

HIGGS PHYSICS AT e^+e^- AND PHOTON COLLIDERS

Michael Spira (PSI)

I Introduction

II Higgs Physics @ ILC

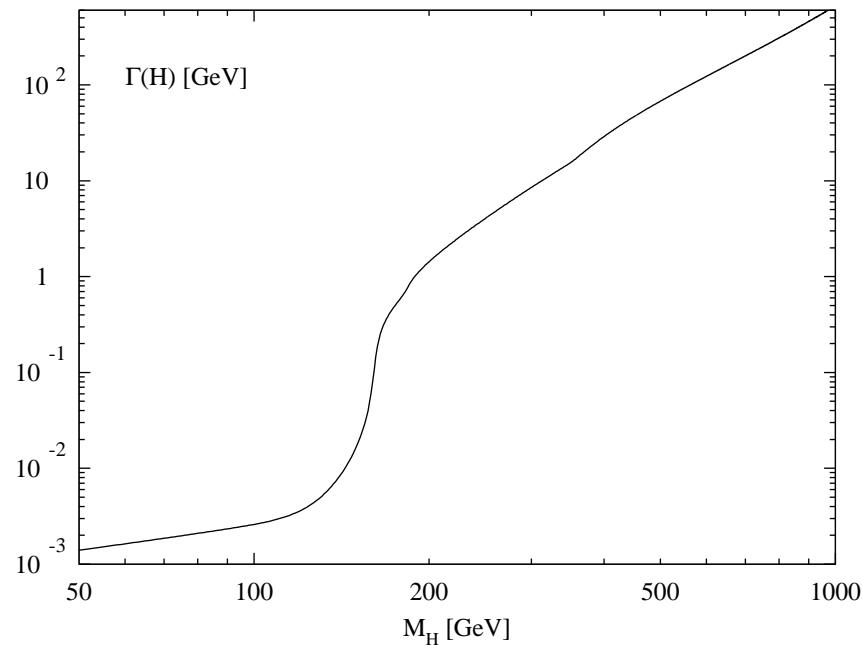
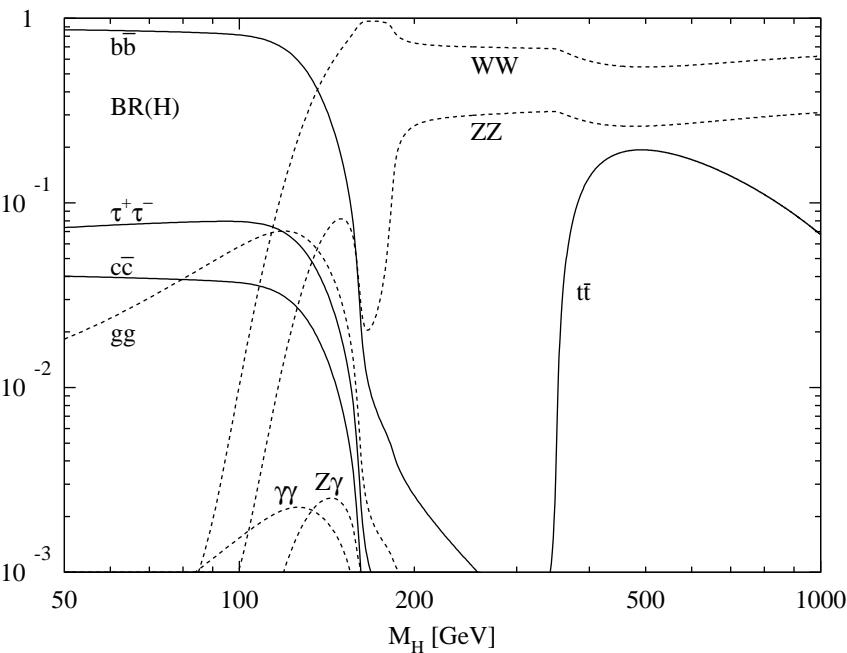
III Higgs Physics @ PLC

IV Conclusions

I INTRODUCTION

(i) Standard Model

- LEP2: $M_H > 114.4$ GeV
- triviality and vacuum stability:
 $\Rightarrow M_H \lesssim 700$ GeV [$\Lambda \sim 1$ TeV]
 130 GeV $\lesssim M_H \lesssim 190$ GeV [$\Lambda \sim M_{GUT}$]
- elw. fits: $M_H \lesssim 185$ GeV (95% CL)

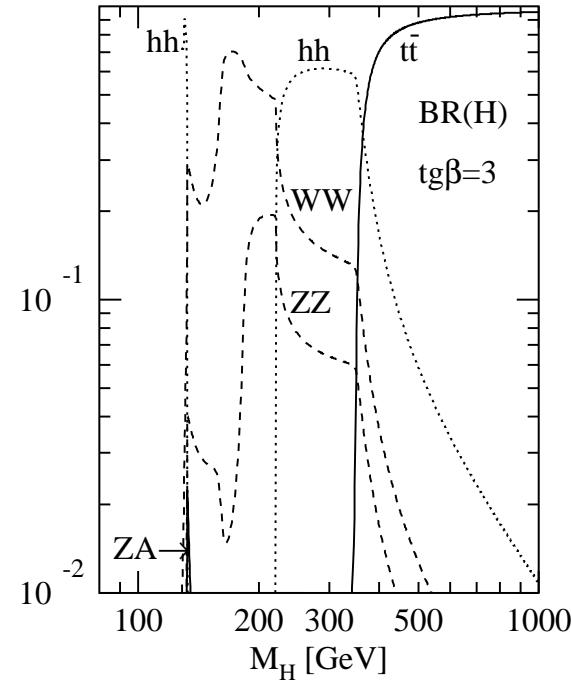
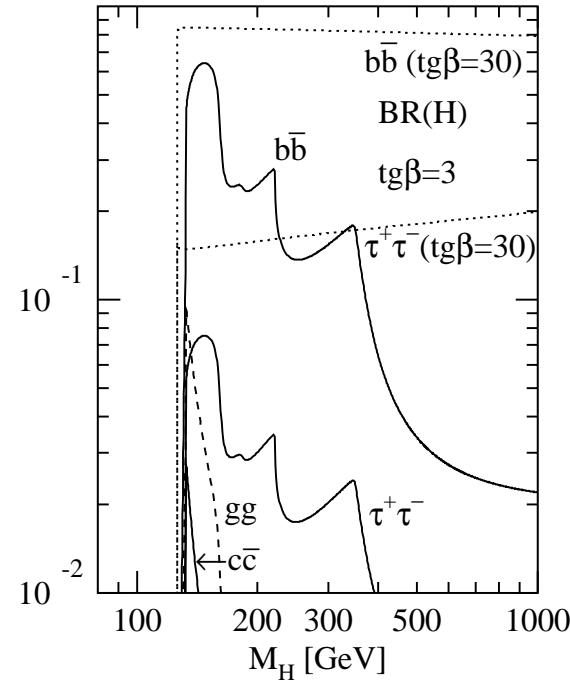
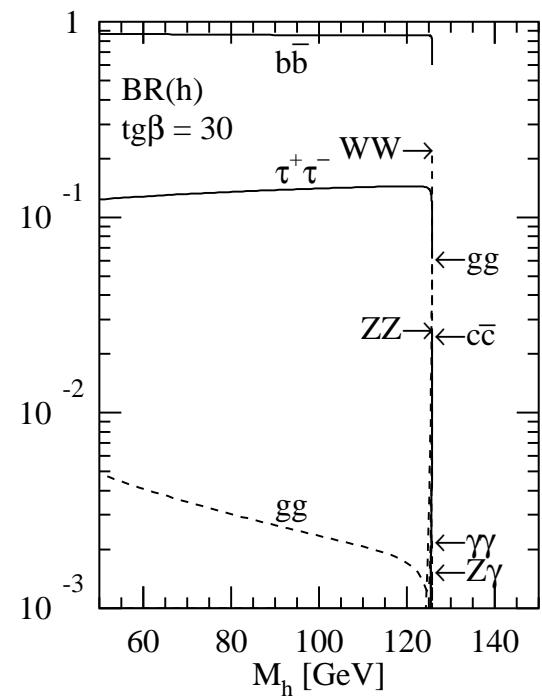
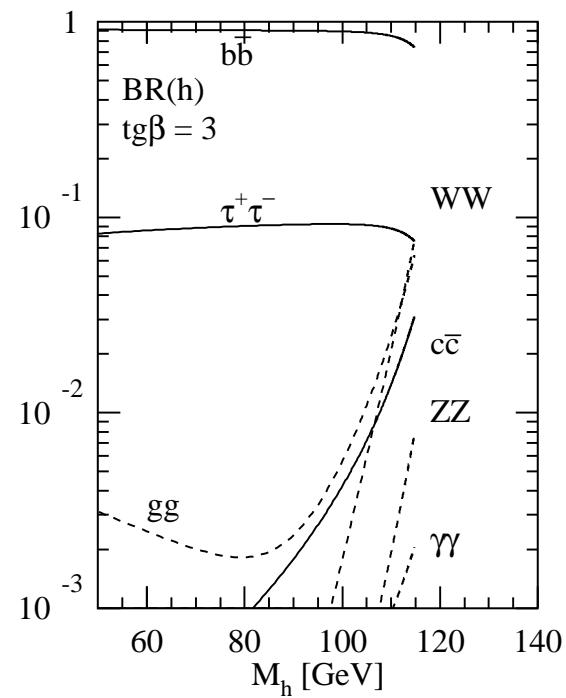


Cabibbo
Sher
Lindner
Lüscher, Weisz
Hasenfratz, ...
...

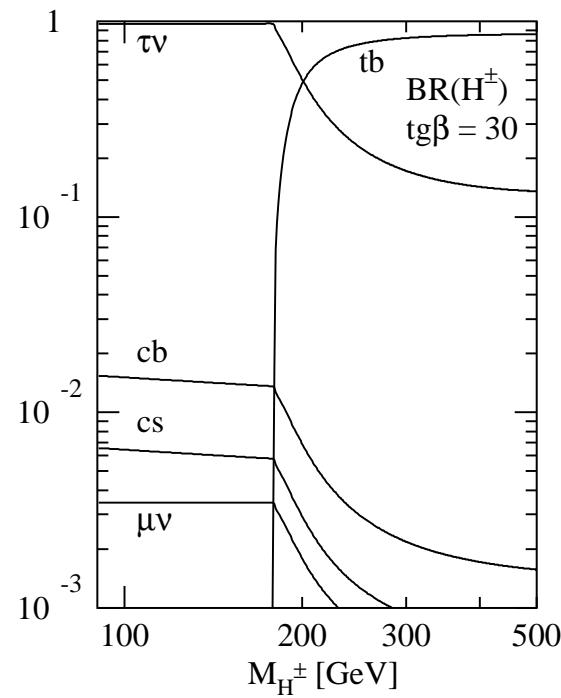
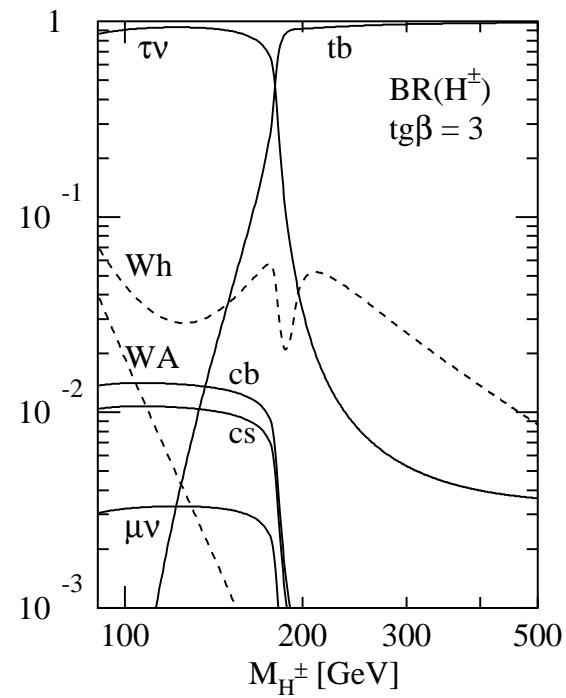
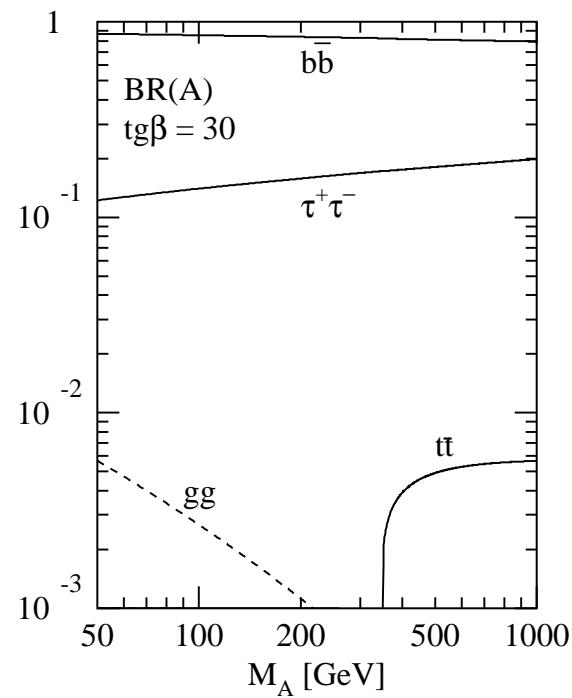
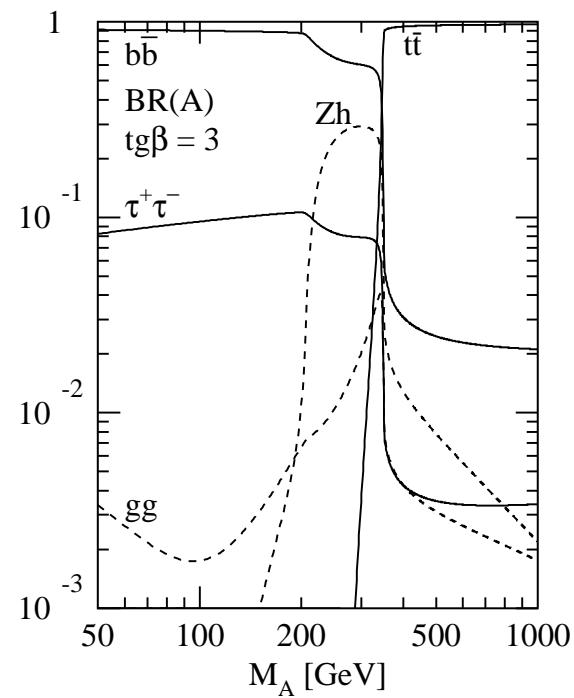
LEP/SLC/Tevatron

