14

Facilities, Assembly, Access and Integration

This chapter addresses the plan for on-site assembly of the detector subsystems and their installation in the experimental hall. It includes consideration of facilities required to assemble the detector, and presents the philosophy [BAR93] for integration of facilities and technical components in a smoothly flowing, continuous process of assembly and installation.

14.1 Facilities

Although many of the BaBar detector components will be fabricated elsewhere, the final assembly and testing procedures will be done at SLAC in the IR-2 hall where the experiment will be operated. This facility is large enough to accommodate, during the operation phase, the detector on the beam line, the radiation shield wall, and detector services on the apron (east side of the facility). The apron provides adequate working and storage space for the assembly of the detector before installation of the detector on the beam line.

Figure 14-1 shows the general configuration of the hall and indicates the designated north direction. There is a 5.96 m-wide by 8.53 m-high roll-up door at the east end of the building. All components associated with the erection and operation of this detector are designed to fit through this door. This facility is equipped with an overhead bridge crane that will be used during installation and maintenance. The rated capacity of this crane is 45 tonne with an auxiliary lift rated at 9 tonne. The crane has a maximum hook height from the concrete foundation of approximately 10.5 m and 11.1 m for the 45 tonne and 9 tonne lifts, respectively.

The building is divided into two separate areas by a concrete shielding wall. The apron in the east area will be used for the erection of the detector and initial testing. The west area will house the detector during operations. After the detector has been commissioned and experiments have begun, the apron will house the electrical, cryogenic, and data analysis support systems as well as maintenance and upgrade facilities. Additional offices for support personnel will be located on the second floor of the building.

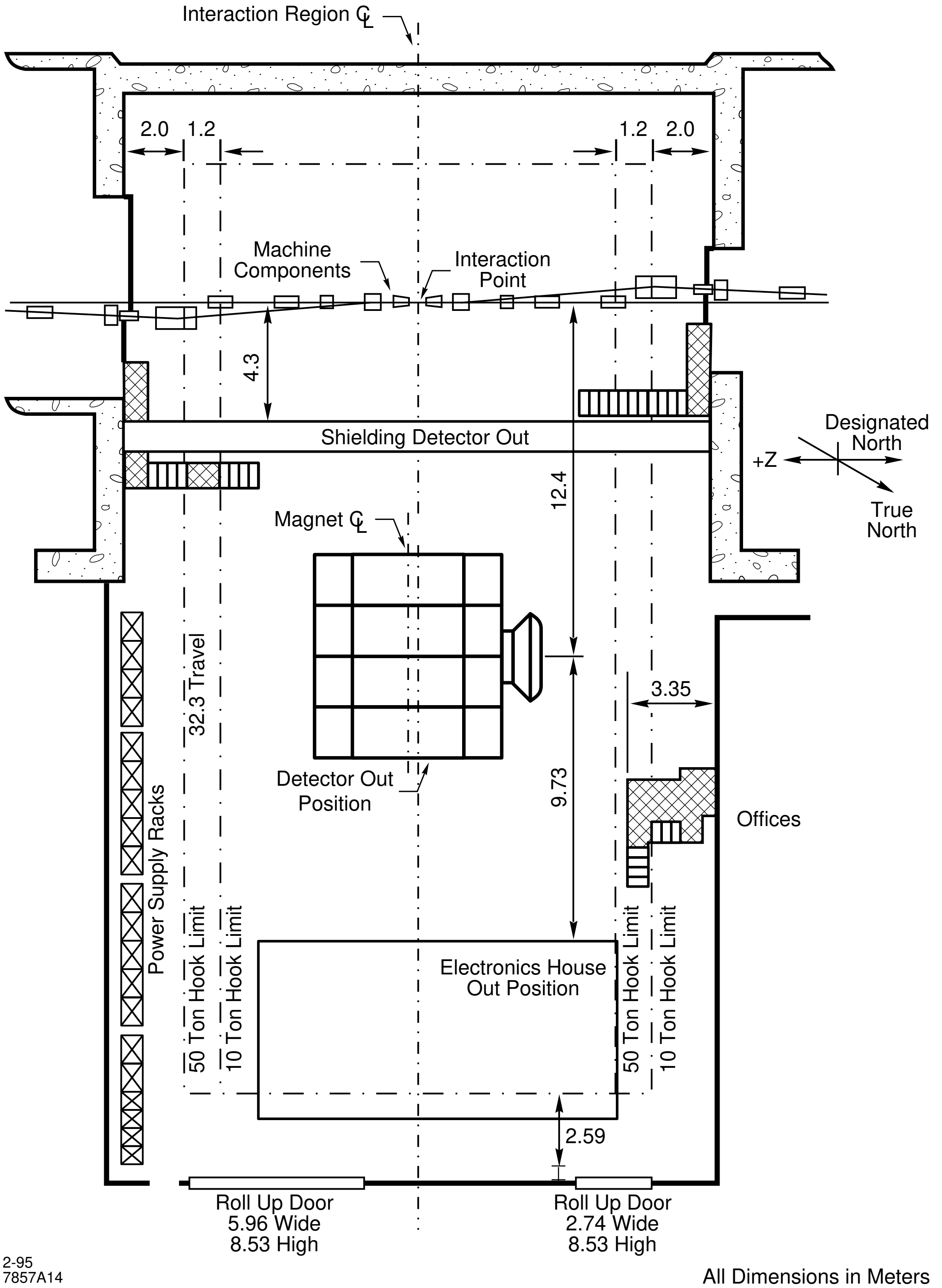

Figure 14-1. *General plan of interaction hall with detector in assembly position.*

14.2 Detector Coordinate System

The *BaBar* detector's right-handed coordinate system has its origin 370 mm axially from the center of the magnet. When installed on the beam line, the origin of the detector coordinate system will be coincident with the interaction point. The positive z axis is coincident with the detector axis and points toward the forward end of the detector. The positive y axis points up. The positive x axis points east. During assembly, the forward end of the detector is oriented toward the south end of IR-2. After installation on the beam line, the positive z direction will be set at an angle of 20 mr with respect to the direction of the high-energy beam.

