SFB project B1: Physics beyond the Standard Model at the ILC

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A few words to introduce myself

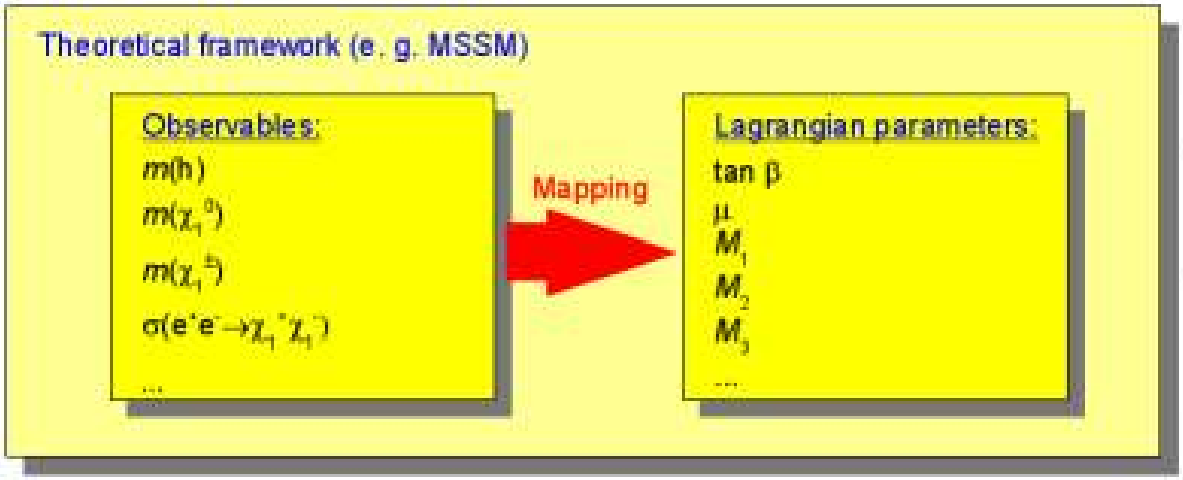
- 1992-1997: Studies of Physics at the University of Hamburg
  - 1996-97: Diploma thesis at the H1 experiment:
    "Detection of J/ψ mesons in inelastic processes at HERA"
- 1998-2000: PhD thesis RWTH Aachen, based at CERN
  "Search for associated production of Higgs and Z^0 bosons decaying to quarks or gluons with the OPAL experiment"
- 2000-2005: Various postdoc positions at DESY and Wuppertal and Hamburg universities working on ILC, H1 & HERA polarimetry, D0 and ATLAS
- since 2006: DFG Emmy-Noether grant for
  "Polarimetry and Dark Matter Searches at the ILC":
  - physics requirement: dP/P = O (0.1%), best so far: 0.5% (SLD)
    => detector R&D!
  - simulation studies in various dark matter scenarios
    => study detector and machine requirements, running strategies,....
    fits very well with SFB!

B1 Project Overview

- five subprojects: mainly SUSY, alternatives concerning dark matter
- project leaders: J. Haller, J. List, P. Zerwas
- currently active:
  - S.Y.Choi (th. visiting scientist, until mid January)
  - U. Martyn (exp. DESY staff)
  - C. Bartels (exp. diploma student)
- starting soon:
  - Nov. 06: D. Käfer (exp. postdoc, part time on SFB matters)
  - ~ Jan. 07: M. Awramik (th. postdoc with B. Kniehl)
  - Jan. 07: C. Bartels (exp. PhD student)
- open positions:
  - exp. postdoc (SFB)
  - 1-2 exp. PhDs (Emmy-Noether grant)

(i) Measurements of basic SUSY parameters:

"Which experimental measurements are needed to determine the fundamental parameters of the theory?"



$$\begin{pmatrix} P_1 \\ P_2 \\ \vdots \end{pmatrix} = \begin{bmatrix} \square & & 0 \\ & \square & \\ 0 & & \square \end{bmatrix} \begin{pmatrix} O_1 \\ O_2 \\ \vdots \end{pmatrix}$$

