Higgs and Top/QCD Summary

Shinya KANEMURA
University of Toyama

LCWS 2007@DESY, May 29. – June 03. 2007, Hamburg, Germany

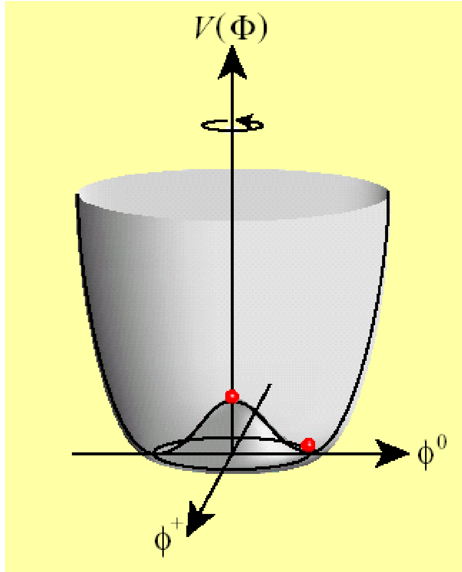
31 speakers

- Higgs
  - A.Juste, I. Ginzburg, M.Maniatis, P.Lutz, T.Barklow, D.Boumediene, R.Godbole, P.Osland, M.Krawczyk, V.Martin, S.Dittmaier, S.Heinemeyer, M.Ohlerich, T.Underwood, R.Nikolaidou, J.Reuter, K.Tsumura, S.Bolognesi, G.Weiglein, M.Battaglia
- Top/QCD
  - Y.Kiyo, A.Hoang, F.Gournaris, S.Boogert, A.Sopczak, A.Hoang, E.Boos, R.Godbole, A.Nomerotski, T.Gehrmann, M.Segond

The SM Higgs sector

- Gauge structure: $SU(3)_C \times SU(2)_I \times U(1)_Y$
- EWSB : $SU(2)_I \times U(1)_Y \rightarrow U(1)_{EM}$

A Higgs doublet $\Phi = \begin{bmatrix} w^+ \\ \frac{1}{\sqrt{2}}(H + v + iz^0) \end{bmatrix}$



$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4 \quad \langle\Phi\rangle = \begin{bmatrix} 0 \\ \frac{1}{\sqrt{2}}v \end{bmatrix}$$

$$m_H^2 = 2\lambda v^2$$

Light Higgs → Weak coupling
Heavy Higgs → Strong coupling

Fields obtain masses from VEV.

Gauge interaction (Higgs mechanism) $|D_\mu\Phi|^2 \rightarrow \frac{g^2v^2}{2}W^+W^-$

Yukawa interaction $y_b(\bar{Q}_L\Phi)b_R \rightarrow \frac{y_b v}{\sqrt{2}}\bar{b}b$

Mass-Coupling relation in the SM

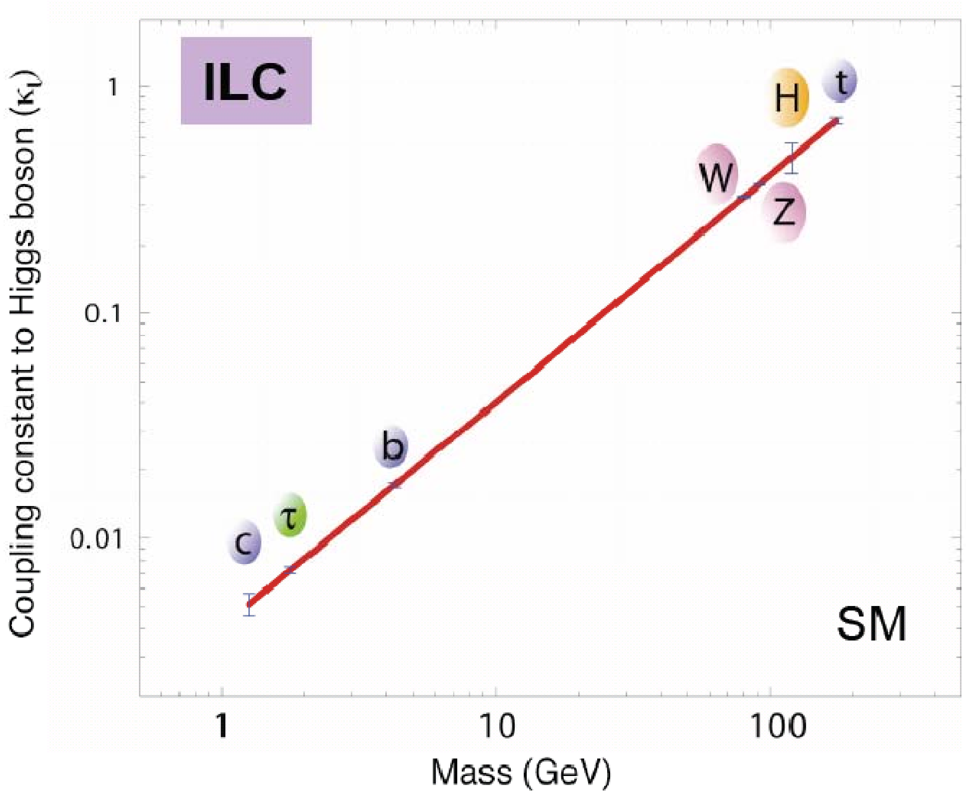
All masses are given in proportion to a unique VEV

$$\frac{2m_W}{g} = \frac{\sqrt{2}m_b}{y_b} = \frac{\sqrt{2}m_c}{y_c} = \frac{\sqrt{2}m_\tau}{y_\tau} = \frac{m_H}{2\sqrt{\lambda}} = v$$

Not measured

The SM is tested by using this universality

Measure both
the mass and the coupling!



In general, this relation does not hold in the extended Higgs models.

What we know about the nature of Higgs already?

Essentially

- Nothing is known about Higgs-to-gauge coupling

  Nature of Higgs mechanism

- Nothing is known about Yukawa coupling

  Nature of fermion mass generation

- Nothing is known about Higgs self-coupling

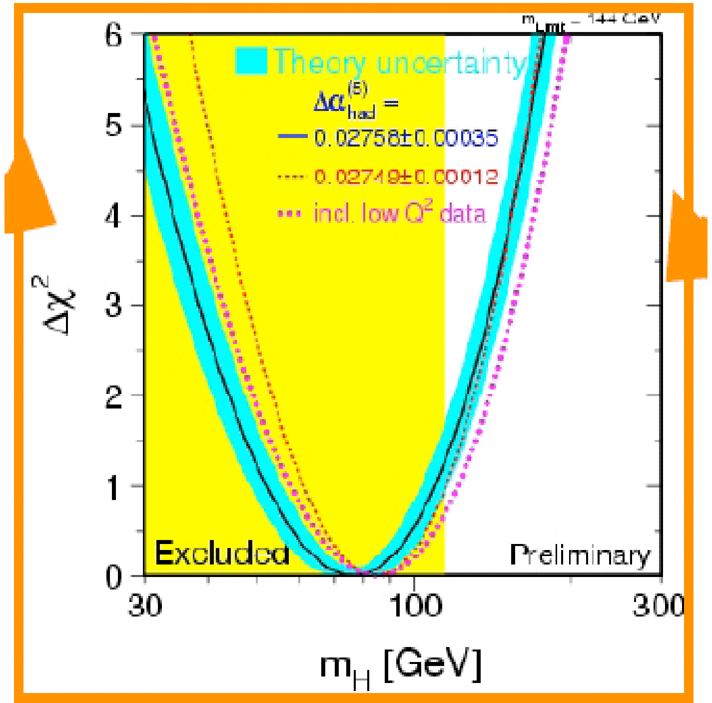
  Nature of EWSB

SM Higgs Mass

the last unkown parameter of the SM

$$m_H^2 = \lambda\langle\Phi\rangle^2$$

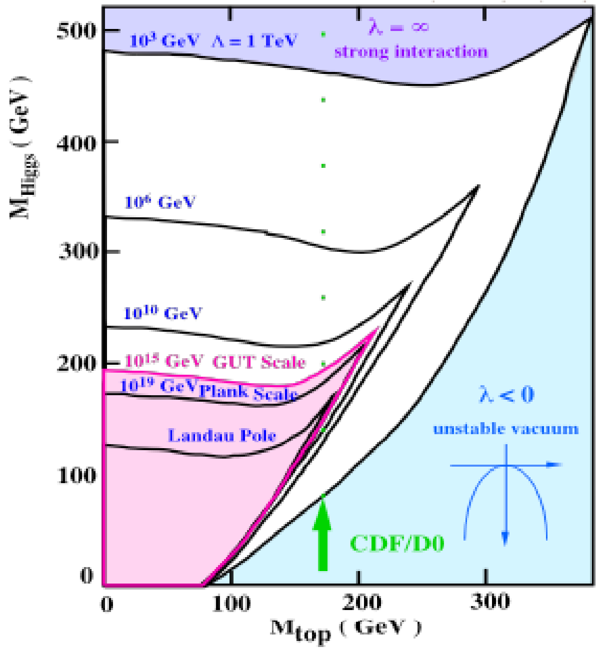
Data



$m_H < 182$ GeV/c^2 at 95% CL

Martin

Theory



$140 < m_H < 175\text{GeV}\ (\Lambda = 10^{19}\text{GeV})$

Favor a light Higgs boson if the SM is correct

Post-Higgs Problem

$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$

SM Higgs sector=Ugly

Lots of problems which the SM cannot explain.

