SUSYGEN III

SUSYGEN, a Monte Carlo Event Generator based on the Helicity Amplitude Method for SUSY particle production at linear colliders

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Outline

- The SUSYGEN project
- Physics content
- The Helicity Amplitude method
- New features of SUSYGEN 3
- How to use SUSYGEN 3 ?
- Future developments

- Where
  http://lyoinfo.in2p3.fr/susygen/susygen3.html

- Package: susygen3.tar.gz / Manual / Makefile

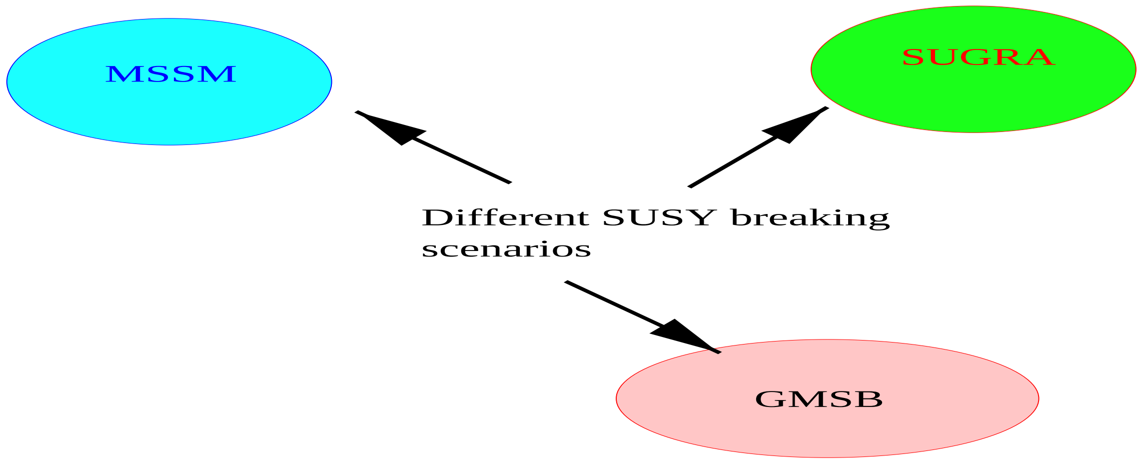
- Who
  N.Ghodbane, S.Katsanevas, P.Morawitz, E.Perez.

- Since 1994 standard SUSY package for LEP II
  All 4 LEP experiments use it $\Longrightarrow$ well debuged program!

- Also available for *ep* colliders

- Big help from :
  S.Melachroinos, I.Laktineh, H.Dreiner, S.Ambrosanio, R.Barbier, S.Lola, M.Diaz et al., S.Paiano, A.Djouadi, M.Spira, D.Zerwas and Janusz Rosiek

- Cover all production processes in MSSM, SUGRA, GMSB and R-parity violating models (with or without beam polarisation and spin correlations)



- MSSM mode : masses are free parameters
  - Gauginos sector $\mu, M_1, M_2, \tan\beta$
  - sfermions: mixing implemented for third generation
- mini SUGRA mode :
  - $\mu, M_1, M_2, \tan\beta, m_0$
  - A_t, A_b, A_τ at the EW scale.
  - m_A pseudo scalar Higgs mass.
  - Sfermions mass evolution from GUT to the EW scale using one loop RGE.
- GMSB mode: determination of the entire mass spectrum with
  - $\mu, M_1, M_2, \tan\beta, m_0$
  - A_t, A_b, A_τ
  - $N_{5,10}$ Number of representations in the messenger sector.
- R-parity can either be assumed to be conserved or not in production and decay of sparticles

$$W_{R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda^{'}_{ijk} L_i Q_j \bar{D}_k + \lambda^{''}_{ijk} U_i D_j \bar{D}_k$$

- Use of matrix elements in calculation of widths and event distribution
- Includes radiative decays $\chi_2^0 \to \chi_1^0\gamma$ and decays to Higgses
- Include lifetime effects in event generation
- Initial state radiation
- Final state radiation
  - PHOTOS for QED
  - JETSET for QCD
- Beam strahlung by an interface to CIRCE
- Hadronisation performed by JETSET

Spin correlations taken into account by using the helicity amplitude method

Recipe :

⇒ Definition of basic building blocks computable once for all:

$$B^{\Lambda}{}_{\lambda_1\ \lambda_2} = \bar{u}_{\lambda_1}(p_1, m_1) P_{\Lambda} u_{\lambda_2}(p_2, m_2)$$

$$\begin{aligned} Z^{\Lambda_1\ \Lambda_2}{}_{\lambda_1\ ...\lambda_4} &= [\bar{u}_{\lambda_1}(p_1, m_1)\gamma^{\mu} P_{\Lambda_1} u_{\lambda_2}(p_2, m_2)] \\ &\times [\bar{u}_{\lambda_3}(p_3, m_3)\gamma_{\mu} P_{\Lambda_2} u_{\lambda_4}(p_4, m_4)] \end{aligned}$$

e.g.

$$B^{L}{}_{-\ -}(p_1, p_2) = \mu_1 \eta_2$$

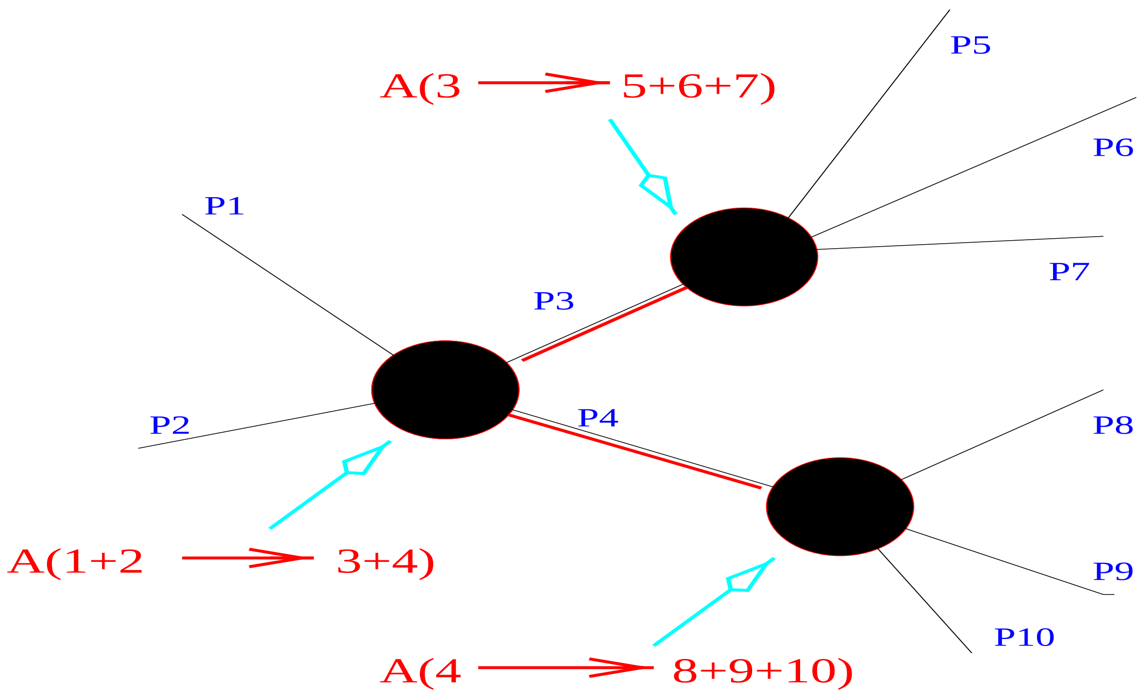
$$B^{L}{}_{-\ +}(p_1, p_2) = 0$$

$$B^{L}{}_{+\ -}(p_1, p_2) = (p_{1y} + ip_{1z})\frac{\eta_2}{\eta_1} - (p_{2y} + ip_{2z})\frac{\eta_1}{\eta_2}$$

