SUSY/BSM at a Linear Collider

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OUTLINE

- Overview of SUSY models
- Reach of a LC for SUSY
- Precision measurements at a LC
- Chargino/neutralino/slepton/squark studies
- Calculations of sparticle masses
- Extrapolations to very high energies
- Conclusions

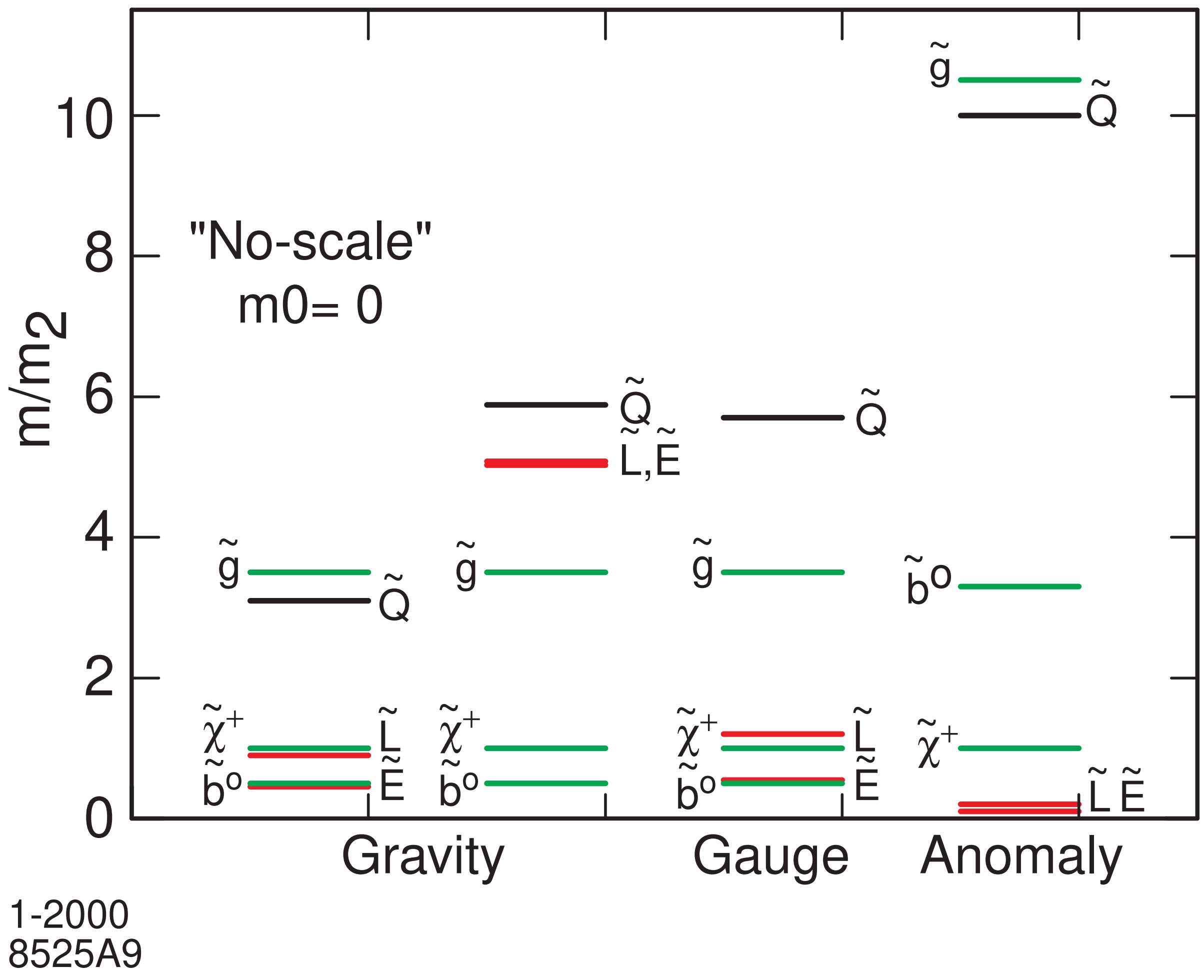
SUSY overview

- Motivations: many!
- The MSSM
  - Gauge symmetry: $SU(3)_C \times SU(2)_L \times U(1)_Y$
  - Matter content: $\hat{Q}_i,\ \hat{U}_i^c,\ \hat{D}_i^c,\ \hat{L}_i,\ \hat{E}_i^c;\ \ i = 1-3$
  - Two Higgs doublets: $\hat{H}_u$, $\hat{H}_d$
  - R-parity conserving superpotential
  - Lagrangian: renormalizable SUSY gauge theory
  - Add all soft SUSY breaking terms
  - Result: 124 parameter model
- Calculate physical eigenstates, mixings, couplings
- MSSM: an effective theory valid below *e.g.* M_{GUT}-M_P?
- Feynman rules for amplitude calculations, etc.

Models of SUSY breaking

- Most conservative: 4-d supergravity (SUGRA)
  - SUSY breaking (SB) occurs in hidden sector
  - SB communicated to visible sector via gravity
  - Stipulate gauge symmetry, matter content, local SUSY, Kähler potential, gauge kinetic function
  - In general: non-universal masses $\Rightarrow$ flavor/CP violation
  - Additional universality assumption suppresses FC/CP violating processes
  - mSUGRA: $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$
- Gauge-mediated SUSY breaking (GMSB)
  - Visible sector$\Leftrightarrow$messenger sector$\Leftrightarrow$ hidden sector
  - mGMSB: $\Lambda,\ M,\ n_5,\ \tan\beta, sign(\mu),\ C_{grav}$
- Anomaly-mediated SUSY breaking (AMSB)
  - Extra dimensional model
  - SUSY breaking occurs on hidden brane
  - SUSY breaking communicated via violation of superconformal anomaly
- Gaugino-mediated SUSY breaking (inoMSB)
  - SUSY breaking occurs on hidden brane
  - SUSY breaking communicated via gauge SFs which propagate in bulk

SUSY spectra from models:



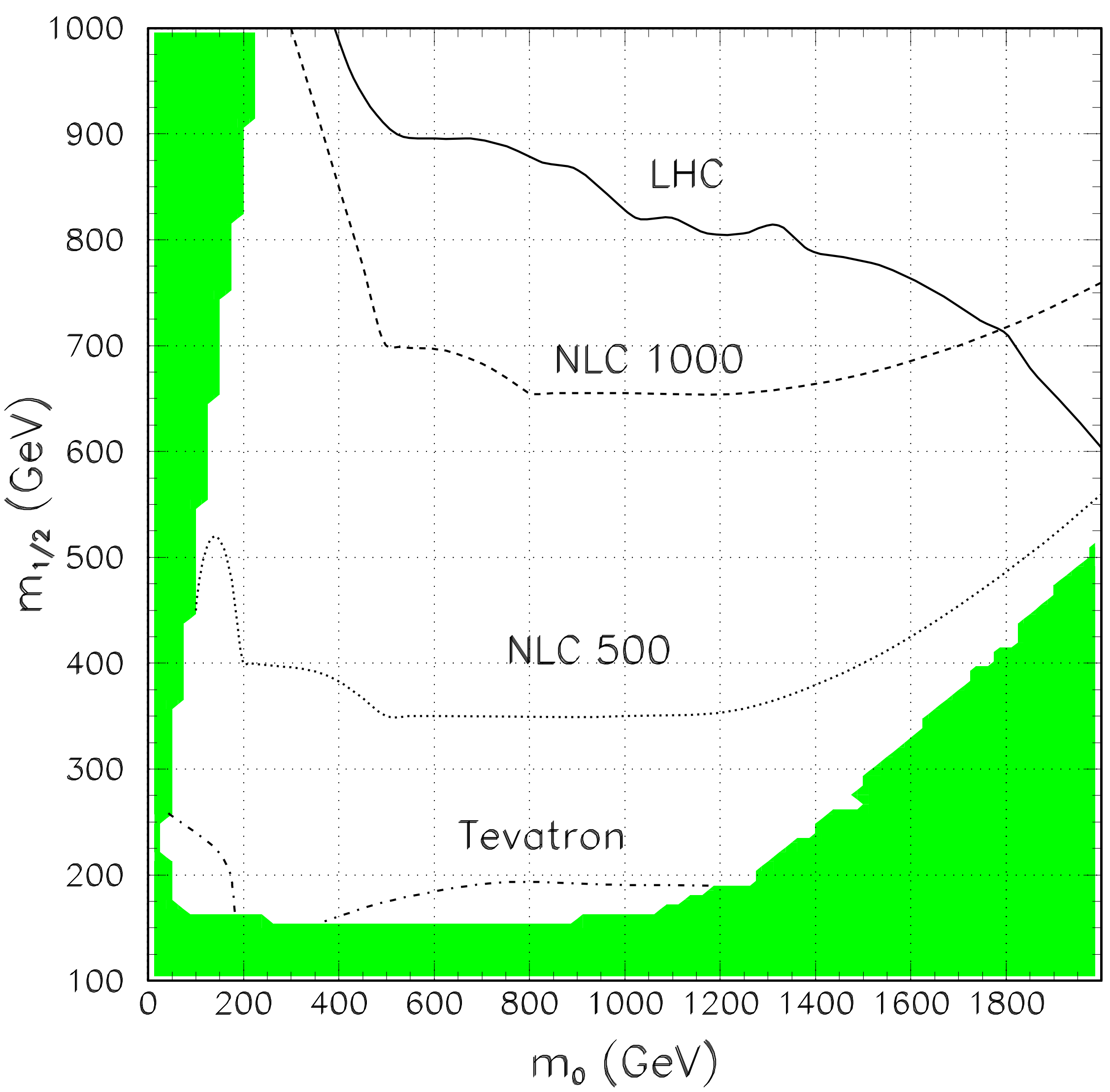
- Precise determination of SUSY/Higgs spectra reveal physical principles valid at very high energy scales *e.g.* M_{GUT} or M_P!
- A linear e^+e^- collider operating at $\sqrt{s} \sim 500 - 1000$ GeV is mandatory for a program of precision SUSY studies!

Advantages of a LC for SUSY:

- clean events
- low backgrounds
- variable beam energy
- beam polarization
- e^-e^-, $e\gamma$ and $\gamma\gamma$ options

- $\Rightarrow$ A program of precision studies!

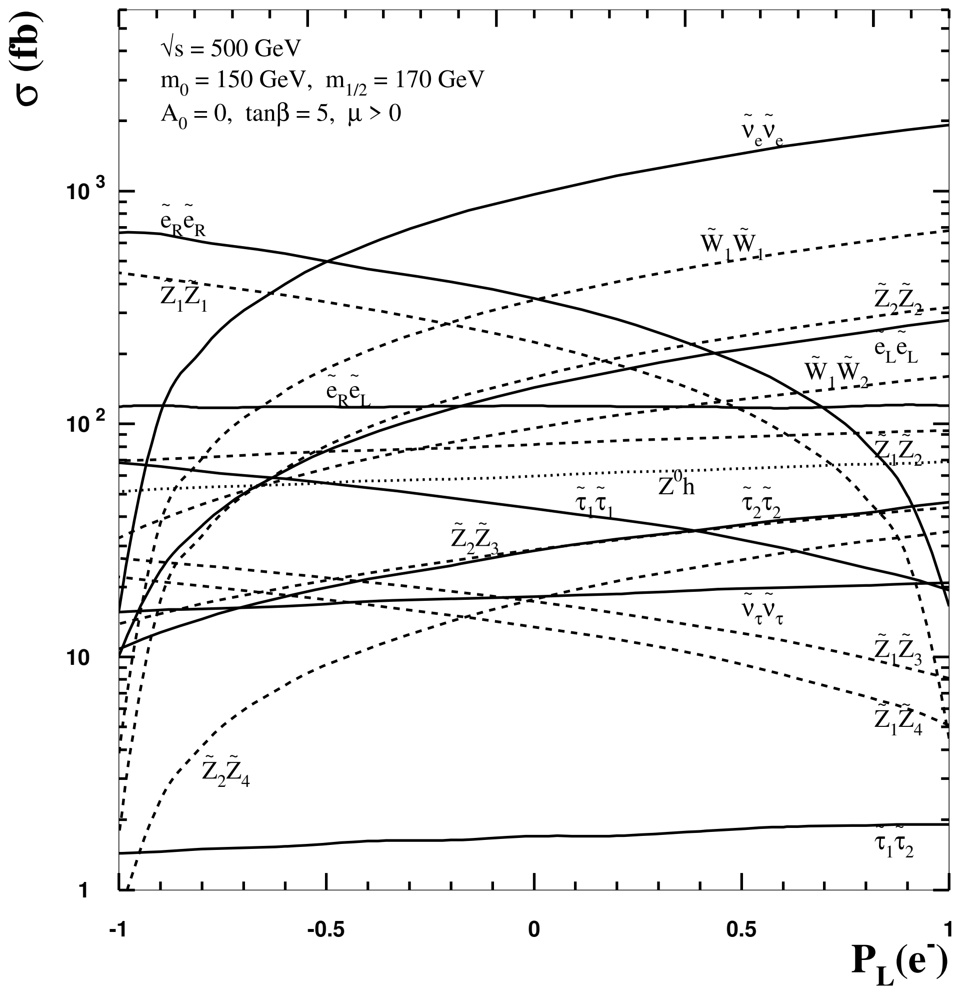
Reach plot for NLC: mSUGRA model



Reach determined by:

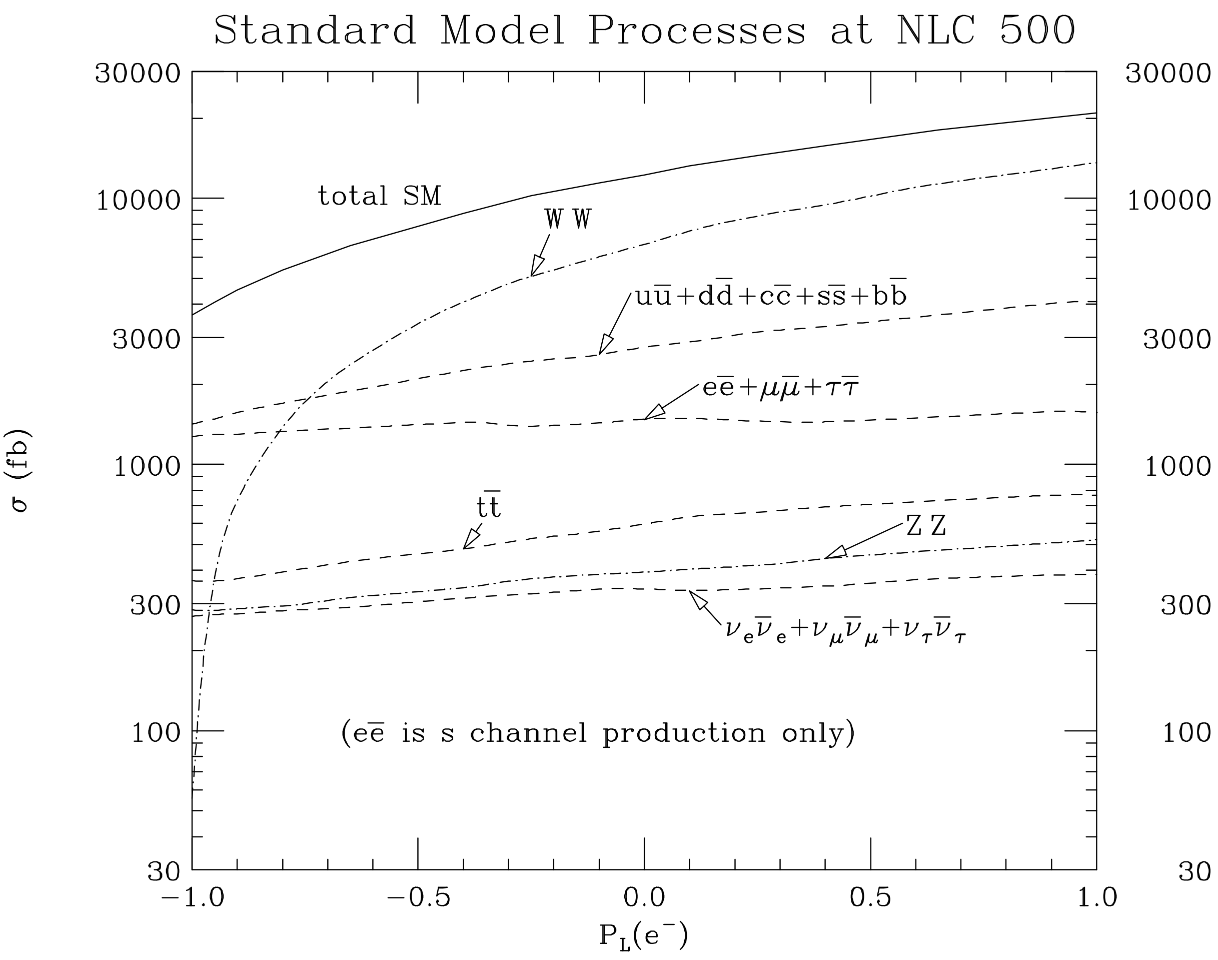
- $\widetilde{W}_1^+\widetilde{W}_1^-$ production
- $\tilde{\ell}^+\tilde{\ell}^-$ production
- $\widetilde{Z}_1\widetilde{Z}_2$ production

SUSY cross sections vs. beam polarization:

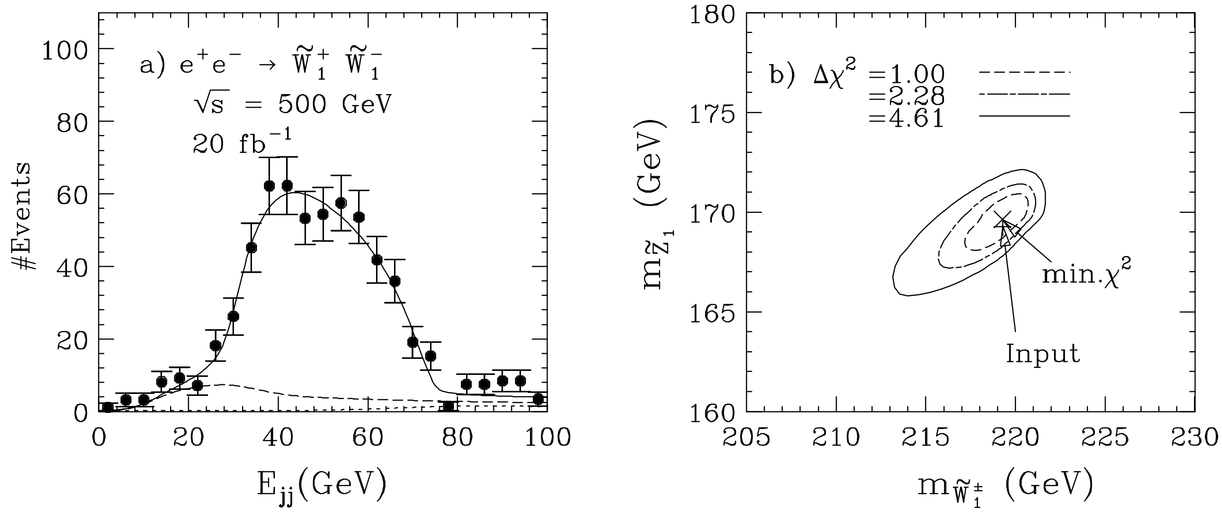


- Sample mSUGRA model parameter point

SM cross sections vs. beam polarization:



