7 Particle Physics at DESY/HERA

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7.1 Electron proton collisions at 300 GeV center of mass energy: overall status of the project

After the most successful year of HERA operation with positrons in 1997, the 1998 run started very late. The vacuum system of the electron ring had been rebuilt to accomodate running with electrons, and the vacuum pressure was rather high initially. Though the pressure improved continuously as expected, the lifetime of the beam was affected for most of 1998, as is evident from Table 7.1. The background conditions in the H1-detector worsened, too. Consequently the overall luminosity, the specific luminosity, the running efficiency did not reach the values of 1997. However, the energy of the proton ring was successfully raised from 800 GeV to 920 GeV, which lifts the available center of mass energy to 318 GeV. The cross section for the production of exotic objects with masses of about 200 GeV increases by a factor of two due to this energy change. Since the accelerators resumed operation in January 1999 already 9.7 pb^{-1} has been accumulated (25. 3. 1999). In March proton currents up to 90 mA and electron currents up to 30 mA lead to up to 15 HERA fills corresponding to 1.5 pb^{-1} per week. The data taking efficiency has also reached the higher level of 1997 again.

A final decision has not been taken, whether the remainder of 1999 after the short shut-down in May will be devoted to electron or positron running.

With last years modest increase of the total event sample, the physics analysis concentrated on finalising those analyses, where last year only preliminary results were available. The principal areas covered can be summarized as follows

- neutral and charged electroweak current cross sections, proton structure functions and parton densities in new domains of Bjorken x and momentum transfer Q^2 [1, 2],
- search for states outside the standard model [3, 4],
- diffractive processes and the structure of the pomeron [5, 6, 7, 8, 9],
- testing perturbative and non-perturbative quantum chromodynamics predictions and measurement of α_s [10, 11, 12, 13, 14, 15, 16],
- production of heavy quark-antiquark states, of open charm and determination of gluon density [17, 18, 19, 20, 21].

We will report below on the analyses in heavy quark sector, where most of the activity of the Zürich goups concentrates below, and also give an update of the data sample at highest momentum transfers ($Q^2 \approx M_W^2$).

Besides the physics analysis, our activities deal with the maintenance, monitoring and continuously improving of the detector components built at Zürich for the central tracker and the first level trigger of H1. As in the past we also continued to be strongly involved in adapting the first level triggers to the varying beam currents and backgrounds at H1. Most

Parameter	1993	1994		1995	1996	1997	1998
	e^-p	e^-p	e^+p	e^+p	e^+p	e^+p	e^-p
Integrated luminosity $\mathcal{L}$							
HERA produced [pb^{-1}]	1.00	0.94	5.1	11.4	14.4	37.6	8.7
HERA physics [pb^{-1}]	0.88	0.85	4.7	10.4	13.3	35.8	8.1
H1 taken [pb^{-1}]	0.57	0.53	3.6	6.4	8.9	30.4	6.5
H1 physics [pb^{-1}]	0.53	0.49	3.5	5.7	8.6	26.4	4.7
HERA efficiency [%]	88	90	94	91	92	95	92
H1 efficiency [%]	60	58	73	55	65	74	58
Average luminosity [$(\mu$b s$)^{-1}$]	0.27	0.62	1.29	2.13	2.64	4.38	2.25
Peak luminosity [$(\mu$b s$)^{-1}$]	1.3	2.6	4.3	5.9	8.4	10.1	8.8
Average p current [mA]	10.8	28.6	41.0	54.0	60.3	74.5	63.2
Average $e^\pm$ current [mA]	7.7	10.5	17.0	18.4	20.6	28.0	15.5
Colliding bunches	84	153	153	174	175	175	175
Pilot (e,p) bunches	10,6	15,17	15,17	15,6	14,6	14,6	14,6
HERA luminosity runs	218	116	176	304	241	411	187
Permanent H1 runs	3190	1141	1816	4208	3582	5369	2769
Average duration [s]	817	1115	1620	884	1159	1431	1163

Table 7.1: Summary of HERA and H1 operation during the last six years.

of our effort, however was directed towards our contribution to the upgrade program of the H1-detector.

7.2 Summary of activities related to the Zürich H1-components and their upgrade

The investigation of rare processes at the limits of the kinematically accessible range at HERA requires a luminosity upgrade of the machine [22]. The most important aspect of this program is the improvement of the focussing properties near the interaction region of the H1 detector. The luminosity is expected to increase by a factor of seven to $L = 7.4 \times 10^{31}$ cm^{-2}s^{-1}.

