6 IR design

6.1 Overview of CESR luminosity upgrade

A five-year program to increase CESR luminosity by a factor of 5 to 10 was begun in Fall 1993. The program is staged in two parts which are referred to as "Phase 2" and "Phase 3."

Phase 2 operation is planned for the period from mid-1994 until installation of the CLEO III detector components in 1997. In this phase we will use bunch trains with a small horizontal crossing angle to store beam currents up to the limit of the 5-cell RF cavities (approximately 300 mA/beam). Nine trains of 3 bunches each will be used. The IR quad configuration will be modified to provide the larger horizontal aperture required for the separate electron and positron orbits. The peak luminosity for this operation will be around 6×10^{32} cm^{-2}sec^{-1}.

Phase 3 equipment will be installed in CESR at the same time as the installation of the CLEO III detector described in this report. Replacement of the four 5-cell RF cavities with four superconducting 1-cell cavities and modification of the IR to allow more closely spaced bunches will permit increasing the beam currents. This configuration will allow us to reach the limits of the ring vacuum chamber (gas desorption and available pumping rate) using 9 trains of 5 bunches each. The proposed IR layout will accommodate values of β_V^* to 1 cm, making further increases in luminosity possible if the bunch length can be shortened comparably. The expected peak luminosity in the Phase 3 configuration is 1 to 2×10^{33} cm^{-2}sec^{-1}.

The IR quad arrangement must be modified from its present configuration to provide greater effective horizontal aperture for crossing angle orbits. The crossing angle operation requires additional aperture in the horizontally focussing quads. This may be achieved by exchanging the two electromagnetic quads on each side (Q1 and Q2) and lengthening the permanent magnet quad using spare sections from the former North area permanent magnet quads. Energy flexibility (4.7 to 5.6 GeV) is possible by moving the Q1 quadrupole longitudinally.

As the bunch spacing is decreased to 14 ns in Phase 3 operation, the first parasitic crossing point moves from 4.2 to 2.1 m away from the interaction point. The combination of small separation and large β_V^* with the Phase 2 optics results in an excessive long range beam-beam tune shift. A high gradient (40 Tesla/m) superconducting quad focuses the beam vertically in the Phase 3 configuration to minimize the tune shift at the parasitic crossing. A 30 cm long stepped permanent magnet quad provides additional focussing as well as shielding of background.

6.2 Accelerator components

Components associated with two major accelerator systems, vacuum and magnets, must share space with the detector. This section describes the requirements and design considerations which led to the present design concept.

6.2.1 IR magnets

In order to reach the high charge densities required for high luminosity, a very short final focal length is needed, leading to placement of the quadrupole focussing magnets as close as possible to the interaction point. Several accelerator physics requirements are considered in choosing the focussing configuration.

6.2.2 Parasitic beam crossings

The minimum bunch-to-bunch spacing is a critical parameter in determining the attainable luminosity. As this spacing decreases, the first parasitic crossing moves closer to the interaction point. The effects of one beam on the other at the parasitic crossings must be minimized. It is known that separation distance, bunch current, β function, and beam size all influence the beam-beam interaction at the parasitic crossing points. In this design study, the long range beam-beam tune shift (calculated for the first parasitic crossing with bunches spaced by 14 ns) was used as the criterion for choice of optics. With 14 ns spacing, the first parasitic crossing point occurs 2.1 m from the interaction point.

6.2.3 Optics

The focal length of the quads must be small enough to achieve the desired optics and must decrease roughly proportionally to the distance from the interaction point to the quads. The effect of chromatic errors of the quads is minimized by keeping the quads close to the interaction point. Operating energy range must be considered in options using permanent magnets. The required energy range was assumed to be 4.7 to 5.6 GeV.

6.2.4 Aperture

The aperture required to avoid particles hitting the vacuum chamber in the interaction region increases as the quads are moved farther from the interaction point. Previously the aperture requirements were most difficult to meet in the vertical plane. The displacement of the horizontal closed orbit resulting from the crossing angle makes the horizontal aperture a critical consideration. The orbits must minimize the horizontal as well as the vertical aperture requirements of the beam.

6.2.5 Mechanical requirements

The inner radius of the quads is determined by aperture requirements and the vacuum chamber thickness. The outer radius is determined by detector clearance requirements, both in operation and during installation. The mechanical stability and reproducibility (*e.g.,*after opening of the poles) must be adequate. A 1 micron transverse motion of an IR quad typically produces an 80 micron peak-to-peak distortion in the closed orbit of the beam.

There are several other magnet functions required in this region. Adjustable dipole steering magnets are needed to correct the closed orbits and also aid in creating localized orbit distortions, or "bumps," to help reduce experiment background and injection losses. The effect of the CLEO solenoid field on the motion of the electrons must be adequately compensated. This will be done as now by rotating normal IR quadrupoles and by additional skew quads.

