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MEASUREMENT OF THE STRONG COUPLING CONSTANT α_s FROM
A STUDY OF W BOSONS PRODUCED IN ASSOCIATION WITH JETS

The UA2 Collaboration

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ABSTRACT

The UA2 experiment at the CERN $\bar{p}p$ Collider has identified a total sample of 251 $W \rightarrow e\nu$ events. Among this sample 221 events are found without jets and 29 with one jet. The yield of one-jet events relative to that of zero-jet events provides a measurement of the strong coupling constant : $\alpha_s(M_W^2) = 0.13 \pm 0.03(\text{stat}) \pm 0.03(\text{syst}_1) \pm 0.02(\text{syst}_2)$, where syst_1 represents the experimental systematic error and syst_2 is an estimate of the theoretical uncertainty.

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1. INTRODUCTION

The UA2 experiment, in operation at the CERN SPS $\bar{p}p$ Collider has collected data which correspond to an integrated luminosity of 142 nb^{-1} at a centre-of-mass energy $\sqrt{s} = 546 \text{ GeV}$ and 768 nb^{-1} at $\sqrt{s} = 630 \text{ GeV}$. An analysis of these data has led to the selection of a sample of 251 events satisfying the hypothesis of a $W \rightarrow e\nu$ decay, with an estimated background contamination of 25.6 events. The kinematical cuts used to define this sample are $p_T^e > 20 \text{ GeV}/c$ and $m_T^{e\nu} > 50 \text{ GeV}/c^2$, where p_T^e is the electron transverse momentum and $m_T^{e\nu}$ is the transverse mass of the electron-neutrino pair. Details about the data analysis can be found in Ref. [1].

In two previous publications, this sample (hereafter referred to as the W sample) was used to measure the parameters of the standard electroweak model [1] and to study the production properties of the W boson [2]. In this letter, we present an analysis of these data leading to a determination of the strong coupling constant α_s .

To leading order, the production of a W boson is described by the Drell-Yan mechanism. The strong interaction accounts for corrections, which result in hadron jets produced in association with the W. To first approximation, the yield of $W + 1 \text{ jet}$ events is proportional to α_s , thus providing a means to measure α_s . More precisely, we choose to determine α_s from the one-jet to zero-jet ratio, by comparing its experimental value, R_{exp} , to the QCD predicted value, R_{MC} , obtained from a Monte Carlo simulation of W production.

2. JET ACTIVITY IN W EVENTS

Jets in W events are defined in the following way : we first consider energy clusters formed by adjacent calorimeter cells containing more than 400 MeV [3]. The straight line joining the interaction vertex to the centroid of each cluster defines the cluster axis. To improve the measurement of the jet energies we then restrict the search for jets to the central region of the UA2 calorimeter because of the incomplete hadronic calorimetry in the two forward regions [4]. This is equivalent to applying a cut $|\eta| < 0.85$ on the pseudorapidity of the cluster axis, η . The energy of each selected cluster is then computed as the sum of the energies contained in all cells whose centres belong to a cone drawn around the cluster axis. The cone half-angle ω_0 was chosen to optimize the jet energy measurement. In adjusting ω_0 two effects must be taken into account : first, a fraction of the jet energy is lost because of jet fragments emitted at large angles outside the cone. Secondly, a part of the cone energy is due to particles belonging to the underlying event and emitted inside the cone. These two effects are illustrated in Fig. 1. The value $\omega_0 \simeq 40^\circ$ is chosen so that the two effects approximately compensate each other on average in the jet energy range of the present sample.

Finally, in order to reduce systematic uncertainties in the jet energy measurement and to decrease the number of jets arising from the underlying event, we only retain jets whose transverse energy exceeds 10 GeV. The splitting of the W sample according to the number of associated jets is presented in Table 1, which also shows the background contamination in each family of events. Background to $W \rightarrow e\nu$ decays comes from fake electrons, electrons from $Z \rightarrow e^+e^-$ decays with one electron escaping the detector acceptance and electrons from $W \rightarrow \tau\nu_\tau$ decays where the τ subsequently decays into $e\nu$. The method used to estimate these backgrounds, already described in our previous publications (see, for example, Ref. [1]), was applied separately to each class of events in the W sample. After background subtraction we deduce from Table 1 :

$$R_{\text{exp}} = \frac{\text{number of } W + 1 \text{ jet}}{\text{number of } W + 0 \text{ jet}} = 0.127 \pm 0.029$$

