TRIUMF Beam Physics Note
TRI-BN-22-xx
Jan.10, 2022

Simulations of TRIUMF U-turn Scan

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Abstract: In this note we summarize the results of simulations that we performed on TRIUMF cyclotron U-turn scan using trim coil 36.

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1 Phase Band of 42°

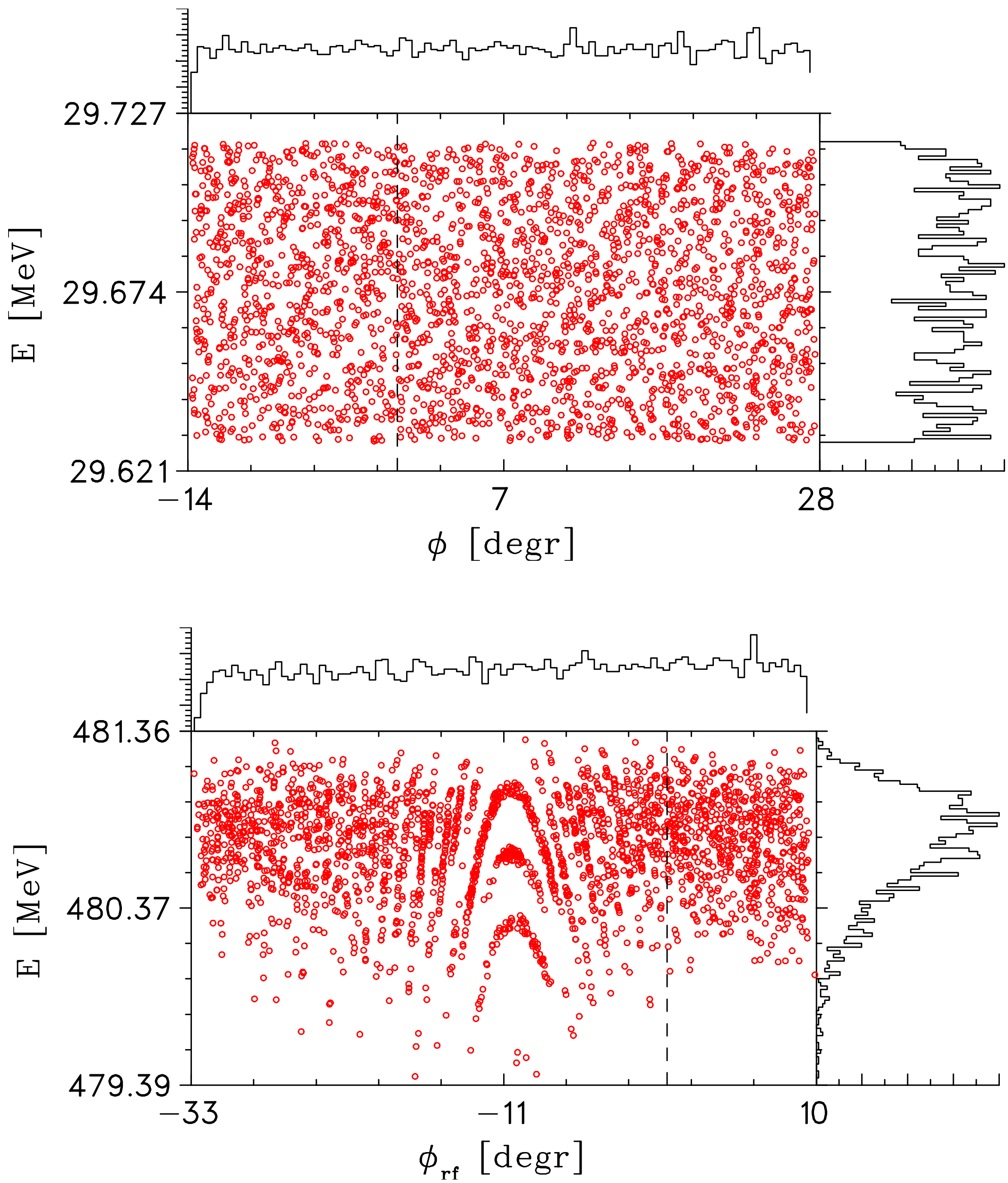

Figure 1: *Longitudinal phase space of the beam at start (upper) and at ∼480 MeV (lower) where it's dumped on a X2A foil. The real phase band is* ∼ 42° *(full bottom width).*

