SECTION III

ACCELERATORS AND COLLIDERS

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THE 1988-1989 TEVATRON COLLIDER RUN SUMMARY

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Abstract The Fermilab Tevatron Collider has concluded a proton-antiproton collider run that lasted from June, 1988 till June, 1989. This paper summarizes the parameters and performance of the various accelerators for this run. Problems encountered during the run are described as well as the factors that limit the peak and integrated luminosities delivered to the experimental program.

INTRODUCTION

The Fermilab Tevatron is the world's highest energy superconducting proton synchrotron. It has been modified[1] to also run as a colliding beam storage ring in order to study proton-antiproton collisions, presently at center of mass energies of 1800 GeV. There have been two collider runs at Fermilab. The first,[2] from February 2 to May 11, 1989, saw peak luminosities of the order of 10^{29} and integrated luminosity of 70 nb^{-1} delivered. The second collider run was between June 1988 and June 1989. In addition to regular high energy and high luminosity running, there were also periods of calibration and lower energy running. This paper deals almost exclusively with the normal 900 GeV on 900 GeV high luminosity running that saw peak luminosities greater that $2x10^{30}$ and delivered almost 10 pb^{-1} to the experimental program.

RUNNING CONDITIONS

This section details typical running conditions and operating parameters of the Tevatron collider. During normal running there are two distinct operating phases of the accelerator complex. The first is "stacking and storage". In this phase there are stored colliding beams

*Operated by the Universities Research Association under contract with the United States Department of Energy.

in the Tevatron. At the same time the Main Ring is accelerating protons to 120 GeV for antiproton production and accumulation in the Fermilab Antiproton source.

The second phase is "shot setup", in which the existing store, if any, is dumped and fresh protons and antiprotons are brought into collision in the Tevatron. This shot setup is a complicated process that consists of transferring 11 bunches of protons from the Booster to the Main Ring, accelerating to 150 GeV, coalescing the protons into a single bunch and transferring it into the Tevatron. This is repeated six times and then the same operation is repeated for antiprotons from the Accumulator ring. At this point there are 6 proton and 6 antiproton bunches in the Tevatron circulating at 150 GeV. The Tevatron is then ramped to 900 GeV, the beams are brought into collision, and the low beta quads are excited.

A average scenario consists of a daily cycle with about 14.5 hours of storage, 3 hours of shot setup and 6.5 hours of down time; although there were good weeks in which the accelerator complex would run with essentially no down time. The shot setup time is dominated by how long it takes for the Tevatron persistent currents to settle down and for the antiprotons in the Accumulator to cool down sufficiently for efficient transfer through the Main Ring to the Tevatron. During this time the various accelerators and beam transfers are checked with both forward and reverse travelling protons. Table I details the typical beam parameters during a transfer.

RUN STATISTICS

This section will present some plots and relevant statistics for the run. Figure 1 shows the integrated luminosity per week, during the course of the run. As one can see in "perfect weeks" the collider could deliver greater than 500 nb^{-1} of integrated luminosity, although 300 nb^{-1} per week is a more typical number. Figure 2 shows the delivered integrated luminosity per store hour. This number folds in the effects of antiproton stack sizes, luminosity lifetimes, transfer efficiencies and store duration. One can see that the best we can do is about 3.6 nb^{-1} per hour which corresponds to an average luminosity of 1.0×10^{30}.

Figure 3 shows the peak luminosities during the course of the run. Typical luminosities of $1.6x10^{30}$ with some stores of greater that $2.0x10^{30}$ are apparent. Table II summarizes the overall numbers for the run.

COLLIDER PROBLEMS AND LIMITATIONS

This section describes some of the major problems during the course of the run and the primary limitations to the peak and integrated luminosities. The peak luminosity limit is a direct result of the beam-beam tune spread that limits the density of protons, and of the Accumulator cooling systems that put an upper limit on the antiproton density. The Tevatron operating point for colliding beams occupies tune space between 19.40 and 19.428 (the fifth and seventh order resonances respectively). Increasing the proton density above the typical numbers shown in Table I would drive the antiprotons into the seventh order resonance. The total number of antiprotons extracted from the Accumulator is limited by the stack size. As the stack gets bigger the percentage of beam extracted drops and the transverse size grows leading to smaller transfer efficiencies through the Main Ring into the Tevatron. In addition the stacking rate drops. All these factors conspire to limit the peak luminosity in order to maximize integrated luminosity.

