2 Particle Physics at DESY/HERA (H1)

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(H1 - Collaboration)

2.1 Electron-proton collisions at a centre of mass energy of 320 GeV - summary

During the first nine years of successful operation of the HERA storage ring, which ended in the year 2000, the H1 - detector has studied collisions of 27.4 GeV electrons and positrons with up to 920 GeV protons with a total luminosity of $\approx$ 200 pb^{-1}. During this phase (HERA-I) both the H1 - and the ZEUS - Collaboration have explored the structure of the proton and tested quantum chromodynamics (QCD) predictions focusing on precise determinations of the neutral and charged electroweak current cross sections at high momentum transfer leading to parton density functions in pre-HERA inaccessible domains of Bjorken x and momentum transfer Q^2, diffractively produced final states, hidden and open charm and beauty production as well as searches for states outside the Standard Model. The analysis of the wealth of data accumulated during this period is by no means concluded, as evidenced by the continuous flow of publications.

Since the HERA-I luminosity was insufficient to obtain large event samples for electroweak processes at the highest momentum transfers ($Q^2 \approx M_W^2$) an upgrade program was started in 2000 and completed in 2001. After solving a series of technical difficulties, which required another longer shutdown in 2003, luminosity and beam currents have reached design values for positron runs with tolerable background levels in the H1- and the ZEUS-detectors in 2004. While HERA-I used only unpolarized beams, HERA-II allows beam polarisations up to 40 %. Present plans call for HERA-II running until 2007, with an expected integrated luminosity of $\approx$ 500 pb^{-1}, split between electron and positron running. This will considerably raise the discovery potential of the HERA machine for beyond the standard model physics in the largely unexplored mass region above 200 GeV$/c^2$.

The components which were built by us for the upgraded H1-detector (a new five-layer inner multiwire proportional chamber with finer granularity and increased redundancy, equipped with new electronics and a new optical readout delivering signals for an improved z-vertex trigger) are now fully operational, and hence require only maintenance. The focus of our work has therefore shifted to data analysis.

Four theses of Zürich graduate students have been concluded (1)-(4). Results from ongoing thesis projects concerning lepton flavor violation and the search for excited fermions and photons within jets are given below in Sec. 2.3.2 and 2.3.3, respectively. The other two projects concern τ-lepton production as a signal for W-production, and the appearance of prompt photons within jets.

The analysis of HERA-I data lead to nine publications (5)-(13), and six more have been submitted or are in print (14)-(19). Additional, however preliminary results have been communicated at the August 2004 high-energy physics conference in Beijing (20)-(29), among them first results from the HERA-II running with polarized positrons (30)-(32), to be discussed briefly in Sec. 2.3.1 below.

A large fraction of these publications deals with searches for states and interactions outside the Standard Model, either of general type (11), or dedicated to specific objects such as supersymmetric partners of light and top quarks (6; 10), gravitinos (15), or magnetic monopoles (16).

Using all e^+p and e^-p data collected during HERA-I running between 1994 and 2000 combined QCD fits have been performed to determine electroweak parameters taking properly into account the correlation with the parton density distributions. The results include among others an improved determination of the W-boson mass, a first determination of the weak couplings of the light quarks to the Z^0 boson at HERA either in a least model dependent way (a) or within the standard model (b). The results are being presented at the upcoming conference on deep-inelastic scattering. As an example we quote only the two results:

a) m_W = 82.87 ± 1.83 (stat.) $^{+0.30}_{-0.16}$ (syst.) GeV/c^2

b) m_W = 80.786 ± 0.207 (stat.) $^{+0.048}_{-0.029}$ (mod.) ± 0.025 (top) ± 0.033 (th.) ± 0.084 (Higgs) GeV/c^2

The latter value can also be interpreted in terms of the Weinberg angle via $\sin^2\theta_W = 1 - M_W^2/M_Z^2$ using the e^+e^--collider world average for M_Z as

$$\sin^2\theta_W = 0.2151 \pm 0.0040 \text{ (exp.) } ^{+0.0019}_{-0.0011} \text{ (th.)}.$$

In scheme (b) the uncertainties quoted refer to the QCD-model (*mod.*) coming mainly from α_s and the starting point of the Q^2 evolution Q_0^2, the accepted ranges of the Higgs-boson and the top quark mass, and Δr (*the.*), the W propagator self energy correction.

