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MEASUREMENT OF W AND Z PRODUCTION PROPERTIES
AT THE CERN $\bar{p}p$ COLLIDER

The UA2 Collaboration

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ABSTRACT

A study has been made of the production characteristics of W and Z bosons produced at the CERN $\bar{p}p$ Collider. The event sample consists of 251 $W \rightarrow e\nu$ decays, and 39 $Z \rightarrow e^+e^-$ decays, identified by the UA2 detector, and corresponds to an integrated luminosity of 142 nb^{-1} at $\sqrt{s} = 546 \text{ GeV}$, and 768 nb^{-1} at $\sqrt{s} = 630 \text{ GeV}$. Measurements of W and Z production cross-sections, of longitudinal and transverse momentum distributions, and of associated jet production, are presented. These measurements are compared with theoretical expectations, which include higher order QCD effects.

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1. INTRODUCTION

In a series of physics runs at the CERN $\bar{p}p$ Collider which ended in 1985, the UA2 detector has collected data which correspond to a total luminosity of 142 nb^{-1} at a centre-of-mass energy $\sqrt{s} = 546 \text{ GeV}$, and 768 nb^{-1} at 630 GeV . As previously reported [1], samples of $251 W \rightarrow e\nu$ decays and $39 Z \rightarrow e^+e^-$ decays, have been identified from an analysis of these data, under clean background conditions. The kinematical cuts used to define the W sample are $p_T^e > 20 \text{ GeV}$ and $m_{T^{e\nu}} > 50 \text{ GeV}$, where p_T^e is the electron transverse momentum and $m_{T^{e\nu}}$ is the transverse mass of the electron-neutrino pair. For $Z \rightarrow e^+e^-$ decays, the corresponding cuts are $p_T^e > 10 \text{ GeV}$, $m(e^+e^-) > 76 \text{ GeV}$ and $\Delta\phi > 60^\circ$, where $\Delta\phi$ is the azimuthal separation between the two electron momenta.

Results from these event samples which are relevant to comparisons with the Standard Electroweak Model have already been reported [1]. In this publication we describe the measured production characteristics of the Intermediate Vector Bosons (IVB), and we compare them with theoretical predictions based on the Drell-Yan mechanism of $q\bar{q}$ annihilation, corrected for higher-order QCD effects.

2. CROSS-SECTIONS

The cross-section σ_W^e for the inclusive process $\bar{p}p \rightarrow W + \text{anything}$, followed by the decay $W \rightarrow e\nu$, is obtained from the relation

$$N_W^e = L \sigma_W^e \varepsilon_W \eta_W \quad (1)$$

where N_W^e is the observed number of $W \rightarrow e\nu$ decays, L is the total integrated luminosity, ε_W is the detector acceptance (which includes both geometrical acceptance and the effect of the kinematical cuts), and η_W is the overall efficiency of the electron identification criteria.

We obtain N_W^e from the event sample described in Ref. [1]. This sample is contaminated by fake electrons, as well as by electrons from $Z \rightarrow e^+e^-$ decays with one electron escaping the detector acceptance, and from $W \rightarrow \tau\nu_\tau$ decays, followed by $\tau \rightarrow e\nu\bar{\nu}$. These backgrounds are estimated as described in our previous publications [1,2], and are given separately in Table I for the two values of $\sqrt{s}$ at which the data have been collected.

We note that the number of events and the values of ε_W and η_W (see Table 1) differ slightly from those published previously [1,2]. At $\sqrt{s} = 546 \text{ GeV}$, the difference is the result of the new $W \rightarrow e\nu$ identification criteria used in the analysis, while at $\sqrt{s} = 630 \text{ GeV}$ we have excluded 4% of the data which were taken with a poorly known track reconstruction efficiency.

Table I gives also the values of L , ε_W and η_W , from which we derive the values

$$\sigma_W^e(546 \text{ GeV}) = 0.61 \pm 0.10(\text{stat.}) \pm 0.07(\text{syst.}) \text{ nb} \quad (2)$$

$$\sigma_W^e(630 \text{ GeV}) = 0.57 \pm 0.04(\text{stat.}) \pm 0.07(\text{syst.}) \text{ nb} \quad (2')$$

where the quoted systematic errors include contributions from uncertainties on ε_W , η_W and L . The uncertainty on L is estimated to be $\pm 8\%$ [3].

