CERN NEUTRINOS TO GRAN SASSO (CNGS): RESULTS FROM COMMISSIONING

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Abstract

The CNGS project (CERN Neutrinos to Gran Sasso) aims at directly detecting $\nu_\mu - \nu_\tau$ oscillations. An intense ν_μ beam is generated at CERN and directed towards LNGS (Laboratori Nazionali del Gran Sasso) in Italy where ν_τ will be detected in large and complex detectors.
An overview of the CNGS beam facility is given. Results from the primary and secondary beam line commissioning performed in summer 2006 are presented. Measurements of proton beam parameters are compared with expectations.

CNGS OVERVIEW

Neutrino beams at accelerators are generated from the decay of mesons, mostly π and K, through $\pi^{+(-)} \rightarrow \mu^{+(-)} + \nu_\mu(\bar{\nu}_\mu)$ and $K^{+(-)} \rightarrow \mu^{+(-)} + \nu_\mu(\bar{\nu}_\mu)$. For the CNGS facility [1, 2, 3], these mesons are produced from a high intensity 400 GeV proton beam extracted from the SPS, transported through a 840 m beam line, before impinging on a graphite target. The positively charged π /K are energy-selected and guided with two focusing lenses (horn, reflector) in the direction towards Gran Sasso. In the 1000 m long decay vacuum tube, these particles decay into muon-neutrinos and muons. All the remaining unwanted particles are stopped by a hadron stop located at the end of the decay tunnel. Two muon detector stations are then used to derive the intensity and profile of the neutrino beam produced.The main components of CNGS are schematically shown in Figure 1.

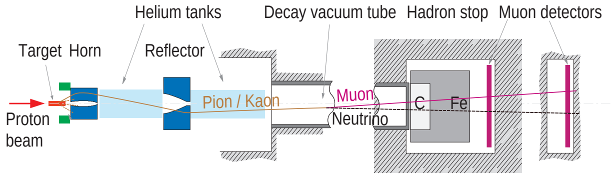

Figure 1: Main components of the CNGS facility.

BEAM LINE DESCRIPTION

Proton beam

The SPS accelerator has been upgraded and modified for its new role as LHC injector. In particular, the extraction system foreseen for the LHC allows fast extracted pulses, and one of the two extraction channels was modified to permit two fast extractions per CNGS cycle [4]. Therefore, both the LHC and the CNGS beams use the same extraction channel. After about 100 m from the extraction point, a string of 8 switch dipole magnets (24 mrad horizontal deflection) is used in order to direct the beam either to the LHC ring or to the CNGS target. The CNGS proton beam line consists of a 620 m long arc to bend the beam in the direction of the Gran Sasso, followed by a 120 m 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 $\sigma = 0.25$ mm to 1.0 mm. The magnetic system of the proton beam line is composed of 73 dipole magnets (nominal field of 1.7 T at 400 GeV [5]), 20 quadrupole magnets (nominal gradient of 40 T/m [6]) and 12 corrector magnets (maximum bending angle of 80 μm [7]). The 5.6% slope of the proton beam line is provided by 32 horizontal dipole magnets tilted by 12.8^o. The beam line can operate from 350 GeV (limited by the vertical aperture in the main bending magnets) to 450 GeV (maximum SPS energy). The nominal CNGS cycle is 6 s long with two SPS-CNGS extractions separated by 50 ms. The nominal proton beam parameters are summarised in Table 1.

Table 1: Parameters of proton beam

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

Beam instrumentation

Beam monitors allow to track the high intensity proton beam and to verify the stringent constraints on its stability [8, 9]. The beam position is measured along the proton beam line using 23 Beam Position Monitors (BPM); all but the last one are button electrode monitors, and all are equipped with 2 plane reading electronics. The last BPM is mechanically coupled to the target in order to provide the beam position as seen by the first target rod. It is an innovative stripline coupler pick up as it is operated in air. As the tolerance requirement on the overall BPM is set to

± 0.6 mm, this monitor is specified to operate with better than ± 0.35 mm tolerance. The 8 beam profile monitors are optical transition radiation monitors (OTR) using either a 75 μm C screen for high intensity operation or a 12 μm Ti screen for low intensity beam. Two Beam Current Transformer monitors (BCT) are measuring the beam intensity at the start and the end of the line. 18 Beam Loss Monitors (BLM, N_2 filled ionisation chambers) measure the beam losses along the beam line. Right downstream of the target, the efficiency with which protons are converted into secondaries is checked with a Secondary Emission Monitor, made of 12 μm titanium foils of 145 mm diameter, measuring the intensity, the asymmetry and the halo of the charged particles exiting the target. Two chambers are located after the hadron stop, separated by 67 m of rock. The chambers are equipped with 42 BLM-type muon monitors each, to measure the muon intensity and profile which, in turn, provide information on the quality of the neutrino beam [10].