$$B^{L}{}_{+\ +}(p_1, p_2) = \eta_1 \mu_2$$

where $\eta = \sqrt{2k_o^{\alpha} p_{\alpha}}$ and $\mu = \frac{m}{\eta}$ with $k_o^{\alpha} = (0, 0, 1, 0)$

⇒ Amplitudes for production and decay expressed in terms of B and Z functions.



⇒ widthless approximation

⇒ Feynman rules complex by default

⇒ transition to phases straightforward

$$M_1 = |M_1|\, e^{i\phi_{M_1}}, \mu = |\mu|\, e^{i\phi_\mu}$$

$$A_t = |A_t|\, e^{i\phi_{A_t}}, A_b = |A_b|\, e^{i\phi_{A_b}}$$

⇒ Multichannel Monte Carlo integration

Available processes (e^+e^- $\mu^+\mu^-$)

Process id	Process	Process id	Process
$\odot$ 1	$\chi_1^0\chi_1^0$	$\odot$26	$\tilde{t}_1\tilde{t}_1$
$\odot$ 2	$\chi_1^0\chi_2^0$	$\odot$27	$\tilde{t}_2\tilde{t}_2$
$\odot$ 3	$\chi_2^0\chi_2^0$	28	$\tilde{u}_L\tilde{u}_L$
$\odot$ 4	$\chi_1^0\chi_3^0$	29	$\tilde{u}_R\tilde{u}_R$
$\odot$ 5	$\chi_2^0\chi_3^0$	30	$\tilde{d}_L\tilde{d}_L$
$\odot$ 6	$\chi_3^0\chi_3^0$	31	$\tilde{d}_R\tilde{d}_R$
$\odot$ 7	$\chi_1^0\chi_4^0$	32	$\tilde{c}_L\tilde{c}_L$
$\odot$ 8	$\chi_2^0\chi_4^0$	33	$\tilde{c}_R\tilde{c}_R$
$\odot$ 9	$\chi_3^0\chi_4^0$	34	$\tilde{s}_L\tilde{s}_L$
$\odot$10	$\chi_4^0\chi_4^0$	35	$\tilde{s}_R\tilde{s}_R$
$\odot$11	$\chi_1^+\chi_1^-$	36	$\chi_1^0\tilde{G}$
$\odot$12	$\chi_1^+\chi_2^-$	37	$\chi_2^0\tilde{G}$
$\odot$13	$\chi_2^+\chi_2^-$	38	$\chi_3^0\tilde{G}$
14	$\tilde{\nu}_e\tilde{\nu}_e$	39	$\chi_4^0\tilde{G}$
15	$\tilde{\nu}_\mu\tilde{\nu}_\mu$	40	$\chi_1^0\nu$
16	$\tilde{\nu}_\tau\tilde{\nu}_\tau$	41	$\chi_2^0\nu$
17	$\tilde{e}_L\tilde{e}_L$	42	$\chi_3^0\nu$
18	$\tilde{e}_R\tilde{e}_R$	43	$\chi_4^0\nu$
19	$\tilde{e}_L\tilde{e}_R$	44	$\chi_1^+l^-$
20	$\tilde{\mu}_L\tilde{\mu}_L$	45	$\chi_2^+l^-$
21	$\tilde{\mu}_R\tilde{\mu}_R$	46	hZ
22	$\tilde{\tau}_L\tilde{\tau}_L$	47	HZ
23	$\tilde{\tau}_R\tilde{\tau}_R$	48	hA
$\odot$24	$\tilde{b}_1\tilde{b}_1$	49	HA
$\odot$25	$\tilde{b}_2\tilde{b}_2$	50	H^+H^-

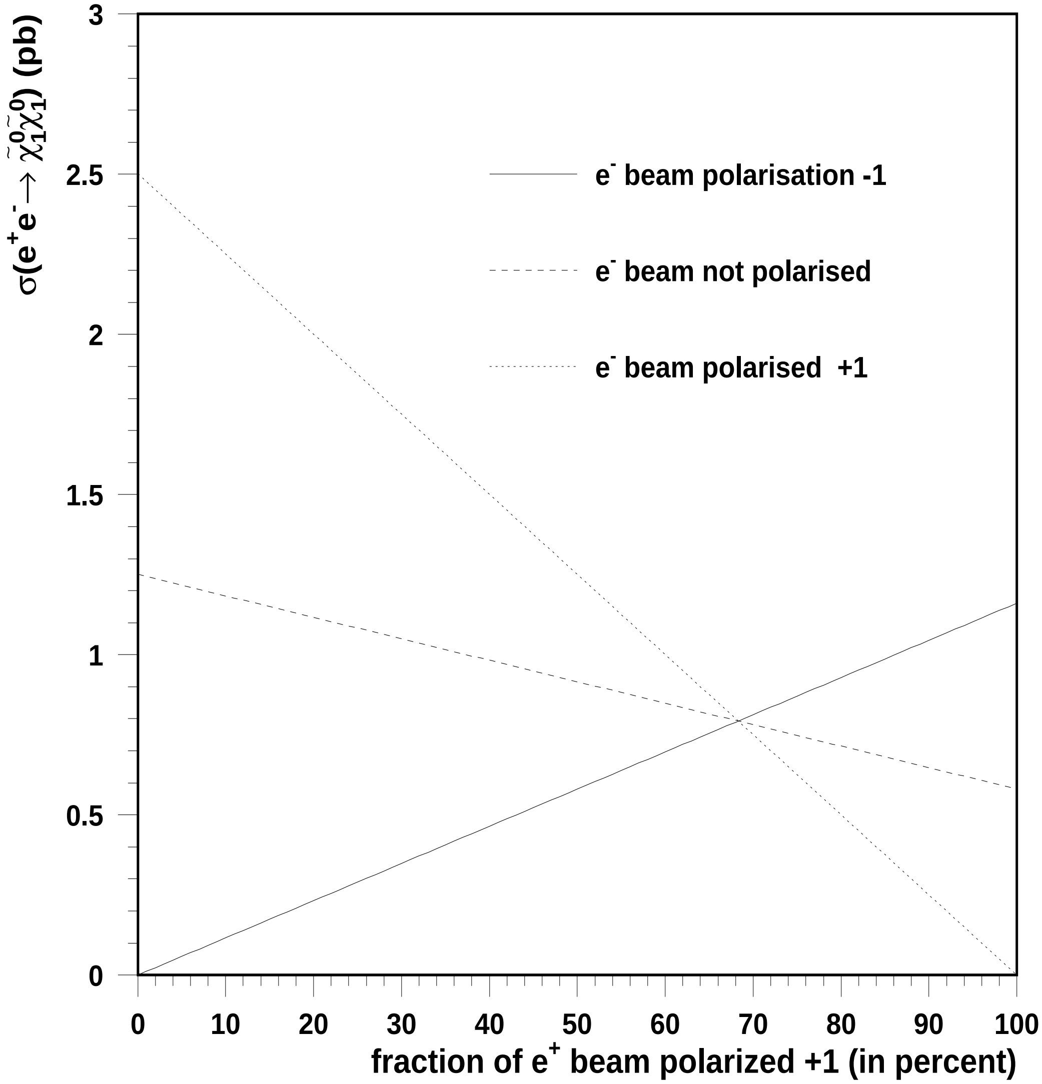
Red : processes available for e^+e^-, $\mu^+\mu^-$, linear collider with or without beam polarisation, beam strahlung and spin correlations

