SIMULATION OF BEAM-BEAM EFFECTS IN TEVATRON[1]

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The Fermilab accelerator complex is in the middle of an upgrade plan Fermilab III. In the last phase of this upgrade the luminosity of the Tevatron will increase by at least one order of magnitude. In order to keep the number of interactions per crossing manageable for experiments, the number of bunches will be increased from 6X6 to 36X36 and finally to ~100X100 bunches. The beam dynamics of the Tevatron has been studies from Beam-Beam effect point of view in a "Strong-Weak" representation with a single particle being tracked in presence of other beam. This paper describes the beam-beam effect in 6X6 operation of Tevatron.

I. INTRODUCTION

The Fermilab Tevatron is a 1.8 TeV/c center of momentum proton-antiproton collider, delivering a peak luminosity greater than 2.E31 cm-2sec-1. In the current collider operation six proton and six antiproton bunches collide at B0(CDF) and D0 interaction points. The two beams are kept separated in a helical orbit at ten other possible interaction locations by electrostatic separators, with approximately 5σ separation. Average intensity of proton and antiproton bunches are about 25E10 and 8E10 respectively. Current Tevatron performance does not seems to be limited by beam-beam effects. In the current operating condition each detector sees on average about 2 interactions per crossing.

The Fermilab III accelerator complex upgrade, including the Main Injector will increase the peak luminosity to 10E32 cm-2sec-1. Higher luminosity is needed to better understand several high pt physics, including top quark physics, reducing uncertainty in W mass and extend the B Physics CP violation reach. Higher luminosity will be achieved by injecting more proton and antiproton bunches with similar intensities to present bunches. Number of bunches will increase from 6X6 to 36X36 and eventually to ~100X100, to keep the number of interactions per crossing at each high energy physics detectors at a managable level.

In this paper we describes the calculations which are being performed to study the beam-beam interaction in the current Tevatron. These calculations will be extended to 36X36 and ~100X100 bunch crossing scenarious of upgraded Fermilab accelerator complex. A modified version of thin element tracking program TEAPOT[1] has been used for these simulations.

II. LATTICE

The Tevatron lattice includes standard magnetic elements dipoles, quadrupoles, sextupoles and correction elements. The lattice includes measured higher order multipoles for dipoles and quadrupoles. The higher order multipoles include both normal and skew components up to 14 poles for dipole and 16 poles for quadrupoles. There are electrostatic separators in the lattice which are used to to put the beam on a helical orbit. In TEAPOT there is no direct provision for electrostatic separator, so its function is achieved by providing a horizontal and vertical kick to the particles at separator locations. The misalignment of all the magnetic elements and beam position monitors has been included in this calculation. The sigma of the alignment error with respect to close a orbit is 0.25 mm in both horizontal and vertical directions. In addition dipole magnets have a roll angle of 0.5 mrad sigma. The horizontal and vertical dipole correction elements are used to correct the closed orbit error due to these errors. The Tevatron has four RF cavities, each operating at Vrf=0.2125 MV. The RF frequency is set to 53 MHz corresponding to a harmonic number of 1113.

The two sextupole families are used to set the chromaticity of the Tevatron to a desired value. The Tevatron has four sets of skew quardupoles. These skew quadrupoles are used to globally decouple the Tevatron.

III. CALCULATIONS

The calculations of Beam-Beam effect is performed by using a thin element tracking code TEAPOT. The code simulates the passage of a single particle in the presence of an oncoming beam by a BEAM-BEAM element. This is necessarily a "weak-strong" representation with the single particle being tracked seeing the constant field of the other beam like those of any other fixed beam-line element. The code takes as an input the transverse beam size, number of particle in the fixed beam, and horizontal and vertical offset from the ideal orbit.

In the 6X6 bunch operation of the Tevatron the single tracked antiproton crosses the proton bunches at twelve locations

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around the ring. We have performed calculations for two operating conditions of the Tevatron at 900 GeV. In the first case the two beams are not colliding at B0 and D0 and in the second case they are. The base tune of the Tevatron is set to (Qx,Qy) = (20.583,20.574) and chromaticity is adjusted to 20., 24. for the first case. The base tune is set to (Qx,Qy) = (20.582,20.577) and chromaticity is lowered to 10.0 and 12.0. The lounched particles have Dp/p = 0.0001.

We have the effects number of particles in the strong beam, no coupling in Tevatron, global decoupling of Tevatron, effects of higher order multipoles in dipoles and quadrupoles and electrostatic separators off. In this paper we present some general feature of the data.

Fig. 1 shows the change in the x and y tune of a small amplitude particle as a function of beam intensity. Simulation clearly shows the beam-beam tune shift.

Fig. 2 is the phase space plot of a particle with initial amplitude of x=3.5mm y=5mm at the maximum beta. Maximum beta is considered away from the low beta region. In this simulation all the higher order multipoles in dipoles and quadrupoles are present and beam-beam effect has been turned off. Fig. 3 shows the phase space of the same particle when the beam-beam effect has been turned on. Clearly, addition of beam-beam increases the occupied phase space.

