Summary talk for ILC Physics

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Higgs Physics and electroweak symmetry breaking
  O. Kong, Little Higgs
  M. Tanabashi, Higgsless model
  Y. Yasui, Higgs self-coupling
  E. Senaha, 2HDM, self-coupling, EW baryogenesis
  C.S. Kim, 2HDM, CPV

SUSY Higgs sector
  S.Y. Choi, CPV, photon-photon
  R. Godbole, CPV, photon-photon
  S. Kanemura, LFV. Fix target experiment

SUSY
  M. Jimbo, tool
  T. Nihei, Dark matter
  R. Godbole, stau, stop, CPV
  B.C. Chung, neutralino, CPV
  T. Nihei, Dark matter

Other new physics model
  N. Okada, Extra-dim
  K. Cheung, Techni-pion, photon-photon

Others
  C.A. Heusch, e-e-
  J.B. Choi, Jet
Higgs Physics

- Important goal of the ILC physics.
- Establish the mass generation mechanism of elementary particles => coupling determination
- Determine the dynamics of electroweak symmetry breaking. “What is the Higgs particle?” One mode of the superstring, or a composite state of a new strong interaction?
- Although the present EW analysis favors a light Higgs boson (<250 GeV) within the SM, the Higgs sector is largely unknown.
- There are new ideas on the Higgs mechanism.
Little Higgs model

Quadratic divergence of the Higgs boson mass can be cancelled by extra fermions and bosons about 1 TeV.

O. Kong
New models based on SU(N)xU(1)

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331 little Higgs Model :-
— there is a solution (existence not \textit{a priori} clear)

<table>
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<th>$tX$</th>
<th>$LLL$</th>
<th>$LLX$</th>
<th>$CCX$</th>
<th>$X^3$</th>
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<tr>
<td>Total</td>
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</tbody>
</table>

Collider physics => TeV new particles
Fermion structure => FCNC

10 TeV
UV completion ?
sigma model cut-off

colored fermion related to top quark
new gauge bosons related to SU(2)
new scalars related to Higgs

1 TeV
200 GeV
1 or 2 Higgs doublets, possibly more scalars
Higgsless model

A new model based on 5 dim space-time. The unitarity of the WW scattering is saved by the Kaluza-Klein modes of the gauge bosons.

Realistic models based on this idea? (Electroweak precision test)
M. Tanabashi

The Higgsless model can be considered as a type of a technicolor model. (Deconstruction model or a lattice model in the 5 dim)

\[ SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y \quad SU(2)_L \times SU(2)_R \rightarrow SU(2)_V \]

\( (y = 0) \quad (y = \ell) \)

\[ SU(2)_L \times SU(2)_R \times U(1)_{B-L} \]

Quarks/leptons

A new strong interaction

Kaluza-Klein modes of gauge bosons

No Higgs boson

10 TeV

1 TeV

200 GeV

Models with "localized" fermions do not satisfy the EW precision constraints => Need modifications.
Collider signals => W' Z' below 1 TeV
Higgs self-coupling

The first information on the Higgs potential

\[ e^+ e^- \rightarrow ZHH \]

produced by GRACEFIG

\[ e^+ e^- \rightarrow (W^+ W^-) \nu \bar{\nu} \rightarrow HH \nu \bar{\nu} \]

etc..

etc..

Y. Yasui

![Graph showing total cross section vs. CM energy](Image)

- solid: \( m_h = 120 \) GeV
- dashed: \( m_h = 180 \) GeV
- W-fusion
- Combined

CM energy [GeV]

[Total Cross Section]
\( \lambda_{hhh} \) Measurement sensitivity

By Yamashita et al. LCWS 2004

\[ \frac{\lambda}{\lambda_{SM}} \]

- 95\% CL upper bound
- 67\% CL range
- 95\% CL lower bound

@1\,TeV
\[ I_{\text{humi}} = 1 \, \text{ab}^{-1} \]
\[ \text{Pol}_{\text{beam}} = -80\% \]
\[ M_h = 120 \, \text{GeV} \]
(SM Higgs Br)

Use only hh \( \rightarrow \) 4b
(Br(hh \( \rightarrow \) 4b) \( \approx \) 47\%)
Eff.(4b) 80\%

Determination of the self-coupling at 10\% level
Radiative correction for $e^+e^- \rightarrow \nu_e \nu_e HH$

$$\delta = \sigma(O(\alpha))/\sigma(tree)-1$$

Yasui et al. ECFA2004 Durham UK

GRACE system Minamitakeya collaboration

10 % effects as pure EW corrections

Automatic calculation of Feynman diagrams (GRACE/SUSY/1LOOP), M. Jimbo

GRACE/SUSY (tree-level) : completed

http://minami-home.kek.jp/

Full electroweak one loop correction ex:

$$e^-e^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$$

1935 1loop diagrams x 7 tree diagrams
Electroweak baryogenesis and the Higgs self-coupling in 2HDM

Baryon number asymmetry can be created at the EW phase transition in 2HDM.

