SUSY Studies

LCWS 05, Stanford, 18-22 March 2005

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Outline

- Key questions
- Why SUSY
- Activities
- The frame
- Recent progress
- What if ...
- Summary and outlook

Key questions

- Origin of mass? Is it the Higgs mechanism, or ...?
- Origin of matter-antimatter asymmetry?
- Properties of neutrinos?
- Unification of forces, including gravity?
- Dark matter, dark energy?

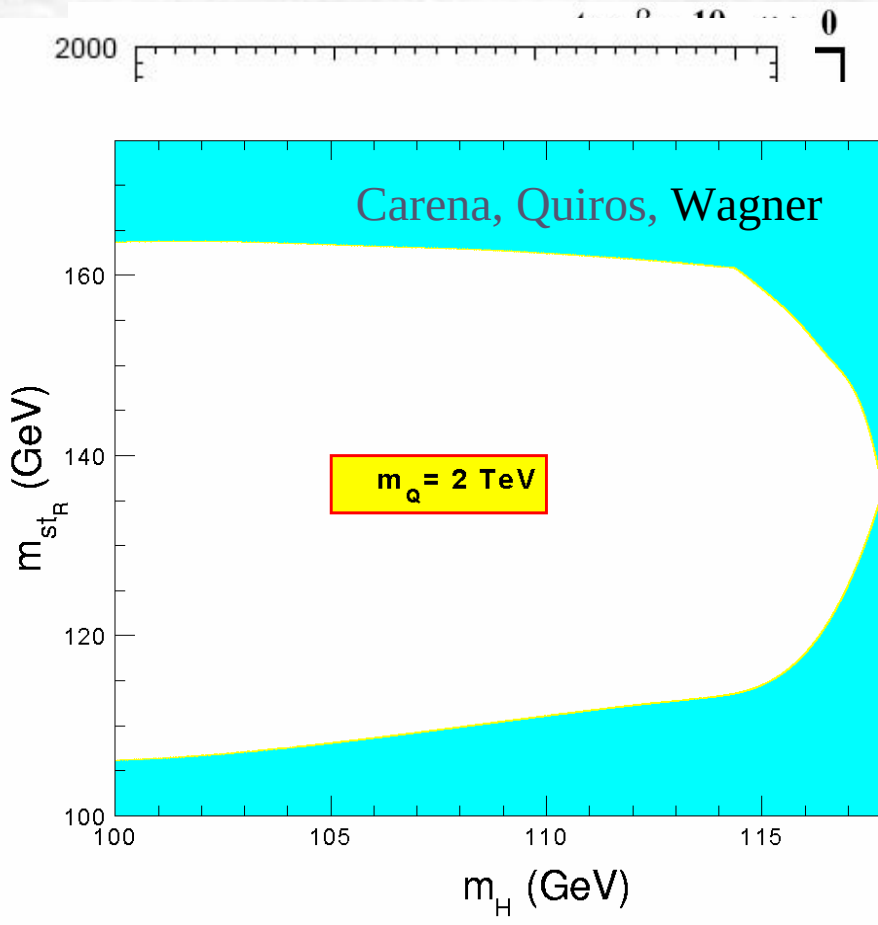
- SUSY may be related to all these questions
- SUSY can be tested at colliders
- the ILC provides essential tools for discovery answers

Discovering SUSY – a revolution in particle physics

Why SUSY ?

Pros:

- predicts gauge unification
- dark matter candidate
  - **WMAP constrains models, e.g.**
  - **but neutralinos are visible at ILC**
- naturally consistent with EW data
- relaxing model assumptions
- electroweak baryogenesis



Cons:

A 'little hierarchy' problem?

- non-minimal SUSY, extra gauge factors, ..
- remove scalars → Split SUSY

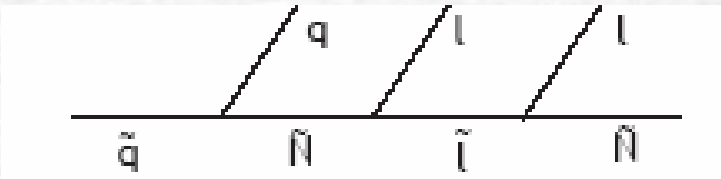
Activities

SUSY WG talks:

W. Hollik - Supersymmetry Parameter Analysis: SPA Convention and Project
P. Bechtle - Supersymmetry Parameter Analysis with Fittino
D. Stockinger - Renormalization and Regularization of SUSY theories
K. Kovarik - Precise Predictions for SUSY Processes at the ILC
W. Kilian - Split Supersymmetry at the Linear Collider
G. Moortgat-Pick - Distinguishing Between MSSM and NMSSM via Combined LHC/ILC Analyses
H. Baer - Crazy SUSY Scenarios for the ILC That Just Might be True
M.A. Diaz - Neutrinos in Supersymmetry
N. Haba - Higgs Mass in the Gauge-Higgs Unification Theory
A. Birkedal - Complementarity of Precision Studies at the LHC and the ILC
P. Osland - Supersymmetric Cascade Decays
R. Godbole/S. Kraml - Fermion Polarization in Sfermion Decays
E. Boos - Impact of Tau Polarization for Study of the MSSM Charged Higgses in Top Quark Decays at ILC
B. Schumm - Forward Selectron Production and Detector Performance
K.C. Kong - Impact of Beamstrahlung on Precision Measurements of New Physics at
H. Nowak - Studies on Scalar Top Quarks, Chargino and Scalar Lepton Production at LC
U. Nauenberg - The Importance of Positron Polarization and the Deleterious Effects of Beam/Bremmstrahlung on the Measurement of Supersymmetric Particle Masses
C. Wagner - Low Energy Supersymmetry and Electroweak Baryogenesis
C. Milstene - Analysis of Stop Quarks With Small Stop-Neutralino Mass Difference at LC
J.L. Kneur - Updated Constraints on the mSUGRA and Prospects for Sparticle Production at the ILC
G. Weiglein - Indirect Sensitivities to the Scale of SupersymmetrySS

The frame

- LHC will see SUSY if squarks/gluinos below 2-3 TeV
- Many channels from squark and gluino decays

