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Booster-to-AGS Multiwires and an Evolution of the Application Profile Display

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introduction:

Follow up on BtA multiwire beam measurements taken during the 2008 polarized proton run has led to a number of better understandings (for the author) associated with the beam instrumentation involved. This history will be reviewed - some "beam-based" results noted -and the present state of the application for these monitors described. The BtA multiwire system seems to be fundamentally an excellent diagnostic for allowing us to get the BtA line well under control in a defendable way. When beam is available in BtA, carrying out some systematic measurements with the system can get us there.

some description:

Four multiwires, each having both a horizontal and a vertical plane of wires, exist along the transfer line between the Booster and the AGS (BtA). The main interface with this instrumentation system is the application program "profileDisplay" found under Booster Instrumentation in Startup. Seth Nemesure is (and hopefully will remain for a significant length of time) the Controls group resource for this software. The physics of how these detectors work is not exactly transparent (see Keith Zeno's C-A/AP note #221, "An Empirical Model for the Response of BtA Multiwires to Different Ions" October, 2005). Charge is removed from or added to each wire as part of the beam interacts with it. That charge is measured outside of the beam line enclosure with no active elements in the tunnel. The resulting profiles can be analyzed and defended or damned using some straight forward "beam-based" testing. One set of profiles for the line is included in an appendix at the end of this note. These are from the 9Mar08 data taking, and are not in any way special.

The multiwires are named by their approximate locations along the transfer line (in feet) namely MW006, MW060, MW125, and MW166. MW006 is just beyond the extraction septum (F6) so gives a beam size measurement independent of the quadrupole settings of the line. The wire spacings for MW006 are 1.5mm. All the other BtA multiwires have 2.5mm wire spacing. All wires have 0.1mm diameters. MW060 is after small (2 degree, DH1) and large (30 degree DH2&3) dipole bends and six quadrupoles. This multiwire is located only a few feet before the beam line enters the long (~18 feet) shielding tunnel drift in the wall between Booster and AGS. MW125 is then on the AGS side of the wall, after a total of 10 quads and one dipole (1 degree DH4). MW166 sees another three quads and two trim dipoles, DH 127 and DH158. The line enters the AGS L20 septum at 206 feet after two more quads (the last, QV15, is usually not powered) and after the 8 degree bender DH5.

A coarse "map" of the line is available from the Operations page. A recently added note (C-A/AP#306 April 2008, J.W.Glenn, "BTA Magnet Field Map Archive And MAD Model") which is a memo from Joe Skelly dated April, 1992, contains information from a BtA MAD model developed by E. Auerbach and Magnet Group magnet measurements digested by Ed Bleser for the quads and dipoles in the line. Current Mad descriptions - the most likely correct description - are available through Vincent Schoefer (Operations).

some recent history:

Just after the end of the proton run, an analysis was carried out of one set of multiwire data to check for consistency with the beam parameters (i.e the a's and ß's) expected in the Booster. (Nick Tsoupas, see Booster-AGS-pp_2008 elog, 18 Mar 08). The conclusion was that the model does not agree well with the measurements. To get agreement between prediction and the measurements using multiple multiwires, either the beam properties at Booster extraction had to be changed or the line optics had to be changed. Since there are many ways the model could be wrong (e.g. currents in the quads) and many ways the measurements could be wrong (e.g. wrong spacing of wires assumed, improper fitting or no fitting), the fix to the problem was not obvious. But as one response, a careful inspection of the instrumentation - the output from the BtA multiwires - was begun. One result from the inspection to be described below was to reinforce the disagreement between the model and the measurements. Using the relative beam widths measured at the multiwires for a given beam, the relative beta functions can be derived (using from the model only the dispersion predictions along with an experimental momentum spread for the beam to make a first order correction for the width contribution from momentum spread - this correction did not affect the conclusion). The ratio of these beta functions is very different from those predicted by the model. This result is shown in figure 1, though the explanation of the data analysis will only come later in this note.