In "perfect weeks" the peak luminosities achieved and the luminosity lifetimes limit the integrated luminosities delivered to about 550 nb^{-1}. In practice most weeks were worse than this because about half the stores were lost due to equipment failures. This had the effect of increasing downtime and also depressing the average antiproton stacks from which beam transfers were taken. Table III give a breakdown of how stores were terminated. As one can see there were many different equipment failures. One failure mode in particular should be mentioned. The beam abort kickers would prefire causing stores to be lost. About half way through the run the cause of this was traced to the trigger firing circuit and a problem that was a major headache in the beginning of the run presented no problems in the second half of the run.

CONCLUSION

The 1988-1989 collider run was very successful and all of the Tevatron I design goals, except that of stacking rate, were achieved or exceeded. The run delivered a total of 9590 nb^{-1} of integrated luminosity at a center of mass energy of 1800 GeV.

REFERENCES

1. Design Report Tevatron I Project, September, 1984, Fermi National Accelerator Laboratory.
2. S. Childress, et al, 1987 DOE Review, TM 1454, Fermi National Accelerator Laboratory.

TABLE I 1988/1989 collider numbers

TEV parameters	TEV I (Design)	Present running (typical)	
N protons	$6.0x10^{10}$ bunch	$7.5x10^{10}$ bunch	at low beta
N pbar	$6.0x10^{10}$ bunch	$2.5x10^{10}$ bunch	at low beta
# bunches	3 * 3	6 * 6	
proton emittances	24 π mm-mrad	24 π mm-mrad	at low beta
pbar emittances	24 π mm-mrad	15 π mm-mrad	at low beta
horizontal beta	1.0 meter	0.53 meter	at CDF
vertical beta	1.0 meter	0.56 meter	at CDF
long emittance	3 eV-secs	3 eV-secs	
initial luminosity	$1.0x10^{30}$	$1.6x10^{30}$	best ever $2.07x10^{30}$
lum lifetime	20 hours	15 hours	t(store)=0 hours
		35 hour	t(store) =20 hours
pbar stack	$50x10^{10}$	$70x10^{10}$	best ever 97.2^{10}
stack rate	10^{10} hour	$1.5x10^{10}$ hr	best ever 2.25^{10}
H,V emittances	2 π mm-mrad	0.7 π mm-mrad	unnormalised
Δ p/p	0.05 %	0.08 %	

TABLE II

Integrated luminosity	9590 nb^{-1}
Integrated store hours	4257
Peak luminosity	$2.07x10^{30}$
Integrated lum/hour	3.5 nb^{-1}
Max integrated luminosity per week	518 nb^{-1}
Max integrated luminosity per store	135 nb^{-1}
Max antiproton stack	$97.2x10^{10}$
Longest store	53 hours
Typical shot setup time	3 hours
Typical controlled store length	21.5 hours
Number of store	295
Percentage abnormal store ends	55 % (average length 9.5 hours)
Percentage abnormal store ends in the last 4 months	35%

TABLE III

Store Loss Explanation	# of occurrences
1. Intentional due to low luminosity	99
2. Intentional for M & D or studies	21
3. C17K abort kicker prefire	20
4. Quench protection system	17
5. TeV power supplies, TECAR	16
6. Lightning and power glitches	15
7. Intentional for experimenters	13
8. B48K abort kicker prefire	11
9. TEV RF system	11
10. Human error	11
11. Cryogenics	9
12. Controls	8
13. Experimental area operations	7
14. Higher order power supplies	7
15. MR VCBs opening	5
16. Dipole correction system	5
17. Vacuum	4
18. Low beta quads	4
19. Pond and LCW water pumps	3
20. Miscellaneous	9