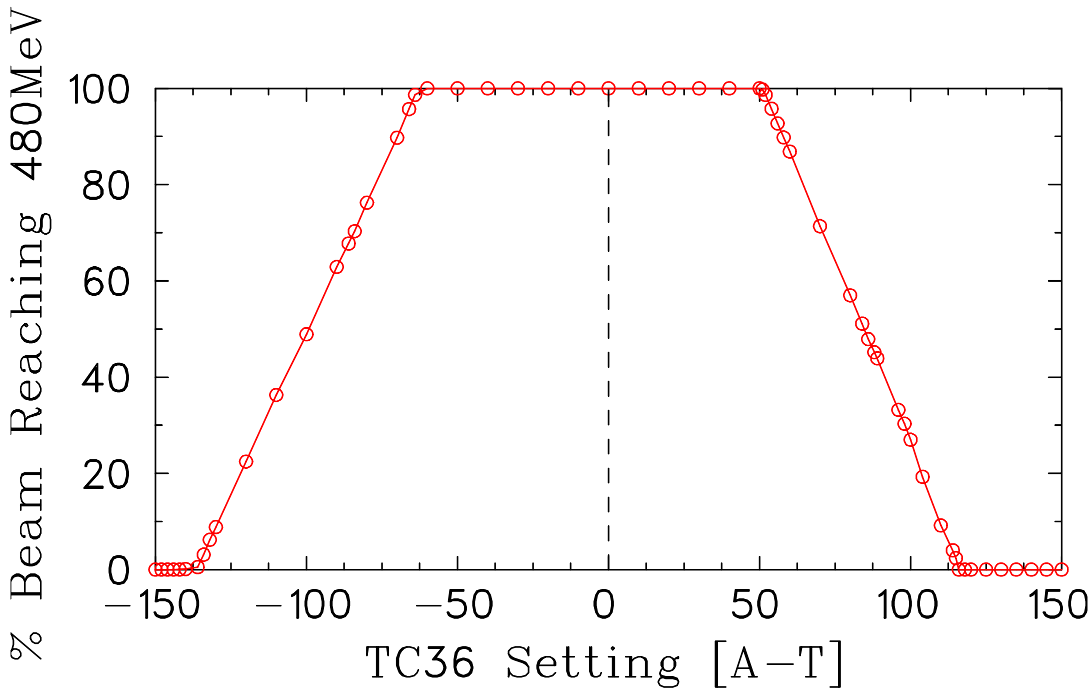

Figure 2: *The X2A current versus TC36 Ampere-turn excitation of the B_z triplet for the U-turn around 206 MeV, where the TC36 is varied starting from 0, upward to +150 Ampere-Turn and downward to* -150 *Ampere-Turn respectively.*

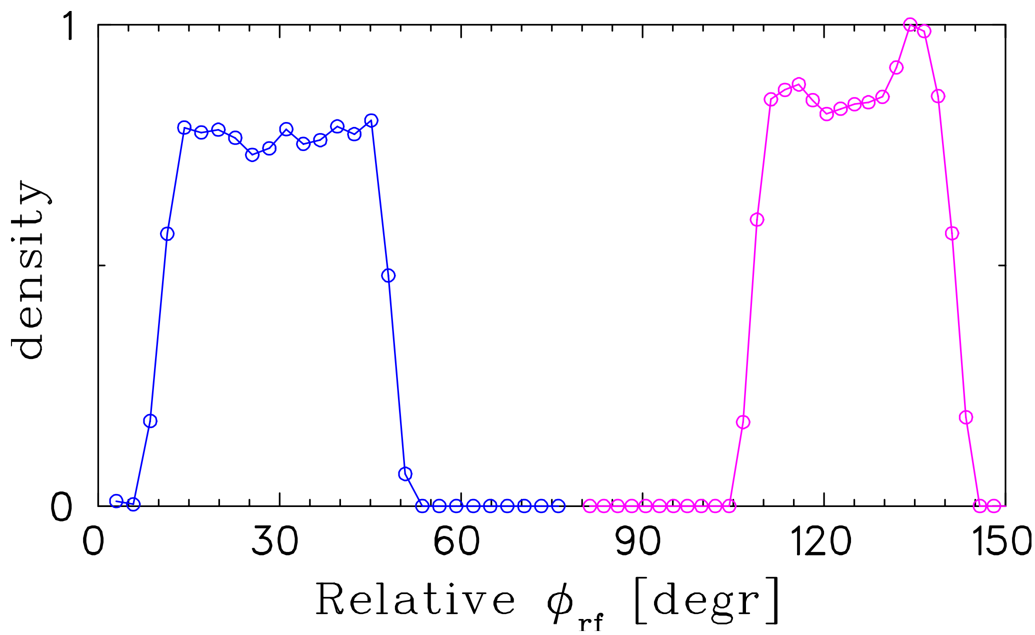

Figure 3: *Resultant beam distrbution in rf phase angle, calculated from Fig. 2 by taking derivative for the TC36 excitation and applying* **a scaling factor of $96°$/(FWHM Ampere-turn change)** *to convert the TC36 Ampere-turn variation into the rf phase.*