14.3 Structural Support of Systems

Because SLAC is located in a seismically active area, special care must be taken to design equipment to withstand seismic activity. Meeting this demand can be greatly eased by the use of earthquake dampers. These dampers can be expected to reduce the peak acceleration in the detector with respect to the ground by a factor of 3 or more. Such dampers were used in the support of buildings in Kobe, Japan, which suffered much less damage in the 1995 earthquake than neighboring buildings supported in a conventional manner. Dampers suited to the detector are available and were used as part of the SLD calorimeter assembly fixture.

The barrel steel rests on four feet which in turn rest on earthquake dampers resting on the floor. These feet have mechanical jacks to adjust the height of the detector. Both the forward and backward end doors are supported in the same manner as the barrel steel. The exception is that during transport of the detector, the doors are rigidly attached to the barrel steel.

The coil in its cryostat is supported inside of the barrel steel. These supports are strong enough to withstand the magnetic de-centering forces on the coil and the seismic forces, which are substantially larger than the expected unbalanced magnetic forces. The calorimeter is suspended from the cryostat. The DIRC is supported by the barrel steel so that the doors at each end can be opened to service the calorimeter electronics.

It is important to protect the relative alignment of the drift chamber and the vertex detector against temperature variations in the hall. The vertex detector is supported by the B1 magnets which are, in turn, mounted inside the support tube which holds the machine components B1 and Q1. The support tube is attached to the DIRC strong support tube in the backward direction and the barrel steel in the forward direction. In order to preserve the relative alignment of the vertex detector and the drift chamber, the drift chamber is supported at its inner radius by the support tube. Large seismically induced relative motion of both Q2/Q4/Q5 pedestals with respect to the support tube must be minimized. The earthquake motion problem is exacerbated by the use of the earthquake dampers beneath the detector: the detector will probably move less than the pedestals.

14.4 Installation Overview

A preliminary installation plan, with schedule, has been formulated for the assembly of the *BaBar* detector in the IR-2 hall. The detector installation requires approximately 14 months. An additional month is needed for installation of the beam line components associated with the interaction region.

The installation critical path is driven by the configuration of the detector systems. The barrel assembly proceeds inward radially. The flux return is assembled. Then the solenoid is installed within that, and the barrel calorimeter is inserted into the solenoid. The DIRC is next installed, and the drift chamber inserted into the DIRC. The aerogel/forward calorimeter assembly is installed. The support tube is inserted, and the doors, containing their RPCs, are closed before a cosmic ray test. Each system's electronics is installed simultaneously with its mechanical components.

While the detector is being assembled and tested in the east end of the IR-2 hall, a concrete shielding wall is placed between the detector and the interaction point so that studies of the machine components may occur during detector assembly. The eastern edge of this wall is located approximately 4.5 m east of the interaction point.

After testing of the assembled detector is complete, the concrete shielding wall is disassembled, and a transport mechanism is used to move the detector to its final position in the PEP-II colliding beams. Figure 14-2 shows the detector in its operational location.

14.5 Detector Component Installations

14.5.1 IR-2 Detector Hall Preparation

Base plates of 50 mm nominal thickness are provided on the floor of the experimental hall. The plates are leveled using hex bolts and secured to the concrete foundation with adhesive anchors. The tops of the plates are positioned 60 mm above the floor of the experimental hall. After erection and leveling of the base plates, the space beneath the plates is grouted solid with a nonshrinking, cementitious, flowable grout. The purpose of the grout is to provide

