Particle Searches at a Linear Collider

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Klaus Desch
University of Hamburg

- **Framework**
- **Higgs**
- **Supersymmetry**
- **Alternative Theories**
- **Summary & Conclusions**

Framework

- Technical feasibility of linear e^+e^-–colliders in the 500-1000 GeV regime intensively studied in the past years (+ study of multi-TeV machine, CLIC)
- Detailed designs (JLC,NLC,TESLA) exist and are very promising
- First phase: 500 GeV Linear Collider could operate few years after LHC start

- Physics case for such machines is seriously studied in several workshops:

Regional Studies	Worldwide Study
ECFA/DESY	Sitges 04/99
ACFA	Fermilab 10/00
US	

- Large participation from experiment and theory

'New Physics' Programme of a Linear Collider

- study Higgs boson properties (couplings, mass, spin, CP)

  $\longrightarrow$ fully establish the mechanism of EW symmetry breaking
- precisely measure the supersymmetric particle spectrum

  $\longrightarrow$ explore SUSY breaking mechanism

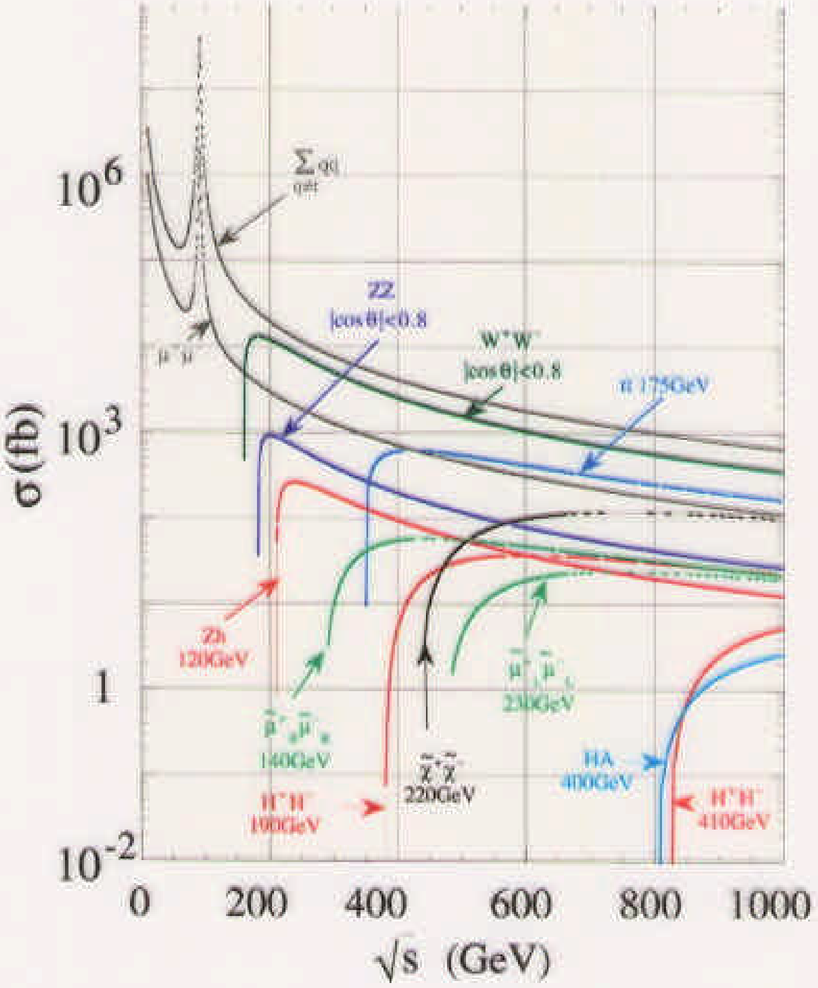
  $\longrightarrow$ extrapolate from EW-scale to GUT-scale
- sensitivity to many alternative scenarios with large complementarity to LHC.

Assumptions for Physics Studies

Machine: $\sqrt{s} = 500 \dots 1000$ **GeV**

High Luminosity: 2-3 $\times\ 10^{34}$ cm^{-2} s^{-1}

$\rightarrow$ several 100 fb^{-1} / year



Polarisation of both beams:

P(e^{-}) = 80 %   P(e^{+}) = 60 %

Assumptions for Physics Studies

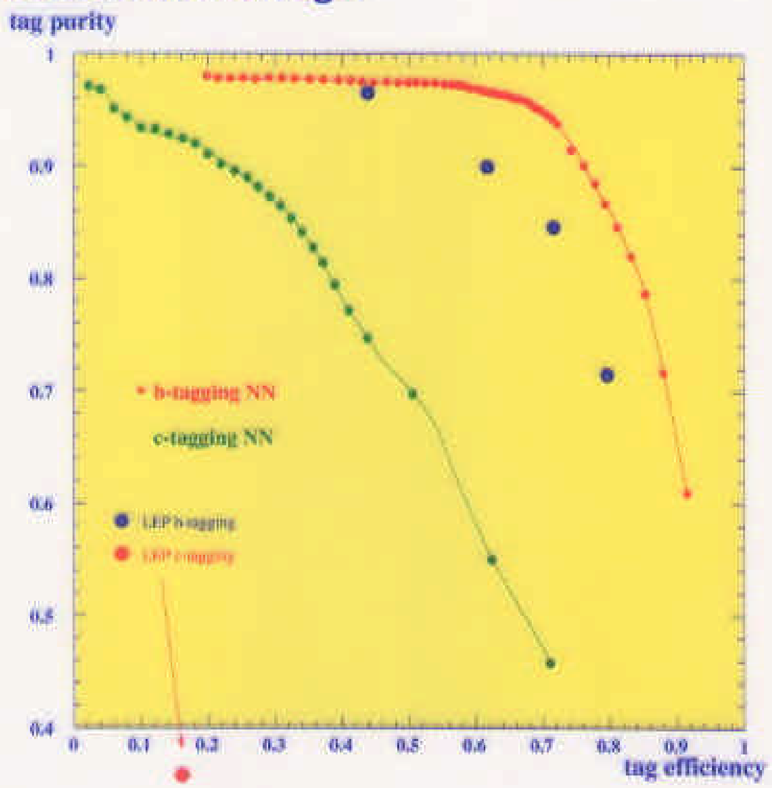
Detectors: guided by LEP/SLD experience

+ technical progress (LHC-expts., ...)

Many detector goals guided by Higgs–physics:

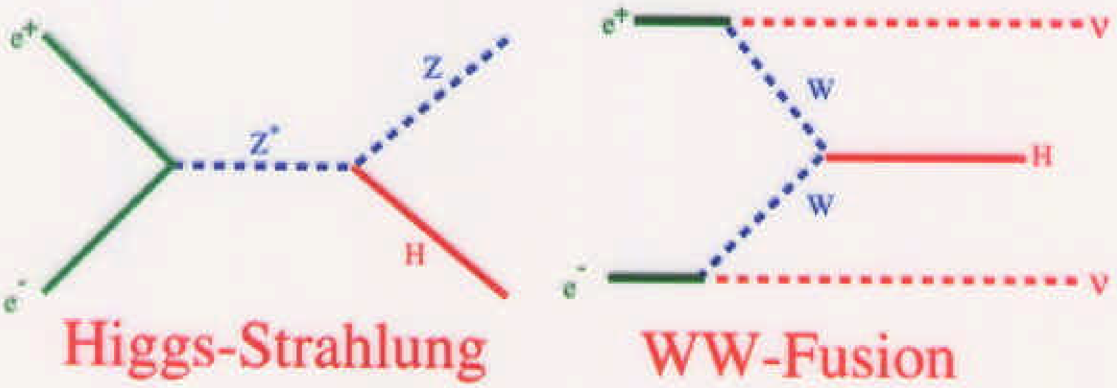
- hermeticity ($H \to$ invisible)
- excellent electromagnetic calorimeter ($H \to \gamma\gamma$)
- excellent momentum resolution ($ZH \to \ell^+\ell^- X$, recoil mass!)
- b/c–separation and τ-ID (Higgs branching ratios)

small beamspot (500 × 5 nm) and small beampipe radius (1.x cm) allow for excellent flavour tags:



Higgs Physics

Abstract 728, ECFA/DESY Higgs LC working group
M.Battaglia, KD, A.Djouadi, E.Gross, B.Kniehl
Higgs Studies with TESLA

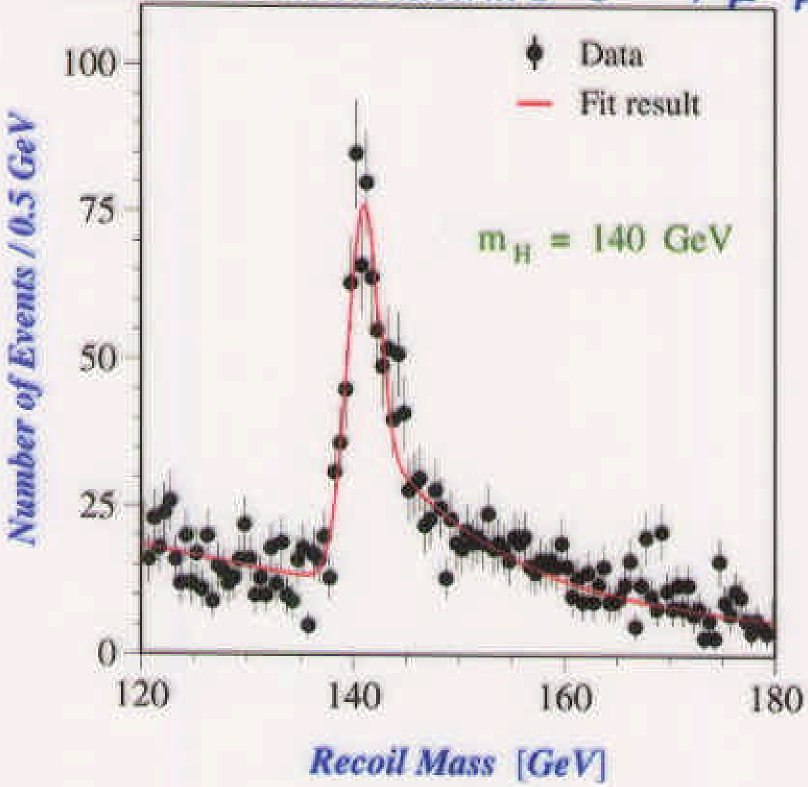


- several 10^4 Higgs bosons produced / year for "light" Higgs
- detection with high efficiency (see LEP)
- nearly background free

Cross Section $HZ, H\nu\nu$

Higgs-Strahlung:

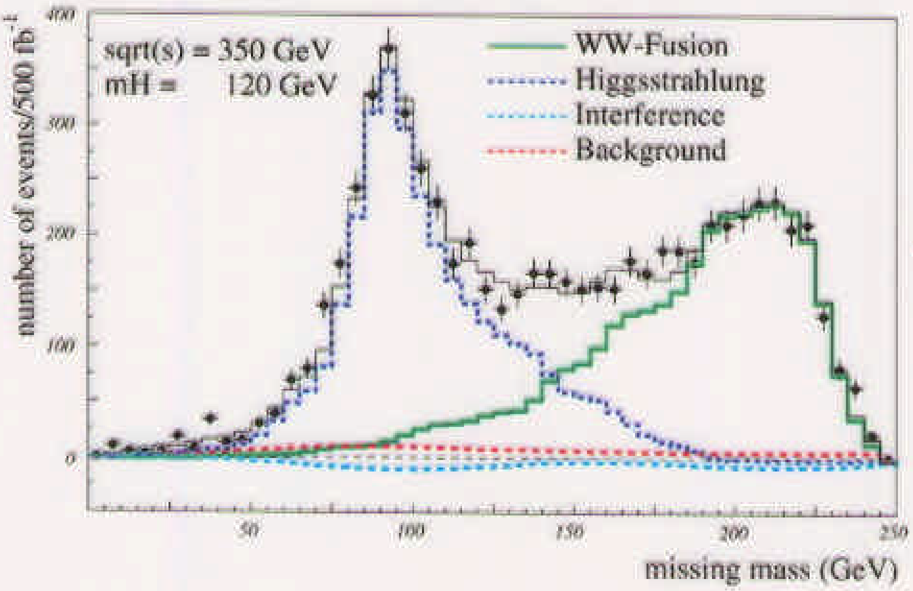
recoil mass distribution in $e^+e^- \to \mu^+\mu^- + X$ events



- very low background
- model independent
- $\Delta\sigma_{ZH} \approx 3\%$
- ($\mu^+\mu^-$ and e^+e^- combi-ned)

P.Garcia-Abia
W.Lohmann
(2000)

WW-Fusion: Missing Mass-Distribution in $\nu\bar{\nu}b\bar{b}$–Events

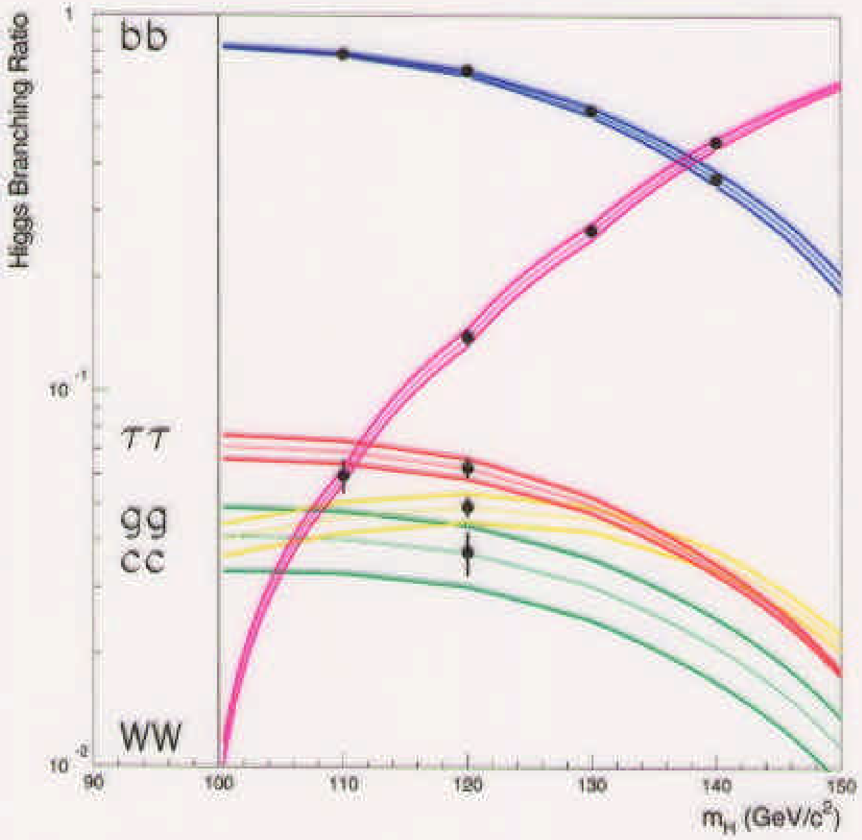


- $\Delta\sigma_{H\nu\nu} \approx 3-8\%$

N.Meyer, KD (2000)

Higgs: Branching Ratios

Simulation of the measurement of Higgs branching ratios:



Battaglia
Borissov
Richard
(1999)

– disentangle $b\bar{b}$, $c\bar{c}$ and gg using simultaneous fit to lifetime-sensitive variables

