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SIGNALS FOR TOP QUARK ANOMALOUS CHROMOMAGNETIC MOMENTS AT COLLIDERS

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ABSTRACT

The Tevatron and the Next Linear Collider(NLC) will be excellent tools for probing the detailed nature of the top quark. We perform a preliminary examination of the influence of an anomalous chromomagnetic moment for the top, κ, on the characteristics of $t\bar{t}$ production at the Tevatron and on the spectrum of gluon radiation associated with $t\bar{t}$ production at the NLC. In particular, we analyze the sensitivity of future data to non-zero values of κ and estimate the limits that can be placed on this parameter at the Tevatron and at the NLC with center of mass energies of $\sqrt{s} = 500$ and 1000 GeV. Constraints on κ from low energy processes, such as $b \to s\gamma$, are briefly discussed.

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The probable discovery of the top quark at the Tevatron[1] has renewed thinking about what may be learned from a detailed study of its properties. It is believed that the details of top quark physics may shed some light on new physics beyond the Standard Model(SM). Amongst others, one set of the top's properties which deserve study is its couplings to the various gauge bosons; up until now such analyses[2] have concentrated on the electroweak couplings of the top. In this work we consider the possible existence of an anomalous chromomagnetic moment, dimension-5 coupling, κ, at the $t\bar{t}g$ vertex and explore the capability of the Tevatron and NLC to probe this kind of new physics. Such interactions may arise in extended technicolor or compositeness scenarios. At present, only rather weak limits on κ (of order 10) exist, in particular, from operator mixing contributions to the $b \to s\gamma$ decay. (See the last paper in Ref. 2). For details of the analysis presented below, see Ref. 3.

At the Tevatron, both $gg, q\bar{q} \to t\bar{t}$ subprocesses are modified by the existence of $\kappa \neq 0$ with the $q\bar{q}(gg)$ case displaying a quadratic(quartic) κ dependence. In the results below only the SM NLO and gluon resummation corrections[4] are incorporated by way of 'K-factors'. For $\kappa \neq 0$ the relative weights of the gg and $q\bar{q}$ subprocesses can be drastically altered as can be seen in Fig.1a. We also see that the total σ can be dramatically increased or decreased via $\kappa \neq 0$; in particular, the CDF σ result can be reproduced if $\kappa \simeq 0.25$. If we assume that in the future the $t\bar{t}$ σ settles down to its SM value, we can estimate the constraints that this would impose on κ including uncertainties(which we estimate using Refs. 1 and 5) due to (i)scale ambiguities, (ii)parton density variations, (iii)NNLO QCD corrections, and $(iv)$the machine luminosity, as well as statistics. For $\mathcal{L} = 100(250, 500, 1000)pb^{-1}$ we obtain the 95% CL ranges of

$-0.14 \leq \kappa \leq 0.15$, $-0.11 \leq \kappa \leq 0.12$, $-0.09 \leq \kappa \leq 0.11$, and $-0.08 \leq \kappa \leq 0.11$, respectively.

One might ask if the top pair p_t-, rapidity(y-), or invariant mass(M-) distributions can be used to increase the sensitivity to $\kappa \neq 0$; we find that the by far dominant effect on these observables (for small values of κ) is an approximate overall rescaling of the observable by the ratio of the κ-dependent to the SM cross sections. (This results from the fact that the $t\bar{t}$ threshold region is found to dominate in the evaluation of σ's.) Almost all deviations from this simple rescaling occur at very large M or p_t values where statistics will always remain quite meager for interesting values of κ. Fig. 1b shows this situation explicitly for the $t\bar{t}$ p_t-distribution. We conclude that the total $t\bar{t}$ cross section provides the best probe of κ at the Tevatron.

