Progress with Isajet v7.72

H. Baer, F. Paige, S. Protopopescu and X. Tata

webpage: `http://www.phy.bnl.gov/~isajet`

manual: hep-ph/0312045

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- SUSY processes in Isajet
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Isajet overview

- Isajet the first of multi-purpose event generators to appear
- Created by Frank Paige and Serban Protopopescu in 1979 to model jet activity expected at the ill-fated BNL Isabelle pp collider
- Original algorithm contained:
  - Hard scattering processes (perturbative QCD)
  - Fox-Wolfram algorithm for final state parton showers
  - Field-Feynman independent hadronization (IH) algorithm
- Isabelle project terminated, but Isajet used for many analyses at CERN $Sp\bar{p}S$ collider: UA1 and UA2
- Jetset/Pythia (Sjöstrand) programs appear circa 1983; string hadronization (SH) model gives correlated $q\bar{q}$ hadronization
- SH and IH models agree well over most of phase space for e^+e^- two jet events, but SH model predicts a depletion of hadronic activity in region between hard jets (verified): result of color flow
- 1983: Sjöstrand develops backward shower algorithm to treat initial state QCD radiation for hadron colliders; incorporated into Isajet as well
- 1985: Marchesini and Webber release Herwig algorithm; angle-ordered parton showers account for some interference effects in multiple gluon emission; Herwig uses a cluster

hadronization model (CH) which accounts for color flow as does SH model; CH model clusters partons that are nearby in phase space into hadrons, thereby eliminating non-local effects that arise in SH model

- all programs include most important $2 \to 2$ SM hard scattering processes for e^+e^-, pp and $p\bar{p}$ colliders; degree of sophistication in modeling varies.
- The challenge of past 22 years is to merge PS algorithm with NLO QCD calculations; several papers every year (see $e.g.$ Sjóstrand; HB/Reno; Soper; Collins; Webber; Mrenna; Nagy; Skands; $\cdots$)