3. W PRODUCTION SIMULATION

The evaluation of R_{MC} is based on a Monte-Carlo simulation of W events. This requires first to simulate the production of a W boson, with ideally all QCD corrections incorporated. In practice, we use the most complete simulation program presently available (hereafter referred to as the EKS Monte-Carlo), which includes the matrix elements of all tree diagrams for W production, up to order α_s^2 [6]. The infrared and collinear divergences associated with such a method are regularized by applying cut-offs on the transverse momentum p_T of each outgoing parton and on the angular separation ω of each pair of outgoing partons :

$$p_T > p_T^{\min} \quad \omega > \omega^{\min} \quad (1)$$

where $p_T^{\min}$ and $\omega^{\min}$ are non-zero minimal values. The EKS simulation represents only a partial calculation of the total W production cross-section, because loop diagrams and tree diagrams with outgoing partons which do not fulfill the conditions (1) are not taken into account. In addition, diagrams of higher order than α_s^2 are not included. The effect of the missing contributions is then described by multiplicative correction factors, which will subsequently be referred to as K-factors.

In order to define these K-factors, we adopt the formalism proposed in Ref. [7] and introduce topological cross-sections related to the production of a W boson with a specified number of outgoing partons obeying conditions (1). In the following, the generic topological cross-section will be denoted by σ_i , where i stands for the considered number of partons. The lowest order contribution to σ_i comes from tree diagrams of order α_s^1 , and will subsequently be referred to as σ_i . In addition, σ_i receives contributions from higher order diagrams where i outgoing partons fulfilling the conditions (1) are produced together with additional virtual gluons and/or outgoing partons not satisfying the criteria (1). While contributions from these individual diagrams suffer usually from infrared divergences, cancellations occur when they are regrouped, making it reasonable to use a perturbative expansion for σ_i :

$$\tilde{\sigma}_i = \sigma_i + \sum_{k=i+1} (\alpha_s)^k a_{ik} \quad (2)$$

The sum of all topological cross-sections gives the total W production cross-section. To describe the difference between σ_i and $\tilde{\sigma}_i$, we define the i-th order K-factor as :

$$K_i = \tilde{\sigma}_i / \sigma_i = 1 + \sum_{k=i+1} (\alpha_s)^k a_{ik} / \sigma_i \quad (3)$$

As for $\tilde{\sigma}_i$ and σ_i , K_i also depends on the cut-offs $p_T^{\min}$ and $\omega^{\min}$.

In practice, the EKS simulation includes tree diagrams up to second-order only and provides the cross-sections σ_i for $i = 0, 1, 2$. This leads us to restrict ourselves to a second-order description of W production, so that only the terms up to order α_s^2 have to be considered in the preceding perturbative expansions. Under such conditions, Eq. (3) shows that K_0 and K_1 must be computed to order α_s^2 and α_s , respectively, while for K_2 we use the lowest order value, which is equal to 1. An estimate of K_0 and K_1 will be given in section 4.

The value of R_{MC} is derived from a complete simulation of W events, which includes five steps. The first one consists of generating final-states composed of a W boson plus zero, one or two outgoing partons, according to the EKS simulation described above. The parameters used for this step are listed in Table 2. The Q^2 choice and the cut-off values will be discussed later. Partons are then fragmented according to the Field-Feynman distribution [8] adjusted to correctly reproduce the experimental energy flow distributions observed for jets in the UA2 experiment. The next step consists in simulating the detector response to all produced particles, including the effects of the UA2 detector acceptance

and the details of the energy response of the calorimeter. The underlying event is simulated at this stage by superimposing onto each generated event an experimental UA2 minimum-bias event, chosen at random, and for which all calorimeter cell energies are multiplied by a factor 1.45. This method is suggested by the observation that minimum bias events whose energy content has been multiplied by a factor $\lambda = 1.45$ reproduce the hadronic activity of W events without jets [2]. Finally, the simulated events are submitted to the same analysis as the actual data. We end up then with three samples of simulated W events, corresponding to the production of a W boson in association with i partons ($i = 0, 1, 2$). We call N_i the total numbers of events in these samples.

