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CNGS progress report 2004

The CNGS project team

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Abstract

The CNGS project is progressing according to schedule, with the aim to be ready for beam in spring 2006. In this paper, the project status and recent changes to the design of systems and components are summarized. The actions taken in response to the recommendations of the 2003 CNGS Review are described. This report has been drafted in view of the third CNGS Review, held in June 2004.

Contents

1. Introduction

The approval of the CNGS project by the CERN council in December 1999 was based on the technical description given in [1.1, 1.2]. Further changes to the CNGS secondary beam layout (target – horn – reflector) during the year 2000 are described in [1.3]. 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.

The CNGS web-site [1.4] 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 [1.5] - 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 [1.6]. An update was provided in [1.7], in preparation of the 2nd CNGS Review in April 2003.

The aim of the present note is to summarise the progress of the CNGS project from May 2003 until May 2004, and to give an overview of the evolution in the design of the various systems. 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.

A summary of 2003 Review recommendations and the actions taken since is given in Appendix I. 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 II.

References:

[1.1] 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.

[1.2] 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

[1.3] 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

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

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

[1.6] 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

[1.7] L. Bruno et al., “CNGS layout and systems: a progress report”, AB-Note-2003-060-CNGS

http://proj-cngs.web.cern.ch/proj-cngs/PDF%20files/CNGS%20progress%20Note_2003.pdf

2. Status of CNGS (May 2004)

The schedule for CNGS construction and installation, leading to the commissioning of the beam in spring 2006, is presented on the CNGS web pages [2.1]. A simplified version of this schedule is given in Figure 2.1. The first phase of civil engineering works (excavation and concreting of all underground structures) was completed on schedule in June 2003.

Figure 2.1 - Simplified CNGS construction schedule

For logistics reasons, the hadron stop (beam dump) had to be installed before the decay tube. Installation of the 1825 tons of iron and 35 tons of graphite blocks started in June and was finished in September 2003. Next, the decay tube exit window had to be transported to the hadron stop area to clear the way for the installation of the tube itself.

Production of steel sleeves for the decay tube, at the contractors' premises, began early 2003. As of September 2003, the 6 metre long sleeves started arriving at the CNGS work site. They were transported through the civil engineering shaft and the access gallery to the target chamber. There, a workshop including a provisional crane had been installed. Three sleeves were welded into 18 metre long sections. The welds were checked carefully with three different methods (dye penetrant, ultrasound and radiography). The decay tube sections were then lowered on rails into the decay tunnel and welded onto the already installed parts. Concrete was filled around the decay tube. In this way, 18 metres of tube were installed and concreted in a 24 hour day. The decay tube was completed in March 2004. The final exit window and a provisional entrance window, each a 50 mm thick steel plate, were installed. On 1 April, the decay tube was ready for the vacuum test by the contractor.

Pumping the decay tube to well below 1 mbar took 35 hours. The vacuum test consisted in closing the valves and observing the pressure rise in the decay tube during 10 days. The results, much better than required by the technical specification, are shown in Figure 2.2.

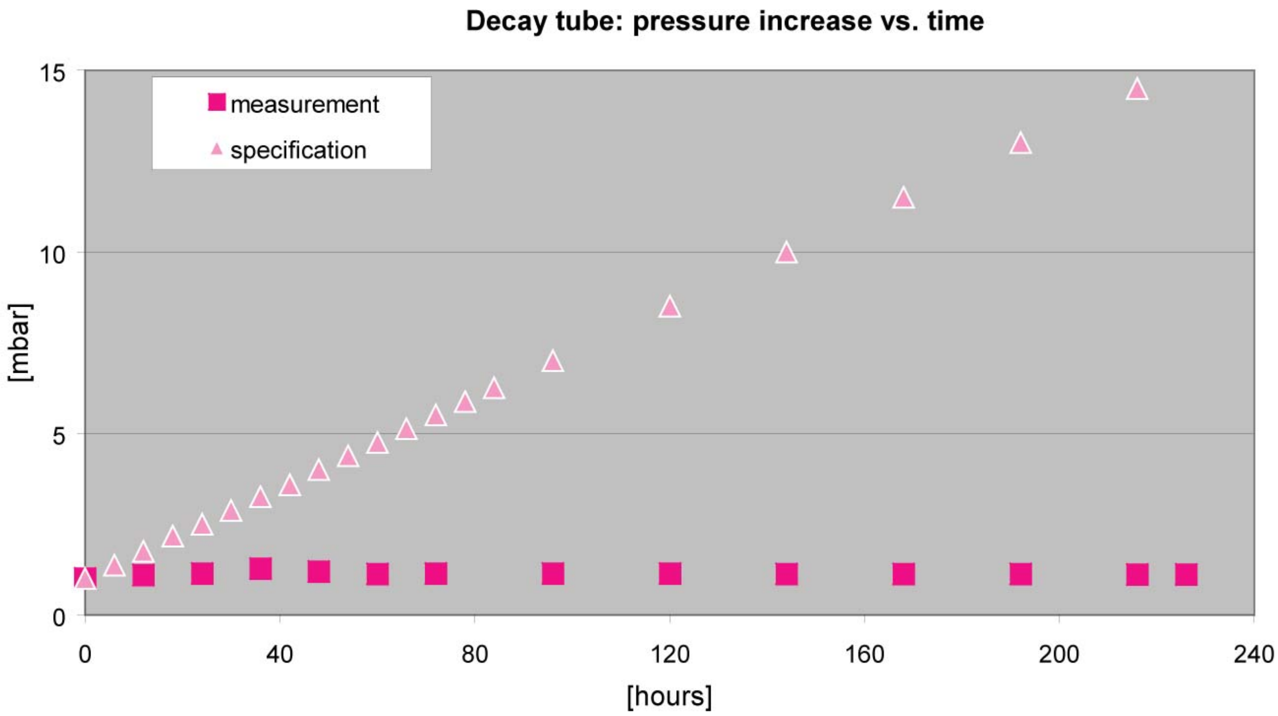

Figure 2.2 - Results of the decay tube vacuum tests

Currently, the second phase of civil engineering is approaching completion: the finishing of the floors in the access gallery and target chamber had been postponed due to the heavy traffic needed during the decay tube works, but is now completed. The provisional civil engineering shaft is being closed and all the buildings on the surface removed, in order to leave the area as it was originally, i.e. as a meadow for farming.

The next phase of works in the CNGS tunnels consists of four main categories: installation of electrical infrastructure, of air-handling equipment and ducts, of equipment and pipe works for the cooling systems, and finally of magnet powering cables and controls cables. For cooling and ventilation, two CNGS-specific contracts have been signed, while for the electrical installations and cables, existing CERN-wide contracts are being used. An important contract has also been signed for the construction and installation of the TCC4 target chamber crane. The installation of this crane is foreseen to take place November 2004 to February 2005.

In preparation of the installation of services in the 800 metre long access gallery, a common support system has been developed. Space is very limited in this gallery, and the largest object to be transported (the reflector) barely passes through the tunnel once all services are installed, as shown in Figure 2.3. Measurements of the profile of the access gallery were taken every five metres, and computer models indicated that the space available seemed sufficient. Nevertheless, as a further check an 11 metre long “test-object”, a metallic structure of 3.1 metres diameter, was passed through the tunnel in April 2004. Over a length of about 30 metres, this object touched the walls indicating that the tunnel dimensions were not according to specifications. It was agreed to correct for this nonconformity by inserting the common supports into 15 cm wide slots cut into the shot-crete walls in the region of concern.

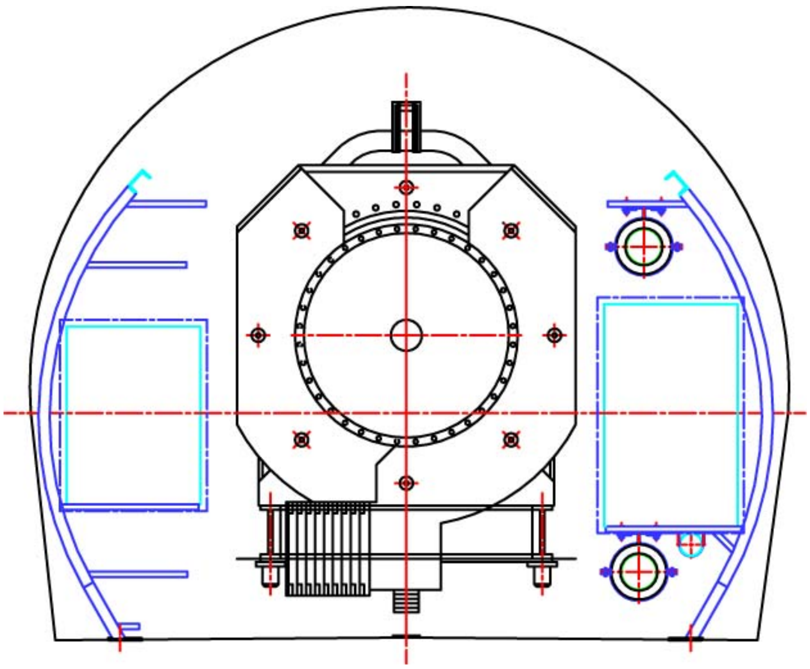

Figure 2.3 - Section of the TAG41 access gallery, showing the common supports for the services, and indicating the reflector being transported to the target chamber

Reference:

[2.1] CNGS schedule, http://proj-cngs.web.cern.ch/proj-cngs/Planning/Planning.htm

3. Proton beam TT41

3.1 SPS extraction kicker (MKE)

Five fast pulsed kicker magnets (MKE) are part of the extraction system used to send the CNGS beam down the proton beam line. During the operation of the CNGS facility, we foresee to have a SPS cycle of 6 seconds with a short flat-top where two 10.5 μs long extractions, separated by 50 ms, are to take place at 400 GeV. The specifications of the MKE kickers are thus very challenging: rise and fall time of 1.1 μs, 2 usable flat top lengths of 10.5 μs, kick pulse flat top ripple of <2% (peak-to-peak), and post kick pulse ripple of < 2%.

During September 2003, SPS extraction tests took place in order to commission the extraction channel in LSS4 and the first 100 metres of TT40. Measurements on the extraction kickers were performed and showed that the usable flat top length (part of the flat top within the specified 2% ripple), taking into account the presently measured rise- and fall-times, was only 8.5 μs, (i.e. below the required 10.5 μs). The rise and fall time, the kick pulse flat top ripple and the post kick pulse ripple were outside the specifications given above [3.1, 3.2].

Following these first experimental results, simulations were performed in order to assess the effect on the beam stability of an increased kicker field ripple on the flat top. Earlier studies [3.3] have demonstrated that the main source of horizontal beam instability at the target was coming from the extraction system, and the effect was traced back mainly to the MKE kicker magnets. Additional simulations have now been performed for 3000 bunches (each of them simulating a batch of protons), taking into account all the magnet and injection errors, which vary from pulse to pulse. The spread of the bunch centre was monitored at the target focal point and is summarized in Table 3.1. Different cases are presented, depending on the value of the MKE flat top field ripple (peak to peak).

Table 3.1 - Spread in horizontal position and angle at the target, for different MKE field ripple

	σ_x [mm]	σ'_x [μrad]	$2\sigma_x$ [mm]
2% MKE field ripple	0.2	8	0.4
3% MKE field ripple	0.24	12	0.48
4% MKE field ripple	0.32	16	0.64

Following these results, and knowing that the overall $2\sigma_x$ beam spread from errors should not be greater than 0.5 mm (see 3.2.3, below), it was confirmed that the MKE field ripple should remain below 3% peak-to-peak.

Rise time and fall time optimisation on the MKE pulse took place during winter 2003-2004, as well as a reduction of the MKE generator Pulse Forming Network lengths. With these improvements, the upgraded MKE kickers were measured in the laboratory and showed that the rise time could indeed be reduced to 1.2 μs (vs. nominal 1.1 μs), the usable batch length was increased to 10.4 μs for the two batches, and the post kick pulse ripple was improved but still in the order of 10% (vs. the nominal < 2%). The MKE pulse flat top ripple as well as the fall time are now within specification [3.4].

Despite this much-improved MKE performance, work remains to be done in reducing the rise time and in decreasing the post kick pulse ripples. In the meantime, simulations are being performed in order to quantify the effect of this large post kick ripple on the second CNGS batch circulating in the SPS before its extraction. Possible resulting emittance growth is being studied. It is also investigated how the SPS damper system could be used to damp the oscillations affecting some of the bunches in the second batch [3.5].

In April 2004, the 5 modified thirty MKE kicker magnet capacitance boxes have been re-installed, followed by the re-installation in June 2004 of the modified five MKE TMRs (Terminating Magnet Resistances). In addition, SPS machine developments are planed in September 2004 in order to test, with beam, the usable flat top length (within the admissible ripple) and the effect of the post kick pulse ripple on the second batch circulating in the SPS. Damping of possible oscillations affecting the second batch by this post kick pulse ripple will be tested with the SPS damper system.

3.2 Possible beam size increase at the target

Following a suggestion by the 2003 Review board, the possibility to increase the proton beam size in order to reduce stresses on target rods and to remove the problems related to the standard titanium windows has been investigated. As indicated in the following, the conclusion at this point is to keep the base-line value of $\sigma_{x,y}$ = 0.53 mm and the base-line target (graphite rods, 5 and 4 mm diameter). If found necessary, and at the cost of neutrino beam production per proton, the beam spot diameter can be increased by a factor 1.3 and the rod diameter to e.g. 6 mm.

3.2.1 Motivation

At ultimate beam intensity ($7x10^{13}$ protons on target per cycle, i.e. $3.5x10^{13}$ protons in 10.5 μs), the short, intense, small CNGS batch is pushing the material resistance of some beam line elements to their limits. This is an issue, in particular, for the standard 100 μm Ti windows.

