W. Majerotto

Oxford, March 20-23, 1999

SUMMARY

- J. Kalinowski et al.,

  Determining the SUSY parameters in $e^+e^- \to \tilde{\chi}_i^+ \tilde{\chi}_j^-$

- G. Moortgat-Pick et al.,

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

  M' (or M_1) dependence

- S. Kraml et al.,

  $e^+e^- \to \tilde{q}_i \tilde{q}_j$ $\tilde{q} = \tilde{t}, \tilde{b}$

  Parameter determination

- M. Besançon

  Experimental aspects of SUSY with $\not{R}$

- G. Moreau

  $\not{CP}$ and FNCN in SUSY with $\not{R}$

2. DETERMINING THE STRUCTURE

Charginos

Tsukamoto et al.
Moortgat-Pick et al.
Feng et al.
Choi et al.
Lafaye et al.
⋮

$W^\pm \Rightarrow \tilde{W}^\pm$ gaugino

$H_1\ H_2 \Rightarrow \tilde{H}_1, \tilde{H}_2$ higgsino

$\psi^\pm = \begin{pmatrix} -i\tilde{W}^\pm \\ \tilde{H}^\pm \end{pmatrix}$

mass term $\quad \psi^- M_c \psi^+ + h.c.$

$$M_c = \begin{pmatrix} M_2 & \sqrt{2}\, m_W \cos\beta \\ \sqrt{2}\, m_W \sin\beta & \mu \end{pmatrix}$$

- M_2 – SU(2) gaugino mass
- μ – Higgs mixing parameter : $\quad \mu H_1 \cdot H_2$
- $\tan\beta = \frac{v_2}{v_1} = \frac{\langle H_2^0 \rangle}{\langle H_1^0 \rangle}$

charginos $\tilde{\chi}_i^\pm$ mass eigenstates

$$m_{\tilde{\chi}^\pm_{1,2}} = \frac{1}{2}\left(M_2^2 + \mu^2 + 2m_W^2 \mp \sqrt{(M_2^2+\mu^2+2m_W^2)^2 - 4(M_2\mu - m_W^2 \sin 2\beta)^2} \right)$$

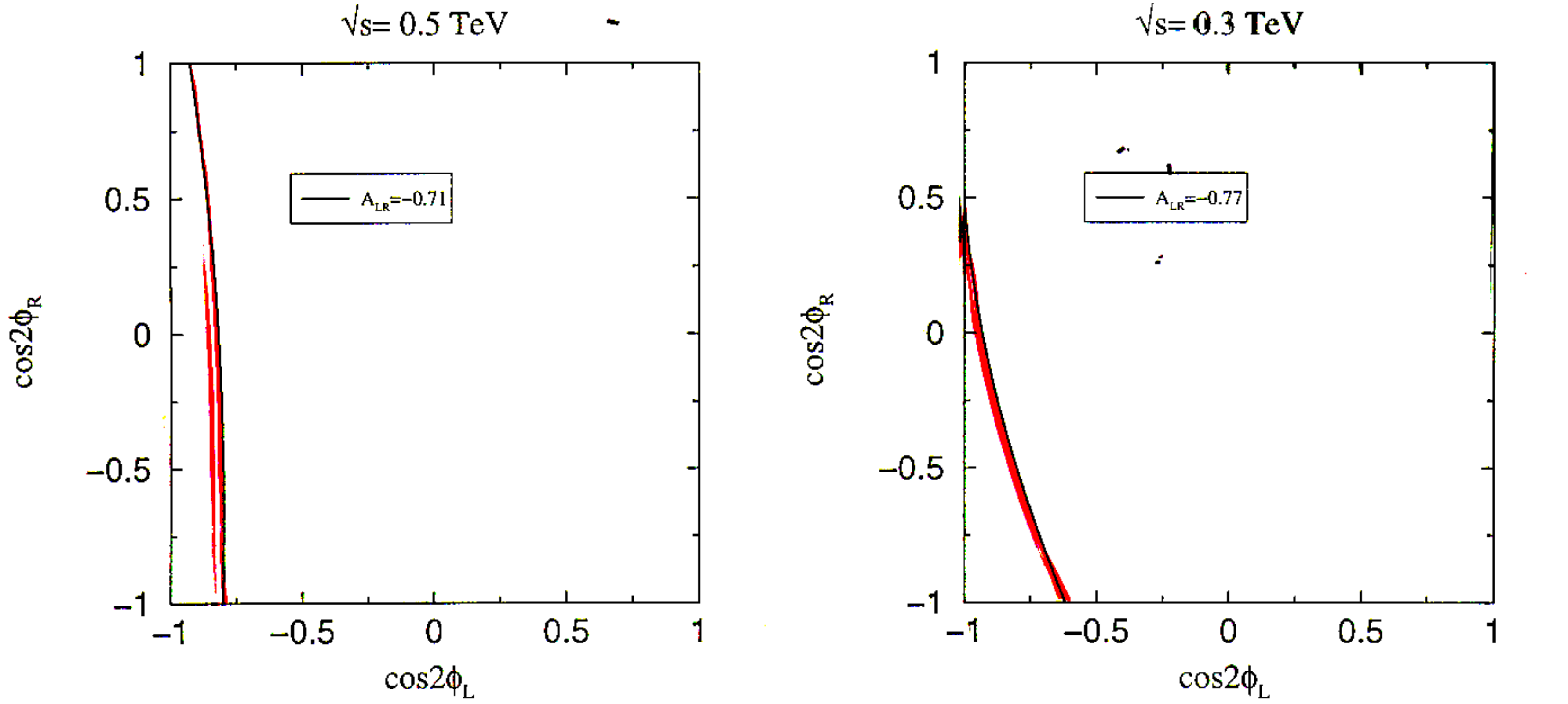
$$\tilde{\chi}^-_{1L} = \tilde{W}^-_L \cos\phi_L + \tilde{H}^-_1 \sin\phi_L$$

