An SDA note: On correlations between pBar transfer efficiencies, bunch intensities, luminosity and luminosity lifetime.

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SDA memo

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Abstract

This abbreviated note summarizes the plots I showed at the Tevatron meeting, held in the Penthouse, March 27 2002. Only Physics results are shown here, discussion on SDA techniques can be found in the previous notes.

1 Introduction

1.1 Store Selection

.

Since we are interested in the overall transfer efficiency, from accumulator to Tevatron, in the HEP phase, we first want to select the shots for which we have such data. Over the last month or so, some 20 shots satisfying this condition and are listed on table 1.

1.2 Caveats

The following peculiarities were observed in the data:

- $C : FBIANG$, set r_000 has a *DAE_SAVE_GET_EXCEPTION*.

Table 1: Summary table of some overall properties of the 20 shots considered in this study.

Shot	# of HEP hours	Proton Int.	B0-Luminosity
-	hours	E9	E30
992	14	4445.2	6.642
994	15	5260.7	12.353
996	14	4910.1	10.465
998	14	4680.0	8.062
1000	14	5303.8	10.575
1013	2	5157.1	0.0
1002	19	5332.5	12.095
1018	13	5673.3	8.442
1020	15	6015.9	6.8
1023	11	5199.5	0.147
1036	14	4719.8	12.223
1038	16	5091.2	11.756
1043	13	4695.7	10.117
1047	12	4502.2	4.647
1048	11	2808.6	4.973
1063	14	6138.0	9.924
1066	12	5901.5	12.126
1070	14	5347.2	8.574
1074	15	5811.8	9.546
1080	13	5422.9	10.241

- Some anomaly in the $C : FBIANG$ can be observed in the *Inject Pbar* case, at least for shot 1070: some bunch appears to be filled at the wrong "set", or presumably at the wrong time: The order in which pbar Tevatron bunches are filled is first 4, then 13-16, 25-28, 5-8, 17-20, ...So, why do we have a relatively large, positive, Fast Bunch Integrator, narrow gate, for pbars, at set 3, for bunch number 12 (15.93, compared to 9.383 and 10.07 for bunches 13 and 14, respectively). Are these intensities reliable if some "proton feed-down" or other unknown cross-talks do occur?

- Store 1013 lasted only 2 hours or so, given us only 2 points for lifetime estimates.

- Store 1023 has low initial luminosity, of .147 E30.

This is only to show that, like any HEP analysis, one has to be careful and look closely at the data before making conclusions...

1.3 The Pbar transfer efficiency, integrated over all bunches vs proton intensity

This efficiency is simply defined as

$$10.0 * (A : IBEAMB[0] - A : IBEAM2[8])/C : FBIANG; HEP/r_{000}$$

where the factor of 10 is a simple conversion factor, the numerator refers to the pbar stack size measured before and after transfer for all 9 transfers. That is, we substract from the total beam current in the accumulator before any transfer the remaining beam current after the last (9th, indexed 8 as we start counting at 0) transfer has been performed. The denominator is the sum over all 36 Tevatron bunch measured at the first HEP case - or phase-, using the same fast bunch Integrator ACNET device.

The second variable is the $C : FBIPNG/r_{000}$, HEP case, set number 1, that is, the fast Bunch Integrator for Proton bunches, narrow gate, taken at the first occurance of HEP, summed over all bunches (I presumed that's what the r_000 occurance means in the HEP table , after a quick and spotty arythmetic check).

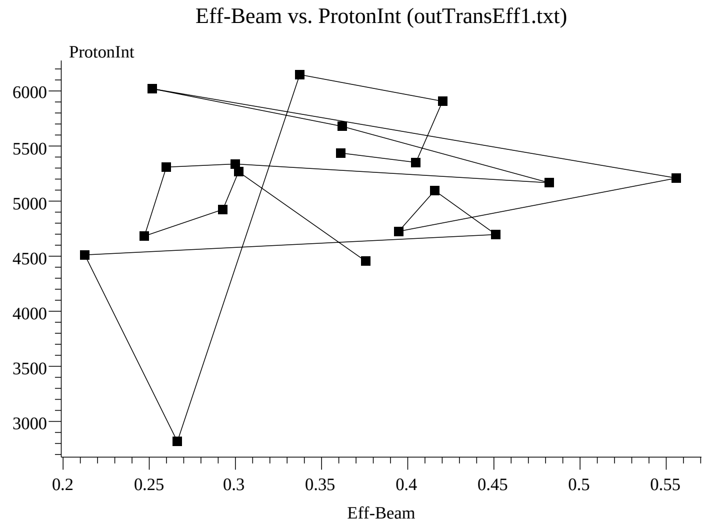

Figure 1: Scatter plot between the proton bunch intensity (E9) and the overall pBar transfer efficiency, from the accumulator to HEP phase.

The correlation plot is shown on figure 1. For these twenty shots, no obvious trends can be seen. May be we are integrating over too many variables, like the bunch number, or, looking over too many steps. However, Mike Church pointed out that, if we keep adding more stores, a trend starts to appear. This is not too surprising, because of the anti-correlation between proton intensity and pbar Squeeze efficiency, shown below.

1.4 On the Pbar "Squeeze" efficiency

The Squeeze efficiency, for each Tevatron bunch is simply defined as the ratio of the $C : FBIANG/r\_00x$, where x refers to the Tevatron bunch number, measured at the last *PBar Inject* case and at the first HEP phase. So this is the combined acceleration, flattop, squeeze, and remove halo efficiency. However, we know that most of the loss occur during the squeeze.

The correlation plots between the Tevatron bunch number and this pbar squeeze efficiency is shown on figure 2. Also shown on figure 3 is the same efficieny, plotted this time versus the proton bunch intensity, $C : FBIPNG/r_{00x}$, at the first HEP phase. The following observations can be tentatively suggested:

- For all but three shots, the efficiency rises at the beginning of a new 12 bunch train (bunch number 13 and 25) [1]. This interesting correlation has been establish a few weeks ago in the Main Control room, confirmed and presented by Mike Maertens at the RunII comissioning meeting, Thursday march 7 2002. We reproduced it here.