Although careful choice of material has been made for the TT41 proton beam and the target area – i.e. Beryllium proton beam exit window and target tube window– the solutions for other equipment are limited and remain critical at ultimate intensity. In particular, the choice of material for the target rods (and the rod size) has strong implication on the secondary particle production: for the baseline target, graphite rods have been chosen. Another concern is the target downstream monitor (TBID). Since no time could be devoted to a new development, it was decided to use the standard SPS Secondary Emission Monitor (SEM) with Ti vacuum windows. It is understood that in case the beam misses the target, the TBID might not survive at the highest intensities, thus the crosscheck on the particle production would rely on the downstream muon detectors.

As a possible way out of these problems, the CNGS review board members recommended in 2003 to examine the option of increasing the proton beam spot size. Results of such studies are presented here, together with the implications on the target stress and on the neutrino production.

3.2.2 Optics study

At the early stages of the CNGS project [1.1], the proton beam line design assumed equal transverse emittance from the SPS and was based on a beta function at the target in both planes of 2.5 m. The corresponding beam sizes were $\sigma_{x,y}$ = 0.26 mm. The proton beam line geometry has been designed to fulfil these requirements. The limited budget imposed to design a beam line as short as possible (which in turn reduces the matching flexibility).

At the start of the target conceptual design study, the beam sizes were requested to be increased in order to enhance the target resistance against the thermo-mechanical shock from the beam pulse. Still assuming equal transverse emittance from the SPS, the beta functions in both planes were matched to 10 m, and this became the CNGS baseline. The corresponding beam sizes are $\sigma_{x,y}$ = 0.53 mm.

In 2003, it was announced that the SPS proton emittance will be unbalanced in the transverse plane. With the baseline beta function of 10 m in both planes, the corresponding beam sizes (1σ) were becoming $\sigma_x = 0.53$ mm, and $\sigma_y = 0.4$ mm. However, the CNGS beam has been designed from the very beginning as a circular beam, and everything was optimised for this geometry. Also in 2003, it was confirmed that there should be no change in the beam size ratio (i.e. deliver round beam at the target). In order to deliver a round beam, the vertical beta function has to be further increased to 20 m.

Starting from this last case – $\beta_x = 10$ m, and $\beta_y = 20$ m ($\sigma_x = 0.53$ mm, and $\sigma_y = 0.56$ mm) – a study was performed in order to investigate if the beta functions at the target focal point could be further enlarged. The optical matching revealed that increasing the beta functions to 30 m in both planes ($\sigma_x = 0.91$ mm, $\sigma_y = 0.7$ mm) is feasible, but is at the limit of some power supplies and of the available aperture. In order to keep a round beam, the ultimate beta functions would therefore be $\beta_x = 20$ m, and $\beta_y = 30$ m ($\sigma_x = 0.75$ mm, and $\sigma_y = 0.7$ mm). In order to achieve this, the power supply of one downstream quadrupole magnet had to be swapped with a quadrupole power supply in TT40 to provide sufficient powering at 450 GeV with a small margin at 400 GeV.

In summary, the optical study has been performed and it has been demonstrated that with the present design of the proton beam line, the beta functions could be increased from $\beta_x = 10$ m, $\beta_y = 20$ m ($\sigma_x = 0.53$ mm, $\sigma_y = 0.56$ mm) to $\beta_x = 20$ m, $\beta_y = 30$ m ($\sigma_x = 0.75$ mm, $\sigma_y = 0.7$mm).

3.2.3 Effect of beam size and beam eccentricity on target stresses

When evaluating the target rod resistance, the important parameters are the proton beam size and the beam stability, i.e. the position of the beam centre at the target pulse after pulse. With the knowledge of these values, it is possible to quantify precisely what will be the surface occupied by the beam when hitting the target rod. In addition, for one or two extractions, extreme beam excursions of a few millimetres cannot be excluded - detecting such errors will lead to a beam interlock for the following SPS cycle.

The main source of horizontal instability for the smaller but continuous beam movements, varying from pulse to pulse, comes from the MKE kicker magnets. It was demonstrated that the MKE field ripple should remain below 3% (peak-to-peak) in order to contain the overall beam errors onto the target rod below 0.5 mm. Investigating further the case of 3% MKE field ripple (vs. the nominal 2%), the margin onto the target rods was evaluated for the nominal beam sizes (σ= 0.53 mm).

On the first two rods of the target (5 mm diameter), the margin left is 0.43 mm (2.5 mm – 3 σ_{beam} + 2 σ_{errors}), as compared to 0.51 mm for the case of the nominal 2% ripple. On the following rods (4 mm diameter), the margin left is -0.07 mm (2.0 mm – (3 σ_{beam} + 2 σ_{errors}), as compared to -0.01 mm for the case of the nominal 2% MKE ripple.

It is seen from these results that the baseline beam parameters are already leaving little or no margin onto the target rods. Decreasing further this margin (by increasing the beam sizes or the beam eccentricity) implies missing the target with part of the beam, i.e. more losses in particle production, more activation downstream of the target, and - in the particular case of larger beam eccentricity - an increase of the rod stresses.

3.2.3.1 Stresses in target rods and beam eccentricity

An analytical model was used to evaluate the maximum stresses in the target rods due to beam eccentricity onto the target [3.6, 3.7]. The study shows that the beam eccentricity is critical as it induces large transversal oscillations in the target rods. In addition, the second pulse in a SPS cycle (after 50 ms) hits the target rods when thermal equilibrium from the first pulse is not yet reached, hence building up overall stresses. Note that the problem discussed here already arises from **one** SPS cycle, i.e. from an unavoidable, though rare, accidental beam mis-steering.

The results on the total stress (in MPa) on the graphite target rods are summarized in Table 3.2, for off centered beam of 1.5 mm (the worst case found in the calculation) and for 2 extractions at ultimate intensity (2 times 3.5×10^{13} protons). Different cases are shown, as a function of the beam size and the target rod radius. (The numbers in parenthesis represent the total stress scaled down to nominal proton beam intensity, 2 times 2.4×10^{13} protons).

Table 3.2 - Worst target rod stresses calculated for graphite (in MPa) for off-centered proton beam and two extractions at ultimate intensity

Rod radius \ beam size	$\sigma = 0.53$	$\sigma = 0.75$	$\sigma = 0.80$
2 mm	38 (26)	27 (18)	
2.5 mm	34 (23)		22 (15)
3 mm	28 (19)		20 (14)

For the particular graphite chosen for the target elements, the safe area (from an engineering point of view) is evaluated to lie between 0 to 18.7 MPa, the area considered to be “limit” between 18.7 to 28 MPa, and the unsafe area above 28 MPa. Note that the value of 18.7 MPa is derived from the measured value of 56 MPa for allowable transverse stresses by applying twice a factor of 2/3 – once to derive the tensile strength, and a second time as a safety factor to protect against otherwise unknown effects of material fatigue etc..

For graphite rods and ultimate intensity, none of the calculated stress values are within the safe range for the presented beam sizes and rod radii. The results in [3.6, 3.7] show that the beam eccentricity must remain below 0.4 mm for ultimate intensity in order to reach stresses in the safe region.

For nominal intensity, and in the case of 0.5 mm beam eccentricity (3% MKE field ripple), the stress values remain marginal for the nominal beam sizes and target rod diameters. At no time, the beam eccentricity should be relaxed beyond 0.5 mm.

3.2.3.2 Different target material

The target magazine offering the possibility to have 5 in-situ target units, a combination of different target materials and rod diameters can be prepared in view of the demanding constraints of high intensity runs.

Some preliminary calculations have been performed for hexagonal Boron Nitride and results on target resistance to off centred beam (by 1.5 mm) are summarised in Table 3.3 for ultimate intensity [3.7].

Table 3.3 - Worst target rod stresses calculated for hexagonal boron nitride (in MPa) for off-centered proton beam and two extractions at ultimate intensity

Rod radius \ beam size	σ = 0.53			
	parallel direction		perpendicular direction	
2 mm	33.3		27.0	
	σz=34.4	σq=-4.1	σz=10.0	σq=21.7
2.5 mm	30.7		29.2	
	σz=31.8	σq=-4.5	σz=11.1	σq=23.2

The safe area for hBN was estimated to lie between 0 to 23 MPa, the "limit" area between 23 to 34.5 MPa, and the unsafe area beyond 34.5 MPa. It was therefore found, in these preliminary calculations, that hBN would still be marginal at ultimate intensity. Much more refined numerical calculations [3.9] have recently confirmed the results for graphite, but have given more optimistic results for hBN. However, fatigue tests recently performed at high temperature (700^{o} C) indicated that hBN might not be suitable as target material in CNGS.

3.2.4 Effect of a beam size increase on the neutrino production

FLUKA simulations have been performed [3.8] in order to quantify the changes on the ν_μ flux and the ν_τ production for different beam sizes and target rod radii. The simulations were done for 10^6 protons on target and assuming a 0.3 mm off-centred proton beam. Results are compared in Table 3.4. to the nominal case (first two rods 5 mm diameter, all other rods 4 mm diameter).

Table 3.4 - Loss in ν_τ charged-current events at Gran Sasso for different target / beam size combinations, compared to the nominal case

Rod radius \ beam size	σ = 0.53	σ = 0.70	σ = 0.80
2 mm			
2.5 mm			-2.8 %
3 mm	- 23 %		-7.0 %

Using FLUKA calculations, it was demonstrated that the combination of nominal beam sizes ($\sigma_{x,y}$ = 0.53mm) and a 6 mm diameter graphite target rod (instead of 4 mm and 5 mm) would lead to an unacceptable drop of 23% in ν_τ CC events. Increasing the beam sizes to $\sigma_{x,y}$ = 0.8 mm, would lead to a 3% drop in ν_τ CC events for a 5 mm diameter target rod and 7% drop in ν_τ CC events for a 6 mm diameter target rod. Increasing the beam sizes further would lead to further losses in production per incident proton.

3.3 Alignment of the TT41 magnets

The proton beam line TT41 must have a final slope relative to the SPS of 5.6% (i.e. 56 mrad) and provide a horizontal deflection of 36^{o}. This is achieved with 73 dipoles. To provide the necessary vertical deflection, 32 of these dipoles are tilted by approximately 12.8^{o}.

It was shown in a study for the LHC transfer line TI8 [3.10], that horizontal bending magnets aligned with a slope relative to the (local) beam reference system introduce a tilt (roll) error into the beam. This error accumulates along the beam line and can become significant. This can lead to a mismatch when the beam is injected into the LHC and results in an emittance growth. In the report [3.10] this issue was studied in great detail and a strategy for the alignment of the elements was developed and proposed. Although the emittance aspect is less a concern for the CNGS proton beam, the steering of the beam on the target and the beam stability are very important issues [3.11, 3.3].

At the time of this study, it is still possible to decide whether the quadrupoles together with the trajectory correction elements (i.e. monitors and correctors) should be aligned in a global system or whether they should be tilted such they follow the (accumulated) beam tilt (i.e. aligned in the local beam reference system). In the latter case, betatron coupling would be avoided and, more important for the CNGS beam line, there will be no cross talk between the planes during trajectory correction and beam steering.

In a previous study [3.3] we have evaluated the stability of the beam on the target, using the expected tolerances of the beam line elements. We have found that the most important contribution to the movement of the beam on the target comes from injection fluctuations, which are mainly in the horizontal plane. The r.m.s. of the beam movement in the horizontal plane is therefore much larger than in the vertical direction. A tilt of the principal beam axes can thus couple the larger horizontal movement into the vertical plane.

In the case where the quadrupoles are tilted into the axes of the beam tilt (i.e. aligned in the local beam reference system), we have demonstrated [3.12] that no coupling is visible from the horizontal into the vertical plane and the trajectory correction is strictly decoupled in the two planes. Although we have found that the effect at the target is small (but observable), we have decided to align the quadrupoles with the beam tilt since it allows a better steering of the beam and relaxes the tolerances on the errors such as power supply ripples on dipole magnets.

3.4 Beam monitoring status

3.4.1 BPG Measurement System

The CNGS beam position monitoring system will be based on button electrode pick-ups followed by a logarithmic amplifier acquisition system. The monitors have all been constructed and are of the same type as have recently been installed in the TI8 transfer line for the LHC, using recuperated LEP button electrodes.

The first prototype of the front-end electronic card is currently being tested, with the aim of using it on a CNGS type pick-up in the SPS before the end of the 2004 run. Experience with a similar logarithmic amplifier system in the TT2/TT10 PS to SPS transfer lines has allowed the CNGS design to be optimised for both performance and robustness. In particular an auto trigger system has been introduced to avoid problems which can occur during the setting-up and commissioning, when the external machine timing is often unstable. The inherent non-linearity of the logarithmic amplifier has been compensated by adding a second “de-phased” logarithmic amplifier to the input stage. By summing the outputs of these two amplifiers the sinusoidal non-linearity can be significantly reduced. Using the auto-trigger principle requires the sum and difference signals obtained to be digitised in the front-end to avoid the need for extra cables and cable delay compensation. This has the added advantage that the results from the horizontal, vertical and sum channels can be multiplexed onto a single output for sending to the VME acquisition electronics. The VME acquisition will be based on the DAB64x card, the standard acquisition card designed by TRIUMF (Canada) for all LHC BPM electronics. Such a card is already integrated into the SPS control system, therefore minimising the time required for software development. The specific FPGA code for the LHC BPM system will be replaced by a simplified code for the CNGS system, to allow the decoding of several input channels on a single board.

The current planning aims to fully test the front-end board by the end of 2004, allowing a series of some 25 cards to be produced during 2005. The interface between this card and the

DAB64x, along with the DAB64x FPGA code alterations will commence towards the end of 2004, so allowing a complete system to be assembled and tested by the summer of 2005.

