TRIUMF Beam Physics Note
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ISIS Tomography

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Abstract: In this note we summarize the measurements that we took for beam profiles in ISIS on 2016-Aug-23 for the purpose of reconstructing the beam tomography in transverse phase spaces.

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1 Beam Profiles

We began with the production tune of ISIS to measure the beam profiles with wire scanners. Just in order to minimize uncertainties which might exist for instance in the effective lengths of quadrupoles, we chose to take the measurements in a very short segment of the beamline, namely, from quad F215 to monitor WS063, as shown in Fig.1.

Some efforts were made to get the beam well centered through the quad F215 both horizontally and vertically. This was done by adjusting the upstream steerers 104,105 and then dithering the quad F215, until the beam centroid movement was minimized at WS063. Usually, this is a necessary step prior to starting to take the data, because we have to minimize the beam steering due to the quad to ensure that the beam does not get lost at the collimator C063, or wherever, before getting to the monitor. Fig.2 and 3 show the beam profiles that we took in series with F215 being set at 1023 DAC down to 0 DAC in a step of about 50 DAC, and then further down to -400 DAC with its polarity being reversed.

All these profiles look pretty good. However, when we simply picked up the values of 2rms size as displayed on the graphs, and plotted them out vs. the quad's setting, they appeared to be fairly scattered, particularly in the horizontal plane, as shown in Fig.4. The square of the 2rms size vs. the quad's setting is expected to be a parabola, but they deviate significantly from a parabola (see Fig.5).

These deviation turn out to be arisen from the cut made improperly in the software to zero off the noise in the background. As an example, Fig.6 shows one of the profiles after being cut improperly in the software, along with the one that I cut after smoothing it out a little bit by using a low pass filter. It's always arguable about whether the shoulder in the profile is real beam or fake, especially when the shoulder is not evolving in a consistent way with the quad's setting. Nevertheless, following the beam transport theory $\sigma_2 = R\,\sigma_1\,R^T$ (where R denotes the transfer matrix from location 1 to location 2 along the beam-line where the beam matrix is resp. denoted as σ_1 and σ_2), we have justification to say that the beam size's square vs. the quad's setting must be a parabola, as long as the measurements were taken for the same beam. Based on this, we attempted to visualize each profile and then make respective cuts, instead of applying the same algorithm to all the profiles and cutting in a batch mode. In this way, we ended up getting a series of clean profiles and the beam sizes accordingly. Gratifyingly, these sizes are now falling on a parabola, as shown in Fig.7.

2 Beam Size Fit

These beam sizes of 56 values in total were then fitted in the beam envelope calculations with `TRANSOPTR` to find the condition of beam at entry into the quad F215. There were only 6 initial parameters to be determined from the fit, namely $(\alpha_{x,y}, \beta_{x,y}, \epsilon_{x,y})$. So, the solution

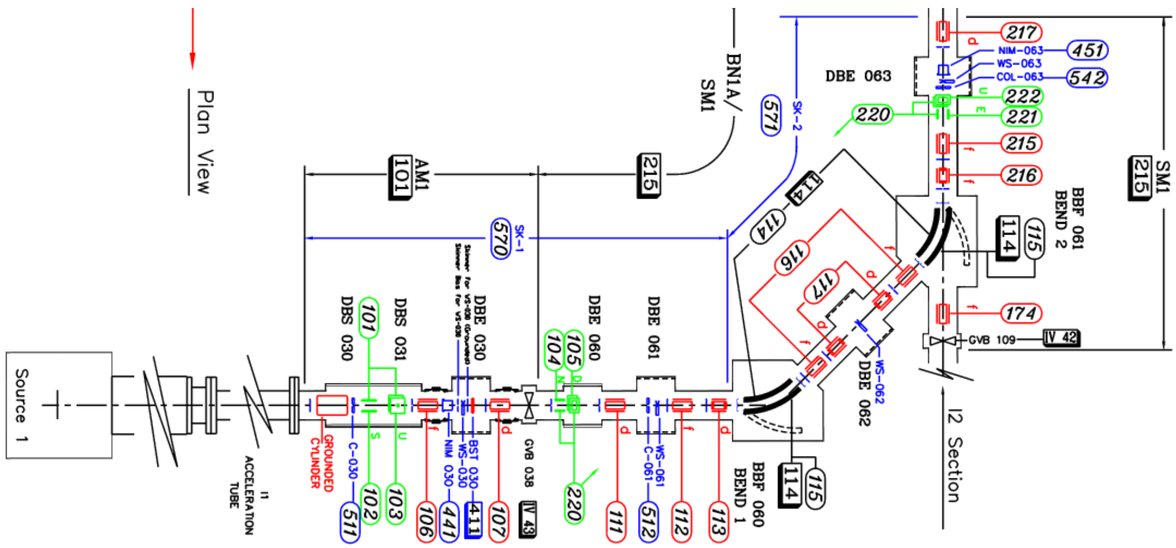

Figure 1: *Drawing showing the front-end of ISIS. The measurements we took was in a segment from the quad F215 to the monitor WS063, about* 15.98″ *long.*

to be sought was over-determined. The calculation was using a current of 580 μA DC with space charge on. The fit was good. See Table 1 for the comparisons between the measured and calculated beam sizes. Table 2 gives the resulting transverse $\sigma-$matrix (2rms) of beam at entry into F215.

Table 2 Transverse $\sigma-$matrix (2rms) of beam at entry into F215, resulted from the fit with 56 measured beam sizes.

	Diagonal	Off-Diagonals (Normalized Form)		
v (mm)	4.11			
θ_v (mrad)	2.97	0.795		
h (mm)	1.23	0.000	0.000	
ϕ_h (mrad)	4.68	0.000	0.000	-.287

3 Beam Tomography

We had the fore-mentioned clean profiles plus the corresponding transfer matrices input into the computer program for iterative computation to reconstruct the 2-D phase space. The resulting beam tomography in H and V phase spaces are shown in Fig.8, where the 2rms values of beam sizes and divergences are labelled. It's seen that these values are well agreed with the above fitted results. Moreover, the tomography reveals the picture of beam halos, offering more information than the statistics of beam. This is the advantage of tomography.

Further, Fig.9−Fig.15 compare the reconstructed projections with the measured ones. All these are well reproduced.

Table 1 Measured and calculated beam sizes (2rms)

F215 Setting (DAC)	Vert. Meas. (inch)	Vert. Calc. (inch)	Hori. Meas. (inch)	Hori. Calc. (inch)
1023	0.117	0.122	0.171	0.173
900	0.087	0.088	0.158	0.159
850	0.076	0.074	0.153	0.153
800	0.062	0.061	0.148	0.148
750	0.049	0.048	0.143	0.142
700	0.038	0.036	0.138	0.137
650	0.029	0.027	0.133	0.132
600	0.024	0.024	0.126	0.127
550	0.035	0.031	0.123	0.122
500	0.044	0.043	0.118	0.117
450	0.056	0.056	0.113	0.113
400	0.069	0.071	0.106	0.108
350	0.085	0.087	0.104	0.104
300	0.099	0.103	0.100	0.100
250	0.116	0.119	0.096	0.096
200	0.132	0.135	0.093	0.092
150	0.150	0.152	0.089	0.088
100	0.168	0.169	0.084	0.085
50	0.189	0.187	0.081	0.081
0	0.203	0.204	0.078	0.079
-50	0.223	0.222	0.075	0.076
-100	0.244	0.240	0.072	0.073
-150	0.261	0.258	0.070	0.071
-200	0.284	0.277	0.068	0.069
-250	0.305	0.296	0.068	0.068
-300	0.318	0.315	0.067	0.067
-350	0.330	0.334	0.067	0.066
-400	0.342	0.353	0.066	0.065

