A TRIPLET INSERTION CONCEPT FOR THE PS2 H$^-$ INJECTION

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Abstract

The PS2, foreseen as a replacement of the CERN PS, is designed as a racetrack shaped machine with two long straight sections (LSS) for injection/extraction and RF, respectively.

Two injection and three extraction systems are required, and in the present study are designed to fit in either a six-cell FODO or a seven-cell DOFO insertion, with a central triplet in order to fit the complete H$^-$ injection in one long drift. This study covers the optimisation of the LSS optics and the arrangement and characteristics of the various insertion elements. The main focus lies on the H$^-$ injection embedded in the triplet cell with the design of the chicane and painting bump according to the limits of Lorentz-stripping, excited H^0 behaviour and the focusing effects of the chicane dipoles on the overall optics.

INSERTION CONCEPT

The long injection straight, Fig. 1, contains all injection and extraction systems [1]. The 4 GeV H$^-$ system is the most challenging and dictates the insertion design. An extraction system with different kickers and septa used for slow (3rd integer), fast and low-loss island (multiturn) extraction is located at the start of the LSS. The single turn fast injection system follows the H$^-$ injection. An internal beam dump system can also be accommodated.

The injection and extraction systems fit into a 6-cell “FODO” lattice, with the central two cells replaced by the triplet [2]. The horizontal phase advance per cell is fixed to 90°, which allows to easily make a π-bump with the multiturn extraction kickers. The extra kick to extract the central island of the low-loss extraction will be provided either by doubling the strength of the first kicker or by a separate kicker located in the dispersion suppressor.

In this concept the beams are extracted before the injection section. Although the injection and extraction lines cross, the transfer line from PS2 to SPS becomes longer and the optics design more flexible. Moreover, a collimation system can be installed after the injection.

INSERTION OPTICS

To accommodate the H$^-$ injection, the LSS contains a triplet with FODO cells on each side. The central drift provides 22 m for the H$^-$ injection and the adjacent drifts 10 m for kickers. The optics, Fig. 2, is presently matched to a negative momentum compaction (NMC) arc, but the LSS can also be easily matched to a FODO arc.

Matching between the FODO cells and the triplet was achieved by varying four quadrupole families and the drift lengths. The triplet structure allowed to reduce the total length of the LSS by ~20 m which were used to increase the drift spaces in the arc for instrumentation and to relax the maximum fields in the main magnets. The space requirements for the RF elements in the opposite LSS are still fulfilled in a total length of 150 m.

The beam has a waist in the centre of the triplet with β_{xy} of 15 m. This is lower than the estimated optimum of ~22.5 m, defined by minimising the foil width by a deliberate mismatch of the optics parameters between the injected beam (α_i, β_i) and the ring (α_r, β_r). For optimum injection the following conditions are required [3]:

$$\frac{\beta_i}{\beta_r} \approx \frac{\alpha_i}{\alpha_r} \approx \left(\frac{\varepsilon_i}{\varepsilon_r}\right)^{1/3}$$

and

$$\frac{\alpha_r}{\beta_r} = \frac{\alpha_i}{\beta_i} = -\frac{x'_r}{x_r}$$

For the PS2 injection we have $\varepsilon_i \approx 1$ π.µrad, and $\varepsilon_r \approx$ 10-15 π.µrad, in both horizontal and vertical planes. Assuming in the triplet insertion that the slope of the beta function in the injection region is small, we have $\alpha \approx 0$, and $x' \approx 0$. A β_{xy} of at least 10 m is needed for the injected beam as a minimum possible from the first estimates of foil heating. This gives for the machine parameters $\alpha_{xy} \approx 0$, $\beta_{xy} \approx 22.5$ m. The preferred location of the foil is at the injection straight centre where $\alpha_{xy} = 0$.