Due to our jet definition and because of acceptance and resolution effects, the number of jets reconstructed in a simulated W event is not necessarily equal to the number of produced partons. Each N_i splits, therefore, into several components, each of them corresponding to a given number of reconstructed jets :

$$N_i = \sum N_{ij}$$

where i stands for the number of partons and j for the number of reconstructed jets. With these notations, the value for the one-jet to zero-jet ratio to order α_s^2 is then :

$$R_{MC} = \frac{K_0 N_{01} + K_1 N_{11} + K_2 N_{21}}{K_0 N_{00} + K_1 N_{10} + K_2 N_{20}} \quad (4)$$

where K-factors have been introduced in the appropriate places. To obtain a second-order prediction, we recall that K_0 must be computed to order α_s^2 and K_1 to order α_s , while K_2 is simply equal to 1. At this point, we should comment on the Q^2 value. In the simulation, we choose a constant scale, $Q^2 = M_W^2$, so that the value of α_s is well determined and remains the same for all simulated events. In addition, the K-factor computations can be decoupled from the simulation, which justifies the K_i factorization in Eq. (4). In writing (4), we nevertheless make an assumption concerning the K-factors. These have indeed been defined to correct the N_i globally, ignoring a possible dependence of these factors on the final number of reconstructed jets in the simulated events. This is presently the best we can do to include all QCD corrections up to order α_s^2 , in the absence of a complete simulation program.

The N_{ij} and K-factors depend on α_s and so does R_{MC} . By varying α_s in the simulation and in the computation of the K-factors, we can obtain R_{MC} as a function of α_s . The experimental value of the strong coupling constant is then the value of α_s which makes R_{MC} equal to R_{exp} . For practical reasons, instead of repeating the simulation and K-factor computations for various α_s , we do it once for a reference value of α_s , called α_s^{MC} in the following. From the values of Q^2 and Λ given in Table 2, we have $\alpha_s^{MC} = 0.154$ (first-order estimate). The values of N_{ij} , K_0 and K_1 for a different value of α_s are then estimated by using the following formulae :

$$\begin{aligned} N_{ij}(\alpha_s) &= (r)^i N_{ij}(\alpha_s^{MC}) \\ K_0(\alpha_s) &= 1 + r \alpha_s^{MC} k_{01} + r^2 (\alpha_s^{MC})^2 k_{02} \\ K_1(\alpha_s) &= 1 + r \alpha_s^{MC} k_{11} \end{aligned} \quad (5)$$

where $r = \alpha_s / \alpha_s^{MC}$. The quantities k_{01} , k_{02} and k_{11} describe the coefficients of the K-factor expansions in power series in α_s . They are deduced from the K-factor computations done for $\alpha_s = \alpha_s^{MC}$. Such formulae implicitly assume that the N_{ij} and the K-factors are independent of the α_s value used in the structure function evolution and depend only on the α_s value used in the matrix elements. The validity of this assumption will be discussed later.

To apply the method described above, K_0 and K_1 must be known, otherwise only a partial result can be obtained under the form $\alpha_s K_1/K_0$, such as the one previously published [2]. Since then, progress has been made in the knowledge of the K-factors. A partial calculation of K_0 and K_1 is now possible, as explained in the next section, thus providing a determination of α_s .

4. K-FACTOR ESTIMATES

The calculation of K_0 to order α_s^2 and of K_1 to order α_s requires the matrix element calculation of all diagrams involved in W production up to order α_s^2 . For the moment, while the matrix elements of all first-order diagrams are known [10], this is only partially the case for the second-order diagrams [11]. Therefore, what can presently be provided is an exact calculation of K_0 limited to order α_s and an approximate calculation of K_1 to the same order. These calculations have been made within the framework of the MS renormalization scheme and are described in the following. More details can be found in Ref. [12].

To order α_s , K_0 is related to the first-order total W production cross-section $\sigma^{(1)}$. By definition of the topological cross-sections, $\sigma^{(1)}$ is equal to the sum of $\tilde{\sigma}_0$ and $\tilde{\sigma}_1$. Given the definition of K_0 and the fact that, to order α_s , $\tilde{\sigma}_1$ is identical to σ_1 , we have :

$$\sigma^{(1)} = K_0 \sigma_0 + \sigma_1$$

This equation leads to :

$$K_0 = \frac{\sigma^{(1)} - \sigma_1}{\sigma_0}$$

where σ_0 and σ_1 are given by the EKS simulation program. For $\sigma^{(1)}$, we use the result of a calculation based on the matrix elements of all first-order diagrams with no soft gluon resummation [13]. The cross-sections σ_0 and $\sigma^{(1)}$ are independent of $p_T^{\min}$ and $\omega^{\min}$, while σ_1 depends on $p_T^{\min}$ only. To order α_s , K_0 is then a function of $p_T^{\min}$, with the dependence as shown in Fig. 2a. Apart from $p_T^{\min}$, the other parameters involved in the calculation are Q^2 , Λ and the structure functions. The values chosen for them are the same as in the program used to simulate W events (see Table 2).

