ZEUS at HERA

Robin Devenish

- HERA and ZEUS
- Oxford ZEUS Group
- Topics
- Future & Resources

Projects Review 2011
HERA (1992 – 2007)

HERA-I (1992-2000); HERA-II (2003-7 after upgrade)

27.5 GeV polarised $e^\pm$ on 920 GeV protons, $E_{cm} = 318$ GeV

Neutral Current $e p \rightarrow e X$, $V = \gamma$ or $Z^0$

Charged Current $e p \rightarrow \nu X$, $V = W^\pm$

Two general purpose detectors: H1 and ZEUS
Oxford ZEUS Group

- Faculty
  - A Cooper-Sarkar, R Walczak, C Gwenlan
  - R Devenish (retired but still active)
  - B Foster (Humboldt Professor, DESY and Hamburg University)

- Graduate students
  - Aileen Robertson (about to submit)
  - (Katie Oliver - successful viva, Aug 2011)

- Consultant Support Staff
  - Mike Dawson, Ewan MacMahon
Oxford Projects

- Strangeness correlations
  - Aileen Roberston & Roman Walczak

- Combining H1 and ZEUS data
  - Mandy Cooper-Sarkar & Robin Devenish

- HERA parton densities
  - Mandy Cooper-Sarkar

- ZEUS data preservation
  - Robin Devenish
Strange baryon pair production ($\Lambda\Lambda$, $\Lambda\bar{\Lambda}$)

- Function of $Q = \sqrt{(M_{\Lambda\Lambda}^2 - 4M_{\Lambda}^2)}$
- LH plot shows $N_{\Lambda\Lambda}/N_{\Lambda\bar{\Lambda}}$ (data - black; MC - red)
  - large excess of $\Lambda\bar{\Lambda}$ at small $Q$
- RH $\varepsilon = (S = 1 \text{ } \Lambda\Lambda \text{ pairs})/(\text{all } \Lambda\Lambda \text{ pairs})$
  - spin states selected using angle between protons from $\Lambda$ decays
  - expect $\varepsilon = 3/4$ for two spin-$1/2$ states coupling statistically

$Q > 4$ GeV
ratio flattens, long range correlations?
Combined H1 and ZEUS analyses

- To gain the ultimate precision in HERA physics

- Some examples
  - inclusive structure functions
  - charm structure function

\[ e^\pm + p \rightarrow e^\pm + X \quad \text{neutral current, NC, (} \gamma^* \text{ and } Z^0 \text{ exchange)} \]

\[ e^\pm + p \rightarrow \bar{\nu}, \nu + X \quad \text{charged current, CC, (} W^\pm \text{ exchange)} \]
Longitudinal structure function $F_L$

\[
\frac{d^2\sigma(e^+ p)}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4x} \left[ Y_+ F_2(x, Q^2) - y^2 F_L(x, Q^2) \mp Y_x F_3(x, Q^2) \right]
\]

where $Y_\pm = 1 \pm (1 - y)^2$ and $1 - y = \frac{E'}{E_e} \sin^2 \frac{\theta_e}{2}$

$F_i$: proton structure functions - given by quark and gluon parton densities

$F_L$ is the longitudinal SF - most difficult to measure;

$Q^2 = sxy \Rightarrow$ require a range of CM energies ($\sqrt{s}$) for fixed $(x, Q^2)$

$F_L$: small but not zero, depends directly on gluon density

Simple QPM gives zero
NC and CC cross-sections vs $Q^2$

**Classic plot - showing electroweak unification for $Q^2 \sim M_W^2$ and larger**

$\Phi_{NC}, \Phi_{CC}$ given by proton parton densities

e.g. $\Phi_{cc}^{(+)} = x\left[\bar u + \bar c + (1-y)^2(d+s)\right]$; $\Phi_{cc}^{(-)} = x\left[u + c + (1-y)^2(\bar d + \bar s)\right]$

$$G_F M_W^2 = \frac{\pi \alpha}{\sqrt{2} \sin^2 \theta_W}$$
F_2(\text{charm})

- LH plot: data from H1, ZEUS separately; RH plot: combined data

- Charm identified using $\Delta m = M(K\pi\pi) - M(K\pi)$, from $D^{*,+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$

- Extrapolate to full phase-space, and use $(c \rightarrow D^*)$ fragmentation probability
Accurate knowledge of proton structure is essential for LHC physics

Crucial measurements still to be completed – e.g.
- ZEUS inclusive NC $e^+p$ cross-sections
- Various H1 and ZEUS inclusive jet measurements

Proposal to form a HERAPDF group from H1 and ZEUS collabs with strong support from the DESY ATLAS and CMS groups

Some examples from recent HERA pdf fitting
Comparison of combined HERA $F_2$ (charm) data with recent PDFs

