

HERA AND DESY ACTIVITIES

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Abstract HERA is a storage ring complex for electron-proton collisions at high center of mass energies. It consists of two independent accelerators designed to store 820 GeV protons and 30 GeV electrons, respectively. The status of the accelerator rings, the injection systems and the infrastructure is summarized. A progress report on the two approved HERA experiments, H1 and ZEUS, is given. Activities at DORIS for high energy physics and synchrotron radiation research are described.

INTRODUCTION

The "Hadron-Electron-Ring-Anlage" HERA at DESY is the first electron-proton-collider ever to be built. Approval to the project was given on April 6, 1984 and construction started on May 15, 1984 with the participation of eleven foreign countries: Canada, China, Czechoslovakia, France, GDR, Israel, Italy, Netherlands, Poland, United Kingdom, and the USA.

The design luminosity for head-on collisions of 30 GeV electrons and 820 GeV protons is $1.6 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$. The main parameters of the HERA rings are listed in Table I.

TABLE I Main parameters of the HERA e-p collider.

	<u>e-ring</u>	<u>p-ring</u>
Energy	30	820 GeV
Circumference		6336 m
Straight sections (4)		360 m
Number of IP's (0°)		4 (3)
Injection Energy	14	40 GeV
No. of bunches		210
Average beam current	58	160 mA
Beam size at IP (σ_h/σ_v)		0.29/0.07 mm
Bunch length (σ_1)	8	110 mm
Luminosity/IP		$1.6 \cdot 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$

A schematic layout of the whole complex is shown in Figure 1. The HERA tunnel with a circumference of 6.3 km exceeds the boundaries of the DESY laboratory by far, but crosses the DESY site, so that the existing accelerators can be used for injection. At the beginning, two large experiments, H1 and ZEUS, will be installed in the straight sections North and South, respectively. Section East will accommodate the first spin rotator for machine physics studies on electron polarization while straight section West at present is reserved for machine utilities.

SITE AND BUILDINGS

The original DESY site which was just big enough for the DESY Synchrotron, DORIS and the 2.3 km PETRA-ring, is much too small for the 6.3 km circumference of HERA. Thus only the experimental hall West (one out of four), the central cryogenic plant, the test facility for the superconducting magnets and some other central facilities like the ac-power station and cooling towers are located on the DESY site. All the rest of the HERA tunnel is under private residential or industrial areas and public parks, and it was necessary for DESY to obtain the permission of all owners for the construction of the 5.2 m diameter tunnel (Figure 2) roughly 15 to 20 meters below their property.

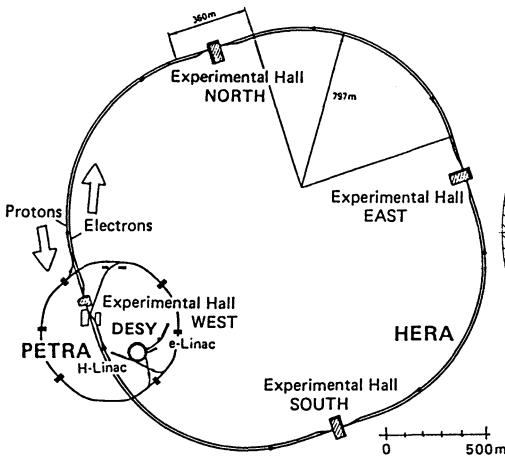


FIGURE 1 Schematic layout of HERA.

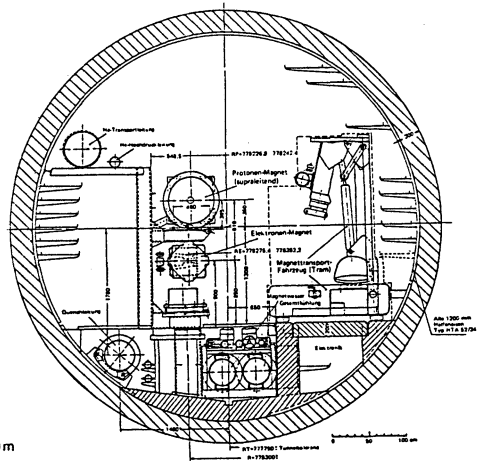


FIGURE 2 Cross section of the HERA tunnel.

