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CNGS layout and systems: a progress report

The CNGS project team

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Abstract

The CNGS (CERN Neutrino beam to Gran Sasso) project was described in a conceptual technical design report in 1998 (the project was then called NGS, cf. report CERN 98-02 / INFN-AE/98-05). An addendum to that report was published in 1999, describing the improvements on the design and performance, in particular in view of the ν_τ appearance experiments to be performed with the CNGS beam (cf. report CERN-SL/99-034(DI) / INFN/AE-99-05). In the time since the publishing of these two reports, the CNGS project was approved by CERN Council and construction work started in September 2000. A further note (SL-Note-2002-012) - written on the occasion of the first CNGS External Review in February 2002 - provided an update concerning changes to the overall layout of the CNGS facility. The present paper describes further layout changes and the modifications to the design of various systems and equipment. This work has been done in preparation of the second CNGS Review, held in April 2003.

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1. Introduction

The approval of the CNGS project by the CERN council in December 1999 was based on the technical description given in [1, 2]. Further changes to the CNGS secondary beam layout (target – horn – reflector) during the year 2000 are described in [3]. Since that time the layout, parameter list and expected performance of CNGS have been evolving, driven by discussions on future higher proton beam intensities and by detailed studies of the various components of the project. Documentation on these discussions can be found in the minutes of the different CNGS working groups. Approval for major changes is given by the CNGS Technical Working Group.

The CNGS web-site [4] is regularly updated to document these changes and to allow an updated overview of the CNGS project. In addition, the web-site provides links to the documents – mostly stored in EDMS [5] - describing the evolution of the CNGS project. Changes to the layout and design aspects of the CNGS project until February 2002, i.e. the time of the 1st CNGS Review, are summarized in [6].

The aim of the present note is to summarise further changes to the project from March 2002 until March 2003, and to give an overview of the evolution in the design of the various systems. While this note is prepared in view of the 2nd CNGS Review, it provides the project team with a concise summary of the recent evolution of the project and the decisions taken. All of the items summarized here are described in more detail in technical reports and minutes of meetings - a reference including a link to the electronic version of the documents is given wherever possible.

In order to facilitate the reading of this note, an overview of the underground structures and two graphs showing the names of galleries and caverns in the CNGS facility are shown in Appendix I.

2. New schedule - start of CNGS beam in 2006

The original schedule of the CNGS facility planned for a start-up with beam in May 2005. During the discussions on cost-saving measures at CERN, a complete stop of the PS-SPS complex in 2005 has emerged as one of the promising ways to save operating costs. (At the same time, it is hoped that personnel for the installation of LHC will become available during such a long shutdown).

The implication for the CNGS schedule is straightforward: the commissioning of the facility is now planned for spring 2006. An additional directive from the management provided further guidance for the scheduling of the works: the project team has been instructed to attempt to delay all spending as far as possible, in order to keep bank loans by CERN as low as possible.

The present schedule for CNGS construction and installation, leading to the commissioning of the beam in spring 2006, is shown in Appendix II. Note that the civil engineering schedule has remained unchanged with respect to the planning of 2000 - work is progressing well and is expected to be completed in May/June 2003, within a few weeks of the originally scheduled date.

Draft versions of detailed installation schedules for the general services and equipment in the proton beam/target area as well as for the hadron stop/muon detector area are also shown in Appendix II.

3. Changes related to civil engineering

3.1. Final sizes and shapes of galleries and caverns

The civil engineering excavations were completed in January 2003, and concreting works are well under way. For the first time at CERN, with the aim of saving construction time and cost, some of the underground structures are being finished with shot-crete. This concerns the CNGS access galleries as well as the service gallery and the muon detector chambers (i.e. all the structures where little or no induced radioactivity is expected). Shot-creting implies, intrinsically, that the finishing of the galleries is less smooth, but also less straight. This has some implications on the installation of pipes, ducts and cable trays along these walls. Studies on the most appropriate fixing system for equipment in such shot-creted galleries are currently under way.

The connection from the TZ82 access gallery to the TNM42 muon detector chamber (see Appendix I for the names of CNGS underground structures) deviates in the most significant manner from the specified dimensions. The construction method (excavation with roadheader) imposes an enlargement of TZ82 near TNM42: a transition from the 3.10 metre diameter access gallery to the 6.50 metre diameter muon detector chamber had to be excavated in a gradual way. Finishing these areas with shot-crete implies that the "extra spaces" cannot be filled with concrete (contrary to cast concrete, shot-crete in the vault can only be applied with a maximum thickness of 25 centimetres).

The TAG41 access gallery has the required cross section of 3.10 metres or is larger, but it is very irregular along its full length. The first section, from ECA4 to the PGCN pit, has been excavated with a roadheader, which leads to a non-circular section. Some 70 metres from the PGCN in the direction of TCV4 were excavated with a larger diameter for the installation of the tunnel boring machine. Finally, the TAG41 is not quite straight (changes of slopes, changes of directions) due to small errors of the tunnel boring machine. The contractor has agreed that he will demonstrate, at the end of the concreting works, that a mock-up model simulating the transport of a CNGS reflector (11 metres long device with a diameter corresponding to the reflector size plus ventilation ducts and cable trays) can pass along the finished TAG41 access gallery. This is a pre-condition for accepting the civil engineering works.

Among the structures finished with cast concrete, the TT41 proton beam tunnel and the TSG40 radioactive storage gallery have a diameter somewhat larger than specified in the CNGS project description, which to date has not been found to be a major drawback.

3.2. Hydrocarbons in the access gallery TAG41

A small amount of hydrocarbons is leaking from the rock through the primary shot-crete lining in the TAG41 access gallery. Over a length of 370 metres, a membrane has therefore to be placed before applying the secondary shot-crete lining. This has the following implications, all presently recognised and – where necessary – under study:

(a) The membrane guides the hydrocarbons into the TAG41 drainage system and thus – together with the small amounts of non-radioactive drainage water - into the sump in the ventilation chamber TCV4. This implies that the treatment of this mixture has to be studied. It is suggested to first measure the quantities of water and hydrocarbons that accumulate in this sump before drawing any conclusions.

(b) The system for fixing cable trays and pipework to the shotcrete, presently in the design phase, must not use bolts longer than 10 centimetres – otherwise the membrane would be punctured and the hydrocarbons would flow along the bolts into the access gallery.

4. Safety systems

4.1. Doors

Much progress has been made in the definition of safety systems and the related doors required. All the doors are now represented in the layout drawings, see [7,8,9], and the function of each door has been specified in the summary notes of recent meetings [10]. In many cases, a single door will obviously have multiple function (e.g. ventilation door + fire protection door + access search gate).

4.1.1. Access doors and search gates

The overall layout of the access system for CNGS has remained unchanged since the 1st CNGS review. One main access point to the CNGS zones is foreseen. This is a standard SPS access point, located in the cavern ECA4. The access point consists of a personnel turnstile and a material door that should be wide enough to allow the passage of large equipment. Details of the layout for this access point still need to be finalized.

The personnel protection system distinguishes two regions of the TT41 proton beam tunnel, separated by an open grill type interlocked door roughly half way down TT41. The upstream part of TT41 will be part of the SPS-TT40 access chain, while the downstream part (which can be accessed during SPS-TI 8 operation) will be part of the CNGS access chain. Another separation of these two zones is at the junction of TAG42 with TAG41.

A number of doors have to be installed for reasons related to ventilation, fire protection or against smoke propagation. In general, it is proposed to equip these doors with "search contacts", allowing limiting the search of the CNGS areas after an access to those zones where a door has actually been opened.

Concerning access to the muon detector chambers, an important decision has been taken in December 2002: there will only be one interlocked door, at the upstream end of TZ80, for the entire area. This door can only be opened with a special key, which must be taken from an interlocked system in the accelerator main control room. This implies, in turn, that access to this area will be very restricted and can only be granted applying a special procedure. The details still need to be defined – the procedures will be documented and must be signed by those wanting to access the muon detector areas.

4.1.2. Ventilation doors

Doors separating air volumes for ventilation purposes are requested at the following locations (see layout drawings [7,8,9]):

- the separation of the ventilation chamber from TSG4, TSG41 (two doors, at ground floor and first floor) and TAG41
- the separation of TAG41 from ECA4
- the junction of TT41 to TJ8
- the junction of TT41 to TAG42

Several of these doors will be built, at the same time, as fire protection doors and will be equipped with a "search" contact (see 4.1.1.).

4.1.3. Fire protection doors

A certain number of doors are specially designed to prevent propagation of fire (for a duration of two hours). Such doors are located at (see the layout drawings [7,8,9]):

- the separation between ventilation chamber TCV4 and the service gallery TSG4
- the separation between ventilation chamber TCV4 and access gallery TAG41
- the separation between ventilation chamber TCV4 and target chamber TCC4
- the separation between proton beam TT41 and target chamber TCC4.

4.1.4. Smoke separation doors in TCC4/TSG4

All the powered equipment in the target chamber region is located in the service gallery TSG4. While there is very little flammable material installed, a small fire cannot be completely excluded, in particular during shutdown maintenance work. In order to prevent propagation of smoke from the service gallery into the target chamber, it has been recommended that all the side galleries (TSG42 to TSG47) are equipped with smoke separation doors. While the design of these is still pending, it was felt reasonable to equip these separation doors with a "search" contact (see 4.1.1.).

4.1.5. Doors to the hadron stopper and the decay tube exit window

The design criteria for the decay tube exit window as well as for the hadron stopper and its cooling system are very strict and should allow operation with beam for 20 years without any need for an access. To this end, the 12 independent circuits of the hadron stop cooling system uses only all-metal tubes and flexible pipes, all-metal valves and very simple mechanical flow-meters, which can not be read-out remotely.

The hadron stop chamber TNB4 is separated from the first muon detector chamber TNM41 by a 30 cm thick concrete shielding wall. A small shielded door (1.0 x 1.4 metres) has been implemented in the design, which will allow access – under very special conditions and with extreme precaution - to the valves and flow-meters of the hadron stop cooling system if needed. Note that for technical reasons the manifold, flow-meters and valves of the 12 independent hadron stop cooling circuits are located in TNB4, but at the very downstream end of the chamber, i.e. in a location with the least induced radioactivity.

At the upstream end, TNB4 is separated from a small air volume around the decay tube exit window by a thin wall (a stainless steel sheet), introduced in the layout to separate the two air volumes. A small door will be built into this wall, which will allow "in principle" to inspect the decay tube exit window. It has to be stressed, however, that this window and the upstream face of the hadron stopper will become very radioactive, and access to this region will only be possible with extreme precaution and after a very long shutdown of the CNGS facility.

4.2. Red telephones

Although seemingly old-fashioned, the "red telephones" for emergency calls to the fire brigade still play an important role for safety. In the CNGS underground structures, 11 such telephones will be installed and linked to the level-3 alarm system (fire brigade). If a person takes a red telephone off the hook, an alarm is automatically generated. Although the exact location of a given red telephone can not be determined in this way, the "zone" (system of tunnels) in which the phone is located is known to the fire brigade. Note that a person in an emergency might not be able to dial the fire brigade's five-digit number on a mobile phone, but might still be able to take a red telephone off the hook.

4.3. Leaky feeder cable (GSM)

The leaky feeder cable is installed in all the tunnels of the SPS/LHC complex, and CNGS will follow this example. This special cable allows communication with GSM telephones, and, most importantly, permits communication among members of the fire brigade on a different set of frequencies. Due to the interruptions in the availability of the network, GSM is seen as a supplement to the red telephones rather than a basic safety system.

4.4. Fire detection and fire extinction

Fire detection systems are foreseen wherever equipment is installed, i.e. in the ventilation chamber TCV4, the service gallery TSG4 and in the alcove TE80. Fire detection is also installed in areas with a difficult access path, such as the muon detector chambers TNM41 and TNM42, which form a "cul-de-sac".

In general, perforated pipes are used in combination with a pump which draws air into a smoke detection system. This allows having the active detection equipment placed in a low-radiation environment. In the case of TSG4, which is over 100 metres long, a special, stronger pump will have to be installed at the upstream end of this gallery, near the electronics racks (see layout drawing [TCC4]).

For the TT41 proton beam line, the fire detection will be performed by a probe located in the return air duct at the entrance to the ventilation unit in TCV4.

A warm foam system for the target cavern TCC4 and the service gallery TSG4 had been suggested during the 1st CNGS review. A meeting between experts concluded [11], however, that such a system would need a volume near TCC4 much larger than available in the CNGS underground structures. On the other hand, it was stated that the heat load given by the typical quantities (50-100 kg) of flammable equipment would not provide sufficient input to create a really serious fire. Local extinction system for e.g. the electronics racks and other equipment are still being considered.

4.5. Evacuation alarms

A system of evacuation alarms (sirens), standard equipment in the tunnels of the SPS/LHC complex, will be installed in the CNGS underground structures. The alarms will be automatically activated in case of detection of fire and when an area is switched into "beam-on" mode. These alarms also can be activated manually, either from push-buttons in the tunnels or from the technical control room (fire brigade).

4.6. Radiation monitors

The positions and functions of the radiation monitors in the TT41 proton beam tunnel and the TCC4 target chamber, as well as in the service gallery TSG4, have been defined (see the corresponding layout drawings, cf. ref. [7,8]). The SPS read-out system for radiation monitors is to be used (an upgrade of this system is envisaged for the period after the commissioning of the LHC).

No dedicated radiation monitor is foreseen for the two muon detector chambers, since no induced radioactivity is expected there. Information from the muon monitors (ionisation chambers) can be used to control the radiation levels in these areas.

4.7. Beam interlocks

Various levels of interlocks will be implemented to protect the equipment in the TT41 transfer line, the target and other equipment in the CNGS facility. A comprehensive document on the future SPS Interlock systems has been published [12]. For CNGS, the Extraction Interlock System and the Software Interlock System are important.

The Extraction Interlock System protects the extraction/transfer lines (e.g. TT41): whenever a failure is detected, it prevents the extraction of the beam to TT41 and requests a beam dump. The basic requirements will be very similar to the ones at the WANF facility. The Software Interlock System provides further protection by a software surveillance of a large number of CNGS equipment (settings, states of magnets, levels of beam-loss, etc.). Details of the Software Interlock System still need to be defined.

5. Proton beam TT40-TT41

5.1. TT41 magnets

5.1.1. MBG deflection magnets

The progress concerning the MBG deflection magnets was described in a talk to the CNGS Technical Working group in December 2002 [13]. Three pre-series magnets have been built and tested at BINP Novosibirsk. The results of the tests and magnetic field measurements are very encouraging: it was found that the pre-series magnets show considerable margin in terms of field strength, field quality and thermal behaviour. The formal "green light" for series production has thus been given. Meanwhile, two of the three pre-series MBG have arrived at CERN and have been installed on a test bench. Final preparations towards testing (thermal interlocks) are underway.

The first six of the series MBG magnets have arrived at CERN in March 2003, another 6 are expected to be delivered in April 2003. The subcontractor to BINP is reaching the nominal series production rate in half-core production, corresponding to about 10 magnets per month. BINP is producing about 7 coils per month. In summary, the MBG series production is well under way and is expected to be completed by the end of 2003. In parallel, the design of the external bus-bars is in preparation. Some questions concerning transport and storage of the MBG magnets at CERN are still under discussion.

5.1.2. QTG quadrupoles

The production status of the QTG quadrupoles was described in a talk to the CNGS Technical Working group on 4 December 2002 [13]. At that time, it was reported that the field quality of the first QTG pre-series magnet was not sufficient. Preliminary results from the second pre-series QTG showed that the improvements in the assembly procedure had paid off: already without chamfering, this QTG met the specifications.

