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6 Civil Engineering and Services (CES)

6.1 Overview

Infrastructure costs for the CLIC project represent approximately one third of overall budget. For this reason, particular emphasis has been placed on Civil Engineering and Services (CES) studies, to ensure a cost efficient conceptual design. This chapter provides an overview of the designs adopted for the key infrastructure cost drivers, such as, civil engineering, ventilation, water cooling, electrical supply, transport & installation etc.

For the purposes of this conceptual design report, the CES studies were based on the assumption that the CLIC facility will be sited on and around the existing CERN laboratory near Geneva, Switzerland. The proposed alignment for the near 50 km long 3 TeV machine straddles the France/Switzerland border, with the Interaction Region (IR) fully located within existing CERN land on the Prevessin campus.

Figure 6.1-1 is a schematic layout of the civil engineering complex for the CLIC project.

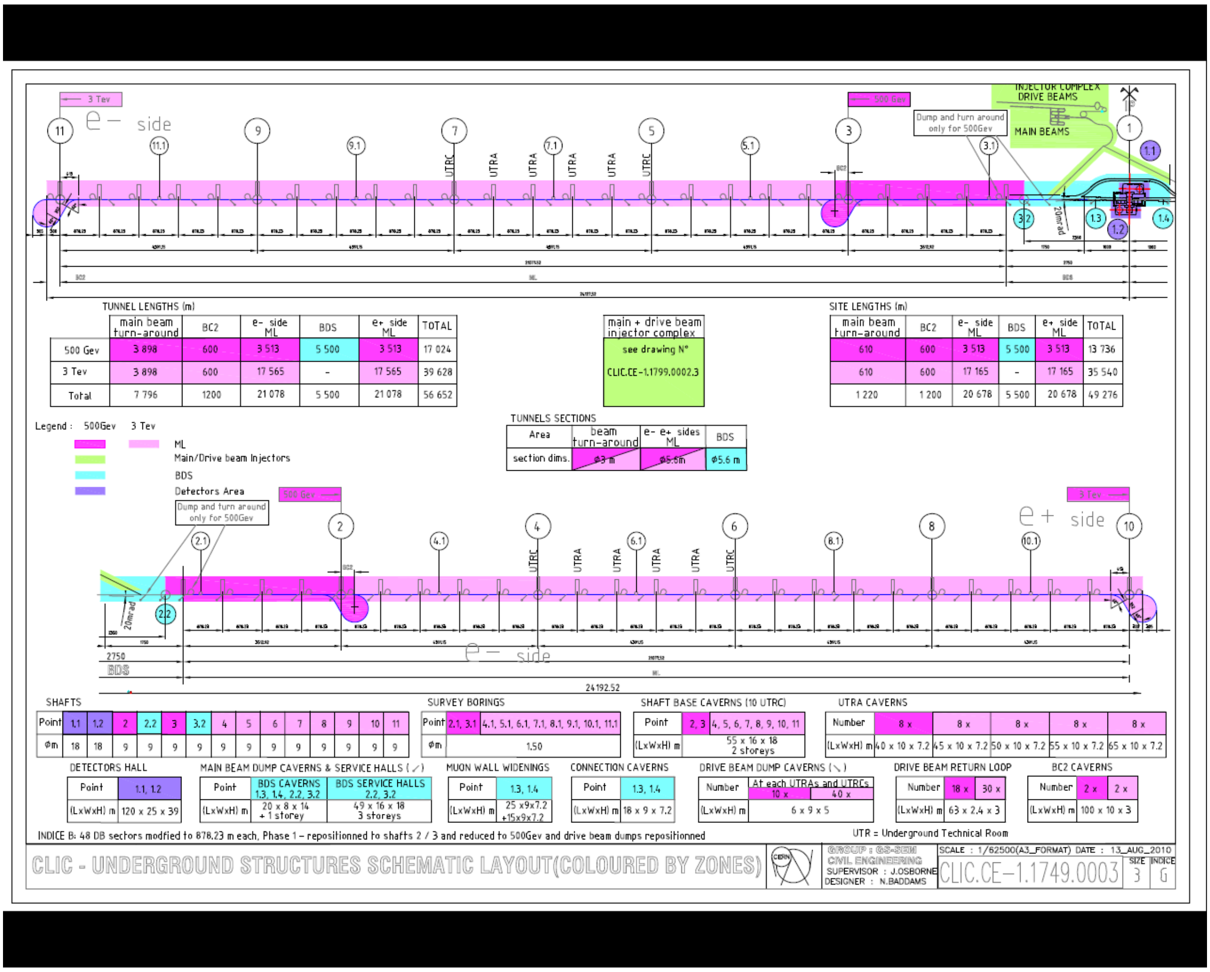

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Figure 6.1-1 : Schematic layout of the civil engineering complex

The key features of this layout are :

- 20 mrad crossing angle and vertical plane symmetry about the collision point
- Tunnels are laser straight i.e. not horizontal like ILC
- Injection complex housed on the Prevessin campus with “cut-and-cover” tunnels and surface buildings
- Shafts and surface installations approximately every 5km
- Main linac is housed within a single tunnel with an internal diameter of 5.6 m.
- 500 GeV machine from shafts 2 to 3, site length 17.74 km
- 3 TeV machine from shafts 10 to 11, site length 49.28 km
- Two independent caverns for detector assembly & maintenance with a common ‘passageway’ leading to a smaller IR cavern

The CES studies presented in this chapter have been performed by the various technical experts within CERN and in collaboration with certain ILC specialists. External consultancy firms have also contributed in some areas of these designs.

6.2 Civil Engineering (J.Osborne & M.Gastal)

This section describes the civil engineering envisaged both on surface and underground for the 500 Gev and 3 TeV machines, including the experimental area.

6.2.1 Location

The proposed siting for the 3 TeV CLIC project is in the North-Western part of the Geneva region near the existing CERN laboratory. The near 50 Km machine straddles the France/Switzerland border, with the Interaction Region (IR) fully located within existing CERN land on the Prevessin campus.The on-surface alignment of the accelerator tunnel is dotted with small villages, farmland and wooded areas.

The CERN area is extremely well suited to housing the CLIC project, with the very stable and well understood ground conditions having several particle accelerators in the region for over 50 years. The civil engineering works for the most recent machine, the LHC were completed in 2005, so excellent geological records exist and have been utilised for this study to minimise the costs and risk to the project. The tunnel will be constructed in the stable Molasse rock at depth of 100-150m in an area with little seismic activity.

CERN and the Geneva region have all the necessary infrastructure at their disposal to accommodate such a project. Due to the fact that Geneva is the home of many international organizations excellent transport and communication networks already exist. Geneva Airport is only

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5km from the CERN site, with direct links and a newly constructed tramway gives direct access from Meyrin to the city centre.

Figure 6.2.1-1 : Tram station outside CERN Meyrin site ***(new photo to be added with GLOBE)***

The governments of France and Switzerland have long standing agreements concerning the support of particle accelerators in the Geneva region, which make it very likely that the land could be made available free of charge, as they did for previous CERN projects.

6.2.2 Land Features

The proposed location for the accelerator is situated within the Swiss midlands embedded between the high mountain chains of the Alps and the lower mountain chain of the Jura. CERN is situated at the feet of the Jura mountain chain in a plain slightly inclined towards the lake of Geneva. The surface terrain was shaped by the Rhone glacier which once extended from the Alps to the valley of the Rhone. The water of the area flows to the Mediterranean Sea. The absolute altitude of the surface ranges from 430 to 500m with respect to sea level.

The physical positioning for the project has been developed based on the assumption the maximum underground volume possible should be housed within the Molasse rock and should avoid as much as possible any known geological faults or environmentally sensitive areas. In addition, it was assumed that the central injection complex and interaction region, would be built on existing CERN land on the French Prevessin Site. The shafts leading to the on-surface facilities have been positioned in the least populated areas, however, as no real discussions have taken place with the local authorities, the presented layouts can only be regarded as indicative, for costing purposes only. In certain areas, where the shafts would be either extremely deep or if a particularly environmentally sensitive area could not be avoided, inclines access tunnels have been foreseen. Although the typical depth for the tunnel below ground level is in the range of 100-150m, at the French end the main linac is accessed via an inclined tunnel, due to the fact that it is situated is several hundred metres. Similary,

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shaft number 5 is also accessed via an inclined tunnel, to avoid surface developments in an environmentally sensitive area.

6.2.3 Geology

Most of the proposed path of CLIC is situated within the Geneva Basin, a sub-basin of the large North Alpine Foreland (or Molasse) Basin. This is a large basin which extends along the entire Alpine Front from South-Eastern France to Bavaria, and is infilled by clastic "Molasse" deposits of Oligocene and Miocene age. The basin is underlain by crystalline basement rocks and formations of Triassic, Jurassic and Cretaceous age. The Molasse, comprising an alternating sequence of marls and sandstones (and formations of intermediate compositions) is overlain by Quatemary glacial moraines related to the Wurmien and Rissien glaciations. The path crosses just below a well known fault at the valley of the Allondon river which is situated South-West of Geneva and filled with sands and gravels. For the 3TeV extension of the project, the tunnel will cross a second valley at Gland, situated North-East of Geneva. The tunnel at the South-West end will enter into some Jurassic limestone.

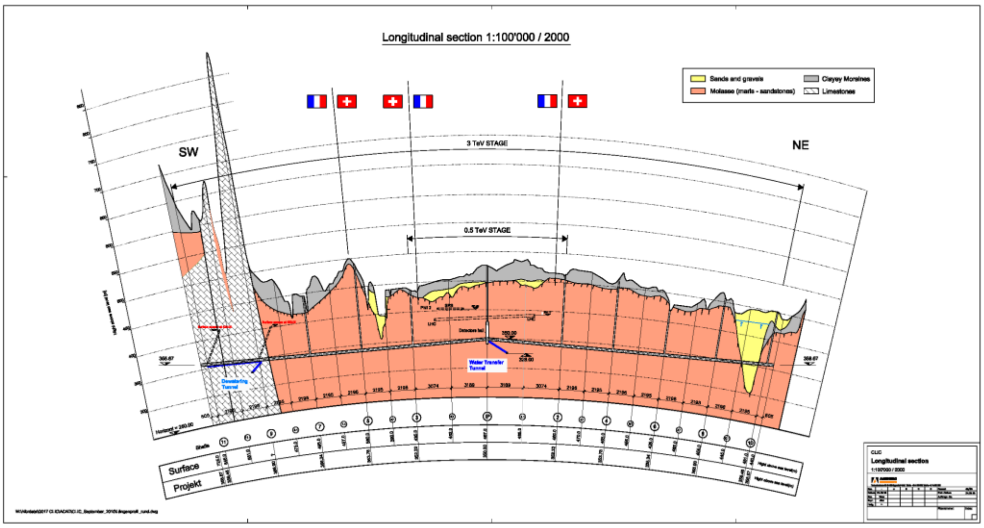


Figure 6.2.3-1 : Longitudinal geological profile (water transfer tunnel to be removed)

6.2.4 Site Development

As most of the central campus is located on the CERN site at Prevessin, it is assumed for the CDR that the existing facilities such as restaurant, main access, road network etc are sufficient and have not been costed. However, for the parts located outside the existing fenceline, but within CERN property, the following items have been included in the costs :

- Roads and car parks
- Drainage networks

- Landscaping and planting
- Spoil dumps

All temporary facilities needed for the construction works have also been included in the cost estimate.

6.2.5 Construction Methods

It is envisaged that Tunnel Boring Machines (TBM's) will be utilised for the main tunnel excavation followed by a second phase of excavation for the turnarounds, approximately every 800m. In the Molasse rock, a shielded TBM will be utilised, with single pass pre-cast segmental lining, followed by injection grouting behind the lining. For planning and costing exercises, an average TBM advancement of 25m per day, or 150/m is predicted. The second phase excavation will be executed using a "roadheader" type machine as shown in Figure 6.2.5-1.

Where the tunnel passes through any areas with potential water ingress eg the "Gland" depression, special excavation techniques such as freezing of the ground have been costed.

Fig. 6.2.5-1: Roadheader type machine

6.2.6 *Central Injection Complex*

The central injection complex consists in a series of facilities connected at their ends to the Main Linac. Figure 6.2.6-1 illustrate the location of the complex.

Fig. 6.2.6-1: Central Injection Complex – Overview

The complex is located on CERN land in Prevessin and includes surface building and shallow underground galleries. It is divided in several parts that will now be described.

The Main Beam Injectors facility consists in seven separate units with their own functionality and geometry: the Primary e$^-$ Beam Linac, the Polarized e$^-$ source, the Positron target, the Injector Linac, the transfer line to the Damping Ring facility, and the Booster Linac. Figure 6.2.6-2 illustrates the geometry and structure of the underground part of the facility.

