The New SPS Injection Channel

J. Uythoven
SL Division, CERN, Geneva, Switzerland

Abstract

The bunch spacing of the LHC ion beam requires a reduction of the SPS kicker magnets' rise time from 145 ns to less than 115 ns. To obtain the shorter kicker rise time the existing kicker magnets have to be reduced in length and the characteristic impedance has to be increased. The resulting loss in magnetic field has to be compensated by the installation of additional magnets.

The layout of the new kicker system, the required kicker strengths and the resulting physical apertures for the different beams are shown. Relating issues, as the possibility to inject into a low gamma-t optics and the MDPH magnet strength, are briefly discussed.

1 SYSTEM REQUIREMENTS

In the LHC era four different types of beams will have to be injected into the SPS. For their injection the MKP kicker magnets in the LSS1 area will be used and a modification of the present system is necessary to fulfil the future needs [1]. Table 1 shows the kicker system requirements for the different types of beam. The most stringent kicker rise time requirement comes from the LHC type ion beam injection. As the PS bunch structure has to be conserved in the SPS, the kicker rise time has to be reduced from the present 145 ns (S-type magnet, 2 - 98 % rise time) to less than 115 ns (0 - 100 % rise time). The total deflection strength required is determined by the relatively high injection energy of the LHC type proton beam. On top of this, the ripple of the magnetic field has to be reduced for both the LHC proton beam and the LHC ion beam. The present ripple is not critical and is around ± 1 %. For the LHC beams the ripple will have to be less than ± 0.5 %.

2 SYSTEM LAYOUT

To obtain the shorter rise time of the kicker pulse the magnets have to be increased in impedance, from 12.5 Ω to 16.67 Ω, and the number of cells will be decreased, from 22 to 17 cells. Both changes decrease the kicker strength and additional magnets have to be added to be able to work with HV values below 50 kV.

The present system layout is shown in figure 1. The new system layout is shown in figure 2. The old layout shows the three kicker tanks with four magnets each. The special arrangement of connecting the Pulse Forming Networks (PFNs) to the kicker magnets in the first two tanks is necessary for lepton injection and will not be required any more in the LHC era.

The new system shown in figure 2 has an additional kicker tank with two magnets placed between the present second and third tank. The magnets in this tank and in the first two tanks have the increased impedance of 16.67 Ω and a reduced length of 17 cells. Because of the reduced magnet length 5 magnets instead of 4 can be placed in each of the first two existing tanks.

In the new layout the magnets in the first three tanks will be used for ion injection and have the required fast rise time. The four magnets in the last kicker tank have an unchanged impedance and length, but changes have to be made to the magnet and the PFN to meet the specification on the ripple and LHC-type beam rise time (< 220 ns). For the fixed target proton beam it is possible to use all kicker magnets or only the first three tanks, the same as for ion operation. The last option has the advantage that the last tank is only used for the LHC proton beam and can be operated with a fixed pulse length of 2.1 μs.

Table 1: The different types of beam to be injected with their kicker magnet requirements

Beam	**Injection Energy**	**Kicker Rise time**	**Kicker Flat top**	**Kicker Fall time**	**Kicker Ripple**
LHC protons	26 GeV/c	< 220 ns	2.1 μs	machine 3/11 full	< ± 0.5 %
Fixed target protons	14 GeV/c	< 1000 ns	10.5 μs	1.0 μs	< ± 1.0 %
LHC ions	12.9 GeV/c	< 115 ns	0.5 μs	machine 3/11 full	< ± 0.5 %
Fixed target ions	12.9 GeV/c	< 1000 ns	2.0 μs	3.8 μs	< ± 1.0 %