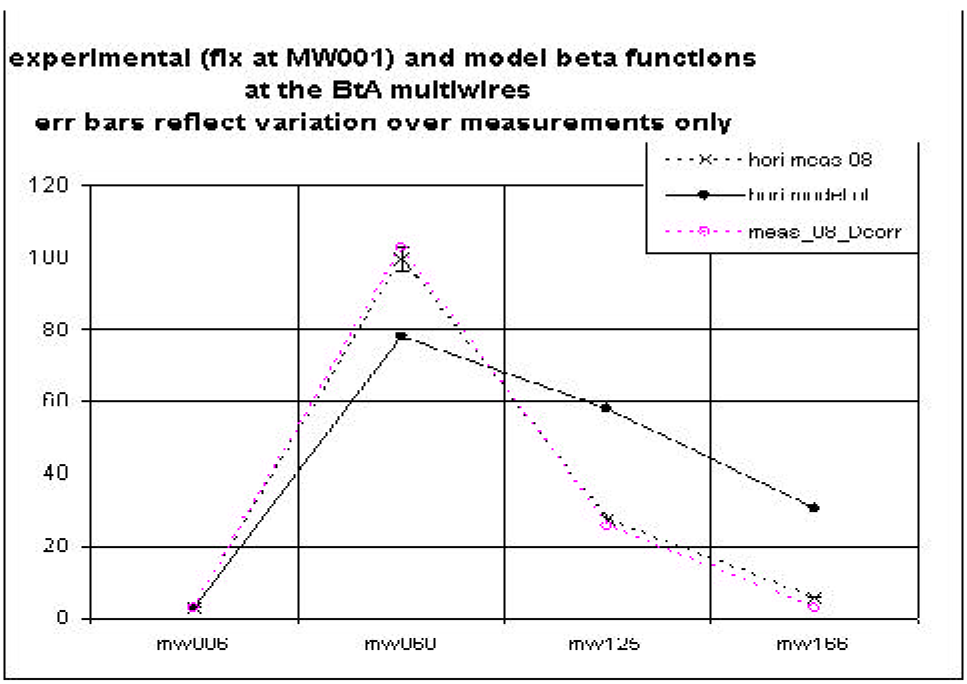


Figure 1: Comparison of relative beta functions, model vs measurement, vert meters

Multiwire data from a fairly large set (~100) of consecutive beam transfers in BtA were logged on the 9th of March. The main objective of the experimenters for this period of running was to measure AGS IPM response to intensity changing. The BtA data just came for free once that the multiwires were inserted. The data was acquired using a very recently introduced logging setup which saved the wire voltages in a format not immediately useable in the normal application. Therefore short term analysis of the data had to happen outside the usual fitting routines in the profileDisplay application. Indeed the work was done by a non-expert (the author) in working with gaussian fitting, using the generic nonlinear least squares routine "solver" in EXCEL. The function to be fit was a gaussian with amplitude, center and sigma as variable and no other freedom. For each AGS cycle, the logged data included a profile acquisition on the Booster "dummy" cycle (no beam, but most other noise sources present) as well as the beam data on the subsequent with-beam cycle. The dummy profile was used for wire-by-wire background subtraction. Processing the data was time consuming but forced the followed of this unusual path which turned out to be useful in an unexpected way.

The processed data - profile areas, offsets, and most importantly sigmas - were investigated in an attempt to gain some confidence in the system. A wealth of useful secondary effects in the data became evident. The first goal (associated with the reason the data was being taken) was to try and estimate the amount the transverse emittance in BtA changes with intensity. For this, the average beam width for each intensity studied was the important thing (see figure 2). A rather large reported change in sigma over the intensity sets was measured; i.e. the data was interesting and perhaps controversial. To judge the significance of the observed effect, the variation with "nothing" changing was important. Because the logging was always on, and the profile monitors always inserted, there was a lot of this "no-change" data.

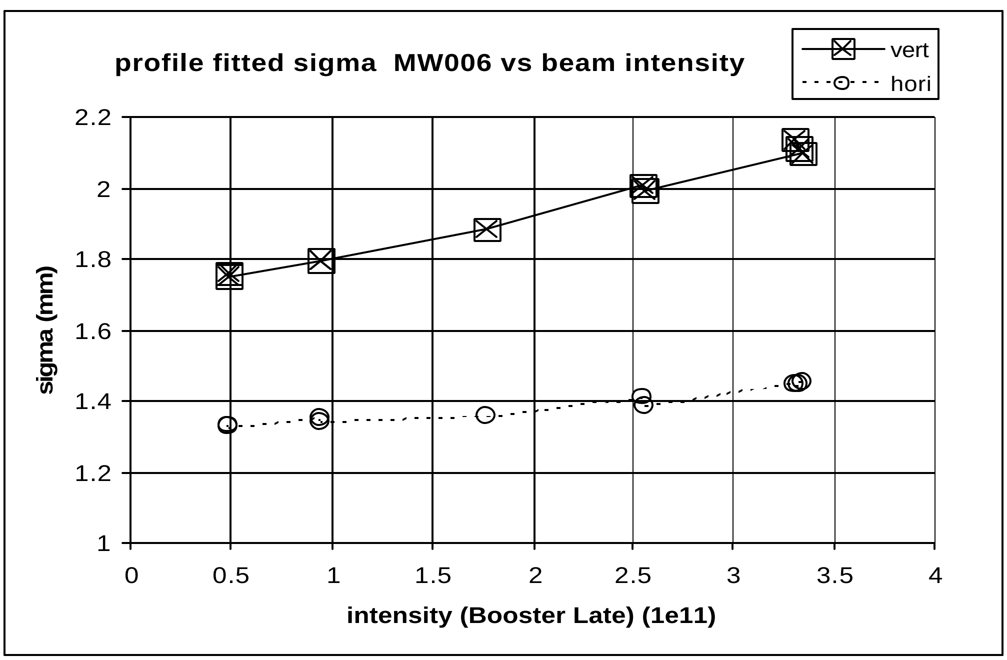


Figure2: response of MW006 to changing beam intensity

Was this data to be believed? Study of a single intensity condition became the focus. Two aspects of this data are mentioned.

