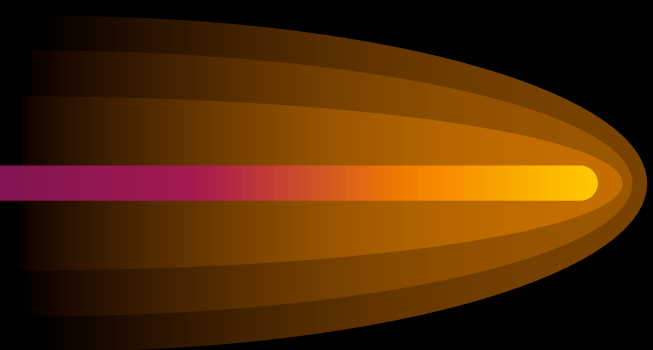


Experimental Overview on Higgs coupling measurements

- 1.introduction
- 2.Measurement scheme
- 3.Examples of Possible Deviation from SM in models
- 4.What kind of issues to be studied, modified, etc..



Satoru Yamashita
(ICEPP, Univ. of Tokyo)

Higgs Sector is unknown

Electroweak fit at LEP/SLC/Tevatron tells
At least one should exist below 300 GeV
which couples to Z and W

Almost NOTHING is known

- NOTHING is known for **Yukawa-coupling**
- NOTHING is known for **self-coupling**

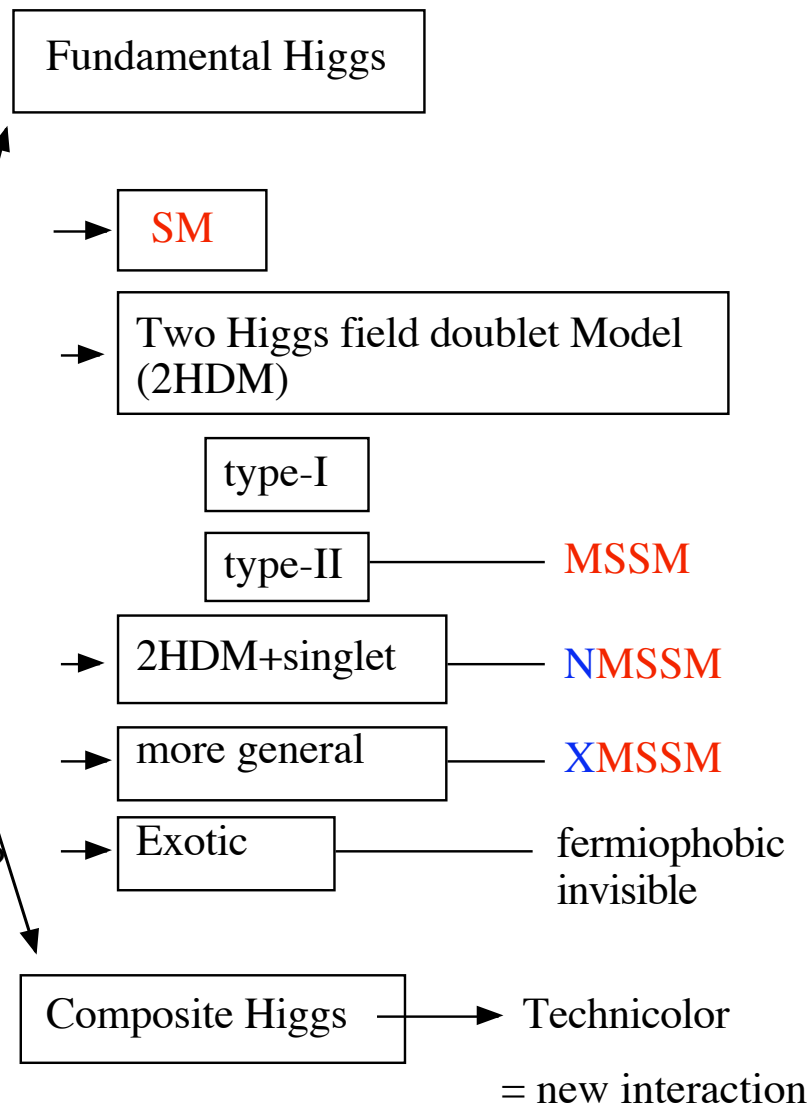
- Single Higgs? Two Higgs field doublets?
- Additional singlet? Triplet?

- SUSY? Extra-dimension?
- **Composite?**
- Type-I? Type-II?

- Why top is so heavy? Special for 3rd generation?

- **CP-violation** in Higgs sector?

- More exotics?



Higgs at ILC

1. The Most Fundamental Issues to be clarified

A. Gauge coupling

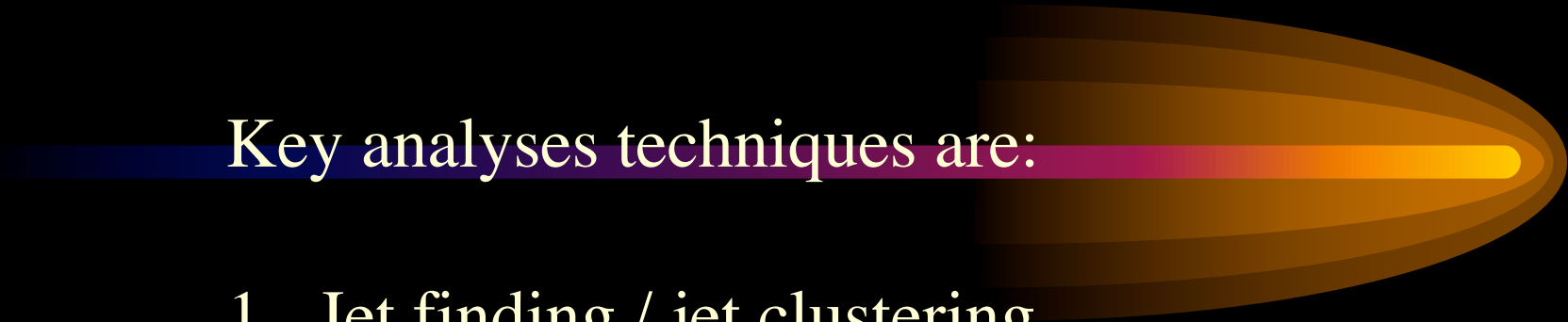
B. Yukawa-coupling

- Up-type vs Down-type - top vs bottom (charm vs bottom)
- Quark vs lepton - bottom vs tau
- 2nd generation vs 3rd generation - mu vs tau, charm vs top

C. Self-coupling

2. Reconstruct the Higgs sector

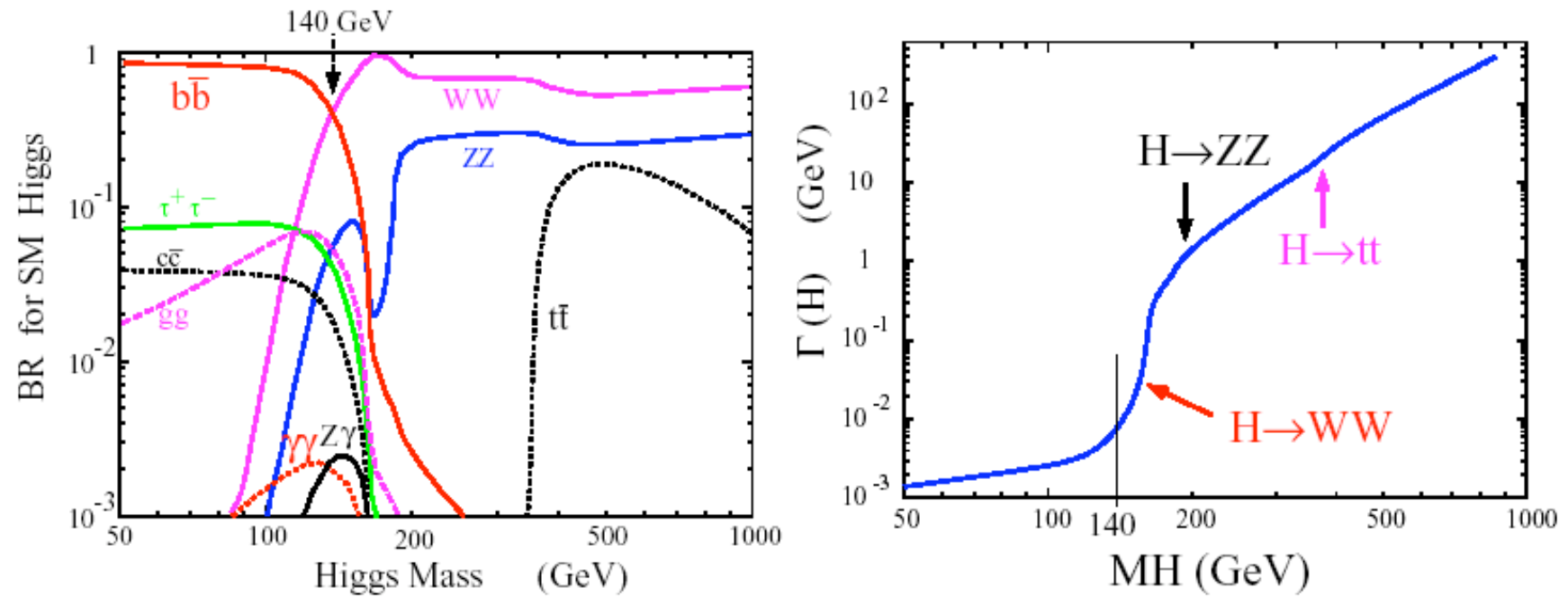
3. Discriminate among various models, Translate the deviation from SM into quantity in New physics models



