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High Precision DIS with the LHeC

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The potential of the LHeC, a future electron-proton collider, for precision Deep Inelastic Scattering measurements is reviewed with particular emphasis on the reduction of uncertainties on the parton distribution functions (PDFs) of the proton. The interpretation of possible Beyond Standard Model (BSM) signals at the LHC is crucially dependent on precise knowledge of the predictions of the Standard Model (SM) and the uncertainties on PDFs are a limiting factor. The LHeC project, running in parallel with later stages of LHC running, would provide much improved precision on the PDFs as compared to the precision expected from LHC data alone.

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1. Introduction

The LHeC project proposes a Large Hadron-Electron Collider using a Linac-Ring configuration with electrons of 50-100 GeV colliding with 7 TeV protons in the LHC tunnel, designed such that e-p collisions can operate synchronously with p-p. The details of the accelerator and the detector are covered in other contributions to this conference. This talk focusses on Deep Inelastic Scattering and low-x physics. Higgs, BSM physics and e-A collsions are covered in other talks. Further details may be found in the Conceptual Design Report (CDR) [1].

The LHeC reperesents an increase in the kinematic reach of Deep Inelastic Scattering and an increase in the luminosity. This allows a potential increase in the precision of parton distributions in the kinematic region of interest for the detailed understanding of BSM physics at the LHC. It also allows the exploration of a kinematic region at low-x where we learn more about QCD- is there a need for resummations beyond DGLAP, or even for non-linear evolution and gluon saturation?

Deep Inelastic Scattering is the best process to probe proton structure. The Neutral Current Cross Sections meaure the sea quarks and access the gluon via the scaling violations and the longitudinal structure function. The Charged Current processes give information on flavour separated valence quarks and the difference between the Neutral Curremt e^+ and e^- distributions probes the valence quarks via the $\gamma - Z$ interference term.

To study the potential of the LHeC a scenario with 50 GeV electrons on 7 TeV protons with 50 fb^{-1} luminosity is simulated. The kinematic region accessed is $0.000002 < x < 0.8$ and $2 < Q^2 < 100,000\text{GeV}^2$. Uncorrelated and correlated systematic errors are simulated using our knowledge of dominant sources such as the electron and hadron energy scales, angular resolution and photoproduction background, based on experience with the H1 detector, see the LHeC CDR [1] for details.

2. Results

In Fig. 1 the current level of our knowledge of valence distributions is shown, comparing various modern PDF sets in ratio to MSTW2008NLO. In Fig. 2 the potential improvement in uncertainty from LHeC data is shown by comparing the uncertainties on the valence PDFs from a fit to just HERA-I combined data [2] to a fit to these data plus LHeC pseudo-data. Fits to HERA plus BCDMS fixed target data and HERA plus LHC W-asymmetry data are also illustrated but these do not bring such a dramatic reduction in uncertainty, even when current LHC data have their uncertainties reduced to reflect our best estimate of the ultimate achievable accuracy.

In Figs. 3, 4 similar plots are shown for the gluon PDF. As an example of the importance of such precision at high x, Fig. 5 left-hand side, shows a plot of the PDF uncertainty on the gluion pair production cross section as a function of energy, from current PDFs and from the projected post-LHeC PDF. Such gain in PDF precision will be necessary to exploit the gain in experimental precision of future searches for gluinos when the LHC luminosity is increased from 0.3ab^{-1} to 3ab^{-1}, see the contribution of M D'Onofrio in these proceedings.

The uncertainty on $\alpha_s(M_Z)$ is also important for many BSM cross sections. The LHeC can deliver per-mille accuracy on $\alpha_s(M_Z)$ and this will be a strong constraint on Grand Unified Theories which predict where the couplings unify [3]. This is illustrated in Fig. 6.