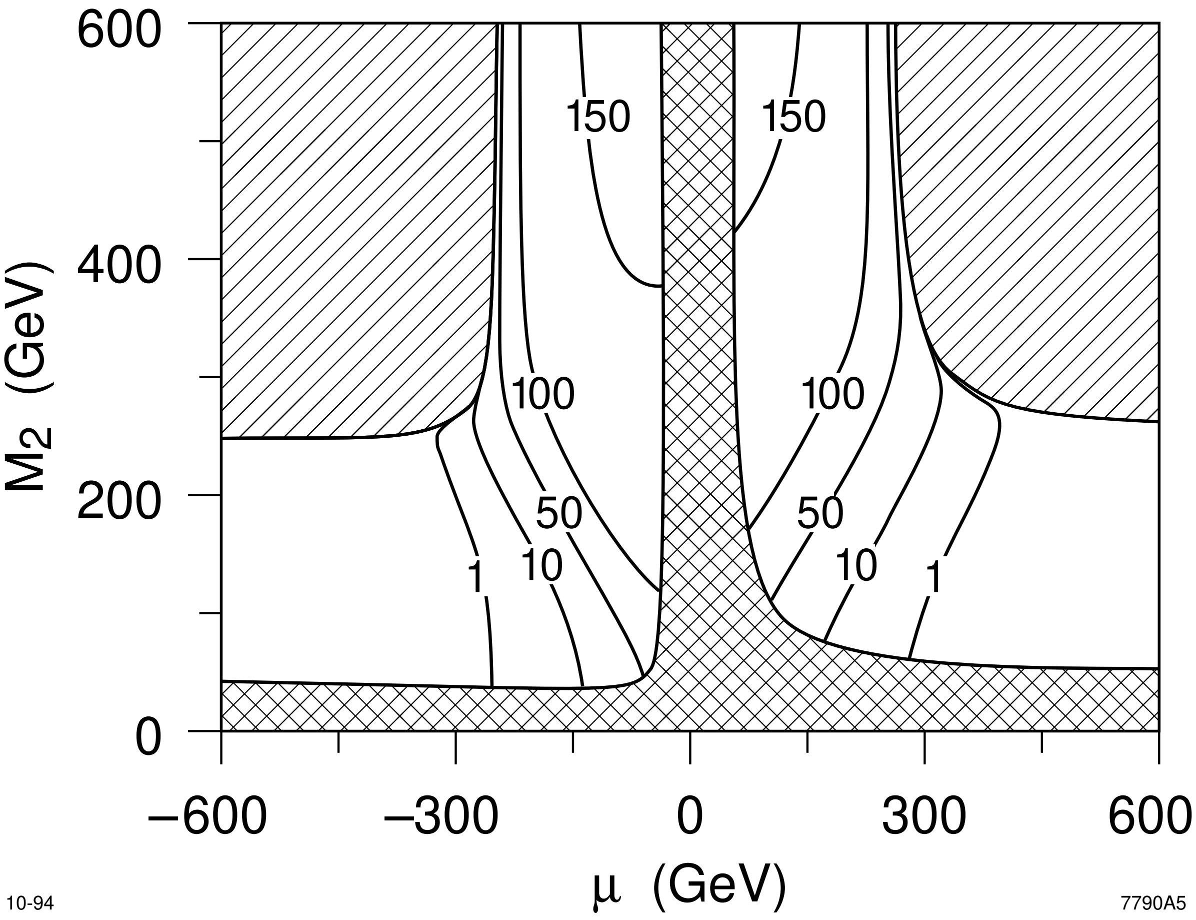
Chargino mass determination



- $e^+e^- \to \widetilde{W}_1^+\widetilde{W}_1^-$; $\widetilde{W}_1 \to W\widetilde{Z}_1$
- chargino mass to $\sim 1\%$ mainly via kinematics

Tsukamoto et al.; HB, Munroe, Tata

Chargino cross section in μ $vs.$ M_2 plane:

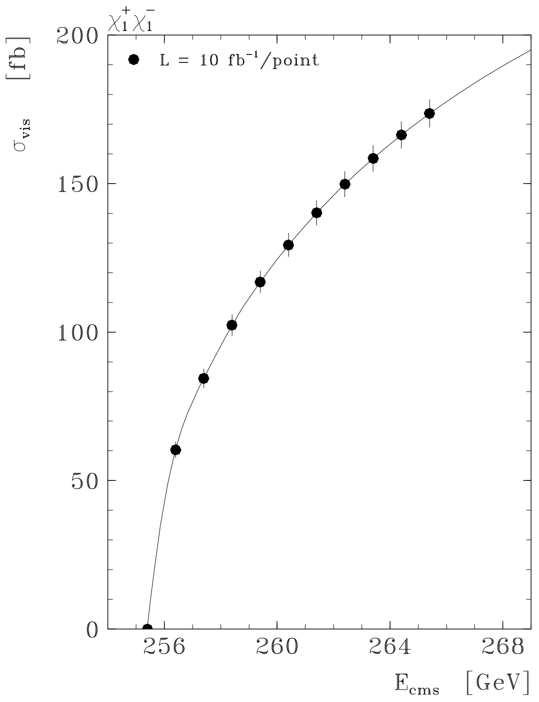


- tree level result Feng, Strassler
- measure of $\sigma(\widetilde{W}_1^+\widetilde{W}_1^-)$, $\sigma(\widetilde{W}_2^+\widetilde{W}_2^-)$ and angular dist'ns $\Rightarrow$ $M_2,\ \mu,\ \tan\beta$
- radiative corrections are necessary!