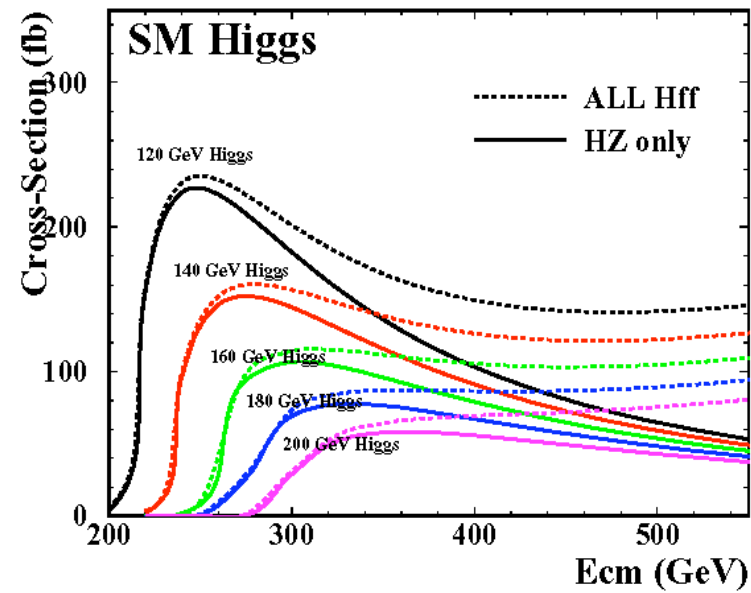
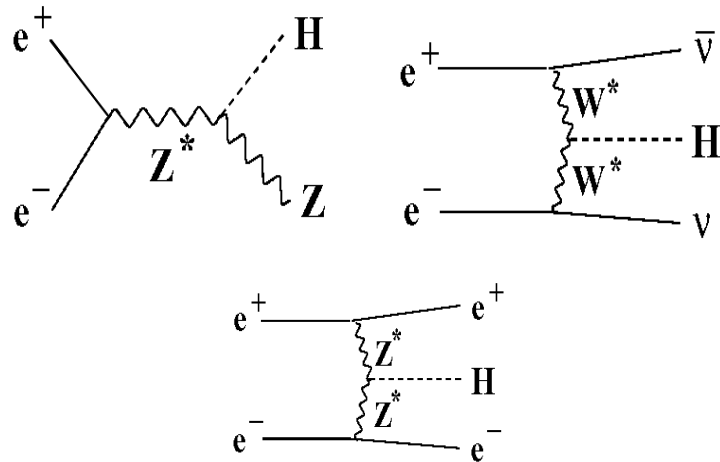
Key analyses techniques are:

1. Jet finding / jet clustering
2. Jet energy calculation
3. b, c, top, tau tagging
4. W, Z tagging
5. Kinematic constraint fit

SM Higgs



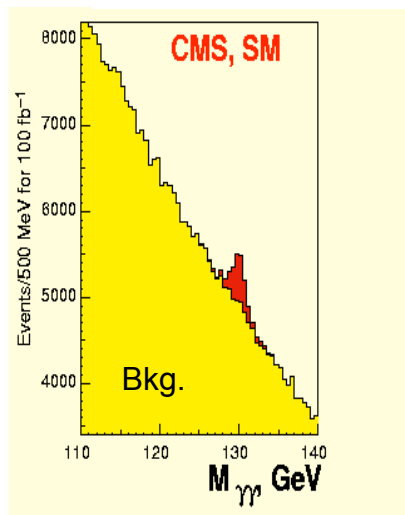
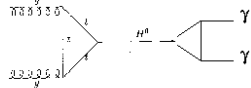
3 main production modes



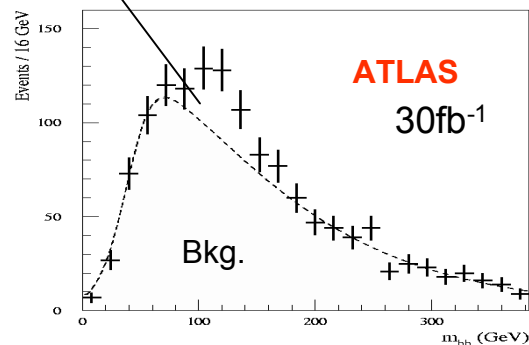
$>10^5$ Higgs
for 500fb^{-1}

LHC Higgs signal

$H \rightarrow \gamma\gamma$

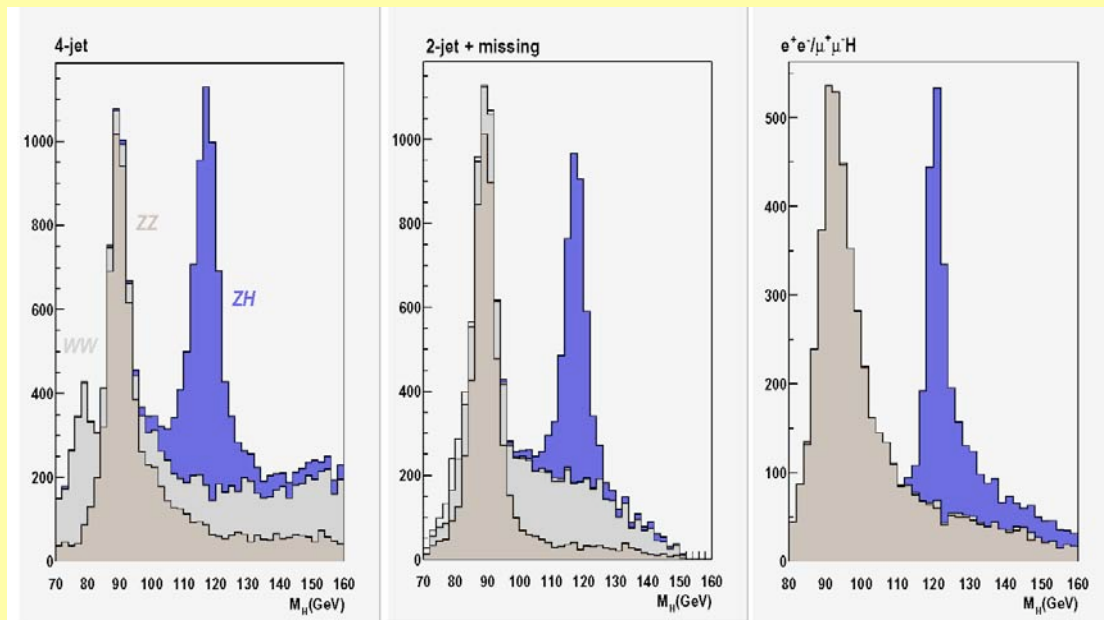


$ttH \rightarrow WbWbbb \rightarrow l\nu jj bbbb$

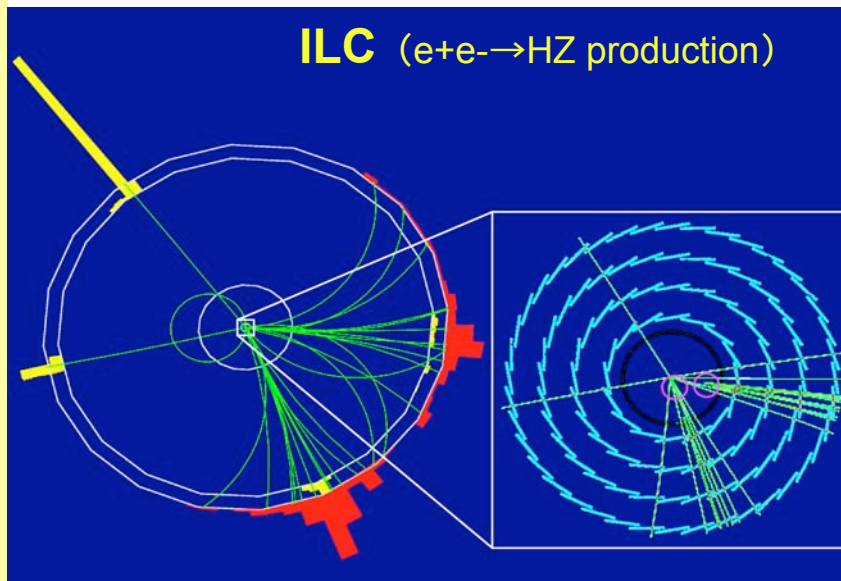


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ILC Higgs signal



ILC ($e+e- \rightarrow HZ$ production)



Typical numbers

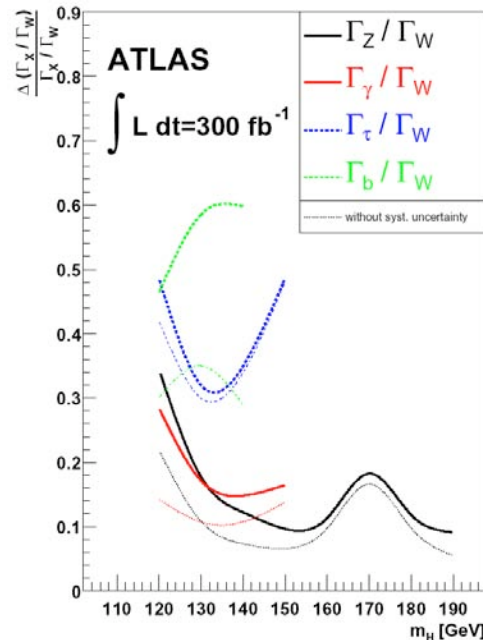
Tagging efficiency
~ 30-50 %

S/N > 1

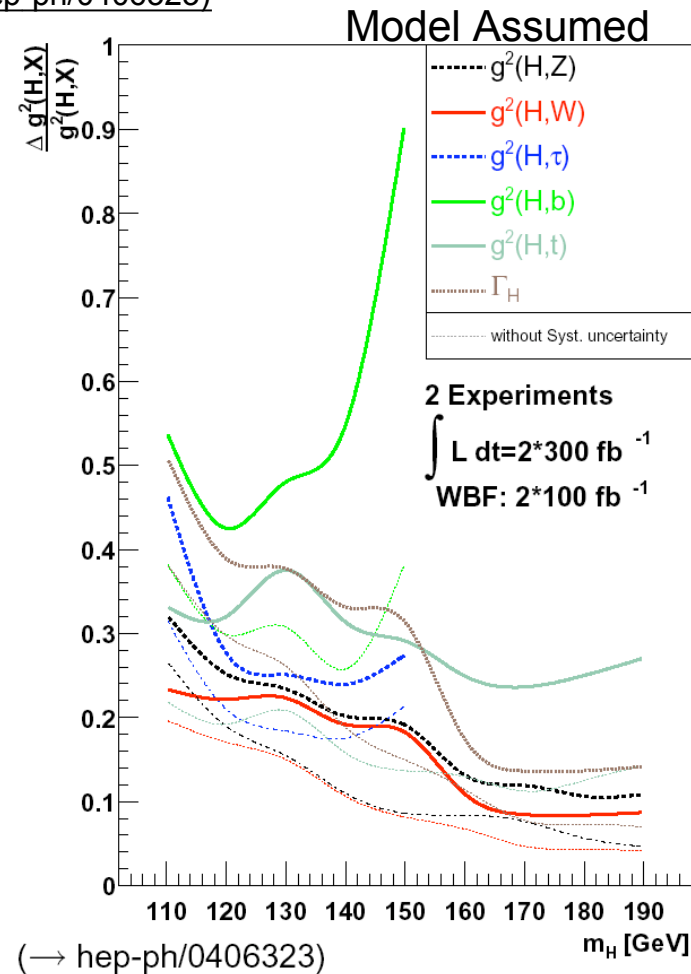
Higgs coupling measurements at LHC

Ratio can be obtained using events with “similar” topology

Michael Duhrssen et al. '04 (hep-ph/0406323)



