BRINGING BEAUTY TO HERA: ON ACCELERATOR MODIFICATIONS FOR THE HERA-B EXPERIMENT AT DESY

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Abstract

During the winter 1995/96 shutdown the e- and p-rings of the HERA collider at DESY were modified to accommodate a new $\boldsymbol{B}$-physics experiment, HERA-$\boldsymbol{B}$ [1]. When data taking with the complete detector starts in early 1998, HERA-$\boldsymbol{B}$ will be the fourth HERA physics detector and will occupy the HERA west hall. The HERA-$\boldsymbol{B}$ detector will use interactions of beam halo protons with internal wire targets and presents a wide variety of accelerator design challenges.

Before modification, the west hall and straight section were occupied solely by accelerator components (injection, abort, collimation, rf and beam diagnostic systems) and a major rearrangement and rebuilding of existing accelerator systems was required to accommodate HERA-$\boldsymbol{B}$. Achieving the final solution described in this paper required a delicate interlacing of e- and p-ring components as well as manufacture of new varieties of dipole and quadrupole magnets. We also outline in this paper some machine physics issues important for successful HERA-$\boldsymbol{B}$ operation in concert with the existing HERA experiments.

1 HERA-B GOALS

HERA-$\boldsymbol{B}$ is primarily an experiment to search for CP violation in the $\boldsymbol{B\bar{B}}$-system. The $\boldsymbol{B\bar{B}}$ events are produced in interactions of 820 GeV protons with internal target wires placed in the beam-halo region of the proton beam. The use of a halo target is intended to allow parallel operation of HERA-$\boldsymbol{B}$ with the present e-p collider experiments, H1 and ZEUS, and an internal target e-ring experiment, HERMES, without affecting present experimental conditions. For HERA-$\boldsymbol{B}$ to acquire sufficient statistics a proton-target interaction rate of 60 MHz is necessary. This rate puts stringent demands on detector and machine performance:

- For the HERA-$\boldsymbol{B}$ experiment, the rate should ideally be distributed equally amongst 8 target wires (located beam top, bottom, right and left at two locations) so that on average during a bunch crossing the $\boldsymbol{B\bar{B}}$ events occur on different wires and can be properly reconstructed.
- For the HERA machine, the proton collimators should be carefully adjusted to avoid increased background levels for the other experiments.

Collider experiment background was checked during '94 and '95 running with a special HERA-$\boldsymbol{B}$ target-test setup [2]. Results indicate that it should be possible to have favorable background conditions with HERA-$\boldsymbol{B}$ running [3] given the proton optics changes described in the next section.

2 PROTON OPTICS FOR HERA-B

In order for the wires to have sufficient interaction efficiency, special proton beam optics are required. The $\boldsymbol{\beta}$-functions are lowered, although not as dramatically as at an e-p interaction point. This is done in order to minimize the importance of coulomb multiple scattering for halo protons which pass multiple times through a target wire. Since on the average it takes many passages of a proton through a thin target wire to produce a hadronic event, reduced $\boldsymbol{\beta}$ (larger angular acceptance) at the target is needed to ensure that with cumulative scattering the proton stays within the machine acceptance and is not lost elsewhere. If too large a fraction of these beam halo protons would be lost before hadronically interacting, then the wires would have to be pushed closer to the beam core to have the 60 MHz interaction rate. Thus the degree to which HERA-$\boldsymbol{B}$ can coexist parasitically with H1 and ZEUS, and use only those protons in the halo, which are not useful for colliding beam luminosity, is directly related to HERA-$\boldsymbol{B}$ target efficiency.

The final choice of target $\boldsymbol{\beta}_{\mathbf{Hor}}$, $\boldsymbol{\beta}_{\mathbf{Vert}}$ is 35 m. An early solution had a $\boldsymbol{\beta}$ of 20 m but gave so little free space that abort kickers would have had to be placed partially inside the experiment in the HERA-$\boldsymbol{B}$ muon system. Monte Carlo studies indicated that particles rescattering from the kicker plates, which are close to the beam, would have significantly increased HERA-$\boldsymbol{B}$ background. Sufficient space was created by:

- Designing and installing a strong quadrupole that takes up less space downstream of HERA-$\boldsymbol{B}$.
- Locating the extra dipoles, needed for compensating the 0.8 mrad deflection of the detector dipole, completely upstream of HERA-$\boldsymbol{B}$.

A scattered proton from a HERA-$\boldsymbol{B}$ wire, with the right trajectory to hit the beampipe in the interaction region quadrupoles upstream of an interaction point, should ideally be caught by the beam collimation system [4]. However there is the following tradeoff:

- If the collimators are pushed too far in towards the beam core, then the HERA-$\boldsymbol{B}$ target efficiency drops.

- If the collimators are too far outside, H1 and ZEUS are not properly protected.

Thus much care was given to providing collimator locations with optimum 150° and 30° phase differences for efficient operation [4]. New vertical and horizontal secondary collimators were installed upstream and downstream (respectively) of HERA-$\boldsymbol{B}$.

