Tau polarization: the probe for long-lived stau in the GMSB at the LC

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Outline

- Long-lived heavy particle in the GMSB models
- Stau pair production (summary of main results)
  - ⋆ identification
  - ⋆ decay length ($c\tau$) analysis
- Tau polarization from stau decay (work in progress)
  - ⋆ Quick review of $\tau_{R,L} \to \nu_\tau A \;\; (A = \pi, \rho, \ldots)$
  - ⋆ Polarization sensitivity at the LC
  - ⋆ Bounds on stau decay length from polarization measurements
- Summary

Gauge mediated SUSY breaking models

Gravitino $\tilde{G}$ mass : $m_{\tilde{G}} = \dfrac{F}{\sqrt{3}M_{\rm pl}}$

$\sqrt{F} \Rightarrow$ fundamental SUSY breaking scale.

For $\sqrt{F} \sim 10^7$ GeV:

- $m_{\tilde{G}} \sim \mathrm{eV} \Rightarrow$ Gravitino is the LSP
- $\tilde{\tau}_R$ ($\tilde{\tau}_1$) or $\widetilde{Z}_1$ is the NLSP

Weak coupling of $\tilde{G}$ (actually goldstino, the longitudinal component) is responsible for a long-lived NLSP.

$$c\tau = 10^3\mathrm{m} \times \left[\frac{\sqrt{F}}{10^7\ \mathrm{GeV}}\right]^4 \left[\frac{100\ \mathrm{GeV}}{m_{\tilde{\tau}}}\right]^5 .$$

Stau pair production and identification at LC

Mercadante, Mizukoshi, Yamamoto

hep-ph/0010067

Linear collider parameters:

- $\sqrt{s} = 500$ GeV, $\int \mathcal{L} dt = 50$ fb^{-1}
- Momentum resolution: $\delta p/p = 5 \times 10^{-5} p$ (GeV)
- ISR and beamsstrahlung (included in the event generator ISAJET)

Signal:

- $e^+e^- \to \tilde{\tau}_1^+ \tilde{\tau}_1^-$

  Back-to-back tracks

Identification tools:

- Kinematics: $E_{\rm beam}$ is fixed, with ISR changing it slightly
- Time of flight (TOF)

  $\Delta t \equiv t_{\rm mass} - t_{\beta=0} > 0.13$ ns, modulo 1.4 ns (bunch separation)

