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CH-1211 Geneva 23
Switzerland

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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.

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
K. Hanke other authors	All GLs	R. Garoby P. Collier F. Bordry R.Saban
		DOCUMENT RELEASED BY: [Releaser]

DOCUMENT SENT FOR INFORMATION TO:

[List of persons to whom the document is sent]

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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 [1]. 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]

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

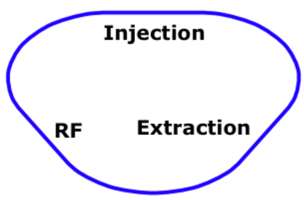
3.1 Technical Description

In the following we will describe the one option chosen as baseline design. Other design 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]

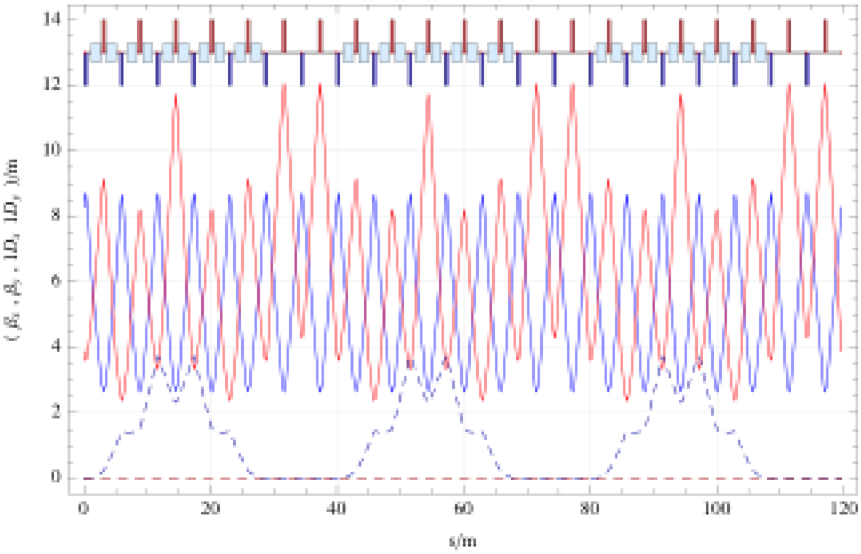


[1] [Foot note]

3.1.2 Optics

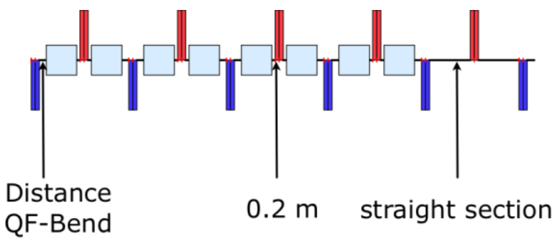
The lattice consists of 21 cells – 5 per arc and 2 per straight section - with a cell length of 5.6993 m. Most space-saving for injection/extraction is a FODO cell structure as here the kick of the QD in the centre of the cell can be exploit (chapter **Error! Reference source not found.**). In this lattice 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 2π 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 Q_H= 4.205 and Q_V= 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