$\odot$: phases can be switched on for masses and cross sections

$\odot$: phases for masses are available

SUSYGEN offers the possibility to fix the beam polarisation

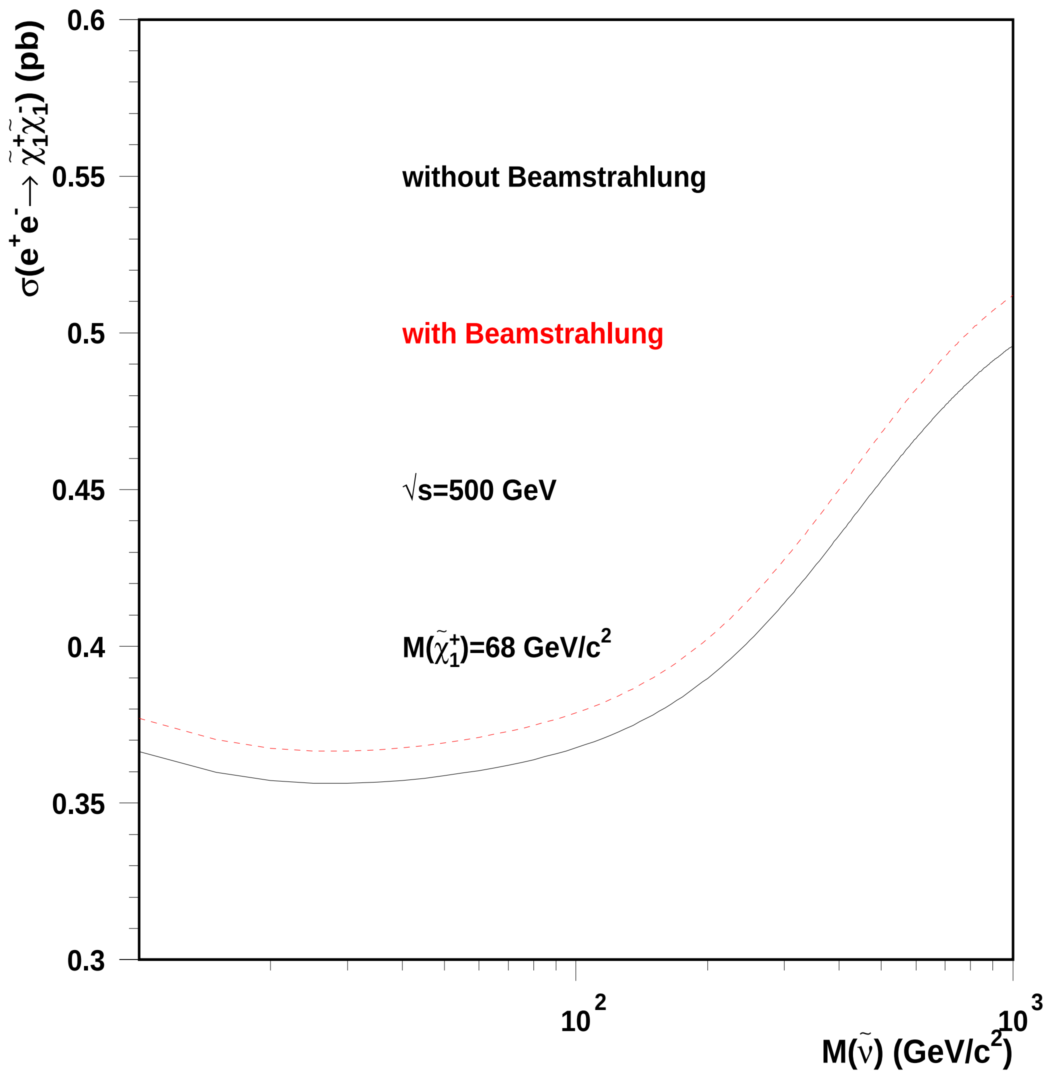
e.g.: $\sigma(\chi_1^0\chi_1^0)$ evolution in terms of the e^+ polarisation



$$\sigma = p_{e^+}^R p_{e^-}^R \sigma_{RR} + p_{e^+}^R p_{e^-}^L \sigma_{RL} + p_{e^+}^L p_{e^-}^R \sigma_{LR} + p_{e^+}^L p_{e^-}^L \sigma_{LL}$$