- In both plots, three stores stands clearly stand apart: 1047, 1048 and 1074. The "12-bunch-train pattern" is not present, and, for two of them, the squeeze efficiency is exceptionally high. In one case (1048) the proton bunch intensity is anomalously low. It might be interesting to figure out what made these squeezes different from the others.

- There might be an anti-correlation between the proton bunch intensity and the pbar squeeze efficiency, driven mostly by shot 1048. (which, by the way, did had not a particularly ridiculously low startup luminosity, compared to others..)

1.5 On the PBar lifetime and Luminosity lifetime.

We have seen correlations suggestive on either longitudinal bunch-to-bunch effect, or parasitic crossings. Are other variable we have readily access to also depends on the bunch number. Two of them is clearly of interest to optimize the integrated luminosity: the lifetime of the pBar bunch intensities in the Tevatron during HEP, and of course the luminosity lifetime.

Both lifetime are estimated based on the hourly SDA data take, typically only ≈ 10 points or less. The measurement errors are assumed to be constant. A simple exponential is assumed. That is, the fit is performed analytically via a simple linear regression based on the natural logarithm of the luminosity or pBar intensity.

Evidently, if pbar are lost, this ought to decrease the luminosity. Thus, both lifetime are correlated, as shown on figure 4. The luminosity lifetime is shorter than the pBar lifetime, as it should be.

[1] On the plot, these correspond to the bunch number 12 and 24.. Sorry, in Java, we start counting at 0, not 1

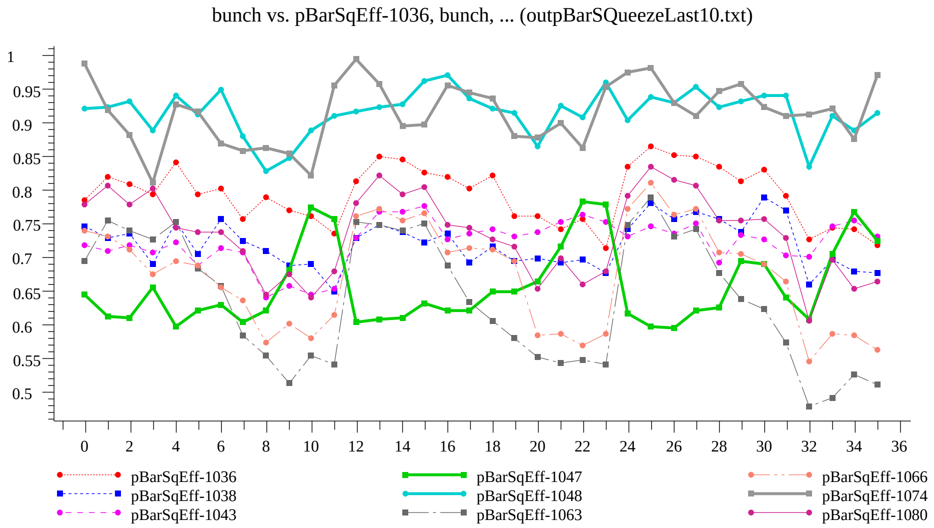

Figure 2: Antiproton Squeeze efficiency versus Tevatron bunch number, for the last 9 shots.

The pBar and B0-luminosity lifetime versus Tevatron bunch number are shown on figure 5 and 6. Again, shot 1048 stands apart, with a long lifetime.

Is there a signficant correlation between the relative lifetime for bunch 10 and 11, particularly for the pBar lifetime? To see this, first, let us simply compute the average lifetimes (pBar and luminosity), Shown on figure 7. Second, let compute for these 9 stores the average of the Δ-lifetime, normalized to the lifetime $\lambda(bunch)$. (e.g. $(1./\lambda) \times d\lambda/dbunch$. Since the shots are taken idependently, an "error" on this quantity can be estimated based on the variance of this distribution over shots. These variance are indicative of all other correlations and uncertainties and are represented as error bars on figure 8 and 9. Note that we have placed a minimal cut on the proton intensity, rejecting the anomalous run 1048.

The last bunch in the 12-bunch train seems to be relatively long-lived with respect to the others. Why is this "caboose-bunch" spared from some pernicious pertubation affecting most of the other bunche ? Although of lesser statistical signficance, this effect can also be seen in the luminosity lifetime.

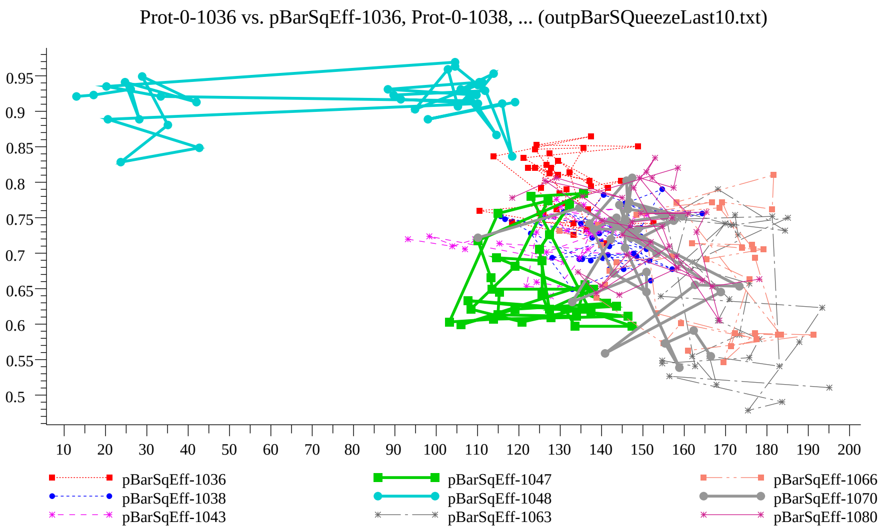

Figure 3: Antiproton Squeeze efficiency versus Proton Intensity, for the last 9 shots.

