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HIGH INTENSITY COMMISSIONING OF THE SPS LSS4 EXTRACTION FOR CNGS

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Abstract

The SPS LSS4 fast extraction system will serve both the anti-clockwise ring of the LHC and the CERN Gran Sasso Neutrino project (CNGS). CNGS requires 2 fast extractions of 10.5 microsecond long batches, 50 milliseconds apart. Each batch will consist of 2.4×10^{13} protons at 400 GeV. These intensities are factor of 10 above the equipment damage limit in case of beam loss. Active (interlock system) and passive protection systems have to be in place to guarantee safe operation and to respect the radiation limits in zones close to the extraction region. In summer 2006 CNGS was commissioned including extraction with high intensity. A thorough setting-up of the CNGS extraction was carried out as part of the CNGS commissioning, including aperture and beam loss measurements, and defining and checking of interlock thresholds for extraction trajectory, beam loss monitors and radiation monitors. The relevant systems and risks are introduced in this paper, the commissioning results are summarised and comparisons with simulation predictions are presented.

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INTRODUCTION

The aim of the CNGS (CERN Neutrinos to Gran Sasso) project is to prove the existence of neutrino oscillations [1]. The ingredients for this endeavour are an intense neutrino beam of a single neutrino type directed at remote detectors. In the case of CNGS, ν_μ neutrinos are generated using the CERN complex and sent to the Gran Sasso laboratory (LNGS) in Italy at a distance of 732 km, which will detect ν_τ appearance events. At CERN the neutrino beam is produced by extracting 400 GeV protons from SPS point 4 (LSS4) and transporting them via the transfer lines TT40/TT41 onto a graphite target 840 m from the extraction point. The required extracted intensity for one of the 6 s long CNGS cycles in the SPS is 4.8×10^{13} protons. This intensity is delivered in two SPS extractions of 10.5 μs batches of 2.4×10^{13} protons separated by 50 ms. These two batches have a 5 ns bunch spacing and fill the entire circumference of the SPS (23 μs) except for two ~1 μs gaps required to accommodate the rise and fall time of the fast extraction kicker system in LSS4. The LSS4 fast extraction [2] is based on a horizontal closed orbit bump, five fast horizontal extraction kicker modules (MKE) and six DC horizontal electromagnetic septum (MSE) magnets. Fig. 1 shows the layout of extraction region with the extraction septa and beam loss monitors BLM1-8 on the septa.

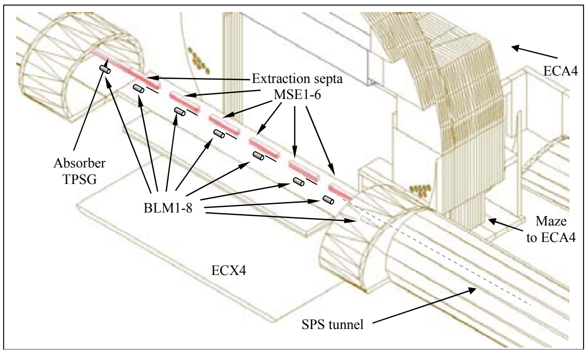

Figure 1: Tunnel, platform, shielding and beam loss monitor layout in the extraction region.

Machine Protection

The nominal extracted intensities for CNGS are an order of magnitude above the limit for equipment damage in case of beam loss. Passive protection is provided by an absorber in front of the septa - the TPSG. It protects the septa from kicker failures or otherwise mis-steered beam. The TPSG in LSS4 is a 2.9 m long diluter with a sandwich structure made of 2.1 m graphite and 0.8 m aluminium alloy. Active protection is provided by a sophisticated extraction interlock system, which monitors many parameters from different systems and only gives the extraction permit to the extraction kickers in case all parameters are within specified tolerances. The beam position at the extraction point, beam losses, bumper and septum currents, the kicker charging voltages and MSE girder position are all interlocked [3].

Extraction Constraints

The aperture must be adequate for the injected beam, the circulating bumped beam and the extracted beam in the extraction channel, to minimise the beam losses in the extraction region and the risk of damage to the septa during e.g. a kicker failure. The design value for the aperture of the circulating bumped beam is $\geq 9.3\ \sigma$ between orbit and TPSG inside edge. For the extracted beam the design is $\geq 6.5\ \sigma$ between the outside edge of the TPSG and the beam axis. ECA4, a zone close to the extraction region, Fig. 1, is freely accessible for radiation workers during beam operation. Radiation monitors measure the equivalent dose rate and cut the beam if these rates are too high. The interlock thresholds on the monitors on the cavern floor and in the equipment barracks were set to 5 μSv/h. Simulations [4] have shown that this dose rate corresponds to a beam loss at the TPSG of about 0.1 % of the nominal extracted CNGS intensity per batch.

