Part V

Integration, Installation, and Commissioning

Contents

Chapter 13

Integration, Installation, and Commissioning

13.1 Introduction

The purpose of this task is to coordinate the installation, integration and commissioning of the various detector components and the mechanical and electrical systems that comprise the BTeV spectrometer.

The BTeV detector is different from the two “central detectors”, CDF and D0, currently operating in the B0 and D0 Interaction regions. CDF and D0 are hermetic detectors with a nested barrel geometry in which each barrel layer occupies a cylindrical annulus that is supported off of an adjacent radial layer. Large “endcaps” fill the upstream and downstream end of the barrel and make its contents somewhat inaccessible. In contrast, BTeV has an open, linear geometry in which each detector occupies its own space along the beamline and is self-supporting. The installation, integration, and maintenance of a detector with this geometry is less demanding than for a hermetic, central region detector. It also permits a piecewise installation strategy. However, even with these advantages, the installation and integration of the BTeV detector in the small C0 enclosure will be a challenging task that will require careful planning and coordination.

Two things complicate the installation of the BTeV spectrometer. First, the C0 collision hall does not have a large crane, hence all components must be rolled into the hall. Second, the installation must not interfere with CDF and D0 data taking during Run II. The installation will need to occur during scheduled down days, upgrade shutdowns, and occasional repair periods of the Tevatron accelerator.

The integration of the various detector components must accommodate two important considerations. First, the physics requirement of a very low mass detector must be met. Second, the integration plan must help minimize the installation time needed in the C0 collision hall as noted above.

The commissioning of the BTeV spectrometer will also be influenced by the installation and integration requirements. First, commissioning procedures for the various detectors must be designed to allow as much commissioning as possible before installation in the C0 hall. Second, the capability for remote commissioning after installation must be incorporated in the design.

Considerations which have gone into determining these requirements include:

- The physics goals of the experiment
- The physical characteristics of both the events of interest and background events
- The physical characteristics of the C0 detector and assembly halls
- The lack of a crane and the limited access to the C0 collision hall
- The use of existing components and systems at Fermilab
- The ES&H issues

The current design of the BTeV detector includes one spectrometer arm along the forward antiproton rapidity direction with a large vertex dipole magnet at the interaction point in C0 and four large iron toroidal magnets, two at either end of the hall. It would be very difficult to install the large, heavy elements - the Vertex Magnet and the toroids - after other components are already in the hall. Therefore, these items will be installed first.A system of overhead tracks or suspension systems will then be installed to support the various detector units after they are rolled into position.

Following this introduction we describe the boundaries between this subproject and the building and Tevatron outfitting subprojects on the one hand and the detector subprojects on the other hand. This is followed by a section describing the requirements for the installation, integration and commissioning. Next we present details of the infrastructure (physical, mechanical and electrical) as well as the detector grounding scheme which is an integrated feature of this infrastructure network. The subsequent section provides an overview of the detector installation correography. Finally we present the details specific to each sub-detector installation.

13.1.1 Interface to WBS 2.0 and WBS 3.0

The detector installation interfaces with the other two major elements of the project, the C0 building outfitting and the C0 interaction region subprojects. The interfaces apply to equipment responsibility and the scheduling of access to various locations of the C0 building. The decision on which group is responsible for providing equipment is generally based on two considerations. Who can perform the work most efficiently and how dependent is the equipment on the detail design of the detector. The schedule interfaces between the Detector installation and the Interaction Region Installation are minimal. The schedule interfaces between the Detector Installation and the C0 building outfitting are managed by phased work in the C0 building which provides beneficial occupancy in sections as required for Detector assembly and installation.

Figure 13.1: Responsibility breakdown between WBS 1.10, WBS 2.0 and WBS 3.0.

13.1.1.1 Detector related equipment provided by WBS 2.0

The Interaction Region subproject provides 5 permanent items of equipment in the C0 building and Tevatron tunnel collision hall interface. The first item is the Low Conductivity Water (LCW) pipe in the assembly hall and collision hall that is used for testing and operation of the Vertex and Toroid magnets and power supplies. The second item is barrier walls at the interface Tevatron tunnel and collision hall that provide Oxygen Deficiency Hazard (ODH) isolation of the collision hall from the Tevatron tunnel. The third item is movable shielding walls at the clam shell around the low beta quadrapole magnets and which are retracted into alcoves located in the Tevatron tunnel just outside the collision hall. The fourth item is a rigging and hoist arrangement that can be used to remove and replace the compensating dipole through the Tevatron tunnel. The fifth item is the isolation gate valves that allow the detector beam tube sections to be isolated from the Tevatron vacuum. Finally the Interaction Region subproject provides a temporary 4" beam pipe through the collision hall with removable sections that are replaced as the permanent detector beam pipe sections are installed.

13.1.1.2 Definition of requirements for infrastructure provided by WBS 3.0

The C0 outfitting subproject constructs the architectural finishes, mezzazine (counting room) structures, heating ventilation air conditioning (HVAC), process piping systems and power required to support the BTeV detector. The Detector subprojects communicate their requirements to the installation and integration subproject (WBS 1.10) which collects, organizes and verifies the data and transmits the information to WBS 3.0 personnel. The data is provided in a variety of formats from tabular to reports and specifications. The data includes tables on heat loads and power consumption in each zone of the C0 building. It also includes specifications on power isolation, grounding and backup power generation needs. The C0 outfitting details are been provided for a concurrence check by the Detector subprojects to assure that the Detector requirements are met and that there is no duplication between the equipment provided in WBS 1.10 and WBS 3.0.

13.1.2 Interfaces to Detector subprojects

The Installation and Integration (WBS 1.10) subproject needs to interface with the detector subprojects in a variety of ways. Information is exchanged on infrastructure needs and solutions. Installation steps are described for each detector subproject with estimates of the required labor and equipment. Finally, schedule information is exchanged about the dates when various pieces of equipment are available and needed.

To establish the requirements for infrastructure, the installation and integration subproject collects and organizes the requirements for power, cooling, gas racks, etc from each of the subprojects. This data is organized and displayed in a variety of tables that are accessible through the document database (DDB). The resulting infrastructure designs that will address these needs will be described in a series of documents and drawings that will also be accessible in the DDB.

Installation plans are generated by each detector subproject that includes a narrative of the installation steps and estimates of the labor and equipment required to accomplish these steps. The plans also indicated what labor resources will be provided by collaborating institutions. These plans are used for developing a baseline schedule and will be used throughout the project. Additional details will be added as they are developed and these installation plans will be a guide to final installation procedures and specifications. The installation plans also define the boundaries of responsibilities between the detector subprojects.

Schedule information on key pieces of equipment is listed in a series of tables titled producer milestones. The producer milestones are accessible through the document database (DDB). The producer milestone tables list key equipment and the date that equipment is available for assembly or installation. The producer milestone information is used with schedule information for C0 building beneficial occupancy and Accelerator shutdown schedules to develop an installation and integration schedule for the complete detector.

13.2 Requirements

This section describes the high-level requirements for the installation, integration, and commissioning of the BTeV spectrometer that are necessary for BTeV to achieve its physics goals.

- The primary goal of the installation coordination is to take maximal advantage of Tevatron down periods throughout the duration of the project in order to install the complete BTeV detector in the C0 collision hall.
- The primary goal of the integration task is to minimize the interferences between the various detector components while simultaneously minimizing the amount of material in the aperture of the spectrometer.
- The primary goal of the commissioning coordination is to ensure that the spectrometer can be completely commissioned in a minimal amount of time.

13.2.1 Installation Requirements

All larger sub-assemblies, to the extent possible, must be staged or assembled in the C0 assembly hall and then, in a time efficient, coordinated way, rolled into the C0 collision hall. They must then be surveyed and adjusted into precise position with respect to the Tevatron. Significant time for cable installation, electrical hookup, mechanical support, and gas interconnections must also be scheduled once the detectors are in the collision hall.

- All spectrometer components must be assembled into sub-assemblies that can be efficiently rolled into the collision hall, installed on the beam line and surveyed and aligned to the Tevatron.
- A detailed timeline must be developed for the assembly and staging of each subsystem in the C0 assembly hall and for the efficient installation of the components in the C0 collision hall as Tevatron down time permits.

- A detailed plan must be developed for the efficient and safe installation of the gas manifolds and gas system monitoring needed by the various detectors in the C0 collision hall.
- A detailed plan for the installation of all cables and for connecting the electrical systems must be developed. This plan includes the electrical isolation and grounding plan for the detector, collision hall electronics and counting house electronics. This plan will also include the mechanism for enforcement of the isolation and grounding rules.
- All spectrometer components must be designed with survey fiducials that maximize the amount of internal survey alignment that can be done during initial assembly and staging in the assembly hall and which minimize the time needed for final alignment or realignment in the C0 collision hall.
- A coordinate reference system for the C0 collision hall must be delineated and must be maintainable over the life of the experiment. This coordinate system should be anchored on the walls of the C0 collision hall and must include the Vertex Magnet as a fundamental element in the primary coordinate system and survey. Provision must be made for easy accessibility to this primary survey reference system as individual components and systems are installed. The survey must be reproducible throughout the course of the experiment.

13.2.2 Integration requirements

The performance ofthe BTeV spectrometer depends on minimizing the amount of material in the spectrometer aperture and also on ensuring that the various detector subsystems fit together in a way that facilitates their installation and maintenance.

- The suspension systems for the various detector elements must be designed to minimize the number of radiation lengths of material in the spectrometer aperture. Similarly any services that will run within the spectrometer apperature should be carefully designed to minimize multiple scattering and generation of secondaries.
- The suspension systems of the various detector elements must be designed to allow efficient installation and maintenance.
- The various electronic assemblies needed for the spectrometer must be designed to allow easy access and maintenance of the detectors and their associated electronics with a minimum of interference between different systems.
- A cable routing plan must be developed for the complete spectrometer. The cables needed for spectrometer readout and monitoring must be designed to allow quick installation and maintenance. They must be kept out of the active aperture of the spectrometer as much as possible. They must be designed to operate (consistent with design goals) over the expected lifetime of the experiment.

13.2.3 Commissioning Requirements

The BTeV spectrometer components must be tested, calibrated and commissioned before data on B-meson decays can be productively acquired. The commissioning must be accomplished with a minimum of access time into the C0 collision hall. The various components of the BTeV spectrometer will be declared commissioned when they have met the requirements stated in their respective requirements documents, and when all as-built construction, operation, and maintenance documents have been assembled. The overall BTeV spectrometer will be declared commissioned when all as-built, operation and safety documentation has been assembled and when the complete spectrometer is installed and commissioned in the C0 collision hall.

- To the greatest extent possible all spectrometer components should be tested before they are installed in the C0 collision hall. All testing that must be done after installation in the C0 detector hall should be designed to facilitate remote testing to the greatest extent possible. Commissioning of all components and systems must include commissioning all DAQ electronics and DC voltage controls associated with those systems.

- In order to effectively and completely commission the spectrometer, each component or system installed must have provisions for control and monitoring. The control and monitoring systems must be assembled and tested before installation. Commissioning of all components and systems must include commissioning of all monitoring, equipment protection, and safety systems associated with those systems. Some BTeV detector and component systems will include alarms and limits on their excitation and status that will be monitored via an interface to the ACNET control system; ACNET interface testing must be included in commissioning these systems.

- The calibration of spectrometer systems should be designed to allow remote calibration to the greatest extent possible. All calibrations should be integrated into the BTeV DAQ and software systems as much as possible and should follow BTeV software standards.

- There will be many mechanical, electronic, electrical and vacuum subsystems in the BTeV spectrometer. They must be installed and commissioned in compliance with all applicable Fermilab Standards as well as any additional standards adopted by the BTeV group. Commissioning of the complete BTeV spectrometer must include the commissioning of all HVAC and other environmental controls needed by the detectors in the C0 collision hall.

- Many BTeV components and systems will have stored energy (electrical, magnetic and vacuum) during testing and commissioning that could constitute a safety hazard. All mechanical aspects of the BTeV spectrometer will conform to the Fermilab ES&H manual on mechanical safety. All electrical aspects of the BTeV spectrometer will conform to the Fermilab ES&H manual on electrical safety. All vacuum systems in the BTeV spectrometer will conform to the Fermilab ES&H manual on vacuum systems.

13.3 Infrastructure

The installation of the basic utilities in the C0 building are covered in WBS 2.0 and WBS 3.0 as described in Section 13.1.1. AC power distribution panels will be in place throughout the building. The counting room will be completed with raised flooring, air-conditioning, chilled water supply, lighting, etc. The facilities for placing the backup generator will be in place.

BTeV has adopted a philosophy of standard infrastructure elements wherever possible. This approach minimizes costs and makes maintenance easier. Personnel training on different systems is minimized. Spare parts inventory is reduced along with the corresponding costs.