6.2.6 Magnet layout options

Several options for layout and magnet technology were considered. Only the (vertically focussing) quad nearest the interaction point was studied, since the next (horizontally focussing) quad was located outside of the CLEO magnet pole tip and the present iron/copper quads are adequate for most configurations. For each option, optics were computed at 5.3 GeV which provided $\beta_V^* = 1.0$ cm and $\beta_H^* = 1$ m. Apertures were designed to accommodate a 12 σ beam stay clear and a ± 2.5 mrad horizontal crossing angle. A double-walled, cooled beam pipe was assumed.

For each configuration three parameters were calculated: 1) the long range tune shift for 10 mA bunches and fixed crossing angle at a point 2.1 m from the interaction point (corresponding to bunches spaced by 14 ns); 2) the chromaticity from the IR quads (on one side only); and 3) the total horizontal aperture required for ± 2.5 mrad crossing angle. The results are summarized in Table 29.

NdFeB and SmCo refer to high B_{rem} permanent magnet material. The NdFeB material has $B_{rem}\simeq 1.2$ Tesla, giving a significant advantage in gradient over the SmCo, which was assumed to have $B_{rem}\simeq 1.0$ Tesla. (The present CESR permanent magnet quads are made from an older type of SmCo which has $B_{rem}\simeq 0.9$ Tesla.) The NdFeB material, however has a lower Curie temperature ($\sim$310 C compared to $\sim$480 C for SmCo) which causes the temperature coefficient to be 4 times larger, and requires special care to avoid exposing the material to excessive temperatures.

The first four rows in Table 29 are design exercises that do not easily accommodate the 4.7 to 5.6 GeV energy range. The SmCo options which can accommodate this energy range (rows 5 to 7) require unrealistically large gradients (k=0.8 m^{-1}) in the associated Fe/Cu quads. The superconducting quad options (rows 8 and 9) require placing the cryostat far

Table 29: Summary of IR quad options.

Quadrupole Configurations	Beam-beam Tune Shift (/1000)		Chromaticity (for 1/2 IR)		Horizontal Apperature (mm)
	dQ_H	dQ_V	Q'_H	Q'_V	H ap
1. NdFeB start at $z = 25$ cm	3.71	2.45	-3.0	-5.9	
2. NdFeB start at $z = 30$ cm	3.51	2.78	-2.7	-6.0	73
3. SmCo start at $z = 30$ cm	3.30	3.94	-2.4	-6.7	73
4. Above with 2 section REQ	3.26	5.09	-2.4	-7.0	73
5. SmCo 4.7–5.6 config: 4.7 GeV	3.88	2.95	-2.7	-6.4	69
6. SmCo 4.7–5.6 config: 5.3 GeV	3.30	4.71	-4.0	-4.8	68
7. SmCo 4.7–5.6 config: 5.6 GeV	3.07	5.61	-4.3	-3.9	70
8. SCQ 70 cm long, start at 60 cm	2.69	4.46	-1.7	-8.6	59
9. SCQ 54 cm long, start at 60 cm	2.82	3.66	-1.8	-7.8	58
10. SmCo 30–60 cm, SCQ 75–145 cm	3.18	4.09	-2.3	-7.4	
11. SmCo 30–60 cm, SCQ 75–125 cm	3.27	3.35	-2.4	-7.0	66
12. SmCo 30–60 cm, SCQ 70–122 cm	3.32	2.93	-2.5	-6.7	
13. 1992 HEP layout, 1.8 cm β^*	2.46	15.6	-2.7	-6.8	51/86