COMMISSIONING OF THE CNGS EXTRACTION

Weeks 28, 30 and 33 of the 2006 SPS run were dedicated to CNGS beam commissioning. In each week half a day was spent purely on calibrating and measuring extraction related equipment and parameters. The measurements defined the loss monitor thresholds to protect the extraction region and verified the aperture in the extraction channel, and were made with low intensity beam (3 × 10^{11} – 2 × 10^{12} protons) and single extractions.

Calibration of Beam Loss Profiles

The TPSG is in the vacuum of both the circulating (inside edge) and extracted beam (outside edge), Fig. 2.

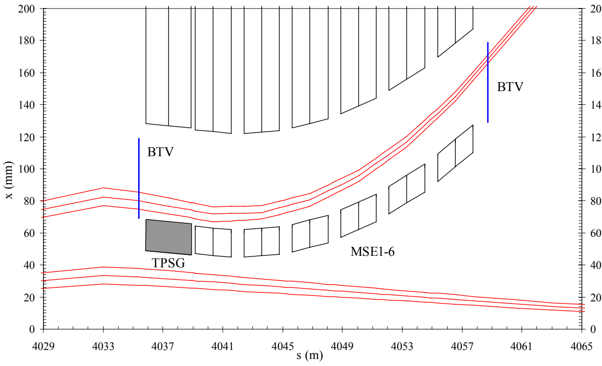

Figure 2: TPSG and MSE, with circulating and extracted beam envelopes (±6 σ).

The beam loss profiles in mGy along the extraction channel for BLM1-8 were measured for beam lost on the inside and on the outside of the TPSG. The two profiles were obtained by steering the beam onto the TPSG:

- Inside edge: circulating beam, no extraction, increasing extraction bump amplitude;
- Outside edge: extracted beam, reducing the kick voltage (nominal bump amplitude).

The measurements showed that, for the same number of lost protons, beam loss on the inside of the TPSG gives almost a factor 10 higher loss reading at BLM1 than loss on the outside, due to the large steel support block of the TPSG. The calibration curves, mGy versus number of lost protons, were established, Fig. 3.

The profiles are the result of combining data of the BCTs in the SPS and in TT40 with the beam loss monitor readings at BLM1 to BLM8.

Aperture Measurements

The horizontal emittance was ~4 µm normalised throughout the commissioning of the extraction channel, a factor 3 smaller than nominal. The aperture in the horizontal plane for the circulating and extracted beam at the TPSG was calculated from the calibrated beam loss profiles and the emittance. Nominal optics (β_x=84.4 m at TPSG) and Gaussian beams were assumed. The beam position at the TPSG was calculated with MAD-X using the measured (calibrated) beam position at the beam position monitor BPCE.418. The resulting aperture for the circulating bumped beam and extracted trajectory is summarised in Table 1.

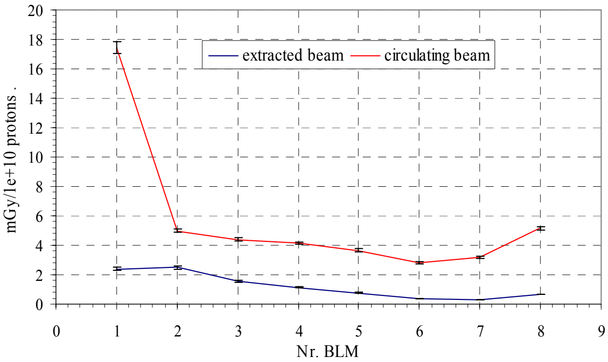

Figure 3: Beam loss per 10^{10} protons for extracted (outside TPSG) and circulating (inside TPSG) beam.

Table 1: Measured Aperture.

Aperture @	**mm**	**σ**	**design σ**
circulating bumped beam	13.0 ±0.3	8.3 ±0.5	9.3
extracted trajectory	10.6 ±0.3	6.8 ±0.5	6.5

Radiation Measurements in ECA4

The radiation measured in ECA4 was compared to simulations carried out with FLUKA [4]. The results summarised in Table 2 were obtained for an intensity of 1.3 x 10^{11} protons lost on the inside of the TPSG, and compared to the predictions scaled to this intensity.

Table 2: Measured radiation in ECA4 during beam loss on the inside edge of the TPSG.

	Calculation	**Measurement**
Top of the shielding	~ 1230 nSv	~ 700 nSv
Barracks	~ 30 nSv	~ 20-27 nSv
ECA floor (entrance TT40)	~ 30 nSv	~ 14-20 nSv

The measurements are reasonably consistent with the predictions. Possible explanations for the discrepancy are:

- The real wall thickness between the ECA4 zone and the extraction region varies between 4.8 m and 5 m. In the simulation 4.8 m was assumed.
- An additional wall (40 cm thickness) at the access chicane was not considered in the simulation.
- The radiation monitors were calibrated with an AmBe source (AmBe neutron spectrum is ranging up to 11 MeV), and the response for the real particle spectrum may be slightly different.