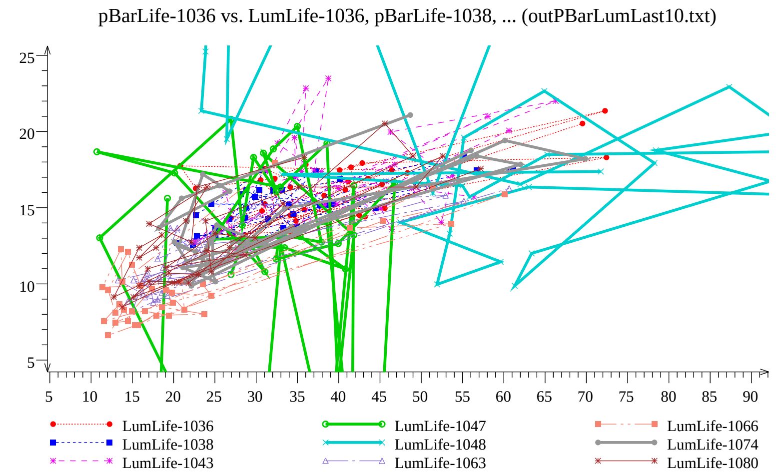

Figure 4: The B0 luminosity life time versus the pBar lifetime

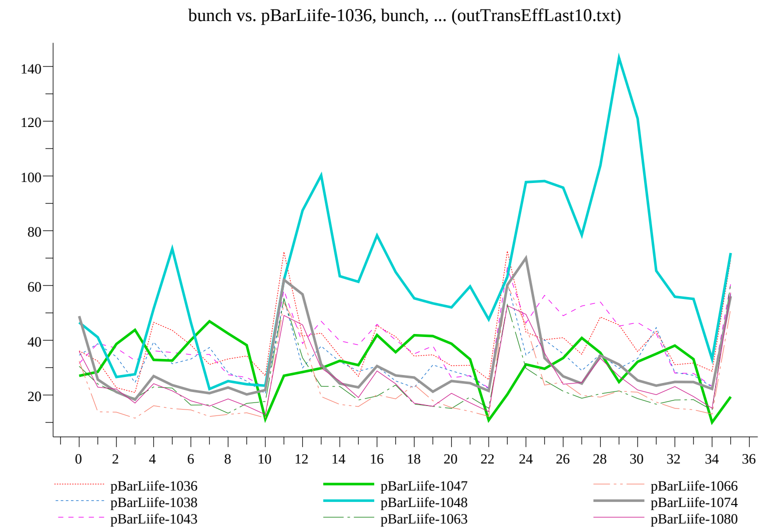

Figure 5: The pBar lifetime versus Tevatron bunch number

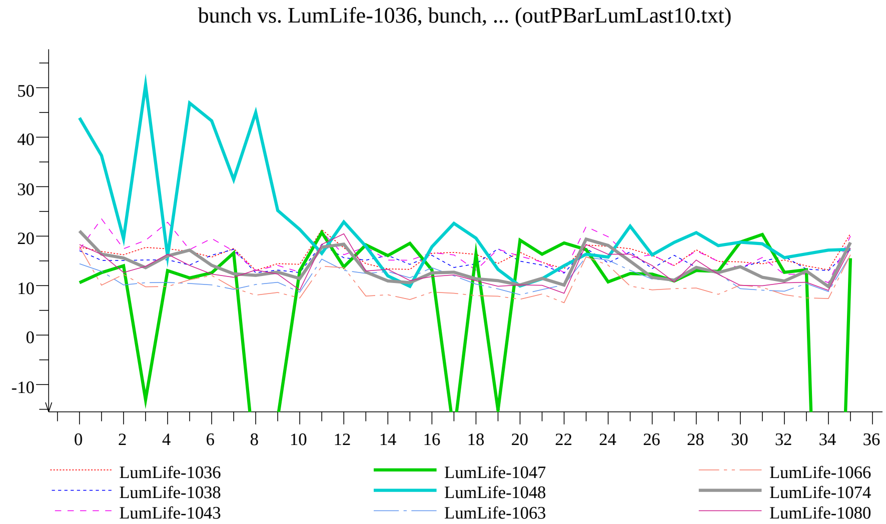

Figure 6: The luminosty lifetime versus Tevatron bunch number

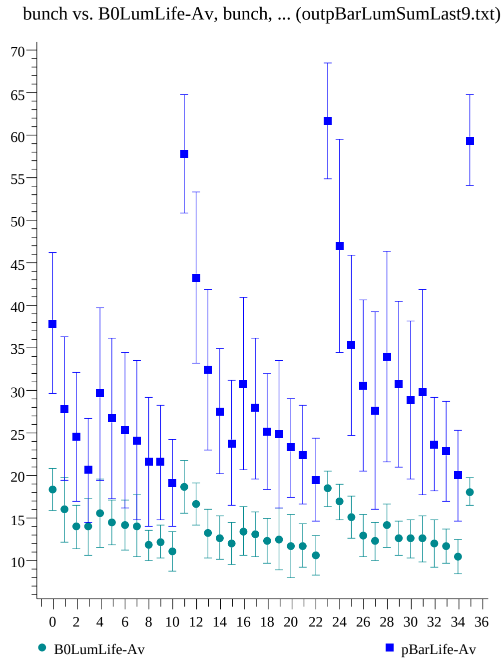

Figure 7: Antiproton lifetime and B0 luminosity lifetime versus Tevatron bunch number, for the last 9 shots.

