**Institute of Theoretical
and Experimental Physics**

42-98

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HERA - B: Status and Results of Test Runs

SCAN-9904039

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M o s c o w 1998

HERA - B: STATUS AND RESULTS OF TEST RUNS¹: Preprint ITEP 42-98/

I. Belyaev - M., 1998 - 20p.

The **HERA - B** experiment is designed to study CP violation phenomena in the B system. The physical program of the **HERA - B** detector includes the measurements of CP asymmetries in $B_d \rightarrow J/\psi K_S^0$ and $B_d \rightarrow \pi^+ \pi^-$ decay channels, search for direct CP violation phenomena and many other items. An overview of detector and trigger technologies, the current status of the detector and the experience gained during the test runs is reported.

В работе представлен обзор эксперимента **HERA - B**, спроектированного для изучения явления нарушения комбинированной чётности в системе прелестных мезонов. Физическая программа эксперимента **HERA - B** включает в себя измерение CP -нечетных асимметрий в распадах $B_d \rightarrow J/\psi K_S^0$ и $B_d \rightarrow \pi^+ \pi^-$, поиск "прямого" нарушения комбинированной чётности и другие вопросы. Обсуждаются элементы детектора и триггера, текущий статус и результаты тестовых измерений.

Fig. - 11, ref. - 16 name.

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¹Invited talk at the III International Conference "Hyperons, Charm and Beauty Hadrons", Genova, Italy, 1998

1 INTRODUCTION

HERA – B experiment is designed for measuring the asymmetry in the decay rates of $B_d \rightarrow J/\psi K_S^0$ and $\bar{B}_d \rightarrow J/\psi K_S^0$. The idea of using the existing 820 GeV/c proton beam of **HERA** accelerator in combination with an internal wire target was presented in the Letter of Intent [1] in 1992 followed by a Progress Report [2] in March 1993. The experiment was approved shortly after the submission of the formal Proposal [3] in May 1994 followed by the Technical Design Report [4] in 1995.

Here only a short overview of the experiment is presented. For details one can refer to more detailed and extensive overviews of the project [5]. The physics potential and performance of the **HERA** – B experiment is summarized in [6].

The **HERA** – B detector is a large acceptance forward spectrometer with an open geometry as sketched in Figure 1.

It consists of

- Silicon Vertex Detector (SVD) providing excellent vertex reconstruction and impact parameter measurements
 - Inner and Outer Tracker (ITR and OTR) providing good pattern recognition and momentum measurements over a wide momentum range
 - electron identification and triggering using the Electromagnetic Calorimeter (ECAL) and Transition Radiation Detector (TRD)
 - hadron-muon separation and muon triggering with the Muon System (MUON)
 - Ring Imaging Čerenkov Detector (RICH) for good hadron identification
-

- special chambers for fast selection of particles with high transverse momenta, especially hadrons from $B \rightarrow h^\pm h^\mp$ decays

The small $b\bar{b}$ production cross section, the high rate of background processes and the necessity to operate with several superimposed interactions per HERA bunch crossing result in events with large charge and neutral multiplicities, hard radiation conditions for detector operation and a challenge for triggering. The technologies chosen for subdetectors, their channel count and the peak occupancies are listed in Table 1.

Table 1: Technologies chosen for **HERA** – B subdetectors and their number of channels and peak occupancy

	Technology	Number of Channels	Peak Occupancy
SVD	double sided silicon wafers	120k	0.1%
ITR	microstrip gas chambers	150k	1%
OTR	honeycomb drift chambers	150k	15%
ECAL	“shashlyk” modules	6k	15%
TRD	fiber radiator and straw tubes	12k	10%
RICH	C_5F_{12} radiator with phototube readout	234	234
High- p_T	gas pixel and pad straw chambers	18	10%
MUON	tube, pad and pixel chambers	40k	1%

