Single charged Higgs boson production at next linear collidiers

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- We investigate various single production processes of the charged Higgs boson ($H^{\pm}$)
- Their cross sections are evaluated in the MSSM
- We discuss the phenomenology
- Summary

1 Introduction

- **Charged Higgs bosons ($H^{\pm}$)**:
  New physics predicted not in the SM
  but in **the extended Higgs sectors** (MSSM, THDM, ...).

  Detection of $H^{\pm}$ (Gauge)
  confirms such non-minimum Symmetry Breaking Sectors
  and gives information of the New Physics.

- Discovery potential for $H^{\pm}$ at future colliders

Hadron colliders (LHC)

Light $H^{\pm}$ ($m_{H^{\pm}} < m_t - m_b$)

produced in top-quark decays

$t \to H^+ + b$

Heavy $H^{\pm}$ ($m_{H^{\pm}} \gtrsim m_t$)

The discovery prospects are less by the falling structure functions and large QCD backgrounds

$gb \to tH^-$

$gg \to tbH^-$

$qb \to q'bH^-$

[redacted]

$qq' \to H^+H^-$

$gg \to H^+H^-$

$qq' \to W^+H^-$

$gg \to W^+H^-$

By taking the decay mode $H^- \to \tau\overline{\nu}$:
a heavy H^- may be probed for large $\tan\beta$

K. Odagiri ('99)

Linear colliders (LC's)

The dominant production process is

$e^+e^- \to H^+H^-$ (the pair production)

if kinematically allowed ($m_{H^\pm} < \frac{\sqrt{s}}{2}$).

For heavier $H^\pm$ ($m_{H^\pm} > \frac{\sqrt{s}}{2}$), the situation was less understood.

Kinematically allowed single H^- production processes should be examined.

- The W associated production process.
  $e^+e^- \to W^\pm H^\mp$ ($m_{H^\pm} < \sqrt{s} - m_W$)
  but only induced at one-loop order.

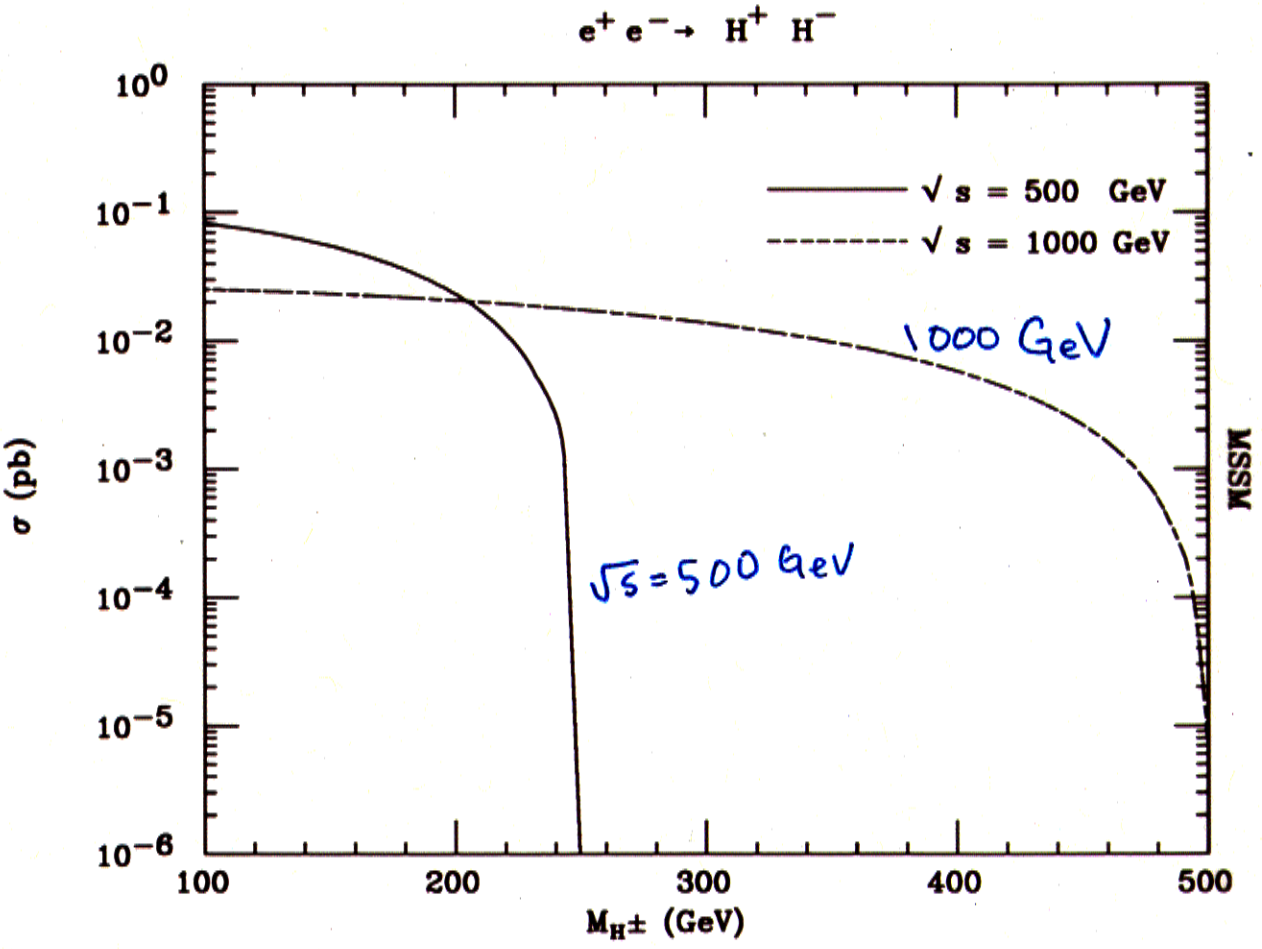
  Zhu ('99)
  S.K. ('99)
  Arhrib et al. ('99)

