Long-Lived Heavy Charged Particle Search

- Gauge-mediated SUSY-breaking models -

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Gauge-mediated SUSY-breaking models

LSP = gravitino ($\tilde{G}$)

NLSP = stau ($\tilde{\tau}^{\pm}$) or neutralino

If $\tilde{\tau}$ is the NLSP

$\rightarrow$ Long-lived heavy charged particle for a large area of parameter space.

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

$\sqrt{F}$: dynamical SUSY breaking scale

If $\sqrt{F} \stackrel{\sim}{>} 10^7$ GeV, then $\tilde{\tau}$ mostly do not decay in the detector.

$\rightarrow$ look like heavy muons

$$\begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix} \xrightarrow{\text{mix}} \begin{pmatrix} \tilde{\tau}_1 \\ \tilde{\tau}_2 \end{pmatrix} \text{ (mass eigenstates)}$$

$\tilde{\tau}_1$: the lighter of the two
('our' $\tilde{\tau}^{\pm}$)

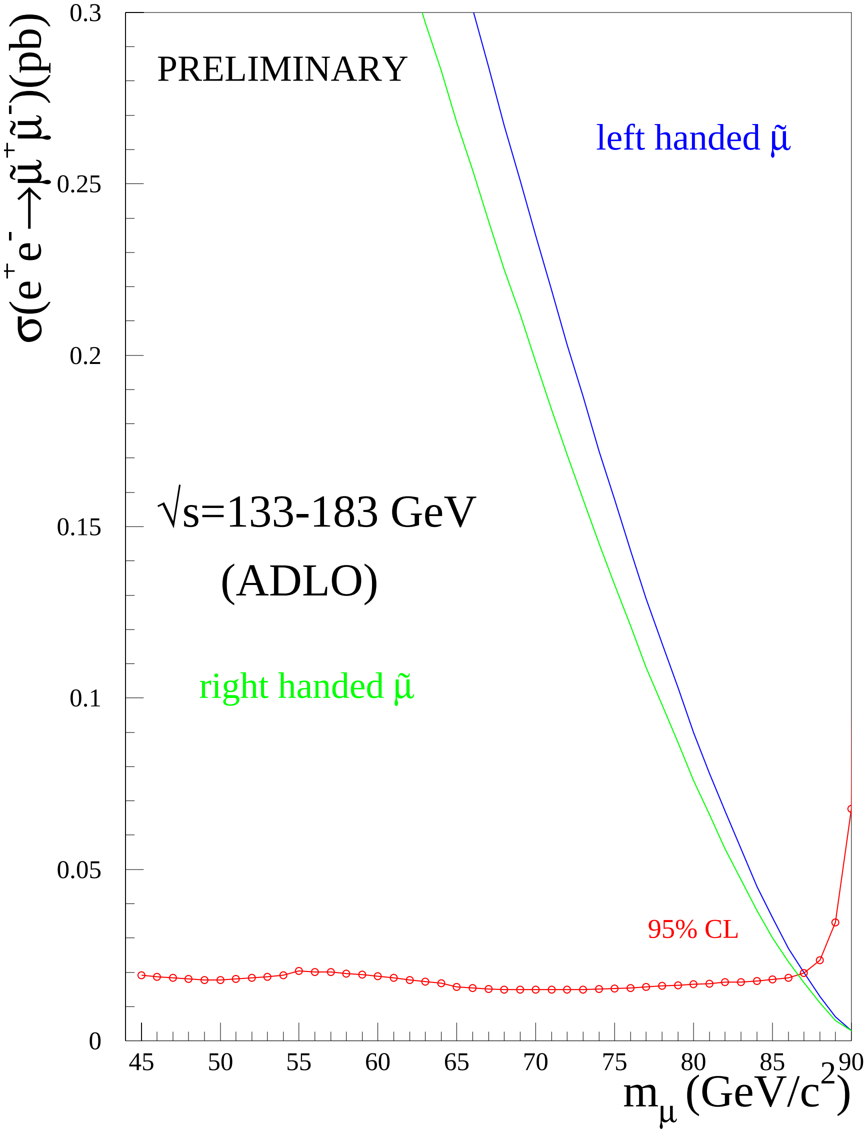
Decay mode:

$$\tilde{\tau} \rightarrow \tau \tilde{G}$$

A clean production mode at LC:
stau pair creation

$$\boxed{e^+ e^- \rightarrow \tilde{\tau}^+ \tilde{\tau}^-}$$

Combined LEP limit on $\tilde{\tau}(\sim \tilde{\mu})$



$m_{\tilde{\tau}} < 87$ GeV (90% c.l.)

At a linear collider, use

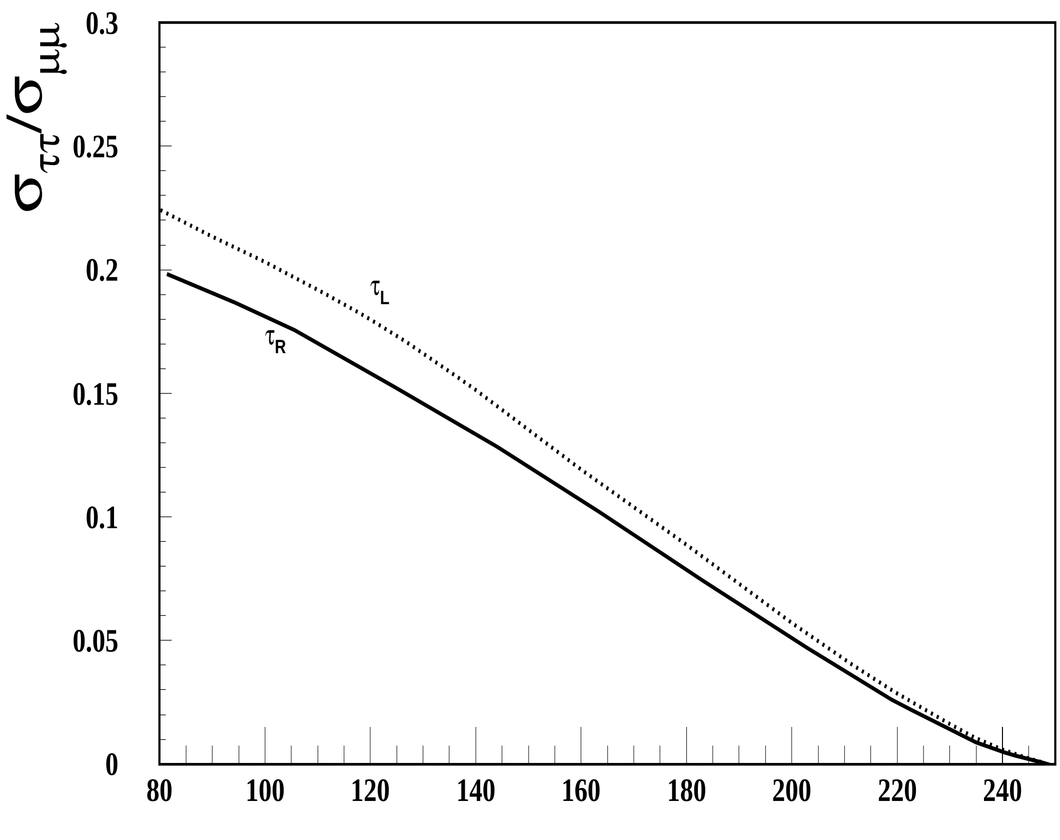
- $\sqrt{S} = 500$ GeV, $\int L dt = 50$ fb^{-1}
- $\delta p/p = 5 \times 10^{-5} p$(GeV)
  (Large detector scenario: 2m radius TPC)
- ISAJET
  (Includes initial-state radiation (ISR)
  & beamstrahlung)

Signature: looks like $e^+e^- \to \mu^+\mu^-$ but heavy.