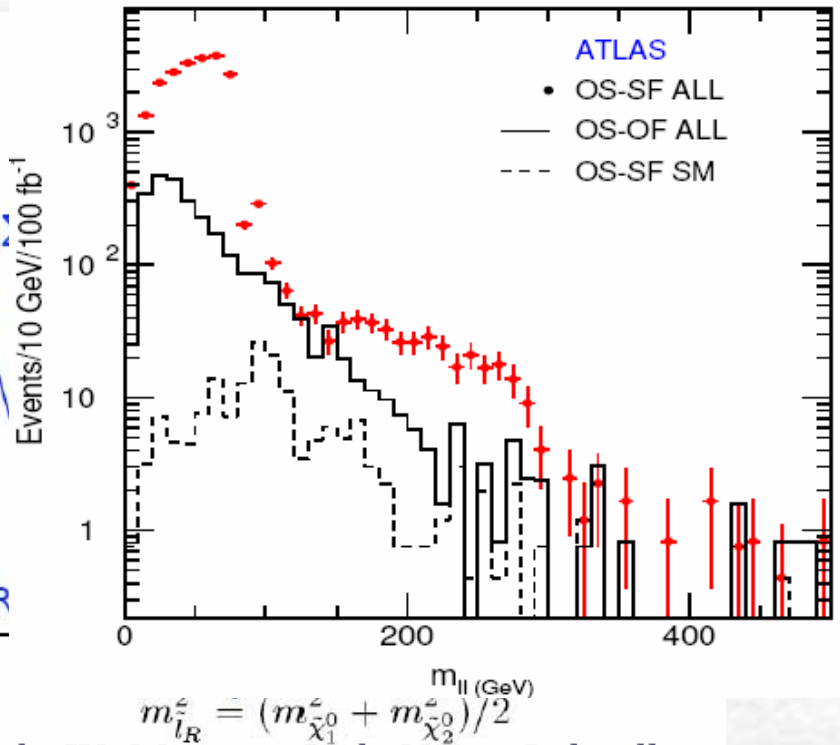


Moreover, ILC can help identifying heavy neutralino at LHC

Even if standard SUSY, false solutions may occur

Need ILC to eliminate them

Peskin



$m^{e}_{l_R} = (m^{e}_{\tilde{\chi}^0_1} + m^{e}_{\tilde{\chi}^0_2})/2$

Desch, JK, Moortgat-Pick, Nojiri, Polesello

- ILC needed for precision and model-independent studies

The frame

From theory: important goals to achieve

- accurate theoretical calculations to match the experimental data
- model-independent reconstruction of Lagrange parameters and SUSY breaking mechanism
- SUSY – a bridge between EW and GUT/Planck scales

to achieve these goals

the SPA Project

has been proposed

→ **http://spa.desy.de/spa**

The SPA Project

SUPERSYMMETRY PARAMETER ANALYSIS

W. Hollik

http://spa.desy.de/spa

- SPA Convention

  renorm. schemes / LE parameters / observables

- Program repository

  th. & exp. analyses / LHC+ILC tools / Susy Les Houches Accord

- Theoretical and experimental tasks

  short- and long-term sub-projects

- Reference point SPS1a'

  derivative of SPS1a, consistent with all data

- Current and future developments

  CP-MSSM, R_pV, Split, nMSSM, effective string th., etc.

Recent progress

DRbar scheme:

D. Stockinger
hep-ph/0503129

1. DRED is mathematically inconsistent and there is no full proof that SUSY is preserved

⇒ Replace ordinary 4-dim space by yet another ∞-dimensional space with some 4-dim characteristics → "quasi-4-dim space"

quasi-4-dim space can be explicitly constructed ⇒ no mathematical problems, no inconsistency, unique results for calculations

Check that DRED preserves SUSY in some interesting cases

2. Problem with factorization -- needs further study

Recent progress

- positron polarisation
- slepton masses
- f $\tilde{f}$ χ chiral structure in

  $\tilde{\tau}$ –> $\chi\tau$ decays

- t –> H^+ b, H^+ –> $\tau\nu$

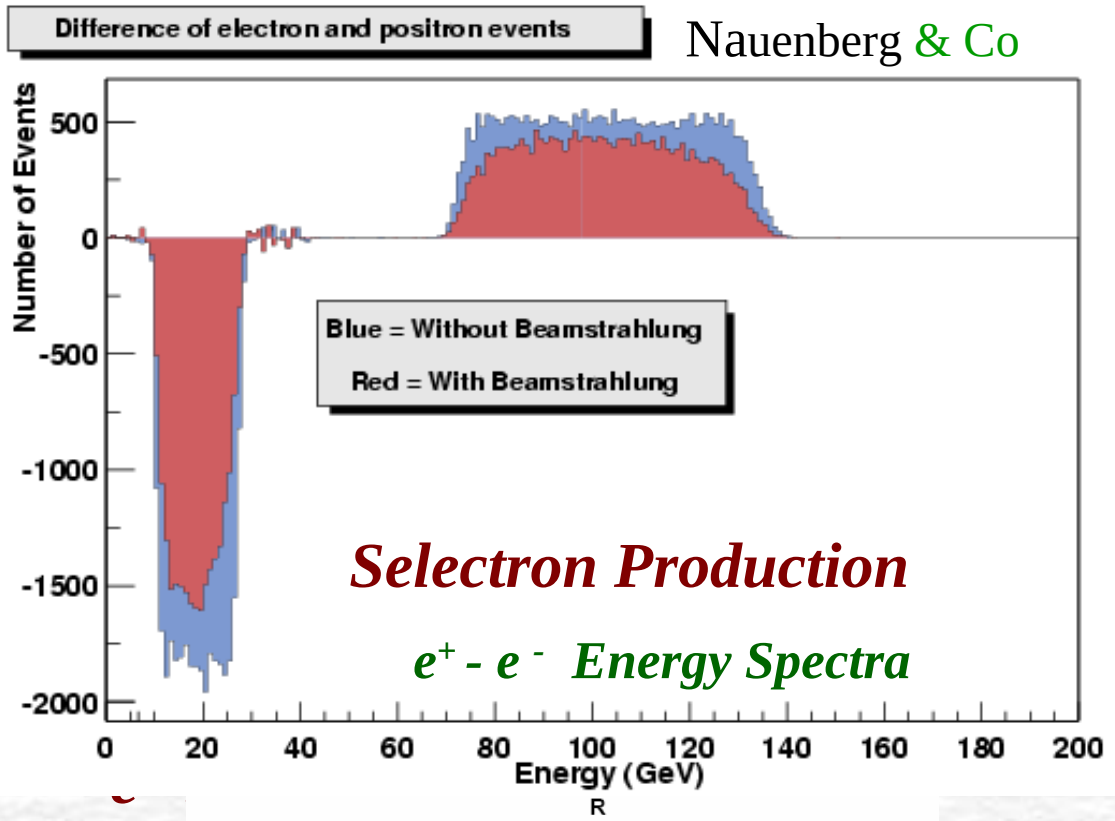
$\tilde{e}^+\tilde{e}^- \rightarrow all\ e\ e$ Boos, Bunichev, Carena, Wagner Nauenberg & Co