First, the fitted profile centers are slightly different for each extraction. This could be instrumentation "noise"; it could reflect jitter in the currents in the magnets in the line; or it could reflect changes upstream of the line in the beam. If the cause were the third, then the shifts in the multiwires down the line should be correlated. Indeed they were to a rather delightful extent (Figure 3). The magnitude of the effect suggested that the F6 septum was the source. (The F3 kicker would have to change ~ 5 times expectations to get the motion seen at MW006. The pattern was very wrong for expected dispersion and would require a momentum swing equal to the beam spread). Independent steering measurements using the F6 dipole are also consistent with this motion.

The second aspect is the correlation among the widths reported down the line, shot-to-shot. A significant correlation is seen (Figure 4) suggesting there is real emittance variation from extraction to extraction at a level above the noise in the multiwire system.

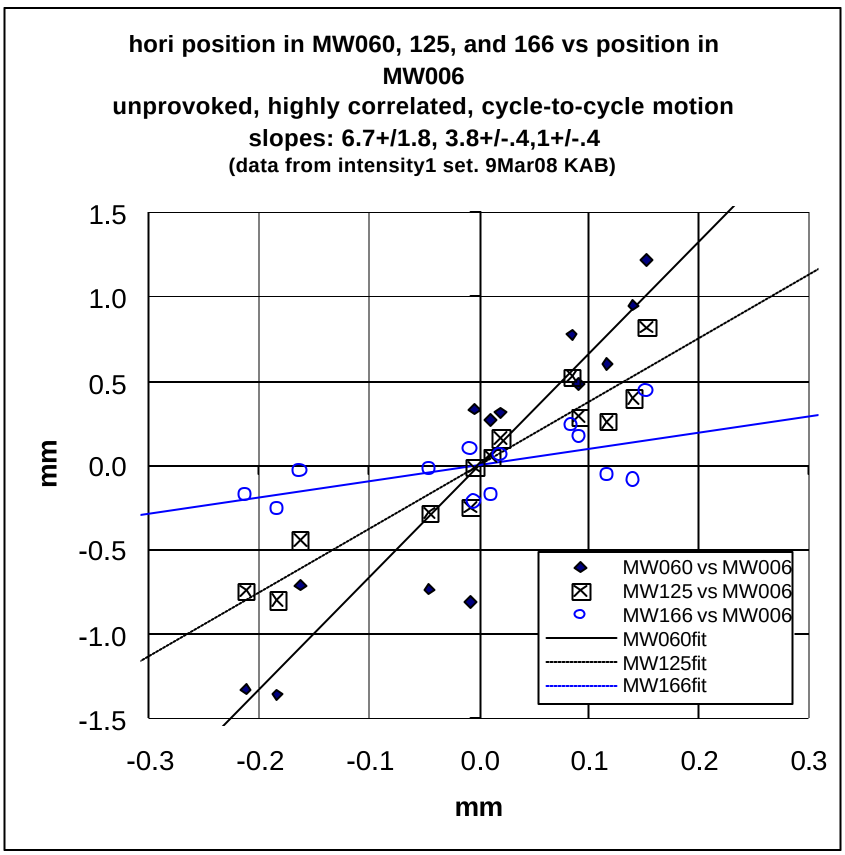


Figure 3: fitted gaussian center for downstream multiwires vs center in MW006

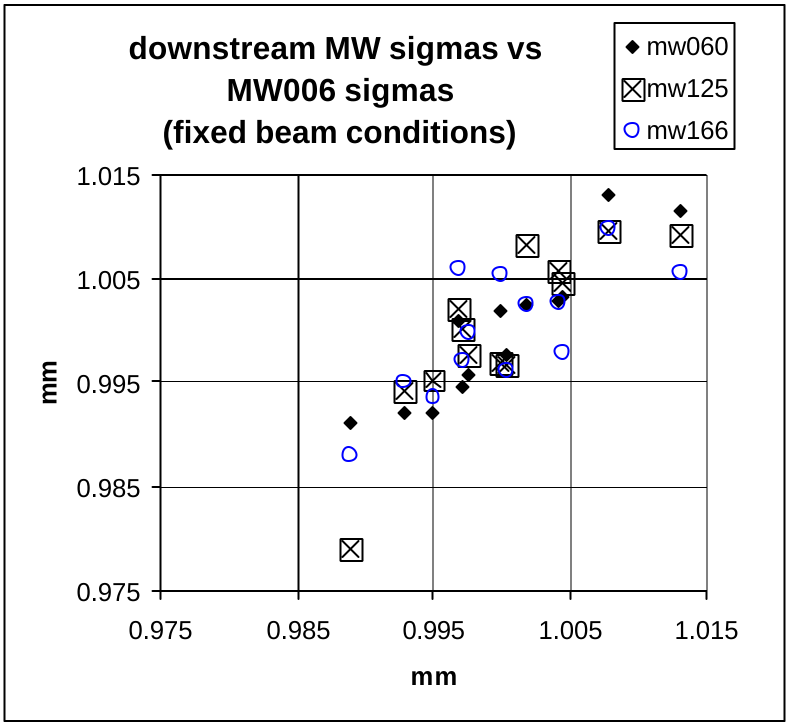


Figure 4: fitted profile widths for downstream multiwires vs mw006 ("fixed" beam conditions)

Finally then we come to the subject of the profileDisplay Controls application:

Very recently the profileDisplay application has been modified to allow the program to accept the new logged wire data that has been described above. This meant a comparison between the fitting results from the application machinery and from the spreadsheet fitting described above (referred to as EXCEL) could be carried out. I expected this would be a "gimme"; I was wrong.

