PROCEEDINGS OF SCIENCE

Workshop summary and outlook

Halina Abramowicz[*†]
Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israelp
E-mail: halina@post.tau.ac.il

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[*]Speaker.
[†]Partly supported by the Israel Science Foundation

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1. Introduction

The series of DIS workshops started as a mean to discuss in a wider forum the early findings in ep collisions at HERA. The fast rise of the proton structure function with decreasing Bjorken x, the appearance of large rapidity gap events at high Q^2, and the unexpectedly large rate of forward jets seem to indicate a new regime of QCD dynamics at low values of x, never reached previously. Soon after, the Tevatron data from $p\bar{p}$ collisions became relevant to these discussions and the scope of the workshops was extended to include all issues relevant to the proton structure, thus the title of the series "DIS and related subjects". By now there are parallel sessions dedicated to parton density functions (PDFs), to low-x dynamics and diffraction, to spin physics, to hadronic final states and to heavy flavor production. There is also a parallel session dedicated to electroweak physics and to searches beyond the Standard Model (SM), where the understanding of the proton structure and perturbative QCD (pQCD) are tested in earnest. The HERA, JLAB, RHIC, FNAL and the ν-communities are represented with the newest addition, the LHC community. Their common denominator is the need to map the structure of the proton and this cannot be done without a profound understanding of QCD dynamics in its various forms. In spite of all the efforts, the jury is still out on whether a new regime of QCD dynamics has been reached in collisions involving protons. All the unanswered questions and the potential of DIS physics to contribute to physics beyond the SM is discussed in the session dedicated to the future of DIS.

In my summary and outlook, I would like to point out the various links between the different areas of research, based on the results and discussions presented at Florence. It is therefore by construction a selective summary, tinted by my own interests. The in-depth summary of the results discussed in this meeting (by various technical means) can be found in the individual summaries presented by the conveners of the working groups.

2. Proton structure and perturbative QCD

Since it is not possible (at least until now) to calculate the proton wave function from first principles, its structure can only be extracted from hard collisions involving parton scattering, which lands itself to perturbative calculations within QCD. However, both initial and final observable-states involve hadrons and the link between partons and hadrons is by necessity subject to modeling.

There are at least four components leading to the hadronic final states in hard collisions involving protons. These are

1. the hard subprocess at the parton level which at leading order is a $2 \to 1$ process in DIS and $2 \to 2$ process in hadron-hadron collisions. The cross section is calculable in pQCD, assuming known probabilities of finding partons in the proton given by the PDFs;

2. higher order QCD processes which result in initial and final state gluon radiation from the interacting partons;

3. additional semi-hard or hard interactions between the remaining partons. They arise naturally in that the integrated cross section for hard scattering diverges for low transverse momenta and becomes bigger than the total cross section, unless multi-parton interactions (MPIs) are invoked;

4. hadronization, the formation of hadrons from partons and from beam remnants.

Each of these steps is subject to modeling with various level of uncertainties, some of which are hard to quantify. Yet, combined they represent our best knowledge of the SM baseline, as essential element in most of the searches for physics beyond the SM.

3. Parton density functions of the proton

There are many parameterizations of the proton PDFs derived in global fits of the (NLO) DGLAP evolution equations to structure functions and hard scattering measurements [1]. A big effort is now vested in quantifying the uncertainties [1] for the precision measurements at the LHC. The worrisome part is that these uncertainties usually come out smaller than the differences between the various PDF sets and this is particularly true for the gluon distribution, the contribution of which dominates the QCD cross section at LHC. The PDF-uncertainties on the so-called standard candles at the LHC and the differences in the expectations of various PDFs are nicely summarized [2] in figure 1, where the cross section for Higgs, $t\bar{t}$, W and Z^0 production at the LHC for center of mass (cm) energy of 7 TeV is plotted as a function of the value of the strong coupling constant α_s appropriate for the PDF sets used in the calculation. The x and Q^2 phase space of the

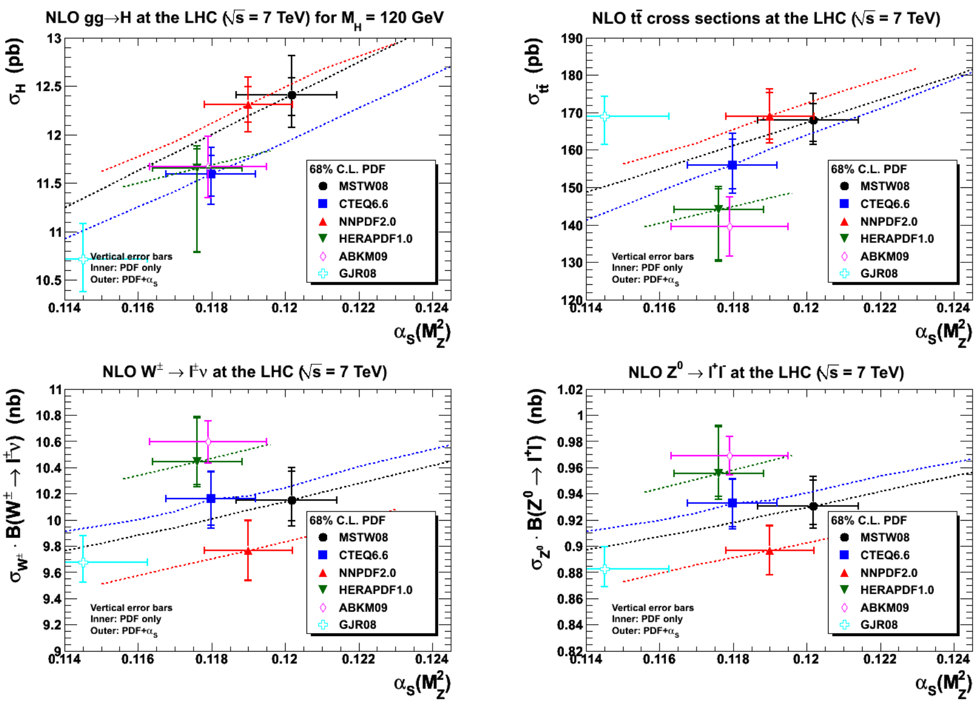

Figure 1: Production cross sections for Higgs, $t\bar{t}$, W and Z^0 at the LHC fo 7 TeV cm-energy expected for different PDF sets as a function of the strong coupling constant α_s used in each set. The error bars represent the uncertainties associated with each set.

