Single slepton with polarized tops at LHC

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Outline

Motivation

- In most supersymmetric models a discrete multiplicative symmetry called R-parity is imposed on the Lagrangian:

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

with spin S, baryon number B, and lepton number L.

Motivation

- The most general superpotential in SUSY contains the following bilinear and trilinear terms, which do not conserve either B or L:

$$\mathcal{W}_{RPV} = \frac{1}{2}\lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}_k + \frac{1}{2}\lambda''_{ijk}\hat{U}_i\hat{D}_j\hat{D}_k + \mu_i\hat{L}_i\hat{H}_2$$

- R-parity violation leads to single SUSY particle exchanges in various subprocesses.
  - assume baryon number conservation
  - strong constraints on the couplings from experiments

Motivation

- The top quark spin is observable through its decay products.
  - decays before it can hadronize
  - polarization properties can prove an added observable at experiments
- R-parity violation gives new production mechanism for top quark.
  - different chiral structure in the interaction vertex for R-parity violating SUSY contribution
  - Would affect the polarization properties of the top quark

Top Polarization

- The spin information of the top
  - depends on its production process
  - reflected in angular distribution of its decay products
- The dominant decay of top quark in the SM

$$t \to bW^+$$

$$\hookrightarrow \quad \ell^+\nu_\ell, u\bar{d}, c\bar{s}$$

Top Polarization

- The angular distribution of a fermion f for a top quark ensemble in the top rest frame:

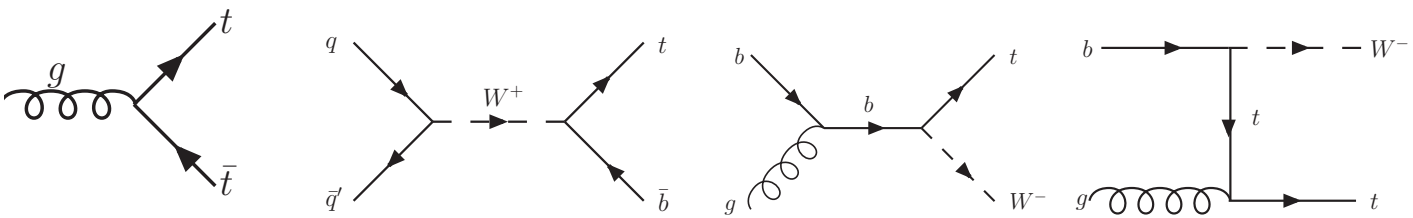
$$\frac{1}{\Gamma_f}\frac{\mathrm{d}\Gamma_f}{\mathrm{d}\cos\theta_f} = \frac{1}{2}(1 + \kappa_f P_t \cos\theta_f)$$

  - κ_f defines the spin analysing power
  - θ_f is the angle between the direction of the motion of decay fermion f and the top spin vector, in the top rest frame
- The degree of polarization P_t is defined as

$$P_t = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$

Top Production in SM

- The dominant modes of top quark production at the LHC
  - $t\bar{t}$, $t\bar{b}$ and tW^-
  - $\gamma^\mu(1-\gamma_5)$ coupling
  - $P_t(t\bar{t}) \sim -10^{-4}$, $P_t(t\bar{b}) \sim -0.68$, $P_t(tW^-) \sim -0.25$

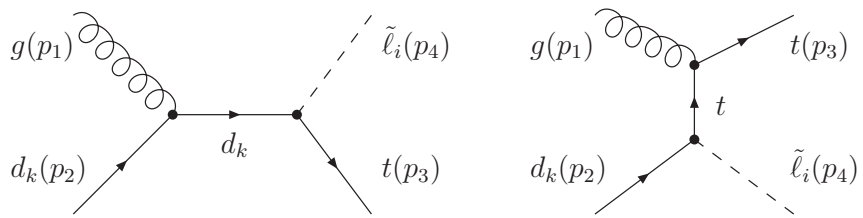


Top-slepton production at LHC

- The parton level process is given through the interaction term $\lambda'_{i3k}\widetilde{\ell}_{iL}\bar{d}_{kR}u_{3L}$