π-meson energy spectrum for MSSM intense coupling point

e^+ 80%

e^+ 0 p

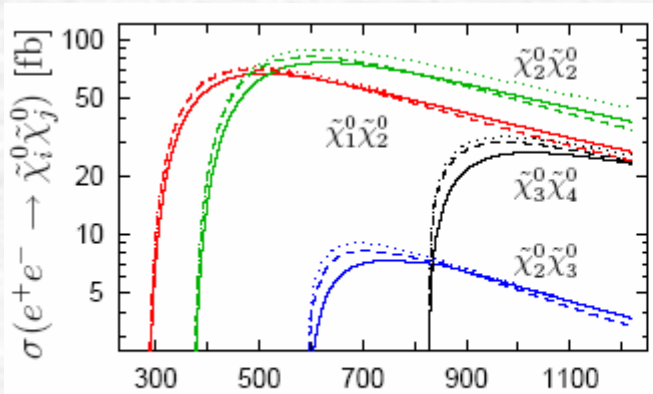
Nauenberg & Co

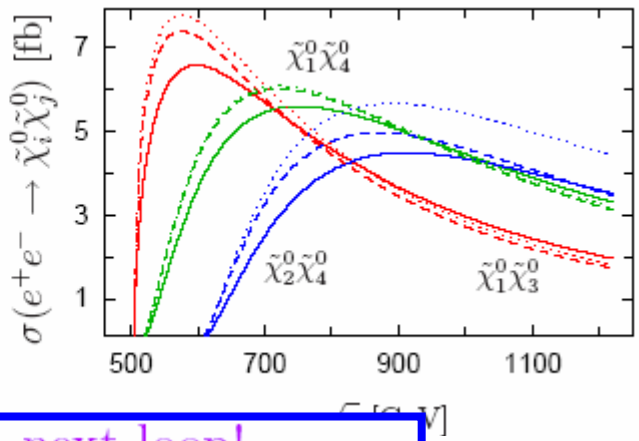


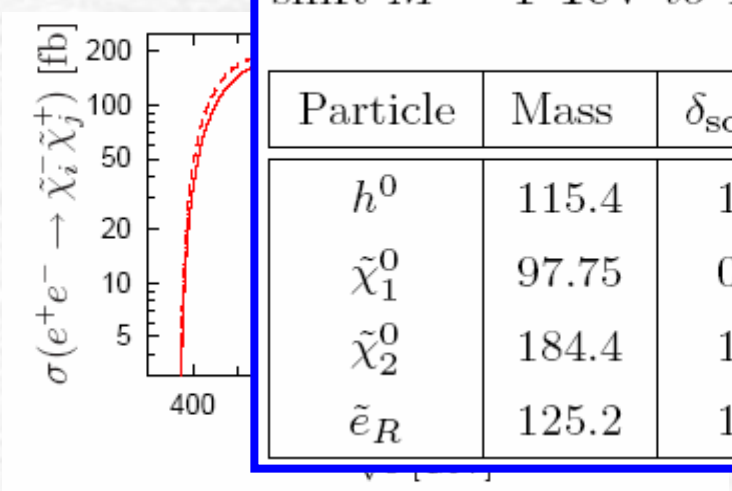
Recent progress

Loop corrections are needed to match experimental precision

K. Kovarik

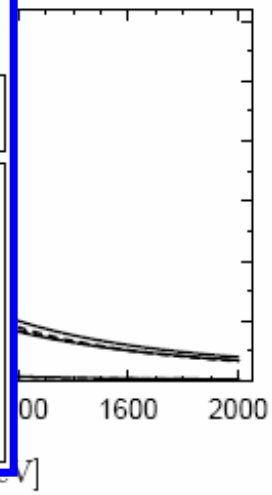






shift $M = 1$ TeV *to* 100 GeV $\Rightarrow$ next loop!

Particle	Mass	δ_{scale}	Particle	Mass	δ_{scale}
h^0	115.4	1.3	$\tilde{u}_R$	547.7	9.4
$\tilde{\chi}_1^0$	97.75	0.4	$\tilde{t}_1$	368.9	5.4
$\tilde{\chi}_2^0$	184.4	1.2	$\tilde{g}$	607.6	1.4
$\tilde{e}_R$	125.2	1.2			