13.3.1 Physical Infrastructure

The basic support systems will be in place in C0 well before detector component installation begins. This building infrastructure includes

- **The C0 Assembly Hall**
  This is a building, shown in Fig. 13.2, adjacent to the C0 Collision Hall that can be used to assemble components of the detector. The Assembly Hall has a 30 ton crane to assist in assembling large devices. At ground level, there is a loading dock for moving large components into the Assembly Hall. The crane coverage extends over the loading dock so that the crane can be used to lower large objects to the Assembly Hall floor. After assembly, components can then be rolled or otherwise transported into the Collision Hall. Access to the Collision Hall from the Assembly Hall for large objects is accomplished by removing the "shielding wall" that separates the Assembly Hall from the Collision Hall. The Collision Hall also has an alcove that houses the power supplies that operate the Vertex Magnet, Compensating Dipoles, and Toroids that are part of the BTeV spectrometer and reside in the Collision Hall. These supplies can also be used to power the magnets for testing and field mapping while the magnets are in the Assembly Hall.

- **The C0 Collision Hall**
  This enclosure, shown in Fig. 13.3, houses the BTeV spectrometer and is where the beams collide. The hall is 24 m long, 9 m wide, and 6.75 m high. It has no crane. The Hall is air-conditioned and the temperature is expected to be stable to 2 degrees and uniform to 5 degrees. There are support structures for all the components and relay racks and cable runs for the electronics. The Collision Hall has a network of survey references for alignment purposes.

Figure 13.2: Layout of C0 Assembly Hall, showing crane coverage.

- **The C0 Counting Room**
  The C0 Counting Room is a three story building, shown in Fig. 13.4 - Fig. 13.6. The first floor contains the HV crates, DAQ and L1 trigger crates. The second floor contains the slow controls racks and space for a control room and office space. The third floor contains the high density computing farm for the L2 and L3 trigger systems.

The general layout of the C0 collision hall, counting rooms, and annex areas are shown in drawings 8918.000-LE-407232(1 sheet) and 8918.000-LE-407322 (2 sheets).

Figure 13.3: Layout of C0 Collision Hall

Figure 13.4: Layout of C0 Counting Rooms: First floor

13.3.1.1 Gas Systems

The gas hut will be constructed outside the main C0 assembly building. Although BTeV does not utilize any flammable gases in the baseline design, the gas shed will be tested and certified as compliant with all the applicable standards for the storage and distribution of flammable gases. The piping for the various gases needed by the BTeV detectors can be installed as far as the Assembly Hall at any time. The final installation of the gas supply headers and exhaust return lines for each detector will take place during the many one and two-day maintenance breaks in the Tevatron operation schedule. The return gases will be vented outside the building following all the applicable Fermilab standards. Individual detectors will be hooked up to the gas system manifolds in the collision hall as they are installed. Before detectors are installed, the gas system elements will be checked for contaminants and cleaned or replaced as needed.

Figure 13.5: Layout of C0 Counting Rooms: Second floor.

13.3.1.2 Chilled Water Supplies

Two chilled water supplies are located in the C0 building. The Chilled Water System, which operates at a temperature of approximately 7 C, will be used for the building air conditioning. The Electronics Cooling Water system will operate at a nominal temperature of 15 C, but at least 5 C above the dew point of the hall. The system will circulate water with corrosion inhibitors. An ultraviolet sterilizer will be part of the system to prevent bacterial induced corrosion. Higher power racks in the counting room first level and collision hall will use air-water heat exchangers within the racks for cooling. The connection points for the racks will be along the walls or under the counting room floor.

13.3.1.3 Facility Protection Systems

Facility protection systems follow different rules than experimental monitoring and control systems. Facility protection in general may not rely upon any software or human intervention

Figure 13.6: Layout of C0 Counting Rooms: Third floor.

to act and the connections must be fail-safe such that failure in any facility protection wiring (open or short) causes the interlocks to be dropped. Proprietary systems such as FIRUS have been developed to follow these rules.

The BTeV experiment shall connect to FIRUS using a minimum of one FIRUS node and console, monitoring at least 64 contacts. All detector systems shall provide inputs from the facility protection system that cause general interlock of all power sources in case of a FIRUS alarm condition.

All facility protection systems shall include connection to a console in the experiment control room that allows operators to monitor the system status and identify, when an alarm is issued, the source of the alarm.

- **High-Sensitivity Smoke Detection (HSSD)**
  The commercial HSSD system previously certified for use at other Fermilab experiments shall be used at BTeV. A minimum of four zones will be used within the collision hall. Relay closures from the HSSD system shall provide contact closures used as

inputs to the FIRUS system. Each zone shall provide unique contacts for "early warning" (minor) and "danger present" (major) inputs, with each zone having uniquely assigned obscuration levels assigned to each output.

The minor and major alarm outputs of the HSSD system shall be hardwired into the experiment-wide interlocks such that all power sources in the zone are optionally interlocked for a minor alarm and always interlocked for a major alarm.

- **Flammable Gas Detection System**
  The baseline detector plan uses no flammable gases. In the event that any flammable gas systems are introduced into the C0 environment, a commercial gas detection system with multiple heads, control panel and solenoid valves will be implemented. Upon detection of any gas leak or detector head failure a major alarm relay closure shall provide input to FIRUS and also close the solenoid valves. Heads shall be positioned at strategic points along the gas route to provide redundant monitoring.

- **Oxygen Monitoring System**
  The Fermilab proprietary system for oxygen monitoring shall be used. Multiple heads shall be distributed throughout the collision hall and any other areas identified as having oxygen deficiency hazards. Oxygen concentration levels shall be provided to the control room console. Levels below safe concentrations shall generate FIRUS alarms and cause annunciators to sound the alarm.

- **Other Facility Protection Safety Issues**
  Telephone systems and annunciators - including a paging system - need be installed to insure that persons in the collision hall and other areas may communicate with the control room and be advised of dangerous conditions. The paging system must provide a sufficient number of speakers distributed throughout the area so that personnel can hear and understand what is said over fan noise and in cramped areas. Telephones in the collision hall and other areas with large concentrations of electronics require amplified headsets.

  Water sprinklers are a necessary part of fire response but present their own problems when combined with fans and electronics. Dry systems should be considered wherever personnel safety considerations do not prevent their use.

  Care must be taken to insure that all fans are interlocked in any fire condition to control the spread of fire. While the interlock of AC power to the electronics already covers the fans used for electronics cooling, small air handling fans used for climate control within the collision hall and/or counting rooms must also be controlled.

13.3.2 Electrical and Electronics Infrastructure

This section will give details regarding electrical and electronics infrastructure components and their proposed locations at C0. Where systems are common to various sub-detectors the overall system approach is discussed in this section of the TDR. Details that pertain to an individual sub-detector are in the discussion of that detector.

For example, high-voltage and low-voltage power are included in both places. The general common features and the utility nature of common power systems are here. The details of its use for each front-end detector are in that sub-detector's section. The overall grounding scheme for the BTeV detector and electronics are presented in this section.

13.3.2.1 Detector DC Power Supplies

The experiment will specify integrated high-voltage and low-voltage systems that are modular in nature. The same control and monitoring systems are preferred throughout experiment. Minimally, the same system should be used throughout each detector subsystem. Remote AC shutdown to handle crowbar issues is preferred.

Remote enable/disable, voltage, current, temperature, status monitoring, voltage adjustment, and over current trip will be part of the larger power supply standard hardware. All supplies will have voltage and current trip threshold capability that are reset either remotely or locally. The preferred industry standard protocol is CAN or I^2C.

- **High-Voltage**
  All HV power supplies are located on a catwalk or "counting room extension" over the access door outside the collision hall and cabled into the C0 hall. This removes the HV systems from the radiation area and greatly improves their reliability.

  A cable tray channel will be created in the top right-hand corner of the C0 Collision Hall shielding door by removing a row of concrete blocks from the top of the door. Additional transfer trays to the detector elements will be installed off of the top right-hand corner tray. Cables will be routed over the top of the shielding door through a labyrinth channel. The high voltage cables will be installed during appropriate Tevatron operations maintenance days. The final installation will be inspected and certified for compliance to all applicable electrical and mechanical safety standards.

  Correct use of input and output filters as specified by the manufacturer are required. HV runs from the first floor annex area require filtering at the load. The high-voltage cabling is consistent with the types and connectors that are allowed by Fermilab safety. The cable's shields are grounded at the load. The power supply end has a safety ground that minimizes the potential for ground loops to be generated.

  The High Voltage supplies which will come tested and certified from the PREP poo lcan be installed in a staged process where we first install the systems needed to debug the control and monitoring as well as test detectors as they are installed. I.e. it is not necessary to install all the high voltage supplies at one time, justenough to make sure the bulk of the installation will go smoothly,and that eachinstalled cable and/or detector can be raise to its operating voltage.

- **Low-Voltage**
  The baseline design has AC to DC power supplies (conventional) located in the racks

associated with each sub-detector. The power is then fed to each detector as required. Low-voltage power supplies used to power electronics should be remote sensed. The supplies will not have leads longer than 15 feet unless supplies are specifically designed for that condition. All supplies will be tested with the same loading and cable lengths as in real installation to insure performance when installed in the experiment.

- **Radiation Tolerance of Power Supplies**
  There are several types of problems to consider when determining the placement of power supplies. Total Ionizing Dose (TID), displacement effects, Single Event Burnout (SEB), Single Event Upset (SEU)and Single Event Latch-up (SEL) are being considered. SEB affects MOSFET power devices over 150V, SEU affects digital ICs, and SEL affects CMOS devices. All of these issues will be considered in the experiment as a whole.

  A study was performed on the radiation pattern in C0. Refer to document http://www-btev.fnal.gov/DocDB/0005/000508/001/AndreiU.pdf . The study found that the radiation exposure rate is low, under 10 kRad, in the area considered for power supply placement. Past experience has shown that a typical commercial supply, like those used in the B0 COTS system, can tolerate a Total Ionizing Dose (TID) of 15 - 20 kRads. Since all semiconductor devices are affected by TID, careful consideration is taken when assigning equipment placement. The low energy neutron fluence was found to be lower than 10^{12} neutrons/cm^2 which will be considered when evaluating displacement effects.

  Radiation effects on power supplies have been addressed by placing all of the sensitive high-voltage supplies behind the shielding wall. Electronics in the collision hall are located in such a way that the vertex magnet and toroids provide shielding whenever possible. All electronics components which will reside in the collision hall will be validated to appropriate levels based on simulations of the radiation environment expected over the life of the experiment.

13.3.2.2 AC Power Distribution and Breaker Panels

The main power shall be controlled using remote trip circuit breakers. Each counting room and associated annex area shall have "crash buttons" that, when depressed, release the remote trip breaker disconnecting all equipment power from that area.

A 250 kW diesel fired backup generator sufficient to run the critical life safety systems for the entire building as well as certain essential detector systems (e.g. the pixel vacuum and cooling systems) for a minimum of twelve hours shall be present. The associated pad, ducts, and transfer switch are an integral part of this system. Switchover shall occur automatically upon failure of the mains. Tests of backup generator performance shall occur periodically.

Each major subsystem shall have its own Faraday shielded transformer to minimize the possibility of large ground loops over which high frequency signals may flow. Transformers may not break the contiguity of the safety ground. Sub-distribution is 208 V, 3-phase done on a rack-by-rack basis. The maximum power to any rack is 10 kW (30 A, 208 V, 3-phase). From the 208 V, 3-phase each rack can tap 120 V, 1-phase and/or 220 V, 1-phase as required.

One double duplex outlet shall be provided to each rack to power the Rack Protection system. This double duplex outlet shall be mounted below the raised floor in each counting room or annex area to discourage use of this power for any other purpose. For racks located in the collision hall itself this outlet shall be color-coded via the use of a red outlet and/or painting the box red. Rack protection AC shall be a separate, non-interlocked circuit fed from a separate breaker in the distribution panel.

13.3.2.3 Quiet and Dirty AC Power

Standard AC power feeds to the experimental area and counting room is 208V, 3-phase. Two types of feeds are available: "Quiet" and "Dirty" AC.

The "quiet" AC power is delivered by a single transformer which feeds a 400A panel that is the main power disconnect. From the 400A panel there are feeds to four 225A panels distributed along the experimental area walls. Such "quiet AC" installations shall be marked by the use of orange outlets.

The majority of AC distributions within BTeV are expected to be "dirty"; that is, with no filtering capacitance phase to phase. Three 75kVA, 3-phase transformers feed their own 225A panels. These transformers are the "dirty" AC power source. Two of the panels are in the counting room and one panel services the utility and other AC power needs of the experiment and C0 building. Such "dirty" AC installations shall be marked by the use of ivory outlets.

13.3.2.4 Detector Subsystem Panels

Detector subsystem panels shall be located in the following areas:

- One panel for on-detector electronics shall be located within the collision hall itself.
- A second panel for other (off-detector) collision hall electronics shall be located within the collision hall.
- One panel for detector electronics test and commissioning shall be located within the assembly hall.
- One panel shall be located within each counting room. A separate sub-panel driven from the counting room panel shall be provided in each counting room annex.

