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Grounding of the ATLAS Experiment

Documentation of the grounding architecture implemented in the ATLAS detectors, infrastructure and back-end systems.

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History of Changes			
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Introduction.

1.1 Scope of the document.

This document describes the implementation of the grounding in the ATLAS experiment and its associated services and control rooms.

The grounding is meant here as all the direct or indirect connections, by means of cables or mechanical links, that connect the equipments, the mechanical structures, the detectors electrical and electronic circuits, and the shields of the cables to the protective earth of the ATLAS facilities.

A distinction is made between the grounding of the facilities and the grounding of the detectors:

- The grounding of the detectors is addressed in the frame of the ATLAS Electromagnetic Compatibility Policy [2]. It results from the discussions maintained with the responsible persons of each detector, in order to achieve a grounding that insures the electrical safety and the proper performance of the detector. A grounding configuration was studied and agreed for each individual case, and is documented extensively on the ATLAS EMC web site [1].
- On the other hand the grounding of the facilities and services follows the rules that are applicable at CERN for electrical distribution, which are based on the rules applicable in the European Union and in Switzerland. The configuration was studied and implemented by the TS/EL group at CERN, in order to guarantee the electrical safety for personnel and for the equipments. The French low voltage standard NF C 15-100 [4], the CERN electrical code C1 [5] and the CERN safety instruction IS24 [6] are used as reference.

Some detectors required to control the electrical isolation with the neighboring detectors. The provision for electrical separation are documented here as well, together with the methods to control it.

1.2 Grounding and electromagnetic compatibility.

The grounding of the facilities and of the non isolated structures and mechanical elements is required as a protection against electrical faults, such that a faulty contact from a live conductor on any of these structures or elements will never develop a voltage potential that might represent a hazard for the personnel or the equipment in contact with it. Also, the grounding of the facilities is associated with the provision of protection devices such that an electrical fault will originate an overcurrent condition that will trigger the protection device associated with the faulty circuit.

The grounding of the facilities carry all the leakage currents of the equipment connected to it. The grounding links are usually long and inductive, therefore voltages are developped across them. Those are known as Common Mode Voltages and are a dominant source of noise for all the electronic systems. To reduce these voltages, the inductance of the grounding links must be reduced. This is achieved by meshing the grounding connections of the facility as document in IEC-61000-5-2 [3]:

- Interconnection between grounding cables.
- Connection of all the metallic structures to the closest grounding cable.
- Interconnection of the metallic structures between themselves.

Whenever possible the structures and the enveloppes of the detectors are binded to the grounding mesh of the facility, in an attempt to reduce the common mode voltages and to provide a mesh with greater density. Also whenever possible the electrical and electronics circuits are referenced to the grounding of the facility.

The grounding of systems to the facility earth is only one of the issues to be addressed for proper performance but is not sufficient by itself. It is reminded that the optimal performance in terms of electromagentic compatibility (in addition to the grounding) is achieved by:

- The procurement and/or design of back end equipment compliant with EMC rules applicable in the European Union (CE marked).
- The use of appropriate cables and adequate connection of the shields.
- The design of front-end systems with an immunity level against conducted noise that is large enough for the required performance.

1.3 Grounding topology.

The grounding for the ATLAS experiment is implemented according to the following topology arranged by decreasing importance:

- The term “grounding” refers in all cases to the protective earth delivered by the electrical supply. The earth reference is formed on the surface at the secondary starpoint of the input power transformers. From that point, it is distributed to all the facilities together with the electrical supply.
- The protective earth or grounding is distributed down to the user electrical plugs to comply with the electrical safety rules.
- The protective earth or grounding is derived from the switchboards to distribute the equipotential network used to link the building steelwork, the structures, the cable trays and the racks. It is also connected to the detector structures and feet and to all the metallic enveloppes.
- The electrical circuits of the detectors are grounded to the equipotential network following the implementation rules as agreed with the collaborations of each detector.
- The shielded interconnects have their shield connected to the equipontential network in at least one side.

2 Surface installations.

2.1 TDAQ room in SDX1.

The grounding of the TDAQ back-end system is implemented in agreement with the electrical safety rules of CERN (figure 1). The protective earth conductor is distributed together with the three phases AC power lines from the switchboard located out of the TDAQ room to six local switchboards in the room. Each of the these switchboards feeds one row of racks. Each rack is fed by two power lines, each containing its own protective earth conductor.

All the computing equipment is grounded to the protective earth distributed by the switchboards through the AC power cables.

In addition to this, the cable trays laying underneath the false floor are fitted with an earth conductor, made of a naked copper cable of 120 mm^2 of cross section. Each row of racks is strapped with a perforated tinned copper strip of 50 mm^2 of cross section. The straps are bonded to the earth conductor in the trays. This provides the grounding of the racks and of the enveloppes of all the equipment in the racks.

The strapping of the racks and their connection to the earth conductor of the trays provide an additional path for the protective earth, and it provides a grounded mesh that helps to contain the emission of interferences of the computing equipment.

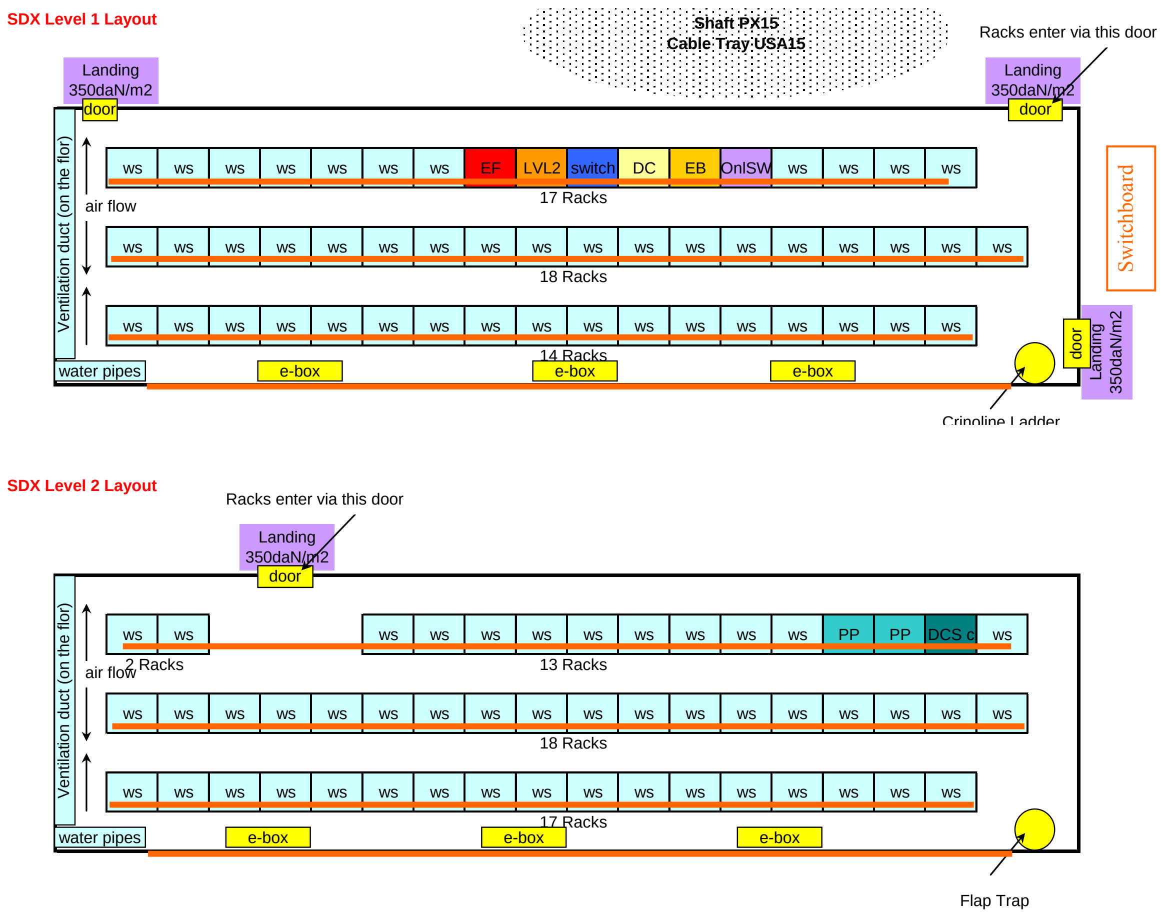

Figure 1: Grounding of the TDAQ racks.

2.2 Control Room SCX1 and other facilities and buildings.

The control room electrical services are implemented through sockets with differential protections, whose installation was made under the responsibility of TS/EL following the electrical safety rules applicable at CERN.

3 Underground installations.

3.1 Technical cavern USA15.

The USA15 technical cavern hosts several installations in different sectors. In this document, the grounding of the back-end control room in USA15 is addressed (figure 2).

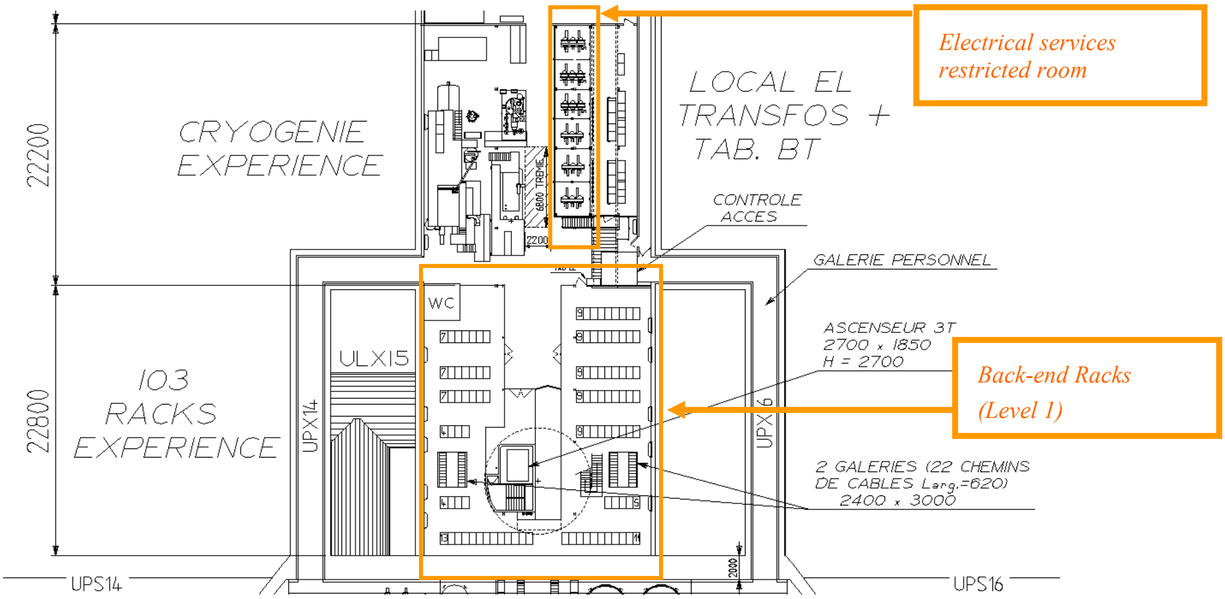

Figure 2: USA15 Back End Integration Area.

3.1.1 *Power distribution and Canalis System.*

The electrical power is distributed to ATLAS in TN-S configuration [4] (figure 3). The power for the back end system is delivered by a set of transformers located in a room for electrical services (figure 2). The secondary star points of the transformers are locally bond to an earth electrode, and to the protective earth conductor (PE); the neutral is routed separately from the PE conductor. The PE conductor carries leakage and ground fault currents

The power is brought to the control room by means of busbars known as Canalis. The protective earth (PE) is distributed with the Canalis busbars to each rack distribution chassis. Every electrical device in the rack is grounded for safety via the Canalis busbars.

It is important to note that the electrical installations of the racks in USA15 are considered as fixed installations, and for this reason none of the racks are fitted with differential breakers. The only protection available in the racks is an overcurrent breaker, sufficient for equipment but not safe for personnel.

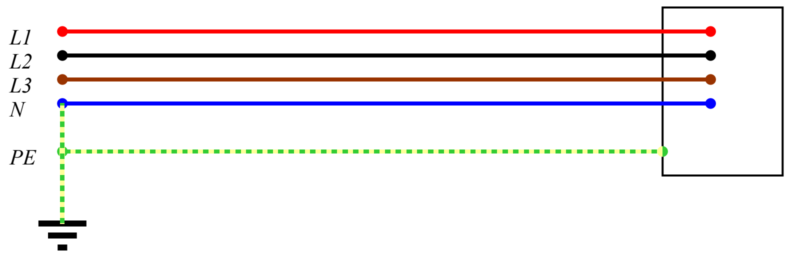

Figure 3: TN-S distribution scheme for the back-end system.

3.1.2 *Metallic structures, cable trays and racks.*

In addition to the grounding of the electrical equipment, the grounding for all the non isolated metallic structures is provided. For this purpose, a grounding network is distributed and linked to all these elements to insure the safety of the area.

3.1.2.1 Steelwork.

The steelwork of the USA15 cavern is linked to earth as documented in [7]. It is grounded at the surface directly to the earth electrode. Four ground plates (figure 5) are available at the second floor of USA15 racks room [8]. Ground bars are welded to the plates (figure 4), each providing six ground ports where the grounding wires for the structures are connected to.

Figure 4: Grounding bar in USA15.

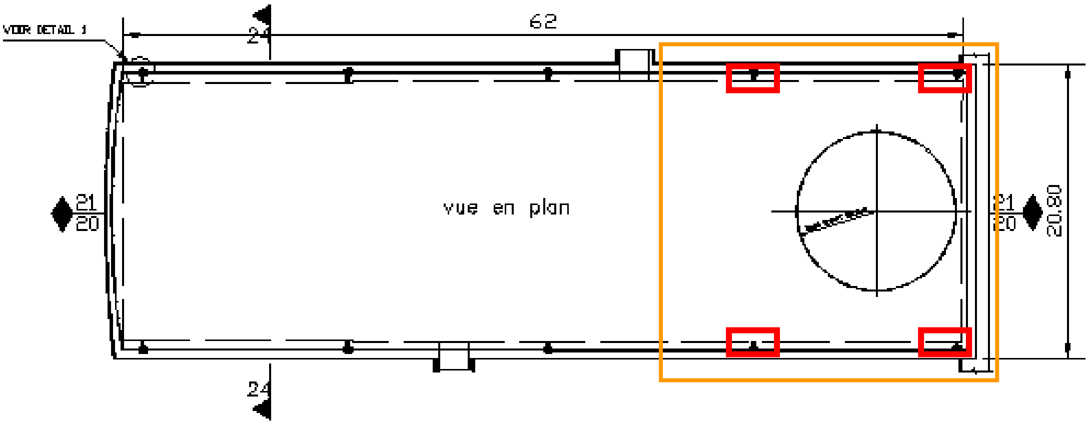

Figure 5: Steelwork grounding of the USA15 technical cavern as documented in [13] with enhancement of the back-end control room.

Other grounding plates are available in other places of the USA15 technical cavern. All are used for the grounding of the structures.

3.1.2.2 Mechanical structures.

The control rooms in USA15 are built on the basis of mechanically assembled steel structures. These structures are bolted and/or welded. The electrical continuity between elements is obtained through the mechanical links (bolts and weld points). The structures are linked to the steelwork, they are indirectly grounded at this level.

There is no provision for straps or other interconnects between the structural elements.The paint is not removed at the interface between elements.

3.1.2.3 Cable trays

The false floor on both levels of the USA15 back-end control room is equipped with ladder type cable trays that carry all the cables used to link the UX15 front-end systems with the back-end racks. The arrangement of the trays is made on several levels as documented in [9] and [10]. For each floor, the top most layer of trays is fitted with a continous naked copper cable of 120 mm^2 connected to the steelwork ground plates (figure 6). The other layers of trays are linked together every 25 meters (figure 7). These grounding cables are then combined together at the entry to the TE14 and TE16 galleries, where one ground cable per stack of trays is then passed towards UX15 (four cables in total).

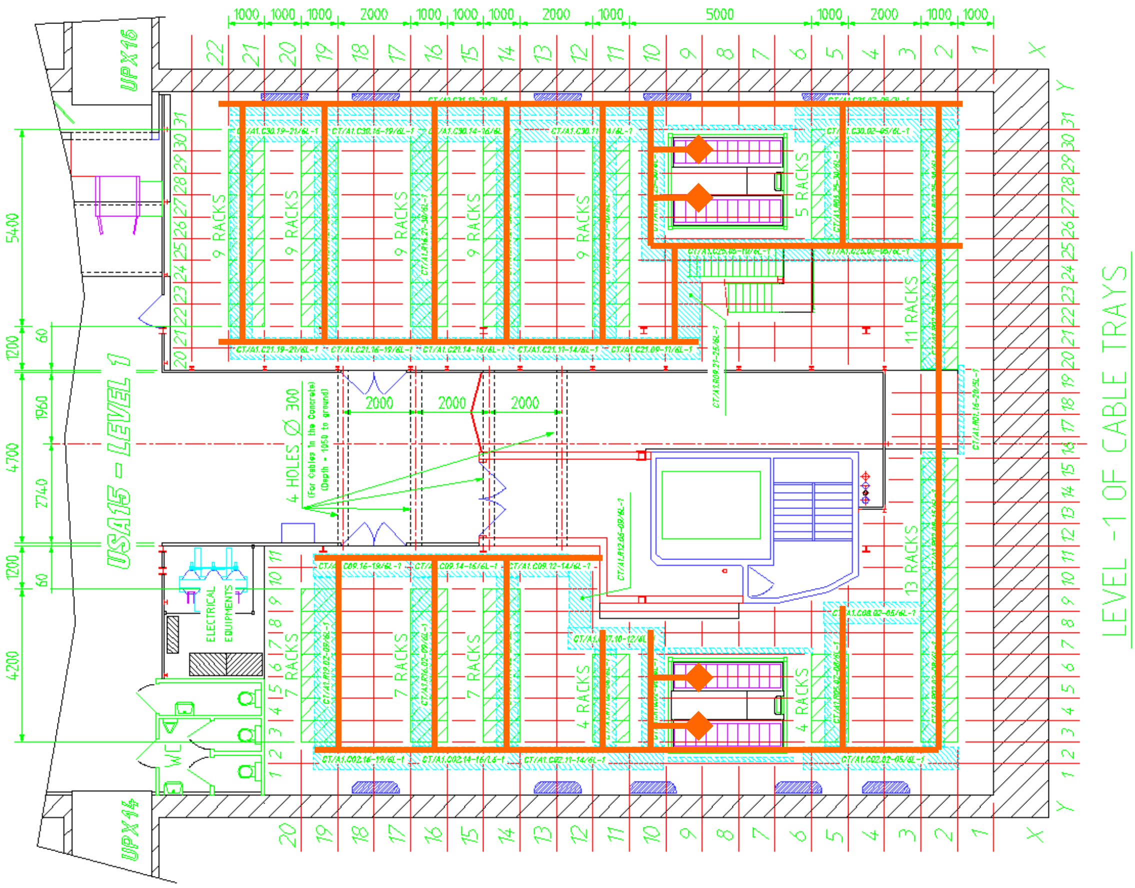

Figure 6: top most layer of cable trays on the first floor of the USA15 back-end control room.

