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Feasibility Study of a Rapid Cycling Synchrotron to replace the PS Booster

ABSTRACT:

This document summarises the outcome of a feasibility study and resource estimate to construct a 2 GeV Rapid Cycling Synchrotron (RCS) to replace the CERN PS Booster.

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1. Introduction [K. Hanke]

1.1 Introduction

Following the feasibility study and cost estimate for an upgrade of the existing PS Booster to a beam energy of 2 GeV [1], the question was raised whether a new machine to replace the Booster would be a viable option. The obvious advantage of such a scenario would be not only to replace a 40 year old machine by a new one, but also to commission the machine off-line before connecting it to the downstream PS and SPS synchrotrons and thus minimising risk and down time.

1.2 Design Choices

A very preliminary suggestion for an RCS lay-out with a suggestion of machine parameters was the outcome of internal discussions and first presented at the Chamonix 2011 workshop [2]. The proposed machine circumference was 1/7 of the PS circumference (89 m), with a three-fold symmetry. A site inside of the PS was suggested, with injection into the PS from the inside. It was suggested that the machine would run at h=3 and fill the PS at h=21 with 6 injections, avoiding the triple splitting in the PS.

Further investigations led us to modifying these initial assumptions. The details are laid out in the following sections. First of all, a circumference of 89 m appeared to leave insufficient space for diagnostics, injection and extraction elements, correction elements, vacuum equipment etc. Therefore a longer variant with 4/21 of the PS circumference was chosen. This would allow operation at h=1 and h=4, where in a first step h=1 is considered the base line while keeping the option of higher harmonics open. The machine would pulse at 10 Hz as originally proposed. The machine parameters are listed in more detail in the following sections.

As for the geometry of the machine a three-fold symmetry appears preferable, with the straight sections assigned to injection, extraction, and accelerating structures. As an alternative solution a race-track and a rectangular geometry were studied...

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Figure 1 — [Caption of the figure]

Table 1 — [Caption of the table]

2. Operational Aspects and Performance [K. Hanke, B. Mikulec, R. Steerenberg]

3. RCS Design and Parameters [H. Schönauer, M. Fitterer, C. Carli]

3.1 Technical Description

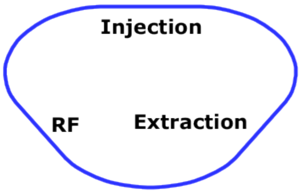
In the following we will describe the one option chosen as baseline design. Other designs have been studied, but will not be described in this report.

3.1.1 Lattice Layout

For civil engineering a triangular shaped ring is most advantageous and was chosen as baseline layout. As illustrated in Figure 2 injection, extraction and RF are each located in one straight section.

Figure 2 — [Lattice Layout]

[1] [Foot note]



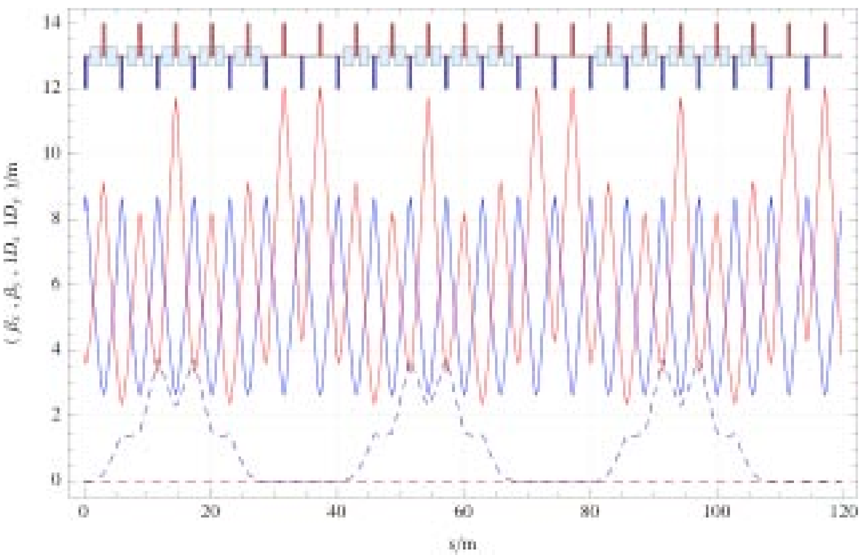
3.1.2 Optics

The lattice consists of 21 cells – 5 per arc and 2 per straight section - with a cell length of 5.6993 m. Most space-saving for injection/extraction is a FODO cell structure as here the kick of the QD in the centre of the cell can be exploited (chapter Error! Reference source not found.). In this lattice only two quadrupole families are used, one QF and one QD.

Injection, Extraction as well as RF require dispersion free straight sections. The dispersion is suppressed by a phase advance of□2 per arc. Thus with only one QF family the dispersion cannot be fully suppressed in the case of working point adjustments, but stays small for small changes. A full suppression could be achieved by powering the quadrupoles next to the straight section individually.

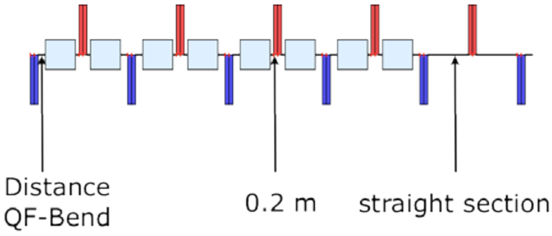
The complete lattice with a working point of QH= 4.205 and QV= 3.572 is shown in Figure 3. The horizontal tune of 4.205 is optimized for dispersion suppression in the straight sections.

Figure 3 — [Optic]



The horizontal/vertical beta function is shown in blue/red, the horizontal/vertical dispersion in dashed blue/dashed red.

Figure 4 — [Space Requirements]



All lattice parameters are listed in Table 2 and the distances indicated in Figure 4.

Table 2 — [Design Parameters]

Circumference	119.68 m
Number of cells	21
Number of cells per straight section	2
Length of straight section	4×2.35 m
Distance QF-Bend	0.65 m
Phase advance per cell (hor.)	72.1°
Phase advance per cell (vert.)	61.2°
Q_H	4.20505
Q_V	3.57156
Gamma transition	3.60
$\beta_{H,max}$	8.73 m
$\beta_{V, max}$	12.06 m
$D_{x, max}$	3.73 m

3.1.3 Acceptance Estimates

The RCS acceptance estimates are based on the known booster acceptance and were downscaled in order to take the higher injection energy of the RCS into account. As reference for the RCS dipoles, the scrapers in proximity of the booster dipoles were taken [Reference to technical drawing] and for the quadrupoles the vacuum chamber inside the booster quadrupoles [PS-SI-3-49-1063.tiff]. The values are listed in Table 3.

Table 3 — [Booster Aperture]

Half gap height Scrapers (vert.)	29.5 mm
Half gap height Scrapers (hor.)	61 mm
Radius vacuum chamber booster quadrupoles (vert.)	60.5 m
Radius vacuum chamber booster quadrupoles (hor.)	67.5 m

For h=1+2 the maximum momentum spread in the RCS is estimated to be around 0.75%, on which we based the calculation of the horizontal RCS acceptance. The dipole acceptance is listed in Table 4 and the quadrupole acceptance in Table 5.

Table 4 — [RCS Acceptance Dipoles]

Vacuum Chamber	5.5 mm
Half acceptance (vert.)	26.0 mm
Closed orbit distortion (vert.)	3 mm
Total half aperture (vert.)	34.5 mm
Half acceptance (hor.)	54.8 mm
Closed orbit distortion (hor.)	5 mm
Total half aperture (hor.)	65.3 mm

Table 5 — [RCS Acceptance Quadrupoles]

Vacuum Chamber	1.5 mm
Half acceptance (vert.)	35.7 mm
Closed orbit distortion (vert.)	3 mm
Total half aperture (vert.)	40.2 mm
Half acceptance (hor.)	67.3 mm
Closed orbit distortion (hor.)	5 mm
Total half aperture (hor.)	73.8 mm

Most challenging in respect to aperture requirements is the nTOF beam with a horizontal emittance of 15 μm and 9 μm vertical at extraction. The current RCS acceptance correspond to minimum 1.81 σ horiz./1.47 σ vert. for the quadrupoles and 1.67 σ horiz./1.58 σ vert. for the dip

3.1.4 Longitudinal Issues:

The RCS is confronted with conflicting requirements between injection and extraction.

The main issue is the longitudinal emittance of the h=1 bunches.

- At 2 GeV: The PS requests bunches of 2eVs for the LHC beams and of even larger emittance for TOF and CNGS beams. There are several options to overcome this difficulty: A fast emittance blow-up by an additional rf cavity in the VHF range. It applies phase modulation jumping between different higher harmonics of the basic rf system. The degree of blow-up achievable this way has to be studied by simulation and/or machine experiments with the new digital beam control system in the PSB.
- At injection: The technique of longitudinal painting with Linac 4 foresees linear energy sweeps between ±1.2MeV within 20 μs. This corresponds to a rectangular 'bunch' of 1.84 eVs; but a reasonably filled (painted!) h=1+2 bucket of this height can hold about only 1.2 eVs. A matched 2eVs bunch has a height of about ±2MeV.

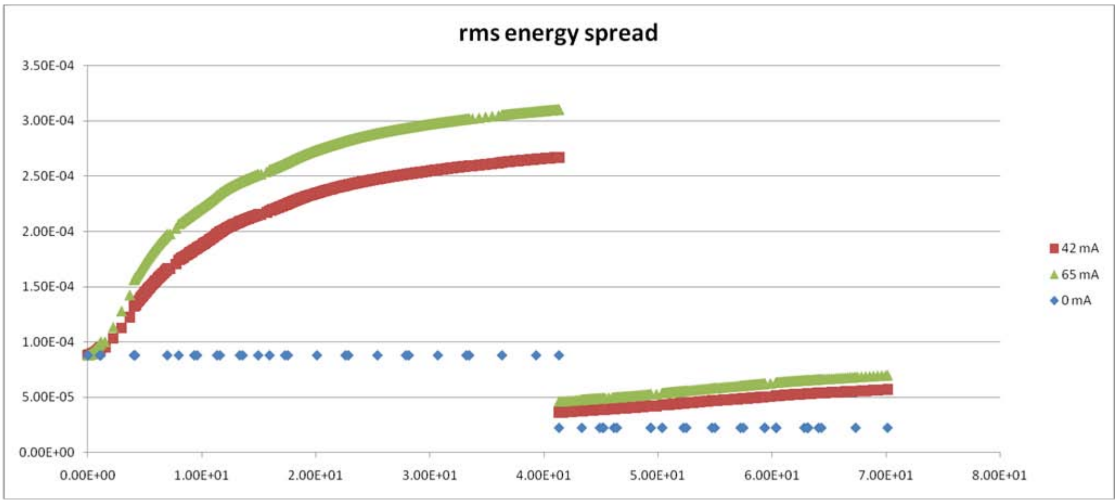
  Actually the existence of the limited energy spread entrains some benefits: As the excursions of the dispersion contribute significantly to the horizontal envelope and the ensuing aperture requirements, their reduction is welcomed.

Injection on a rising cycle, as foreseen in the PSB to reduce the time spent in the high space-charge regime at low energies, would require even higher painting energy range. For this reason, a sinusoidal magnet cycle was assumed in this chapter.

Nevertheless there may be a way out:

The quoted Linac4 energy modulation range of ±1.2 MeV is limited mainly by the distortion of phase at the debuncher located at 42 m from Linac4 exit. In the present RCS implantation layout, this is about the distance from Linac4 to the RCS injection area. One could envisage dropping the debuncher and painting the bunch shape with a broader "brush". This would allow a modulation of ±2 MeV, allowing the creation of 2eVs bunches. The injection energy would be lowered to 158 MeV, which should not be a problem. The width of the brush is given by the space-charge driven blow-up in the injection line. Figure nn shows the rms. width as a function of distance for the nominal average Linac4 currents of 40 mA and 26 mA. The latter one would be best for painting an LHC beam of 3.25E12 p within 20μs, i.e. within one sweep. Again, the consequences of painting with a 200-300keV wide brush would have to be studied by simulation.

Figure 5 — [Blow-up of Linac4 rms Energy Spread along the Injection Line]
Courtesy A. Lombardi



Another potential difficulty arises for the LHC beams from the fact that the PS requires bunch lengths up to 180 ns, corresponding to $\Delta\varphi = \pm 77$ deg. The matched RF voltage of a bunch of area 2 eVs is about 2 kV and the synchrotron frequency as low as 150 Hz. Consequently, stretching the RCS bunches to this length near flat top is no longer an adiabatic process. It may be possible to produce these bunches by a carefully adapted RF voltage programme but it remains an operational burden. A safer approach consists in a fast bunch rotation preceding extraction: Dropping the voltage from 60 kV to 14 kV rotates the bunch from initially $\Delta\varphi = \pm 36$ deg to the desired length in 0.8 ms.

3.1.5 Effect of Transverse Space Charge:

The defocusing due to space charge forces creates a tune spread which extends in general from the bare working point to a maximum tune shift, which is the one that experience the particles with vanishing betatron amplitudes. In the present PSB, it reaches values of about -0.5 in the vertical plane. From this experience one can infer that the RCS will allow tune shifts of this order, perhaps even a little more as the beam is accelerated much faster.