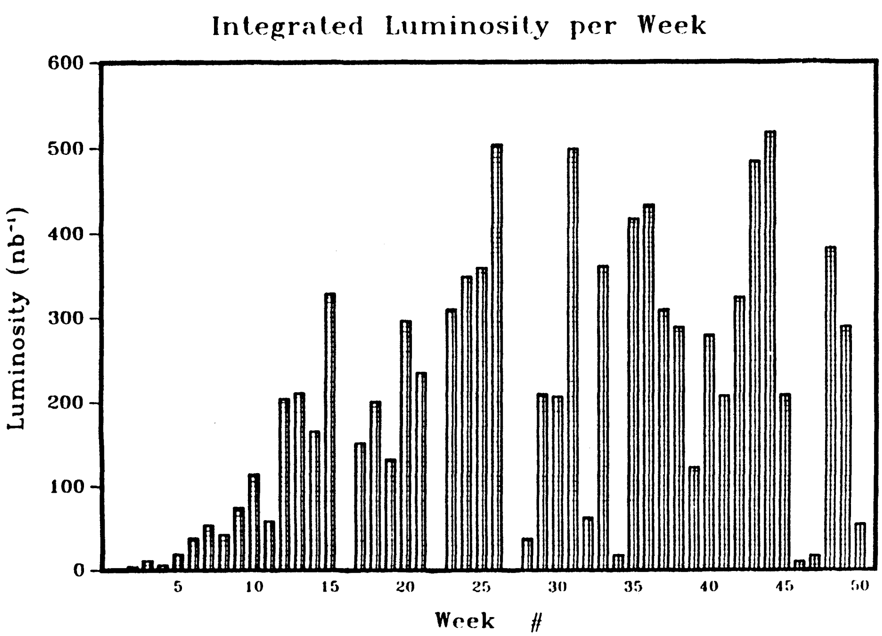

FIGURE 1

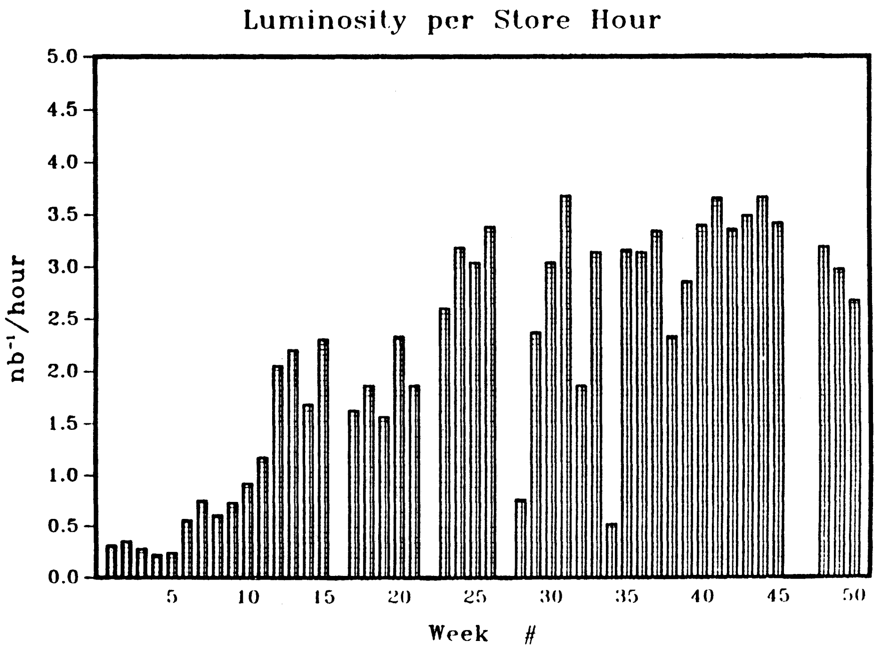

FIGURE 2

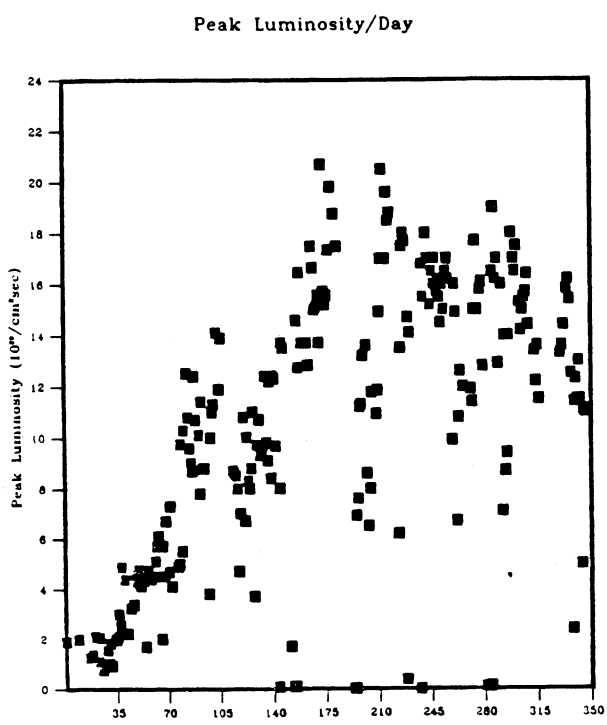

FIGURE 3