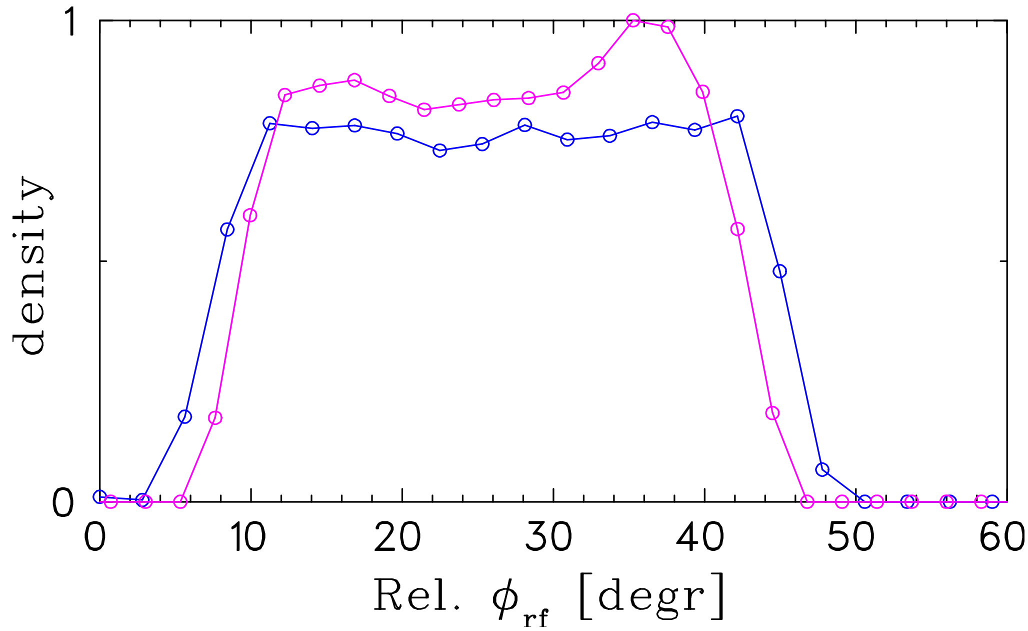

Figure 4: *Comparison of the 2 phase profiles as shown in Fig. 3. The upward scan (magenta) gives a phase band of* $\sim 42°$ *(full bottom width). This agrees with Fig.1, but the downward scan (blue) gives somewhat broader result for some reason.*