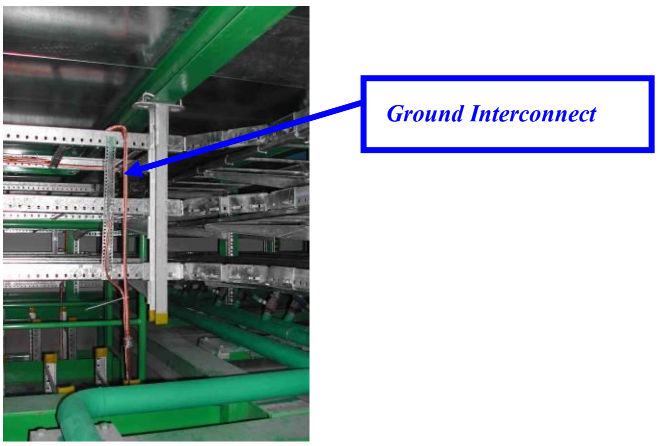

Figure 7: Interconnection of the stacked cable trays in USA15.

3.1.2.4 Racks.

Each row of racks in USA15 is interconnected by means of a tinned and perforated copper strip bolted to the ground studs of the racks (figure 8). For each row, the copper strip is linked to the ground cable placed in the cable tray.

The side plates, the removable roof plates and the back door of each rack are strapped to the ground studs of the rack by means of a 6 mm^2 isolated pigtail.

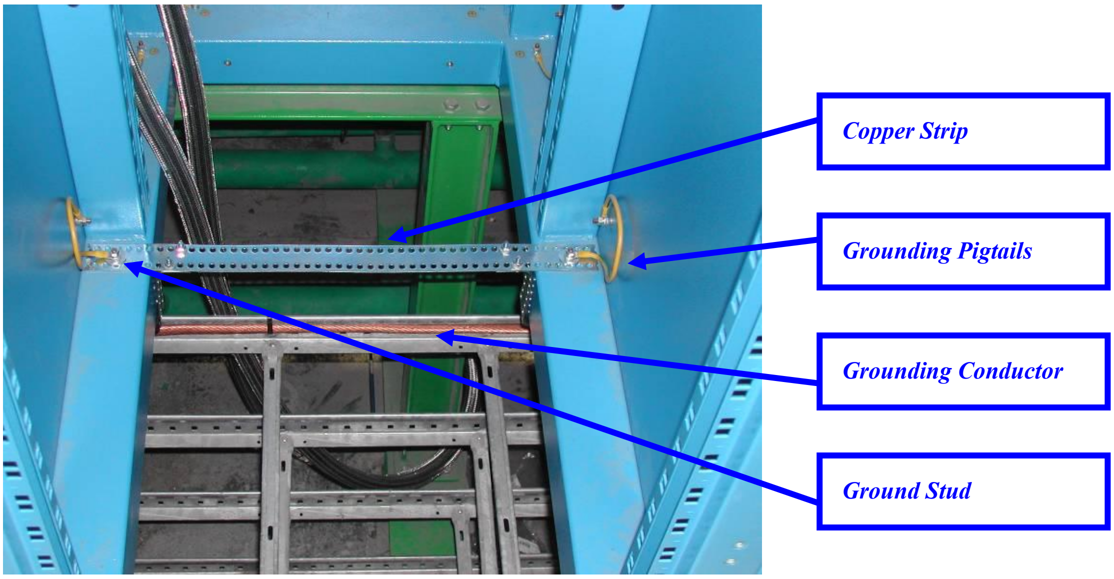

Figure 8: Racks grounding copper foil, and grounded cable tray underneath.

3.1.3 Back-end electronics.

The back-end electronics that is installed inside the racks of USA15 is grounded at two places:

- The electrical circuits of all the back-end equipments are protected by the protective earth circuit that is distributed together with the Canalis bus bars. This connection is mandatory in order to allow the overcurrent breakers to trip in case of electrical fault inside the rack (short to the enveloppe).
- The enveloppe of all the back-end systems is mechanically screwed to the rack, which is grounded (§ 3.1.2.4). It provides an additional equipotential connection that reinforces the safety of the installation and helps to reduce the emission of electromagnetic noise (meshed ground).

3.2 Technical cavern US15.

The US15 technical cavern hosts several installations for the ATLAS experiment and for the LHC. In this document, the grounding of the ATLAS back-end electronics on the second floor of US15 is discussed (figure 9).

Figure 9: US15 Level 2 back-end room.

3.2.1 Switchboard distribution.

The electrical power is distributed in ATLAS in the TN-S configuration (figure 3, § 3.1.1). The power for the back-end system in US15 is delivered by a dedicated switchboard located inside the control room (EXD1/15). The power to each rack is distributed with individual cables each containing a protective earth conductor.This PE conductor carries the leakage and ground fault currents.

It is important to note that the electrical installations of the back-end room in US15 are considered as fixed, and for this reason none of the racks are fitted with differential breakers. The only protection available is an overcurrent breaker, sufficient for equipment but not safe for personnel.

3.2.2 Metallic structures, cable trays and racks.

In addition to the grounding of the electrical equipment at the switchboard level, the grounding of all the non isolated metallic structuires is provided. For this purpose, a grounding network is distributed and linked to all these elements to insure the safety of the area.

3.2.2.1 Steelwork.

The steelwork of the US15 technical cavern is linked to equipotential network of the LHC tunnel.

3.2.2.2 Mechanical structures.

The control room in US15 is built on the basis of mechanically assembled steel structures. These structures are bolted and/or welded. The electrical continuity between elements is obtained through the mechanical links (bolts and weld points). The structures are linked to the steelwork, they are indirectly grounded at this level.

3.2.2.3 Cable trays.

The false floor on level 2 of US15 is equipped with ladder type trays that carry all the cables to link the racks to the switchboard, and to interface the back-end with the front-end systems in UX15. The top most layer of cable trays is fitted with a naked continuous copper cable of 120 mm^2. The other layers of trays are linked together every 25 meters as in USA15 (§ 3.1.2.3).

The equipotential network of US15 is passed towards UX15 through one of the openings of the UX15 wall (one cable).

3.2.2.4 Racks.

Each row of racks in US15 is interconnected by means of a tinned and perforated copper strip bolted to the ground studs of the racks as made for USA15 (figure 8). For each row, the copper strip is linked to the ground cable of the tray that lays underneath of it.

The side plates, the removable roof and the back door of each rack are strapped to the ground studs of the rack by means of a 6 mm^2 isolated pigtail.

3.2.3 Equipment inside the racks.

The back-end electronics that is installed inside the racks of US15 is grounded at two places:

- The electrical circuits of all the back-end equipments are protected by the protective earth circuit that is distributed by the electrical switchboard. This connection is mandatory in order to allow the overcurrent breakers to trip in case of electrical fault inside the rack (short to the enveloppe).
- The enveloppe of all the back-end systems is mechanically screwed to the rack, which is grounded (§ 3.2.2.4). It provides an additional equipotential connection that reinforces the safety of the installation and helps to reduce the emission of electromagnetic noise (meshed ground).

3.3 Experimental cavern UX15.

The grounding of the UX15 experimental cavern addresses the following items, independently of the detectors installed inside of it:

- Grounding of the cavern steelwork and provision of grounding plates.
- Grounding of the metallic structures and scaffoldings.
- Grounding of the racks on the structures.
- Grounding of the feet of the experiment.

The interconnection of the above items forms the equipotential network in UX15 (figure 10).

The grounding of the detectors and of the experiment services are addressed in section § 3.4.

3.3.1 Grounding of the UX15 cavern steelwork.

Similarly to the USA15 and US15 technical caverns, the steelwork of the UX15 experimental cavern is linked to the earth electrode on surface. Ten grounding plates (figure 11) are welded to the beams of the cavern walls, available at both levels 0 and 7 [13].

A 120 mm2 naked copper grounding cable links the grounding plates between them [14, 15, 16] at levels 0 and 7/8.

This circuit consitutes the reference grounding network for the ATLAS detectors.

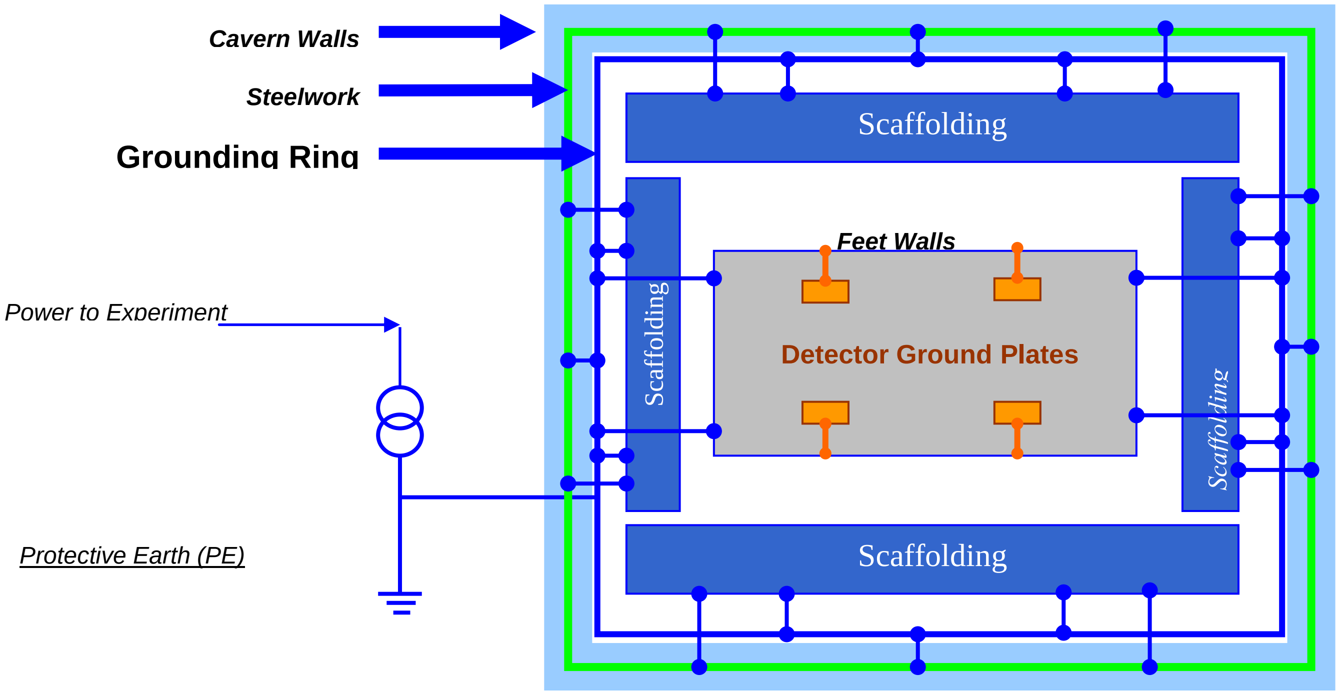

Figure 10: Equipotential network in UX15.

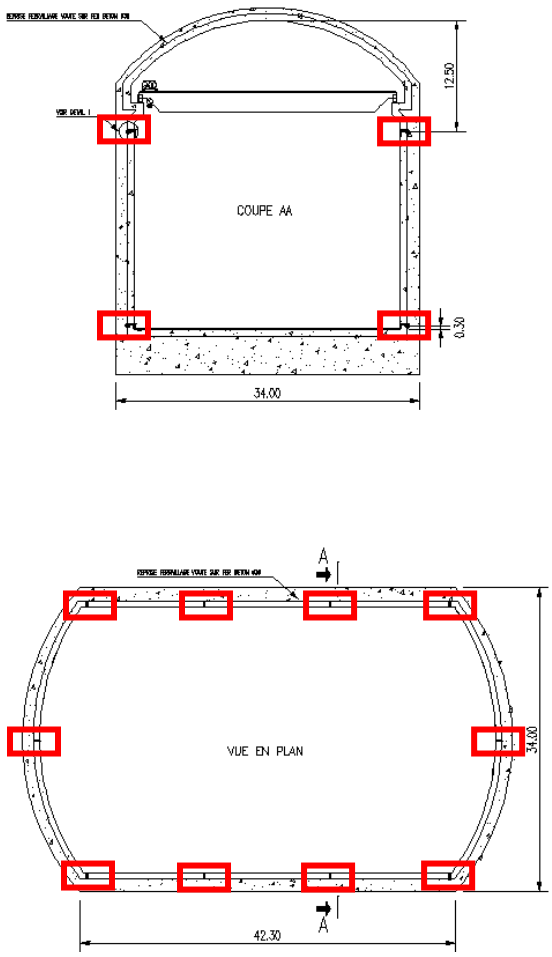

Figure 11: Identification of grounding plates in UX15.

3.3.2 HO and HS structures.

The earth loop that is linked to the steelwork is connected to all the main beams of the HO and HS structures (figures 10 and 12). The connection is bolted on a plate that is itself welded to the beam. The HO and HS structures are made of bolted profiles and the electrical continuity is made at the mechanical interfaces; no strapping is provided between the different parts of the structure.

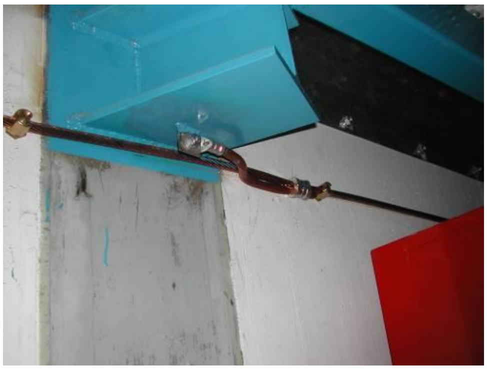

Figure 12: Grounding of the HO and HS structures.

3.3.3 Feet.

The ATLAS feet consist of six stainless steel supporting structures that sit on the bedplates. The electrical continuity between neighbouring feet through the bedplates was measured to be less than 1 ohm. The grounding of the feet is achieved by means of four perforated and tinned copper foils ($50mm^2$) that attach the corners of the feet (figures 10, 13 and 14) to the grounding ring of the UX15 cavern (figure 11 and 12). The foils are routed on the floor and in the trenches. A 120 mm2 naked copper pigtail links the foil with a grounding plate that is welded to the feet (figure 14).

The parts of the ATLAS feet are made of stainless steel. The electrical continuity between them is made by contact at the mechanical interfaces. No straps are provided.

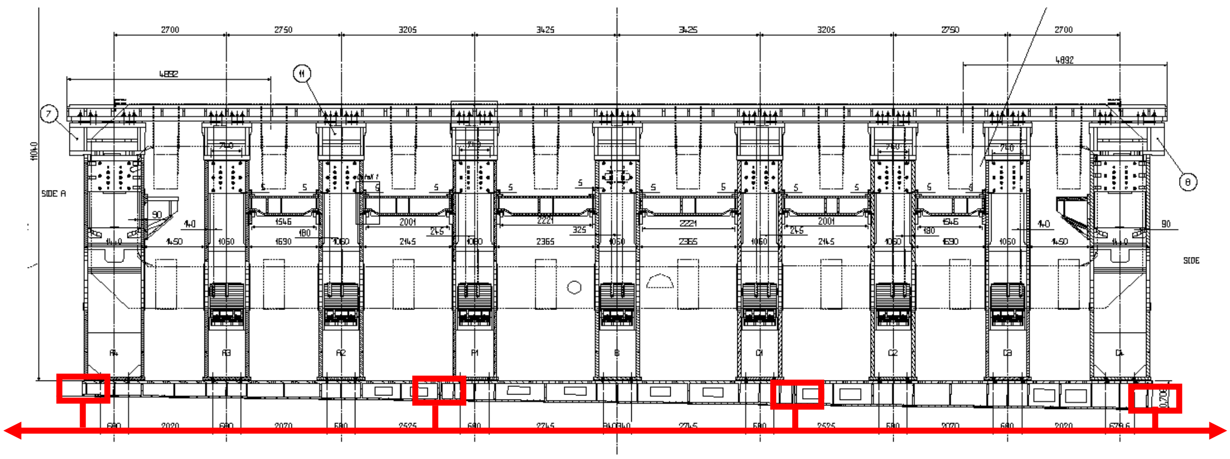

Figure 13: Grounding connections on ATLAS Feet.

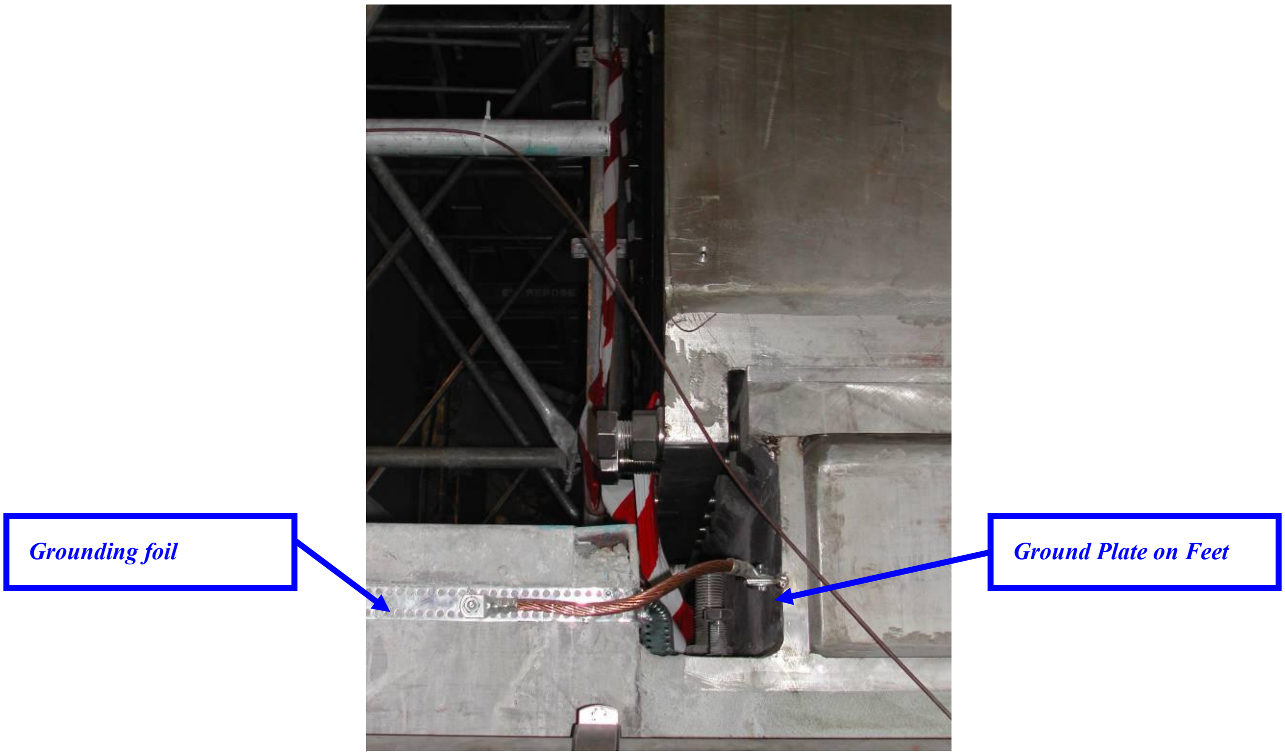

Figure 14: grounding pigtail on USA15-A side that links the grounding foil to the feet grounding plate.

