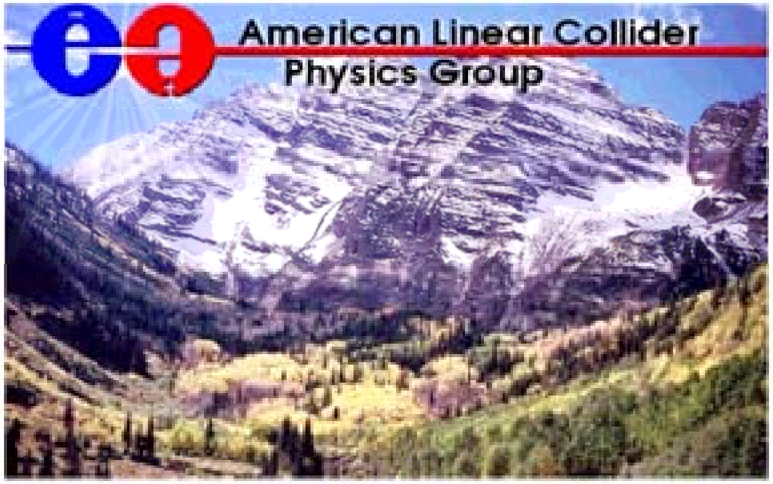
SUSY WG Summary Report: Tools and Experimental Aspects



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and Second ILC Accelerator Workshop
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Alexei Safonov

(UC Davis)

ILC Physics: Ingredients of Success

- SUSY "navigation" tools
  - Navigate in the enormous SUSY parameter space, account for existing low energy and cosmological constrains
  - Cross-sections, SUSY mass spectra,…
- Precision MC event generators
  - Optimize analyses and probe sensitivity
- Detector simulation
  - Provide realistic picture of the detector performance
- Tools to interpret new discoveries
  - Not enough to measure masses and couplings, our goal is understanding the complete structure of SUSY