  Cuts in $|p|$ and $p_z^{\rm tot}$ relaxed.
- dE/dX

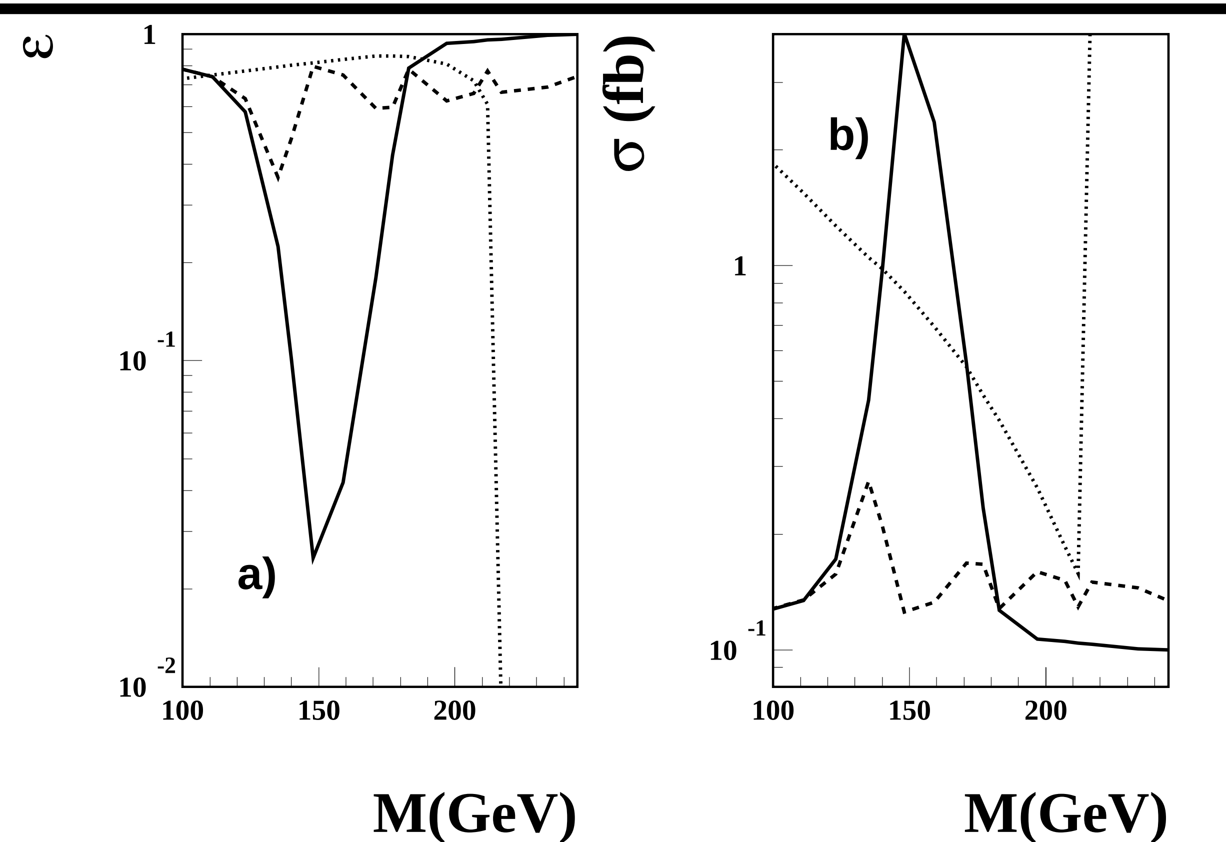
  Energy deposited by ionization depends on $\beta\gamma$.

$$\frac{dE/dX(mass) - dE/dX(muon)}{\sigma(dE/dX)} > 3$$

  5% resolution for argon

Statistical significance:

$$S = \epsilon\sigma_{\rm sig}\sqrt{\int \mathcal{L} dt/\sigma_{\rm bkg}} \geq 3, \quad \epsilon \equiv \text{ efficiency after cuts}$$



—— dE/dX cut

- - - - time of flight cut

········ kinematic cuts

a) The efficiency for the signal.

b) The reach in cross section for a integrated luminosity of 50 fb^{-1}

Stau decay length

$c\tau$ measurement gives information of $\sqrt{F}$

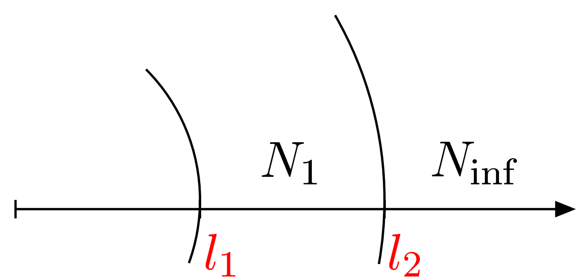
Probability of $\tilde{\tau}$ to travel distance l: $\mathrm{e}^{-\alpha l}$,

where $\alpha = 1/\beta\gamma c\tau$.

