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Status of the outer tracker for the HERA-B experiment

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Abstract

The outer tracker system of the HERA-B experiment is composed of large size, small diameter drift chambers operated with an Ar–CF_4–CO_2 (65–30–5) gas mixture. The general layout and details of module construction are described. An intensive R&D program has been carried out to ascertain the long-term behaviour of honeycomb modules under irradiation; results of irradiated prototypes are presented. A set of operational conditions, gas mixture, clean assembly materials and adequate production techniques have been found which ensure proper operation of the outer tracker during several years in the harsh HERA-B environment. © 2000 Elsevier Science B.V. All rights reserved.

1. Introduction

HERA-B is an experiment to study CP-violation in the B system using an internal target at the HERA proton ring, presently being set up at DESY, Hamburg [1]. Despite the small B meson production cross section, the experiment can achieve enough statistics within a reasonable time by operating at an interaction rate of 40 MHz. Around 200 particles traverse the detector every 96 ns. This high particle flux poses severe constraints to the technology of the tracking detectors, readout and trigger electronics. The goals of HERA-B imply the development of new technologies now which will be needed by the future LHC experiments at Cern. The Outer Tracker, a set of large area modules of drift tubes, is one of those detectors that can be called of new generation, despite the fact that it is based on the operating principles of standard single-wire proportional counters. A variety of technological details makes it adequate for the harsh HERA-B environment.

2. The outer tracker layout

The tracker of HERA-B has to reconstruct particle tracks to measure momentum with a precision $\Delta p/p = 10^{-4}$ and to provide fast trigger signals for the First Level Trigger. Due to the approximately $1/R$ dependence of the particle flux, where R is the radial distance to the proton beam pipe, different technologies and granularities are used dividing the tracker into three subsystems: a vertex silicon detector followed by two gas-based detectors, the inner and the outer tracker. The inner tracking area covers with MicroStrip Gas Chambers [2] an angular range larger than 10 mrad and extends up to radial distances of 20–25 cm from the beamline. Immediately after, the outer tracker uses honeycomb chambers installed up to 250 mrad, filling 1000 m^2 of active area with around 120 000 electronic channels.

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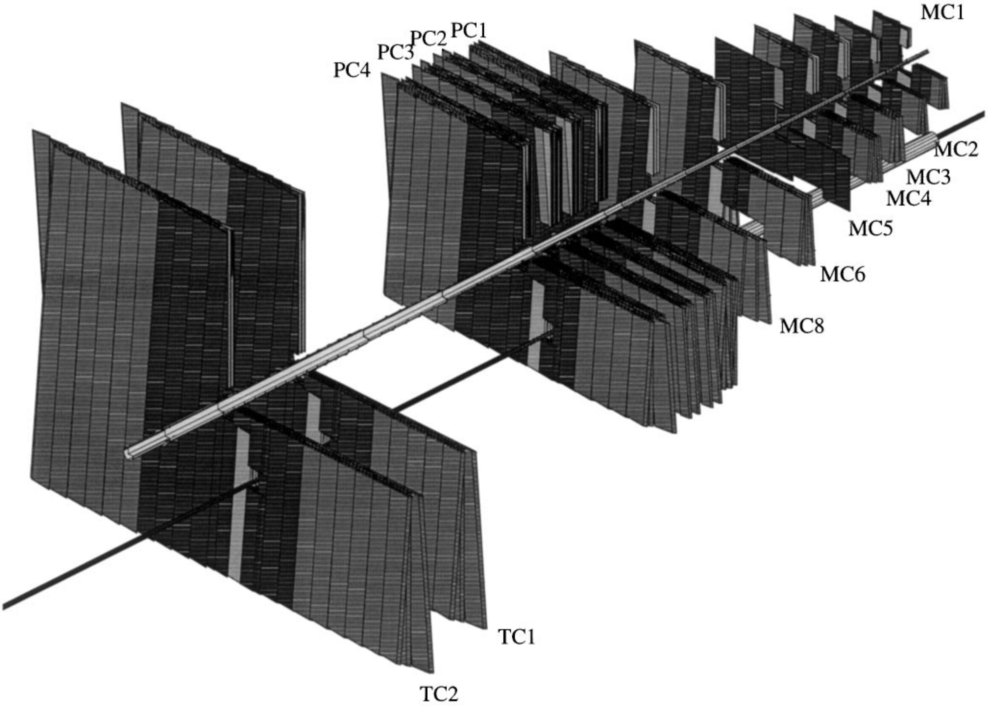

Fig. 1. Scheme of the outer tracker layout. The upper right quadrant has been removed. The total length of the set-up is about 10 m and the different superlayers size from 1×1.2 to 6×4.5 m^2.

