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Abstract

The CNGS facility (CERN Neutrinos to Gran Sasso) aims at directly detecting νμ→ντ neutrino oscillations [1].

An intense νμ beam (1017 νμ per 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.

Having resolved successfully some initial issues that occurred since its commissioning in 2006, that will be briefly summarized here, the facility had its first complete year of physics with 1.78×1019 protons extracted towards CNGS. The experiences gained in operating this 500 kW neutrino beam facility along with highlights of the beamperformance in 2008 are discussed.

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Abstract

The CNGS facility (CERN Neutrinos to Gran Sasso) aims at directly detecting $\nu_\mu \rightarrow \nu_\tau$ neutrino oscillations [1]. An intense ν_μ beam (10^{17} ν_μ per 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. Having resolved successfully some initial issues that occurred since its commissioning in 2006, that will be briefly summarized here, the facility had its first complete year of physics with 1.78×10^{19} protons extracted towards CNGS. The experiences gained in operating this 500 kW neutrino beam facility along with highlights of the beam performance in 2008 are discussed.

THE CNGS FACILITY

After six years of construction, the CNGS facility was first operated in July 2006 for an approved physics program of five years with a total of 22.5×10^{19} protons on target (4.5×10^{19} protons/year). A schematic overview of the CNGS neutrino facility showing the target and the downstream elements is shown in Figure 1.

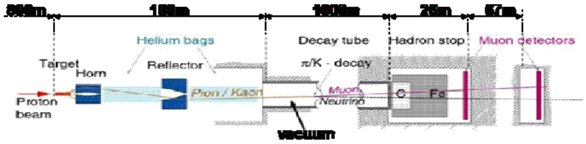

Figure 1: Schematic layout of the CNGS secondary beam.

Two pulses of nominal 2.4×10^{13} protons at 400 GeV/c separated by 50 ms are fast extracted per 6 s in a nominal CNGS cycle, from the CERN SPS and directed via a 840 m beam tunnel towards a carbon target producing secondary particles, mainly pions and kaons, corresponding to an average power at the target of 510 kW. The positively charged pions (π+) and kaons (K+) are energy selected and guided using two magnetic focusing lenses, the so-called horn and reflector, in the direction towards Grand Sasso. These particles decay in a 1000 m long 2.5 m diameter vacuum tube into muons and muon-neutrinos. The non-interacting part of the primary proton beam, along with all the secondary hadrons that have not decayed, are stopped in a 18 m long dump made of graphite and iron. A set of two muon detection stations downstream the hadron stop separated by 70 m allow the measurement of the beam profile in both the horizontal and vertical plane, thus providing useful information on the direction and quality of the ν beam. In the earth that follows, the muons are ultimately absorbed thus leaving only the muon neutrinos (ν_μ) arrive at the Grand Sasso experiments. The main parameters of the CNGS facility are summarized Table 1. During the commissioning in 2006, the beam optics and parameters of the extracted beam were verified [2].

Table 1 : The CNGS proton beam parameters

Parameter	**Nominal Value**
Beam energy	400 GeV
Normalized emmittance	H=12, V=7 μm
Momentum spread	0.07%±20%
Extractions per cycle	2 – separated by 50 ms
Extraction batch length	10.5 μs 2100 bunches, 5 ns spaced
Bunch length [4σ]	2 ns
Beam β at focus	H=10, V=20 m
Beam size at target	0.5 mm at 400 GeV/c
Horn(Reflector) parameters	7 m long, 0.7 m in diameter 1.8mm thick inner conductor of variable diameter from 30 to136 mm 150(180) [kA]

CNGS OPERATION

Operating a high-intensity beam facility like CNGS is very challenging. The high-power, high-intensity beams required for CNGS impose significant challenges to the accelerators involved for the beam production and operation. Presently due to increased losses in the extraction process from PS and reduced RF capture efficiency at SPS, the beam intensity is limited to 2.1×10^{13} protons per extraction. The proposed solution using multi-turn resonant extraction from PS [3] made significant progress in 2008, was tested during the last day with beam at SPS, and is expected to be operational in 2009.

The CNGS target with its shielding and the downstream secondary beam elements were designed to cope with the radiation environment created by the intense proton beam at its impact on the target. The choice of materials, shielding configurations, remote handling capabilities for maintenance and exchange of equipment were carefully designed and optimized. Despite all these efforts, running such a facility is always a challenge as proven to be when

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during the first years of operation, failures in several systems occurred. In Table 2 the summary of the operation statistics for CNGS is shown.