The total cross-section for W production is predicted to be [4] $\sigma_W(546 \text{ GeV}) = 4.7^{+1.4}_{-0.7} \text{ nb}$, and $\sigma_W(630 \text{ GeV}) = 5.8^{+1.8}_{-1.0} \text{ nb}$, where the errors reflect theoretical uncertainties on the structure functions and ambiguities in the choice of the Q^2 scale. Using these values and the results of our measurements (Eqs. 2 and 2') we obtain

$$B(W \rightarrow e\nu) = 0.10 \pm 0.01(\text{exp.})^{+0.02}_{-0.03} \quad (\text{theor.})$$

for the decay branching ratio, where the second error results from the theoretical uncertainty on σ_W mentioned above. This value agrees with the Standard Model prediction, which, in the case of three fermion families, falls in the range 0.086 - 0.11 depending on the mass of the top quark.

The ratio between the W production cross-sections at the two $\sqrt{s}$ values is measured to be

$$r = \sigma_W^e(630 \text{ GeV})/\sigma_W^e(546 \text{ GeV}) = 0.93 \pm 0.17.$$

This value, which has a small systematic uncertainty, is 1.8 standard deviations lower than the theoretical prediction [4], $r = 1.23$, which has practically no theoretical uncertainty.

We obtain the cross-section σ_Z^e for the inclusive process $\bar{p}p \rightarrow Z + \text{anything}$, followed by the decay $Z \rightarrow e^+e^-$, from the relation

$$N_Z^{ee} = L \sigma_Z^e \varepsilon_Z \eta_Z \quad (3)$$

where N_Z^{ee} is the observed number of $Z \rightarrow e^+e^-$ decays, ε_Z is the detector acceptance, which includes both geometrical acceptance and the effect of the kinematical cuts, and η_Z is the efficiency of the selection criteria described in Ref. [1]. A list of relevant quantities is given in Table II. The contribution from hadronic background given in Table II has been estimated by applying to the present data the method described in Ref. [2]. Other sources of background, such as the decay $Z \rightarrow \tau^+\tau^-$ followed by the decay $\tau \rightarrow e\nu\bar{\nu}$ for both τ -leptons, are negligible. We note that the value of η_Z is larger than that of η_W (see Table I) in spite of the presence of two electrons, because of the much looser selection criteria used to identify $Z \rightarrow e^+e^-$ decays.

We find

$$\begin{aligned} \sigma_Z^e(546 \text{ GeV}) &= 116 \pm 39(\text{stat.}) \pm 11(\text{syst.}) \text{ pb}, \\ \sigma_Z^e(630 \text{ GeV}) &= 73 \pm 14(\text{stat.}) \pm 7(\text{syst.}) \text{ pb}. \end{aligned} \quad \begin{matrix} (4) \\ (4') \end{matrix}$$

The total cross-section for Z production is predicted to be [4] $\sigma_Z(546 \text{ GeV}) = 1.3^{+0.4}_{-0.2}$ nb, and $\sigma_Z(630 \text{ GeV}) = 1.7^{+0.5}_{-0.3}$ nb. Using these values and the results of our measurements (Eqs. 4 and 4') we obtain

$$B(Z \rightarrow e^+e^-) = 0.046 \pm 0.008(\text{exp.})^{+0.008}_{-0.014} \quad (\text{theor.})$$

for the decay branching ratio, where the second error results from the theoretical uncertainties on σ_Z . This value is consistent with the Standard Model prediction, which for three fermion families is in the range 0.031 to 0.035, depending on the value of the top quark mass.

The ratio between the Z production cross-sections at the two $\sqrt{s}$ values is measured to be

$$r = \sigma_Z^e(630 \text{ GeV})/\sigma_Z^e(546 \text{ GeV}) = 0.6 \pm 0.3,$$

to be compared with the theoretical prediction [4], $r = 1.25$.

3. LONGITUDINAL MOMENTUM DISTRIBUTIONS

The fractional longitudinal momentum $x_W = 2p_L^W/\sqrt{s}$ carried by the W bosons is related to the fractional momenta of the partons involved in W production. At the energies of the CERN $\bar{p}p$ Collider, these partons are mostly quarks in the proton and antiquarks in the antiproton.