NORMAL OPERATION – LOSSES

The three commissioning weeks were followed by two weeks of CNGS run. The interlock thresholds were adjusted according to the commissioning results [5].

During this period the number of extracted protons per batch was 1.7 × 10^{13}, with two extractions per cycle.

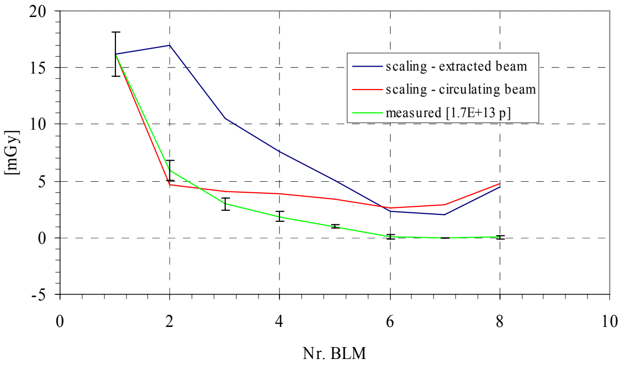

Figure 4: Comparison of loss profiles. The green curve is the measured averaged loss profile.

Fig. 4 shows the averaged losses on the eight beam loss monitors in the extraction region for a 9 h period on 27th of August. Two previously obtained profiles are also shown, scaled to the loss at the TPSG monitor – one for loss on the inside of the TPSG and one for loss on the outside of the TPSG. By equating the number of protons lost at the TPSG with the measured mGy at the first monitor, using the calibration curves, allowed an estimate to be made for beam loss per extraction. The measured profile, Fig. 4, tends to follow the red profile (losses on the inside of the TPSG), indicating that the losses are mainly on the circulating beam side. The estimated extraction loss level is 0.05 %, well below the estimated value of 0.3% [6]. The origin of these losses was identified as due to spurious particles in the kicker gap being swept across the TPSG during extraction, see Fig. 5.

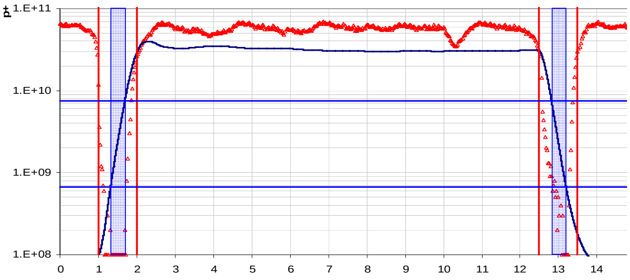

Figure 5: Measured particle distribution in red and kick waveform in blue.

Swept beam leads to losses on the inside and the outside of the TPSG. Since, however, losses on the inside of the TPSG lead to larger signals on the BLMs than loss on the outside, the calibration curves for mGy versus lost particles to determine the number of lost particles during normal running and to set the interlock thresholds were the ones obtained with losing beam on the inside of the TPSG. The interlock thresholds on the monitors BLM1-8 were set to 38 mGy at the TPSG and 18 mGy elsewhere.

ECA4 Radiation Measurements

Within the two weeks of the CNGS run a total dose of 72 µSv (background subtracted) was measured on the ECA4 floor close to the TA40 entrance. The measured dose rate on the different monitors corresponds to 0.043% to 0.057% of the extracted intensity lost on the TPSG per extraction. These numbers confirm the measurement of about 0.05 % of the extracted intensity lost on the TPSG during normal operation obtained with the beam loss monitors.

SUMMARY

The extraction system in LSS4 was successfully commissioned with high intensity beam as part of the CNGS commissioning in summer 2006. About three half-days out of three commissioning weeks were dedicated to setting up the extraction and verifying the extraction system parameters and response. The response of the extraction beam loss monitor system and radiation monitoring system in ECA4 close to the extraction region were calibrated with beam. Interlocking thresholds could be set to respect the radiation limits in the critical ECA4 zones. The aperture in the extraction channel and for the circulating bumped beam was measured and confirmed to be as expected.

Extraction losses during normal operation were measured in the two weeks of normal CNGS running and calibrated using the earlier results. The conclusion is that the CNGS extraction was cleanly set up in the transverse plane, with little or no losses arising from transverse scraping of beam tails. The measured losses on the TPSG were shown to be due to beam present in the kicker rise/fall time gaps. Both beam loss monitor calibration and radiation monitor calibration delivered the same result of about 0.05 % of the extracted intensity lost on the TPSG during the first extraction. Assuming this loss rate for a continuous CNGS operation with an intensity of 4.8 x 10^{13} protons per double batch extraction, a dose rate in the range of 3 µSv/h can be expected in accessible parts of the ECA4 area.

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