The grounding network is furthermore extended from the feet to four grounding plates that are symmetrically located in sector 13 cable trays (figure 15). The four cables that connect the feet to these plates are labelled (Table 1). The ground plates are made available for the grounding of the detectors; they are made of plain copper and they are provided with holes to allow for an easy connection of lugs.

Item Id	Function	Standardfield	Length	Diameter	Cross Section	Cable Description	Cable Characteristic	Startpoint Location	Endpoint Location
2874001	Grounding	EC/HBF.A-S12.XB/Gs/CT.X.Z1.S13C-S12	20	17.2	95	UX15 grounding network	Endpoint bonded to cable tray	ATLAS Feet USA side A side	CT/X.Z1.S13C-S12/2W3
2874002	Grounding	EC/HBF.C-S12.XB/Gs/CT.X.Z1.S13C-S12	20	17.2	95	UX15 grounding network	Endpoint bonded to cable tray	ATLAS Feet USA side C side	CT/X.Z1.S13C-S12/2W3
2874003	Grounding	EC/HBF.A-S14.XB/Gs/CT.X.Z1.S13C-S12	20	17.2	95	UX15 grounding network	Endpoint bonded to cable tray	ATLAS Feet US side A side	CT/X.Z1.S13C-S14/2W3
2874004	Grounding	EC/HBF.C-S14.XB/Gs/CT.X.Z1.S13C-S12	20	17.2	95	UX15 grounding network	Endpoint bonded to cable tray	ATLAS Feet US side C side	CT/X.Z1.S13C-S14/2W3

Table 1: Grounding cables that link the feet to the ground plates in sector 13.

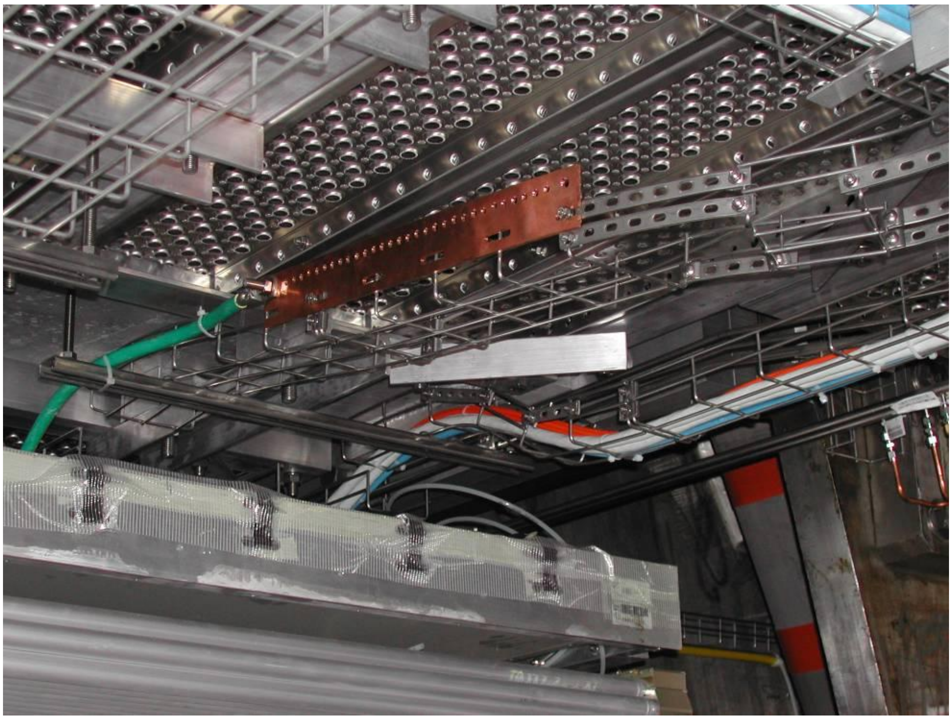

Figure 15: grounding plate in sector 13.

3.3.4 Cable trays and racks in UX15.

The experimental cavern contains about one hundred racks with back end systems, patch panels and power supplies. As for the control rooms, the racks are grounded to the equipotential network by means of a dedicated net of grounding cables. The racks are scattered on the HO and HS structures, some of them are grouped in small bunches.

The cavern also contains a large quantity of cable trays of all types that interconnect the control rooms (USA15, US15), the UX15 racks, and the detectors front-end electronics and services. The equipotential network is delivered in the TE14 and TE16 galleries by the four grounding cables that proceed from the USA15 cable trays (§ 3.1.2.3). Each of these cables is split into two new cables, one of them is run along the arches, the other one is run in the trench; they are then interconnected on the US15 side at level 4.

The racks in UX15 are then connected to these 8 main grounding cables (120 mm^2 naked copper) with individual pigtails. Grouped racks are interconnected by a tinned copper foil (50 mm^2) bolted to the roof, and the group is grounded to the nearest main grounding cable with a single pigtail.

3.3.4.1 Start and end points for the UX15 cable trays grounding cables.

The four grounding cables that proceed from USA15 are available in the following trays of the TE14 (figure 16) and TE16 galleries (figure 17):

Arch	Start Point	Endpoint
RC1	CT/X.DPC.RC1T22-TE16/6L1-7	CT/X.RC1.S3-1/6L2-3
RC2	CT/X.DPC.RC2T22-TE16/6L2-6	CT/X.RC2.S3-1/6L1-2
RA1	CT/X.DPA.RA1T23-TE14/6L1-8	CT/X.RA1.S3-1/6L1-3
RA2	CT/X.DPA.RA2T22-TE14/6L2-6	CT/X.RA2.S3-1/6L1-1

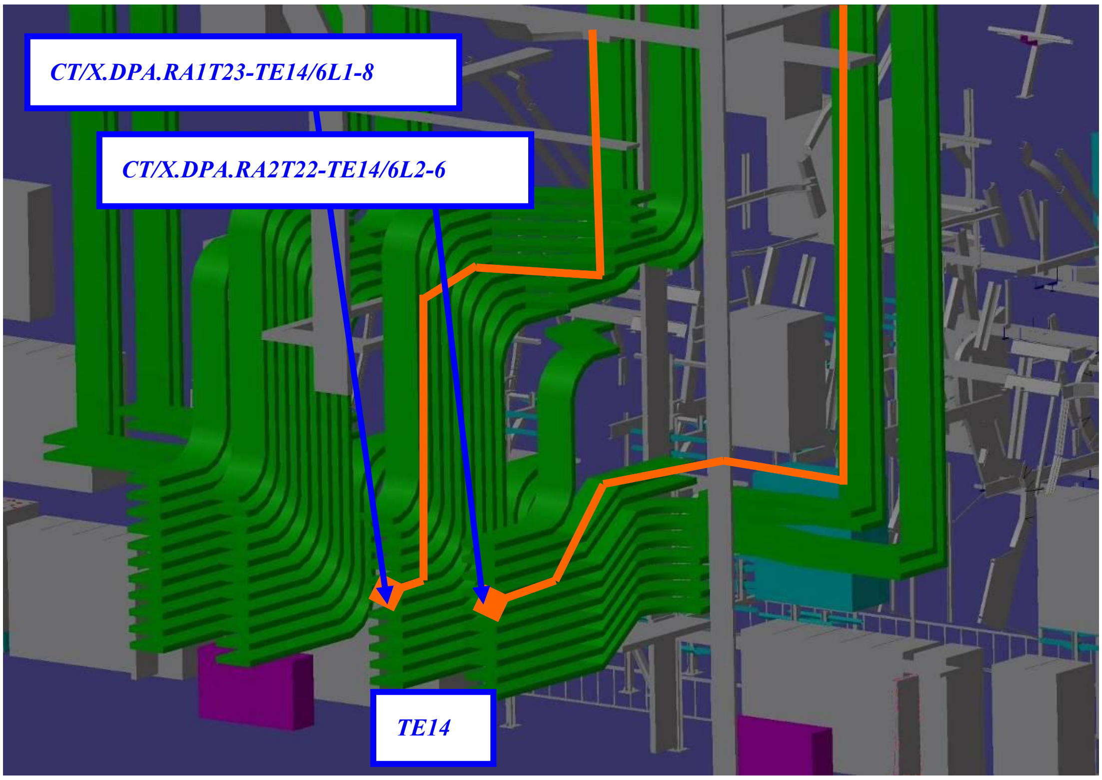

Figure 16: start point for the grounding of the UX15 cable trays in TE14 gallery for the A side arches.

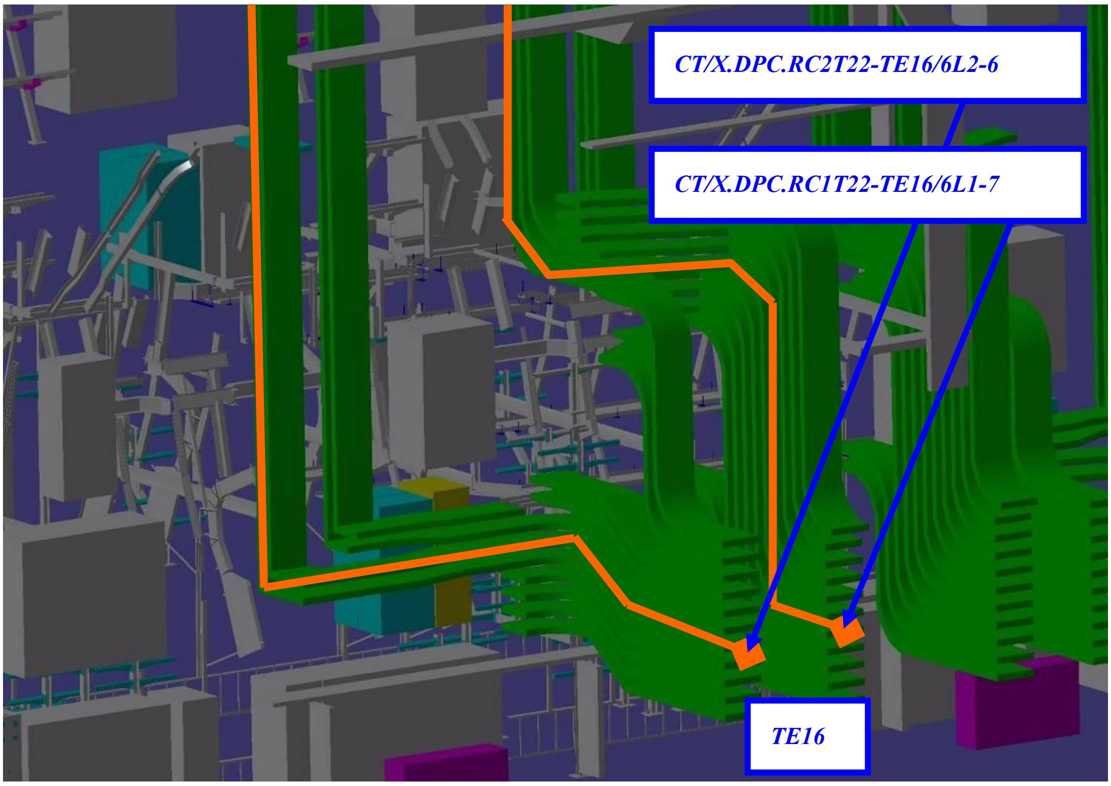

Figure 17: start point for the grounding of the UX15 cable trays in the TE16 gallery for the C side arches.

3.3.4.2 Grounding cables in the arches.

Four grounding cables are placed along the four arches in the cable trays RA1, RA2, RC1 and RC2 (Figure 18). The cables are bonded to the trays at three locations (figure 18) by means of a bi metallic plug. The cables are bonded to the start point cables that come from USA15 (§ 3.3.4.1).

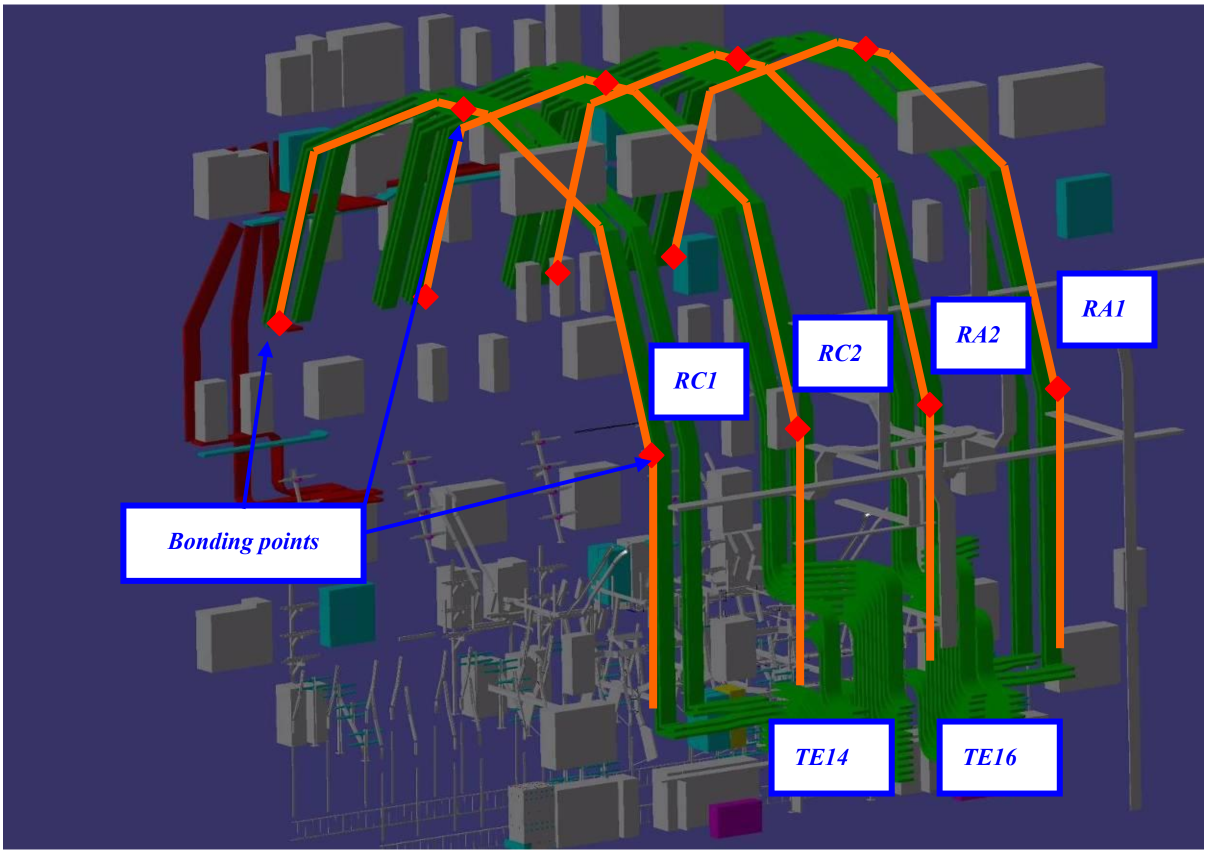

Figure 18: grounding cables and bonding locations along the arches.

3.3.4.3 Grounding cables in the trenches.

Four grounding cables are placed in the four stacks of cable trays that cross the trenches (Figures 19 and 20). The cables are bonded to the trays at three locations (figures 19 and 20) by means of bi metallic plugs. The cables are bonded to the start point cables that come from USA15 (§ 3.3.4.1).

3.3.4.4 Grounding of the racks in UX15.

Because the racks are scattered in small bunches in UX15, their connection to the grounding network is implemented on a case by case basis with the following guidelines:

- The grouped racks are strapped with a tinned and perforated copper strap (50 mm^2).
- The internal ground stud of each rack is connected either to the copper strip or directly to the grounding cable of the closest arch or trench cable tray. The connection is made with a 50 mm^2 naked copper pigtail.
- The copper strip is connected directly to the grounding cable of the closest arch or trench cable tray. The connection is made with a 50 mm^2 naked copper pigtail.

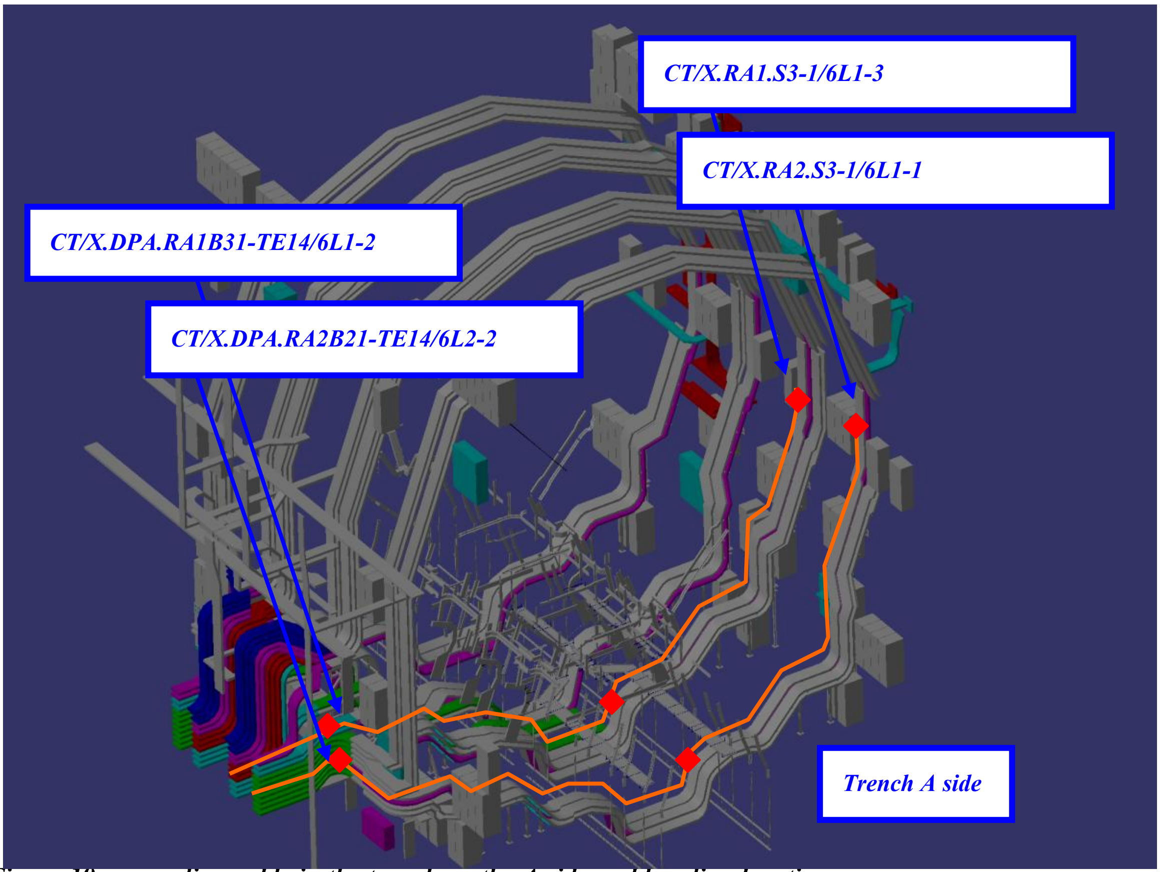

Figure 19: grounding cable in the trench on the A side and bonding locations.