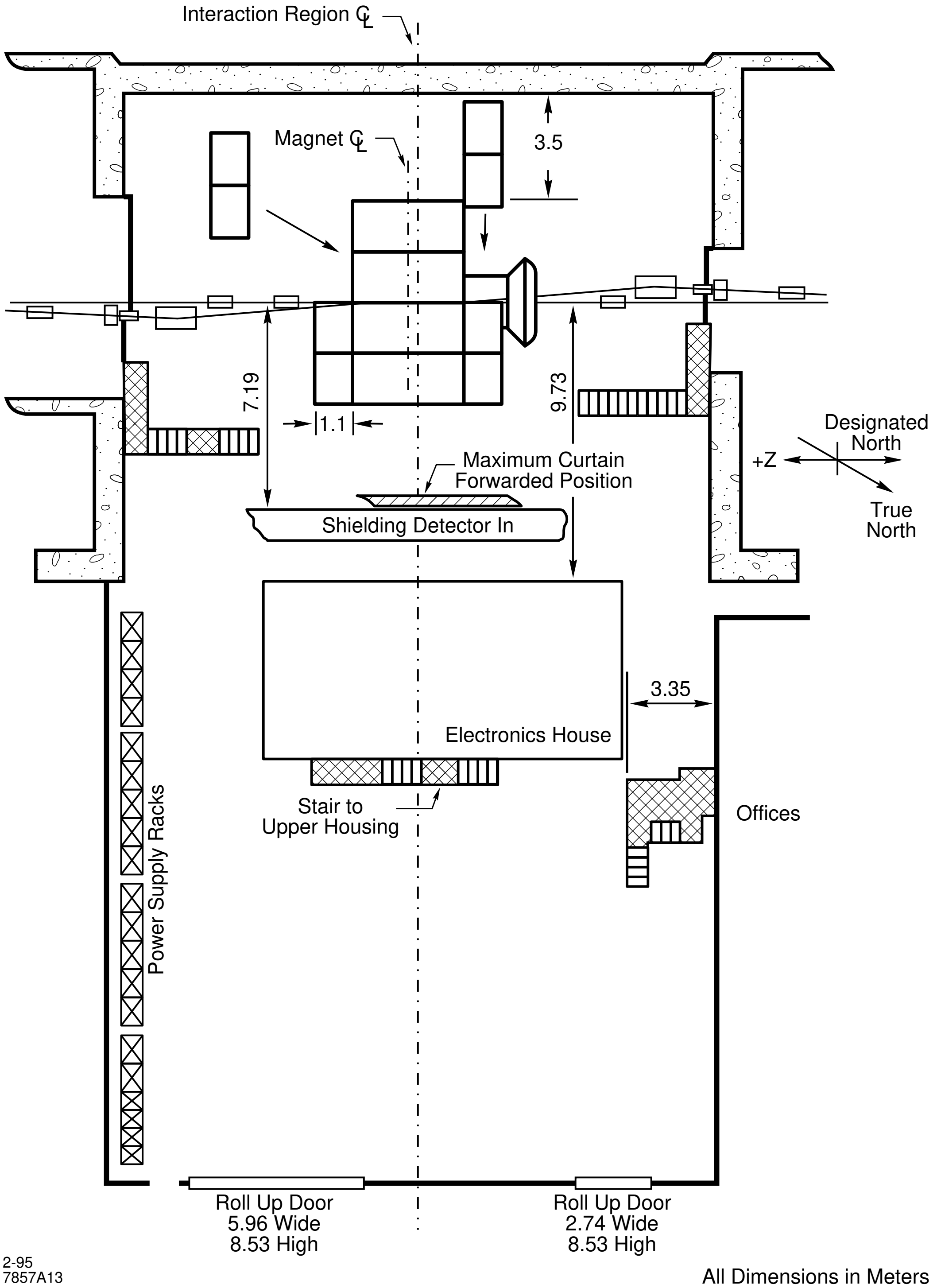

Figure 14-2. *General plan of interaction hall with detector on beam line.*

the base plates with a level supporting surface and to provide uniform bearing between the plate and the concrete foundation. The grout is placed as a continuous flow without air pockets and allowed to cure 28 days prior to commencement of the erection of the barrel flux return [KRE93].

14.5.2 Coil and IFR Installation

The assembly of the barrel flux return assembly is begun at a point approximately 12.4 m east and 0.5 m north of the interaction point. The barrel axis is parallel to the bridge of the overhead crane. During assembly, it will be necessary to move the detector barrel toward the south end of the building. The magnet barrel is a self-supporting structure and houses its own transport mechanism. The transport mechanism will be tested before installation commences. Figure 14-1 shows the location of the detector in IR-2 during the assembly process.

The barrel flux return is composed of six inner blocks and six outer blocks. The barrel RPCs are installed in these blocks while the blocks are horizontal. The muon system is serviced by a variety of signal cables, high voltage cables, and gas piping. All of the connections to the individual detectors are made during the assembly process. During the assembly process, the 45 tonne capacity overhead crane is used to lift the blocks into place. Figure 14-3 shows the assembly procedure.

The electronics platforms and stairways will be partially preassembled into large components and installed on the outer surfaces of the barrel flux return at this time. The manifold connections for the barrel RPCs are now made. These connections link the barrel detectors to the hall utilities [TRI92]. These manifold connections are located on the upper service platform. The manifold gas utility feeds run along the west wall of IR-2 and connect with the detector at both ends of the hall. The signal cables and high voltage cables are routed to crates located externally to the detector on the electronics platforms. The detailed routing of services from the RPC detectors to the crates and manifolds is still being investigated. All connections are inspected and tested to ensure proper operation of the system.

The solenoid junction box and cryo-chimney are mounted to the cryostat prior to its installation. The cryostat is installed into the barrel flux return from the backward direction as shown in Figure 14-4, using a beam and carriage system that will transport the coil's gravitational load along the axis of the beam. To install the coil into the magnet steel, a structural steel beam, referred to as the transfer beam, is inserted through the bore of the coil from the backward side. There are three tripod supports for this beam. One is located at the north end of the assembly area and a second at the south end. The third tripod support, the floater, is positioned on either the north or south side of the detector, depending on the device to be installed. For insertion of the coil, the floater is positioned on the north

