Physics Summary at KILC 12

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University of TOYAMA

KILC12, Daegu, Korea, April 26, 2012

Thanks to all 22 speakers

14 Higgs (EWSB) or Higgs related:

H. Ono, J. Tian, C. Calancha, H. Tabassam,
T. Suehara, K. Tsumura, T. Shindou, M. Peskin,
M. Patra, E. Senaha, Y. Kikuta, K. Yagyu,
T. Nabeshima, O. Stal

6 Others:

R. Katayama, M. Berggren,
B. Vormwald, R. Poeschl & V. Marcel,
R Godbole, S. Choi

Tevatron: P. Grannis

CLIC: F. Simon

11 Experimentalists

11 Theorists

Current Status

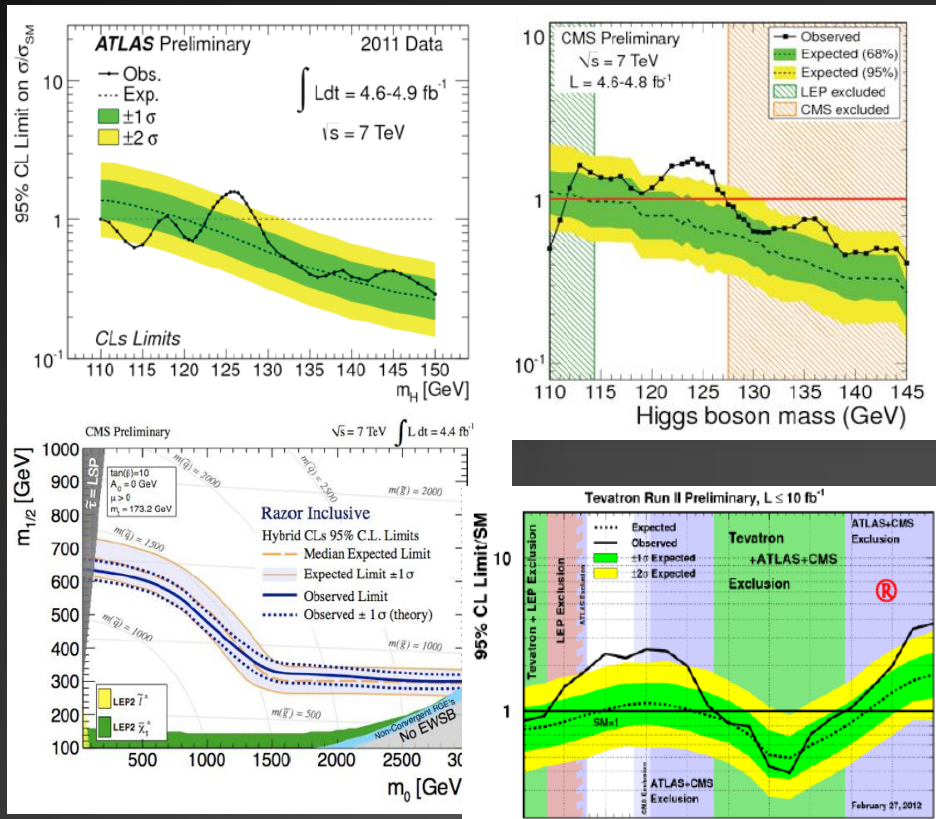
Higgs mass is strongly constrained to be around 115-127 GeV

(Higgs around 125 GeV ?)

No new (colored) particles found below about 1 TeV

Data consistent with SM

Victory of our Standard Model?



[T.J. Kim]

[Grannis]

Why still new physics?

We all know the SM must be replaced by a model of new physics beyond the SM

Reasonable motivations for BSM

- Theoretical
  - Unification, Hierarchy, Flavor symmetry, …
- Empirical
  - Neutrino Mass & Mixing, Dark Matter, Baryon Asymmetry of the Universe, …

All of them cannot be explained in the SM

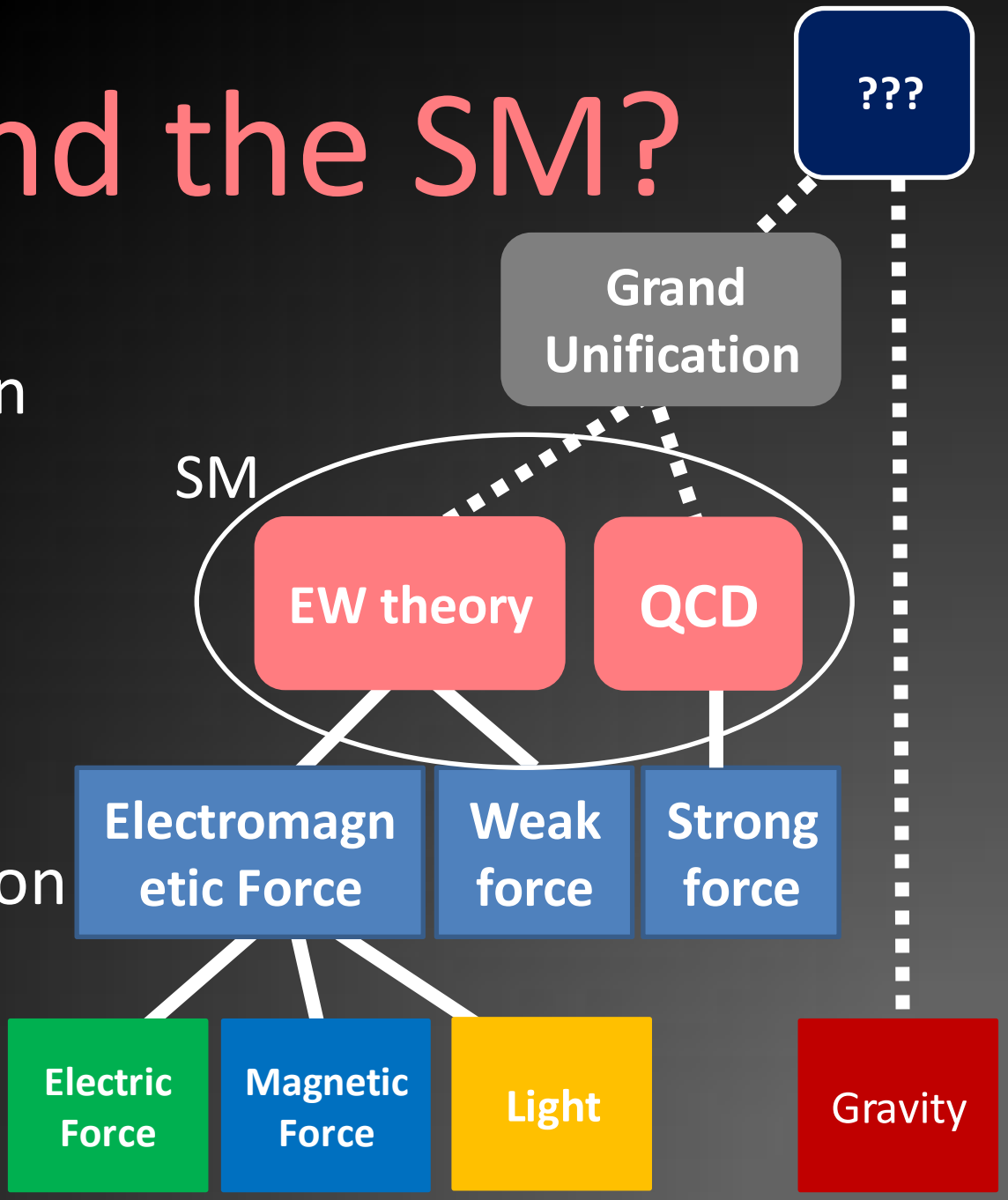
Beyond the SM?