Meanwhile, chamfering has been completed and the requirements of the Technical Specifications [14] were fully met in the region inside R = 21 mm. However, it also appeared that it would be extremely difficult to meet specifications in the region from 21 to 27 mm radius. In discussions with the TT41 expert, it was concluded that the minimum requirements could be relaxed to the following, both for pre-series and series QTG:

(a) integrated gradient homogeneity inside R = 21 mm must be better than ±0.002

(b) integrated gradient homogeneity from R = 21 to 25 mm must be better than ±0.005.

The quality assurance report for the first pre-series magnet has been discussed with BINP. This QTG will arrive at CERN by the beginning of April 2003. Magnetic measurements on this pre-series magnet are in preparation at CERN. The "green light" for series production will be given as soon as the tests have been successfully completed. This corresponds to a slight delay with respect to the schedule, but is of no importance for the CNGS installation schedule.

5.1.3. MDG correctors

The preliminary design of the MDG corrector magnets was presented in a talk to the CNGS Technical Working Group [13]. At that time it was anticipated that design studies, tender drawings and Technical Specification for the MDG would be produced by BINP. Meanwhile, it was realised that it would be less expensive to have this work done at CERN.

Urgent work on two magnets at the PS have further delayed the design work of the MDG, and the call for tender will most likely be sent out in August 2003 (rather than June, as scheduled earlier).

5.2. Trajectory correction studies, corrector magnets and beam diagnostics

A comprehensive study of the proposed TT41 trajectory correction scheme has been performed [15], using the correction algorithms recently implemented in the new MAD-X program. The aim of the study was to test the validity of the correction scheme proposed in 2001 and to investigate whether some monitors or corrector magnets could be removed from the layout (as cost saving measures). Finally, possibly critical scenarios were investigated where one or several of the correctors and/or monitors were assumed to be faulty.

The correction scheme of 2001 was based on a "2 in 3" scheme, in which 2 consecutive quadrupoles out of 3 are equipped with position monitors (BPM) and correctors. This implies that, in general, only one plane (either horizontal or vertical) of a BPM is implemented. In the originally proposed scheme only the last two BPM upstream of the target, i.e. after the regular lattice of the line, were equipped both in X and Y.

The study revealed that the correction scheme initially proposed was not sufficient to allow for an accurate trajectory correction. In particular, it was found that the so-called π-bumps (experienced with a phase advance close to $\pi/2$, e.g. at LEP) would most often not be visible with the proposed layout of the single plane monitors. A beam position monitor was also missing in the 2-in-3 pattern of the scheme. For further details, see [15]. The study recommended equipping all BPM monitors foreseen along TT41 in the X and Y plane, and strongly suggested the addition of a beam position monitor.

Even with these improvements, the scheme has little redundancy, i.e. little protection if more than one monitor should fail at any given moment.

Efficiency studies of the dipole correctors were performed and confirmed the preliminary specification given in the definition of the design of these new correctors. In turn, it was found that two corrector magnets (one standard MDG and one recuperated MDSV corrector - for which a vacuum chamber and a power supply would have had to be specially built) could be removed from the TT41 layout. Finally, it is suggested that two bending magnet groups in the upstream part of TT41 should be used as additional trajectory correction elements.

The suggestions have been discussed and approved in the CNGS project team and the corresponding changes implemented in the TT41 layout.

5.3. Aperture studies and beam stability

The aperture of the TT41 line and the beam stability in position and angle at the target have been checked in a second series of simulations. The method used and results obtained are described in [16] and are summarized here.

The available aperture was checked by tracking particles in TT41 with an emittance 4 times larger than nominal, allowing the artificial population of the tails of the distribution, which otherwise would have poor statistics. The energy spread of 0.06% r.m.s. is close to the value expected, according to the SPS experts. Different simulations with aperture displacements and momentum offset have been performed, with 100000 particles tracked in each case. Zero particle loss was observed, as expected from the TT41 design, for aperture displacements up to ± 4 mm and a momentum offset up to $dp/p = 0.0015$.

The beam stability at the target was checked against a variety of possible imperfections, such as injection errors, main dipole field errors, main dipole tilt errors, main quadrupole errors, dipole and quadrupole power supply errors. In the tracking studies, it was (pessimistically) assumed that the trajectory due to these errors is not corrected. If all imperfections are assumed to be present together, but within the limits of the technical specifications, it is found that the effective spot size at the target is increased from the nominal $\sigma_{x,y} = 0.53$ mm to 0.64 mm, the divergence from the nominal 0.53 mrad to 0.57 mrad. Note that these effective values have to be understood as the average of the values from many SPS extractions, the single extraction beam size and divergence is not affected and remains at the nominal values.

The study concludes that the aperture of TT41 is as expected, and that the beam stability at the target is within an acceptable range, provided that the equipment performs to specification. The most critical item appears to be the ripple of the magnetic field of the SPS extraction kicker, at the start of the extraction flat top. This ripple must stay within the specified ± 1%.

5.4. TT41 vacuum system exit window

The proton beam at the target will be focused to a very small spot, nominally with $\sigma_{x,y} = 0.53$ mm. The intensity per 10.5 μs extraction will be 2.4×10^{13} protons on target (p.o.t.) nominal, 3.5×10^{13} p.o.t. in the upgrade phase. Such instantaneous intensities lead to an energy deposition in a titanium foil (the standard used for SPS beam line vacuum windows), which would, in theory, increase the temperature beyond the melting point of this metal. The identical problem poses itself with the thin titanium windows and the titanium foils in the secondary emission monitors foreseen upstream (see 4.4.) and downstream of the target (see 5.3.5).

Vacuum windows made of beryllium have been used around accelerators for many years. At the LEAR low energy antiproton ring at CERN, for example, all the external beam lines were equipped with 100 μm Be windows. A study has been launched in order to determine the optimal size and thickness of a Be window at the end of the TT41 proton beam, i.e. upstream of the CNGS target (size and thickness to be optimised w.r.t. vacuum parameters, beam parameters, safety and cost).

5.5. Beam monitoring upstream of the target

In the CNGS base-line design, the beam monitoring at the upstream end of the target was foreseen to consist of two sets of detectors:

(1) A last BPG pick-up monitor to measure the X, Y position of the beam using the same technology as in all of the TT41 proton beam line. This monitor must be installed on the target chamber floor, i.e. it is independent from the target itself. An absolute accuracy in position of ± 0.2 mm has been requested.

(2) A SEM monitor (secondary emission of electrons from thin Ti foils) closest to the target, which would allow to measure the intensity, position and the beam profile (moving SEM wire) very close to the beam focus. This monitor must be mounted on the target table, i.e. it should follow the position of the target upstream end (either due to ground movement or due to movement by the target table motors.)

As described above (section 5.4.), the SEM monitor appears not to be feasible due to the very concentrated, high and instantaneous intensity of the proton beam at the focus. As an alternative solution, the use of an electromagnetic coupler (if possible the LHC standard device), operated in air, is under investigation. Note that it is expected that a coupler device (using a magnetic rather than electric signal) should not be sensitive to electrons produced by the beam in vacuum windows and air. This monitor would not allow the measurement of the beam profile at the target, but would give an accurate beam position measurement. Since such a coupler has not been operated under such conditions, tests at the PS booster accelerator are in preparation to investigate its behaviour in air with short, intense proton beam pulses.

Should the scheme with a coupler operated in air work, there would still be one remaining disadvantage w.r.t. the baseline design: We will not have a beam profile measurement directly at the entrance of the target. For the time being, there is no technical solution to this problem: the beam profile will have to be inferred from the 6 profile measurements along the TT41 line and from the knowledge of the beam optics in the line.

The intensity would be given by the upstream BFCT (located –12m from the coupler). It is also noted that the sum signal from the coupler may be provided alternatively with one of the X or Y signal, giving a redundant measurement of the intensity (after careful calibration with the BFCT).

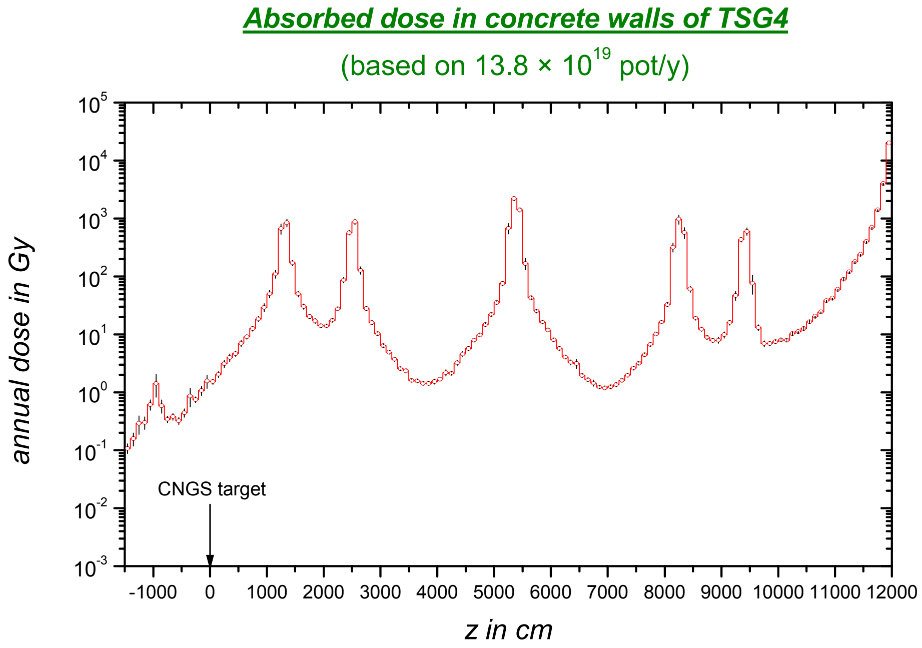
5.6. Beam monitoring: functional specification for TT41

The detailed definition of all the beam monitoring devices along the TT41 line has been described in a the functional specifications. This document has been discussed with the experts of the AB-BDI beam instrumentation group. The functional specification in its final form [17] is currently in the formal EDMS approval process.

6. Target chamber TCC4 and service gallery TSG4

6.1. Expected radiation levels in the target chamber and the service gallery

Based on the final CNGS beam layout, but on an approximated layout of the target chamber shielding, the FLUKA code has been used to calculate a map of induced radioactivity [18] in the target chamber TCC4 and the service gallery TSG4, as well as in the connecting side galleries (in particular TSG45, where the highest radiation levels of all the side galleries are expected). Some of the results are shown in Fig. 6.1 and 6.2.



Absorbed dose in concrete walls of TSG4

(based on 13.8 × 10^{19} pot/y)

Fig. 6.1: Absorbed annual dose in the service gallery TSG4, for the ultimate intensity operation of CNGS. The peaks in this logarithmic plot correspond to the location of the differeent connecting galleries between TCC4 and TSG4.

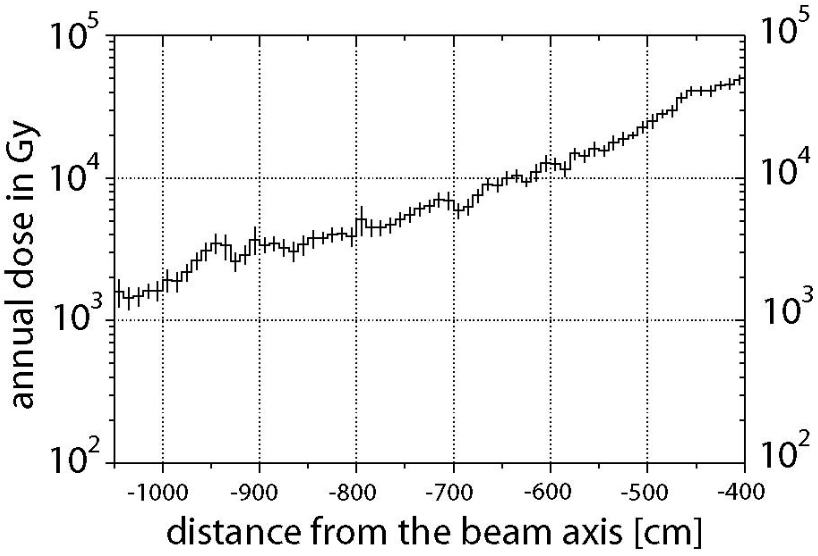


Fig. 6.2: Expected annual dose along the TSG45 side gallery, for ultimate intensity operation of CNGS. Note that the target chamber TCC4 is to the right (smallest distance from the beam axis), TSG4 to the left in this plot.

6.2. Radioactive handling working group

A new CNGS working group on radioactive handling (RHWG), presently with five permanent members, started its work in fall 2002. One of the first items to be discussed was the future use of the crane in the target chamber TCC4. Once CNGS is operating, the most important use of the crane will be to exchange a target module or a horn.

6.2.1. Design study of the target chamber crane

Discussions in the RHWG quickly revealed that there was not enough confidence in the (rather preliminary) design of the crane in TCC4. In particular, it was felt crucial that the approach distances to the cavern wall and the maximum height under the hook of the crane be confirmed by an independent design study. Moreover, the positional accuracy for a load on the crane should be investigated independently. Such a study was launched (contracted to a specialised engineering consultancy firm) in February 2003, and the relevant documents will be received before mid-May 2003.

6.2.2. Common handling device for horn, reflector and target table

Considerable effort went into studying the handling device originally foreseen to manipulate the magnetic horns. In the discussions, it turned out that such a device, if made shorter (2.7 instead of 4.0 metres), could also be very useful to exchange the target table. It was concluded that a re-design of the mechanics of horn and reflector would still be possible, and that a common handling device should be built (see Figure 6.3). Moreover, it became clear that the accuracy of ±2mm in the 3 movements, originally announced for the TCC4 crane, could only be achieved at the level of the 'chariot', not at the level of the load. The design of all systems was therefore adjusted: conical guiding systems will allow the placing of an object (horn, target) accurately, even if the crane could only place the load with an accuracy of ±10 mm.

6.2.3. Other aspects of radioactive handling

The work of the RHWG had largely concentrated on the crane. A list of other topics to be discussed and to be decided in the course of 2003 has now been established. This list is appended to this document (Appendix III).