Interface to CIRCE for Beamstrahlung

e.g.: $\sigma(\chi_1^+\chi_1^-)$ evolution in terms of the sneutrino mass

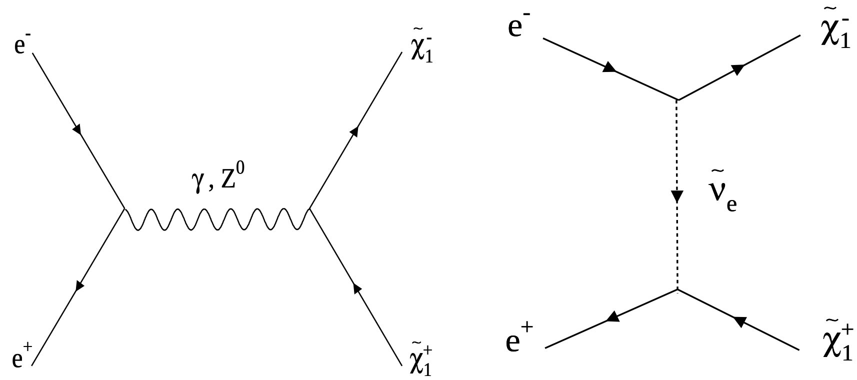


New Features: spin correlations

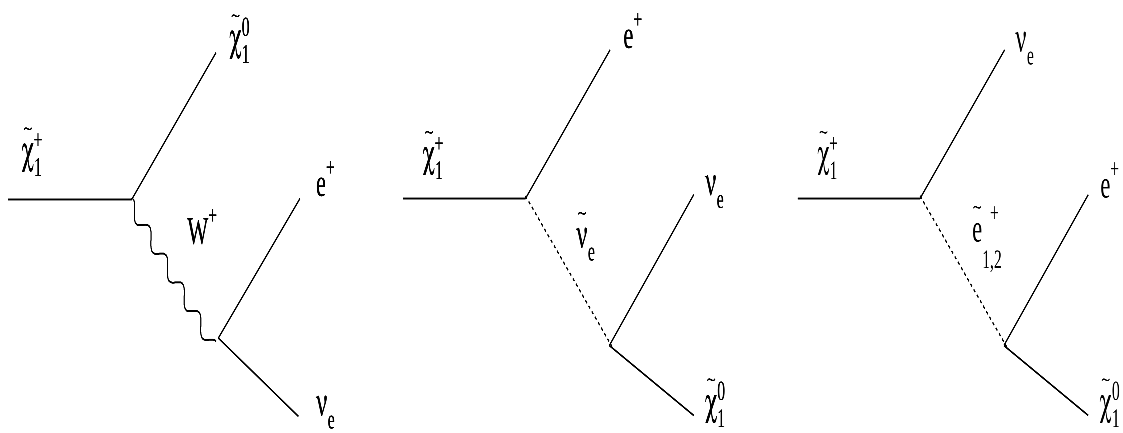
- Charginos

◇ $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 e^+\nu_e \tilde{\chi}_1^0 e^-\bar{\nu}_e$

Associated Feynman diagrams for production (γ, Z^o and $\tilde{\nu}_e$)

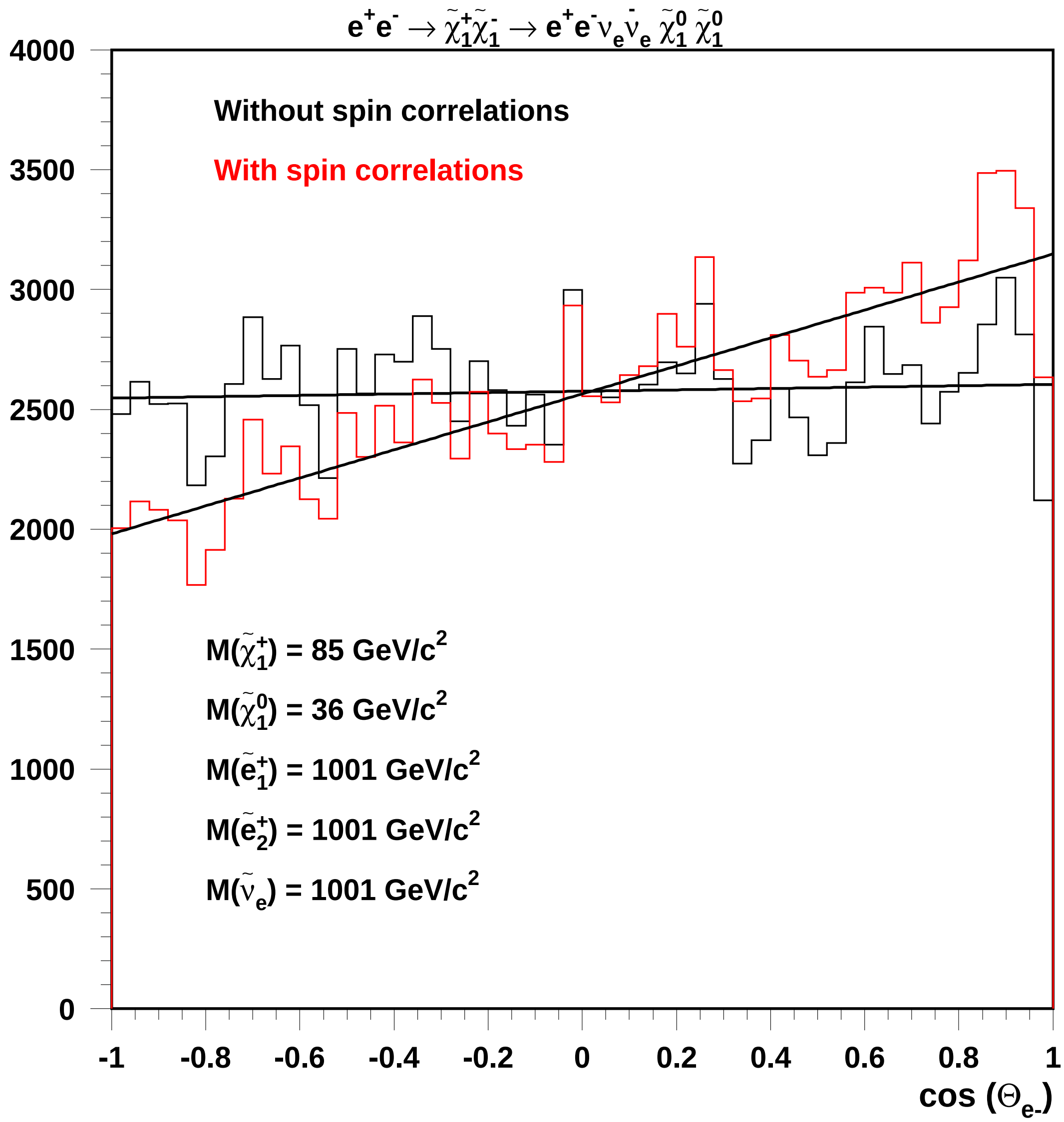


Associated Feynman diagrams for decay (W, $\tilde{e}_1$, $\tilde{e}_2$ and $\tilde{\nu}_e$)



New Features: spin correlations

e.g.: e^- angular distributions



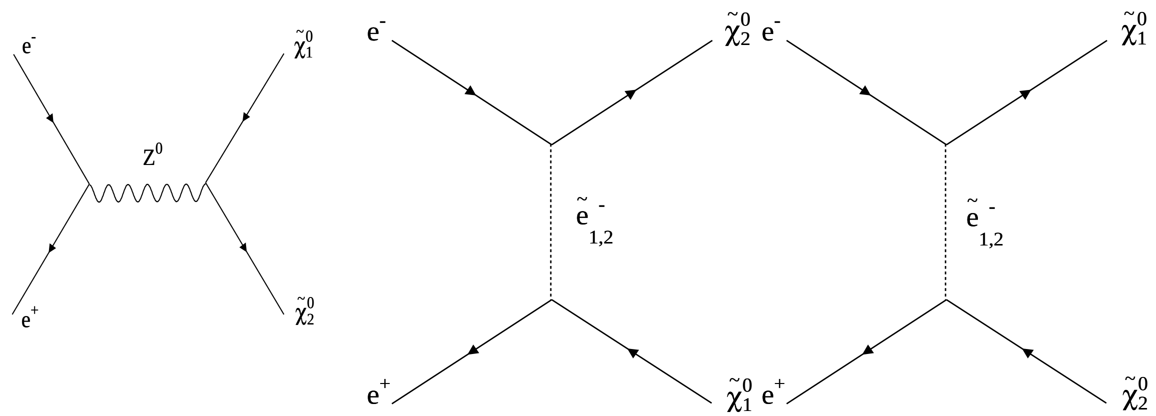
At LEP II effects present but negligible