Tools for signal detection:

- Total production cross section (w.r.t. $\sigma_{\mu\mu}$)
- Kinematics: $m^2 = E^2_{\text{beam}} - p^2$
- TOF ($\sigma_T = 50$ ps)
- dE/dx (5% resolution)
- Cerenkov ($1 < \beta\gamma < 8$)

$e^+e^- \rightarrow \tilde{\tau}^+\tilde{\tau}^- \quad (\sqrt{s} = 500\ \text{GeV})$



$(\sigma_{\mu\mu} = 500\ \text{fb}^{-1})$

Backgrounds:

- π, K, p, e

  Require hits in muon chamber

- Two-photon events: $e^+e^- \to e^+e^-\mu^+\mu^-$
  Tau pairs: $e^+e^- \to \tau^+\tau^-$, $\tau \to \mu\nu\nu$

  $|p| > 0.5E_{\text{beam}}$, $|(P_{\text{tot}})_z| < 0.25E_{\text{beam}}$

- Radiative $\mu\mu$: $e^+e^- \to \mu^+\mu^-\gamma$

  No photons detected anywhere

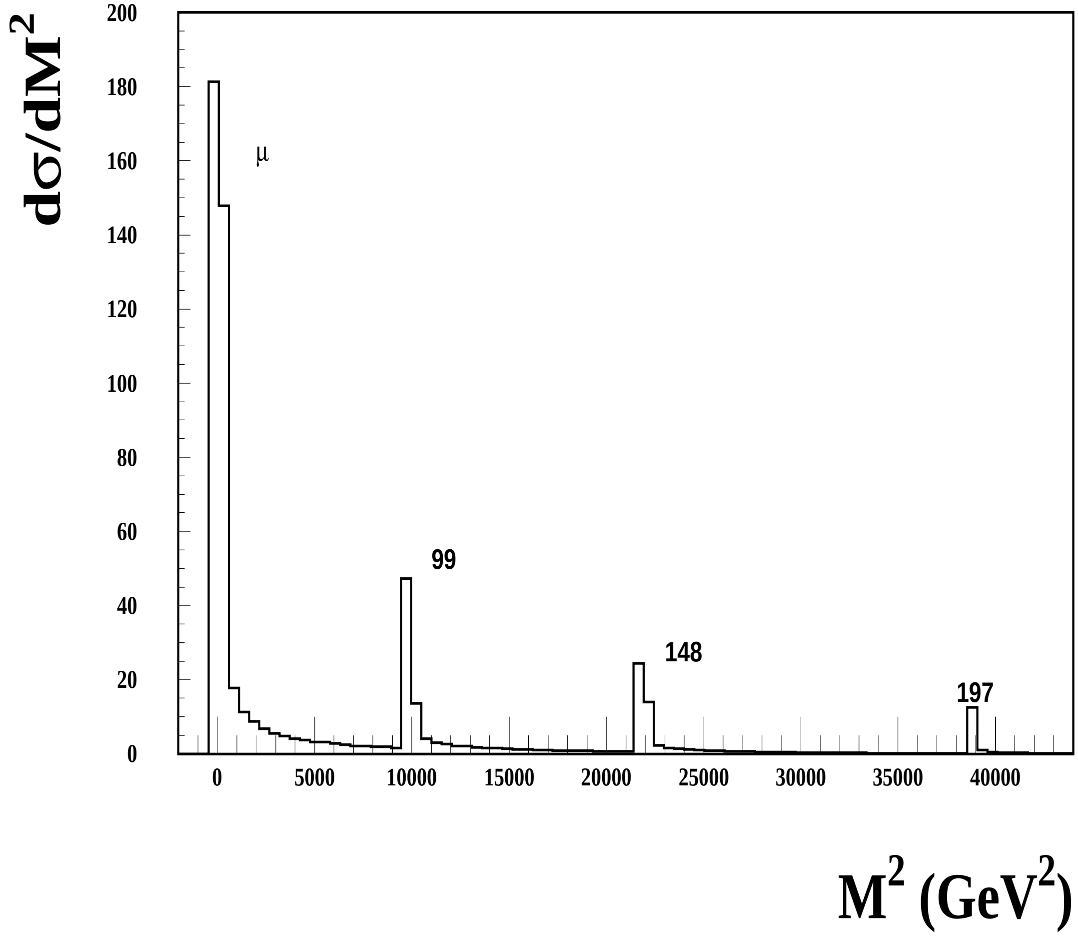
- $e^+e^- \to \mu^+\mu^-$

Effect of beamstrahlung+ISR on p_μ

$(e^+e^- \to \mu^+\mu^-)$

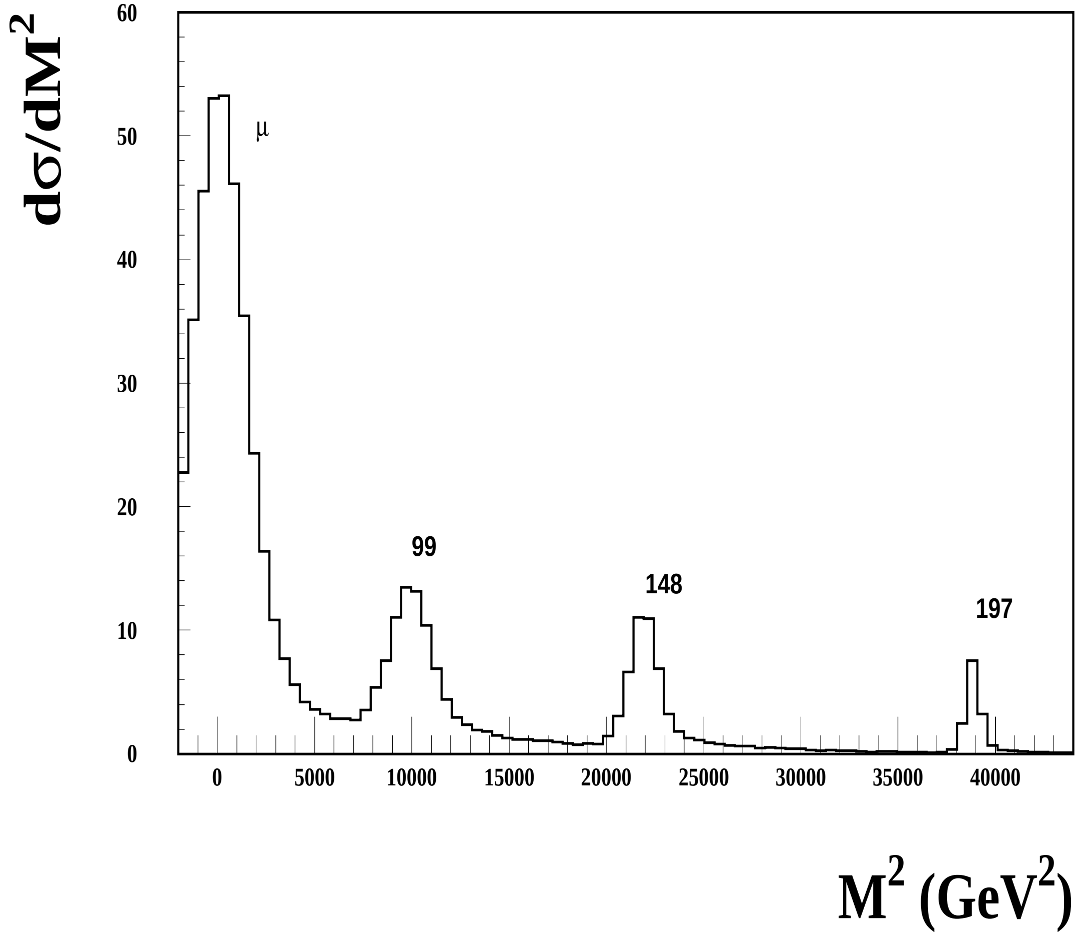
ISAJET @500 GeV Ecm