History tells us unification of low in the nature

Unification is GOAL

We are still on the way to the unification

It must be…



Beyond the SM?

Established
Phenomena
Beyond the SM

Baryon Asymmetry

DM

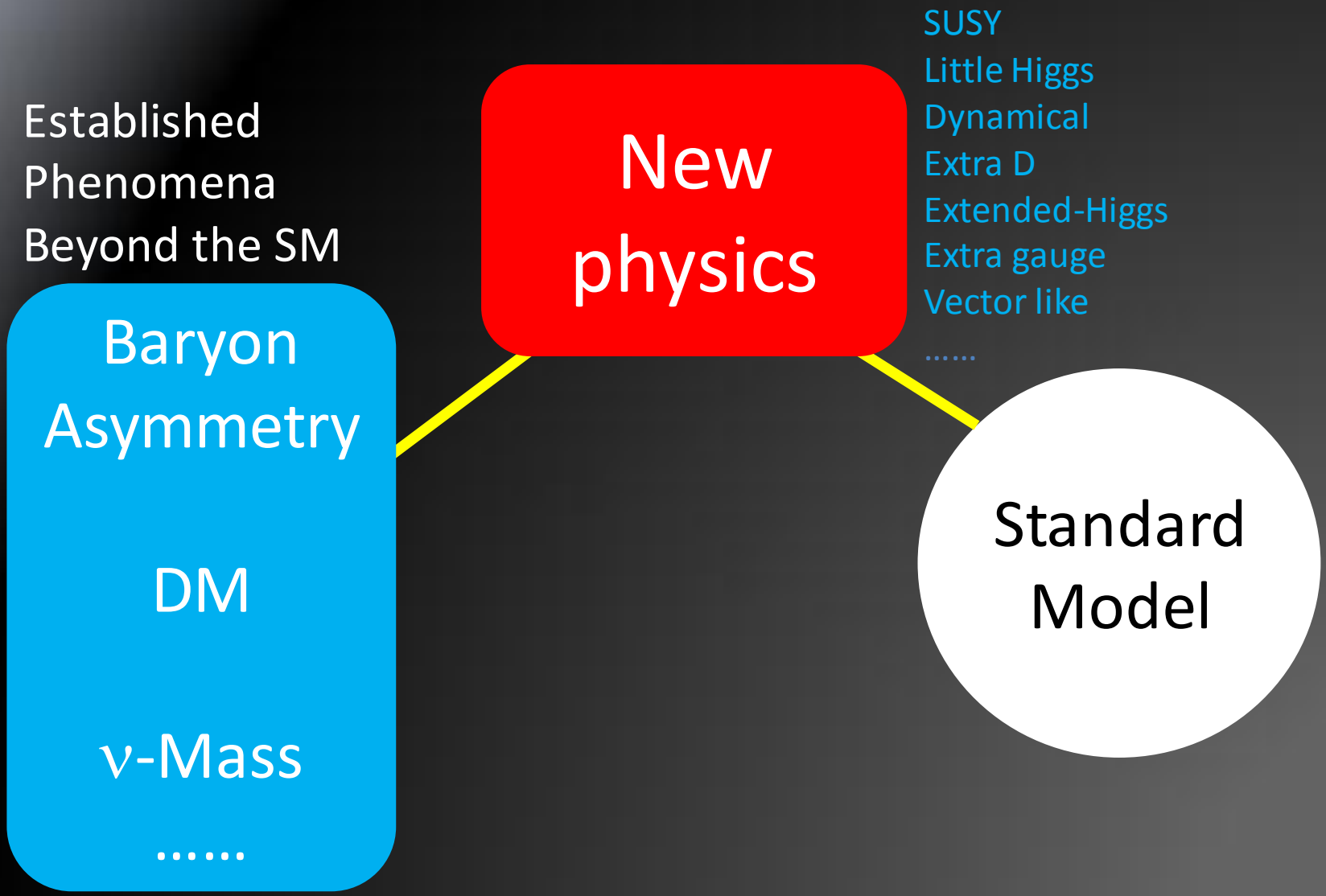
ν-Mass

.....

Not connected

Standard Model

Beyond the SM?



SM must be replaced

Where is it ?

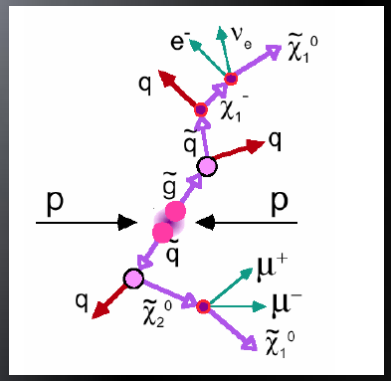
TeV scale? ---------- Planck Scale?

Terascale?

- Hierarchy Problem
  (Be just above the EWSB scale!)
  - Λ = 1 TeV mild fine tuning
  - 10 TeV more fine tuning
  - 10^{16} GeV huge fine tuning
- Dark Matter
  - WIMP hypothesis: m_{DM} = 1GeV - 1 TeV

NP candidate
SUSY
Little Higgs
Dynamical
Extra D
……

LHC tells us about SUSY

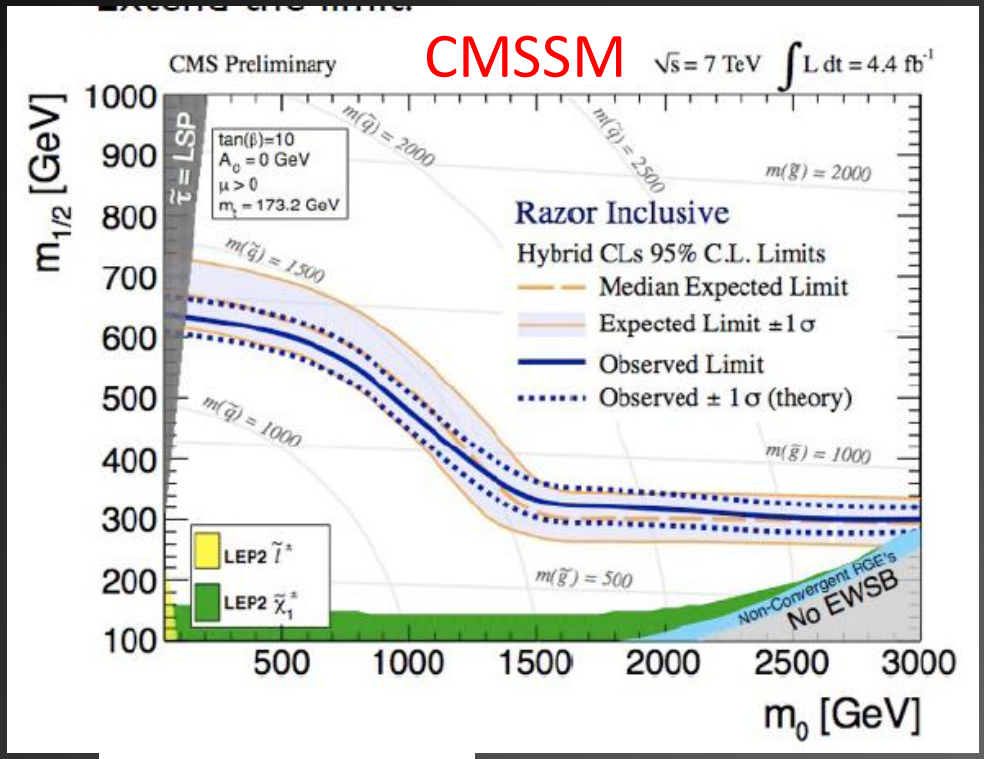


Produce via QCD process:

gluinos, squarks

Signal:

JETs+MET(+leptons)



CMS-SUS-12-005

[Tae Jeong Kim]

No signal found up to now

Excluded up to ~ 1.35 TeV for m(squark)= m(gluino)

CMSSM (MSUGRA) is in trouble

It is time to give up on the cMSSM. But what should replace it ?

