HERA Beyond Year 2000

Jörg Gayler
DESY

HERA will run from year 2000 onwards with luminosities increased by a factor of about 5, compared to present data taking. The implied changes for the machine and consequences for the H1 and ZEUS detectors as well as examples of the gained physics potential are presented. [1]

1 Introduction

Since the beginning of operation of the ep collider HERA in 1992, the experiments H1 and ZEUS produced interesting physics results in deep inelastic scattering (DIS) and photo-production. Interesting, because HERA allowed to explore a completely new kinematic regime, about 2 orders of magnitude in momentum transfer Q^2 and in $1/x_{Bjorken}$ or in the hadronic final state energy squared W^2 above previous fixed target experiments. This led, unexpected for most, to the observation of a pronounced rise of the proton structure function F_2 versus small $x_{Bjorken}$ already on the basis of data taken in 1992 with only small integrated luminosities of about 25 nb^{-1} [1].

Since then the integrated luminosities delivered by HERA for the experiments steadily increased from about 1 pb^{-1} in 1993 to about 35 pb^{-1} in 1997, leading to physics results which range from tests of the electro-weak theory and QCD in inclusive neutral and charged current (NC and CC) ep interactions [2], QCD analyses of jet and particle production in DIS and photo-production [3], investigations of the relation of perturbative QCD to phenomenological Regge models [4], which describe diffractive scattering and soft photo-production processes to searches for new particles [5].

Most of the previous data have been taken with positrons (e^+) of 27.5 GeV colliding with protons of 820 GeV. Since 1998 HERA runs with increased proton energy of 920 GeV and electrons (e^-) of 27.5 GeV.

The discussions on the "Future Physics at HERA" [6] during a workshop in 1995/96 showed that for future progress a substantial increase of luminosity would be most desirable, both in view of precise tests of electro-weak physics and QCD and also in view of possible new observations not covered by the standard model.

Also discussed in [6] were options for the more distant future: acceleration in HERA of light and heavy nuclei as well as polarized protons. The physics potential of the latter was studied especially in later workshops [7]. These future possibilities are not further discussed in the present talk nor the long term DESY future beyond HERA [8].

Currently considerable effort at HERA and the experiments goes into the preparations for an upgrade in year 2000, aiming for an increase of the luminosity by about a factor of 5 with the prospect to collect a total integrated luminosity of ~ 1 fb^{-1} up to

[1]Invited talk at *Hadron Structure 98*, Stara Lesna, Slovakia, September 1998

around 2005. The implications for the machine and the H1 and ZEUS experiments are discussed in detail in [9].

The outline of the talk is as follows: section 2 reminds of current physics results and questions which call definitely for larger data samples, i.e. increased luminosity. The upgrade plans for the HERA machine and the detectors are covered in sections 3 and 4. Finally in section 5 examples are given for the physics prospects of the upgrade program.

2 Current HERA Physics, Main Questions

The first 6 years of data taking at HERA led to remarkable progress in the understanding of ep interactions in a wide kinematic range from photo-production ($Q^2 \approx 0$) to deep inelastic scattering (DIS) at very large momentum transfers up to $Q^2 \approx 40000$ GeV^2.[2] Below a few points are mentioned which make enlarged data samples particularly desirable.

The plans to upgrade HERA got certainly strong support by the observation of an excess of NC events beyond the standard model (SM) expectations, as reported in early 1997 on the basis of data taken in 1994 to 1996 [10]. The data of 1997 alone did not support the magnitude of this excess, but taking all data together, H1 observes at $Q^2 > 15000$ GeV^2 22 events, where 14.7 ± 2.1 are expected and ZEUS observes at $Q^2 > 35000$ GeV^2 2 events with an expectation of only 0.29 ± 0.02 [11].