The tunnel is embedded in sand with about two thirds of its circumference below the ground water table. The experimental halls have 7 floors below ground, with the 40x25 m² detector areas on the lowest level. The two tunnels connecting HERA to PETRA for p^+/e^+ and e^- -injection are below the west and northwest parts of the DESY site.

While tunnel construction was finished in March 1988, all civil engineering work was complete by the end of 1988 in accordance with the original time schedules and with less than 1% deviation from the original budget. Also all basic supplies like high voltage, ac and dc, low voltage ac, and cooling water became available towards the end of 1988.

THE HERA INJECTORS

With the exception of DORIS which continues to serve as a 5.3 GeV e^+/e^- colliding beam facility for high energy physics as well as a synchrotron radiation light source, all other accelerators already existing or under construction on the DESY site are part of the HERA e^-/e^+ and p^+ injection schemes (Figure 3). In all, 10 machines will have to be operated from the DESY Central Control Room.

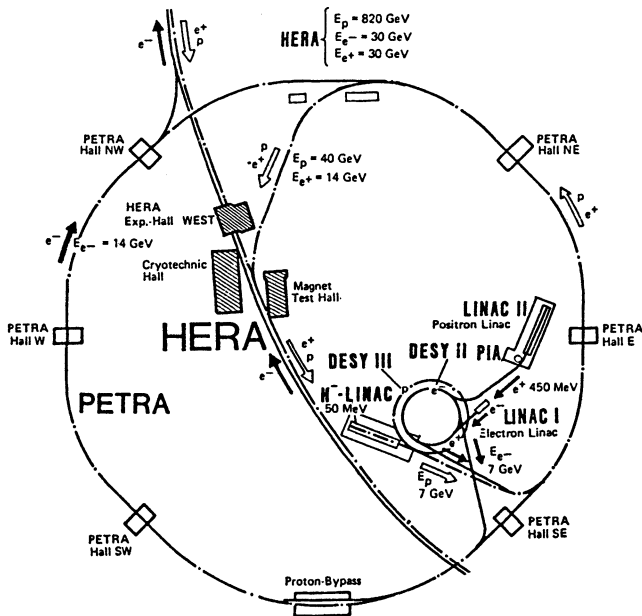


FIGURE 3 HERA injection scheme.

- **LINAC I** in its 200 MeV version (in 1985 upgraded from 55 MeV) will go on to serve as a dedicated e^- -source.
- **LINAC II/PIA** even though they could in principal be used as an e^- -source as well, are normally only used as positron injectors for the DESY II e^-/e^+ synchrotron. In LINAC II, electrons are accelerated to 350 MeV for the generation of positrons in a tungsten converter target (1 % efficiency). In 6 more accelerator units downstream from the target, the positrons are brought up to 450 MeV. 7 shots from the linac are accumulated and compressed in bunch length in the 450 MeV PIA Accumulator Ring prior to injection in DESY II. PIA with its two rf-systems (10.4 and 125 MHz) was also used to test the HERA p^+ -Main Ring beam position monitors at 1 to 2 m bunch length.
- Since 1987, **DESY II** replaces the then 24 year old DESY I- 7.5 GeV e^+/e^- synchrotron. DESY I was a combined function 50 Hz machine, whereas DESY II with its modern separated function lattice has only a 12.5 Hz repetition rate, which is sufficient for its role as a dedicated injector synchrotron but allows the use of a solid stainless steel vacuum chamber inside the ac magnetic field, instead of an expensive ceramic chamber used in DESY I. Most of the rf-system and many high power components for the 12.5 Hz resonant magnet circuits, however, are still the same as for DESY I. The new machine is located on the inner side of the DESY I tunnel at a somewhat smaller radius, while the DESY III p^+ -synchrotron uses the old DESY I concrete ring girder as its foundation. Since in both machines the rotating beams are on the same level, all beam lines to or from DESY II have to cross the DESY III lattice. Most of these beam lines pass through straight sections of DESY III. For some of the charged particle transport systems, however, compensation of magnetic fields from DESY III had to be provided. DESY II also generates 3 photon test beams for detector component testing.
- **LINAC III** is the first link of the p^+ -accelerator chain. H^- -ions from an 18 KeV magnetron type source are accelerated to 750 KeV by means of an rf-quadrupole. 3 Alvarez tanks increase the energy to 50 MeV for injection into DESY III, where, exactly at the injection point, the electrons are stripped from the H^- -ions by passing them through an extremely thin Al_2O_3 foil (30 $\mu\text{g}/\text{cm}^2$!).