A "crash button" remote trip shall be provided for each detector subsystem panel, located within 10 feet of the panel itself.

13.3.3 BTeV Detector Grounding Scheme

Electrical noise in experiments has been a major problem for sensitive analog electronics. It can come from a number of sources: poor grounds, ground loops, digital electronics, power supplies, etc. BTeV has attempted to mitigate the noise problem with attention to all these issues. Power supply location, filtering, and grounding are based on our own work and discussions with other experiments. Another major source of noise has been that generated by the transmission of digital signals, both radiated and conducted. BTeV has, where possible, mandated the use of fiber optics to eliminate both of these noise sources.

A detailed grounding and isolation plan has been developed for the full experiment, including systems in both the collision hall and counting room. We believe that strict discipline will be required to guarantee that the full detector has a low noise environment. This is viewed as essential for rapid commissioning and smooth operation. A task force on Racks and Grounding has been established to fully define the grounding plan and ensure proper implementation in the detector and electronics installation plans. Refer to Figure 13.7 for the grounding schematic.

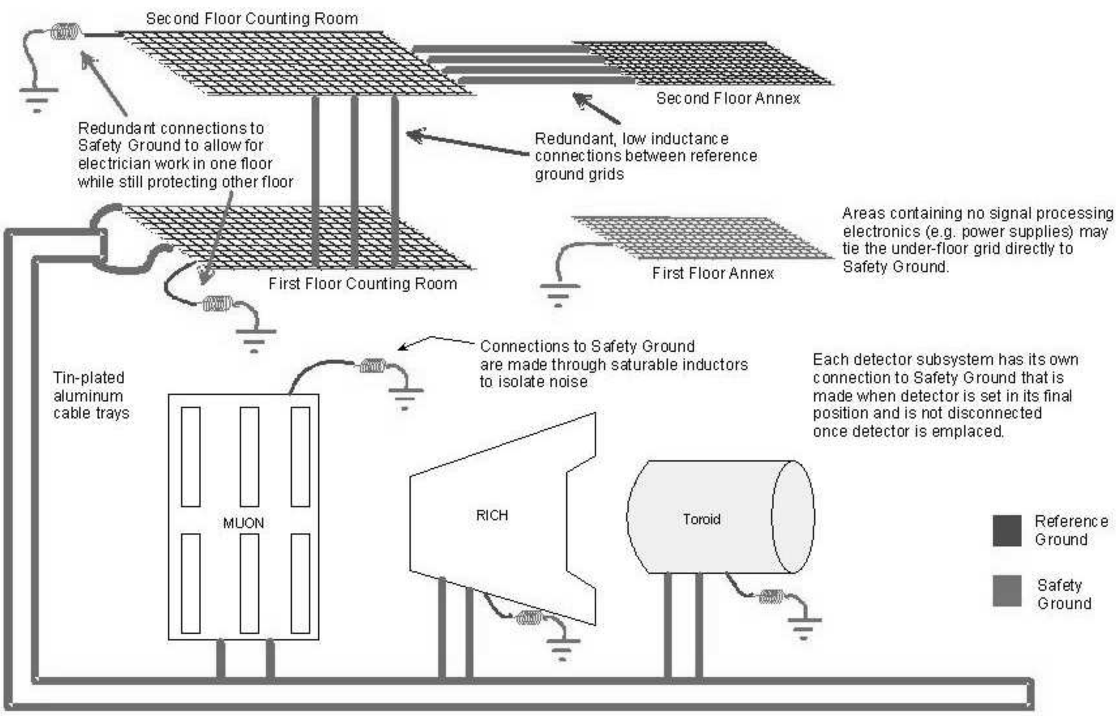

Figure 13.7: BTeV grounding scheme.

13.3.3.1 Distinction between Reference and Safety Ground

The term “ground” is commonly overused to the point where its exact meaning is lost. Many people erroneously use the term “ground” when the term “return” is required. To insure that the reader is aware of the context used by the authors throughout this document, the following definitions are provided:

- A *ground* is a large conducting body whose number of free charge carriers is sufficiently large relative to any current in the system that its absolute voltage potential does not measurably vary at any time.
- The *reference ground* is a ground that, by careful design and implementation, carries as close to zero current as possible at all times such that it forms a systemic zero point voltage reference for all subsystems at all times.
- The *safety ground* is a ground that, under normal conditions of operation, carries no current but is designed and chosen such that under any foreseeable fault condition all unintended current flow caused by the fault flows in the safety ground to the earth ground, which is a sub-milliohm connection to the largest ground body available (typically a copper rod driven multiple feet into the soil).
- A *return* is the conductor that carries the image current equal and opposite to the desired signal current that flows in the "hot" or "supply" conductor. A common example is a power supply, where the colored wire is the "hot" and the black wire is the "return."

The purpose of the grounding scheme described herein, and all good wiring practice for noise control, is to reduce the current in the reference ground to as near zero as possible by insuring that the return currents for every signal are as completely as possible carried on the return wire for that signal.

13.3.3.2 Interconnected Modular Segments

Each major detector subsystem of the BTeV detector that moves into or out of the C0 building is considered a segment. Each segment uses its large metal body as the reference ground for that detector subsystem. Multiple low inductance connections (e.g., wide copper sheets and/or braids) are used to connect each segment together once installed in place to create a contiguous reference across the detector.

Other segments include the under-floor reference grid found in each counting room, the metallic bodies of the high-voltage and monitoring system, first and second floor extension areas, and the cable trays used to deliver DC power between the counting rooms and the detectors themselves. When fully installed, all of these metallic objects are electrically tied together to create a building-wide reference ground used throughout the experiment.

Each detector segment's reference ground shall be connected to the experiment's reference ground system with a minimum of two parallel connections. Each connection shall be designed to provide a connection with a total resistance of no more than 1 milliohm and minimal inductance.

The first floor annex houses the High-voltage system. Since the High-voltage system provides floating potentials, the ground grid will be connected directly to safety ground. No signal processing will occur on this floor. The second floor annex will house signal processing electronics and therefore be connected to the reference ground. Several low inductance connections will be made between the second floor counting house grounding grid and the annex grid. The monitoring system on each of the annex floors will be the same as that used on the counting house floors.

Cable trays shall be segregated into two types, those that carry DC power and those that carry signals. All DC power cable trays shall be conductive and shall connect the reference grounds of the counting rooms to the reference grounds of the detector segments.

13.3.3.3 Connection of Reference Ground to Safety Ground

The reference ground of each detector segment shall be connected to the safety ground using inductive coupling to isolate high frequency noise. Safety to reference ground loops will be prevented by the use of the grid system and saturable inductor elements.

13.3.3.4 Safety Grounding

All AC panels and feeds shall provide a unique Safety Ground (the green or bare wire) that is distinct from the neutral (typically a white wire). Conduits, cable trays and other raceways carrying AC power shall all be metallic and shall be electrically contiguous with the Safety Ground contact point of the panel from whence they run. All wiring shall be done in accordance with current and applicable NEC and local codes. All wiring within relay racks or panels shall provide a Safety Ground connection capable of continuously handling the sum of all AC currents from all phases wired to that rack or panel.

DC power supplies shall all be Safety Grounded by connecting the case of the supply to the Safety Ground via a wire capable of handling the full AC current that may flow to the supply. All DC supplies with floating outputs designed to supply less than 50V differential between the outputs need not connect either output to the Safety Ground, although proper practice of connection to the Reference Ground is required. DC supplies of greater then 50V output potential are required to provide, at the output terminal that connects to Reference Ground, a resistive connection to Safety Ground of sufficiently low impedance that, should the supply fault at maximum output current, the voltage drop across that resistance is less than 50V. The resistance used for such fault protection shall be capable of dissipating the total fault wattage indefinitely.

Metallic portions of raised floors are required to be connected to the Safety Ground using a copper wire of no less than 4AWG, connected to a minimum of two points at opposing ends of the floor.

Cable trays shall be segregated into "power" and "signal" types. "Power" cable trays carry only DC power supply cables and "Signal" cable trays carry only differential signal or fiber optic cables. "Power" cable trays shall be of low-resistivity construction and all shall connect redundantly at both ends to the Reference Ground (and via that connection, to the Safety Ground). "Signal" cable trays shall be of non-conductive construction.

13.3.3.5 BTeV Detector Reference Ground: Avoiding Ground Loops

The use of a star routing structure for grounding prevents ground currents from running past sensitive electronics in an uncontrolled fashion. A star routing configuration is realized by providing each subsystem with a unique return path to ground thereby minimizing subsystem interference.

All inter-system connections should ideally be via fiber optic cables. The use of fiber optics completely eliminates the ground return current problem arising from data transmission. For cable runs that go from the pit to the counting room only fiber optics will be used.

13.3.3.6 Grounding of Relay Racks

The method used to ground electronics racks and subracks is shown in Figure 13.8.

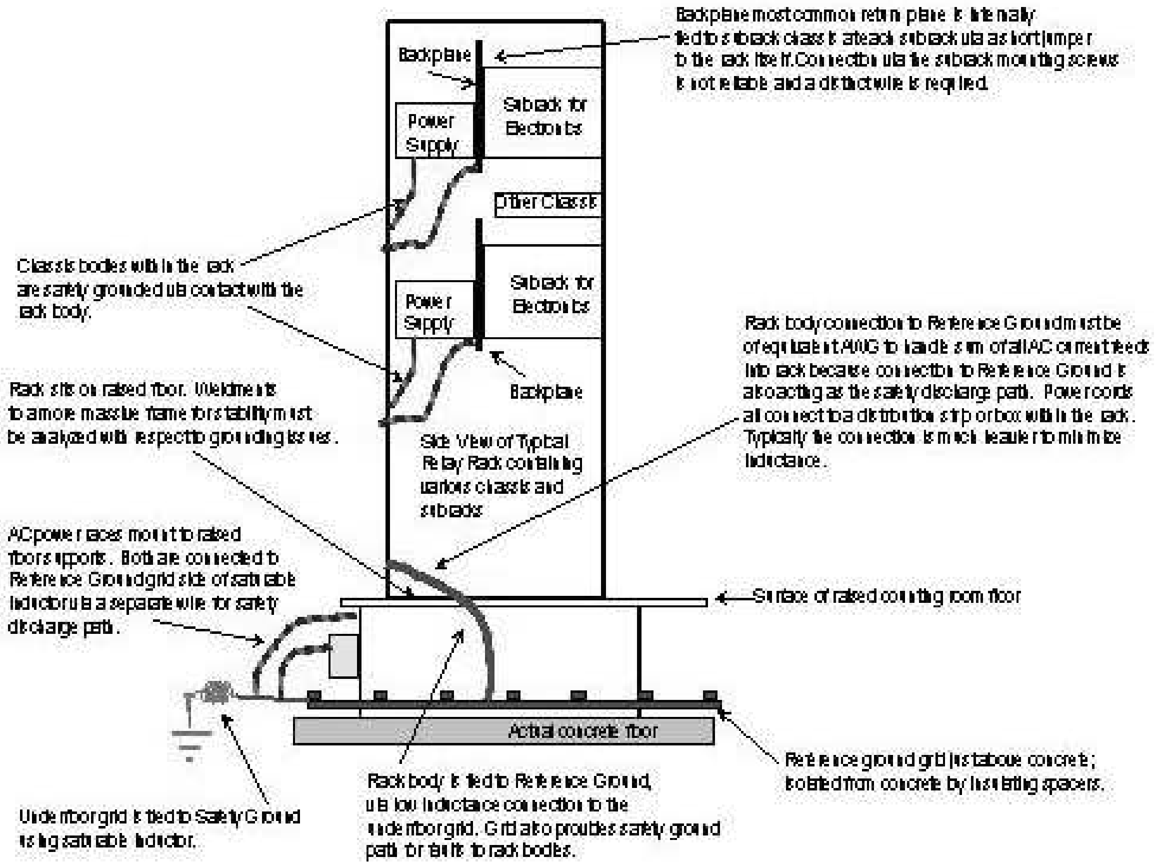

Figure 13.8: BTeV grounding scheme.

All electronics racks are tied to the reference ground by a low inductance connection to the underfloor reference ground grid. These connections must be made of sufficient gauge to carry the sum of all AC current feeds into the rack since this connection also acts as the safety discharge path. Each subrack chassis has an internal connection to the most common return plane on the associated backplane. Each backplane is connected to the electronics rack with a short jumper. Subrack mounting screws are not considered an adequate connection. The power supply chassis is connected to the electronics rack via a short jumper. The rack is connected to the reference ground grid system thereby, completing the path.