One practical form is given by the expression

$$\Delta Q_{s.c.} = -\frac{N_b}{\varepsilon_n} \frac{r_p}{4\pi \beta\gamma^2} \frac{F\,G\,H}{B_b}$$ with

ε_n ... Normalised r.m.s. emittance
N_b...p/bunch
F ...Image Factor ≅ 1
G ...Distribution Factor (transverse): Gaussian =2, uniform =1
H ...Aspect Ratio Factor: $H_x \propto \left\langle \frac{1}{a(a+b)} \right\rangle$, $H_y \propto \left\langle \frac{1}{b(a+b)} \right\rangle$;
a,, b ... Beam radii, hor. contains $< D_{x,rms}$ dp/p> added quadratically
B_b...Bunching Factor, average/peak line density of single bunch
β, γ...Lorentz Factors

The rather large radial dispersion in the arcs of the lattice ($<D_{x,rms}$ dp/p >= 1.67m) together with a bunch height of up to dp/p ≅ ±0.006 helps to reduce the max. tune shifts in both planes.

In Table-6 are compiled the computed tune shifts during the critical phase till 15ms for the most critical beams. Although better transverse distributions can be painted with H- injection, Gaussians have been assumed in both transverse planes to take into account possible redistributions. The emittances used in the calculations have been reduced by 20% w.r.t. the nominal ones to provide some margin for blow-up or minor losses.

Table 6 — [Space Charge Tune Shifts during early Acceleration]

Sinusoidal Magnet Cycle 50 ms rise			Bunch Area 1.2 eVs		LHC Beam 3.25E12 p/p $\varepsilon_{n\ x,z}$=2µm		nTOF Beam 1E13 p/p $\varepsilon_{n\ x,z}$=8µm	
t (ms)	Vrf (kV)	T(MeV)	Bunching Factor	Bunch Height (MeV)	-dQx	-dQz	-dQx	-dQz
0	10	160	0.482	1.29	0.36	0.52	0.37	0.45

2	20	165	0.421	1.77	0.33	0.54	0.39	0.48
3.2	22	172	0.424	1.70	0.32	0.52	0.37	0.46
5	25	189	0.428	1.96	0.29	0.46	0.33	0.40
8	35	237	0.427	2.33	0.22	0.34	0.24	0.30
15	60	443	0.337	4.15	0.12	0.18	0.13	0.16

The maximum vertical tune shift of -0.54 of the LHC beams appears somewhat risky, but it should be borne in mind that a transverse Gaussian is a pessimistic assumption compared with the distributions made possible by transverse painting.

4. RCS Injection and Extraction [W. Bartmann, B. Goddard]

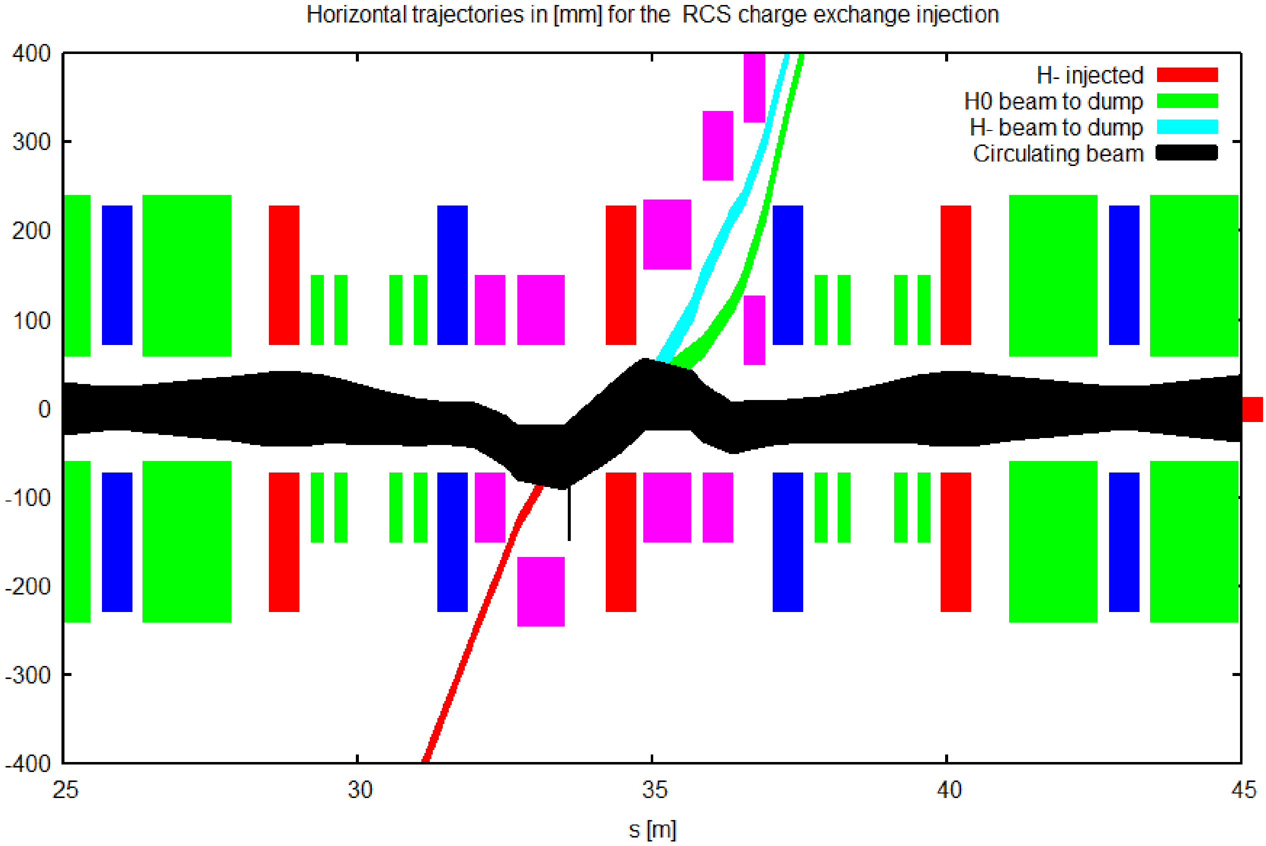
4.1 Technical Description

4.1.1 Injection system

The charge exchange injection comprises a horizontal 4 magnet chicane bump (D1-D4), a 4 magnet painting bump per plane (MKH1-MKH4 and MKV1-MKV4) and 3 stripping foils (F1-F3), see Fig. 4.1.

The injection is housed by two empty FODO cells with a focusing quadrupole in the centre. The circulating proton beam (black) is bumped with an angle across the horizontal axis to be merged with the incoming H- beam (red) in the D2 chicane dipole. The D1 chicane dipole deflects only the circulating beam and will therefore be a septum like magnet.

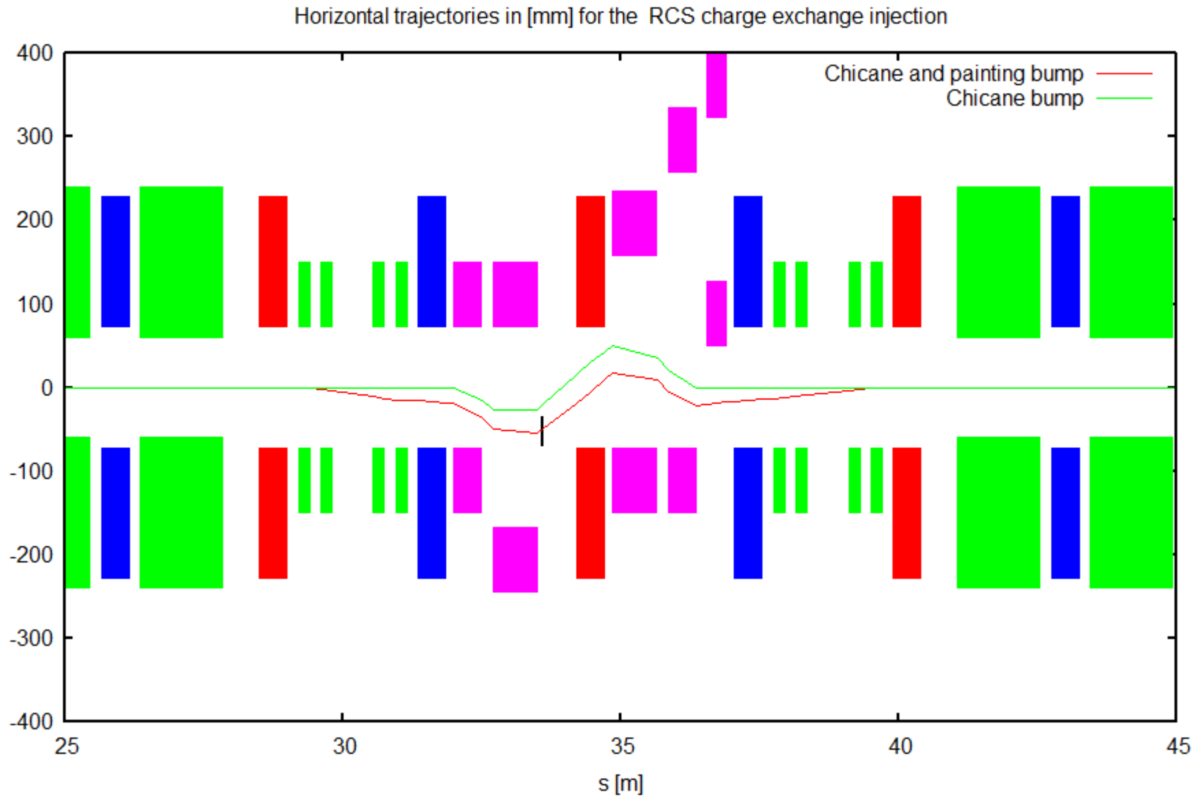
Figure 4.1 — [Layout of the H^- injection system. Boxes indicate main bends (green, wide), focusing quadrupoles (red), defocusing quadrupoles (blue), horizontal and vertical painting bumpers (green, small) and chicane bumpers (magenta).]



The stripping foil F1 is placed downstream of D2 to strip the H- ions to protons. The foil thickness has to be optimised with respect to stripping efficiency, foil heating and emittance blow up of the circulating beam. The unstripped H- (turquois) or partially stripped H0 (green) need to be deflected into a dump line. The D5 dipole will deflect the waste beams only to reach clearance at the downstream QD in direction to the dump.

The painting bump amplitude reaches at the foil 30 mm in the horizontal and 32 mm in the vertical plane. 20 cm long magnets are needed for the horizontal bumpers with nominal fields of about 0.085 T (compared to 0.058 T in KSW magnets of present PSB – which are 40 cm long). The length of the vertical bumpers is increased to 40 cm to decrease the field below 200 mT and, thus, allow deploying ferrites. Figure 4.2 shows the shape of the chicane and painting bump in the horizontal plane.

Figure 4.2 — [Horizontal bump shapes]



Beta beating will result from the strong chicane magnets. Its effect on the lattice focusing for full chicane strength is shown for SBEND and RBEND in Figures 4.3 and 4.4, respectively.

Figure 4.3 — [Beta beating for RBEND chicane and painting magnets]

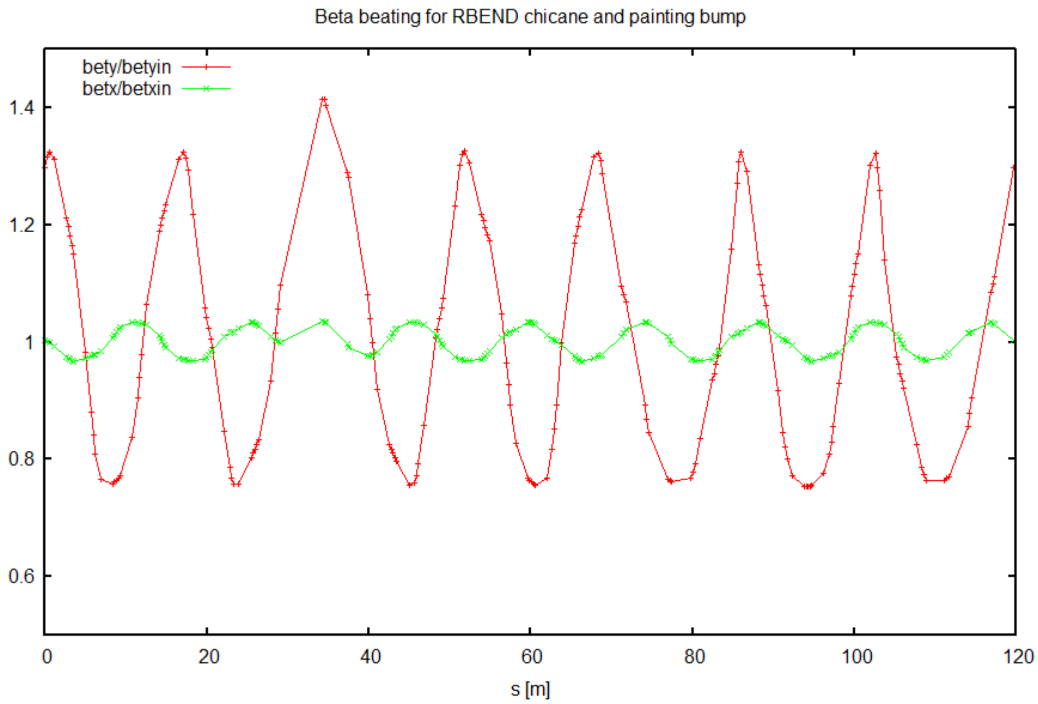


Figure 4.4 — [Beta beating for RBEND chicane and painting magnets]