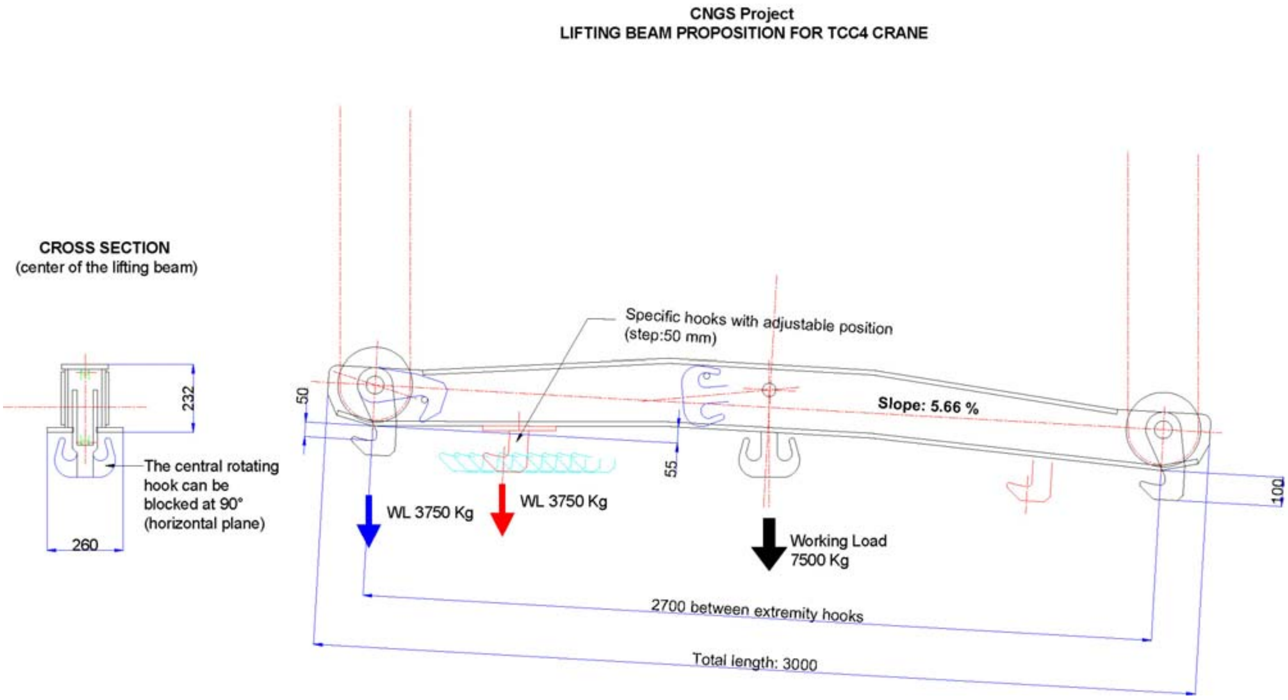


Fig. 6.3: Common handling device for horn, reflector and target, showing the extreme hook position of 2.7 metres as well as the central hook. The external hooks can be placed at regular intervals all along the lifting beam, but must always be installed symmetrically.

6.3. Target station T40

6.3.1. Design guidelines

Due to the high level of induced activity, the CNGS Target Station is designed to be remotely installed, serviced and dismantled by the crane. This strategy is strongly pursued not only in view of decommissioning, but also as a way to cope with presently unforeseeable future upgrades or modifications of the target facility. In particular, automatic lifting and self-centring systems ease the remote handling of the station's sub-assemblies, which will engage and disengage automatically in their seats without any direct human intervention. In this respect, the crane is foreseen to handle the subassemblies with a positioning accuracy of +/- 10 mm. Human interventions in zones difficult to access have been either excluded or minimized, while sensitive equipments have been placed in the passage side. For simplicity, a reference co-ordinate system is chosen for T40 in which the X-axis is horizontal, the Y-axis is vertical and the Z-axis points in the beam direction. It is noted that this system is skew (not orthogonal) due to the target chamber slope (5.66% = 3.28 degrees).

6.3.2. Layout

The vertical cross-section of the Target Station is shown in Fig. 6.4. Starting from the bottom up, the first (and most bulky) objects visible are:

- the floor of the TCC4 cavern with the trench to the service gallery, for cables and cooling duct;
- a set of concrete supports ("feet"), which provide a horizontal reference for the target station and allow cold air to flow under the target shielding;
- the shielding base, containing an opening for the air cooling of the target;
- the front shielding, with a 1-metre-long collimator;
- the target assembly, made of the alignment mechanism, an integrated beam monitor (BPKG), the target magazine (5 target units);
- the shielding cap, which is opened by sliding it upstream on a horizontal steel frame to let the crane access the "target enclosure" (the "heart" of the target station hosting the "target assembly");

Two cast-iron shielding walls close the target station on the passage- and the vault-side. On the passage-side, a marble shield is placed for personnel protection to reduce the remanent dose rate in case of intervention.

The interface between the CNGS Target Station and the neighbouring horn is set by the vertical plane between the T40 cast-iron shielding and the marble wall downstream T40, which is part of the horn shielding. Accordingly, the downstream beam monitor is not part of T40.

6.3.3. Shielding

The design of the T40 shielding aims at providing an 800 mm thick lateral iron shield around the active target unit, with an additional 400 mm-thick marble layer on the passage side of the shielding; the thickness of the front shielding is 600 mm, while the target enclosure is open downstream towards the horn (see Figs. 6.4 and 6.5). Since no radiation sensitive equipment is located between the Target Station and the cavern wall and human access is not needed in that area, no marble layer is foreseen between the station and the vault. The same applies to the shielding cap, where human access is envisaged for redundancy only to assist the alignment procedure of the target.

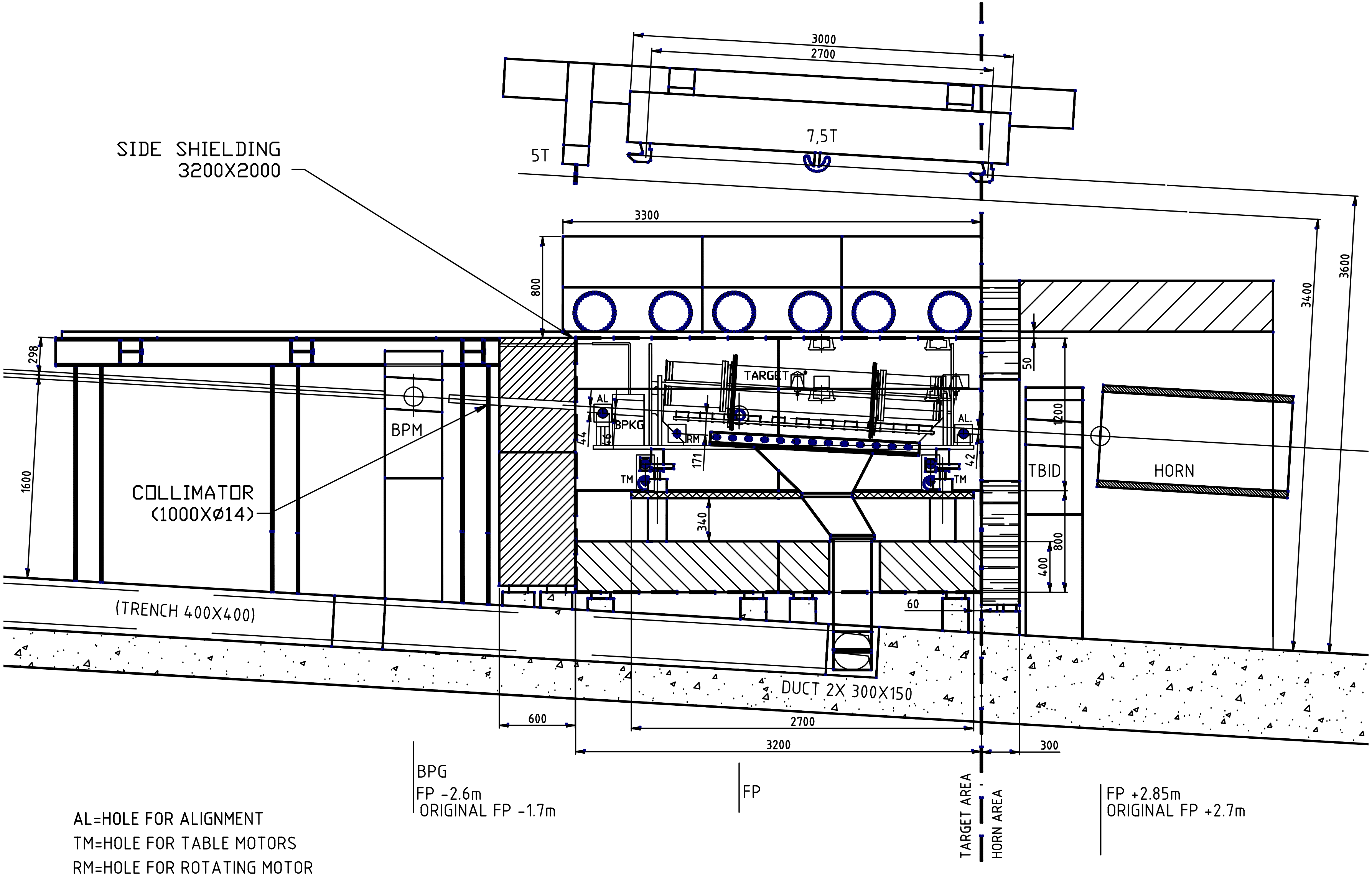


Fig. 6.4 Vertical layout of the CNGS target station

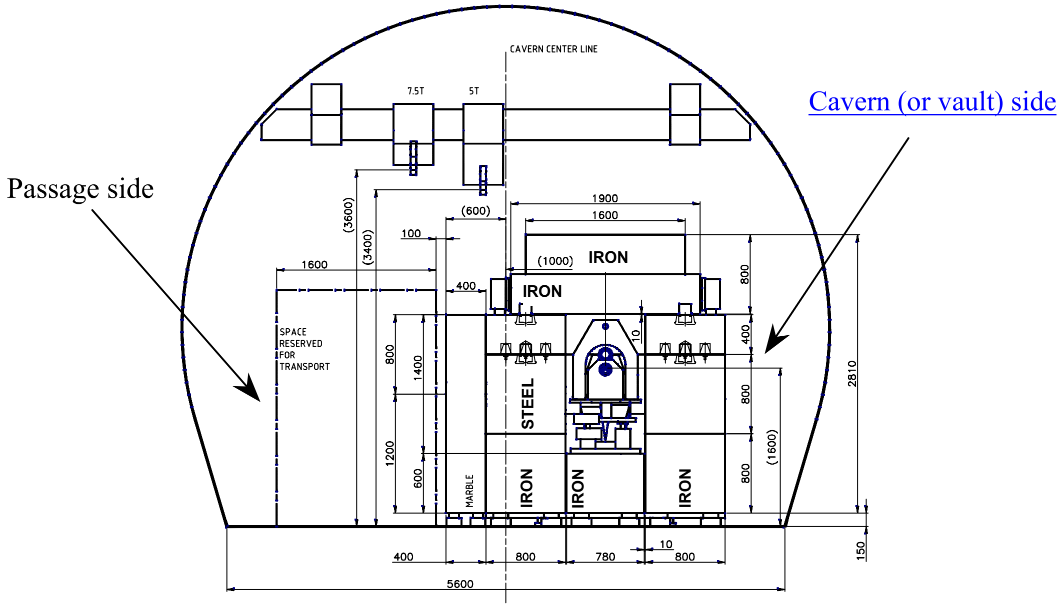
The cast iron part of the CNGS Target shielding is built by superimposing shielding blocks with a gap between them of 1 mm at most. The horizontal reference and relative position of the lower shielding blocks relies on concrete supports; floor movements that could significantly change these positions and create gaps are not expected.

The design of the T40 shielding is presently based on standard CERN cast iron blocks 1600×800×800 mm^3 and 1600×800×400 mm^3, with a maximum weight of 7.4 tons. The blocks will be cleaned and painted by radiation-hard painting. A limited machining is foreseen to improve their mechanical tolerances where needed and to provide each block with self-centring and lifting fixtures. Locally, where penetrations or special shapes are needed, a limited number of new blocks will be cast or assembled by stacking steel plates. It is noted that steel is ~10% denser than cast-iron, which acts in favour of the shielding efficiency where penetrations or cavities are located. Details of the penetrations in the target shielding (especially those of the downstream ones) are being studied to address all relevant issues for radiation safety (tapering, plugging, distance from the beam axis, etc.).

The shielding cap slides backward on rails to open the target station and to allow the exchange of the BPKG monitor or the unit's magazine without interfering with the horn shielding. A gap of 10 mm between the shielding cap and the sidewalls is allowed. The cap is made of three equal non-overlapping sections, each supported by four wheels, which move jointly; the possibility of manually uncoupling them will be provided to partially open the shielding when the BPKG only is to be serviced, in order to reduce the exposure to radiation. Should a wheel fail, the corresponding section of the shielding cap can be uncoupled and removed independently of the other two, which stay in place. The bottom face of the top shielding will become active; in the present design when the shielding cap is open, the bottom of it will be directly visible from operators close T40, which will be avoided.

The target base is detached from the neighbouring shielding sub-assemblies and provides an independent support for the target assembly.

The upstream space available in front of T40 is limited: the BPM, vacuum tube and the collimator are located there. In addition, preliminary estimates of the dose rate on the outer surface of the front shield hint at remanent dose rates that might require remote handling. Interventions in this zone are therefore minimized and simplified. In particular, the removal of the collimator can be eased by splitting it longitudinally in two parts, while its re-alignment is considered an unlikely major intervention.



Passage side

Cavern (or vault) side

Fig. 6.5 Front-view layout of the CNGS target station

6.3.4. From target elements to target assembly

A target unit contains 13 unequally spaced 100 mm-long graphite rods (the "target elements"), which add up to a 2 metre long target. The elements are suspended by carbon fibre reinforced-carbon (C-C) composite pins, which are held in place by a C-C composite support bar. The amount of material in the C-C composite support structure is optimised (reduced) in order not to interfere with the particles produced by the target elements and to reduce the heating. A "no target" position is available in each target unit in the region where the beam misses the target elements and the C-C composite support structure.

The bar is simply supported by two bushes inside a leak-tight aluminium finned tube, along whose axis the target elements are aligned. Two windows close the tube at both ends by means of bolted aluminium flanges and helicoflex joints. The tube is filled by helium at atmospheric pressure at room temperature. A main design issue presently concerns the windows: it is known that Ti will not withstand the high intensity, well focused fast extracted beam. Beryllium is an option, but other alternatives are also being investigated.

The energy deposition in the materials other than the target elements has been found to be around ~2.5 kW (in the target elements, it is 1.4 kW in total). This allows the use of forced air convection to cool the active target unit, with temperatures of the aluminium tube below 100 degrees, even at the highest beam intensities foreseen at CNGS. In order to increase the radiative heat transport to the tube, the latter will be blackened inside.

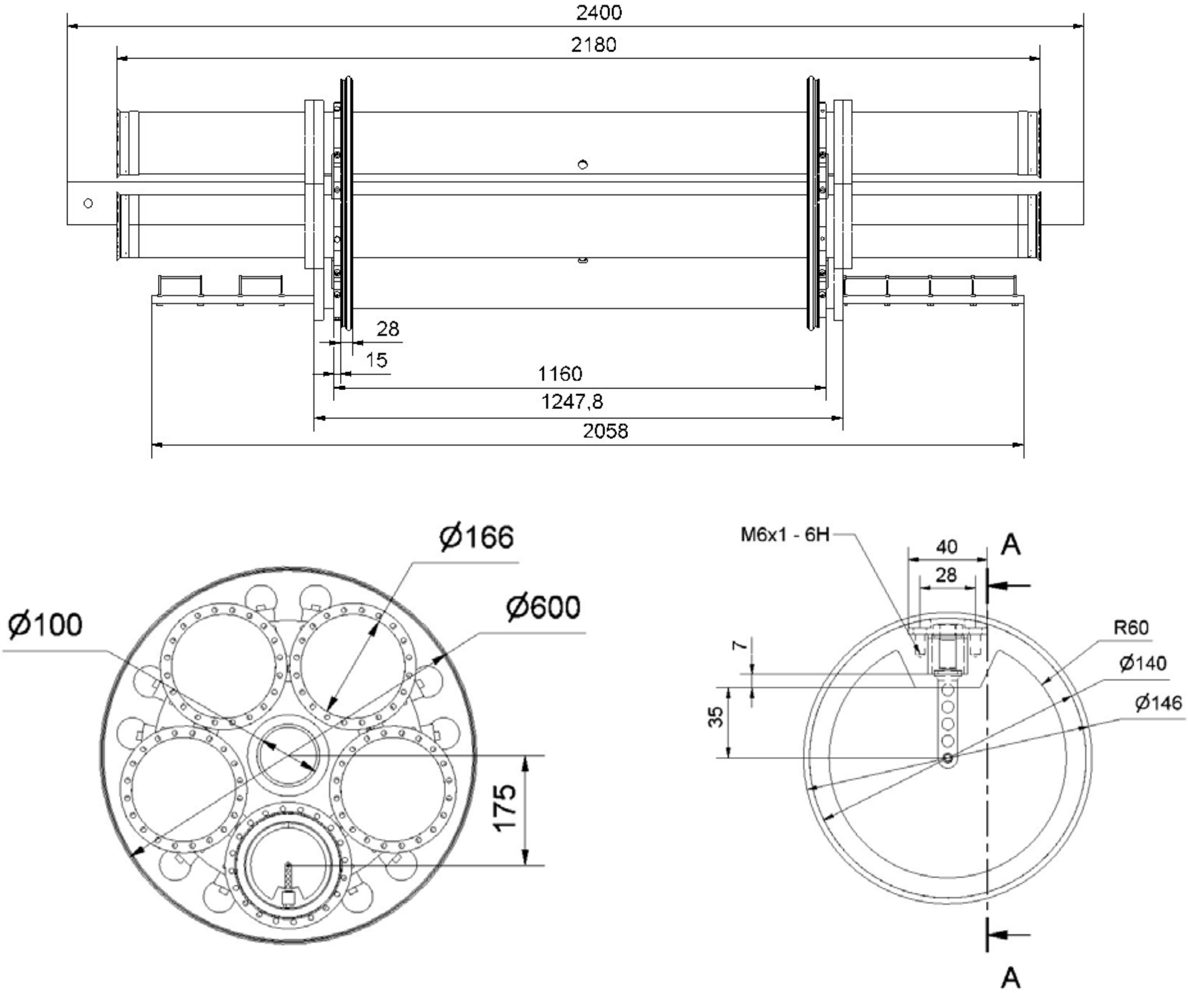


Fig. 6.6 Sketches of the target magazine and target unit. The lower unit in the magazine is represented without the end caps, in order to show the inner structure. The cooling fins are not represented.

