Summary of Experimental Results in the Structure Functions and Low-x Working Group

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A summary of the recent experimental results reported in the Structure Functions and Low-x working group at the DIS 2008 Workshop are presented in this proceedings.

1 Introduction

The discovery potential of new physics at the LHC relies on the current knowledge of the proton parton distribution functions (PDFs). The new simulation studies at the LHC show the urge to improve the precision in the determination of the PDFs. In order to achieve this goal, the experiments at HERA and at the Tevatron devoted tremendous efforts to produce new high precision measurements. In addition, the new studies show that the LHC data also has the potential to better constrain PDFs.

At HERA, the first direct measurement of the longitudinal structure function, F_L, could help the understanding of the gluon at low x. Also, the H1 and ZEUS collaborations provide the first combined HERA-I cross section data sets using a coherent treatment of the systematic uncertainties which result in a substantial reduction in the total errors. This precise data is then used in the QCD fit to produce HERA PDFs with an impressive precision compared to the global fits.

New results from the Tevatron, with its kinematic coverage between HERA and the LHC, bring significant information to the global PDF fits. The accuracy of the Tevatron measurements has increased to the level which enables to produce precision measurements to further constrain PDFs.

The most important experimental results reported in the Structure Functions and Low-x working group at the DIS 2008 Workshop are summarised in this proceedings.

2 Longitudinal structure function F_L at HERA

The highlight of the workshop was the measurement of the longitudinal structure function performed at HERA. The measurement of F_L at small x is of high importance, as it is a more direct probe of the gluon density in the proton than deriving it from the scaling violation of the structure function F_2. Previously, the F_L was extracted at HERA only indirectly, making assumptions on the behaviour of F_2 at low x. To measure F_L directly, cross section measurements at two or more center-of-mass energies are necessary. For this reason, in addition to the operation at the nominal proton beam energy $E_p = 920$ GeV, at the end of

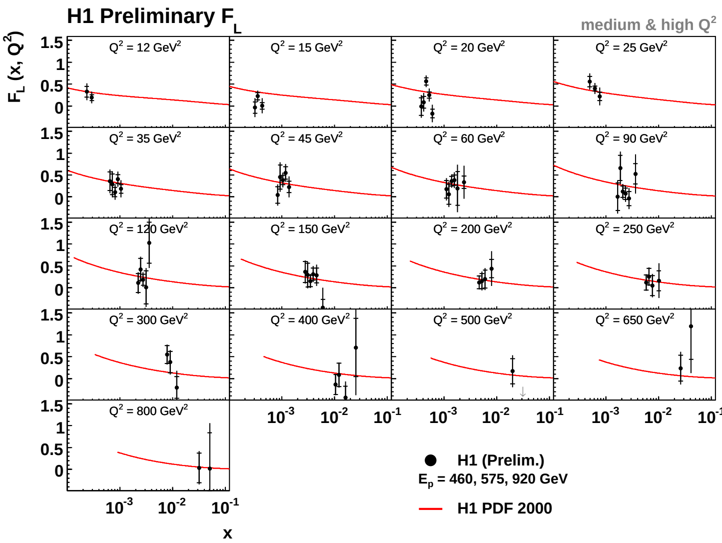

Figure 1: The $F_L(x, Q^2)$ measurement from H1 as a function of x at fixed values of Q^2. The curve represents the NLO QCD prediction derived from the H1 PDF 2000 fit.

running, HERA was operated at two lowered proton beam energies of 460 GeV and 575 GeV. During these running periods both the H1 and ZEUS experiments accumulated sufficient data to perform a direct measurement of F_L. The first results were presented at the DIS 2008 workshop.

2.1 Direct F_L measurement at the H1 experiment

The results of two independent H1 analyses were presented by B. Antunović and V. Chekelian covering two partially overlapping ranges in Q^2, the medium Q^2 region between $12 \leq Q^2 \leq 90$ GeV^2 and the high Q^2 region between $35 \leq Q^2 \leq 800$ GeV^2. These regions correspond to the acceptance of the backward lead-scintillator calorimeter (SpaCal) and the Liquid Argon calorimeter (LAr), respectively. Both analyses benefit from the high efficiency in finding and reconstruction of low energy scattered electrons. In addition, the analyses used the statistical background subtraction method based on the sample of events which have electron candidates associated with the wrong charge track.