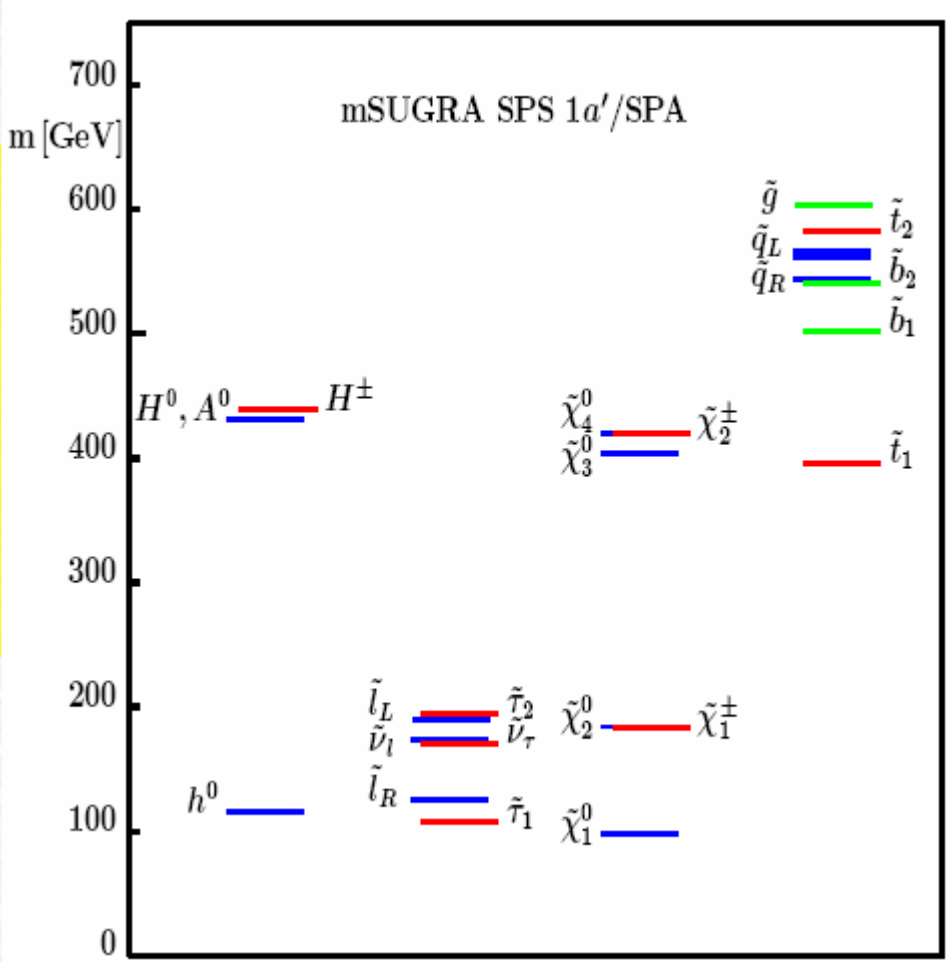
Higher order calculations mandatory

- SPS1a'- derivative of the SPS1a point

mSUGRA values:

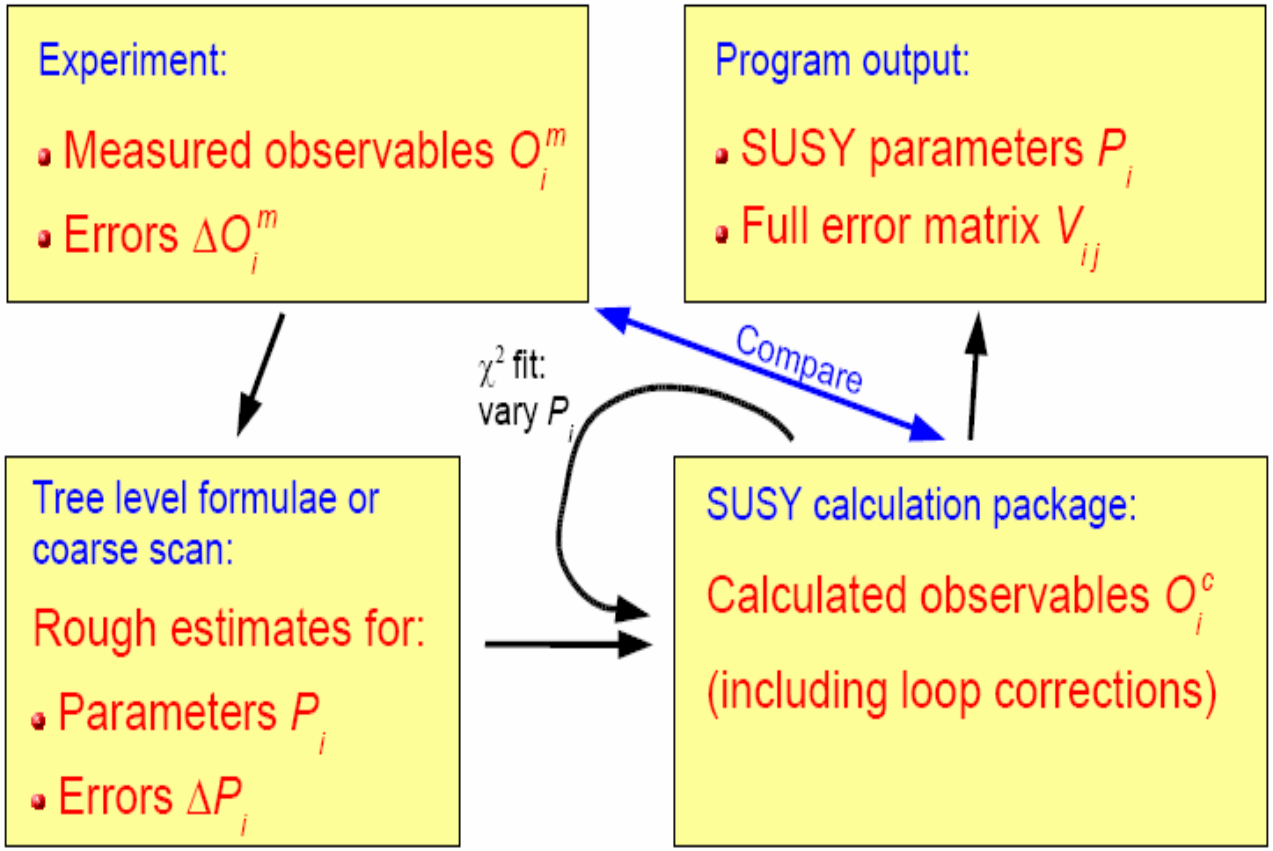
m_0	70 GeV
$m_{1/2}$	250 GeV
A_0	-300 GeV
$\tan\beta$	10
sign μ	$+$

$$BR(b \to s\gamma) = 3.0 \times 10^{-4}$$
$$\Delta[g_\mu - 2]/2 = 33 \times 10^{-10}$$
$$\Omega_{cdm}h^2 = 0.10$$