In addition to the new HERA-$\boldsymbol{B}$ luminosity optics, a new injection optics is needed to ensure:

- Optimum 90° phase difference between the septum and injection kickers.
- Favorable matching conditions for injection beamline.
- Adequate acceptance at critical spots, including the HERA-$\boldsymbol{B}$ vertex tank, via lower β-peaks.

During the recent commissioning the injection and luminosity optics were found to be as planned.

3 HERA-P BEAM ABORT SYSTEM

The p-ring beam abort system consists of one beam absorber and 8 kickers with pulsers and corresponding trigger/control electronics [5]. The 6.5 m long absorber is located $\approx$80 m downstream of the west hall. Originally the kickers were arranged about a central quadrupole, in two groups of four, spanning the west hall region. Each kicker is driven by its own pulser and these pulsers are housed in an adjacent room for an average pulser to kicker cable run of 46 m. As short as possible cable run is critical since the pulser and kicker form a resonant L-C circuit in which added inductance reduces the maximum possible kick. The kicker current pulse is initially sinusoidal with a risetime of t_r=1.3μs. After reaching its maximum at 3t_r, the current decays exponentially with a fall time $>21\mu$s, the revolution time in HERA. The kicker vertical deflecting field extracts the beam in one turn and sweeps the beam downwards from 55 to 110 mm across the dump face.

Rearranging the beam abort system in the west we were led to consider solutions that:

- Kept beam absorber in place.
- Used same abort kicker pulsers operating within their maximum voltage limit of 25 kV.
- Located all abort kickers downstream of HERA-$\boldsymbol{B}$ for smallest possible proton ring aperture inside detector.

Having the abort kickers closer to the absorber (from 80 to 55 m) reduced the lever arm and would not have yielded adequate deflection at the absorber; this 32% reduction meant that new stronger deflection units had to be produced. This was achieved by carefully reducing the kicker aperture. 8 new kickers were designed and built at DESY in two types:

- 5 upstream Type-A kickers with useful aperture 40$\times$40 mm (horizontal $\times$ vertical).
- 3 Type-B kickers with 56$\times$60 mm useful aperture.

At 25 kV and 1.3μs risetime, the total kick from all 8 units is 1.4 mrad$\times$TeV or 40% more than for the old system.

Previously all pulsers were ramped the same as a function of energy; however, now the pulsers must be individually ramped in order to:

- Move the kick centroid downstream at low energy.
- Balance contribution of each unit to total kick.

At low energy the proton beam requires more physical aperture. A significant fraction of the aborted beam could be deposited in accelerator components if the effective kick center was not moved closer to the absorber; on the other hand no single kicker should make too large a contribution to the total deflection to ensure that the beam is fully aborted even in the event this kicker misfires. For the final system the fractional contribution of the 8 kickers ranges between 9% and 15% as compared to an ideal 12.5%. The new abort system has been tested in operation with beams at 40 GeV and 820 GeV. The system behaves as predicted and the beam is aborted correctly.

4 HERA P-RING BEAM IMPEDANCE

Without taking special precautions the HERA-$\boldsymbol{B}$ vertex tank is a device which is potentially troublesome for machine operation. The large vertex tank (2.2 m length, 1 m diameter) contains detector paddles which come close (10 mm) to the proton beam axis [1]. If no rf-shielding is provided, the corresponding heating of the tank and paddles at full beam intensity, and the excitation of multibunch instabilities, would be quite intolerable. This conclusion stems from estimates [6] based on a combination of MAFIA calculations [7] and impedance measurements (made at Naples [6]) with a scale model.

Several shielding configurations were investigated. The most effective arrangement considered has 12 wires distributed parallel to the beam (distance adjustable 10-20 mm from axis) and suppresses the impedance by more than an order of magnitude; however, these wires can overheat if the beam image current would be non-uniformly distributed amongst the wires. In addition, since the paddles move in/out for luminosity/injection, the wires also have to move and supporting a movable wire is a complicated, delicate affair. A thin-walled tube with pumping holes and slots for the vertex detector paddles has also been tested. A tube provides satisfactory rf-shielding but is also mechanically delicate due to the small wall thickness sought by HERA-$\boldsymbol{B}$ to reduce multiple scattering effects. For the time being the final solution is still under discussion.

5 INFLUENCE ON HERA E-RING

The major impact of the HERA-$\boldsymbol{B}$ experiment on the e-ring is physical interference. Throughout the west straight section the e-ring has a regular FODO quadrupole focusing structure. This periodic 5.6 m half cell spacing had to be broken in the west hall to gain 20 m of space for the detector. Quadrupoles were shifted from the middle of the hall to the outside in order to create a pair of quadrupole doublets. The four quadrupoles in these doublets are on new independent current circuits and their excitations are adjusted to match the periodic FODO optics solution while providing a small beam envelope across the long drift section traversing the HERA-$\boldsymbol{B}$ detector.