Independent of the few unexpected events it is very important to have precise data in the region of high Q^2 and x.[3] This is apparent from fig. 1, which shows the NC high Q^2 results of H1 based on $\sim$ 34pb^{-1} [12]. The decrease in the e^+p cross section at very large Q^2 due to $\gamma^* - Z_0$ interference gets just visible, and the data at large x, especially around $x = 0.45$ are not yet sufficient for a definite SM test.

The electroweak theory can be tested by the determination of the propagator mass M_W, which enters the charged current cross section $\mathrm{d}\sigma/\mathrm{d}Q^2 \sim G_\mu^2(M_W^2/(M_W^2+Q^2))^2$, where G_μ is the μ decay constant (Fermi constant). The present sensitivity can be seen from fig. 2 based on a luminosity of 47 pb^{-1}. The propagator mass is determined to $M_W = 78.6^{+2.5}_{-2.4}(\mathrm{stat})^{+3.3}_{-3.0}(\mathrm{syst})$ GeV [13]. Comparable results exist from H1 [12]. Stringent electroweak tests will be possible going to a luminosity of 1 fb^{-1}, expecting that at the same time the uncertainty in the measurement of the hadronic energy will be reduced from present 3%...4% to 1%...2%.

The H1 collaboration reported recently [14] on the observation of 5 events containing an isolated muon and a hadronic jet with $p_t \gtrsim 30$ GeV with missing $p_t \gtrsim 20$ GeV. The SM expectation for such events, for which the dominant process is W production, is only 0.8 ± 0.2 events. ZEUS observed no such event [15]. The observation of corresponding events with isolated electrons or positrons (1 e^-, 3 e^+ for H1 and ZEUS respectively)

[2] The momentum transfer Q^2 is defined as $-(k_e - k_{e'})^2$, where k_e and $k_{e'}$ are the four-vectors of the incident and scattered lepton respectively.

[3] $x \equiv x_{Bjorken} = Q^2/2pq$, where p is the four-momentum of the incident proton and q of the exchanged gauge boson.

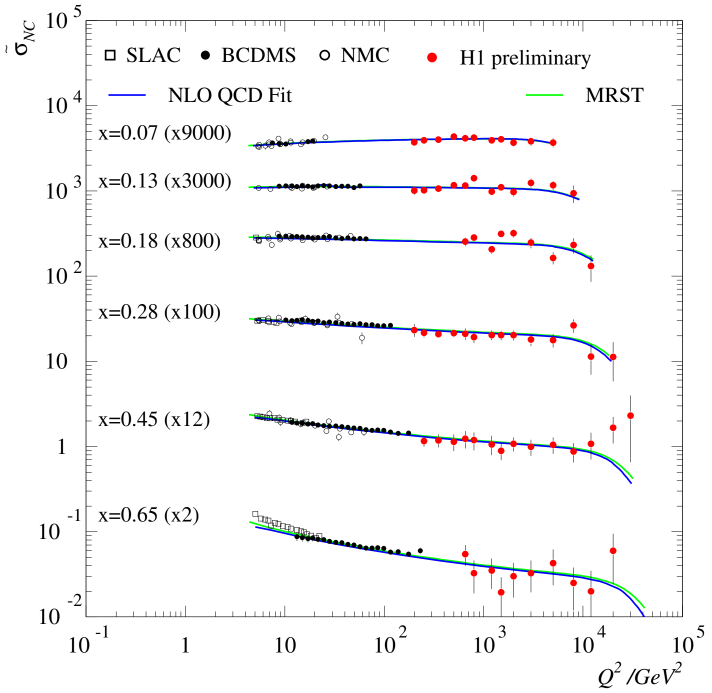

Fig. 1: "Reduced" e^+p cross section $xQ^4/2\pi\alpha^2(1+(1-y)^2) \times \mathrm{d}^2\sigma_{NC}/\mathrm{d}x\mathrm{d}Q^2$ vs Q^2 for various x.