Five target units are mounted in a rotating magazine whose load is supported by a central rigid shaft fixed to a “target table”, the active target unit being the lower one (see Fig. 6.6). The target magazine is provided with a gear wheel/tangent-screw rotary mechanism driven by a DC motor fixed on the outer surface of the cast-iron passage wall; a sliding shaft with a universal joint allows the target to be displaced freely in X and Y within +/- 15 mm. The rotating mechanism was found to be advantageous with respect to horizontally or vertically moving magazines in terms of space needs and mechanics.

The magazine rotates up to a mechanical stop, which provides a reliable alignment reference; by these means, the active unit in the magazine is positioned within +/- 0.1 mm with reference to the nominal beam position. An indexer could be used outside the shielding to rotate the magazine by discrete angles. Any radiation sensitive components as electronic switches will be avoided inside the shielding.

The target table is plugged onto an “alignment table”, which is provided with two radiation-resistant alignment supports (“nests”) placed as close as possible to the beam line. A plug-in beam monitor (BPKG) is located in front of the target magazine on the alignment table, where a 250 mm space in the longitudinal direction is reserved for it. The BPKG design is based on a ~14 kg compact structure made of stainless steel (Al could be used) connected by radiation resistant cables housed in steel tubes.

The alignment table is supported by the alignment mechanism made of two vertical lifting jacks supporting a horizontal linear guide at each end of the table. Jacks and linear guides are driven by four motors fixed on the outer surface of the cast-iron passage-wall and hosted in recesses inside the marble-side shielding. A “base table” resting on the target base shielding is placed underneath the alignment mechanism, allowing its removal by the crane (Fig. 6.7).

Each of the target, alignment and base tables are placed on 3 points (one fixed, one sliding and one free support point) which allow pre-alignment and accurate positioning.

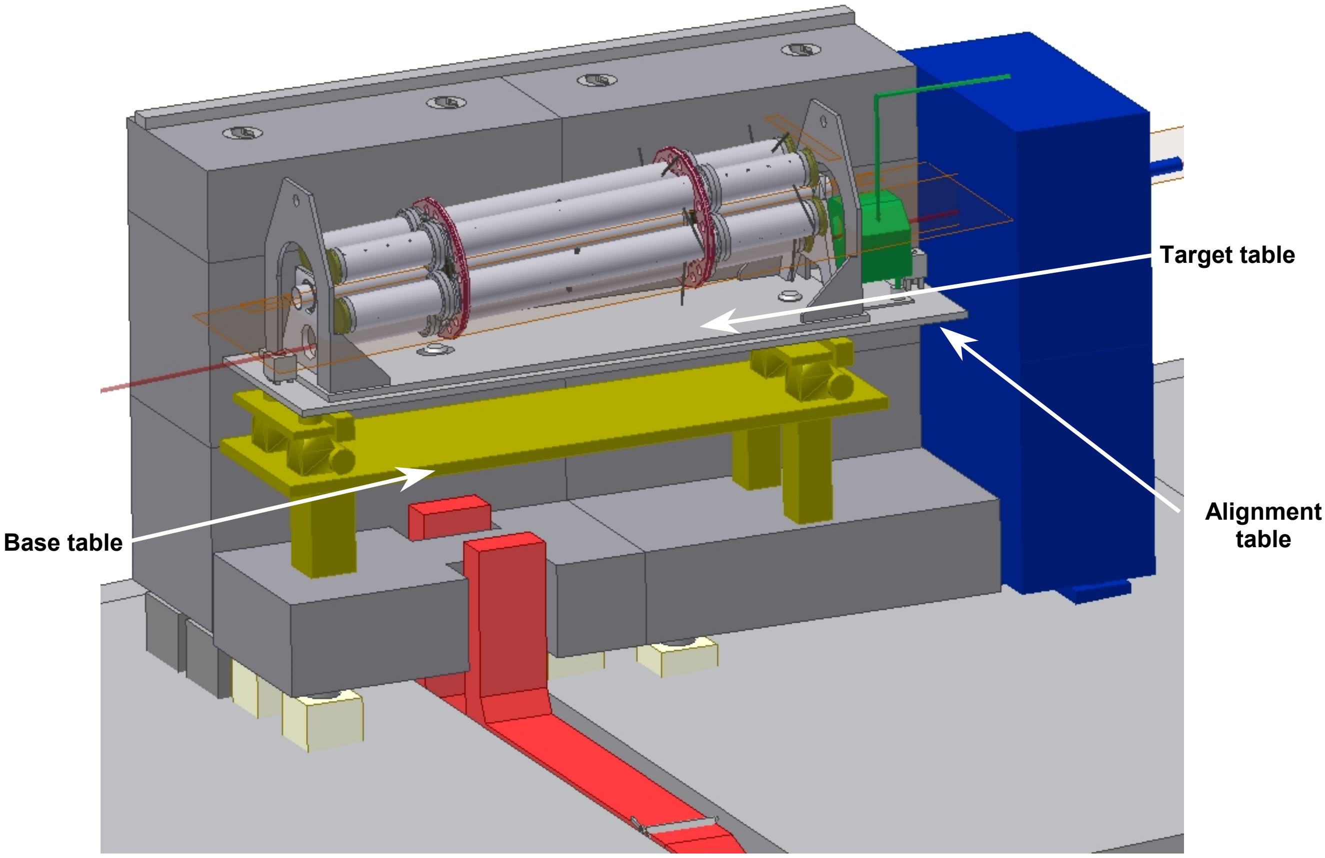


Fig. 6.7 Sketches of the target assembly. The cooling manifolds and nozzles are not shown.

6.3.5. Cooling

An open loop, forced-convection air-cooling system is envisaged for the CNGS target. A standard cooling unit with a cooling power of 15 kW is placed in the service gallery and linked to T40 by an inlet-cooling duct housed in a trench in the concrete floor. Since the T40 cooling circuit is open, no return duct is needed; a suction duct passing on top of a passage tunnel is nevertheless foreseen to provide the "hot" (~25 °C) air to the cooling unit directly from the target chamber. A square 350×350 mm^2 duct is fitted inside the trench, in which air can be pulsed at a maximum speed of 15 m/s, an inlet temp of 16°C and a pressure loss estimated in ~3 Pa/m. Because the dew point in the target chamber is set around 0°C, no insulation to prevent condensation is needed for this duct. The average temperature in the target chamber is 25°C; thus the inlet cold air in its way to T40 warms up by ~3°C, which is deemed acceptable. Fine standard filters of F8/F9 type are foreseen to keep the cooling coil clean and reasonably prevent dust to be pulsed through the cooling circuit. Pressure losses in these filters are expected to be negligible.

The air-cooling duct is split at the T40 entrance into two ducts that end in longitudinal manifolds running along the inner face of the sidewalls and below the base table. Each manifold blows air along the whole active unit's length by means of nozzles.

A surface increase factor of 10 is attainable by standard annular fins with a volume (weight) increase factor of 4, thus improving by ~2.5 the thermal heat exchange. An air mass flow rate of ~1.27 kg/s (~1 m^3/s) would be enough to ensure a heat transfer coefficient of ~14 W/m^2 °C and a temperature increase of <100 °C of the sealing tube. The air speed in the square 350×350 mm^2 duct coming from the service gallery would be ~8 m/s (<15 m/s).

6.3.6. Alignment

The motorization of the CNGS target station can independently adjust the upstream and downstream end of the target vertically and horizontally, i.e. by separately acting on 4 degrees of freedom. The transversal "tilt" of the alignment table is manually aligned when the target station is installed; it is estimated that any further remote correction of the tilt is not needed after installation.

Geometers will align the "alignment table" supporting the BPKG monitor and the target magazine, both relying on a reproducible plug-in system. The alignment is performed from the passage side only: two horizontal, rigid, removable bars penetrating through the passage-side-wall shielding are envisaged to measure the position of the alignment table both in x and y; each bar will rest, on one side, on a permanent radiation resistant nest fixed to the target table; on the other side, each bar will be instrumented and rest on an adjustable support hosted in a recess within the marble layer of the side shielding (as the alignment motors do). No obstacle (the downstream nest, in particular) is located within a radius of 40 mm of the beam axis in order not to intercept the intense part of the shower of secondary particles coming out of the target.

Though it is envisaged to perform the alignment of the target from the passage side only, redundant penetrations will be provided through the top shielding to allow the introduction of two auxiliary vertical bars.

6.3.7. Target upstream collimator

The high intensity proton beam may be mis-steered in the target region, e.g. due to an equipment failure. The object most in danger in such a situation would be the neck of the horn (18 mm open diameter, at 10.3 metres from the proton beam focus). Should the full proton beam at ultimate intensity ($7.2x10^{13}$ p.o.t. for this simulation) hit this region, the energy deposition in the neck would lead to a local temperature increase by 1000 ^{o}C.

Simulations with FLUKA [19] have shown, however, that a 1 metre long graphite (or hexagonal boron nitride) collimator would reduce the proton flux by about a factor of ten. The resulting immediate temperature rise in the neck of the horn are reduced to somewhat below 80 degrees. Since this result is obtained with in the pessimistic approximation of $7.2x10^{13}$ p.o.t. in one instant (while the running scenario foresees two fast extractions separated by 50 ms), it is assumed that the one metre long collimator is sufficient protection.

In the same round of simulations, using the same beam assumptions, it was found that the temperature in the collimator itself would rise to around 1000 degrees in the hottest region, some 25 cm from the entrance face of it.

The operating scenario would be to allow at most one proton beam cycle at high intensity to hit this collimator - an interlock should prevent extraction of further cycles. It was shown in the simulations quoted above that an ionisation chamber at an angle of 135 degrees to the beam direction, placed in 1 metre distance from the collimator entrance face, would see some 10^9 hadronic charged particles at energies higher than 10 MeV - the proof that a standard beamloss monitor can well be used to create an interlock for high intensity beam hitting the collimator.

The diameter of the collimator opening has been assessed [20] using the geometry of the orthogonal steering elements, the calculated beam sizes and divergences, and the positions of the focal point and the neck of the horn. The conclusion of this study was that a collimator with a hole of 14 mm diameter would protect the neck of the horn in all but the most extreme accident scenarios. At the same time, the target unit cylinders and other equipment near the beam axis (though at radii larger than the opening of the neck of the horn) are also protected by this collimator.

The detailed design of the collimator, as well as the final choice of the material, are still pending.

6.4. Target downstream SEM monitor (TBID)

The CNGS baseline design foresees the installation of a standard SEM (secondary emission) monitor downstream of the target, a TBID. The main purpose of this monitor is to measure the overall yield of charged particles from the target (called "multiplicity" in SPS terminology). This will allow the commissioning of the CNGS facility step-wise: first the proton beam is tuned using the monitors in TT41, then the target position can be tuned using the 4 motors on the target table and observing the (normalised) multiplicity in the TBID. Finally, the operation of the horn and reflector will be checked by comparing the muon yield and profiles in the two muon detector chambers with the expectations from Monte Carlo simulations.

After the commissioning phase (with at maximum 10% of the nominal intensity), the high instantaneous intensities might eventually destroy the TBID, in particular in a scenario where the proton beam misses the target completely and passes through the TBID at full intensity. Presently, no alternative technology to the SEM at the location between target and horn is known. Therefore, the TBID will be installed and used for commissioning – should it stop operating at a later stage, the beam monitoring will have to rely on the proton beam instrumentation and the muon detectors alone. This is considered acceptable, since it is assumed that the CNGS beam will have been sufficiently well studied and understood by that time.

6.5. Horn and Reflector

6.5.1. Mechanical design of horns and striplines

The mechanical design of horns and striplines elaborated by IN2P3/LAL/Orsay is in its final phase. The corresponding drawings and minutes of the horn working group are available at [21]. The work packages for manufacturing of all items have been placed by LAL/Orsay, most of the work has been contracted out. The reception of the two horn inner conductors is due by end of March 2003.

Special attention has been given to the quick horn to stripline coupler (QHSC). An elementary contact piece has been mounted on the electrical test bench of BA7 at CERN and has been successfully tested. Some questions related to manipulation and transport are still under consideration in the RHWG group (see section 6.2. of this report).

6.5.2. New capacitors for horn/reflector powering

For reasons of space and due to safety rules, re-using the old WANF capacitors would have implied the construction of a new building near the existing BB4. Such a building had been studied in detail and was found to be quite costly.

The suggestion to look for new capacitors with high energy density has been followed up in view to reduce the volume of the capacitor banks and thus find a possibility to house them in existing buildings (6.5.3 below). Preliminary offers have been collected from several manufacturers (MONTENA, AVX) that indicate that this option is technically feasible and financially interesting. A market survey has been launched in November 2002 (ref. MS-3172/EP/CNGS) and 4 companies have been selected for the call for tender. The final specification (ref. IT-3172/EP/CNGS) is included in the call for tender, to be launched in March 2003; it has been elaborated by EP-TA3 in consultation with AB-PO group, which will, in the future, be in charge of operation and maintenance of this equipment. The safety aspects have been discussed with TIS Division and AB-PO group and the recommendations are taken in account in the specifications as well as for the installation.

6.5.3. New layout for powering equipment in existing buildings

Three options have been considered for housing of the electrical components (charging power supplies, capacitor banks and discharge switches) in existing buildings:

a) in pit ECA4
b) in the so-called counting barracks of PA4
c) in BHA4 (building housing the PAM4 access pit)

The best solution retained is c), mainly for following reasons

- easy access in case of fire
- no load capacity problems of the floor
- almost all necessary general services are readily available

The layout for the installation of the powering equipment in BHA4 has been presented to the CNGS Technical Working Group in July 2002 and can be found at [22].