Here are two options:

1. Find a type of SUSY model in which the mass scale is least constrained by the condition of naturalness.

2. Accept that the theory of electroweak symmetry breaking might involve strong interactions.

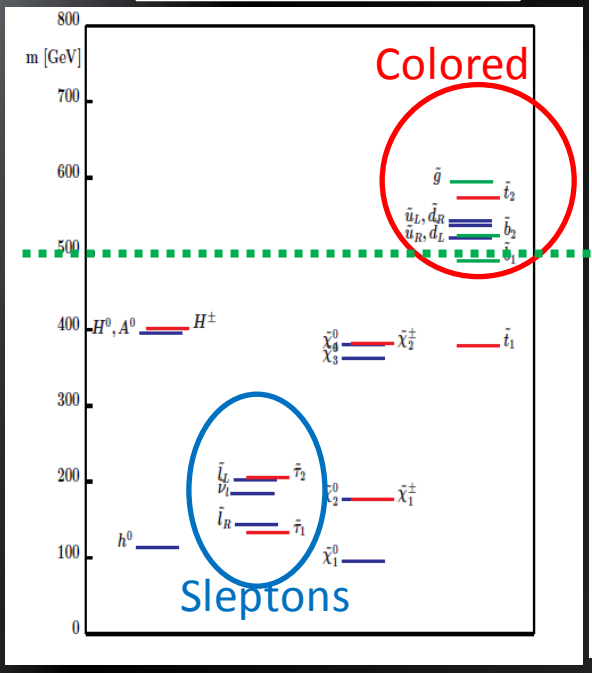
Where do these ideas lead ?

Michael Peskin, Summary Talk at LP11, Aug 2011

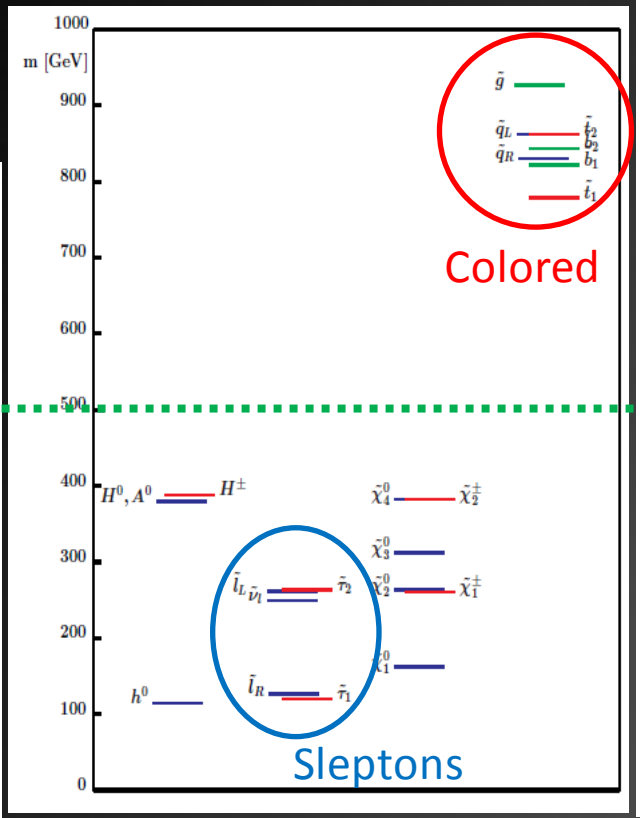
Colored sparticles are constrained from below by LHC

We need mass splitting between the colored sector and the uncolored sector

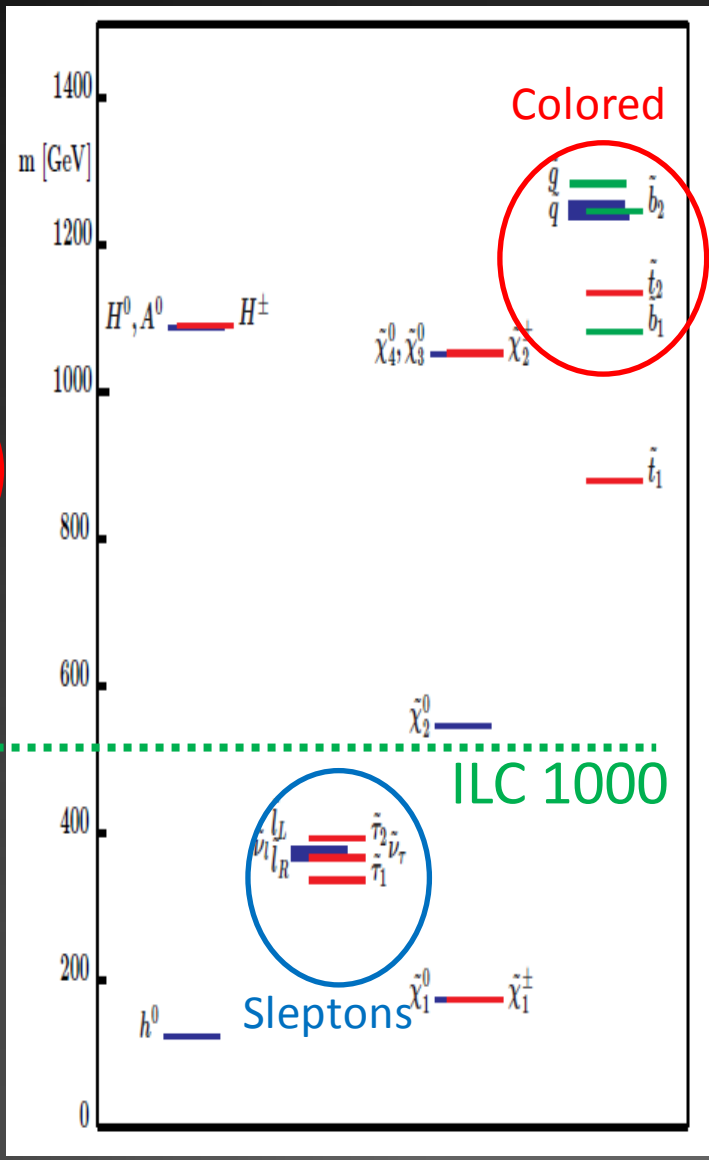
Typical CMSSM scenario



Typical GMSB scenario



Typical AMSB scenario



S. Heinemeyer

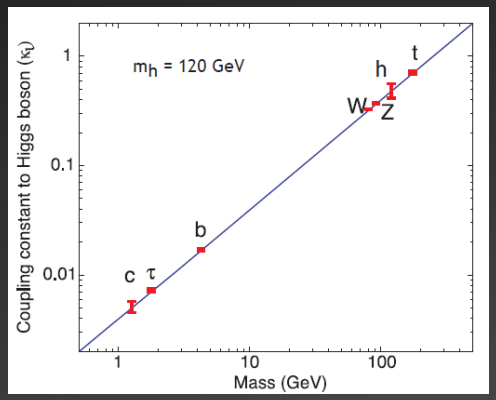
New Physics Paradigm

H. Murayama

What is the point?

