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SEARCH FOR SCALAR ELECTRONS AND WINOS AT THE CERN $\bar{p}p$ COLLIDER

The UA2 Collaboration

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Abstract

A search for supersymmetric decays of the Z boson into a pair of scalar electrons or winos (partners of the electron and W boson) has been made with the upgraded UA2 experiment at the CERN $\bar{p}p$ collider at $\sqrt{s} = 630$ GeV. The analysis of the sample of electron pairs, corresponding to an integrated luminosity of 7.4 pb^{-1} , shows no evidence for such exotic decays. The 90% confidence level lower mass limits obtained exclude selectron masses up to $40 \text{ GeV}/c^2$ in the case of a light photino, and wino masses up to $45 \text{ GeV}/c^2$ in the case of a light scalar neutrino.

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1 INTRODUCTION

Scalar leptons and gauginos, partners of leptons and gauge bosons in supersymmetric (SUSY) models [1,2,3] can be produced in hadron colliders through the decay of Intermediate Vector Bosons. In a previous letter [4] we reported the results of a search for scalar electrons ($\tilde{e}$), and winos ($\tilde{W}$) in the exotic decay of the Z. That analysis was performed using the data accumulated by the UA2 detector during the period 1983-85, corresponding to an integrated luminosity of 910 nb^{-1} .

The UA2 detector has been rebuilt, including new end-cap calorimeters and a new central detector. The commissioning of the new Antiproton Accumulator Complex (AAC) enabled the CERN $\bar{p}p$ collider to run at peak luminosities of up to $3 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1}$.

Thanks to this successful operation of the CERN $\bar{p}p$ complex, the upgraded UA2 detector has collected a total data sample of $\sim 7.8 \text{ pb}^{-1}$ during the 1988 and 1989 collider runs, out of which $\sim 7.4 \text{ pb}^{-1}$ has been used in this analysis.

We report here on the search for exotic decays of the Z boson into final states containing electron pairs, using that data sample. We have studied electron pairs as a possible signal for:

$$\begin{aligned} Z &\rightarrow \tilde{e}\tilde{e} \rightarrow ee\tilde{\gamma}\tilde{\gamma} \\ Z &\rightarrow \tilde{W}\tilde{W} \rightarrow ee\tilde{\nu}\tilde{\nu} \end{aligned}$$

The previous UA2 limits on $m_{\tilde{e}}$ and $m_{\tilde{W}}$ [4] are significantly improved, due to the ~ 8 times increase in the integrated luminosity and the improved detector performance.

In section 2, we present a brief description of the UA2 apparatus, emphasising the parts relevant to the analysis presented here. In section 3, the electron selection criteria and the resulting electron pair sample are discussed. Estimate for rates of known electron pair sources in UA2, mainly genuine electron pairs from Drell-Yan, and of fake electrons from the QCD background are given in section 4. Section 5 is devoted to the discussion of a possible SUSY signal and its signatures. Finally in the last section, we present the regions in the $(m_{\tilde{e}}, m_{\tilde{\gamma}})$ and $(m_{\tilde{W}}, m_{\tilde{\nu}})$ planes excluded by this analysis.

A search for squarks and gluinos produced by the strong interaction, with data collected by UA2 during the same running period, is presented in an accompanying letter [5].

2 THE UA2 APPARATUS

The UA2 detector has been upgraded, during the period 1985 to 1987, in order to exploit the increased luminosity of the CERN $\bar{p}p$ collider [6]. The main goals of the upgrade programme were:

- full calorimeter coverage to improve the missing transverse momentum ($\cancel{P}_T$) measurement
- improved electron identification
- a new trigger and data acquisition system to cope with the increased luminosity.

