RECENT RESULTS FROM HERA COLLIDER

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Abstract. HERA collaborations H1 and ZEUS are publishing final analyses based on complete $e^{\pm}p$ statistics of ~ 0.5 fb^{-1} per experiment and using combinations of their data sets. Here selected recent results are presented from three areas: structure of the proton, searches for new physics and investigations of QCD phenomena at low Bjorken x.

1 Introduction

HERA – so far unique ep collider – ended its operation in June 2007. Since then two general purpose experiments H1 and ZEUS are finalising physics analyses using full e^+p and e^-p data samples collected with unpolarised (1993-2000) and longitudinally polarised (2003-2007) lepton beams.

Rich physics landscape of HERA is based upon its unique capabilities in three areas. First, it is a super-microscope with a record resolution power allowing a structure of matter to be probed down to 10^{-18}m. Second, it is a high energy frontier machine with *c.m.s.* energy of $\sqrt{s} = 319$ GeV, which permits a search of new physics beyond the Standard Model (SM) in a way complementary to e^+e^- and pp colliders. Third, it proved to be a powerful QCD laboratory, putting the theory of strong force into stringent tests, especially in low Bjorken x regime, which is one of the specifics at HERA.

In this brief overview recent results from all three areas are presented. Although they represent by far not complete account of all latest HERA results, two important aspects of HERA analyses are nevertheless covered: a) precision measurements and b) search for novel phenomena, both within and beyond the SM.

2 Inclusive Measurements and Proton Structure

Inclusive deep inelastic scattering (DIS) cross sections are measured at HERA over six orders of magnitude in negative four-momentum-transfer squared, Q^2, and in Bjorken x and used to determine proton structure and interprete it in terms of parton density functions (PDFs). Combination of H1 and ZEUS data allows not only to achieve better statistical precision, but also to improve accuracy due to cross calibration of both experiments properly taking into account correlated and uncorrelated systematic uncertainties. As a result 1% precision is achieved in the bulk region for combined neutral current (NC) cross section. Combined HERA I data are used to extract the HERAPDF1.0 set [1]. Adding HERA II cross sections improved accuracy especially at high Q^2 and

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high x domain. This combination provides HERAPDF1.5 set [2]. Figure 1 illustrates inclusive NC cross sections, extracted HERAPDF1.5 at a certain scale ($Q^2 = 10$ GeV^2) and confronts the predictions based on those PDFs with recent LHC data on lepton asymmetry. Comparison of jets cross sections measured at Tevatron [3] with NLO QCD prediction using HERAPDF1.0 is also shown. Both comparisons show fair agreement with the data. Improvement in low x gluon density determination due to HERA data is crucial for hadron colliders. It allows to constrain basic SM processes calculation much better than before. Next step under work now is adding jet and charm data into final simultaneous global fit of proton PDFs and α_s.

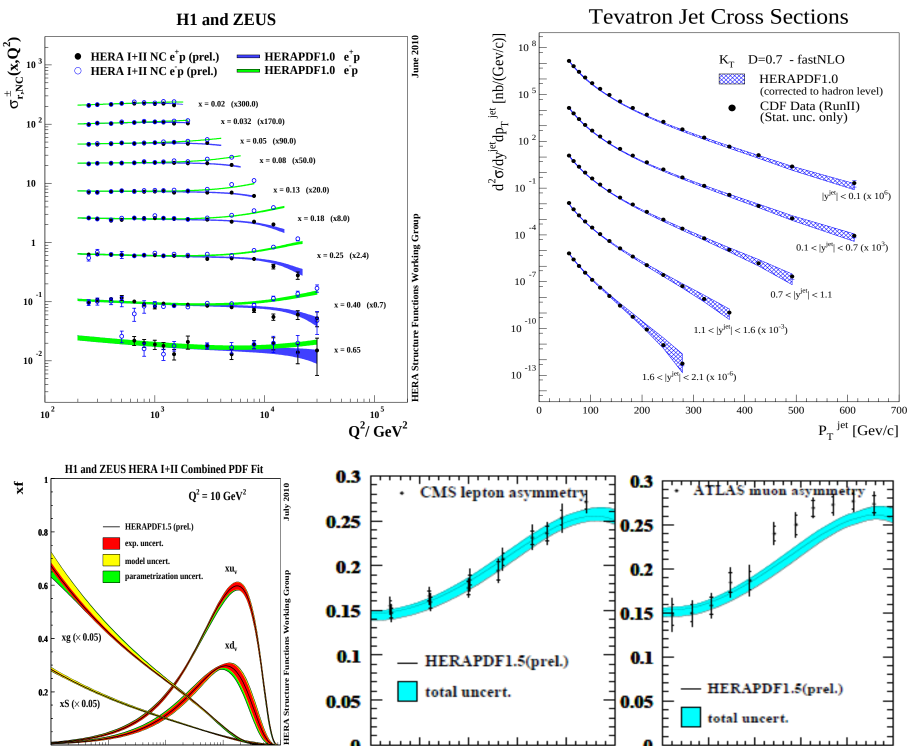

Figure 1: Top left: HERA I combined NC cross sections for e^-p and e^+p interactions. Top right: jet production at D0 compared with prediction obtained using HERAPDF1.0. Bottom left: HERAPDF1.5 extracted from combined HERA I+HERA II data. Bottom right: Recent LHC results on lepton asymmetry compared with prediction obtained using HERAPDF1.5

3 Searches of New Phenomena at HERA

A search for new physics in most promising specific final state topologies has been recently published using ~ 1 fb^{-1} of combined H1 and ZEUS data [4, 5]. Overall good agreement with the SM is found. The largest deviation of 2.6σ has been observed for multilepton events with high transverse momentum, $\sum P_T^l >$ 100 GeV, in e^+p collisions.