- It should be O(1) TeV, but …
- Whether the mass of a new particle is 300 GeV, 500 GeV, 1 TeV, or even 3 TeV strongly depends on the model
- This would be a serious situation from the experimental view point, especially in designing future colliders
- Surely we need luck

Solid target is the Higgs sector



- "Higgs" is really the origin of mass?
- Incomplete part in the SM
  - Gauge interaction is beautiful, but
  - The SM Higgs has no principle (ugly!)
  - Just a guess [Peskin]
  - Various possibility for (extended) Higgs sectors

- Current data strongly suggest that the Higgs boson is a light (SM-like) Higgs boson
  - Notice that SM-like ≠ SM !

SM Higgs

SM Higgs

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

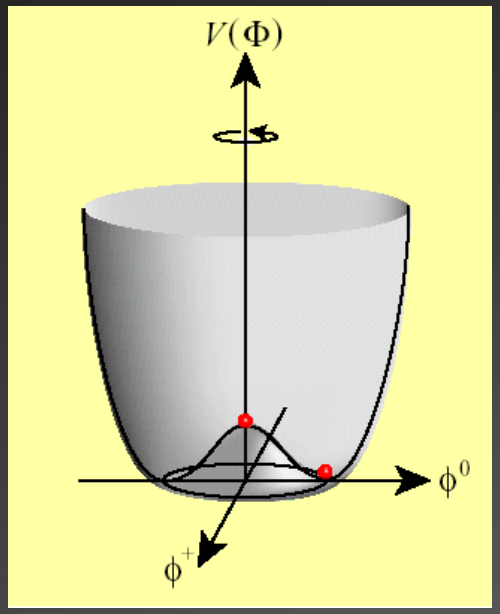
m_h: free parameter

$$m_h^2 = 2 \lambda v^2$$

Hint for the Higgs dynamics

Light Higss ⇔ Weakly interacting

Heavy Higgs ⇔ Strongly coupled



Higgs dynamics determines the nature of EWSB

But the SM Higgs sector has no principle !!

Higgs and New Physics

What is the essence of the Higgs field?

Higgs nature	⇔	New Physics scenario
– Elementary Scalar?		**Supersymmetry**
– Composite?		**Dynamical Symetry Breaking**
– Pseudo NG Boson?		**Little Higgs**
– A gauge field in Extra D?		**Gauge-Higgs unification**
– ……		……

Each model has a specific Higgs sector

Higgs sector = Window to new physics

Extended Higgs sector

- If the Higgs sector contains more than one scalar bosons, possibilities would be
  - SM Higgs doublet + Extra singlet
  - SM Higgs doublet + Extra doublet
  - SM Higgs doublet + Extra triplet
  - ….

Nabeshima

Tsumura

Yagyu

Higgs dynamics

There are possibilities

(1) Light (125GeV) Higgs with weakly interacting

T. Shindou

Standard SUSY models,
Gauge-Higgs Unification

If there is the principle for $m_h^2 \neq \lambda v^2$ then

(2) Light (125GeV) Higgs with strongly coupled

Higgs as pseudo scalar
(Little Higgs, Holographic Higgs, …)
SUSY with extra Chiral superfields
Electroweak Baryogenesis

M. Patra, Y. Kikuta、E. Senaha

How we distinguish ?

Precision measurement of *h !!*

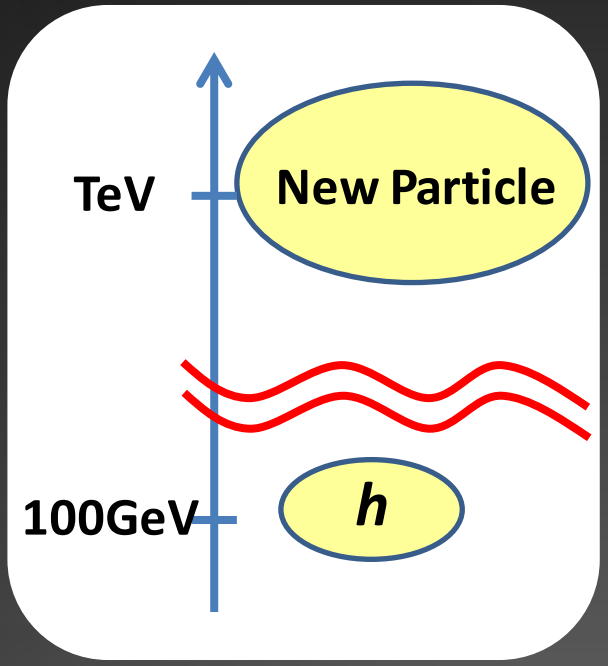
Decoupling/Non-decoupling

Decoupling Theorem

Appelquist-Carazzone 1975

New phys. loop effect in observables

$1/M^n \rightarrow 0$ (decouple for $M \rightarrow \infty$)



Violation of the decoupling theorem

- Chiral fermion loop (ex. Top, 4th gen.)

$m_f = y_f v$

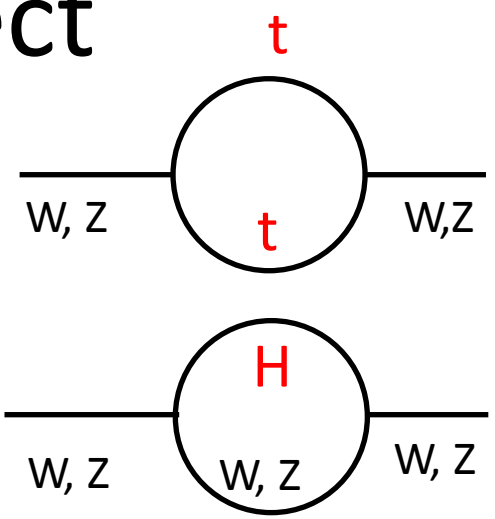
- Boson loop (ex. H^+ in non-SUSY 2HDM)

$m_\phi^2 = \lambda_i v^2 + M^2$ (when $\lambda v^2 > M^2$)

