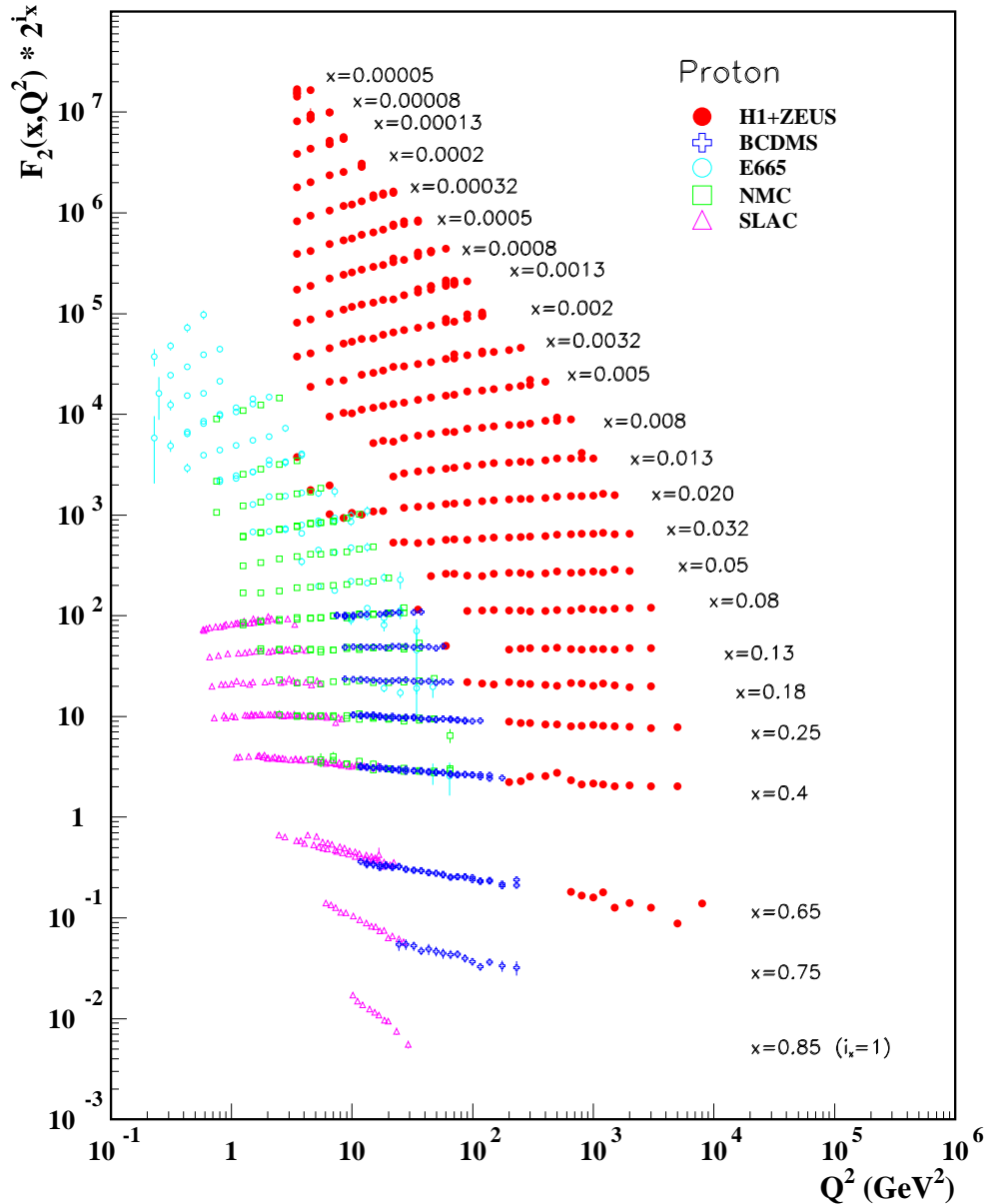
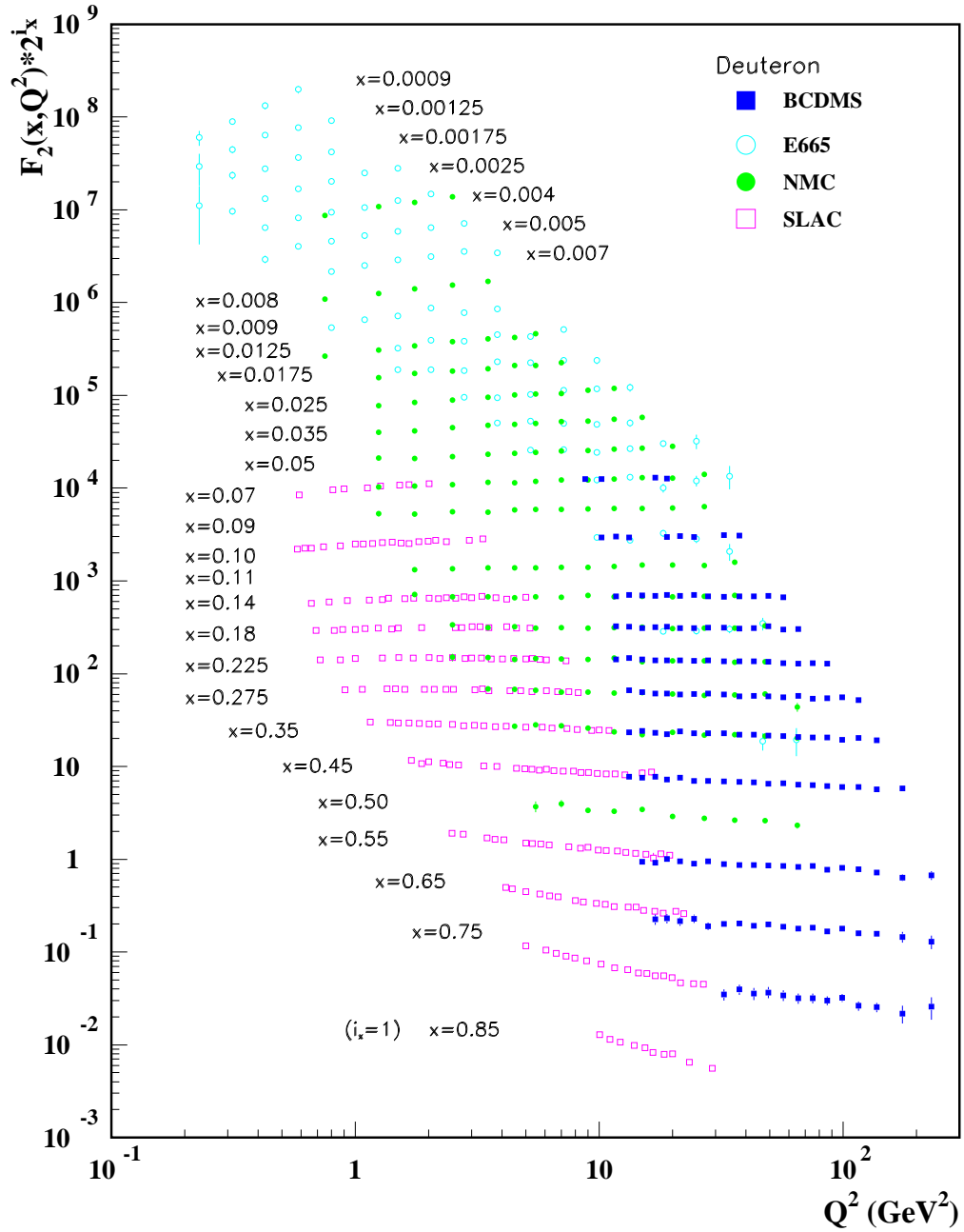