Γ_{tot} is unknown..
Absolute strength is
difficult to measure



Using moderate
model assumption

Limit on g_W^2 and g_Z^2 :
 $\frac{g_W^2}{g_W^2(\text{SM})}, \frac{g_Z^2}{g_Z^2(\text{SM})} < 1 + 5\%$

For m_H 115-150 GeV

$\delta\Lambda_\tau / \Lambda_\tau \sim 15\%$

$\delta\Lambda_b / \Lambda_b > 20\%$

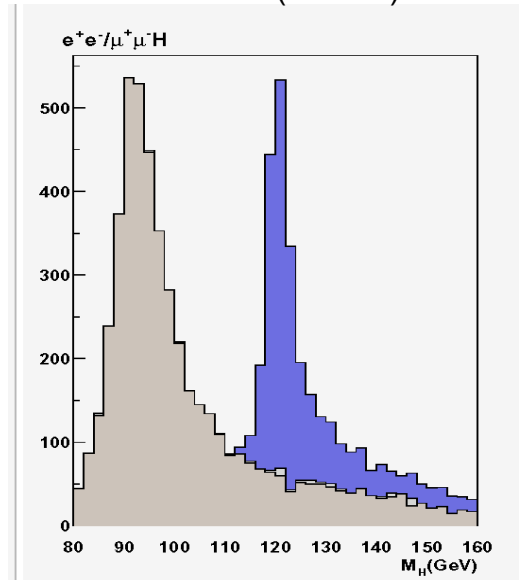
Mainly from $t\bar{t}H$ process

$\delta\Lambda_{\text{top}} / \Lambda_{\text{top}} \sim 15-20\%$

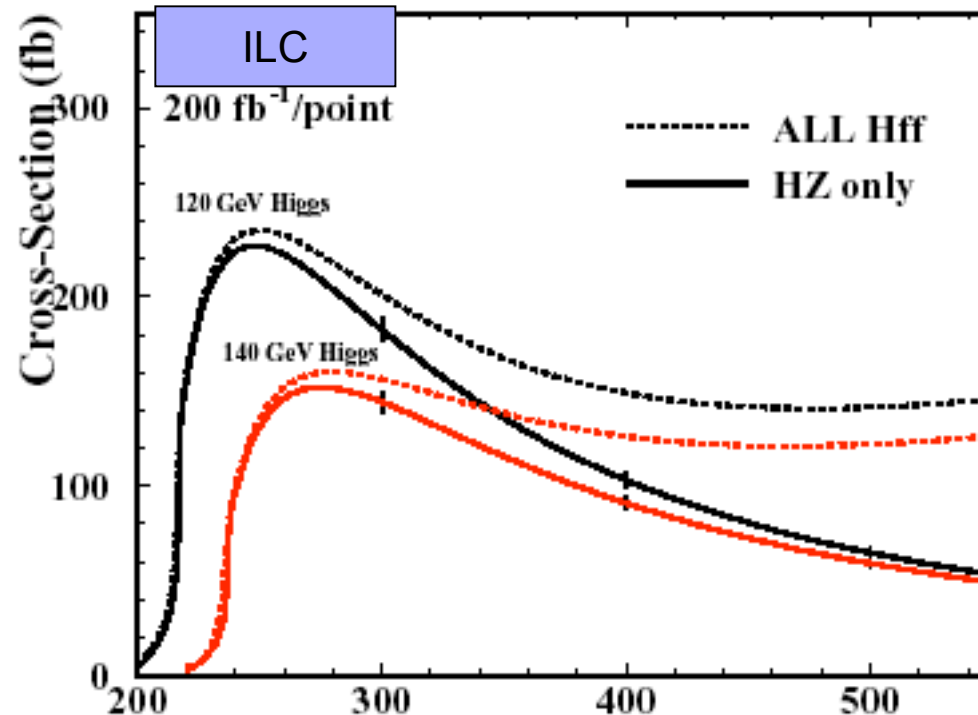
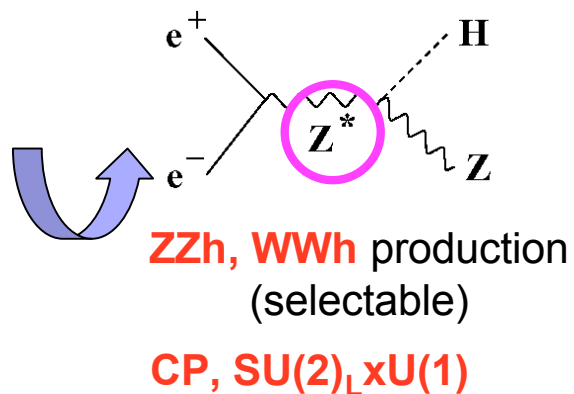
ILC Higgs

Invisible width

Use Recoil mass(no bias)



Beam polarization



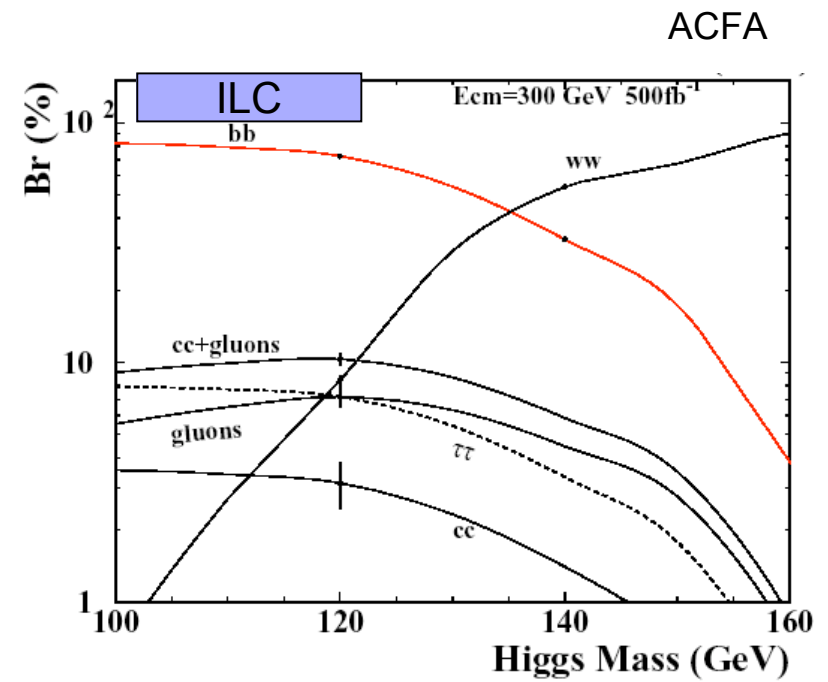
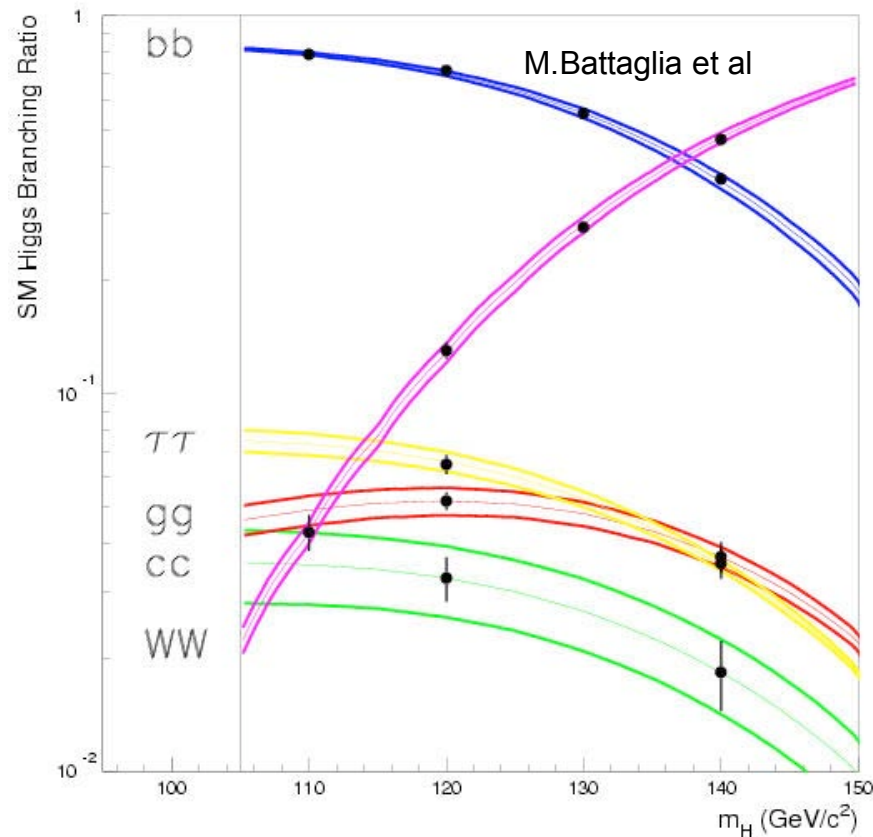
Mass & Cross-section measurement
= **Gauge coupling** measurement