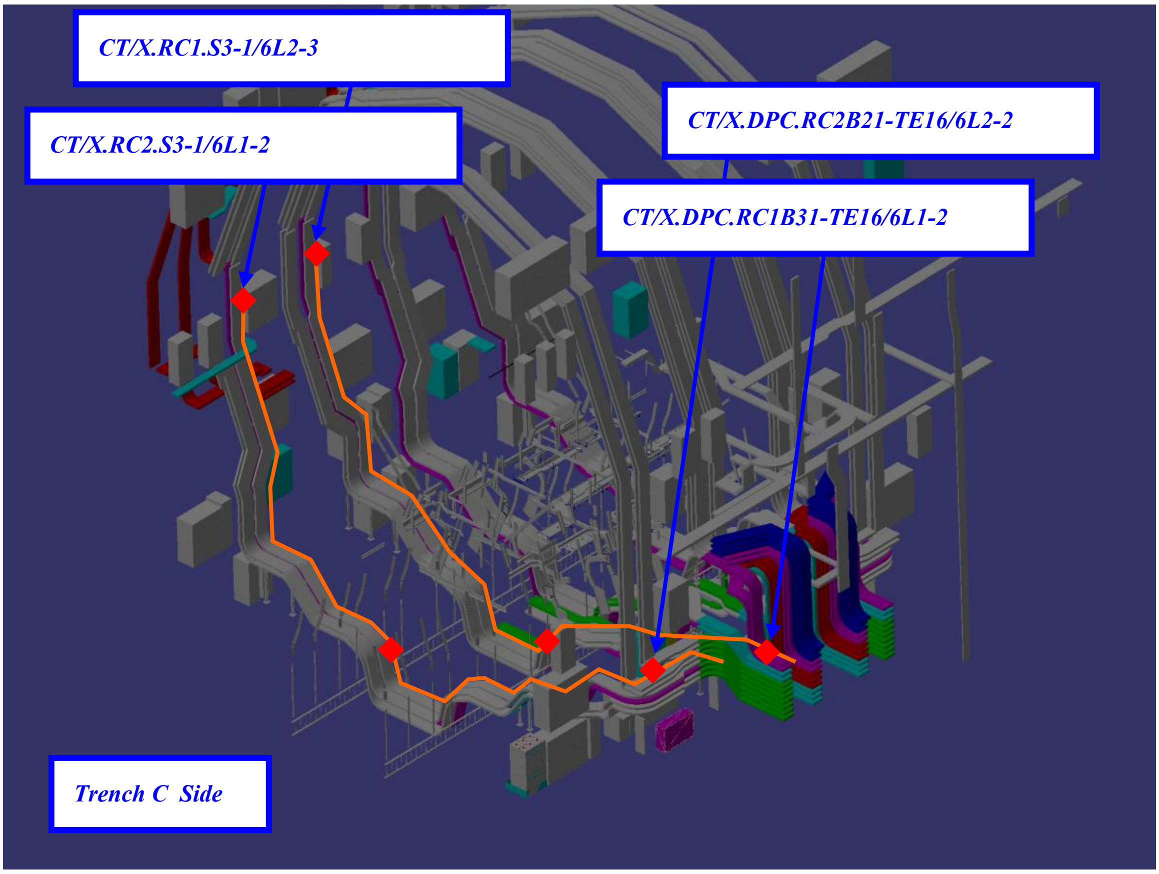

Figure 20: grounding cables in the trench on the C side and bonding locations.

3.4 Grounding of the ATLAS detectors.

3.4.1 Coordination with the systems.

The grounding of the detectors was discussed extensively within the collaboration of each detector and system. Because each system has its own particularities, every system is grounded in the way that allows the best performance for the front-end electronics while still maintaining the safety for personnel and for equipment as specified in the ATLAS Electromagnetic Compatibility Policy [2].

3.4.2 Electromagnetic compatibility issues.

The different detectors are installed in a way that provides some degree of electrical isolation between them. It must be noted that given the density of the installation of these detectors, even when grounded the coupling of noise between systems remains possible at the frequencies where the detectors are operated (between 1 MHz and 100 MHz):

- Capacitive coupling between enveloppes and systems.
- Inductive coupling between adjacent cables.
- Common impedance coupling between systems that share a common ground or power cable.

The grounding of the systems by means of cables is known to have a limited effectiveness to reduce the noise couplings [3], because at the frequencies of interest the impedance of such cables is much larger than the impedance of stray capacitances between systems.

3.4.3 Calorimeters.

3.4.3.1 Arrangement of calorimeters.

Two calorimeters are installed in ATLAS:

- the Tile hadronic calorimeter.
- the Liquid Argon electromagnetic calorimeter.

Each of those is composed of one barrel and two endcaps (A and C). The tile calorimeter is built as a cylinder that fully encloses the liquid argon calorimeter.

3.4.3.2 Indirect grounding of the Tile Calorimeter.

The Tile calorimeter is supported on rails where it can slide. The rails are mechanically linked to the feet. Steel brackets serve as guides along the rail supports. Once in place, the calorimeter is supported by stopping jacks.

The supporting structure of the Tile calorimeter isn't isolated from the rails where it stands. Because the feet are grounded to the UX15 equipotential network (§ 3.3.3), the steel of the tile calorimeter is indirectly grounded to the cavern through its supports.

The continuity between the Tile calorimeter steel and the earth in UX15 was measured on the three cylinders before the installation of the grounding cables.

3.4.3.3 Isolation of the Liquid Argon Calorimeter.

The cryostats of the Liquid Argon calorimeter are electrically isolated with respect to their supports, pipes and neighbouring systems. Grounding is insured by a single connection to the racks in USA15 for each one of the cryostats. The isolation of the cryostats (Barrel and Endcaps A+C) from their surroundings includes following important points:

3.4.3.3.1 Isolated cryostat supports from the Tile calorimeter.

The barrel (endcap) warm vessel is supported by the barrel tile (extended barrel tile) calorimeter at four points. Support plates (A-frames for the barrel, EB LAr support plates for the endcaps) are bolted to the Tile calorimeter iron plates and fixed on the saddle support at about 45 degrees from the bottom vertical. Electrical isolation of the cryostats from the Tile calorimeter is realized through a thin G10 layer installed between the top plate and the top block of the cradle in the support assemblies. Despite this, a capacitive coupling between the cryostat cylinder and the tile calorimeter cylinder was estimated to be around 23 nF, that is less than 1 Ω at 10 MHz.

3.4.3.3.2 Isolation of cryostats on the outer surface:

The space between the Tile calorimeters and the warm outer vessels of the LARG calorimeters is in average about 39mm. To avoid contacts between the two subsystems local grounds a thin isolating foil is wrapped around the warm outer vessels and complemented with fixed isolation plates for the bulkheads faces overlaps.

3.4.3.3.3 Isolation of cryostat on the barrel inner surface:

The inner tracker is supported by ledges glued to the inside of the inner warm vessel along all of its length. Also, the inner vessel and the warm bulkhead will support the necessary services. The isolation of the two systems includes:

- Tracker support rails are welded to the cryostat. Consequently, the central tracker is isolated from the rails.
- Tracker services like cooling lines, signal and power cables will be supported by the inner warm vessel and/or by the cryostat bulkhead. ID cable trays will be electrically isolated from the vessel.
- Some of the tracker services in the gap region (cooling pipes, manifolds and patch panels) will be supported either by the cryostat or by the Tile calorimeter. All will be electrically insulated from the cryostat as well as from the Front-end crates

It must be noted that the barrel mounting flange is electrically bonded to the Tile Calorimeter, which is earthed. Therefore, all the inner detector services are earthed indirectly at the mounting flange.

In the inner detector volume, the cable trays are electrically insulated from the warm vessel. All the services are provided with insulating links when leaving the trays in the inner detector volume.

3.4.3.3.4 Isolation to the superconductive coil solenoid

- The barrel LARG calorimeter and the superconductive solenoid share a cryostat to reduce the radiation length in front of the calorimeter and save radial space.
- The power and cryogenic lines penetrate through the calorimeter walls but are totally isolated from the cryostat walls as well as the coil and the cylinder support.
- The coil and the support cylinder are supported by triangle supports made of fiber-glass reinforced plastics (GFRPS).
- The power and cryogenics lines are connected to the top part of the coil on side A, bundled together and routed along the wall of the cold-vessel bulkhead to the top of the cryostat. Dedicated supported struts fix such lines to the warm bulkhead in order to prevent from twisting and quenching during coil charge.
- The whole service is covered by thermal super-insulation.
- The superconducting bus line is routed to the chimney through a flange at the top of the LARG cryostat. At 50cm from the flange there is a chimney break (50cm in length) for access purposes. The break is joined by a bellows unit with vacuum flange on both ends.

3.4.3.3.5 Isolation of power supplies for readout crates

Each power supply module is installed in between the Tile calorimeter fingers supported on 2 rails bolted to the fingers from the bottom. Metal plates from the top and in the front shield the module from external noise sources and reduce the magnetic field. The power supply chassis is held in place but isolated from the Tile calorimeter structure through G10 rails and isolated screws.

3.4.3.3.6 Isolation of cables and services in the gap region

All cables and services approaching the calorimeter front faces pass via the gaps between Tilecal fingers. They are isolated from the cable trays placed on and electrically connected to the Tilecal surface.

3.4.3.3.7 Isolation of beam pipe

The beam pipe needs a support between the barrel and the end-cap cryostats. The warm bulkhead provides the support of the light structure that will keep the beam pipe in position. Such a structure supports also a pump. The beam pipe support is isolated from the cryostat. The same is true for the support of the beam pipe trough the endcap inner tube.

3.4.3.3.8 Isolation of services

To avoid the formation of ground loops, metal pipes, metal cable trays and any other metal object connecting to the calorimeter must have an electrical break point, not necessarily at the point in which joins the calorimeter vessel.

3.4.3.4 Direct grounding of the Tile Calorimeter.

The steel of the three cylinders of the tile calorimeter is connected to the UX15 equipotential network (earth) by means of one dedicated grounding cable of 95 mm^2 (with insulation) per cylinder.

The barrel ground cable is bolted on one end onto a calorimeter crossplate at sector 13, side A. The cable is routed towards Z=0 where it reaches the cable trays. The other end of the cable is bolted to a grounding plate in sector 13, on USA15-A side. This ground plate is part of the UX15 equipotential network.

The endcap ground cables (one per endcap) are bolted on one end onto a calorimeter corssplate in sector 13. The cable is routed inside the respective flexible chains in sector 15 (US side), and they both reach the ATLAS feet following existing cable trays. The cables are connected directly onto the feet grounding plugs where the copper strip is bolted to. The feet are connected to the UX15 equipotential network.

The three grounding cables are labelled (Table 2).

Item Id	Function	Standardfield	Length	Diameter	Cross Section	Cable Description	Cable Characteristic	Startpoint Location	Endpoint Location
2874005	Grounding	EC/LB.S13.XB/Gs/CT.X.Z1.S13C-S12	10	17.2	95	Tilecal Barrel Ground	Endpoint bonded to cable tray	Tilecal Barrel sector 13 Z=0	CT/X.Z1.S13C-S12/2W3
2874006	Grounding	EC/EA.S13.XB/Gs/HBF.A-S14.XB	30	17.2	95	Tilecal Endcap A	Endpoint bonded to feet	Endcap A	
2874007	Grounding	EC/EC.S13.XB/Gs/HBF.C-S14.XB	30	17.2	95	Tilecal Endcap C	Endpoint bonded to feet	Endcap C	

Table 2: Tilecal ground cables.

3.4.3.5 Direct grounding of the Liquid Argon Calorimeter.

The whole Liquid Argon calorimeter is designed such that it is perfectly isolated from earth in UX15 (§ 3.4.3.3) in order to allow for a well controlled ground connection point. The cryostats of the calorimeters are actually connected to the equipotential network in USA15 by means of 95 mm^2 ground cables (Table 3).

The barrel cryostat is connected to two cables of 95 mm^2, close to the gap 14C in sector 5. The cables are routed together with the trigger, they exit the detector at sector 9, and they reach USA15 through a hole in the wall that provide the shortest path for the ATLAS trigger signals. The ground cables are connected to the frame of the rack Y.24-02.A2, which is connected to the USA15 equipotential network.

The endcaps cryostats are connected to two cables of 95 mm^2 each, close to gaps 12A and 12C in sector 5. The cables are routed in the flexible chains of sector 9 to reach the same trigger cable tray used for the barrel grounding cables. The four cables cross the USA15 wall with the trigger cables and are connected to the frame of the rack Y.24-02.A2, which is connected to the USA15 equipotential network.

3.4.3.6 Isolation monitor for the Liquid Argon Calorimeter.

The cryostats are designed to be fully isolated from earth in UX15. However, several services such as cables and pipes are placed on its surface, and any of those is a potential hazard for indirect grounding of the cryostat.

The control of the isolation of the cryostat can only be done in DC. To carry on this control while keeping the connection to earth, a current source in USA15 injects a reference current (up to 500 mA) onto the cryostat under test using a dedicated test cable (ID 2431121 on the barrel, Table 3). If the cryostat is fully isolated (as designed) from the earth in UX15, the injected current returns entirely through the ground cables of the cryostat, back to USA15. A high precision DC current probe (part number ICPT, manufactured by Bergoz) is used to measure the differential current between the injected and the returned currents (figure 21). The output of the current probe is coupled to a voltage comparator that triggers an alarm in the experimental cavern UX15 when a current leak is detected, providing instantaneous warning to the operators during installation and maintenance. The accuracy of the monitor allows for a detection of current leaks as low as one milliampere, which turns out to be sufficient to detect weak or accidental indirect contacts between a grounded device and the cryostat. The readings of the current monitor can be viewed on-line through by means of a web enabled data logger (WebIO). Whenever an alarm is triggered, the WebIO device sends an SMS and an email notification tothe person in charge of controlling the grounding.

Item Id	Function	Standardfield	Diameter	Cross Section	Manufacture Reference	Cable Characteristic	Startpoint Location	Startpoint Room	Endpoint Location	Endpoint Room
2431101	Cryostat safety ground	AL/H.HV04.L14/Gs/Y.24-02.A2	23	95	CERN stock number 04.08.61.975.0	Sector 5	Barrel Side C - Bolted to Cryostat, gap 14C	UX15	Y.24-02.A2	USA15
2431111	Cryostat safety ground	AL/H.HV04.L14/Gs/Y.24-02.A2	23	95	CERN stock number 04.08.61.975.0	Sector 5	Barrel Side C - Bolted to Cryostat, gap 14C	UX15	Y.24-02.A2	USA15
2431121	Cryostat ground monitor	AL/H.HV04.L14/Gs/Y.27-19.A2	4.3	0	CERN stock number 04.08.61.206.4	Sector 5	Barrel Side C - Bolted to Cryostat, gap 14C	UX15	Y.27-19.A2	USA15
2431201	Cryostat safety ground	AL/A.HV03.L12/Gs/Y.24-02.A2	23	95	CERN stock number 04.08.61.975.0	Sector 5	EC Side A - Bolted to Cryostat, gap 12A	UX15	Y.24-02.A2	USA15
2431202	Cryostat safety ground	AL/A.HV03.L12/Gs/Y.24-02.A2	23	95	CERN stock number 04.08.61.975.0	Sector 5	EC Side A - Bolted to Cryostat, gap 12A	UX15	Y.24-02.A2	USA15
2431301	Cryostat safety ground	AL/C.HV03.L12/Gs/Y.24-02.A2	23	95	CERN stock number 04.08.61.975.0	Sector 5	EC Side C - Bolted to Cryostat, gap 12C	UX15	Y.24-02.A2	USA15
2431302	Cryostat safety ground	AL/C.HV03.L12/Gs/Y.24-02.A2	23	95	CERN stock number 04.08.61.975.0	Sector 5	EC Side C - Bolted to Cryostat, gap 12C	UX15	Y.24-02.A2	USA15

Table 3: Liquid Argon Calorimeter grounding cables.

3.4.4 Inner detector.

The grounding and the shielding of the inner detector is explained in details in the *ATLAS Inner Detector Grounding and Shielding, Engineering Implementation* [17]. The main lines are reviewed in this section.

3.4.4.1 Isolation between systems.

The three detectors that form the inner detector (SCT, TRT, Pixels) are designed such that they are electrically isolated between them and from earth at all places. Therefore the detectors are floating by design, which provides the possibility for a controlled ground connection.

3.4.4.2 Contact sensor.

For its assembly and positionning, the different parts of the inner detector are slided from the A and C sides towards the interaction point. In order to control the exact placement of these elements but avoiding any direct contact between the shield enclosures, a contact sensor is placed on both sides of the barrel (figures 22 and 23).

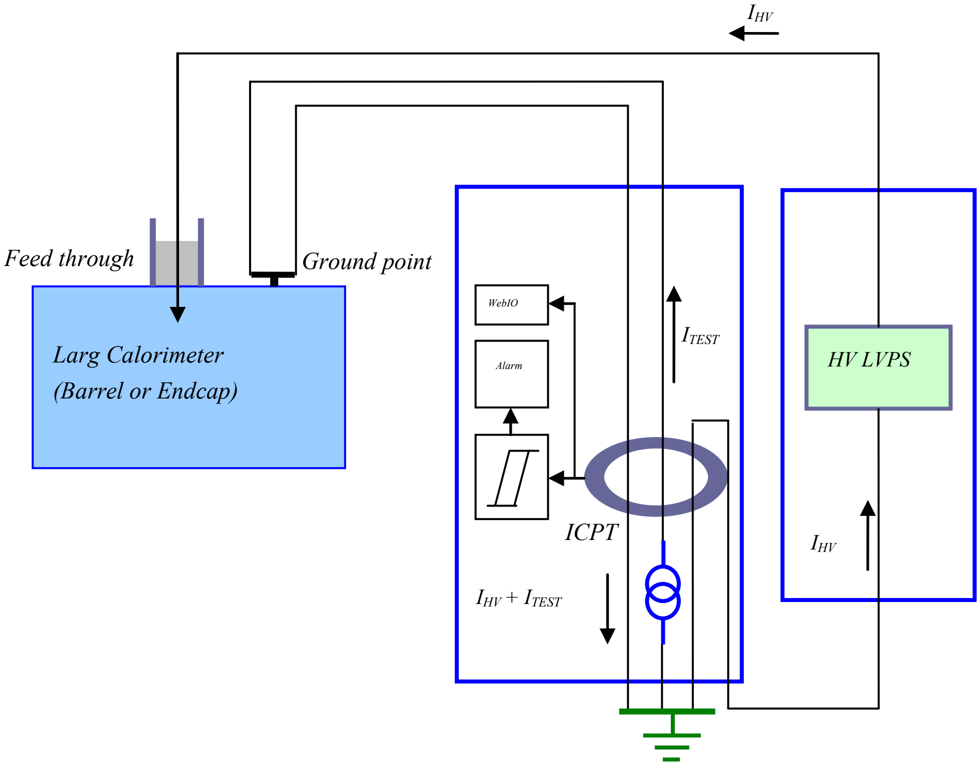

Figure 21: isolation monitor for the liquid argon cryostats. The current monitor ICPT from Bergoz has a full scale dynamic range of ± 10 mA and the readings are available through a web enabled data logger (WebIO).

