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EXTENDING THE KINEMATIC RANGE FOR W_R SEARCHES IN e^-e^- COLLISIONS AT THE NLC

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ABSTRACT

While the much discussed lepton-number violating process $e^-e^- \to W_R^-W_R^-$ provides an excellent probe of both the Majorana nature of the right-handed neutrino and the symmetry breaking sector of the Left-Right Symmetric Model, it is likely that W_R's are too massive to be pair produced at the NLC with $\sqrt{s}$ in the 1-1.5 TeV range. We are thus lead to consider the single W_R production process $e^-e^- \to W_R^-(W_R^-)^* \to W_R^- + jj$ in order to expand the collider's kinematic reach. After pointing out that W_R's with masses of order 1 TeV may be missed by future hadron collider searches, we demonstrate that this three-body process possesses a significant cross section, of order several fb, at the NLC with $\sqrt{s}$ in the range above. The angular distribution of the produced W_R's is shown to be essentially flat and the potential backgrounds from standard model processes are shown to be small.

The possibility of producing like sign pairs of W bosons in e^-e^- collisions has been discussed for some time[1]. Such a process, if it exists, signals the existence of new $|\Delta L| = 2$ interactions which may manifest themselves as Majorana masses for neutrinos. Within the Standard Model(SM) gauge group, it is difficult to generate a large cross section for this reaction while simultaneously satisfying the constraint of tree-level unitarity at large values of the center of mass energy, s, and the bounds on the effective neutrino mass arising from the lack of observation of neutrinoless double beta decay. These difficulties can be easily circumvented by extending the gauge group to that of the Left-Right Symmetric Model(LRM)[2] and considering instead the reaction $e^-e^- \to W_R^-W_R^-$, where W_R is the right-handed charged gauge boson. This process occurs quite naturally in the LRM as a result of the see-saw mechanism used to generate small masses for the ordinary 'left-handed' neutrinos.

The amplitude for $e^-e^- \to W_R^-W_R^-$ gets both $t-$ and $u-$channel contributions from the exchange of heavy 'right-handed' neutrinos(N), with mass M_N, as well as an $s-$channel contribution from the exchange of a doubly-charged Higgs boson(Δ), with mass M_Δ. (Any mixing between the SM W and W_R will be neglected in what follows.) Since the $e^-e^-\Delta$ coupling is proportional to M_N and the e^-NW_R coupling is chiral, the total amplitude is found to be proportional to M_N. Thus, as the Majorana mass of N vanishes so does the amplitude, which is just what we would expect since

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it is this Majorana mass term which generates the $|\Delta L| = 2$ interaction. At NLC energies, *i.e.*,$\sqrt{s} = 0.5 - 1.5$ TeV, the cross section for $e^-e^- \to W_R^- W_R^-$ is quite large, of order a few *pb*, fairly sensitive to the values of M_N and M_Δ, and has a rather flat angular distribution. The $s-$channel Δ may appear as a resonance depending upon the value of $\sqrt{s}$. Unfortunately, the 'reach' is rather limited since we are restricted to W_R masses less than $\sqrt{s}/2$ and there are substantial reasons to believe[3] that W_R's are relatively heavy with masses $M_R \geq 0.5$ TeV. It is reasonable to contemplate that W_R pair production may not be kinematically accessible at these center of mass energies. This forces us to consider[4] the possibility of *singly* producing W_R's via the reaction $e^-e^- \to W_R^-(W_R^-)^* \to W_R^- jj$. We limit ourselves to this jj mode to allow for the possibility that $M_N > M_R$ in which case W_R can only decay to jj barring the existence of exotics. It is interesting to note that all collider searches for W_R rely on it's leptonic decay as a trigger; if $M_N > M_R$ it is quite possible that W_R's may not be observable at the Tevatron or LHC[5] and may be missed until the NLC turns on.