2 Phase Band of 22°

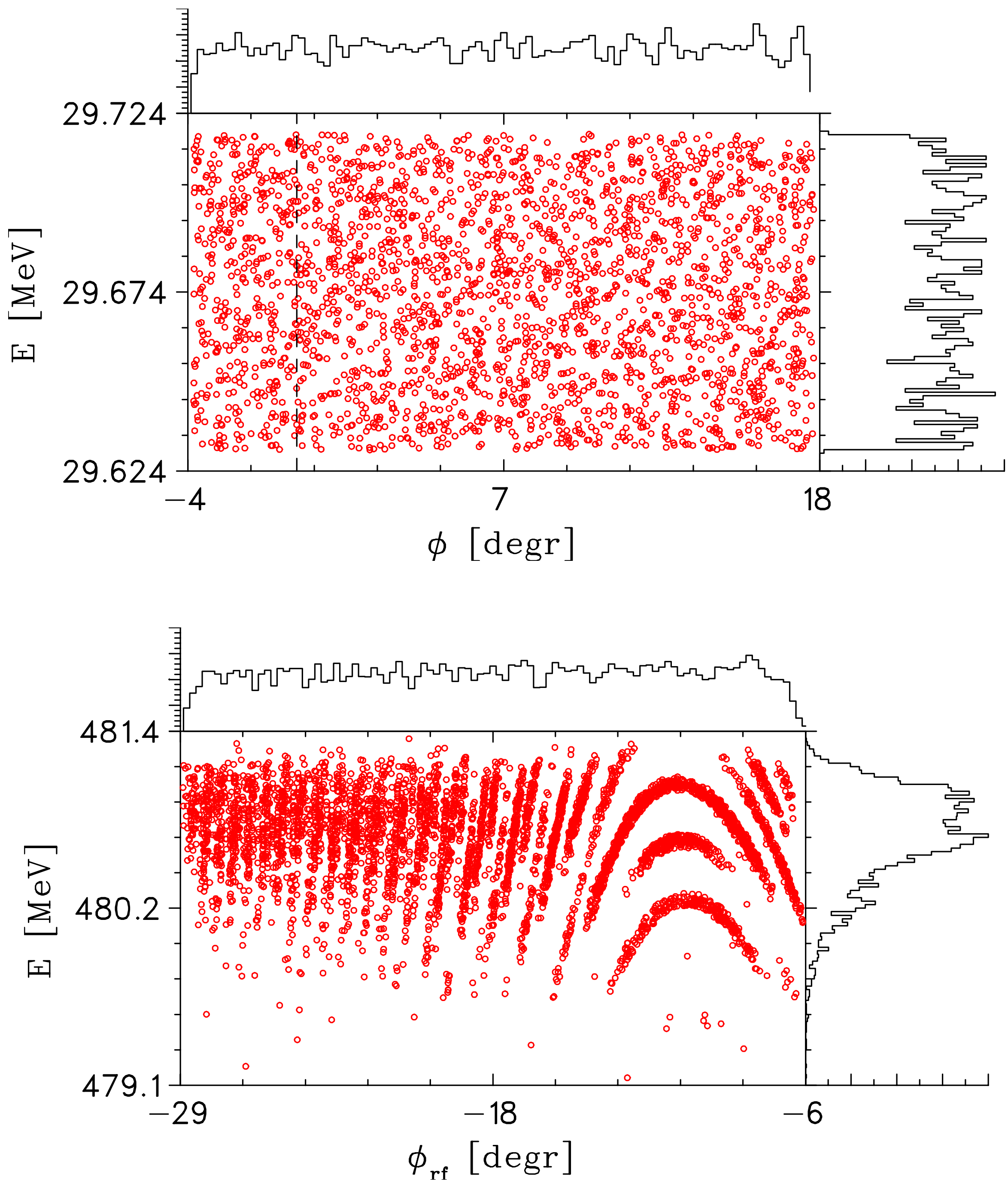

Figure 5: *Longitudinal phase space of the beam at start (upper) and at ∼480 MeV (lower). The real phase band is* ∼ 22° *(full bottom width).*

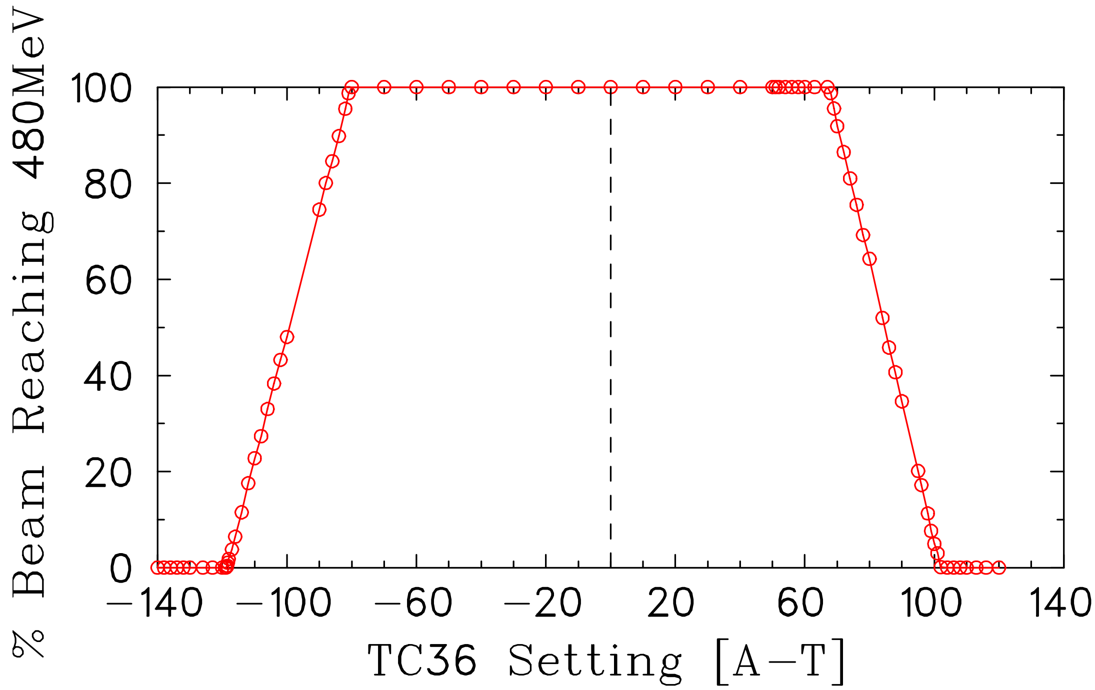

Figure 6: *The X2A current versus TC36 Ampere-turn setting of the B_z triplet for the U-turn around 206 MeV.*