- The heavy fermion associated production processes.
  $e^+e^- \to \tau\nu H^\pm$
  $e^+e^- \to bbW^\pm H^\mp$

  A.Gutierrez-Rodriguez, Sampanyo ('99)
  S.Moretti, K.Odagiri ('97)

In this talk,
we discuss these processes in greater detail
together with other single $H^\pm$ production channels
in order to complement the pair production process
both above and below the threshold.

H^+H^- production



The cross section ~ 0.1 pb - 0.01 pb

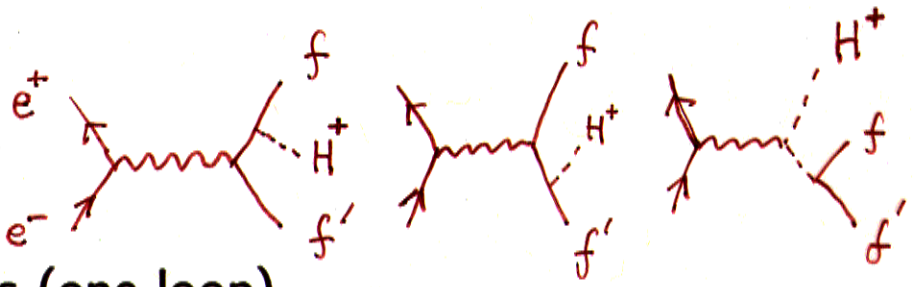
But near the threshold, the rate damps rapidly.

2 Production Processes

Heavy fermion associated processes

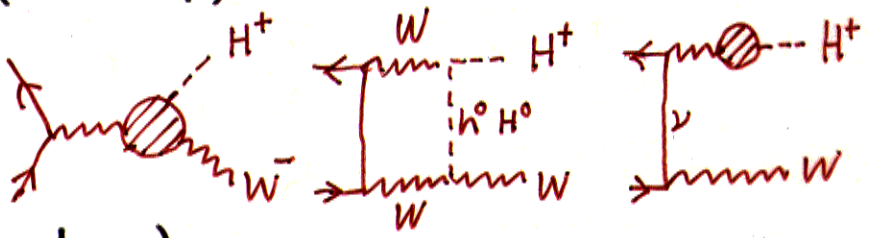
(1) $e^+e^- \to \tau^+\nu H^-$

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



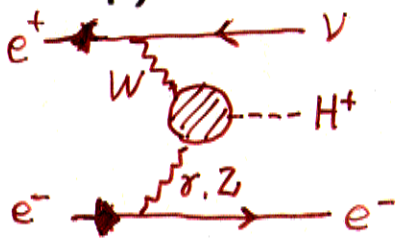
W associated process (one-loop)

(3) $e^+e^- \to W^+H^-$



WZ fusion process (one-loop)

(4) $e^+e^- \to e^+\nu H^-$

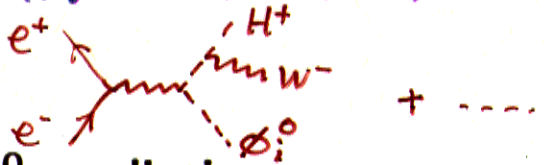


WZ association

(5) $e^+e^- \to Z^0W^+H^-$

Neutral Higgs boson association

(6)-(8) $e^+e^- \to \phi_i^0 W^+H^-(\phi_i^0 = h^0, H^0, A^0)$

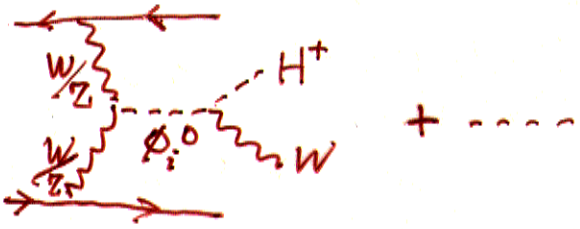


Gauge boson fusion with ϕ_i^0 mediation

(9) $e^+e^- \to e^+e^-W^+H^-$

(10) $e^+e^- \to \nu\bar{\nu}W^+H^-$

(11) $e^+e^- \to e^+\nu Z^0H^-$



3 Production cross sections

We evaluate production cross sections for these 11 processes in the Minimal Supersymmetric Standard Model (MSSM).