Otherwise the parton density program of H1 broadens its kinematical base by including QED Compton scattering (9) and radiative events (23).

The other two areas, where our group has been active in the past, charm and beauty production (13; 14; 18; 19; 21; 22; 24) benefit strongly from the precise tracking information available from the silicon vertex detector, which was built almost exclusively by the Swiss groups within the H1-collaboration.

The studies of the diffractive component of deep inelastic scattering and photoproduction have been refined by going from inclusive to exclusive final states (25; 26) and also including the charged current data (28). Data on diffractive charm production, which was first studied in the Zürich thesis of S. Hengstmann on the basis of a handful of events recorded up to 1997, are now available over a larger kinematical region (25) which allows a more stringent test of the underlying QCD-predictions.

The H1 experiment has observed an excess of events with respect to the Standard Model W-production in the search for isolated, high p_T, single electrons and muons. Stefania Xella is working on the search for isolated, high p_T, single τ leptons from W-production, in the framework of the new object oriented software. The focus of the analysis is on hadronic decays of τ. First results from this analysis are available in (29).

Another Zürich project (C. Schmitz, K. Müller) is trying to determine the photon content of jets. The goal is first to identify photons inside a hadron jet and then to measure the energy fraction of the jet carried by the photon. This should allow to determine the quark-to-photon fragmentation function (35) which is not yet measured in the kinematic regime of HERA and can not be estimated by QCD calculations due to its non-perturbative component. If successful this analysis will yield important input to the simulation of physics processes at LHC, especially background processes for the Higgs search in the $\gamma\gamma$ channel.

2.2 Data taking

2.2.1 Status of the HERA accelerator

Since the end of the HERA shutdown in September 2003 the vacuum and background situation has significantly improved. This was achieved by the installation of an additional ion getter pump, increased pumping power and lead shielding around the beam pipe for better synchrotron radiation protection. From January 2004 to August 2004 HERA–II was running with positrons and delivered 90 pb^{-1}, of which 60 pb^{-1}were useful for physics analysis with average beam currents $I_p = 80$ mA ($I_p^{max} = 122$ mA) and $I_e = 25$ mA ($I_e^{max} = 53$ mA). In 2005 HERA–II runs with electrons, but background conditions have so far limited the beam currents and only 35 pb^{-1}of the about 50 pb^{-1}were useful for physics analysis. The slope of the curves displayed in Fig. 2.1 showing the integrated luminosity versus time however is promising and vacuum conditions are bound to improve. The maximum instantaneous and specific luminosity, $3.65 \cdot 10^{31}$ cm^{-2}/s and $1.72 \cdot 10^{30}$ cm^{-2} mA^{-2}/s, respectively, have reached the HERA-II upgrade design values.

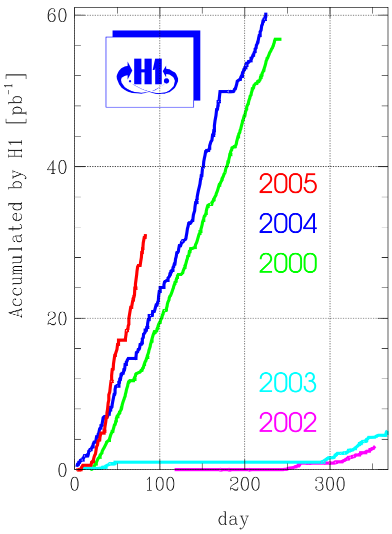

Figure 2.1:
Integrated luminosity produced by HERA–I (2000) and HERA–II (since 2002) as a function of day of the year. In the years 2000 - 2004 positrons were accelerated, in 2005 electrons.