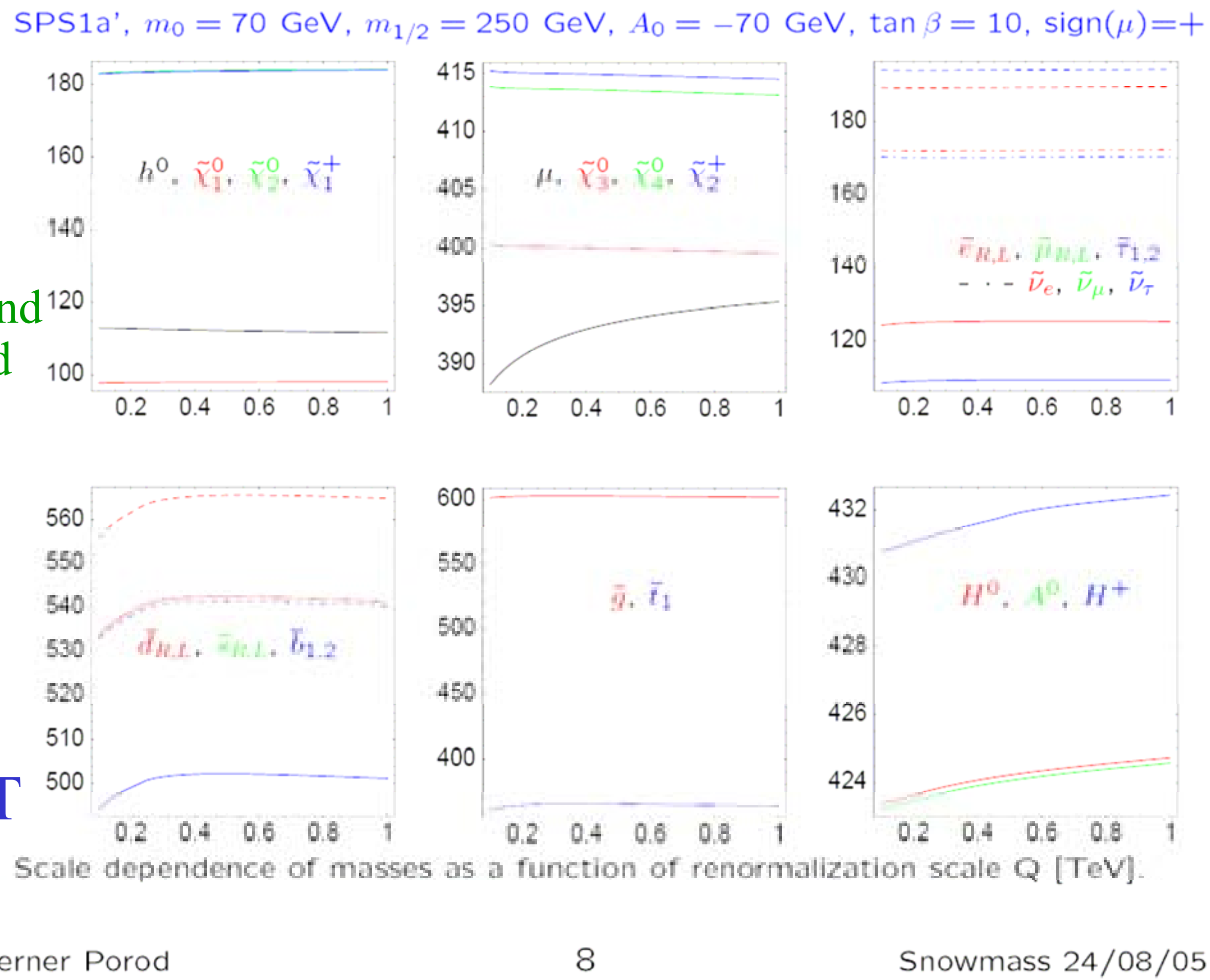
SUSY “Navigation” Tools

- SUSY mass spectra calculations:
  - Several tools available on the market
    - Isajet (Baer, Paige, Protopopescu, Tata)
    - SuSpect (Djouadi, Kneur, Moultaka)
    - SoftSUSY (Allanach)
    - SPheno (Porod)
  - Ideally, differences are a ~ measure of theoretical uncertainty
- Tools to check compatibility of a given SUSY model with the existing data:
  - Dark Matter constraints, (g-2), BR’s, EW data:
    - Neutdriver, DarkSUSY, micrOMEGAs, Isatools
    - Many private codes: SSARD (Olive), Drees, Roszkowski …
- Importance of standardized interface (LHA)

Mass Spectra Calculators

(see talk by W. Porod for details)

- Masses:
  - SoftSusy, SUSPECT have same structure as SPheno
    - Differences are due to approximations in calculation of gauge and Yukawa couplings and SUSY masses
  - ISAJET: different strategy: decoupling of SUSY parameters at different scales
- Decays: excellent agreement with ISAJET and SDECAY



Mass Spectra Calculators

- 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

Mass Spectra Calculators

- Differences on the previous slide cannot be interpreted as uncertainty
  - Large difference in relic density is a derivative of differences in spectra
- *Baer & Porod:* "Differences are due to different approaches of running RGE's"
  - Work in progress to resolve this
- While there is a need to understand these differences in better detail, one important conclusion:

<u>"Always specify soft SUSY breaking parameters at the electroweak scale "</u>

Calculations of DM Density

(see talks by A. Belyaev, 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
- New developments:
  - Isatools (new package), MicrOmega v2.0 (beyond MSSM)

Dark Matter: New Developments

(see talks by G. Belanger, A. Belyaev for details)

- MicroOmega v2.0:
  - Calculation of the DM relic density in any generic model given spectra and couplings
    - NMSSM example fully implemented
    - UED and Warped Xtra-Dim are under development
  - Next step – tools for 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
      - "hard" photons from loop processes
      - Continuum from pair of neutalinos into b,t,W,Z,h…
- IsaSUSY – new tool for Isajet:
  - Calculations of relic density, muon (g-2), BF($b \to s\gamma$, Bs $\to \mu\mu$ Bd $\to \tau\tau$),

MC Event Generators: Old School

(see talk by H. Baer for details)

- Popular Multi-purpose MC generators:
  - Isajet (Baer, Paige)
  - Herwig (Marchesini, Webber)
  - (S)Pythia (Sjostrand, Mrenna)
- Different fragmentation/hadronization models provide important complementarities
- Most 2→2 processes incorporated for ep/ee/pp collisions
- Many improvements, e.g. proper handling of tau polarizations, beam/brem-strahlung in Isajet

- Next challenge: combine NLO ME with Parton Showering algorithms
  - Need to avoid double counting
  - Selected successes, but no consistent framework

MC Event Generators: New Generation

(see talk by J. Reuter for details)

- Precision measurements require precision tools:
  - Spins of new particles, mass measurements, couplings
  - Radiative corrections, off-shell contributions, spin correlations
  - SM and SUSY backgrounds: in general no factorization for signal/background
- "General purpose" generators offer limited help
- New generators solve many of these obstacles:
  - and the old ones like CompHEP/CalcHEP package

- **Helas/(S)Madgraph/MadEvent**
  K. Hagiwara, F. Maltoni, T. Plehn, D. Rainwater, T. Stelzer
- **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

Detector Issues

(see talks by M. Battaglia, Z. Zhang, S. Hillert for details)