Tree level

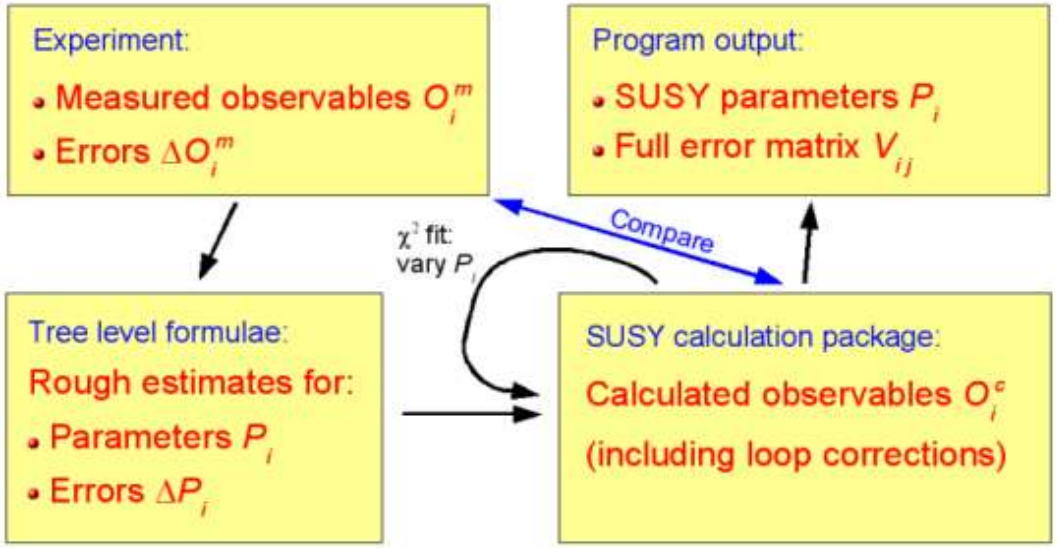
$$\begin{pmatrix} P_1 \\ P_2 \\ \vdots \end{pmatrix} = \begin{bmatrix} \square & & \neq 0 \\ & \square & \\ \neq 0 & & \square \end{bmatrix} \begin{pmatrix} O_1 \\ O_2 \\ \vdots \end{pmatrix}$$

Loop level

=> use programs like Sfitter, Fittino to figure out the required precision on the observables!

Plan:

- D. Käfer will start on this
- P. Bechtle - author of Fittino invited for second half of November



Measuring the Spin of SUSY particles

- important inputs are not only masses and cross sections, but also **spins**
- paper in preparation by S.Y. Choi, U. Martyn, P. Zerwas (with K. Hagiwara, K. Mawatari)
- observables:
  - cross section rise at threshold ~ β or β^3 (s-wave or p-wave)
  - polar angle distribution $d\sigma/d\cos\theta$
- allow clear distinction of SUSY from other scenarios, e.g. Kaluza-Klein existed states in Universal Extra Dimensions
- example of combined LHC & ILC analysis and interpretation:
  - ILC: neutralinos, charginos
  - LHC: gluinos

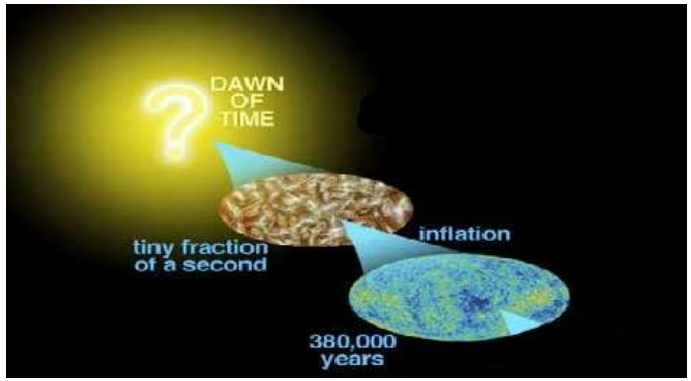
(ii) Dark Matter scenarios in SUSY...