Part of the H1 upgrade plan [23] is the replacement of the existing inner two proportional chambers (CIP) and the inner drift chamber (CIZ) by a new five-layer proportional chamber. The goal to improve z-vertex triggering and track reconstruction, as well as the rejection capability of background events from synchrotron radiation and proton beam gas interactions can be achieved by increasing the number of readout channels both along the z-axis and in azimuthal direction. The implementation of five chambers instead of two will help to resolve ambiguities from the central silicon tracker (CST). The increased number of readout channels also requires new readout and trigger electronics.

The new CIP will have pad readout in 16 azimuthal sectors. The trigger scheme is based on a projective geometry of the pads along the z-axis, thus requiring a varying number of pads in each layer ranging from 119 to 93 pads for the innermost and outermost layer, respectively.

The University of Zürich is responsible for the mechanical design and construction of the multiwire proportional chambers. The high density of readout channels and new front-end electronics made it neccessary to build a cylindrical prototype of the innermost chamber for which the space limitations are critical. The construction of this prototype at 1/3 of the full length has started end of 1998 and will be completed in spring of 1999. The inner cylinder of the prototype chamber consisting of the inner cathode and anode wire layer is shown in Figure 7.1. Testing of the detector and the electronics will be done using a pion beam at PSI.

The construction of the full-length five-layer chamber will start in early summer of 1999 and should be completed within 16 months, thus being ready for the installation in the H1 detector in September 2000 during the HERA shutdown.

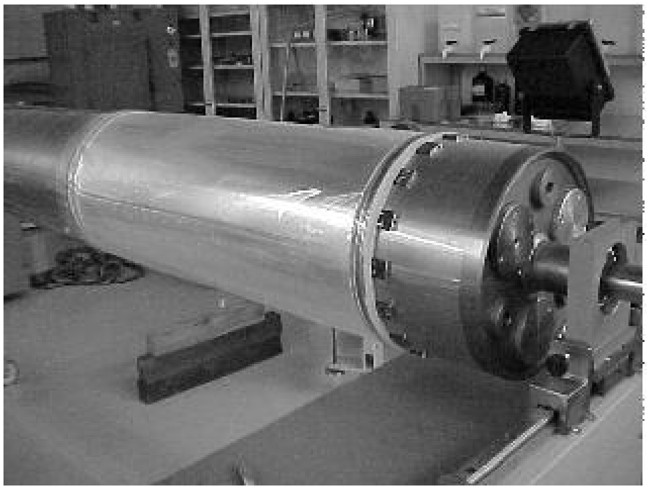

Figure 7.1: The prototype of the new central inner proportional chamber being built in the Physik-Institut shops.

7.3 Results from recent analyses

7.3.1 Deep inelastic scattering at highest momentum transfer and the standard model

The analysis of the high-momentum transfer ($150 < Q^2 < 30000$ GeV^2) neutral and charged current data taken between 1994 and 1997 has been completed [24, 2]. We have already given some preliminary results last year. With an integrated luminosity of 36 pb^{-1} this analysis increases the statistics of the previously published results by an order of magnitude with smaller systematic errors and an expanded region of x_{Bjorken} and Q^2. The proton structure function is extracted from the measured cross section $d^2\sigma/dxdQ^2$ and the Q^2 evolution of the parton densities predicted by quantum chromodynamics is tested for $0.0032 < x < 0.65$. No significant deviations from the electroweak standard model are found. The integrated cross section $d\sigma/dq^2$ (Figures 7.2 and 7.3) varies over seven orders of magnitude. The same holds for the preliminary data extracted from the electron runs (5 pb^{-1}) [1], which are also shown in Figure 7.2.

The published data sample comprises 75000 neutral current and 700 charged current events. The kinematical cuts are $E_e' > 11$ GeV, $y_e = 1 - (E_e'/27.5)\sin^2(\theta_e/2) < 0.9$ for the neutral current (NC), and $p_T^{\mathrm{miss}} > 12$ GeV, $0.03 < y_{\mathrm{hadron}} < 0.85$ for the charged current (CC) events. Photoproduction background is suppressed by requiring either $\sum E_i(1-\cos\theta_i) > 35$ GeV (in a perfect detector without initial state radiation this sum would equal 55 GeV) for NC events, or for CC events the ratio of the transverse energy flow along the direction of the outgoing electron to that opposite to it to be less than 0.15.