$$\Gamma_W = f(M_h) \times \sigma$$

$\delta g/g \sim 1\%$

$\delta M_h \sim 40 \text{ MeV}$

Branching ratio measurements



ILC Examples of Higgs *Model Independent* Analyses

$$\Gamma_{h^0 \rightarrow W^+W^-} = \Gamma_{h^0 \rightarrow W^+W^-}^{\text{SM}} \times \frac{\sigma_{h^0 Z^0}}{\sigma_{h^0 Z^0}^{\text{SM}}}$$

$$\Gamma_{h^0} = \frac{\Gamma_{h^0 \rightarrow W^+W^-}}{\text{Br}(h^0 \rightarrow W^+W^-)} = \Gamma_{h^0}^{\text{SM}} \times \frac{\text{Br}^{\text{SM}}(h^0 \rightarrow W^+W^-)}{\text{Br}(h^0 \rightarrow W^+W^-)} \times \frac{\sigma_{h^0 Z^0}}{\sigma_{h^0 Z^0}^{\text{SM}}}$$

$$\lambda_f^2 = \lambda_{f,SM}^2 \times \frac{\text{BR}(h^0 \rightarrow f\bar{f}) \cdot \sigma_{\text{HZ}} \cdot \text{BR}^{\text{SM}}(h^0 \rightarrow W^+W^-)}{\text{BR}^{\text{SM}}(h^0 \rightarrow f\bar{f}) \cdot \sigma_{\text{HZ}}^{\text{SM}} \cdot \text{BR}(h^0 \rightarrow W^+W^-)}$$

Total width measurement

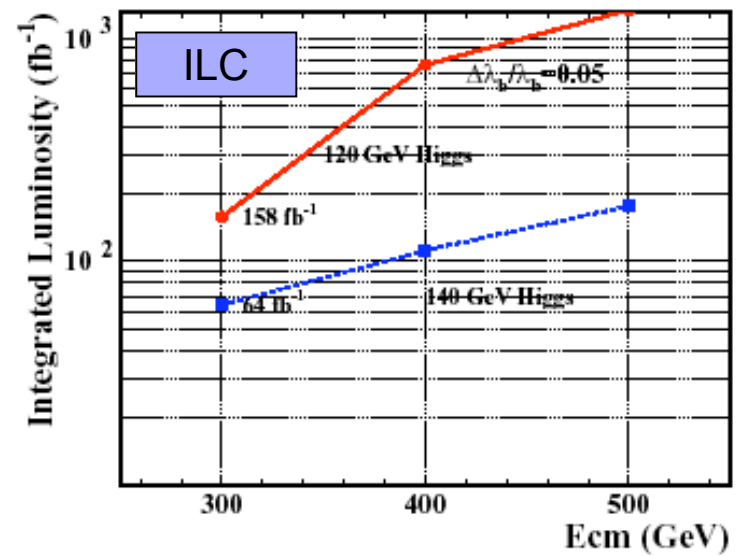
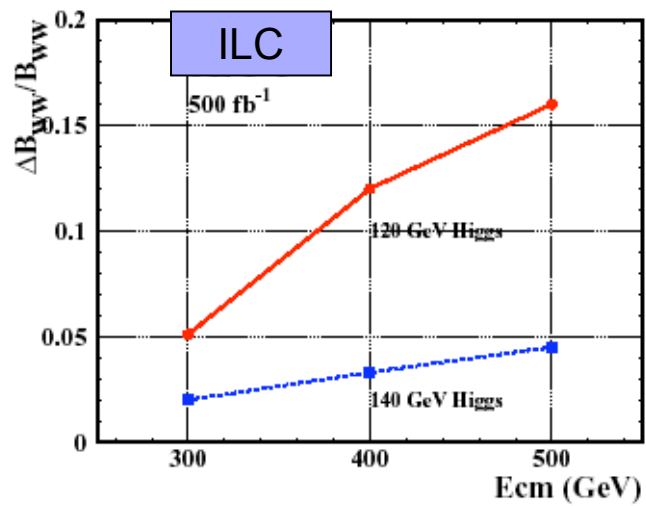
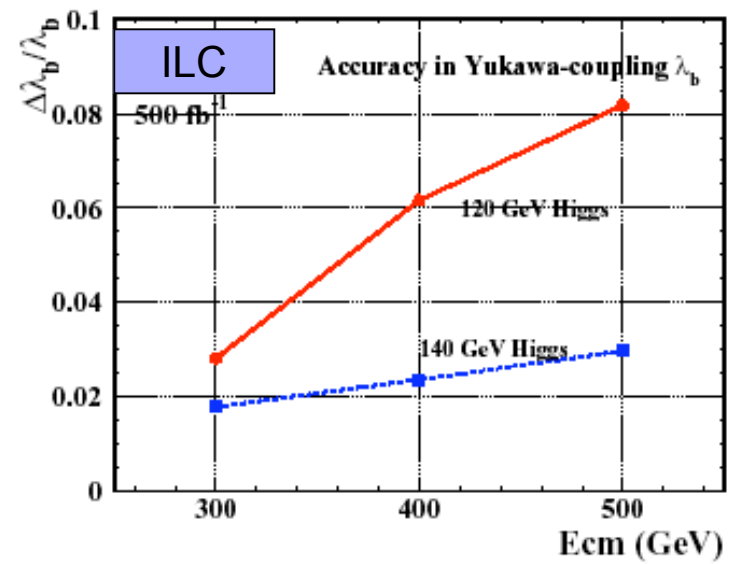
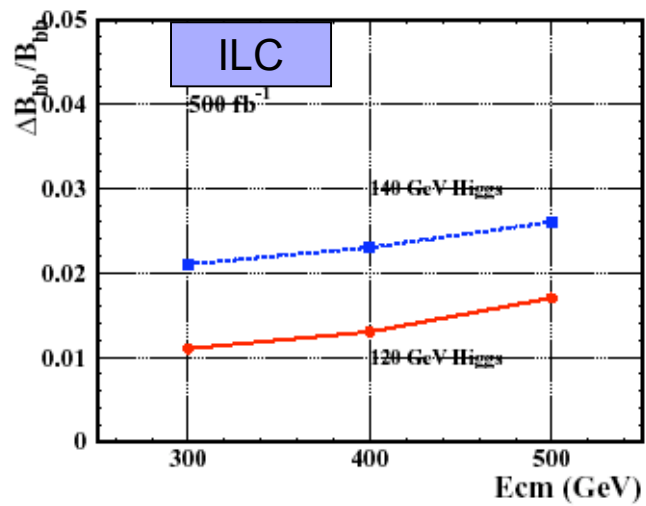
$$\Gamma_{\text{tot}} = \Gamma_W / \text{Br}(H \rightarrow WW)$$

$$\delta\Gamma_{\text{tot}} / \Gamma_{\text{tot}} \sim 5\%$$

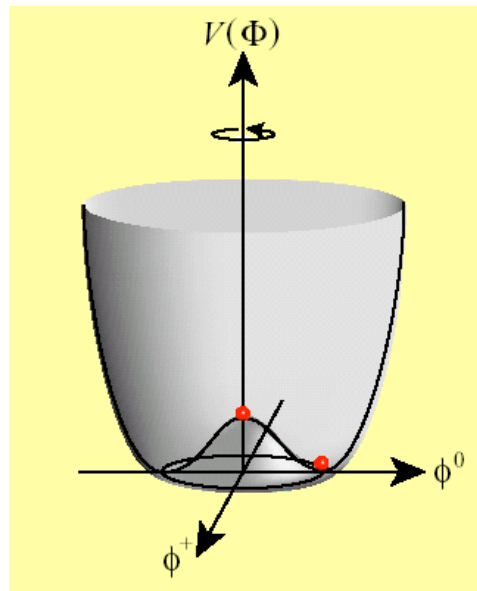
Absolute strength of Yukawa-Coupling determination

$$\Lambda_f^2 = C(M_h) \times \text{Br}(H \rightarrow f\bar{f}) \times \Gamma_{\text{tot}}$$

$$\delta\Lambda_b / \Lambda_b \sim 3\%, \delta\Lambda_t / \Lambda_t \sim 4\%, \\ \delta\Lambda_c / \Lambda_c \sim 8\%, \delta\Lambda_u / \Lambda_u \sim 4\%$$

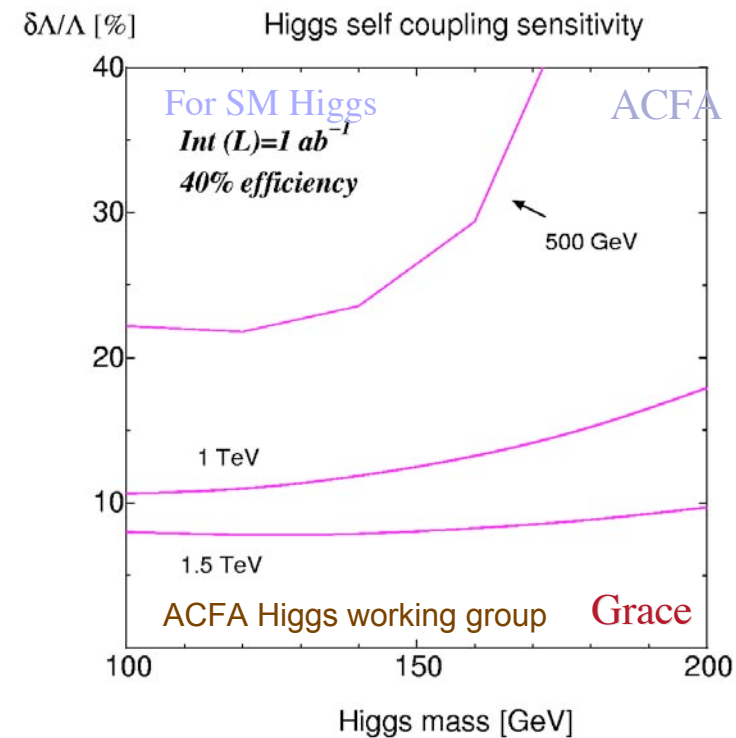
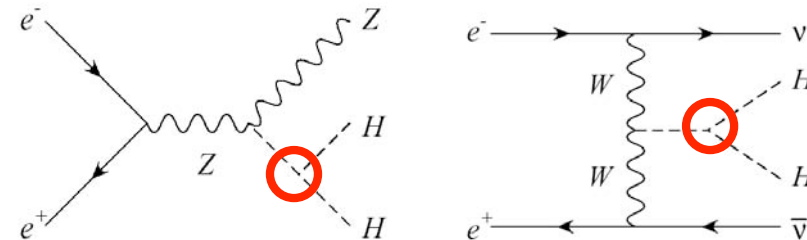