checks : *Choi et al., Moortgat-Pick et al.* *(GRACESUSY)*

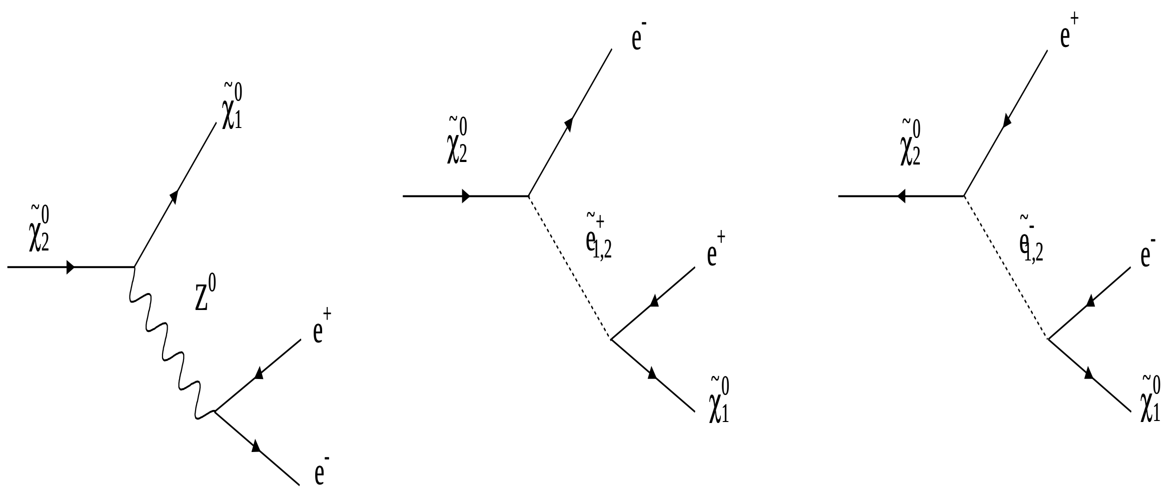
- Neutralinos

◇ $e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_1 \to \tilde{\chi}^0_1 e^+ e^- \tilde{\chi}^0_1$

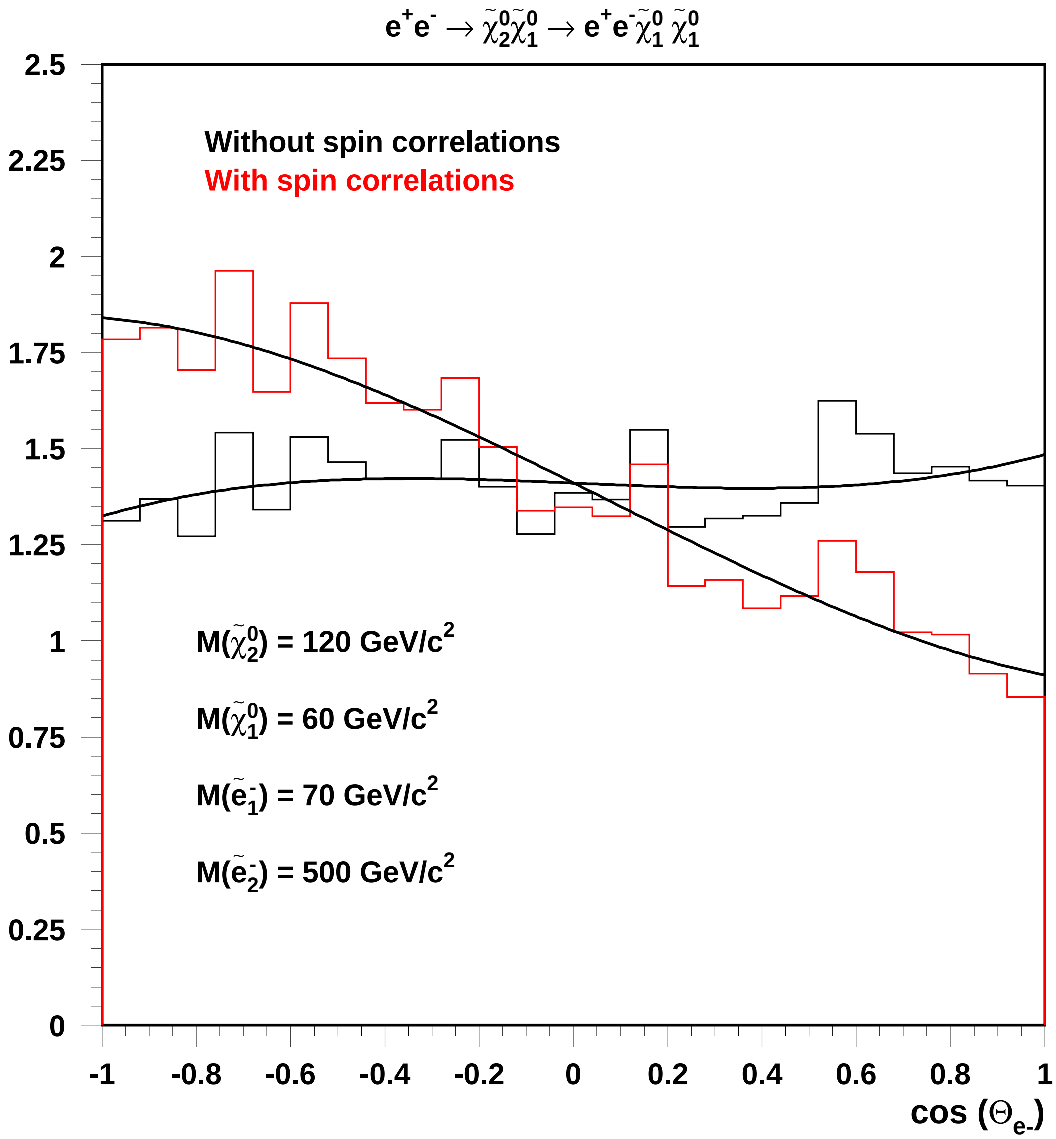
Associated Feynman diagrams for production (Z^o $\tilde{e}_1$ and $\tilde{e}_2$)



Associated Feynman diagrams for decay (Z^o, $\tilde{e}_1$, $\tilde{e}_2$)



