SIMULATION OF SIMULTANEOUS BEAM SHARING BETWEEN INTERNAL TARGETS AND SLOW EJECTION AT THE CPS

M. Bell and W. Kubischta
CERN, Geneva, Switzerland

Summary

The slow ejection of the CPS, going either to the West or East Hall, shares the beam regularly with one of the two internal targets feeding the South Hall. A simulation program has been written, in order to understand the process of sharing, especially the losses (about 5% to 7% for typically 30% to 50% on the internal target; the efficiency of the ejection itself is 95% to 97%) and the emittance blow-up (about a factor 2 for the vertical emittance) associated with it. In this program, a number of particles are followed through the resonant extraction process, while the target is treated using a Monte-Carlo method. Calculated values for efficiencies and emittance blow-up are given and compared with measured values.

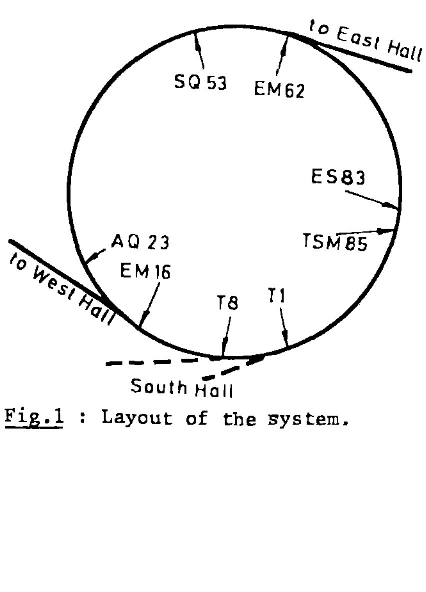
1. Introduction

The CPS provides protons for counter experiments in four areas : East Hall (slow ejection from s.s. 62), West Hall (slow ejection from s.s. 16), and two internal targets in the South Hall (one in s.s. 1, one in s.s. 8). In order to make efficient use of these facilities, the two slow ejection areas are served turn about (runs of 3 weeks), always sharing the beam with one of the internal targets.

First machine experiments[1] and calculations[2] had shown that with the former integer resonant extraction system the efficiency of the sharing process would have been unacceptably low, but with a third integer resonance test scheme, rather favorable results could be obtained[3]. In parallel with the installation of the final system, which has been running now for almost two years, the sharing process was studied by computer.

2. The Sharing System

The ejection system is schematically shown in Fig. 1. The required sextupolar component is provided by one non-linear lens (semi-quadrupole, SQ 53). A quadrupole (AQ 23) together with the quadrupolar component of the semi-quadrupole shifts the Q-value at the centre of the vacuum chamber from about 6.235 to the resonance 6 1/3. The accelerated beam is put in the inside half of the aperture, then debunched, and drifts into the resonance due to a slope on the flattop of the main magnetic field.



SQ : semi-quadrupole
AQ : auxiliary quadrupole
ES : electrostatic septum
TSM : thin septum magnet
EM : extractor magnet
T : internal target (orbit bumps are omitted for the sake of simplicity)

Fig.1 : Layout of the system.

The phase of the separatrices is chosen so as to have the maximum jump at the first septum, which is electrostatic (foil ∿ 0.15 mm effective thickness). 1/8 betatron wavelength downstream there follows a thin septum magnet (1.5 mm septum). Depending on the required operation, the beam then enters either the extractor magnet in s.s. 16 (to West Hall), or s.s. 62 (to East Hall). Except for the extractor magnet and the corresponding orbit deforming dipoles, the system is identical for both channels. Further details on some of the extraction channel elements are given in Ref. 4.

The internal target is put at a position as required by the secondary beams, and by means of a servo-loop acting on two orbit deforming dipoles, the sharing ratio is adjusted.

The servo-system for the ejection acts on a separate quadrupole and works independently of the target servo.

3. Description of the Program

The program is an extensively modified version of the program of ref. 5, treating the target similarly to ref. 6.