Higgs potential = Origin of EW symmetry breaking



The first access to the Higgs potential through double Higgs-boson production.

$$\delta\Lambda/\Lambda \sim 10 - 15 \%$$



Higgs Mechanism

Coupling-mass relation

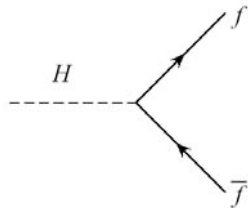
The Higgs vacuum-expectation-value

$$m_i = v \times K_i$$

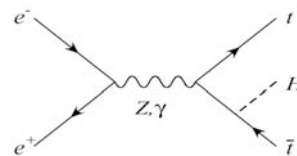
Particle mass

Higgs coupling constant

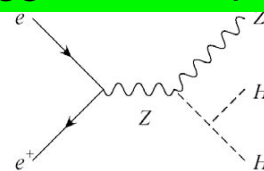
Higgs boson branching ratios



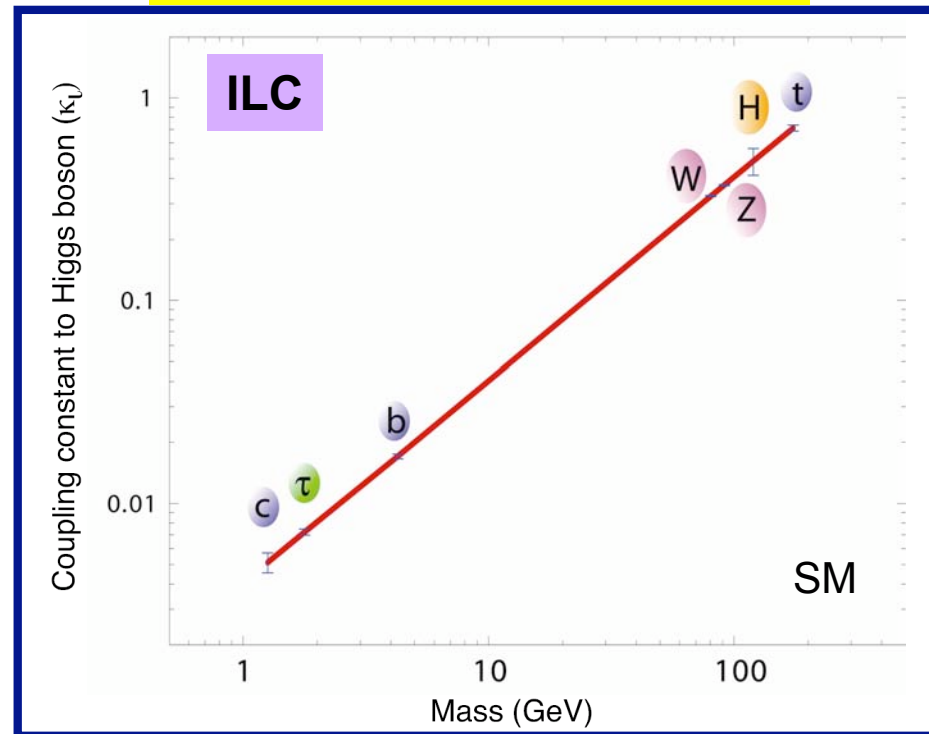
Top Yukawa coupling



Higgs Self-coupling

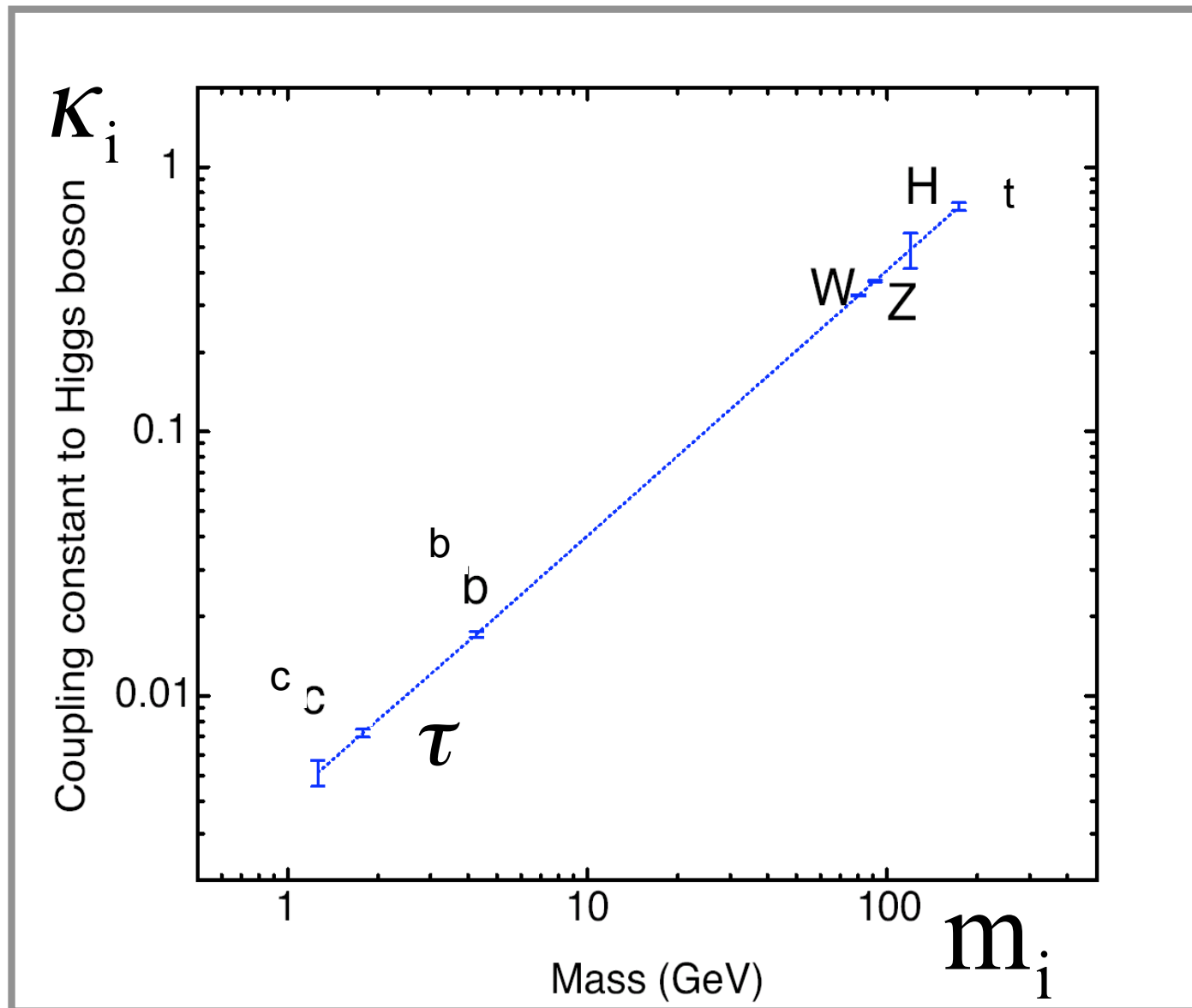


If one Higgs generate all masses



Different pattern If SUSY, Multi-Higgs etc..

Mass-generation mechanism



ILC Examples of Higgs Model Independent Analyses

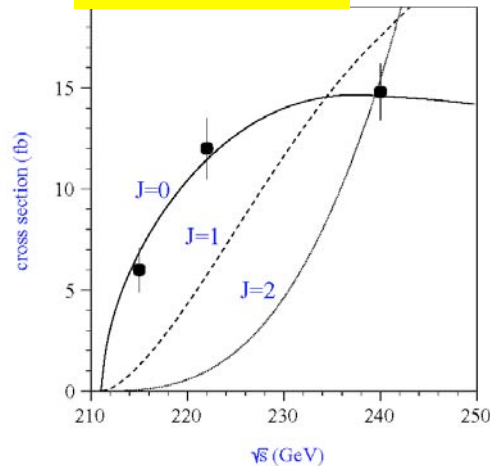
Mass & Cross-section measurement
= **Gauge coupling** measurement

$$\Gamma_W = f(M_h) \times \sigma$$

$$\delta g/g \sim 1\%$$

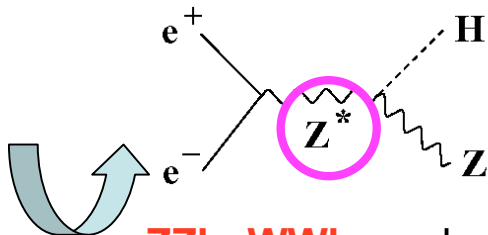
$$\delta M_h \sim 40 \text{ MeV}$$

Energy scan



Spin, Parity

Beam polarization

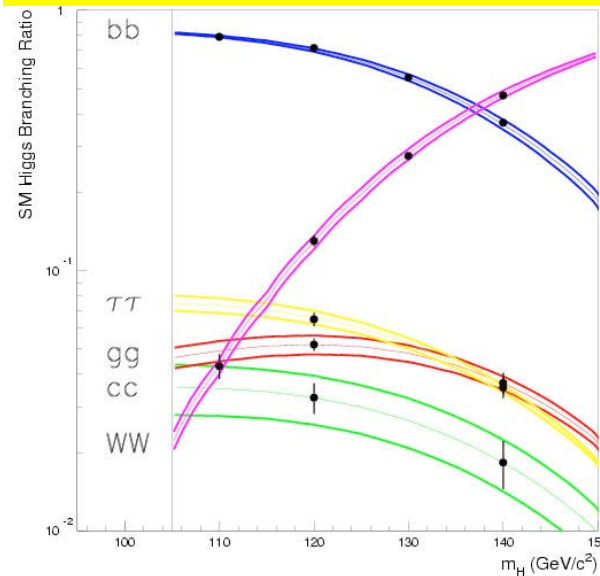


ZZh , WWh production
(selectable)

