SLAC-PUB-13635
May 2009

CHANGING THE PEP-II CENTER-OF-MASS ENERGY DOWN TO 10 GEV AND UP TO 11 GEV *

M. Sullivan#, K. Bertsche, A. Novokhatski, J. Seeman, U. Wienands, SLAC, P.O. Box 20450, Stanford, CA 94309, U.S.A.

Abstract

PEP-II, the SLAC, LBNL, LLNL B-Factory was designed and optimized to run at the Upsilon 4S resonance (10.580 GeV with an 8.973 GeV e- beam and a 3.119 GeV e+ beam). The interaction region (IR) used permanent magnet dipoles to bring the beams into a head-on collision. The first focusing element for both beams was also a permanent magnet. The IR geometry, masking, beam orbits and beam pipe apertures were designed for 4S running. Even though PEP-II was optimized for the 4S, we successfully changed the center-of-mass energy (E_{cm}) down to the Upsilon 2S resonance and completed an E_{cm} scan from the 4S resonance up to 11.2 GeV. The luminosity throughout most of these changes remained near 1×10^{34} $cm^{-2}s^{-1}$. The E_{cm} was changed by moving the energy of the high-energy beam (HEB). The beam energy differed by more than 20% which produced significantly different running conditions for the RF system. The energy loss per turn changed 2.5 times over this range. We describe how the beam energy was changed and discuss some of the consequences for the beam orbit in the interaction region. We also describe some of the RF issues that arose and how we solved them as the high-current HEB energy changed.

INTRODUCTION

The initial plan for Run 7, the last running cycle of PEP-II, was to continue running on the 4S resonance and collect about 50% more integrated luminosity while on the 4S. In addition, there was a plan to run at the Upsilon 3S resonance for a brief time (about 2 weeks) sometime in June or July. We had just started the accelerator on Dec. 15th and had begun to scrub the vacuum with first delivery to BaBar on Dec 18th , when, on Dec. 19th , we learned that the PEP-II run was going to be severely curtailed because of budgetary issues. Since we did not know how shortened the run was going to be, on Dec. 21st we immediately decided to move the accelerator to the 3S resonance in order to at least obtain some data at this resonance. We had very briefly moved the accelerator to the 3S resonance in the fall of 2002 during the startup phase of that run so we had developed a method to get to this resonance which we describe in more detail below.

IR DESIGN AND CONSTRAINTS

Before we discuss changing the beam energy of PEP-II we need to describe the design of the interaction region (IR). Aside from the IR, the rest of PEP-II was able to change the beam energy. However, the machine elements inside BaBar were constructed of permanent magnet material because of the surrounding detector solenoidal field. We had two strong dipole magnets (B1) located between 21 and 70 cm from the interaction point (IP). These magnets brought the two asymmetric-energy beams into and out of a head-on collision. Immediately following these magnets were two vertically focusing quadrupoles (QD1) that both beams went through. These 1.2 m long quadrupoles started 0.9 m from the IP. The beam separation started by the inside dipoles was further increased by these quads. Together these magnets produce an ±11 mrad bend in the HEB and a ±50 mrad bend in the low-energy beam (LEB). The beams are then separated enough at 2.5 m to get the beams into separate beam pipes. Outboard of 2.5 m we have three separate septum magnets, the first of these completes the final focus doublet for the LEB and the next two complete the final focus for the HEB. Figure 1 shows a layout of the IR.