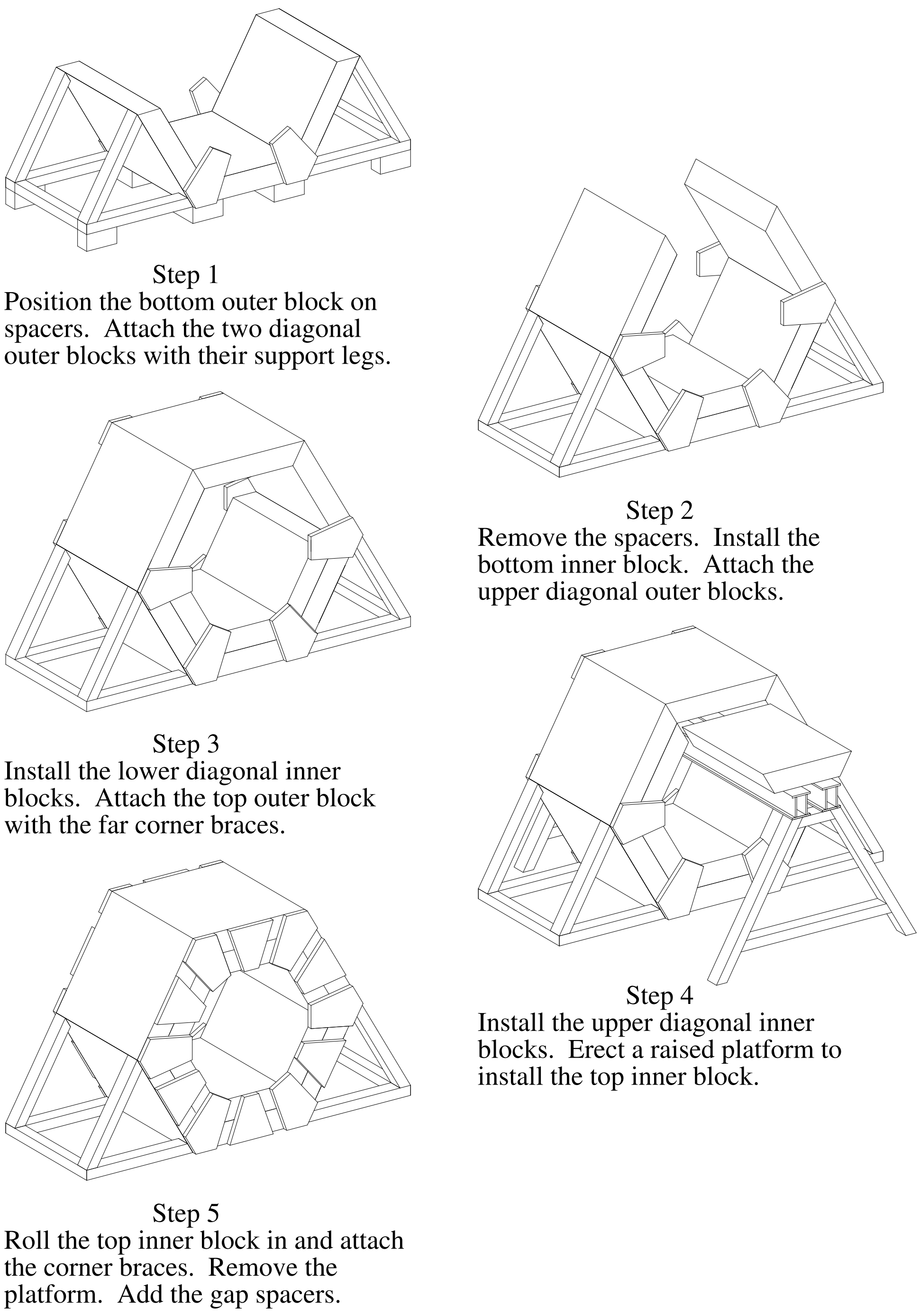

Figure 14-3. *Magnet barrel assembly.*

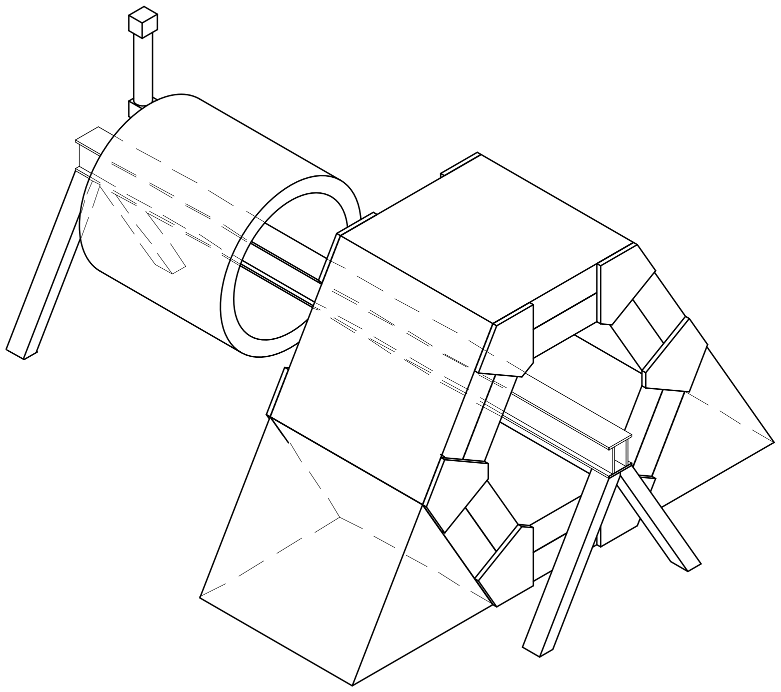

Figure 14-4. *Installation of the Solenoid using a beam and carriage system.*

side. The transfer beam is temporarily supported on the two tripod supports on the north side and the strongback carrying the barrel calorimeter is positioned on the forward side of the barrel flux return. The transfer beam is then threaded through the coil and secured to the tripod located at the south end of the assembly area. The tripods are provided with x and y translation capability to enable accurate alignment of the coil relative to magnet steel. The coil will be cooled and the cryogenic safety systems tested. The cryogenic services are supplied via flexible transfer lines from the helium liquefier/refrigerator which is located outside the IR-2 experimental hall, near its southeast corner. The flexible transfer lines are routed along the building periphery from the refrigerator to the west wall. These lines pass through the wall to the cryo-chimney. This chimney is accessible from the upper platform. The location of the magnet dump resistor and the magnet power supply has not been decided. It is preferred that the power supply be installed on the apron outside the radiation wall to permit access for maintenance.

