

Proceedings of the workshop

HERA and the LHC

workshop series on the implications of HERA for LHC physics

2006 - 2008, Hamburg - Geneva

Editors: Hannes Jung, Albert De Roeck

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Preface

In April 2004 the first meeting of what would become a series of HERA-LHC meetings took place at CERN. Over 250 participants joined and helped to shape the goals and objectives of this workshop. These are:

- To identify and prioritize those measurements to be made at HERA which have an impact on the physics reach of the LHC;
- to encourage and stimulate transfer of knowledge between the HERA and LHC communities and establish an ongoing interaction;
- to encourage and stimulate theory and phenomenology efforts;
- to examine and improve theoretical and experimental tools;
- to increase the quantitative understanding of the implication of HERA measurements on LHC physics;

That HERA deep inelastic scattering and photoproduction data and knowledge acquired will have an impact on the analysis of LHC data is a priori obvious. First and foremost there is the question on the structure of the proton. HERA is the first and so far only collider for lepton-proton scattering to date. The data from the 27.5 GeV electron beams scattered on the 820 (920) GeV protons have delivered an accurate picture of the Structure of the proton in a wide kinematic range. Precise predictions of cross sections at the LHC critically depend on the knowledge of the parton density functions (PDFs) in the proton. It can be the largest uncertainty in measurements, as the detector systematics will get under control to the anticipated level. The precision measurements at HERA in the last 15 years have boosted our knowledge on the parton distributions by several orders in magnitude in kinematic reach and by specific measurements of heavy flavors, such as bottom and charm quark PDFs. Final states allow to study multi-jet production, complementing the impressive LEP results by measurements in an environment with an additional important complication, namely in the presence of an object containing color: the proton. The understanding of these data will be a key to the study of LHC jet data especially at medium jet energies. Measurements of this type, together with the PDF data, allow for precision tests of QCD dynamics, e.g. to test classical approaches such as DGLAP evolution, or more sophisticated ideas, including e.g. special $\log(1/x)$ terms, angular ordering etc. The HERA data are also instrumental in understanding double parton scattering, a phenomenon which is expected to be very important at the LHC. HERA has elevated the studies of diffraction to precision physics, and the LHC is expected to carry on that program. Finally, many tools have been developed over the last years for the analysis and understanding of HERA data, which can be adapted for future studies at the LHC.

In view of this anticipated synergy between HERA and the LHC the workshop has defined six working groups

- Parton density functions and related questions
- Multi-Jet final states and energy flows
- Heavy quarks (charm and beauty)
- Diffraction
- Cosmic Rays, HERA and the LHC
- Monte Carlo generators and tools

The *Parton Density Functions* working group had the most obvious task, namely getting to understand what the present precision - both from data and from theory- is to determine parton distributions, and what are the consequences of these uncertainties on LHC measurements. At an early stage in the workshop it became obvious that the combination of the H1 and ZEUS experiments would be very beneficial. Such lessons had been learned from LEP and are now applied at HERA. It turns out that the gain of a common analysis of the data of the two experiments on the precision of the PDFs is substantially larger than when these data-sets are used individually in fits. Benchmark test have been performed to check the systematics of the different assumptions in the QCD fit procedures, keeping certain assumptions and data sets in the fits fixed. At the start of the workshop there was some controversy on the NLO gluons at low- x , being very different between different PDF fit groups. This could be resolved by measuring F_L , requiring lower energy running at HERA. The workshop has strongly supported that proposal and the last months of HERA have been used to measure F_L . First results are now being released by the experiments. Steps on getting towards common procedures to be used in the PDF fitting community and to get the most optimal PDFs are being defined and followed up in a special PDF forum called PDF4LHC, which is a spin-off of this workshop

The *Multi-Jet final states and energy flows* working group has studied in detail the novel jet algorithms, designed to be infrared and collinear safe, such as the SISCone and the (anti)- k_T algorithms. Jet algorithms and performances as used in the experiments are discussed. A jet quality measure has been defined. The perturbative calculation of higher order corrections has been studied in detail and a comparison of all order analytical resummation with Monte Carlo parton shower approaches has been performed. An important issue to understand better the details of the final states in experimental data is the concept of k_T factorization. A formalism for extracting e.g. the needed unintegrated gluon distributions from fits to data is proposed. Implications for the LHC are studied e.g. on the case of gauge boson production, and boson production in association with heavy quarks. Forward so called "Mueller-Navalet" jets predictions have been made for the LHC. Very forward jet measurements opportunities e.g. using forward CASTOR detector in CMS look promising. Finally prompt photon production, high density systems and handles to multi-parton event discoveries have been discussed.

