Physics Session Summary

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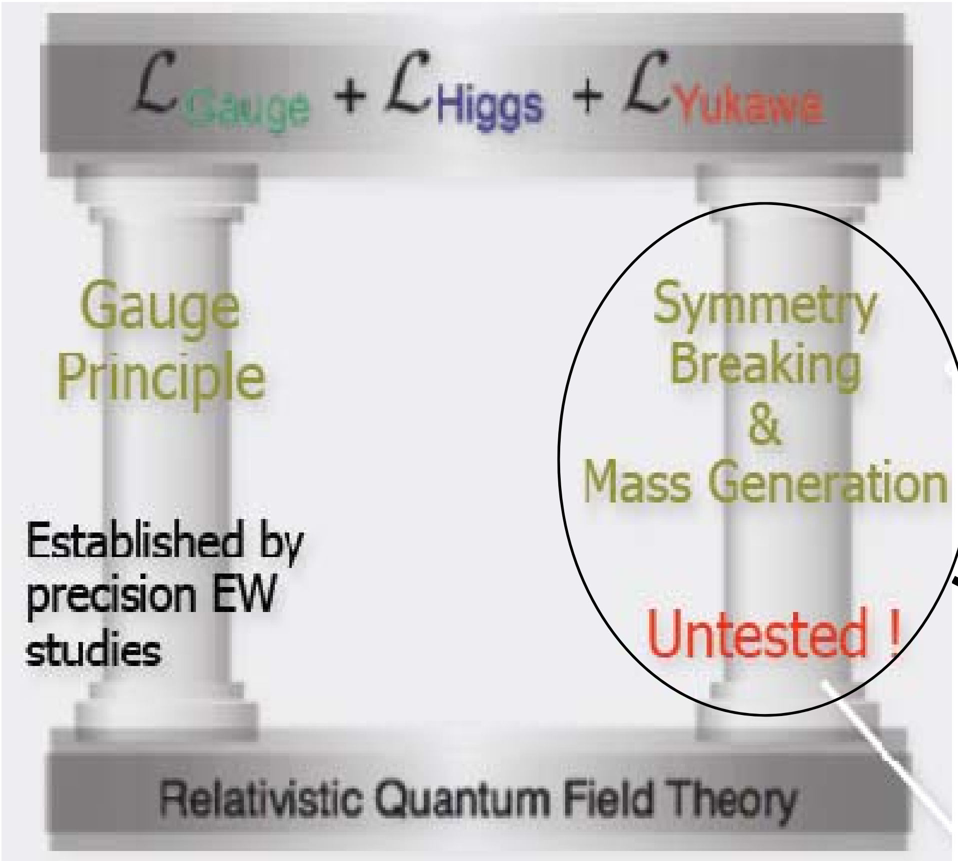
Structure of the Standard Model (SM)



Based on gauge field theory with spontaneous sym. breaking

Two pillars:

1. Gauge principle

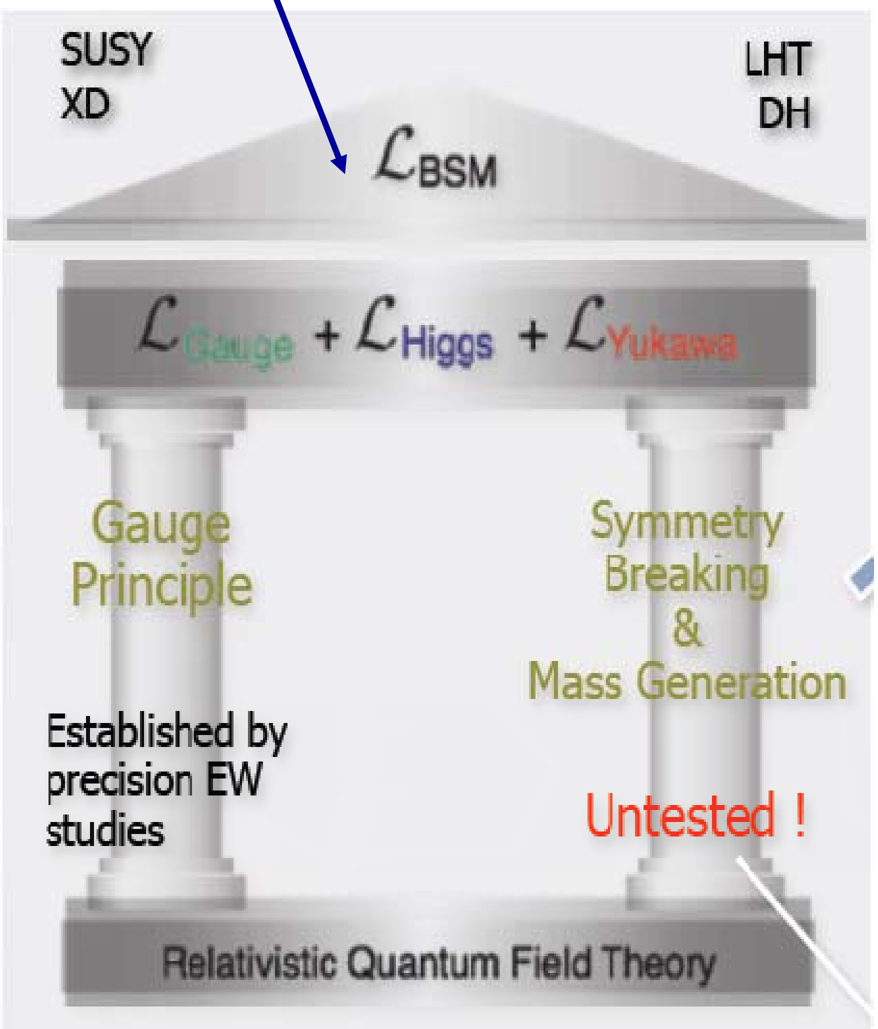
→ **well established by PEWM**

2. Symmetry breaking & mass generation

→ **Higgs sector**

Untested!

Roof: New Physics beyond the SM (BSM)



Problems in the SM

(1) gauge hierarchy problem

→ **need TeV scale BSM**

(2) WIMP dark matter

$$\Omega_{DM}h^2 \simeq 0.1 \quad \leftarrow \textbf{Observation}$$

$$\sim \frac{\alpha}{4\pi}\left(\frac{1}{1\,\mathrm{TeV}}\right)^2$$

again, TeV scale BSM!

TeV scale BSM!

Mission of Future Collider experiments

(1) discover/confirm <u>new fundamental interactions</u>

in the Standard Model (SM)

→ <u>Higgs sector and mass generation mechanism</u>

establish the other pillar

(2) discover of New Physics beyond the SM

and more (precise measurements)

→ <u>BSM at TeV scale</u>

put the BSM roof

LHC comes first → discovery of Higgs, New particles etc.