LHC physics extends into areas which are still subject to large uncertainties, sometimes theoretical, sometimes experimental. Below, I summarize the measurements presented at this conference which have a potential to alter future extractions of PDFs.

3.1 Low energy HERA data

The new HERA data [3] are still an important player in the extraction of PDFs. In particular, the inclusion of neutral current (NC) cross section measurements performed with the proton beam of 460 GeV (half the nominal energy) in the global fit to the H1+ZEUS combined HERAI data leads to a PDF set which does not describe well the very low Q^2 measurements, especially if the fit is performed on measurements above $Q^2 > 5\,\mathrm{GeV}$. This is shown in figure 2. The reason may

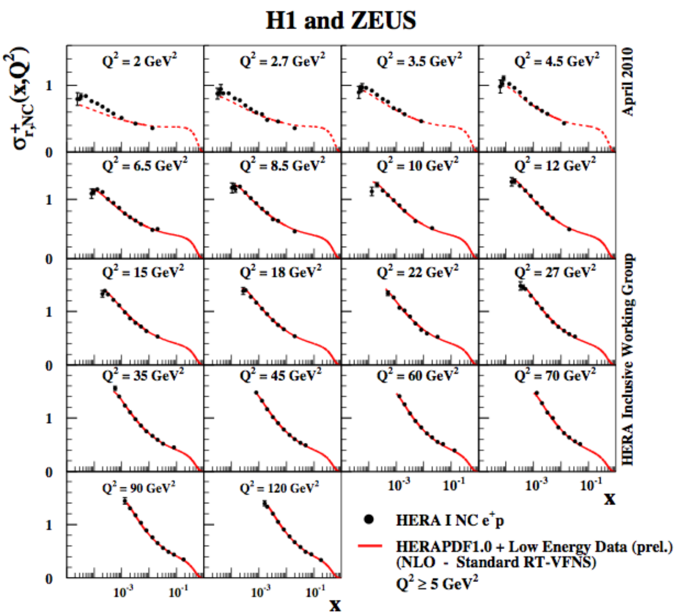

Figure 2: The reduced NC ep cross section obtained by combining the H1 and ZEUS, HERAI measurements at proton beam energy of 920 GeV as a function of x for different values of Q^2, compared to the HERAPDF global fit [5] performed on these measurements and on the cross sections measured with proton beam energy of 460 GeV (not shown). In the fit only data for $Q^2 > 5\,\mathrm{GeV}^2$ are used.

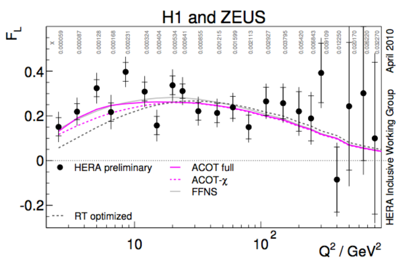

Figure 3: Combined H1 and ZEUS measurements of F_L as a function of Q^2 averaged in x bins (as denoted in the figure). Superimposed are expectations from HERAPDF fits performed under various treatments of the heavy flavor contribution.

be traced back to the fact that for $Q^2 < 10\,\mathrm{GeV}^2$, the longitudinal stucture function F_L extracted at HERA [4] tends to lie above the NLO DGLAP calculations performed with the HERAPDF standard fits as shown in figure 3. The agreement between measurements and expectations is improved if the scheme used to treat heavy flavor evolution is changed from the optimized RT VFN scheme [6] to that of ACOT [7] or to the FFN scheme [8].

3.2 Heavy flavor contribution

Presently, the precision with which the contribution of charm production to the F_2 structure function of the proton, $F_2^{c\bar{c}}$, can be measured at HERA [9] is such that it starts having an important impact on the extraction of parton distributions through its dependence on the gluon PDF. When $F_2^{c\bar{c}}$ is included in the HERAPDF fits, the low Q^2 measurements show sensitivity to the treatment of mass effects (standard vs optimised RT variable flavor number schemes [6]) and the value of the charm mass assumed in the fits (see [9] for details). This is shown in figure 4 where the results obtained with two different mass treatment schemes and two values of the charm mass are compared to the data. Independently of the scheme, the low Q^2 data are not well described by the fit. The ambiguity between the two schemes and the two mass values cannot be resolved at present with the HERA data alone. The charm quark mass entering the evolution equations may