One problem had already surfaced before this "identical data" comparison. The application allows wires known to be giving poor measurements to be excluded from the set used in the fitting. These wires are labeled "bad". What became evident once a careful inspection was carried out was that the way these bad wires were handles was wrong. They were indeed removed from the set, but then the remaining wired were relocated to be equally spaced with their overall position then shifted to make this possible. As a result the reported width was too small if a bad wire occurred within the region that had significant beam, and the center position was shifted if there were bad wires anywhere. Only one multiwire has a bad wire in the high beam region, (MW166 vertical), and the center position is primarily used in a relative sense, so these errors were not very important, which explains why they had crept in unnoticed. These problems were corrected.

The first result from a comparison of the fittings is shown in figure 5. For six (processing is still rather labor intensive) of the ~ identical transfers, here taken from the highest intensity set, the fitted gaussian sigmas - from the application and from the spreadsheet fitting - are plotted. The "full scales" on the two axes are the same.

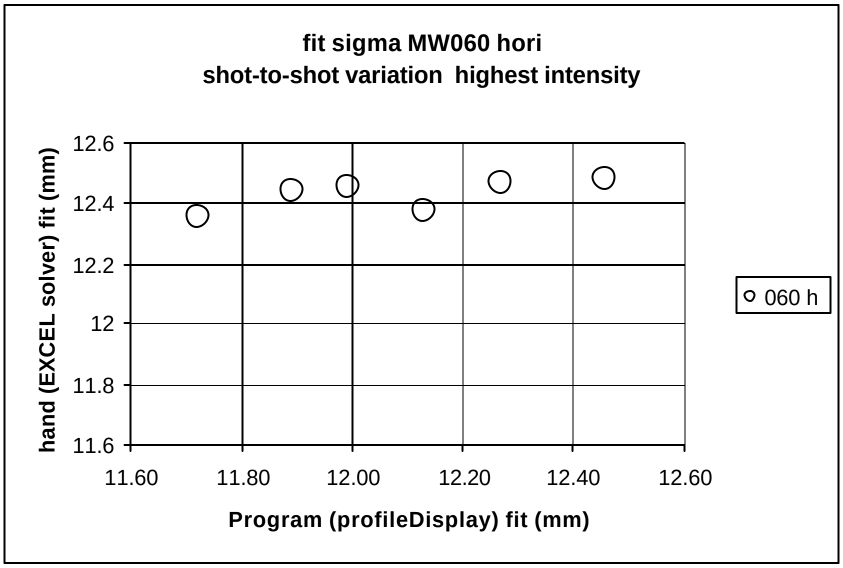


Figure 5: Comparison of fitted profile widths from the Application and from EXCEL

The distressing result was that the scatter in sigma from the application was an order of magnitude larger than the scatter from the EXCEL fit stuff. Since the results from the EXCEL fitting showed encouraging correlations (the above figures) which would not appear if the resolution washed by an order of magnitude, the application fitting was suspect.

Further investigation came up with two differences between the fitting routines. The application was weighting the points in the fit by 1 on the square root of the value of profile amplitude at the point. This is a weighing appropriate for fitting histogram data known to be generated via Poisson statistics. The effect is to weight the points near the center of the distribution heavier than those out on the tails. The second difference was that the application allowed the fit to include the freedom of an overall offset. With these differences removed from the application fitting routine, the two machineries gave identical results.

We take the observation that the original root amplitude proportional weighing rule resulted in an order of magnitude greater spread in sigmas under identical extraction conditions as reason enough to abandon this rule. That does leave us more sensitive to the distribution tails of course. The effect of including the freedom of an offset is not so clearly judged from the data analyzed here. Comparing nine "identical" extractions, the sigmas scatter differently for the four multiwires, but with no obvious trend. In this set the dependence of sigma on the inclusion of an offset degree of freedom for MW006 is nearly negligible. For the vertical planes these comparisons are shown in figure 6.