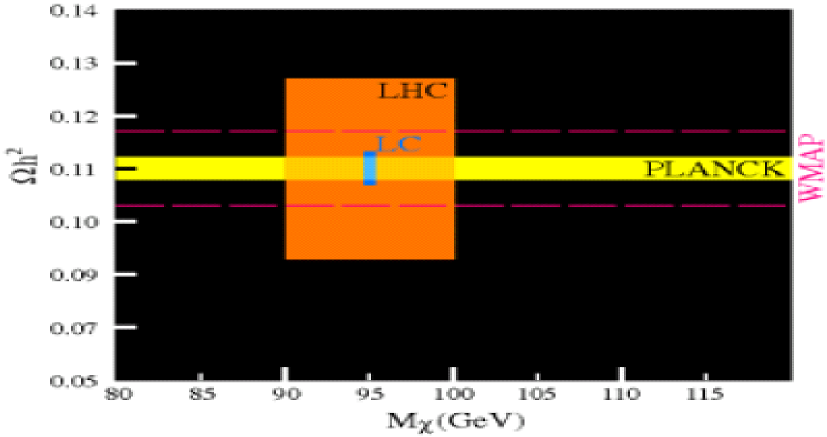
ILC follows → ILC offers more precise measurements

- tunable collider energy
- beam polarizations
- high luminosity

→ necessary to
- establish the other pillar
- distinguish possible BSMs

Ex) calculate DM relic density by using parameters measured

Ex) SUSY model



Physics sessions

Physics and Benchmark (15 talks)

full simulation studies on benchmark modes

with different detector concepts

→ Summarized by Suehara san

Joint session with gamma-gamma (2 talks)

THDM & SM Higgs

Physics session (9 talks)

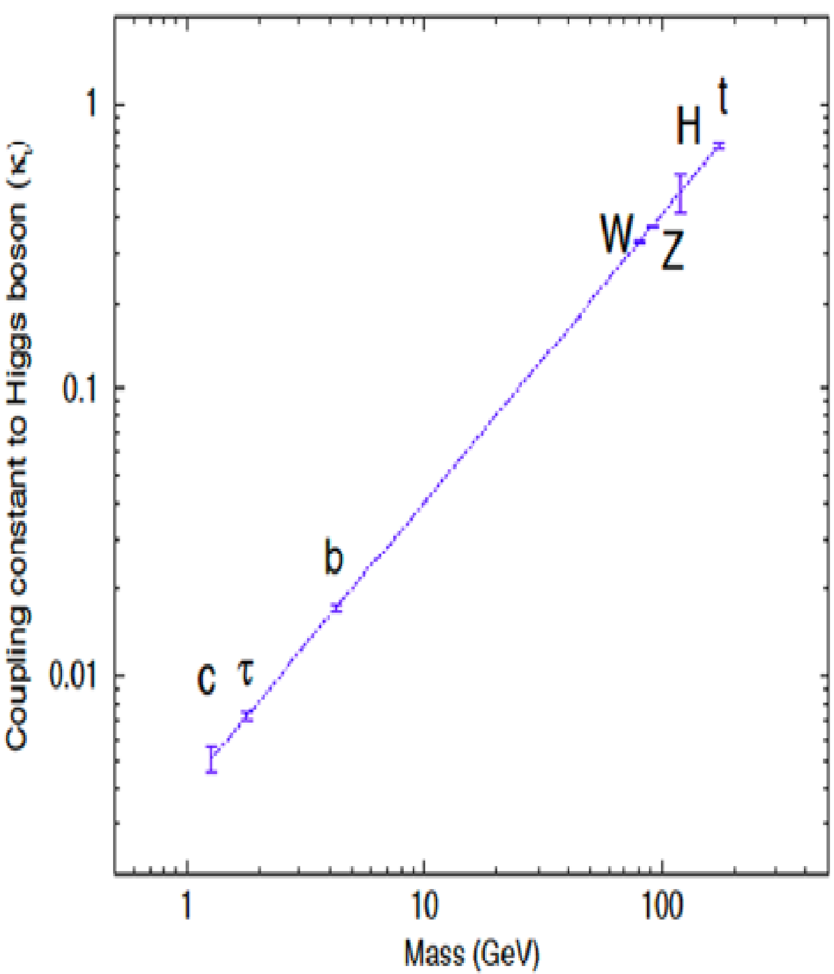
simulation studies for non-benchmark modes

more theoretical talks

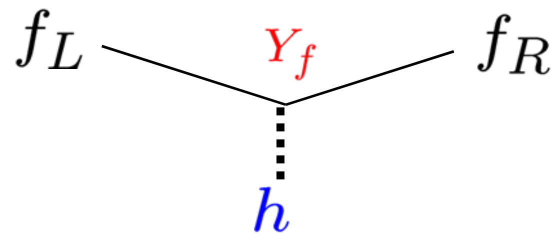
→ This summary

Feasibility of ILC to establish the second pillar

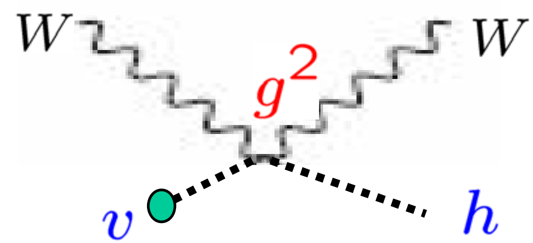
Mass generation mechanism → measure Higgs coupling



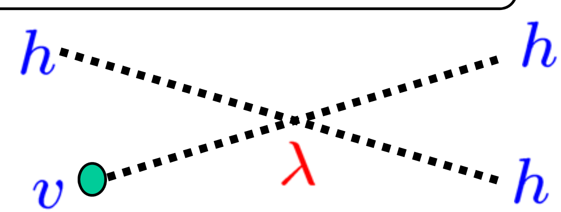
Fermion mass ← Yukawa coupling



Gauge bosons ← gauge coupling

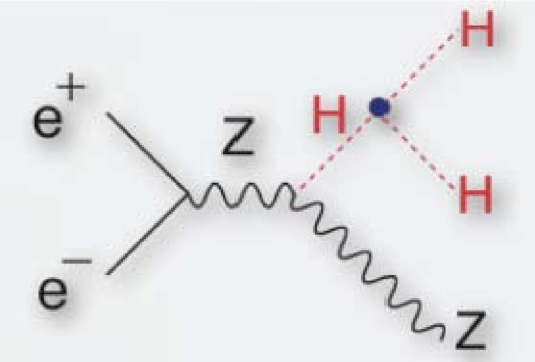


Higgs mass ← self coupling



Studies on Higgs self coupling & top Yukawa coupling measurements at ILC with 500 GeV $m_h = 120$ GeV

``Analysis of 6-jet mode in ZHH'' by Yosuke Takubo



Analysis mode: ZHH→qqHH

- Higgs mass: 120 GeV
  - ✓ Higgs mainly decays into bb with ~70% branching ratio.
- Integrated luminosity: 2 ab^{-1}

	qqHH	tt	tbtb
• No cut	: 270	1167290	2154
• $\chi^2 < 20$	: 219	615456	1810
• $90 < M_{H1,2} < 140$GeV $60 < M_Z < 110$GeV	: 196	529501	1607
• Nlepton=0	: 178	411467	1102
• missing E < 70GeV	: 156	302953	816
• $N(HH)_{b\text{-tag}} = 4$	: 20.1	475	38.7
• $N(Z)_{b\text{-tag}} = 2$	: 4.3	0	0.6

