First Operational Experience Of The CNGS Facility

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Abstract. The CNGS project (CERN Neutrinos to Gran Sasso) aims at directly detecting $\nu_\mu - \nu_\tau$ oscillation. An intense muon-neutrino beam ($10^{17}\nu_\mu$/day) is generated at CERN and directed towards the Gran Sasso National Laboratory, LNGS, in Italy, where the ν_τ will be detected in large and complex detectors.

An overview of the CNGS beam facility is given. The performance of the primary and secondary beam line during beam commissioning and physics operation is discussed. Modifications on the magnetic focusing lenses (horn and reflector) are described.

Keywords: CNGS, neutrino beam, beam extraction, horn
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INTRODUCTION

The CNGS beam is extracted from the SPS accelerator and sent down an 840m long proton beam line onto a carbon target producing kaons and pions. The positively charged π/K 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 1000 m long 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 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. This allows concluding on the intensity of the neutrino beam produced and on the beam profile. A schematic overview of the CNGS neutrino beam facility [1] at CERN is shown in FIGURE 1.

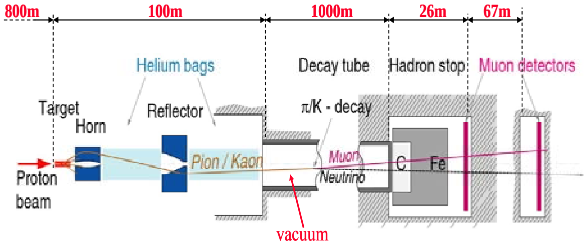

FIGURE 1: Main components of CNGS.

BEAM LINE DESCRIPTION

The CNGS beam is extracted from the SPS using the same extraction channel as for one of the two LHC beams. After about 100m from the extraction point, a string of switch magnets is used in order to direct the beam either to the LHC or to the CNGS target. The CNGS proton beam line consists of a 620m long arc to bend the beam in the direction Gran Sasso with a slope of 5.6%, followed by a 120m long focusing section to obtain the desired beam sizes onto the target. The tunability of the optics allows varying the beam sizes onto the target from σ=0.25mm to 1.0mm [2]. Beam monitors allow to track the high intensity proton beam and to verify the stringent constraints on its stability.

TABLE 1. Parameters of the proton beam.

Parameters	Nominal Values
Normalized emittance [μm]	H=12, V=7
Physical emittance [nm]	H=28, V=16
Momentum spread	0.07% ± 20%
Extraction number per cycle	2 (50ms apart)
Extraction batch length [μs]	10.5
Number of bunches per extraction	2100
Intensity per extraction	$2.4 \cdot 10^{13}$
Bunch length [ns] (4 σ)	2
Bunch spacing [ns]	5
Beam at focus [m]	H=10, V=20
Beam sizes at 400 GeV [mm]	0.5

During a nominal CNGS cycle, i.e. every 6s, there are two SPS extractions (10.5µs each, separated by 50ms) of 2.4 $\cdot 10^{13}$ protons each at 400GeV/c. The nominal parameters for the CNGS beam are shown in TABLE 1.

The CNGS target is designed to withstand the beam induced stress (thermo mechanical shocks, heat deposit) up to $3.5 \cdot 10^{13}$ protons per extraction with 400 GeV/c (up to 750 kW average power) [3]. The CNGS target magazine consists of five target units. One unit is used in the beam; the other four are in-situ spares. Each target unit is made of 13 graphite rods which are 10 cm long and interspaced by 9 cm. The diameter of the first two rods is 5mm; the other rods have a diameter of 4 mm. The target magazine as well as the surrounding iron shielding is air-cooled. The target alignment to the proton beam is specified to ±0.1mm transversally.

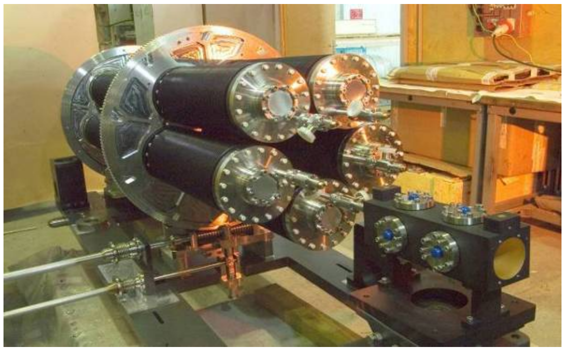

FIGURE 2: CNGS target magazine consisting of five target units. The bottom unit intercepts the proton beam; the other four units are spares.

The magnetic focusing system, comprising the horn and reflector (each 7 m long), is installed downstream of the target. The horn and reflector are toroidal lenses with a focusing magnetic field between the inner and outer conductor, created by a pulsed high current. The shape of the inner conductor provides the desired focusing for particles with a wide range of momenta and angles. The horn is pulsed twice every 6s cycle with a current of 150 kA during a few milliseconds, the reflector with 180 kA. The two pulses are separated by 50 ms, synchronized with the two beam pulses. The water cooling systems of the horn is designed for a proton intensity of $7.2 \cdot 10^{13}$ protons per 6 s cycle ($3.6 \cdot 10^{13}$ protons/extraction) at 400 GeV/c. The corresponding total power to be evacuated in the horn is 26 kW, coming from the particle interactions in the horn and the applied current.