$$\tilde{\chi}^-_{1R} = \tilde{W}^-_R \cos\phi_R + \tilde{H}^-_2 \sin\phi_R$$

$$M_2,\ \mu,\ \tan\beta \Rightarrow m_{\tilde{\chi}_1^\pm},\ \phi_L,\ \phi_R$$

$\Leftarrow$?

add A_{LR} if available



unique solution ⇒ $m_{\tilde{\chi}_1^+} = 95$ GeV

$\cos 2\phi_L = -0.8$

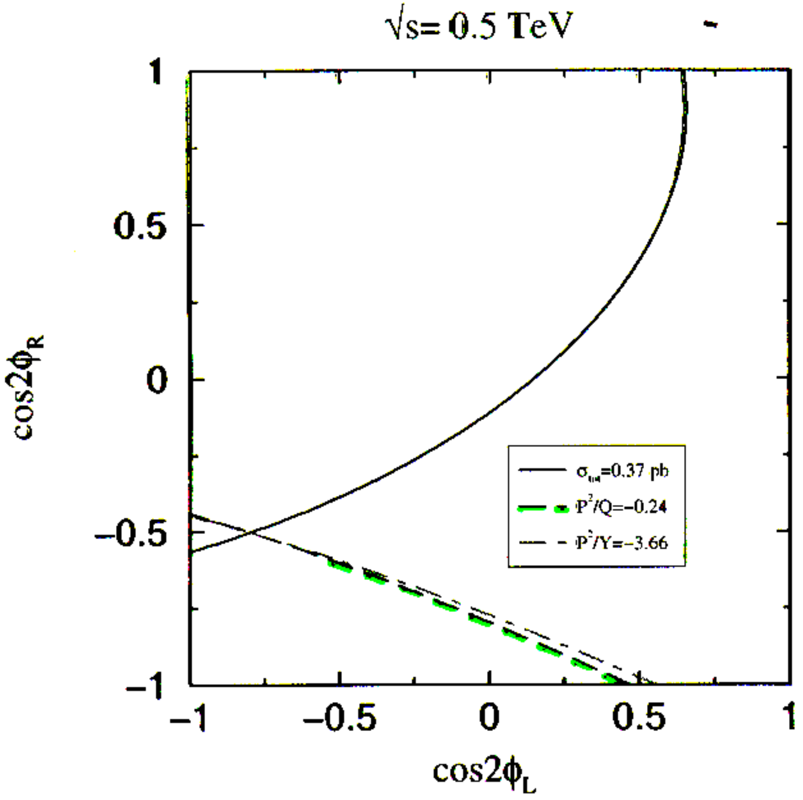
$\cos 2\phi_R = -0.5$

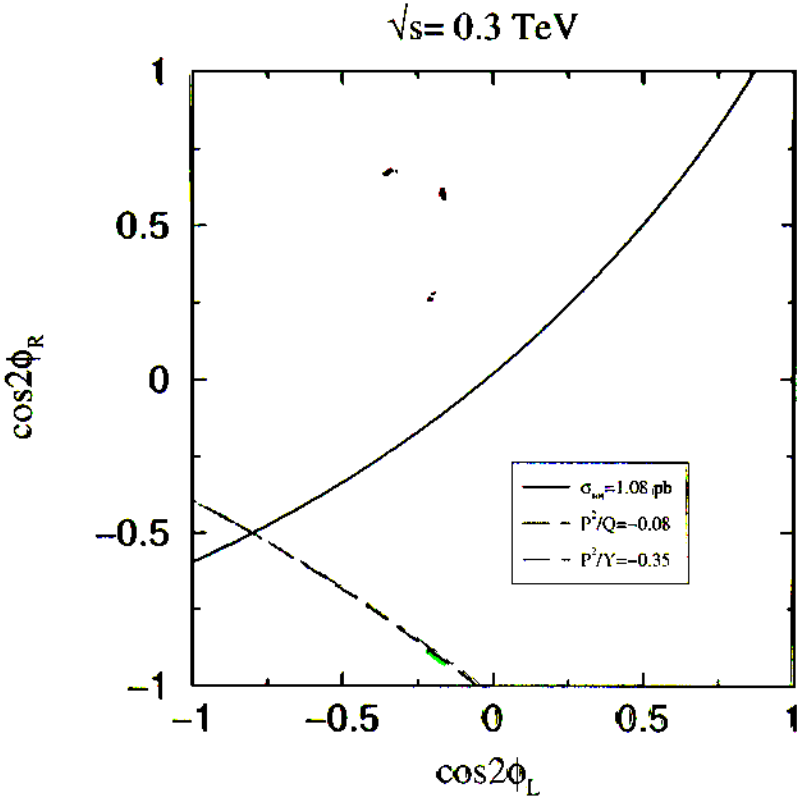
⟶ fundamental parameters

$\tan\beta$	1.06	3.33	
M_2	83	248	GeV
μ	−59	123	GeV

two-fold ambiguity

physical observables → physical parameters (vary energy as well)