2.2.2 Status of the H1 experiment

This years short summer shutdown was used to exchange electronics on the central silicon vertex detector, which suffered from radiation damage. Since this required access to the inner detector our group used the opportunity, too, to exchange a few CIP preamplifier and readout cards. Unfortunately the backward silicon detector had to be removed completely and will, after replacement of its radiation damaged components be reinstalled next year. Data taking resumed in October 2004, but useful electron running only started in 2005. Otherwise all H1-components function satisfactorily. The new z-vertex trigger built by us (34) is an essential component of nearly all trigger elements for regular data taking and cosmic calibration runs.

2.3 Results from recent analyses

2.3.1 First results from measurements with polarised beams

In the past years the HERA electron ring was tuned such that the electrons acquired a transverse polarisation of 50-60 %. After 2000 two pairs of spin rotators were installed around the H1 and ZEUS interaction regions, and the compensating magnets were removed. In autumn 2002 the latter spin rotators were switched on and polarized positrons were produced successfully. In spring 2003 HERA demonstrated a high degree of polarisation (45-50%) with both experiments taking data. Under typical running conditions in 2004 values around 35 ± 5 % have been reached.

The lepton polarisation is measured with two Compton polarimeters:

- the transverse polarimeter (TPOL) located near HERA-B outside the spin rotators, where the longitudinal component is zero, measures the transverse component of the beam polarisation.
- the longitudinal polarimeter (LPOL) located between the spin rotators near HERMES measures the longitudinal component at a place, where the transverse component of the polarisation is zero.

Both polarimeters detect Compton scattered laser light from the colliding the lepton beam. The polarisation is determined by comparing the cross section for left- and right-circularly polarized laser light. The polarimeter activities are coordinated by the POL2000 group with members from H1, ZEUS, HERMES, and DESY. Stefan Schmitt from our group was the speaker of this group from August 2002 to September 2004.
One of the main physics topics with longitudinally polarized leptons at H1 is the direct search for right-handed charged currents using the relation $\sigma_{CC} = (1 \pm P) * \sigma_L + (1 \mp P) * \sigma_R$. The linear dependence on the polarisation is quite evident from the data presented by the H1-collaboration at ICHEP04 (30; 32), which are shown in Fig. 2.2. The data are consistent with those of the ZEUS-collaborations, agree with standard model predictions and do not require right-handed charged currents.
A linear fit to the positron data points at large momentum transfer ($Q^2 > 400$ GeV^2) and inelasticity $y < 0.9$ yields a result consistent with the SM prediction $\sigma_{CC}(RH) = 0$:

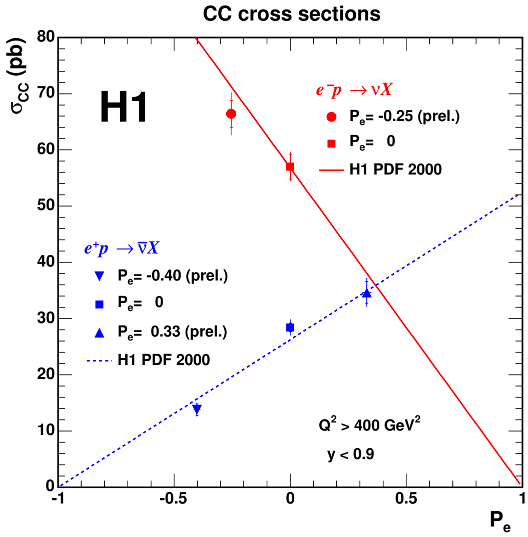

Figure 2.2:
Charged current cross section versus polarisation. HERA-II positron (2003/4) and electron data (2005) for Q^2 >400 GeV^2 and inelasticity y <0.9 are combined with unpolarised lepton data from 1999/2000 (e^+) and 1998 (e^-). The solid lines represent the standard model predictions using particle density functions derived from H1 neutral current data.

e^+p	P	σ_{CC}	$\mathcal{L}$
	0.33 $\pm$ 0.02	34.7 ± 1.9 (stat) ± 1.7 (syst)	15.3 pb^{-1}
	0	28.4 ± 0.8 (stat) ± 1.2 (syst)	65.2 pb^{-1}
	-0.40 $\pm$ 0.02	13.8 ± 1.0 (stat) ± 1.0 (syst)	21.7 pb^{-1}
	-1	-3.7 ± 2.4 (stat) ± 7.7 (syst)	extrapolated