2 THE MAIN DETECTOR SUBSYSTEMS

2.1 Internal Target

One of the most specific features of **HERA** – B is an Internal Wire Target. The target wires and manipulators are mounted with the Silicon Vertex Detector inside the Vertex Vessel. For the success of the experiment a uniform interaction rate of up to 40 MHz should be provided without off-bunch background and large rate fluctuations. The test measurements proved that it is possible to get 40 MHz interaction rate without large interference with the e-p operation mode of the HERA accelerator. The main results obtained during the 1996 and 1997 test runs with an internal wire target are the following:

- a stable rate for periods comparable with the time between proton beam refilling is achieved in close cooperation with the HERA machine team and other HERA experiments

- interaction rates of 40 MHz were reached without significant degradation of the proton beam lifetime
- automatic wire steering procedures were developed
- different target materials (C,Cu,Al) and shapes (wires and ribbons) were tested
- target efficiency (the ratio of the interaction rate to the natural beam losses) of 50-90% was achieved, depending on the target material and HERA collimator positions.

In spite of this large success, there still exist some problems to be solved in the 1998 test run:

- non-equal HERA bunch population (see Figure 2)
- off-bunch population for outer wire
- the target material must be fixed during 1998 test run

Special HERA machine runs are scheduled in 1998 for the solution of these problems.

2.2 Silicon Vertex Detector

The technology chosen for the vertex detector is based on double-sided silicon strip detectors. Eight double-sided wafers with a $50 \times 60 \text{ mm}^2$ active zone form one super-layer of the vertex detector. Seven super-layers are housed inside the vertex vessel, a conical extension of the beam pipe. The vertex detector provides about 90% the acceptance coverage for products of B decays with mean number of 12 hits per B-track within the acceptance.

The detectors are operated at a distance of about 10 mm from the proton beam. An huge radiation dose of 10 Mrad per year in the hot spot of the detector dictates the necessity for the rearrangement of the detectors during operation and the necessity for the replacement of the detector wafers once per year. The detectors are shielded from the machine vacuum by aluminum caps and mounted inside Roman pots. An extensive R&D study of this type of vertex detector was performed earlier at the CERN SPS-Collider [9] A sophisticated manipulator system was designed and implemented for detector retraction during beam injection and adjustment.

The tests were performed in the 1996 test run with 3 double sided detectors mounted inside the vertex vessel. The impact points of tracks, reconstructed with this rudimentary vertex detector are shown in Figure 3. A clear "tomography" image of target wires can be easily observed. The transverse width of the wire images corresponds to an impact point resolution of about 300 μm .

Other three double sided detectors were installed into the vertex vessel for the 1997 test run. Large statistics of reconstructed "tracks" collected during this run allowed self-alignment of the SVD planes to be performed and the performance of the detectors to be measured. Some selected results are listed in Table 2. All details can be found elsewhere [10].

Table 2: The measured performance of SVD using reconstructed "tracks"

Single face efficiency	$\geq 98\%$
Tracking efficiency	$\geq 97\%$
Track residuals [μm]	~ 30
Mean value of signal-to-noise ratio	12-17
Impact parameter resolution [μm]	300

2.3 Inner Tracker

The **HERA** - B Inner Tracker is based on the microstrip gas chamber technology. The chambers with a diamond-like coating were shown to survive high doses of X-ray irradiation and have excellent high-rate capabilities. Unfortunately tests at the PSI test beam and in the real **HERA** - B environment during the 1996 test run show that the chambers are destroyed within hours. The effect is attributed to the influence of heavily ionizing particles, inducing sparking and destroying of the electrode strips. The problem is solved by introducing a gas electron multiplication foil [11] into the drift space of the microstrip gas chamber, providing a first gas amplification step and therefore splitting the overall gain of about 3000 into two steps - typically 150 in MSGC and of about 20 with GEM foil.

The new chamber performs well is resistance to sparking. Chambers did not show any degradation in performance after irradiation with a gaseous α -source corresponding to more then two years of **HERA** - B operation. During the 1997 test run chambers of this design worked about 60 hours within the real **HERA** - B environment at full interaction rate.