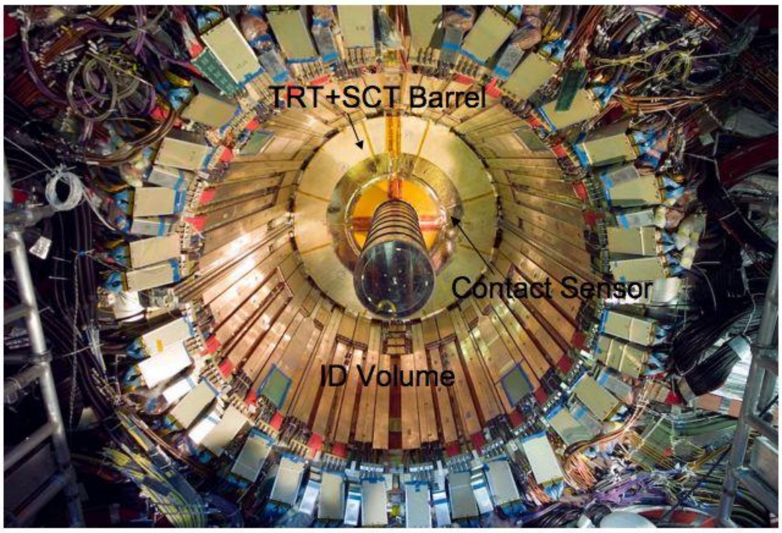

Figure 22: placement of the contact sensor in the inner detector volume.

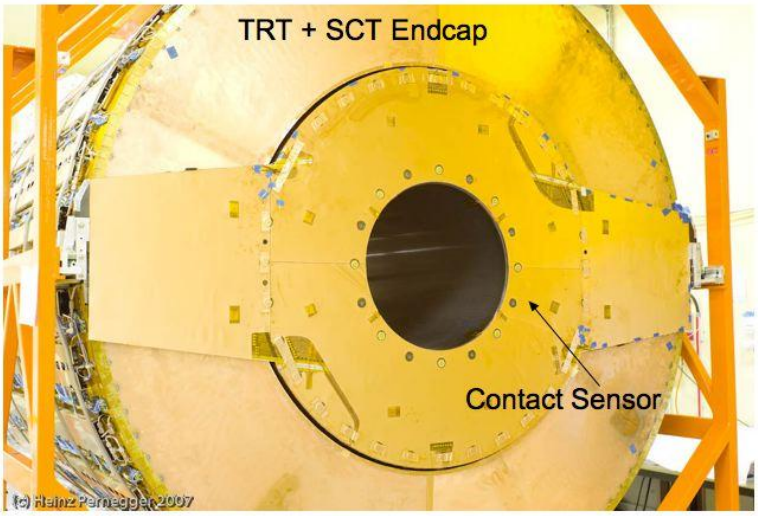

Figure 23: contact sensor geometry.

3.4.4.3 Star ground connection IDGND and ground plate IDGNDPC.

The inner detectors are grounded at controlled location identified as IDGND.

IDGND (Figure 24) is a star connection of all safety grounding cables for ID system sub-detectors (Pixel, SCT, and TRT) and common items (support structure, pipes for cooling and gas, heaters, and DCS sensors). The IDGND star connection located between the Tile calorimeter and the first level of Muon chambers, at the IDGNDPC grounding plate (Figure 25). The IDGNDPC grounding plate is connected to the ATLAS equipotential network (UX15) at ATLAS feet by means of a dedicated, 95 mm^2 grounding conductor.

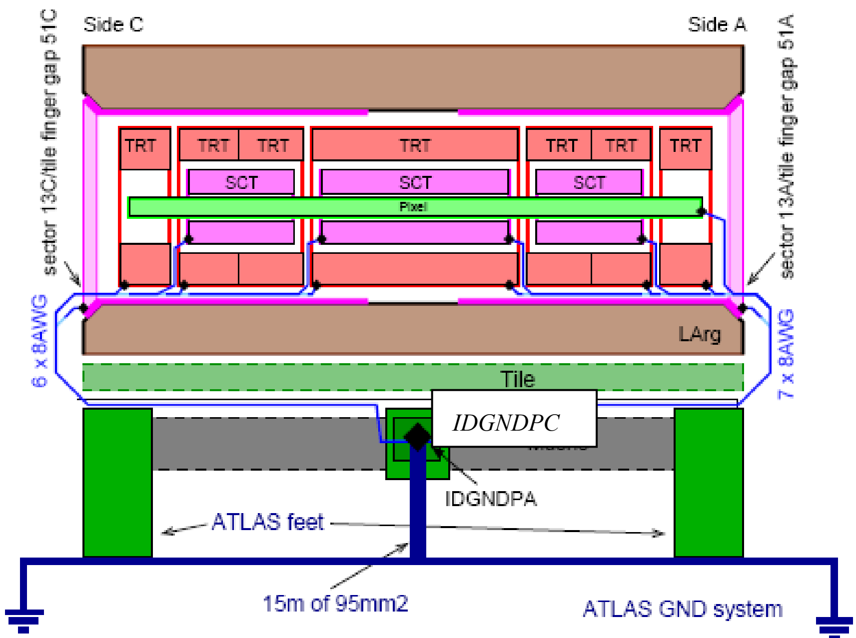

Figure 24: Location of the IDGND Grounding Plate.

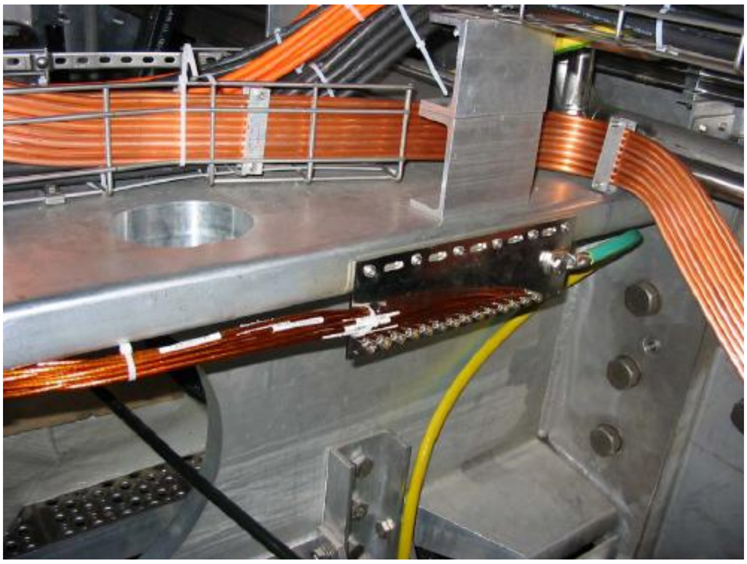

Figure 25: IDGNDPC Grounding Plate.

In order to provide reasonable isolation of the sub-detectors and at the same time to complete the requirements for the safety grounding, all connections to the IDGND from any sub-detector is done from its electromagnetic (EM) shield using a single point connection. The floating power supplies are referenced in most cases on the detector modules (analogue and digital grounds) and on PP1 (connection of detector module grounds to the EM shields).

3.4.4.4 Grounding of the inner detectors.

The inner detector (Figure 24) is made of three detectors (SCT, Pixels and TRT). The detailed schemes of the subsystems might be found in following notes: ATL-IS-EN-0014 [18] (SCT end cap), ATL-IS-ES-0056 [19] (SCT barrel), ATL-IC-ES-0007 [20] (heaters), ATL-IC-EN-0004 [21] (old document for Pixel and SCT), and ATL-IT-EN-0050 [22] (TRT).

The Pixel detector is the inner most item and its grounding scheme (Figure 26) [17] describe the overall grounding topology. Each detector module is referenced at the patch panel zero (PP0), and all the PP0 patch panels are grounded with the EMI shields and with the beam pipe shield at PP1. All the PP1 patch panels are grounded together and they are connected to a common ground point (IDGND) through only one out of two installed grounding cables (Table 4).

The SCT detectors (figure 27) [17] are fully enclosed by EMI shields that are bonded to the base plates of the patch panels PPB1 (barrel) and PPF1 (endcaps). The EMI shield are connected to the common ground point (IDGND) by means of three well identified grounding cables (EC-C, EC-A, B, Table 4).

The TRT detectors (figure 28) [17] are fully enclosed by EMI shields that are connected to the IDGNDPC by means of three grounding cables (EC-A, EC-C, B, Table 4).

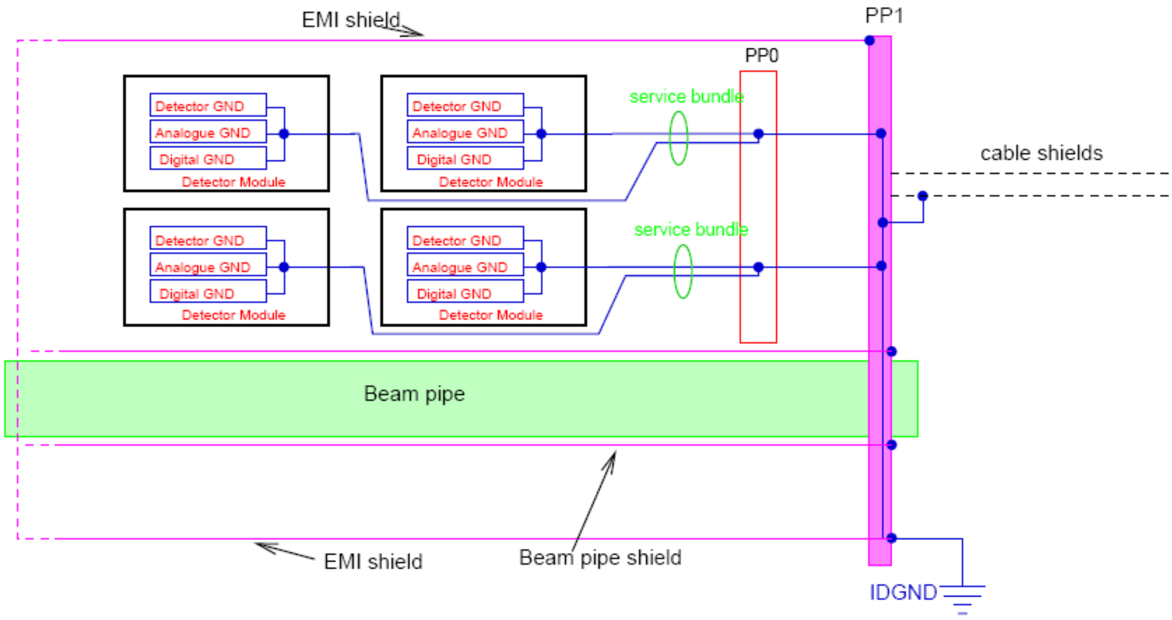

Figure 26: Pixel detector simplified grounding scheme.

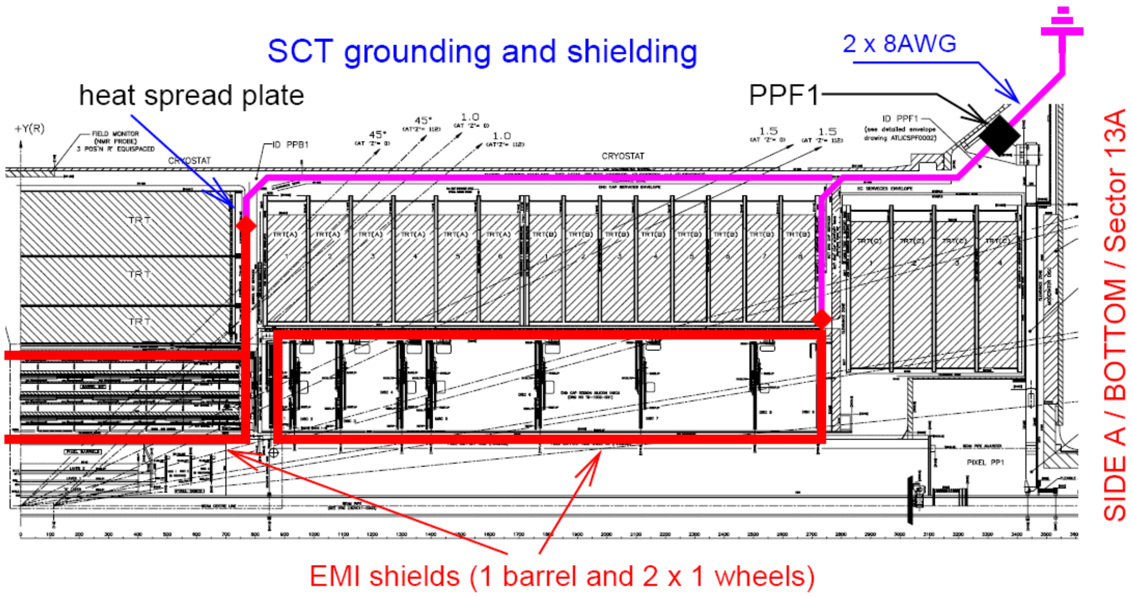

Figure 27: grounding scheme for the SCT detector.

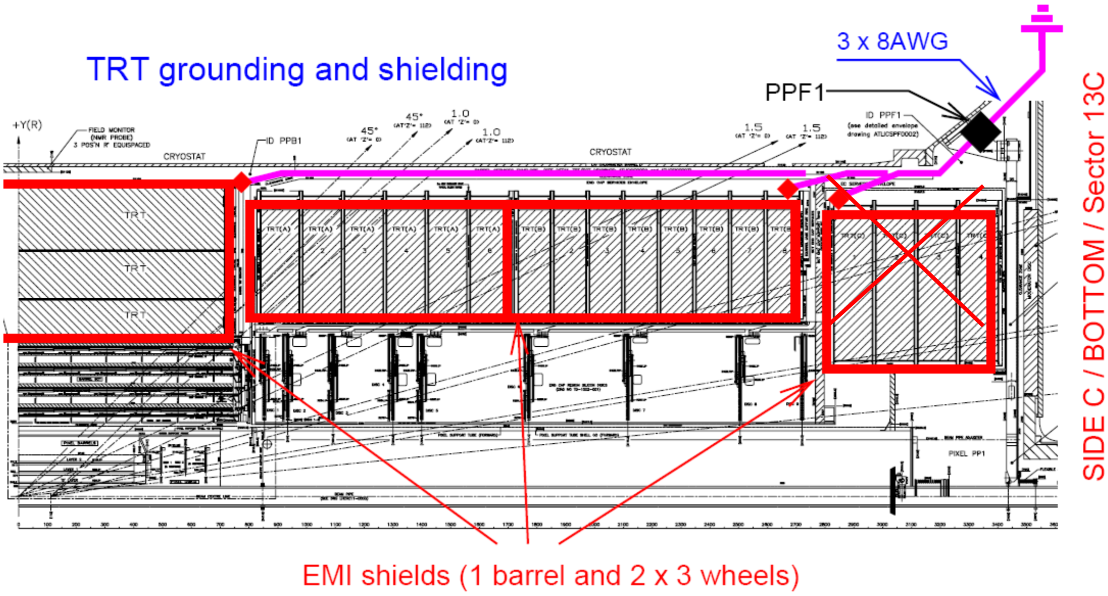

Figure 28: grounding scheme for the TRT detector.

Item Id	Detector	Function	Subsystem	Type	Standardfield	Userfield	Cable Characteristic	Startpoint Location	Startpoint Room	Endpoint Location	Endpoint Room
2391202	INDET	ID grounding cable - SCT barrel	SCT-B-A	Grounding /shielding cable	ISB/A.B28.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	B28.L51	UX15	IDGNDPC	UX15
2391201	INDET	ID grounding cable - SCT end cap	SCT-E-A	Grounding /shielding cable	ISE/A.F43.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F43.L51	UX15	IDGNDPC	UX15
2391203	INDET	ID grounding cable - TRT barrel	TRT	Grounding /shielding cable	ITB/A.B29k.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	B29k.L51	UX15	IDGNDPC	UX15
2391204	INDET	ID grounding cable - TRT wheel A B	TRT-E-A	Grounding /shielding cable	ITE/A.F44.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F44.L51	UX15	IDGNDPC	UX15
2391205	INDET	ID contact sensor wheel C	Wheel C	Grounding /shielding cable	ITE/A.F44.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F44.L51	UX15	IDGNDPC	UX15
2391206	INDET	ID grounding cable - Pixel	Pixel-A|	Grounding /shielding cable	IP/A.O7.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	O7.L51	UX15	IDGNDPC	UX15
2391207	INDET	ID grounding cable - ID ground plate	INDET	Grounding/shielding cable	IC/A.F43.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F43.L51	UX15	IDGNDPC	UX15
2391208	INDET	ID grounding cable - SCT end cap	SCT-E-C	Grounding /shielding cable	ISE/C.F43.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F43.L51	UX15	IDGNDPC	UX15
2391209	INDET	ID grounding cable - SCT barrel	SCT-B	Grounding /shielding cable	ISB/C.B28.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	B28.L51	UX15	IDGNDPC	UX15
2391210	INDET	ID grounding cable - TRT barrel	TRT-B	Grounding /shielding cable	ITB/C.B29k.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	B29k.L51	UX15	IDGNDPC	UX15
2391211	INDET	ID grounding cable - TRT wheel A B	TRT-E-C	Grounding /shielding cable	ITE/C.F44.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F44.L51	UX15	IDGNDPC	UX15
2391212	INDET	ID contact sensor wheel C	Wheel C	Grounding /shielding cable	ITE/C.F44.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F44.L51	UX15	IDGNDPC	UX15
2391213	INDET	ID grounding cable - Pixel	Pixel	Grounding/shielding cable	IP/C.O7.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	O7.L51	UX15	IDGNDPC	UX15
2391214	INDET	ID grounding cable - ID ground plate	INDET	Grounding/shielding cable	IC/C.F43.L51/Gs/IDGNDPC	E(C)/4.8/RH	Sector 13	F43.L51	UX15	IDGNDPC	UX15

Table 4: inner detector grounding cables (red mean not installed).

3.4.4.5 Control of isolation.

The grounding of each of the inner detectors is designed for a controlled grounding connection at the IDGNDPC grounding plate. In order to control the correct grounding, and in particular the absence of indirect or accidental ground points, a grounding monitor identical to the one used for the Liquid Argon is used. Because the grounding controller cannot be left in place (radiation and magnetic field), the test is to be performed during installation and during maintenance phases only.

A test current can be injected using a current source on the grounding cable under test, this test current shoud return through the other grounding cables of the system under test. The use of a precision current probe (Bergoz ICPT) allows the detection of weak contacts (figure 29 and 30).

When a ground fault is detected the monitoring circuit, a loud buzzer is triggered to inform in real time the operator that caused the fault. Also, for each fault a SMS and an email is sent to the person in charge of the inner detector grounding.