Target and Horn systems

The target has to reliably intercept a 400 GeV high intensity beam (designed for 7×10^{13} protons per 6 s cycle) of up to 750 kW average power [11]. The beam is fast extracted (10.5 μs) and strongly focused at the target ($\sigma = 0.5$ mm). The target alignment to the proton beam is specified to ± 0.1 mm transversally. The target was designed to withstand the thermomechanical shocks from the fast extracted beam and to evacuate the deposited thermal energy. The target assembly contains an innovative target magazine, equipped with 5 target units -only one intercepts the beam, the others provide in-situ spares. Each target unit is made of a series of 10 cm long graphite rods; the first two rods are 5 mm in diameter, the remaining 11 rods have a diameter of 4 mm. The target magazine has been designed to be remotely exchanged using a crane - a spare magazine has already been built and tested.

Downstream of the target assembly, the secondary beam line magnetic focusing system consists of 2 magnetic horns (horn and reflector), pulsed twice every 6 s with a current of 150 kA for the fist horn and 180 kA for the second one [12]. Detailed description and experience from operation are presented in [13].

RESULTS FROM COMMISSIONING

As part of the early phase of the CNGS commissioning, in September 2004, the extraction system and beam channel were successfully checked with beam. During the 2006 facility start up, in depth checks and analysis were performed [14]. In dedicated periods from February to April 2006, the proton and secondary beam lines were commissioned without beam. All equipment and controls were carefully checked until declared fully operational. Commissioning with beam took then place in a three weeks period in July-August 2006. On 11 July 2006, the first proton extraction was transported through the beam line and measured already well centred along the line and onto the target [15]. The importance of having installed a sufficient number of OTRs was put into evidence as it provided the first information on the beam positioning, the BPM system suffering from triggering problems [16, 17]. Due to the low start-up intensity (2×10^{11} protons per extraction), the BPMs were commissioned using short batch length (2 μs), the electronics trigger being set at 1 μs with a 400 ns integration gate. As soon as the nominal setting up intensity was reached, the BPM system was operated at nominal specifications i.e. batch length of 10.5 μs, trigger at 1 μs and gating of 8 μs or trigger at 2 μs and gating of 400 ns. The BPM system was found to be very sensitive to the batch structure and intensity at these very low intensities, but showed very good performance at the specified intensities of 2×10^{12} protons per extraction and above. The trajectory along the proton beam line was at maximum ± 2 mm, well within the specified ± 4 mm [18]. The beam position stability [19] onto the target is of importance for the target integrity and to limit the equipment activation. Over the first three days of operation, the proton beam stability was excellent: 110 μm r.m.s in the horizontal plane and 50 μm r.m.s in the vertical plane [20]. This small ripple demonstrates the great care with which the extraction systems has been designed and built, to fulfill the specifications (main ripple sources being the septum magnets). With such an excellent short term stability, a single trajectory correction per day using 1 or 2 correctors was sufficient to maintain the r.m.s. drift at the target below 100 μm in both planes. Over a 10 day long period of the first August 2006 CNGS physics run, the total r.m.s. drift was 0.15 mm in the horizontal plane and 0.4 mm in the vertical plane. For the latter, the main part of the drift actually originated in the SPS ring and was not due to changes in the extraction system or CNGS beam line itself.

The dispersion was measured by recording the trajectory along the proton beam line as a function of the beam momentum in the SPS. The measured and fitted optics dispersion are shown in Figure 2 and Figure 3 [20]. The agreement is good all along the line. In addition, the momentum aperture of the transfer line was determined to be +0.9% for positive momentum offsets (not measured for the negative offsets).

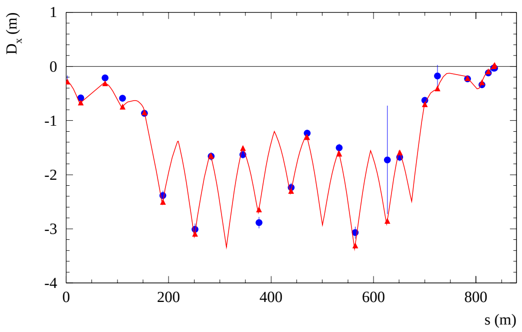

Figure 2: Horizontal dispersion. Points are measured values, the line is the result of a fit to the initial condition, using nominal optics.

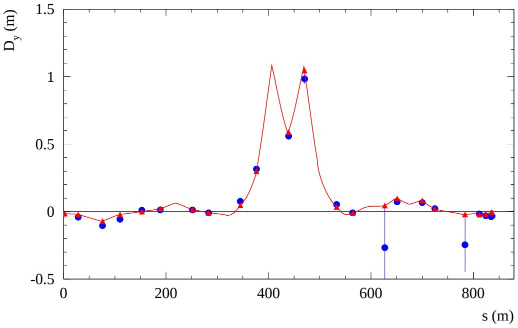

Figure 3: Vertical dispersion. Points and line as described in Figure 2.