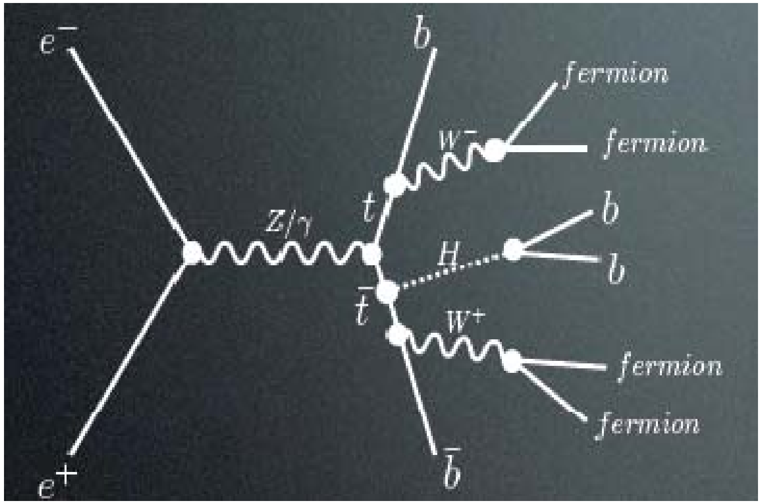
Significance : ~3

Near confident obs.

Next step

→ Full simulation

``Measurement of top-Yukawa coupling at ILC'' by Ryo Yonamine



In the case of $H \to bb$

- 1-lepton - 6-jet ~45% ○
- 8-jet ~44%
- 2-lepton + 4-jet ~11%

Preliminary

1-lepton + 6-jet mode $1000 fb^{-1}$

	TTH	TTZ	TT
No Cut (1L+ 6-Jet)	440 (200)	710	5×10^5
# of isolated lepton = 1	154	232	173386
	Forced 6-Jet clustering		
Ycut > 0.002	135	173	21577
4 b-tag + Mass Cut (W, t, H)	25	6	4

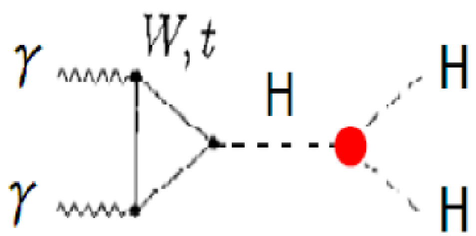
Significance : $\frac{25}{\sqrt{(25+6+4)}} \sim 4$

Nest step:

include ttg background

(which would be the main background)

``Feasibility study of Higgs pair creation in gamma-gamma collider''
by Norizumi Maeda



For measuring Higgs self coupling

Higgs mass =120 GeV

Optimized photon collision E = 270 GeV

$HH \to bb\bar{b}\bar{b}$ **(BR=0.43)**

$\gamma\gamma \to WW$

condition	# of BG	# of Signal
nocut	10,000,000	50,000
# of jets = 4	8.09E+06	4.97E+04
# of loose b-tagged jets = 4	923	1.62E+04
# of tight b-tagged jets ≧ 3	135	1.33E+04
χ2(H) < 18	12	1.03E+04
χ2(W) > 5	2	9.15E+03
maximum charged particle energy ≧ 2GeV	0	6.60E+03

16 events/year → 4.6 sigma (10 years)

Nest step: another modes

$HH \to bBWW^{*}$(B.R.=0.18)

Other studies on the SM

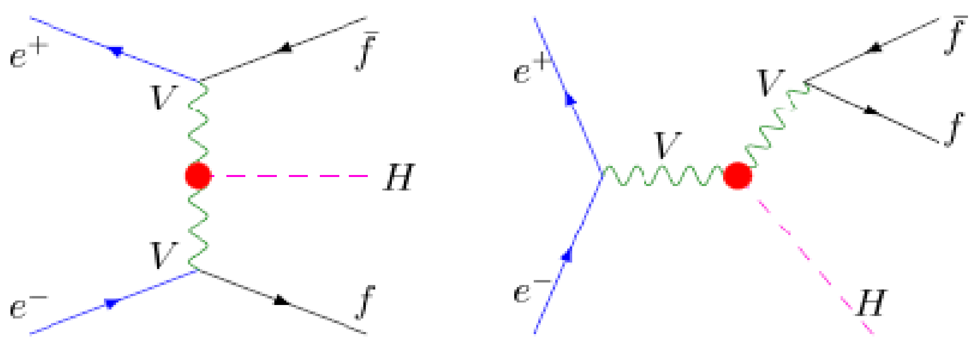
``Role of polarization in probing anomalous VVH interactions at the ILC''
by Sudhansu S. Biswal

Most general couplings:

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

$$g_W^{SM} = e \cos\theta_w M_Z, \quad g_Z^{SM} = 2e m_Z / \sin 2\theta_w$$

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



$M_H = 120$ 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}

Polarization of initial/final states improves the sensitivity

Effect of longitudinal beam polarization: ZZH case

	Using Polarized Beams		Unpolarized States	
Coupling	Limits	Observable used	Limits	Observable used
$\|\Re(\tilde{b}_Z\|$ $<$	0.067	$\mathcal{O}_{UD}(R2;e)$	0.067	$A_{UD}(R2;e)$
$\|\Re(\tilde{b}_Z)\|$ $\leq$	0.17	$\mathcal{O}_{UD}(R1;\mu)$	0.91	$A_{UD}(R1;\mu)$
$\|\Im(\tilde{b}_Z)\|$ $\leq$	0.011	$\mathcal{O}_{FB}(R1;\mu,q)$	0.064	$A_{FB}(R1;\mu,q)$

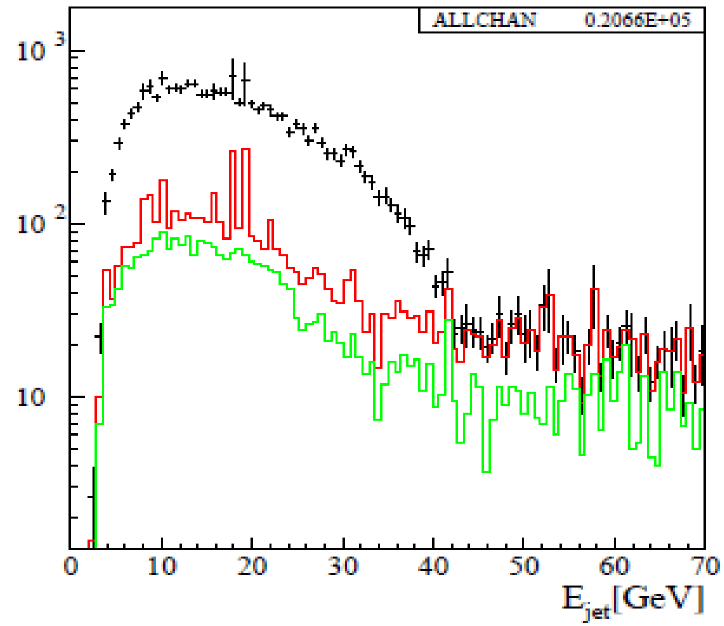
Use of τ Polarization with unpolarized beams

