Fermion polarisation in sfermion decays.

- Introduction.
- τ polarisation probed using 1-prong hadronic decay.
- τ polarisation as a probe of SUSY parameters.

Some of the refs:

M. Guchait, D.P. Roy and R.G., [arXiv:hep-ph/0411306]. Use of the inclusive single π channel to measure P_τ at the ILC.

M. Guchait and D. P. Roy, Phys. Lett. B535(2002)243; B541(2002)356. Use of the method for SUSY searches at Tevatron/LHC.

S. Raychaudhuri and D. P. Roy, Phys. Rev. D52(1995)1556; D53(1996)4902; D. P. Roy, Phys. Lett. B459(1999)607. Use in charged Higgs searches.

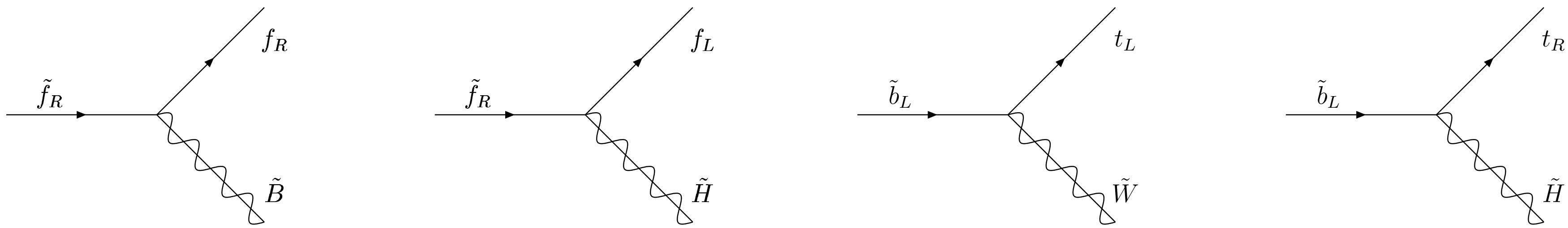
S. Kraml, T. Gadosijk, R.G., JHEP **0409**, 051 (2004) [arXiv:hep-ph/0405167]. Predictions of CPV SUSY for P_τ.

• τ has hadronic decay modes. The energy distribution of the π produced in the decay, $\tau \to \nu_\tau \pi$ as well as those in $\tau \to \rho \nu_\tau, \tau \to a_1 \nu_\tau$ depends on the handedness of the τ. Thus τ polarisation can be determined using decay π energy distribution. K. Hagiwara, A.D. Martin and D. Zeppenfeld, PLB **235** 198 (1990), B.K.Bullock, K.Hagiwara and A.D.Martin, PRL **67**, 3055 (1991), NPB **395**, 499 (1993), D.P.Roy, PLB **277**, 183 (1992).

• Third generation sfermions expected to be among the lightest. $\tilde{\tau}$ is NLSP even in many situations. Polarisation of the decay fermions can carry information on SUSY model parameters, sfermion or chargino/neutralino composition. Third generation sfermions $\Rightarrow$ third generation fermions among the decay products. t, τ among them.

$\tau(t)$ produced in stau/stop decay. M. Nojiri, PRD **51** (1995) 6281 [hep-ph/9412374]

$f = t/\tau$



- In MSSM mass eigenstates of $\tilde{f}$ (sleptons/squarks) $\tilde{f}_1, \tilde{f}_2$, are mixtures of $\tilde{f}_L$ and $\tilde{f}_R$, $f = t, \tau$.
- Mixing affects gauge couplings of $\tilde{f}_i, i = 1, 2$ and hence the production rates.
- The $\tilde{\chi}_j^{\pm}, j = 1, 2$, $\tilde{\chi}_j^0, j = 1, 4$ are mixtures of higgsinos and gauginos.
- Couplings of sfermions with higgsinos flip chirality whereas those with gauginos do not.
- Net helicity of produced f in the decay $\tilde{f}_i \to \tilde{\chi}_j^0 f$ AND $\tilde{f}_i \to \tilde{\chi}_j^{\pm} f'$ depends on the L–R mixing in the sfermion sector and on the gaugino-higgsino mixing.