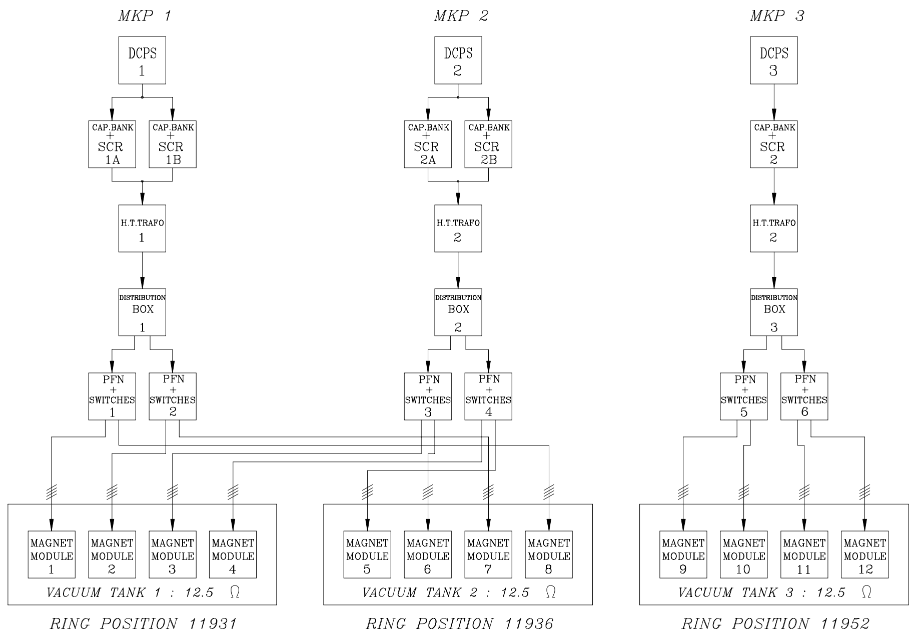

Figure 1: Present kicker system layout.

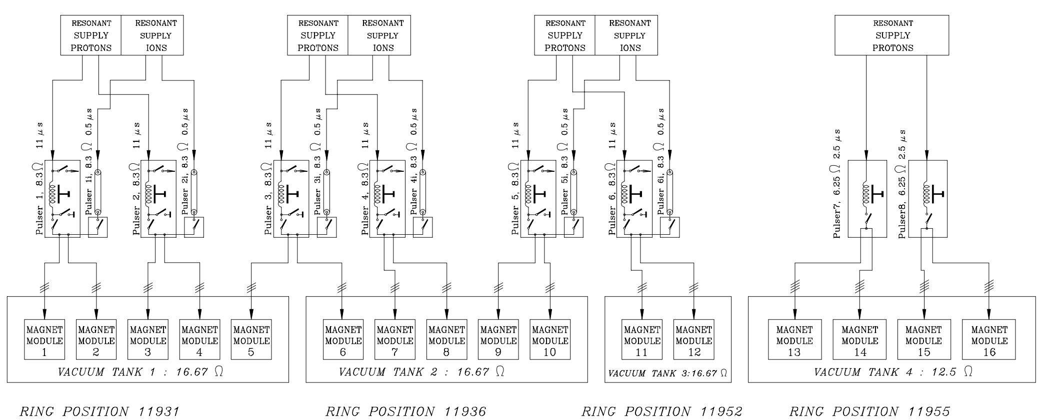

Figure 2: New kicker system layout.

Figure 2 also shows a Pulse Forming Line (PFL) in parallel with the PFN (indicated with pulser 0.5 μs). As it is not certain that the specifications on rise time and ripple can be met by using a PFN, it might be necessary to use PFLs for the LHC ion beam injection. Because the required pulse length for this beam is only 500 ns, a PFL cable length of about 60 m will be sufficient.

2 PHYSICAL APERTURES AND REQUIRED KICKER STRENGTH

2.1 Horizontal Plane

A computer model of the injection system has been made. The model is used to calculate the required kicker strengths and examine the physical apertures available in the kicker region for the old and for the new system layout.