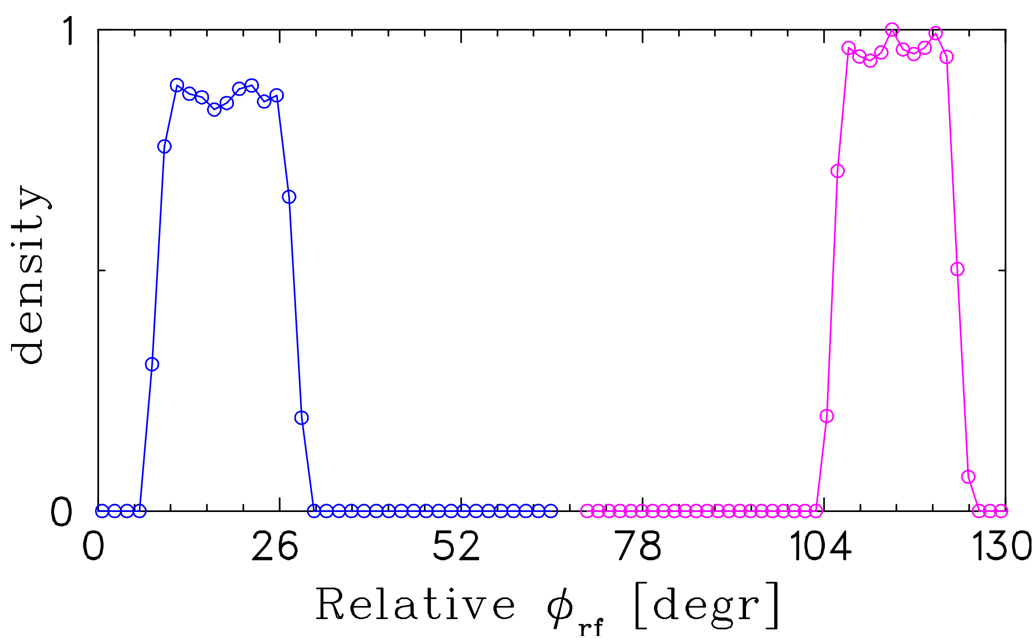

Figure 7: *Resultant beam distrbution in rf phase, calculated from Fig. 6 by taking derivative for the TC36 setting and applying* **a scaling factor of 96°/(FWHM Ampere-turn change)** *to convert the TC36 Ampere-turn variation into the rf phase.*

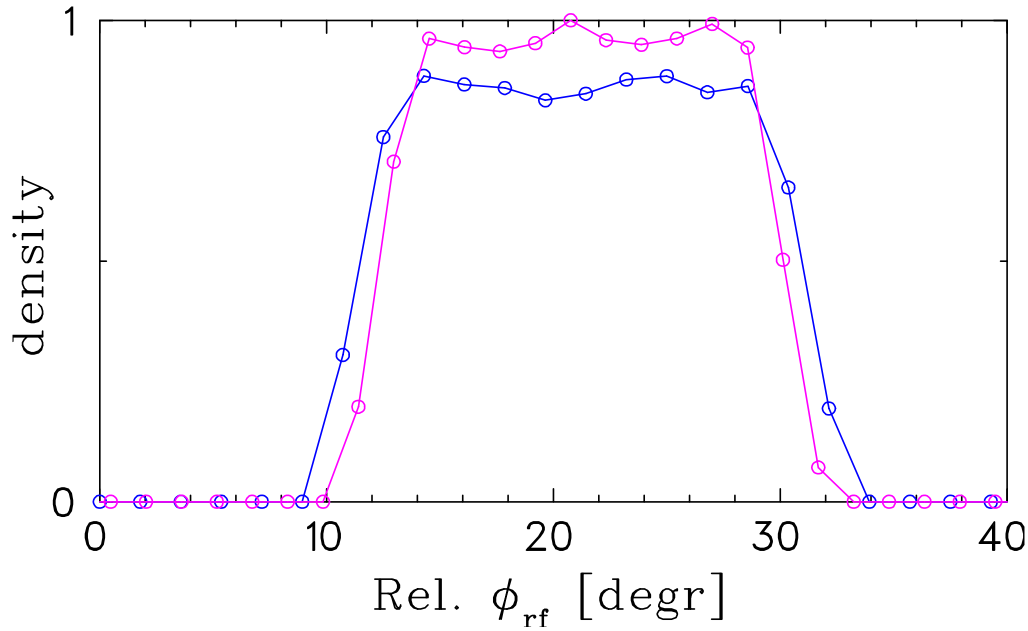

Figure 8: *Comparison of the 2 phase profiles as shown in Fig. 3. The upward scan (magenta) gives a phase band of* $\sim 22^\circ$ *(full bottom width). This agrees with Fig.5, but the downward scan (blue) gives somewhat broader result for some reason.*

