Multibunch Operation in the Tevatron Collider

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Abstract

The Tevatron Collider at Fermilab is the world's highest energy hadron collider, colliding protons with antiprotons at a center of mass energy of 1800 GeV. At present six proton bunches collide with six antiproton bunches to generate luminosities of up to 9×10^{30} $cm^{-2}s^{-1}$. It is estimated that to reach luminosities significantly greater than 10^{31} $cm^{-2}s^{-1}$ while minimizing the number of interactions per crossing, the number of bunches will have to be inceased. Thirty-six bunch operation looks like the most promising plan. This paper looks at the strategies for increasing the number of particle bunches, the new hardware that needs to be designed and changes to the operating mode in filling the Tevatron. An interactive program which simulates the filling of the Tevatron collider is also presented. The time scale for multibunch operation and progress towards running greater than six bunches is given in this paper.

I. Introduction

The long range Fermilab program requires fully capitalizing on the world's highest energy accelerator, the Tevatron, throughout the decade of the 90's. The program calls for increasing the collider luminosity with each successive run until peak luminosities of $> 5 \times 10^{31}$ $cm^{-2}s^{-1}$ with the MainInjector and integrated luminosities of in excess of 100 pb^{-1} per run are achieved, effectively doubling the mass range accessible for discovery.

The present collider operates with 6 proton and 6 antiproton bunches colliding at the two detectors, CDF and D0. For the present configuration, the minimum spacing between bunches is 185 buckets. For the present typical initial luminosity, $5 \times 10^{30} cm^{-2}s^{-1}$, the number of interactions in the detectors per bunch crossing is 0.79 (assuming a cross section of 45 mbarns). For the upcoming collider run, the typical initial luminosities are expected to exceed $1 \times 10^{31} cm^{-2}s^{-1}$. Since the number of bunches per beam will remain at 6 for that run, the number of interactions per crossing will exceed 1.57. Certain types of physics - not including the discovery of the top quark - are done more efficiently if the number of interactions per crossing is kept well below one. For the subsequent collider run, the typical initial luminosity is expected to remain near $1 \times 10^{31} cm^{-2}s^{-1}$. However, the number of bunches per beam will be increased to 36, in order to reduce the number of interactions per crossing to 0.26. For this configuration, the minimum spacing between bunches will be 21 buckets. With the Main Injector, the typical initial luminosity will exceed the Fermilab III goal of 5×10^{31} $cm^{-2}s^{-1}$, and the number of interactions per crossing will be 1.31, again exceeding one. If necessary for the types of physics to be done, some modest improvements to the Antiproton Source and the Tevatron can provide 99 bunches per beam with 7 bucket spacing. This would keep the number of interactions per crossing near one for luminosities of 1×10^{32} $cm^{-2}s^{-1}$.

† Operated by the Universities Research Association,Inc, under contract with the U.S. Department of Energy

II. Tevatron Injection Simulation

An interactive X Window program has been developed to model the Tevatron multibunch injection process. The program consists of three windows. The first window is a control window which has a list of which proton and antiproton buckets are filled, a display of the number of crossings at the two experimental areas B0 and D0, and a menu bar. In the menu bar there are controls to inject a single bunch, a batch of bunches, clear bunches, and RF cog bunches for both protons and antiprotons. The kicker rise time, flattop time, and fall time can also be adjusted interactively. The resulting bunch configuration can be saved to a file and recalled for later use. Figure 1 shows the control window with a thirty-six bunch bucket configuration.

There are two types of graphical displays provided. The first one is a snapshot of the Tevatron at the moment of time when proton and antiproton buckets number one are crossing F0 (the RF straight section). The inner "hash"