The shape of the curve in Fig. 2a results from the $p_T^{\min}$ dependence of σ_1 . In particular, for large values of $p_T^{\min}$, σ_1 vanishes so that K_0 tends asymptotically towards a constant value $K_{\text{tot}} = \sigma^{(1)}/\sigma_0$. With the Q^2 and Λ values used in the calculation and for our choice of structure functions (see Table 2), this asymptotic value is $K_{\text{tot}} = 1.40$. On the other hand, as $p_T^{\min}$ decreases, σ_1 diverges because $p_T^{\min}$ is no longer an effective cut-off against infrared divergences. This explains the divergence of K_0 at low $p_T^{\min}$. In fact, this divergent behaviour means that a perturbative calculation for K_0 is no longer valid at low $p_T^{\min}$ values, so that the result of the calculation can only be trusted for $p_T^{\min}$ above a few GeV/c.

The estimation of K_1 to order α_s uses a recent calculation of the W transverse momentum distribution to second-order in α_s , $d\sigma^{(2)}/dp_T^W$ [11]. If we integrate this distribution from $p_T^{\min}$ to ∞ and use an α_s^2 expansion for the topological cross-sections, we get the following relation :

$$\begin{aligned}
\int_{p_T^{\min}}^{\infty} \frac{d\sigma^{(2)}}{dp_T^W} dp_T^W &= \int_{p_T^{\min}}^{\infty} \frac{d\tilde{\sigma}_0}{dp_T^W} dp_T^W + \int_{p_T^{\min}}^{\infty} \frac{d\tilde{\sigma}_1}{dp_T^W} dp_T^W + \int_{p_T^{\min}}^{\infty} \frac{d\tilde{\sigma}_2}{dp_T^W} dp_T^W \\
&= A + B + C
\end{aligned}$$

Only the last integral can be exactly computed, using the EKS simulation program. The following approximations are introduced for the two other terms : $A = 0$ and $B = \tilde{\sigma}_1$. These approximations amount to neglecting the contribution from particular event configurations, where two outgoing partons are emitted and obey the following conditions, respectively :

$$\begin{aligned}
p_T^1 < p_T^{\min}, p_T^2 < p_T^{\min}, \omega > \omega^{\min}, p_T^W > p_T^{\min}; \\
p_T^1 > p_T^{\min}, p_T^2 < p_T^{\min}, \omega > \omega^{\min}, p_T^W < p_T^{\min}.
\end{aligned}$$

With the above approximations, we deduce :

$$K_1 = \frac{1}{\sigma_1} \int_{p_T^{\min}}^{\infty} \left(\frac{d\sigma^{(2)}}{dp_T^W} - \frac{d\sigma_2}{dp_T^W} \right) dp_T^W \quad (6)$$

In fact, the calculation of Ref. [11] concerns only valence-valence (vv) diagrams, which are the dominant ones for W production at the CERN Collider, so that it does not provide exactly the distribution $d\sigma^{(2)}/dp_T^W$. To get an estimate for it, we therefore assume :

$$\frac{d\sigma^{(2)}}{dp_T^W} = K(p_T^W) \frac{d\sigma^{(1)}}{dp_T^W}$$

where $K(p_T^W) = |(d\sigma^{(2)}/dp_T^W)/(d\sigma^{(1)}/dp_T^W)|_{vv}$ is the ratio of the second-order differential cross-section to the first-order one, computed for valence-valence diagrams only, using the results of Ref. [11]. It is assumed to remain the same when non-dominant diagrams are taken into account. Finally, the range in p_T^W chosen for the integral in Eq. (6) allows us to use the EKS simulation program to calculate the first-order distribution, since $d\sigma^{(1)}/dp_T^W = d\sigma_1/dp_T^W$ when $p_T^W > p_T^{\min}$.