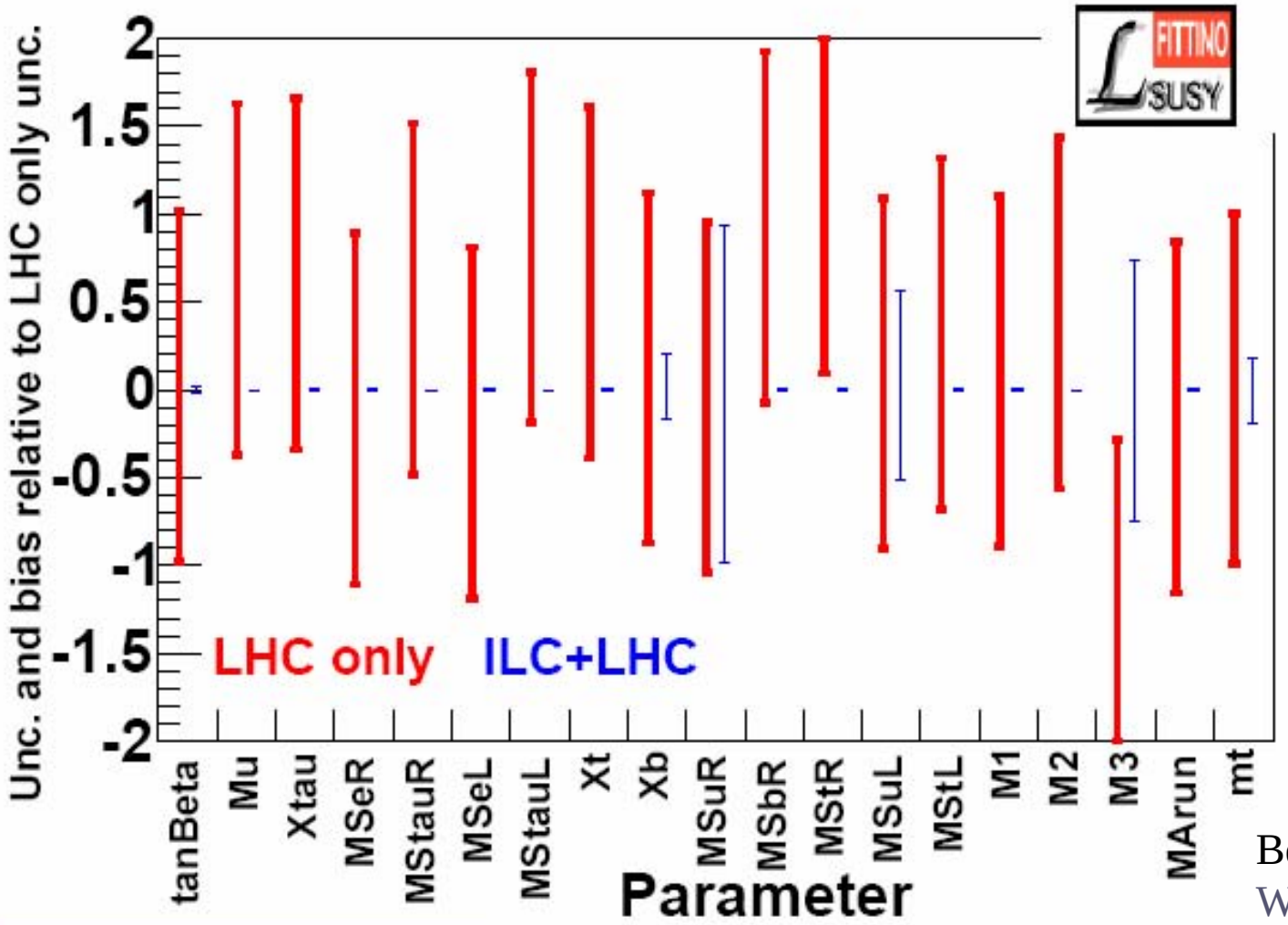


Reconstructing Lagrange param.

- global analysis codes:
  SFitter (R. Lafaye, T. Plehn and D. Zerwas)
  Fittino (P. Bechtle, K. Desch, P. Wienemann)
- fit masses + xsecti
  and BR
- radiative correction
- ex: Fittino