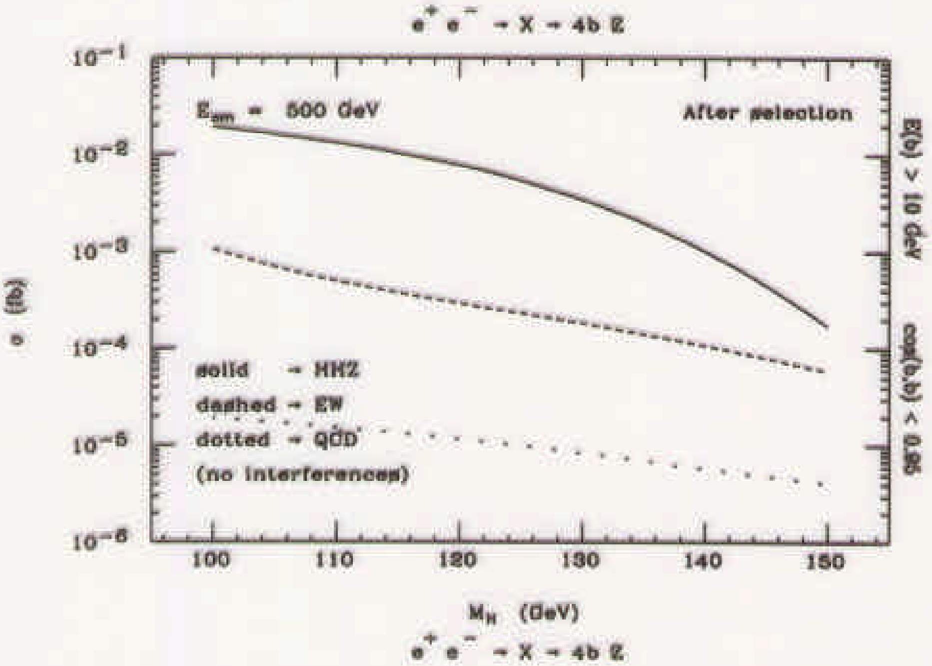
Decay	Precision
$H \rightarrow b\bar{b}$	2.4 %
$H \rightarrow c\bar{c}$	8.3 %
$H \rightarrow gg$	5.5 %
$H \rightarrow \tau^+\tau^-$	6.0%
$H \rightarrow W^+W^-$	5.4%
$H \rightarrow \gamma\gamma$	10-15%

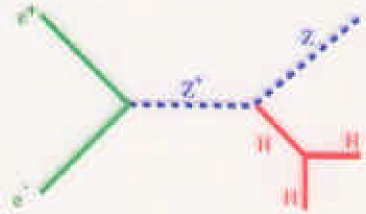
(for 500 fb^{-1})

Higgs selfcoupling and ttH coupling

Higgs Potential: $V(\Phi) = \lambda(\Phi^\dagger\Phi - v^2/2)^2$

– accessible at LC through trilinear Higgs coupling λ_{HHH}





Mühlleitner et.al. (1999)
Miller
Moretti
(1999)

– $\sigma < 0.1$ fb $\rightarrow$ accessible with very high luminosity

Signature: $e^+e^- \rightarrow ZHH \rightarrow q\bar{q}b\bar{b}b\bar{b}$

After selection: S/B $\approx$ 1/1, efficiency $\approx$ 15%

$\rightarrow$ $\Delta\lambda/\lambda \approx 20\%$ is possible with 500 fb^{-1}.

Gay,Lutz (2000)

Top Yukawa coupling:

Signature:

$e^+e^- \rightarrow t\bar{t}H \rightarrow W^+bW^-\bar{b}b\bar{b} \rightarrow 4q4b, 2q\ell\nu 4b$

$\rightarrow$ $\Delta g_{ttH}/g_{ttH} \approx 6\%$ is possible with 1000 fb^{-1} at $\sqrt{s} = 800$ GeV.

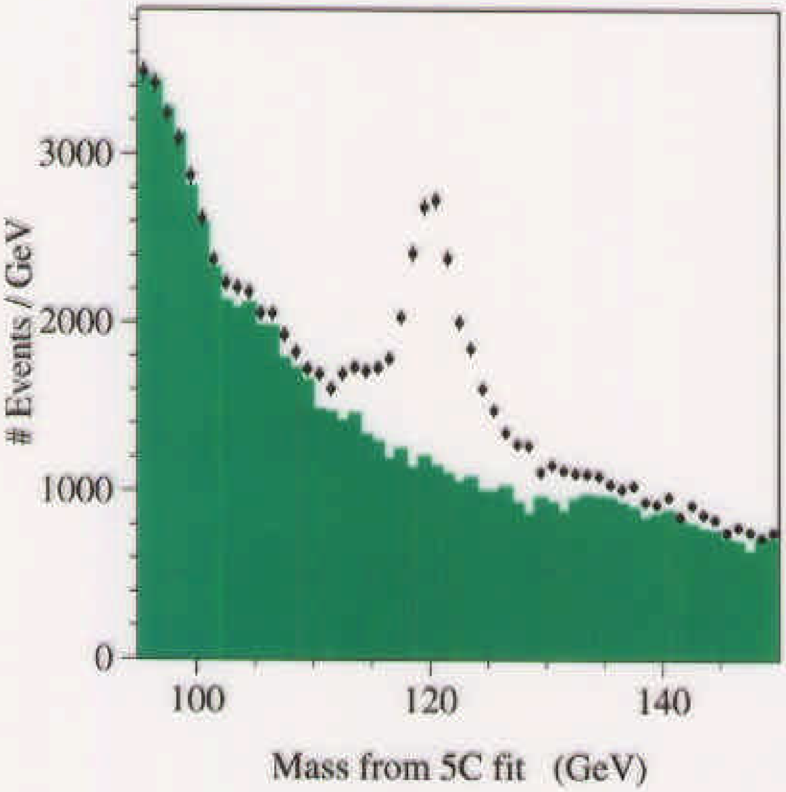
Mass, Width, Spin, CP

Higgs mass measurement:

Best from 5C-Fit in $b\bar{b}q\bar{q}$–events (if $H \rightarrow b\bar{b}$ is large)

Otherwise: use recoil mass spectrum

$\Delta m_H \approx 50$MeV



P.Garcia-Abia
W.Lohmann
(2000)

Total decay width: indirect from BR and cross section measurements:

$\Delta\Gamma_H \approx 5\%$

Spin: from angular distributions and/or from $\gamma\gamma \rightarrow H$

CP, anomalous couplings: polar and azimuthal angular distributions (under study)

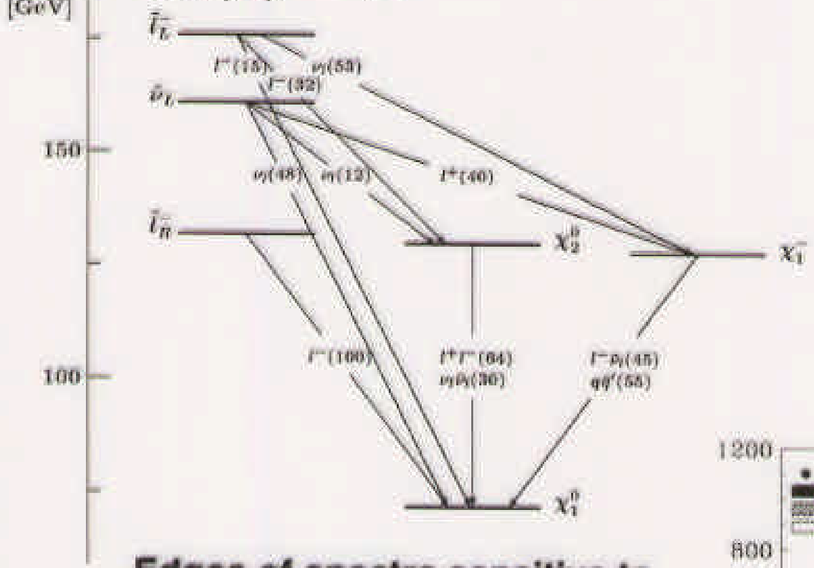
(Kilian, Krämer, Zerwas (1995); Skjold, Osland (1995); Hagiwara, Ishihara, Kamoshita, Kniehl (1999)

Supersymmetry

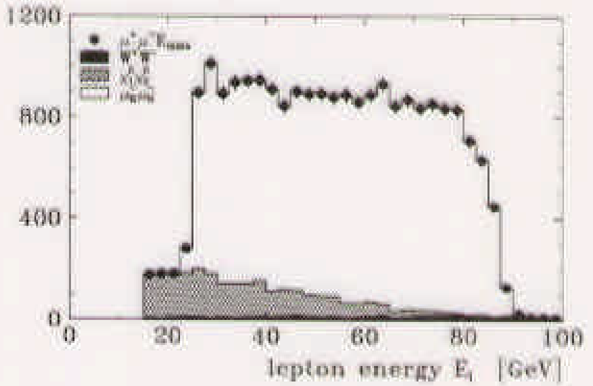
Aim: Precise mass and cross section measurement of all kinematically accessible sparticles
→ explore SUSY breaking mechanism
→ unification at high energy?

Case study: $m_0 = 100$ GeV, $m_{1/2} = 200$ GeV, $A_0 = 0$, $\tan\beta = 3$, sgn$(\mu) = +$.

Martyn,Blair(2000)



Edges of spectra sensitive to masses, e.g. $m_{\tilde{\mu}_R}$ and $m_{\chi_1^0}$ in $\tilde{\mu}_R \rightarrow \chi_1^0 \mu$



Precision of mass measurements:
$\mathcal{O}(200\text{MeV})$ from spectra
$\mathcal{O}(50\text{MeV})$ from threshold scans
Why is such precision needed?

Extrapolation to High Energies

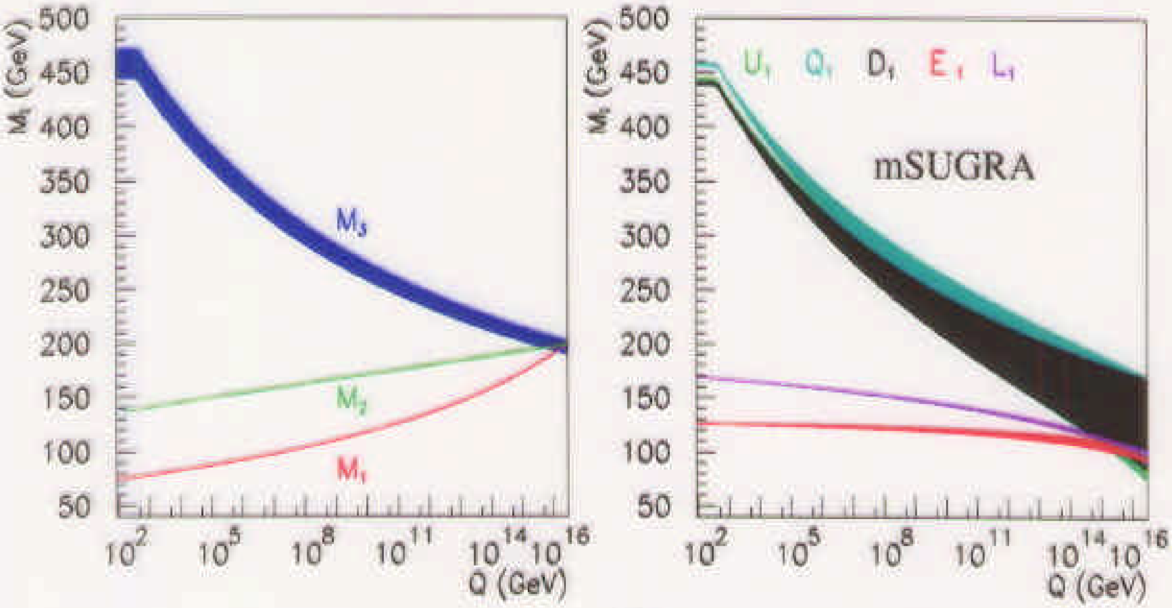
What can be learned from the measured parameters?