"Figure out detector & machine requirements to make sure the ILC can cover the WMAP allowed MSSM regions" - two examples:

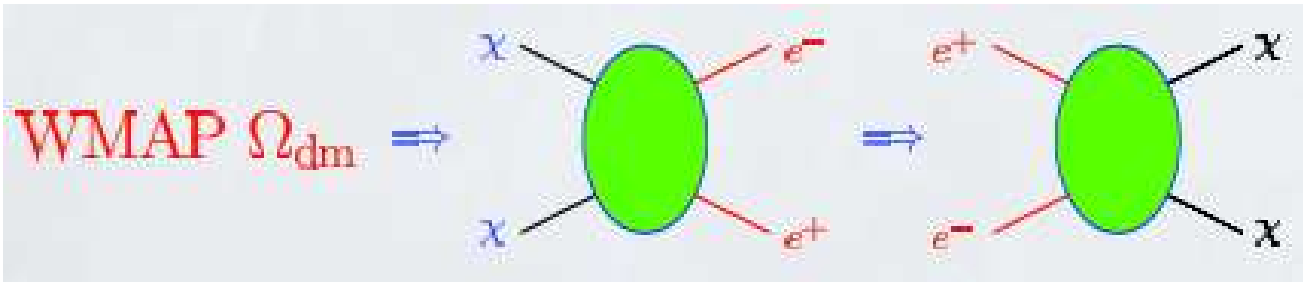
- "stau-coannihilation" scenario:
  Lightest SUSY Particle (LSP, stable!): neutralino $\tilde{\chi}_1^0$
  Next-to-LSP: $\tilde{\tau}_R$, not much heavier: $\Delta m \approx$ few GeV
  => τ from decay very soft => experimentally challenging
  => benchmark process for defining accelerator parameters
  status: existing studies from DESY, Orsay, Colorado
  => different conclusions? => discussions / cross-checks ongoing!
- gravitino is LSP, NLSP ($\tilde{\tau}$) is meta-stable
  => trapped in detector for hours, days, months,....
  => very special experimental requirements
  2 day workshop dedicated to this topic beginning of December (W. Buchmüller)

(ii) ... and model-independent analysis

- "What can we learn about WIMP dark matter without assuming a specific scenario?"

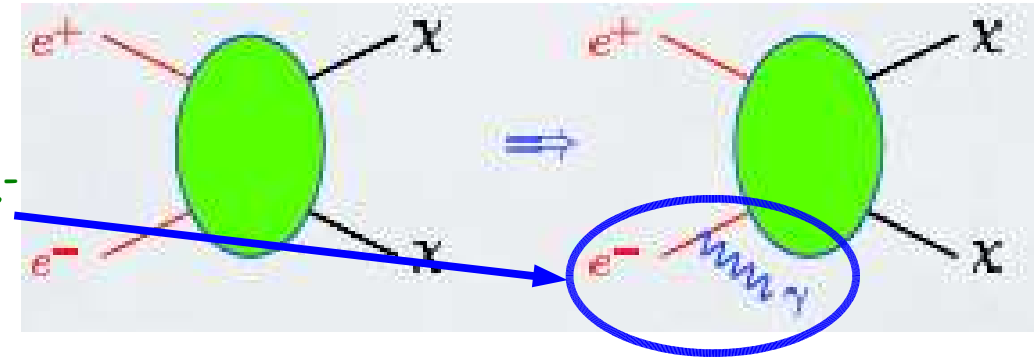


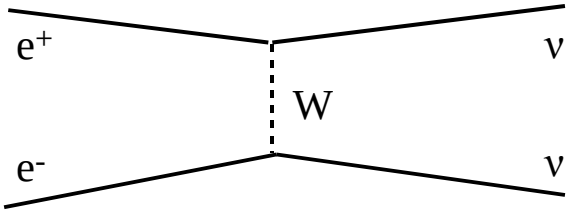
- reminder:
  - early, hot universe: WIMPs (χ) in thermic equilibrium
  - expansion => cool down => WIMPs "freeze out"
- idea:
  - relic density Ω_{dm} depends on rate of χχ -> SM particles
  - (this is a model assumption – e.g. stau-coannihilation NOT covered)
  - crossing symmetry: => rate e^+e^-->χχ ! [A.Birkedal et al hep-ph/0403004]

