Measurements of the proton structure at HERA and their impact for LHC

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The \( ep \) collider HERA

- Circumference: 6.3 km
- \( 27.5 \times 920(820) \) GeV, \( \sqrt{s_{ep}} = 319 \) GeV
- 2 collider experiments: H1 and ZEUS
- HERA I: 1992-2000
- Luminosity upgrade: mid 2000 – end 2001
Inclusive DIS at HERA

Neutral current

\[ Q^2 = -(k - k')^2 \] - four momentum transfer squared in the reaction

\[ x = \frac{Q^2}{2P(k - k')} \] - fraction of the proton momentum carried by the parton

\[ y = \frac{Q^2}{sx} \] - fraction of the lepton’s energy loss

\[ s = 4E_e E_p \] - center-of-mass energy squared

Charged current
Cross sections and structure functions

**NC Cross Section:**

NC Reduced cross section: $\bar{\sigma}_{NC}(x, Q^2)$

$$ \frac{d^2 \sigma_{NC}(e^\pm p)}{dx dQ^2} = \frac{2\pi \alpha^2}{x Q^4} Y + \left[ \tilde{F}_2 - \frac{y^2}{Y_+} \tilde{F}_L + \frac{Y_-}{Y_+} x \tilde{F}_3 \right] $$

$Y_i = 1 \pm (1 - y)^2$

- The proton structure function $F_2$ in QPM:
  $$ F_2 = \sum_i e_i^2 x [q_i(x) + \bar{q}_i(x)] $$ - sum of the (anti)quarks density distributions weighted with their electric charge squared

- Structure function $F_L \sim$ gluon density $g(x)$ in NLO QCD and 0 in QPM
- $xF_3 \sim 2 \sum_i e_i a_i x[q_i(x) - \bar{q}_i(x)]$ - provides info from the valence quark distributions

**CC $e^\pm p$ Cross Sections:**

$$ \sigma^+ = x[\bar{u} + \bar{c}] + (1 - y)^2 x[d + s] $$

$$ \sigma^- = x[u + c] + (1 - y)^2 x[\bar{d} + \bar{s}] $$

flavour separation at high $x$
Kinematic plane

- QCD evolution extrapolates HERA measured PDFs to LHC
- HERA data cover LHC central rapidity range for $M>100$ GeV
F\textsubscript{2} at Q^{2}<150 \text{ GeV}^{2}

- Combined H1 data in the region of inelasticity 0.005<y<0.6 with a precision of 1.3-2\% , for HERA I period

- Data are compared to NLO QCD fit to the H1 data alone – H1PDF2009
Combined H1 & ZEUS data

- Combination of H1 & ZEUS HERA I data provides a model independent tool to study consistency of the data and to reduce systematic errors.

- New average based on the complete HERA I inclusive DIS data set with a total luminosity of $L=240$ pb$^{-1}$.

- The error reductions after the averaging procedure are clearly observed.
H1 & ZEUS combined results

H1 and ZEUS

• HERAPDF1.0 is a new NLO QCD fit to the complete inclusive HERA I data

• Scaling violations are well described over 4 orders of magnitude in $x$ and $Q^2$ by the fit with $\chi^2/\text{ndf} = 532/582$

• Fixed target data are also described by new fit
• Due to the precision of the combined data set, the HERAPDF1.0 parameterisation has total uncertainties at the level of a few percent at low $x$.

Sea and gluon distributions are divided by a factor of 20.
CC and NC cross section measurements

- The combined collected luminosity of 1 fb$^{-1}$ by H1 & ZEUS experiments provides a good test of the SM
- Neutral and Charged current cross sections at $Q^2 \geq M^2(Z/W)$ scale become similar: EW unification
- Agreement between H1, ZEUS and QCD fit over seven orders of magnitude in cross section
Measurement of $F_L$ by H1 & ZEUS

- Measurement of $F_L$ can be performed by measuring cross section for the same $Q^2$-$x$ but with different proton beam energies (different $y$):

$$\sigma_r = F_2 - f(y)F_L$$

- The new preliminary measurement of $F_L$ cover the range of $2.5 \leq Q^2 \leq 800$ GeV$^2$ and $0.00005 \leq x \leq 0.06$

- Data are in a good agreement with HERAPDF1.0 for $Q^2 > 10$ GeV$^2$
Melzner et al. 

- Sea quark dominated process
- Prediction based on HERAPDF1.0 and MCFM 5.7 calculation
- Exp. precision <1%, total uncertainty <5% for $y<2.5$
- Can be used as a luminosity monitor for LHC
• Gluon dominated process, which is measured at HERA from scaling violation

• Small experimental uncertainties
• Recent structure function results from the H1 and ZEUS Collaborations are presented

• The combined data set covers the wide kinematic range of $0.2 \leq Q^2 \leq 30000 \text{ GeV}^2$ and $5 \cdot 10^{-6} < x < 0.65$

• The combined measurements are analysed in a NLO QCD fit, and a set of parton density functions, HERAPDF1.0, is extracted from these data alone

• The high precision of presented data is essential for predictions of physics at the LHC

Summary