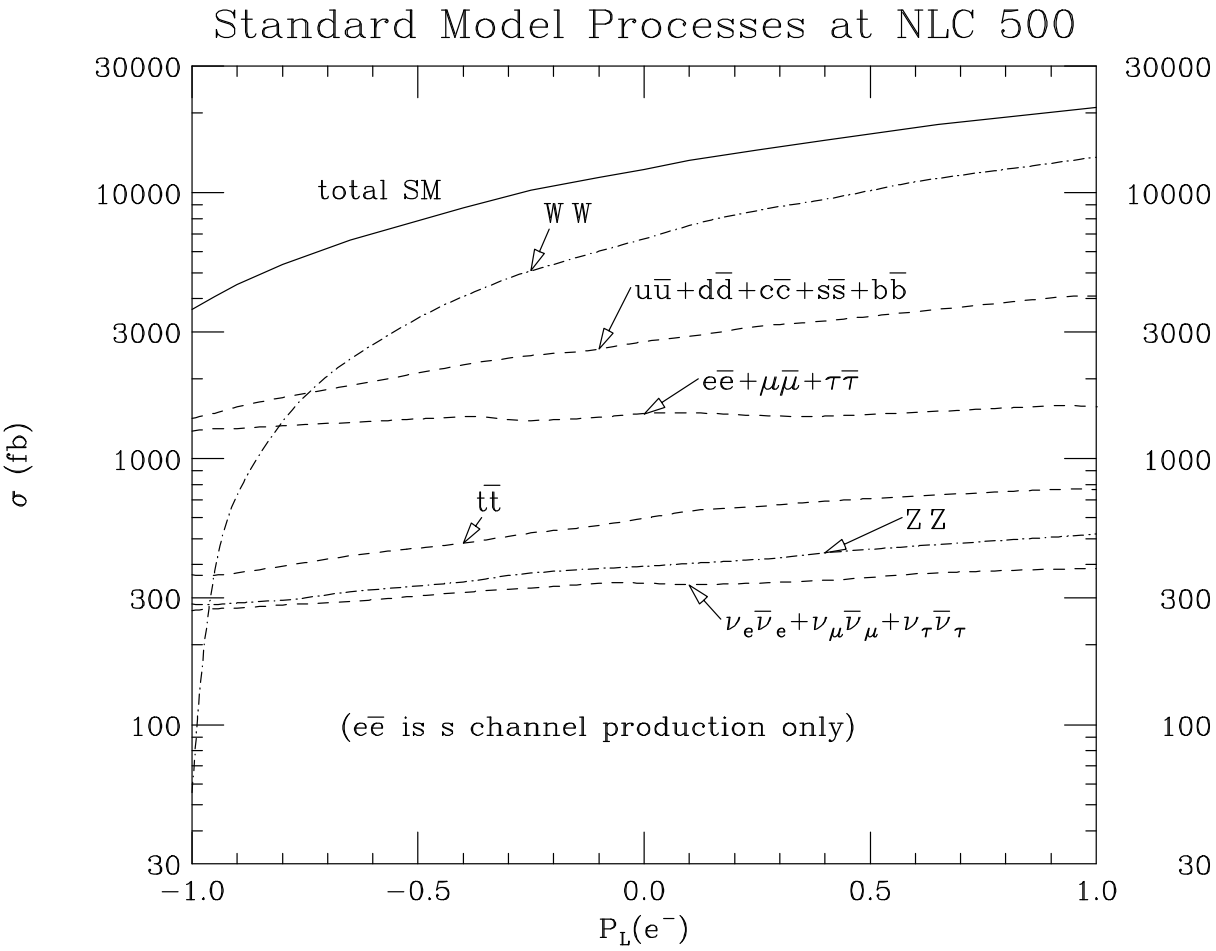
SUSY in Isajet

- 1984: primitive SUSY production processes plus one-step decays in Isajet used for UA1 and UA2 analyses
- 1989: HB and X. Tata develop SUSYSM program: parton level sparticle production with cascade decays
- 1990: interface SUSYSM with Pythia for SH model
- 1991: Jim Freeman (CDF) was entire SUSY group at FNAL; rough patch of SUSYSM into Isajet
- 1992: F. Paige and HB incorporate sparticle production and cascade decays into isajet 7.00; release 1993
- 1994 Colorado: $e^+e^- \to SUSY$ into Isajet while on honeymoon; add WW, ZZ and ZH production; Isasugra SUSY RGE solution incorporated into Isajet
- 1995: Susygen (Katsanevas)
- 1996: Spythia (Mrenna)
- 1996: polarized beams into isajet
- 1997: P. Chen brem/beamstrahlung distribution into Isajet; large $\tan\beta$ SUSY event generation; treatment of τ helicity states
- 1998: 3-body decay MEs
- 1998: Suspect spectrum calculator
- 2001: SoftSUSY spectrum calculator

- 2002: SUSY in Herwig using Isajet decay table (Isawig)
- 2003: Spheno spectrum and decay calculator
- 2003: full one loop sparticle mass formulae in Isajet
- 2003: Les Houches accord (Skands et al.) to allow various spectra calculators interface with event generators
- 2004: add $\gamma\gamma \to f\bar{f}$; P. Chen $\to$ Peskin beam/brem eDFs
- 2005: Isatools release: $\Omega_{\widetilde{Z}_1}h^2$, $BF(b \to s\gamma)$, Δa_μ, $B_s \to \mu^+\mu^=$, $\sigma(\widetilde{Z}_1 p)$

SM processes versus beam polarization

- *EPOL* keyword stipulates e^- and/or e^+ polarization
- $P_L(e^-) = (n_L - n_R)/(n_L + n_R)$



Models for SUSY in Isajet (all are MFV models)

- MSSM (weak scale inputs; no RGE solution)
  - MSSMA: $m_{\tilde{g}}$, μ, m_A, $\tan\beta$
  - MSSMB: m_{Q_1}, m_{D_1}, m_{U_1}, m_{L_1}, m_{E_1} (1st gen.)
  - MSSMC: m_{Q_3}, m_{D_3}, m_{U_3}, m_{L_3}, m_{E_3}, A_t, A_b, A_τ (3rd gen.)
  - MSSMD: m_{Q_2}, m_{D_2}, m_{U_2}, m_{L_2}, m_{E_2} (2nd gen. optional)
  - MSSME: M_1, M_2 (independent gaugino masses; optional)
- mSUGRA model (invokes RGE running solution)
  - m_0, $m_{1/2}$, A_0, $\tan\beta$, $sign(\mu)$
- SUGRA (non-universal soft terms)
  - NUSUG1: M_1, M_2, M_3
  - NUSUG2: A_t, A_b, A_τ
  - NUSUG3: m_{H_d}, m_{H_u}
  - NUSUG4: m_{Q_1}, m_{D_1}, m_{U_1}, m_{L_1}, m_{E_1} (1st/2nd gen.)
  - NUSUG5: m_{Q_3}, m_{D_3}, m_{U_3}, m_{L_3}, m_{E_3} (3rd gen.)
  - NUHM: μ, m_A
- GMSB
  - Λ, M, n_5, $\tan\beta$, $sign(\mu)$, C_{grav}
  - $\not{R}$, $\delta m^2_{H_d}$, $\delta m^2_{H_u}$, $D_Y(M)$, n_{5_1}, n_{5_2}, n_{5_3}
- AMSB

- m_0, $m_{3/2}$, $\tan\beta$, $sign(\mu)$
- c_Q,c_D,c_U,c_L,c_E, c_{H_d}, c_{H_u}