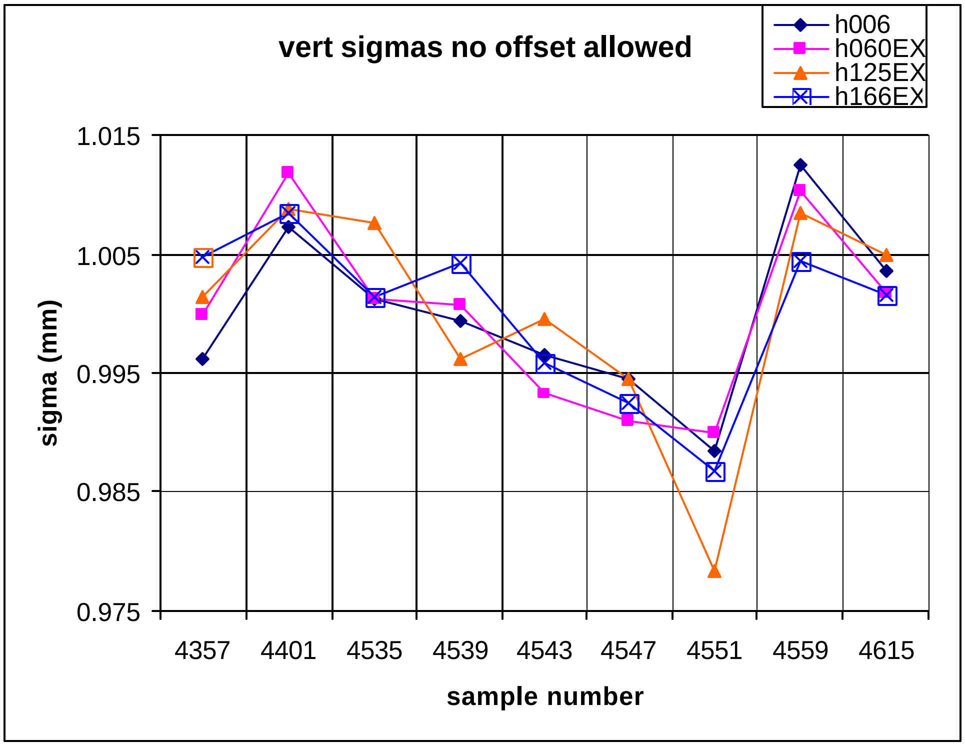


Figure 6a: scatter in fitted sigmas, "identical" data sets, offsets fixed to zero

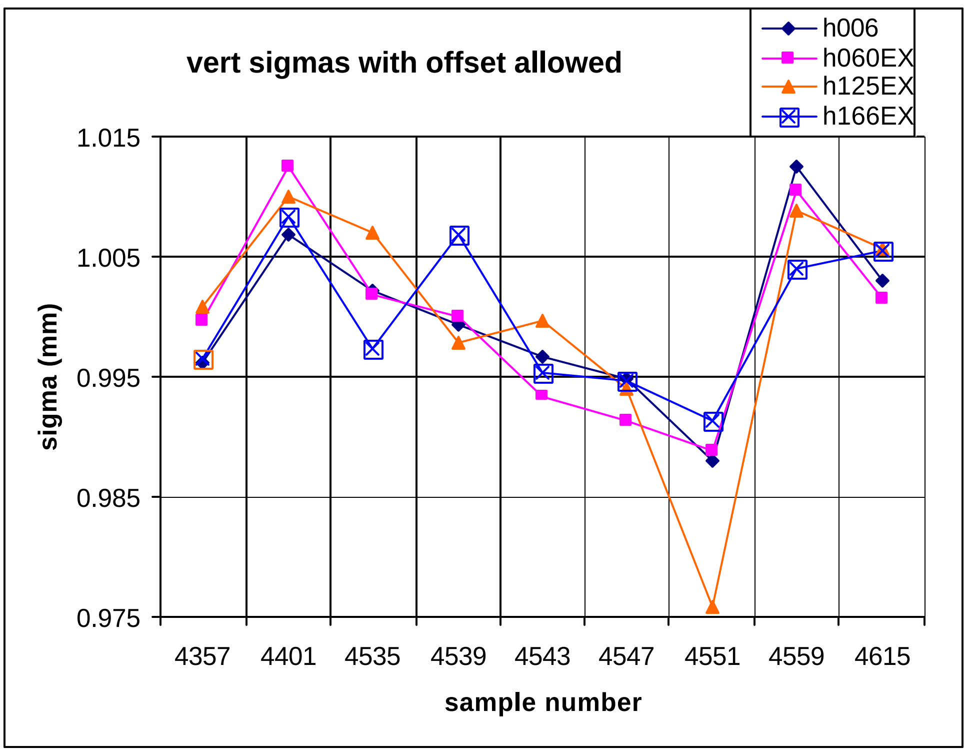


Figure 6b: same as 6a except offsets are now allowed to float

Conclusions:

The profileDisplay application has been modified as described above and more.

The "bad wire" feature is now handling bad wires properly. An additional feature allowing wires to be temporarily removed for the fitting - "ignore wire feature" - which was needed during the trouble shooting has been left in the menu selections.

The fitting gives all points equal weight.

The decision to allow an offset in the fitting is left as a menu selectable option.

A measure of goodness of fit is included in the visible outputs from the fitting.

The bottom line question here is whether any of this work on the BtA transverse beam measurements can be translated into a better understanding of the beam properties going into AGS. That remains to be seen, and if the answer is no, then this work is of no fundamental significance. So that step is essential.

