# HERA Status and Plans

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*Abstract*
In 1994, the HERA electron-proton collider delivered an integrated luminosity of 6.1 $pb^{-1}$ to the ZEUS and H1 experiments each, about a factor of six more than in the previous year. The peak luminosity reached $4.7\times10^{30}$ $cm^{-2}$ $s^{-1}$ corresponding to 31% of the design value. This paper reviews the present performance limitations of HERA concerning luminosity operation and the plans for future improvements. After successful commissioning of the spin rotator in 1994 (65% longitudinal polarisation was achieved) the HERMES experiment has been installed during the winter shutdown and will start taking data this year. Further plans concern machine modifications for the installation of the HERA-B internal target experiment in the proton ring (study of CP violation).

## I. INTRODUCTION

The Hadron Electron Ring Accelerator HERA operates at DESY for High Energy Physics experimentation since 1992. It consists of a 30 GeV electron ring and a superconducting 820 GeV proton ring, placed in a common tunnel of 6336 m length. The ring geometry has a fourfold symmetry, with experimental halls in the center of each of the four 360 m long straight sections (see fig.1). The two beams are brought into collision in the north and south straight sections, where the H1 and ZEUS experiments, respectively, for the study of e/p collisions are installed. In the east section the HERMES experiment has been installed during the 1994/95 winter shutdown. This new experiment will investigate the nucleon spin structure by studying the interaction of the longitudinally polarized electron beam with an internal polarized gas target. The modifications of the magnet lattice necessary to accomodate HERMES (separation of e- and p-beamlines, installation of a spin rotator pair) were already done during the 1993/94 winter shutdown. The straight section west of HERA has so far been reserved for machine utilities (e.g. p-injection and beam abort systems, collimators, rf-cavities). In the future, this section will house a fourth experiment, HERA-B, which has recently been approved. HERA-B will use protons in the halo of the beam interacting with an internal wire target and study CP violation in the b-quark system.

The construction of HERA started in April 1984 and was finished by the end of 1990. Over 40 institutes from 12 countries participated in the international HERA collaboration, contributing machine components as well as manpower during the design and construction phase of the machine. Commissioning of the e/p collider took place in 1991 and first beam collisions were observed on Oct. 14, 1991. Data taking for the H1 and ZEUS experiments began in June 1992.

In the following, the status of HERA concerning e/p luminosity operation is reviewed, the performance limitations for both rings are discussed and an outlook to future operation is given.

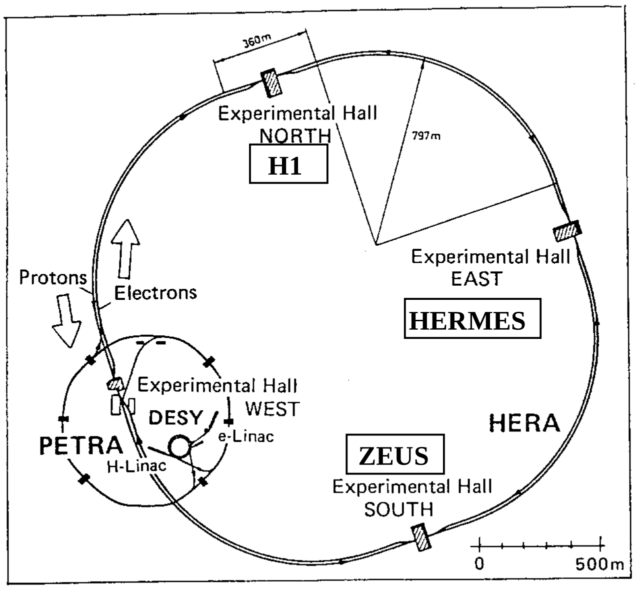


Fig. 1: General layout of HERA

## II. LUMINOSITY OPERATION

The improvement in the machine performance over the past three years of luminosity operation is demonstrated by the increase in the yearly integrated luminosity delivered to ZEUS and H1 (see fig.2). In the first phase of the 1994 run the machine performance was significantly limited by lifetime problems of the electron beam at high intensities (see section 3). This limitation was overcome by switching to positron operation in mid-July 1994, resulting in an increase of integrated luminosity per day by about a factor of two. The main machine parameters for the 1994 run are shown in table 1. HERA was operated with 156 colliding bunches, in addition 12 non-colliding electron and 14 proton bunches were stored to measure the background. The average luminosity at the beginning of a fill reached $2.5\times10^{30}$cm$^{-2}$ s$^{-1}$, 17% of the design value. The main limitations for the luminosity were the proton and electron bunch intensities (typically 30% and 60% of