2.1. Superlayer structure

The Outer Tracker has to give space points along the ≈ 10 m of track length. It is composed of 13 superlayers located at different z-positions along the beam pipe following a conical layout. The superlayers have sizes from about 1×1.2 to 6×4.5 m^2 (Fig. 1). Each superlayer is divided in two halves to facilitate access and maintenance of the detectors, as well as if needed, to allow access to the HERA tunnel by removing part of the spectrometer. Due to the presence of two beam pipes (HERA is a e^-p collider) in the experimental area, both halves are asymmetric. This is an obvious design complication in the hottest region of the detector, and for instance, a complex comb structure made out of carbon-fibre was designed to overlap half-superlayers. Rigid steel frames run around the active area hosting cables, front-end electronics and VME TDC crates.

Per half superlayer, the honeycomb modules and part of the front-end electronics are embedded in a common gas volume, called gas box. This approach avoids difficult individual gas supply for such large quantity of cells. If needed, the boxes can be re-opened to replace or repair damaged models.

2.2. Modules

Fig. 2 shows how a single layer is assembled from three folded foils. 25 μm Au/W sense wires are inserted in the middle of half-hexagonal cells. A support bridge made out of 100 μm thick fibre-glass with metal pads, having the full module width, is glued along different positions of the wire layers. Wires are soldered, while the corresponding cells are still open, on the printed boards to keep them in position within 50 μm accuracy, interrupt sectors and to shorten the free wire length to avoid electrostatic problems in such small diameter cells. The structure is self-supporting, it has large radiation length and it is very light thanks to the

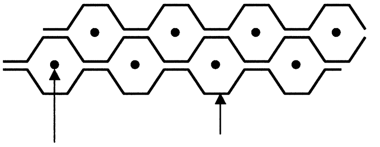

Fig. 2. Schematic assembly of a single layer from three-folded polycarbonate foils. 25 μm Au/W sense wires are inserted in the middle of half-hexagons, while the corresponding cells are still open.

polycarbonate foil (75 μm thick Pocalon-C[1]) used as cathode. This foil combines two important properties: (i) as compared to, for instance, metallized kapton it has bulk conductivity that helps reducing cross-talk, and (ii) it is mechanically more stable than for example thin aluminium. Actually, the foil is coated with few nm of gold to ensure homogeneous conductivity (see Section 4).

The chamber design has been optimized to have nearly constant occupancy over the different regions of the superlayers independent of the particle flux. To achieve this goal, two different cell sizes, 5 and 10 mm diameter, depending on the distance to the beamline, and subdivision of the chamber height into sub-sectors have been implemented. Some layers near to the beam are active only in the innermost region and the outer part uses a 75 μm thick Cu/Be wire, which does not amplify, connecting short active areas to the external readout electronics. Many layers, overlapping sensitive and non-sensitive areas, are needed in order to keep a maximal geometrical acceptance. Nevertheless, the occupancy in the tracker region between the rich and the calorimeter, will be as high as 30%.

To guarantee good First Level Trigger track finding, hit finding efficiency should be better than 98%. Each superlayer is formed by stereo layers positioned at -5°, 0° and 5° with respect to the vertical direction to achieve ≈ 200 μm spatial resolution in the bending plane.

Due to the bunch crossing each 96 ns, the charge signal has to be collected very fast. This influences the gas selection, some geometry considerations and the choice of readout electronics: ASD-8 chips (amplifier, shaper and discriminator) mounted on the chamber and custom-made TDC boards with individual TDC and digital pipeline per channel [3].

3. Module production and quality assessment

More than 1000 modules of different shape and size are needed to cover the whole active area. The module production has been shared between 5 worldwide collaborating institutes,[2] each specialized in some type of module geometry.

Considering that the particle rate in the hottest regions of the detector will be around 2×10^3 mips mm^2/s, resulting in about 0.5 C/cm accumulated charge per year (10^7 s), a careful selection of materials, construction procedures, clean room assembly, etc., are mandatory to minimize gas aging problems. Modules have been built following unified, strict production rules [4]. All information during manufacturing, like wire tensions, high voltage stability on air, material batch, etc., are recorded in a database.