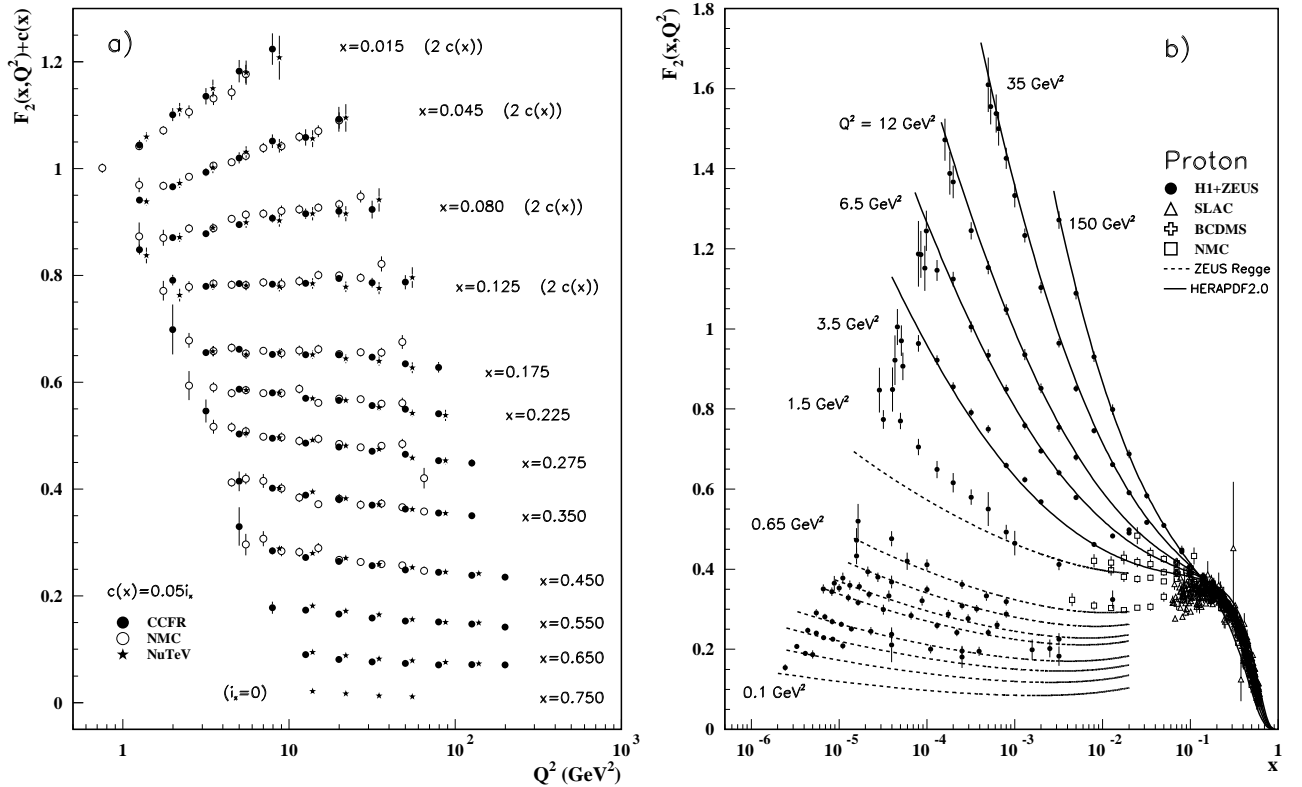
NOTE: THE FIGURES IN THIS SECTION ARE INTENDED TO SHOW THE REPRESENTATIVE DATA. THEY ARE NOT MEANT TO BE COMPLETE COMPILATIONS OF ALL THE WORLD'S RELIABLE DATA.



