Proton Vertical Emittance Blow up by Antiprotons

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- Abstract: Two stores 4411 and 4431 are analysed for the emittance growth of the proton bunches. A common effect for all proton bunches is the IBS growth and gas scattering. However, we find a correlation of the growth rate with the strength of the beam beam interaction. We define this strength as proportional to the sum of the pbar bunch intensity that a proton bunch encounters at B0 and D0. We find that the proton emittance growth rate is a function of this variable . The interaction slowly decays during the store

1.0 Data Analysis

Two stores were selected: 4411 and 4431. The first is a low luminosity store and the second is a store near the record. The second store has nearly twice the pbars that were in the first store. In addition there is a large variation in the individual size of the pbar bunches which leads in turn to a large variation in the beam-beam interaction as seen by the individual proton bunches. The proton bunches are very uniform in size and thus provide a window of opportunity to see the effect of the pbars on the protons.
The data collected from each store were the following:

T:SBDPIS PROTON INTENSITY x 10^9
T:SBDAIS PBAR INTENSITY x 10^9
T:SBDPWS PROTON WIDTH IN NS.
T:PVEMIT PROTON VERTICAL EMITTANCE IN MM MR

All of the variables were fit with appropriate functions so as to give continuous functions of time after the final scraping. The fits were all excellent. An example is shown in Figure 1 below where the three sets of proton vertical emittance {1,2,3}, {13,14,15}, and {25,26,27} are shown with a simple exponential fit. (bunches 1, 15, 25 are the top row)

Store 4431 proton vertical emitance and fit

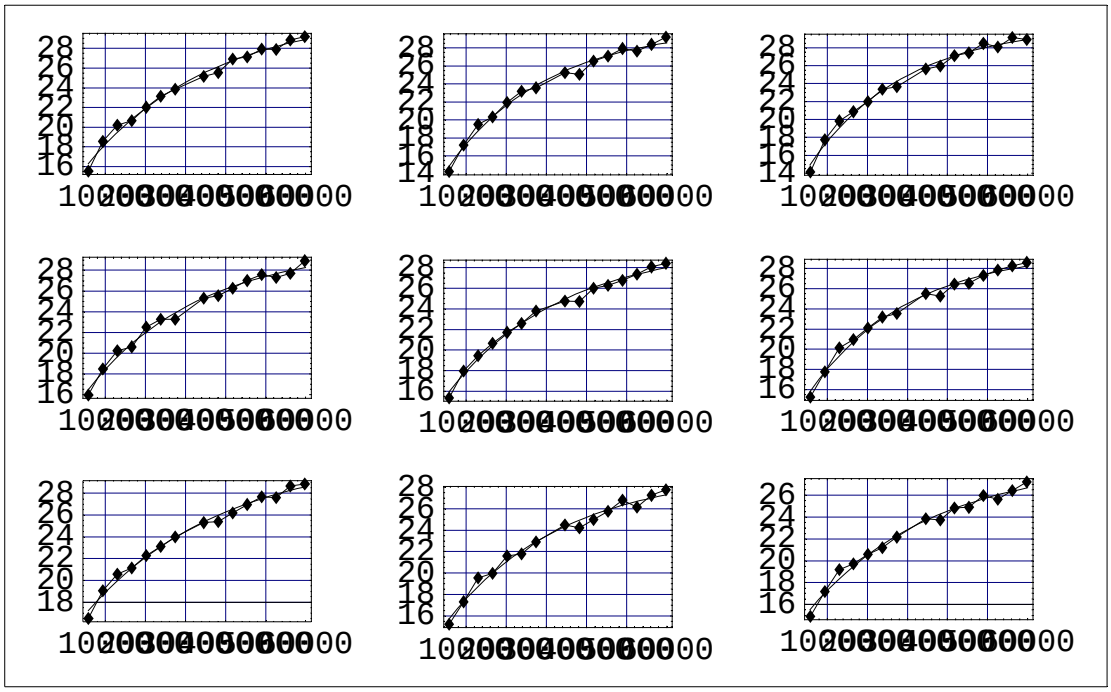

Figure 1

We now define an interaction strength for the growth of an individual proton bunch as the sum if the number of pbars seen at crossings B0 and D0 in units of 10^9. Due to the unequal intensities of the individual pbar bunches this number can have wide variations around the average value of Npbar/18. The following plot shows this interaction strength for the 36 proton bunches at the start of store 4411

Store 4431 has a similar plot except that the pbar intensity is nearly twice as high.