In $W \rightarrow e\nu$ events the neutrino longitudinal momentum, p_L^ν , which is not measured directly, is obtained by constraining the invariant mass of the $e\nu$ pair to be equal to the W mass. Such a constraint provides two solutions for p_L^ν , of which one is found to be unphysical in 6.2% of the events. In the other cases, we choose the solution corresponding to the smaller value of $|p_L^W|$ (Monte Carlo studies show that this procedure gives the correct value of p_L^ν in $\sim 70\%$ of the events). We note that in most $W \rightarrow e\nu$ events the sign of the electron charge is not measured, and a separate determination of the p_L^W distributions for W^+ and W^- is not possible. The experimental distribution $dn/d|x_W|$ is shown in Fig. 1a, where it is compared with the distribution expected from the structure functions of Duke and Owens [5], taking into account detector acceptance, resolution and our definition of p_L^W .

In the case of Z events, p_L^Z is determined unambiguously from the measurement of the electron momenta. A comparison of the distributions $dn/d|x_Z|$ with expectations is shown in Fig. 1b.

For both W and Z events, the agreement between the observed and expected distributions is consistent with a production mechanism dominated by quark-antiquark annihilation.

4. IVB TRANSVERSE MOMENTUM AND ASSOCIATED HADRONS

The IVB longitudinal momentum distribution discussed in the preceding section is accounted for to leading order by the Drell-Yan annihilation diagram. However, this process implies that the IVB transverse momentum, p_T^{IVB} , is equal to zero. Non-zero values result from higher order QCD contributions in which hadrons are produced in association with the IVB.

Existing calculations of higher order QCD contributions assume that the associated hadrons can be unambiguously separated in two families. A first family results from the hadronisation of gluons radiated by the quark-antiquark pair annihilating in the Drell-Yan process. A second family results from the independent interaction of the remaining incoming partons (spectators). Reliable descriptions of the first family are available [4,6], in particular if large transverse momentum hadrons are produced [7] or if soft gluon resummation techniques can be used [4,8]. There exists, however, no calculation related to the second family. While its contribution to p_T^{IVB} is expected to be negligible, it is likely to account for a large fraction of the total hadronic transverse energy, ΣE_T^H .

From an experimental point of view a direct measurement of p_T^{IVB} is only possible in the Z case for which $\vec{p}_T^{IVB} = \vec{p}_T^{e^+} + \vec{p}_T^{e^-}$. In the W case, in which the decay neutrino is undetected, the total transverse momentum of the associated hadrons, $\vec{p}_T^H = -\vec{p}_T^{IVB}$, could be measured instead. However, only part of the associated hadrons are produced inside the UA2 acceptance and their momenta are less accurately measured than those of electrons (in particular in the forward regions of the UA2 detector). As a result our measurement of p_T^W is less reliable and less accurate than that of p_T^Z . The latter is measured with an average uncertainty of ± 2 GeV, mostly due to the uncertainty in the measurement of the energies of the decay electrons. If we consider instead p_{η}^Z , the component of $\vec{p}_T^Z$ on the bisector of the e^+ and e^- transverse momenta (Figure 2), an even better accuracy, ~ 0.23 GeV, is obtained : this quantity is only affected by angular measurement errors [9], and its distribution can be directly compared with theory. This is done in Figure 2 for the $Z \rightarrow e^+e^-$ events previously discussed. The theoretical p_{η}^Z distribution is deduced from the p_T^Z distribution of Ref. [4] under the assumption that the directions of the Z transverse momentum and spin are uncorrelated.

The measured p_{η}^Z distribution corresponds to an average value $\langle p_T^Z \rangle = 8.6 \pm 1.5$ GeV of the Z transverse momentum.

The distributions of p_T^{seen} and ΣE_T^{seen} , the total transverse momentum and total transverse energy of the hadrons detected in the UA2 acceptance, are shown in Figure 3 for the W and Z samples separately. We have shown in the preceding section that the observed W and Z bosons have very similar longitudinal momentum distributions despite their different decay configurations (the neutrino is not confined to the UA2 acceptance). We expect therefore the associated hadrons to be produced with very similar rapidity distributions : those detected in UA2 should exhibit no significant difference between the W and Z samples, and this is indeed what is observed in Figure 3.

