SYNCHROTRON RADIATION ABSORPTION AND VACUUM ISSUES IN THE IR*

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Abstract

The PEP-II B-Factory (3.1 GeV e+ x 9.0 GeV e-) at SLAC operated from 1999 to 2008, delivering luminosity to the BaBar experiment. PEP-II surpassed by four times its design luminosity reaching 1.21x10^{36} cm^{-2} s^{-1}. It also set stored beam current records of 2.1 A e- and 3.2 A e+ in 1732 bunches. Continuous injection was implemented with BaBar taking data. PEP-II was constructed by SLAC, LBNL, and LLNL with help from BINP, IHEP, the BaBar collaboration, and the US DOE OHEP [1, 2].

The interaction region at PEP-II had to bring the multi-ampere beams into collisions at one point, produce small vertical beta functions (~1 cm), provide beam separation for parasitic beam crossings, provide low backgrounds to the detector, and remove heat generated by synchrotron radiation and higher order modes. All of these constraints made the IR design very complicated. The synchrotron radiation generated by the many dipole and quadrupole magnets had to be absorbed without generating a lot of emitted gas which would cause beam-gas interaction, lost particles, and detector backgrounds. A complication was the permanent magnet dipoles and quadrupoles near the collision point inside the Babar detector used to focus the beam and to provide the beam separation [3, 4]. The IR region extended away from the collision point by about 65 m on each side to accomplish all the needed requirements.

Table 1: PEP-II Collision Parameters

Parameter	Units	Design	April 2008 Best	Gain Factor over Design
I+	mA	2140	3210	x 1.50
I-	mA	750	2070	x 2.76
Number bunches		1658	1732	x 1.04
β_y*	mm	15-25	9-10	x 2.0
Bunch length	mm	15	11-12	x 1.4
ξ_y		0.03	0.05 to 0.06	x 2.0
Luminosity	10^{34} $/cm^2/s$	0.3	1.2	x 4.0
Int lumin per day	pb^{-1}	130	911	x 7.0

PEP-II PARAMETERS

In PEP-II the Low Energy Ring (LER) was mounted 0.89 m above the High Energy Ring (HER) in the 2.2 km tunnel as shown in Figure 1. The interaction region is shown in Figure 2 where the beams were collided head on. Figure 3 shows the Be vacuum chamber inside the detector with the permanent magnet dipoles on either side. The interface cone angle at the IR between BaBar and PEP-II was at 300 mrad. To bring the beams into collision, LER was brought down 0.89 m to the HER level and then with a horizontal deviation for both rings were made to collide. Since both rings have the same circumference, each bunch in one ring only collides with one bunch in the other ring making the beam-beam interaction much easier. Parameters are shown in Table 1.

Figure 1:PEP-II tunnel with LER above the HER.

The high beam currents were supported large RF systems consisting of 1.2 MW klystrons at 476 MHz and high power copper cavities with HOM absorbing loads. An RF cavity had three HOM loads with the capability of 10 kW each. At the peak currents the HER cavities each received 285 kW and the LER cavities 372 kW. The average klystron power was 1.01 MW. An overhead of about 20% in power was needed to allow the RF feedback systems to be stable. The power from synchrotron radiation was ultimately deposited in the walls of the vacuum system and had to be removed by water cooling.

The vacuum systems were extruded copper in the HER arcs and extruded aluminium with antechambers and photon-stops in the LER arcs. Both rings had stainless steel double walled chambers in the non-IR straight

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sections. The chambers were water cooled continuously over their 2.2 km lengths due to beam heating from synchrotron radiation, HOM heating, and resistive wall heating. From beam-off to beam-on the vacuum chambers expanded and high power expansion bellows were needed (Figure 4).

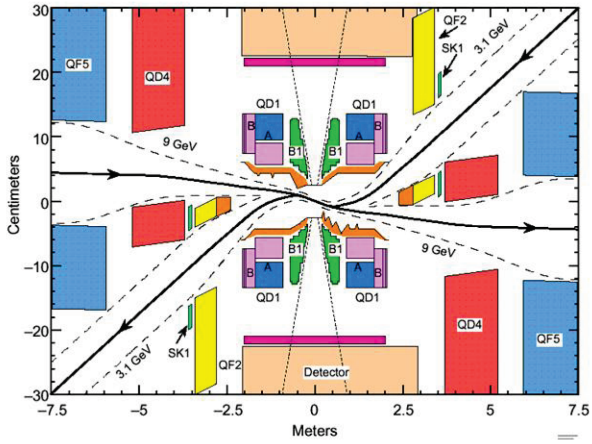

Figure 2:PEP-II Interaction Region (IR) with head-on collisions. There are four permanent magnets within the BaBar 1.5 T solenoidal field covering +/- 2.5 m. B1 is a dipole. A is a fixed quadrupole. The two magnets “B” were rotatable quadrupoles with two longitudinal slices each so that a skew quadrupole term could be introduced or an adjustable quadrupole (S. Ecklund, M. Sullivan).