At the beginning, radial and vertical co-ordinates are chosen corresponding to an approximately Gaussian beam profile. All particles are given the same momentum, as we assume that the sharing process is independent of momentum within the momentum spread of the debunched beam.

After each machine turn, the radial position and accordingly the Q-values are changed to simulate the drift of the beam, and checks are made to see if the target is hit, if the particle enters the field of the first septum or if it is lost on the walls of the vacuum chambers.

While the magnetic septa are taken into account with their actual septum thickness, the thickness of the electrostatic one is neglected. This is justified by the experience that the losses on this septum are proportional to the ejected beam intensity.

3.1 Internal target

As in ref. 6, each particle is assumed to represent a large number of protons, given by its "intensity" μ_i, which is set to 1 at the beginning. If a superparticle hits the target or its support, a certain fraction $\Delta\mu$ is lost by nuclear interactions

$$\Delta\mu = \mu_i \left(1 - e^{-\frac{D\rho}{\lambda}}\right) \qquad (1)$$

D is the length of the target (or support), λ the total nuclear mean free path, and ρ the density of the target material. The surviving part loses energy by ionisation

$$\Delta E = - L.D.\rho \qquad (2)$$

where L is a material constant characterizing the ionisation energy loss.

Moreover, the angle of the super-particle is changed by multiple Coulomb scattering. The distribution of the projected scattering angles is assumed to be Gaussian with r.m.s. θ_s (Rossi formula)

$$\theta_s^{\,2} = \left(\frac{E_s}{\beta cp}\right)^2 \frac{D\rho}{X_o} \qquad (3)$$

with E_s = 15 MeV, βcp measured in MeV, and X_o the radiation length depending on target material.

3.2 Definition of efficiencies

In the program, a superparticle can have the following "fates" :

- after many target traversals, its betatron amplitudes may have grown such that it hits the vacuum chamber either vertically or horizontally; or
- after having passed through the deflecting field of the electrostatic septum, it may hit one of the septum magnets either radially or vertically; or
- after having passed through the deflecting field of the electrostatic septum, it may be extracted.

The sum of the intensities of the latter superparticles divided by the original total intensity, gives the extracted fraction η_e. The sum of all $\Delta\mu$'s (eq. 1) divided by the original total intensity, gives the fraction η_t lost by nuclear interactions.

In a separate run, with all ejection lenses switched off, the fraction η_{to} has been computed as reference value. We define then the relative fraction of the beam on the target by

$$f_t = \frac{\eta_t}{\eta_{to}} \qquad (4)$$

and the computed sharing efficiency by

$$\eta_c = \eta_e + f_t \qquad (5)$$

This corresponds to the efficiency η_m as defined in [3] for measurement purposes

$$\eta_m = \frac{\eta_{es}}{\eta_e} + \frac{\alpha_{st}}{\alpha_t} \qquad (6)$$

with η_e the measured ejection efficiency without target, η_{es} the measured ejection efficiency with sharing, α_t and α_{st} being the integrated and normalised signals from a counter near the internal target, the former measured when all ejection lenses are switched off (reference), the latter measured during sharing. All efficiencies and fractions are to be understood with respect to the beam after all preceding operations like fast ejections or short target bursts.

3.3 Emittances

As emittance, two times the mean squared betatron amplitude is taken.

$$\varepsilon = 2 < a^2 > = 2 \frac{\Sigma \mu_i \, a_i^{\,2}}{\Sigma \mu_i} \qquad (7)$$

with, for the vertical co-ordinates,

$$a_i^{\,2} = \beta \, y_i'^{\,2} + 2\alpha y_i \, y_i' + \gamma \, y_i^{\,2} \qquad (8)$$

For a Gaussian distribution, this emittance contains 86.5 % of all particles; 95% of a measured profile (projected distribution) are between $\pm\sqrt{\beta\varepsilon}$.

The radial emittance in the case of a slow ejection is, of course, not at all elliptic, and the distribution is not Gaussian. Nevertheless, a formula similar to (8), with empirical constants, was used to calculate a "betatron amplitude" and the emittance calculated using formula (7).