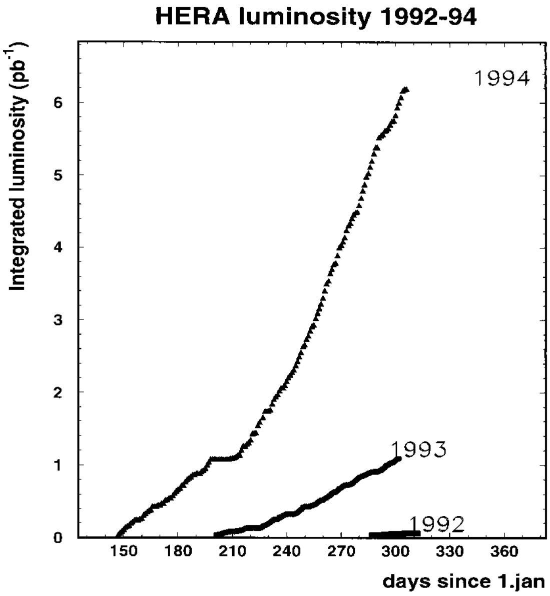


Fig. 2: Yearly integrated luminosity delivered to each of the two colliding beam experiments.

the design value, respectively). The specific luminosity, defined as the luminosity divided by the product of beam intensities, was higher than the design value, a result of the small proton beam emittance and a mini-β optics with $\beta^*_{x,y}$ 30% below the design values. The luminosity lifetime of about 5h was mainly determined by the positron beam lifetime ($\tau_{e+}$ = 6...10h, the specific problems with electron operation are discussed in the following section) and the proton emittance growth rate due to the beam-beam interaction (0.5...1 mm×mrad/h for the normalised 2σ-emittances). The proton beam lifetime in collision was typically of the order of 100h, together with an efficient beam collimation system an important prerequisite for low background at the experiments. The operation efficiency, defined as the luminosity time devided by the total time scheduled for e/p operation, was 32%, averaged over the entire 1994 run. This has to be compared to a maximum possible efficiency (limited by the unavoidable magnet cycle, beam filling and energy ramping times) of about 70%. The best monthly figure for the efficiency was about 50% in October 1994.

| | **94 average** | **design** | |
|---|---|---|---|
| # bunches | 156 (+12/14) | 210 | |
| $E_e$ | 27.5 | 30 | GeV |
| $E_p$ | 820 | 820 | GeV |
| $N_e$/bunch | 2.0 | 3.6 | $10^{10}$ |
| $I_e$ | 27 | 58 | mA |
| $N_p$/bunch | 3.0 | 10 | $10^{10}$ |
| $I_p$ | 40 | 160 | mA |
| $\gamma\varepsilon_{x,y}$ (p) | 12, 16 | 25, 25 | mm×mrad |
| $\sigma^*_{x,y}$ (e) | .29, .045 | .27, .036 | mm |
| $\sigma^*_{x,y}$ (p) | .20, .055 | .27, .08 | mm |
| $L_{spec}$ | 4.4 | 3.4 | $10^{29}$cm$^{-2}$ s$^{-1}$ mA$^{-2}$ |
| L | 2.5 | 15 | $10^{30}$cm$^{-2}$ s$^{-1}$ |
| $\eta_{lumi}$ | 32 | ≈ 70 | % |
| $\int Ldt$ | 6.1 | ≈ 75 | pb$^{-1}$ |

Table 1: Main machine parameters during 1994 luminosity operation and design goals

The experience concerning machine reproducibility and orbit stability, in particular with keeping the beams in collision, has been very good. Only occasionally (a few times per day) local orbit corrections at the interaction points were applied. This demonstrates the low level of ground motion effects [1], a result not only important for HERA operation but also in view of possible future projects.

