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Update of changes to CNGS layout and parameters

The CNGS project team

**M. Clément, K. Elsener, H. Gaillard, L.A. Lopez-Hernandez, J.M. Maugain,
M. Meddahi, G.R. Stevenson, H. Vincke, M. Wilhelmsson**

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. The construction schedule remains unchanged, with the first neutrinos from CERN to Gran Sasso expected in May 2005. The present note - written on the occasion of the CNGS External Review in February 2002 - provides an update concerning changes to the overall layout of the CNGS facility and some of the minor modifications, which have all been approved by the CNGS Technical Working Group since the publication of the 1999 addendum.

Geneva, Switzerland
March 2002

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) 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, and it should be noted that approval for major changes is only be given by the CNGS Technical Working Group. The CNGS web-site [4] is regularly updated to document these changes and to allow a view of the actual CNGS project at any given time. In addition, the web-site provides links to all the documents describing the evolution of the CNGS project. The aim of the present note is to summarise the main changes to the project, thus allowing a concise picture of information otherwise scattered in the summary notes of the different meetings. Major changes to some of the access galleries are described in chapter 2, while a number of smaller civil engineering modifications are described in chapter 3. The need for a new building (or annex) in the region of point 4 of the SPS is documented in chapter 4, where the proposed BB4 annex is described in some detail. Further changes concerning the adjustments for horn/reflector, the shielding in the target chamber, treatment of sump water and the muon monitoring system are described in chapters 5-8.

Some of the modifications to the CNGS project are driven by the potential of the SPS accelerator and its injectors to provide higher proton beam intensities than those described in the 1999 addendum [2]. In Appendix I of the present note, we summarise the nominal and the potential future proton intensities [5], which form the basis of the detailed design of CNGS components.

One of the first decisions taken by the CNGS project team was to use the SPS naming conventions for tunnels, caverns and equipment throughout the project. Documents giving guidelines for the names of the underground structures led to a new list of abbreviations, providing identifiers for all tunnels, galleries and caverns. In some cases this involved renaming structures, which can be found in the civil engineering drawings (e.g. 'Neutrino Access Gallery' became 'TAG41'). A list of these identifiers and some overview drawings are given in Appendix II.

2. Changes to access galleries

2.1. Change of the access path to the CNGS hadron-stop / muon-detector areas

There is no direct access from the target chamber to the hadron-stop, since no gallery parallel to the decay tube will exist. In the approved version of the project, it was intended to give access to these downstream areas via a gallery starting at the existing alcove RE88 of the LHC, to the west of the decay tunnel of CNGS. This gallery was to descend steeply and cross under the LHC tunnel at a distance similar to that of the decay tube itself, i.e. some 10 metres. The space requirements in RE88 by the LHC project itself left only a very narrow passage for CNGS, which passed noisy equipment. Another solution had to be found.

After examining many different possibilities, the most attractive option found was to connect the hadron stop and muon detector chambers, TNB4, TNM41 and TNM42, to the LHC injection tunnel TI 8. The new access tunnels are called TZ80 (for the connection from TI 8 to the junction for the second muon detector chamber), TZ81 and TZ80 (for the parts connecting TZ80 to TNM41 and TNM42) – see Figure 1.

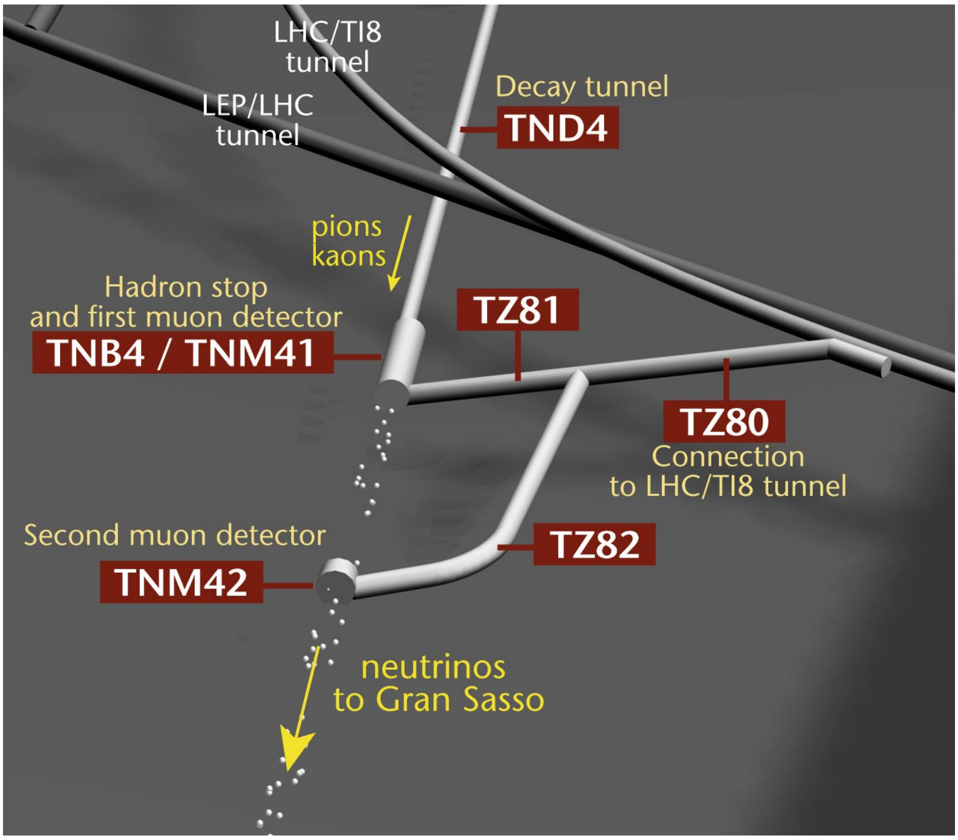


Fig. 1: New layout showing the access path from TI 8 to TNM41 and TNM42.

Excavation of these galleries will take place after dismantling the Tunnel Boring Machine used to excavate the majority of the tunnels, including the hadron-stop area, i.e. in two phases from May to December 2002. No extra cost is expected from this layout change, since the length of the tunnels is shorter than in the original project, and the geometry is simpler - however, confirmation from the contractor on this point is still pending.