Statistical errors on N_1 and $N_{\rm inf}$ $\Rightarrow$

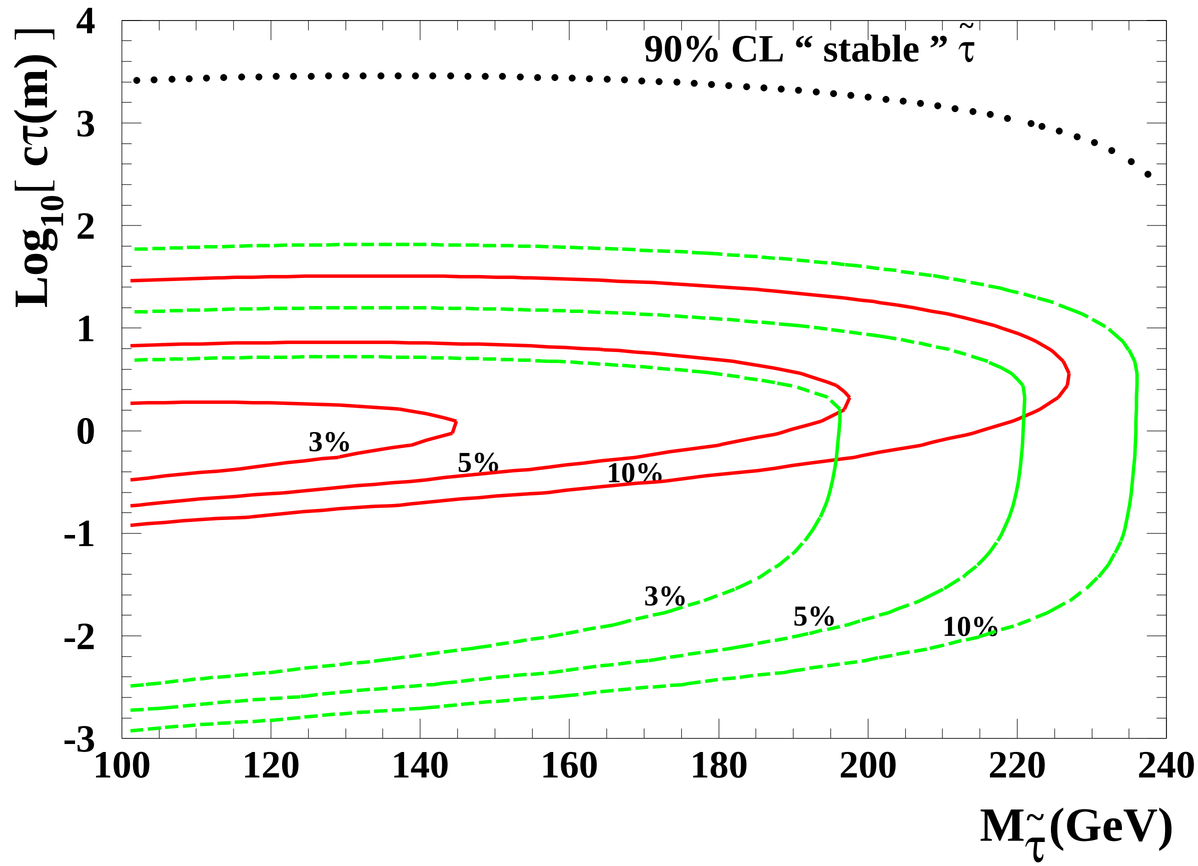
$$\frac{\sigma_{c\tau}}{c\tau} = \frac{1}{\sqrt{N}} \frac{\sqrt{R}}{\log(1+R)},$$

$$R = \frac{N_1}{N_{\rm inf}}, \quad N = N_1 + N_{\rm inf}$$



l_1 : inner limits of $\tilde{\tau}$ detections

l_2 : detector outer limits



Contours of constant error $\sigma_{c\tau}$ on the measurement of $c\tau$. The solid lines stand for the case $l_1 = 1$ m and dashed lines are for $l_1 = 0.01$ m. The dotted line on the top of the figure indicates at 90% CL the case stau is stable up to the detector.