4. Injection and Extraction [B. Goddard]

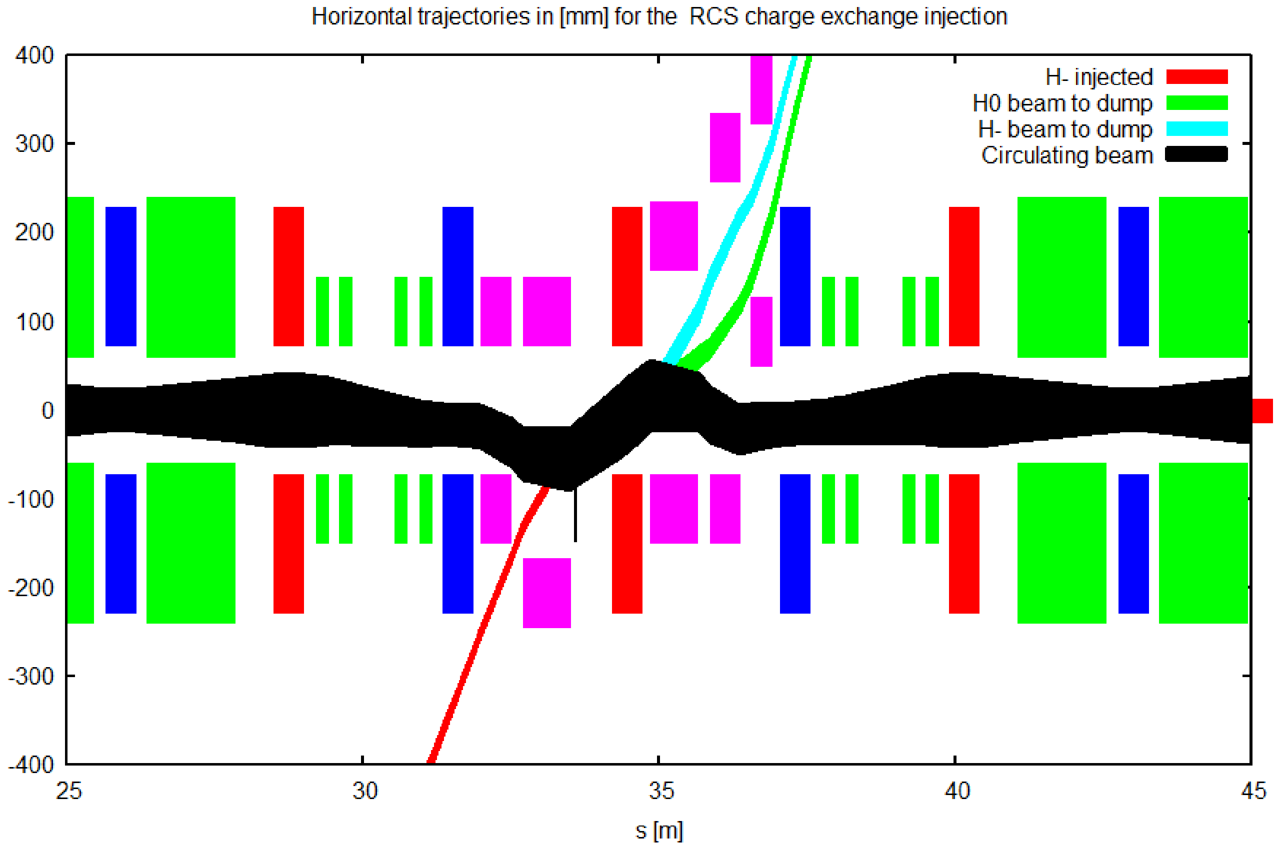
4.1 Technical Description

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).]

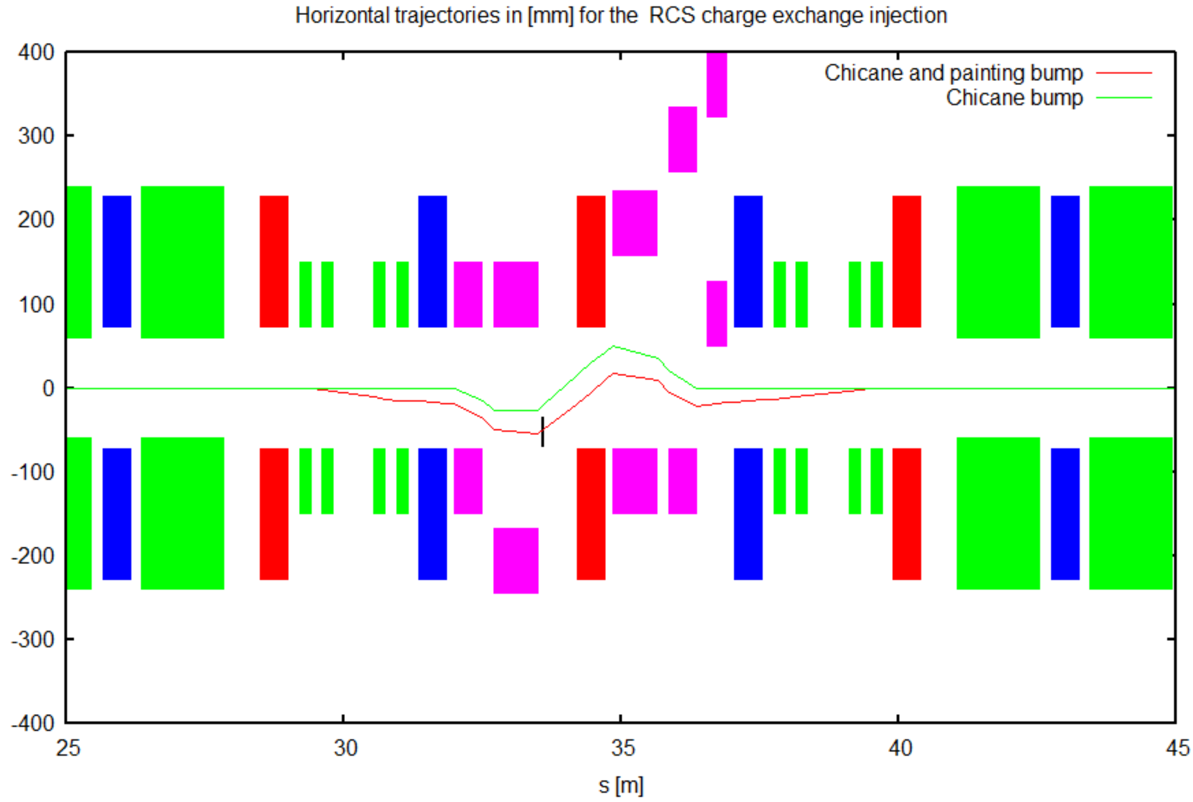


The stripping foil F1 is placed downstream of D2 to strip the H- ions to protons. The foil thickness has to be optimised with respect to stripping efficiency, foil heating and emittance blow up of the circulating beam. The unstripped H- (turquois) or partially stripped H0 (green) need to be deflected 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 horizotal 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 to deploy 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 focussing 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]