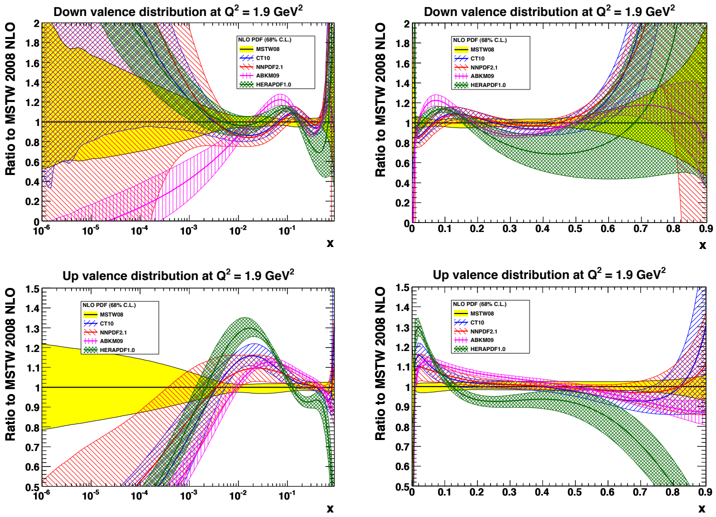

Figure 1: Up and down valence distributions for various modern PDF sets in ratio to MSTW2008NLO. Log and linear axes illustrate the level of uncertainty at low and high-x, respectively.

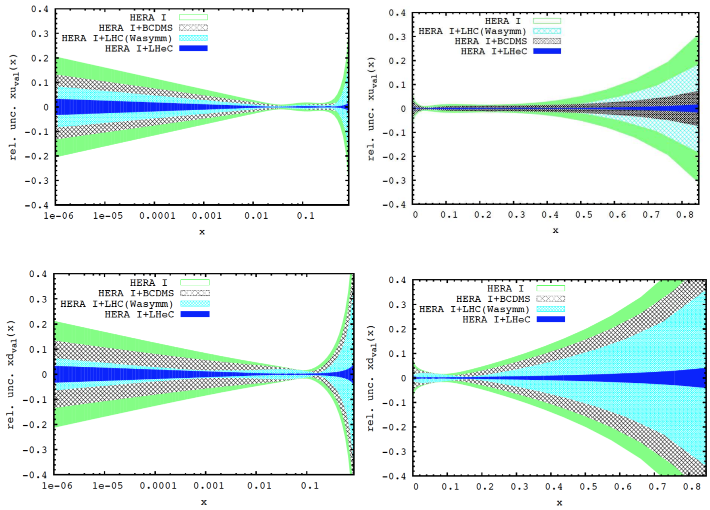

Figure 2: The PDF uncertainty on the valence distributions from a fit to just HERA-I data, HERA-I+BCDMS data, HERA-I+LHC W-asymmetry data and HERA-I+LHeC pseudo-data.

In Fig. 4 comparisons of the current and post-LHeC levels of uncertainty on the gluon PDF are also shown for the low-x region. HERA sensitivity stops at $x > 5 \times 10^{-4}$ whereas the LHeC can probe down to $x \sim 10^{-6}$. Thus one can better explore the low-x region where DGLAP evolution may need to be supplemented by $ln(1/x)$resummation (BFKL resummation) and one may enter into a kinematic regime where non-linear evolution is required, possibly leading to gluon saturation.

In DGLAP based QCD fits we get the gluon from the scaling violations at low-x

$$dF_2/dln(Q^2) \sim P_{qg} xg(x,Q^2)$$

The shape of the gluon extracted may be incorrect if the splitting function P_{qg} needs modification.

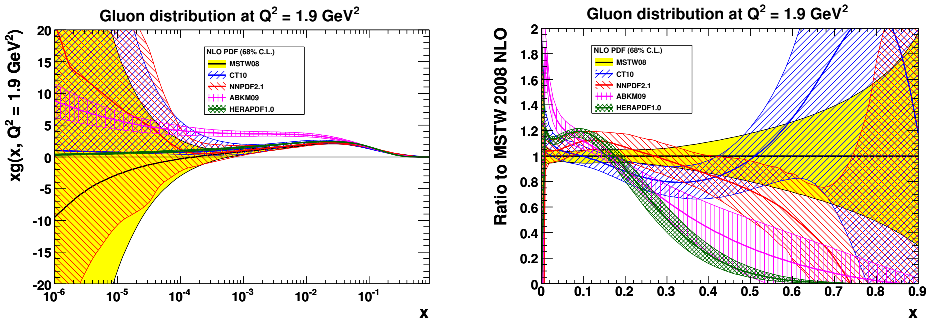

Figure 3: Gluon distributions for various modern PDF sets(left-hand side) and in ratio to MSTW2008NLO (eight hand-side). Log and linear axes illustrate the level of uncertainty at low and high-x, respectively.

