Studying Very Light Gravitino at Future Linear Colliders

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Ref:

Matsumoto and TM, PLB 701 (2011) 422

1. Introduction

One of the most important tasks of the ILC:

$\Rightarrow$ Precise measurement of new-physics parameters

$\Rightarrow$ Collider phenomenology depends on new-physics model

Today, I consider the following class of SUSY model:

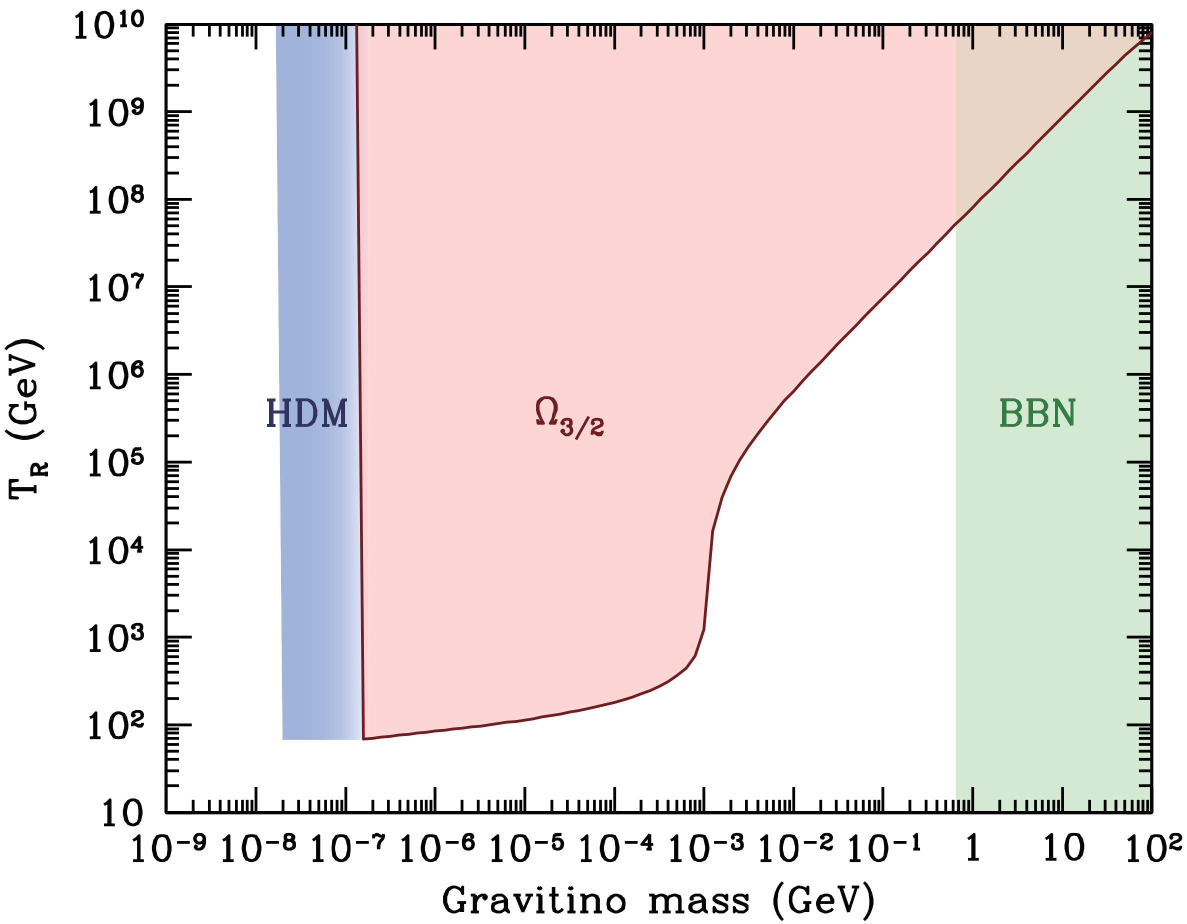
- Gravitino mass is $m_{3/2} \sim 10$ eV
- Stau $\tilde{\tau}$ is the NLSP

  $\Rightarrow$ Information about gravitino is obtained using the ILC

Motivation: low-scale gauge mediation model

- Gauge-mediated model solves the SUSY FCNC problem
- Such a model is cosmologically favored

Upper bound on reheating temperature as a function of $m_{3/2}$



$\Rightarrow$ Information about the gravitino mass is also useful for the understanding of cosmological history

Idea: use the relation between the stau lifetime and $m_{3/2}$

$$c\tau_{\tilde{\tau}} = \left[\frac{1}{48\pi} \frac{m_{\tilde{\tau}}^5}{m_{3/2}^2 M_{\rm Pl}^2} \right]^{-1} \simeq 2 \text{ mm} \times \left(\frac{m_{3/2}}{10 \text{ eV}} \right)^2 \left(\frac{m_{\tilde{\tau}}}{100 \text{ GeV}} \right)^{-5}$$