Figure 3:IR double-walled Be collision chamber with nearby water cooling and permanent magnet dipoles.

The vacuum chambers were cooled with water using various techniques. The first was double walled chambers with several mm layer of water between the walls which was used in the straight sections and some in the IR region. The second was cooling channels extruded into the vacuum chamber seen mostly in the LER arcs and some of the IR chambers (Q4 and Q5). The third was copper cooling lines e-beam welded or brazed onto the outside of the copper chambers. The fourth was stainless tubing welded or brazed on the outside of smaller odd shaped components such as stainless steel flanges, discrete masks, and collimator jaws.

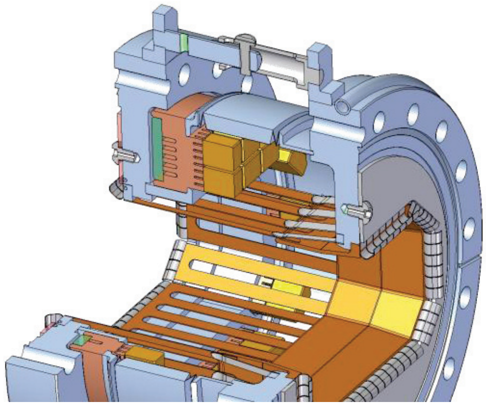

Figure 4:Ultimate design of the PEP-II high power expansion bellows module with sliding fingers, compression (hold down) fingers, beam RF seals at the ends, and water cooled HOM absorbers tiles. This bellow could handle over 3 amperes with 1700 bunches with a bunch length (sigma) of 1 cm (N. Kurita).

IR VACUUM SYSTEM

The beams in a circular e+e- collider emit synchrotron radiation photons in the dipoles and quadrupoles in the interaction region and deposit them in the nearby vacuum chambers [5]. These photons must be absorbed in the vacuum chambers with the deposited power taken away and the emitted gasses pumped away not to cause beam-gas backgrounds. A discussion of how this was done in the PEP-II IR will be presented and implications for a Higgs Factory will be shown. The beam-stay-clears in the two rings as a function of distance from the IP are shown in Figures 5 and 6.

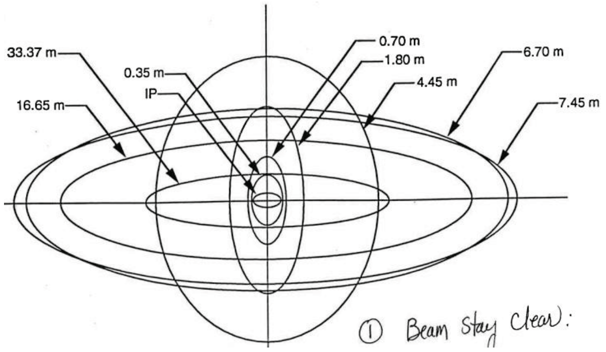

Figure 5:HER horizontal and vertical beam stay clears as a function of distance from the interaction point. This information is used to design the vacuum chamber dimensions (M. Sullivan).

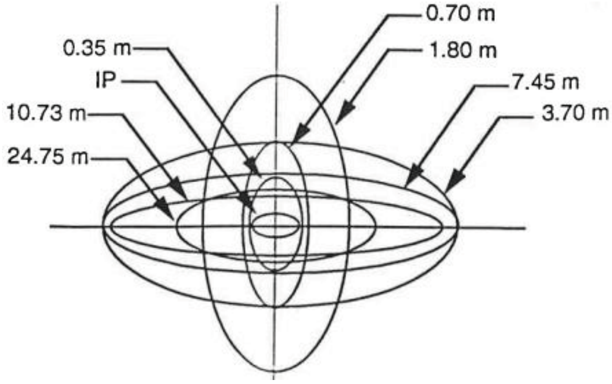

Figure 6:LER horizontal and vertical beam stay clears as a function of distance from the interaction point. This information is used to design the vacuum chamber dimensions (M. Sullivan).

The two energy beams produced x-ray fans inside the detector depending on the location and strength of the quadrupole and dipole magnets. The radiation fans for the incoming HER beam is shown in Figure 7 and for the incoming LER in Figure 8. The masking was designed so that no single scattered x-ray off a mask tip could hit the Be chamber at the IP in the detector.

The Be chamber was a double walled chamber with about 1 mm of water in radius that flowed along its length. The cooling could remove about 1 kW of power safely. The cooling lines were arranged so that the water flowed in one side, travelled down the length and then return back on the other side. The cooling water system had a sub-atmospheric pressure so that if a leak developed, no water would enter the BaBar detector. The Be chamber and the permanent magnets were support in a "support tube" that was stainless steel on both ends and a Be cylinder on the center. The diameter was about 60 cm.

