Higgs Physics and Supersymmetry at e^+e^- Linear Colliders

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Outline

– Machine designs

– Higgs Physics

– Supersymmetry

Machine designs

			$\sqrt{s}$	$\int \mathcal{L}$
Phase I	NLC/JLC	conventional	500 GeV	50–200 fb^{-1}
	SLAC/KEK	high-grad	1000 GeV	340 fb^{-1}
	TESLA DESY	supercondg. cavities	500 GeV 800 GeV	300 fb^{-1} 500 fb^{-1}
Phase II	CLIC CERN	2-beam accelerator	500 GeV 3–5 TeV	100 fb^{-1} 300 fb^{-1}

TESLA: polarisation: $\mathrm{P}[e^-] = 80\ \%$

$\mathrm{P}[e^+] = 40/60\ \%$

satellite modes: e^-e^- $\quad \mathcal{E}/\mathcal{L} = 100/20\ \%$

$e\gamma$ $\quad \mathcal{E}/\mathcal{L} = 90/40\ \%$

$\gamma\gamma$ $\quad \mathcal{E}/\mathcal{L} = 80/40\ \%$

Giga Z: $2 \times 10^9\ Z$ bosons

Higgs Physics

Study properties of Higgs particles that can be tested at future high-energy colliders.

MOTIVATION: Establish the Higgs mechanism experimentally.

HIGGS MECHANISM: Production of particle masses without violating gauge principles.

EXPERIMENTAL VERIFICATION of the Higgs mechanism:

(I) Discovery of the Higgs particle(s)

$\Downarrow$

(II) Yukawa and gauge couplings

$\Downarrow$

(III) Spin and CP properties

$\Downarrow$

(IV) Determination of the Higgs self-couplings

$\Downarrow$

Experimental verification of the creation of particle masses via the Higgs mechanism.

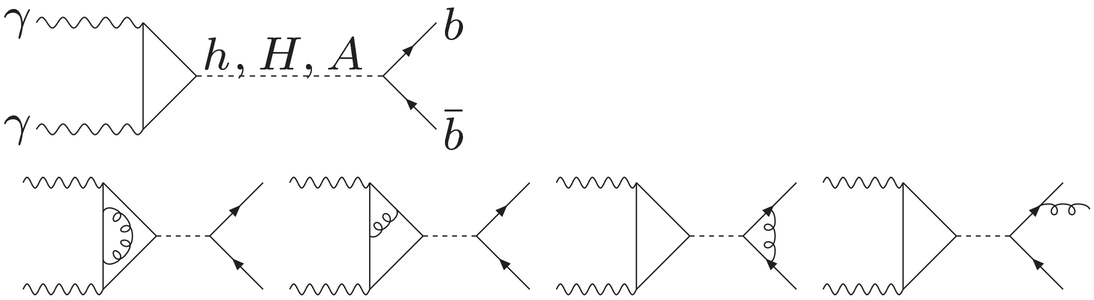
(I) Production of MSSM Higgs bosons in $\gamma\gamma$ collisions.

Krämer,MM,Spira,Zerwas, Phys.Lett.B508(2001)311

Motivation:

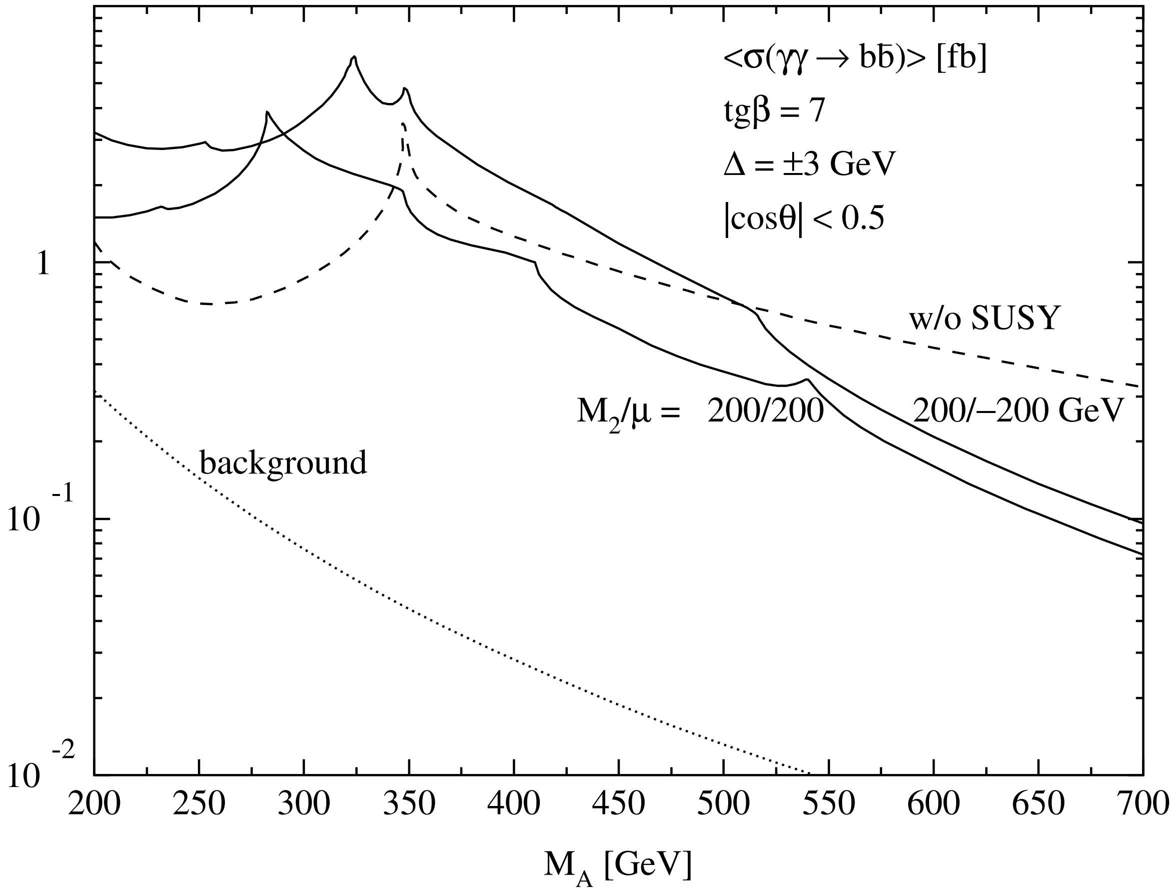
LHC: No H, A discovery for $M_{H,A} \gtrsim 200$ GeV and
$6 \lesssim \tan\beta \lesssim 15$.
LCs in e^+e^- mode: $\sqrt{s_{ee}} \geq 2M_{H,A}$ required.
(H and A can only be pair produced.)

Most promising channel: Process $\gamma\gamma \to h, H, A \to b\bar{b}$



Technical Details:

- Restriction to 2-jet final states (signal/bkg $\uparrow$)
- Higher order corrections to signal, bkg, interf.
- Polarisation of $e^\pm$, laser beams (signal/bkg $\uparrow$)
- Cut on b-quark scattering angle (signal/bkg $\uparrow$)



H, A discovery for $M_{H,A} \lesssim 0.8\sqrt{s_{ee}}$ and moderate to large $\tan\beta$.

