PHENO SYMPOSIUM, Madison, WI, May, 1

Measuring a Light (Dark Ma
Neutralino Mass at the IL

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MSSM Neutralino Mixir

- MSSM Neutralino Mass Mixing Matrix in ($\tilde{B}$, $\tilde{W}^3$,

$$\mathcal{M}_0 = \left(\begin{array}{ccc} M_1 & 0 & -M_z \cos\beta \sin\theta_w \\ 0 & M_2 & M_z \cos\beta \cos\theta_w \\ -M_z \cos\beta \sin\theta_w & M_z \cos\beta \cos\theta_w & 0 \\ M_z \sin\beta \sin\theta_w & -M_z \sin\beta \cos\theta_w & \mu \end{array} \right.$$

- What do we know about the Mass of $\tilde{\chi}_1^0$?

Experimental Search at L

- Chargino Search: $M_{\tilde{\chi}_1^\pm} > 94\,\text{GeV} \quad \Rightarrow \quad |\mu|,\, M_2 \gtrsim 1$

- Higgs search: $\tan\beta \gtrsim 1.5$

- Assume: $\boxed{M_1 = \frac{5}{3}\tan^2\theta_w\, M_2} \quad \Rightarrow \quad M_1 \gtrsim 50\,\text{GeV}$

- Insert into Neutralino Mass Matrix: $\Rightarrow \quad \boxed{M_{\tilde{\chi}_1^0} \gtrsim 4}$

- **Now drop above assumption on** $M_1,\, M_2$

Massless Neutralino

- Set $\det(\mathcal{M}_0)=0 \quad \Rightarrow \quad M_1 = \frac{M_2 M_Z^2 \sin(2\beta) s_W^2}{\mu M_2 - M_Z^2 \sin(2\beta) c_W^2}$

- Choose: $\{M_2, \mu, \tan\beta\} \quad \Rightarrow \quad \exists\, M_1 : M_{\chi_1^0} = 0$

- Some fine-tuning required

$$M_1 \approx \frac{M_Z^2 \sin(2\beta) s_W^2}{\mu} \approx 2.5 \text{ GeV} \left(\frac{10}{\tan\beta}\right) \left(\frac{150 \text{ G}}{\mu}\right.$$

- $\Longrightarrow M_{\chi_1^0} = 0$ consistent in MSSM

$M_{\chi_1^0} = 0$ consistent with all la

- Invisible Z^0–width
- $e^+e^- \longrightarrow \chi_1^0\chi_1^0\gamma$
- $e^+e^- \longrightarrow \chi_2^0\chi_1^0;$ $\chi_2^0 \to Z^0\chi_1^0;$ $Z^0 \to q\bar{q}$
- Precision Observables ($\delta\Gamma_{\rm inv}$, $\delta\Gamma_Z$, M_W, δa_μ, EDM
- Monojets
- Rare Meson Decays
- Supernova Cooling
- Dark Matter: Lee–Weinberg bound: $M_{\chi_1^0} \gtrsim 6$ G

  Cowsik–McClellan bound: $M_{\chi_1^0} \lesssim 0.7$

Publications

- *A Supersymmetric solution to the KARMEN time anomaly*
  D. Choudhury, HD, P. Richardson, Subir Sarkar
  Phys. Rev. D61:095009,2000; e-Print: hep-ph/9911365

- *Supernovae and light neutralinos: SN1987A bounds on supe*
  HD, C. Hanhart, U. Langenfeld, D.R. Phillips
  Phys. Rev. D68:055004,2003; e-Print: hep-ph/0304289

- *Discovery potential of radiative neutralino production at the*
  HD, O. Kittel, U. Langenfeld
  Phys. Rev. D74:115010,2006; e-Print: hep-ph/0610020