2.2. Additional access gallery towards the proton beam tunnel

Soon after the start of civil engineering works, the underground civil engineering contractor approached CERN with a proposal to build an additional gallery, from a point in the main access gallery (TAG41) just upstream of the civil engineering shaft to the TT41 proton beam tunnel (see Fig. 2). The main motivation for the proposal was the possibility to advance excavation on two fronts, i.e. with the Tunnel Boring Machine via TAG41 to TCC4 and into the decay tunnel TND4, and with a road header via TAG42 into TT41. The contractor forwarded an interesting proposal for sharing the cost and risks for the construction of this new gallery, and this proposal was finally accepted by CERN. According to the modified contract, the final cost to CERN for this gallery is linked to the completion date of the civil engineering works (no cost to CERN if the underground construction finishes late) – so until construction work is finished, any extra cost cannot be assessed.

This new gallery will be kept open with provisional lighting and ventilation at least until the end of the installation of equipment in TT41 - it has not yet been decided whether the potential benefits of such a gallery during operation of the SPS-LHC / CNGS complex will justify the eventual cost of equipping the gallery with permanent ventilation, lighting and access control systems.

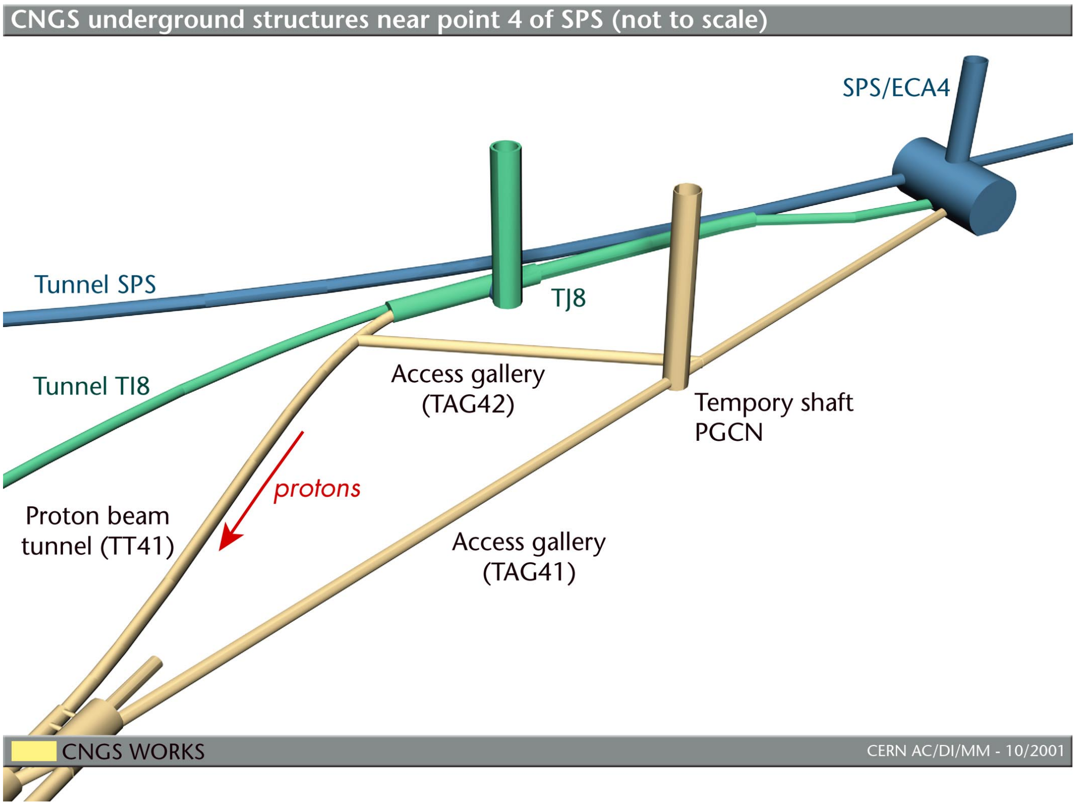


Fig. 2: Layout of the upstream part of CNGS, showing the additional gallery TAG42.

3. Other changes to civil engineering

3.1. Modification of the junction between TCC4 and TCV4

At the time of the CNGS approval, the details of the overhead crane in TCC4 had not yet been studied. Discussions with the experts knowing the problems encountered at the WANF neutrino facility revealed that the cables powering and controlling the crane must be stowed away in an area upstream of the target during operation of CNGS. Various solutions were discussed, and finally that shown schematically in Fig. 3 was adopted: The rail carrying the cable trolleys will be continued through the junction and into the upper level of the ventilation chamber. This will allow the cables to be stored away safely, and will not provide an obstacle for transporting and manipulating equipment, whether the crane is in its parking position in the most upstream section of TCC4, or it is in use in the cavern.

This solution implied a modification to the civil engineering layout, in particular an enlargement of the connecting gallery between TCC4 and TCV4. An Engineering Change Request for this modification was approved by the Technical Working Group.