Errors

RR 2 ($\tan\beta = 30$)

	$\mathcal{L} = 50\ fb^{-1}$	$\mathcal{L} = 500\ fb^{-1}$
$m_{\tilde{\chi}^\pm} = 132,\ 285$ [GeV]	0.1	0.1
$\cos 2\phi_L = 0.49$	0.12	0.02
$\cos 2\phi_R = 0.86$	0.02	0.005
$M_2 = 150$ [GeV]	7.03	1.20
$\mu = 263$ [GeV]	4.0	0.68
$\cos 2\beta = -0.9978$	0.33	0.056
$\sin 2\beta = 0.0666$	0.19	0.033
$\tan\beta = 30$	(7.6 – ∞)	(20.2 – 59.6)
$M_1 = 75.4$	1.96	0.40
(−74)	1.46	0.32

large luminosity crucial for $\tan\beta$!

G. Moortgat – Pick et al,

Contents

1. **Investigated Process**
   - Feynman Diagrams
   - Motivation for M' Range
2. **Beam Polarization**
   - Polarization–Asymmetry
   - Forward–Backward Asymmetry
3. **Numerical Results**
   Constraining M'
   - $m_{\tilde{e}_L} \approx m_{\tilde{e}_R}$
   - $m_{\tilde{e}_L} \ll m_{\tilde{e}_R}$
   - $m_{\tilde{e}_L} \gg m_{\tilde{e}_R}$
4. **Conclusions**
5. **Outlook**

1. Investigated process (MSSM)

Neutralino production with leptonic decay:

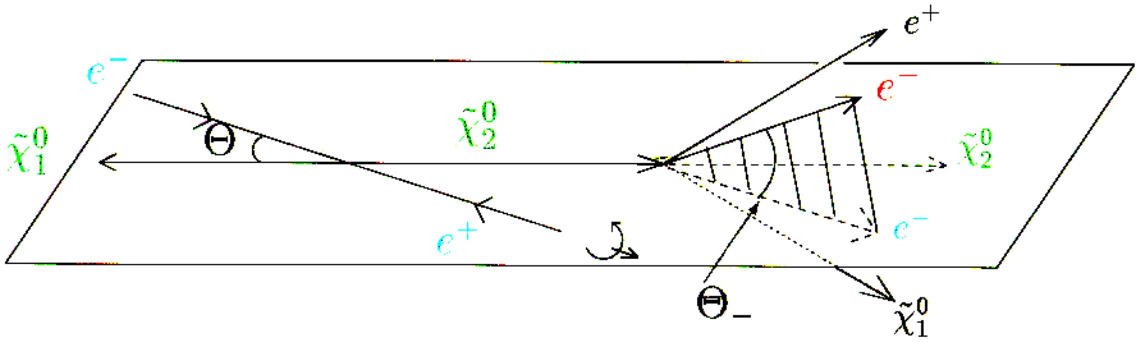
$$e^+ + e^- \to \tilde{\chi}_1^0 + \tilde{\chi}_2^0$$

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

⇒ Including the complete spin correlations between production and decay!

Kawasaki '73
Dicus '85
Feng '97
M.-P. '97, '99
} et al.

Decay Angular Distribution of e^- in the Laboratory System



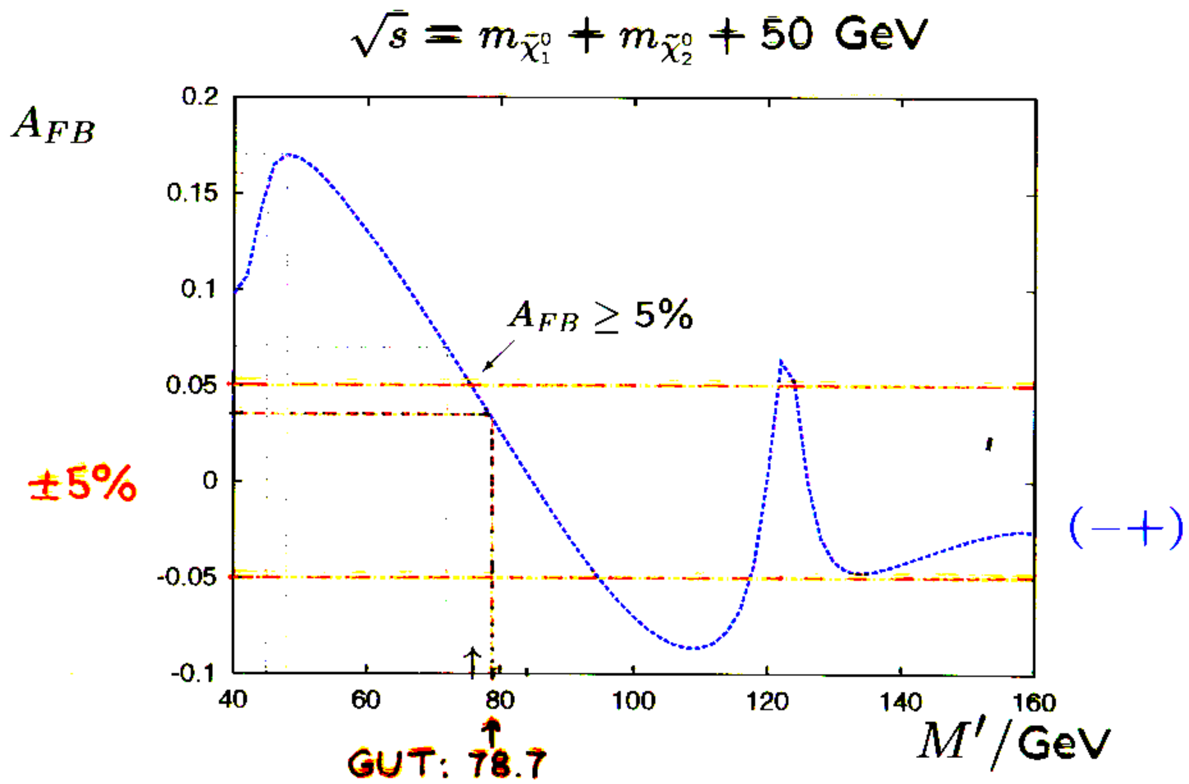
- Production:
  No forward-backward asymmetry!
  (Majorana character!)