The DIRC support structure is mated to the backward end of the barrel flux return assembly using the overhead crane. This assembly consists of the DIRC strong support tube and the structural bracing that connects the assembly to the barrel steel. The structure is properly aligned and bolted into place.

Each endcap flux return is assembled as two doors. Each end door has a transport mechanism built into its base. Using the overhead crane, an assembly of 20 vertical plates, containing RPCs which were installed along with cables and services while the assemblies were horizontal, is mounted on the base along with a 30 tonne counterweight. The counterweight helps minimize the potential for overturning during movement of the doors. The forward end doors also contain the plug assembly that is used to divert the magnetic flux away from the beam line components. The doors are attached to the barrel for magnet testing. The backward steel plug is temporarily inserted into the backward end doors and removed after field mapping is completed. Services for the door RPCs are connected.

The coil is powered at low current and the electrical safety systems tested. While the current is ramped up, the cooling system and decentering forces are monitored. It may be necessary to de-energize the magnet and adjust the position of the solenoid at this time to minimize the forces on the coil due to nonuniformities in the flux return. After initial testing is complete, the doors are opened, and the field mapping hardware is installed. NMR probes are installed to monitor the field during field mapping. These probes will be removed after field mapping, and reinstalled after drift chamber installation. After the field is mapped, the doors are removed and stored against the wall of the IR-2 experimental hall, and the field mapping hardware is removed. The location at which the end doors are to be stored has not yet been decided.

14.5.3 Barrel Calorimeter Installation

After magnetic mapping is complete, the installation of the barrel calorimeter commences. The fully aligned, cabled, and tested barrel calorimeter arrives at IR-2 from the calorimeter assembly building, B109. A system test is performed to ensure that no damage occurred during transport to the hall. A final check of the module alignment may also be done at this stage if necessary.

The installation of the calorimeter into the coil bore is very similar to the installation of the coil into the magnet steel. Once the transfer beam has been threaded through the coil a structured beam is bridged between two pins on each side of the calorimeter and tied to the end-flange pick up points. To maintain internal alignment of modules the pickup points and support points must be the same. Figure 14-5 shows the installation method and the transfer of loads. The flange on the forward end of the calorimeter support structure is bolted directly to the end flange of the solenoid cryostat. Eccentric pins on the end flange of the cryostat allow the horizontal and vertical positioning of the calorimeter. The backward end of the calorimeter support structure is secured to the cryostat using adjustable radial support arms. Shimming may be required between the flanges of the calorimeter and the cryostat.

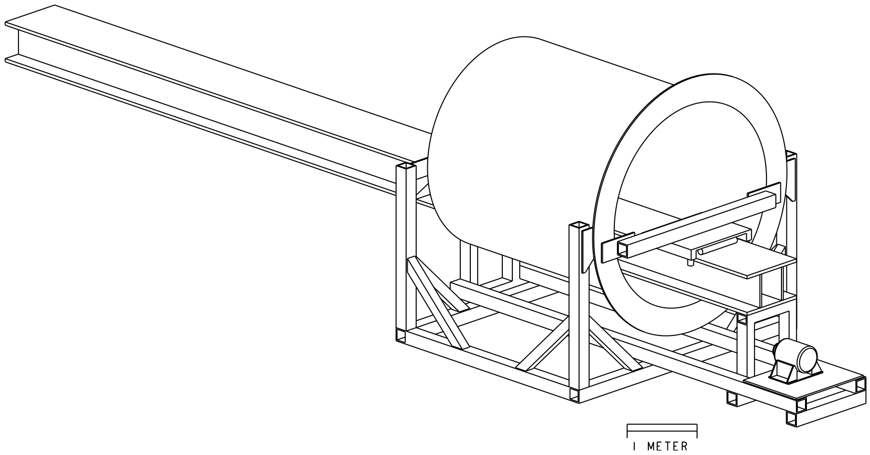

Figure 14-5. *Sequence of barrel calorimeter installation into the coil.*

The distribution system for the freon cooling for the barrel calorimeter is installed at this time. It consists of multiple manifolds which are routed to the calorimeter along the cableways between the barrel flux return and the forward and backward doors. The fiber-optic cables and the dry nitrogen supply and return lines are also installed in this space.

14.5.4 DIRC Tube Assembly Installation

The central support tube containing the DIRC quartz sectors and the standoff box assembly are transported to IR-2 while the barrel calorimeter is being installed.

The transfer beam is removed from the forward end of the detector barrel, which is then moved 0.87 m to the south. No additional movement of the barrel will be necessary prior to installation into the beam line. The floating tripod support is then moved to the forward end of the barrel.

Using the overhead crane, the DIRC tube assembly is positioned at the backward end of the barrel. The transfer beam is then threaded through the DIRC tube assembly and the bore of the barrel calorimeter, and secured to the tripod support stands. The gravitational load of the DIRC tube assembly is transferred to the transfer beam and the DIRC tube assembly is rolled into the bore of the barrel calorimeter. The DIRC is aligned and secured to the strong support tube of the DIRC support structure. The central support tube is then suspended at the forward end from the barrel calorimeter end flange using temporary supports. The transfer beam and the tripod support stands are removed from the barrel and moved to storage.