13.3.3.7 Signal Cable Grounding

For fiber runs grounding, of course, isn't an issue. For shielded twisted pair cable, the distinction between a signal return and the shield is discussed. A return is the conductor that carries the image current equal and opposite to the desired signal current that flows in the "hot" or "supply" conductor. Reference ground will not be used as a signal return path.

Intra-system connections that are not fiber will be via shielded differential pair. The electric field shield for the preferred LVDS level signals, either foil wrapping or non-insulated drain, shall be terminated to reference ground at the end of the cable where the signal receiver is grounded.

13.4 Common Installation Activities

This section describes the common installation items, notably relay racks, cables, slow controls, gas and water distribution systems and the survey system for the collision hall and detector.

13.4.1 Overview of BTeV Relay Racks

A common rack system will be used by all BTeV subsystems. Standard Cabtron relay racks, the same as those used elsewhere at Fermilab, will be used in the experiment. These relay racks will have 3-phase AC power supplied to a break-out box. The break-out box will be configured to supply the necessary AC voltage to the equipment in that rack.

A standard rack includes: subrack mounting hardware, blower, water manifolds, air/water heat exchangers, smoke detectors, leak detectors, air and water flow detectors, rack protection chassis, and a interlocked AC distribution chassis. Individual detector groups will procure subracks. Standard rules are applied to all sub-rack installations to insure consistent grounding and adherence to safety considerations. Cooling and protection elements are consistent across all racks. A typical rack equipment layout is shown in Figure 13.9.

All equipment racks will contain a Rack Protection system that controls the flow of all AC power within that equipment rack. The Rack Protection system shall contain sensors to detect smoke, airflow, water flow, temperature, humidity and water drip. Upon sensing any trouble condition the Rack Protection system shall drop the interlock. Dropping the interlock shall render the entire equipment rack, except for the Rack Protection system itself, completely powerless until reset. The interlock mechanism will be appropriate for the

Figure 13.9: Arrangement of equipment in a typical relay rack.

expected magnetic field and/or radiation dose in the area. Each relay rack has a "crash" button to kill the AC power in that rack. This kill will remove all the power from the rack except the rack monitor system.

13.4.1.1 Rack Cooling

The preferred method of cooling is forced air up through heat exchangers and sub-racks. The cooling system is designed to dissipate 10kW maximum. Subracks can dissipate a maximum of 1.5kW depending on their size and the design of the subrack electronics.

The water temperature must be kept above dew point. To comply with this requirement humidity monitors are required. Temperature monitors on heat exchanger inlet and outlet pipes will monitor system performance rack-by-rack. The heat exchanger will connect to the rack water inlet and outlet manifolds. The manifold has a throttle valve on the outlet heat exchanger connection for adjusting flow, set to obtain a temperature drop of approximately 5C. This technique will properly cool the air with efficient chiller operation. Typical flow rates are expected to be 3-5 gpm per rack.

13.4.1.2 Rack Protection System

The rack protection electronics can operate either remotely or autonomously. Each rack system has a local and remote reset and is monitored by the slow control system. Items monitored by autonomous controls are the following:

- Smoke detector
- Water leak detector
- Blower Speed Monitor
- Air Flow Monitor
- Water Flow Monitor
- External Fault Inputs
- Temperature Inputs

Provisions will be made that allow equipment to be shut down due to external fault conditions. Examples are detector cooling systems and/or VESDA fire system fault conditions. Each fault condition will be reviewed to determine if it is safe to reset remotely or if a visual inspection is required.

13.4.2 Counting Room Racks

The first floor counting room will house the 45 racks used for the L1 trigger and DAQ systems and networking equipments. The first floor annex will contain the 14 racks used for the HV power supplies. The annex area will also house the 3 slow controls racks. The third floor counting room houses the high density computing for the L2 and L3 trigger systems which will reside in 30 of the approximately 48 racks which could potentially be installed in that space. Due to the high power density in these racks special air handling systems will be installed in the third floor counting room. All counting room racks are single-height without a pedestal.

13.4.3 Collision Hall Racks and Access Platforms

Equipment racks will be installed near each detector element. They will be in a two high configuration with a total of 34 racks in 17 two-high units. The lower level will be accessible from the collision hall floor. A platform will be installed to provide access to the upper level racks. Portions of this access platform must be made easily removable to allow for servicing and installation of detector elements.

Each rack in the stack will be completely independent to facilitate smoke detection in case of a fire. Space will be provided between them for top/bottom access of cables and other utilities. Space will be provided beside each rack to provide space for cable drops from the overhead trays.

13.4.4 Cables

The cabling systems in the BTeV experiment fall into four catagories: signal cables (DAQ), low voltage, high voltage, and slow controls. The separation of cable types between different cable trays and the cable grounding plan are addressed in Section 13.3.3.

13.4.4.1 DAQ Cables

Connections from the detector elements to the data combiner boards (DCB) will be copper cable. These are within the scope of the individual detector subprojects. The DAQ connection from the DCB crates in the collision hall to the L1 trigger crates in the first floor counting house will be fiber optic links. The detector systems will use 12-channel fiber links with a total of 224 fibers required. Timing and control signals will use an additional 100 duplex fiber links.

The DAQ fibers enter the collision hall through a series of penetrations consisting of 6" schedule 80 PVC pipe. The fibers will be gathered into conduits holding 6 fibers each with 10 conduits inserted through each penetration. The packing factor is $< 60\%$ so cable installation should not be difficult. Once in the collision hall the fibers will run in cable trays, again bundled in sets of 6 fibers within a protective conduit, until they reach the DCB racks. The use of loosely packed conduit also allows for easy replacement of individual fibers. Figure 13.10 shows the nominal cable packing in the penetrations and cable trays.

13.4.4.2 Low Voltage Cables

Low voltage is defined as any supply voltage below 50V. The low voltage cables provide the power to the DCB crates as well as readout chip bias voltages required for the different detector systems. The former will be provided by 48V supplies, while the latter is typically 5V or less. The DCB power will be provided by 28 shielded twisted pair cables. The bias voltage for the pixel detector system will require over 8400 cables, and the strip detector will require an additional 4900 cables. Alpha Wire 5610B2016 will be used for these installations.

13.4.4.3 High Voltage Cables

The high voltage supplies in BTeV are typically delivering 500-2000V. Every detector system uses some form of HV. There are a total of 5100 HV cables required in BTeV. Of these, 1520 will provide the bias voltage for the pixel sensors. The muon system will use 1474 cables. The next largest contributions are the RICH detector that requires 782 cables for their PMT and MAPMT systems and the EMCAL that will use 606 cables. The pixels, strips and EMCAL will use RG179 while the muons, RICH and straws will employ RG58. Figure 13.11 shows a tentative plan for populating the HV cable trays with these cables. Two trays are currently planned, but a third tray may be added to reduce the packing factor to facilitate a more rapid installation and ease access to the cables after installation. These cables will pass over the shielding wall door into the first floor annex, rather than going through penetrations in the collision hall wall.

Figure 13.10: Layout of DAQ fibers in the collision hall wall penetrations and cable trays.

Figure 13.11: Layout of the HV cables in the collision hall cable trays.

13.4.4.4 Slow Controls Cables

The slow controls (monitoring) systems will actively monitor the building environment, the magnets, all detector subsystems and the relay racks both in the collision hall and the counting house. A total of 2700 cables will be required with a typical length of 180-190 feet. Roughly half of the cables are 22 AWG twisted pair with a drain wire and the remiander are 4-conductor 22 AWG with a drain. Figure 13.12 shows a tentative plan for populating the slow control cable tray with these cables. A single cable tray can accomodate all required cables.

13.4.5 Slow Controls and Monitoring

Monitoring and control at the global level of necessity requires a consistent physical implementation and protocol. A simple method to achieve this is the use of standard network protocols such as Ethernet. However, care must be taken to insure that this implementa-

Figure 13.12: Layout of the HV cables in the collision hall cable trays.

tion neither emits unwanted radiation nor provides inadvertent ground loops. A hierarchical structure utilizing commercial networks to processors organized to service unique geographic areas and the use of more specialized wiring from these processors to the areas served may be used as cost or noise control warrant.

The major safety systems require specific connection to Laboratory-wide safety systems. One computer of extreme reliability, separate and distinct from all other machines used for monitoring and control, is required for this connection. Typically a PC running a more stable and non-multitasking operating system than the usual desktop machine (e.g. not Windows or Linux, but an industrial OS) is used that receives the required status information using hardwired RS-485 connections and transmits the required data via the Laboratory-specific network (e.g. ACNET).

Counting rooms contain a large amount of electronics that are sensitive to temperature and humidity concerns. Excessively high temperatures and excessively dry conditions or those conducive to condensation may create situations where large amounts of electronics may be damaged. Continuous monitoring allows room air conditioning to be adjusted as required.

In addition to the requirements imposed upon the counting rooms, the collision hall must also be monitored for any oxygen deficient (ODH) conditions, sufficient airflow in any confined spaces and for radiation conditions. The radiation (luminosity) monitors need to be interlocked with accelerator controls. Information regarding the conditions within the collision hall can and should be made available as a separate data packet for reporting to the main control room.

Power supplies are located throughout the experiment. All supplies will provide consistent monitoring features and control capabilities to insure operators understand actual supply status and to minimize extraneous access requests once the experiment is in operation. Every supply will, at minimum, provide the following feature set:

- Remote enable/disable of each DC output
- Remote measurement of supplied voltage and current of each output
- Remote measurement of supply operational temperature
- Digital information indicating any and all outputs disabled, and the reason why (overcurrent trip, over/undervoltage trip, external interlock, overtemperature)

Every power supply shall provide a remote method to reset any trip condition. This shall include any crowbar condition that the supply may find itself in and shall include remote enable/disable of the AC line input whenever required. Any such remote control of the AC line input shall be implemented in series with and may not interfere with safety system AC line shutdown.

All power supply monitoring and control should, whenever possible, be implemented on the same bus structure used to monitor the local environment that the supply is in. As an example, supplies within an equipment rack should use the same physical bus for monitoring and control, as does the equipment rack itself.

13.4.6 Gas and Coolant Distribution Systems

The basic gas and water distribution systems include delivery of low conductivity water (LCW) for the magnets, chilled water for cooling the detector electronics, liquid nitrogen for the pixel cooling and vacuum systems, liquid helium for the pixel vacuum system, dry nitrogen gas and dry air for purging various detector volumes to avoid contamination and condensation. In addition there will be dedicated gas supplies for the RICH, straw tube chambers and muon chambers.

Low Conductivity Water (LCW) for the magnets is supplied from the Tevatron LCW system in the beam tunnel. Chilled Water is supplied from the Electronics Cooling Water system described in Section 13.3.1.2. Liquid and gas cryogens will be supplied from dewars located outside the C0 building. The detector gasses will be supplied from an above ground gas shed, which is shown along with all the connections in Fig. 13.13.

Figure 13.13: Schematic of the gas and cooling system connections.

13.4.7 Survey and Alignment

The Tevatron-based C0 coordinate system used for Collision Hall survey is a right-handed Cartesian coordinate system. The Tevatron beam centerline is defined by the center of the C0 low beta quadrapole at a specified elevation. The Interaction Point is half-way between the upstream and downstream quadrupole in the center of the enclosure but is 7.6 mm above the line joining their nominal centers due to the vertical 3-bump formed be the vertex magnet and compensating dipoles sitting inside the toroids.

Survey is accomplished with the following instruments:

- Laser Trackers, which use a laser distance meter and two precision angle encoders to calculate store and display the real-time three dimensional position of a mirrored target over the desired point or feature,
- V-STARs, portable non-contact three dimensional digital photogrammetric systems,
- BETS – Brunson Electronic Theodolite,
- Optical (Wild N3) and Electronic Levels (Leica NA3000) for elevation,
- Stick micrometers for very short one dimensional distance measurements.

13.4.7.1 Collision Hall Survey Network

The Collision Hall will have a "network" of survey reference points, shown in Fig. 13.14. The reference points consist of tie-rods along the wall at a height of 6' from the floor for vertical reference and dead bolts on the open floor and wall for horizontal reference. All reference fixtures provide a receptacle for Laser Tracker and optical tooling fixtures, such as SMR's (Spherically Mounted Retroreflector).

13.4.7.2 Detector Survey

Three types of fiducials will be used for aligning the detector components:

- 0.250" Bushing Holes located at the corners of the component,
- 2×2 in^2 construction plates, with 0.250" holes in the center, welded to the component,
- 0.5" Tooling Balls, used only if necessary.

The BTeV Alignment Plan consists of the following steps:

- Install all component fiducials and survey markers,
- Reference detector components using Laser Tracker or V-STAR, or in some cases a CMM,
- Establish the relative location of the components on a common support in the Assembly and/or Collision Hall using the Laser Tracker and V-STAR,
- Final survey in collision hall using the Laser tracker and V-STAR together with the Collision Hall survey network.

Figure 13.14: C0 Collision Hall Survey Network. The larger circles are the TeV/C0 network that was put in in 1998. The smaller circles are the proposed C0 Collision Hall network that will be tied to the TeV/C0 network.