**Figure 18.8:** The proton structure function  $F_2^p$  measured in electromagnetic scattering of electrons and positrons on protons (collider experiments H1 and ZEUS for  $Q^2 \geq 2 \text{ GeV}^2$ ), in the kinematic domain of the HERA data (see Fig. 18.10 for data at smaller  $x$  and  $Q^2$ ), and for electrons (SLAC) and muons (BCDMS, E665, NMC) on a fixed target. Statistical and systematic errors added in quadrature are shown. The H1+ZEUS combined values are obtained from the measured reduced cross section and converted to  $F_2^p$  with a HERAPDF NLO fit, for all measured points where the predicted ratio of  $F_2^p$  to reduced cross-section was within 10% of unity. The data are plotted as a function of  $Q^2$  in bins of fixed  $x$ . Some points have been slightly offset in  $Q^2$  for clarity. The H1+ZEUS combined binning in  $x$  is used in this plot; all other data are rebinned to the  $x$  values of these data. For the purpose of plotting,  $F_2^p$  has been multiplied by  $2^{i_x}$ , where  $i_x$  is the number of the  $x$  bin, ranging from  $i_x = 1$  ( $x = 0.85$ ) to  $i_x = 24$  ( $x = 0.00005$ ). References: **H1 and ZEUS**—H. Abramowicz *et al.*, Eur. Phys. J. **C75**, 580 (2015) (for both data and HERAPDF parameterization); **BCDMS**—A.C. Benvenuti *et al.*, Phys. Lett. **B223**, 485 (1989) (as given in [96]); **E665**—M.R. Adams *et al.*, Phys. Rev. **D54**, 3006 (1996); **NMC**—M. Arneodo *et al.*, Nucl. Phys. **B483**, 3 (1997); **SLAC**—L.W. Whitlow *et al.*, Phys. Lett. **B282**, 475 (1992).



**Figure 18.9:** The deuteron structure function  $F_2^d$  measured in electromagnetic scattering of electrons (SLAC) and muons (BCDMS, E665, NMC) on a fixed target, shown as a function of  $Q^2$  for bins of fixed  $x$ . Statistical and systematic errors added in quadrature are shown. For the purpose of plotting,  $F_2^d$  has been multiplied by  $2^{i_x}$ , where  $i_x$  is the number of the  $x$  bin, ranging from 1 ( $x = 0.85$ ) to 29 ( $x = 0.0009$ ). References: **BCDMS**—A.C. Benvenuti *et al.*, Phys. Lett. **B237**, 592 (1990). **E665, NMC, SLAC**—same references as Fig. 18.8.

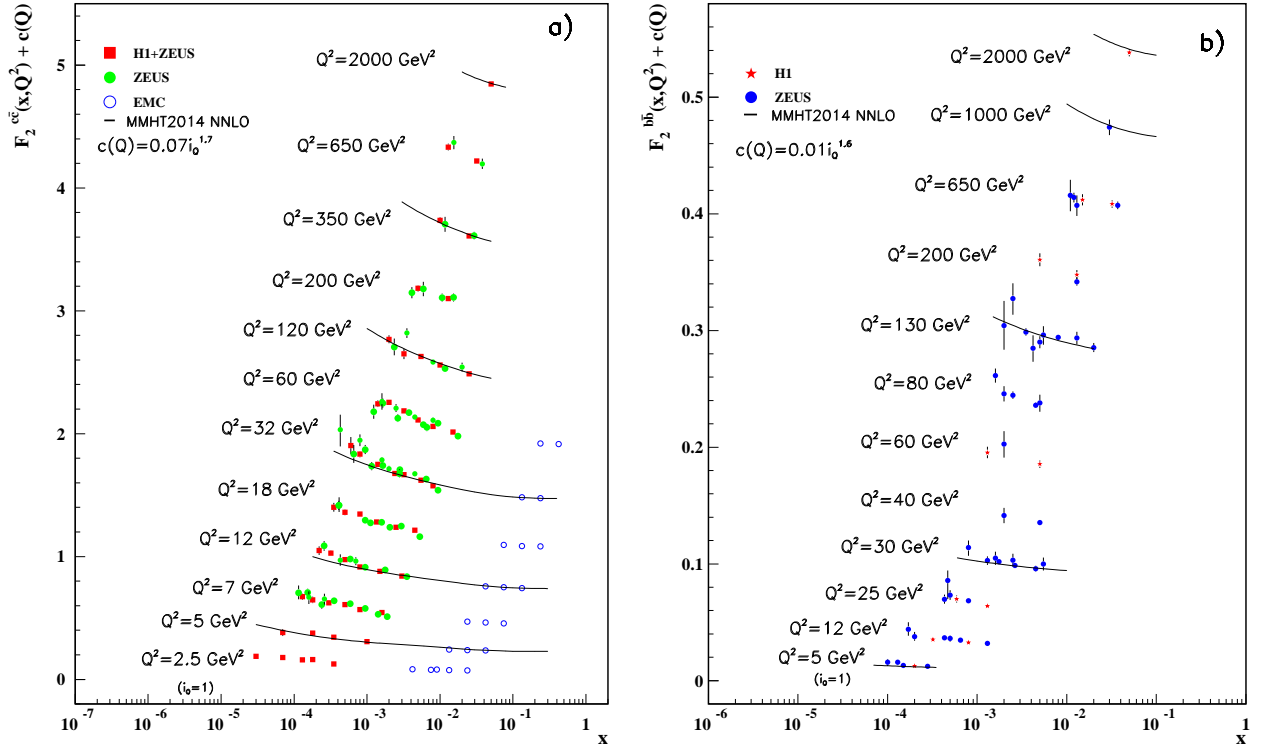


**Figure 18.10:** a) The deuteron structure function  $F_2$  measured in deep inelastic scattering of muons on a fixed target (NMC) is compared to the structure function  $F_2$  from neutrino-iron scattering (CCFR and NuTeV) using  $F_2^\mu = (5/18)F_2^\nu - x(s + \bar{s})/6$ , where heavy-target effects have been taken into account. The data are shown versus  $Q^2$ , for bins of fixed  $x$ . The NMC data have been rebinned to CCFR and NuTeV  $x$  values. For the purpose of plotting, a constant  $c(x) = 0.05i_x$  is added to  $F_2$ , where  $i_x$  is the number of the  $x$  bin, ranging from 0 ( $x = 0.75$ ) to 7 ( $x = 0.175$ ). For  $i_x = 8$  ( $x = 0.125$ ) to 11 ( $x = 0.015$ ),  $2c(x)$  has been added. References: **NMC**—M. Arneodo *et al.*, Nucl. Phys. **B483**, 3 (1997); **CCFR/NuTeV**—U.K. Yang *et al.*, Phys. Rev. Lett. **86**, 2741 (2001); **NuTeV**—M. Tzanov *et al.*, Phys. Rev. **D74**, 012008 (2006).