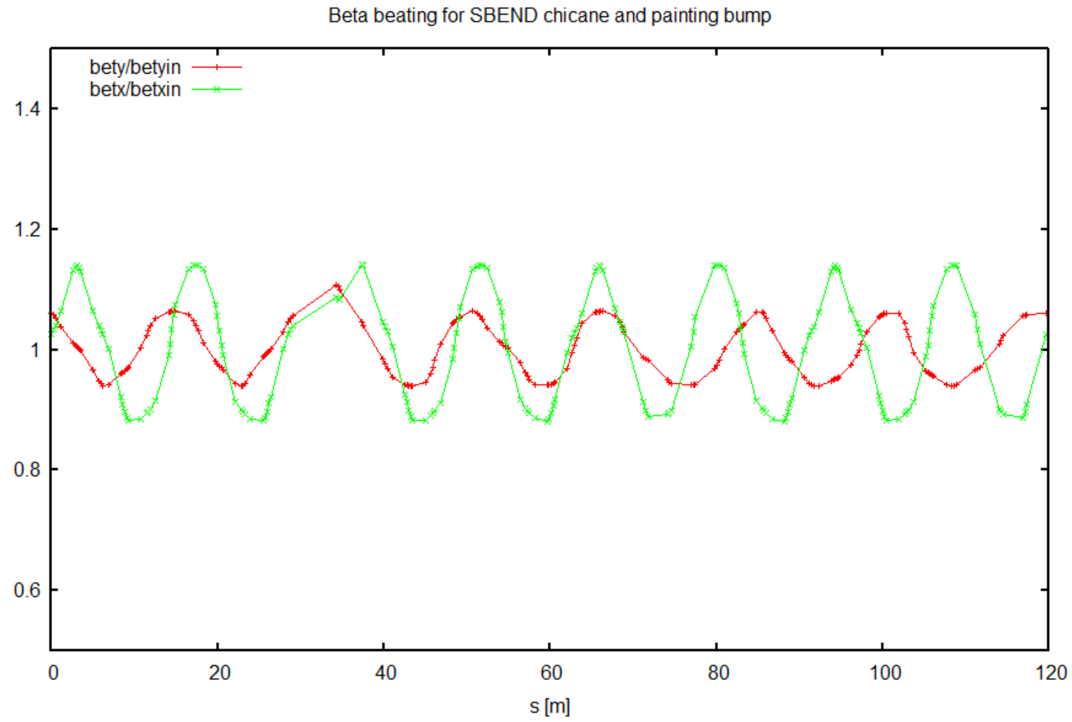


Table 4.6 — [Chicane magnet kicks and integrated fields at 160 MeV kinetic energy]

Magnet	Kick angle [mrad]	Length [m]	Integral field B.dl [Tm]	Field [T]
D1	-58.3	0.5	0.111	0.22
D2	117.5	0.8	0.223	0.28
D3	-127.1	0.8	0.241	0.30
D4	80.3	0.5	0.153	0.31
D5	155.0	0.35	0.295	0.84

Table 4.2 — [Painting magnet kicks and integrated fields at 160 MeV kinetic energy]

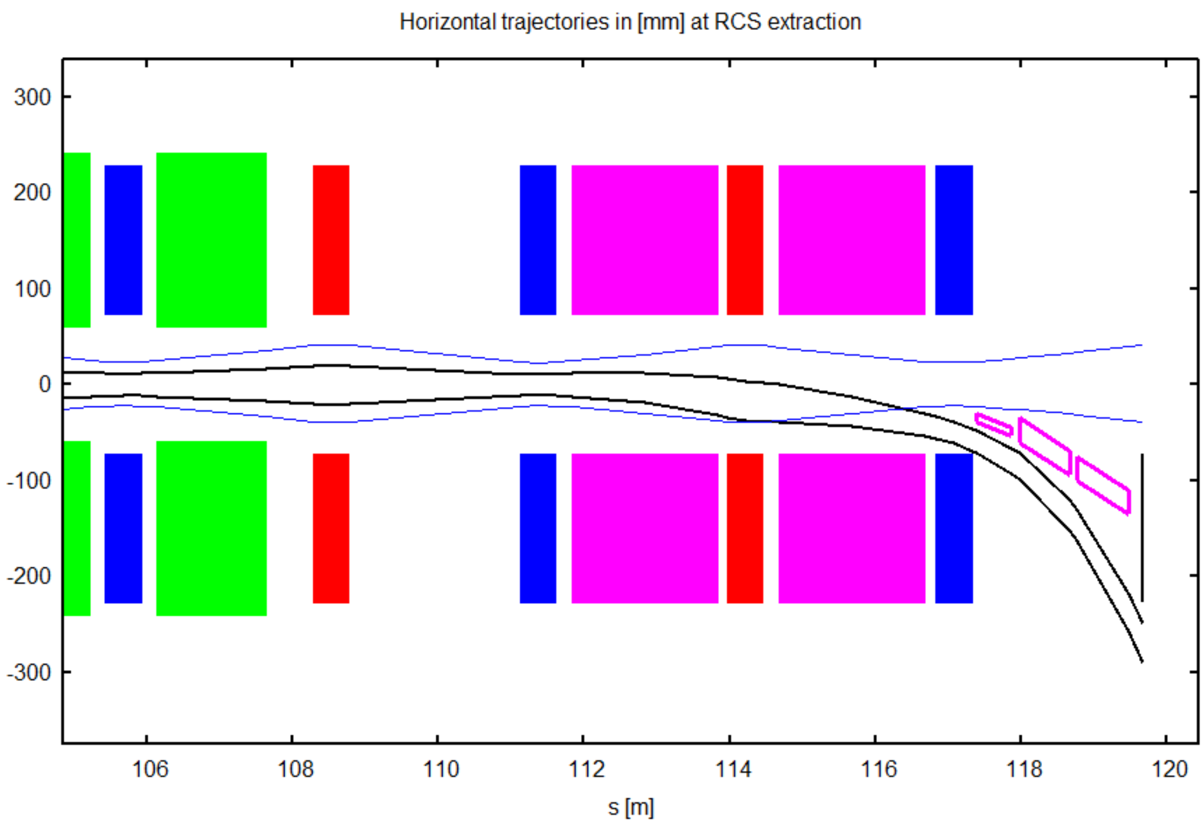
Magnet	Kick angle [mrad]	Length [m]	Integral field B.dl [Tm]	Field [T]
MKH1	-9.0	0.2	0.017	0.085
MKH2	8.2	0.2	0.016	0.078
MKH3	2.3	0.2	0.004	0.022
MKH4	-7.5	0.2	0.014	0.071
MKV1	39.9	0.4	0.076	0.190
MKV2	-30.6	0.4	0.058	0.145
MKV3	-20.4	0.4	0.039	0.097
MKV4	29.6	0.4	0.056	0.141

4.1.2 Extraction

The extraction is a fast bunch-to-bucket transfer with a kicker and septum system placed around a defocusing quadrupole, Fig. 4.5.

The kicker system consists of 2 tanks filling two adjacent half cells. The required rise time is 40 ns. The horizontal and vertical half-apertures are assumed to be 40 and 74 mm, respectively.

Figure 4.5 — [Extraction at 2 GeV kinetic energy from RCS. The filled boxes in magenta show the extraction kicker, the magenta lines the septum blades. The black line indicates the width of the downstream quadrupole. Beam envelopes (blue at injection, black at extraction) are shown for 3 sigma beam size including a closed orbit distortion of 3 mm.]



The septum consists of a thin (8 mm) eddy-current septum and two thick (25 mm) magnetic septa with a vertical gap height in the extraction channel of 40 mm. The kick strengths and fields for the extraction elements are shown in Table 4.3.

Table 4.3 — [Kicker and septum strengths and fields at 2 GeV kinetic energy]

Magnet	Kick angle [mrad]	Length [m]	Integral field B.dl [Tm]	Field [T]
MKE (x4)	6	1	0.056	0.056
MST	12	0.5	0.111	0.22

MSE (x2)	55	0.75	0.510	0.68

4.2 Budget Estimate

4.3 Time Estimate

5. RCS-PS Transfer Line [W. Bartmann]

5.1 Technical Description

5.2 Budget Estimate

5.3 Time Estimate

6. PS Injection [W. Bartmann, B. Balhan, J. Borburgh, S. Gilardoni, B. Goddard, M. Hourican, L. Sermeus, R. Steerenberg]

6.1 Technical Description

The use of conventional septa in DC mode - as is usually the choice for fast cycling hadron machines for reliability reasons – requires injecting into a long straight section (2.4 m) of the PS. A short extension of the existing PSB-PS transfer line would allow to inject into the long SS46 instead of the existing injection into the short SS42 (1 m). This implies a new geometric design of the transfer line and a re-shuffling campaign of RF cavities, kickers and dumps in the PS.

As an alternative it is considered to inject into SS42 deploying eddy current septum technology for both the injection septum and the bumper. For this option the transfer line geometry remains unchanged and major modifications to the PS are avoided. Drawbacks are the reduction of the vertical septum gap height from 60 to 48 mm and the complexity of the under-vacuum eddy current device. A second kicker system needs to be installed in SS53, as it is also foreseen in case of the PSB upgrade to 2 GeV.

Figure 13.1 shows the horizontal beam size when injecting into SS42. The kicker in SS45 cannot provide the 30% increase in kick strength for the 2 GeV high-intensity beams where a fall time of 68 ns (2-98%) is required. A second system is installed 180 deg downstream to compensate for the kick leakage. Both kicker systems (the existing KFA45 and the foreseen KFA53) can be pulsed at 10 Hz.

Figure 13.1 — [Horizontal beam size in [mm] for the HI beam at PS injection in SS42.]

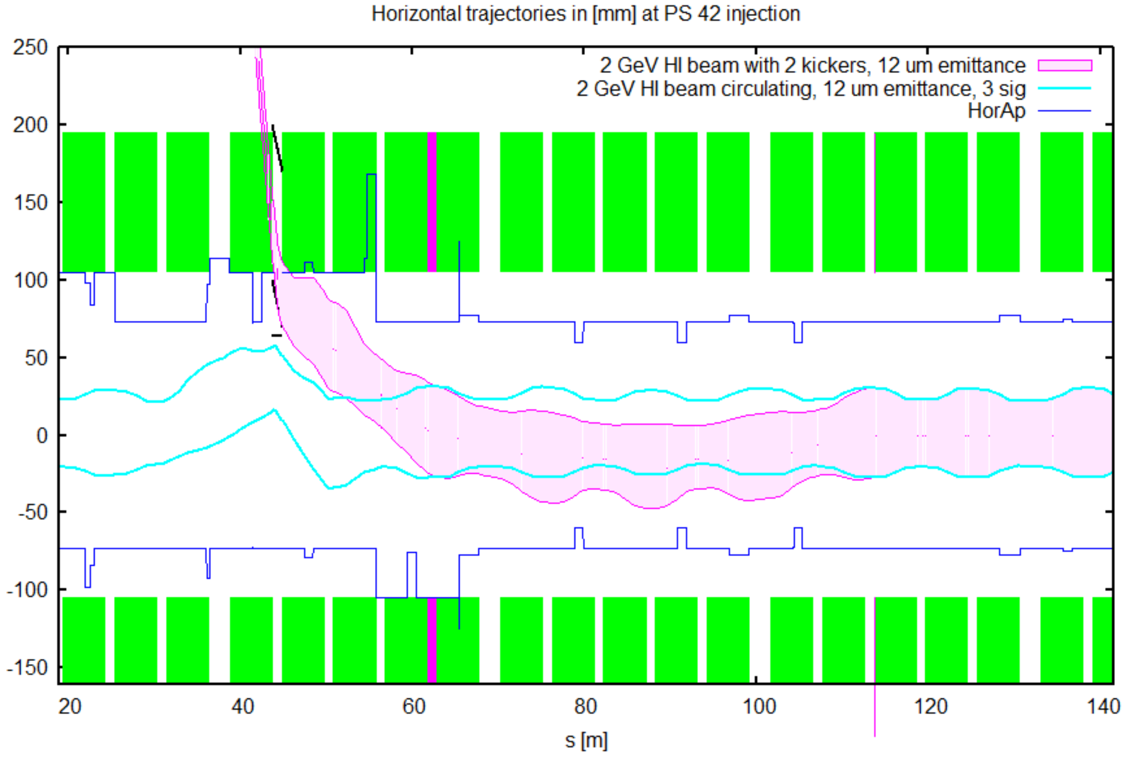


Figure 13.2 — [Combined septum-bumper system with view from upstream end (left) and downstream end (right)]

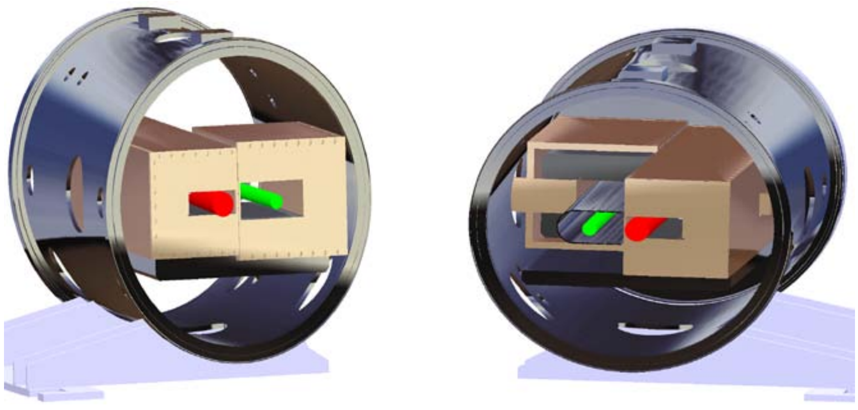


Figure 13.2 shows the combined under-vacuum septum-bumper system with injected beam (red) and circulating beam (green).