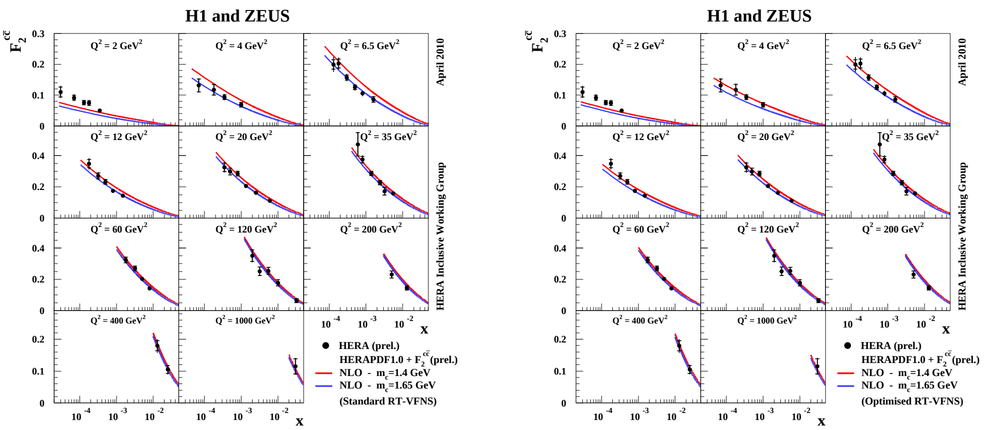

Figure 4: Combined HERA, H1 and ZEUS, $F_2^{c\bar{c}}$ measurements as a function of x in bins of Q^2 comapred to NLO DGLAP fits to F_2 (HERAI) and $F_2^{c\bar{c}}$ with the standard RT VFN (left) and the optimized RT VFN schemes for heavy flavor treatment. Two different masses of the charm quark were used as denoted in the figures.

however be extracted from opposite-sign dimuon production in charged current ν_μ interactions, where the wrong sign muon originates from the semileptonic decay of a charm quark. The Nomad experiment provides the largest sample ever of dimuon events [10]. The ratio of dimuon cross section $\sigma_{\mu\mu}$ to the charged current cross section σ_{cc} is shown in figure 5 as a function of x together with the statistical and systematic uncertainties. When the analysis will be finalized it is expected that the uncertainty on the strange quark content will be reduced to about 3% and the mass of the charm quark will be know to 60 MeV.

3.3 d/u ratio

The d/u ratio is most precisely measured from the charge asymmetry in W production in $p\bar{p}$

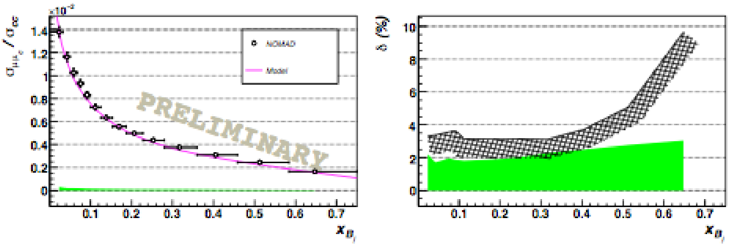

Figure 5: Ratio of the dimuon cross section $\sigma_{\mu\mu}$ to the charged current cross section σ_{CC} as a function of Bjorken x, x_{Bj}. The line represents a model calculaltion based on NuTeV/CCFR fit [11]. The statistical (crosses) and systematic (band along the $y = 0$ vertical axis) uncertainties are shown together with the ratio, left plot, and also separately in the right plot.

interactions at the Tevatron. It is an essential input to all global DGLAP fits. New measurements of the muon charge asymmetry have been presented from RunII data corresponding to an integrated luminosity up to $\mathscr{L} \simeq 5\,\mathrm{fb}^{-1}$, about factor five larger than the previous measurements [12]. The lepton charge asymmetry as a function of the lepton pseudorapidity, η, is shown in figure 6. It is compared to the expectations of RESBOS [13] with the CTEQ6.6 PDF [14] for lepton transverse energy $E_T^l > 35\,\mathrm{GeV}$. For large values of lepton transverse energy, the agreement between data and

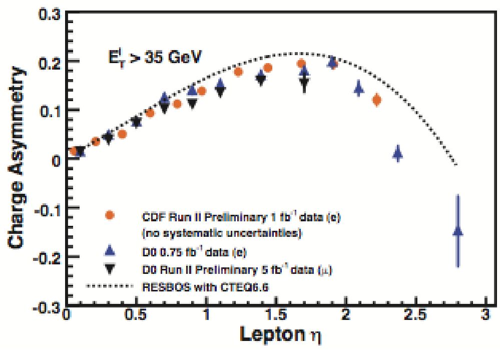

Figure 6: The lepton charge asymmetry from W decays as a function of pseudorapidity η of the lepton as measured by CDF and D0 experiments for the lepton transverse energy $E_T^l > 35\,\mathrm{GeV}$ compared to expectations of RESBOS with CTEQ6.6 PDF.

expectations is not very good especially at higher η. This disagreement may be due to the improper simulation of the transverse momentum of the parent W (see discussion in [12]) but it could also mean that the d/u parameterization as a function of x used in global fits requires further tuning, especially a larger values of x.

3.4 High-x region

Further impact on the determination of PDFs, especially at high-x values, close to the kinematic limit, may be expected when all the DIS cross section measurements from HERAII will be finalized. The existing DIS measurements of the proton structure function in the region where higher twist effects may be neglected are limited to $x < 0.75$. It turns out that the HERA NC data can be used to constrain the phase space up to $x \simeq 1$. At HERA, for events in which the hadronic final state fully disappears down the beam-pipe, x cannot really be measured however Q^2 may be determined with high accuracy from the scattered lepton present in the main detector. A cross section integrated over the corresponding x region up to the kinematic limit can be thus performed in bins of Q^2. Preliminary measurements of the NC e^-p cross section up to $x \simeq 1$ are presented in figure 7. The measurements are compared to expectations of CTEQ6D [14]. In general, a good agreement is observed up to the highest x values. Up to Q^2 of about 4000 GeV^2 the statistical power of the data is such that it may provide in the future important constraints on the extracted PDFs.