The target magazine and the horns (i.e. horn and reflector) have been designed to be remotely exchanged using a crane.

Two muon detector stations provide on-line feedback for the quality control of the neutrino beam. They are installed downstream of the hadron stopper and are separated by 67 m of rock. In each of the two CNGS muon detector chambers 42 muon detectors are installed. They are assembled in a cross-shaped array to provide the muon intensity and the vertical and horizontal muon profile [4].

BEAM LINE COMMISSIONING

During three weeks in July and August 2006 the primary beam line (from the SPS extraction to the target) and the secondary beam line (from the target to the muon monitors) were commissioned. The beam monitoring equipment was tested and measurements were compared with simulations.

The proton beam position monitors (BPMs) revealed that the primary beam line was well tuned over its 800m after only a minor magnetic correction.

The maximum trajectory beam excursion is well within the specification [5]. The beam position stability onto the target has been averaged over several days and measured to be ~50µm r.m.s. [6,7].

Using the muon monitor profile information (centroid and symmetry) the alignment between the proton beam, the target and the horn/reflector is optimized. The muon measurements confirmed the stability of the proton beam and showed that the beam equipment downstream of the target performed as expected [4,8].

CNGS OPERATION

The first CNGS physics run started as scheduled on 18th August 2006 and lasted 12 days. Another run dedicated for beam optimizing has been foreseen for 2 weeks starting on 26th October 2006. This run had to be stopped after two days due to a leak in the water cooling circuit of the reflector. During the physics run in total $\sim 8.5 \cdot 10^{17}$ protons were delivered to the target. The average beam intensity during the physics run was at the order of $\sim 1.4 \cdot 10^{13}$ protons on target (p.o.t.) per extraction at 400 GeV/c. The maximum beam intensity reached in 2006 was $1.75 \cdot 10^{13}$ p.o.t. per extraction.

HORN AND REFLECTOR MODIFICATIONS

The horn and reflector are water cooled through a set of water inlets with sprayers mounted on top of the outer conductor. Water at a pressure of 1.3 bars arrives at the electrically insulated water inlets, sprays the inner conductor and flows through insulated outlets at the bottom of the outer conductor in a collector tube.

In October 2006, a leak was detected in the water cooling circuit of the reflector. After remotely dismounting part of the shielding, the location of failure was visually identified as one out of five ceramic muffs that electrically isolate the water outlets between outer conductor and drainage tube. The ceramic muff fractured at a machined shoulder, close to where the ceramic is brazed to its titanium flange.

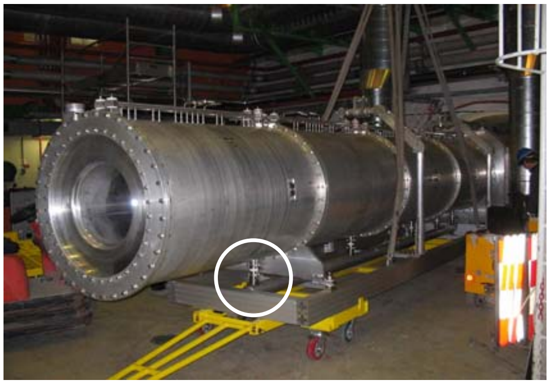

FIGURE 3: CNGS Reflector. One of the five water outlets is encircled.

Destructive tests on spare outlets confirmed that the shear and compressive stress due to machining and brazing led to the ceramic's failure. Therefore, the new water outlet assembly avoids brazing. Water tightness and reducing stress is realized by keeping the ceramic under compression and using a soft graphite seal (see FIGURE 3).

As an additional preventive measure, all brazed ceramics (i.e. water inlets and water outlets) on both horn and reflector are exchanged with the new brazing-free solution, thus increasing the reliability of the horn and reflector cooling circuit.

FIGURE 3: Left: old water outlet assembly (brazed). Right: new water outlet assembly (under compression).

While handling of shielding and horns is done remotely, the exchange of the water outlets and inlets involves human intervention. To reduce the dose absorbed by the intervening personnel, each horn was taken out of its beam position towards a location upstream in the target chamber with low residual dose rate.

Mobile lead screens were placed around the horns and a dedicated shielded cabin was used for the intervention on the top of the horns (water inlets). Together with careful planning, rehearsal of procedures on the clean spare horn and the use of adapted tooling, the aforementioned shielding reduced the dose for the intervening personnel drastically. The total dose of the interventions was 1.6mSv while the work was carried out by up to 8 people at the time.

The modifications were finished in time and the facility restarted with beam as scheduled in 2007.

SUMMARY

The CNGS facility was successfully commissioned in 2006. The first physics run in August 2006 lasted 12 days as scheduled. During the physics run in October 2006 a leak in the water cooling circuit of the reflector appeared. The origin of the leak was identified. The necessary repair as well as additional preventive measures was successfully performed during 2007 and followed by the restart of the CNGS beam as scheduled.

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