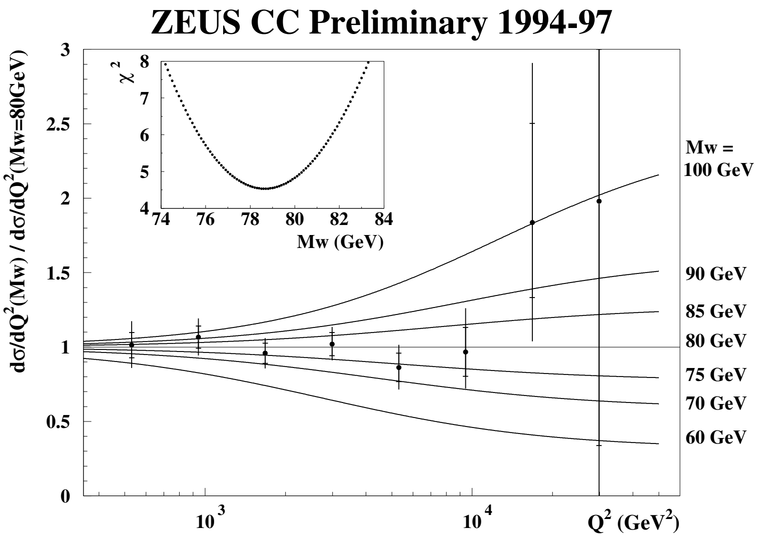

Fig. 2: Ratio of measured CC cross section to SM prediction. The curves show the expected deviation of the ratio assuming values M_W different from nominal $M_W = 80 GeV$.

is in agreement with expectations. Only much more data will allow to decide whether we just observed a fluctuation.

Finally, the gluon density in the proton can be determined, both from scaling violation in inclusive DIS and more directly from open charm production, as the $c\bar{c}$-pairs are predominantly produced by the boson-gluon fusion process. The present data roughly confirm the consistency of these different approaches, but much larger data samples are needed for an accurate determination of the gluon density as well as for precise tests of the QCD description of charm production.

3 HERA Upgrade and Impact on Detectors

It is planned to increase the HERA luminosity from the design value of 1.5×10^{31} cm^{-2} s^{-1} to about 7×10^{31} cm^{-2} s^{-1} [9]. It is expected to achieve an integrated luminosity of 1 fb^{-1} for the experiments H1 and ZEUS in the period 2000 to 2005 with the choice of electrons or positrons [4].

The main present and future parameters of HERA are given in table 1.

HERA Parameters	1997	Design	Upgrade
p beam energy (GeV)	820	820	$820^{\star}$
e beam energy (GeV)	27.5	30	$30^{\dagger}$
Number of bunches (proton/electron)	180/189	210	180/180
Number of protons/bunch	7.7×10^{10}	10×10^{10}	10×10^{10}
Number of electrons/bunch	2.9×10^{10}	3.6×10^{10}	4.2×10^{10}
Proton current (mA)	105	160	140
Electron current (mA)	43	58	58
Hor. proton emittance (nm rad)	5.5	5.7	5.7
Hor. electron emittance (nm rad)	40	39	22
Proton beta function x/y (m)	7/0.5	10/1	2.45/0.18
Electron beta function x/y (m)	1/0.7	2/0.7	0.63/0.26
beam size $\sigma_x \times \sigma_y$ (μm)	200×54	247×78	118×32
Synchrotron Rad. at IP (kW)	6.9	9.7	25
Specific luminosity (cm^{-2} s^{-1} mA^{-2})	7.6×10^{29}	3.4×10^{29}	1.56×10^{30}
Luminosity (cm^{-2} s^{-1})	1.4×10^{31}	1.5×10^{31}	7.00×10^{31}

Table 1 HERA upgrade parameters compared to those achieved in 1997 and to the original design.
$\star$ present proton energy 920 GeV.
$\dagger$ 30 GeV maximum energy assumed for calculation of synchrotron radiation.