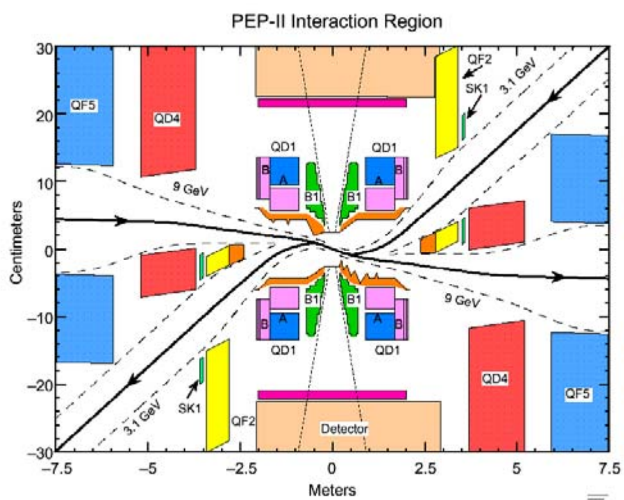

Figure 1. Layout of the PEP-II Interaction Region. Note the exaggerated vertical scale.

We had electric quadrupole trim windings on the QD1 permanent magnets which allowed us to adjust the magnet strength by ±2%, but we ended up setting them once to correct for the small (~1%) loss in field strength due to the detector solenoidal field. The fact that these magnets were shared discouraged any casual use of the trim windings.

CHANGING THE CENTER-OF-MASS ENERGY

Running at the 3S

The permanent magnet design of the IR made changing the LEB energy difficult. Changing the LEB energy

*Work supported by the Department of Energy under contract number DE-AC03-76SF00515
#sullivan@slac.stanford.edu

Contributed to the 2009 Particle Accelerator Conference, 05/04/2009 -- 05/08/2009, Vancouver, Canada

required changing the strength of the shared QD1 magnets which then also changed the lattice functions of the HEB. Changing the energy of the HEB was considerably easier. We could leave the strength of the QD1 magnet alone and adjust the coefficient used to change the strength of the QD4 magnet (see fig. 1) which is the primary vertical final focus magnet for the HEB. The LEB magnets are then left untouched and overall minimal changes were made in the final focus magnets for both rings. This procedure of changing only the HEB energy was adopted early in PEP-II running. We used it to move the E_{cm} 40 MeV below the 4S resonance in order to collect off resonance data.

Now, however, we wanted to move the E_{cm} down 225 MeV to reach the 3S which meant lowering the HEB energy 377 MeV. We had done this earlier but only briefly (~24hrs total running time). On Dec 21[st] we lowered the HEB energy and scanned the resonance to find the peak and we were sitting on the peak collecting data in a little over 24 hrs. Because we had just started up the accelerator it took several weeks to ramp up the luminosity to 10^{34}. In less than one week we were delivering data at a good rate. The running at the 3S with good luminosity proved to be fairly easy. However, the 3S resonance is much narrower than the 4S which made us more sensitive to beam energy drift. The beam energy spread is about the same as the width of the 4S resonance so our energy drift sensitivity nearly doubled when we moved to the much narrower 3S. We did struggle with energy drift for the first 4 weeks of running and suspect the main cause to be changing temperatures in the tunnel. While running on the 3S, we found that we could get an increase in luminosity and a decrease in detector backgrounds by adjusting the HEB x angle at the IP. Figure 2 shows the luminosity plot of PEP-II during the 3S resonance run.

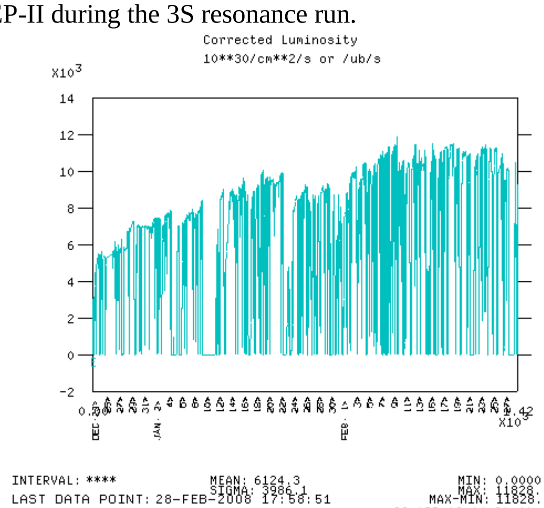

Figure 2. PEP-II luminosity plot during the 3S run.