Using the overhead crane, the DIRC standoff region is now mated to the backward flange of the DIRC strong support tube and securely fastened. A structural steel pedestal is then inserted and installed on the lower surface of the strong support tube. The pedestal is provided with a set of rails that extend beyond the backward end of the DIRC standoff box.

14.5.5 Drift Chamber Installation

While the DIRC is being installed, the drift chamber and its assembly fixture are mated to an insertion frame. The base of the insertion frame is provided with rollers and also with vertical height adjustment capability. The drift chamber temporary backward support frame is inserted through the DIRC assembly from the backward end and secured. The drift chamber is then inserted into the bore of the DIRC central support tube from the forward direction. The drift chamber is properly positioned and temporarily cantilevered from the its backward support frame. The drift chamber insertion frame is then removed and taken to storage. The temporary supports that hold the DIRC central support tube are then removed from the forward end of the barrel.

The signal cables, high voltage cables, and gas lines exit the drift chamber from the backward end where they are routed outward radially to the inner surface of the DIRC strong support tube. They are then routed in z along this surface until they exit the detector at the backward end of the DIRC standoff box. The detailed routing of these cables and gas lines is under evaluation.

14.5.6 Aerogel/Forward Calorimeter Installation

The assembly frame, carrying the loaded and tested endcap segment, will be transported to the experimental area where the endcap segment is transferred to the installation jig. The aerogel segment is attached to the front of the calorimeter. The half-endcap is brought into its mating position with the barrel, defined by conical pins locating into holes drilled into the barrel end flange, and fixed in place, as shown in Figure 14-6. At this stage in the installation, there is 5–10 mm between the adjoining barrel and endcap conical surfaces. The endcap is aligned in the vertical plane to ensure uniform clearance, and final fixing holes drilled. The endcap is now in its *park* position.

The second endcap is similarly installed in its park position and the two segments bolted together to form the complete endcap, making a conic section. Provision is made for the endcap to be wound into the barrel, using adjustable bolts at three points on the barrel flange, and contact switches used to enable precision mating. Removal of the endcap involves winding it back to its park position, unbolting the two segments, attaching each in turn to

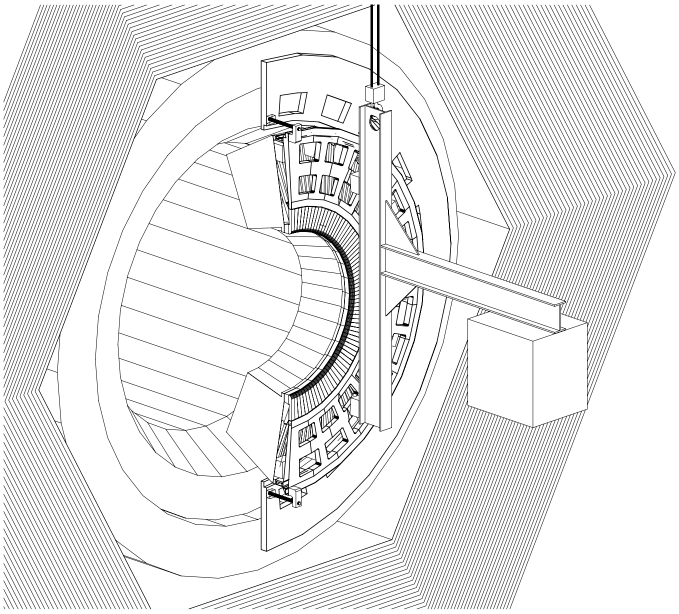

Figure 14-6. *Schematic view of the installation of an endcap segment including mating to the barrel forward flange. (The aerogel is not shown.)*

the installation frame and removing them one after the other. This procedure decouples the endcap from the barrel and ensures that the alignment of the latter is not disturbed.

The distribution system for the freon cooling for the forward calorimeter is installed at this time. These cooling tubes are routed along the cableways between the barrel flux return and the forward end door. The high voltage and signal cables for the aerogel are routed out and around the forward calorimeter. They also exit the detector radially through the space provided between the barrel assembly and the forward end door.

14.5.7 Vertex Assembly Installation

The vertex assembly that contains the beam pipe, vertex detector and the two B1 and two Q1 beam line magnets is installed from the forward direction. This is done by cantilevering the assembly from a temporary external support fixture and carefully inserting the assembly through the bore of the drift chamber using the overhead crane. When the vertex assembly is properly positioned, the permanent drift chamber supports are installed on both ends. The vertical pole structures that support the vertex assembly from the barrel flux return are installed in the backward and forward ends of the detector. The temporary supports on the drift chamber are then removed.

14.5.8 Backward End Plug Installation

Using the overhead crane, the backward end plug is mated with the DIRC rail system. The backward end plug is rolled into position and securely fastened to the DIRC strong support tube.

14.5.9 Electronics House

The initial processing of data occurs in the detector-mounted electronics. This equipment is not accessible while beams are circulating. The closest accessible electronics are located in the electronics house. The quantity and layout of the electronics located there are being evaluated. The electronics house is mounted to a structural steel frame. The frame is provided with heavy-duty rollers similar to those used for the detector barrel. Prior to movement of the detector into the beam line, the frame of the electronics house is mechanically connected to the barrel support structure so that they move as a single mechanical unit. The concrete radiation shielding wall is re-erected between the detector and the electronics house after the detector is moved onto the beam line.