Chargino pair studies

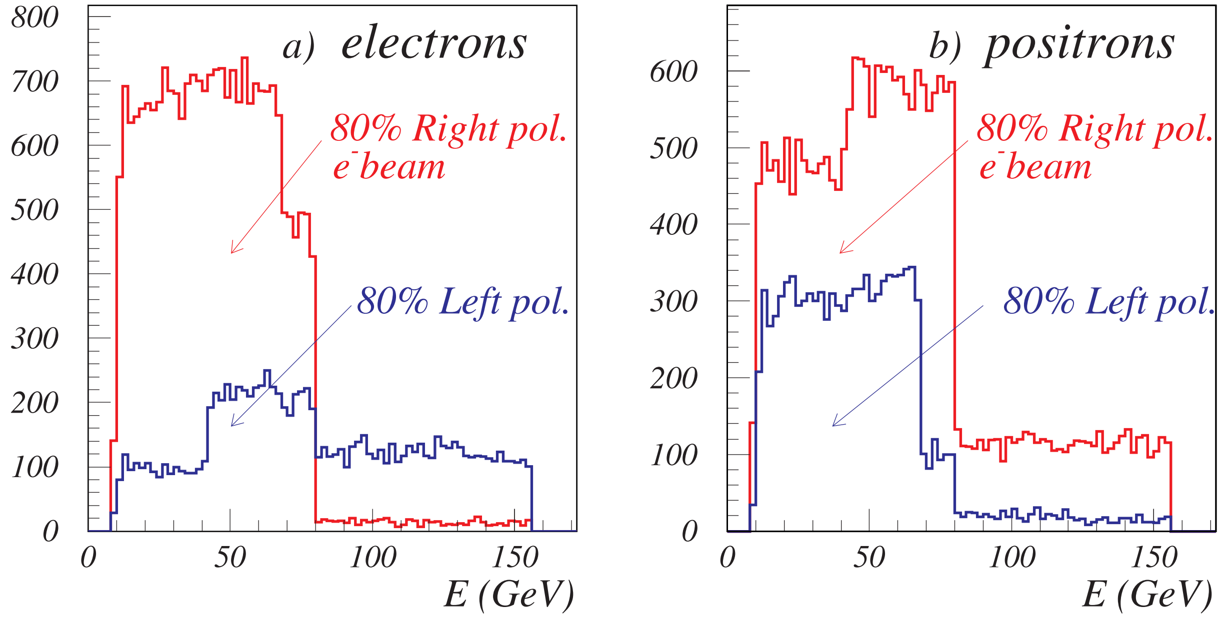
- measure $\sigma(\widetilde{W}_1^+\widetilde{W}_1^-)$, $\sigma(\widetilde{W}_2^+\widetilde{W}_2^-)$ using polarized beams
  - radiative corrections Diaz, King, Ross; Kiyoura, Nojiri, Pierce, Yamada
  - 1-loop corrections to σ, A_{FB}, A_{LR}: Blank, Hollik
  - 1-loop corrections to helicity amplitudes: Diaz, Ross
- knowledge of $\widetilde{W}_1$, $\widetilde{W}_2$ decays
  - SUSY EW corrections to $\widetilde{W}_1 \to W\widetilde{Z}_1$ Zhang, Ma, Wan
- spin-correlations
  - with beam polarization G. Moortgat-Pick, Bartl, Fraas, Majerotto
- continuuum measurements $\Rightarrow m_{\widetilde{W}_1} \sim 1\%$ or
- threshold scans: $m_{\widetilde{W}_1} \sim 0.1\%?$ Blair, Martyn

Threshold scans:



- $\widetilde{W}_1^+\widetilde{W}_1^-$ threshold scan Blair, Martyn
- measure $m_{\widetilde{W}_1}$ to 0.1%

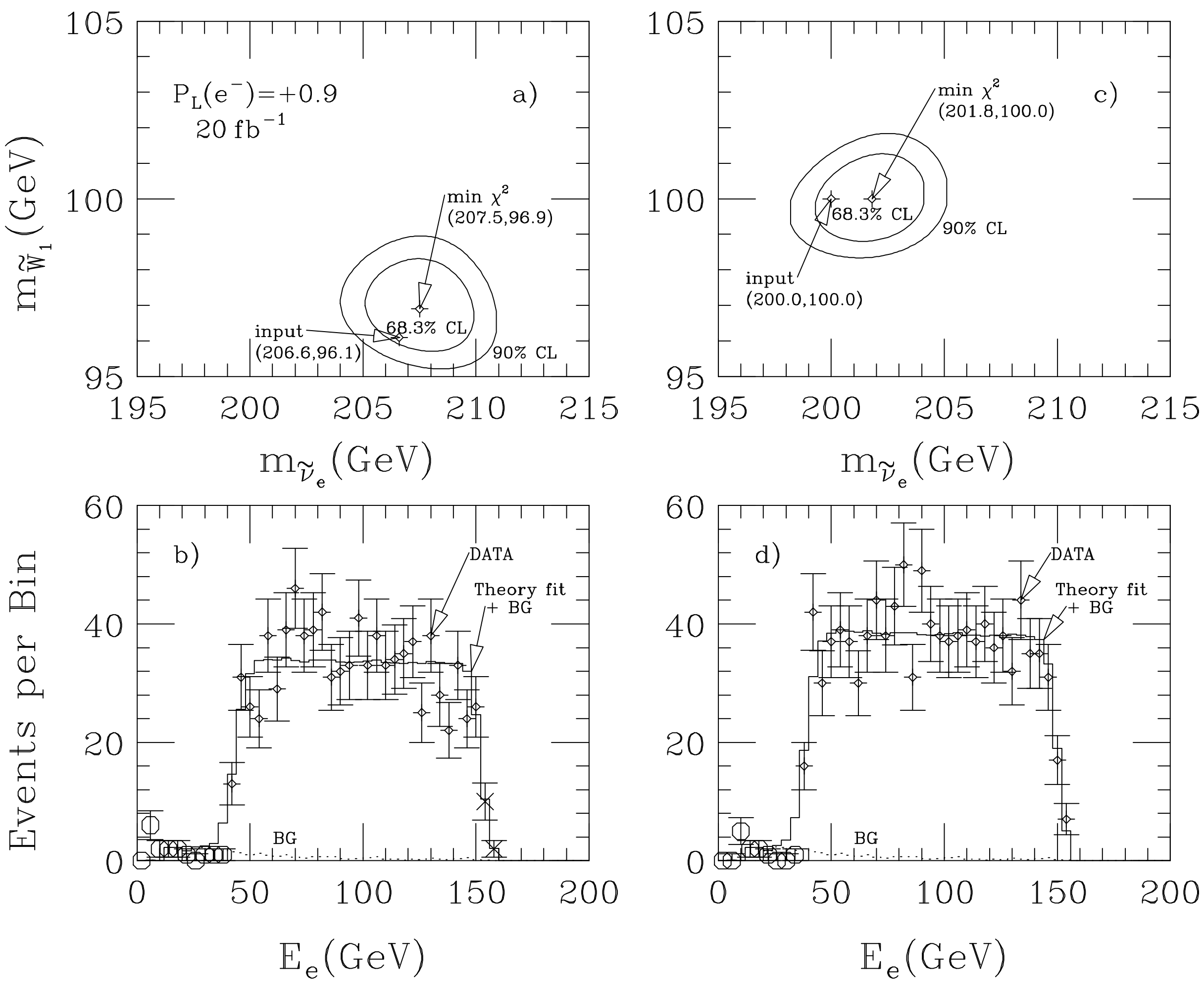
Selectron pair studies



- $e^+e^- \to \tilde{e}_R^+\tilde{e}_R^-,\ \tilde{e}_R^+\tilde{e}_L^-,\ \tilde{e}_L^+\tilde{e}_R^-,\ \tilde{e}_L^+\tilde{e}_L^-$ enhanced by t-channel graphs
- numerous kinematic edges allow $m_{\tilde{e}_R}$, $m_{\tilde{e}_L}$, $m_{\widetilde{Z}_1}$ to $\sim 1\%$