- The MSSM Higgs sector: (h^0, H^0, A^0, $H^\pm$)
  2 free parameters $m_{H^\pm}, \tan\beta$.
  The cross sections will be given as a function of $m_{H^\pm}$ for $\tan\beta = 1.5, 7, 30, 40$

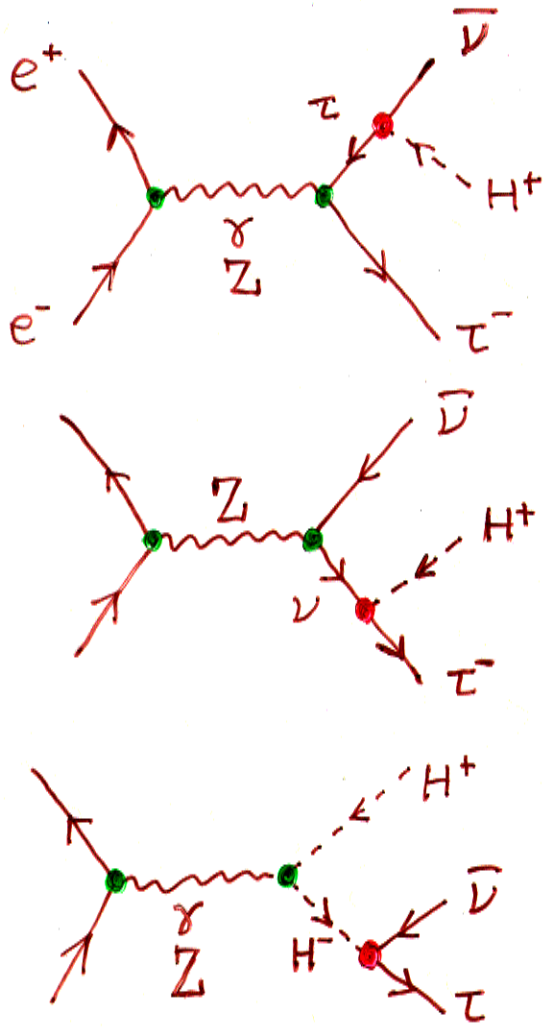
- We evaluated only leading contributions.

- The collider energies ($\sqrt{s}$) assumed to be 500 GeV (1000 GeV).

Assuming integrated Luminosity: 500 fb^{-1}/year.
$\Rightarrow 10^{-5}$ pb production cross section : 5 events/year

In this talk, we do not discuss the back ground reduction procedure in detail, and just naively take 10^{-5} pb as the threshold of signal detectability.

(1) $e^+e^- \to \tau^-\bar{\nu}H^+$

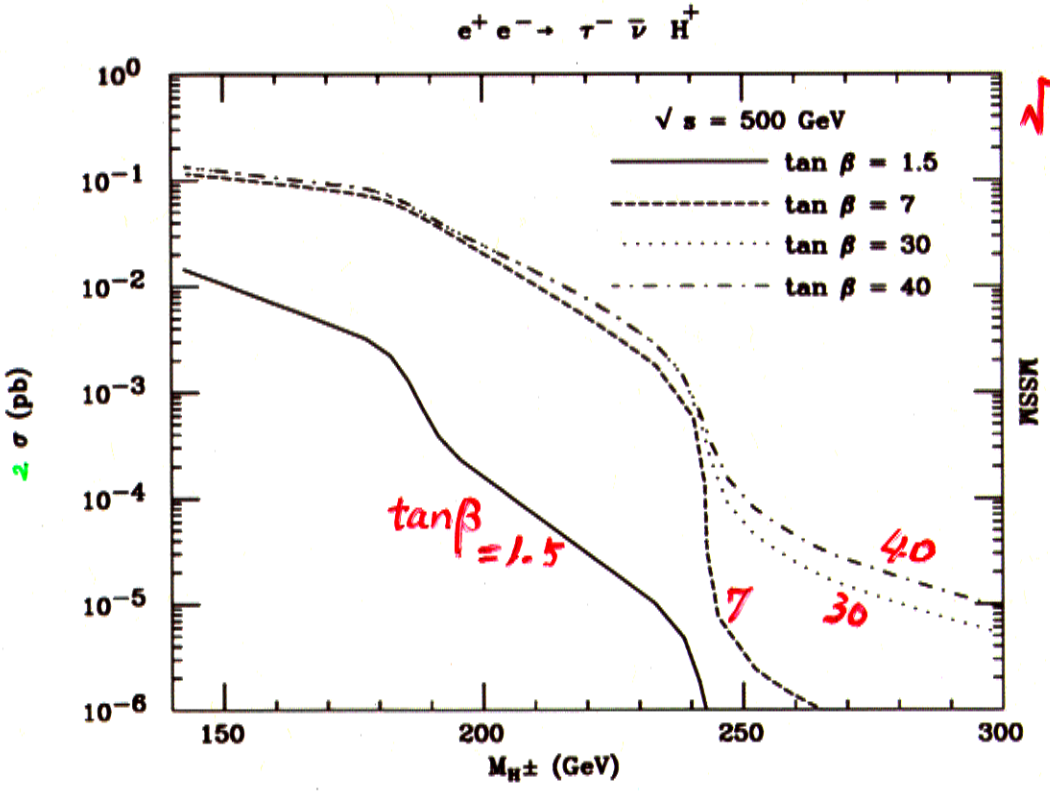


coupling

g_{EW}^2 (τ-Yukawa)

