# Chapter 1

# Subdetectors

## 1.1 Instrumented Iron

The iron return yoke is instrumented to supplement calorimetric measurement of hadronic energy flow and to allow the detection of penetrating muons over the polar angle range $4^\circ < \theta < 176^\circ$ and the entire azimuth. As the return yoke is preceeded by the electromagnetic and hadronic calorimeters, a total of about six interaction lengths of material, the amounts of hadronic energy deposited in it are not large. Calorimetric measurements with accuracy $\Delta E/E \sim 0.85/\sqrt{E}$ (E in GeV) are thus adequate. They may be used in two ways:

- to improve the energy flow measurements in all events in which there is hadronic energy;
- to identify a sample of events in which no energy leaked through the hadronic calorimeter, allowing the most accurate possible measurement of hadronic energy.

The identification of high momentum muons allows the study of much interesting physics. It is thus important that the instrumented iron provide highly efficient muon identification for muons with a momentum greater than about 5 GeV. In general, the determination of the charge and momentum of these muons may be done accurately in the vertex and inner tracking detectors and in the TPC; no independent measurement is necessary within the iron. Hence, while the accuracy of measurements in the iron must be sufficient to allow unambiguous association of penetrating muons with tracks in the central tracking system, it does not need to reach the precision necessary for momentum measurements. An accuracy of the order of 1 cm in two coordinate directions is adequate. Higher accuracy instrumentation of parts of the end-cap regions is foreseen to facilitate the determination of muon charge and momentum using accurate tracking through the end-cap iron. This includes accurate measurement at the inner face of the end-caps in order to use optimally the available lever arm for muon charge and momentum determination before the muons enter the iron. Toroidal spectrometers surrounding the beampipe outside the iron end-caps enable the study of muons at the extremes of the polar angular range.

A further requirement is that the muon system provide a trigger signal. This has two uses, firstly to indicate the presence of a muon with high momentum during the physics operation of the detector and secondly to provide a cosmic ray trigger to facilitate calibration and testing. As aspects of the instrumentation of the barrel and end-cap sections of the yoke are different, they are considered separately in the following.

### 1.1.1 Barrel

The barrel section of the iron return yoke is dodecagonal in shape, that is, it has twelve-fold symmetry. The total thickness of the iron is 180 cm. Experience at the LEP [1, 2, 3] and HERA detectors [4] and at the SLD [5] has shown that the required energy resolution can be obtained in a calorimeter with iron as passive material if sampling is done about every 5 cm (the interaction length of iron, $\lambda_{Fe}$, is 16.8 cm). However, it is not necessary to make calorimetric measurements throughout the entire yoke, which presents about $11\lambda_{Fe}$ to particles at normal incidence. For muon identification purposes, adequate reconstruction of the path of a penetrating muon can be performed if the position of the muon is determined every $\lambda_{Fe}$. The yoke is therefore constructed from 20 layers of 5 cm thick iron, followed by 5 layers of 15 cm thick iron and a final layer of thickness 5 cm.

The measurement of the hadronic energy deposited in the iron and the tracking of muons is done using resistive plate chambers (RPCs) [6]. These are inserted in 3 cm wide slits between the iron layers. In addition, two layers of RPCs are inserted between the cryostat housing the coil and the iron, providing calorimetric read-out and a space point on muon tracks. The following twenty slits each contain one layer of chambers. These allow for calorimetric read-out and the determination of, alternately, the $\phi$ and $z$ coordinates of muon tracks. The iron layer following the twentieth slit is the first which is 15 cm thick. This is followed by a slit of width 3 cm which houses a chamber instrumented to provide $\phi$ and $z$ coordinates on muon tracks. This pattern is repeated four more times until the final 5 cm thick iron layer is reached. The last layer ensures that the outermost chamber is adequately shielded from any low energy background in the surrounds of the experiment. The above configuration, illustrated in figure 1.1, leads to a total thickness of the iron structure of 2.55 m.

The proposed RPC design is as illustrated in figure 1.2. Each chamber consists of two layers of bakelite between which there is a 2 mm gas gap. The outer surfaces of the bakelite are painted with a conducting graphite layer and the inner surfaces are treated with linseed oil. Adjacent to the graphite layers are printed circuit boards on the external faces of which are the read-out strips or pads. These give coordinate

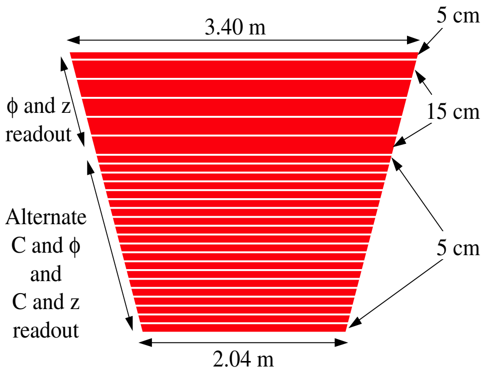


Figure 1.1: Cross section through one of the twelve symmetrical segments of the barrel of the iron return yoke showing the slits into which the resistive plate chambers are inserted; these are instrumented with calorimetric (C), $\phi$ and $z$ read-out as indicated.