14.5.10 Detector Transport System

The detector transport system, which is similar in concept to those used on previous detectors, is used to move the detector in the IR-2 hall. It consists of a structural steel frame with two hydraulic cylinders. The frame is bolted to the floor base plates, and the cylinder rams are pinned to the detector assembly. Pressurizing the hydraulic cylinders extends the rams, thus pushing the detector. When the ram reaches its maximum travel, the transport system is removed and the rams retracted. The system is then reinstalled closer to the detector and the process is repeated until the detector is located in the desired position.

14.5.11 Final Position of Detector in Beam Line

After the detector has been moved to the interaction point, it is rotated 20 mr about its vertical axis using the detector transport system. The support legs of the detector rest on seismic isolation pads; the pads will absorb energy caused by ground motion during an earthquake. Jacks provided in the barrel assembly allow the vertex detector to be aligned vertically with the interaction point. The detector legs are shimmed appropriately at the seismic isolation pads and secured to the concrete foundation.

14.5.12 Service Space

Services for the various systems enter the detector via three paths. The first path is radially out between the barrel steel and the door. A gap of 100 mm is provided between the coil cryostat and the door for calorimeter services. The blocks between the barrel steel and the door occupy about 40% of the azimuth. These are placed at 60° intervals at the corners of the hexagon. Beyond the coil, a gap of 150 mm is provided between the barrel steel and the door. This allows space for the IFR services. All services passing this way will be in closed conduit to assure that they fit in the space available and to protect them when the door is open and when the door is being closed.

The services for the drift chamber exit the detector at the backward end along the inside of the DIRC tube. They proceed through the DIRC and around the water tank.

Routing of vertex detector services has not been resolved.

14.6 Detector Maintenance Access

Ready access to detector components eases the reliability requirements on those components, thus reducing cost without compromising performance. The ability to make accesses of short duration when needed to ensure data quality reduces loss of beam time. Parasitic use of accelerator downtime allows repair of less pressing detector problems if access times are commensurate with typical planned and random accelerator outages [BAR93]. The design timescale for access for minor repairs is a few hours to a day. Annual accelerator shut-downs will be used for more extensive repairs and for upgrades. Access to the electronics house is not limited. Access to electronics, power supplies, and services located inside the radiation wall but outside of the detector is possible by turning off the beams. All DIRC readout components can be repaired in this way. The timescale for such a controlled access is less than an hour.

Repairs that require access to the inside of the detector will be discussed in the balance of this section. Before the doors are opened, the solenoid is de-energized. However, the solenoid will remain cold. Only when specifically required will the solenoid be warmed to room temperature.

Forward Detector Internal Access

Two schemes for access into the detector at the forward end are under consideration. In the first, the doors are moved outward at an angle of 30° relative to the beam line. This option provides 4.6 m clearance between the barrel and the forward doors. In the second, the doors are moved outward at an angle of 85° relative to the beam line. This scheme provides minimal but acceptable access to the RPCs and minimizes potential conflicts with machine components Q2, Q4 and Q5. In both schemes, the barrel and endcap calorimeter electronics are readily accessible. The aerogel inner ring of readout devices can also be repaired. The time needed to open the doors is approximately one hour. In order to access the end of the drift chamber or the outer ring of aerogel readout, it will be necessary to remove one or both endcap segments. This requires use of special fixtures during a longer access.

Backward Detector Internal Access

Inner detector access in the backward region is complicated by the extension of the DIRC assembly through the backward end doors. The barrel RPC detectors and the electronics on the backward end of the barrel calorimeter are accessed by opening the backward flux return end doors. These doors open perpendicular to the magnet axis. Access to the vertical DIRC support plate and the cryo-chimney is also available. The time needed to open the backward doors is approximately one hour.

The backward end of the drift chamber and some of the vertex detector electronics can be accessed by removing the backward end plug. This requires installation of a special jig and rails. This operation will take about one shift. The backward end plug is rolled back until it is positioned beyond the DIRC standoff box. It is then removed using the overhead crane. Once the plug is removed, it is possible to enter the interior of the DIRC along the beam line to access the face of the drift chamber. Quarters will be tight, since the inside diameter of the DIRC is only about 1.6 m. Special jigs will provide a temporary floor for access.

Repair of drift chamber wires requires that the forward doors be opened, the forward calorimeter and aerogel segments be removed, and the backward end plug removed.

Vertex Detector Access

Access to the vertex detector will require removing the support tube from *BaBar*. This requires dismantling numerous beam line components and will entail substantial downtime.

14.7 Detector Integration

The Detector Integration Group is responsible for ensuring integration of the detector subsystems and of the detector with the collider and the experimental facility. The detector