The main challenges of this system are magnetic and impedance screens, the internal support structure, vacuum pumping, the bake-out system, feedthroughs and the remote displacement system.

Simulations show that deploying a full sine current limits the field leakage from the septum into the circulating chamber at the circulating beam centre to about 1 permille. The field homogeneity in the septum is about 1%.

Table 13.1 — [Septum and bumper characteristics]

	Unit	Eddy current under vacuum septum SMH42	Eddy current under vacuum Bumper Septum 42
Deflection	Mrad	55	13
Septum Thickness	mm	5+1	5
Nbr Turn		1	1
Gap Height	mm	48	76 (70 for beam)
Gap Width	mm	120	165
Magnetic Length	mm	950	375
Induction in Gap	T	0.57	0.32
Required Current	A	21000	20000
Power Consumption	kW	< 0.4	<0.2
Magnet Resistance	mOhms	0.09	0.04
Magnet Inductance	uH	2.5	1
Beam size acceptance	mm	48 x 100	70 x 140

Differences to injection from an upgraded PSB that need to be studied:

- Reduced vertical acceptance for the injected beam in case of EC septum

  The emittances coming from the PSB or RCS have to be compared to the minimum beam acceptance in the PS which should allow to inject with a certain mismatch and still attain the target emittance in the PS. Other possible improvements are the addition of a collimation in the transfer line and a change of the injection optics which is limited by the PS optics flexibility.

- Continuous losses due to the injection bump in the PS ring

  Beam losses due to the circulating beam bumped to the aperture limits will occur 10 times more often in case of the RCS, however with a lower circulating intensity for the first injections. The total loss is expected to be about 5.5 times higher for a similar bump fall time, assuming that tails are repopulated in the 100 ms between injections.

- Lifetime of an eddy current device with respect to conventional septum technology

6.2 Budget Estimate

6.3 Time Estimate

7. **Magnets** [A. Newborough]

7.1 Technical Description

The magnets considered for this feasibility study are the main bending and main quadrupole magnets for the RCS ring only, as they will contribute the most to the overall magnet budget. There will be several other magnet families required, such as the main ring correction magnets (dipoles, multi-poles etc...) and the transfer line magnets from the LINAC 4 to the RCS machine and from the RCS machine to the present ISOLDE experiment and PS machine. The costs of the transfer line magnets will be included as part of the general transfer line estimation.

7.1.1 Main Bending Magnets

Operating at a frequency of 10 Hz, it is envisaged that the main bending magnets will be able to achieve a field of up to 1.3 T. To achieve this field the magnets must be designed below saturation levels with special attention paid to the construction of the magnetic circuit. In particular it is planned to use a relatively thin lamination of grain orientated high silicon content steel. The use of this steel with the grain orientation in direction of the majority of the magnetic flux will have the effect of narrowing the hysteresis cycle and increasing the electrical resistance, thus minimising the adverse dynamic effects to within acceptable levels (delay between current and field, field quality perturbation, iron losses etc...).

The parameters shown in Table 1 have been calculated from the initial figures given for the required free vertical aperture of 71 mm (+/- 35.5 mm) and a horizontal good field region of 130 mm (+/- 65 mm). The total integrated bending field is 58.3 Tm, provided by 30 identical magnets each with an effective length of 1.5 m. The magnet characteristics provided are based around a magnet with 12 turns and an r.m.s. current density of 5 A/mm2. If required the number of turns can be altered to help in the design of the power supply by increasing or decreasing the required peak current, magnet inductance etc... However, a maximum voltage potential of 10 kV (+/- 5 kV to ground in normal operation) would dictate no more than 18 turns. Figure 1 shows a simple 2D magnetic field map of a preliminary design, while figure 2 shows a possible magnetic cycle.

Table 1, Main Bending Magnet Parameters

Approx. Magnet Dimension	
Iron length (m)	1.426
Total length (m)	1.626

Iron Width (m)	0.94
Iron Height (m)	0.66
Aperture height (m)	0.071
Aperture width (m)	0.27
Approximate weight (kg)	6000
Magnetic Parameters	
Magnet type	H – laminated, water cooled
Field (T)	1.3
Magnetic length (m)	1.5
Integrated field (Tm)	1.946
# turns per pole	6
# turns total	12
Electrical Parameters	
Current at peak field (A)	6106
Current at Injection (A)	1256
Current r.m.s. (A)*	3793
Resistance @ 20 °C (m☐)	1.08
Resistance warm [☐T = 30°C] (m☐)	1.14
Inductance (mH)	1.36
Max. Volt-drop (V)**	226
Copper Losses, warm (kW)	16.4
Iron Losses (kW)	1.7
Total Dissipated Power (kW)	18.1
Cooling parameters	
Flow [☐T = 20K] (l/min)	12
Required Pressure Drop (bar)	8
RCS Machine - Bending	
# Magnets in series (incl. Ref. magnet)	31
Total magnet resistance warm (m☐)***	35
Total magnet inductance (mH)	42
Total dissipated power (kW)	562
Total volt drop (kV)	7.0

* Approximation from magnetic cycle (see figure.2)

** Assumes ramp down time of 0.03 seconds

*** Does not include connections and cables

Figure 1, 2D magnetic field map

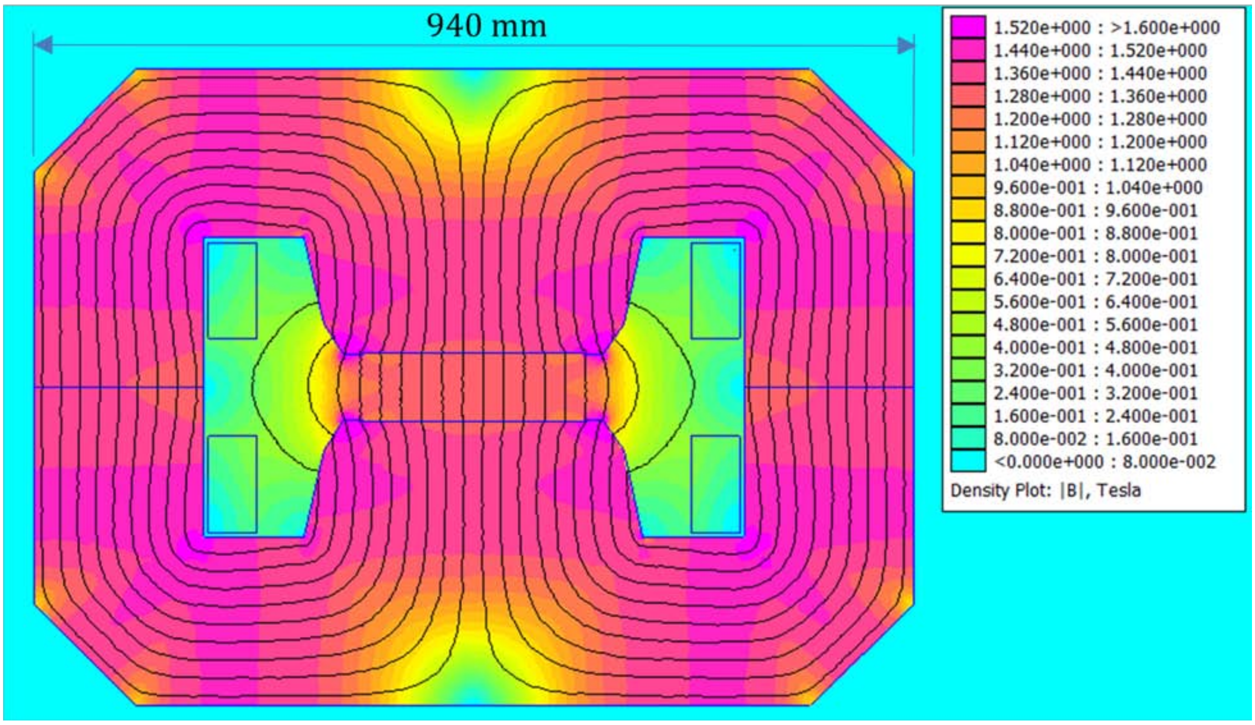
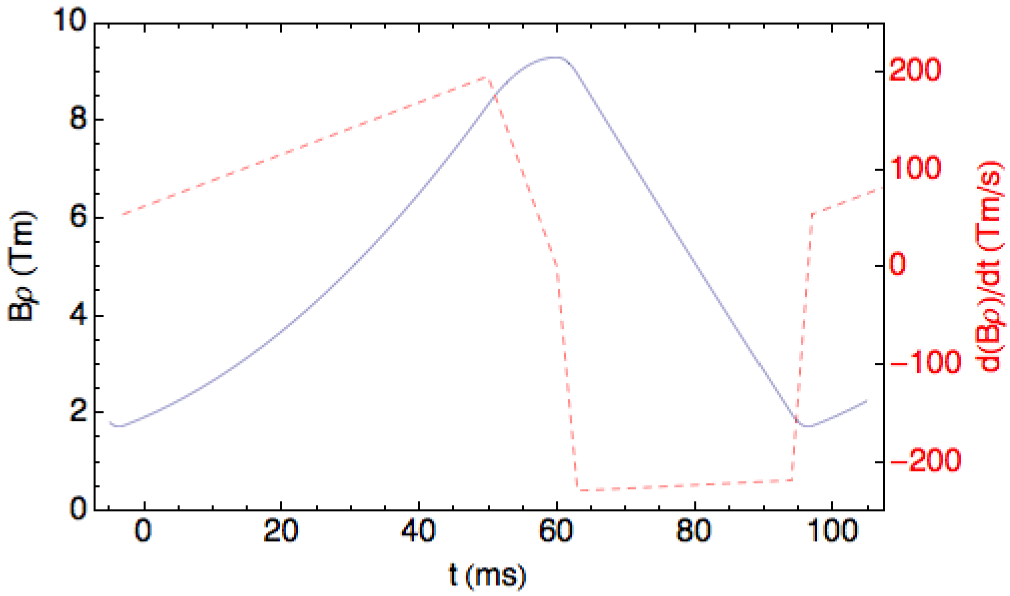


Figure 2, possible magnetic cycle



7.1.2 Quadrupole Magnets

As per the main bending magnets, the quadrupole magnets will be constructed from a thin lamination of high silicon content grain orientated steel. Limiting the pole tip field to approximately 0.80 T allows designing a magnet which operates below saturation. The required horizontal aperture of approximately 75 mm has been given as a baseline for the design of the magnet, this will dictate a minimum inscribed radius of

100 mm to be able to guarantee the field quality to within a few units in 10-4. If the required field homogeneity is not as critical at the limit of the required aperture then a reduction could be made. For field quality issues a symmetrical design is desirable, however, it would be possible to use other designs if required. For example, if around the injection and extraction points of the machine it is seen that the symmetrical quadrupole magnet is too wide, then a reduction in the width and an increase in the height could be considered for these regions. The maximum required gradient for the quadrupole magnets is approximately 8.0 T/m with an effective length of 0.5 m. Table 2 shows approximate parameters for the quadrupole magnet with a physical aperture of 100 mm radius. Figure 3 shows a simple 2D magnetic field map of a preliminary design.

Figure 3, 2d magnetic field map of the main quadrupole.