After production, each module is tested under high voltage in counting gas and shortly irradiated with ^{55}Fe or ^{106}Ru sources. A complete wire mapping is performed, looking for signals and currents. Gain uniformity along the wires is also measured. Bad behaving wires are trained under voltage and shorts are repaired or disconnected. Similar quality checks are repeated for a completed superlayer, after the final electrical connections are made. After the production and repairs less than 1% of the channels remained dead. At most additional $\approx 2\%$ channels have been lost during superlayer assembly, transportation and installation in the experimental area.

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[1] Pocalon-C is produced at BASF, Germany.

[2] DESY – Hamburg, Germany; DESY – Zeuthen, Germany; Institute for High Energy Physics – Beijing, China; Tsinghua University – Beijing, China; JINR-Dubna, Russia.

4. Chamber operation

Several studies have been carried out in low-rate particle beams to study the basic behaviour of the honeycomb drift tubes and to determine their working point, cross-talk, attenuation length and to estimate efficiency and space resolution. Satisfactory results have been found elsewhere [5,6]. On the contrary, soon after the first prototype modules are built and run in the HERA-B environment in the early 1994, many operational problems appeared. Severe gas aging was manifested as gas gain loss after few hours of irradiation (μC/cm accumulated charge) accompanied by Malter-like currents, that impossibilitate further operation of the detectors. An intensive R&D phase was started, including high rate beam tests, irradiation under X-rays and also at HERA-B. Systematically, the effects are found and/or triggered in controlled irradiation conditions, and it is observed that larger irradiation areas and/or hadronic beams make effects more likely to appear.

Sets of long-term measurements have been carefully designed and performed using a beam of 100 MeV alphas to irradiate several module prototypes.[3] Operation conditions like gas distribution, gas flow, construction technology, assembly materials, cathode material and gas mixture were varied in order to understand long-term effects as well as to validate construction techniques and materials for mass production. The following observations have been made:

- Gas exchange rate, at the level of 0.1, 1 and 10 times volume exchange per hour, seems not to affect the aging rate.
- Controlled, individual gas supply per cell with thin capillaries against open gas flow (supplied to the common gas box) does not improve the aging behaviour.
- A set of assembly materials like wire type, wire support bridge, glues, and sealing agents, and construction procedures have been validated for mass production.

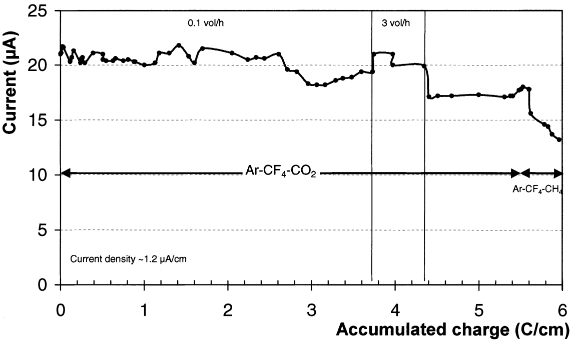

Fig. 3. Current measured during X-ray irradiation of a honeycomb module in Ar–CF$_4$–CO$_2$ as a function of accumulated charge. More than 5 C/cm are accumulated with negligible gain loss; the small drop at the end is due to a confirmed variation of rate supplied by the X-ray tube. Replacing CO$_2$ by CH$_4$ triggers an immediate and non-recoverable gain loss in the irradiated wire.

- Gas aging is avoided by replacing the hydrocarbon in the gas mixture Ar–CF$_4$–CH$_4$ (65–30–5) by CO$_2$. This effect has been systematically reproduced also under other irradiation conditions. Fig. 3 shows the current measured during X-ray irradiation as a function of accumulated charge in both gas mixtures. In Ar–CF$_4$–CO$_2$ more than 5 C/cm are accumulated with no gain loss; the small drop at the end is due to a variation of rate supplied by the X-ray tube; comparison of ^{55}Fe spectra taken at the beginning and end of the test confirms it. Substitution of CO$_2$ by CH$_4$ triggers an immediate and non–recoverable gain loss in the irradiated wire. Fig. 4 shows a fast anode aging in the CH$_4$ gas mixture, around 70% after 0.4 C/cm. A partial recovery is observed if the gas volume exchange is increased by a factor of 5, and a total recovery when CO$_2$ is added, indicating that wire deposits are etched away, presumably by the chemical action of oxygen released from CO$_2$ in the plasma discharge.
- The Malter-like currents are associated to the cathode nature. Normally, in gas-filled counters they are related to thin insulating coating that may be deposited on the cathode surface by a mechanism involving polymerization. In the case of the honeycomb chambers, it can be also attributed to inhomogeneous surface

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[3] The tests were done at the Forschungszentrum in Karlsruhe, Germany.