$$m^2 = \sqrt{E_{\text{beam}}^2 - p^2}$$
$$(E_{\text{beam}} = 250 \text{ GeV})$$



No momentum smearing

$$m^2 = \sqrt{E_{\text{beam}}^2 - p^2}$$
$$(E_{\text{beam}} = 250 \text{ GeV})$$



With momentum smearing

TOF

Time resolution of $\sim$ 50 ps possible using scintillator.

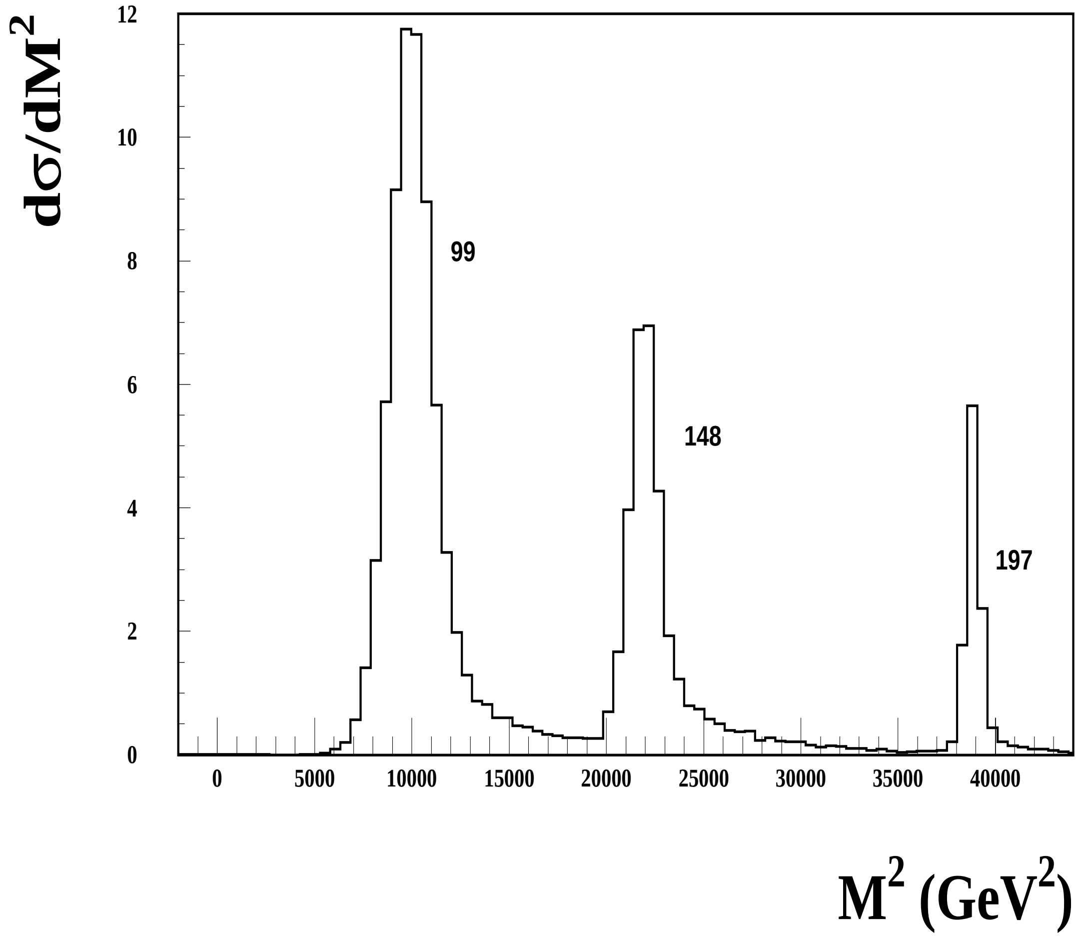
Flight path $\sim$ 8 ns
(varies from 6 ns to $\sim$12 ns
- depends on the dip angle and curvature of the track)

Can the correct bunch identified?