At the NLC, the $t\bar{t}g$ vertex can only be directly explored via the QCD radiative process $e^+e^- \rightarrow t\bar{t}g$[5]. Relative to the Tevatron, this results in a substantial loss in statistics which can be compensated for by the cleanliness of the environment as well as a reduction in the associated theoretical uncertainties. Since the new κ-dependent interaction is proportional to the gluon 4-momentum, we are thus lead to a study of the gluon energy distribution associated with $t\bar{t}$. The dominant effect of $\kappa \neq 0$ is to induce an increase in the high energy tail of this distribution. This same energy dependence leads to the observation that the finite κ contributions grow rapidly with increasing $\sqrt{s}/2m_t$, implying increased sensitivity at an NLC with $\sqrt{s} = 1$ TeV instead of 500 GeV. In this first study, we ignore effects from top decay(except in the statistics) and perform a LO analysis following the work in Ref. 5. To reduce scale ambiguities and contributions from higher orders, we employ the scheme of Brodsky *et al.*(BLM) in Ref. 6. Estimates of contributions from these higher order are lumped into the uncertainties when obtaining limits. Fig. 2a shows this distribution for the case of $\sqrt{s} = 1$ TeV for $\alpha_s = 0.10$ while Fig. 2b shows the result of integrating this distribution for values of $z = 2E_{glu}/\sqrt{s} > 0.4$. Assuming that the SM results are realized, bounds on κ may be obtainable by either (i)counting excess events with high energy gluon jets or (ii)by a fit to the gluon energy distribution via a Monte Carlo analysis. Events are selected with at least one b-tag as well as one high p_t lepton and gluon jet energies larger than 200 GeV. Such large jet energies will allow a clean separation from the top decays and will simultaneously place us in the region of greatest κ sensitivity. For a luminosity of 200 fb^{-1} the resulting 95% CL allowed range is found to be $-1.0 \leq \kappa \leq 0.25$. Substantial improvement is obtained by fitting the spectrum itself; Fig. 2c shows the Monte Carlo generated spectrum and best fit($\kappa = 0.06$) assuming that the SM is realized. At 95% CL, one now obtains the allowed range of $-0.12 \leq \kappa \leq 0.21$ for the same luminosity as above. For a $\sqrt{s} = 500$ GeV machine with an integrated luminosity of $30fb^{-1}$, these limits are significantly loosened; following the same procedure yields the corresponding bounds $-1.98 \leq \kappa \leq 0.44$. A full analysis including the effect of top decay and NLO corrections should be performed to confirm these 'first pass' results.

Both the Tevatron and the NLC provide complementary windows on the possible anomalous chromomagnetic couplings of the top with different systematics. If such a coupling were observed, it would provide a unique signature for new physics beyond the Standard Model.

References

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Fig. 1: (a)NLO cross sections for the $q\bar{q} \to t\bar{t}$(dash-dotted) and $gg \to t\bar{t}$(dotted) subprocesses as well as the total cross section(solid) at the Tevatron as functions of κ for $m_t = 170$ GeV using the CTEQ parton distribution functions. The horizontal dashed lines provide the $\pm 1\sigma$ CDF cross section determination while the horizontal dotted line is the D0 95% CL upper limit. (b)p_t distribution for top quark pairs produced at the Tevatron assuming $m_t = 170$ GeV and CTEQ parton densities. The solid curve is the SM prediction and the upper(lower) dash-dotted, dashed, and dotted curves correspond to $\kappa = 1,\ 0.5,\ 0.25(-1,\ -0.5,\ -0.25)$, respectively.

Fig. 2: (a)Gluon jet energy spectrum assuming $\alpha_s = 0.10$ for $m_t = 175$ GeV at a $\sqrt{s} = 1$ TeV NLC. The upper(lower) dotted, dashed, and dot-dashed curves correspond to κ values of 3(-3), 2(-2), and 1(-1) respectively while the solid curve is conventional QCD with $\kappa = 0$. (b)Integrated gluon energy spectrum for the same input parameters and labelings as in Fig. 3 as a function of κ assuming $z_{cut} = 0.4$. (c)Best fit gluon spectrum through the points generated by the Monte Carlo analysis corresponding to $\kappa = 0.06$.