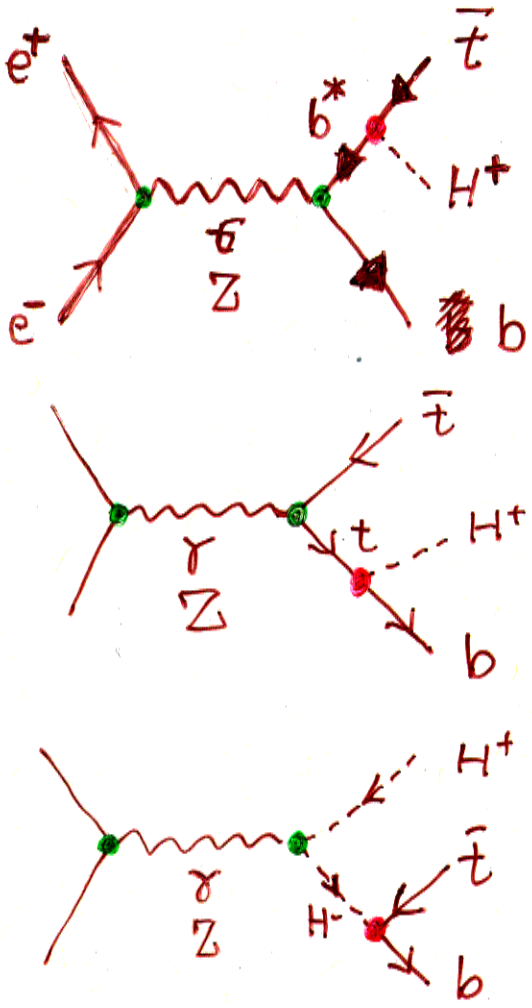
$\sim g_{EW}^2 \frac{m_\tau}{v} \tan\beta$

H^+H^- production only $m_H < \frac{\sqrt{s}}{2}$



$\sqrt{s} = 500$ GeV

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



(top pair)

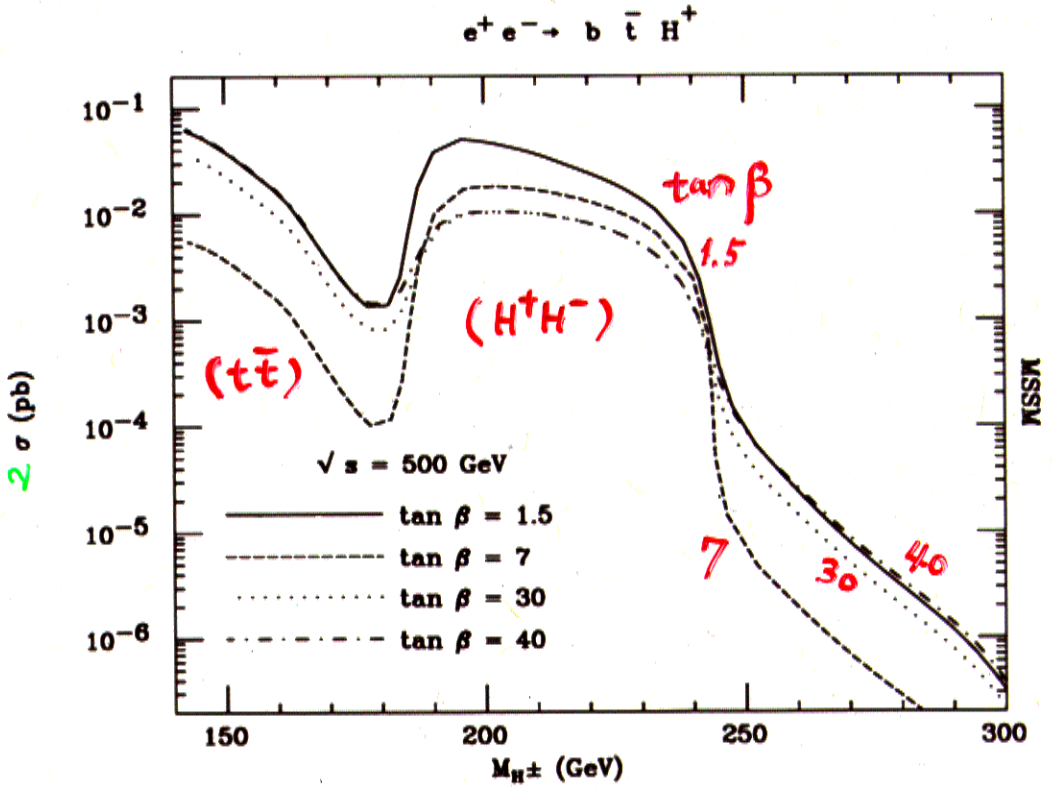
($H^\pm$ pair)

Coupling

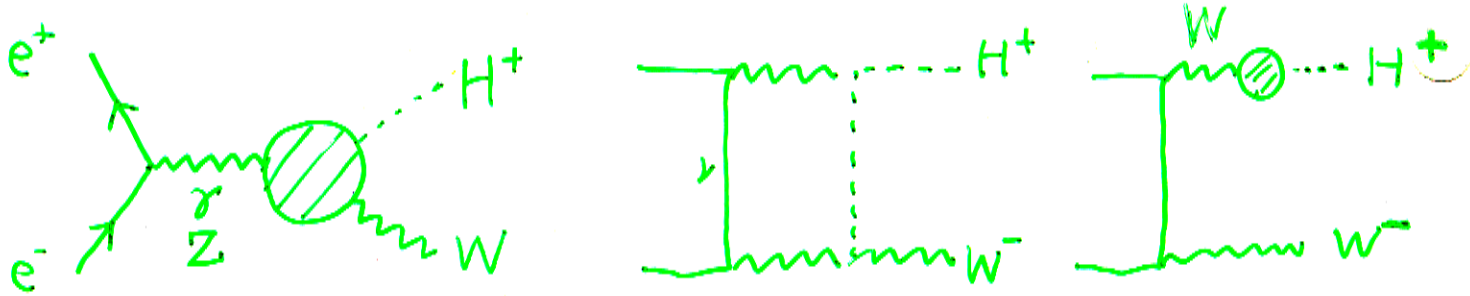
$\propto g_{EW}^2$ (t, b-Yukawa)