- In **DESY III**, the protons are subsequently accelerated to 7.5 GeV and then transferred to PETRA. DESY III already had circulating beam for the first time in December 1988. The commissioning however, is still going on. Meanwhile, 7.5 GeV protons are available for injection/acceleration tests in PETRA. The 48 DESY I-combined function magnets are incorporated in the new DESY III lattice, but additional quadrupoles were needed to push γ -transition from 5.6 to 8.7 GeV, i.e. above the maximum DESY III energy, and to provide space for long straight sections (rf; injection/ejection).

- **PETRA II** is the only accelerator of the HERA complex which, on a time-sharing basis, has to handle both electrons (or positrons) and protons for filling the two Main Rings. Since the maximum energies of DESY II and DESY III are similar, injection into PETRA II in both cases will be achieved at 7 to 7.5 GeV. For injection into the HERA e^- -ring, 14 GeV is sufficient, whereas for the superconducting HERA p^+ -Main Ring 40 GeV are necessary as a minimum because of difficulties at low fields in the superconducting magnets (persistent currents, etc.). 40 GeV, on the other hand, is the maximum one can achieve with the existing normal conducting PETRA dipole magnets.

By the end of 1986, PETRA I was closed down as a 2x23 GeV-colliding beam machine for high energy physics. The four detectors CELLO, JADE, MARK J and TASSO were removed from the straight sections, the magnet lattice of which in turn was changed to FODO instead of "mini-B"-type. 75% of the rf-transmitters and cavities were transferred to the HERA e^- -Main Ring since in PETRA II two twin-transmitters with 1 MW_{cw} each and 2x8 seven-cell cavities are sufficient for e^-/e^+ -acceleration up to 14 GeV. A magnetic bypass in parallel to these 16 cavities was provided to avoid interference of the bunched proton beam with the impedancies of the high Q 500 MHz copper cavities. For p^+ -rf- acceleration, a 52 MHz-system built in Canada was installed in straight section East of PETRA. The old dipole magnet power supply which was good enough for 24 GeV magnet excitation, was replaced by a modern triple-unit for ramping up to 40 GeV. While testing this new power supply in June this year, it was found that the outer epoxy-glass type insulation of the dipole coils had suffered seriously from synchrotron radiation during the

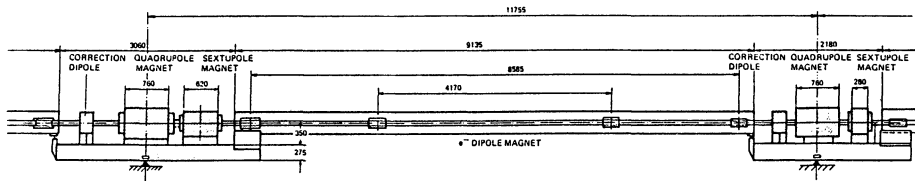
years of high energy physics operation at energies up to 23.3 GeV per beam when the hunt for the top quark was on. 11 magnets needed repairs even for safe 14 GeV operation as scheduled for 1989, and more repairs and/or coil replacements will be necessary early in 1990 before further tests on 40 GeV-ramping for proton acceleration. Also, parts of the vacuum and beam position monitor systems including the cabling needed repairs or replacements because of corrosion and radiation damage.