- Production$\times$Decay:
  Angular distribution of e^- depends on polarization of $\tilde{\chi}^0_2$ $\quad (P^3_{\tilde{\chi}^0_2} \sim \cos\Theta!)$
  $\Rightarrow$ Large forward-backward-asymmetry of decay e^- possible:
  $$A_{FB} = \frac{\sigma(\cos\Theta_- > 0) - \sigma(\cos\Theta_- < 0)}{\sigma(\cos\Theta_- > 0) + \sigma(\cos\Theta_- < 0)}$$

- Cross Section:
  $$\sigma_e = \sigma \times BR = \int \frac{d\sigma}{d\cos\Theta_-} d\cos\Theta_-$$

a) Small slepton mass splitting, $m_{\tilde{e}_L} \approx m_{\tilde{e}_R}$

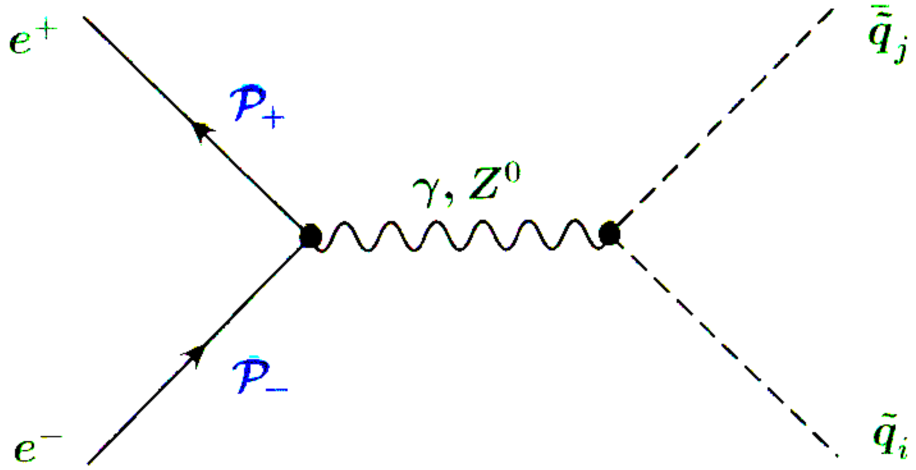
Forward-backward asymmetry of decay lepton with beam polarization:



- complex interplay between production and decay (→ 'spin correlations')
- strong dependence on M'
- $|A_{FB}| > 5\%$: range of M' can be further constrained
- independent of $\Gamma_{\tilde{\chi}_2^0}$

S. Kraml et al.

Squark production in e^+e^-



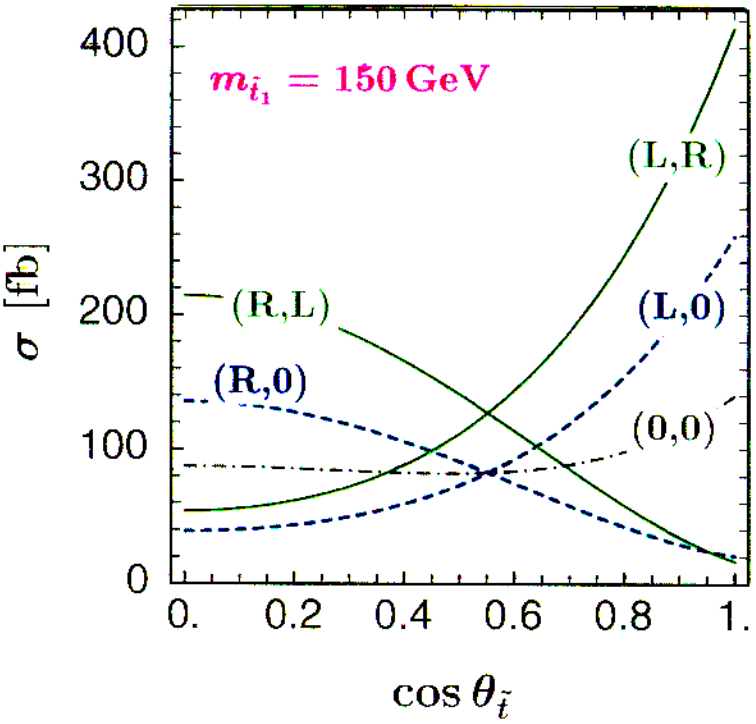
$\mathcal{P}_-$ is the degree of polarization of the e^- beam and $\mathcal{P}_+$ that of the e^+ beam. $\mathcal{P}_\pm \in [-1, 1]$ with

$$\mathcal{P}_\pm = \begin{cases} -1 & \text{if } e^\pm \text{ is left–polarized,} \\ 0 & \text{if } e^\pm \text{ is unpolarized,} \\ +1 & \text{if } e^\pm \text{ is right–polarized.} \end{cases}$$