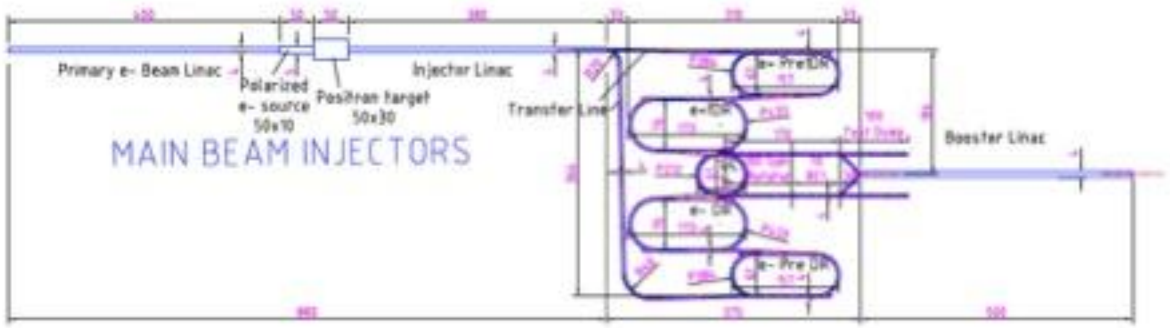


Fig. 6.2.6-2: Main Beam Injectors – Overview

The shallow galleries are referred to as cut and cover surface tunnels. Surface buildings have been foreseen to connect the underground facility to the surface. Nine of them are presented on the reference drawings: Klystron Gallery, Linac1 Target Cavern, Linac2 Target Cavern, Compton Ring Cavern, e$^+$ Pre Damping Ring Cavern, e$^-$ Pre Damping Ring Cavern, e$^+$ Damping Ring Cavern, e$^-$ Damping Ring Cavern, Delay Loop Cavern. Figure 6.2.6-3 presents the location of the surface buildings and their geometry.

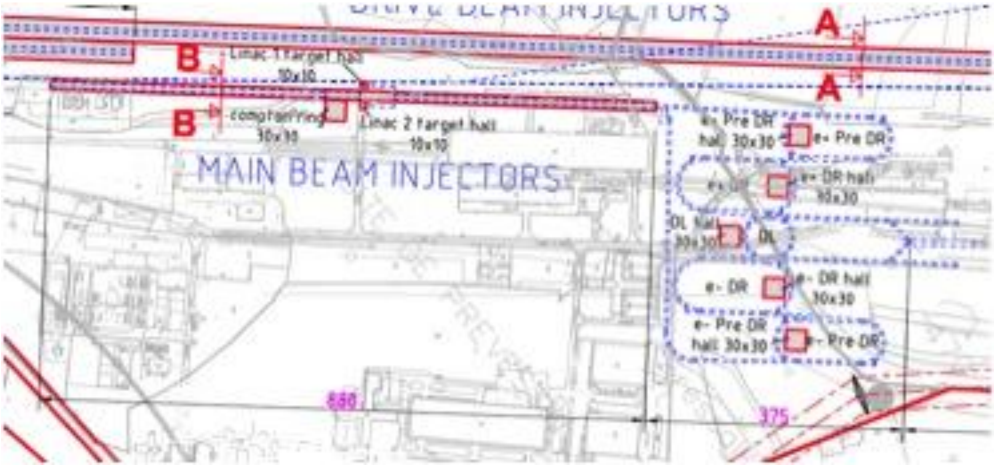


Fig. 6.2.6-3: Main Beam Injectors– Surface Building (highlighted in red)

The cross section BB illustrates the way the largest building, the Klystron Gallery, is connected to the underground facility. Figure 6.2.6-4 shows the surface building, the surface tunnel five meters underground and the vertical link between them.

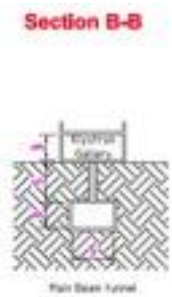


Fig. 6.2.6-4: Section B-B

The Drive Beam Injector facility consists in four separate units with their own functionality and geometry: the Drive Beam Accelerator, the Delay Loop, the Combining Ring 1, and the Combining Ring 2. Figure 6.2.6-5 illustrates the geometry and structure of the facility.

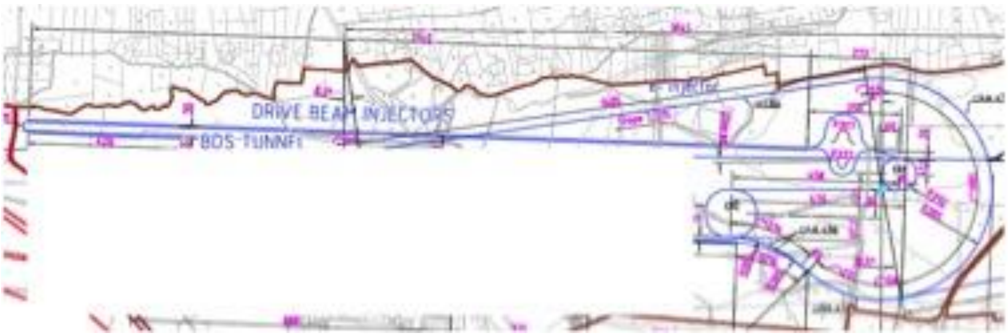


Fig. 6.2.6-5: Drive Beam Injectors – Overview

Surface buildings have been foreseen to connect the underground facility to the surface. Three of them are presented on the reference drawings: Klystron and Modulator Building, Combining Ring1

Cavern, and Combining Ring2 Cavern. Figure 6.2.6-6 presents the location of the surface buildings and their geometry.

Fig. 6.2.6-6: Drive Beam Injectors– Surface Building (highlighted in red)

The cross section AA illustrates the way the largest building (2608m long – 30m wide – 9m high), the Klystron and Modulator Building, is connected to the underground facility. Figure 6.2.6-7 shows the surface building, the surface tunnel five meters underground and the vertical link between them.

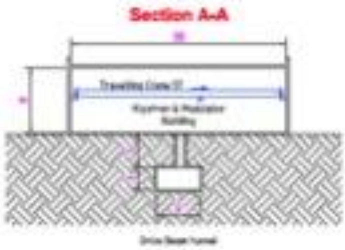


Fig. 6.2.6-7: Section A-A

The e+ and e- injectors connect the end of the Main Beam Injectors and the Drive Beam Injectors facilities to the Main Linac. In their straight sections they start at a depth of five meters and finish at the level of the Main Linac Tunnel. The e^- injector tunnel goes down with a slop of 7.12% while the e^+ injector tunnel only has a slope of 4.68%. The bended section of the e- injector remains in a horizontal plane.

6.2.7 Main Linac

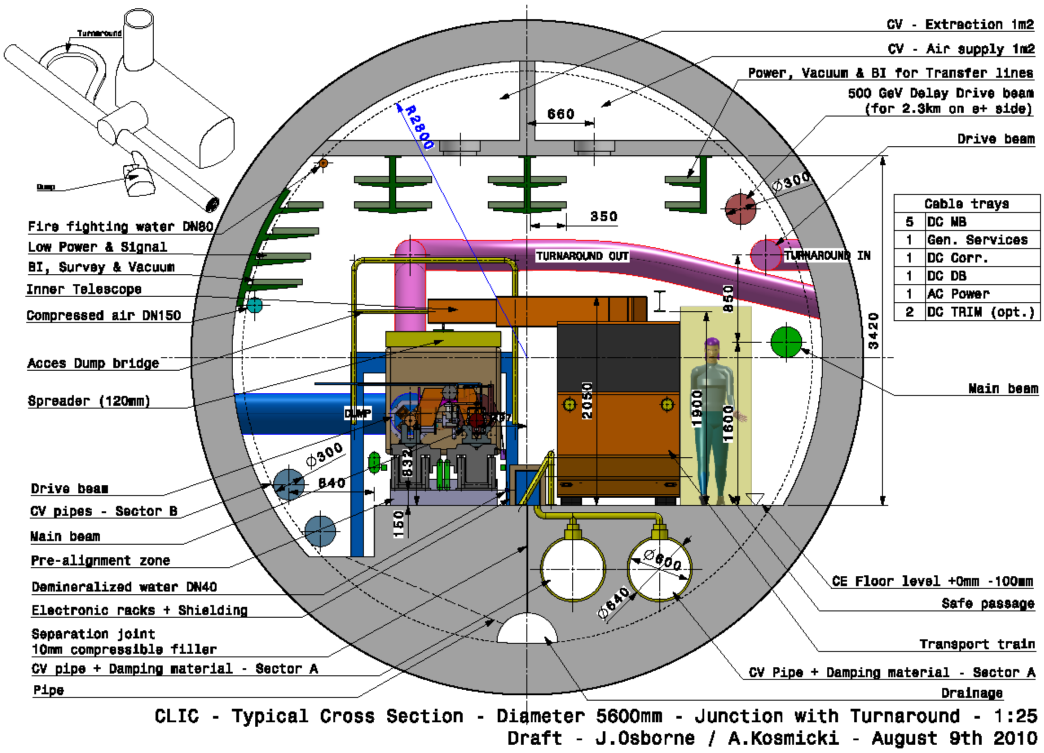
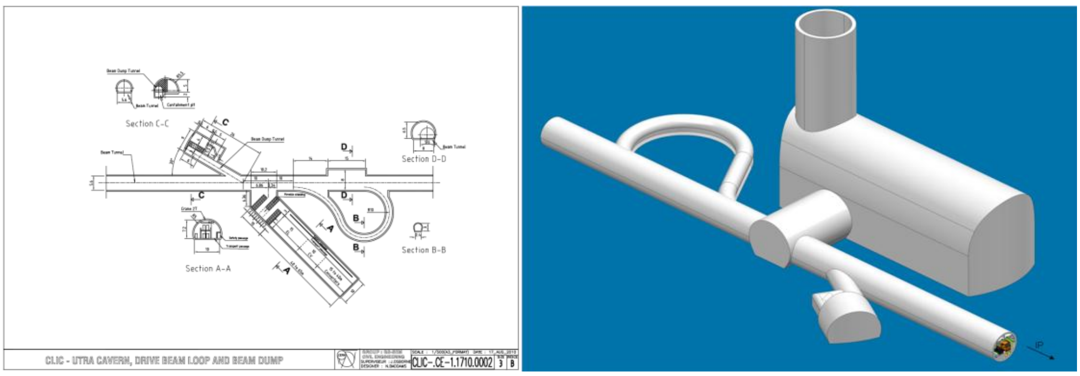


Fig. 6.2.7-1: Typical tunnel cross section : 5.6m

6.2.8 *Drive Beam Turnarounds*



6.2.9 *Interaction Region and BDS*

In the middle of the CLIC accelerator complex, the region dedicated to the handling of collisions is divided in two: the Interaction Region and the Beam Delivery System. The BDS handles the incoming and outgoing beams in and out of the Interaction Region, which hosts the Detector Caverns. Figure 6.2.9-1 illustrates the geometry and structure of the IR and BDS facilities.

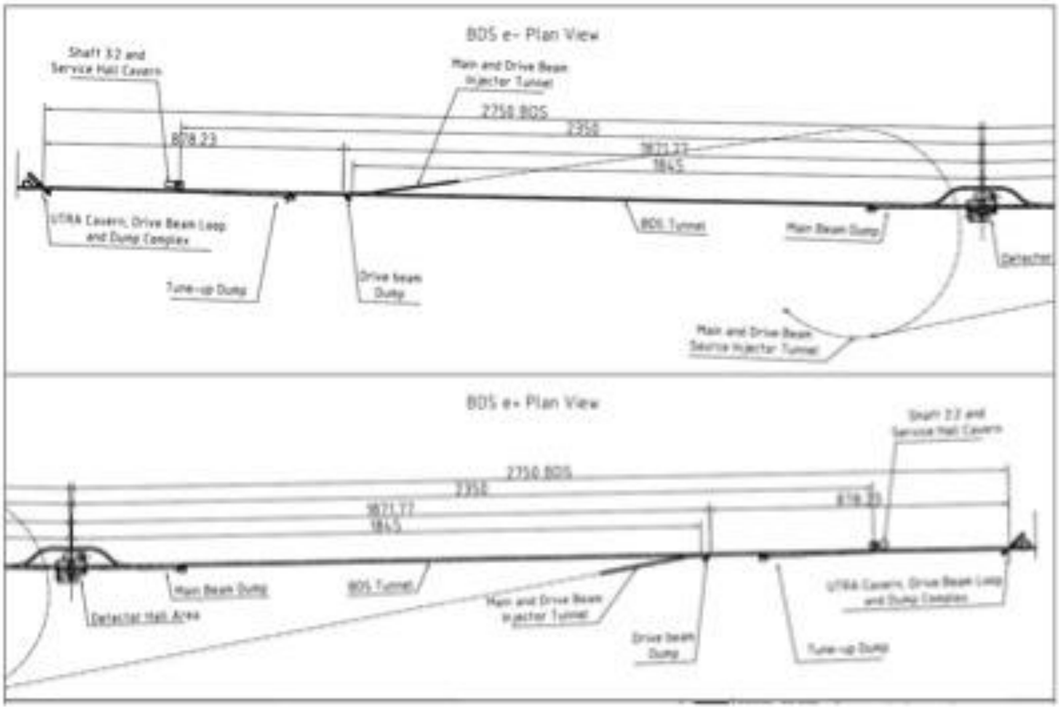


Fig. 6.2.9-1: BDS and IR overview

The BDS consists in several facilities duplicated on both sides of the IR: Main Beam Dump, BDS Tunnel, Drive Beam Dump, Tune-up Dump, Shaft and Service Cavern Cavern, ULTRA Cavern, Drive Beam Loop and Dump complex. The BDS Main Beam Dumps will now be described. The other elements of the BDS that also appear in the rest of the tunnel are described in the Main Linac section.