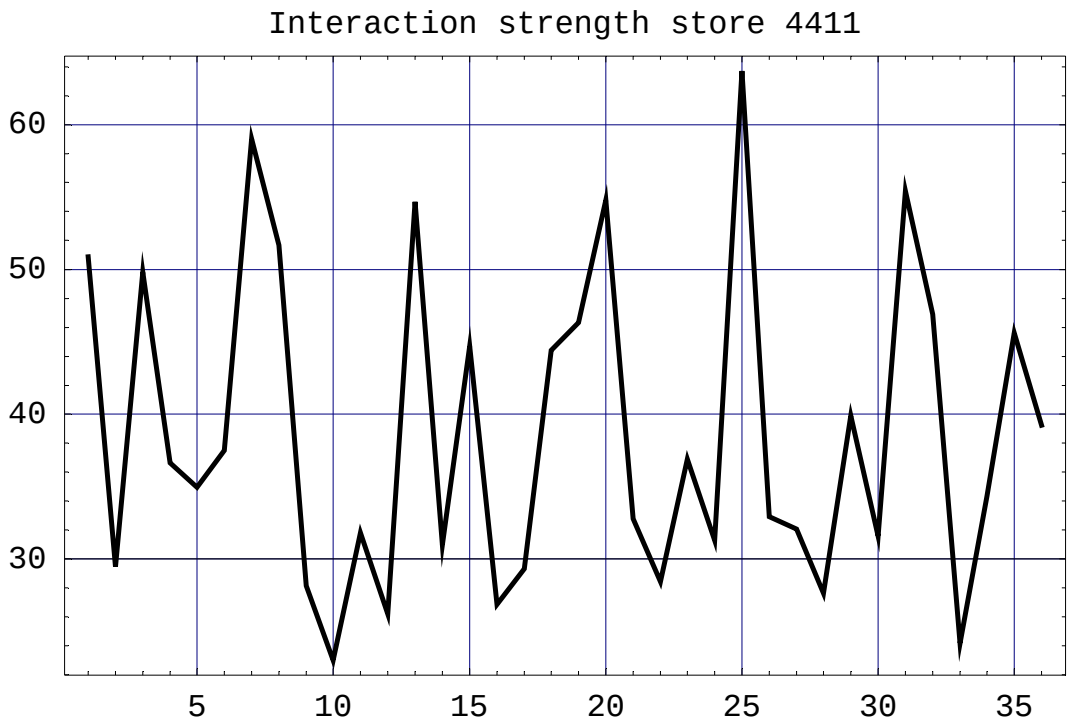

Figure 2

We now combine the data from the two stores. First of all, we order the proton bunches in the two stores in order of their interaction strength. These two sets are then joined and the time rate of change of proton vertical emittance is calculated from the fit to the proton vertical emittance fits.. Note that the two stores are not ordered in combination but their intensities are so different that the overlap region is very small and seems to be continuous. The result of this is shown in the plot below:

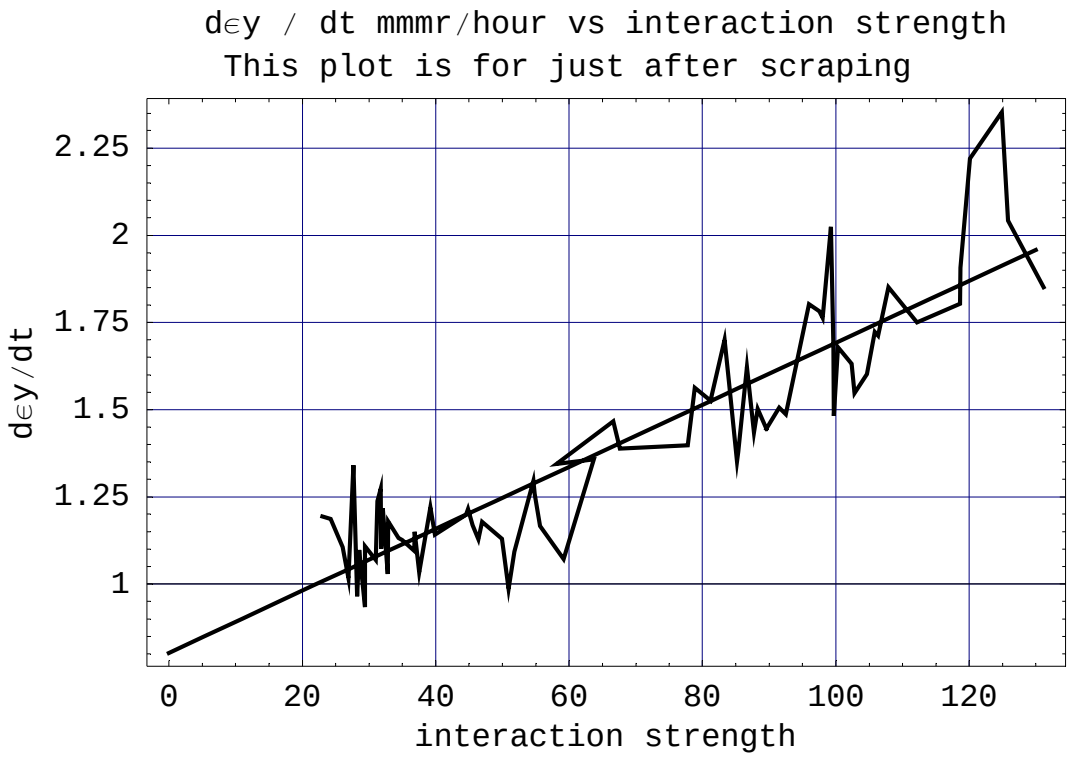

Figure 3

The fit equation is

$$d\epsilon y / dt = c1 + c2 \text{ (interaction strength) in mm mr/hour}$$

c1 should represent IBS scattering for the average proton bunch plus gas scattering and any other process that causes transverse blow up. In what follows, we will assume that these other processes are small compared to IBS at t = 0. The table of fits is:

Sec after scrape	fit to dϵy / dt
0	0.802731 + 0.00888637 is
5000	0.768828 + 0.00713535 is
10000	0.728708 + 0.00560412 is
15000	0.685919 + 0.00425432 is
20000	0.6428 + 0.00305738 is
25000	0.600506 + 0.00199903 is
30000	0.559463 + 0.00107471 is
35000	0.519778 + 0.000283086 is
40000	0.481483 − 0.0003786 is
45000	0.444628 − 0.000916639 is
50000	0.409292 − 0.00134093 is

If we assume that the constant term for the first line represents IBS scattering, we can use this to scale IBS growth rate for all of the bunches using the following formula which is a simplification of the correct IBS scattering theory:

$$d\epsilon IBS[t] / dt = 0.802\ (Np/253)\ (1.735 / \sigma t)\ (15.02 / \epsilon y)^{1.5}$$

where Np is the number of protons or pbars in the bunch, σt is the bunch length, and ϵy is the vertical emittance all at the time t. The three constants correspond to the average proton bunch at t =0 for store 4411 (the store with the smallest number of pbars). Note: since the constant 0.802 could include some gas scattering, the above equation will give an overestimate of IBS. The question of gas scattering is somewhat open. In Dec 2004 during an IBS test, we measured dϵy/dt = 0.26 mm mr/hourdue to gas scattering. During a similar test in Aug 2005, the observed gas scattering growth rate was essentially zero. We don't have a recent proton only store with which to compare. The following plot shows the collective behavior:

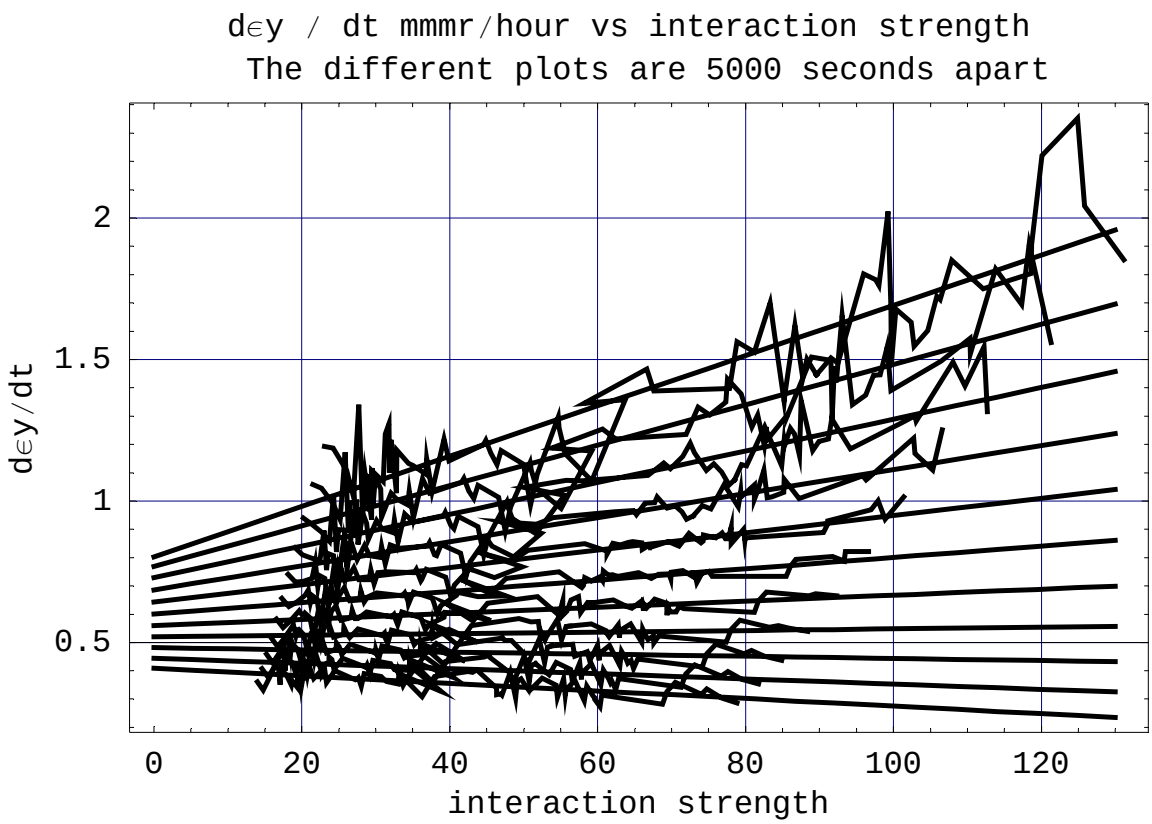

Figure 4

2.0 Remove IBS and plot beam-beam effect on the protons

With the above caveats, we will proceed to remove the IBS contribution during the store and derive the time dependence of the pbar effect on the protons. The above equation is used with the smooth fits to the number of protons in each bunch, the bunch width, and its instantaneous emittance. The interaction strength is evaluated at each time. The plot corresponding to figure 4 is shown below.

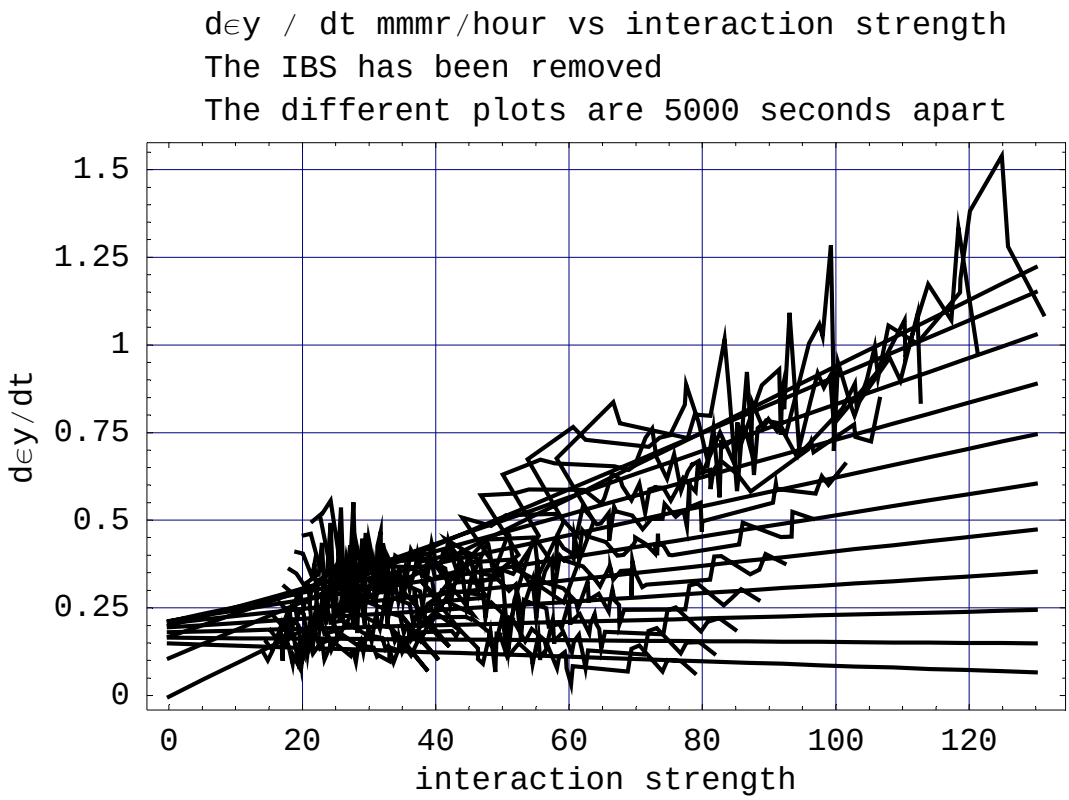

Figure 5

The table of the above fits is:

Sec after scrape	fit to d∈y / dt
0	−0.00340743 + 0.00942601 is
5000	0.106258 + 0.0080335 is
10000	0.167524 + 0.00662744 is
15000	0.198769 + 0.0053088 is
20000	0.211279 + 0.0041049 is
25000	0.21223 + 0.00301809 is
30000	0.205624 + 0.00205614 is
35000	0.194426 + 0.00121408 is
40000	0.180376 + 0.000490485 is
45000	0.164834 − 0.000123223 is
50000	0.148741 − 0.000637375 is

In the following plot, we show the slope (ie coef of second term in the table above) vs time in hours to show how the interaction develops over time:

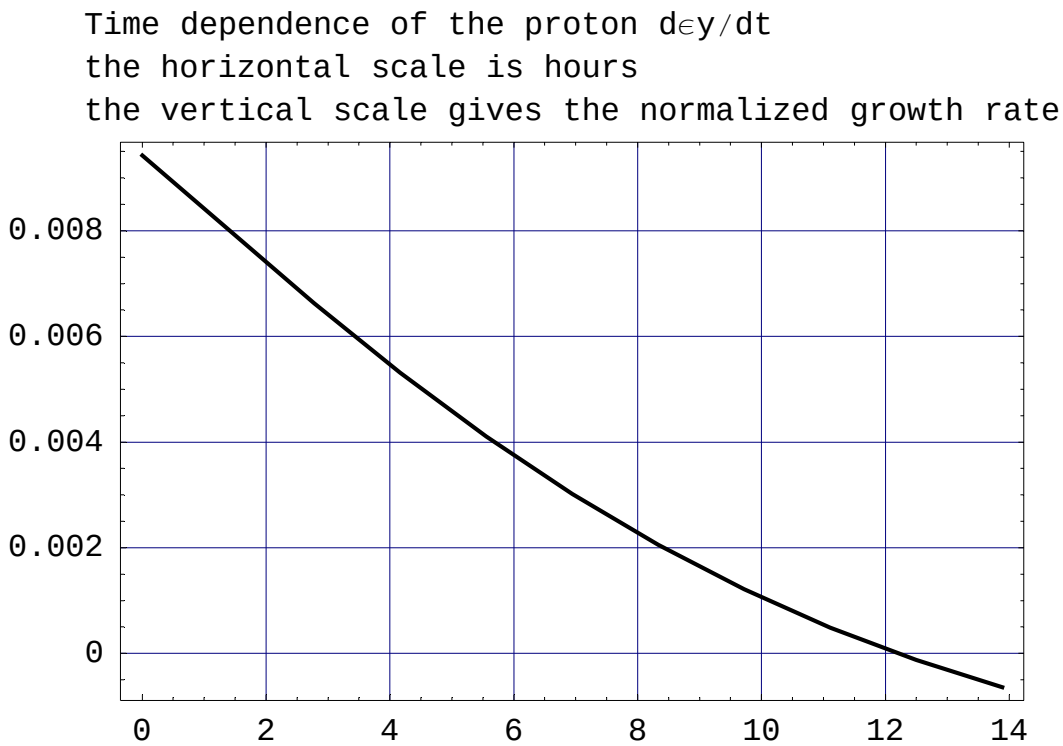

Figure 6

3. Some comments

This is a preliminary study and it raises some questions. It is not clear that different stores can be combined. If the tune of the machine is different from store to store, this could affect the interaction. However the overall fit seems pretty good. A question remains of what parameters other than the bunch intensity of the pbars effect the growth rate. The interaction strength as defined above seems to be a nice parameter. Note that in Figure 6, the decrease in time is not due to pbar bunch intensity as that is already accounted for

The intercept shown in Figure 5 indicates that perhaps the IBS scaling formula we used has the wrong constants due to gas scattering. It might also be an indication of some emittance blow up due to the long range beam-beam interaction that is not measured by our variable ,"interaction strength"', which only covers the interaction regions.