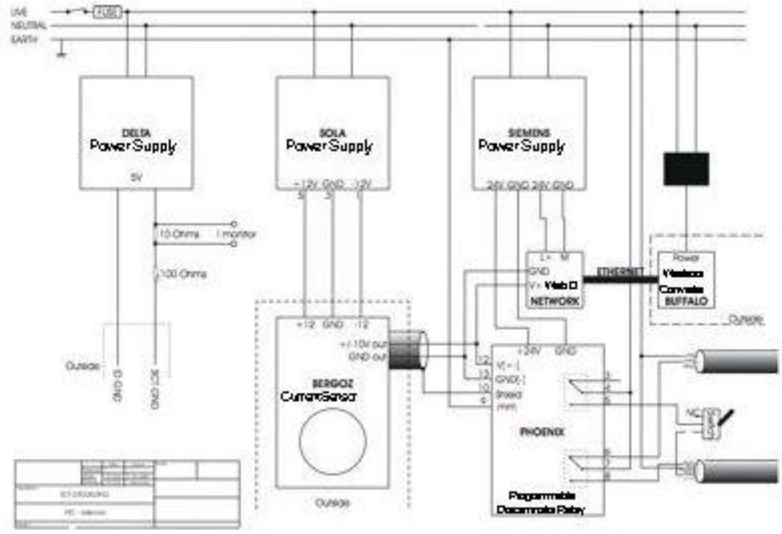

Figure 29: ID grounding monitor system.

Figure 30: grounding monitor with ICPT, alarm and control system.

3.4.5 Muons spectrometer.

The muons spectrometer is composed of several muon chambers located at different areas of the detector:

- Muon Drift Tubes Chambers (MDT) and Resistive Plate Chambers (RPC) are placed all around the barrel on three layers.
- Muon Drift Tubes Chambers (MDT) and Thin Gap Chambers (TGC) are located on big wheels as end caps of the experiment.

The grounding of each type of chamber is addressed separately and has its own implementation.

3.4.5.1 MDT and RPC Chambers on the Barrel.

3.4.5.1.1 MDT and RPC Chambers on the barrel: naming convention and layout.

The MDT and RPC chambers naming convention [23] is described in the TDR. The final layout [24] of the chambers is found in CDD. The parameters for all chambers are maintained in the MDT/RPC parameter book [25]. The barrel chambers are arranged in 16 sectors, each one having 6 positions towards C side, and 6 more positions towards A side. The chambers are named as function of their position around the barrel (figure 31).

The barrel standard chambers are named in terms of Inner (I), Middle (M) and Outer (O) , Small (S) and Large (L) chambers.

The barrel special chambers are named in terms of Inner (I), Extra (E), Middle (M), Outer (O).

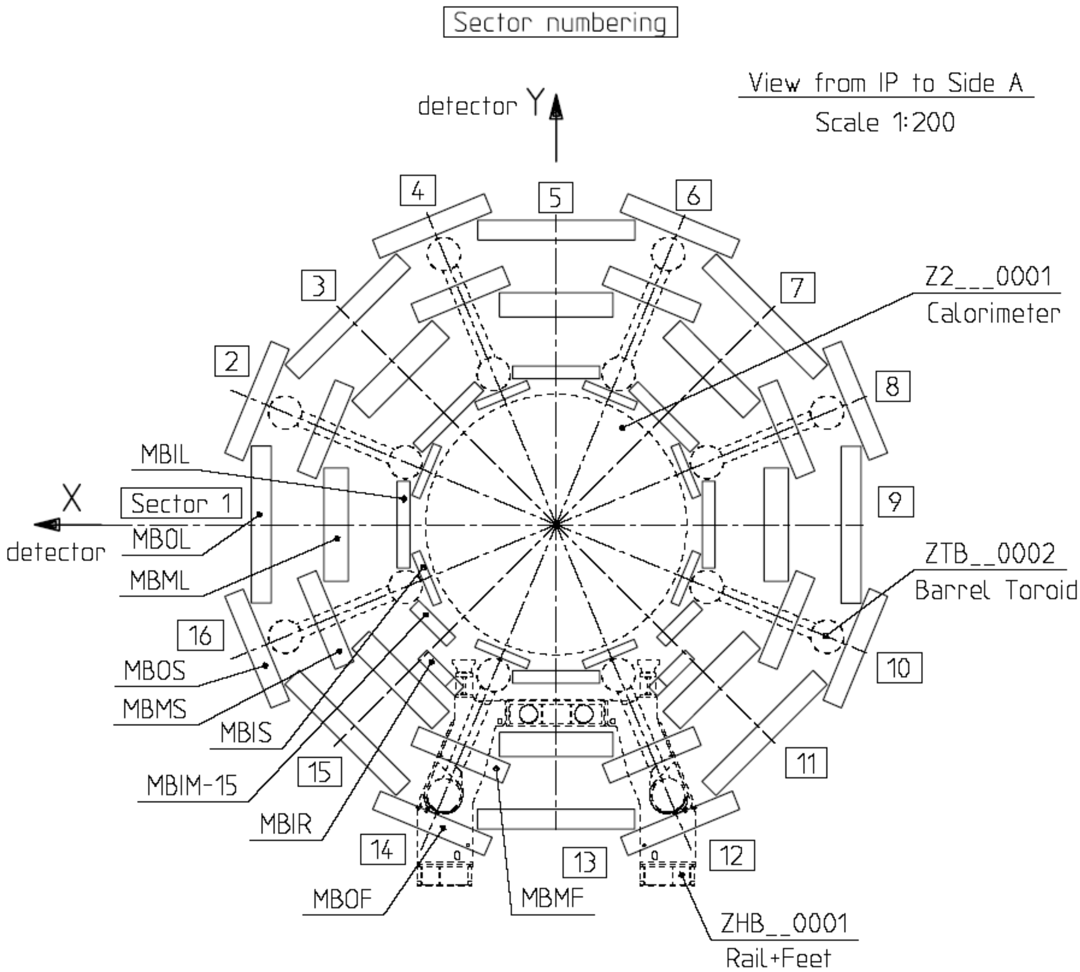

Figure 31: MDT/RPC Barrel chambers naming convention.

3.4.5.1.2 Assembly of Barrel MDT and RPC chambers on common support.

One MDT chamber and one RPC chamber are stacked together; two stacks are put together on both sides of a common support to form a single muon station (figure 31). The barrel chambers are provided with insulating kinematic mounts (figures 31 and 32), used to fix and align the chambers in the ATLAS detector. By design the chambers are DC insulated from their neighbors and in particular from the rails at the kinematic mounts. By construction, the RPC faraday cage is bonded to the common support while the MDT chambers are insulated from it. Therefore there is no galvanic link between the MDT and RPC chambers; also there is no galvanic link between the MDT or RPC with the supporting rails.

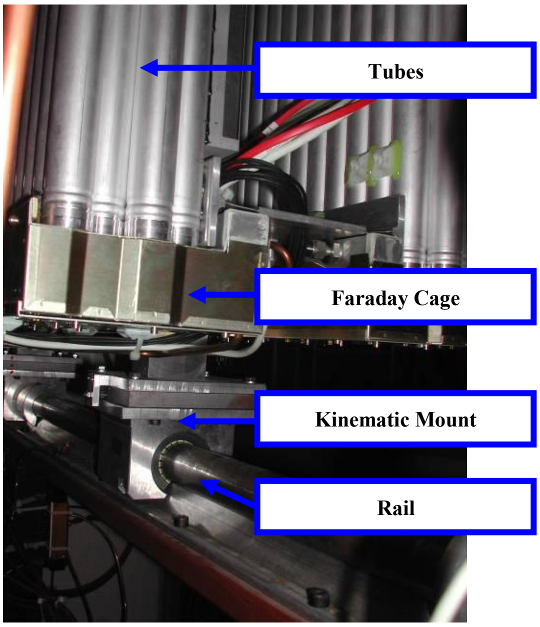

Figure 32: MDT chamber (left), tubes, faraday cage, kinematic mount and rail (right)

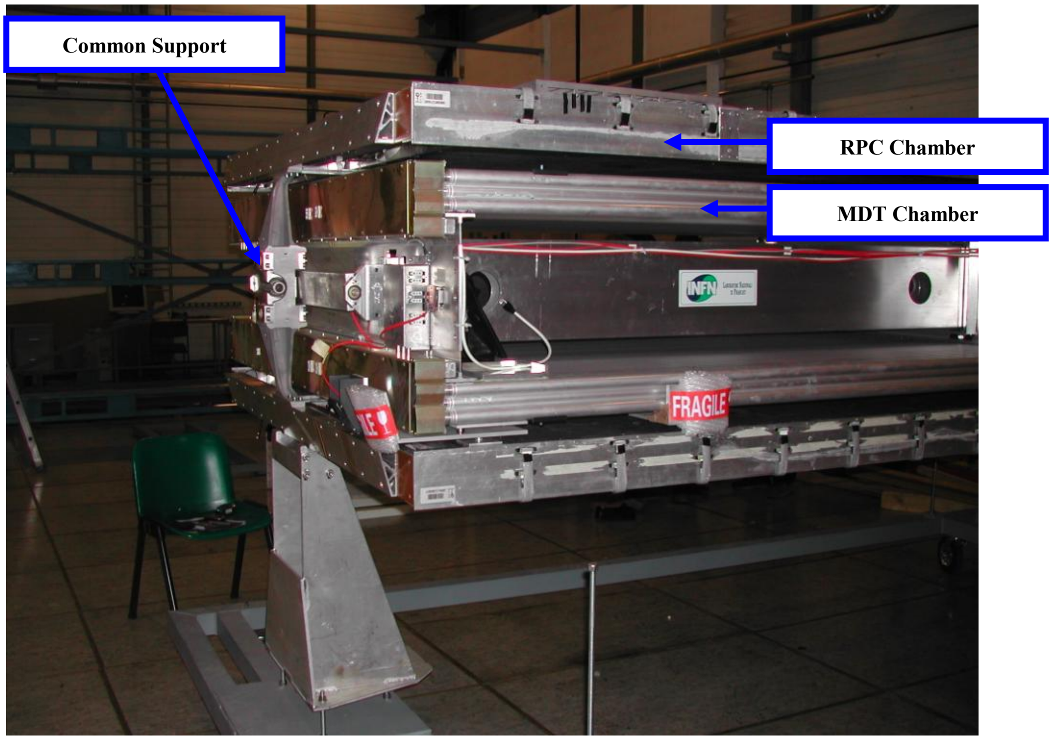

Figure 33: RPC and MDT assembly for the barrel.

3.4.5.1.3 MDT Barrel chambers: grounding scheme and implementation.

The electrical and grounding layout of the MDT is described in the MDT grounding document [26]. Its implementation is shown here below (figures 34 and 35).

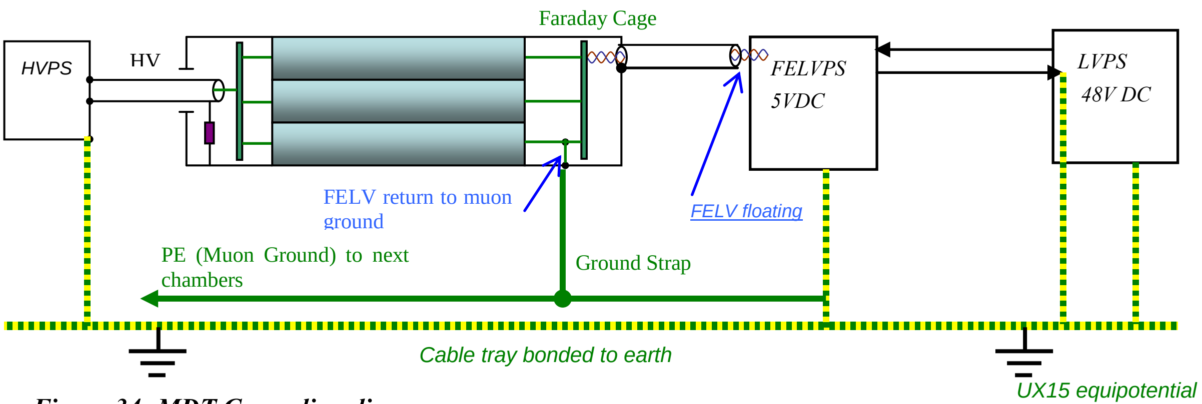

Figure 34: MDT Grounding diagram.

The power supplies and crates are electrically bonded to the rack that contain them; the racks are themselves bonded to the UX15 equipotential network (§3.3.4.4).

By construction, the MDT chambers and their faraday cages are connected to the low voltage return line (figure 34).

The chambers are electrically insulated from the rails and from the common support that support them. A ground conductor, known as Muon Ground (figures 34 and 35), is brought from each MDT power supplies rack (UX15) to the barrel MDT chambers in a grounded cable tray. A ground strap (figures 34 and 35) connects the chamber faraday cage to the MDT Muon Ground. There is one ground strap per barrel MDT chamber spliced to the Muon ground (figure 36). The muon ground conductor is bonded to the UX15 equipotential network at the level of the power supply rack (figure 35). The Muon Ground is a 6 mm^2 insulated conductor, with a maximum length of 50 meters; its is connected to a maximum of 12 MDT chambers.

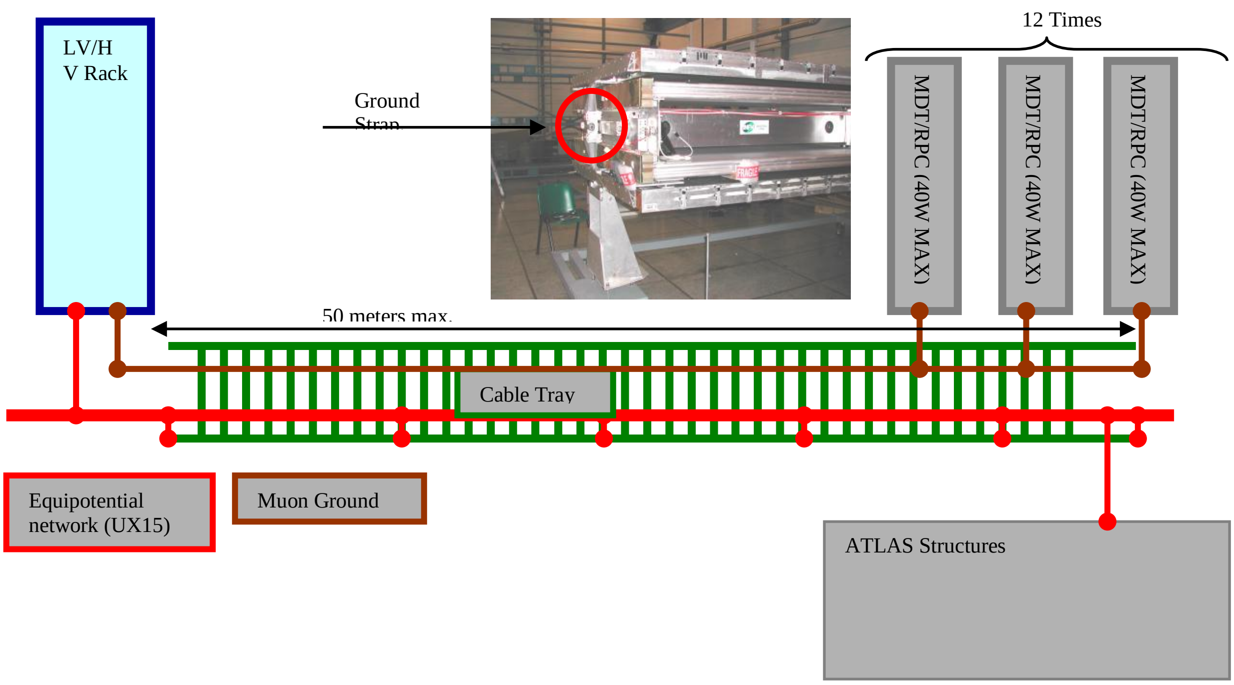

Figure 35: Cable trays and Muons Ground.

The connection from the MDT ground strap to the Muon Ground is made with insulated splices (figure 36), namely Electro-Tap from Tyco Electronics (part number 735411 for 6 mm^2 wires). A maximum of 12 splices per circuit are allowed.

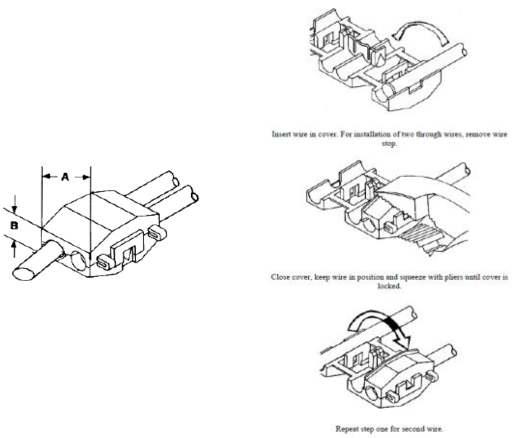

Figure 36: Splicing of the Muon Ground cable.

3.4.5.1.4 RPC Barrel Chambers: grounding scheme and implementation.

The grounding of the RPC chambers is done in the same way as for the MDT chambers but on a separated grounding network.

The power supplies and crates for the RPC are electrically bonded to the rack that contain them; the racks are themselves bonded to the UX15 equipotential network (§3.3.4.4).

By construction, the RPC chambers and their faraday cages are connected to the low voltage return line (figure 34).

The RPC chambers are electrically bonded to the common support, which is insulated from the rails and from the MDT chambers. A ground conductor, known as Muon Ground (figures 34 and 35), is brought from each RPC power supplies rack (UX15) to the barrel chambers in a grounded cable tray. A ground strap (figures 34 and 35) connects the chamber common support to the Muon Ground cable. There is one ground strap per barrel RPC chamber spliced to the Muon ground (figure 36). The muon ground conductor is bonded to the UX15 equipotential network at the level of the power supply rack (figure 35). The Muon Ground is a 6 mm^2 insulated conductor, with a maximum length of 50 meters; its is connected to a maximum of 12 RPC chambers.

3.4.5.2 Small and Big Wheels.

3.4.5.2.1 Arrangement of chambers on the wheels.

The muons endcaps are arranged on wheels with different types of chambers (figure 37):

- MDT, TGC and CSC (Cathode Strip Chamber) chambers on the Small Wheels.
- MDT and TGC chambers on the Big Wheels.
- MDT chambers on a Big Wheel bonded to the HO structure.

The implementation of the grounding is the same for all of these wheels:

- The cable trays of each wheel are fitted with a ground conductor (naked copper 50 mm^2) that is ran all around the wheel. The racks and services located on the wheels are strapped to these ground conductors. The ground cable is connected to the UX15 equipotential network.
- The chambers mounted on the wheels are insulated from the support. The grounding of the chambers is done as for the barrel: an insulted ground wire is distributed to all the chambers. The wire is bonded to the power supplies racks on one end, and to the faraday cages on the other end.

