Prospects of a Determination of α_S from Jet Rates

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Abstract: Prospects of the direct determination of the running strong coupling constant $\alpha_S(Q^2)$[1] based on jet rates in deep inelastic ep-scattering at HERA for a future integrated H1-luminosity up to 1000 pb^{-1} will be presented. After a few introductory remarks on the basic method the error treatment in the present α_S analysis will be briefly reviewed [1, 2, 3]. Subsequently the impact of an enlarged luminosity on the errors of α_S in the three investigated Q^2 bins and at the scale equal to the mass squared of the Z^0-boson, M_Z^2, is estimated.

1 Introduction

The physics of jets in deep inelastic scattering is a promising subject at HERA. Considering the current discrepancy between α_S measurements from fixed target deep inelastic scattering experiments, $\alpha_S(M_Z^2) = 0.112 \pm 0.002(\text{stat.}\oplus\text{sys.}) \pm 0.004$ (scale uncert.) [4], and for example hadronic event shapes in the experiments at the SLC and LEP colliders, $\alpha_S(M_Z^2) = 0.122 \pm 0.007$ [4], HERA can contribute to a better understanding. Therefore a very precise measurement of $\alpha_S(M_Z^2)$ is aimed at to draw a conclusion by HERA.

The error discussion on $\alpha_S(Q^2)$ presented here is based on an extraction of the running strong coupling constant essentially following the strategy of the previous measurement [5]. The fractional (2+1)-jet rate $R_{2+1}(Q^2, y_c) = \frac{\sigma_{2+1}(Q^2,y_c)}{\sigma_{\text{tot}}(Q^2)} = f(\alpha_S(Q^2))$ is chosen to explore the running of $\alpha_S(Q^2)$ [6], where $\sigma_{\text{tot}}(Q^2)$ represents the sum of the (1+1)- and (2+1)-jet cross sections. The resolution criterion of the applied modified JADE [9] jet algorithm[2] is $y_{ij} = 2E_iE_j(1-\cos\theta_{ij})/W^2 > y_c$, with the resolution parameter y_c set to 0.02 in this analysis. Here W^2 denotes the invariant mass squared of the total hadronic final state. Since the proton remnant, which can only partially be observed in the detector, is included in the clustered objects, the algorithm takes into account a pseudo-particle representing the missing longitudinal momentum in the measured events. Then R_{2+1} is obtained by dividing the number of events with two current jets observed in the final acceptance region, N_{2+1}, by N_{tot}, the number of events with one or two jets in this region. Using a full event generator like LEPTO 6.3 [10], these measured jet rates at the detector level are corrected to the parton level. Here they can be compared with NLO, i.e. up to $\mathcal{O}(\alpha_S^2)$, QCD predictions, which are available in the PROJET and MEPJET Monte Carlo integration programs [7, 8]. Based on the independent α_S measurements in bins of Q^2 with their statistical errors a fit to the renormalization group equation (RGE) is performed as discussed in [5]. Afterwards a value for $\alpha_S(M_Z^2)$ is evaluated.

[1]In the study presented here, the renormalization and factorization scales μ_r^2 and μ_f^2 are identified with Q^2, the absolute four-momentum transfer squared between the in- and outgoing electron.

[2]Two objects i and j are recombined to a new one k by taking the sum of the four-momentum-vectors: $p_k = p_i + p_j$.

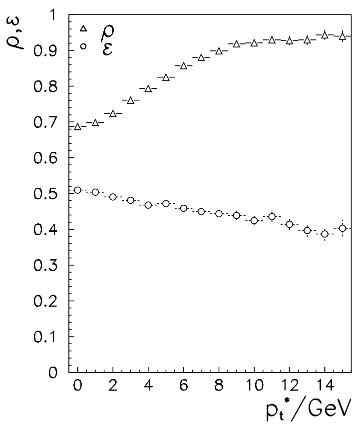
2 On the error determination

The present analysis is based on data taken in 1994 with the H1-detector corresponding to an integrated luminosity of $\mathcal{L} = 2.74$ pb^{-1}. A range of 150 GeV$^2 < Q^2 <$ 4000 GeV^2 was selected, where the (2+1)-jet cross section is dominated by quark initiated processes and the corresponding parton densities are well known.