Bottom up approach:

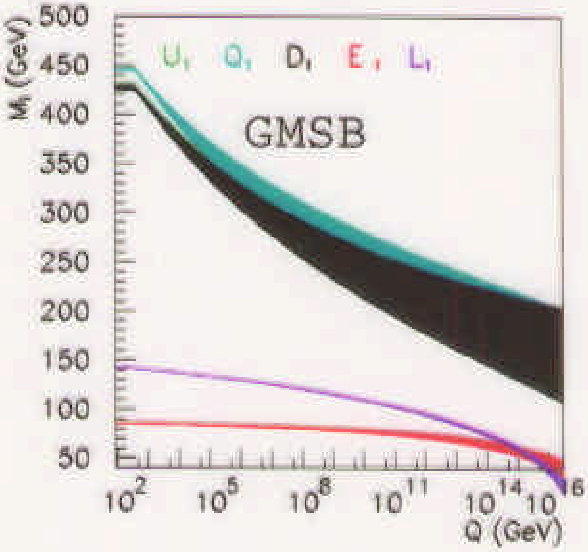
Generate a set of physical observables from some (e.g. mSUGRA) scenario

Reconstruct the mass parameters at the EW scale (with errors)

Evolve those parameters to high scale through RGE's



e.g. GMSB yields a different HE pattern:



Blair,Porod,Zerwas(1999)

Anomaly Mediated Susy Breaking (AMSB)

Abstract 323
Signal of anomaly mediated Wino LSP in a LC
D.K.Ghosh,P.Roy,S.Roy

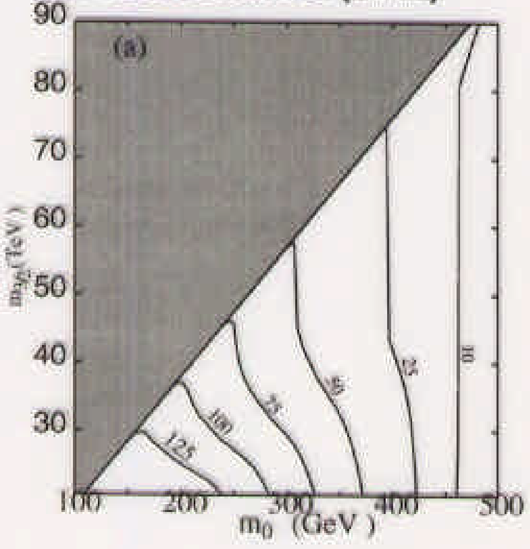
Phenomenology: small $\Delta M = m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0}$ (o(100 MeV))
$\rightarrow$ chargino production difficult to access

If sleptons are kinematically accessible, they provide a striking signal:

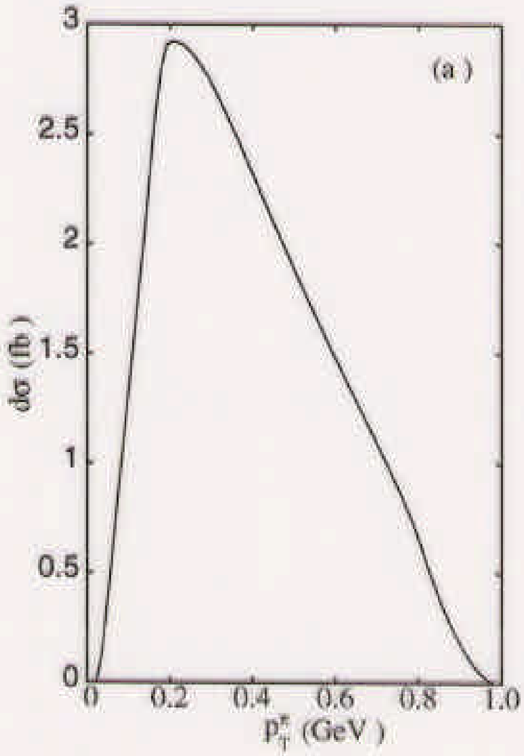
$$e^+e^- \rightarrow \tilde{e}(\tilde{\mu})\bar{\tilde{e}}(\bar{\tilde{\mu}}) \rightarrow \nu\chi^+e(\mu)\chi^0$$

$$\rightarrow e(\mu) + (\mathrm{soft})\pi^\pm + \mathrm{miss.E_T}$$

cross sections (in fb)