Running at the 2S

After successfully running on the 3S for 2 months the BaBar detector collaboration asked to run for one month on the 2S resonance. This we had never done before. We applied the same technique we used to get to the 3S. We moved the HEB energy down another 542 MeV to 8.050 GeV and thereby lowered the E_{cm} down 332 MeV to 10.023 GeV, the mass of the 2S. The 2S running was much more problematic. The lower beam energy with the same RF voltage significantly shortened the bunch length. This produced a significant increase in HOM power and in fact we managed to damage one of our beam position pickup feedthroughs through overheating thus causing a vacuum failure. After repairing the leak, we lowered the HER RF voltage from 16.5 MV to 14 MV in order to prevent further problems while running at the 2S. For the upcoming energy scan we again raised the HEB total RF voltage to 16.5 MV. While on the 2S, we had a great deal of trouble finding a high luminosity running point with low detector backgrounds. Adjusting the IP x angle did not help and we concluded that although we wanted to further adjust the IP x angle to improve the luminosity we were moving the beam too close to the vacuum chamber wall and consequently shortening the beam lifetime and creating detector backgrounds. We tried to improve the situation by moving the collision x position but that also did not help significantly.

Center-of-Mass Energy Scan

During the final week of run 7 we performed a center-of-mass energy scan starting at the 4S resonance (actually just below the resonance) and increasing the E_{cm} value in 5 MeV steps up to a center-of-mass energy of 11.2 GeV. This is a total scan range of 660 MeV in the Ecm and 1.15 GeV for the HEB. The total number of steps was about 132 and each step took, in general, less than one hour. The BaBar detector wanted to collect 3 pb^{-1} at each energy step. With 100% efficiency and a luminosity of at least $1\times10^{34}cm^{-2}s^{-1}$ the scan would have taken about 4.5 days. We completed the scan in a little over 7 days. We had very few long (> 1hr) downtimes during the energy scan in spite of the fact that we were pushing the accelerator into new territory throughout the scan.

In order to minimize the energy change time we developed a button macro that would adjust the ring magnets up in small enough steps (about 5) so that the stored beam was not lost and then ramp up the HEB injection line magnets in one step. This would take about 20-30 sec. The procedure was a follows:

- The detector data taking was paused.
- The steady state (trickle) injection was stopped.
- The button macro was pushed.
- The beam energy was checked to make sure it moved (the updating frequency was increased to every 10 sec for this scan).
- If all looked ok, the operators would start up ring injection
- The detector control room was then told they could start taking data again

The entire turn around time was generally between 1-2 minutes. Since each energy step lasted approximately an hour there was not much time to optimize the machine for peak performance. The operators spent most of the time trying to improve performance but there was never enough time to fully tune up the machine before the next energy step. Each change in energy would slightly change the HEB orbit as it traveled through the interaction region due to the fixed field strength of the permanent magnets. This in turn would alter the coupling of the HEB from the detector solenoidal field. Each of these small changes would gradually detune the fully optimized machine and the operators were constantly trying to keep up. Figure 3 shows the HEB energy, HEB current and the Luminosity during the entire energy scan.