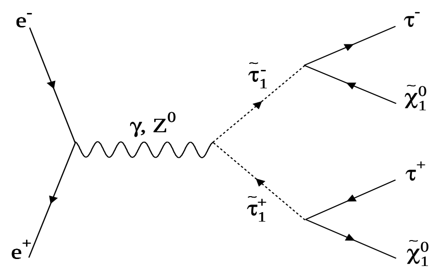
e.g.: e^- angular distributions



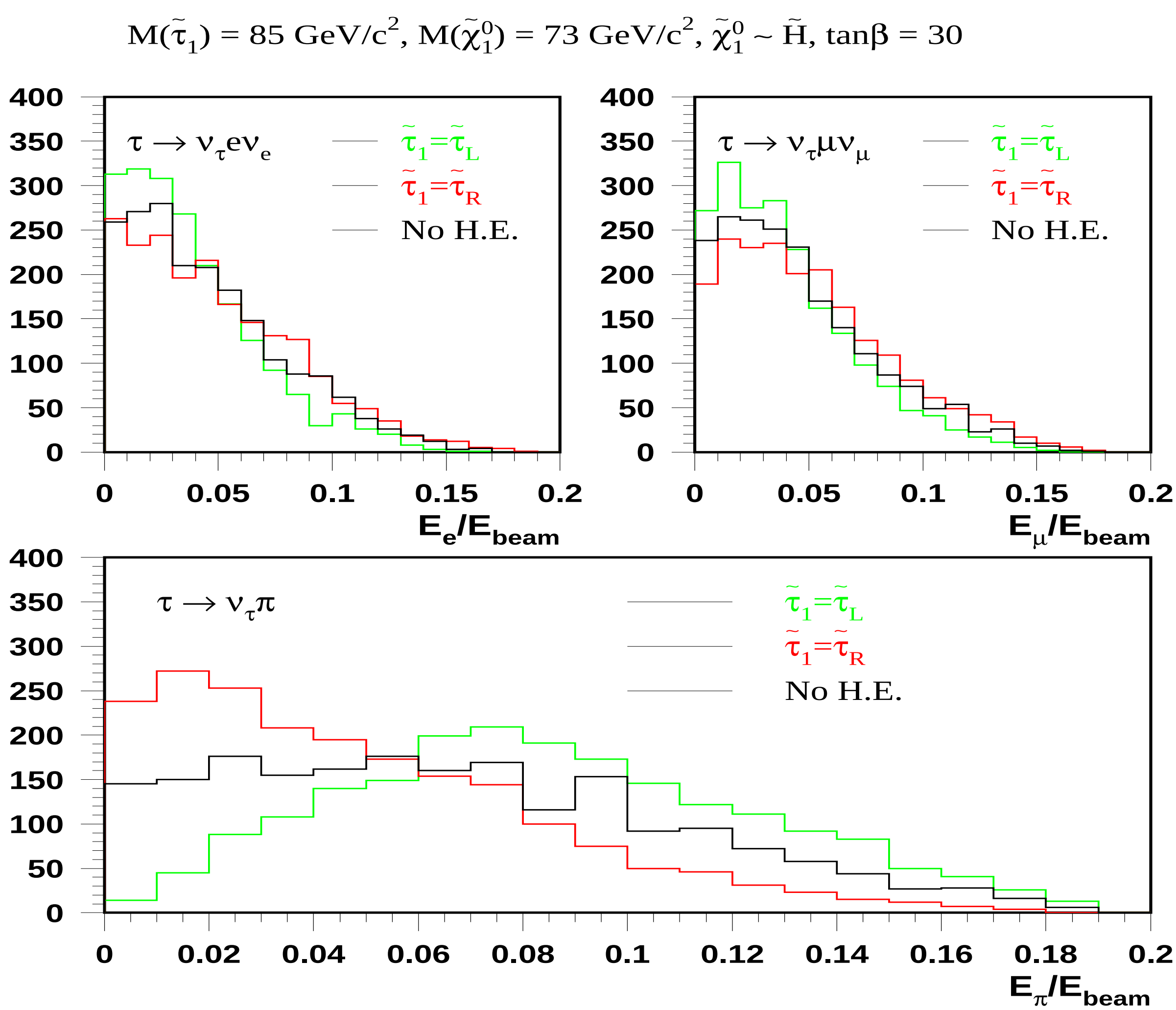
Effects more important than for charginos
checks :*Moortgat-Pick et al.*

◇ sfermions : the $\tilde{\tau}$ case : τ decay performed by TAUOLA

◇ $e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1 \rightarrow \tau^+\tilde{\chi}_1^0\tau^+\tilde{\chi}_1^0$



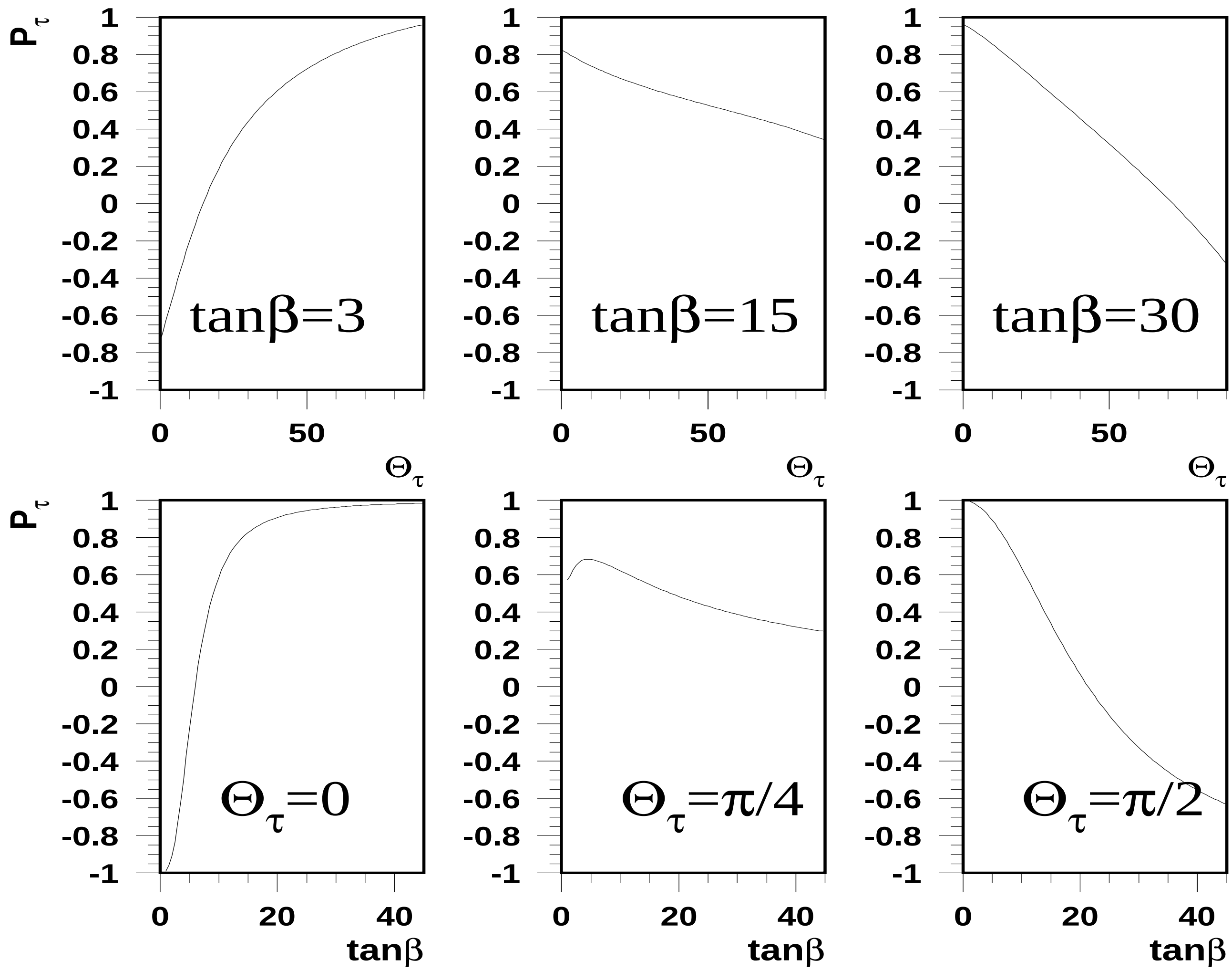
e.g: Energy distribution for $\tilde{\chi}_1^0 \equiv \tilde{H}$



