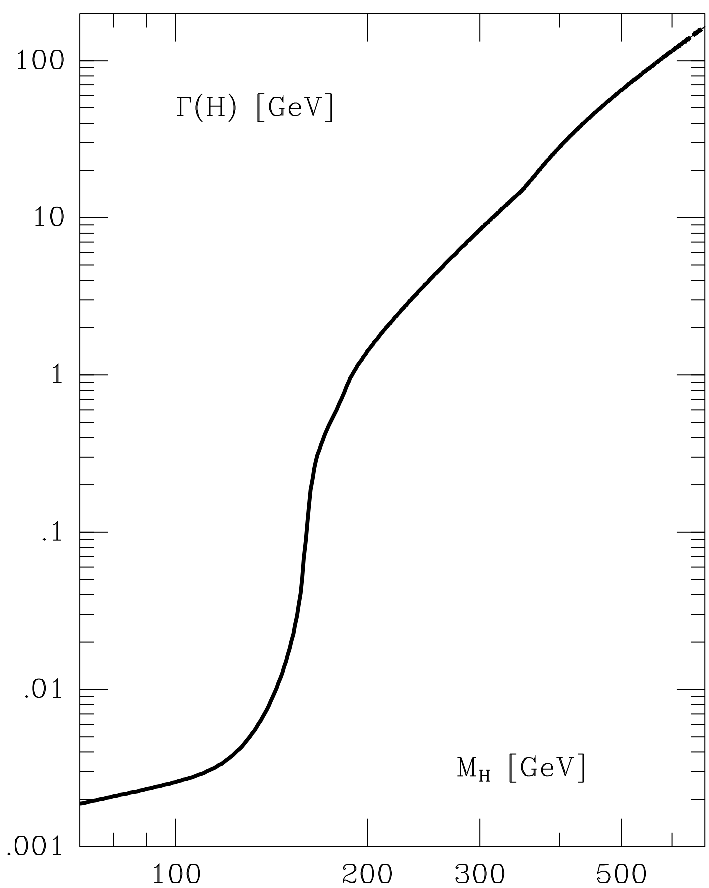
- Partial widths:

$$\Gamma(H \to \mathrm{f\bar{f}}) = \frac{N_c^{(f)} G_\mu}{4\sqrt{2}\pi} m_f^2(m_H) m_H (1 + \delta_{QCD}^{(f)})$$

$$\Gamma(H \to VV) = \frac{3 G_\mu^2 m_\mathrm{Z}^4}{16\pi^3} m_\mathrm{H} R_V(m_V^2/m_\mathrm{H}^2)$$

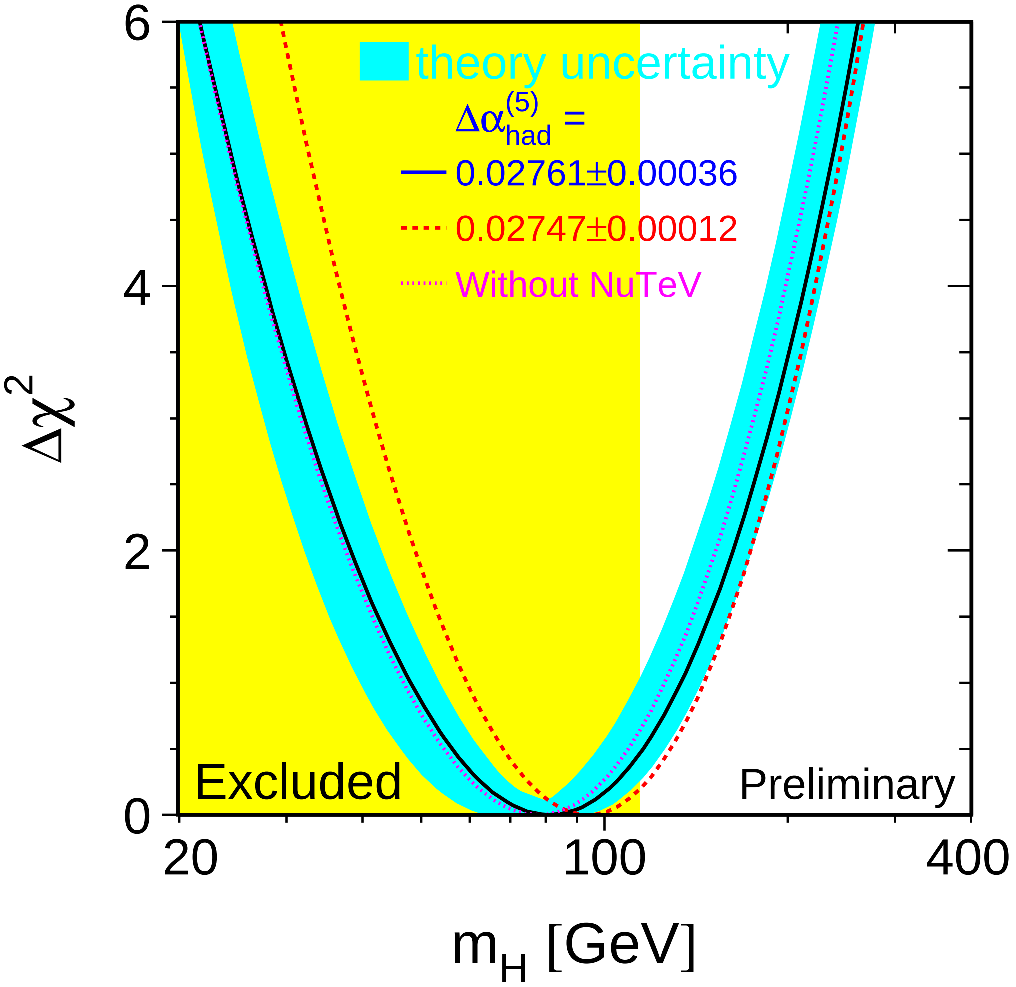
$$\to 2(1)\frac{\sqrt{2} G_\mu}{32\pi} m_\mathrm{H}^3 \quad [V = W(Z)]$$





Limits on m_H

- direct searches at LEP: $m_\mathrm{H} > 114\,\mathrm{GeV}$
- hint of a signal at $m_\mathrm{H} \approx 115\,\mathrm{GeV}$
- electroweak precision data

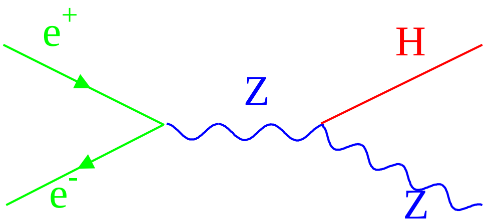


$\Rightarrow m_\mathrm{H} < 200\,\mathrm{GeV} \quad (95\%\mathrm{c.l.})$

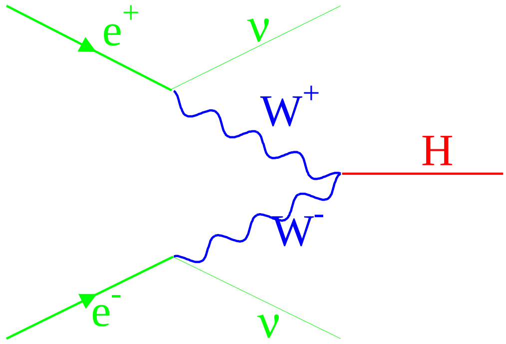
- perturbativity and vacuum stability if SM valid up to M_{pl}: $m_\mathrm{H} \sim 120 - 180\,\mathrm{GeV}$

Higgs production

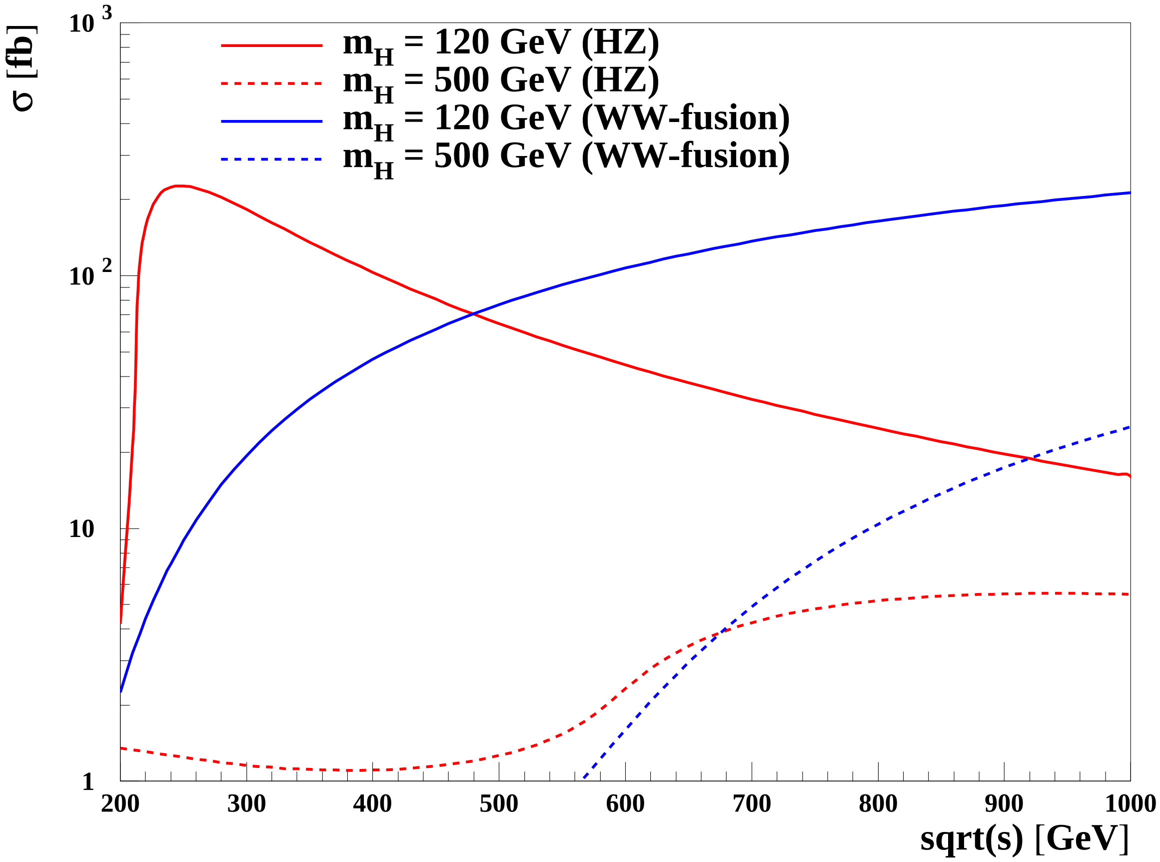
Higgsstrahlung



W-fusion



Cross section:



- both channels accessible at LC
- cross section $\sim 100(\sim 10)$ fb for $m_{\mathrm{H}} = 120(500)$ GeV
- ➧ few$\times 10^4(10^3)$ Higgses per year

MSSM:

SUSY needs two Higgs-doublets (H_1, H_2) to generate masses of down- and up-type particles

Physical particles:

$$\begin{aligned} h &= H_2 \cos\alpha - H_1 \sin\alpha \\ H &= H_2 \sin\alpha + H_1 \cos\alpha \\ A & \quad \mathrm{CP-odd} \\ H^{\pm} & \quad \text{charged Higgses} \end{aligned}$$

Define $\tan\beta = \frac{v_2}{v_1}$ = ratio of expectation values ($v_1^2 + v_2^2 = v_{SM}^2$)

Born Formulae:

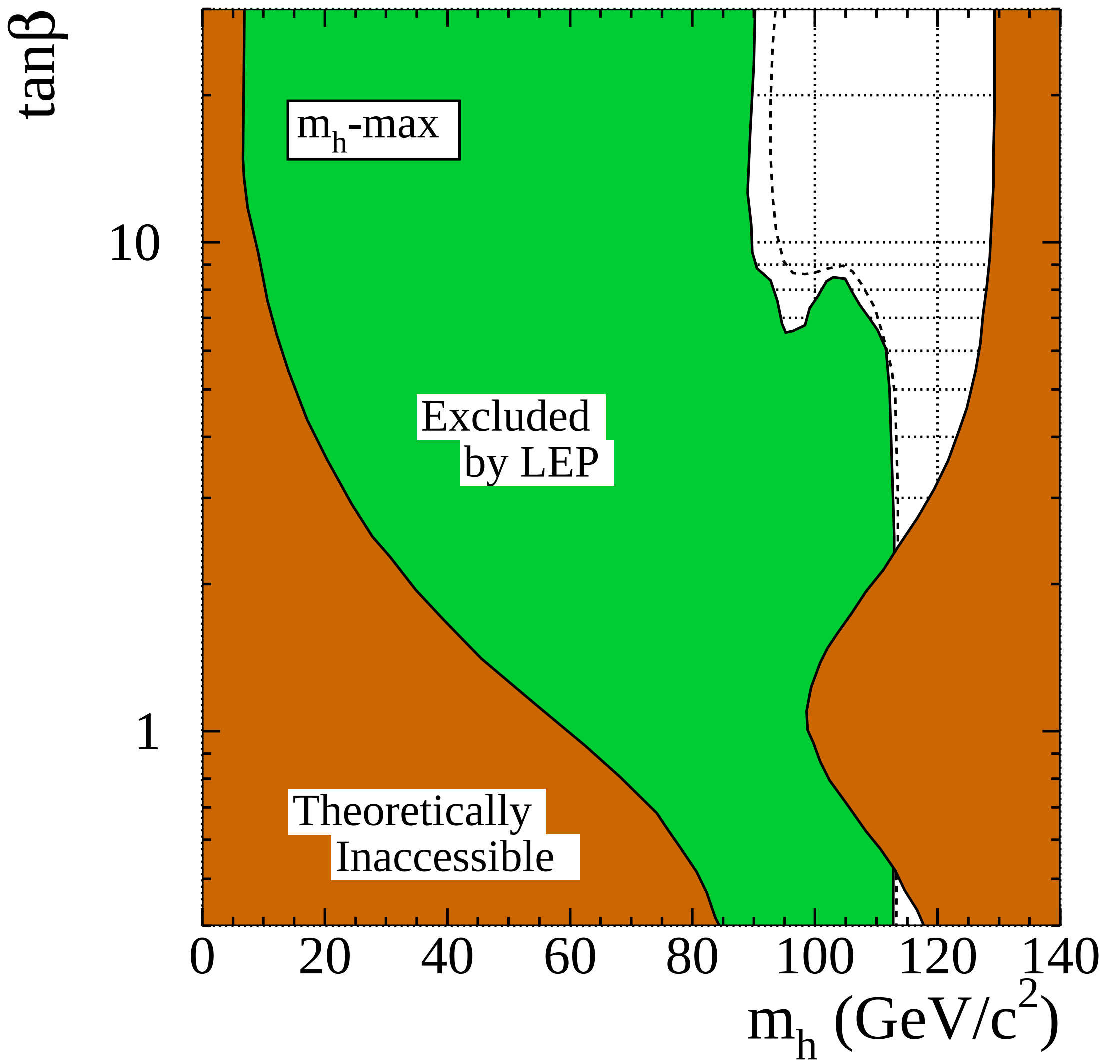
$$\begin{aligned} m^2_{h,H} &= \frac{1}{2}\Big[m_A^2 + m_Z^2 \mp \\ & \qquad \sqrt{\left(m_A^2 + m_Z^2\right)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta}\Big] \\ m_h &< m_Z \\ m_H &> m_Z \\ m^2_{H^\pm} &= m_A^2 + m_{\mathrm{W}}^2 \\ \tan 2\alpha &= \tan 2\beta \frac{m_A^2 + m_{\mathrm{Z}}^2}{m_A^2 - m_{\mathrm{Z}}^2} \; (-\frac{\pi}{2} < \alpha < 0 < \beta < \frac{\pi}{2}) \end{aligned}$$

Higgs sector described by two free parameters

However large radiative corrections:

- shift of m_h up to $\sim 130\,\text{GeV}$
- prediction gets dependent on other SUSY parameters, especially on mixing in stop sector
- strong dependence on top mass: $\Delta m_h/\Delta m_{\rm t} \approx 1$

Currently allowed region:



$\tan\beta > 2$ preferred!

