EVOLUTION BEAM PARAMETERS DURING INJECTION AND STORAGE OF THE HIGH BRIGHTNESS BEAMS ENVISAGED FOR THE LINAC4 INJECTION INTO THE CERN PS BOOSTER

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Abstract

Recent studies on the planned 160 MeV H^- charge exchange injection and beam dynamics of high intensity or brightness beams in the CERN PS Booster (PSB) are reviewed. Orbit simulations of the 160 MeV injection with longitudinal and transverse painting and emittance evolutions during the first 20 ms are reported. Benchmarking of Orbit and Accsim simulations against measurements carried out in the PSB on a stored beam at 160 MeV are presented.

INTRODUCTION

A bottleneck of the present accelerator chain for the generation of high-brightness LHC beams is the present Linac2 50 MeV multi-turn injection scheme into the PSB due to direct space charge effects. Raising the injection energy from 50 to 160 MeV by replacing Linac2 with Linac4 aims at doubling the brightness (same direct space-charge tune shift after doubling the intensity within unchanged normalized emittances) and providing beams with parameters given in Table 1.

In addition, the injection losses of about 50%, inherent to the present conventional multi-turn injection scheme are expected to decrease drastically by the implementation of an H^- charge-exchange injection scheme [3] comprising transverse and longitudinal painting.

Acceleration to 1.4 GeV will be similar to the present situation and last ≈0.5 s using first and second harmonic cavities.

LONGITUDINAL PAINTING SCHEME

Making use of the Linac4 beam chopper and with an H^- charge exchange injection, the present injection of a coasting beam followed by pseudo-adiabatic capture can be replaced by an injection with longitudinal painting. The low RF voltages of 8 kV for the main h=1 system and 6 kV for h=2 system (in anti-phase to improve the bunching factor) imply little (but non-negligible) motion in longitudinal phase-space during injection and, thus, rule out the usage of synchrotron motion for painting. An active longitudinal painting scheme based on a triangular modulation of the Linac4 output energy is thus proposed and depicted in Fig. 1. It aims at filling the double harmonic buckets, assuming an addition injection onto a moderate ramp ($d(B\rho)/dt \approx 10$ Tm/s), as homogeneously as possible.

During the first ten turns or so, the mean Linac4 output energy decreases from a positive offset of ≈1.1 MeV to a negative offset of ≈-1.1 MeV(instantaneous r.m.s. energy spread 120 keV). Linac4 bunches arriving outside a contour of ≈80% of the bucket area (Fig. 2, dashed line) are removed by the chopper. During the next ten turns the Linac4 energy is raised again and the bucket is filled once more (i.e., 20 turns in all lasting 20.16 μs, yielding the 3.25×10^{12} protons per ring required for nominal LHC operation). Higher intensities can be achieved by injecting during several energy modulation periods and/or increasing the period of the energy modulation.

Table 1: Beam intensities and emittance figures to be provided by the PSB with Linac4 [4].

Beam	**PSB intensity per ring (1.4 GeV)**	**PSB normalized r.m.s. emittances**
LHC nominal (single batch with Linac4)	3.25×10^{12} (2 bunches/ring)	(H) 2.5 [μm] (V) 2.5 [μm]
LHC ultimate (double batch with Linac4)	2.55×10^{12} (1 bunch/ring)	(H) 2.5 [μm] (V) 2.5 [μm]
CNGS (single batch with Linac4)	1.25×10^{13} (2 bunches/ring)	(H) 11.5 [μm] (V) 4.6 [μm]
ISOLDE beam (single batch with Linac4)	1.6×10^{13} (1 bunch/ring)	(H) 12.0 [μm] (V) 7.0 [μm]

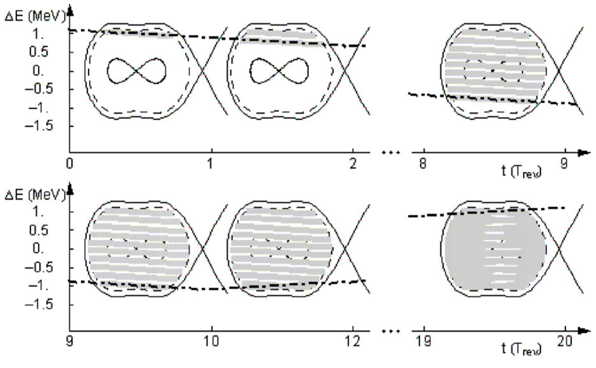

Figure 1: Proposed longitudinal painting scheme.