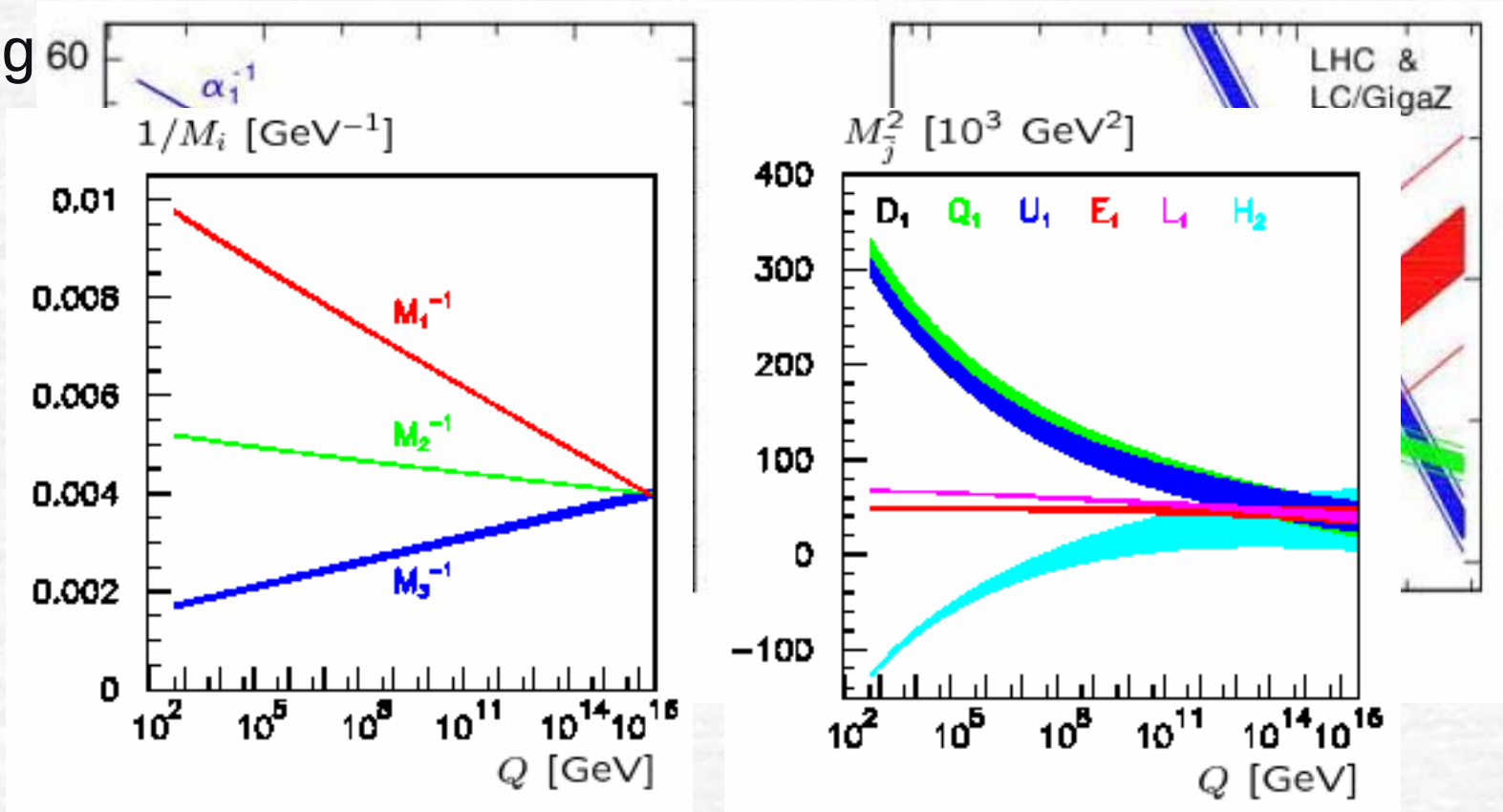
Comparison of LHC and ILC+LHC



Bechtle, Desch Wienemann

High-scale extrapolation

- gauge couplings α^{-1}
- g

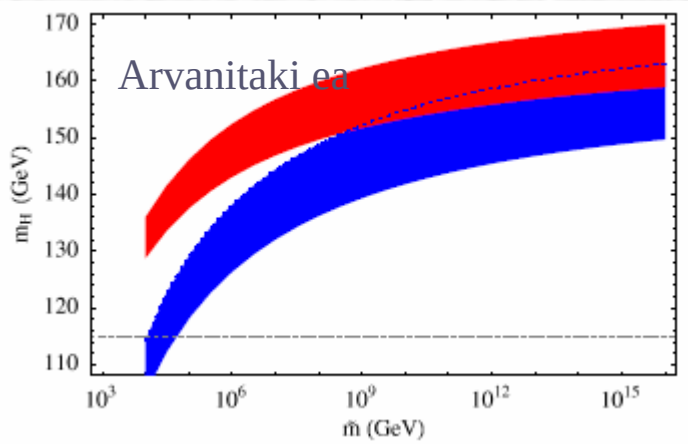


- universality can be tested in bottom-up approach

What if ...

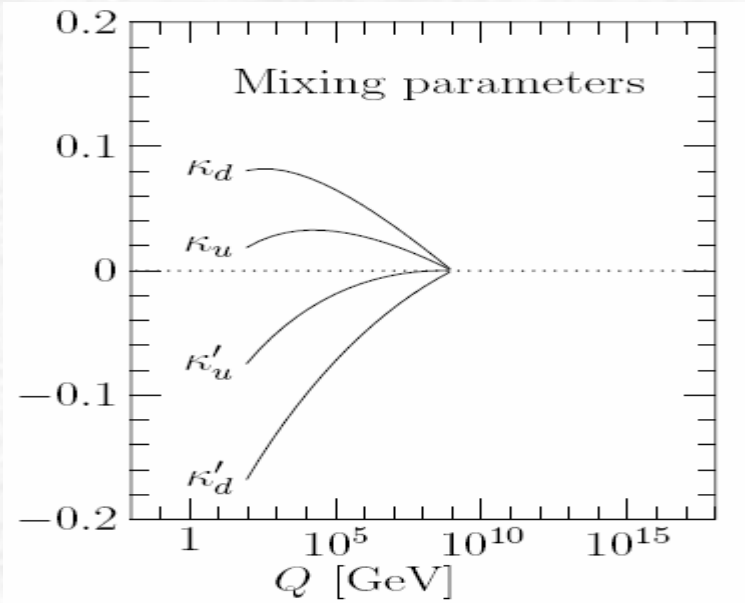
- Split SUSY — Arkani-Hamed, Dimopoulos

$$\begin{aligned}\mathcal{L} \supset\ & \tilde{B}(\kappa_1' h^\dagger \tilde{H}_1 + \kappa_2' h \tilde{H}_2) \\ & + \tilde{W}^a(\kappa_1 h^\dagger \tau^a \tilde{H}_1 + \kappa_2 \tilde{H}_2 \tau^a h) - \lambda |h|^4 \\ & - \mu \tilde{H}_1 \tilde{H}_2 - \frac{1}{2}(M_1 \tilde{B}\tilde{B} + M_2 \tilde{W}\tilde{W} + M_3 \tilde{g}\tilde{g})\end{aligned}$$



Signature:

- **heavier SM-like Higgs boson**
- **LHC: long-lived gluino**
- **ILC: measure Yukawa couplings**