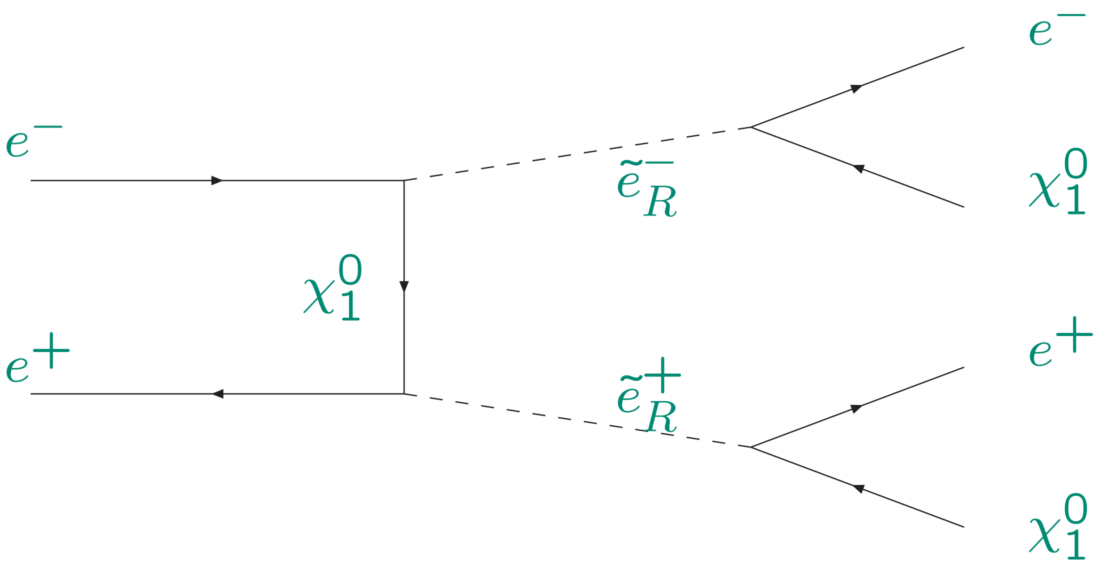
- *Mass Bounds on a Very Light Neutralino*
  HD, S. Heinemeyer, O. Kittel, U. Langenfeld, A.M. Weber, G
  Eur.Phys.J.C62,2009; e-Print: arXiv:0901.3485

- *Rare Meson Decays to a Light neutralino*
  HD, S. Grab, D. Koschade, M. Krämer, U. Langenfeld, B. O'L
  Phys. Rev. D80:035018,2009

Measuring a Light Neutralino Mass

Work in progress with Bonn group: John Conley, HD, Peter Wi

- Consider the process:

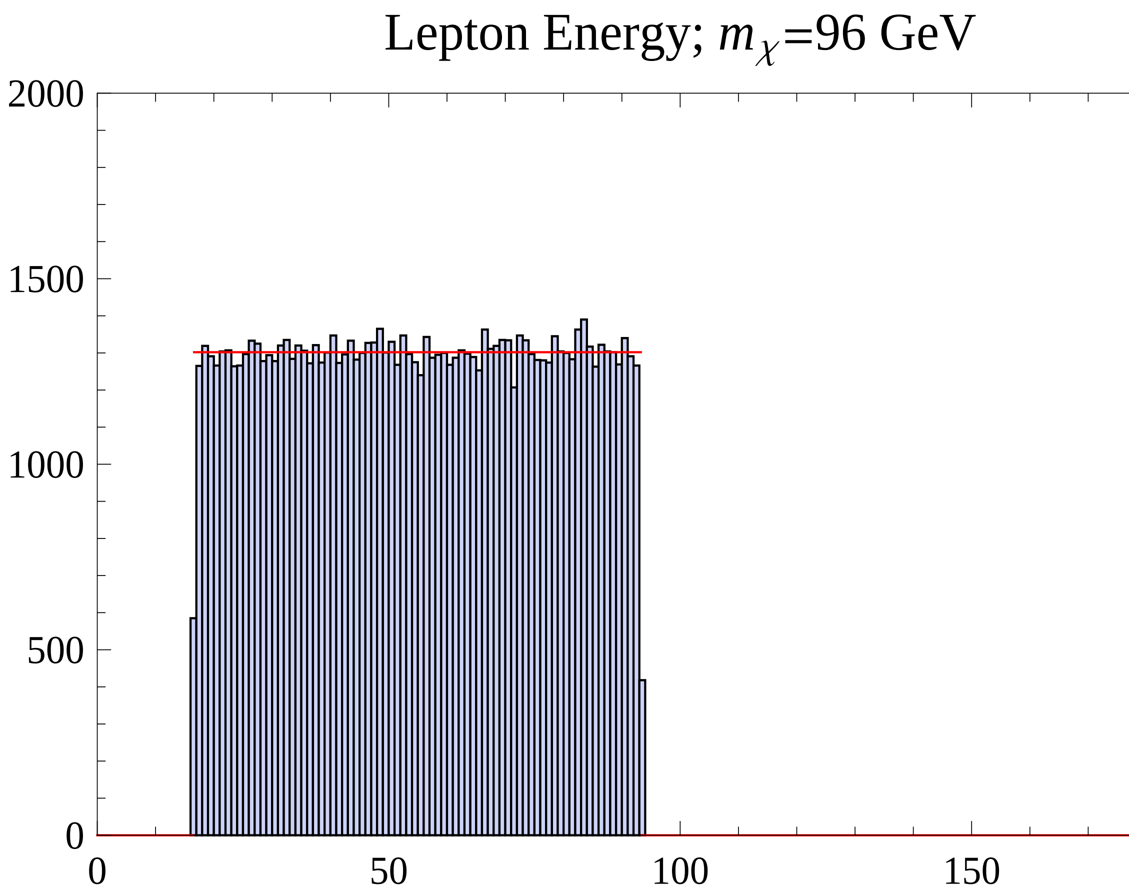


- Measure $e^\pm$ energies $\Longrightarrow$ determine $M_{\chi_1^0}$

- Earlier work by Uli Martyn (DESY): $M_{\chi_1^0} \gtrsim$ 95 GeV

- How well does this work for light neutralinos?

Electron Energy Distribut



- Electron energy distribution is flat, with sharp cut
- Here chosen: SPS1a: $M_{\tilde{e}R} = 143\,\mathrm{GeV}$ and $\sqrt{s} = 4$

Simple Kinematics

- θ_0: angle between $\vec{p}(e)$ in slepton rest–frame and $\vec{p}$

$$. \qquad E_e = \frac{\sqrt{s}}{4}\left(1 - \frac{M^2_{\chi^0_1}}{M^2_{\tilde{e}}}\right)(1 + \beta_{\tilde{e}} \cos\theta_0) \,, \qquad \beta_{\tilde{e}}$$

- Max/Min Electron energy: $E_\pm$ for $\cos\theta_0 = \pm 1$

- Solve for the SUSY Masses

$$\boxed{M_{\tilde{e}} = \sqrt{s}\,\frac{\sqrt{E_+ E_-}}{E_+ + E_-} \,, \qquad M_{\chi^0_1} = M_{\tilde{e}}\sqrt{1 - \frac{E_+}{\sqrt{}}}}$$