The Main Beam Dumps are located 315m downstream from the Interaction point. Figure 6.2.9-2 illustrates the position and geometry of the Main Beam Dumps.

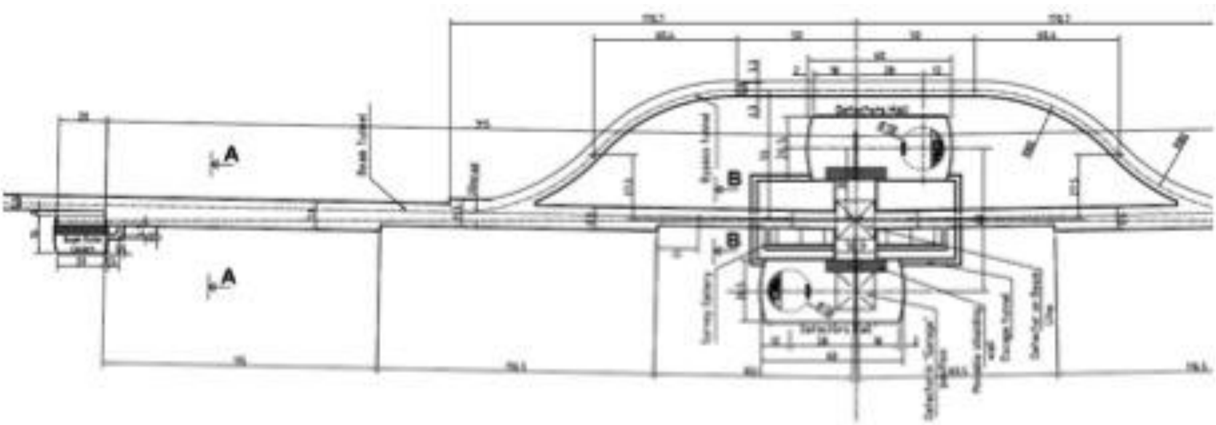


Fig. 6.2.9-2: Location and geometry of Main Beam Dumps

In order to prevent the radiations produced in the dump from propagating into the Beam Tunnel, a two-meter thick concrete wall has to be built. Figure 6.2.9-3 illustrates the structure of the Main Beam Dump cavern and tunnel with respect to the Beam Tunnel.

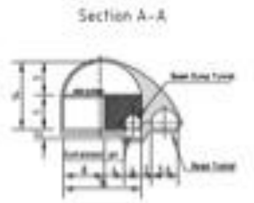


Fig. 6.2.9-3: Structure of Main Beam Dumps tunnel and cavern

The Interaction Region consists of four main elements: two Detector Caverns, the Transfer Tunnel, the Bypass Tunnel. The Detector Caverns will host the detectors during their installation underground and when there are in “Garage” position. The Transfer Tunnel links the two Detector Caverns together and allows sliding a detector in beam position. The Push-Pull system used to move the detectors in and out of the beam line is described in the MDI chapter. Figure 6.2.9-4 describes the Interaction Region.

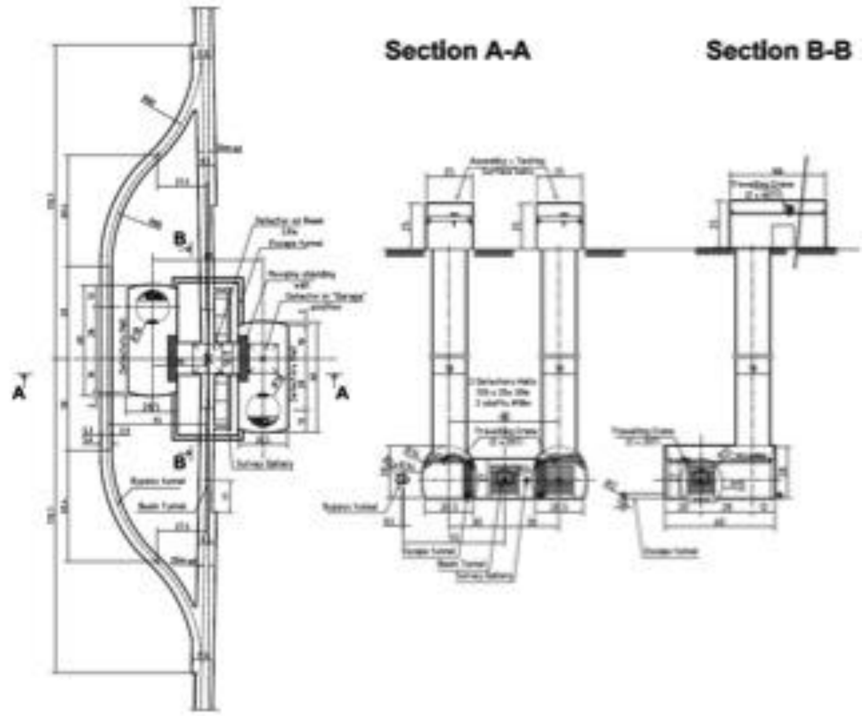


Fig. 6.2.9-4: Interaction Region

Each Detector Cavern is connected to a safety shelter located in the other Detector Cavern by an escape tunnel. In addition, a survey gallery will allows the alignment of the magnets located in the beam tunnels on both sides of the interaction region.

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A two-meter thick movable shielding wall is foreseen at the interface between the Detector Cavern and the Transfer Tunnel. It prevents the radiations produced in the Transfer Tunnel from propagating into the Detectors Caverns.

Two 18m-diameter shafts connect the Detector Caverns with corresponding Surface Caverns where the detectors will be assembled and tested before being lowered underground.

In order to assemble and service the detectors, travelling cranes have to be installed. Each Surface Cavern is equipped with two 80ton cranes. The Detector Caverns are each equipped with one 20ton crane.

6.2.10 Surface Buildings

		Shaft Area				2,3	2.1,3.1	1,2.2,3.2	1	4,5,6,7,8,9,10,11	4.1,5.1,6.1,7.1,8.1,9.1,10.1,11.1			
	Building Type / Area System		**Main Beam Inj. System**	**Drive Beam Inj. System**	**Transfer Line**	**Main Linac 500GeV Phase**	**Survey Points 500Gev**	**Beam Delivery Syst**	**Experimental Area**	**Main Linac 3 TeV Phase**	**Survey Points 3 TeV Phase**	**Crane Capacity**	**L, W, H**	**Total**
		No. buildings	*0*	*0*	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*4*	*2*	***2***
1	Detector Assembly	*Tot. Surface m2*	*0*	*0*	*0*	*0*	*0*	*0*	*5000*	*0*	*0*	*80t*	*100x25x25*	***5000***
		"	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		***0***
2	Offices for Technical Staff	"	*0*	*0*	*0*	*0*	*0*	*0*	*1200*	*0*	*0*	*0*	*60x20x10.5*	***1200***
		"	*1*	*1*	*0*	*2*	*2*	*2*	*1*	*8*	*8*	*0*	*1*	***25***
3	Electrical building	"	*1600*	*1600*	*0*	*800*	*200*	*800*	*1600*	*3200*	*800*	*0*	*80x20x6*	***10600***
		"	*4*	*4*	*0*	*0*	*0*	*2*	*2*	*0*	*0*	*2*	*2*	***12***
4	Cooling Tower & Pump Station *	"	*2800*	*2800*	*0*	*0*	*0*	*1300*	*1750*	*0*	*0*	*3.2t*	*35x25x16*	***8650***
		"	*1*	*1*	*0*	*2*	*2*	*2*	*1*	*8*	*8*	*1*	*1*	***25***
5	Cooling Ventilation building	"	*600*	*600*	*0*	*1200*	*1200*	*1200*	*1125*	*4800*	*4800*	*10t*	*45x25x13*	***15525***
		"	*1*	*0*	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*2*	*2*	***3***
7	Cryo - Warm Compressor	"	*300*	*0*	*0*	*0*	*0*	*0*	*900*	*0*	*0*	*20t*	*25x18x12*	***1200***
		"	*1*	*0*	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*2*	*2*	***3***
8	Cryo - Surface Cold box	"	*200*	*0*	*0*	*0*	*0*	*0*	*900*	*0*	*0*	*20t*	*25x18x12*	***1100***
		"	*0*	*0*	*0*	*2*	*2*	*2*	*1*	*8*	*8*	*0*		***23***
9	Survey building	"	*0*	*0*	*0*	*100*	*100*	*100*	*800*	*400*	*400*	*0*	*100x8x4*	***1900***
		"	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*		***1***
10	Control Room	"	*0*	*0*	*0*	*0*	*0*	*0*	*1250*	*0*	*0*	*0*	*50x25x7.5*	***1250***
		"	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*1*	*1*	***1***
11	Workshop	"	*0*	*0*	*0*	*0*	*0*	*0*	*450*	*0*	*0*	*10t*	*30x15x12*	***450***
		"	*0*	*0*	*0*	*2*	*2*	*2*	*1*	*8*	*8*	*0*	*1*	***23***
12	Site Access building	"	*0*	*0*	*0*	*200*	*100*	*200*	*100*	*800*	*400*	*0*	*10x10x3.5*	***1800***
		"	*0*	*0*	*0*	*2*	*0*	*2*	*0*	*8*	*0*	*10**	*0*	***12***
13	Shaft Access	"	*0*	*0*	*0*	*1400*	*0*	*1400*	*0*	*5600*	*0*	*20t*	*0*	***8400***
		"	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*1*	***1***
14	Reception building	"	*0*	*0*	*0*	*0*	*0*	*0*	*480*	*0*	*0*	*0*	*40x12x7*	***480***
		"	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*1*	***0***
15	Central area Machine Cooling Towers		*0*	*0*	*0*	*0*	*0*	*0*	*1250*	*0*	*0*	*5t*	*50x25x30 ??*	***1250***
			0	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*1*	***1***
16	Gas building	"	*0*	*0*	*0*	*0*	*0*	*0*	*400*	*0*	*0*	*0*	*40x10x4*	***400***

6.2.11 Cost Considerations

The cost estimate for 500GeV and 3TeV machine will be prepared, based on the CDR layouts presented in this chapter and the approved Project Breakdown Structure (PBS). The estimate includes all aspects of construction, final engineering designs and construction management. Many of the rates used to formulate this estimate were based on real construction costs from LHC experience (1998-2005).

In order to allow cost caparison with the ILC Project, the same basic methodology will be adopted wherever possible.

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6.3 Electricity Supply (C. Jach)

6.3.1 System Overview

Electrical power is categorized by three major systems:

- RF power (modulators);
- Conventional power (normal conducting magnet power supplies, electronic racks, cooling and ventilation systems and infrastructure components);
- Emergency power provided by back-up generators (emergency lighting, sump pumps and ventilation systems for sub-surface enclosures).

The power requirements are dominated by the RF system (modulators) located in the Central Campus area. Table 6.3-1 gives an overview of the estimated nominal power consumption for 3 TeV center-of-mass operations, broken down by system area and load types. It is assumed that for each load power factor will be compensated to approximately 0.95 either by using modern power conversion technology or by static var compensation (SVC) depending on the non-linear load and the dynamic behaviour of the load, especially the RF (Modulator) system. Nominal power distribution losses are assumed to be approximately 5%. This results in ratio of wall-plug power to apparent power of 0.9.

Subsystem	Location			
	Central Campus		Main tunnel	
Power	Wall-plug [MW]	Apparent [MVA]	Wall-plug [MW]	Apparent [MVA]
Main Beam Production	65	72		
Drive Beam Production	362	402		
Two-beam accelerators			43	46
Beam Instrumentation	8	9	8	9
Detectors	15	17		
CV and infrastructure	45	50	5	5
Total	**495**	**550**	**56**	**60**

Table 6.3.1-1: Estimated nominal power loads (MW) for 3 TeV center-of-mass operations.

6.3.2 System Configuration

High voltage connection to the utility system is in the Main Substation located Central Campus area at 400 kV. Voltage level selected for the medium voltage (MV) distribution system is 36 kV providing maximum utilization of the standard MV equipment (dry transformers, switchgear, cables, etc.) at the same time optimizing the cost of MV power distribution.
Low voltage (LV) distribution system nominal voltage is 400 V allowing for utilization of standardized equipment.
The HV and MV protection, monitoring and communication systems are based on state-of-the-art relays fully utilizing IEC 61850 substation automation standard.

6.3.3 Distribution for the Main Tunnel

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Power for the Main Tunnel comes from the main substation located in the Central Campus area. It constitutes approximately 10% of the total power consumption. Three 36 kV cable lines are routed along the Main Tunnel:

- Two 36 kV cable lines provide power to conventional loads (power supplies, electronic racks, cooling and ventilation systems and infrastructure components) to each cavern along the tunnel. For redundancy a return line is added forming a loop with MV circuit breakers located in main substation and remote substations sited on the surface in each shaft area.
- The second MV system provides emergency power backed up by generators (emergency lighting, sump pumps and ventilation systems for sub-surface enclosures, fire alarms, smoke detectors etc.)

