FROM HERA TO LHC: IMPLICATIONS AND CONSTRAINTS

Luca Stanco
I.N.F.N. Padova, via Marzolo 8, Padova, Italy

Abstract

Starting of LHC sometime this year and the long expected and unexpected new physics results which will be granted in the near future, will be challenged by the capacity to keep under control most of the Standard Model physics. The results from the HERA machine in terms of Parton Density Functions from very low to high x-Bjorken, jet flow and structures of the underlying event, as well as diffraction production, are all key issues to be considered by LHC community. A personal short overview of the HERA results from H1 and ZEUS experiments are given together with their connection to LHC physics.

1 Introduction

This year the more and more awaited LHC startup will constitute the most important event of the last decade in particle physics and one of the most relevant from the discovery of the Neutral weak Currents more than 30 years ago. In the last three decades many important theoretical and experimental discoveries raised to the horizon of the particle physics community. They can be roughly divided into two sets of discoveries: those verifying more and more deeply the Standard Model (from the proves of the ElectroWeak radiative corrections at LEP to the Top discovery at the Tevatron) and those opening new unexpected scenarios not fitting in the Standard Model (from the observation of neutrino oscillations to the dark matter to the frightening theoretical "discovery" of the superstring models). Either set is anxiously waiting for any hint may come from the first measurements of LHC experiments. To be astringent a general hope and believe is that Standard Model be living his last days, based on the lack of a SM Higgs observation around the 170 GeV region 1) which should indicate a possible void observation also in the lower energy range[1].

However, new physics at LHC will come together the usual Standard Model production. It is matter of consideration wether and how the SM physics will overburden the new production, without discarding the importance to study the known with much better precision and at rather different energy ranges (one for all it will be extremely interesting to measure the top-top production as hint for inclusive new physics) 3). The SM physics production as expected from previous or current experiments will constitute a multiway challenge for LHC. In this report we will focus on the challenges which come from the HERA measurements.

HERA was an electron(positron)-proton collider with a center-of-mass energy around 300 GeV. The two experiments H1 and ZEUS collected together 1 $fbarn^{-1}$ during the years 1992-2007 providing an extended gathering of data in the so called low x-Bjorken region of the Deep Inelastic Scattering regime, together with new insights in the *parallel* productions of photoproduction and diffraction. As a result completely new and exhaustive measurements of structure function F_2 of the proton have been provided in many extended x regions.

We will discuss (pompously talking) the relevance of these HERA aspects for LHC. Likely the original physics aspects which happened to be studied in the $e-p$ collisions at few hundreds of GeV may own a counterexample at

[1]This conclusion is not completely justified being formulated on the basis of SM constraints. For a exhaustive report, I like to refer to [2] and references therein. Personally I would tend to conclude no Higgs signal either SM or BSM will be found in the 100-200 GeV energy range, while the new physics would happen to emerge beyond 200 GeV.

LHC at few TeV. Throughout this short report we will discuss explicitly about this point. Moreover, it is clear that HERA themes constitute real physical constraints in case the long awaited new physics will raised up without striking signals. That is, we will focus on the constraints which experimenters at LHC have to take into account wether no *smoking-gun* analysis will be available by Nature to get the new physics understandable, and instead long exhaustive analysis will be needed to analyze primarily the Standard Model production and eventually its discrepancies from data. To this respect, HERA results will constitute an important, and unavoidable, key-corner by their restraints on the Parton Density Functions of gluons and quarks.

2 LHC expectations

It is much easier for me to start saying few words about LHC and eventually address the HERA issues. LHC is the *biggest* for many aspects: the biggest accelerator ever built, the biggest involvement of physicists/engineers ever tried, the biggest enterprise ever challenged in particle physics, the biggest ever potential place for new discoveries. Last but not least, LHC will also constitute a serious (experimental) wager to connect Particle Physics and Cosmology. LHC machine is supposed to start operations sometime the second part of this year[2], hoping for a "Stage A" operation at 10 TeV in *c.o.m.* with a luminosity around $10^{32} cm^{-2} sec^{-1}$ which will provide few inverse *picobarns* to ATLAS and CMS experiments.

It is by now a well known example that looking for new physics at LHC will correspond to grabble a needle in 100,000 haystacks[3] by comparing the relative cross sections of new particles at 1 TeV scale and electroweak coupling with the total proton-proton cross section. It is easy to identify the "needles" with particles like the Higgses (Standard Model or SuperSymmetric ones), supersymmetric particles, extradimensions, micro black holes etc., while the haystacks can be essentially fractionalized into 4 classes: total proton-proton cross section, jet (with heavy flavor) production, photon-production, Standard Model candles (W, Z and top). All these four classes may correspond to a sort of QCD **mobocracy**[4] to point out that QCD will pervade all the different analysis performed at LHC.