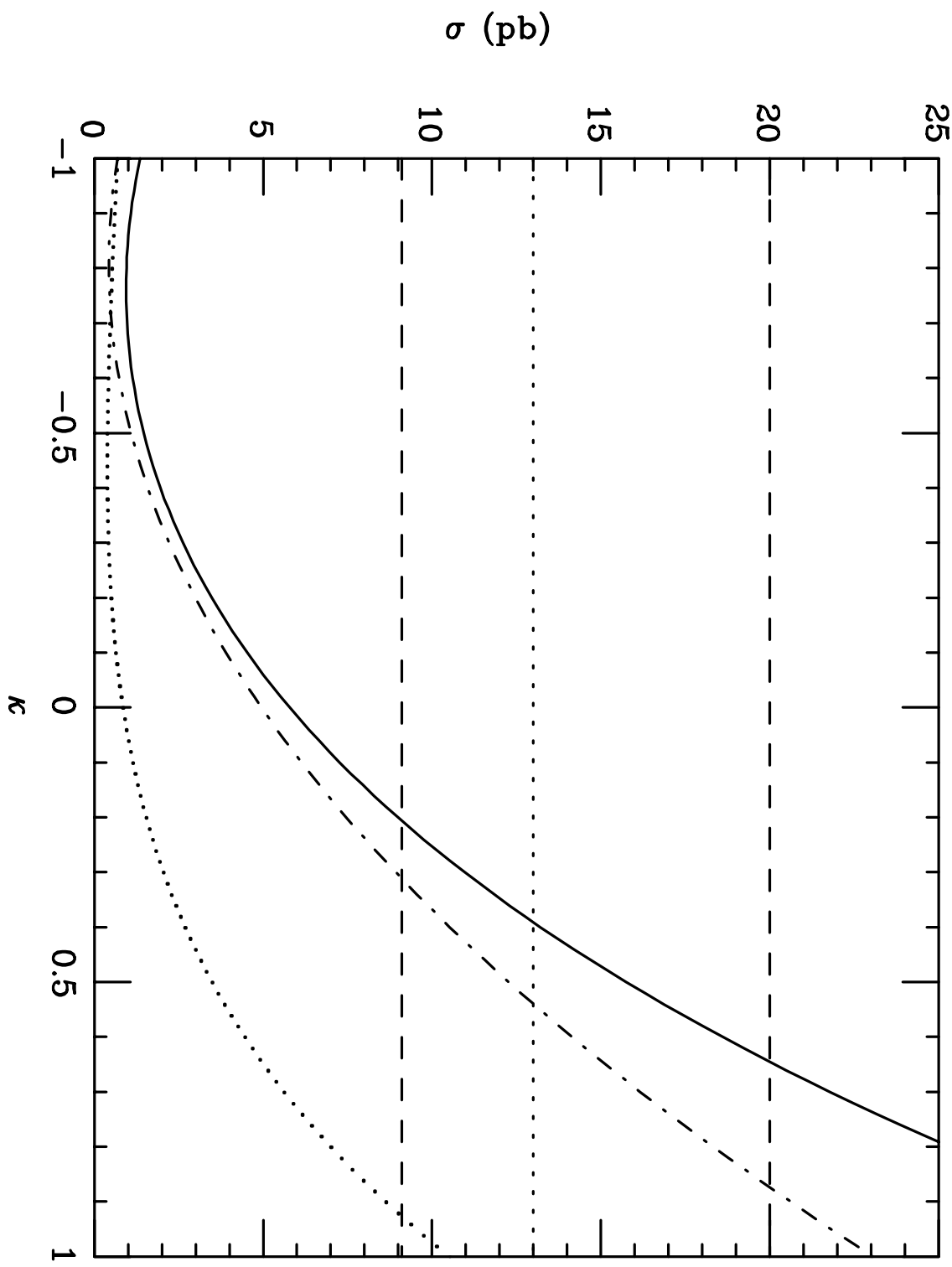

Figure 1

