OPTIMIZATION OF INTEGRATED LUMINOSITY IN THE TEVATRON*

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Abstract

We present the strategy which has been used recently to optimize the performance of the Fermilab Tevatron proton-antiproton collider. We use a relatively simple heuristic model based on the antiproton production rate, which optimizes the number of antiprotons in a store in order to maximize the integrated luminosity. A store is terminated as soon as the target number of antiprotons is reached and the Tevatron quickly resets to load another store. Since this procedure was implemented, the integrated luminosity has improved by ~35%. Other recent operational improvements include decreasing the shot setup time, and reducing beam-beam effects by making the proton and antiproton brightness more compatible, for example by scraping protons to smaller emittances.

TEVATRON RUN II PERFORMANCE

Since the beginning of the Collider Run II [1] in 2001, the Tevatron has delivered over 6 fb^{-1} of integrated luminosity to both CDF and D0 experiments, thus meeting its goal to deliver between 5.7 fb^{-1} and 6.8 fb^{-1} to the experiments by the end of September 2009. If additional running time is given, then the goal will be to obtain between 7.2 fb^{-1} and 8.6 fb^{-1} by the end of another year of operation (the spread reflects the different assumptions for the complex's reliability). All major technical improvements which were part of the Run II Upgrade project [2] were completed by 2006-2007. Nevertheless, since then, the performance of the complex continues to improve (Fig.1): weekly integrated luminosity is up by 63% (record of 72 pb^{-1} compared to 46 pb^{-1} in 2007), peak instantaneous luminosity is up 24% (from $2.92 \cdot 10^{32}$ cm^{-2} s^{-1} in 2007).

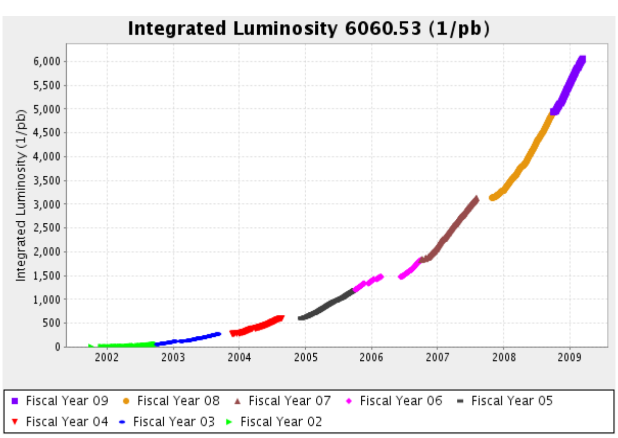

Figure 1: Tevatron total luminosity from 2002-present.

The latest improvements were mostly the result of a procedural change in the way the complex was being run. The duration of the stores were previously determined by the instantaneous luminosity decay rate, which was assumed to be the limiting factor in the optimization model. However, the latest improvements to the antiproton average production rate prompted that the collider running scenario be revisited.

HEURISTIC MODEL

The approach taken in the elaboration of the model was to account for all of the losses in intensity that occur in the accelerator chain from the storage of freshly captured antiprotons in the Accumulator ring to their final use for producing luminosity. Each step has an associated efficiency, which has some dependence on the number of antiprotons manipulated and which is extracted from large sets of data. Then, a step-by-step description of the accelerator chain was implemented in Excel™ to simulate the flow of antiprotons from the Accumulator to the Tevatron [3]. A set of adjustable parameters and logical expressions were used to maximize the integrated luminosity output from this model. Note that although there is some possibility to account for failures, we based our strategy on the assumption that the accelerators are available 100% of the time.

In the model, the antiproton accumulation rate in the Accumulator (i.e. stacking rate) is based on up-to-date measurements of the Zero Stack Stacking Rate (ZSSR) and the Zero Rate Stack Size (ZRSS). From these two parameters we generate a stacking rate as a function of the stack size in the Accumulator. Then, in the model we can adjust two parameters to maximize the Accumulator-to-Recycler transfer efficiency: the unstacking percentage (i.e. the amount of antiprotons removed from the stack, which is not entirely arbitrary) and the stack size at which a transfer is initiated is currently $35\text{x}10^{10}$. In a typical stacking and stashing[**] sequence, 10-12 transfers are completed in order to produce a large enough antiproton stash to be used in the Collider. Figure 2 shows the antiproton flow in the Accumulator and Recycler for one week in the model.

