The Physics Argument for NLC Positron Polarization

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Motivation

Why do we need the Linear Collider?

- Discovery of new physics (if Tevatron/LHC miss it)
- High-precision measurements of SM (if Tevatron/LHC see nothing new)
- Quantifying new physics (once Tevatron/LHC find it)

Why do we need Electron Beam Polarization $\mathcal{P}_-$?

- Sensitivity to chiral couplings
- Enhancing/suppressing special channels
  - Better statistics
  - Extraction of couplings (signal free from signal)
  - Background suppression

Do we also need Positron Polarization $\mathcal{P}_+$?

What should be addressed for the Orange Book/Snowmass?

$\mathcal{P}_+$ for Disentangling Susy

$$\mathbf{e^+e^- \to \widetilde{e}_L\widetilde{e}_L, \widetilde{e}_R\widetilde{e}_R, \widetilde{e}_L\widetilde{e}_R}$$

s-channel γ/Z^*

t-channel $\widetilde{\chi}^\circ$ exchange

Example from Uli Martyn's LCWS2000 talk

	$\mathcal{P}_- = -80\%$	$+\mathcal{P}_+ = 60\%$
$\widetilde{e}_L\widetilde{e}_L$	900 fb	1100 fb
$\widetilde{e}_R\widetilde{e}_L$	200 fb	100 fb
$\widetilde{e}_R\widetilde{e}_R$	50 fb	30 fb

$\widetilde{e}_L\widetilde{e}_R$ has only $\widetilde{\chi}^\circ$ dependence (in the absence of mixing)

Sensitivity to heavy states $\Rightarrow$ right $\sqrt{s}$ for NLC++

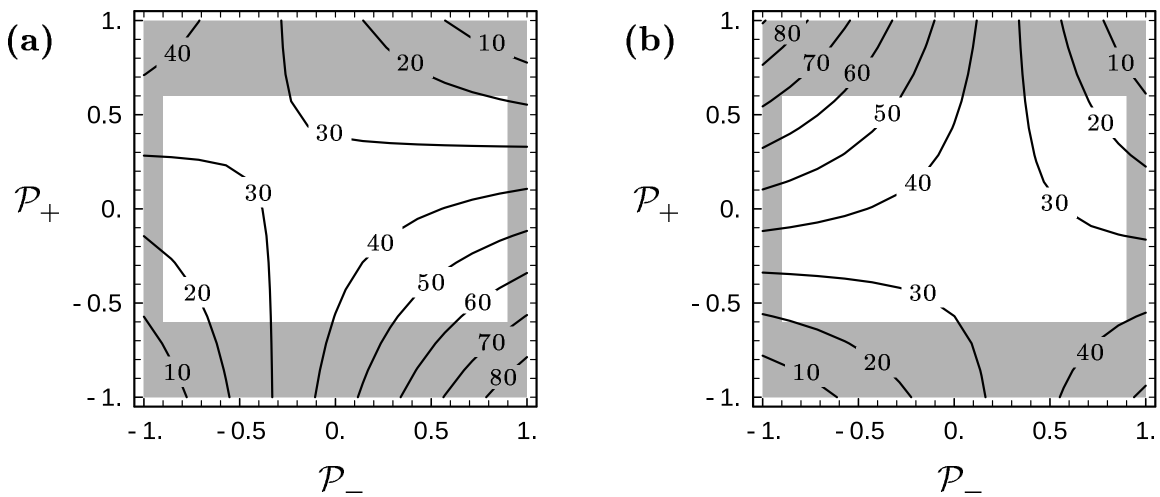
Sfermions difficult for hadron colliders except for kinematic accidents

$$e^+e^- \to \tilde{t}_1\tilde{t}_1^* = (\tilde{t}_L \cos\theta_{\tilde{t}} - \tilde{t}_R \sin\theta_{\tilde{t}})(\tilde{t}_L^* \cos\theta_{\tilde{t}} - \tilde{t}_R^* \sin\theta_{\tilde{t}})$$

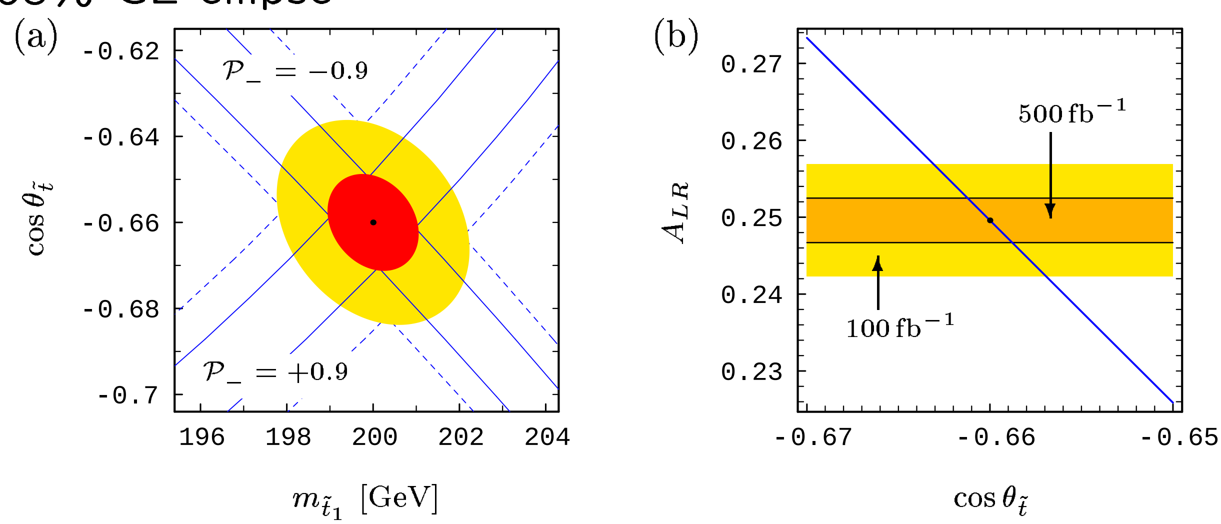
Berggren, et al., hep-ph/9911345; Bartl, et al., hep-ph/0010018