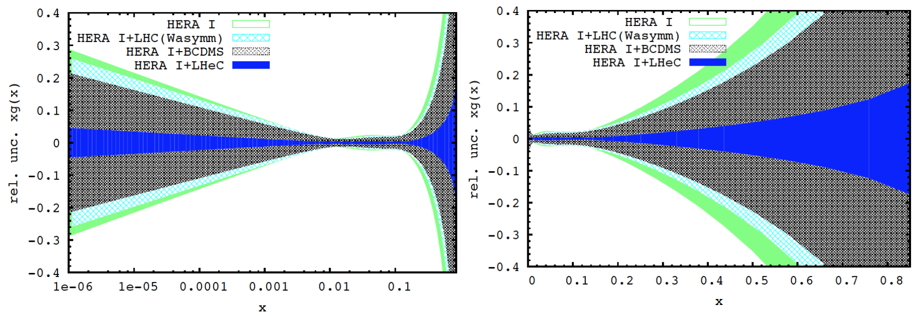

Figure 4: The PDF uncertainty on the gluon distribution from a fit to just HERA-I data, HERA-I+BCDMS data, HERA-I+LHC W-asymmetry data and HERA-I+LHeC pseudo-data.

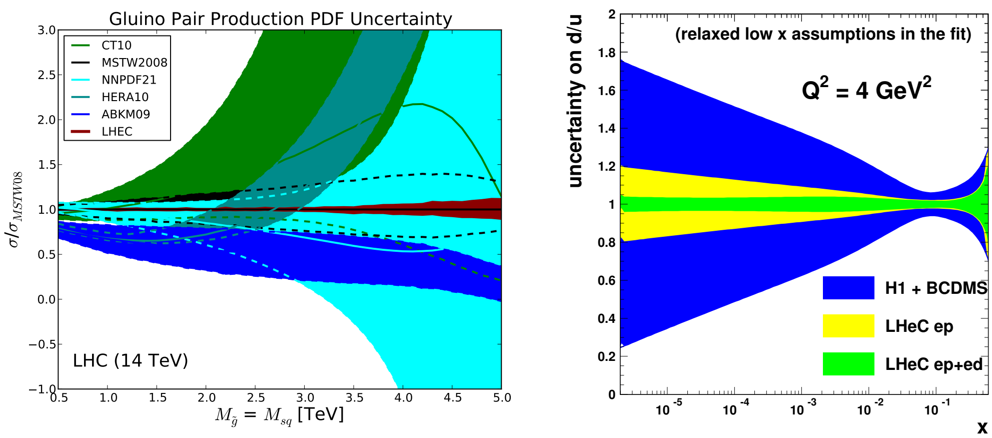

Figure 5: Left-hand side: Gluino pair production cross-section for various PDFs in ratio to MSTW2008, as calculated in NLO SUSY QCD assuming squark mass degeneracy and equality of squark and gluino masses. Right-hand side: PDF uncertainty on the d/u ratio, relaxing the assumption $\bar{d} = \bar{u}$ at low x, for current data and after LHeC pseudo-data is used from both ep and eD runs.

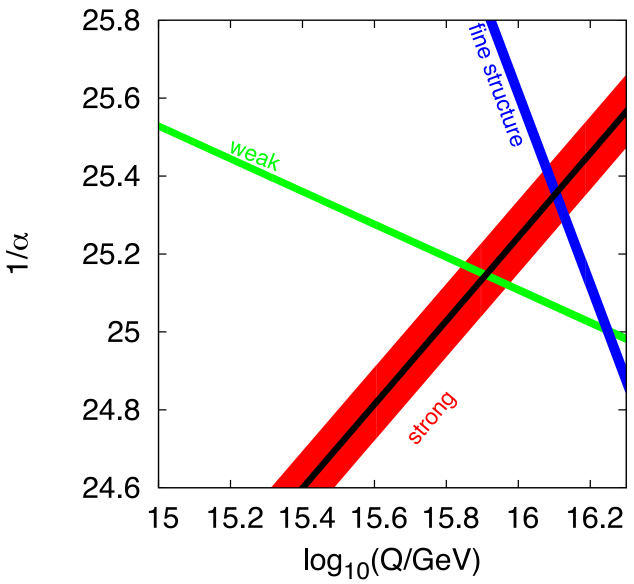

Figure 6: Extrapolation of the coupling constants ($1/\alpha$) to the GUT scale in MSSM as predicted by SOFT-SUSY. The width of the red line shows the uncertainty on the current world average of $\alpha_s(M_Z)$ and width of the black-line shows the projected accuracy of an LHeC measurement.