The alignment tolerances for the BTeV detector components are not very demanding. Typically, we would like transverse positions to be accurate to ± 0.25 mm and the position along the beam to be accurate to ± 1 mm. Internal alignment of the pixel detector components is much more critical and will be done with a CMM. Additional requirements will be placed on the roll, pitch, and yaw of chamber planes, mirrors, etc. Large, awkward components, such as the Vertex Magnet or the Toroids, will have more relaxed requirements. In many cases, small positioning errors do not have to be eliminated but do have to be carefully measured.

We will make sure that adjustments on all our support stands have adequate resolution and adjustability to achieve the required alignment tolerance. We will also make sure that all fiducials needed for positioning detectors in the hall will be visible when the full detector is installed. We will have methods for checking for settling of the hall relative to the beam tunnel and differential settling within the C0 Collision Hall.

It is worth noting that the experimenters have developed methods for using the data from recorded tracks to establish the relative alignment of detectors to search for subtle rotations and non-uniformities and to monitor alignment over time. These are used to correct the data for such problems. In BTeV, these programs will be running continuously during data taking and the results will be immediately available to the experiment operators.

13.5 Installation Sequence

The installation of the BTeV spectrometer is governed by two factors: the limited space for assembly of subcomponents under the crane in the Assembly Hall, and the limited access to the Collision Hall due to ongoing Tevatron operations. The large components, the vertex magnet and the muon toroids, must be assembled first and then rolled into the collision hall. This then provides the space for the assembly of the remaining sub-assemblies in the Assembly Hall, and provides the spectrometer backbone for positioning and supporting the remaining detector sub-assemblies in the Collision Hall.

13.5.1 Installation Overview

Installation activities at C0 will involve the installation activities for 6 large detector elements (3 magnets, ECAL, RICH and Tracking) and many activities for the installation of infrastructure, cables and racks. The most complicated installation phase will occur near the end of the project with the installation of the Pixel detector and the Forward Tracking Straw and Silicon Strip Detectors. All preceeding installation activities must be accomplished efficiently to provide as much time as possible for the final installation phase.

The first large elements to be installed will be the south (un-instrumented) Toroid and the Vertex magnet. Approximately one week is required to move, align and connect each one. These must be moved to the collision hall to clear the assembly hall for the assembly of the north Toroid and the RICH detector tank. When ready, the north Toroid can be installed in approximately one week. The vacated space in the assembly hall can then be used to assemble the ECAL support structure. The Muon Chambers and ECAL crystals can be installed either in the assembly hall or the collision hall and will likely have some installation performed in both halls. The RICH will have mirrors and some or all PMT arrays mounted while in the assembly hall. The partially crystal loaded ECAL structure will be installed in the collision hall before the large RICH tank. The final large elements to be installed will be the Pixel tank and Forward tracking. The Pixel detector must be installed first followed by the forward tracking beam pipe. Once the Beam Pipe is installed and leak checked the Forward Tracking can be installed. The Forward Tracking Straw and Silicon Strip detectors mount around the beam pipe and slide to the final mounting positions. Extensive cable and utility routing occurs as each Forward Tracking station is positioned.

The installation of infrastructure, cables and racks occurs between and during the installation of the large detector elements. Installation activities in the assembly hall and the counting rooms can generally occur at any time after the building outfitting of these areas is complete. Installation activities for equipment and cables in the collision hall must be coordinated with collision hall access and the installation periods for the large detector elements. The installation of DAQ and Trigger Systems in the counting rooms can occur at any time after the infrastructure is in place. The installation of infrastructure, cables, racks, DAQ and Trigger systems must be sequenced so that these elements are in place to match the phased commissioning of the detectors they are connected with.

13.5.2 Detailed Installation Sequence

13.5.2.1 Clearing the C0 collision hall

Three large bending magnets are currently in the C0 collision hall as part of the Tevatron lattice. These magnets rest on stacked concrete shielding blocks. Some of these magnets and shielding blocks must be removed from the collision hall before any large detector components can be installed. The most efficient operation would be to remove all the magnets and most of the shielding blocks currently in the collision hall while the assembly hall is empty. After this is accomplished some collision hall outfitting such as installing smoke detection equipment, cable trays and low conductivity water lines could proceed with unobstructed access to the entire collision hall with lift equipment. The equipment currently in the collision hall can be removed or partially removed while the assembly hall is occupied with the vertex magnet and toroid magnet but operations will be less efficient as there will be limited space to maneuver under crane coverage in the assembly hall. Likewise, infrastructure installation on the high walls and ceiling will be less efficient if the floor coverage by lift vehicles is limited.

13.5.2.2 Initial infrastructure installation in the assembly and collision halls

The initial infrastructure installed in the assembly and collision hall will support the testing and operation of the vertex and toroid magnets. It will also isolate activities in the collision hall from other activity in the Tevatron. Fire protection and detection will be completed in both halls. Power for the magnet power supplies will be installed in the assembly hall. Low conductivity water lines will be extended from the Tevatron tunnel to both halls. Power leads and water cooled bus will be installed between the collision hall and the magnet power supply location in the assembly hall. Barrier walls will be installed at the collision hall/Tevatron tunnel interface to eliminate any oxygen deficiency hazard (ODH) in the collision hall from a cryogen venting in the Tevatron tunnel. Vacuum gate valves will be installed just outside the collision hall to allow isolation of the vacuum of the beam pipe in the collision hall from the Tevatron vacuum. A temporary beam pipe will be installed in the collision hall with pump out ports and flange connections to allow removal of sections as detector components are installed.

13.5.2.3 Other C0 building outfitting requiring access to the assembly hall

Access to the assembly hall will be limited during phase I of the C0 building outfitting. In addition to installing the infrastructure for testing the magnets, access to the assembly hall will be needed for installing the elevator and constructing the block wall that will close off the counting rooms from the assembly hall high bay. The only other access to the assembly hall that is required is in phase II of the building outfitting when the HVAC equipment is moved to the mechanical room located under the loading area. This operation only requires a few days access to the east end of the assembly hall.

13.5.2.4 Installing the South Toroid and Vertex magnet

Assembly of the South Toroid and Vertex magnet can proceed after beneficial occupancy of the assembly hall from C0 outfitting phase I is accomplished. Assembly of both magnets will require a few months and magnetic field mapping will require an additional few months. The magnets will be arranged so that the South toroid can be installed first. This is not essential but it eliminates an extra shift of the vertex magnet as the toroid magnet can not pass by the vertex magnet when it is in its final position in the collision hall. In preparation for opening the large shield door both magnets must be shifted to the east end of the assembly hall to clear a path for the shield door.

After the shielded door is opened, the four 500 ton Hilman rollers used for moving the door are removed from the door and mounted to the toroid transportation beams. The two transportation beams tie the two toroid iron sections together at the bottom. The two toroid sections are always connected at the top by a pair of beams. Thus the two sections are always moved as one unit. The toroid is moved with the same tie rod and hydraulic cylinder equipment that is used to move the shield door. The weights of the toroid pair (400 tons) and the door (500 tons) are similar. The ends of the tie rods connect directly or through a spreader beam to anchor points in the floor and collision hall walls. These anchor points were built in to the collision hall and assembly hall at several locations when the C0 building was constructed.

At the same time, beam pipe work can be taking place in the collision hall. The isolation gates valves will be closed and any temporary beam pipe sections and its supports will be moved aside.

It will require one day or less to move the South toroid to its approximate position. Final adjustment will require additional time. When the South toroid is in the collision hall shield blocks left from the current configuration can be rearranged to provide a support for a second B2 compensating dipole that will be installed at the north end of the collision hall. The shielding blocks and B2 (5 ton) compensating dipole will be installed with a forklift. The Vertex magnet weighs approximately 400 tons and is moved with the same Hilman rollers and tie rod and hydraulic cylinders as the toroid. The initial move and final adjustment will require approximately the same time.

After either magnet is in place, work can proceed with connecting power, LCW, control and monitoring. These activities can proceed in parallel or in series and will require a few days per magnet for a two man crew.

The temporary beam pipe can be reconnected after the appropriate sections are removed. The B2 compensating dipoles have integral stainless steel beam tubes. Once these magnets are installed sections of beam pipe connected to them can not be baked. Prior to this installation phase some studies will have been conducted to determine the best method for vacuum conditioning of the temporary beam pipe. These methods may include additional isolation valves that permit baking of sections or additional pumping or a combination of the two. Whatever the method, reconnecting the beam pipe and establishing an acceptable vacuum level will be a priority in the scheduling of the activity for this shutdown.

Complete installation of the vertex magnet and B2 compensating dipoles will allow beam studies of these two elements of the final detector. However the essential function of this installation phase is to clear the assembly hall to provide space for the assembly of following detector components. Even if the installations are not complete the essential function will have been accomplished when one or both magnets are moved from the assembly hall.

13.5.2.5 Additional infrastructure installation in the collision hall

Distribution of power to breaker panels located along the West wall of the collision hall could be scheduled at a variety of times. However, it will likely occur during the same shutdown when the South toroid and vertex magnet are installed. Since this work does not require access to the ceiling, the installation can be accomplished as easily before or after magnet installation.

Also the collision hall work described as initial infrastructure installation could be accomplished during this shutdown but would be best performed before magnet installation and would require a longer shutdown.

13.5.2.6 Installing the North Toroid and First Muon Chambers

The assembly of the North toroid will be very similar to the South toroid. However, the North toroid will have a 4" thick steel filter plate extending on the north side. The North toroid will also have features for mounting the Muon chambers. It is expected that the North toroid will be in the assembly hall long enough for the first Muon chambers to be completed. After the toroid and B2 compensating dipole is assembled and tested the Muon chambers that are available will be mounted to the toroid assembly. The Muon chambers and their support system are designed so that the Muon chambers can be installed in the collision hall without the use of a separate overhead crane. These design features will be tested as the Muon chambers are installed in the collision hall.

It is expected that the North toroid will be in the assembly hall at the same time as the construction of the tank for the RICH detector. The assembly of both requires a significant amount of welding and will be a somewhat dirty operation. There are advantages to performing this assembly work in the same time frame but it is not essential.

It is expected that the outfitting of the mechanical room will be accomplished during this period. Some of the large equipment installed in this room will pass through the east end of the assembly hall to this room. This is not expected to be a significant disruption to the work in the assembly hall.

Installing the North toroid will be a similar operation to installing the South toroid. The isolation gate valves will be closed and sections of the temporary beam tube will be removed. The B2 compensating dipole and the shielding blocks it is mounted on will be moved or removed. This B2 will be retained as a spare. The vertex magnet will be moved to the south to provide a clear path. Some connections may stay in place but this requires further study.

The time required for moving the vertex magnet, installing the North toroid and reestablishing the beam pipe vacuum will be very similar to the time required for installing the South toroid and the initial installation of the vertex magnet.

With the installation of the first Muon chambers, the first detector elements are installed in the collision hall. Some gas lines, racks and cables to support the Muon chambers will be installed.

As with the previous magnet installation the essential function is to clear the assembly hall to provide space for the assembly of following detector components.

13.5.2.7 Final infrastructure installation in the collision hall

The final C0 outfitting equipment installed in the collision hall are the fan coil units that supplement the central HVAC. The HVAC equipment installed in the mechanical room also needs to be commissioned and final adjustments may need to be made to the ductwork in the collision hall. It is expected that this work could be accomplished during the same shutdown as the installation of the North toroid.

13.5.2.8 Beam test of pixel and tracking elements

It is expected that at the time of the shutdown to install the North toroid, that a 10The 10 these tests is not complete but some utilities, racks, power and data cables will need to be installed to support these tests. The utilities will be not the permanent gas and cooling systems.

13.5.2.9 ECAL and RICH assembly in the assembly hall

After the North toroid is installed, the support structure for the ECAL will be assembled in the collision hall. After it is assembled and aligned, crystal and PMT assemblies will be loaded in the structure as they are available. Work on the RICH will continue. This work includes mounting mirrors, windows and PMT arrays. The assembly hall work for both of these detectors is scheduled by the detector subprojects as the work flow is very dependent on the schedule of components.

13.5.2.10 Installation of racks in counting rooms

It is expected that the C0 building outfitting phase II that finishes the counting rooms will be completed in early CY 2008. At this point the computer room floors are finished and power is distributed to breaker panels. The final configuration for racks should be known at this time.

Racks for the 1st floor counting room will be available for installation in early CY 2008. These racks require power, water cooling and rack protection monitoring connections. The work for distributing and connecting these services to the rack can begin.

All but a few racks in the 3rd floor counting room are for the L2/3 trigger. These are high density computing racks and it is expected that they will be cooled by air-chiller units that circulate air through the floors to vents in front of the racks to form a warm aisle-cold aisle circulation pattern. The equipment for this cooling arrangement is installed as part the phase II outfitting. However, power will need to be distributed to the individual racks.

