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SPS

Measurement of the energy loss of Pb^{53+} ions in an aluminum stripper 1 mm thick

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Summary

The relative energy loss of 4.22 GeV/u (kinetic energy) Pb^{53+} ions in the aluminum stripper 1 mm thick installed in the transfer line TT2 between CPS and SPS has been measured. A Pb^{53+} ion beam was injected in the SPS ring (stripper out) and its revolution frequency compared with that of Pb^{82+} (stripper in) on the same first turn trajectory. The measured relative energy loss is $(3.69 \pm 0.13) \times 10^{-3}$, which is in fair agreement with the value 2.8×10^{-3} given by the the Bethe - Bloch formula.

Introduction

During the 1995 startup of the lead ion run the correct magnetic settings for the transfer line TT10 and the SPS ring were found by using a proton beam at a kinetic energy of 11.95 GeV, using the same supercycle and timing foreseen for the lead ion run. A proton beam of 11.95 GeV has the magnetic rigidity of Pb^{82+} ions of a kinetic energy of 4.22 GeV/u.

In order to accelerate Pb^{53+} to the kinetic energy of 4.22 GeV/u the magnetic dipole field in the PS has to be increased at extraction by the factor 82/53. However, the energy loss in the aluminum stripper (1 mm thick) has to be taken into account by increasing the energy of Pb^{53+} ions at extraction in the PS, in order to deliver Pb^{82+} ions of the same kinetic energy to the SPS. The accuracy of the magnetic field measurement in a reference dipole in the PS is of the order of 10^{-4} [1] and the radial position of the beam before extraction is monitored with an accuracy corresponding to a relative energy error of a few 10^{-4} [1]. This guarantees the correct scaling of the lead ion energy.

The extraction energy of the lead beam was fine tuned in order to obtain the same average radial position of the first turn trajectory like that of the 11.95 GeV proton beam without changing any magnetic strength neither in TT10 nor in the SPS ring. As a result of this it was found that the correction to be added to the magnetic field strength at extraction in the PS ring corresponded to a relative energy increase of 9×10^{-3}, that is 3 times larger than expected if this energy difference is interpreted as the energy loss in the stripper [1]. The relative energy loss of a 4.22 GeV Pb^{82+} ion in 1 mm thick aluminum foil calculated from the Bethe-Bloch formula is 2.8×10^{-3} [2].

An independent measurement has been performed to clarify the discrepancy with respect to this theory and to have the possibility to calculate the energy loss for other stripper thicknesses in case their use is justified (minimization of the emittance growth, optimization of the stripping efficiency).

Description of the measurement.

In order to measure the first turn trajectory in the SPS within the necessary precision, the PS reduced the bunch length of the lead ion beam from 15 ns (physics conditions) to about 5 ns. Otherwise neither PS machine nor beam parameters were changed during the MD. Only the first batch (of the four provided by PS) was injected in the SPS.

The energy loss measurement consisted of two steps, using Pb^{82+} ions in the first and Pb^{53+} ions in the second:

1) The average radial beam position of the first turn trajectory in the SPS ring was measured with the COPOS system. The revolution frequency of the injected beam along the flat bottom was determined by measuring the injection frequency and by observing the position of the debunching beam (no RF voltage applied) on an oscilloscope triggered with the revolution frequency. The revolution frequency is generated by dividing the injection frequency by the harmonic number h = 4620.

2) The magnetic fields of all the magnets in TT10 and the currents of the main magnets (dipoles and quadrupoles) in the ring were scaled up by a factor 82/53 and Pb^{53+} (stripper out) was injected. The current in the main ring bends was carefully adjusted in order to have the same average radial position and hence the same trajectory length of the fully stripped ions. Transverse beam oscillations at injection, tunes and chromaticities were trimmed accordingly. A transmission efficiency of about 85 % for the first 2.4 s of the injection plateau (beam dump at 2.4 s) was obtained. The revolution frequency was determined according to the method above described.

From the two frequency measurements one can precisely determine the difference in kinetic energy between the two cases.

Results

Measurements with Pb^{82+} :
average radial position x_{82}: 3.749 ± 0.68 mm (average of 11 measurements)
injection frequency f_{82}: 197.0750 ± 0.0005 MHz

Measurements with Pb^{53+} :
average radial position x_{53}: 3.523 ± 0.208 mm (average of 10 measurements)
injection frequency f_{53}: 197.0953 ± 0.0005 MHz

From these measurements the kinetic energies of the stripped and unstripped beams have been determined:

$$T_{82} = u\left(\frac{1}{\sqrt{1-\left(\frac{2\pi f_{82} R}{ch}\right)^2}} - 1\right) = 4.20778 \pm 0.00040\ GeV/u$$

$$T_{53} = u\left(\frac{1}{\sqrt{1-\left(\frac{2\pi f_{53} R}{ch}\right)^2}} - 1\right) = 4.22337 \pm 0.00039\ GeV/u$$

$$R = R_o + x$$

where u = 0.931494323 GeV is the unified atomic mass unit, R_o = 1100.0093 ± 0.00015 m [3] is the measured average SPS radius, c = 299792458 m/s is the speed of light in vacuum.

The error in the kinetic energy measurement was estimated according to the expression below:

$$\sigma_T = \frac{T(T+u)(T+2u)}{u^2}\sqrt{\left(\frac{\sigma_f}{f}\right)^2 + \left(\frac{\sigma_R}{R}\right)^2}$$

where

$$\sigma_R = \sqrt{\sigma_x^{\ 2} + \sigma_{R_0}^{\ 2}}\ .$$

The relative kinetic energy loss ΔT/T is therefore

$$\frac{\Delta T}{T} = \frac{T_{53} - T_{82}}{T_{53}} = (3.69 \pm 0.13) \times 10^{-3}\ .$$

Conclusion

The measured relative kinetic energy loss of 4.22 GeV/u Pb^{53+} ions is (3.69 ± 0.13) x 10^{-3}, whilst the value calculated with the Bethe - Bloch equation (2.8 x 10^{-3}) is about 25% smaller. The theoretical value was obtained by assuming that the Bethe - Bloch equation is correct for lead ions at 4.22 GeV/u (which is not exactly the case [4]) and that the stripping process occurs in a surface layer whose thickness is negligible compared to the total thickness of the stripper.

References

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[3] T. Linnecar, private communication.
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