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SOLENOIDAL DETECTOR NOTES

Zη PRODUCTION WITH SDC

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Abstract

This document discusses detection of a new gauge boson with the SDC detector. Observation via the final states e^+e^-, $\mu^+\mu^-$ and $\tau^+\tau^-$ are discussed.

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If the gauge group of electroweak interactions is extended beyond $SU(2) \times U(1)$, the existence of additional heavy gauge bosons will be predicted. The masses and couplings of these gauge bosons are model dependent. Here we will be concerned with a neutral boson that occurs if the gauge group is extended to $SU(2) \times U(1) \times U(1)'$. In this case there will be an additional neutral gauge boson (called Z_η). More complicated extensions can have more neutral and also charged gauge bosons. In order to specify the couplings we will assume that the standard model is embedded in a grand unified E_6 theory. Such a theory can undergo symmetry breaking [3] so that $E_6 \to SO(10) \times U(1)_\alpha \to SU(5) \times \times U(1)_\alpha \times U(1)_\beta \to SU(3) \times SU(2) \times U(1) \times U(1)_\alpha \times U(1)_\beta$, producing two additional gauge bosons.[1] The gauge boson that we consider is a linear combination of these two:

$$Z' = Z_\alpha \cos\alpha + Z_\beta \sin\alpha \tag{1}$$

.

A special case occurs when E_6 breaks directly to a rank 5 group at the grand unified scale. In this case there is only one new gauge boson, Z_η, which corresponds to the case $\tan\alpha = -\sqrt{5/3}$.

We shall assume that there are no new fermions beyond those of the standard model that have a mass less than $M_{Z'}$. The couplings of the Z' to a fermion f are written as

$$\frac{e}{2\cos\theta_W} Z'_\mu \overline{f} \gamma^\mu (L_f(1-\gamma_5) + R_f(1+\gamma_5)) f \tag{2}$$

where $u_L = -u_R = d_L = -e_R = c_1$ and $\nu_L = e_L = -d_R = c_2$, with $c_1 = (\sqrt{5/72}\cos\alpha + \sqrt{1/24}\sin\alpha)$ and $c_2 = (\sqrt{5/72}\cos\alpha - \sqrt{3/8}\sin\alpha)$ In these equations θ_w is the usual weak mixing angle and α is a new angle. We shall neglect possible mixing between the Z' and the Z of the Standard model.

The width of Z' is then given by

$$\Gamma = \frac{5\alpha_{em}}{2\cos^2\theta_W} M_{Z'} (2c_1^2 + c_2^2) \tag{3}$$

and the branching ratio to $\ell^+\ell^-$ by

$$BR = \frac{c_1^2 + c_2^2}{15(2c_1^2 + c_2^2)} \tag{4}$$

[1] Other breakings leading to new charged gauge bosons at low energy are also possible. [3]

The couplings of the Z' to quarks and leptons are smaller (by approximately a factor of $\sin\theta_W$) than those of the Standard Model Z. Hence $\Gamma/M_{Z'}$ which varies as a function of α in the range 0.5% to 1.2%, is smaller than the corresponding ratio for the Standard Model Z. These smaller couplings also imply that a smaller range of masses can be probed at SSC than for other models [4].

Figures 1 and 2 show the invariant mass spectra of dilepton pairs (e^+e^- or $\mu^+\mu^-$) from the Z_η for masses of 800 GeV, 2 TeV, 3 TeV and 4 TeV, as well as the background from continuum Drell-Yan processes. There are no other relevant backgrounds.[2] The resolutions and efficiencies are as described in [1]. In the e^+e^- channel, the mass resolution of the detector is comparable to the natural width of the Z_η. Thus the mass can be determined and a limit can be placed on the width. To test universality in the μ and τ channels, the resolution must be sufficient to measure the rate. These figures show that the broad peak in the μ channel enables the rate to be measured and a measurement of the branching ratio to $\mu^+\mu^-$ to be made.