The use of PROJET as in earlier analyses [1, 5] results in $\alpha_S(M_Z^2) = 0.124 \pm 0.006(\text{stat.}) \pm 0.008(\text{sys.})$ [2, 3], which, in view of theoretical discrepancies when PROJET is replaced by MEPJET, cannot be taken as a measured value of α_S. For the purpose of this study the explicit value of $\alpha_S(M_Z^2)$ can be considered as arbitrary and only the determined errors are of interest. The event selection requirements are: $W^2 > 5000$ GeV^2, $E_e > 11$ GeV, $10° < \theta_e < 150°$, and $y_e < 0.7$. To suppress higher order QCD effects a jet acceptance cut of $10° < \theta_{jet} < 145°$ is applied and in addition, for (2+1)-jet events, $z_p > 0.1$. In the CMS of the hard subprocess z_p is defined by the smaller (with respect to the incoming parton) polar angle $\theta^\star_{jet}$ of the two current jets: $z_p = \frac{1}{2}(1 - \cos\theta^\star_{jet})$.

The systematic experimental and theoretical error on $\alpha_S(M_Z^2)$ was estimated by analyzing different scenarios taking into account possible correlations between the error sources. For this task the cuts relevant for the jet analysis were varied around their central values as defined above. The error includes uncertainties due to detector effects, y_c, acceptance cuts, QCD models, hadronization effects, parton densities (and the Λ_{QCD} used therein), μ_r and μ_f. The final systematic experimental (± 0.006) and theoretical error (± 0.006) was taken from the maximum spread of the fit results of all the corresponding scenarios investigated. Their quadratic sum is taken as the total systematic error.

As errors on the measured values of $\alpha_S(Q^2)$ in the three Q^2 bins the spread of all values of the different cut scenarios belonging to each Q^2 bin is considered as the systematic error. The total systematic error on $\alpha_S(Q^2)$ is given in the same way as described above. This procedure assumes that errors in the different Q^2 bins are uncorrelated and gives an upper estimate of the true systematic error. The statistical and total systematic error are summed in quadrature to give the total error.



$p_t^* > 0$ GeV	N_1	N_2
N^1	75.74%	9.66%
N^2	4.57%	10.03%

$p_t^* > 15$ GeV	N_1	N_2
N^1	98.20%	1.04%
N^2	0.05%	0.71%

Figure 1: *Purity $\rho = N_2^2/(N_2^2 + N_1^2)$ and efficiency $\varepsilon = N_2^2/(N_2^2 + N_2^1)$ of the jet classification after kinematical cuts in dependence of a p_t^* cut, where N_n^m denotes the number of simulated events which are classified as $(n+1)$-jet events at the parton level and as $(m+1)$-jet events at the detector level. In addition, the correlation matrices for $p_t^* > 0$ GeV and $p_t^* > 15$ GeV are explicitly given.*

3 Error estimate for increased luminosity

The systematic experimental error in the present analysis is dominated by the error due to the hadronic energy scale (4% uncertainty). Therefore a realistic hadronic energy scale uncertainty of 2% [11] is assumed for the estimation of the future experimental error. The systematic theoretical error is dominated by parton shower effects and hadronization parameters/models estimated with LEPTO and HERWIG [12]. At higher luminosity it is possible to reduce this error by a cut on the transverse momentum p_t^* of the two current jets in the hadronic centre-of-mass system, because the jets become narrower with increasing p_t^*. Besides a p_t^* cut improves the purity of the jet classification as shown in Fig. 1. In order to estimate the effects of different p_t^* cuts on the error, the parton and hadron levels are studied explicitly for different parton shower and hadronization parameters in LEPTO while the correction factor from the hadron to the detector level is taken over from the present analysis. Here the theoretical cross sections are calculated with MEPJET. It is assumed that the behavior of the uncertainty due to HERWIG tends to be similar to that of the LEPTO parameters.

The resulting error estimations are summarized in the tables 1 and 2. In addition, Fig. 2 compares the errors of the present analysis [2, 3] and the error estimations for an integrated luminosity of $\mathcal{L} = 250$ pb^{-1} (with and without a cut $p_t^* > 15$ GeV) with measurements by other experiments.