PETRA II with its new lattice as well as the two new beam transport systems for e^- and p^+/e^+ were successfully tested already in 1988 (the latter with e^+). Subsequently, PETRA II served as e^- -injector for the preliminary commissioning of the HERA- e^- -Main Ring in August 1988. This year, starting again in August the machine will be used for the same purpose. In addition, interesting studies on multibunch instability thresholds will be possible with the combination of a 2x4-cell duplex 500 MHz superconducting accelerating structure in one cryostat installed in PETRA straight section Northeast (5 MeV/m were achieved) and the new magnetic bypass for the 16 normal conducting multicell rf-cavities. Furthermore, new schemes for multibunch operation - transverse feedback using broad-band kickers and digital filters for bunch-selection, - will be tested in PETRA in September this year. Last but not least, first studies for p^+ -beam transfer from DESY III to PETRA II, proton injection in PETRA and acceleration (presently limited to 14 GeV because of the radiation damage of the dipole coils mentioned above), and proton-beam transfer to the first octant of the superconducting HERA p^+ -Main Ring are still due for this year.

THE ELECTRON MAIN RING

From the parameter list, the 6.336 km HERA Electron Ring at first sight looks like a conventional and very conservative design. All magnets are normal conducting, the dipole field at the nominal energy of 30 GeV is only .164 Tesla. There are, however, some very interesting engineering aspects. The FODO-structure of the 4 bends consists of 400 half cells, each of which is made up from one 9 m long dipole, one quadrupole, one sextupole, and a horizontal or vertical

correction magnet. All of these are mounted and prealigned on one girder one end of which rests on the supported end of the next girder. This very elegant construction (Figure 4) minimizes the number of expensive adjustable supports and, in addition, is very helpful for the machine alignment procedure. The 80 mm x 40 mm vacuum chamber is made from three sections of extruded copper: one section for the beam, one section for the distributed electromagnetic pumps and one section for cooling water. These sections with all accessories such as flanges etc. were brazed at 800°C for the full length (up to 12 meters) in only one oven cycle. The combination of 4 mm copper wall thickness and 5 mm lead profiles along the chambers is sufficient to prevent most of the synchrotron radiation from emerging from the vacuum chamber.



HERA: MAGNETMODULES for the ELECTRON RING

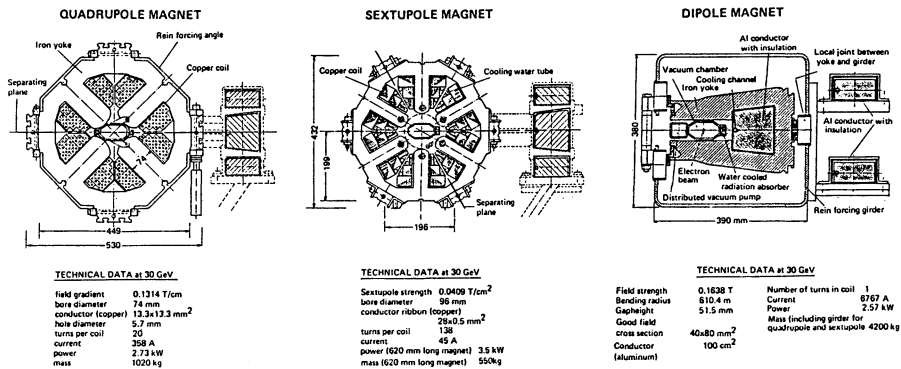


FIGURE 4 Electron magnet module, magnet cross sections and data.