Of course, allowing one of the W_R's to be off-shell we are forced to pay the price of an additional gauge coupling as well as three-body phase space. This results in a substantial reduction in the cross section from the on-shell case to the level of a few fb. This implies machine luminosities in the range of $\mathcal{L} = 100 - 200 fb^{-1}$ are required to make use of this channel. The complete expression for the cross section is given in Ref. 4. The total event rates for $e^-e^- \to W_R^-(W_R^-)^* \to W_R^- jj$ are found in Figs. 1 and 2, in which we have set $\kappa = 1$ and scaled by an integrated luminosity of $100 fb^{-1}$. ($\kappa = g_R/g_L$ is the ratio of the two gauge couplings in the LRM.) Fig. 1a shows the number of expected $W_R + jj$ events, as a function of M_R, at a $\sqrt{s} = 1$ TeV e^-e^- collider for different choices of M_N and M_Δ. The results are seen to be quite sensitive to the values of these mass parameters even when M_R is fixed. In Fig. 1b(c), we fix $M_R = 700$ GeV and plot the event rate as a function of $M_N(M_\Delta)$ for various values of $M_\Delta(M_N)$. Typically, we see event rates of order several hundred/yr except near the Δ resonance (where very large rates are obtained) or when M_N is small (as the cross section vanishes for massless N since it probes the N's Majorana nature). Increasing $\sqrt{s}$ to 1.5 TeV, as shown in Fig. 2a, we see substantial cross sections are obtainable even assuming W_R's in the 1-1.2 TeV mass range for some parameter choices. Fixing $M_R = 1$ TeV in Figs. 2b and c, we again see reasonable event rates for most choices of M_N and M_Δ assuming $\sqrt{s} = 1.5$ TeV. The exact rate is, however, a sensitive probe of both the N and Δ masses. For most choices of the input masses we obtain extremely flat distributions, however, when N is light a significant angular dependence is observed. This is simply a result of the $t-$ and $u-$ channel poles which develop as M_N tends to zero. Of course, small M_N also leads to a small cross section, as shown in Figs. 1 and 2, as might be expected since the matrix element vanishes in this massless limit.

Potential backgrounds to the process $e^-e^- \to W_R^-(W_R^-)^* \to W_R^- + jj$ at the NLC are easily controlled and/or removed. For example, there may be some contamination from the SM process $e^-e^- \to W_L^- W_L^- \nu\nu$, but this can be easily eliminated by using missing energy cuts and demanding that the W_R final state be reconstructed from either the jj or $eN \to eejj$ decay modes. (Since the on-shell W_R decays to either jj or $eN \to eejj$ there is no missing energy in the signal process.) In addition, with polarized beams, we can take advantage of the fact that W_R couples via right-handed

currents while any SM background must arise only via left-handed currents. Within the LRM itself a possible background could arise from a similar lepton-number conserving processes such as $e^-e^- \to W_R^- W_R^- NN$. Even if such a final state could be produced, in comparison to the process we are considering, the subsequent N decays would lead to a final state with too many charged leptons and/or jets.

In this talk the following points have been addressed: (*i*) While $e^-e^- \to W_R^- W_R^-$ is an excellent probe of both the Majorana nature of N and the symmetry breaking sector of the Left-Right Symmetric Model, it is more than likely that W_R's are too massive to be pair produced at the NLC if $\sqrt{s} = 1 - 1.5$ TeV forcing us to consider the production of a single on-shell W_R via the process $e^-e^- \to W_R^-(W_R^-)^* \to W_R^- + jj$. (*ii*) Since the pair of on-shell W_R's cross section was generally very large, we would expect that the single W_R rate would be significant if integrated luminosities in the $100 fb^{-1}$ range were available. From the explicit calculations we found that these expectations were realized for most of the model parameter space with cross sections of order $1 - 10 fb^{-1}$. (*iii*) For values of the input parameters that lead to significant rates, the W_R angular distribution was found to be rather flat implying that angular cuts will not significantly reduce the cross sections. The rates themselves were found to be quite sensitive to the particular values of the masses of N and Δ. Masses for both these particles beyond the kinematic reach of the NLC were found to be probed by the single W_R production process.

e^-e^- collisions allow us to probe the Majorana nature of the heavy neutrinos in the LRM even when they are too massive to be directly produced.