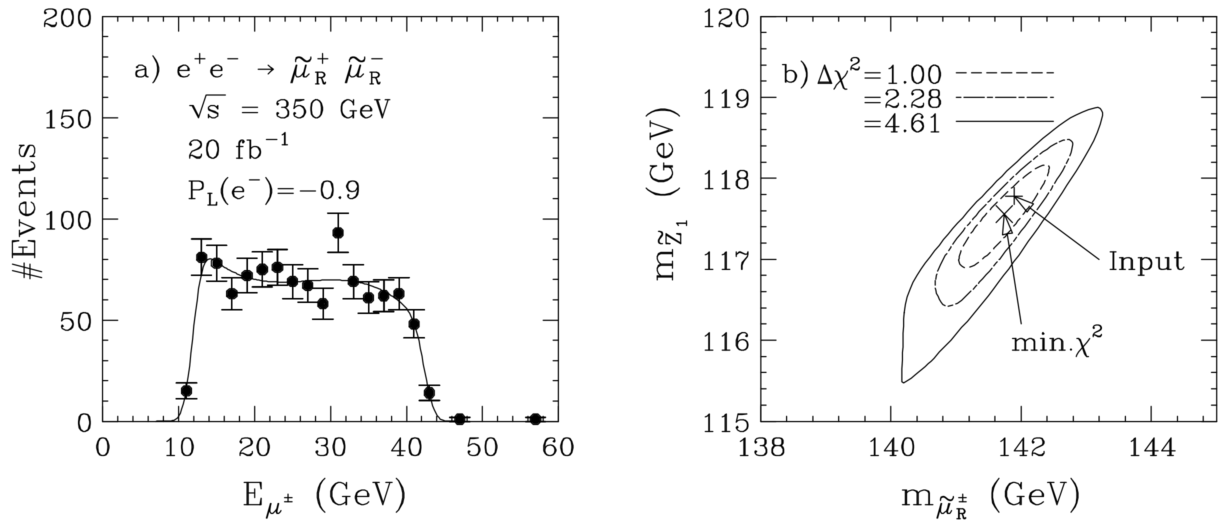
  Tsukamoto et al., HB, Munroe, Tata; Nauenberg et al.
- beam polarization
- e^-e^- option
- width/brem effects near threshold Freitas, Miller, Zerwas

Sneutrino pair studies



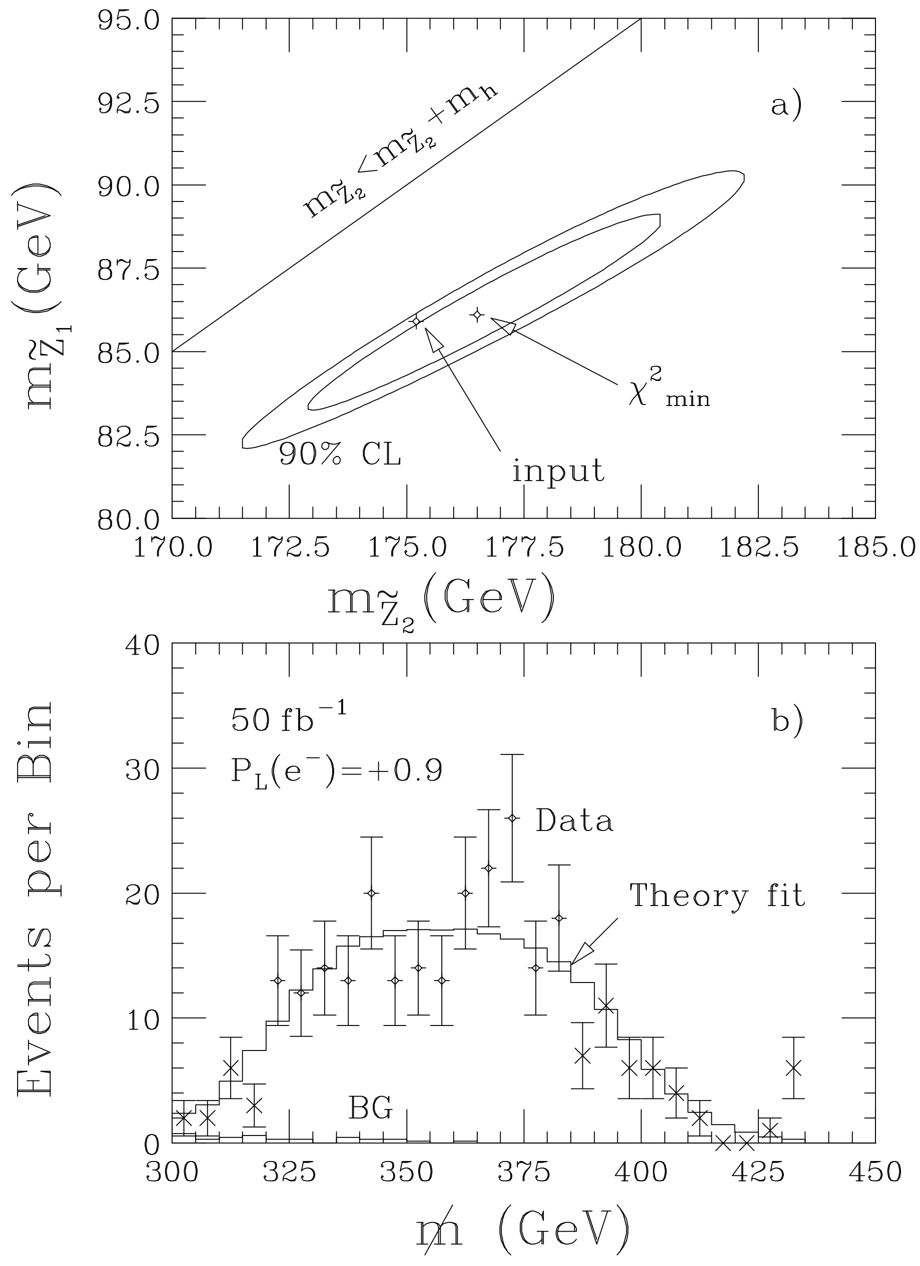
- $e^+e^- \to \tilde{\nu}_L\tilde{\nu}_L$; $\tilde{\nu}_L \to e\widetilde{W}_1$
- enhanced by t-channel $\widetilde{W}_i$ exchange
- $m_{\tilde{\nu}_L}$, $m_{\widetilde{W}_1}$ to $\sim 1\%$ via kinematics HB, Munroe, Tata
- beam polarization
- $\tilde{\nu}_{\mu L}$, $\tilde{\nu}_{\tau L}$ much harder/lower rate