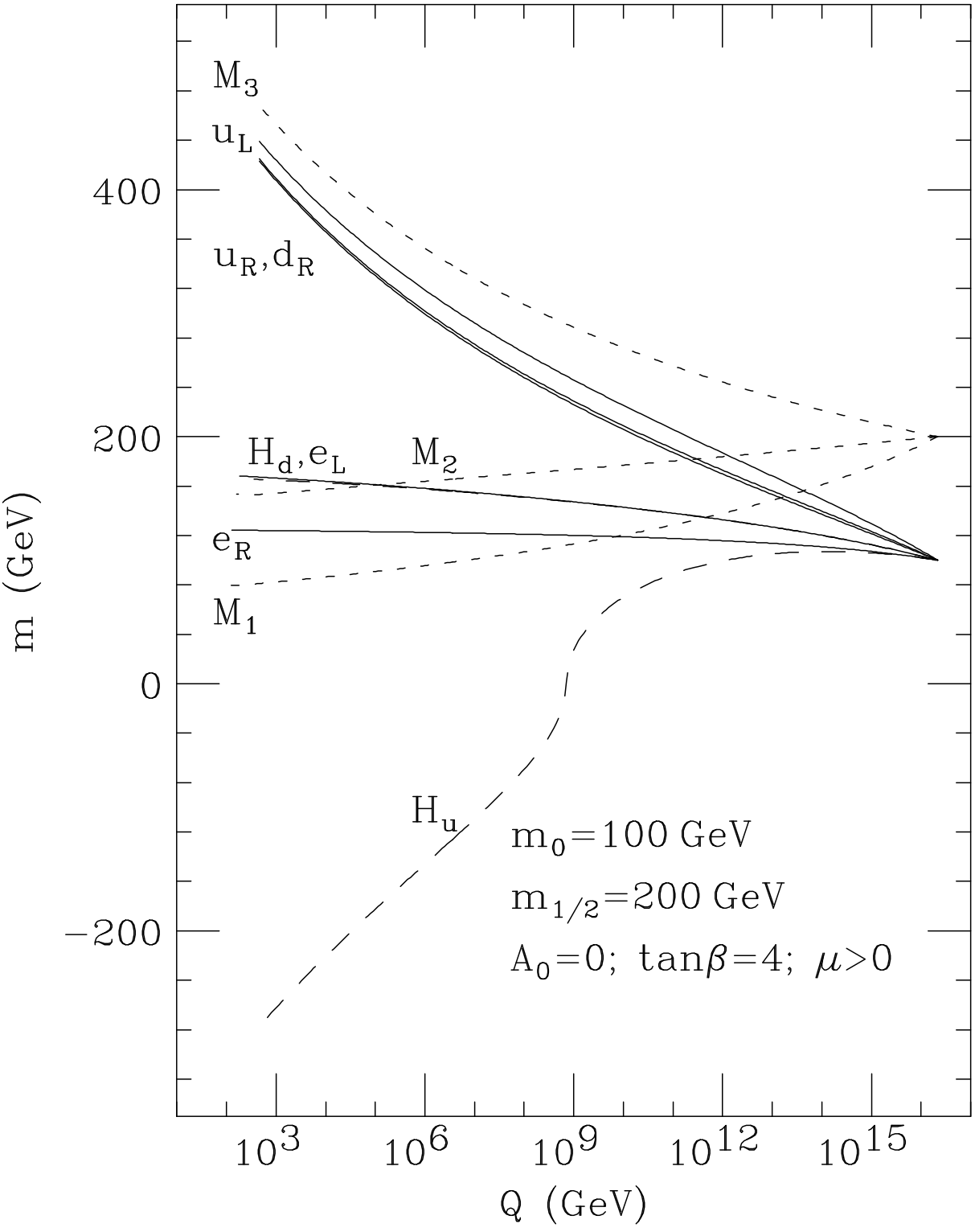
- SUGRHN
  - m_{ν_τ}, M_N, A_ν, $m_{\tilde{\nu}_R}$
- SSBCSC (select BC scale other than M_{GUT})

Isajet RGE solution (bottom-up approach)

- Begin with $\overline{DR}$ gauge and Yukawa couplings at $Q = M_Z$
- Evolve up in E to where $g_1 = g_2$ (defines M_{GUT})
- Impose soft SUSY breaking masses at M_{GUT} and evolve back down to $Q = M_Z$; freeze out each soft term at scale $Q = m_{soft}$
- Calculate spectrum at $Q \sim M_{weak}$; use RG improved 1-loop eff. pot. evaluated at (optimized) scale choice $Q = \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$ (accounts for leading 2-loop terms)
- sparticle mass corrections at 1-loop at scale $Q = m_{sparticle}$
- Evolve back up, this time include Yukawa threshold corrections at scale $Q = \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$
- Iterate process until convergent solution is achieved
- Good agreement between Isajet, Suspect, SoftSUSY, Spheno in bulk region or where all scales are similar; predictions differ if sparticle masses are highly split