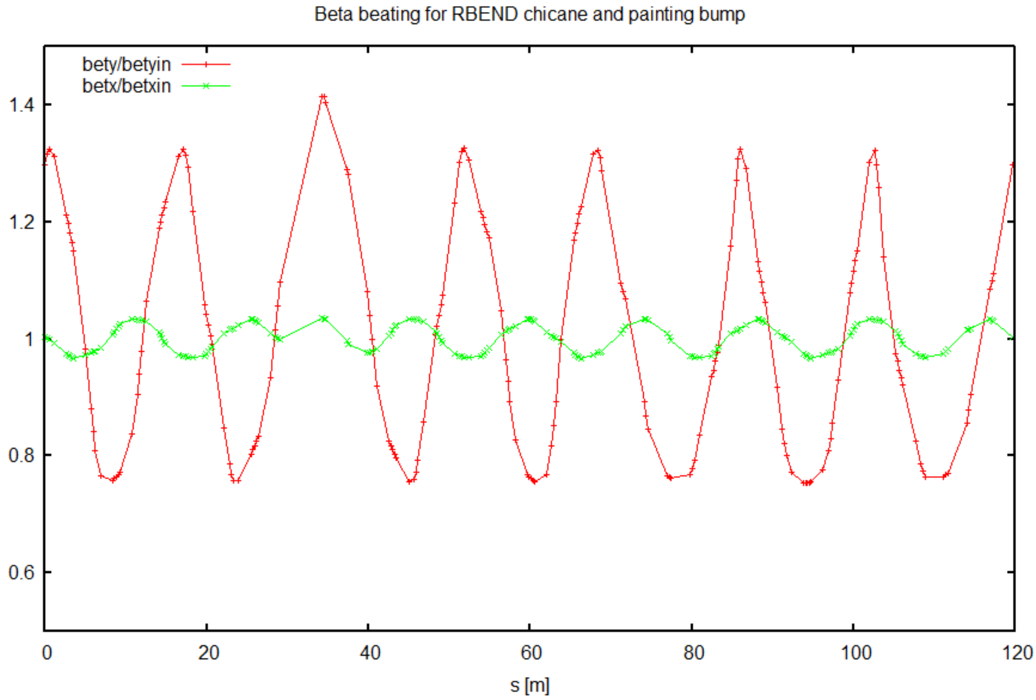


Figure 4.4 — [Beta beating for RBEND chicane and painting magnets]

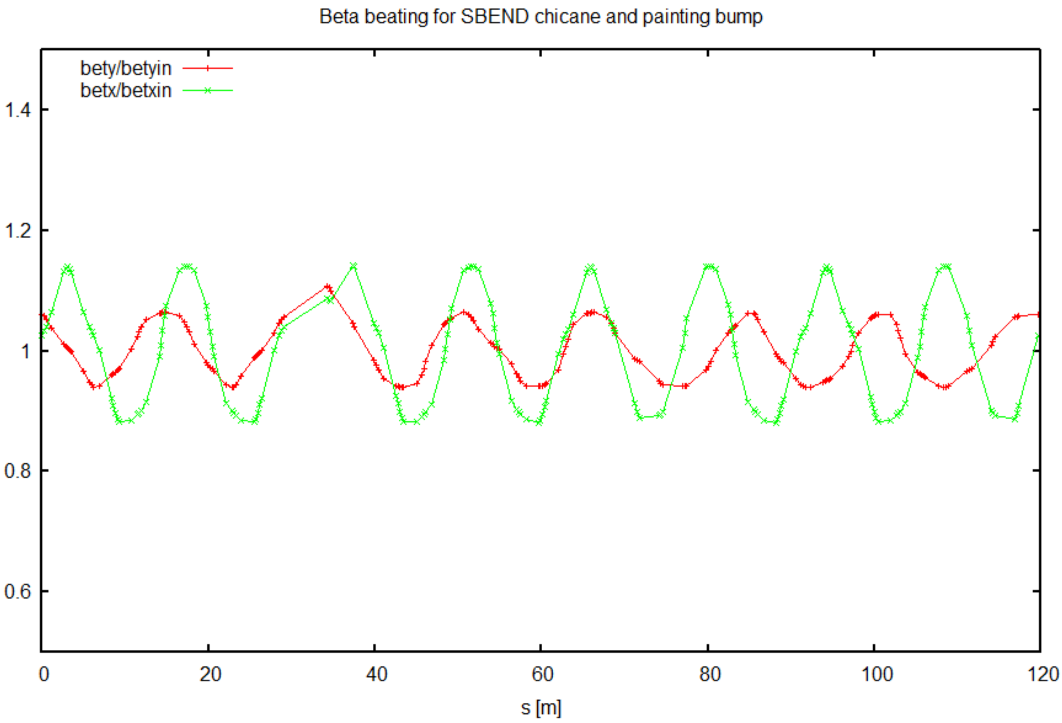


Table 4.6 — [Chicane magnet kicks and integrated fields at 160 MeV kinetic energy]

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]