The efficiency and the average strip multiplicities in the magnetic field for

such microstrip chamber with GEM foil are plotted in Figures 4 and 5. The average strip multiplicity in the magnetic field at a detection efficiency of about 95% was found to be 1.65, which is only a little bit larger than for the microstrip chambers without GEM foil.

In May 1998 one half superlayer with sixteen equipped chambers was installed into the **HERA** – B detector for tests and commissioning. According to the current chamber production rate of about 2 chambers per day, the whole detector is expected to be ready in November 1998. All details can be found elsewhere [12, 13].

2.4 Outer Tracker

The Outer Tracker for the **HERA** – B detector is based on Honeycomb Drift Chamber technology with tube diameters of 5 and 10 mm. Several large prototype modules of OTR system were tested during the 1997 test run in the **HERA** – B environment. The measured occupancy was found to be in a good agreement with MC predictions (see Figure 6).

Unfortunately during high-rate operation several damaging effects were observed including increasing and persistent currents (see Figure 7).

The effects were surprising since chambers were proved to be immune to a very large X-ray doses up to 5 C/cm. The collaboration was forced to stop mass production and start extensive studies to find the appropriate solution. All damaging effects were reproduced in α -beam tests at the Karlsruhe cyclotron in spring 1998. The influence of gas mixture components, gas flow, gluing and soldering techniques and different types of Pokalon surface coating were intensively studied. A solution with gold-coated Pokalon and Ar/CO₂/CF₄ (65%/5%/30%) gas mixture was found to be able to survive within the **HERA** – B environment for approximately 1.5 year. Figure 8 shows the significant difference of damaging behavior between the new and previous chamber design. Mass production is expected to be resumed by October 1998 and the essential for First Level Trigger purposes part of Outer Tracker chambers is to be ready by Spring of 1999.

2.5 Čerenkov Detector

The Čerenkov detector combines a C₄F₁₀ gas radiator and phototube based photon detector. A detailed review of the **HERA** – B Ring Imaging Čerenkov Detector and its status was presented at this Conference by Dr. J.Pyrlik [14]

2.6 Electromagnetic Calorimeter

The “shashlik” technology was chosen for the Electromagnetic Calorimeter of **HERA** – B detector. The granularity of calorimeter cells follows roughly the occupancy at the calorimeter surface and varies from $2.2 \times 2.2 \text{ cm}^2$ in the inner part to $5.6 \times 5.6 \text{ cm}^2$ in the middle part and to $11.2 \times 11.2 \text{ cm}^2$ for the outer part. As absorber tungsten was chosen for inner part, and lead is used in the middle and outer parts.

A large block of middle modules was installed during the 1996 test run and in December 1996 a clear m.i.p. signal was observed in the real **HERA** – B environment (see Figure 9).

For the 1997 test run this large block was rearranged into two smaller blocks placed symmetrically around the proton beam pipe. A clear π^0 signal observed in the calorimeter during the 1997 test run is shown in Figure 10. These observations in stand alone mode support our expectation of the possibility for physical calibration in addition to a traditional calibration with LED signals.

The whole calorimeter was assembled in February 1998. It will be equipped with readout pretrigger electronics and LED monitoring systems by autumn 1998. The ECAL is expected to serve as the main trigger device for the 1998 test run.

2.7 Transition Radiation Detector

Transition Radiation Detector for the **HERA** – B experiment consists of fiber radiators for emission of soft X-ray photons and drift straws with Xe-based gas mixture for detection of transition radiation.

A full-scale block of about 20% of the whole detector was installed into the real **HERA** – B environment for the 1996 test run and almost immediately a clear transition radiation signal was observed (see Figure 11).

The TRD detector operated successfully during the entire period of 1996 and 1997 test runs [15]. No aging effects were observed.

Currently four large blocks of TRD detector (more than 80% of the whole detector) are ready and are planned to be installed in the **HERA** – B detector in August 1998. The remaining four smaller blocks are expected to be ready in November 1998.