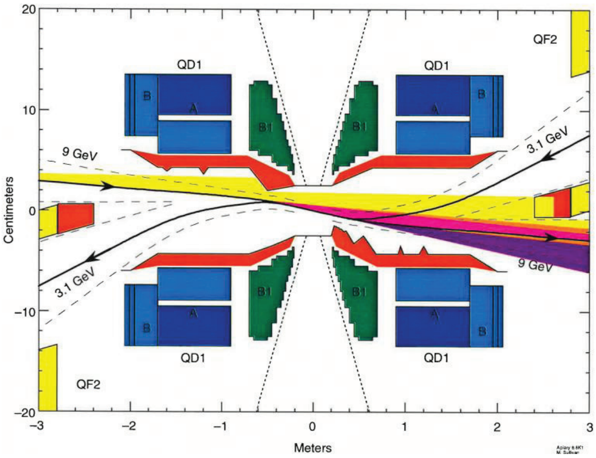

Figure 7:Radiation fans on the incoming HER beam showing the masking for backgrounds and the exiting high power photon beam (M. Sullivan).

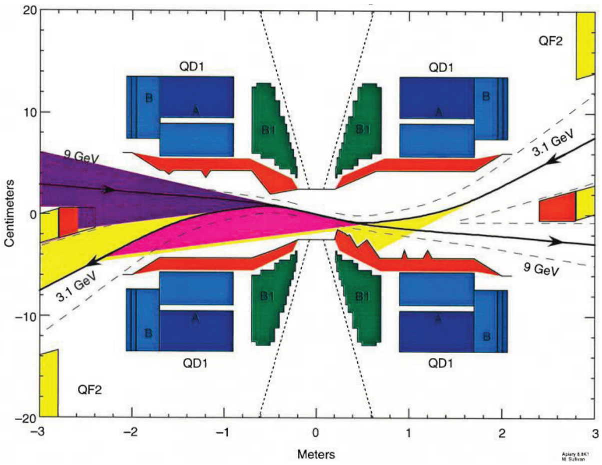

Figure 8:Radiation fans on the incoming LER beam showing the masking for backgrounds and the exiting high power photon beam (M. Sullivan).

A vacuum chamber schematic near the entrance and exit of BaBar is shown in Figure 9. Here, the chamber divides from one to two for the two accelerators as the beam separate. The various styles of vacuum pumps can be seen in the drawing using any space available. An enlargement of the vacuum chambers in the B1 dipole and the Q2 quadrupole are shown in Figures 10 and 11 showing their three dimensional shapes.

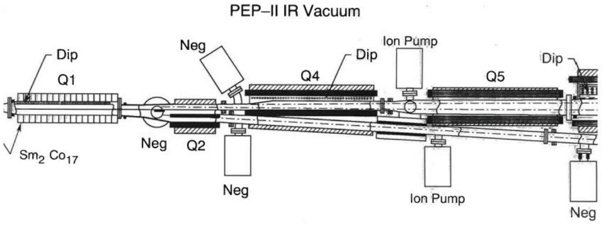

Figure 9:Schematic layout of the vacuum chambers just outside of BaBar showing the pumping arrangement.

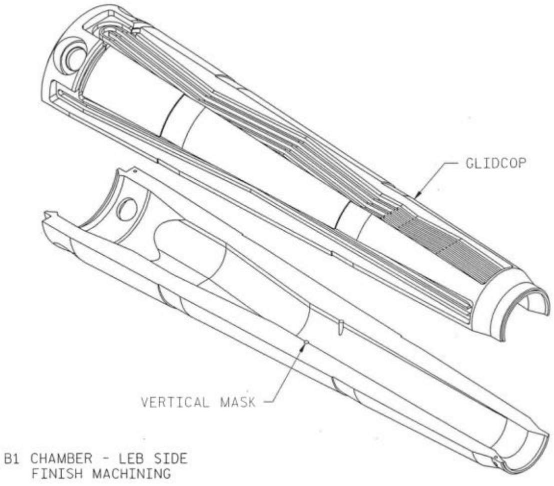

Figure 10:B1 chamber showing taper and masking.

Figure 11:Q2 chamber showing taper, masking and heavy duty water cooling with tapered sided to reduce local synchrotron radiation heat loading and stresses (S. Ecklund, N. Kurita).

The vacuum pressure in a heavily heating chamber from synchrotron radiation will outgas. But with time as a function of dose the outgassing rate will reduce. In Figure 12 is shown the reduced outgassing rate with an integrated dose of over 10^{25} photons/m. The reduction with dose does not saturate but keeps reducing.

