PHYSICS/MACHINE INTERFACE

PROSPECTS FOR ENERGY AND LUMINOSITY AT LEP2

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1 Introduction

This paper is a shortened and updated version of Ref. [1] where the status and scope of the LEP Energy Upgrade Programme as per June 1995 are also reported. Its aim is to provide concise information about further steps towards higher energies, as discussed at the 1995 Chamonix LEP Performance Workshop [2] and by the LEP2 Physics Workshop [3]. The steps are determined by discrete layout modifications and equipment upgrades creating space and capacity for additional sets of superconducting cavities. LEP layouts, expected energies, peak luminosities, schedules and global costs estimates are given for each step considered. After a discussion of limitations in Section 2, steps to upgrade the LEP2 beam energy up to 96 GeV, which are within the cooling power of the present cryogenic plants, are presented in detail in Sections 3 to 5. Further steps, up to an ultimate beam energy of 104 GeV, which were studied in the framework of the LEP2 Physics Workshop and require an upgrade of the cryoplants, are outlined in Appendix A.

2 On the Path to Higher Energies

2.1 Energy and Luminosity

2.1.1 Computing Energy and Peak Luminosity

The calculations for energy, peak luminosity, and HOM power, leading to the figures shown in the various tables (see e.g. Table 2b, Section 3) were performed with the following assumptions:

- The beam energy for a given voltage has been computed for a quantum lifetime of 15 hours, for the 108° phase advance lattice [4].
- A horizontal emittance of 30 nm at 90 GeV scaled with γ^2. This corresponds to the value anticipated for the 108° phase advance lattice.
- A vertical to horizontal emittance ratio (4%) equal to the β ratio (which ensures that the beam-beam tune shifts in the horizontal and vertical planes are equal)
- Operation with 8 bunches per beam except in the scenarios 'Y' (see Appendix A) where the electro-static separators are removed in order to make space for additional sc cavities.

- Bunch currents limited by the Transverse Mode Coupling Instability (at injection energy) to 0.75 mA with 100% of the copper cavities remaining in the tunnel and 1.0 mA with 50% or more removed.
- Total beam current limited by the amount of installed RF power, assuming 1 MW available for the beam from each installed klystron and one klystron per 8 cavities. Note that the situation which is considered foresees that all cavities are available but are being operated below their maximum gradient by an amount (corresponding to an accelerating voltage of about 160 MV) which would allow them to be driven rapidly to the nominal gradient in the event of two groups of eight cavities tripping simultaneously. This is necessary to avoid total beam loss each time a group of cavities trips.
- The copper RF system is capable of providing 2.8 MV per installed cavity (340 MV for 120 cavities).
- The HOM power per cavity is calculated by adding the powers associated with each bunch and the fields associated with each counter-rotating beam. Each cavity is equipped with two HOM couplers allowing to carry to room temperature loads a total power of 1600 W.

2.1.2 Integrated Luminosity

The aim for LEP2 integrated luminosity was and still is 500 pb^{-1} in three years. From the achieved results on LEP1 in 1993 and 1994 this yearly integrated luminosity aim of 170 pb^{-1}/year would require a peak luminosity of around 9×10^{31} cm^{-2} s^{-1}, for a yearly net physics time of 100 days and an overall efficiency equal to the average of that achieved in 1993 and 1994. It can be seen from the tables given for the different phases that this value is exceeded in all scenarios with 8 bunch operation.

However there are several reasons why extrapolation from LEP1 may be somewhat optimistic and operation at LEP2 energies may be different from that of LEP1.

- The technical efficiency of the machine may be reduced due to the large number of superconducting cavities and the dependence on the simultaneous availability of four cryogenic systems.
- The intensity lifetime at higher energies is known [5] to be less than at 45 GeV.
- It is rather unlikely that LEP2 can be operated at the beam–beam limit throughout the coast as is the case for LEP1. This means that the luminosity may decrease as I^2, rather that I for LEP1. Against this, operation in the energy range 65 to 70 GeV at the end of 1995 showed that very small emittance ratios of less than 0.5% could be routinely achieved [6].

With these considerations it would be more reasonable to aim for a peak luminosity of around 1×10^{32} cm^{-2} s^{-1}, to be assured of the target integrated yearly luminosity. It can be seen from the tables given for the different phases described later that this value appears within reach for all scenarios with 8 bunch operation.

2.2 Equipment limits

2.2.1 Accelerating Gradient

When considering the likelihood of reaching higher accelerating gradients, we should consider the following.

Radiation

The experience gathered so far [7] shows that when increasing the gradient from 6 to 7 MV/m, radiation increases from a few Gy/h to nearly 100 Gy/h. Besides damaging the organic seals of the cryostats (max. dose 10^5 to 10^6 Gy), it has also been ascertained that radiation enhances electron multipactoring in the main couplers. The 2.5 kV dc bias [8] in the main couplers has proved to suppress multipactoring, but extended operational experience must still be gathered. Should multipactoring occur, the RF power is shut down for equipment safety. High radiation levels might therefore reduce the availability of the sc accelerating system to unacceptable levels.

Further, intense radiation may constitute a source of background for the experiments.

Field Strength in the Main Couplers

When going for example from 6 to 7 MV/m, the equivalent coupler power in the fixed main couplers increases to $(7/6)^2$, or 36%. As a consequence, the main coupler might be driven at a regime where multipactoring may occur. As discussed above, this would entail a reduced system availability.

Impact of Synchrotron Radiation

Following the experience from KEK, dedicated collimators have been installed in LEP to protect the sc cavities from the synchrotron radiation (SR) created in the arcs. With the sc cavity modules installed in LEP so far, no difficulties linked to SR have been encountered. However, this has to be confirmed at higher energies.

Experience with other accelerators

Superconducting cavities have been operated in TRISTAN [9] (KEK) and are in operation at HERA [10] (DESY) and CEBAF [11]. All the cavities in these accelerators are Nb-sheet cavities, which are subject to thermal quenches, contrary to the Nb-film cavities of LEP.

At TRISTAN (f = 500 MHz, T = 4.2 K), the average accelerating gradient in 1994 was 3.8 MV/m, the maximum achieved in operation being 4.7 MV/m. Without beam an average of 7 MV/m was measured in 1994. Thermal quenches, multipactoring at the input couplers and discharges due to SR stimulated gas desorption are quoted as limiting factors.