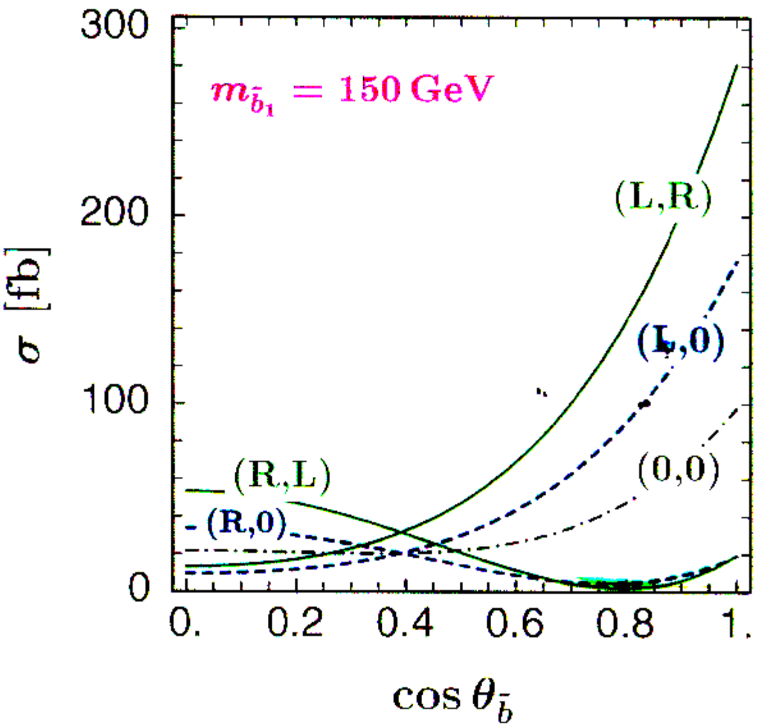
cross sections
incl. SUSY–QCD and ISR corrections

S.Kraml et al.

$e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1$



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



$(\mathrm{L},\mathrm{R}) \equiv (\mathcal{P}_- = -0.9,\ \mathcal{P}_+ = +0.6)$, etc. ...

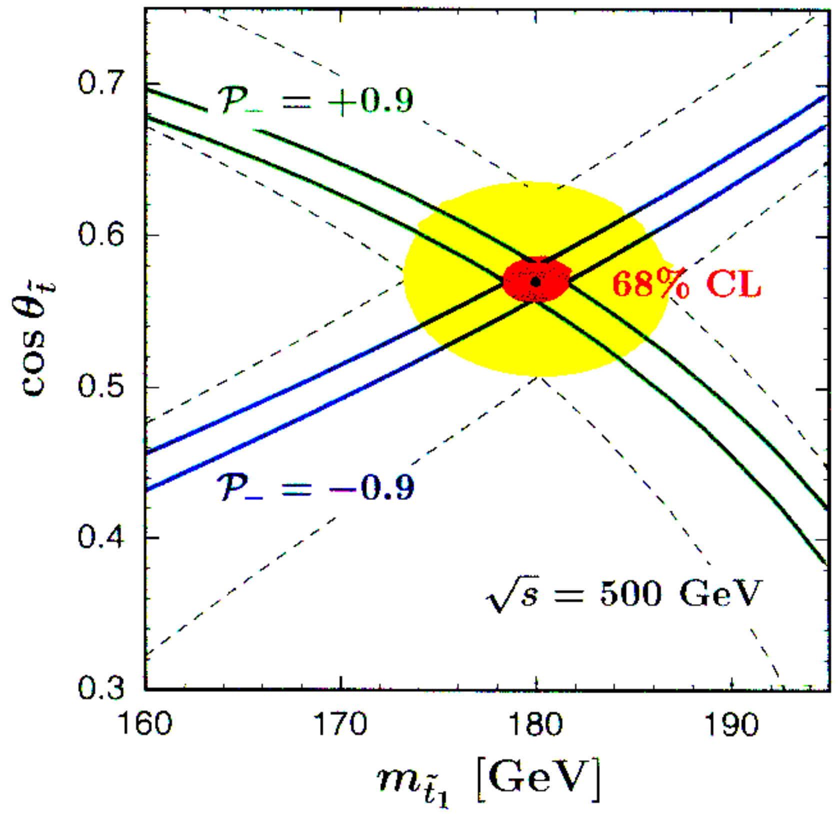
$m_{\tilde{t}_2} = m_{\tilde{b}_2} = m_{\tilde{g}} = 600$ GeV, $\sqrt{s} = 500$ GeV.