From Eq. (6), it appears that K_1 is a function of $p_T^{\min}$ and $\omega^{\min}$, the $\omega^{\min}$ dependence being introduced through the second-order cross-section $d\sigma_2/dp_T^W$. The result of the calculation is illustrated in Fig. 2b, for the same Q^2 and Λ values, and the same structure functions as for K_0 (see Table 2). The curves of Fig. 2b show that K_1 remains finite provided that $p_T^{\min}$ and $\omega^{\min}$ are not too small, otherwise they are no longer effective cut-offs against infrared and collinear divergences. As for K_0 , the result of a perturbative estimate for K_1 can be trusted only for $p_T^{\min}$ above a few GeV/c and $\omega^{\min}$ above 10° .

Finally, for $p_T^{\min} = 6$ GeV/c and $\omega^{\min} = 20^\circ$, which correspond to the values chosen in the simulation program, the curves in Fig. 2 show that K_0 and K_1 are far from the divergence region,

indicating that this choice of cut-off values is safe. The corresponding K-factor values, for $\alpha_s^{\text{MC}} = 0.154$, are :

$$K_0 = 1.04 ; \quad K_1 = 1.31 .$$

The absence of the second-order term in the computation of K_0 and the approximations made in the computation of K_1 lead to an uncertainty on the above K-factor values which is difficult to evaluate. We take as a reasonable estimate of this uncertainty $\Delta K_i = \pm 0.2$ ($i = 0,1$), which will be used in the following to describe the effect of the approximations made for the K-factor computations. It is expected that exact computations of K_0 to order α_s^2 and of K_1 to order α_s will be available in the near future, thus reducing the theoretical uncertainty.

5. RESULTS

We now have all the elements required to determine the value of the strong coupling constant using the method described in section 3. Starting with the results of the simulation and of the K-factor computations made for $\alpha_s = \alpha_s^{\text{MC}}$, we obtain :

$$R_{\text{MC}}(\alpha_s^{\text{MC}}) = 0.155 \pm 0.003$$

which is different from the experimental value R_{exp} . To compute R_{MC} for other α_s values, we use the formulae (5), where k_{01} and k_{11} are deduced from the first-order K-factor computations for $\alpha_s = \alpha_s^{\text{MC}}$, while k_{02} is set equal to zero. Under these conditions, we find that the value of α_s which makes R_{MC} equal to R_{exp} is :

$$\alpha_s(M_W^2) = 0.126 \pm 0.032(\text{stat})$$

To complete this result, we consider all known sources of systematic uncertainties in turn and evaluate their contributions to the error on α_s . The experimental sources will be first reviewed.

- a. To search for possible systematic effects in the data analysis, the jet definition algorithm itself was changed : first, energy clusters were used instead of cones, then the cone opening angle ω_0 was changed from 40° to 30° , and finally, the transverse energy threshold applied to define a jet was increased from 10 GeV to 15 GeV in steps of 1 GeV. In each case, the observed change in α_s was compatible with statistical fluctuations, providing no evidence for systematic effects.
- b. Systematic uncertainties on the absolute calibration of the UA2 central calorimeter induce a $\pm 4\%$ uncertainty on the jet energy scale [14]. A more important effect, when considering low energy jets, results from uncertainties in the calorimeter response to low energy particles, leading to an additional uncertainty of $\pm 10\%$. The final uncertainty on the jet energy scale is thus estimated to be $\pm 11\%$, and the resulting systematic uncertainty on α_s amounts to :

$$\Delta \alpha_s = \pm 0.02$$

- c. To evaluate the influence of structure functions, the α_s measurement was repeated for different parametrizations [15,16]. The largest deviation was found to be $+ 0.008$, but the corresponding systematic uncertainty is conservatively taken to be :

$$\Delta \alpha_s = \pm 0.01$$

- d. The jet energy scale and the number of reconstructed jets in the detector are affected by the underlying event. To study the corresponding systematic effect, the simulation of the underlying event was modified by varying the scaling factor $\lambda = 1.45$ (see section 3) by ± 0.15 [2]. The resulting systematic uncertainty is then :

$$\Delta \alpha_s = \pm 0.01$$

- e. The effect of the fragmentation model was studied by using a fragmentation algorithm based on the model of Ref. [18]. The systematic uncertainty amounts to :