The Z sample provides an opportunity to compare the distribution of $\vec{p}_T^Z$ with that of $\vec{p}_T^{\text{seen}}$, thereby giving an evaluation of the accuracy of the indirect measurement of p_T^W from $\vec{p}_T^{\text{seen}}$. Two factors contribute to the observed difference between $\vec{p}_T^Z$ and $\vec{p}_T^{\text{seen}}$: the limited precision achieved in measuring $\vec{p}_T^{\text{seen}}$ and the limited detector coverage. In order to study this effect, it is convenient to project $\vec{p}_T^{\text{seen}}$ on $\vec{p}_T^Z$ ($p_{\parallel}^{\text{seen}}$) and on the orthogonal direction ($p_{\perp}^{\text{seen}}$). An ideal detector with complete angular coverage would give $p_{\perp}^{\text{seen}} = 0$ and $p_{\parallel}^{\text{seen}} = -p_T^Z$. We find $\langle |p_{\perp}^{\text{seen}}| \rangle = 3.1$ GeV on average : we expect the balance relation, $p_T^Z + p_{\parallel}^{\text{seen}} = 0$, to be satisfied to a similar accuracy. While most events show indeed a clear tendency for p_T^Z and $p_{\parallel}^{\text{seen}}$ to balance each other, we measure an average imbalance $\langle p_T^Z + p_{\parallel}^{\text{seen}} \rangle = 3.2$ GeV, as a result of the incomplete angular coverage of the UA2 detector.

These results demonstrate that p_T^W cannot be measured to better than 5 GeV or so. In particular, a measurement of the shape of the p_T^W distribution is not possible in the region $p_T^W < 5$ GeV. We note that detectors with much larger rapidity coverage, while ensuring that no high- p_T hadron escapes detection, have still a limited precision because the measurement of p_T^{seen} involves a large number of particles emitted over a large rapidity interval, resulting in a measurement error of several GeV [10].

It is instructive to compare the IVB-associated hadrons with those produced in minimum-bias interactions. A major difference is the much rarer occurrence of hadron jets in the latter case. We restrict this study to the central UA2 calorimeter in which jets are defined from transverse energy clusters of adjacent calorimeter cells [11,12]. In each event we select the cluster having the largest transverse energy, E_T^{max} . The distributions of E_T^{max} for W events and minimum-bias events are compared in Figure 4. In contrast with minimum bias events several W events have E_T^{max} in excess of 10 GeV. They can be ascribed to a process in which a hard gluon was radiated from the quark-antiquark pair producing the W boson, and will be considered in detail in the next section. In addition to this hard component, the distribution of Figure 4 contains a soft component at low E_T^{max} , whose shape is broader than that measured in minimum bias events (the two shapes become similar if in the case of minimum bias events E_T^{max} is multiplied by 1.45 ± 0.15). We cannot say whether this effect results from the radiation of soft gluons off the quark-antiquark pair producing the W or from a difference between minimum bias interactions and spectator interactions (or from both). Empirically, we find that minimum bias events in which all hadron momenta have been multiplied by 1.45 are very similar to W-associated hadrons in events without jets. The ΣE_T^{seen} distribution of such "inflated" minimum bias events is compared to that of W-associated hadrons (including those with jets) in Figure 3b.

We have applied transverse Lorentz boosts to these "inflated" events using the theoretical p_T^W distribution of Ref. [4], under the assumption that the hadronic system recoiling against the W has an invariant mass of 40 GeV, as measured, on average, for the Z sample. The resulting p_T^{seen} distribution is compared in Figure 3a to that of W events. The good agreement suggests that such "inflated" minimum bias events can be conveniently used to describe the W-associated hadrons of non-perturbative origin.

5. HADRON JETS ASSOCIATED WITH IVB PRODUCTION

As previously noted, non-leading QCD contributions to IVB production generate final states in which one or more gluon or quark jet is produced in association with the IVB at a rate depending on the value of the strong coupling constant α_s . The singularities associated with the collinear emission of gluons from massless quarks imply that most jets from initial state gluon radiation tend to go in the directions of the beams, and therefore escape detection. Sometimes, however, they have large enough transverse momenta to be detected. Furthermore, the IVB can be produced in association with a quark from the interaction of an incoming quark-gluon pair. The production cross-sections have been calculated to $\mathcal{O}(\alpha_s^2)$ in perturbative QCD [7]. A comparison with our W event sample provides a quantitative test of the theory.

