Tuning of the Monte Carlo generator ARIADNE

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Abstract: The Monte Carlo generator ARIADNE, version 4.10, is compared with deep-inelastic scattering data from the *ep*-collider HERA. The model parameters specific to HERA are tuned in order to achieve a better description of data.

1 Introduction

Monte Carlo Generators are an essential tool in modern day experimental High Energy Particle Physics. They play a crucial role in the analysis of data, in particular in the assessment of systematic errors. In that sense, it is of the greatest importance that the Monte Carlo programs give results as close as possible to experimental data; therefore they need to be tuned.

This paper aims at the tuning of the Monte Carlo event generator Ariadne [1],version 4.10, implementing the Colour Dipole Model (CDM) [2]. Extensive use is made of the package HzTool [3], which is a FORTRAN library containing a collection of experimental results from H1 and ZEUS Collaborations.

In the CDM, all gluon emissions constituting the QCD cascade start as radiation from the colour dipole formed between the struck quark and the proton remnant. All subsequent radiation arises from independent colour dipoles formed either from $q\bar{q}$ pairs or softer gluons radiated by the previously produced gluons. Furthermore, the fact of considering the proton remnant as an extended object results in a suppression of radiation in the proton direction. Also the struck quark is treated as extended, as the photon probes it to a distance inversely proportional to the transferred momentum. These features correspond to a cut-off in the phase space available for gluon emission. In the context of this work, the influence of the parameters (listed in table 1) that control the phase space "properties" has been systematically investigated.

The use of HzTool facilitates the comparison between theory and data, providing the user with a set of theoretical simulated results obtained under the same conditions (kinematical cuts, etc.) as for the experimental data. Also the quality of the description of each data distribution is quantitatively assessed by means of the χ^2 defined as

$$\chi^2 = \frac{1}{n}\sum_{i=1}^{n}\frac{[\mathrm{MC}(i) - \mathrm{Data}(i)]^2}{\sigma^2_{\mathrm{MC}(i)} + \sigma^2_{\mathrm{Data}(i)}} \tag{1}$$

where Data(i), MC(i) stand for the values of the data and Monte Carlo distributions in bin i, respectively; the sum runs over the n data bins.

2 Tuning

The philosophy of this study closely followed that of a previous tuning [4]. However, two extensions were made: on the one hand, jet data were now available for inclusion in the tuning; on the other hand, the behaviour of the parameter PARA(25) was considered for the first time. The distributions that were most sensitive to the parameters under investigation were first ascertained. Next a combined χ^2 was calculated for each parameter setting according to

$$\chi^2_{Comb} = \frac{1}{nsets} \sum_{i=1}^{nsets} \chi^2_i \tag{2}$$

where χ^2_i represents the total (average) χ^2 of data set i. The parameter combination that yields the minimum of the overall χ^2_{Comb} corresponds to the tuned result.

PARAMETER	Default	Tuned	Description
para(10)	1.0	1.6	power in soft suppression for the remnant
para(15)	1.0	0.5	power in soft suppression for the struck quark
para(25)	2.0	1.4	governs probability of emissions outside the soft suppression cut-off
para(27)	0.6	0.6	square root of primordial k_T^2 in GeV

Table 1: *values of the Ariadne parameters before and after tuning.*

The four model parameters considered in this paper are listed in table 1, which includes a short description of their influence. The two parameters PARA(10) and PARA(15) govern the slope of the suppression line (in the phase space available for gluon emission) for the proton and the struck quark, respectively. PARA(25) governs the probability of emissions outside the soft suppression cut-off, while PARA(27) corresponds to the square root of the primordial k_T^2 in the proton. The following distributions were chosen. They are here identified by their DESY preprint number:

- jane: scaled momentum x_p distributions in the current region of the Breit frame [5];
- hiq2e: flows of transverse energy in the hadronic center-of-mass system [6];
- 97098: differential distributions and evolution of mean of event shape variables thrust T_c and T_z, jet broadening B_c and jet mass ρ_c in the current region of the Breit frame [7];
- 97108: fragmentation functions and charged particle multiplicities in the current region of the Breit frame [8];
- 98038: differential and integrated jet shapes as a function of pseudorapidity η and transverse energy E_T [9];
- 98087: (2+1) jet event rate as a function of the transferred momentum Q [10].

