PC-BASED SOFTWARE TOOLS FOR

WIRE SCANNER MEASUREMENTS AT THE TTF

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Monday, 26 February 2001

Abstract

Wire scanner measurements at the TTF of beam position and profile ("single" measurements) and beta-beat and beam emittance ("group" measurements) will be presented. The intention is to show on one hand the wealth and complexity of the data (and the difficulties in quantifying errors in, for example, beam emittance) and on the other the ease in using the devices for on-line measurements of beam quality. PC-based tools will be used for this purpose.

1 INTRODUCTION

1.1 Layout of Components

The diagnostics in the region of the TTF undulators are described in detail in [1] and [2]. A sketch of the layout in Figure 1 shows the names and relative positions of components that are discussed in this note; see also Figure 15. Diagnostic blocks are installed between and at both ends of the 3 undulator modules. Each diagnostic block contains wires for measuring beam profiles in the horizontal and vertical planes. The stations are denoted H1,V1; H2,V2, H3,V3; and H4,V4. A scintillator paddle connected to a photomultiplier tube (PMTs) is positioned behind each diagnostic block to measure the electrons scattered off the wires. The PMT signals are digitised with 1 MHz ADCs; the channels are denoted ADC-1, -2, -3 and -4. A fifth scintillator located at the end of the undulator region is also used. These PMT signals are used in the beam-loss interlock, reducing the flexibility to set the high voltage for optimal signal amplitudes.

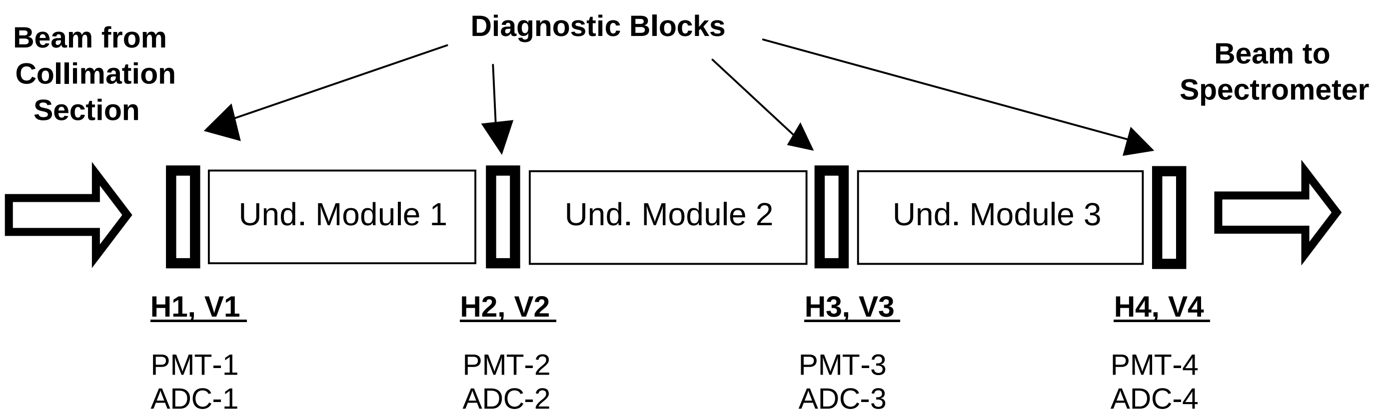


Figure 1. A sketch of the layout of the region of the undulators at the TTF, showing the wire scanners and PMTs with their associated ADC channels.

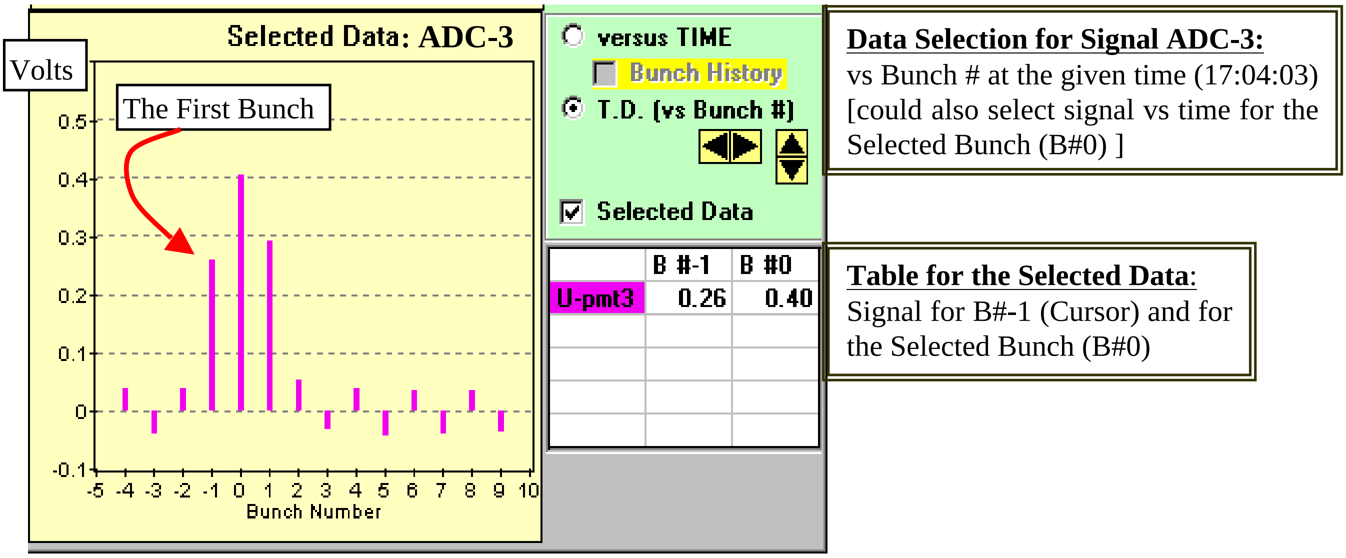


Figure 2: The TD (Time Domain) data of ADC-3 in the linac pulse on 17 Dec 17:04:03. The vertical scale in all plots of PMT signals is Volts. Note the oscillation of the signal in the empty bunches. Three bunches were produced. The first bunch should be in position 0; this timing error is discussed in the text.

1.2 The Signals

Scintillation counters next to the diagnostic blocks are used in the beam profile measurements to measure the electrons scattered off the wires. A plot of the bunch-signal from ADC-3, from the scintillator between the second and third undulators, for a single linac pulse with 3 bunches during a scan of wire H3 is shown in Figure 2.

The 1 MHz ADCs are used for many beam diagnostic signals at the TTF. Typically they are programmed to take 2048 samples for each linac pulse; this data is known as the TD or Time Domain data. A reference bin, the Sample Time, is often used to indicate the position in the 2048-bin data set of the first bunch in the bunch train. Typical values are about 800. For example, for ADC-3, channel /UND1.ADC3/CH02 on server **vmeund1,** the expected bin of the first bunch is 789. This timing must be checked occasionally: in Figure 2 one sees that the first bunch does not appear in position zero, but in position –1, indicating a discrepancy between the expected ADC time-bin and the actual bin of the first bunch. The timing was not checked before these measurements made in December.

Note the oscillation of the signal in the empty buckets: Pre-bunches are used to measure noise and are subtracted from the bunch-data. The noise for even bunches (e.g. 0 and 2) is taken from bunch position –4, and for odd bunches (e.g. 1 and 3) from position –3.

1.3 The Software Tools

It is not possible to measure the profile of a single bunch using the wire scanners; a beam profile is currently produced by moving the wire slowly and collecting the signals from many linac pulses. This procedure is controlled by the client (the user-interface program) not by the server: the wire is moved to a position, when it's reached the client collects the required data for the requested number of linac pulses and the client then moves the wire to the next position in the scan. Data is collected at typically 20-30 positions. Software is available/being prepared to speed-up and to simplify the procedures.

Bunch-charge and bunch-orbits must be collected to monitor bunch-to-bunch and shot-to-shot differences (jitter and drifts) in the beam parameters. The acquisition of the required beam-diagnostic data is performed by seven front-end servers: The orbit is measured with 52 beam position monitors (of which about 40 are connected); the charge is measured with 11 toroids; 4 ADC channels are used for measurement of losses in the collimator region and 5 channels for the scintillator-signals for the profile data. These signals are all digitised with 1 MHz ADCs (with the exception of 3 BPMs in the injector which are read-out with SEDAC electronics with one position measurement per linac pulse). These data are needed for each linac pulse, for a group of bunches, and with the strict requirement that the data come from the same linac pulse. Since these data with these specifications are of potential interest to many clients, a middle-layer server (TTFBEAM) has been written to perform the data collection centrally. In the current configuration, the data for 10 bunches and 2 pre-bunches (4 for the scintillator signals) are collected; the pre-bunches are useful for timing checks (see Figure 2). Configuration information, for example the Sample Time (position of the first bunch in the 2048 TD buffer) for each ADC channel, and the bunch spacing (bunch frequency) are used by TTFBEAM to produce 2-dimensional bunch-data "objects." For example, the horizontal orbit is a 624-element array of position versus monitor number (52) and bunch number (12).

A central archive server automatically stores these and other relevant data; the client program that performs the scans also collects the data and stores a subset in a file for ease of analysis. Another program is used to access beam position and charge data, both live and archived. A general-purpose program exists to access and display all of the data stored by the central archive server.

The plots in this note are taken directly from these 3 user-programs (copied and pasted into the document, and possibly cropped), thus in addition to displaying the data the architecture of the user-interfaces can also be shown. The figures thus contain more information than just analysis results; an attempt is made to explain the functions of the various buttons and check-boxes visible in the figures. An additional difficulty is that colours are used in the software to distinguish curves. A copy of the (colour) document can be found at /afs/desy.de/user/l/lump/public/ttf/ws.doc and \minfiles\lump\Public\ttf\ws.doc.

Example profile data will be shown and discussed, together with archived data of the beam conditions during measurements. The calculation of optical functions and beam emittance will be covered briefly.

2 PROFILE DATA

2.1 Single Scans

The data files of profile measurements performed from Dec 1999 through 2000 are available for analysis. Scans were made with typically 1 bunch with a charge of 1 nC.