Dominant decay mode: $\tilde{\tau} \to \tau + \text{gravitino}$

$\Rightarrow$ If $\tau_{\tilde{\tau}}$ is known, we can obtain information about the gravitino mass

If $c\tau_{\tilde{\tau}} \lesssim O(1 \text{ mm})$, $\tilde{\tau}$ decays before hitting trackers

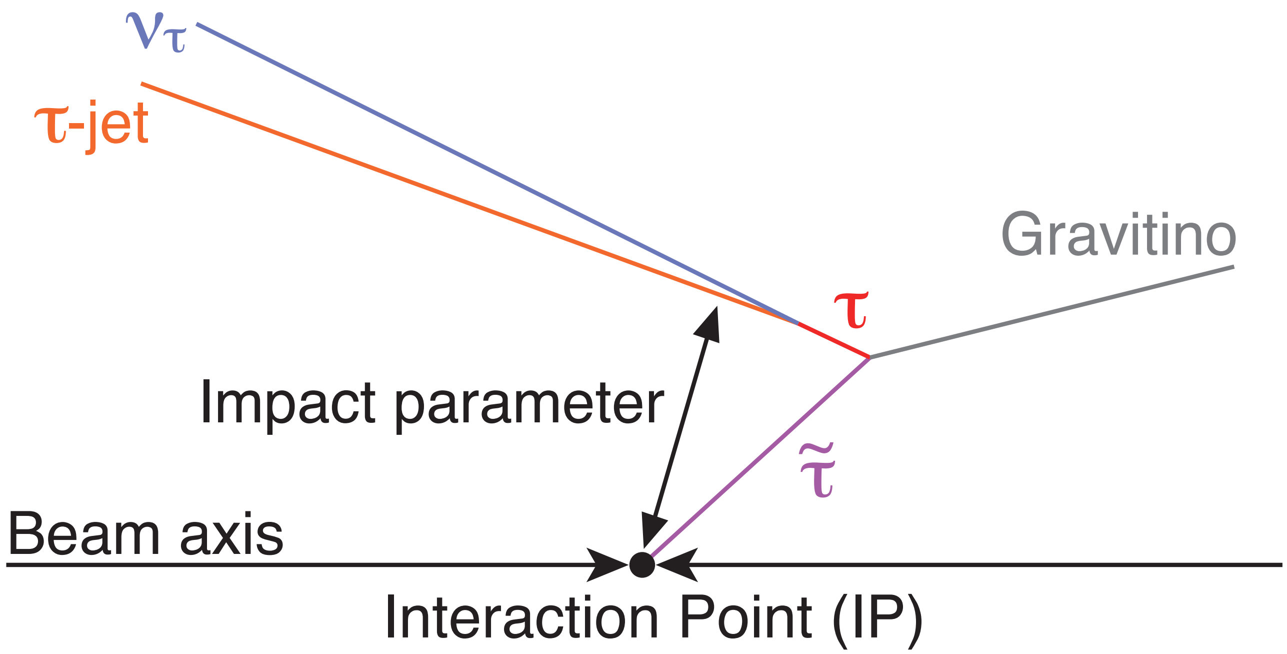
$\Rightarrow$ In SUSY events, there exist τ-jets with sizable impact parameter

$\Rightarrow$ $\tau_{\tilde{\tau}}$ can be determined from impact-parameter distribution

[Matsumoto & TM]

2. Lifetime Determination

Impact parameter: Distance to the track from the IP



- The impact parameter is typically of the order of the largest $c\tau$ of the particle in the decay chain
- Decay length of τ-lepton: $c\tau_\tau \simeq 87\ \mu$m
- Impact parameter determination at the ILC: $\delta b \sim 10\ \mu$m

Dominant $\tilde{\tau}$ production process: $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$ (+ ISR)

- $\tilde{\tau}$ decays as $\tilde{\tau} \to \tau +$ gravitino
- We use hadronic decay of τ, so signal contains two τ-jets

Dominant standard-model backgrounds:

- $\tau\tau$-BG: $e^+e^- \to \tau^+\tau^-$ (+ ISR)
- WW-BG: $e^+e^- \to W^+W^- \to \tau^+\tau^-\nu\bar{\nu}$ (+ ISR)
- ZZ-BG: $e^+e^- \to Z^0Z^0 \to \tau^+\tau^-\nu\bar{\nu}$ (+ ISR)
- $\gamma\gamma$-BG: $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-\tau^+\tau^-$

  $\Rightarrow$ $\gamma\gamma$-BG is eliminated by requiring E_{vis} is large enough

