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Lead Ion Transverse Emittance Blow-up at the TT2-TT10 Stripper: Revised

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Abstract

Pb^{53+} ion beams are accelerated up to a kinetic energy of 4.22 GeV/u in the PS, extracted and stripped to Pb^{82+} in the TT2-TT10 transfer line from PS to SPS where they are injected and accelerated up to 156.8 GeV/u. The emittance growth in aluminium strippers of different thicknesses has been measured in 1995. Recently it has been observed that the model used to interpret the data overestimated the growth by a factor two. Furthermore in 1998 a campaign of measurements of the optics of the injection line has been performed. Here we revise the comparison of the model to the experimental data.

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1 Introduction

Pb^{53+} ion beams are accelerated up to a kinetic energy of 4.22 GeV/u in the PS, extracted and stripped to Pb^{82+} in the TT2-TT10 transfer line from PS to SPS where they are injected and accelerated up to 156.8 GeV/u [1]. The emittance growth in aluminium strippers of different thicknesses has been measured in 1995. Recently [2] it has been observed that the model used in [3] to interpret the data was erroneous, furthermore in 1998 a campaign of measurements of the optics of the injection line has been performed [4]. Here we revise the comparison of the model to the experimental data.

The basic parameters of the Pb^{53+} lead ion beam extracted from the PS are summarised in Table 1.

Momentum per nucleon [GeV/c/u]	5.07
Momentum per charge [GeV/c/Z]	19.89
Relativistic β factor	0.98354
Relativistic γ factor	5.534
2 σ physical emittance [μm] (H/V)	1.8/1.6

Table 1. Basic parameters of the beam extracted from the PS [5].

2 Emittance Blow-up

Emittance was measured with two sets of three SEM monitors in each plane, one set is located at extraction from the PS (before the stripper: MSF257/MSF267/MSF277) and the other in proximity of the injection point in the SPS (after the stripper: BSG102737/ BSG102837/ BSG102937). The emittance blow-up $\Delta\varepsilon$ is defined here as the increase in the 2σ-emittance of the beam as a consequence of the multiple scattering and of the straggling in the stripper. The contribution due to the scattering is given by [6]:

$$\left(\Delta\varepsilon_{H,V}\right)_{scattering} = 2\Theta_0^2\left[\beta_{H,V} + x\alpha_{H,V} + \frac{x^2}{3}\gamma_{H,V}\right] \approx 2\Theta_0^2\beta_{H,V}$$

(in [3] it was erroneously assumed: $\Delta\varepsilon_{H,V}=4\beta_{H,V}\Theta_o^2$) where $\beta_{H,V}$,$\alpha_{H,V}$ and $\gamma_{H,V}$ are the Twiss parameters at the stripper, x is the stripper thickness and Θ_o is the rms projected scattering angle given by (in the range $10^{-3} < x/X_o < 100$) [7][8]:

$$\Theta_o\,[\text{rad}] = 13.6\, z\, (\beta p)^{-1}\, (x/X_o)^{1/2}\, [1 + 0.038 \ln(x/X_o)\,]$$

where p [MeV/c], βc and z are the momentum, velocity and charge number (assumed to be 82) of the ion and X_o is the radiation length of the stripper material (for Al X_o = 89 mm). The contribution due to the straggling is [6]:

$$\left(\Delta\varepsilon_{H,V}\right)_{straggling} = 2\left[\beta_{H,V} D_{H,V}^{'}{}^2 + 2\alpha_{H,V} D_{H,V} D_{H,V}^{'} + \gamma_{H,V} D_{H,V}^2\right]\left(\frac{\sigma_p}{p}\right)^2$$

where $D_{H,V}$ and $D'_{H,V}$ are the dispersion and its derivative at the stripper and σ_p/p is the rms momentum spread associated with the straggling. The optical parameters at the stripper, listed in Table 2 below, have been deduced from the optical parameters at PS extraction. These have been measured in 1998 and recalculated recently to account for the latest known values of the calibration curves for the TT2 quadrupoles. The optical parameters at PS extraction (cf. Table 8 in [9]) are listed in Table 3 below.

	H	V
β [m]	23.50	22.13
α [1]	-1.71	1.13
γ [m^{-1}]	0.17	0.10
D [m]	-2.95	-1.06
D' [1]	-0.34	0.06

Table 2. Optical parameters at the stripper for the extraction conditions in Tab.3 and the optics used in 1995.

	H	V
β [m]	26.42	5.72
α [1]	-2.35	0.31
D [m]	3.63	-0.48
D' [1]	0.4	0.03

Table 3. Optical parameters measured at PS extraction in 1998 (cf. Table 8 in [9]).

Table 4 lists the expected energy straggling of a 4.22 GeV/u Pb^{53+} beam after the aluminium stripper for different stripper thicknesses [10]. The resulting contribution to the emittance growth ($\Delta\varepsilon_{H,V\ straggling}$) is negligible (few percents) as compared to that due to the scattering ($\Delta\varepsilon_{H,V\ scattering}$) as shown in Table 4. The assumption that the scattering and straggling contributions add linearly to the original emittance is valid for thin strippers as for the case in consideration [6], the quadratic summation gives similar results.

