PEP-II Status

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for the

PEP-II Team
Outline

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  – Records

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• Summary
Run 7

• After shutting down last September 2007 and installing the last improvements into PEP-II, we started up in December

• We got both beams into the rings with collisions on Dec 15th and started to deliver data to BaBar on the 17th

• On Dec 19th we were told that the run would be cut short and immediately BaBar decided to move the $E_{cm}$ of PEP-II to the Upsilon 3S resonance to get as much data as possible

• BaBar was already planning to move to the 3S sometime during the run for a couple of weeks

• We moved to the 3S resonance on Dec 21st and proceeded to collect data there over the holidays and for the first 2 months of 2008
More Run 7

• The performance of PEP-II at the 3S resonance prompted BaBar to ask for another month of running in order to collect a data sample at the 2S. They wanted at least 100 million 2S events. They were granted a one month extension.

• On Feb 29th we moved the PEP-II $E_{cm}$ down to the 2S and collected data at the 2S throughout March.

• During March, BaBar and PEP-II began developing a plan to scan the $E_{cm}$ above the 4S resonance up to 11.2 GeV $E_{cm}$.

• On March 28th, we began this energy scan and we have just completed this scan on Monday April 7th when we turned off PEP-II.
Changing $E_{cm}$

- PEP-II was designed and optimized to run at the Upsilon 4S resonance.
- The optimal beam energies are 3.12 GeV and 8.97 GeV.
- The final focus quadrupole for both beams is a permanent magnet and the final bending magnet that puts the beams into a head-on collision is a permanent magnet.
- The HER however has another vertical focusing magnet just outboard of the shared vertical focusing magnet.
- Adjusting the amount of change in this magnet in order to account for the non-changing shared quadrupole allowed us to change the HER beam energy.
- M. Donald constructed such a knob for changing the HER beam energy in 1997. The knob has a surprisingly large range of functionality. We used this knob to move the HER beam energy from 8.00 GeV to 10.08 GeV giving us enough range to span the 2S resonance (10.023 GeV) up to 11.2 GeV in the $E_{cm}$.
- In addition, we were able to adjust the orbit to accommodate the non-changing B1 dipole magnets.
PEP-II Status

PEP-II Interaction Region

Permanent magnets
Luminosity was maintained near $1 \times 10^{34}$ sec$^{-1}$cm$^{-2}$ until the very highest beam energies.

We had to lower the HER beam current near the top of the energy scan above the 4S due to overheating of vacuum chambers and also because of limits in available RF power.

Magnet power supplies had adequate range and did not cause any problems.

We did start to have trouble with the Distributed Ion Pumps (DIPs) as we approached the top of the energy scan. This problem (outgassing bursts) continued to bother us even after we lowered the HER beam energy on the last 2 days of running.
As the beam energy increased the RF power load increased to our upper limit and to the limit of the water cooling system for the vacuum chambers.
DIP vacuum pressures

One of the Distributed Ion Pumps (DIPs) in the HER ring that had gas bursts.

Some of the pumps were well behaved.
Some PEP-II Achievements

• Peak luminosity of $12 \times 10^{33}$ cm$^{-2}$s$^{-1}$
  – 4 times design

• Delivered $>550$ fb$^{-1}$ in 7 yrs
  – 2.5 times the design of 30 fb$^{-1}$/yr

• Maximum HER beam current $>2.0$ A
  – 2.5 times the design current 0.75 A

• Maximum LER beam current $>3.2$ A
  – 1.5 times the design current of 2.14 A
BaBar

• The BaBar collaboration has:
  – Collected 433 fb\(^{-1}\) of data on the 4S resonance
  – Collected 30 fb\(^{-1}\) of data on the 3S resonance – more than 10 times the world data sample
  – Collected 14.5 fb\(^{-1}\) of data on the 2S resonance – about 100 million 2S events
  – A finely spaced (5 MeV steps) energy scan above the 4S resonance
PEP-II Monthly Integrated Luminosity

fb^{-1}

Mar-09, Jun-09, Sep-09, Dec-09, Mar-00, Jun-00, Sep-00, Dec-00, Mar-01, Jun-01, Sep-01, Dec-01, Mar-02, Jun-02, Sep-02, Dec-02, Mar-03, Jun-03, Sep-03, Dec-03, Mar-04, Jun-04, Sep-04, Dec-04, Mar-05, Jun-05, Sep-05, Dec-05, Mar-06, Jun-06, Sep-06, Dec-06, Mar-07, Jun-07, Sep-07, Dec-07, Mar-08