In the case of the decay to τ, the situation is more complex. One can look in three final states: $e\mu$, e (or μ) π or π–π. In all cases, there is an irreducible background from the pair production of τ's (Drell-Yan) and from the decays of τ's produced from the decays of $W's$ from $t\bar{t}$ events. In the case of an 800 GeV Z_η, the top background is larger than signal by two orders of magnitude. We do not at the moment know of a set of cuts sufficient to reduce this background to a manageable level. For heavier Z_η masses, it is possible to reduce the top background considerably by requiring the tracks have large p_t, large invariant mass and be almost back to back in azimuth, and by requiring that the events have missing E_t whose azimuthal angle is close to one of the tracks. Figure 3 shows the rate of production of $e\mu$, e (or μ) π and π–π pairs (all channels summed), where the particles are required to be isolated and to have $p_t > 200$ GeV. We have also required that there be at least 100 GeV of missing E_t and that the missing E_t vector in the transverse plane is within 30° of either track. The signal corresponds to a Z_η mass of 4 TeV. Backgrounds from $t\bar{t}$ production ($m_t = 150$ GeV), Drell-Yan production of τ pairs and QCD jet production are

[2]The absence of serious backgrounds for high p_t dileptons has been demonstrated in the UA1, UA2 and CDF experiments. The ratio of the Z_η cross section to QCD background at the SSC is similar to the ratio of Z production to QCD at current collider energies.

shown. For sufficiently large values of the invariant mass of the two track system, the Z_η produces a small but statistically significant excess of events, allowing a test of universality.

It is necessary to comment here on the assumptions used in calculating the dijet background. Resolution effects, including non-gaussian tails, have been incorporated using the parameterizations described in SSC-SDE-35. In addition, the jet cross section has been multiplied by a factor of 10^{-3} per jet (10^{-6} per event) to account for the probability that a jet fragments into a leading $\pi^\pm$ that carries almost all of the energy of the jet. The correct value for this probability for high E_t jets will not truly be known until it is measured at the SSC. We have here used a number consistent with the following CDF measurements:

- For dijet events with invariant mass in the range 80 GeV $< M_{jj} <$ 140, GeV a one sigma upper limit on the integrated fragmentation function for $z > 0.8$ is 1.4×10^{-3}[5]. (The effects of finite momentum resolution and systematics of jet energy corrections make this a limit rather than a measurment.)
- In the transverse momentum range 27 GeV $< p_t <$ 35 GeV, the ratio of the isolated π^0 cross section to the jet cross section is $\sim 5 \times 10^{-4}$[6]. Here isolation means less than 15% additional energy in a cone of size $\sqrt{\eta^2 = \phi^2} = 0.7$ centered on the π^0.

We note that the fragmentation function at large z should decrease with increasing jet E_t and thus the CDF estimates should be taken as a lower bound.

By measuring the asymmetry in the leptonic decays, one can gain information on the helicity structure of the couplings of the Z_η. Events are selected for which the Z_η is moving with pseudorapidity η. If η is sufficiently large, then, since the quarks in a proton have distributions that have more support at larger x than the antiquarks, the quark (anti-quark) that produced the Z_η is likely to have been moving in the same (opposite) direction from the Z_η itself. If the couplings of the quarks to the Z_η violate parity, the Z_η's will then be produced with some preferred helicity. If the leptonic couplings also violate parity, then by determining the lepton sign one can determine an asymmetry

$$A = \frac{\int_0^{\pi/2} dN/d\cos\theta - \int_{\pi/2}^{\pi} dN/d\cos\theta}{\int_0^{\pi/2} dN/d\cos\theta + \int_{\pi/2}^{\pi} dN/d\cos\theta}$$

where θ is the angle between the direction of the positively charged lepton and the Z_η in the Z_η rest frame.

In general extraction of the couplings from an asymmetry measurement is complicated. The asymmetry varies as a function of the the invariant mass of the dilepton pair since, as one moves away from the peak, interference effects between the photon, Z and Z_η become important. Recall that the Z_η has smaller couplings to fermions than the Z.

The angular distribution is shown in Figure 4 which shows an asymmetry. In the case of a 4 TeV Z_η, the asymmetry is more pronounced in the muon channel since the forward muon system enables a better measurement of the signs of forward going leptons. The asymmetry is a function of the mixing angle α (see Equation 1). It is maximal for $\cos\alpha \sim -0.6$. Figure 5 shows the angular distribution in this case. The asymmetry is much more pronounced than that shown in Figure 4, and it is clear the two cases are clearly distinguished. Note that for fixed $M_{Z'}$ the production cross section depends on α. Hence the total number of events in Figures 4 and 5 are not equal.

References

[1] I. Hinchliffe and M.D. Shapiro SSC-SDE-35.

[2] See for example, V. Barger *et al.*, "Signature for Extra Gauge Bosons of E_6 at the SSC" in *Proc. of the 1986 Snowmass Summer Study*, ed. J. Marx and R. Donaldson, FNAL (1987).

[3] P. Langacker, R.W. Robinett and J.L. Rosner, Phys. Rev. **D30,** 1470 (1984.

[4] E. Eichten *et al.*, Rev. Mod. Phys. **56**, 579 (1984).