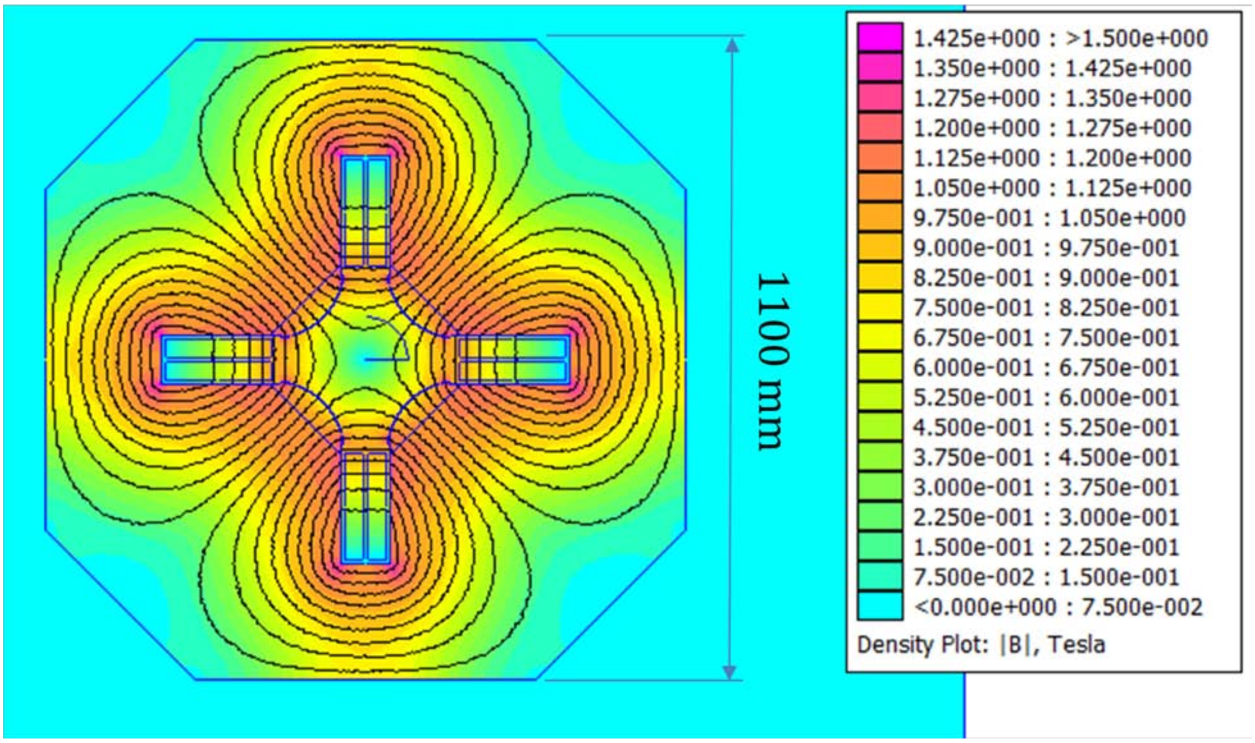


Table 2, Main Quadrupole Magnet Parameters

Approx. Magnet Dimension	
Iron length (m)	0.433
Total length (m)	0.6
Iron Width (m)	1.1
Iron Height (m)	1.1
Inscribed Radius (m)	0.1
Approximate weight (kg)	2950
Magnetic Parameters	
Magnet type	Tapered pole - laminated, water cooled

Gradient (T/m)	8.0
Magnetic length (m)	0.5
Integrated Gradient (T)	4
# turns per pole	8
# turns total	32
Electrical Parameters	
Current at peak field (A)	3979
Current at Injection (A)	815
Current r.m.s. (A)*	2470
Resistance @ 20 °C (m□)	1.79
Resistance warm [□T = 30°C] (m□)	1.89
Inductance (mH)	1.46
Max. Volt-drop (V)**	155
Copper Losses, warm (kW)	11.5
Iron Losses (kW)	0.7
Total Dissipated Power (kW)	12.2
Cooling parameters	
Flow [□T = 20K] (l/min)	8.5
Required Pressure Drop (bar)	8
RCS Machine – Quadrupole***	
# Magnets in series	21 QF or 21 QD
Total magnet resistance warm (m□)****	40
Total magnet inductance (mH)	31
Total dissipated power (kW)	257
Total volt drop (kV)	3.4

* Approximation from magnetic cycle (see figure.2)

** Assumes ramp down time of 0.03 seconds

*** Values are stated per circuit, 21 QF or 21 QD magnets and are the maximum value.

**** Does not include connections and cables

7.2 Budget Estimate

The following estimate covers the cost of the main magnets only; it does not include other required magnets, supports, cabling, manpower, installation etc...

	Magnet	Dipole	Quadrupole	
Magnet	Number of magnets (incl.spares)	33	46	#
	Total mass/magnet	6000	2950	Kg
Total Costs	Total order mass	198	136	Tonnes
	Total fixed costs	215	170	kCHF
	Total Material costs	894	788	kCHF
	Total Manufacturing costs	3302	3335	kCHF
	Total magnet costs	**4411**	**4445**	**kCHF**
	Unit cost	**134**	**97**	**kCHF**
		8856		**kCHF**

7.3 Time Estimate

From the time of project approval, including design and manufacturing, an estimate for the availability of all the main units is approximately 36 months. This estimation would include the fabrication and evaluation of the pre-series magnets.

As part of the study the construction of a scaled version of the bending magnet is being built to evaluate the performance of the grain orientated high silicon content electrical steel. To achieve the results within a short time the yoke is to be designed around and assembled with an existing pair of spare coils, the construction and testing is planned for summer 2011. The construction of a scaled quadrupole will also be considered.

8. Magnet Interlocks [P. Dahlen, B. Puccio]

8.1 Technical Description

The Warm magnet Interlock Controller (WIC) solution is proposed. This system is currently deployed in LEIR, in Linac3, in the SPS-LHC-CNGS transfer lines and is also protecting the normal conducting magnets of the LHC.

The WIC solution is a PLC based system. It protects the normal conducting magnets from overheating by switching off the power converter when a fault such as overheating of magnets occurs. In order to optimise safety, the Siemens “F” Series PLC is used, offering a self checking safety environment that ensures system integrity. The WIC system performs self testing of its own hardware and software to detect failures and corruption, and goes into a safe state in the event of an abnormality. In the present case, it means that the Power-converters will be all the time switched off.

The study, the preparation of the material, the lab tests, the commissioning activities and the maintenance are handled by the Machine Interlock section of the TE/MPE group. The PLC software and the PVSS application are both managed by the EN/ICE group.

8.2 Budget Estimate

The cost will depend of many parameters: number of water-cooled magnets, number of additional sensors (water-flow meters, red-buttons, etc...) and the cables length for magnets and converters connections.

As a very first estimation, the budget will be between 300kCHF and 500kCHF.

8.3 Time Estimate

From the time of project approval, including study, ordering, manufacturing and testing in the lab, an estimate for readiness to a commissioning is approximately 12 months.

9. **Power Supplies** [S. Pittet]

9.1 Technical Description

For this preliminary study, the power supplies for the RCS ring only have been studied in detail. With a 10Hz machine, the preliminary design focuses on minimizing the impact on the 18kV general network as well as minimizing the idle time between successive accelerations. Flexibility on the current waveform is also kept as an important feature for operation.

The costs of the transfer line power supplies will be included as part of the general transfer line estimation.

9.1.1 Main bending power supply

Considering the main bending magnets characteristics, two options can be considered and will be developed and quoted in this document. A detailed and long study would still be needed on each option to confirm the technical feasibility:

- A resonant system also called a White circuit is often used in fast cycling accelerators with a repetition rate of 10Hz to 50Hz (ESRF, SRS, J-PARC,...). This topology is highly cost effective but does not allow any freedom on the current waveform for operation.
- A semiconductor based 4-quadrant converter with local capacitive energy storage as developed for the PS. This topology is significantly more expensive but allows more freedom on the current waveform and is well known and understood at CERN.

9.1.2 White circuit option

The associated supply to this LC resonant circuit only compensates for the losses in the magnets and the cables and helps to “tune” the oscillation frequency. This notably decreases the rating of the power supply needed for a given current and voltage applied on the magnets. The main drawback of this system is that only sinusoidal waveforms with a predefined operating frequency can be produced. Furthermore several seconds are needed to change the minimal and maximal current, which excludes PPM operation with different energies. Adding some trimmers to shape some portions of the cycle significantly decreases the efficiency of this method and then its interest. Alternatives option would be to introduce low order harmonics (fermilab synchrotron option) or to actively modify the resonant frequency within a basic cycle.

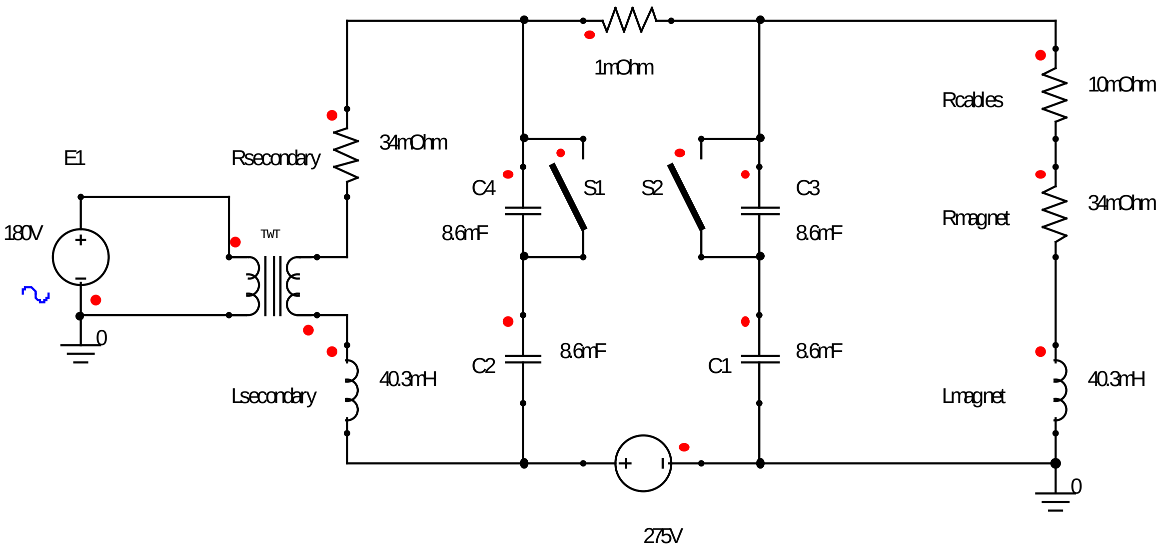


Figure 1: Example of resonant circuit with “tuneable” capacitors.

Switches S1 and S2 are closed when the voltage on C3 and C4 is at 0V and the current At its minimal value, increasing by this way the effective capacitance and slowing down the acceleration. The switches and related control must be designed carefully to avoid destructive discharge of the capacitors when charged.

This topology has never been implemented and the technical feasibility of asymmetric waveform still needs to be confirmed.

The magnet chain can be divided in n sub-modules in order to reduce voltage stress to ground by a factor 2n.

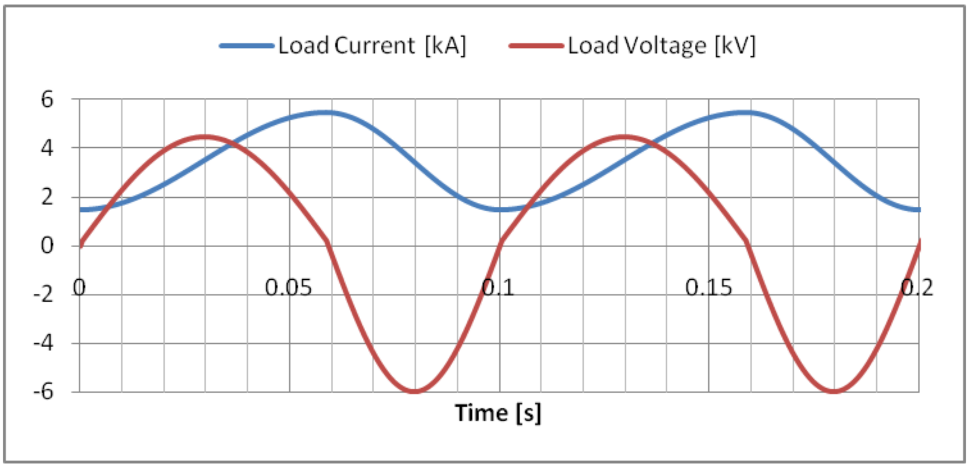


Figure 2: Asymmetric sinusoidal waveform on the load (magnet + cables)

Only two “small” power supplies can induce the 14MVA needed on the load:

DC power converter ratings: 300V/3500A => 1MVA

AC power converter ratings: 200V/5000A => 1MVA including margin for 2% variation of the natural resonant frequency of passive components.

Space requirement: 400m^2

9.1.3 POPS type option

This option was already considered for the upgrade of existing PS booster. The basic principle of a POPS-like topology is to manage the energy transfer between the magnets and a huge capacitor bank installed near the power converter. Only the power needed to compensate the electrical losses is driven from the 18 kV network, considerably reducing its stress. This would allow more flexibility on the MPS cycle without disturbing other users on the Meyrin site.

10Hz operation of this system seems to be challenging but achievable. It still have to be demonstrated.