Table 2 : Summary of operation statistics for CNGS

	Protons on target
2006 - commissioning	6.87×10^{15}
2006 - operation	8.48×10^{17}
2007- commissioning	5.0×10^{16}
2007 – operation	7.86×10^{17}
2008 - operation	1.78×10^{19}

The limited operation time for the first two years: 2006 due to a failure in the cooling system of the reflector and 2007 due to radiation effects on installed electronics, corresponded to a period when the OPERA brick target was under completion thus implying not a big loss in statistics.

Startup Issues

The run in 2006 was interrupted when a leak in the cooling circuit of the reflector was observed. Following an in-situ inspection, still possible due to low radiation levels, the leak was identified in one of the ceramic insulating connectors in the outer conductor of the reflector (see Figure 2).

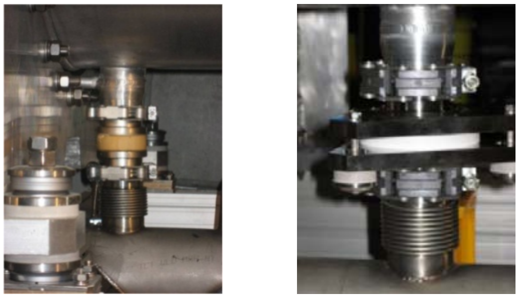

Figure 2: Left: photo of the broken ceramic connector. The water escaping from the left is visible. Right: the modified outlet connections.

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. As the radiation levels were low, it was decided to repair the reflector and as preventive maintenance replace all similar ceramic joins both reflector and horn. The operation was done in-situ taking all necessary precautions and optimization to reduce the collective and individual dose to personnel, including dry runs with the spare horn.

In preparing the 2007 run, it was discovered that one of the cables in the flexible striplines that bring the current to the reflector was broken. The flexible striplines were introduced to accommodate for geometrical errors and mis-alignments between the thick rigid parts of the striplines. Metallurgical analysis of the broken cable, showed traces of beachmarks, striations and secondary cracks confirming the failure due to metal fatigue. In situ vibration measurements showed that the flexible striplines moved with amplitudes as high as ±2.2 mm during pulsing. The flexible parts were then replaced by solid plates carefully designed to adapt to the existing geometry and accommodate for the thermal dilatation. The measured vibration amplitudes were 10-times slower than before thus validating the new design. Again as preventive maintenance all the flexible cable striplines for the horn and reflector circuits were replaced.

After reaching about 6.0×10^{17} protons on target in the 2007 period, successive failures in the ventilation units occurred, clearly correlated with the presence of the beam. The μ-controllers that failed were installed in the adjacent service tunnels, however as simulations showed, the radiation levels there, in particular the flux of energetic hadrons known to cause single event failures on electronics[4] were still quite high. The ventilation system for CNGS is rather complex, designed to guarantee the proper temperature, cooling and humidity level in the tunnels and the various equipment. It also has special filters to control the air flow to the environment and has different modes to allow safe access into the tunnels during maintenance operations. Operating the facility without the proper ventilation is not possible. During the winter shutdown, additional shielding was installed in order to create a "radiation safe" area where the sensitive electronics from all systems were moved to. In total 53 m^3 of concrete were poured in-situ to create a 2.4 and a 6 m thick shielding wall, all the ventilation ducts were rerouted and all the systems (ventilation, electrical distribution and supervision, horn cooling system etc.) were reconfigured. According to FLUKA simulations of the new layout, a reduction factor of 100÷1000 is achieved which assures a faultless operation of the facility at nominal conditions.

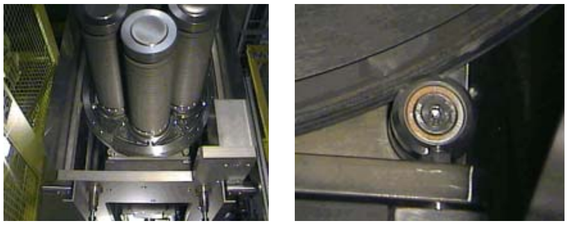

Figure 3: Left: photo of the target assembly showing the in-situ spare heads. Right: zoom in one of the ball bearings, where clear marks of rust are visible.