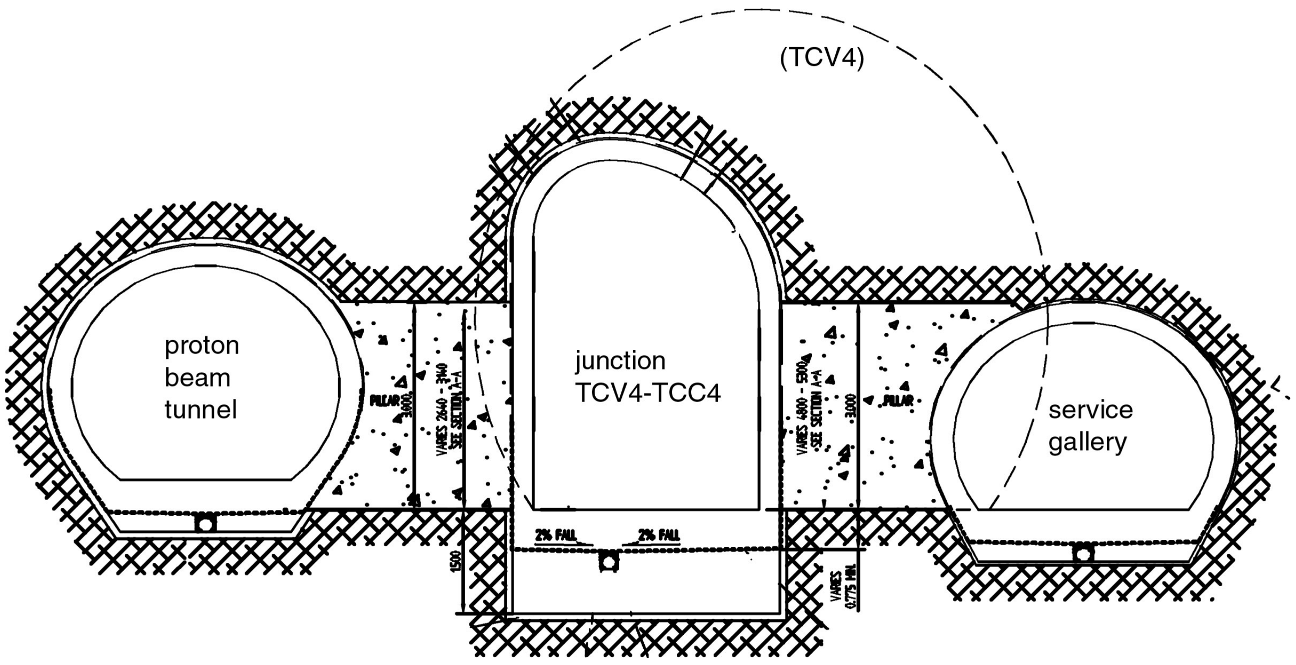


Fig. 3: Enlarged section of the junction gallery between TCV4 and TCC4.

3.2. Hole from LHC to CNGS decay tunnel

The decay tunnel of CNGS is acting as a huge “collimator” for the beam - pions decaying in flight inside the decay tube vacuum will form the beam towards Gran Sasso. In order to obtain additional confirmation on the correct alignment of the decay tunnel, it was decided to drill a vertical hole from LHC downwards - the Tunnel Boring Machine is expecting to pass below this control point around 20 February 2002. Due to the valuable cross-check it provides on the overall alignment of CNGS, this temporary hole of 22 cm diameter was felt to be worth its cost of about 17 KCHF. *Note added in proof: On 4 March 2002, the tunnel boring machine passed under the LHC tunnel - the vertical hole mentioned above was found as expected.*

3.3. No concrete around the hadron-stop

In the earlier phases of the CNGS project, proposals for the installation of a ‘near’ detector, less than 1 km from the beam dump, had been put forward. Such a ‘short-baseline’ detector would have been very sensitive to the correct shielding (absorption) of muons, both on and off the beam axis. It had therefore been decided to fill the void around the iron blocks of the beam dump in the hadron-stop cavern TNB4 with concrete.

The evolution of neutrino physics, together with the excessive cost for a detector cavern at the ‘near’ location, had as a result that the ideas for such ‘short-baseline’ experiments were not pursued. This allows us, in the present version of CNGS, not to fill the voids around the dump in TNB4 with concrete. An additional benefit of this solution would become apparent should the dismantling of the hadron-stop sometime after the end of CNGS operation be required. A section across the hadron-stop in TNB4 is shown in Figure 4.

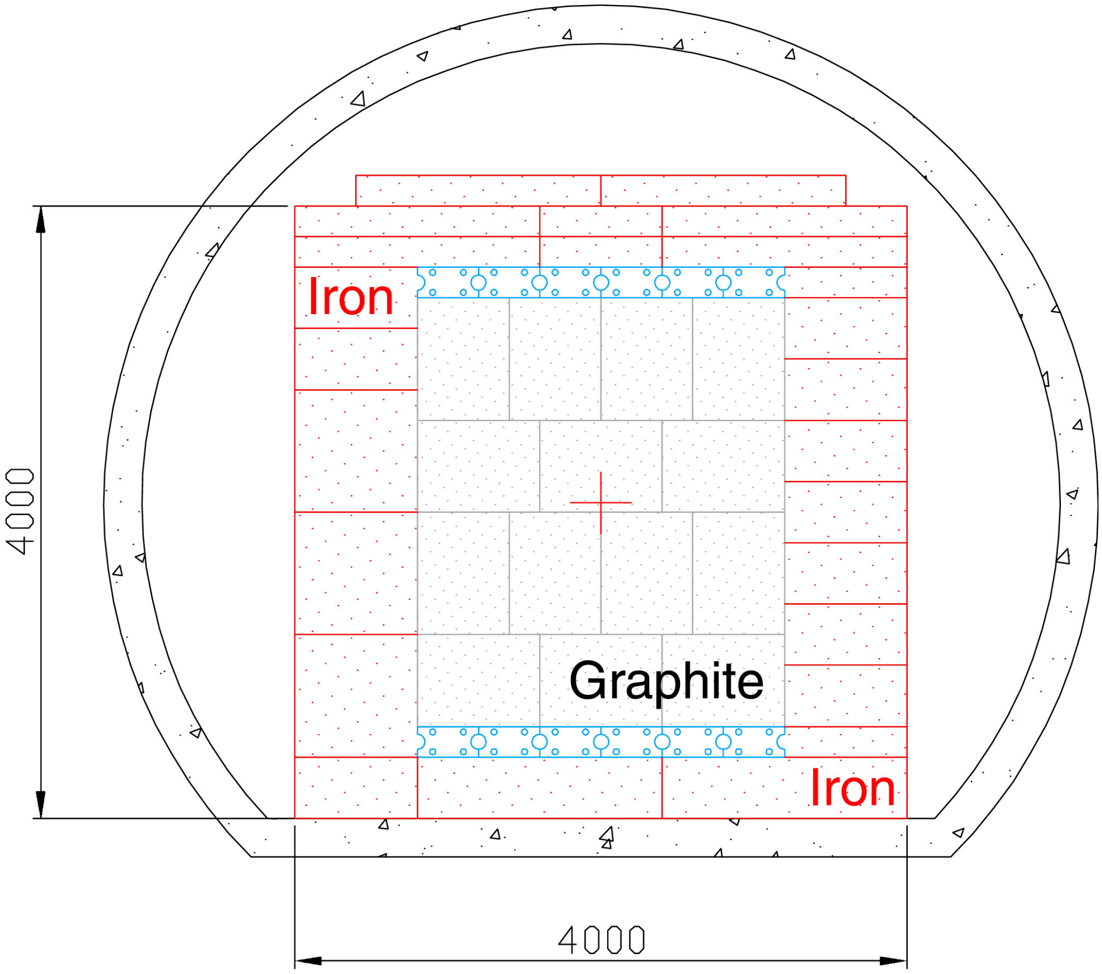


Fig. 4: Schematic cross section of the hadron stop cavern, showing the beam dump with its graphite core, the top and bottom cooling plates, surrounded by iron blocks. No concrete filling around the iron is foreseen.