b) The proton structure function  $F_2^p$  mostly at small  $x$  and  $Q^2$ , measured in electromagnetic scattering of electrons and positrons (H1, ZEUS), electrons (SLAC), and muons (BCDMS, NMC) on protons. Lines are ZEUS Regge and HERAPDF parameterizations for lower and higher  $Q^2$ , respectively. The width of the bins can be up to 10% of the stated  $Q^2$ . Some points have been slightly offset in  $x$  for clarity. The H1+ZEUS combined values for  $Q^2 \geq 3.5$  GeV<sup>2</sup> are obtained from the measured reduced cross section and converted to  $F_2^p$  with a HERAPDF NLO fit, for all measured points where the predicted ratio of  $F_2^p$  to reduced cross-section was within 10% of unity. A turn-over is visible in the low- $x$  points at medium  $Q^2$  (3.5 GeV<sup>2</sup> and 6 GeV<sup>2</sup>) for the H1+ZEUS combined values. In order to obtain  $F_2^p$  from the measured reduced cross-section,  $F_L$  must be estimated; for the points shown, this estimate is obtained from HERAPDF2.0. No  $F_L$  value consistent with the HERA data can eliminate the turn-over. This may indicate that at low  $x$  and  $Q^2$  there are contributions to the structure functions that cannot be described in standard DGLAP evolution.

References: **H1 and ZEUS**—F.D. Aaron *et al.*, JHEP **1001**, 109 (2010) (data for  $Q^2 < 3.5$  GeV<sup>2</sup>), H. Abramowicz *et al.*, Eur. Phys. J. **C75**, 580 (2015) (data for  $Q^2 \geq 3.5$  GeV<sup>2</sup> and HERAPDF parameterization); **ZEUS**—J. Breitweg *et al.*, Phys. Lett. **B487**, 53 (2000) (ZEUS Regge parameterization); **BCDMS, NMC, SLAC**—same references as Fig. 18.8.

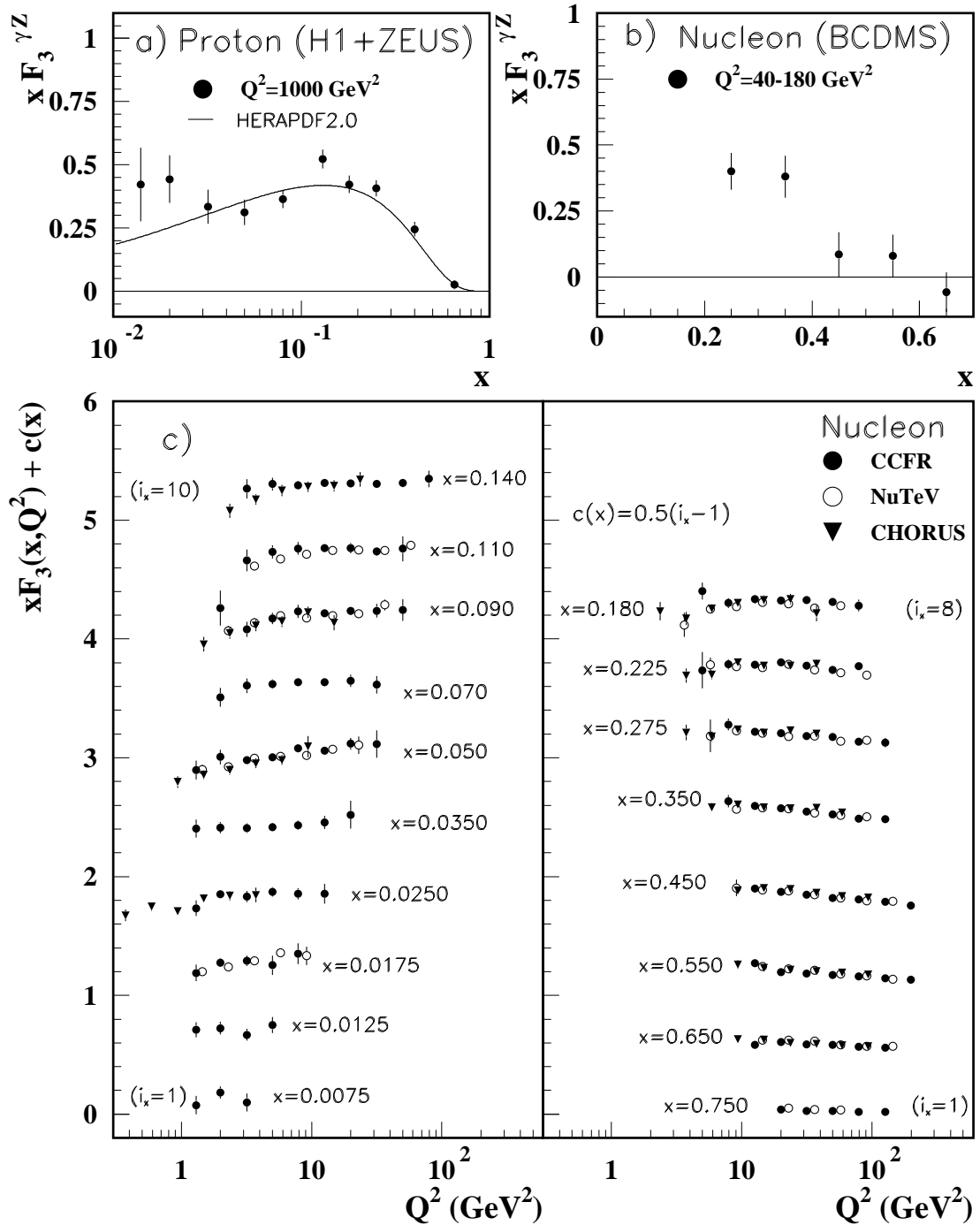
Statistical and systematic errors added in quadrature are shown for both plots.