- Measure E_+ and E_-: thus determine $M_{\chi^0_1}$

Neutralino Mass Sensitiv

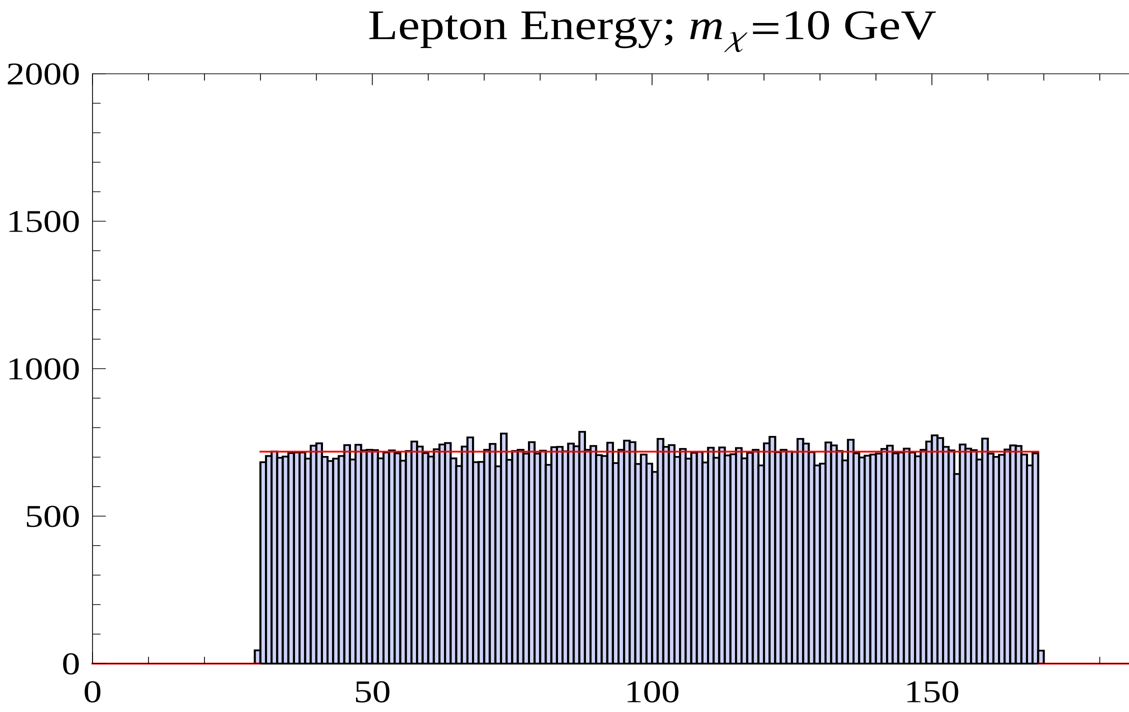
. $$E_{\pm} = \frac{\sqrt{s}}{4}\left(1 - \frac{M^2_{\chi^0_1}}{M^2_{\tilde{e}}}\right)(1 \pm \beta_{\tilde{e}}) \, , \qquad \beta_{\tilde{e}} = \sqrt{1$$

- Detailed ILC study by Uli Martyn for heavy neutra

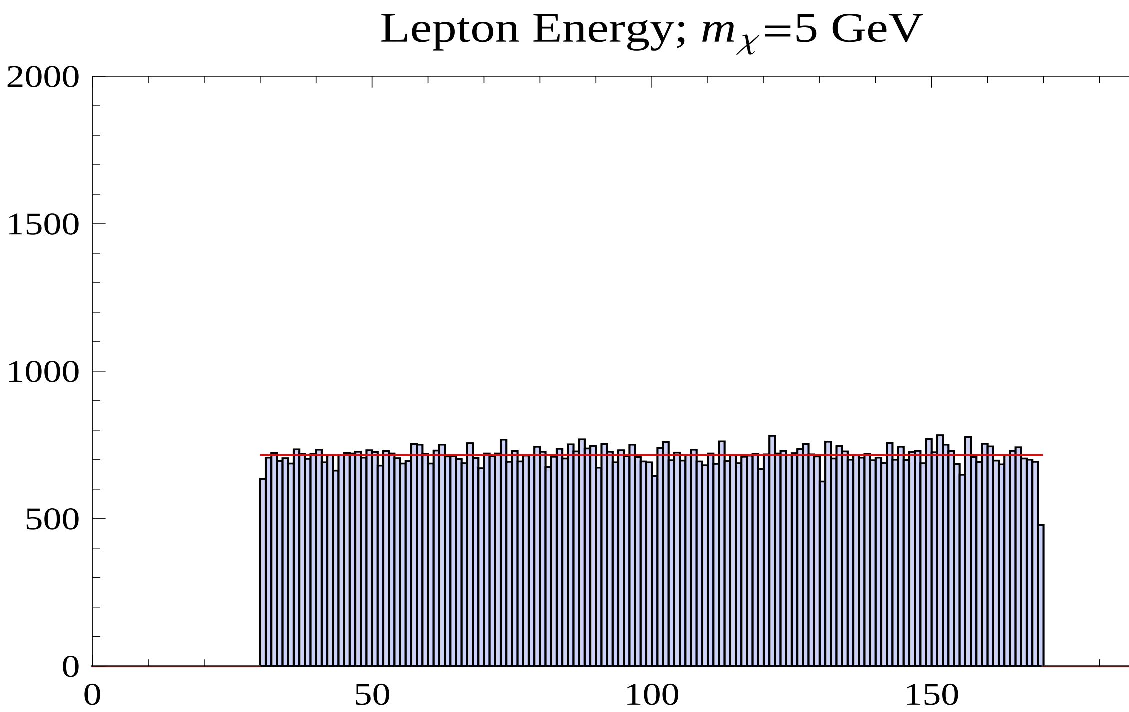
$$\frac{\Delta M_{\chi^0_1}}{M_{\chi^0_1}} < 0.2\%$$