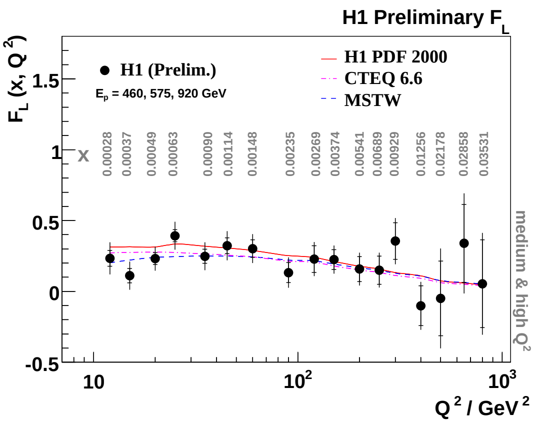

Figure 2: The measured $F_L(Q^2)$ averaged in x at given values of Q^2 compared to the NLO/NNLO QCD predictions.

The neutral current (NC) cross sections were measured for all three available beam energies in overlapping regions of (x, Q^2) to allow for an F_L extraction. For medium Q^2 analysis the luminosities of the data samples used for $E_p = 920$ GeV, 575 GeV and 460 GeV were 21.9 pb^{-1}, 6.2 pb^{-1} and 12.4 pb^{-1}, respectively, while for the high Q^2 analysis they were 46.3 pb^{-1}, 6.2 pb^{-1} and 12 pb^{-1}, respectively.

Figure 1 shows the measured values of F_L for $12 \leq Q^2 \leq 800$ GeV^2 and $0.00028 \leq x \leq 0.0353$ where a combined SpaCal/LAr analysis was performed in the overlapping Q^2 region. Figure 2 shows the F_L values averaged over x at fixed Q^2. The measurement is consistent with the NLO QCD prediction based on the H1 PDF 2000 fit [2] as well as with other PDF fits [3, 4].

2.2 Direct F_L measurement at the ZEUS experiment

The measurement of F_L at ZEUS presented by D. Kollár was performed in the kinematic region $24 \leq Q^2 \leq 110$ GeV^2 and $0.0006 \leq x \leq 0.005$. The Q^2 range was given by the acceptance of the tracking system in the backward direction. ZEUS has extended this acceptance as compared to its previous measurements by making use of individual hits in the tracking detectors instead of fully reconstructed tracks.

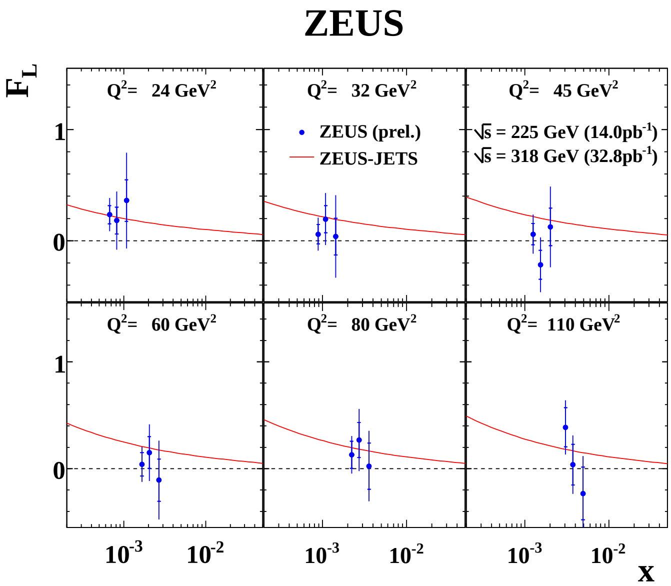

Figure 3: Measured F_L as a function of x for fixed values of Q^2 compared to SM expectations evaluated using ZEUS-Jets PDFs.

The data from two runs were used in the F_L measurement, 32.8 pb^{-1} of data taken at $E_p = 920$ GeV and 14 pb^{-1} of data taken at $E_p = 460$ GeV. Figure 3 shows the measured values of F_L as a function of x at fixed Q^2. The values of F_L measured by ZEUS are consistent with both the prediction using the ZEUS-Jets PDFs [5] as well as with $F_L = 0$ within uncertainties.

Adding a dataset at third proton beam energy $E_p = 575$ GeV as well as other improvements are planned for the near future.