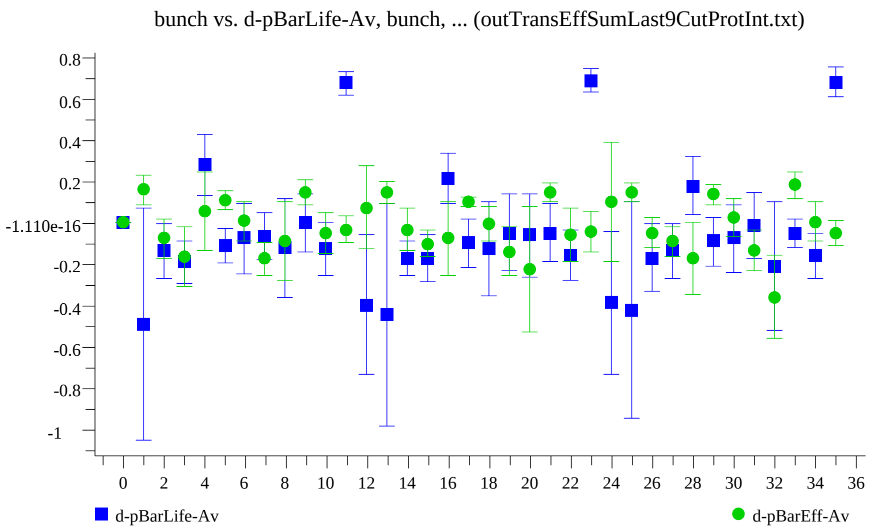

Figure 8: The derivate of the pBar lifetime with respect to bunch number, versus bunch number, average over the last 9 stores. Also shown is the overal pBar transfer efficiency, which is rather flat. The "Squeeze 13" effect is masked by other transfer inefficiencies)

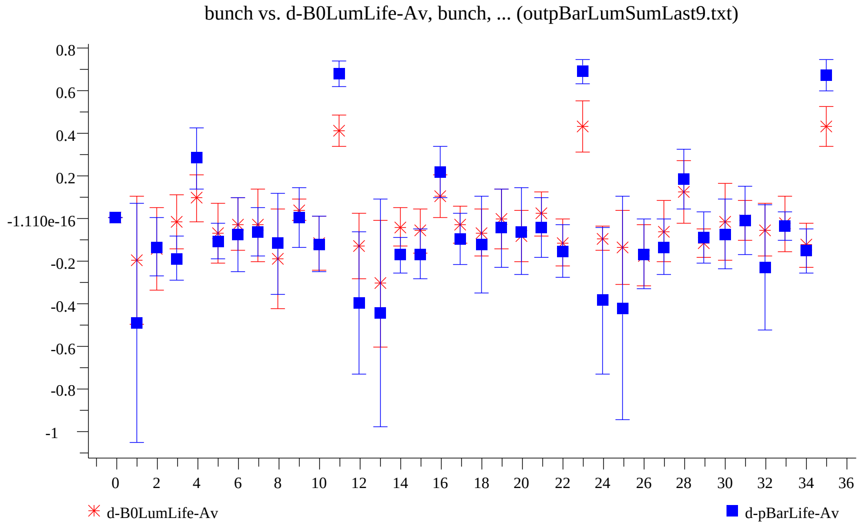

Figure 9: The derivate of the pBar and B0lum lifetime with respect to bunch number, versus bunch number, average over the last 9 stores.

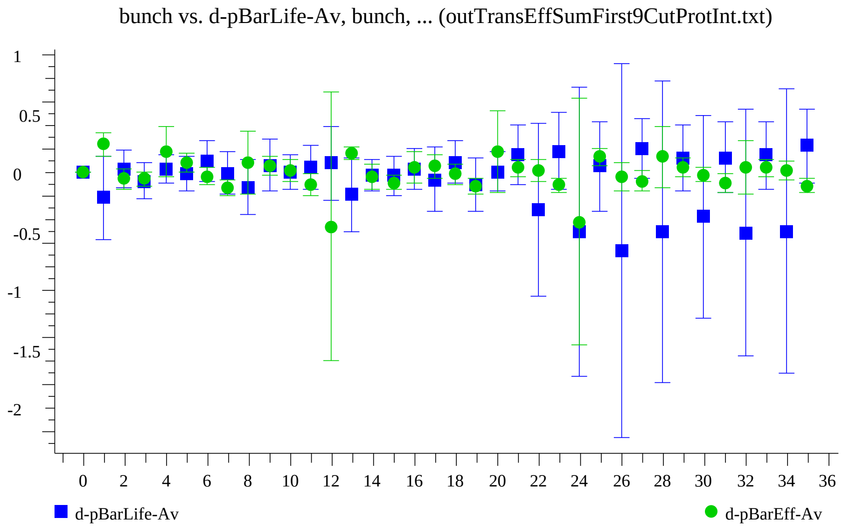

Figure 10: The derivate of the pBar lifetime with respec to bunch number, versus bunch number, average over the first 10 stores.

This is relatively recently phenomena. The first 10 shots in the studied sample do not exhibit such a behavior. See figure 10.

1.6 On luminosity and pBar lifetime vs proton intensity

Finaly, we expect that the luminosity lifetimedepends on the proton bunch intensities, due to uncompensated beam-beam tune shifts (or perhaps othee effects). This is shown on figure 11 and 12, for the last 9 stores and for the bunch which are not last in the train, and on figure 13 for the other bunches. The initial luminosity for a given bunch must be above 0.1E30.

This correlation -as well as other effects- adversely affects the overall performance of the Tevatron: the integrated luminosity also tends to be better for these "caboose bunches", as shown on figure 14[2]. This integrated

[2]A few recent stores have been added, and the lifetime will are now fitted assuming that the B0Lum measurement error is proportional to the amplitude B0lum instead of

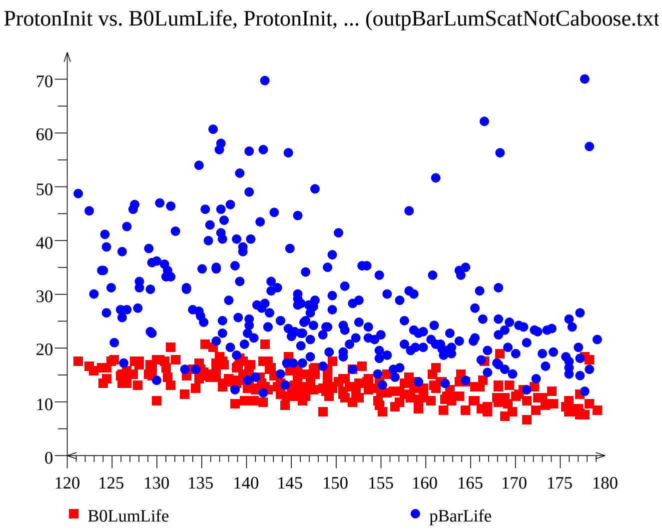

Figure 11: Correlation between prton bunch intensities (E9) and B0-luminosity lifetime, for bunches 1-11, 13-23 and 25-35.