Negative mass in the potential?

A spin 0 particle: Unnatural behavior in UV area

fine tuning

Nature of Yukawa coupling

Why only top quark obtain a natural size mass from the EWSB point of view?

- Paradigm for gauge unification
- Neutrinos
- Cosmology Baryogenesis, Dark Matter, Dark Energy

The SM cannot be fundamental.

New Physics solve these problems. Where? Tera scale!

ILC

- LHC starts this year

  Higgs or anything may be found in a few yrs

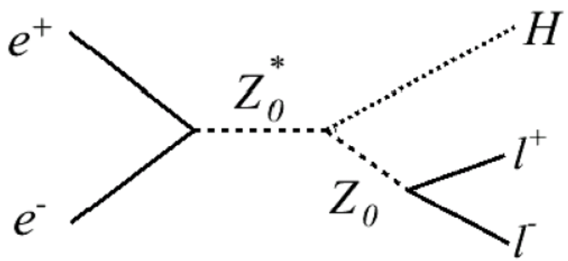
- ILC solve Post-Higgs Problem
  - Reconstruct Lagrangian of physics beyond the SM
  - Measure precisely mass, spin, couplings of the SM and also NP particles.
  - Precise measurements

  requre higher order calculation

Higgs mass

Higgs boson mass

- LHC [1GeV]
- ILC [50 MeV]
- recoil mass measurement Ohlerich



Recoil Mass Analysis

M.Ohlerich

Higgs strahlung

- Recoil Higgs mass (Model Independent)

$$m_h^2 = s + m_Z^2 - 2E_Z\sqrt{s}$$

- Coupling strength

$$g_{ZZH}^2 \propto \sigma = N / L\varepsilon$$

Simulation study

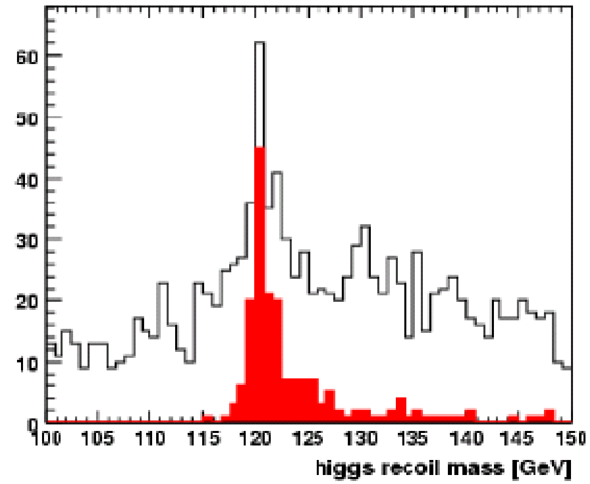
SM m_H=120GeV E_{cms} = 250 GeV

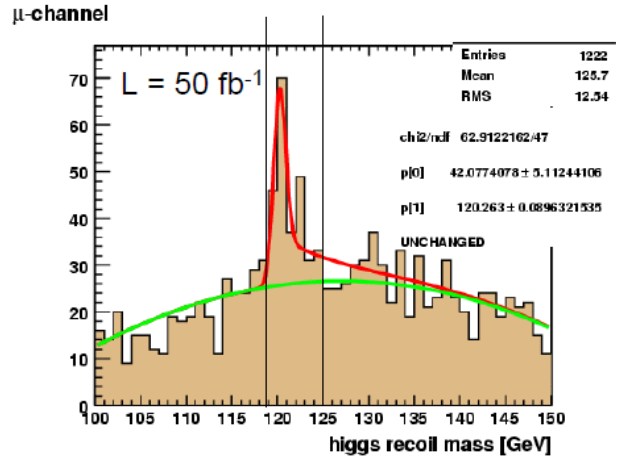
PYTHIA, SHERPA BHWIDE → (HEPEvt) → Mokka → (SLCIO) → Marlin / MarlinReco

Mokka: Detector Simulation

Marlin / MarlinReco: Full reconstruction of isolated leptons

signal likelihood cut for e, μ channel
for improving Signal-to-BG ratio
⇒ as signal accepted events





combined X-section:
245.4 fb ± (10.4%)

Higgs Recoil Mass

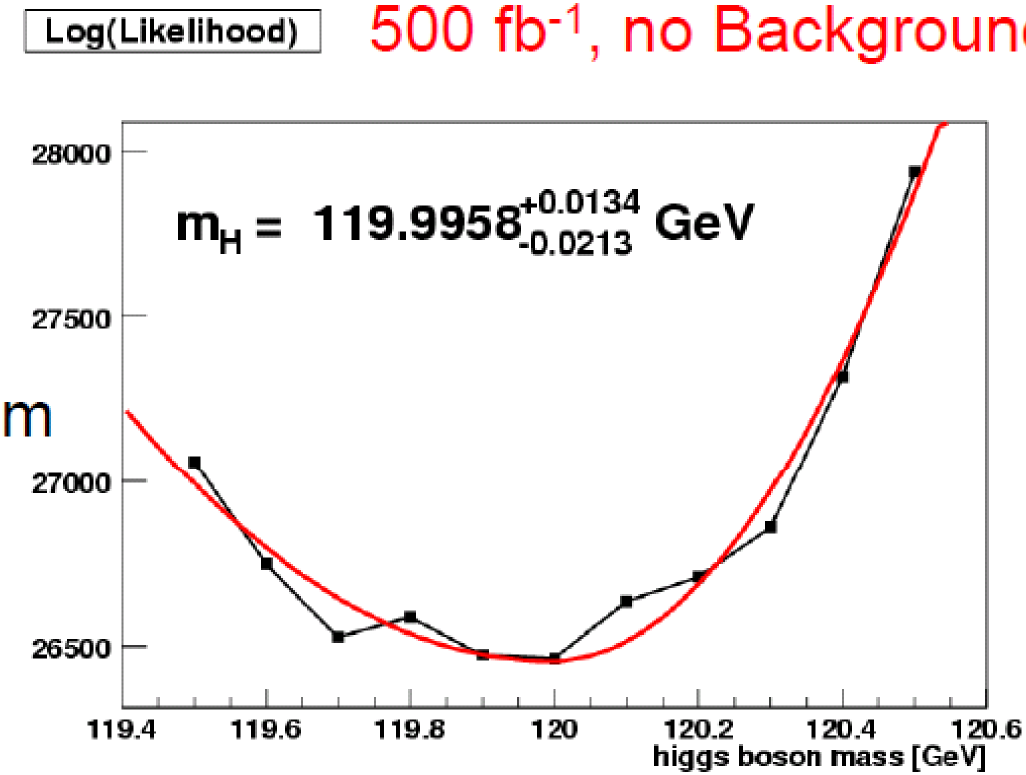
Event Generator : create samples for different Higgs mass values

Detector Simulation / Reco

Calculate the likelihood from histrogrammed spectra

No Bias

500 fb^{-1}, no Background



Errors due to parameter fitting reducible by higher MC statistics

Top quark mass

- Most important parameter which affect many predictions

- We want to have 0.1% accuracy for mt
  EWSB (indirect mH determination)
  Indirect determination of new physics parameters
  (eg SUSY parameters, …, GUT informaiton)

  – Threshold scan of ttbar   accurate mt measurement possible
  – Direct mass reconstruction

Combined information with higher order calculation can make it possible to determine new physcics parameters.

EX)   Theory calculation in MSSM

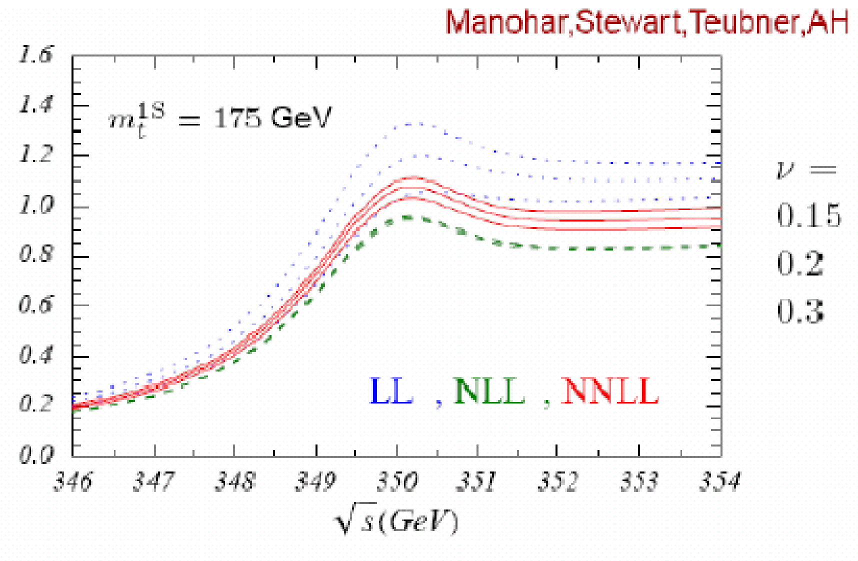
Top-Pair Threshold Study

- Theory
  - QCD Fixed Order (NNNLO) Kiyo
    RGE (NNLL) Hoang
  - EW
- Experiment
  - Development of ttbar MC Gournaris
  - Luminosity Spectrum Boogert
- Application
  - stop-pair threshold Sopczak
  - tth production Hoang