A Central Calorimeter (pseudorapidity range $-1 < \eta < 1$) and two End Cap Calorimeters [7] ($1 \leq |\eta| \leq 3$) provide full azimuthal ($0^\circ \leq \phi < 360^\circ$) coverage, down to 6° from

the beam axis. The calorimeters are subdivided into 624 cells and are made of lead/iron-scintillator sandwiches. The energy resolution for electromagnetic showers is typically $\sigma_E \sim 17\% \sqrt{E}$ (E in GeV). With the improved calorimeter coverage, a good measurement of the missing transverse momentum ($\cancel{P}_T$) is achieved. The $\cancel{P}_T$ resolution, Δ , can be parametrised as:

$$\frac{dn}{d(\cancel{P}_T)^2} \sim (1/\Delta^2) e^{-(\cancel{P}_T/\Delta)^2}$$

$$\Delta = \alpha(E_T^{tot})^\beta, \text{ with } \alpha = 0.8 \text{ and } \beta = 0.4$$

where E_T^{tot} is the total transverse energy measured in the calorimeter. A more comprehensive discussion of the $\cancel{P}_T$ measurement and resolution can be found in reference [5].

A longitudinal section of a quarter of the UA2 detector is shown in Figure 1. It consists of:

- a Scintillating Fibre Detector (SFD) [8] divided into a tracking part (6 stereo triplets) followed by a 1.5 radiation length thick lead converter, and two more stereo triplet layers, used as a preshower detector. The SFD is the outer component of the central detector.
- two layers of silicon pad detectors (SI) [9], one immediately outside the beam pipe at a radius of 3.5 cm, the second at a radius of 14.5 cm. The counters are used for tracking and ionisation measurements.
- a Transition Radiation Detector (TRD) [10] consisting of two sets of radiator + X-ray detector, which can be used to improve the electron signature.
- a cylindrical drift chamber, with jet geometry, the Jet Vertex Detector (JVD) [11], located between the two silicon layers, used for track reconstruction.

The central detector is complemented in the end-cap regions by a system of proportional tubes (ECPT) [12], which provides both tracking and preshower information. A Time Of Flight (TOF) system provides a triggering signal.

A three level trigger system [13] is used, based mainly on calorimeter information. The analysis presented here uses the data from the electron pair trigger. At least two electromagnetic clusters ($|\eta| \leq 2$), separated by at least 60° in azimuth, and with transverse energies above 5.5 GeV, are required for an event to satisfy this trigger. Electromagnetic clusters (EM) are selected with respect to the lateral (cluster radius) and longitudinal shower profile. The data sample selected by the electron pair trigger consists of ~ 300000 events (1988 + 1989).

3 ELECTRON SELECTION

Electron candidates are selected by requiring an electromagnetic cluster (CAL cut), associated with a reconstructed track (TRK cut) and a preshower hit. A quality factor ($P(\chi^2)$) for the track - calorimeter shower profile match is computed by comparing the calorimeter lateral and longitudinal shower profiles, to those expected from isolated electrons, impinging along the track direction. Further cuts use this quality factor ($P(\chi^2)$ cut), the preshower pulseheight and its displacement (PS cut). In addition, in the end

cap regions, where more background from photon conversions in the material near the beam pipe is observed, we require the outer silicon pulse height to be compatible with one minimum ionizing particle (Si Cut).

The efficiency of these cuts as measured using electrons from W events [14] in the central (CC) and end cap (EC) regions is:

$$\varepsilon_e^{CC} = \varepsilon_{CAL} \star \varepsilon_{TRK} \star \varepsilon_{PS} \star \varepsilon_{P(\chi^2)} = 65.6 \pm 2.0\%$$

$$\varepsilon_e^{EC} = \varepsilon_{CAL} \star \varepsilon_{TRK} \star \varepsilon_{PS} \star \varepsilon_{P(\chi^2)} \star \varepsilon_{Si} = 55.0 \pm 2.6\%$$

The electron pair sample discussed below contains mainly electrons with lower P_T than those from $W \rightarrow e\nu$ decay. Varying the selection cuts has shown that no significant additional loss of efficiency occurs for low P_T electrons [15].

