$\mathcal{TWIST}$ Technote 93

Effect of proton beam position variations on $\mathcal{TWIST}$ results

G.M. Marshall
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The purpose of this note is to record and assess some information which can be used to establish the systematic uncertainty in $\mathcal{TWIST}$ results due to variations in the proton beam position. When the proton beam position on the 1AT1 production target changes, the effective source of surface muons may also change. This in turn affects the position and shape of the muon beam at the end of M13, and in principle the measured values of Michel parameters could also change. The uncertainty associated with this potential change is estimated to be small compared with 10^{-3}, but to measure it more carefully requires at least one simulation result which we don't yet have.

1 Muon beam dependence on proton beam position

In fall 2003, data were taken with the beam tuning and characterization apparatus (fast chamber) with the proton beam intentionally mis-steered at 1AT1 by the maximum amount compatible with beam protect monitors and other restrictions on the BL1A tune, such as radiation monitors following T1 and protect monitors at 1AT2. Table 1 shows the results from online estimates of numbers describing the beam profiles in x and y for five runs, one with the proton beam at the nominal position and four with it steered via steering magnets 1ASM4 (vertical) and 1ASM5 (horizontal) to the limits that could be obtained with full proton beam intensity. These runs were recorded and offline distributions are available if better precision or shape variation estimates are needed; Dave Gill has done this analysis. Note that the steering limits were well beyond any position variations that would be tolerated by TRIUMF operators in normal running, as they caused protect monitors and in some cases radiation monitors to read unacceptably high. In fact, the proton beam had to be retuned downstream of T1 in order to keep the readings at T2 within trip limits. The numbers in the table were derived from x and y distributions similar to those in Fig. 1, corresponding to the muon beam tune used for data taking in fall 2003.

A simple estimate of the vertical dependence of the muon beam position on the proton beam position is $d\bar{y}_\mu/dy_p = 0.25$ from runs where the beam is steered up and down. The horizontal dependence is $d\bar{x}_\mu/dx_p = 0.5$, made from the runs with the proton beam steered right and left. Because of the crudity of the analysis, there is an uncertainty of probably 25%, as estimated by comparison with the unsteered run 15314, and also by using the mean of $x_{\mu,HLavg} = (x_{\mu,H} - x_{\mu,L})/2$ instead of $\bar{x}_\mu$. Shapes do not change significantly, as can be seen from the comparative stability of $\sigma_{x\mu}$ and $\sigma_{y\mu}$, and the consistency of $x_{\mu,HLavg}$ and $\bar{x}_\mu$.

Run	15314	15315	15316	15317	15318
p beam	nominal	high	low	right	left
SM4(V)	-73	-45	-101	-73	-73
y_p (mm)	0.0	+0.8	-0.8	0.0	0.0
$\bar{y}_\mu$ (mm)	+0.8	+1.05	+0.65	+0.88	+0.82
$\sigma_{y\mu}$ (mm)	3.8	3.7	3.8	3.8	3.8
SM5(H)	+117	+117	+117	+164	+45
x_p (mm)	0.0	0.0	0.0	+0.8	-1.0
$\bar{x}_\mu$ (mm)	+0.5	+1.0	+0.6	+0.2	+1.1
$\sigma_{x\mu}$ (mm)	8.5	8.4	8.5	8.6	8.2
$x_{\mu,L}$ (mm)	-10.8	-11.6	-11.9	-12.3	-10.9
$x_{\mu,H}$ (mm)	+13.0	+14.4	+14.3	+14.3	+15.2

Table 1: Measurements of muon beam position for different proton beam positions (see p. 165, Beam Studies log book #2, and Beam Studies binder). Subscripts indicate proton (p) or muon (μ), lower (L) or upper (H) half-height position. The latter two were recorded for x because the distribution was not symmetric.

There does not appear to be any significant $d\bar{y}_\mu/dx_p$, but the numbers show that $d\bar{x}_\mu/dy_p$ could also be about 0.25.

