Beta Beams in the CERN complex: PS studies

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Abstract. For the Beta Beams to become a solid option for a future neutrino-physics facility at CERN, it is fundamental to demonstrate the feasibility of storing and accelerating the Beta Beams ions in the PS and SPS. This work identifies the key issues that should be assessed for the PS, presents the status of the ongoing studies and, in particular, discusses the choice of the injection energy and recent space-charge measurements.

1. Introduction

Beta Beams aims at the production of a pure electron neutrino and anti-neutrino beam from the β–decay of radioactive ions, for oscillation experiments. The baseline design considers ^{6}He and ^{18}Ne as respectively antineutrino and neutrino emitters and it is based as much as possible on existing technology and on CERN facilities [1]. In particular, it relies on ISOLDE experience and infrastructure for the isotopes production, while the ions accelerator chain includes the PS and SPS. The main motivation of this approach is to reduce the cost of the facility and to profit of the experience in machine operation. However, PS and SPS are not optimized for the Beta Beams, therefore it is necessary a careful study on how to accommodate our radioactive ions in these existing machines.

This work is focused on the CERN-PS, assuming the baseline parameters [2], although an optimization of the entire beam transfer chain is ongoing [3]. Activities are done in close collaboration with the LHC Injectors Upgrade (LIU) Project [4], as several issues are in common between Beta Beams and the Upgrade proposal to increase the PS injection energy to 2 GeV. Studies in the CERN-PS include: radiation protection issues, vacuum, injection scheme and collective effects such as space-charge on the injection long flat-bottom and fast head-tail instabilities at transition crossing.

2. PS Injection scheme

The baseline scheme [5] foresees the injection in the PS at 3.5 GeV proton-equivalent kinetic energy. A batch of 20 bunches, arriving from the RCS with a repetition rate of 10 Hz, are accumulated on a long flat bottom (1.9 s), then accelerated up to 26 GeV proton-equivalent and sent to the CERN-SPS.

2.1. Injection energy

The 3.5 GeV injection energy, to be compared with the CERN operational beams energy of 1.4 GeV, has been chosen from space charge consideration and it is based on a maximum Laslett tune shift of 0.22 [6], obtained by considering the bunch parameters summarized in Table 1. This

Table 1: Parameters at PS injection for the Beta-Beams baseline ions [2]

Ion species			^{6}He	^{18}Ne	p-equivalent
Kinetic energy per nucleon	E_k/A	(GeV)	0.787	1.65	3.5
Relativistic gamma	γ		1.84	2.77	4.73
Half life	$\tau_{1/2}$	(mm mrad)	1.49	4.63	–
Normalized horiz. emittance (rms)	ε^*_H	(mm mrad)	10.3	10.3	10.3
Normalized vert. emittance (rms)	ε^*_H	(mm mrad)	5.5	5.5	5.5
Harmonic number	h		21	21	–
Bunch length (rms)	τ	(ns)	21.5	21.5	–
Momentum spread (rms)	dp/p	(10^{-3})	0.23	0.15	–

is a safe margin, as some high intensity operational beams in the PS have a space-charge tune spread larger than 0.3 (although they are immediately accelerated after injection).

Considerations of septum technology, kicker strength and straight-sections length in the PS, indicate that injection at 3.5 GeV p-equivalent is challenging, as also confirmed by PS and injection experts [7, 8].

It is therefore here proposed to lower the Beta-Beams injection energy to 2 GeV p-equivalent. This value corresponds to what is studied for the LIU Project and will allow Beta Beams to profit of synergies with this project and eventually to use the same equipments.

A recent study of a 10 Hz RCS as a PS pre-injector, to replace the CERN-PS Booster [9], proposes the Eddy-Current technology for the septum and the bumper, plus an extra kicker in addition to what already installed in the PS, to provide the 30% increase in kick strength for the 2 GeV injection energy. This work, which will be the starting point when a detailed study of the Beta-Beams injection scheme is required, also identifies issues that need careful study in case of multiple bunches injection from the RCS, namely losses due to the injection bump, the lifetime of eddy-current devices and a vertical acceptance reduction at the septum, compared to what the PS can accept nowadays.

2.2. Long flat bottom

The injection flat-bottom is 1.9 s long, since the PS is receiving 20 injections at 10 Hz from the RCS. This has two consequences. First of all, due to decay losses, on the long flat bottom there is a 43% reduction of the ^{6}He intensity and a 18% for ^{18}Ne. Studies [10] of dose deposition in the magnets indicates that the air activation in the tunnel is well within the limits and that the PS tunnel would remain accessible as a limited-stay controlled area after a few days, depending on the position along the ring and on the operation mode. The report does not take into account beam losses in "hot" regions (e.g. at the septum) and operation losses (injection, transition, extraction). More specific Fluka studies are ongoing now.

The second issue is represented by collective effects and in particular space-charge, which may induce beam blow-up and losses on the long injection flat bottom.

3. Space charge

Space charge induces tune spread in the beam and can make particles in high-intensity and high-brightness beams cross betatron resonances and either be lost, or contribute to emittance growth. Usually the value of $|\Delta Q_{SC,max}| = 0.22$ is assumed for the determination of the maximum allowed Laslett tune-shift. This is safe margin, useful in the design process, but it can be relaxed.