3.4.2 BPKG Monitor

The BPKG monitor is the final monitor in the CNGS proton beam line and will be positioned and aligned directly on the target table (see Figure 3.1). This monitor is currently designed as a stripline coupler able to operate in air (such monitors are usually operated under vacuum). Such a design alleviates the problems related to vacuum windows at these high instantaneous beam intensities and reduces the amount of equipment required to be located in or near to a very high radiation area. The problem with these monitors is that the induced air ionisation, which is very important, is seen to affect the signals coming from the beam. Tests in 2003 in the CERN-PS Booster showed that the stripline monitor, with its detection principle based on electro-magnetic coupling, was much less sensitive to such perturbations than an electrostatic button electrode monitor. However, significant noise coming from what is believed to be the air ionisation was still visible on the raw electrode signals. In 2004 a test was again performed in the PS-Booster, where a solenoidal magnetic field of ~10mT (20A in 100 windings) was used to try and expel the electrons generated by air ionisation from the active BPM region. No effect was seen on the signal from such a field, even when the intensity of the beam was reduced by a factor of two. Increasing the magnetic field much further will be difficult and therefore alternative approaches to solving this problem are now being sought. One idea is to use high voltage clearing electrodes to attract the electrons away from the signal electrodes. This will again be tested in the PS-Booster during a later 2004 run. Additionally, a stripline coupler in air has been installed in the TT40 extraction line towards the LHC and CNGS.

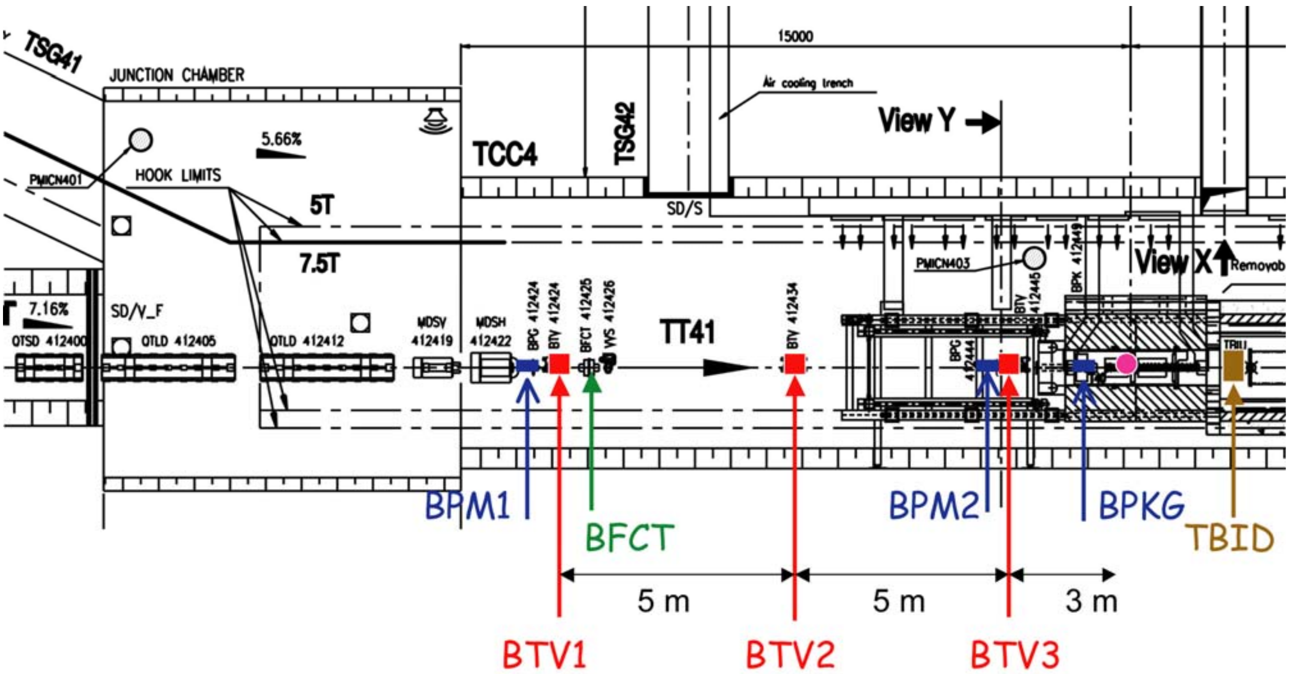

Figure 3.1 - Beam monitoring equipment around the T40 target station

Data taking from this pick-up will take place during the autumn, both for the CNGS extractions with low intensity, 200MHz structure beams and for the high intensity, 40MHz, LHC extractions. The results from these tests should allow the design of the BPKG coupler to be finalised by early 2005.

The integration of this monitor into the target area layout is proceeding well. The method of positioning and alignment are currently under discussion and a first monitor design exists. A layout also now exists for the routing of the semi-rigid radiation hard coaxial cables required to carry the signals to the outside of the target shielding.

3.4.3 Profile monitors around the target

3.4.3.1 Motivation for additional BTV's in front of the target station

Beam instrumentation specifications have been written [3.13] and stressed that the knowledge of the beam sizes at the target is of great importance for the target integrity. The preferable set-up foresaw the use of two BTV profile monitors (Optical Transition Radiation (OTR) screens observed by a camera), positioned (1) at the exit of the proton beam line last quadrupole magnet, and (2) as close as possible to the target station. It was added that if it was impossible to place a profile monitor in front of the target station, the beam sizes at the target would have to be derived from the upstream profile readings, with a precision affected by the uncertainty on the knowledge of the beta functions.

A proposal for the layout (see Figure 3.1.) of the BTV's was recently made, taking into account the high radioactive environment in front of the target [3.14] with the consequence that a CCD camera might not survive long in this place. Knowledge on the resistance of modern cameras in such an environment is missing due to the lack of experience. It was decided that a BTV monitor will be placed in front of the target, but another BTV will be added 5 m upstream. This additional monitor would serve as a back-up in case the one closest to the target would fail. It was agreed that maintenance on the last monitor will only be considered at the end of a shutdown period, when the equipment will be less radioactive. With a two monitor scheme as now proposed, measurements of the beam sizes at the target will be performed within the precision required and on line monitoring will be available to make sure that the proton beam remains within the allowable beam sizes.

3.4.3.2 Status of BTVG's

Three TV observation stations (*BTV**G***'s, i.e. BTV in the proton line to **G**ran Sasso) will be installed in the ten meters upstream of the target station. The purpose of these monitors is to measure the beam profiles and also complement the beam position monitors in the measurement of the beam centre. Considerations of the radiation levels in this area suggest to install the simplest system possible, still compatible with the required performances; this in order to minimize the maintenance interventions.

It has been estimated that the effects of the foreseen radiators on the beam emittance is sufficiently small to allow the last radiator to be permanently inserted in the beam. This allows the suppression of an important source of concerns, the screen manipulation mechanisms, which would require regular maintenance. The redundancy of devices also offers a safety margin; a major failure on one of the devices will not force a "*hot intervention*", but will instead give the possibility to better choose the terms of the intervention.

Although the functionalities of the two systems closer to the target will be simpler compared to the standard *BTVG* type foreseen for the rest of the *CNGS* line, it was nevertheless decided to use these standard *BTVG* tanks also for the two upstream target profile monitors and strip them of the features which are not required. This will increase standardization (important in case of maintenance interventions) and reduce design and integration costs.

The standard *BTVG* tanks, including the second and third ones upstream of the target, consist of a vacuum tank equipped with two motorized radiator holders, a motorized set of optical attenuation filters, an illumination circuit for the check and set-up of the system and a standard *CCD* camera. For the last target area monitor the screen positioning mechanism will not be installed, as mentioned above, and the *CCD* camera will be replaced with a radiation resistant device.

Two solutions are available for the last camera; the "standard", in-house developed radiation hard, *VIDICON* camera and a more sophisticated solid-state *CID* camera. Both devices have strengths and drawbacks. The *VIDICON* camera has proven over the years to be very resistant to ionising radiation. This quality is obtained, however, by using very simple, tube based, electronics circuits, and has the drawback of being almost 100 times less sensitive than a *CCD*. The response is also not perfectly linear (both spatially and in intensity, with non linearity's in the range of 10%) and requires calibrations to compensate for drifts of the components. The lifetime of the tube is also limited to a few thousand hours of operation, not compatible with an eventual *always-on* use; these cameras are normally used for occasional beam observation only.

The *CID* camera, on the other hand, has performances comparable with a standard *CCD* (similar technology), with good sensitivity and linearity, and does not require any calibration. The draw back of this device is that the specified levels of radiation resistance are close to those anticipated in *CNGS*, at least for the cameras closest to the target. Also the perturbation of the image quality due to the radiation flash caused by the impact of the protons on the target remains to be verified. For these reasons a *CID* device will be tested in the coming months at an irradiation facility of *PSI* near Zurich. If the tests confirm the expected results the *CID* will be chosen for the two *BTVG* systems nearest to the target. Both technologies, *CID* and *VIDICON*, would fulfil the requirements in terms of measurement accuracy (resolution order 10 to 20 % of the beam sigma, depending on the monitor location). In fact the *CID* system would give much better results, in the order of a few percent only, on the beam parameters.

The choice of the material used for the radiators has not yet been finalized. There are however only two candidates, either titanium or graphite, in both cases used as Optical Transition Radiators (backward *OTR*). The foreseen thickness is 12 μm for the Ti case and 100 μm for graphite. There are advantages and drawbacks for both. Graphite is much better in terms of thermal behaviour, it can withstand easily the energy deposited by the beam, and damage to the radiator can be reasonably excluded. Carbon screens have been already used in other high brilliance applications around the world. The draw back of graphite is that the surface quality of the foils is quite far from mirror-like and consequently the collimated emitted *OTR* light is spread over a much larger angle and is less intense.

The titanium foils have a better surface quality (although still much worse than aluminium, for example) and can thus increase sensitivity. On the other hand the thermal load on the screens is close to the limit for titanium and the effects of such high temperatures on the surface quality are not well known (titanium acts as a getter pump at high temperature). The reflectivity level is not an issue in the case of solid-state cameras like *CID's* or *CCD's*, but could become important in the case of the *VIDICON's*. The choice of the material will thus be made once the choice of the camera has been confirmed.

The filters will be installed and set up during the commissioning time. However, it is not planned to maintain the filter motorisation in the long term since there are no reasons to change the filters after the initial set-up (the specified beam intensity range of $1x10^{12}$ to $3.5x10^{13}$ per extraction is small enough to be covered by the camera itself.)

Concerning the control and acquisition system, the newly developed standard LHC/CPS VME 64x cards will be used. The VME 64x crates will be installed in a counting room in a surface building in order to simplify the set-up and the maintenance, all BTVG installations of the CNGS proton beam line will be controlled from the same location. Apart from the control of all the parameters of the screens, filters, lights and cameras, this new card incorporates a frame grabber that allows the synchronous acquisition of one image per camera. Due to the limited speed of the VME bus it will however not be possible to record both pulses (50 ms apart) in one SPS cycle. The timing can be adjusted in order to select either one of the two extractions.

3.4.4 TBID

In order to observe the particle production in the CNGS target, a monitor will be installed about 2 m downstream of the target focal point. This monitor will measure the multiplicity, asymmetry and tails population.

The system consists of a sequence of 12μm thick titanium foils cut in different ways and polarized. The secondary emission current of each active section will be recorded and analysed. The secondary emission current consists of electrons released from the foil surface under the influence of the incoming charged particles. Typical yields are of the order of *~0.05* electron per incoming charge. For titanium this value has been observed to be quite stable in time (on the contrary, aluminium foils have shown pronounced aging effects).

The first foil is a plain foil (ϕ *200 mm*) and gives a signal proportional to the total number of secondary charged particles escaping from the target. When comparing this measurement to the BCFT upstream of the target, this foil allows measuring the multiplicity. The second foil consists of a disk split in two along the vertical diameter. This will provide the asymmetry between the number of secondary particles on the left and the right side. The third is analogous to the previous one with the vertical cut replaced by a horizontal one; this stage gives the up-down asymmetry. Finally the last stage consists of a foil with a 10mm hole in the centre. This will give a signal proportional to the secondary particles outside of the core of the beam. This signal, together with the one from the first (integral) foil, gives a measurement of the population of the tails. Before, after and in-between these foils there will be additional bias foils installed. The bias voltage assures that the emitted secondary electrons, coming from the measurement foil surfaces, will be collected, avoiding cross talk between layers and assuring a uniform response.

The whole system is placed inside a vacuum vessel equipped with thin (100 μm) titanium input and exit windows brazed on stainless steel flanges. Standard TBID tanks as the one described exist as spares for other SPS target stations and can be used “off the shelf”. An option for CNGS is presently under study: the TBID vacuum tank, if equipped with a NEG layer, could be pumped in the laboratory before installation and then sealed. In this case, no pumping would be needed, since the vacuum level expected would be sufficient for the lifetime of the detector. The feasibility of this solution still being verified by the vacuum group.

Similarly to the BTV’s, the signals from the TBID will be transported to the surface building where they will be analysed and recorded using a standard VME electronics card for SEM read-out at the SPS.

3.5 TT41 layout updates

Layout updates have been performed since the last review. In the following the links to the layout drawings are given.

TT41 layout:	https://edms.cern.ch/document/323172
TT41 cross-section:	https://edms.cern.ch/document/343380 and
	https://edms.cern.ch/document/343381
TT41 safety equipment layout:	https://edms.cern.ch/document/391743
TT41 electrical distribution layout:	https://edms.cern.ch/document/457545

References:

[3.1] E. Gaxiola; Summary notes of the CNGS Technical Working group meeting held on 22 October 2003, IDMS Id 410082, https://edms.cern.ch/document/410082.

[3.2] E. Gaxiola; Summary notes of the CNGS Technical Working group meeting held on 3 December 2003, IDMS Id 427498, https://edms.cern.ch/document/427498.