(ii) MSSM

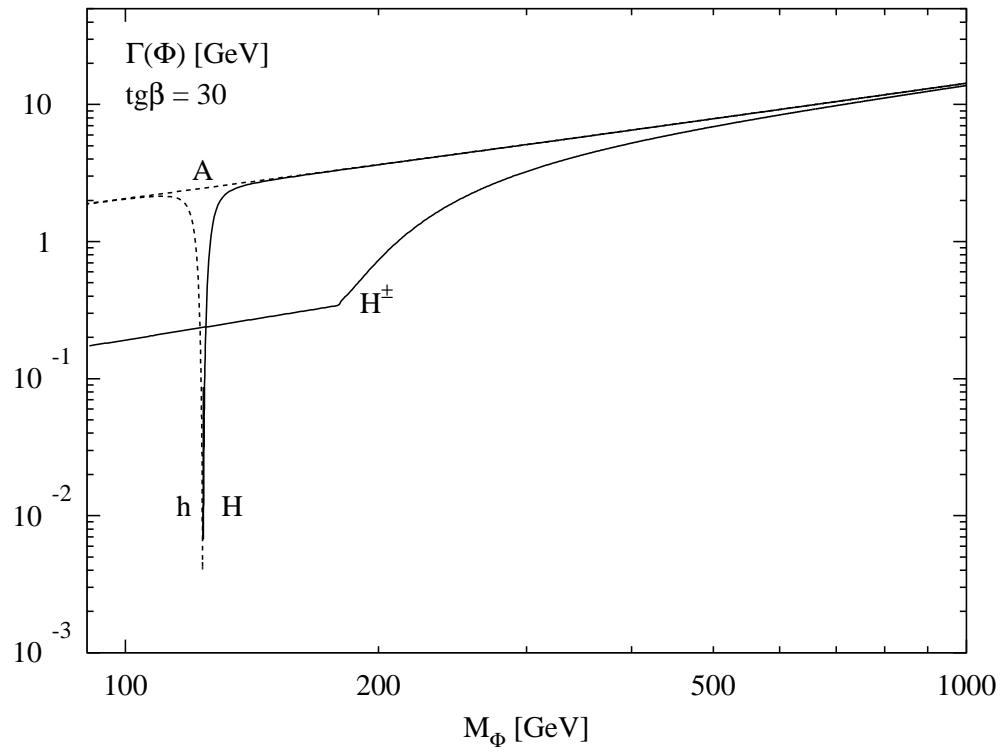
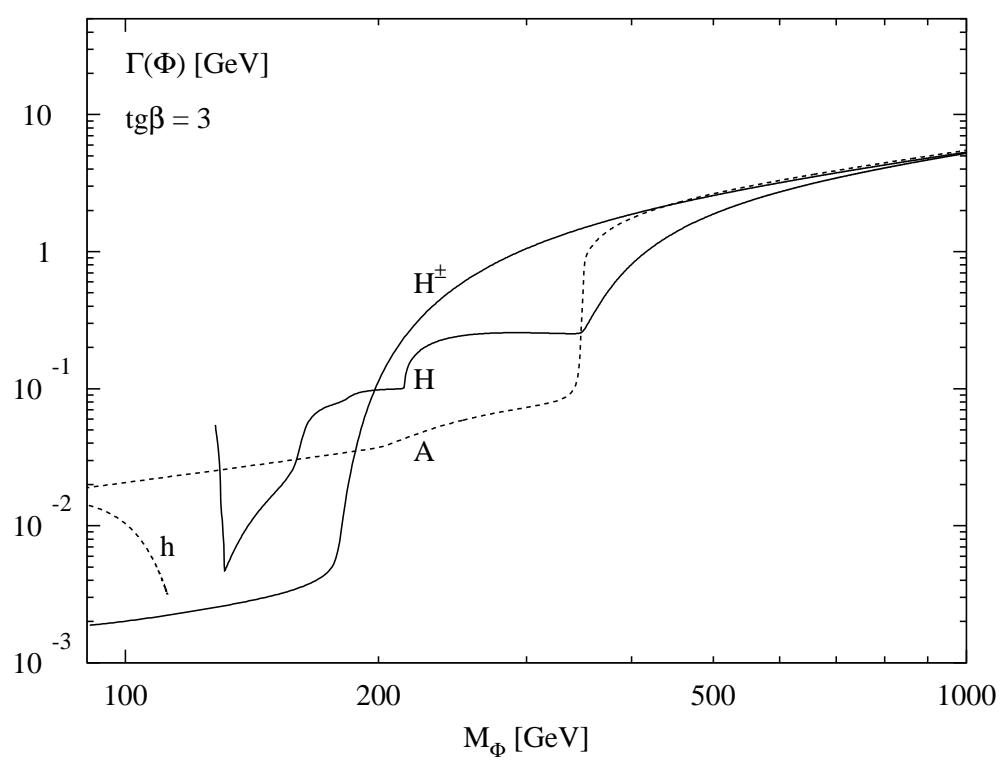
- 2 Higgs doublets $\xrightarrow{\text{ESB}}$ 5 Higgs bosons: h, H, A, H^\pm
 - LO: 2 input parameters: $M_A, \tan\beta = \frac{v_2}{v_1}$
 - radiative corrections $\propto m_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}$ $\rightarrow M_h \lesssim 140 \text{ GeV}$
 - Yukawa couplings: $\tan\beta \uparrow \Rightarrow g_u^\phi \downarrow \quad g_d^\phi \uparrow \quad g_V^\phi \downarrow$
- Haber
 Carena, ...
 Heinemeyer, ...
 Zhang
 Slavich, ...
 ...



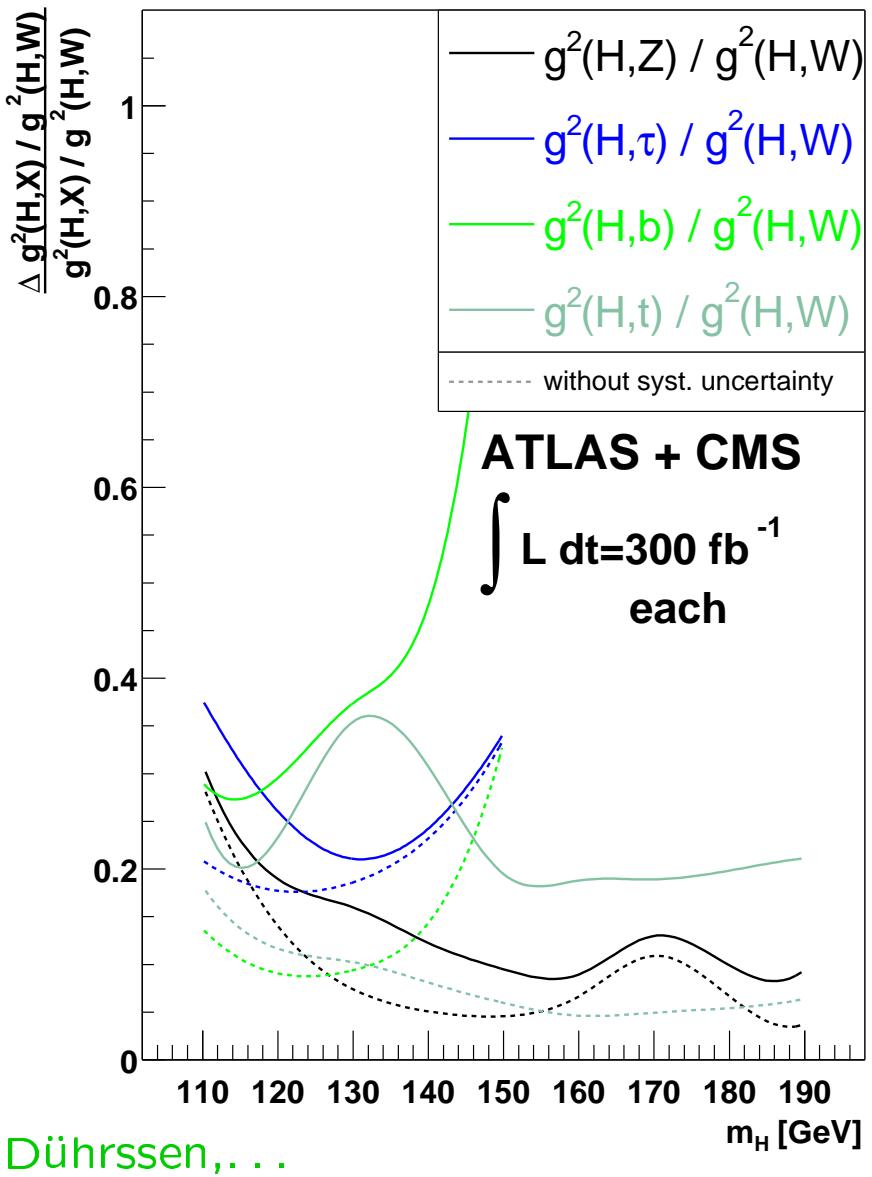
HDECAY



HDECAY

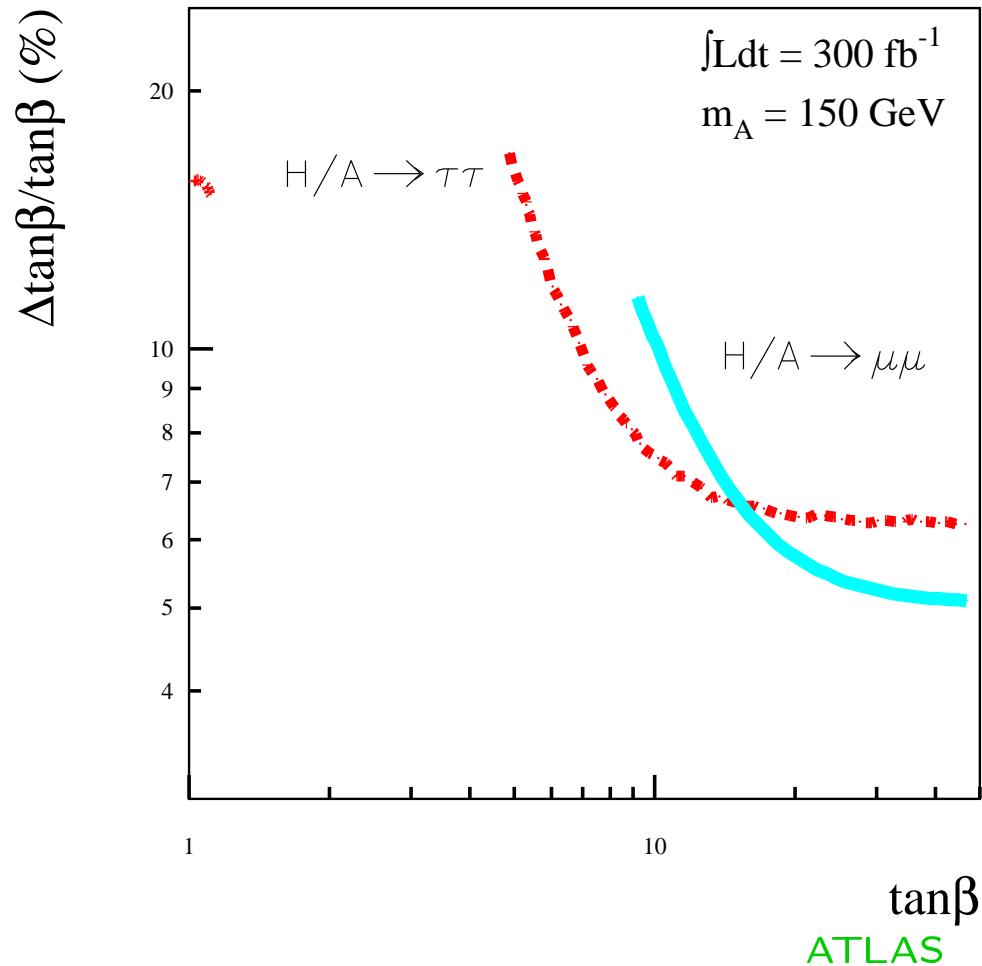


HDECAY



Dührssen, . . .

