Determination of the proton PDFs at HERA

Rencontres de Moriond,
QCD and High Energy Interactions

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On behalf of the H1 and ZEUS Collaborations
HERA collider. H1 and ZEUS experiments.

• HERA was unique $e^\pm p$ collider:
  • located at Hamburg, Germany;
  • operated during 1992 — 2007;

• Two general purpose collider experiments H1 and ZEUS:
  • optimised for measurement of the proton structure;
  • collected $\sim 0.5$ fb$^{-1}$ of integrated luminosity per experiment.
HERA collider. H1 and ZEUS experiments.

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- **momentum transfer:** \( Q^2 = -q^2 = -(k - k')^2 \)
- **Bjorken scaling variable:** \( x = \frac{Q^2}{2p \cdot q} \)

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Sensitivity of inclusive data to the proton PDF

**H1 and ZEUS**

\[ \sigma_{\gamma NC}^+ (x, Q^2) \]

- **HERA I+II NC e^+p (prel.)**
- **HERAPDF1.0 e^+p**

\[ Q^2 / \text{GeV}^2 \]

- **HERA Structure Functions Working Group June 2010**

- **HERA preliminary**

\[ F_L \]

- **HERA preliminary**
- **HERAPDF1.0**
Sensitivity of inclusive data to the proton PDF

\[ e^- \rightarrow W^- + \nu_e \]

\[ e^+ \rightarrow W^+ + \bar{\nu}_e \]

H1 and ZEUS

\[ \sigma_{\text{CC}}(x|Q^2) \]

\[ Q^2 = 300 \text{ GeV}^2 \]

\[ Q^2 = 500 \text{ GeV}^2 \]

\[ Q^2 = 1000 \text{ GeV}^2 \]

\[ Q^2 = 1500 \text{ GeV}^2 \]

\[ Q^2 = 2000 \text{ GeV}^2 \]

\[ Q^2 = 3000 \text{ GeV}^2 \]

\[ Q^2 = 5000 \text{ GeV}^2 \]

\[ Q^2 = 8000 \text{ GeV}^2 \]

\[ Q^2 = 10000 \text{ GeV}^2 \]

\[ Q^2 = 15000 \text{ GeV}^2 \]

\[ Q^2 = 20000 \text{ GeV}^2 \]

\[ Q^2 = 30000 \text{ GeV}^2 \]

\[ x \]

\[ \times 10^{-2} \]

\[ \times 10^{-1} \]

\[ \times 10^0 \]

\[ \times 10^1 \]

\[ \times 10^2 \]

\[ \times 10^3 \]

\[ \times 10^4 \]

\[ \times 10^5 \]

\[ \times 10^6 \]

\[ \times 10^7 \]

\[ \times 10^8 \]

\[ \times 10^9 \]

\[ \times 10^{10} \]

HERA I CC e\(^+\)p

HERAPDF1.0

HERA+II CC e\(^-\)p (prel.)

HERAPDF1.0

HERA Inclusive Working Group June 2010
QCD analysis

Analysis strategy:

- Parametrise PDFs at the starting scale $Q_0^2$
  - $xg, xu_V, xd_V, x\bar{U} = x(\bar{u} + \{\bar{c}\}), x\bar{D} = x(\bar{d} + \bar{s} + \{\bar{b}\})$
- Evolve PDFs using DGLAP equations to $Q^2 > Q_0^2$
  - NLO and NNLO DGLAP evolution QCDNUM [Comp. Ph. Comm. 182 (2011) 490]
  - Heavy flavours treated in GM-VFNS RT as for MSTW08
- Construct cross sections from PDFs and coefficient functions for every data point
- Perform $\chi^2$ fit to the experimental data

HERA unique data:

- Consistent set of measurements $\leftrightarrow \chi^2_{min} + 1$ criterion
- No need for:
  - nuclear corrections
  - neutrino heavy target corrections
Jet data is sensitive to the gluon PDF and to the value of $\alpha_s (M_Z)$. 