We try to think to a correspondence between QCD and New Physics at LHC, with respect to the correspondence between the first analyzed mea-

[2] At the time of this writing, it has been decided that the first circulating beams will occur on September 10^{th}.

[3] See for example the presentation at plenary of EPS07 conference by J. Ellis, http://www.hep.man.ac.uk/HEP2007/.

[4] Mobocracy is the governance of mob people (plebs), opposite to oligarchy.

surements and the first signals, as well as between the most exhaustive measurements and the detailed analysis, and how these correspondences will be enlighten by HERA results. Moreover, what may be expected at LHC in term of diffraction is an open interesting issue, while few aspects of Electroweak (and nones on Heavy Flavors) Physics will be further addressed.

Actually, the presence of a QCD *mobocracy* at LHC will correspond to a much better understanding of the PDF issues, provided the huge enlargement of phase space, the jet (and heavy quarks) production, the diffraction reactions. Finally, one has not to forget the "second order priority" analysis which will take place to test QCD at high scale, smallest-x ever studied (and the corresponding questions on parton saturation), possibility of new phases in QCD and, last but not least, possibility to observe non-linear phenomena.

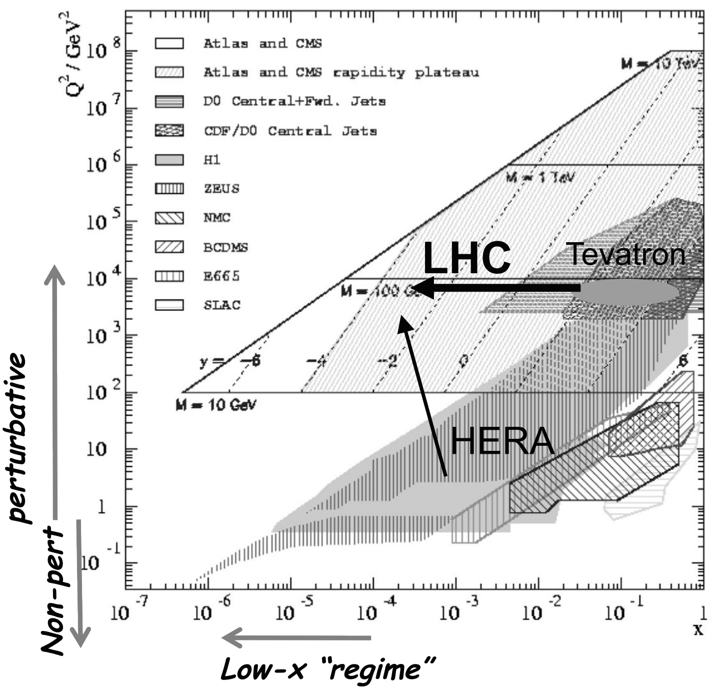

Figure 1: *The phase space region in terms of x and Q^2. The LHC accessible region is largely dominated either in the high Q^2 or the small-x regions. Arrows on the axis indicate the usually undertaken domains of (non)perturbative and low-x regimes. The two arrows inside the picture indicate the propagation by QCD evolution equations from the experimentally measured regions by HERA and Tevatron to the unexplored LHC ones.*

3 HERA: the QCD machine

The interaction of electron(positron) and proton at HERA is described by two independent variables usually handpicked as Bjorken-x and Q^2, the momentum fraction of the proton and the energy transferred on the electron side. The artwork of the available phase space in terms of x and Q^2 is shown in fig.1 for different machines and experiments.

The naturalness of investigating the proton structure through a quasi-real/virtual photon probe explains easily the character of QCD testing machine for HERA. We meditate the F.Wilczek quotation *"... The most dramatic of these (experimental consequences), that proton viewed at ever higher resolution would appear more and more as a field energy (soft glue), was only clarified at HERA twenty years later* [4].

As can be noted from a careful look at fig.1 the two colliders HERA experiments were able to analyze a large new part of phase space. A real HERA's legacy is wonderfully reported in fig.2 were preliminary results on the combined data from H1 and ZEUS were reported [5] together with the corresponding extracted fits of PDF[5].

The studies of Standard Model signals at LHC will definitively need the HERA results on PDF. A very good example comes from the W bosons production, dominated by the sea-quark density and probably used as a source of luminosity measure. Their systematic errors will be dominated by the PDF inputs, as exhaustively reported e.g. in the paper of M. Diehl [6].

It is also time to point out that already sometime ago several groups and workshops have been settled by HERA people in touch with theorists and interested LHC community.
All references can be looked at http://www.desy.de/∼heralhc/.

