Characteristics of the Beam During The Second Fermilab Collider Run.

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Abstract

This paper describes some of the characteristics of the beam during the 1988-1989 run in the Fermilab collider and as such provides a base line for comparison with the beam properties measured during future collider runs.

Introduction

The measure of accelerator performance, during collider operation, is the luminosity which can be calculated from the measured beam parameters. (We also need to know the lattice functions but the problem of determining these is outside the scope of this paper.) A simplified, approximate, expression for the luminosity $\mathcal{L}$ can be written in terms of the measured characteristics of the beam is: [1]

$$\mathcal{L} = \mathcal{C}(L) \cdot N_p \cdot N_{\overline{p}} / (\beta_h \cdot \epsilon_h \cdot \beta_v \cdot \epsilon_v)^{1/2}$$

where:

$\mathcal{C}(L)$ is a function of the bunch length, L.

N_p is the number of protons in a bunch.

$N_{\overline{p}}$ The number of anti-protons in a bunch.

ϵ_h is the horizontal emittance of a bunch.

ϵ_v is the vertical emittance of a bunch.

β_h and β_v are the values of the amplitude function at the interaction point.

This paper will concentrate on those beam characteristics needed to calculate the luminosity. All the data described here have been culled from the COLL88 data base generated during Collider Run II. Only the data recorded during low-β operation on or after Nov. 6,1988 (store 1728) are used in this paper (a total of 135 stores). [2] The data stored for each of the measured beam properties was either averaged over a predetermined length of time (typically 15 minutes) or stored whenever the value of the device changed. Thus the bunch intensities and bunch lengths are averaged while the transverse emittances are recorded whenever they are measured.

The data of each bunch were fit to a polynomial in time after the flying wires were first flown *after* the TEVATRON was at low-β. This is typically one hour after the time low-β was achieved. Thus we are *not* describing the beam characteristics immediately after the start of collisions in the TEVATRON.

Bunch Intensities

The intensities of the 6 proton and 6 anti-proton bunches were measured by the SBD (Sampled Bunch Display). The data were recorded by the data logger and these data were averaged over a 15 minute interval and stored in the data base. The intensity of each bunch, as a function of time, was well fit by a first order polynomial in time. Table I summarizes the characteristics of the fit to the bunch intensities *during low-β operation.*

Table I.[3]

Quantity	Particle	Value $\cdot 10^{-9}$	$\Sigma \cdot 10^{-9}$
N_0	p	62.6	13.1
$dN/dt\|_{t=0}$	p	-0.40 / hr	0.19 / hr
"σ"	p	0.44	0.23
N_0	$\overline{p}$	20.4	5.9
$dN/dt\|_{t=0}$	$\overline{p}$	-0.17 / hr	0.10 / hr
"σ"	$\overline{p}$	0.36	0.30

The fraction of the $p(\approx 0.006/\mathrm{hr})$ and $\overline{p}(\approx 0.009/\mathrm{hr})$ lost per hour are similar. The lifetime (defined as $-N/(dN/dt)$)

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[1] This formula cannot be used to calculate the luminosity when there is more than one proton and anti-proton bunch or when the p and $\overline{p}$ have different emittances but it does identify the beam parameters required to calculate the luminosity

[2] All the data are from the period during which we used the procedure to "kill unwanted beam". Using this procedure beam in unwanted buckets was removed and the emittance of the p beam was deliberately increased to reduce the beam-beam interaction.

[3] The Σ given for the fitted coefficients gives an indication of the variation, over the many sets of data fitted, in the value of the fitted parameter. The quantity described as "σ" in the table is an indication of the error that would be assigned to the data to have the expected χ^2 for the fit.

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of the bunch intensities is in excess of 100 hours.

If the data are fit to a second order polynomial in time then the bunch lifetime begins at greater than 50hours and reaches more than 100hours in 4-8 hours. The lifetime of the proton bunches is longer than the lifetime of the anti-proton bunches.

Transverse Emittances

The transverse emittances (horizontal and vertical) of the 6 proton and 6 anti-proton bunches were measured by flying wires at C48 (horizontal and vertical wires) and A17 (horizontal wire). The measured σ of each bunch was converted into an emittance using values of the amplitude function β and the dispersion function η calculated using the code **TEVLAT**. (The calculation was done including the values of the high order multi-poles measured at **MTF**.) The emittance of each bunch was fit to a first order polynomial in time. Table II summarizes the characteristics of the fit to the bunch emittances *during low-β operation.*

