CERN NEUTRINOS TO GRAN SASSO (CNGS): STATUS AND FUTURE PROTON BEAM OPTIONS

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The CERN Neutrinos to Gran Sasso project (CNGS) aims at directly detecting $\nu_\mu - \nu_\tau$ neutrino oscillations. 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, 732 km away from CERN where large and complex detectors will allow detecting, in particular, the rare tau-neutrinos. In summer 2006 the first CNGS physics runs were carried out after a successful commissioning of the CNGS facility. In the presently approved physics programme, it is foreseen to run the facility for five years with $4.5 \cdot 10^{19}$ protons/year at 400 GeV/c on the CNGS target. The maximum proton intensity to CNGS is summarized for upgrades with different beam injector scenarios.

Introduction

An overview of the CNGS neutrino beam facility[1)] at CERN is shown in Figure 1. During a nominal CNGS cycle, i.e. every 6s, two SPS extractions (10.5μs each, separated by 50ms) of $2.4 \cdot 10^{13}$ protons each at 400GeV/c are sent down the 800m long proton beam line to the target. 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.

In the CNGS graphite target, pions and kaons are produced. The positively charged π/K are energy-selected and guided with two focusing lenses, i.e. horn and reflector, in the direction towards Gran Sasso. In the 1000m long decay vacuum tube these particles decay into muon-neutrinos and muons. The analysis of the two muon detector stations is used to derive the intensity of the neutrino beam produced, the beam profile and an indication on the neutrino beam spectrum.

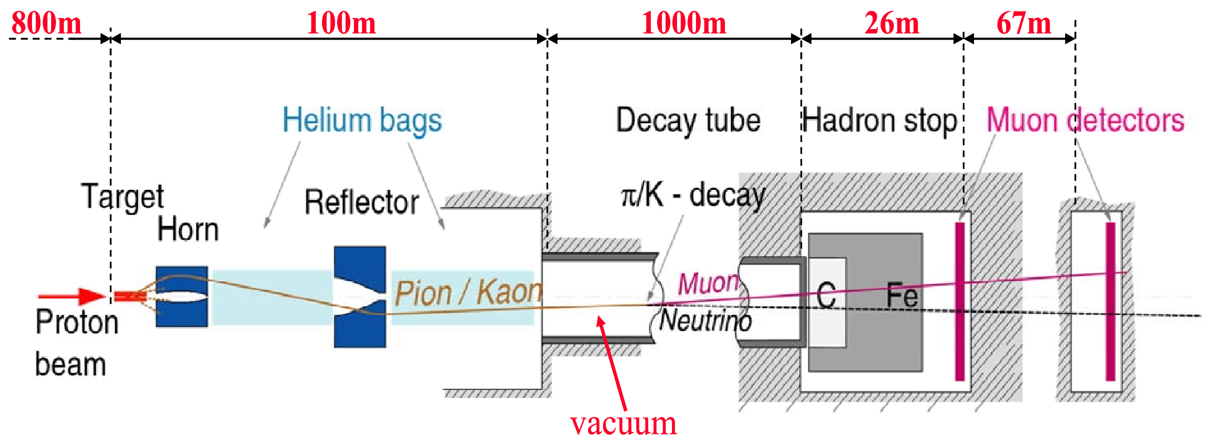

Figure 1: CNGS layout.

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[2)]. The beam position stability onto the target has been averaged over several days and measured to be ~50μm r.m.s. [3) 4)].

The muon detectors provide on-line feedback for the quality control of the neutrino beam. The muon detectors are nitrogen-filled, sealed ionization chambers[5)] and are designed to measure up to 10^8 muons per cm^2 and per extraction. There are 41 fixed detectors and one movable detector installed in each of the two CNGS muon detector chambers. They are assembled in a cross-shaped array to provide the muon intensity and the vertical and horizontal muon profile.

Using the muon monitor profile information (centroid and symmetry), we are able to optimize the alignment between the proton beam, the target and the horn/reflector (see Fig. 2). The muon measurements confirmed the stability of the proton beam and showed that the beam equipment downstream of the target performed as expected[6)].