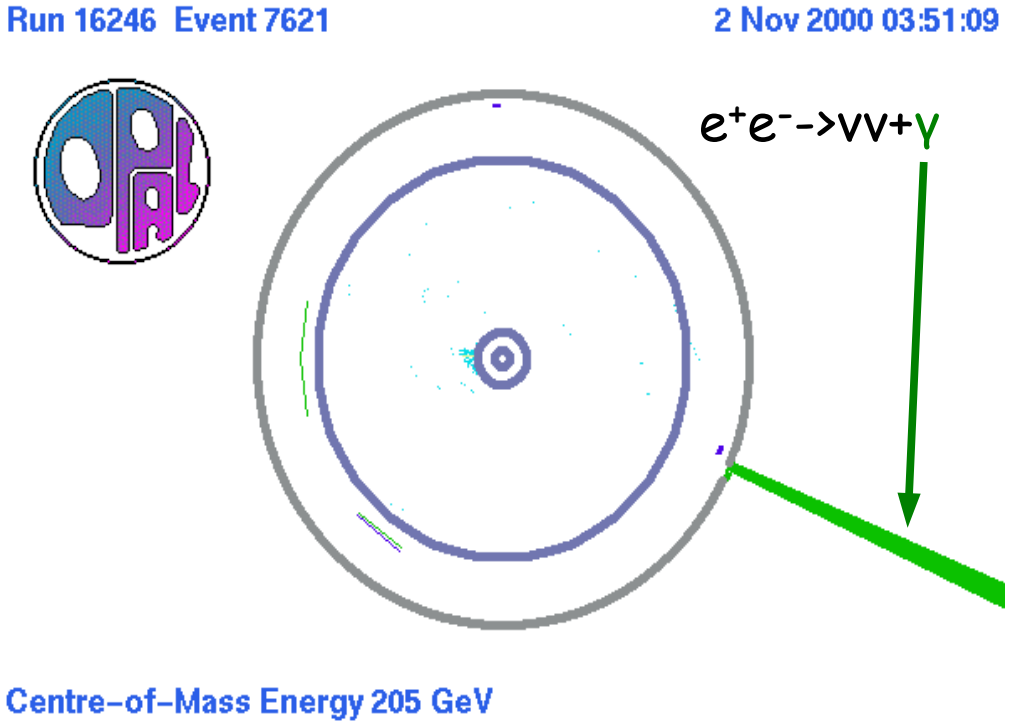


Detection in Collider Experiment?

- problem:
  χ is invisible in detector!
- trick: use photon radiated off e^+ or e^-
- WMAP => $\sigma(e^+e^- \to \chi\chi\gamma) \approx 0.1 \ldots 10$ fb
  ~ 50....5000 events / 4 years ILC
- is this possible?
  in principle: yes!
  => compare LEP measurement:
  $e^+e^- \to Z^0 \to \nu\nu\ (+\gamma)$
  but: not easy!
- main background: $e^+e^- \to \nu\nu\ (+\gamma)$