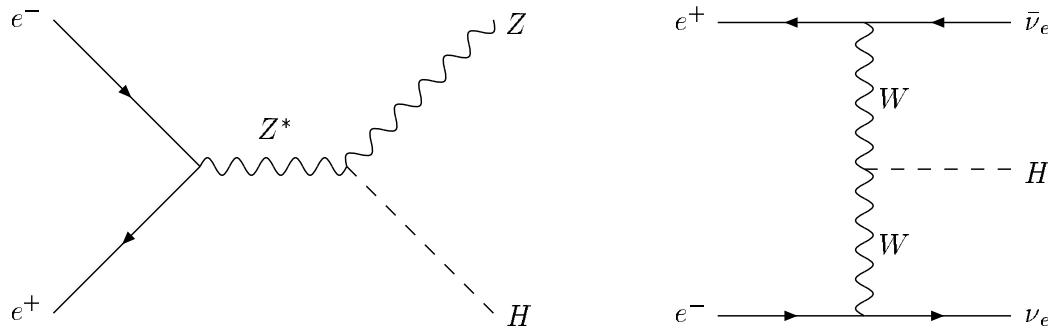
- $\delta M_H/M_H \sim 10^{-3}$



$\tan\beta$
ATLAS

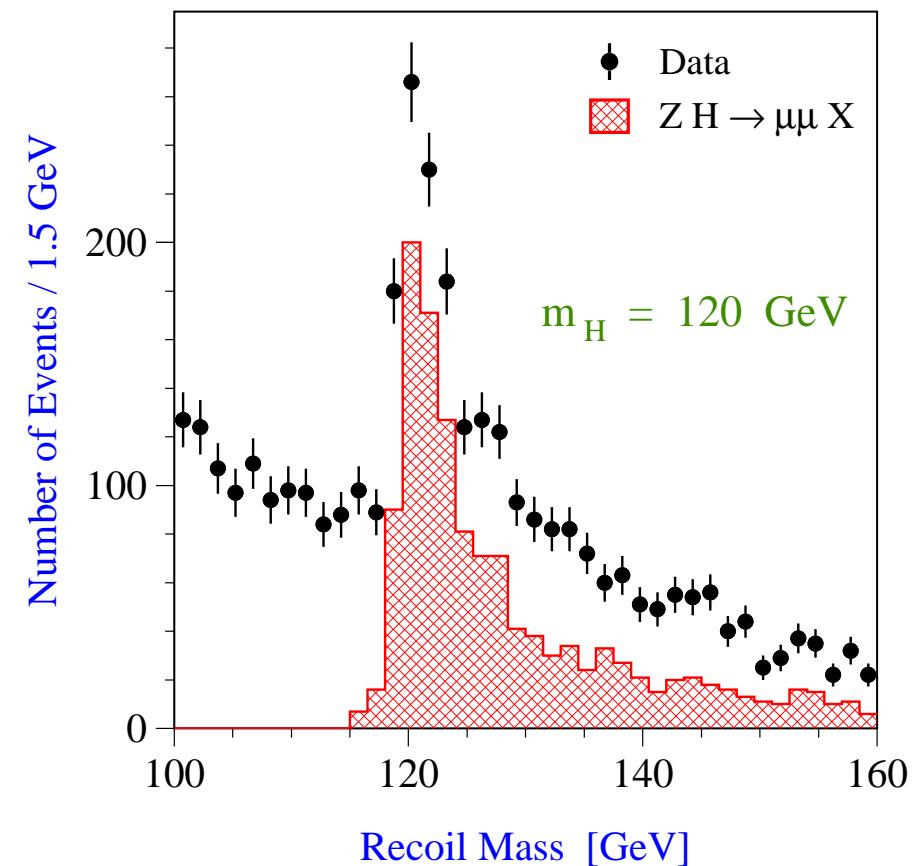
II HIGGS PHYSICS @ ILC

- Higgs boson production analogous to LEP2

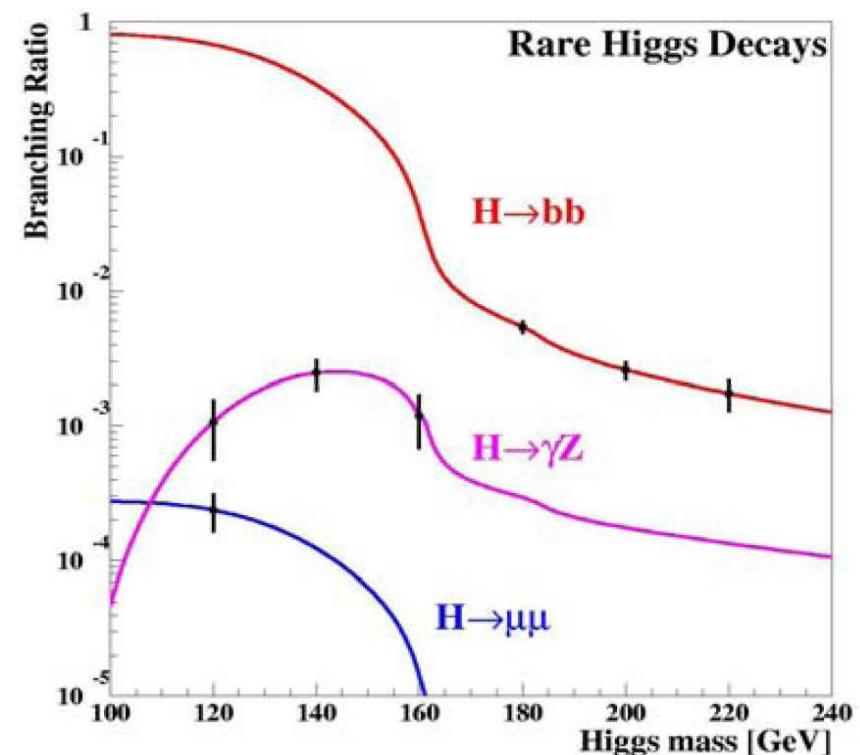
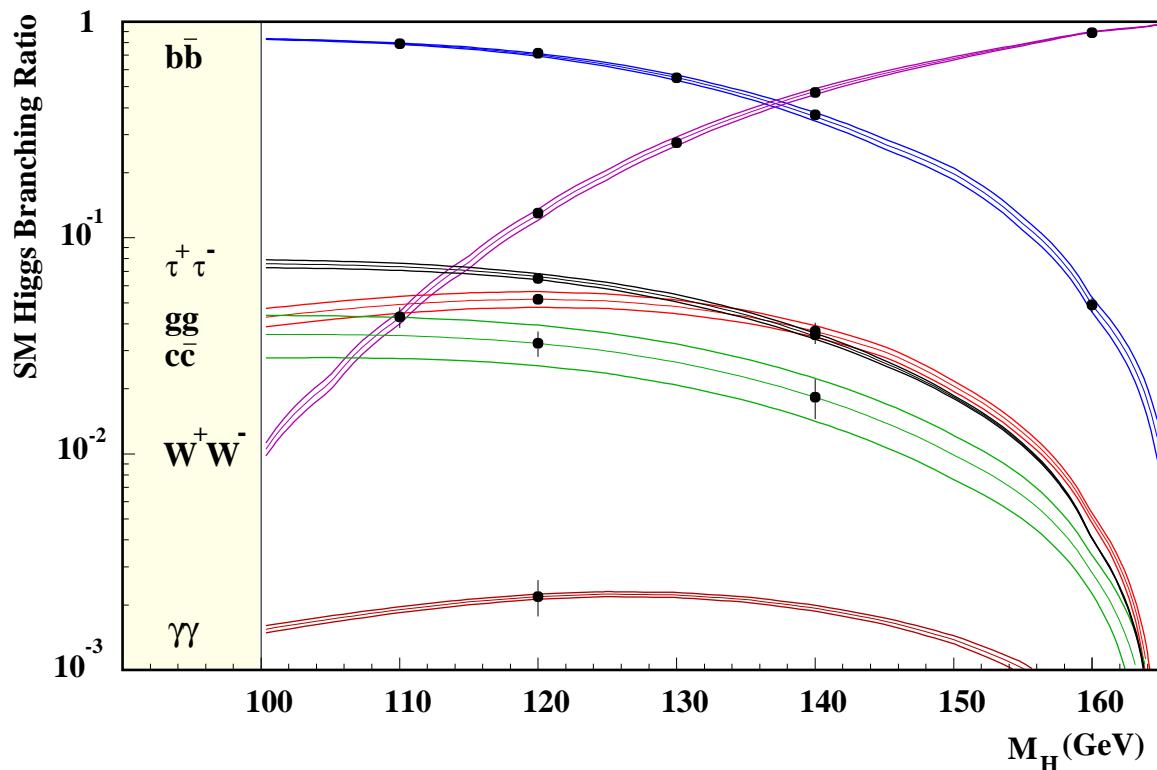


- discovery up to $M_H \lesssim 0.7\sqrt{s}$
- Higgs-strahlung $e^+e^- \rightarrow ZH$:
 Z monoenergetic
 $\Rightarrow M_H^2 = (p_{e^+} + p_{e^-} - p_Z)^2$
 $= s - 2\sqrt{s}E_Z + M_Z^2$
 \Rightarrow reconstruction from recoil mass
- mass: $\delta M_H \lesssim 40 - 80$ MeV