pion transverse momentum



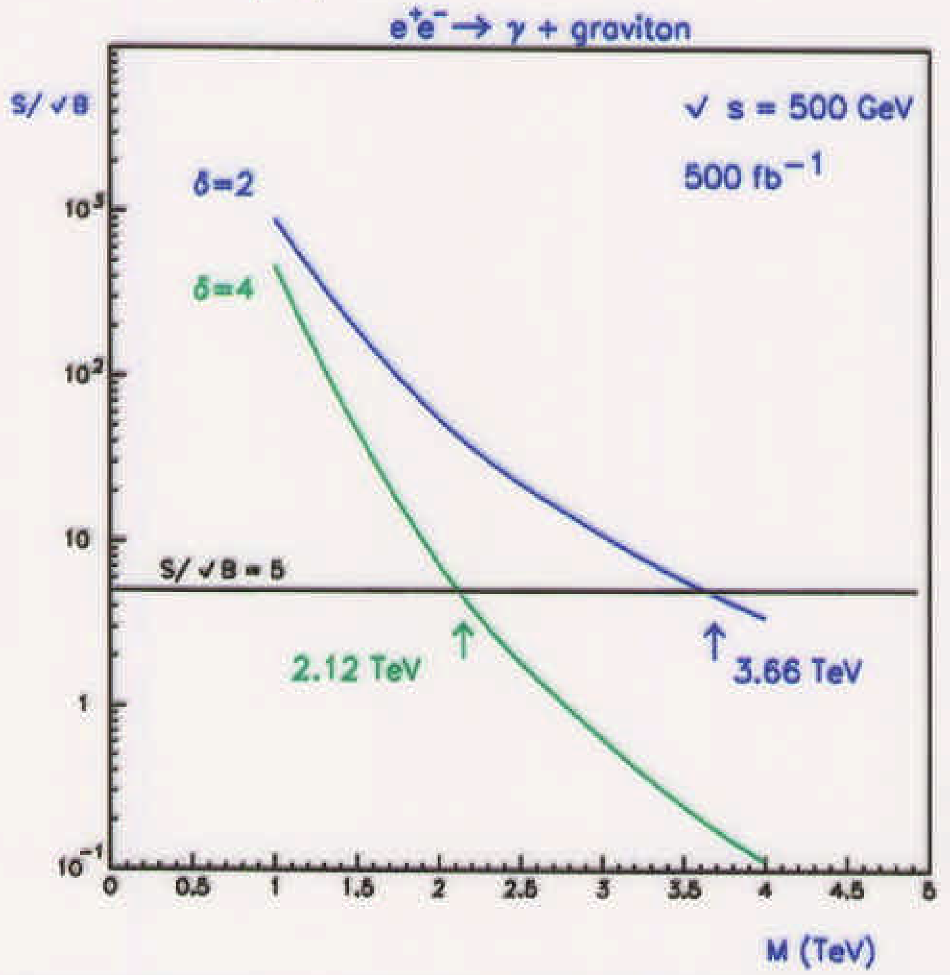
Alternative Theories (few examples)

1. Extra space dimensions:

Motivated by superstrings + solve hierarchy problem

Look for direct graviton production:

$e^+e^- \to \gamma + G$



M.Besancon (1999)

Even higher sensitivity (up to 9 TeV) can be obtained with beam polarisation (supress $\nu\nu\gamma$–background)

G.Wilson (2000)

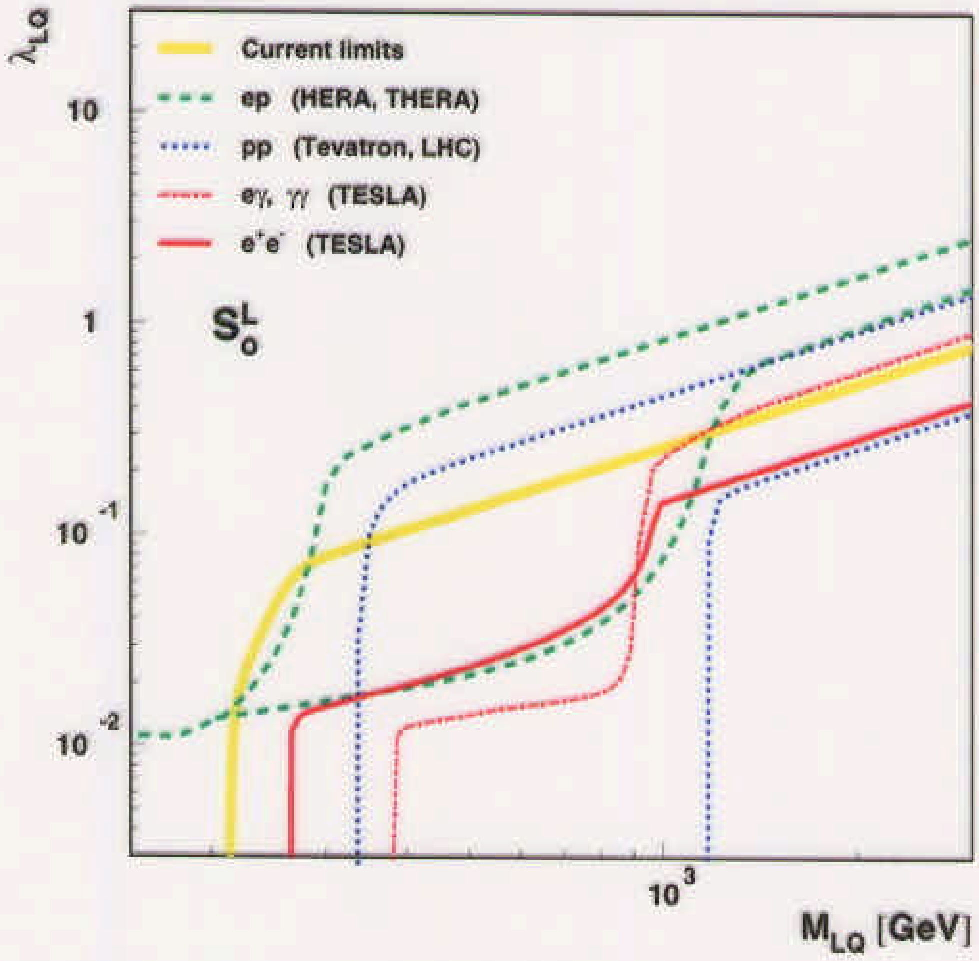
Alternative Theories (few examples)