In each scan one obtains a profile from each of the 5 ADCs for each of the bunches. In Figure 3 are shown data from a scan of the horizontal wire in the first station (H1) made on 17 Dec at 19:04 (note the date in the file name). The scan was started with 10 bunches but when the wire reached the beam, the high losses triggered the fast interlock to reduce the number of bunches produced to 3. Out of the 15 beam profiles available in the file, those recorded by ADCs 1, 2 and 3 for the first bunch are shown on the upper plot and those recorded by ADC-2 of the three bunches are shown on the lower plot. The largest signal is measured at ADC-2, downstream of the first undulator module.

The table beneath the plots contains the mean positions and widths calculated analytically and with a simple least-squares fit to a Gaussian for the 5 ADCs (for a selected bunch) or for 5 bunches (for a selected ADC). The positions are relative to the middle of the chamber as given by alignment data; this plotting-option was selected for all plots shown in this note. Two other examples of the plethora of data in a single scan are shown in Figures 4 and 5. The scans were made in September 2000 with one bunch. They are meant to illustrate the qualitative differences between the profiles recorded by different ADCs for the same beam, with the same wire.

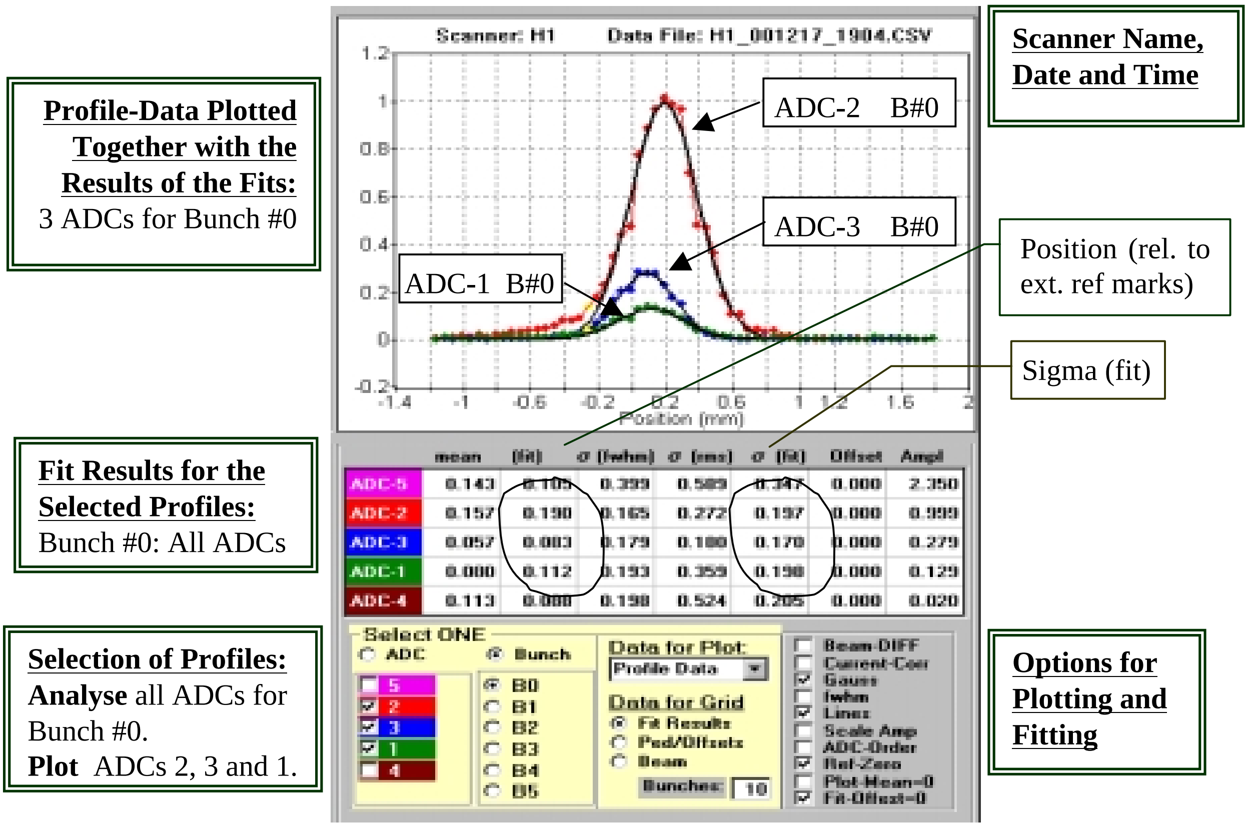
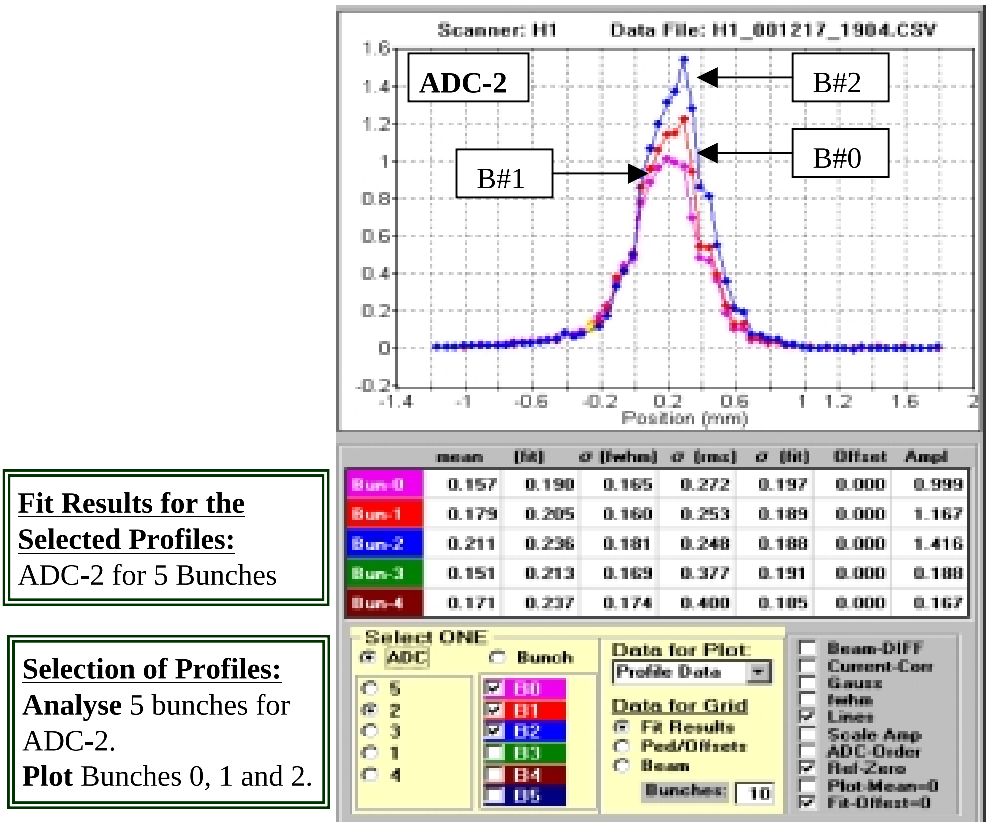


Figure 3. Selected profiles from a single scan of scanner H1 on 17 Dec 19:04. Top: Profiles for Bunch #0 recorded by ADCs 1, 2 and 3 overlaid with the results of the least-squares fit to a Gaussian. The largest signal is measured at ADC-2, downstream of station H1, after the first undulator module. Bottom: Profiles recorded by ADC-2 of the first 3 bunches.



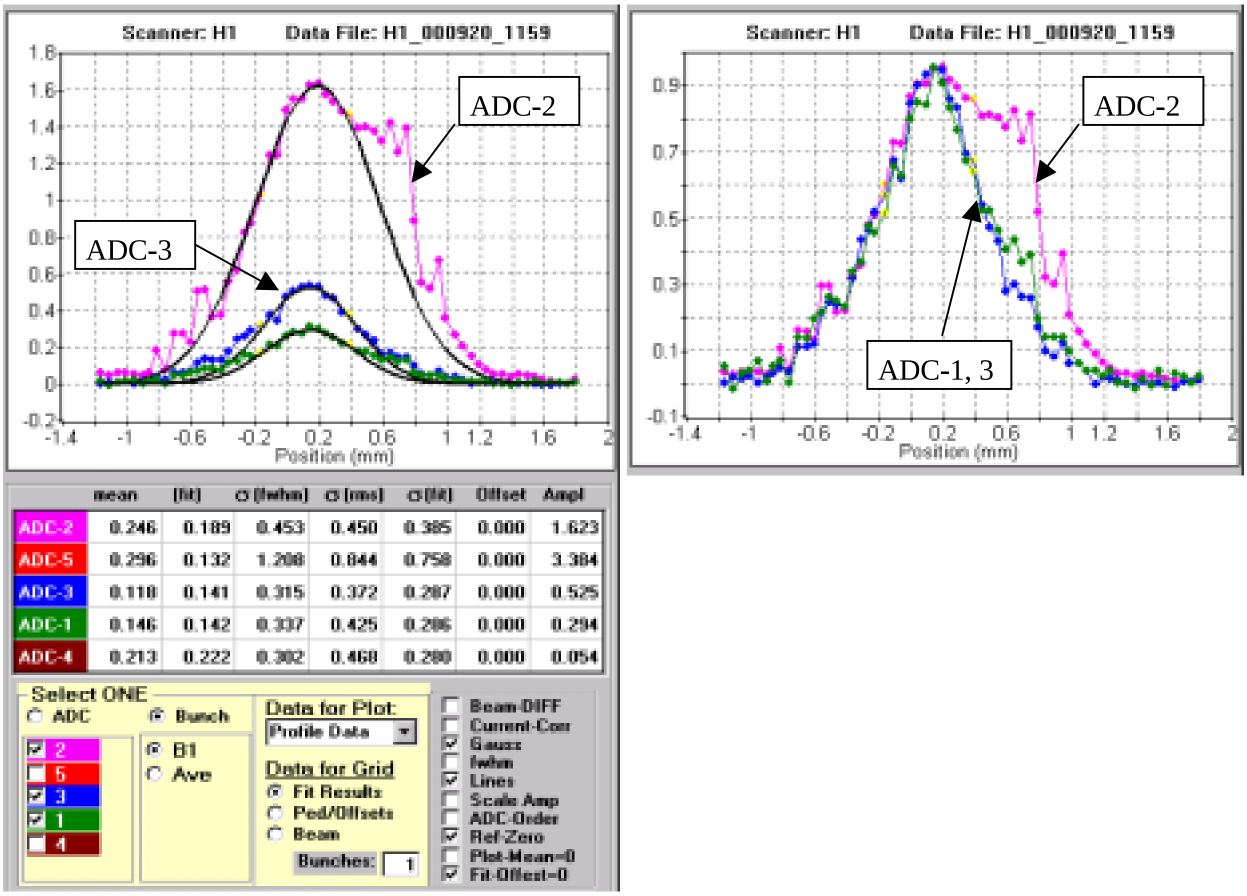


Figure 4 Comparing ADC-Profiles: A shoulder in the profile of ADC-2 is not in those of the other ADCs. Left: Profiles overlaid with the results of the least-squares fit to a Gaussian. Right: The three profiles scaled to a maximum value of 1; The profiles recorded by ADCs 1 and 3 overlap very well.