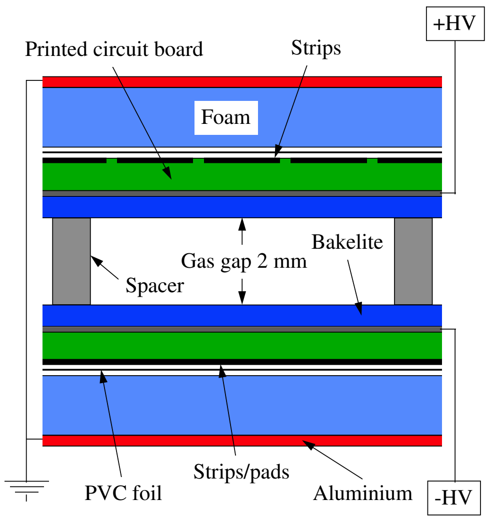


Figure 1.2: Cross section through a resistive plate chamber.

and calorimetric information, respectively. The read-out strips are of width 2.75 cm and pitch 3 cm and the pads are of dimensions varying from about $30 \times 30\,\mathrm{cm}^2$ to $60 \times 60\,\mathrm{cm}^2$. Smaller pads with digital read-out have been successfully used by the E771 Collaboration [9]. Chambers required to measure space points on muon tracks are equipped with two sets of orthogonal strips, those required to provide calorimetric information and one coordinate have one pad and one strip layer. Contact with the strips is made at the edges of the chamber, that with the pads via cables running over the surface of the printed circuit boards. A PVC foil covers the outer faces of the pads and strips. Improved mechanical stability is achieved by mounting the chambers in an aluminium foam sandwich, with aluminium supports at the chamber edges. Connections to the gas and high voltage supplies are made at these edges. The total thickness of the chambers is 2.2 cm.

Research is underway as to the desirability of using materials such as phenolic-melanine instead of bakelite, of increasing the size of the gas gap to about 6 mm [7], or of using a multi-gap structure [8]. The iron slits are wide enough to accommodate such chambers. In addition, tests of the performance of analogue pad read-out of RPCs must be made.

The sizes and locations of the chambers are chosen to ensure that no dead solid angle is generated due to the inevitable loss of chamber efficiency around the spacers. The pad sizes and locations are similarly chosen to provide a projective tower structure matching the towers in the electromagnetic and hadronic calorimeters.

### 1.1.2 End-caps

The instrumentation proposed for the end-caps of the iron yoke is similar to that described for the barrel, with the exception that at two depths within the end-caps the standard RPCs are replaced with chambers allowing more accurate position measurement, perhaps RPCs with finer strip pitch and incorporating ADC readout. These aid determination of muon charge and momentum. Studies are still underway of the necessary chamber resolutions and best locations. These depend on the details of the magnetic field configuration in the end-caps. Further information on the charge and momentum of muons in the end-cap region is obtained using the end-cap muon tracker. This consists of two orthogonal sets of five planes of hexagonal straw tubes, similar to those described in [10] and used in the inner tracker of the LC detector. The end-cap muon tracker chambers are of width 1 cm and maximum length 3 m. High voltage and gas distribution is done at the outer end of the tubes. Read-out is via TDCs at each end of the tube using electronics similar to that of the inner tracker. This allows determination of the coordinates of a muon track with an accuracy of about $100\,\mu$m in the drift direction and about 1 cm along the wire. A study is being performed of the levels of background these chambers will experience and the consequences this has for their operation. Furthermore, the possibility of using inductive strip read-out to extract more accurately the position of a hit along the wire is under investigation [11].

### 1.1.3 Toroidal spectrometers

The end-cap spectrometers each consist of a toroidal magnet sandwiched between layers of straw tube chambers. The iron magnets, similar to those used in the H1 detector [12], have inner radius 0.4 m, outer radius 3.0 m and a depth of 1.5 m. Current carrying coils are wound around the iron, producing a magnetic field of a strength of about 2 T. The hexagonal straw tubes described above are used here also, two orthogonal sets of five planes of tubes being placed before and after the magnets. This system allows the determination of the charge of muons with momenta of up to about 250 GeV in the polar angle region given by $2^\circ < \theta < 14^\circ$.

### 1.1.4 Read-out and trigger

The RPC strips are read out digitally, the pads using analogue electronics. The total number of strips is about 200 000. The pad signals are summed to give a measure of the energy deposited in the inner 10 and outer 11 layers of each tower, resulting in a total number of about 7 000 channels.

A trigger signal is formed using the strip read-out. Two trigger modes are foreseen. In the first the trigger logic searches for hit patterns corresponding to the signals expected from high momentum muons coming from close to the interaction point. In the second, designed for test and calibration purposes, much less stringent directional criteria are required in the trigger.

The chambers described above have a time resolution of about 1 nsec. In addition to the benefits this provides when used as a trigger, either for electron-positron annihilation or cosmic ray studies, this enables rejection of halo muons using the differences between their time of arrival and those of muons from electron-positron interactions.

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