	Using Pol. of final state τ^-			Unpolarized τ's	
Coupling	Limits		Observable	Limits	Observable
	40% eff.	20% eff.			
$\|\Im(b_z)\|$ $\leq$	0.11	0.15	A^L_{comb}	0.35	A_{comb}
$\|\Re(\tilde{b}_z)\|$ $\leq$	0.28	0.40	A^L_{UD}	0.91	A_{UD}

Studies on New Physics

SUSY: Study on stau pair production on SPS1a' by Mikael Berggren

- In SPS1a', the $\tilde{\tau}$ is the NLSP.
  $M_{\tilde{\tau}_1} = 107.9 \text{ GeV}/c^2, M_{\tilde{\chi}_1^0} = 97.7 \text{ GeV}/c^2$
  $\Delta(M) = 10.2 \text{ GeV}/c^2$.
- Extract the signal.
  - Exactly two jets.
  - Charge of each jet $= \pm 1$,
  - $E_{within\ 30^{deg}\ to\ beam} < 4$ GeV
  - $M_{vis} > 20 \text{ GeV}/c^2$,
  - anti-$\gamma\gamma$ cut,
  - $E_{vis} < 120$ GeV,
  - Two jets with charge ± 1,
  - $|\cos\theta_{jet}| < 0.9$ for both jets,
  - $\cos\theta_{acop} < -0.2$,
  - $|\cos\theta_{missing\ p}| < 0.75$,



- All background - SUSY and SM - included.
- $\Delta(M_{\tilde{\tau}_1}) = 80 \text{ MeV}/c^2 \oplus 1.3\Delta(M_{\tilde{\chi}_1^0})$.

Little Higgs model:

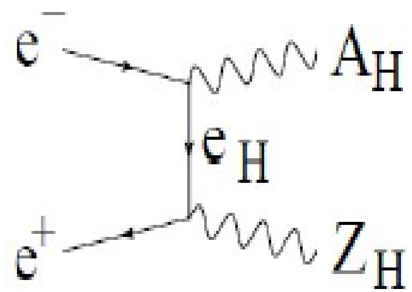
``Study of Little Higgs Model with T-parity'' by Yosuke Takubo

Little Higgs partner (T-odd) of photon → A_H **(Dark matter)**

Z, W bosons → Z_H, W_H

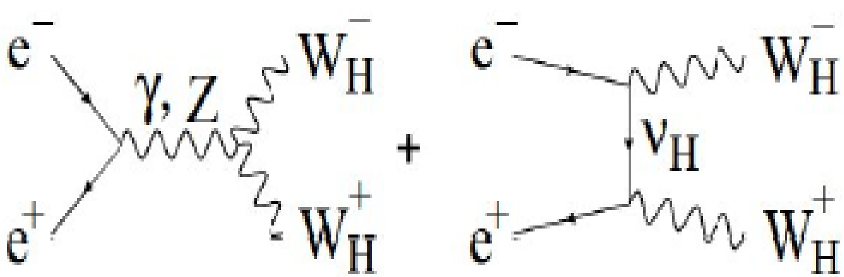
Analysis modes

- $A_H + Z_H$ @ $E_{CM} = 500$ GeV
  - xsec: 1.91 fb
  - $Z_H \rightarrow H + A_H$
  - $M_{AH} + M_{ZH} = 450.9$ GeV



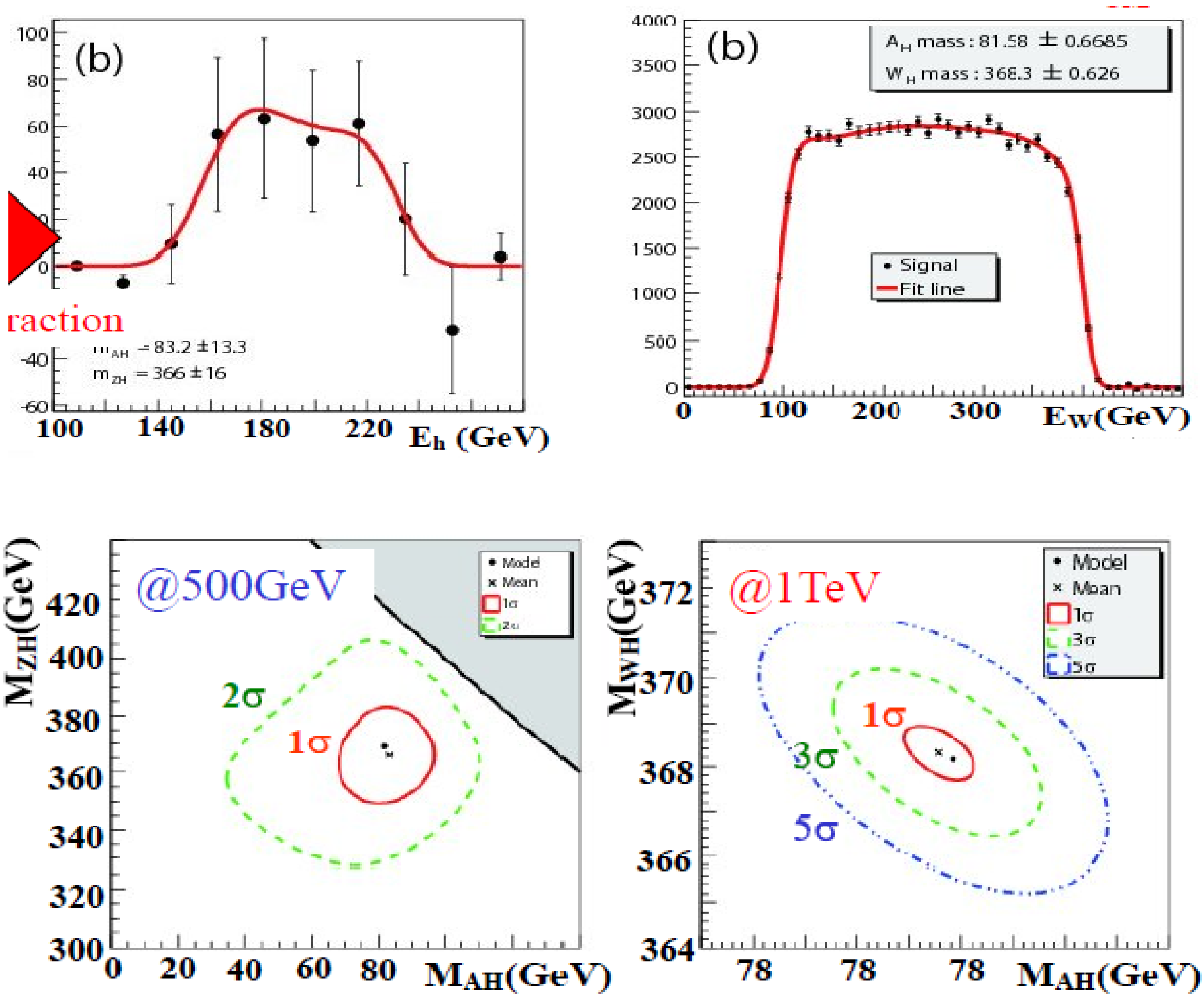
$$Z_H \to H + A_H$$

- $W_H^+ + W_H^-$ @ $E_{CM} = 1$ TeV
  - xsec: 277 fb
  - $W_H \rightarrow W + A_H$
  - $M_{WH} + M_{WH} = 736$ GeV