References

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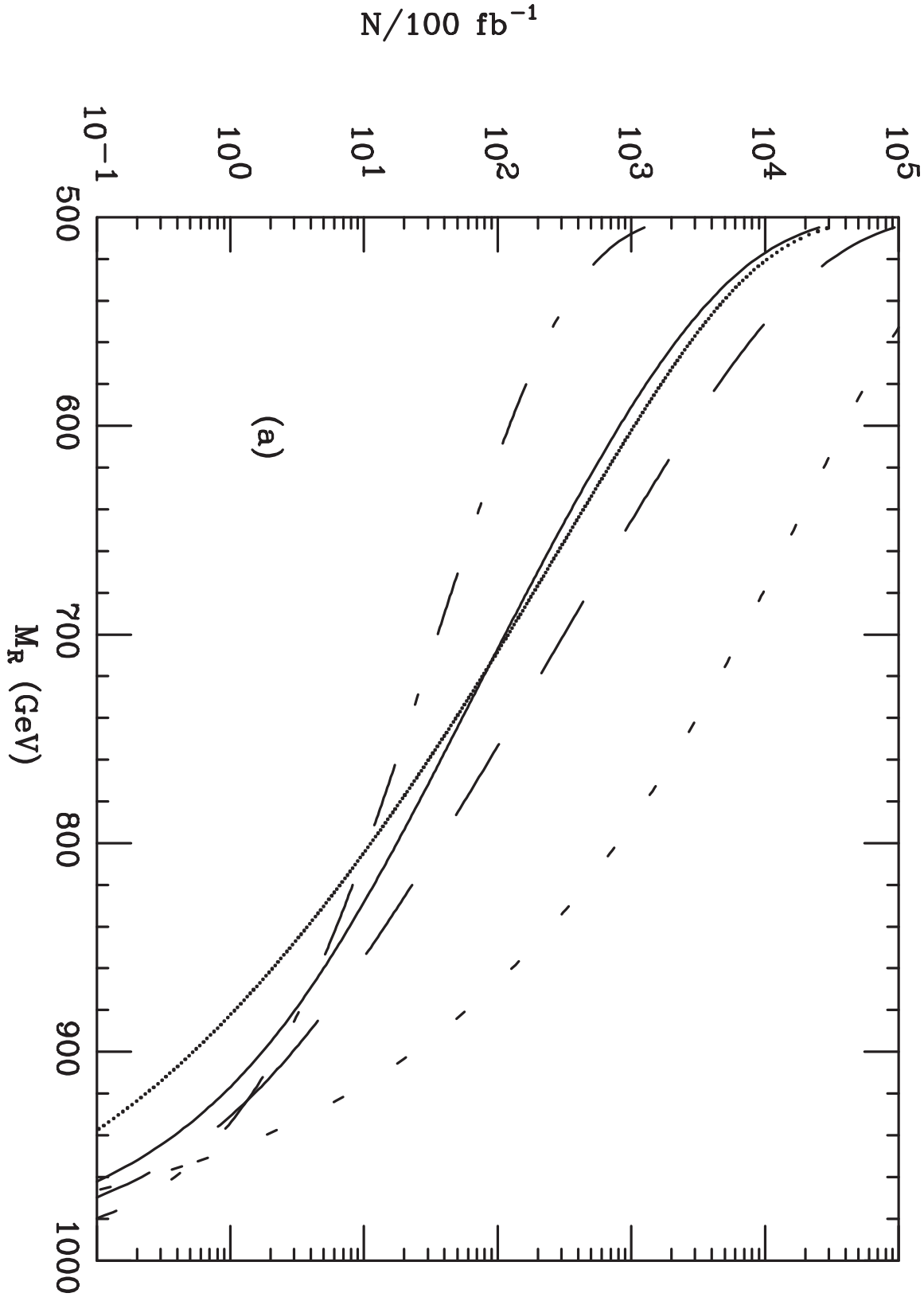
Fig. 1: Event rates per $100 fb^{-1}$ for $W_R + jj$ production at a 1 TeV e^-e^- collider assuming $\kappa = 1$ (a) as a function of M_R for $M_N = M_\Delta = 1$ TeV (dots), $M_\Delta = 1.2$ TeV and $M_N = 0.4$ TeV (dashes), $M_\Delta = 0.3$ and $M_N = 0.1$ TeV (dash-dots), $M_\Delta = 2$, $M_N = 0.6$ TeV (solid), or $M_\Delta = 1.8$ and $M_N = 0.6$ TeV (square dots); (b) with $M_R = 700$ GeV fixed as a function of M_N for $M_\Delta = 0.3(0.6, 1.2, 1.5, 2)$ TeV corresponding to the dotted(dashed, dash-dotted, solid, square-dotted) curve; (c) as a function of M_Δ for $M_N = 0.2(0.5, 0.8, 1.2, 1.5)$ TeV corresponding to the dotted(dashed, dash-dotted, solid, square-dotted) curve.