$\boxed{\text{$\gamma\gamma$ colliders provide a valuable possibility for the heavy H/A production.}}$

(II) Measurement of the Higgs boson lifetime

KILIAN,MM,SPIRA,ZERWAS, IN PREPARATION

Motivation:

SM model Higgs boson with intermediate mass has small lifetime/total width $\Gamma_{tot} \Rightarrow$

Exploit the relation $\boxed{\Gamma_{tot} = \Gamma_i / BR_i.}$

For example:

Production $WW \to H \sim \Gamma_{WW}$ and
Exclusive Decay $WW \to H \to WW \sim \Gamma_{WW} BR_{WW}$

WW channel: $\mathcal{L} = 500$ fb^{-1}, $M_H = 120...160$ GeV
$\delta\Gamma_{tot}/\Gamma_{tot} \sim 4...13\%$

$\gamma\gamma$ channel: $\delta\Gamma_{tot}/\Gamma_{tot} \sim 20\%$

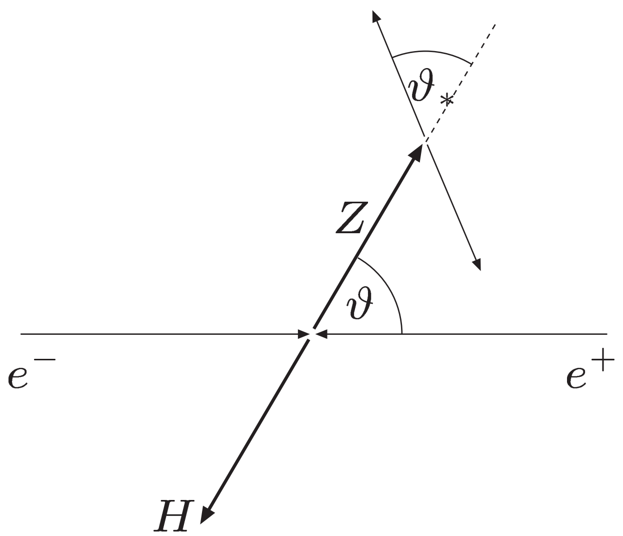
MSSM: 5 Higgs particles $[\Phi = h, H, A, H^{\pm}]$,
couplings $\Phi b\bar{b}$ from $e^+e^- \to b\bar{b}\Phi$,
more complicated.

(III) Measuring the spin of the Higgs boson

MILLER, CHOI, EBERLE, MM, ZERWAS, PHYS. LETT. B505(2001)149

Threshold behavior: $\sigma(ZH) \sim \beta$ for $0^+, 1^+, 2^+$

Angular correlation: $\frac{d\sigma}{d\cos\theta \, d\cos\theta *}$ to rule out $1^+, 2^+$



$J^P = 0^+$ can be determined in a model-independent way.

(IV) Determination of the Higgs self-couplings

DJOUADI, KILIAN, MM, ZERWAS, EUR.PHYS.J.C10(1999)27;
DJOUADI, KILIAN, MM, ZERWAS, EUR.PHYS.J.C10(1999)45.

Motivation: Reconstruction of the Higgs potential.

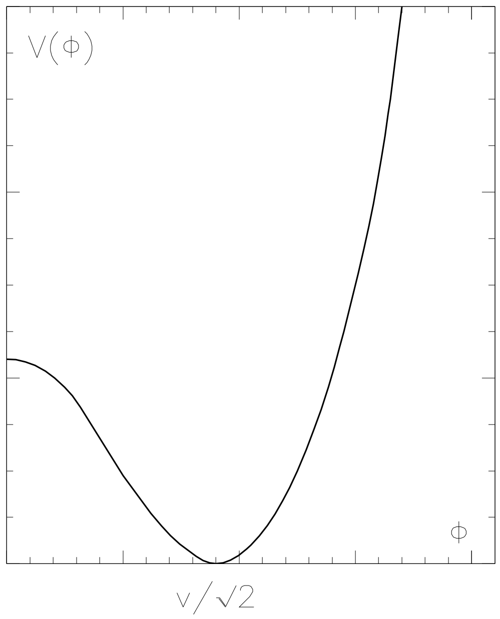
Higgs potential $\boxed{V(H) = \frac{1}{2}M_H^2 H^2 + \frac{M_H^2}{2v} H^3 + \frac{M_H^2}{8v^2} H^4}$