[3.3] W. Herr and M. Meddahi; Aperture and stability studies for the CNGS proton beam line TT41, SL-Note-2003-020 AP, March 2003, https://edms.cern.ch/document/383852.

[3.4] E. Gaxiola; Summary notes of the CNGS Technical Working group meeting held on 3 March 2004, IDMS Id 451304, https://edms.cern.ch/document/451304.

[3.5] W. Hofle and E. Vogel, Summary notes of the Accelerator Performance Committee held on 30 January 2004,

http://ab-div.web.cern.ch/ab-div/Meetings/APC/2004/apc040130/apc300104.html

[3.6] A. Bertarelli, and L. Bruno, Summary notes of the CNGS Technical Working group meeting held on 10 September 2003, IDMS Id 40431504, https://edms.cern.ch/document/404315.

[3.7] A. Bertarelli, and L. Bruno, Summary notes of the CNGS Technical Working group meeting held on 22 October 2003, IDMS Id 410082, https://edms.cern.ch/document/410082.

[3.8] A. Ferrari, A. Guglielmi, P. Sala, Summary notes of the Secondary beam working group meeting held on 24 June 2003, EDMS Id 394382, https://edms.cern.ch/document/394382.

[3.9] L. Bruno, private communication (report from CRS4 in preparation).

[3.10] B. Goddard, M. Gyr, V. Kain and T. Risselada; Geometrical alignment and associated beam optics issues of transfer lines with horizontal and vertical deflection,LHC Project Report 719 (2004).

[3.11] W. Herr and M. Meddahi; Trajectory Correction studies for the CNGS proton beam line, SL-Note-2002-015 AP, May 2002, https://edms.cern.ch/document/355912.

[3.12] W. Herr, M. Meddahi, T. Risselada; Effect of geometrical alignment on the beam optics of the TT41 CNGS proton transfer line, AB-Note-2004-XXX ABP, June 2004.

[3.13] J.-P. Koutchouk; Functional specification, Beam measurements for the CNGS beam line, CNGS 2003-01, EDMS Id 376330, https://edms.cern.ch/document/376330.

[3.14] H. Vincke and G. R. Stevenson; Absorbed annual dose upstream of the CNGS target, TIS-RP/TN/2002-009, https://edms.cern.ch/document/339039.

4. Target chamber TCC4

4.1 Target station T40

The target station is described in the earlier CNGS reports [1.2, 1.3, 1.4]. The most important points having evolved since the 2003 CNGS Review are summarized here.

4.1.1 Target elements

Early calculations to optimise the neutrino beam for a ν_τ appearance experiment have shown that low-Z target materials are best suited for CNGS target rods. The materials selected were graphite, carbon-carbon composite and hexagonal boron nitride (hBN). Graphite is the best-known material of the three. Preliminary calculations indicated that graphite rods of 4 and 5 mm diameter would be sufficiently resistant to the ultimate intensity beam impact (3.5×10^{13} protons per 10.5 μs extraction), at all parameters of beam impact (on and off-axis). In these calculations, a round proton beam with the nominal beam size σ=0.53 mm was used.

A huge effort was made to complete detailed ANSYS calculations for off-axis beam impact. It was finally concluded that, within the computing resources available, this code was not the appropriate tool for the task at hand. Instead, an analytical model was developed, which allowed within some approximations to calculate the stresses due to different beam eccentricities, for a variety of target rod diameters and beam sizes. The results of this work have been presented at two meetings and are summarized in tables 3.2 and 3.3 for graphite and hBN rods, respectively. More details can be found in the TWG summary notes [4.1, 4.2].

More recently, the results obtained in the analytical model have been corroborated, by CRS4 (Cagliari, Italy) [4.3] with detailed numerical studies using a tool better adapted than ANSYS. It turns out that indeed from this mechanical point of view, hBN is better suited than graphite, and a first look at high-density C-C composites also gives promising results. Note that in all of these calculations, no damping of the oscillations produced by the beam impact has been introduced.

Among the possible laboratory tests on target rods are the fatigue tests. A series of such tests has recently been completed at different temperatures for the hBN material. The test results indicate a behaviour at high temperature (700 ^{0}C), which is difficult to interpret, but which does not give confidence in this material as a good choice for the CNGS target. Similar tests for graphite rods are in preparation – results are expected before the end of 2004.

Recently, the idea of using a laser doppler vibrometer to measure the characteristic frequencies of the oscillation after beam impact as well as the damping in a target rod has been put forward. Test-of-principle measurements with a graphite rod have been successfully performed at the ISOLDE facility (2.1 GeV/c protons). During fast-extraction tests on the new TT40 beam line, with 400 GeV protons and a beam-spot about twice the nominal CNGS beam at the target, these measurements will be repeated. These tests are scheduled for autumn 2004 and are expected to give valuable impact for a comparison with calculations.

4.1.2 Target unit, target magazine and tables

The design of the "heart" of the target station has been vigorously pursued during the past year. One significant simplification has been introduced w.r.t. earlier ideas: The BPKG beam position monitor, which is located immediately upstream of the target and must give the position of the beam relative to the target, is now fixed on the same table as the target magazine (see Fig. 4.1). In the unlikely case of failure of the BPKG, other beam position and profile monitors just upstream of the target station can provide the necessary information. On the other hand, the cost of such a monitor is rather minor w.r.t. to the cost of a target magazine. It is therefore acceptable that replacing a target magazine implies also replacing this monitor.

The detailed design of the target unit is completed. A complete target unit prototype is in production. Given the tight tolerances, the more than 2 metre long C-C tube, which holds the target rods, is considered to be the most difficult item from a production point of view. A prototype production has therefore been launched in collaboration with industry, and has been successfully completed. The rough tube has been ready in May 2004, and precision machining took place end of June 2004. After initial checks by the company, the tube will be shipped to CERN and will undergo accurate metrological tests.

The C-C will be housed in an aluminium cylinder with cooling fins. An order for 15 aluminium tubes is ready and production will start shortly. The entrance window will be a standard Be window purchased on its stainless steel flange. In order to reduce the amount of material (i.e. the possibility of beam heating and thus mechanical stresses), the exit Be window will be welded directly onto the aluminium tube. C-C target holders and graphite target rods are also being produced for the prototype target unit.

The cooling of the target rods takes place by radiation to the aluminium tube and/or by convection. For the latter, the target unit needs to be filled with an inert gas. A detailed study of the thermal behaviour of the CNGS target unit has been performed by the Computational Fluid Dynamics team of the CRS4 (Cagliari, Italy) [4.4]. With this study, problems of heat gradients between bottom and top of a target unit (which could lead to deformation) can be assessed. The radiated and convected heat for the cases of argon, helium and nitrogen gas has been calculated. While helium appears to be the best choice for the total heat transferred to the aluminium tube (~1850 Watt), this gas also leads to the largest temperature gradient between top and bottom (76 K). Nevertheless, among the gases studied, helium is clearly favoured.

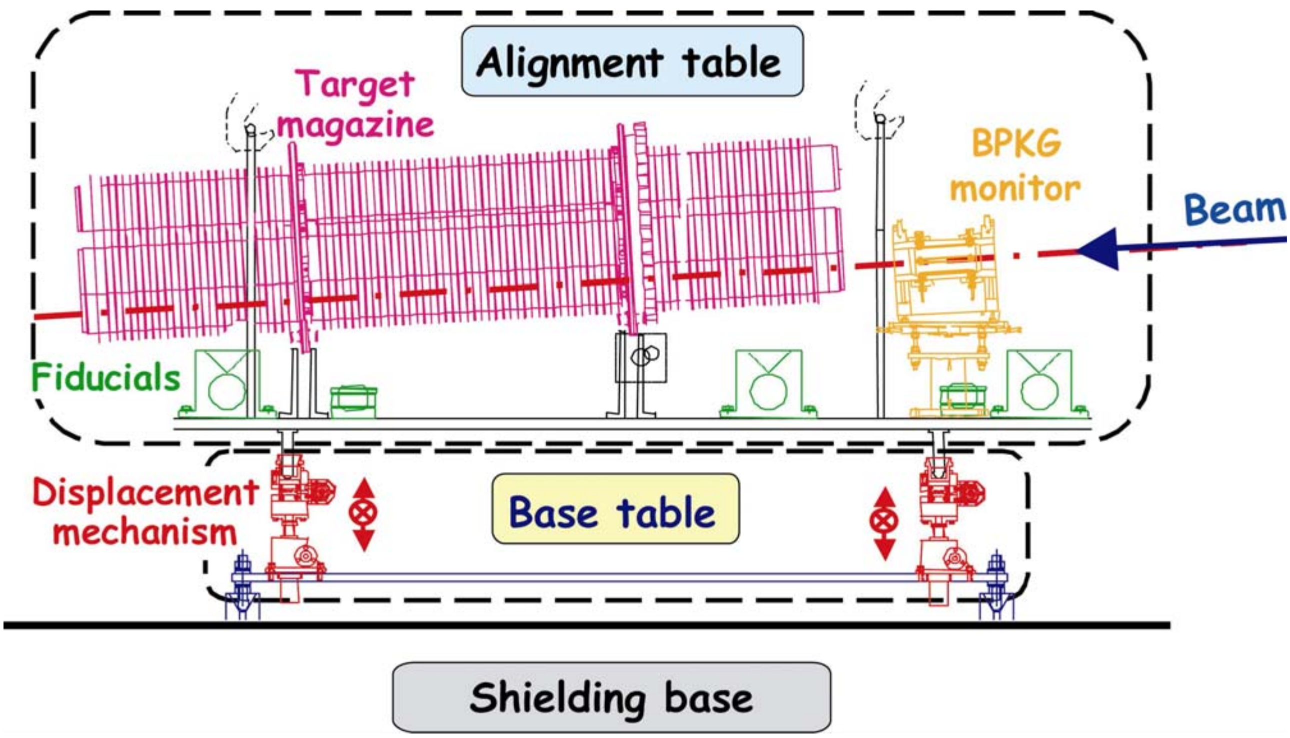

Figure 4.1 - Target station tables and equipment

Further considerations related to the stresses on the Be windows of the target unit recently lead to consider the possibility of keeping the unit under vacuum rather than filling it with an inert gas. The gas heats up during beam-on periods, and then cools down during beam-off, which leads to repeated bending of the window. This in turn could hamper the lifetime of the Be windows. A decision on "vacuum" or "helium" is currently pending.

Five target units will be installed in the target magazine, the active unit being the lowest one. The magazine is made of two disks connected by a rigid shaft; a circular guide way is fixed to each disk and supported by track rollers mounted on the alignment table. The upstream disk (see Figure 4.2.) is provided with a gear-wheel / tangent screw mechanism driving the rotation. The fixations of the target units within the target magazine allow axial free thermal expansion and rotations of each aluminium tube.

The magazine can rotate both clockwise and counter-clockwise up to a mechanical stop. A torque limiter disconnects the motor driving the rotation when the mechanical stop is reached. This rotating mechanism was found advantageous with respect to horizontally or vertically moving target magazines, both in terms of space needs and mechanics.

A specially shaped notch is machined on the border of the upstream disk (indexing disk) for each target unit. An indexing finger is pressed by a spring against the disk border and slides on it by means of a roller fixed at its tip. When the finger enters the notch, the torque limiter stops the rotation. Before any further rotation, the finger is disengaged from the notch by acting against the spring, and released afterwards. The finger-notch indexing system requires that the finger approaches the notch always from the side, namely clockwise for an observer looking at the magazine from upstream of the target.

In between the notches positioning the target units other notches are machined on the border of the upstream disk, in order to index the magazine in no-target positions in between the units. All target notches have different depths, allowing identifying the target in use, while all no-target notches have the same depths.

4.1.3 Energy deposition, heating and cooling of target structures

In order to assess the energy deposition by particles in the various components of the target station, a FLUKA model of T40 has been created [4.5]. In this model, only the active target unit (aluminium tube with cooling fins, C-C support, target rods and their holders) has been considered - the four spare target units have been omitted. Care has been taken to correctly model the shielding around the target in the configuration known at that time (the upstream collimator inside its shielding blocks have not been introduced - this should make no difference to the results of interest here).

In addition to the real objects in the target station, the energy density absorbed has been recorded in 6 artificial monitoring planes. This allows estimating, for a given object (e.g. a support jack, a table etc.) the deposited energy once the size and mass of the object are known. The energy density in the target unit has been obtained in much detail - this information has been used as input to the detailed thermal studies of the target unit [4.4].

The results of these calculations led to a number of decisions concerning the target station design. A few examples are given here:

(1) The downstream marble wall, 30 cm thick and installed to protect personnel having to work e.g. on the feet of the horn in the unlikely case of a repair or replacement, was originally designed to have an opening of only 60x60 cm to let the particles pass. The simulation showed that the beam-heating of the marble was going to be unacceptable, and the opening has been enlarged to be 80x140 cm.