3.4. Additional holes for air-conditioning in TCC4

The potential for future higher proton intensities delivered to the CNGS target is very promising and must be taken into account (see Appendix I for the nominal and future intensity figures). The high-intensity, high-energy proton beam implies that a significant amount of energy will be deposited in the structures of the CNGS facility. Simulations show that for a well-centred beam on target, around 50% of this energy will be absorbed by the structures in the target cavern (e.g. shielding blocks), another 25% of the energy will be deposited along the decay tube in the steel, concrete and rock, and around 10% of the energy will be deposited in the hadron-stop (the remaining 15% is due to particles interacting or stopping farther away from the CNGS structures). This absorbed energy will result in the heating of the structures.

Cooling of the hadron-stop with water, along the principles used in beam dumps at CERN and elsewhere, had been part of the CNGS project since 1998. After extensive studies and three-dimensional modelling of the temperature distribution in and along the decay tube, it has recently been concluded that special additional cooling for the decay tube is not necessary - the hottest point in the area would reach less than 60 °C even in extreme running scenarios (highest intensity, non-stop operation for 20 years).

The heat deposited in the structures of the TCC4 target cavern is such, however, that the cooling power from the ventilation system foreseen for this area could not cope - see Figure 5. In anticipation of higher proton beam intensities, it was therefore decided to provide the possibility for additional cooling. The solution adopted is to reserve space for five air-conditioning units in the service gallery TSG4 (50 kW cooling power per unit), and to drill two holes (in addition to the passages TSG41...TSG47, of which some might be used in the future for the same purpose) from TCC4 to TSG4. Ducts in TCC4 will distribute the cold air along the floor, and the hot air will be sucked in from the ceiling. The air-conditioning units contain a fan and a cooling coil connected to a chilled water circuit. The details of this system are still under study, but the size (1.10 metre diameter) and the location of the two additional holes has been decided (one near the target station, one near the upstream end of the reflector).

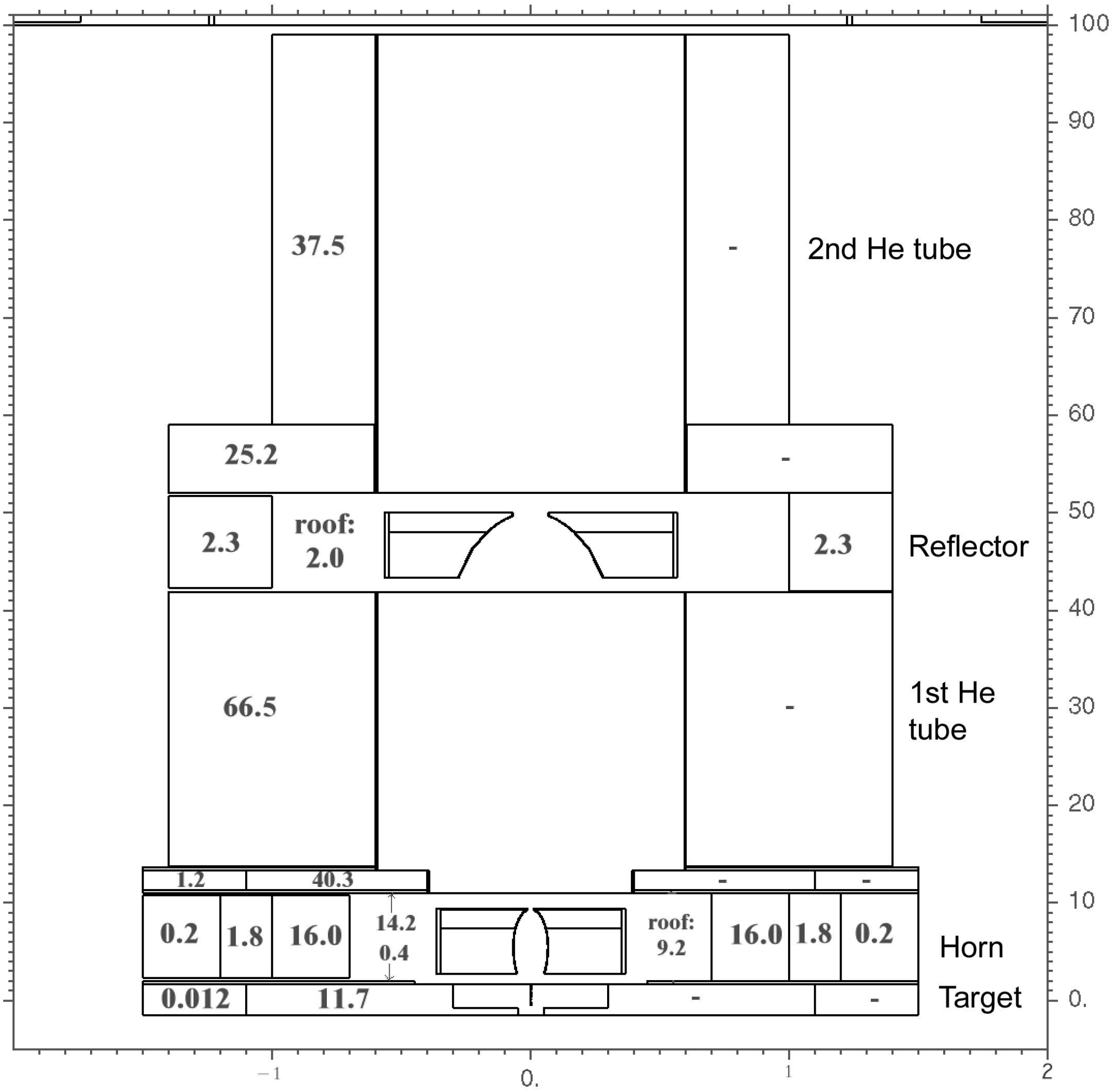


Fig. 5: Heat load in the target chamber TCC4. *Note the strongly distorted scale (in metres)!* **The numbers indicate the power deposited by in kW, for a maximum beam load of the CNGS facility corresponding to 200 days running with a total of 13.8×10^{19} protons on target (see Appendix I). For fully symmetric arrangements (left, right, top and bottom shielding), the total number of kW deposited is indicated on the left hand.**

4. Annex to the BB4 building

Point 4 of the SPS has become the focus of much installation activity for the new East extraction system, the TI 8 transfer line and the CNGS project. While it was felt initially that space would be available for all the equipment in the existing structures, it soon became evident that space and safety constraints made it necessary to build an additional light structure, now called the BB4 annex (see Figure 6 for the location of this annex).