Smuon pair studies



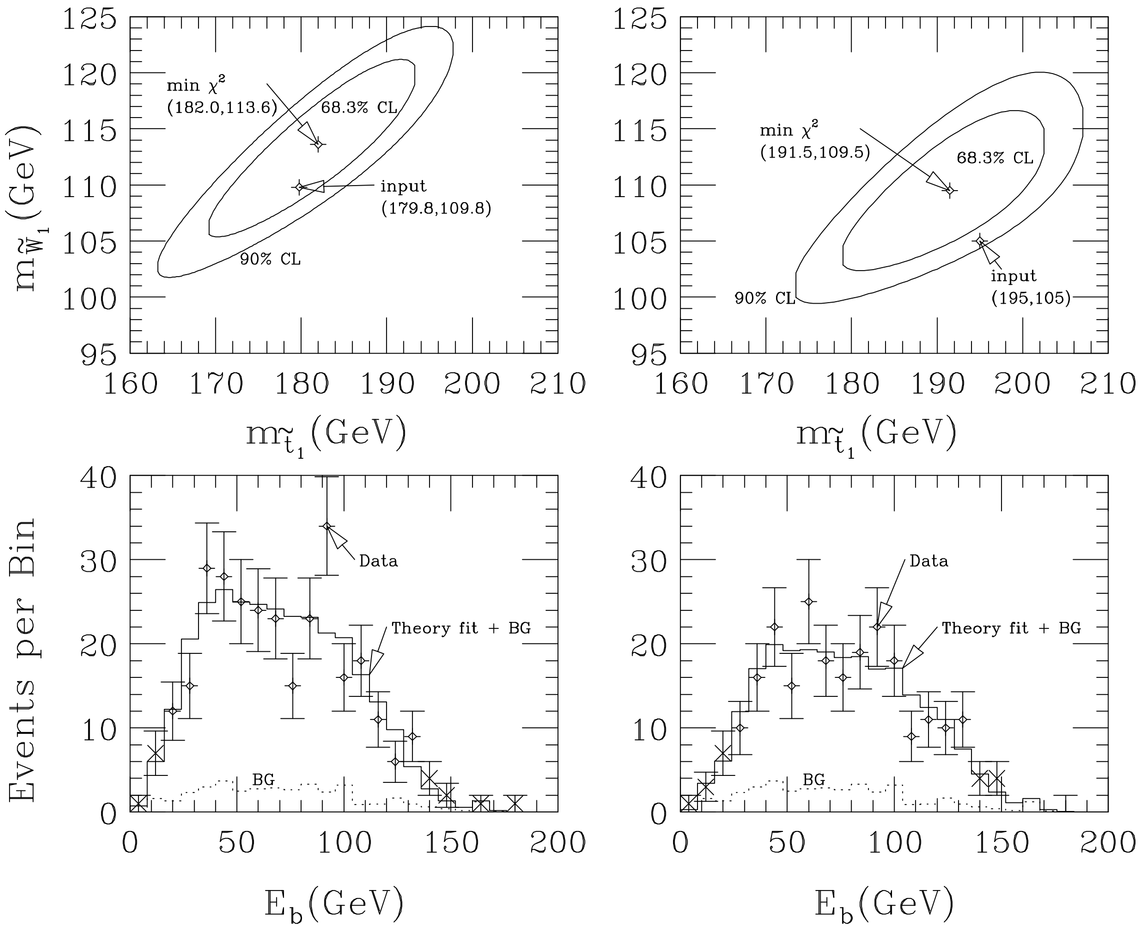
- $e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-$; $\tilde{\mu}_R \to \mu\widetilde{Z}_1$
- only s-channel γ, Z exchange
- $m_{\tilde{\mu}_R}$, $m_{\widetilde{Z}_1}$ to $\sim 1\%$ via kinematics Tsukamoto et al., HB, Munroe, Tata
- beam polarization

Neutralino pair studies



- $e^+e^- \to \widetilde{Z}_1\widetilde{Z}_2$; $\widetilde{Z}_2 \to \widetilde{Z}_1 h \to \widetilde{Z}_1 b\bar{b}$
- $m_{\widetilde{Z}_2}$, $m_{\widetilde{Z}_1}$ to $\sim 3\%$ mainly kinematics HB, Munroe, Tata