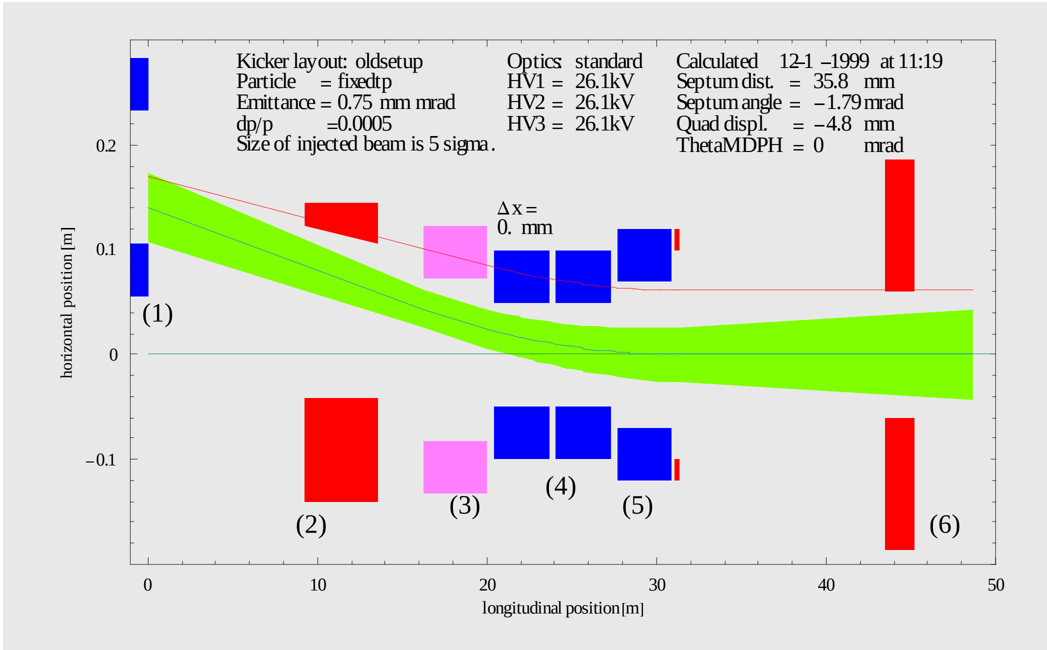

Figure 3: Model of the present system in the horizontal plane, showing kicker strengths and physical apertures. The numbers in the drawing correspond to the following elements: 1) Injection septum magnet; 2). High-energy beam dump (TIDV); 3) Quadrupole QDA119; 4) Kicker tanks MKP1 to MKP3; 5) Dump magnet for the injected beam (MDPH); 6) Beam dump for the injected beam (TBSJB).

Figure 3 shows the present layout in the horizontal plane. The position of the beam at the septum exit is taken from measurements. The necessary kicker HV values and injection angle of the beam have been calculated to obtain a beam at and parallel to the machine axis. The calculated HV values (26.1 kV) agree with the actually used values. The model includes the displacement of the quadrupole QDA119 in both the horizontal and vertical plane. This displacement, as it actually present in the machine, was optimised to obtain a maximum physical aperture of the dumped high-energy beam (see section 5.2).

The beam plotted in figure 3 is the present fixed target proton beam. In all graphs the 5 σ beam size is plotted. The particle emittance and energy spread used in the calculation of the beam size are indicated in the graph. A list of the different beam parameters used for the different type of beams is given in table 2. The optical functions used to calculate the beam size (beta and dispersion function) are taken from the standard transfer line optics as it is described in [2].

Table 2: Beam parameters for the different types of beam.

Beam	**ε_x, inj [mm mrad]**	**ε_y, inj [mm mrad]**	**$\Delta p/p$, inj**
LHC protons	0.11	0.11	0.0011
Fixed target protons	0.75	0.50	0.0005
LHC ions	0.20	0.20	0.0004
Fixed target ions	0.80	0.30	0.00015

The horizontal physical aperture of the present system is most critical at the entrance of the first kicker tank, see figure 3. At this position the physical aperture is 5 σ + 8.3 mm.