S. Kraml et al,

Determination of MSSM parameters with polarized e^- beams

— high lumi —

$m_{\tilde{t}_1} = 180$ GeV, $\cos\theta_{\tilde{t}} = 0.57$



$\mathcal{L} = 300\ \text{fb}^{-1}$: we ESTIMATE errors

$\mathcal{P}_- = -0.9$ ... $\sigma(\tilde{t}_1\bar{\tilde{t}}_1) = 61.2 \pm 1.5$ fb

$\mathcal{P}_- = +0.9$ ... $\sigma(\tilde{t}_1\bar{\tilde{t}}_1) = 57.1 \pm 1.4$ fb

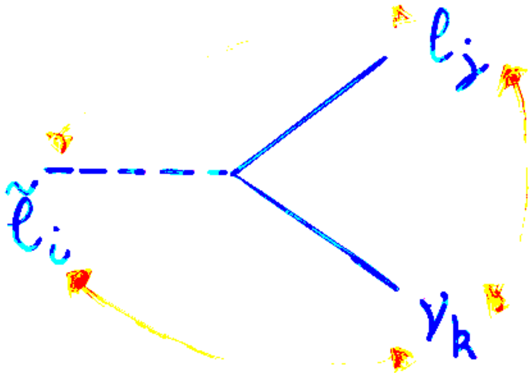
SUSY–QCD corrections taken into account

$\Rightarrow$ $m_{\tilde{t}_1} = 180 \pm 1.65$ GeV, $\cos\theta_{\tilde{t}} = 0.57 \pm 0.0012$

M. Besançon

$$\lambda_{ijk} \quad L_i L_j E_k$$

$i \neq j$ (9 termes)

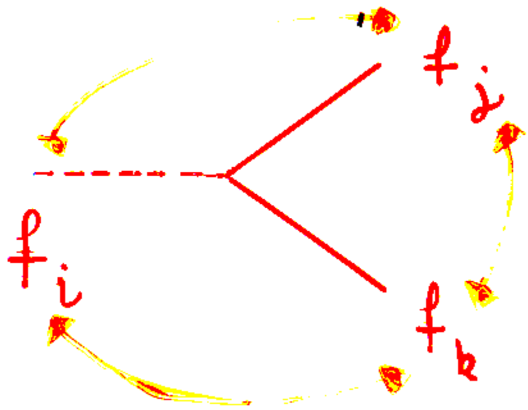


$\not{L}$

$+$

$$\lambda'_{ijk} \quad L_i Q_j \bar{D}_k$$

(27 termes)

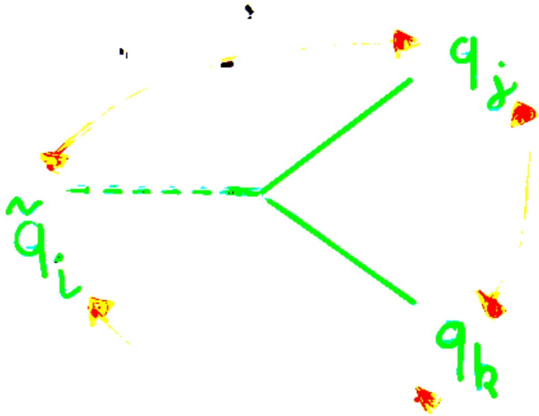


$\not{L}$

$+$

$$\lambda''_{ijk} \quad \bar{U}_i \bar{D}_j \bar{D}_k$$

$j \neq k$ (9 termes)

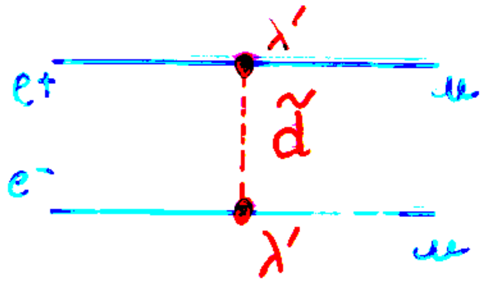


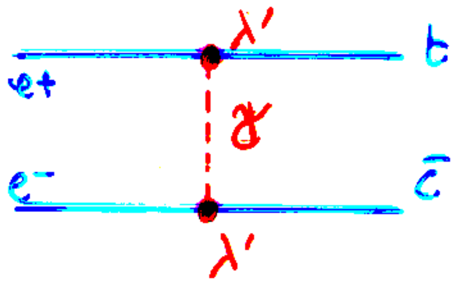
$\not{B}$

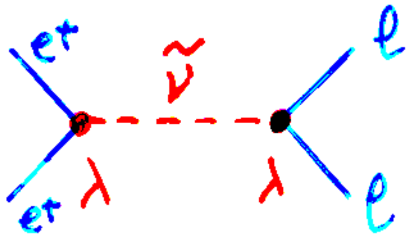
$$R_p = (-1)^{3B+L+2S}$$

Phenomenology at e^+e^- colliders

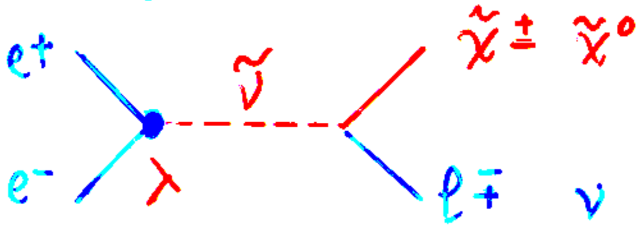
- indirect effects $e^+e^- \to f\bar{f}$ (resonant also)