While doing the standard maintenance tests for the 2009 operation, an unexpected high-torque in the motorization for the target head exchange was observed: 30 Nm instead of 8 Nm! The CNGS target assembly (see Figure **3**) is designed with five in-situ spares, each capable of intercepting the 400 GeV beam of 510 kW average power. The change of target heads can be done remotely without requiring access to the facility. Due to the high-radiation environment a lot of attention was paid in the choice of materials. An in-situ investigation of the target assembly revealed that the four ball-bearings that support the target magazine were all rusted (one was not even rotating), that easily explains the observed torque increase. A metallurgical analysis of the same bearings of the spare unit is in progress to help understanding the origin of the problem. The target head used in 2008 will be used also in 2009 and if it fails, then the whole target assembly will be exchanged with the available spare that will be modified in the meantime, most likely using full ceramic bearings, as foreseen.

Beam performance in 2008

In Figure 4 the integrated number of protons to CNGS during the 2008 run is shown. The overall efficiency for the accelerator complex was about 62%. Major inefficiencies were the replacement of a broken vacuum pipe when an accidental beam loss of the high-intensity CNGS beam drilled a hole in the vacuum pipe in an SPS magnet, the replacement of a faulty PS magnet and the repair of the 18 kV electrical cables that powers the CNGS line.

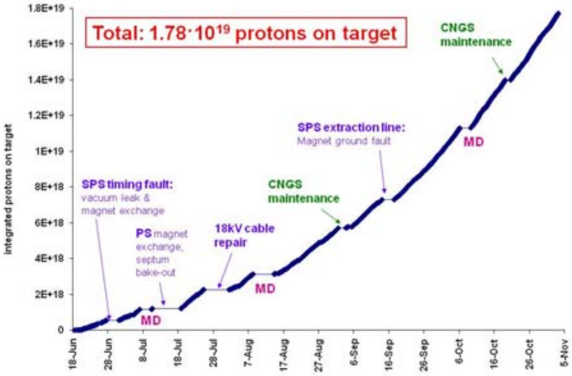

Figure 4: Graph of the integrated number of protons on target versus time.

In Figure 5 the beam intensity distribution per extraction is shown. For most of the period the facility operated 2.0×10^{13} protons per extraction which should be improved once the multi-turn extraction becomes operational in 2009. However the main limitation in the number of protons to CNGS comes from the time sharing with the fixed target program and the LHC beams setup. The typical SPS operation was with 48 s super-cycle with three CNGS cycles (37.5% duty factor), increased to a 50.4 s super-cycle with 7 CNGS cycles (83% duty factor) once the LHC and fixed target users were stopped. Stressing the facility with such high duty factor was very useful to test equipment closer to their design limits.

Overall the beam performance and stability throughout the run was excellent. Over the 10^6 extractions during the run, the beam position at the target (Figure 5) has an rms of 50 μm. The muon beam centroid at the second muon chamber, reconstructed from the signal of 18 beam loss monitors (BLM), has an rms of 2(3) cm in the horizontal(vertical) direction, verifying excellent stability of the beam and its direction towards Grand Sasso.

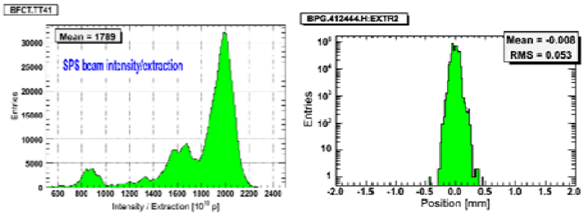

Figure 5: Left: profile of the beam intensity per pulse Right: the beam positing profile at the target from 10^6 extractions.

During 2008, the OPERA experiment recorded 10100 on-time events with 1700 candidate interactions in the bricks. The experimental apparatus and the analysis chain worked well, also when running with the increased duty cycle at the end of the year, where about 100 bricks were extracted and analyzed per week. With the present statistics no ν_τ event is expected. However the 2008 data sample allows important studies to be made to understand the backgrounds, in particular that from the charm mesons produced from ν_μ interactions.

SUMMARY

Thanks to the efforts of many CERN colleagues, the CNGS facility had its successful first year of physics with 1.78×10^{19} protons on target. The startup incidents we faced, although successfully resolved, demonstrate the difficulty in the design and operation of such high-intensity facilities. The complete and redundant monitoring capabilities built into the CNGS beam line along with the full simulation model is an important asset assuring early detection of problems, guidance to technical solutions and cross-check of beam stability as required by the experiments. We look forward to the coming years to complete the physics program of CNGS.

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