Collinear approximation for the $\tilde{\tau}$ decay; i.e. $m_\tau \ll m_{\tilde{\tau}_1}$

$$\begin{aligned} P_\tau &= \frac{\left(a^R_{11}\right)^2 - \left(a^L_{11}\right)^2}{\left(a^R_{11}\right)^2 + \left(a^L_{11}\right)^2}, \\ a^R_{11} &= -\frac{2g}{\sqrt{2}} N_{11} \tan\theta_W \sin\theta_\tau - \frac{g m_\tau}{\sqrt{2} m_W \cos\beta} N_{13} \cos\theta_\tau, \\ a^L_{11} &= \frac{g}{\sqrt{2}} \left[N_{12} + N_{11} \tan\theta_W\right] \cos\theta_\tau - \frac{g m_\tau}{\sqrt{2} m_W \cos\beta} N_{13} \sin\theta_\tau, \end{aligned} \tag{1}$$

where

$\tilde{\chi}_1 = N_{11}\tilde{B} + N_{12}\tilde{W} + N_{13}\tilde{H}_1 + N_{14}\tilde{H}_2,$

Essentially different SPS points:

♢ mSUGRA: $\tilde{\chi}_1^0 \sim \tilde{B}$ Small $\tan\beta, \cos\theta_\tau$ small $\Rightarrow P_\tau \simeq +1$.

$\tan\beta \Rightarrow$ larger $(\cos\theta_\tau)$

P_τ still close to $+1(> 0.90)$ over the allowed SUGRA parameter space.

♢ Nonuniversal SUGRA models. The gauge kinetic function determined by the non-singlet chiral superfield, at the GUT scale, representations 75,200. LSP dominated by the Higgsino component over most of the parameter space. $P_\tau \simeq \cos^2\theta_\tau - \sin^2\theta_\tau$,

♢ AMSB : $\tilde{\chi}_1^0$ is Wino like: expect $P_\tau = -1$.

♢ GMSB the LSP is the gravitino $\tilde{G}$, while the $\tilde{\tau}_1$ is be theNLSP over a large part of parameter space

Thus the $\tilde{\tau}_1 \to \tau\tilde{G} \Rightarrow P_\tau = \sin^2\theta_\tau - \cos^2\theta_\tau$.

♢ If $\tilde{\tau}_1$ is heavier than the $\tilde{\chi}_1^0$, then GMSB is like mSUGRA.

♢ Expected polarisations: $1, -1/2, -1, +1/2$ if one uses $\cos\theta_\tau = 0.5$.

• How does one get information on τ polarisation using hadronic decay of τ.? K. Hagiwara, A.D. Martin and D. Zeppenfeld, PLB **235** 198 (1990)

• τ decays: $\tau \to \pi^{\pm}\nu, \rho^{\pm}\nu, a_1^{\pm}\nu$. The CM angular distribution of the decay meson [J=0, π] [J=1, $\rho, a_1 J = 1$] depends on τ polarisation:

$$\frac{1}{\Gamma_\pi}\frac{d\Gamma_\pi}{d\cos\theta} = \frac{1}{2}(1 + P_\tau \cos\theta)$$

$$\frac{1}{\Gamma_v}\frac{d\Gamma_{vL,T}}{d\cos\theta} = \frac{\frac{1}{2}m_\tau^2, m_v^2}{m_\tau^2 + 2m_v^2}(1 \pm P_\tau \cos\theta),$$

• L,T are longitudinal and transverse states of vector mesons v. These can be distinguished using the fact that transverse (longitudinal) vector mesons share the energy of parent meson evenly (unevenly) among the decay pions. Energy distribution of decay pions can be used then to measure the τ polarisation.

• A lot of nice analyses of τ polarisation and hence of the MSSM parameter determination at LC exist. They Use the $\tau \to \rho/a_1\nu_\tau$ (multiprong) mode. M.M.Nojiri, PRD **51** (1995) 6281 [hep-ph/9412374], M.M.Nojiri et al PRD **54**, 6756 (1996) [hep-ph/9606370], E.Boos et al, EPJC **30** (2003) 395 [hep-ph/0303110].

- Our New work: (M. Guchait, D.P. Roy and R.G.:[hep-ph/0411306])

- 1-prong π final state used previously to sharpen up $H^{\pm}$ signature S. Raychaudhuri, D. P. Roy, PRD52(1995)1556; D53(1996)4902; D.P. Roy, PLB459(1999)607.

Developed a variable for τ polarisation analysis.

- Look at $R = p_{\pi^{\pm}}/p_{\tau-jet}$. and study

$$f = \frac{\sigma(0.2 < R < 0.8)}{\sigma_{total}}$$

- f a good discriminator of τ polarisation.

- If region $R < 0.2$ is inacessible due to the difficulty in τ identification for a soft track, use the $\sigma(0.2 < R)$ for normalisation.