$$W_H \to W + A_H$$

ILC has excellent sensitivity



``Distinguishing dark matter nature'' by Masaki Asano

WIMP (weakly interacting massive particle) hypothesis

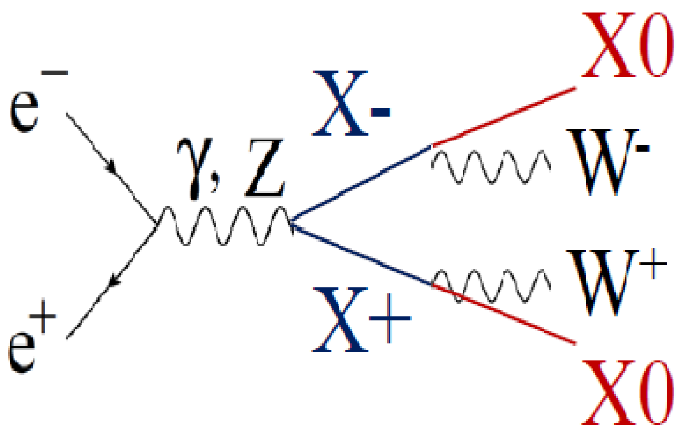
	$SU(2) \times U(1)_Y$		Parity
X	$\mathcal{R}$	Y_X	odd

→ $X_1^0, X_2^0, \cdots$ (DM candidate: X_1^0)

$X^{\pm}, X^{\pm\pm}, \cdots$

WIMP dark matter is normally accompanied by charged particle

Charged particle productions at ILC



Different models

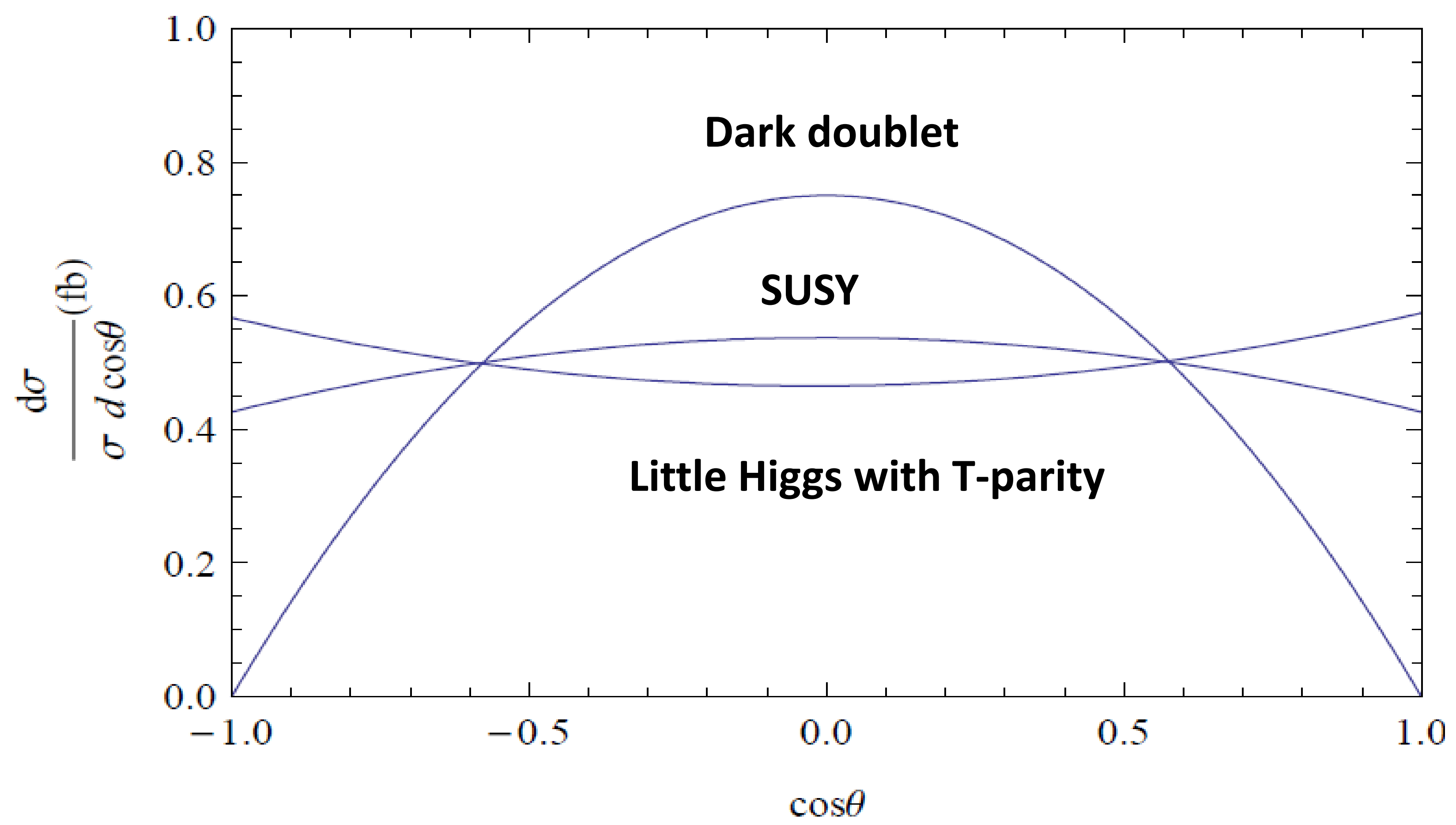
	X_1^0	$X^{\pm}$	Model example
spin	0	0	dark doublet
	1/2	1/2	SUSY
	1	1	Little Higgs w/T-parity

How accurately can the ILC distinguish dark matter properties?