Mass: $M_H = \sqrt{2\lambda} v$

Trilinear: $\lambda_{HHH} = 3M_H^2/M_Z^2$

Quartic: $\lambda_{HHHH} = 3M_H^2/M_Z^4$

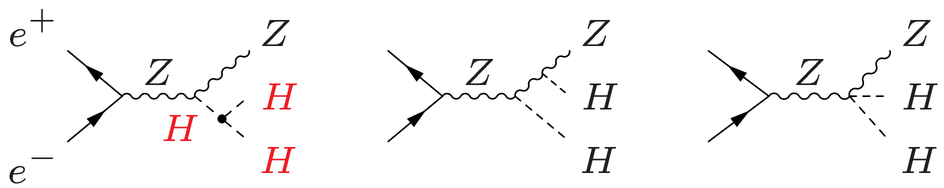
[units $\lambda_0 = 33.8$ GeV$/\lambda_0^2$]

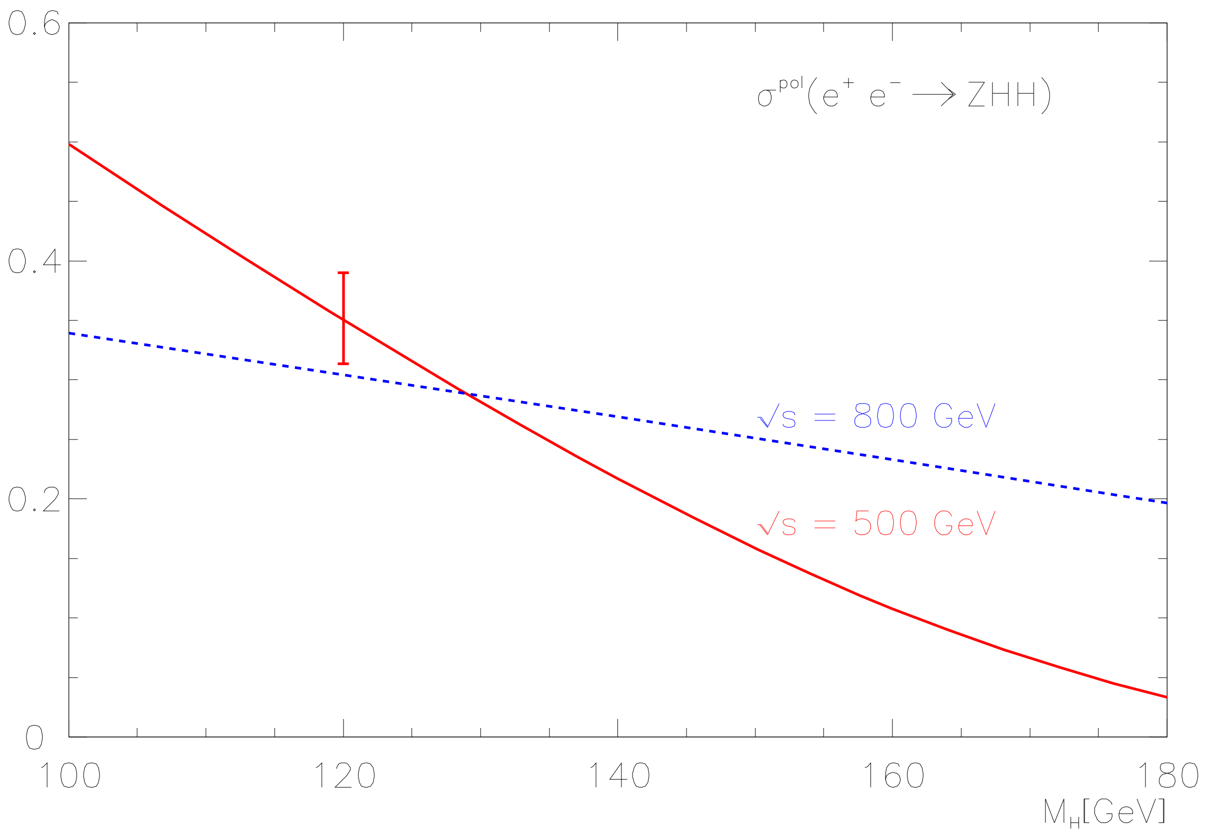


λ_{HHH} determination at LC's:

WW Fusion: $e^+e^- \to \bar{\nu}_e \nu_e HH$

double Higgs-strahlung: $e^+e^- \to ZHH$





- polarized $e^{\pm}$ beams $\to$ $\sigma^{pol} = 2\sigma^{unpol}$
- "bar" $\delta\sigma_{ZHH}$ for $\delta\lambda/\lambda_{SM} = 20$ %
- $\sqrt{s} = 500$ GeV good choice for $M_H = 120$ GeV:
  σ large, sensitivity to λ_{HHH} large

Expected accuracy: $M_H = 120$ GeV, $\int \mathcal{L} = 2000$ fb^{-1}

Gay,...

$$\boxed{\delta\lambda/\lambda \lesssim 20 \text{ \%}}$$

Measurement of λ_{HHH} and λ_{HHHH} $\Rightarrow$
Reconstruction of the Higgs potential.

Summary – Higgs Physics

(I) Discovery of the Higgs particle(s)

$\Downarrow$

(II) Yukawa and gauge couplings

$\Downarrow$

(III) Spin and CP properties

$\Downarrow$

(IV) Determination of the Higgs self-couplings

$\Downarrow$

The accurate study of the Higgs boson properties needed to establish experimentally the Higgs mechanism as the mechanism of electroweak symmetry breaking can be performed in the clean environment of e^+e^- linear colliders.

Supersymmetry

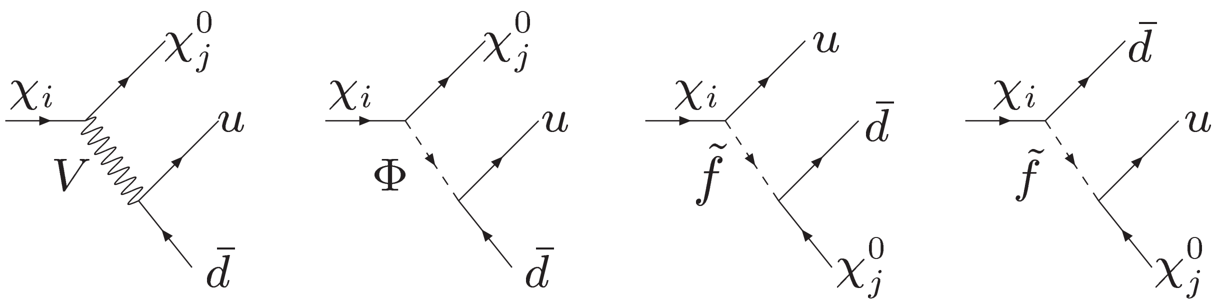
Symmetry fermions $\leftrightarrow$ bosons $\Rightarrow$
gauge coupling unification
avoid hierarchy problem ...

(1) Chargino and neutralino three-body decays.

Djouadi, Mambrini, MM, Eur.Phys.J.C20(2001)563

Motivation:

Detailed study of production and decay properties:
· reconstruction of the SUSY lagrangian at low scale
· derivation of the structure of the theory at high scale



- Analytical formulae for Dalitz densities and fully integrated $\Gamma_{\tilde{\chi}_i}$
- Polarization of decaying particle
- Dependence on final state fermion masses
- Rad. corr. to Yukawa couplings and $\tilde{\chi}_i^0, \tilde{\chi}_i^\pm$ masses

Fortran code SDECAY

Djouadi,Mambrini,MM, in preparation.

· 2- and 3-body decays of (heavy) $\tilde{\chi}_i^{\pm}$, $\tilde{\chi}_i^0$
· 2-, 3- and 4-body decays of top squarks
· all relevant decay modes of the other sfermions
· 3-body decays of the gluinos
· interface with SUSPECT Djouadi,Kneur,Moultaka
· interface with HDECAY Djouadi,Kalinowski,Spira

(2) Loop induced Higgs and Z boson couplings to neutralinos.