SIMULATION OF THE INJECTION

The 160 MeV H^- charge exchange injection is investigated with the code Orbit including the planned longitudinal painting and transverse painting as described in [3] and depicted in Fig. 2 The closed orbit shown in blue is the superposition of two orbit bumps: (i) the chicane with a height of about 61 mm is created with the BS magnets and collapses only after completion of the injection and (ii) and a ≈29 mm painting bump, which starts collapsing from the beginning of the injection, created by bumper magnets installed outside the region shown; it is assumed that at the beginning of the injection, the incoming beam shown in red arrives exactly on the closed orbit. Particles not stripped to H^+ are shown in purple and green and will by intercept by a dump.

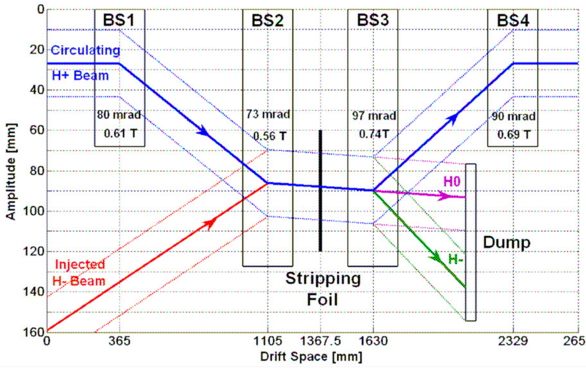

Figure 2: Proposed [3] PSB injection region.

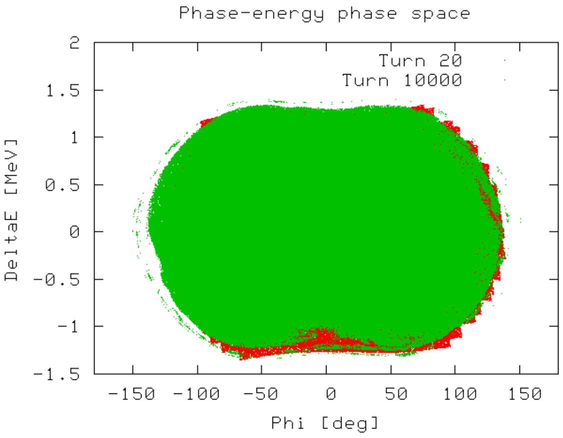

Figure 3: Orbit longitudinal profile at turn 20 after completion of the H- injection (the active painting pattern is apparent) and at turn 10000 (917200 macro-particles).

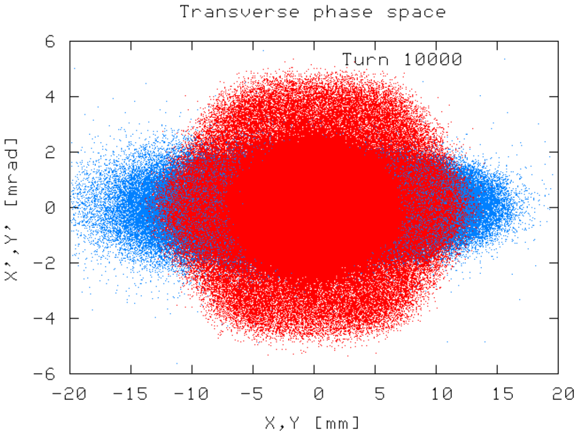

Figure 4: Orbit horizontal & vertical phase space plots (917200 macro-particles). Some halo develops in vertical.

The 1.5 µm (340 µg/cm^2) thick carbon stripping foil was taken into account and all dipoles for bump creation were modelled as thin elements. For the simulation presented here, injection on a plateau is assumed for simplicity.

For the simulations, 20 files, each one containing 6D initial coordinates for one injected turn, taking transverse and longitudinal painting into account, have provided. Simulations with in total 229240 macro-particles and with 917200 macro-particles have been carried out. The working point is $Q_{H,V}$=4.28/5.45.