TESLA



- Yukawa couplings: from branching ratios



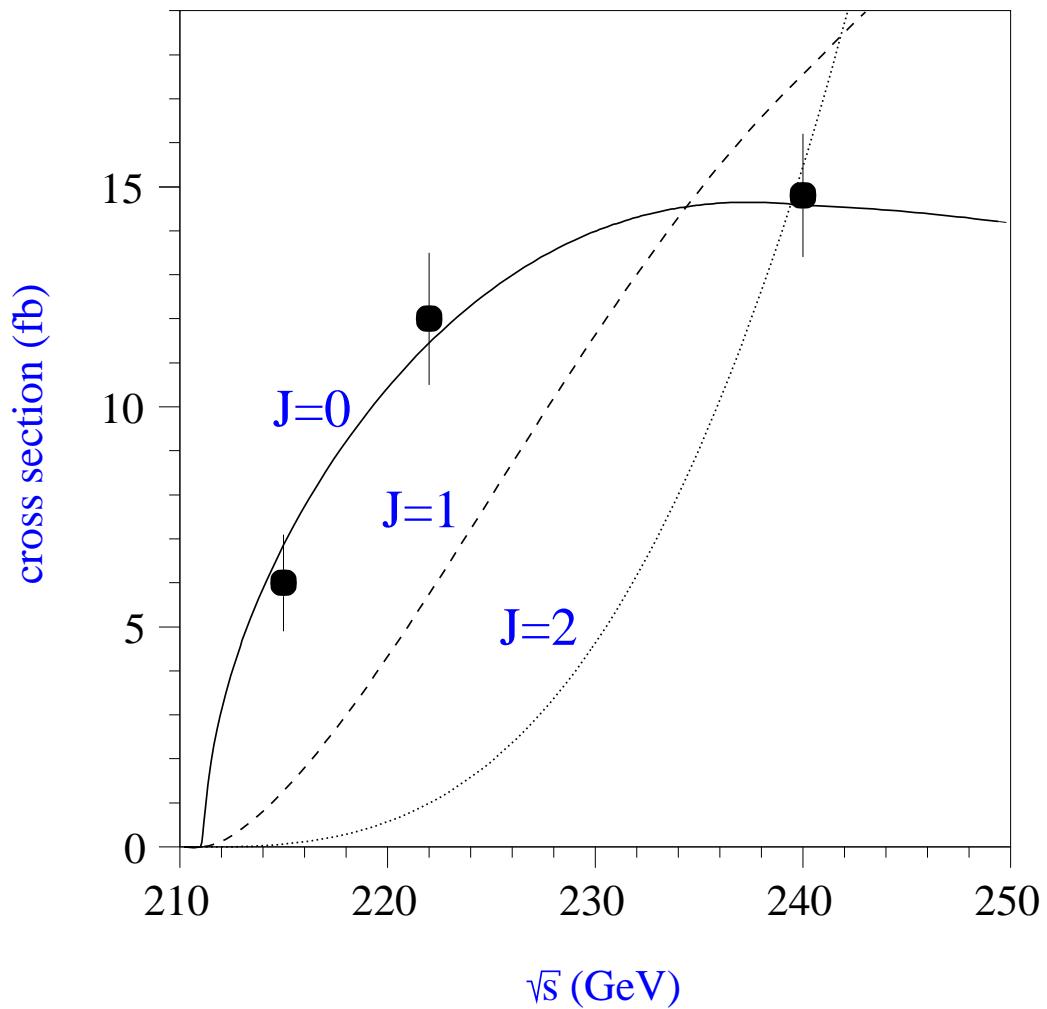
TESLA

- Summary on branching ratios (state-of-the-art)

	Higgs Mass (GeV)			
	120	140	160	200
$\Delta B_{bb}/B_{bb}$	0.016	0.018	0.020	0.090
$\Delta B_{WW}/B_{WW}$	0.020	0.018	0.010	0.025
$\Delta B_{gg}/B_{gg}$	0.023	0.035	0.146	
$\Delta B_{\gamma\gamma}/B_{\gamma\gamma}$	0.054	0.062	0.237	
$\Delta B_{\tau\tau}/B_{\tau\tau}$	0.050	0.080		
$\Delta B_{cc}/B_{cc}$	0.083	0.190		

$\Rightarrow \delta BR/BR \sim \text{few \%} \Rightarrow \text{Test } g_f \propto m_f$

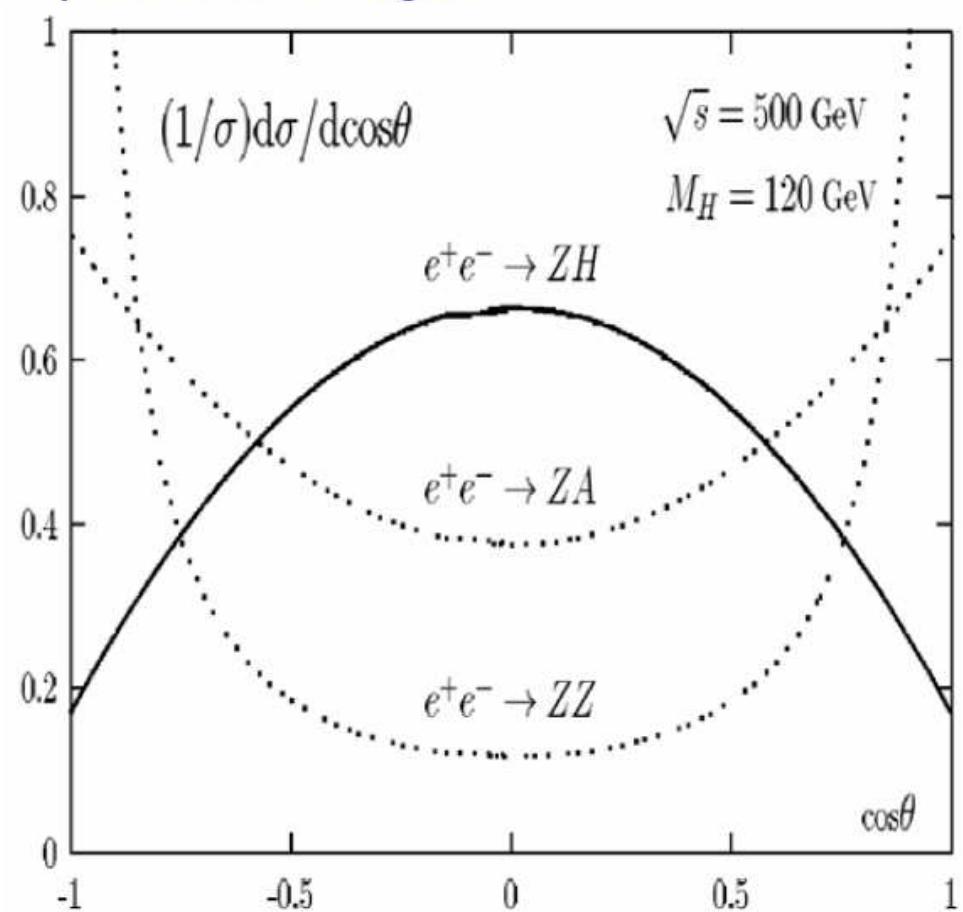
- spin: threshold behaviour $\sigma(e^+e^- \rightarrow ZH) \propto \beta^{J+1}$



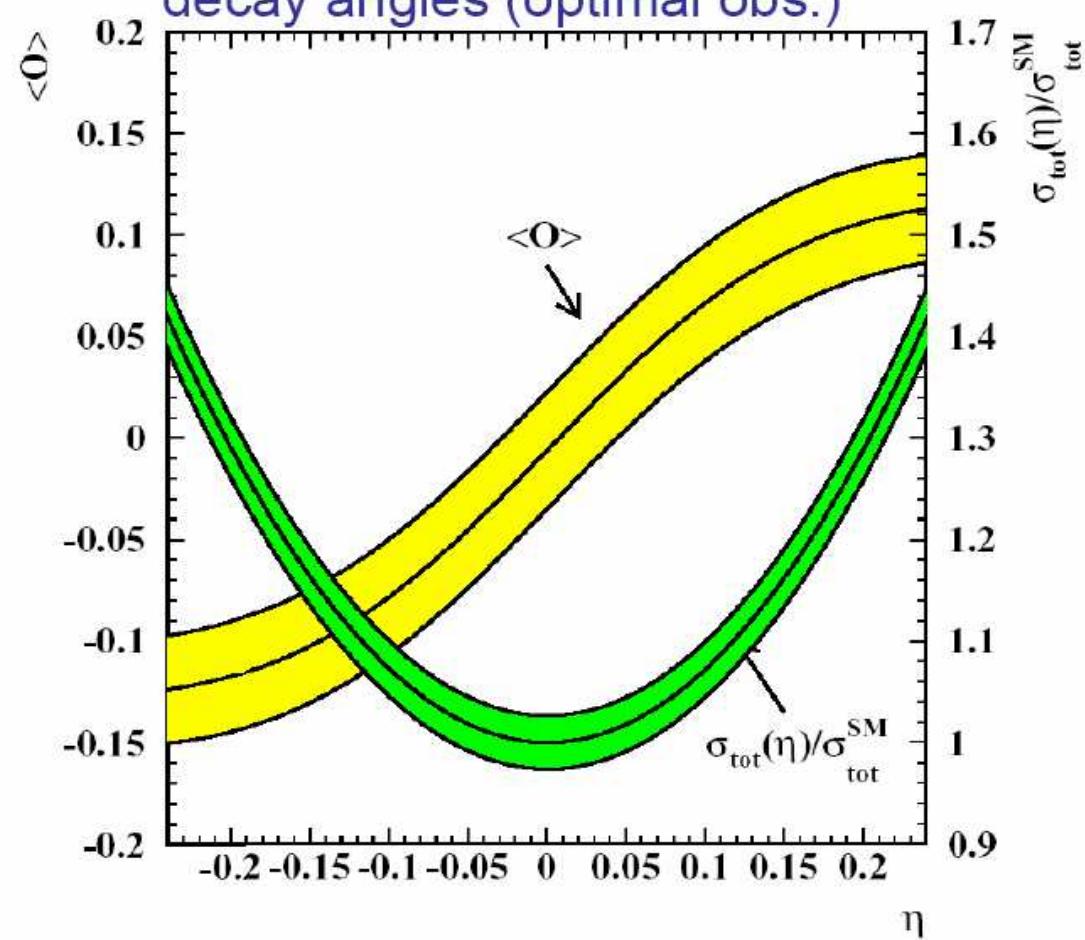
Miller, Choi, Eberle, Mühlleitner, Zerwas
Dova, Garcia-Abia, Lohmann

- \mathcal{CP} quantum numbers:

production angle

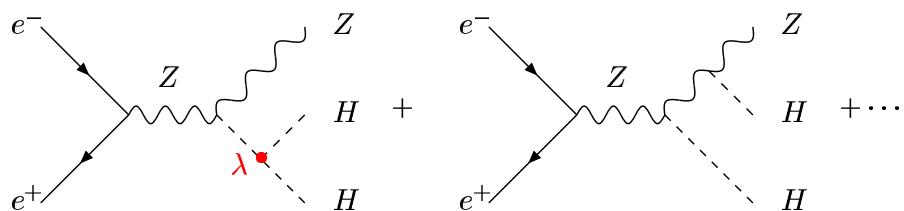


joint analysis of production and decay angles (optimal obs.)

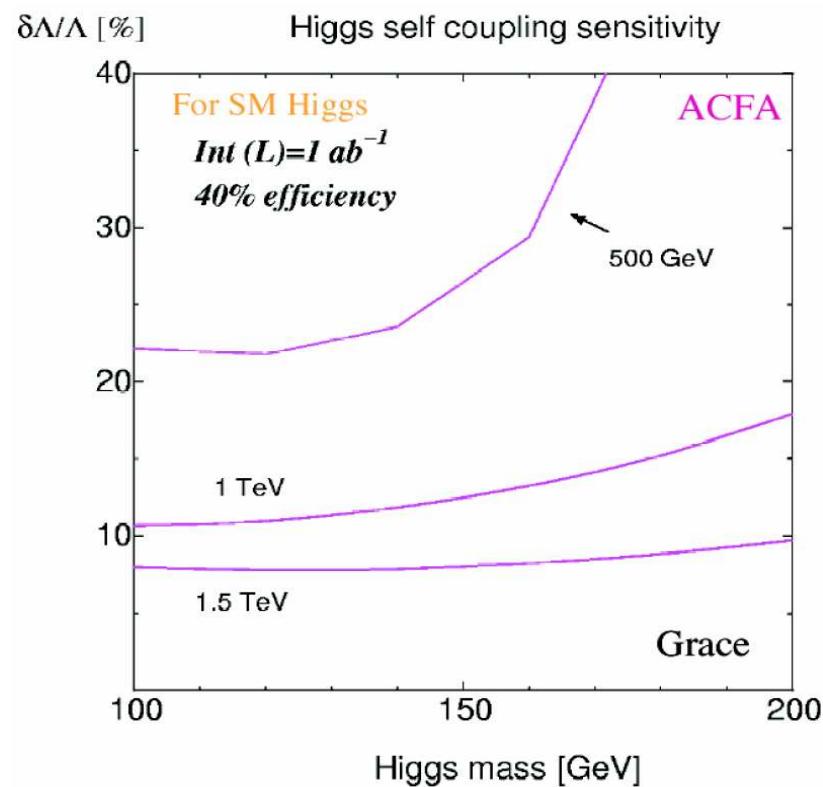
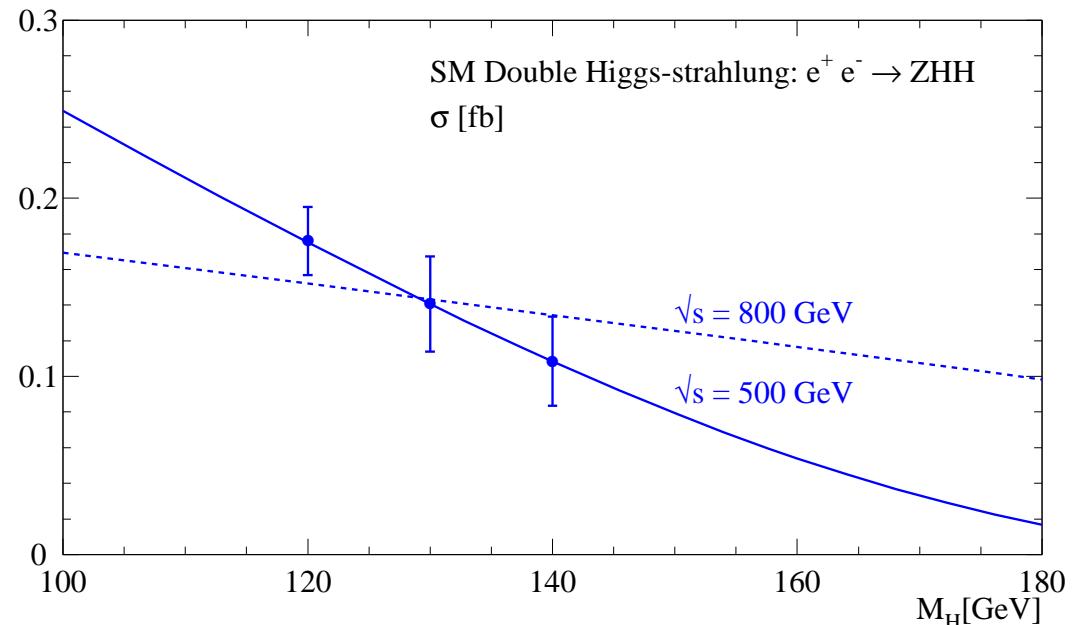


$$\eta = \text{CP-odd admixture to CP even amplitude: } \mathcal{M} = \mathcal{M}_{HZ} + i\eta \mathcal{M}_{ZA}$$