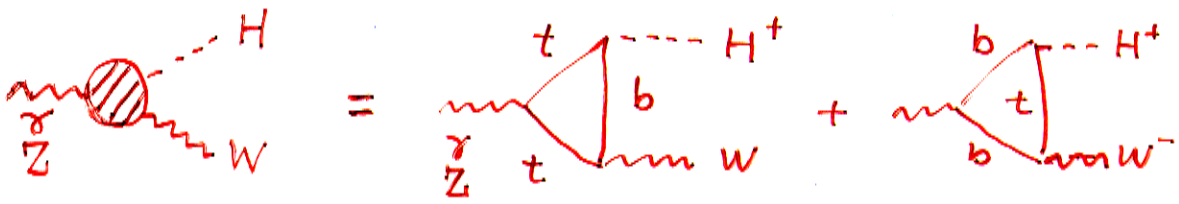
$\sim g_{EW}^2 [\, m_t \cot\beta \pm m_b \tan\beta \,]$

(minimum at $\tan\beta \sim \sqrt{\frac{m_t}{m_b}} \sim 7$)



(3) $e^+e^- \to W^-H^+$ (One-loop induced)

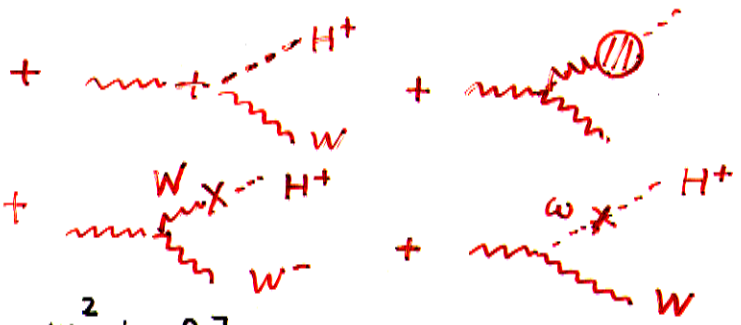




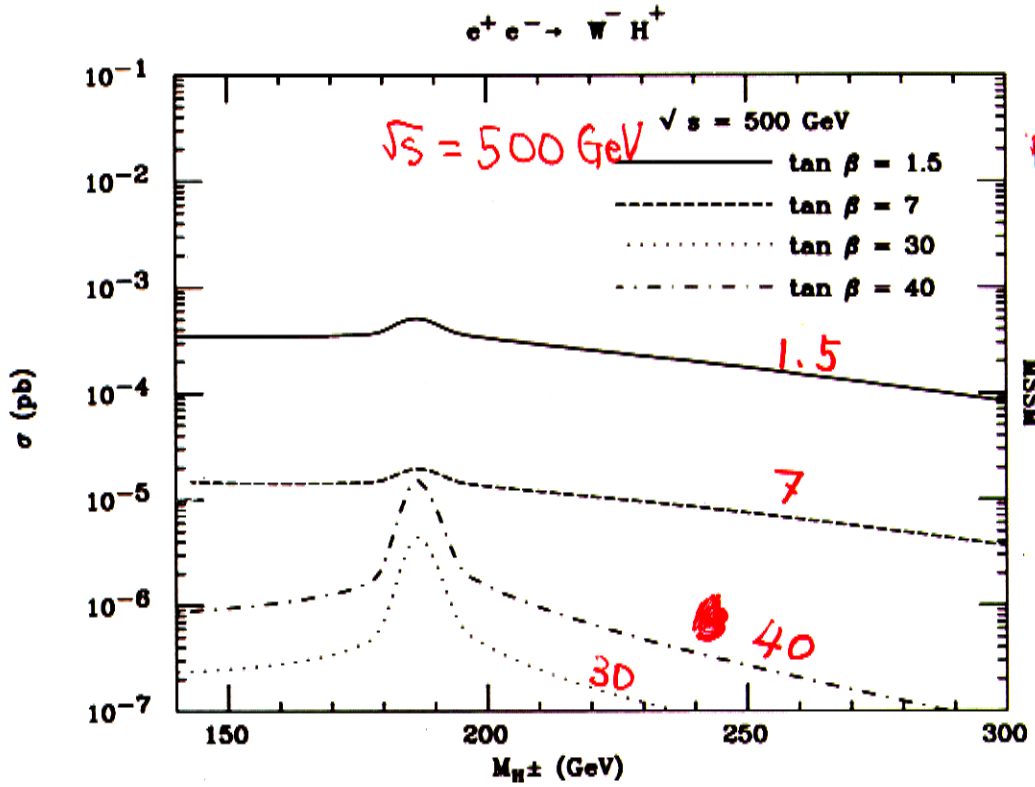
+ (boson loop)