In addition to the selection criteria discussed above, we require a reconstructed event vertex to be within ± 300 mm of the detector centre. The corresponding efficiency is $\varepsilon_{vx} = 98 \pm 1\%$.

Applying these electron selection criteria to both electron candidates in the event, we obtain a total sample of 562 electron pair candidates with a mass above $10 \text{ GeV}/c^2$. The e^+e^- mass spectrum for these events is shown in Figure 2. After background subtraction, the spectrum of genuine electron pairs can be extracted (see section 4.2).

Decays of the Z boson into $\bar{e}$ and $\tilde{W}$ pairs are expected to produce, in general, electron pairs of rather high invariant mass. We restrict our analysis therefore to the subsample of electron pairs with masses above $20 \text{ GeV}/c^2$. This sample contains 243 events ($M_{ee} > 20 \text{ GeV}/c^2$), of which 123 have masses larger than $70 \text{ GeV}/c^2$ and are identified as $Z \rightarrow e^+e^-$ decays [14]. A detailed study of the low mass region ($10 < M_{ee} < 20 \text{ GeV}/c^2$) and of the Drell-Yan signal will be reported in a separate paper [15].

4 DRELL-YAN SIGNAL AND BACKGROUND ESTIMATION

Genuine electron pairs from the Drell-Yan process,

$$p + \bar{p} \rightarrow \gamma/Z + X \rightarrow e^+e^- + X$$

and fake electrons, from QCD processes, are the two main contributions to our electron pair sample. The "QCD background" where hadronic jets fake the electron signature can be estimated using the data.

4.1 Background evaluation

Starting from the sample of electromagnetic cluster pairs ($\sim 300\,000$ events, EM-EM sample), we apply the electron cuts to one cluster in the event, to extract the so called EM-E sample. The final sample (E-E sample) is obtained by requiring both candidates to satisfy the electron selection criteria. Neglecting events consisting of a genuine electron produced in association with an electromagnetic cluster from a jet, we can establish the following relations:

$$N_{EM-EM} = B + S$$

$$N_{EM-E} = \left(\frac{2}{R} - \frac{1}{R^2}\right) \star B + (2\varepsilon - \varepsilon^2) \star S$$

$$N_{E-E} = \frac{1}{R^2} \star B + \varepsilon^2 \star S$$

where:

N_x is the number of events in sample x

B is the number of background electromagnetic jet pairs (fake electron pairs)

S is the number of genuine electron pairs

R is the rejection against hadrons

ε is the efficiency for electrons

For our data sample, at low masses (below $\sim 50 \text{ GeV}/c^2$):

$$\frac{1}{R} \star B \gg S$$

We can then compute the rejection R , by comparing the (EM-E) and (EM-EM) distributions. The background fraction in the final sample (E-E sample) is estimated to be $1/R^2 \star B$. The results are summarized in Table 1, for different mass bins, together with the corresponding numbers of events. The background rejection in the Central ($R_{CC} \sim 40$) and the End-Cap ($R_{EC} \sim 30$) regions being different, the background estimate is done separately for each of these regions.

4.2 Estimate of the Drell-Yan signal

We use a simple Monte Carlo generator of Drell-Yan pairs, which contains lowest order matrix elements for Drell-Yan and Z production:

$$q\bar{q} \rightarrow \gamma/Z \rightarrow e^+e^-$$

$$\text{and} \quad q\bar{q} \rightarrow \gamma/Z \rightarrow \tau^+\tau^-; \tau^\pm \rightarrow e\nu\nu_\tau$$

In this simulation we use the structure functions of reference [16]. The e^+e^- transverse momentum, P_T , is generated according to the model of reference [17]. The simulation program takes into account the detector geometrical acceptance and the effect of the trigger threshold, as well as the electron energy resolution. The P_T resolution is parametrized as a function of the electron pair P_T as described in reference [18].