The condition of the strong first order phase transition
=>
A large radiation correction to the triple Higgs boson coupling.

\[ V_{eff}(\phi, T) \leftrightarrow V_{eff}(\phi, 0) \]

\[ \Delta \lambda_{hhh}/\lambda_{hhh} \gtrsim 10\% \]
SUSY

- ILC is an ideal place to study SUSY. Mass, spin, and coupling determinations
  Energy scan, beam polarization, photon-photon and e- e- options.

- Cosmological connection: SUSY dark matter

- New analysis includes CP violation
SUSY dark matter

LSP neutralino relic abundance

WMAP -> an allowed line  “focus point”, “stau coannihilation”, “A-pole”
Effects of CP phases in gaugino masses

\[ m_A = 500 \text{ GeV} \]
\[ m_{\tilde{f}} = 800 \text{ GeV} \]
\[ A_f = 800 \text{ GeV} \]
\[ \mu = 200 \text{ GeV} \]
\[ M_2 = 300 \text{ GeV} \]

GUT-like

New allowed regions

Nihei, Sasagawa
CP violation in SUSY models

- Many new sources of CP violation in general SUSY model.
  - Higgs sector, chargino/neutralino sector, squark/slepton sector.
- In general, various EDM experiments put strong constraints.
- Many phenomenological implications. (CP-even and CP-odd observables)

\[ \gamma \gamma \rightarrow H/A (\rightarrow tt) \]

Heavy Higgs boson mixing including imaginary part, S.Y. Choi

\[ \gamma \gamma \rightarrow H_i \rightarrow \tau^+ \tau^- \]

Tau polarization for a light Higgs case (CPX scenario) R. Godbole

\[ \tilde{\tau} \rightarrow \tau \chi^0 (\tilde{t} \rightarrow t \chi^0) \]

CP phase effects on tau (top) polarization. R. Godbole
CP violation in the neutralino sector

Neutralino pair production and decays

B.C. Chung

Selection rules on the angular momentum at the production threshold and at the end point of lepton invariant distribution in the CP conserved case.

\[ e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \]

\[ \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^- \]

- S wave <-> P wave
- P wave <-> S wave
- S wave <-> S wave (CPV case)

• Triple vector correlation in the decay of polarized \( \tilde{\chi}_2^0 \) from the selectron decay.

S.Y. Choi
Large Extra Dim Model

Indirect signal of KK gravitons

Angular distribution of $ee \rightarrow HH$ => Spin two nature

$\cos \theta$

$\text{dN}/\text{d} \cos \theta$

$\sigma [\text{fb}]$

$e^+e^- \rightarrow HH$ \quad $\sqrt{s} = 1 \text{ TeV}$

$m_h = 120 \text{GeV}$

$m_h = 120 \text{GeV}$, $M_s = 2 \text{ TeV}$, 500/fb
Photon-photon scattering at the photon collider

K. Cheung

Large extra dim

Techni –pion production

Low-scale model

SM BG

Rescaled model

\[ \sqrt{s_{ee}} = 1 \, \text{TeV} \]
e-e- option

Merits of e-e- options

Right-handed selectron production

Left-handed and right-handed selectron productions

Precise mass determination

Gaugino phase dependence in the left-handed selectron production

C.A. Heusch

J.L. Feng

S. Thomas
LFV search in eN-\(\rightarrow\)\(\tau\)X process

SUSY loop effects can induce LFV Higgs couplings. S. Kanemura

The eN-\(\rightarrow\)\(\tau\)X cross section becomes large for a larger electron energy.

\[10^5\text{ taus at } E_e=250\text{ GeV}.\]

Non-observation of the signal would improve the current limit on the \(N\)-e-\(\bar{N}\) coupling from tau LFV decay search by \(10^{(4-5)}\).
Summary

- Higgs and electroweak symmetry breaking
  “Understanding the origin of the Higgs mechanism”
- New physics, “New directions”
  CPV, LFV, Cosmological connections, etc.
- Options
  “Physics case for each option”