- Detector coverage
  - Missing PT measurement (cracks, forward region)
  - Veto gamma-gamma background (far forward calorimeter)
- Lepton-ID
  - Reconstruction of low momentum tracks
  - Electron/muon identification
  - Tau identification (VTX tag?)
  - Full reconstruction of tau decays for detailed stau study
- Jet reconstruction
  - Jet energy resolution with PFA
  - b-tag and c-tag capability
  - Jet charge determination

Real needs can only be understood by doing simulation-based analysis using representative benchmark points

Selected Detector Issues

(see talk by Z. Znang for details)

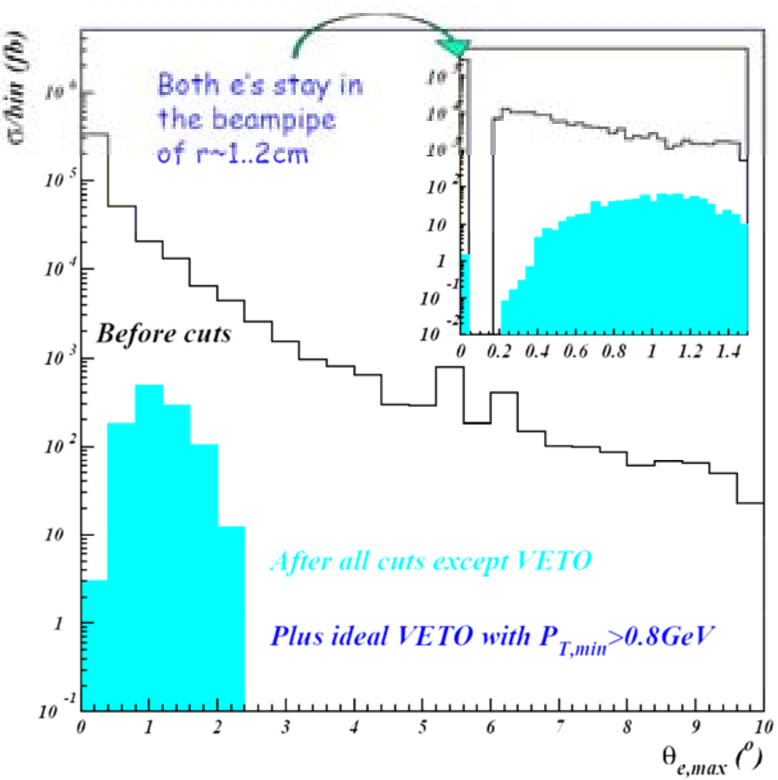
- Stau co-annihilation region (favored by WMAP)

Benchmark point D from Battaglia et al, hep-ph/0306219:

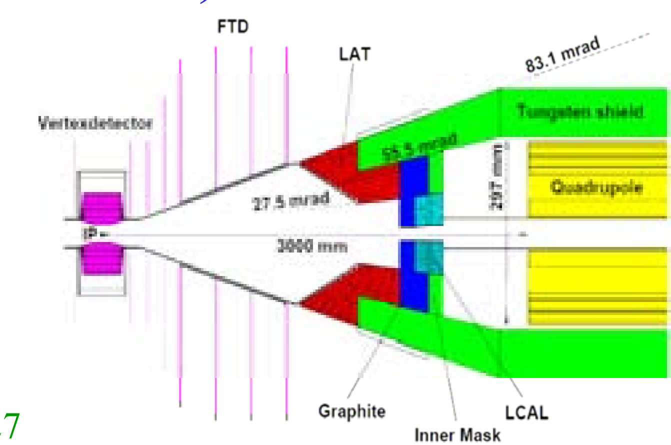
[$M_{1/2}$=525GeV, m_0=101GeV, tanβ=10, μ<0, m_χ=212GeV, $m_{s\tau}$=217GeV, $\Omega_{DM}h^2$=0.09]