- $E_{\pm}$ depends on $\frac{M^2_{\chi^0_1}}{M^2_{\tilde{e}}}$ $\Longrightarrow$ Expect less sensitivity

$$M_{\chi^0_1} \ll M_{\tilde{e}} \quad \text{or as} \quad M_{\chi^0_1} \longrightarrow 0$$



Lepton Energy; m_χ=10 GeV
2000
1500
1000
500
0
0
50
100
150



Lepton Energy; m_χ=5 GeV
2000
1500
1000
500
0
0
50
100
150

Work in Progress: Simple Sin

- Do not consider full detector simulation. Instead s
- Consider $\tilde{e}_R^- \tilde{e}_R^+$– and $\tilde{\mu}_R^- \tilde{\mu}_R^+$–Production
- $\tilde{e}_R^- \tilde{e}_R^+$ dominant
- $\sqrt{s} = 500\,\text{GeV}$
- Beam polarisations $(\mathcal{P}_{e^-}, \mathcal{P}_{e^+}) = (+80\%, -60\%)$
- Include Beam Strahlung: $\sqrt{s} \longrightarrow \sqrt{s'} < \sqrt{s}$

  This smears out the $E_\pm$–edges

Further Details of Simula

- Approximate detector resolutions

$$\Delta\left(\frac{1}{p_T}\right) = 1\cdot 10^{-4}\ \text{GeV}^{-1} \qquad \text{(trac}$$

$$\frac{\Delta E}{E} = \frac{0.166}{\sqrt{E/\text{GeV}}} \oplus 0.011 \qquad \text{(EC}$$

- Smear electron energy according to minimum of t
- For muons always choose momentum resolution
- This further smoothes out the edges
- We then fit the edges using basically the convoluti
  and an upward or downward step function.

Fit Functions

$$f_-(E) = \begin{cases} \frac{1}{2}\left[\mathrm{erf}\left(\frac{E-\hat{E}_-}{\sqrt{2}\sigma_1^-}\right) + 1\right] & : \quad E < \hat{E} \\ \frac{1}{2}\left[\mathrm{erf}\left(\frac{E-\hat{E}_-}{\sqrt{2}\sigma_2^-}\right) + 1\right] & : \quad E > \hat{E} \end{cases}$$

$$f_+(E) = \begin{cases} \frac{1}{2}\left[\mathrm{erfc}\left(\frac{E-\hat{E}_-}{\sqrt{2}\sigma_1^-}\right)\right] & : \quad E < \hat{E} \\ \frac{1}{2}\left[\mathrm{erfc}\left(\frac{E-\hat{E}_-}{\sqrt{2}\sigma_2^-}\right)\right] & : \quad E > \hat{E} \end{cases}$$