The CNGS facility will use two magnetic lenses, the horn and the reflector, to focus the secondary particles from the target into a parallel beam towards Gran Sasso. These pulsed magnetic devices will be powered in a fashion analogous to the former WANF neutrino facility, i.e. a circuit charges capacitor banks, which are then discharged in phase with the beam pulses from the SPS. Transformers located close to the horn/reflector change the voltage-pulses into high-current pulses. For the base-line design of CNGS, two beam pulses per 6 second cycle are foreseen, and an option for a third pulse is kept open (future high-intensity beam for CNGS).

This powering equipment, together with its control units, requires a surface area of $200\ \mathrm{m}^2$ equipped with a false floor for cables. Although it was initially hoped that this equipment could be installed in ECA4 on top of the TI 8 and CNGS access "bunkers", this now appears not to be feasible: the space needed for the new extraction equipment leaves insufficient room for the CNGS horn / reflector powering equipment.

A working group has studied the possibility of building an annex to BB4, at ground level but very near the CNGS access point at BB4. The technical details (power, ventilation, false floor, transport issues etc.) have been examined and solutions evaluated. The safety issues have been addressed (oil retention in each rack, smoke detection, fire alarm, protecting wall towards BB4). The findings of this group have been presented to the CNGS Technical Working Group. The technical justification for constructing this annex was demonstrated, and the Technical Working Group accepted the proposal. The layout of the powering equipment inside this new building is shown in Figure 7.

(*Note added after the CNGS Review*: *It appears likely that, with new capacitors of a higher density, the space available in ECA4 will be sufficient. Since these capacitors do not contain oil, there is no particular safety hazard. In conclusion, the BB4 annex described above might finally not be needed).*

5. Horn and Reflector adjustments

Detailed computer simulations have been performed in order to assess the sensitivity of the neutrino beam intensity for a given detector at Gran Sasso on possible alignment errors in the construction or during operation of the CNGS facility. This work is summarised in [6]. It is concluded that the sensitivity to alignment errors of the horn and reflector are small. Therefore, remote position adjustments of the horn and reflector during operation of the facility appear to be unnecessary. Manual adjustments for the initial alignment of these elements, and for the eventual re-alignment in case of major movements of the TCC4 cavern, are sufficient. The CNGS Technical Working Group accepted this proposal.

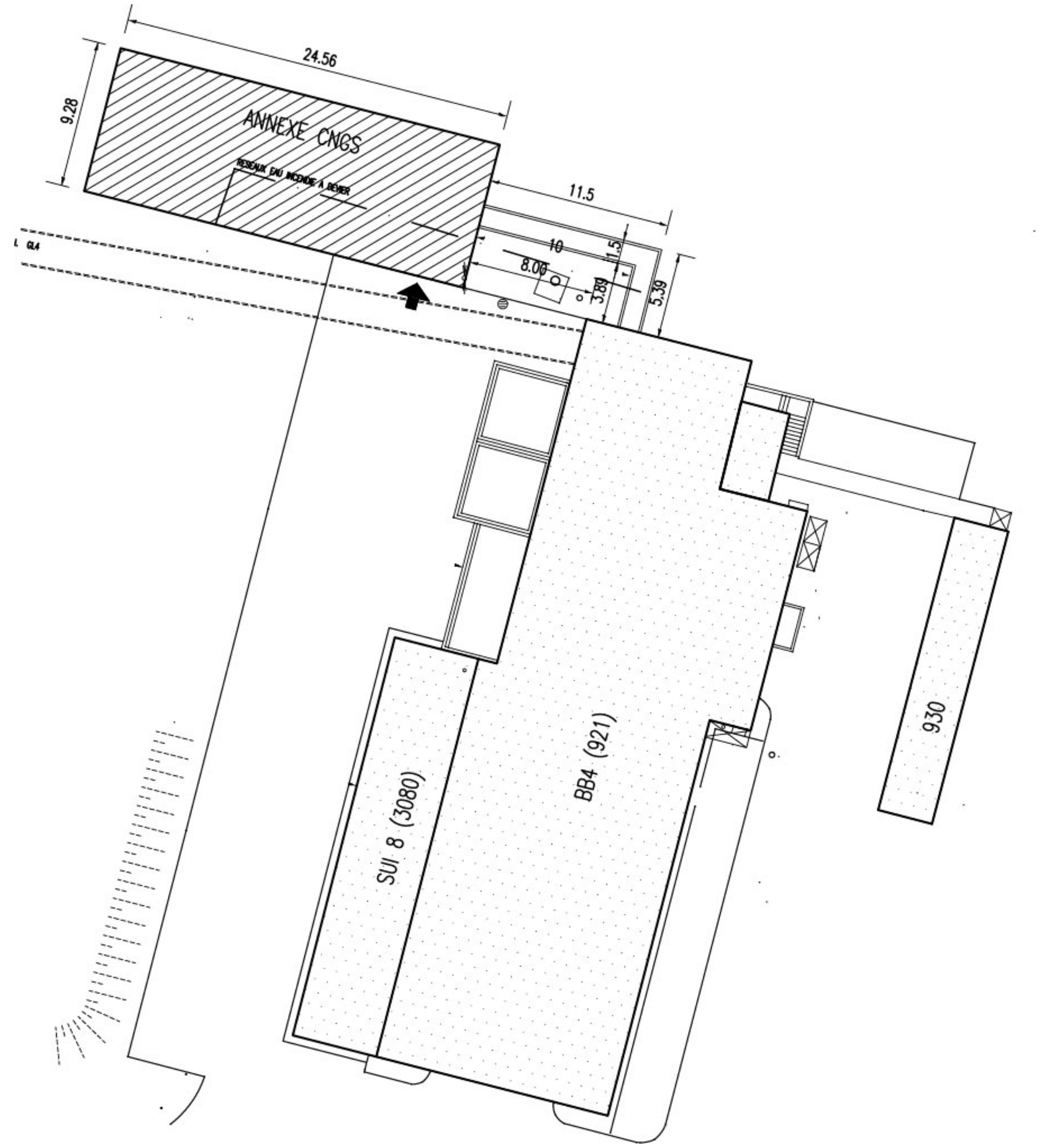
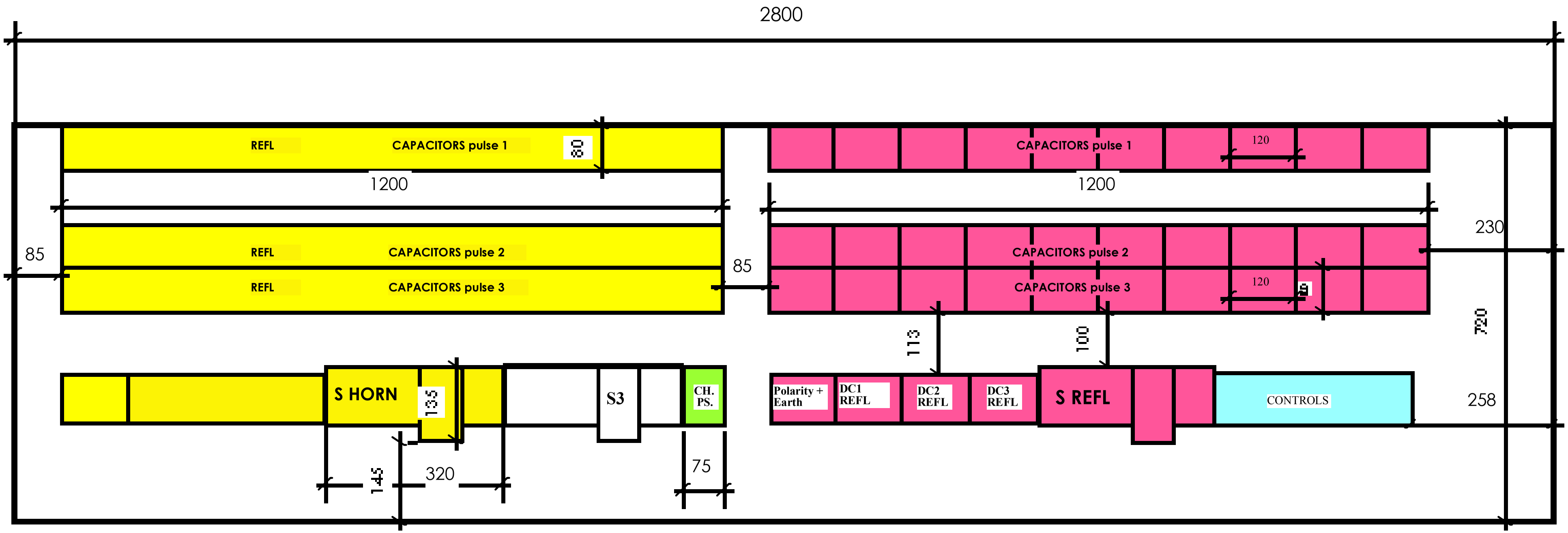