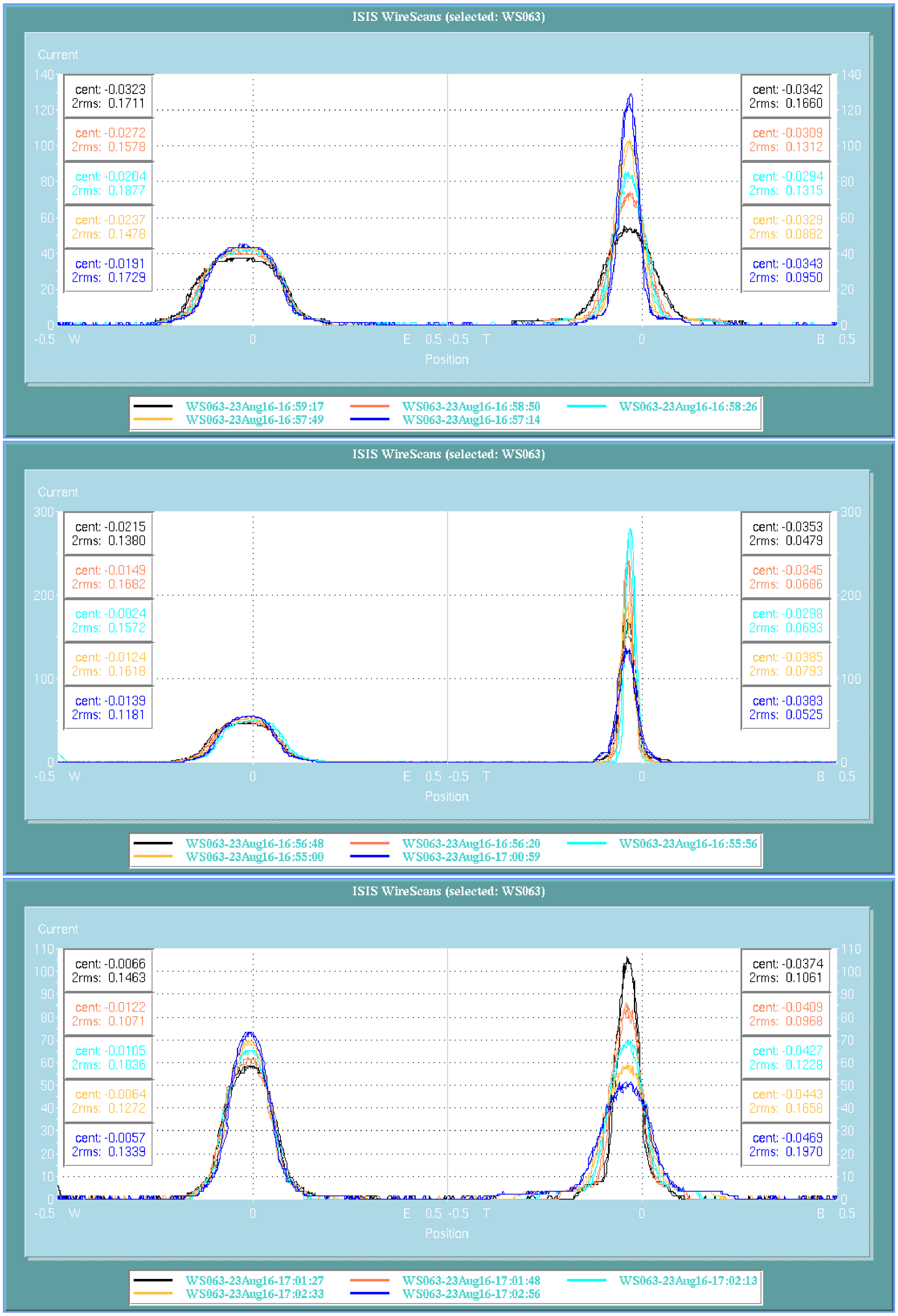

Figure 2: *Beam profiles taken with F215 being set at 1023, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300 and 250 DAC respectively from top to bottom.*

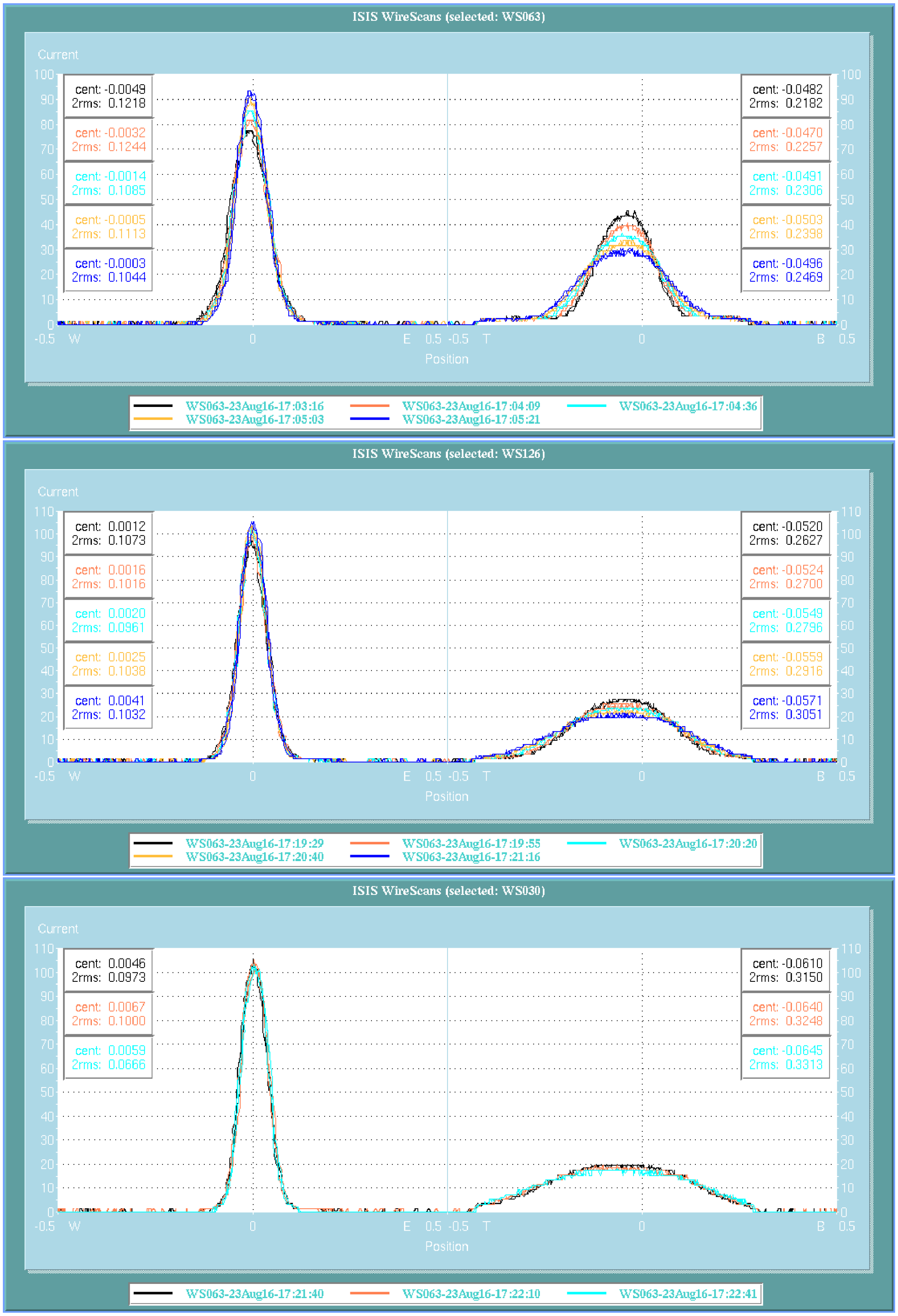

Figure 3: *Continued from Fig.2: Beam profiles taken with F215 being set at 200, 150, 100, 50, 0, -50, -100, -150, -200, -250, -300, -350, -400 DAC from top to bottom. Here the negative setting means that the quad was being reversed with its polarity.*