Squark pair studies

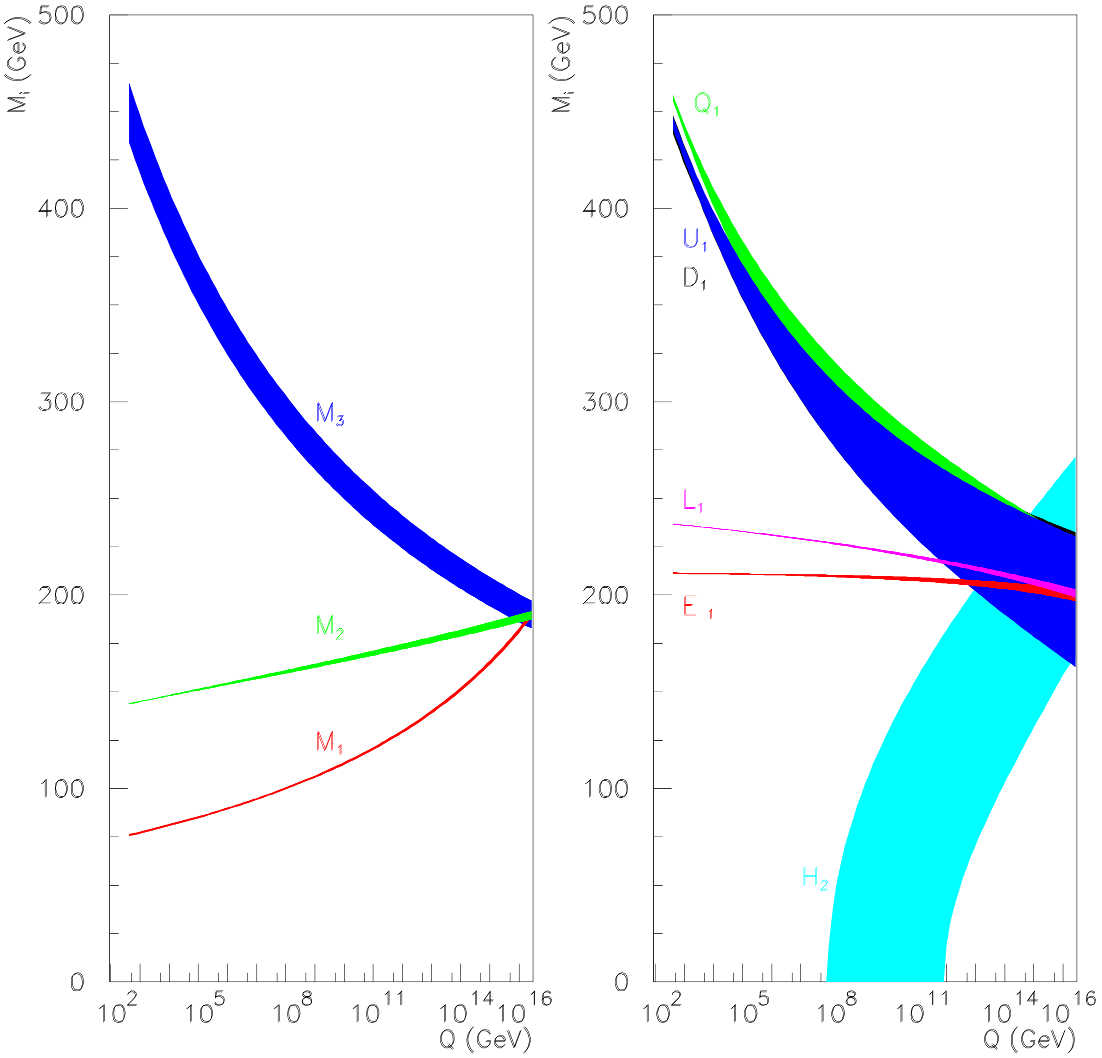


- $e^+e^- \to \tilde{t}_1\tilde{t}_1;\ \tilde{t}_1 \to b\widetilde{W}_1$
- QCD corrections to production, decay Bartl, Eberl, Kraml, Majerotto, Porod; Djouadi, Hollik, Junger
- EW corrections to $\tilde{q}$ decay Gausch, Hollik, Sola

Sparticle mass determinations:

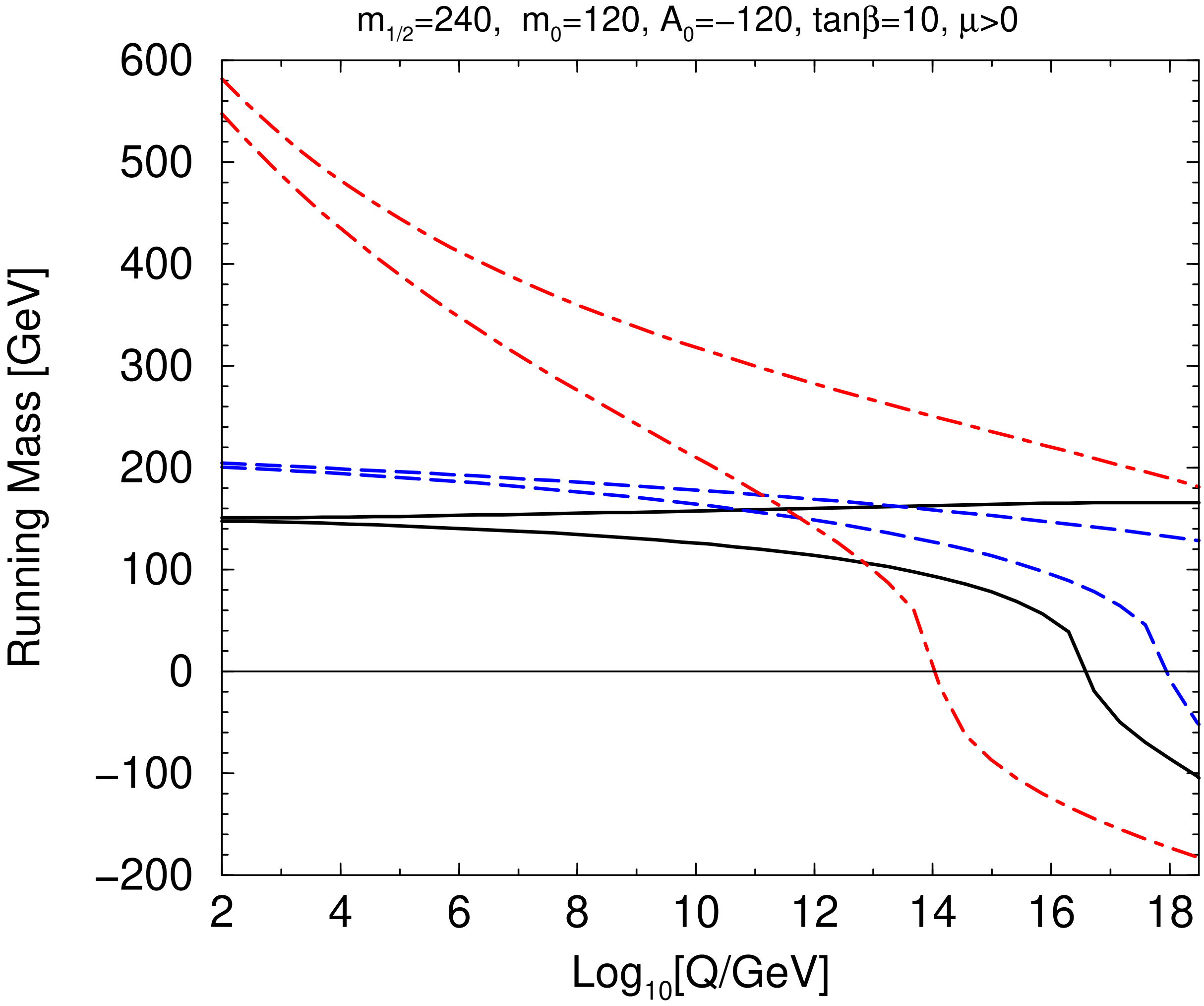
- Two loop RGEs, Gen. SS models (MSSM) Martin, Vaughn; Yamada; Jack, Jones
- W, Z self-energy: Grifols, Sola; Chankowski, Pokorski, Rosiek; Drees, Hagiwara, Yamada; Chankowski, Pluciennik, Pokorski
- t, b, τ: Hall, Rattazzi, Sarid; Pierce, Bagger, Matchev, Zhang (PBMZ)
- $\tilde{g}$ self-energy Martin, Vaughn
- charginos, neutralinos Papadopoulos, Pierce; Fritzsche, Hollik
- squarks and sleptons PBMZ
- two-loop effective potential in MSSM; EWSB/value of μ Martin

Blair, Porod, Zerwas extrapolation:



- Study based on overly optimistic mass estimates
- $e.g.\ m_{\tilde{\nu}_\tau} \sim 0.5\% \Rightarrow > 10\%$ or undetermined HB, Belyaev, Mizukoshi, Tata

Steve Martin extrapolation:



- intermediate/optimistic precision assumptions
- uncertainty of $m_{\tilde{g}}$ feeds into RG running

Conclusions

- A LC would allow a program of precision determinations of sparticle properties (mass, spin, couplings)
- determining spectra and SUSY parameters points to SUSY breaking model/ window to high scale physics
- precision calculations of sparticle masses, cross sections, decay rates is underway
- much remains to be done!