The High Voltage power supply racks will be located in the 1st level electronics bridge. The racks will be installed and power distributed to them. These racks are air cooled with heat dissipated to conventional HVAC.

The slow controls racks will be installed in the 2nd level electronics bridge. The racks will be installed and power distributed to them. These racks are air cooled with heat dissipated to conventional HVAC.

Installation will be scheduled for efficiency while meeting the installation schedules of the detector subprojects.

13.5.2.11 Preparing and installing cable plant

The majority of the cable for installation will not be available until CY 2008. At this point a cable plant plan will be fully developed with cable ID and termination points set for each cable.

As cables arrive they will be tested, labeled and bundled according to the cable plant plan. At this point in time it appears that cable penetrations will be adequate to allow termination of most of the cables before installation.

The majority of the cables that will pass through penetrations out of the collision hall are High-Voltage, Slow Controls, or fiber DAQ cables. Cable bundles will be staged for installation during scheduled and unplanned shutdowns.

13.5.2.12 Installing the ECAL and RICH Tank

The partially loaded ECAL structure can be installed in any shutdown of sufficient length to allow the venting and vacuum recovery of the beam pipe through the collision hall along with opening and closing of the large shield door. The ECAL uses rails mounted to the floor to allow a small motion along the beam axis to provide service access in front of the ECAL. Some preparation work for mounting the rails can be performed during prior periods of short access to the collision hall.

To prepare for installation the isolation gate valves are closed and a section of the beam pipe is removed for the ECAL to move on to the beam line. The ECAL is stabilized by its transportation fixture and rolled in to the collision hall. A half crystal loaded ECAL would weigh approximately 10 tons. After the ECAL is mounted to rails attached to the floor, the transportation fixture can be removed. A short section of beam pipe is eventually mounted in the middle of the ECAL. The ECAL does not touch this pipe. At this point the temporary beam pipe can be reconnected or the installation of the RICH Tank can begin. If the RICH Detector is to be installed the ECAL will be moved north to its service position to allow as much clearance as possible for the RICH tank.

The RICH tank with top PMT array weighs approximately 10 tons. It would be rolled in to place with small Hilman or similar rollers. The RICH beam tube would most likely be installed through the RICH front and back windows prior to installation. The RICH tank without MAPMT arrays can just fit past the vertex magnet when it is in its final position. If necessary the vertex magnet can be shifted south for more clearance.

The time required for moving the ECAL and RICH and reestablishing the beam pipe vacuum will be very similar to the time required for installing two magnets.

Additional RICH PMT arrays can be mounted and aligned during shorter access periods. The RICH MAPMT arrays can not be permanently installed until the Forward Tracking stations are installed.

Additional crystals and PMT assemblies can be installed in the ECAL during short access periods.

The ECAL and RICH detectors are the last two objects to be assembled in the assembly hall. After these are installed the assembly hall can be used for staging of racks and the Forward Tracking components. Some space can also be used for semi-permanent installation of support systems.

13.5.2.13 Installing support systems

A variety of systems are required to supply gas and cooling for the detectors. Some of these are infrastructure items meaning that the design, parts acquisition and installation are managed completely within the detector installation and integration subproject. These include electronics cooling water, nitrogen liquid and gas, argon gas compressed dry air. Other systems are used only by a particular detector subproject and thus the design and parts are provided by that subproject. Some subassembly may be performed by the subproject but the final installation at C0 is managed by the detector installation and integration subproject.

The gas mixing systems for the Straw and Muon Detectors will be located in the gas house provided by the C0 building outfitting. Other systems will generally be located somewhere in the assembly hall. Since assembly hall space is very limited until the ECAL and RICH tank are installed the support systems will generally not be installed until after the ECAL and RICH are installed. These systems are generally not required until after the middle of CY2008 because no detectors other than some Muon chambers are permanently installed prior to that time.

The somewhat flexible installation schedule of the support systems does not apply to the distribution lines for these systems that are located in the collision hall. Because access to the collision hall is limited, distribution lines in the collision hall may be installed before the supply for that system is in place in the assembly hall.

13.5.2.14 Installing collision hall racks

After the RICH and ECAL the installation of many of the collision hall racks can proceed. The power for the racks needs to be distributed from the breaker panels mounted on the West wall. Some of racks will have water cooled heat exchangers and will need to be connected to the electronics cooling system. Planning for all connections must be done with consideration to the point that all the detector elements will need to shift 4.85" West when the new IR is installed.

13.5.2.15 The 4.85" shuffle

When the new CO Interaction Region lattice is built in to the Tevatron the beamline through the C0 collision hall will shift 4.85" West from the normal straight section beamline. Thus all detector elements that have been installed on the beam line will need to shift to the new beamline location.

13.5.2.16 Installing the Pixel Detector and Forward Tracking Straws and Strips

The final major detector elements to be installed are the Pixel detector, forward tracking beam pipe and the forward tracking Straw and Strip detectors. The forward tracking beam pipe includes a large window that forms a vacuum seal with the Pixel detector vacuum vessel. The Pixel detector must be installed first followed by the forward tracking beam pipe. Once the Beam Pipe is installed and leak checked the Forward Tracking can be installed. The Forward Tracking Straw and Strip detectors mount around the beam pipe and slide to the final mounting positions. Half of the pixel cables are routed around the straw chambers and out of the magnet through gaps in the coils. The cables and utilities for the Straw and Strip detectors of stations 1, 2 and 3 are also routed out between the magnet coils. This region accounts for the majority of cables in the detector and will require considerable time to route and check cable connections. The nested nature of these detectors also requires that sufficient checks be performed on each station before the succeeding stations is installed.

The RICH detectors MAPMT arrays must be out of the way to allow access to the narrow region between the end of the vertex magnet and the front of the RICH detector. They will be installed after the last forward tracking stations are installed. The west MAPMT assembly must be staged to the west side of the collision hall prior to installation of tracking stations 4 through 6.

The station 7 Straw detectors can be installed at any point after the ECAL and RICH are installed. Some of the support hardware could be installed more easily before the ECAL or RICH are in place. This support includes beams that mount to the top of the North Toroid and extend over the ECAL. Once the support hardware is in place station 7 super-modules can be installed and aligned during short access periods.

13.5.2.17 Installing final collision hall racks and rack access platforms

In the final stage of the detector installation all, racks are installed in the collision hall. The number of racks required is large enough that most racks are stacked two high. To position, load and service these upper racks, an access platform design has been developed. The access platform provides a second floor with rails and stairs and equipment hoists. The access platform is modular and allows specific sections to be easily disassembled for service access to detector elements.

13.6 Detector Installation Details

13.6.1 Magnets and Beam Pipes

When the C0 sector of the Tevatron is restored to a standard straight section in 2005, a temporary beam pipe section will be installed which provides sufficient modularity for the phased installation of the remaining BTeV components in subsequent summer shutdowns. As each segment of the detector is installed, the corrosponding section of temporary beam pipe will be replaced with the final pipe section.

The vertex magnet and toroids require the assembly of massive iron slabs in the C0 assembly hall, coil installation and full power testing prior to being rolled into the collision hall. The assembly of each of these three magnet systems requires utilization of the majority of the assembly hall and the 30-ton crane. The south toroid pair and compensating dipole assembly will be assembled first, then moved to one end of the assembly hall to make space for assembly of the vertex magnet. After assembly, each magnet will be connected to the power supplies in the Assembly Hall alcove and undergo an extensive set of magnetic field measurements using the Ziptrack magnetic field measuring device. During the 2006 summer shutdown these two items will roll into the collision hall and will be positioned on the Tevatron beam line. Figure 13.15 shows the toroid assembly mounted on the Hilman rollers for the move from the assembly hall to the collision hall.

During the following collider operations period the north toroid and compensating dipole will be assembled in the assembly hall. Once this magnet assembly is completed it will be moved to one end of the assembly hall to make space for assembly of the RICH tank. The beryllium beam pipe segment through the RICH is an integral part of the RICH tank. During this period muon chamber assembly may also take place in the assembly hall and any available muon chambers may be installed on the north toroid so that they can be rolled into the collision hall with the toroid during the summer 2007 shutdown.

Figure 13.15: Toroid pair assembly mounted on Hilman rollers ready for the move from the assembly hall to the collision hall.

Both the Vertex Magnet and the Muon Toroids are designed to allow the 500-Ton Hilman rollers from the Collision Hall shielding door, and the pneumatic pull rods in the two areas, to be used to move these assemblies. After each magnet assembly is rolled into its final location in the C0 Collision Hall, the permanent power, control, and safety connections for the magnet system will be made. The remote operation, readout, and control of the magnets and their safety systems will be checked. The ability of the current in the compensating dipoles to follow the MDAT ramp of the main Tevatron magnet excitation current will be verified.

The connection of the magnets to the necessary power, LCW, control, and monitoring systems will be done under the supervision of Beams Division Electrical Department Staff. The existing ACNET control system and protocols will be employed and will follow standard Beams Division Electrical safety standards.

The beam pipe assemblies will be thoroughly tested elsewhere on the Fermilab site. They will be brought directly to the Collision Hall and assembled as needed. The most important aspect of this procedure is the need to ensure that the Tevatron vacuum can be pumped down to its normal operating range, about 10^{-8} Torr, rapidly each time the beam pipe is let up to air. Two sections of the beam pipe will be thin-walled beryllium: the section extending from the pixel tank to the front of the RICH and the section through the RICH. The former will be installed during the 2009 shutdown when the Pixel vessel is installed, while the latter will be installed with the RICH tank, which provides significant protection to this section of pipe.

13.6.2 Pixel Detector

The pixel detector will arrive at the Assembly Hall as a fully assembled and tested device. Further testing could be done in the Assembly Hall if the need arises. Rolling the Pixel Detector into the Collision Hall and installing it in the BTeV Vertex Magnet will require an extended Tevatron operations down period since the Tevatron beam pipe must be removed and reconnected for this operation. Also the various mechanical, cryogenic and vacuum pumping systems associated with the Pixel Detector must be assembled and made fully operational before the Tevatron can return to normal operations. This activity is scheduled to take place during the final BTeV installation shutdown in 2009.

13.6.2.1 Preparatory work on infrastructure and services at C0

Prior to delivery of the pixel detector assembly to C0 a significant portion of the services infrastructure should be installed and tested. The cryogenic supply system should be made fully operational, including all process controls external to the vertex magnet. Similarly all external vacuum system components should be made fully operational and tested. All crates, electronics, data links and power supplies should be installed and tested, including verification of each channel with a test pixel module, prior to connection of the installed detector to these services.

After the connection of all cables and lines, all components of the system will be tested for continuity. Connections to and from the central Control, Timing and Monitoring (C&T/M) system to the pixel data combiner boards (PDCB) will be tested. These tests will include the functioning of the clock into the data combiner board, which in turn will send the clock signals to all the pixel modules. This clock signal will be tested for synchronization at various clock speeds. Other pixel sub-systems such as the vacuum system, vacuum monitoring gauges, temperature control sensors, position control systems, and the cooling system will be tested for functionalities. The slow control and monitoring interfaces as well as the alarm/interlock interfaces of the various systems to the overall BTeV control/monitoring system and alarm/interlock system will be tested. The data combiner boards will be read out by either a preliminary test system (which will be used during the production phase of the PDCB) or the full DAQ.

13.6.2.2 Installation of the Pixels in the Vertex Magnet

The pixel assembly will arrive with all of the cables which run from the feed through boards on the pixel tank to the data combiner boards already installed. The mechanical installation will proceed as follows:

- The detector will be unloaded from the truck onto the C0 assembly hall loading dock and moved to the assembly hall floor using the assembly hall crane. A trained crane operator will be required.
- The detector will be transported from the assembly hall to the experimental hall and prepared for insertion into the vertex magnet.
- Using a transportation fixture, the detector will be lifted and attached to overhead rails attached to the magnet. Note that the same rails may be used for the installation of the 1st, 2nd and 3rd straw stations.
- The detector will be rolled into the magnet, attached to the support brackets, and then disconnected from the rails. Details of this operation will be defined later, when a more detailed detector design will be available. The brackets will be installed and tested before detector installation.
- The temporary flanges will be dismounted and the end windows will be mounted in their places and connected to the rest of the beam pipe.
- Using support brackets, the pixel detector will be finally aligned and secured. Surveyors will be needed. It is expected that the precision of the final alignment of the vessel fiducials will be better than 250 microns.

Following the mechanical insertion of the detector, all services must be routed and connected to the pixel dectector. Cables will need to be routed out of and strain relieved to the vertex magnet and out to the relay racks in the collision hall. A template for the three innermost straw stations will be utilized to ensure that the cable routing leaves sufficient clearance for installation of those detector elements. All external vacuum and cooling connections will be made and the system will be pumped down following the detailed pump-down plan which has been developed. The actuator system will also be connected to the external drive system via hydraulic lines. All monitoring and controls systems will be fully implemented during the connection and commissioning of the pixel services.