The next to leading order QCD-fit shown superimposed to the data is derived from 235 H1 data points (including 77 from our previous analysis up to 1994 [25]) and 452 data points from previous fixed target experiments at the low Q^2 end. At the highest Q^2 the fit to the data requires the inclusion of the Z^0-exchange in addition to γ-exchange in the NC-case. In the CC-case the cross section is sensitive via the propagator term also to the mass of charged vector boson. We find $m_W = 79.2 \pm 3.1$(stat.) ± 1.6(syst.) ± 3.5(theor.). The inclusion of

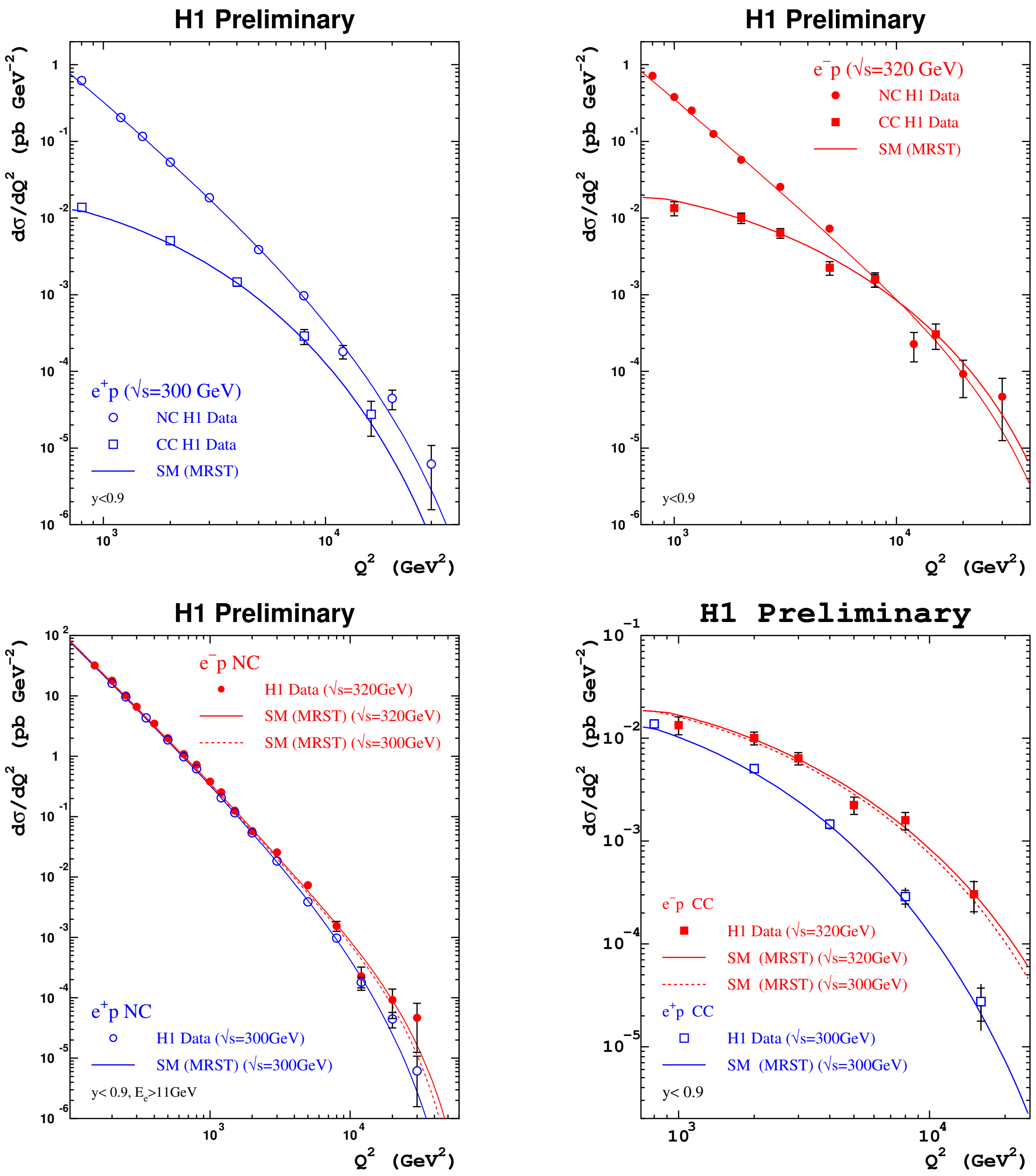

Figure 7.2: High momentum transfer charge and neutral cross sections for positron and electron deep inelastic scattering: e^-p preliminary data from 1998/99 (5 pb^{-1}) at $E_p = 920$ GeV and e^+p published data from 1994-97 (36 pb^{-1}) at $E_p = 800$ GeV.