**Figure 18.11:** a) The charm-quark structure function  $F_2^{c\bar{c}}(x)$ , i.e. that part of the inclusive structure function  $F_2^p$  arising from the production of charm quarks, measured in electromagnetic scattering of positrons on protons (H1, ZEUS) and muons on iron (EMC). For the purpose of plotting, a constant  $c(Q) = 0.07i_Q^{1.7}$  is added to  $F_2^{c\bar{c}}$  where  $i_Q$  is the number of the  $Q^2$  bin, ranging from 1 ( $Q^2 = 2.5 \text{ GeV}^2$ ) to 12 ( $Q^2 = 2000 \text{ GeV}^2$ ). References: **H1 and ZEUS run I combination**—H. Abramowicz *et al.*, Eur. Phys. J. **C73**, 2311 (2013); **ZEUS run II**—H. Abramowicz *et al.*, JHEP **05**, 023 (2013); H. Abramowicz *et al.*, JHEP **05**, 097 (2013); H. Abramowicz *et al.*, JHEP **09**, 127 (2014); **EMC**—J.J. Aubert *et al.*, Nucl. Phys. **B213**, 31 (1983).

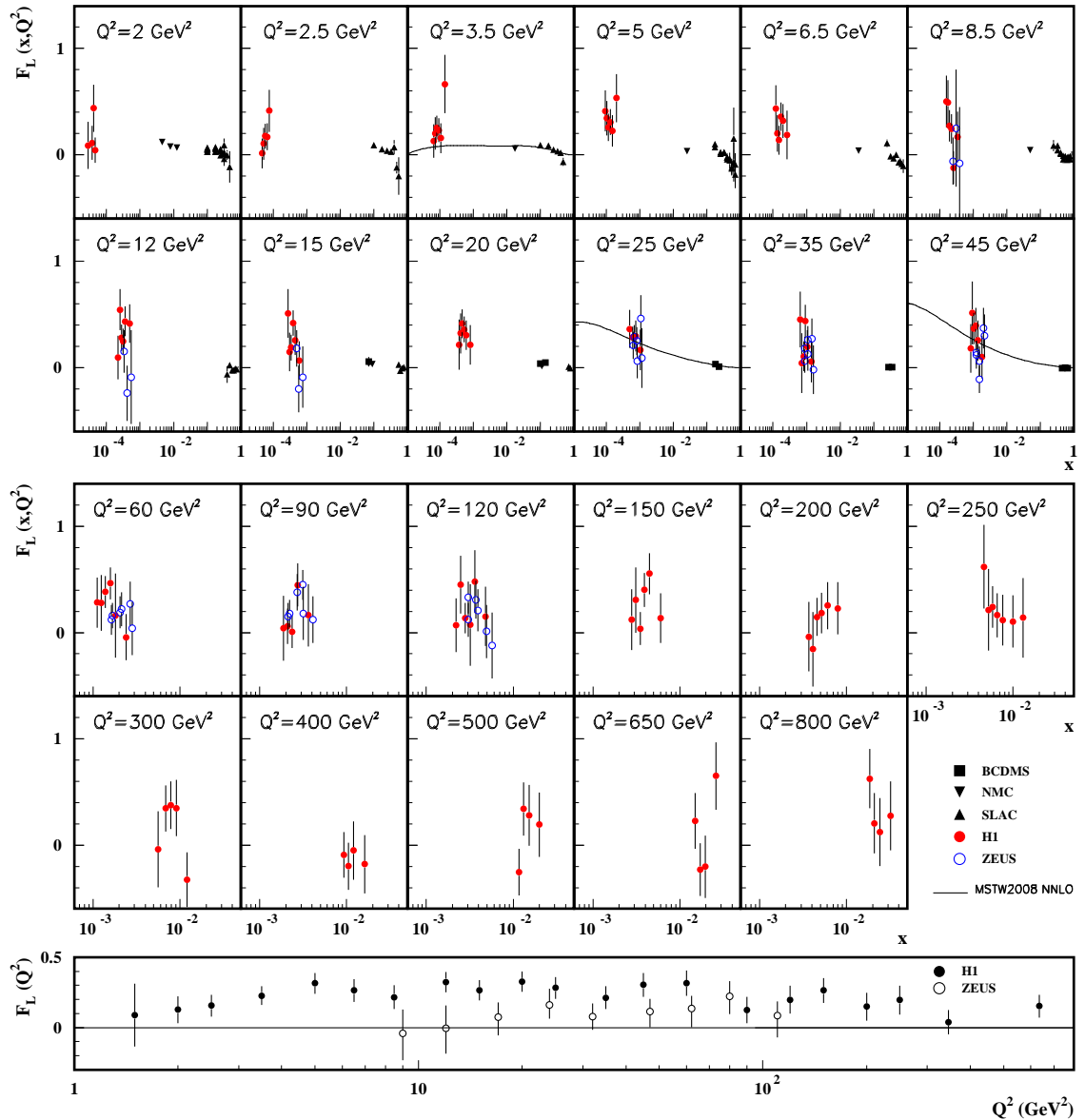
b) The bottom-quark structure function  $F_2^{b\bar{b}}(x)$ . For the purpose of plotting, a constant  $c(Q) = 0.01i_Q^{1.6}$  is added to  $F_2^{b\bar{b}}$  where  $i_Q$  is the number of the  $Q^2$  bin, ranging from 1 ( $Q^2 = 5 \text{ GeV}^2$ ) to 12 ( $Q^2 = 2000 \text{ GeV}^2$ ). References: **ZEUS**—S. Chekanov *et al.*, Eur. Phys. J. **C65**, 65 (2010); H. Abramowicz *et al.*, Eur. Phys. J. **C69**, 347 (2010); H. Abramowicz *et al.*, Eur. Phys. J. **C71**, 1573 (2011); H. Abramowicz *et al.*, JHEP **09**, 127 (2014); **H1**—F.D. Aaron *et al.*, Eur. Phys. J. **C65**, 89 (2010).