4. Results

We have concentrated mainly on three systems (for the main parameters see Table 1). While systems I and II correspond essentially to the present situation, system III assumes larger emittances for the internal beam as expected for a future operation at higher intensity[7]. All computations were done for 24 GeV/c. The target dimensions used for calculations are slightly different from the dimension of the targets now used in operation (usually 2 x 1 x 10 mm, 100 to 200 mrad angle), but by a few computer runs we could verify that the influence of target dimension is small. The same argument is valid for a change in target material from Be to B_4C. The material constants used are given in Table 2.

System	Ejection Channel (s.s.)	Emittances of int. beam hor.	vert.	Target s.s.*	Mat.	width	height	length
		(10^{-6} π m.rad)				(mm)		
I	16	1.	1.	1	Be	1.	1.	20.
II	16	1.	1.	8	Be	1.	1.	20.
III	62	3.	1.7	8	Be	1.	1.	20.

Table 1 : Main parameters of systems

* Straight section 1 is radially focussing, straight section 8 radially defocussing.

Material : Be		
Ionisation loss L	2.	MeV/(g/cm^2)
Radiation length X_o	62.5	g/cm^2
Nuclear mean free path λ	56.5	g/cm^2
Density ρ	1.84	g/cm^3

Table 2 : Target Material Components

In order to keep the use of computer time at an acceptable level, the calculations were done with relatively small numbers of superparticles (usually 300).

4.1 The process in general

Already for rather modest fractions on the internal target, practically all ejected protons have passed through the target or support at least once (90% for $f_t \sim 0.1$). Some of them have lost so much energy that they become unstable at a radial position outside the normal range (see Fig. 2 for a typical example). They reduce the width of the hole created by the first septum, and a certain part is lost radially on the magnetic septa.

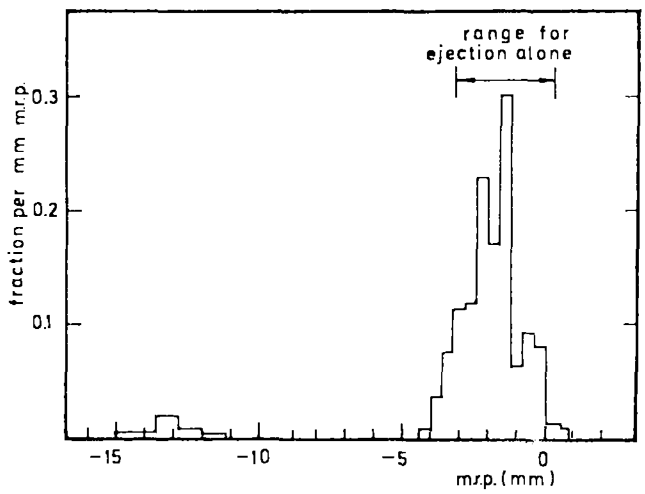


Fig. 2 : Mean radial position of superparticles entering the electrostatic septum. (Typical case).

Some protons are "locked in" to the target, they lose energy so fast that they do not become unstable in spite of the drift and their emittance growth. A small fraction of these protons, however, is scattered across the first septum (mrp $\sim$ -13 mm in Fig. 2), creating a diffuse vertical halo around the ejected beam, and is usually lost vertically on one of the magnetic septa (as it has no yoke, the electrostatic septum is no obstacle in the vertical direction).

4.2 Efficiencies and emittances

All results are presented on Figs 3 to 6 as a function of f_t, the relative fraction on the internal target, as defined in section 3.2.

For the sharing efficiency (Fig. 3) we give two curves for each system. The lower curve assumes a rather poor alignment of the septa, while the upper curve assumes no radial losses on the septa at all. By careful alignment of all septa, efficiencies between the two curves can be expected. A slightly smaller efficiency seems to result when a target in a D-section is used, but this difference has not been found experimentally. The measured points correspond to system I, but with different target dimensions (see above 4.).