At HERA (f = 500 MHz, T = 4.2 K), the sc cavities were tested to 5 MV/m before installation, have run at a maximum of 4 MV/m with beams, and are routinely operated at about 2.6 MV/m. The relatively low maximum gradient in operation is due to a Q degradation because of hydrogen contamination of the Nb sheet. Multipactoring in the input couplers (no dc bias) was the major reason of faults in the RF system.

At CEBAF (f = 1.5 GHz, T = 2 K), the nominal value of 5 MV/m has already been exceeded in the first period of operation, an average of 6.2 MV/m has been reached and 7.3 MV/m are expected in the future, though the average value achieved during the tests in the vertical cryostat has been 9.5 MV/m. The main limitation is field emission.

Given the very limited experience with low-frequency SC cavities above 4 MV/m, it is believed that for the LEP2 sc cavities the nominal value of 6 MV/m should be considered as the maximum possible gradient in operation.

2.2.2 Number of SC Cavities

The layout of the straight sections at Points 2 and 6 was originally optimized for the Cu accelerating system (64 Cu cavities at each Point) and subsequently partially modified to accommodate sc cavities as well.

The layout at Points 4 and 8 has been completely redesigned for the LEP2 Programme, to allow the installation of maximum 96 sc cavities at each of these Points.

By removing all the Cu cavities and making the layout of Points 2 and 6 identical to that of Points 4 and 8, a total of 384 sc cavities could be installed in LEP, provided that the 16 separators for the Bunch Trains Scheme are removed from LEP as well (each separator occupies the location of a four-cavity module), precluding operation with more than four bunches per beam.

2.2.3 The Cryogenic Limits

Present Cryoplants

The LEP2 cryoplants are designed to deliver an ultimate equivalent refrigeration power of 18 kW at 4.5 K. In their present configuration, they deliver an equivalent power close to 11.5 kW at 4.5 K, both suppliers being at the lower end of the 5% contractual tolerance admitted for the specified 12 kW.

The cryoplants have to cope with two basic load types, one that is independent of the accelerating field in the cavities and one that is field dependent, proportional to $\mathrm{E}^2_{\mathrm{acc}}/\mathrm{Q}$, where Q is the cavity quality factor. Figure 1 shows the contribution of the various loads to the overall cryogenic budget, for the cases where 64, 72 or 80 sc cavities are installed and the nominal Q(E) acceptance curve shown in Fig. 2 is considered. The constant losses are a function of the length of the transfer lines and of the number of cavities. Their cumulated value is shown in Fig. 1 for 64 cavities. It can be computed that, with the given assumptions, the cryogenic power limit of 11.5 kW at 4.5 K would be reached by operating 64 sc cavities at about 6.9 MV/m, 72 sc cavities at 6.5 MV/m or 80 sc cavities at 6.1 MV/m.

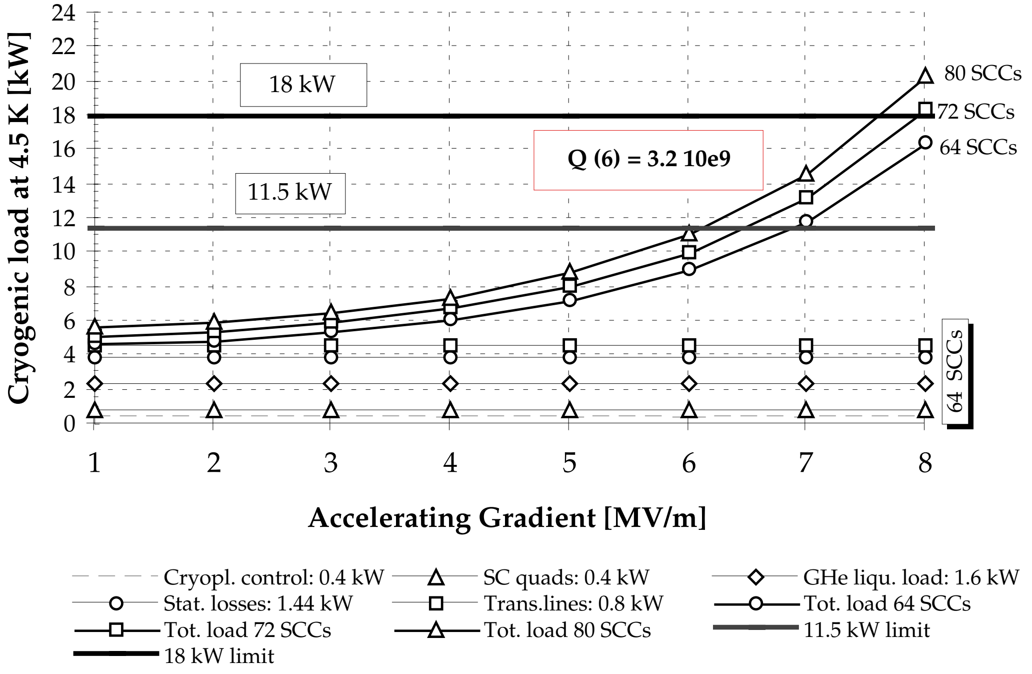

Figure 1: Cryogenic Load (64 to 80 SC Cavities) as Function of the Accelerating Gradient

At the time or writing, no experience is available with the operation of a large number of sc cavity modules and some prudence should be applied when discussing the optimum use of the spare cryogenic power that appears to be available. In fact, it could be used to:

i) cope temporarily with accidental higher losses in some modules (due e.g. to a leak of cryostats' vacua or to a contamination of cavities),

ii) add more modules and operate them at the nominal 6 MV/m,

iii) operate the nominal number of modules at fields higher than 6 MV/m,

iv) cover possible HOM losses reaching the liquid Helium bath.