2.3 Example Group-Scan Data

Using a single wire one can measure beam position and profile. Combining the profile data of a set of wires one can fit optical parameters and get a beam emittance. The standard procedure was to measure with all 8 wires, four profiles in each plane, one wire after the other. In Figures 6 and 7 are examples of such “group” scans, all with the “same” beam conditions.

3 OBSERVATIONS

Studying these plots, from each ADC for each bunch, and imagining oneself analysing the curves to find mean positions, widths and to estimate the errors, with the goal of measuring the beam emittance, a number of questions concerning qualitative aspects of the data may come to mind.

1) Differences between ADC profiles: There are 5 ADC profiles for each scan of a wire. The relative signal amplitudes depend on the positions of the scintillators relative to the wire. In some cases there are also qualitative differences in the shapes of the profiles: In Figure 4 the shoulder in ADC-2 is not present in the other scintillator signals. This may be due to shadowing effects. In Figure 5, judging by-eye, there seem to be differences between the goodness of the fits to a Gaussian. The quantitative differences in the results for the mean position and width of the profiles may, or may not, be dominated by “statistical” (random) errors.

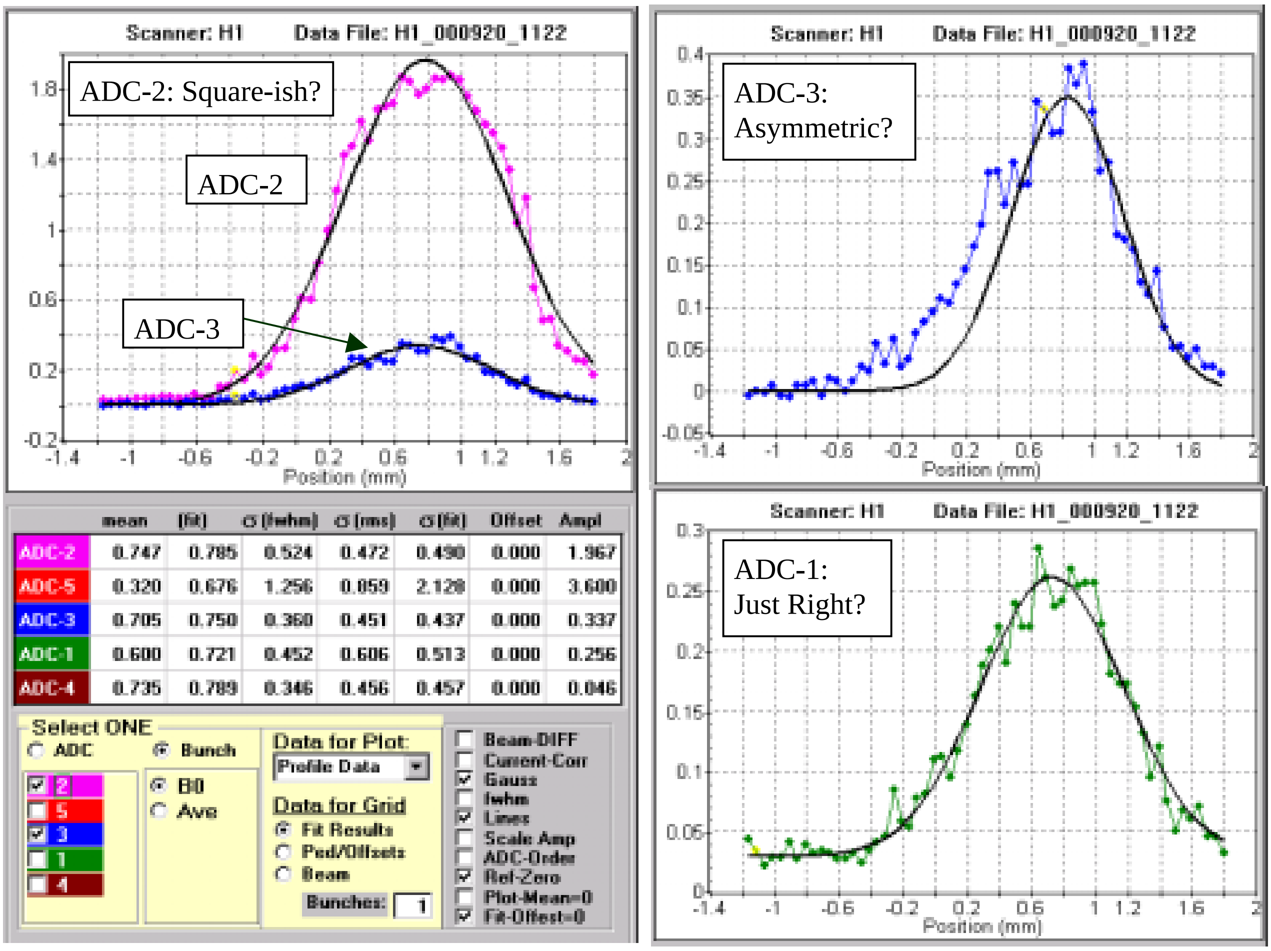


Figure 5: Are the data well represented by a Gaussian? Judging "by eye" (e.g. looking at the number of data points above and below the curve) the qualitative goodness of the fit to a Gaussian is different for each ADC.

2) Differences between Bunch Profiles: The positions and widths of the bunches, measured with the same ADC, are not exactly equal. It is important to determine if these differences between the bunches in orbit and emittance are significant, or due to random errors. The usefulness of fast wire measurements (profiles measured with a single linac pulse) depends on understanding (i.e. detecting and correcting) such bunch-to-bunch differences in orbit and profile. Comparison with other orbit and profile diagnostics (position monitors and optical transition radiation) might be helpful in understanding the measured bunch-to-bunch differences.
3) The Quality of the Fit: Is the data well represented by a Gaussian? The determination of position and width of profiles by fitting to a Gaussian depends, of course, on how well the data is represented by a Gaussian: are the deviations random, or is the profile simply non-Gaussian? To answer this question quantitatively requires understanding the sources of "errors", including changes (both jitter and drifts) in bunch charge and orbit during the scan. Qualitative answers, based on fitting by-eye, indicate non-Gaussian features of the profiles, including asymmetries and tails. For non-Gaussian profiles other quantities may be used to measure the width of the distribution, for example the full-width-half-maximum or the RMS.
4) Stability of Beam Parameters during a Scan. The "missed" and "misplaced" shots shown in Figure 6 are examples of large changes in beam parameters that can occur during a scan. Smaller changes in beam orbit or charge could explain non-Gaussian features of some profiles. The error in profile-analysis due to shot-to-shot jitter (random variations) can be reduced by collecting data from more than one linac pulse at each point in the scan, and then averaging the values; this approach is not helpful for drifts. In any case, to go beyond qualitative results (without an error estimate) toward well understood measurements of profiles, including errors, requires a good understanding of shot-to-shot stability and drifts of beam parameters and ADC signals, which requires monitoring and analysis of the beam orbit and charge.