We normalise the expected distribution to the number of events observed in the Z region ($M_{ee} > 70 \text{ GeV}/c^2$, 123 events), thus reducing the uncertainty on the theoretical prediction arising from higher order terms (K-factors). The results of this estimation for $p\bar{p} \rightarrow Z/\gamma \rightarrow e^+e^-$ and $p\bar{p} \rightarrow Z/\gamma \rightarrow \tau^+\tau^-; \tau^\pm \rightarrow e\nu\nu_\tau$ processes are summarized in Table 1.

Using the Eurojet Monte Carlo [19], we have estimated the contribution of $b\bar{b}$ production where both quarks decay into electrons. Because of the much lower efficiency of the selection criteria for the non-isolated electrons from b decays, this contribution was found to be negligible.

Table 1 shows that, after subtracting the QCD background, the observed signal is in fair agreement with the expected Drell-Yan signal.

	$20 < M < 32$	$32 < M < 50$	$50 < M < 70$	$M > 70$
Data	77	30	13	123
QCD Back.	41.2 ± 2.7	10.1 ± 0.7	1.1 ± 0.1	0.4 ± 0.1
Drell-Yan/Z [†]	47.1 ± 6.8	19.1 ± 4.3	7.3 ± 2.7	123 ± 11

[†] Only statistical errors are included for the estimate of the expected Drell-Yan/Z contribution

Table 1: Number of events in different mass bins (M in GeV/c²)

5 SCALAR ELECTRON OR WINO PRODUCTION

A possible signal from decays of the Z boson into $\tilde{e}$ or $\tilde{W}$ pairs is estimated using the Monte Carlo described above, where we have included the matrix elements for:

$$q\bar{q} \rightarrow \gamma/Z \rightarrow \tilde{e}\tilde{e} \quad (A)$$

$$q\bar{q} \rightarrow \gamma/Z \rightarrow \tilde{W}\tilde{W} \quad (B)$$

The first process (A) is generated assuming that:

- the supersymmetric partners of the left handed electron ($\tilde{e}_L$) and of the right handed electron ($\tilde{e}_R$) are degenerate in mass ($m_{\tilde{e}_L} = m_{\tilde{e}_R}$). In this case:

$$\Gamma(Z \rightarrow \tilde{e}\tilde{e})/\Gamma(Z \rightarrow ee) = 0.5 \quad (m_{\tilde{e}} \simeq 0)$$

- the photino ($\tilde{\gamma}$) is the lightest supersymmetric particle (LSP) and stable (conservation of R-parity). The $\tilde{e}$ decays into an electron and a photino ($\tilde{e} \rightarrow e + \tilde{\gamma}$), with the $\tilde{\gamma}$ escaping detection.

For the second process (B), we assume that :

- the $\tilde{W}$ is a pure gaugino. The Z coupling to $\tilde{W}$ pairs is then relatively strong :

$$\Gamma(Z \rightarrow \tilde{W}\tilde{W})/\Gamma(Z \rightarrow ee) \sim 9.6 \quad (m_{\tilde{W}} \simeq 0)$$

- The $\tilde{\nu}$ is the LSP, and the branching ratio for the decay $\tilde{W} \rightarrow e + \tilde{\nu}$ is larger than 20 %. The $\tilde{\nu}$ escapes detection.