The inclusion of beam-beam effect also changes the location in x and y plane a particle occupies. Fig 4 and 5 shows the turn by turn plots of a particle without and with beam-beam.

The Tevatron spends most of its time colliding beam at B0 and D0. We have looked at the phase space of a small amplitude particle in the presence of Beam-Beam. Fig 6. shows the phase space of that particle.

IV. OUTLOOK

In this paper we have presented initial results of a long simulation program we are about to undertake to study the Beam-Beam effects in the Fermilab Tevatron. These studies will be extended to 36X36 and ~100X100 bunches operations of the Tevatron and will be published elsewhere[2].

V. REFERENCES

[1] L. Schachinger and R. Talman, Particle Accl 22, 35 (1987).

[2] C. S. Mishra and S. Assadi to be submitted to Phy Rev E.

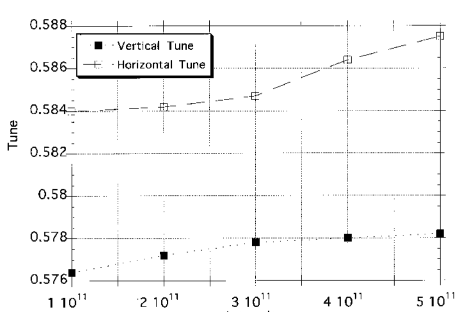

Fig. 1) Betatron tune shift increases as intensity increases.

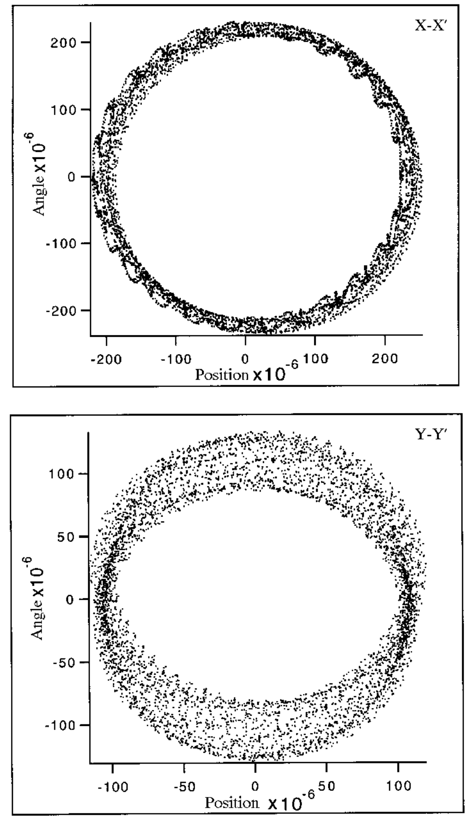

Fig. 2) Normalized horizontal and vertical phase space plots; single beam with higher order multipoles.

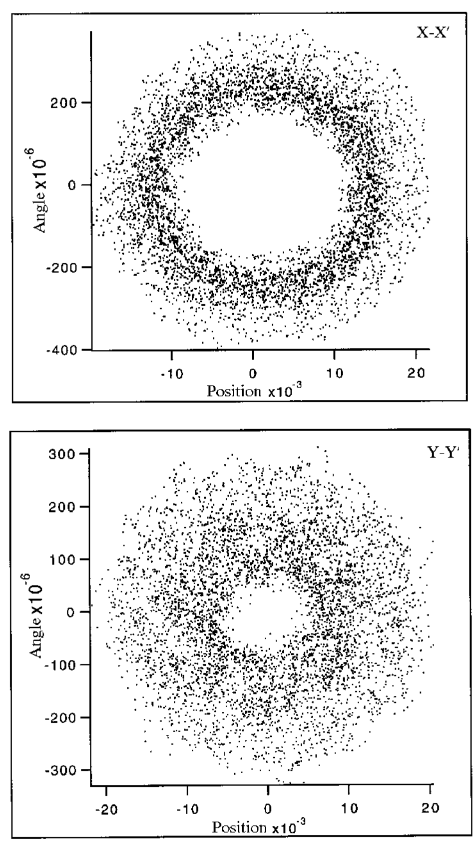

Fig.3) Horizontal (upper) and vertical (lower) normalized phase space plots for beam-beam with higher order multipoles is shown.

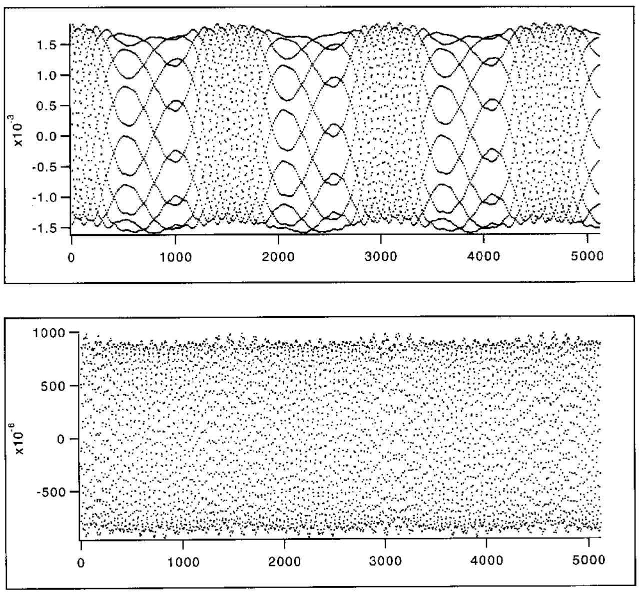

Fig. 4) Turn by turn plots of a particle without beam-beam but all higher order multiples present; (top plot is horizontal and the bottom plot is vertical).