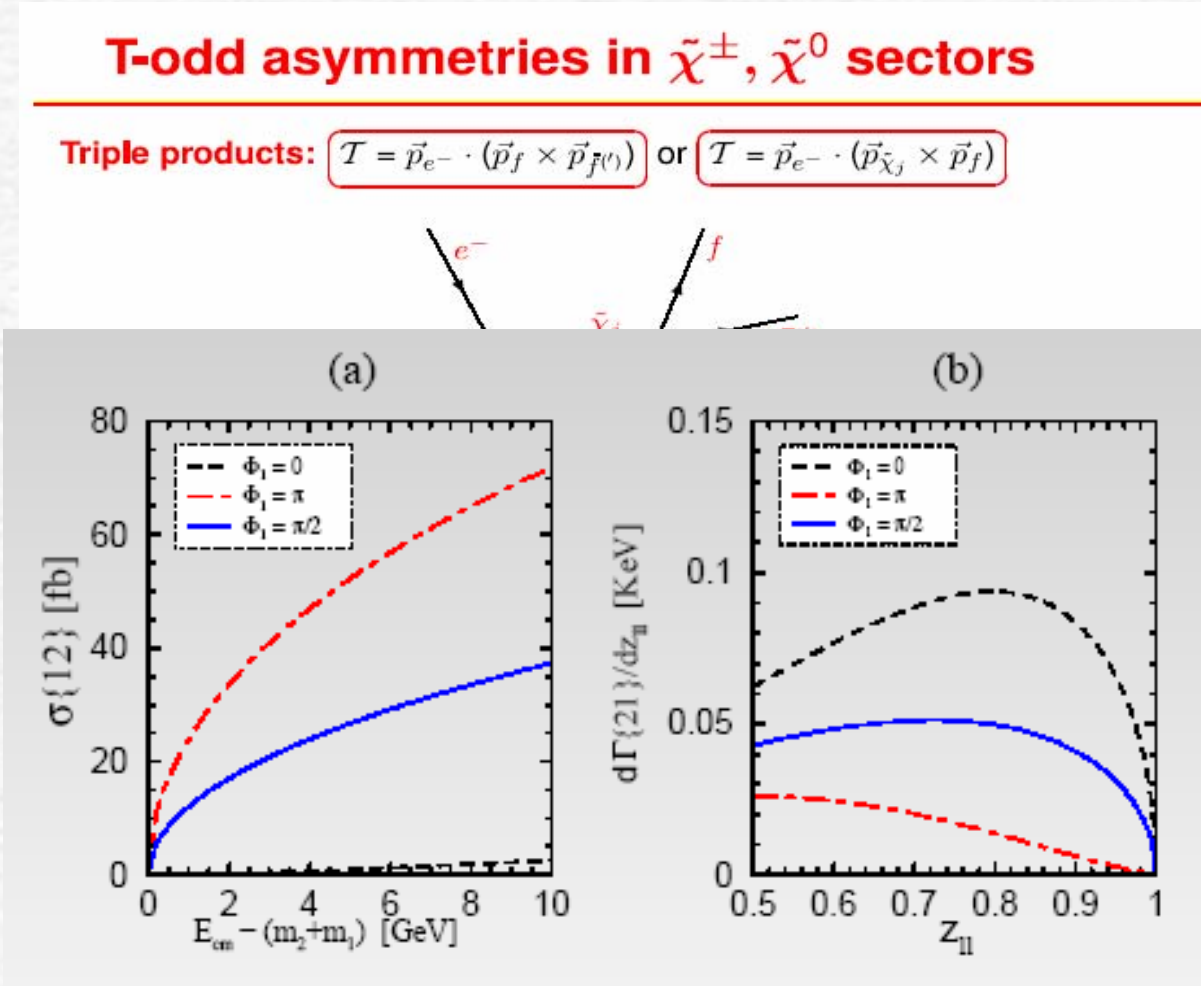


testable at LHC+ILC

Kilian, Plehn, Richardson, Schmidt hep-ph/0408088

What if ...

- Split SUSY
- CP-violated MSSM
  - CP-odd asymmetries in gaugino/higgsino
    Hesselbach et al.
  - Majorana nature in neutralino prod.+dec.
    B. Chung et al.



What if ...

- Split SUSY
- CP-violated MSSM
- NMSSM

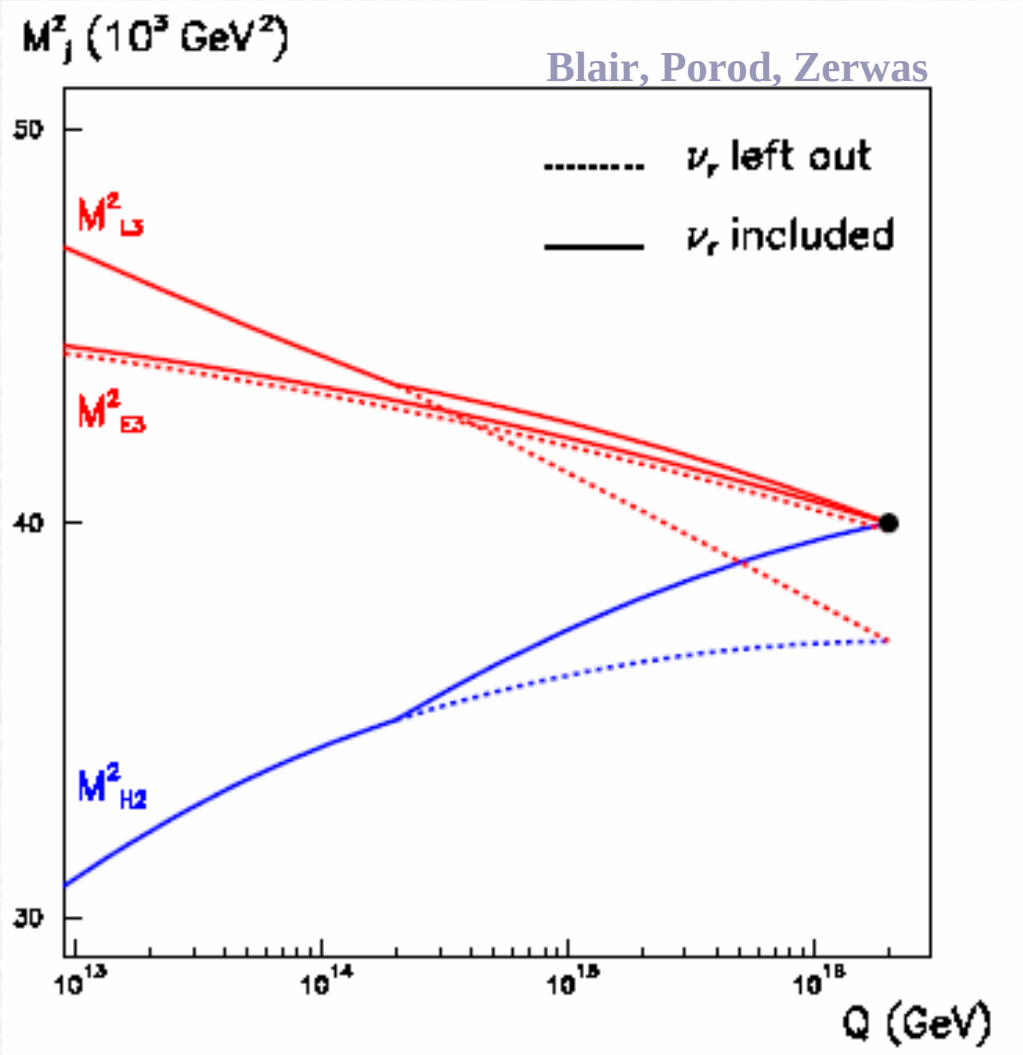
  - two more Higgses and one more neutralino

Moortgat-Pick et al.