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** "Stashing" is the term we employ to describe accumulation of antiprotons in the Recycler as opposed to "stacking" which refers to accumulation in the Accumulator

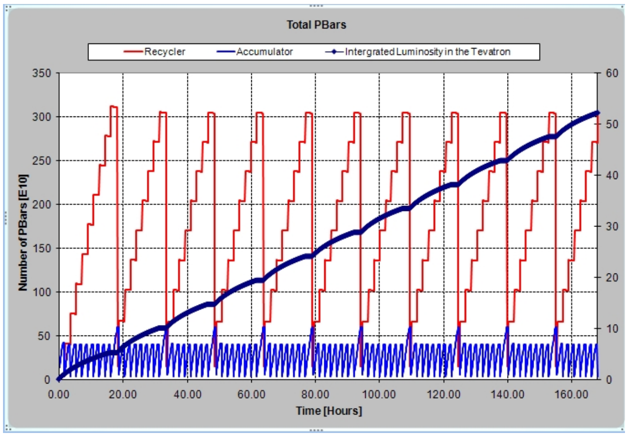

Figure 2: Stacking /Stash sequence over 168 hour period.

For this figure the following assumptions were made:

ZSSR	30 $x10^{10}$/Hr
ZRSS	300 $x10^{10}$
Transfer made at	35 $x10^{10}$
Unstacking percentage	90 %
Transfer efficiency	95 %
Transfer Duration	0.05 hrs
Recycler Lifetime	500 hrs.

These numbers reflect the typical operating parameters for the antiproton production portion of the complex. The ZSSR is obtained by measuring the base line stacking rate starting from an empty Accumulator. As the Pbar stack is accumulated over time, the overall stacking rate drops off. The rate at which it drops off can be expressed as a function of ZSSR and ZRSS. In turn, we can determine the stacking rate as a function of the stack size. The stack size at which a transfer to the Recycler is initiated is determined by several factors: the impact to the overall stacking rate, the transfer efficiency to the Recycler and the unstacking percentage from the Accumulator stack. To maximize the overall antiproton production rate of the complex, great effort has been made to reduce the non-stacking time during the transfer process. In this model, that time is fixed to ~ 1 minute, based on recent performance.

To simplify the model, the Proton parameters for the Collider shot are kept fixed around our current operating point as shown in the table below:

Proton Shot table

- Intensity range per bunch 300-330 $x10^{9}$
- Transverse emittance ~14 π mm-mr
- RMS Bunch length ~1.5 ns

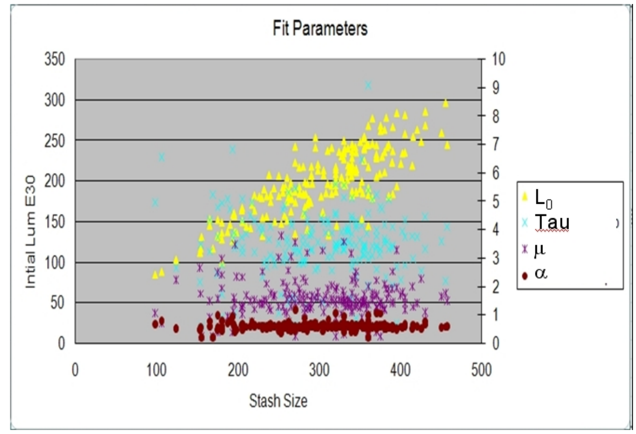

Figure 3: Historical data over the last 300 stores.

Then, because the antiproton beam quality extracted from the Recycler is very reproducible, we can express the initial instantaneous luminosity of a store, L_0, solely as a function of the number of antiprotons available.

The last part of the model deals with the luminosity decay rate, which must be accounted for when trying to optimize the operation of the accelerator complex. This decay is well modeled by the expression [3]:

$$L(t) = L_0 e^{-\left(\frac{t}{\tau+\mu t^{\alpha}}\right)} \quad (1)$$

where L_0 increases roughly linearly with the stash size up to $400x10^{10}$ and the fit parameters, τ, μ and α are found to be independent of luminosity (or stash size). Figure 3 shows the historical data for these parameters as a function of the stash size over the last 300 stores. Eq.(1) can be integrated numerically and together with the information contained in Figure 3, we obtain the total integrated luminosity for the duration of the store as a function of the number of antiprotons available.

Collider and Operation Strategy

Our strategy has been to maximize integrated luminosity as a function of the antiproton production rate. While a simple analytical model can be used to understand this approach [4], for daily operations a more detailed view must be taken. This was accomplished in our model by assuming a fixed stacking rate while varying the stash size for a shot. In the model, the shooting stash size is kept constant through the 168-hour week to determine the weekly integrated luminosity for that data point. Then, the stash size is incremented by 5×10^{10} antiprotons per step for each consecutive calculation. The projected luminosity for each 168-hour week is recorded. This process is repeated until a 600×10^{10} stash size is reached. Figure 4 shows the results of this modelling procedure. Figure 5 shows the actual results of using this strategy for the week of December 8th 2008, which little to no down time due to failures.