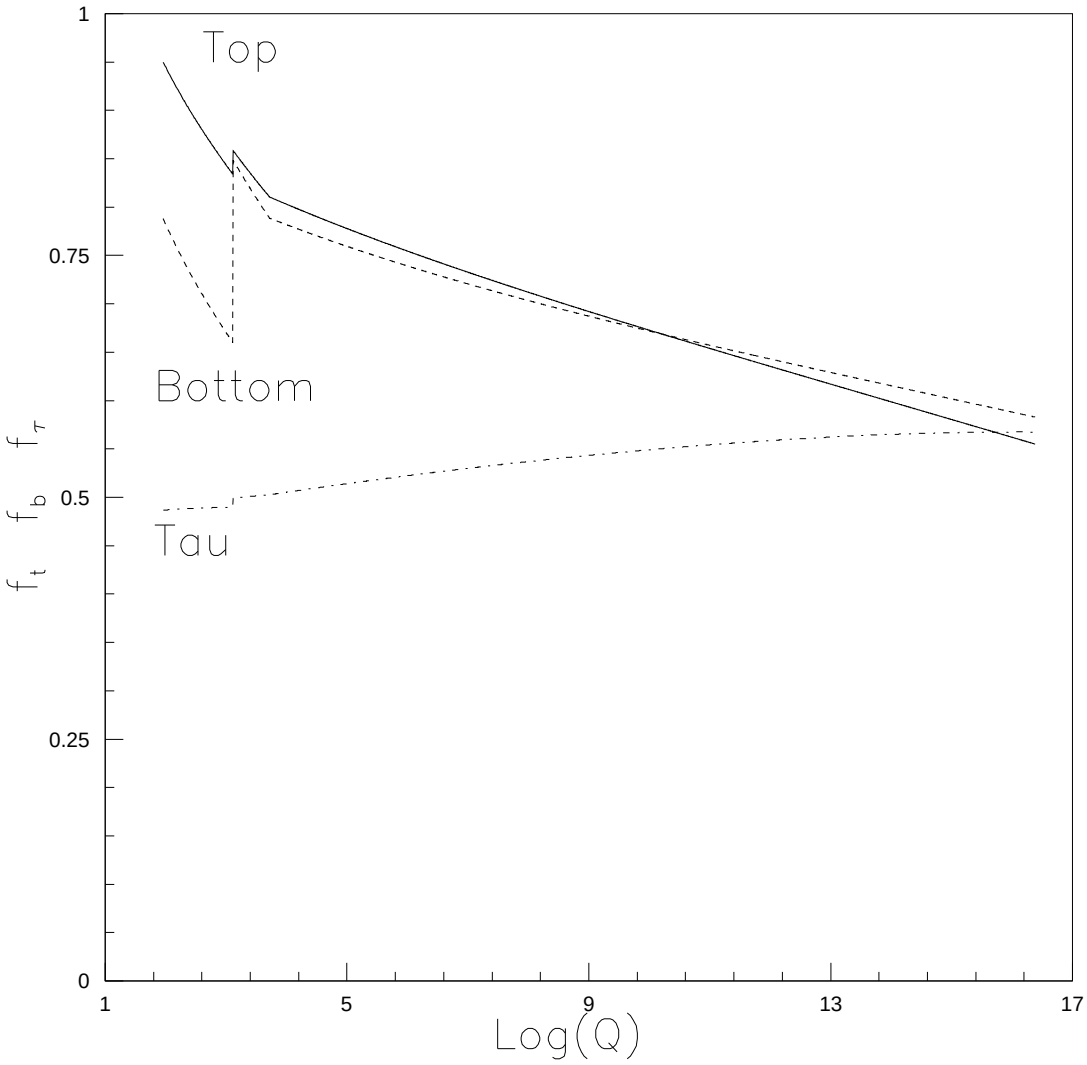
Isajet RGE solution for sparticle masses

- Isasugra soft term evolution



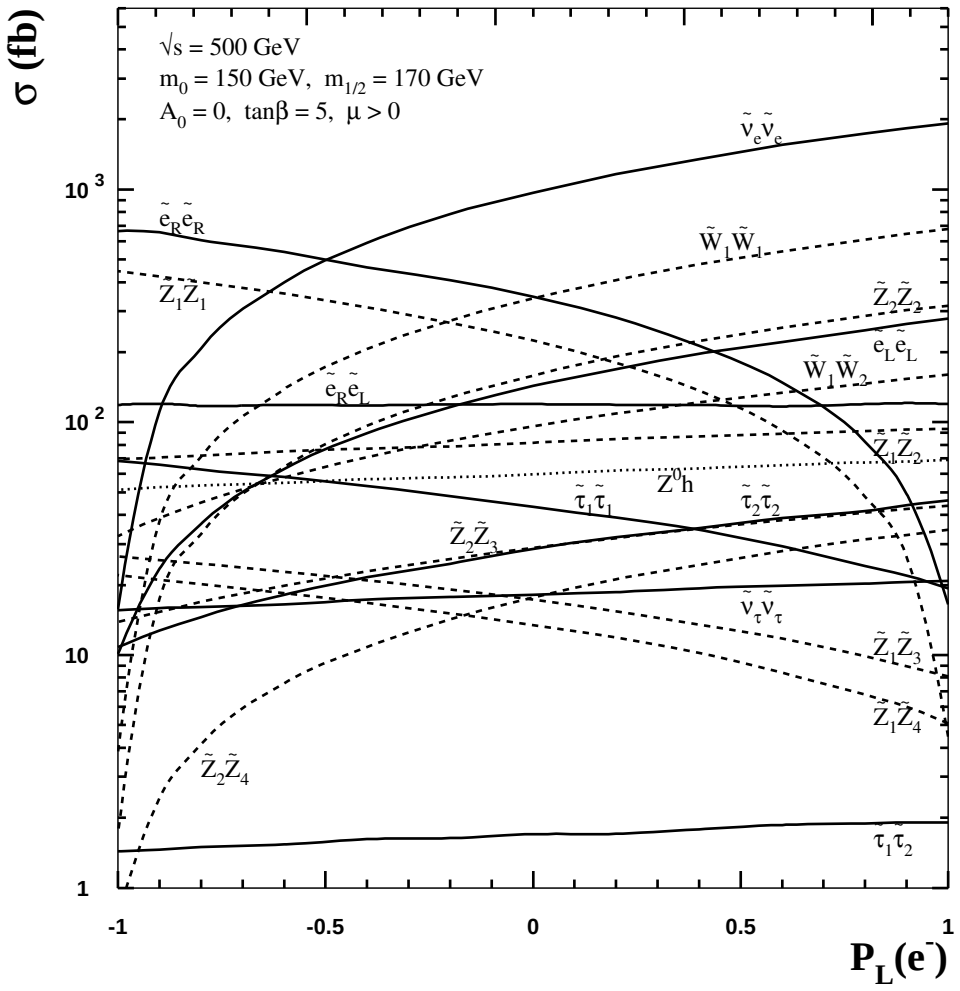
Isajet RGE solution for Yukawa coulings

- Note MSSM-SM threshold corrections at $Q = \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$