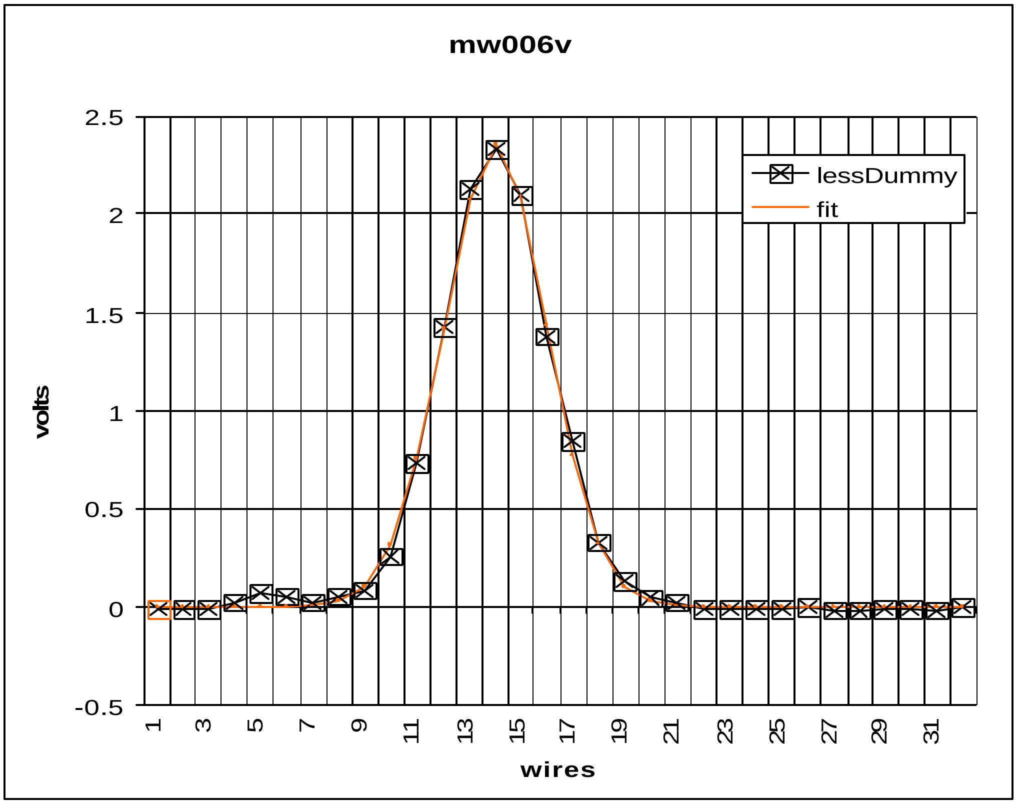
Appreciation:

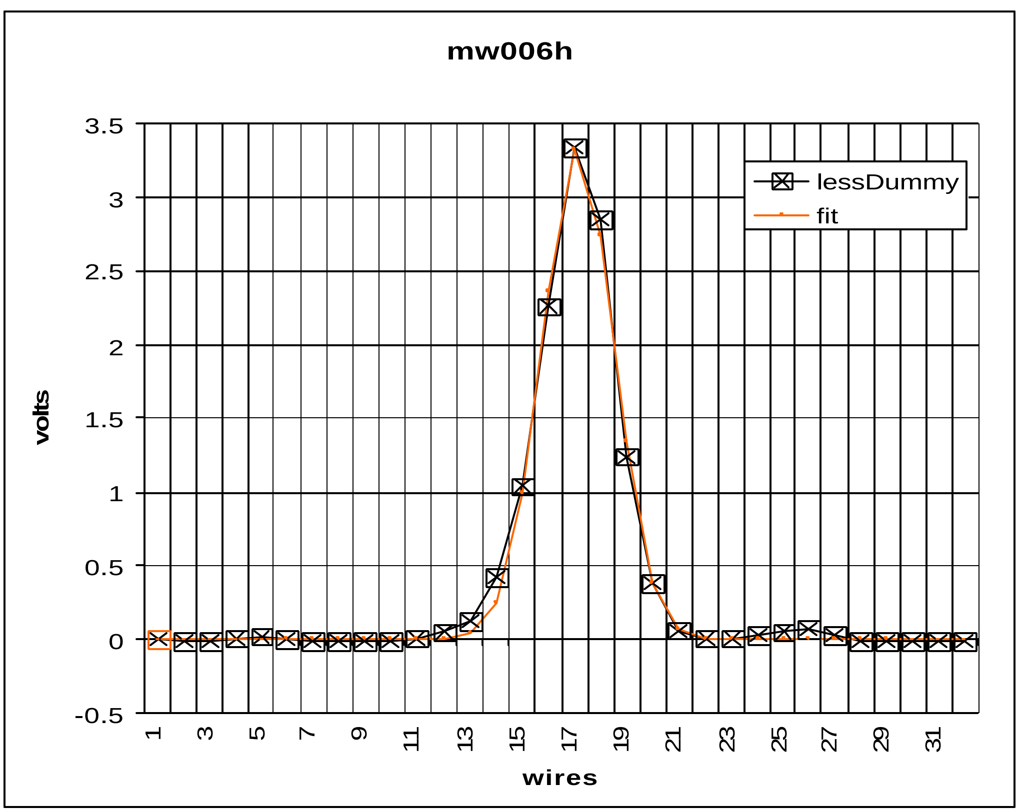
As must be clear from the above, there was a lot of work for the application software person (who is not the author) during this exercise. This person was Benjamin Pucci early on and went to Seth Nemesure for the fitting exorcism and beyond. The improvement in the application which I think was achieved rested on the work of these guys.