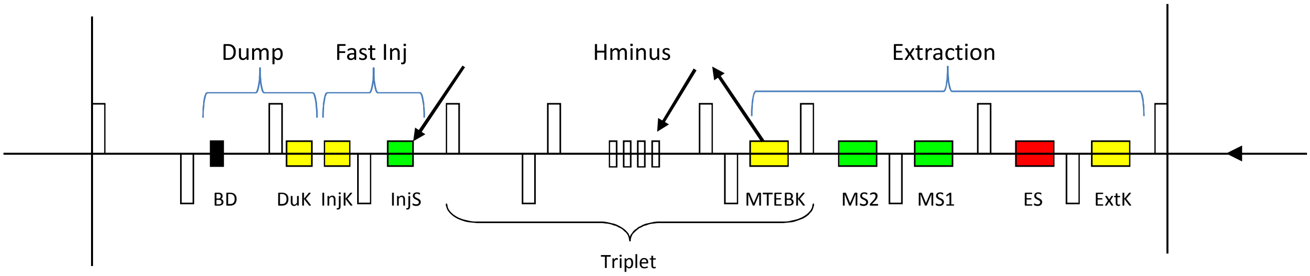

Figure 1: Injection/extraction insertion. Kickers are in yellow, magnetic septa in green and electrostatic septa red.

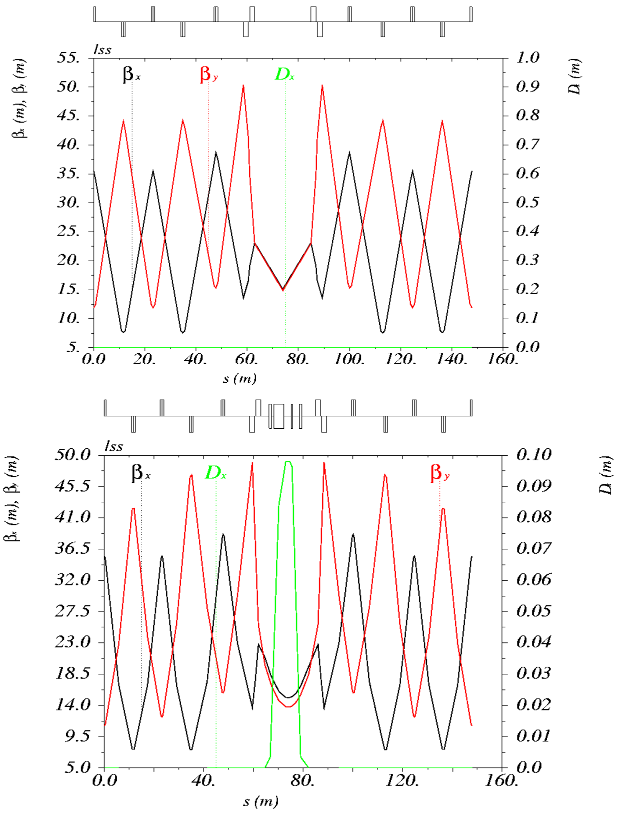

Figure 2: Insertion optics functions without (top) and with (bottom) injection chicane powered.

The injection chicane perturbs the vertical optics, since rectangular bend magnets are presently assumed. It is envisaged to ramp these chicane magnets to zero field shortly after injection, which will remove the perturbation – however this needs detailed study since the optics matching will need to change on the same timescale. An alternative is to build the magnets as sector bends, but this has the disadvantage that when ramping down the orbit changes in the magnet, again introducing edge focussing which requires compensation elsewhere in the lattice.

H$^-$ INJECTION

The long straight between the triplets will house the H$^-$ injection system, Fig. 3. A long 'soft' D2 dipole merges the H$^-$ and circulating p$^+$ beams, with a stripping foil located in the fringe field at the exit. The D3 chicane dipole is strong with B around 1.5 T. The position and strength of these chicane dipoles are adjusted to close the dispersion bump. A second foil between D3 and D4 converts unstripped H^0 to p+ to be extracted. Phase space painting kickers can be located inside the straight section.

At the stripping foil, the stripping efficiency can be about 95% with a 400 μg/cm^2 foil, Fig. 4. A few percent of H^0 emerges in excited quantum states which will decay to p$^+$ in a magnetic field. The H$^-$ yield will be below 10^{-4}, and this H$^-$ is stripped to H^0 in the first few mm of D3.