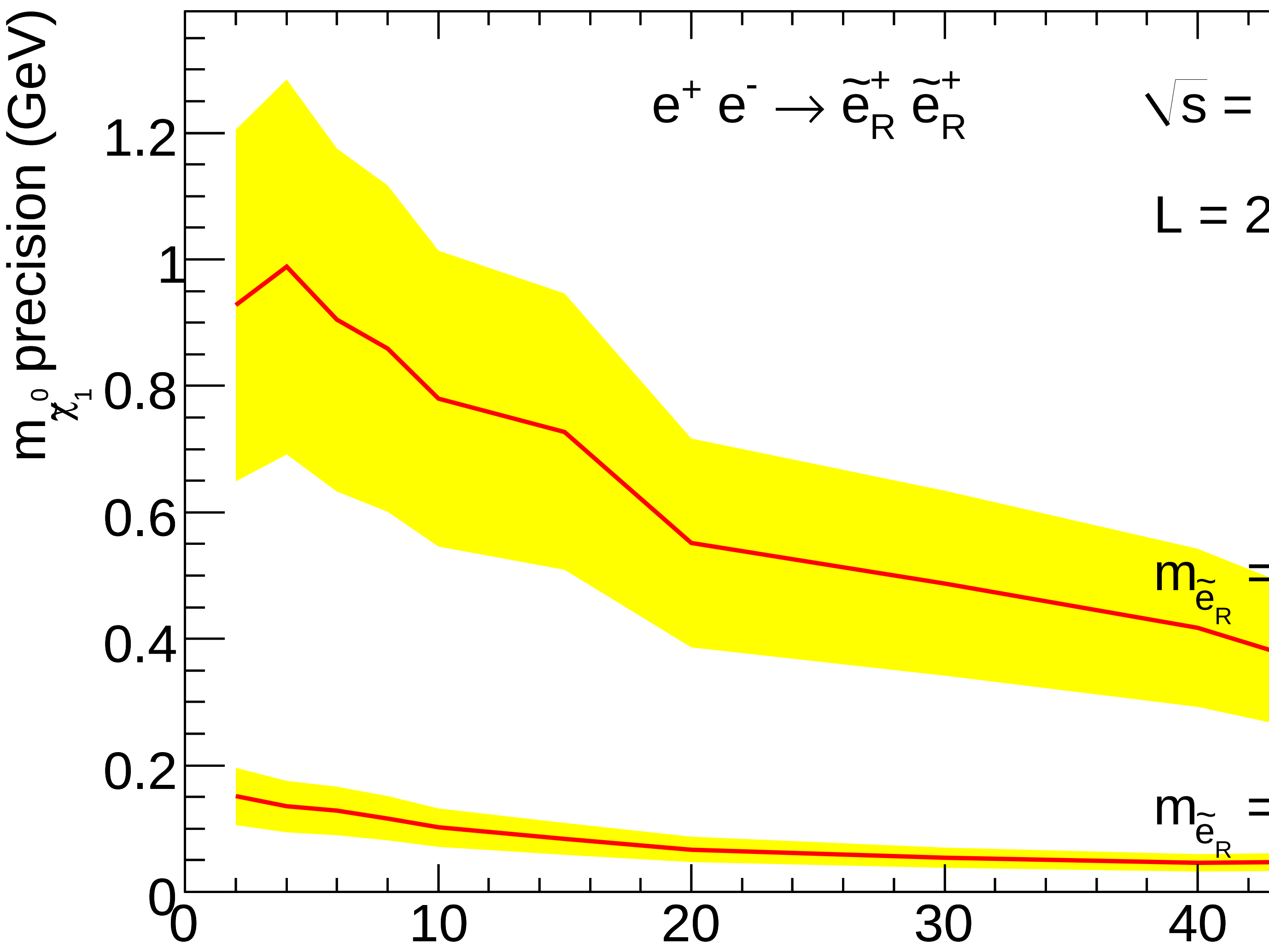
$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2} dt$$

$$\mathrm{erfc}(x) = 1 - \mathrm{erf}(x)$$

- $\sigma_1 \neq \sigma_2$ because of asymmetric beam strahlung

Results

- Reproduced detailed detector study by Uli Martyn
  and $\sqrt{s} = 400\,\mathrm{GeV}$ to within $\pm 30\%$
- Used this as a systematic error for our analysis of



- $\sqrt{s} = 500\,\mathrm{GeV}$
- Integrated Luminosity: $\int \mathcal{L} dt = 250\,\mathrm{fb}^{-1}$

Summary & Conclusion

- A massless neutralino is consistent with all data
- For $M_{\tilde{e}_R} = 100\,\text{GeV}$ can measure $M_{\chi_1^0}$ down to les
- For $M_{\tilde{e}_R} = 200\,\text{GeV}$ can measure $M_{\chi_1^0}$ down to ab
- Implications for Dark Matter