4 Conclusion

To achieve a precision measurement of $\alpha_S(M_Z^2)$ and to prove the running of the strong coupling constant according to the RGE at HERA high luminosity is needed. In that case the systematic uncertainties can be reduced significantly and the errors can be expected to reach a magnitude comparable to the error of the present world average.

Luminosities above 250 pb^{-1} might allow a better understanding of the hadronic energy scale than assumed here, possibly leading to a decrease in the systematic experimental error. For very high luminosity it might even be feasible to use a higher p_t^* cut in order to reduce the systematic uncertainties and migrations in the jet classification further.

	$\mathcal{L} = 2.74$ pb^{-1}			$\mathcal{L} = 250$ pb^{-1}			$\mathcal{L} = 1000$ pb^{-1}		
	stat	sys	tot	stat	sys	tot	stat	sys	tot
$p_t^* > 0$ GeV	0.006	0.008	0.010	0.0006	0.007	0.007	0.0003	0.007	0.007
$p_t^* > 10$ GeV				0.0008	0.006	0.006	0.0004	0.006	0.006
$p_t^* > 15$ GeV				0.0013	$^{+0.004}_{-0.005}$	$^{+0.004}_{-0.005}$	0.0007	$^{+0.004}_{-0.005}$	$^{+0.004}_{-0.005}$

Table 1: *The statistical, systematic and total errors on $\alpha_S(M_Z^2)$ in the present analysis and for an increased luminosity for several p_t^* cuts.*

Q^2 range	$\mathcal{L} = 2.74$ pb^{-1}				$\mathcal{L} = 250$ pb^{-1}			$\mathcal{L} = 1000$ pb^{-1}		
[GeV^2]	$\alpha_S(Q^2)$	stat	sys	tot	stat	sys	tot	stat	sys	tot
150-300	0.202	0.020	$^{+0.027}_{-0.035}$	$^{+0.034}_{-0.040}$	0.002	$^{+0.027}_{-0.035}$	$^{+0.027}_{-0.035}$	0.001	$^{+0.027}_{-0.035}$	$^{+0.027}_{-0.035}$
300-700	0.149	0.016	$^{+0.032}_{-0.012}$	$^{+0.036}_{-0.020}$	0.002	$^{+0.032}_{-0.006}$	$^{+0.032}_{-0.006}$	0.001	$^{+0.032}_{-0.006}$	$^{+0.032}_{-0.006}$
700-4000	0.137	0.018	$^{+0.013}_{-0.021}$	$^{+0.022}_{-0.028}$	0.002	$^{+0.010}_{-0.021}$	$^{+0.010}_{-0.021}$	0.001	$^{+0.010}_{-0.021}$	$^{+0.010}_{-0.021}$
150-300	0.202				0.003	$^{+0.026}_{-0.033}$	$^{+0.026}_{-0.033}$	0.001	$^{+0.026}_{-0.033}$	$^{+0.026}_{-0.033}$
300-700	0.149				0.002	$^{+0.031}_{-0.005}$	$^{+0.031}_{-0.005}$	0.001	$^{+0.031}_{-0.005}$	$^{+0.031}_{-0.005}$
700-4000	0.137				0.003	$^{+0.010}_{-0.021}$	$^{+0.010}_{-0.021}$	0.001	$^{+0.010}_{-0.021}$	$^{+0.010}_{-0.021}$
150-300	0.202				0.004	$^{+0.025}_{-0.032}$	$^{+0.025}_{-0.032}$	0.002	$^{+0.025}_{-0.032}$	$^{+0.025}_{-0.032}$
300-700	0.149				0.004	$^{+0.030}_{-0.004}$	$^{+0.030}_{-0.006}$	0.002	$^{+0.030}_{-0.004}$	$^{+0.030}_{-0.004}$
700-4000	0.137				0.004	$^{+0.008}_{-0.020}$	$^{+0.009}_{-0.020}$	0.002	$^{+0.008}_{-0.020}$	$^{+0.008}_{-0.020}$