[5] B. Hubbard, "Fragmentation Properties of Jets Produced in Proton-Antiproton Collisions at $\sqrt{s} = 1.8$ TeV," PhD Thesis, LBL-27687.

[6] R. Harris, for the CDF Collaboration, "Recent Results on Direct Photons from CDF," to be published in the *Proceedings of the Workshop on Hadron Structure Functions and Parton Distribution Functions,* Fermilab, April 1990.

Figure Captions

Figure 1: The cross-section $d\sigma/dM$ for the production of a lepton pair (e^+e^- (solid curve) or $\mu^+\mu^-$ (dashed curve)) as a function of the lepton pair invariant mass. The background is from the continuum production of lepton pairs (Drell-Yan). The peaks correspond a Z_η with mass of 800 GeV and 2 TeV . The dotted curve shows perfect resolution.

Figure 2: The cross-section $d\sigma/dM$ for the production of a lepton pair (e^+e^- (solid curve) or $\mu^+\mu^-$ (dashed curve)) as a function of the lepton pair invariant mass. The background is from the continuum production of lepton pairs (Drell-Yan). The peaks correspond to a Z_η with mass of 3 TeV and 4 TeV . The dotted curve shows perfect resolution.

Figure 3: The rate for the production of $e\mu$, e (or μ) π or π–π final states from the process $Z_\eta \to \tau\overline{\tau}$ with $m_{Z_\eta} = 4$ TeV. The pair is required to have invariant mass $m_{tt} > m_{tt_0}$. The tracks are required to have $p_T > 200$ GeV, to be back-to-back within 30° and to be isolated *i.e.* there is less than 5 GeV of additional energy in a cone of $\Delta R = 0.4$ around the track direction. The events are also required to have missing E_t of at least 100 GeV, and the missing E_t vector in the transverse plane is required to be within 30° of either track. Also shown is the background from $t\bar{t}$ production with $m_t = 150$ GeV (dotted), the Standard Model prediction for Drell-Yan production of τ pairs also shown (dot-dashed) and QCD jet production (dashed).

Figure 4: The cross-section $d\sigma/d\cos\theta$ for the production of a lepton pair (e^+e^- (solid curve) or $\mu^+\mu^-$ (dashed curve)). for a Z_η with mass of

800 GeV and 4 TeV . The reconstructed dilepton invariant mass is required to be $M_{Z_\eta} \pm 100$ GeV in the former case and $M_{Z_\eta} \pm 1000$ GeV in the latter. The longitudinal momentum of the Z_η greater than 500 GeV (1 TeV) in the former (latter) case.

Figure 5: Same as Figure 4 except that $\cos\alpha = -0.6$ has been used (see text).