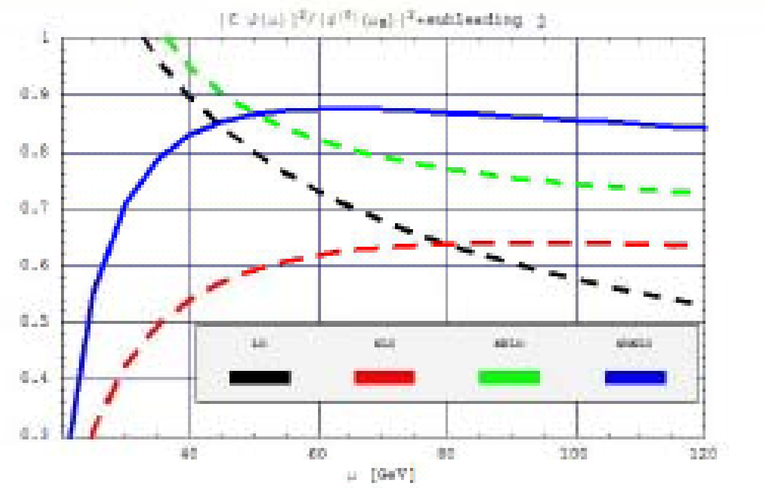
Theory talk for threshold ttbar production

Recent progresses on $\sigma(e^+e^- \to t\bar{t})$: NNLL RG improvement and NNNLO computation of the threshold cross section.

- The NNLL' stabilize the cross section $\delta\sigma_{t\bar{t}}/\sigma \sim \pm 6\%$ against μ variation (A. Hoang's talk)
- The NNNLO dynamical gluon and potential: Preliminary estimate $\Rightarrow$ 10% shift and 5% scale dependence. (Y. Kiyo's talk)



Hoang



Kiyo

Experimental study for ttbar threshold

"Towards a MC generator for ttbar production at threshold", F.Gournaris
A long-waited threshold event generator

"Determination of dL/dE and total CM energy", S. Boogert's talk
Threshold scan relys on the precise knowledge of the beam profile: (energy spread $\sim 0.1\%$, beamstrahlung between$0.2 - 2.0$ %, ISR)

Scalar Tops

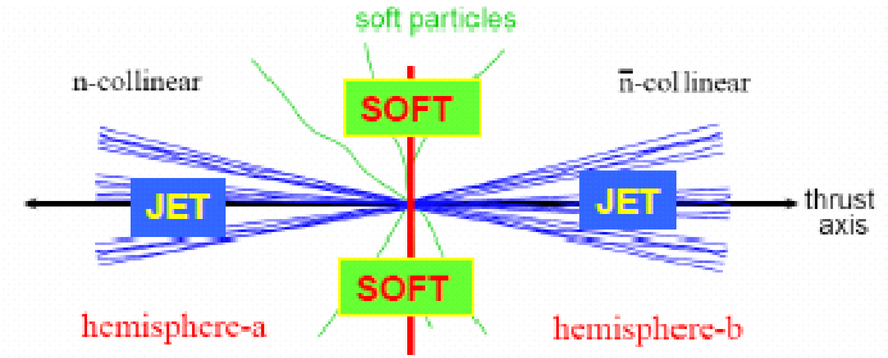
Sopczak, Finch, Freitas, Milstene, Nowak, Schmitt

- From discovery sensitivity (Morioka'95) to precision mass determination.
- Importance of beam polarization, e^+ pol. in addition.
- c-quark tagging vertex detector benchmark and finding c-jets in multi-jet scenarios.
- SPS-5 parameter and cosmology-motivated small neutralino-stop mass difference studied.
- Method with two center-of-mass energies, one at threshold, increases mass determination much, and gives Ω_{CDM} uncertainty similar to WMAP.

Top mass determination in the continuum

- Direct reconstruction of invariant mass distribution of   t->Wb.
- Which mass is reconstructed?
- New conceptual work   “Jet-Mass”

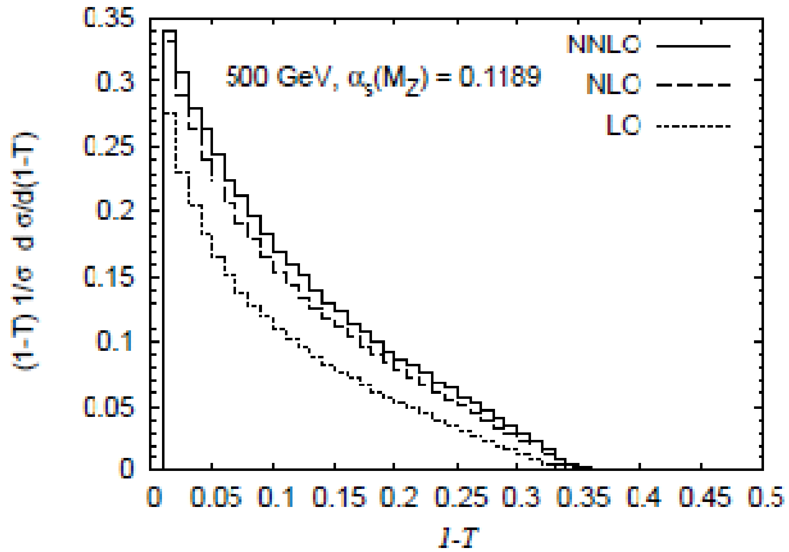
A.H.Hoang



Details see Loop Summary by Steinhauser

QCD

- Importance of determining alpha_s (goal ~1%)
- Gehrman NNLO for 3Jets has just completed.



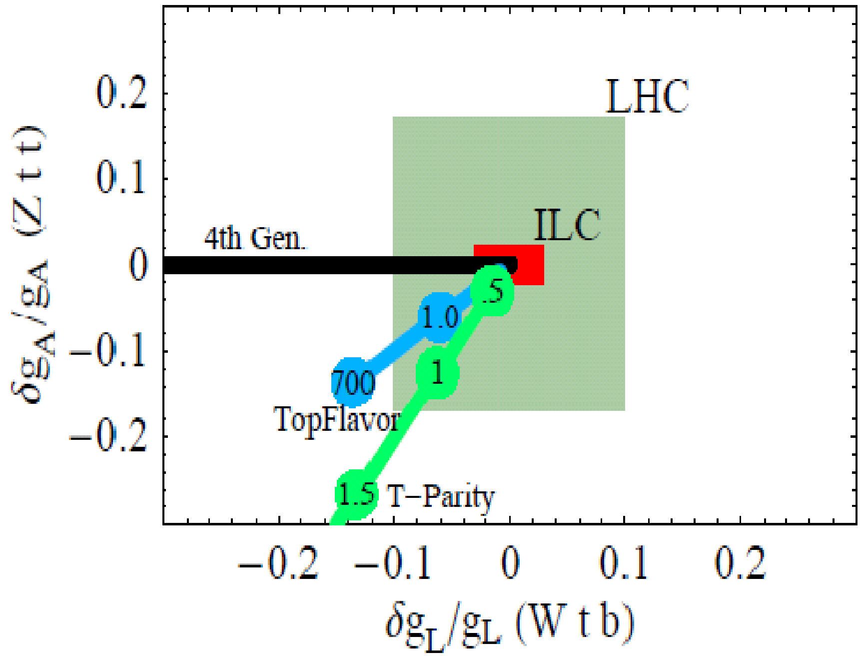
Segond
Opportunity to test BFKL at ILC via exclusive rho pair production

Ztt, Wtb

Nomerotski

At ILC, using better Vertex Detecto
Resolution LEP X2-3
Polarization further X2
(80%e-, 60%e+),
we can make preision
measurements of anomalous
coupling. New Physics search

Tait



Anomalous coupling

V-A; =1 in SM V+A; =0 in SM

$$\mathcal{L} = \frac{g}{\sqrt{2}}\Big[W_\mu^- \bar{b}(\gamma_\mu f_{1L} P_- + \gamma_\mu f_{1R} P_+) t - \frac{1}{2M_W} W_{\mu\nu} \bar{b} \sigma^{\mu\nu} (f_{2R} P_- + f_{2L} P_+) t \Big]$$

Magnetic couplings; = 0 in SM

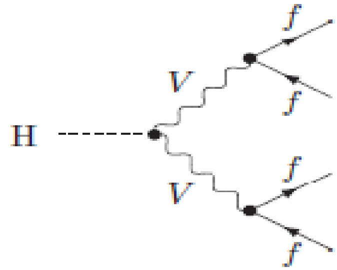
Boos

Single top production from e-gamma collision is the main Production mechanism for Wtb

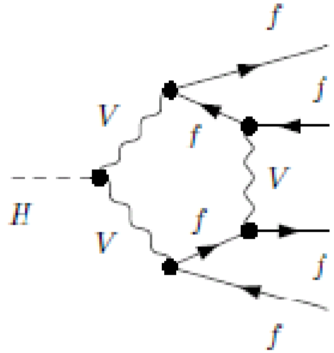
H $\longrightarrow$ WW/ZZ $\longrightarrow$ 4 fermions