Fig. 6: The location of the annex to the BB4 building, here labelled "Annexe CNGS".



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CNGS HORNS - capacitor banks 5 sept.2001

Fig. 7: Layout of the powering equipment inside the proposed BB4 annex building.

6. Collimation / Shielding in the target chamber

The initial plan for the shielding against the unwanted particles in the target chamber TCC4 was inspired by the West Area Neutrino Facility layout: a few massive shielding blocks, called "collimators" at that time, were foreseen. The layout given in [1] provided the space needed for these collimators located at the exit of the target (part of the target shielding structure), upstream of the horn, between horn and reflector, and in the most upstream part inside the decay tube. The layout presented in [2], for the beam optimised for ν_τ appearance, foresees only a very short distance between the target and horn. It was therefore no longer possible to install collimators as in WANF. Instead, continuous shielding from the target to the end of the first helium tube was introduced. (At that stage in the project, shielding on top of the horn did not seem necessary). Additional shielding was foreseen right after the reflector, and the collimator inside the decay tube was moved into the TCC4 target chamber itself.

In the present layout of TCC4 [7], continuous shielding all around the target, horn, the reflector and both helium tubes is foreseen. A section of the layout is shown in Figure 8. (It was found that for the future increased proton intensities, the dose rate to the target chamber walls, including the crane rails etc., could become intolerably high if no roof shielding was foreseen along the secondary beam).

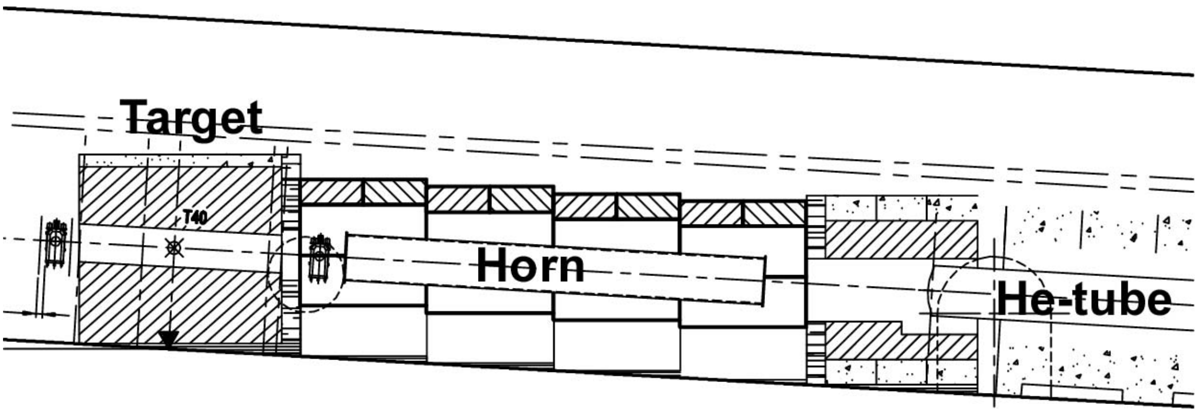

Fig. 8: Vertical section of the shielding in the region around target and horn.

7. Sampling and transport of sump water

In the initial plans for both the target and hadron-stop areas, special sumps were planned to collect any water leaking or accidentally spilt in the areas together with any ground-water infiltrating into them. Final decisions concerning the connection or not of these sumps to the normal drains were left in suspense. It has now been decided not to connect these sumps to the drains directly but to provide a means of emptying the sumps into special containers (in upstream part of the service gallery TSG4 for the target area and at the junction to TI 8 for the hadron-stop area). These containers will then be transported to the surface where tests will be made of the pH and radioactivity levels before any decisions are taken as to discharge of the water via the normal drains. This operation is not expected to take place more than once per year.

8. Muon monitoring system

The CNGS technical design report [1] was based on the very positive experience at CERN neutrino beam facilities with arrays of silicon detectors as a muon monitoring system. Accurate profile measurements were obtained with these detectors, and calibration with emulsions as well as cross-calibration with a set of motorised detectors (calibration box) allowed an absolute flux measurement. Moreover, many of the detectors used in the WANF are stored and could be re-used. At the present stage of the CNGS project, the use of ionisation chambers (very similar to the SPS beam loss monitors) instead of the silicon detectors is proposed, for the reasons outlined below.