For both processes, the final states contain an electron pair in association with missing transverse momentum, resulting from the escaping $\tilde{\gamma}$ or $\tilde{\nu}$. In addition, combining the

		Selection 1	Selection 2
Data	Nb. of events	5	2
QCD back. + Exp. Drell-Yan	Nb. of events	3.0	0.8
$Z \rightarrow \tilde{e}\tilde{e}$ $m_{\tilde{e}} = 35$, $m_{\tilde{\gamma}} = 20$ (GeV/c ²)	Acceptance (%)	46 %	38 %
	Exp. Nb. Evt.	7.1	5.9
$Z \rightarrow \tilde{W}\tilde{W}$ $m_{\tilde{W}} = 42$, $m_{\tilde{\nu}} = 0$ (GeV/c ²)	Acceptance (%)	65 %	61 %
	Exp. Nb. Evt.	16.5	15.4

Selection 1 : $20 < \text{Mass} < 70$ GeV/c² , $\cancel{E}_T > 10$ GeV/c

Selection 2 : $20 < \text{Mass} < 70$ GeV/c² , $\cancel{E}_T > 10$ GeV/c , $P_{T\eta} > 7$ GeV/c

Table 2: Expected rates for SUSY processes

electron pair topology with the $\cancel{E}_T$ measurement results in an increased rejection against rare cases of background events, in which large $\cancel{E}_T$ is generated by experimental effects.

This is illustrated by the $P_{T\eta}$ versus $\cancel{E}_T$ distribution, shown in Figure 3 for the decay $Z \rightarrow \tilde{e}\tilde{e}$ with a particular set of masses. $P_{T\eta}$ is the projection of the pair transverse momentum on the e^+e^- internal bisector :

$$P_{T\eta} = (P_{Te1} + P_{Te2}) * \cos(\delta\phi/2),$$

where P_{Te1} and P_{Te2} are the electron transverse momenta, and $\delta\phi$ the azimuthal angle between the two electrons. $P_{T\eta}$ is a good measure of the electron pair topology and is less sensitive to shower fluctuations in the calorimeter. While $\cancel{E}_T$ and $P_{T\eta}$ are expected to be rather uncorrelated in conventional processes , they are strongly correlated in the case of a signal from SUSY particles.

Table 2 summarizes the rates expected in UA2, after two sets of kinematical cuts, for $m_{\tilde{e}} = 35$, $m_{\tilde{\gamma}} = 20$ GeV/c² (process A), $m_{\tilde{W}} = 42$ GeV/c² , $m_{\tilde{\nu}} = 0$ (process B). The normalization factor is identical to the one used for the Drell-Yan/Z estimate. The observed number of events, and the expectations from conventional processes (QCD background, Drell-Yan and Tau pair production) for the same kinematical cuts are also included in this table.

6 SCALAR ELECTRON AND WINO MASS LIMITS

To derive limits on the $\tilde{e}$ and $\tilde{W}$ mass values, we compare our sample of e^+e^- pairs with invariant masses above 20 GeV/c² with the predictions of the model, where we have included contributions from either process $Z \rightarrow \tilde{e}\tilde{e}$ or $Z \rightarrow \tilde{W}\tilde{W}$, in addition to the signal from Drell-Yan ($p\bar{p} \rightarrow \gamma/Z \rightarrow e^+e^-$ or $\tau^+\tau^-$ with $\tau \rightarrow e\nu\nu_\tau$) and QCD background. This analysis is carried out using three kinematical variables to characterize an event :

- the e^+e^- pair mass (M_{ee})
- the missing transverse momentum $\cancel{P}_T$
- the η projection of the electron pair transverse momentum ($P_{T\eta}$)

Figure 4 shows the distribution of electron pairs with masses below 70 GeV/c², in the $(\cancel{P}_T, P_{T\eta})$ plane. As shown in Table 2, we observe two events in the region $\cancel{P}_T > 10$ GeV/c and $P_{T\eta} > 7$ GeV/c, where most of the contribution from SUSY processes is expected.