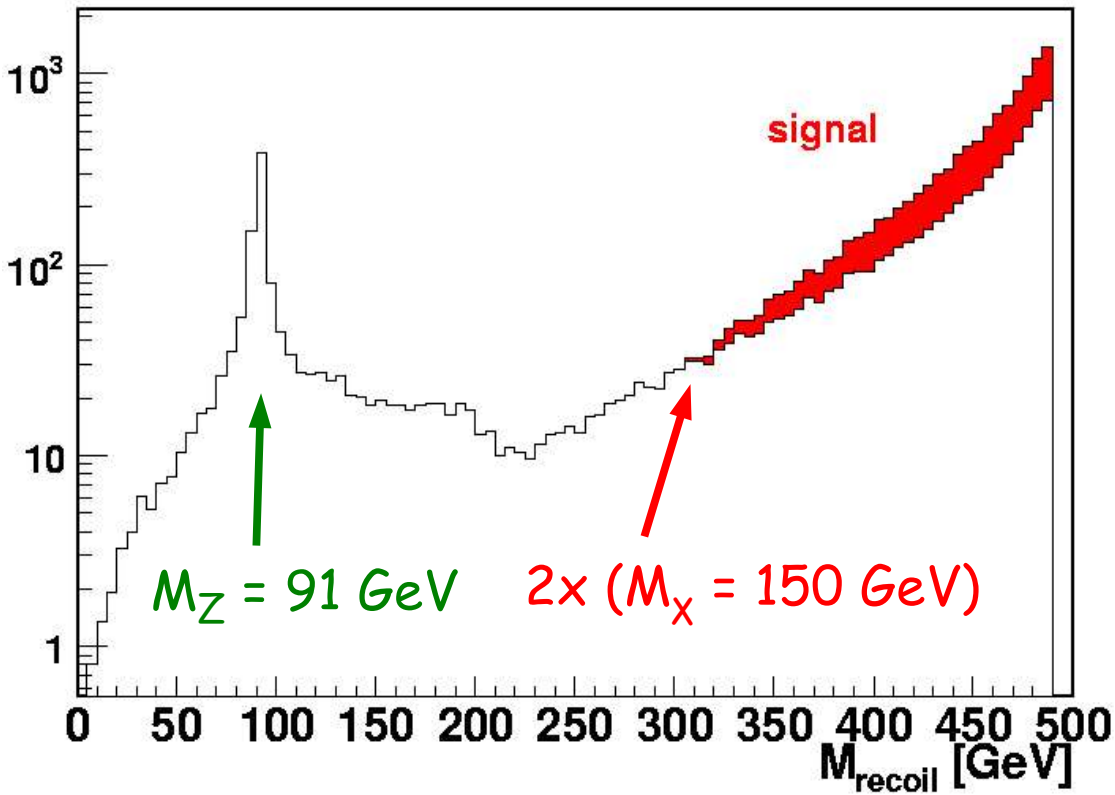






Study by C.Bartels (work in progress)

- e^+e^- collisions at $\sqrt{s}$ = 500 GeV, P = 0 and P = 80% (e^-) , 60% (e^+)
- MC generator NUNUGPV: $e^+e^- \rightarrow \nu\nu$ + up to 3γ's
  reweight in energy and polar angle of photon to signal cross section according to WIMP mass, spin & coupling to e^+e^- (κ_e)
- signal cross section currently only for non-relativistic WIMPs
  => M > 80 GeV @ 500 GeV
- **full detector simulation:**
  Large Detector Concept
  (successor of TESLA)
- backgrounds not yet included:
  - machine (beamstrahlung)
  - instrumental (misidentified events from other processes)
- no systematics yet