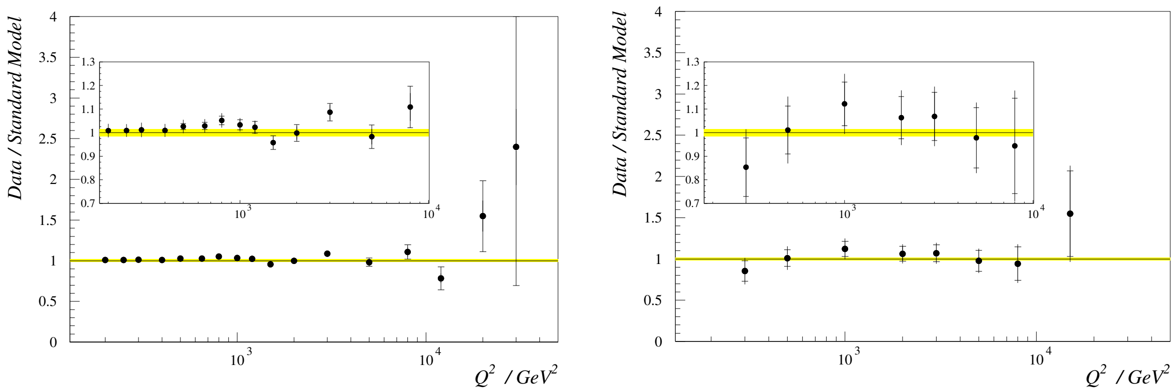

Figure 7.3: Ratio of the obserevd neutral (left) and the charged (right) current cross sections $d\sigma/dQ^2$ to that predicted by the standard model. The gray band indicates the normalisation error from the luminosity measurement. The inner error bars represent the statistical, the outer the systematical errors.

the 1997 data weakened the statistical significance of the deviations from the standard model prediction seen for $Q^2 > 10000$ GeV^2 and $x \approx 0.4$ [24].

The data were also subjected to a thorough analysis searching for leptoquark bosons and lepton flavor violation [4]. The Yukawa couplings of first generation scalar and vector leptoquarks in the Buchmüller-Rückl-Wyler effective model [26] have been constrained, taking into acount both s- and u- channel contributions as well as interference with standard model boson exchange. E. g. scalar leptoquarks are excluded with masses up to 275 GeV, for a coupling of electromagnetic strength. The exclusion limits derived improve not only previously extracted limits from HERA experiments, but also extend the coupling-mass domain covered so far at other colliders with a small branching ratio to eq. Leptoquarks possessing couplings to mixed fermion generations, which could lead to signals for lepton flavor violation are searched in events with a high transverse momentum μ or τ. No $\mu + X$ or $\tau + X$ event candidate is found that is compatible with the specific hypothesis of lepton flavor violation due to a leptoquark. The corresponding constraints can in some cases also extend the mass range set at other colliders and by low energy experiments such as $\mu \to e\gamma$ and K-decay.

In reference [3] we reported on the observation of a small number of events with a high p_T isolated lepton or large P_T^{miss}. The number of events seen and their kinematical distribution was found not to be consistent with the assumption of W production. Table 7.2 presents an update which includes the electron data. Unfortunately no new candidates have appeared [1].

7.3.2 Heavy quark production

Heavy quarks have become an increasingly interesting part in the physics field opened up by HERA. In the QCD picture of electron proton interactions, charm and beauty production involves the coupling to gluons. With the statistical power reached in the data now, charm quarks have become a direct probe of the gluonic component of hadronic structure. Since their masses are large compared to the QCD parameter Λ_{QCD}, they set the hard scale which is necessary for the methods of perturbation theory to be applied. The production process is therefore also an important testing ground for perturbative QCD. On the experimental side, the first observation of b production at HERA last year has created interest. The still preliminary result indicates an unexpectedly high cross section. An independent measurement

Data set Luminosity	e^+p at $\sqrt{s} = 300$ GeV 36.5 pb^{-1} 1994-97 published [3]	e^-p at $\sqrt{s} = 320$ GeV 5.1 pb^{-1} 1998-99 preliminary
e events found	1	0
e events expected	2.4 ± 0.5	0.37 ± 0.07
e events from W decay	1.7 ± 0.5	0.23 ± 0.07
μ events found	5	0
μ events expected	0.8 ± 0.2	0.14 ± 0.04
μ events from W decay	0.5 ± 0.1	0.09 ± 0.02

Table 7.2: High transverse momentum p_T lepton and missing transverse momentum $p_T^{\rm miss}$ events seen by the H1-detector. The selection requires $p_T^{\rm calo} > 25$ GeV, $p_T^{\rm track} > 10$ GeV and no closeby other tracks.