Complementarity of cross sections:

$$\sigma(e^+e^- \to Zh) = \sin^2(\beta-\alpha)\sigma_{SM}$$
$$\sigma(e^+e^- \to Ah) = \cos^2(\beta-\alpha)\bar{\lambda}\sigma_{SM}$$

($\bar{\lambda}$: P-wave suppression)

If m_A large:

- $\beta - \alpha = \pi/2 \;\Rightarrow\; \sigma(e^+e^- \to Zh) = \sigma_{SM}$
- $m_H \approx m_{H^\pm} \approx m_A$

➠ Only one SM-like Higgs can be seen

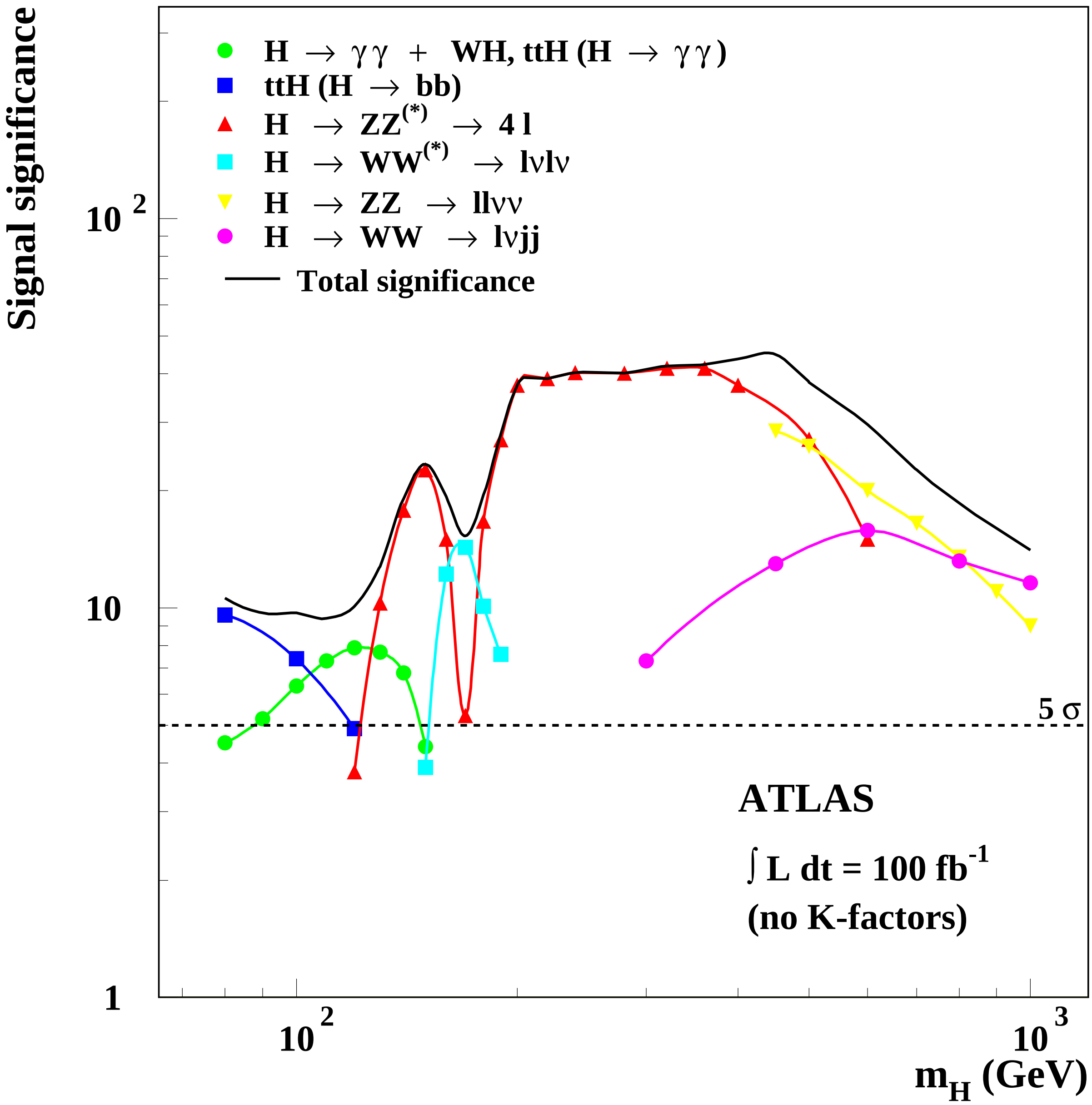
Branching ratios:

$$\Gamma(h \to U\overline{U}) = \frac{\cos^2\alpha}{\sin^2\beta}\Gamma_{\rm SM}(h \to U\overline{U})$$
$$\Gamma(h \to D\overline{D}) = \frac{\sin^2\alpha}{\cos^2\beta}\Gamma_{\rm SM}(h \to D\overline{D})$$

- For m_A large also branching ratios become SM like
- however, it turns out that some sensitivity remains in regions where no other Higgs than h can be seen

LHC discovery of the Higgs

A SM-like Higgs cannot be missed by the LHC

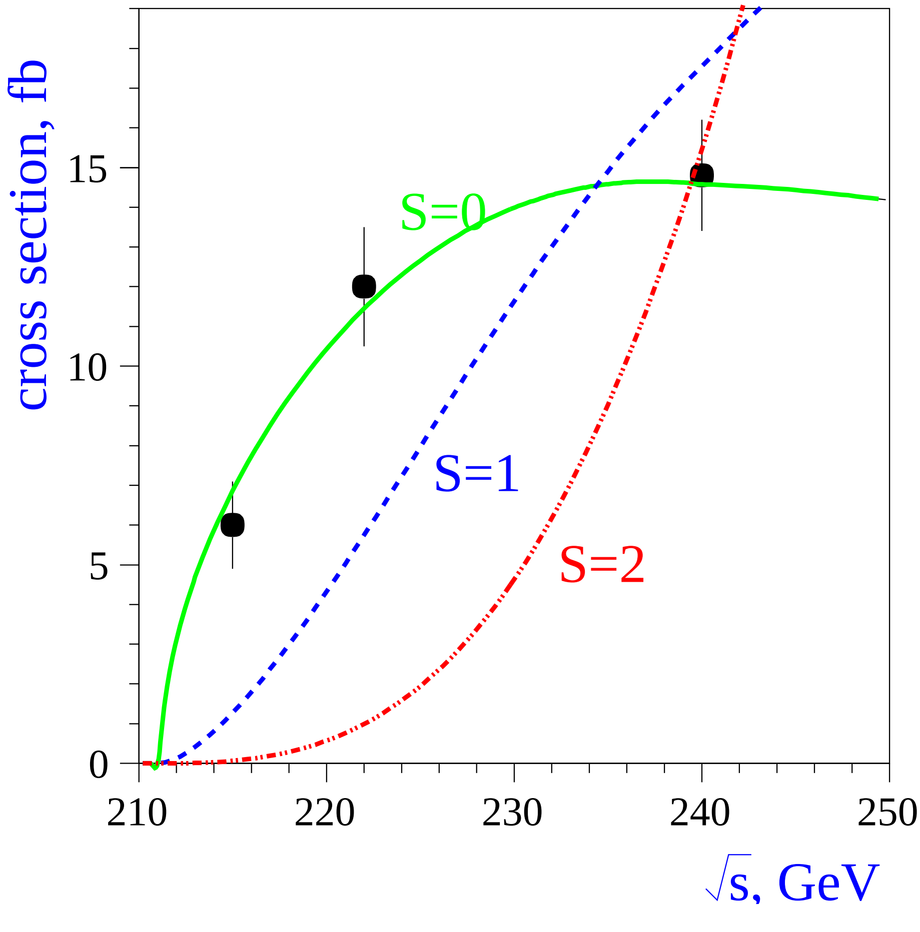


The task of the LC is then precision measurements

Measurement of the H quantum numbers

After the H has been discovered it has to be proven that its quantum numbers are really 0^+

At the LC this can be done with a threshold scan of $e^+e^- \rightarrow ZH$:



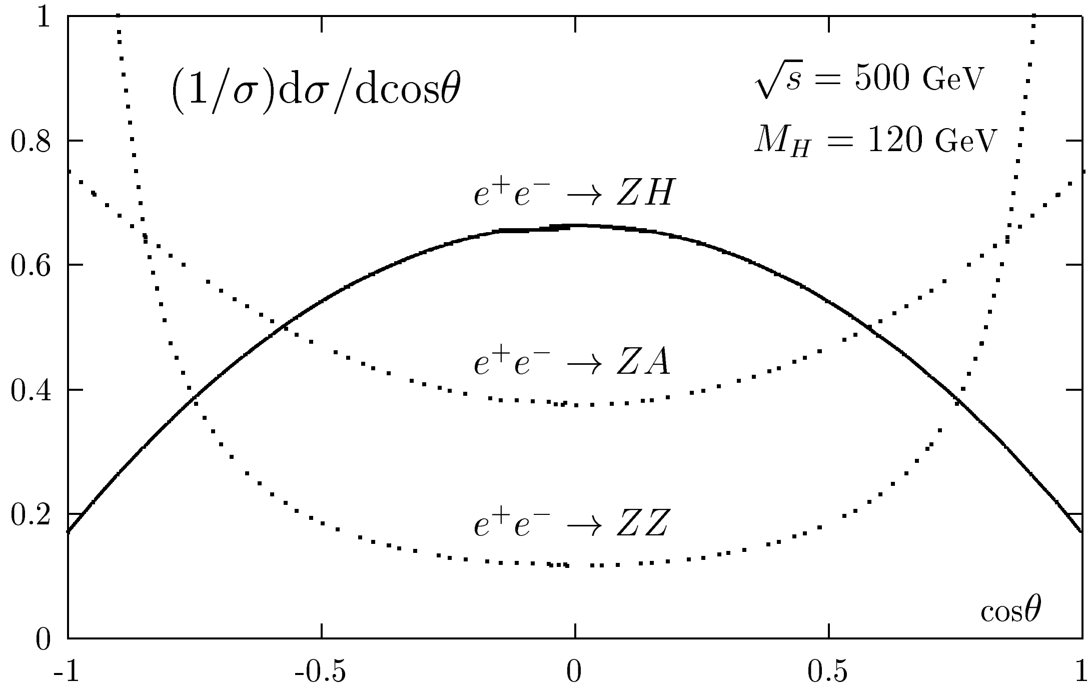
- Large sensitivity to the different states
- The few remaining ambiguities can be resolved from angular dependences and the observation of $H \rightarrow \gamma\gamma$
- Alternatively spin/parity can be measured in transverse/longitudinally polarized $\gamma\gamma$-collisions

What can the LHC do on J,P?

- $H \to \gamma\gamma$ excludes J=1
- if $H \to ZZ$ is visible S should be measurable from spin correlations

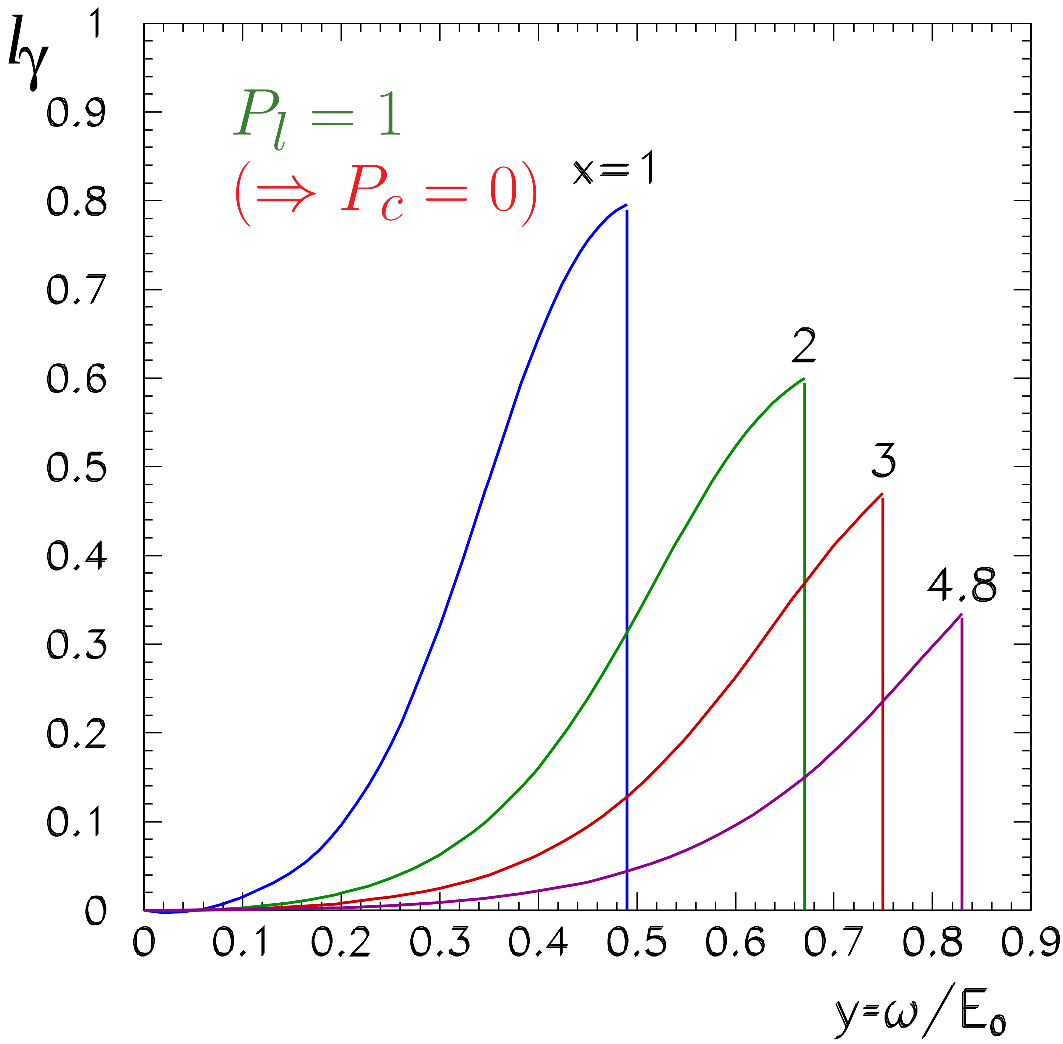
The Higgs CP quantum numbers

- Angular distributions give admixture of CP odd Higgs $|\eta|$
  LC: 3%
  LHC: 30%



- However CP-odd Higgs doesn't couple to vector boson pairs directly
  $\to$ η =mixing angle $\times$ loop factor
  ➠ might not be visible

- Alternative: $\gamma\gamma$ collisions:
  - Use linear beam polarization $\vec{\varepsilon_1}$, $\vec{\varepsilon_2}$
  - CP-even Higgs: $\sigma \propto \vec{\varepsilon_1} \cdot \vec{\varepsilon_2}$
  - CP-odd Higgs: $\sigma \propto [\vec{\varepsilon_1} \times \vec{\varepsilon_2}] \cdot \vec{k_\gamma}$
  - Coupling strength roughly equal
  - Asymmetry measures CP-even - CP-odd mixture
  - Problem: transverse beam polarization large for small x $\longrightarrow$ small $\sqrt{s}$



⇒ fine for small m_H, difficult for large m_H (heavy SUSY Higgses)