- selfinteraction: $e^+e^- \rightarrow ZHH$



$$\Rightarrow \delta\lambda/\lambda \sim 20\%$$

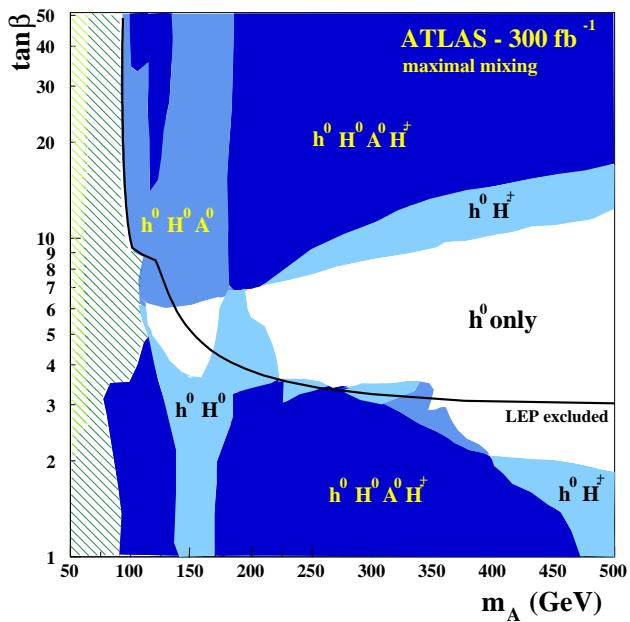


← large contribution from
 WW fusion $e^+e^- \rightarrow \nu_e \bar{\nu}_e HH$

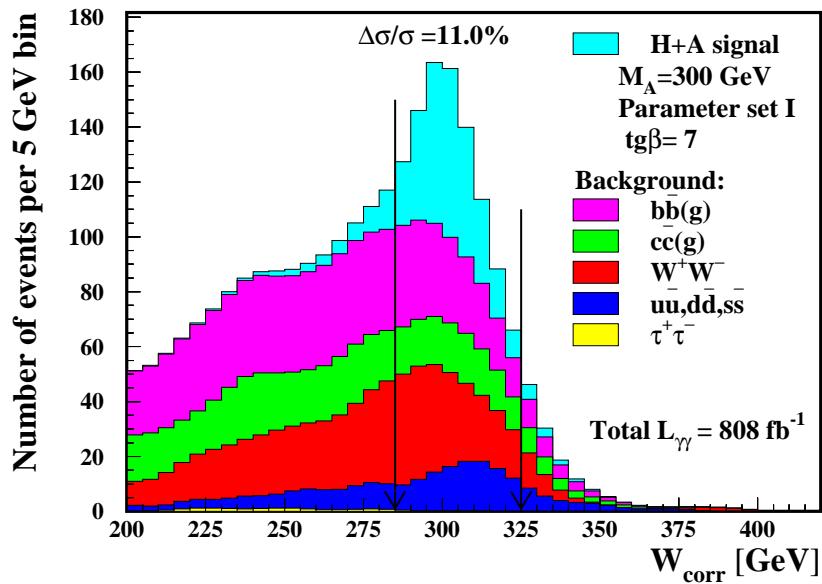
Djouadi, Kilian, Mühlleitner, Zerwas
Castanier, Gay, Lutz, Orloff

- SUSY Higgs bosons:

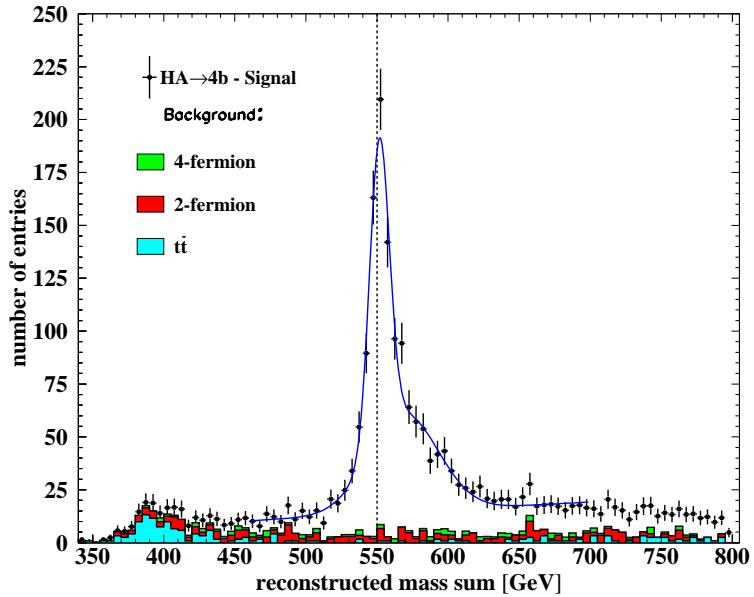
LHC: blind wedge



$\gamma\gamma \rightarrow H, A \rightarrow b\bar{b}$



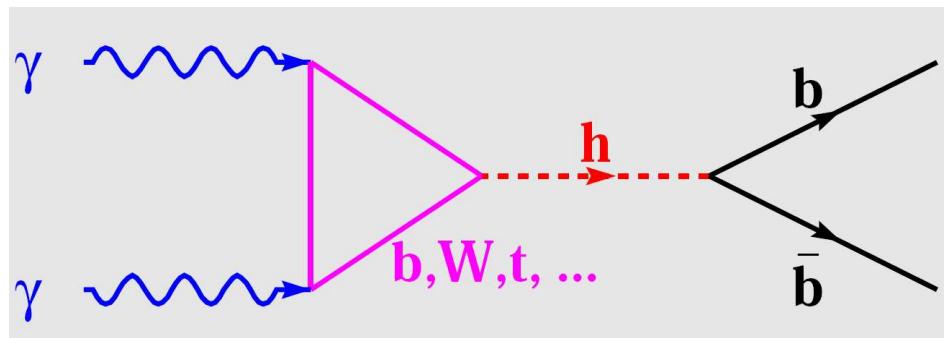
ILC: pairs with mass up to E_B



Desch,...

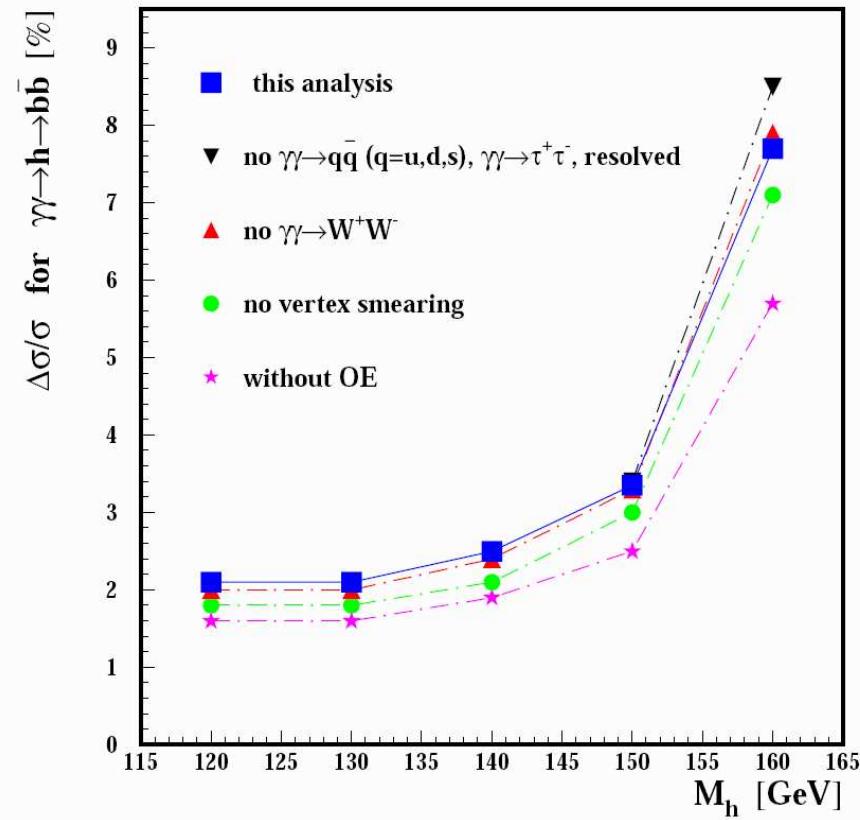
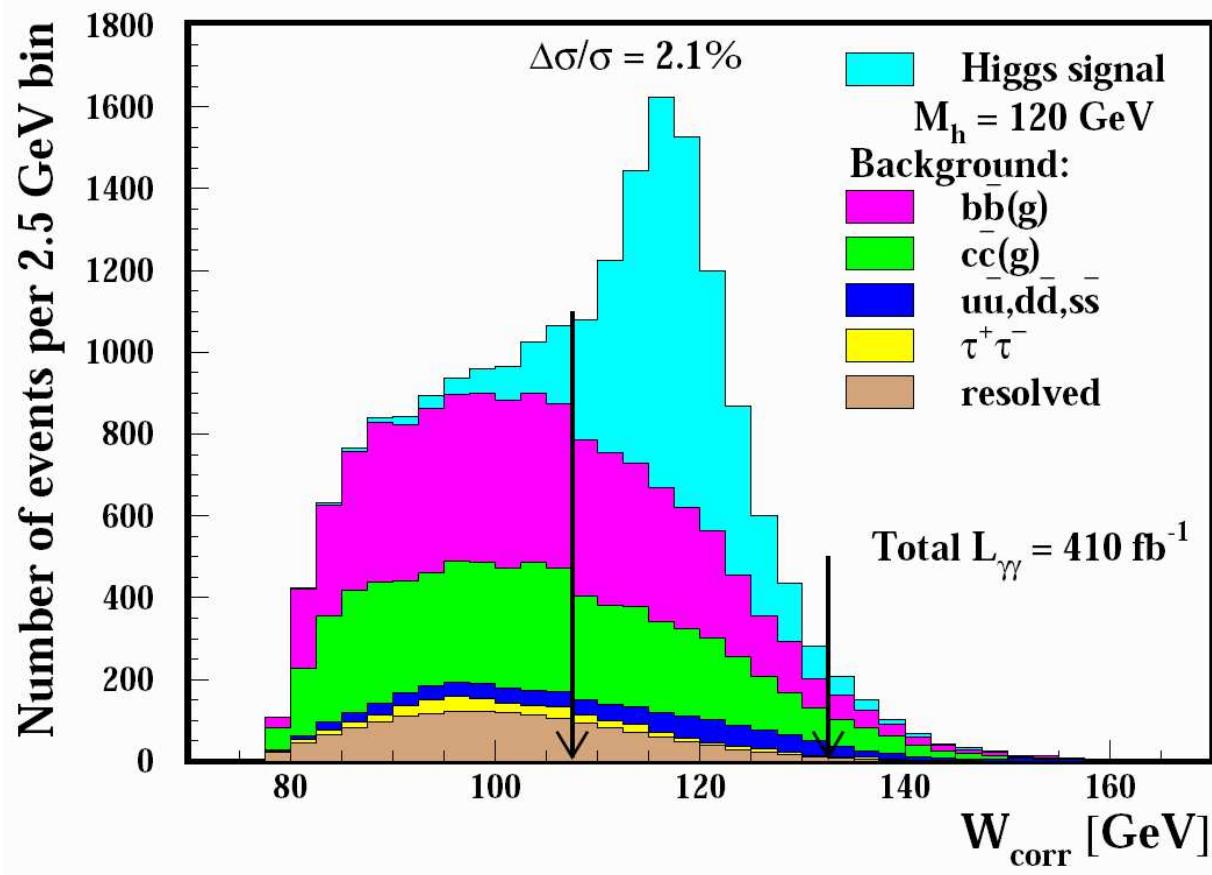
Mühlleitner,...
Gunion,...
Nieżurawski,...