SUSY processes versus beam polarization

- Case study from BMT: PRD54, 6735 (1996)

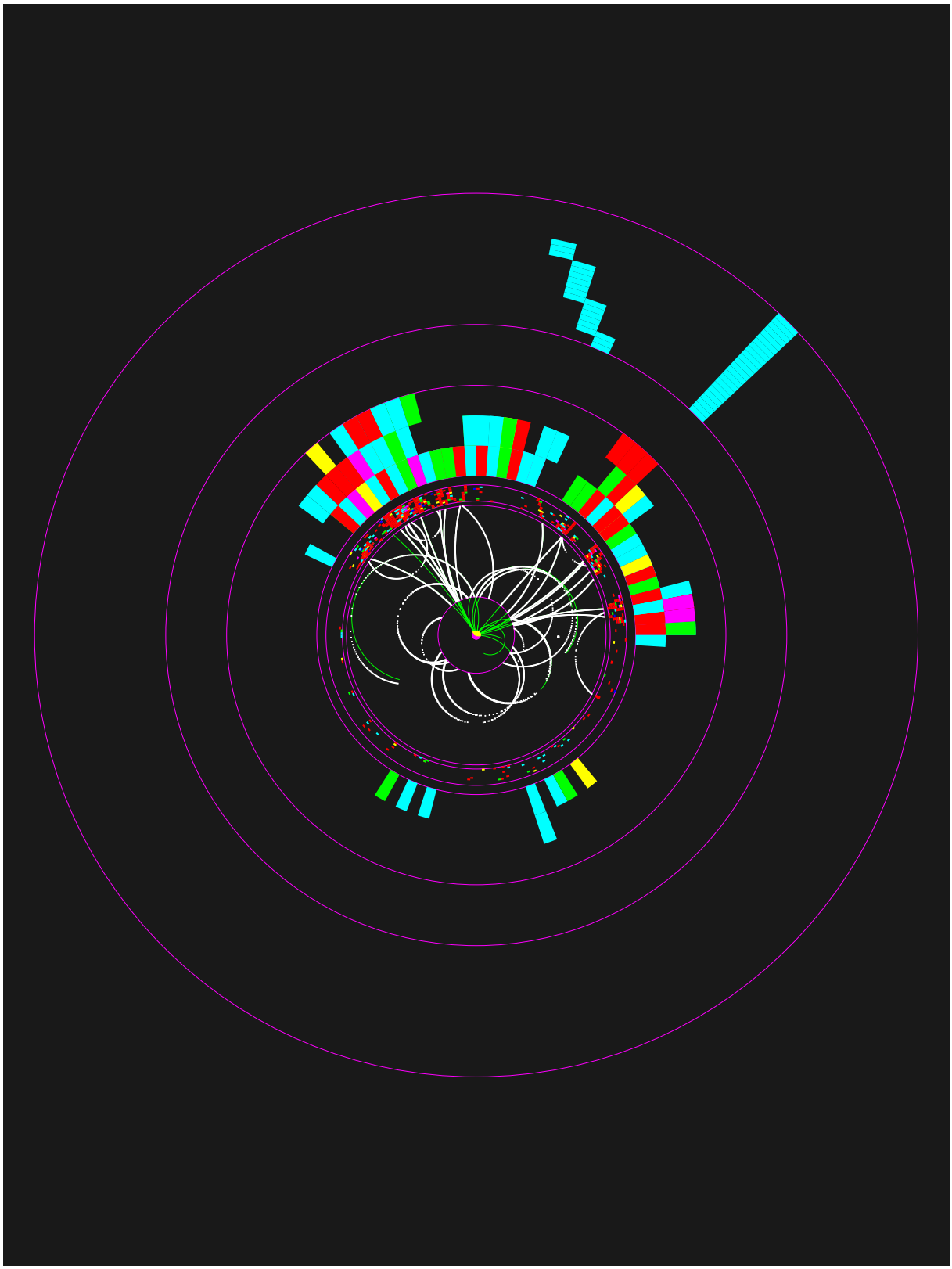


Decays in Isajet

- Implement full set of sparticle cascade decays; valid at all values of $\tan\beta$
- spin correlation: production/decay neglected
- 3-body decays include exact matrix elements for E dependence
- τ decays: Isajet calculates rate to τ_L and τ_R; decays them appropriately