- We have studied its application to the ILC studies.

More on inclusive 1-prong τ decay τ identification best done through the hadronic decay.

1-prong inclusive hadronic decay corresponds to 80% of hadronic decay and 50% of total width.

Main decay modes contributing to 1-prong decay (about 90% of total 1-prong decay) are: $\tau \to \nu_\tau \pi$, $\tau \to \rho \nu_\tau, \tau \to a_1 \nu_\tau$

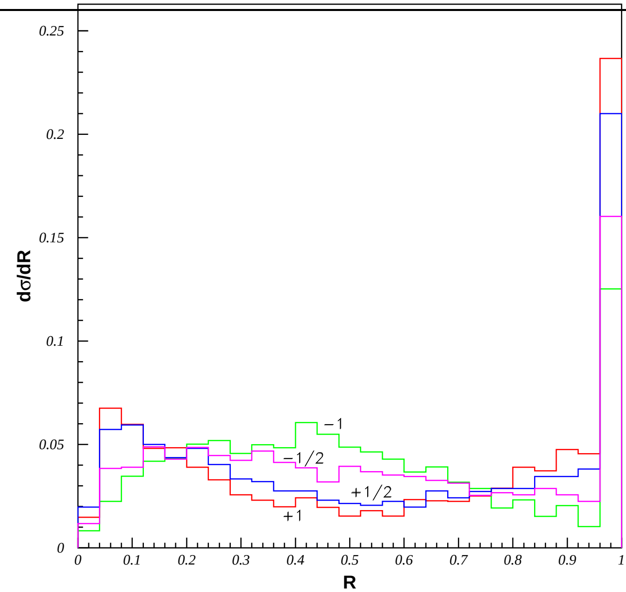
Define x as the fraction of the τ lab momentum carried by its decay meson. In the collinear approximation x is given by:

$$x = \frac{1}{2}(1 + \cos\theta) + \frac{m_{\pi,v}^2}{2m_\tau^2}(1 - \cos\theta) = \frac{p_{\tau-jet}}{p_\tau}.$$

For τ decay the only measurable momentum is τ-jet momentum.

If $P_\tau = 1$: hard jets come from $\pi, \rho_L, a_{1L} \Rightarrow$ uneven sharing of momenta among the decay π coming from v. $\Rightarrow$ Distribution in R is peaked at $R < 0.2$ and $R > 0.8$.

If $P_\tau = -1$: hard jets come from $\rho_T, a_{1T} \Rightarrow$ even sharing of momenta among the decay π coming from v. $\Rightarrow$ R distribution peaked in the middle.