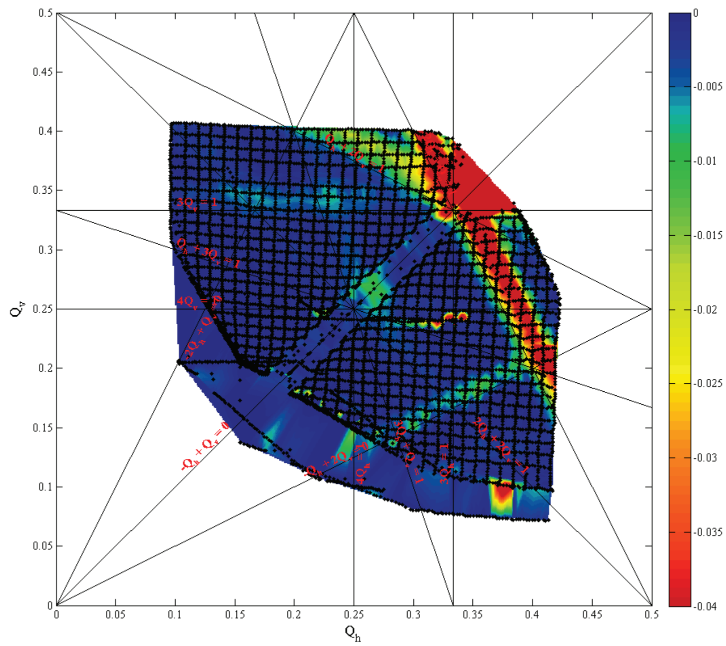

Figure 1: Tune diagram resulting from the loss measurement at 2 GeV. The color scale indicates the derivative of the BCT signal, i.e., the red lines indicate the larger losses.

The identification of the destructive resonance lines and the determination of the optimum working point and the maximum Laslett tune-shift, via beam-based measurements, is fundamental to fully exploit the PS intensity performances for the Beta-Beams, especially if, as discussed in the previous paragraph, an injection at a lower energy (2 GeV p-equivalent) has to be implemented. For the following measurements, the proton beams available in the PS are used, but the results can be easily scaled to the Beta-Beams ions.

3.1. Tune scan for destructive resonance-lines identification

The identification of the most dangerous resonances is realized by applying the method proposed in [11]: a large emittance, moderate intensity, not space-charge dominated beam is kept on a 1.2 s magnetic flat bottom at constant energy of 2 GeV. The emittance of the beam is chosen to be large enough to fill at maximum the vacuum chamber, in such a way that even a weak resonance produces a limited increase of the betatronic amplitude for which losses should become visible. During the scan, the tune is slowly varied with a predefined function and the beam intensity is recorded: if an excited resonance is crossed, beam losses are observed as a slope in the Beam Current transformer (BCT) acquisition.

Figure 1 shows the tune scan for the bare machine (without non-linear elements such as sectupoles, octupoles or Pole Face Windings). Only part of the tune diagram could be explored, because the working point was controlled via two families of quadrupoles which are limited in strength. The black dots indicate the points at which the tune and losses were measured. The colorplot is then obtained by a Matlab© interpolation function. The losses are quoted in terms of the derivative of the BCT signal dN/N.

The plot identify the lines from which the working point should be kept far from. It indicates that the most destructive line is the $2q_x + q_y = 1$ and that the 4^{th} order line $4q_y = 1$ is not excited, but it is the 3^{th} order $3q_y = 1$.

3.2. Space-charge dominated beam measurements

A first attempt was made to measure the losses and the transverse emittance increase for space-charge dominated beams. Two different beams have been used: a) a high-brightness “LHC–like” beam, characterized by a transverse normalized emittance of about 2.5μm mrad and b) a high-intensity “ToF–like” beam, more similar to Beta Beams, with large transverse emittances, to fill as much as possible the vacuum pipe.

For the first, high–brightness low–emittance beam, different regimes have been identified, depending on the working point and on which resonance line is touched. As expected from studies done in the past [12], crossing the integer induces losses-free emittance blow-up on this kind of beam. A different effect was identified for a vertical tune of $Q_y = 6.30$, namely losses with bunch shape degradation. The cause may be the large chromaticity of the beam and particles crossing the $3q_y = 1$ line. Measurements should be repeated after chromaticity correction.

Results for high–intensity, large–emittance beams are more difficult to interpret as any beam blow-up will immediately translate into losses.

4. Conclusions

Efforts are ongoing to assess the feasibility of using CERN-PS to accelerate Beta Beams and possible issues have been identified. Injection at 3.5 GeV p-equivalent is a challenge with existing equipments and therefore we propose to reduce it to 2 GeV, which is the value chosen for the PS Upgrade, within the LIU Project.

The main issue may be space-charge on the long injection flat-bottom, therefore a campaign of measurement has been started, in collaboration with the LIU colleagues. Tune scans have identified the destructive resonance that should be avoided when choosing the working point. The aim of the ongoing space-charge dominated beams is to identify the different mechanisms of beam degradation that may take place and try to find a cure, e.g. chromaticity correction or resonance compensation, in order to accommodate the largest possible Laslett tune spread (i.e. the highest beam intensity at a given energy) for the optimum value of working point.

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References

[1] Zucchelli S 2002 A novel concept for a Neutrino Factory: the Beta-Beam *Phys. Let. B* **532** 166
[2] Wildner E *et al.* 2011 Beta beams database
[3] Wildner E 2011 private communication
[4] Garoby R *et al.* 2011 *Proc. IPAC11*
[5] Benedikt M *et al.* 2008 Conceptual design report for a Beta-Beam facility *The European Phys. J. A - Hadrons and Nuclei* **47** 1-32
[6] Benedikt M *et al.* 2007 Parameter and intensity values, v.3 EURISOL DS Task note 12-25-2009-0014
[7] Gilardoni S 2011 private communication
[8] Goddard B 2011 private communication
[9] Hanke K *et al.* 2011 EDMS-1154705
[10] Magistris M, Trovati S, Kirk M and Delahaye P 2009 CERN-SC-2009-051-RP-TN
[11] Schutt P, Franchetti G, Franczak B 2004 GSI-Acc-Note-2004-05-001
[12] Giovannozzi M *et al.* 2003 *Proc. PAC03*