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Jet data is sensitive to the gluon PDF and to the value of $\alpha_s(M_Z)$.
The $F_2^{c\bar{c}}$ allows to determine the optimal charm mass parameter ($m_c^{\text{model}}$) for the various schemes.
Sensitivity of $F_2^{c\bar{c}}$ to charm and gluon PDFs

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HERAPDF1.0 + $F_2^{c\bar{c}}$(prel.)

- RT standard
- RT optimised
- ACOT-full
- S-ACOT-$\chi$
- ZMVFNS

H1 and ZEUS (prel.)

$\chi^2$ vs $m_c^{\text{model}}$ / GeV
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HERA I+II inclusive, jets, charm PDF Fit

$Q^2 = 10$ GeV$^2$

- HERAPDF1.7 (prel.)
- exp. uncert.
- model uncert.
- parametrization uncert.

$xf$ vs. $x$

$xf = 10$ GeV$^2$

$xg (\times 0.05)$

$xd (\times 0.05)$

$xS (\times 0.05)$

[Herapdf1.7 (prel.), H1prelim-11-143, ZEUS-prel-11-010]
HERAPDF predictions for LHC

HERAPDFs provides competitive predictions for $pp$ processes at high energy.

[CMS NOTE 2011/004]  [arXiv:1112.6297]
HERAPDF1.5 NNLO provides a prediction consistent with measurements at LHC.
HERAFitter is an open source QCD fit package for pPDF determination. herafitter.hepforge.org

- **Data:**
  - DIS $ep$
    - Inclusive
    - Jets
  - DY $pp$ and $p\bar{p}$
    - $W, Z$ cross sections
    - $Z$ rapidity
    - $W$ asymmetries
    - Jets

- **Output:**
  - PDFs predefined scales
  - LHAPDF grids
  - Theory predictions per data points
  - Pulls per data points

- **Theory (DIS):**
  - ZM-VFNS accessed from QCDNUM
    - [Comp. Ph. Comm. 182 (2011) 490]
  - RT optimal as in MSTW

- **Treatment for jets:**
  - FastNLO: [hep-ph/0609285]
    - A wrapper around NLOjet++
    - A wrapper around MCFM, NLOjet++

- **Error treatment:**
  - Correlated, uncorrelated
  - Hessian method
  - MC method

- **Parametrisation studies:**
  - Standard functional form of PDFs
  - CTEQ
  - Chebyshev
Summary and conclusions

- New precise determination of pPDF HERAPDF 1.7 based on:
  - combined inclusive HERAI + HERAII NC and CC data;
  - reduced proton energy data;
  - HERA jet data;
  - combined $F_{2}^{c\bar{c}}$.

- Inclusion of jet data reduces strong correlation between $\alpha_s$ and gluon PDF.
- Combined $F_{2}^{c\bar{c}}$ is sensitive to the gluon and charm content of the proton and the charm mass parameter.
- Predictions based on the proton PDFs extracted from $e^\pm p$ data alone provide good description of the LHC data.

- Open source HERAFitter$\beta$ project.
NLO and NNLO DGLAP evolution QCDNUM

RT-VFNS (as for MSTW08)

PDF parametrisation at $Q^2$: $xg, xuv, xdV, x\bar{U} = x(\bar{u} + \{c\}), x\bar{D} = x(\bar{d} + \bar{s} + \{b\})$

- 10 free parameters fit (HERAPDF1.0, HERAPDF1.5 NLO)
  \[ xf(x, Q^2_0) = Ax^B (1 - x)^C (1 + Dx + Ex^2) \]

- 14 free parameters fit (HERAPDF1.5 NNLO, HERAPDF1.6, HERAPDF1.7)
  \[ xf(x, Q^2_0) = Ax^B (1 - x)^C (1 + Dx + Ex^2) - A' x^{B'} (1 - x)^{25} \]
HERAPDF1.5 (prel.)
exp. uncert.
model uncert.
parametrization uncert.

$$x_f^2 = 10 \text{ GeV}^2$$

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March 2011

H1 and ZEUS HERA I+II 10 parameter PDF Fit

HERAPDF1.5 (prel.)
exp. uncert.
model uncert.
parametrization uncert.

HERAPDF1.5f (prel.)
HERAPDF1.5 (prel.)

D.

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