Appendix: typical multiwire profiles.

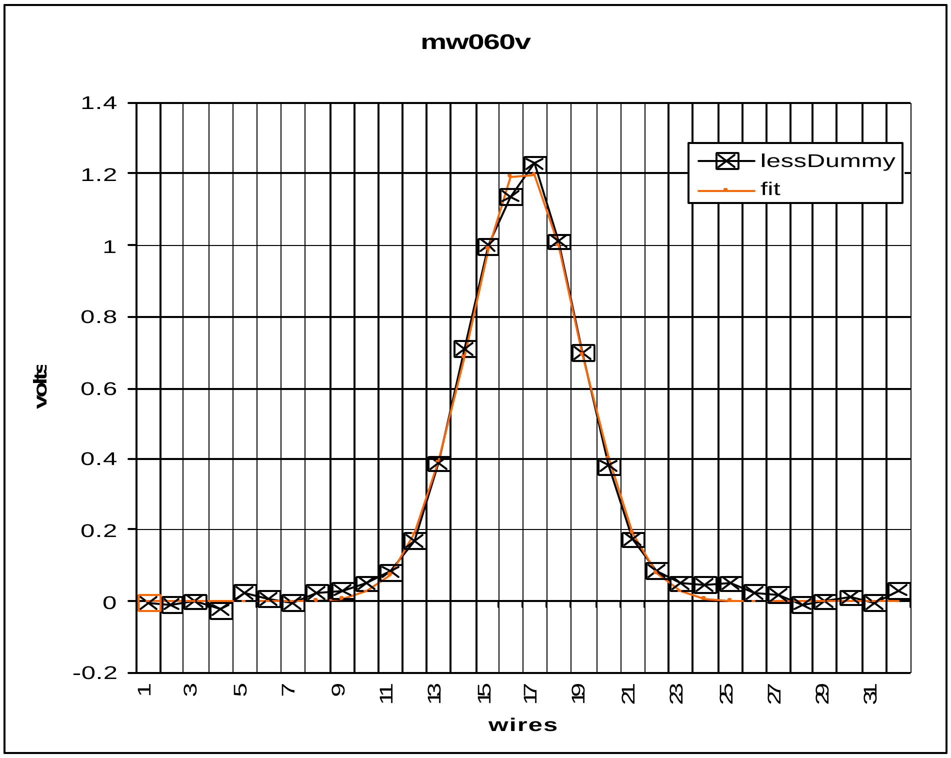
These are "the third extraction from the second intensity set (next to highest) and chosen at random - well for convenience at the time.