Non-decoupling effect

Non-decoupling effect

Example (Electroweak *T* parameter)



$$\rho = \frac{m_W}{m_Z \cos\theta_W}, \quad \Delta\rho = \rho - 1 = \alpha T$$

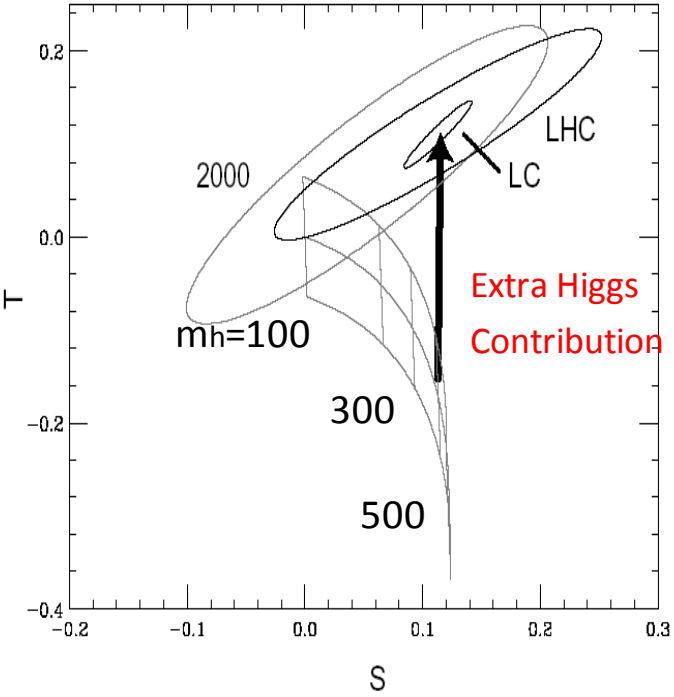
Data $|T| < 0.1$

$$\Delta T_{\text{top}} \propto \frac{m_t^2}{M_W^2}$$

$$\Delta T_{\text{Higgs}} \simeq -\ln\frac{m_H^2}{M_W^2} \quad \text{(SM)}$$

$$\Delta T_{\text{Higgs}} \sim -\ln\frac{m_h^2}{M_W^2} + \frac{(m_A^2 - m_{H^\pm}^2)^2}{M_W^2 m_A^2} \quad \text{(2HDM)}$$

Quadratic mass contribution
(non-decoupling effect)



Higgs potential

To understand the essence of EWSB, we must know the self-coupling in addition to the mass independently

$$V_{\rm Higgs} = \frac{1}{2} m_h^2 h^2 + \frac{1}{3!} \lambda_{hhh} h^3 + \frac{1}{4!} \lambda_{hhhh} h^4 + \cdots$$

Effective potential $$V_{\rm eff}(\varphi) = -\frac{\mu_0^2}{2}\varphi^2 + \frac{\lambda_0}{4}\varphi^4 + \sum_f \frac{(-1)^{2s_f} N_{C_f} N_{S_f}}{64\pi^2} m_f(\varphi)^4 \left[\ln \frac{m_f(\varphi)^2}{Q^2} - \frac{3}{2}\right]$$

Renormalization Conditions $$\left.\frac{\partial V_{\rm eff}}{\partial \varphi}\right|_{\varphi=v} = 0, \quad \left.\frac{\partial^2 V_{\rm eff}}{\partial \varphi^2}\right|_{\varphi=v} = m_h^2, \quad \left.\frac{\partial^3 V_{\rm eff}}{\partial \varphi^3}\right|_{\varphi=v} = \lambda_{hhh}$$

SM Case $$\lambda_{hhh}^{\rm SMloop} \sim \frac{3m_h^2}{v}\left(1 - \frac{N_c m_t^4}{3\pi^2 v^2 m_h^2} + \cdots\right)$$

Non-decoupling effect

Non-decoupling effect

h → gg (loop induced)

h → γγ (loop induced)

Logarithmic non-decoupling effect can give O(10)% corrections (ex. Extra scalars)

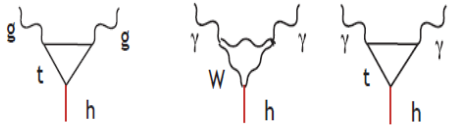
In these vertices (esp. gg), the effect of vector-like particles can also be relatively large (5-10 % level) [Peskin]

These effect probably cannot be seen at the LHC but will be visible at the ILC

Now we discuss more specifically the loop-induced decays

$$h \to gg\ ,\ h \to \gamma\gamma\ ,\ h \to \gamma Z^0$$

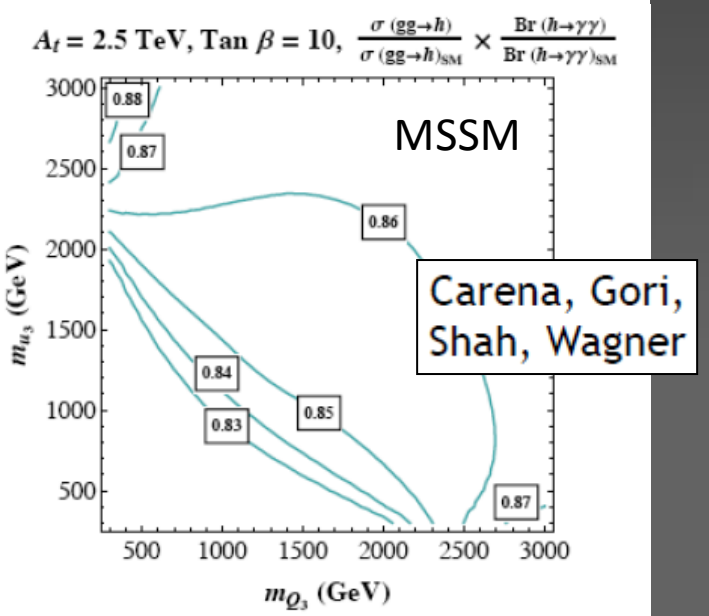
In the Standard Model, these decays go through



$$\Gamma(h \to gg) = \frac{\alpha\alpha_s^2}{576\pi^2 s_w^2}\frac{m_h^3}{m_W^2}\cdot 2$$

$m_h \ll 2m_W$

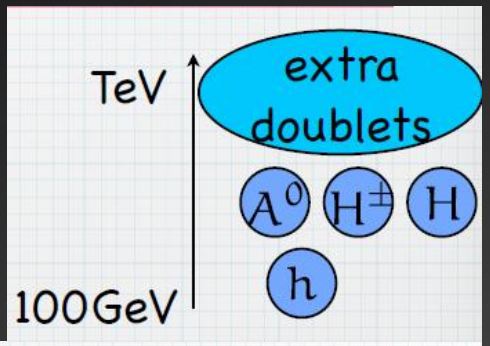
$$\Gamma(h \to \gamma\gamma) = \frac{\alpha\alpha_s^2}{576\pi^2 s_w^2}\frac{m_h^3}{m_W^2}\cdot\left|\frac{21}{4} - 3\left(\frac{2}{3}\right)^2\right|^2$$

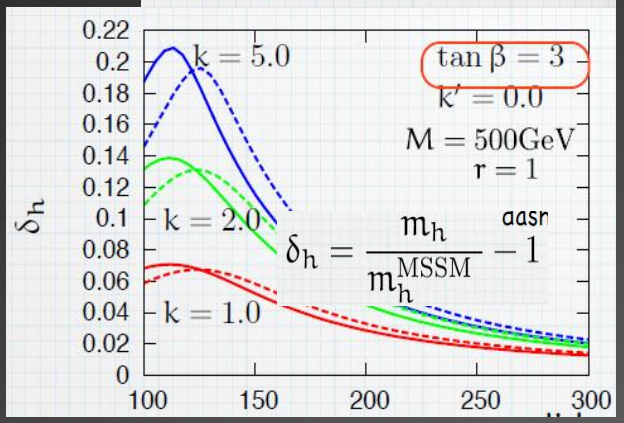


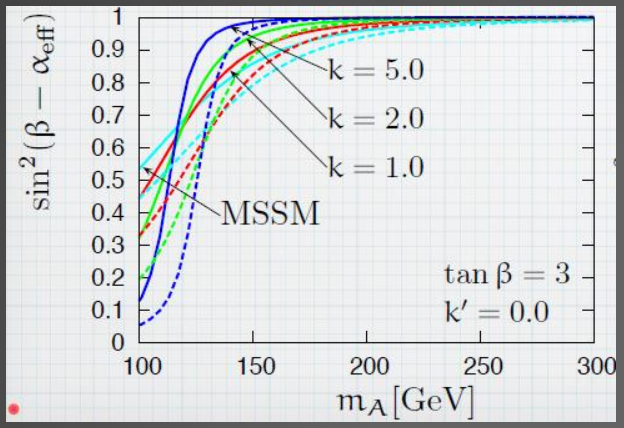
Extended Higgs sector

- SUSY 4HDM (Shindou)
  - Quasi-nondecoupling effect due to the B-term between the first two doublets and the rest two.
  - Deviation from the MSSM predictions can be significant
  - O(10) % deviation (mh, hVV)