→ simulation studies are being performed

results will come out soon

Angular distribution of charged particles

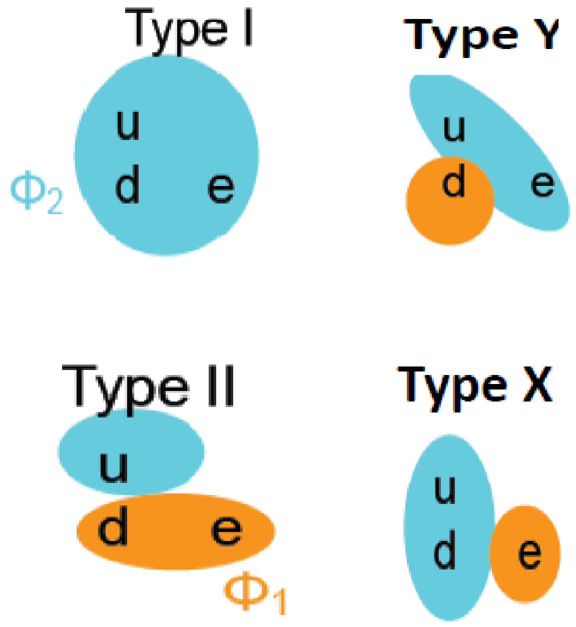


Studies on Two Higgs Doublet Models

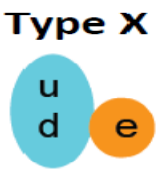
- Simplest extended Higgs model
- SM : Φ_1 THDM : Φ_1, Φ_2
- Physical states : H_{SM} $h, H, A, H^{\pm}$

4 typical THDMs by discrete symmetry

	Φ_1	Φ_2	Q^i	L^i	u_R^i	d_R^i	e_R^i
Type-I	+	−	+	+	−	−	−
Type-II	+	−	+	+	−	+	+
Type-X	+	−	+	+	−	−	+
Type-Y	+	−	+	+	−	+	−



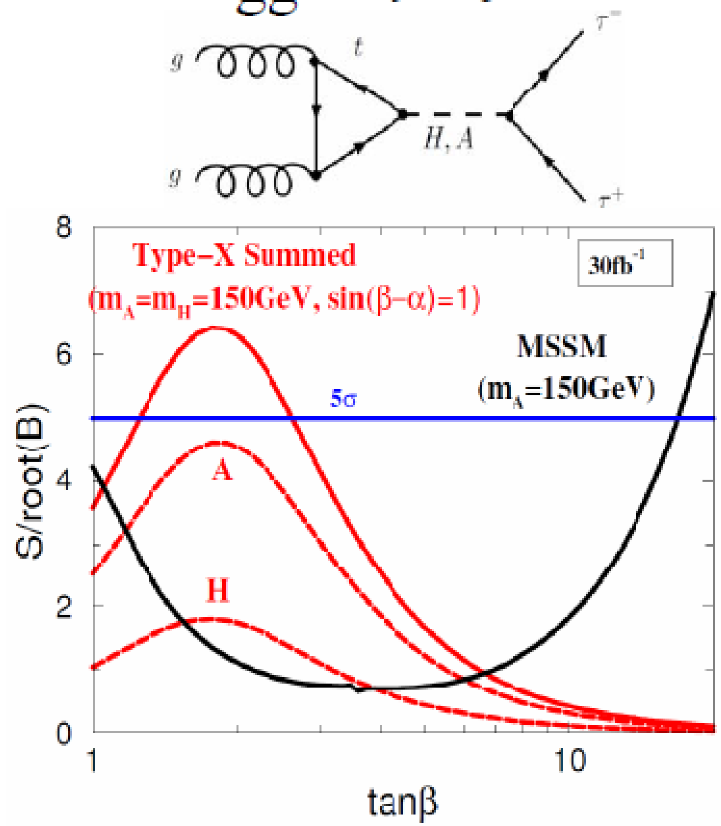
Collider phenomenology on type-X THDM by Kei Yagyu



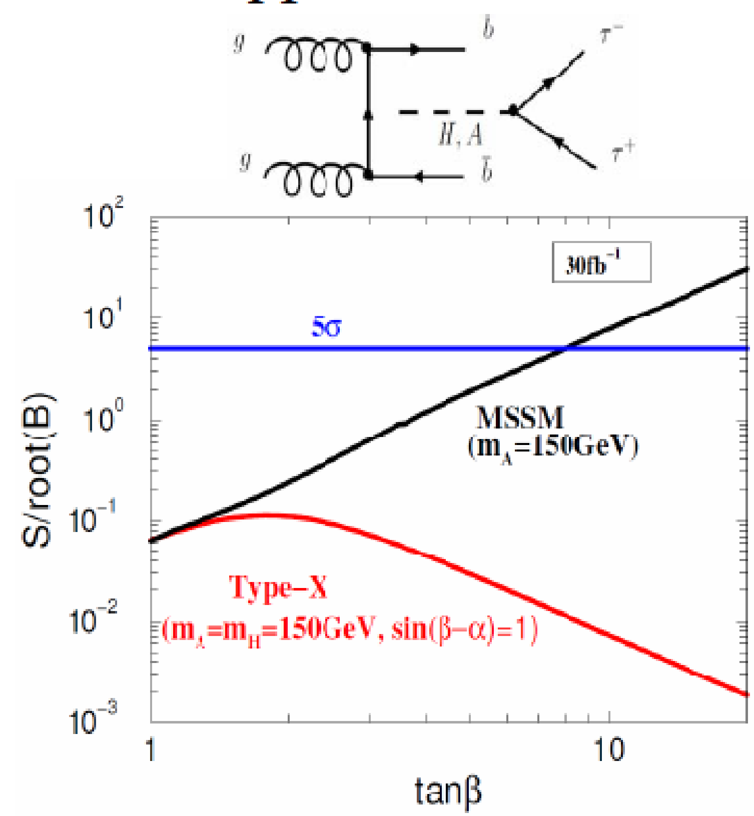
→ One Higgs doublet has Yukawa coupling with only leptons

A/H production at LHC

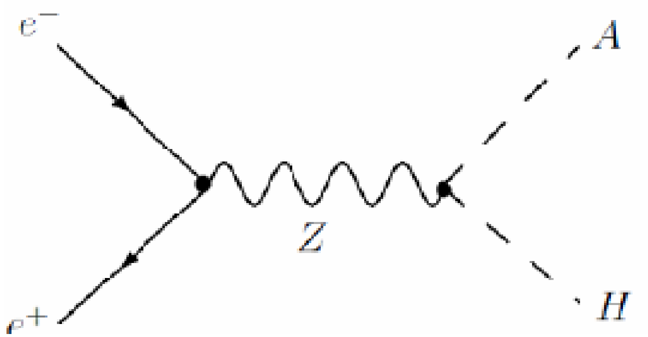
$gg \to \tau^+ \tau^-$



$pp \to bb\, \tau^+ \tau^-$



AH pair production at ILC



$m_A = m_H = 150$GeV, $\sin(\beta - \alpha) = 1$, $\tan\beta = 10$
and root(s)=500GeV