Stau polarization

In the MSSM

$$\begin{pmatrix} \tilde{\tau}_1 \\ \tilde{\tau}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{\tau}} & \sin\theta_{\tilde{\tau}} \\ -\sin\theta_{\tilde{\tau}} & \cos\theta_{\tilde{\tau}} \end{pmatrix} \begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix}$$

Mixing angle $\theta_{\tilde{\tau}}$ determination:

- cross section is very sensitive to polarized electron beam
- τ polarization analysis:

  $\tilde{\tau}_1^{\pm} \to \tau^{\pm}\tilde{G}$

  $\tau\tilde{\tau}\tilde{G}$: chirality conserving interaction

$$\boxed{P(\tau) = \sin^2\theta_{\tilde{\tau}} - \cos^2\theta_{\tilde{\tau}}}$$

Quick review of $\tau_{R,L} \to \nu_\tau A$ $(A = \pi, \rho, \ldots)$

Decay width for τ

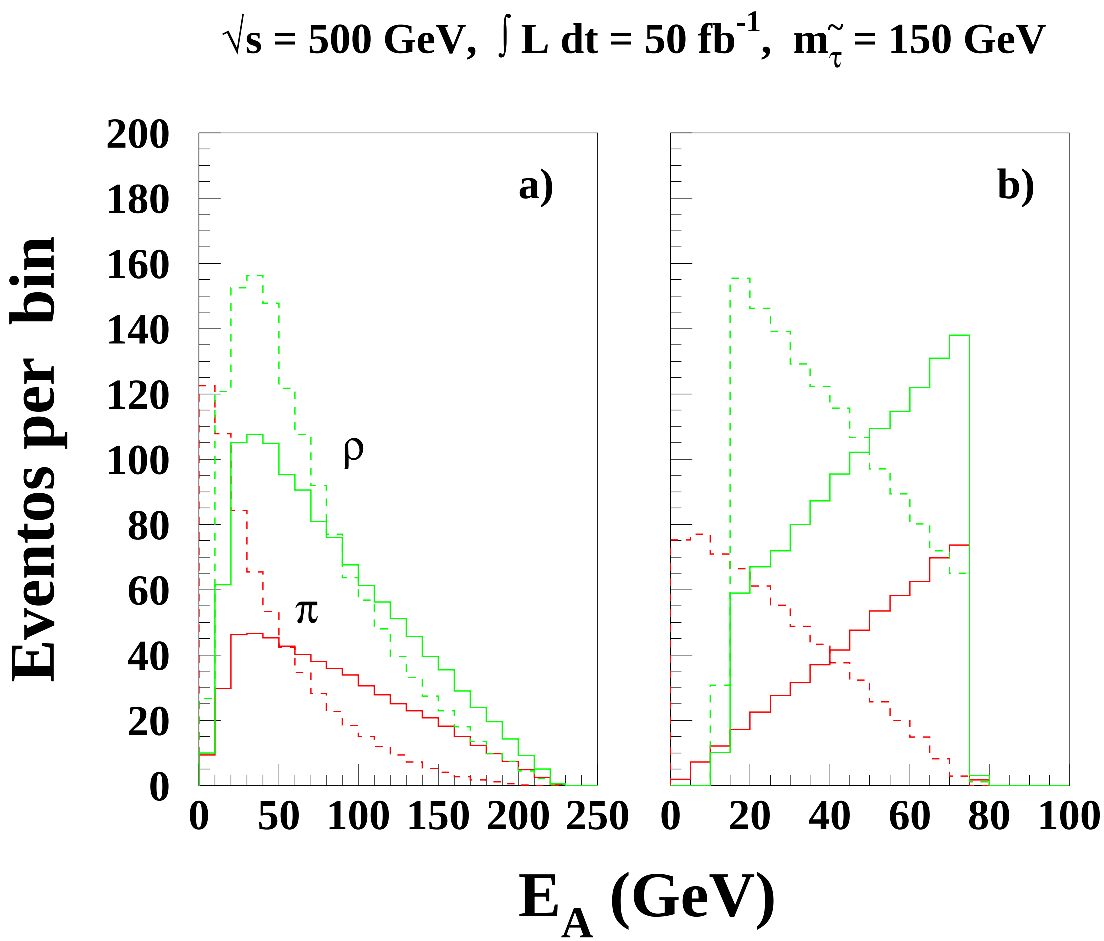
$$d\Gamma(\tau \to \nu_\tau A) = \frac{1}{2m_\tau}\frac{1}{4\pi^2}|\mathcal{M}|^2 d_2(PS)$$