Access conditions to the CNGS muon detector stations will be via TI 8 only (cf Figure 1), and is therefore extremely long and difficult (this access implies stopping the transfer of protons to LHC). The muon detector chambers only have one entrance/exit once the decay tube windows are installed, and access will therefore require very particular, stringent safety measures. Very accurate absolute knowledge of the beam intensity is not needed in a $\boldsymbol{\nu}_\tau$ appearance experiment as planned for the first phase of CNGS (more sophisticated muon detectors can be installed at a later stage, if needed). Ionisation chambers have been used for many years as beam-loss monitors (BLM) at the CERN SPS, and several thousand new chambers will be built for the same purpose at the LHC. The reliability of these systems has been proven to be excellent, and the accuracy is largely sufficient for the present CNGS physics programme. Moreover, this solution is found to be less expensive than the cost for the muon detection system originally foreseen. The proposal to install 17 fixed and one motorised BLM in each of the two muon detector chambers has been put forward to the CNGS Technical Working Group and has been accepted.

9. References

[1] G. Acquistapace et al., “The CERN Neutrino Beam to Gran Sasso - Conceptual Technical Design”, CERN 98-02 and INFN/AE-98/05.
[2] R. Bailey et al., “Addendum to report CERN 98-02”, CERN-SL/99-034(DI)
[3] A.E. Ball et al., “CNGS: Update on secondary beam layout”, SL-Note-2000-063 EA
[4] http://proj-cngs.web.cern.ch/proj-cngs/
[5] R. Cappi et al., “Increasing the proton intensity of PS and SPS”, CERN-SL-2001-032, CERN-PS-2001-041-AE.
[6] A.E. Ball et al., “CNGS: Effects of possible alignment errors”, CERN-EP/2001-037
[7] The TCC4 layout drawing can be accessed in the EDMS tree of CNGS, or directly at http://edmsoraweb.cern.ch:8001/cedar/doc.info?document_id=310296&version=3

Appendix I: Proton beam intensities at CNGS

The SPS accelerator complex achieved its best performance in terms of protons delivered on target in 1998, when a maximum number of protons were requested for the West Area Neutrino Facility (NOMAD and CHORUS experiments). During that year, the highest intensity of accelerated protons per cycle was 4.8×10^{13} protons, and the overall operating efficiency (delivered / expected protons on target) was 55%. This includes, by definition, all the down time due to the SPS accelerators, its injectors, and the transfer line to the target, as well as periods of operation with reduced intensity due to minor faults.

The 1998 performance of the SPS was used as a basis for the estimated number of protons on target to be expected in the CNGS facility [2]. Two fast extractions from the SPS are feasible in a CNGS cycle time of 6 seconds – this leads to 2.4×10^{13} protons on target per extraction. In addition to the number of protons per cycle and the efficiency of 1998, a mixed operational scenario was taken into account: LHC filling, standard fixed target (experiments and tests) as well as a potential LHC ion run were considered. In this way, the total estimated number of protons on target per year turns out to be 4.5×10^{19}.

During operation of an accelerator complex. improving the performance of these machines in small steps is a continuing process. Beyond these smaller steps achievable by gradual advance investment, i.e. additional hardware, is often needed. The SPS and its injectors have a crucial role for the LHC accelerators, and considerable effort and investment is going into the upgrade of these accelerators to meet the requirements of the LHC. Most of the investment is also directly beneficial for CNGS: for example, it is expected that the maximum intensity accelerated in the SPS (with acceptable losses!) will be 7 rather than 4.8×10^{13} protons. Work is ongoing at the injectors (in particular the PS accelerator) to achieve this goal. Since CNGS is designed to operate at least for 10 years, such potential improvements are taken into account.

For the engineers designing CNGS equipment, there are two potentially important numbers:

(1) The expected number of protons per extraction (potentially dangerous due to the thermo-mechanical shock, e.g. in the target rods, in the vacuum windows, etc.)

(2) The average number of protons on target over a longer time period, and – consequently – the total number of protons delivered on target per year.

The former may be important for issues such as cooling the beam dump, and both of these values are important for radiological considerations (e.g. air activation, induced radioactivity etc.).

An overview of nominal (i.e. used for assessing the physics reach of CNGS) and "ultimate" (i.e. used for engineering purposes) proton beam parameters is given in Table A1.

	nominal	**"ultimate"**
protons on target **per extraction**	$2.4\text{x}10^{13}$	$3.5\text{x}10^{13}$
protons on target **per cycle**	$4.8\text{x}10^{13}$	$7\text{x}10^{13}$
average p.o.t. **per second**	$2.6\text{x}10^{12}$	$8\text{x}10^{12}$
total p.o.t. **per year** (200 days)	$\mathbf{4.5\text{x}10^{19}}$	$13.8\text{x}10^{19}$

Table A1.1: Proton intensities on CNGS target for nominal and "ultimate" operation at 400 GeV/c.

Appendix II: CNGS naming conventions

At the time of the approval of CNGS, the civil engineering project was already well advanced and the underground structure had been given "meaningful" names in all the drawings, e.g. "proton beam tunnel", "neutrino access gallery". Since the beam for the CNGS facility was to be provided by the SPS accelerator via a high energy proton transfer line, it was soon decided to introduce codes for all the structures and equipment, which follow the naming conventions for the SPS. There is one exception: the muon detector chambers are accessible only via a gallery linked to the TI 8 tunnel. Since TI 8 is part of the LHC project, the names for these access galleries are following the LHC conventions (TZ for access galleries) rather than the SPS conventions (TA for access galleries).

Below in table A2.1, a list of codes is provided together with the names for tunnels etc. found on civil engineering documents. Figures 1 and 2 already show some of these codes. A full description for the target chamber area is given in Figure A2.1.