- $\sqrt{s} = 500$ GeV, $m_{\tilde{t}_1} = 200$ GeV, $\mathcal{L} = 500\ \text{fb}^{-1}$

$\cos\theta_{\tilde{t}} = 0.4$ $\cos\theta_{\tilde{t}} = 0.66$



68% CL ellipse



Increased accuracy ($\sim$ 25%) in stop mass and mixing angle

$$\mathbf{e^+e^-} \to \widetilde{\chi}^-\widetilde{\chi}^+$$

- Measurement of M_2, μ, $\tan\beta$, $m_{\widetilde{\nu}_e}$ from:

$$\sigma_R = \int d\Omega \frac{d\sigma}{d\Omega}[P_L = -\bar{P}_L = +1]$$
$$\sigma_L = \int d\Omega \frac{d\sigma}{d\Omega}[P_L = -\bar{P}_L = -1]$$
$$\sigma_T = \int d\Omega (\frac{\cos 2\Phi}{\pi}) \frac{d\sigma}{d\Omega}[P_T = \bar{P}_T = +1, \eta = \pi]$$

using $\widetilde{\chi}_1^+\widetilde{\chi}_1^-, \widetilde{\chi}_1^+\widetilde{\chi}_2^- + \widetilde{\chi}_1^-\widetilde{\chi}_2^+, \widetilde{\chi}_2^-\widetilde{\chi}_2^+$

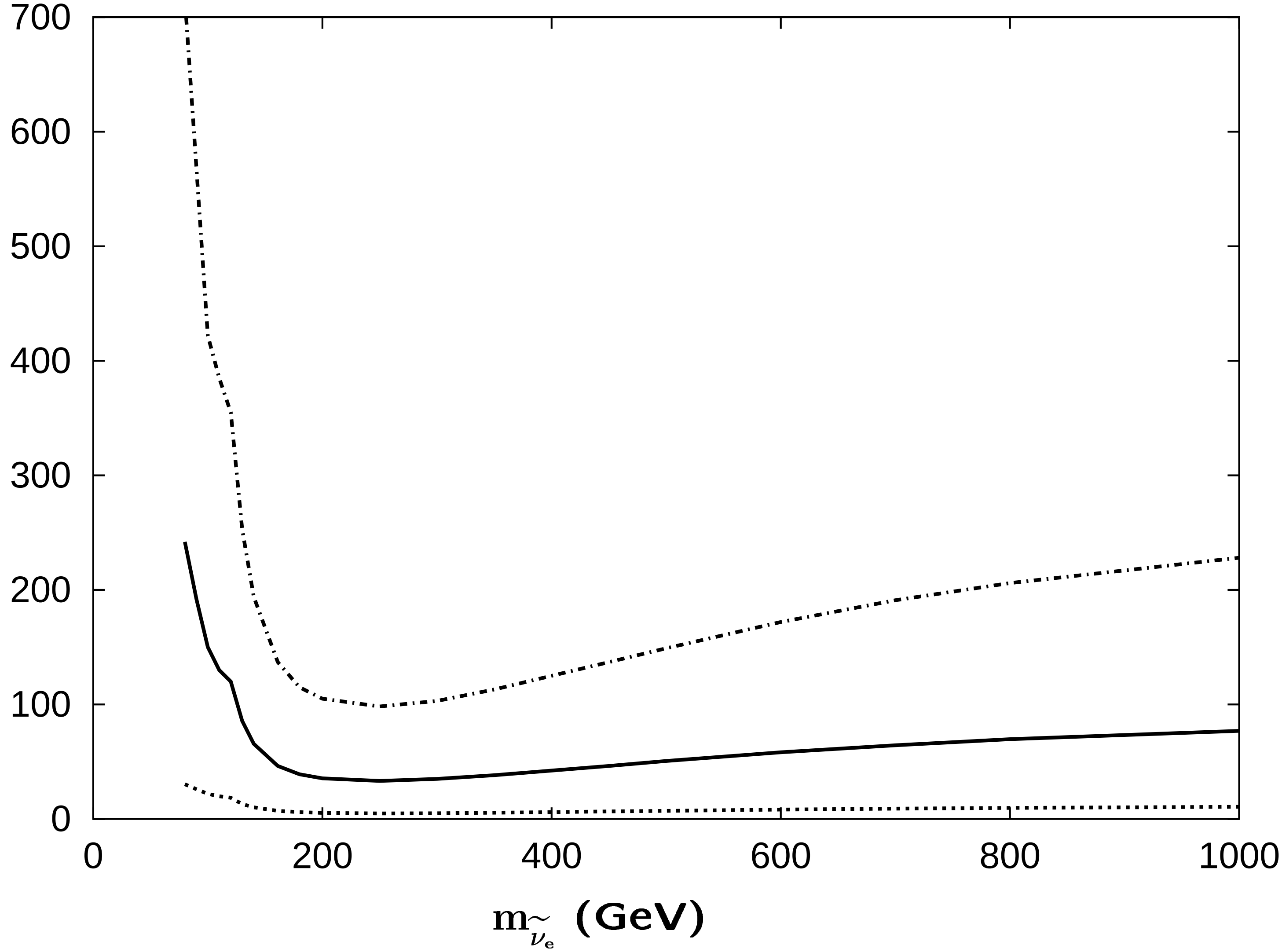
If only $\widetilde{\chi}_1^\pm$ is accessible, then + $m_{\widetilde{\chi}^\circ}$ + variable $\sqrt{s}$