A preliminary analysis of the electron data taken in February and March 2005 can be combined with unpolarised data from 1998 (see also Fig. 2.2) and yields:

e^-p	P	σ_{CC}	$\mathcal{L}$
	0.25 $\pm$ 0.04	66.4 ± 2.4 (stat) ± 3.0 (syst)	17.8 pb^{-1}
	0	57.0 ± 3.9 (stat) ± 2.4 (syst)	16.4 pb^{-1}

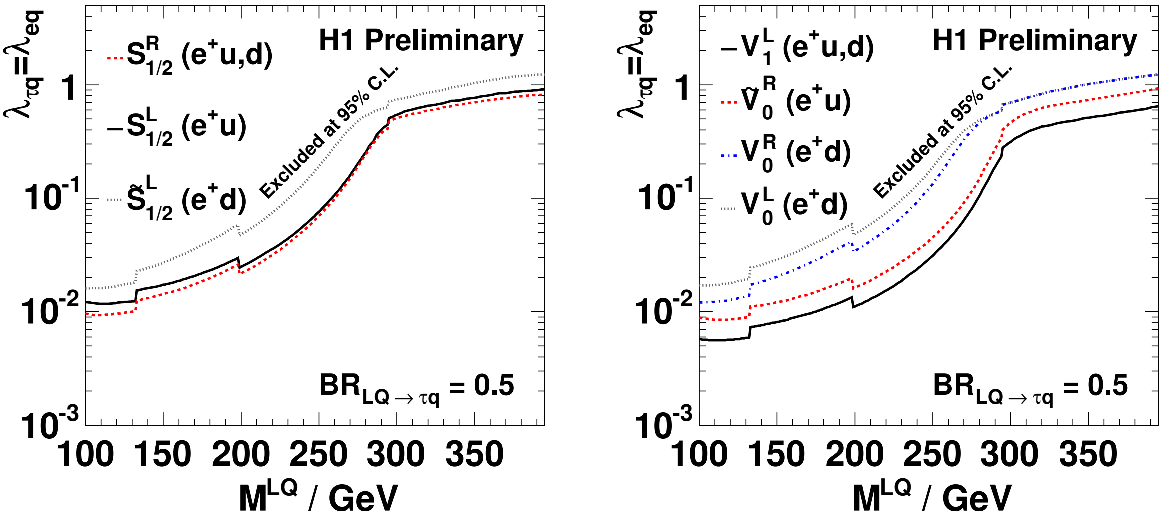

Figure 2.3:
Limits on the coupling strength $\lambda_{\tau q}$ at 95 % confidence level as a function of the LQ mass for scalar (left) and vector (right) LQs in the τ channel.

For neutral currents the dependence of the cross section on the polarisation is less pronounced, since it enters through the vector (v_e) and axial vector (a_e) quark coupling constants in the electroweak interference between γ and Z-exchange. By measuring both electrons and positrons, polarised and unpolarised one can disentangle the individual quark flavors. This program however requires high Q^2 and high statistics.

2.3.2 Search for lepton flavor violation

Lepton-flavor-violating (LFV) processes can be mediated by leptoquarks (LQ) possessing couplings to mixed fermion states. Leptoquarks are color triplet scalar or vector bosons, carrying both lepton (L) and baryon (B) number. The fermion number $F = L + 3B$ is conserved and takes values of $F = -2$ for e^-q and $F = 0$ for e^+q. In a search using the 1999/2000 e^+p-data (integrated luminosity 66.5 pb^{-1}) limits were derived on the Yukawa coupling of seven leptoquarks with $F = 0$ to a μ- or τ-lepton and a light quark, $\lambda_{\mu q,\tau q}$, in the Buchmüller-Rückl-Wyler effective model (36), as well as on the branching ratio, $B_{\mathrm{LQ}\to\mu q,\tau q}$, for the LQ decaying to a μ or τ (33). This analysis covers large parts of the PhD thesis of Linus Lindfeld. The limits are shown in Fig. 2.3, separately for scalar and vector LQ. The analysis uses the high p_T pencil-like (narrow cone and low track multiplicity) jet characteristic for a hadronic decay of a high p_T τ as signature. High p_T dijet events ($p_T > 25$ and > 15 GeV, resp.) have been selected. The 2005 data from e^-p-collisions will open the sensitivity to the other seven LQs with $F = 2$ which are possible in the BRW-model.