The 500 MHz rf-system will be installed in two steps. For first commissioning at beam energies up to 26 GeV, 82 multicell copper cavities and 6 double transmitters (altogether 12 klystrons à 600 to 800 kW_{CW}) will be used, all of which were transferred from PETRA to the straight sections North, East, and South of HERA. In 1990, a first generation of 8 cryostats with sixteen 4-cell superconducting niobium

cavities (prototype already tested in PETRA with 5 MeV/m) will be installed in straight section West to boost the maximum beam energy beyond 30 GeV in order to reduce the time constant for the build-up of transverse spin polarization from about 50 minutes at 26 GeV to about 25 minutes at 30 GeV (or, in a further step, to 14 minutes at 33 GeV).

In line with the original time schedule, in mid August 1988 the installation of all standard components of the Electron Ring was complete for a preliminary test run, the main purpose of which was to make sure that there were no basic errors in the layout of the machine and/or the design of the components. At this early stage, there was still a number of restrictions:

- only 14 out of the already installed 82 rf cavities were connected to one of the klystron transmitters, and the cooling water for most of the magnet circuits was not yet available. Hence the maximum beam energy was limited to 14 GeV (instead of 26 GeV).
- controls and instrumentation were not complete; e.g. only 24 out of 288 beam position monitors could be read out simultaneously, and no feedback for fighting instabilities was available.
- in the interaction regions stainless steel pipes were used for a temporary vacuum system.

On August 20th after only 4 days for injection, first turn steering and circulating beam, a stored beam at the injection energy of 7 GeV was achieved for the first time. Subsequently, further tests were made at 7 and 10 GeV injection energy and, after energy ramping in HERA, at approximately 14 GeV. Beam life time at 14 GeV was $1\frac{1}{2}$ hours, the maximum single bunch intensity was $0.3 \text{ mA} = 4 \times 10^{10}$ particles. The alignment of the machine, betatron frequencies, chromaticity, β -functions, and linear and dynamic acceptances were found to be consistent with the expected values. The single bunch current was satisfactory. It was not possible, however, to increase the circulating current by injecting more bunches.

This year, a second test period has just started, again in mid August, which will make use of a complete orbit measurement and correction system, tune control, and an rf-system sufficient for ramping up to 26 GeV. Transverse and longitudinal feedback systems, however, and the additional superconducting rf-system for 30 GeV as well as a polarimeter will only become available in 1990.

Consequently, studies on multibunch instabilities and the attempt to approach the design intensity (58 mA in 210 bunches) as well as investigations on whether or not it will be possible to achieve transverse spin polarization in a real machine of the HERA e^- -Ring dimensions, will not proceed until 1990. In the meantime, preliminary tests with new feedback schemes will be made in PETRA.

Also in 1990, the rather complex vacuum systems on both sides, from the interaction points (or detectors) up to the points where the e^- and p^+ - vacuum systems merge, will have to be installed. Moreover, the magnets, vertically adjustable supports, and vacuum components for one pair of spin rotators (to turn the spin orientation from the natural transverse direction to the longitudinal as desired by the high energy physics experiments) are ready for installation in straight section East as soon as first experimental evidence for transverse polarization has been found.

THE PROTON MAIN RING

The conventional components of the proton ring, i.e. the two rf-systems (52 MHz and 208 MHz) for bunch compression and acceleration, the beam diagnostic equipment, the injection elements and the beam abort system are under construction and most of them should be installed by the end of this year.

In the straight sections of HERA, normal conducting magnets are used to guide the proton beam. An accumulated length of 1 km is equipped with 123 dipoles and quadrupoles, all of which have been delivered, measured and installed. The corresponding vacuum system is nearing completion.

The liquid helium for the superconducting magnets, which form the arcs of the HERA proton ring, is provided by a refrigerator plant on the DESY site. The cryogenic system is subdivided into three identical units, each delivering 6.6 kW cooling power at 4.3 K, 20.4 g liquid helium per second and 20 kW cooling power at 40 K. The helium plant has been in routine operation for two years without problems.