Only data with $Q^2 > 80$ GeV^2 were considered in order to minimize theoretical uncertainties. This cut also reflects the need to analyse the consequences of the new treatment at high Q^2 of Ariadne [11]. Table 2 summarises the total χ^2 for each of the six sets of data, together with the combined χ^2_{Comb} given by equation 2. A more detailed list of all the distributions considered in the tuning can be found in tables 3, 4, 5, 6, 7 and 8.

The tuning has been performed using the GRV94 parton density function [12]. Indeed, the use of the parton density function CTEQ4M results in a slightly worse value for χ^2_{Comb}. By default we therefore mean the use of the default values for all parameters and switches except for the choice of the parton density function and the application of the new high Q^2 treatment, activated by setting MHAR(151)=2.

Source	$\chi^2_{default}$	χ^2_{tuned}
jane	1.94	2.60
hiq2e	0.85	0.65
97098	1.69	1.70
97108	0.58	0.65
98038	17.34	12.49
98087	8.10	3.08
$\chi^2_{Comb} = \frac{1}{nsets} \sum_{i=1}^{nsets} \chi^2_i$	5.08	3.53

Table 2: *summary of the χ^2 values obtained before and after tuning for all sets of hadronic final state data.*

The results of this tuning agree very well with those previously obtained [4] for the same parameters. Both transverse energy flows (table 4) and jet data (tables 7 and 8) strongly favour high values for PARA(10), in contrast to the value favoured by the fragmentation functions (tables 3 and 6). Again the value PARA(15)=0.5 yields a better overall description of data, as compared to its default value of 1.0. Jet variables are particularly sensitive to PARA(15). The behaviour of PARA(25) was studied for the first time. Although its influence is not large in general, it clearly has a significant effect on the predictions related to the (2+1) jet event rate (table 8), on the multi-jet event rate and on transverse energy flows. The results suggest a lower value compared to the default one. Parameter PARA(27) is a relatively insensitive parameter, but the data disfavour high values, such as 0.8-1.0 GeV, when describing transverse energy flows and jet shapes.

The improvement achieved with the tuned parameters is mostly due to a better description of jet shapes and (2+1) jet event rates (see figures 1 and 2). Unfortunately, a very good agreement with the jet data leads to a worse description of other distributions such as fragmentation functions and transverse energy flows (see figures 3 and 4). Conversely, the new treatment at high Q^2 of Ariadne describes much better than before transverse energy flows and event shape variables, but lessens the agreement with the data on jet shapes [13]. The current study seems to suggest that a simultaneous description of jet and charged particle distributions is difficult. H1 has recently published new measurements of internal jet structure in dijet production in DIS [14], where, for the first time, subjet multiplicities have been studied. ZEUS has also published measurements of multiplicities and momentum spectra in the current and target regions of the Breit frame in DIS [15]. These latest results may help to clarify the situation.

3 Conclusion

The latest version of the Monte Carlo event generator Ariadne has been tuned comparing the CDM model predictions with data from deep-inelastic scattering at HERA. In general, the available variety of data is now better described, although it appears that the treatment at high Q^2 of Ariadne seems to worsen the agreement between the generated and jet-related data.

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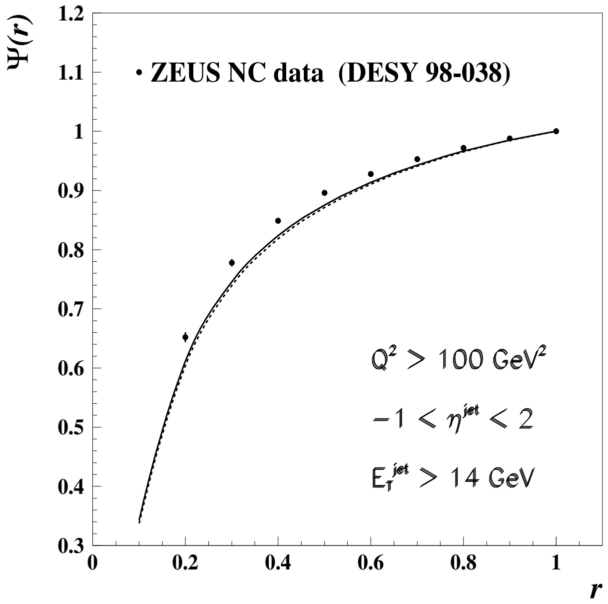