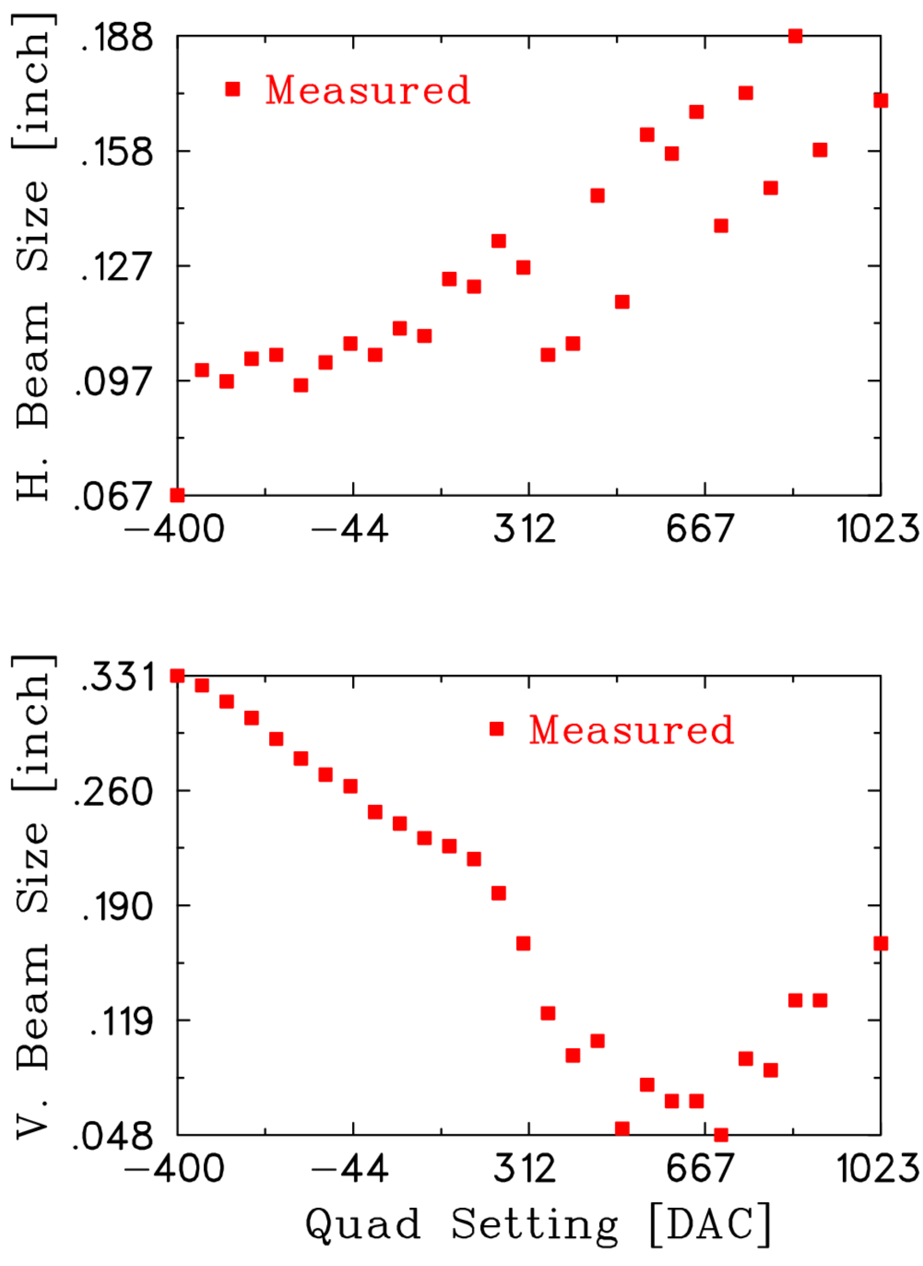

Figure 4: *The 2rms beam size in H and V vs. the DAC setting of quad F215. The data appear to be scattered horizontally, and have a bump vertically. These data were taken directly from the above profiles displayed. They were calculated internally from the wire scanner software.*

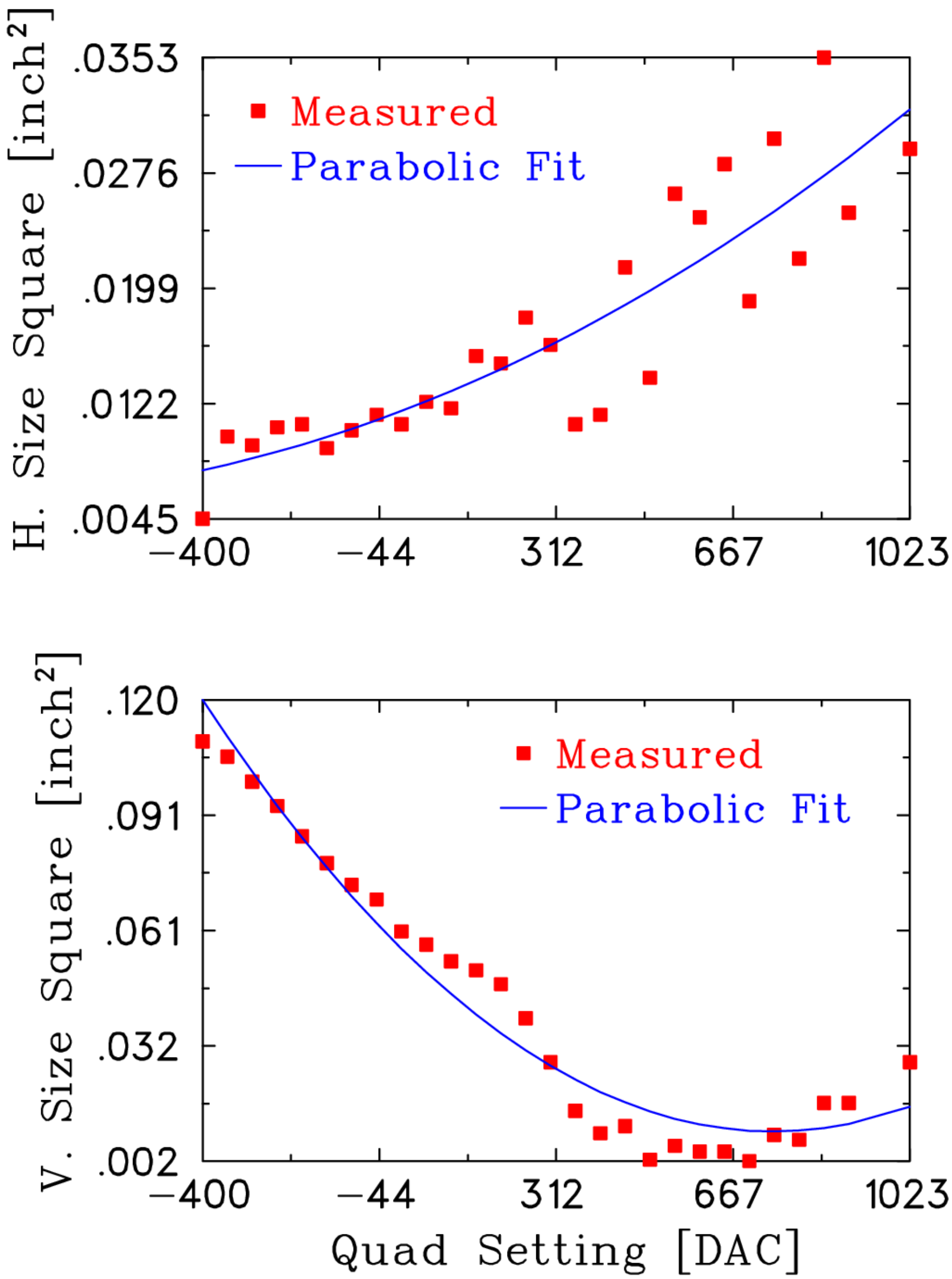

Figure 5: *Square of the 2rms beam size in H and V vs. the DAC setting of quad F215. Apparently, they deviate significantly from a parabola.*

