Questions for “Beyond the Standard Model at Colliders” lecture 2
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1. Consider pair production of sleptons \( \tilde{\ell}_R \) at the ILC, with decays to the corresponding lepton and the lightest neutralino \( \tilde{N}_1 \):

\[
e^+ e^- \rightarrow \tilde{\ell}_R \tilde{\ell}_R \rightarrow \ell^+ \tilde{N}_1 \ell^- \tilde{N}_1.
\]

Use conservation of relativistic momentum and energy to derive the formula for the energy of one of the leptons in the centre-of-mass frame (set \( m_\ell \) to zero):

\[
E_{\ell}^{CM} = \frac{M_{\tilde{\ell}R}^2 - M_{\tilde{N}_1}^2}{4M_{\ell R}^2} \left( \sqrt{s} + \sqrt{s - 4M_{\ell R}^2 \cos \theta^*} \right),
\]

where \( \cos \theta^* \) is the angle, in the \( \tilde{\ell} \) rest frame, between the direction of the \( \tilde{\ell} \) motion and the emission angle of its daughter lepton. The collider centre-of-mass energy is denoted \( \sqrt{s} \) as usual. This formula gives the maximum \([\cos \theta^* = 1]\) and minimum \([\cos \theta^* = -1]\) lepton energies (endpoints) in terms of the SUSY particle masses. [Hint: start in the rest frame of one of the sleptons.]

2. Calculate the masses of the Kaluza-Klein states for a massless scalar particle propagating in an extra dimension of length \( L \), with periodic boundary conditions. (Hint: all you need is de Broglie and relativity.)