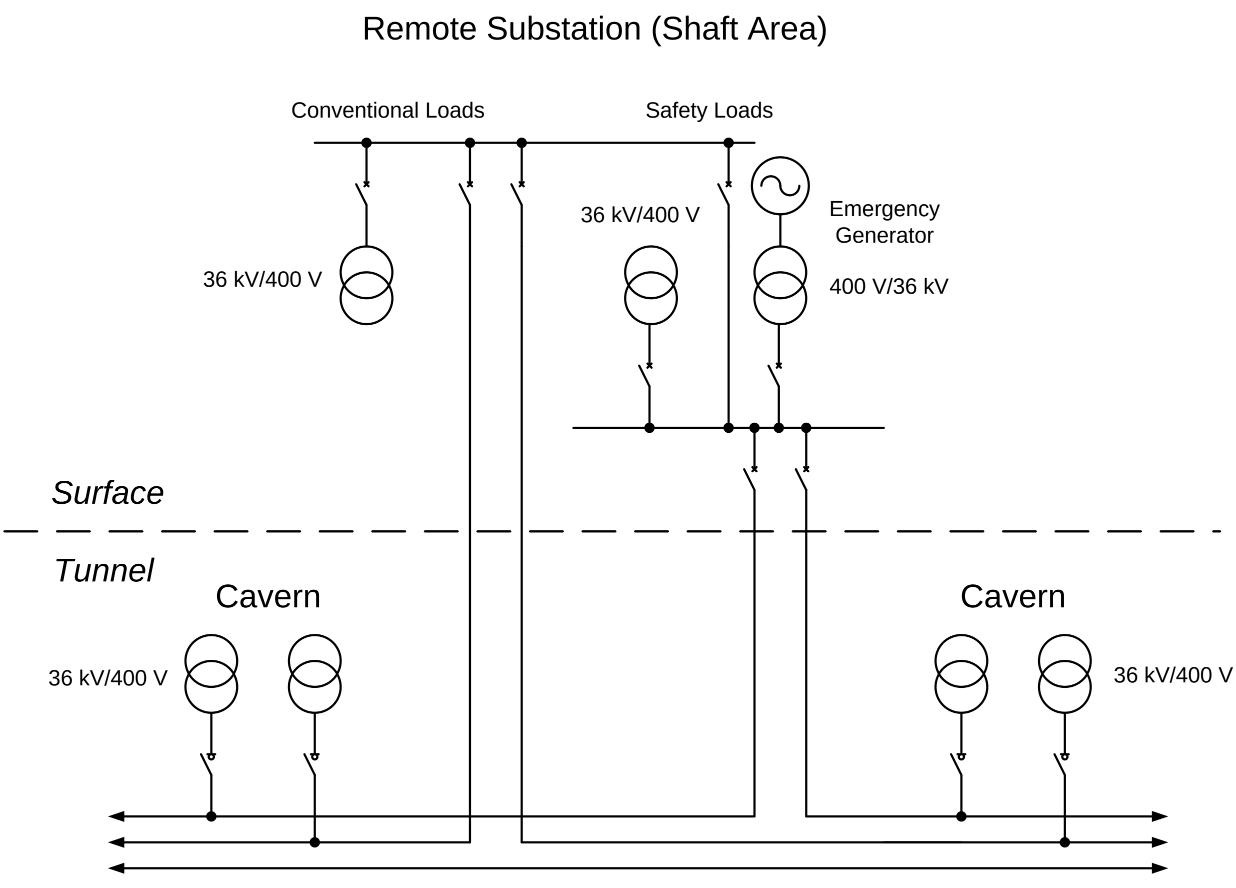

Figure 6.3.3-1: Simplified concept of the power distribution for the Main Tunnel.

6.3.4 Distribution for the Central Campus

Power for the drive and main beam production, beam transport and frequency multiplication comes from the main substation located at the Central Campus area. It constitutes approximately 90% of the total power consumption. The main substation houses: 400/36 kV transformers, switching equipment, system protection and substation automation, etc. Power from the main substation is routed at 36 kV level as close as possible to the individual loads (injectors, damping rings, beam transport, frequency multiplication) for farther transformation and utilization. Each individual system's substation is provided with a backup generator used for emergency lighting, sump pumps and ventilation systems for sub-surface enclosures, fire alarms, smoke detectors etc.

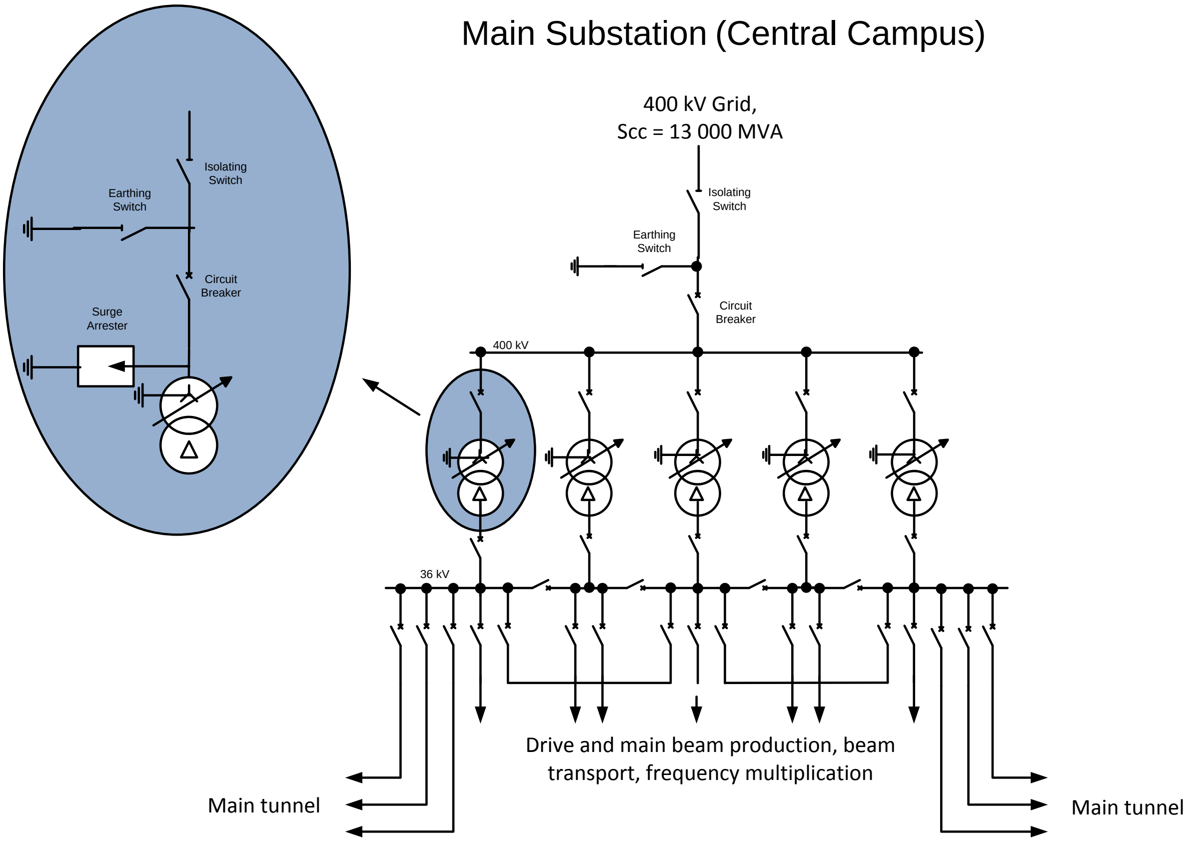

Figure 6.3.4-2: Simplified concept of the power distribution for the Central Campus.

6.3.5 Emergency Supply Systems

The emergency supply system is based on stand-by diesel generator systems. Each generator set supplies a protected substation, which is normally supplied by the utility power. During a utility power interruption, the diesel engines start automatically and transfer the critical load when ready.
Any critical system which cannot accept any power interruption is provided with an Uninterruptible Power Supply (UPS) system.

6.3.6 Cost Considerations

The cost estimate for electricity supply will be developed based on the following assumptions:

- Existing 400 kV connection will be utilized,
- Existing and new accelerator complex will not be operating at the same time
- A new main substation will be located in existing BE substation area utilizing existing infrastructure as much as possible

6.3 Fluids and Gases (M.Nonis)

6.3.1 Water Cooling

6.3.2 Ventilation

6.3.3 Gas Systems

6.3.4 Cost considerations

6.5 Transport and installation (K Kershaw and I Ruehl)

6.5.1 Overview and challenges

This chapter considers transport and installation activities for the construction of the CLIC accelerator starting from the unloading of accelerator and technical services components when they arrive at the CERN site. Transport and installation information for the experimental area, including overhead travelling cranes and lifts, is not covered here; it is covered in section **Error! Reference source not found.**.

For the CLIC machine, the underground transport and installation of modules was identified as the main transport and handling issue to be addressed at an early stage because of their influence on the 3-D tunnel integration studies and also because of the large quantity (over 20,000) of modules to be installed over the length of the machine. It was apparent that special equipment will be needed for their installation in view of the drive to keep the tunnel cross section as small as reasonably possible for cost reasons and also to be able to install modules rapidly in order to have an acceptable installation timescale.

Although the modules can be considered the most demanding items from an installation point of view, it is necessary to consider all the items to be transported.

6.5.1.1 Items to be transported

The quantity and variety of equipment to be installed for CLIC is huge. For the underground areas it includes:

- Modules and their supports
- Magnets

- Vacuum pipes,
- Beam dumps
- Cooling and ventilation equipment
- Electrical cables and cable trays
- Racks

Transport and handling solutions will need to be defined in detail for all of the above types of equipment. For equipment such as racks, cooling and ventilation equipment, electrical cables and cable trays it is foreseen to use industrial standard handling equipment. For modules and their supports, magnets, beam dumps and vacuum pipes it will be necessary develop special handling equipment.

The transport and installation operations include

- Unloading, transfer within and between buildings on the surface for the purposes of assembly test and storage,
- Transport to the access sites along the length of the accelerator where items will be either installed in surface buildings or lowered to the underground areas,
- Transport along the tunnel(s) and final installation.

6.5.2 Surface and shafts

6.5.2.1 Transport to CERN site

Transport of equipment to CERN site will be covered by the supply contracts of each item of equipment. This will include transport to assembly halls, storage areas or tunnel access points as appropriate.

6.5.2.2 Surface transport and handling at CERN

Surface transport operations will include transfers inside and between buildings on the main laboratory site as well as transfers between the main laboratory site and the tunnel access points. This will be carried out using a fleet of road transport vehicles. Any specific requirements for these vehicles will be determined during the component design and development phases.

Vehicle unloading and handling within buildings will be carried out as appropriate by mobile cranes, industrial lift trucks or overhead travelling cranes installed in surface buildings.

The capacities of overhead travelling cranes to be installed in the new CLIC surface buildings are listed in the table below.

Table 6.5.2.2-1: Overhead travelling cranes in CLIC machine surface buildings

Building Type	**Crane load capacity (tonnes)**	**comments**
Detector Assembly	80	Also permits lowering to underground area via shafts
Cooling Tower and Pump station	3.2	
Cooling and Ventilation	20	

Cryogenic Warm compressor	20	
Cryogenic Surface Cold Box	20	
Workshop	10	
Central Area Machine Cooling Towers	5	
Shaft Access	20	For lowering to underground area via shafts

In addition to handling means necessary for initial installation, it is foreseen that remote handling techniques will need to be incorporated into the positron target facility design to allow maintenance once the machine is operational.

6.5.2.3 Transfer between surface and underground

Access points for equipment to be lowered to the tunnel are 10 shafts and 2 inclined tunnels; inclined tunnels are used only when shafts are not feasible for geographical reasons.

The surface buildings above these access shafts are equipped with overhead travelling cranes with sufficient lift heights to lower equipment to the caverns at the base of the shafts via handling openings reserved in the shaft cross section. In addition 3 tonne capacity goods/personnel lifts allow personnel access and will also be used to lower equipment. Emergency access stairwells will be installed next to the lifts. The cross section of a machine access shaft with crane handling opening and lift shaft is shown below.