The increase of luminosity will be reached mainly by stronger focusing of the proton and the electron beam at the interaction points. The much smaller β functions for

[4] at present HERA runs with e^- of 27.5 GeV and protons of 920 GeV.

both beams are achieved by focusing magnets closer to the interaction point. As a consequence the electron beam, which must not see the strong proton magnet fields, has then to be separated more early from the proton beam, in fact already in the detector regions. A schematic view of the new interaction region is given in fig. 3.

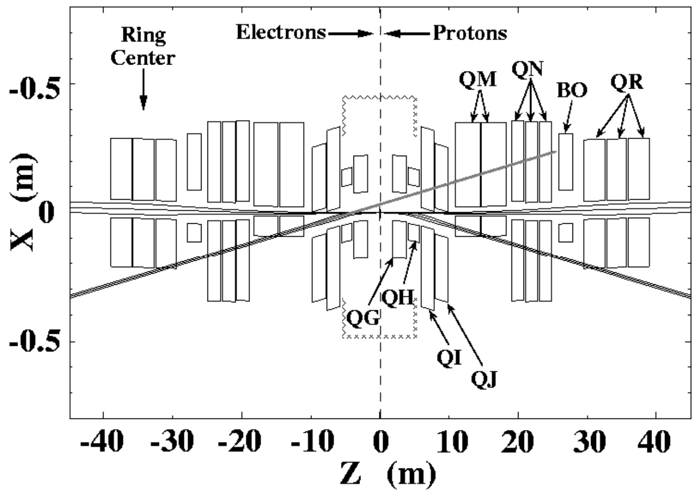

Fig. 3: Top view of the new HERA interaction region. Superconducting combined function magnets provide horizontal bending and vertical focusing of the electron beam inside the indicated detector region. The beams are separated at Z=11m, where vertical focusing of the protons begins. The synchrotron radiation produced by the magnets inside the detector is passed to absorbers at $Z = 11$m, 19m and 25m [9].

Superconducting combined function magnets are positioned inside the detectors on both sides of the ep interaction point. They separate the beams by a bend of the e-beam of 2×8 mrad in the horizontal plane, and also contribute to the vertical focusing of the electrons. Fig. 4 shows as an example the forward magnet in case of the H1 detector. The magnet of about 3 m length is positioned around the beam inside the cryostat of the liquid argon calorimeter.

The bending of the e-beams inside the detectors leads to strong synchrotron radiation of about 25 kW. No shielding against the primary radiation is foreseen as the beam pipe will be designed to transport the full fan of the radiation outside the detector region to absorbers positioned 11, 19 and 25m downstream.

Another new background source will be off momentum particles in the electron beam which the magnets may bend into the detectors. Special efforts will be needed to reduce the e-beam gas interactions up stream of the detectors by improved vacuum and geometric layout of the beams.

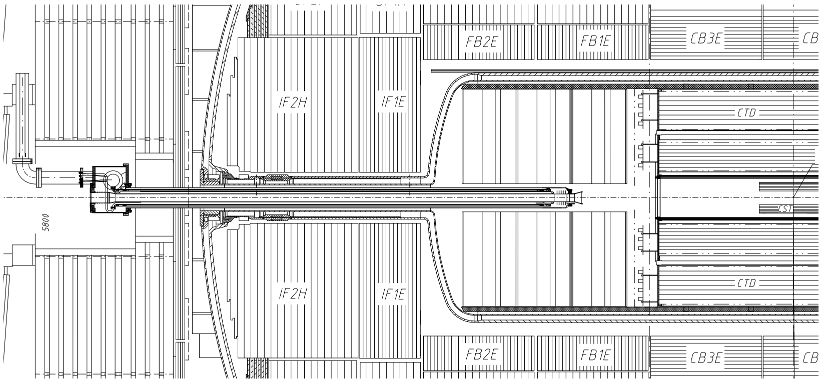

Fig. 4: The forward magnet inside the H1 detector (electron beam from the left). The magnet will be supported within H1 by the cryostat of the liquid argon calorimeter with a structure placed between the trackers.