2.8 High- p_T chambers

The High- p_T system of **HERA** - B consists of three layers of pad chambers placed inside the **HERA** - B magnet. A detailed review of the High- p_T pretrigger, its physical motivation and current status was presented at this Conference by V.Eiges [16]

2.9 Muon Detector

The **HERA** - B muon detector consists of four superlayers separated by steel and heavy concrete absorber. The last two superlayers are equipped with pad chambers, while the first two superlayers consist of tube chambers with a pitch of 15 mm. In the region nearest to the beam pipe, where the occupancy is high, small gas-pixel chambers are used.

Eight pad and twenty tube chambers were installed in **HERA** - B for the 1996 test run. Measurements of currents and occupancies were performed. A detector synchronization was achieved using only the measured data on detector occupancy.

All tube, pad and gas-pixel chambers were produced by February 1998. And the first superlayer was completely installed into the **HERA** - B detector. For August 1998 one half of the third and fourth superlayers are planned for installation. The whole detector is expected to be installed and equipped by February 1999.

3 PLANS FOR 1998 RUN

For the 1998 run, the whole RICH detector, the assembled ECAL, a significant part of the Muon Detector, a reduced Vertex detector, several full scale detectors of the High- p_T pretrigger, one half of an Inner Tracker superlayer and several test prototypes of Outer Tracker chambers are installed.

The plans for 1998 test runs are

- to test and to prove the new OTR technology
 - commissioning of the installed detectors
 - to prove the calorimeter calibration strategies
 - test for common DAQ, pretrigger and trigger hardware and software
 - test for higher level software triggers
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- tests for Muon and High- p_T coincidence-based triggers
- measurement of direct J/ψ production with ECAL-based trigger

4 SUMMARY

The **HERA** - B detector will reach its design performance during the 1999 HERA run. The exact schedule depends strongly on the actual schedule of HERA shutdowns. The most essential part of the Outer Tracker used in the First Level Trigger is to be ready in spring 1999. The detector will be continuously upgraded during long and short shutdowns of the accelerator, and therefore converting from test detector set-up to a full scale experiment.

Figure 1. Schematic side view of the **HERA** – B detector

Figure 2. HERA bunch population: normal case (upper plot) and the worst case (lower plot). For the worst case a non-uniform bunch population and a significant off-bunch population is clearly seen.

Figure 3. Impact points in the target plane for track candidates reconstructed with the three modules of the vertex detector available in the 1996/1997 runs

Figure 4. Efficiency of Inner Tracker chamber with GEM-foil in the magnetic field as a function of threshold

Figure 5. Average strip multiplicity for Inner Tracker chamber with GEM-foil in the magnetic field as a function of threshold

Figure 6. Occupancies measured in different parts of the Outer Tracker chambers as a function of wire number

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Figure 7. Ageing effects in OTR chambers observed in the real **HERA** - B environment. High voltage (upper plot), chamber current (middle plot) and beam radiation intensity (lower plot) in arbitrary units are displayed as functions of time. The effects of increasing current and persistent current are clearly seen

Figure 8. Comparison between ageing of the old type OTR chamber (upper curve), displaying increasing and persistent current, and the OTR chamber of new design (lower curve), showing no such effects

Figure 9. M.I.P. signals observed in the **HERA** - B calorimeter during the 1996 test run

Figure 10. The π^0 signal observed in $\gamma\gamma$ invariant mass distribution with prototype of the **HERA** - B calorimeter in the 1997 test run

Figure 11. Distribution of energy deposited in TRD straws for real data taken during 1996 tests run (upper plot), Monte Carlo simulation for electrons (middle plot) and Monte Carlo simulation for hadrons (lower plot). A clear tail due to soft X-ray photons are seen on the plot. Vertical scales are arbitrary

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НЕРА - В: Статус и результаты тестовых сеансов.

Подписано к печати 12.II.98 Формат 60х90 1/16
Усл.-печ.л.1,25. Уч.-изд.л.0,9. Тираж 91 экз. Заказ 42.
Индекс 3649

Отпечатано в ИТЭФ, ИИ7259, Москва, Б.Черемушкинская, 25

Индекс 3649

Препринт 42 -98, ИТЭФ, 1998