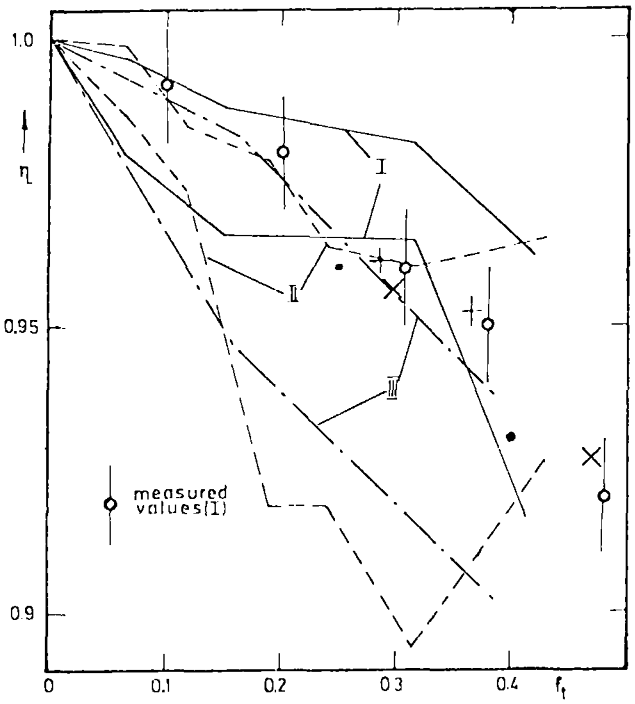


Fig. 3 : Calculated and measured sharing efficiencies (Roman numbers are system numbers from Table 1). Single points, which are not measured points, correspond to the pessimistic curve of system I, but with different targets :
- • Be, 1x1x10mm
- + Be, 4x1x10mm
- × B_4C, 1x1x20mm

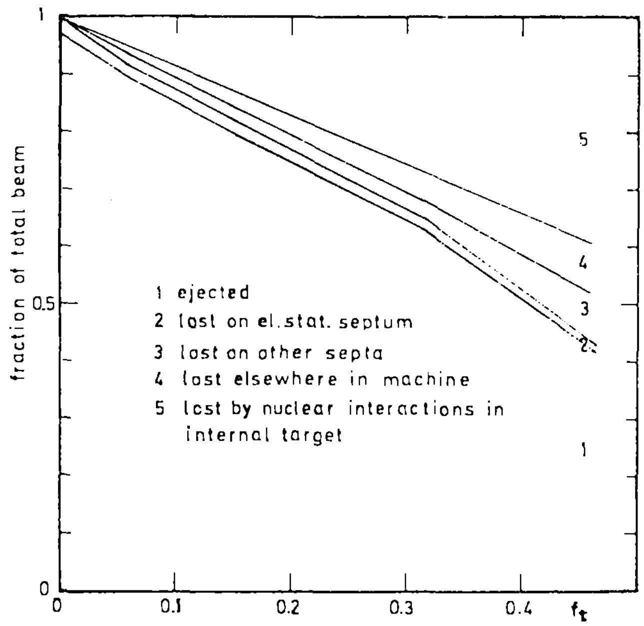


Fig. 4 : Repartition of protons as function of f_t. Unlike the rest of the report, the losses on the electrostatic septum are shown explicitly.

Fig. 4 presents the results for system I in a different way (only the conditions corresponding to the pessimistic curve in Fig. 3 are shown). From the point of view of radiation damage to the whole machine[8], the additional losses due to the sharing process (region 3 and a small part of 4) are small compared to the damage due to the use of any internal target at all (region 5 and most of 4). Even if the losses on the magnetic septa can partially be avoided by careful alignment, the irradiation of these delicate magnets represents however one of the most important limitations of the sharing scheme.

Figs 5 and 6 show the blow-up of the emittances by the sharing process. Again, it seems that a target in a D-section is slightly worse than a target in an F-section. Measured points for system II[9] are probably too optimistic, as they have been measured rather far downstream in the ejected beam line, and there are indications that a small part of the beam might have been shaved off on the way (in our calculation, all particles passing through the extractor magnet have been included).