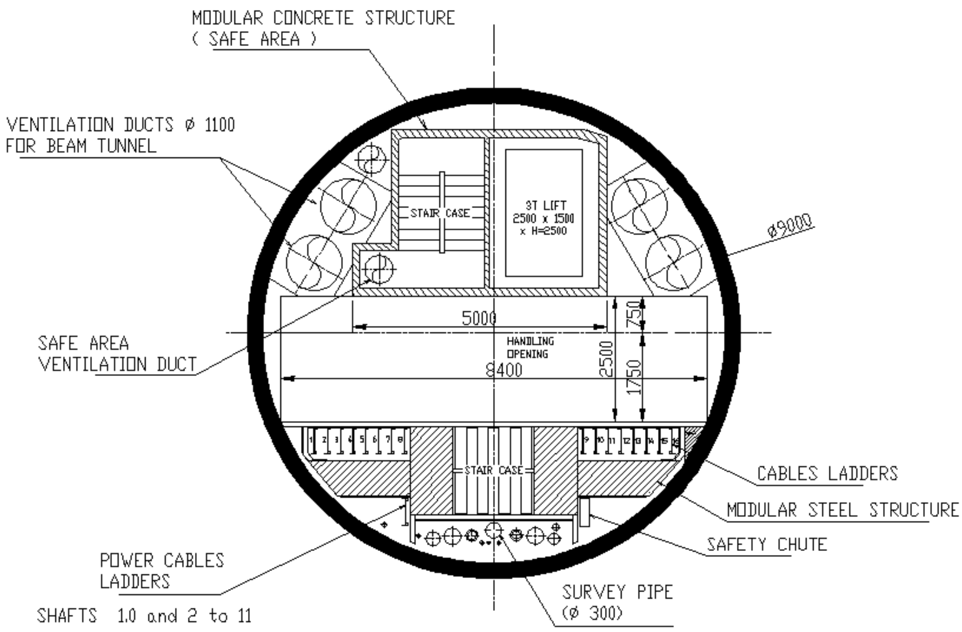

Fig. 6.5.2.3-1: Cross section of access shaft

For the access points where underground access for equipment and personnel is made via sloping access tunnels, a vehicle-based system will be developed for personnel and goods transit between the surface and underground areas. The system will be designed to ensure adequate throughput as required by the installation schedule and also to ensure safe exit for personnel working underground in the event of fire or accident.

6.5.3 Underground

Initially the full width of the tunnel will be available for installation of services, allowing the use of standard industrial tractors and trailers. The available space for transport will narrow once the modules and their supports start to be installed. For tunnel construction cost reasons the transport passage will be kept to a minimum, this means that module transport vehicles, for instance, will not be able to pass each other in the tunnel.

Special equipment will be developed for the transport and installation of modules and magnets in order to achieve the highest rates of installation compatible with the space, precision, interconnection and fragility constraints. The module transport and installation equipment is described in more detail in a separate section.

Personnel transport in the tunnel will be mainly by means small electrical tractors or bicycles.

6.5.3.1 Module transport and installation

The space required for module transport and installation in the tunnel has a major influence on the tunnel cross section. Studies were therefore carried out to identify how the modules could be transported and installed in the tunnel. These studies had a secondary goal of feeding some design requirements related to transport and installation into the module design.

The large number of modules and module supports to be transported and installed in the tunnel means that it is important to optimise the whole sequence of module transport to allow rapid transport and installation. The table below shows the number of modules.

Table 6.5.3.1-1: Module and supports – transport study input data

ITEM	**Quantity (3 TeV)**		**Quantity (500 GeV)**		**Dimensions(mm)**	**Mass**
	Per sector	total	Per sector	total		
Module	436	20924	436	4248	2010x1550x1200	~1500kg
Module support	436	20924	436	4248		

Before a module arrives at its installation point its supports will be installed and aligned; the geodesic survey equipment is installed before the module arrives at its point of installation. This order of installation means that the module has to be transferred laterally over the survey stretched wire equipment before being lowered into place on its supports. This results in a constraint that the module will have to be supported from above during the transfer from the tunnel transport vehicle onto its supports.

A conceptual design of vehicle with its own on-board lifting equipment was then produced in order to reserve the necessary space in the tunnel integration design work. By using lifting devices installed on the vehicles the unloading and installation operation time can be minimised. Figure 2 shows the conceptual design of the module transport vehicle; the module is shown as a rectangular block in transport and unloading positions.

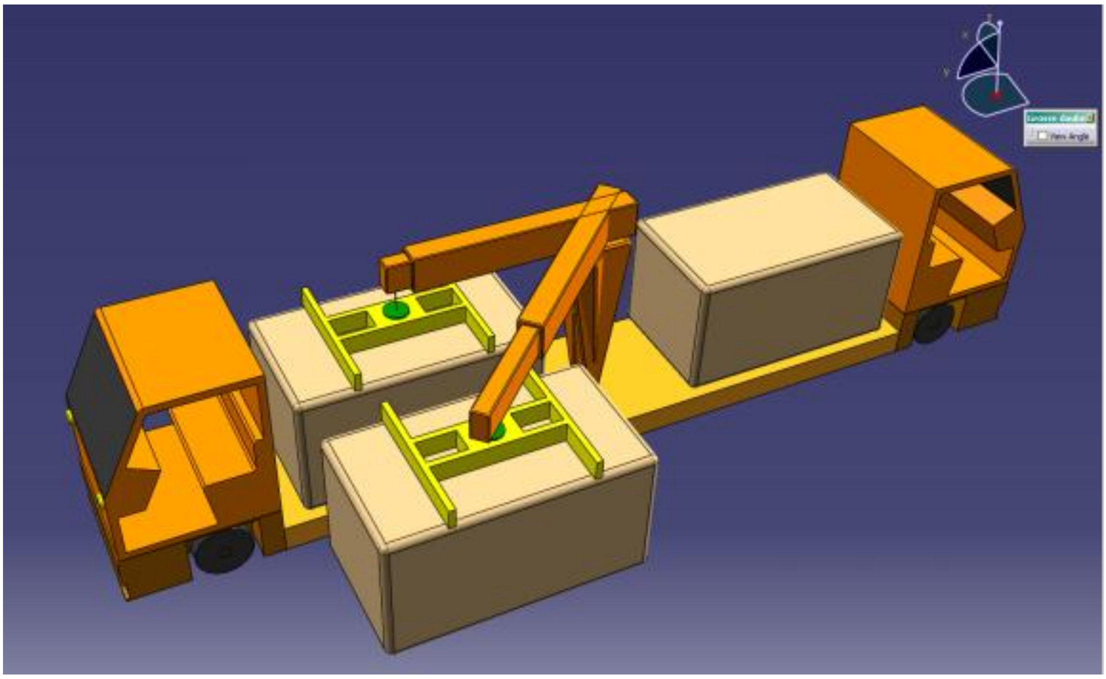

Fig. 6.5.3.1-1: Conceptual design of module transport vehicle

Figure 3 below shows the module transport vehicle unloading a module onto its supports in the tunnel cross section. Note the I section monorail above the vehicle to be used for electrical power supply to the vehicles and also the safety barriers at the module side of the transport passage.

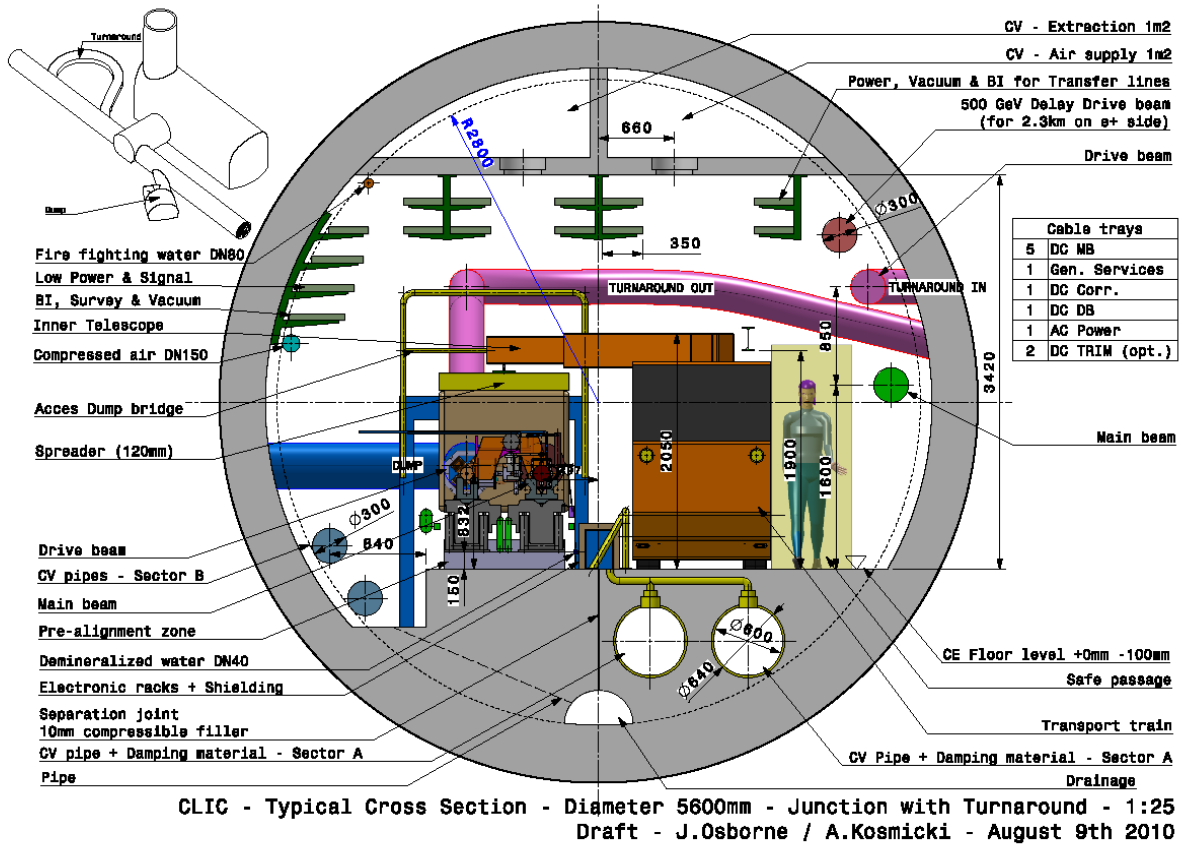

Fig. 6.5.3.1-2: Cross section of CLIC tunnel showing vehicle installing a module

In view of the narrow transport passage and the distances to be travelled, the module transport vehicles will be equipped with automatic guidance system. The operator on the vehicle will be required to ensure that the floor is clear of personnel and equipment.

Although module installation logistics should aim for sequential installation, the installation process must allow installation of modules between two previously installed modules in the event of supply delays. In addition the system must be able to remove a previously installed module if major repairs are needed.

A key requirement for module design identified during the study is the need for a clear interconnection plane between modules so that they can be lowered into their final position without interference with the adjacent modules(s). As the clearance between adjacent modules will be minimised (10 mm or less) modules will need to be carefully guided during the installation process.

In addition to the clear interconnection plane, adapting the module design for transport requires the inclusion of lifting points and support points to allow the whole sequence of transport and handling operations. These operations will be needed during the phases of module assembly, testing, storage, road transport to access points, lowering, tunnel transport and installation. The module design effort includes the design of any transport restraints and special lifting beams to be used when handling fully assembled modules during the installation process.

6.5.3.2 Underground infrastructure design for transport of modules etc

In addition to the transport along the tunnel it is also necessary to design the infrastructure for the transfer from the surface, taking into account the need to minimise time taken because of the large number of items to be installed. Lowering of modules from the surface to the underground will be carried out using the personnel/goods lifts as this is faster and requires less operator skill and vigilance than using overhead travelling cranes. The modules will be fitted to custom pallets in order to allow handling by powered pallet trucks.

At the tunnel level the UTRC caverns are designed so that the modules and other equipment to be installed can be taken from the lift and moved to a position close to the waiting module underground transport and installation vehicles. They are then loaded on to the vehicle. It is planned that each vehicle will be able to simultaneously transport two modules for logistics reasons. Loading of modules onto the vehicle can be carried out by the vehicle’s own lifting equipment or by the travelling crane installed in the UTRC service cavern.

Items outside the capacity of the lift will be lowered down the handling opening in the shaft and transferred to vehicles waiting in the UTRC cavern.

Once the vehicles are loaded they will be driven from the UTRC cavern into the tunnel. If necessary due to co-activity constraints (for example interconnection shifts alternating with transport shifts) several vehicles can be parked along the tunnel in the area between the two junction galleries where the liaison galleries from the service cavern join the main tunnel.

During the module installation phase it is planned to use the whole UTRC gallery surface for transport activities such as a buffer parking space for loaded vehicles and for vehicle maintenance – for example using the travelling cranes installed in the UTRC cavern to lift vehicles for maintenance access.