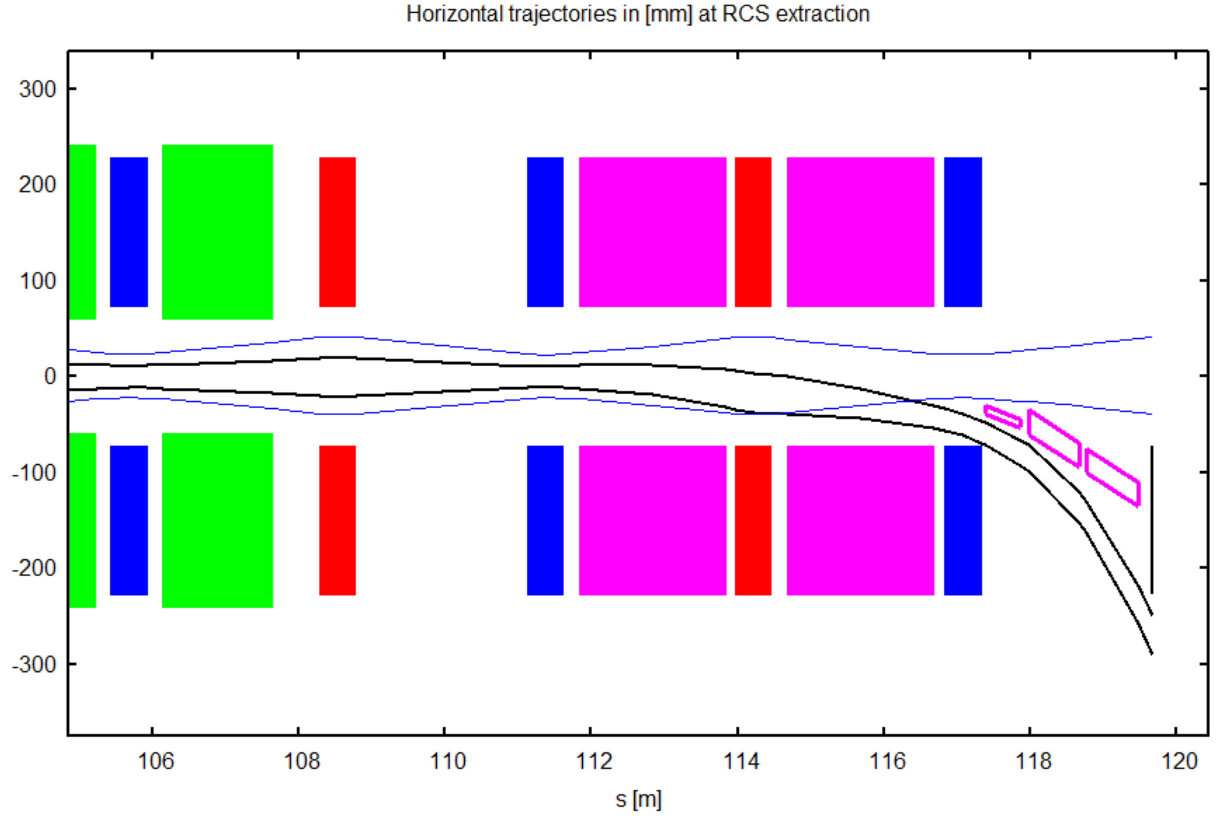
Magnet	Kick angle [mrad]	Length [m]	Integral field B.dl [Tm]	Field [T]
MKH1	-9.0	0.2	0.017	0.085
MKH2	8.2	0.2	0.016	0.078
MKH3	2.3	0.2	0.004	0.022
MKH4	-7.5	0.2	0.014	0.071
MKV1	39.9	0.4	0.076	0.190
MKV2	-30.6	0.4	0.058	0.145
MKV3	-20.4	0.4	0.039	0.097
MKV4	29.6	0.4	0.056	0.141

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. Magnets [A. Newborough]

5.1 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, multipoles 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.

5.1.2 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 67.2 mm (+/- 33.6 mm) and a horizontal good field region of 98 mm (+/- 49 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/mm^2. 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)	0.9

Iron Height (m)	0.65
Aperture height (m)	0.0672
Aperture width (m)	0.24
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)	5779
Current at Injection (A)	1189
Current r.m.s. (A)*	3590
Resistance @ 20 °C (mΩ)	1.05
Resistance warm [ΔT = 30°C] (mΩ)	1.1
Inductance (mH)	1.3
Max. Volt-drop (V)**	205
Copper Losses, warm (kW)	14.3
Iron Losses (kW)	1.7
Total Dissipated Power (kW)	16
RCS Machine - Bending	
# Magnets in series (incl. Ref. magnet)	31
Total magnet resistance warm (mΩ)***	34
Total magnet inductance (mH)	40
Total dissipated power (kW)	494
Total volt drop (kV)	6.4