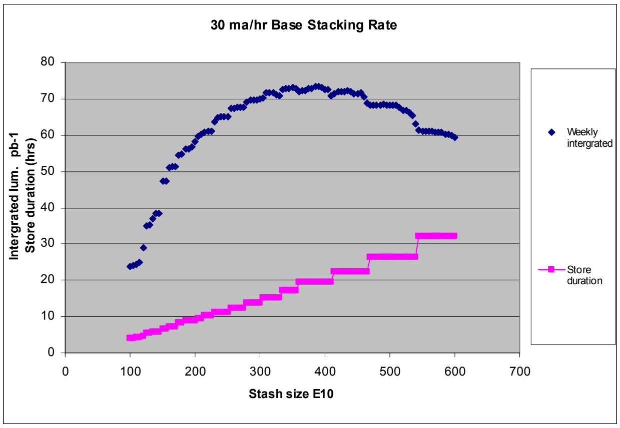

Figure 4. Integrated Luminosity as a function of the stash size at a 30 x10^{10}/hr antiproton production rate (ZSSR).

The above plot indicates that shooting from a stash size of ~375×10^{10} antiprotons would maximize our weekly integrated luminosity. The model also outputs a corresponding approximate store duration time, which in this case is ~20 hours.

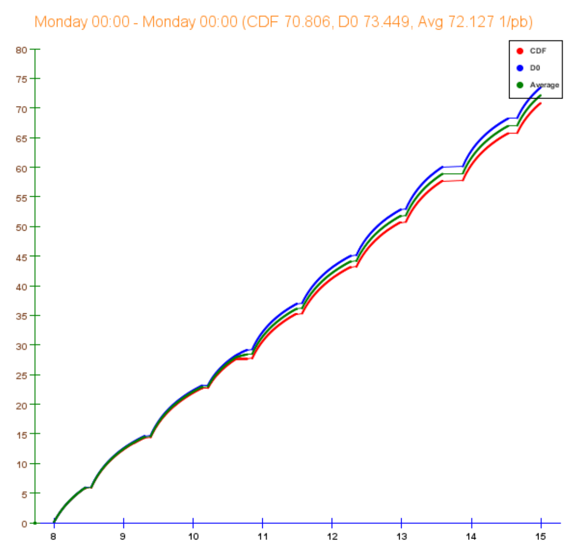

Figure 5. Record integrated luminosity for the week of December 8th 2008 was generated using the strategy described for cycling a store.

An additional tool that has been developed is the "Tevatron Luminosity Decay Summary" plot (Figure 6), which is generated in real time and updated throughout each store. The plot shows the instantaneous luminosity, the integrated luminosity, and the current stash and stack size.

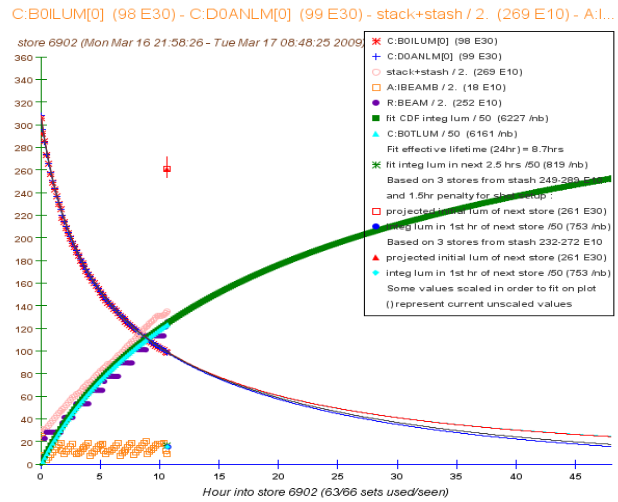

Figure 6. Real-time Tevatron Luminosity Decay Summary plot, used in daily operations to help determine the store termination time.

The program also projects the initial luminosity of the next store based on historical data and the current stash size. From this projected initial luminosity and historical decay data, integrated luminosity over the first hour of the next store is automatically predicted. This number is then compared to the projected integrated luminosity of our current store over the next 2.5 hours, thus taking into account the non integration time of the shot setup process. By using this process we can gauge on a store-by-store basis at what point we would be integrating more by terminating the store and putting in a new one.

CONCLUSION

With the many improvements to the accelerator complex over the past several years, the model described here has been used to optimize the Tevatron integrated luminosity, which has increased over this time by nearly 35%. As other improvements are made to the accelerator complex the model is reviewed and adjusted as needed.

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[4] M. Syphers, ID2506, these proceedings.