Here new results are presented on search of contact interactions [6, 7] and leptoquarks [8] at HERA using full high Q^2 NC and CC $e^{\pm}p$ statistics. New physics phenomena in $l - q$ scattering experiments may manifest themselves in deviations of the differential cross section $\mathrm{d}\sigma/\mathrm{d}Q^2$ from the SM expectation, and may be related to new heavy particles with masses M_X much larger than the electroweak scale. In the low energy limit $\sqrt{s} \ll M_X$ such phenomena can be described by an effective four-fermion CI model. Since the data are found to be consistent with the expectation from the SM alone lower limits on the compositeness scale Λ at 95% CL are set in the range 3.6 TeV to 8.9 TeV depending on the model and the sign of the coupling coefficient. Also, search for possible quark substructure manifestations are performed using standard form factor approximation $f(Q^2) = 1 - \langle R^2 \rangle Q^2/6$ (see Figure 2). Best limit of 0.63×10^{-3} fm is set by ZEUS [6].

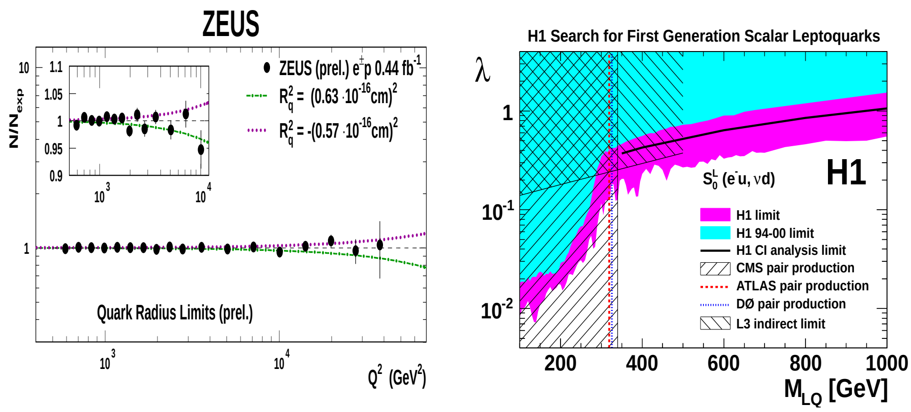

Figure 2: Left: best $95\%CL$ exclusion limits on the effective quark radius obtained by comparing ZEUS NC data with the SM expectations. Right: exclusion limits at $95\%CL$ on the coupling λ as a function of the leptoquark mass for the S_0^L leptoquarks in the framework of the BRW model [9]

New exclusion limits for 14 types of first generation scalar and vector leptoquarks are derived by H1 collaboration (see an example on the right part of Figure 2). Assuming coupling strength of $\lambda = 0.3$ leptoquarks are ruled out up to masses of 800 GeV, which is beyond the current limits from hadron colliders.

4 Jet Production in low x Regime

HERA provides wide variety of processes to study QCD dynamics in low x regime. An incomplete list includes diffraction, exclusive vector meson production, jets, heavy flavours. An interesting question is whether perturbative QCD at next-to-leading order exploiting DGLAP evolution equations is sufficient to describe HERA data, or there are experimental evidences on new dynamics beyond DGLAP. Here we present some results on multijet production in various topologies. These processes are also important because they allow a direct measurement of the strong coupling α_s. On Figure 3 measurements of inclu-