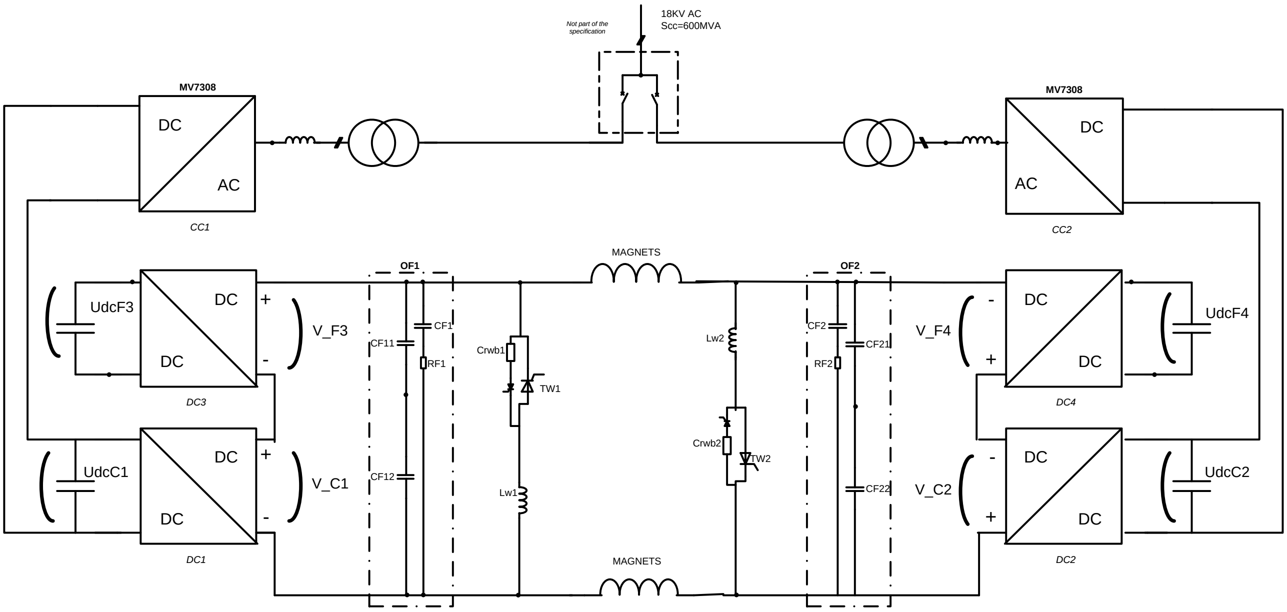


Figure: General converter layout for POPS type alternative.

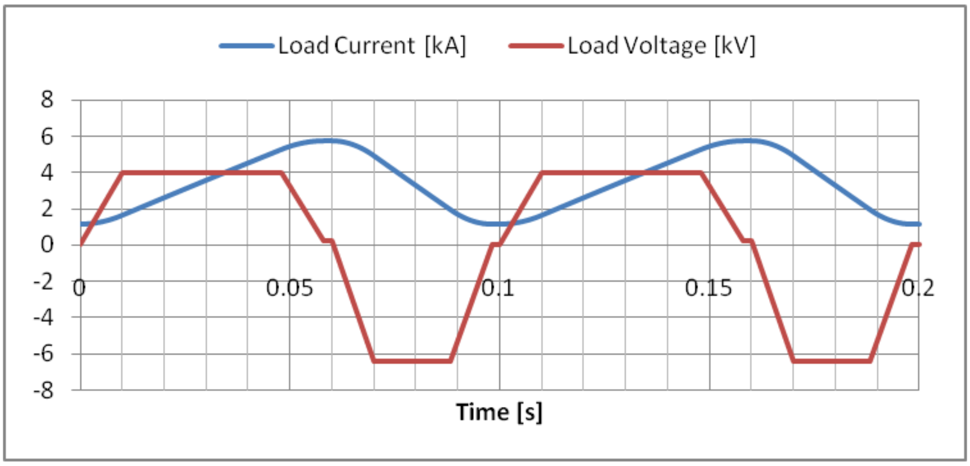


Figure: Current cycle example with POPS alternative.

Active power from the 18kV network: 700kW

Power converter ratings: 6500V/6000A => 39MVA

Space requirement: 400m^2

9.1.4 Main quadrupoles power supply

Flexibility on the current adjustment is an important add-on to suppress the dispersion in the three machine straight section. One large 7000V/4000A main supply with active trimmers could be used, but the stability of such a system at a 10Hz repetition rate is not confirmed yet. We then propose to split the focusing quadrupoles string in 4 similar sub-strings (3 times 6 magnets and 1 time 3 magnets).

In order to minimize the number of power converter families, the same strategy is applied to the defocusing magnets.

for each of the 8 quadrupole power supplies:

Active power from the 400V network: 100kW

Power converter ratings: 1000V/4000A => 4MVA

Space requirement: $400m^2$

9.1.5 Correction magnets

Those magnets have to been specified yet, but the requirements can be extrapolated from comparable machines.

Assuming that all types of magnets are installed in the machine, only a part of them would be needed at the same time, reducing the number of converter to be installed.

Correction dipoles: 2 per 3 cells => 14

Quadrupoles, sextupoles and octupoles: 2 per cell => 42

Typical converter rating: 10kW

9.2 Budget Estimate

Civil engineering, services, water cooling, ventilation, 18kV feeders, magnet cables and fire detection not included.

Bending magnets power supply, asymmetric resonant option: 8MCHF.

Bending magnets power supply, POPS type option: 12MCHF.

8 Quadrupoles magnets power supplies (+1 hot spare): 12MCHF.

Correction magnets power supplies: 2MCHF.

9.3 Time Estimate

Starting from the formal approval of the project, 2 years would be needed for optimization, feasibility studies and converter pre-design. Another 3 years should be foreseen for production, installation and commissioning.

10. RF System [M. Paoluzzi]

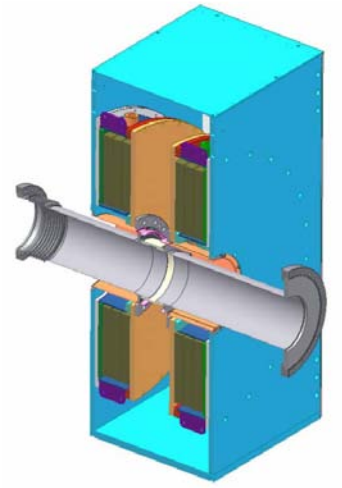
10.1 Technical Description

The main RCS parameters, from the RF system point of view, are listed in table X. The wide frequency range, the fast cycling and the limited available space in the straight sections, suggest the use of high-permeability materials and Finemet® is the magnetic alloy of choice because of the high value of its figure of merit, $\mu_p Qf$, which translates into limited losses and high accelerating gradients. In addition, its very low quality factor, Q, allows the entire frequency range to be covered without any tuning system which would, at the specified 10 Hz repetition rate, introduce a substantial additional complexity. Moreover, the wideband characteristic enables multi-harmonic operation.

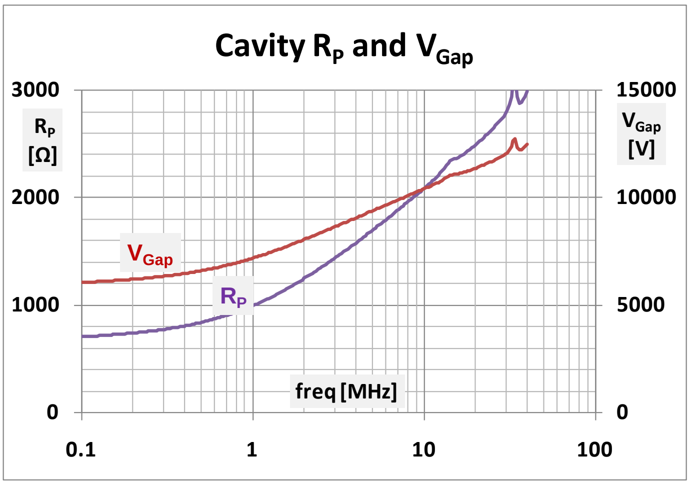
Table X — Main parameters

Parameter	Value
Energy range	160 MeV to 2 GeV
Repetition rate	~10 Hz
RF voltage	60 kV
Revolution Frequency	1.1? MHz to 3.3? MHz
Harmonic numbers	h = 1 to 4
Frequency range	1.?? MHz to 10.?? MHz
Available length	4.5 m ??
Beam intensity	1e13 ppp
Energy increase	~ 3 kJ
Required power	60 kW (acceleration in 50 ms)

The foreseen RF cavity (similar to the LEIR ones) is a coaxial resonator with the accelerating gap in the centre (see Fig. Y-a). Each cavity contains 6 Finemet® rings (OD=670 mm ID=305 mm, T=25 mm), is 0.5 m long and at the proven water cooling capabilities (620 kW/m^3 of Finemet®) the CW gap voltage will span from 7.2 kV at 1 MHz to 10.4 kV at 10MHz (see Fig. Y-b). Limiting the low frequency duty-cycle to ~75 %, a nominal gap voltage of 8 kV can be achieved over the whole band.



a



b

Figure Y — Cavity structure

The cavity is basically a push-pull device with a very loose coupling between the two cavity halves that imposes a differential drive and thus a push-pull configuration for the final amplifier.

At low frequency, the cavity gap impedance is mainly dependent on the Finemet® characteristics and is strongly affected by the number of cores. At high frequency the response is primarily driven by the system capacitance which mostly depends on the resonator geometry. To achieve the required wideband response the system capacitances have to be compensated and this is achieved including them into a multi-section filter (Fig ZZ).

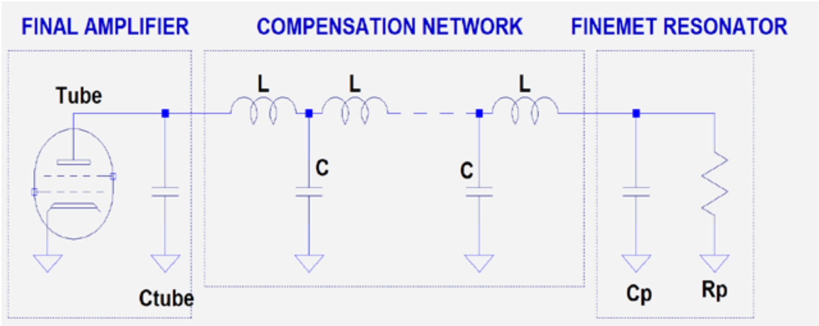


Figure ZZ — System capacitances compensation scheme

As a counterpart some ripples appear in the transfer function and its amplitude, phase and delay behavior are a compromise among the different system components.

Each cavity will be driven by a push-pull final stage built around 80 kW Thales tetrodes type RS1084CJ. This is a water cooled device widely used in the PS complex for which simulation and testing tools are readily available.

System simulations have been carried-out showing that the expected performances can be achieved. Figure Z plots the frequency response and table W lists the RF system parameters.

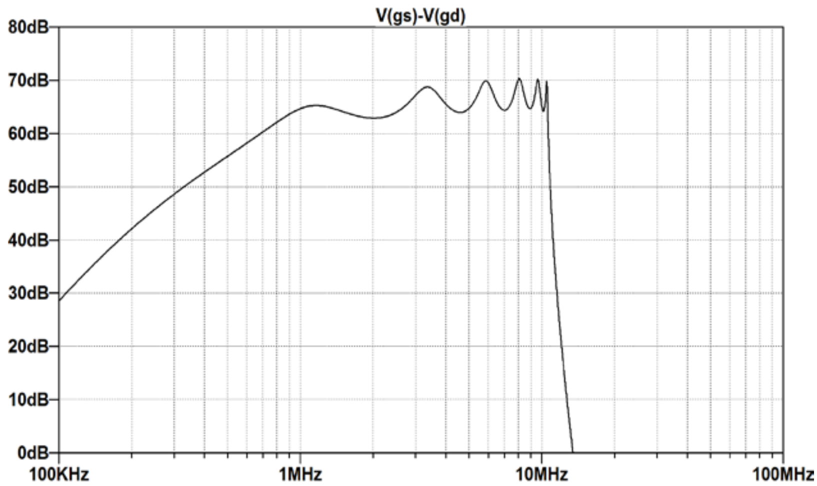


Figure Z — Frequency response

Table W — RF system parameters

Parameter	Value

Cavity Gap Voltage	8 kV
Frequency range	1.0 to 10.0 MHz
Cavity power	26 kW
Cavity length	0.5 m
HV supply voltage	8 kV
HV supply current	~20 A
Plate power dissipation	55 kW
Driving power	250W
Repetition rate	~10 Hz
Number of cavities	8

The circuit configuration selected to cover the wide frequency range does not allow the implementation of a fast RF feedback loop for beam loading compensation. Nevertheless alternatives exist such as the feed-forward scheme schetched in fig. ZZZ and successfully used in J-PARC[2]. The concept has proved its ability of reducing the beam induced voltages by more than 20 dB.

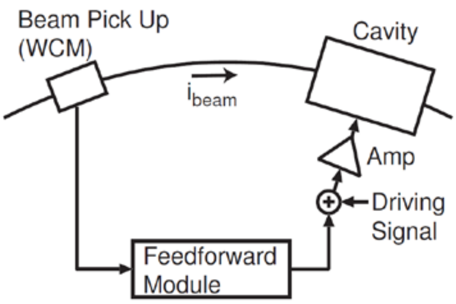


Figure ZZZ — Feed forward beam loading compensation.