Sensitivity to extra, charged states?

- Extraction of $m_{\tilde{\nu}_e}$

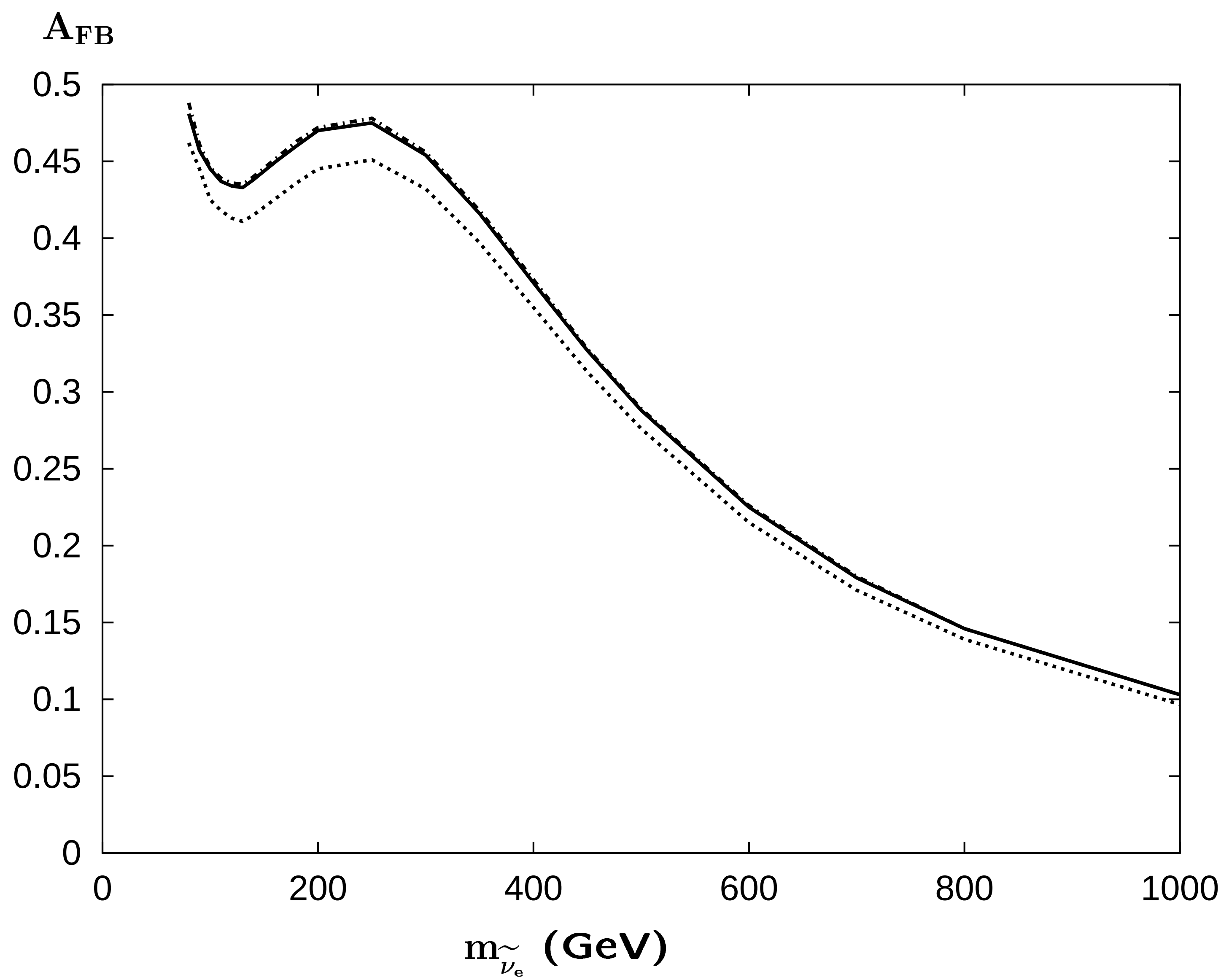
G. Moortgat-Pick and H. Fraas, [hep-ph/9904209]