6.5.4. The use of the existing WANF transformers

An important saving in money and manpower investment could possibly be achieved if it was possible to re-use the WANF pulse transformers. In spring 2002, these have been dismounted from the radioactive WANF beam line area and installed in the BA7 test hall. The bigger transformer on the left hand side in Fig. 6.8 is one of the two recuperated ratio-32 WANF transformers.

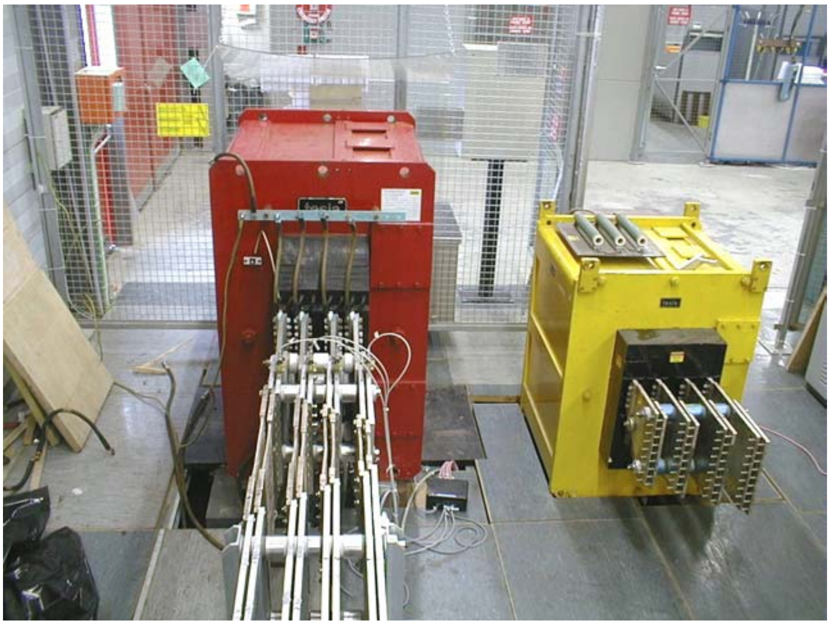


Fig. 6.8: Pulse current transformers in the BA7 test stand. The larger one to the left is one of the recuperated ratio-32 transformers from WANF.

The possibility of re-using these transformers has been studied and assessed with electrical tests. An important limitation is the magnetic time constant of the transformers that defines the time needed for the transformer to de-magnetize and come back to its remanent magnetic induction (see the presentation to the CNGS Technical Working Group in December 2002, accessible at [23]). Further tests since the time of that

presentation confirm that the WANF transformers are fast enough to produce a second pulse 50 ms after the first one. A report is in preparation.
Ratio 32, which is the base ratio of the WANF transformers, produces a pulse that is unnecessarily long in terms of horn heating. A special coupling has been manufactured and mounted on the secondaries of one of the WANF transformers (see Figure 6.9) in order to achieve a ratio 16 mode producing a 7 ms long pulse - this is close to the nominal 5.8 ms pulse length [6].

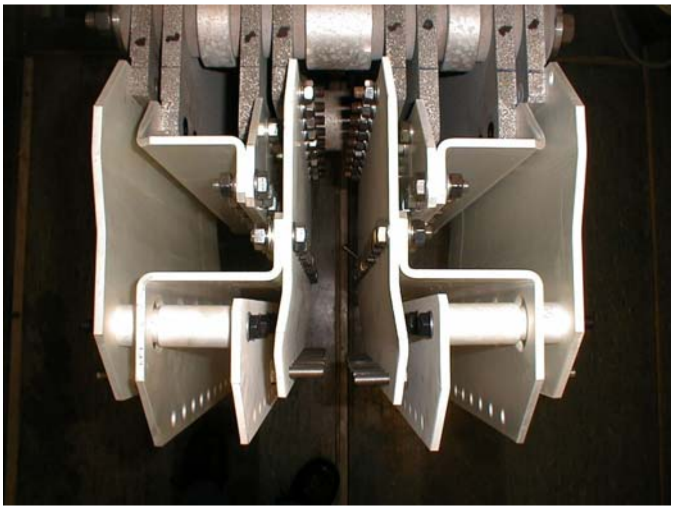


Fig. 6.9: Modifications to a recuperated WANF transformer: the secondary side is coupled such as to change a ratio-32 into a ratio-16 transformer.

Electrical testing of the prototype horn with this modified transformer (ratio 16) gives positive results. A decision has thus been taken to power the horn at 150 kA with the modified WANF transformer in this mode. Heating is not an issue for the reflector. Powering this latter one at 180 kA with a non-modified WANF transformer (ratio 32 base mode) is thus considered. In this way, one can take advantage of a lower current on the primary side. It should be noted that a strategy towards providing a spare transformer for CNGS has been worked out. The final electrical working points for the horn and reflector system will be presented in the corresponding talk at the 2003 CNGS review.

6.6. Helium tanks and helium gas system

The final size of the helium tanks in TCC4 will be given by the detailed design of the equipment around these tanks (horn, reflector, decay tube shutter safety system). The detailed design of the helium tanks will start in fall 2003.

A first round of discussions on the former WANF helium system revealed that the gas rack, valves, manometers and the oxygen meter (purity control at the return of the helium gas indicating possible leaks) can all be recuperated and re-used for CNGS. It has been suggested to add a simple flow meter ("yes-no" device used for the MWPC profile monitors in SPS secondary beams) in the gas return line.

Space at the surface, in a small service building, has been reserved for the He gas system. Racks of helium gas bottles can be placed outside this building, where access by truck is easy. It is expected that the rack of bottles will have to be exchanged about once or twice per year.

7. Decay Pipe

7.1. Decay pipe construction and quality control

A detailed description of the method to be used to construct and install the decay pipe and the concreting works around the pipe, as well as a specification of all the quality control procedures, can be found in [24]. We attempt to give a brief summary here.

The material used for the decay pipe is specified to be steel P355NH, according to the Euronorm EN10028. At production of the steel plates, the corresponding quality criteria are applied. In particular, ultrasonic tests are to be performed on 20% of the steel plates manufactured (according to standard EN10160).

Sections of pipe (around 6 metres long) will be transported via the PGCN shaft, the TAG41 access gallery to the target chamber region. The TCC4 target chamber itself may be used as a workshop for assembling several pipe sections (and controlling the welds) before introducing these larger sections into the decay tunnel. For handling and transportation of the pipe sections, internal spider cross-bars must be used to guarantee the stability of the sections. These spiders shall only be removed once the concrete around the decay pipe in the decay tunnel has hardened.

Welding of the sections of pipe must be performed according to strict procedures (standard EN288). Qualification and performance of the welders and operators must be in accordance with standard EN287. The quality control of the welds includes the following steps:

a) in the workshop and in the TCC4 target chamber

- visual examination of 100% of the welding joints
- ultrasonic examination of 85% of the welding joints
- dye penetrant testing of 100% of the welds
- radiographic examination the 15% welding joints not controlled by ultrasonic tests

b) during installation in TND4

- visual examination of 100% of the welding joints
- ultrasonic examination of 100% of the welding joints
- dye penetrant testing of 100% of the welds

Additional inspections and tests will be performed by an independent control agency, which will report directly to CERN.

The contractor will be fully responsible for the leak-tightness (vacuum with a stable pressure of 1 mbar) of the decay pipe. An air tightness test at the end of the installation works will be a decisive criterion for the final approval of the works.

The annular concrete filling around the decay pipe will be executed by pumping the concrete through two pipes located underneath the steel pipe. The type of concrete to be used will be a mix called Self Placing Concrete, which does not require vibration. The Contractor will propose the mix design and the preliminary tests for approval by CERN and, during the works, tests according to Standard NFP18-404 will be used for quality control of the concrete production.

7.2. Decay pipe windows

7.2.1. Entrance window

The decay tube entrance window should cause as little particle loss as possible, while providing a high degree of mechanical safety. The choice of the WANF facility, i.e. a 2 mm thick titanium window of 1.45 metre diameter, has been investigated in detail. In particular, the heating of the window (and the structures on which it will be mounted) due to particles was studied using FLUKA simulations and ANSYS for the mechanical analysis [25]. It was concluded that air-cooling would be sufficient to remove the heat deposited in this region. Note that the ventilation system provides fresh, cool air at this end of the TCC4 target chamber – a careful design of the ventilation ducts in this area will allow efficient cooling of the decay tube entrance window.

The thermo-mechanical shock due to the full proton beam hitting the window (in the scenario where the beam misses the target) was also analysed and found to be of no danger – provided this unusual scenario would not prevail for more than a few minutes [25].

In conclusion, the WANF window was found to be the appropriate choice for CNGS. In turn, the spare WANF window was found to have been stored under good condition. The window was mounted on a flange and successfully tested in 2002 (see reference [26], test report by G. Musso / EST-DEM).

7.2.2. Exit window

The decay tube exit window is a 5 cm thick steel plate. Technical drawings of this exit window can be found at [27]. Particle losses at this location are not an issue, mechanical strength can be easily guaranteed with such a steel plate. The heat deposited in the last metres of the decay tube and this exit window has been of concern, in particular in the transition region (decay tube embedded in concrete – decay tube in air). In order to remove all doubts on this point, a water-cooling loop was designed and will be installed around the downstream end of the decay tube. This is a minor addition to the hadron stop cooling system, for which 12 independent cooling loops are already foreseen.

7.3. Decay pipe vacuum system

The technical specifications for the vacuum pumps can be found at [28]. The pumps for the decay pipe vacuum system will be located in the downstream part of the TSG4 service gallery. Two pumps will be used initially to evacuate the decay pipe, later the pumps will work in an alternate way to maintain the vacuum in the decay pipe (one pump as spare). The absorbed dose in the relevant region of TSG4 is found to be around 50 Gy/year in the ultimate intensity scheme – care has therefore to be taken with the choice of materials in these pumps.

In order to avoid corrosion in the decay tube, these pumps must be available already at the end of the decay tube construction in summer 2004. At that stage, general services (power, water, exhaust pipe for the pumps) will however not yet be available. It was therefore decided to order two so-called "dry" pumps, which do not create noxious exhaust and which are either air-cooled or have their own independent closed cooling circuit. A provisional powering link will have to be provided in 2004.

The control unit of the pumps will be located next to the pumps for the initial pumping phase without beam, but will later be moved to the upstream part of TSG4 into a low radiation area.

7.4. What happens if the decay tube window breaks during CNGS operation?

One of the potential dangers in operating the CNGS facility stems from the very large evacuated volume in the decay pipe. While in “beam-off” conditions the thin titanium entrance window is protected by a solid shutter, there is a risk (which has to be considered extremely small, given the safety factors applied to the design) that the entrance window might break during operation with beam. In such a scenario, damage to material is of no consideration. However, the closest location where a person could be present is ECA4, about 1km away from the decay tube. The system of tunnels leading from the decay tube to ECA4 is complex: in the target chamber, the tunnels split - the access gallery TAG41 leads directly to ECA4, while the proton beam tunnel TT41 leads to ECA4 via TJ8 and TT40. The following paragraphs summarize the status of investigations into the possible consequences of a rupture of the decay tube window during beam operation.

7.4.1. Simulation of a "worst case" scenario

Simulations of the “shock-wave” in the CNGS structures and ECA4 following the rupture of the decay tube window have been performed in the framework of a diploma thesis. The results are given in [29]. The model used is necessarily a simplified one, in which all assumptions were slanted towards making the effects in ECA4 worse. The main conclusions were that

- At 2-3 seconds after the rupture, a pressure drop is observed in ECA4. The pressure is reduced by as much as 5500 Pa during about 6 seconds
- During the same time, the wind speeds in ECA4 can reach 80 m/s
- The situation improves considerably at a location a few metres above the ECA4 floor, i.e. outside the direct “view” of the access gallery - this result was not included in the report, but is documented in a presentation by R. Blom [30]
- Introducing “baffles”, i.e. obstacles covering part of the access gallery and proton beam tunnel sections, improves the situation in ECA4 but in an insufficient manner.

7.4.2. Effects on personnel working in ECA4

Results from the simulations described above were used to assess the consequences on personnel working in ECA4 - see the report [31]. It was found that a pressure drop of 5500 Pa does not imply a risk for eardrum rupture or lung haemorrhage. However, the high wind speeds found in the simulation translate into very severe danger for persons in ECA4. For an average person of 75 kg weight, the high wind speed lasting 6 seconds would result in an impact velocity of the body against the nearest obstacle of around 30 m/s. Values above 3 m/s are considered a risk for skull fracture, while at impact velocities above 7 m/s the probability of a skull fracture is basically 100%. Similarly, injuries from flying objects would be extremely serious.

7.4.3. Suggestions towards solutions

The danger for persons working in ECA4 in case of a decay tube rupture is very serious, and measures need to be taken to improve the situation in case of an accident. The initial ideas of introducing "baffles" have been shown to yield insufficient reduction of air speed in ECA4. Recent suggestions concentrate around two measures:

- Increase the air volume available, in an attempt to "feed" the underpressure shock wave with more air before it reaches ECA4. This can be done by linking the two volumes of the PGCN and PGC8 pits (civil engineering pits for CNGS and TI8) to the underground structures of CNGS. In a first step, an additional campaign of simulations will be needed to assess the improvement from such measures. The technical implementation should be relatively simple.
- Use the ventilation ducts - linking the TAG41 access gallery and the TA40 access gallery to the SUI8 building at the surface above ECA4 - to supply the necessary air to compensate for the underpressure shock wave. Here, the idea is to use very simple "weak plates" in the ventilation ducts at some metres above the ECA4 floor - these should be the weakest part in the system, i.e. the air should be sucked in through these locations rather than at the floor level. Note that no person is allowed to be present at those levels of the ECA4 cavern due to the risk of accidentially high radiation levels. The forces on the ventilation ducts in such a scenario need to be assessed, and the strength needed of the doors linking the two access galleries to ECA4 needs to be calculated.

We still need to carefully assessed whether - with the relatively simple systems described above - the protection of personnel in ECA4 can be guaranteed.

8. Hadron stop and cooling

The design of the hadron stop and its cooling system has been completed and all components ordered. Figure 8.1 shows the main components: Iron blocks, cooling modules and graphite blocks. Installation of the hadron stop is presently planned for July-September 2003.