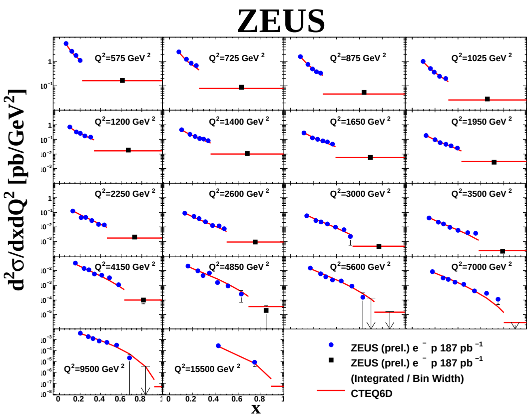

Figure 7: The differential NC section for e^-p interactions as a function of x at fixed values of Q^2. In the last bin of x, the integrated cross section divided by the bin width (shown in the figure) is drawn in the bin center.

3.5 Low-x and DGLAP evolution

The validity of the DGLAP evolution equation in the low-x regime, in particular in the NLO approximation, has been intensely debated in the literature. There is no consensus on this issue and it is fair to say that only data at lower x values and higher scales will be able to resolve it. At present, it is assumed that if the measurements of structure functions can be accommodated by NLO DGLAP, then the resulting PDFs are correct. For the first time during this workshops cracks appear in the description of structure functon measurements by NLO DGLAP. As already mentioned, once the low energy data from HERA are included in the fits, the very low-Q^2 F_2 measurements are hard to include [3]. There are also problems in describing the low-Q^2, $F_2^{c\bar{c}}$ measurements [9]. From the perspective of LHC physics, these low scales, $Q^2 \sim 2\,\text{GeV}^2$, are not relevant. However, a closer look at the experimental coverage of the x and Q^2 kinematic plane (see figure 8), leads to the conclusion that if the low-Q^2 region is not to be included in the fits, the constraints on the low-x region are substantially weakened. An analysis in this spirit performed by the NNPDF group [15] indicates that the candle cross-sections (see figure 1) at the LHC may be affected, though the claim is that the relevant cross sections change by at most 1σ of the present uncertainties.

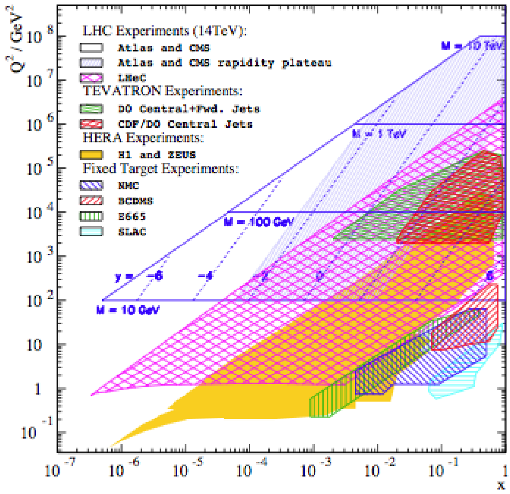

Figure 8: The x and Q^2 kinematic plane with indicated areas covered by various experiments with sensitivity to PDFs. Also indicated is the region probed by the LHC interactions at 14 GeV cm-energy as well as the one that would be probed by the LHeC option.

4. Perturbative QCD

The challenges awaiting the LHC community in the seach for signals beyond the SM can be assessed from the search for the SM Higgs at the Tevatron [16]. As an example, the dijet mass distribution in b-tagged events is shown in figure 9 and compared to the expectations of the SM, with a long list of background sources included. A very good command of QCD expectations

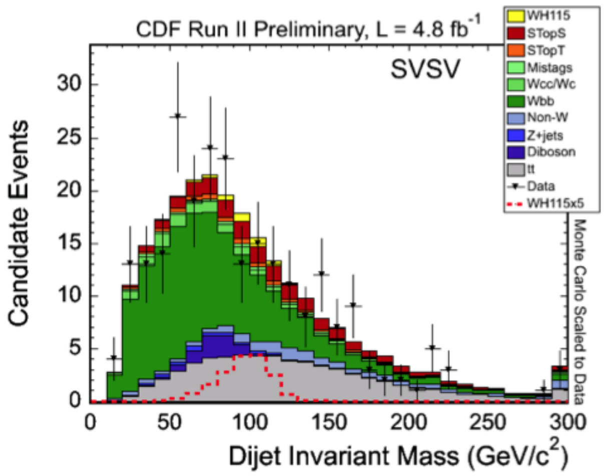

Figure 9: Dijet invariant mass in b-tagged events as measured by the CDF experiment compared to expectations of the SM.

is therefore crucial for increasing the sensitivity to beyond the SM effects. The present status of pQCD tools that are being developed has been summarized by Thomas Gehrmann [17] at this workshop. The progress includes improved jet algorithms, NLO multi-leg calculations, first NNLO calculations for precision observables, NNLO PDFs, and landmark results at three and four loops (see [17] for details).

One of the outstanding issues, which was not really discussed in the meeting, is the combining of NLO calculations with parton shower generators. It has an impact on analyzes involving hadronic activities in the event, transverse momenta and missing transverse energy distributions, all of which are input to searches beyond the SM. An extreme example how important it is to include the NLO matrix elements in event generation is presented in figure 10, where the transverse momentum distribution of the hardest B-hadron in t-channel single-top production obtained with POWHEG [18] interfaced to PYTHIA [19] parton showers and with PYTHIA alone are compared. The LO calculation dramatically underestimates the high transverse momentum tail.

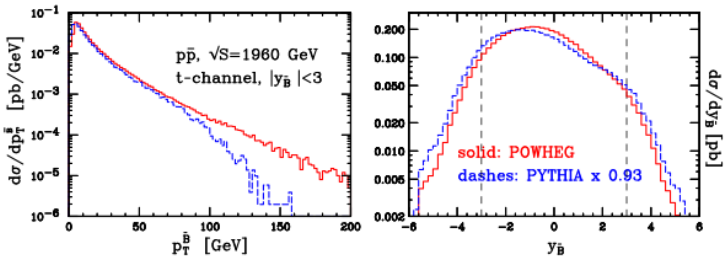

Figure 10: Comaprison between POWHEG interfaced to PYTHIA parton showers and PYTHIA alone scaled by 0.93 for (a) the transverse momentum distribution of the hardest $\bar{b}$-flavored hadron, $P_T^{\bar{B}}$ and (b) its rapidity $y_{\bar{B}}$ distribution expected in t-channel single top production at the Tevatron.