(Courtesy Dr. F. Tamura, J-PARC)

10.2 Budget Estimate

The cost of the complete RF system composed of 8 cavities and amplifiers, power supplies, spares, ancillary equipment and a test stand has been estimated to approximately kCHF 13,000.

10.3 Time Estimate

Provided a Finemet® FT3L production facility is made available for the required ring size (presently the only possibility is in J-PARC), 2 years are required for the prototype design, development and testing. Two additional years are needed for the final production and installation.

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[2] Fumihiko Tamura, J-PARC RF group, private communications.

11. Beam Intercepting Devices [O. Aberle]

11.1 Technical Description

For the RCS we consider the implementation of 1 beam dump + 1 spare and 2 beam stoppers + 1 spare. Other beam intercepting devices (collimators, scrapers...) are not included in this estimate. The beam parameters are: Beam energy of 2 GeV with Linac 4 intensities?

11.2 Budget Estimate

Based on the PSB studies the budget is estimated to 800 kCHF, including Fluka and thermo mechanical studies, design, material and manufacturing of 2 dumps and 3 beam stoppers.

11.3 Time Estimate

A period of 2 years is required for design, construction and testing of the objects.

12. Beam Instrumentation [J. Tan]

12.1 Technical Description

In [https://twiki.cern.ch/twiki/bin/view/PSBUpgrade/MinutesMeeting20April2011], a list of beams diagnostics for the RCS was proposed. In the following, a brief description of each instrument is given, without any detailed specification (resolution, precision, threshold...), considering the new ring and its transfer line towards the PS. The transfer line between the Linac4 and the RCS is not included here as it uses most of the diagnostics systems which are already funded by the Linac4 project.

12.2 Synchrotron Monitors

12.2.1 Beam position monitors

Orbit measurement is possible only with bunched beams. A couple of horizontal signals can be sent to the LLRF for radial loop. With the working point of Q_H=4.2053 and Q_V=3.95, it is proposed to implement 4 dual-plane BPMs per betatron wavelength, which gives a total of 16 units. The revolution frequency at 2GeV being 2.37MHz, one can estimate a maximum rms bunch length of 200ns for a filled bucket (h=1) and a minimum of 10ns for the LHCPROBE beam. A capacitive BPM, in addition to its good linearity, is a broadband structure : it keeps information on the beam waveform and allows turn-by turn measurements. Due to space restrictions, it is proposed to use PS-type BPMs (see figure XX), which would save significant space as they can be inserted into vacuum pump manifold.

Figure XX : Capacitive pick-up in the PS ring.

12.2.2 Wide band pick-up

A wide band pick-up is generally used for longitudinal phase space reconstruction. A wall current monitor with some hundreds of MHz bandwidth (300MHz for the PSB) is suitable for these applications. An operational unit and a spare one is recommended. About 400mm of machine space (flange to flange) is required.

12.2.3 Q-measurement

The FFT of the measured beam transverse oscillations gives the non-integer part of the tune. Again owing to space restriction, a set of dual-plane kicker and pick-up (stripline type) is proposed for this task. However they can be inserted inside quadrupole magnets.

12.2.4 Current transformers

In a synchrotron, a DC current transformer measures coasting beam currents while a semi-fast transformer allows studies of injection efficiency (turn by turn) : one of each monitor is needed in the RCS. About 550mm of machine space per monitor (flange to flange) is necessary. The transformers are integrated in the machine protection system (comparators...).

12.2.5 Beam Loss Monitors

BLMs are also integrated in the machine protection system. Fast monitors are required for a 10Hz cycling machine. From the proposed lattice, about of 20 BLMs would be spread around the ring.

12.2.6 Fast Wire Scanners

Beam profiles can be obtained with a Fast Wire Scanner (one device per transverse plane) for extracting the emittances. About 400mm of machine space per monitor (flange to flange) is necessary.

12.2.7 Scintillating screens

Such device is used for observing the beam nearby the injection foil.

12.3 Extraction Line Monitors

12.3.1 Beam trajectory measurements

For the RCS to PS extraction line, it is not possible to use the trajectory system foreseen for the Linac4, based on shorted striplines : wrong bandwidth and poor sensitivity in the MHz range are the main arguments to rule them out. It is proposed instead to equip the new transfer line with the inductive PUs, like those in the extraction-recombination line from the Booster to the PS (see figure YY). With a set of 10 units which would be re-used from the decommissioning of the extraction-recombination line, about 15 additional monitors are needed to uniformly equip the RCS to PS extraction line.

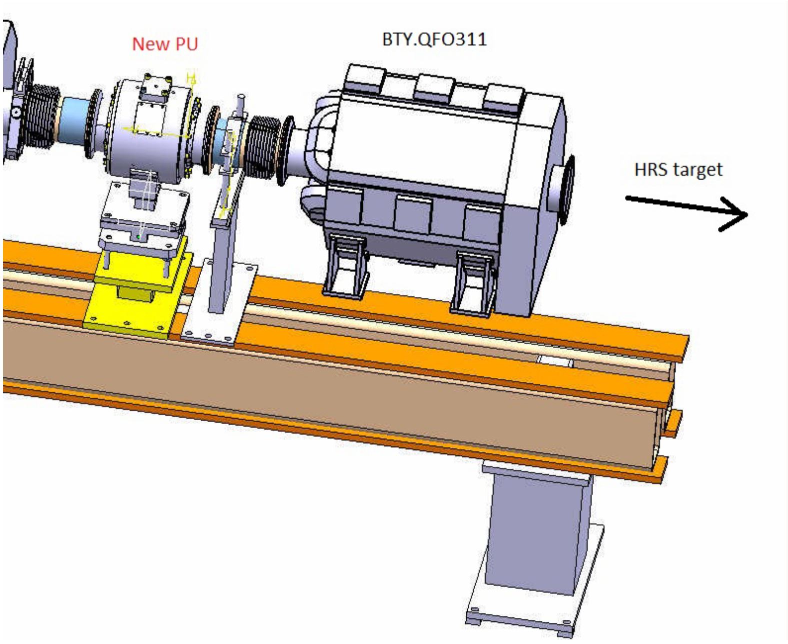

Figure YY : Integration of the inductive pic-up in Isolde transfer line

12.3.2 Current transformers

Fast transformers (see figure AA) are implemented in the transfer lines (injection and extraction). The present BT.TRA can be moved right downstream the RCS extraction point. The fast transformers are integrated in the machine protection system (watchdog). Basically the cost would be more related to the acquisition chain (electronics, cables, controls) than to the monitor itself.

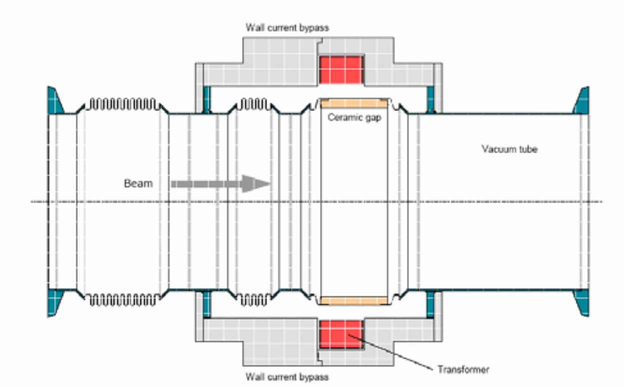

Figure AA : Principle of a fast current transformer

12.3.3 Beam Loss Monitors

The number of BLMs in the transfer line depends on the optics. As a rule of thumb, they are placed nearby a septum, kicker or bending magnets. Ten BLMs as first guess seems to be a minimum prerequesite

12.3.4 Scintillating screens

This monitor is generally housed in the extraction septum tank. A screen is associated with BLMs, which gives about 10 units placed along the extraction line.

12.3.5 SEM grids

In case the measurement line is kept, it is proposed to build new SEM grids, with integrated resistors for self testing, and shorter wire spacing for improved resolution. A set of three monitors has to be foreseen.

12.4 Budget Estimate

The total budget estimate is the minimum needed as some instruments shall be taken from the decommissioning of the PSB and its transfer line. The table below summarizes the request per instrument, including : the monitor, the tank and its support, the drawing office, the controls (crates, CPUs, timings), the acquisition chain (ADCs, amplifiers), the cables, and some external support (FSU). A spare is foreseen for critical instruments.

Instrument	Budget [kCHF]	Comments
Pick-ups	760 + 640	RCS + transfer line
Wide band pick-up	165	RCS
Q measurement	176	RCS
DCCT + Fast BCT	190	RCS

Beam loss monitors	205	RCS + transfer line
Fast wire scanners	181	RCS
Scintillating screens	366	RCS + transfer line
SEM grids	200	transfer line
TOTAL [kCHF]	**2,883**	

Manpower Estimate

13. Beam Interlocks [B.Puccio]

13.1 Technical Description

The Beam Interlock System (BIS) is a generic solution to protect CERN accelerators and facilities. It is currently in operation for the SPS ring, the SPS transfer lines and for the LHC. It will be deployed in LINAC4 and PSB.

The system is composed of remote User Interfaces (CIBUs) and Controller(s). The latter is embedded in VME crate: it receives the CIBUs information and evaluates the USER_PERMIT signals in order to produce a BEAM_PERMIT signal.

13.2 Budget Estimate

The cost will mainly depend of the number of connected systems, and their distance (=> cables length) with the Beam Interlock Controller(s).

For a first estimation, we assume that the number of User systems will be equivalent to the Booster and the BIS architecture will be the same as well. Therefore, the corresponding budget will be roughly 200 kCHF.

13.3 Time Estimate

From the time of project approval, including study, ordering, manufacturing and testing in the lab, an estimate for readiness to a commissioning is approximately 12 months.

14. **Civil Engineering** [L.A. Lopez-Hernandez]

14.1 Technical Description

The civil engineering to be carried out is at the CERN site of Meyrin and consists of one tunnel (approx 127 m long), situated 13m below finished ground level, and one surface building (approx 54 m long by 32 m wide).

Several concrete ducts will connect the tunnel and the building and a concrete structure will provide access for personnel and equipment at the tunnel by means of a lift shaft and stairwell.

The existing tunnel Linac4 will be modified to allow for connection of the new RCS tunnel.

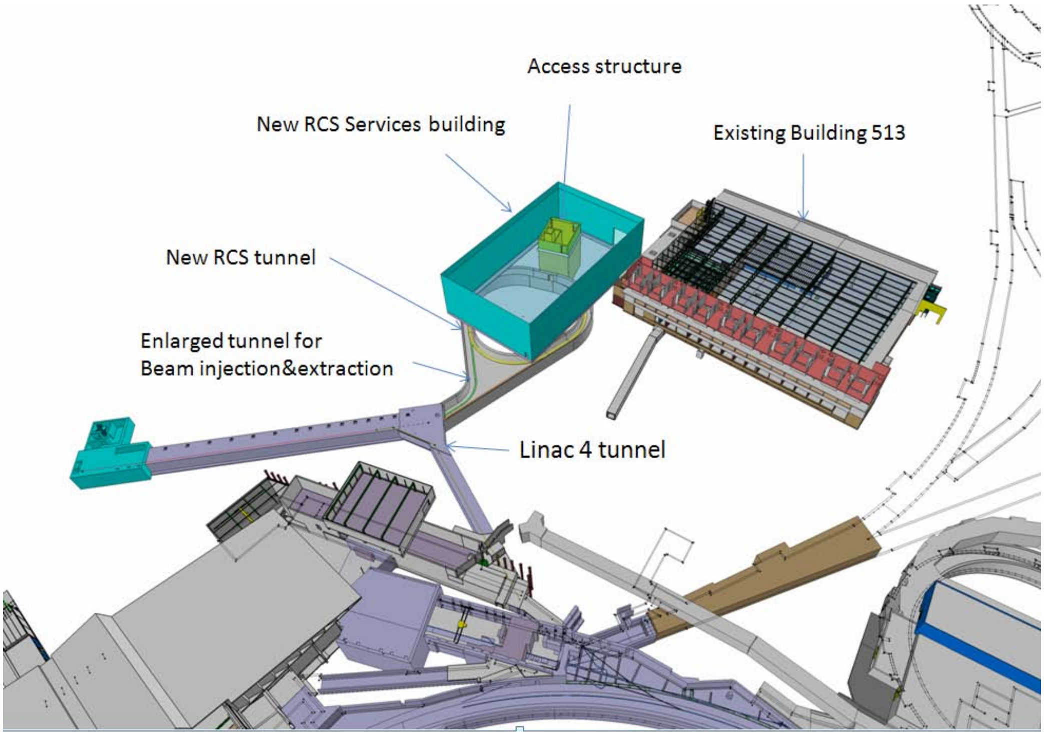

Figure 1 – RCS design May 2011

14.1.1 Description of the site and geotechnical aspects

The RCS site is located in the CERN site of Meyrin, on French territory, between building 513 and the Rutherford road.

The work area site covers the southern area of the parking building 513 but it also crosses the road Rutherford and part of the road Feynman.