The liquid helium and the 40 K helium gas are supplied by a fourfold transfer line to the feed boxes which are installed at the ends of each octant in the ring. The transfer line is installed over the full length of 6.3 km. A cold test of one half ring was

successfully carried out in June 1989 and the second half ring will be tested in October 1989 after the electron test phase.

The arrangement of the superconducting magnets within one of the 104 unit cells is shown in Figure 5. In addition to the main dipoles and quadrupoles correcting dipoles, quadrupoles and sextupoles are needed for orbit correction and variability of the optics. Also, 10-pole and 12-pole coils are necessary to compensate the persistent current effects at the rather low injection energy of 40 GeV.

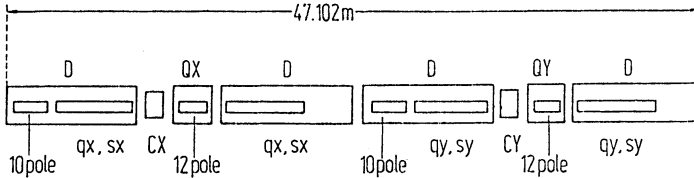


FIGURE 5 Unit cell of the proton ring
 D main dipole
 QX, QY main quadrupoles
 qx, qy quadrupole correction coils
 sx, sy sextupole correction coils
 CX, CY correction dipoles.

The sextupole/quadrupole correction coils, which are directly wound on the beam pipe and the superferric dipole correction magnets have been designed in collaboration by DESY and NIKHEF. All the correction magnets (440 S/Q-coils, 250 dipoles and 40 quadrupoles) have been produced, tested and accepted. The 10-pole and 12-pole compensation coils have also been built and tested.

The main quadrupoles have been developed by CEA Saclay. In total, 224 quadrupole magnets with lengths between 1.861 m and 1.514 m are needed. The nominal gradient at 820 GeV is 91.18 T/m. The series production of the 246 quadrupoles ordered is completely finished, one half being a French contribution to HERA, the other half coming from two German companies. Approximately 190 quadrupoles have been tested at liquid helium temperature and accepted; 75 of them have already been installed in the HERA tunnel. The mean value of the quench current at 4.6 K is (7370 ± 100) A compared with a nominal operating current of 5027 A at 820 GeV. The integrated quadrupole gradient has a rms fluctuation of $7 \cdot 10^{-4}$. The field homogeneity of the quadrupoles is excellent (Figure 6).

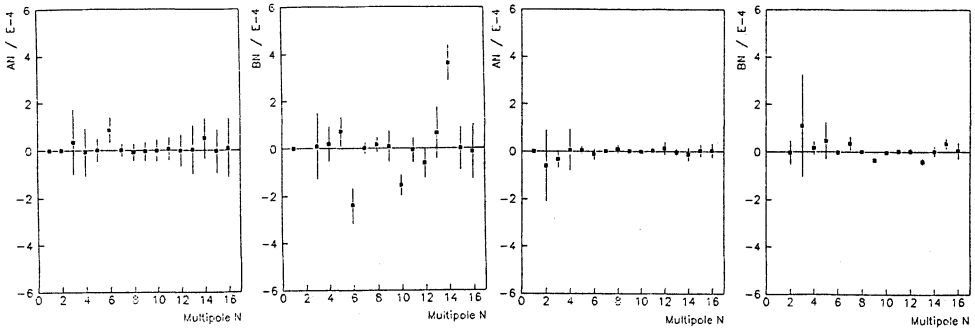


FIGURE 6

Average values of the multipole coefficients ($r_0 = 25$ mm) for the s.c. quadrupoles measured at full field.

Average values of the multipole coefficients ($r_0 = 25$ mm) for the s.c. dipoles measured at full field.

