# PERFORMANCE AND OPERATIONAL EXPERIENCE OF THE CNGS FACILITY

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*Abstract*

The CNGS facility (CERN Neutrinos to Gran Sasso) aims at directly detecting muon to tau neutrino oscillations. An intense muon-neutrino beam ($1.0 \cdot 10^{17}$ muon neutrinos/day) is generated at CERN and directed over 732km 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 the tau-neutrino appearance. The facility is approved for a physics program of five years with a total of $22.5 \cdot 10^{19}$ protons on target. Having resolved successfully some initial issues that occurred since its commissioning in 2006, the facility had its first complete year of physics in 2008. By the end of 2009 the facility delivered in total $5.4 \cdot 10^{19}$ protons on target corresponding to an expected ~2-3 tau neutrino events in the OPERA detector, according to the most probable physics parameter oscillation model of today. The experiences gained in operating this 500 kW neutrino beam facility along with highlights of the beam performance in 2009 are discussed.

## THE CNGS FACILITY

The CNGS facility (see Fig. 1) was first operational in July 2006 for an approved physics program of five years with a total of $22.5 \cdot 10^{19}$ protons on target ($4.5 \cdot 10^{19}$ protons/year). The 400GeV/c CNGS beam is fast extracted from the CERN SPS accelerator. The nominal intensity is $2.4 \cdot 10^{13}$ 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.

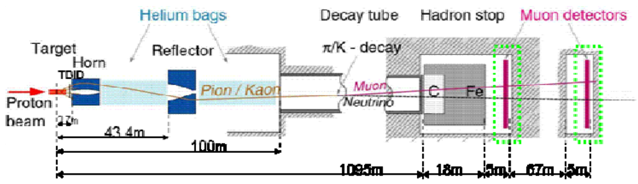


Figure 1: Layout of the CNGS Facility.

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. These detectors are arranged in a cross-shaped array and measure the muon intensity and the vertical and horizontal muon profiles that allows concluding on the quality and intensity of the neutrino beam produced and on the beam profile.

## CNGS OPERATION

### *Protons on Target*

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 $1.78 \cdot 10^{19}$ protons on target. In 2009 in total $3.52 \cdot 10^{19}$ protons on target were cumulated. The total number of protons accumulated in 2008 and 2009 correspond to an expected ~2-3 tau neutrino events in the OPERA detector.

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

| | **Protons on Target** |
|---|---|
| 2006 | $8.55 \cdot 10^{17}$ |
| 2007 | $8.4 \cdot 10^{17}$ |
| 2008 | $1.78 \cdot 10^{19}$ |
| 2009 | $3.52 \cdot 10^{19}$ |
| **Total** | $\mathbf{5.47 \cdot 10^{19}}$ |

The CNGS beam operation for 2010 started on 20 April, the beam will run until 22 November 2010 and is expected to deliver $3.8 \cdot 10^{19}$ protons on target.

### *Technical Issues*

The high intensity, high energy proton beam, the intense short beam pulses (designed for up to $3.5 \cdot 10^{13}$

protons per 10.5μs extraction) with small beam spots (<1mm) pushes the CNGS secondary beam line equipment and instrumentation to the limits of radiation hardness and mechanical stress. Although the materials, shielding configurations, remote handling capabilities for maintenance and exchange of equipment were carefully chosen, designed and optimized, several start-up issues demonstrated the difficulty in the design and operation of such a high intensity facility.

Details of the major technical issues and improvements taking place between 2006 and 2009 are summarized in [3]. These issues comprise a water leak in the horn cooling circuit, metal fatigue in cables of flexible stripline connections, radiation effects in the electronics, high torque in target motorization, and cartridges improvements in the cooling water system of the horns.

During the shutdown 2009/2010 modifications works on the CNGS drainage and sump system were performed in order to avoid contamination of the drain water by tritium produced in the target chamber. Two new sumps were constructed to remove the drain water before it reaches the target area and consequently gets in contact with the tritiated air. In addition, studies and modifications of the ventilation system and its operation were performed. This assures that the target chamber, where the tritium is produced, remains in all cases in under-pressure with respect to the neighbouring areas. It also prevents the tritiated air to propagate into other areas and in particular to get in contact with the drain water.

## CNGS PERFORMANCE

The results of the CNGS run 2008 are summarized in [4]. In 2009 a record intensity of $3.52 \cdot 10^{19}$ protons on target was achieved (cf. Fig. 2).