- The question:
  - → MSSM - NMSSM separation with light particles
  - → numerical example (including some exp. errors)
  - → assumption: no separation@LC_{500} possible
- The answer:
  - → LHC/LC interplay
  - → motivation for using LC_{650}

What if ...

- Split SUSY
- CP-violated MSSM
- NMSSM
- LR SUGRA
  - kink in evolution of 3rd generation

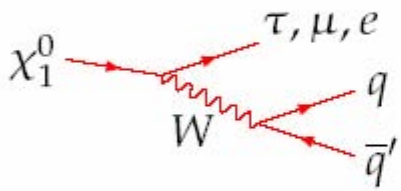


What if ...

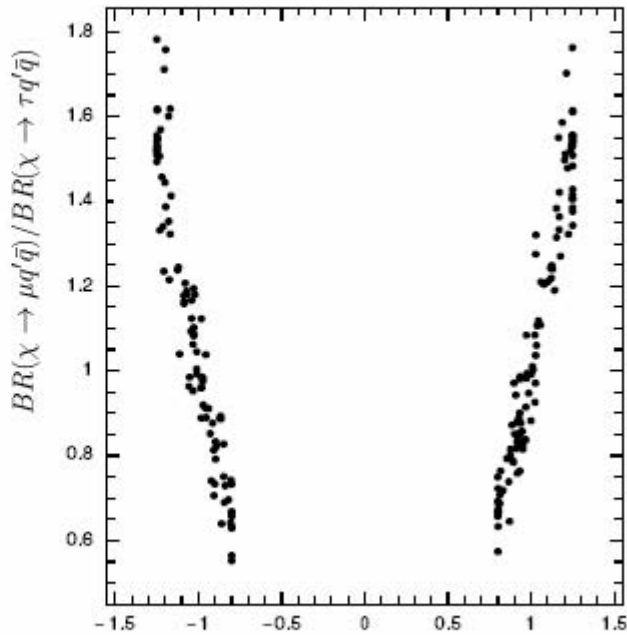
- Split SUSY
- CP-violated MSSM
- NMSSM
- LR SUGRA
- R_p violation
  - neutrinos mix with neutralinos

Neutralino Decays

In the presence of BRpV a neutralino LSP is not stable:



Ratios of BR are closely related to the Λ_i parameters.

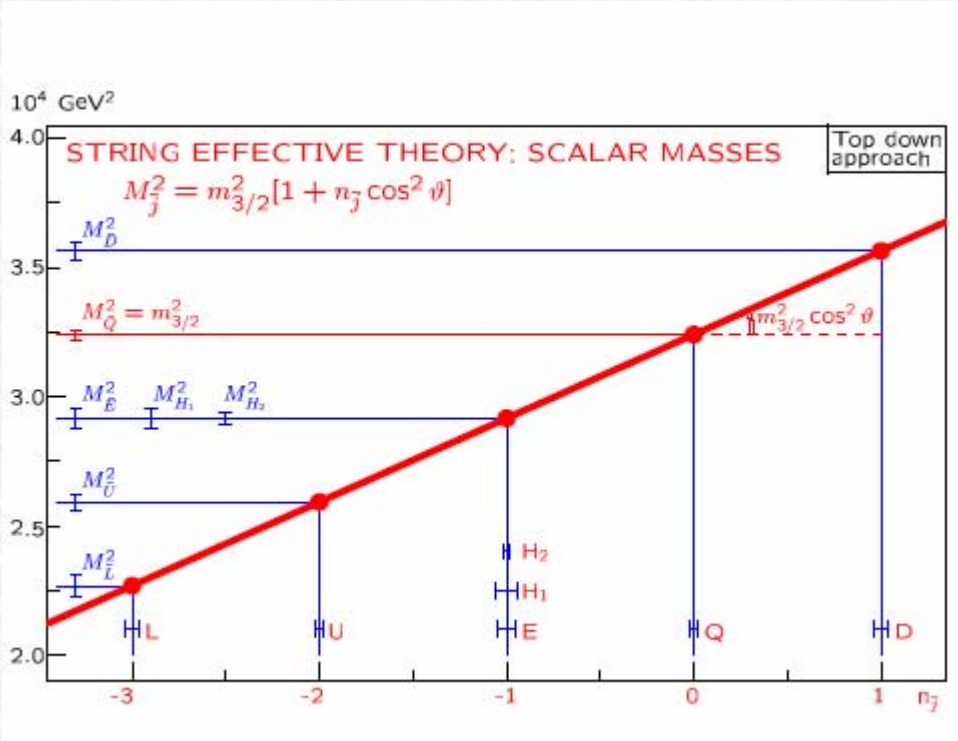


Collider Physics ⇔ Neutrino Physics

Díaz, Hirsch, Porod, Romao, Valle

What if ...

- Split SUSY
- CP-violated MSSM
- NMSSM
- LR SUGRA
- R_p violation
- Superstring eff. model
  - integer modular weights



Summary and outlook

- Many interesting avenues explored
- SPA: a joint interregional th. and exp. effort

Bottom-up approach:

max exploitation of measurements taking full account of theoretical knowledge

- cosmology strongly constrains certain SUSY models
- precision LHC/ILC + WMAP/PLANCK ⇨ consistency checks on cosmological models
  - our next stop: ILC Workshop in Snowmass

- LHC+ILC – telescope to GUT/Planck physics