– $f_{CP} < 0.2$ at 95% C.L. might be possible for $m_H = 120\,\mathrm{GeV}$

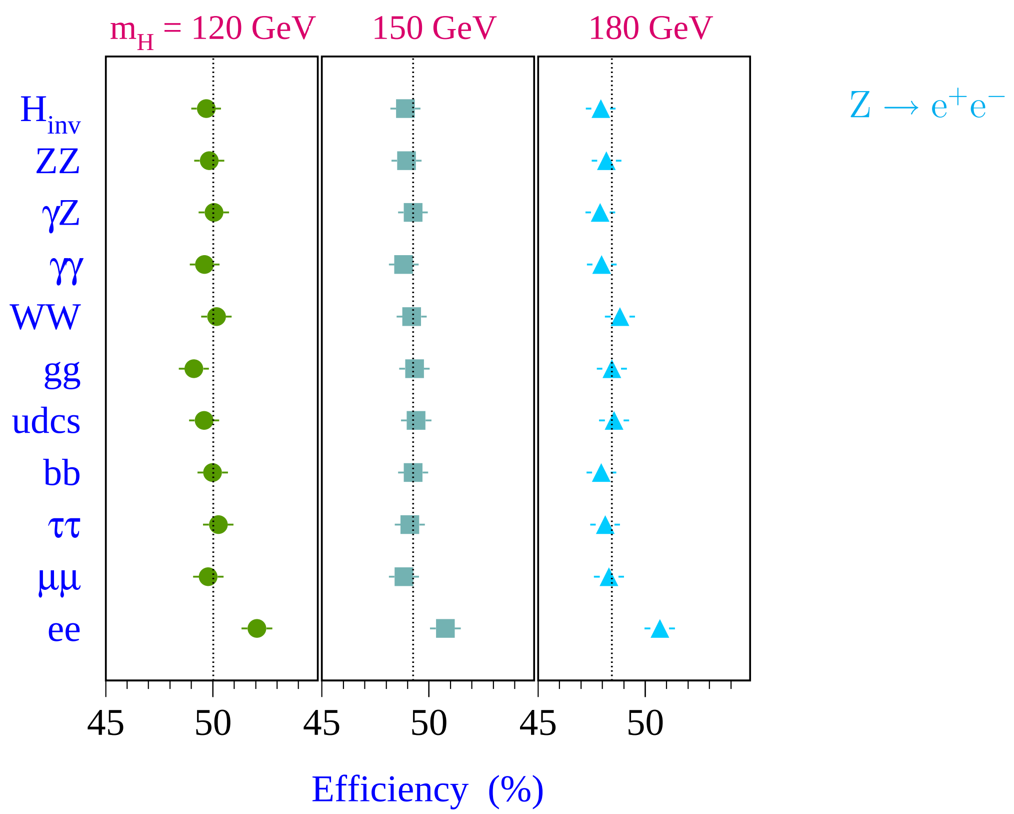
Measurement of the $e^+e^- \to HZ$ cross section

Need a measurement of the total cross section $\sigma(e^+e^- \to HZ)$ independent of the H decay mode:

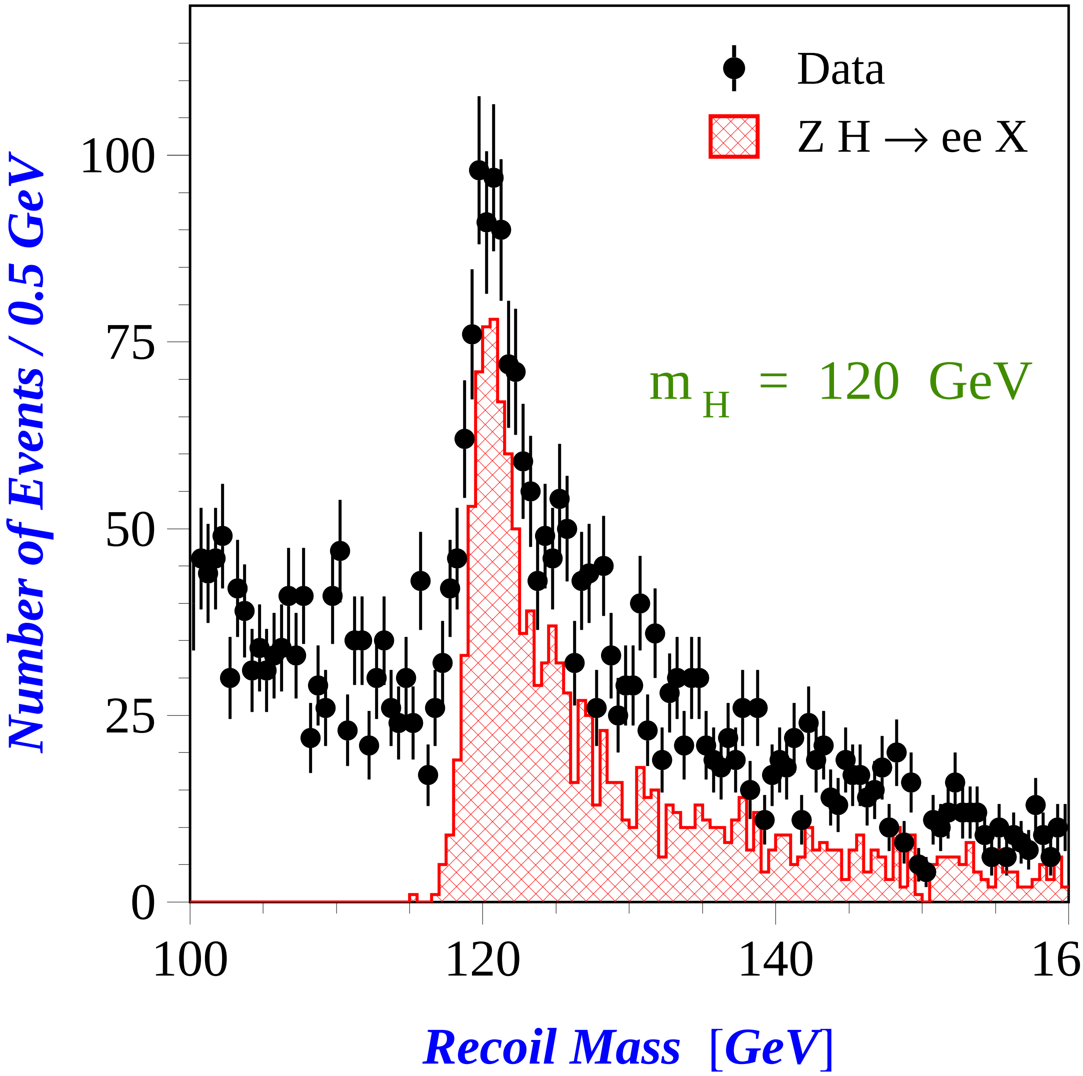
- $\sigma(e^+e^- \to HZ)$ measures $\Gamma(H \to ZZ)$
- absolute normalization for H-branching ratio measurements

Method

- select HZ events with $Z \to e^+e^-, \mu^+\mu^-$ only by looking at the leptons cutting on $m_{\ell\ell} \sim m_Z$
- efficiency (almost) independent of H-decay mode



- fit recoil mass distribution
- Higgs signal clearly visible with some tails from ISR and beamstrahlung



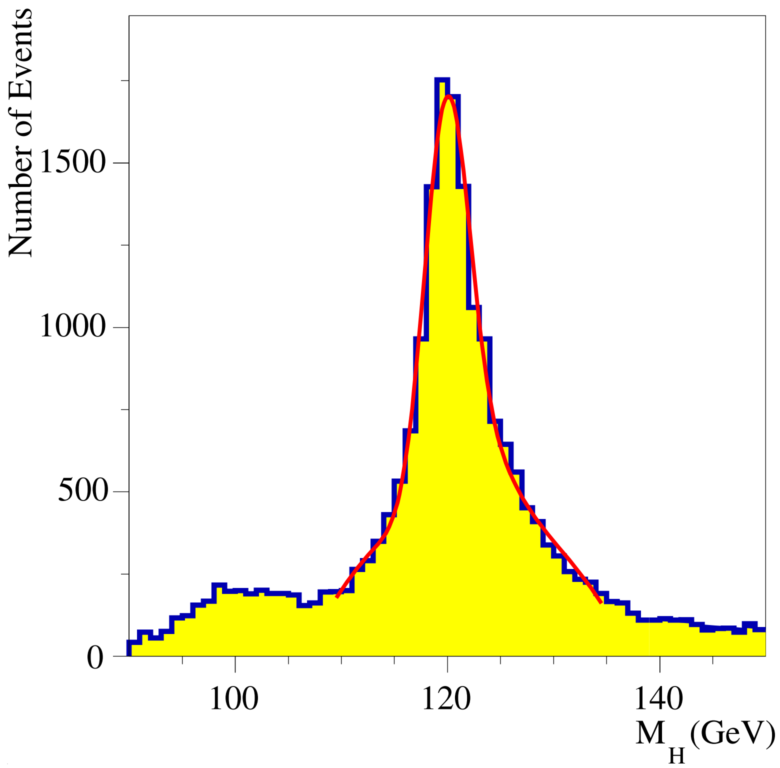
- Results:
  ($\sqrt{s} = 350\,\mathrm{GeV}$, $\mathcal{L} = 500\,\mathrm{fb}^{-1}$, $\mathrm{m_H} \sim 120\,\mathrm{GeV}$)

$$\Delta\sigma(\mathrm{e^+e^-} \rightarrow \mathrm{HZ}) \approx 2.4\%$$

$$\Delta m_{\mathrm{H}} \approx 140\,\mathrm{MeV}$$

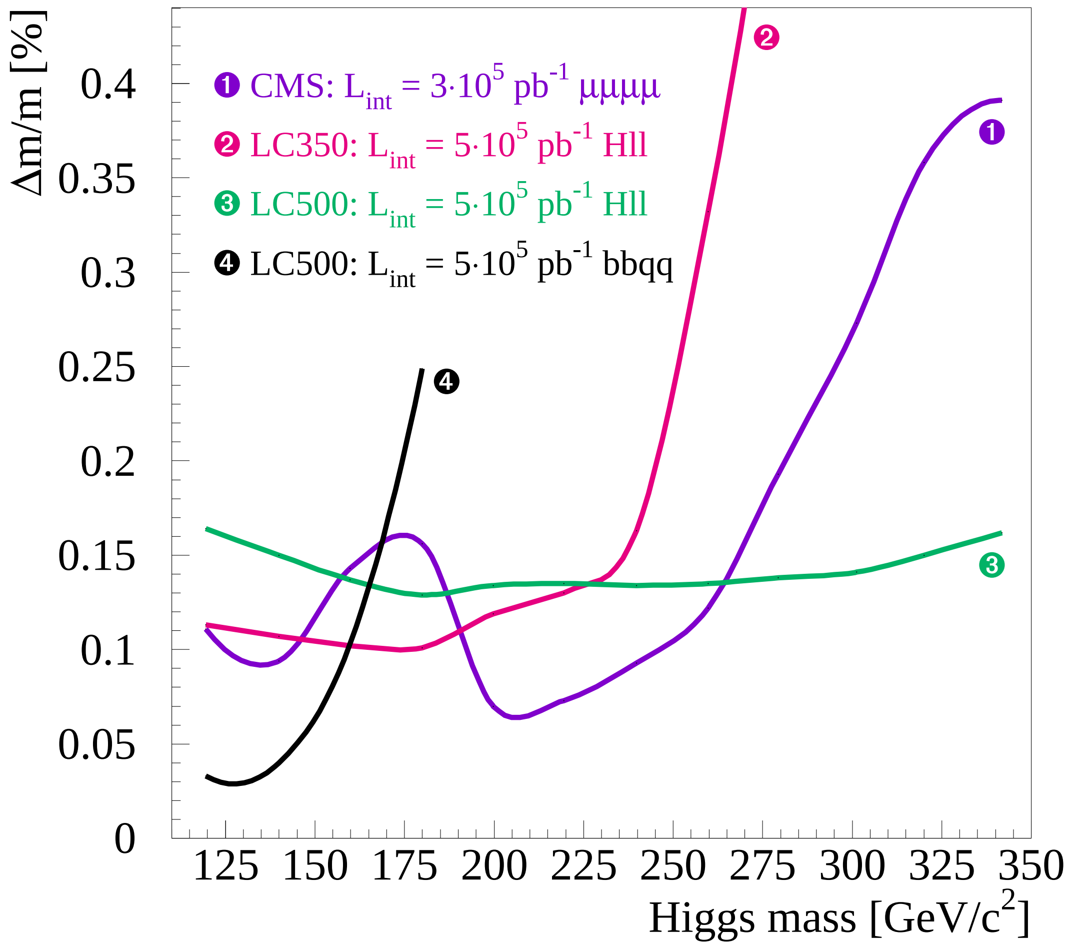
Measurement of m_H

- from Z recoil mass: $\Delta m_H \approx 140\,\mathrm{MeV}$
- alternative: constrained fit similar to m_W at LEP:
  - Analysis with $m_H = 120\,\mathrm{GeV}$, $\mathcal{L} = 500\,\mathrm{fb}^{-1}$
  - Select $e^+e^- \to HZ$-events
  - perform constrained fit imposing energy/momentum conservation and taking into account ISR/beamstrahlung



  - $\Delta m_H \approx 50\,\mathrm{MeV}$ for $\mathcal{L} = 500\,\mathrm{fb}^{-1}$
    combined with $HZ \to \ell\ell b\bar{b}$: $\Delta m_H \approx 40\,\mathrm{MeV}$
  - For larger m_H precision stays at 0.05% level using recoil mass and fit to $ZH \to q\bar{q}W^+W^-$ mass distribution

Comparison of Higgs-mass determination at LC and LHC



- recoil-mass method similar to LHC over the full mass range
- direct reconstruction with $H \rightarrow \mathrm{b\bar{b}}$ superior at low m_{H}
  needs to be tried with $H \rightarrow WW, ZZ$ at higher masses
- threshold scan not yet explored

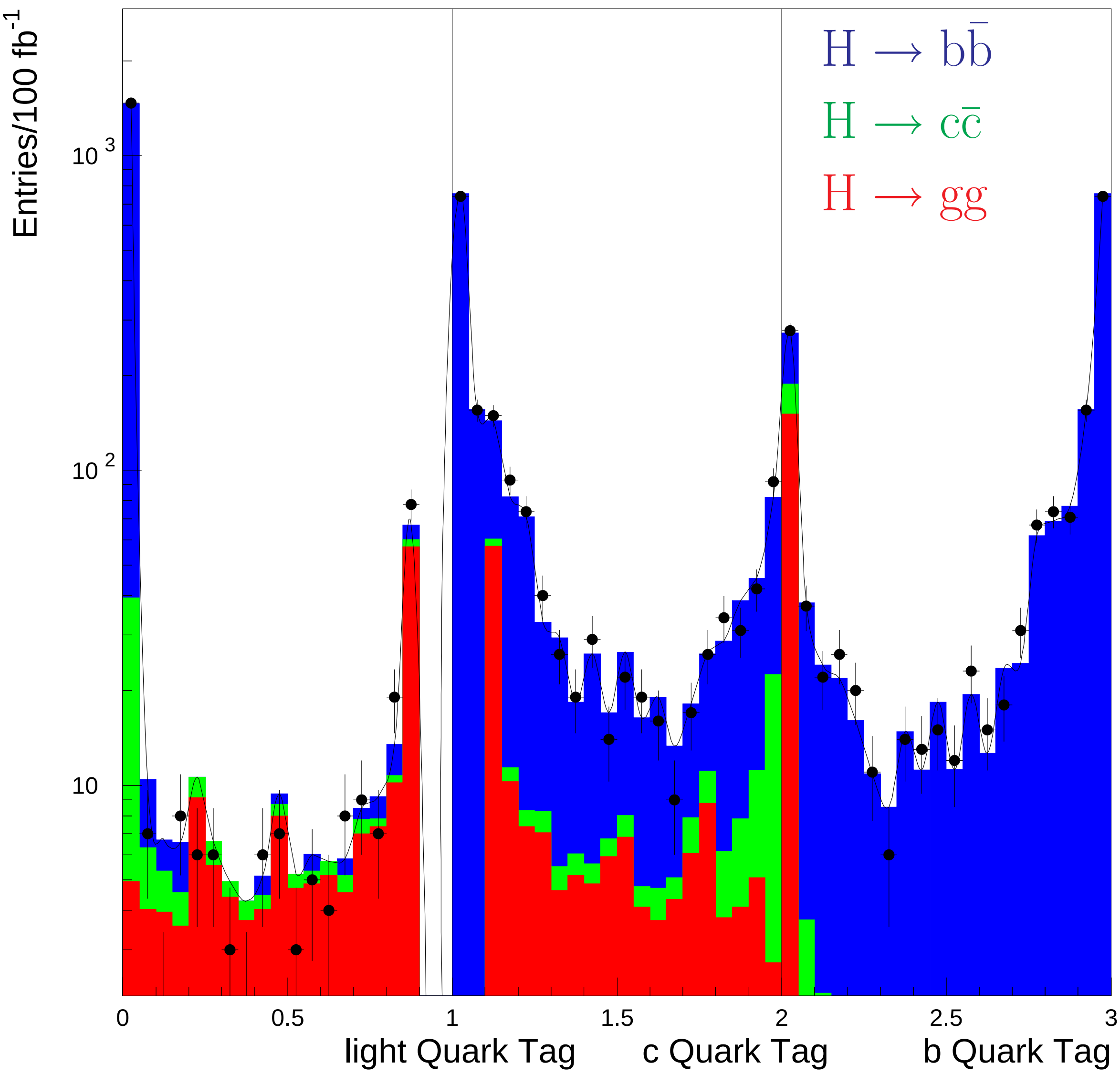
How well do we need to know m_{H}

- SM: dependence of precision observables on m_{H} only logarithmic
  $\Rightarrow \Delta m_{\mathrm{H}} \sim 1\,\mathrm{GeV}$ largely sufficient
- Beyond SM, e.g. SUSY: m_{H} connected with fundamental parameters of the theory
  $\Rightarrow$ need m_{H} as good as possible
  However:
  - large radiative corrections from top-sector ($\delta m_{\mathrm{H}}/\delta m_{\mathrm{t}} \approx 1$)