Fig. 2: Same as Fig. 1, but for a 1.5 TeV e^-e^- collider. In (b) and (c), a W_R mass of 1 TeV is assumed.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10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
500
600
700
800
900
1000
M_R (GeV)
(a)

Figure 1a

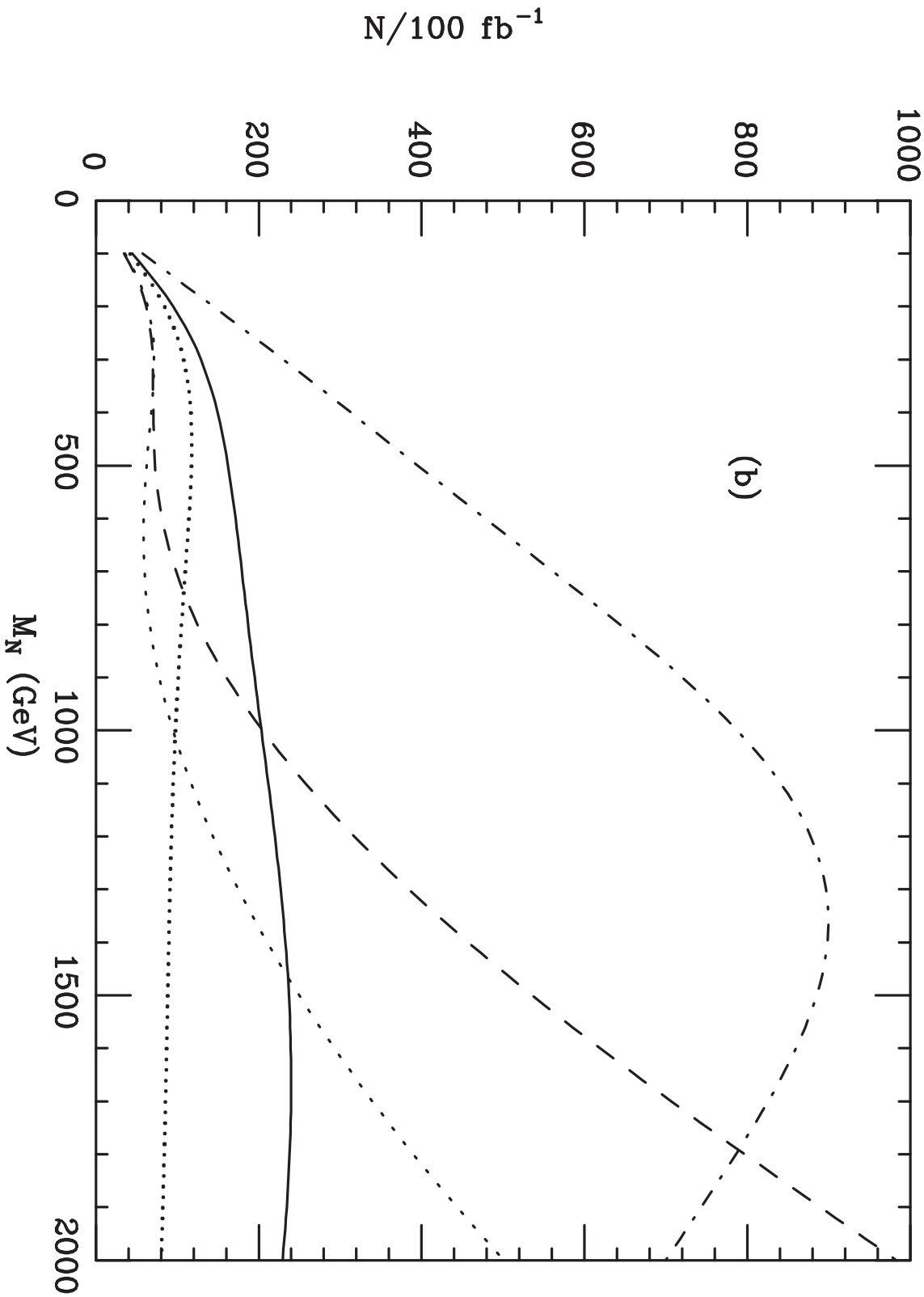


Figure 1b

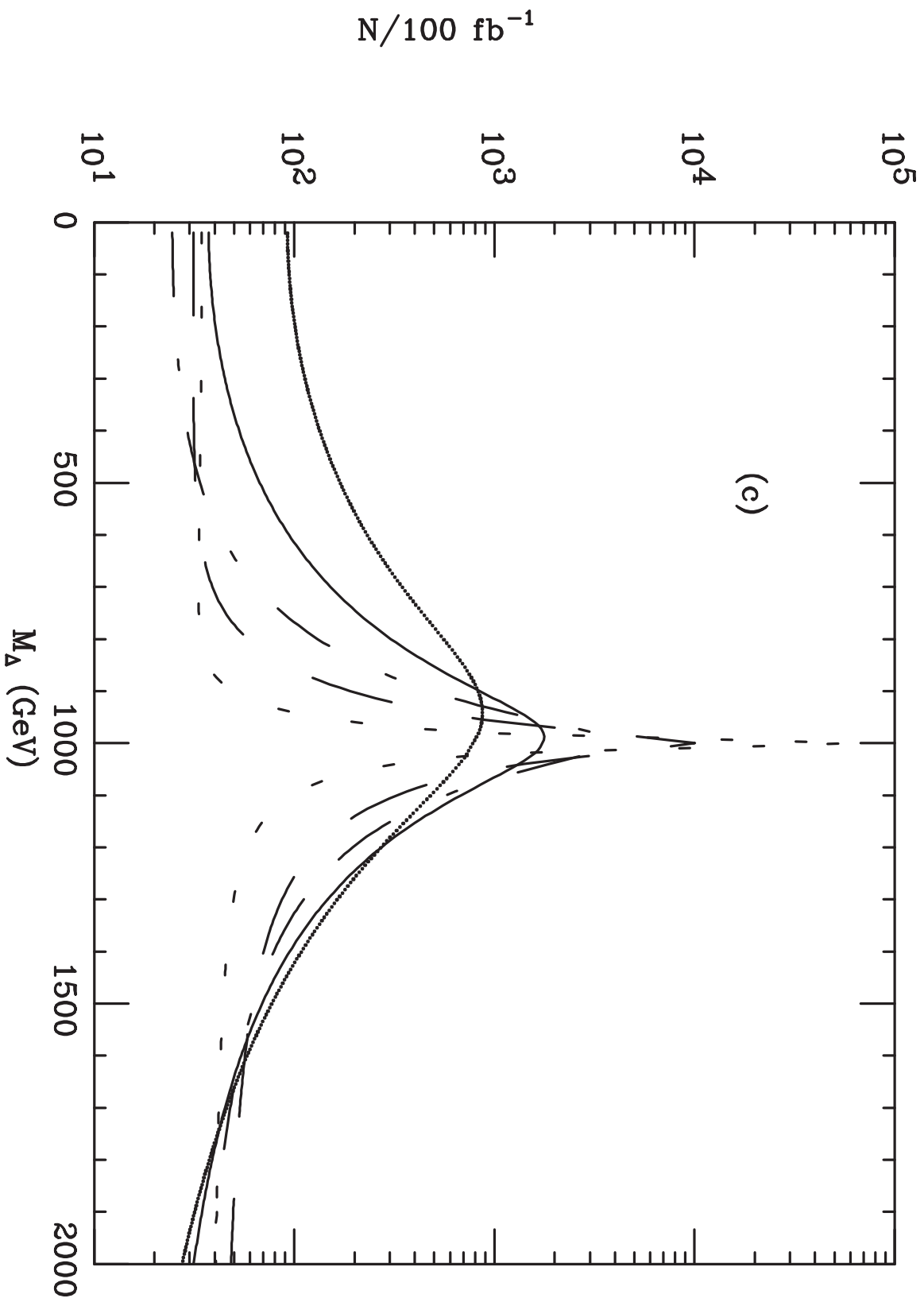


