Calculation of the Effect of a Tilt (Pitch) on the Position of the IP at B0.

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Abstract

The effect of a change in the tilt of the 6 low-β quads at B0 on the position of the IP has been calculated. The tilt of the magnet at B09-4 (the middle element of the triplet) has the greatest effect on the position at the IP but the effect is small. A change in the tilt of 100μr changes the vertical position of the IP by only ~30μm. This is not enough to account for the long term persistent vertical motion of the IP at B0.

Introduction

It has been known for some time that the pitch (or tilt - I use the terms interchangeably in this note) of the low-β quadrupoles changes over time. While it may be an attractive hypothesis to associate the change in the vertical position of the B0 interaction point with the change in the tilt there is no evidence that this is so. In an earlier work (Beams Doc #1935) I could not find a strong correlation between the changes in the tilts of the low-β magnets at B0 and the motion of the IP. Since the completion of the previous note the tracking code Tevlat has been modified to incorporate the pitch of magnets in its calculations. The enhanced version of Tevlat has been used to calculate the change in the position of the IP due to tilts of the low-β magnets at B0.

Pitch

The pitch of a magnet is defined as a rotation of the magnet about the X axis, where the Y axis is vertical and the Z axis is along the nominal beam direction. A positive pitch is defined as one in which the downstream end of the magnet (in the proton direction) is lower than the upstream end.[1] Since the rotation is about the X axis the horizontal coordinate and slope of the beam do not change do to the pitch.

Let us refer to Figure 1 to understand the effect of the pitch. The rectangle represents a magnet rotated about an axis perpendicular to the plane of the figure and through the center of the magnet. The horizontal line, representing the nominal beam orbit centered on the nominal center line of the magnets, enters the magnet above the center line of the magnet and at a angle, relative to the center line, equal to the tilt of the magnet.

To track the particle through the tilted magnet we transform the particle to a system where the Z axis lies along the axis of the magnet, transform these new coordinates through the magnet, and finally reverse the initial transformation. In the example diagrammed above the initial coordinate of the particle is positive and the initial slope is negative.

The center of rotation for the tilt need not be at the center of the magnet. The distance between the center of the magnet and the center of rotation I will call the offset. The offset will be positive if the center of rotation is to the right of the magnet center.

[1] Todd Johnson, private communication.

For a dipole the tilt will have no effect on the beam as long as the tilt angle is small.[2] For long, strong quadrupoles the tilt can have a noticeable affect on the beam. The results of the calculation for different offsets are shown in Figure 2.

The effect of the tilt on the beam will generally be greater for a vertically defocusing quadrupole (an F quad) then for a quad which is vertically focusing D (Figure 3.) [3]

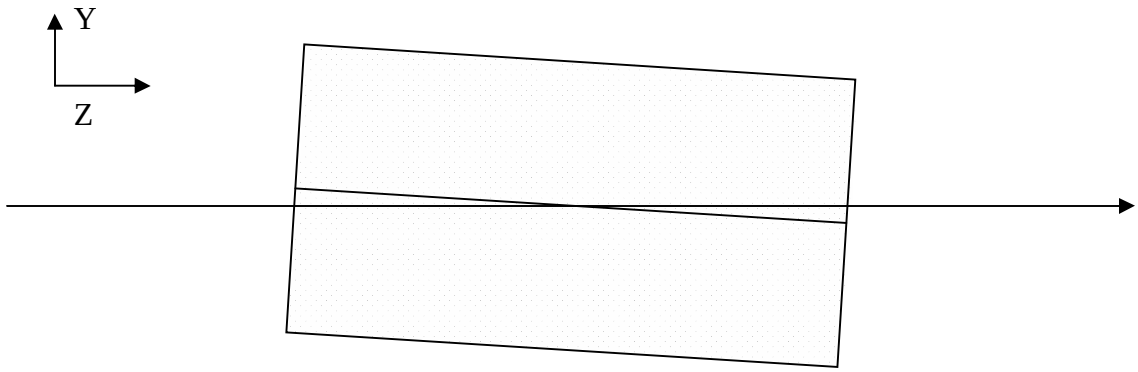

Figure 1. Tilted Magnet

The effect of a 100μr tilt of the center member of the triplet is shown in Table I as well as a rotation centered at -1m (upstream of the magnet center) and +1m (downstream) of the magnet center.