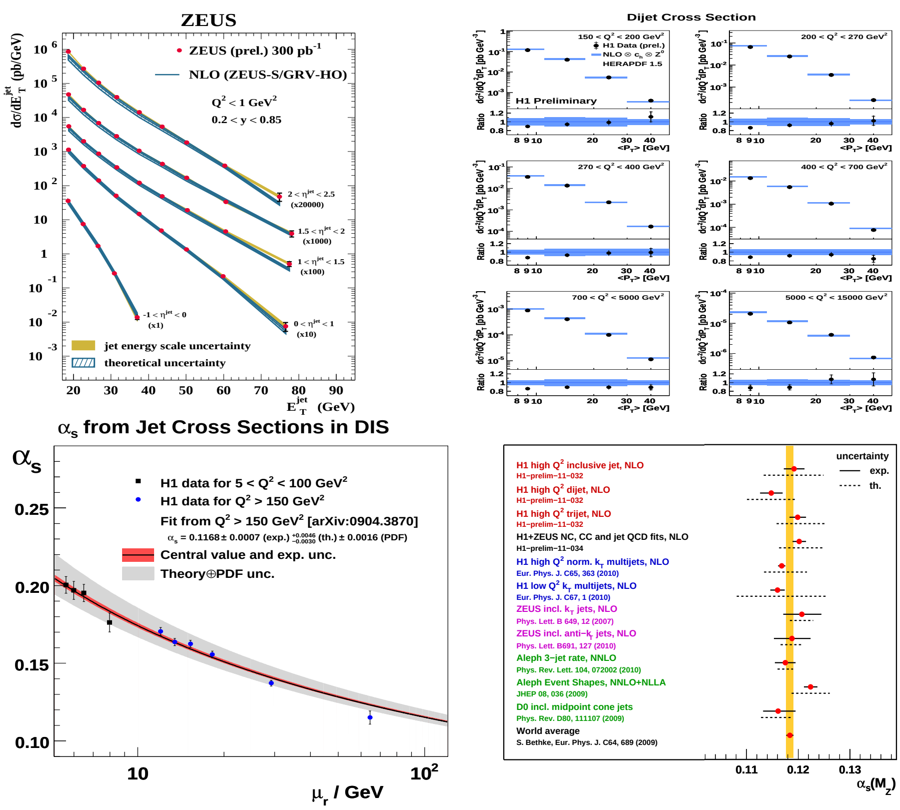

Figure 3: Top left: differential cross sections for inclusive jet photoproduction in different pseudorapidity regions [10]. Top right: the dijet cross sections in NC DIS as a function of the average transverse momentum of two the leading jets in Breit frame [11]. Bottom left: running α_s as a function of renormalisation scale, $\mu_r = \sqrt{(Q^2 + P_T^2)/2}$, determined from H1 jet production in DIS regime. Bottom right: strong coupling $\alpha_s(M_Z)$ measured at HERA as compared to e^+e^- results and world average.

sive jet cross section in photoproduction [10] ($Q^2 < 1$ GeV^2) and dijet cross section in DIS [11] ($Q^2 > 150$ GeV^2) are presented. High statistics and dedicated calibration allowed to reach jet transverse energy scale precision below 1%. NLO QCD calculations gives very good description of these data, thus permitting to extract running α_s as a function of renormalisation scale in a single experiment. A summary of $\alpha_s(M_Z)$ determination from different observables at HERA shows good agreement with the world average. It is worth noting that in most measurements high experimental precision is achieved, such that the dominant uncertainty comes now from theory (mainly from missing higher orders of pQCD expansion).

In order to reach lowest $x \sim 10^{-4}$ a measurement of multijets production in lower $5 < Q^2 < 80$ GeV^2 DIS has been performed in extended phase space, covering lower jet $E_T > 4$ GeV and requiring at least one forward jet $\eta > 1.73$ [14]. A comparison of 3-jet cross sections with $\mathcal{O}(\alpha_s^3)$ NLOJET++ [15] calculations in Figure 4 shows that while for 2 central + 1 forward jet sample NLO QCD provides fair description, a significant excess at lowest x bin is observed in the sample with 2 forward and 1 central jet. This might be explained by a contribution of unordered in p_T parton evolution in low x kinematic domain.

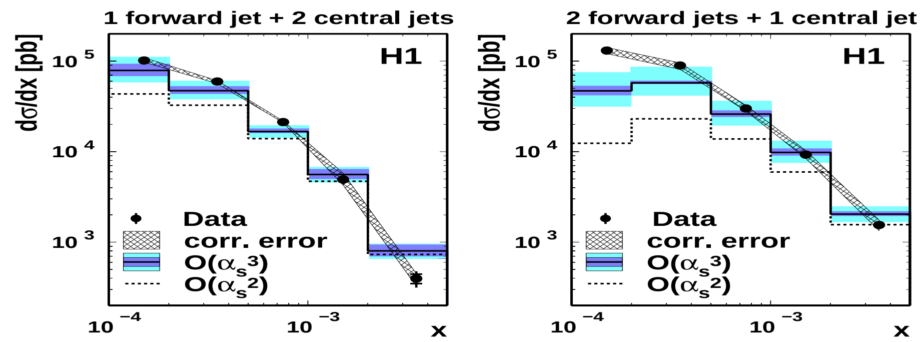

Figure 4: Trijet cross sections as a function of Bjorken x in different jet topologies compared LO and NLO QCD predictions based on DGLAP evolution equations

This observation has an important impact on the hadron collider physics programme, requiring to implement alternative parton evolution schemes into Monte Carlo models, used to simulate QCD final states at the LHC.

Conclusions

The Standard Model survived 1 fb^{-1} of HERA data and is now waiting for next challenges expected at the LHC.

Combined high precision H1 and ZEUS inclusive neutral-current and charged-current DIS cross sections provide new proton PDFs, in particular constraining gluon and sea quarks at low x, which allow for better precision of SM background estimate in pp collisions, thus improving the sensitivity to new physics at the LHC.

NLO DGLAP QCD is surprisingly successful down to low Q^2 and low x in describing bulk of HERA data. Although some room for novel parton evolution beyond DGLAP is found at specific corners of phase space, there are no unambiguous evidence for parton saturation at low x yet.

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