Figure 1c

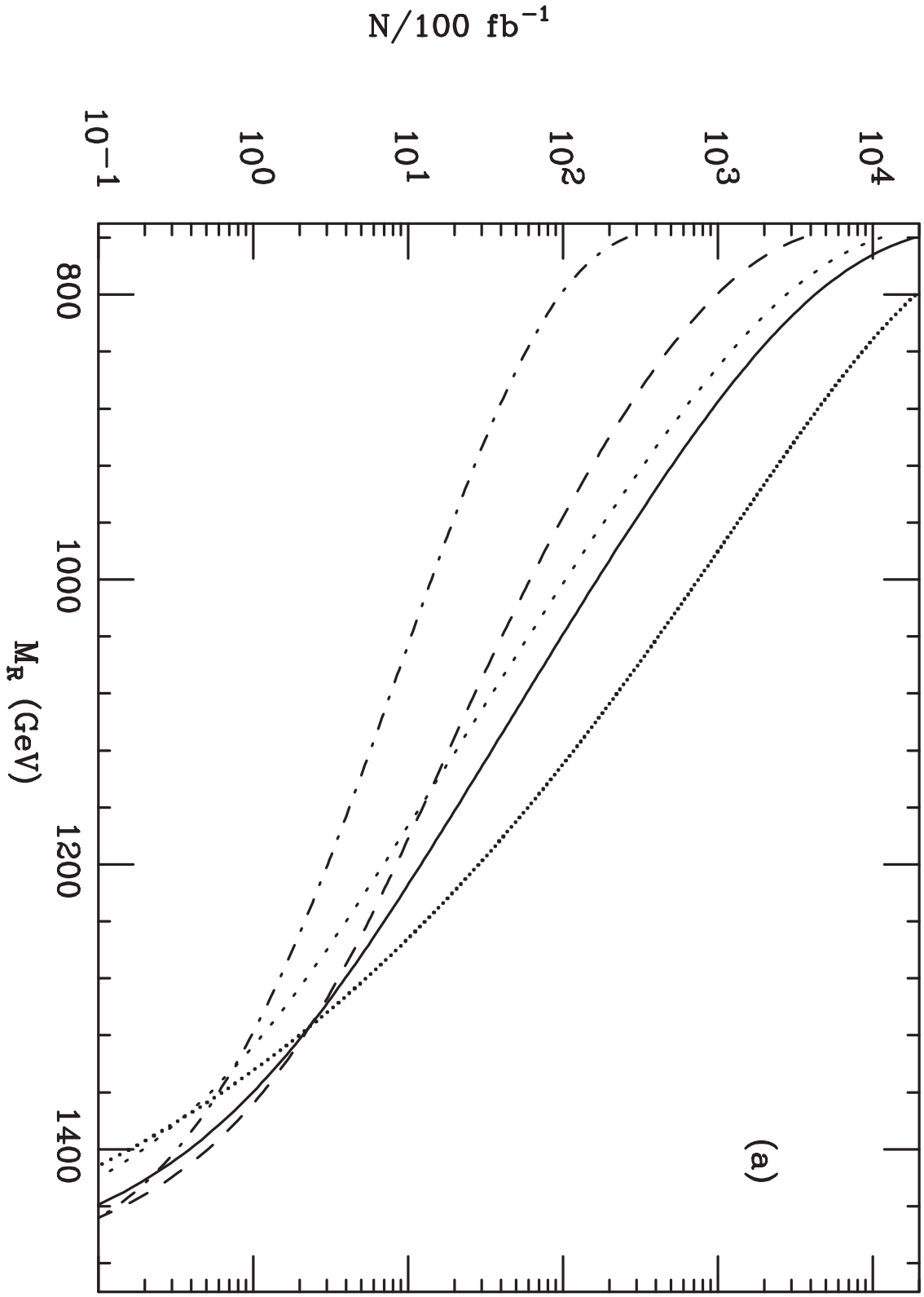
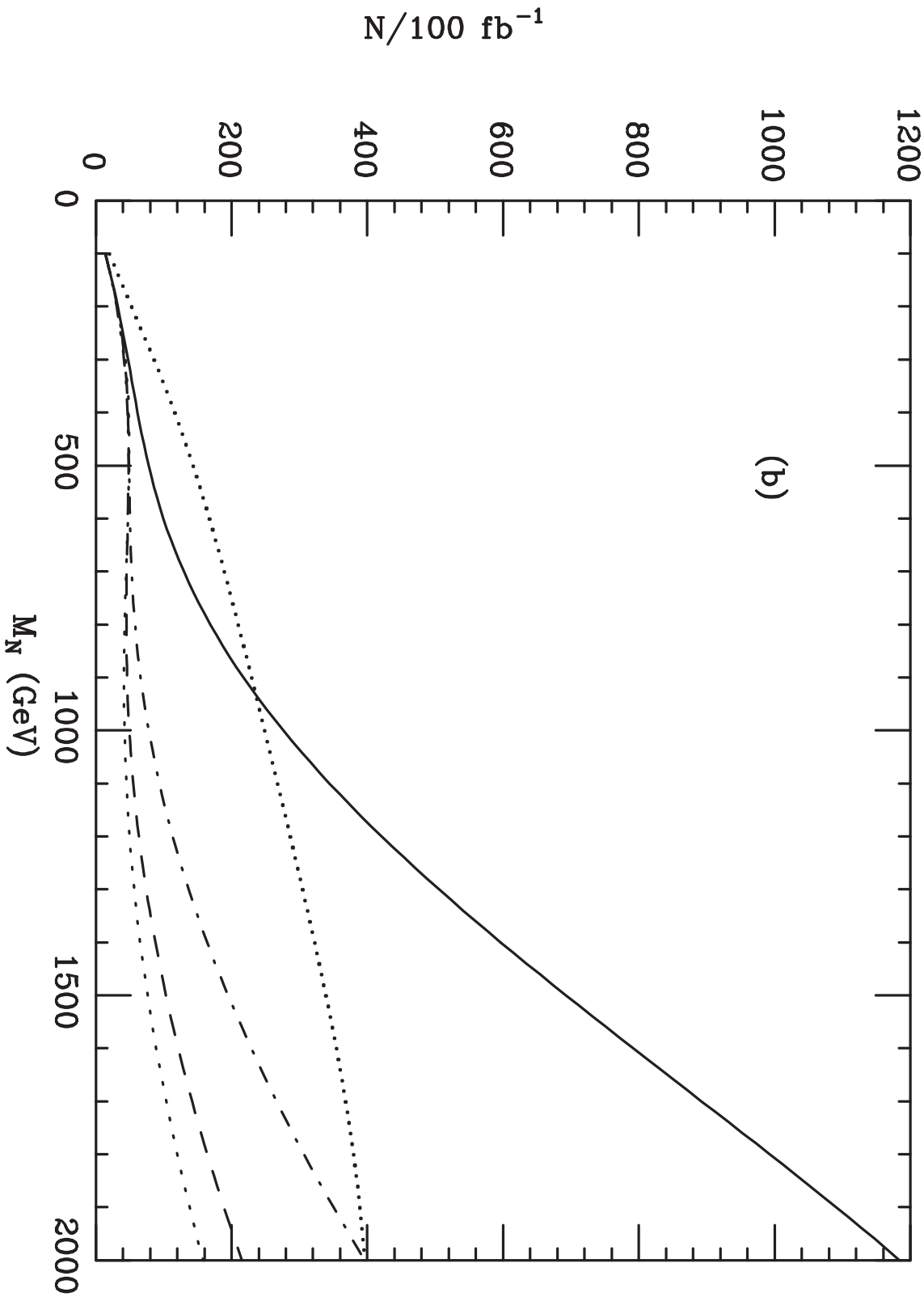


