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# THE CNGS FACILITY: PERFORMANCE AND OPERATIONAL EXPERIENCE

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The CNGS facility (CERN Neutrinos to Gran Sasso) aims at directly detecting muon to tau neutrino oscillations. An intense muon-neutrino beam (1E17 muon neutrinos/day) is generated at CERN and directed over 732 km towards the Gran Sasso National Laboratory, LNGS, in Italy, where two large and complex detectors, OPERA and ICARUS, are located. CNGS is the first long-baseline neutrino facility in which the measurement of the oscillation parameters is performed by observation of tau-neutrino appearance. In this paper, an overview of the CNGS facility is presented. The experience gained in operating this 500 kW neutrino beam facility is described. Major events since the commissioning of the facility in 2006 are summarized. Highlights on CNGS beam performance since the start of physics run in 2008 are given.

## 1. Introduction

The CNGS facility was first operational in July 2006 for an approved physics program of five years with a total of 22.5E19 protons on target (4.5E19 protons/year). The 400GeV/c CNGS beam is fast extracted from the CERN SPS accelerator. The nominal intensity is 2.4E13 protons on target per 10.5μs extraction. During the 6s cycle, there are two extractions separated by 50ms. The beam is sent down an 840m long proton beam line with a slope of 5.6% onto a carbon target producing kaons and pions, corresponding to an average power at the target of 510kW. The positively charged pions and kaons are energy-selected and guided with two focusing lenses, the so-called horn and reflector, in the direction towards Gran Sasso. These particles decay in a 1000m long, 2.5m diameter decay vacuum tube into muon-neutrinos and muons. All the hadrons, i.e. protons that have not interacted in the target, pions and kaons that have not decayed in flight, are absorbed in a hadron stopper. Only neutrinos and muons can traverse this 18m long block of graphite and iron. The muons, which are ultimately absorbed downstream in around 500m of rock, are measured in two muon detector stations. They are arranged in a cross-shaped array, measure the muon intensity and the vertical and horizontal muon profiles which allows concluding on the quality and intensity of the neutrino beam produced and on the beam profile. A schematic overview of the CNGS neutrino beam facility at CERN is shown in Fig. 1.

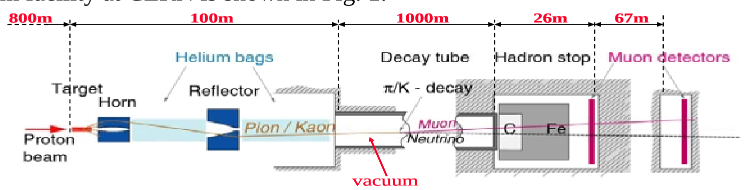


Figure 1: Main components of the CNGS facility.

## 2. CNGS Operation

CNGS was commissioned successfully in 2006 [1]. During 2007 CNGS was running for 6 weeks. After the completion of the OPERA detector [2] and finishing successfully some initial issues that occurred in the facility, CNGS had its first complete year of physics in 2008 with 1.78E19 protons on target. In 2009 so far (status of 2nd October 2009) 2.43E19 have been cumulated and OPERA has collected more than 14400 on-time events and more than 2400 candidate interactions in the bricks [3].

Table 1: Cumulated protons on target for CNGS to date.

| | protons on target |
|---|---|
| 2006 | 7.56 E17 |
| 2007 | 6.13 E17 |
| 2008 | 1.78 E19 |
| 2009 | 2.43 E19 |
| **Total** | **4.2 E19** |

## 3. Start-up Issues

Physics requirements have been pushing the needed power of the proton beam on target to values around and above 500 kW. The CNGS secondary beam line, starting with the target, has to cope with this situation, which pushes the beam line equipment and instrumentation to the limits of radiation hardness and mechanical stresses during the CNGS operation. The choice of materials, shielding configurations, remote handling capabilities for maintenance and exchange of equipment were carefully designed and optimized. However, the startup issues faced demonstrate the difficulty in the design and operation of such high intensity facilities. In the following major technical issues and improvements are summarized.

*Water leak in the Horn Cooling Circuit*

During the 2006 CNGS run, after only 4E5 horn pulses, a leak in a water outlet of the 2$^{nd}$ horn (reflector) cooling circuit has been detected. This was caused by a design fault in a ceramic insulator brazing. A new design was developed that avoids machining and brazing of the ceramic which is now only under pressure, maintaining the water and vapour tightness. Thanks to detailed dose planning, tooling and training as well as additional local shielding a repair was possible.

*Metal Fatigue in Cables of Flexible Stripline*

Before starting the run 2007 a broken cable in the flexible striplines that bring the current to the reflector was discovered. Metallurgical analysis of the broken cable showed traces, striations and secondary cracks confirming the failure due to metal fatigue. All the flexible parts for the horn and reflector were replaced by solid plates carefully designed to adapt to the existing geometry and accommodate for the thermal dilatation.

*Radiation Effects in the Electronics*

During the CNGS run in 2007, five days prior to the end of the run, successive failures occurred in the control of the ventilation system which was installed in the tunnel adjacent to the target chamber. This was caused by radiation effects in the electronics (SEU, single event upsets due to high energy hadron fluence). The remedy during the winter shutdown was to move as much electronics as possible out of the CNGS tunnel area. In addition a radiation safe area for the electronics was created in the tunnel by adding shielding: in total 53m$^3$ of concrete were poured in-situ to create up to 6m thick shielding walls. According to FLUKA [4] simulations this new layout decreased the radiation to electronics by up to a factor 10$^6$, which assures normal operation of the facility at nominal conditions.

