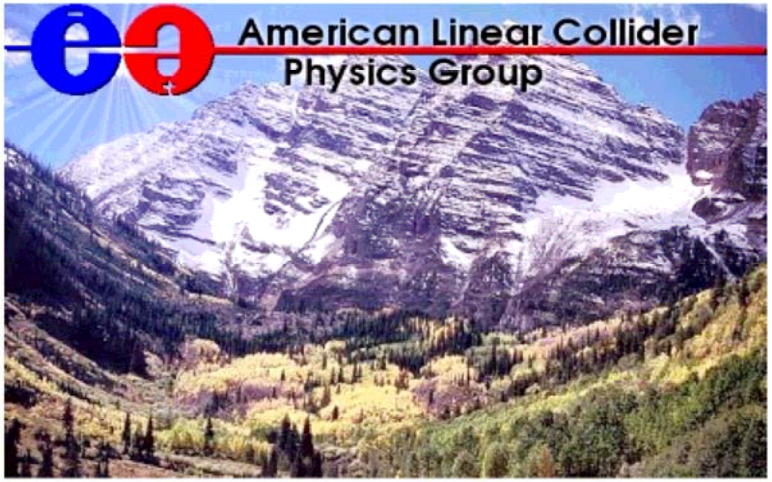
SUSY Tools



2005 International Linear Collider Physics and Detector Workshop
and Second ILC Accelerator Workshop
Snowmass, Colorado, August 14-27, 2005

Alexei Safonov
(UC Davis)

Means and Purposes

- Three-prong task:
  - Monte Carlo event generating tools suitable for data analysis and phenomenological projections given a model
    - SUSY mass spectra, cross-sections
  - Effective tools to check compatibility of a given SUSY model with the existing data
    - EWK measurements, Dark Matter density
  - Extract (fit for) SUSY parameters using experimentally measured observables
    - Low energy parameters
    - GUT scale parameters (via reversed RGE's) needed to understand exact mechanism of SUSY breaking
- Lots of interplay
- Importance of standardized interface (LHA)

MC Event Generators

- Popular "all-purpose" generator packages:
  - Isajet (Baer, Paige)
    - First "general purpose" generator, independent hadronization; now includes beam/brem-strahlung
  - Herwig (Marchesini, Webber)
    - ~NLL fragmentation (angular ordering etc.), cluster model hadronization
  - (S)Pythia (Sjostrand, Mrenna)
    - ~NLL fragmentation, string model hadronization
- All three have most $2 \rightarrow 2$ processes incorporated for ep/ee/pp collisions
- Main challenge: combine NLO matrix elements with Parton Showering algorithms
  - Need to eliminate double counting
  - Selected successes, but no consistent framework