In the τ rest frame:

$$|\mathcal{M}|^2(\tau_{R,L}) = |f|^2[(1 \pm \cos\theta) + \frac{2m_A^2}{m_\tau^2}(1 \mp \cos\theta)]$$

	π	ρ	a_1
$\frac{2m_A^2}{m_\tau^2}$	~ 0.025	~ 0.38	~ 0.92

For $A = \pi$ and ρ the energy spectrum depends strongly on τ polarization



Energy distribution for the $\pi^{\pm}$ and $\rho^{\pm}$ decaying from right- (solid line) and left-handed (dashed line) $\tilde{\tau}$. In a) lab. frame, b) $\tilde{\tau}$ rest frame.

Polarization sensitivity at the LC

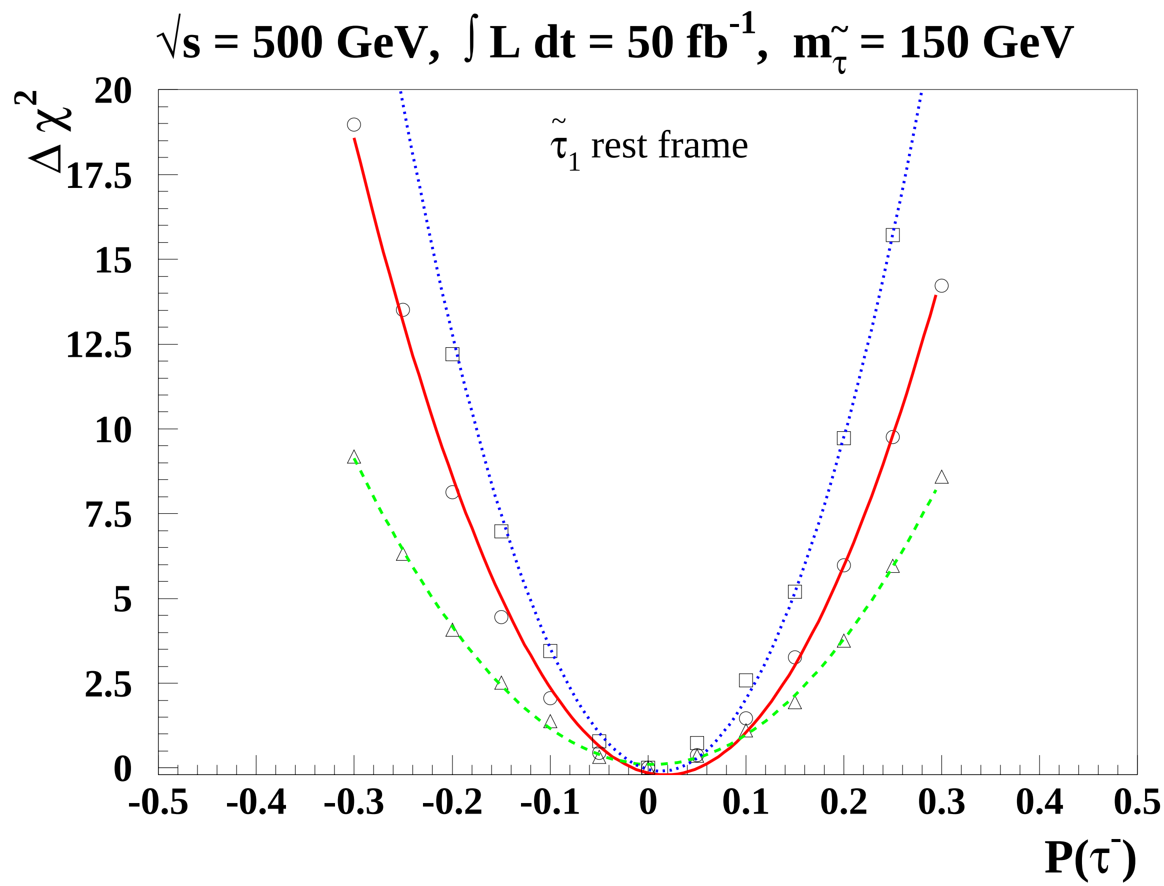
Case study: $P(\tau) = \sin^2\theta_{\tilde{\tau}} - \cos^2\theta_{\tilde{\tau}} = 0$