* 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

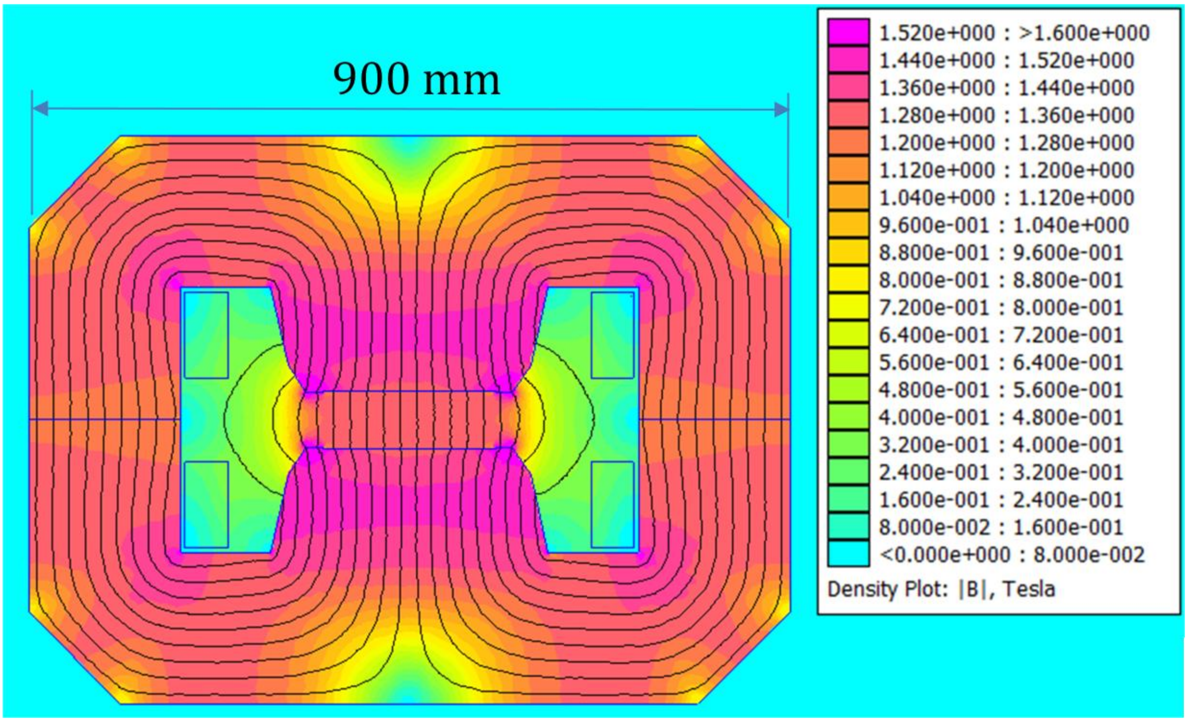
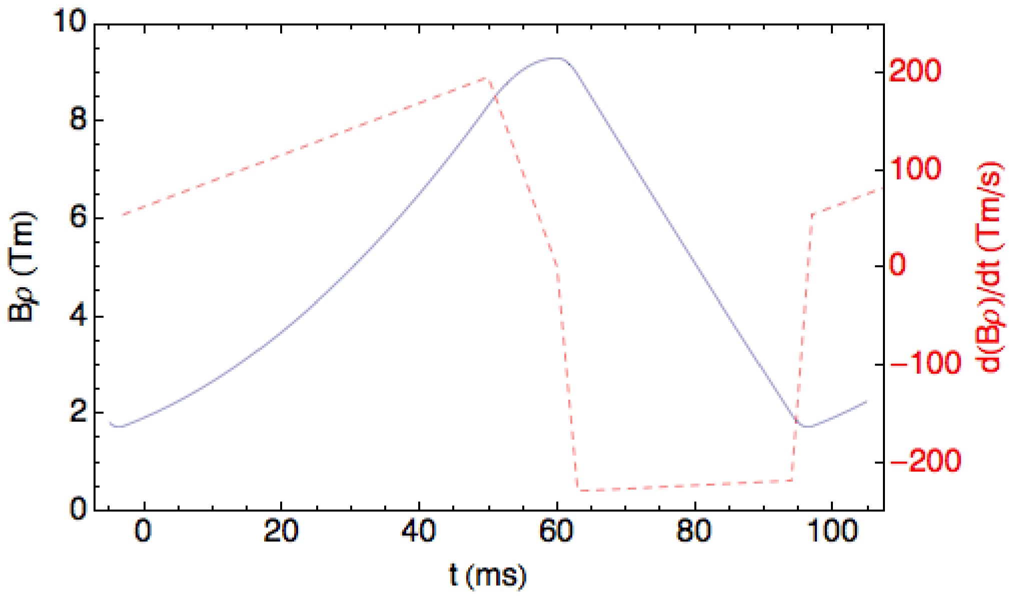