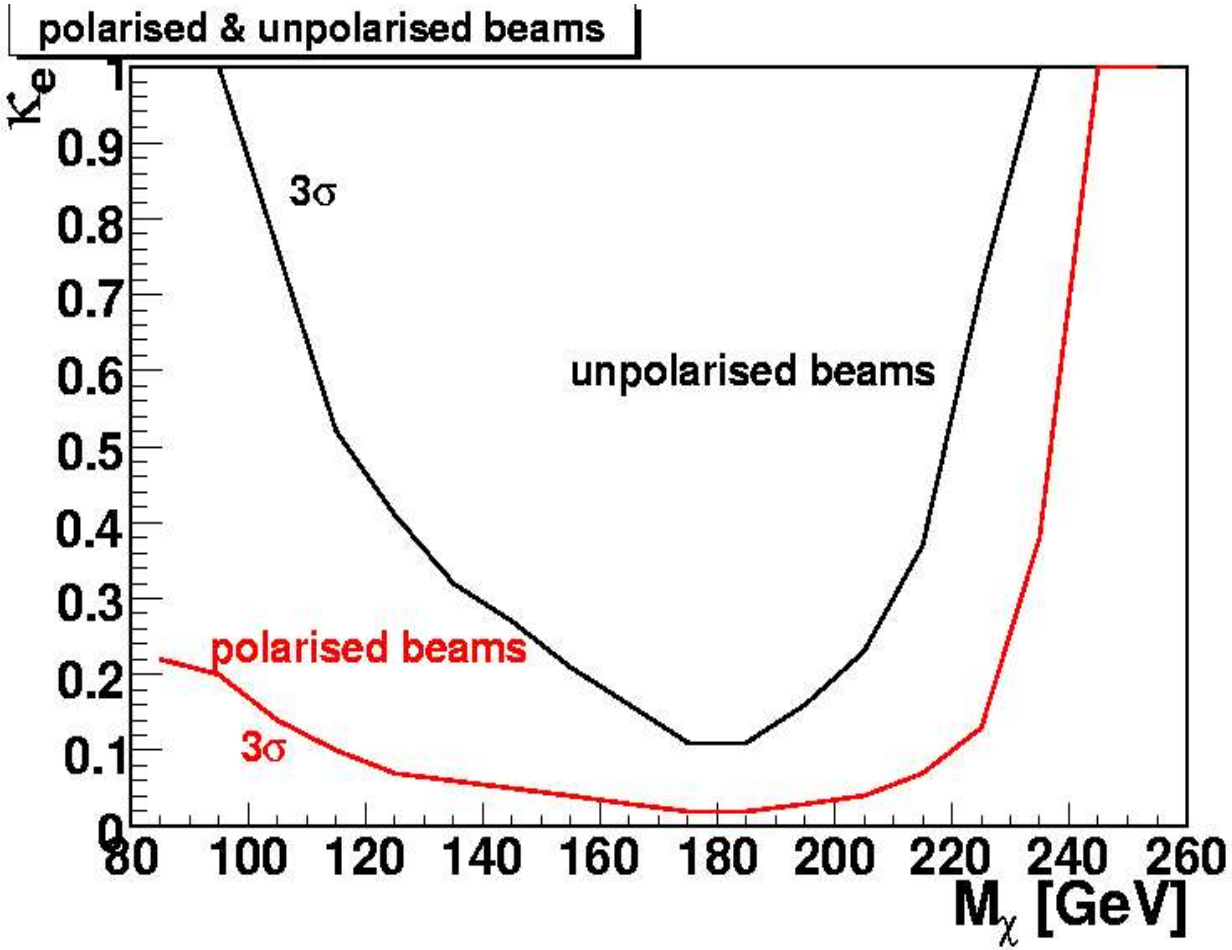


Observation Reach

- 3σ sensitivity for integrated luminosity of 50 fb^{-1} (less than 1 year of ILC running):
  - Polarisation dependency: 'best case' assumed, i.e. WIMPs behave opposite to SM neutrinos