For both plots, statistical and systematic errors added in quadrature are shown. The data are given as a function of  $x$  in bins of  $Q^2$ . Points may have been slightly offset in  $x$  for clarity. Some data have been rebinned to common  $Q^2$  values. Also shown is the MMHT2014 parameterization given at several  $Q^2$  values (L. A. Harland-Lang *et al.*, Eur. Phys. J. **C75**, 204 (2015)).



**Figure 18.12:** The structure function  $x F_3^{\gamma Z}$  measured in electroweak scattering of **a)** electrons on protons (H1 and ZEUS) and **b)** muons on carbon (BCDMS). The line in **a)** is the HERAPDF parameterization. References: **H1 and ZEUS**—H. Abramowicz *et al.*, *Eur. Phys. J.* **C75**, 580 (2015) (for both data and HERAPDF parameterization); **BCDMS**—A. Argento *et al.*, *Phys. Lett.* **B140**, 142 (1984). **c)** The structure function  $x F_3$  of the nucleon measured in  $\nu$ -Fe scattering. The data are plotted as a function of  $Q^2$  in bins of fixed  $x$ . For the purpose of plotting, a constant  $c(x) = 0.5(i_x - 1)$  is added to  $x F_3$ , where  $i_x$  is the number of the  $x$  bin as shown in the plot. The NuTeV and CHORUS points have been shifted to the nearest corresponding  $x$  bin as given in the plot and slightly offset in  $Q^2$  for clarity. References: **CCFR**—W.G. Seligman *et al.*, *Phys. Rev. Lett.* **79**, 1213 (1997); **NuTeV**—M. Tzanov *et al.*, *Phys. Rev.* **D74**, 012008 (2006); **CHORUS**—G. Önençüt *et al.*, *Phys. Lett.* **B632**, 65 (2006).

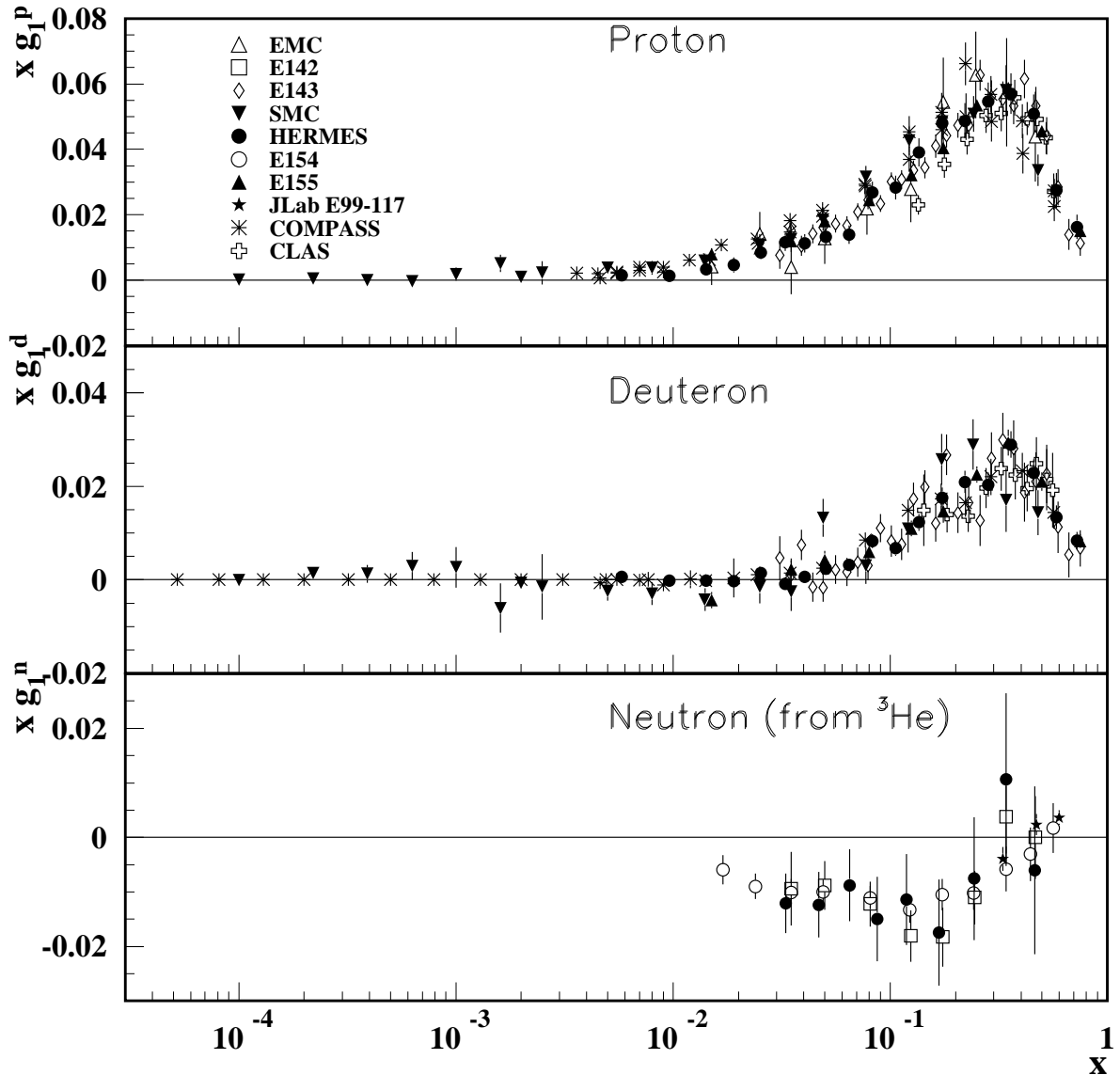
Statistical and systematic errors added in quadrature are shown for all plots.