- Higgs Triplet model (Yagyu)
  - Type Ⅱ Seesaw model
  - At tree, ρ ≠ 1.
  - Study of radiative correction
  - Prediction on *hγγ (-40%)* and *hhh (>20%)*







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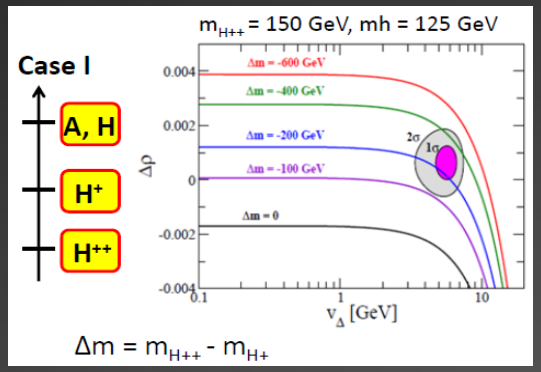
$$(m_\nu)_{ij} = h_{ij}\frac{\mu\langle\phi^0\rangle^2}{M_\Delta^2} = h_{ij}v_\Delta$$



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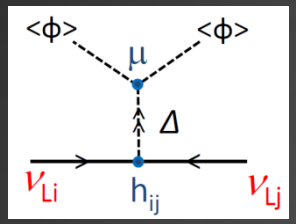
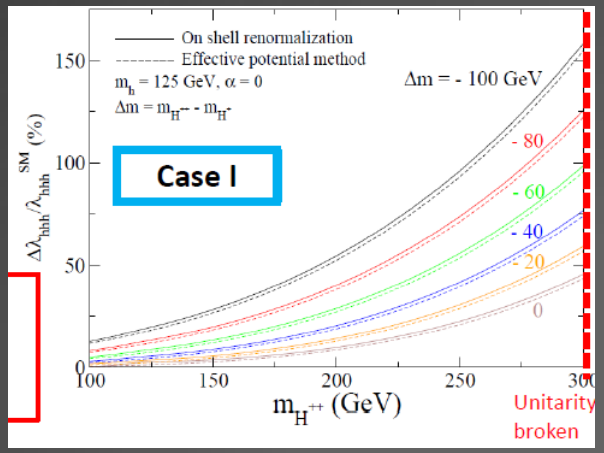
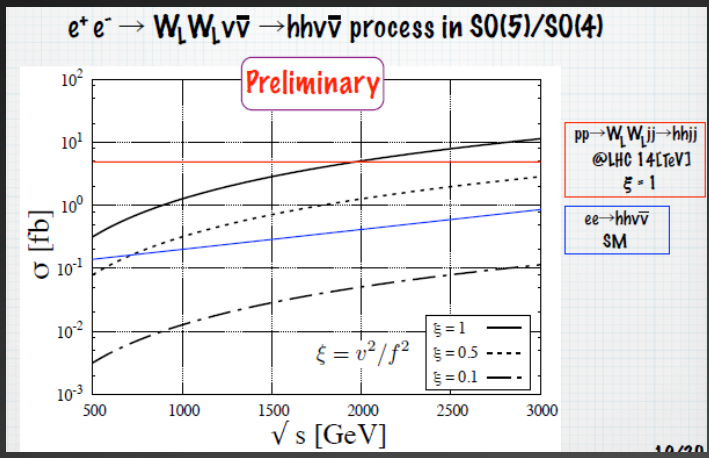




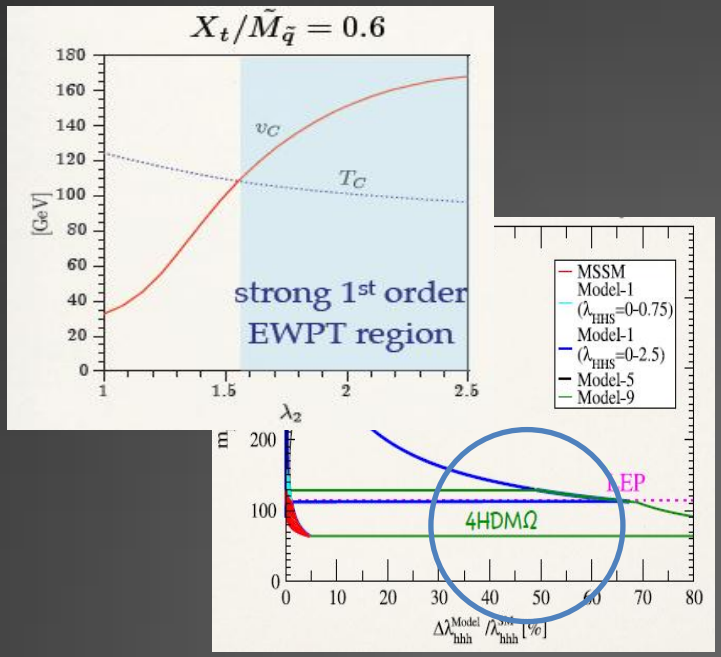
Extended Higgs sector

- Strongly interacting light Higgs (pseudo NG) with N-doublets [Kikuta]

  $W_LW_L \rightarrow W_LW_L, Z_LZ_L, hh, HH, AA, \ldots$
  Collider physics underway



- New SUSY extended Higgs model for Electroweak Baryogenesis [Senaha] (4HDM+Ω(charged singlets))
  - A 125 GeV Higgs with the strong coupling of the new F-term
  - Strongly 1st Order Phase Transition realized by non-decoupling effect
  - Prediction on *hhh* (>40% deviation from the SM prediction)
  - Connection between Higgs physics and Cosmology!