3 Why is $96°$ phase acceptance?

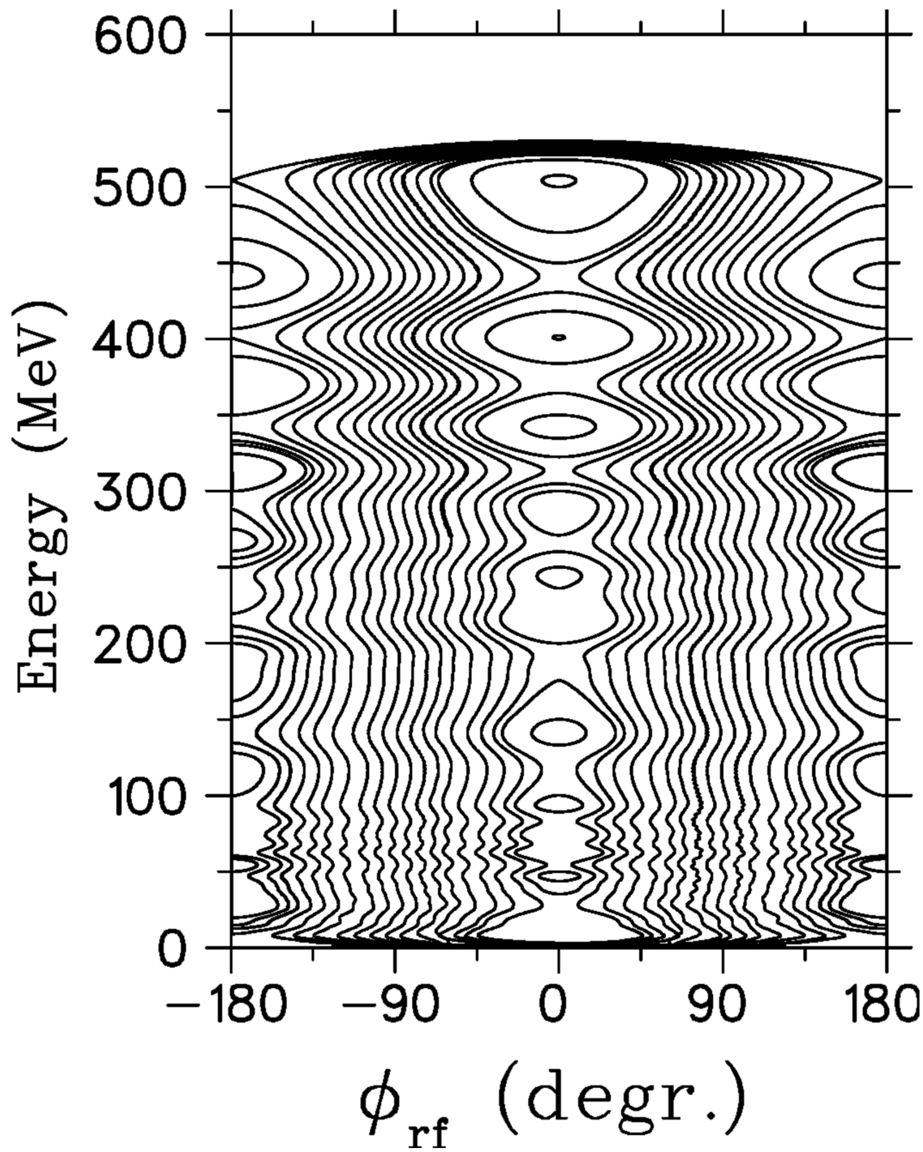

Figure 9: *Longitudinal phase space of TRIUMF cyclotron. Beam is allowed to accelerate up to* $\sim$*520 MeV through the wiggled parallel paths between the islands as a result of imperfect isochronism of the magnetic field. It's worthy to mention that the phase angle* ϕ_{rf} *in this plot has been shifted by* $90°$ *on purpose just in order to follow the synchrotron convention of using* $\sin\phi_{rf}$ *instead of* $\cos\phi_{rf}$.