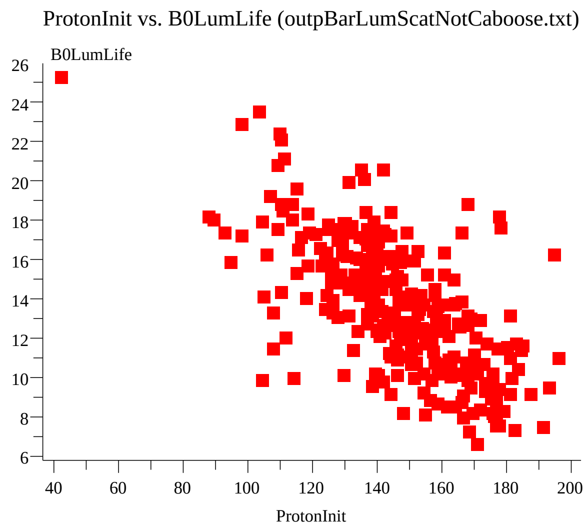

Figure 12: Correlation between proton bunch intensities (E9) and B0-luminosity lifetime, broad scale for bunches 1-11, 13-23 and 25-35.

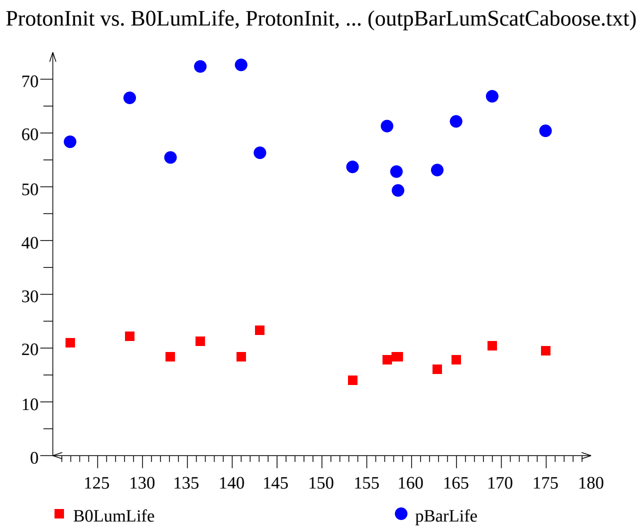

Figure 13: Correlation between proton bunch intensities and B0-luminosity lifetime, for the long-lived bunches 12, 24, 36.

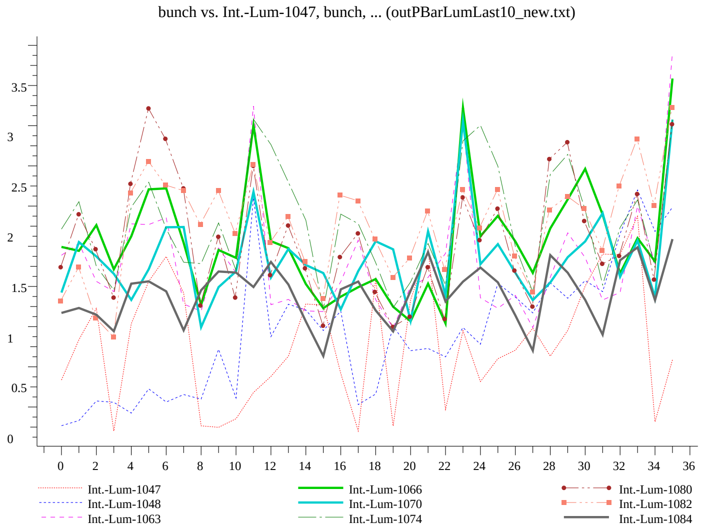

Figure 14: The Integrated Luminosity at B0 versus bunch number, for 9 good shots.

luminosity is computed based on an exponential decay fit, with a single lifetime. Note that we have large fluctuations, the worst buch number 10, 22, .. can be off with respect to the good ones by as much as a factor ≈ 3.

Last week-end, Jerry Annala changed slightly the betatron tune, in order to improve the pBar lifetime. Here is the e-mail he send us:

```
Qh -> Horizontal tunes setting (tune quads)
DQhCol -> Shift in Proton tune = -1 * shift in Pbar tune (feeddown
sextupoles).
Calc Htune ->  calculated shift in Proton tune
Calc HPbtune ->  calculated shift in Pbar tune

                                          Qh                      dQhCol
                        calc Htune    calc HPbtune
Before Friday           20.572                   +.0027 0      0
```

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constant. This is a detail...