Table I
Change in the Vertical Position and Slope
Due to a Tilt of 100μr of the 232" Low-β Quad
Quad Length 5.893m
Quad Strength k=0.20335/m

Offset (Distance from the tilt center to the magnet center.)	**Δy(μm)**		**Δy'(μr)**	
Magnet Type	**F**	**D**	**F**	**D**
0m	56.2	-86.6	-7.8	-9.4
1m	119.8	-167.4	11.1	-40.1
-1m	-7.4	-5.8	-26.7	21.2

[2] The magnet field in the Y direction, B_y becomes $B_y\cos(\theta)$ where θ is the tilt angle.
[3] It is amusing to observe that for some value of the offset, in this case ~-1m the beam will exit the magnet on the initial beam line and that the special offset is nearly the same for a F or a D magnet.

It is clear that tilts of ~100μr generate significant changes in the position and slope of the beam. It is also clear that the center of rotation of the magnet also affects the changes.

It is important in trying to understand the effect that the tilts can have on the position of the IP to calculate the change in the IP position as magnets are tilted. TEVLAT was modified to allow tracking through tilted magnets.

Model Calculations

The computer model of the Tevatron used for the calculations had a nominal β^* of 0.35m in each plane. The high order multipoles measured at 4KA were also used. The values of a_1 were corrected for the cold lift and the subsequent reshimming. The fractional tune was adjusted to $[\nu_x]$= 0.5875 and $[\nu_y]$= 0.5775. The chromaticities were set to ξ_x= 8.4 and ξ_y= 8.2. The results are not sensitive to these values for the settings.

Figure 4 show the change in the position of the vertical IP for a tilt of 100μr and for different offsets, of the different magnets in the low-β triplet. The largest change in the IP would occur when the downstream middle member of the triplet is tilted. The change in the IP would be ~32μm for the 100μr tilt. Figure 4 also shows that the change in the position of the IP is not sensitive to the location of the tilt center within the ±2m range over which I calculated the IP position. It is clear that despite the large affect a tilted magnet can have on a particle going through it, the effect on the closed orbit is much smaller.

<u>Conclusions</u>

The earlier work in Beams Doc #1935 failed to identify a correlation between the measured tilt of the low-β quadrupoles and the motion of the IP at B0. In this note I have calculated what is the effect of tilting the low-β quads on the position of the IP. The tilt of the quad at the middle of the downstream triplet has the greatest effect on the IP but the effect is only ~30μm for a 100μr tilt.

This is to small to explain the long term upward drift of the IP. Uncorrected the IP would probably have drifted up by more than 850μm in the last year. This have required the tilt of the magnet at B09-4 to have changed by ~2.8mr, far in excess of any observed change in the measured tilts.

I have not excluded the possibility that a combination of tilts of the low-β quadrupoles could account for the motion of the IP but I regard that as unlikely. The tilt meters on the magnets do not show the consistent long term behavior as does the vertical motion of the IP at B0.

I believe that in order to understand the motion of the IP at B0 we will need a functioning HLS system on the low-β quads and on the CDF. I suspect that it will show that the motion is due to the detector sinking but this is a suspicion, a supposition, not a result.