Figure 1: *the integrated jet shape* $\Psi(r)$ *before (dashed line) and after (solid line) tuning.*

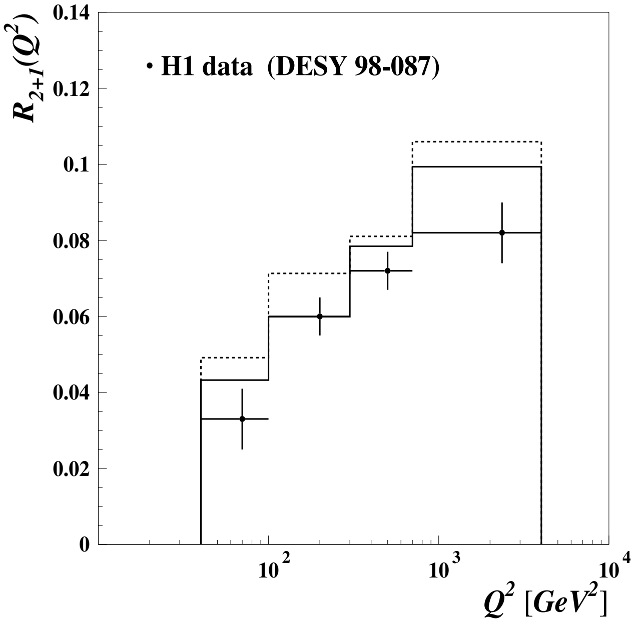

Figure 2: *the (2+1) jet event rate* $R_{2+1}(Q^2)$ *before (dashed line) and after (solid line) tuning.*

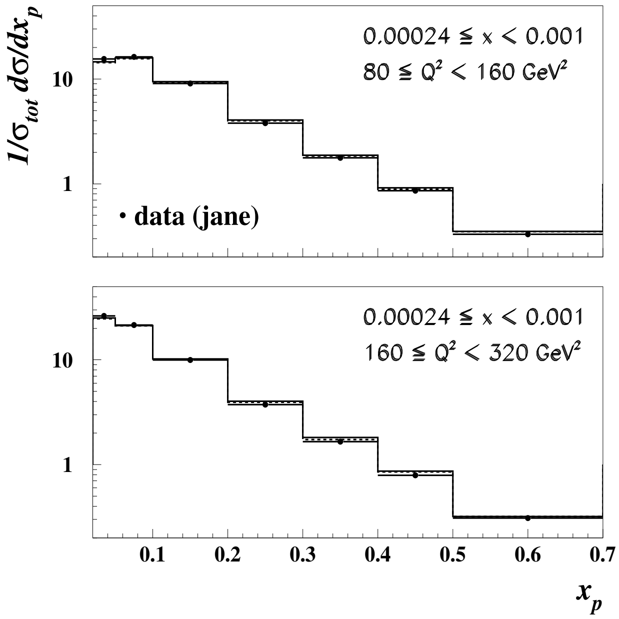

Figure 3: *scaled momentum x_p distributions in the current region of the Breit frame before (dashed line) and after (solid line) tuning. Are shown only two distributions at medium Q^2 from table 3.*