4 LHC and HERA interplay

The LHC studies can be temporarily divided following the years of data taking and the corresponding acquired luminosity. The first step of few *inverse picobarns* will allow the LHC experiments to have a threefold clear look at: a) charge particle production, underlying event, multipartons pile-up; b) detectors calibration and tuning and c) early (un)discovering of new physics from leptons signatures. In this context the HERA experience (as well the Tevatron one) may help a little just from human (and potentially Monte Carlo) experience.

[5] At the time of the talk the combined fits of H1 and ZEUS were not available yet. For a very recent preliminary fit result see ICHEP08 conference at the plenary session, http://www.hep.upenn.edu/ichep08/talks/misc/schedule, talk-id=460.

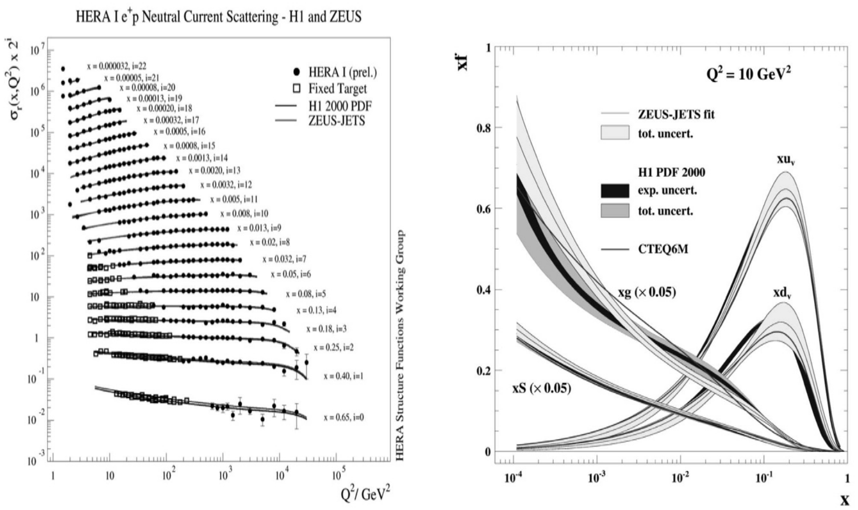

Figure 2: *The full set of combined (H1 and ZEUS) measurements of the Neutral Current cross-section (left) and the corresponding extraction of PDF (right) internally arranged by either H1 or ZEUS collaboration.*

Furthermore, once some tens of *inverse picobarns* will be available at LHC, analysis with jets will open up. At this moment HERA will display its full impact. Careful and exhaustive analysis interplaying between HERA PDF fits and LHC jets will have to be considered. For the time being, not all the HERA data have been used for PDF fitting yet, nor an overall analysis which takes into account data from both experiments (H1 and ZEUS) as well as other data for F_L, the longitudinal structure function, has been fully elaborated yet. The gluon density is still an open issue, especially at low-x and low-Q^2 (low at HERA not at LHC!) [7]. The radiative corrections at low-x are quite important and they drive large discrepancies in the extracted theoretical fits at LO, NLO, NNLO (see fig.3).

In synthesis the issue about the small-x and the Q^2 evolutions as they will occur at LHC is a hot open issue. That is represented by the arrow of fig.1 which indicates the evolution path of the HERA data into the LHC domain. There have been several recent theoretical studies [9] to disentangle the possible different QCD evolutions and resummations at low-x. All of them seem to point towards a BFKL evolution. As all we know, life for experimenters is usually harder than antecedently foreseen. It may also happen that BFKL evolution at LHC points unto Double Unintegrated Parton Density, *id est* parton densities

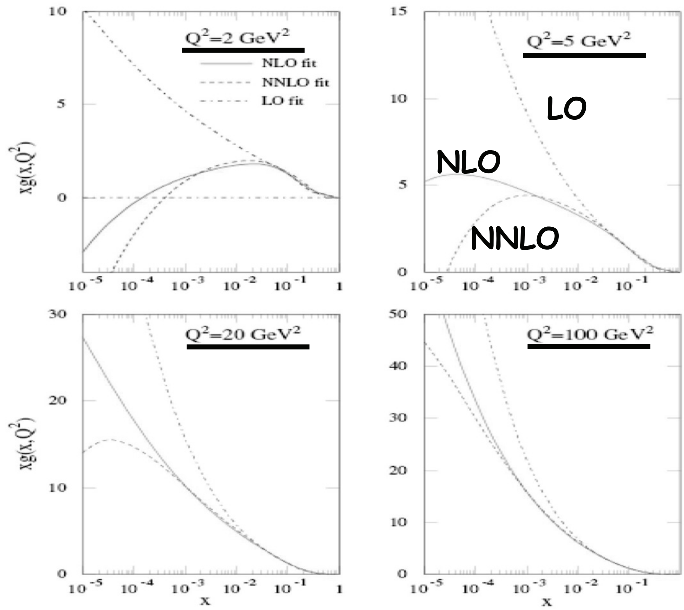

Figure 3: *The gluon density function as extracted from different order approximation (from R. Thorne at HERA-LHC workshop* [8]*) at different* Q^2 *values.*

not integrated over the usual k_T and virtuality parameters. If such be the case, a long and painful work await LHC analyzers.