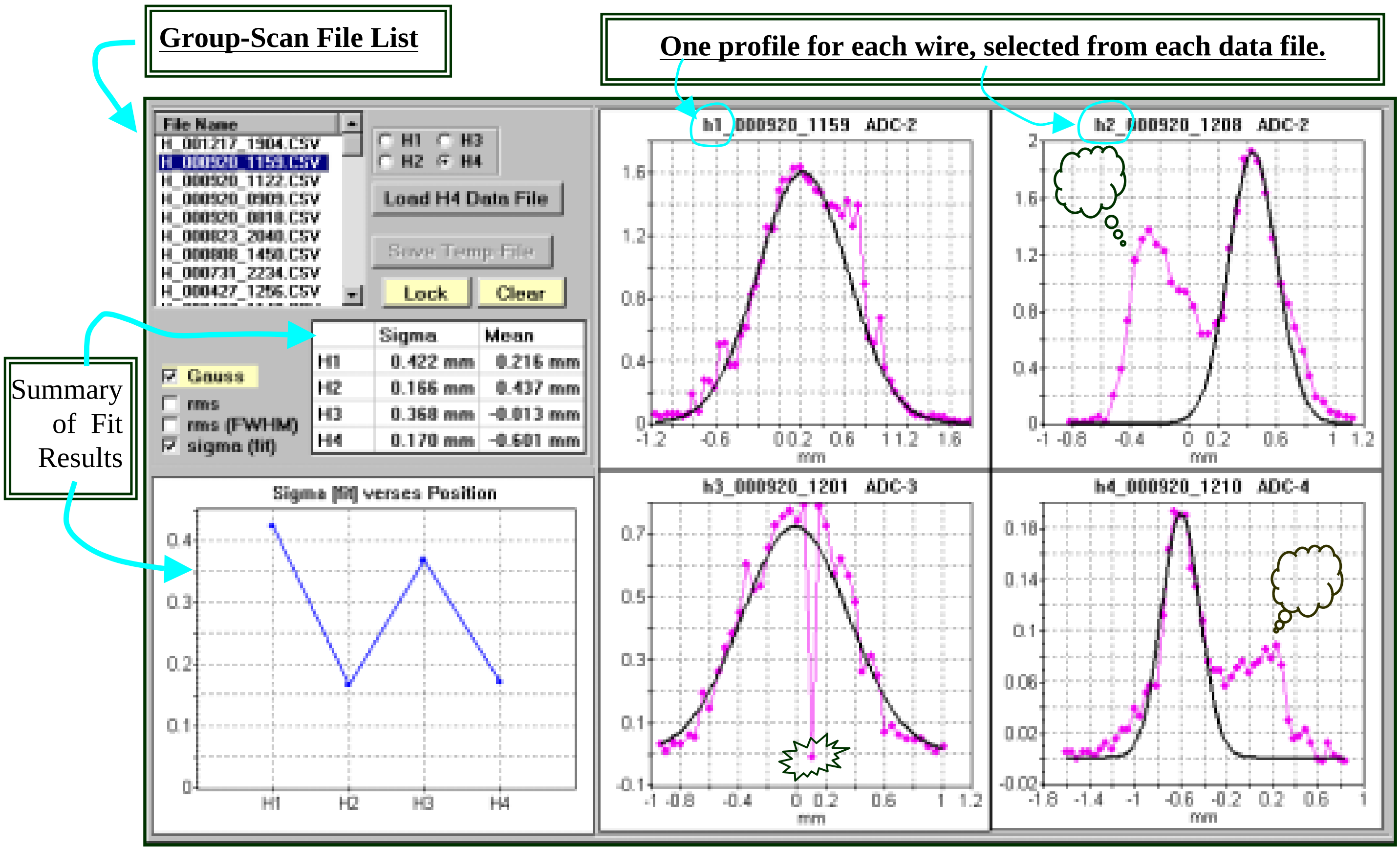
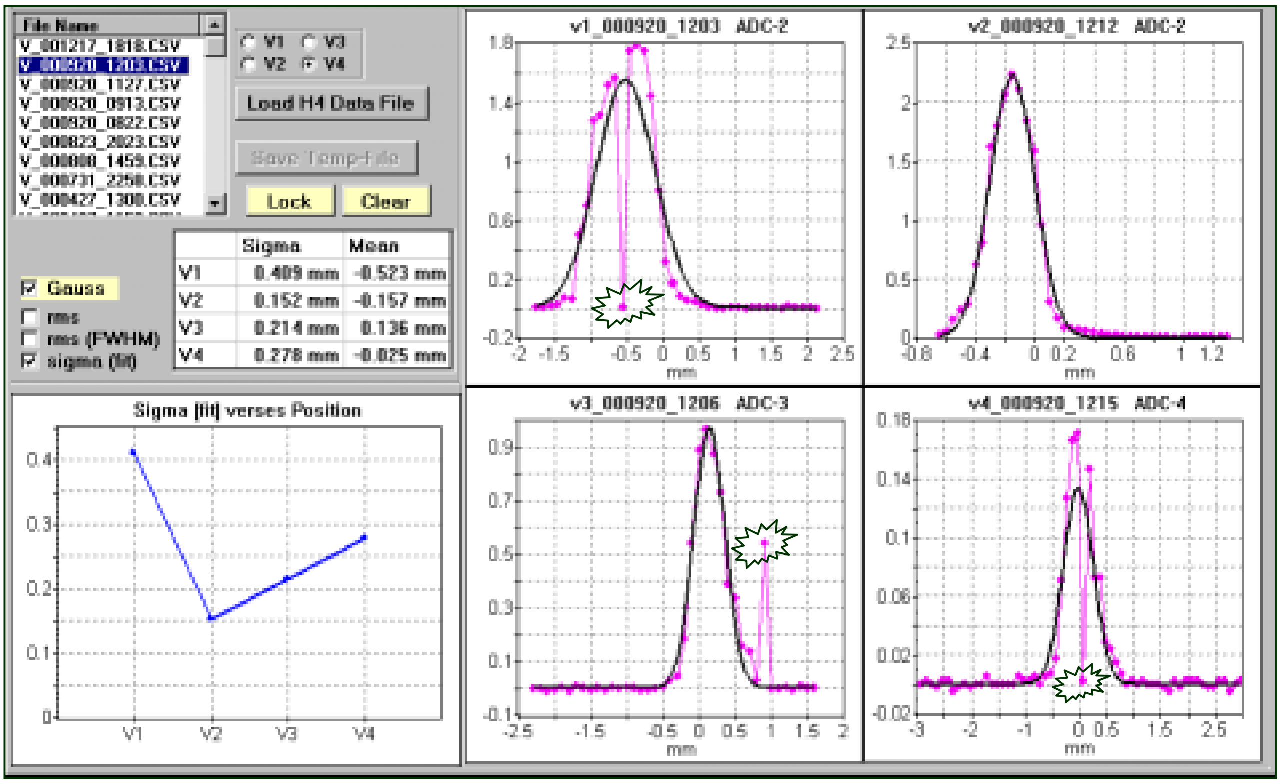


Figure 6 : A group-scan made during 15 minutes on 20 Sep 12:00. Above: Results for the horizontal plane, Below: for the vertical plane. The "missing" pulses in the scans of H3, V1 and V4 and the "misplaced" pulse in V3 could be due to orbit jumps. Note the interesting double profiles of H2 and H4 and the non-Gaussian profiles for H3, V1 and V4. The horizontal beam size through the undulators appears to be modulated, with differences up to a factor of 2.5. The beam size in the vertical plane also changes significantly through the undulator region.



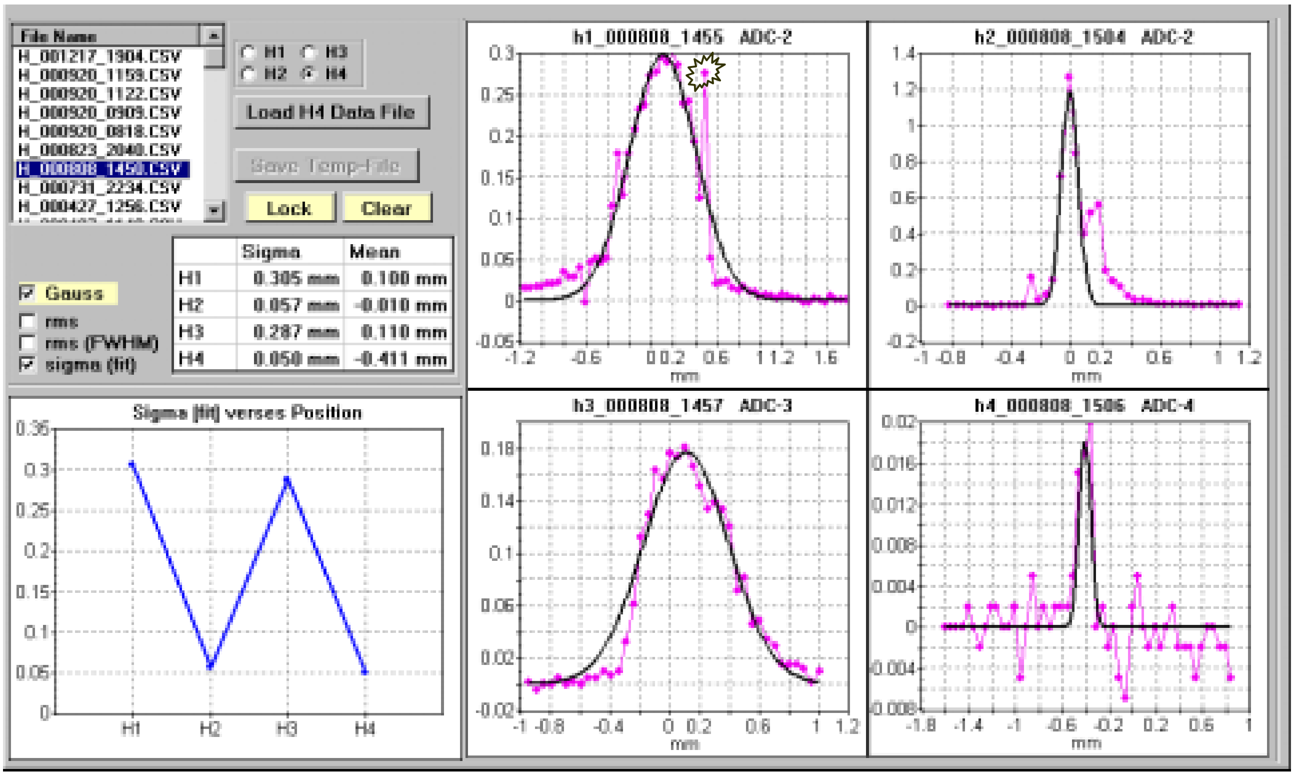
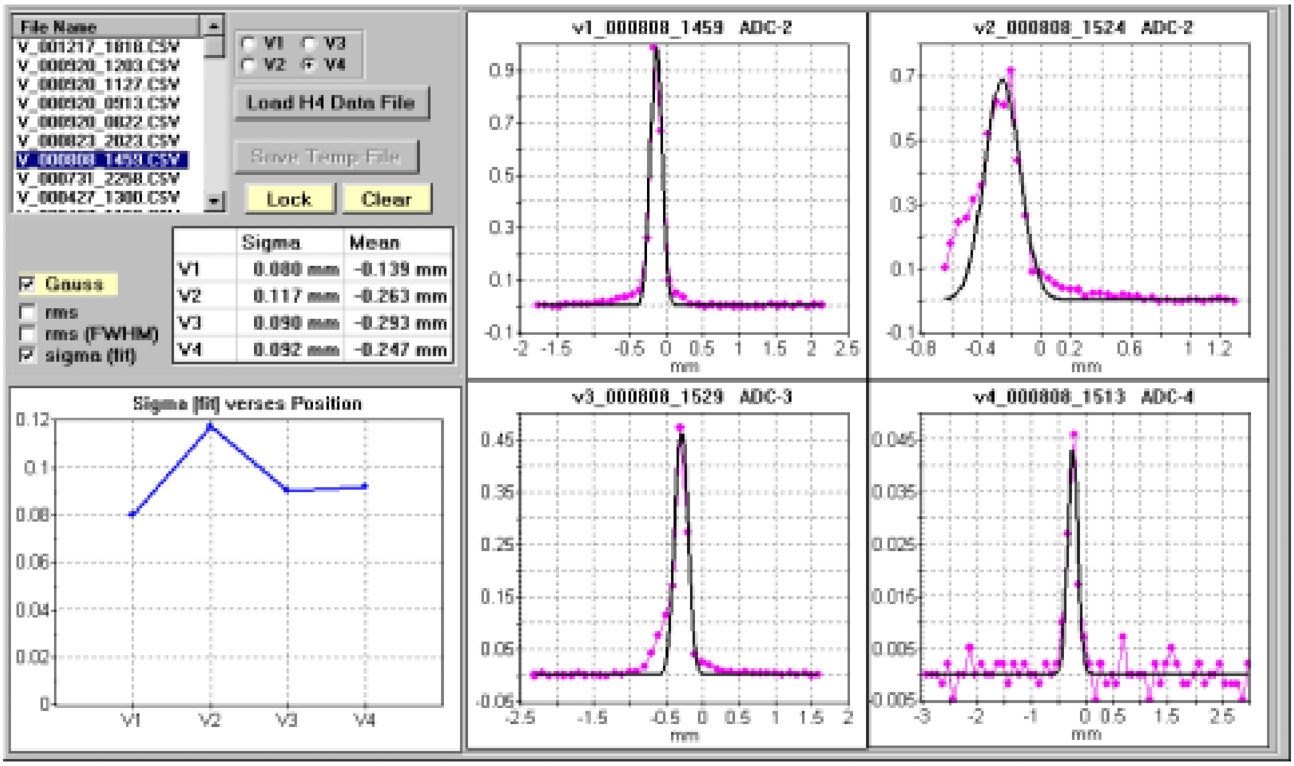


Figure 7 A group-scan made on 8 Aug 15:00. Above: Results for the horizontal plane; Below: Results for the vertical plane. Note the rather non-Gaussian profiles of H1 and H3. More points in the vertical scans would have been helpful. The vertical beam sizes at the 4 stations are nearly equal; in contrast, the beam sizes in the horizontal plane differ by up to a factor of 6, indicating an optic mis-match into the undulator producing a very large beta-beat.