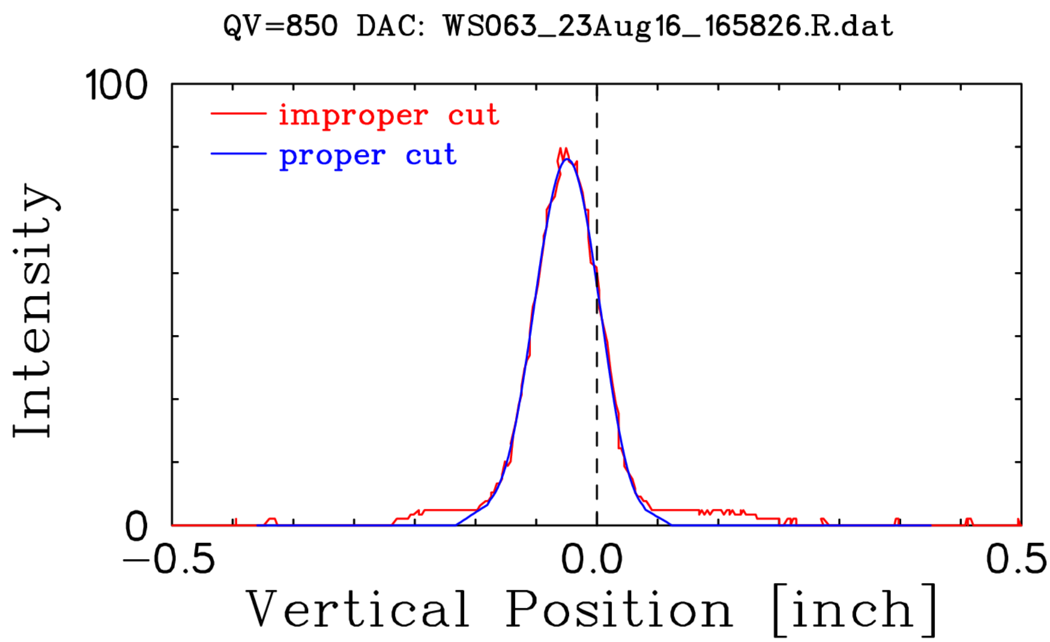

Figure 6: *As an example, this shows one of the profiles we took, after being cut improperly inside the software (Red), and after I smoothed it out and then cut (Blue).*

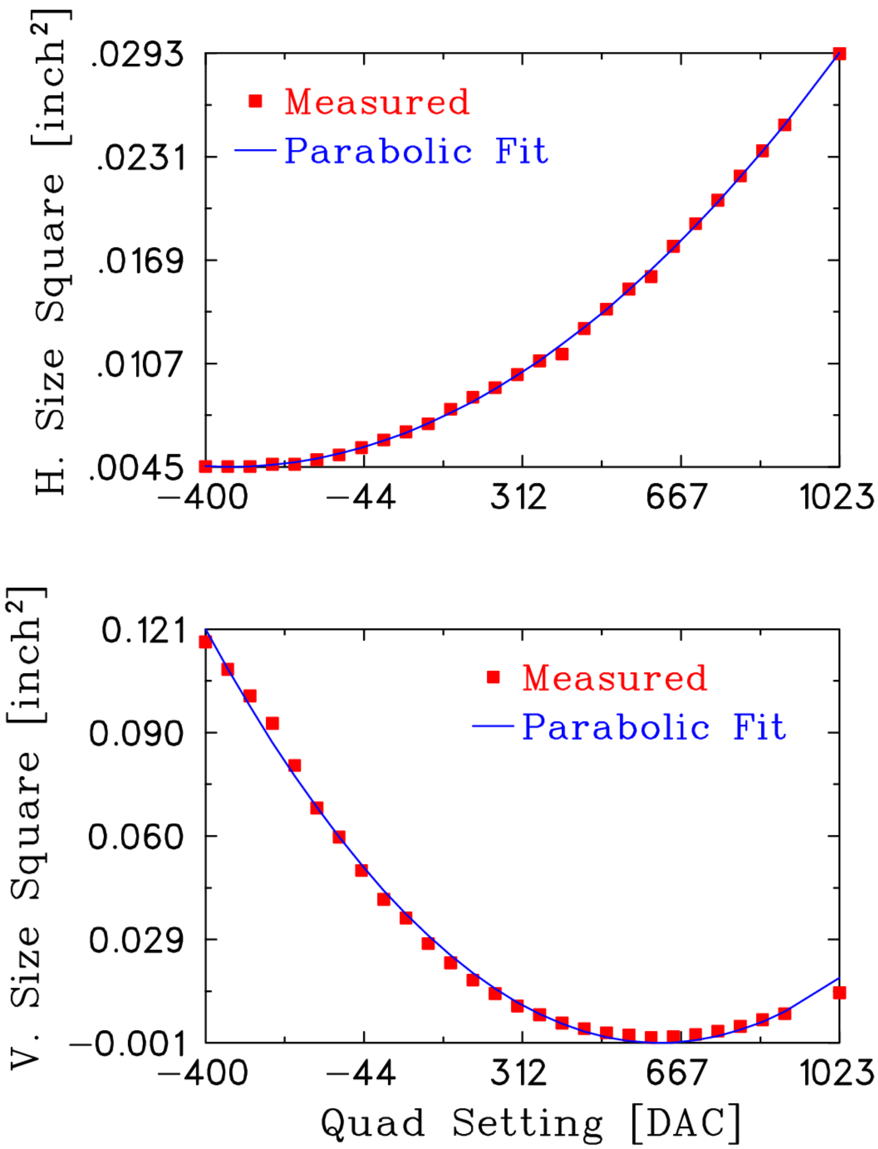

Figure 7: *Beam sizes resulted from respective cuts made for each of the profiles shown in the Fig.2 and Fig.3. Gratifyingly, they are now falling on a parabola in both H and V planes.*