III HIGGS PHYSICS @ PLC

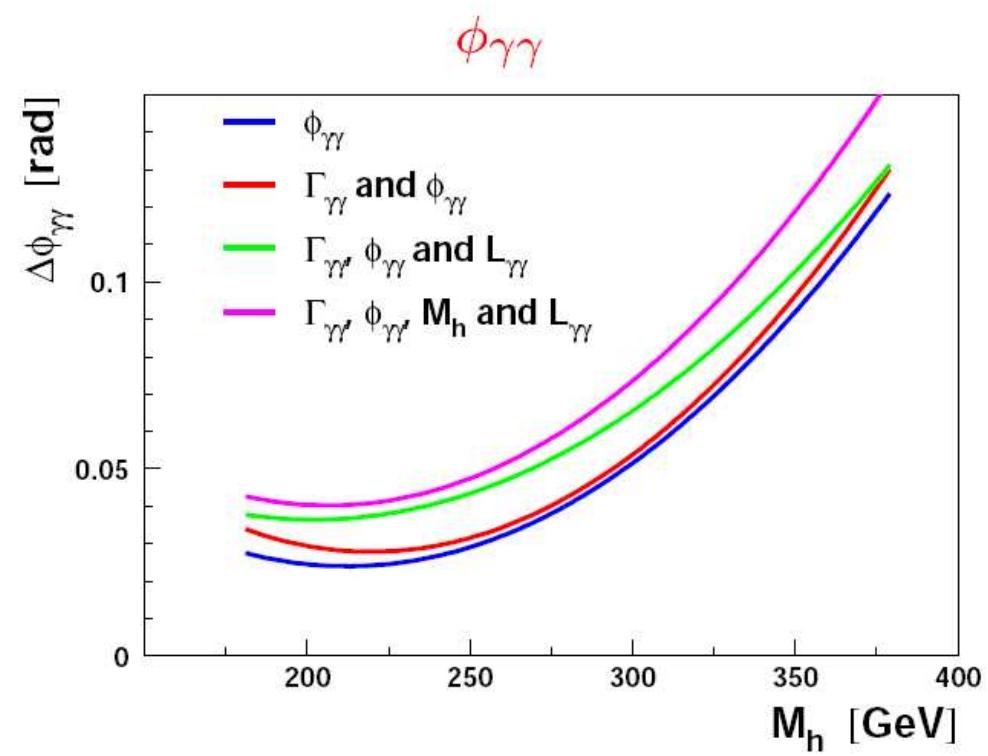
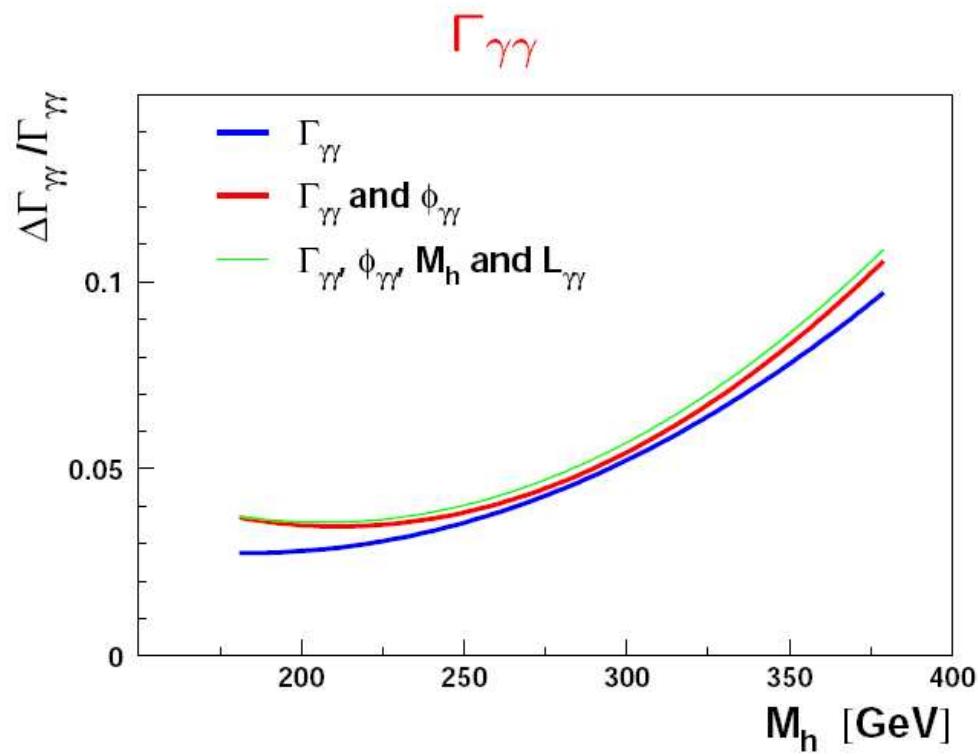


$$\Gamma(H \rightarrow \gamma\gamma) = \frac{G_F \alpha^2 M_H^3}{128\sqrt{2}\pi^3} |\mathcal{A}|^2$$

$$\mathcal{A} = |\mathcal{A}| e^{i\phi_{\gamma\gamma}}$$

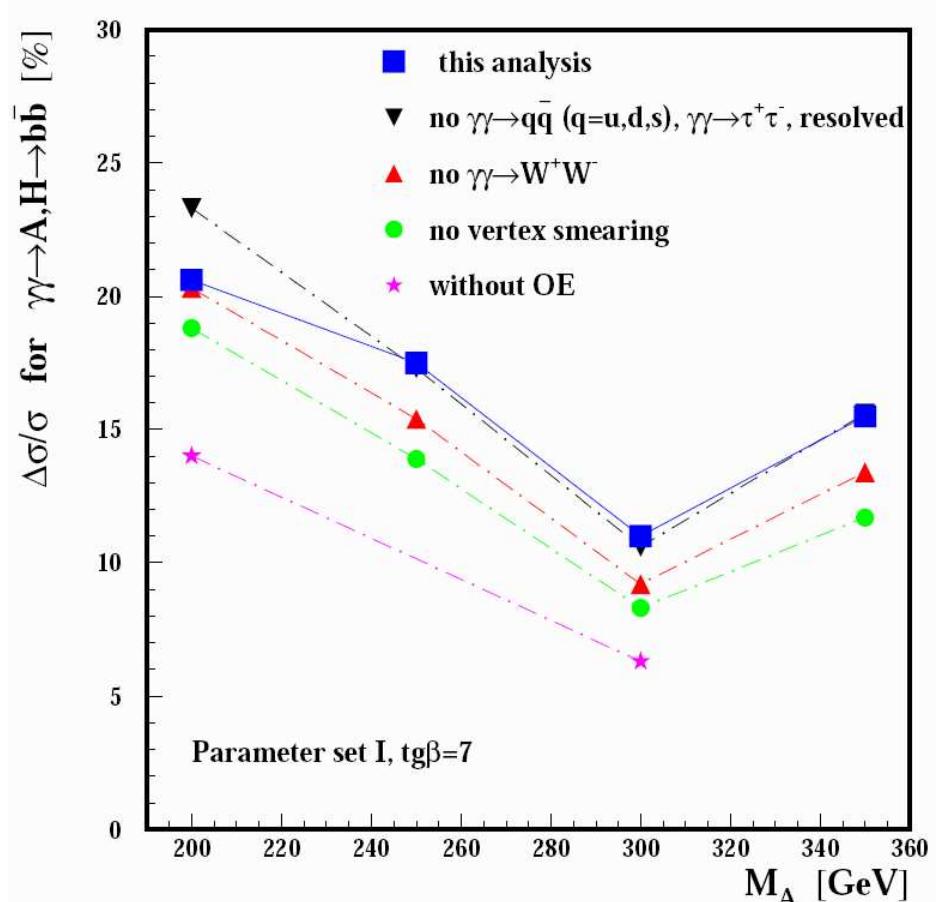
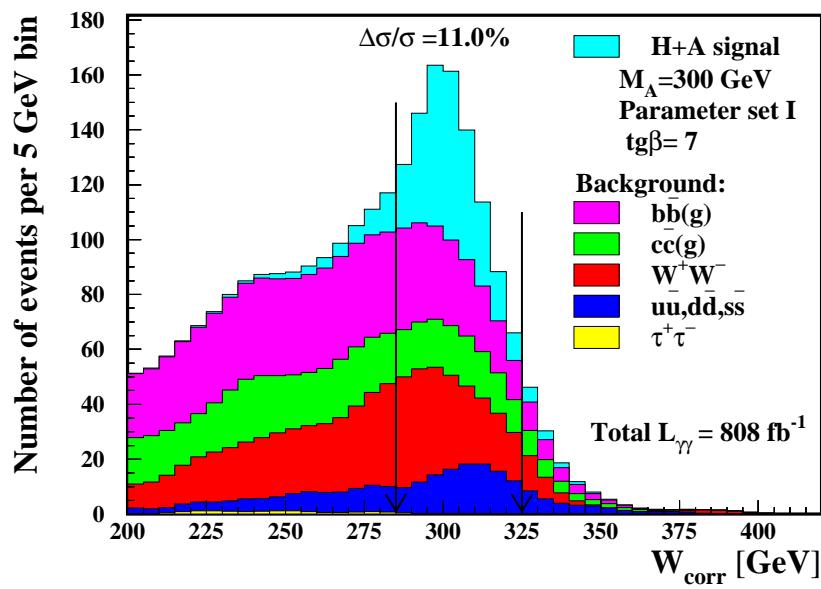


Nieżurawski, Żarnecki, Krawczyk
Jikia, Söldner-Remboldt



Nieżurawski, Żarnecki, Krawczyk

- SUSY Higgs bosons:

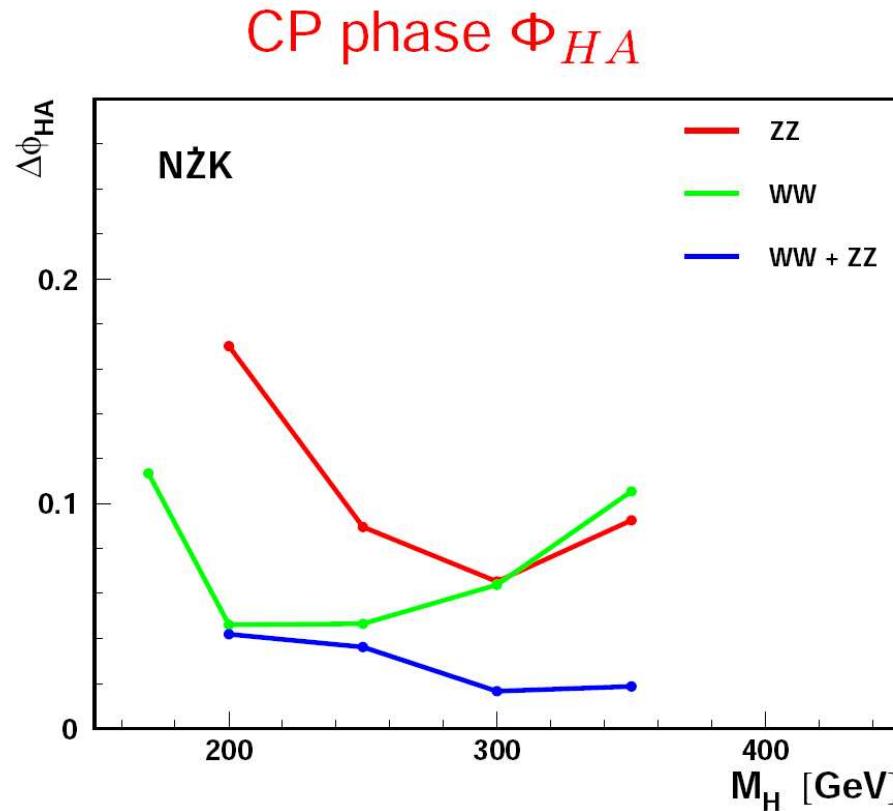


Mühlleitner, Krämer, S., Zerwas
 Asner, Gronberg, Gunion
 Niežurawski, Żarnecki, Krawczyk