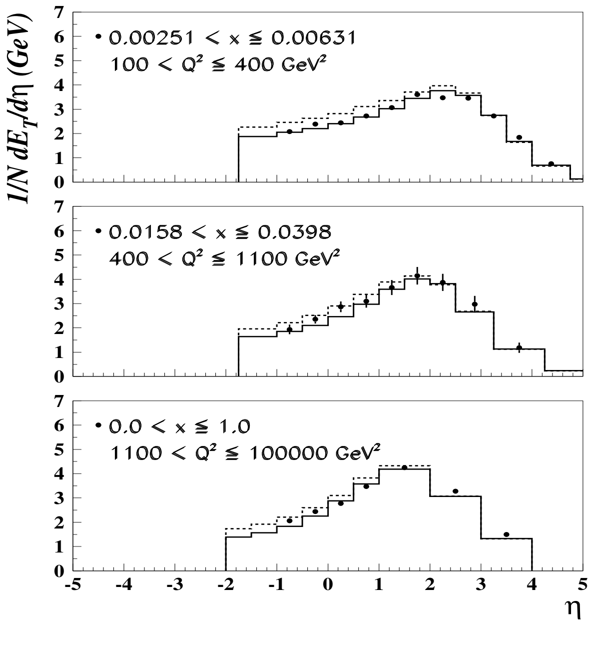

Figure 4: *flows of transverse energy in the hadronic center-of-mass system before (dashed line) and after (solid line) tuning. These distributions refer to the first set in table 4.*

Data from JANE	Remarks		$\chi^2_{default}$	χ^2_{tuned}
$1/\sigma_{tot} d\sigma/dx_p$	$x = 0.24 - 1.0 \cdot 10^{-3}$	$Q^2 = 80 - 160$ GeV^2	1.47	3.27
		$Q^2 = 160 - 320$ GeV^2	1.07	2.34
	$x = 1.0 - 5.0 \cdot 10^{-2}$	$Q^2 = 160 - 320$ GeV^2	0.67	0.89
		$Q^2 = 320 - 640$ GeV^2	1.25	1.63
		$Q^2 = 640 - 1280$ GeV^2	2.95	2.97
	$x = 0.025 - 0.15$	$Q^2 = 1280 - 2560$ GeV^2	3.57	4.03
	$x = 0.05 - 0.25$	$Q^2 = 2560 - 5120$ GeV^2	2.63	3.05
total			1.94	2.60

Table 3: χ^2 *values obtained before and after tuning for ZEUS data on scaled momentum* $x_p = 2p/Q$ *distributions in the current region of the Breit frame [5].*

Data from HIQ2E	Remarks		$\chi^2_{default}$	χ^2_{tuned}
$1/N dE_T/d\eta$	$Q^2 = 100 - 400$ GeV^2	$x = 2.51 - 6.31 \cdot 10^{-3}$	1.36	0.29
		$x = 6.31 - 15.8 \cdot 10^{-3}$	1.12	0.44
		$x = 1.58 - 3.98 \cdot 10^{-2}$	0.94	0.27
	$Q^2 = 400 - 1100$ GeV^2	$x = 6.31 - 15.8 \cdot 10^{-3}$	1.34	1.02
		$x = 1.58 - 3.98 \cdot 10^{-2}$	0.60	0.78
		$x = 0.0398 - 1.0$	0.20	0.41
	$Q^2 = 1100 - 10^5$ GeV^2	$x = 0.0 - 1.0$	0.53	0.34
$1/N dE_T/d\eta$	$Q^2 = 100 - 220$ GeV^2		1.07	0.37
	$Q^2 = 220 - 400$ GeV^2		0.37	0.81
	$Q^2 > 400$ GeV^2		0.92	1.73
total			0.85	0.65

Table 4: χ^2 *values obtained before and after tuning for H1 data on transverse energy flows [6]. The first (second) set of distributions refers to data obtained with (without) a cut on the forward energy.*