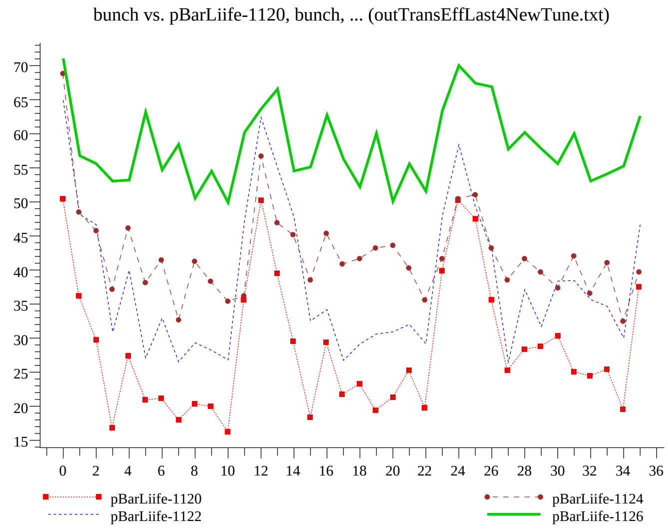


Figure 15: The Integrated Luminosity at B0 versus bunch number, for 9 good shots.

```
store 1120                20.571                  +.0037   0      -.002
store 1122                20.5705                 +.0042    0      -.003
```

```
stores after 1122 had the same settings as store 1122.  The tunes were
changed in the last sequence of the squeeze table.  Much of this
probably doesn't matter to you at all.  It would be interesting,
however, to know the the effect on lifetime of these changes.
```

Indeed, there seems to be an improvement, as shown on figure 15

Beside the 12-bunch train periodicity, there might be an other higher frequency in this plot: every 4th bunch, the first bunch seems to perform better, as the $\delta P/P$ is smaller. This might be related to a known problem with the longitudinal motion of the pBar bunches at pBar injection, due to beam loading[3]. The $\delta P/P$, as reported by the flying wire (ACNET device T:WEA00), after scraping (case "Remove Halo"), is shown on figure 16

[3]private, casual "corridor" conversation with Valdimir Shieltsev and Shekar Mishra

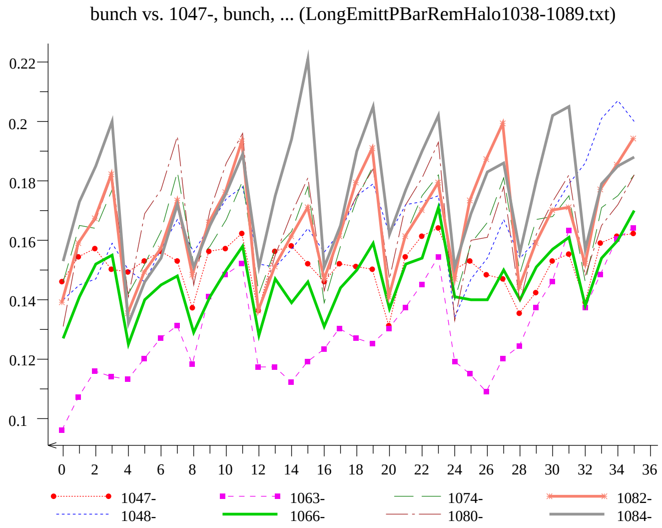


Figure 16: The $\delta P/P$ versus bunch number, measured after scraping.

Let us come back to the pBar lifetime issue, and let us study the correlation between Proton bunch intensities and this pBar lifetime. To study this a bit more systematically, we compute the Pearson correlation coefficient between these variables. This coefficient is simply defined as

$$C_{ij} = \sum (Prot(i)_r - \bar{P}rot(i))\,(x(j)_r - \bar{x}(j))/(\sigma_{Prot}\,\sigma_x)$$

where i is the Proton bunch index, j is the bunch index (proton or pBar, depending on the quantity x), and x is the variable of interest. The summation index r runs over the the shot numbers. Prot(i) is the bunch intensity measured after the first hour of HEP, by the Fast Bunch Integrator (FBIPNG). Let us first consider two such simple variables, to calibrate the method and make "confort" plots. The Correlation between the proton bunch intensity measured after scraping and $Prot(i)$ is shown on figure 17, versus j. Evidently, if $i = j$, the two variables ought to be maximally correlated, as we know that the Proton loss over an hour are relatively small, and the these bunch intensisites are measured with the same device. This is why there is always one point with $C_{ij} \approx 1.$. Overall, there is a positive correlation: The

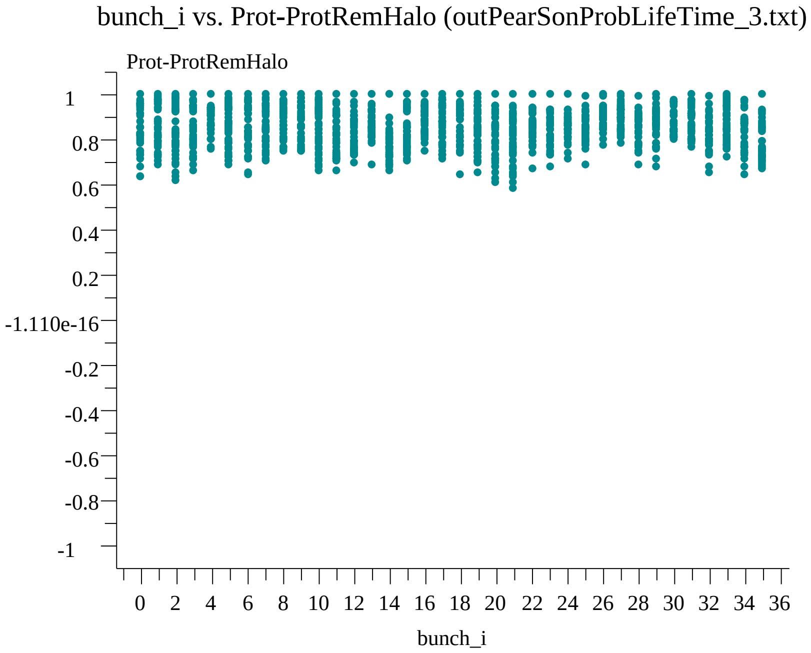


Figure 17: The Pearson Correlation Coefficient between the Proton bunch intensities, measured after scraping and after one hour of HEP

proton intensities measured at closely related times ought to be correlated, via the overal performance of the other accelerators and transfer lines in the complex.

The second check is shown on figure18, where x is simply a random number, flat distribution between 0. and 1. No correlation is observed, because the average of the 36 point for a given j is zero. The spread is large, though, because we had only ≈ 10 shots.