Figure 2, possible magnetic cycle



5.1.3 Main 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 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.

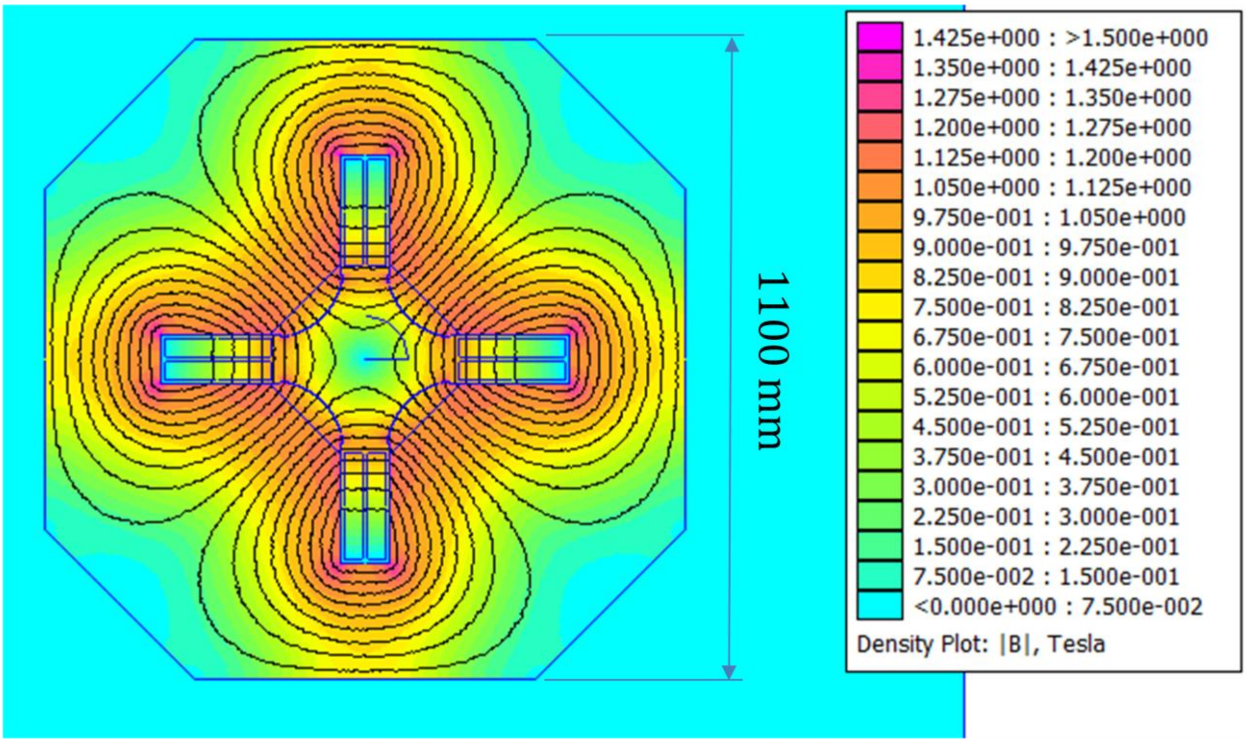


Table 2, Main Quadrupole Magnet Parameters

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 (mΩ)	1.79
Resistance warm [ΔT = 30°C] (mΩ)	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
RCS Machine – Quadrupole***	
# Magnets in series	21 QF or 21 QD
Total magnet resistance warm (mΩ)****	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

5.2 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	Magnet	**Dipole**	**Quadrupole**	
	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**

5.3 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.

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

6.1 Technical Description

6.2 Budget Estimate

6.3 Time Estimate

7. **RF System** [M. Paoluzzi]

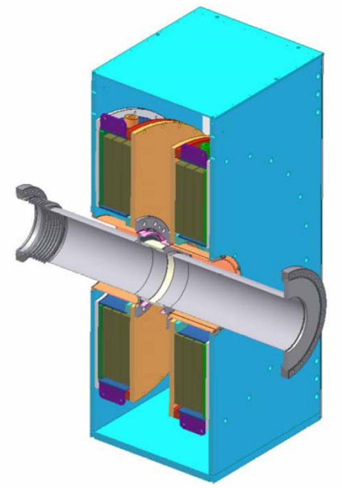
7.1 Technical Description

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.



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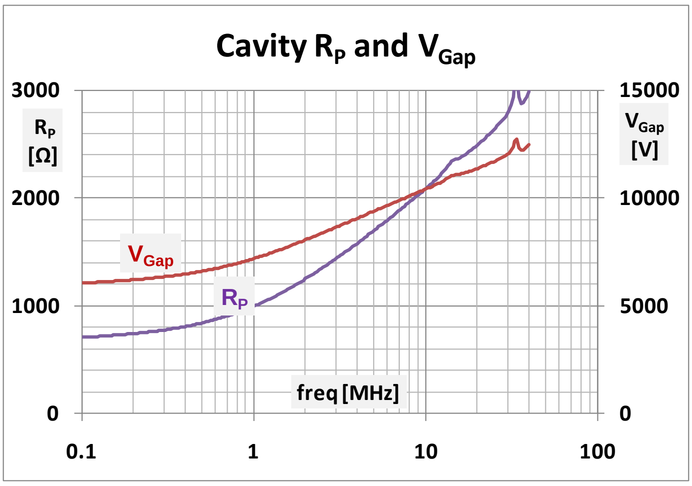

b

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).

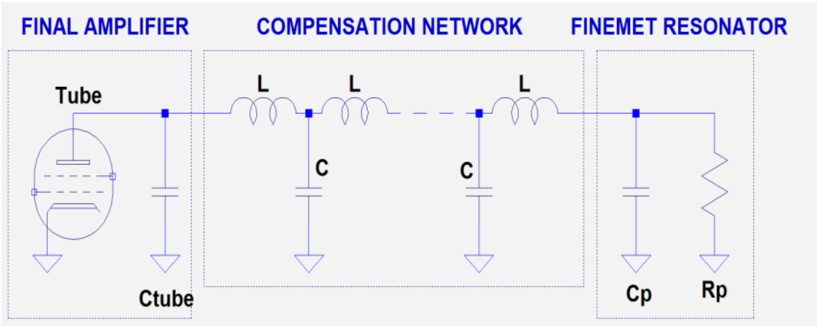

Figure ZZ — System capacitances compensation scheme

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.

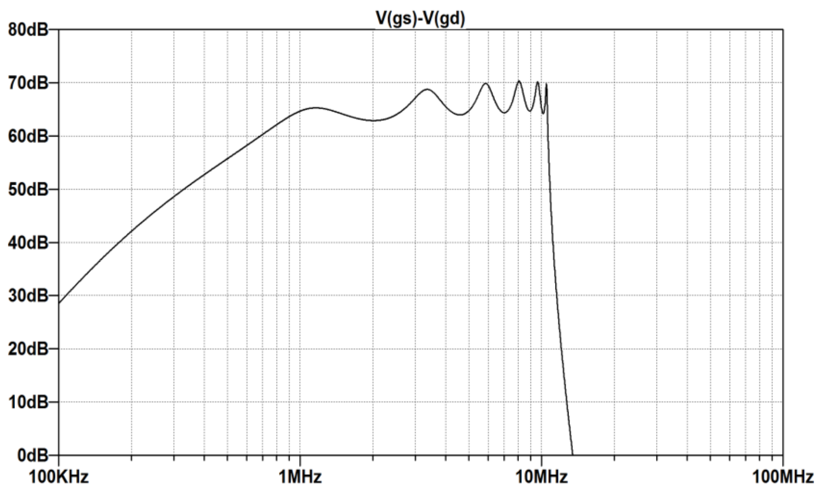

Figure Z — Frequency response

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.