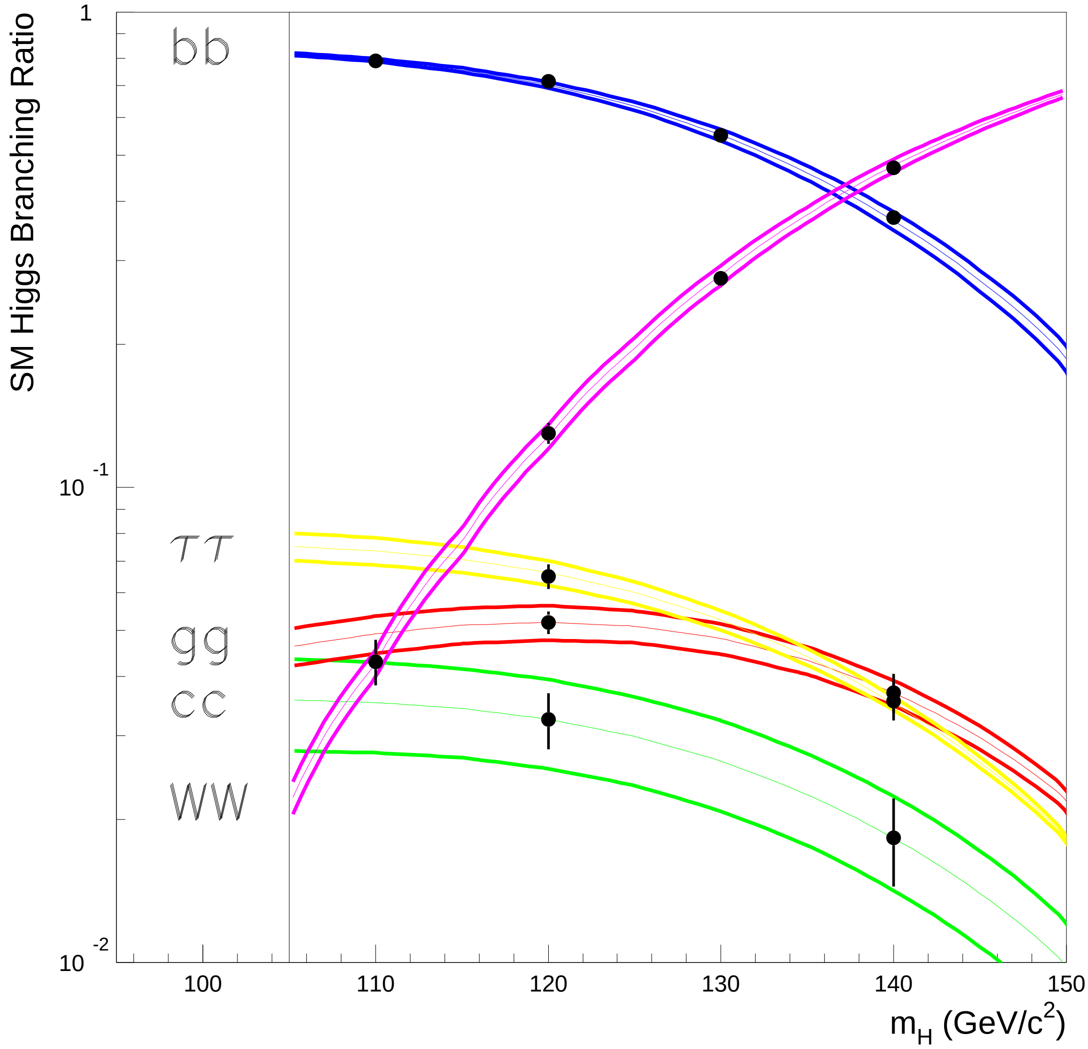
➡ Top mass error might be limiting factor

Measurement of the Higgs branching ratios

- absolute branching ratios can be measured from the $Z \to \ell\ell$ sample
- ratios of branching ratios can also be obtained from other channels
- different 2-jet modes can be separated by b-tagging



Results: $(\sqrt{s} = 350\,\mathrm{GeV},\ \mathcal{L} = 500\,\mathrm{pb}^{-1})$

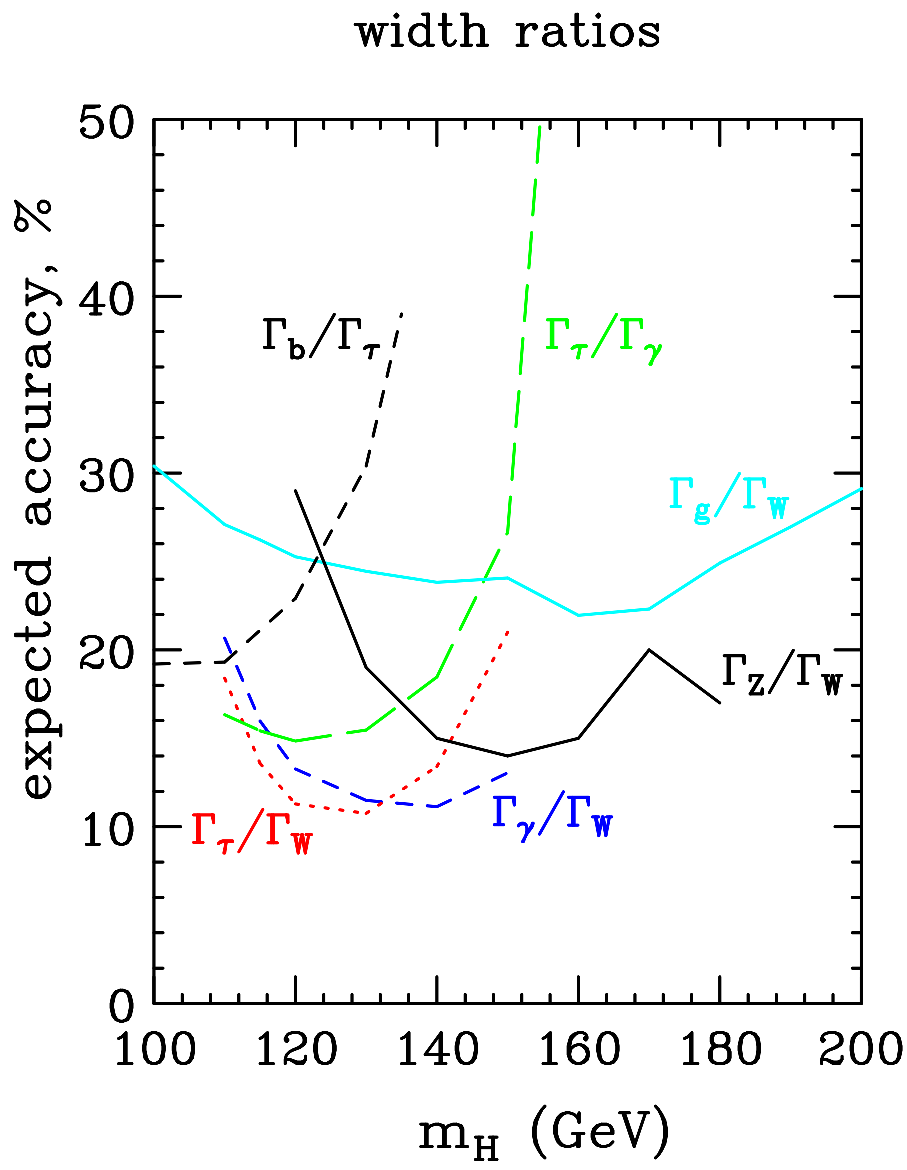


$m_\mathrm{H} = 120\,\mathrm{GeV}$:

Channel	$\delta(BR(H \to X)/BR$
$H^0/h^0 \to \mathrm{b\bar{b}}$	± 0.024
$H^0/h^0 \to \mathrm{c\bar{c}}$	± 0.083
$H^0/h^0 \to gg$	± 0.055
$H^0/h^0 \to \tau^+\tau^-$	± 0.050
$H^0/h^0 \to WW^*$	± 0.051

LHC results on branching ratios

LHC can measure Higgs decays into several channels
$\Rightarrow$ direct measurement of ratios of partial widths



To get partial width the LHC always needs assumptions ($b-\tau$ universality!!)

Even with these assumptions it is about a factor 4 worse than LC

The total width of the Higgs

For $m_{\mathrm{H}} < 2m_{\mathrm{W}}$

$$
\begin{aligned}
BR(H \to X\bar{X}) &= \Gamma(H \to X\bar{X})/\Gamma_{\mathrm{H}} \\
\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{HZ}) &\propto \Gamma(H \to ZZ) \\
\sigma(\mathrm{W}^+\mathrm{W}^- \to \mathrm{H}) &\propto \Gamma(\mathrm{H} \to \mathrm{W}^+\mathrm{W}^-)
\end{aligned}
$$

Assuming SU(2) invariance for the Higgs couplings:

$$
\Gamma_{\mathrm{H}} \propto \frac{\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{HZ})}{BR(\mathrm{H} \to \mathrm{W}^+\mathrm{W}^-)}
$$

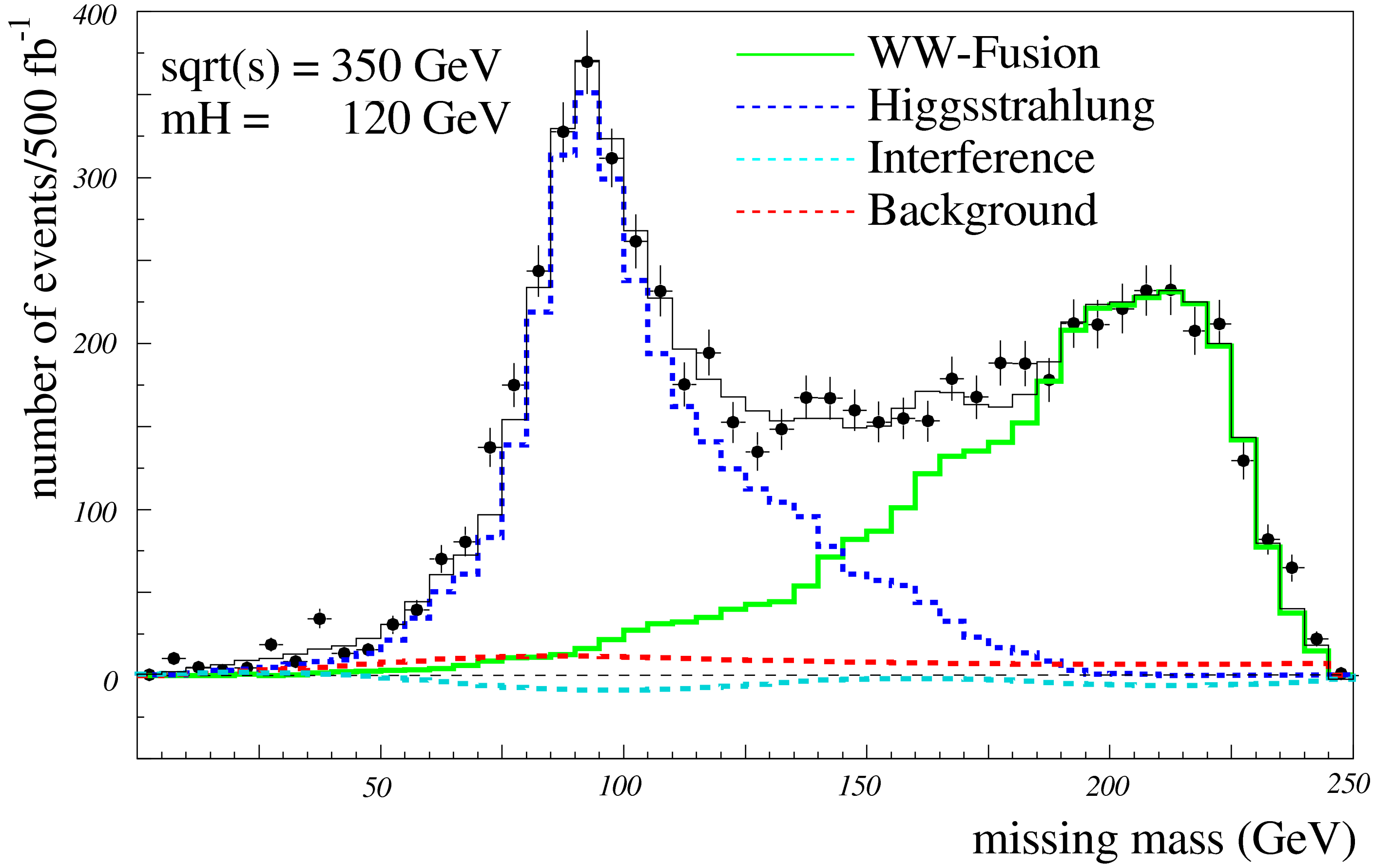
➠ Can obtain Higgs width with $\Delta\Gamma_{\mathrm{H}}/\Gamma_{\mathrm{H}} < 6\%$ up to $m_{\mathrm{H}} \sim 180\,\mathrm{GeV}$

Drop assumption of SU(2) invariance

➨ Have to measure Higgs-fusion cross section

Measurement of $e^+e^- \to \nu\nu H \to \nu\nu b\bar{b}$

- $e^+e^- \to \nu\nu H \to \nu\nu b\bar{b}$ events are selected using b-tag, m_{rec}, m_{miss} and E_{miss}



- $e^+e^- \to ZH$ with $Z \to \nu\nu$ and $WW \to H$ are separated by a fit to the missing mass distribution
- for $m_H < 140\,\text{GeV}$ Γ_H can be determined with similar accuracy without any assumptions
- for $m_H > 140\,\text{GeV}$ the necessary analysis of of $e^+e^- \to \nu\nu H \to \nu\nu WW$ is not yet done

Indirect Γ_H at LHC:

- LHC can do an indirect measurement of Γ_H with 20% precision
- however several assumptions are needed for that
  - b-τ universality
  - W-Z universality
  - no unexpected H-decays

The Higgs width for $m_H > 2m_W$

- For $m_H > 2m_W$ the Higgs becomes very wide ($\Gamma_H \propto m_H^3$)

➠ Γ_H can be fitted from the resonance curve

- example $m_H = 240\,\mathrm{GeV}$
  - LHC: $\Delta\Gamma_H/\Gamma_H = 25\%$
  - LC : $\Delta\Gamma_H/\Gamma_H = 10\%$

  improving with m_H

Interpretation in the MSSM:

$m_A \gg m_Z \Rightarrow \beta - \alpha = \pi/2 - \eta$ with

$$\eta = \frac{m_Z^2 |\cos 2\beta|}{m_A^2} \sin 2\beta$$

$$\Rightarrow \frac{\sin^2\alpha}{\cos^2\beta} = 1 - 2\eta \tan\beta$$

$$\sin^2(\beta - \alpha) = 1 - \eta^2$$

$$\frac{\cos^2\alpha}{\sin^2\beta} = 1 + 2\eta/\tan\beta$$

In addition for large m_A:

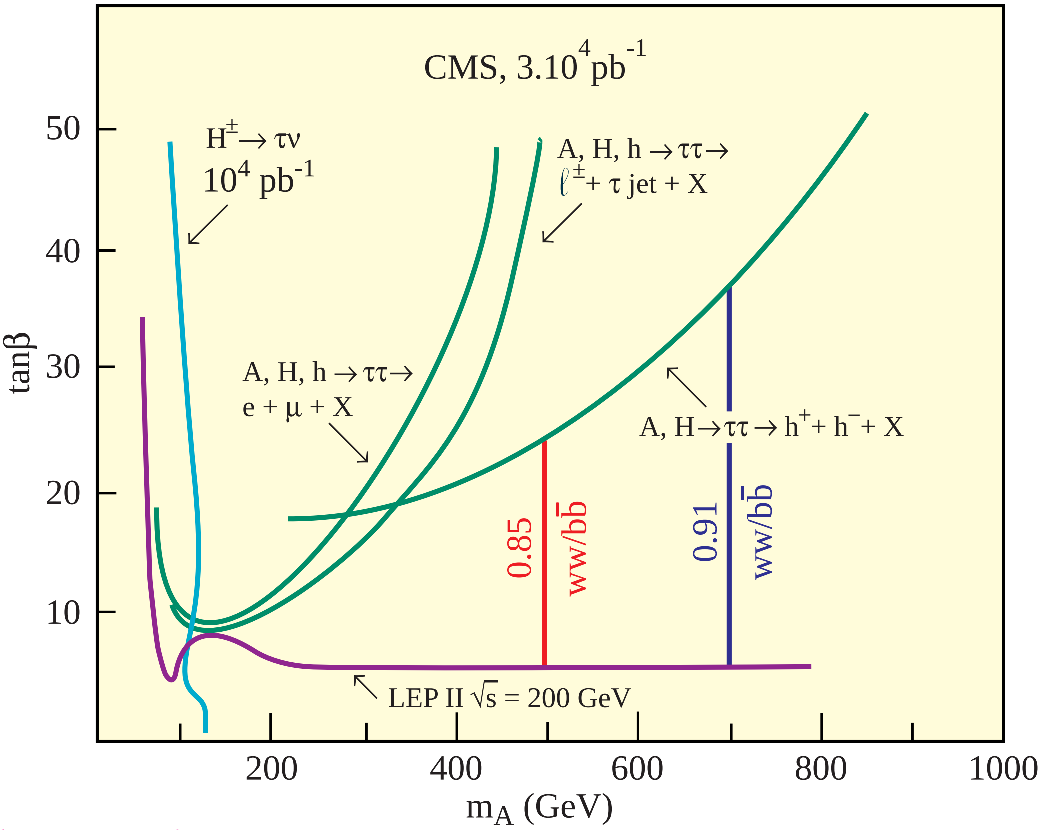
$$\eta \tan\beta = -\frac{m_Z^2 |\cos 2\beta| + m_h^2}{m_A^2}$$

For $\tan\beta > 2$ (suggested by LEP) $|\cos 2\beta| \approx 1$

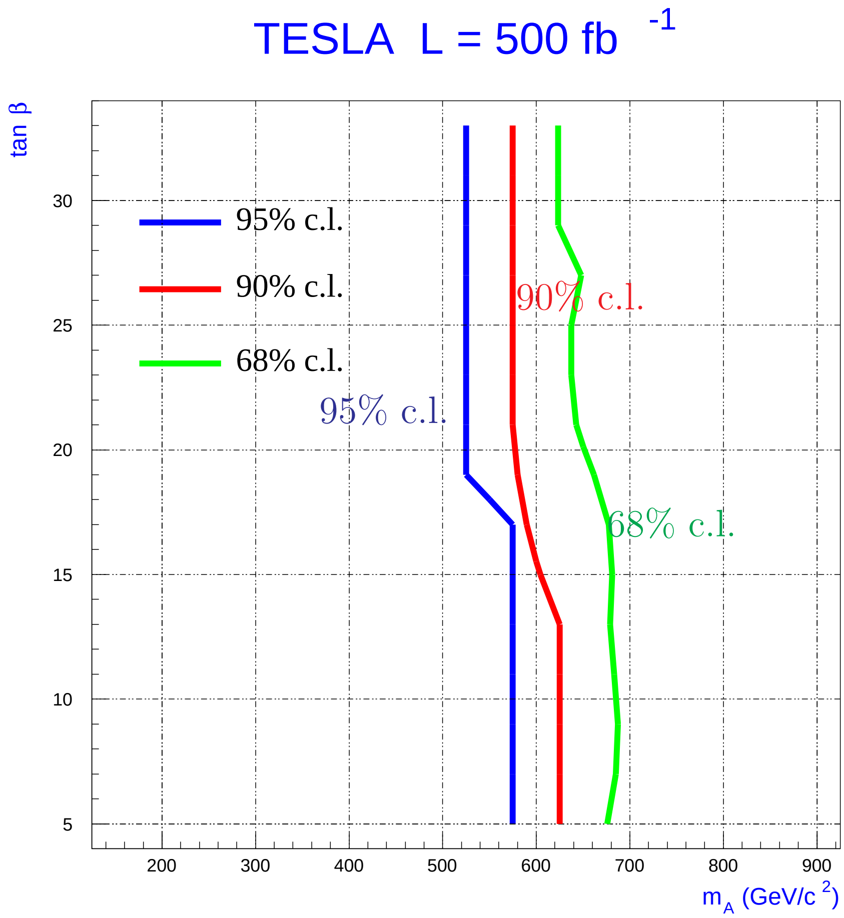
$\Rightarrow \eta \tan\beta = -\frac{m_Z^2 + m_h^2}{m_A^2}$ independent of $\tan\beta$

- $BR(h \to b\bar{b})/BR(h \to W^+W^-)$ sensitive to m_A
- Effects on $BR(h \to c\bar{c})$ suppressed by $1/\tan\beta$ and knowledge of m_c

Quantitatively:



Exclusion limits



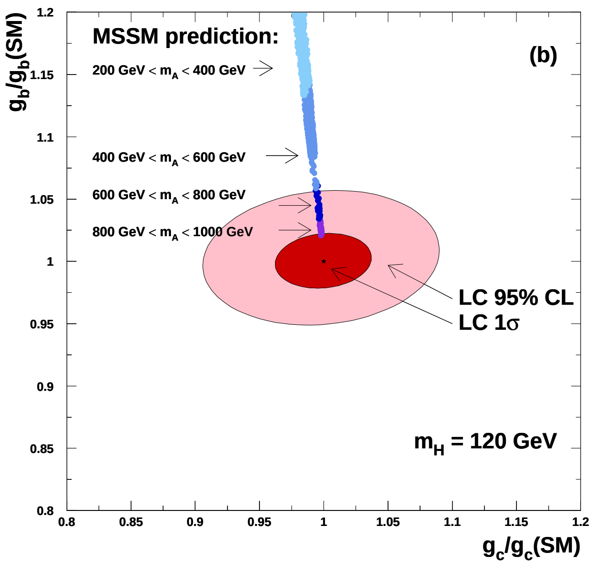
Determination of Higgs couplings

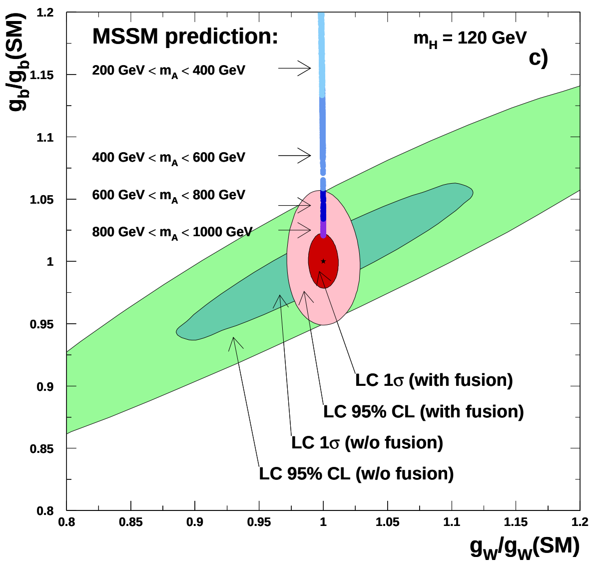
Measurement of Higgs BRs and total width allows determination of Higgs couplings:

$$\Gamma(\mathrm{H} \to \mathrm{X\overline{X}}) = \mathrm{BR}(\mathrm{H} \to \mathrm{X\overline{X}}) \cdot \Gamma_{\mathrm{H}}$$
$$\propto g^2_{\mathrm{H}\to\mathrm{X\overline{X}}}$$

Couplings are obtained from a fit to all related measurements

Model independent Higgs couplings can be compared to model predictions





Measurement of $\Gamma(H \to \gamma\gamma)$

- $H \to \gamma\gamma$ is loop induced process sensitive to couplings of heavy particles to the Higgs
  (e.g. stop heavier than 250GeV can give effects of $> 10\%$)
- $BR(H \to \gamma\gamma)$ can be measured to $\sim 10 - 15\%$ for $m_\mathrm{H} = 120\,\mathrm{GeV}$, rapidly getting worse when Γ_H increases

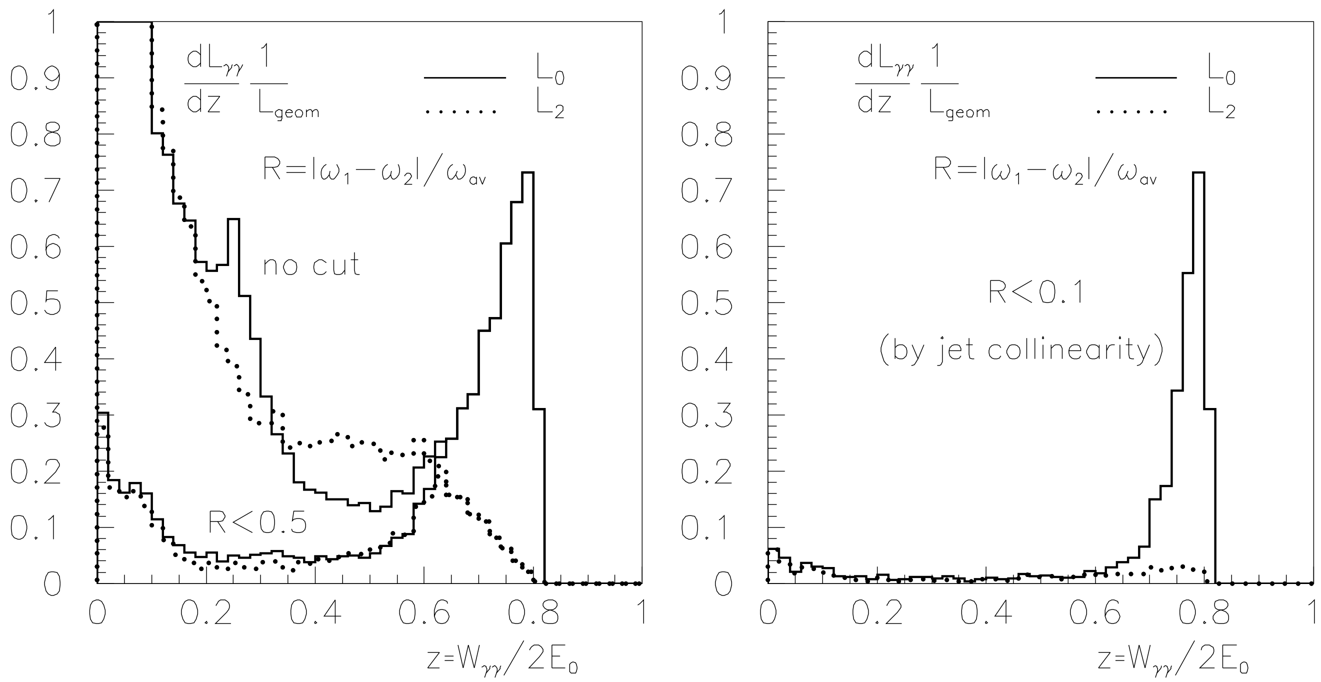
Alternative: measure $\sigma(\gamma\gamma \to H)$ in photon-collider

- cross section for $\sqrt{s_{\gamma\gamma}} = m_\mathrm{H}$:

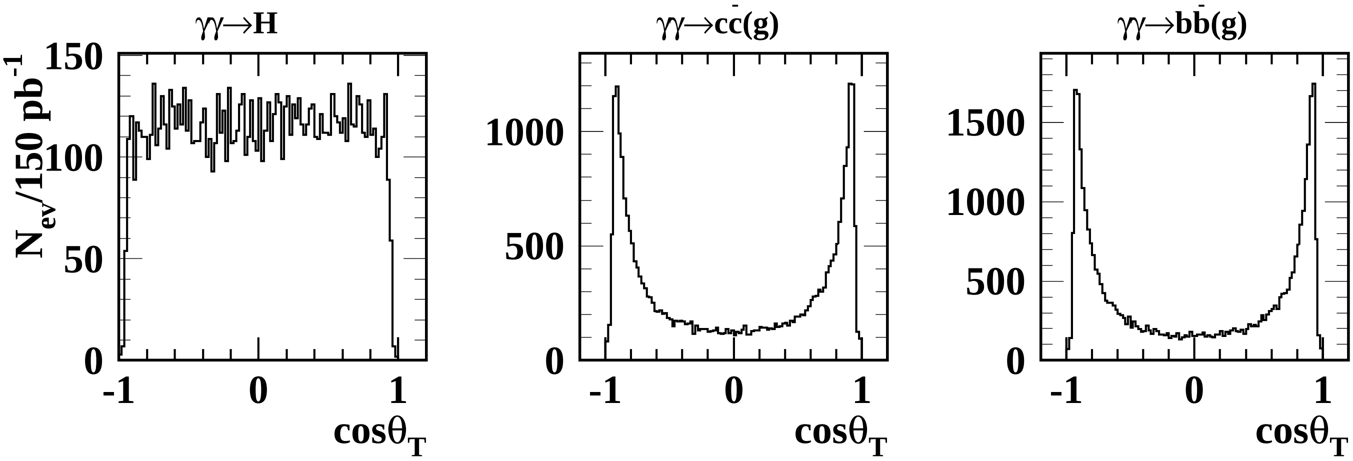
$$\sigma(\gamma\gamma \to \mathrm{H} \to \mathrm{X}) = \frac{4\pi^2}{\mathrm{m_H^3}}\Gamma(\mathrm{H} \to \gamma\gamma)\cdot\mathrm{BR}(\mathrm{H} \to \mathrm{X})(1+\lambda_1\lambda_2)$$

  (λ_i = helicity of photon i)
- m_H is already known when measurement is done
  $\Rightarrow$ can tune $\gamma\gamma$ energy (peak of dist.) to m_H
- analysis up to now done for light Higgs with $\mathrm{H} \to \mathrm{b\bar{b}}$

Can adjust polarization to be mainly $J_z = 0$

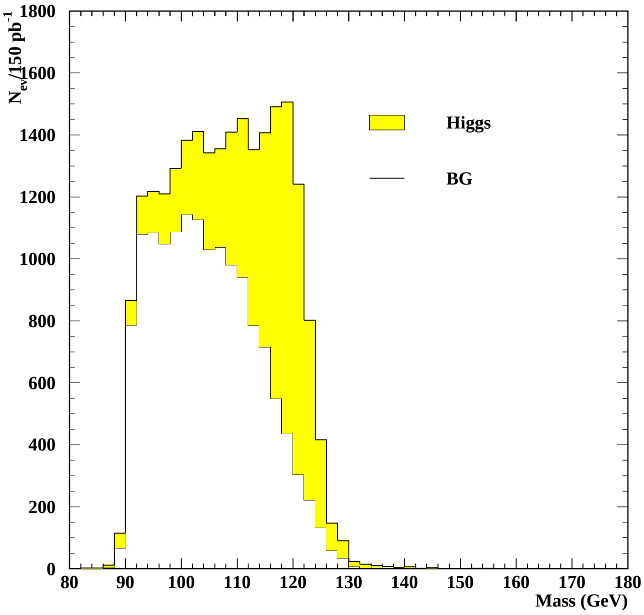


- signal cross section $\sim 0.1\,\text{pb}$
- background: QED $\gamma\gamma \to q\bar{q}$
  – cross section $\propto Q_q^4 \Rightarrow$ b's suppressed
  – $J_z = 0$ cross section suppressed by m_q^2/s, however $\sim 100\%$ QCD corrections
  – total background from $J_z = 0, 2 \sim$ equal
  – background strongly forward peaked



cut on $|\cos\theta| < 0.7$

– background more concentrated at lower masses



apply mass cuts

– suppress light quarks completely and $c\bar{c}$ by factor 20 using b-tagging

- final purity $\sim$ 40% with $b\bar{b}$- and $c\bar{c}$-background about equal
- for $\mathcal{L}_{\gamma\gamma}(0 < z < z_{\mathrm{max}}) = 150\,\mathrm{fb}^{-1}$ corresponding to $\mathcal{L}_{\gamma\gamma}(0.65 < z < z_{\mathrm{max}}) = 43\,\mathrm{fb}^{-1}$ corresponding to $\mathcal{L}_{ee} = 200\,\mathrm{fb}^{-1}$ about 8000 signal events are selected