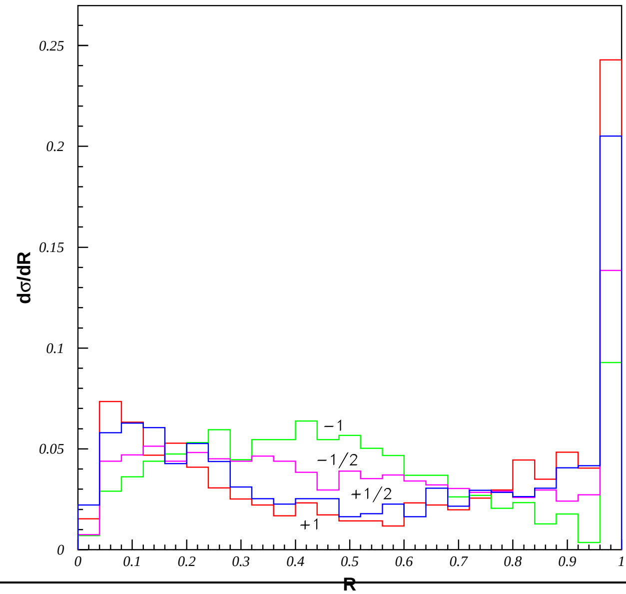
Results presented for

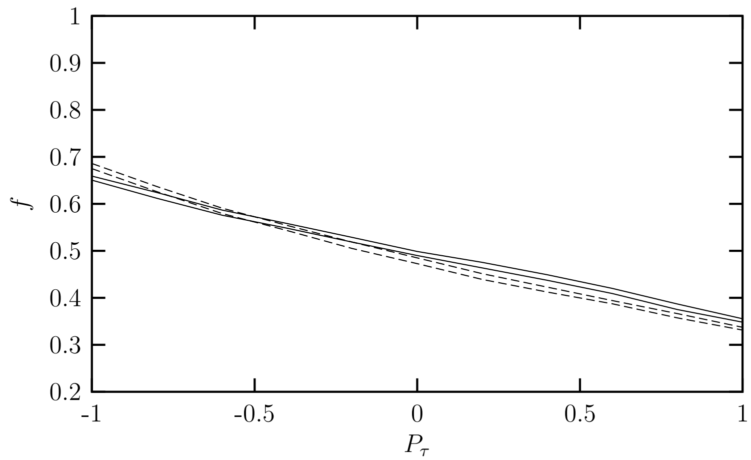
$\sqrt{s} = 350$ GeV, $m_{\tilde{\tau}_1} = 150$ GeV, $m_{\tilde{\chi}_1} =$ 100 GeV

$p^T_{\tau-\text{jet}} > 25$ GeV$, \cos\theta_{\tau-\text{jet}} < 0.75$

Top :Distribution in R. Different curves for values of polarisation $P_\tau = -1, -.5, 0.5, 1.0$ indicated on the different curves.

Bottom: The same thing for a cut on $P_\tau >$ 50 GeV.





f as a function of P_τ. Uncertainty due to the difft. parametrisations of the a_1 and non-resonant contributions to the π. Estimated using Tauola. $\Delta P_\tau = \pm 0.03 (\pm 0.05)$ for $P_\tau = -1 (+1)$ Additional error from error in measurement of f.

- $p^T_{\tau-jet}$ >25 GeV cut (solid lines): f changes from 0.65 to 0.35 for $P_\tau = -1$ to 0.35 at $P_\tau = +1$. For $p^T_{\tau-jet} >$ 50 GeV (dashed line) decrease is steeper.

- Use of inclusive 1-prong channel, robust method of determining τ polarisation. If the aim is only polarisation determination this has the advantage of higher statistics and smaller systematic errors, compared to the exclusive channel.

- CP violating phases can affect the couplings, masses of the sparticles, affect CP-even variables the rates of production, decay widths, branching ratios.

- CP odd observables constructed out of final state decay products will have non-zero value

Back to τ/top polarisation expected in MSSM

□ Polarisation of $f(f')$ produced in $\tilde{f}_i \to f\tilde{\chi}_j^0$, $\tilde{f}_i \to \tilde{\chi}_j^{\pm} f'$, depends on L–R mixing and gaugino/higgsino content

♢ CP-violating phases of A_f, μ, M_i in MSSM affect L–R mixing and guagino/higgsino content

□ Polarisation of f, f' can carry information on CPV phases as well.

♢ NOTE: polarisation itself is a CP-even variable

- Polarisation for CPV case for $\tilde{\tau}$ studies mentioned briefly in A.Bartl, K.Hidaka, T.Kernreiter and W. Porod, PRD **66** (2002) 115009 [hep-ph/0207186].
- Our study: S. Kraml, T. Gadosijk, R.G JHEP **0409**, 051 (2004)

How well does the P_f probe the CPV phases?

Polarisations that can be measured: t, τ.

Decays we studied:

$\tilde{f} \to f\tilde{\chi}_j^0$, $\tilde{f} = \tilde{t_1}, \tilde{ti_2}, \tilde{\tau_1}, \tilde{\tau_2}$

$\tilde{f} \to f'\tilde{\chi}_l^{\pm}$, $\tilde{f} = \tilde{b_i}, f' = t, \tilde{\nu_\tau}, f' = \tau$.

• An example for $\tilde{\tau}_1 \to \tau \tilde{\chi}_1^0$

$$P_f = \frac{Br(\tilde{f}_1 \to \tilde{\chi}_1^0 f_R) - Br(\tilde{f}_1 \to \tilde{\chi}_1^0 f_L)}{Br(\tilde{f}_1 \to \tilde{\chi}_1^0 f_R) + Br(\tilde{f}_1 \to \tilde{\chi}_1^0 f_L)}$$

• Take A_f, M_2, M_1, μ complex. Safe to choose μ real $\Leftarrow$ (EDM CONSTRAINTS).