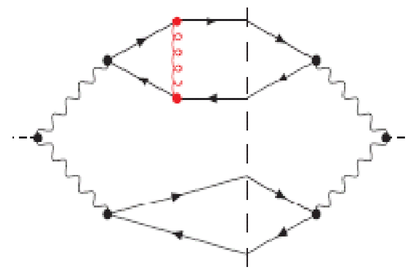
S. Dittmaier

# of diagrams O(200-400)



- Importance of $\mathrm{H} \rightarrow \mathrm{WW}^{(*)}/\mathrm{ZZ}^{(*)}$
- LHC
  - WW: Most important decay for mH > 125GeV
  - ZZ: Precise measurement of mH (> 130GeV) (leptonic)
- ILC
  - Branching ratio at % level
  - Full reconstruction of $\mathrm{H} \rightarrow \mathrm{WW}$ (leptonic, hadronic)

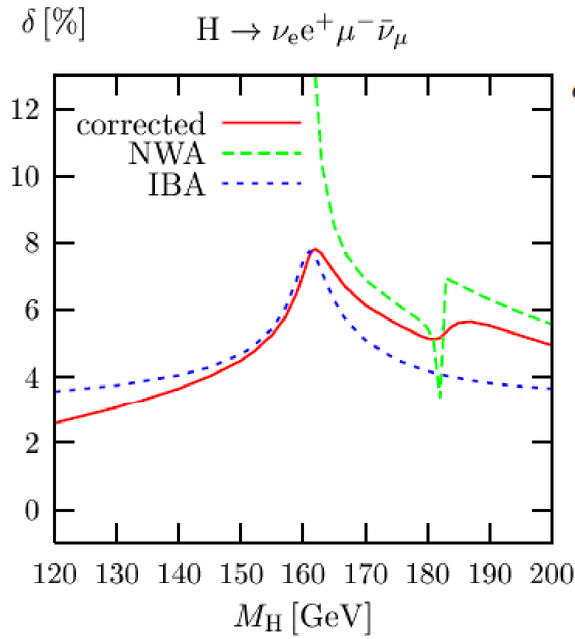




Radiative correction QCD+EW
long history

PROPHECY4f

MC generator with
EW and QCD corr.
All final state 4f
Proper description of
distribution



$\delta = \frac{\Gamma}{\Gamma_{\mathrm{Born}}} - 1$

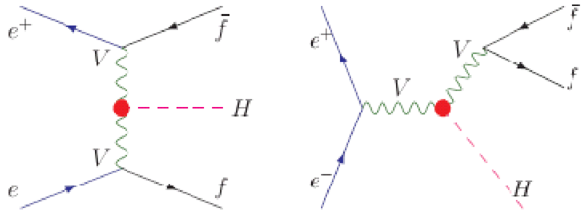
Bredenstein, Denner, S.D., Weber '06

↑ Coulomb singularity for $M_{\mathrm{H}} \sim 2M_{\mathrm{W}}$

↑ threshold effect in loops for $M_{\mathrm{H}} \sim 2M_{\mathrm{Z}}$

First results of PROPHECY4F on $\mathrm{H} \to \mathrm{WW}/\mathrm{ZZ} \to 4f$

- partial decay widths: EW corrections of $\mathcal{O}(8\%)$ for $M_\mathrm{H} \lesssim 500\,\mathrm{GeV}$
  (reproduced by a simple improved Born approximation within $\lesssim 2\%$ for $M_\mathrm{H} \lesssim 400\,\mathrm{GeV}$)
- angular distributions: EW corrections of $\mathcal{O}(5-10\%)$ distort shapes
- invariant-mass distributions of W's and Z's:
  EW corrections of some 10% distort shapes (depend on inclusiveness of γ radiation)
- QCD corrections can be associated with W/Z decay (interference effects negligible)



Anomalous VVH coupling

Rohini Godbole

$$\Gamma_{\mu\nu} = g_V \left[a_V \; g_{\mu\nu} + \frac{b_V}{M_V^2} \left(k_\nu^1 k_\mu^2 - g_{\mu\nu} k^1.k^2\right) + \frac{\tilde{b}_V}{M_V^2} \epsilon_{\mu\nu\alpha\beta} k^{1\alpha} k^{2\beta} \right]$$

$M_H = 120$ GeV, $Br(H \to b\bar{b}) \approx 0.68$
b-quark detection efficiency $= 0.7$
$\sqrt{s}$ = 500 GeV, $\mathcal{L}$ = 500 fb^{-1}

$a_W^{SM} = 1 = a_Z^{SM}$, $b_V^{SM} = 0 = \tilde{b}_V^{SM}$, and $a_V = 1 + \Delta a_V$.

Unpolarized: robust limit on $\Re(b_z)$, $\Re(\tilde{b}_Z)$ and $\Im(\tilde{b}_Z)$.
No direct probe for WWH

Polarized beam:

Initial state beam polarization
Improves the sensitivity to
up to a factor of 5-6

Unpolarized Beam	Polarized Beam	Observable used
$\lvert\Re(\tilde{b}_z)\rvert \leq 0.41$	$\lvert\Re(\tilde{b}_z)\rvert \leq 0.070$	$A_{UD}^{-;+}(R1;\mu)$
$\lvert\Im(\tilde{b}_z)\rvert \leq 0.042$	$\lvert\Im(\tilde{b}_z)\rvert \leq 0.0079$	$A_{FB}^{-;+}(R1;\mu,q)$

final state τ Polarization

Measurement of final state τ polarization helps to get stronger limit on $\Im(b_Z)$.

higher c.m. energy. probe WWH couplings better.
Increase in energy helps improve the probing of $\Re(b_Z)$ even after inclusion of both ISR and Beamstrahlung effects.

Higgs CP property via ttH

Rohini Godbole

CP property: very important

- Is it the SM Higgs?
- CP-odd state? (A^0 in 2HDM?)
- CP mixed state? (CPV in Higgs sector)

Top decays before hadronization

- Spin information kept=decay distribution

Parametrize $t\bar{t}\phi$ coupling

$$g_{t\bar{t}\phi} = -ig_2 \frac{m_t}{2m_W}(a + ib\gamma_5) \quad (g_{ZZ\phi})_{\mu\nu} = -ic\frac{g_2 m_Z}{\cos\theta_W} g_{\mu\nu}$$

SM case: $a = 1 = c$ and $b = 0$.

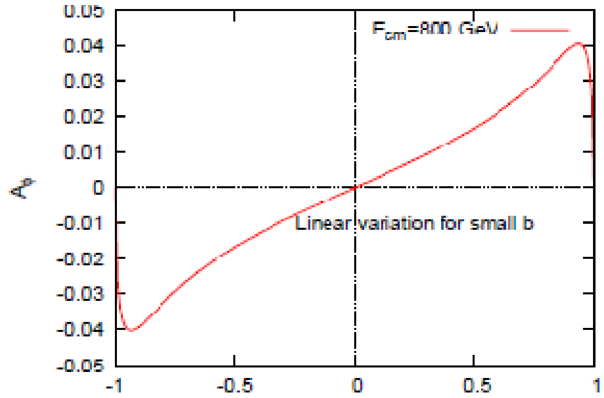
Study case: $|a|^2 + |b|^2 = 1$; a, b both being real.

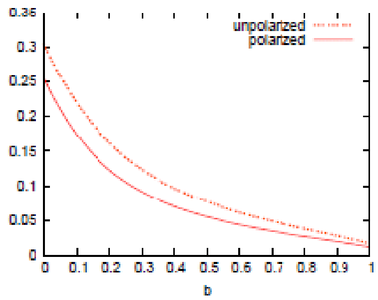
Up-down asymmetry

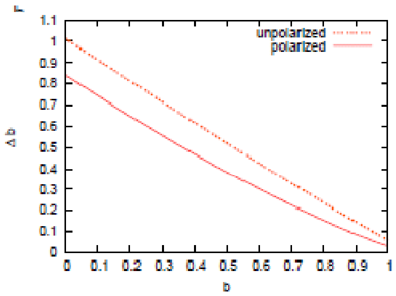
$$A_\phi = \frac{\sigma_{\rm partial}(0 \le \phi_4' < \pi) - \sigma_{\rm partial}(\pi \le \phi_4' < 2\pi)}{\sigma_{\rm partial}(0 \le \phi_4' < \pi) + \sigma_{\rm partial}(\pi \le \phi_4' < 2\pi)},$$

$$\sin\phi_4' = \frac{\vec{P}\cdot(\vec{p}_3 \times \vec{p'}_4)}{|\vec{P}|\cdot|\vec{p}_3 \times \vec{p'}_4|} \qquad (\vec{P} \equiv \vec{p}_1 - \vec{p}_2)$$

$$A_\phi = \frac{x_\phi\, ab}{x_t - y_t\, b^2} = \frac{x_\phi\, ab}{\sigma_{tot}}$$



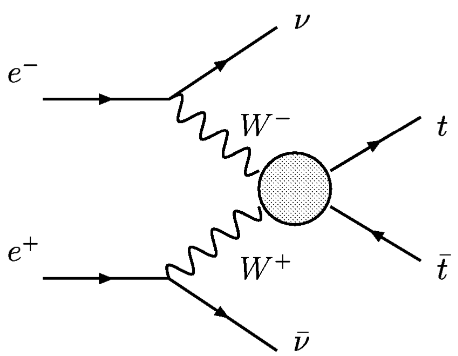




For cross section

For polarization asymmetry

Not so sensitive exccept for b ~ 1
Still polarlization asymm is still a good observables to study pure CP-even, odd cases



New Physics effect on the Top-Yukawa

K. TSUMURA

- In Effective theory, new hysics effect is characterized by dim.6 operators

$$\mathcal{L}_{dim.6} = \frac{1}{\Lambda^2} \sum_i C_i \mathcal{O}_i$$

- They are constrained by current data and partial wave unitarity

(ttH production Han et al.)