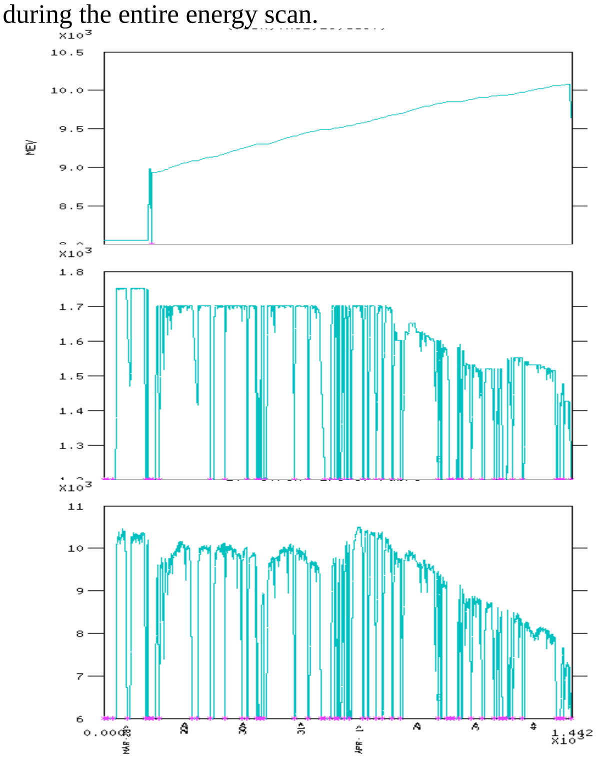

Figure 3. Three plots. The top plot is the HEB energy, the middle plot is the HEB current in mA and the bottom plot is the luminosity throughout the entire energy scan.

THE HIGH-ENERGY BEAM RF SYSTEM

During the energy scan the HEB RF system was pushed harder than it had ever been before. Near the top of the energy scan the RF system was delivering more than 10 MW of power to the HEB. Below we show some plots of the klystron power and the high-voltage power supply output power.

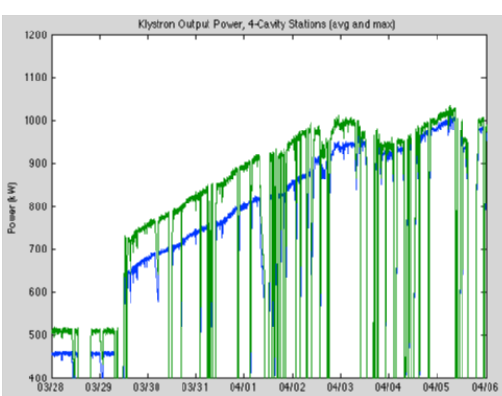

Figure 4. Plot of the klystron output power for the 4 cavity stations. The blue line is the average and the green line is the maximum during the time of the energy scan. Several klystrons were delivering 1 MW of output power.

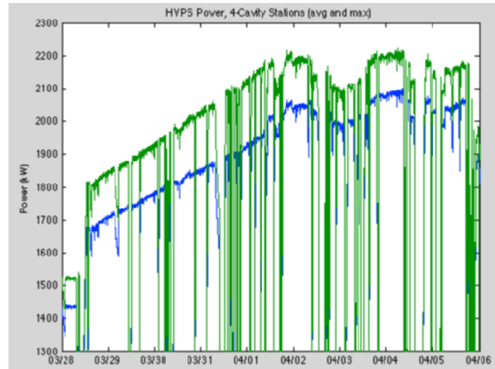

Figure 5. Plots of the high-voltage power supply output power during the energy scan. The maximum (green line) reached 2.2 MW, the maximum rating of these power supplies. The blue line is the average.

SUMMARY

PEP-II, although optimized for running on the 4S resonance (10.580 GeV) and with an interaction region that contained permanent magnets was able to adjust the center-of-mass energy of the accelerator down to the Upsilon 2S resonance (10.023 GeV) and up to 11.200 GeV in a center-of-mass energy scan. This was done by adjusting only the high-energy beam energy and required changing the beam energy from 8.0 GeV to 10.08GeV. We were able to maintain a luminosity close to $1{\times}10^{34}cm^{-2}s^{-1}$ throughout these energy changes except near the top of the energy scan where the high-energy beam energy was the highest. At the top end of the energy scan the RF system was being pushed to its limit and the greatly increased synchrotron radiation power was getting close to the upper limit set by the temperature sensors around the ring. These two limits led us to lower the high-energy beam current as the beam energy was further increased to complete the energy scan. This gradually lowered the luminosity from a high of $10.5x10^{33}$ to a low of about $7.5x10^{33}$ at the end of the scan.

ACKNOWLEDGEMENTS

We would like to thank all of the people who helped to make PEP-II such a success. This is particularly true for the PEP-II team and we want to especially thank all of the operators who tirelessly strove to improve machine performance.