## III. ELECTRON RING

### *A. Beam Lifetime Problem*

The breakdown of the electron beam lifetime effectively limited the beam intensity during the 1993 run to about 15 mA. At higher beam current the lifetime dropped to typically 1...2 h shortly after ramping the energy from $E_{inj}$=12 GeV to $E_{lumi}$=27 GeV and remained low even with decreasing beam current. Studies showed that the breakdown of beam lifetime can be triggered by switching the Ti sputter pumps integrated in the dipole magnet vacuum chambers. The problem could be reduced by lowering the operating voltage of the pumps. This modification allowed to increase the electron beam intensity to 20...25 mA for the 1994 run, the lifetime typically being 2...3 h, inconsistent with the vacuum pressure of $<10^{-8}$ mbar. After switching to positron operation, the lifetime breakdown effects completely disappeared (see fig. 3).

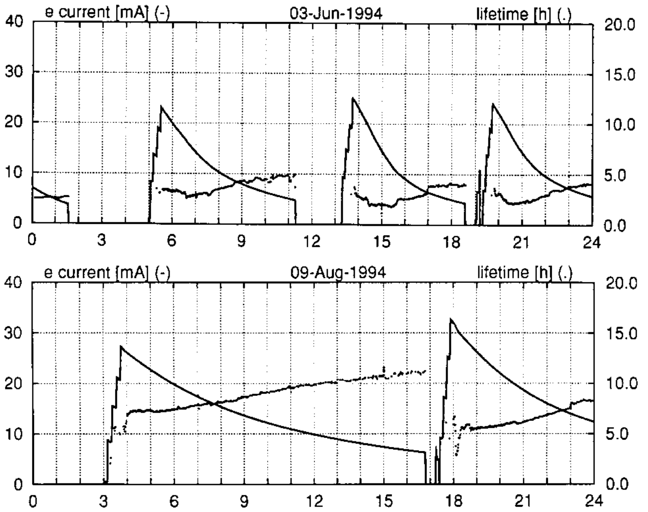


Fig. 3: Behavior of beam current (full line) and lifetime (dotted line, right hand scale) for typical electron fills (upper figure) and after switching to positron operation (lower figure).

The observed effects are most likely caused by the trapping of small (< 1 µm) "dust" particles which are ionized and trapped in the beam. The role of the ion getter pumps is not fully revealed yet, one hypothesis is that the macroparticles are ejected from the pump channels by the electric field of the pump. For a more detailed discussion of this problem, see [2].

## *B. Intensity Limitations (positrons)*

Whereas the single bunch charge in HERA-e is far away from coherent instability limits, the large total intensity stored in up to 210 bunches gives rise to strong multibunch instabilities in both the transverse and the longitudinal planes, driven by the parasitic modes of the accelerating cavities. The instabilities are cured by broadband feedback systems [3], which have been routinely in operation since 1993. During the 1994 e+/p run, the beam intensity was kept below 35 mA, favoring operational stability instead of pushing the rf-system closer to its limit. During machine studies in November 1994 a maximum current of 54 mA was stored. This could, however, only be achieved by deactivating the superconducting rf-system (16 4-cell cavities powered by a 1.5 MW klystron), which during routine operation contributes about 30% (40 MV) of the circumferential voltage. The problem was later traced down to an instability of the cavity phase regulation loop [4] and it is expected that this intensity limitation is no longer present for the 1995 run.

## *C. Spin Polarisation*

In April 1994 the new electron ring beam optics with the modified straight section east was commissioned and a high degree of transverse polarisation (65%) was achieved by applying well established orbit correction and optimisation techniques [5]. The newly installed spin rotator pair was switched on for the first time on May 4, and a longitudinal polarisation of more than 50% was obtained without further optimisation. In subsequent runs up to 65% of longitudinal polarisation was obtained and reproduced later in November during machine studies (fig. 4), see [6] for more details.

