BUNCH PATTERN WITH MORE BUNCHES IN PEP-II*

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Abstract

The number of bunches in the PEP-II B-Factory has increased over the years. The luminosity has followed roughly linearly that increase or even faster since we have also lowered the spot size at the interaction point. The recent steps from 939 bunches in June of 2003 to about 1320 in February 2004 (and 1585 in May) should have been followed by a similar rise in luminosity from $6.5\cdot10^{33}$ 1/cm$^2\cdot$1/s to $9.1\cdot10^{33}$ 1/cm$^2\cdot$1/s (or even $11\cdot10^{33}$ 1/cm$^2\cdot$1/s in May). This didn't happen so far and a peak luminosity of 'only' $7.3\cdot10^{33}$ 1/cm$^2\cdot$1/s (or $9.2\cdot10^{33}$ 1/cm$^2\cdot$1/s in May) was achieved with less bunch currents. By filling the then partially filled by-3 pattern to a completely filled by-3 pattern (1133 bunches) we should get $7.9\cdot10^{33}$ 1/cm$^2\cdot$1/s with scaled currents of 1400 mA (HER) on 1900 mA (LER). We were typically running about 1300 mA on 1900 mA with 15% more bunches in February (and 1550 mA on 2450 mA with 40% more bunches in May). The bunch pattern is typically by-2 with trains of 14 bunches out of 18 (or 67 out of 72). The parasitic beam crossings or electron cloud effects might play a role at about a 5-10% luminosity loss. Also the LER *x*-tune could be pushed further down to the ½ integer in the by-3 pattern. On the other hand, we might not push the beam-beam tune shift as hard as in June of 2003 since we have started trickle injection and therefore might avoid the highest peak luminosity which probably has a higher background.

INTRODUCTION

The number of bunches was been raised quite remarkably over this last run (Fig. 1). This is faster than the beam currents and the luminosity.

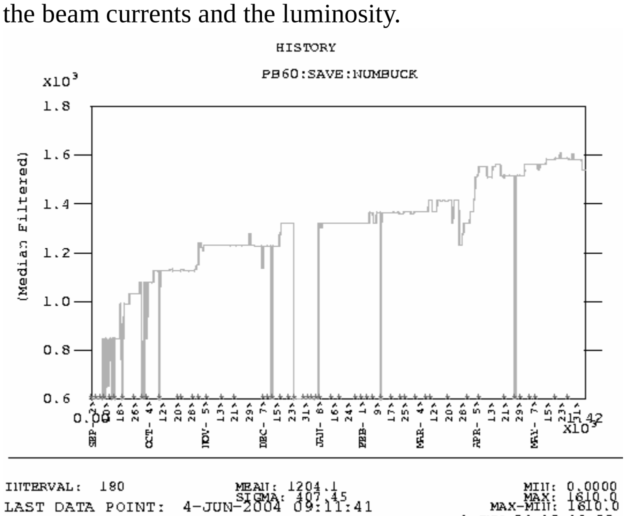

Fig. 1: Number of bunches in PEP-II since Sep-2003.

Studying the luminosity increase versus the number of bunches can reveal many insights as to how the higher luminosity is achieved. Higher luminosity per bunch indicates a push for higher beam-beam tune shifts, while less luminosity per bunch shows that we avoid tune-space trouble and give the operators room to decrease the spot sizes and emittances.

As mentioned in the abstract we are running the PEP-II rings quite differently than a scaled version from early June of 2003 running. How and why this change happened and the obstacles in achieving more bunches will be described in detail.

PUSH FOR MORE BUNCHES

The highest luminosity per bunch was achieved in early June of 2003. The tune space was very tight and only the best operators could get to that point (HER *x*-tune down over some resonances). So the number of bunches was raised twice from 939 to 986 to 1034 (+10%) with only a moderate increase in the currents: 5.8 and 3%. This gave the same or even higher luminosity (compare Table 1 and Fig. 2) and easier tune management.