To check this one can measure other gluon related quantities like the longitudinal structure function F_L, which is gluon dominated at low x, $F_L(x,Q^2) \sim xg(2.5x,Q^2)$. Currently F_L is not measured with sufficent accuracy to challenge DGLAP. However, Fig. 7 compares current measurements with the projected LHeC measurements of F_L, which should be discriminating.

Further low-x studies include relaxing the conventional assumption, used in all PDFs, that $\bar{u} = \bar{d}$ at low-x. The right-hand side of Fig. 5 shows PDF uncertainties on the d/u ratio with this constraint relaxed, and compares current levels of uncertainty with the projections from LHeC pseudo-data. Further improvement could be achieved with LHeC eD data.

LHeC data will also allow us to increase our knowledge of the heavy flavour partons as illustrated in Fig. 8, which shows projected measurements of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ compared to present measurements.

Finally the LHeC will allow improved precision in the determination of electroweak (EW) parameters if the electron beams are polarised at a level of $P \sim \pm 0.4$. For example, a simultaneous fit of PDF and EW parameters can be performed to account for the impact of PDF uncertainty on the EW parameters. Fig. 9 illustrates the improvement expected in the precision of the neutral current couplings a_u, a_d, v_u, v_d.

3. Summary

The LHeC would allow improvement in the precision of PDF determinations both at low x and at high x. Improvement at high x, together with improved precision in the determination of $\alpha_s(M_Z)$ which is also expected at the LHeC, would allow us to predict BSM cross sections with sufficent accuracy to distinguish between different explanations of new physics phenomena. At

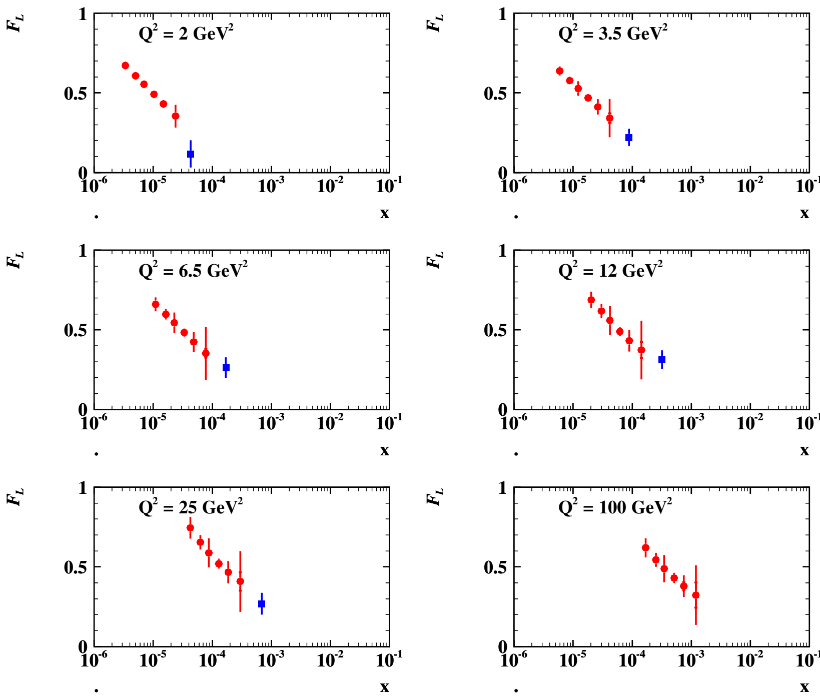

Figure 7: The current measurements of F_L from HERA data (in blue) compared to projected measurements of F_L at the LHeC (in red).