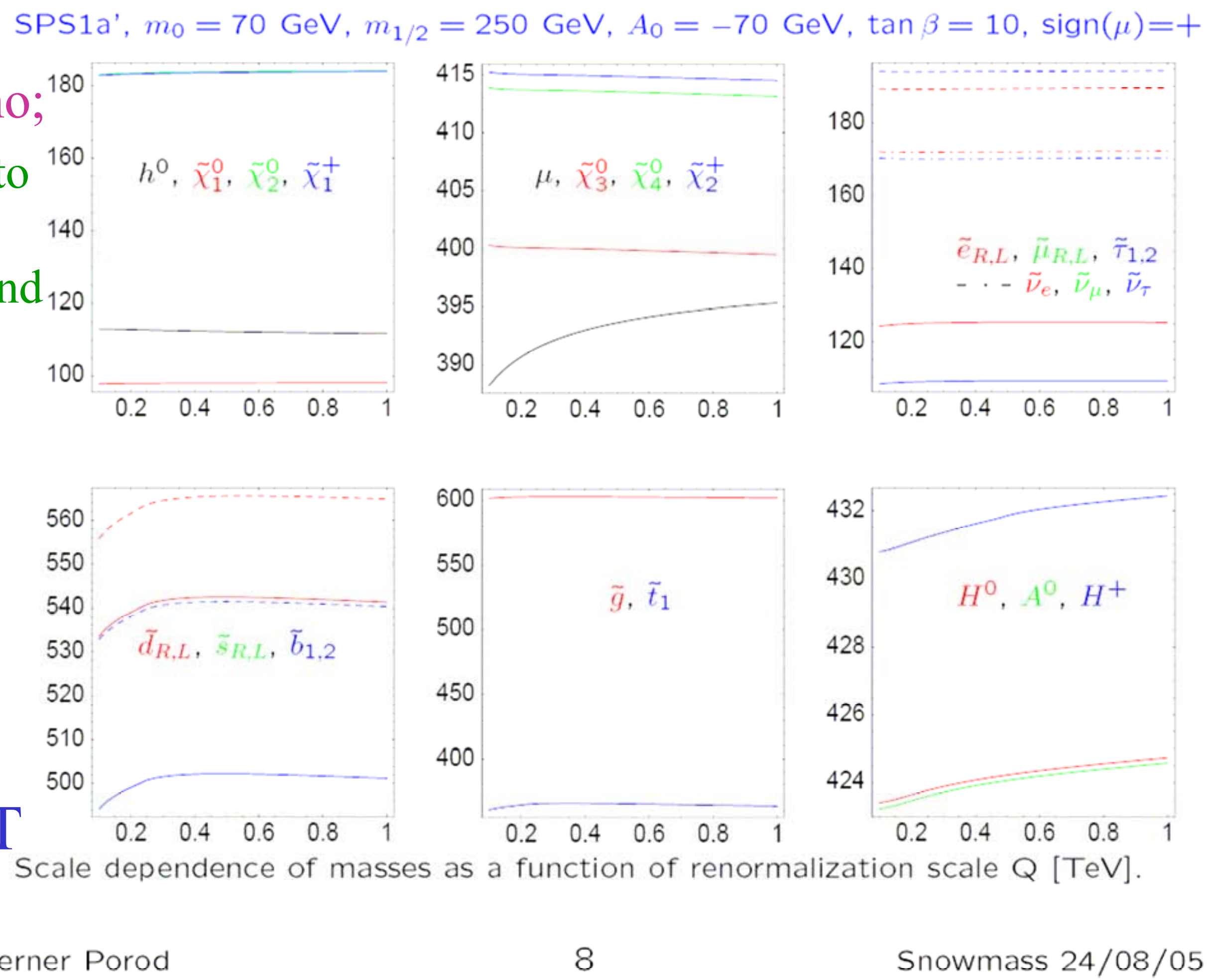
SUSY Mass Spectra

- Several packages on the market
  - Isajet (Baer, Paige, Protopopescu, Tata)
  - SuSpect (Djouadi, Kneur, Moultaka)
  - SoftSUSY (Allanach)
  - SPheno (Porod)
- "European" packages use similar RGE running algorithm, Isajet is different
  - Ideally, differences are a ~ measure of theoretical uncertainty

SPheno

(see talk by W. Porod for details)

- Masses:
  - SoftSusy, SUSPECT, same structure as SPheno;
    - Main differences due to approximations for calculation of gauge and Yukawa couplings as well as SUSY masses
  - ISAJET: different strategy: decoupling of SUSY parameters at different scales
- Decays: excellent agreement with ISAJET and SDECAY



SUSY Mass Spectra

- Compare @ SUSY focus point region:
  - http://cern.ch/kraml/comparison/

```
m0          = 3000
m12         = 400
A0          = 0
tan(be)     = 30
sgn(mu)     = 1
mt          = 175
mb          = 4.214
alphas(MZ)  = 0.1172
```

Sparticle	Isajet	Softsusy	Spheno	Suspect	(max-min)	diff[%]
nt_1	133.95	168.69	170.17	168.75	36.22	22.58
nt_2	184.62	313.11	328.49	312.40	143.87	50.54
nt_3	190.95	424.85	584.81	421.49	393.86	97.12
nt_4	362.67	452.42	596.05	449.88	233.38	50.16
ch_1	168.47	312.61	328.63	311.87	160.16	57.12
ch_2	354.16	452.33	597.12	449.77	242.96	52.44
omega	2.47e-02	8.96e+00	2.66e+01	8.56e+00	2.65e+01	240.65

SUSY Mass Spectra

- Differences on the previous slide cannot be interpreted as uncertainty
  - Large difference in relic density is a derivative of differences in spectra
- Per Baer & Porod, differences are due to different algorithm of running RGE's
  - Details in the benchmark discussion, also talks by Baer and Porod
- While there is a need to understand these differences in better detail, one important conclusion:

"We should always specify electroweak scale soft SUSY breaking parameters"

Next Generation Generators

(see talk by J. Reuter for details)