$$\Delta \alpha_s = \pm 0.01$$

We come now to the discussion of the theoretical systematic uncertainties. The main sources of systematic effects are the approximations made in the K-factor computations, which result from an incomplete second-order description of W production, the missing higher-order corrections and the inclusive definition of K-factors with regard to the number of jets present in a W event. Among the induced systematic effects, the only one which can presently be studied is the dependence of the α_s measurement on the cut-off values. By varying $p_T^{\min}$ and $\omega^{\min}$, we found the value of α_s to be independent of $\omega^{\min}$, but to depend on $p_T^{\min}$. This can be explained by the fact that the $\omega^{\min}$ dependence is introduced by second-order terms in R_{MC} , while the $p_T^{\min}$ dependence results already from first-order terms. We find $\partial \alpha_s / \partial p_T^{\min} = + 0.002 \text{ (GeV/c)}^{-1}$. This variation cannot be interpreted as a statistical effect. There is at present no means to correctly evaluate the systematic uncertainty on α_s due to theoretical biases in the measurement method. To get an estimate of it, we assume that the major source of systematic error comes from the missing second-order calculations. The estimated uncertainty on the K-factor values (see section 4) lead then to the following systematic uncertainty on α_s :

$$\Delta \alpha_s = \pm 0.02$$

The effect of the missing contributions in the K-factor estimates is also illustrated in Fig. 3, which displays the variation of the measured α_s value, when the formulae (5) are modified by the introduction of both a non-zero k_{02} and a factor k'_{11} describing the correction to add to the approximated k_{11} to obtain the exact first-order term of K_1 . The area allowed by the estimated uncertainty $\Delta K_i = \pm 0.2$ ($i = 0,1$) is also shown.

Finally, a study has been performed to check the procedure used to obtain R_{MC} as a function of α_s with the help of Eq. (5). Such formulae have been introduced because it would have been too time consuming to repeat the complete simulation for different values of α_s . As already mentioned (see end of section 3), this method implicitly assumes that the results of the simulation and the K-factor values do not depend on the α_s value used for the structure function evolution. To check this point, we repeated the complete calculation of R_{MC} for various values of α_s , each time using the same value of α_s in both the structure function evolution and the computation of the QCD matrix elements. But, in order to save time, the simulation was done at the parton level only. It was verified that, due to the optimized jet algorithm, the difference between the calculation at the parton level and the complete simulation is small (around 3%). To test various α_s values, Q^2 was kept equal to M_W^2 and only Λ was changed, so that Λ becomes the measured parameter. To obtain a second-order determination of it, only next-to-leading order structure functions have been used, namely the three sets of Ref. [16] and the set of Ref. [17], which correspond respectively to $\Lambda_{\overline{MS}} = 107, 178, 250$ and 300 MeV. Comparing R_{exp} to $R_{MC}(\Lambda)$, it was found that the $\Lambda_{\overline{MS}}$ value which fits R_{exp} is approximately 275 MeV, corresponding to $\alpha_s(M_W^2) = 0.126$, which agrees with the value obtained from the method based on Eq. (5).

A summary of the systematic uncertainties is given in Table 3. By adding all the experimental systematic uncertainties in quadrature, we arrive at the result :

$$\alpha_s(M_W^2) = 0.13 \pm 0.03(\text{stat}) \pm 0.03(\text{syst}_1) \pm 0.02(\text{syst}_2)$$

where syst_1 represents the experimental systematic uncertainty and syst_2 is the estimated theoretical error. The statistical and systematic uncertainties are too large to allow a precise measurement of $\Lambda_{\overline{\text{MS}}}$. Nevertheless, this method has the advantage of measuring the strong coupling constant in a Drell-Yan process at a large enough Q^2 value to keep theoretical uncertainties under control. It is possible to compare this result with other experimental determinations as shown in Fig. 4, where the most recent results are presented together with second-order QCD expectations. The continuity of the QCD curves through flavor thresholds is ensured by changing the value of $\Lambda_{\overline{\text{MS}}}$ according to the prescription of Ref. [19]. The $\Lambda_{\overline{\text{MS}}}$ values indicated on the Figure correspond to five flavours. Plotted results come from :

- Υ spectroscopy, α_s being deduced from the measurement of either $R_\gamma = \Gamma(\Upsilon \rightarrow \gamma g g)/\Gamma(\Upsilon \rightarrow g g g)$ [20] or $R_\mu = \Gamma(\Upsilon \rightarrow g g g)/\Gamma(\Upsilon \rightarrow \mu^+ \mu^-)$ [21],
- deep inelastic scattering experiments [22],
- high energy e^+e^- experiments, α_s being measured either from the total hadronic cross-section $R = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+ \mu^-)$ [23] or from the energy-energy correlation asymmetry $A(\theta)$ [24].