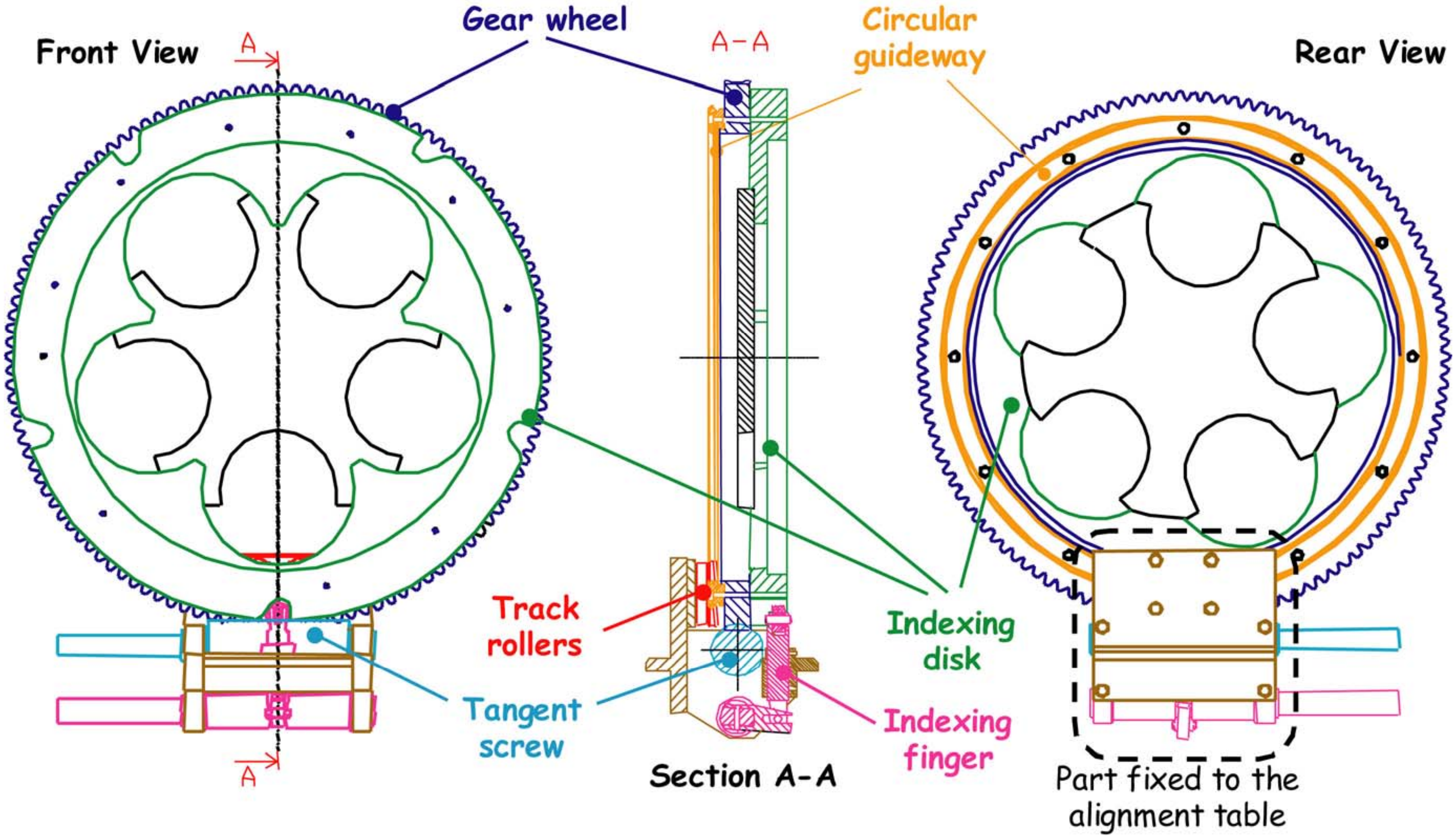

Figure 4.2 - Upstream target magazine support wheel (a more simple wheel will support the target units at the downstream end). The positions for the 5 target units and the corresponding notches for the indexing finger can be seen. Not indicated are the 5 holes (no-target positions) in the support wheel

(2) Cooling of the target unit by blowing air onto the outside of the unit had been foreseen since the early stages of the target station design. The simulations have shown that it is necessary to also cool the base shielding and the side shielding walls. In order to achieve this, the air stream from the ventilator is split into two: an upstream part which is guided into the target station and further split to cool the two side walls, and a downstream part which is further split to cool the target unit (from below) and the target base shielding. A schematic view of the air-cooling system is shown in Fig. 4.3, details can be seen on the target station drawings [4.6].

In spite of this air-cooling system, heating of the 1.6 metre high target support structure (shielding base, jacks, etc.) remains a concern in particular in the downstream end of the target station. In the present design, a pessimistic assumption of 100 ^{0}C in this area would lead to a shift of the target exit by up to 1 mm.

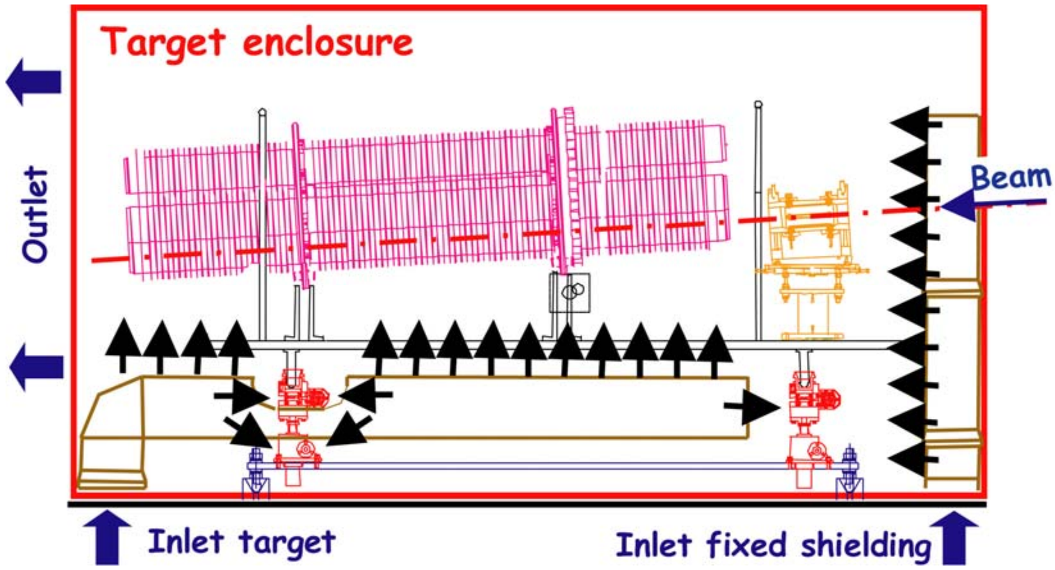

Figure 4.3 - Schematic side view of the T40 air cooling system

4.1.4 Radiation protection issues and handling

The remnant dose rates around the T40 target station have been calculated using a new method that replaces the Omega-factor approach. The new method consists of two steps, both using FLUKA:

(1) simulation of the production of isotopes, calculation of build-up and decay of radioactive isotope, storage of produced radionuclides in a file;

(2) sampling of photons, electrons and positrons from radioactive decay, simulation of electromagnetic cascades, calculation of remanent dose rates at points of interest.

This new method has been compared with experimental data from irradiated samples of concrete, iron, titanium, copper, etc.. and very good agreement has been found [4.7].

For the remanent dose rates around T40, the standard CNGS operating scenario for engineering calculations has been used, i.e. 200 days of running with an average intensity of 8x1012 protons on target per second (note that this corresponds to three times the number for standard CNGS operation). For the time being, scenarios with 1 day or 1 week of cooling time have been studied. The results have been shown in a presentation [4.8] and will be summarised in a report.

The most important findings are:

(a) for 1 day of cooling, the contribution to the total dose rate in the aisle from the concrete of the target chamber cavern is dominating, whereas after 1 week of cooling, the target station itself is the major source;

(b) for the emergency repair of a target station motorization block (estimated to last 14 minutes in total) after 200 days of operation, the total dose is estimated to be about 700 μSv/person after 1 day of cooling and 12 μSv/person after 1 week of cooling, respectively. If a target magazine would have to be changed after 200 days of operation (intervention time 25 minutes in total), the total dose would be 1250 μSv/person after 1 day or 21 μSv/person after 1 week of cooling. The marble shielding wall on the passage side contributes very significantly to keep the values for 1 week of cooling reasonably low. Note that the CERN design criterion is 2mSv / year / person.

These studies will be extended to dose rates for possible alignment checks and other operations. Work is presently on-going to perform similar calculations for interventions around the horn.

4.1.5 Alignment

A detailed description of the alignment procedure for the various components of the T40 target station, including the collimator, is being prepared. This includes both the procedure for alignment during lab tests and at the time of installation. An advanced draft version of this document can be found at [4.9].

The accuracy of the target alignment w.r.t. to the theoretical beam axis will be determined by four major parts:

(1) the positioning of the alignment table (carrying the target magazine and the BPKG beam position monitor) in the target chamber

(2) the reproducibility of the target magazine rotation

(3) the positioning of the target units in the target magazine

(4) the position of the target rods within each target unit.

The design, fabrication procedures and machining tolerances of these 4 items should allow achieving an error of ± 0.1 mm each. These errors are independent, the total alignment error for a target is therefore estimated to be ± 0.2 mm transverse to the beam axis. The longitudinal position of the target with respect to the proton beam focal point will be accurate to within ± 1 mm .

4.1.6 Thin Windows

The standard SPS vacuum windows are produced by brazing 100 μm commercially-pure Ti foils onto stainless steel flanges. Such Ti windows are likely not to withstand the high instantaneous proton beam intensities in the region around the focal point: temperatures on the Ti foils would locally reach more than 900 ^{0}C for the ultimate CNGS beam intensities. Following the recommendations of the 2003 CNGS review, alternative possibilities have been studied in a preliminary approach. A summary of the present knowledge can be found in [4.10]. An interesting alternative material for windows could be Ti-γ, an alloy containing 45% of aluminium (more accurately Ti45.5Al2Nb2Cr).

The solutions chosen for CNGS are largely driven by the lack of manpower and time for extensive R&D on windows. This leads to the following decisions:

(1) For the TT41 proton beam exit window, a commercially available standard Be window will be used. A 2 mm thick C-C disk will be installed just upstream of the Be window, in order to prevent Be contamination in the vacuum tube in case of a rupture.

(2) For the T40 target units, Be windows will be chosen. The upstream window chosen is a commercially available window already welded onto a stainless steel flange. The downstream window will be directly welded onto an aluminium part, which will form the downstream end of the target unit aluminium tube.

The possible use of Ti-γ for the vacuum windows and / or secondary emission foils of the TBID monitor are still under discussion.

4.2 Horn and reflector

4.2.1 Mechanical design and construction of the horns

The mechanical design and the construction of the horn (and a spare horn), the reflector and the striplines are the responsibility of LAL/IN2P3, in the framework of the French contribution to the CNGS project.

The two inner conductors for the horns were delivered to CERN on schedule, in April 2004. Measurements by the CERN survey team showed that these inner conductors are within the specified mechanical tolerances. One of the inner conductors was then shipped to LAL for the assembly of the first horn, the second one was introduced into the CERN test-horn in BA7.

During this assembly at the BA7 test-stand, a non-conformity was found: the grooves on the inner conductor, foreseen to receive the cables of the “spider” system designed to hold the inner conductor in place, were found to be longitudinally mis-placed by 75 mm. A solution to this could be found, the full non-conformity report is available on EDMS [4.11].

Changes in the LAL personnel made it necessary for the management there to form a new team in charge of the horn project for CNGS, as of the end of 2003. A new schedule for the design, construction and delivery of the horns, striplines and water-cooling systems was established and accepted by CERN. This schedule foresees delivery of the first horn to CERN end of March 2004, delivery of the spare horn end of May 2004, and delivery of the reflector in July/August 2004. Since this schedule was very tight, a number of acceptance tests were to be done at CERN, rather than at LAL as originally planned.

The first horn was delivered to CERN on 7 April (Figure 4.4) and installed in the BA7 test stand. Before testing began, a number of points which must be changed (to assure reliable operation of the horn in the aggressive environment with beam) were stressed. These include the electrical insulation rings on the water outflow pipes, the quality of the screws, the base frame, etc.. Other improvements, more related to the quality of manufacture and assembly, have been suggested. A detailed list of these points can be found at [4.12]. Discussions are under way with LAL on the procedures to implement the changes.

The first horn was linked to the transformer, and the test series started at the end of April. So far, a test series of 65’000 double pulses at nominal working conditions has been performed (150 kA, 50 ms delay between pulses, a double pulse every 6 s). The temperatures of inner and outer conductor, cooling water, striplines and transformer have been monitored and are found to be within the expected ranges.

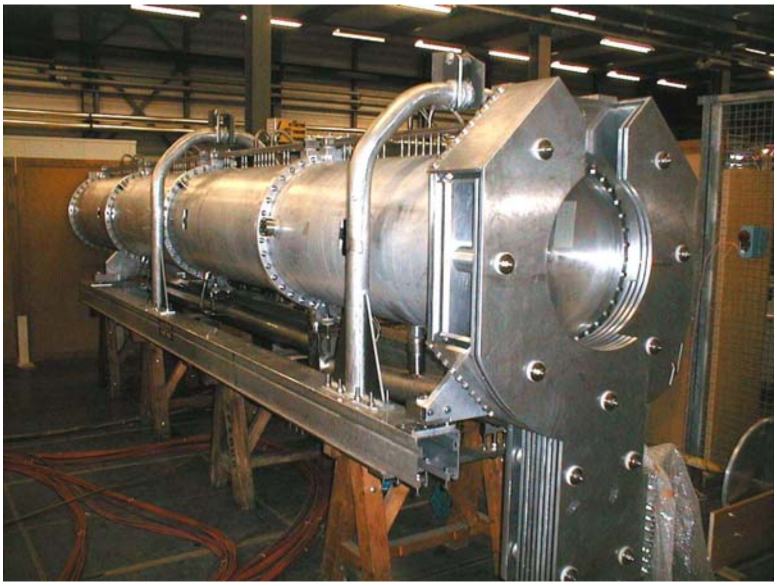

Figure 4.4 - First horn arrived at CERN

In addition, vibration measurements of the inner conductor (observing the displacement of the flexible end cap with a laser doppler interferometer and with capacitive sensors) have been performed for a series of different time delays between the two pulses. Results are being analyzed.

Additional tests to be performed are (a) the control of the straightness of the inner conductor with a self-centering gauge associated to a laser tracker; (b) the measurement of the magnetic field in the horn.

4.2.2 Design and construction of the striplines

Following the comments received at the 2003 Review, the design of the stripline routing from the horns towards the transformers in the service gallery has been modified and the fast coupling system – developed by LAL - has been revised.