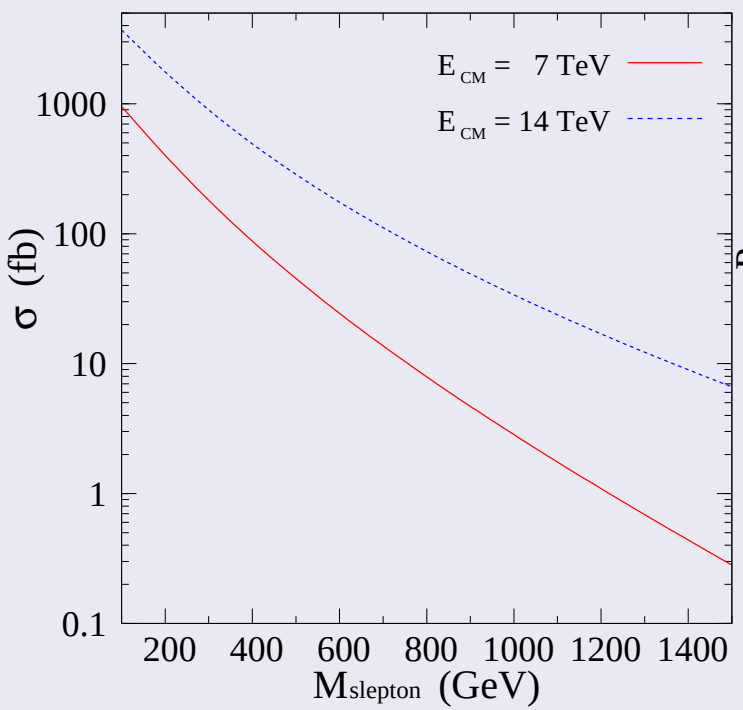
$$g(p_1)\ d_k(p_2) \to t(p_3, \lambda_t)\ \widetilde{\ell}^{-}_{iL}(p_4),$$

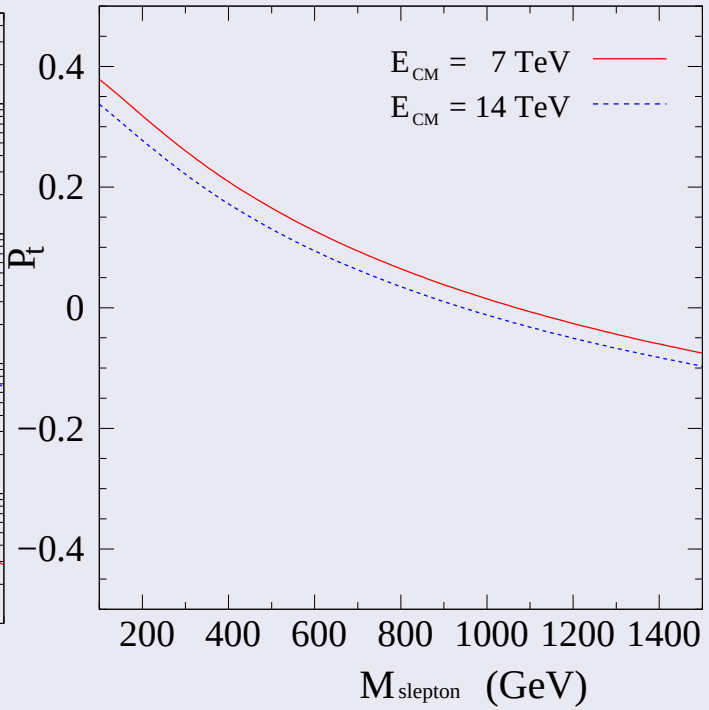
- Interaction vertex $\sim P_R = \frac{1}{2}(1+\gamma_5)$



$\lambda' = 0.2$

$$P_t = \frac{\sigma(+,+) - \sigma(-,-)}{\sigma_{tot}}$$





- The large difference in the asymmetry from SM can prove to be useful in distinguishing its signals from the SM.
- The lepton from the top decay is the most efficient spin analyzer with $\kappa_{\ell+} = 1$
- The difference in produced top's polarization $\Longrightarrow$ distinct correlations in kinematic variables
- We use the MadGraph+MadEvent package to generate and study the final state kinematics.

Decay modes for slepton

The slepton decays to the following final states

$$\widetilde{\ell}_{iL}^{-} \to \ell_i^{-} \widetilde{\chi}_j^0, \quad \widetilde{\ell}_{iL}^{-} \to \nu_{\ell_i} \widetilde{\chi}_j^{-},$$
$$\widetilde{\ell}_{iL}^{-} \to \bar{t} d_k \quad \text{(via RPV coupling)}$$
$$\widetilde{\chi}_1^0 \to \nu_i b \bar{d}_k, \quad \bar{\nu}_i \bar{b} d_k$$

Upper 2σ bounds on the R-parity violating couplings.