Signal background analysis for $\tau\ \tau\ \ \tau\ \tau$ events

$\sigma_{\tau\tau\tau\tau}$ [fb]	AH	ZZ	$Z\gamma$	$\gamma\gamma$
No cut	27.0	0.482	0.804	0.371
$\lvert\cos\theta\rvert < 0.99$	26.5	0.449	0.645	0.269
$\lvert\cos\theta\rvert < 0.9$	25.0	0.324	0.423	0.171
$M_{\tau\tau} \lessgtr m_\Phi \pm 15$ GeV	14.7	0.021	0.039	0.021

For L=500fb^{-1}
After cuts

S~7350
B~41

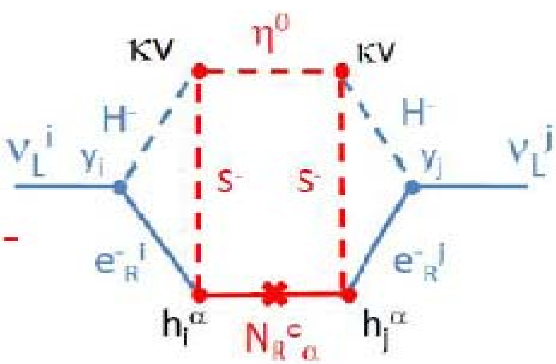
Type-X THDM + singlets by Shinya Kanemura

Type-X + right-handed neutrinos

+ singlet scalars (η^0, S^+)

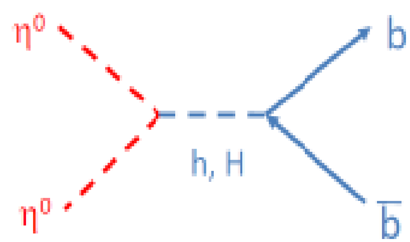
Model accounting for neutrino mass, dark matter and electroweak baryogenesis

Radiative neutirno mass



Correct DM relic density

for $m_\eta = 40 - 65$ GeV

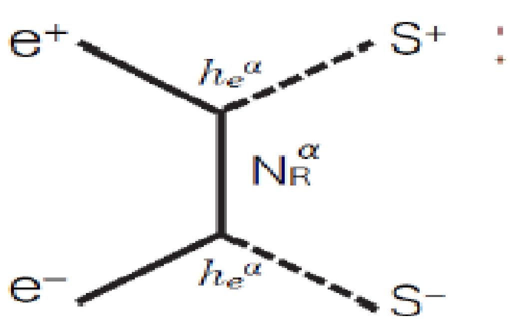


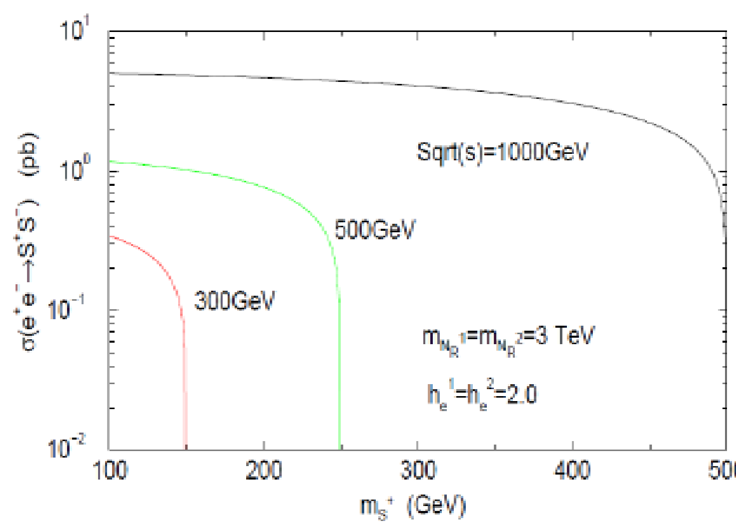
EW baryogenesis

Strongly 1st order phase transition is achieved

$m_s \sim 400$GeV

ILC phys.



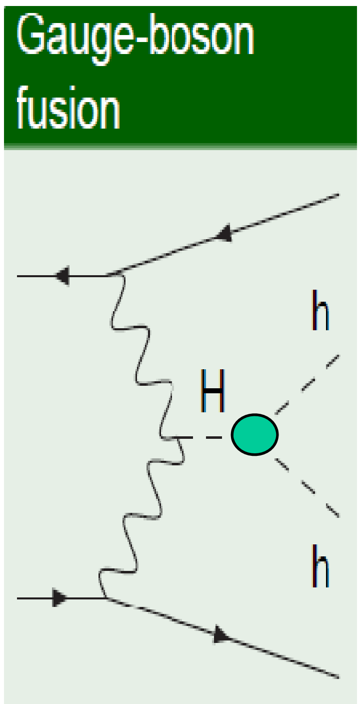


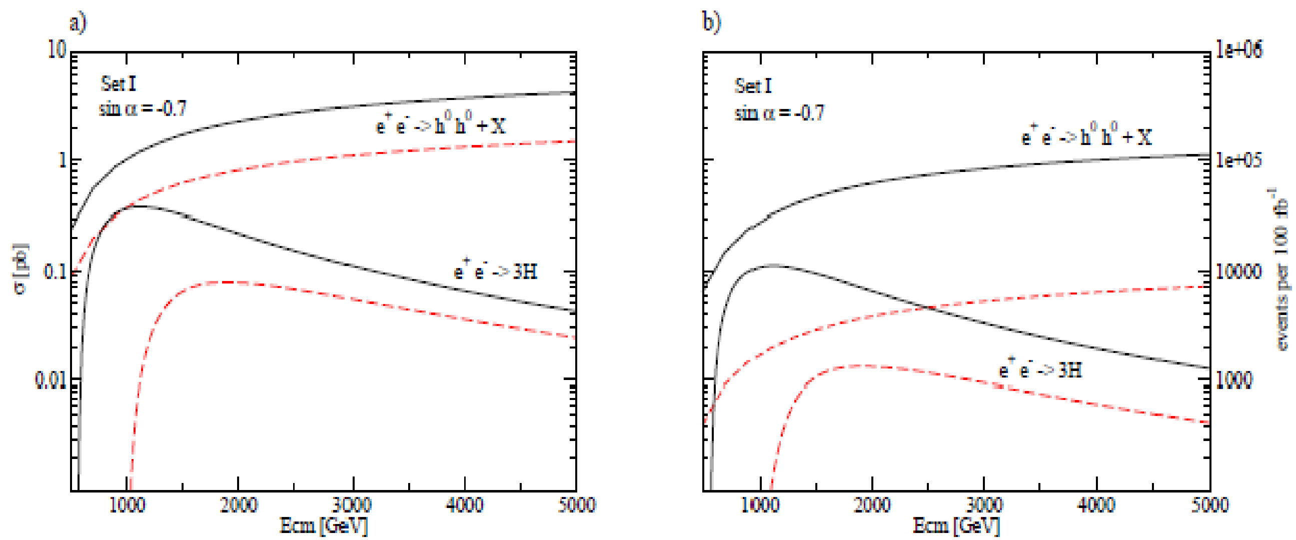
Higgs pair production in THDM

``Enhanced multi-Higgs production within the general 2HDM''
by Robert N. Hodgkinson