In this context also a letter is being prepared (37) presenting the analysis of S. Schmitt, which entails a complete search for LQs coupling to first generation fermions using e^+p data collected at a center-of-mass energy of $\sqrt{s_{ep}} = 300$ GeV, and e^-p as well as e^+p data collected at $\sqrt{s_{ep}} = 320$ GeV, corresponding to integrated luminosities of 37, 15 and 65 pb^{-1}, respectively, and representing the full statistics accumulated by the H1 experiment between 1994 and 2000. The search considered the decays LQ$\to eq$ and LQ$\to \nu q$ which lead to final states similar to those of deep-inelastic neutral and charged current interactions at very high Q^2. Results for scalar LQs are compared to those from other experiments in Fig. 2.4.

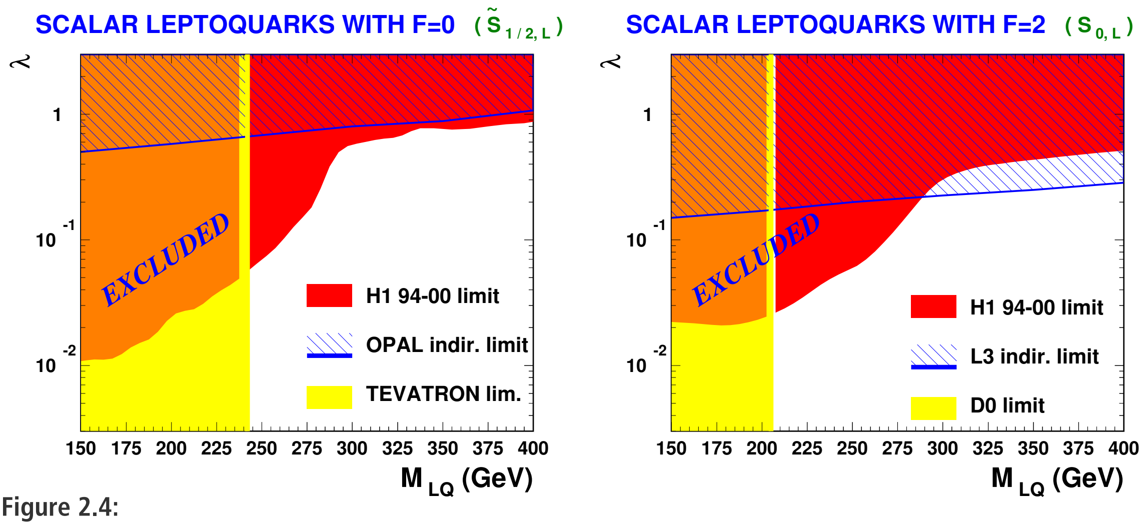

Figure 2.4:
Limits at 95% CL on the Yukawa coupling λ as a function of the LQ mass for scalar LQs with $F = 0$ (left) or $F = 2$ (right) in the BRW model [36]. Shaded and hatched domains are excluded. For $\tilde{S}_{1/2,L}$ the indirect limit from the OPAL-experiment and the combined direct limit from the CDF- and D0-experiments are shown, whereas for $S_{0,L}$ the indirect limit from the L3-experiment and the only available direct limit from the D0-experiment are shown. See ref. [37] for references.

2.3.3 Excited fermions

If leptons and quarks are not elementary particles but composite objects, excited states of these fermions can exist. These states can decay into an ordinary fermion and a gauge boson, e.g. $e^* \to e+\gamma$ or $q^* \to q+g$. At HERA, excited electrons and quarks can be produced by t-channel exchange of a photon or a Z-boson; similarly excited neutrinos can be produced by t-channel exchange of a W-boson. All possible decay channels are accessible with the H1 detector.