4 Upgrade of Experiments

H1 and ZEUS plan to improve their detectors for the high luminosity running. Only some points can be mentioned here.

Polarization

After 2000 both experiments will obtain spin rotators as already existing for the HERMES experiment. Longitudinal polarization $P \approx 60\%$ is expected. As the polarization and the number of electrons may vary from bunch to bunch, it will be necessary to measure the degree of polarization for individual bunches. An accuracy below 2% is required by the experiments. These conditions call for a new device [16] which goes beyond the present HERMES polarimeters. Since the transverse polarization is the same everywhere around the ring and equal to the longitudinal polarization at the interaction points, it is sufficient to provide a common system for all 3 experiments, which will measure the transverse polarization with improved precision. The principle is, as for the present HERMES device, to measure in a calorimeter the up down assymetry of light (Ar laser, 514 nm), which is back scattered off the transversely polarized electrons. Also the longitudinal polarization will be measured as independent check.

Luminosity Measurement

The luminosity measuring devices of H1 and ZEUS count γ's from the $ep \to ep\gamma$ Bethe-Heitler process. The requirement to measure the luminosity for individual bunches due to possibly different polarizations together with expected increased event rates and high radiation doses (~ 3.8 kW synchrotron radiation) led to a new proposal for the H1 luminosity system [17]. It foresees as γ detector a longitudinally segmented Cerenkov quartz fibre spaghetti calorimeter (presampler of $\approx 4X_0$ W, main calorimeter $\approx 25X_0$

Pb and $\lesssim 2X_0$ passive low Z material in front to absorb synchrotron radiation).

Tracker upgrade plans

ZEUS plans to add a micro vertex detector (H1 has one in operation).

Both experiments improve their forward (in proton beam direction) track detectors. Whereas H1 adds more conventionally 3 planes of drift chambers with 6 sense wires each, ZEUS proposes a straw tube chamber of 8 planes with each 3 layers of straw (outer diameter 8 mm). In both cases hodoscope ambiguities will be strongly decreased leading to track efficiencies above 90%. This will be particularly interesting for electron detection at high Q^2 at $\Theta_e \gtrsim 5°$ and for heavy quark detection at large x.

H1 plans to optimize the backward silicon strip detector (BST) with respect to the modified geometrical acceptance of the backward electromagnetic calorimeter (SPACAL).

Triggering

The challenge will be to cope with increased backgrounds and to reject the bulk of events of meanwhile uninteresting soft physics, but to retain on the other hand, specially interesting events as e.g. charm production in addition to the rare but easy to trigger high p_t scattering events.

H1 will improve the determination of the vertex position on the first trigger level by new planes for the inner cylindrical proportional chamber (CIP). Triggering by the liquid argon calorimeter will be improved by full exploitation of its granularity.

A demanding project is a fast track trigger system studied by H1, in which following the QT analysis, track elements with transverse momenta etc. are available after 25 μsec and after 800 μsec calculations like that of $\Delta(m_{D^*} - m_D)$ for charm tagging could be performed with rejection rates of typically a factor of 100.

5 Prospects of Physics

It is expected that the experiments collect up to around year 2005 total integrated luminosities of ~ 1 fb^{-1} divided on e^+ and e^- with different polarizations ($P \approx 60\%$). This allows for a very rich experimental program which can be sketched here only by a few examples.

Proton structure at low and medium Q^2

QCD fits to inclusive ep data will allow to determine the strong coupling constant $\alpha_s(M_Z^2)$ to $\Delta\alpha_s \lesssim 0.003$ and the gluon density $g(x)$ in the proton with $\Delta g(x)/g(x) \approx 3\%$ depending on the achieved systematic errors and the available data sets at different energies. The impressive precision on $xg(x)$, demonstrated in fig. 5, assumes errors on the luminosity of 1%, on the electron energy of 0.5% to 1% and 2% on the hadron energy [6]. However, such precision calls also for a reduction of present theoretical uncertainties.