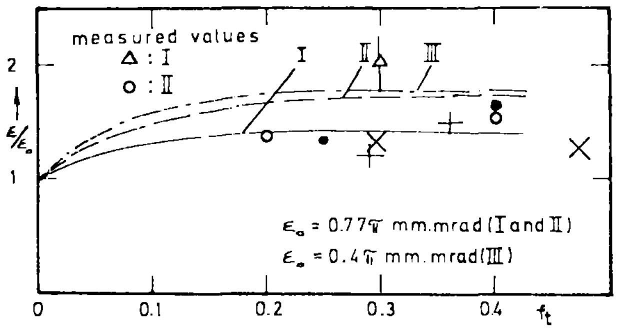


Fig. 5 : Blow-up of radial emittance. Single points other than measured points have the same meanings as in Fig. 3.

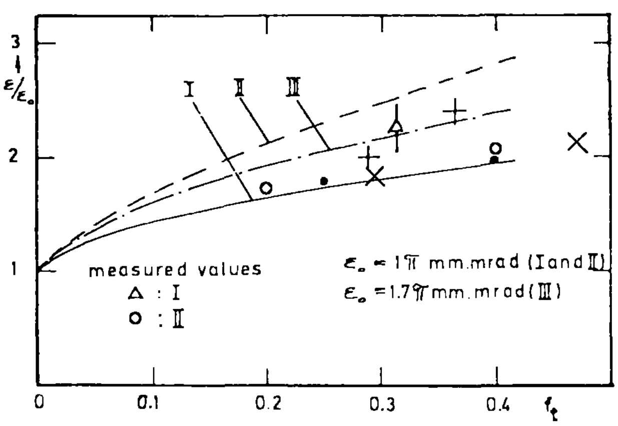


Fig. 6 : Blow-up of vertical emittance. Single points other than measured points have the same meaning as in Fig. 3.

5. Conclusions

On paper, beam sharing between slow ejection and internal targets at the CPS looks rather efficient, and experience supports this result. Under the conditions prevailing at CERN, it allows an optimal use of experimental facilities.

Taking the machine as a whole, the difference in radiation damage between an operation with an internal target alone and a sharing operation is small. The additional losses however occur mainly on the magnetic septa, as these are the aperture limitations in the first part of the extraction channels (both radially and vertically). The growth of the radial emittance of the extracted beam is small, but the vertical emittance is blown up considerably (by about a factor 2 for $f_t \sim 0.3$), which leads to losses in the external beam transport and increases the spot size on the external target.

In order to keep these effects tolerable, usually one choses f_t not bigger than about 0.35 (fraction of the beam after all previous operations), which corresponds to about 20% to 30% of the total accelerated beam.

6. Acknowledgements

We would like to thank Mrs. D. Dumollard and D.J. Simon for their emittance measurements, and G. Cuisinier, Ch. Serre and Ch. Steinbach for their help during machine development sessions.

References

1. Kissler K.H., CERN/MPS/SR/MD 70-4.

2. Baconnier Y., "Sharing the CPS Beam between an Internal Target and a Slow Extraction", CERN/MPS/DL Note 70-18.

3. Kubischta W., "A Multiple Target-Extraction Sharing Scheme at the CPS", Proc. of the 8th Int. Conf. on High Energy Accel., CERN, 1971.

4. The CPS Staff, "The CPS Improvements 1965-1973, An Assessment", Proc. of this Conference.

5. Barbalat O., "Fortran Programs for the CPS Resonant Extraction Calculations", CERN/MPS/Int.DL/69-1.

6. Hereward H.G., Ranft J., Richter W., "Efficiency of Multi-Traversal Targets", CERN 65-1.

7. Barbalat O., "Beam Emittance Estimates", CERN/MPS/DL Note 72-42.

8. Gouiran R., "High Intensity Running Implication on Magnet Irradiation and Radioactivity", CERN/MPS/SR/Note 73-43.

9. Dumollard D., Simon D., "Caracteristiques du Faisceau SE 62 et des Branches e_9 en 1973", CERN/MPS/MU-EP/Note 74-6.