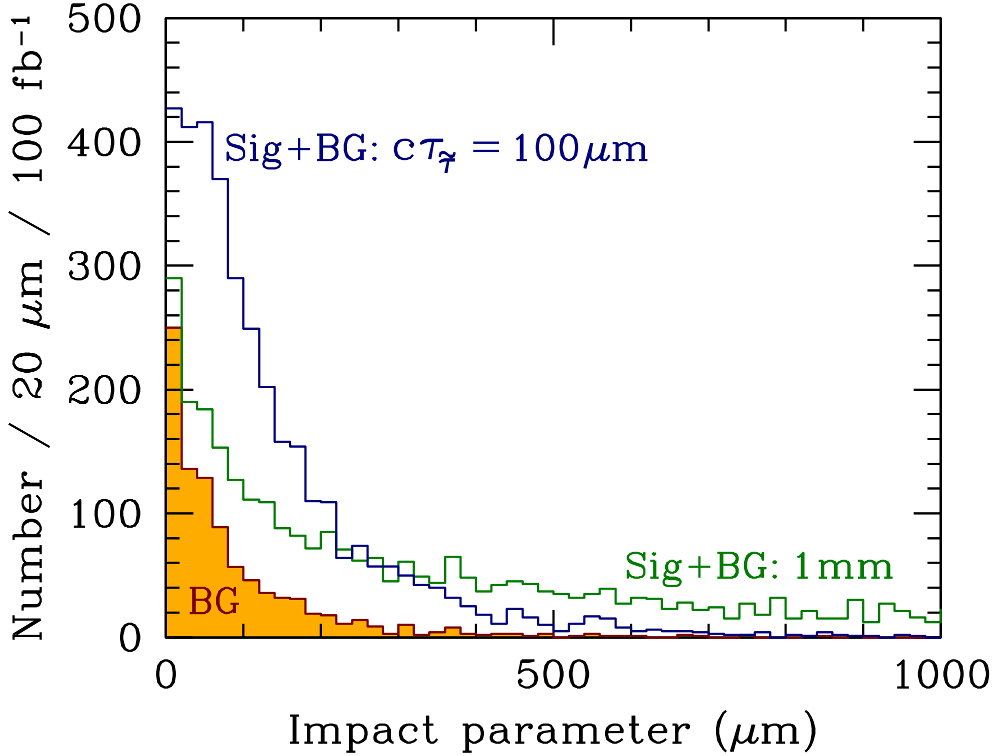
Cuts and cut statistics for $\mathcal{L} = 100$ fb^{-1} (using HERWIG)

1. The number of τ-jet $= 2$ & $E_{\rm vis} \geq 70$ GeV
2. $|\cos\theta_{j_\tau}| \leq 0.85$ for both τ-jets
3. $-0.95 \leq \cos(\phi_{j_{\tau,1}} - \phi_{j_{\tau,2}}) \leq 0.25$.
4. $|\hat{\mathbf{P}}_{j_{\tau,1}} \times \hat{\mathbf{P}}_{j_{\tau,2}} \times \hat{\mathbf{p}}_\gamma| \geq 0.1$, if γ with $p_T > 20$ GeV exists

	Signal	$\tau\tau$-BG	WW-BG	ZZ-BG
Cut 1	2630	45172	3911	247
Cut 1+2	2197	1798	911	79
Cut 1+2+3	1316	525	362	26
Cut 1+2+3+4	1307	116	353	26