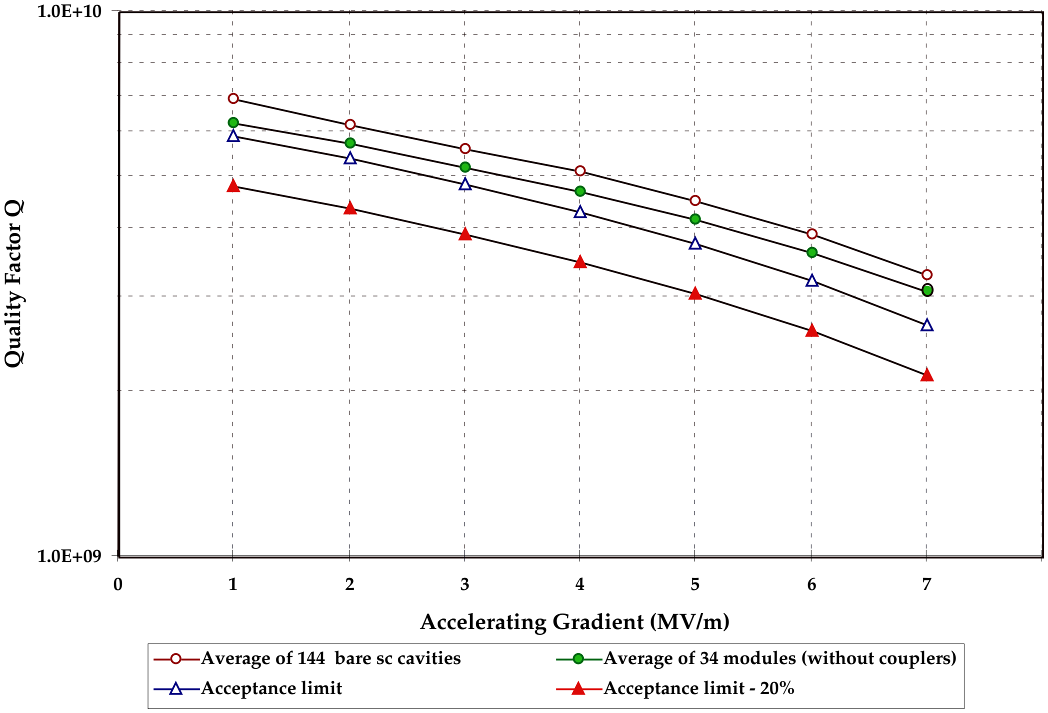

Figure 2: Quality Factor Q vs Accelerating Gradient

In order to establish some reference figures and sound limitations, the computations of the overall cryogenic load were made also for the case that the average effective Q(E) values of the modules would be 20% below (see Fig. 2) the Q(E) curve admitted for the acceptance of the modules not yet equipped with couplers.

Under these conditions, the cryogenic power limit of 11.5 kW at 4.5 K would be reached by operating 64 sc cavities at about 6.4 MV/m, 72 sc cavities at 6.0 MV/m or 80 sc cavities at 5.6 MV/m. By comparing the total accelerating voltages achievable with these parameters, it can be seen that an increase from 72 to 80 sc cavities would bring a gain of only 27 MV (instead of nearly 81 MV if they could be operated at the nominal 6 MV/m), making the additional investment useless.

Until experience has been gathered with the operation of large numbers of cavities, possibly by end 1996, we therefore do not recommend to install more than 72 sc cavities at any LEP

Point, unless the cryoplants are appropriately upgraded to keep a reserve for coping with unforeseen difficulties or driving cavities at higher gradients.

Partial Upgrading of the Cryoplants

Figure 3 shows the estimated cryogenic budgets for the cases where 80, 88 or 96 sc cavities are to be cooled by a cryoplant.

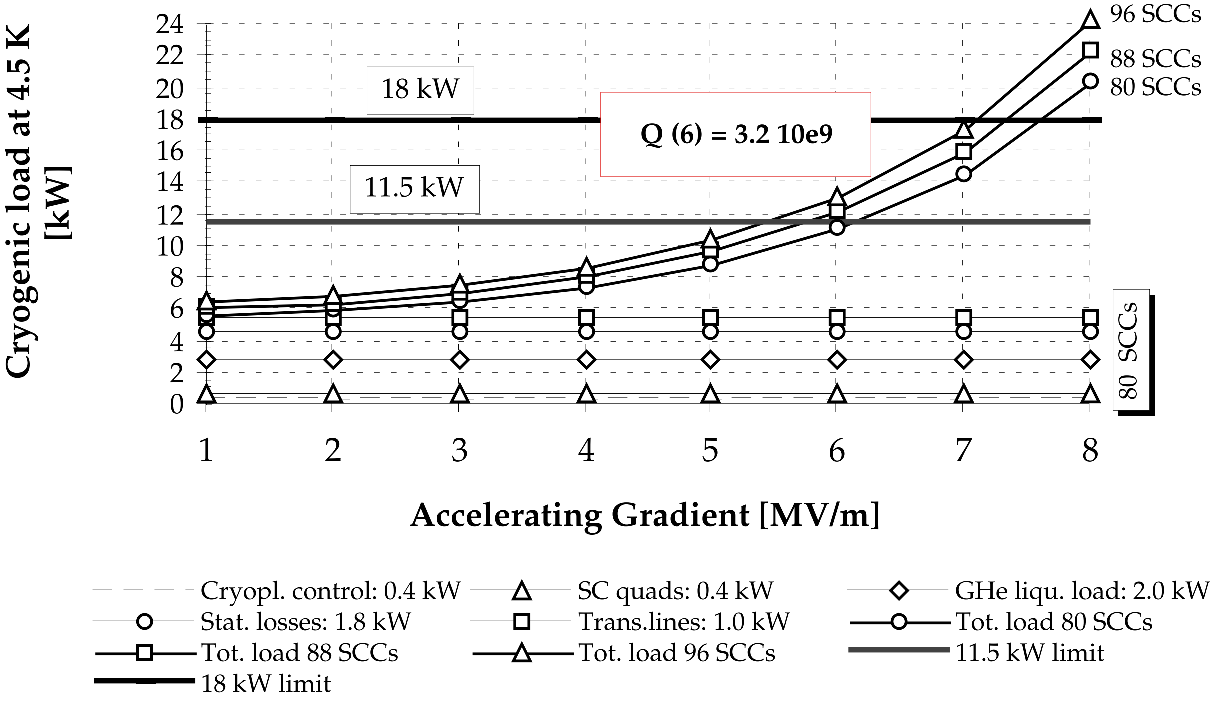

Figure 3: Cryogenic Load (80 to 96 SC Cavities) as Function of the Accelerating Gradient

It can be computed that a partial upgrade to an equivalent cryogenic power of 15 kW would be enough for allowing to drive 96 sc cavities at an accelerating gradient of about 6.5 MV/m, provided that the average Q values follow the nominal acceptance curve. For the pessimistic case where the effective Q(E) values are 20% below the acceptance curve of Fig. 2, a gradient of 6.1 MV/m could still be sustained with 96 sc cavities.