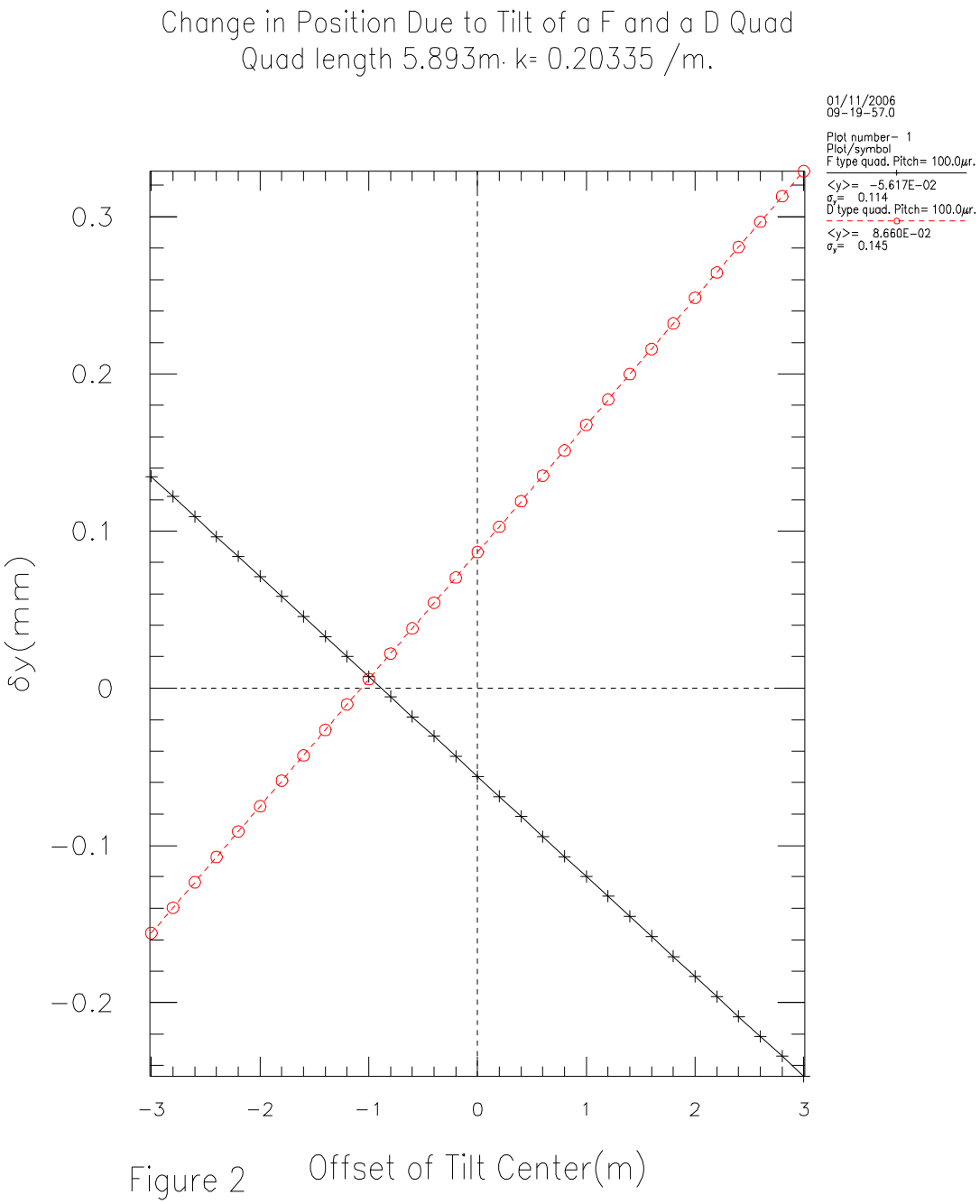
Change in Position Due to Tilt of a F and a D Quad
Quad length 5.893m· k= 0.20335 /m.
01/11/2006
09-19-57.0
Plot number- 1
Plot/symbol
F type quad. Pitch= 100.0μr.
<y>= -5.617E-02
σy= 0.114
D type quad. Pitch= 100.0μr.
<y>= 8.660E-02
σy= 0.145
0.3
0.2
0.1
0
-0.1
-0.2
δy(mm)
-3
-2
-1
0
1
2
3
Offset of Tilt Center(m)