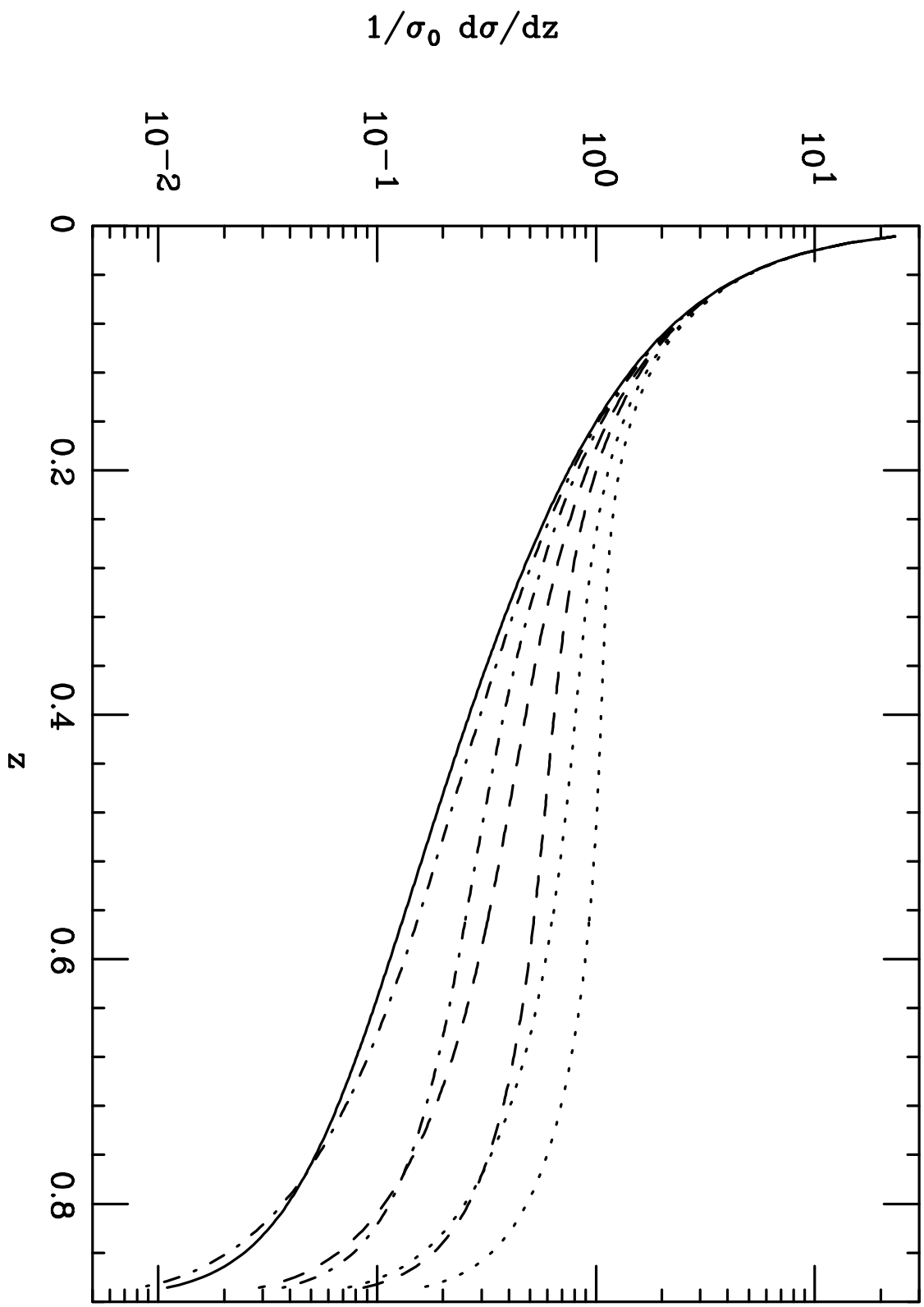

Figure 2a