– using lifetime information based on the new Silicon vertex detector – is of high importance and within reach.

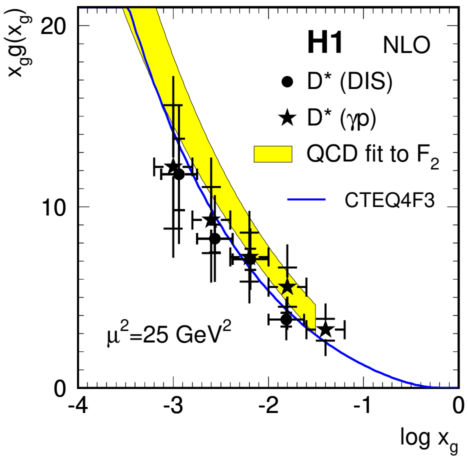

Figure 7.4: Gluon densities obtained from the two D^* analyses. The inner error bars represent the statistical and the outer the total error. The systematic error is a quadratic sum of all contributions, dominated by the theoretical uncertainty. Both results are compared to the result of the H1 QCD analysis of the inclusive F_2 measurement [25] at $\mu^2 = 25$ GeV^2 (light shaded band) and the CTEQ4F3 parameterization.

The measurement of the gluon density in the proton via charm production – observed through the fragmentation and decay chain $c \to D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$ –in deep inelastic scattering (Thesis D. Müller [18]) has been discussed in our previous annual report. In 1998, a measurement following the same principle has been performed in photo-production. It strongly relies on differential cross section results (Thesis M. zur Nedden [19]) which demonstrate that the Next-to-Leading Order (NLO) QCD calculations used to extract the parton density information provide an adequate description of the data in the kinematic regime under consideration. The theses have been completed, and both results were published together [21]. Figure. 7.4 shows that they agree well with each other and also with the gluon density determined by H1 [25] from a QCD analysis of the scaling violations of the proton structure function F_2. This amounts to an important verification of our understanding of the application of QCD and to a demonstration of the universality of the gluon distribution in the proton.

Pursuing these concepts further, charm production may also shed light on the dynamics of diffractive scattering. A fraction of about 10 % of the DIS events has a “rapidity gap”: in contrast to the general case the region surrounding the outgoing proton beam is void of any particles. This distinctively "diffractive" topology leads to an interpretation of the events in terms of the exchange of a color-less object, which may be identified with the Pomeron ($I\!P$) in the framework of hadron-hadron interaction phenomenology. HERA offers the possibility to study these phenomena in a perturbative regime and to investigate the partonic structure of the exchange, where charm production again singles out the gluonic component.