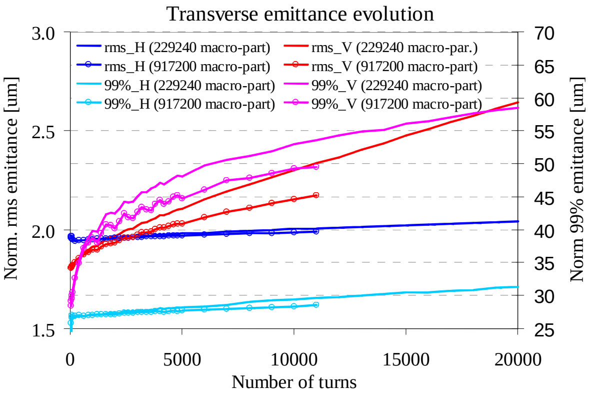

Figure 5: Orbit normalized r.m.s. and 99% emittance evolutions after H$^-$ injection (note that ε^n_V exceeds the 2.5 µm PSB emittance budget after 20000 turns, i.e., ≈20 ms).

Figs. 3-4 show longitudinal and transverse scatter plots and Fig. 5 the evolution of the emittances for the latter case with a larger number of macro-particles. The results show moderate vertical emittance blow-up and some halo development. Increasing the number of macro-particles decreases the emittance blow-up. This indicates that a part of the low-up is likely generated by numerical artefacts.

BENCHMARK WITH MEASUREMENTS

The aim is to benchmark Accsim and Orbit simulations with measurements performed with beam at 160 MeV in the PSB. The evolution of the transverse emittances of a high-intensity beam on a 160 MeV energy plateau has been measured [6] and is given in Table 2. The second harmonic RF system has been used to lengthen or shorten the bunch length in order to vary the transverse space charge detuning.

Accsim and Orbit simulations (including space charge) aiming at reproducing these measurements are summarized in Figs. 6-9. The longitudinal phase plots in Fig. 6 show the effect of the phase of the second harmonic RF system. Emittance evolutions plotted in Figs. 7-8 show reasonable agreement between measurements and orbit simulations, whereas Accsim yields much faster blow-up. The longitudinal blow-up observed with Accsim can be explained by a few particles leaving the bucket.

Table 2: Beam characteristics from experiments [6]

	Long bunch	Short bunch
RF cavities (h=1 & h=2)	8 kV in anti-phase (1 ring, 1 bunch)	8 kV in phase (1 ring, 1 bunch)
Working point	$Q_{H,V}$=4.21/4.35	$Q_{H,V}$=4.21/4.45
Measurements at t=0 ms (160 MeV)	105×10^{11} protons $\varepsilon^n_H(1\sigma)$ = 13.7 µm $\varepsilon^n_V(1\sigma)$ = 6.8 µm ε_L (1σ) ≈ 0.25 eVs	103×10^{11} protons $\varepsilon^n_H(1\sigma)$ = 19.2 µm $\varepsilon^n_V(1\sigma)$ = 7.1 µm ε_L (1σ) ≈ 0.20 eVs
Measurements at t=200 ms (160 MeV)	103×10^{11} protons $\varepsilon^n_H(1\sigma)$ = 13.1 µm $\varepsilon^n_V(1\sigma)$ = 7.1 µm ε_L (1σ) ≈ 0.25 eVs	96×10^{11} protons $\varepsilon^n_H(1\sigma)$ = 20.4 µm $\varepsilon^n_V(1\sigma)$ = 7.3 µm ε_L (1σ) ≈ 0.20 eVs

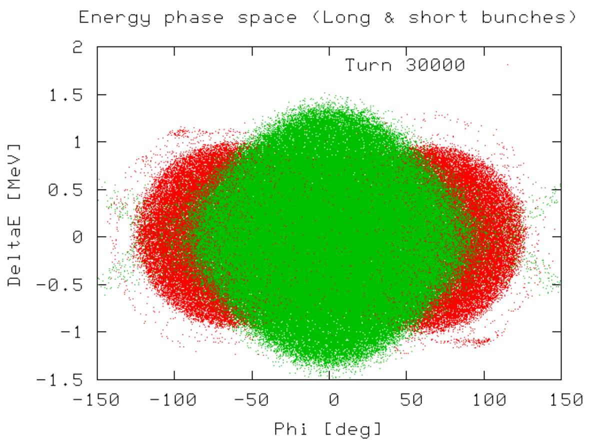

Figure 6: Orbit longitudinal phase space at turn 30000 for the long and short bunches (2×10^5 macro-particles).