The efficiency of secondary particle production was carefully checked during the commissioning phase. Extensive scans with low intensity beam have been performed where the proton beam position and angle were varied while the response of the position and intensity monitors upstream and downstream of the target were recorded. An example is shown in Figure 4. Such scans allowed to precisely align the proton beam w.r.t the target rod center.

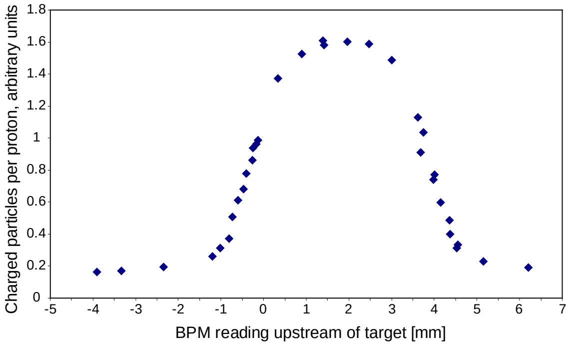

Figure 4: Horizontal proton position scan: number of charged particles in arbitrary units produced for different proton beam positions onto the target, as read by the BPM upstream of the target.

The production of muons was then checked and proton beam scans were performed while recording the signal from the muon monitors in the two muon detector stations. This allowed to precisely align the complete ”proton beam-target-horns” system for the optimum secondary particle production. Information on data taken with the muon monitors can be found in [13].

SUMMARY

Thanks to the detailed hardware and controls checks performed without beam, the commissioning with beam went smoothly and already the very first SPS proton extraction was found well centered along the proton beam line. The beam instrumentation installed in the facility proved its importance in all steps of the commissioning and worked as specified. In August 2006, the CNGS facility was declared operational.

The authors would like to thank the CERN colleagues who contributed to the success of the CNGS construction and commissioning and the colleagues from around the world who participated in this project.

REFERENCES

[1] General Description of the CNGS Project, 2000, http://proj-cngs.web.cern.ch/proj-cngs/

[2] K.Elsener (Ed.) et al., The CERN Neutrino Beam To GRAN SASSO, Conceptual Technical Design, CERN-98-02, INFN/AE-98/05.

[3] R. Bailey et al, The CERN Neutrino To GRAN SASSO, Addendum to report CERN-98-02, INFN/AE-98/05, CERN-SL/99-034 (DI), INFN/AE-99/05.

[4] B. Goddard et al, The New SPS Extraction Channel For LHC and CNGS, EPAC’00, Vienna, June 2000.

[5] K. Schirm, The Bending Magnets For The Proton Transfer Line Of CNGS, CERN AT-Note 2006-23.

[6] Th. Zickler, Design Report Of The QTG Quadrupoles For The CERN CNGS Line, CERN SL-2000-049 MS.

[7] B. Langenbeck, Design Report Of The MDG Correctors Magnets, EDMS[1] Id 399883.

[8] L. Jensens, Beam Instrumentation For The CNGS Facility, CERN AB-Note 2006-22.

[9] R. Jones, CNGS Primary and Target Instrumentation, EMDS[1] Id 610790.

[10] B. Dehning, CNGS Muon Monitors, EMDS[1] Id 481835.

[11] L. Bruno et al., CNGS progress report 2004, AB-Note-2004-063-CNGS, EDMS[1] No 478683. L. Bruno,The CNGS Target: Expectation Vs. Experience, EDMS[1] Id 772307.

[12] J.-M. Maugain et al., CNGS Horns, EMDS[1] Id 383834, 383394, 485613, 481832, 481833, 607171, 787376, 772651.

[13] E. Gschwendtner et al, Design and Performance of the CNGS Secondary Beam Line, PAC’07, Albuquerque, June 2007. E. Gschwendtner, CNGS: Commissioning and First Operation, NSS-IEEE06 San Diego, 2006, CERN-AB-2007-005 ATB.

[14] V. Kain et al, Commissioning of the CNGS Extraction in SPS LSS4, CERN AB-Note-2007-007 OP; V.Kain et al, High Intensity Commissioning of the SPS LSS4 Extraction for CNGS, PAC’07, Albuquerque, June 2007.

[15] T. Pieloni et al, Orthogonal Steering of the CNGS Beam on Target: Optics Model Expectation vs. BTV and BPM Measurements during Commissioning, EDMS[1] Id 850339.

[16] R. Jones, Operational Experience With The CNGS Beam Position Measurement System, EMDS[1] Id 771824.

[17] E. Bravin, Performance Of The BTVs During The Commissioning, EDMS[1] Id 771826.

[18] W. Herr et al, Trajectory Correction Studies For The CNGS Proton Beam Line, CERN AB-2004-44.

[19] W. Herr et al, Aperture and Stability Studies For The CNGS Proton Beam Line, CERN AB-2004-45.

[20] J.Wenninger et al, Beam Stability And Optics Studies Of The CNGS Transfer Line, CERN AB-Note-2007-008 (OP).

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[1] access to EDMS $http : //proj - cngs.web.cern.ch/proj - cngs/accessEDMS.htm$