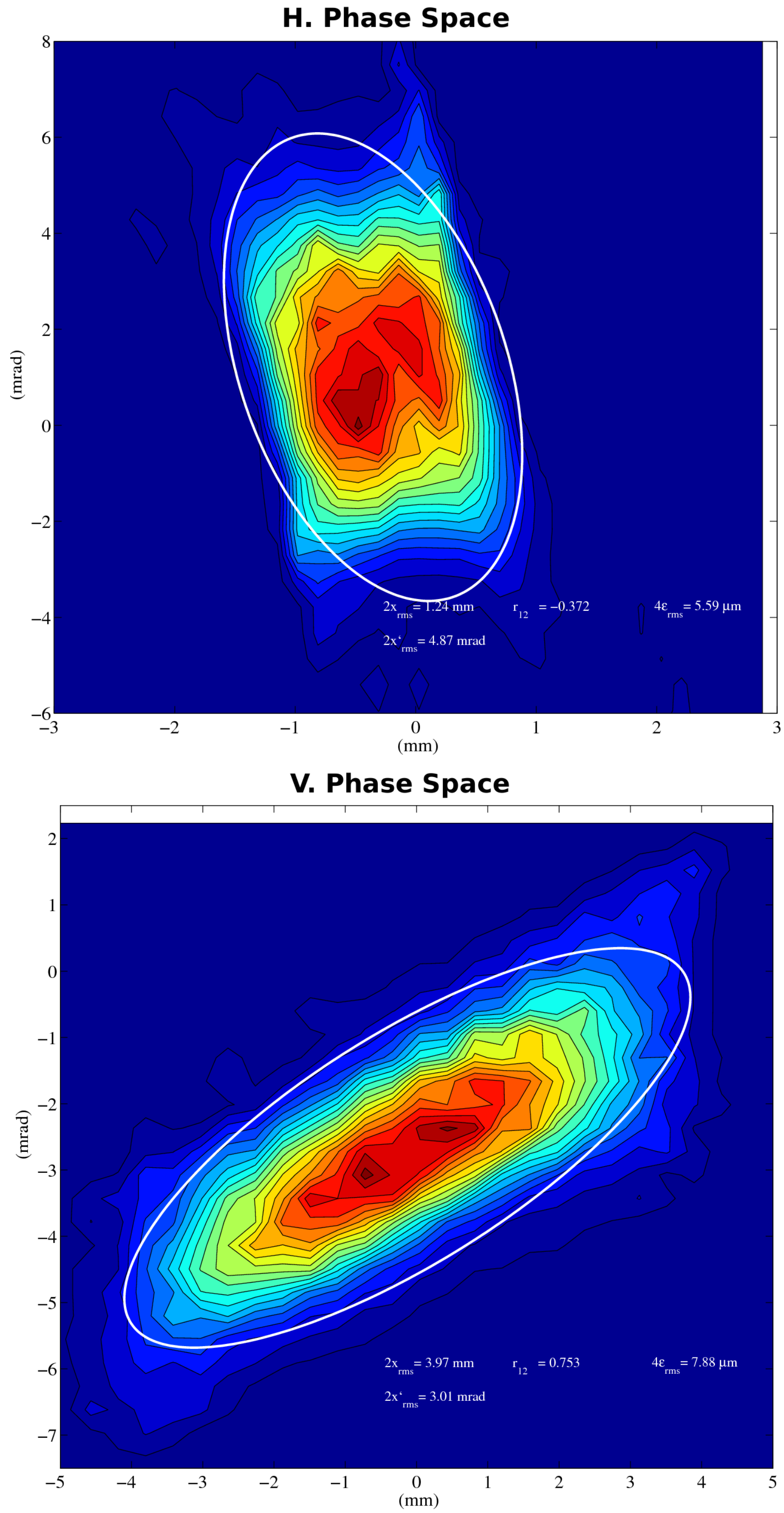

Figure 8: *Beam tomography in H (Upper) and V (Lower) phase spaces, where the 2rms values of sizes and divergences are labelled in white.*