Table 3 gives an overview of the required kicker voltages and the resulting physical apertures in the horizontal plane. If all kicker magnets are activated (HV1 to HV4) the tightest physical aperture is at the entrance side of the first kicker tank. If the last kicker magnet is not activated (HV4 = 0), the injection angle is steeper because the centre of deflection is shifted to the left. This creates some additional physical aperture for the injected beam. However, if the injected beam is dumped, the most critical physical aperture now appears at the exit of the fourth kicker tank. In table 4 this is indicated with 'dump side' in the physical aperture column. The situation with the tightest clearance for the dumped beam is illustrated in figure 4 for the fixed target ion beam and is equal to 5 σ + 3.5 mm. This is the tightest physical aperture to be expected for future operation.

From table 3 it can be concluded that with the new layout all required kicker voltages are below 50 kV which is well within the capabilities of the present hardware. The physical aperture is ample for the future LHC beams. For the future fixed target beams the physical aperture is slightly reduced for the new system relative to the present situation, but is still well over 5 σ. It should also be noted that the high-energy beam dump TIDV functions as a good protection of the kicker magnets for badly injected beams.

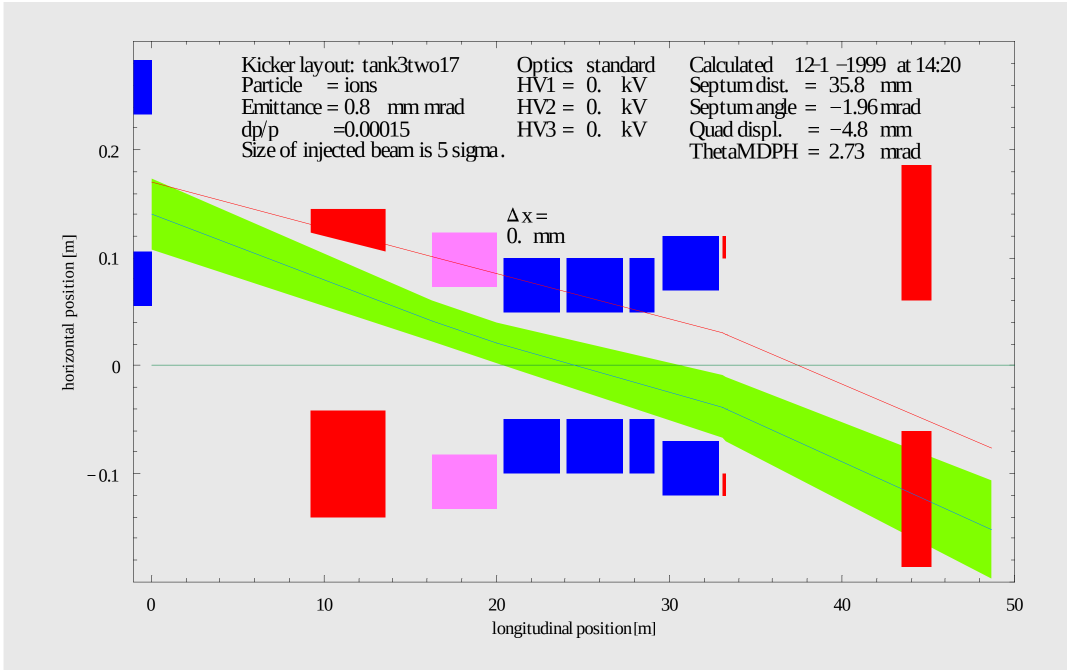

Figure 4: Ion fixed target operation with the beam dumped on the injection dump. This situation has the tightest physical aperture to be expected in the new layout, with a clearance of 5 σ + 3.5 mm at the exit of the fourth kicker tank.

Table 3: Calculated kicker HV values and physical apertures in the horizontal plane for the different beams.