Studies are in progress [12] about the cryoplant upgrades necessary for the LHC; as a result of a possible gradual implementation of these upgrades, at least the reliability of the LEP2 cryoplants could be increased in the next years by the installation of additional Helium compressors.

2.2.4 Limitations from the Magnet System and its Power Converters

Energy limitations due to the magnets' design were reviewed [13] at the 1995 Workshop on LEP Performance. For the sake of completeness, they are summarized in the Table 1, with additional information about the capabilities of the magnets' power converters (the 108°/60° optics is assumed). The nominal power converters' ratings can be found in Ref. [14]; the figures between brackets are achievable with limited effort [15].

Table 1:

Magnet	Magnet Type	Max. Energy [GeV]
Main Bends	Arc Dipoles	125
	Power Converter	100 (105)
	Injection Dipoles	100 (120)
	Power Converter	100 (105)
Quadrupoles	Arc Quadrupoles (MQ)	114
	Power Converter	100 (114)
	MQA Quadrupoles	97* (110)*
	Power Converters	97* (110)*
	SC Low-β Quadrupoles	100 (105)
	Power Converters	100 (105)
Sextupoles	SD Sextupoles	> 125
	Power Converters	98 (103)
	SF Sextupoles	> 125
	Power Converters	120

* The figures for the MQA quadrupoles are dependent on the final optimization of the optics parameters for the Bunch Trains Scheme, which is not yet complete for LEP2.

3 Increasing the LEP Energy within the Cryogenic Limit

Two new LEP2 phases, named Phase IIIb and IV, respectively, were discussed at the 1995 Chamonix Workshop on LEP Performance; Tables 2a and 2b summarize cavity number and distribution, expected energies and luminosities, respectively.

Table 2a: Cavity distribution

Phase	Point 2			Pt 4	Pt 6		Pt 8	Totals			Total MV max
(Cavity type)	Cu	Nb & prot.	NbCu	NbCu	Cu	NbCu	NbCu	Cu	Nb	NbCu	(MV)
IIIb	26	24	40	56	26	64	56	52	24	216	2557
Use of 16 active spares and replacement of 8 prototypes											
IV	26	24	40	72	26	64	72	52	24	248	2884
Maximum energy upgrade with present cryoplants											

Table 2b: Energy and luminosity (limiting parameter underlined)

Phase	MV max (MV)	E max (GeV)	MV oper. (MV)	E oper. (GeV)	U_{max}/ beam (mA)	Beam Power (MW)	ξ_{bb}	L_{max} 10^{31} cm^{-2} s^{-1}	HOM Power/cavity (W)
IIIb *1)*	2557	94.7	2394 *2190*	93.1 *91.0*	7.19	30.5	0.0383	11.1	1010
IV *1)*	2884	97.6	2721 *2489*	96.2 *94.0*	7.13	34.5	0.0344	10.3	995

1) Figures for an accelerating gradient reduced by 0.5 MV/m.

3.1 Making spare modules active (Phase IIIb)

Four modules have been ordered as spares; space for their installation can be efficiently made available at Points 2 and 6, the schematic layout is shown in Fig. 4. Phase IIIb requires the procurement of four klystrons, four circulators, waveguides and RF controls for four modules, vacuum and cryogenic equipment for module installation and operation. Additional high pressure storage tanks for He gas are also necessary. The extension of the cryogenic transfer lines was already included in the original LEP2 Programme.

3.2 Adding 32 sc cavities (Phase IV)

At each of Points 4 and 8, 16 cavities can be added, reaching thus the cryogenic limit of 72 sc cavities established under Section 2.2.3. Their installation would take place between the quadrupoles QS9 and QS10 (see the schematic layout of Fig. 4). In addition to the procurement of 32 sc cavities, Phase IV requires the procurement of two new RF units (each consisting of a klystron power converter, HV cabling, a HV filter capacitor, the klystrons protection system, two klystrons, two circulators, waveguides and controls for eight modules), the extension of the cryogenic transfer lines as shown in Fig. 4, and the vacuum and cryogenic equipment necessary for module installation and operation. Additional high pressure storage tanks for He gas are also necessary.

An examination of Table 2b shows that the Phase IV configuration allows to reach 95 GeV per beam with a reasonable confidence.

4 Schedules

4.1 Boundary Conditions

Schedules have to cope with the following:

- tendering procedures requiring the adjudications' approval by the Finance Committee, require a 6 to 9 month's period;
- deliveries must occur at the beginning of the winter shutdowns (SD) at latest;
- sc cavities: provided that basic materials are procured by CERN before the order is placed, bare cavity delivery can start 6 months after contract adjudication. Orders for sc cavities are to be placed so as not to have large time gaps in their manufacture. The average sc cavity production rate achieved so far with three firms is 60 sc cavities/year; module delivery followed with a time lag of 9 months;
- RF power and controls: delivery within two years after contract adjudication;
- cabling of RF controls: for a set of 8 modules, a total of 6 months is necessary (two months of racks precabling before the winter shutdown, 4 months underground installation). Because of CERN staff availability, parallel work is limited at 2 × 8 modules;
- cryogenics: the extensions of cryogenic transfer lines require one year after contract adjudication. Transfer lines should be installed and tested one winter shutdown before that for module installation, because of incompatible activities. The delivery of additional high pressure storage tanks for He gas occurs 18 months after contract adjudication.

4.2 Tentative Schedule

Taking into account the above boundaries, a tentative installation schedule has been worked out [16], which includes in a global approach the realisation of Phases III [1], IIIb and IV. A favourable decision for Phases IIIb and IV is foreseen for December 1995 which will allow us to complete the LEP2 upgrade by May 1998.

The optimum installation schedule foresees the following major milestones:

1995–1996 SD: extension of cryogenic transfer lines at Points 2, 4, 6 and 8, cabling of RF controls at Points 4 and 8.

1996–1997 SD: installation at Point 2 of the eight sc cavity modules ordered for Phase III, installation at Points 4 and 8 of the four spare modules and of the four modules driven out of the original layout because of the Bunch Trains separators.

1997–1998 SD: installation at Point 6 of the eight modules to be ordered for Phase IV.

Tables 3a and 3b summarize cavity number and distribution, and expected energies for the years 1996 to 1998. The schematic layouts corresponding to this schedule are shown in Fig. 4.