Preliminary analysis:

- Events generated by ISAJET
- No ISR and beamstrahlung
- No smearing on $\tilde{\tau}$ momentum
- Detection efficiency 100%
- No cuts to suppress potential backgrounds

Signal: $e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tau^- + \not{E}_T$

One $\tau^\pm \to \nu_\tau\pi^\pm,\ \nu_\tau\rho^\pm$.



$\Delta\chi^2$ compared to the reference point $P(\tau) = 0$ for $\pi^\pm$ (solid line) $\rho^\pm$ (dashed line) and combined (dotted line) energy distribution fit.

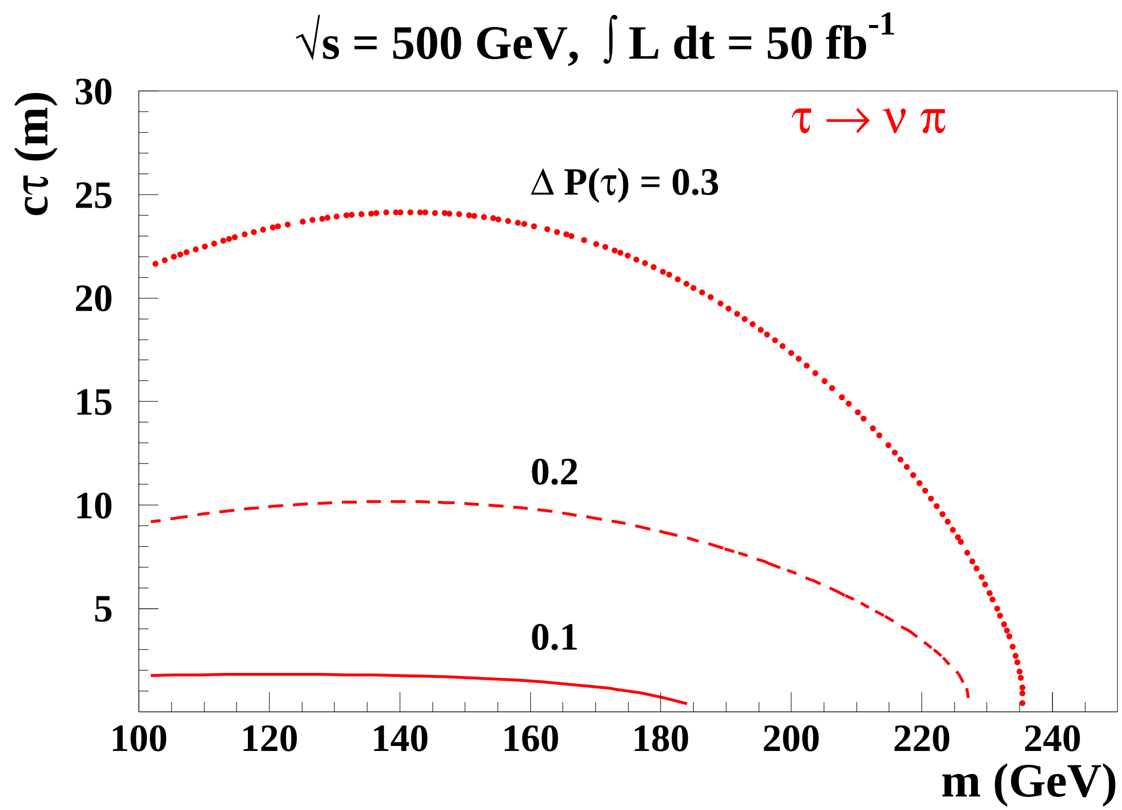
$\Delta\chi^2$ is a function of number of events

Not all the $\tilde{\tau}$'s decay inside the detector.