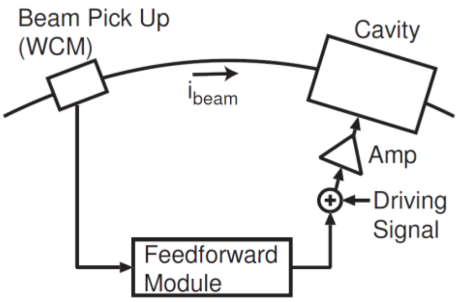

Figure ZZZ — Feed forward beam loading compensation.

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

7.2 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.

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

7.3 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.

8. Beam Intercepting Devices [O. Aberle]

8.1 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?

8.2 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.

8.3 Time Estimate

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

9. Beam Instrumentation [J. Tan]

9.1 Technical Description

9.2 Budget Estimate

9.3 Time Estimate

10. Civil Engineering [L.A. Lopez-Hernandez]

10.1 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.

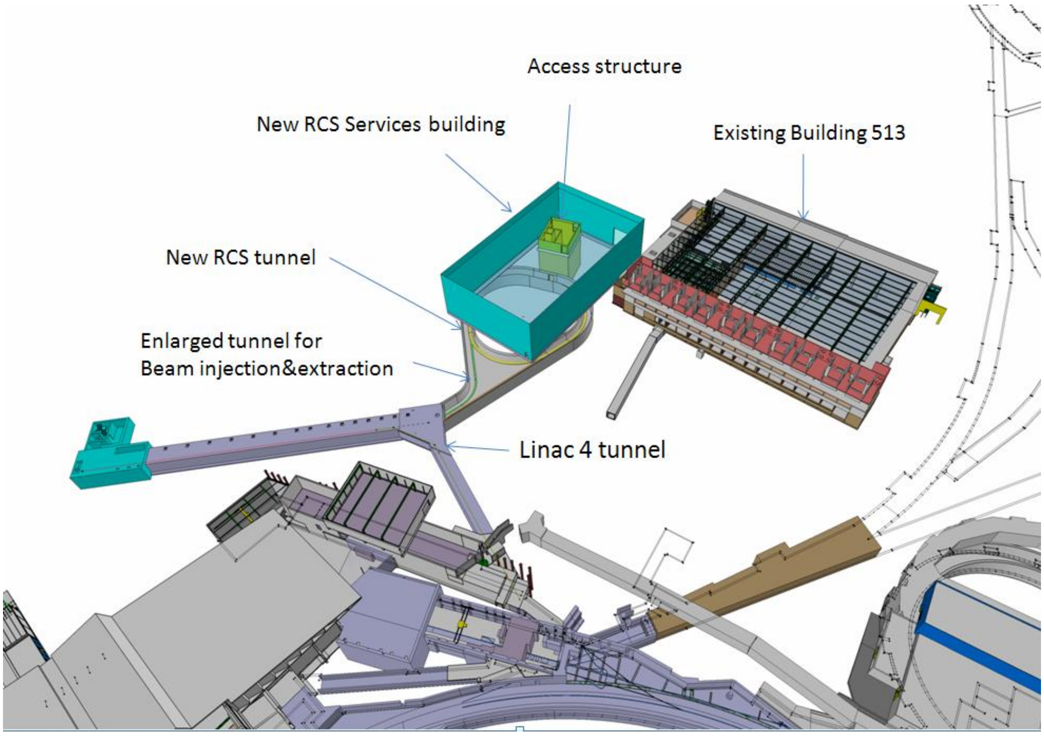

Figure 1 – RCS design May 2011

10.1.1 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.

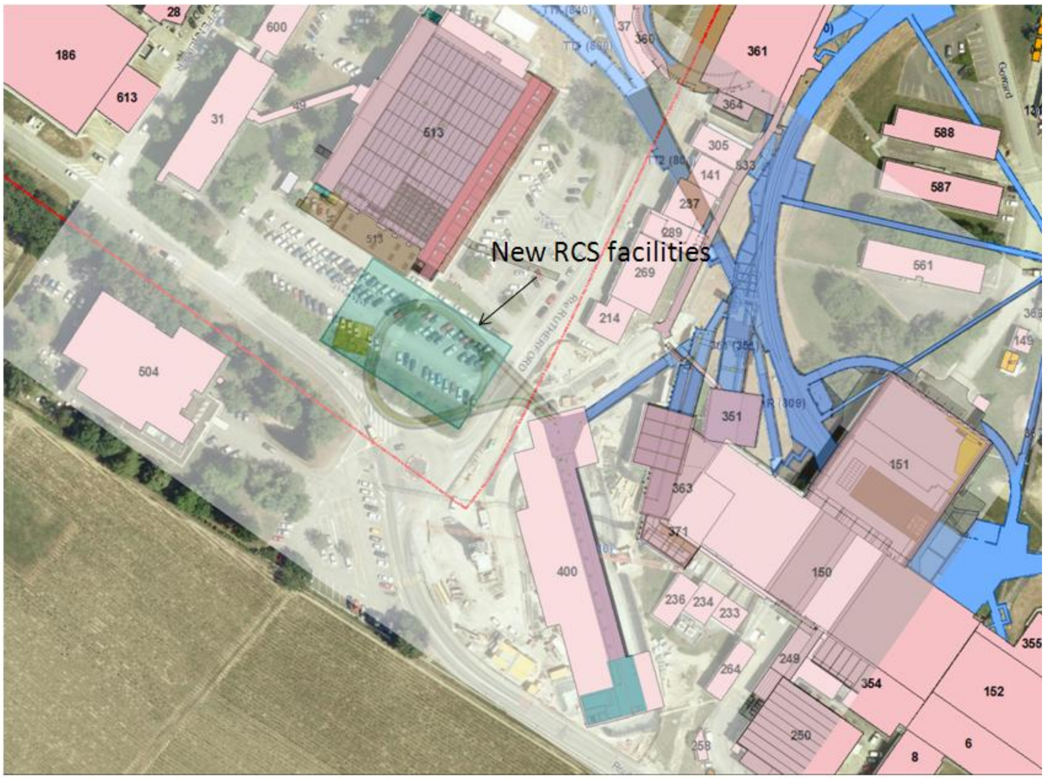

Figure 2 - RCS location

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.