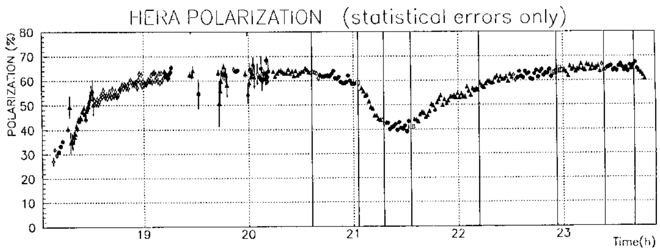


Fig. 4: Positron spin polarisation measured in November 1994 with the spinrotator in the east straight section switched on.

There were no indications that the activation of the rotator causes a degradation of the achievable degree of polarisation.

During part of the 1994 collider run, the influence of the beam-beam interaction on the polarisation was studied. At this time the rotator was switched off (note that the polarisation axis remains vertical at the north and south e/p interaction points in any case, for the present configuration with only one rotator pair installed). Up to the maximum beam-beam tune shift parameter of $\Delta Q_{e,y} = 0.018$ reached in 1994 (at about 40% of the design proton bunch intensity), no significant reduction of spin polarisation was observed. There are indications from tracking simulations with SITROS [7] that depolarising effects may become important at higher beam-beam strength [8], obtained when the proton bunch intensity approaches its design value.

Concerning depolarising effects due to the spin polarisation axis tilt caused by vertical closed orbit deviations, an improvement is expected by applying a beam-based calibration procedure [9] which allows to determine the relative transverse alignment of the beam position monitors w.r.t. the magnetic center of the nearby quadrupoles with an accuracy of about 0.05 mm. Using this method, up to about 80% of polarisation seems possible.

## IV. PROTON RING

### *A. Preaccelerators and Beam Transfer*

The limitation on the bunch intensity in the HERA proton ring was mainly determined by the performance of the preaccelerators. The DESY-III synchrotron routinely accelerated a beam current of 180 mA (12 % above the design value) to 7.5 GeV. The longitudinal instability, which had been observed earlier at high intensity, was successfully cured by a new feedback system [10]. The beam transfer and injection efficiency from DESY-III to PETRA was typically about 70%, another 15% of beam get lost in PETRA during the ramp from 7.5 to 40 GeV. The highest beam current so far accelerated in PETRA was 108 mA in 60 bunches, 85% of the design value [11]. The emittance of the beam stored in PETRA, however, showed a significant correlation with the intensity, see fig. 5, mainly a result of intensity dependent emittance growth in DESY-III.

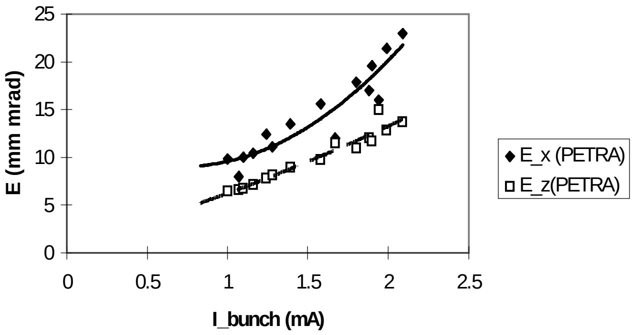


Fig.5: Transverse proton beam emittances in PETRA at 7.5 GeV (injection energy) vs. bunch current [11]. The design bunch current is 2.1 mA.

On average, the bunch intensity transferred from PETRA to HERA was around 40% of the design value. Further losses during transfer, injection and energy ramping in HERA led to an average bunch charge of $3\times10^{10}$ (30% of design) for luminosity operation. The highest beam current stored in the proton ring was 60 mA in 170 bunches ($N_p=4.5\times10^{10}$ per bunch). An improvement of the capture efficiency of the bunches in the HERA 52 MHz rf-buckets was obtained by applying a bunch rotation in longitudinal phase space by suitable manipulation of the PETRA rf-phase and amplitude before transferring the beam.