Djouadi, Drees, Fileviez Perez, MM, to appear in Phys.Rev.D.

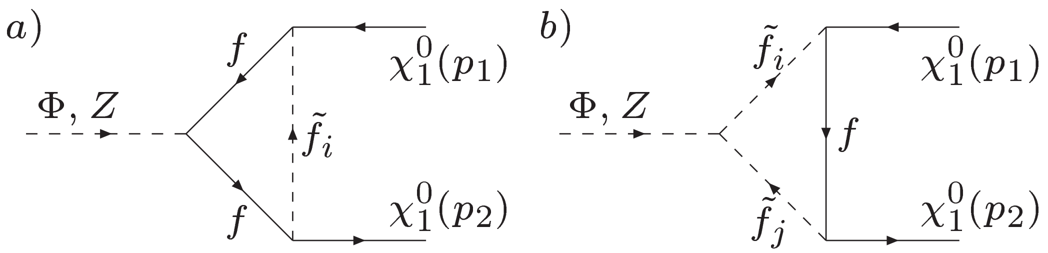
Motivation:

Higgs, Z couplings to $\tilde{\chi}_1^0$ important for collider phenomenology and cosmology

(i) $\tilde{\chi}_1^0$ often LSP and stable (R-parity) $\rightarrow$ final state $\tilde{\chi}_1^0\tilde{\chi}_1^0$ contributes to invisible Higgs and Z widths.

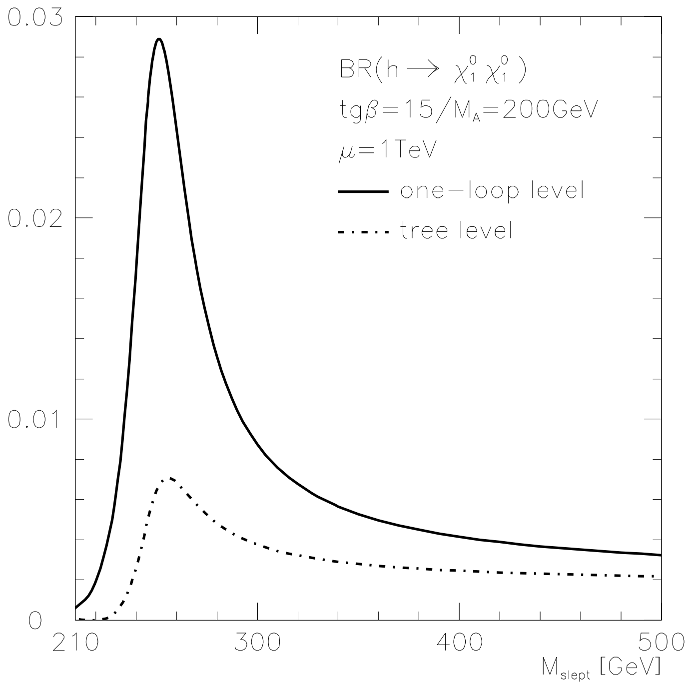
(ii) $\tilde{\chi}_1^0$ good DM candidate, size of detection signal and relic density depends on Higgs/Z couplings to $\tilde{\chi}_1^0\tilde{\chi}_1^0$.

Tree level Higgs/Z couplings to gaugino-like $\tilde{\chi}_1^0$ small $\Rightarrow$ Calculation of couplings at one-loop level.



$BR^1(h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0)$ is O(%)

Measurable at future e^+e^- linear colliders via Z recoil mass in ZH.



Summary – Supersymmetry

Search for the (lightest) supersymmetric particles is one of the most important tasks of future e^+e^- colliders.

High accuracy can be achieved on SUSY masses and couplings in the study of the SUSY particle production and decay properties. $\Rightarrow$

Determine the mechanism of SUSY breaking and extrapolate the theory to high scales.