Figure 2a


N/100 fb^{-1}
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200
400
600
800
1000
1200
0
500
1000
1500
2000
M_N (GeV)
(b)

Figure 2b

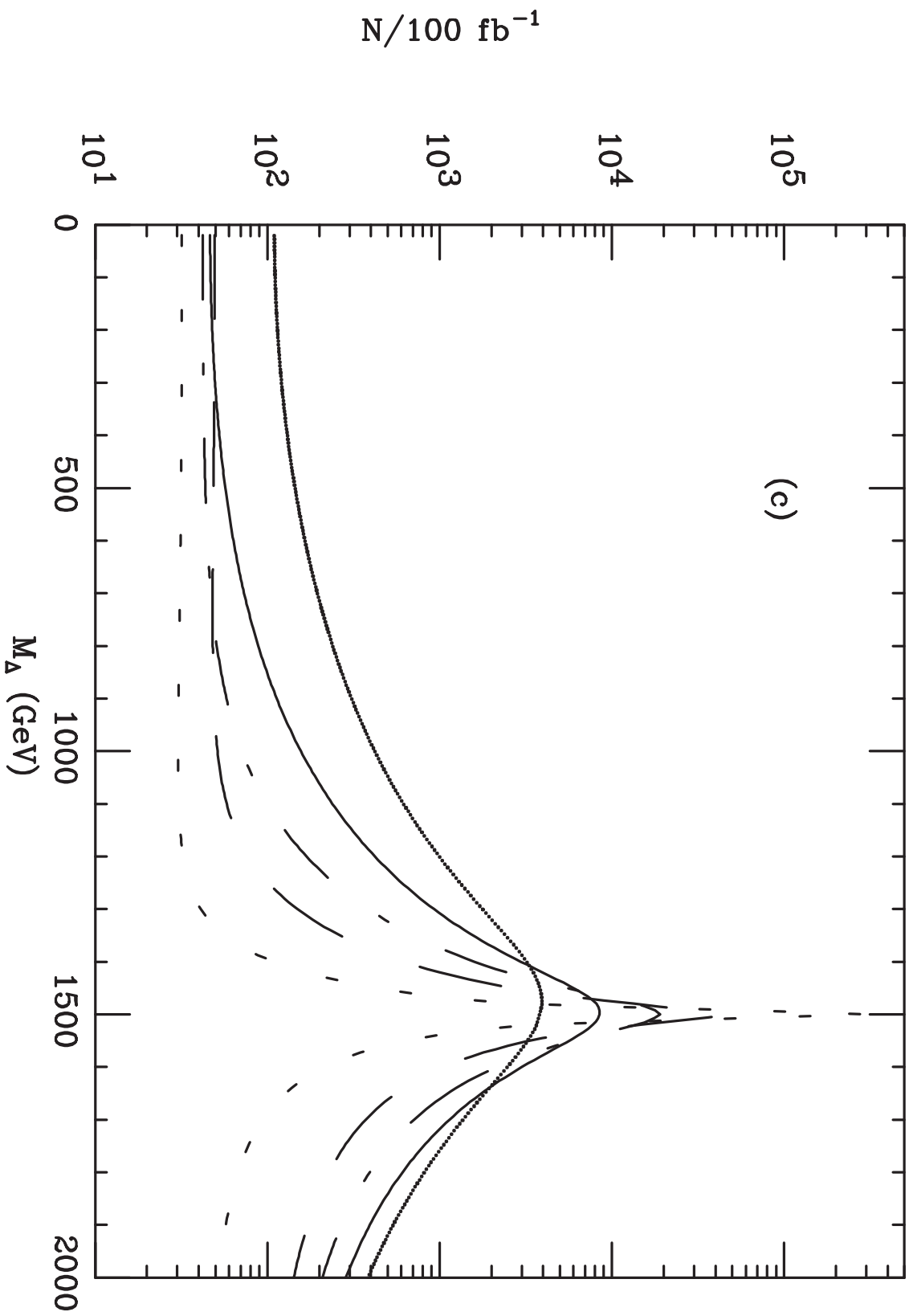

Figure 2c