3 Parton distribution functions

3.1 Parton distribution functions at HERA

HERA ceased its operation in June 2007 accumulating $\sim$1 fb^{-1} of $e^{\pm}p$ scattering data. The data taken during the HERA-I period has been analysed and published by both the H1 and ZEUS collaborations [6, 7] separately yielding accurate neutral and charged current (CC) deep inelastic cross section measurements. The measurements expand over a large kinematic range in $1.5 < Q^2 < 30000$ GeV^2 and $0.0006 < x < 0.65$. The combination of these data was presented by J. Feltesse and it relies on a new model independent method of averaging cross section measurements [8]. The only assumption made in this procedure is that both experiments measure the same cross section at the same kinematic points.

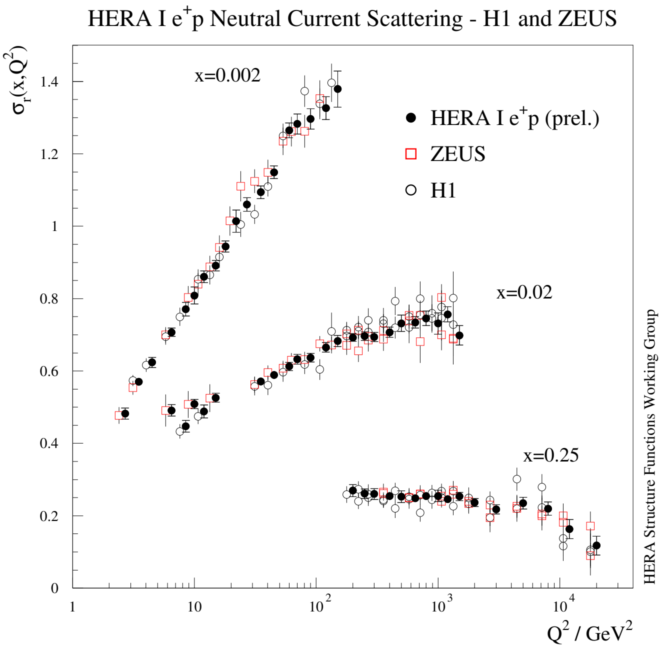

Figure 4: The H1 (open points) and ZEUS data (open squares) are compared to the new combined data (close points). The error bars show the total uncertainty.

This averaging procedure reduces the 1153 individual NC and CC measurements to 554 unique points. The method takes into account the systematic error correlation through a coherent approach, as if each experiment calibrates the other one. Hence, it enables a significant reduction of the correlated systematic uncertainties. The most notable reductions are observed for the H1 backward calorimeter energy scale by a factor of three, and the ZEUS uncertainty of modelling forward hadronic energy flow by a factor of four. Figure 4 shows the combined data compared to the individual measurements from the H1 and ZEUS collaborations in three x bins as a function of Q^2. The resulting systematic uncertainties are significantly smaller than the statistical errors.

Since at HERA the high Q^2 cross-section data can be used to determine the valence distributions and the low Q^2 data is sensitive to the sea and gluon distribution, the PDF fits can be made to the HERA data alone. A. Cooper-Sarkar has presented a new determination of the PDFs, HERAPDF0.1, where this precise combined HERA-I data is used as a sole input in a next-to-leading order (NLO) QCD fit.

The fit is performed by solving the DGLAP evolution equations at NLO in the massless $\overline{MS}$ scheme with the input scale set to $Q_0^2 = 4$ GeV^2 and the renormalisation and factorisation scales set to Q^2. In this fit, the running strong coupling α_S was fixed to the