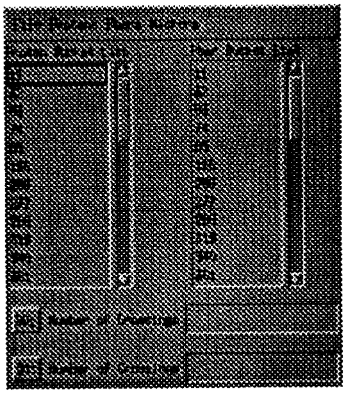

Figure 1: Bunch Injection Control Window

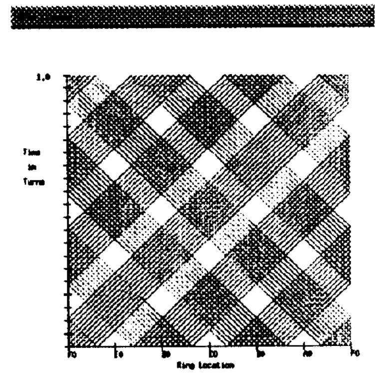

Figure 3: Space-time Diagram

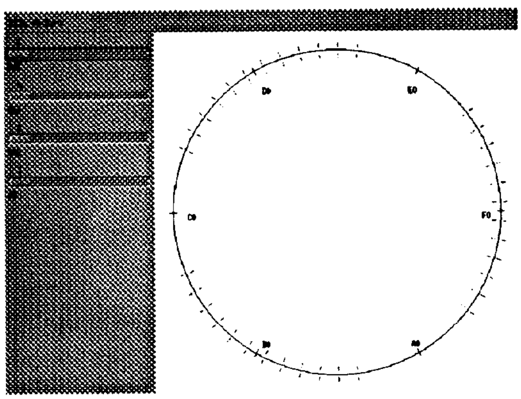

Figure 2: Snapshot in Time of the Tevatron

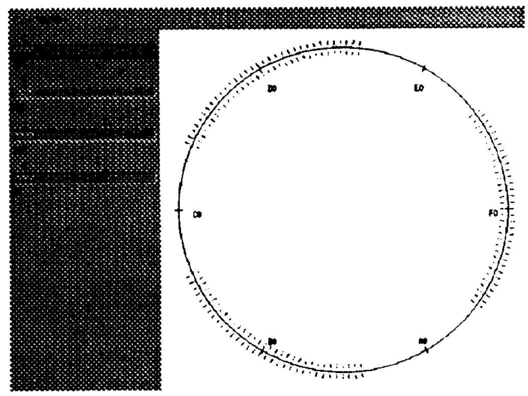

Figure 4: A Time Snapshot for 99x99

marks represent protons, the outer "hash" marks represent antiprotons. The second display is a space-time [1] diagram of the Tevatron. Space (distance around the ring) is plotted on the horizontal axis and time (in number of revolutions) is plotted on the vertical axis. Protons move diagonally up to the left, the antiprotons to the right. Figure 2 is a time snapshot of a 36x36 configuration. Figure 3 is a space-time diagram for the same configuration.

The program was used to simulate loading of the Tevatron under various constraints. One constraint is that there must be an equal number of crossings at both experimental areas (B0 and D0). Another important constraint is the abort gap length. There must be a large enough gap for the abort kicker rise time. A workable configuration calls for three batches of protons and antiprotons containing twelve bunches each. The three batches are spaced evenly around the ring. The protons can be loaded as three batches of twelve bunches each. The bunches within a batch are twenty-one buckets apart or 376 nsec. The antiproton loading scheme will be to load four bunches three times for each of the three batches. Under this scenario a kicker with a rise time of less than 376 nsec and a flattop of at least 1224 nsec (four antiproton bunches twenty-one buckets apart) is required. A kicker meeting these requirements is under development.

Some adjustments to the present abort kicker timing will have to be made for 36x36 operation. At present, the abort kicker rise time to full voltage is 4 μsec. The present abort gap is 3.5 μsec. The beam can be ejected when the kicker has reached 75% of its full value. With 36 bunches, the abort gap shrinks to 2.6 μsec. Preliminary calculations [2] show that by changing the capacitance and moving the beam orbits downward, this requirement can be met.

In the ninety-nine bunch scenario, the required antiproton injection kicker rise time would be 112 nsec but the abort gap would be larger than that for thirty-six bunches. Figure 4 shows a time snapshot for the 99x99 configuration.

References

[1] G. Dugan. *Considerations of Bunch-Spacing Options for Multi-Bunch Operation of the Tevatron Collider.* Fermilab, TM-1637, December 1989.

[2] Bruce Hanna, private comunication.