A direct QCD test is possible by measurements of the longitudinal structure function F_L with dedicated runs of lower proton beam energy of ≈ 30 pb^{-1} in total [6]. At

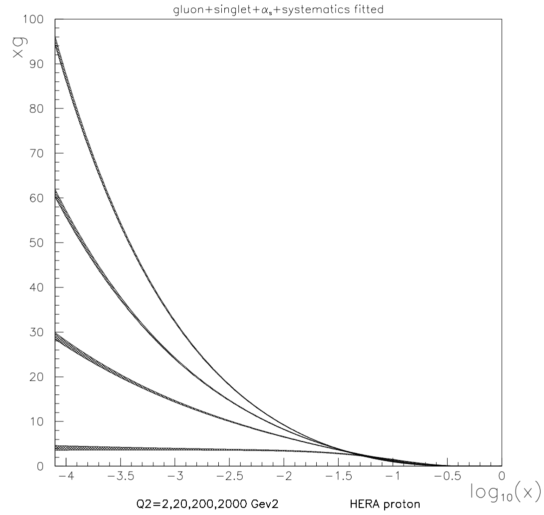

Fig. 5: Gluon distribution $xg(x)$ in the proton as expected from future F_2 data for Q^2 = 2, 20, 200, 2000 GeV^2 (bottom to top). The error bands are also shown outside the kinematic range for $x < Q^2/s$.

$Q^2 \lesssim 20$ GeV^2 and x in the range 10^{-4} to 10^{-3} systematic errors of $\sim 8\%$ and comparable statistical errors can be reached.

Heavy quark production

Very detailed measurements of the charm contribution to the total inclusive F_2 and corresponding tests of QCD calculations of charm production will be possible as shown fig. 6. The simulation based on photon-gluon fusion and NLO graphs uses the gluon

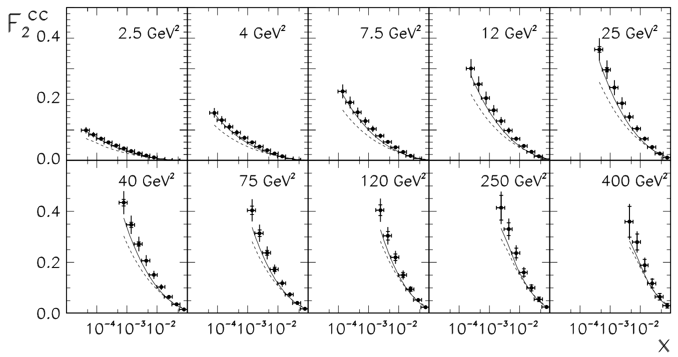

Fig. 6: Expected $F_2^{c\bar{c}}$ for a luminosity of 500 pb^{-1} vs. x for various Q^2.

density in the proton as input as determined from inclusive ep-scattering. In the end, charm production may supply the most reliable probe for the gluon density in the proton.

The large data samples will also allow to decrease present limits on $D^0\bar{D}^0$ mixing and rare decays, such as e. g. $D^0 \to \mu^+\mu^-$ below 10^{-6} [6], a factor of 4 below present limits.

The ratio $F_2^{b\bar{b}}/F_2^{c\bar{c}}$ will be measurable with a precision of 10%...30% [6].