Table 2: *The statistical, systematic and total errors on $\alpha_S(Q^2)$ in the three Q^2 bins in the present analysis and for an increased luminosity without (first part) and with a p_t^* cut ($>$ 10 GeV: second part; $>$ 15 GeV: third part). For the scenarios at high luminosity studied here the total error is dominated by systematics.*

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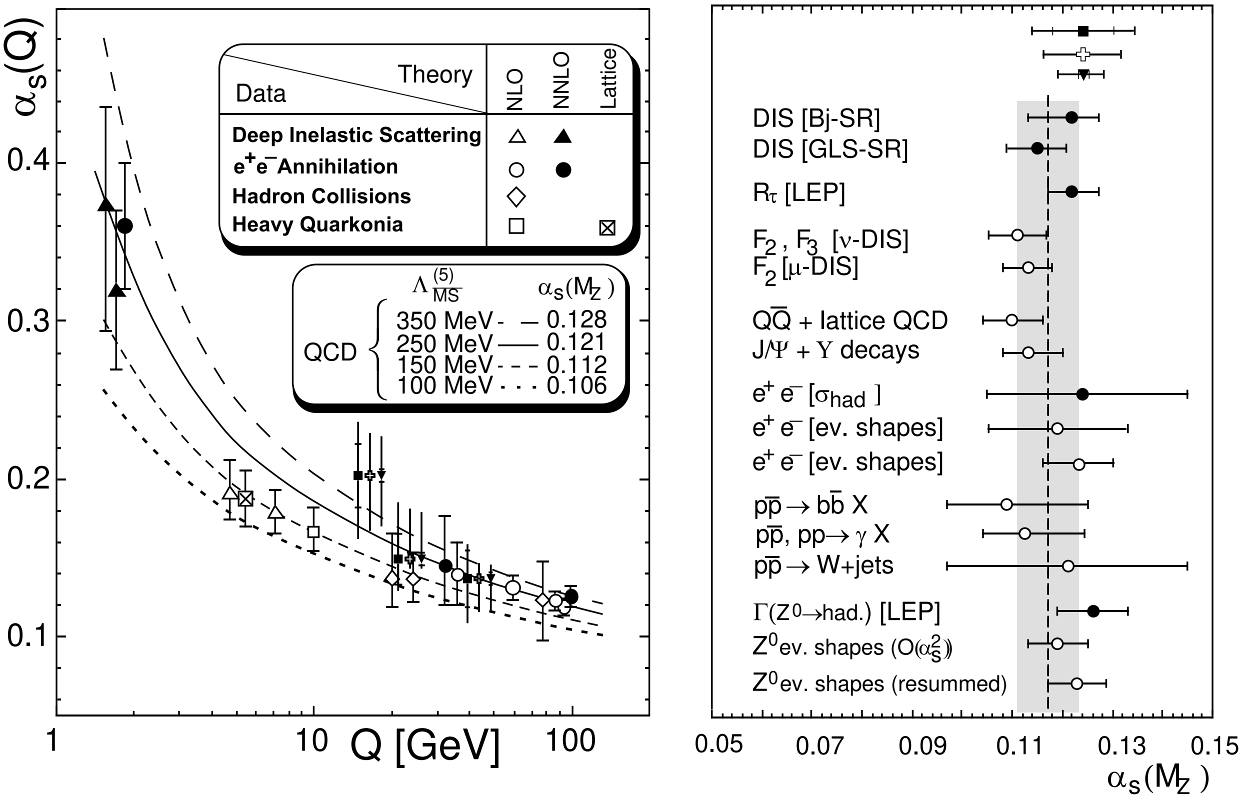

Figure 2: *Errors on the $\alpha_S(Q^2)$ (left plot) in the three different Q^2 bins for the present H1-analysis (■) (the inner error bar corresponds to the statistical error and the full error bar to the total error) and error estimates for an integrated luminosity of $\mathcal{L} = 250\ pb^{-1}$ without (+) and with (▼) a cut $p_t^* > 15\ GeV$ in comparison to α_S measurements by other experiments [13]. The plot on the right hand side shows a comparison for the derived/expected $\alpha_S(M_Z^2)$ errors. The shaded area represents the world average of $\alpha_S(M_Z^2) = 0.118 \pm 0.005$ [13].*

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