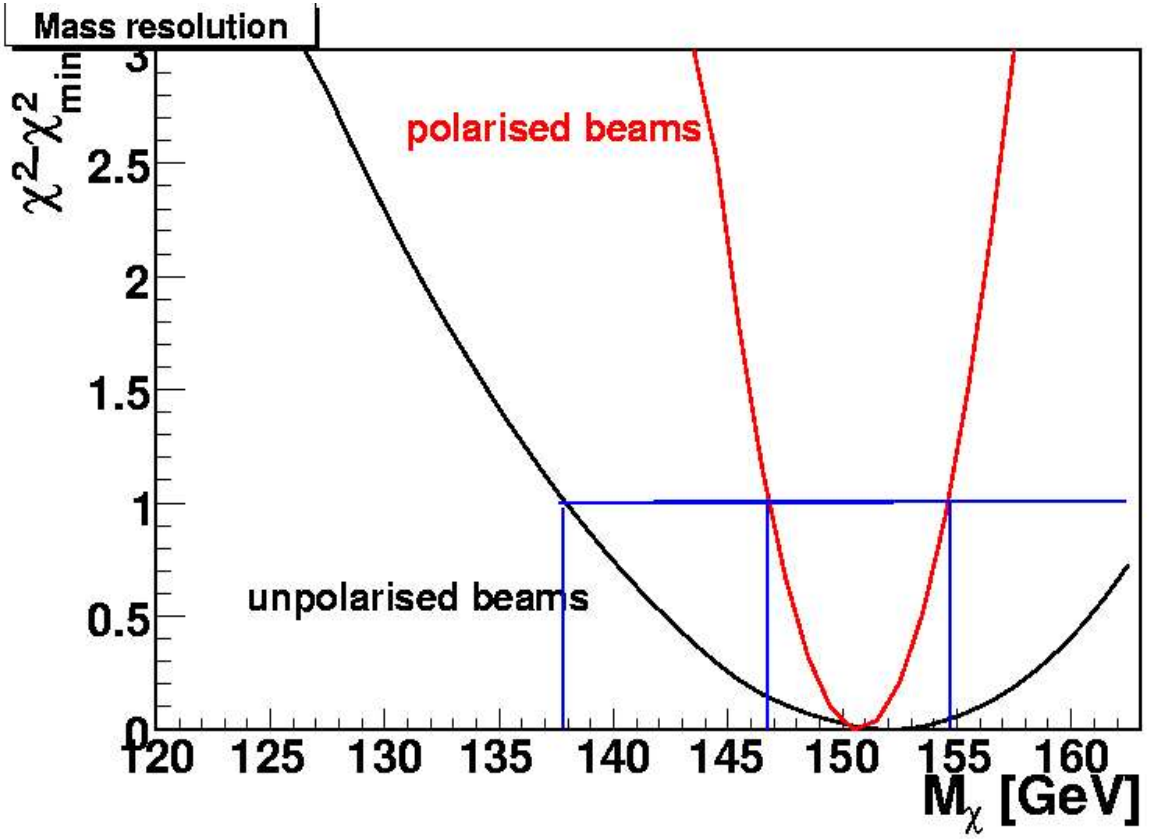
    $P(e^-) = 80\%$

    $P(e^+) = 60\%$



Mass Resolution

- again for integrated luminosity of 50 fb^{-1} (less than 1 year of ILC running):
  - χ^2 test w.r.t. template recoil mass distributions
  - resolution:
    ± 4 GeV to ± 14 GeV
- not a precision measurement but interesting if e.g.
  - SUSY not found @ LHC
  - scenario not clear
  - visible SUSY particles too massive for the ILC
  - SUSY without stable LSP, i.e dark matter must be something else



(iii) Higgs and SUSY particles beyond the MSSM

"What happens if there is an additional Higgs singlet or an additional (broken) U(1) gauge symmetry ?"

- work in progress on theoretical side: "USSM = MSSM x U(1) "
  - suggested by GUT / Superstring models
  - upper limit on lightest Higgs mass increased
  - one additional scalar, two more neutralino states
  - paper in preparation by S.Y. Choi, P. Zerwas (with H. Haber, J. Kalinowski) -> mass spectra, cross sections, partial widths
- experimental studies: no plan (person power) yet

(iv) Reconstruction of the fundamental SUSY theory and its breaking mechanism

"What could we encouter when extrapolating SUSY from observations at TeV scale to GUT scale? Are there intermediate scales?"

- consequences of neutrino masses (A. Freytas, W. Porod, P. Zerwas):
  if small neutrino masses due to see-saw mechanism
  => see-saw scale will affect evolution of soft SUSY breaking terms, especially for third generation
  => universality broken at electro-weak scale
  => can determine see-saw scale!
- detailed SO(10) analysis in progress (P. Zerwas, W.Porod, F. Deppisch)
- universal mass parameters at GUT (mSugra) or intermediate (GMSB) scales?
- effects of string theories (if reduced to effective field theories)?

(v) Multi-loop precision studies in SUSY

- experimental precision expected at ILC typically below 1% level

=> need matching (even better) precision for theoretical predictions

=> need two-loop order!

- M. Awramik developed numerical method for efficient multi-loop calculations in SM
  - currently: application to M_W, $\sin\theta_{eff}$, bb, Γ_Z
  - next year: extension to SUSY-loops & quantities planned

Conclusions

- some activities already started or are expected soon:
  - model-independent WIMP-search
  - studies on spin determination for SUSY particles
  - visit from Fittino-author
  - workshop on stau-gravitino dark matter scenario
  - USSM
  - neutrino masses
  - SUSY calculations @ two-loop-level
- currently mainly limited by lack of person power
  (open postdoc & PhD student positions)