Another important ingredient of pQCD calculations is the value of the strong coupling constant α_s. An update has been prepared by Claudia Glasman [20] based on results discussed at this workshop (see [21] for details) and is shown in figure 11.

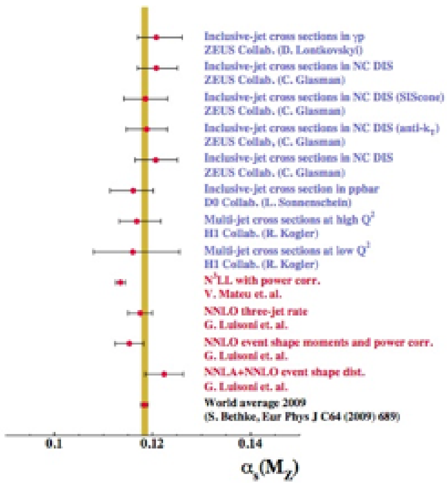

Figure 11: Compilation of the strong coupling constant α_s values recently extracted from measurements of jet production and event shape.

5. Underlying event and multiparton interactions

The presence of partons from hard scattering is identified by their hadronic realization, collimated jets of particles. In real life, jets may also contain contributions from particles which do not belong to the parton fragmentation, thus the momentum vector of a jet does not necessarily represent the momentum vector of the parent parton and pQCD calculations may not directly apply to jet variables. The radiation from color strings connecting the partons as well as contributions from the color radiation of the beam remnants after the hard scattering and possibly also from other soft, semi-hard or, in case of LHC even hard, secondary parton interactions, may contribute to the jet. These contributions sum up to what is called the underlying event. The ability to estimate the contribution of the underlying event is essential for comparison with pQCD. The underlying event is subject to modeling in the MC generators (see [22] for discussion). The least known is the contribution of MPIs and it is reflected in the fact that models which described the underlying event at the Tevatron may differ by a large amount when applied to the kinematics of LHC.

There are first attempts to formulate the problem of MPIs in QCD. At this workshop, two such attempts have been presented [23, 24]. MPIs are induced by unitarity because the integrated cross section for hard scattering diverges for low transverse momentum and becomes bigger than the total cross section. Till now, it was generally assumed that the additional interactions were relatively soft and independent of the primary hard interaction [25]. At the LHC however, hard double-parton scattering (DPS) is likely as the cross section increases faster with energy than that of single parton scattering (SPS), leading to additional backgrounds to some interesting search channels. As an example, the possible background contribution of DPS to Higgs boson production in the $Wb\bar{b}$ channel [25] is shown in figure 12. The issue whether the two hard interactions can be

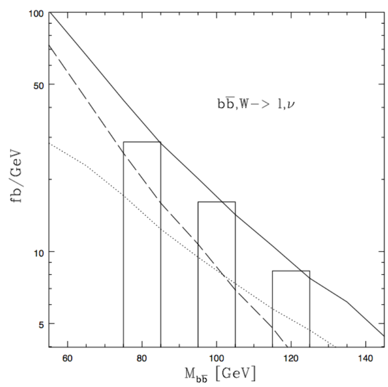

Figure 12: Double-parton scattering background (dashed line) to Higgs boson production as a function of the $b\bar{b}$ invariant mass, $m_{b\bar{b}}$, compared to the expected Higgs signal for three different Higgs masses. Also shown is the $m_{b\bar{b}}$ distribution from single parton scattering (dotted line).

independent has been addressed in [23]. It turns out that the DGLAP evolution derived for double-parton distribution function (dPDF) will correlate the two partons, even if in the initial conditions factorization is assumed [23]. The simplest reason for that is momentum and flavor conservation. The difference between the evolved double-gluon distribution at the same scale and the product of two single-gluon PDFs is shown in figure 13. A set of equal-scale dPDFs is presently available in LO, the GS09 set [23]. For quite some time now, it has been assumed that the spatial distribu-

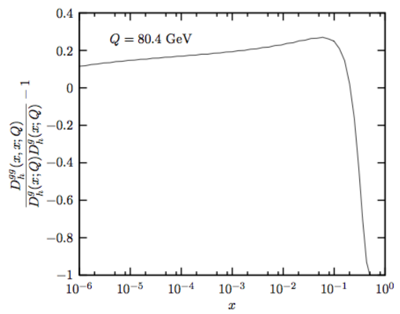

Figure 13: Double-gluon correlation ratio R_{gg} at $Q = 80.4\,\mathrm{GeV}$ obtained using MSTW2008LO [26] factorised inputs.

tion of partons inside the proton will play a role in multi-parton interactions [27]. The best way to study the three-dimensional structure of the proton and the correlation between transverse and longitudinal momenta of the partons is through exclusive processes in DIS such as for example the deeply virtual Compton scattering (DVCS). The non trivial partonic structure of the proton is encoded in the so-called generalized parton distribution functions (GPDs) [28]. Usual PDFs are given by squared wave functions and therefore represent probabilities (integrated over all transverse momentum components) while GPDs correlate the wave functions for different parton configurations. An attempt, as presented in [24] to make a connection between the mechanism of MPIs and GPDs promises further progress in building a reliable phenomenology.