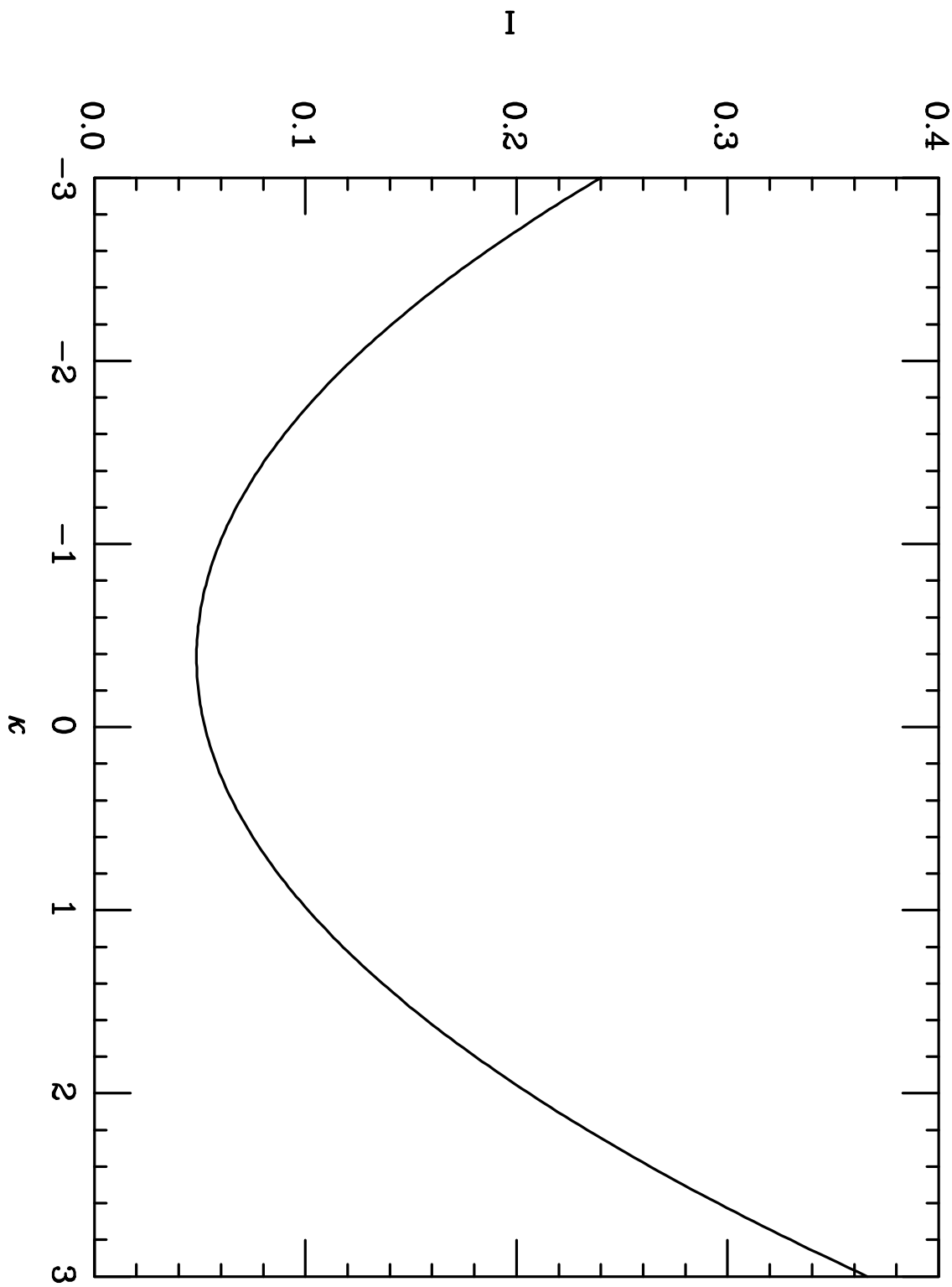

Figure 2b