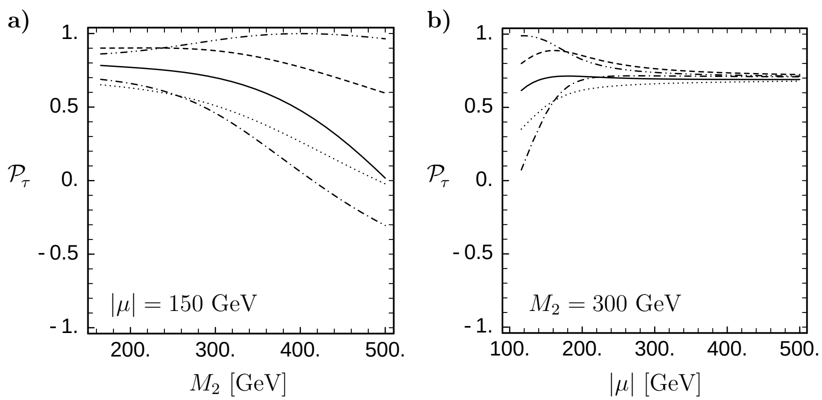
♢ P_f sensitive to CPV and nonzero even if ONLY one phase (either in sfermion sector or gaugino sector) is nonzero. $m_{\tilde{f}}$ not relevant for predictions of P_f.

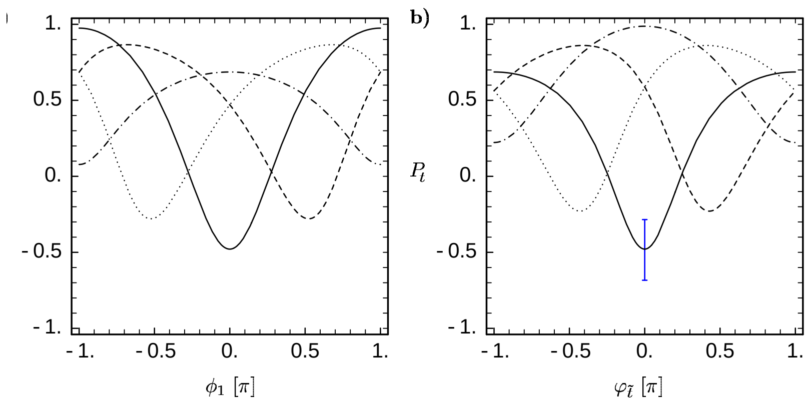
• Effects large for larger Yukawa Couplings and enhanced if $\tilde{\chi}_1^0$ is a guagino-higgsino mixed state.

□ P_t has significant dependence on the phases even when $\mu \simeq M_2$

♢ P_f can be used to extract information on phases ONLY in conjunction with other observabels which will give info. on μ, M_2, M_1 etc.

♢ Polarisation information need be included in a global analysis of MSSM parameter determination at ILC.





Some Results:

Average polarisation for τ for $\theta_{\tilde\tau} = 130^\circ$ and $\tan\beta = 10$: in a) as a function of M_2 for $|\mu| = 150$ GeV, in b) as a function of $|\mu|$ for $M_2 = 300$ GeV. The full, dashed, dotted, dash-dotted, and dash-dot-dotted lines are for $(\phi_1, \varphi_{\tilde\tau}) = (0,0)$, $(0, \frac{\pi}{2})$, $(\frac{\pi}{2}, 0)$, $(\frac{\pi}{2}, \frac{\pi}{2})$, and $(\frac{\pi}{2}, -\frac{\pi}{2})$.

Average polarisation of top for $\theta_{\tilde t} = 130^\circ$, and $\tan\beta = 10$: in a) as a function of ϕ_1 for $M_2 = 225$ GeV and $|\mu| = 200$ GeV; in b) as a function of $\varphi_{\tilde t}$ for $|\mu| = 200$ GeV and M_2 adjusted such that $m_{\tilde\chi^0_1} = 100$ GeV. The full, dashed, dotted, and dash-dotted lines are for $\varphi_{\tilde t}$ $(\phi_1) = 0, \frac{\pi}{2}, -\frac{\pi}{2}, \pi$ in a (b).

Conclusions:

• τ/t polarisation a very useful probe of chirality of the interactions responsible for t/τ production.

• Fraction of events in the inlcusive pion spectrum with $0.2 < R < 0.8$ where $R = \frac{E_\pi}{E_{jet}}$, is correated nicely with τ polarisation. This is a new observable to measure the τ polarisation.

• CP violating phases in the MSSM affect the CP–even polarisation of $\tau(t)$ produced in stau/stop/sbottom decays. Effects larger for the t due to larger Yukawa coupling. Effects larger when $\tilde{\chi}_j^0, \tilde{\chi}_i^\pm$ is a mixed gaugino–higgsino state. Determination of CP phases requires combining the polarisation information with knowledge of magnitudes of MSSM parameters from other observables.