λ'_{131}	$0.019 \times (m_{\tilde{t}_L}/100\ GeV)$	λ'_{132}	$0.28 \times (m_{\tilde{t}_L}/100\ GeV)$
λ'_{231}	$0.18 \times (m_{\tilde{b}_L}/100\ GeV)$	λ'_{232}	$0.45 \times (m_{\tilde{s}_R}/100\ GeV)$
λ'_{i33}	$\mathcal{O}(10^{-4})$		

Model Inputs

Representative points in the MSSM parameter space

Parameters	I	II
$(M_1,\ M_2)$	$(100,\ 300)$	$(100,\ 500)$
A_i	-1000	-1500
$(\mu,\ \tan\beta)$	$(250,\ 10)$	$(600,\ 5)$
$(M_{\ell L},\ M_{\ell R})$	$(200,\ 200)$	$(500,\ 500)$
$(M_{\tilde{\chi}_1^0},\ M_{\tilde{\chi}_1^\pm})$	$(93,\ 218)$	$(97,\ 478)$
$(m_{\tilde{\ell}_L},\ m_{\tilde{\ell}_R})$	$(205,\ 205)$	$(502,\ 502)$
$m_{\tilde{\nu}_L}$	190	496
λ'_{231}	0.2	0.5

Possible combinations in the final state

- t decays to 1 b-jet and 2 light jets (J) and $\widetilde{\mu}_L$ decays to a μ^- and $\widetilde{\chi}_1^0 \Longrightarrow \mu^- + 2b\text{-jets} + 3J + \not{E}_T$
- t decays to 1 b-jet and 2 light jets and $\widetilde{\mu}_L$ decays to a $\bar{t}$ and d quark $\Longrightarrow 2b\text{-jets} + 5J$ ($\bar{t}$ decays hadronically)
  $\Longrightarrow \ell_j^- + 2b\text{-jets} + 2J + \not{E}_T$ ($\bar{t}$ decays semileptonically)
- t decays to 1 b-jet, ℓ_k^+ and a neutrino while $\widetilde{\mu}_L$ decays to a μ^- and $\widetilde{\chi}_1^0 \Longrightarrow \mu^- \ell_k^+ + 2b\text{-jets} + 1J + \not{E}_T$
- t decays to 1 b-jet, ℓ_k^+ and a neutrino while $\widetilde{\mu}_L$ decays to a $\bar{t}$ and d quark $\Longrightarrow \ell_k^+ + 2b\text{-jets} + 3J + \not{E}_T$ ($\bar{t}$ decays hadronically)
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Our choice

$$pp \longrightarrow \mu^- e^+ b\bar{b} + \not{E}_T + X$$

Selection Cuts

- $p_T^\ell > 10$ GeV and $|\eta^\ell| < 2.5$.
- $p_T^b > 20$ GeV and $|\eta^b| < 2.5$.
- A minimum missing transverse energy, $\not{E}_T > 50$ GeV.
- To resolve the final state particles:
  $\Delta R_{\ell_i \ell_j} > 0.2, \Delta R_{\ell b} > 0.4$ and $\Delta R_{bb} > 0.7$
  where $\Delta R_{AB} = \sqrt{\Delta\phi_{AB}^2 + \Delta\eta_{AB}^2}$.

SM background

$t\bar{t}$ and Triple gauge boson production

$$BR(\widetilde{\mu}_L \to \mu\widetilde{\chi}_1^0) = 0.76, \quad BR(\widetilde{\mu}_L \to \bar{t}d) = 0.24 \quad (m_{\widetilde{\mu}_L} = 205\ GeV),$$
$$BR(\widetilde{\mu}_L \to \mu\widetilde{\chi}_1^0) = 0.09, \quad BR(\widetilde{\mu}_L \to \bar{t}d) = 0.90 \quad (m_{\widetilde{\mu}_L} = 502\ GeV).$$

Cross sections

	$\sqrt{s} = 7$ **TeV**	$\sqrt{s} = 14$ **TeV**
$m_{\widetilde{\mu}_L} = 205$ GeV $(\lambda' = 0.2)$	6 fb	19 fb
$m_{\widetilde{\mu}_L} = 502$ GeV $(\lambda' = 0.5)$	12 fb	69 fb
SM	208 fb	1.08 pb