10.1.2 Description of the underground structures

10.1.2.1 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.

10.1.2.2 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.

10.1.2.3 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.

10.1.2.4 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.

10.1.2.5 Modifications to existing Linac4 tunnel

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

10.1.3 Description of the surface structures

10.1.3.1 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.

10.1.3.2 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.

10.1.3.3 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.

10.1.3.4 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 IN THE SCOPE

-Cooling and ventilation

-Electrical infrastructure

-Handling and lifting equipment

-Access control, safety and interlock systems

-Mechanical features

10.2 Budget Estimate

10.2.1 Budget estimate

	Cost (kCHF) (estimate may 2011)
Civil engineering studies	
Main CE works	
Minor CE works	
Site supervision	
Finishing works/contingency	
TOTAL	

10.2.2 Spending profile

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
KCHF						

10.2.3 Manpower estimate

In FTEy	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Eng.						
Tech.						

10.3 Time Estimate

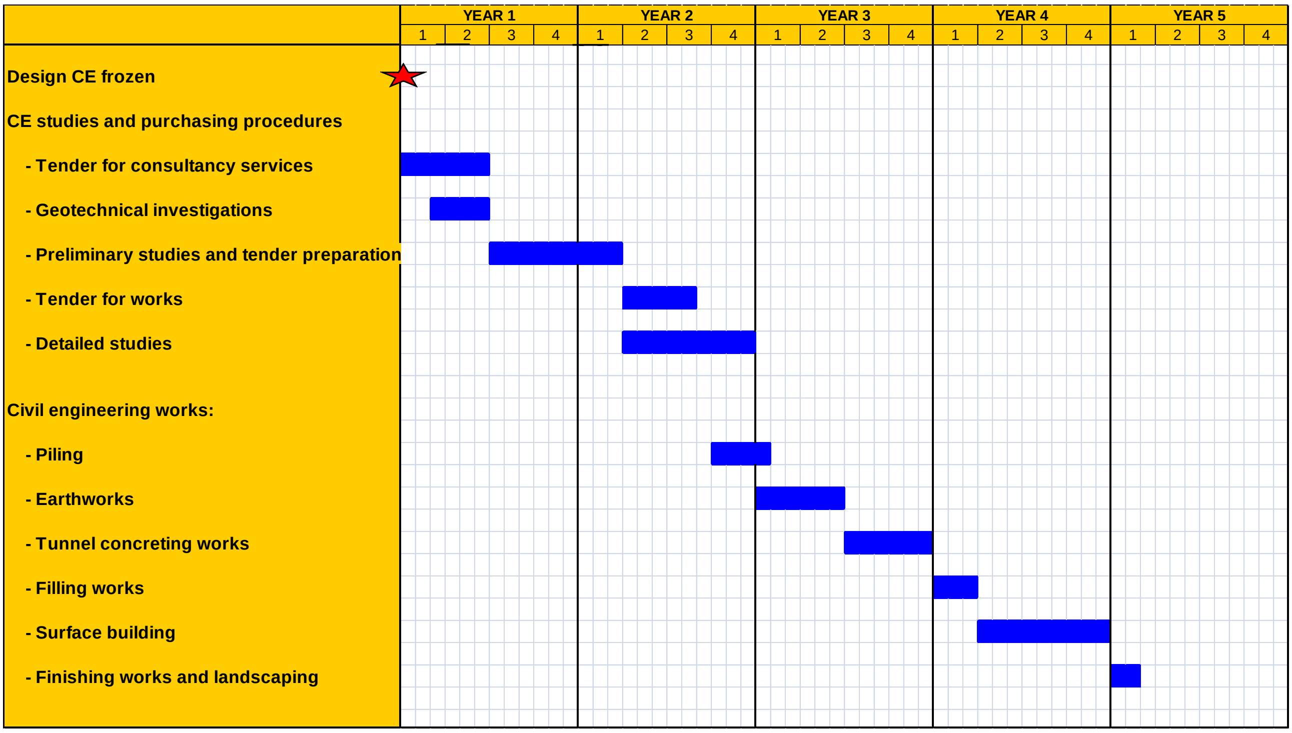

Figure 2.- Preliminary works schedule

11. **Transfer Line** [K. Hanke, M. Widorski, L.A. Lopez-Hernandez]

11.1 Technical Description

11.2 Budget Estimate

11.3 Time Estimate

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

12.1 Technical Description

12.2 Budget Estimate

12.3 Time Estimate

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

13.1 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.

13.2 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.

13.3 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

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

14.1 Technical Description

14.2 Budget Estimate

14.3 Time Estimate

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

15.1 [LEVEL 2 TITLE]

system	**cost estimate [kCHF]**	**time estimate**
RF Systems	13,000	2y development 2y production/installation

16. **Planning Summary** [K. Hanke]

16.1 [LEVEL 2 TITLE]

17. 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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