2 Proton beam position stability

The calibration of the proton beam position at T1 (at the protect monitor) is accomplished during the low intensity target scans[1]. An example of one of these scans is shown in Fig. 2. A beam of about 1 μA is steered both vertically using steering magnet 1ASM4 (controlled by thumbwheel TW60) and horizontally using 1ASM5 (TW61). The DAC setpoint units are recorded along with the currents caused by the proton beam hitting the separate bottom, top, left, and right plates. The DAC values at which the current climbs to half of its maximum on a plate corresponds to the mean of the beam moving 2.5 mm from a centered position in the corresponding direction, since the plates are separated by 5.0 mm. This calibrates the beam position versus SM4 and SM5 DAC setpoints. The lines with arrows indicate the approximate half-height points.

The vertical scan shows half-height points at about -130 and $+60$, giving a central position of -35 with 38 DAC/mm. The region with nearly zero current on both plates is only about 10 DAC units or 0.4 mm wide. The edge widths are consistent with a beam 90% contained within about 150 DAC units, or 4 mm vertically. Since this almost fills the 5 mm separation, there is high sensitivity of the protect monitor currents to vertical movement.

The horizontal scan has half-height points at about -50 and $+280$, for a central position of $+115$ with 66 DAC/mm. The region with nearly zero current is much wider than for the vertical scan, about 22 DAC units or 3.3 mm, because the beam is narrower horizontally than vertically. The edge widths are consistent with 90% containment within about 100

DAC units or 1.5 mm horizontally, although the right side leads to a somewhat narrower estimate than the left. Contrary to the vertical situation, this means that the beam can move about ±1.75 mm without significantly striking the protect monitors, at least at 1 μA.

At higher currents as used for the measurements of Table 1, the beam can be moved only with great difficulty by ±0.8 mm either horizontally or vertically. This is presumably because the horizontal tails of the beam extend more than vertically, so that as the current is raised, the horizontal tails nearly fill the 5 mm protect monitor gap. Note that there was a slight difference in steering magnet DAC to position calibration used in the data of Table 1, probably due to small variations in other aspects of the beam tune or stripper foil position.

With the calibration, we can estimate the variation in position of the beam by checking the history of the setpoints of SM4 and SM5. For example, Fig. 3 shows vertical corrections of typically 5-10 DAC units, or about 0.25 mm, while there was only one horizontal correction of about 5 DAC units or 0.1 mm. The large variations, which are clipped off in the plot, do not correspond to normal beam delivery but are mostly due to steering required for the weekly maintenance day target scans. A more careful survey of the variations of the steering magnets for particular data sets can be done as required from the history files.

3 Muon beam position variation due to proton beam movement

Multiplying the proton beam position variations with the dependences of the muon beam position on proton beam position, the typical muon beam position variations are in the range of 0.05 mm both horizontally and vertically. Since the extents of the distributions in Fig. 1 are a hundred times greater, the effects on the muon decay parameters should also be small compared to other muon beam position variation effects, at least for a measurement at 10^{-3}. Comparisons exist of decay parameters for simulations with the pre- and post-October (2002) beam tunes, showing insignificant effects at the level of 10^{-3} except for ξ, which is about 2.5 σ at 6.3×10^{-3}[2]. The two beam tunes used as input for the two simulations differ substantially, compared to 0.05 mm from a proton beam position variation. Therefore, we would not expect a systematic effect at the level of 10^{-3} from proton beam instability. The distributions are shown in $\mathcal{TWIST}$ Technical Note 91[3]. The effects of proton beam instability can be determined more precisely, but will require an analysis which is not yet available in which the beam is moved. For example, the tests with dipole B2 adjusted by ±10 G, which in turn move the beam left or right by about ±25 mm as shown in [3], could be scaled according to beam movement. These data will be analyzed anyway, so the results can be applied when they are available. Scaling could be tested if necessary by a similar shift of the input beam by a smaller distance, such as 5 mm. However, the conclusion at this stage is that the proton beam position variation is not a dominant systematic effect for $\mathcal{TWIST}$ measurements at a precision of 10^{-3}.