In the *Heavy Quarks (Charm and Beauty)* working group a summary of experimental results on fragmentation functions, gluon densities and charm/beauty masses from HERA has been collected. Prospects for heavy quark measurement at the LHC are discussed. In the theory area important and significant progress has been made in the understanding of heavy quark mass effects in the evolution of parton density functions. In a common contribution from members of CTEQ and MRST the progress in understanding of mass effects and its impact on the global analysis of parton density functions is reviewed and documented. In addition also progress in the calculation of fragmentation functions including mass effects is discussed. Finally the progress in calculation of higher order corrections to $t\bar{t}$ production at the LHC is summarized.

The working group *Diffraction* brought about an important information transfer between HERA (and Tevatron) and the LHC on the experience with near beam detectors operation and calibration issues. Since the start of the workshop, there are several near beam detector projects that have been launched in the experiments. Diffractive and forward physics is now in the blood of the LHC experiments. CMS, TOTEM and ALICE present their physics program, also what can be achieved without near beam detectors by using rapidity gaps instead. Major progress has been achieved in understanding central exclusive production at pp colliders, with a tight re-evaluation of the theoretical calculations, and foremost with the exclusive measurements made at the Tevatron. Factorization in diffractive processes remains mysterious. It is known not to work between ep and pp data. Now also within ep data at HERA it is found not to work for diffractive di-jet photoproduction events. The deployment of diffractive PDFs from ep to pp data has therefore to be done with care.

In the working group *Cosmic Rays, HERA and the LHC* the impact of laboratory measurements for the understanding of the source and propagation of high energy cosmic rays has been discussed. These cosmic rays are measured mainly via air-showers and for their simulation measurements at high energy lepton hadron and hadron hadron colliders are important. The main sources of uncertainties come from cross sections (elastic and inelastic), secondary particle production and multiplicity distributions. Hadron production in the forward region especially from HERA and also the LHC can provide important constraints. On the theory side the application of perturbative QCD for the calculations, hadron production in the forward region, the relation to multi-parton interaction and non-linear effects arising at highest energies (i.e. at small

x) have been discussed.

The goals of working group *Monte Carlo and Tools* was to examine and improve the Monte Carlo event generators for the use at LHC, to provide a framework for tuning and to develop new tools and libraries for the analysis of data. The available Monte Carlo generators are reviewed and tools like HZtool and RIVET, tools for fitting like Professor and Proffit (in *Multi-Jet nal states and energy flows* WG) are discussed. Multiparton interaction and underlying event structures was a major issue, also in close connection with *Multi-Jet nal states and energy flows*.

The special character of this workshop was – apart from its clear charge on the connection between HERA and LHC – that it was alternative held at CERN and at DESY. Note that Tevatron was always an invited guest at the table, and its data and interpretation of the results have always been part of the input in the discussions.

The last workshop in this series was held at CERN, where the series started, and over 200 participants attended. This clearly shows that the workshop has been established to be a beacon and forum for discussions of QCD for the preparation of the LHC. With the termination of the HERA accelerator in 2007 and the turn on of the LHC, the series was terminated and the results are written up in these extensive proceedings. But clearly there is a need and community for targeted forum on LHC QCD questions, and no doubt a workshop of this kind will emerge in the near future, as soon as the first data arrive.

Finally we wish to thank all the participants of the HERA and the LHC workshops for making this series so interesting and lively. We thank especially the conveners for their enormous work in the preparation of the many meetings and finally the proceedings

Last but not least we wish to thank A. Grabowsky, D. Denise, S. Platz and L. Schmidt for their continuous help and support during all the meetings. We thank B. Liebaug for the design of the poster. We are grateful to R. Eisberg, O. Knak and S. König for recording the talks and all technical help. We thank M. Mayer, K. Sachs and M. Stein for their help in printing the proceedings. We are grateful to the CERN and DESY directorates for financial support of the workshops and for their encouragement to investigate the HERA - LHC connection in detail.

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