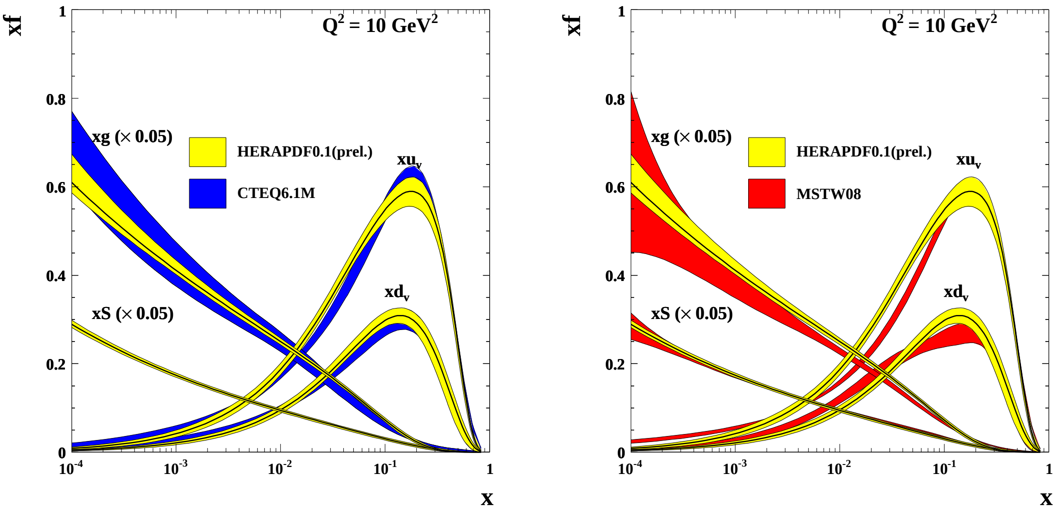

Figure 5: HERAPDF0.1 at $Q^2 = 10$ GeV^2 compared to the CTEQ6.1 PDFs (left) and to the preliminary MSTW08 PDFs (right).

world average value. In order to remain in the perturbative QCD domain, the data is restricted to $Q^2 > 3.5$ GeV^2. The variations of these values are considered sources of the model uncertainties, together with these of the heavy quarks, and fractions of charm and strange in the sea distributions. In this fit, the PDFs were parametrised using a generic polynomial form where the number of parameters is chosen by the saturation of the χ^2. Different parametrisations have been tried and compared to assess an additional model uncertainty. The consistent treatment of systematic uncertainties of the combined H1 and ZEUS data ensures that experimental uncertainties on the PDFs do not require an increase in χ^2 tolerance. The HERAPDF0.1 resulting from the fit has greatly reduced experimental uncertainties compared to the separate analyses of the ZEUS and H1 experiments. Figure 5 shows the HERAPDF0.1 distributions compared to the CTEQ6.1 PDFs [9], which also use a zero-mass variable flavour number scheme, and to the preliminary MSTW08 PDFs [10], which use a massive variable flavour number scheme.

3.2 Constraints on parton distribution functions from Tevatron

Recent new data from Tevatron have the statistical power to provide significant contributions to the global PDF fits. The most relevant electroweak measurements such as W charge asymmetry, Z cross sections and QCD measurements such as inclusive jet cross sections are summarised here. There are other new promising measurements such as the forward W, the $W + c$, and the $Z + b - jet$ analyses at CDF, and the $\gamma + jet$, the $W + c$ production at DØ but have yet to increase their statistical powers in order to provide useful information on PDFs.

3.2.1 *W charge asymmetry*

At Tevatron, the W boson is produced mainly from a quark in the proton and an anti-quark in the anti-proton. The difference in the u and d quarks causes a charge asymmetry in the W boson rapidity distribution. This asymmetry is sensitive to the ratio of the d and u momentum distributions. Therefore, the measurement of the W charge asymmetry can provide a valuable constraint on this ratio. Both the DØ and CDF experiments presented separate analyses of this measurement using 0.3 fb^{-1} and 1 fb^{-1} of data, respectively. However, the DØ experiment measures the lepton charge asymmetry which is a convoluted observable, while CDF provides first measurement of the absolute W charge asymmetry, as shown in Figure 6, presented by S. Malik and K.S. McFarland. The CDF measurement is also compared to the NNLO and NLO theoretical predictions. It can be observed that at high rapidities the experimental uncertainties are smaller than those of PDFs. Therefore this measurement could provide an additional constraint to PDFs in the global fits.