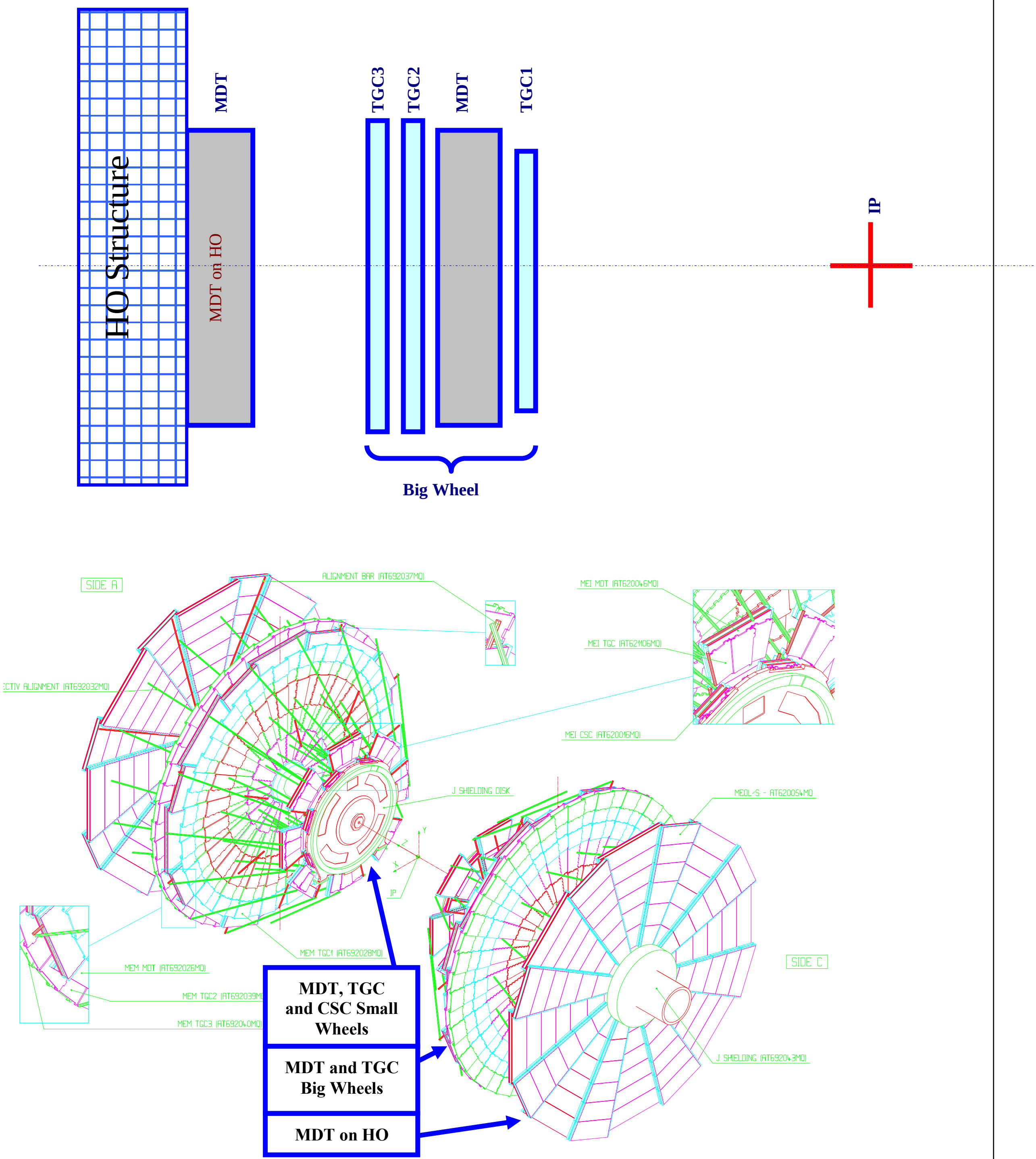

Figure 37: Wheels arrangements.

3.4.5.2.2 Grounding of the MDT chambers on the wheels sectors.

Each faraday cage of the MDT chambers is bonded to a 6 mm^2 ground wire (figure 38). The faraday cage is made of aluminium. Two MDT chambers are mounted on both sides of a common frame. Each MDT chamber is first connected to a common point on this supporting frame with a small pigtail. The ground strap is then run from this common ground point to the grounding wire that connects to the power supplies rack.

To prevent corrosion of the aluminium at the interface between the tinned copper wire and the aluminium frame, the bolts and washers used to bond the wires are Cadmium plated (figure 39). The contact area on the frame is first cleaned with a dry contact cleaner, then a conductive grease (loaded with silver powder) is applied. Also, to insure the contact reliability, the faraday cage is alodined; there, Cadmium plated bolts and washers are used as well, but the conductive grease is not required (figure 40).

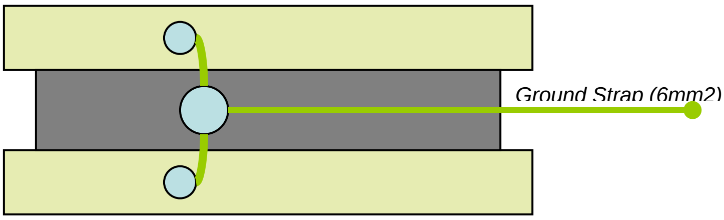

Figure 38: MDT Chambers ground wires.

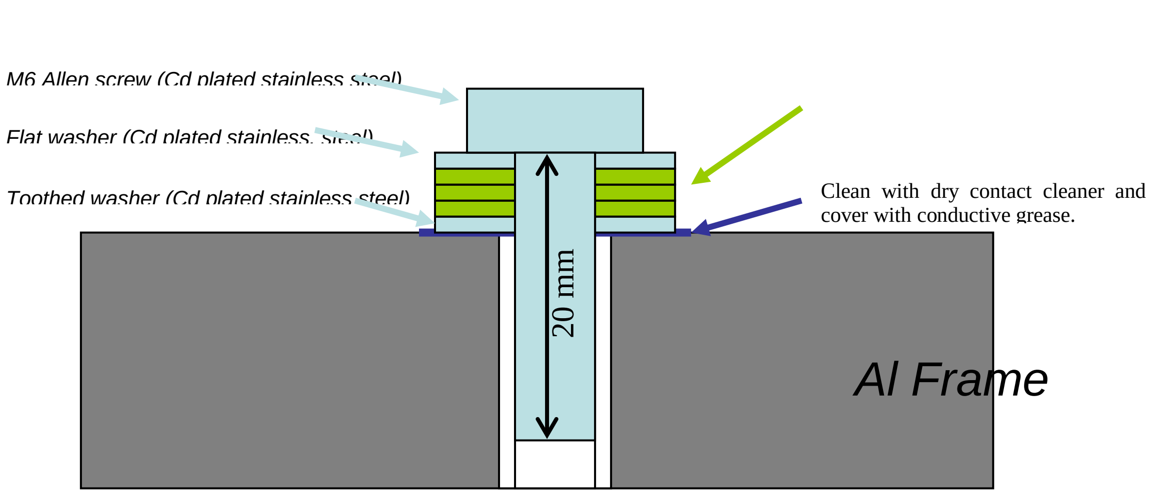

Figure 39: Bonding to aluminum frame.

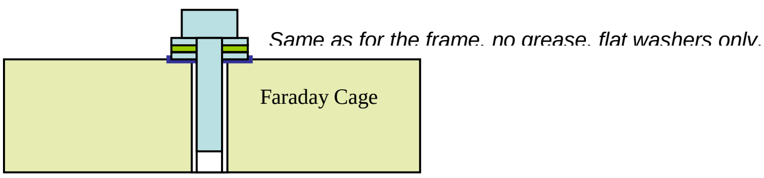

Figure 40: Bonding to Faraday Cages.

Each sector is provided with a 6 mm^2 insulated protective earth conductor along one of the spokes. Each chamber is connected by means of an Electro-Tap[1] device to this wire. The common ground wire ends on

[1] Electro-Tap: AMP part number 735411-0, yellow type for 6mm^2 wires.

the rim of the sector (figure 41). When linking the sectors in the cavern, the sector ground wire is to be bonded to a second ground wire (35 mm^2) running along the rims. This wire gets bonded to the rack that contain the DC/DC converters for 4 sectors.

The interconnection between the spoke wire (6 mm^2) and the rim wire (35 mm^2) is made with a grounding junction box[2].

3.4.5.2.3 Grounding of the MDT sectors to the UX15 equipotential network.

The MDT wheels are serviced by 4 racks symmetrically placed (figure 41). Each rack deserves 4 sectors. The 35 mm^2 ground wires are bonded to the rack frame. The four racks are bonded to the UX15 equipotential network by means of a 16 mm^2 PE conductor (figure 42). The cable trays on the rims are fittedd with a naked copper ground wire (50 mm^2) that forms an equipotential network between the sector structures, the trays and the racks fixed on it. A flexible ground conductor (insulated 95 mm^2) links this equipotential conductor with the UX15 ground. The link is passed in a flexible chain located in the trench, on the US15 side, that carries all the power and data links to the wheels.

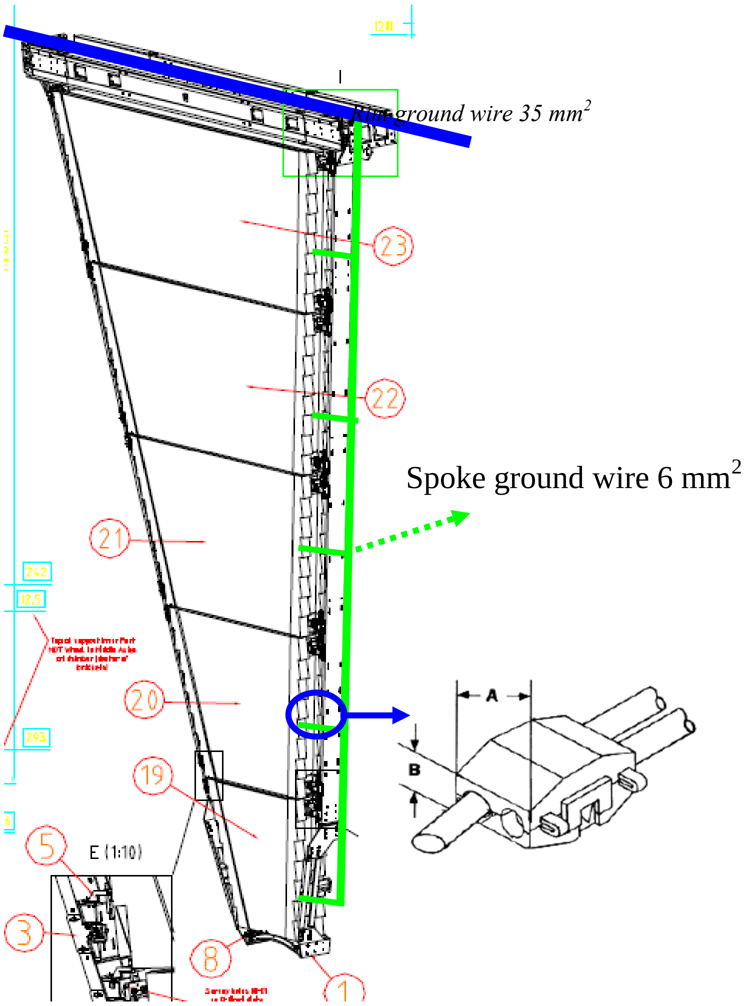

Figure 41: Sector grounding implementation with Electro-Taps.

[2] Block terminal ZETA Z35-6, 2 poles 35 mm^2, 4 poles 16 mm^2, from CEMBRE.

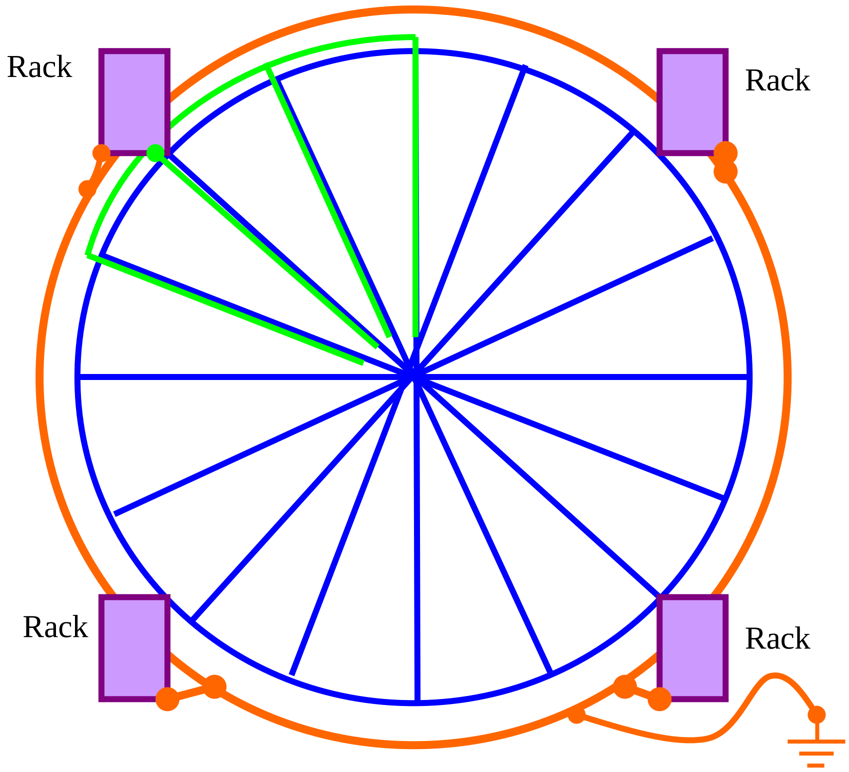

Figure 42: Arrangement of MDT racks and PE wires of the MDT sectors, and connection to UX15 equipotential network.

3.4.5.2.4 Grounding of the TGC chambers on the wheels sectors.

The TGCs are arranged on three wheels (figure 33). The first wheel TGC1 (M1) is a TGC triplet (3 layers of chambers), while TGC2 (M2) and TGC3 (M3) are TGC doublets (two layers of chambers). Each big wheel hosts 7 layers of TGC chambers on each of the twelve sectors. The TGC chambers are mounted on ladders of different sizes, that are finally assembled together to form the wheel. Miniracks are mounted on the TGC wheels frames, and an on-wheel scaffolding allows accessing the front end electronics (figure 43). By design the chambers are DC insulated from their neighbors and in particular from the ladders.

Each TGC chamber is provided with front end electronics located on one edge. It is shielded by means of copper sheet assemblies that form a faraday cage. The copper faraday cage is equipotential with the low voltage return of the front end electronics power supplies.

The primary power supplies are located in the TGC1 miniracks on the big wheels, and deliver a bulk DC voltage to the front end low voltage power supplies located either in the miniracks of TGC1 or to the crates on TGC3 .

A insulated ground wire (figure 45), 6 mm^2, links the faraday cage to a common ground wire of the same cross section, routed along the sector cable tray. The interconnection is made with a permanent tap (figure 45). The common ground wire is bonded to the miniracks located on the rim, that is in turn bonded to the PE wire of the AC power line. It must be noted that the shields of the cables are grounded to the faraday cage as well by means of pigtails (figure 44).

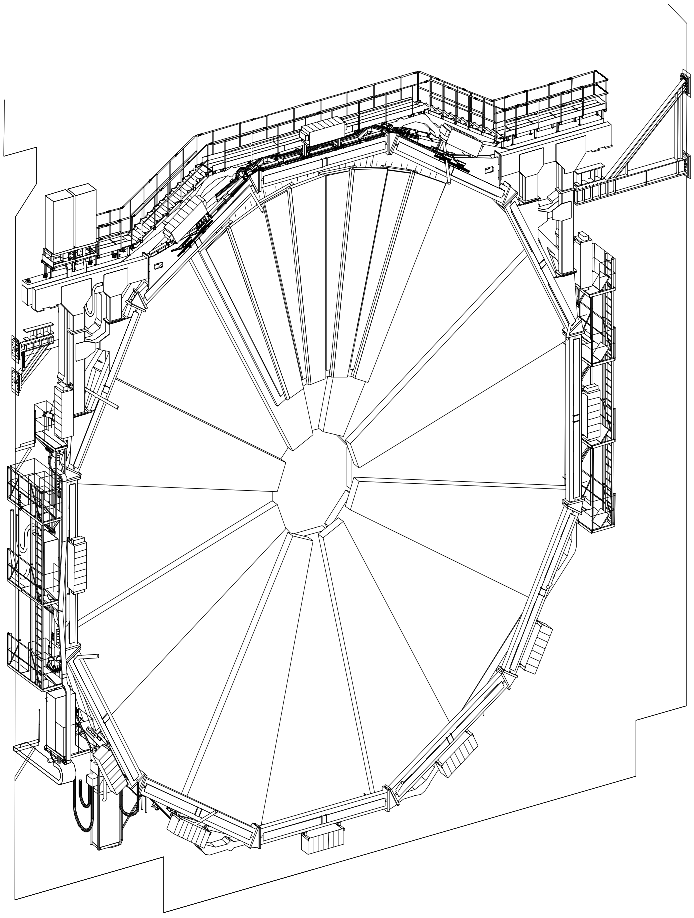

Figure 43: TGC Big Wheel, miniracks and scaffoldings.

Figure 44: Faraday cage ground connection.

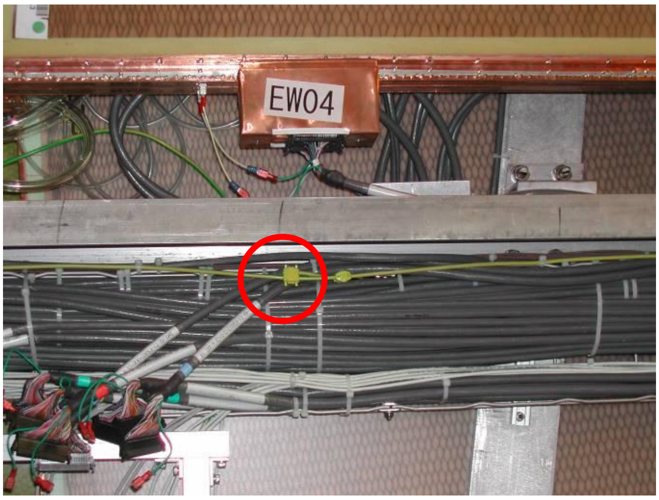

Figure 45: Tap connection of the ground wire.

3.4.5.2.5 Grounding of the TGC sectors to the UX15 equipotential network.

The TGC wheels are serviced by miniracks and crates symmetrically placed on TGC1 and TGC3. A naked copper 50 mm^2 ground wire is bonded to all the cable trays along the rims that forms an equipotential network between the sector structures, the trays and the racks fixed on it. The miniracks are bonded to this copper wire by means of short pigtails. A flexible ground conductor (insulated 95 mm^2) links this equipotential conductor with the UX15 ground. The link is passed in a flexible chain located in the trench, on the US15 side, that carries all the power and data links to the wheels.

In the TGC1 miniracks a CAEN A3486 AC/DC converter generates the 48VDC power for the three wheels. Its chassis is bonded to the protective earth through the AC mains (figure 46) but also to the UX15 equipotential network through the flexible ground conductor located in the flexible chain for the big wheel services. The output of the converter is floating by design. The 48V return line is grounded to the converter chassis, such that a ground fault to the structure causes a trip of the 48V power supply.