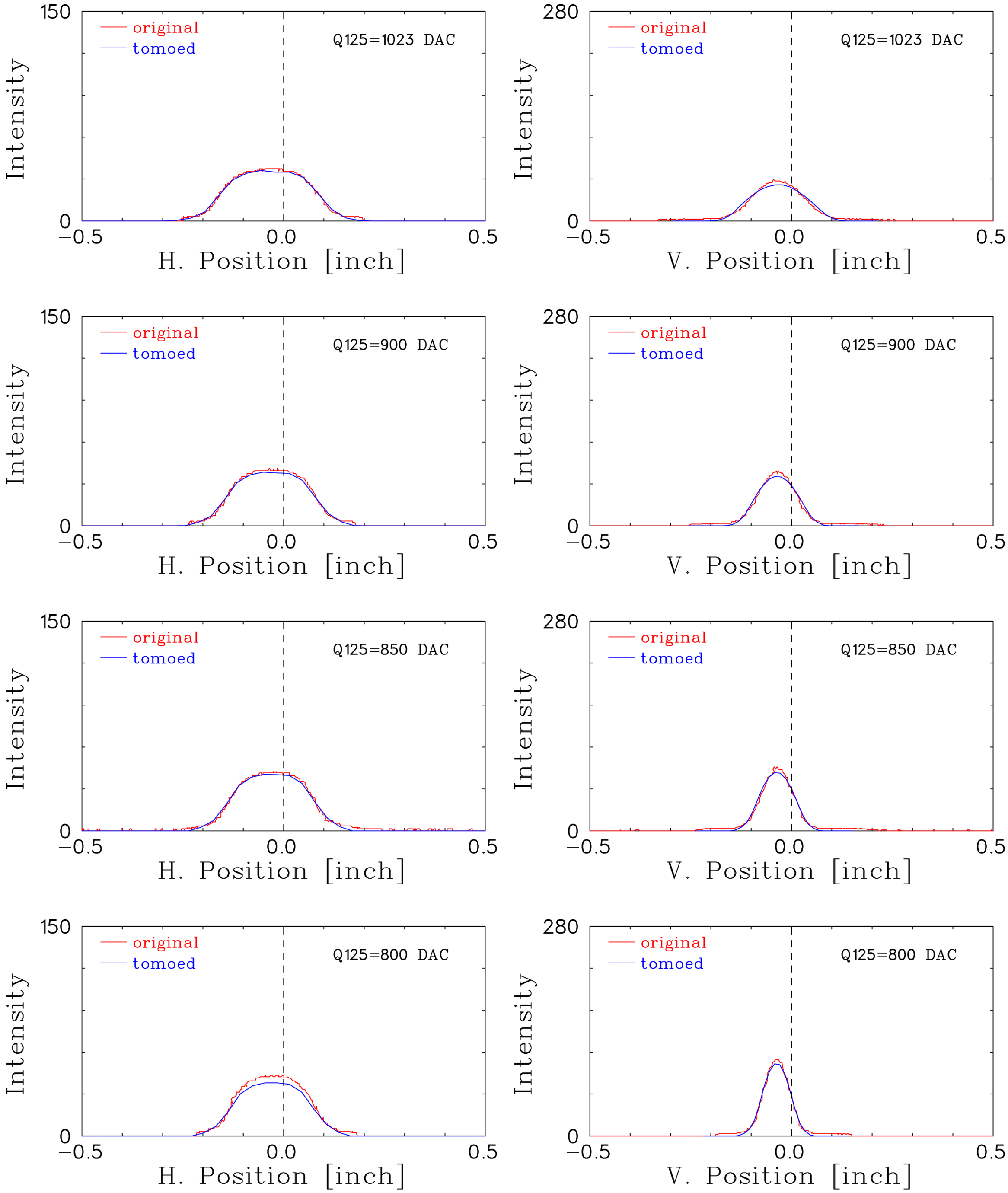

Figure 9: *Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*

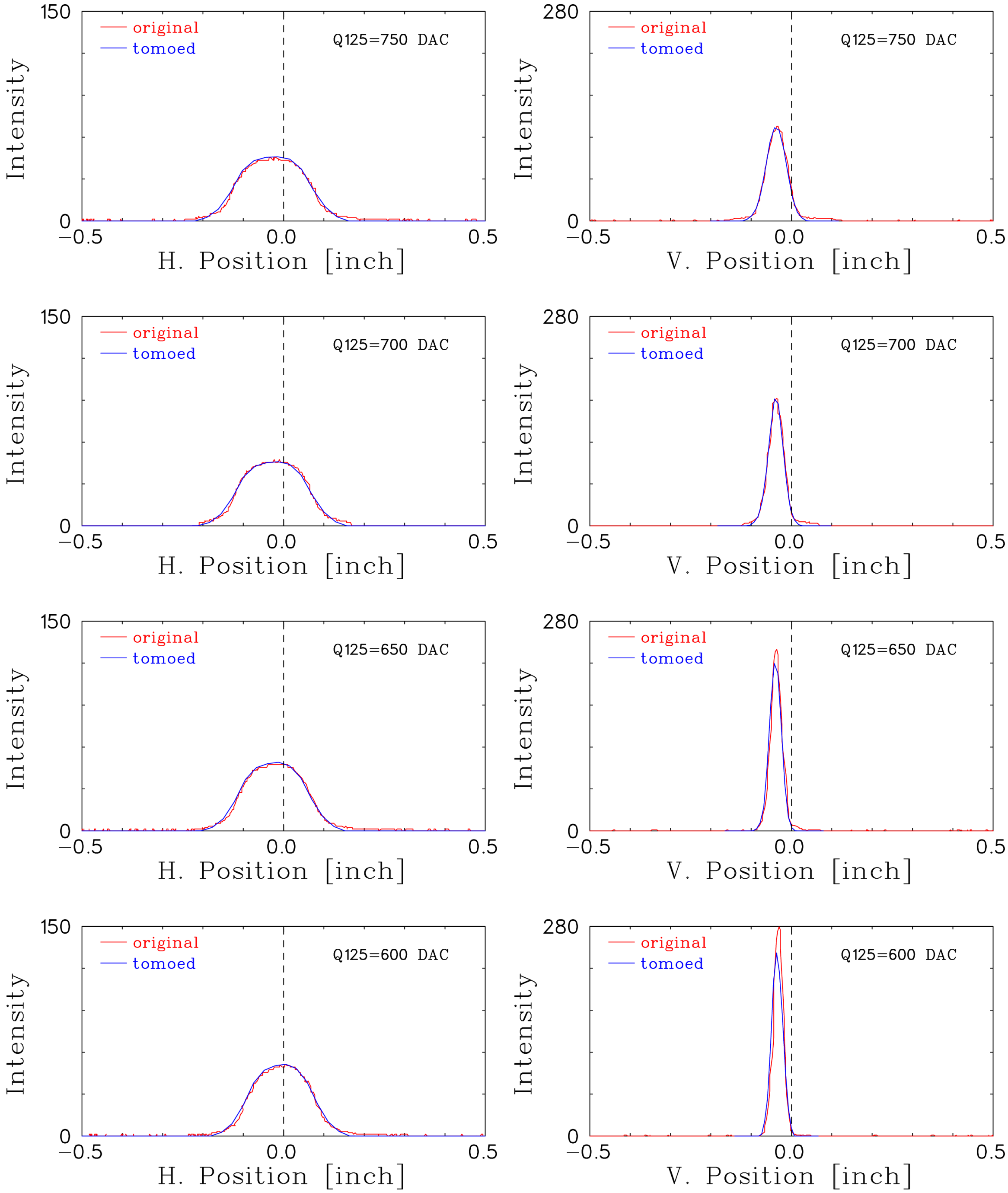

Figure 10: *(Continued from Fig.9) Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*

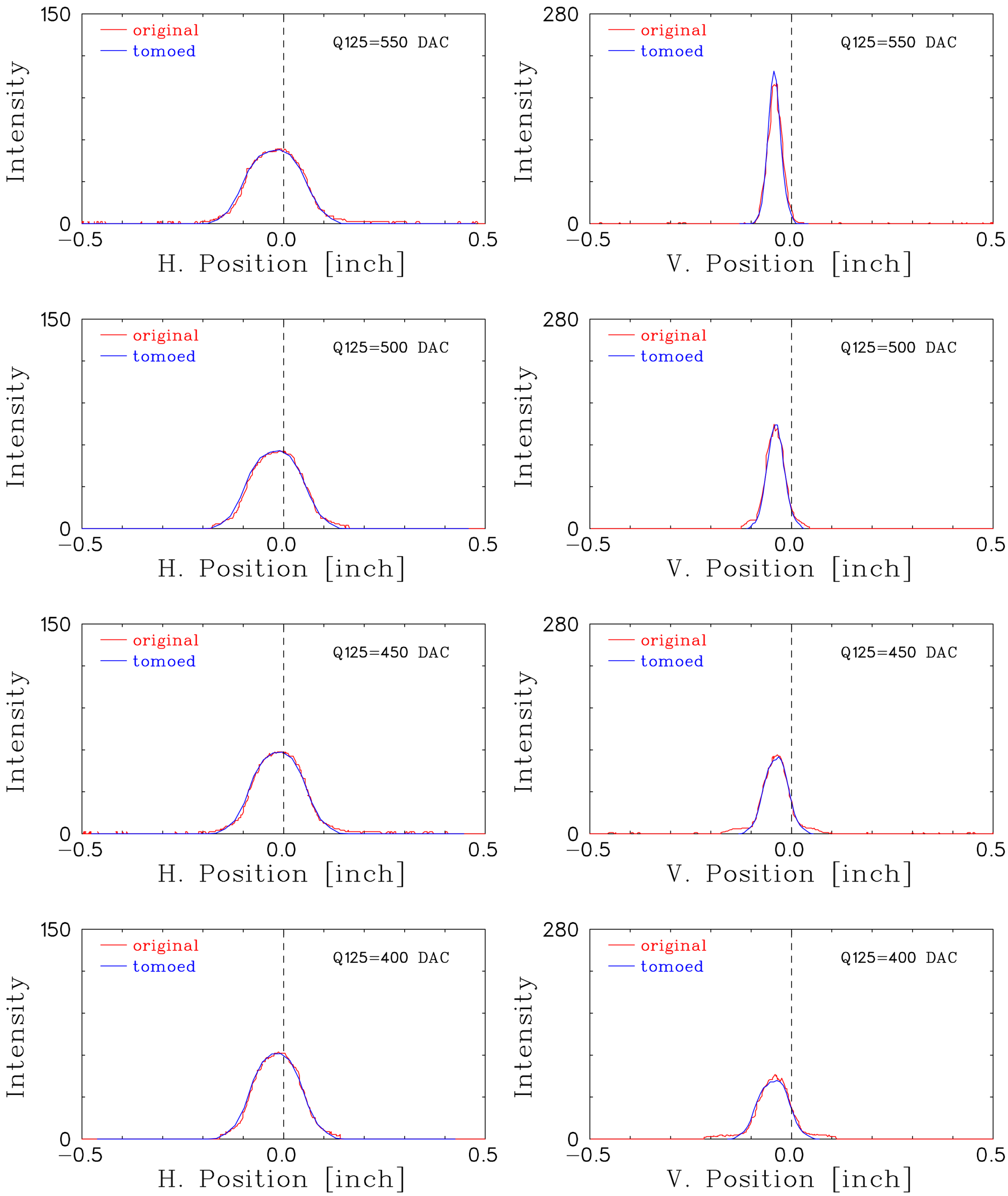

Figure 11: *(Continued from Fig.9) Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*