For completion, a table of SPS equipment codes and the person responsible for the names beyond the first letter, i.e. for detailed naming of equipment, is shown in Table A2.2.

code	object in CNGS	other names used
TAG41	Access gallery to target chamber	Neutrino access gallery
TAG42	Access gallery connecting TAG41 to the proton beam tunnel TT41	Proton beam access gallery
TT41	Proton beam tunnel	TN4 (obsolete)
TCV4	Ventilation chamber	
TCC4	Target chamber	Target cavern, Neutrino cave
T40	Target station	
TSG4	Service gallery	
TSG40	Service gallery	Radioactive materials storage
TSG41...TSG47	Service galleries connecting TSG4 and TCC4	Cross galleries
TSG48	Service gallery connecting TSG4 and the decay tunnel TND4	
TND4	Decay tunnel	
TNB4	Beam dump cavern	Hadron stop chamber
TNM41	First muon detector chamber	First muon pit
TNM42	Second muon detector chamber	Second muon pit
TZ80	Access Gallery from TI 8 towards the muon detector chambers - links to TZ81 and TZ82 (see Figure 1).	
TZ81	Access Gallery, links TZ80 and TZ82 to TNM41	
TZ82	Access Gallery, links TZ80 and TZ81 to TNM42	

Table A2.1: Codes used for CNGS tunnels, caverns and galleries.

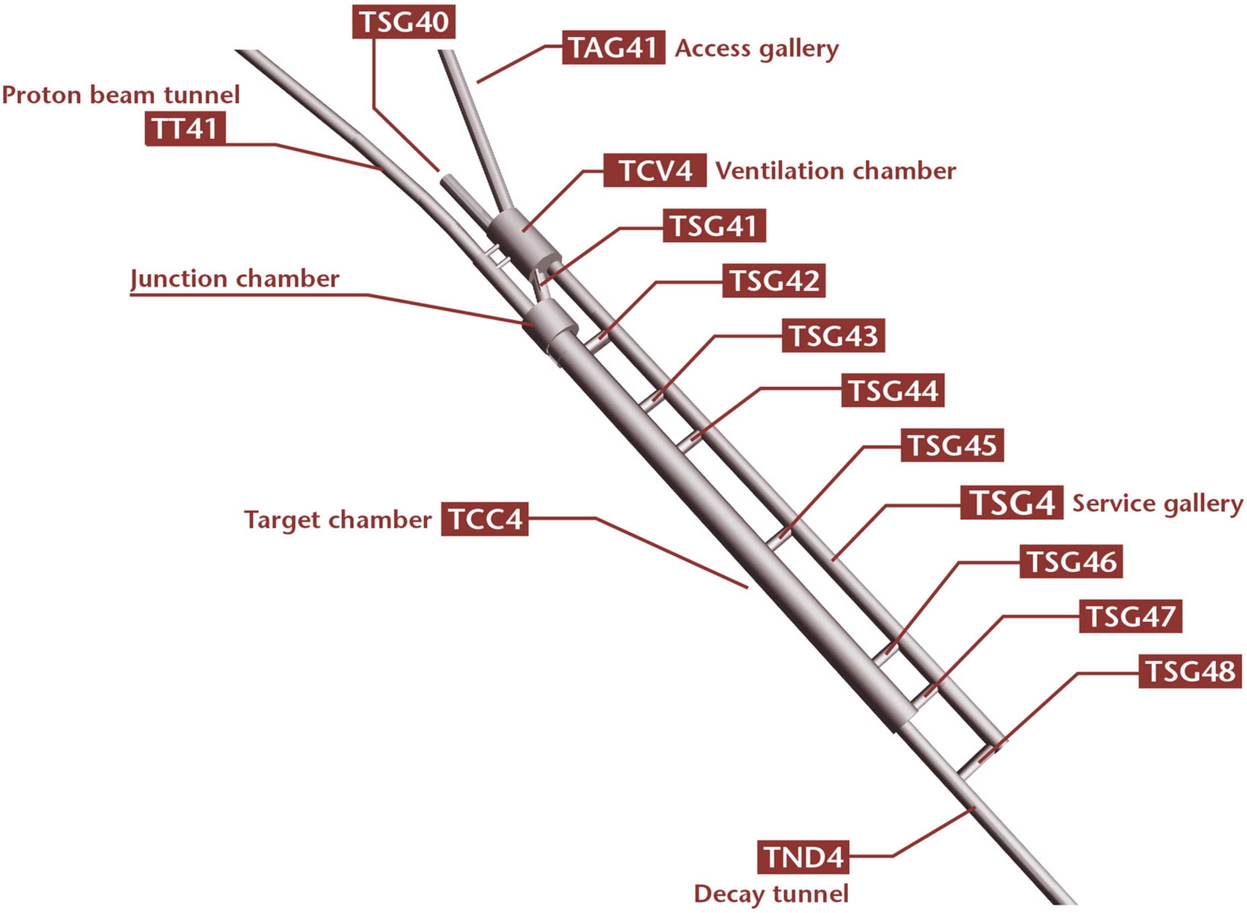

Figure A1.1: Code names of caverns and galleries in the target chamber area.

SPS Equipment Codes and People Responsible for Naming

Code	Equipment Description	Responsible	Group
A	Acceleration Cavities + RF Equipment	T. Linnecar	SL-HRF
B	Beam Monitoring Devices	H. Schmickler	SL-BI
C	Communications +	R. Parker	IT-CS
	Controls Equipment	G. Coianiz	SL-CO
D	unused		
E	Electrical Supply + Distribution Equip.	J. Pedersen	ST-EL
F	Fluid Distribution	M. Wilhelmsson	ST-CV
G	Girders + Supports	M. Mathieu	EST-ESM
H	Handling Devices + Special Equipment	I. Ruehl	ST-HM
I	LEP Transfer Equipment		
J	unused		
K	Kicker Equipment (magnets use ‘MK’)	L. Ducimetiere	SL-BT
L	Lenses other than Quadrupoles +	W. Kalbreier	SL-MS
	Layouts.	J. Ramillon	EST-ESM
M	Magnetic Deflection Devices	W. Kalbreier	SL-MS
N	unused		
O	unused		
P	Personnel Safety (Radiation)	D. Forkel-Wirth	TIS-RP
Q	Quadrupoles	W. Kalbreier	SL-MS
R	Racks + other Enclosures	to be named	
S	Power Supply Equipment	R. Genand	SL-PO
	(Power Converters follow magnet name)	M. Royer	
T	Targets, Dumps, Collimators, etc.	L. Bruno	SL-BT
U	Ventilation & Air Handling	M. Wilhelmsson	ST-CV
V	Vacuum Equipment	P. Strubin	LHC-VAC
W	unused		
X	Experimental Area Equipment	M. Clement	SL-EA
Y	Access + Miscellaneous Equipment	E. Cennini	ST-AA
Z	Electrostatic Devices	B. Goddard	SL-BT

Table A2.2: Equipment codes for CNGS, following the SPS conventions.