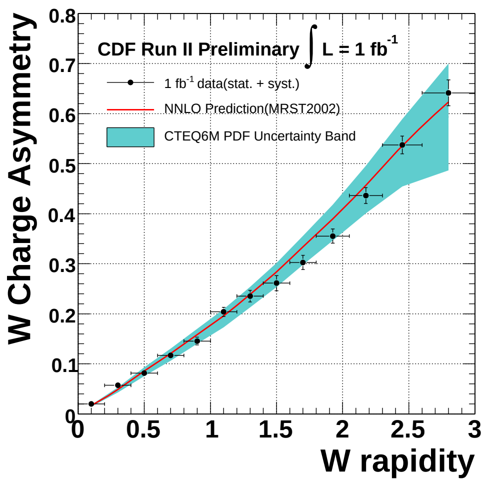

Figure 6: W Charge Asymmetry at CDF

3.2.2 *Z boson rapidity measurement*

The Z boson cross section is produced at Tevatron via $q\overline{q}$ annihilation. The calculation of the Z boson cross section is based on the PDFs, hence a measurement of it provides a good test of PDFs and QCD. The Z boson rapidity is directly related to the momentum fraction of the integrated partons. Both DØ and CDF perform measurements of the Z boson rapidity using the electron decay channel. The DØ experiment analyses only 0.4 fb^{-1} of data and the results are in agreement with the NNLO predictions of MRST2004 PDFs [11] as presented by J. Hays. The CDF collaboration measures this using a significantly larger data sample corresponding to 2.1 fb^{-1} of integrated luminosity. The results presented by S. Malik and C. Galea are compared to the NNLO

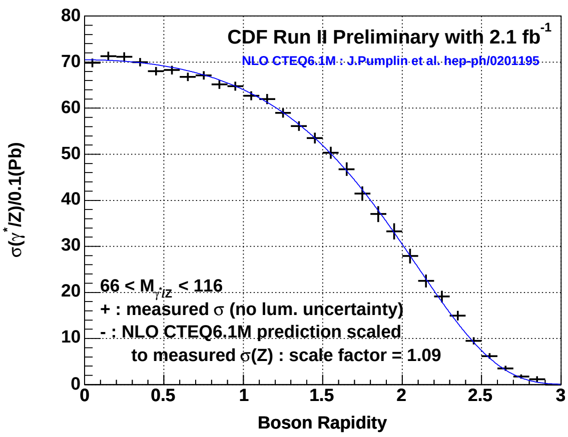

Figure 7: $d\sigma/dy$ for $Z/\gamma* \rightarrow e^+e^-$

and NLO theory predictions and agree best with the calculations based on CTEQ6.1M PDFs [12], as shown in Figure 7. This measurement can be used to place additional constraints on PDFs and it was already included in the new global fit of MSTW2008 PDFs.

3.2.3 Inclusive jet production

Inclusive jet production provides a stringent test of QCD, in particular it provides a powerful constraint on the gluon distribution at high x. The experiments at Tevatron measure the double differential cross section using 0.7 fb^{-1} of data for the DØ and 1.13 fb^{-1} for the CDF analyses based on the MidPoint cone algorithm [13] for the jet reconstruction. The CDF collaboration also used the k_T algorithm [14] for the jet reconstruction using 1 fb^{-1} of data. Figure 8 shows the results produced by both collaborations and they are consistent with the NLO predictions in all rapidity regions. In can be seen that in the forward region the experimental uncertainty is even smaller than the PDF errors, therefore these measurements could be further used in the global fits.

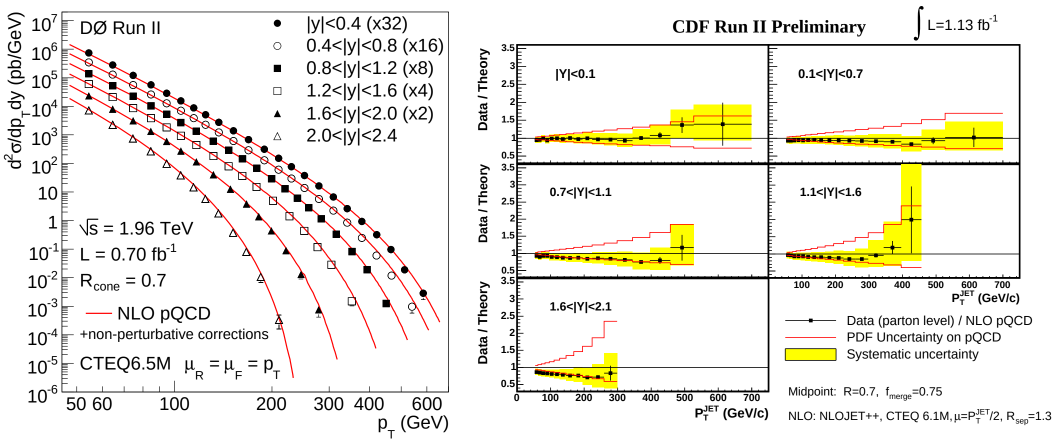

Figure 8: The inclusive jet cross-section measurements using the MidPoint algorithm for the DØ (left) and the CDF (right) experiments.