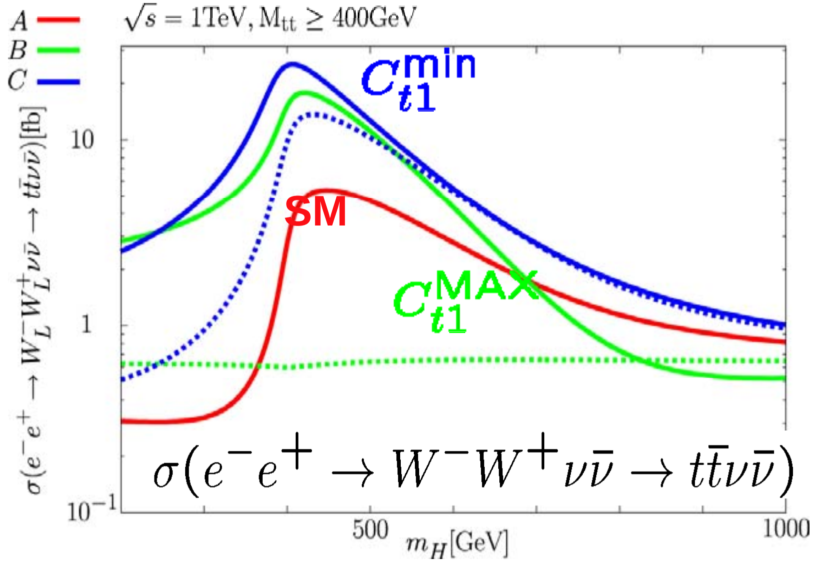
Buchmuller et. al

$$\mathcal{O}_{t1} = \left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)\left(\bar{q}_L t_R \tilde{\Phi} + \text{h.c.}\right)$$
$$\mathcal{O}_{t2} = i(\Phi^\dagger D_\mu \Phi)\bar{t}_R \gamma^\mu t_R + \text{h.c.}$$
$$\mathcal{O}_{t3} = i(\tilde{\Phi}^\dagger D_\mu \Phi)\bar{t}_R \gamma^\mu b_R + \text{h.c.}$$
$$\mathcal{O}_{Dt} = (\bar{q}_L D_\mu t_R)\left(D^\mu \tilde{\Phi}\right) + \text{h.c.}$$
$$\mathcal{O}_{tW\Phi} = (\bar{q}_L \sigma^{\mu\nu} \vec{\tau} t_R)\tilde{\Phi}\vec{W}_{\mu\nu} + \text{h.c.}$$
$$\mathcal{O}_{tB\Phi} = (\bar{q}_L \sigma^{\mu\nu} t_R)\tilde{\Phi} B_{\mu\nu} + \text{h.c.}$$

Top-Higgs interaction in W-fusion

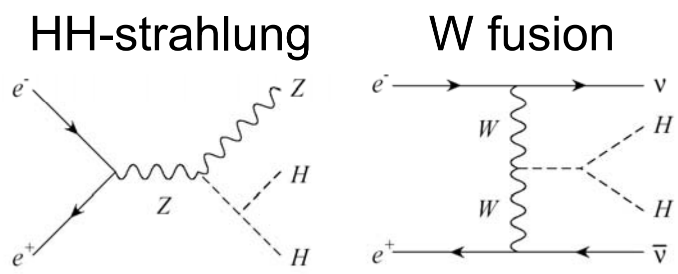
Dim.6 couplings can enhance the cross section by several 10 %

Such an effect may be observed in the WBF.

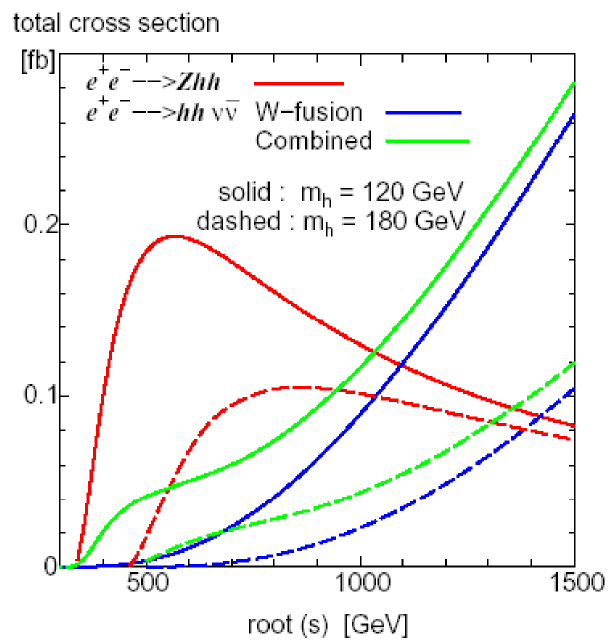


Higgs-self coupling

- Most important issue
- What we can know from hhh?
  - Nature of EWSB
  - New Physics models
  - EW Phase transition
    (1st order, 2nd order?)



Baur, Plehn, Reinwater



- LHC (HH to W^4) challenging
- ILC Simulation study

  Barklow, Boumediene

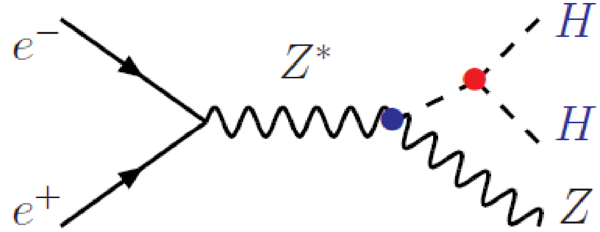
HHH measurement at ILC

T. Barklow

$$e^+e^- \to ZHH \to q\bar{q}b\bar{b}b\bar{b}$$

$$\sqrt{s} = 500\ GeV$$

$$L = 2000\ fb^{-1}$$

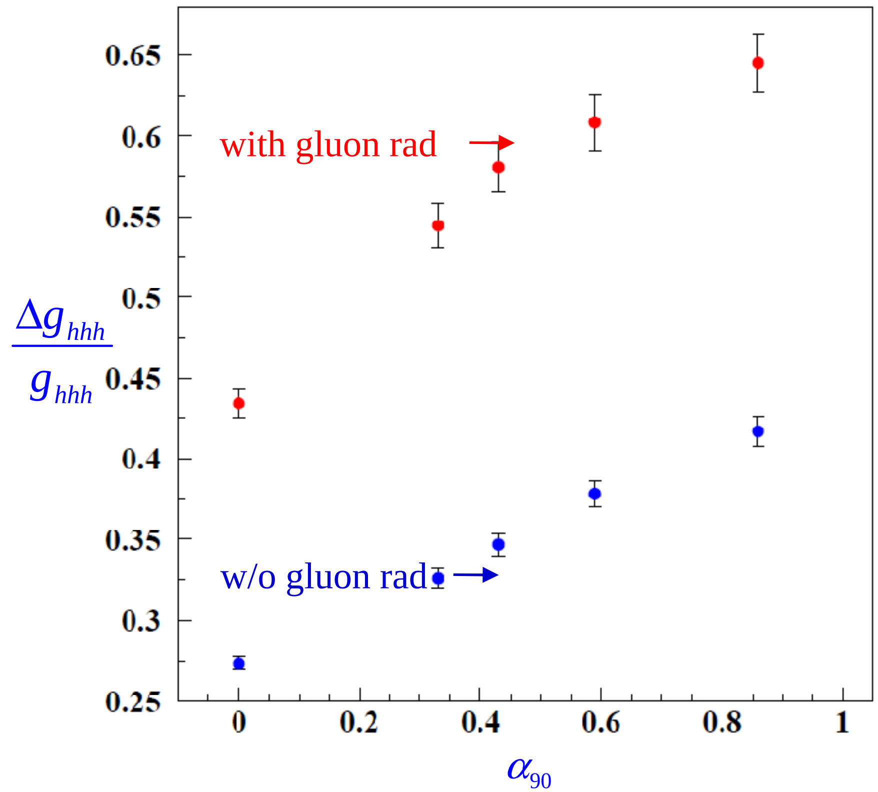


All background
Neural network analysis

Energy resolution dependence large
Effective L gain 40% if the jet energy
Resolution is improved from 60%
to 30%