MSTW NLO and NNLO PDFs (blue lines)

HERAPDF1.0
(line + light blue uncertainty band)

Good description for $Q^2 > 4 \text{ GeV}^2$
Using $F_2$(charm) explicitly in the HERA pdf determination fixes the charm mass parameter quite precisely.
Impact of new high $Q^2$ data sets

HERA II (high $Q^2$) data reduces the uncertainties for all parton densities.
HERA pdf with everything

HERA I+II inclusive, jets, charm PDF Fit

\[ Q^2 = 10 \text{ GeV}^2 \]

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

June 2011

HERAPDF Structure Function Working Group

\[ x_f \]

\[ x_g \times 0.05 \]

\[ x_S \times 0.05 \]

\[ x_d \]
Data preservation

- HERA stopped running in 2007

- Unique data set – how best to preserve for posterity?

- Common Ntuple in ROOT and PAW formats – only ROOT is guaranteed to survive

- Started with HERA-II data plus Monte-Carlo samples (most time consuming)
Common ntuple analysis model

- **ZEUS Common Ntuple**: Very simple ROOT-based ntuple (same format as PAW ntuple converted with h2root) containing high level objects (electrons, muons, jets, energy flow objects, ...) as well as low level objects (tracks, CAL cells, ...)

- **Very good progress with Common Ntuple preparations + usage**
  Already first ZEUS paper and many public preliminary results from common ntuple version v02 (April 2009) and later

- **Ntuple version v06 (May 2011) - recommended for all analyses**
  Total size (data+MC, MC production still ongoing):
  \(~2.5 \times 10^9\) events, \(~100\) Tb

- **Final ntuple version v08 (planned summer 2012) will become the ONLY input for ZEUS analysis from 2013 onwards**
  \(\rightarrow\) strong IT support needed
A future for HERA physics?

My dream:

- **Simultaneous** analysis of inclusive HERA I+II DIS over *full* phasespace,
  + charm and beauty contributions,
  + $s,u,d$ contributions (leading $\phi$, leading charged particles, calibrated with inclusive PhP dijets)

=> direct measurement of $b,c,s,u,d$ fractions

=> ultimate and fully correlated information on flavour composition + gluon (also from jets)

2015? 2020?

Achim Geiser – valedictory – ZEUS physco
Next steps for Oxford ZEUS

- Complete strangeness analysis
- Ensure ZEUS data is preserved for posterity
- Join HERA pdf project (proposal for joint HERA-LHC parton densities) - AMCS

Resources

- Access to local and DESY computing facilities
- Occasional advice and help from local IT staff
BACKUP
$\alpha_s$ from HERA data
Deep Inelastic Scattering at HERA

Neutral Current  \( ep \rightarrow eX, \quad V=\gamma \text{ or } Z^0 \)

Charged Current  \( ep \rightarrow \nu X, \quad V=W^\pm \)

Kinematics

\[ Q^2 = -(k-k')^2 \quad x = \frac{Q^2}{2p.q} \quad y = \frac{p.q}{p.k} \quad q = k-k' \]

\[ s = (k+p)^2 \quad Q^2 = sxy \quad Y_\pm = 1 \pm (1-y)^2 \]

\[
\frac{d^2 \sigma^{NC}(e^\pm p)}{dx dq^2} = \frac{2\pi\alpha^2}{xQ^4} \left[ Y_+ F_2^{NC}(x, Q^2) + Y_- x F_3^{NC}(x, Q^2) \right]
\]

\[
\frac{d^2 \sigma^{CC}(e^\pm p)}{dx dq^2} = \frac{G_F^2}{4\pi x} \frac{M_W^4}{(Q^2 + M_W^2)^2} \left[ Y_+ F_2^{CC}(x, Q^2) + Y_- x F_3^{CC}(x, Q^2) \right]
\]

\[ F_2^{NC} = \sum_i e_i^2 x(q_i + \bar{q}_i) \quad (\gamma \text{ only}); \quad F_2^{CC} = \sum_i x(q_i + \bar{q}_i); \quad xF_3^{CC} = \sum_i x(q_i - \bar{q}_i) \]

\( q_i(x, Q^2) \) - momentum density of quark flavour \( i \) in proton

† \( F_L \) has been ignored
$e + p \rightarrow e + X$  Neutral Current, $Q^2 = 2.5 \times 10^4$ GeV$^2$, $x = 0.34$

Sensitivity to $\sum_i A_i(Q^2) \times (xq_i + xq_i)$; proton pdfs and $Z^0$ axial and vector couplings
\[ e + p \rightarrow \nu + X \quad \text{Charged Current,} \quad Q^2 = 1.7 \times 10^4 \text{ GeV}^2, \quad x = 0.32 \]

Missing transverse energy

Sensitivity to W mass and pdf flavour selectivity

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