$\sigma_{e^-} \equiv \sigma(\tilde{\chi}^- \tilde{\chi}^+) \times \mathrm{BR}(\tilde{\chi}^- \to e^- + X)$ (fb)



$(\mathcal{P}_-, \mathcal{P}_+)$

$(0,0)$=solid, $(0.85,0)$=dot, $(-0.85,0.6)$=dash-dot

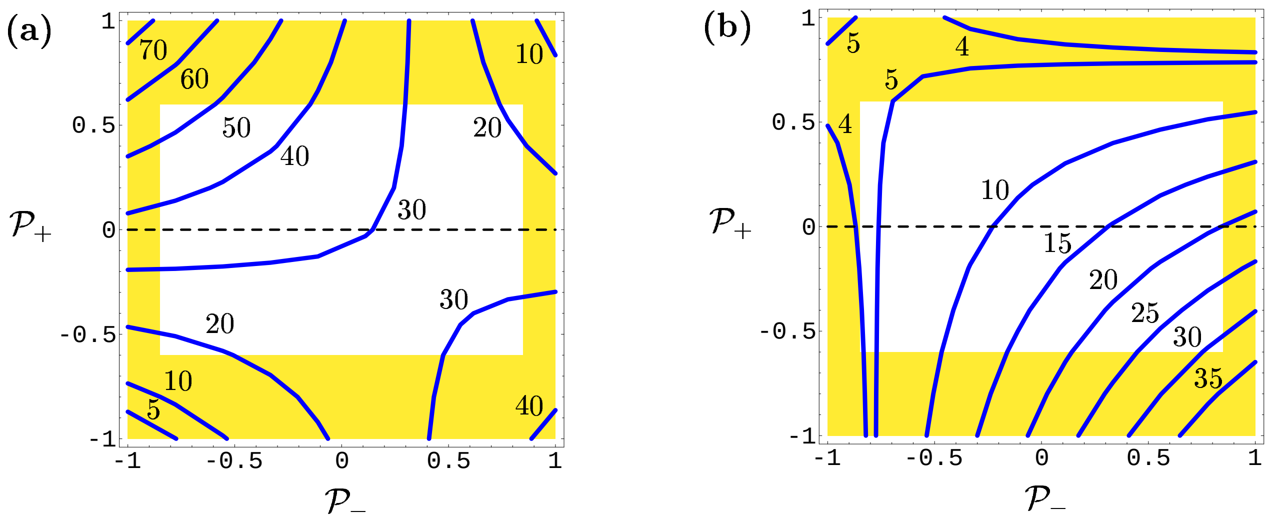


$(0,0)$=solid, $(0.85,0)$=dot, $(-0.85,0.6)$=dash-dot

Higgsino-like models more difficult

$\mathbf{e^+e^- \to \widetilde{\chi}^\circ \widetilde{\chi}^\circ}$

$\sigma(e^+e^- \to \widetilde{\chi}^\circ_1 \widetilde{\chi}^\circ_2)$, $\sqrt{s} = 230$ GeV, $m_{\widetilde{\chi}^\circ_1} = 71$ GeV, $m_{\widetilde{\chi}^0_2} = 130$ GeV

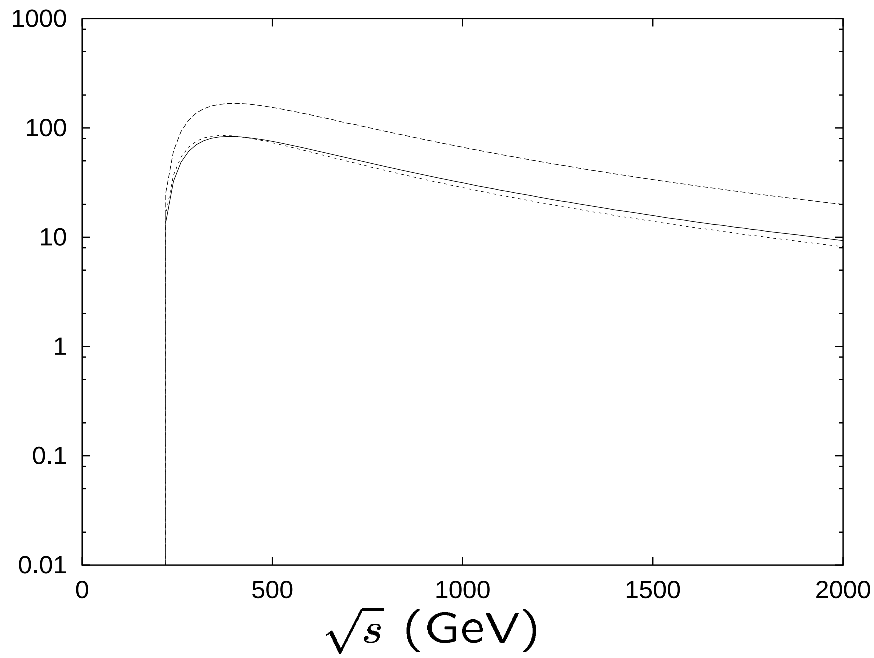


$\widetilde{e}_R, \widetilde{e}_L = 132, 176$ GeV

$\widetilde{e}_R, \widetilde{e}_L = 132, 500$ GeV

$\sigma(\widetilde{\chi}^\circ_1 \widetilde{\chi}^\circ_2)$ (fb); (00)=solid, (+−)=dot, (−+)=dash