Large gluon rad effect

W/o gluon rad = 32-38%
Inclu gluon rad =53-63%



Better b/c-tagging, b/bbar discrimination should improve the result

HHH measurement at ILC

Boumediene

- Study realized for a center of mass energy of 500 GeV
- Additional backgrounds w.r.t published analysis
- m_H = 120 GeV, Br(H→bb) = 68%
- Signal cross section 0.18 pb

  $\Delta\lambda_{hhh}/\lambda_{hhh} \sim 1.75\ \Delta\sigma_{hhZ}/\sigma_{hhZ}$
- Presence of 6 jets, 8 jets events → overlap → importance of jet reconstruction (typical final state for ILC physics)

The expected statistical precision on hhh is evaluated to 15% with a typical detector configuration and for a luminosity of 2ab-1

Signal : 3 channels

- hhqq
  - 6 jets
  - m_h & m_Z
- hhνν
  - 4 jets
  - missing energy
  - M_h
- hhll
  - 4 jets
  - 2 energetic leptons
  - m_Z & m_h

Higgs in New Physics Models

- SUSY
  - FeynHiggs — Heinemeyer
  - CMSSM Higgs production — Weiglein
  - HA production — Battaglia
  - Stop pair — Sopczak
- Little Higgs
  - Discriminate Little Higgs models — Reuter
- Two Higgs Doublet Model — Ginzburg, Krawczyk, Lutz, Maniatis, Osland
- Dim-6 — Tsumura
- SM+Phantom — Underwood

SUSY Higgs

MSSM Higgs potential contains two Higgs doublets:

$$V_H = m_1^2 H_{1i}^* H_{1i} + m_2^2 H_{2i}^* H_{2i} - \epsilon^{ij}(m_{12}^2 H_{1i} H_{2j} + m_{12}^{2\,*} H_{1i}^* H_{2j}^*)$$

$$+ \frac{1}{8}(g_1^2 + g_2^2)(H_{1i}^* H_{1i} - H_{2i}^* H_{2i})^2 + \frac{1}{2} g_2^2 |H_{1i}^* H_{2i}|^2$$

$$\begin{pmatrix} H_{11} \\ H_{12} \end{pmatrix} = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}(\phi_1 - i\chi_1) \\ -\phi_1^- \end{pmatrix}$$

$$\begin{pmatrix} H_{21} \\ H_{22} \end{pmatrix} = e^{i\xi} \begin{pmatrix} \phi_2^+ \\ v_2 + \frac{1}{\sqrt{2}}(\phi_2 + i\chi_2) \end{pmatrix}$$

Complex phases $\arg(m_{12}^2)$, ξ can be rotated away

$\Rightarrow$ Higgs sector is $\mathcal{CP}$-conserving at tree level

CP violating SUSY Higgs Sector

CPV induced at loop level from phases of

μ: Higgsino mass parameter

$A_{t,b,\tau}$: trilinear couplings

$M_{1,2}$: gaugino mass parameter (one phase can be eliminated)

$m_{\tilde{g}}$: gluino mass

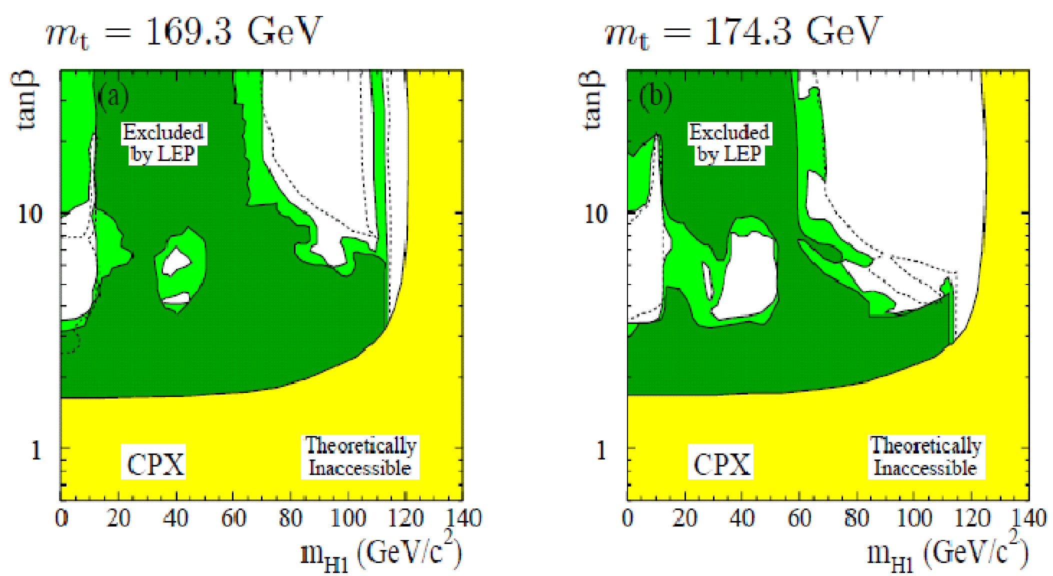
$\mathcal{CP}$-violating mixing between neutral Higgs bosons h_1, h_2, h_3

Phenomenology different from CP conserving case,

Holes in CPX plane:
Resuction of coupling by mixing
Large $\mathrm{BR}(h_2 \to h_1 h_1)$

$\mathcal{CP}$-violating case (CPX scenario): LEP exclusion bounds

[LEP Higgs Working Group



⇒ no lower limit on M_{h_1}: light SUSY Higgs not ruled out!
sensitive dependence on m_t

no lower limit on M_{h_1}: light SUSY Higgs not ruled out!
sensitive dependence on m_t

New results on loop effects in the MSSM with complex parameters

G. Weiglein

New results in MSSM Higgs sector with complex param.:

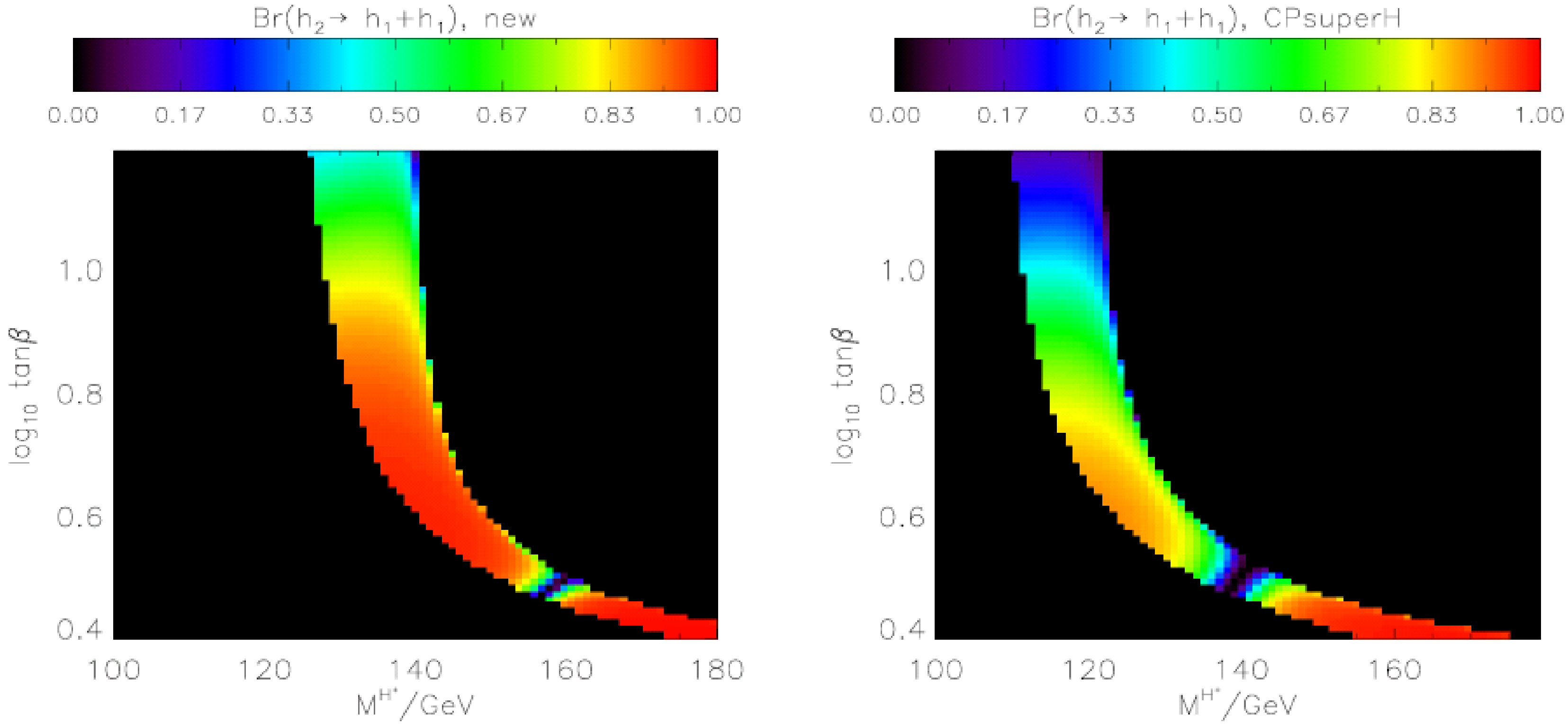
Complete one-loop results for masses, mixings, $\Gamma(h_2 \to h_1 h_1)$, $\Gamma(h_i \to f\bar{f})$ + two-loop $\mathcal{O}(\alpha_t \alpha_s)$ corrections