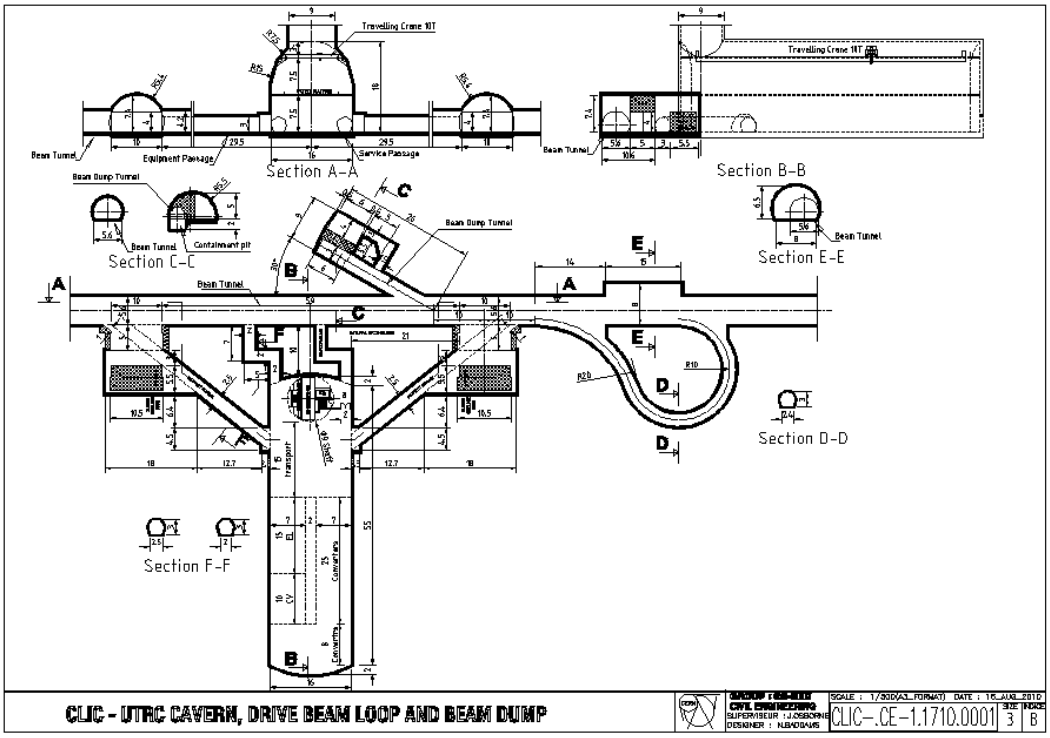

Fig. 6.5.3.2-1: UTRC cavern

Overhead travelling cranes to be installed underground are listed in table 2 below.

Table 6.5.3.2-1: Overhead travelling cranes in CLIC machine underground area

Cavern	**Crane load capacity (tonnes)**	**comments**
UTRC	10	Transfer of equipment onto vehicles after lowering from surface. Transport equipment maintenance.

Additional cranes may be installed, for example, for beam dump handling as the design process goes into more detail.

6.5.3.3 Magnet transport and installation

The tunnel integration design includes beam lines attached to the tunnel vault, including in positions above the modules. Specially designed vehicles with integrated lift and transfer devices will be developed to allow safe and rapid installation of the magnets for these beam lines. The magnets to be installed are listed in the table below.

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Table 6.5.3.3-1: Transport input data - magnets

ITEM	Quantity (3 TeV)		Quantity (500 GeV)		Mass Estimate (kg)	Notes
	Per sector	total	Per sector	total		
Main Beam Transfer line						
magnets	4	200	4	42		
Turn-around						
magnets		1640		1640		
Drive Beam Transfer line						
Transfer Line Quadrupole	16	768	16	160	320	Estimated length 1-2m, Outer diameter ~200mm
Beam pipe 10m long elements	88	4224	88	880		
Drive Beam Turn Around Loop						
quadrupole	39	1872	39	390	500	
dipole	24	1152	24	240	500	
dipole CO	39	1872	39	390	300	
Sextupole	24	1152	24	240	300	
Drive Beam Dump						
Quadrupoles, Dipoles	20	960	20	200	5000	Rough estimate only

The number of types of magnet transport vehicles for tunnel transport and installation will depend on the dimensional and weight details of the magnets as well as their final installation position in the tunnel.

6.5.3.4 Transport and installation of other accelerator equipment

Further studies covering the transport, handling and installation of other accelerator equipment will be carried out as more detailed information is generated by the machine design process.

6.5.4 Cost Considerations

To keep handling equipment procurement costs down, standard transport and handling equipment will be used where possible. For items where space constraints mean that specialised handling equipment is needed all requirements will be coordinated at an early stage so that the amount of equipment and procedures to be developed are minimised.

Experience from the LHC installation indicates that manpower costs will be of the same order as equipment costs; to reduce manpower costs during installation logistics will need to be considered early on during the design phase. Accelerator equipment and infrastructure integration will be optimised, where possible for handling and transport during the design phase in order to reduce transport and installation times and hence manpower costs.

Transport issues and requirements have been included in the inputs to the test module design process in order to allow installation issues to be considered and trials to be carried out when the test modules are installed on their supports in the test facility.

Use of a short section of full scale tunnel mock-up to test installation equipment and procedures before the start of installation operations will allow problems to be ironed out early and thus save time and money during tunnel installation.

6.6 Safety Systems (T.Otto, P.Ninin/M.Jonker, F.Corsanego, S. Mallows)

6.6.1 Access control systems

6.6.2 Radiation Safety and Radiation Protection

*6.6.2.1 Beam loss*The intensity of ionizing radiation in an accelerator and thus the magnitude of the observed effects are proportional to the rate of beam loss. Conservative estimates of beam loss in CLIC are derived from considerations of beam dynamics. In the drive beam decelerator (876 m length), a loss of more than a fraction of 10^{-3} of the injected beam current would modify the parameters of the beam in such a way that the drive beam energy can no longer be efficiently absorbed in the PET structures. In the main beam, a fractional beam intensity loss of 10^{-3} over the whole of one main beam (20 km length) would lead to significant changes in luminosity and would be unacceptable from the viewpoint of a physics detector. These two observations define a conservative upper limit of fractional beam loss. Table 1 shows the planned beam intensity in CLIC and the resulting rate of particle loss per metre in the drive beam and the main beam.

Table 1: CLIC beam parameters (columns 2 – 4) and estimated maximum beam loss rate (column 5), based on a fractional loss of 10^{-3} over the length of the beam (Main Beam) or one Drive beam station (Drive Beam). All estimations of radiation effects were performed at the maximal and minimal energies of the respective beam (columns 2 and 3) and with the fractional beam loss rate indicated in the last column.

	***Max Energy* (GeV)**	***Min Energy* (GeV)**	***Particles per Bunch Train***	***Repetition Rate* (Hz)**	**Beam Loss (m^{-1})**
MAIN BEAM	1500	9	$1.16\ 10^{12}$	50	$5\ 10^{-8}$
DRIVE BEAM	2.4	0.24	$1.5\ 10^{14}$	50	$1.15\ 10^{-6}$

6.6.2.2 Model of the Accelerator

Simulations of electron beam losses at 4 energies corresponding to the maximum and minimum energy of each beam line were made using version 2008.3.5 of the FLUKA code [reference FLUKA]. For each of the four loss energies, the build-up and decay of radiation over an 11½ year period, with cycles of 180 days continuous running followed by 185 days shutdown, was simulated. The residual ambient dose equivalent rates at various waiting times within the shutdown periods were calculated. In addition, quantities related to the potential damage to electronic devices: the prompt absorbed dose, the 1 MeV neutron equivalent fluence on silicon and the fluence of hadrons with energies higher than 20 MeV, were calculated.

The scope of the study has been limited to the lowest and highest energies, i.e. 2.4 GeV and 240 MeV for the drive beam and 9 GeV and 1500 GeV for the main beam.

The FLUKA geometry includes an air-filled concrete tunnel 5.7 m in diameter, tunnel floor, silicon carbide girders and beam line components. The FLUKA representation of the beam line components including quadrupole magnets, PETS, acceleration structures and beam position monitors (BPMs) is shown in figure 2. The quadrupoles consist of iron poles and yokes with copper blocks surrounding the poles. The type and sequence of the modules used in main beam simulations were consistent with design specifications [3]. In the model used for simulations at 1500 GeV, the main beam quadrupoles are 193.5 cm in length and in the model for simulations at 9 GeV, they are 42 cm in length. The drive beam quadrupoles are 27 cm in length. The span of the main beam quadrupole is 25 cm and the drive beam quadrupole, 31 cm. The PETs are modelled as solid copper cylinders, of outer radii 6.5 cm with a vacuum chamber of radius 1.15 cm running through the centre. The accelerating structures are modelled as copper cylinders with outer radii 4 cm with a vacuum chamber of radius 0.5 cm running through the centre. The accelerating structures are modelled with central “cross’ of reduced density (4.5 g cm-3) to represent void regions along the accelerating structure. The drive beam BPMs are modelled as cylinders 1.2 cm in diameter and 6.5 cm in length of a half iron and half copper mix with reduced density (4.0 g cm-3) to represent void regions. All concrete shielding components have a density of 2.3 g cm-3 with the following chemical composition: oxygen (52.9%), silicon (33.7%), calcium (4.4%), aluminium (3.4%), iron (1.4%), hydrogen (1.0%), carbon (0.1%), magnesium (0.2%), sodium (1.6%) and potassium (1.3%). Figure 1 and 2 show views of the simplified geometry of the accelerators implemented within FLUKA.

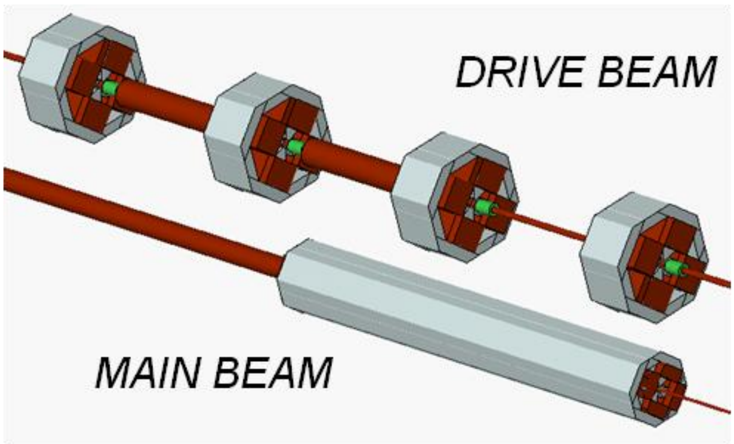

Figure 1: View of the simplified accelerator geometry implemented in FLUKA. The figure shows two CLIC modules. Each module has two drive beam quadrupoles, for the main beam one is equipped with 8 accelerating sections (left) and one with a four-unit long quadrupole. This configuration is found in the high-energy part (E >750 GeV) of CLIC.

Figure 2: Cuts in a plane orthogonal to the beam through the simulation models of the drive beam quadrupole (left) and the main beam quadrupole (right). Red: copper coils, grey: iron yokes, white: air or vacuum.

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*6.6.2.3 Radiation Damage*Under the generic term “radiation damage” one understands in more detail material damage, as well as total dose displacement damage in semiconductors, based on neutron fluence, and an unacceptably high rate of single event effects (SEE), based on the high-energy hadron fluence.

At very high neutron fluence (as in a nuclear reactor), displacement damage would also induce material damage (brittleness), but neutron fluences in CLIC are not high enough for this to occur. In an accelerator environment, one considers the following magnitudes of radiation damage effects as acceptable:

Table 3: Radiation damage mechanisms and tolerable levels leading to negligible damage of accelerator components or electronics

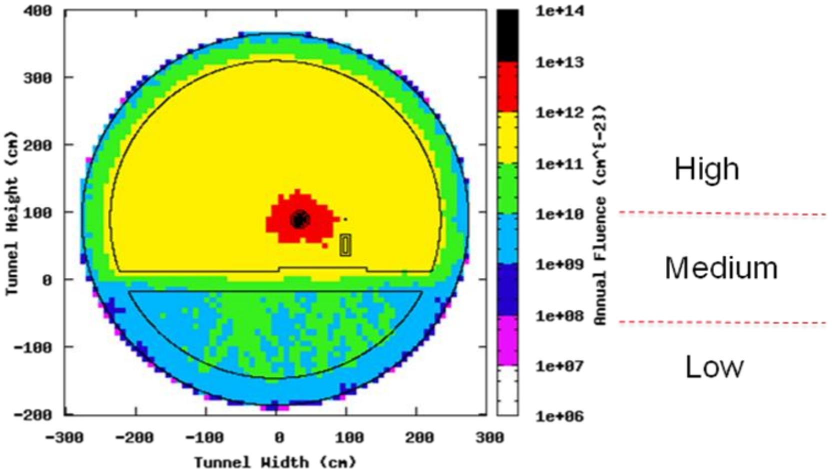
Based on the beam loss estimates given in the previous section, the Monte-Carlo Radiation transport code Fluka 2008.3.5 [reference FLUKA] has been used to model the development of the secondary radiation cascade. Estimators of absorbed dose and for the fluence of neutrons or energetic hadrons provided by the code permit to estimate the magnitude of the three effects of radiation damage.

Absorbed dose has been estimated in the coils of the quadrupole magnets of the Drive Beam and the Main Beam accelerators. Table 4 lists the maximum permissible fractional beam loss in the low- and high-energy ends of each accelerator. At this loss rate, an absorbed dose of 1 MGy would be accumulated in one year, possibly inducing magnet failure after 10 years of operation. In all estimated cases, the beam loss to reach 1 MGy y^{-1} is smaller than the assumed beam loss rate . However, in the low-energy part of the drive beam accelerator the safety margin is only a factor of 1.5.

Table 4: Fractional beam loss required to accumulate an absorbed dose of 1 MGy in quadrupole magnet coils. The first column indicates the accelerator (DB – Drive Beam, MB Main Beam) and the energy. Column 2 lists the assumed beam loss point. Columns 3 and 4 show the calculated fractional beam loss which will lead to 1 MGy in the following quadrupole. The normalisation is per quadrupole (col. 3) or per metre, assuming 2 DB-quadrupoles per CLIC module or 1 DB – Quadrupole.