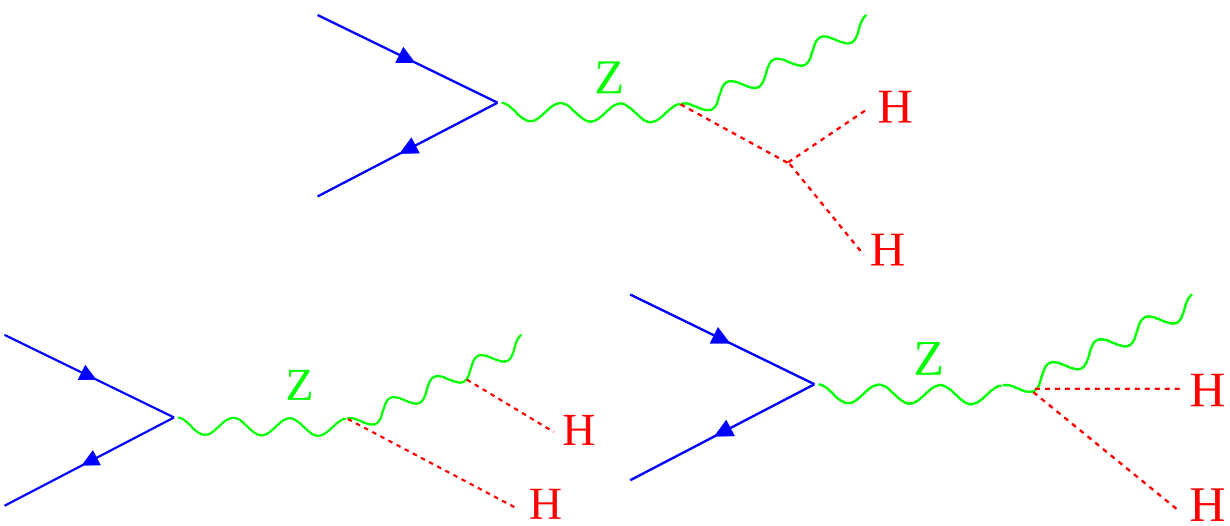
➨ $\frac{\Delta\Gamma(H\to\gamma\gamma)BR(H\to b\bar{b})}{\Gamma(H\to\gamma\gamma)BR(H\to b\bar{b})} \approx 2\%$

➨ with $\Delta BR(H \to b\bar{b}) = 2.4\%$: $\frac{\Delta\Gamma(H\to\gamma\gamma)}{\Gamma(H\to\gamma\gamma)} \approx 3\%$

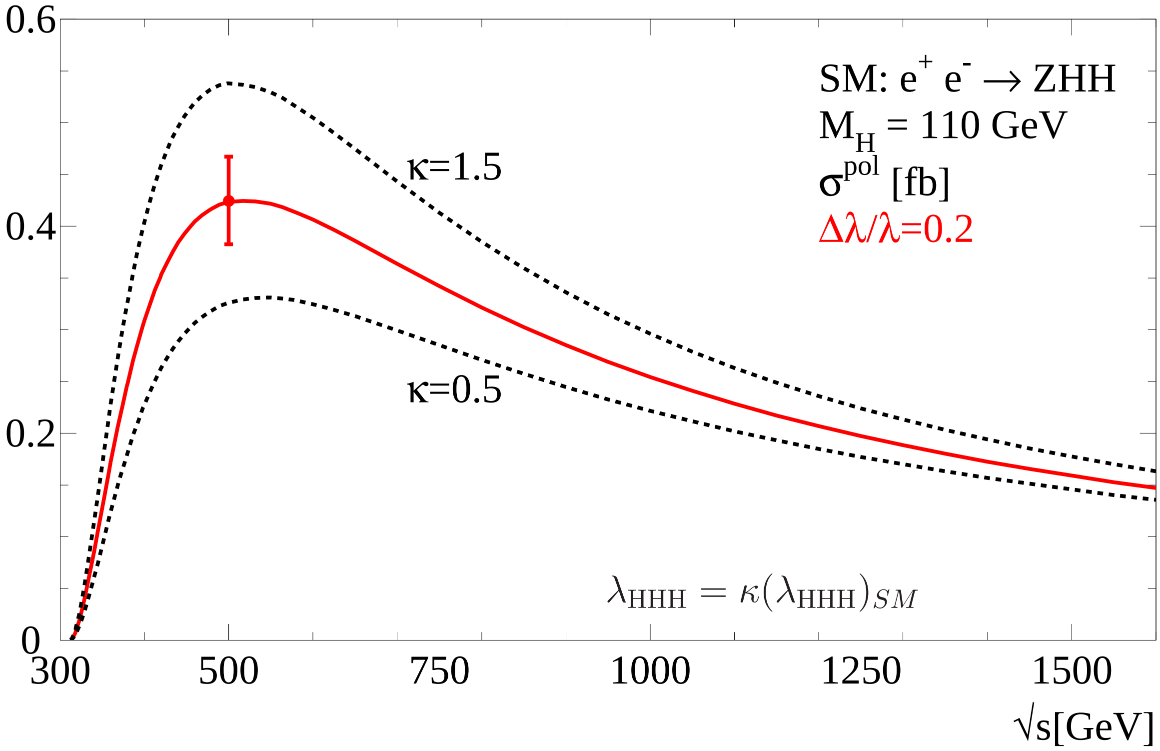
Measurement of the Higgs self-couplings

- Higgs potential $V(\Phi) = \lambda(\Phi^*\Phi - v^2/2)^2$
- Inside the SM completely known once m_{H} is measured
- Have to reconstruct the Higgs potential as much as possible to prove that the Higgs is really responsible for electroweak symmetry breaking
- trilinear Higgs coupling:
  $\lambda_{\mathrm{HHH}} = 3m_{\mathrm{H}}^2/m_{\mathrm{Z}}^2\lambda_0$, $\lambda_0 = m_{\mathrm{Z}}^2/v$
- quadrilinear Higgs coupling:
  $\lambda_{\mathrm{HHHH}} = 3m_{\mathrm{H}}^2/m_{\mathrm{Z}}^4\lambda_0$
- trilinear coupling can be seen at LC, quadrilinear coupling too small

Processes for $\mathrm{e^+e^-} \rightarrow ZHH$:



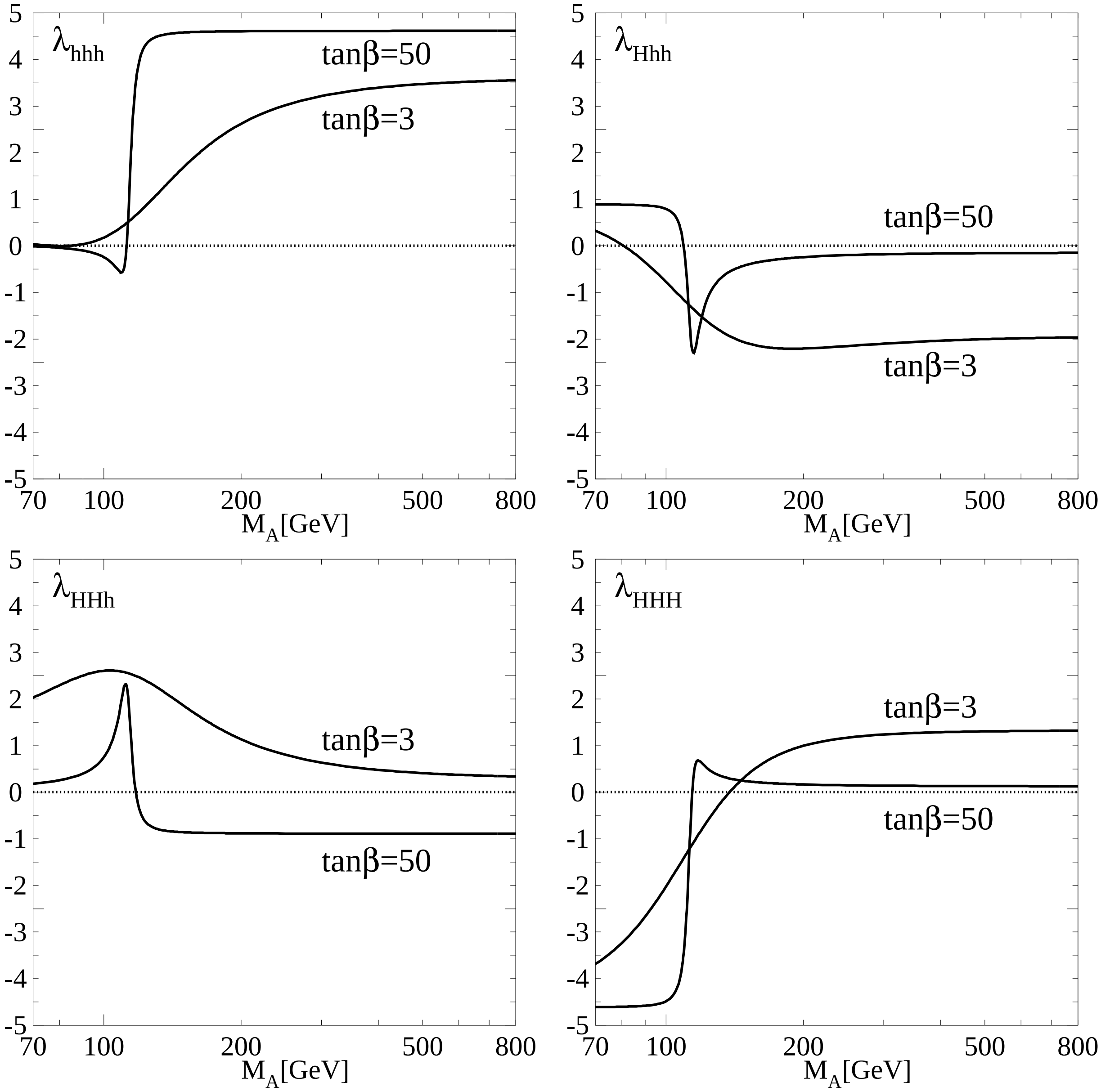
Cross section and sensitivity to λ_{HHH}:



For a light Higgs it should be possible to establish Higgs-self-coupling with $\sqrt{s} = 500\,\mathrm{GeV}$ and several hundred fb^{-1} luminosity

For heavier Higgses WW fusion can take over

Situation more complicated in SUSY

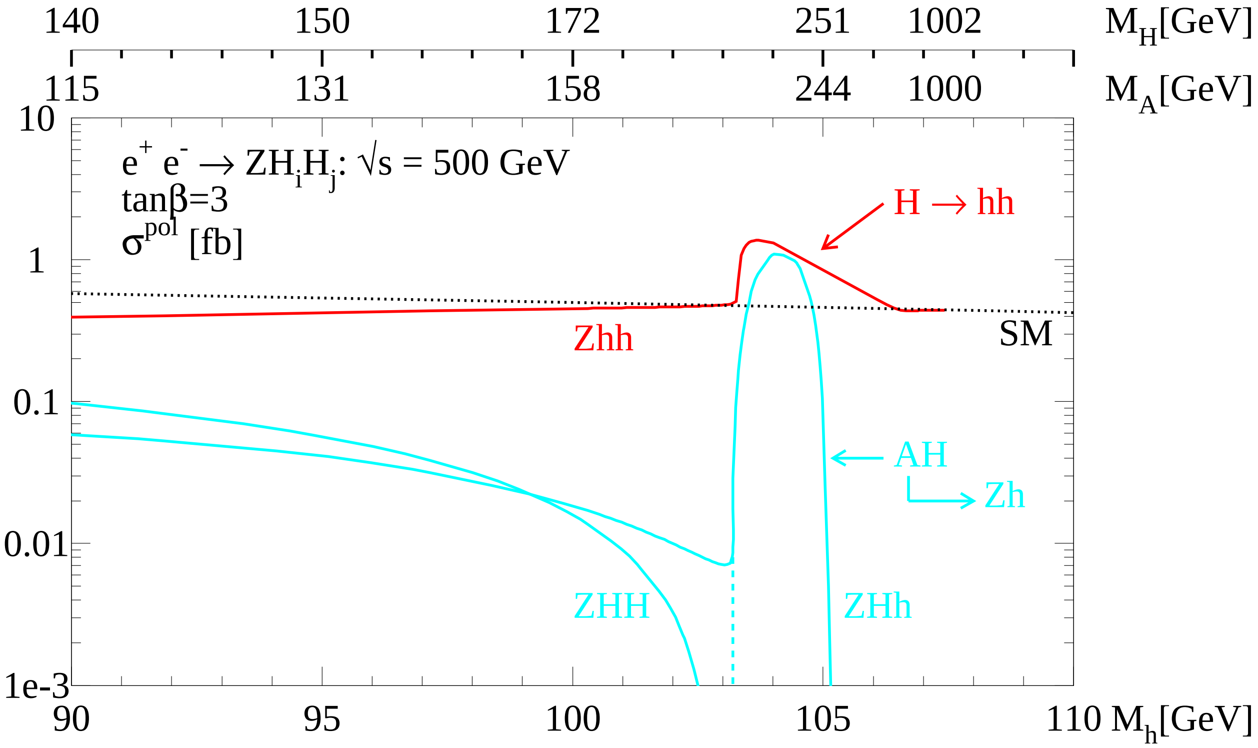


(hAA, HAA couplings generally small)

Has to be folded with Zhh (ZHH) coupling

(SM: $\lambda \approx 5$)

Some effects should remain visible



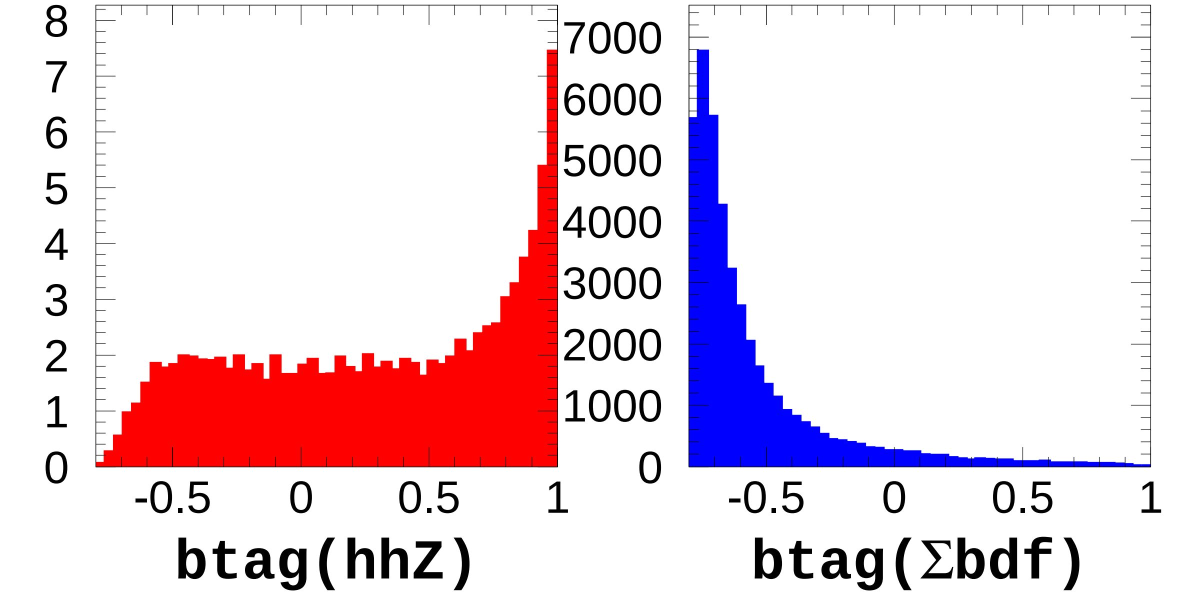
- Experimental SM analysis exists
- SUSY analysis to be done