In the present analysis the search for jets is restricted to the central UA2 calorimeter [12] which detects electromagnetic and hadronic showers over the full azimuth range for pseudorapidities $|\eta| < 1$. We have developed a jet definition algorithm optimised for a reliable measurement of the jet energies. The measured energy pattern is first reduced to a set of clusters of adjacent cells [11]. Jet axes are then defined as straight lines joining the cluster centroids and the reconstructed interaction vertex. Finally, jet energies are measured as the sum of the energies of all calorimeter cells having their centre within a cone of half-angle ω with respect to the jet axis. In adjusting ω we have taken two effects into account: the contribution of jet fragments outside the cone was estimated from e^+e^- data [13] in the appropriate energy range (7 to 17 GeV) and cross-checked against UA2 data, and the contamination of spectator interactions inside the cone was studied from W events observed in the UA2 detector with no associated jet activity. We adopt the value $\cos \omega = 0.76$ ($\omega \simeq 40^\circ$) for which each contribution amounts on average to $\simeq 1.8$ GeV resulting in an approximate cancellation of the two effects.

In the following we only retain jets having a transverse energy (measured inside the cone) exceeding 10 GeV and having their axis within the pseudorapidity interval $|\eta| < 0.85$. The rare occurrence of such jets in minimum bias events ($\simeq 0.6\%$, see also Fig. 4) indicates that this cut should allow for a reliable comparison between data and lower order perturbative QCD. The W sample is found to contain 221 events without jet, 29 events with one jet, and 1 event with two jets. The distribution of the jet transverse energy is shown in Fig. 5. For the event containing two jets the sum of their transverse energies is plotted. This event (having jet transverse energies of 41 and 24 GeV) and the event having the largest jet transverse energy (74 GeV) stand out from the rest of the sample. They were discussed in more detail in previous publications [2,14].

The comparison between the data and the QCD model [7] requires defining cut-offs to ensure that the parton configuration in the final state is free of divergences. A similar situation was met in an earlier study [15] dealing with three-jet final states, to which we refer the reader for details. Here we impose that the outgoing parton or partons have transverse energies exceeding 6 GeV and be separated by more than 20° from each other. The K-factors, which account for the effect of higher order α_s terms not included in the perturbative expansion, depend on this choice. The cross-sections are calculated using structure functions [16] evolved to $Q^2 = m_W^2$ with a value $\Lambda = 0.4$ GeV for the strong interaction scale. As was the case in Ref. [15] this choice of Q^2 is somewhat arbitrary when large transverse momentum jets are associated with the IVB, a fundamental limitation when comparing the values of α_s obtained from different processes. The QCD calculation is implemented within the frame of a Monte-Carlo simulation of the experiment which includes the effects of the acceptance of the UA2 detector and the details of the energy response of the central calorimeter. Parton fragmentation follows an algorithm [17] adjusted to correctly describe the observed energy flow distribution around the jet axis. The underlying event associated with spectator interactions is simulated by superimposing onto each W + jet(s) event a measured UA2 minimum-bias event, chosen at random, and for which all calorimeter cell energies are scaled by a factor 1.45 (see the preceding section). The Monte Carlo generated events are submitted to the same selection criteria as the actual data. The number of accepted Monte Carlo events is normalized to the total number of W events (after background subtraction) in order to study the relative occurrence of associated jet production.

The jet transverse energy distribution obtained with $\alpha_s = 0.15$ is compared in Fig. 5 to that observed in the data. The agreement is well within statistical uncertainties. In particular there are 26.1 $W + 1$ jet events (background subtracted) against an expectation of 28.1, one $W + 2$ jets event against an expectation of 2.9 and 2 events having a total jet transverse energy in excess of 50 GeV against an expectation of 3.3. This comparison implicitly assumes that the factor K_n associated with final states containing n partons does not depend on n . In fact the relative population of $W + 1$ jet events provides essentially a measure [15] of $\alpha_s K_1/K_0 = 0.13 \pm 0.03$, where the quoted uncertainty is only statistical. This result is affected by systematic uncertainties on the structure and fragmentation functions used in the Monte Carlo, as well as by uncertainties on the jet energy scale and on the simulation of the underlying event, resulting in an overall systematic error of $\pm 20\%$. Different choices of the Q^2 scale give slightly different values of $\alpha_s K_1/K_0$, most of the difference being the effect of the Q^2 dependence of the structure functions.