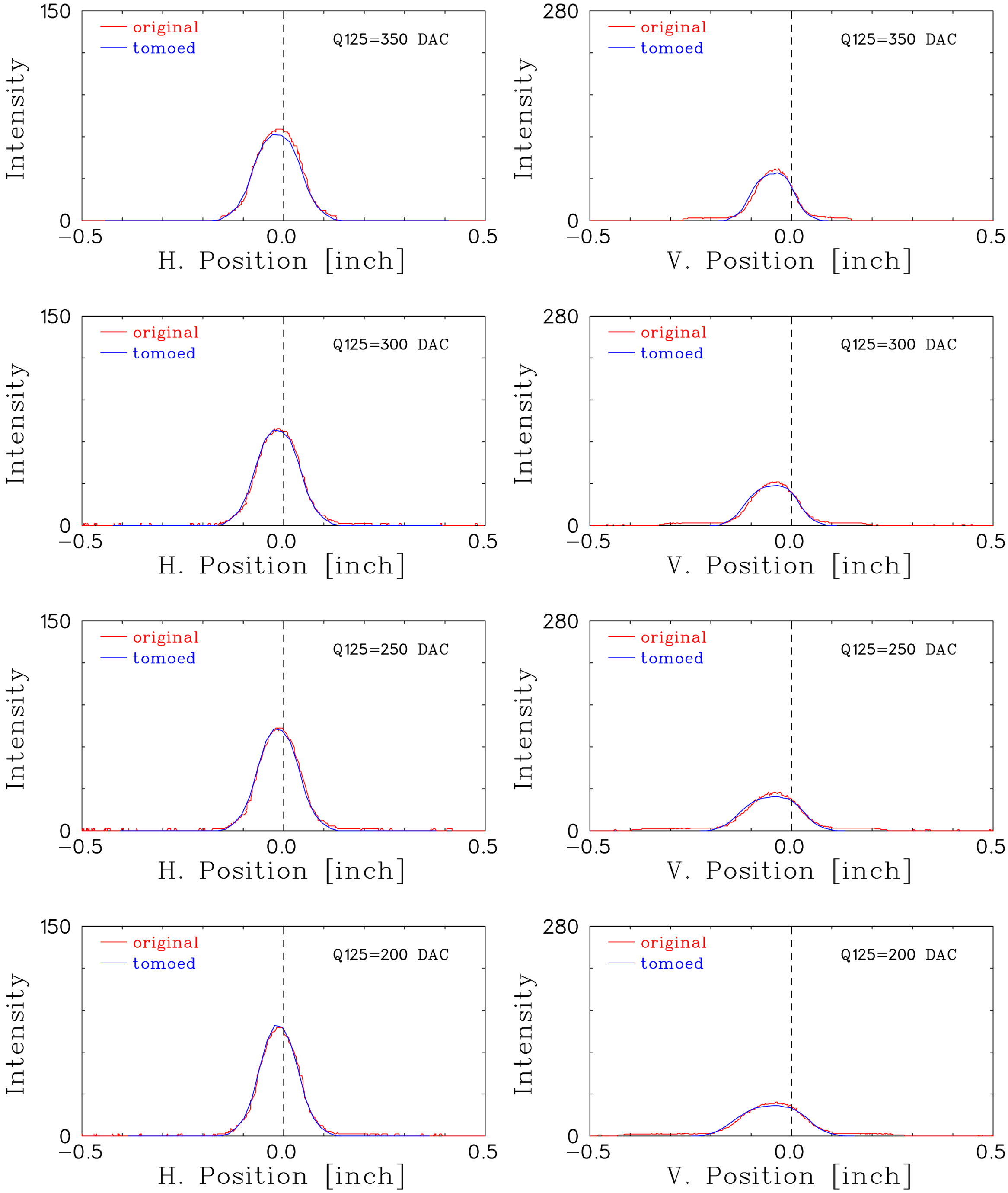

Figure 12: *(Continued from Fig.9) Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*

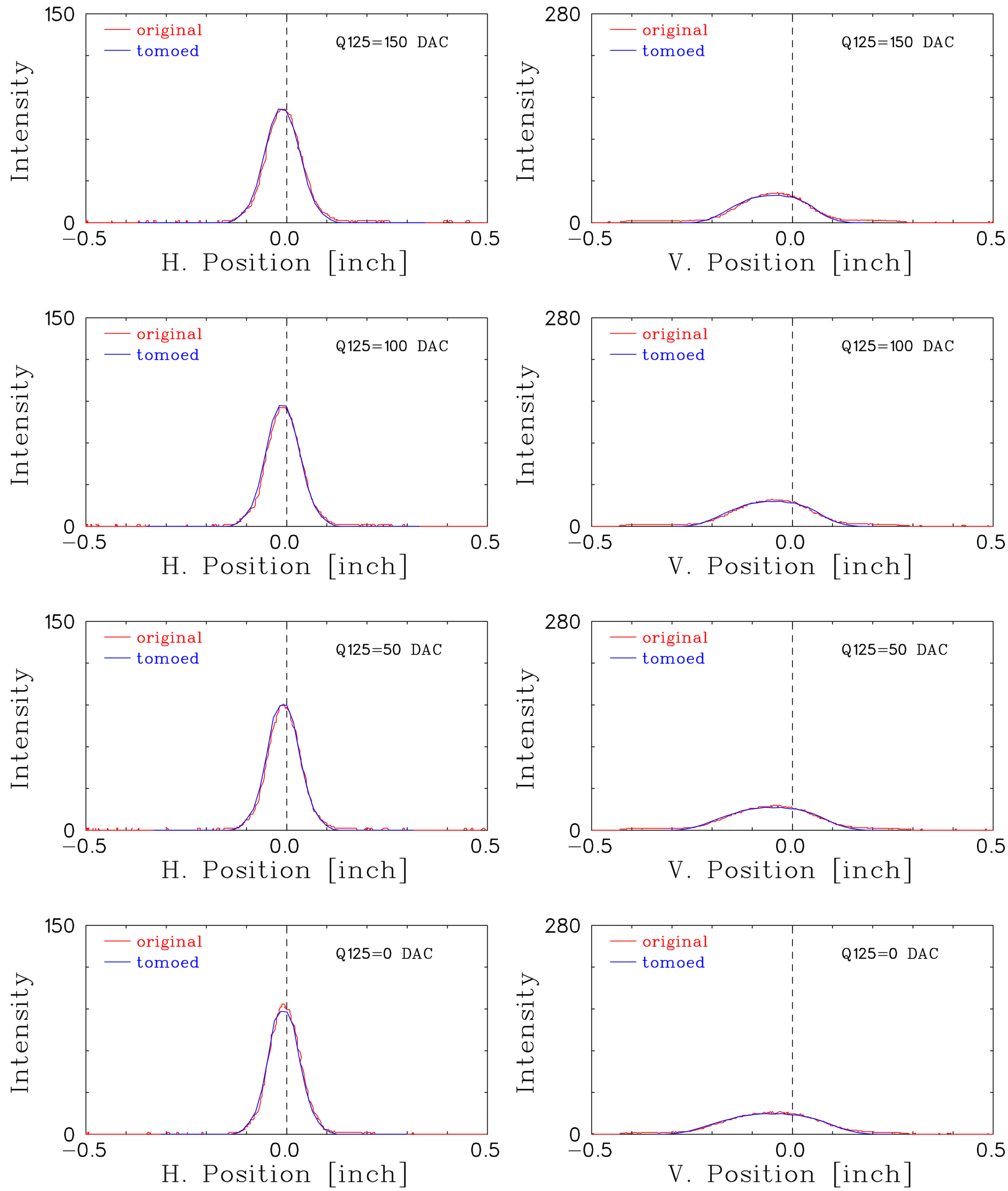

Figure 13: *(Continued from Fig.9) Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*