$e^+e^- \to stau^+\, stau^- \to \chi^0\tau^+\, \chi^0\tau^-$

- Very soft taus in the final state – $\Delta m \sim 5$ GeV



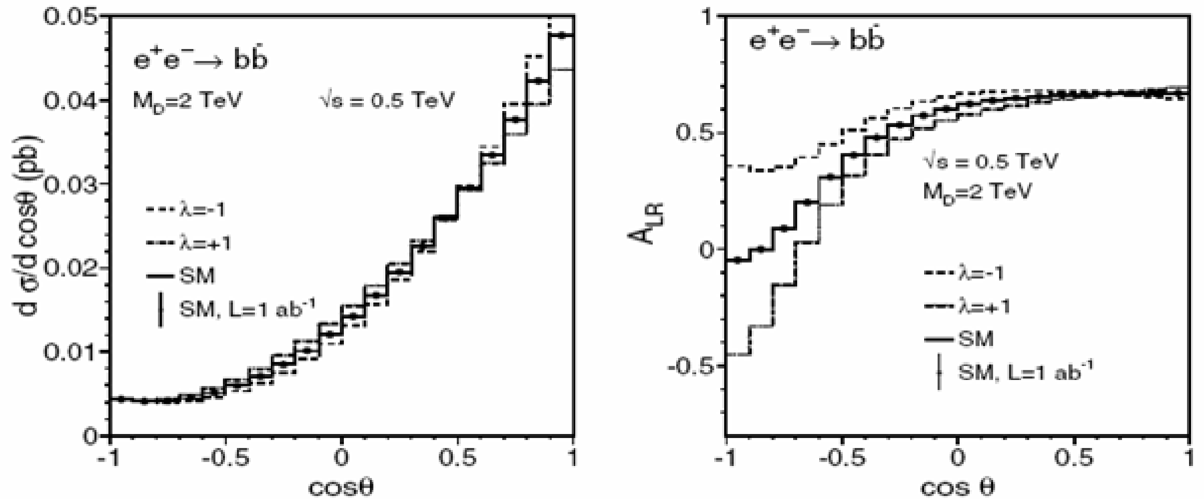
- Enormous backgrounds $ee \to ee\tau\tau$
- Can be effectively suppressed only by tagging spectator e (very forward electron)



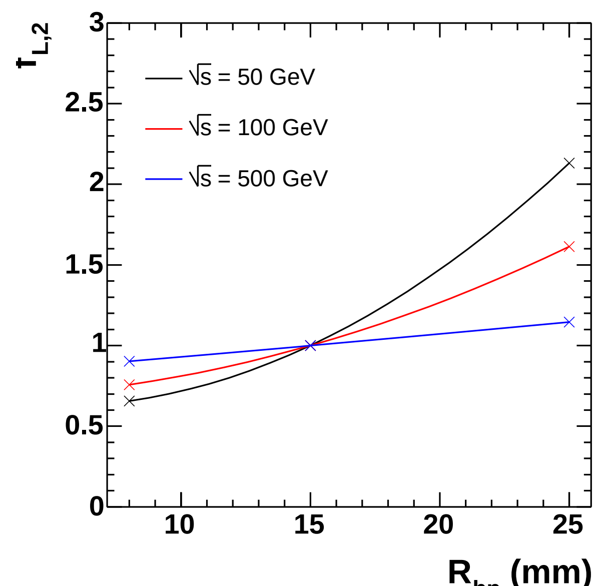
Selected Detector Issues

(see talk by S. Hillert for details)

- In some cases, knowledge of the charge of a jet can significantly improve sensitivity



- Algorithm selects displaced tracks assigned to the tagged b-jet to calculate charge of the b-jet
  – Significant dependence on the position of the closest silicon layer (and thus the beampipe radius)
- Similar algorithm for c-jets – work in progress



Detector Study Benchmarks

- LCC and Detector benchmarks have been proposed
- SUSY WG has discussed a set of BP for detector studies
  - Better suited for synergy studies (LHC/ILC/cosmology/EW)
  - Pragmatic approach: reinterpretation for points already studied (e.g. SPS)
- Final choice to be determined in the coming weeks

- Full GEANT simulation important, but should start with simplified MC studies (not very different from e.g. fast MC)
- Already have people interested in this work:
  - J. Proulx and Colorado group, A. Belyaev, A. Birkedal, G. Pauletta, …
- Need more people. Please volunteer!

Summary

- ILC SUSY Perspective:
  - ILC will play a decisive role in understanding and interpreting expected LHC discoveries
  - ILC is a unique machine to understand the nature of dark matter
- Tools/Phenomenology - many important developments:
  - New and improved tools in traditional MC packages
  - New generation of MC generators (spin, off-shell contributions etc.)
  - Techniques for interpreting LHC/ILC data are gaining pace
- Study of SUSY benchmark points is a critical issue:
  - Some already have been worked out (e.g. SPA1a)
  - Time to close the circle for others
  - These have an outmost importance for <u>detector design</u>

Many Thanks to…

- The organizers of this Workshop for creating this excellent opportunity
  - Special thanks to U. Nauenberg, M. Oreglia, M. Peskin for their support and help
- All people who have contributed to the work of the SUSY WG
  - Special thanks to H. Baer, G. Belanger, W. Porod, P. Zerwas and many others for working with us on the benchmark points
- Other conveners of the SUSY WG for the great collaborative spirit and their hard work
  - S. Belyaev, J. Kalinowski, S.Y. Choi, K. Kawagoe