$m_{\tilde{\tau}} = 120$ GeV, $\sqrt{s} = 500$ GeV

Impact-parameter distribution of τ-jets



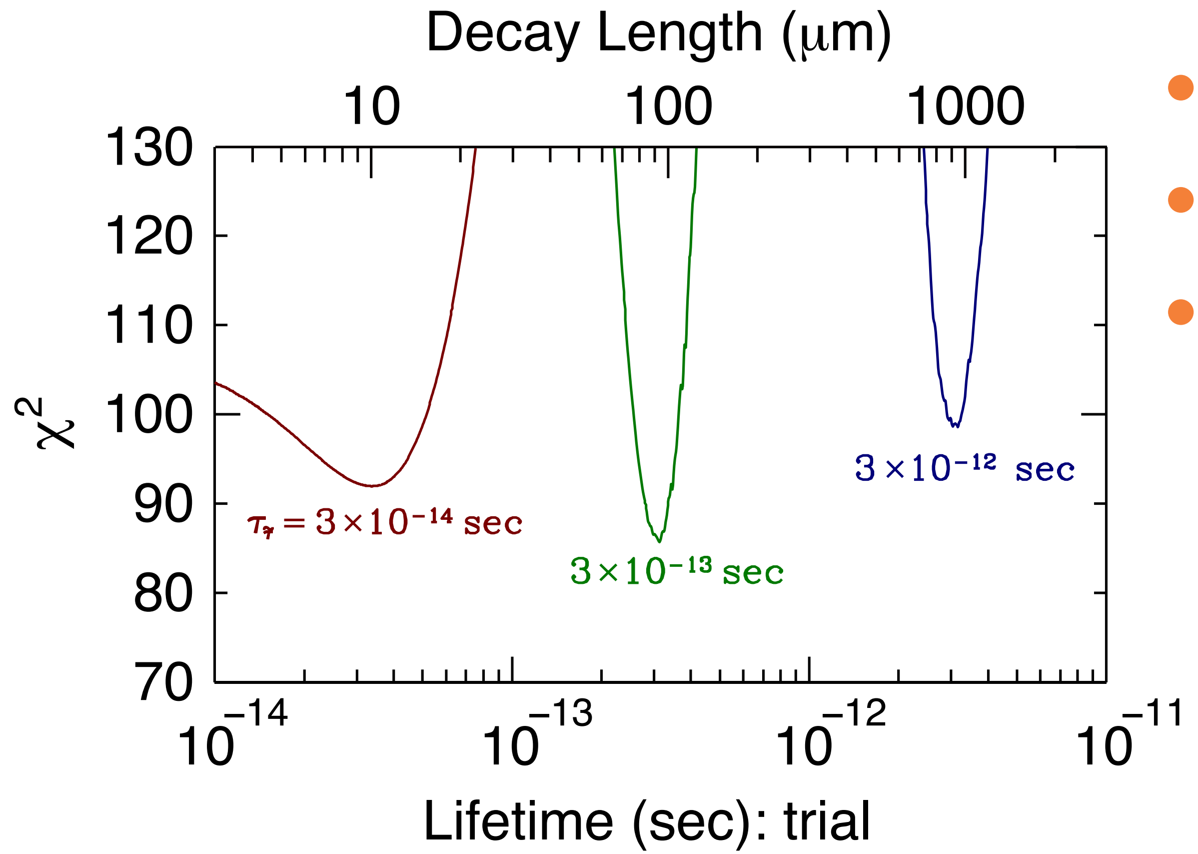
- $\sqrt{s} = 500$ GeV
- $m_{\tilde{\tau}} = 120$ GeV

- Signal: $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$ (72 fb)
- BG: $\tau\bar{\tau}$, W^+W^-, Z^0Z^0

We use χ^2 analysis to estimate the expected accuracy

$$\chi^2(\tau_{\tilde{\tau}}; \tau_{\tilde{\tau}}^{(\text{trial})}) \equiv \sum_i \frac{1}{N_i^{(\text{th})}(\tau_{\tilde{\tau}}^{(\text{trial})})} \left(N_i(\tau_{\tilde{\tau}}) - N_i^{(\text{th})}(\tau_{\tilde{\tau}}^{(\text{trial})}) \right)^2$$

$\tau_{\tilde{\tau}}$ can be determined when $c\tau_{\tilde{\tau}} \gtrsim 10\ \mu$m



- Fit: 0 – 2 mm, 100 bins
- $\mathcal{L} = 100$ fb^{-1}
- $\delta b = 10\ \mu$m

$\Rightarrow$ Uncertainty is a few % level if $c\tau_{\tilde{\tau}} \gtrsim 100\ \mu$m

$\Rightarrow$ $m_{3/2}$ can be determined with the same level of accuracy

3. Summary

I discussed $\tau_{\tilde{\tau}}$ determination in low-scale gauge mediation

$\Rightarrow$ Impact parameter distribution is useful

$\tau_{\tilde{\tau}}$ (input)	$m_{3/2}$	$\tau_{\tilde{\tau}}$ (ILC 1-σ)
3×10^{-14} sec	1.1 eV	$(3.36^{+0.62}_{-0.62}) \times 10^{-14}$ sec
3×10^{-13} sec	3.6 eV	$(3.13^{+0.06}_{-0.15}) \times 10^{-13}$ sec
3×10^{-12} sec	11.4 eV	$(3.16^{+0.07}_{-0.17}) \times 10^{-12}$ sec

$m_{\tilde{\tau}} = 120$ GeV, $\sqrt{s} = 500$ GeV

We can use the result for the gravitino mass determination

- $$\frac{\delta m_{3/2}}{m_{3/2}} = \sqrt{\left(\frac{1}{2}\frac{\delta\tau_{\tilde{\tau}}}{\tau_{\tilde{\tau}}}\right)^2 + \left(\frac{5}{2}\frac{\delta m_{\tilde{\tau}}}{m_{\tilde{\tau}}}\right)^2} \simeq O(1\ \%)$$
- Similar study is challenging at the LHC, because the velocity distribution of $\tilde{\tau}$ is hardly understood at the LHC

Backup

Measurement accuracy of the stau lifetime