- differences: jet definitions, cuts

S., Niežurawski, Żarnecki, Krawczyk

- $\phi = H \cos \Phi_{HA} + iA \sin \Phi_{HA}$: $\phi \rightarrow ZZ, WW \rightarrow 4f$



Choi, Miller, Mühlleitner, Zerwas
Żarnecki, Nieżurawski, Krawczyk

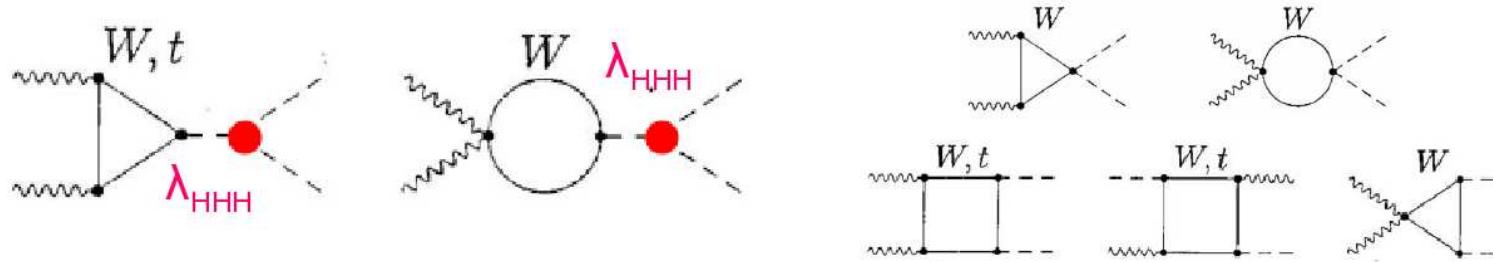
- $\gamma\gamma \rightarrow \phi \rightarrow t\bar{t}$

Asakawa, Hagiwara

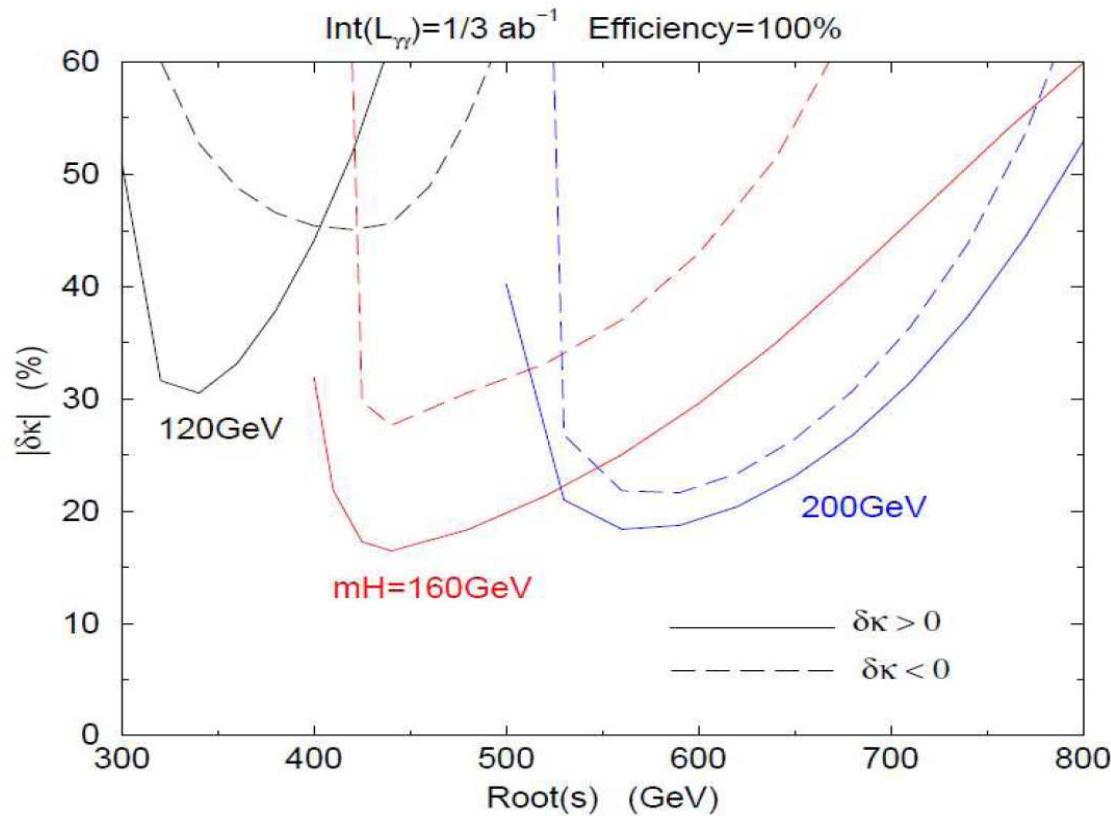
- $\gamma\gamma \rightarrow \phi \rightarrow \tau^+\tau^-$

Desch, Imhof, Was, Worek

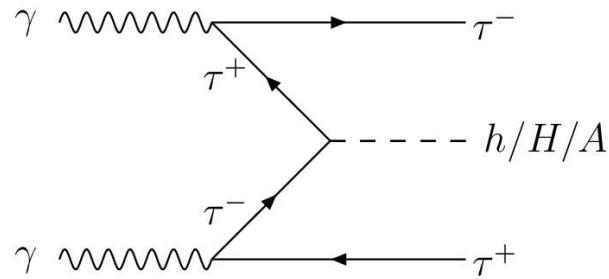
$$\lambda_{HHH} = \lambda_{HHH}^{SM}(1 + \delta\kappa)$$



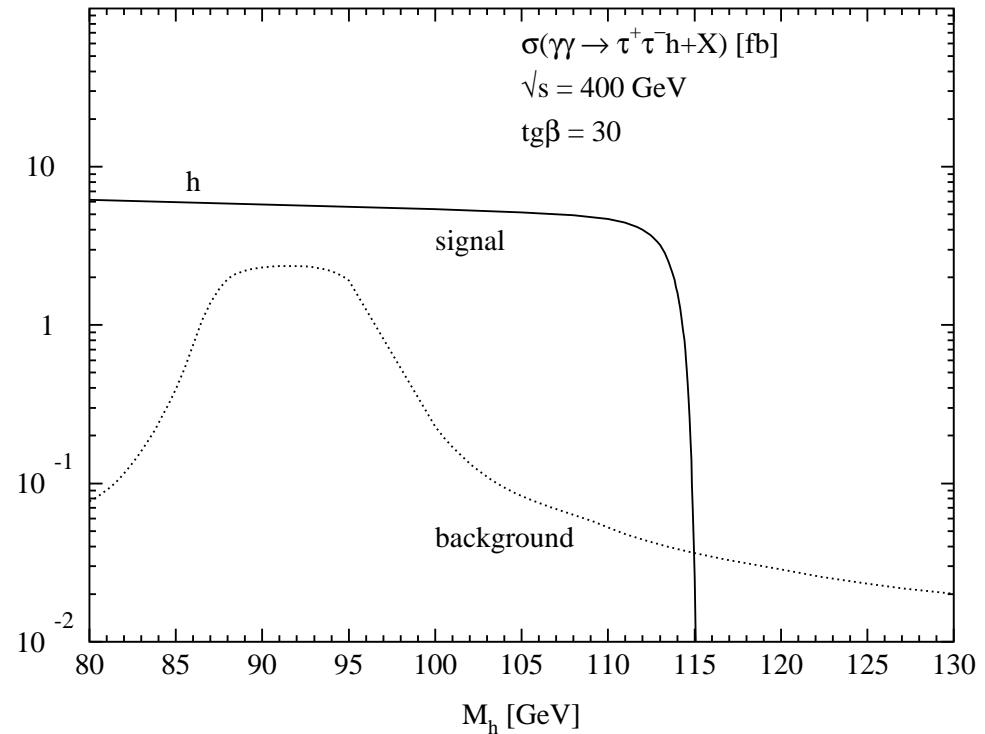
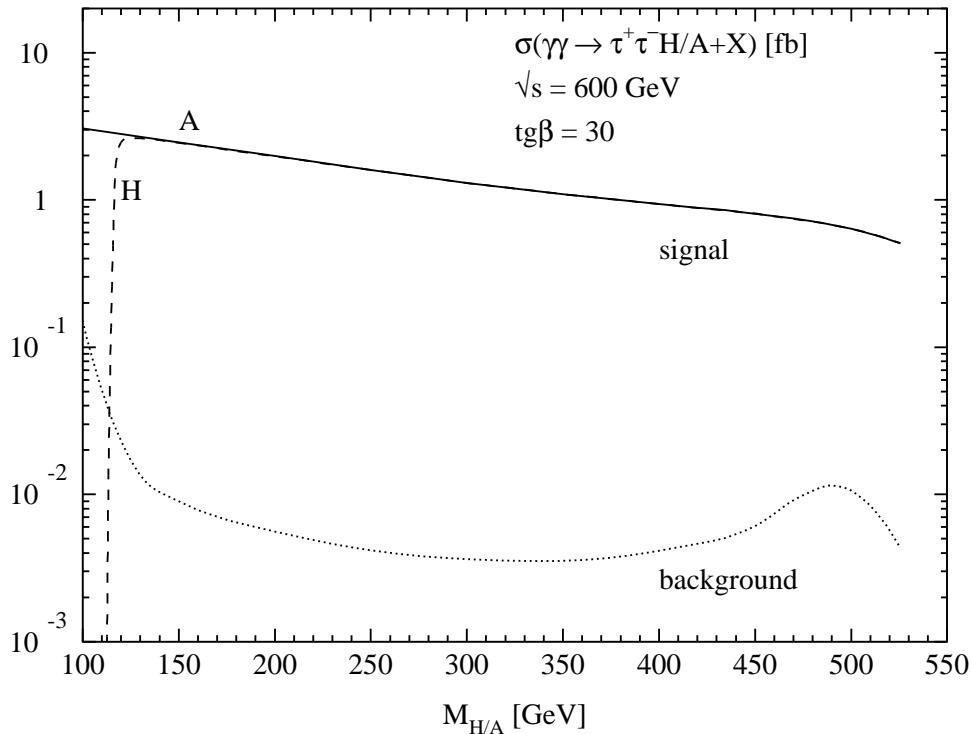
Higgs Self-Coupling Sensitivity



Asakawa, Harada, Kanemura,
Okada, Tsumura



Choi, Kalinowski, Lee,
Mühlleitner, S., Zerwas



$\tan\beta$	$E_{\gamma\gamma} = 400$ GeV, $\mathcal{L} = 100$ fb $^{-1}$					$E_{\gamma\gamma} = 600$ GeV, $\mathcal{L} = 200$ fb $^{-1}$				
	M_h [GeV]	$A \oplus H : M_A$ [GeV]				$A \oplus H : M_A$ [GeV]				
		100	100	200	300	100	200	300	400	500
10	12.9%	12.8%	10.7%	13.9%		12.3%	9.0%	11.2%	13.2%	16.5%
30	3.7%	3.7%	3.5%	4.6%		3.5%	3.0%	3.7%	4.4%	5.3%
50	2.2%	2.2%	2.1%	2.7%		2.1%	1.8%	2.2%	2.6%	3.2%

IV CONCLUSIONS

- Higgs physics @ LHC, ILC & PLC major endeavours
- LHC will find at least one Higgs boson [light h]
- profile of the Higgs bosons can be studied partially @ LHC
→ completed @ ILC, PLC with much higher accuracy
- PLC: precise measurement of $H\gamma\gamma$ coupling
2HDM: complementarity of LHC, ILC, PLC