NC at high Q^2

Possible results for inclusive e^+p scattering assuming the SM on the basis of 500 pb^{-1} are shown in fig. 7. The constraints on parton densities at large x will be tight and the

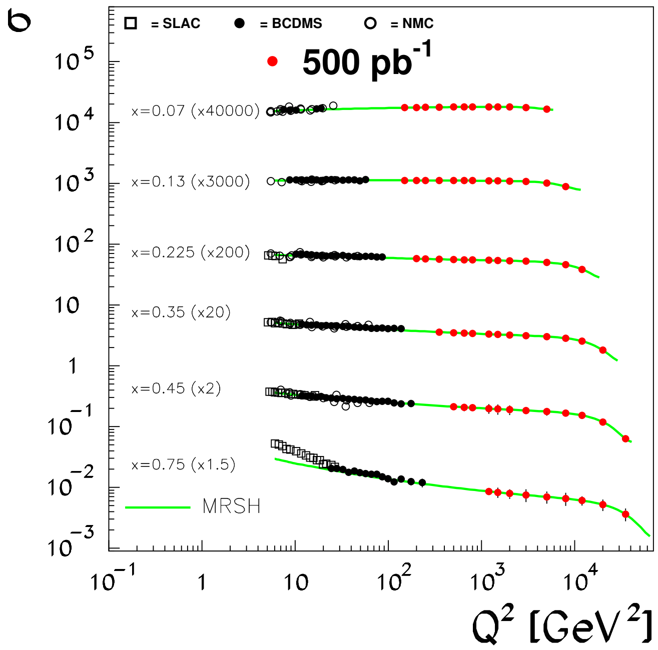

Fig. 7: Simulation of the measurement of the "reduced" e^+p cross section vs Q^2 for various x, assuming an integrated luminosity of 500 pb^{-1} (full points).

room for statistical deviations will be very small compared to the present data (example of H1 in fig. 1). Comparable results for e^-p will allow to measure F_2 and xF_3.

Tests of electroweak theory

The expected data samples of NC and CC interactions from e^+p and e^-p scattering with different polarizations allows for interesting tests [6] of the electroweak theory.

- The ultimate precision that can be reached at HERA testing the electroweak theory is illustrated in fig. 8. Here we take from the SM parameters α, m_Z, m_W, m_t and the Higgs mass (m_H), the first two from experiment, i.e. not G_μ. The contours in the (m_W, m_t) plane show the constraints imposed by e^-p NC and CC (or

CC only) data using negative polarization (P = -0.7). Here the assumption of 1% systematic errors on the measurements is made. The constraints are very similar to that given by G_μ, but at HERA we measure not μ decay but at momentum transfers of order 10000 GeV^2. If also the top mass is taken from experiment, this electroweak test can be expressed as constraint $\Delta m_W \approx 55$ MeV for a fixed Higgs mass (m_H) of 100 GeV. To concentrate on e^-p with negative helicity is however unrealistic, but 250 pb^{-1} with e^- with P = -0.7 still yield $\Delta m_W \approx 80$ MeV.

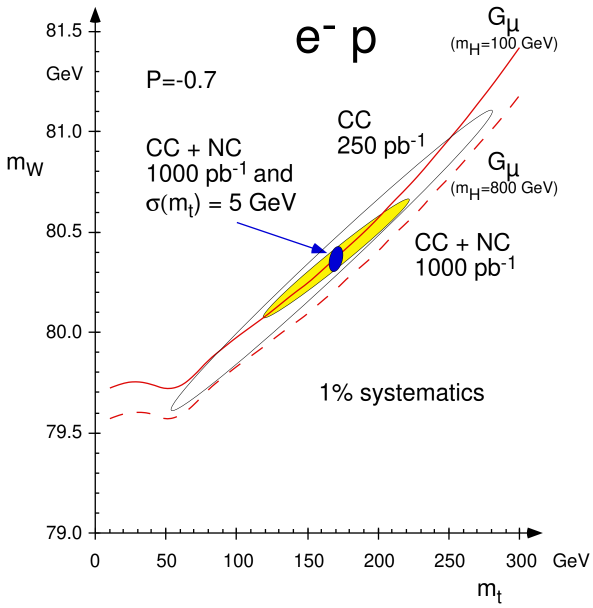

Fig. 8: 1σ confidence contours in the (m_W, m_t) plane from polarized e^- scattering (see text).