MSSM

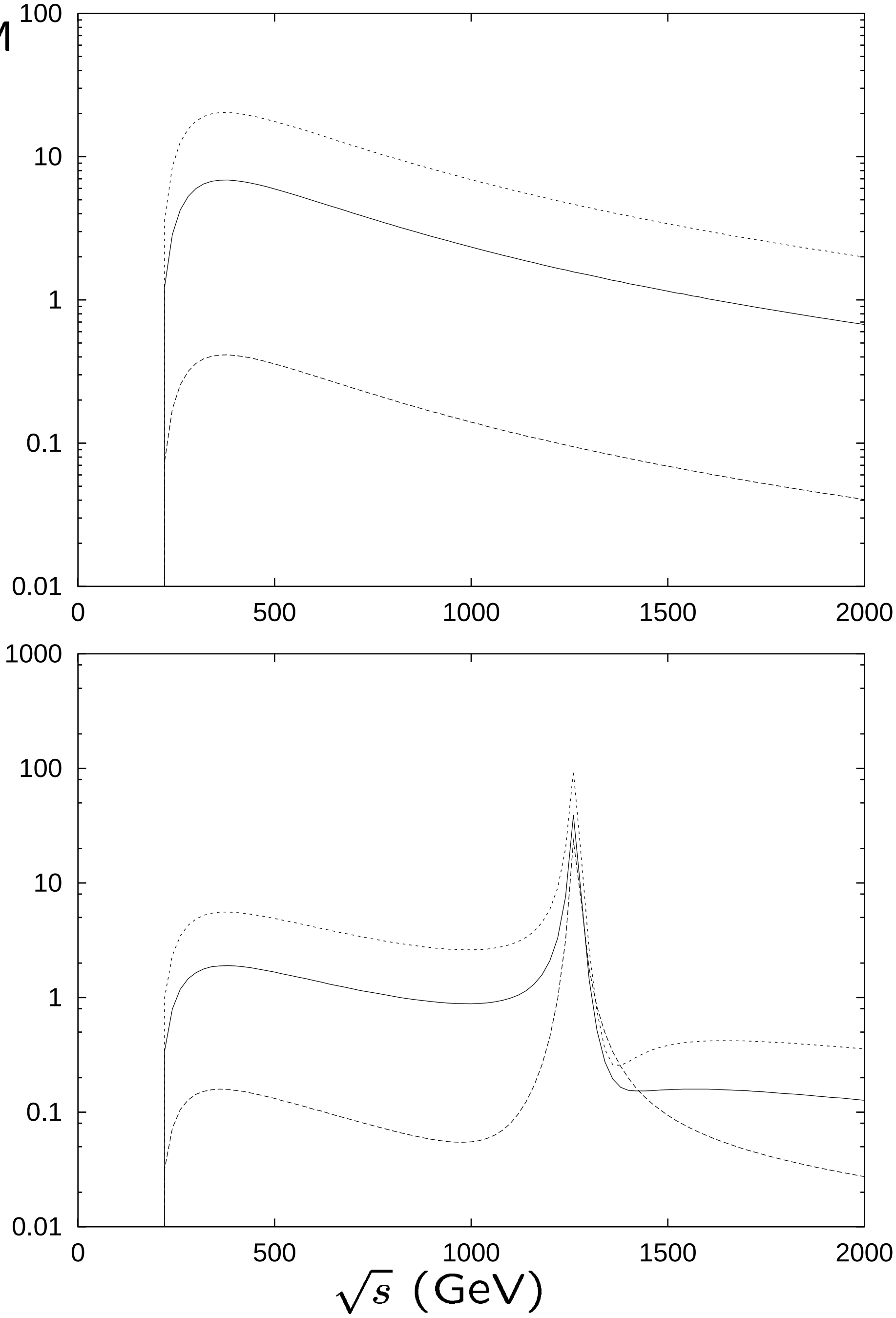


Extensions of the MSSM can contain Majorana fermion partners to gauge singlets – singletinos

$\sigma(\widetilde{\chi}^{\circ}_1\widetilde{\chi}^{\circ}_2)$ (fb); (00)=solid, (+−)=dot, (−+)=dash

NMSSM

E_6



Contact Interactions

- Compositeness (ETC)
- Heavy Z'
- Leptoquarks

$$\mathcal{L}_{\text{contact}} = \frac{\tilde{g}^2}{\Lambda_{\alpha\beta}} \eta_{\alpha\beta} (\bar{e}_\alpha \gamma_\mu e_\alpha)(\bar{f}_\beta \gamma_\mu f_\beta), f \neq e, t$$

$$\begin{aligned}
\frac{d\sigma}{d\cos\theta} &= \frac{3}{8}[(1+\cos\theta)^2 \sigma_+ (1-\cos\theta)^2 \sigma_-] \\
\sigma_+ &= \frac{D}{4}[(1-P_{\text{eff}})\sigma_{LL} + (1+P_{\text{eff}})\sigma_{RR}] \\
\sigma_- &= \frac{D}{4}[(1-P_{\text{eff}})\sigma_{LR} + (1+P_{\text{eff}})\sigma_{RL}] \\
D = 1 - \mathcal{P}_+\mathcal{P}_-, P_{\text{eff}} &= \frac{\mathcal{P}_- - \mathcal{P}_+}{1 - \mathcal{P}_-\mathcal{P}_+}
\end{aligned}$$

Extract components by varying $P_{\text{eff}} = \pm P$:

$$\sigma_{LL} = \frac{1}{D}[-\frac{1-P}{P}\sigma_+(P) + \frac{1+P}{P}\sigma_+(-P)], etc.$$

Reach on $\Lambda_{\alpha\beta}$ increased by $20-40\%$.