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PEP-II Status

e+e- Factories
Apr. 14–16, 2008
PEP-II Daily Average for each Month

Design of 135 pb$^{-1}$
PEP-II Records

Peak Luminosity

\[12.069 \times 10^{33} \text{ cm}^{-2} \text{sec}^{-1}\]

1722 bunches 2900 mA LER 1875 mA HER

August 16, 2006

Integration records of delivered luminosity

Best shift (8 hrs, 00:00, 08:00, 16:00) 339.0 fb\(^{-1}\) Aug 16, 2006

Best 3 shifts in a row 910.7 fb\(^{-1}\) Jul 2-3, 2006

Best day 858.4 fb\(^{-1}\) Aug 19, 2007

Best 7 days (0:00 to 24:00) 5.411 fb\(^{-1}\) Aug 14-Aug 20, 2007

Best week (Sun 0:00 to Sat 24:00) 5.137 fb\(^{-1}\) Aug 12-Aug 18, 2007

Peak HER current 2069 mA Feb 29, 2008

Peak LER current 3213 mA Apr 7, 2008

Best 30 days 19.776 fb\(^{-1}\) Aug 5 – Sep 3, 2007

Best month 19.732 fb\(^{-1}\) August 2007

Total delivered 557 fb\(^{-1}\)
High Current Running

• High beam currents find any weakness in the vacuum system as well as in the feedback systems and in the RF systems.

• Throughout the life of PEP-II these three systems were upgraded and improved as problems were found and fixed.

• I will concentrate on the vacuum system.
PEP-II Vacuum system

• There are two main issues with respect to the vacuum system: SR and HOM

• Synchrotron radiation
  – In general the PEP-II design did a good job of understanding and controlling SR
  – The IR design was adequate for all possible beam conditions
  – We did have a few early problems with SR that were fixed
  – A few items had to be upgraded
Vacuum

• Higher-Order-Mode power
  – This issue is more difficult to quantify
  – As the beam currents in PEP-II went up we found many different types of vacuum component failures
    • Vacuum valves – RF shield failure
    • Bellows heating
    • TSP connector failure (In only one place!)
    • Design weakness in a bellows near the detector
    • BPM failure
    • Flex flange RF seal failure
    • Pump screens that were too thin
General Vacuum Levels

• **HER**
  – The base pressure in the ring is generally less than 0.1 nTorr
  – The dynamic pressure is about 1 nTorr/A

• **LER**
  – The base pressure in the LER ring is generally about 0.1 nTorr
  – The dynamic pressure in is about 0.5 nTorr/A

• **IR**
  – There is a very low pressure chamber in the HER upstream of the detector. The pressure is 0.1-0.3 nTorr at 1.5A beam current.
  – The LER pressure upstream of the detector is about 0.5 nTorr with the pressure just upstream (~10m) at 0.2 nTorr at 2.5 A current.

• **A lot of credit for this low vacuum comes from the scrubbing history PEP-II has. The LER ring has ~60,000 A-hr. The HER ring has ~40,000 A-hr.**
At the beginning of the last run we had an average of 9 beam aborts each day.
At the end of the last run we had an average of 9 beam aborts each day.
The number of RF related aborts was about 3.5 each day.
Many of the other aborts were of the type we call “fast vertical”. These are aborts where we see the HER beam starting to go unstable in the Y plane however the feedback system would recapture the beam however the beam loss would be enough to trigger the beam abort.
LER “Fast vertical” Instability

Extremely fast growing coherent motion involving whole beam coincident loss of beam current trips interlock.
Tune lines become very broad, noisy

We first discovered these kinds of instabilities in December of 2005
Misplaced Gap Ring
Vacuum spike problem near the detector

• Sudden large vacuum spikes just upstream of the detector for the LER beam (> 1000 nTorr). This is too high for the detector to survive. They would force a beam dump.