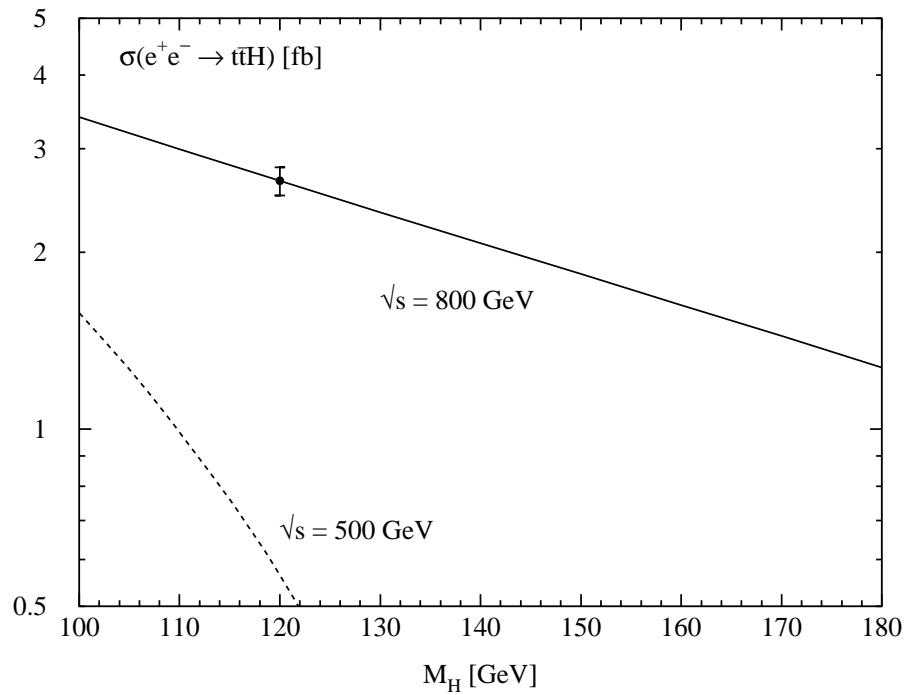
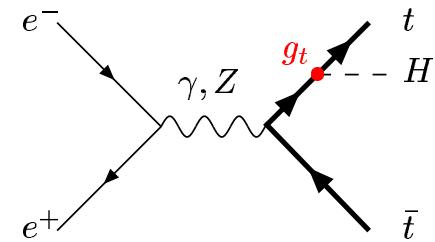
Nieżurawski, Żarnecki, Krawczyk
doubly charged Higgs pairs $\gamma\gamma \rightarrow H^{++}H^{--}$

Cieza Montalvo, Cortez, Tonasse

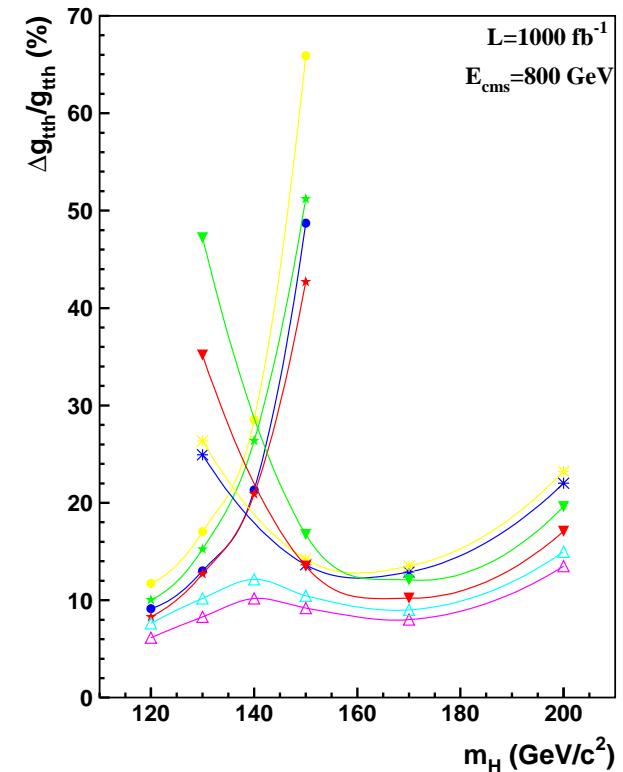
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BACKUP SLIDES

- top Yukawa coupling: $e^+e^- \rightarrow t\bar{t}H$

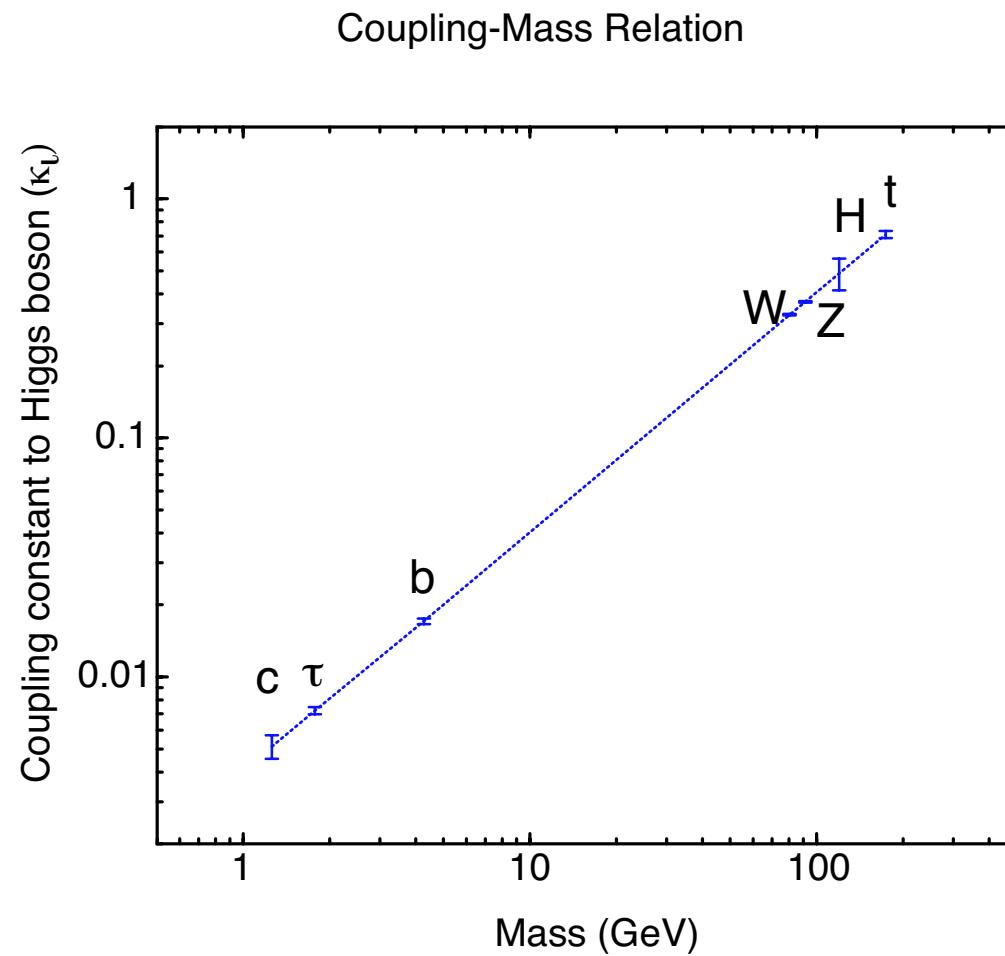


- $H \rightarrow bb$ semilep; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow bb$ semilep; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- $H \rightarrow bb$ hadro; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow bb$ hadro; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- $H \rightarrow WW$ 2 like sign lep; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow WW$ 2 like sign lep; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- $H \rightarrow WW$ 1 lep; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow WW$ 1 lep; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- 4 channels combined; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- 4 channels combined; $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$

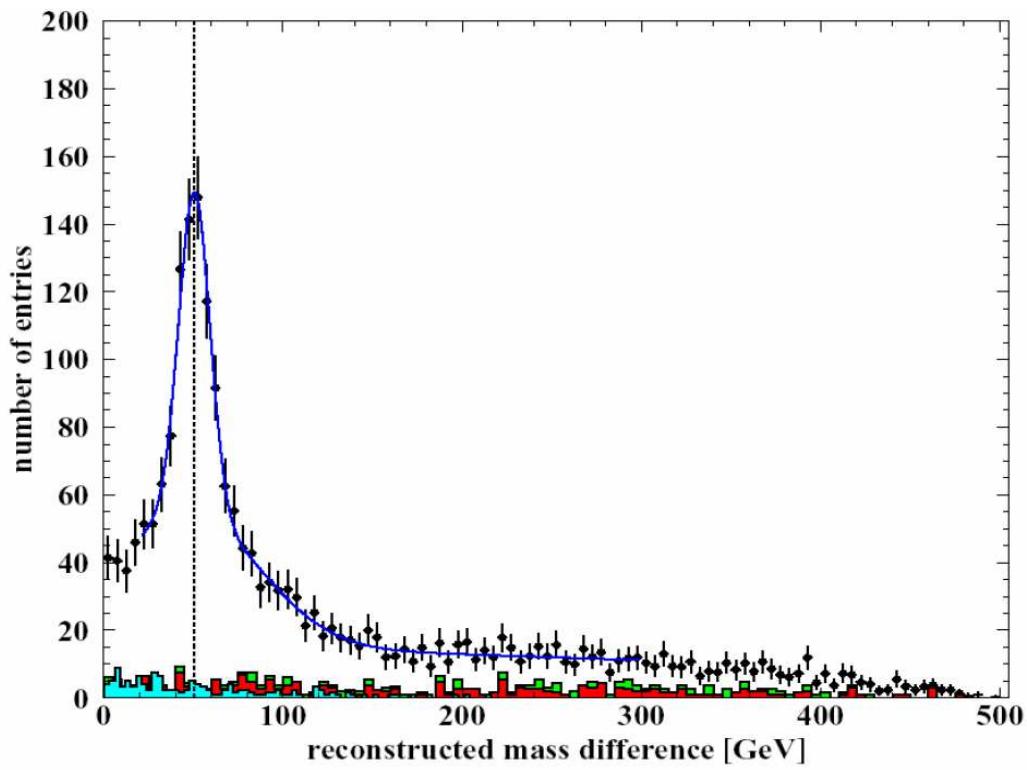
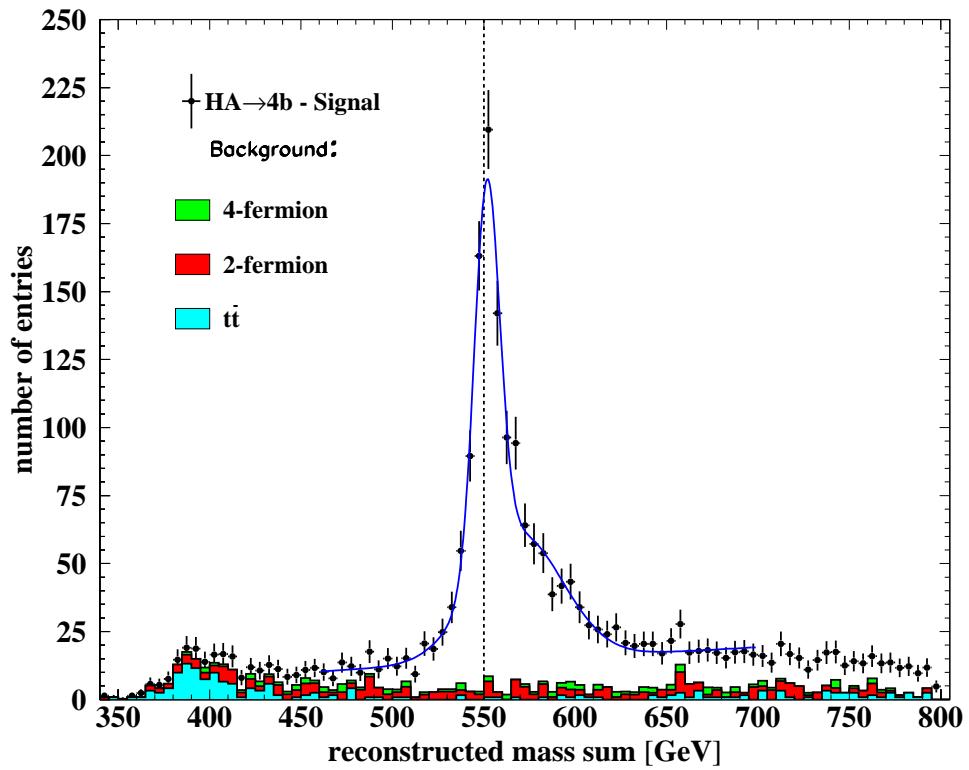


Gay

- ⇒ model-independent measurements of Higgs couplings
→ test $g \propto \text{mass}$: $g_i = \sqrt{2\sqrt{2}G_F} m_i$



- MSSM Higgs masses: $e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$



$$\delta M_{H/A} \sim 100 - 1000 \text{ MeV}$$