In the new layout, the stripline segment permanently attached to the horn has a “branch” sideways, and the fast coupling is located away from the beam axis. This is shown in Fig. 4.6. The new system has two advantages: (a) the five screws which need to be opened to change a horn are more accessible, (b) almost all of the stripline is now outside of the shielding, i.e. away from the main particle flux.

All the parts, which form the fast coupling system designed and built by LAL, are being used in the present tests of the horn in BA7 (see the picture, Figure 4.7). The first results are very positive as far as the quality of the electrical contacts is concerned. On the other hand, a number of improvements on the mechanical design are still mandatory in order to facilitate the plug-in operation (remote handling with the crane). These improvements are currently being discussed with LAL.

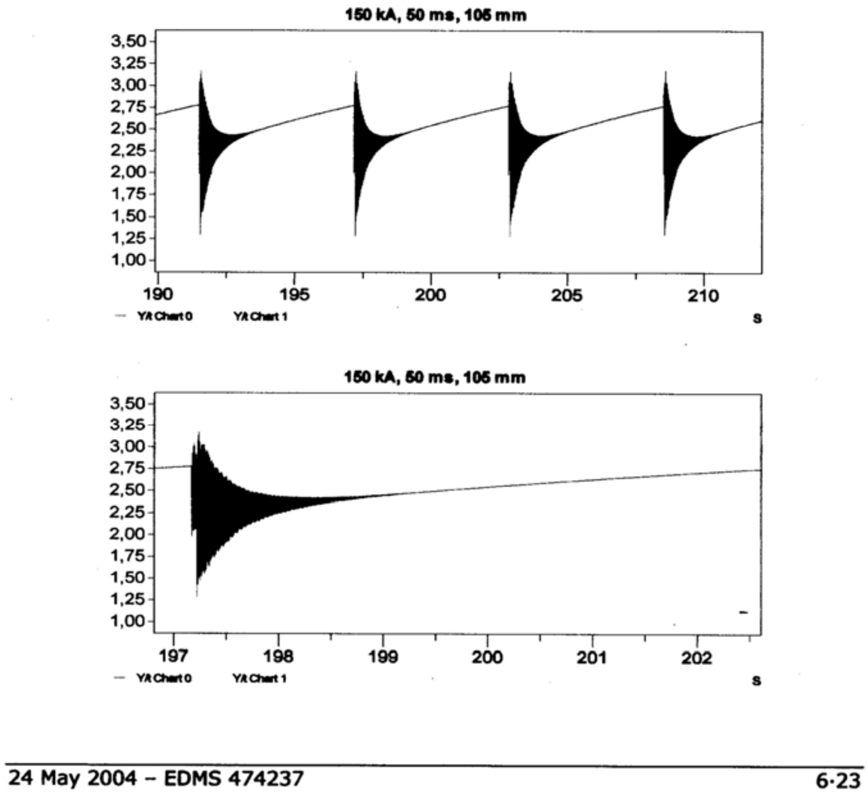

Figure 4.5 - Vibration analysis using a capacitive gauge on the horn entrance flange (Extracted from a report by A. Herty [4.13])

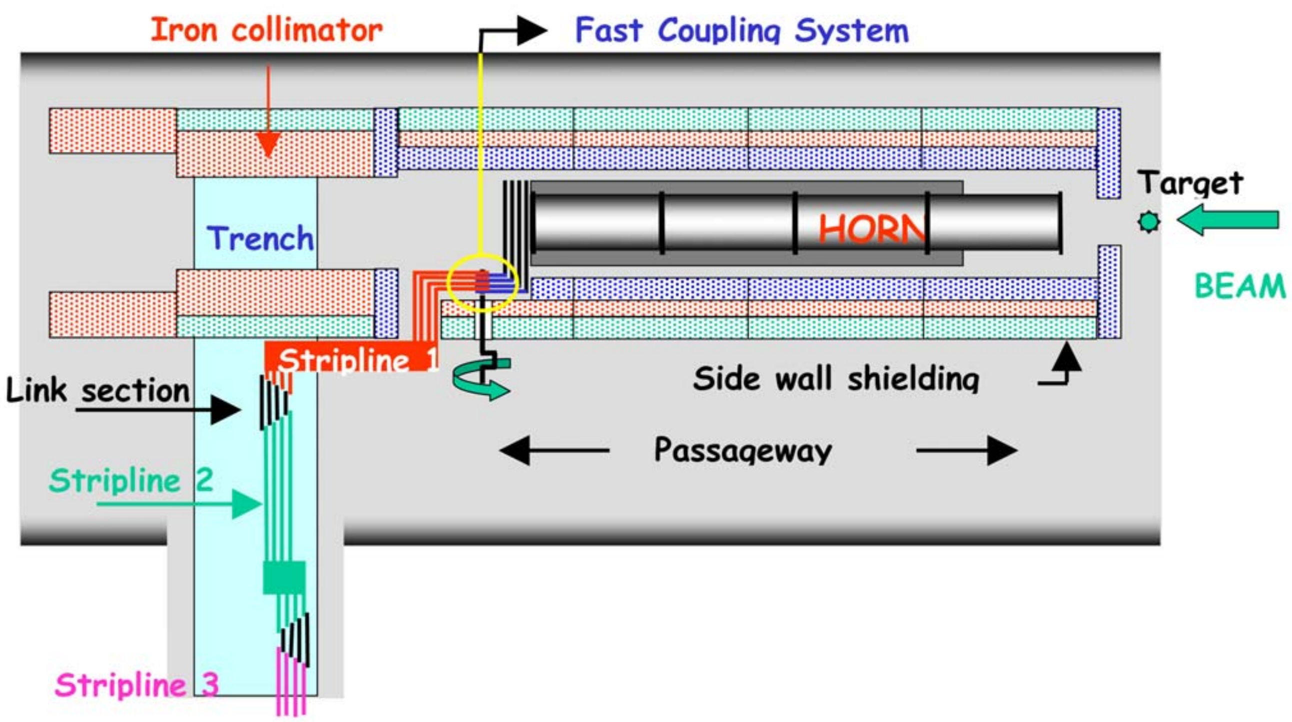

Figure 4.6 - Modified stripline layout - in the version presented to the 2003 CNGS review, the stripline continued straight along the beam direction until reaching the trench

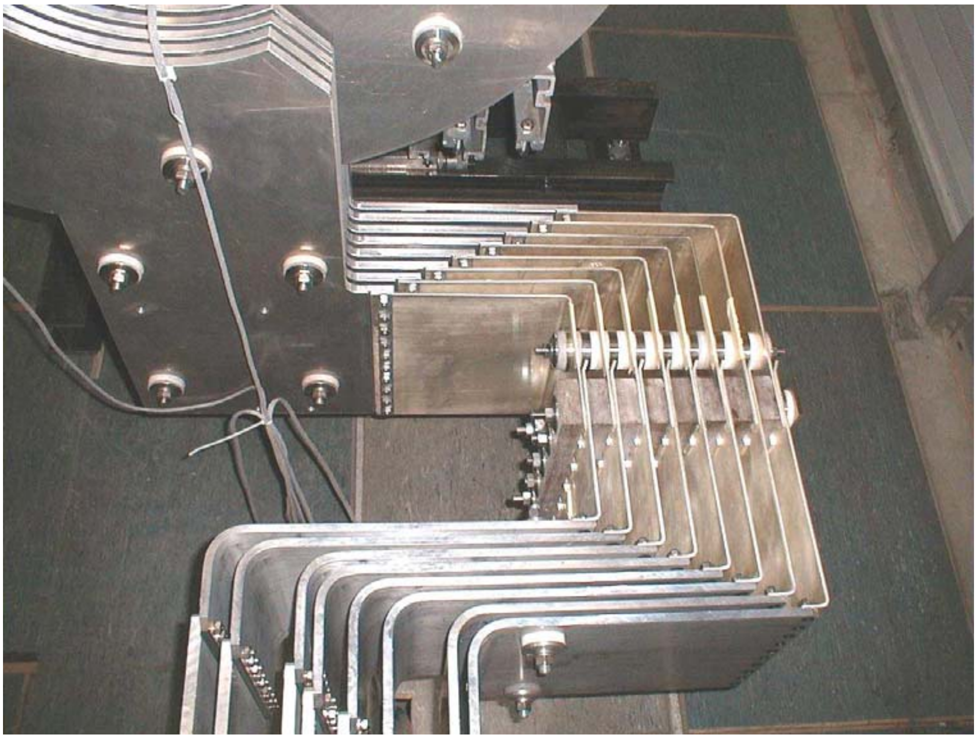

Figure 4.7 - Fast coupling system, in the "inverted" version as used at the test stand in BA7

4.2.3 Electrical systems and WANF transformers

The powering and discharge systems are being completed. New 10 kV transformers have been installed on the powering side. New capacitors have been ordered for the discharge system: the four prototype capacitors installed in BA7 have performed satisfactorily, and the full series of capacitors is expected to arrive at CERN in September 2004.

An expert for EMC effects has been visiting the horn test installation in BA7 and has given his advice concerning possible electromagnetic disturbance of signals on cables near the 1 kilometre long horn/reflector powering cables. A report is available [4.14]. To the opinion of the expert, there is no risk of EMC noise from these long power cables.

Following the decision, in March 2003, to re-use the existing WANF transformers, the secondary ratio of the horn transformer had to be changed from 32 to 16 in order to avoid an unnecessarily long pulse. This change implies that the current in the secondary coils is now twice as high. In order to cope with this load, the water-cooling system was modified to a parallel distribution. The coil temperature was monitored during the horn tests and the result showed that the modification to the cooling water circuit is efficient and sufficient.

4.2.4 Remaining design and construction work

The LAL responsibility includes the supports for the horns, the water-cooling plants and the striplines (with the exception of the connection to the transformers). The manually adjustable support jacks have been designed and manufacturing has started. The cooling water plants and the striplines are still in the design phase. All of these works must be completed before the end of 2004.

4.2.5 Installation in BHA4 and in the target chamber

Preparations are under way for the false floors and fire protection walls in BHA4, i.e. the area that will house the powering equipment and the control for the horns. These areas are scheduled to be accessible for installation works in October 2004. Pending the tests still to be done in BA7, the powering equipment will be transferred to BHA4 as of November 2004. Tests without load are scheduled to start in BHA4 during April 2005.

4.3 Additional monitoring in the target chamber

The CNGS base line foresees to install a TBID (secondary emission monitor SEM) immediately downstream of the target. This should allow measuring the produced particle multiplicity, i.e. the quality with which the beam hits the target. Apart from temperature measurement points, no other monitors are foreseen in the target chamber.

Standard SPS beam-loss monitoring systems allow connecting up to 18 monitors on one cable and into one VME card. In the present layout, only 10 BLM's are needed in TT41, and 2 are kept as spares. Two BLM's will be installed to observe the back-scattered particles produced when protons are hitting the collimator upstream of the target. This leaves 4 BLM's free for additional monitoring in the target chamber. A schematic view on the possible use of these 4 monitors is shown in Figure 4.8.

As a back-up for the TBID, and in order to have redundant information on the particle multiplicity, it is proposed to install two BLM's on the support frame of the TBID monitor (left and right of the TBID vacuum vessel). Standard SPS BLM's are known to be extremely robust monitors - they will be able to cope with the high particle fluxes and will give, at least, qualitative information on the beam hitting or missing the target. FLUKA simulations as well as integration drawings still need to be done.

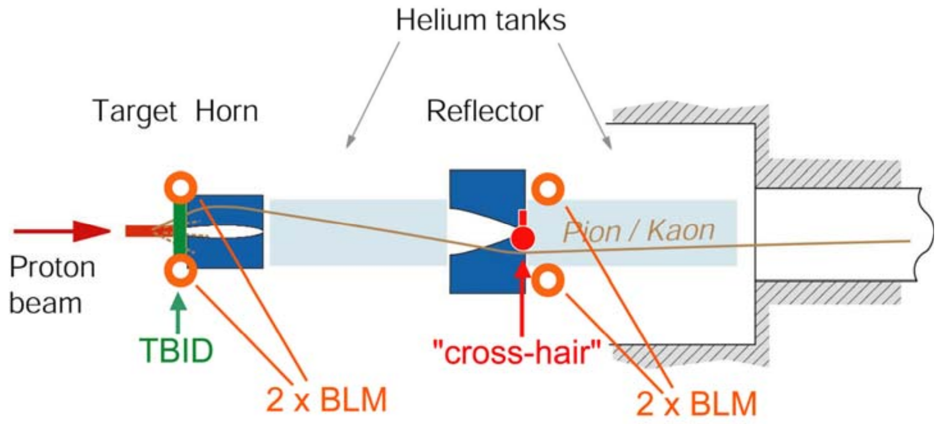

Figure 4.8 - Proposed additional monitoring equipment (BLM's) in the target chamber

Following a scheme developed for the NuMI beam at Fermilab, we propose to install a metallic "cross-hair" system downstream of the reflector. Two BLM's would be installed downstream and out of the beam axis. The "hair" has to be thick enough to produce a significant signal in the BLM's. Such a system will allow to get a more accurate measurement of the proton beam angle in the target chamber (lever arm would be 50 metres, rather than 10 metres between the BPM's upstream of the target).

4.4 Target chamber layout updates

The layout of the target chamber and its adjacent galleries is regularly updated. The latest version of this drawing can be found at https://edms.cern.ch/document/310296. Detailed drawings have been produced for the horn and reflector shielding [4.15], and an approval process had been launched. These drawings are currently being revised and a final version is expected to be available in September 2004. The documents for steel and concrete shielding blocks to be used in the target chamber are in preparation, to be ordered in November 2004.

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[4.3] L. Bruno, private communication (report from CRS4 in preparation).