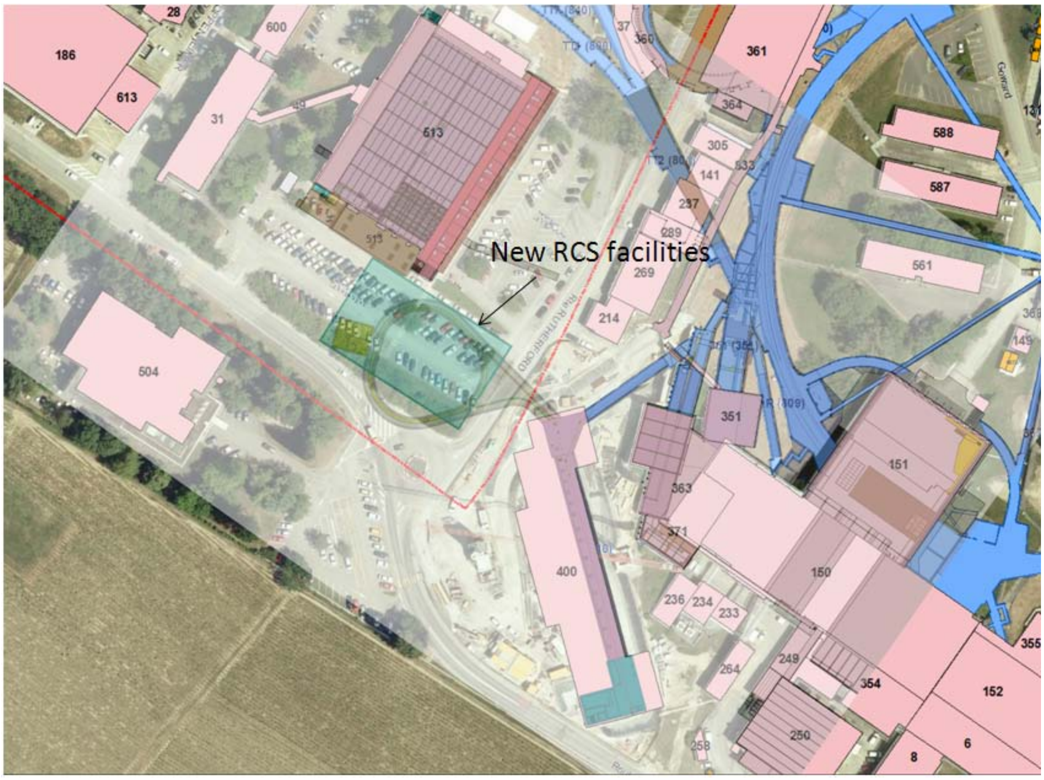

Figure 2 - RCS location

The ground through which and in which the underground structures will be excavated consists of a relatively thin superficial deposit of glacial moraine above a mixed sequence of molasse.

The molasse consists of irregular, sub-horizontally bedded tenses of rock with lateral and vertical variations from very hard and soft sandstones, to weak marl. Significant property variations occur between and within each gradational lens, making it difficult to assign parameters which are truly representative of the rock mass. It is possible that certain contaminants such as hydrocarbons could be found within the molasse which are to be selectively loaded and disposed in a certified dump.

Several networks are present on the site. These networks will have to be diverted before the start of the works.

14.1.2 Description of the underground structures

14.1.2.1 Introduction

The structures designed from a CE point of view are listed below. Each structure has a description, function and particular specification. All structures must have a design life of fifty years.

All underground structures will be provided with an inner lining of concrete and be totally free from all visible signs of water ingress either from joints, cracks or elsewhere.

It is foreseen to carry out the excavation works using piled walls anchored with prestressed anchor bolts and supported on the molasse. The excavation for each pile shall be made by drilling through the soils and into rock. After the piles have been installed, the earth is excavated along the piles wall and protected by means of projected shotcrete.

Instrumentation and monitoring of excavations and of the existing structures, particularly the buildings 513 (Computer center) and 400 (Linac 4) are key elements of the construction process.

The possibility to carry out this work using underground methods has yet to be evaluated. Indeed, while being very costly in view of the lengths of structures and their depth, this option would allow to preserve the existing networks and it significantly reduce the nuisance to the Meyrin site such as the deviation of roads Rutherford and Feynman.

14.1.2.2 RCS Tunnel

The function of this tunnel is to house the RCS machine.

The RCS tunnel is envisaged to be approximately 120 m long and have internal dimensions of 3.00 m width and 3.50 m height. It will be situated 13 m below finished ground level.

The tunnel is connected with the surface via one access structure, and with the Linac 4, via an enlarged tunnel approximately 40 m long, containing the transfer lines for the injection and extraction of the beam.

14.1.2.3 Enlarged tunnel for beam injection and extraction

The purpose of this tunnel is to transfer the H– ion beam from the Linac4 to the RCS and from the RCS to the PS.

This tunnel is envisaged to be approximately 40 m long and have internal dimensions of 3.5 m height and between 6.0m and 20m width. It will be horizontal and situated 13 m below finished ground level.

This tunnel will connect into the Linac4 tunnel and will pass under the existing building 400 which will have to be suspended above the open excavation and remain operational.

14.1.2.4 RCS access structure

The function of the RCS access structure is to provide an access for personnel, equipment and services into the RCS tunnel.

The RCS access structure will house a lift shaft and a stair well.

14.1.2.5 Modifications to existing Linac4 tunnel

The concrete wall of Linac4 tunnel will be partially demolished for the connexion of the injection/extraction tunnel.

14.1.3 Description of the surface structures

14.1.3.1 Introduction

There is one surface structure associated with this project. This building will be similar to existing CERN buildings, i.e. steel frame with cladding.

14.1.3.2 RCS building

The function of this building is to house the equipment, the racks and services needed for the RCS operation.

It will be a steel frame with cladding and have the dimensions shown on the drawings. The building will be equipped with a 10 t capacity gantry crane.

14.1.3.3 Car parks, roads and services

Car parking, roads, surface water drainage and landscaping of the area around the new Klystrons building will be part of the civil engineering works for this project.

14.1.3.4 Architectural Building work and finishes

The amount of building and finishing Works is minimal, consistent with industrial type structures. Internal architectural building and finishing works will include:

-Concrete block partition walls with rendering and gypsum plaster

-Doors and windows

-Sanitary ware and waste water disposal

-Supply of potable water

-Fire doors, industrial doors and access doors

-Stairs, walkways, balustrades and footbridges

-Rainwater gutters

Not included:

-Cooling and ventilation

-Electrical infrastructure

-Handling and lifting equipment

-Access control, safety and interlock systems

-Mechanical features

14.2 Budget Estimate

14.2.1 Budget estimate

	Cost (CHF) (estimate may 2011)
Sub-surface works	10 890 000
Surface works	8 530 000
CE studies and site supervision	2 100 000
Miscellaneous	1 610 000
TOTAL	**23 130 000**

14.2.2 Spending profile

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
KCHF	450 000	900 000	8 000 000	8 000 000	4 000 000	1 780 000

14.2.3 Manpower estimate

In FTEy	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Eng.	1.0	1.0	1.0	1.0	0.3	0
Tech.	1.0	1.0	1.5	1.5	1.0	0.5

14.3 Time Estimate

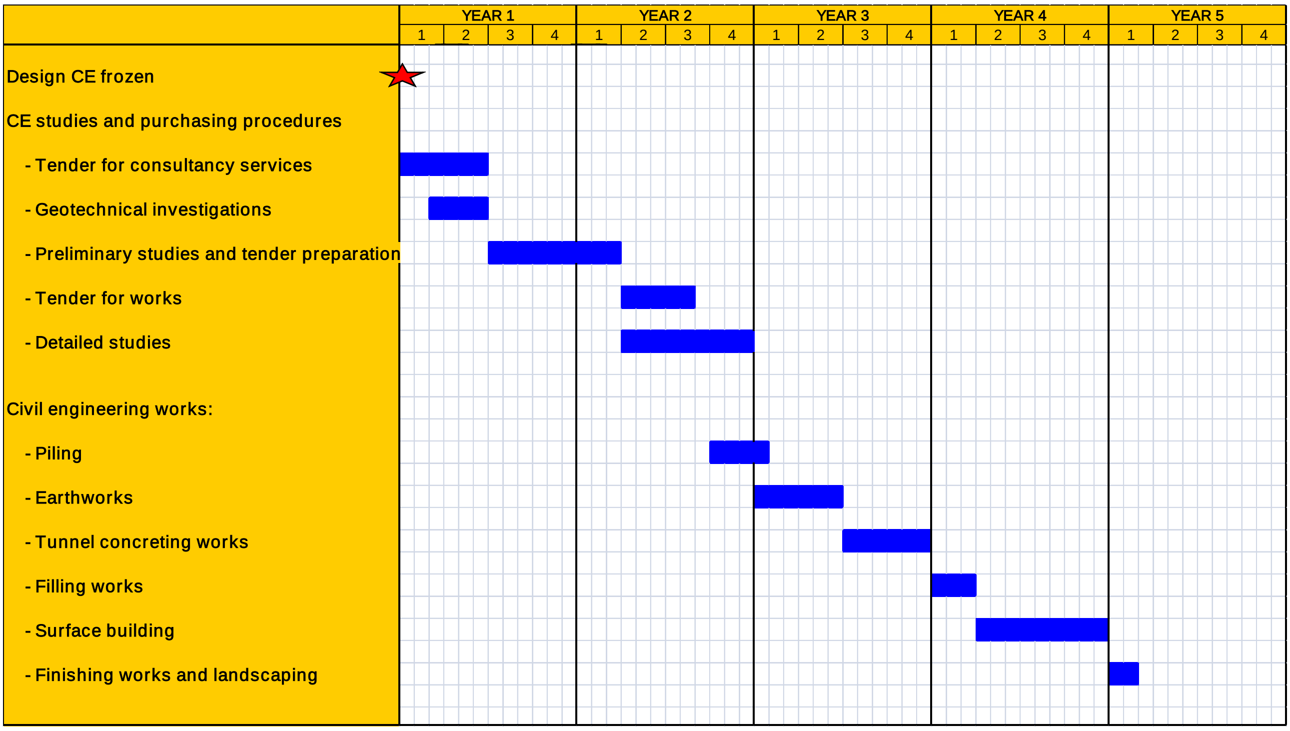

Figure 2.- Preliminary works schedule

15. **Cooling and Ventilation** [M. Nonis]

15.1 Technical Description

15.2 Budget Estimate

15.3 Time Estimate

16. **Transport Systems** [I. Ruehl]

16.1 Technical Description

The installation of a lift with 2t capacity will allow the transfer of people and goods from the surface to the accelerator zone. The lift access will have to form an integral part of the interlock system.

The surface building will be equipped with a double girder Electrical Overhead Travelling (EOT) crane of 20t capacity.

The accelerator zone will be equipped with three 10t capacity EOT cranes of which two can be coupled to lift loads of up to 20t.

The floor transport equipment in the accelerator zone will be a standard electrical tractor with a pulling force of 20t. A set of trailers with capacities ranging from 1t to 20t will be required to transport the miscellaneous machine components. No guiding system required provided that there is enough clearance available. This requires detailed integration studies and a sufficiently reserved big transport zone.

16.2 Budget Estimate

1 Lift	2t capacity	interlocked	200kCHF (depending on floor levels)
1 EOT crane	20t capacity	double girder	200kCHF (depending on span)
3 EOT cranes	10t capacity	single/double girder	300kCHF (depending on span)
1 Tractor	20t capacity	battery vehicle	60kCHF
Set of trailers 1-20t			80kCHF
Auxiliary handling equipment			50kCHF
TOTAL cost estimate			890kCHF

Please note that the estimated costs for the installation of the four EOT cranes do not include the crane rails. These are normally provided via the civil engineering works.

16.3 Time Estimate

Installation and commissioning of 2t lift	3 months
Installation and commissioning of 20t EOT crane	1 month
Installation and commissioning of three 10t EOT cranes	1.5 month

17. **Radiological Protection** [M. Widorski]

17.1 Technical Description

17.2 Budget Estimate

17.3 Time Estimate

18. **Budget Summary** [K. Hanke]

18.1 [LEVEL 2 TITLE]

system	**cost estimate [kCHF]**	**time estimate (from project approval)**
Operational Aspects	-	-
Design & Paramters	-	-
RCS injection and extraction	xxx	xxx
RCS2PS Transfer Line	xxx	xxx
PS Injection	xxx	xxx

Magnets	8856	36 m
Magnet interlocks	300-500	12 m
Power supplies	22000 (resonant) 26000 (POPS type)	2 y study & design 3 y production, installation, commissioning
RF Systems	13000	2 y development 2 y production/installation
Beam Intercepting Devices	800	2 y
Beam Instrumentation	2883	-
Beam Interlocks	200	12 m
Civil Engineering	23130	4 y 2 m
Cooling & Ventilation	xxx	xxx
Transport Systems	890	3 m
Radiological Protection	xxx	xxx
Linac4 Modifications	xxx	xxx

19. Planning Summary [K. Hanke]

19.1 [LEVEL 2 TITLE]

20. References

[1] K. Hanke et al, PS Booster Energy Upgrade Feasibility Study - First Report, https://edms.cern.ch/document/1082646/3

[2] C. Carli et al, Alternative / complementary possibilities, Chamonix 2011 LHC Performance Workshop, Session 9, http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=103957

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