9 Particle Physics at DESY/HERA (H1)

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Figure 9.1 taken from an article in the April 2012 issue of the CERN-Courier illustrates which domains in the (x, Q^2) plane are accessible to the LHC-, HERA- and fixed-target experiments, with Bjorken-x designating the longitudinal fraction of the incoming proton's momentum that is carried by the interacting parton (quark or gluon), and Q^2 marking the square of the four-momentum exchanged in the hard scattering process. Uncertainties in the parton-density functions (PDFs), i.e. the probability density for finding a parton with longitudinal momentum fraction x at momentum transfer Q^2 in the available kinematic regions dominate the precision of all theoretical predictions of cross sections at the LHC, extending now to next-to-next-to-leading order in QCD. The improved extraction of the PDFs from the HERA data therefore remains a central topic of the ongoing analyses of the data collected until 2007.

The two lines of approach to augment the precision of the PDFs are well documented through the preliminary data presented recently[1, 2]. On the one hand the H1-collaboration fine tunes the analysis in order to reduce the systematic errors of their HERA-II as well as their HERA-I data [3–5]. On the other hand a mixed team from both the H1- and the ZEUS-collaboration continues to combine the data in a systematic way considering correlated and uncorrelated errors, and adds successively also exclusive channels [6, 7].

An example of the former approach is an alternative method to determine the integrated luminosity by using elastic QED Compton scattering $e^+p \to e^+p\gamma$ events [5]. This process is characterized by a small momentum transfer at the proton vertex with both the electron and the photon having significant transverse momentum and can be calculated at high precision in perturbative quantum electrodynamics (QED). The results compare favorably with the default measurements of the integrated luminosity using Bethe-Heitler events.

The second approach started in the year 2009 by combining the H1 and ZEUS measurements of the inclusive deep inelastic ep scattering (DIS) cross sections. Both neutral current (NC) and charged current (CC) unpolarized results from the HERA-I period 1994-2000 were considered [8]. The data span six orders of magnitude in Q^2 and x and correspond to twice 63 pb^{-1}. A next-to-leading order (NLO) QCD analysis was performed which determined a new set of parton distributions, HERA PDF1.0,

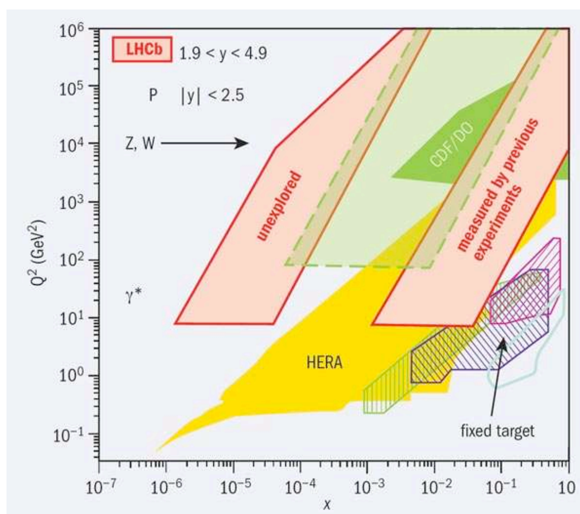

FIG. 9.1 – *Domains in the (x, Q^2)-plane accessible to the three experiments Atlas, CMS and LHCb at the LHC in (p, p) collisions, to the two experiments H1 and ZEUS at HERA in (e, p) collisions and to various fixed target experiments. Source: CERN-Courier, April 2012.*

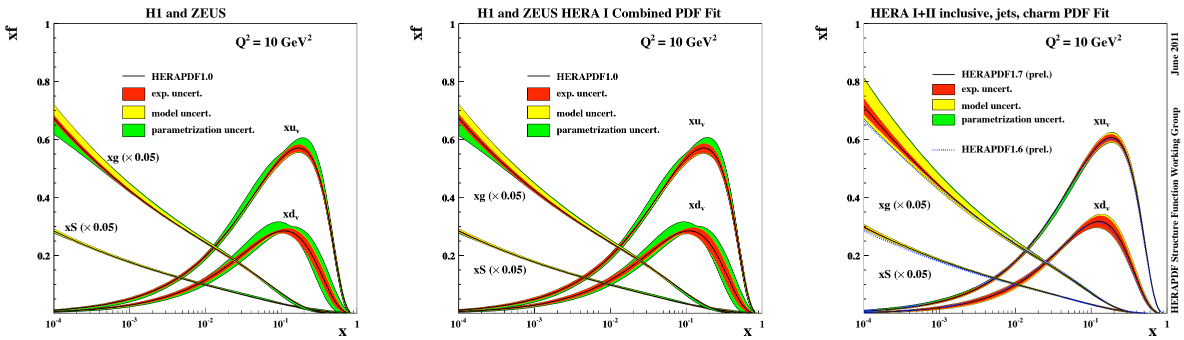

FIG. 9.2 – *Evolution of the PDFs determined from the combined H1- and ZEUS-data, from HERA PDF 1.0, to HERA PDF 1.5 and HERA PDF 1.7 for $Q^2 = 10$ GeV^2.*