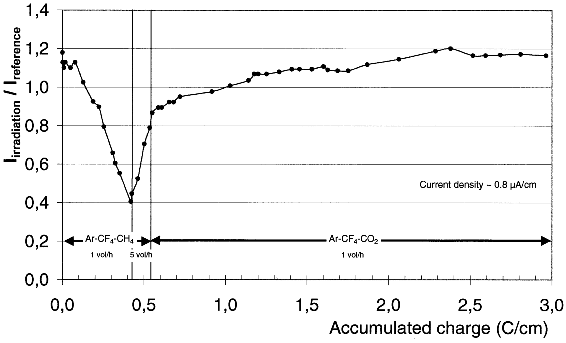

Fig. 4. Complete rejuvenation of a heavily damaged chamber in Ar–CF_4–CH_4 when it is further irradiated with X-rays substituting the hydrocarbon by CO_2. A partial recovery is also observed if the gas exchange rate of the polymerizing gas mixture is increased by a factor 5.

conductivity, particular to the pure Pocalon-C. This would also explain why the Malter currents appeared almost immediately. Presently, cathode foils are coated with a 50 nm underlayer of copper followed by 40 nm of gold[4] to ensure a proper cathode surface. Honeycombs modules built with coated foils and irradiated in several conditions have not shown Malter-like currents.

- Honeycomb modules irradiated in the presence of small concentrations of water in the gas mixture develop ohmic currents. Currents are not permanent, i.e. slowly disappear if gas is dried out, but if present they are large enough to disturb chamber operation. The current has been located in the wire support bridge, which is an insulator connecting anode and cathode, that seems to become conductive under the mentioned conditions. This effect has an immediate impact in the gas box design as well as in the gas system. Presently, chambers are operated at HERA-B while water level is continuously monitored and kept under 500 ppm.
- Wire etching of irradiated counters in CF_4-based mixtures is a well established fact [7,8]. This effect has also been observed in some honeycomb modules irradiated for more than 1–2 C/cm of wire ($>$ 2 HERA-B years), accompanied by a slight decrease of gas gain. A way to minimize or prevent this process is still under study.

Since 1998 the honeycomb modules are built and operated following the acquired knowledge. Since then, irradiated modules have not shown significant operational problems up to collected charges well exceeding 1 C/cm of wire.

5. Running in HERA-B

Several final superlayers and some prototypes of reduced size were built following the acquired knowledge during the R&D phase and installed in nominal positions at HERA-B during 10 months of running period, from August 1998 to May 1999. The tracking system was integrated into the common DAQ system and the analysis of the TDC spectra, efficiency and tracking were carried out under full target rate (40 MHz).

During the long running period, the detectors have been routinely operated at different target rates, and they have been exposed to more than 400 h equivalent to 40 MHz operation; this would correspond to around 14% of one HERA-B year running at nominal conditions. During this period all detectors have been carefully monitored and they have demonstrated to be very robust and stable. No aging problems have been recorded, in clear contrast to the operation of the very first prototype modules run in the same environment, when chambers did not survive more than 10 h of operation.

Extensive studies have been carried out with one of the final superlayers, MC2, located in the magnet region. The superlayer is equipped with 5 and 10 mm cells in all three projections. Some modules are also divided vertically into several sensitive regions. All channels are equipped with the final readout system. Fig. 5 shows the average occupancy in different sectors of half MC2 superlayer as a function of the target rate. There is a clear linear dependence up to twice the 40 MHz nominal rate.

Tracks have been determined by reconstructing in several superlayers space points using the hit information registered in different stereolayers.

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[4] Coated performed at APVV, Essen, Germany.

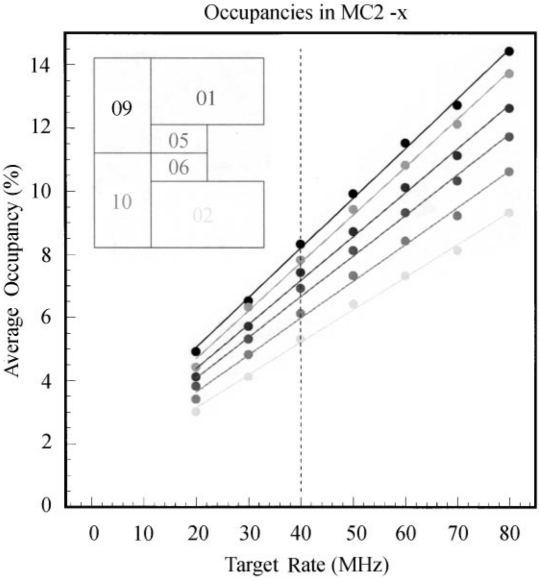

Fig. 5. Linear dependence of the average occupancy with the target rate measured in different sectors of the MC2 half-superlayer, also shown in the caption.