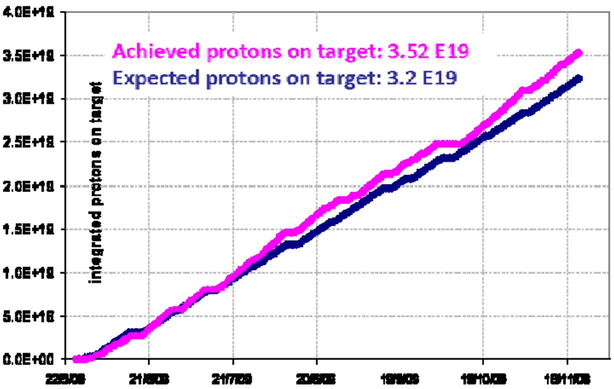


Figure 2: Achieved protons on target for 2009.

This is 10% more than originally scheduled for the SPS operation that year; CNGS profited from improvements made in the SPS control system which now allows switching quickly between super-cycles and consequently optimizing the duty cycle for CNGS. In addition the shutdown work and improvements in the CNGS facility paid off. No additional stops for maintenance or repair were needed.

The overall efficiency of the accelerator complex was very good, i.e. 73%. The average beam intensity per extraction during the entire CNGS run 2009 was $1.93 \cdot 10^{13}$pot/extraction (see Fig.3). This intensity was already reached about 2 weeks after the beam start-up. Limits on the intensity were due to losses in the PS injector and due to a lack of margin in the RF system of the SPS. Due to beam sharing on the SPS with other users, an average beam power of about 300kW was delivered to the CNGS facility.

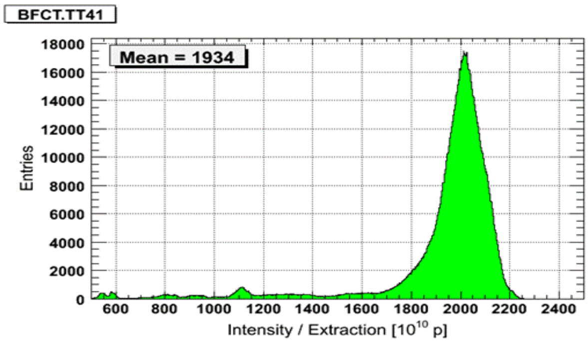


Figure 3: Protons on target per extraction during 2009.

In total there were nearly 2 million extractions from the SPS to CNGS. Injection losses were at the order of 6%. The typical SPS transmission of the CNGS beam throughout the full SPS cycle was 94%.

The overall beam performance and the stability of the primary proton beam line on the target beam position was excellent throughout the run: 90$\mu$m r.m.s in the horizontal plane and 40$\mu$m r.m.s in the vertical plane were achieved. No active position feedback was necessary, 1-2 small manual steering corrections per week were sufficient.

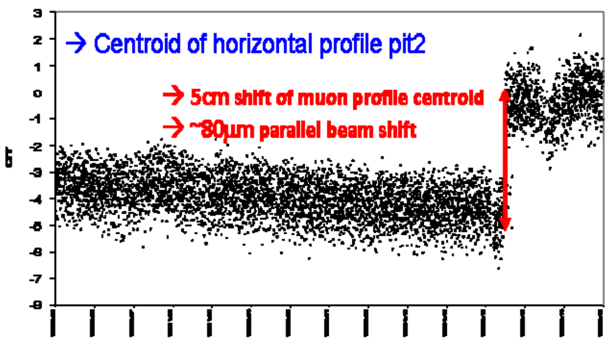


Figure 4: Centroid of the horizontal muon profile in the second muon detector station. A parallel beam shift of 80μm on the target corresponds to a 5cm shift of the muon profile centroid.

The muon detector stations [5] are very sensitive to any misalignment between the proton beam, the target and the horn. For example an 80μm parallel beam shift on the target corresponds to a 5cm shift of the muon profile centroid (see Fig.4) in the second muon detector station.

Hence scanning the proton beam w.r.t. the target and comparing the muon monitor profiles yielded optimal secondary particle production efficiency and a precise alignment of the beam w.r.t the target.