6. Spin physics

While the saga of the missing spin of the proton is still continuing, the underlying physics has led to intricate studies of inclusive, semi-inclusive and exclusive processes, mostly in leptoproduction. An important goal of these studies is to project out the GPDs and the transverse momentum distributions (TMDs) of the nucleon. The observables of the proton structure accessible in measurements with polarized beams are schematically depicted in figure 14. As pointed out in section 5, imaging of the proton beyond its longitudinal momentum structure may have important implications for high energy final states such as the ones at the LHC. For a detailed account of the latest achievements the reader is referred to the summary of the Spin Physics working group [30].

7. High-energy regime

The rapid rise of the gluon density in the proton with decreasing x, increasing cm-energy, raises the question whether the proton may then still be viewed as a dilute collection of partons which do not interact with co-moving partons, the assumption that underlies the application of DGLAP evolution to the measurements of the proton structure function. The present understanding is that for each value of x there is a saturation scale Q_s (for a recent review see [31]), below which there

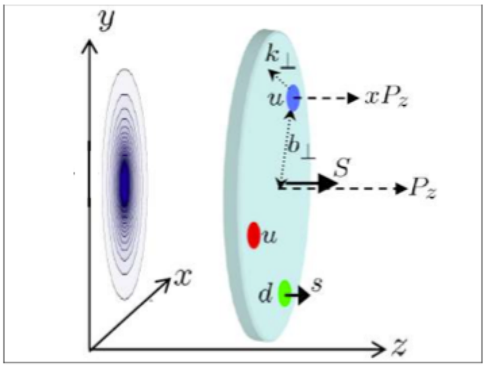

Figure 14: A sketch of the proton structure as obtained from longitudinal and transverse polarization observables [29].

is a new regime, the saturation regime, where the proton becomes a dense many-body system of gluons.

One of the questions that were addressed at this meeting was whether one may expect correlations in the impact parameter space [32] due to inherent fluctuations of the partonic configurations in the proton. The naive estimate would be that the correlations vanish over the length $\Delta b \propto 1/Q_s$. Turns out that due to fluctuations in the parton denisty, correlations persist at much larger distances leading to homogenous parton densities over quite large distances. It is not yet clear whether this issue is of any relevance in the near future, but it is definitely something to keep in mind when for example modeling MPIs.

Diffractive scattering is an integral part of the high energy dynamics in strong interactions. Diffractive scattering in the presence of a large scale lends itself to parturbative calculations, through the so-called diffractive parton distributions (DPDFs, not to be confused with double-parton distribution functions, dPDF). Contrary to the fully inclusive hard interactions, the QCD factorization theorem does not apply to diffractive scattering [33]. In particular, DPDFs extracted from diffractive DIS at HERA largely overestimate the rate of dijet production in single-diffraction at the Tevatron [34]. The suppression of these large rapidity gap events is understood as originating from rescattering of the spectator partons. An important observation, which has been discussed at this meeting [35] is that the suppression factor depends on the kinematics of the hard scattering as shown in figure 15 where the rate of diffractive dijet events measured by CDF [34] as a function of the parton x from the diffractively scattered $\bar{p}$, $x_{\bar{p}}^-$, is compared to NLO expectations based on the latest DPDFs [36]. The ratio of data to NLO expectations substantially decreases with $x_{\bar{p}}^-$ as shown in figure 15. Kinematically, the larger the $x_{\bar{p}}^-$ values the smaller the x of partons in the proton. The simplest interpretation [37] is that the rescattering probability is smaller when valence-like partons are involved in the interaction as opposed to sea quarks. It would be very interesting to study the suppression factor as a function of the jet transverse energy to understand the correlation to the transverse size fluctuations of the proton. Since rescattering is related to partonic configurations in the proton, these type of studies could have implications for understanding of the dynamical structure of the proton.

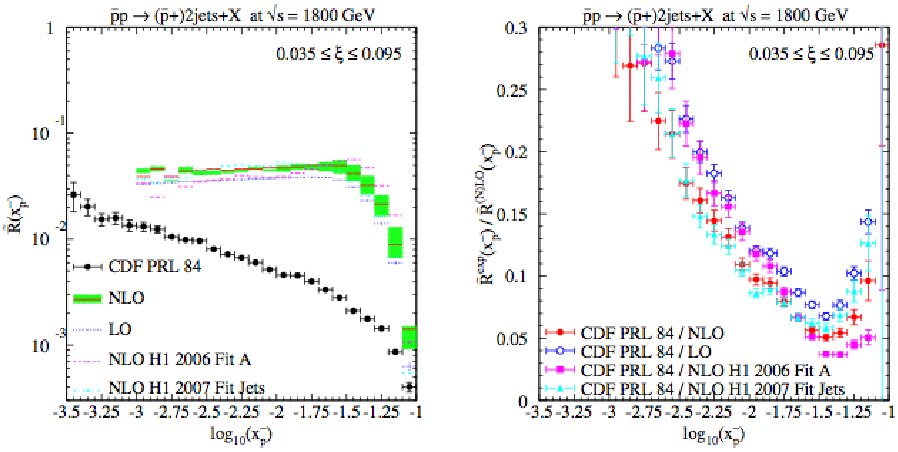

Figure 15: Rate of diffractive dijet production relative to non-diffractive dijet production in $p\bar{p}$ interactions with a quasi-elastically scattered $\bar{p}$ as a function of the x of the parton in $\bar{p}$ compared to the NLO expectations obtained with DPDFs extracted at HERA (left). The ratio of data to the NLO expectations is shown on the right.