5 Cost estimates for Phases IIIb and IV

The cost estimates for Phases IIIb and IV are of 7 and 29 MCHF, respectively. These estimates are based on the unit prices paid so far. The high pressure He storage tanks, estimated at 3 MCHF are not included in the above sums; they are foreseen in the LHC budget, as they are needed anyhow for LHC and would constitute a pilot production for the full LHC needs.

6 Acknowledgements

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Table 3a: Cavity Distribution vs Time (Assuming an approval of Phases IIIb and IV by December 1995)

Year	Point 2			Pt 4	Pt 6		Pt 8	Totals			Total MV max
(Cavity type)	Cu	Nb & prot.	NbCu	NbCu	Cu	NbCu	NbCu	Cu	Nb	NbCu	(MV)
Oct 1996	60	16	16	56	60	32	56	120	16	160	2110
May 1997	26	24	40	72	60	32	72	86	24	216	2654
May 1998	26	24	40	72	26	64	72	52	24	248	2884
Phase IV											

Table 3b: Energy and Luminosity vs Time (limiting parameter underlined) (Assuming an approval of Phases IIIb and IV by December 1995)

Year	MV max (MV)	E max (GeV)	MV oper. (MV)	E oper. (GeV)	I_{max}/ beam (mA)	Beam Power (MW)	ξ_{bb}	L_{max} 10^{31} cm^{-2} s^{-1}	HOM Power/cavity (W)
Oct 96 *1)*	2110	90.0	1946 *1810*	88.0 *86.1*	$\underline{6.0}$	20.3	0.0379	8.7	704
May 97 *1)*	2654	95.6	2490 *2300*	94.1 *92.1*	$\underline{6.0}$	26.6	0.0310	7.6	704
May 98 *1)*	2884	97.6	2721 *2503*	96.2 *94.2*	7.13	$\underline{34.5}$	0.0344	10.3	995

1) Figures for an accelerating gradient reduced by 0.5 MV/m.

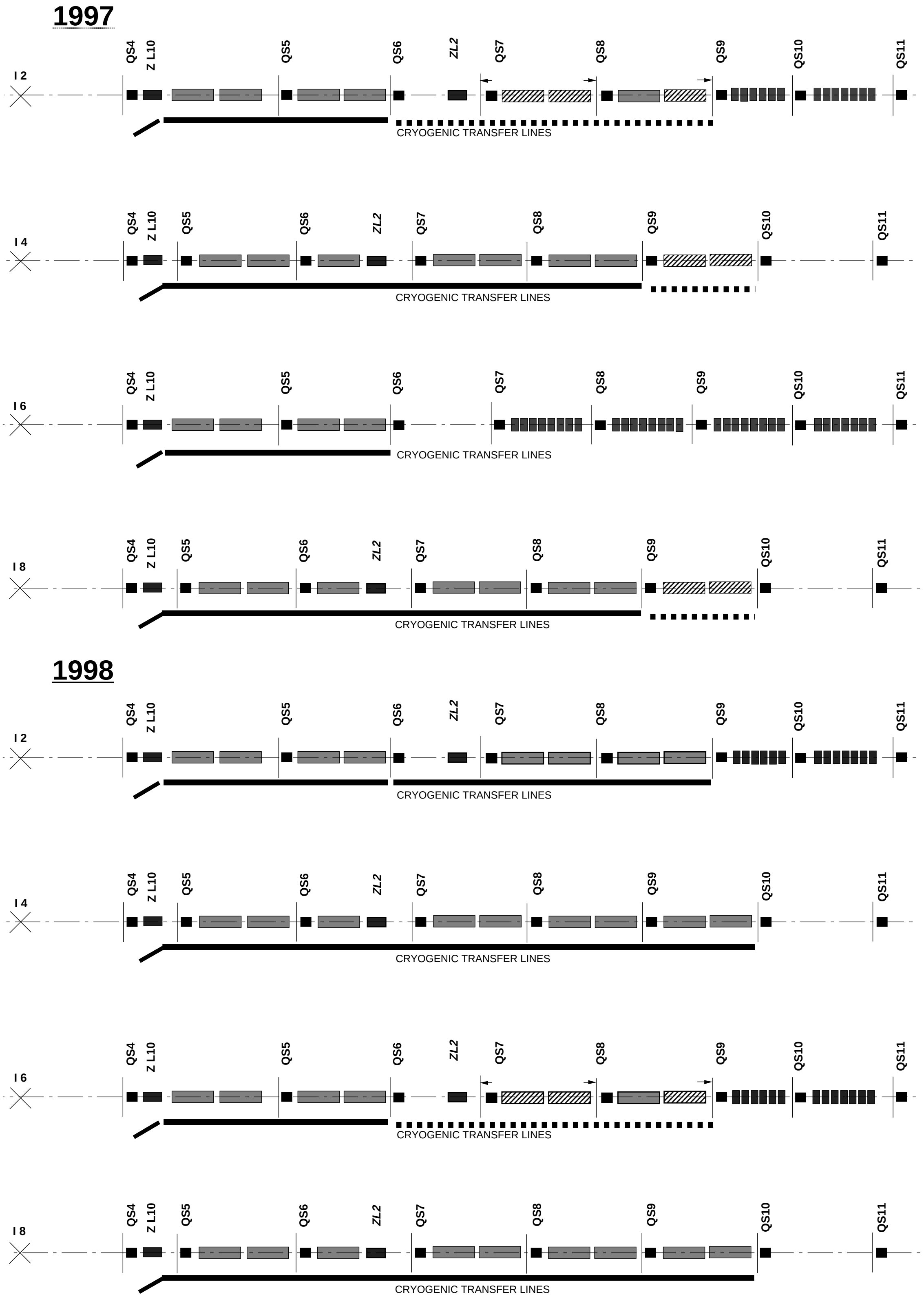

Figure 4: Schematic layout of the RF sections in the years 1997 and 1998

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APPENDIX A

A.1 Increasing the LEP Energy beyond the present Cryogenic Limit

In the following, information is given about the LEP2 potential, should it be decided to make a step in energy requiring an upgrade of the cryoplants. Different scenarios can be envisaged, by increasing importance of modification. Essentially two families of options can be considered, the first (X label) conserves the Bunch Trains separators in LEP to maximize luminosity, the second (Y label) does away with Bunch Trains to maximize energy.

A.2 Keeping the Bunch Trains Separators (X Phases)

The phases described in the following are successive increments from Phase IV. Tables A1a and A1b summarize cavity number and distribution, expected energies and luminosities for the Phases X1, X2 and X3 described below.