4 MONITORING THE LINAC STATE AND BEAM CONDITIONS

The collection and storage of beam diagnostic information together with machine settings is of general interest for many clients, not just for interpreting the measurements with the wire scanners. A central archive server based on the Machine-Data Archiving System running at HERA has been brought into operation for TTF data. The central archive server collects the required data over the network and if necessary, stores them in files with the associated time stamp. Data requests from clients are serviced by an archive-reader; the client supplies the desired data-property and the time or the time interval.

The decision to store a particular piece of data at a particular time is made based on a set of rules including user-configurable tolerances and the current machine state. The declaration of basic machine-states is performed by a state-server (TTFSTATE), using information from, for example, the BIS about the state of the interlock (e.g. the Linac Operation Mode and the Pulse Mode). In this way the archive server can determine if beam in the linac is possible and thus whether or not to archive, for example, beam diagnostic information. The central archive server is a client of the TTFBEAM middle-layer server, so the diagnostic data are collected and archived as complete “objects” for each pulse to enable analysis (and comparison) of individual pulses. Slowly changing parameters (i.e. those not linked to linac pulses) such as set-values and power levels are useful to observe slow drifts and to follow machine-settings over long periods of time and can be archived less frequently. For example, with beam (checking the BIS and the charge measurement of Bunch#0 at toroid B1) the default archiving frequency of the bunch charges is once per second and of the orbits once every ten seconds. The power of klystron 3 is stored when it goes out of a tolerance of 10%, and at least once every 15 minutes (the so-called heartbeat) if the value doesn’t change.

In the following figures, examples are shown to illustrate the types of data collected and stored and the general-purpose program available to access them. In Figure 8 is shown an overview of linac operations for an 8 hour period on 17.Dec.00 The display begins at 12:00; wire scanner measurements began around 16:00. Selected beam and linac information are plotted to give a quick overview of the linac performance: the charge of Bunch#0 at the beginning (toroid B1) and end (toroid T6) of the linac, together with basic parameters such as the power of klystron-3 and the accelerating voltage in one cavity of each accelerating module are selected by default. Note the 3 events when the RF systems were off (tripped?). In Figure 9 the time development of the charge of Bunch #0 measured by toroid B1 is plotted; the shot-to-shot jitter at bunch charges of 4 nC was about 1 nC (peak-to-peak) with jumps of the charge to more than 8 nC. During the wire scanner measurements made at 1 nC, the peak-to-peak jitter was about 0.15 nC. In Figure 10 the time development of position measurements are shown. Plotted is the horizontal beam position of Bunch #0 measured at the monitors 1COL1, 2COL1 and 1EXP3. Position jitter at 4 nC was up to 1 mm; at only 1 nC the jitter at the collimators was about 0.1 mm.

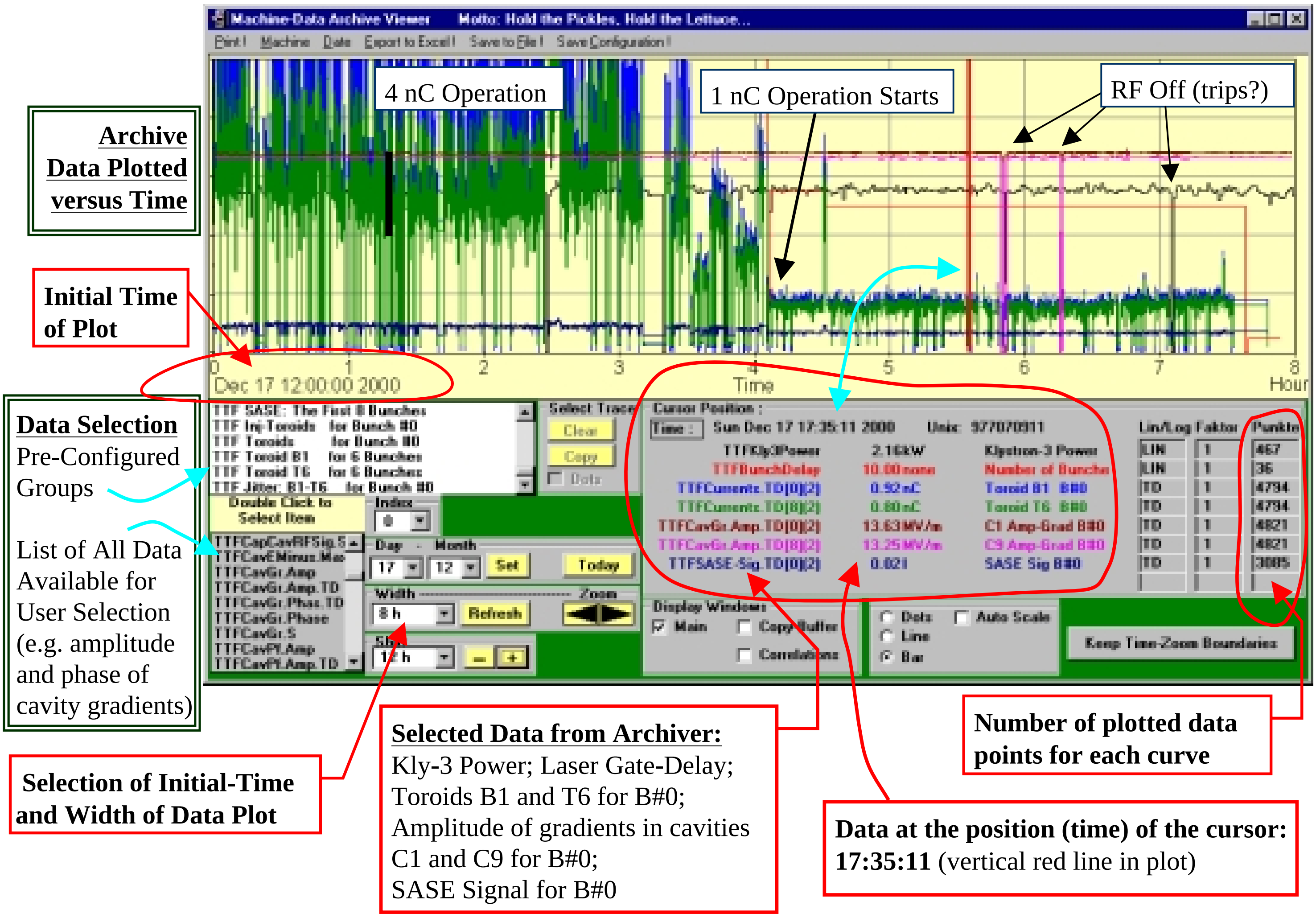


Figure 8. A general-purpose viewer of data stored by the central archive server. Plotted is an overview of TTF operation on 17 Dec 00 between 12:00 and 20:00. Bunch charges of 4 nC (with large fluctuations) were produced until about 16:00, when wire scanner measurements were started. Note the 3 RF trips (?) at about 18:00.

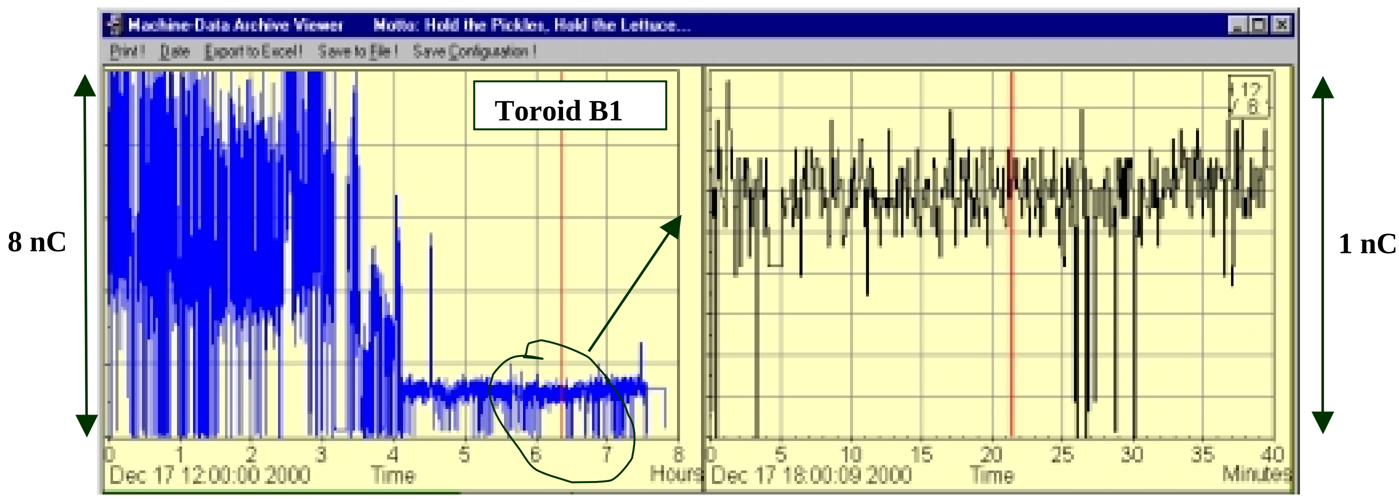


Figure 9. Charge in Bunch #0 measured at toroid B1 during the 8 hour period shown in Figure 8. Right: Zoom to show fluctuations during operations at 1 nC. The shot-to-shot jitter is about 15% (0.15 nC) peak-to-peak.