8. First results from LHC

The LHC became a new addition to this workshop. Results were shown by the three collider experiments on inclusive particle production. The results span the cm-energy range from 900 GeV to 7 TeV. The average charged multiplicity distribution for inelastic events with a least one track in the central region as measured by the ALICE experiment [38] is shown in figure 16 at three different cm energies. At 7 TeV, a clear departure from the negative binomial distribution is observed for large multiplicities. The various tunes of PYTHIA underestimate the large multiplicities by a large margin while PHOJET [39] overestimates the contribution of the latter. The transverse momentum,

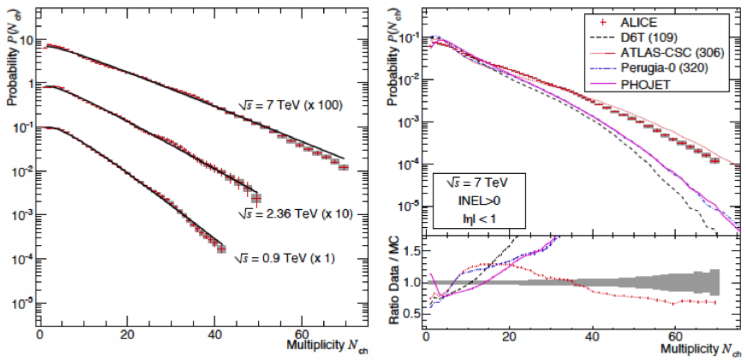

Figure 16: Central $|\Delta\eta| < 1$ charged particle multiplicity, N_{ch}, distribution in pp collisions at the LHC at 0.9, 2.7, 7 TeV cm-energy as measured by ALICE, with fits of the negative binomial distribution (left) and at 7 TeV compared to various PYTHIA tunes and PHOJET (right).

p_T, distribution of charged particles contained within $|\Delta\eta| < 2.5$ as measured by the ATLAS experiment [40] is shown in figure 17 for cm-energy of 7 TeV. Even in this relatively low p_T range, the spectra are quite poorly described by the various MC generators. A first look at the forward

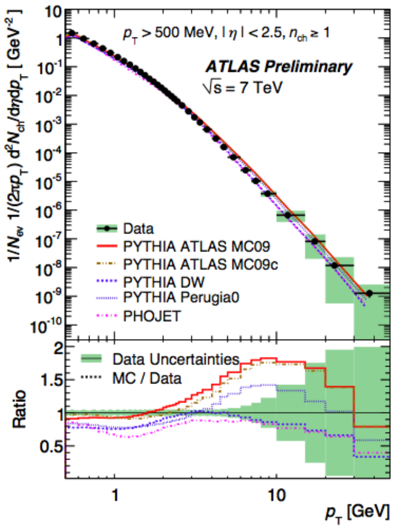

Figure 17: The invariant transverse momentum, p_T, distribution of charged particles contained within $|\Delta\eta| < 2.5$ at 7 TeV cm-energy as measured by ATLAS, compared to various PYTHIA tunes and PHOJET. Also shown is the ratio of data to the MC expectations.

pseudorapidity distribution has been presented by the CMS experiment [41]. The spectra measured at 2.7 and 7 TeV cm-energy are divided by those measured at 0.9 TeV as shown in figure 18. In the ratio, detector related systematic effects cancel out. The resulting ratios are compared to PYTHIA D6T tune. Here again a larger hadronic activity is observed at 7 TeV than expected by the MC, which reproduces quite well the difference between the 2.7 and the 0.9 TeV spectra. It is

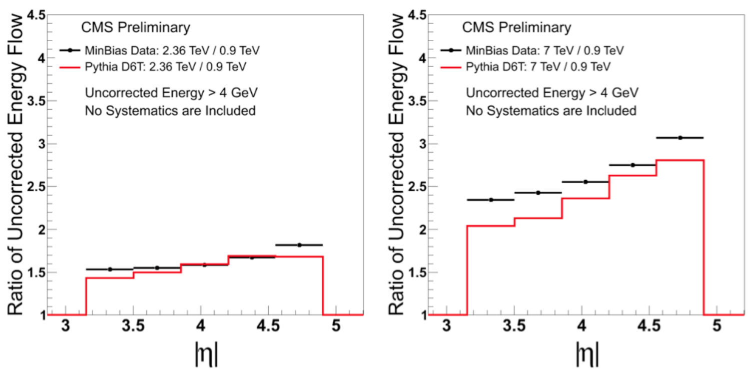

Figure 18: Ratio of forward pseudorapidity, $\Delta\eta$, distributions for 2.7 and 0.9 TeV (left) and for 7 and 0.9 TeV (right) cm-energies as a function of $\Delta\eta$ as measured by CMS, compared to PYTHIA D6T expectations.

quite clear in this early stages of analyzing the pp interactions at new energy frontiers that there is still a long way to a proper description of strong interactions.

9. Outlook

This summary was far from being a complete or even objective representation of what has been discussed in this workshop – for that the reader is referred to the summaries of the working groups. In this era of LHC, it was meant to point out the connections between various areas of research on the proton structure and QCD, especially those which are or may turn out to be important for the LHC physics. The DIS meetings are the natural place to discuss these issues as it brings together all the relevant expertise. Florence was no exception in spite of the havoc spread by the Eyjafjallajökull volcano erruption in Iceland which prevented almost half of the participants from reaching the meeting in person. Since there is obviously still a lot of work ahead of us, I am looking forward to the next meetings.....

References

[1] S. Forte, Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)005;
C. Glasman, D. De Florian and S. Tapprogge, "QCD and final states in DIS and hadron colliders: WG summary ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)015.

[2] G. Watt, "PDF benchmarking for LHC processes: MSTW report", presented at the PDF4LHC Meeting, 26 March 2010, CERN,
`http://indico.cern.ch/conferenceDisplay.py?confId=87871`.

[3] V. Radescu, "Combined H1 and ZEUS fits using low energy data", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)047, H1-prelim-10-044, ZEUS-prel-10-008.

[4] H1 and ZEUS Collaborations, " Combined Measurement of the Inclusive e+ p Scattering Cross Sections at HERA for Reduced Proton Beam Energy Runs and Determination of Structure Function F_L", H1-prelim-10-043, ZEUS-prel-10-001.