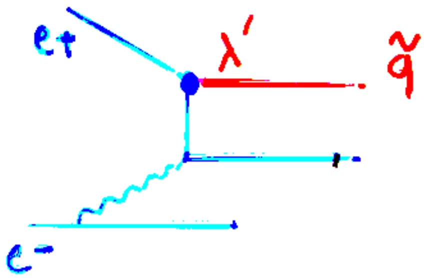






- single production of SuSy particles





➡ See G. Moreau talk at this workshop

- effects in decays

"ordinary" pair production of susy particles

followed by either direct decay $\tilde{f}_i \to f_j f_k$

or indirect decay $\tilde{f}_i \to f_i \tilde{\chi}_i$

$\hookrightarrow f_i' f_j f_k$

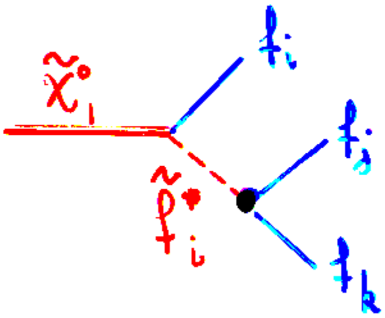
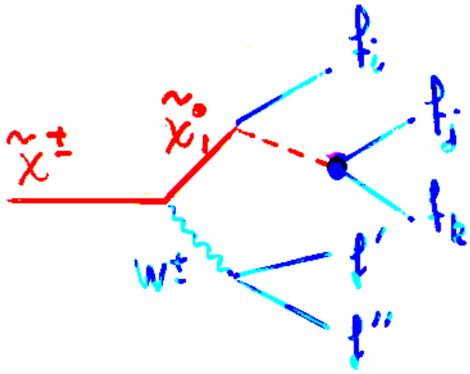
- For decay to happen inside detector

$\lambda \gtrsim 10^{-5}\ 10^{-6}$ (Gauginos)

$\lambda \gtrsim 10^{-7}\ 10^{-8}$ (Sfermions)

M. Besançon

Signature : multilepton - multijets

	λ_{ijk}	λ'_{ijk}	λ''_{ijk}
	$2\nu\, 4\ell$	$2\ell + 4q$ $2\nu + 4q$	$6q$
	$4\ell+2\nu+4q$ $4\ell+2\nu+2q+\ell\nu$ $4\ell+2\nu+2\ell+2\nu$	$8q+2\ell$ $6q+2\ell+2\nu+2\ell$ $4q+2\ell+2\ell+2\nu$	$10q$ $8q+\ell\nu$ $6q+2\ell+2\nu$

$$N_{jet} \stackrel{?}{=} N_q$$

M. Besançon

Search for $\tilde{\chi}_1^o$ with a λ'' coupling

- Pair production of $\tilde{\chi}_1^o$ (LSP)
  cross-section high
- assume λ''_{223} coupling
  one of the less constrained $\lambda''_{223} < 1.25$
- leads to 6 jets signature including 2 b-jets
- opportunity vs LHC ?
  QCD background at LHC ?
- assume so called mSUGRA
  several points in the parameter space

M. Besançon

SELECTION

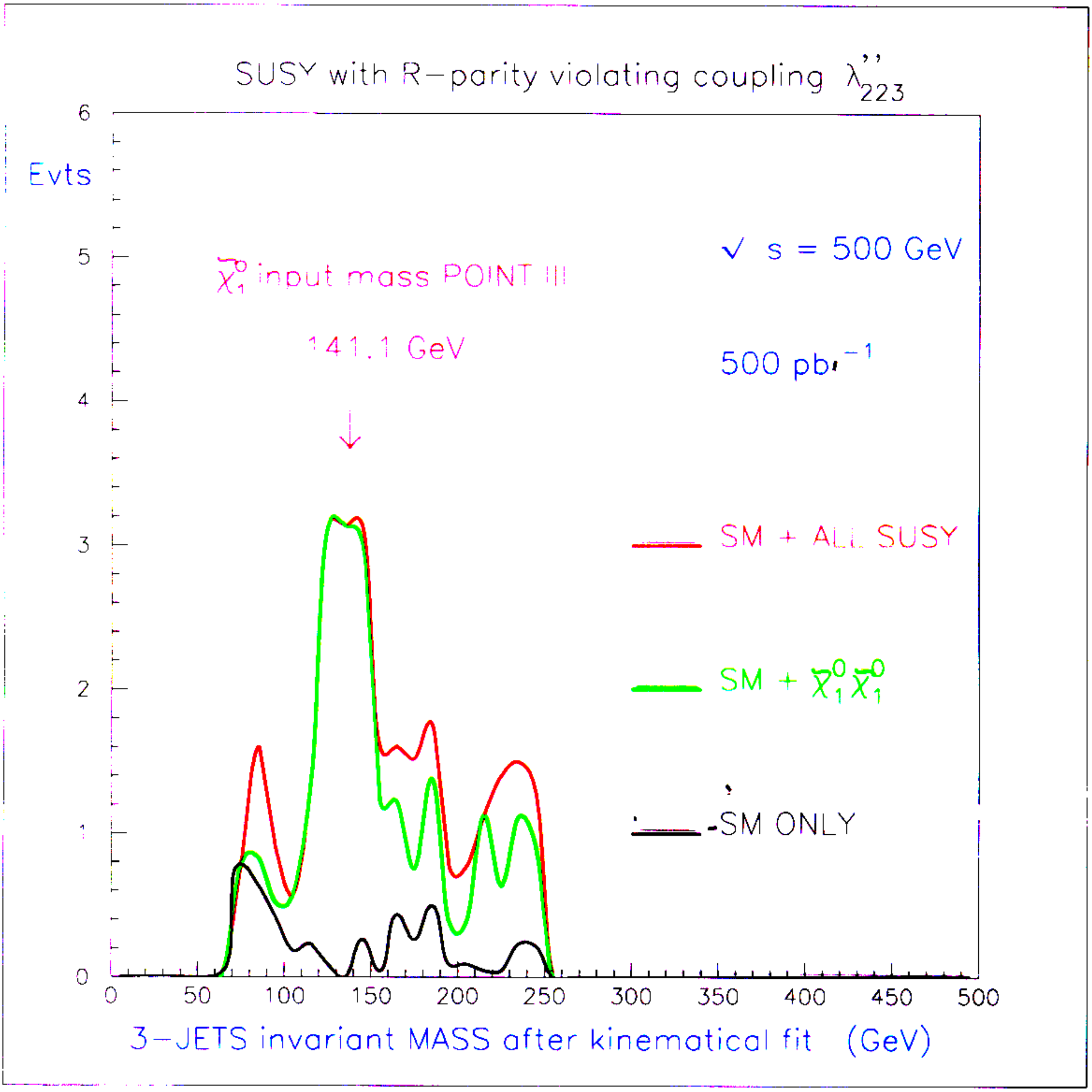
- $N_{tot} > 12$ and $N_{charged} > 6$
- $N_{jet} = 6$
- $E_{tot} > 300$ GeV and $E_{\gamma}^{max} < 80$ GeV
- θ_{jets} in $[10^o, 170^o]$
- apply b-tagging
- apply 5 Contraints kinematical fit on jets