- Data on W-production are sensitive to the γWW triple gauge boson vertex and will yield limits on anomalous couplings which are comparable to those of LEP [18], but in the space-like region of momentum transfers, and to projected limits of the Tevatron (see [15] for present limits by ZEUS). The situation at HERA is particularily clean as the sensitivity to the WWZ vertex is very small.
- The vector and axial NC-couplings v_f and a_f, given in the SM by $a_f = I_3^f$ and $v_f = I_3^f - 2e_f sin^2\Theta_W$, with weak isospin I and Weinberg angle Θ_W, can be measured for the light u and d flavours with precisions better 20%.

Not discussed future physics

It was not possible to cover here the exciting possibilities of observations beyond the SM. Especially the scattering of left handed e^+ and right handed e^- may lead to unexpected effects. For right handed couplings, Leptoquarks, SUSY particles, in particular R parity violation, excited fermions, contact interactions, I refer to [5] and the discussions in [6].

Future possibilities in diffractive scattering were discussed in [6] and recently in [19].

6 Conclusions

The HERA upgrade plans for year 2000 and beyond are a challenging program for both, machine and detectors which leads to polarized e^+ and e^- beams and compared to present running 5 times increased luminosity. It allows precision measurements in the frame of QCD and electroweak theory. It opens a window to yet unknown physics.

Acknowledgments
I am grateful to Dusan Bruncko for the invitation to this interesting workshop, to U. Schneekloth for helpful information during the preparation of this talk and to J. Dainton, M. Erdmann, M. Fleischer, S. Schlenstedt and N. Tobien for useful comments to the manuscript.

References

[1] H1 Collab., I. Abt et al.: *Nucl. Phys. B* **407** (1993) 515;
ZEUS Collab., M. Derrick et al: *Phys. Lett. B* **316** (1993) 412;

[2] S. Riess, these proceedings.

[3] Talks of T. Haas, W. Hoprich, M. Wing, S. Wölfle, these proceedings.

[4] P. Newman, these proceedings.

[5] N. Brummer, these proceeedings.

[6] Proceedings of the Workshop *Future Physics at HERA*, edited by G. Ingelman, A. De Roeck and R. Klanner, 1996.

[7] Proceedings of the Workshop *Physics with Polarized Protons at HERA*, edited by A. De Roeck and T. Gehrmann, 1997.

[8] M. Leenen, these proceedings.

[9] U. Schneekloth, editor, *The HERA Luminosity Upgrade*, DESY HERA 98-05, 1998.

[10] H1 Collab., C. Adloff et al.: *Z. Phys. C* **74** (1997) 191;
ZEUS Collab., J. Breitweg et al.: *Z. Phys. C* **74** (1997) 207;

[11] T. Doyle, Proc. 29th Int. Conf. on High-Energy Physics, Vancouver, 1998.

[12] H1 Collab., paper 533, 29th Int. Conf. on High-Energy Physics, Vancouver, 1998.

[13] ZEUS Collab., paper 751, 29th Int. Conf. on High-Energy Physics, Vancouver, 1998.

[14] H1 Collab. C. Adloff et al.: *DESY* **98-063** (1998) ;

[15] ZEUS Collab., paper 756, 29th Int. Conf. on High-Energy Physics, Vancouver, 1998.

[16] V. Andreev et al., Proposal *Polarization 2000*, H1-Note 06/98-545, ZEUS-Note 98-043, DESY-PRC 98-07, June 1998.

[17] V. Andreev et al., *Proposal for an Upgrade of the H1 Luminosity System and its Associated Electronics for HERA 2000*, DESY PRC-98/05, June 1998.

[18] S. Jézéquel, these proceedings.

[19] H. Jung, DESY preprint 98-130 (1998), Proceedings *LISHEP98*, Rio de Janeiro, 1998.