### *B. Beam Dynamics*

After careful orbit and chromaticity correction, the measured dynamic acceptance in HERA-p at injection energy was 2.4 mm×mrad, in good agreement with tracking simulations [12]. The beam lifetime was above 10h for the well-optimised machine. The variation of the "persistent current" sextupole component in the s.c. dipoles during injection and the early phase of the energy ramp was kept under control by improved automatic procedures, thus minimizing beam losses due to reduced lifetime.

Longitudinal Bunch compression in HERA was done during the energy ramp by raising the voltage in the 2nd (208 MHz) rf-system. During luminosity operation the bunch length was typically $\sigma_s$ = 20 cm. The 208 Mhz rf-system was operated with low amplitude at injection energy in order to provide stronger Landau damping, which turned out to be necessary for longitudinal beam stability.

In the transverse plane, a single bunch coherent instability was observed during the energy ramp, typically at about 80 GeV. The measured risetime was above 100 ms, to be compared with a measured decoherence time for betatron oscillations of 30 ms. At present the most likely explanation a loss of Landau damping due to an approximate cancellation of non-linear detuning from the sextupoles with amplitude dependent space charge tune shift (note that the latter does not contribute to the measured decoherence) [13]. The pragmatic approach to cure the effect was to turn up the sextupole circuits during the ramp. During machine studies, a broad-band feedback system was successfully tested, which will be used to damp coherent transverse excitations.

Further investigations of beam dynamics concerned the beam lifetime and emittance growth during e/p operation. The frequency spectrum of the beam loss rate at one of the collimators was used as an effective diagnostic tool [14]. Certain frequency components of this loss-spectrum caused by power supply ripple could be minimised by artificially adding tune modulation and adjusting the phase and amplitude properly [15]. Whether this compensation scheme can effectively reduce the observed beam emittance growth with colliding beams, remains to be shown.

## V. OUTLOOK

### *A. Improvement of Luminosity Operation*

The most important goal for the near future is to approach the designe/p luminosity in HERA. For the

1995 run the following main improvements are foreseen:

- 170 instead of 156 colliding bunches
- reduction of horizontal $e^+$ beam size at the IP by ≈20...30% (match p-beamsize)
- higher p-bunch intensity (> 40% on average) with improved transfer efficiencies in the injector system
- achieve design e+ beam intensity with improved rf-system stability

For 1995 an integrated luminosity of 15 $pb^{-1}$ per IP during the run period from May to November is planned. The peak luminosity is expected to reach $10^{31}$ $cm^{-2}s^{-1}$. Further machine studies are scheduled to investigate the electron beam lifetime problem. In addition, for the 1995/96 winter shutdown an exchange of the Ti sputter pumps with passive NEG-pumps in a significant fraction of the e-ring circumference is planned.

### *B. Operation with HERMES*

First tests with a gas storage cell in 1994 showed that running the HERMES experiment in parallel with e/p operation does not cause an intolerable beam lifetime reduction, in agreement with expectations. Also from 1994 experience, a high degree of spin polarisation seems possible with colliding beams so that data taking of HERMES in 1995 should be compatible with e/p operation. However, with increasing proton intensity in the future, additional spin matching concepts to avoid depolarisation by the beam-beam effect may have to be applied. At higher $e^+$ intensity, a good match between the e- and the p-beam height at the IP becomes more important and requires to maintain a sufficiently large positron beam vertical emittance. This has been provided in the past by using additional dispersive orbit bumps, a concept which may have to be improved in order to minimise depolarising effects.

### *C. HERA-B*

The internal fixed target experiment "HERA-B" for the study of CP-violation has recently been approved as the 4th HERA experiment. During test runs in 1994 it was demonstrated that with a wire target moved into the halo of the proton beam the required interaction rate of $3\times10^7 s^{-1}$ could be achieved [16]. The influence on the background rates at H1 and ZEUS was tolerable so that operation of the target does not interfere with data taking at the colliding beam experiments. Installation of HERA-B will require to rebuild the straight section west of HERA. The necessary machine modifications have been investigated in detail [17] and are scheduled to be implemented during the 1995/96 winter shutdown. Commissioning of the new beam optics and first tests for HERA-B will take place in 1996. The experiment is scheduled to start taking data in 1998.

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