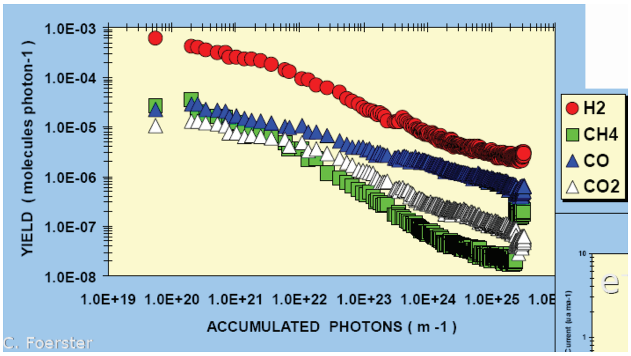

Figure 12:Outgassing rates as a function of synchrotron radiation dose (N. Kurita).

The reduced transverse dimensions of the vacuum chambers in the IR plus the addition of x-ray masks allow for the capture of HOM fields and associated power deposition from a high power beam. A calculation of HOM fields and frequencies for the PEP-II IR geometry is shown in Figure 13 and the associated modes are shown in Figure 14. The HOM modes added several kilowatts of integrated local power that had to be cooled. The fields were excited by both beams. Because of geometry with two oppositely traveling beams, the two sets of fields could either coherently add or subtract. PEP-II had some modes that added and some that subtracted fields with two beams. A lot of the generated fields were not trapped in the IR chamber but flowed out along the beam line and were dissipated in the vacuum chambers away from the IR, sometime many 10s of meters away.

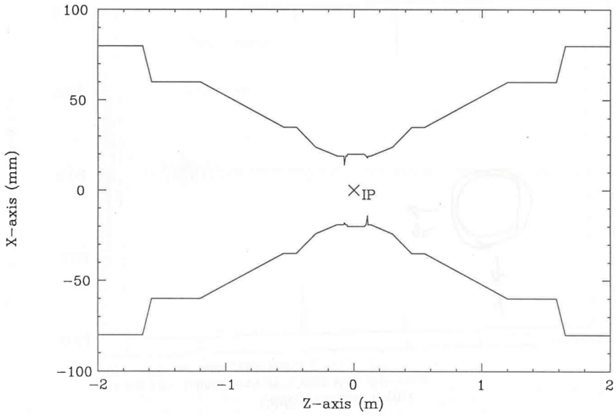

Figure 13:Schematic of the IP showing where higher order modes could be trapped between x-ray masks.

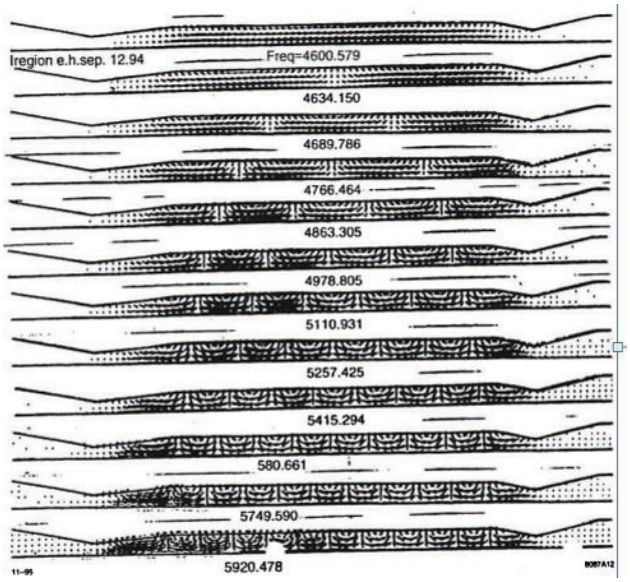

Figure 14:Various frequency HOM modes from the bunched beam as displayed in the IR vacuum chamber.

IR PERFORMANCE IMPROVEMENTS

Over the years several improvements to the vacuum system in the IR were done.

A) The small (10 cm diameter) expansion bellows on each end of the IP Be chambers had to have extra air and water cooling installed to survive the higher combined beam currents.

B) The synchrotron and lost particle masking near detector was improved as the currents were raised.

C) The high power vacuum expansion bellows went through several designs being able to handle ever increasing HOM powers. See Figure 6 for the best design.

D) The HOM screens for the NEG pumps in the IR had to be replaced as some beam HOM power was leaking through the screens and heating the NEG strips to several hundred degrees causing vacuum issues.

CONCLUSIONS

In the design of an interaction region for an e+e- Higgs factory the designer must minimize the SR power lost in various components and their vacuum chambers. It is important to find creative possibilities to provide vacuum pumping near the IR. Pumping inside of the detector is important if possible. Finally, it is important to shield carefully the detector from x-rays and lost particles for detector data integrity.

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