Table II. - Transverse Emittance

Quantity	Particle	Value (πmmmr)	Σ (πmmmr)
$\epsilon_h\|_{t=0}$	p	19.5	3.2
$d\epsilon_h/dt\|_{t=0}$	p	+0.34 / hr	0.13 / hr
"$\sigma(\epsilon_h)$"	p	0.62	0.37
$\epsilon_v\|_{t=0}$	p	21.8	4.4
$d\epsilon_v/dt\|_{t=0}$	p	+0.35 / hr	0.20 / hr
"$\sigma(\epsilon_v)$"	p	1.4	1.5
$\epsilon_h\|_{t=0}$	$\overline{p}$	12.0	2.3
$d\epsilon_h/dt\|_{t=0}$	$\overline{p}$	+0.30 / hr	0.10 / hr
"$\sigma(\epsilon_h)$"	$\overline{p}$	0.56	0.42
$\epsilon_v\|_{t=0}$	$\overline{p}$	14.5	2.9
$d\epsilon_v/dt\|_{t=0}$	$\overline{p}$	+0.30 / hr	0.19 / hr
"$\sigma(\epsilon_v)$"	$\overline{p}$	1.23	1.61

The growth of the emittance is approximately the same for both p and $\overline{p}$ and in both transverse planes at about 0.3 πmmmr/hr. The growth rate of the proton bunches is slightly larger than that of the anti-proton bunches.

The large value of Σ and σ obtained for the vertical emittance reflects problems with the vertical wire during part of the run.

Bunch Length, Longitudinal Emittance and $\delta p/p$

The bunch lengths of the 6 proton and 6 anti-proton bunches were measured by the **SBD** (Sampled Bunch Display). The data were recorded by the data logger and these data were averaged over a 15 minute interval and stored in the data base. From the measured bunch length, the calculated transition γ and a knowledge of the operating conditions of the TEVATRON (such as the energy and the *r.f.* voltage) the longitudinal emittance and the value of $\delta p/p$ can be calculated.[4] The data for each bunch were fit to a first order polynomial. Tables III,IV,V summarize the characteristics of the fit to the data *during low-β operation.*

Table III.- Bunch Length.

Quantity	Particle	Value (cm)	Σ (cm)
$L\|_{t=0}$	p	50.0	2.4
$dL/dt\|_{t=0}$	p	+0.56 / hr	0.18 / hr
"σ"	p	0.73	0.37
$L\|_{t=0}$	$\overline{p}$	50.3	3.0
$dL/dt\|_{t=0}$	$\overline{p}$	+0.62 / hr	0.17 / hr
"σ"	$\overline{p}$	0.98	0.59

Table IV.- Longitudinal Emittance.

Quantity	Particle	Value (eV-s)	Σ (eV-s)
$\epsilon_l\|_{t=0}$	p	2.95	0.35
$d\epsilon_l/dt\|_{t=0}$	p	$6.6 \cdot 10^{-2}$/ hr	$3.1 \cdot 10^{-2}$/ hr
"σ"	p	0.11	0.12
$\epsilon_l\|_{t=0}$	$\overline{p}$	2.91	0.40
$d\epsilon_l/dt\|_{t=0}$	$\overline{p}$	$6.9 \cdot 10^{-2}$/ hr	$2.6 \cdot 10^{-2}$/ hr
"σ"	$\overline{p}$	0.13	0.14

Table V.-$\delta p/p$

Quantity	Particle	Value	Σ
$\delta p/p\|_{t=0}$	p	$1.37 \cdot 10^{-4}$	$1.71 \cdot 10^{-5}$
$\frac{d(\delta p/p)}{dt}\|_{t=0}$	p	$1.60 \cdot 10^{-6}$/ hr	$1.47 \cdot 10^{-6}$ / hr
"σ"	p	$2.91 \cdot 10^{-6}$	$2.71 \cdot 10^{-6}$
$\delta p/p\|_{t=0}$	$\overline{p}$	$1.36 \cdot 10^{-4}$	$2.57 \cdot 10^{-4}$
$\frac{d(\delta p/p)}{dt}\|_{t=0}$	$\overline{p}$	$1.60 \cdot 10^{-6}$/ hr	$8.4 \cdot 10^{-5}$ / hr
"σ"	$\overline{p}$	$3.26 \cdot 10^{-4}$	$3.11 \cdot 10^{-6}$

Again we see that the proton and anti-proton bunches behave in a similar manner though the growth in the longitudinal emittance of the anti-protons is slightly larger than for protons. The bunch length grows typically by about 6mm/hr. The corresponding change in $\delta p/p$ is approximately $1.60 \cdot 10^{-4}$%/hr. The growth of the longitudinal emittance is $\approx$ 0.06eV-s/hr.

Luminosity

The interaction rate at B0 has been measured by the CDF collaboration, and they have expressed that rate as a luminosity using a number of assumptions. This "measured" luminosity is referred to as C:B0LUMP and is known to exhibit a short lifetime in the period shortly after low-β is reached. The lifetime of C:B0LUMP is observed to increase as the store evolves.