The main dipole magnets, shown in Figure 7, have been designed at DESY. 416 superconducting dipoles of 8.824 m length and 6 vertically deflecting dipoles of 3.356 m length are needed to complete the HERA ring. The nominal field of 4.682 T, corresponding to 820 GeV, is reached at an excitation current of 5027 A. INFN in Italy contributes half of the dipole magnets to the HERA project. The remaining part of the dipoles is being built in Germany. At present 70 of the 453 dipoles ordered have been delivered to DESY. The mean value of the quench current at 4.6 K is (6470 ± 100) A and the rms variation of the integrated field is $6 \cdot 10^{-4}$. For the dipoles as well, the magnetic field homogeneity is very good (Figure 6).

Before the start up of the electron ring in July 1989, 5 dipoles were installed in the HERA tunnel and the first unit cell, on top of the electron machine, was completed.

One complete unit cell of series magnets has already been thoroughly tested at DESY. Many cycles between room temperature and liquid helium temperature have been performed without problems. The heat load of the whole magnet string was in good agreement with the expected value and the quench protection system worked very reliably.

The installation of the HERA-p machine will continue in October 1989 after the electron test period. The cool down of the first complete octant and the injection of protons into HERA are planned for the end of 1989. It is hoped that the installation of all

superconducting magnets will be finished in autumn 1990, the timescale being determined by the delivery schedule of the main dipoles.

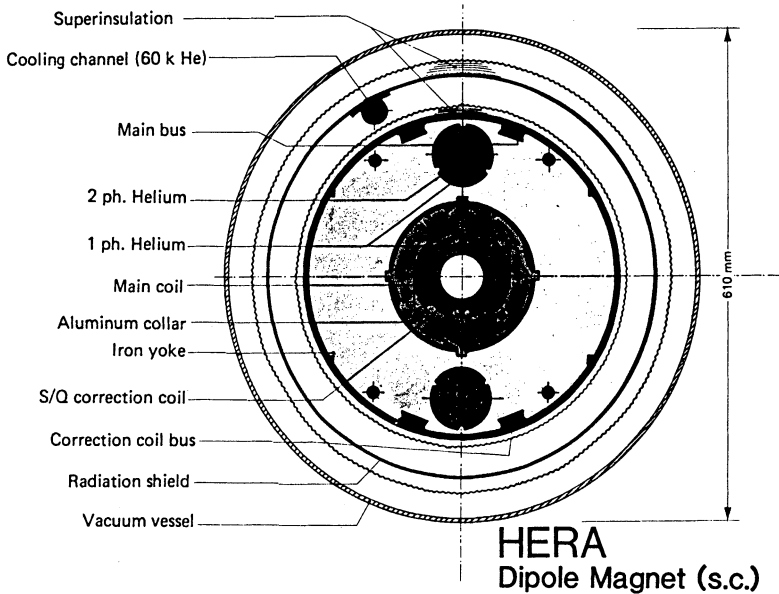


FIGURE 7 Vertical cut through a main dipole.

EXPERIMENTS

For the HERA accelerator two experiments, called H1 and ZEUS, have been approved. Both detectors (Figure 8) have in common the combination of a tracking device in a solenoidal field with extensive calorimetry for electrons and photons and for hadrons.

The H1 collaboration, with 300 physicists in 30 institutions, has chosen a liquid argon calorimeter with lead and steel as absorber material. The calorimeter is housed inside a large superconducting coil. This design gives emphasis to good e/π rejection and good energy resolution in the electromagnetic calorimeter.

The ZEUS collaboration, involving more than 350 physicists from 50 institutions, is building a depleted uranium-scintillator calorimeter outside a superconducting solenoid. This solution results