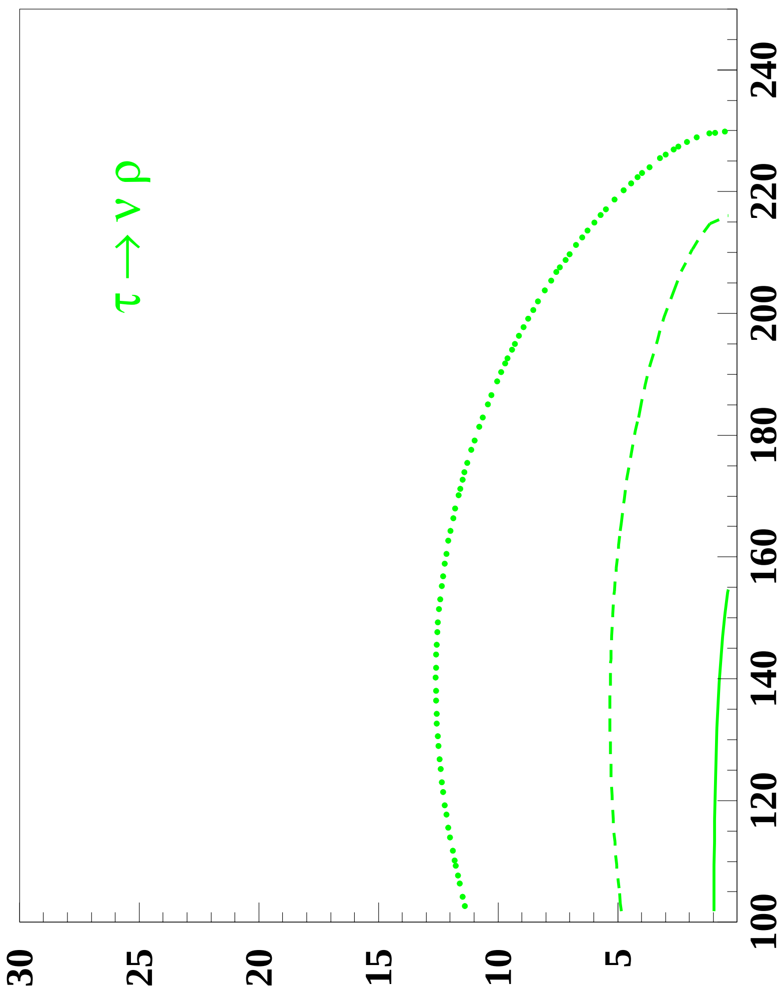
Remember that $N = N_0\, e^{\alpha l_1} \Rightarrow \Delta\chi^2$ depends on $c\tau$, for a given detector size l_1.