α
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b
p
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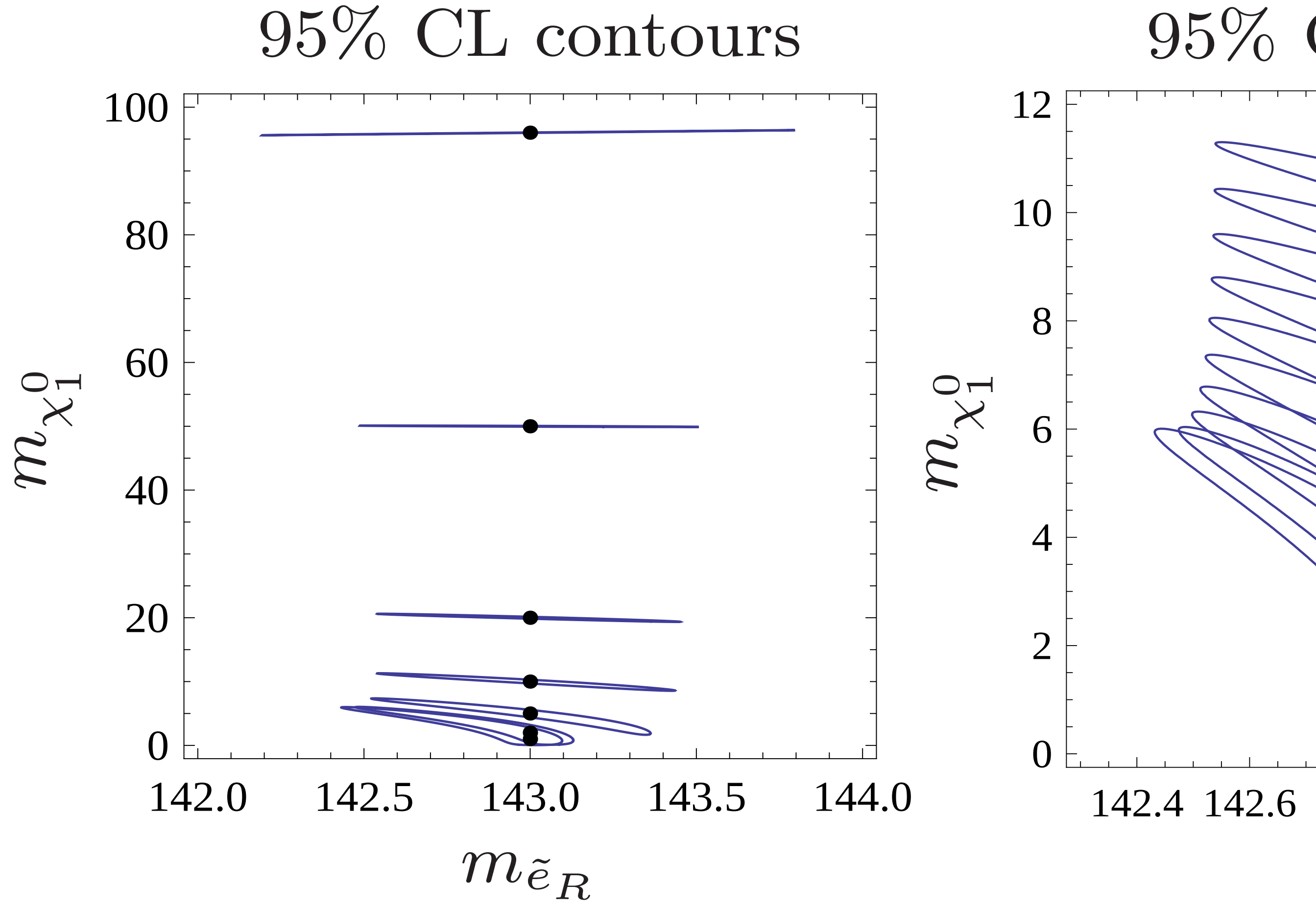
t


95% CL contours
100
80
60
40
20
0
142.0
142.5
143.0
143.5
144.0
$m_{\tilde{e}_R}$
$m_{\chi_1^0}$
95% C
12
10
8
6
4
2
0
142.4
142.6
$m_{\chi_1^0}$