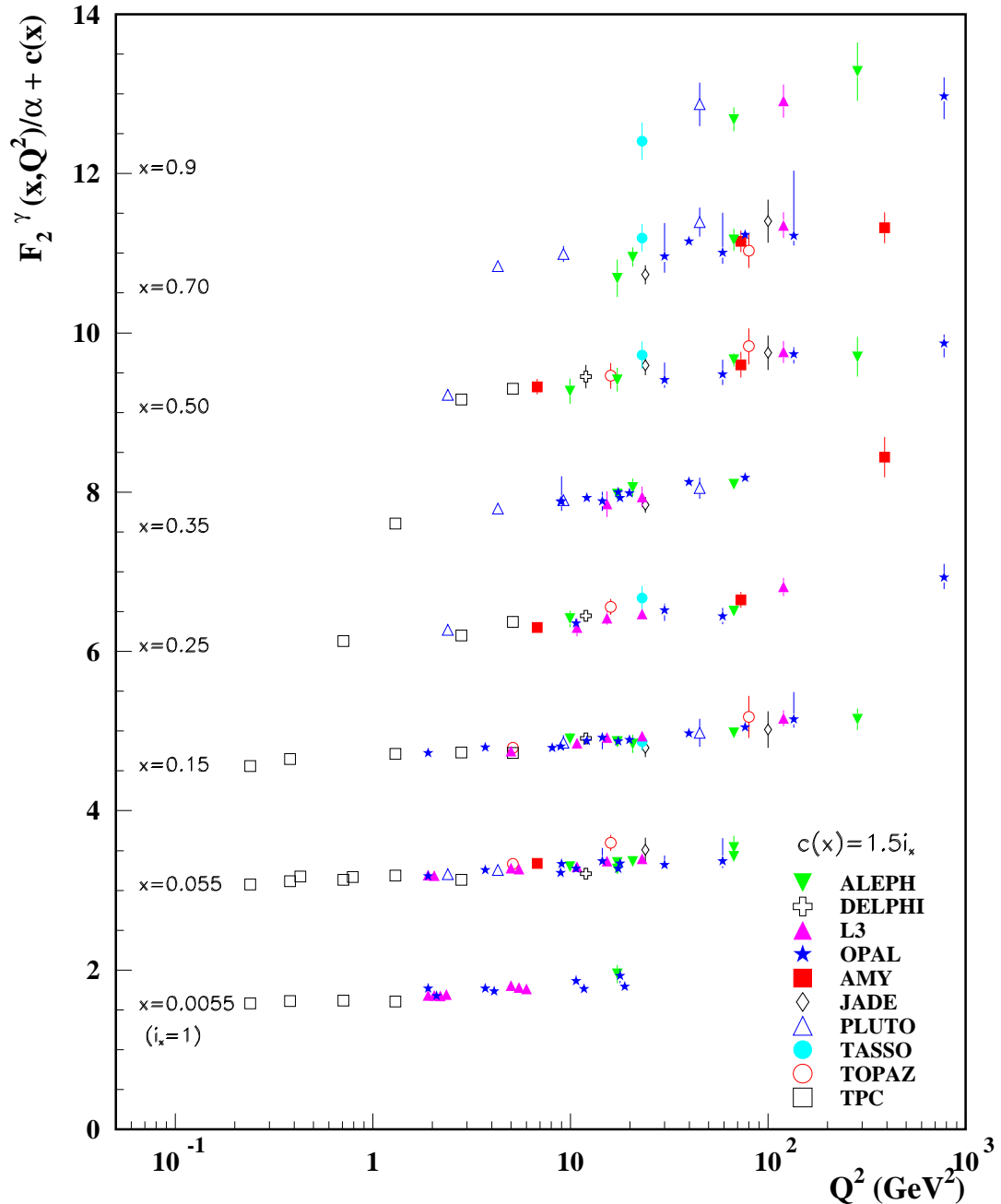
**Figure 18.13:** Top panels: The longitudinal structure function  $F_L$  as a function of  $x$  in bins of fixed  $Q^2$  measured on the proton (except for the SLAC data which also contain deuterium data). BCDMS, NMC, and SLAC results are from measurements of  $R$  (the ratio of longitudinal to transverse photon absorption cross sections) which are converted to  $F_L$  by using the BDCMS parameterization of  $F_2$  (A.C. Benvenuti *et al.*, Phys. Lett. **B223**, 485 (1989)). It is assumed that the  $Q^2$  dependence of the fixed-target data is small within a given  $Q^2$  bin. Some of the other data may have been rebinned to common  $Q^2$  values. Some points have been slightly offset in  $x$  for clarity. Also shown is the MSTW2008 parameterization given at three  $Q^2$  values (A.D. Martin *et al.*, Eur. Phys. J. **C63**, 189 (2009)). References: **H1**—V. Andreev *et al.*, Eur. Phys. J. **C74**, 2814 (2014); **ZEUS**—S. Chekanov *et al.*, Phys. Lett. **B682**, 8 (2009); H. Abramowicz *et al.*, Phys. Rev. **D90**, 072002 (2014); **BCDMS**—A. Benvenuti *et al.*, Phys. Lett. **B223**, 485 (1989); **NMC**—M. Arneodo *et al.*, Nucl. Phys. **B483**, 3 (1997); **SLAC**—L.W. Whitlow *et al.*, Phys. Lett. **B250**, 193 (1990) and numerical values from the thesis of L.W. Whitlow (SLAC-357).

Bottom panel: The longitudinal structure function  $F_L$  as a function of  $Q^2$ . Some points have been slightly offset in  $Q^2$  for clarity. References: **H1**—V. Andreev *et al.*, Eur. Phys. J. **C74**, 2814 (2014); **ZEUS**—H. Abramowicz *et al.*, Phys. Rev. **D90**, 072002 (2014).

