CNGS, CERN NEUTRINOS TO GRAN SASSO, FIVE YEARS OF RUNNING A 500 KILOWATT NEUTRINO BEAM FACILITY AT CERN

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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 (10^{17} 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.

The CNGS facility started with the physics program in 2008 and delivered until the end of the physics run in 2012 more than 81% of the approved protons on target ($22.5 \cdot 10^{19}$ pot).

An overview of the performance and 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 the CNGS beam performance are given.

THE CNGS FACILITY

The layout of the CNGS facility is shown in Fig. 1. A 400 GeV/c proton beam is fast-extracted from the CERN SPS accelerator. The beam is sent down an 840 m 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 510 kW. The positively charged pions and kaons are energy-selected and guided with two focusing lenses, the so-called horn and reflector, in the direction of Gran Sasso.

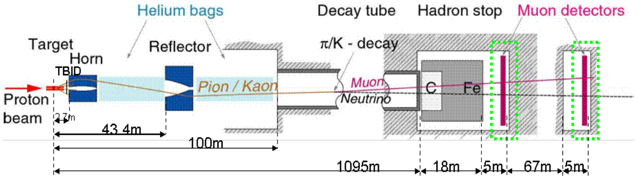

Figure 1: Layout of the CNGS Facility.

These particles decay into muon-neutrinos and muons in a 1000 m long, 2.5 m diameter decay vacuum tube. 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 18 m long block of graphite and iron. The muons, which are ultimately absorbed downstream in around 500 m 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 allow concluding on the beam profile and on the quality and intensity of the neutrino beam produced.

CNGS OPERATION

The CNGS facility 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 physics program of CNGS is now completed and the CNGS beam will not restart in 2014 after the CERN Long Shutdown 1. Table 1 shows the operational statistics per year for CNGS; 81% of the approved protons on target i.e. $18.24 \cdot 10^{19}$ protons, have been delivered to CNGS.

Table 1: Operation Statistics Per Year for CNGS

Year	Mode	Protons on target per year
2006	Commissioning	$0.08 \cdot 10^{19}$
2007	Commissioning	$0.08 \cdot 10^{19}$
2008	Physics	$1.78 \cdot 10^{19}$
2009	Physics	$3.52 \cdot 10^{19}$
2010	Physics	$4.04 \cdot 10^{19}$
2011	Physics	$4.84 \cdot 10^{19}$
2012	Physics	$3.9 \cdot 10^{19}$
TOTAL		$18.24 \cdot 10^{19}$

Figure 2 shows the integrated protons on target per year as a function of operation days. In 2011 and 2012, CNGS physics started earlier, profiting from several weeks of dedicated run (during this period the protons from the SPS did not have to be shared with other SPS users). The slope in 2012 is lower than in the previous years, mainly due to the fact that the proton intensity per extraction was decreased by ~25% (see also Fig. 3) due to radiation limits in the PS.

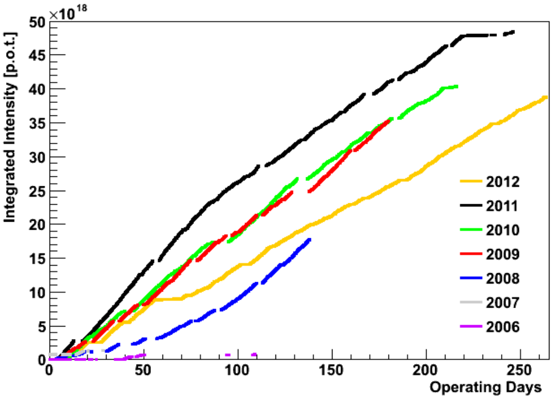

Figure 2: Integrated protons on target per year.

Nominal CNGS Beam

The nominal proton intensity is $2.4 \cdot 10^{13}$ protons on target per 10.5 μs extraction. During the 6 s cycle, there are two extractions separated by 50 ms. The average beam intensity during the 5 years of physics run (between 2008 and 2012) was $1.8 \cdot 10^{13}$ protons per extraction. The limit in the beam intensity originates from the losses in the PS injector and is also due to a lack of margin in the RF system of the SPS. The beam intensity per extraction as a function of time is shown in Fig. 3.

Due to beam sharing on the SPS with other users (LHC, fixed target experiments), an average beam power of about 160 kW was delivered to CNGS. However, the maximum beam power delivered was 480 kW and the sustained maximum during a day was 330 kW.