2. Leptoquark searches:

Abstract 451

A.F.Zarnecki

Leptoquark Searches at Future Colliders



- **LHC has in general better sensitivity**
- **LC has high sensitivity to couplings (in $e\gamma$ mode, single LQ prod.)**
- **LC can study structure of coupling using polarisation of e- and γ beam.**

Alternative Theories (few examples)

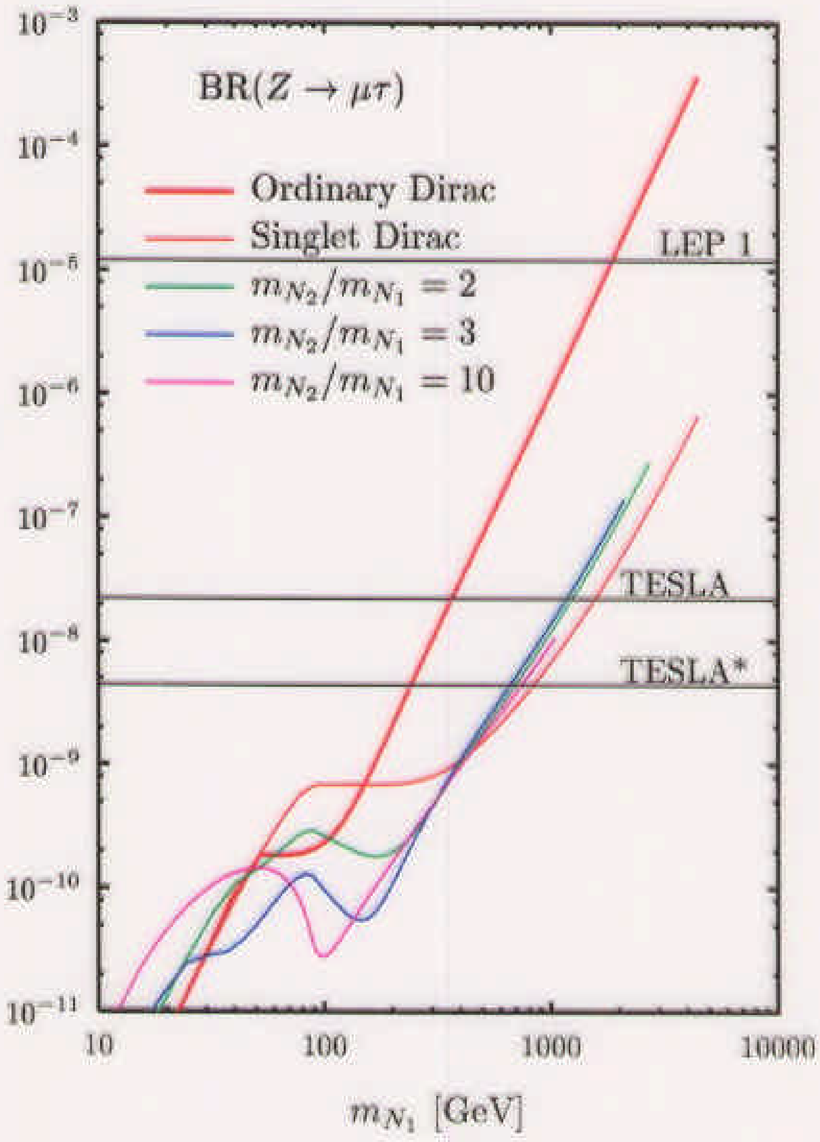
3. Rare Z^0-decays, Lepton-Flavour-Violation at "Giga-Z" (TESLA):

Abstract 469
J.I.Illana, M.Jack, T.Riemann
Lepton Flavour Violation(LFV) in Z decays

Possibility to operate a LC at $\sqrt{s} = m_Z$ with very high luminosity:
$10^9 Z^0$ / year. → allows to extend sensitivity of many searches
e.g. search for LFV Z^0–decays: $Z^0 \to \mu^\pm \tau^\mp$

LFV may arise from

- heavy neutrinos (Dirac or Majorana)
- Leptoquarks
- Heavy neutral gauge bosons (Z')
- Supersymmetery (with slepton intergeneration mixing)



Summary and Conclusions

- An e^+e^-–Collider with 500...1000 GeV has a very rich program of new physics.
- In many cases complementary to LHC:

$\longrightarrow$ precise exploration of Higgs boson properties

$\longrightarrow$ establish essential elements of the Higgs mechanism

$\longrightarrow$ very precise measurement of SUSY spectrum (extrapolate to GUT scale)

$\longrightarrow$ valuable information also in alternative scenarios

- Studies have been performed on a very detailed (theory + expt.) level all around the world.

LC is the right machine shortly after the LHC start.

LC gives a complete and precise picture of physics at the EW-scale and allows a glance to even higher scales through extrapolation of precision measurements