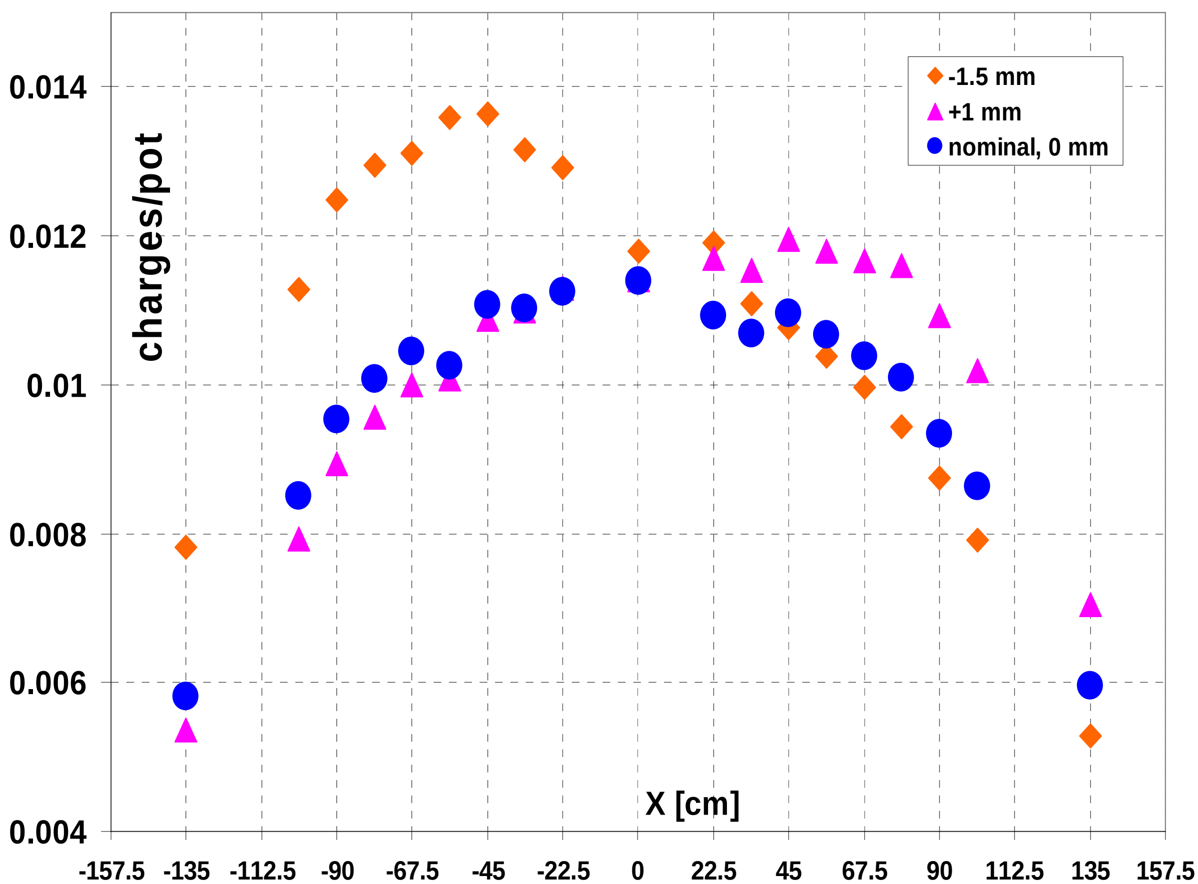

Figure 2: Vertical muon profile in the second muon detector chamber for different beam versus target alignments (0mm, +1mm, -1.5mm). Each point corresponds to a detector and shows the measured induced charges per proton on target (~2700 charges/muon are produced in a detector). The statistical accuracy is limited (as indicated by the fluctuations of the data points) because the dynamic range of the readout electronics is adjusted to the nominal CNGS intensity ($2.4 \cdot 10^{13}$ p.o.t./extraction). The measurements were performed with $\sim 2 \cdot 10^{12}$ p.o.t./extraction.