13.6.2.3 Connection to DAQ and Electrical Checkout

The final electrical connections at the relay racks will be done in concert with functionality testing of each module as it is integrated into the system. This is the procedure used by the collider detectors during hook-up of the Run II silicon detectors. Each DCB connects to one half-plane of pixels. Given this modularity it is assumed that all cables may be installed, followed by testing each half-plane and finally larger detector sections.

In addition to the electrical hook-up and functionality tests, a final survey and alignment of the pixel detector to the Tevatron beam line must be performed prior to installation of the forward tracking stations which will block the line of site to the pixel vessel. This task concludes the work required prior to commencement of installation of the forward tracking stations.

13.6.2.4 Systems Test and Commissioning

This section describes the system tests and commissioning phases of the pixel installation. This work can be done in parallel with the installation of the forward tracking stations.

- **Full Readout System Testing**
  Once all power supplies and cables are in place, an initial electrical test will be made to insure that both HV and LV can be turned on for all of the pixel modules. The current will be monitored. A turn-on and turn-off sequence will be worked out in preparation for this test (during testing at SIDET). This test will also be useful to exercise the control/monitoring software and interface to the overall BTeV control and monitoring system. All voltage settings and read-back currents will be monitored and recorded in a database. After this initial set of full downloads of the system more detailed studies of noise and pedestals will be undertaken and a set of optimal LV and HV settings, thresholds and kill pattern will be established for each readout chain.

- **Vacuum Tests**
  After the pixel vacuum tank is connected to the rest of the beam pipe via the dome shaped exit window all pumping ports, flanges, gauges, and other monitoring connections will be made and leak checked. The vacuum system will then be turned on and left running. The vacuum reading will be monitored continuously. The vacuum must be maintained at a level close to 10^{-8} torr in the beam region. Readout tests of the pixel detector will also be performed to make sure that there is no degradation in performance of the detector. Finally, the remote operation, readout, control and alarm/interlock interface of the vacuum system by computer will be tested. Note that before the installation of the pixel detector, a vacuum failure mode analysis will be performed. Furthermore, a study on the responses of the alarm/interlock to vacuum failure will need to be checked.

- **Cooling System Tests**
  The cooling system will most likely be installed outside the experimental hall and long

insulated transfer lines will be used to convey the liquid nitrogen from the dewar and recycling system to the pixel detector. After installation, the system will be turned on. The temperature at the entry and exit point of the liquid nitrogen recycler will be monitored together with the pressure at a few places in the system (entry and exit points of the pixel detector vessel for example). The temperature at various pixel stations will also be monitored continuously. Adjustments will be made to achieve the required stability as specified in the Pixel Requirements Document. This is done by a combination of the flow rate and the temperature control system on each substrate. The remote operation, monitoring, alarm/interlock interface of the cooling system will then be tested. Any adverse effect on the performance of the detector and the vacuum system will also be checked and appropriate measures will be taken to solve any problems encountered.

- **Actuator Tests**
  The pixel detector will be moved out and into the data-taking position by a set of 8 actuators. The actuators will be tested extensively before installation. After installation, we will run tests to make sure all the connections (electrical and hydraulic) are intact. We will then exercise the movement a number of times to make sure that the detector can be moved out and into the right position. Furthermore, we will check various operational parameters to make sure that these will not be affected by the operation of the actuators. These parameters include the current seen in the detector, temperature of the detector, vacuum, magnetic field map. For emergency and safety reasons, there will be a manual backup system (in case one ore more of the actuators fail in some way). This system will also be tested during the check out.

13.6.3 RICH

The present installation scenario is for the RICH detector tank to be assembled in the assembly hall partially instrumented. The tank will not be instrumented with MAPMTs, and perhaps not the PMTs. The gas enclosures for the PMT arrays, the top PMT array fully instrumented, front entrance window, liquid radiator vessel, rear exit window, mirrors and mirror support structure, and beam pipe are part of the tank assembly when rolled into the collision hall in the 2008 summer shutdown. When all of the instrument enclosures are in place, an initial gas leak check is performed. Once the tank is assembled in the assembly hall, it is transported using rollers into the collision hall. The RICH tank is installed after the Vertex Magnet and Toroid Magnets are installed into the collision hall. At a later date, suitable to the installation schedule, the MAPMT enclosures are installed along with the PMT beehives and tubes. The RICH is completed in the collision hall at the end of the summer 2009 shutdown.

13.6.3.1 Assembly Hall Activities

Starting Late 2006 and continuing up up to the 2008 shutdown the following steps must be performed before rolling the tank assembly into the collision hall:

- Assembling the tank frame by welding the walls together;
- Attaching the liquid radiator vessel to the tank;
- Mounting the front window to the frame;
- Installing the mirrors and mirror support structure;
- Inserting the beam pipe into the tank and making the beam pipe to window seals;
- Mounting all of the PMT enclosures completely instrumented;
- Installing the Gas Radiator Passive Expansion Volume;
- Pre-aligning the mirror tiles;
- Initial gas leak check of the tank frame, window seals, and instrument enclosures.

13.6.3.2 Installation in the Collision Hall

The current schedule calls for installation of the tank assembly in the collision hall during the summer of 2008. At this point the PMT installation may or may not be completed, but subsequent PMT installation in the collision hall is straightforward during short Tevatron access periods without impact on other detector subsystems. During the installation of the RICH tank the Tevatron vacuum will be opened and a section of the temporary piping will be replaced with the final beryllium beam pipe section which resides inside the RICH. The EMCAL must already be in place on the beam line. The Tevatron beam pipe must be restored with a vacuum of 10^{-8} torr before operations can recommence.

13.6.3.3 MAPMT Array Installation

The MAPMT array installation is performed after the straw tube installation is complete. The MAPMT array includes the MAPMT enclosure, exterior magnetic shielding, MAPMT modules and associated electronic cooling and electronic cables. The MAPMT arrays are independent to the assembly structure and can be installed when received.

Repair of an individual module requires the removal of the exterior magnetic shielding (500lbs) on the MAPMT enclosure, opening the MAPMT enclosure, replacing the defective module, making the necessary electronic and cooling connections, then closing the MAPMT enclosure and replacing the exterior magnetic shielding.

13.6.3.4 PMT Array Installation

The PMT array installation is performed at a convenient time in the installation schedule and is not affected by the installation of other components. The PMT array includes the mu-metal beehive, PMT enclosure, exterior magnetic shielding, PMT modules and associated electronic cooling and electronic cables. These will be installed either during the 2008 shutdown when the RICH tank is installed or during the 2009 shutdown when the MAPMTs are installed, depending on the delivery schedule for the PMTs.

13.6.3.5 Integration and Commissioning the RICH

After installation, a full system check will be made to bring the RICH subproject to an operational state. This includes the gas, power supply, cooling, electronics, DAQ software, control/monitoring, and alignment systems.

- **Infrastructure tests**
  After the connection of all cables and lines, all components of the system will be tested for continuity, Connections to and from the central Control, Timing and Monitoring (C&T/M) system to the RICH data combiner boards will be tested. These tests will include the functioning of the clock on the data combiner board, which in turn will send the clock signals to all the MAPMT and PMT modules. This clock signal will be tested for synchronization at various clock speeds. Other RICH sub-systems such as the gas system, liquid radiator system, temperature control sensor, cooling system will be tested for functionalities. The slow control and monitoring interfaces as well as the alarm/interlock interfaces of the various systems to the overall BTeV control/monitoring system and alarm interlock system will be tested.

- **Electronic test of front end devices**
  Before the installation, the front-end electronics are tested with stand-alone PCI based test stands. Once the whole system is connected we will test with a real readout chain for the DAQ in the experiment. The test is aimed at testing all MAPMT and PMT modules extensively in order to detect problems and fix them.

  The test will include following steps:

  - Pedestal and noise calibration with no HV applied. We will read out the system with no signal sources but with a threshold scan. Most of the problems with front-end electronics show up with abnormal pedestal and noise pattern.
  - Pedestal and noise calibration with HV applied. This test can tell us if the HV connection and grounding are proper so the pedestal and noise performance will not be affected much by the applied HV.
  - Test with electronic pulse. The front-end electronics has the function to use an external signal pulse mimic the real signal. With this test we can determine if the gain of certain channels is at the desired value. These tests require 2 physicists for 4 weeks to complete.

- **Test on light response of photo sensitive devices**
  The electronic test of front-end electronics does not include the functionality of the photon sensitive devices: MAPMT and PMT. In this test we use photons from light sources installed inside the RICH vessel to simulate the Cherenkov photons. An electronic pulser is used to drive the light source and trigger system. We read out the response of the MAPMT and PMT to the light source. Using point light sources, the response between neighboring channels should be quite uniform. This test will also be used to provide a quick check of the system before running when the experiment starts to collect physics data.

- **Check alignment of MAPMT arrays and mirrors**
  The mirror tiles will be carefully aligned with respect to the supporting structure before the structure is mounted into the RICH vessel. The MAPMT arrays and mirror supporting structure are aligned with surveying. Once everything is installed, we rely on a collimated light system to check the alignment besides of using the data of isolated tracks. Collimated light sources will be mounted on the sides inside the RICH vessel. The positions and directions of the light sources are properly adjusted so that the reflected light from the mirror will be received by the MAPMT arrays on the opposite side. This test will take about 6 weeks calendar time.

13.6.4 Electromagnetic Calorimeter

The mechanical support structure for the EMCAL will be assembled in the C0 assembly hall after the vertex magnet is installed in the collision hall. Once the super-structure is assembled inside the assembly hall, the process of installing crystals can begin. It is not necessary to fully populate the structure with crystals before it is installed on the beam line in the collision hall. Installation in the collision hall will require breaking the Tevatron vacuum system between the vertex magnet and previously the north toroids. The EMCAL must roll in prior to the RICH.

Once positioned on the beam line the cooling and purge gas services will be connected and cabling done for whatever crystals are already installed. Installation of crystals will continue over a prolonged period as they are produced, processed and tested. The installation of individual crystal-PMT assemblies takes very little time so crystals may be installed during short Tevatron access periods throughout the year, as well as during the annual shutdowns.

13.6.4.1 Integration and Commisioning

While final commissioning will be done only after the full complement of crystals is installed in the EMCAL detector, an initial integration of the EMCAL system with the BTeV DAQ and Slow Controls system can begin once a significant fraction of the device is installed. The list of specific integration items is shown below:

- The support structure will be surveyed and aligned to within 1mm;

- The environmental control system will be tested for proper temperature and humidity regulation;
- The interlock system for the power with cooling systems will be tested and verified;
- Single and multi-crate tests will be run using the calibration system to verify the performance of the PMTs and bases;
- Full system readout using the DAQ system.

The final commissioning will include a calibration of the full array of crystals using vertical cosmic rays (or beam if available) and the pulser system.

13.6.5 Muon Chambers

This section describes the installation plans for the BTeV muon system. The octants shipped to Fermilab will already have undergone a rigorous testing and quality assurance program at the production sites. The muon chambers are assembled in wheel structures with 4 octants (a.k.a. planks) per wheel. Any available muon chambers will be installed on the north toroid assembly while it is still in the assembly hall to reduce the amount of installation required in the collision hall.

13.6.5.1 Installation of Muon System Elements at C0

The muon octants are designed so that they can be inserted from the wide aisle side of the detector hall. One dynamically creates a mounting "wheel." The mounting wheel will be supported from beams attached between the toroids, see Figure 13.16. The upper two beams will support the ≈ 1500 lb weight of each wheel. Additional beams will prevent the wheel from swaying. In principle, the muon system can roll with the toroid if one needs to move the toroids to service accelerator magnets.

The first octant plate is inserted from the side and then rolled to the bottom position on a series of rollers that contact the octant plate circumference. The next octant plate is then attached to the previous plate using specially designed knitter brackets. One then rolls the two octant partial wheel into a position that allows the attachment of the third plate. Once all 4 plates of a wheel are assembled, the wheel is lifted off of the floor and mounted from beams attached to the toroid and the floor wheels are removed and used for the installation of the next wheel. In all, 8 wheels are used for each station.

The process can be reversed for repairs. In the worse case, the replacement or repairs of a single plank will require de-cabling its wheel and sequential dismounting and rotation of the wheel until the affected octant is in a convenient position for repairs.

13.6.5.2 Connection of Electrical, Gas, and Electronics

Once all the octants in a wheel are installed we make all gas, electrical, data acquisition, and slow control connections. As each wheel is installed, the gas system will be tested for leaks

Figure 13.16: The mounting wheel will be supported from beams attached to the toroid. The upper two beams will support the ≈ 1500 lb weight of each wheel, the additional beams will prevent the wheel from swaying.

and proper flow. When wheels are mounted, we will perform a rough survey of the wheel location.