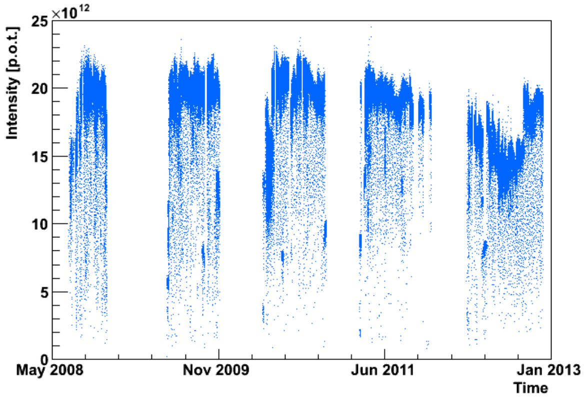

Figure 3: CNGS beam intensity per extraction during the physics run between 2008 and 2012.

LHC Type Bunched Beam

Following the initial neutrino time-of-flight results in 2011, an LHC-type bunched beam was sent to the CNGS target in order to allow much more accurate time-of-flight measurements and consequently to scrutinize the time measurements of the Gran Sasso experiment. For this purpose, extractions consisting of four bunches, with a bunch intensity of $2.5 \cdot 10^{11}$ protons/bunch and a bunch separation of 524 ns were delivered for ~2 weeks in October/November 2011 to CNGS. With this type of beam the muon detectors were used for beam steering, as the beam position monitors did not respond to this low bunch frequency. In May 2012 a bunched beam with an intensity of $1.25 \cdot 10^{11}$ protons/bunch, with 100 ns separation time, 16 bunches per batch and 4 batches per extraction was sent to CNGS. This allowed increasing the neutrino TOF statistics by a factor of 4 with respect to the so-called 500 ns bunched beam. Details on the production of the 100 ns beam can be found in [1]. Eventually the measurements with this type of beam lead to consistent results on the neutrino time of flight and contributed significantly to closing this issue.

TECHNICAL ISSUES

The CNGS facility is a high power, high intensity facility imposing significant challenges to the beam equipment, instrumentation and to the experimental area and pushing the limits, e.g. in terms of radiation hardness and thermo-mechanical stresses.

Although the materials, shielding configurations, remote handling capabilities for maintenance and exchange of equipment were carefully chosen, designed and optimized, several issues that occurred during the CNGS physics run demonstrated the difficulty of the design and operation of such a high intensity facility. Table 2 shows a summary of all modifications, repairs and improvements done during the winter shutdowns in the CNGS facility.

Table 2: Modifications during the winter shutdowns in the CNGS facility.

Winter shutdown	**Modifications, repair work done during winter shutdown**
2006/2007	Repair and improvements of the horn and reflector. Modifications of the horn strip-lines.
2007/2008	Additional shielding, reconfiguration of the services and electronics.
2008/2009	Target inspection.
2009/2010	Civil engineering works for the drains and for water evacuation.
2010/2011	Modification of the ventilation system.
2011/2012	Modification of the timing system, installation of additional muon detectors. New capacitor units for the horn.

During the commissioning run in 2006, beam stopped due to a water leak in the cooling circuit of the reflector. Repair work for both the horn and reflector was done in-situ during the winter shutdown 2006/2007. In addition, the strip-lines bringing the current to the horn and reflector, respectively, were modified due to some failures caused by metal fatigue.

During the 2007 run, successive failures in the ventilation system appeared due to radiation effects in the electronics. Therefore a major effort was carried out to mitigate the radiation issue in the winter shutdown; additional shielding (in total 53 m^3 of concrete) was installed to create a “radiation safe” area (reducing radiation by a factor of 100-1000) where sensitive electronics from all systems were moved to.

While preparing for the 2009 run, an unexpectedly high torque in the motorization for the target exchange (rotation) was observed. An in-situ inspection of the target assembly revealed that the four ball bearings supporting the target magazine were all corroded. Since the performance of the CNGS target remained stable during the entire physics run, the target has never been changed. (A spare target assembly is available and could have been used in case of target failure).

In the 2009/2010 shutdown, modifications to 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 drain water before it reaches the target area and gets in contact with the tritiated air.

During the shutdown 2010/2011, modifications to the ventilation system and its operation were made. 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 from propagating into other areas and in particular from getting into contact with the drain water. The combined effect of modifying the drainage and the ventilation system resulted in a factor of 10 reduction of tritiated water.