A.2.1 Addition of a Set of 32 SC Cavities (Phase X1)

We can see from Fig. A1 that at Points 4 and 8, space is still available for the installation of 2 modules between the quadrupoles QS10 and QS11; the corresponding cryoplants must be upgraded.

A.2.2 Replacement of the Remaining Cu Cavities by 32 SC Ones (Phase X2)

Progressing in the stepwise approach to increase the beam energy, one could consider the replacement at Points 2 and 6 of the remaining 52 Cu cavities, which still provide some 150 MV. From the schematic layout given in Fig. A2, it can be seen that each group of Cu cavities can be replaced by a four-cavity module; another set of 32 SC cavities could so be installed, providing a net increase of about 180 MV in accelerating voltage. The cryoplants at Points 2 and 6 will need to be upgraded.

A.2.3 Identical RF Layouts (Phase X3)

The next step would then be to make the layout of Points 2 and 6 identical to that of Points 4 and 8 (see Fig. A3). This will require a complete rearrangement of the quadrupole magnets, the sc cavity modules, the vacuum system, the cryogenic transfer lines, and of the RF power distribution system. This intervention will certainly need a prolonged shutdown; no planning study has been made so far. After rearrangement, it would be possible to install 16 additional sc cavities, with a net gain of about 163 MV.

Table A1a: Cavity distribution

Phase	Point 2			Pt 4	Pt 6		Pt 8	Totals			Total MV max
(Cavity type)	Cu	Nb & prot.	NbCu	NbCu	Cu	NbCu	NbCu	Cu	Nb	NbCu	(MV)
X1	26	24	40	88	26	64	88	52	24	280	3211
Cryoplants upgrade at Points 4 and 8											
X2	0	24	56	88	0	80	88	0	24	312	3390
Cryoplants upgrade at Points 2 and 6											
X3	0	24	64	88	0	88	88	0	24	328	3554
Symmetrical LEP, all even Points identical											

Table A1b: Energy and luminosity (limiting parameter underlined)

Phase	MV max (MV)	E max (GeV)	MV oper. (MV)	E oper. (GeV)	I_{max}/ beam (mA)	Beam Power (MW)	ξ_{bb}	L_{max} 10^{31} cm^{-2} s^{-1}	HOM Power/cavity (W)
X1	3211	100.2	3047	98.9	7.12	38.5	0.0316	9.7	991
1)			*2802*	*96.9*					
X2	3390	101.6	3227	100.3	7.34	42.0	0.0313	10.0	1054
1)			*2955*	*98.2*					
X3	3554	102.8	3390	101.6	7.32	44.0	0.0300	9.7	1048
1)			*3104*	*99.4*					

1) Figures for an accelerating gradient reduced by 0.5 MV/m.