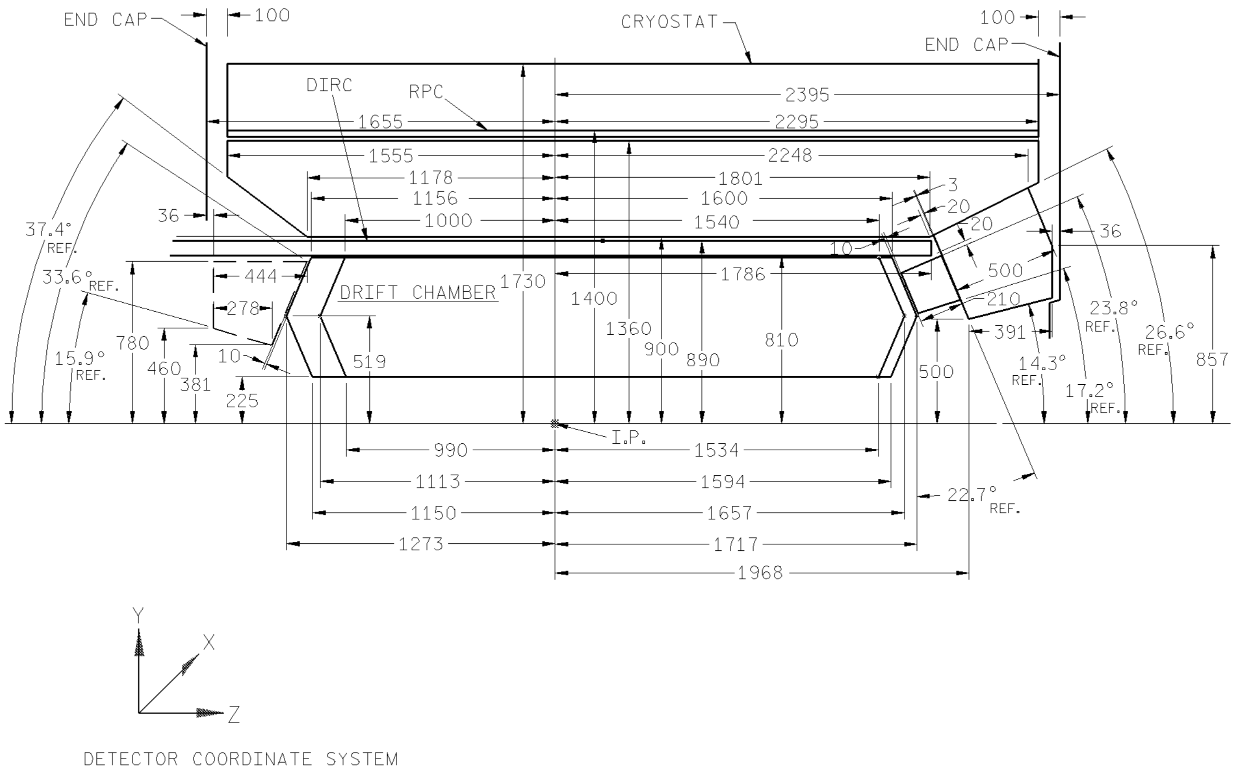

Figure 14-7. *Overall detector dimensions(mm).*

integration group maintains control of the physical interfaces including envelope dimensions, mechanical attachments, obscurations, cable and utility routing, and alignment [KIR93]. Figure 14-7 shows a cross section of the central section of the *BaBar* detector indicating the subsystem envelopes.

The detector integration group has the responsibility for installation of the detector elements in the experimental hall as well as for preparation of the experimental hall prior to commencement of the detector assembly process.

14.7.1 Assembly Clearances

In order to avoid damage to the detector systems during the assembly process, an inter-system clearance of 20 mm is generally required. The 20 mm criterion is based on experience with SLD. The 20 mm clearance is intended to provide for inaccuracies in fabrication of the large parts, for tolerance build-up, and for assembly without extremely elaborate guidance fixtures. In addition, the clearance must be adequate to accommodate any relative motion of systems during an earthquake. As a typical example, the clearance between the cryostat and the inner flat RPC is 20 mm.

An exception to the 20 mm rule has been made for the clearance between the drift chamber and the DIRC central support tube because it is expected that both systems can be made with close circularity and straightness tolerances and that a simple but effective installation fixture can guide the drift chamber inside the DIRC for assembly. Another exception is the gap between the aerogel and the forward calorimeter, where only 3 mm are provided because the aerogel will be mounted directly on the calorimeter. Only 10 mm is provided between the aerogel and the drift chamber because these objects are not large and because there is good visibility available during the assembly process. The clearance between the forward calorimeter and the endcap steel is 36 mm because the steel is not expected to be very flat and is expected to deflect by about 8 mm due to magnetic forces.

14.7.2 Good Neighbor Policy

Each system must obey a Good Neighbor Policy, *i.e.,* the system must not pass its problems to its neighbor without the neighbor's agreement. For example, each system must dispose of any heat it generates without simply passing it on to its neighbor. This is particularly important in cases in which temperature stability is required for a system for mechanical alignment or accuracy of response. Each system must return its temperature to ambient by whatever means is required, and do so within its own geometrical envelope.

Heat is not the only operating problem. Electrical and mechanical noise must also be considered. Each system must take care to prevent or contain such interference with its neighbors.

It is expected that each system will take care to minimize the risk of leakage of fluids or gases which can harm other systems. For example, a leakage of helium could damage the phototubes of the DIRC, and water could damage CsI crystals.

14.7.3 Common Services

Use of common fixtures in the assembly process will be optimized. For example, the fixture used to install the cryostat may be suitable for installing the barrel calorimeter.

Easily erected, modular scaffolds will be used during the assembly phase and during the operation stage. Such scaffolds were employed to great advantage in SLD.

A centralized system will provide HVAC (heating, ventilation, and air conditioning), clean AC power, emergency power, uninterruptible power, and oxygen deficiency and fire alarms.

References

[BAR93] B. Barish *et al.*, "GEM Technical Design Report," GEM–TN–93–262 (1993).

[KIR93] T. Kirk *et al.*, "Solenoidal Detector Collaboration—Project Management Plan," SGT–000006 (1993).

[KRE93] H.J. Krebs *et al.*, "Solenoidal Detector Collaboration—Preliminary Design Report—Muon Barrel Toroid Support System," SDT–000168 (1993).

[TRI92] G. Trilling *et al.*, "Solenoidal Detector Collaboration—Technical Design Report," SDC–92–201 (1992).