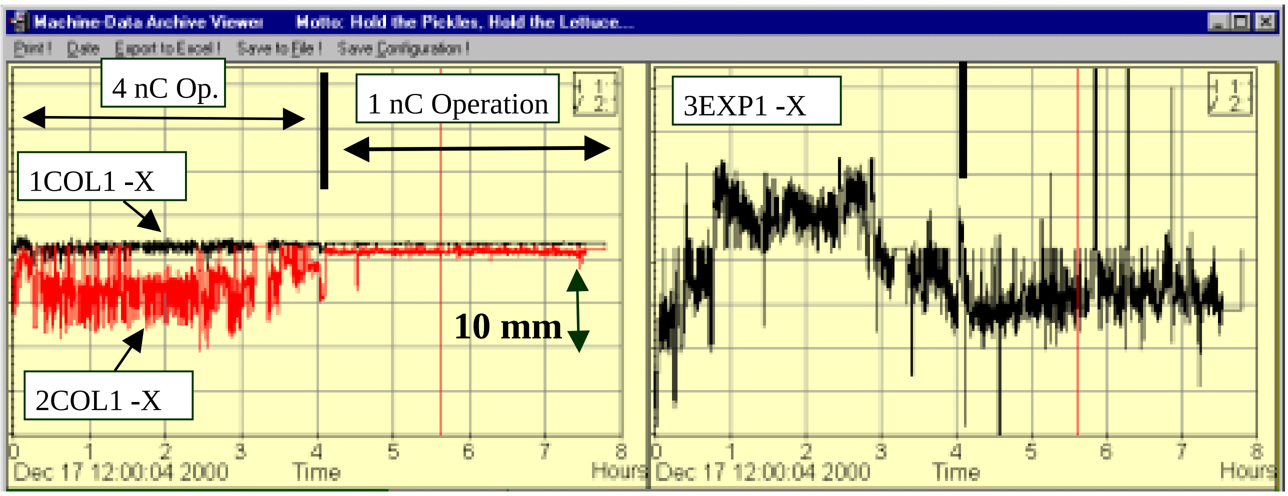


Figure 10. Horizontal beam position of Bunch #0 measured at 1COL1 and 2COL1 (left plot) and 1EXP3 (right plot) during the 8 hour period shown in Figure 8. The position jitter at 1 nC at the collimators is less than 0.1 mm and at 1EXP3 (a measure of the energy jitter) is about 4 mm peak-to-peak.

The shot-to-shot jitter observed in the measurements of the bunch charge and the beam position is a combination of beam-jitter overlapped with measurement noise. A better estimate of the actual jitter in the beam position at the wires and in the charge can be made by combining all monitors and using the correlations between them. For example, by studying orbits and orbit differences, and not just single monitors, one may detect betatron oscillations propagating through the linac. Techniques such as Model Independent Analysis may also be helpful to eliminate noise.

The general-purpose viewer of archive data, which plots single quantities versus time, is not well suited for such system-specific displays. Beam orbits are displayed using a program modelled after those in use at other accelerators at DESY. Various slices of the 2 dimensional orbit data can be displayed: the beam position (for a selected bunch) as a function of the position along the linac (the "orbit") or the beam position (at a selected monitor) for each bunch (the TD or Time-Domain data). The orbit of Bunch #0 along with other associated data is shown in Figure 11 for a linac pulse during the wire scanner measurements. In Figure 12 is shown a difference orbit, comparing the orbit shown in Figure 11 to an orbit archived about 10 minutes later. In Figure 13 is shown the difference orbit between two bunches in that linac pulse.

The beam position is also measured with the wire scanners. Shown in Figure 14 are plots of the orbit in the undulator region with the positions from the scans edited into the reference files. The orbit shown in Figure 11, measured on 27Apr00 (one of the last measurements with the SEDAC readout of the BPMs in the first two undulator modules), and the difference orbit are also shown in Figure 14.

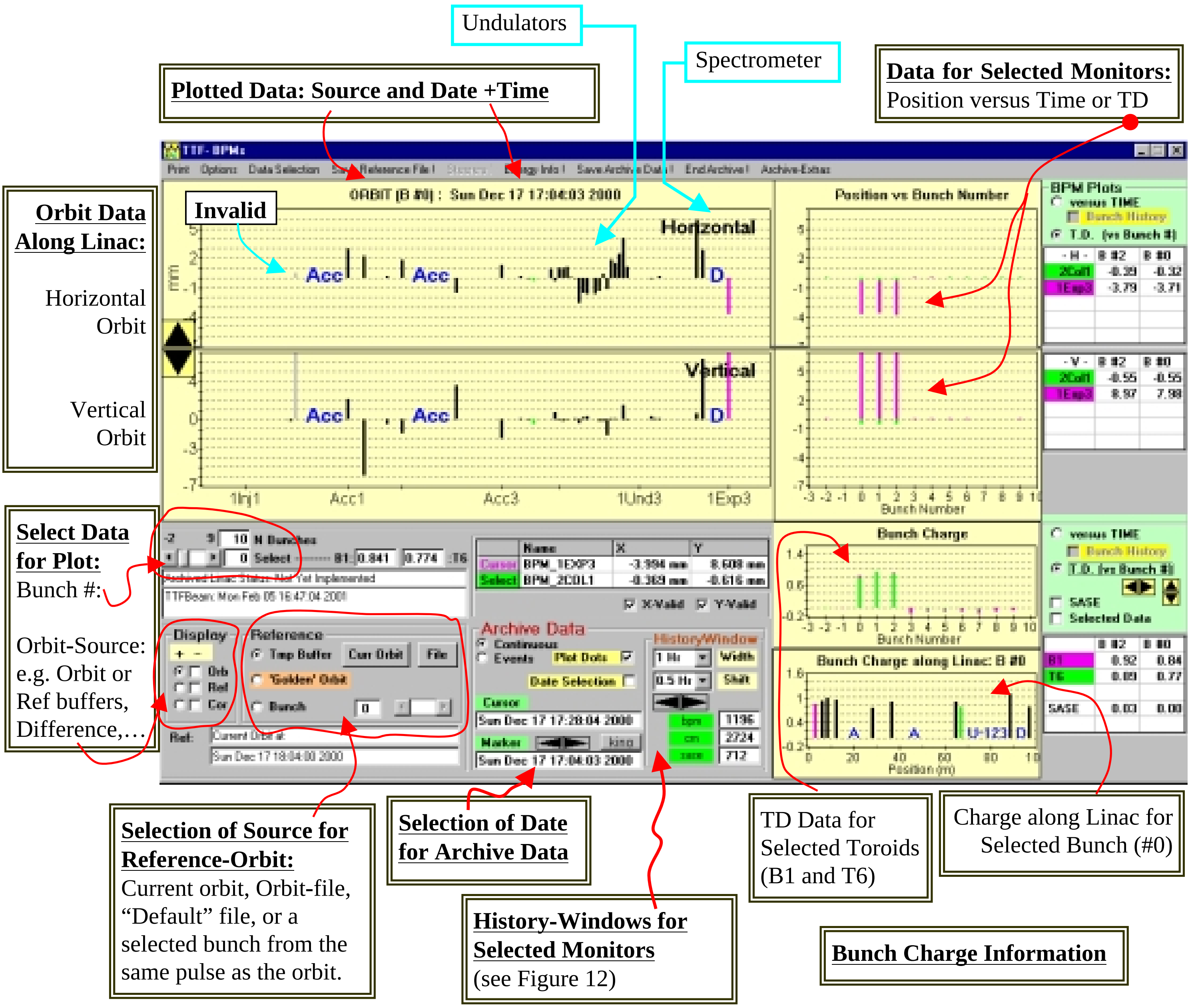


Figure 11. A display program for 2-dimensional orbit and charge data. The program “mode” is set to display data from the central archive server; plotted are data archived <u>for a single linac pulse</u> during the wire scanner measurements on 17 Dec 17:00.

<u>Selected Bunch:</u> Bunch #0; <u>Selected Linac Pulse:</u> 17 Dec 17:04:03; Three bunches.

<u>Orbit Data:</u> The orbit along the linac of the selected bunch for the selected pulse is shown. The Time-Domain data of the selected position monitors (2COL1 and 1EXP3) for the selected pulse are shown.

<u>Charge Data:</u> The charge along the linac of the selected bunch for the selected pulse is shown. The Time-Domain data of the selected toroids (B1 and T6) for the selected pulse are shown.