Complex phases can have large impact on Higgs phenomenology:

- 2-loop contrib. yield large enhancement of phase dep.
- large effect on $\mathrm{BR}(h_2 \to h_1 h_1)$
- Confirmation of “CPX holes”

Comparison of $\mathrm{BR}(h_2 \to h_1 h_1)$*, CPX scen.,* $\varphi_{M_3} = 0$*:*
New diagramm. result (left) vs. CPsuperH (right)

Comparison takes into account conversion of $|A_t|$ from on-shell scheme to $\overline{\mathrm{DR}}$ scheme [*G. W., K. Williams '07*]



⇒ Qualitative agreement, $\mathrm{BR}(h_2 \to h_1 h_1)$ enhanced

⇒ Confirmation of "CPX holes"

Feyn Higgs for the ILC

Sven Heinemeyer

Latest version: FeynHiggs 2.5.1 (02/07)

version FeynHiggs 2.6 to be released within two weeks . . .

real MSSM:

contains all available higher-order corrections
to Higgs boson masses and couplings

FeynHiggs contains
– full 1 loop calculations
– all available 2 loop calculations (leading and subleading)
– very leading 3 loop contributions

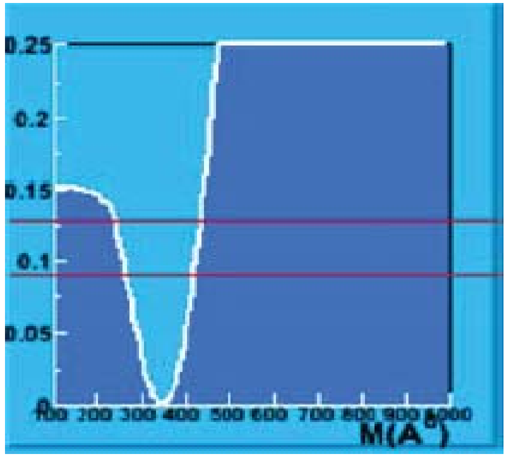
complex MSSM:

contains nearly all available results
(we are (even currently) working on the rest)

www.feynhiggs.de

HA reconstruction at LCC4 with Full Simulation

Battaglia



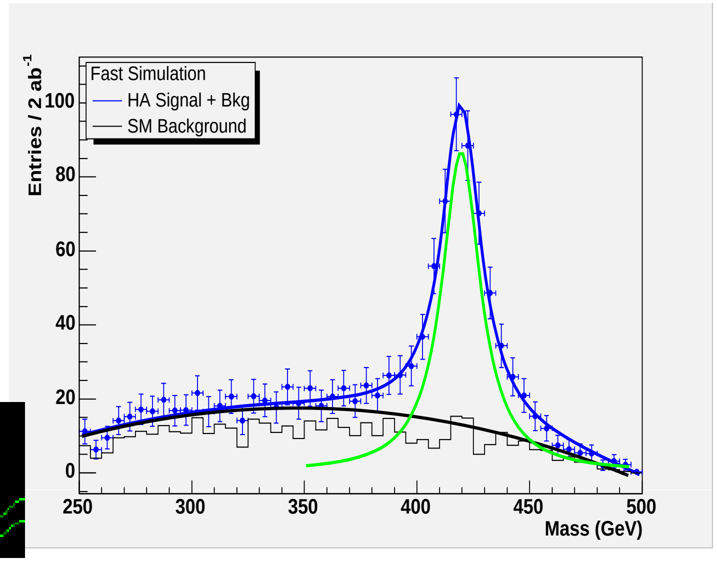
[LCC4] DM motivated parameter point to characterizes with $m_A/2m_\chi \sim 1$, which need to study in great deal with high accuracy.

Not only m_A but also Γ_A should be determined precisely.

At LHC, LCC4 may be beyond reach.

At ILC (1TeV), A produced in pair with H.

$$e^+e^- \to AH \to (b\bar{b})^2$$



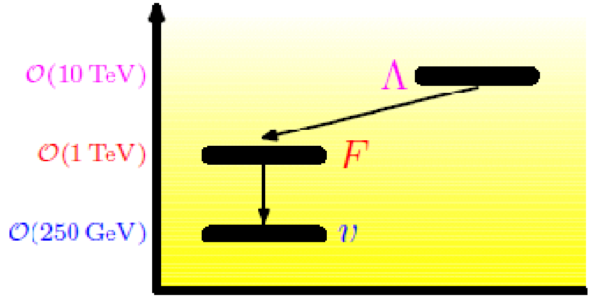
Re-analysis of HA channel for LCC4 at 1 TeV using full simulation and MarlinReco started;

study of HA decays allows to promote the relative accuracy on Ωh^2 from 0.16 to 0.08 thus matching the accuracy of the first WMAP determination;

Distingish Little Higgs models

J. Reuter

Little Higgs: Higgs as a pseudo Goldstone boson



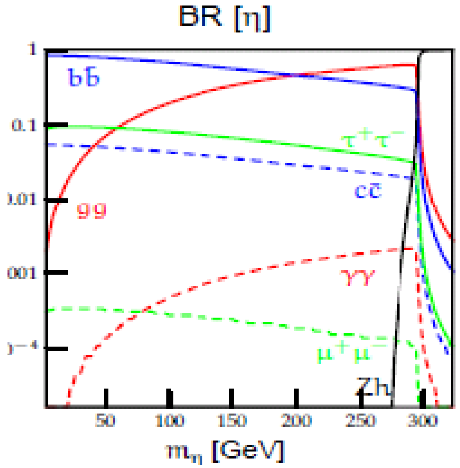
$$m_H \sim \frac{g_1}{4\pi}\frac{g_2}{4\pi}\Lambda$$

– Extended global symmetry

– Specific functional form of the potential

– Extended gauge symmetry:
$\gamma', Z', W'^{\pm}$

– New heavy fermions: T, but also $U, C, \ldots$
η axion-like particle:



Product Group Models
(Littlest Higgs)

Simple Group Models
(Simplest Higgs)

Rich collier phenomenolgy

$ZH\eta$ coupling

forbidden in Product Group Models

Invisible decay

$ZH\eta$ coupling as a discriminator

two Higgs-triplets with a $\tan\beta$-like mixing angle

2HDM

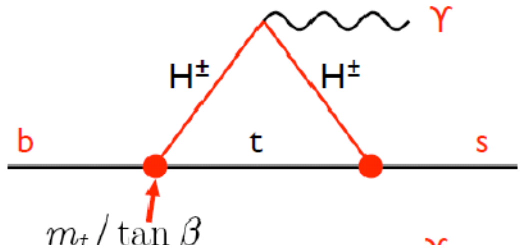
$$V_{2HDM} = \frac{1}{2}\lambda_1(\phi_1^\dagger\phi_1)^2 + \frac{1}{2}\lambda_2(\phi_2^\dagger\phi_2)^2 + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1)$$
$$+\frac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right] + \left[(\lambda_6(\phi_1^\dagger\phi_1) + \lambda_7(\phi_2^\dagger\phi_2))(\phi_1^\dagger\phi_2) + \text{h.c.}\right]$$
$$-\frac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\}$$

In general 14 parameters: $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, m_{11}^2, m_{22}^2, m_{12}^2$
however only **11** independent physical parameters

- Often set $\lambda_6 = \lambda_7 = 0$ for avoiding FCNC
- Then 2 type Yukawa couplings (Model I or II (MSSM like))
- If complex λ_5, CP violation

LCWS2007	Lutz	Charged Higgs at LEP
	I.Ginzurg, Maniatis,	Vacuum Structure, Formulation
	P. Osland, M. Krawczyk	Constraint on 2HDM, charged Higgs mass

Constrain parameters of 2HDM



P. Osland

Positivity

Perturbative unitarity

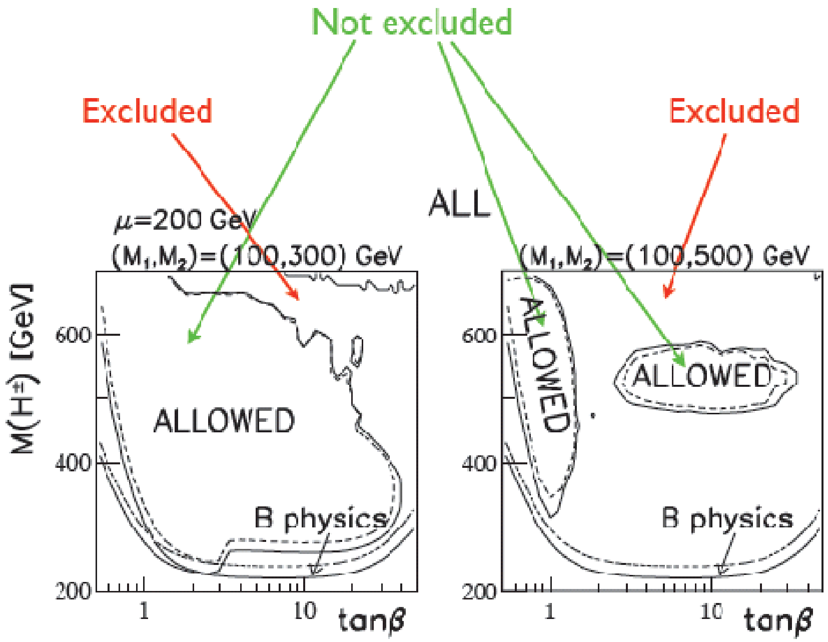
Experimental constraints

Misiak et al: $\mathcal{B}(\bar{B} \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$