CP, $SU(2)_L \times U(1)$

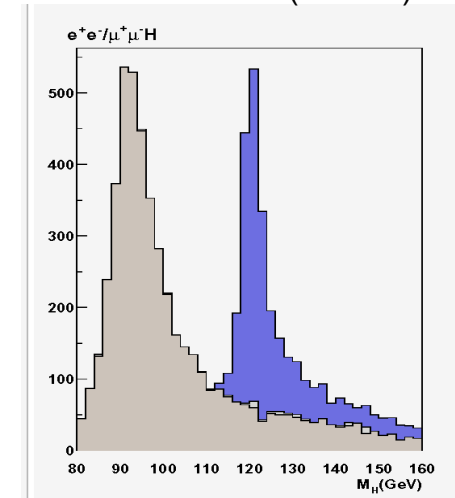
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Branching ratio measurements



Invisible width

Use Recoil mass(no bias)



Total width measurement

$$\Gamma_{\text{tot}} = \Gamma_W / \text{Br}(H \rightarrow WW)$$

$$\delta \Gamma_{\text{tot}} / \Gamma_{\text{tot}} \sim 5\%$$

Absolute strength of Yukawa-Coupling determination

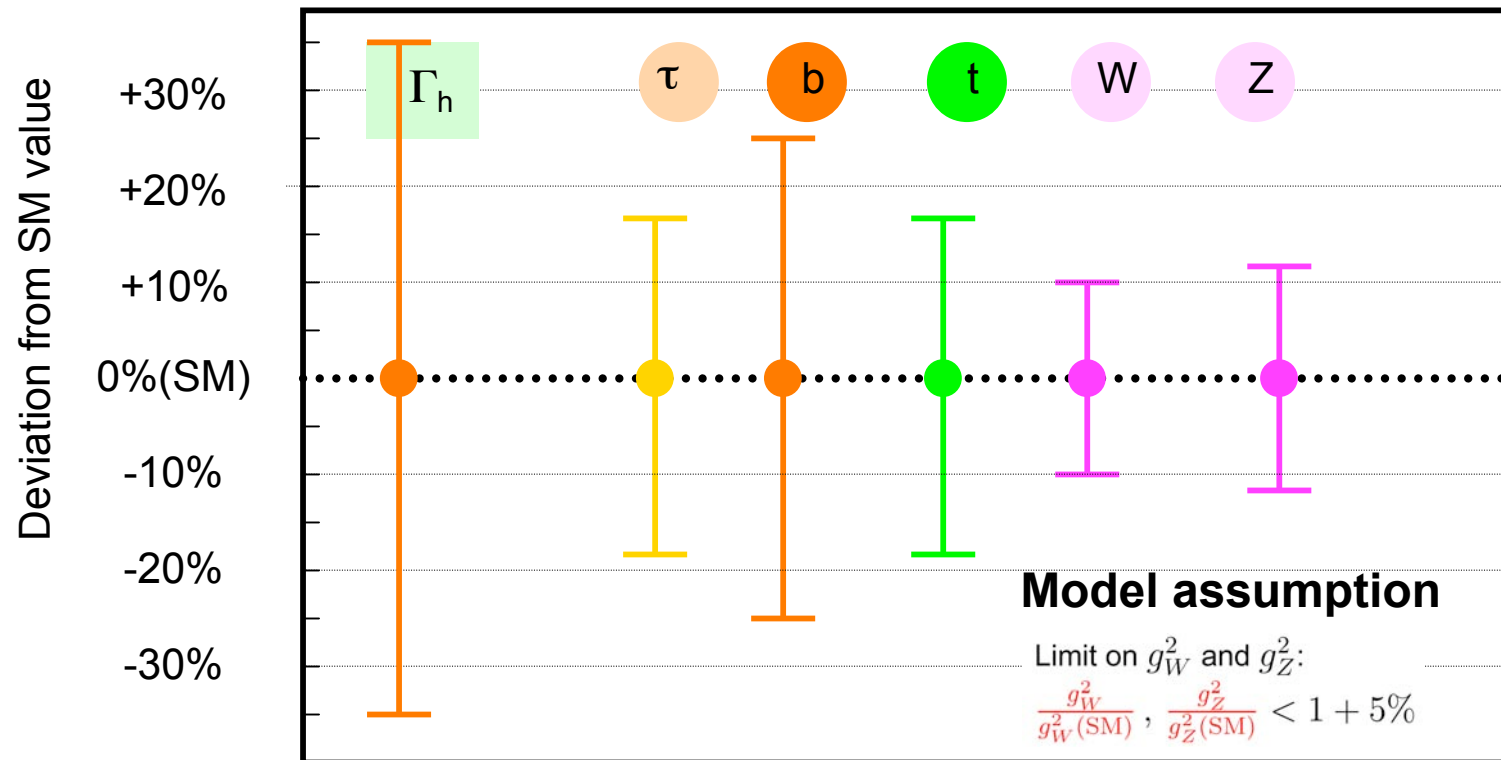
$$\Lambda_f^2 = C(M_h) \times \text{Br}(H \rightarrow ff) \times \Gamma_{\text{tot}}$$

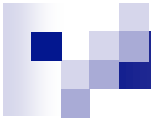
$$\delta \Lambda_b / \Lambda_b \sim 3\%, \delta \Lambda_\tau / \Lambda_\tau \sim 4\%, \\ \delta \Lambda_c / \Lambda_c \sim 8\%, \delta \Lambda_u / \Lambda_u \sim 4\%$$