No other tracks except for $\tilde{\tau}$'s $\rightarrow$ bunch identification may not be reliable.

$\rightarrow$ Take modulo bunch spacing (1.4 ns)
($-0.15 < \Delta t < 1.25$ ns)
Δt: $t_{\text{meas}} - t_{\text{expected}}(\mu)$

$$m^2 = \sqrt{E_{\text{beam}}^2 - p^2}$$
$$(E_{\text{beam}} = 250 \text{ GeV})$$

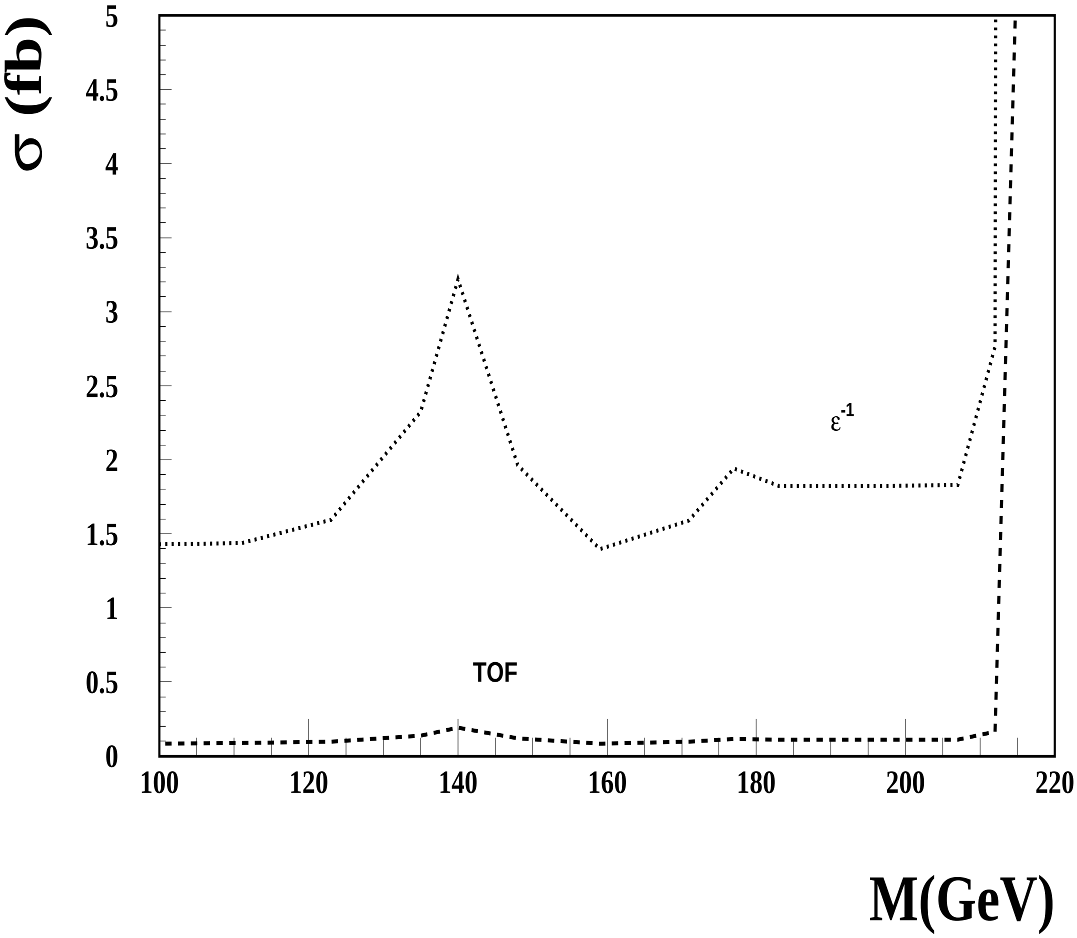


With TOF cut on both tracks

$\Delta t > 0.12$ ns ($\sim 1\%$ of each μ survives)