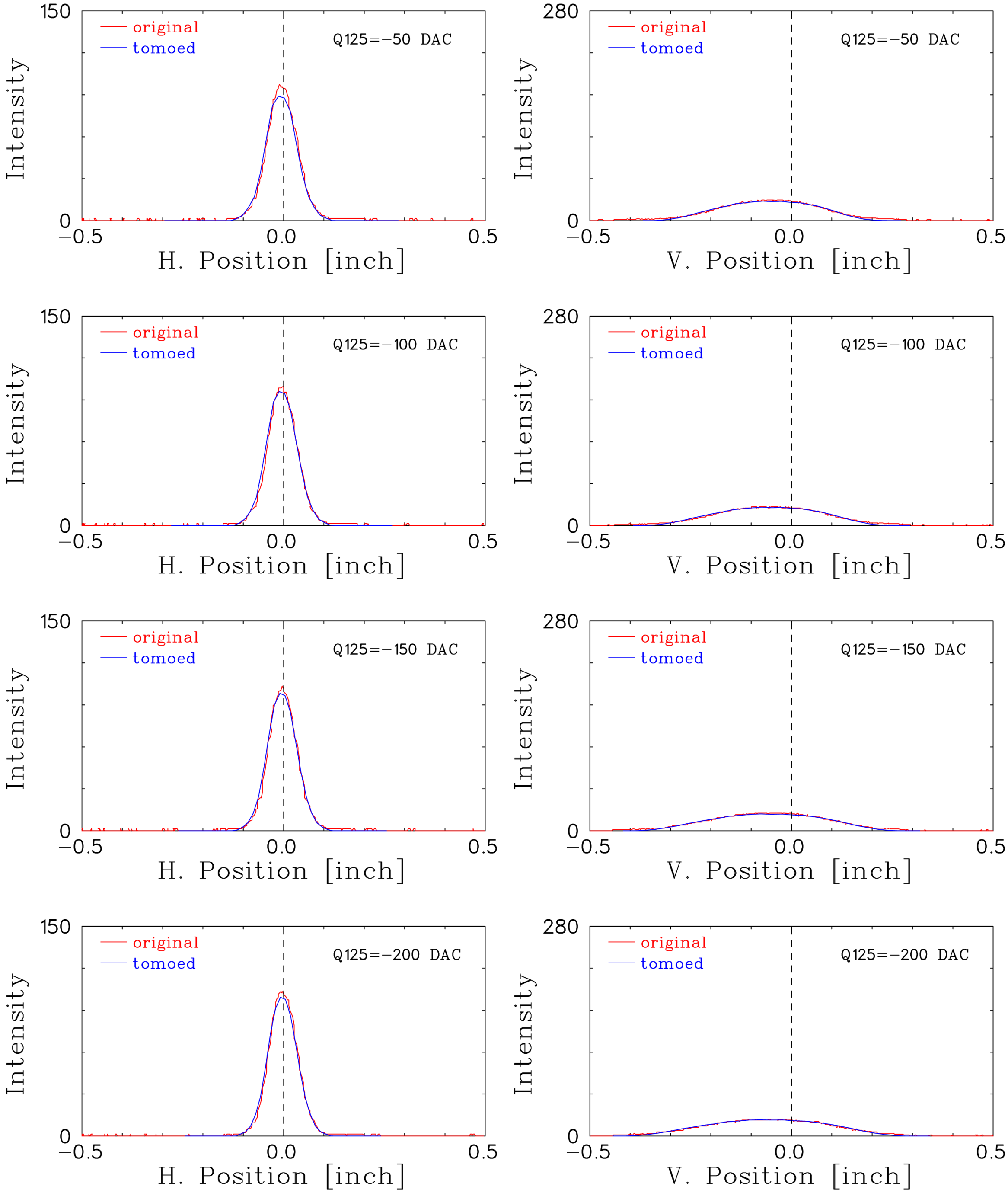

Figure 14: *(Continued from Fig.9) Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*

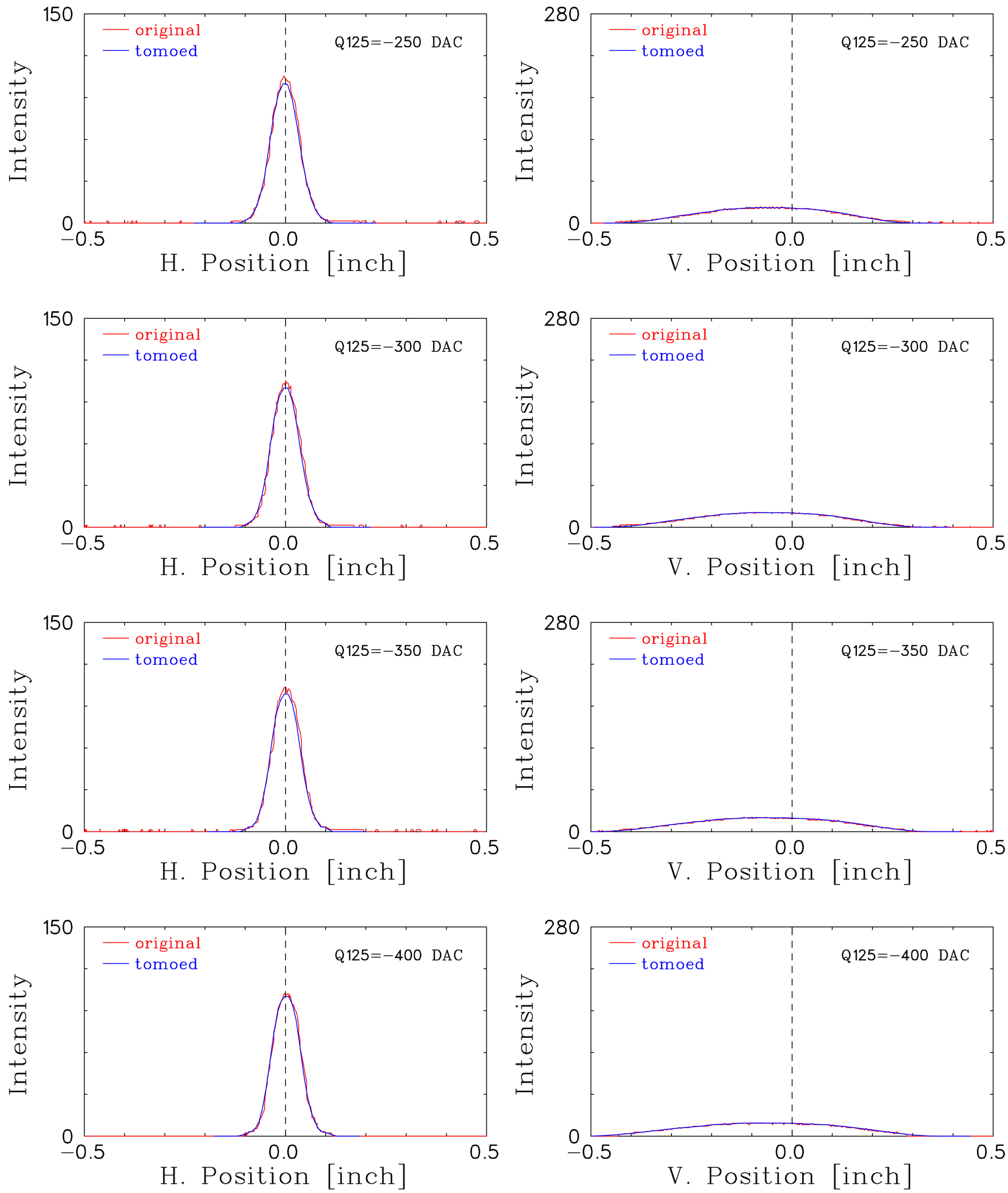

Figure 15: *(Continued from Fig.9) Comparison between the measured projections and the tomographically reconstructed ones under various settings of F215. Here by original is meant the profiles as displayed on the VAX console.*