S. Yamashita Snowmass

Coupling Precision

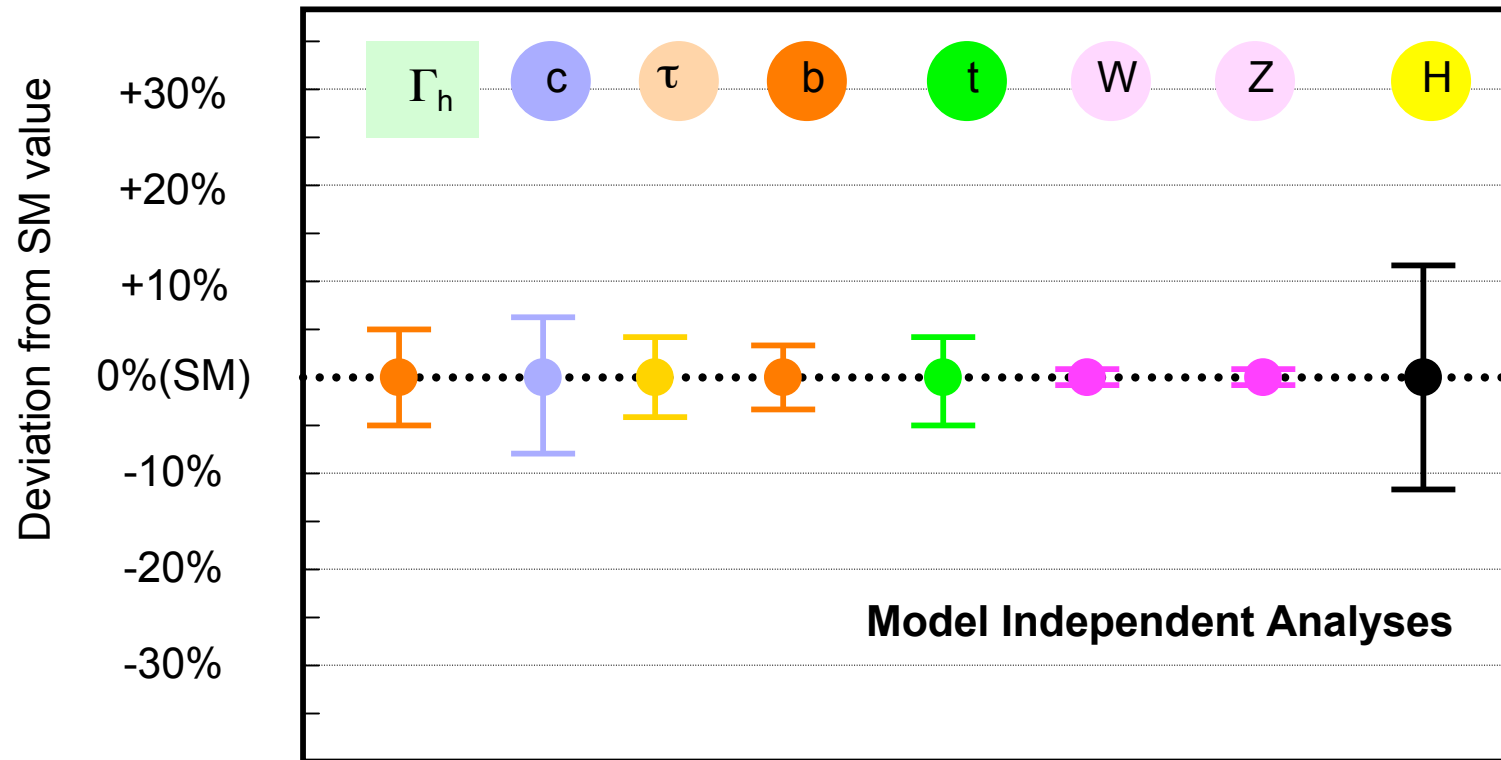
LHC 300 fb⁻¹ x 2





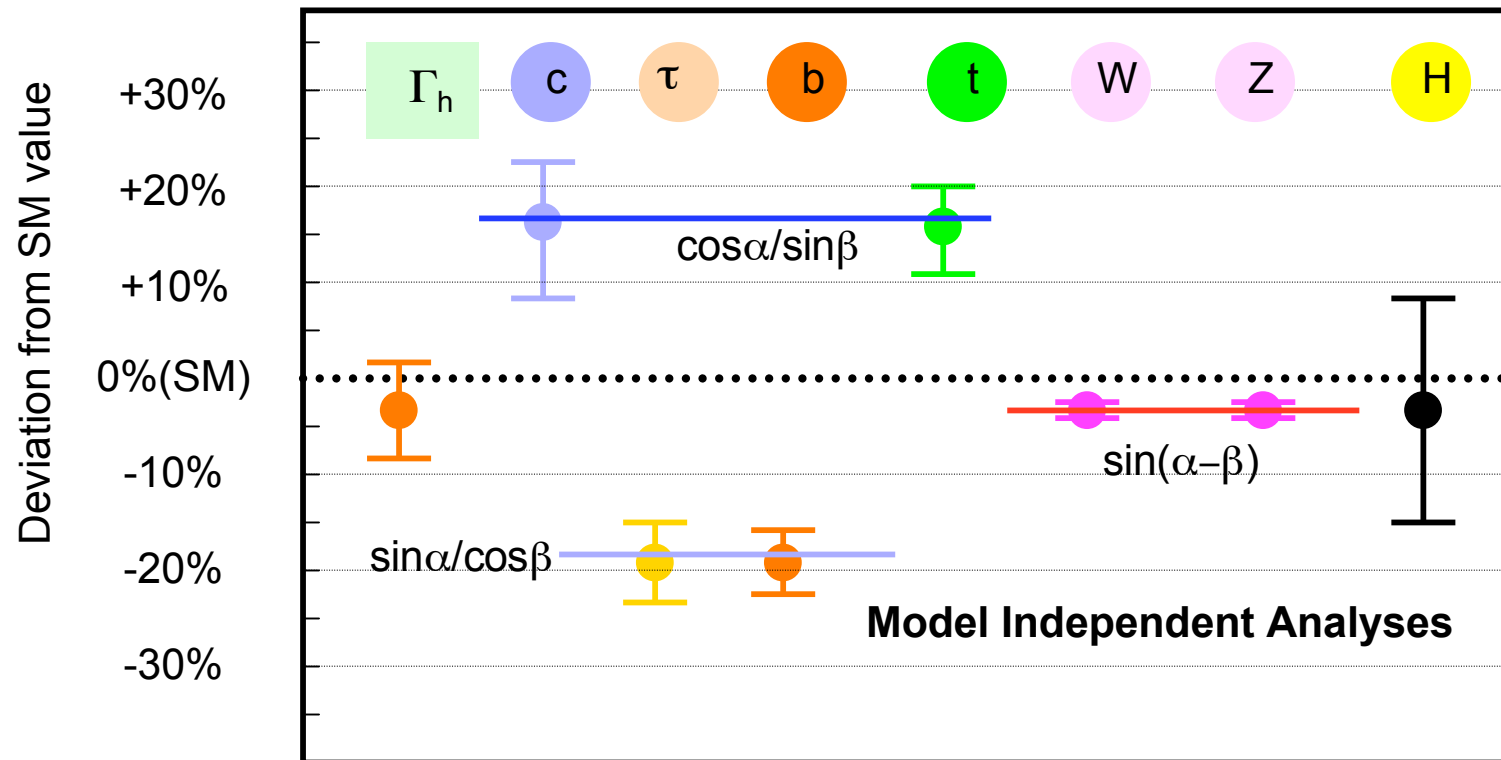
Coupling Precision

ILC



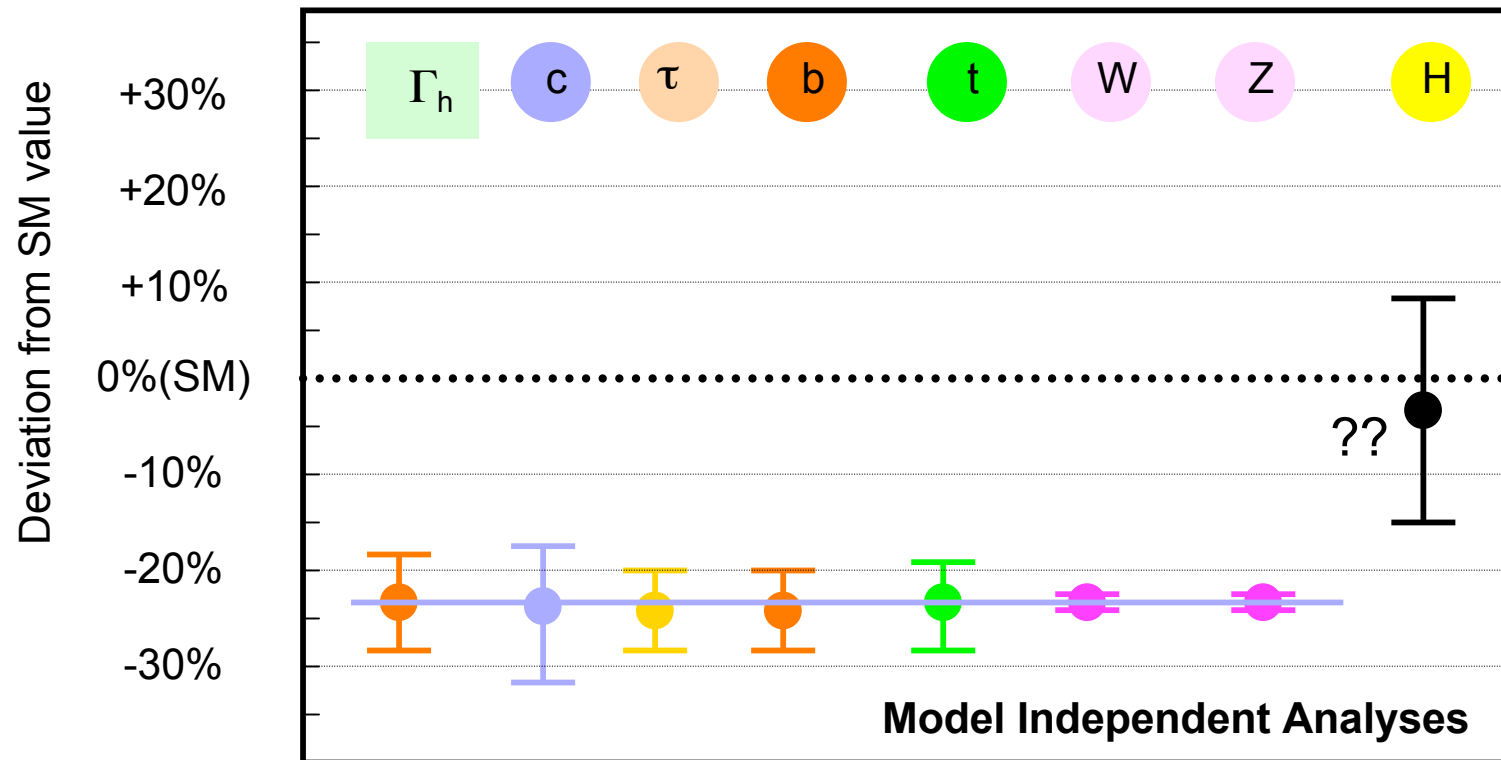
SUSY or 2HDM

ILC



Extra-dimension (radion-Higgs mixing)