- Tau polarisation

$$P_\tau = \frac{BR\left(\tilde{\tau}_1 \to \tau_R \tilde{\chi}_1^0\right) - BR\left(\tilde{\tau}_1 \to \tau_L \tilde{\chi}_1^0\right)}{BR\left(\tilde{\tau}_1 \to \tau_R \tilde{\chi}_1^0\right) + BR\left(\tilde{\tau}_1 \to \tau_L \tilde{\chi}_1^0\right)}$$

depends on θ_τ, $\tan\beta$ and on the nature of $\tilde{\chi}_1^0$.



- P_τ **determination will give valuable information for :**

  1) Neutralino nature $(\tilde{B},\ \tilde{H})$

  2) $\tilde{\tau}$ **mixing angle** $(\tilde{\theta})$

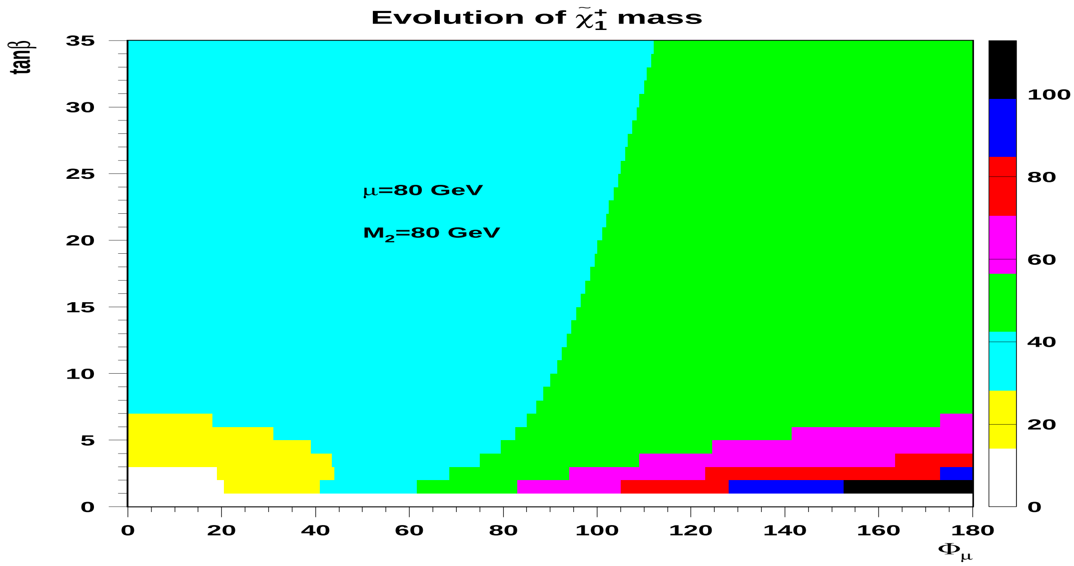
  3) MSSM parameters $(M,\ \mu,\ \tan\beta)$

	$\tilde{\tau}_1 \equiv \tilde{\tau}_L$	$\tilde{\tau}_1 \equiv \tilde{\tau}_R$
$\tilde{\chi}^0_1 \sim \tilde{B},\ \tilde{W}_3$ **and** $\tan\beta$ **small**	$P_\tau \approx -1$	$P_\tau \approx +1$
$\tilde{\chi}^0_1 \sim \tilde{H}^0_1,\ \tilde{H}^0_2$ **and** $\tan\beta$ **high**	$P_\tau \approx +1$	$P_\tau \approx -1$