13.6.5.3 Installation Testing Plan

As each octant is installed and connected, we will bring them up to voltage and verify that they are drawing the expected current. We will check a channel or two in each plank with a scope to verify that they seem to be behaving as expected with regard to signal shape and noise levels. We will then readout each channel and verify that each is connected to the DAQ and functioning as expected.

13.6.5.4 Integration and Commissioning

The program of testing and integration leading to a fully commissioned muon system are as follows:

- **Stand-alone subsystem testing**
  We will look for cosmic rays and at beam background when the accelerator is on. This will allow us to debug our readout software, reconstruction software, and the muon trigger before beam arrives.

- **Combined systems testing**
  We plan to be using the DAQ early on, even in our "stand alone" tests. We also plan to use these tests to debug the muon trigger. So, the above "stand alone" tests will also be integration tests with the DAQ and trigger, two important elements that we connect with. We also will want to investigate higher level triggering, which will require information from the tracking systems. Once the tracking systems become available, we will start these tests.

13.6.6 Straw Tracker

The Straw Detector is an assembly of seven standalone stations positioned along the beam line. Each station includes three views. Each view of Stations 1-6 is assembled from two modular half-views. Because of its large size, each view of station seven is assembled from eight 'supermodules'. Stations 1-6 are delivered to C0 fully assembled. Station 7 will be recieved as supermodule subassemblies. All front-end electronics and signal cables will be installed and tested before delivery. Stations 1-6 will be delivered to the C0 assembly hall as fully assembled and tested station. These will be parted into half-stations, rolled into the collision hall and then reassembled around the beam pipe into full stations. Figure 13.17 shows one half of station 4 mounted on the installation ring which allows it to be brought into and then rotated around the beam pipe. For station 7 the super-modules will be transported to C0 and installed in the collision hall individually.

Figure 13.17: Straw station 4 half-station mounted to the installation wheel. The wheel allows the half-station to be brough in to the beam pipe and then rotated around the beam pipe into position. The second half station is similarly brought into place and then the two halves are mated and hung from their overhead supports.

13.6.6.1 Testing Before Arrival at C0

Each wire will be tension tested and checked to see that it holds high voltage as it is strung, and then again when the half-view, or super-module, asembly is complete. Gas and cooling water lines will be attached and leak tested. Each half-view has an environmental sensor to monitor temperature and humidity; the readout from this will be tested. The functionality of the front-end electronics will be tested with pulses injected at the pre-amplifier inputs. The threshold voltages and other programmable registers will be set and read back. The full data readout chain will be tested with a radioactive source and/or cosmic rays. The six half-views of stations 1-6 will be assembled and aligned. The wire positions will be surveyed with respect to external fiducials on the station frames and supermodules.

13.6.6.2 Installation of Straw Detector at C0

The dtailed assembly sequence is:

- In the C0 assembly hall, stations 1-6 and the supermodules for station 7 will be inspected and electrically retested to ensure they were not damaged in transit. Stations 1-6 will be separated into half-stations for installation around the beam pipe. Half-stations and supermodules will be transported into the collision hall with a dedicated cart. The frames used to deliver stations 1-6 are also used for their installation.
- The cart will have provisions for safely positioning the assembly onto a rail system that will allow it to be safely slid transversely around the beam-pipe. Two half-stations will be attached to the rails and connected to make a full station.
- The corresponding forward silicon station may be attached at this point.
- Power supply and signal cables will be attached and tested. Gas and cooling water lines will be attached and leak checked.
- The fully assembled station will be slid into the proper z-position with a set of longitudinal rails. Once at the proper z position the station will be lowered a few centimeters and attached to more stable support brackets.
- The straw stations must be installed in the following order: 1,2,3,6,5,4. Station 7 will be treated separately as it is in a very confined space between the RICH and the ECAL.
- Gas and cooling water lines will be attached to the main C0 systems, power cables connected to patch panels and signal cables connected to Data Combiner Boards (DCBs).
- The positions of the straw stations will be surveyed using external fiducials on the half-view frames.
- Install gas monitoring system

13.6.6.3 Integration and Commissioning

After installation the following integration tests will be done:

- Leak test gas and cooling water systems.
- Test temperature and humidity monitoring and check that power supplies are shut off in the event of a cooling failure, or if humidity is too high.
- Test gas monitoring systems (gas gain, drift velocity, contaminant level), check functionality and integrate into slow control system and database.
- Check that all modules hold HV.
- Threshold voltages and other programmable registers will be set and read back
- Test Front-end electronics with pulses injected at pre-amp inputs
- Test readout into Data Combiner boards

The commissioning of the straw tracker will consist of reading pulser data and horizontal cosmic rays (or beam, if available) data through the DAQ system. This will be done in conjunction with the commissioning of the other tracking systems after the final assembly of all BTeV detector elements.

13.6.7 Silicon Strip Tracker

Once micro-strip half planes are assembled and checked at SiDet, they are ready for the final installation at C0. It is worth noting that micro-strip half planes are already internally aligned to ensure a sufficient relative precision when combined to form a plane and even a station. This means that the most crucial operation during the installation is to position the first plane, on the basis of which the station is built. Micro-strip installation has to be coordinated with that of straw tubes. The installation of the full micro-strip system consists of seven almost identical procedures of single station installation. In the present base-line design, we foresee an independent support for each micro-strip station, but are trying to investigate the possibility to directly integrate the micro-strip support in the straw structure of the same station.

13.6.7.1 Installation Steps

The installation sequence for a single station consists of the following steps:

- Installation of the station support and all the connections to power supplies
- cooling system, and DAQ & control
- Installation of the first plane

- Installation of the second plane
- Installation of the third plane
- Installation of the station enclosure

13.6.7.2 Integration and Commissioning

During the station assembly we plan to execute only some tests to check for the continuity of all the connections; cooling lines, in particular, have to be leak checked and pressure tested. Once the station is completely installed and sealed inside its enclosure, it can be turned on and run. Cooling circuit parameters, such as flows and temperatures, will be continuously monitored while the system is approaching its stationary regime. An extensive check of all the functionality and performance of the station detectors will be carried out by electrically pulsing the FE chips and reading it out through the final DAQ system. Particular care will be devoted to establish a clean grounding of the system. Once the station is fully checked, it will be ready for the final positioning. The station will be smoothly rolled into the final position together with the straw chambers. A final survey of all the fiducials on the station support will be done prior to installation of the next station.

We intend to perform all of these electrical tests using the final DAQ readout system, so this process will also complete the integration of the individual stations with the BTeV DAQ, monitoring and constrols systems. The final commissioning of the tracker will involve recording horizontal muon or beam data, if available, and reconstruction of those tracks.

13.6.8 Trigger

The trigger system will be developed in a three-step process of prototype, pilot, and production hardware. The prototype and pilot hardware will not be used at C0, so details of those components are not included here. The production hardware will be tested using a three-step process before the hardware is integrated at C0. Once the hardware is located at C0, we envision that integration of the trigger system with the DAQ and BTeV detectors will be the primary focus of our effort. This means that we will concentrate on any remaining system issues at C0, since individual modules and trigger subsystems will have undergone previous testing.

13.6.8.1 Summary of Testing Prior to Moving to C0

The three steps of production hardware testing are individual module tests, module interconnections tests, and system integration tests. These tests will be done on all modules before they can become part of the system at C0. The initial testing will be done at other appropriate sites at Fermilab or, in the case of the Muon trigger, Fermilab and/or UIUC. Since the muon trigger will utilize a considerable amount of hardware identical to the pixel trigger, it is advantageous to plan a test stand for the muon trigger at Fermilab, adjacent to the pixel trigger. If the muon trigger development is staged through this test stand at

Fermilab (prior to moving to C0), then all of the following sections addressing transport, installation, and testing will apply equally to the pixel and muon triggers.

13.6.8.2 Installation of the Trigger Elements at C0

Empty electronic racks are first installed in the counting room. Then sub-racks are installed and then the trigger modules inserted. Cables are routed and connected and then system tests begin. Note that the L2/3 PC farm is planned to be installed in a counting room above the one where the L1 trigger is installed. Due to the procurement schedule for the L2/3 PC farm, where 50% of the farm is purchased in the last fiscal year, installation of the L2/3 PC farm will be staged.

Fire and chilled water safety system testing can be part of the building infrastructure testing. Both should be tested before or during trigger system installation.

13.6.8.3 Control and Monitoring Systems

Control and Monitoring system connectivity and testing will be very flexible. The trigger system will be able to emulate the experiment run control system so there is no dependency on that operation. The internal Supervisor and Monitoring systems will be distributed applications that can be activated incrementally, adding resources as needed. The slow control connections will be activated as soon as possible so all testing will have temperature and airflow monitoring.

13.6.8.4 Timing and Clock Systems

There will be two connections to the timing/clock system, one is the pixel data preprocessor level and one at Global Level 1. Both connections will have emulators available for substitution when the experiment timing/clock system is unavailable. No other experiment systems require and/or depend on information from the trigger system.

13.6.8.5 Stand-Alone Subsystem Testing

There are four major subsections in the trigger system; 1) L1 muon trigger, 2) L1 pixel trigger, 3) Global Level 1 trigger, and 4) L2/3 trigger farm. Each subsystem will be designed to operate independently from the others for subsystem tests, generating simulated input data as needed and emulating upper level control functions. Each subsystem will have a granularity that allows a partial subsystem to demonstrate subsystem functionality with a reduced capacity. Stand-alone testing can occur within a partial subsystem or for any combination of partial subsystems. Stand-alone testing of the whole trigger system will first occur as a partial system test of partial subsystems. For the trigger system, this section applies both to the subsystem and system stand-alone testing.

13.6.8.6 Multiple Subsystem Testing for the Trigger

The trigger system gets input from the pixel detector, muon detector, timing/clock system and some detector system trigger primitives. All of these inputs will be emulated until the associated hardware can produce the required data. As these data streams are developed, they can be applied to the trigger system for testing and integration. The trigger system sends output to the DAQ, offline data logging, and the experiment run control system. Testing of the trigger system does not require any of these systems, and as they are developed, the trigger system can connect to them for testing and integration.

The vertical slice hardware initially installed at C0 will be capable of connecting to and testing an equivalent slice of the associated detectors and experiment systems. This can happen in a one to two month time scale after the trigger hardware is functioning stand-alone. Expansion to the full trigger system with all of it's interconnects should take six to eight months if all the hardware is available at the start of the integration.

13.6.9 DAQ

13.6.9.1 Summary of Testing Prior to Moving to C0

The entire readout chain will be tested before moving to C0. These tests include front end modules (provided by the detector groups), Data Combiner boards, optical links and the L1 Buffer system. Integration tests will be performed for the Data Combiner - Front End module interface(s), the interface between the L1 Buffer system and the trigger system as well as for the interface between the timing systems and the detector electronics. Included in those tests is not only the hardware but also the software integration of the central run control and configuration systems, user applications and detector component specific components.

13.6.9.2 Installation of DAQ Elements at C0

Components of the readout and controls system will be placed in the C0 detector hall, the counting room and in the control room (both of which are in the C0 building). Installation of most of the readout and electronics components in the detector hall will be coordinated with the detector sub-groups. As soon as space becomes available, *i.e.* is no longer needed for the insertion of detector components, we will install the racks that house the DCBs and the optical switch modules.

For each component cables need to be installed to connect the front end modules to the DCB/Optical Switch box - about 3,000 cables in total. The connection to the counting room is provided by approximately 256 optical fiber bundles (each with 12 fibers). Before we can run these bundles we will install special inner-ducts in the ducts connecting the detector hall with the counting room. This way we will be able to replace individual fibers should a problem develop. Approximately 300 cables will connect each DCB/Optical Box with the timing system.

Installation of readout and controls equipment in the counting room starts with the relay racks, power and cooling. Once these services are available we will install the L1 Buffer system and the Data Combiner modules that are not located in the detector hall. Approximately 3,000 network cables have to be installed between the L1 Buffer system, the switching network and the Level 2/3 farm. Work in the control room can proceed in parallel. Installations steps include setting up the control room furniture, the network infrastructure as well as the computer/operator consoles. Just as the readout system the detector control system requires equipment to be installed in different location. Most of the monitoring and control system in the detector hall will be installed by the sub-detector groups. Network (Cat 5) and field-bus cables will connect these systems to the supervisor components of the control system that are located in the counting room. The precise location of the equipment computer (Detector Manager and Control Manager/Supervisor) still needs to be defined. While most of these workstations will be placed in the counting room some need to be close to the hardware and will reside in the detector hall. The elements of the Global Detector Control System will be split between the counting room (supervisor CPUs) and the control room (workstations with the user interface(s)).

13.6.9.3 Multiple Subsystem Testing for DAQ

The final commissioning of the DAQ system will simply repeat the internal test program developed previously using the Integration Test Facility including tests of the entire readout chain and the detector control system. At this point the full BTeV detector, trigger and DAQ system will be installed, integrated and commissioned.