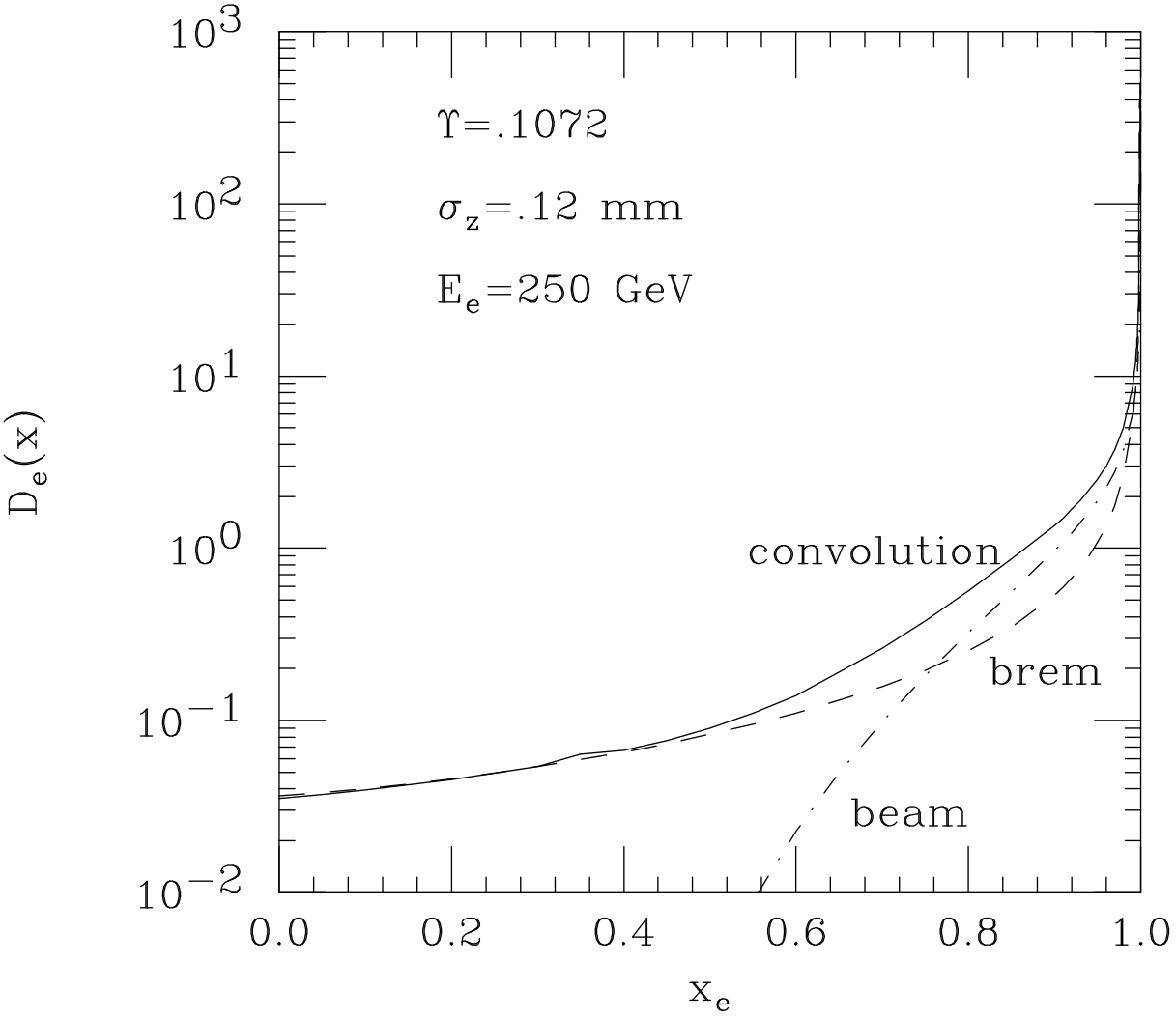
SUSY event for LC

- Isajet $e^+e^- \rightarrow SUSY$ event from Norman Graf for LC



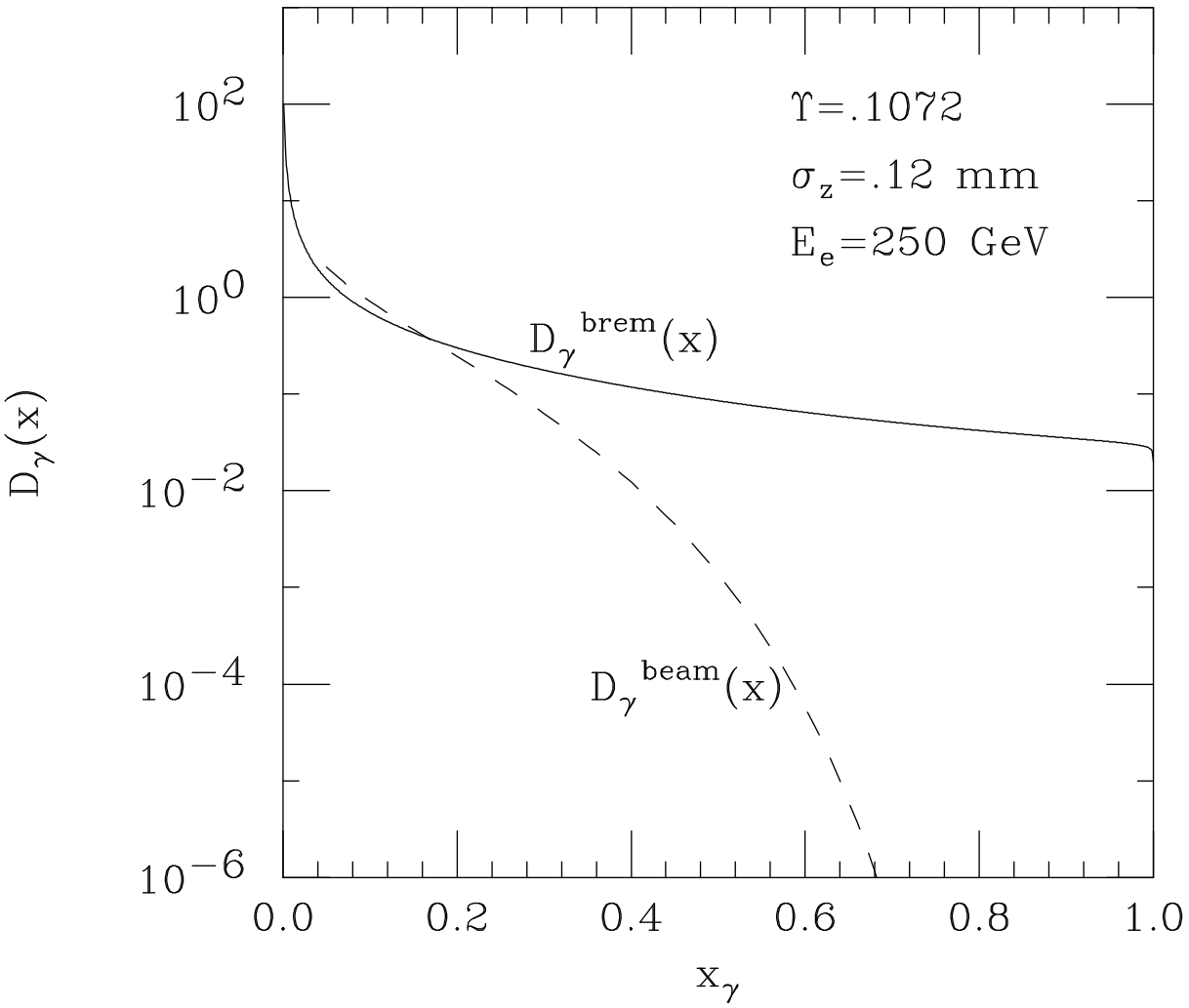
Brem/beamstrahlung convolution

- Bremsstrahlung: Fadin-Kurayev distribution
- Beamstrahlung: use Michael Peskin distributions
- Convolution: $D_e(x) = \int_x^1 dz D_e^{brem}(\frac{x}{z}, Q^2) D_e^{beam}(z)/z$