Standard-Model Like Higgs Boson

$$\sigma(\mathbf{e^+e^-} \to \mathbf{ZH})$$
$$\propto (1+\mathcal{P}_-)(1-\mathcal{P}_+).58 + (1-\mathcal{P}_-)(1+\mathcal{P}_+).42$$

$\mathcal{P}_-$	$\mathcal{P}_+$	100% Pol.	80% e^-, 60% e^+
0	0	1	1
+1	0	0.84	0.87
−1	0	1.16	1.13
+1	−1	1.68	1.26
−1	+1	2.32	1.70

$$\sigma(\mathbf{e^+e^-} \to \nu\bar{\nu}\mathbf{H}) \sim \sigma(\mathbf{e^+e^-} \to \mathbf{W^+W^-})$$
$$\propto (1+\mathcal{P}_-)(1-\mathcal{P}_+)$$

$\mathcal{P}_-$	$\mathcal{P}_+$	100% Pol.	80% e^-, 60% e^+
0	0	1	1
+1	0	0	0.2
−1	0	2	1.8
+1	−1	0	0.08
−1	+1	4	2.88

$$\sigma(\mathbf{e^+e^-} \to \mathbf{ZZ})$$
$$\propto (1+\mathcal{P}_-)(1-\mathcal{P}_+).655 + (1-\mathcal{P}_-)(1+\mathcal{P}_+).345$$

$\mathcal{P}_-$	$\mathcal{P}_+$	100% Pol.	80% e^-, 60% e^+
0	0	1	1
+1	0	0.69	0.75
−1	0	1.31	1.25
+1	−1	1.37	1.05
−1	+1	2.62	1.91

- Improve S/B
- Dial off WW-fusion

Excited Leptons

Eboli, et al., hep-ph/9509257

With Polarization:

- Determine if $S = 1/2, 3/2$
- Study γ couplings
- $e^-\gamma$ is superior in sensitivity

Anomalous Top Quark couplings

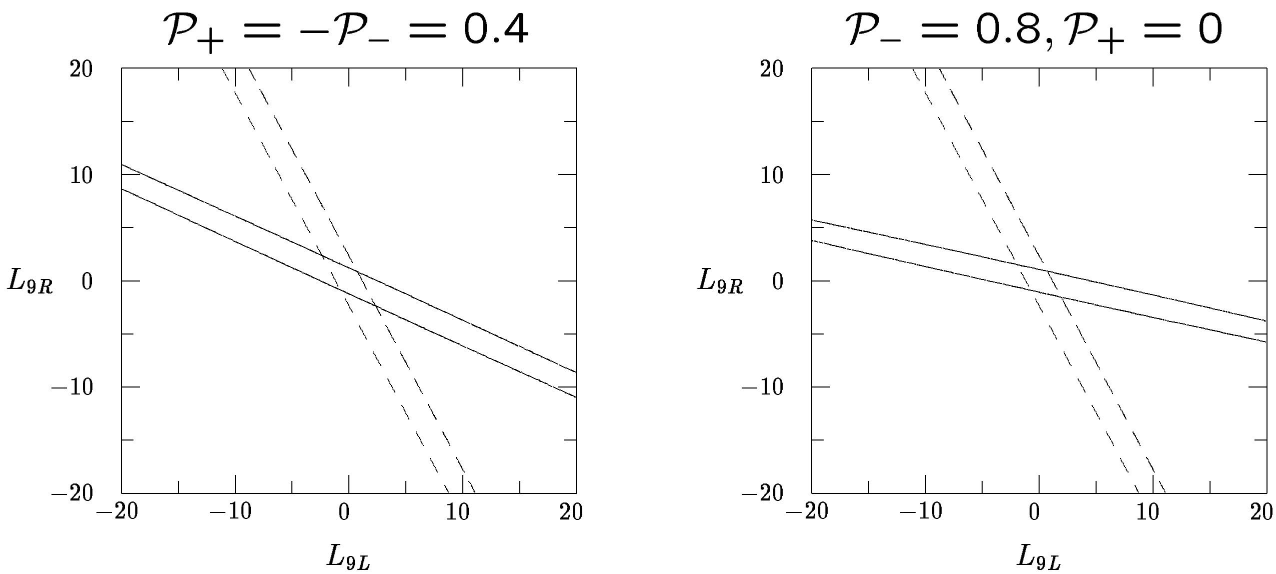
Hioki, hep-ph/9908345

- Consider $e^+e^- \to t\bar{t} \to \ell^\pm + X, \ell^+\ell^- + X$
- Assume $\delta g_{t\bar{t}\gamma,Z} \sim 0.1$
- $\mathcal{P}_+ \neq 0$ improves sensitivity from $2\sigma \to 3\sigma$