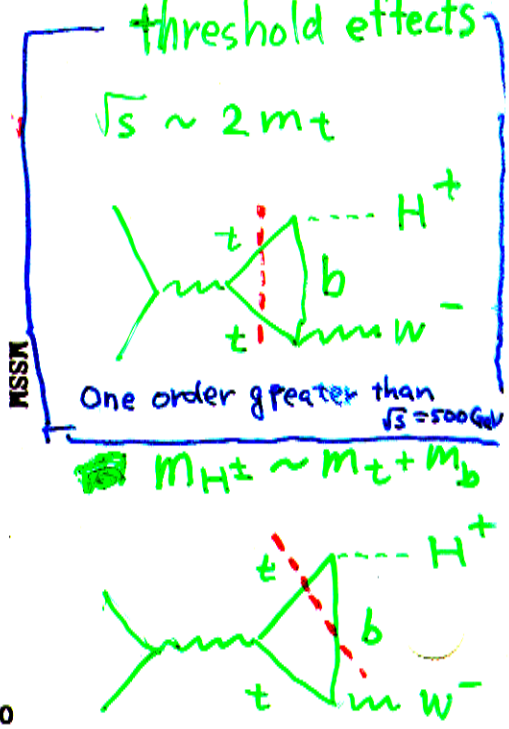
Renormalization

$\begin{cases} \Pi^{\omega H}(m_H) = 0. \\ \Pi^{WH}(m_H) = 0. \end{cases}$

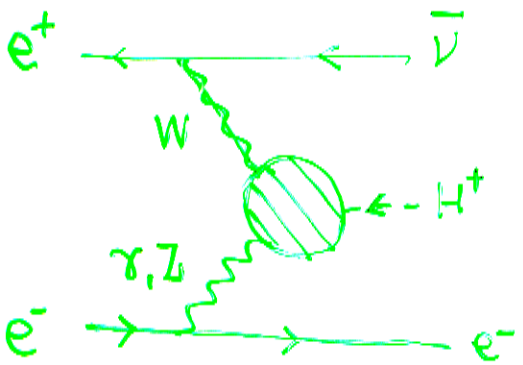


coupling $\sim g_W^2 [m_t^2 \cot\beta \pm m_b^2 \tan\beta]$





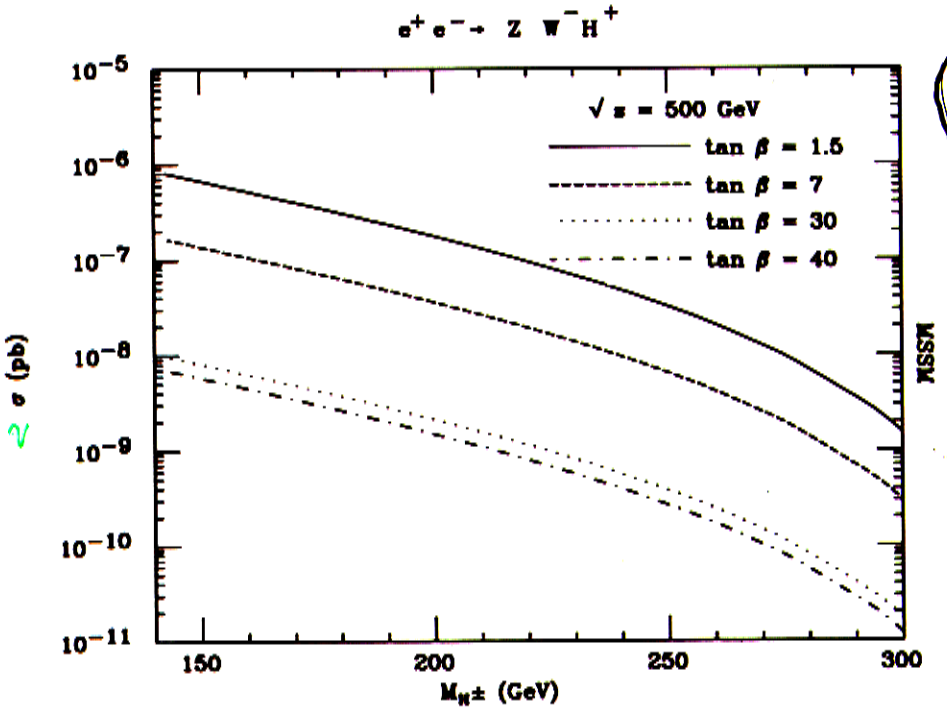
(4) $e^+e^- \to e^-\bar{\nu}H^+$



- parameter dependence similar to the WH production
- The cross section much smaller

(5) $e^+e^- \to Z^0W^-H^+$

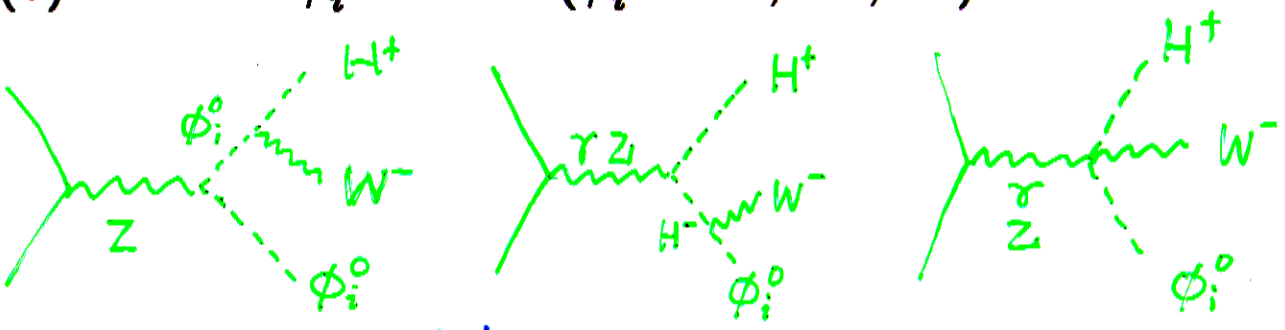
- coupling suppression $g_{EW}^4 \cos(\alpha-\beta)\sin(\alpha-\beta)$
- Cancellation between graphs of h^0 and H^0.