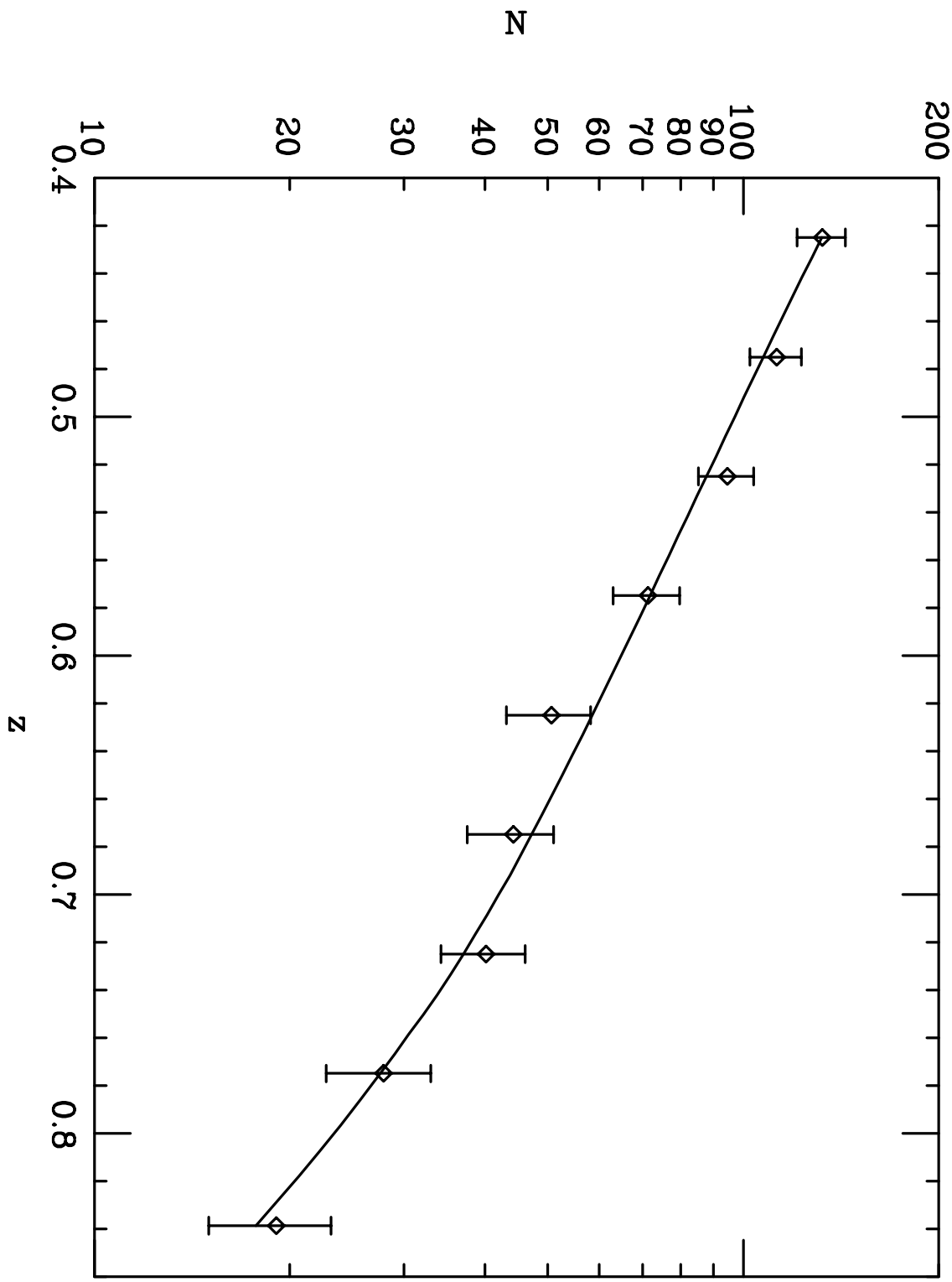

Figure 2c