Jan Becker analyzed in his PHD thesis the decay of excited quarks into a quark and a photon. The event signature is a high energy photon together with a high energy jet, both pointing predominantly into the forward region of the detector. The dominating standard model background comes from neutral current events with a misidentified electron and from photoproduction events without a scattered electron in the detector. In the latter case prompt photons or isolated neutral mesons (π^0, η) misidentified as photons contribute.

The analysis used 1999/2000 data (integrated luminosity of 63 pb^{-1}) doubling the statistics of a published H1 search (39). It was optimized to get a good signal efficiency for masses of the excited quark larger than 100 GeV with low background from standard model processes.

The photon candidate is required to have a transverse momentum above 40 GeV/c and a scattering angle between 10° and 80°. No track is allowed to point to the photon candidate within 10 cm. Additionally a veto on hits in the proportional chambers is applied. The transverse momentum of the jet has to be larger than 50 GeV/c. This high p_T selection of events has a signal efficiency of roughly 40% and rejects the background very efficiently. In total 7 ± 2.7 events remain, while 8.5 ± 0.4 (stat) ± 3.0 (syst) are expected from the standard model. No excess of the data in the invariant mass is observed (Fig. 2.5a)). The limits derived in this analysis improve the existing H1 limits (39) in the high mass region (Fig. 2.5b) and c)).

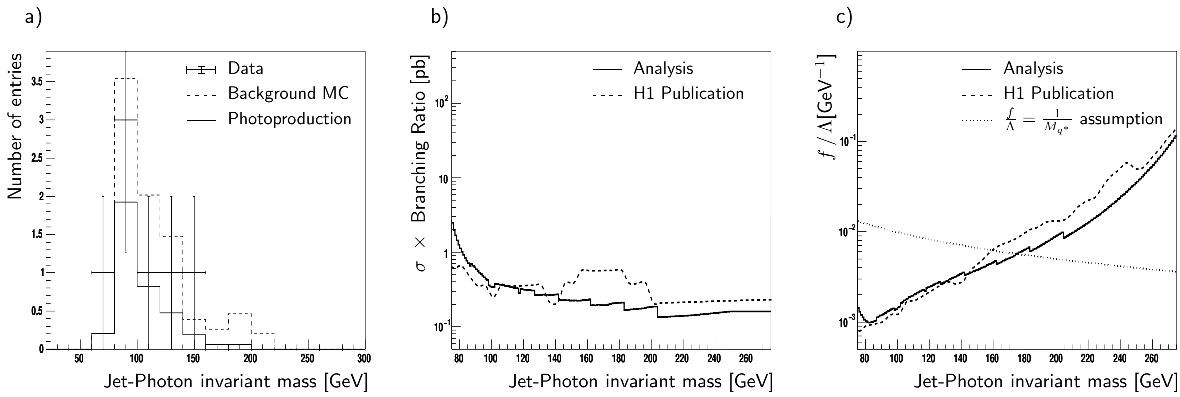

Figure 2.5:
a) Invariant mass calculated from the jet and the photon.
b) Limit on the cross section for an excited quark decaying into a jet and a photon.
c) Limit on the coupling parameters for excited quarks.

[1] **Measurement of Charged Current Cross Sections in Positron Proton Collisions at HERA**, Nicole Werner, PhD Thesis, University of Zürich (2004).

[2] **A Measurement of the QED-Compton Cross Section in Electron-Proton Scattering with the H1-Experiment at HERA**, Nicolas Keller, PhD Thesis, University of Zürich (2004).

[3] **A Multitrack Method for b-Tagging**, Ilaria Foresti, PhD Thesis, University of Zürich (2004).

[4] **The New CIP2K z-Vertex Trigger for the H1-Experiment at HERA**, Max Urban, PhD Thesis, University of Zürich (2004).

[5] **Measurement of Dijet Production at Low Q^2 at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 03 – 206, hep-ex/0401010, Eur.Phys.J.**C37** (2004), 141 - 159.

[6] **Search for Squark Production in R-Parity Violating Supersymmetry at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 025, hep-ex/0403027, Eur.Phys.J.**C36** (2004), 425 - 440.

[7] **Measurement of Anti-Deuteron Photoproduction and a Search for Heavy Stable Charged Particles at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 032, hep-ex/0403056, Eur.Phys.J.**C36** (2004), 413 - 423.