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[4.6] Target station drawings, https://edms.cern.ch/document/362376

[4.7] S. Roesler, M. Brugger, H. Khater, S. Mayer, A. Prinz, L. Ulrici and H. Vincke, "Benchmark Studies of Induced Radioactivity in LHC Materials, Part II: Remanent Dose Rates", to be published in Proceedings of the 10th International Conference on Radiation Shielding ICRS-10, Funchal, Madeira, 9-14 May, 2004

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[4.14] A. Charoy, AEMC, Report on EMC effect of cables, in French, https://edms.cern.ch/file/478335/1/Horn_EMC_Report.pdf

[4.15] Target chamber layout drawings, https://edms.cern.ch/document/310296/
Layout of shielding in the horn area, https://edms.cern.ch/document/438808/
Layout of shielding in the reflector area, https://edms.cern.ch/document/440435/

5. Muon detectors

A total of 17 fixed and one motorized muon monitors (ionisation chambers) are foreseen in each of the two muon detector chambers. Progress has been made both on the infrastructure and on the detectors themselves.

5.1 Mechanical supports, infrastructure

The muon monitors will be mounted perpendicular to the beam direction, at the downstream end of the muon detector chambers. The spacing chosen between the detectors is the result of Monte-Carlo simulations and is described in the functional specifications [5.1]. The mechanical support structure as presently foreseen is shown in figure 5.1. The moveable monitor is located downstream of the fixed ones to avoid obstruction in case of a failure of the motorisation. Since access to the muon detector chambers is very limited, a video camera is located in each muon detector chamber and allows verifying the movements of the motorised monitor.

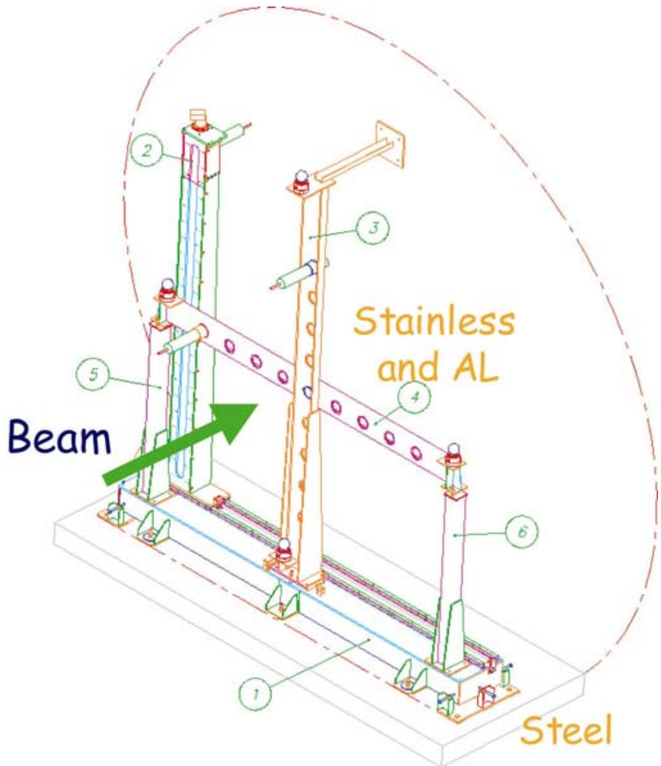

Figure 5.1 - Mechanical support structure for the muon monitors

5.2 Electronics, front end software

The video camera to be used is part of the standard SPS TV system. All components including front end software driver exist. Cables have been ordered and will be installed in 2005.

The current integrator and data acquisition electronics are part of a well-tested standard CERN system for beam-loss monitors. All components exist and are ready to be installed.

5.3 Ionisation chambers

The nitrogen-filled ionisation chamber design is based on the SPS beam loss monitoring system, which has successfully operated during more than 20 years. Low intensity tests show a very good linearity of the system. Recent tests at the PS booster, with intensities between $6x10^9$ and $9x10^{10}$ protons per cm^2 in a 50 ns long pulse, show indications of a deviation from linearity. These intensities are about 100 times higher than the peak CNGS muon intensities under ultimate operating condition. Further linearity tests at the SPS are planned to take place in 2004 and should allow covering the gap in the interesting range of intensities.

Much development on the beam loss monitors is currently on-going for the LHC system. It is planned to use chambers of the LHC design for the CNGS muon monitors. Production of these chambers will be done in Protvino during 2005.

5.4 Neutrons from the hadron stopper

The first muon detector chamber is separated from the hadron stop chamber by a concrete wall made of bricks. Contrary to an early design, the hadron stop itself (18 metres long, iron with a graphite core) is not embedded in concrete but is in air. Neutrons produced in the hadron stopper could scatter out sideways and potentially could find there way through the concrete wall into the muon detectors. In order to assess this potential problem, FLUKA simulations have been performed to assess the neutron flux and energy spectrum in the muon detector chamber. The results are described in [5.2, 5.3] and are summarized here.

Firstly, it appears that in the muon detector chamber, the neutron flux changes barely when comparing the hadron stop surrounded by air and the hadron stop embedded in concrete. On the other hand, the concrete wall separating the muon chamber from the hadron stop chamber reduces the neutron flux by about a factor of 10, as is demonstrated in Fig. 5.2.

In the simulations, a 30 cm thick concrete wall of density 2.1 g/cm^3 was assumed. Since it was found that the wall thickness could be increased for little extra cost to 40 cm (concrete bricks with density 2.0), it was decided to do so in order to make up also for possible spaces between the bricks, feed-trough of water cooling pipes etc..

In summary, a neutron intensity of about 1000 times less than the muon intensity in the interesting part of the muon profile is found in the simulations - this is an acceptable background.

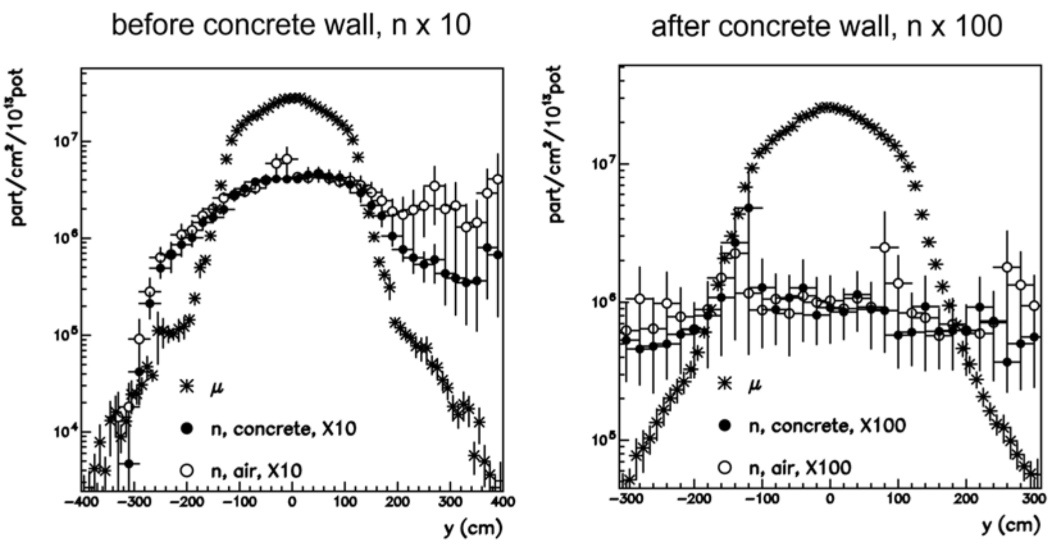

Figure 5.2 - FLUKA simulation results of particles in the first muon detector chamber. Muons and neutrons are compared before and after a concrete separation wall

References:

[5.1] Functional specification "Measurements with the CNGS muon detection system",

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[5.2] P.R. Sala, presentation to the TWG meeting of 21 April 2004

https://edms.cern.ch/file/470772/2/PSala_TWG210404.pdf

[5.3] A. Ferrari, A. Guglielmi and P.R. Sala, "Neutron background in the CNGS first muon detector chamber", https://edms.cern.ch/file/479120/1/Neutrons_TNM41.pdf

6. 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 - clearly, this status report can not do justice to all the work done during the past year.

The help of A. Bertarelli, R. Hanni, G. Patti, M. Sans, S. Sgobba and P. Sievers towards the final design of the target station has been of particular value to the project. The contributions from R. Jones and E. Bravin to the proton beam monitoring sections of this report are gratefully acknowledged.

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

Finally, we are very grateful to the colleagues from other laboratories around the world, in particular from the NuMI and MiniBoone facilities (Fermilab) and from K2K (KEK), for the fruitful discussions which have helped to further improve the design of the CNGS facility over the years. The series of Neutrino Beam Instrumentation (NBI) workshops, where colleagues building and operating neutrino beams are openly discussing all the technical details and the problems encountered at their facility, has been a great success and has contributed substantially to the evolution of the CNGS neutrino beam project.

Appendix I: Recommendations from the 2003 CNGS Review, and action taken

In the report of the 2003 CNGS Review Board, a number of recommendations were issued. The table below attempts to summarize those recommendations and to describe the action taken since. Results or pending items are listed.

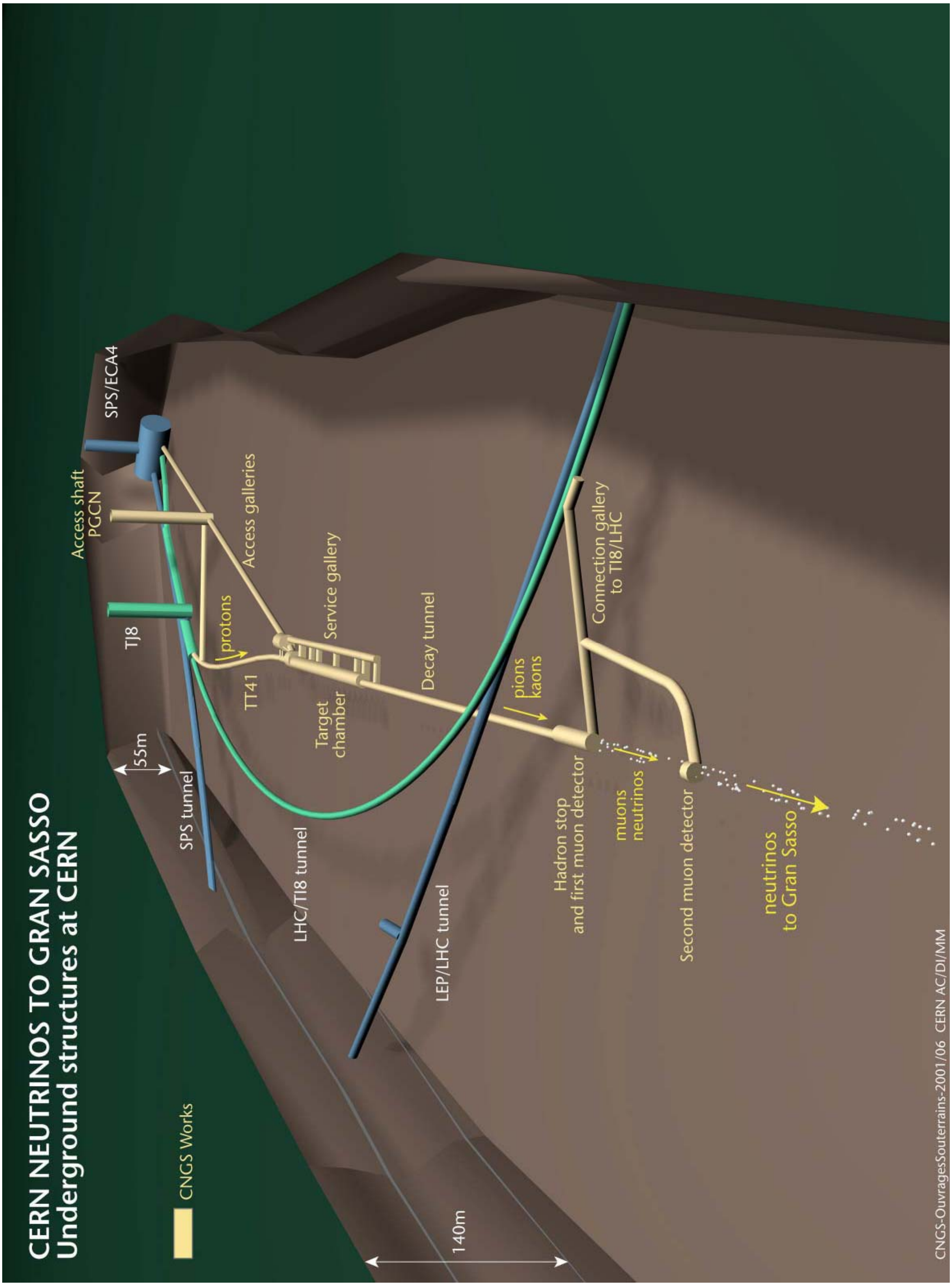
2003 Review Recommendation	Status June 2004
Vigorous efforts should be make to increase the resource for calculation of beam heating and residual radiation in the near term.	Following interventions in various committees, a fellow position has been granted. Due to admini-strative procedures, the fellow started working only in Feb. 2004. **Results:** (1) Remnant dose rates at T40 obtained (by S. Roesler, June 2003); (2) Beam heating of T40 component obtained (by M. Sans, report Jan. 2004) (3) All details of horn, stripline and the horn shielding have been introduced in the FLUKA simulation by M. Lorenzo Sentis (target and shielding taken from S. Roesler); ready to run; remnant dose rates expected for end of July 2004 **Outlook:** As a next step, beam heating of horn supports and heating of stripline will be calculated.
We suggest that the design team examine the option of increasing the beam spot size to see if it makes sense.	Optics study done by M. Meddahi; increase of beam spot diameter by factor 1.3 is possible; overall benefit not clear - option kept open
The Committee recommends the appointment of an 'Installation Coordinator' also in charge of driving the 'Master Installation Schedule' which should be the guide for all technical groups.	A. Spinks is acting as CNGS installation co-ordinator since summer 2003; organises installation meetings for general services (TS) and equipment (AB, PH); works in close collaboration with H. Gaillard, responsible for the schedule
If mis-steered beam on target would endanger the target, we recommend studying the possibility to reduce the magnification factor between injection and target errors, although a better option may be to ensure the target is robust to such mis-steering.	Cf. the point concerning a larger proton beam spot at the target.
If a Be-window is chosen, add protection to avoid contamination of the whole TT41/TT40 lines in case of window failure (a fast valve or an upstream titanium window?).	A Be window has been chosen - a 2 mm thick C-C disk will be inserted immediately upstream of the Be window as a protection.