Stripper thickness [mm]	rms energy straggling [MeV]	σ_p/p [10^{-5}]	$\Delta\varepsilon_{H,V\ scattering}$ [μm]	$\Delta\varepsilon_{H,V\ straggling}$ [μm]
0.5	57	5.5	0.19/0.18	0.004/0.0003
0.8	72	6.9	0.33/0.31	0.007/0.0005
1	82	7.4	0.42/0.39	0.009/0.0006

Table 4.Straggling vs. stripper thickness[10] and estimated emittance growth from scattering and straggling.

In Fig. 1 the measured horizontal and vertical emittance growths for different stripper thicknesses are compared with the expected values. The error bars in the expected values are calculated assuming a relative error of 10% in the initial Twiss parameters at extraction from PS.

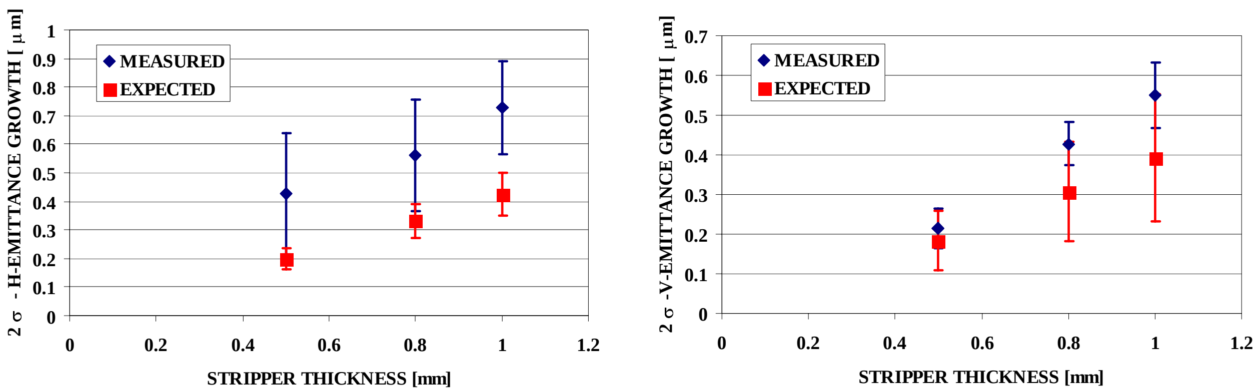

Figure 1. Measured and expected horizontal (left) and vertical (right) emittance growth vs. Al stripper thickness for the optical parameters in Table 2.

Conclusions

The results of the measurements of the emittance growth of a 4.22 GeV/u Pb^{53+} through an aluminium stripper for different stripper thicknesses have been compared to the model using the most recent information on the optical parameters of the line. Some discrepancies remain between the measurements and the model, which seems to underestimate the emittance growth, in particular in the horizontal plane.

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References

[1] D. Warner, ed., “CERN Heavy-Ion Facility Design Report”, CERN 93-01.

[2] D. Möhl, private communication.

[3] G. Arduini, R. Bailey, T. Bohl, H. Burkhardt, R. Cappi, C. Carter, K. Cornelis, M. Dach, G. de Rijk, A. Faugier, G. Ferioli, H. Jakob, M. Jonker, D. Manglunki, G. Martini, M. Martini, J. P. Riunaud, C. Scheidenberger, B. Vandorpe, L. Vos, M. Zanolli, “Lead ion beam emittance and transmission studies in the PS-SPS complex at CERN”. CERN SL/96-19(OP) and CERN PS/96-26(PA). Proceedings of the Fifth European Particle Accelerator Conference (EPAC ’96), 10-14 June 1996, Sitges (Barcelona), Spain. S. Myers, A. Pacheco, R. Pascual, Ch. Petit-Jean-Genaz and J. Poole Eds., pp. 380-382.

[4] G. Arduini, G. Crockford, C. Despas, M. Giovannozzi, K. Hanke, D. Manglunki, M. Martini, G. Metral, C. Niquille, “Betatron and Dispersion Matching of the TT2/TT10 Transfer Line for the Fixed-Target Lead Ion Beam”, SL-Note-99-018 MD and PS-Note-99-009 CA.

[5] G. Arduini, R. Blanchard, T. Bohl, K. Cornelis, G. Crockford, G. de Rijk, C. Niquille, “Measurement of the energy loss of Pb^{53} ions in an aluminum stripper 1mm thick”, CERN-SL-MD-Note-196.

[6] A.-S. Müller, “Description of Beam-Matter Interaction in the Covariance Matrix Formalism”, CERN/PS 2001-0013 (AE).

[7] Particle Data Group, ‘Review of Particle Properties’, Phys. Rev. D50, 1253 (1994).

[8] S. Datz and H. F. Krause and C. R. Vane and H. Knudsen and P. Grafstrom and R. H. Schuch, "Effect of Nuclear Size on the Stopping Power of Ultrarelativistic Heavy Ions", PRL 77, (1996) 2925.

[9] G. Arduini, M. Giovannozzi, K. Hanke, M. Martini, “Measurement of Twiss Parameters and Dispersion in the TT2/TT10 Transfer Line for Indium Ions”, AB-Note-2003-087 (OP).

[10] C. Scheidenberger, private communication.