Data from 97098	Remarks	$\chi^2_{default}$	χ^2_{tuned}
$< 1 - T_c >$ vs. Q		4.64	4.13
$< 1 - T_z > /2$ vs. Q		2.90	4.07
$< B_c >$ vs. Q		0.38	0.58
$< \rho_c >$ vs. Q		2.27	1.51
$1/Ndn/d(1 - T_c)$	bin 1	0.47	0.42
	bin 2	0.55	0.54
	bin 3	0.28	0.34
	bin 4	0.14	0.17
	bin 5	1.47	1.52
	bin 6	0.83	0.86
$1/Ndn/d(1 - T_z)$	bin 1	0.38	0.60
	bin 2	1.50	2.27
	bin 3	2.95	2.26
	bin 4	2.14	1.71
	bin 5	2.58	2.06
	bin 6	1.24	1.12
$1/Ndn/dB_c$	bin 1	0.37	0.47
	bin 2	3.09	3.75
	bin 3	2.68	2.61
	bin 4	3.55	3.20
	bin 5	3.59	3.44
	bin 6	1.13	1.34
$1/Ndn/d\rho_c$	bin 1	0.22	0.11
	bin 2	0.23	0.18
	bin 3	0.45	0.24
	bin 4	2.92	2.85
	bin 5	2.61	3.32
	bin 6	1.77	1.87
total		1.69	1.70

Table 5: χ^2 *values obtained before and after tuning for H1 data on event shape variables thrust* T_c *and* T_z*, jet broadening* B_c *and jet mass* ρ_c *in the current region of the Breit frame [7]. Bins 1 to 6 refer, respectively, to the kinematic ranges of* Q *=8-10, 14-16, 16-20, 20-30, 30-50, 50-100 GeV.*

Data from 97108	Remarks		$\chi^2_{default}$	χ^2_{tuned}
$\ln(1/x_p)_{\rm peak}$ vs. Q	$Q^2 = 12 - 8000$ GeV^2		0.04	0.00
$\ln(1/x_p)_{\rm width}$ vs. Q			0.06	0.01
$< n_{ch} >$ vs. Q			0.89	1.09
$1/Ndn/dx_p$	$Q^2 = 100 - 8000$ GeV^2		0.90	1.20
$1/Ndn/d\ln(1/x_p)$			1.13	1.29
$1/Ndn/dn_{ch}$	$Q^2 = 100 - 500$ GeV^2	$x = 0.2 - 1.0 \cdot 10^{-2}$	0.85	0.83
		$x = 0.1 - 2.0 \cdot 10^{-1}$	0.17	0.13
total			0.58	0.65

Table 6: χ^2 *values obtained before and after tuning for H1 data on fragmentation functions and charged particle multiplicities in the current region of the Breit frame [8].*

Data from 98038	Remarks		$\chi^2_{default}$	χ^2_{tuned}
$\rho(r)$ binned in η^{jet}	$E_T^{jet} > 14$ GeV	$-1 < \eta^{jet} < 0$	7.34	7.34
		$0 < \eta^{jet} < 1$	17.36	14.69
		$1 < \eta^{jet} < 1.5$	13.58	8.67
		$1.5 < \eta^{jet} < 2$	9.64	5.25
$\rho(r)$ binned in E_T^{jet}	$-1 < \eta^{jet} < 2$	$14 < E_T^{jet} < 21$ GeV	22.91	19.95
		$21 < E_T^{jet} < 29$ GeV	16.81	9.69
		$29 < E_T^{jet} < 37$ GeV	2.76	1.52
		$37 < E_T^{jet} < 45$ GeV	2.39	1.76
$\Psi(r = 0.5)$ vs. η^{jet}			20.64	13.76
$\Psi(r = 0.5)$ vs. E_T^{jet}			17.36	10.97
$\Psi(r)$			59.99	43.73
total			17.34	12.49

Table 7: χ^2 *values obtained before and after tuning for ZEUS data on differential* $\rho(r)$ *and integrated* $\Psi(r)$ *jet shapes as a function of pseudorapidity* η *and transverse energy* E_T *[9]. All data are for* $Q^2 > 100$ *GeV*^{2}*; unless stated otherwise, one also has* $E_T^{jet} > 14$ *GeV and* $-1 < \eta^{jet} < 2$.

Data from 98087	Remarks	$\chi^2_{default}$	χ^2_{tuned}
$R_{2+1}(Q^2)$	$Q^2 = 40 - 4000$ GeV^2	8.10	3.08

Table 8: χ^2 *value obtained before and after tuning for the (2+1) jet event rate [10](H1 data).*