References

[1] T.A. Porcelli, General Procedure for Proton Beam Monitoring, September 11, 2002. https://twist.phys.ualberta.ca/forum/view.php?bn=twist_general&key=1031779881.

[2] See the $\mathcal{TWIST}$ systematics listings. http://e614db.triumf.ca/private/systematics/SysTable2.html#Beam_tune.

[3] D.R. Gill, $\mathcal{TWIST}$ Technical Note 91. https://twist.phys.ualberta.ca/forum/view.php?bn=twist_technotes&key=1083888399.

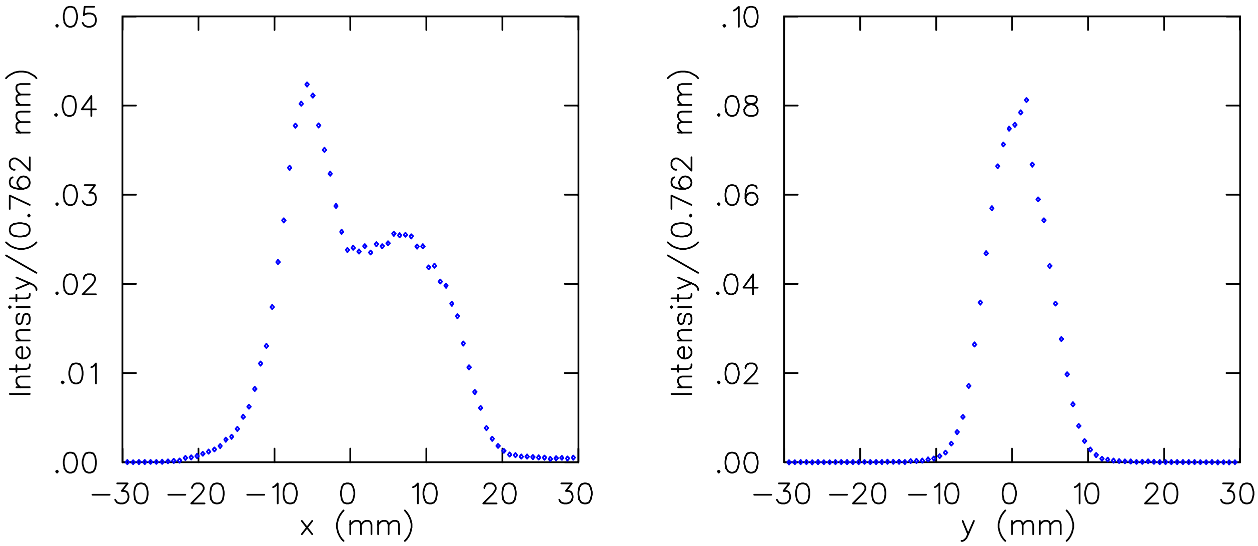

Figure 1: Plots of horizontal (x) and vertical (y) surface muon beam distributions, from the 2003 tune. Because of the asymmetry in the shape of the x distribution, widths from both rms and half-heights were recorded.