	Loss point	Fractional Beam Loss per QP – for 1 MGy/yr in coils	Fractional Beam loss (m^{-1}) for 1 MGy/yr in coils
DB – 240 MeV	End of PET (before QP)	2.1 E-6	2.1 E-6
DB - 2.4 GeV	End of PET (before QP)	2.0 E-5	2.0 E-5
MB – 9 GeV	End of AS (before QP)	4.8 E-5	2.4 E-5
MB – 1500 GeV	Continuous in AS (1m)	4.3 E-7	4.3 E-7

Neutron fluence (more precisely, the 1 MeV neutron equivalent fluence, i.e. the neutron fluence of a hypothetical mono-energetic neutron flux at 1 MeV which infers the same damage to Silicon as an arbitrary particle fluence with a specific energy spectrum) and the fluence of hadrons with an energy above 20 MeV were scored in the whole tunnel volume for the four beam loss conditions from table 1. As an example, Figure 3 shows the distribution of the 1MeV neutron equivalent fluence and Figure 4 the energetic hadron fluence in the tunnel cross section for beam loss in the main beam at the maximal energy.



	1-MeV neutron eq. fluence Close to accelerator (cm^{-2} $year^{-1}$)	1-MeV neutron eq. fluence Close to tunnel wall (cm^{-2} $year^{-1}$)
DB – 240 MeV		
DB - 2.4 GeV		
MB – 9 GeV		
MB – 1500 GeV		

	20-MeV hadron fluence Close to accelerator (cm^{-2} $year^{-1}$)	20-MeV hadron fluence Close to tunnel wall (cm^{-2} $year^{-1}$)
DB – 240 MeV		
DB - 2.4 GeV		
MB – 9 GeV		
MB – 1500 GeV		

6.6.2.4 Radiation Protection

Radiation protection is concerned with the protection of workers and the public against the detrimental effects of ionizing radiation. For the conceptual study, the activation of accelerator materials and the subsequent irradiation of workers have been studied with help of radiation transport and activation simulations. The Code FLUKA 2008.3.5 has been used in these studies. It combines radiation transport algorithms with a nuclear interaction model. It is in principle able to predict the distribution of activation products in material irradiated with energetic particles. The follow-up of radioactive decay of the activation products then permits estimation of dose and dose equivalent after an arbitrary decay time. These algorithms have been validated for short lived products (up to t ½ = xx years) after proton irradiation (REF. Markus Bruggers thesis and papers). A similar validation for primary

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electron beams is currently in process , (REF Aria).In this study, the focus is on a scenario where all short-lived (t1/2 < 1 year) and some important other radionuclides (60-Co) are near their equilibrium concentration. Dose equivalent rates are given for different waiting times in a shutdown after 1 year of CLIC operation with beam loss assumed equally to the previous section.

Figure 5 shows the two-dimensional distribution of ambient dose equivalent rate $\dot{H}^*(10)$ in the high-energy part of the CLIC tunnel after different delays ("waiting time") after turning off the accelerator running at nominal intensity and the associated rate of beam loss. Tables 7 and 8 give the evaluated ambient dose equivalent rates for a location close to the accelerator and in the passageway for the same delay times as in the Figure 5.

Figure 5:: Ambient dose rate map in a plane orthogonal to the beam at the high-energy end of CLIC (E=1.5 TeV) after 1 year of exploitation at nominal beam intensity and an average beam loss of 5 10^{-8} m^{-1}.Ambient dose rate is evaluated for different delay times after turning off the accelerator. The scale is in μSv h^{-1}.

	Ambient dose equivalent After 4 hours	Ambient dose equivalent After 1 week	Ambient dose equivalent After 4 months
DB – 240 MeV			
DB - 2.4 GeV			
MB – 9 GeV			
MB – 1500 GeV			

	Ambient dose equivalent After 4 hours	Ambient dose equivalent After 1 week	Ambient dose equivalent After 4 months
DB – 240 MeV			
DB - 2.4 GeV			
MB – 9 GeV			
MB – 1500 GeV			

In the optimization process required for interventions in radiation areas, one would have to combine the dose rates with time estimates for interventions. Without a more precise knowledge of these, only general statements can be made. According to the presented estimations, justified urgent and non-recurrent interventions not taking longer than 1 hour would be possible after 4 hours of waiting time after turning off the accelerator. The personnel would receive a personal dose of up to 1 mSv during such an intervention. Work requiring longer access times can be undertaken after about one week delay time. At this moment, the ambient dose equivalent rate in the passageway is between 10 and 100 μSv h^{-1}. Dose rates close to the accelerators will be higher, but a discussion of the local distribution of activation and dose rate is beyond the scope of this study, which is based on a coarse approximation of beam loss.

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6.6.3 Fire safety chapter for CLIC conceptual design report:

Fire safety goal of is that of protecting occupants, rescuers, external population/environment, facility and continuity of mission.
The problem is extended to the whole facility, including the underground premises and the surface buildings.
Detailed Fire Risk Assessment and scenarios will have to be made of every specific different area i.e. tunnels, experiment caverns, alcoves for equipment, linking galleries, once more information will be made available in the layout and in the way they are interconnected by means of the ventilation systems.
The more efficient protection strategy is that of enforcing a set of multi level "safety barriers", with a bottom up structure, allowing trapping most of the fire events at stages with no or little consequences, and limiting considerably probability and impact of the largest ones.
Large adverse events have to become possible only in very unlikely cases of failure of many barriers.
This can be done by implementing measures at every possible level of functional design:

- In the conception of every single piece of equipment (i.e. materials used in the electric components, circuit breakers, etc.),
- in the grouping of equipment as in racks or boxes (i.e. generous cooling of racks, use of fire retardant cables and fire detection with power cut within each single rack, etc.),
- in the creation and organization of internal rooms, (i.e. fire detection, power cut and fire suppression inside a room with equipment),
- in the definition of fire compartments
- in the definition of firefighting measures

It is impossible to describe in details all these of measures, but the basic concepts, including most of the more severe constraints for the conceptual design are reported in the next chapters.
The measures proposed here may require deep revisions in function of the evolution of the design.

6.6.3.1 Legal Constraints

Given the legitimate right to know which level of risk a National State is assuming by allowing CLIC into its territory, the project will most probably require approvals by the territorial Authorities Having Jurisdiction (AHJ) before construction.
The AHJ will typically apply the existing legislation for well identified cases (as, for instance, surface buildings), and typically will ask to the CLIC design group to elaborate fire risk analyses to be evaluated by their fire safety experts for the more complex premises, like the underground accelerator complex.
This process has become, in the last decade, more and more based on fire scenario predictive calculation methods, and it is to be expected that this trend will continue in the future.
Further constraints or modifications, can therefore be legitimately asked by the AHJ.

6.6.3.2 Measures limiting probability of onset of fire:

The following measures are basic samples of the principles to be followed in the design of the equipment of the facilities. Several different disciplines are involved in these aspects, indicated as follows:

- Electric design (EL)
- Civil engineering design (CE),
- Ventilation design (VE),

- Physics design (PH),
- Fire safety design (FS)
- Radiation Protection (RP)

Measure	Discipline
Put to the maximum extent possible, combustibles equipment and materials on surface, in a balanced approach (i.e. considering that also cables linking equipment to devices inside the tunnel are one of the variables),	EL
Avoid, in underground spaces, equipment with liquid combustible fluids (oil condensers, oil transformers, oil pumps, oil based hydraulic actuators, etc.)	EL
Segregate, in compartmentalized spaces (racks, huts, rooms), combustible equipment, and protect them by means of fire detection, automatic shut off and fire suppression	EL,CE, FS
Seal in metallic or other non combustibles boxes and containers, combustible part of equipment or cables trays,	EL
Study carefully all possible cooling aspects of dissipated power, including those connected with cable laying and “ampacity” limits	EL
Avoid flammable gases as much as possible.	PH
For gas mixtures, mix in surface to concentration below flash point	PH
Give preference to less dangerous materials in place of dangerous (as cables fire retardant zero halogen and fire retarding non halogenated printed circuit board cards, borated polyethylene in place of normal ones, etc)	EL, PH
Implement onboard local fire detection on combustible equipments, linked to automatic shutoff devices and/or fire Suppression devices.	EL,PH, FS
Use, to the maximum extent technically possible, equipment devices and item warranted under the label of quality certification authorities (like CE labeled equipment, or equivalent international)	EL,PH

6.6.3.3 Measures aimed to allow early detection and intervention:

A factor that is of help in allowing people to escape from fire and limit damage is the readiness of reaction to the initial onset of fire.

The main role of a fire detection and alarm system is precisely that of giving an early warning (normally located on the ceiling or at the ventilation outlets and surveying the whole room where equipments are installed).

Measure	Discipline
Fire detection shall be located in all the areas with concentration of Equipment and all areas critical for evacuation	EL, ,PH FS
Fire detection units shall be shielded by radiations, and protected areas shall be considered in the early design	CE, FS
Fire detection shall be properly echeloned in order to protect specific critical equipment and offer a general protection of the whole hall.	EL, FS

Selective power cuts triggered by automatic fire detection shall be considered.	EL,FS
Fire detection shall trigger general warning system (evacuation alarm) and trigger immediate intervention of fire safety teams.	FS
Public address systems shall be considered to diffuse specific voice emergency messages to workers underground	FS
Fire detection and evacuation system shall preserve their function in case of fire for at least 2hrs.	CE, FS

6.6.3.4 Measures aimed to protect the evacuation of the people eventually present in the underground structures:

6.6.3.4.1 Evacuation pathways in areas exposed to smoke:

For caverns, this distance from any point to the nearest protected egress path should be limited in some 10m to 30m in function of the availability or not of a secondary egress path.
This requirement is still reasonably applicable in underground halls, where smoke protected stairwells with access at every floor of the gangways system can be implemented in the design.
Accelerator tunnels, for certain aspects similar to road and railroad tunnels, require more detailed analysis and a solid concept is order to make the evacuation of the structure still feasible.
Even with all the possible mitigating factors, distance should not go beyond limits that have been defined for road and railroad tunnels. This limit is fixed in a value between 200m and 600m, with a reported value of 500 meters in the EU directive 2004/54.
Several options are possible for this goal; splitting the long tunnel in compartments with solid doors and fire walls, parallel the gallery with internal longitudinal passages (conceptually similar to side galleries), look as the simplest and most reliable.
The ventilation system should be capable of creating a lower pressure in the compartment affected by the fire, and an over pressure in the areas at the sides, therefore a capacity to configure in function of which sector is affected is necessary.

Measure	Discipline
Travel distance in tunnels should allow reaching a safe zone in a reasonable distance and time (600m between safe heavens?) Several options are possible (a decision so far seems not to have been fully outlined): - Direct exits shafts to surface - Cross links with into another area non affected by the smoke, like a parallel tunnel - Splitting each tunnel into transversal compartments with fire doors system and proper ventilation system (Figure 1 and Figure 2)	CE,CV,EL,PH
Travel distances in halls and other areas having relatively high probability of being occupied by large number of people shall be limited to a distance ranging from 10m (blind corridors) to 30m (2 exits). This can be done by providing access to pressurized areas at each level of the gangways.	CE,CV
Evacuation flow should proceed from higher to lower areas of radiation hazards both for the main and the secondary exit	CE, RP
Design should avoid to force people to have to pass near to high radiation areas to evacuate (as targets , collimators, or similar)	CE,RP
In tunnels ensure adequate clearance for emergency vehicles allowing to	CE

overtake slow bulk transportations and obstacles	
Compartment shall be fire resistant for a reasonable time (2hrs of more in function of the fire load)	CE, CV

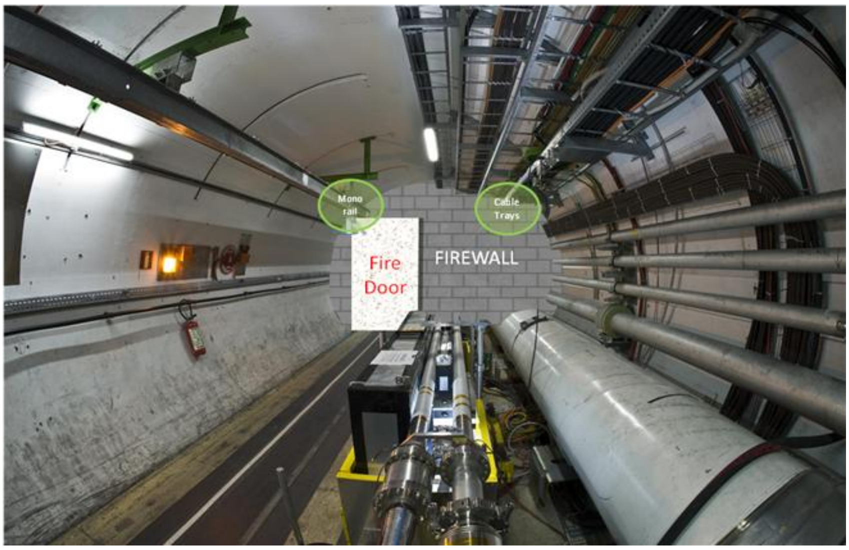

Figure 1- Conceptual representation of a firewall transversal to the tunnel orientation

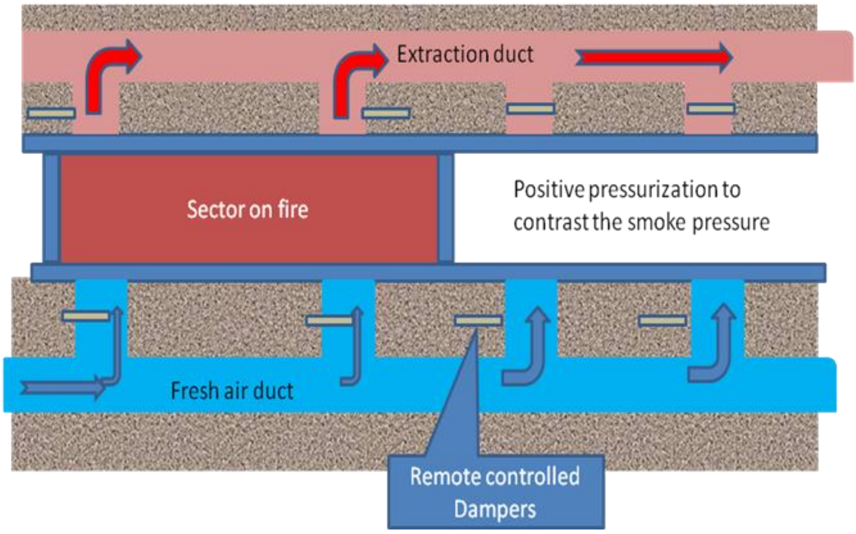

Figure 2 Schematic representation of the pressurization of a sector adjacent to the sector on fire

6.6.3.4.2 Evacuation pathways in areas protected from smoke:

Due to the deep underground location of the accelerators, the only possible way to separate occupants from the source of fire is that of providing them a safe escape path.
The governing idea is that these protected refuges shall be close enough, be reached quickly, and once in, they shall give all the time needed to proceed calmly and safety to the outside.