  4C: 4-momentum conservation

  1C: 2 objects with equal mass
- $D_{min} < 15$ GeV and $\chi^2_{5C} < 90$
  D_{min} is the difference of the two 3-jets invariant masses with the combination of 3-jets which minimizes this difference

Look at 3-jets invariant mass = mass of $\tilde{\chi}_1^o$

M. Besançon



SUSY with R-parity violating coupling λ''223
Evts
$\tilde{\chi}_1^0$ input mass POINT III
141.1 GeV
√s = 500 GeV
500 pb⁻¹
SM + ALL SUSY
SM + $\tilde{\chi}_1^0 \tilde{\chi}_1^0$
SM ONLY
0
1
2
3
4
5
6
0
50
100
150
200
250
300
350
400
450
500
3-JETS invariant MASS after kinematical fit (GeV)

Broken R parity contributions to Flavor Changing Neutral Currents & CP Violation: $\ell^+\ell^- \to \bar{f}_J f_{J'}, \tilde{f}^*_J \tilde{f}_{J'}$

G. Moreau

FCNC rates

$$\sigma(\bar{f}_J f_{J'}) \approx \left(\frac{\lambda}{0,1}\right)^4 \left(\frac{100\,\text{GeV}}{\tilde{m}}\right)^{2,5} 10\ \text{fb}$$

$$B(Z \to \bar{f}_J f_{J'}) \approx \left(\frac{\lambda}{0,1}\right)^4 \left(\frac{100\,\text{GeV}}{\tilde{m}}\right)^{2,5} 10^{-9} \quad \sim B\ (\text{S.M.})$$

$$\sigma(\tilde{f}^*_J \tilde{f}_{J'}) \approx \left(\frac{\lambda}{0,1}\right)^4 10\ \text{fb} \quad \lesssim \sigma'(\text{M.S.S.M.})$$

CP Asymmetries

$$\mathcal{A}(\bar{f}_J f_{J'}) \approx (10^{-2} - 10^{-3}) \sin\psi$$

$$\mathcal{A}(Z \to \bar{f}_J f_{J'}) \approx (10^{-1} - 10^{-3}) \sin\psi \quad \gtrsim \mathcal{A}\ (\text{S.M.})$$

$$\mathcal{A}(\tilde{f}^*_J \tilde{f}_{J'}) \approx (10^{-2} - 10^{-3}) \sin\psi \quad \gtrsim \mathcal{A}(\text{M.S.S.M.})$$

$\psi \equiv$ CP odd complex phase

involving the λ, λ' $\not{R}_p$ couplings

Conclusions

- There are different methods to determine the SUSY parameters $M', M, \mu, \tan\beta$
- High $\mathcal{L}$ + polarization of e^- (and e^+) crucial for a precise determination of the SUSY parameters
- $R\!\!\!/_p$ leads to a rich phenomenology, multilepton and multijet events (difficult at LHC!)

Talks at Sitges

S Ambrosanio	GMSB studies
H-U Martyn	mSUGRA studies
A Sopczak	$\tilde{\tau}\tilde{\tau}$ production
M Besançon	R_p violating SUSY
S Choi	$\chi^+\chi^-$ analysis
G Moortgat-Pick	$\chi^0\chi^0$ analysis
H Eberl	$\tilde{q}\tilde{q}$ production
G Moreau	CP violation ~~and~~ FNCN in R_p violating SUSY

Tasklist

expt:

- include more difficult models
- update, improve, refine analysis
  mass measurements, esp. multi-jets
  more decay channels, Br determination
  exploit polarisation $e^-_L e^+_R$ & $e^-_R e^+_L$

theo:

- determine errors on SUSY parameters
  given the achievable expt. resolutions
- map out accessible parameter space
  SUGRA, non-SUGRA, CP phases, ...
- use polarisation of both beams
- radiative corrections

all:

- quantitative comparison with LHC potential