Table 1: Peak Luminosity [10^{33} 1/cm$^2\cdot$1/s]

Lumi	Bunches	Currents	L/bunch	Date
6.485	939	1465, 1140	6.9	8-Jun-03
6.582	1034	1550, 1175	6.4	19-Jun-03
6.643	1230	1940, 1330	5.4	12-Nov-04
9.213	1588	2450, 1550	5.8	21-May-04

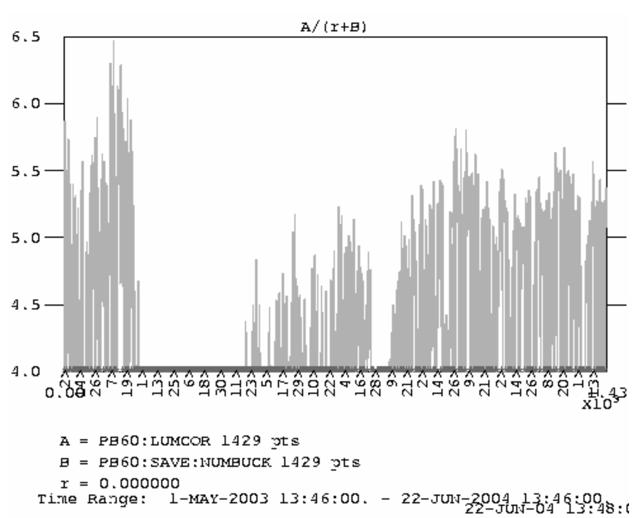

Fig. 2: Luminosity per bunch [10^{30} 1/cm$^2\cdot$1/s] since May 2003. The highest peak of 6.9 was on 8-Jun-2003.

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At the start of the present run we expected to increase the number of bunches in the by3 pattern until we reached 1133 bunches and then go to a by2 pattern with trains where every other bucket is filled. An early test of a week in a by2 pattern gave about 10% less luminosity, so some hit was expected. At the end of October 2003 more RF come online so a higher current could be supported and a by2 pattern with more bunches was necessary (see Fig. 1).

In a by2 pattern the beam experience a parasitic tune shift of up to 0.03 in *y* [1], which has to be adjusted. But the first and the last bunch of a bunch train see only half that tune shift. This makes it harder to get to the right tune space with the highest luminosity for all bunches. The first and last one have often lower lifetime and have to be filled more frequently, which is not too much of a problem since we trickle inject into the rings [2]. Single (or pilot) bunches have typically even lower lifetime or are effectively lost, especially in the LER.

In Fig. 3 the luminosity is shown for 432 bunches. We typically increase the number of bunches by adding one bunch to each train and making sure the gap between trains is not too big.

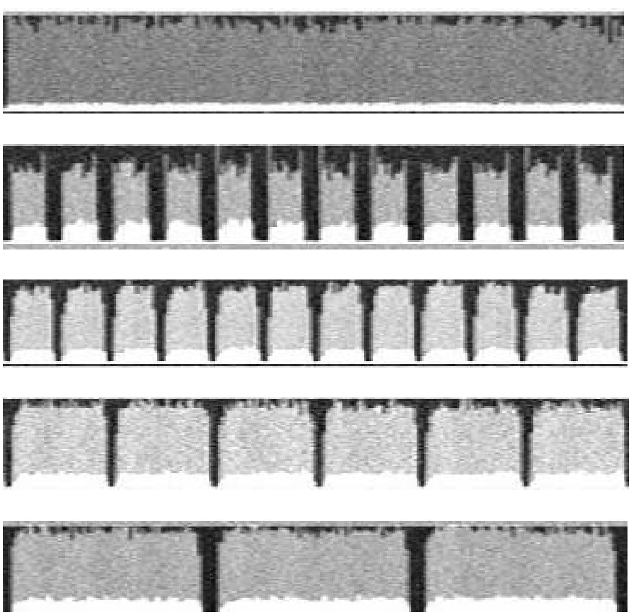

Figure 3: Luminosity along 432 bunches for different times. The top shows the flat luminosity for a full by3 bunch pattern, while the next is a by2 pattern with trains of 13 out of 18 places (1230 bunches). The first and last bunch of some trains showed initially higher luminosity. Then later in time, after tuning and more bunches (15 out of 18, 1420 bunches) the first and last bunch show about 30% less luminosity or 4% overall. Therefore more trains got combined to 31 out of 36 places (1469 bunches) and finally 67 out of 72 places (1588 bunches).