Higgs coupling measurement

For model descrimination, theorist requires

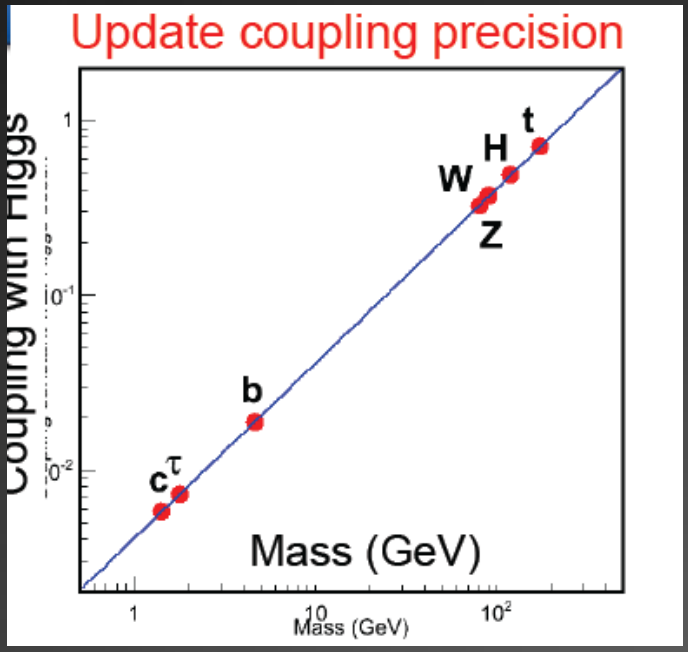
1 % level precision for

hWW, hZZ, hττ, hbb, hgg, hγγ

10 % level for hhh, htt

LHC cannot attain such accuracies…

We do hope that LC can reach



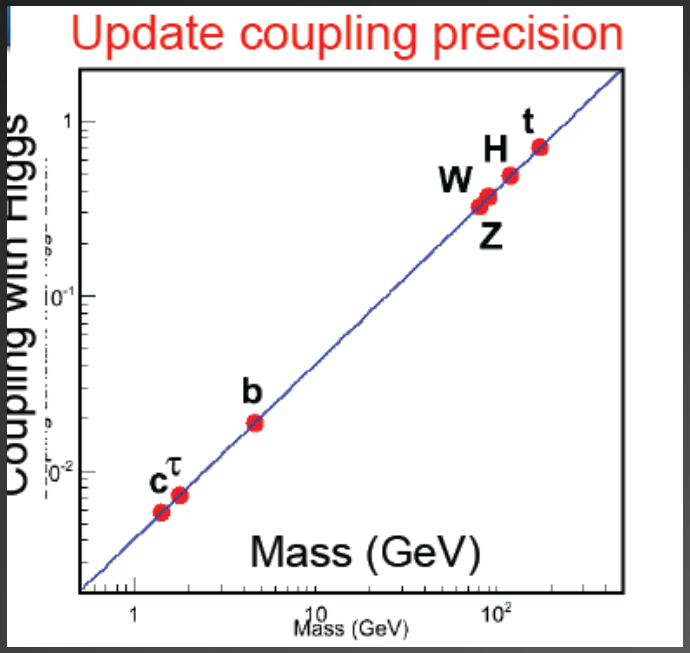
Higgs coupling measurement

Simulation Studies

- Higgs branching ratio [Ono]
  E_{cm}=250 GeV, L=250fb^{-1}
  Higgsstrahlung (ZH)
  WW*→4q, lvqq ΔBr/Br~8%

- HWW coupling (Tian)
  E_{cm}=500GeV, L=500 fb^{-1}, W-fusion
  Δg/g~1.4%, ΔΓ/Γ~5%
  W polarization can also be measured

- Hγγ coupling [Calancha]
  Ecm = 250 GeV, L=250 fb-1
  Challenging, Underway for DBD

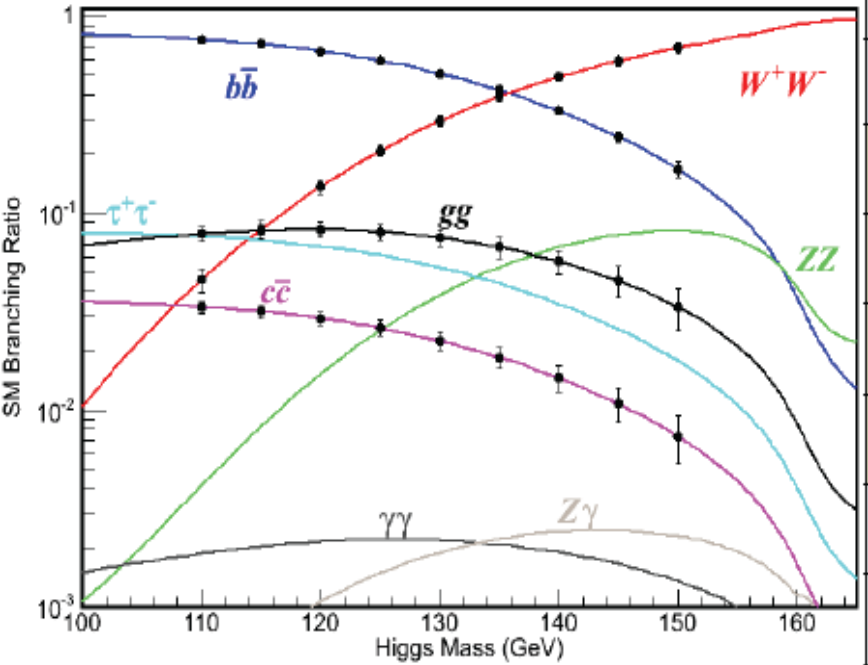


Slide by Ono

Summary table of Higgs BR study

E_{cm}=250 GeV, L=250fb^{-1}, P(e+,e-)=(+0.3, -0.8) or (-0.3, +0.8)

Higgs BR v.s. M_H



Scale from 120 GeV results

Mh	120 GeV			125 GeV		
σ (fb)	354.1 fb			279.9 fb		
H decay	BR	σxBR	ΔBR/BR	BR	σxBR	ΔBR/BR
H→bb	64.1%	227.1	2.7%	59.5%	188.6	3.0%
H→cc	3.1%	10.8	8.1%	2.6%	8.3	9.1%
H→gg	7.0%	24.9	9.0%	8.0%	25.5	9.6%
H→WW*	15.0%	35.3	8.4%	20.8%	43.2	7.2%
H→ττ	8.7%	30.9	TBD	6.1%	19.4	
H→ZZ*	1.7%	6.1	Ono	2.6%	8.1	
H→γγ	0.27%	0.95	Tino	0.2%	0.7	
H→Zγ	0.13%	0.45	Tino	0.2%	0.5	

Assuming σ_{ZH} uncertainty: $\Delta\sigma/\sigma$=2.5%

Whizard+pythia and HDECAY

Higgs coupling measurement

Simulation Studies

- Higgs self-coupling (hhh) [Suehara]

  E_{cm} =500GeV, L=500fb^{-1}

  HHZ coupling sensitivity 57% (2011)

  Under Improvement by developing

  jet clastering, vertex finder,… toward DBD

- Top Yukawa coupling [Tabassam]

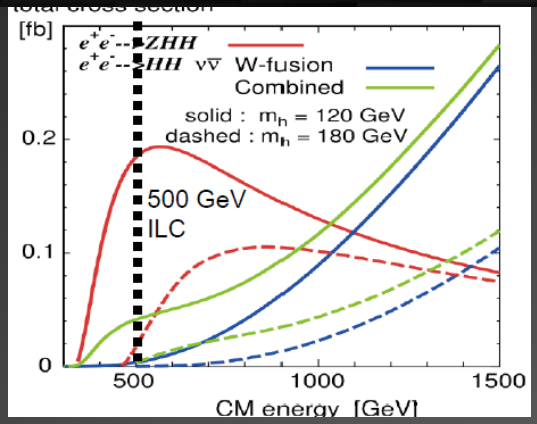
  E_{cm} =500GeV (1 TeV), L=1 ab^{-1}

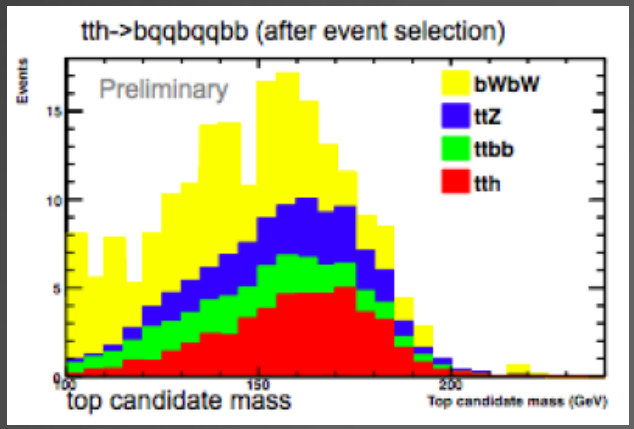
$$e^+ e^- \rightarrow \bar{t}\, tH \rightarrow \bar{b}W^- bW^+ \bar{b}\, b$$

Signal yield: 29
Background: 33(ttbar), 24(ttZ), 24(ttbb)
Significance ~2.9 (stat.)