Also shown in Fig. 4 are other measurements performed by hadronic collision experiments using multijet events [25]. By a method similar to the one described in this letter, a measurement of $\alpha_s K_3^j/K_2^j$ can be deduced from the three-jet to two-jet ratio, where K_2^j and K_3^j are K-factors for two-jet and three-jet production, respectively. K_2^j and K_3^j remain unknown and, are much more difficult to calculate than in the case of W production. For this reason, and despite the present small number of events, the use of W events appears to be a promising method for future measurements of α_s at hadron colliders.

6. CONCLUSION

We have presented an analysis of the final UA2 W sample. From the measurement of the one-jet to zero-jet ratio we have deduced an approximate second-order determination of the strong coupling constant within the $\overline{\text{MS}}$ scheme :

$$\alpha_s(M_W^2) = 0.13 \pm 0.03(\text{stat}) \pm 0.03(\text{syst}_1) \pm 0.02(\text{syst}_2)$$

where the two systematic errors refer to the experimental and theoretical uncertainties, respectively. The statistical and systematic uncertainties are of the same order of magnitude and do not presently allow a precise derivation of $\Lambda_{\overline{\text{MS}}}$. The main contributions to the systematic error arise from the uncertainty in the estimate of K-factors for W production and from the uncertainty in the jet energy scale. Our result is found to be compatible with other determinations. In the future, this result is likely to be improved at the CERN or Fermilab $\bar{p}p$ Colliders, provided larger data samples are available as well as exact calculations of K_0 to order α_s^2 and of K_1 to order α_s .

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FIGURE CAPTIONS

1. Variation with $\cos\omega_0$ of :
 - a. the jet energy loss from jet fragments outside the cone, as obtained from e^+e^- data [5].
 - b. the contribution from spectator particles falling inside the cone, as measured from W events without jet activity.

2. Results from the first-order K-factor estimates, as described in the text :
 - a. variation of K_0 with $p_T^{\min}$.
 - b. variation of K_1 with $p_T^{\min}$ and $\omega^{\min}$.

3. Variation of the α_s measurement with :
 - k_{02} , coefficient of the second-order term of K_0 ,
 - k'_{11} , correction to add to the estimated k_{11} to obtain the exact coefficient of the first-order term of K_1 .

The α_s value quoted in this letter corresponds to : $k_{02} = k'_{11} = 0$. Also shown is the area allowed by the uncertainties on K-factors : $(\alpha_s^{\text{MC}})^2 \Delta k_{02} = \pm 0.2$ and $\alpha_s^{\text{MC}} \Delta k'_{11} = \pm 0.2$.

4. Recent experimental determinations of α_s , compared to second-order QCD predictions. Apart from the three points related to the measurement of $\alpha_s K_3^J/K_2^J$ (full triangles), all the results are determinations of α_s deduced within the $\overline{\text{MS}}$ scheme. Statistical and systematic uncertainties have been added in quadrature. The indicated $\Lambda_{\overline{\text{MS}}}$ values correspond to five flavours.

TABLE 1

Jet activity in W - events. We recall the jet selection criteria : $|\eta| < 0.85$, $E_T > 10$ GeV.

	number of events	background	signal
W + 0 jet	221	21.9 ± 1.9	199.1 ± 15.0
W + 1 jet	29	3.7 ± 0.5	25.3 ± 5.4
W + 2 jets	1		1

TABLE 2

Parameters used in the simulation program at parton level.

Parameter	Reference choice
Structure functions	Glück, Hoffmann, Reya [9]
Number of flavours	5
Q^2	M_W^2
Λ	0.4 GeV
$p_{T \min}$	6 GeV/c
$\omega_{\min}$	20°

TABLE 3

Systematic uncertainties affecting the α_s determination.

Source of systematic effect	$\Delta\alpha_s$
Experimental sources :	
- Jet definition algorithm	—
- Jet energy scale	± 0.02
- Structure functions	± 0.01
- Underlying event simulation	± 0.01
- Fragmentation model	± 0.01
Total :	± 0.026
Theoretical sources :	
- Approximations done in K-factor estimates	± 0.02

Figure 1

Figure 2a

Figure 2b

Figure 3

Figure 4