Mass limits for SUSY particles are obtained by dividing the $M_{ee}, \cancel{P}_T, P_{T\eta}$ space into 19 independent regions and evaluating for each region the contribution from Drell-Yan conventional processes and QCD background as well as the expected SUSY signal. The latter is calculated using the Monte Carlo simulation for any choice of $(m_{\tilde{e}}, m_{\tilde{\gamma}})$ or $(m_{\tilde{W}}, m_{\tilde{\nu}})$ mass values. The results are then used to define a likelihood ratio RL :

$$RL_{exp} = \prod_{i=1}^{19} \left[\frac{P_i^0}{P_i^s} \right]^{N_i}$$

where N_i is the number of events in zone i and P_i^0 (P_i^s) is the expected fraction of events in zone i without (with) the SUSY contribution.

For each set of mass values for SUSY particles, a likelihood ratio distribution is then generated by a Monte Carlo program for the case of no SUSY signal (dn^0/dRL), and if a SUSY signal is present (dn^s/dRL). A 90 % CL exclusion value, RL_{90} , is then defined by the relation:

$$\frac{\int_{RL_{90}}^{\infty} (dn^s/dRL) dRL}{\int_{RL_{90}}^{\infty} (dn^0/dRL) dRL} = 0.1$$

The chosen set of mass values for SUSY particles is then excluded to a confidence level of at least 90 % if $RL_{exp} > RL_{90}$.

There is no evidence for a SUSY signal in our data, and the regions of the $(m_{\tilde{e}}, m_{\tilde{\gamma}})$ and $(m_{\tilde{W}}, m_{\tilde{\nu}})$ planes excluded at the 90 % confidence level are shown in Figure 5.

Because of the normalisation procedure used in this analysis, the theoretical uncertainties on the Z production cross section do not affect rates of SUSY particles. The systematic uncertainties on the mass limits of Figure 5 are dominated, therefore, by the uncertainties on the estimate of the QCD background, and of higher order, mass dependent, corrections to the Drell-Yan cross section, as well as by the incomplete knowledge of the $\cancel{P}_T$ resolution and of the transverse momentum distribution of the e^+e^- pairs. The shaded area in Figure 5, obtained by varying the above parameters, shows the effect of these systematic errors on our limits.

Recent results from e^+e^- experiments are also included [20]. A recent analysis of lepton pairs with missing transverse momentum by the L3 collaboration [21] excludes selectron masses below 41 GeV/c² and wino masses below 44 GeV/c² at 95 % confidence level, using more pessimistic assumptions on the $\tilde{W}$ decay branching ratio. For photinos lighter than 35 GeV/c², $\tilde{e}$ masses up to 43.5 GeV/c² and $\tilde{W}$ masses up to 45.5 GeV/c² are excluded at 95 % confidence level by the ALEPH experiment [22].

7 CONCLUSIONS

The present study excludes at the 90 % confidence level the existence of scalar electrons with masses up to 40 GeV/c² in the case of a light photino. Similarly, within the assumptions discussed in section 5, winos lighter than 45 GeV/c² are also excluded at 90 % CL, in the case of a light scalar neutrino.

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Figure captions

Fig. 1 Partial and schematic longitudinal view of the UA2 detector.

Fig. 2 Distribution of the electron pair mass, M_{ee} , for the selected events.

Fig. 3 SUSY Monte Carlo distributions for $Z \rightarrow \tilde{e}\tilde{e}$ decays, with $m_{\tilde{e}} = 35 \text{ GeV}/c^2$ and $m_{\tilde{\gamma}} = 20 \text{ GeV}/c^2$:

- a) $\cancel{E}_T$ versus $P_{T\eta}$
- b) $P_{T\eta}$ projection of a)
- c) $\cancel{E}_T$ projection of a)
- d) Electron pair mass

Fig. 4 Same as Figure 3a) for the final data sample with $20 < M_{ee} < 70 \text{ GeV}/c^2$

Fig. 5 Excluded regions at 90 % confidence level:

- a) In the $(m_{\tilde{e}}, m_{\tilde{\gamma}})$ plane. The dashed area indicates the effect of systematic uncertainties.
- b) Same as a) in the $(m_W, m_{\tilde{\nu}})$ plane.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5a

Figure 5b