Fig. 6 shows the X coordinate of reconstructed tracks extrapolated to the $z = 0$ plane. A clear peak is seen at around -2 mm, which corresponds to the target position. Track correlation with other detectors, like the silicon vertex, RICH or calorimeter have been done. Fig. 7 shows the distributions of track angles reconstructed by the outer tracker and the vertex detector for the same or random events. In the first case both systems reconstruct the same track.

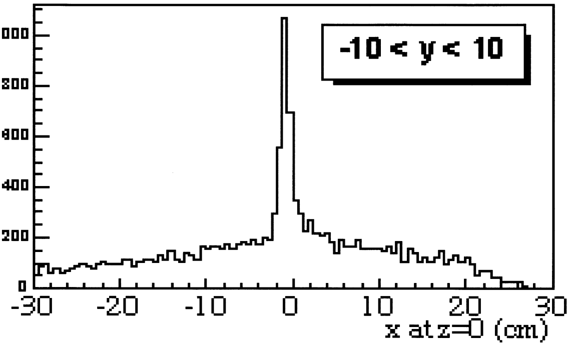

Fig. 6. X coordinate of tracks reconstructed from space points in the stereo layers of different superlayers and extrapolated to the $z = 0$ position. The peak corresponds to the target position. All point to point combinations to find a track are included explaining the large background.

6. Summary

The outer tracker of HERA-B is a high rate, large size detector composed of 13 superlayers of honeycomb drift tubes made out of thin polycarbonate foil. Modules built following the initial proposal have shown immediate, unstable operation in the harsh HERA-B environment: fast gas gain drop

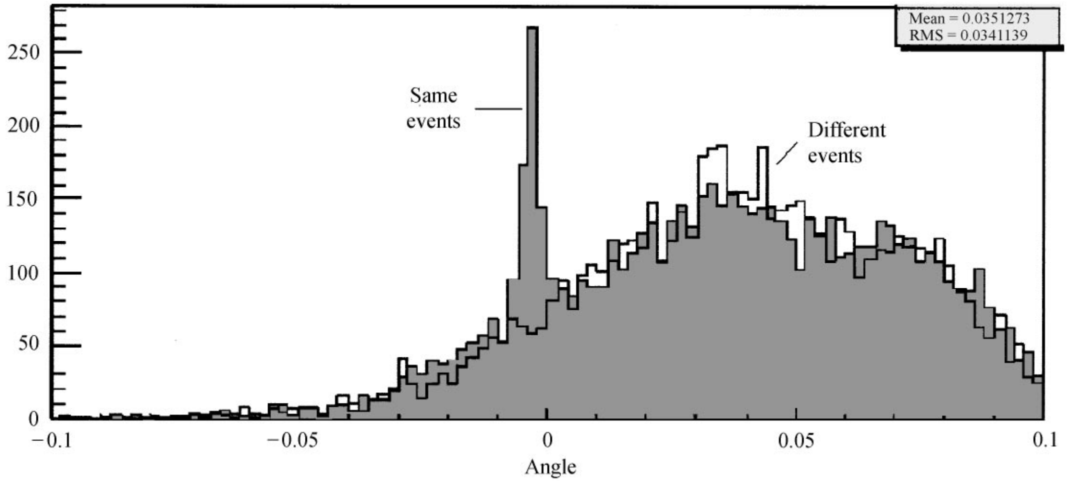

Fig. 7. Distributions of track angles reconstructed by the outer tracker and the vertex silicon detector for the same and random events.

and Malter-like currents. It is observed in different experimental set-ups that large irradiation areas and/or hadronic beams make aging effects more likely to appear. An adequate choice of the gas mixture, cathode foil, assembly materials and construction techniques led to the production of modules that have been carefully tested in different radiation environments and demonstrated stable operation for periods equivalent to several years of operation in HERA-B. The production of more than 1000 modules to complete the outer tracker for HERA-B has been resumed and they are presently being installed and commissioned in the experimental area.

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