LEP 2 LAYOUT PHASE X1

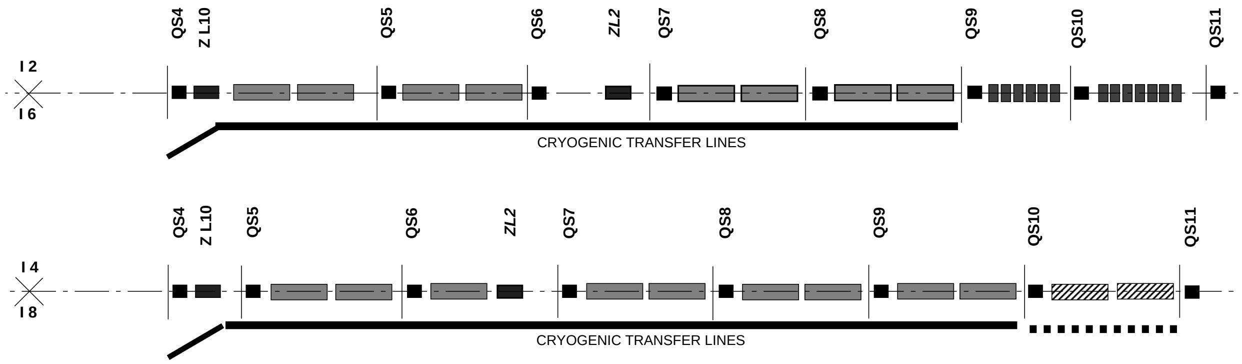

Fig. A1

LEP 2 LAYOUT PHASE X2

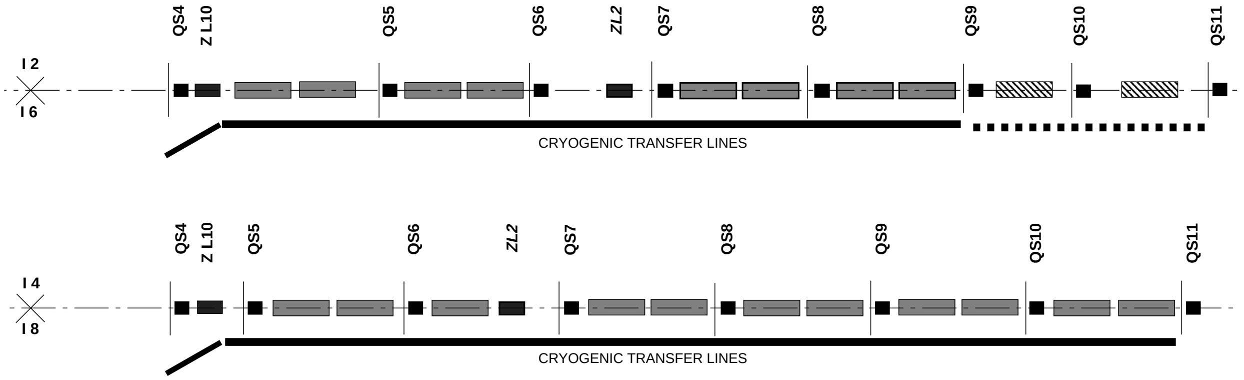

Fig. A2

LEP 2 LAYOUT PHASE X3

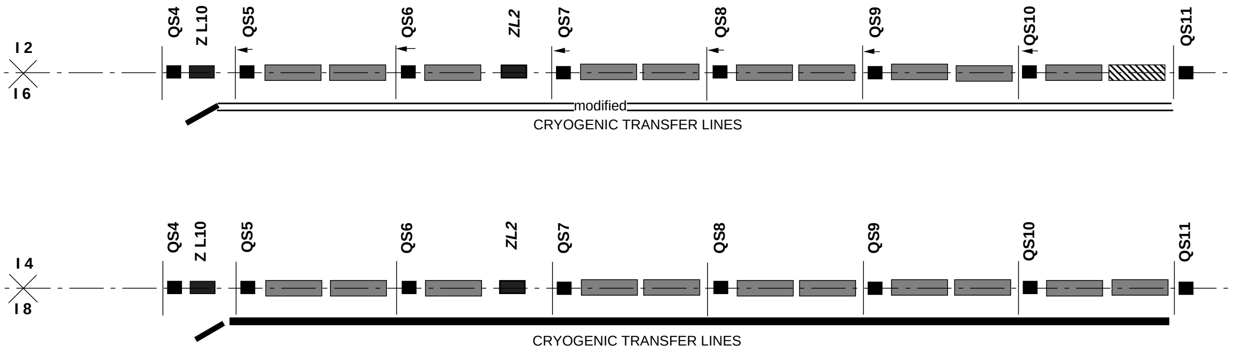

Fig. A3

A.3 Taking out Bunch Trains separators to make Room for Cavities (Y Phases)

The phases described in the following are additions relative to Phase IV. Tables A2a and A2b summarize cavity number and distribution, expected energies and luminosities for the phases Y1 to Y3 described below.

A.3.1 Addition of a Set of 48 SC Cavities (Points 4 and 8, Phase Y1)

The replacement of the separators with sc cavity modules is a relatively simple operation at Points 4 and 8, as the cryogenic transfer lines were foreseen for feeding those modules and the RF cabling for them was already made before the choice of installing separators. Klystrons and circulators were also already foreseen there. As originally foreseen, waveguides and controls can be installed there during a winter shutdown. Phase Y1 corresponds to Phase X1 plus 16 sc cavities, the corresponding layout is shown in Fig. A4.

Table A2a: Cavity distribution

Phase	Point 2			Pt 4	Pt 6		Pt 8	Totals			Total MV max
(Cavity type)	Cu	Nb & prot.	NbCu	NbCu	Cu	NbCu	NbCu	Cu	Nb	NbCu	(MV)
Y1	26	24	40	96	26	64	96	52	24	296	3374
ZLs removed, filling Points 4 and 8 with SCCs											
Y2	0	24	64	96	0	88	96	0	24	344	3717
ZLs removed, filling also Points 2 and 6 with SCCs											
Y3	0	24	72	96	0	96	96	0	24	360	3880
All-out Maximum Energy configuration											

Table A2b: Energy and luminosity (limiting parameter underlined)

Phase	MV max (MV)	E max (GeV)	MV oper. (MV)	E oper. (GeV)	I_{max}/ beam (mA)	Beam Power (MV)	ξ_{bb}	L_{max} 10^{31} cm^{-2} s^{-1}	HOM Power/cavity (W)
Y1	3374	101.4	3211	100.2	4.00	22.8	0.0342	5.9	626
1)			*2952*	*98.2*					
Y2	3717	104.0	3554	102.8	4.00	25.2	0.0317	5.6	626
1)			*3254*	*100.6*					
Y3	3880	105.3	3717	104	4.00	26.5	0.0305	5.5	626
1)			*3404*	*101.8*					

1) Figures for an accelerating gradient reduced by 0.5 MV/m.

A.3.2 Addition of a second set of 48 SC cavities (Points 2 and 6, Phase Y2)

At Points 2 and 6, the simple section of the cryogenic transfer line between QS6 and QS7 can be replaced with a new section equipped for feeding a module. The RF power could be provided by the klystrons driving a neighbouring group of modules, considering that with only four bunches only half of the previously provided RF power will still be needed. The 52 Cu cavities would be replaced by 32 sc ones as for Phase X2, the corresponding layout is shown in Fig. A5.

A.3.3 Identical RF Layouts (Phase Y3)

The reach the maximum number of 384 cavities that can be installed in LEP, one has to make all accelerating sections identical, allowing thus to add a final set of 16 sc cavities, the corresponding layout is shown in Fig. A6.