MW006

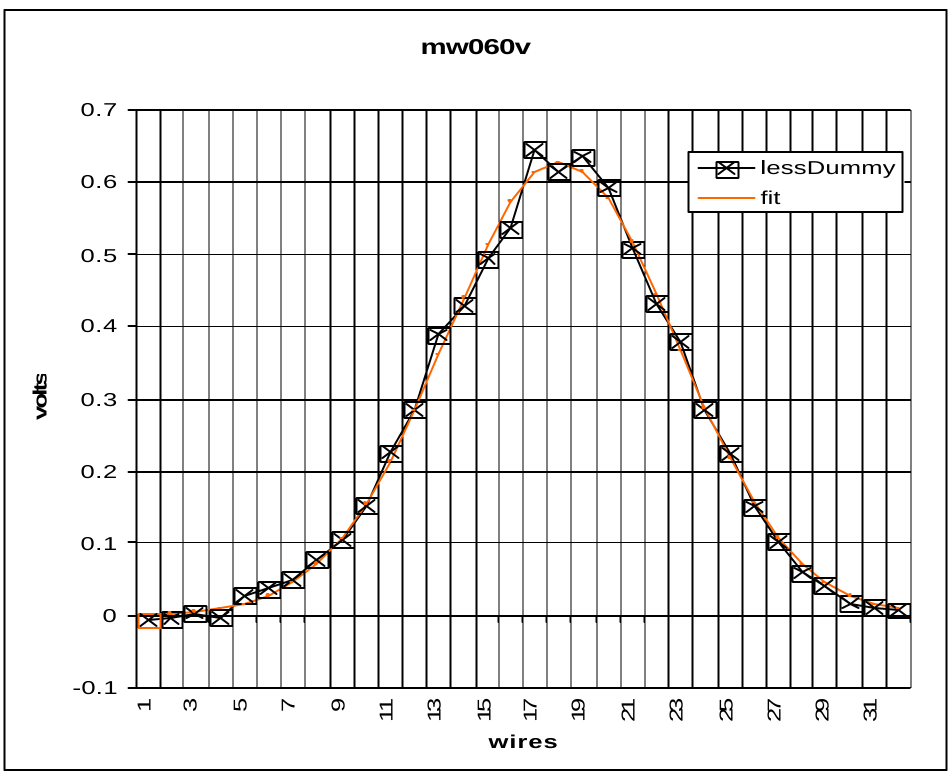




MW060

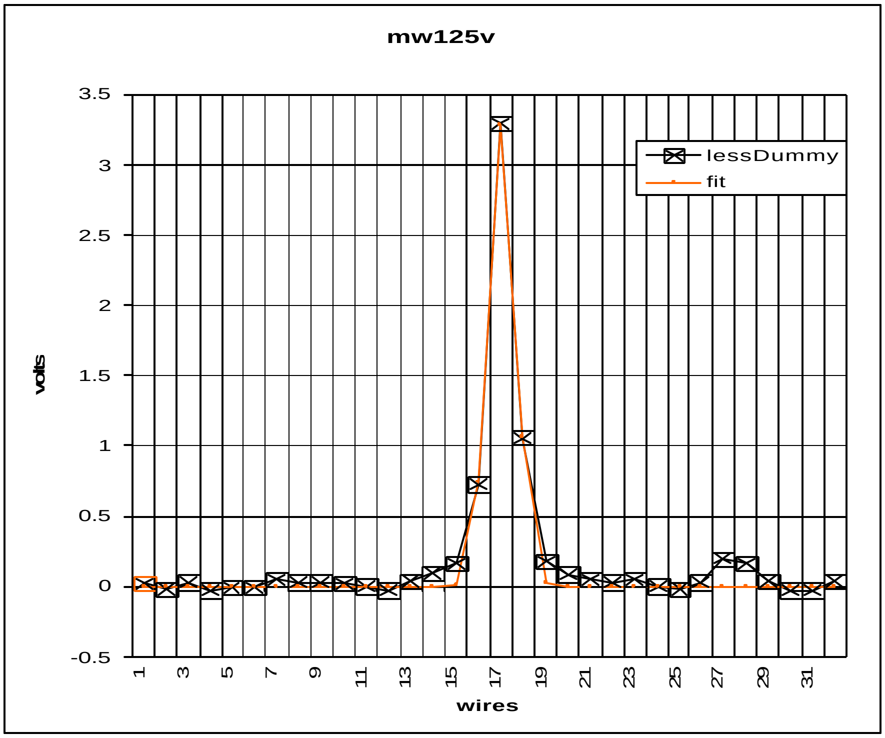


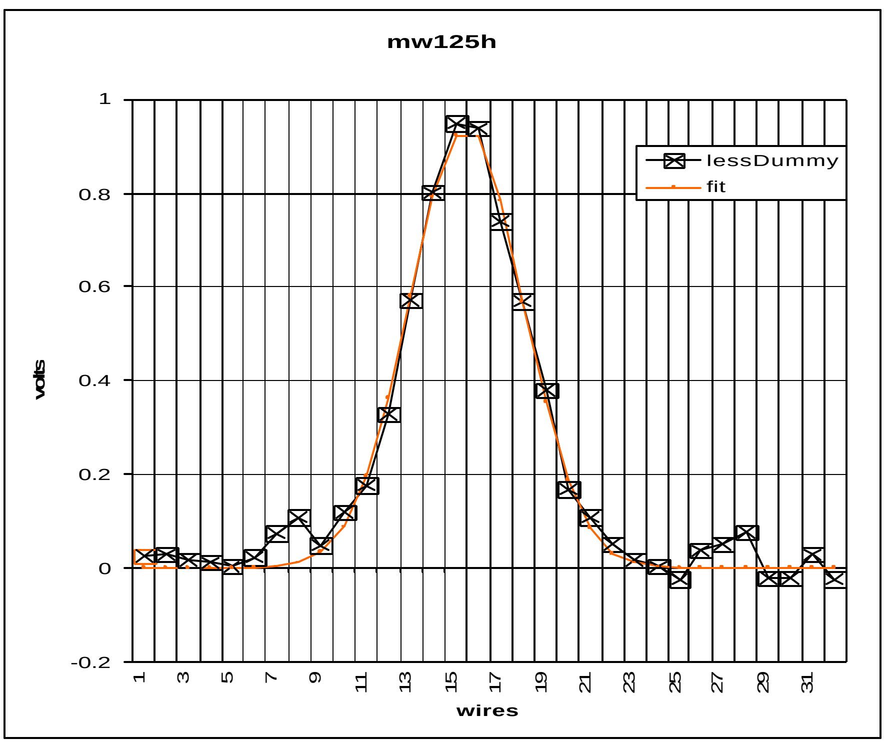
(the next is really MW060h the horizontal plane, just mislabeled on moving over, sorry)



MW125

The vertical profile is very narrow - so fit very dependent on the relative gains of the three wires that see significant beam, but signal-to-noise is very good.





MW166

showing the bad vertical wires (excluded from the fit)