LUMINOSITY ALONG BUNCH TRAINS

Besides the different luminosity for the first and last bunch in a train, there was typically a luminosity drop along bunch trains over the years [3-5]. Their effect could be reduced by using short trains, which is believed to reduce the build-up of an electron cloud along the positron bunch train. The effect that the beam size increases with its own current and only in colliding beam conditions was only in *x*. But this effect disappeared in May of 2003 when we moved the LER *x*-tune from close to 2/3 (0.64) to just above the ½ integer (0.52). So three conditions were necessary: electron cloud, beam-beam, and the tune just below a resonance.

These days we see normally no or only a very small luminosity drop along the bunch trains (Fig. 4). After the first three to five bunches, which might have different charge (see below), the variation is within ±2%. Sometimes when the machine is not well tuned, there can be luminosity degradations of up to 10% (Fig. 5). Which beam dimension varies to account for these conditions has not been determined, since they don't last very long, but it would be interesting to study it further. In addition, the luminosity is lower in the front part due to an RF phase transient and the hourglass effect.

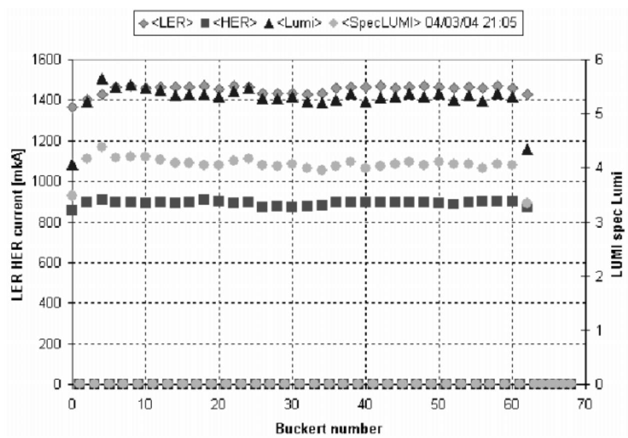

Figure 4: Average luminosity along all trains of 32 bunches. The luminosity is mainly flat along the trains. The first and last bunch show about 25% less luminosity. The LER has typically a current ramp in the front to adjust for otherwise overfilling.

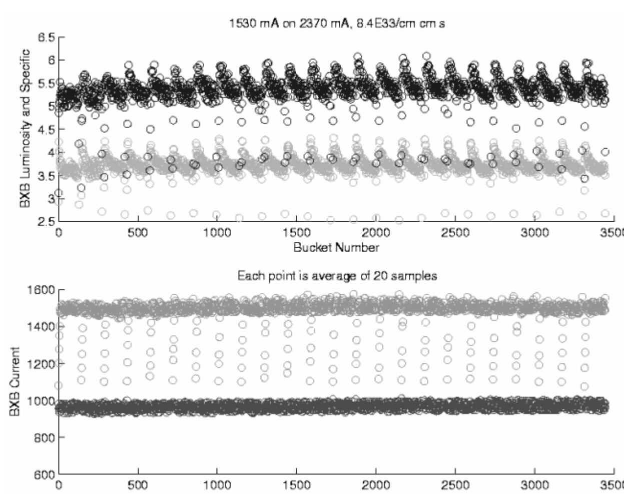

Figure 5: Luminosity along all bunches. Here 10% luminosity degradation along the trains is visible. The front end of the whole fill has also some lower luminosity.

FLAT CURRENT DISTRIBUTION

It is very important to get a flat current distribution. Since the BIC (bunch intensity control) software measures the quadratic sum of an I-and-Q signal it is very sensitive to the exact balancing of the system. It typically overshoots the front and therefore we adjust the requested current profile to cancel that effect. The HER has typically 95% in the first bunch and the LER starts at 88% for the first bunch and has a short ramp over five bunches. This is visible in Fig. 4 and 5, but is not in the real distribution.

There is also typically a change over the whole fill from the beginning to the abort gap. Figure 6 shows the scope picture for the HER raw signal of a BPM. The HER had already a correcting slope of -8% which had to increase to -11%. The impact of a non-flat distribution is not directly obvious, but it influences how far be can move the tunes and push the beam-beam tune shift to the highest performance.