- Precision measurement of SUSY parameters requires precision tools:
  - Spins of new particles, mass measurements, couplings
  - Precise predictions for “background” SUSY processes
  - Radiative corrections
  - Off-shell intermediate states and full gauge-invariant diagram classes needed b/c of non-factorization of processes into $2 \to 2$ production processes and decays
  - SM and SUSY backgrounds: in general no factorization for signal/background
  - Spin correlations
- “General purpose” generators offer limited help

Next Generation Generators

(see talk by J. Reuter for details)

- New generators (and old ones like CompHEP/CalcHEP) solve many of these obstacles:

- **Helas/(S)Madgraph/MadEvent**
  K. Hagiwara, F. Maltoni, T. Plehn, D. Rainwater, T. Stelzer
- Ω **WHiZard/O'Mega**
  W. Kilian, T. Ohl, J. Reuter
- **Amegic++/Sherpa**
  T. Gleisberg, S. Hoeche, F. Krauss, T. Laubrich, S. Schumann, C. Semmling, J. Winter

- Lots of validation work by comparing generators against each other - completed

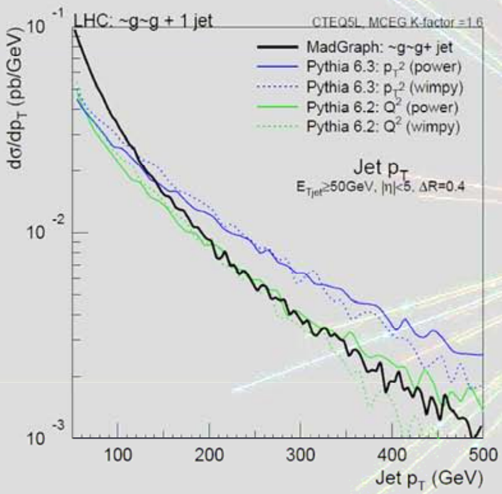
Next Generation Generators

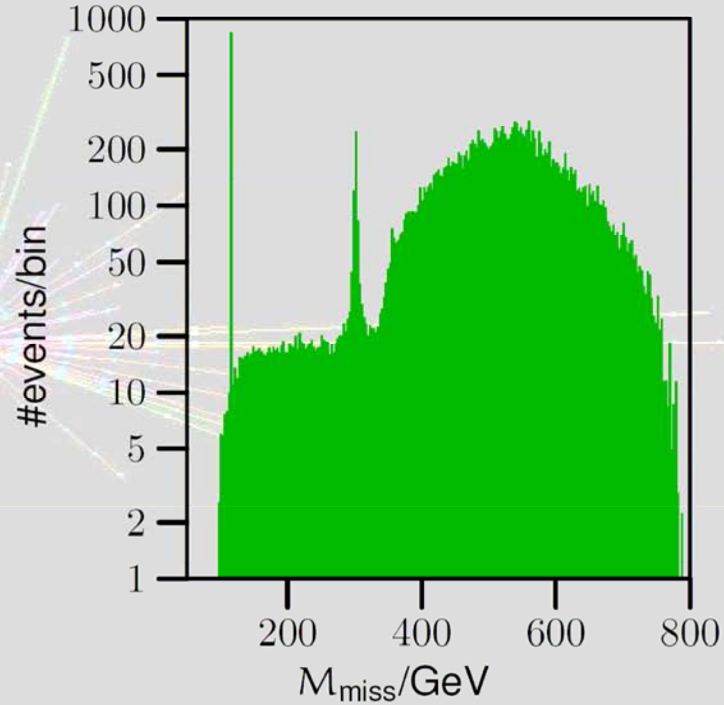
(see talk by J. Reuter for details)

T. Plehn, D. Rainwater, P. Skands: Adapt PYTHIA showers to exact results on jet radiation

ILC:

$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 b\bar{b}$





(Work in Progress)

J. Reuter MSSM event generators Snowmass 2005, 20

Calculations of DM Density

(see talk by G. Belanger for details)

- Strong evidence for dark matter
- CMB (WMAP) gives precise information on the amount of dark matter
- Most attractive explanation for dark matter: new weakly interacting particle, for example those present in R-parity conserving SUSY model
- WMAP measurement strongly constrains models of cold dark matter in particular supersymmetric models
- Need for a precise and accurate computation of the relic density of dark matter
- Codes that compute relic density +… :
  - Neutdriver, DarkSUSY, micrOMEGAs, Isatools
  - Many private codes: SSARD (Olive), Drees, Roskowski …

MicrOmegas_2.0

(see talk by G. Belanger for details)