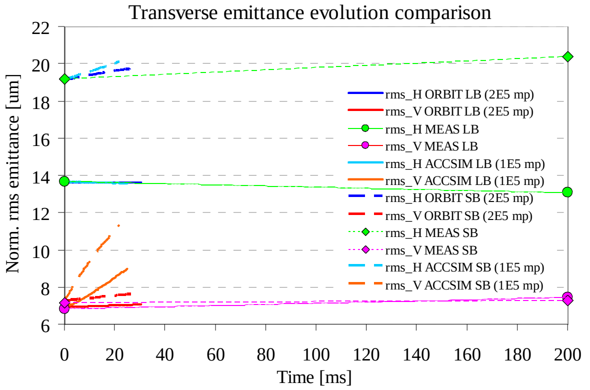

Figure 7: Simulated and measured normalized transverse r.m.s emittance evolution (thick continuous/dashed lines represent long/short bunch simulations, circles/diamonds long/short bunch measurements, thin continuous/dashed lines denote long/short bunch measurement fits).

CONCLUSIONS

A realistic modelling of the injection process with both active longitudinal and transverse painting has been set up. Results of the simulations show that tailoring of the longitudinal and transverse beam distributions to reduce peak densities is quite effective, that a dispersion mismatch of the injected beam is not a concern and that the heating of the stripper foil is moderate.

Measurements at 160 MeV in the PSB were in reasonable agreement with Orbit simulations. Accsim simulations disagreed with measurements and Orbit simulations.

In summary all these simulations and measurements are evidently essential to better understand the space charge mechanisms in consideration of the future replacement of Linac2 at 50 MeV by Linac4 at 160 MeV.

ACKNOWLEDGEMENTS

We would like to thank M. Chanel for taking measurements in the PSB, B. Goddard for providing input data to simulations and both for stimulating discussions.

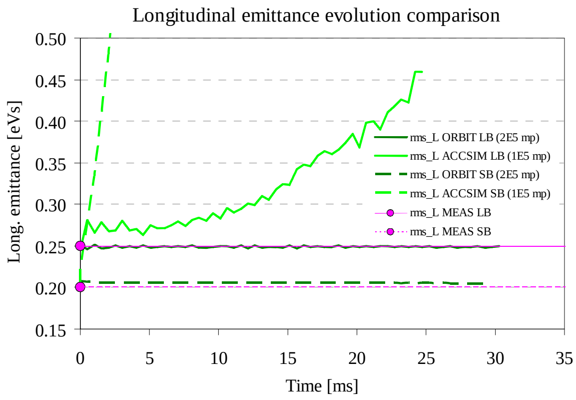

Figure 8: Simulated and measured longitudinal emittance evolution (thick continuous/dashed lines denote long/short bunch simulations, circles/diamonds long/short bunch measurements, and thin continuous/dashed lines denote long/short bunch measurement fits).

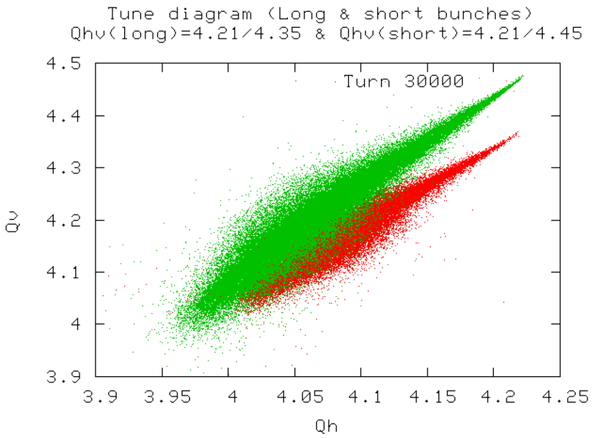

Figure 9: Orbit Tunes: $\Delta Q_{h,v}$(long bunch)≈-0.20,-0.32, $\Delta Q_{h,v}$(short bunch)≈-0.26,-0.48 (2×10^5 macro-particles).

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