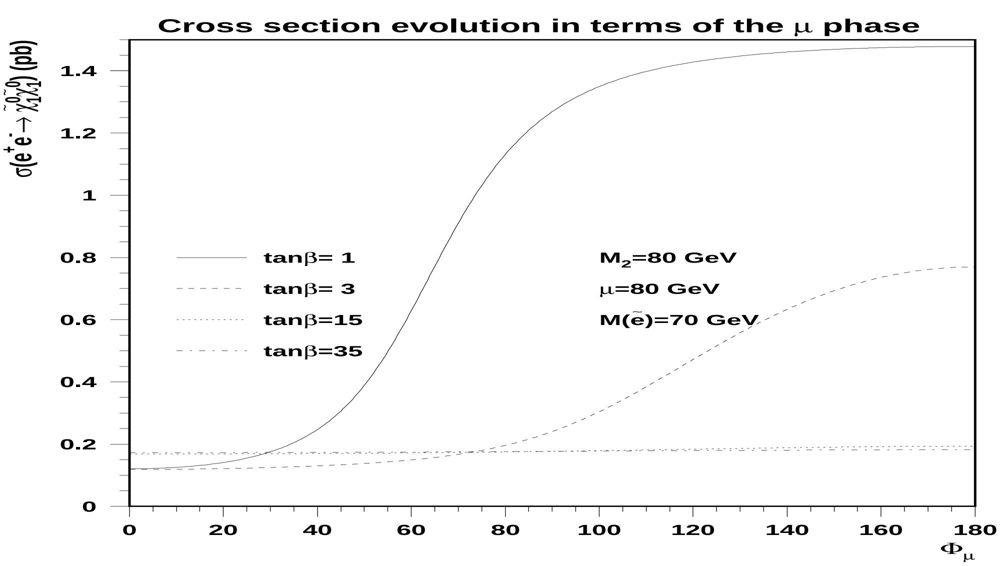
see *Nojiri et al*

Phases in μ, M_1, A_t and A_b

e.g. $\tilde{\chi}_1^+$ mass evolution in terms of Φ_μ and $\tan\beta$



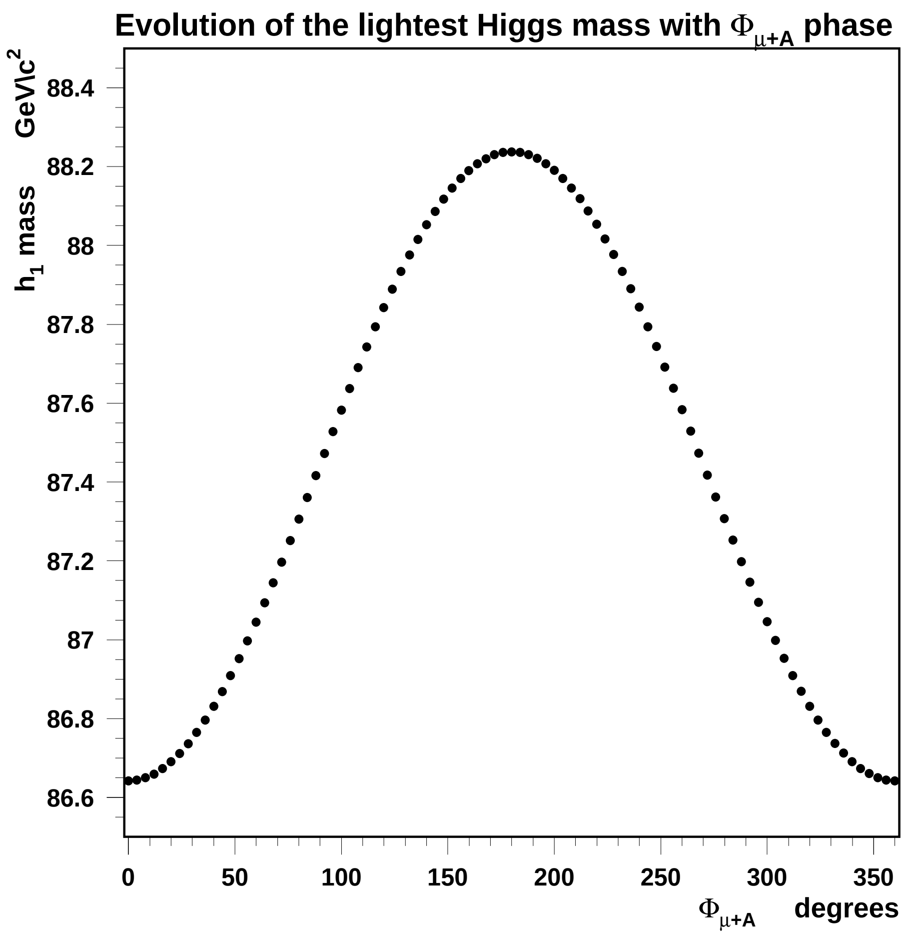
e.g. $\sigma(\tilde{\chi}_1^0\tilde{\chi}_1^0)$ evolution in terms of Φ_μ



◇ Phases interpolation between $\mu > 0$ $(\phi_\mu = 0)$ and $\mu < 0$ $(\phi_\mu = \pi)$

Complex MSSM parameters : the Higgs sector

Evolution of the lightest Higgs mass with Φ_{A_t} and Φ_μ



SUSYGEN enables to scan practically all MSSM inputs

⇒ **MSSM parameters :**
M_1, M_2, M_3, μ, m_0, $\tan\beta$, A_t, A_b, A_τ,

⇒ **squarks and sleptons masses :**
$M_{\tilde{q}}$, $M_{\tilde{t}}$, $M_{\tilde{b}}$, $M_{\tilde{\ell}}$, $M_{\tilde{\nu}_\ell}$, $M_{\tilde{\tau}}$,

⇒ **the mixing angle of the sfermions :** $\theta_{\tilde{t}}, \theta_{\tilde{b}}, \theta_{\tilde{\tau}}$,

⇒ λ **couplings if R-parity is not assumed to be conserved,**

⇒ **the beam polarisation** $P_{\lambda_{e+}}, P_{\lambda_{e-}}$,

⇒ **the phases associated to complex parameters:**
A_t, A_b, M_1 **and** μ,

⇒ **the center of mass energy.**

with or without a fixed step
(see examples of manual).

Interface by an input data card :susygen.input

MODES 1 ⟵ *specify model (SUGRA)*
M1 -1.
M2 50.
M3 -1.
MU -150.
M0 40.
RS 1. ⟵ *Gauge mass unification breaking scale*
TANB 1.5
RPARITY TRUE ⟵ *R-parity flag*
PHASES FALSE ⟵ *Assume MSSM parameters complex or not ?*

C——- SET COLLIDER TYPE
C——- 1 : E+ E- 2 : MU+ MU- 3 : E P
BTYPE 1 ⟵ *specify the collider type*
C——- DO YOU WANT BEAMSTRAHLUNG ?
BEAMSTR 0 ⟵ *include beam strahlung ?*

C——- INCLUDE OR NOT BEAM POLARISATION AND SPIN CORRELATIONS ?
C——- 0 : NO SPIN CORRELATIONS
C——- 1 : BEAM POLARIZATION
C——- 2 : BEAM POLARIZATION AND SPIN CORRELATIONS
HELICITY 1 ⟵ *specify*

C——- BEAM POLARISATION
POLP 0.8 ⟵ *probability for* e^+ *beam to be polarised +1*
POLM 0.5 ⟵ *probability for* e^- *beam to be polarised +1*

PARCIRCE 2 5 19980505 1

C——- WHAT PROCESSES TO GENERATE ?
ZINO TRUE ⟵ *selected process is* χ^0
C——- SPECIFY A PARTICULAR PROCESS (1 - 50)
PROCSEL 0 ⟵ *specify a particular process see table*

C——- FIX Z0 AND W DECAY MODES ⟵ *force the* Z^0 *and* W *to decay in one particular channel*
DECSEL 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 ⟵ *specify a subprocess if* `HELICITY` *is set to 2*

C——- CENTER OF MASS ENERGY
ECM 500.

C——- INITIAL AND FINAL STATE RADIATION ?
ISR 0
FSR 0
C——- GENERATE EVENTS OR NOT ?
GENER 1
C——- NUMBER OF EVENTS
SUSEVENTS 100. ⟵ *total number of events to be generated*
C——- WRITE OUT EVENTS TO FORTRAN FILE UNIT 12
LUWRIT TRUE

⇒ **Inclusion of phase constraints (EDM) (collaboration with I. Laktineh, J. Rosiek and S. Pokorski)**

⇒ **Calculation of SUGRA spectrum through** `SUSPECT` **(*Djouadi et al.*)**

⇒ **Next leading order for charginos cross sections**

⇒ **Full Higgs treatment of polarized beam production and decay by using the Helicity Amplitude Method**

Future developments II

⇒ rewrite the entire Monte Carlo Generator by using object oriented language :`SUSYGEN IV`

- Motivation:

Native C++ event generators needed to optimise the couplings with LC simulation (e.g. `GEANT` 4) and analysis.
Possiblity to share code between different generators. (reuse of classes)
Definition of standard classes like `EventHandler` and `Particle` classes (should be the same for every generator).

- Strategy:

  - Scalar functions B and Z of the Helicity Amplitude Method are optimally suited for object oriented implementation since amplitude is defined with these fundamental blocks.
  - Multichannel integration looks also well adapted for object oriented treatment.
  - Tools for Monte Carlo integration e.g. random number generation, Lorentz boost,etc.. available (`CLHEP` project)

We would gladly participate to a world effort for definition of standards.