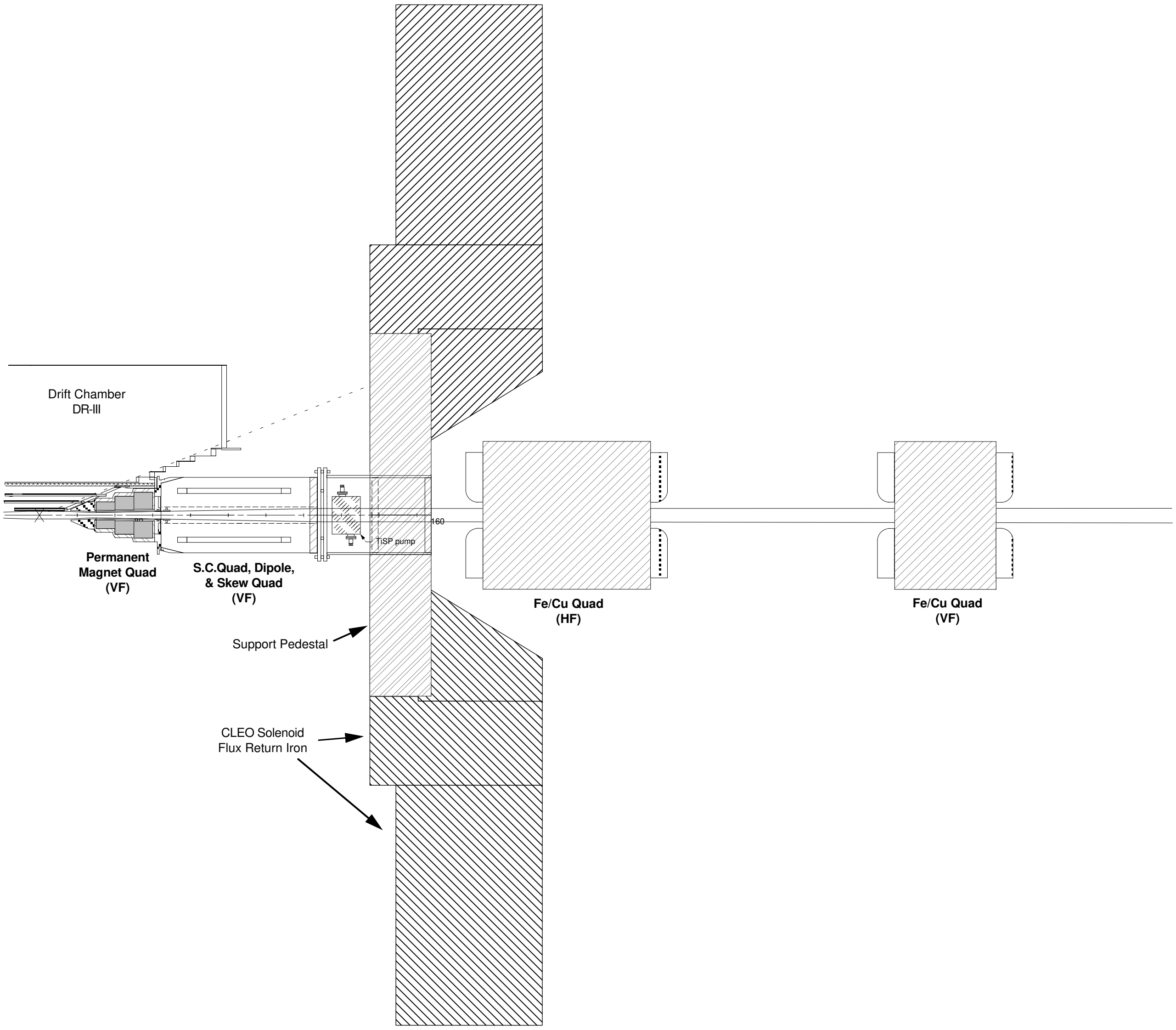

Figure 55: Proposed CESR Phase 3 interaction region quadrupole layout.

inside the drift chamber which places undesirable constraints on the cryostat and the drift chamber design.

Hybrid options (rows 10 to 12) using SmCo and superconducting quads satisfy all of the requirements discussed earlier. The SmCo is most effective when high fields are required in small volumes. It also is a very effective mask against high energy particle background. The superconducting quads provide a controllable high-gradient field and offer the capability to include additional magnet coils in the same cryostat. We plan to install in the cryostat horizontal and vertical dipole correction coils and skew quad coils for detector solenoid compensation. The option in row 11 of Table 29 was chosen because it provides the best set of machine parameters while providing sufficient space for mounting detector and accelerator hardware. A drawing of the proposed quads is given in Fig. 55.

Current densities for the quadrupole windings are modest—less than 300 A/mm^2. Peak magnetic fields at conductors are approximately 3.5 Tesla, not including the solenoid field.

6.2.7 Mounting and support

We have chosen to support the superconducting and permanent quads from a double pedestal fastened to the CLEO magnet return yoke. This removes any support structures from the space between the drift chamber endplate and the endcap particle ID and calorimeter. It allows the quads to maintain accurate alignment even after opening the pole for access to the endplate. A detailed analysis of the mechanical properties remains to be done; however, preliminary results show the static properties to be satisfactory.

Since the permanent magnet quadrupoles have a smaller inner radius than the beam pipe at the end of the drift chamber, they must be assembled on the pipe with the vertex detector before installation in the drift chamber. They have been designed to fit well within the drift chamber, allowing room for a temporary support structure during installation.

6.2.8 Vacuum system

The vacuum system must achieve sufficiently low pressures for acceptable beam lifetime and low CLEO background rates. It must be compatible with masks to control synchrotron radiation and shield against particle background. The inner surface should have sufficient conductivity and smoothness to minimize resistive and higher order mode RF losses. Adequate cooling must be provided to remove the heat deposited by electro-magnetic and synchrotron radiation processes. The chamber radius must be large enough to accommodate the full beam-stay-clear requirements. The central chamber should present a minimum of scattering material to the decay products from the interaction point.

The vacuum system is similar in concept to that planned for Phase 2 upgrade operation. The double-walled beryllium central pipe will handle the heat load expected in Phase 3 operation. The pipe in the permanent magnet and superconducting quads will be double walled with coolant circulating between the inner and outer skins. Pumping would be provided by a titanium sublimation or NEG pump located just beyond the superconducting quad.

Beam diagnostic instrumentation will be installed as part of the vacuum system (*e.g.,*beam position monitors, luminosity monitors, beam loss detectors). These are not considered in detail in this study.