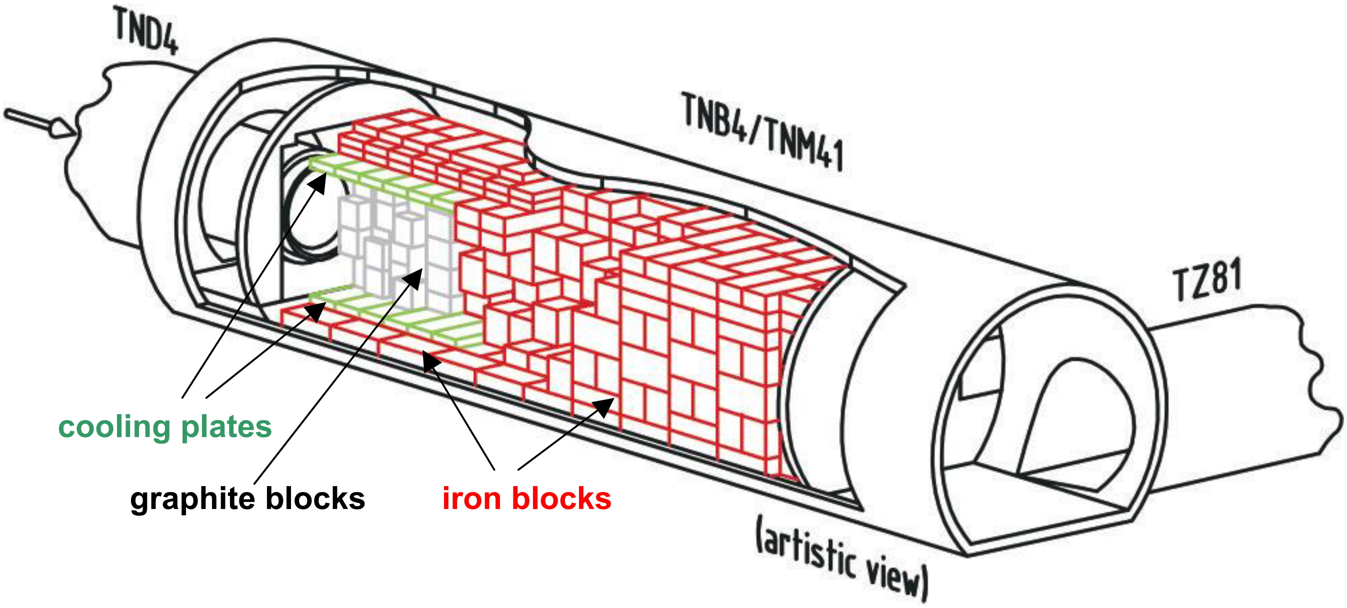


Figure 8.1: Hadron Stop overview

The major points in the evolution of this part of CNGS (w.r.t. to the 1st CNGS review) are the following:

- Recuperation of iron blocks from WANF has been completed in May 2002 (40% to LHCb)
- Cleaning of these iron blocks is under way in March/April 2003 (no painting foreseen)
- Additional iron blocks (in particular the smaller sizes) have been recuperated elsewhere at the SPS
- Installation of the hadron stop has been completely contracted out to the civil engineering firm in charge of building and installing the decay tube. This implies a considerable reduction in risks related to transport and handling of the blocks (originally foreseen to be done by very old CERN equipment). A detailed installation procedure has been established and communicated to the contractor.
- Graphite blocks and handling tools for these have been ordered (delivery completed April 2003) - the technical specifications for these blocks can be found at [32].

The cooling system design has been finalized, still aiming at 100 kW total water-cooling power. The entire system consists of two cooling plates (one above and one below the graphite core, see Figure 8.1) where each cooling plate is composed of 6 identical cooling modules. As shown in Figure 8.2 each cooling module is made up of a cast aluminium block with an embedded stainless steel circuit. The technical specifications for the cooling modules can be found at [33]. Flexible all-metal hoses connect each of the 12 independent cooling circuits to a manifold located at the downstream end of the hadron stop (Figure 8.3). A technical description of these hoses can be found at [34]. From there, two DN50 pipes connect to the heat exchanger and pumps in the TE80 alcove, next to the TI8 tunnel.

The definition of separating walls and doors in the hadron stop area has been completed in March 2003 (see Figure 8.4 and the layout drawing [9]). The upstream separation is a 1 mm thick stainless steel sheet, while the downstream separation consists of a 300 mm thick concrete wall.

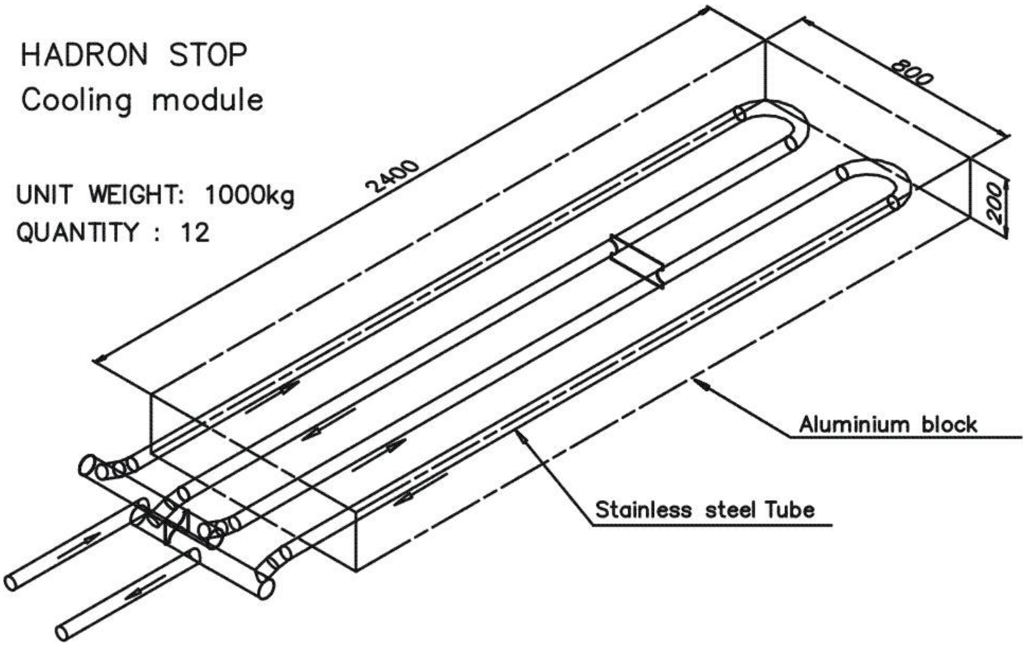


Figure 8.2: Hadron stop cooling module

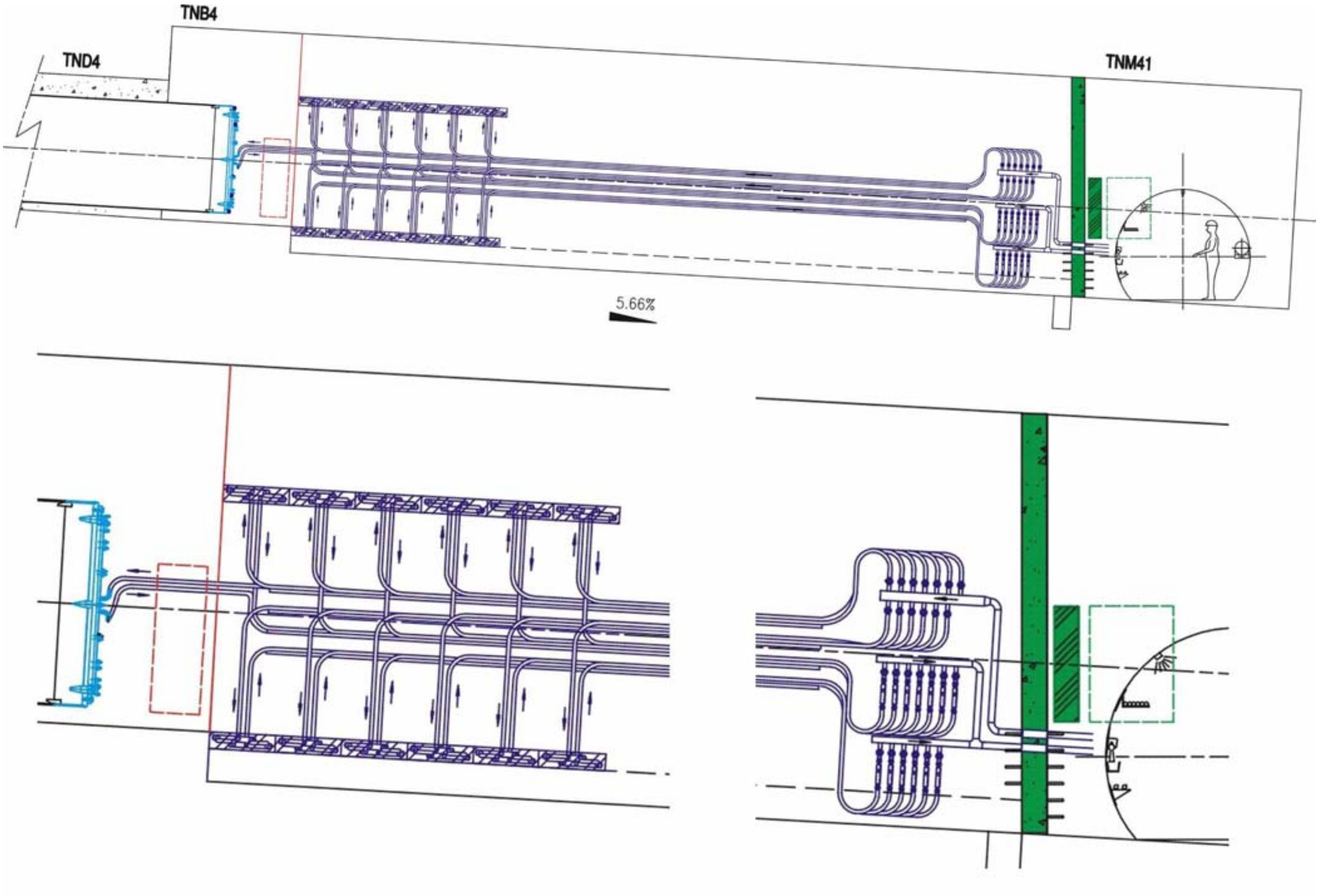


Figure 8.3: Hadron stop cooling circuit (with details of upstream and downstream end)

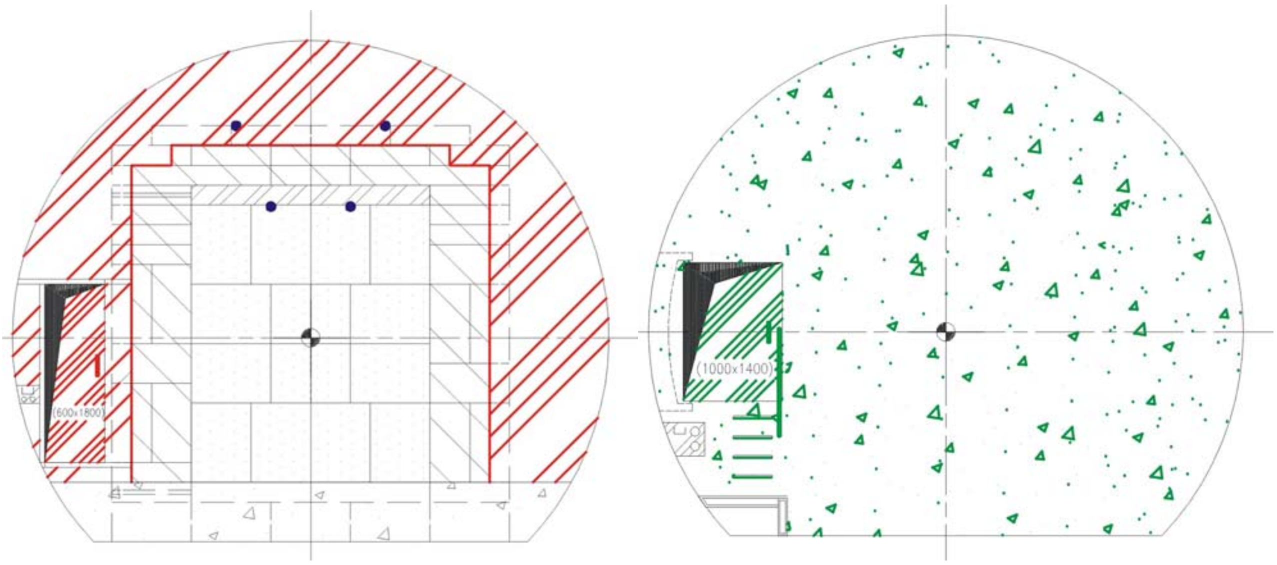


Figure 8.4: Upstream (left) and downstream (right) separation walls with doors

9. Muon detector specifications

The basic design choice for the muon detection system is a grid of 17 fixed ionisation chambers (of the type used as beam loss monitors at the SPS, or similar) in both muon detector stations TNM41 and TNM42. In addition, one moveable monitor of the same type should allow the mapping of the muon beam profile and the cross-calibration of the fixed monitors. The functional specifications for the muon detection system have been approved and can be found on EDMS [35].

Among the suggestions for potential cost savings was the proposal not to equip the second muon detector station TNM42 for the start-up of CNGS. The Secondary Beam Working Group has published a note [36] describing in detail why TNM42 is essential and must be equipped in time for the commissioning of CNGS.

10. Temperature measurements

10.1. Temperature measurements in the target chamber TCC4

The measurement of temperatures in critical places around the target, horn and reflector is being specified and prepared by the project engineers responsible. Additional temperature measurement points needed to be added to the layout, once it became evident that the whole target chamber would be air-cooled. In the latest version of the layout drawing [7], a total of 8 points are shown at which the temperature must be measured. These locations include the two helium tank entrance windows, the decay tube entrance window and its flange, as well as the decay tube itself. In order to avoid an excessive cost for radiation hard cables, it is expected that some of these temperature measurements will not be operational after one or two years of CNGS operation. However, by that time the temperature evolution and the cooling requirements as a function of proton beam intensity will be understood.

10.2. Temperature measurements along the decay pipe

The contract for the installation of the decay pipe and the concreting around it includes a chapter (see 3.8 in [24]) on instrumentation for a temperature survey. The probes are to be located at two distances from the end of TCC4, i.e. at 105 and at 270 metres. At both locations, 8 temperature probes are to be installed:

- 3 probes at R = 3 metres in the surrounding rock
- 3 probes in the shot-crete (at R about 1.6 metres)
- 2 probes on the steel pipe itself.

The probes must be able to measure temperatures from 0 to 250 degrees with an accuracy of +/- 5 degrees, resist to humidity and external pressures, and must remain operational for at least 2 years of high intensity running of the CNGS facility.

10.3. Temperature measurements in the hadron stop and muon detector areas

The most critical areas in the hadron stop chamber are the end of the decay tube (including the exit window) and the upstream part of the hadron stopper. Water-cooling will be installed on the decay tube exit window (one circuit) and on the hadron stopper (12 independent circuits). The cooling power provided should be largely sufficient even for the scenario of ultimate proton beam intensity. For an improved understanding of the heating/cooling in this region, a number of temperature probes will be installed. The location of these probes is shown in the layout drawings [9].

Four probes are to be installed on the decay tube exit window and its flange, while another four are located at the front face of the hadron stopper. One probe is installed on the last part of the decay tube itself (around 1 metre upstream of the window). Finally, one probe is installed on the concrete wall in the region of the decay tube window.

The air temperature in the two muon detector chambers is not controlled (ventilation, but no air-conditioning). One probe is to be installed in each of TNM41 and TNM42 to complete the array of temperature measurements in the downstream region of the CNGS facility.

11. Acknowledgements

Many persons at CERN, both staff and industrial contract labour, are contributing to the CNGS project. Their help and enthusiasm for this project is greatly appreciated.

We also wish to thank the staff of IN2P3 in Paris (building the magnetic horn systems) and of BINP in Novosibirsk (building the deflection magnets and quadrupoles for TT41) for their invaluable contribution to this project.

Colleagues from the USA and Japan, themselves building or operating long baseline neutrino beams, have contributed with numerous comments and suggestions, during the Neutrino Beam Instrumentation workshops as well as with private communications. This has created a very positive, constructive atmosphere between the teams involved in building "classical" neutrino beams and has greatly helped the advancement of the CNGS project.

12. References and links

[1] G. Acquistapace et al., “The CERN Neutrino Beam to Gran Sasso - Conceptual Technical Design”, CERN 98-02 and INFN/AE-98/05 http://doc.cern.ch/cgi-bin/setlink?base=cernrep&categ=Yellow_Report&id=98-02.