*High Torque in Target Motorization*

The CNGS target assembly has five target units, one is used in the beam, and the other four are in-situ spares. The change of target units can be done remotely without requiring access to the facility. While doing the standard maintenance tests for the 2009 operation, an unexpected high-torque of 30Nm (instead of 8Nm) in the motorization for the target unit exchange was observed: An in-situ investigation of the target assembly revealed that the four ball-bearings that support the target magazine were all rusted. As any on-site exchange of the ball-bearings is impossible due to the high radiation levels, the target unit already in the beam in the previous years is used for the 2009 run. In the unexpected case of target unit failure, the entire target assembly will be exchanged with the available spare one.

*Cartridges Improvements of the Horns*

The CNGS horns are cooled by a water circuit that includes demineralization cartridges to avoid horn corrosion. The cartridges originally installed in 2006

reached saturation and needed to be exchanged every 4 weeks, causing beam time loss during access and a high amount of radioactive waste.
In 2009, new cartridges were developed in-house and have been installed in the horn cooling circuit since June 2009. The new cartridge system has a double or triple capacity (and therefore lifetime), resulting in fewer accesses. The cartridges are designed to be recycled, i.e. only the saturated resin is radioactive waste, while the shell of the cartridge can be re-used with new resin. This reduces the radioactive solid waste by about 250kg per year.

## 4. CNGS Performance

During the first complete CNGS physics run in 2008 in total 1.78E19 protons on target were cumulated. Detailed results can be found in [5] and [6].
The CNGS physics run in 2009 started on 1st June 2009 and is scheduled until 23rd November 2009. The overall efficiency of the accelerator complex is very good, i.e. 74%, resulting to 2.4E19 integrated number of protons on target until today (status 2nd October 2009), which is 9% higher than expected (2.2E19), (see Fig. 3).
For most of the time the facility operates with 2E13 pot/extraction. This should be even improved once the multi-turn extraction system becomes fully operational, expected by the end of this year's running period. The overall beam performance and stability throughout the run is excellent: 110$\mu$m r.m.s in the horizontal plane and 50$\mu$m r.m.s in the vertical plane.

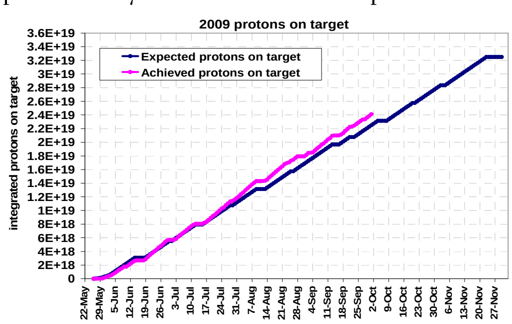


Figure 3: Expected and achieved integrated protons on target for 2009 up to date.

The muon detector [7] stations are very sensitive to any misalignment between the proton beam, the target and the horn. This allows to precisely optimizing on-line the secondary particle and neutrino production. Comparison between the muon profiles measurements and FLUKA [4] simulations shows very good agreement (see Fig. 4). This proves that the CNGS facility is very well understood and special features of the facility are considered: e.g. in the horizontal muon profiles an asymmetry between operating in neutrino mode (focusing of mesons with positive charge) and anti-neutrino mode (mesons with negative charge) has been observed. This can be explained due to the earth magnetic field in the 1000m long decay tube which results in the profile shifts of the observed magnitude [8].

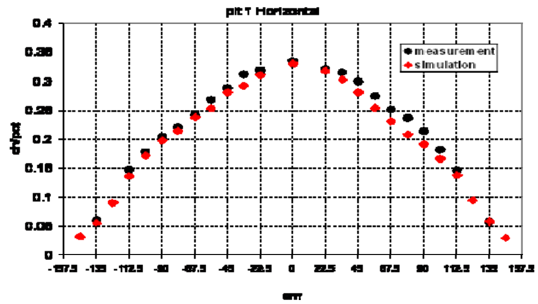


Figure 4: Measured (black circles) and simulated (red rectangles) horizontal muon profile in the first muon detector station. Each point corresponds to one ionization chamber readout.

## 5. Summary

The startup incidents we faced after the commissioning of the CNGS facility in 2006 demonstrate the difficulty in the design and operation of such high intensity facilities. After successfully resolving these issues, CNGS started the physics run in 2008 and has since then 4.2E+19 protons on target cumulated. With the present statistics, the first tau-neutrino events are expected by the end of this year's physics run.

## References

1. M. Meddahi et al, CERN-AB-2007-039, PAC07, pp692, Albuquerque, USA (2007).
2. R. Acquafredda et al, 2009 JINST **4** P04018 (2009).
3. J. Marteau, this conference, 11th ICATPP, Villa Olmo, Como, Italy (2009).
4. A. Fasso, A. Ferrari, P.R. Sala, Proc, MonteCarlo 2000, Lisbon, 23-26 Oct. 2000, A. Kling et al., eds., Springer-Verlag, Berlin, p. 159-164, p 995-960 (2001).
5. I. Efthymiopoulos et al, 'First Year of Physics at CNGS' presented at PAC08, Vancouver (2008).
6. E. Gschwendtner, 'CNGS: First Year of Operation', AB-Seminar, CERN, Nov. 2008 (2008).
7. A. Marsili et al, CERN-AB-Note-2008-044-BI (2008).
8. E. Gschwendtner, CERN-AB-Note-2008-050-ATB, POS: NuFact08, pp008, Valencia, Spain (2008).