A critical comparison between this result and measurements of α_s obtained from the study of other processes [15,18] is beyond the scope of the present study, and we simply stress the overall agreement between data and theory. In particular, the two outstanding events mentioned earlier, which happen to have occurred in the early stages of data taking, do not require any particular mechanism other than that provided by the standard model of strong and electroweak interactions. A further illustration of this fact is given in Fig. 6 where we plot the invariant mass distribution of the $W + \text{jet(s)}$ system (the neutrino longitudinal momentum is evaluated according to the same prescription as described in Section 3). Data and theory are in good agreement and we find no evidence for an additional production mechanism.

The Z sample contains 4 events with one jet and no event with two or more jets. Their configurations are in agreement with theoretical expectations.

6. CONCLUSIONS

We have presented a study of IVB production properties based on data collected by the UA2 detector from $\bar{p}p$ collisions at $\sqrt{s} = 546$ and 630 GeV. This study includes the measurement of the production cross-sections, and the measurement of the IVB longitudinal and transverse momentum distributions. A detailed study of the hadrons produced in association with the IVBs has been made. It includes a qualitative description of the set of low transverse momentum hadrons and a detailed comparison with perturbative QCD for the occurrence of large transverse momentum hadron jets. In all cases the data agree with the predictions of the standard model of strong and electroweak interactions.

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FIGURE CAPTIONS

1. Distributions of the variable $x = 2 p_T/\sqrt{s}$ for W production (a) and Z production (b). The curves are predictions using the structure functions of Ref. [5].
2. The distribution of the η -component (see insert) of the Z transverse momentum (histogram) is compared with theoretical predictions obtained from Ref. [4] using two different sets of structure functions (DO1 is for Duke Owens 1, see Ref. [5], and GHR is for Glück, Hoffmann and Reya, see Ref. [16]), which correspond to two different values of the strong interaction scale Λ (GeV).
3. The p_T^{seen} and ΣE_T^{seen} distributions of hadrons observed in association with W-bosons (black circles) and Z-bosons (open circles) are compared with :
a) the transverse momentum distribution of "inflated" minimum bias events (see text) boosted according to the W-transverse momentum distribution of Ref. [4],
b) the ΣE_T distribution of "inflated" minimum bias events.
4. The transverse energy distribution of the central calorimeter cluster having the largest transverse energy. Full circles : W events. Broken line : minimum-bias events. Full line : "inflated" minimum-bias events (see text).
5. Transverse energy distribution of W-associated hadronic jets. The dotted line is obtained using the QCD model of Ref. [7]. The shaded event is the only one containing two jets.
6. Invariant mass distribution of the W + jet(s) system. The shaded event is the only one containing two jets. The dotted line is the QCD prediction obtained using the model of Ref. [7].

TABLE I
The $W \rightarrow e\nu$ event sample.

$\sqrt{s}$ (GeV)	546	630
Integrated luminosity (nb^{-1})	142	738
Acceptance ϵ_W	0.61 ± 0.02	
Detection efficiency η_W	0.72 ± 0.06	
Number of $W \rightarrow e\nu$ candidates	42	206
Hadronic background	1.8 ± 0.3	9.4 ± 1.7
$W \rightarrow \tau\nu, \tau \rightarrow e\nu\bar{\nu}$	0.8 ± 0.1	4.2 ± 0.4
$Z \rightarrow e(\text{detected}) e(\text{undetected})$	1.5 ± 0.2	7.8 ± 1.3
$W \rightarrow e\nu$ signal	37.9 ± 6.5	184.6 ± 14.5

TABLE II
The $Z \rightarrow e^+e^-$ event sample.

$\sqrt{s}$ (GeV)	546	630
Integrated luminosity (nb^{-1})	142	768
Acceptance ϵ_Z	0.57 ± 0.02	0.55 ± 0.02
Detection efficiency η_Z	0.94 ± 0.03	
Number of $Z \rightarrow e^+e^-$ candidates	9	30
Hadronic background	0.2	1.1
$Z \rightarrow e^+e^-$ signal	8.8 ± 3.0	28.9 ± 5.5

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6