Kinematic Distributions

- $\Delta\phi_{b_1 e}$

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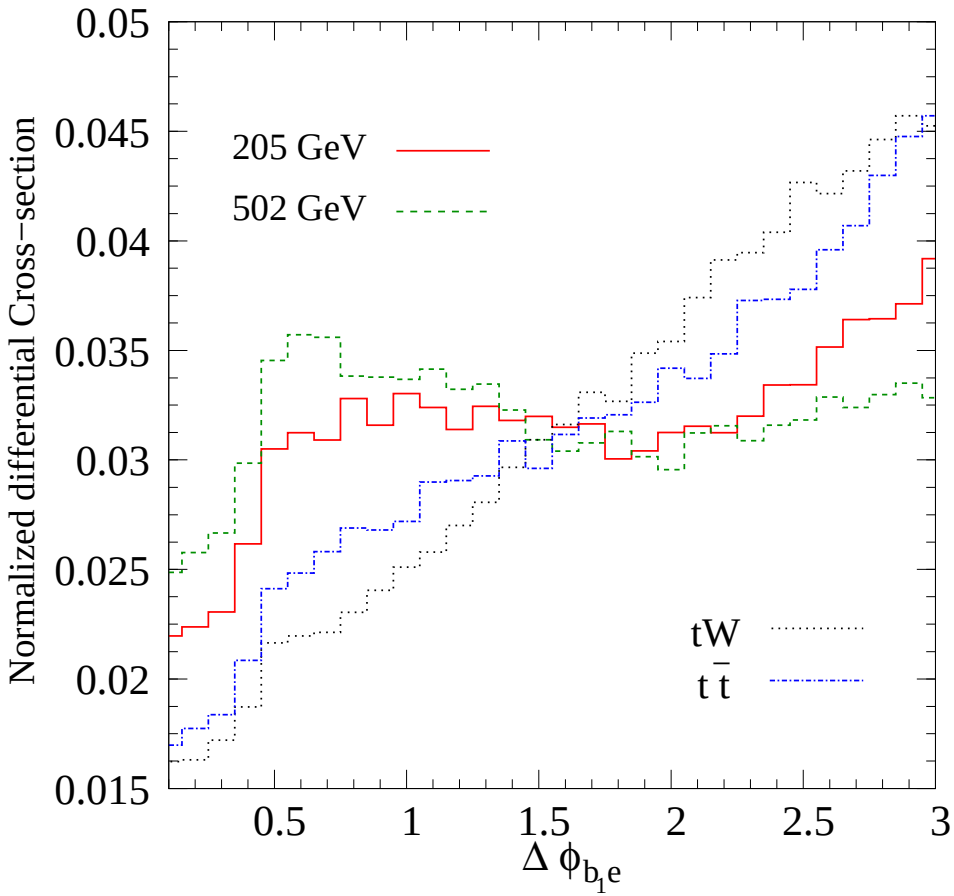

Kinematic Distributions

- $\Delta\phi_{b_1 e}$
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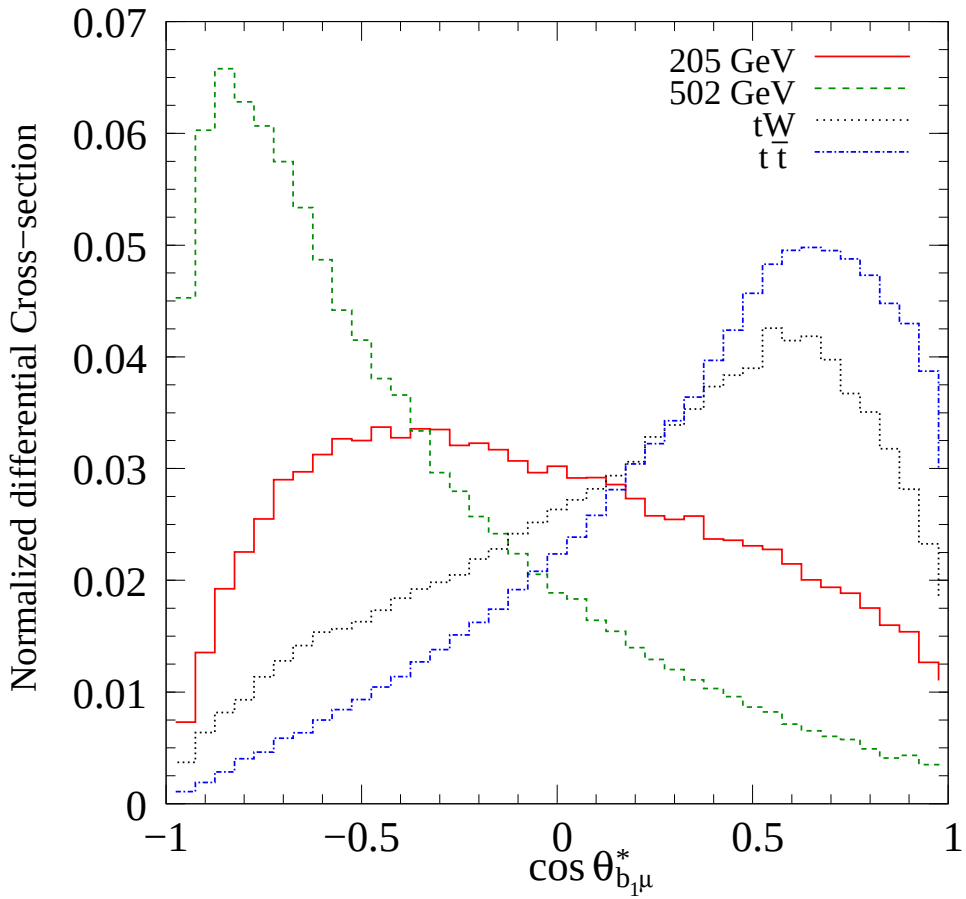