with small experimental uncertainties. As an example the PDFs are shown for $Q^2 = 10$ GeV^2 in Fig. 9.2. The structure functions F_2, F_L and F_3 which appear in the general expression for the neutral current cross section ($Y_\pm$ are kinematical functions and y is the energy loss of the electron or positron)

$$\frac{d^2\sigma^\pm_{\rm NC}}{dx\,dQ^2} = \frac{2\alpha\pi^2}{xQ^4}\left(Y_+F_2 \mp Y_-xF_3 - y^2F_L\right)$$

are sensitive to the quark (antiquark) $q(\bar{q})$ and gluon g distribution functions:

$$\begin{aligned} F_2 &\propto \sum_i e_i^2(xq_i + x\bar{q}_i) \\ xF_3 &\propto \sum_i e_i^2(xq_i - x\bar{q}_i) \\ F_L &\propto \alpha_s \times g\,. \end{aligned}$$

The gluon distribution is obtained either from the scaling violation of F_2 or from F_L at NLO. Similar expressions hold for the charged current cross section yielding a flavor decomposition:

$$\frac{d^2\sigma^-_{\rm CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2+Q^2}\left(u + c + (1-y^2)(\bar{d}+\bar{c})\right)$$

$$\frac{d^2\sigma^+_{\rm CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2+Q^2}\left(\bar{u} + \bar{c} + (1-y^2)(d+c)\right)$$

The PDF-fits use typically parametrisations such as

$$xu(x) = Ax^B(1-x)^C(1+Ex^2)$$

for the distribution of the valence up-quarks (A, B, C are different for $d, g, \bar{u}, \bar{d}$, $E = 0$ for all except u).

In July 2010 the preliminary HERA-II results have been included. The experiments contribute ≈ 500 pb^{-1} each and were in very good agreement. An example of the resulting PDF-set HERA 1.5 is shown in Fig. 9.2 [6].

Next, jet and charm production cross sections were included in the analysis enhancing the sensitivity to the gluon PDF. The resulting present best set HERA 1.7 (see also Fig. 9.2) is based on 674 NC and CC data points, 41 data points probing the charm content in the proton, 106 inclusive-jet data points and 224 low proton energy data points. The charm quark mass was fixed at 1.5 GeV from a scan and the strong coupling constant at $\alpha_s = 0.119$ [7]. The analysis indicates a steeper rise of $g(x)$ and demonstrates the consistency of the HERA-data, even though some input data are still preliminary.

Other subjects which have been addressed in the articles published last year include:

- Extension of the structure function measurements to high inelasticity and direct assessment of the longitudinal component using also data from the runs with lower energy proton beams [9];
- Search for contact interactions, leptoquarks and lepton flavor violation [10–12];
- Heavy flavour photo- and electroproduction [13, 14];
- Various aspects of diffraction studied either inclusively or exclusively (through specific final states) [15–19].

Lastly, new results on normalized inclusive jet, dijet and trijet differential cross sections in DIS have been presented [20]. The regularized unfolding procedure extends an earlier analysis [21]. Detector effects like acceptance and migrations as well as statistical correlations between the multi-jets and the inclusive DIS events are taken into account this way. A phase space of $150 < Q^2 < 15000$ GeV^2 and $0.2 < y < 0.7$ was covered. The jets are reconstructed in the Breit frame of reference using the k_T jet algorithm within the laboratory pseudorapidity range $-1.0 < \eta_{\mathrm{lab}} < 2.5$ and the Breit frame transverse momentum range $7 < P_T < 50$ GeV ($5 < P_T < 50$ GeV for di- and trijet), and the invariant mass of the two leading jets larger than 16 GeV. Compared to a previous publication on normalized multi-jet cross sections, the new analysis extends the range in pseudorapidity and reduces the hadronic energy scale uncertainty to 1% . The unfolded cross sections are compared to QCD calculations at NLO and values for the strong coupling $\alpha_s(M_Z)$ are extracted.

[1] Europhysics Conference on High Energy Physics 2011, Grenoble, France, July 20-27, 2011;

[2] International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2012), Bonn, March 26-30, 2012;

[3] *Combined Electroweak and QCD Fit of Inclusive Neutral and Charged Current Data with Polarized Lepton Beam*
presentation 364 by E. Rizvi [1].

[4] *High Q^2 Neutral and Charged Current in Polarised Collisions at HERA II*
presentation 973 by S. Habib [1].

[5] *Luminosity Measurement at HERA with Elastic QED Compton Events*
presentation 109 by S. Schmitt [2].

[6] *Combined Measurement and QCD Analysis of the Inclusive ep Scattering Cross Section at HERA (H1 and ZEUS)*
presentation 993 by V. Chekelian [1].

[7] *NLO QCD analysis of inclusive, charm and jet data from HERA (HERA PDF1.7)*
presentation 35 by K. Nowak [2].

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F.D. Aaron *et al.* [H1], DESY 12 – 041, arXiv:1203.4495 [hep-ex], Eur. Phys. J. **C** (2012), in print

[20] *Normalised Multi-jet Cross Sections using Regularised Unfolding and Extractions of $\alpha_s(M_Z)$ in Deep-Inelastic Scattering at high Q^2 at HERA*
presentation 163 by D. Britzger [2].

[21] *Jet Production at HERA and determination of α_s*
presentation 987 by A. Baghdasarian [1].