Let us now plot the quantity of interest. The first one is the pBar lifetime during HEP, shown on figure19. The pBar "caboose bunches" are uncorrelated with the proton intensities, while the bunches in the middle of the trains are clearly anti-correlated ($C_{ij} < 0.$) with this proton intensitiy. The pattern of the correlation between the $\delta P/P$ and the Proton Bunch intensities is different, we now recognize the 4-bunch periodicity, presumably due

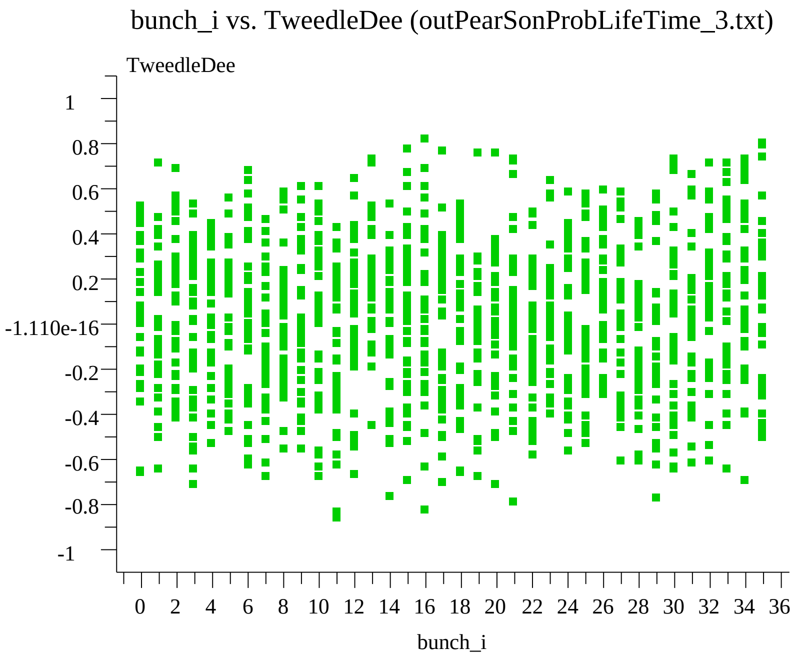


Figure 18: The Pearson Correlation Coefficient between the Proton bunch intensities, measured after scraping and after one hour of HEP

to beam loading problems (see Figure 20)

There might be some more information to gain from the correlation between proton intensities and pBar lifetime. The "most" correlated pairs of proton bunches/antiproton bunches are shown on figure 21. The pattern does not look random: the probabilibty for the first proton train to interact with the last antiproton train might be real. If this correlation is due to poorly compensated beam-beam tune shift, and if this is not a statistical fluke, than the bad crossing seems to occur preferably at, or around the B0 sector, towards the C0 sector.[4].

Given the statistical weakness of this signal, during the discussion, it appeared that this interpretation is highly tentative. Meanwhile, we clearly should measure more, and sweep in tune, to see a change in both pBar lifetime and emittances.

2 Outlook

This note is probably already too long, and the most relevant plots have not been presented. For instance, we are eager to study the evolution of the transverse and longitudinal emittance, versus proton intensities, pBar instensities, and so forth. Hopefully, the Sync Light Monitor will be calibrated and used in the HEP phase on a regular basis, as well as during the Squeeze. Meanwhile, we plan to improve the SDAViewer, complete and fix the ACNET device's values we store in SDA and increase the frequency of such measurement. We will increase the frequency from once every hour to every 10 min. Evidently, the flying wire will stay put, one time at "Initiate Collision" and one atime at the end of the store will allow us to cross-calibrated the SyncLite and Flying Wire.

3 Acknowledgment

Thanks to many members of the Beam Divisions for allowing me to get at this data! In particular, thanks to Mike Church, Stan Pruss, Shekar Mishra

[4]Let me quote Jerry Annala, about bunch numbering around the ring :*Proton bunch 1 collides in time with Pbar bunch 1 at C0 and at F0 when the normal collision cogging point is achieved. This means that P1 collides with A13 at D0 (P2 collides with A14, etc.) At B0, P1 collides with A25 (so P2 collides with A26, etc.)*

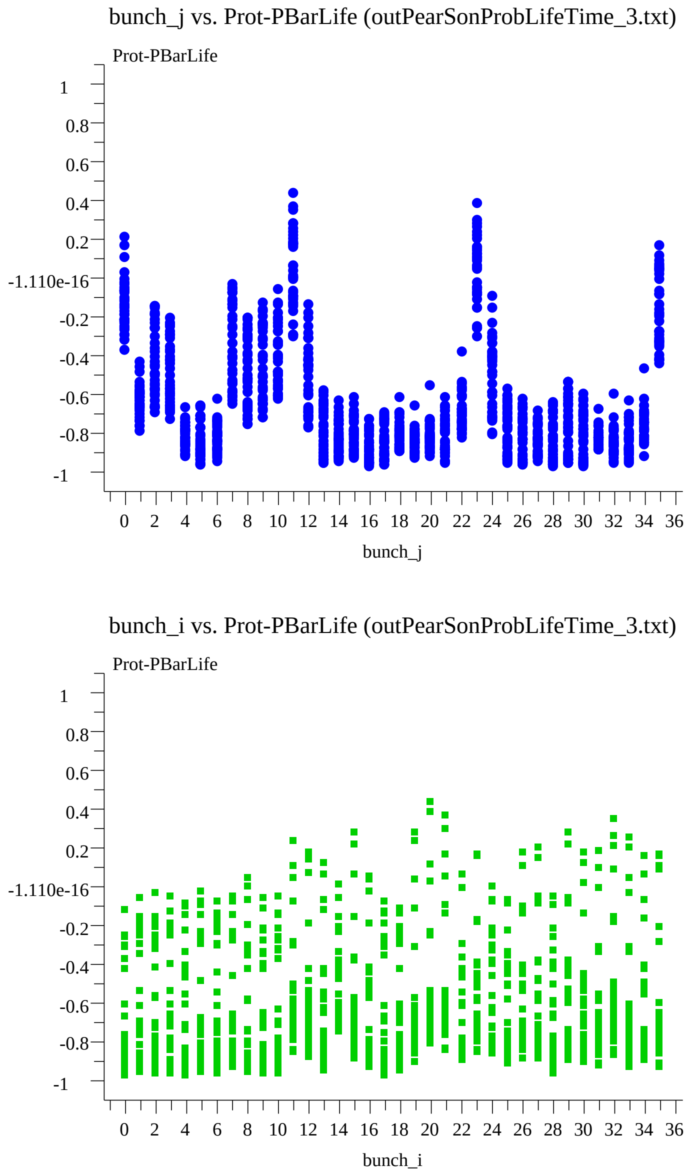
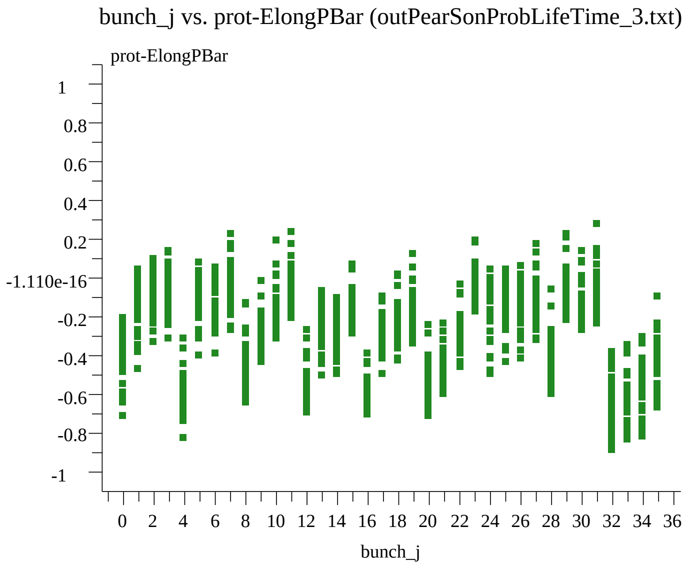