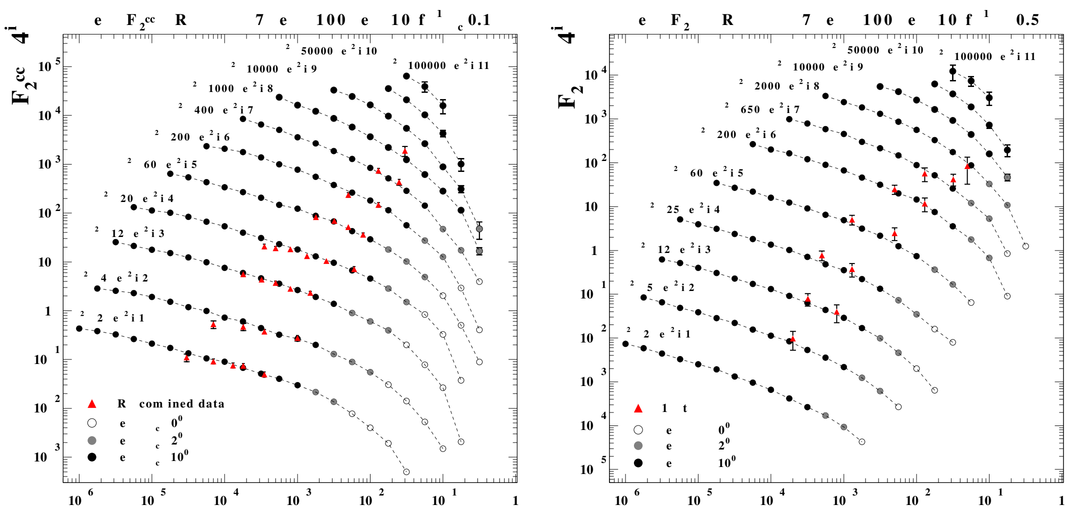

Figure 8: Current measurements of $F_2^{c\bar{c}}$ (left) and $F_2^{b\bar{b}}$ (right) from HERA (in red) compared to projected measurements at the LHeC (in black).

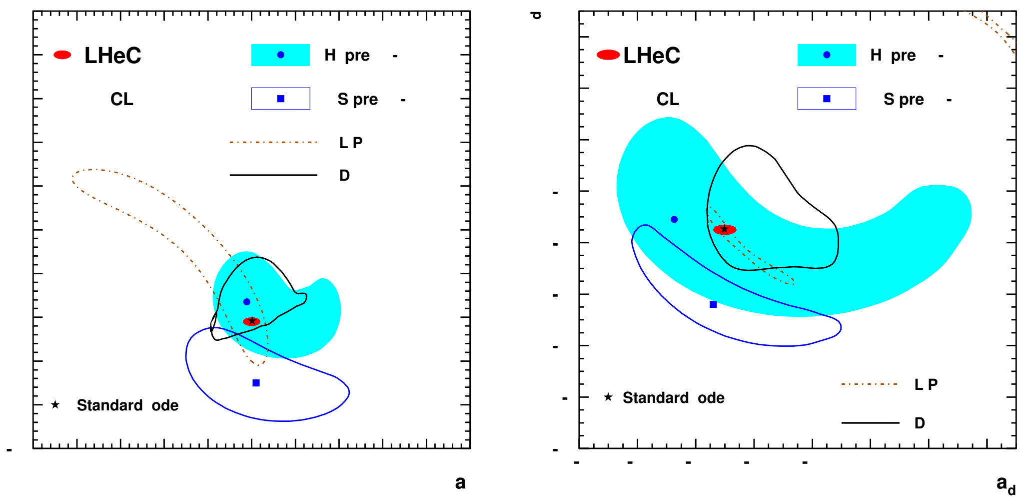

Figure 9: The neutral current couplings a_u vs v_u (left-hand side) and a_d vs v_d (right-hand side) as determined by HERA, D0 and LEP compared to the projected LHeC measurement.

low x it has long been expected that extension of the conventional QCD DGLAP resummation is necessary to explain the data, but distinguishing between different possible scenarios such as BFKL resummation, non-linear evolution or the onset of gluon saturation, has not been possible. The improvement in accuracy at low x at the LHeC would allow such discrimination. The LHeC is also able to make precision electroweak measurements. The projections for the luminosity now make it a viable Higgs factory, see the contribution of Uta Klein in these proceedings. There are many more interesting phenomena measured in Deep Inelastic Scattering, such as jet production, vector meson production, diffraction and deeply-virtual compton scattering, which it is not possible to cover in such a short talk. The reader is referred to the CDR for details [1]

References

[1] LHeC Study group, CERN-OPEN-2012-015

[2] F. D. Aaron *et al.* [H1 and ZEUS Collaboration], JHEP **1001** (2010) 109 [arXiv:0911.0884 [hep-ex]].

[3] LHeC Study group, LHeC-Note-2012-005 GEN