[2] R. Bailey et al., “Addendum to report CERN 98-02”, CERN-SL/99-034(DI) http://doc.cern.ch/archive/electronic/cern/preprints/sl/sl-99-034.pdf

[3] A.E. Ball et al., “CNGS: Update on secondary beam layout”, SL-Note-2000-063 EA http://proj-cngs.web.cern.ch/proj-cngs/PDF%20files/sl-note-2000-063.pdf

[4] CNGS web site, http://cern.ch/cngs

[5] CNGS-EDMS tree structure, https://edms.cern.ch/home/CNGS

[6] M. Clément et al., “Update of changes to CNGS layout and parameters”, SL-Note-2002-012 http://proj-cngs.web.cern.ch/proj-cngs/PDF%20files/CNGSupdate_note_final.pdf

[7] The TT41 layout drawing can be accessed at https://edms.cern.ch/document/323172

[8] The TCC4 layout drawing can be accessed at https://edms.cern.ch/document/310296

[9] The layout drawing of the hadronstop area can be accessed at https://edms.cern.ch/document/364662

[10] Summary notes of meetings on doors in the CNGS facility,
1st meeeting: https://edms.cern.ch/file/371835/1/CNGSdoors310103.pdf
2nd meeting: https://edms.cern.ch/document/376995

[11] Summary notes of a special meeting on “Warm foam system in TCC4”, attached to CNGS project team minutes 27 March 2002, https://edms.cern.ch/file/341096/1/project-team_270302.pdf

[12] R. Giachino et al., “Architecture of the SPS Beam and Extraction Interlock Systems”, CERN-AB-2003-xxx OP, http://lhc-mpwg.web.cern.ch/lhc-mpwg/documents/SPS_Hw-Interlock_Report.pdf

[13] K. Schirm and T. Zickler, presentations to the CNGS Technical Working Group of the 4 December 2002, https://edms.cern.ch/document/364853

[14] T. Zickler, QTG Technical Specification, https://edms.cern.ch/document/310742/

[15] W. Herr and M. Meddahi,
“Trajectory correction studies for the CNGS proton beam line”, SL-Note-2002-015 AP http://documents.cern.ch//archive/electronic/cern/others/sl/sl-note-2002-015.pdf

[16] W. Herr and M. Meddahi,
”Aperture and stability studies for the CNGS proton beam line TT41”, AB-Note-2003-020 ABP, http://proj-cngs.web.cern.ch/proj-cngs/PDF%20files/AB_note_2003_020.pdf

[17] CNGS proton beam diagnostics: functional specification, https://edms.cern.ch/document/376330

[18] H. Vincke and G.R. Stevenson, “Improved shielding in the CNGS target chamber”, in https://edms.cern.ch/file/307111/1/project-team-280201.pdf

[19] Summary notes of the 2nd meeting on the target upstream collimator, https://edms.cern.ch/file/364031/1/T40collimator_251102.pdf

[20] Summary notes of the 1st meeting on the target upstream collimator, https://edms.cern.ch/file/363975/1/collimator_meeting_031002.pdf

[21] IN2P3 web-page on CNGS horns, http://www.lal.in2p3.fr/technique/secap/cornes-magnetiques

[22] J.M. Maugain, Summary notes of CNGS Technical Working Group meeting held on 10 July 2002, https://edms.cern.ch/file/350260/1/cngs_twg_100702.pdf .

[23] J.M. Maugain, Presentation given at the CNGS Technical Working Group meeting held on 4 December 2002, https://edms.cern.ch/file/364853/1/JMMaugain_041202.ppt

[24] "Installation of Decay Tube for the CNGS Project", Technical Specification to contract No. T064/ST/CNGS, https://edms.cern.ch/file/356471/2/Technical_Specification_October-2002.doc

[25] A. Bénéchet, “Calculs par éléments finis de la fenêtre d’entrée du tunnel de désintégration CNGS”, Note EST/ME 2001-007, https://edms.cern.ch/file/322158/1/2001-007.pdf

[26] G. Musso, “Strain measurements on the entry window of the disintegration tunnel CNGS during a pressure test”, Technical Note EST-ME/2002-005, https://edms.cern.ch/file/364554/1/2002-005.pdf

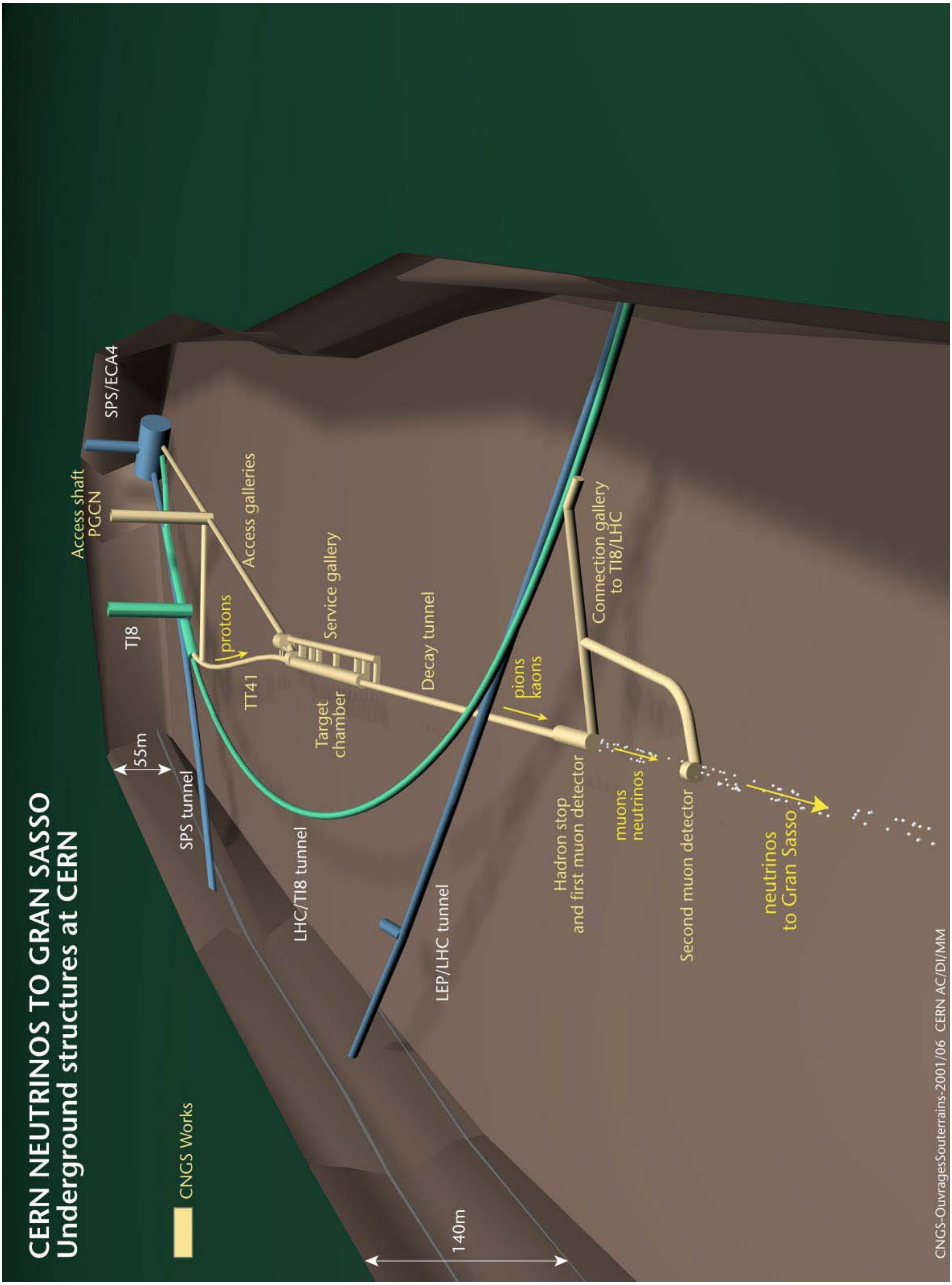
[27] Exit Window Decay Tube: Technical drawings, https://edms.cern.ch/document/365046

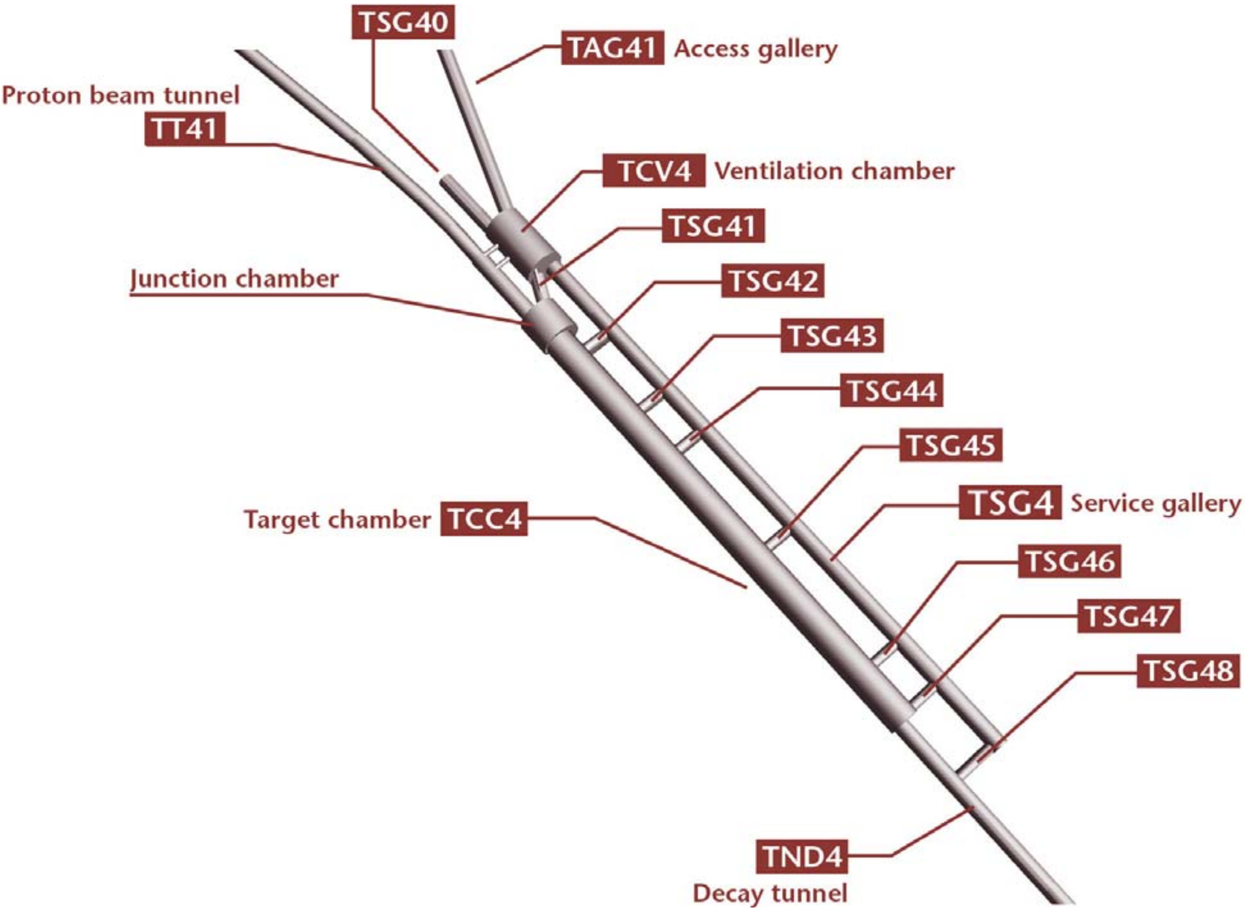
[28] Technical Specification for a vacuum-pumping unit, https://edms.cern.ch/document/376362

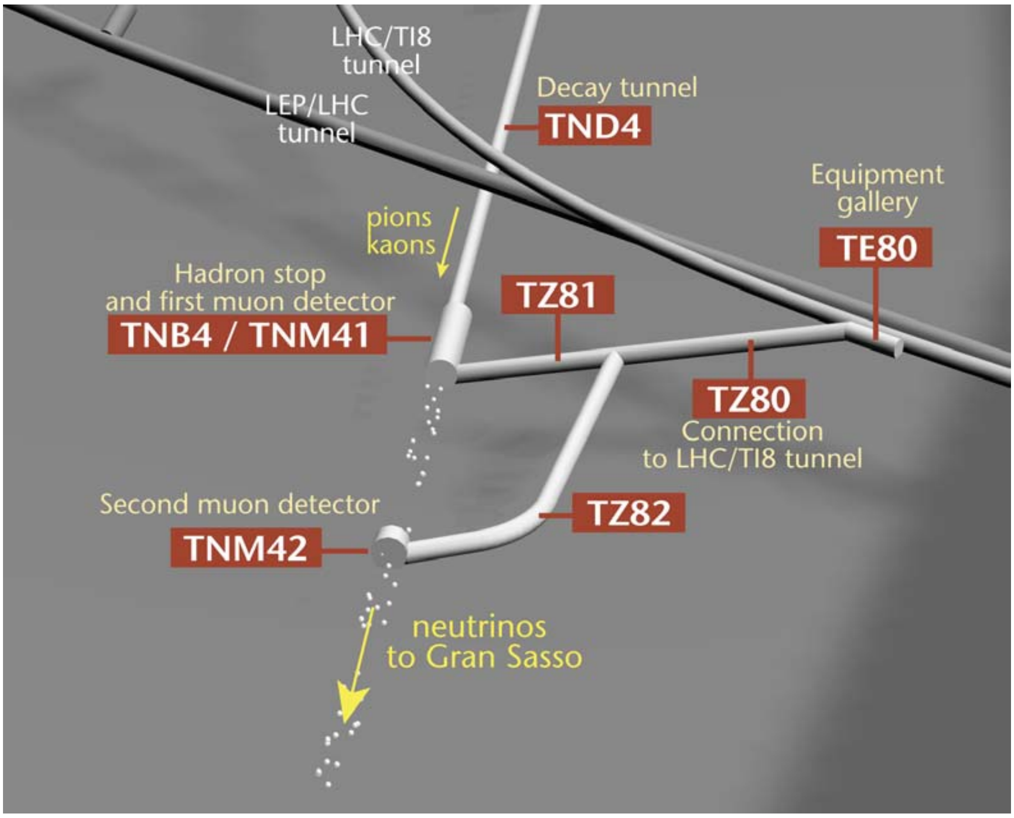
[29] R. Blom, “Airflow in the CNGS tunnel structures - a study for ensured operational safety”, ST-Note-2002-004, http://proj-cngs.web.cern.ch/proj-cngs/PDF%20files/st-note-2003-004.pdf

[30]R. Blom, presentation to the CNGS project team, 7 August 2002, https://edms.cern.ch/document/352373
[31] M. Vadon, “Consequences on the personnel of the implosion of the CNGS vacuum window”, internal report CERN-TIS-2003-01-GS-IR, https://edms.cern.ch/document/382508
[32] Technical Specification for the production of modular blocks in artificial graphite, https://edms.cern.ch/document/338192
[33] Technical Specification for a Modular cooling system of Cast Aluminium blocks with Integrated Stainless Steel tubes, https://edms.cern.ch/document/347318
[34] Technical Description for Flexible Metallic Hoses, https://edms.cern.ch/document/376360
[35] Functional specification of the muon detection system at CNGS, https://edms.cern.ch/file/357964/5/Func_Spec_Muon_Det_2.pdf
[36] A.E. Ball et al., “Why do we need both muon detector stations at the start-up of the CNGS neutrino beam?”, CERN-SL-2002-040 EA, https://edms.cern.ch/file/362548/2/SL_note_2002_040_EA.pdf