The values of C:B0LUMP provided by CDF have been averaged over a fifteen minute interval and stored in the data base. The values of C:B0LUMP recovered from the

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[4] The average *r.f.* voltage for the protons is $\approx$ 4% larger than that of the anti-protons. As a result, even though the anti-proton bunch length is, on the average, slightly larger than that of the protons, the longitudinal emittance ϵ_l and the $\delta p/p$ of the protons is, on average, slightly larger than that of the anti-protons

data base have been fit to a second order polynomial in the time after the TEVATRON reached low-β. [5]The fit to these data (Figure 1) shows an initial lifetime of the order of 14hours rising to more than 17hours after the first hour of collisions. After 10 hours the luminosity lifetime is on the order of 24hours.

The measured luminosity can be compared with the luminosity calculated from the measurements made on the beam in the TEVATRON. We select measurements of the luminosity made at the same time as the measurements made of the beam properties needed to calculate the luminosity. The ratio of the two determinations of the luminosity is plotted in Figure 2.

It is obvious that there is good agreement between the determinations but it is also obvious that the measured luminosity decreases with time faster than the calculated luminosity, the ratio changes by $\approx -0.2\%/\mathrm{hr}$. The calculated luminosity does not depend on any other accelerator or beam parameters other than those discussed here. [6]

The difference in the time dependence between the measured and calculated luminosity implies that the one or more of the devices used to make the measurements has a rate or time dependent calibration. Thus if the intensity counters were rate sensitive and saturated then the calculated luminosity would decrease more slowly than the true luminosity. Similarly the measured luminosity could be more sensitive to rate or background than assumed, with the result that the measured luminosity could be larger than the true luminosity early in the store. These possibilities are pure speculation. If the question is to be resolved, much more effort in the calibration and monitoring of beam instrumentation will be necessary. It is not clear that such an effort can be justified in terms of more efficient accelerator performance.

Acknowledgements

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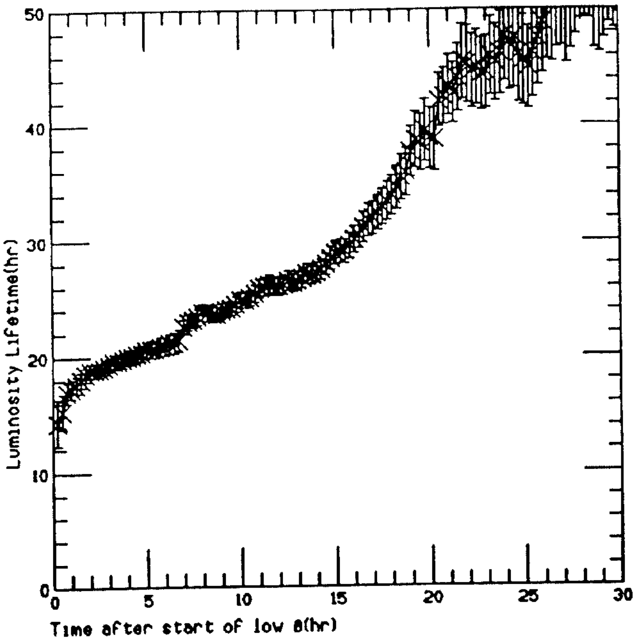

Figure 1: Measured Luminosity Lifetime as a Function of Time into the Store

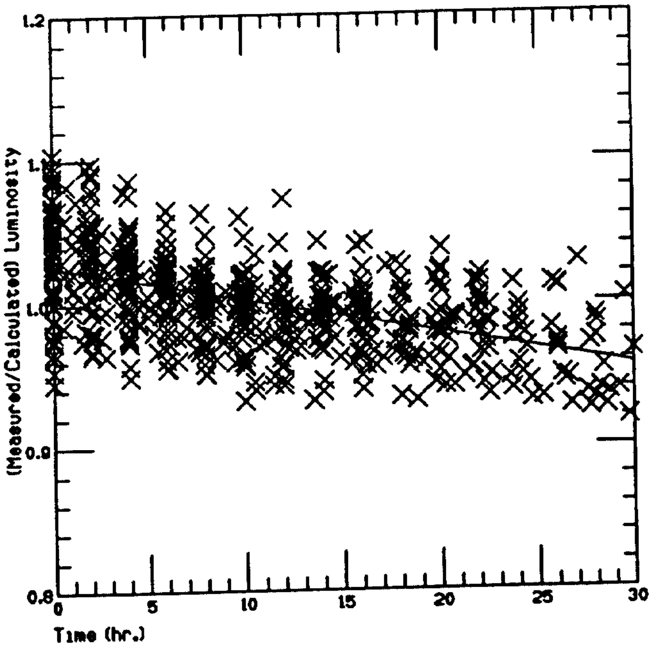

Figure 2: Ratio of the Measured Luminosity to the Calculated Luminosity as a Function of Time into the Store

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[5] Please note that since the value of C:B0LUMP does not require the data from the flying wires it is available *right* after we reach low-β.

[6] The details of the calculation of the luminosity can be found the paper "Computation of the TEVATRON Luminosity Using Measured Machine Parameters" submitted to this conference.