Figure 2

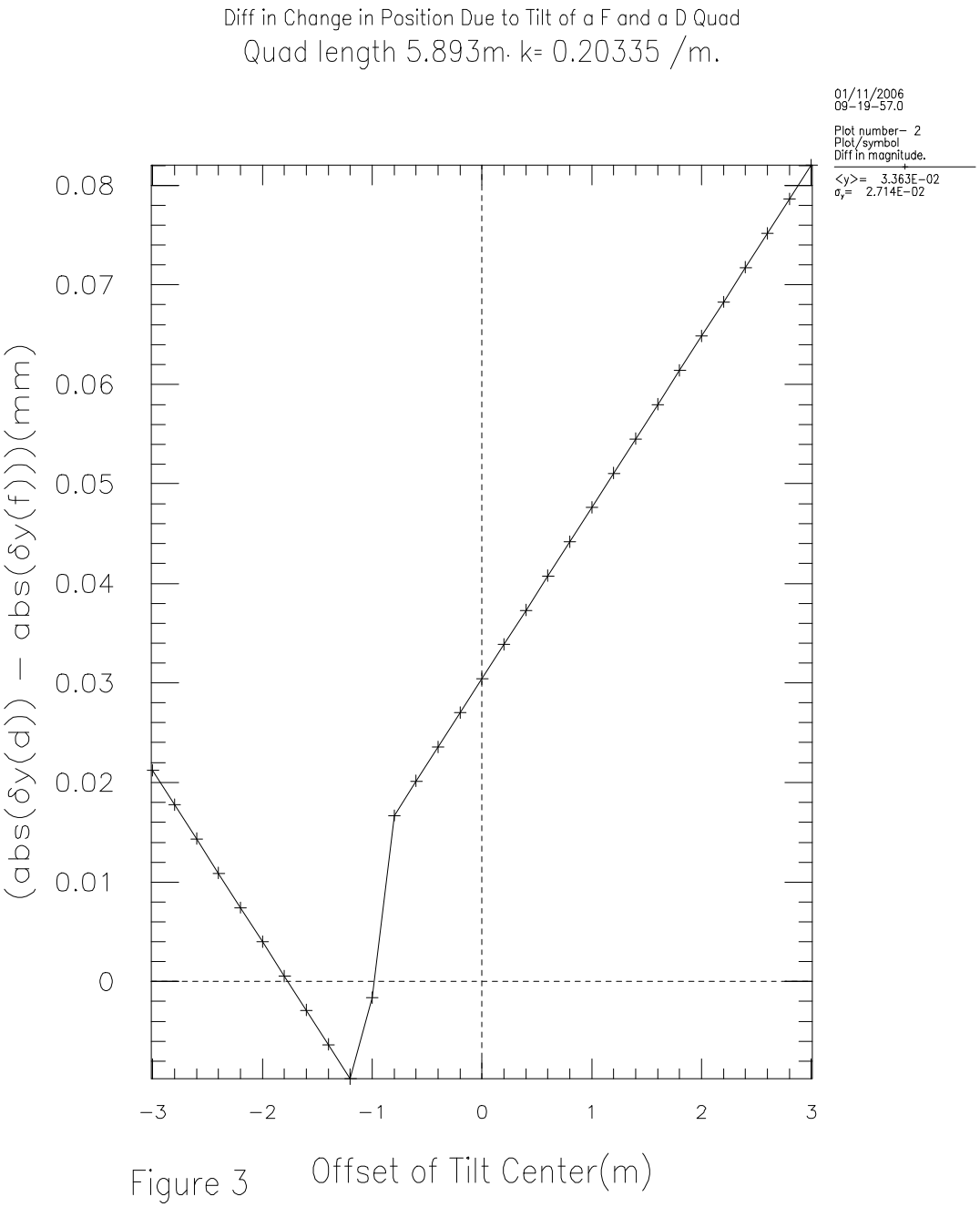
Diff in Change in Position Due to Tilt of a F and a D Quad
Quad length 5.893m· k= 0.20335 /m.
01/11/2006
09-19-57.0
Plot number- 2
Plot/symbol
Diff in magnitude.
<y>= 3.363E-02
σy= 2.714E-02
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
(abs(δy(d)) - abs(δy(f)))(mm)
-3
-2
-1
0
1
2
3
Offset of Tilt Center(m)