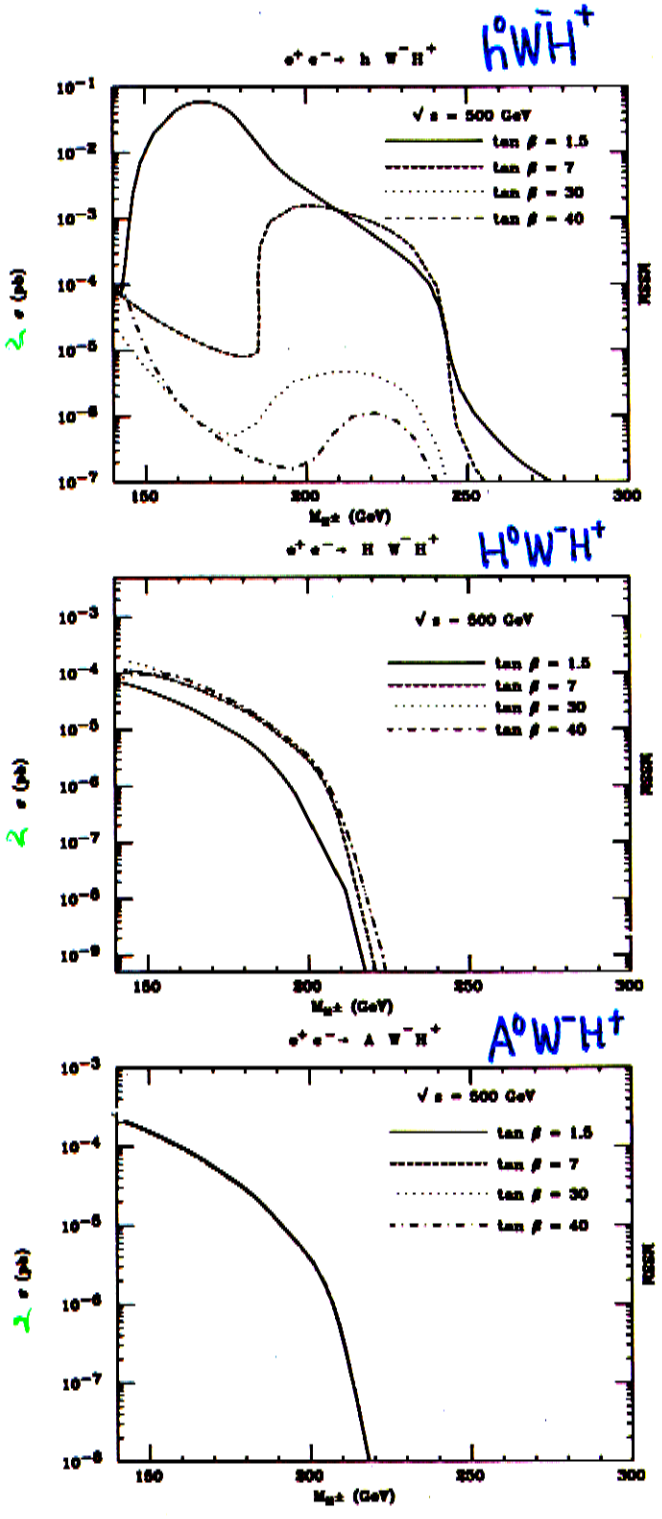


cross section small

$< 10^{-6}$ pb

(6)-(8) $e^+e^- \to \phi_i^0 W^- H^+$ $(\phi_i^0 = h^0, H^0, A^0)$





enhanced if

$H^+ \to W h^0$ is large

↑ low $\tan\beta$ with small $m_{H^\pm}$

For large $m_{H^\pm}$: coupling suppression

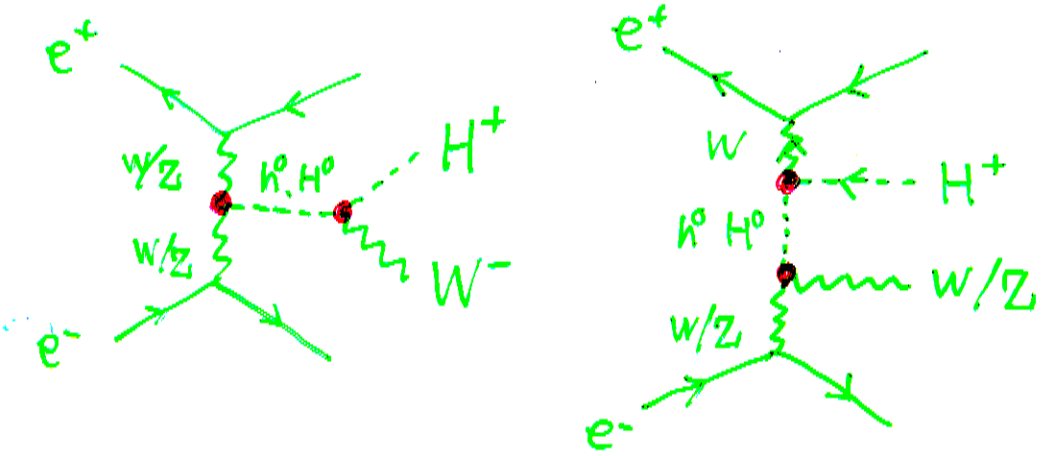
No coupling suppression

But kinematically suppressed.