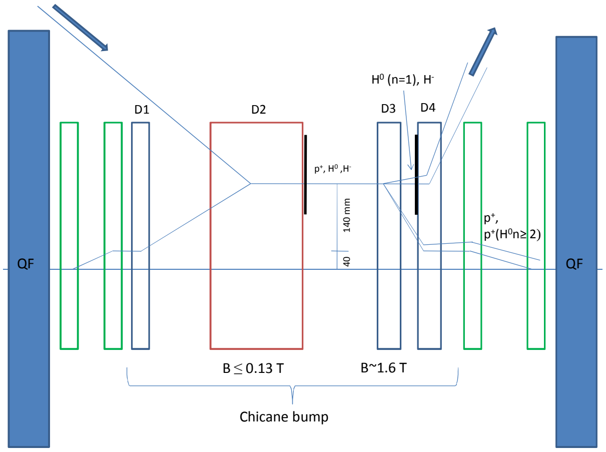

Figure 3: H$^-$ Injection. The first chicane dipole (red) has low field $B \le 0.13$ T to avoid Lorentz stripping the incoming H$^-$. Kickers (green) make the painting bump.

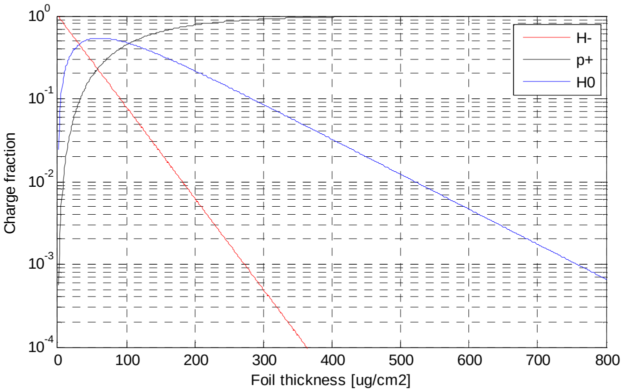

Figure 4: 4 GeV H$^-$, H^0 and p$^+$ yield vs. C foil thickness.

With the foil located in the D2 fringe field, a field of about 0.07 T will ensure that all states with $n=5$ and above are immediately field-stripped at the foil, Fig. 5, increasing the effective stripping efficiency.

With the D3 chicane magnet field of 1.5 T, the $n=1$ state passes through D3 unchanged and is stripped by a foil at the entrance to D4, and extracted as a waste beam.

The state $n=2$ penetrates deep into the fringe field before stripping, Fig. 6, which results in an angular spread of 0.8 to 3 mrad, Fig. 7. This would cause halo which might need dedicated collimation. The $n=3,4$ states have angular errors of up to 0.3 and 0.08 mrad; the $n=4$ state would therefore remain within the machine acceptance.

A reduction in the length of the D3 fringe field by a factor of 5 with respect to that shown in Fig. 6 improves these angular spreads significantly to about 0.3, 0.04 and 0.02 mrad respectively, Fig. 8. In this case the $n=2$ state is the only one which would need more careful evaluation, since the others would remain within the machine acceptance. The effect on halo and emittance is to be evaluated in detail, as does the similar effect for decay of H^0 in D3 and of $n \geq 5$ at the foil.

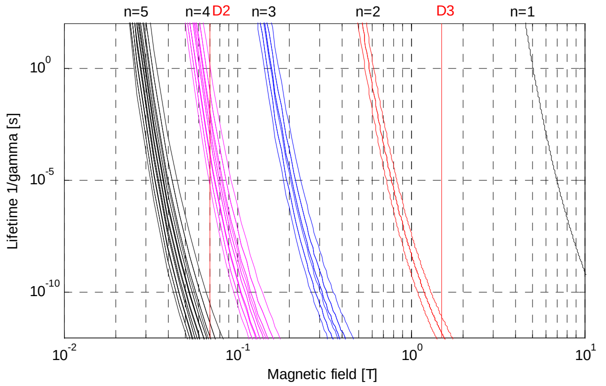

Figure 5: Lifetime of excited H^0 states in magnetic field.