- Generic program to calculate the relic density of DM in any model
  - Input:
    - All couplings and masses of all particles
  - Code:
    - Finds "LSP" and resonances
    - computes all annihilation and coannihilation cross-sections
    - Solves the evolution equation and obtains the relic density
  - Working example:
    - micromegas_nmssm
  - Under development:
    - UED (Csaba Balazs, et al)
    - Warped Xtra-Dim (G. Servant + micromegas)

- Further developments - direct DM observation:
  - Pair of DM particles annihilate, products – signal for dark matter
    - Positrons from neutralino annihilation in the galactic halo
    - Photons from neutralino annihilation in center of galaxy
    - Neutrinos from neutralino in sun
  - Module being finalized: photons (with S. Rosier-Lees, P. Brun)
    - "hard" photon line from loop processes (F. Boudjema, A. Semenov, D. Temes)
      - Agrees with PLATON, DarkSUSY (except for γZ)
    - Continuum from pair of neutalinos into b,t,W,Z,h…

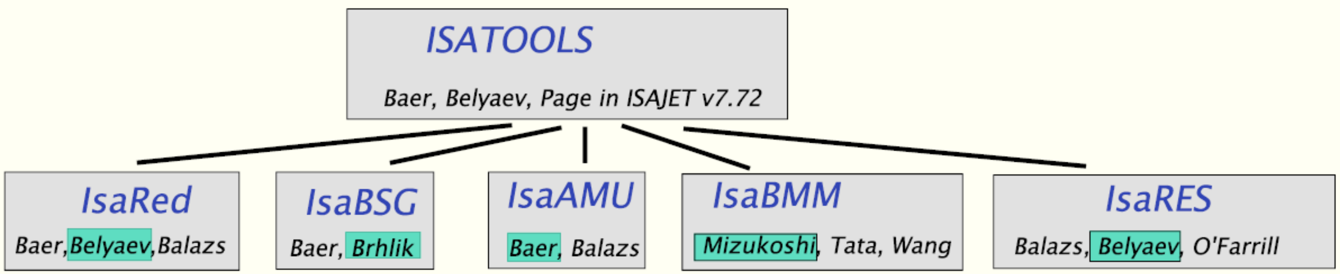
IsaTools

(see talk by A. Belyaev for details)

The structure of ISATOOLS package

IsaTools is a package of subroutines for the evaluation of various supersymmetric constraints using the Isajet supersymmetry code.

by Baer, Belyaev, Paige



- *IsaRED – to evaluate the relic density of neutralino dark matter*
- *IsaBSG – to evaluate the branching fraction* $BF(b \to s\gamma)$,
- *IsaAMU – to evaluate SUSY contributions to* $\Delta a_\mu \equiv (g-2)_\mu/2$,
- *IsaBMM – to evaluate MSSM* $BF(B_s \to \mu^+\mu^-)$ *and* $BF(B_d \to \tau^+\tau^-)$
- *IsaRES – to evaluate the spin-independent and spin-dependent neutralino-proton/neutron scattering CS*

A.Belyaev (MSU) "Progress report on ISATOOLS", Snowmass 2005, Colorado 4

Extraction of SUSY Parameters

- Measuring masses of new particles is not sufficient to understand the exact SUSY mechanism
- One needs to fit observed experimental data to obtain low energy SUSY parameters
- It is then important to calculate parameters at GUT scale (by reverse RGE's) to understand structure of the SUSY model chosen by nature
- Complementary efforts:
  - Fittino (P. Bechtle, K. Desch, P. Wienemann)
  - Sfitter (R. Lafaye, T. Plehn and D. Zerwas)
  - SPA Project (SPA Collaboration)

Fittino

(see talk by P. Bechtle for details)

