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Search for Long-Lived Parents of the Z^0 Boson

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We present the results of a search for new particles with long lifetime that decay to a Z^0 boson. A long-lived parent of the Z^0 is predicted by several models in addition to being an experimentally clean channel. We vertex dimuons with invariant mass near the Z^0 peak and study the decay length distribution. No evidence of a long-lived component is found, and cross-section limits are presented on a fourth generation quark model.

Keywords: Z boson; fourth generation quark; SUSY; displaced vertex.

1. Introduction

We present a search for long-lived particles decaying to Z^0 bosons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV with the CDF detector[1] at the Tevatron. We search for non-prompt sources of $Z^0 \to \mu^+\mu^-$ by vertexing muons and searching for an excess at large transverse distances from the beam, L_{xy}. These results extend previous searches[2].

There are several models that predict a long-lived particle decaying to a Z^0. For example, gauge-mediated SUSY models where the gravitino is the LSP[3] allow a long lifetime. In a 4^{th} generation quark model, if $m_{b'} < m_t$, its decay is $b' \to bZ^0$ via a loop diagram, causing a long lifetime. Beyond model dependent motivations, this is an experimentally appealing channel limited only by track reconstruction.

2. Data Sample & Event Selection

This search is performed using 163 pb^{-1} of data collected between March 2002 and September 2003. The trigger requires a muon with $p_T > 18$ GeV/c. We select Z^0 events offline having two muons with $p_T > 20$ GeV/c, well-measured tracks, and an invariant mass within 10 GeV of the Z^0 peak. When the two tracks are nearly back-to-back in ϕ, a small offset in the impact parameter of one track can lead to a large shift in L_{xy}, so we require $\Delta\phi < 175°$, rejecting 99.8% of background and remaining efficient for signal. High transverse momentum of the Z^0 is a generic

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feature of signals, so we require $p_T^Z > 30$ GeV. We search both with and without this cut, broadening the model independence and adding sensitivity at long lifetimes.

We define, *a priori*, a minimum L_{xy} for the signal region based on the expected background calculated from Standard Model Z^0 generated with PYTHIA[4] and processed with a full detector simulation. The requirement is $L_{xy} > 0.3$ mm, which is tightened to $L_{xy} > 1.0$ mm in the case without a p_T^Z cut.

3. Backgrounds

The dominant background is from Standard Model Z^0 bosons where misreconstruction of one of the muon tracks produces a large L_{xy}. We measure this background from Monte Carlo using the data in the non-signal region to tune the Monte Carlo resolution. Three tuning methods are used and the differences are taken as a systematic uncertainty on the background prediction. We find backgrounds of 1.1 ± 0.8 events in the $p_T^Z > 30$ GeV case and 0.72 ± 0.27 events without the p_T^Z cut.

Another background is from QCD events with large L_{xy}. We estimate this background using Monte Carlo normalized to the number of large L_{xy} events in the data in an independent mass window, and find a background of 0.06 ± 0.06 events. Cosmic rays, our final background, have inherently large L_{xy}. We estimate this background from the number of events removed by cosmic rejection cuts together with the efficiencies of those cuts and find a background of 0.0004 ± 0.0001 events.

4. Acceptance $\times$ Efficiency

We use b' Monte Carlo to quantify the acceptance$\times$efficiency as a function of lifetime and mass, and normalize the efficiencies to those measured with Standard Model Z^0 candidates in data. Uncertainties on the efficiencies arise from the statistical precision with which they can be measured in the data and from systematic uncertainties in the simulation modeling. We find the dominant systematic uncertainty on the efficiency to be 7.4% from simulation modeling. Systematics on acceptance arise from incomplete knowledge of initial and final state radiation (ISR/FSR) and parton distribution functions (PDF). We find a systematic uncertainty of 11.4% on the acceptance.

5. Results

We plot the L_{xy} distribution in Figure 1. We observe three events with $L_{xy} > 0.3$ mm when we require $p_T^Z > 30$ GeV and two events with $L_{xy} > 1.0$ mm without the p_T^Z cut. In both cases, we see no events in the negative L_{xy} control region.

The observed number of events is consistent with the background expectation, and *a posteriori* inspection of the events shows them to be consistent with misreconstruction as expected for background. We calculate limits using the b' model for the acceptance$\times$efficiency. The cross section limits are plotted as a function of lifetime and mass in Figure 2 along with the LO theoretical cross section.

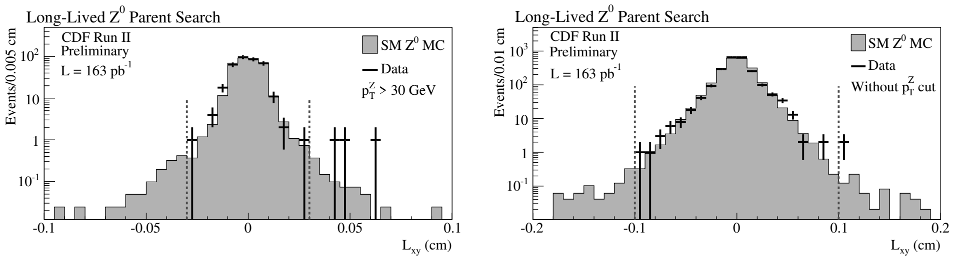

Fig. 1. L_{xy} distributions in data (points) and Monte Carlo (histogram). Left: With $p_T^Z > 30$ GeV. Right: Without. The dashed lines indicate the signal and control regions.

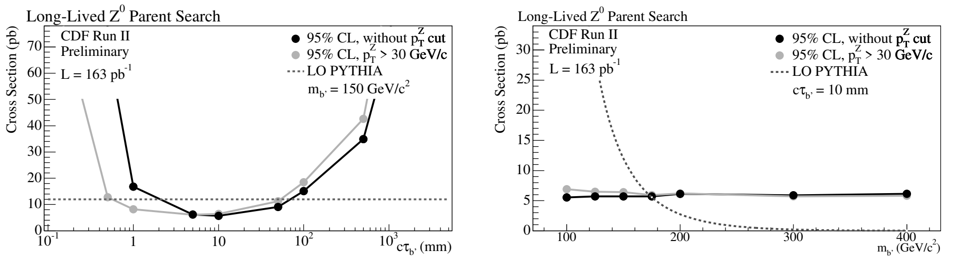

Fig. 2. Left: Cross section limits as a function of lifetime for $m_{b'} = 150$ GeV/c^2. Right: Cross section limits as a function of mass for a lifetime of $c\tau_{b'} = 10$ mm.

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References

1. The CDFII Detector Technical Design Report, Fermilab-Pub-96/390-E
2. F. Abe, *et al.*, *Phys. Rev. D* **58**, 051102 (1998).
3. S. Ambrosanio, *et al.*, *Phys. Rev. D* **54**, 5395 (1996)
4. T. Sjostrand, *et al.*, *Comput. Phys. Commun.* **135**, 238 (2001).