LEP 2 LAYOUT PHASE Y1

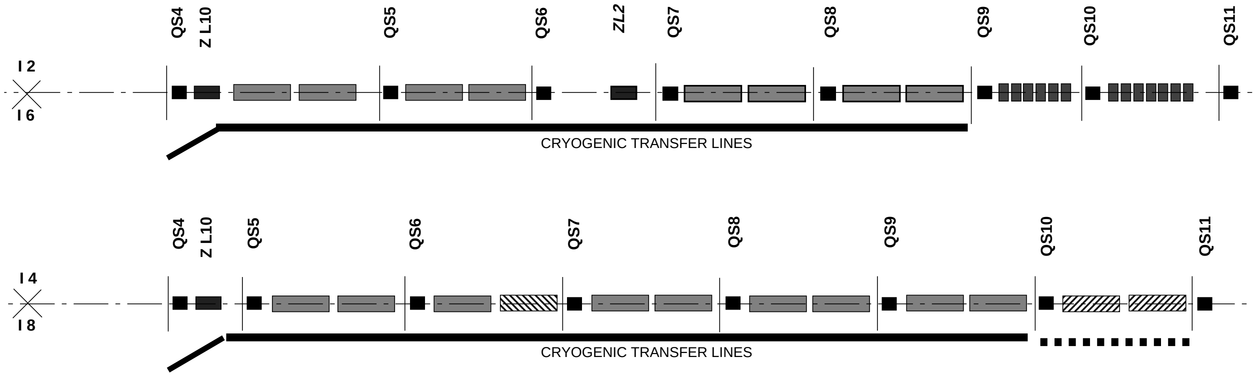

Fig. A4

LEP 2 LAYOUT PHASE Y2

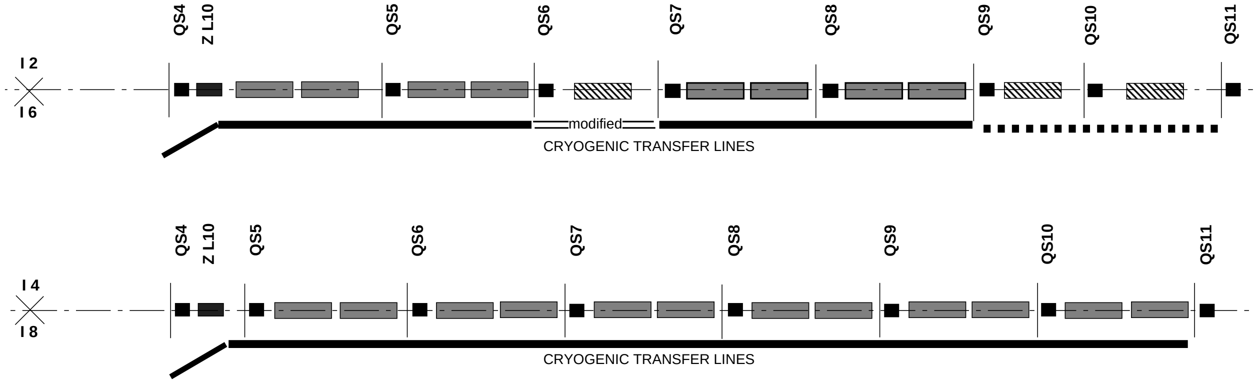

Fig. A5

LEP 2 LAYOUT PHASE Y3

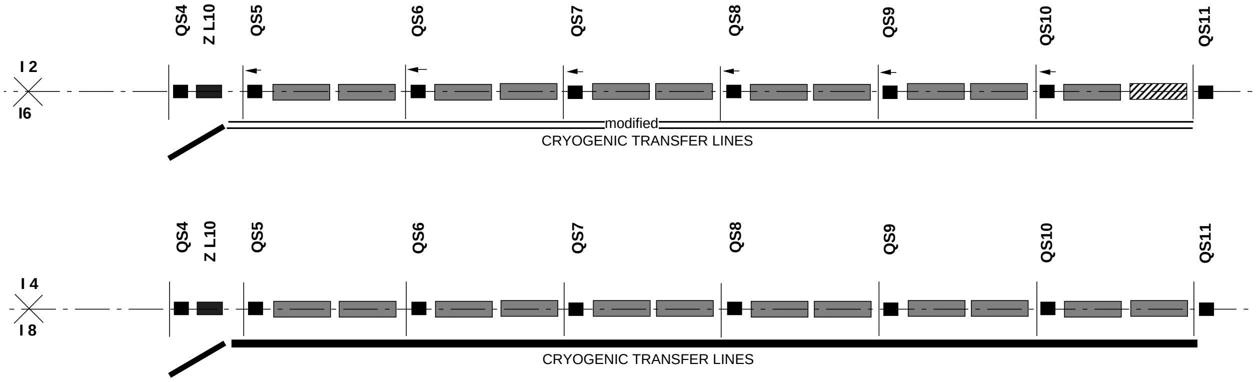

Fig. A6

A.4 Schedules and cost estimates for the X and Y Phases

From the considerations given in Chapter 4 of this note, it can be inferred that about 30 to 36 months (a cryoplants upgrade requires two years after contract adjudication), depending on the phase which would be retained, are necessary for the realization of a possible next step in energy. The complete reshuffling of the straight sections at Points 2 and 6 is guessed to add at least 6 months to the above quoted figures. Better estimates would require at least a preliminary planning study. The above quoted 30 to 36 months are to be understood as the time necessary from taking the formal decision to equipment commissioning.

Concerning costs, Fig. A7 shows in graphical form the outcome of crude estimates for the various phases. Although the cost of modules, RF power and controls, cryogenic and vacuum equipment for the modules is known, the cost estimate for other items requires more work. Among the latter, one can quote the cost (estimated here at 3.5 MCHF per plant) for the partial upgrading of the cryoplants, the cost of industrial support and the cost of making the layouts of all even Points identical.

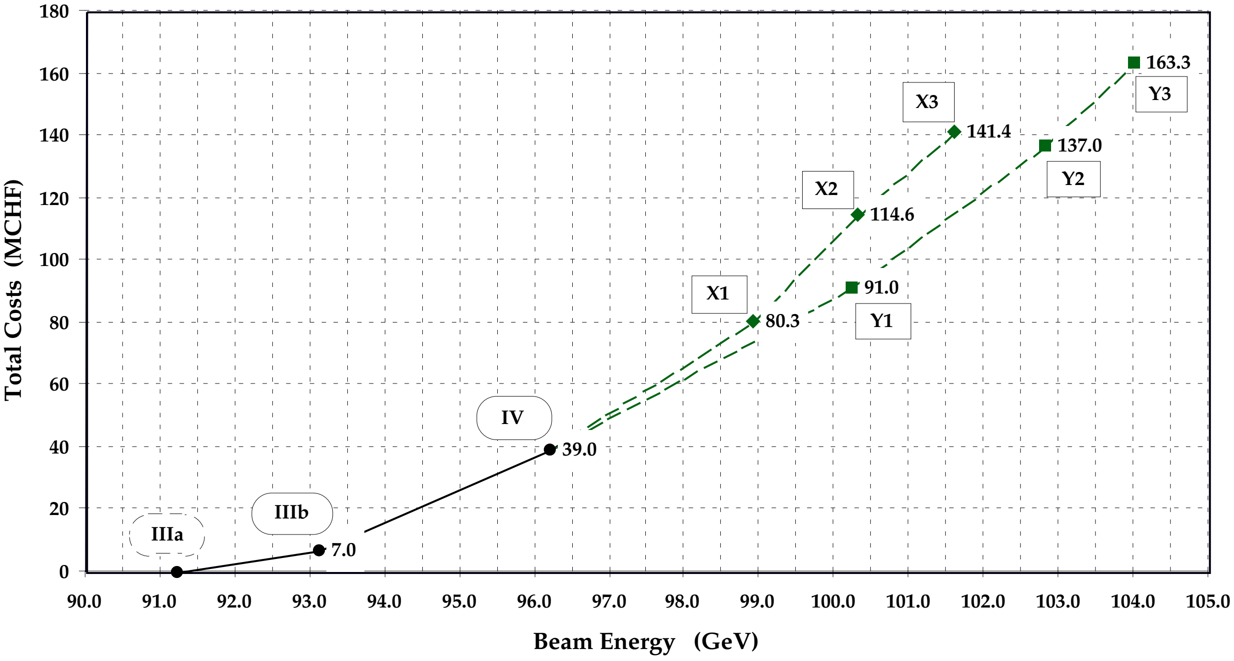

Figure A7: Upgrade Costs vs Operational Energy. Phases IIIb and IV: Final Estimates. Phases X, Y: Preliminary Estimates.