In the 2011/2012 shutdown, the GPS timing system was modified and diamond detectors were installed in the muon pits to directly determine the GPS timing of the neutrino “start” time at CERN. As a result it was shown that the GPS timing for CNGS at CERN is internally consistent [2].

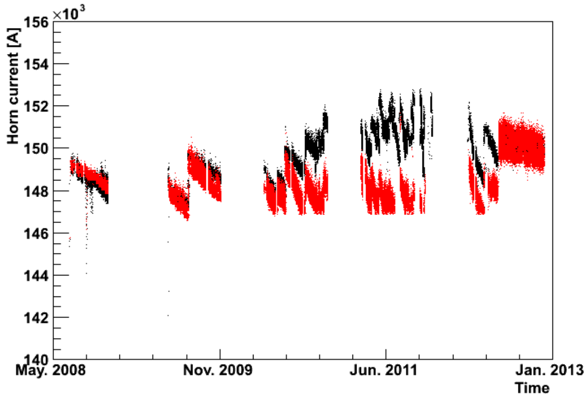

Figure 4: Horn current, first extraction (red) and second extraction (black).

Although the capacitors of the horns were designed for 20 million pulses with an expected capacitance drop of 5%, the capacitors of the horn (reflector) saw already a 50% (90%) reduction after 10 million pulses in 2011/2012. In order to assure reliable operation of CNGS during 2012, new capacitor banks were installed for the horns in May 2012, thus regaining the full capacities as shown in Fig. 4. The reason for the unexpected lack of performance of the capacitors is not yet understood.

CNGS PERFORMANCE

The efficiency of the accelerator complex increased over the years; the integrated efficiency in the SPS for CNGS was 61% in 2008, 73% in 2009, 80% in 2010, 79% in 2011 and 82% in 2012.

The overall beam performance and the stability of the CNGS primary proton beam line on the target position was excellent throughout the 5 years’ run. An r.m.s. of below 100 μm was achieved in the horizontal as well as the vertical plane. Only one or two small beam steering corrections per week were necessary. The muon detector stations are the most sensitive elements in the secondary beam line, responding to any misalignment between the proton beam, the target and the horn, as well as any deterioration of the target and the horns.

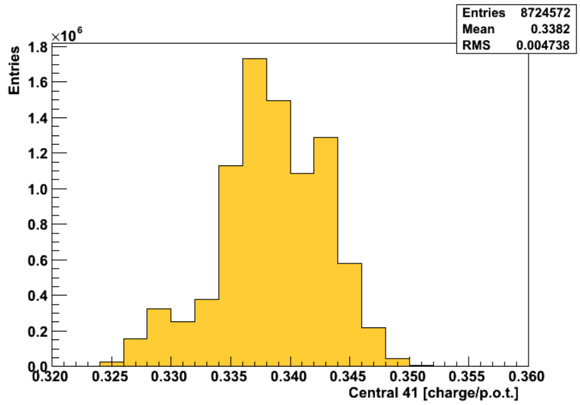

Figure 5: Central muon detector signal during the 5 years of physics run (2008 – 2012).

Figure 5 shows the signal from the muon detector in the centre of the detector station in the first muon pit during the 5 years of CNGS operation. The mean value is 0.338 charges/p.o.t. with an r.m.s. of 0.005, showing that the stability of the secondary beam line elements was remarkable during the 5 years; the target yield (and thus the number of muons observed) remained constant and no deterioration of the target has been observed.

The effect of deteriorated horn capacitors was seen in the muon yield, though only at the ~1% level.

SUMMARY

Since 2006, the CNGS facility has successfully delivered beam to the Gran Sasso experiments. The careful design, the complete and redundant monitoring capabilities and the continuous maintenance paid off and is mandatory to assure early detection of problems, guidance to technical solutions and crosschecks of beam-stability.

The start-up issues as well as the many modifications and improvements that needed to be done during the winter shutdown demonstrate the challenge in the design and operation of such high-intensity facilities.

ACKNOWLEDGMENT

The authors would like to thank the CERN accelerator operation teams for the preparation and smooth operation of the beam as well as the technical groups for all the modifications and improvements.

REFERENCES

[1] H. Damerau et al., “RF Manipulations for Higher Brightness LHC-type Beams”, WEPEA044, these proceedings.
[2] H. Jansen et al., JINST-039P-0812, 2012.