$e^+e^- \to W^+W^-$

Likhoded, Han, Valencia, Phys. Rev. D **53**, *4811 (1996)*

- No-Higgs EW Chiral Lagrangian

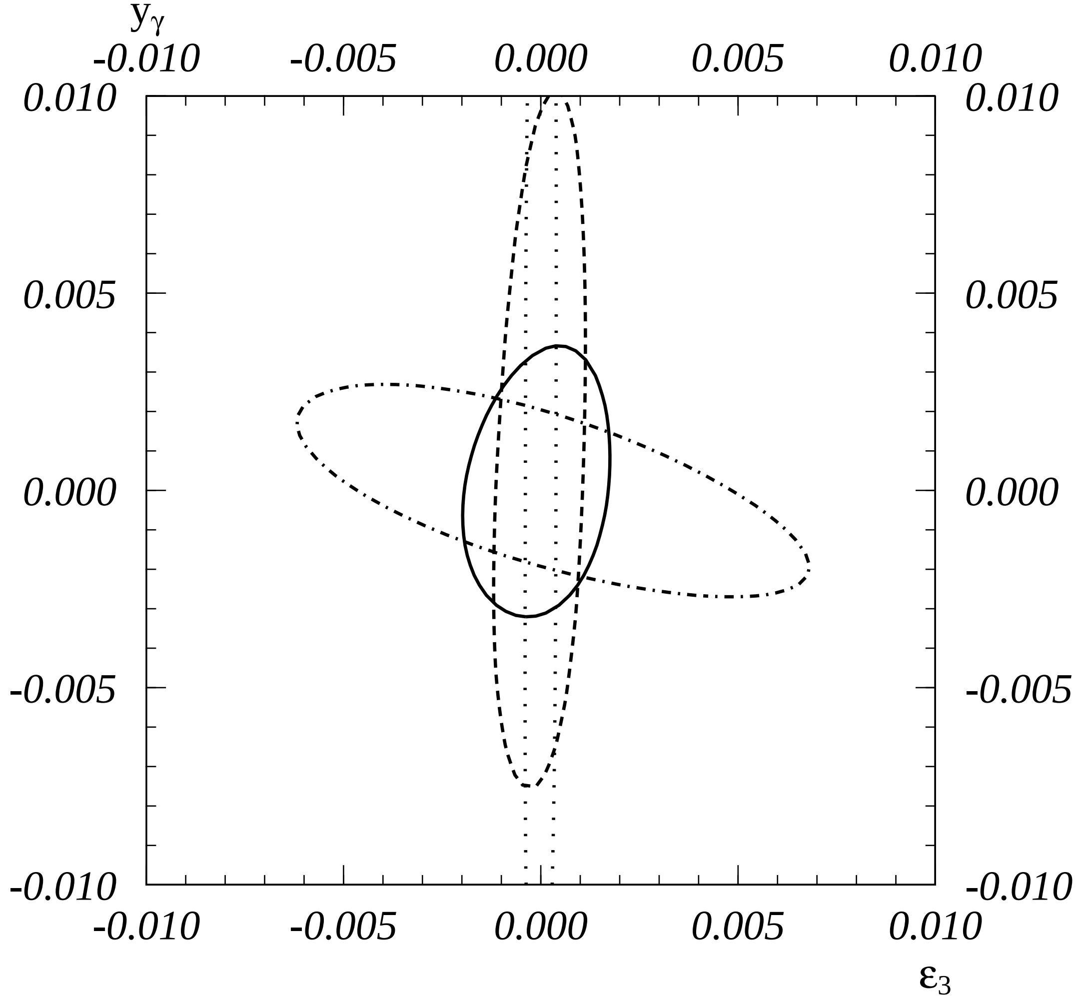


Allowed region for the $L_{9L} - L_{9R}$ parameters at $\hat{\alpha} = 0$ for cuts on the scattering angle $-0.989 \leq \cos\theta \leq 0.4$ for beam polarizations (dashed contour represents the unpolarized case)

Casalbuoni, De Curtis, Guetta, hep-ph/9912377

- One Example: γWW, ZWW effective Lagrangian with global $SU(2)_L$ symmetry

$$\mathcal{L}_{eff} = ie\frac{y_\gamma}{M_W^2}[A, W, W] + e\epsilon_3\left(\frac{t_\theta}{c_{2\theta}}\bar{f}Zf - \frac{s_\theta}{c_{2\theta}2\sqrt{2}}\bar{f}Wf'\right)$$



90% CL bounds, $\sqrt{s} = 500$ GeV, $\mathcal{L} = 300$ fb^{-1}

$(0.9, 0.6)$=dash, $(0.9, -0.6)$=dot,
$(-0.9, 0.6)$=dash-dot, $(0, 0)$=solid

A_{LR} with Positron Polarization (Comment)

JLC Group

Keisuke Fujii, KEK

in place of

Tsunehiko Omori, KEK

This is to call your attention to the usefulness of positron polarization in reducing the systematic error on A_{LR} as described in our old note: KEK Preprint 95-127