$\sigma_{\tilde{\tau}^+\tilde{\tau}^-}$ upper limit

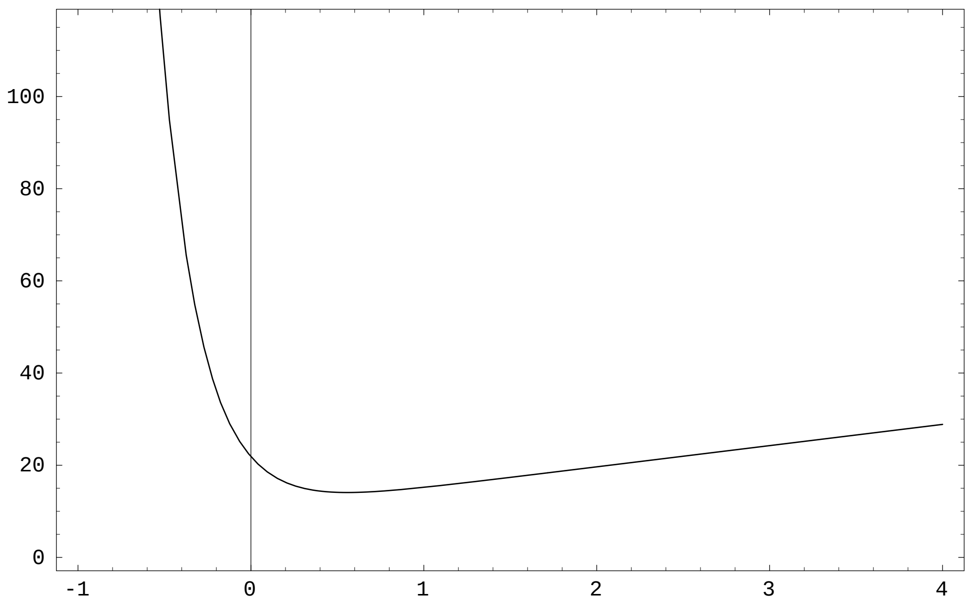
($E_{\text{beam}} = 250$ GeV, 50 fb^{-1})



With TOF cut

dEdX

Identifies heavy charged particles for $\beta\gamma < 1.0$
(or equivalently, $m > \frac{E_{\text{beam}}}{\sqrt{2}} = 177$ GeV)



$\log_{10}(\beta\gamma)$

If the relativistic rise is significant (depends on the dEdx truncation cut), dEdx may be able to give double-valued solution for $\beta\gamma > 1$.

Cerenkov device

BaBar DIRC can measure β for $1 < \beta\gamma < 8$.

The lower end matches well with
the upper end of dEdx.

$\rightarrow$ dEdx and Cerenkov (DIRC) allows us to cover
essentially the entire kinematic range.

Summary

- LC has an advantage over hadron machines: Kinematic mass reconstruction in $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$.

- If the cross section is as large as expected from gauge-mediated models, the kinematic reconstruction alone is quite adequate.

- In order to set more stringent upper limit on the production cross section, one needs TOF, dEdx, Cerekov device or combinations there of.

- dEdx is effective for $m_{\tilde{\tau}} \stackrel{\sim}{>} E_{\text{beam}}/\sqrt{2}$.

- TOF can cover most of the kinamatic range. May need bunch identification for actual mass determination.

- Cerenkov (DIRC or RICH) can be used to cover $1 < \beta\gamma < 8$ for mass determination.

To-do list

- More detailed study of dEdx technique.
- Study of intermediate-lifetime cases
  (i.e. a large fraction decay inside detector).
- Study of short-lifetime cases
  (i.e. vertex detector).
- Tau polarization ($\tilde{\tau}_R$ or $\tilde{\tau}_L$)