Beam	**Layout**	**HV values** (HV1, HV2, HV3, HV4)	**Smallest physical aperture**
Fixed target protons	Present layout	(26.1, 26.1, 26.1, -)	5.0 σ + 8.3 mm
Fixed target ions	Present layout	(24.2, 24.2, 24.2, -)	5.0 σ + 7.9 mm
LHC protons	New layout	(48.4, 48.4, 48.4, 48.4)	5.0 σ + 14.1 mm
Fixed target protons, Option I	New layout	(49.2, 49.2, 49.2, 0)	5.0 σ + 4.4 mm (dump)
Fixed target protons, Option II	New layout	(26.1, 26,1, 26.1, 26.1)	5.0 σ + 4.7 mm
LHC ions	New layout	(45.5, 45.5, 45.5, 0)	5.0 σ + 16.5 mm (dump)
Fixed target ions	New layout	(45.5, 45.5, 45.5, 0)	5.0 σ + 11.7 mm 5.0 σ + 3.5 mm (dump)

2.2 *Vertical Plane*

In the vertical plane the physical aperture is tight. This is illustrated in figure 5 for the fixed target proton beam. The aperture is less than 5 σ and is limited at the high-energy dump TIDV. This is the same situation as in the present layout and no difference for the future operation from the behaviour in the vertical plane is expected.

3 LOW GAMMA-T OPTICS

A special low gamma-t optics for the SPS is being considered [3]. Many of the low gamma-t optics proposals have a large absolute value of the dispersion at the injection point. For the present SPS optics the dispersion at the exit of the fourth kicker tank is 0.26 m and with a matched transfer line optics the dispersion has a maximum value, for the region under study, at the exit of the septum magnet and is equal to 3.37 m [2]. For a version of the low gamma-t optics [4] the dispersion at the injection point is –3.01 m. If the transfer line is matched to this dispersion [5], the resulting dispersion at the exit of the septum magnet is –9.73 m. The increase in beam size for the otherwise very small LHC type proton beam is large and is shown in figure 6. It can be concluded that care should be taken that any low gamma-t optics has a small dispersion function at the injection point, otherwise the beam will be too large at the end of the transfer line.