HFAG (exp): $\mathcal{B}(\bar{B} \to X_s\gamma) = (3.55 \pm 0.24 \pm \cdots) \times 10^{-4}$

Experimental constraints:

Independent of neutral sector	• $B \to X_s\Upsilon$	excludes low $M_{H^\pm}$
	• $B \to \bar{B}$ oscillations	excludes low tanβ
	• $B \to \tau\nu$	excludes high tanβ, low $M_{H^\pm}$
Depend on neutral sector	• $\Gamma_{Z\to b\bar{b}}$	excludes low tanβ
	• LEP2 non-discovery	light H decouples
	• $\Delta\rho$	spectrum compact
	• $(g\text{-}2)_\mu$	rel. only at very large tanβ



(M₁,M₂)=(100, 300) GeV (M₁,M₂)=(100, 500) GeV

$\mu^2 = (200\ \text{GeV})^2$

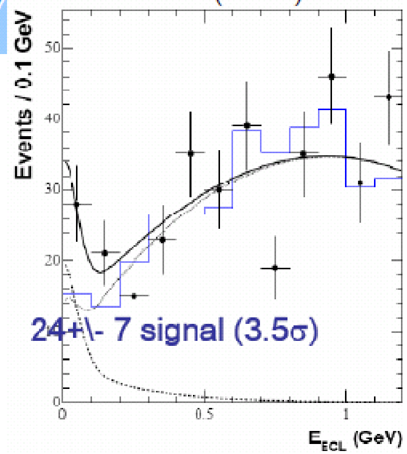
LHC may provide total exclusion (or discovery)

B+ -> tau+ nu

M. Krawczyk

$B+ \to \tau^+\nu$

Belle PRL 97 (2006) 25180



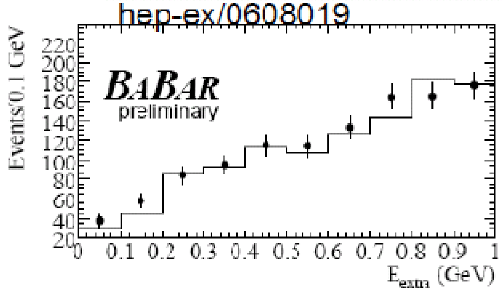
Tag side reco of:
hadronic B decay (Belle, ε = 0.15%)
or $D^0\, l\, X\, \nu$ decay (BaBar, ε = 0.6%)

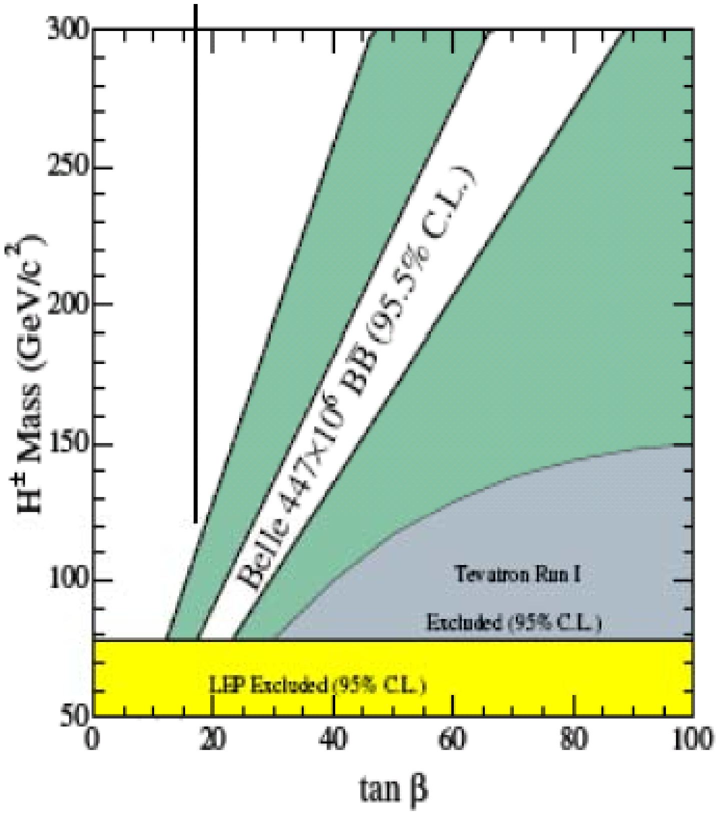
& signal side τ
(Belle: leptonic or 1- or 3-prong, ε = 16%)
(BaBar: leptonic or 1-prong, ε = 13%)
& no other tracks & small extra ECAL energy

HFAG BF($B \to \tau\nu$) = 1.34 ± 0.48 10^{-4}

Consistent with SM.

hep-ex/0608019





SM + Phantom model

T. Underwood

Introduce a minimal lepton number conserving "phantom" sector to the Standard Model

"Phantom" $\rightarrow$ singlet under the Standard Model gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$

Very simple extension leading to:

- Dirac Neutrino Masses
- Dirac Leptogenesis
- Higgs Phenomenology

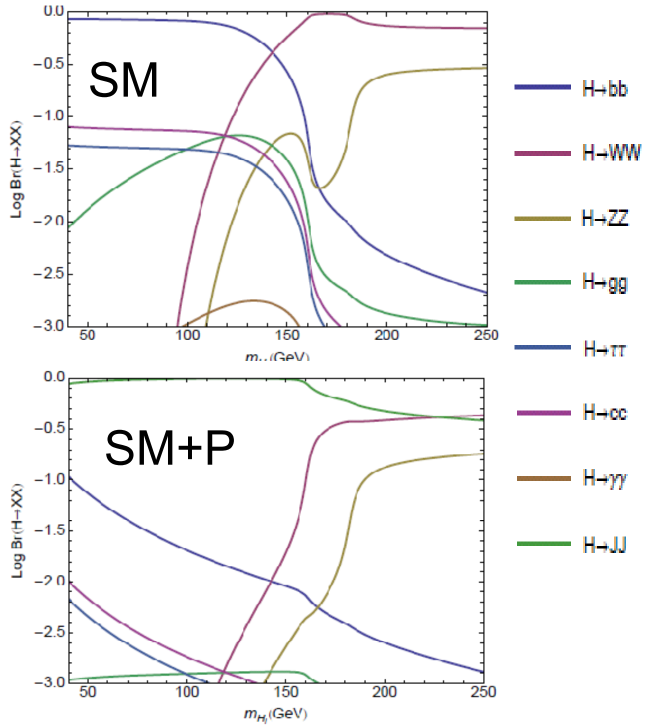
$$V = \mu_H^2 H^* H + \mu_\Phi^2 \Phi^* \Phi + \lambda_H (H^* H)^2 + \lambda_\Phi (\Phi^* \Phi)^2 - \eta H^* H \Phi^* \Phi$$

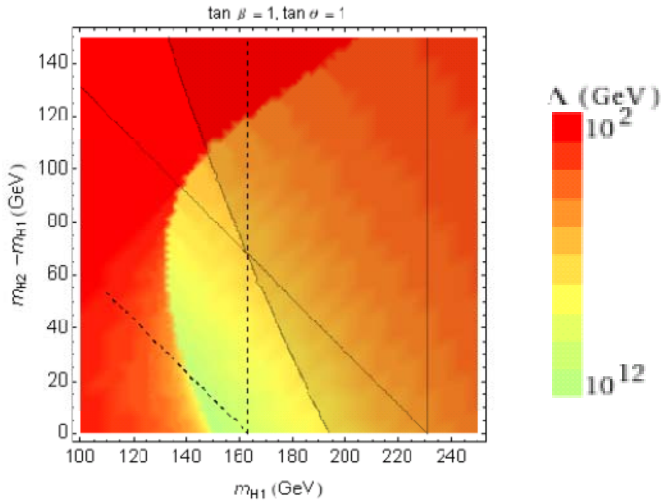
Spontaneous breakdown of Global $U(1)_D$
EWSB

the Goldstone bosons: G (eaten as usual) and J
h and ϕ mix (due to the η term) and become two massive Higgs bosons H_1 and H_2

Higgs invisible decay

Model constraint from LEP data, Positivity, Triviality





Out Look

- To explore nature of EWSB and new physics is the top priority in high energy physics
  - LHC will open Tera scale
  - ILC then solve Post-Higgs Problem (Reconstruct New physics Lagrangian)
- Highly precise calculation and full detector simulation in various observables
  - QCD,EW — Many developments recently
  - Coupling measurement — Higgs self-coupling, Top-Yukawa
- More new physics scenarios beyond SM

  Little Higgs, 2HDM, dim-6, extra D, phantom,

  gauge-Higgs, Higgsless, …
- In either way, let us be prepared whatever the outcome from LHC will be.