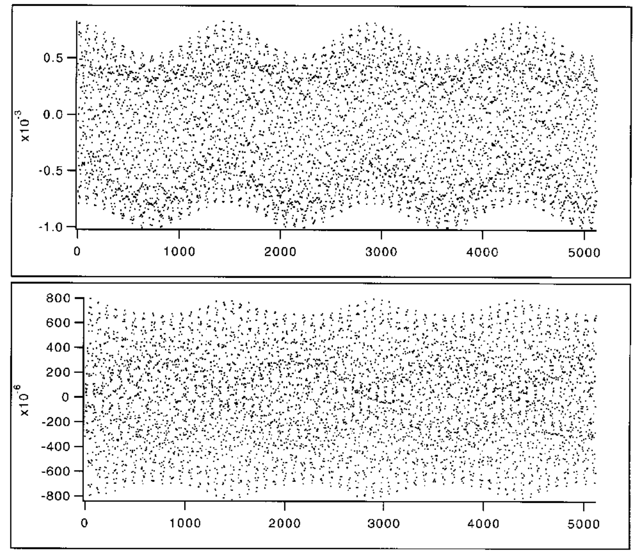

Fig. 6) Turn by turn plots of a particle with beam-beam and all higher order multiples at lowbeta; (top plot is horizontal and the bottom plot is vertical).

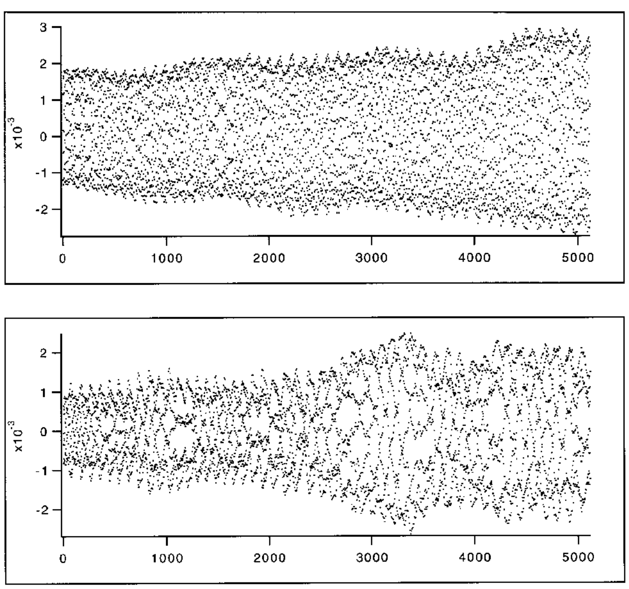

Fig. 5) Turn by turn plots of a particle with beam-beam and all higher order multiples present; (top plot is horizontal and the bottom plot is vertical).

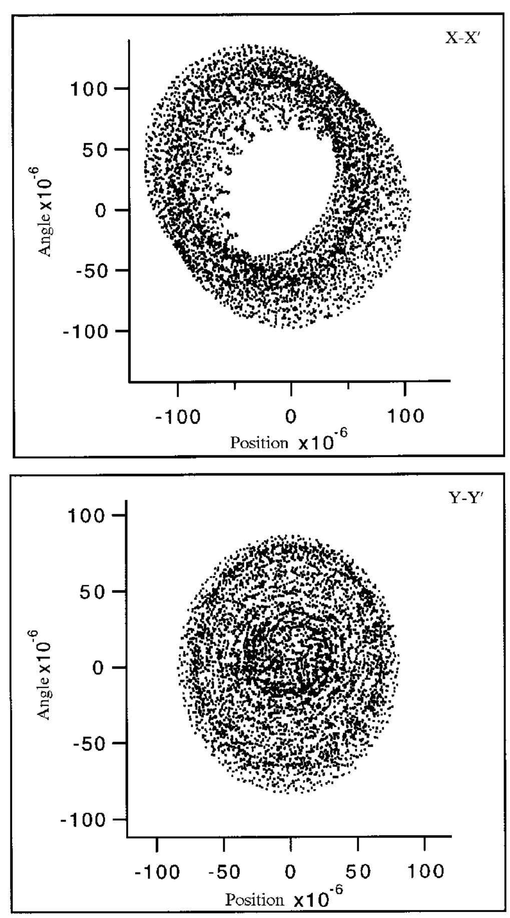

Fig.7) Normalized phase space plots; beam-beam with higher order multipoles at lowbeta location.