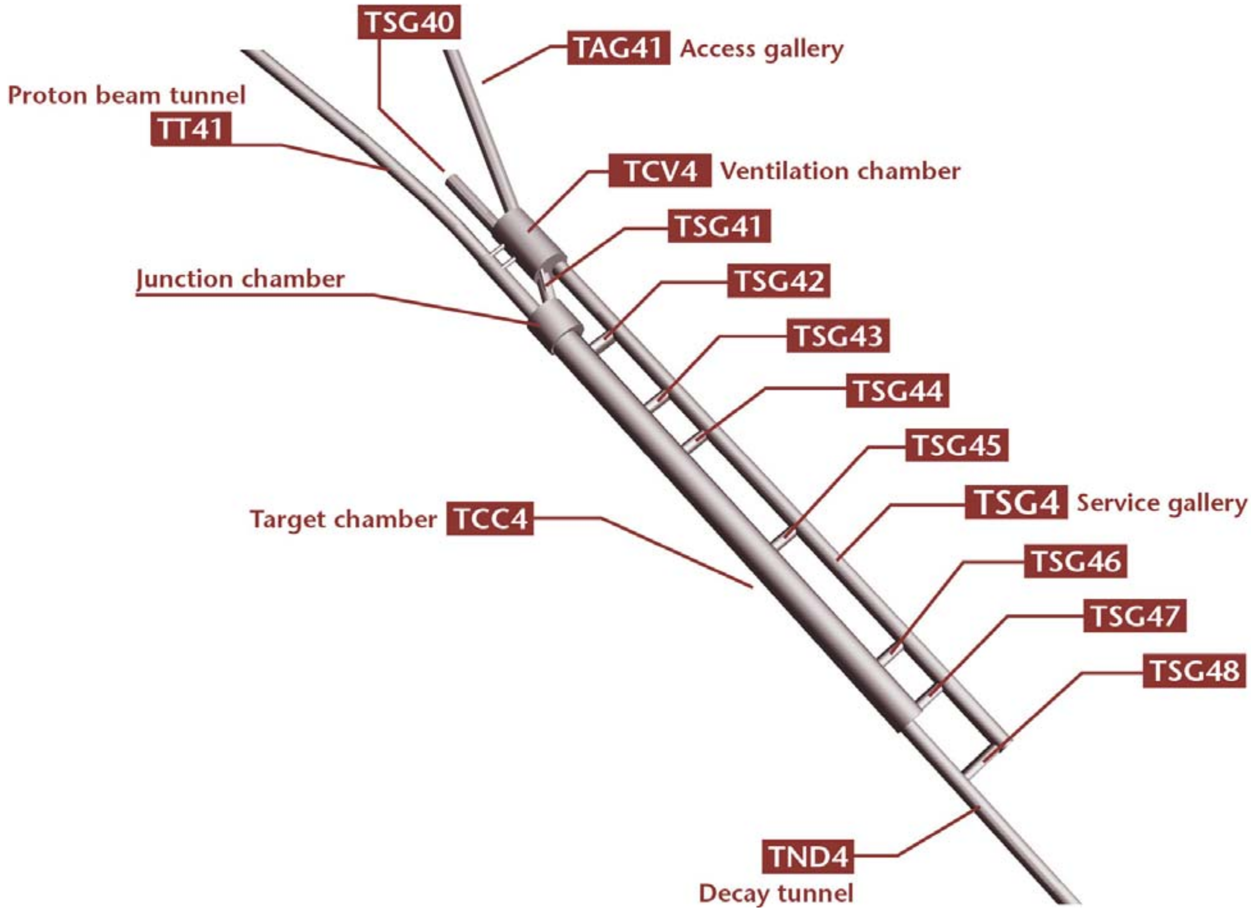
Vigorous studies should be continued to clarify: - Limits for titanium windows as a function of the beam size, - Temperature rise + strength estimation for various window materials vs. Ti, - Choice of the window material, - Cost / schedule implications. In the case of choice of beryllium, that may preferred for its precedent use in HEP installations (with good and bad experiences in this respect - e.g. see FNAL experience), failure analysis should be made with the aim to minimise the risk connected with Be contamination. As mentioned in the proton beam section, segmentation of the vacuum line with a fast valve or an additional (titanium?) window is worth considering.	As recommended, a broad study has been started in the framework of the “groupe méthodes”, in TS department. Due to lack of resources, CNGS cannot pursue such studies at this time. Beryllium windows have been chosen for the proton beam and the target units, while standard Ti windows are installed on the (existing) TBID monitor. Indeed, beryllium is the choice for CNGS. In the case of the proton beam, the contamination in case of a failure will be very localised thanks to the C-C protection disk. A detailed failure analysis for the target units is still missing. A large safety factor is, in any case, mandatory for these windows.
Target rods: Fatigue tests on single graphite elements are recommended to validate the lifetime of an element and its support under longitudinal and radial oscillation modes as found in off-axis irradiation.	Fatigue tests have been launched - to be performed by Fraunhofer Institute, at high temperature and in He gas atmosphere;
Target station: The overall alignment incertitude should be estimated. The actual status leads us to recommend a study of the target response to a systematically misaligned beam.	The engineering specification for the alignment of the target station states an overall uncertainty w.r.t. the theoretical beam axis of ±0.2 mm. A further 0.35 mm must be added quadratic ally due to the beam monitoring uncertainties. Analytical and numerical studies of the target response to a misaligned beam have been performed - the most critical item at this point is the single-cycle misalignment, which can be larger than 1 mm and appears to be inducing dangerous transverse oscillations in the graphite rods.
Target station: A low intensity proton scan across the target with TBID readout should allow one to centre the beam on the target, and monitor it. However, we were told the survivability of the TBID is in doubt because of the small intense beam spot size. The use of the TBID (or a replacement) and/or the muon detectors to diagnose the status of the target thus has to be clarified, as this is a critical function.	Low intensity proton beam scans across the target are part of the standard commissioning and beam-restarting procedures. We are confident that after an initial beam period with the TBID, the response of the muon monitoring system during such beam scans will be sufficiently well understood to allow us to use muon monitor data only. It is presently proposed to add 2 beam loss monitors next to the TBID, as additional back-up information on target multiplicity.

Target station: The installation, alignment and removal should aim at a fully remote controlled handling in view of (i) the unknown delay required between turning off the proton beam and first access (ii) the unknown dose rate at the maintenance work place (iii) the announced increased radiation protection safety requirements. If the project will instead rely on human intervention, for instance to connect or maintain the motors on the marble wall in the current design, this must be justified by the presentation of calculations showing that the dose from such operations will be acceptably low.	Remote handling of the target magazine is foreseen; the design of the target station w.r.t. this issue is completed. Human interventions are necessary to exchange a motor in the marble wall, and calculations show that the dose from operations such as changing a motor, are acceptably low (after 1 or several days of waiting time, depending on the CNGS intensities and the SPS accelerator efficiency, scheduling etc.). More work is needed e.g. to assess the dose to survey personnel during re-alignment of the target.
Target station: Energy deposition and estimation of dose rates within the target area are mandatory to complete the design. Energy deposition through the entire support assembly will need to be estimated in order to understand the effects on alignment of thermal expansion.	Energy deposition has been modelled by M. Sans using the FLUKA code. Thermal expansion of the support structure may lead to a vertical movement of the downstream end of the target magazine (in the extreme operational scenario considered, a movement by 1 mm can not be excluded). Remanent dose rates have been calculated by S. Roesler using the FLUKA code.
Recommendations concerning the stripline design: (i) The entire stripline from floor to horn is a rigid structure, which may not have enough flexibility to allow for thermal expansion due to beam heating of the stripline. (Note WANF for example of a flex joint). The first step to study this is a Monte Carlo calculation of beam heating of the stripline. (ii) The remote clamping of the stripline to the horn, while an interesting design, will likely need revision once dose rate to the person loosening/tightening bolts is calculated. (The connection for the horn feet may have similar concern). The design should be done in close cooperation with the Radioactive Handling Working Group. (iii) The bolt heads to be loosened in case of horn horizontal position adjustment are in too awkward a location. (iv) The permanent stripline fingers at the floor appear very difficult to repair if they get damaged in a horn changeover or develop some other problem. A repair scheme, or else at least a risk analysis, should be presented.	In May 2003, CERN proposed a different design of the strip-line, which was accepted by LAL in June 2003 (see section 4.2.2). The new design has as main features: (i) that the stripline is no longer along the beam axis, but rather outside the shielding for all of its length (ii) the remote clamping (fast coupling system) is much simpler - only five screws need to be loosened/tightened, and this can be done through a hole in the shielding from the passage way (iii) the adjustable part of the stripline is now easily accessible in the passage way - horizontal and vertical position adjustment are a lot easier (iv) the connection to the permanent part of the stripline is more easily accessible, the stripline parts in the passage way and in the trench can be exchanged without excessive dose.

Decay tube exit window: Beam heating for the case with beam hitting the target should also be checked in determining the energy deposition in the windows and resulting thermal stresses.	This calculation has been performed by A. Pardons - the results show that the situation is less severe than in the case of the proton beam missing the target, presented in 2003.
Hadron stop cooling: ... Therefore, if not checked yet, it is suggested to calculate/estimate the vibrations of the cooling system and their possible influence on fatigue life of the hoses and of the remaining parts of the cooling system. This seems to be essential in view of accessibility and radiation constraints.	The issue of vibrations of the cooling system has been discussed once again with the experts - there appears to be no danger of such vibrations.
Monitors in the target chamber: Produce a map of expected residual radiation for use in evaluating hot handling schemes, and include the maintenance scenarios in the specifications of the monitors.	The detailed work along the lines of this recommendation is still missing. Some information is, however, available from the work done by S. Roesler on the remanent dose rate around the target station. This shows that all but the most downstream monitors can be accessed by personnel for interventions after several days of cooling. The BPKG monitor, inside the target shielding, is considered a "consumable item", not to be exchanged or repaired. It will only be replaced together with a complete target magazine on a new alignment table.
From 2002 Review: Treat non-conformities in a systematic way.	M. Meddahi (CNGS) and A. Suwalska (EDMS team) have implemented a rather simple system (inspired by the CMS method) - several non-conformities have already been treated using this method.

Appendix II: CNGS underground structures




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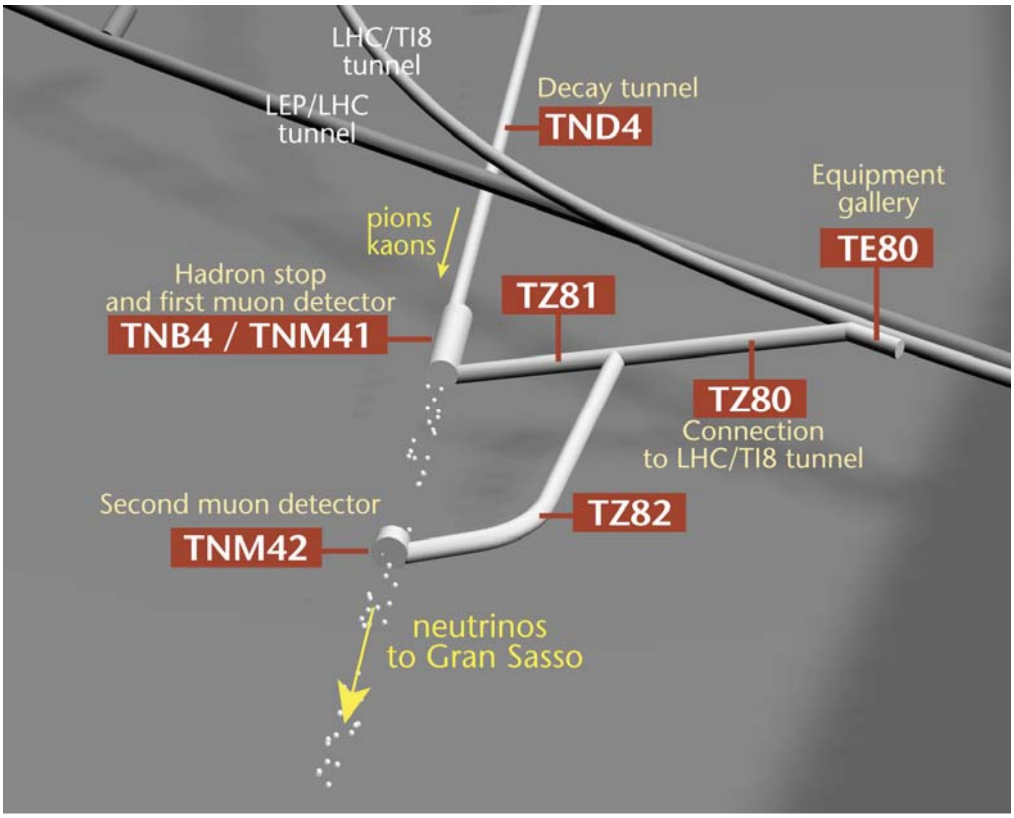
Target chamber TCC4
TSG4 Service gallery
TSG46
TSG47
TSG48
TND4
Decay tunnel


LHC/TI8
tunnel
LEP/LHC
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TND4
Equipment
gallery
TE80
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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