CNGS Operation

The first CNGS physics run started as scheduled on 18^{th} August 2006 and lasted 12 days. Another run dedicated for beam optimizing has been foreseen for 2 weeks starting on 26^{th} October 2006. This run had to be stopped after two days due to a water 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.

Analysis of the Maximum Potential Proton Flux to CNGS

The limitations of the proton flux which can be sent to the CNGS facility have been studied together with the estimation of the maximum attainable flux[7)] for two scenarios: (a) operating with the present injector chain, and (b) operating with new injectors - LINAC4, SPL and PS2, as proposed by the PAF working group[8)]. The proton flux was calculated with the assumption of 200 days of operation per year and 80% injector availability. The intensity limitations coming from equipment (as designed) in the CNGS facility are summarized in Table1.

With the present injectors, the maximum achievable beam intensity in the SPS is estimated at $5.7 \cdot 10^{13}$ protons per cycle with machine improvements aimed mainly at beam loss reduction. With $5.7 \cdot 10^{13}$ protons per cycle, about $1.1 \cdot 10^{20}$ p.o.t. per year can be obtained in the scenario of 85% of the SPS beam time dedicated to CNGS.

With new injectors (after 2016), assuming a major upgrade of the SPS RF power capability and solutions to the e-cloud problems, beam instabilities and the heating by the beam current of numerous equipment in the SPS, the maximum number of protons accelerated per SPS cycle can reach $1 \cdot 10^{14}$. The integrated proton flux can potentially attain $2.4 \cdot 10^{20}$ p.o.t. per year if the SPS is dedicated 85% of the time to CNGS and the SPS cycle length is 4.8 s. Beyond $7 \cdot 10^{13}$ p.o.t. per cycle and/or beyond $1.38 \cdot 10^{20}$ p.o.t. per year, the design limit of most of the secondary beam line equipment is reached and a full redesign is mandatory to address higher intensities.

Table 1: Intensity limitations from equipment (as designed) in the CNGS facility

Intensity limitation	**Protons per batch**	**Protons per 6s cycle**	**Proton flux [protons on target per year]**
Radiation protection calculation and optimisation			Soil/concrete activation: $4.5 \cdot 10^{19}$ Air/water activation: $7.6 \cdot 10^{19}$
Target design	$3.5 \cdot 10^{13}$	$1.4 \cdot 10^{14}$	Radiation damage: $2 \cdot 10^{20}$
Horn design	$3.5 \cdot 10^{13}$	$7 \cdot 10^{13}$ (2x 10^7 cycles)	Horn air cooling system: $1.38 \cdot 10^{20}$
Shielding, Decay Tube, Hadron stop design			Cooling: $1.38 \cdot 10^{20}$
Kicker system	$3.5 \cdot 10^{13}$	$1 \cdot 10^{14}$	
Instrumentation	$3.5 \cdot 10^{13}$		

Operation beyond the present nominal CNGS parameters implies that all radiation protection calculations/studies have to be revised, including radioactive waste studies and the corresponding area classifications. A new INB approval from IRSN will be mandatory for operation beyond nominal parameters. The replacement of the initial equipment in the target cavern after the nominal 5 year run for CNGS will be extremely challenging and its many years radiation down-cooling time must be estimated. In the second scenario (new injectors) the CNGS facility itself will need a major rebuild, because of the difficulty to replace the first generation of equipment in the target building (activation and risk of contamination) and also because of the need to reassess all radiation protection issues and to dimension the new equipment, tunnel and cavern accordingly.

Summary

The CNGS facility has been successfully commissioned and operated for a first physics run below nominal intensity. The true challenge of CNGS starts now, with the planned continuous high intensity operation, resulting in high radiation levels in much of the CNGS area and in fatigue effects on target, horn and reflector from pulsed operation and from the beam impact on the equipment.

The experience that will be gained operating the present CNGS facility will be crucial to benchmark the design values, confirm or improve the models used in simulations, and hence contribute to the design of any upgraded future facility.

Acknowledgment

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