The third big step in LHC analysis will be devoted to precise measurements. At this minute LHC will become a real SM factory. HERA data will probably be used only to calibrate the signals and the PDF fits, without forgetting the (second class) possible discovery of new physics by comparing data and extrapolation of HERA results at very high Q^2.

A completely different issue refers to *Diffraction.* As defined by Bjorken in 1994 after the first observations of HERA [10], *... the diffraction reactions can be operatively termed as the class of reactions with non-exponentially suppressed large rapidity gaps* (on the longitudinal axis). In this field there are several open issues and many studies available [11]. I will only write down a personal skeletal synthesis: HERA brought up to the particle physics community the attention on diffraction at high energies with new physics perspectives and ideas. Furthermore, several analysis tools have been developed, together with new parameters in analysis and physics descriptions. IF at LHC more new physical aspects (or the ones already explored but at different regions of phase space) will appear, THEN the diffractive counterbalance between HERA and LHC will be(come) extremely important.

5 Conclusions

The importance of the interlude between the HERA machine and LHC has been discussed and illustrated by pointing out some issues related to QCD and Parton Density Functions.

The already long history of PDF results from the two HERA experiments, H1 and ZEUS, led to important (almost final) fitting analysis. Their application to the LHC context especially in term of Standard Model physics will put somehow strong constraints on the extraction of new BSM physics as well on the prospect to make use of SM signals for the measurement of the luminosity. Although studies are progressing and LHC data will enter themselves in the analysis procedures, the first years of analysis at LHC will undergo severe limitations due to the actual knowledge of QCD in a limited phase space region. Indeed the inclusive studies at LHC could easily be overwhelmed by a so called QCD mobocracy, a fully pervaded SM production.

We also clear out the need for awareness while new portion of unexplored phase space in x and Q^2 will be analyzed at LHC. Even if the evolution equations via their specific resummations underwent recent theoretical developments arranging a beneficial ground for LHC, surprises may arise up due to the small-x corrections and the new regime of the parton dynamics. All that by taking note that the small-x regime will be probably unsettled at HERA. Therefore it may turns out to be a big question mark at LHC.

Similarly, the diffraction production received new exciting inputs from HERA data and analysis. It may be considered as a ”new story” at HERA, will it be considered as an ”interesting story” at LHC ?

In summary, the first years of LHC analysis will be (probably heavily) constrained by the HERA results. This will be ulteriorly true wether the SM Higgs and no signal of new (supersymmetric)physics will be early discovered below the 200 GeV energy range. In such a case, greater energy ranges will be analyzed mostly in terms of QCD jets where its mobocracy will dominate. However at that further time the LHC data by themselves will certainly be able to overcome the SM production and perform more accomplished studies.

6 Acknowledgements

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2. K. Jakobs and M. Schumacher, "Prospects for Higgs Boson Searches at the LHC", in "Perspectives on LHC physics", G.Kane and A. Pierce editors, World Scientific (2008).

3. Physics studies from the two collider experiments, ATLAS and CMS, are relevant if not conclusive. For general studies refer e.g. to CMS physics TDR, A. Ball et al, CERN-LHCC-2006-021, CMS-TDR-008-02 (2006).

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7. See e.g. A.D.Martin et al., Phys. Lett. B **652**, 292 (2007) also in arXiv:0706.0459v3 [hep-ph] and therein fig.8 where comparison of the gluon density predictions by MSTW2006 and Alekhin2006 PDF fits at NNLO, at $Q^2 = 5\,GeV^2$ and low-x region ($10^{-3.5}$), shows big discrepancy (around a factor 4) due mainly to the different treatments of the sea-quarks evolutions.

8. R. Thorne, HERA-LHC workshop of 3/07, (2007).
   The figure has been updated at the HERA-LHC workshop of 5/08, see http://www.desy.de/~heralhc/Agenda, (2008).

9. For recent works see e.g. M.Ciafaloni et al., JEHP **0708**, 046 (2007) also in ar.Xiv:0707.1453 [hep-ph];
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