ILC

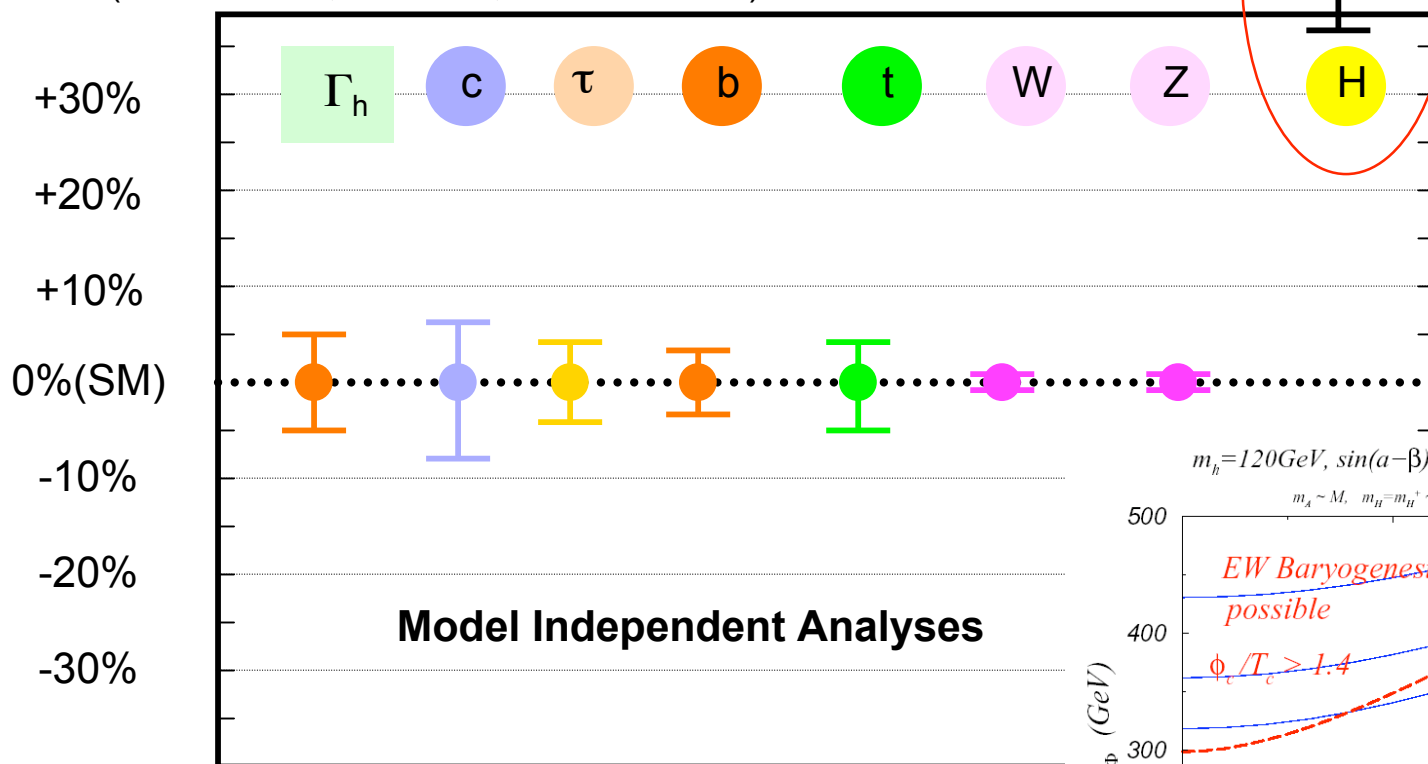


Electroweak Baryogenesis

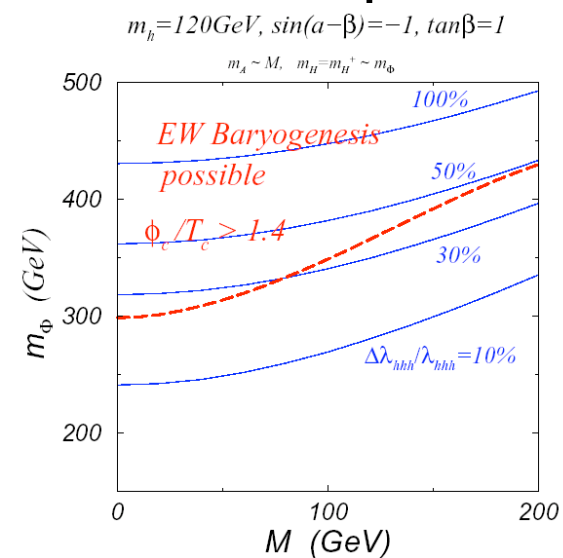
(S.Kanemura, Y.Okada, E.Senaha '04)

ILC

Deviation from SM value

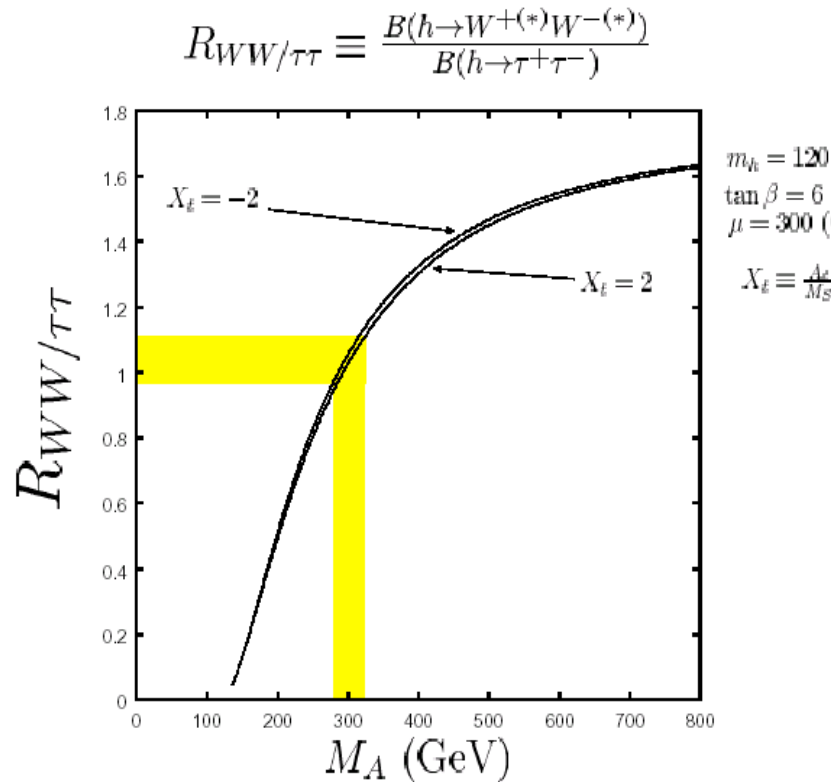


Model Independent Analyses

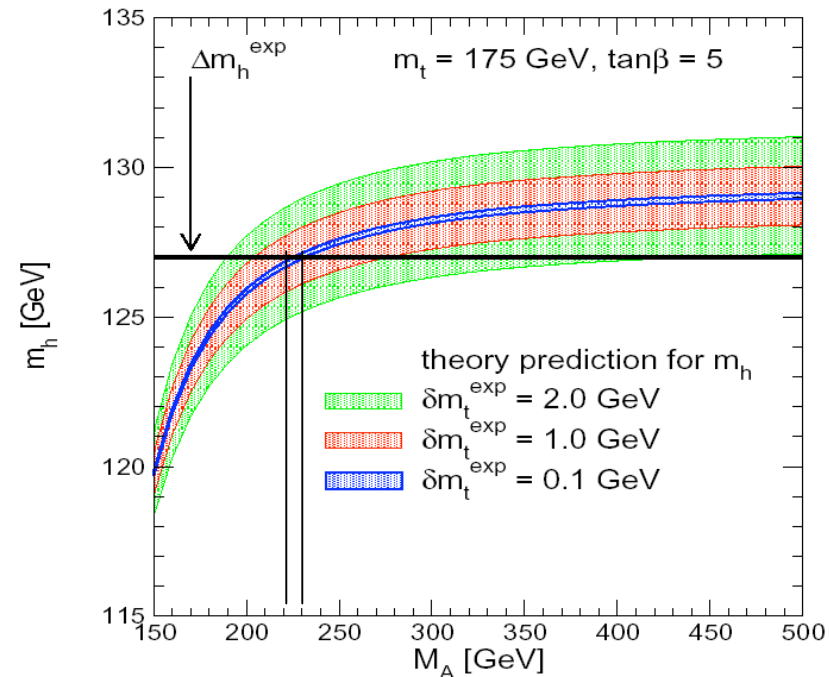


More than one Higgs boson?

$h, H, A, H^\pm$ in the Minimal Supersymmetric Standard Model.



Accurate coupling measurements tell us M_A



Top mass is also essential

Direct and indirect searches for heavy Higgs bosons at ILC.

What to do (from experimental technical point of view)

Key analyses techniques are:

1. Jet finding / jet clustering
2. Jet energy calculation
3. b, c, top, tau tagging
4. W, Z tagging
5. Kinematic constraint fit

--> All techniques and results must be UPDATED

Most Fundamental Issues to be clarified

Gauge coupling

Yukawa-coupling

- Up-type vs Down-type top vs bottom (charm vs bottom)
- Quark vs lepton bottom vs tau
- 2nd generation vs 3rd generation mu vs tau, charm vs top

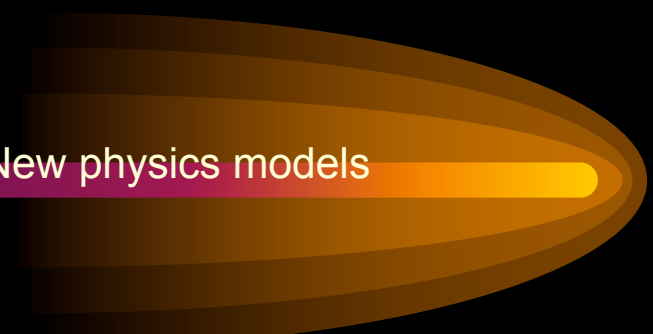
Self-coupling

---> We should clarify well the research potential of Higgs mass dependence for $M_h > 160$ GeV

What to do (requests to theorists)

Discrimination among various models

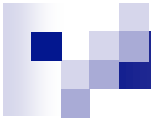
Translation of the deviation from SM into quantity in New physics models



- More concrete examples of model selection,
- Show ILC mass (energy scale) reach for new physics
- Please add many models (new/old) and summarize the power of Higgs study at ILC !



reserve



$\sqrt{s}$	300 GeV	400 GeV	500 GeV
Δm_h (lepton-only)	80 MeV	—	—
Δm_h	40 MeV	—	—
$\Delta\sigma/\sigma$ (lepton-only)	2.1%	2.5%	2.9%
$\Delta\sigma/\sigma$	1.3%	—	—
$\Delta(\sigma_{h\nu\nu}\cdot\text{Br}(b\bar{b}))$	2.0%	—	—
ZZH-coupling $\Delta\text{ZZH}/\text{ZZH}$	1.1%	1.3%	1.5%
WWH-coupling $\Delta\text{WWH}/\text{WWH}$	1.6%	—	—
$\Delta\Gamma_{h^0}/\Gamma_{h^0}$	5.5%	12%	16%
Yukawa coupling $\Delta\lambda/\lambda$			
λ_b	2.8%	6.1%	8.1%
λ_τ	3.5%	—	—
λ_c	11.3%	13%	15%
λ_b/λ_τ	2.3%	—	—
λ_b/λ_c	11%	12%	14%
$\lambda_{\text{up-type}}$	4.1%	—	—
$\lambda_{\text{down-type}}/\lambda_{\text{up-type}}$	3.2%	—	—
$\Delta(\sigma\cdot\text{Br})/(\sigma\cdot\text{Br})$			
$h^0\rightarrow b\bar{b}$	1.1%	1.3%	1.7%
$h^0\rightarrow W^+W^-$	5.1%	12%	16%
$h^0\rightarrow \tau^+\tau^-$	4.4%	—	—
$h^0\rightarrow c\bar{c}+gg$	6.3%	—	—
$h^0\rightarrow c\bar{c}$	22%	23%	27%
$h^0\rightarrow gg$	10%	11%	13%
$h^0\rightarrow \gamma\gamma$	—	—	—
$h^0\rightarrow Z^0\gamma$	—	—	—

ACFA
(2002)