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

[6] R. S. Thorne and R. G. Roberts, Phys. Rev. D **57** (1998) 6871 [arXiv:hep-ph/9709442]; R. S. Thorne, Phys. Rev. D **73** (2006) 054019 [arXiv:hep-ph/0601245]; R. S. Thorne, "Variation in variable flavour number schemes", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)053.

[7] M. 1. Kramer, F. I. Olness and D. E. Soper, Phys. Rev. D **62** (2000) 096007 [arXiv:hep-ph/0003035].

[8] E. Laenen, J. Phys. G **26** (2000) 493 [arXiv:hep-ph/9912349]; S. Riemersma, J. Smith and W. L. van Neerven, Phys. Lett. B **347** (1995) 143 [arXiv:hep-ph/9411431].

[9] A. Cooper-Sarkar, "PDF fits incuding HERA combined $F_2^{c\bar{c}}$ data ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)023, H1-prelim-10-045, ZEUS-prel-10-009.

[10] R. Petti, "Precise measurement of charm dimuon production from neutrino interactions at NOMAD', Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)170.

PoS(DIS 2010)020

[11] M. Goncharov *et al.* [NuTeV Collaboration], Phys. Rev. D **64** (2001) 112006 [arXiv:hep-ex/0102049]; D. A. Mason, “Measurement of the strange - antistrange asymmetry at NLO in QCD from NuTeV dimuon data”, Phys. Rev. Lett. **99** (2007) 192001.

[12] H. Schelmann, "W asymmetries at CDF and D0", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)049.

[13] G. A. Ladinsky and C. P. Yuan, Phys. Rev. D **50** (1994) 4239 [arXiv:hep-ph/9311341]; C. Balazs and C. P. Yuan, Phys. Rev. D **56** (1997) 5558 [arXiv:hep-ph/9704258]; F. Landry, R. Brock, P. M. Nadolsky and C. P. Yuan, Phys. Rev. D **67** (2003) 073016 [arXiv:hep-ph/0212159].

[14] P. M. Nadolsky *et al.*, Phys. Rev. D **78** (2008) 013004 [arXiv:0802.0007 [hep-ph]].

[15] F. Caola, S. Forte and J. Rojo, “HERA data and DGLAP evolution: theory and phenomenology,” arXiv:1007.5405 [hep-ph]; F. Caola, S. Forte and J. Rojo, "Deviations from NLO DGLAP at small-x within the combined HERA-I dataset ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)022.

[16] K R. Herner, "Standard model Higgs searches at the Tevatron", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)195.

[17] T. Gehrmann, "Status of QCD", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)004.

[18] S. Alioli, P. Nason, C. Oleari and E. Re, JHEP **1006** (2010) 043 [arXiv:1002.2581 [hep-ph]].

[19] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP **0605** (2006) 026 [arXiv:hep-ph/0603175]; T. Sjostrand, S. Mrenna and P. Z. Skands, Comput. Phys. Commun. **178** (2008) 852 [arXiv:0710.3820 [hep-ph]].

[20] C. Glassman, private communication.

[21] C. Glasman, D. De Florian and S. Tapprogge, "QCD and final states in DIS and hadron colliders: WG summary ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)015.

[22] N. Moggi,"Minimum bias and underlying event studies at CDF ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)126.

[23] J. R. Gaunt, "The GS09 double parton distribution functions", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)030; J. R. Gaunt and W. J. Stirling, JHEP **1003** (2010) 005 [arXiv:0910.4347 [hep-ph]].

[24] M. Diehl, "Multiple interactions and generalized parton distributions ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)223, [arXiv:1007.5477 [hep-ph]].

[25] A. Del Fabbro and D. Treleani, Phys. Rev. D **61** (2000) 077502 [arXiv:hep-ph/9911358]; A. Del Fabbro and D. Treleani, arXiv:hep-ph/0301178.

[26] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C **63** (2009) 189 [arXiv:0901.0002 [hep-ph]].

[27] T. Sjostrand and P. Z. Skands, JHEP **0403** (2004) 053 [arXiv:hep-ph/0402078].

[28] M. Diehl, Phys. Rept. **388** (2003) 41 [arXiv:hep-ph/0307382] and references therein.

[29] P.Haegler, talk presented at the Workshop on GPDs, Institute of Nuclear Theory, University of Washington, September 2009.

[30] C. Riedl, C.A. Aidala and S. Liuti, "Spin Physics: session summary", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)018.

[31] E. Iancu, Nucl. Phys. A **782** (2007) 134.

[32] S. Munier, "Correlations in impact-parameter space in saturation models ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)083.

[33] J. C. Collins, J. Phys. G **28** (2002) 1069 [arXiv:hep-ph/0107252].

[34] A. A. Affolder *et al.* [CDF Collaboration], Phys. Rev. Lett. **84** (2000) 5043.

[35] M. Klasen, "NLO QCD analysis of single-diffractive dijet production at the Tevatron ", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)073; M. Klasen and G. Kramer, Phys. Rev. D **80** (2009) 074006 [arXiv:0908.2531 [hep-ph]].

[36] A. Aktas *et al.* [H1 Collaboration], JHEP **0710** (2007) 042 [arXiv:0708.3217 [hep-ex]].

[37] A. B. Kaidalov, V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. C **66** (2010) 373 [arXiv:0911.3716 [hep-ph]].

[38] S. Masciocchi, "Results on charged particle production from the ALICE experiment at LHC", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)123.

[39] PHOJET event generator, `http://lepton.bartol.udel.edu/ÌČeng/phojet.html.`

[40] T. Wengler, "Highlights from ATLAS", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)007.

[41] F. Sikler, "Highlights from CMS", Proceedings of the XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, PoS(DIS 2010)006.