Combined Polarization

$$P_{comb} \equiv \frac{P_- - P_+}{1 - P_- P_+}$$

right-handed helicity basis:
P=-1 means 100% left-handed

A_{LR}

$$A_{obs} \equiv \frac{N_L - N_R}{N_L + N_R} = -P_{comb}\, A_{LR}$$

$$\frac{\Delta A_{LR}}{A_{LR}} \simeq \sqrt{\left(\frac{\Delta P_{comb}}{P_{comb}}\right)^2 + \frac{1}{N\left(P_{comb} A_{LR}\right)^2}}$$

Systematic Error on P_{comb} dominates if N >>1

A_{LR} with Positron Polarization (Comment)

JLC Group

Reduction of Systematic Error

Polarization measuement will be dominated by systematic error

$$\Delta P_{comb} = \left(\frac{\partial P_{comb}}{\partial P_-}\right)\left(\frac{\Delta P_-}{P_-}\right)P_- + \left(\frac{\partial P_{comb}}{\partial P_+}\right)\left(\frac{\Delta P_+}{P_+}\right)P_+$$

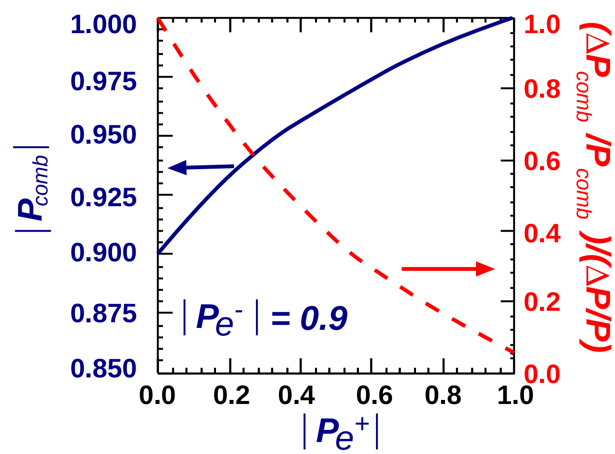
Linear Error Propagation

Identical apparatuses will be used for both electrons and positrons

$$\frac{\Delta P_-}{P_-} = \frac{\Delta P_+}{P_+} \equiv \frac{\Delta P_\pm}{P_\pm}$$

$$\boxed{\frac{\Delta P_{comb}}{P_{comb}} = \frac{1 + P_- P_+}{1 - P_- P_+}\left(\frac{\Delta P_\pm}{P_\pm}\right)}$$

Significant reduction of systematic error already at $P_{e^+} = 0.5$



TeV String Effects

Peskin, Perelstein, Cullen, Phys.Rev.D62:055012(2000)

- Muliply SM amplitudes by Veneziano amplitudes
- Factorize into resonances near string scale M_S

$$\mathcal{A}(\gamma_R\gamma_R \to \gamma^*_{01}) = \sqrt{2}eM_S \qquad \mathcal{A}(\gamma_L\gamma_L \to \gamma^*_{02}) = \sqrt{2}eM_S$$
$$\mathcal{A}(e^-_R e^+_R \to \gamma^*_{03}) = \sqrt{2}eM_S \qquad \mathcal{A}(e^-_L e^+_L \to \gamma^*_{04}) = \sqrt{2}eM_S$$

$$\mathcal{A}(e^-_R e^+_L \to \gamma^*_1) = \sqrt{\tfrac{3}{2}}eM_S\epsilon^\mu_+ \qquad \mathcal{A}(e^-_L e^+_R \to \gamma^*_1) = \sqrt{\tfrac{3}{2}}eM_S\epsilon^\mu_-$$
$$\mathcal{A}(e^-_L e^+_R \to \gamma^*_2) = \sqrt{\tfrac{1}{2}}eM_S \cdot \tfrac{1}{\sqrt{2}}[\epsilon^\mu_-\epsilon^\nu_0 + \epsilon^\nu_-\epsilon^\mu_0]$$
$$\mathcal{A}(e^-_R e^+_L \to \gamma^*_2) = \sqrt{\tfrac{1}{2}}eM_S \cdot \tfrac{1}{\sqrt{2}}[\epsilon^\mu_+\epsilon^\nu_0 + \epsilon^\nu_+\epsilon^\mu_0]$$
$$\mathcal{A}(\gamma_L\gamma_R \to \gamma^*_2) = \sqrt{2}eM_S\epsilon^\mu_-\epsilon^\nu_-$$

- Want $\mathcal{P}_+$ (or $\gamma\gamma$) to study spin-0 resonances?

Final Thoughts (Questions)

- $\mathcal{P}_+$ is useful, but is it indispensable?

  Is there a No-Lose argument that requires $\mathcal{P}_+$?

- If $\mathcal{P}_- = \pm 1$ is not realistic, does $\mathcal{P}_+$ help?

  What minimal $\mathcal{P}_+$ with what $\delta\mathcal{P}_+$?

- Is background suppression, signal enhancement enough?

  Reduction of systematic errors?

- What $\mathcal{L}$ for $\mathcal{P}_+ = 0$ versus $\mathcal{P}_+ \neq 0$ to make the same measurement?

- Will signals be more confusing than we suspect?

  Better safe than sorry?

- Does it make sense to concentrate on SUSY?

- Is it intellectually interesting only to set better limits?

- What are the minimal requirements for the NLC to make scientific progress?

  Save $\mathcal{P}_+$ for the NLC++?