[8] **Forward π^0 Production and Associated Transverse Energy Flow in Deep-Inelastic Scattering at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 051, hep-ex/0404009, Eur.Phys.J.**C36** (2004), 441 - 452.

[9] **Measurement of the Proton Structure Function F_2 at low Q^2 in QED Compton Scattering at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 083, hep-ex/0406029, Phys.Lett.**B598** (2004), 159 - 171.

[10] **Search for Bosonic Stop Decays in R-parity Violating Supersymmetry in e^+p Collisions at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 084, hep-ex/0405070, Phys.Lett.**B599** (2004), 159 - 172.

[11] **A General Search for New Phenomena in ep Scattering at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 140, hep-ex/0408044, Phys.Lett.**B602** (2004), 14 - 30.

[12] **Measurement of Prompt Photon Cross Sections in Photoproduction at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 118, hep-ex/0407018, Eur.Phys.J.**C38** (2005), 437 - 445.

[13] **Inclusive Production of D^+, D^0, D_s^+ and D^{*+} Mesons in Deep Inelastic Scattering at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 156, hep-ex/0408149, Eur.Phys.J.**C38** (2005), 447 - 459.

[14] **Measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at High Q^2 using the H1 Vertex Detector at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 209, hep-ex/0411046, Eur.Phys.J.**C** (2005), in print.

[15] **Search for Light Gravitinos in Events with Photons and Missing Transverse Momentum at HERA**, H1-Collaboration, A. Aktas *et al.*, DESY 04 – 227, hep-ex/0501030, Phys.Lett.**B** (2005), in print.

[16] **A Direct Search for Magnetic Monopoles Produced in Positron-Proton Collisions at HERA**,

H1-Collaboration, A. Aktas *et al.*, DESY 04 – 240, hep-ex/0501039, Eur.Phys.J.**C** (2005), in print.

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[18] **Measurement of Beauty Production at HERA Using Events with Muons and Jets**, H1-Collaboration, A. Aktas *et al.*, DESY 05 – 004, hep-ex/0502010, submitted to Eur.Phys.J.**C** (2005).

[19] **Measurement of Charm and Beauty Photoproduction at HERA $D^*\mu$ Correlations**, H1-Collaboration, A. Aktas *et al.*, DESY 05 – 040, hep-ex/05003038, submitted to Phys.Lett.**B** (2005).

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[21] **Measurement of Beauty Production in Deep Inelastic Scattering at HERA**, [20] (5-0165).

[22] **Measurement of Charm and Beauty Production in Deep Inelastic e^+p Scattering at High Q^2 at HERA**, [20] (5-0167).

[23] **Measurement of the Inclusive DIS Cross Section at Low Q^2 and High x Using Events with Initial State Radiation**, [20](5-0170).

[24] **Measurement of Beauty Photoproduction at HERA using Inclusive Lifetime Tagging**, [20] (5-0760).

[25] **Comparison between Diffractive Dijet Electroproduction and Photoproduction**, [20] (6-0177).

[26] **Diffractive D^* Meson Production in Deep Inelastic ep Collisions at HERA**, [20] (6-0178).

[27] **Exclusive Photoproduction of Photons at Large $|t|$**, [20] (6-0183).

[28] **Measurement of the Diffractive Cross Section in Charged Current Interactions at HERA**, [20] (6-0821).

[29] **Search for Events with τ Leptons in ep Collisions at HERA**, [20] (12-0188).

[30] **First Measurement of the Polarisation Dependence of the Total Charged Current Cross Section**, [20] (4-0756).

[31] **Analysis of High Transverse Momentum Particle Production with HERA II Data** , [20] (12-0765).

[32] **Charged and Neutral Current Cross Sections at HERA I and HERA II**, S. Schmitt, Proc. [20], to be published.

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[38] H1-Collab. C. Adloff *et al.* Eur.Phys.J.**C11** (1999), 447 [erratum: ibid. **C14** (1999), 553]; Phys.Lett.**B523** (2001), 234.

[39] H1-Collab. C. Adloff *et al.*, Eur.Phys.J.**C17** (2000), 567.