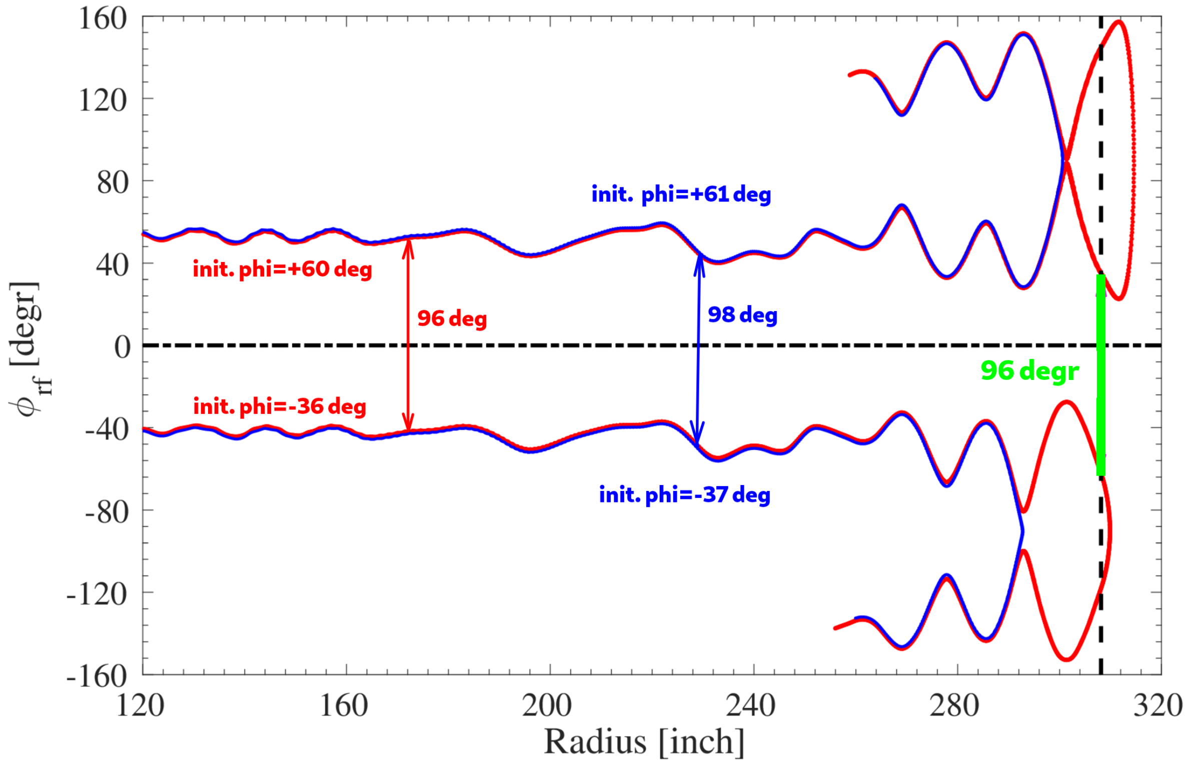

Figure 10: *Longitudinal phase acceptance of TRIUMF cyclotron, showing that beam particles are able to accelerate to pass through the energy of* $480\,MeV$ *(marked with the vertical dash line) within a phase window of* $\sim 96°$ *(green), that is, between* $-36°$ *and* $+60°$ *at start of* $\sim 30\,MeV$ *(e.g. the 2 red curves), while outside this window any particle (e.g. the 2 blue traces) will be U-turned before it reaches 480 MeV. Here we adhere to the cyclotron convention of using* $\cos\phi_{rf}$.

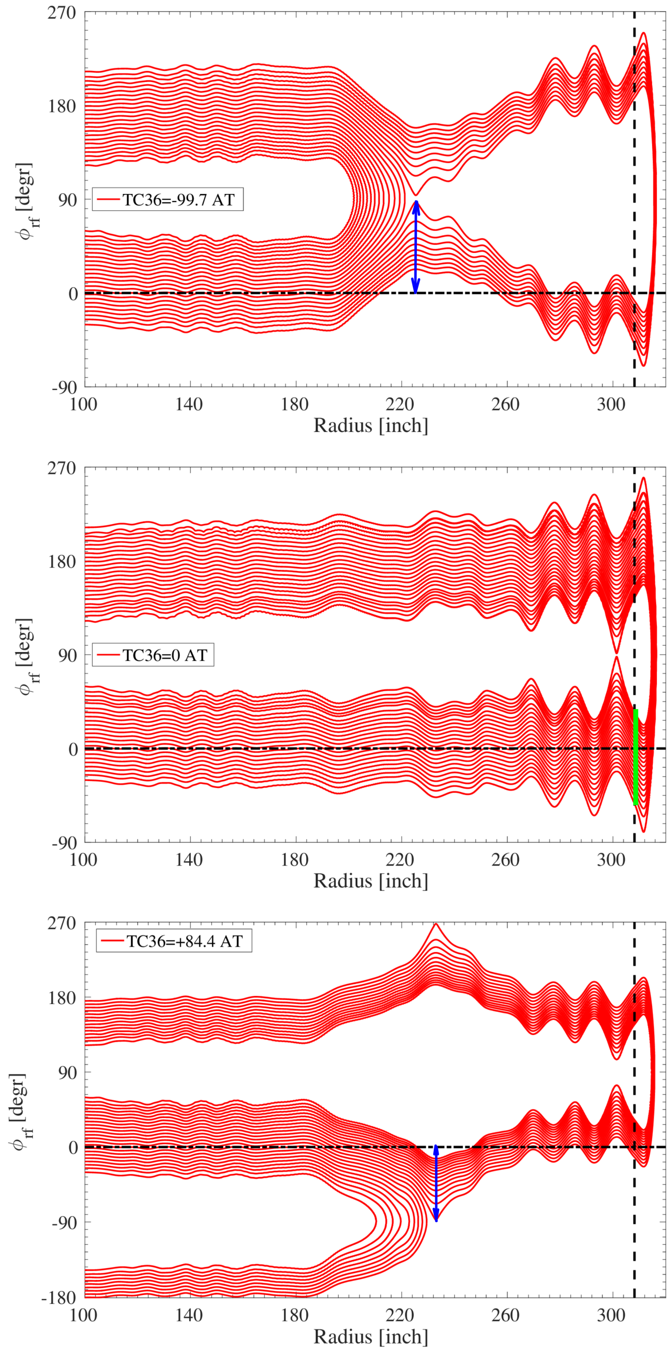

Figure 11: *The history of* 90° *phase band beam under the TC36 excitations of* $-99.7\,AT$ *(top),* $0\,AT$ *(middle) and* $+84.4\,AT$ *(bottom) respectively, where the* $-99.7\,AT$ *and* $+84.4\,AT$ *correspond to the two settings of half maximum (shown in Fig. 2) under which half amount of beam gets U-turned before reaching* $480\,MeV$ *(marked with the vertical dash line).* **Indeed, the phase angle is changed by 180° from $+90^\circ$ (top, blue) to -90° (bottom, blue) for the central orbit, and this change occurs around $228''$ rather than at the final extraction radius of $308''$. At the final extraction radius of $308''$ (480 MeV), any phase variation must be within a 96° window (middle, green) otherwise the particle will get U-turned before it reaches 480 MeV**. *This is similar to the picture of beam displacement under steering, shown in Fig. 13.*