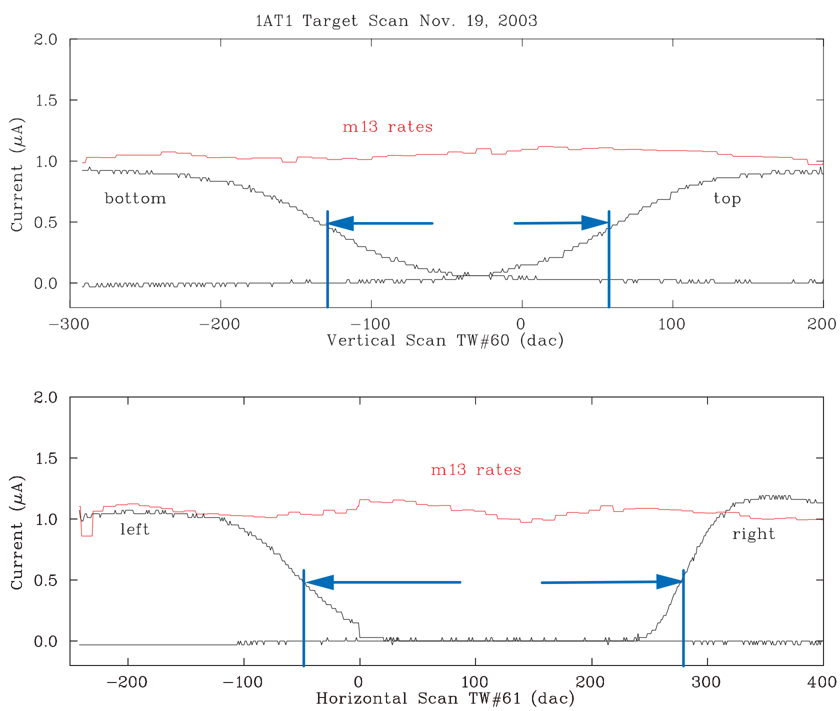

Figure 2: Typical low intensity target scan. The arrows indicate the half-height positions as the beam is steered onto the individual plates. The known plate separation of 5 mm gives the calibration in terms of thumbwheel (TW) setting.

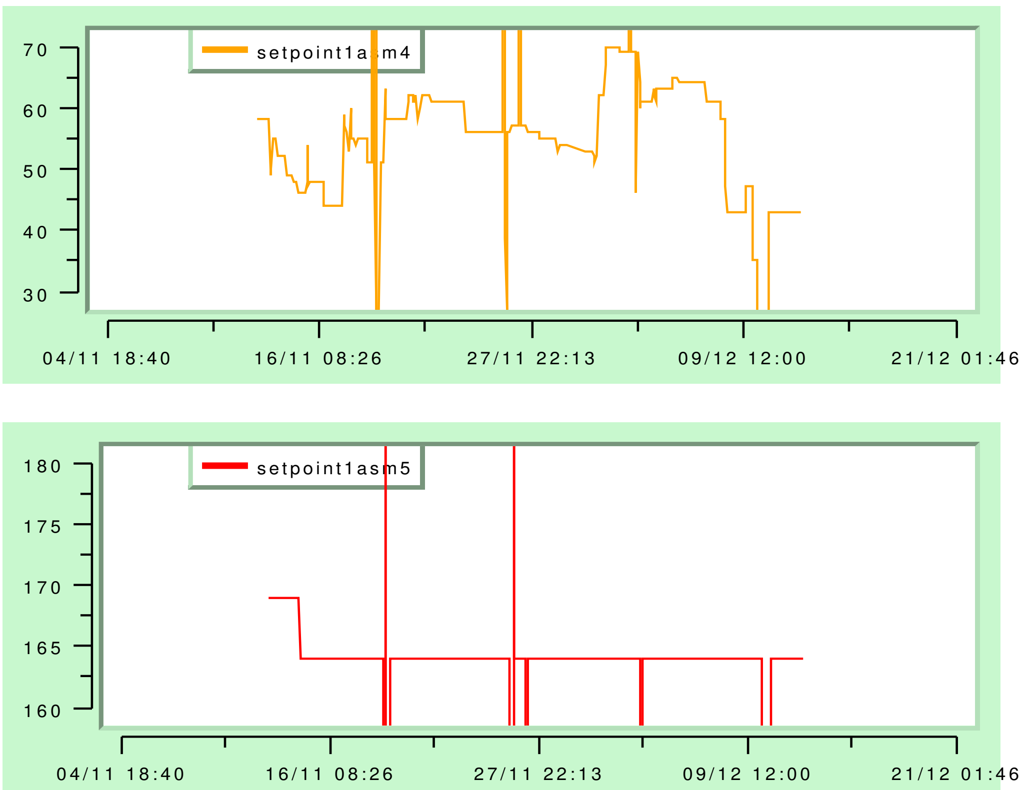

Figure 3: Stripchart plots of vertical (1ASM4) and horizontal (1ASM5) DAC settings for a four-week period in fall 2003. Large excursions are from maintenance day activities such as beam scans, but the smaller ones are typical of corrections made by operators during normal beam delivery.