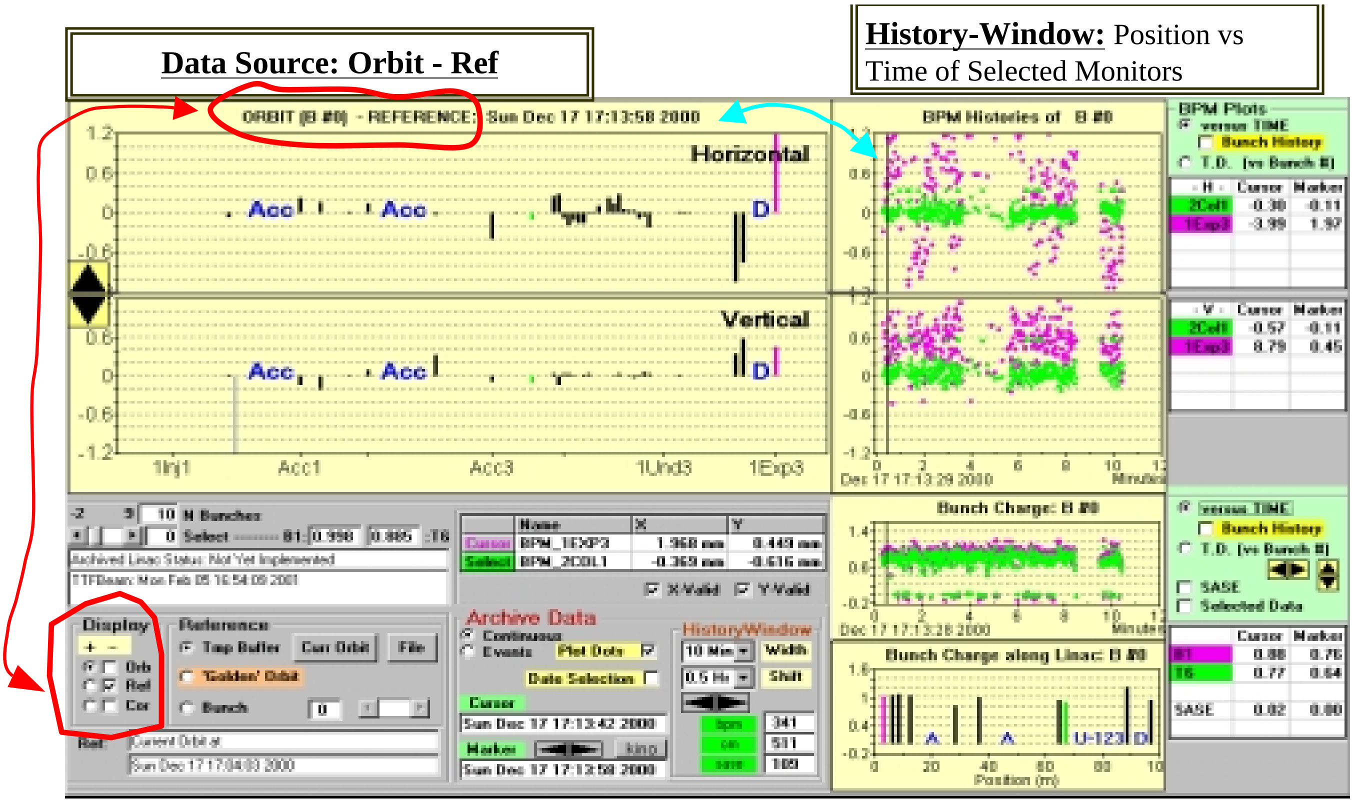


Figure 12. An example of the selection of a Difference Orbit as orbit-source and the History Window option for selected position and charge monitors.
Plotted in the orbit along the linac is the difference between orbits of Bunch #0 in linac pulses at 17:13:58 and 17:04:03 (the reference orbit) on 17 Dec 00. A betatron oscillation through the linac in each plane may be observed.
The position at the selected monitors (2COL1 and 1EXP3) and the charge at the selected toroids (B1 and T6) for the selected bunch over a 10-minute period are also shown; the time of the selected linac pulse (at 17:13:58) is indicated by a vertical line in the three history plots. A large position-jitter is evident in monitor 1EXP3.

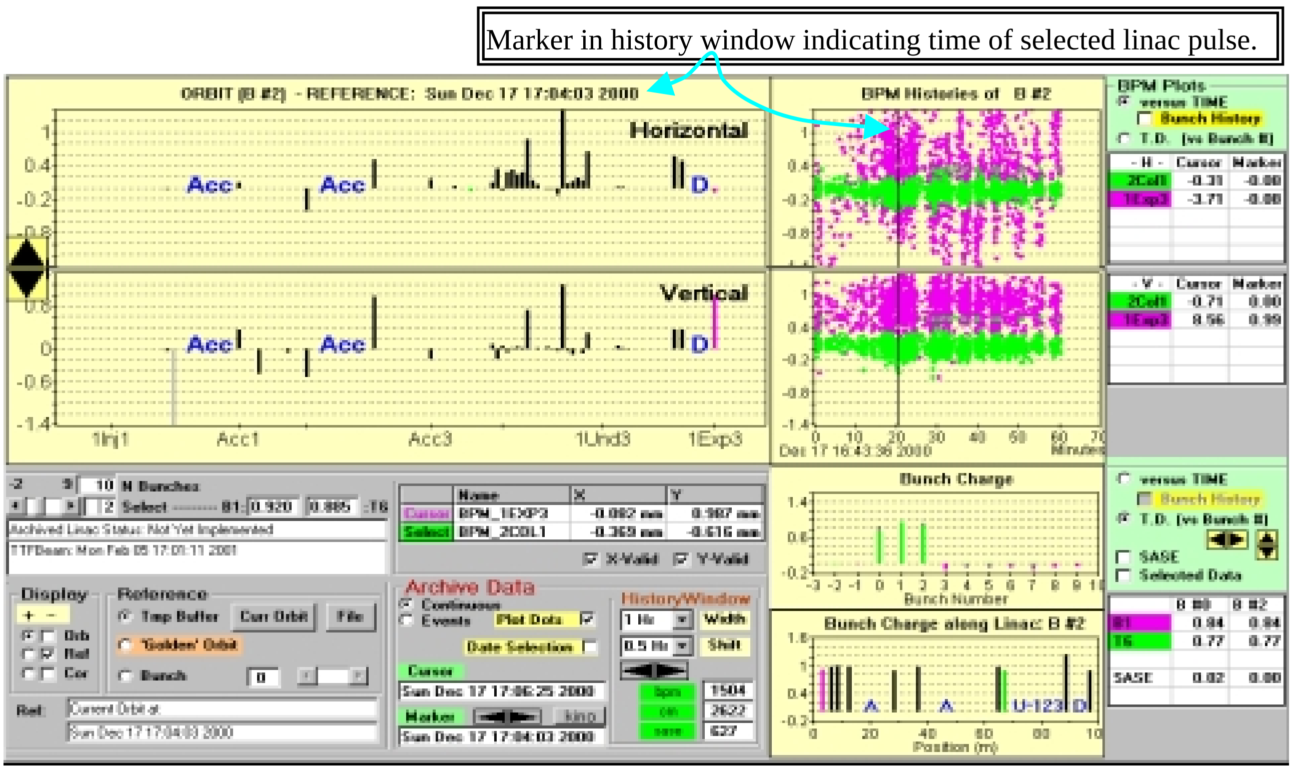


Figure 13: Difference between the orbits of Bunches #2 and #0 (the reference orbit) from the same linac pulse, at 17:04:03. Might the difference-orbits be explained by a betatron oscillation? Also shown are the positions at selected monitors for the selected bunch (B#2) over a 60-minute period.

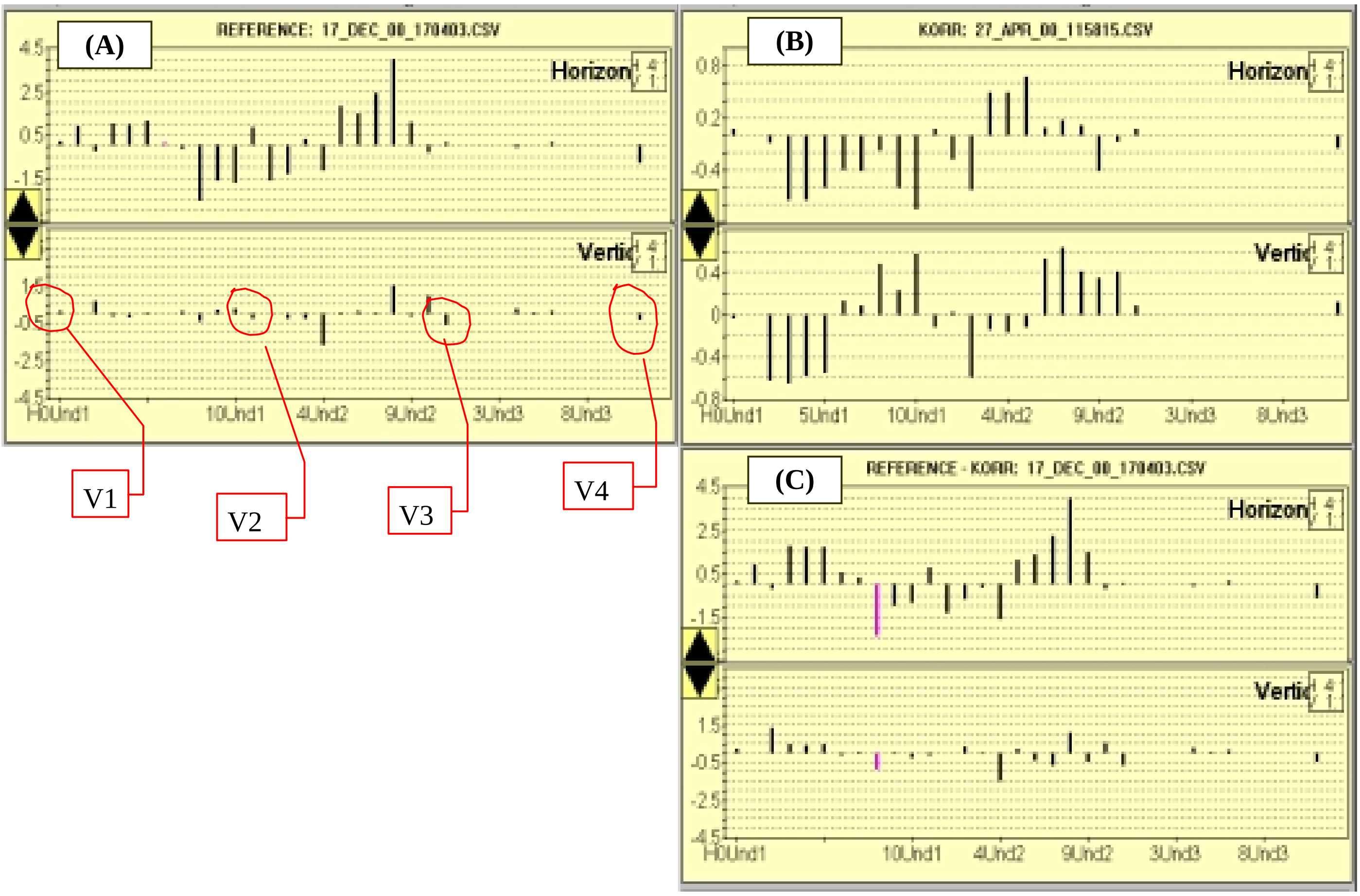


Figure 14. Reference orbits in the undulator (zoomed) including the data from wire scanner position measurements. The positions of the wire scanners are indicated in the plot of the orbit in the vertical plane.
(A) Data measured on 17 Dec 00; 3 BPMs in Undulator 3 are connected.
(B) Data measured on 27 Apr 00; no BPMs in Undulator 3 are connected.
(C) The difference of the two reference orbits.