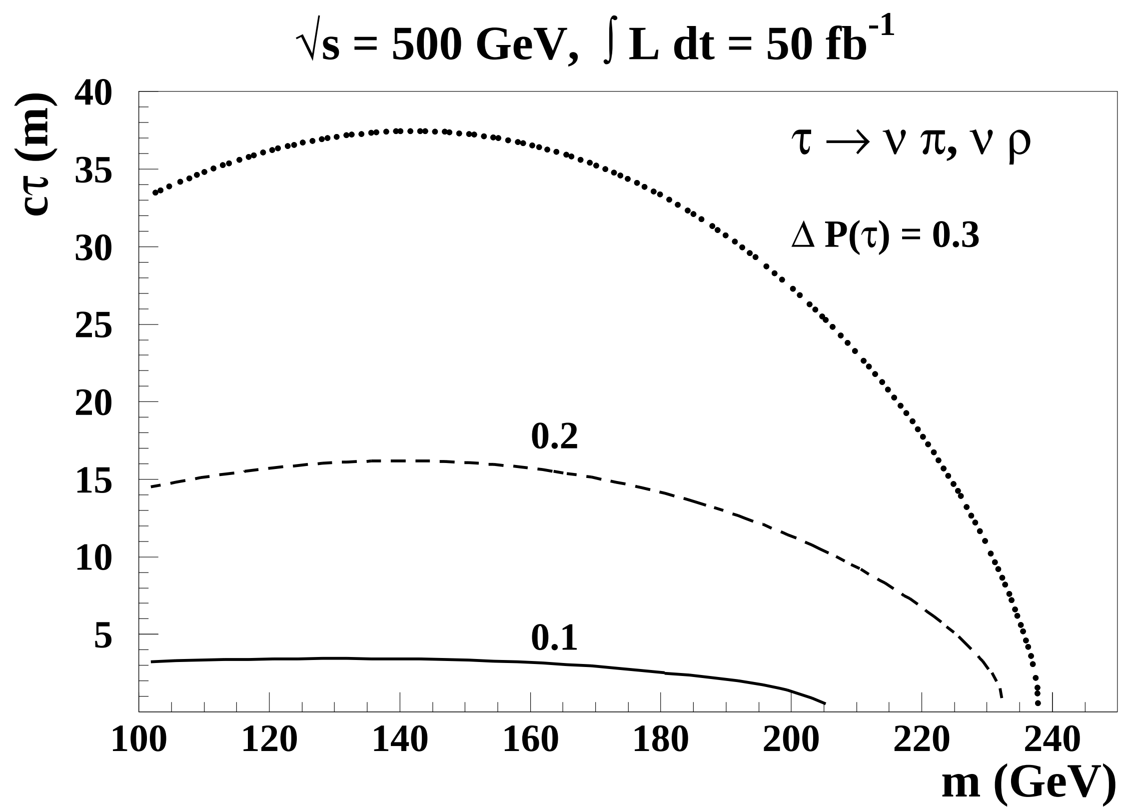
In order to determine $P(\tau)$ sensitivity:

- For sake of simplicity, a round detector is assumed
- Polarization error fixed to be $\Delta P(\tau) = 0.1, 0.2$ and 0.3, where $P(\tau) \sim 0 + \Delta P(\tau)$
- Require $\Delta\chi^2 = 1$ (1-sigma level) for $-\Delta P(\tau) < P(\tau) < \Delta P(\tau)$



Upper bound on $c\tau$ with constant error on $P(\tau)$ for the $\tilde{\tau}$ mass range relevant to the LC. Fitting $\pi^{\pm}$ energy distribution at $\tilde{\tau}$ rest frame.


τ → ν ρ
100
120
140
160
180
200
220
240
5
10
15
20
25
30



Upper bound on $c\tau$ with constant error on $P(\tau)$ for the $\tilde{\tau}$ mass range relevant to the LC. Fitting combined energy distribution at $\tilde{\tau}$ rest frame.

Summary

- Kinematic analysis allows $m_{\tilde{\tau}}$ determination up to $\sim 0.8 E_{\mathrm{beam}}$

  Further coverage, up to kinematic limit, is possible with time of flight or dE/dX devices

- Mixing angle $\theta_{\tilde{\tau}}$ can be probed from kinematic analysis of decay products of τ

- Confronting with results from e^- beam polarization, we can check the coupling $\tau\tilde{\tau}\tilde{G}$

To-do list

- More realistic analysis:
  - ⋆ Consider momentum smearing of $\tilde{\tau}$
  - ⋆ $\tau, \rho, \ldots$ identification efficiency
  - ⋆ ISR and beamstrahlung

After these considerations, the overall efficiency can be $\sim 1/2$ or even $\sim 1/3$ compared to the plain analysis.