• This problem showed up in November of 2005

• We were unable to get beam currents above 1500 mA LER and 1000 mA HER when in August, the summer before we shut down, we were able to get to 2990 mA LER and 1700 mA HER.

• Eventually tracked down to a design flaw in which the Cu fingers of the RF seal engaged against the HOM absorbing tiles instead of the Cu underneath the tiles in a bellows section next to the detector.
Side view of BaBar

- Backward Q1/Q2 bellows
- Forward Q1/Q2 bellows
- Forward Q2 chamber
- Large vacuum spikes here
Q1/Q2 bellows section

Q1 side of bellows
Close up of tile damage
The RF seal next to the tiles

The damage can not be seen with a borescope
New RF seal – Close up of tile side
Final solution

The new MKIII bellows
Damaged RF shields for bellows

We found 3-4 bellows sections out of 192 that were damaged. Found by locating vacuum spikes in nearby pumps.

One was also identified by noticing a reflection in a HOM pickup located about 50 m from the IP in the LER when a single beam bunch was in the HER.
Damaged RF seals

• In Run 5 we found that we were getting beam aborts from unknown locations in the ring. These events were discovered by some of these events producing a vacuum spike in nearby vacuum pumps.

• Investigation led to the finding that we had RF seals that had failed in the HER. The HOM power was getting behind the shield and heating up the stainless steel holding the RF shield fingers.

• We decided to try to instrument these seals even though there were no good locations to monitor the temperature.

• We found surprising high temperatures and eventually concluded we needed to replace as many of these seals as we could during the last downtime.
RF seal from Arc 7

Arcing deposits enough heat to locally melt the copper
These pictures are from the worst RF seal found in arc 1

Copper melts at 1080 deg C

SS melts at 1540 deg C (2550 deg F)

The SS plate is distorted

PEP-II Status
These pictures are from the worst RF seal found in arc 5

I estimate about 200 W of power are needed to melt the SS washer.
New RF Seal Design

Same as the old design but omega fingers made out of silver plated Inconel. The entire SS plate is silver plated.
This groove was discovered last fall when we were replacing damaged RF seals.
NEG heating

- We discovered that HOM power was getting past the relatively thin screens we have between the NEG pumps and the beam in the region before the detector in IR2. We were more worried about pumping speed than we were about HOM screening when we designed the IR.

- The NEG pumps can absorb RF power (the materials are very lossy). If RF power gets through the screen they will heat up and start to outgas (we effectively start regenerating the NEG)

- Some of the screens were worse than others so we removed the NEG pumps from the beam chambers with the thinnest screens and lost about 10-15% of our total pumping capacity in this area.

- We have also installed HOM absorbing bellows sections and HOM absorbing sections of beam pipes

- We discovered that the HER can go unstable if there is too much gas in the ring. We found this out by deliberately heating a NEG.
Pressure rise from heating Q5 NEG pump

The pressure rise at this location was about 30 nTorr of $H_2$ over approximately 3 m. The HER spot size did increase.

If we increased the pressure further (up to 60 nTorr) the HER beam went unstable and could not be controlled by the transverse feedback system but stayed in the ring.

Lowering the pressure immediately settled the beam and restored the luminosity.

The beam current was $\sim$1200 mA in 1722 bunches.
Test chamber with NEG pump

- The NEG washers absorb HOM energy
- They outgas above 350°F
- Offending NEGs got replaced by HOM absorbers
Summary

• PEP-II was an accelerator on the high-current frontier

• High beam currents together with short beam bunches tend to uncover any weakness that exists in the vacuum system

• High frequency HOM power can find the smallest nooks and crannies
Summary (2)

• We have found that unexplained beam losses can be evidence of arcing in the vacuum system.

• Arcing metal generally does not make a gas signature (at most a very small signal).

• The metal pieces (micron size) that result from the arcing that get into the beam path are believed to be what makes the beam go unstable (either an ion cloud or an electron cloud).
Summary (3)

• PEP-II has been one of the most successful accelerators in that it far exceeded its design parameters. Part of this success is due to the friendly competition we had from KEK.

• SLAC now leaves the field as a site with a HEP accelerator

• SLAC will continue to support HEP efforts around the world both in physics and in accelerator development

• Many thanks are in order for the tremendous team we had that kept the machine running and that continued to work on improving the machine performance.