Experimental analysis of HHH-coupling

- Assume $\sqrt{s} = 500\,\mathrm{GeV}$, $\mathcal{L} = 500\,\mathrm{fb}^{-1}$, $m_\mathrm{H} = 100\,\mathrm{GeV}$
- Signal $\mathrm{e^+e^-} \to \mathrm{ZHH} \to \mathrm{b\bar{b}b\bar{b}f\bar{f}}$ $\sigma \sim 0.5\,\mathrm{fb}$
- Background: after preselection $\sim 500\times$signal (WW, Zγ, ZZ, WWZ, ZZZ, hZ)

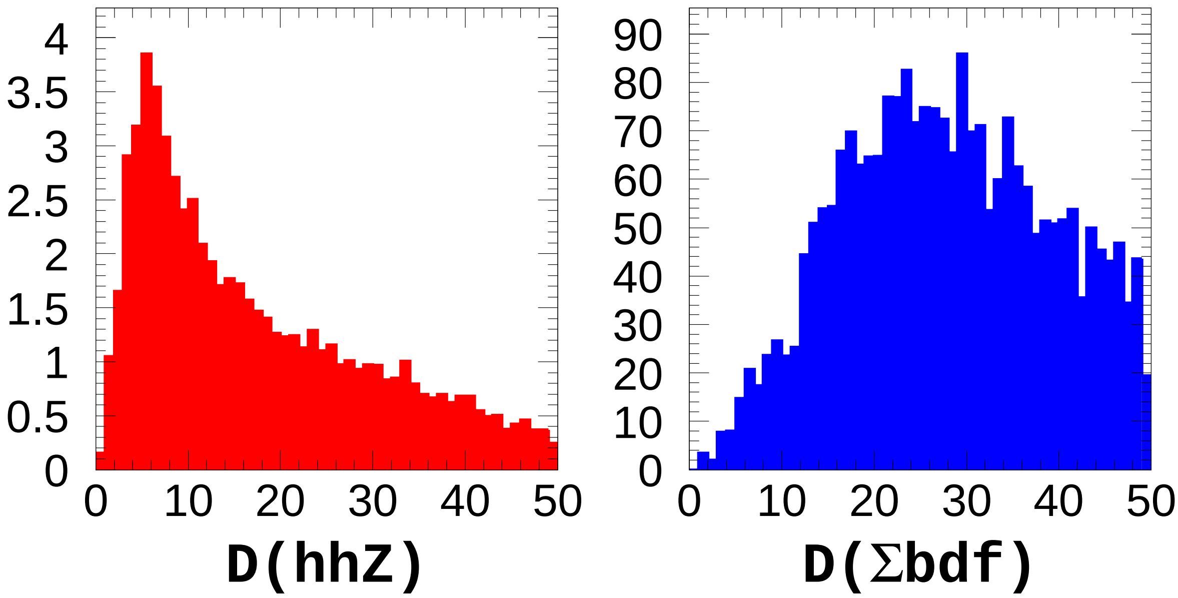
- Key: b-tagging

Combined b-tagging variable (from 6 jets)



- plus topological cuts after constrained fit

$$D = \sqrt{(m_{12} - m_{\mathrm{H}})^2 + (m_{34} - m_{\mathrm{H}})^2 + (m_{56} - m_{\mathrm{Z}})^2}$$

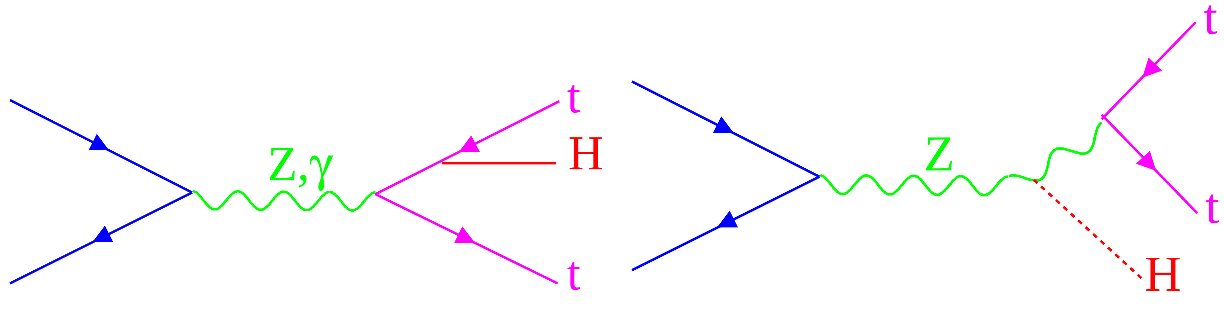


- final efficiency $\varepsilon = 15\%$ with $\mathrm{S/B} \sim 1$
- final backgrounds mainly $\mathrm{Z}(\gamma)$, WW, ZZ, ZZZ; 75% with one $\mathrm{Z} \rightarrow \mathrm{t\bar{t}}$ or $\mathrm{W} \rightarrow \mathrm{tb}$

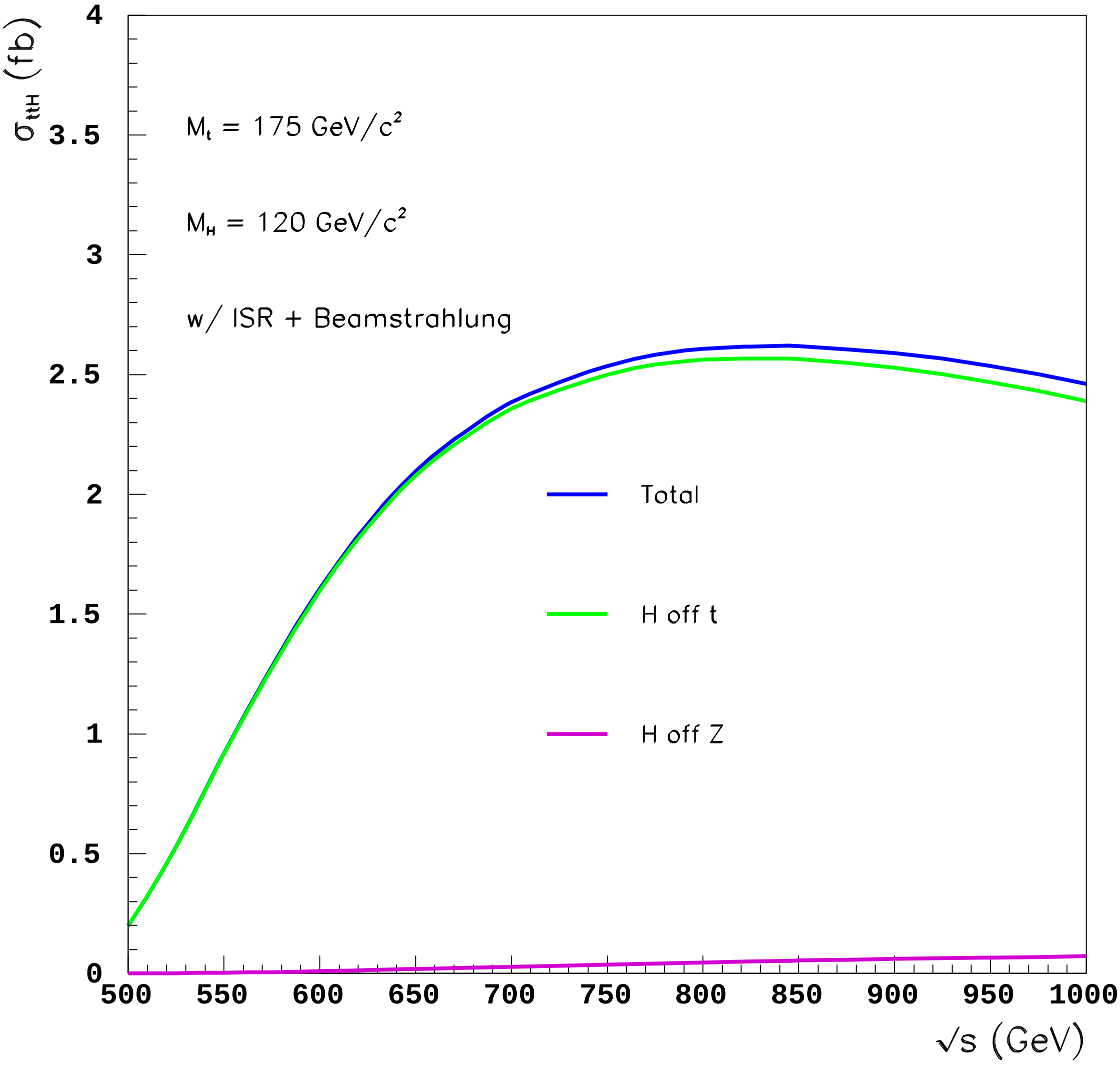
➡ $\Delta\lambda/\lambda \approx 0.2$ is possible

The $\mathrm{Ht\bar{t}}$-Yukawa coupling

- If the Higgs is responsible for mass generation its couplings should be proportional to the particle mass
- The couplings HZZ, HWW are known from the cross sections $\mathrm{e^+e^-} \to \mathrm{ZH}$ and $\mathrm{WW} \to \mathrm{H}$
- The Yukawa couplings $\mathrm{Hb\bar{b}}$, $\mathrm{Hc\bar{c}}$, $\mathrm{H}\tau^+\tau^-$ can be obtained from the partial decay widths
- The top-Yukawa coupling is especially interesting since $g_{\mathrm{ttH}} \sim 1$ and the top-quark plays a special role in some theories
- A $\sim$ 35% estimate of the top-Yukawa coupling can be obtained from the $\mathrm{t\bar{t}}$-threshold scan
- The top-Yukawa coupling can be measured from $\mathrm{t\bar{t}H}$- events



Cross section:



Event signatures:

$t\bar{t}H \rightarrow WbWbb\bar{b} \rightarrow 4q4b,\ 2q\ell\nu 4b$

(2($\ell\nu$) events and H decays not to $b\bar{b}$ are not considered)

Assumptions:

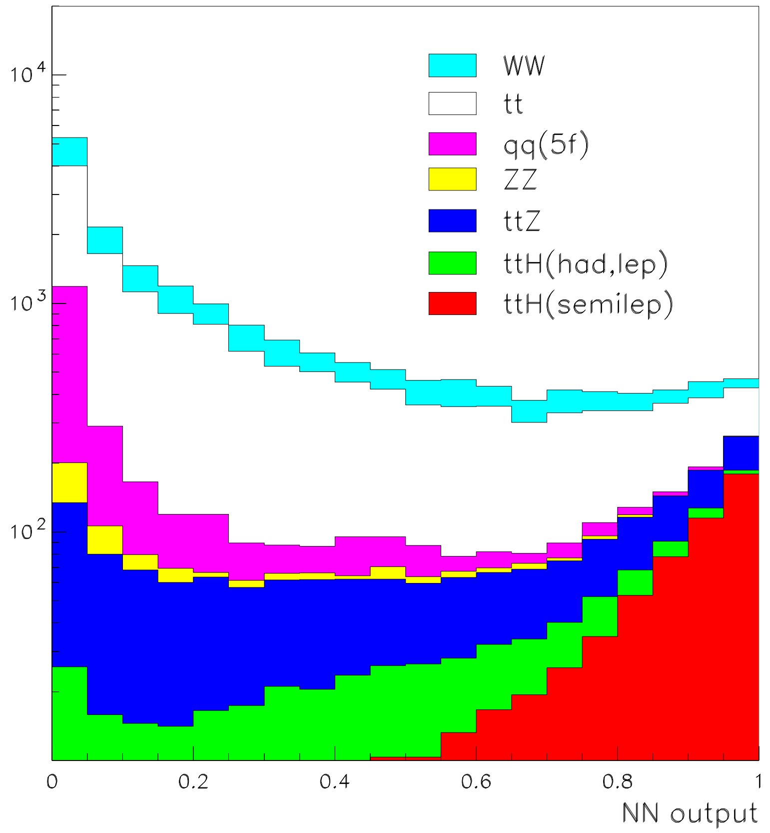
$\sqrt{s} = 800\,\mathrm{GeV},\ \mathcal{L} = 1000\,\mathrm{fb}^{-1},\ m_H = 120\,\mathrm{GeV}$

Example: $2q\ell\nu 4b$ analysis

- start with preselection cuts, mainly to separate "round" from "jetty" events
- after preselection

Signal ($\varepsilon = 54\%$)	0.61 fb
Most dangerous backgrounds:	
$t\bar{t}$	10.97 fb
WW	4.05 fb
Total background:	17.59 fb

Process events with neural network including event shapes, b-tagging, lepton-id

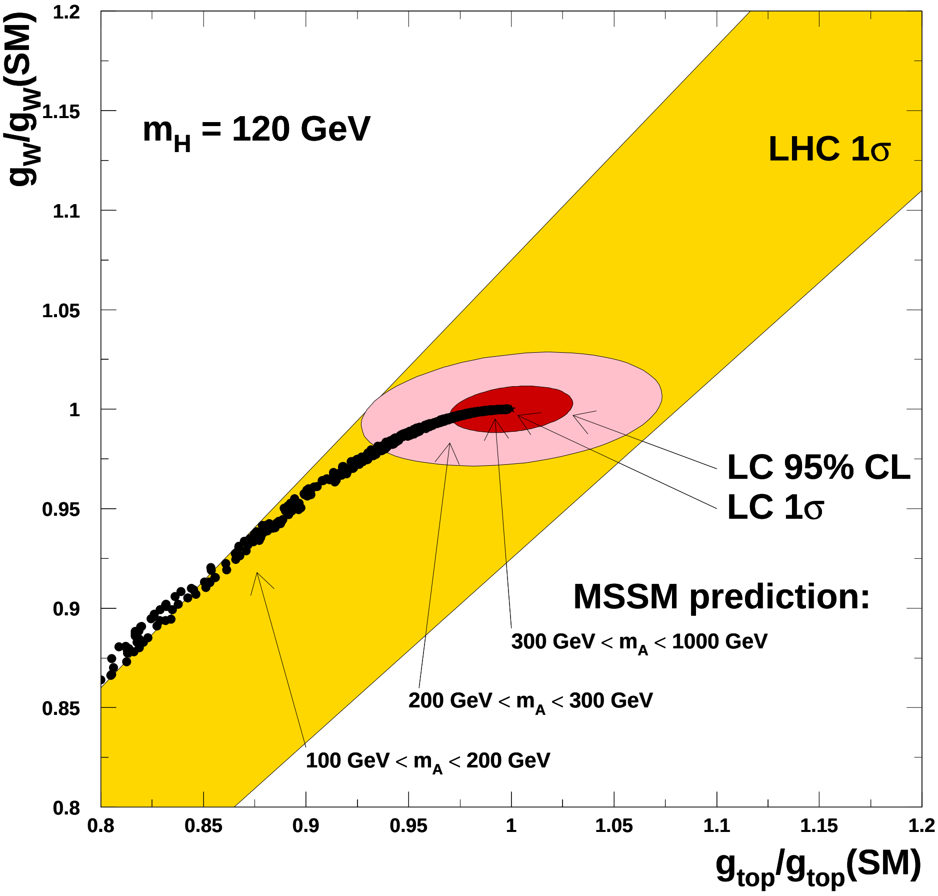


Results:

- Can achieve $S/B = 0.5$ with $\varepsilon = 27\%$

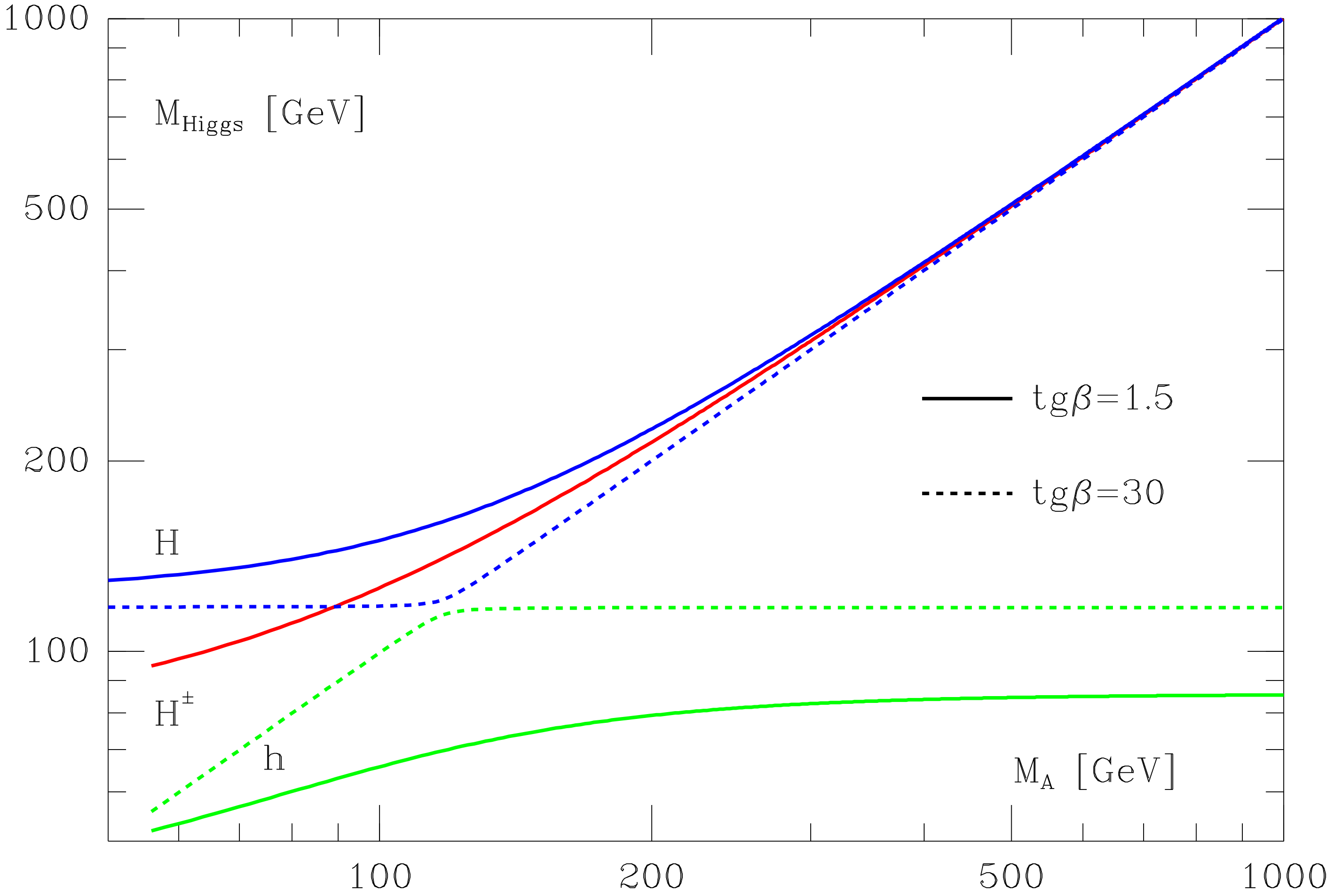
➠ $\Delta g_{\mathrm{ttH}} = \pm 5.1\%(\mathrm{stat}) \pm 3.8\%(\mathrm{syst})$ for 5% error on background normalization

- slightly worse results in fully hadronic channel
- total error of $\Delta g_{\mathrm{ttH}} = \pm 5.5\%$ seems possible
- $\sim$ factor 3 better than LHC



Other SUSY Higgses

Masses of Higgs bosons:



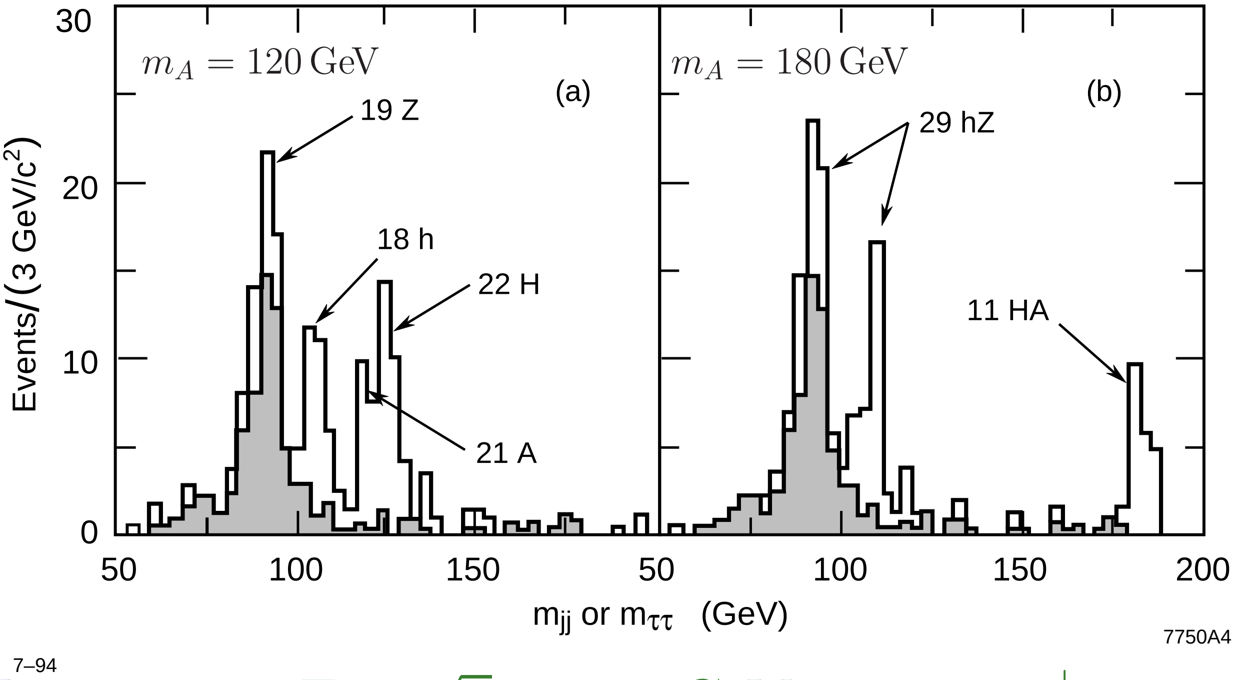
If A heavy ($m_A > 200$ GeV):

- $\sin^2(\beta - \alpha) \approx 1 \Rightarrow$
  - h is SM like
  - H produced mainly in $e^+e^- \rightarrow HA$
- H,A,$H^{\pm}$ almost degenerate in mass

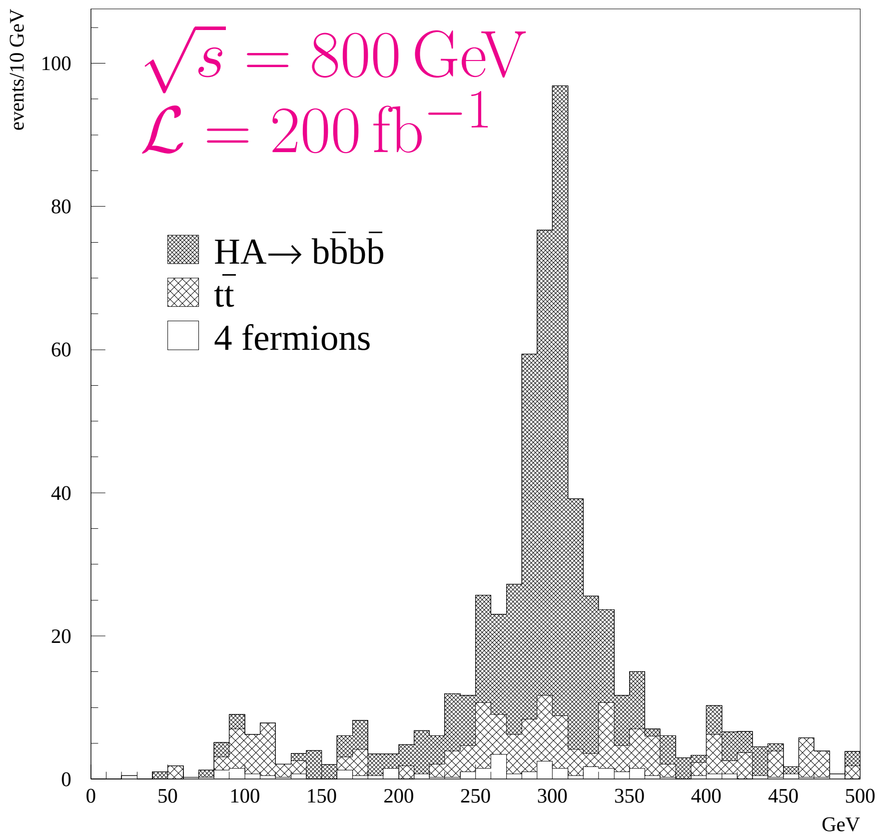
➨ if $m_A > \sqrt{s}/2$ only h can be seen
if $m_A < \sqrt{s}/2$ full spectrum in reach

Modest m_A: no problem to see $e^+e^- \to Zh$, $e^+e^- \to ZH$ and $e^+e^- \to HA$

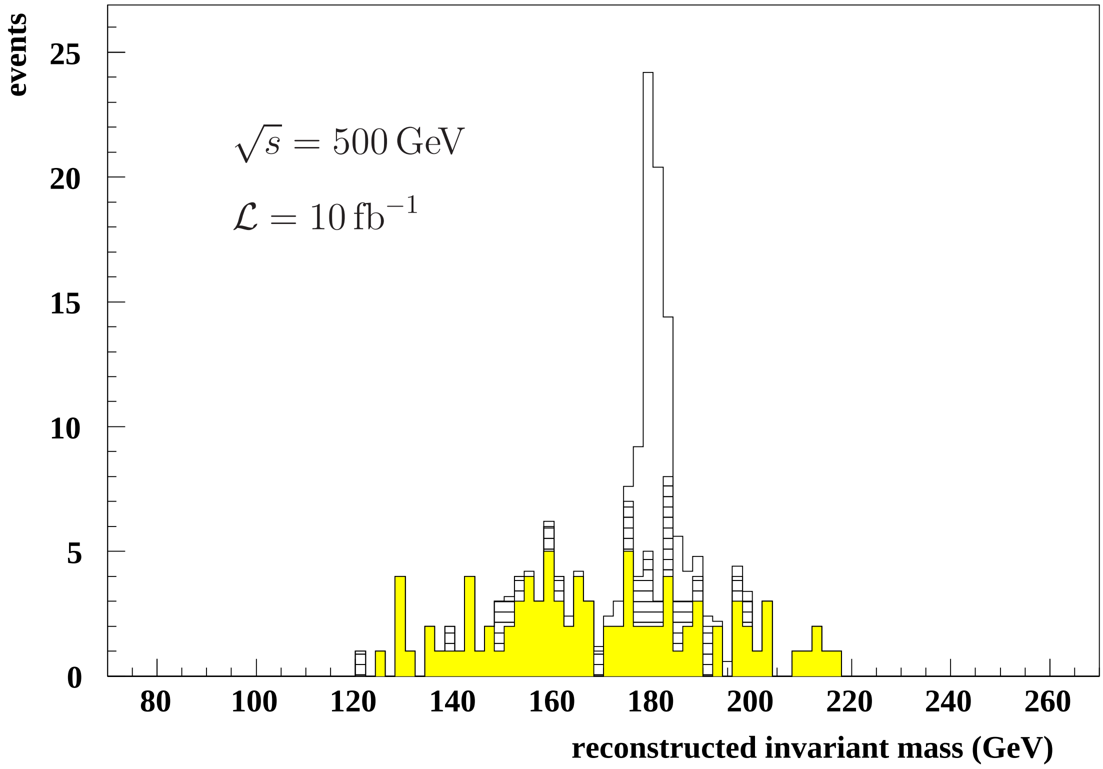
$\sqrt{s} = 400\,\mathrm{GeV}$, $\mathcal{L} = 10\,\mathrm{fb}^{-1}$



Large m_A: For $\sqrt{s} = 800\,\mathrm{GeV}$ can see $e^+e^- \to HA$ up to $m_A \sim 350\,\mathrm{GeV}$



Charged Higgses can be detected, independent of the decay mode up to $\sim 80\%\sqrt{s}/2$ with low luminosity:

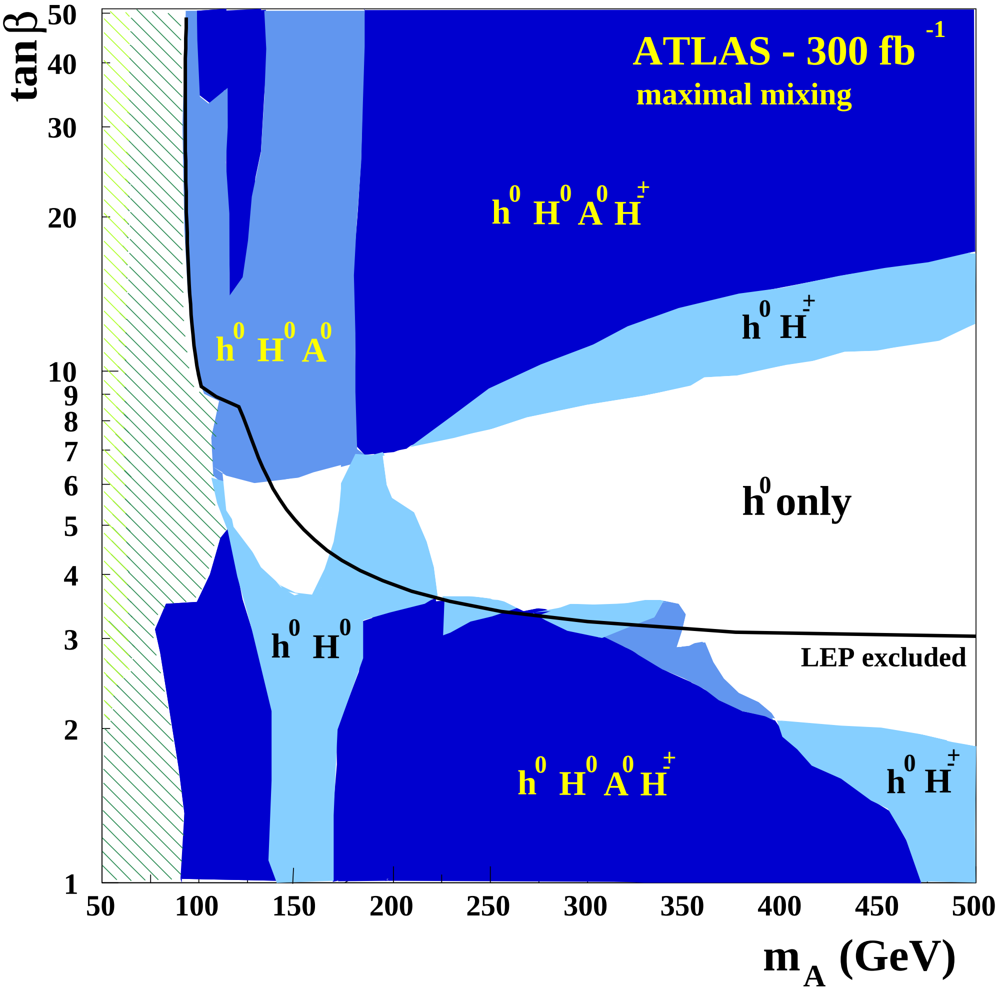


$\gamma\gamma$ collider

- Higgses are produced singly
- $\sqrt{s}_{max} \approx 0.8\sqrt{s}_{ee}$
- can see H,A up to 650 GeV for $\sqrt{s}_{ee} = 800\,\mathrm{GeV}$

Heavy SUSY Higgses at LHC

- LHC results are very dependent on $\tan\beta$
- $\tan\beta$ small: (almost) excluded by LEP $\rightarrow$ ignore
- $\tan\beta$ large: H,A-Strahlung off b-quark largely enhanced
  ➠ can see H,A in $b\bar{b}\tau^+\tau^-$ events up to fairly high masses
- $\tan\beta$ moderate: "wedge region" no heavy Higgses seen (however there are chances if the Higgses decay into SUSY particles)



Summary Higgs physics

- A SM-like Higgs definitely will be discovered at LHC
- If a Higgs exists in the LC energy range, it will be seen
- The task of the LC will be to measure the properties of the Higgs and to show that it is really responsible for electroweak symmetry breaking.
- The present analyzes mostly assume a light Higgs, for a heavier Higgs they have to be redone replacing a $b\bar{b}$-pair by a W-pair.
- The Higgs-mass can be measured to $\approx 50\,\mathrm{MeV}$
- The Higgs couplings to heavier fermions and to gauge bosons can be measured at the few percent level
- The trilinear Higgs-coupling can be established on the 20% level
- Not covered here: One can construct exotic models, where the LHC doesn't see the Higgs, but the LC still can