Figure 3

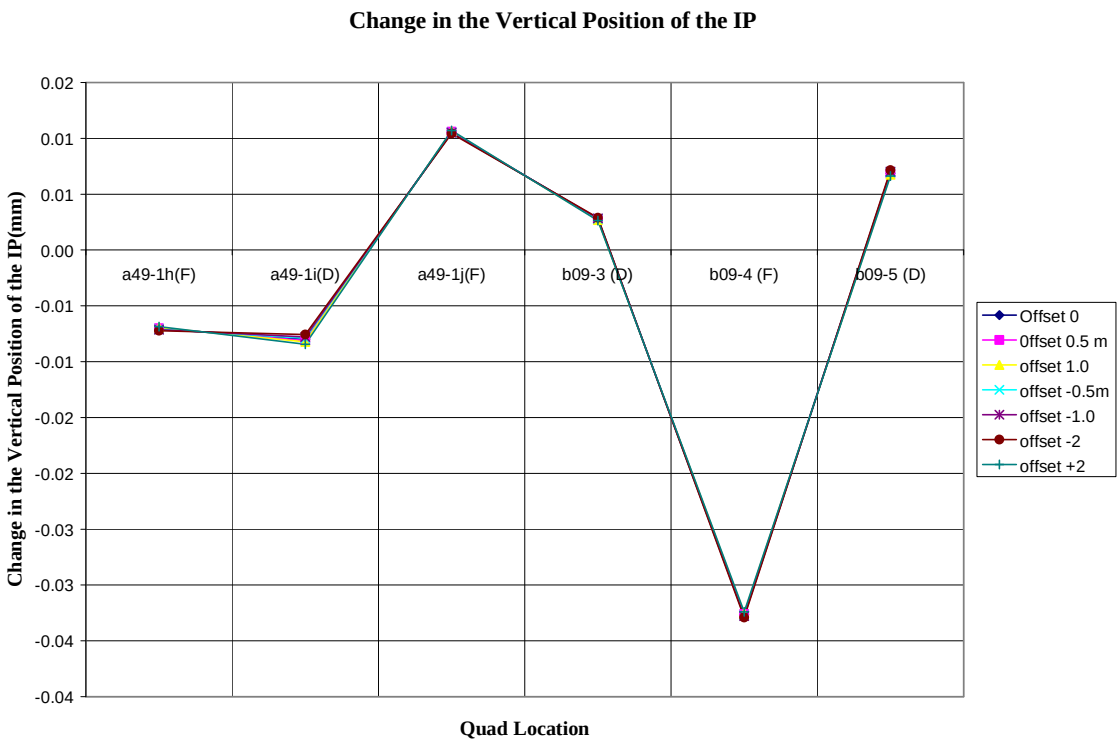
Change in the Vertical Position of the IP
Change in the Vertical Position of the IP(mm)
0.02
0.01
0.01
0.00
-0.01
-0.01
-0.02
-0.02
-0.03
-0.03
-0.04
-0.04
a49-1h(F)
a49-1i(D)
a49-1j(F)
b09-3 (D)
b09-4 (F)
b09-5 (D)
Quad Location
Offset 0
0ffset 0.5 m
offset 1.0
offset -0.5m
offset -1.0
offset -2
offset +2

Figure 4