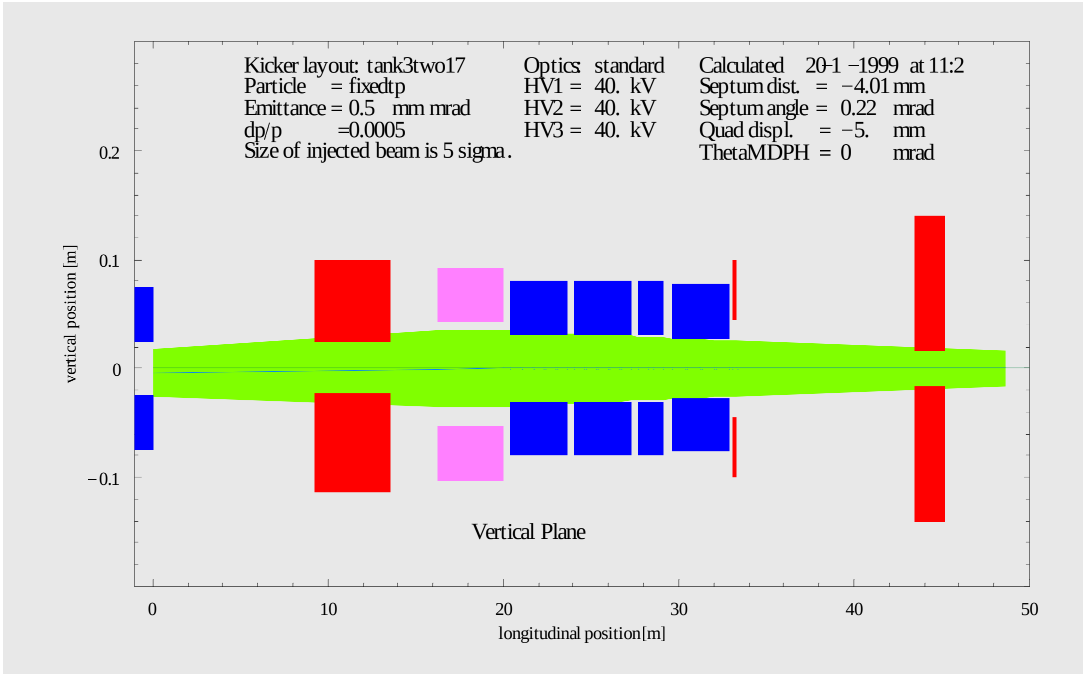

Figure 5: Physical apertures in the vertical plane. The physical aperture is clearly less than 5 σ, but it is limited by the high energy dump, where the layout does not change relative to the present situation.

4 MDPH MAGNET

The MDPH magnet is used during set-up to dump the injected beam on the injection dump TBSJB, see figure 4. It has been verified that for the present proton beam the measured dumped beam position agrees with the calculations. The nominal deflection angle of the MDPH magnet is 2.73 mrad for fixed target protons. The LHC type proton beam to be injected in the SPS has a higher beam energy and the MDPH magnet has a corresponding smaller maximum deflection angle of 1.6 mrad for this beam. Figure 6 shows that for this deflection the LHC type beam is just dumped at the edge of the TBSJB dump. It is advisable to increase the strength of the MDPH magnet (i.e. by doubling the magnet) as to properly dump the beam closer to the centre of the dump.

5 ADDITIONAL ITEMS CHECKED

5.1 Stored Beam Aperture

It has been verified that the stored beam is not limited in physical aperture by the MKP kicker system. As the MKP aperture is larger than the machine acceptance it could be envisaged to radially displace some of the kicker modules to create additional physical aperture for the injected beam if this is found to be necessary.

5.2 Transverse Quadrupole Displacements

The quadrupoles QDA117, QFA118 and QDA119 have been displaced horizontally and vertically by several millimeters (up to 16.5 mm for QFA118 in the vertical plane). These displacements create closed orbit bumps between QDA117 and QDA119. As the injected beam passes off-axis through QDA119, the additional inward displacement of QDA119 by 4.8 mm in the horizontal plane reduces further the required kicker strength. The kicker voltage for the LHC proton beam would be 49.9 kV with QDA119 on axis and 48.4 kV with the quadrupole as it is actually displaced.

It has been suggested to put the mentioned quadrupoles back on axis. Calculations have shown that the displacement of these quadrupoles is very functional in both planes as it increases the physical aperture in QFA118 in both the horizontal and vertical plane for a dumped high-energy beam. For this reason it is advised not to move these quadrupoles unless there is a stringent need to do so.

6 CONCLUSIONS

The LHC-type ion beam that will be injected in the SPS requires a fast injection kicker rise time of less than 115 ns. To be able to produce this fast rise time a new layout of the MKP kicker system for injection into the SPS has been determined. An additional short fourth kicker tank with only 2 short, high impedance magnets will be positioned between the present second and third tank. In the first two tanks the magnets will also be reduced in length and have an increased impedance. In total 4 more magnets will have to be installed and 2 additional PFNs are necessary. The magnets in the last tank will also have to be modified to obtain the specification on the ripple of ± 0.5 %.

As it is not certain that the required kicker magnet rise time can be obtained with PFNs, the option to use a Pulse Forming Line instead of a PFN is being studied.

In the new set-up all required kicker voltages for the different types of beam are calculated to be below 50 kV. The physical apertures are sufficient, with a 5 σ + 3.5 mm being the smallest aperture, calculated for the dumped fixed target ion beam.

Care has to be taken to have a sufficiently small dispersion value at the injection point for any future low gamma-t optics. A too large dispersion function leads to a too small physical aperture in the transfer line.