The results shown in the bottom plot require the assumption of the validity of the QCD form for the  $F_2$  structure function in order to extract  $F_L$ . Statistical and systematic errors added in quadrature are shown for both plots.



**Figure 18.14:** The spin-dependent structure function  $xg_1(x)$  of the proton, deuteron, and neutron (from  ${}^3\text{He}$  target) measured in deep inelastic scattering of polarized electrons/positrons: E142 ( $Q^2 \sim 0.3 - 10 \text{ GeV}^2$ ), E143 ( $Q^2 \sim 0.3 - 10 \text{ GeV}^2$ ), E154 ( $Q^2 \sim 1 - 17 \text{ GeV}^2$ ), E155 ( $Q^2 \sim 1 - 40 \text{ GeV}^2$ ), JLab E99-117 ( $Q^2 \sim 2.71 - 4.83 \text{ GeV}^2$ ), HERMES ( $Q^2 \sim 0.18 - 20 \text{ GeV}^2$ ), CLAS ( $Q^2 \sim 1 - 5 \text{ GeV}^2$ ) and muons: EMC ( $Q^2 \sim 1.5 - 100 \text{ GeV}^2$ ), SMC ( $Q^2 \sim 0.01 - 100 \text{ GeV}^2$ ), COMPASS ( $Q^2 \sim 0.001 - 100 \text{ GeV}^2$ ), shown at the measured  $Q^2$  (except for EMC data given at  $Q^2 = 10.7 \text{ GeV}^2$  and E155 data given at  $Q^2 = 5 \text{ GeV}^2$ ). Note that  $g_1^n(x)$  may also be extracted by taking the difference between  $g_1^d(x)$  and  $g_1^p(x)$ , but these values have been omitted in the bottom plot for clarity. Statistical and systematic errors added in quadrature are shown. References: **EMC**—J. Ashman *et al.*, Nucl. Phys. **B328**, 1 (1989); **E142**—P.L. Anthony *et al.*, Phys. Rev. **D54**, 6620 (1996); **E143**—K. Abe *et al.*, Phys. Rev. **D58**, 112003 (1998); **SMC**—B. Adeva *et al.*, Phys. Rev. **D58**, 112001 (1998), B. Adeva *et al.*, Phys. Rev. **D60**, 072004 (1999) and Erratum-Phys. Rev. **D62**, 079902 (2000); **HERMES**—A. Airapetian *et al.*, Phys. Rev. **D75**, 012007 (2007) and K. Ackerstaff *et al.*, Phys. Lett. **B404**, 383 (1997); **E154**—K. Abe *et al.*, Phys. Rev. Lett. **79**, 26 (1997); **E155**—P.L. Anthony *et al.*, Phys. Lett. **B463**, 339 (1999) and P.L. Anthony *et al.*, Phys. Lett. **B493**, 19 (2000); **Jlab-E99-117**—X. Zheng *et al.*, Phys. Rev. **C70**, 065207 (2004); **COMPASS**—E.S. Ageev *et al.*, Phys. Lett. **B647**, 330 (2007), M.G. Alekseev *et al.*, Phys. Lett. **B690**, 466 (2010), C. Adolph, *et al.*, Phys. Lett. **B753**, 18 (2016) and C. Adolph, *et al.*, Phys. Lett. **B769**, 34 (2017); **CLAS**—K.V. Dharmawardane *et al.*, Phys. Lett. **B641**, 11 (2007) (which also includes resonance region data not shown on this plot — there is also low  $W^2$  CLAS data in Y. Prok *et al.*, Phys. Rev. **C90**, 025212 (2014) and N. Guler *et al.*, Phys. Rev. **C92**, 055201 (2015)).



**Figure 18.15:** The hadronic structure function of the photon  $F_2^\gamma$  divided by the fine structure constant  $\alpha$  measured in  $e^+e^-$  scattering, shown as a function of  $Q^2$  for bins of  $x$ . Data points have been shifted to the nearest corresponding  $x$  bin as given in the plot. Some points have been offset in  $Q^2$  for clarity. Statistical and systematic errors added in quadrature are shown. For the purpose of plotting, a constant  $c(x) = 1.5i_x$  is added to  $F_2^\gamma/\alpha$  where  $i_x$  is the number of the  $x$  bin, ranging from 1 ( $x = 0.0055$ ) to 8 ( $x = 0.9$ ). References: **ALEPH**–R. Barate *et al.*, Phys. Lett. **B458**, 152 (1999); A. Heister *et al.*, Eur. Phys. J. **C30**, 145 (2003); **DELPHI**–P. Abreu *et al.*, Z. Phys. **C69**, 223 (1995); **L3**–M. Acciarri *et al.*, Phys. Lett. **B436**, 403 (1998); M. Acciarri *et al.*, Phys. Lett. **B447**, 147 (1999); M. Acciarri *et al.*, Phys. Lett. **B483**, 373 (2000); **OPAL**–A. Ackerstaff *et al.*, Phys. Lett. **B411**, 387 (1997); A. Ackerstaff *et al.*, Z. Phys. **C74**, 33 (1997); G. Abbiendi *et al.*, Eur. Phys. J. **C18**, 15 (2000); G. Abbiendi *et al.*, Phys. Lett. **B533**, 207 (2002) (note that there is overlap of the data samples in these last two papers); **AMY**–S.K. Sahu *et al.*, Phys. Lett. **B346**, 208 (1995); T. Kojima *et al.*, Phys. Lett. **B400**, 395 (1997); **JADE**–W. Bartel *et al.*, Z. Phys. **C24**, 231 (1984); **PLUTO**–C. Berger *et al.*, Phys. Lett. **142B**, 111 (1984); C. Berger *et al.*, Nucl. Phys. **B281**, 365 (1987); **TASSO**–M. Althoff *et al.*, Z. Phys. **C31**, 527 (1986); **TOPAZ**–K. Muramatsu *et al.*, Phys. Lett. **B332**, 477 (1994); **TPC/Two Gamma**–H. Aihara *et al.*, Z. Phys. **C34**, 1 (1987).