Figure 1

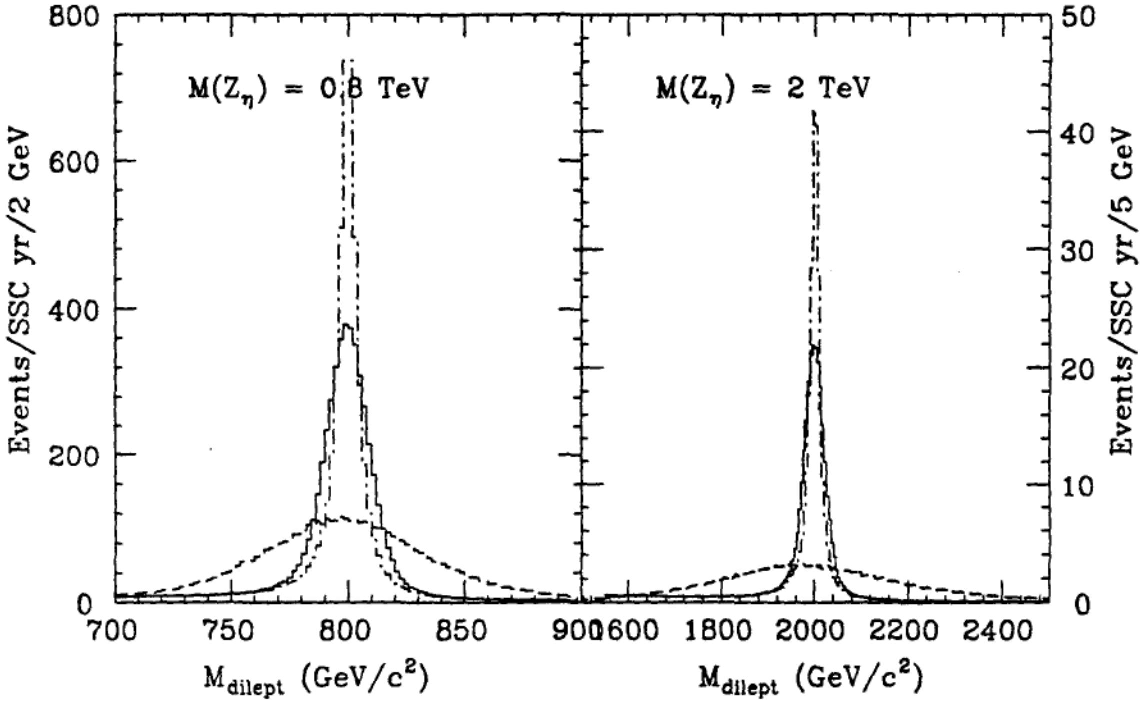

Figure 2

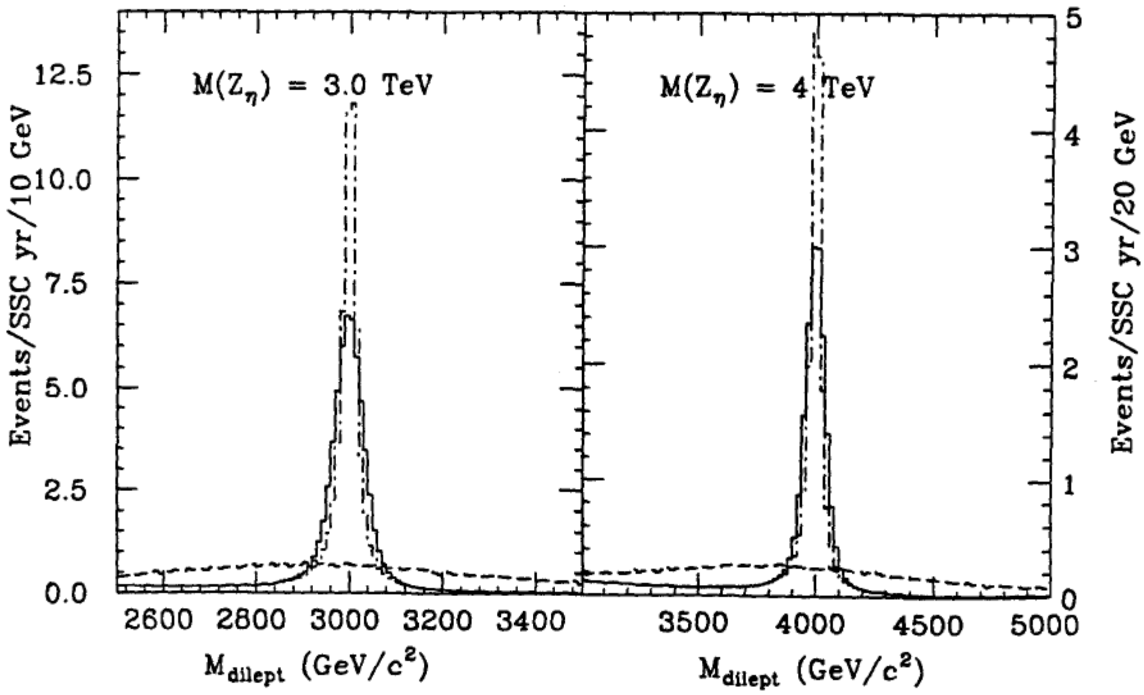