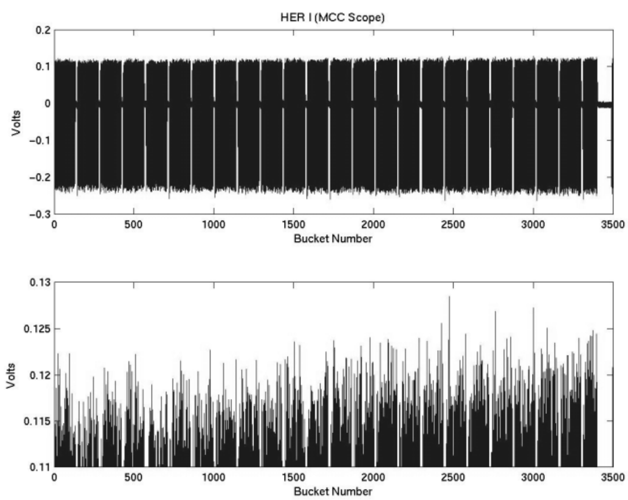

Figure 6: Raw BPM current reading. The raw button signal is displayed on a scope and gives an additional check to see whether the beam current has a flat distribution. Here a positive slope of 3 to 4% in the HER got corrected after finding it.

At some point the LER had a current slope of up to +7%. This came when we changed to an older bunch pattern with a smaller ramp and replaced the same time a few bunches at the end with low charge pilot bunches. This made the gap transient bigger and therefore also influenced the flatness of the current fill. The problem was not directly obvious since only a zoomed in view of a picture like the top of Fig. 6 showed it finally. The obvious problem was actually the HER and there it was the poor injection. The stored HER beam is kicked vertically up to a septum magnet current sheet during injection. Since it gets blown up by beam-beam forces in the vertical, we see typically some losses near the septum at injection. These losses were varying or pulsating by a factor of five. Since the injection kicker bump is not perfectly closed a similar signal can be observed at a beam loss monitor near a vertical collimator and recorded versus bucket number (Fig. 7). 7% more positron current increased the HER blow-up that the losses were six times bigger.

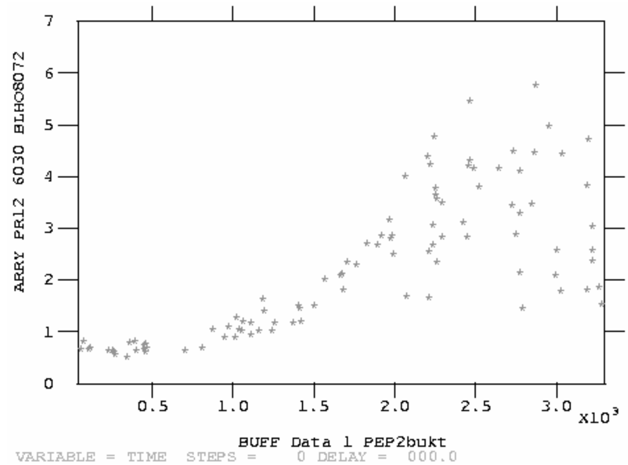

Figure 7: HER beam loss near vertical collimator versus bucket number. The HER beam gets blown up in *y* due to beam-beam forces at the IP. In this case the LER had a current ramp of +7% since pilot bunches made the abort gap bigger and therefore the non-equal filling. After flattening the LER fill the tail end reduced from a reading of 6 to 1, but there was still a small bump up to 2.5 in the middle. The data was taken by pretending to inject and using the slow non-closure of the injection kicker to ping the beam.

OUTLOOK

The present bunch pattern of in PEP-II is almost filled up. 1588 bunches out of about 1728 (with shortest gap so far tested) gives just less than 10% more space to fill in additional bunches. This would give a luminosity of “just” $10.0 \cdot 10^{33}$ 1/cm^2·1/s with 1690 on 2670 mA. After that we have to push the charge per bunch up. Extrapolating the June 2003 performance a $12 \cdot 10^{33}$ 1/cm^2·1/s with 2100 on 2700 mA seems possible, when the by-2 pattern is filled in.

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