Having the e-beam go through the HERA-$\boldsymbol{B}$ detector turned out to be unavoidable. Sufficiently strong bends to bypass the e-beam around the detector would

- Produce unacceptably high levels of energetic synchrotron radiation in both the detector and superconducting rf-cavities located downstream of HERA-$\boldsymbol{B}$.
- Lead to partial blockage of the HERA tunnel (sufficient to prohibit transport via the HERA tram).
- Yield a large path difference for the e- and p-rings.

A disadvantage to having the e-beam pass through the HERA-$\boldsymbol{B}$ experiment, besides reduced detector acceptance and interface complications, is that the e-beam must be gingerly shielded from the influence of a spatially varying magnetic field (maximum 0.8 T) over the 4.5 m length of the HERA-$\boldsymbol{B}$ dipole. To this end a combined active/passive field compensation system was developed. Without compensation the e-beam polarization, which is needed for the HERMES experiment in the east, could be spoiled. A specification for the polarization vector, not to be rotated by more than 5 mrad, was determined.

The e-beam passes off axis in the HERA-$\boldsymbol{B}$ dipole and skims the lower pole face. A trough is cut in this pole to provide room for a compensation system. In the HERA-$\boldsymbol{B}$ dipole, at the position of the e-beam, the local dipole field is tilted from the vertical. A large fraction of this field is actively canceled via appropriately tilted dipole windings about the e-beampipe. Full suppression of remaining components is assured by concentric shells of iron and additional solenoidal windings to prevent saturation where the compensator iron passes the HERA-$\boldsymbol{B}$ main windings. Field measurements confirm that the residual field seen by the e-beam are acceptable; however, as of this writing we have yet to try for high polarization with the HERA-$\boldsymbol{B}$ magnet on, so final data are not available. Additional small dipole corrector magnets are installed upstream, downstream, and in a gap inside HERA-$\boldsymbol{B}$, so it is possible to correct small residual tilts due to unexpected compensation errors and to provide fine orbit control.

Many secondary interferences involving p-ring modifications to implement the new HERA-$\boldsymbol{B}$ optics and e-ring components were mitigated via careful component positioning. For example initially it was expected that two e-ring superconducting rf-cavity cryostats would have to be relocated to make room for p-ring quadrupoles; however, upon closer examination it was found possible to squeeze these magnets into short gaps between the cryostats. Also near the e-ring transverse and longitudinal feedback systems positions we used a combination of existing HERA warm quadrupoles and no longer needed PETRA interaction region quadrupoles in a p-ring lattice which leaves the feedback systems with their complicated waveguide, support, and diagnostic connections untouched.

One e-ring system essential to the HERMES experiment, the polarimeter, also had to be modified. As originally constructed the polarimeter laser beam passes at tunnel crown elevation, through the west hall, on its way to the polarimeter. This evacuated beamline would have to go through many HERA-$\boldsymbol{B}$ detector components including the the detector dipole unless we:

- Added mirrors to laser path, which would inevitably degrade precision of polarization measurement (crucial for final HERMES systematic error).
- Dug a shaft to the HERA tunnel and constructed a new building to house the laser and associated electronics (too costly).
- Drilled through $\approx$7 m of reinforced concrete in order to reach the tunnel crown downstream of HERA-$\boldsymbol{B}$ and relocated the laser to a storage area atop the west hall (the solution chosen).

The polarimeter system modification was made without incident and the laser beamline has the same number of mirrors as before.

6 CONCLUSION

A new design for the HERA west straight section has been implemented during the Winter Shutdown 1995/96 and a new lattice is now available to accommodate the fourth HERA experiment, HERA-$\boldsymbol{B}$. With the modified lattice in place, the HERA-$\boldsymbol{B}$ detector can be installed in a staged manner, with data taking with the full detector scheduled for 1998. The present upgrade has been completed within schedule and budget in April 1996.

Despite many unavoidable constraints and restrictions, which naturally occur if an existing lattice is modified, a satisfactory solution was found and the solution was confirmed during recent HERA re-commissioning. It has been demonstrated, in particular, that the new abort kicker system is working properly under more demanding conditions. Beam optics and aperture margins have been verified and appear to be adequate. The new magnets required in this lattice have the expected strengths and field qualities. An important milestone in increasing the physics potential of HERA has thus been achieved.

7 REFERENCES

[1] HERA-$\boldsymbol{B}$ Design Report, DESY PRC 95-01, January 1995.

[2] C. Hast, *et. al.*, DESY 94-119, July 1994.

[3] E. Lohrman and M. Seidel, DESY 95-04, April 1995.

[4] M. Seidel, Ph.D. Thesis, DESY 94-103, June 1994.

[5] M. Schmitz, DESY HERA 92-18, August 1992.

[6] R. Wanzenberg, contribution to “HERA Seminar St. Engelmar 1996,” to be published.

[7] S. G. Wipf, priv. comm.