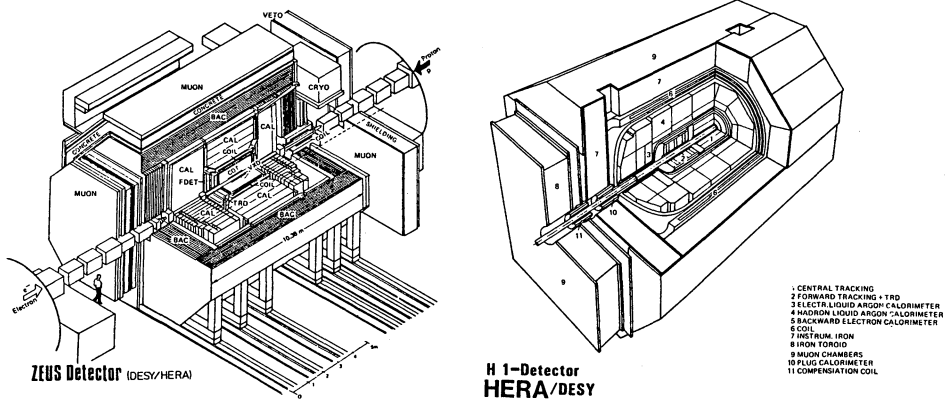


FIGURE 8 HERA experiments.

in an excellent resolution for hadronic showers, which is of particular importance for the investigation of charged current events. The return yoke of the magnetic field is in both cases instrumented and used as back-up calorimeter and for μ identification. In addition, in the proton forward direction special tracking devices and e/μ -identification are foreseen. At present the large iron structures for both experiments have been erected in the experimental halls North and South, respectively. Both superconducting coils are already installed and the fabrication of the many different components is progressing well in the home institutions and at DESY.

The final assembly of the detectors is planned for 1990 and the roll-in into the interaction regions is scheduled for late autumn 1990.

ACTIVITIES AT DORIS

DORIS II is the only accelerator at DESY which is not occupied by the HERA injection scheme. The ARGUS detector, as the only high energy physics experiment, will be upgraded at the end of this year, in particular by adding a micro vertex chamber with a resolution of $\approx 30 \mu\text{m}$. A collaboration with about 90 physicists will continue the investigation of B meson physics until the early 1990's with an average luminosity of $1 \text{ pb}^{-1}/\text{day}$.

In addition, DORIS II serves extensively as synchrotron light source for HASYLAB, which is used yearly by approximately

750 scientists from many various disciplines. In the second half of 1990 the DORIS II machine will be converted to DORIS III by adding a bypass, as shown in Figure 9. This modification allows the insertion of additional wigglers and undulators and considerably increases the number of synchrotron light beams with intensities and brightness up to an order of magnitude higher than currently available.

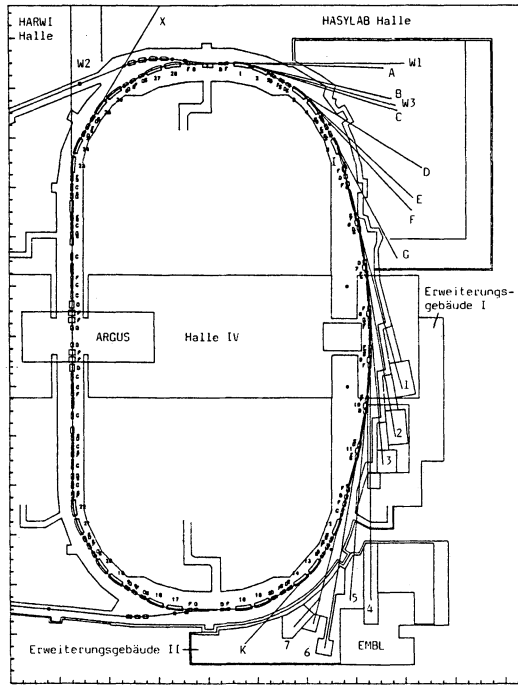


FIGURE 9 DORIS bypass project.

CONCLUSIONS

At DORIS III the upgraded ARGUS experiment will continue running in the T(4S)-region and HASYLAB expects a bright future with the advent of the bypass for more synchrotron radiation light next year.

The first five years of HERA construction have seen the completion of the civil engineering work, of the injection system, of the infrastructure as well as the first successful operation of the electron machine. In the next year the effort will concentrate on the installation of the superconducting proton ring and the assembly of the two detectors H1 and ZEUS.