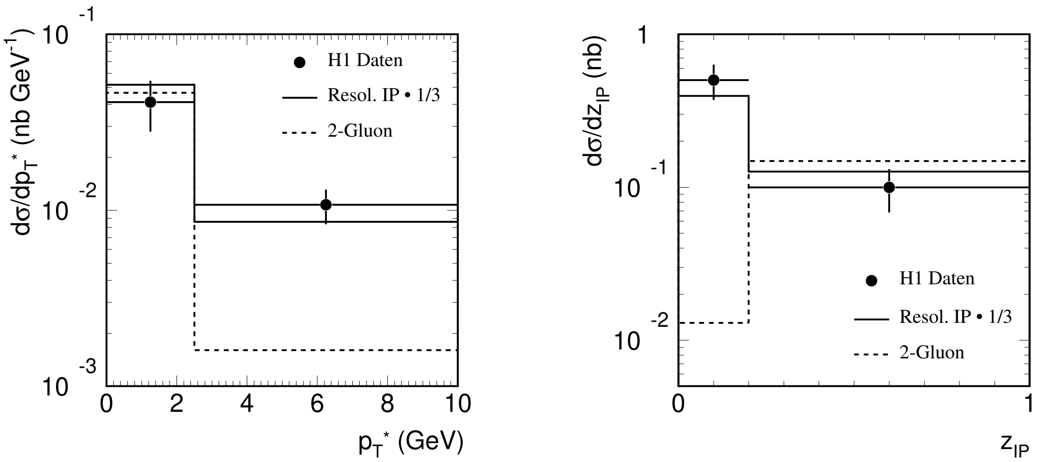

Figure 7.5: Differential cross sections for diffractive D^* production in DIS. with four-momentum transfer $Q^2 > 2$ GeV^2 and $p_\perp(D^*) > 2$, as a function of $p_\perp^*$ measured in the hadronic centre-of-mass frame, and of $z_{I\!P}$ which approximates the momentum fraction of the interacting parton as part of the exchanged object. The histograms represent the predictions of the "resolved Pomeron" model, scale by a factor 1/3, and the "two gluon" model.

The integrated luminosity accumulated in the years 1995-97 allows for the first time to take a step towards differential cross sections for diffractive D^* production (Thesis S. Hengstmann). In Figure 7.5 the data are compared to two different model predictions. In the "resolved Pomeron" model [27],the structure of the exchanged object is described in terms of quark and gluon densities which have been obtained from a fit to inclusive diffractive DIS data. In the "two gluon" model [28], the color-less exchange is realized in terms of two perturbative gluons, and cross sections are sensitive to the gluon density in the proton. The two approaches lead to remarkably different kinematic distributions; examples can be seen in Figure 7.5. $p_\perp^*$ denotes the transverse momentum of the D^* meson in the hadronic centre-of-mass frame, and $z_{I\!P}$ is an observable correlated with the momentum fraction which the parton interacting with the $c\bar{c}$ pair holds as part of the exchanged object. In the "$2g$" model, $z_{I\!P} = 1$ would hold if the partons could be directly observed. The data reveal that the "resolved $I\!P$" approach gives a fair reproduction of the shape of the spectra, but fails in overall normalization. The "two gluon" model, on the other hand, matches the data at high $z_{I\!P}$, but a lack of higher order, low $z_{I\!P}$ contributions is apparent. The data thus provide valuable and rather distinctive indications for further refinement of the theoretical description.

Tagging heavy quark production with D^* mesons suffers from the low fragmentation and decay fraction of the preferred channel of 0.7% which is then further reduced by experimental efficiencies. Much higher tagging efficiencies can be obtained by making use of the long lifetimes of c and b hadrons which can be measured with micro-vertex detectors. With its central silicon tracker (CST), H1 is the first experiment at HERA to be in the position to exploit these techniques. Fully commissioned in 1997, the CST is now being integrated into physics analyses. As an example of the first studies made, we show in Figure 7.6 the lifetime distribution of D^0 mesons originating from D^* decays. The lifetimes for each event have been obtained from a measurement of the decay length in the transverse detector plane - using the D^0 decay tracks measured in the CST - and from the the transverse momentum of the D^0 meson.The fitted curve is the convolution of a Gaussian resolution function – mainly reflecting the beam spot size – and an exponential decay law. It describes the gross features of the distribution well. Apart from developping the skills and understanding in dealing with the new detector, the motivation for the study is that contributions from beauty decays $B \to D^*X$ would give rise to excessively long reconstructed lifetimes, due to the additional B decay path. This may illustrate that the window to new physics opportunities is just now being opened.

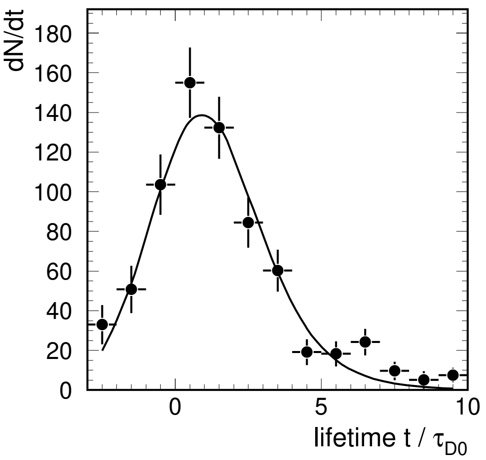

Figure 7.6: Distribution of D^0 meson lifetimes, calculated from the decay length measured with the CST, and the D^0 momentum, in units of the D^0 mean lifetime. The curve is a convolution of a resolution function and an exponential decay law.

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