5 OPTICS MEASUREMENTS USING GROUP-SCAN DATA

A group-scan provides 4 beam profiles in each plane. Knowing the transfer functions of the undulator modules, one can use these data to find the unknown optical parameters alpha and beta of the beam as it enters the undulator region and the beam emittance. A fit of the 3 unknowns to the four profiles has been implemented in MATLAB [3]. The optics program TRACE 3-D [4] can also be used for these calculations; as an interactive optics program it can be used to quickly gain experience with the procedures, the sensitivity of the results on errors in the measurements and in the beam energy. The required optics information for input to the program are all available from P. Castro. The results presented in this section are only qualitative; comparisons with Pedro’s results have not yet been made. The quadrupoles have been entered as single elements and the dipoles have been left out.

Shown in Figure 15 is an output of TRACE 3-D for the undulator region, starting at the end of the second accelerating module through to the spectrometer area. The beam envelopes in the two planes together with the optical elements are plotted. A zoom of the undulator region, starting at the first wire scanner station and ending at the fourth, is shown. One sees that with the optic of the incoming beam well-matched to the undulator, the beam sizes measured at the wire scanners are nearly equal, with only the small modulation by the F0D0 lattice.

The group-scan measurements made on 8 Aug 15:00, shown in Figure 7, revealed large differences in the horizontal beam size between the undulator modules, indicating a large horizontal

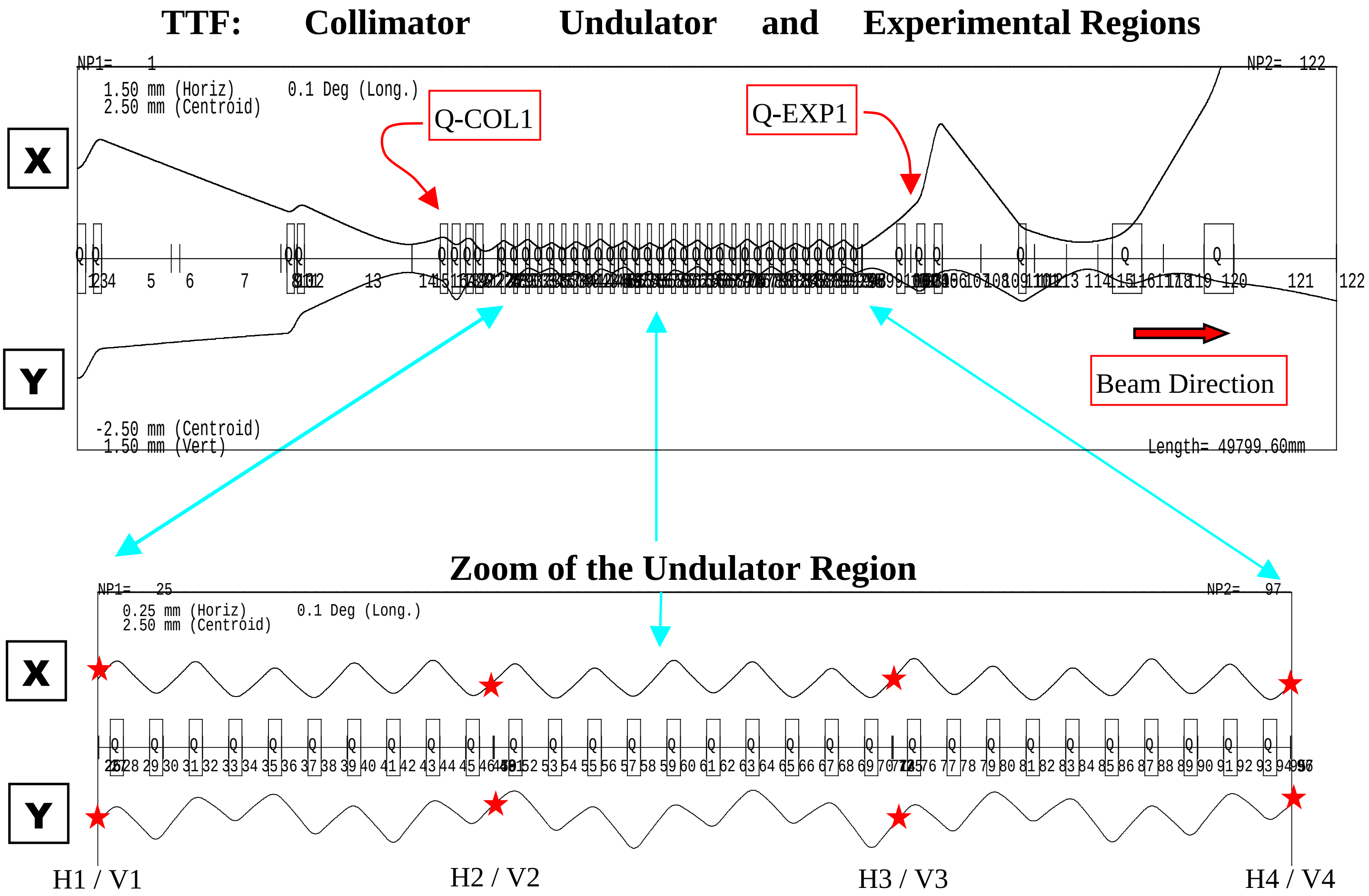


Figure 15 TRACE 3-D Output in the undulator region for "nominal" beam conditions showing optical elements and the beam envelopes in the horizontal and vertical planes. The results are only qualitative. Above: Calculations starting at the end of the 2nd accelerating module through to the spectrometer. Below: a zoom of the undulator modules, the positions of the wire scanners are indicated with stars. The beam envelope in the undulator for a well matched incoming beam is constant with only the modulation of the undulator F0D0 cells.

mis-match into the undulator. Shown in Figure 16 are the results of fitting the beam envelopes to the beam sizes measured at wire scanner stations 1, 2 and 4. The expected beam size at station 3 based on these results is 0.302 mm horizontally and 0.118 mm vertically, which is in good agreement with the measured values. For this fit the horizontal wires are positioned near the maxima and minima of the oscillation, whereas the vertical wires are not, thus the predicted vertical beta-beat is larger than that expected on the basis of the measured beam sizes. Preliminary observations based on studies of old scans indicate sensitivity of the results to the assumed beam energy (and the resulting phase advance of the undulator cells) and to errors in the profile measurements. In the case of some measurements, no solution for the optical parameters could be found. Extrapolation up- and down-stream to other profile monitors would be of interest as a consistency check.

6 SUMMARY

Software has been written to aid in the collection and analysis of data for wire scanner measurements at the TTF. A middle-layer server TTFBEAM performs the function of combining the large amount of monitor data from each linac pulse into objects for other clients; a central archiving system, a copy of one in use at HERA, is used to collect complete beam diagnostic data objects from TTFBEAM and to store them with machine settings and other slowly varying

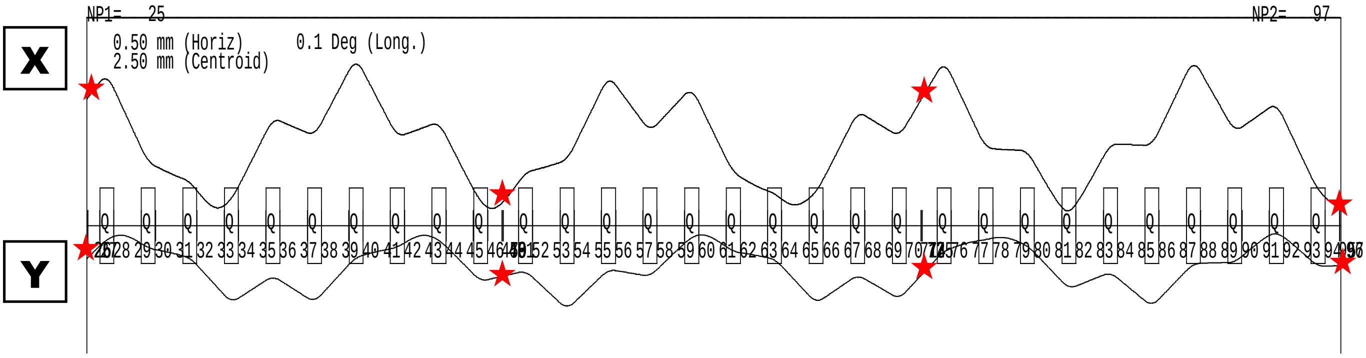


Figure 16. TRACE 3-D output for the undulator region after fitting the beam envelopes to the values measured at scanner stations 1, 2 and 4 on 8 Aug 15:00 (shown in Figure 6). A large mis-match of the beam entering the undulator is calculated. The positions of the wire scanners are indicated with stars. Note that for this solution the horizontal beam size is measured near the maxima and minima of the beta-beat; this is not the case in the vertical plane.

parameters for later analysis. Console applications for the display and analysis of wire scanner profiles, of the beam orbit and charge, and of the data stored by the central archiving system have been shown. The problem of access to the large amount of data needed to interpret wire scanner measurements has been addressed; the applications have been written with the intention of being used on-line, with required “off-line analysis” features built-in for simplicity.

Simple qualitative analysis of the beam profiles is revealing. The distributions are often well described by a Gaussian, but some measurements show non-Gaussian features of the beam, including asymmetries and tails. Measurements in each plane at the four diagnostic blocks are useful to detect optic errors of the beam coming into the undulator: The beam sizes at the four locations are often nearly equal, as expected, but some measurements show large deviations, indicating a large mis-match with resulting beta-beat. These qualitative features are easily visible using the console-application described here.

Quantitative analysis of the profiles and the determination of the beam emittance require analysis of the jitter and drifts in the beam orbit and charge during the scans. Noise in the measurements must also be taken into account. The use of complete diagnostic information from each pulse is necessary to accomplish these goals. The software tools described here are only a first step; work on additional analysis software, for example using Model-Independent-Analysis, is necessary.

ACKNOWLEDGEMENTS

I would like to thank the Wire Scanner Team for the interesting collaboration. I would like to thank Phil (“Just do it”) Duval for his tireless enthusiasm for the required Infrastructure Software: for the gateways to the data in the DOOCS servers, for the middle-layer server to combine the data into client-friendly “objects”, for the central archive system for storing and delivering the data… u.s.v.m…. The Visual Basic programs shown in this note are, after all, just Oberflaechen…..

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