It is also advisable to increase the strength of the MDPH magnet, which is presently used to dump the injected beam.

ACKNOWLEDGEMENTS

The work presented in this paper is the result of the efforts of many members of the BT/FP section.

REFERENCES

[1] L.Ducimetière, G. Schröder, J. Uythoven, E.Vossenberg, “Upgrading of the SPS injection kicker system for the LHC requirements”, EPAC’98, Stockholm, June 1998, also CERN SL-98-050 BT.

[2] G.Arduini, M.Giovannozzi, K.Hanke, J.-Y.Hémery, M.Martini, "MMAD and BeamOptics description of the TT2/TT10 Transfer Lines Part I: Optics without Emittance Exchange Insertion", SL-Note-98-040 OP.

[3] K.Cornelis, "Additional quadrupoles in the SPS, what can they be used for?", these proceedings.

[4] M.Lamont, private communication.

[5] K.Hanke, private communication.

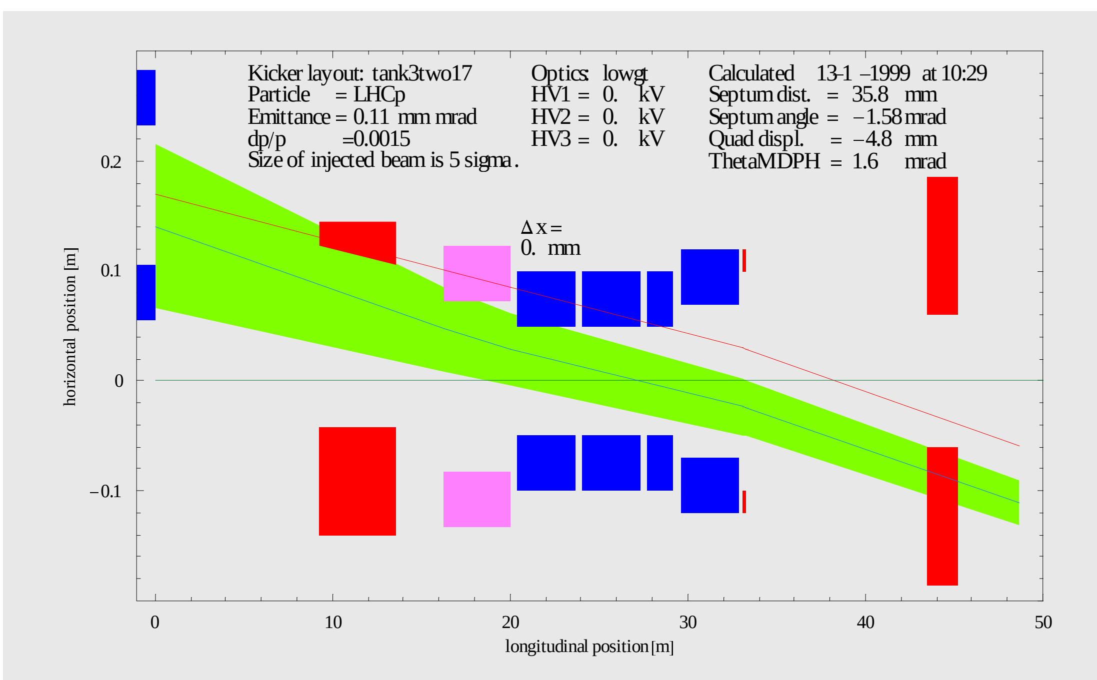

Figure 6: Physical aperture in the horizontal plane for a transfer line matched to a low gamma-t optics in the SPS. The 5 σ beam is plotted for an increased energy spread of Δp/p=0.0015, resulting in a clearance at the quadrupole of 3.3 σ. With the standard Δp/p=0.0011 the clearance would be 4.5 σ. The figure also shows the marginal strength of the MDPH magnet, which is used to dump the beam.