Full simulation undeway toward DBD

Tiny cross section of 0.2fb
(and only half contribute to
self coupling diagram)
Background (top-pair, ZZH etc.)
must be very strongly suppressed





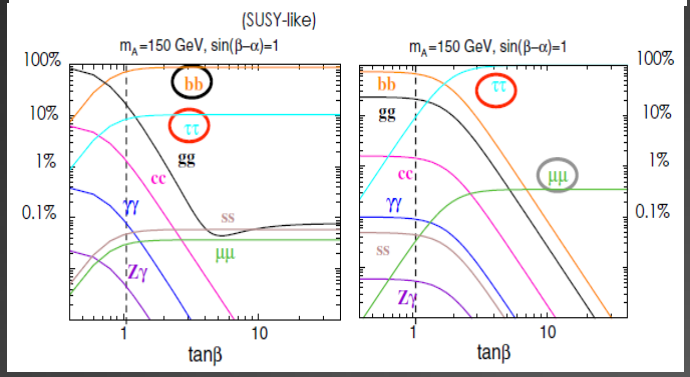
Direct searches of additional scalars

Leptophilic (type X) 2HDM [Tsumura]

- For neutrino mass, dark matter, …
- Discussed difference from MSSM-like (type II) 2HDM

$$\mathcal{L} = +\overline{Q} Y_u u_R H_q + \overline{Q} Y_d d_R H_q + \overline{L} Y_\ell \ell_R H_\ell + \text{H.c.}$$

	Φ_1	Φ_2	u_R	d_R	ℓ_R	Q, L
Type-I	+	-	-	-	-	+
Type-II	+	-	-	+	+	+
Type-X	+	-	-	-	+	+
Type-Y	+	-	-	+	-	+



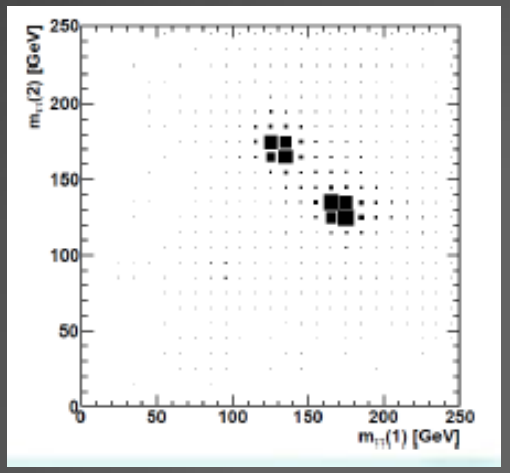
HA production at LHC vs ILC

HA → 4 tau signal

Simulation study

- At LHC endpoint analysis
- At ILC invariant mass analysis with colinear approx.

Direct probe of the pair production

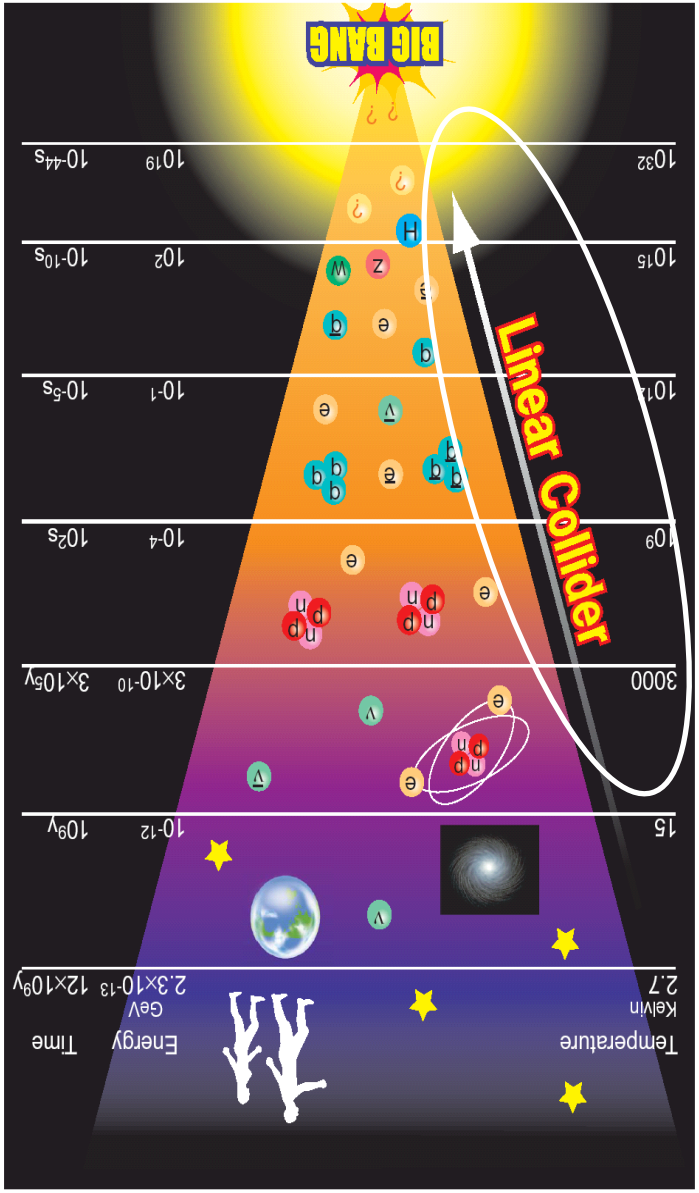


Outlook

- A light Higgs boson seems suggested from current data
- No new particle has been found yet
  (We do not know the scale where new particle appears)
- Where we go?
  - SM Higgs has no principle, but nature seem to suggest "SM-like" Higgs boson (SM-like ≠ SM)
  - various possibilities for extended Higgs
- Higgs sector can be reached at the LHC
- But precision measurement of the Higgs sector will be possible only at LC Higgs factory (0.25-0.5 TeV)
- Energy extension to 1 or muliti-TeV (*hhh, htt*)

Higgs as a probe of new physics

Thank you for all the speakers again!
S. Choi, P. Grannis, F. Simon, H. Ono, J. Tian,
C. Calancha, H. Tabassam, T. Suehara,
K. Tsumura, T. Shindou, M. Peskin, M. Patra,
E. Senaha, Y. Kikuta, K. Yagyu, T. Nabeshima,
O. Stal, R. Katayama, M. Berggren,
B. Vormwald, R. Poeschl & V. Marcel,
R. Godbole

We need LC

Thank you very much