Figure 3

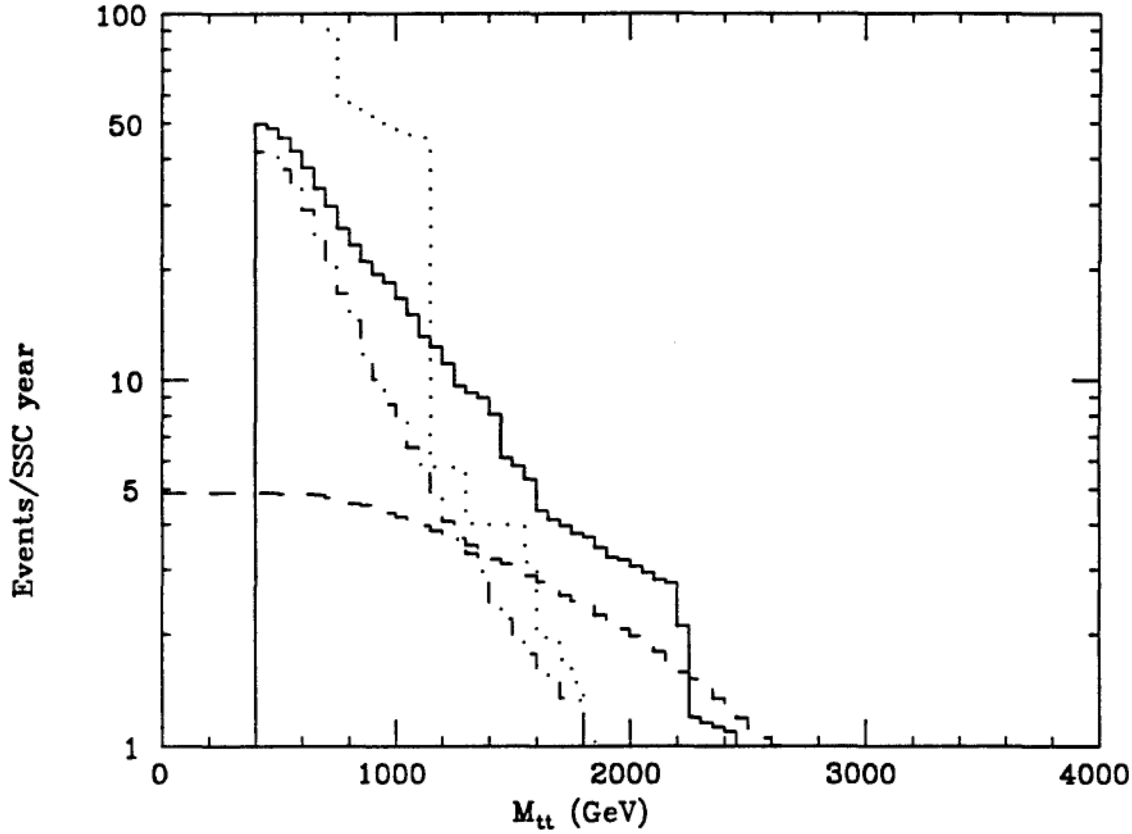

Figure 4

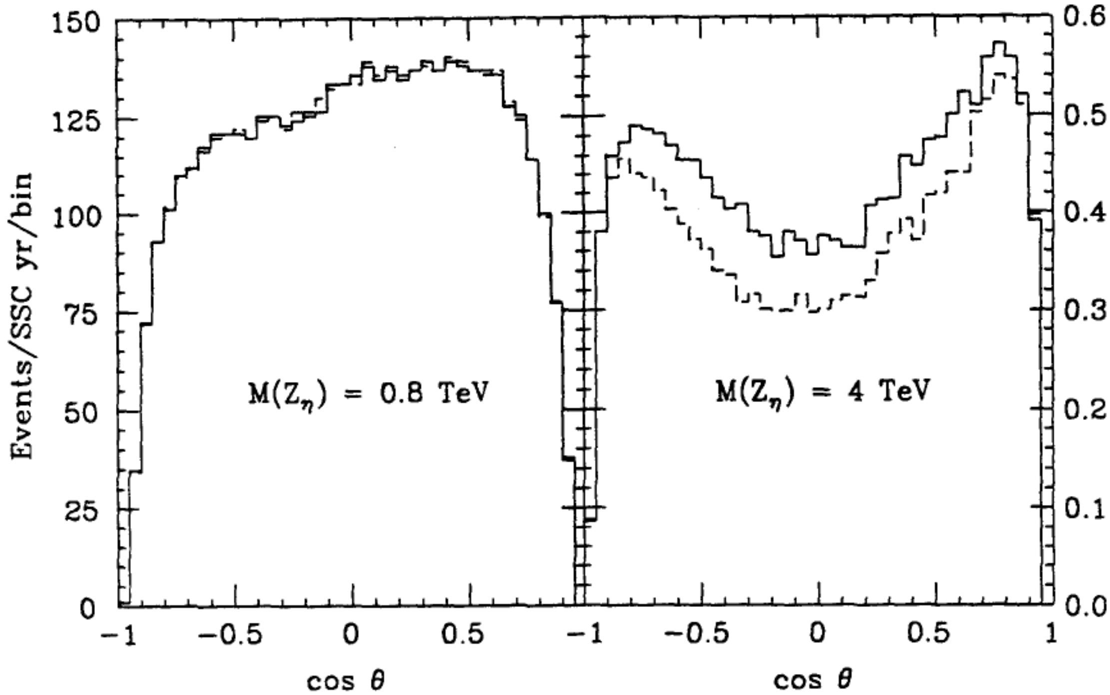

Figure 5