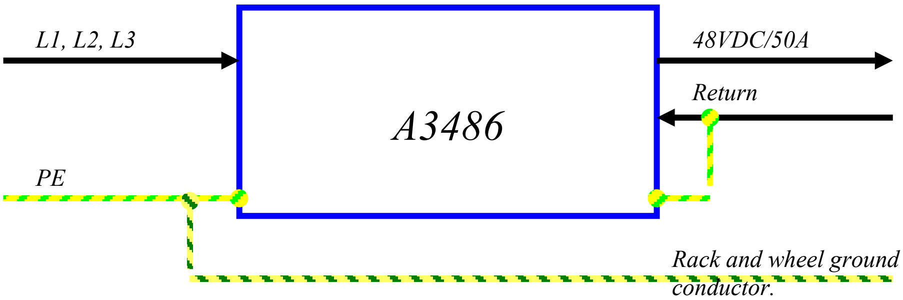

Figure 46: 48VDC circuit grounding scheme.

DC/DC converters that sit in an CAEN EASY crate in TGC1 and TGC3 generate the front-end low voltage. The chassis of the EASY crate is equipotential with the wheel structure and with the protective earth. The outputs (+3, -3, +3.3) have their return line commoned on the TGC chambers faraday cage (figure 47). The faraday cage is grounded to the wheel ground conductor by means of a ground strap, which is connected to the ground conductor with a tap[3].

[3] Electro-Tap: AMP part number 735411-0, yellow type for 6mm^2 wires.

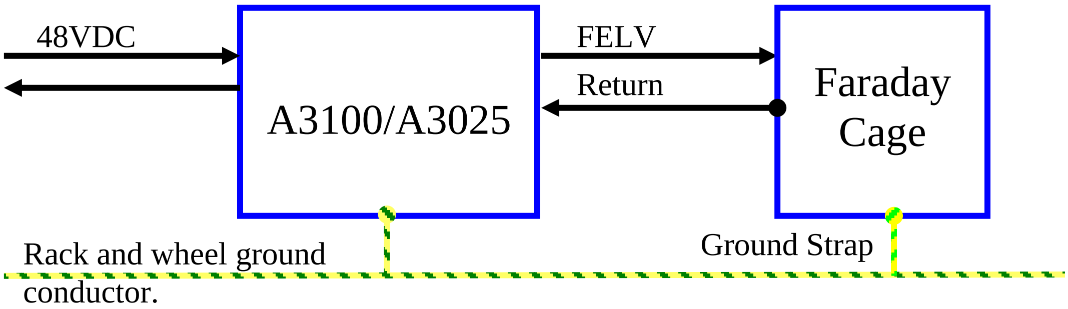

Figure 47: FELV circuit grounding scheme.

3.4.5.2.6 Grounding of the CSC chambers on the small wheels.

The CSC chambers (figure 48) are located on the small wheels. The front-end electronics and the detector itself is enclosed in a faraday cage. All the return lines and reference grounds of a chamber are bonded to the faraday cage.

The power supplies for the CSC system are located inside UX15 racks. The power supplies outputs are floating, and the output cables feed directly the chambers.

The grounding of the chambers is made at the level of the power supplies outputs (figure 49). The low voltage and high voltage return lines are connected to earth at the rack (figure 50). These return lines are equipotential with the whole chamber faraday cage. The faraday cage is mounted on the small wheel structure by means of insulating brackets, therefore the chambers are connected to earth exclusively at the power supply racks through the return lines.

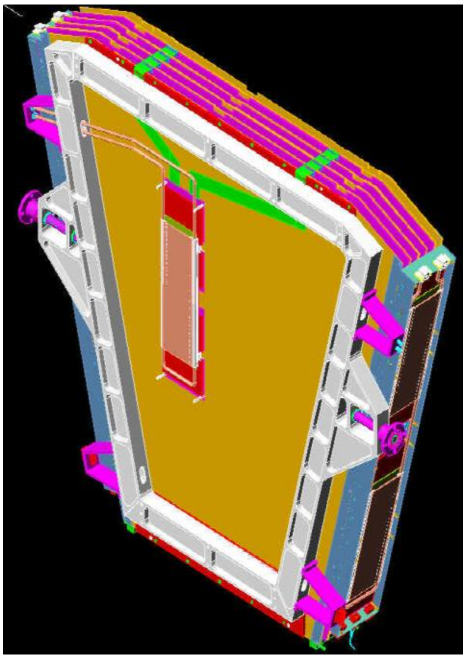

Figure 48: CSC Chamber.

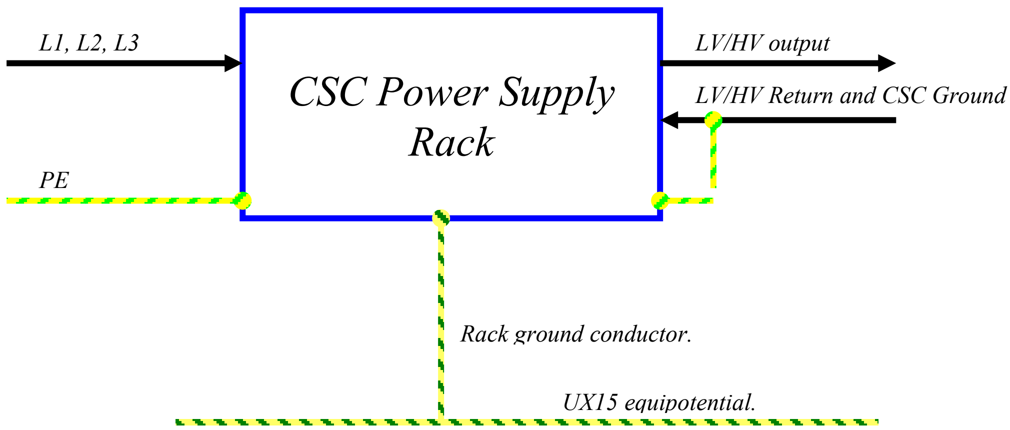

Figure 49: CSC grounding in the power supplies racks.

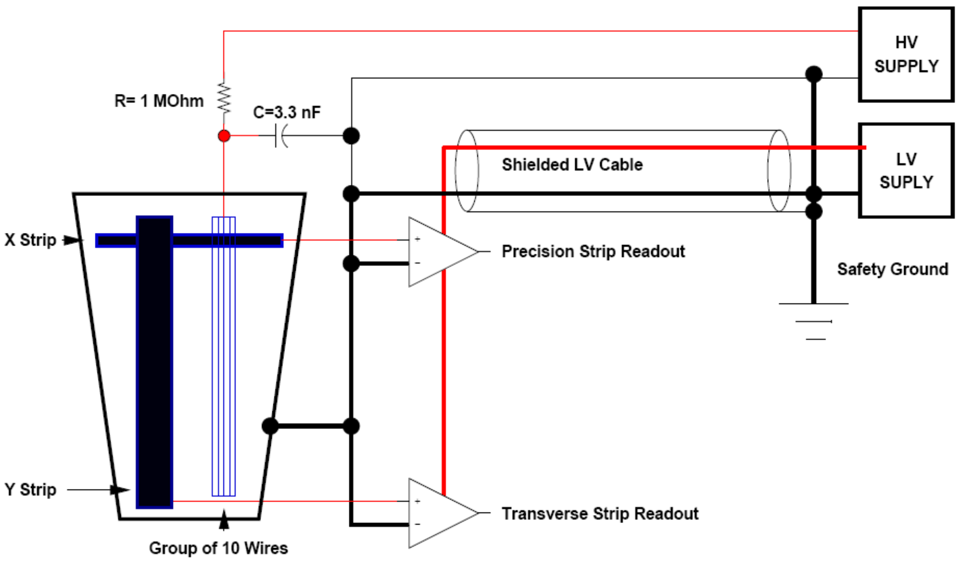

Figure 50: CSC grounding scheme.

3.4.5.3 Testing for ground loops.

Each muon chamber is designed to be isolated from earth and is connected to ground through a single pigtail to the nearest muon ground cable. Therefore, this tree structure of grounding is free of any ground loop in DC.

To verify that there is no indirect or unwanted grounding path for a given chamber, a ground loop tester should be used (for instance HEME GEO 30 manufactured by LEM). The tester is clamped around the grounding pigtail that is connected to the chamber under test. The device measures the impedance of a loop circuit by injecting inductively a test current in the loop. In a tree configuration like the one desired for the muons grounding, the loop impedance has to be infinite. If an indirect ground path exists, the device will record a low loop impedance (less than five ohms).

Several chambers were tested in this way and in very few cases indirect ground paths were found. Unwanted contacts were found between some chambers and devices of the alignment or to cable shields. None of these loops turned out to degrade the performance of the chambers concerned.

3.5 Magnet system.

The ATLAS magnets are made of supraconducting coils that carry large DC currents (up to 20 kA) at low voltage. The circuits are designed floating with respect to earth, and they are conatined in stainless stell cryostats.

Floating circuits require to be monitored against ground leaks. Any accidental connection to earth or ground leak will a reference point for the circuit, but will not prevent its normal operation. The magnets must be kept operating even in case that a ground faullt occurs, in order to be able to perform a controlled shutdoown preventing a ny damage on the magnets system. However, the ground faults must be detected and a griound fault monitor is required for this purpose.

The ATLAS magnets are powered by power converters as those used for the LHC magnets [27]. They are provided with an active earth fault detection based on an active detection with a DC current source connected between earrth and the return line of the protected circuit [27]. A current leak greater than 50 mA will be tagged as earth fault in the power circuit, trioggering the corresponding protection proecdures.

3.5.1 Barrel Toroid.

The barrel toroid is made of eight coils connected in series and powered by power converters in USA15. Each coil is contained in a vacuum vessel, and the vessels are interconnected. Large busbars are used to feed the magnets from USA15.

The electrical isolation of the eigth coils was measured during the commissioning phase of the magnet. Actually one of the eight coils, known as BT3, presented a negligible ground leak through a leak impedance greater than 10 kΩ.

Each coil of the toroid is bonded to the grounding network by means of 120 mm^2 copper cables. The cables are bolted on a bracket welded on the vacuum vessel in the vicinity of the cryorings (figure 51), on the section that is nearest to the beam. The cables are routed outwards along existing cable trays up to the grounding cables of in RA1 (figure 52). They are linked together with C lugs.

Figure 51: M15 link point of the grounding cables on the BT vacuum vessels.

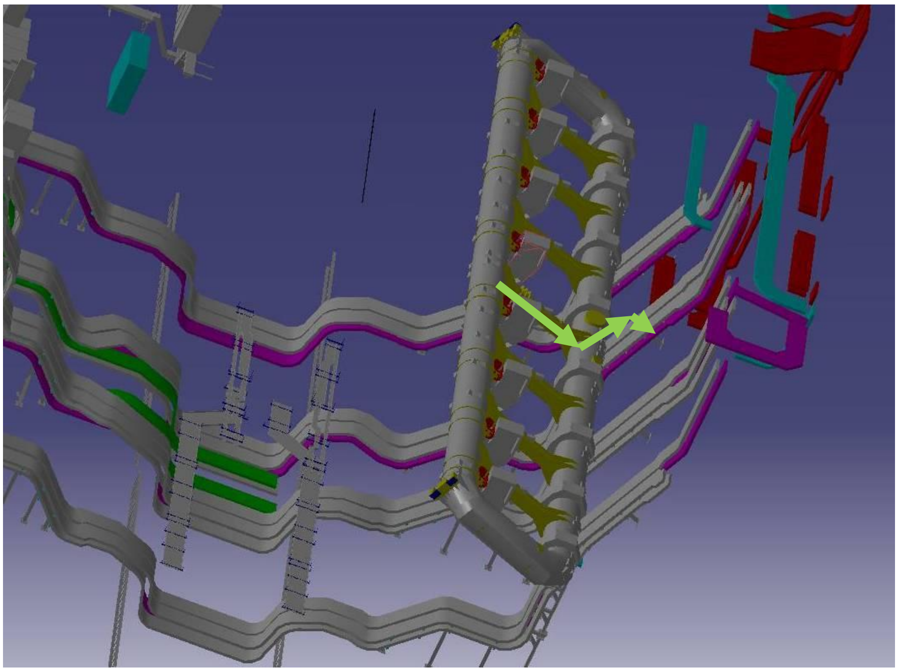

Figure 52: grounding path to the barrel toroid.

3.5.2 Cryoring.

The eight coils of the barrel toroid have their electrical and cyogenic services linked together by means of a cryogenic ring. This is implemented with 8 sections close to Z=0. The enveloppe of each cryoring section is linked to the grounding cable of the barrel toroid coil that is routed next to it (figure 53).

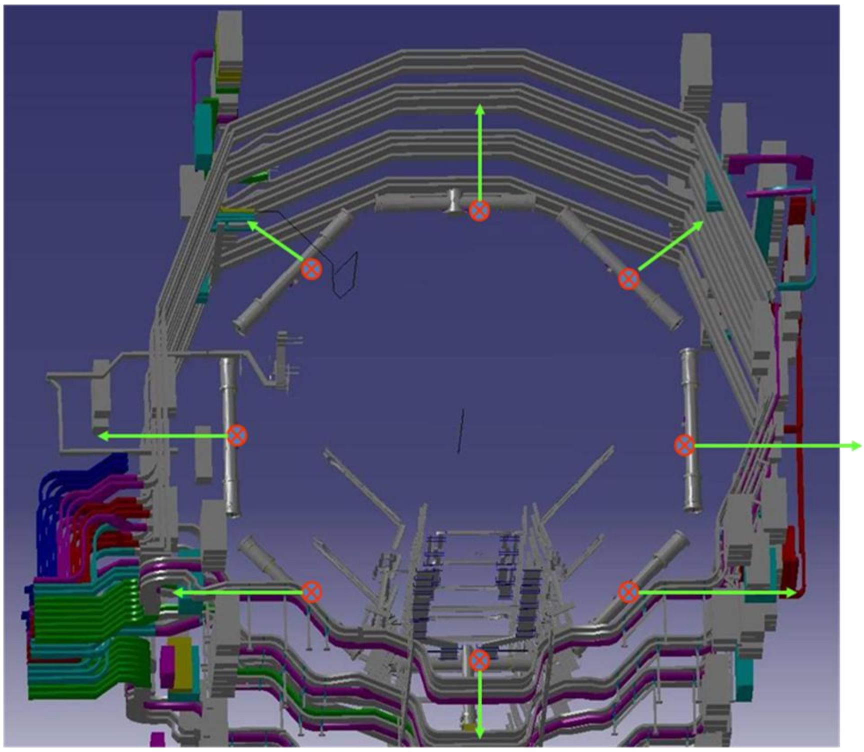

Figure 53: grounding points for the cryoring.

3.5.3 Endcap toroid.

The endcap toroids are are contained in a cryostat, and the circuit is fed through a tower located on the top of the of the vessel. The magnet can be moved along the Z axis, and the services all go through a flexible chain placed on a platfrom above the cryostat.

The grounding of UX15 is brough from the grounding wires of the arches into a cabinet located on the top of the detector close the these arches. The grounding link is made on a ground bar inisde this cabinet, where all the cable shields and the cabinet are connected to. A flexible, insulated grounding cable of 95 mm2 is run from this point into the flexible chain that brings the services to the endcap toroid, and it is terminated on a copper plate next to the services tower. The services, the trays and the cables shields are grounded at this point.

A 95 mm2 flexible cable is run from this second plate down to the cryostat of the endcap toroid where the earthing of the vessel is provided.

3.5.4 Barrel Solenoid

The solenoid magnet is contained in the cryostat of the Liquid Argon calorimeter, which is earthed in USA15 (§ 3.4.3.5).

4 Conclusion and summary.

A nested grounding network has been provided for the ATLAS experiment as a basic infrastructure that ensures the safe installation of the detectors and associated services in the control rooms and in the experimental cavern. The network is derived from the earth point implemented on te secondary star points of the power trasnformers of the facility. The network is extended to the steelwork of the facility and of the different caverns by means of naked copper cables with appropriate cross section.

The racks, cable trays, and in general all the enveloppes of the detectors, of the magnets and of the services are linked to this grounding network. With this, any electrical fault to a conductive enveloppe to which personnel could be exposed is safely connected to earth.

The implemented meshed grounding network provides also an effective path for earth leakage and noise currents. The mesh of earth loops using the structures and the services is known as an effective method to damp the electromagnetic interferences [3]. The densely interconnected mesh of steelworks, racks, grounding cables and cable trays provides a reduced impedance path for the high frequency noise currents, reducing in this way the sensitive couplings to the electrical and electronics circuits of the detectors.

Some detectors have an enveloppe that is used as active return conductor. Those detectors are installed by means of controlled isolation supports and interfaces, and a dedicated single point grounding tree as been arranged. These dedicated grounding nets are ultimately connected at a single point to the meshed earth network.

The nested ground involves sometimes long grounding cables, in particular for the grounding of isolated detectors. It must be noted that the use of shielded cables is the best method to achieve a good protection against the couplings of electromagnetic interferences [2,3]. This is particularly important in ATLAS because the density of the cabling often does not allow providing the required separation between cables within the trays.

5 Reference documents and links.

[1] [ATLAS EMC] http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/EMC/
[2] [ATC-TE-IP-0001] ATLAS EMC Policy
[3] [IEC-61000-5-2] EMC - Installation and Mitigation Guidelines - Earthing and Cabling
[4] [NFC 15-100] Installations Electriques Basse Tension
[5] [C1_E] CERN Electrical Code C1
[6] [IS 24] Regulations applicable to electrical installations
[7] [LHCEIE___1011] USA15 Equipotential Network.
[8] [ATFIU___0023] Integration USA15 Zones et Services.
[9] [ATFIU___0030] All cable trays in false floor of USA15 level 1.
[10] [ATFIU___0036] All cable trays in false floor of USA15 level 2.
[11] [LHC-EM-ES-0001] https://edms.cern.ch/file/113154/2/LHC-EM-ES-0001-00-20.pdf
[12] [LHC-E-EN-0001] Liaisons equipotentielles et protections electromagnetiques.
[13] [LHCEIE__1010] UX15 Equipotential Network.
[14] [LHCEIE__1025] UX15 Equipotential network level 0.
[15] [LHCEIE__1026] UX15 Equipotential network level 7.
[16] [LHCEIE__1027] UX15 Equipotential network level 8.
[17] [ATL-IC-ES-0011] https://edms.cern.ch/document/428149/2
[18] [ATL-IS-EN-0014] https://edms.cern.ch/document/353742/2
[19] [ATL-IS-ES-0056] https://edms.cern.ch/document/324664/1
[20] [ATL-IC-ES-0007] https://edms.cern.ch/document/383794/1
[21] [ATL-IC-EN-0004] https://edms.cern.ch/document/108383/1
[22] [ATL-IT-EN-0050] https://edms.cern.ch/document/432739/3
[23] [Naming Convention] Muons Naming Convention.
[24] [Muons Layout] Muons Layout
[25] [Parameter Book] Muons Parameter Book.
[26] [MDT Grounding] MDT Grounding.
[27] [LHC-D-ES-0001 r. 2] EARTHING OF THE LHC DC ELECTRICAL CIRCUITS