A measurement of two-jet decays of the $W$ and $Z$ bosons at the CERN $\bar{p}p$ collider

UA2 Collaboration


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Received 24 July 1990

Abstract. A study of the two-jet mass spectrum measured with the UA2 calorimeter has revealed a signal from hadronic decays of $W$ and $Z$ bosons above a large background. Production and decay properties of the signal have been measured. The combined production cross-section $\sigma \cdot B(W, Z \to \text{two jets})$ is $9.6 \pm 2.3 \text{(stat.)} \pm 1.1 \text{(syst.)}$, compared with an expectation of 5.8 nb calculated to order $x^2$. A limit on the production cross-section of additional heavy vector bosons decaying into two jets is given as a function of the boson mass.

1 Introduction

Hadronic jets represent the dominant contribution to high transverse momentum processes in proton-antiproton collisions. High-$p_T$ jets were observed in the early phase of experimentation at the CERN $\bar{p}p$ collider [1] and their production properties are successfully described by perturbative QCD [2].

Intermediate vector bosons, $W$ and $Z$, are expected to decay predominantly into quark-antiquark pairs which evolve into jets very similar to those originating...
from QCD processes. Studies of $W$ and $Z$ bosons at $\bar{p}p$ colliders have therefore been restricted to their leptonically decaying modes [2–5] providing a cleaner experimental signature which separates them from hadronic background. The motivations to measure the hadronic decays of $W$ and $Z$ bosons are manifold:

(i) While the properties of $Z$ decays are being thoroughly studied in $e^+e^-$ collisions [6], $W$ bosons are currently the domain of $\bar{p}p$ colliders which provide the only direct access to their hadronic decay properties.

(ii) $W$ and $Z$ decays to quark-antiquark pairs provide a reference signal to verify experimentally the assignment of jets to parent partons. Ambiguities in this assignment do exist due to higher order QCD effects resulting in the production of more than two high-$p_T$ partons. Such contributions have recently been calculated to order $\alpha_s^3$ [7]. Since partons fragment into the experimentally measured hadrons the definition of a jet is no longer unique and requires instead a prescription for which hadrons to include ("jet algorithms"). The observation of a peak in the two-jet mass spectrum provides a direct test of such prescriptions.

(iii) Once the assignment of jets to their parent partons is verified, two- or multi-jet mass distributions can be used to search for new particles using the measured parameters of the $W$ and $Z$ bosons as a calibration ("jet spectroscopy"). Hadronic decay modes may provide the only direct experimental access to a possible right-handed $W$ boson if its leptonic decays are suppressed or inhibited by the large mass of the right-handed neutrino [8].

The similarity between two-jet final states from the weak production and decay of $W$ and $Z$ and those originating from strong parton-parton interactions excludes an analysis on an event-by-event basis. Instead the peak structure from hadronic $W$ and $Z$ decays has to be observed as a departure from the smooth two-jet mass spectrum from QCD processes. The background is expected to exceed the signal by about two orders of magnitude. The mass resolution for two-jet final states in UA2 is of the same order as the mass difference between the $W$ and the $Z$ (about 10 GeV), so that the two peaks cannot be resolved.

A previous UA2 search [9] for $W$ and $Z$ bosons in the two-jet mass spectrum revealed a signal of $632\pm 190$ events with shape and position consistent with expectations. The signal size expected from the Standard Model was $340\pm 80$ events. The analysis was based on a data sample corresponding to an integrated luminosity of 0.73 pb$^{-1}$. The present analysis uses data collected during the 1989 collider run, corresponding to a sample 6 times larger of 4.7 pb$^{-1}$.

The following Section briefly describes the components of the upgraded UA2 detector relevant to this analysis. Section 3 explains the jet identification methods used at the trigger level and in the data analysis. The two-jet mass spectrum is described in Sect. 4. In Sect. 5 the production and decay parameters of the signal are determined. A cross-section is given and compared with the Standard Model prediction. A search for additional heavy vector bosons decaying into jet pairs is reported in Sect. 6.

2 UA2 apparatus

The entire UA2 apparatus was upgraded during the years 1985 to 1987. A global overview of the different components can be found in [10]. In order to handle the high jet production rates down to two-jet invariant masses well below the $W$ mass region with the UA2 trigger and data acquisition system, only data from the calorimeter were recorded, thus keeping the readout time and event size small.

2.1 Calorimetry

This Section summarizes the main features of the UA2 calorimeter relevant to the analysis presented here. A more complete description can be found in Ref. [11].

Calorimetry is provided over the full azimuthal range, $0^\circ < \phi < 360^\circ$ and the pseudorapidity region $|\eta| < 3$. The calorimeters are subdivided into the central calorimeter (CC) covering pseudorapidities $|\eta| < 1$ and two end-cap calorimeters (EC) covering the region $0.9 < |\eta| < 3$.

The CC is segmented into 240 cells subtending $10^\circ$ in $\theta$ and $15^\circ$ in $\phi$. The electromagnetic part is a multi-layer sandwich of lead and scintillator 17 radiation lengths deep, while the hadronic part, subdivided into two compartments, is an iron-scintillator sandwich, resulting in a total thickness of 4.5 absorption lengths including the electromagnetic compartment.

Each EC consists of 12 azimuthal modules, each subdivided into 16 cells. While the cells closest to the beam axis ($2.5 < |\eta| < 3.0$ and $2.2 < |\eta| < 2.5$) cover $30^\circ$ in azimuth, all cells in the pseudorapidity interval $1.0 < |\eta| < 2.2$ have a segmentation of $\Delta \phi = 15^\circ$ and $\Delta \eta = 0.2$, with one electromagnetic and one hadronic compartment. The cells closest to the beam axis have only hadronic compartments. The electromagnetic compartment is a multi-layer sandwich of lead and scintillator with a total thickness varying from 17.1 to 24.4 radiation lengths depending on the polar angle. The hadronic calorimeter is a multi-layer sandwich of iron and scintillator corresponding to about 6.5 absorption lengths, including the electromagnetic cells. Cells with only hadronic calorimetry cover the pseudorapidity interval $0.9 < |\eta| < 1.0$ to measure the energy of particles which could otherwise escape detection in the interface between EC and CC modules. To minimize dead spaces in the boundaries between two neighbouring EC modules, the modules have been rotated by 50 mrad around their symmetry axis normal to the beam.

The initial absolute calibration of the calorimeters was obtained by exposing every cell to beams of electrons, pions and muons of known momenta. The calibration stability was monitored by measuring the calorimeter response to a radioactive source (Co$^{60}$). The accuracy