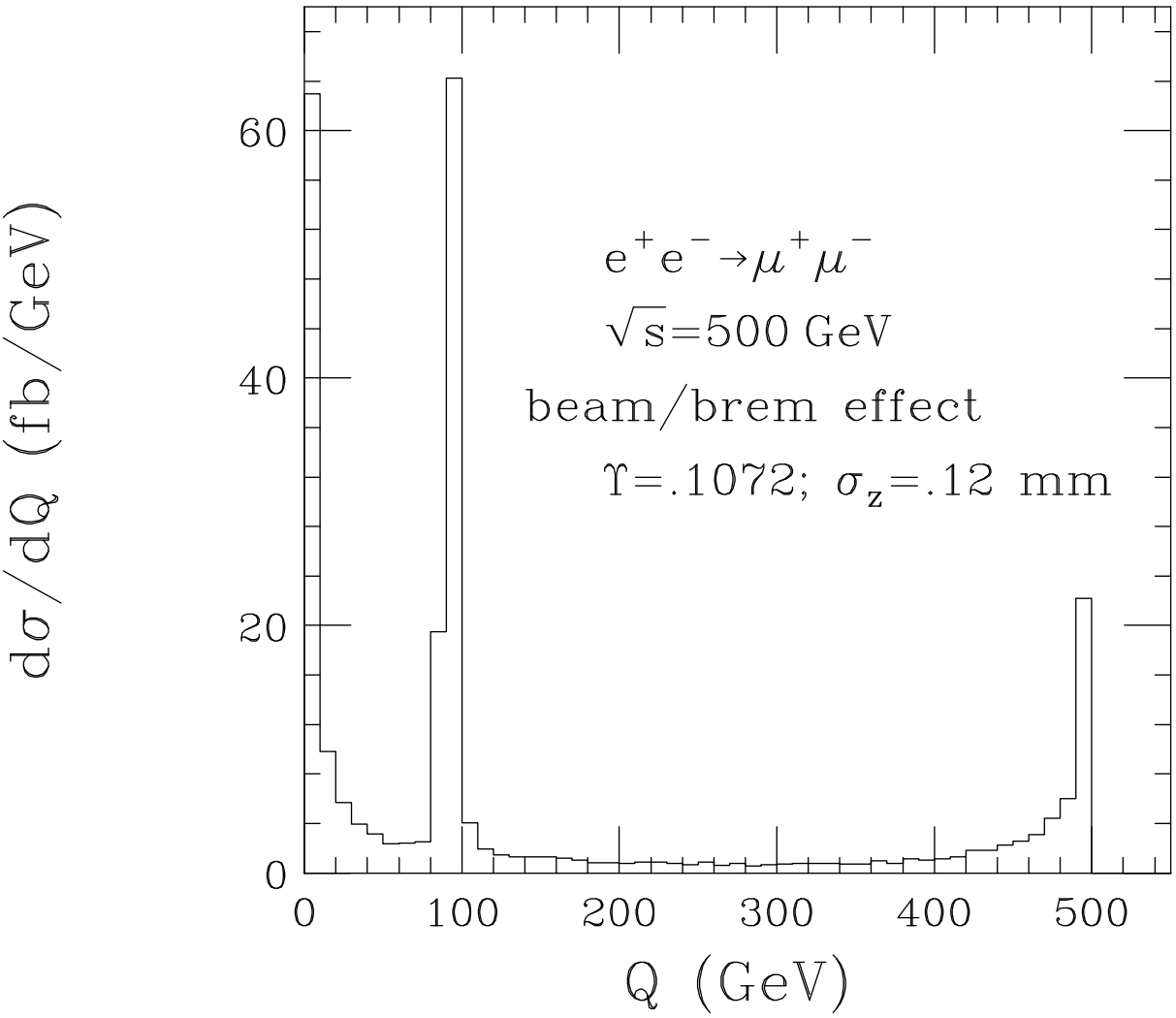
Photon structure function

- Bremsstrahlung: Weizsacker-Williams
- Beamstrahlung: Peskin distribution



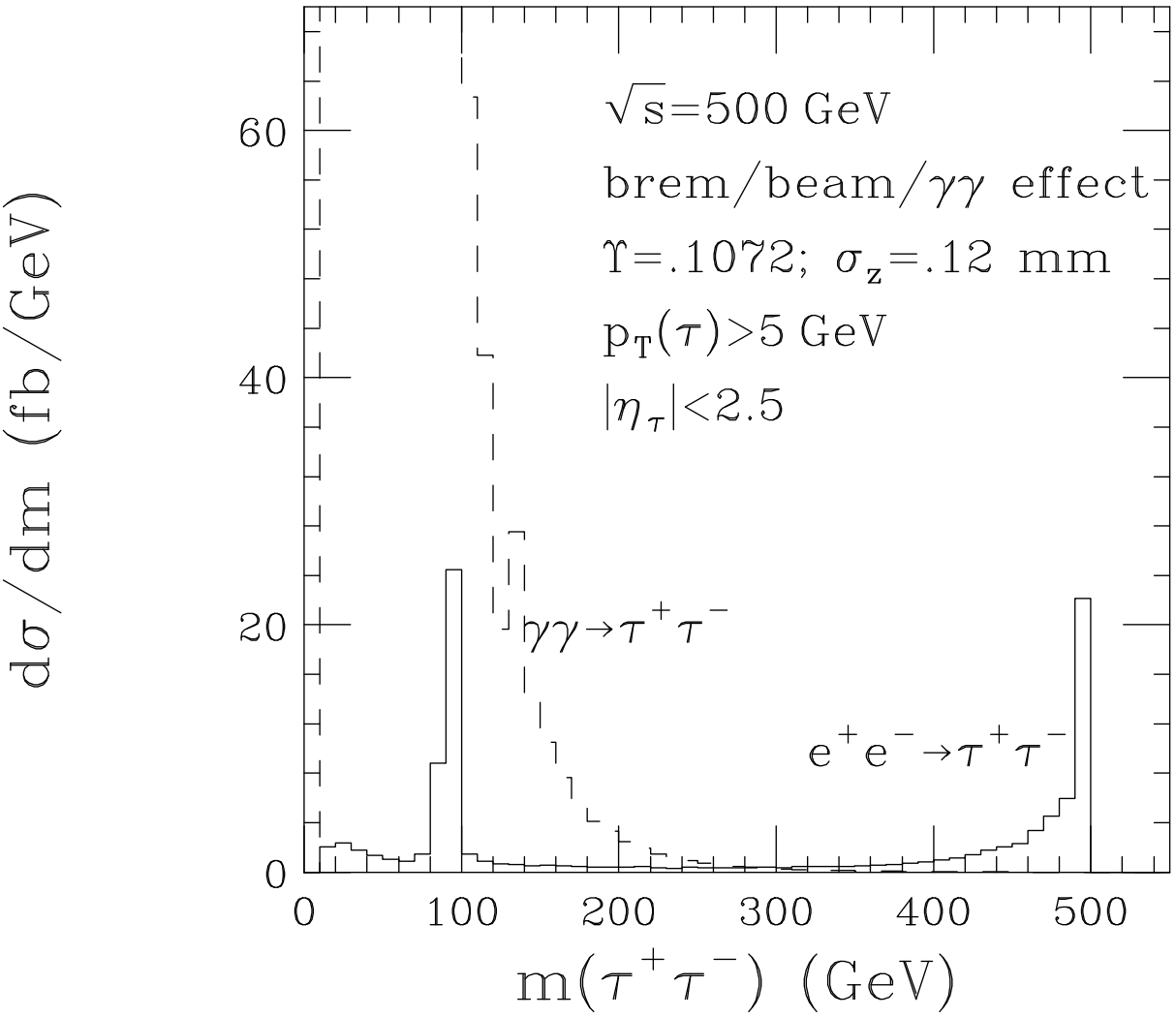
$e^+e^- \to \mu^+\mu^-$ including brem/beamstrahlung

- Note γ and Z peaks



$e^+e^- \to \mu^+\mu^-$ via $\gamma\gamma \to f\bar{f}$: Isajet 7.70

- Note $\gamma\gamma$ dominance at low m



Future and conclusions

- Isajet allows for integrated program for production of a variety of SM and SUSY processes
  - sparticle mass spectrum calculation (Isasugra or Isasusy)
  - sparticle and Higgs boson decay table
  - all $2 \to 2$ SM, sparticle and Higgs pair production reactions
  - event generation for e^+e^-, pp and $p\bar{p}$ colliders including
    - subprocess generation
    - initial/final state parton showers
    - hadronization
    - underlying event
    - e^- and e^+ beam polarization
    - bremsstrahlung/ beamstrahlung e and γ PDFs
    - complete 3-body decay MEs
    - correlated $\tau_{L/R}$ decays
- Isatools: see talk by Belyaev
- current work: improved RGE algorithm with decoupling β-functions