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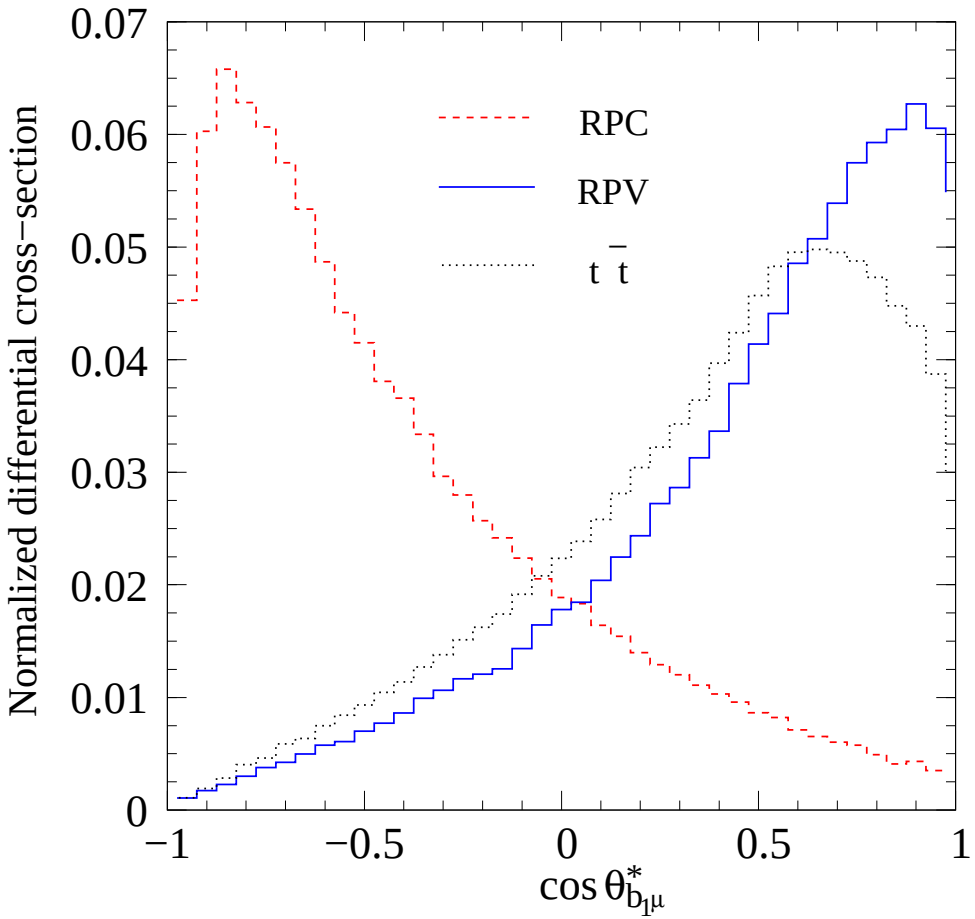

Summary

- The top spin can prove an effective tool in search for new physics.
- The Lorentz structure at the interaction vertex of top has significant effect on top polarization.
- Final state kinematics are found to be sensitive to top polarization.
- An interesting angular variable is defined which may be sensitive to the spin of the particle.
- A natural extension to this work is studying the associated production of charged Higgs with top quark. (work in progress)