$$\lambda_{HHH} = \frac{3}{2}\frac{eM_H^2}{s_W M_W}$$

Trilinear coupling can be large for Heavy Higgs



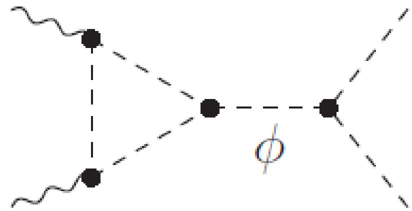


$\tan\beta \simeq 25(4)$ $\tan\beta \simeq 14(2)$

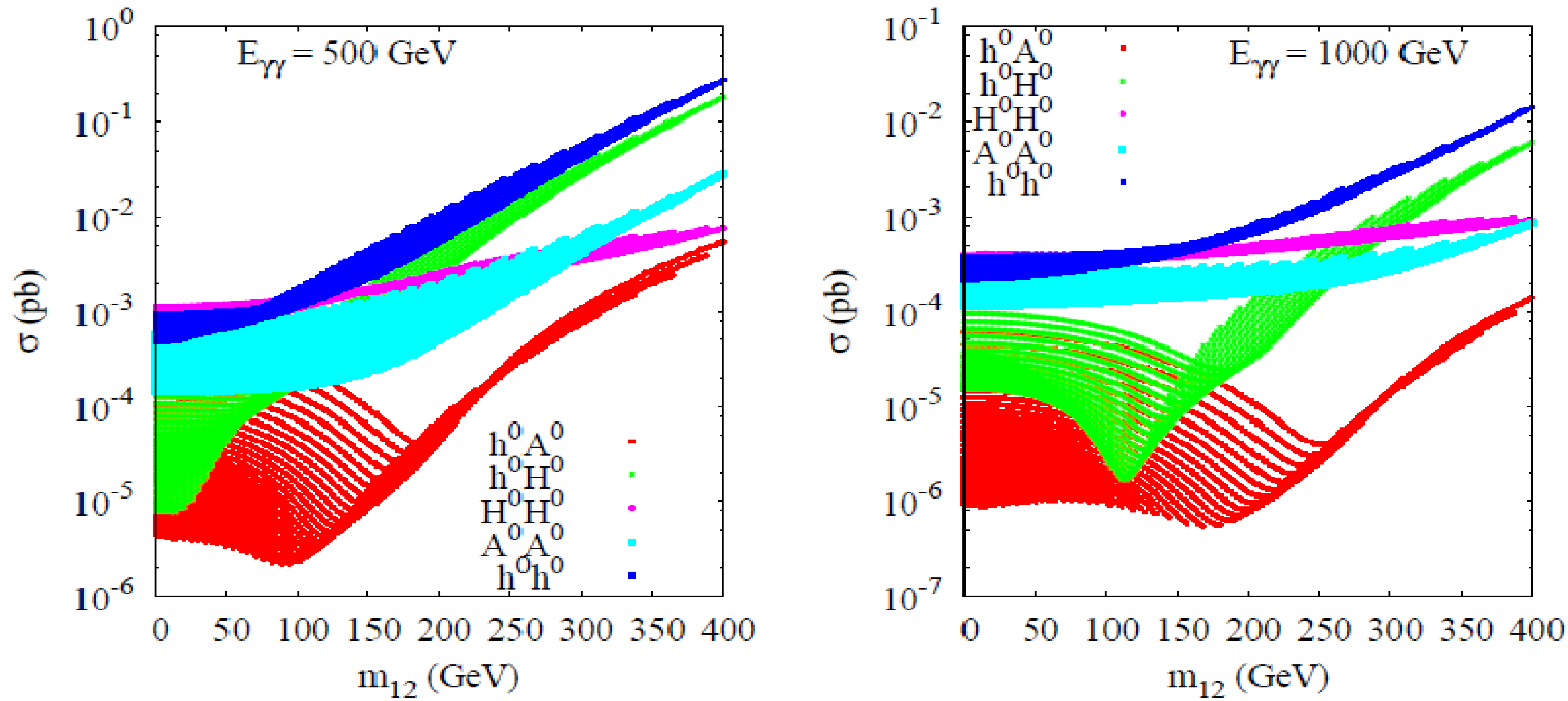
	M_{h^0} [/GeV]	M_{H^0} [/GeV]	M_{A^0} [/GeV]	$M_{H^\pm}$ [/GeV]
Set I (solid)	100	190	360	350
Set I' (dash)	100	190	800	800

``Neutral Higgs boson pair production in phton-photon annihilation in the Two Higgs Doublet Model'' by Rui Santos

Many diagrams:



etc. etc.



$m_{h^0}, m_{H^0}, m_{A^0}, m_{H^\pm} = 115, 160, 160, 250$ GeV

$\sin\alpha = -0.4$ and $1 \leq \tan\beta \leq 10$.

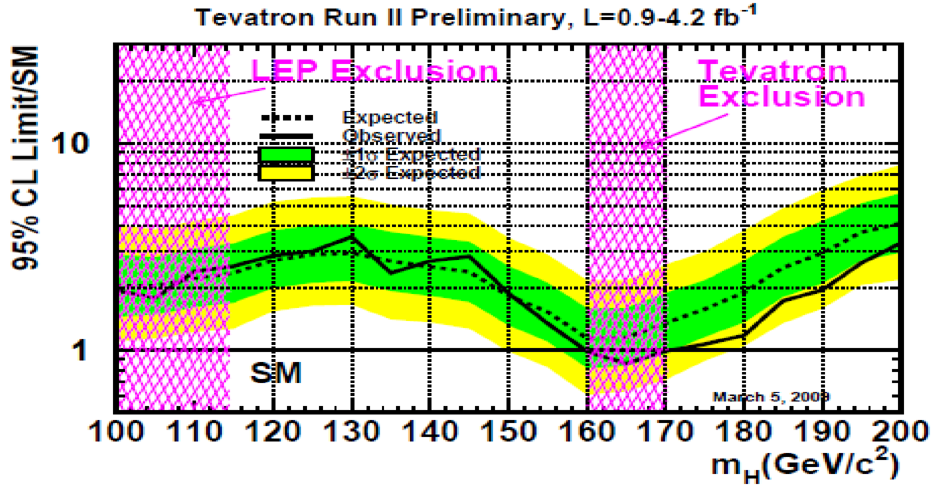
Many studies on Higgs physics have been reported and more results will be obtained near future

Higgs mass is a big issue for precise measurements of Higgs couplings (Yukawa, self coupling)

Yukawa coupling measurements (c, tau, b)

→ Higgs mass < 2 W mass, otherwise H->WW, ZZ hides ff modes

Good news



Also, many interesting ILC studies on BSMs have been reported, some of which can/cannot be observed at LHC.

LHC should tell us something about the next direction