4 TC Scan Similar to the Target Scan

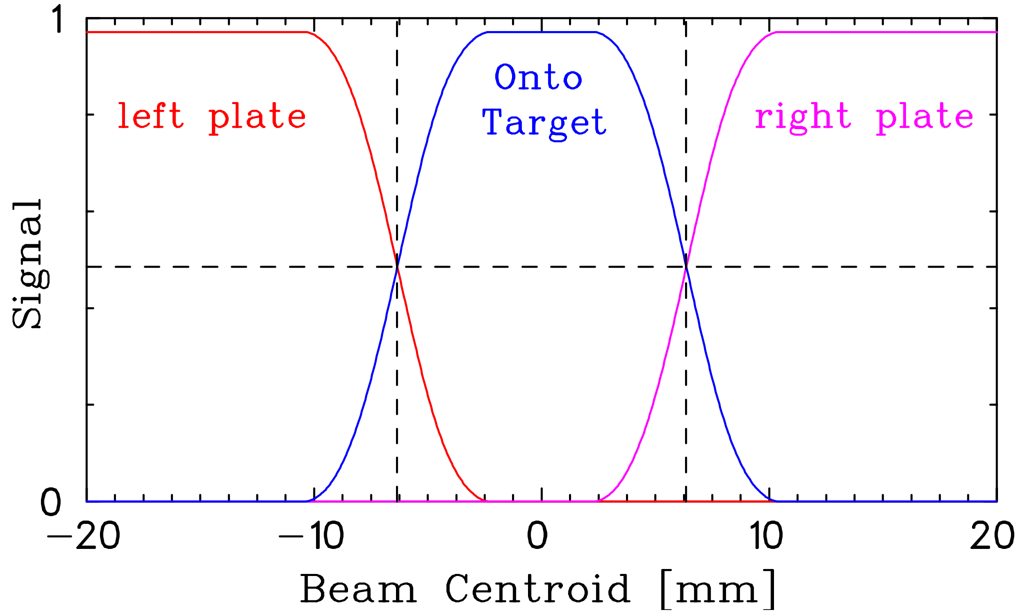

Figure 12: *The target protect monitor scan technique often used in the TRIUMF primary beamlines, showing the amount of beam going through the aperture of the protect monitor and ending up on the final target (blue) when the beam is steered from left to right. The two vertical dash lines mark the straight jaw of the left and right plates of the protect monitor. This technique in principle is the same as the fore-mentioned TC scan method.*

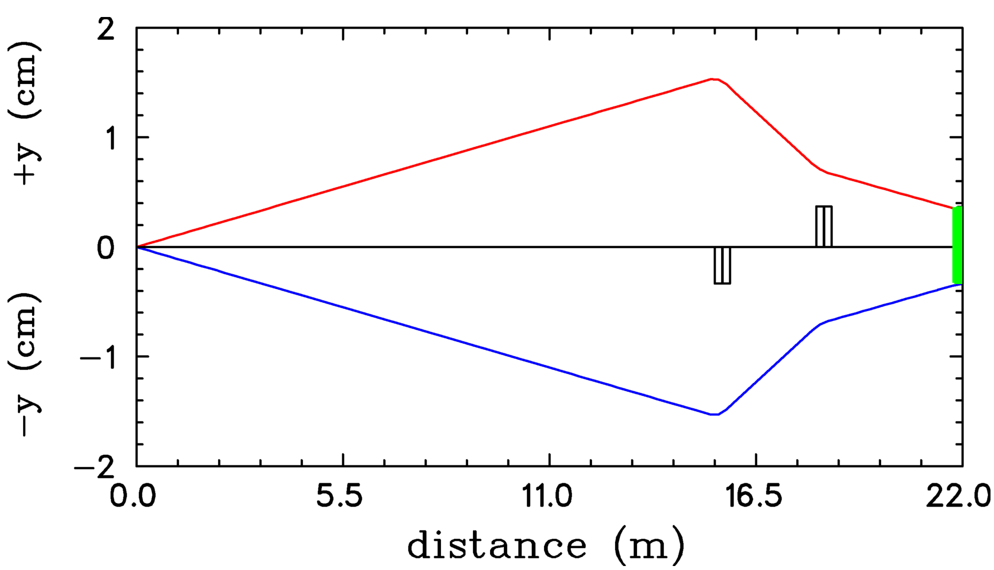

Figure 13: *A schematic diagram showing the beam centroid displacement along a beamline due to a steering at start. The two bars represent quad's focusing strengths.* **It's seen that the maximum dislacement, occuring at $\sim 15.4\,$cm, is NOT equal to the aperture of the final acceptance window (green).**