3.3 Parton distribution functions at the LHC

Studies on the impact of the current PDF uncertainty and the possibilities to reduce it using data collected by ATLAS and CMS were presented by S. Goy López. These studies show that the PDF uncertainties have large impact on the W and Z cross sections, the W mass measurements, and the Drell-Yan high mass spectrum determination. In the measurements of the W and Z production cross sections, the knowledge of the PDF is the dominant source of the uncertainty after the luminosity uncertainty. A study performed by the ATLAS collaboration shows that current PDF uncertainty causes a systematic error on the W mass measurement of $\sim$ 25 MeV, compared to other systematic uncertainties which are of the order of few MeV. Since the productions of W and Z are similar at the LHC, the PDF uncertainty could be improved by using information from the Z decays. The study shows that on a 10 fb^{-1} of collected data the systematic error due to the PDFs in the W mass measurement is expected to be reduced to few MeV. The PDF uncertainties also have a large impact on Drell-Yan high mass spectrum determination. Using different PDF sets the estimates of Drell-Yan cross sections vary within $\pm 7\%$ for the dilepton mass spectrum greater than 1 TeV.

Electroweak LHC data can be used to constrain the PDF uncertainties. Most of the systematic effects can be cancelled in the ratios such as the ratio of rapidity spectra of Z and W ($A_{Z,W}$), the W asymmetry (A_W), defined as the difference in rapidity spectra of W^+ and W^- divided by its sum, and the W lepton asymmetry (A_l), defined as the difference of lepton rapidity spectra from W^+ and W^- decays divided by its sum. Experimental effects are reduced better in the A_W and A_l ratios and will have discriminating power between predictions from different PDF sets, constraining for the first time valence distributions at low x.

The LHCb experiment is designed to make measurements of CP violation and rare B decays in the forward region. Therefore, it could provide precision electroweak measurements at high rapidities ($\eta > 2.5$) unique at the LHC. This would allow to probe the PDFs in the kinematic region not covered by measurements so far. Simulation studies presented by R. McNulty show that LHCb has the potential to trigger on and reconstruct W and Z bosons with high efficiency and purity. The studies show that with just 50 pb^{-1} of data, the Z cross section measurement will be limited by systematic uncertainties to about $\sim 1\%$, assuming precise luminosity determination (up to $\sim 3\%$).

Although the LHCb experiment is only instrumented in the forward region, studies have shown that Ws could be reconstructed from the presence of a single high transverse momentum muon. The systematic errors are expected to have a precision similar to that of the Z channel. The knowledge of the PDFs dominates the theoretical predictions and ranges between 2–5%. Therefore these measurements could be used to constrain the PDFs. The luminosity uncertainty can be bypassed by comparing ratios and asymmetries of the $W^\pm$ and Z differential cross sections to maximise/minimise the dependence on the PDFs. These ratios and asymmetries are expected to be experimentally determined to 1% constraining the PDFs. Studies of low invariant mass Drell-Yan dimuon states indicate that LHCb can rapidly improve the knowledge of PDFs down to x values of 2×10^{-6} and Q^2 of 5 GeV^2 and significantly improve our knowledge of the small-x gluon.

4 Conclusions

The importance of precise PDFs increases in the view of the LHC startup. The simulation studies presented here by the LHC experiments show the urge to reduce the PDF uncertainties. Therefore, it is encouraging to see huge progress in understanding of the PDFs in both the theory and experiment.

Exciting new results have been presented with highlights from HERA where the first direct measurements of the structure function F_L was presented by both the H1 and ZEUS experiments. The prospects are to include these measurements in the global PDF fits. In addition, new analyses from the both experiments are underway with the aim to reach to the lower Q^2 region, where discrepancies exist among different theory predictions.

First combined HERA-I PDFs have been presented indicating a huge potential of the HERA data for the PDF fits. This will be followed by even more accurate data from complete HERA running periods.

The reduction of the uncertainties of the CDF and DØ measurements brings an era of precision measurements at the Tevatron. As summarised here, various measurements have the potential to bring additional constraints on the PDF. Numerous measurements with increased statistics are underway to make a significant contribution to the global PDF fits.

A new era of high energy physics is about to begin with the start of of the LHC operation. Possibly, there will be first data presented at the next DIS workshop in Madrid, 2009.

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