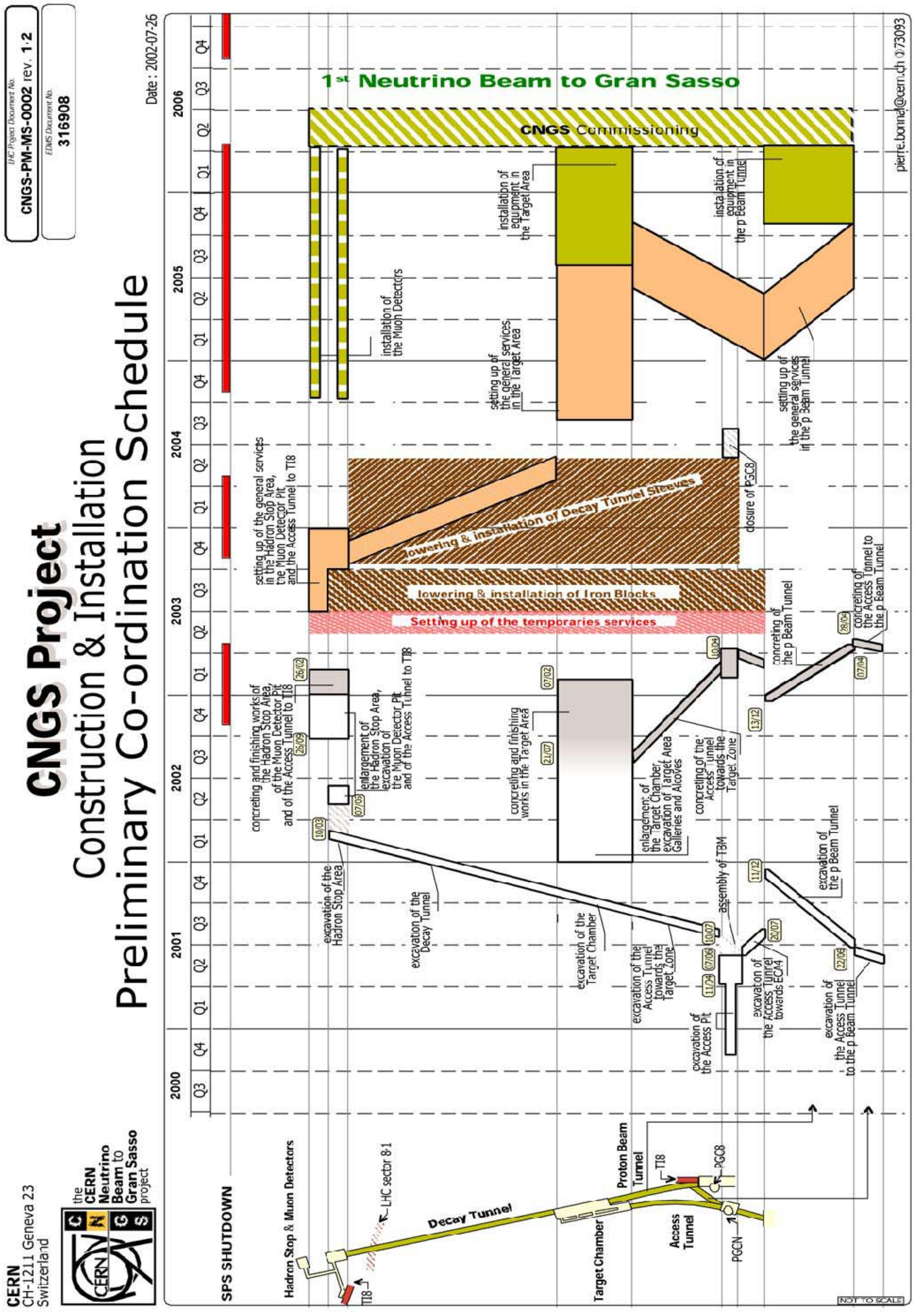
Appendix I: CNGS underground structures




TSG40
TAG41 Access gallery
Proton beam tunnel
TT41
TCV4 Ventilation chamber
TSG41
Junction chamber
TSG42
TSG43
TSG44
TSG45
TSG4 Service gallery
Target chamber TCC4
TSG46
TSG47
TSG48
TND4
Decay tunnel


LHC/TI8 tunnel
LEP/LHC tunnel
Decay tunnel
TND4
Equipment gallery
TE80
pions
kaons
Hadron stop and first muon detector
TNB4 / TNM41
TZ81
TZ80
Connection to LHC/TI8 tunnel
Second muon detector
TNM42
TZ82
neutrinos to Gran Sasso

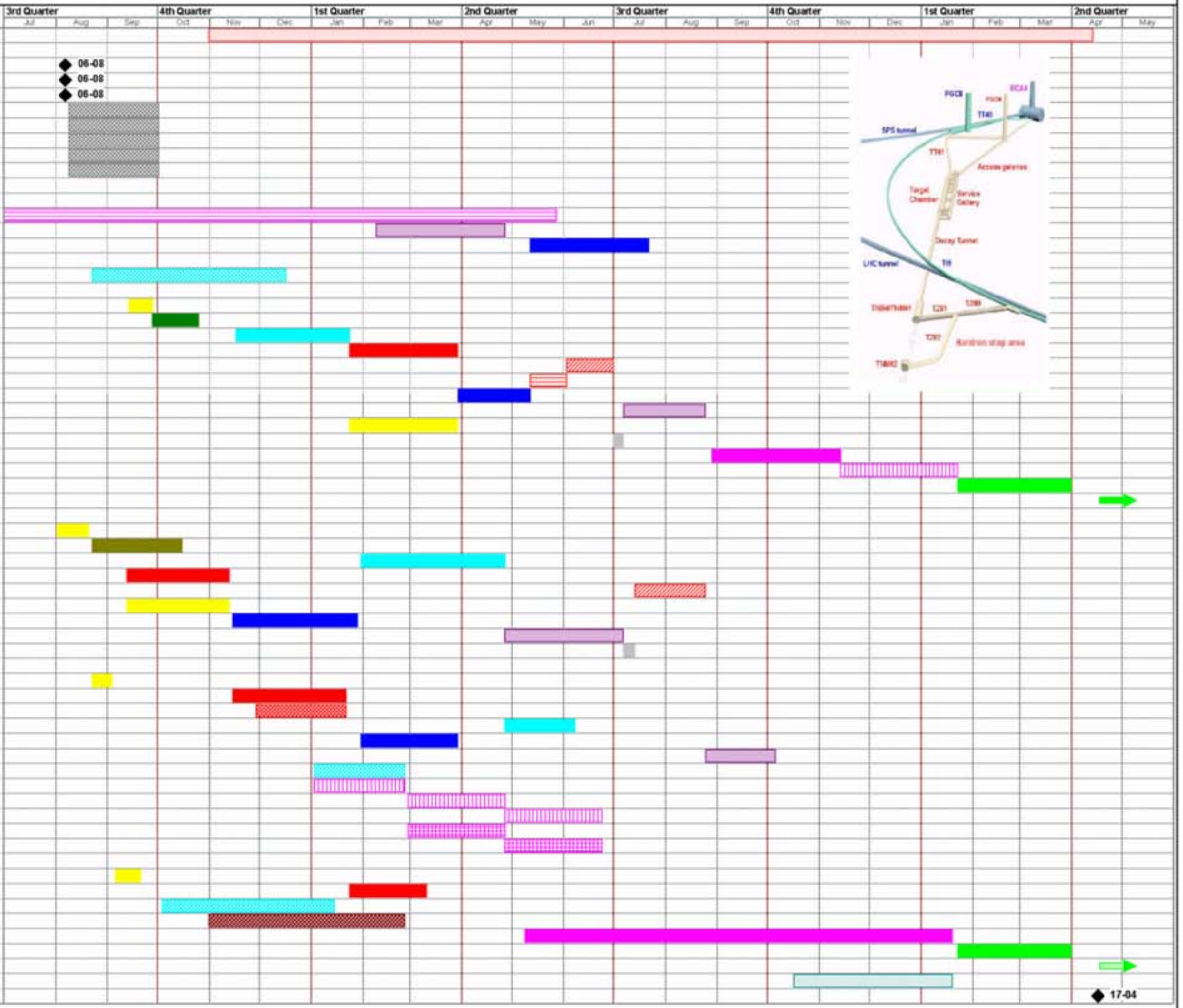
Appendix II: CNGS schedule



CNGS Project
Installation access & services areas + target chamber

CNGS-PM-MS-0004 rev 0.6
AC-TCP/hg
Date : 28.04.03

ID	Task Name
1	**SPS SHUTDOWN**
5	**Génie civil**
8	Mise à disposition TT41
9	Mise à disposition TAG41/42
10	Mise à disposition galeries de service
15	Exécuter les forages ventilation entre TCV4 et TT41
16	Exécuter les réservations pour rails de guidage en TSG41
17	Exécuter la tranchée "cible" en TCC4
18	Exécuter les forages " radiation" en TCC4
19	Exécuter le raccordement du drainage CNGS sur le drain ECA4
[illegible]	
60	**BHA4**
61	Installer les équipements de puissance pour la Corne & le Réflecteur
62	Tirer les câbles puissance et signaux BHA4 --> TAG41
63	Installer les tuyauteries verticales
64	**SUI8**
65	Installer la centrale de ventilation
66	**TT41**
67	Installer les services provisoires
68	Tracer la position des éléments au sol
69	Installer la gaine de ventilation
70	Installer les services généraux électriques
71	Installer le rail d'alimentation électrique
72	Installer la détection incendie
73	Installer les tuyauteries
74	Tirer les câbles puissance et signaux
75	Installer le câble à perte (GSM)
76	Peindre la bande de lecture optique
77	Installer les éléments magnétiques
78	Raccordements
79	Commissioning sans faisceau
80	Commissioning avec faisceau
81	**TAG41**
82	Installer les services provisoires
83	Installer les supports communs
84	Installer les gaines de ventilation
85	Installer les services généraux électriques
86	Installer le rail d'alimentation électrique
87	Installer le câble à perte (GSM)
88	Installer les tuyauteries
89	Tirer les câbles puissance et signaux
90	Peindre la bande de lecture optique
91	**TSG41 + TSG42 à 48**
92	Installer les services provisoires
93	Installer les services généraux électriques
94	Installer la sous station électrique
95	Installer les gaines de ventilation
96	Installer les tuyauteries
97	Tirer les câbles puissance et signaux
98	Installerles les unités de traitement d'air + gaines
99	Installer la station de refroidissement de la Corne
100	Installer la station de refroidissement du Reflecteur
101	Installer la station de refroidissement de la Cible
102	Installer l'alimentation de la Corne
103	Installer l'alimentation du Reflecteur
104	**TCV4 + TCC4 + TA/TSG41**
105	Installer les services provisoires
106	Installer les services généraux électriques
107	Installer la centrale de ventilation
108	Installer le pont roulant
109	Installer la cible et le faisceau secondaire
110	Commissioning sans faisceau
111	Commissioning avec faisceau
112	Installer les équipements de sécurité et de contrôle
113	Mise à disposition pour tests avec faisceau



CNGS-PM-MS-0004 rev 0.6
AC-TCP/hg
Date : 28.04.03

CNGS Project
Installation zone Hadron Stop (2003/2004)

ID	Task Name
1	SPS SHUTDOWN
5	**Génie civil**
6	Mise à disposition TE80
7	Mise à disposition zone Hadron
12	Installer le blindage en TNB4
13	Installer le tube de désintégration
14	Fermeture du puits de génie civil
20	Exécuter les forages profonds géodésiques en TCC4 et TNM41
21	Construire le mur de séparation amont en TNB4
22	Construire le mur de séparation aval + porte blindée + passerelles d'accès en TNB4
23	**Services Provisoires**
24	Mise à disposition blocs acier pour blindage
25	Mise à disposition modules de refroidissement du blindage
26	Installer l 'alimentation électrique des chantiers G.C. + Installation
27	Installer et mesurer les repères GGPSO
28	Installer l' éclairage et la force provisoires zone Hadron + TT41 + TAG41 1p. +TAG42
29	Installer la ventilation provisoire zone Hadron + TT41 + TAG41 1p. +TAG42
30	Installer le télephone rouge zone Hadron + TT41 + TAG41 1p. +TAG42
31	**Hadron Stop Area**
32	**Electricité**
33	Installer les services généraux éléctriques en TNM42 + TZ82
34	Installer les services généraux éléctriques en TZ81/TZ80
35	Installer les services généraux en TNB4/TNM41
36	Installer la sous station électrique en TE80
38	Installer le câble à perte en TZ80/81/82
39	Tirer les câbles de TE80 vers TMN42 et TMN41
40	**Ventilation**
41	Installer la gaine de ventilation en TMN42/TZ82
42	Installer la gaine de ventilation en TZ81/TZ80/TE80
43	Installer la station de ventilation en TE80
44	**Refroidissement**
45	Installer la station de refroidissement en TE80
46	Installer les tuyauteries en TZ81/TZ80/TE80
47	**Equipements**
48	Installer le système de manutention fenêtre en TNB4
49	Transporter la fenêtre en TNB4
50	Stocker la fenêtre en TNB4
51	Installer la fenêtre sur Decay Tube en TNB4
52	Démonter le système de manutention fenêtre en TNB4
53	Installer les supports pour les flexibles de refroiddissement
54	Installer et raccorder les flexibles sur modules de refroidissement
55	Installer et raccorder le manifold
56	Raccorder les flexibles sur le manifold
57	Tester le circuit de refroidissement
58	Installer le câblage pour les sondes de température
59	Installer les sondes de température
112	Installer les équipements de sécurité et de contrôle

Appendix III: RHWG - Proposition of program from March 2003 to Dec 2003

Months	N°	Id	Sections	Operations	Sub-operations	Details
March	1	1/6	Horns	Horn change	Removal of the shielding wall	Automatic (new development) or standard clamping - Storage of the blocks
	2	2/6	Horns	Horn change	Transport to storage gallery	approach discussion about the method (shielded trailer?)
	3		G.S			General Services (maintenance, repairs, lighting…) EXTRA RHWG Meeting
April	4	1/6	Target	Target cradle ch.	Transport to storage gallery	approach discussion about the method (shielded trailer?)
	5	2/6	Target	Target cradle ch.	Opening the roof - Extraction	Detail of the operations
May	6	3/6	Target	Dismantling	Removal shielding blocks	Automatic (new development) or standard clamping accepted
	7		Crane			Prestudy REJLERS - Remarks and conclusions
June	8	3/6	Horns	Strip-line horn ch.	Removal parts 1, 2 and 3	Low probability to exchange the strip-line but manual operations
	9		Monitors	Up-stream ch.	Transport to storage gallery	approach discussion about the method (shielded trailer?)
July	10	4/6	Horns	Horn change	Transport to storage gallery	Proposal solutions for transport to the storage gallery
	11	4/6	Target	Target cradle ch.	Transport to storage gallery	Proposal solutions for transport to the storage gallery
August	**HOLIDAYS**					
Sept	12		Shielding			Installation / de-installation procedures / roof opening
	13		He tube			Installation / de-installation procedures
Oct	14	5/6	Horns	Horn change	Transport to storage gallery	Choice of the final solution for transport the horn to the storage gallery
	15	5/6	Target	Target cradle ch.	Transport to storage gallery	Choice of the final solution for transport the target assembly to the storage gallery
Nov	16	6/6	Horns	Horn change	Transport to storage gallery	Detail of the complete exchange procedure
	17	6/6	Target	Target cradle ch.	Transport to storage gallery	Detail of the complete exchange procedure
Dec	18	**General summarize**				