The Fit Program Fittino

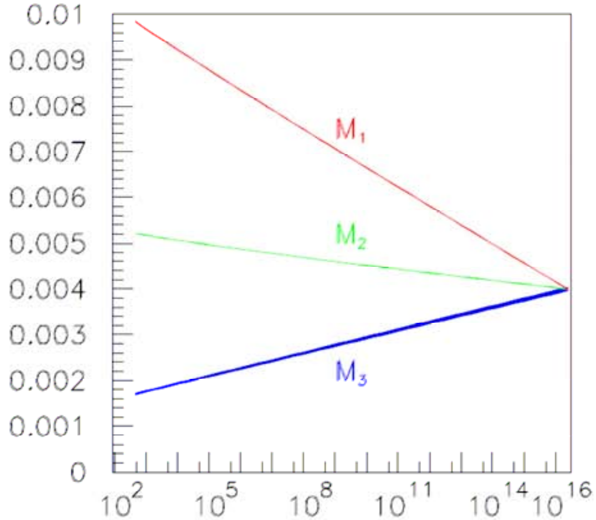
- Determine the low-energy MSSM Lagrangian parameters from the observables from the ILC and LHC in a global fit
- Use full theoretical precision, all available loop effects
- Bottom-up approach, no assumption on SUSY breaking mechanism
- Fittino (as SFitter) is independent of SPS1a, mSUGRA, etc...
- To be unbiased: Use no prior knowledge of the parameters at any step
- Goals:
  - Unambiguous parameter determination without human bias?
  - Determine precision of parameter measurements
  - Test the necessary experimental and theoretical precision
- More information in `http://www-flc.desy.de/fittino/`
- Similar Program: SFitter by R. Lafaye, T. Plehn and D. Zerwas

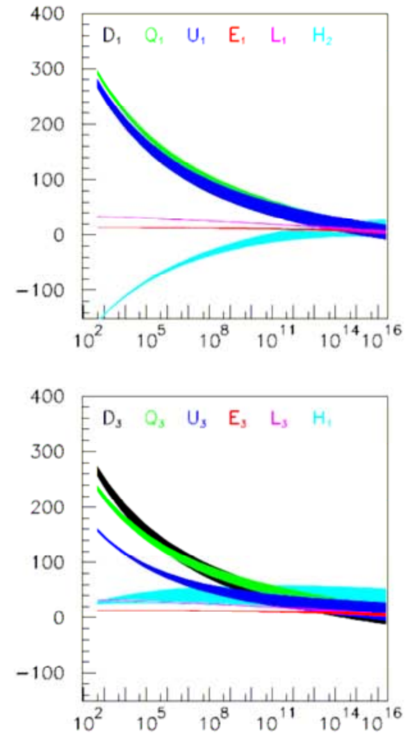
Fittino

(see talk by P. Bechtle for details)

The Evolution to the GUT Scale

- Based on the results of the low-energy parameter fit (with edges):





- from Werner Porod

FITTINO SUSY

Philip Bechtle, Snowmass 05, 24.08.2005 – p.14

http://spa.desy.de/spa

SUPERSYMMETRY PARAMETER ANALYSIS

The SPA project is a joint study of theorists and experimentalists working on LHC and Linear Collider phenomenology. The study focuses on the supersymmetric extension of the Standard Model. The main targets are

- High-precision determination of the supersymmetry Lagrange parameters at the electroweak scale
- Extrapolation to a high scale to reconstruct the fundamental parameters and the mechanism for supersymmetry breaking

The SPA convention and the SPA Project are described in the report SPA.draft.ps.

Coordinators

This list contains the coordinators from Europe only; for each sector, the coordinators from America and Asia will be added soon.

SPA Program Repository

- Scheme translation tools

  DRbar ⟺ MSbar ⟺ on-shell

- Spectrum calculators: Lagrangian ⟺ masses

  ex: FeynHiggs, SPheno, SuSpect, SoftSusy,IsaJet, ...

- Other observables: cross sections, decay rates, LE param., astrophysics, cosmology

  ex: HDecay, NMHDecay, SDecay, Prospino, micrOMEGAs, ...

- Event generators: IsaJet, Phytia, Whizard, ...

- Analysis programs: SFitter, Fittino

- RGE: M ⟺ $M_{GUT/Pl}$: SPheno, SoftSusy, IsaJet/IsaSusy, ...

➡ **http://spa.desy.de/spa**

SPA SUPERSYMMETRY PARAMETER ANALYSIS

Summary

- Many important developments:
  - New and improved tools in traditional MC packages (e.g. IsaTools)
  - New generation of MC generators extending beyond traditional 2→2 processes (spin, off-shell contributions etc. – e.g. MadGraph, Sherpa, O'Mega)
  - Many tools are being extended towards scenarios beyond MSSM
    - MicrOmega, Spheno, …
  - Techniques for interpreting LHC/ILC data are gaining pace
    - SPA Project, Fittino, SFitter, …
- Comparisons of results from complementary packages is important for validation:
  - Comparison of mass spectra from different programs revealed significant differences in the important focus region → this emphasize importance of providing low energy SUSY parameters