"Protected" in this case means protection from smoke, gases, heat, and all other possible effect of a fire (as structural collapse)

Measure	Discipline
Refuge areas shall have an area large enough for the temporary accumulation of workers (the reference density is of 3pp/m2)	CE
Refuge areas shall be connected to the outside via a protected walking passage, (people shall have possibility to leave the underground during a fire)	CE
Refugees (and their lifts) shall ensure evacuation capability in case of fire events and power cut	CE, EL
Pressurization shall allow to prevent smoke and gases from entering	CE, CV
No electric, gas, or any technical installation is allowed inside and equipment except those strictly functional to the protected refuge itself.	CE, EL
No combustible materials are allowed inside	PH,EL
Refugees and their structures shall be fire resistant for at least 2hrs	CE, EL

6.6.3.5 Measures aimed to limit the propagation of fire along the facility

Fire propagation is to be limited by creating fire compartments.
Typically the value of fire resistance will be of at least 2h, or more, in function of the fire load.
The areas to be protected will be as follows:

Measure	Discipline
Each large hall shall be a fire compartment	PH, CE, CV, EL
Rooms with considerable amounts of electric equipment or gas handling equipment shall be fire compartment	PH,CE, CV, EL
Safe Protected egress paths shall be fire compartment	CE, CV
Sectors of tunnels, still to be identified, shall be fire compartment	PH, CE, EL, CV, transports
All crossing for services shall be sealed with the same level of fire resistance as for the compartments.	EL, CV
All ventilation ducts shall be properly sealed by dampers located at the walls.	CV
For surface buildings, technical galleries shall be isolated by the rest of the buildings and be separated fire compartments	CE

6.6.3.6 Measures aimed to limit the propagation of smoke:

The action of splitting the facility into compartment needs to be accompanied by a coherent design of the ventilation and smoke handling systems.
Smoke coming from a fire has to be controlled for a number of reasons:
It is toxic for bystanders
It creates damage with the compartments in function of its composition and concentration
It is essentially made by hot partially combusted flammable species, that can reignite in any point of the facility and propagate the fire far from the origin
Smoke control shall be aimed to perform the following goals:

Measure	Discipline
Prevent propagation of the smoke from one compartment to another, by	CV

defining sectors of ventilation and smoke extraction, and by dynamic configuration capability, associated to smoke detection.	
In high ceiling multi-floors caverns smoke control shall ensure a slow descent of the smoke layer to allow evacuation – specific fire scenario can be evaluated to calculate the needed flow rates.	CV
Put in overpressure the areas on fire and reduce the pressure in the areas affected by fire, by means of dynamic controls of motorized fire dampers and regulation of the flow rates. This shall keep into account also the volume of hot gases and the pressure field typical of fire.	CV,RP
Be built under specification ensuring to withstand the thermal impact of fire and continuity of function	CV
Normal ventilation system must be capable to shut off or be reconfigured in order to avoid spreading of fire.	CV
In case of activated fire hazard, specific filters shall be developed to prevent activated smoke to be rejected outside	CV

6.6.3.7 Firefight Measures:

A set of measures have to be present in order to allow fire fighting and rescue in the premises:

Measure	Discipline
Allow rapid circulation for the rescuers in long tunnels by means of electric vehicles	CE, FS
Allow local control and override of smoke extraction and ventilation system	CV
Allow communication underground via radio systems, mobile phones, fixed phones	EL
All systems must remain efficient for the time required for firefight operations and for not less than 4 hours	EL
A fire fight water network shall be installed in all the tunnels and underground facilities	CE, CV
Fire fight hoses shall be installed in the main caverns and all areas with important fire load	CV
Additional firefight means as fixed fire fight systems shall be installed in all areas with a relevant fire load and difficulty of access during a fire	CE, EL, FS, CV
All areas where workers can be shall have passages large enough to pass by with a stretcher in horizontal position	CE,
Lifts shall be large enough to allow a stretcher to be laid down horizontally	CE

6.7 Survey and alignment (H.Mainaud Durand)

6.7.1 Geodesy and networks

A coordinate system, CERN Coordinate System (CCS) and a reference system, CERN Geodetic Reference Frame (CGRF) must be associated to the project as soon as possible as they provide a 3D framework. CCS is a right handed 3D Cartesian coordinate system used to define the relative position of all the detectors and accelerators at CERN. CGFR defines the coordinates in latitude, longitude as well as height coordinate measured along a normal of the surface. This ellipsoidal surface is not accurate enough concerning the measurements of heights: it does not take into account the direction of the gravity field. A model of geoïd, describing the equipotential surface of the gravity field, must be determined locally, taking into account the deflection of vertical. This geoïd model is modellized thanks to a combination of astro-zenithal, Global Positioning System (GPS) and gravimetric measurements.

For an optimal stability of the machine, the linacs will be set up in a tunnel located in the most appropriate underground structure. The tunnel will be linked to the surface by shafts. Survey boreholes, with a diameter of 1.5 m, will be added between two machine shafts, in order to have a distance between shafts below 2.5 km. Through these shafts is transferred reference into the tunnel, from the surface geodetic network to the tunnel geodetic network, within ± 1 mm rms.

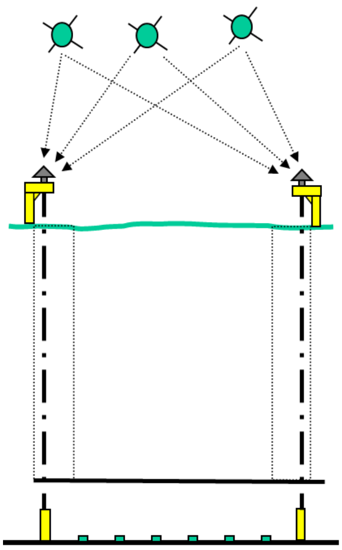

Fig. 6.7.1-1 Transfer of reference into the tunnel

The geodetic surface network will consist of pillars located close to the shafts determined in position by means of GPS. In parallel, measurements of vertical deflection will be performed on these same points. The transfer of reference into the tunnel through the shafts will be carried out using the methods developed for the previous CERN accelerators: a combination of optical and mechanical measurements (3D triangulation and trilateration coupled with vertical wires acting as plumb lines between surface and tunnel). When possible (diameter of shaft large enough), astro zenithal measurements from the bottom shaft will be added. The points located at the bottom of the shafts will be the backbone of the underground geodetic network. This underground network consists of reference points sealed in the ground, in the transport area, every 50 m, defined in CCS and CGRF. These points will be determined by angle, distance, wire-offset, direct optical leveling and gyroscopic measurements with respect to the pillars located at the bottom of the shafts, considered as fixed for the computation of data. This geodetic network is necessary for the implantation of all the general services (cables trays, cabling, piping, lightening) and the marking of all the components (beam, jacks) in the tunnels. It must be determined before any installation of general services.

In the case of the main linac and BDS, additional steps are needed: gravimetric measurements will be performed all along the tunnel, and an additional network will be installed from the underground geodetic network the Metrological Reference Network (MRN). MRN consists of parallel stretched wires, metrological plates equipped with Wire Positioning Systems (WPS) sensors and Hydrostatic Leveling Systems (HLS) sensors, defined in CCS and CGRF. This metrological network will be implemented and computed as soon as possible, in order to allow an "absolute" positioning of all the modules within ± 2 mm maximum pit to pit.

6.7.2 Machine installation and alignment

6.7.2.1 Measurements for installation

Special long rods will be sealed deep under floor, in contact with solid stable rocks, in order to provide a stable reference, considered as fixed for all levelings. These special deep levelling references will be located around each shaft or specific area (for example damping ring).

As-built measurements will be performed at different stages of installation, in specific "crowded" area, in order to prevent interferences between services and components. These measurements are carried out with Laser Scanner; 3D models are then re-constructed and can be integrated in the theoretical CAD models.

6.7.2.2 Fiducialisation

Before the installation in the tunnel, all the components to be aligned in the tunnel (or the supports on which they have been pre-aligned) must be fiducialised. This fiducialisation step is the determination of the external alignment references (fiducials) of the components (or their supports), with respect to the beam axis. The uncertainty of measurement concerning fiducialisation ranges from a few microns (main linac and BDS supports) to a few tenths of millimetre. Several methods will be used according to the accuracy needed (precision and accuracy of the machining, assembly jigs, laser tracker measurements, Coordinate Measuring Machine). Some additional measurements can take place at that stage: shape of vacuum pipe inside a magnet, mechanical position of the BPM with respect to the magnet. Then, a referential will be associated to each component (or support) fiducialised.

6.7.2.3 Preparatory works

The preparatory works are composed of the following steps in all tunnels (except main linac and BDS):

- Marking on the floor:

  The vertical projection of the beam line, and of the components (or their supports) will be marked on the floor. This work must be performed before the installation of services as it provides clear positioning for anybody working in the tunnels. The accuracy of the marks is ± 2 mm rms.

- Positioning of the jacks:

  Jacks need to have an adjustment range of ± 10 mm in radial and ±20 mm in vertical: the errors of the floor, the errors in their own positioning, the mechanical interface error and ground motion during the life of tunnel must be taken into account. The heads of jacks are positioned within ± 2 mm with respect to the underground geodetic network before the installation of the components (or their supports), using displacement screws of the mechanical plate on which jacks are pre-positioned, or by shimming or grinding if no interface with ground settlement is foreseen. During that operation, adjustment screws of the jacks remain in their middle position. Once in position, jacks are sealed on the floor.

Concerning the main linac and BDS, marking phase will take place with the implantation of each module. Then, plates meant for mechanical initial alignment equipped with actuators of DB and MB at mid range will be positioned with respect to the MRN network.

6.7.2.4 Alignment of the components (or supports of components)

The alignment of the standard components (or their supports) consists of two steps:

- First positioning:

  Each component (or its support) is aligned independently with respect to the underground geodetic network, within ± 0.3 mm rms. At the same time, small local smoothing will take place between adjacent components (or supports) in order to validate the initial alignment (within ± 0.2 mm). This first positioning will be performed by direct optical levelling in vertical, and tacheometer/laser tracker measurements in radial (coupled with wire offsets concerning radial smoothing). Adjustment is performed by acting on the jacks screws.

- Smoothing:

  This step takes place once components (or their supports) are inter-connected, under vacuum, so that all mechanical forces are taken into account. This final positioning step does not refer any more to the geodetic network and concerns all components (or their supports) between two shafts. The relative position between components (or their supports) is measured thanks to direct optical levelling in vertical, and wire offsets in radial over a distance of 150 m, with a radial and vertical accuracy of ± 0.15 mm rms. Then components (or their supports) are adjusted on the best fit curve line calculated after a global least mean square adjustment of the measurements. Adjustment (if needed) is performed by acting on the jacks screws.

Concerning the main linac and BDS, the first positioning of the modules will take place with respect to the MRN. Once all the modules (shaft to shaft) are equipped with sensors and there is no more co-activity in the area, the active pre-alignment can take place, using the readings of sensors, and re-adjusting thanks to actuators. For further details, see §5.15.

CES DRAFT

6.7.3 Cost considerations

The cost estimate will cover the works necessary from the technical design of the project until successful completion of the machine installation. Same hypotheses than ILC will be considered: cost includes the equipment needed for the various works in the tunnels, workshops and calibration base, as well as resources (staff + temporary manpower) who will perform the tasks.

Work cadences are based on the achieved LHC survey and alignment cadences: they are based on real experience.