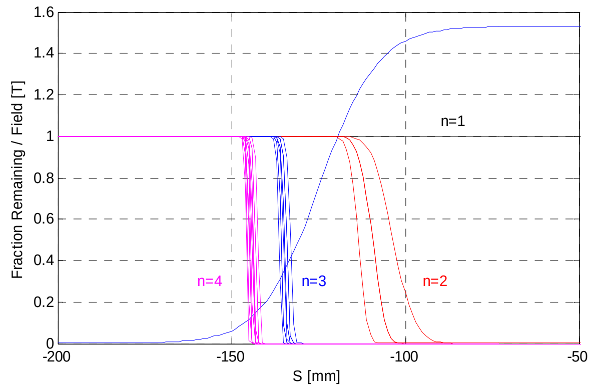

Figure 6. Excited state decay lengths in D3 fringe field.

If such a D3 magnet design with improved fringe field is not feasible an alternative is to reduce the D3 field to about 0.7 T, such that the $n=2$ states traverse without stripping, and so the waste beam consists of the H^0 states $n=1,2$ at D4. However, this would simply shift the problem to the $n=3$ state, which would have a large angular spread – an evaluation of the expected relative yields of the different states is still required to be able to decide on the optimum arrangement.

The H^0 stripped at the second foil is deflected outwards by D4 and needs to be transported to an external beam dump. This beam is also composed of the unstripped H^- fraction, which is normally expected to be very small, but also contains any H^- which has missed the foil for any reason. This is less easy to evaluate in percentage terms, since it depends on the details of the operational setup and also on any local damage or changes to the foil size, which could evolve during operation. It is therefore assumed that this fraction could reach a few percent, comparable with the unstripped H^0 and requiring similar consideration. Since the H^- is stripped to H^0 in the first part of D3, an increase in the angular beam spread will also be present – although in this case larger values are probably acceptable since the beam must only be transported through a short line to a beam dump.

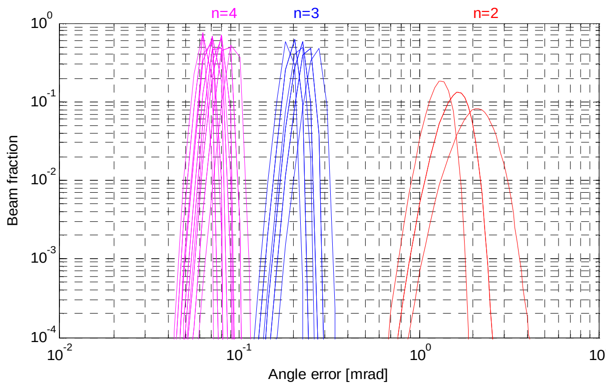

Figure 7. Angular spread due to the fringe field.

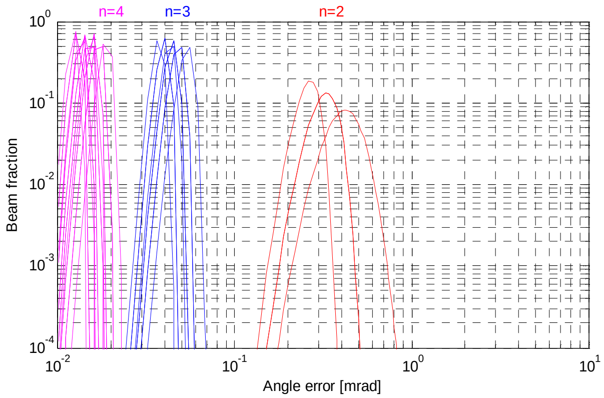

Figure 8: Angular spread with fringe field length reduced by a factor 5.

CONCLUSION

A promising injection-extraction straight concept is being developed for PS2. The optics of the LSS is well matched to the arc. Fast injection and extraction elements are located in the outer FODO cells while a central triplet provides the necessary drift space to house the complete H^- injection chicane system and painting dipoles. The unstripped or partially stripped H^- beamloss control is dominated by foil physics and the angular spread of different excited H^0 stark states due to stripping in dipole fringe fields. States with $n \geq 2$ should remain in the circulating beam, and for a given accepted emittance blow-up this defines the magnet fringe field specification. For similar reasons the transport of the waste beam to an external dump also needs careful consideration.

REFERENCES

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[2] D. Johnson, “Main Injector H^-Injection”, Fermilab Accelerator Advisory Committee, May 10th – 12th, 2006.

[3] G.Rees, Handbook of Accelerator Physics and Engineering, 2nd edition, A.Chao et al. (eds.) p502, 2002.