Target scans in the beginning of the 2009 run (May) and in the end (November) revealed a horizontal target shift of ~1.5mm during the year 2009. This was also confirmed by a horizontal beam position change on the last beam position monitor during the run 2009. As a result of the excellent beam position stability on the target, also the position stability of the muon beam in the second muon detector station was very good, i.e. 2.5mm r.m.s. for the full year 2009.

The CNGS secondary beam line equipment was very stable. The target yield kept constant and no deterioration of the target has been observed. During the 2009 run the horn and reflector continued working reliably and were pulsed ~$3\cdot10^6$ times (which is less than 10% of the design value of $4\cdot10^7$ pulses). The associated cooling system also ran very stably. The improved filtering system (cartridges) of the cooling water needed to be exchanged only every 2 months, which was done in the shadow of other technical stops of the accelerators, causing no additional down-time of the CNGS run.

During the 2009 run beam was provided from the PS to the SPS with the classical "continuous transfer" extraction scheme. In parallel, the novel multi-turn-extraction (MTE) scheme [6] was prepared and commissioned on dedicated MD cycles which also provided beam to CNGS, but with lower intensity [7].

The start of the CNGS run 2010 was very smoothly. Beam from PS was delivered in the multi-turn extraction only. The accumulated protons per day are above the expected ones (see Fig. 5).

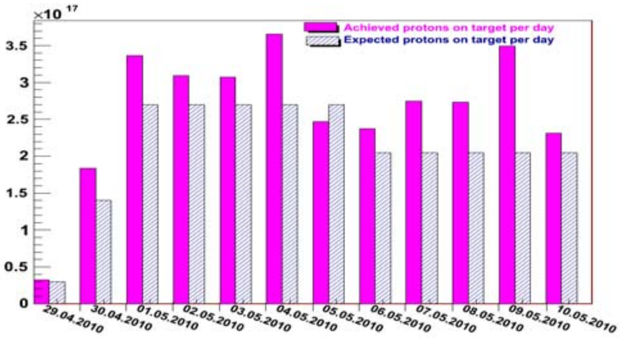


Figure 5: Achieved and expected protons on target per day since the start of the CNGS run 2010.

## *Gran Sasso Experiments*

The OPERA experiment had a smooth run, so far collecting in total 31500 on-time events with 5200 candidate muon neutrino interactions in the bricks, thus proving the full chain of event handling and data analysis. The electronics detector performance is reliable and well understood. A systematic "decay search" started on all events in order to find all possible decay topologies. About 20 charm events were found, as expected. The global analysis is progressing well, studies on event kinematics and hadronic interaction backgrounds are on-going [8].

ICARUS–T600 started the cooling and filling phase and will be operational in May 2010 [9].

# SUMMARY

After resolving the start-up issues since the beam commissioning in 2006, CNGS has successfully delivered beam to the Gran Sasso experiments for physics in 2008 and 2009. Until today $5.48\cdot10^{19}$ protons on target have been cumulated. Within the accumulated data at Gran Sasso, first tau-neutrino events are expected to be found.

By the end of 2010 it is planned to deliver a further $3.8\cdot10^{19}$ protons on target. The total accumulated protons by then will result in 40% of the initially approved number of protons on target for the CNGS physics programme.

# 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] E. Gschwendtner et al, “The CNGS Facility: Performance and Operational Experience”, EuCARD-CON-2009-014, 11th ICATPP Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physics Applications, 5-9 October 2009, Villa Olmo, Como, Italy, (2009).
[4] I. Efthymiopoulos et al, “First Year of Physics at CNGS”, EuCARD-CON-2009-013, PAC09, 4-8 May 2009, Vancouver, Canada, (2009).
[5] A. Marsili et al, CERN-AB-Note-2008-044-BI (2008).
[6] R. Cappi, M. Giovannozzi, “Novel Method for Multi-Turn Extraction: Trapping Charged Particles in Islands of Phase Space”, Phys. Rev. Lett. 88 104801 (2002).
[7] S. Gilardoni et al., ”First Results for the Beam Commissioning of the Multi-turn Extraction”, CERN-ATS-2009-038 (2009).
[8] D. Autiero et al, 45th Recontres de Moriond EW 2010, 6-13 March 2010, La Thuile, Aosta Valley, Italy (2010).
[9] A. Menegolli (on behalf of the ICARUS Collaboration), “Status of the ICARUS T600 Detector at the LNGS”, J. Phys.: Conf. Ser. 203 012107 (2010).