Figure 19: The Pearson Correlation Coefficient between the Proton bunch intensities and the P bar lifetime during HEP, versus pBar number (top) and proton bunch number (below).



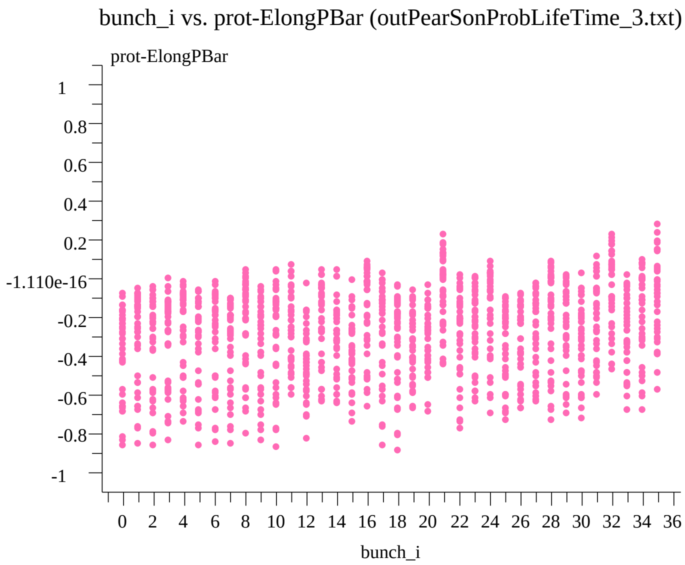


Figure 20: The Pearson Correlation Coefficient between the Proton bunch intensities and the $\delta P/P$ during HEP, versus pBar number (top) and proton bunch number (below).

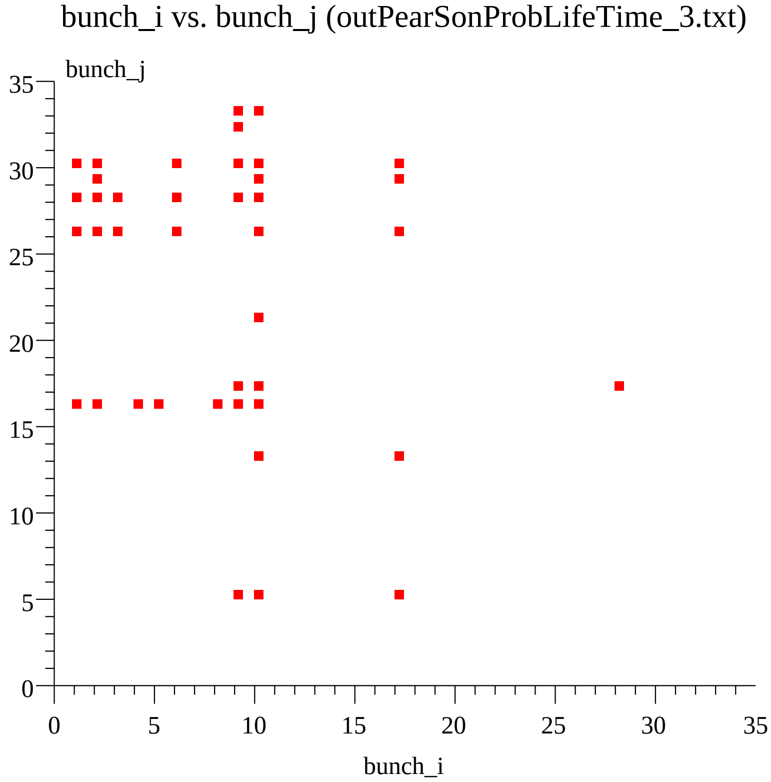


Figure 21: The 36 by 36 map, proton bunch number (horizontal axis) versus antiproton bunch number (vertical axis), for bunch pairs which have a Pearson coefficienct less than 0.95.

for their guidance, and to Timofey Bolshakov, Elvin Harms for their patience in presenting the SDAViewer. The discussion with the Valery L., Valery S., Yuri, XL, Mike,.. was clearly fruitful, for me at least. I enjoyed it!.