$m_{H^\pm} \sim m_{A^0} \sim m_{H^0}$

For large $m_{H^\pm}$.

(9)-(11) $e^+e^- \to e^+e^- W^+ H^-$, ...



- Coupling suppression $g_{EW}^4 \cos(\alpha-\beta)\sin(\alpha-\beta)$
- Cancellation between the h^0 and H^0 graphs

<very small>

cross section $\leq 10^{-6}$ pb $(\sqrt{s} = 500\ \text{GeV})$

Summary of the production cross sections

For smaller $m_{H^\pm}$ ($m_{H^\pm} < \frac{\sqrt{s}}{2}$),

$e^+e^- \to \tau^-\bar{\nu}H^+$

$e^+e^- \to \bar{t}bH^+$

$e^+e^- \to \phi_i^0 W^- H^+$ (esp. $\phi_i^0 = h^0$)

] final state $b\bar{b}W^+H^-$

Large (10^{-1}-10^{-3} pb) due to the H^+H^- production

For large $m_{H^\pm}$ beyond the H^+H^- threshold

$e^+e^- \to \tau^-\bar{\nu}H^+$ (at large $\tan\beta$)

$e^+e^- \to W^-H^+$ (at small $\tan\beta$)

can be 10^{-3}-10^{-5} pb at $\sqrt{s} = 500$GeV

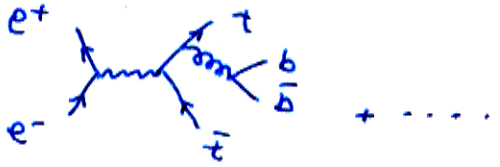
Note: The other channels are smaller, because of
- kinematical suppression (phase space)
- coupling suppression $\sim \sin(\alpha-\beta)\cos(\alpha-\beta)$
- cancellation between diagrams of the h^0 and H^0 mediation.

4 Phenomenology (Outline of tagging)

$\underline{b\bar{b}W^-H^+}$

(1) If $H^\pm \to \tau\nu$ is the main decay mode,
$b\bar{b}W^-H^+ \to b\bar{b}(jj)(\tau\nu)$
$\Rightarrow$ determine the ν 4-momentum
$\Rightarrow$ reconstruct $m_{H^\pm}$.

(2) If $H^\pm \to tb$ opens, $\quad \frac{4}{9}$
$b\bar{b}W^-H^+ \to bb\bar{b}\bar{b}W^+W^- \to bb\bar{b}\bar{b}(l\nu)(jj)$
Background
$b\bar{b}t\bar{t} \Rightarrow \mathcal{O}(\alpha_{EW}^2\alpha_S^2)$: small after cutting soft b's



$\underline{W^-H^+}$

(1) If $H^\pm \to \tau\nu$ is dominant,
$W^-H^+ \to (jj)(\tau\nu)$
Eliminate WW background by cutting events where small $m_{H^\pm}$ is given.

(2) If $H \to tb$ is dominant,
$W^-H^+ \to W(tb) \to b\bar{b}W^+W^-$
Background process $t\bar{t}$, which can be reduced by α_{EW} by cutting events with two top quarks.

$$\frac{\#\ \text{Signal events}}{\#\ \text{reduced BG}} \sim 0.1$$

for $\sigma(e^+e^- \to H^+W^-) = 0.5$ fb

signal $\sim$ 250 events/year.

$\tau^- \bar{\nu} H^+$

(1) $H^\pm \to \tau\nu$ dominant

$\tau^+\tau^-\nu\bar{\nu}$: similar to H^+H^- production. (same)

(2) If $H^+ \to t\bar{b}$ is allowed

$$\tau^-\bar{\nu}H^+ \to \tau^-\bar{\nu}\, t\bar{b} \quad (t \to W^+ b) \to W^+ b\bar{b}\,\tau\nu$$

~~Bkg~~ Background

$$t\bar{t} \to W^+\bar{b}\,W^-b \quad (W^- \to \tau\nu)$$

reconstruct mass of $(\tau\nu)$

cut events which ~~some~~ results $W \to \tau\nu$ from.

5 Summary

We discussed various processes of the single $H^{\pm}$ production at LC.

Their cross sections can be large enough for us to use these modes to study properties of $H^{\pm}$

Above the H^+H^- threshold, their cross sections are rather small, but the signal remains visible in some channels.

We found that the W^-H^+, $\tau^-\bar{\nu}H^+$ and $b\bar{b}W^-H^+$ modes are all useful.

W^-H^+ (esp. at low $\tan\beta$)
$\tau^-\bar{\nu}H^+$ (esp. at high $\tan\beta$)
$\Rightarrow$ promising channels for $m_H > \frac{\sqrt{s}}{2}$.

$b\bar{b}W^-H^+$: ($\bar{t}bH^+$, $\phi_i^0 W^-H^+$, $Z^0W^-H^+$)
kinematically suppressed for large $m_{H^{\pm}}$.
For small $m_{H^{\pm}}$, this mode is interesting.
Many channels contribute to this final state.
Useful for the probe of underlying theory.

In future, our analysis needs to be complemented by a study of the decay modes and the back grounds, and ultimately detector level simulations.