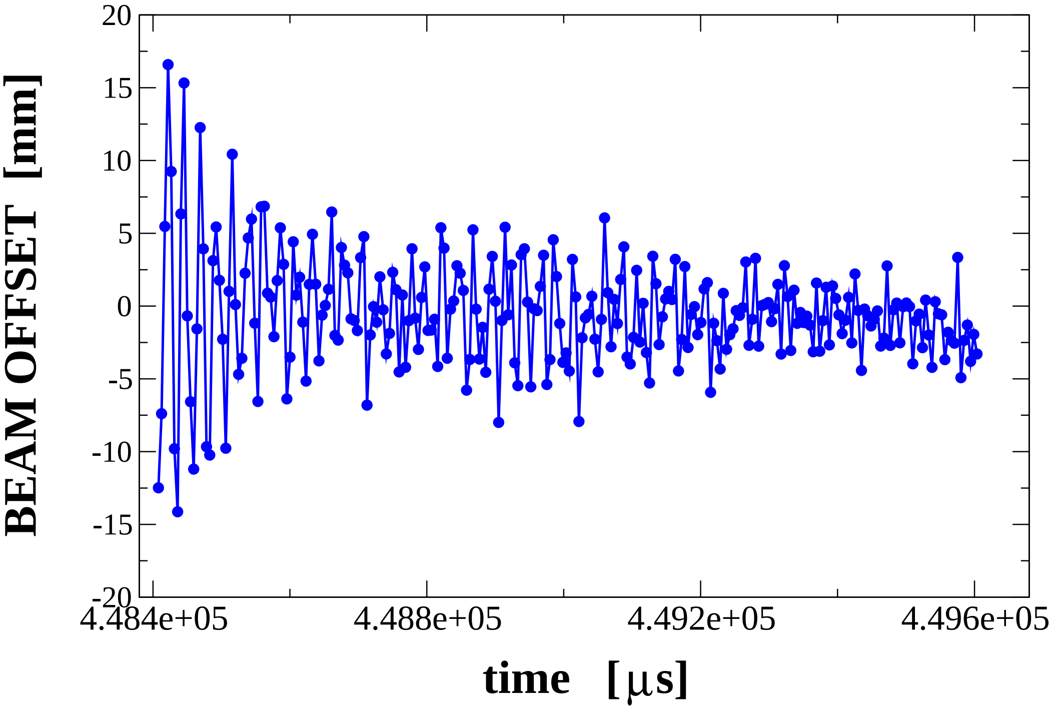
NEW PC DATA ACQUISITION SYSTEM

RESULTS OF THE FIRST TEST
IN THE SIS USING A KICKED BEAM

23,10,2003


VERTICAL BETATRON OSCILLATIONS [256 turns]

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Chapter 1

Experiment results

1.1 General considerations

The aim of this experiment was to test the new data acquisition system to perform turn-by-turn BPM sampling. This goal has been achieved using a fast PCI card with four channels installed on a PC, the master RF signal as clock and the event generator as trigger. The on-line software written by Peter Moritz provides a binary file containing the data from each channel (integer number $0 < I < 2^{12} - 1 = 4095$). The post-processing software written by Andrea Franchi reads this file, converts the Σ and Δ signals in Volt, isolates the betatron oscillations from the full data set and rescales the oscillation pattern in millimeters. The FFT of this pattern is then performed and the main spectrum peaks (position, amplitude and phase) are detected and saved on file.

As first application, we measured the SIS-18 tunes, using only two channels of one PCI card (Σ and Δ signal from a phase pick-up). The next steps consist in using all the four channels to perform a simultaneous sampling in both planes, and, later on, to install two cards with four channels to get the position data in both planes from two BPMs.

The present setup is already suitable to measure the chromaticity, whereas for the magnet strength measurement using the Normal Form we need the complete setup with two PCI cards.

1.2 Physics considerations

- The measured betatron tunes are different with respect to the input values given in `SISMODI` (see fig. 2.2):

$$\begin{array}{ll} Q_x = 0.3189 \pm 0.0002 \;\; [.2900] & \quad Q_y = 0.1971 \pm 0.0005 \;\; [.2100] \\ Q_x = 0.3379 \pm 0.0002 \;\; [.3100] & \quad Q_y = 0.1875 \pm 0.0001 \;\; [.2000] \end{array}$$

$$Q_x^{EXP} - Q_x^{INPUT} \simeq 0.028 \qquad Q_y^{EXP} - Q_y^{INPUT} \simeq 0.013$$

These differences are historically known (0.02 in x and 0.01 in y). The presence of the solenoidal field from the cooler during our measurement could be the reason of the discrepancy with the historical data.

- The solenoidal field from the the cooler produces a linear coupling between the two planes. The presence of the horizontal tune line in the vertical spectrum $V(1,0)$ is a proof of this and it is a good indication that this analysis is suitable for linear coupling study using the Normal Form. We expected to observe also the vertical tune line in the horizontal spectrum $H(0,1)$ but this did not occur, probably because of the poor signals from the horizontal pick-up.
- The measured betatron tunes are well reproducible. The performed FFT using N =256 turns ensures us an error $\propto 1/N^2 \approx 10^{-5}$. The maximum measured fluctuation is within 0.3% (Q_y in the first set).
- The betatronic oscillations in the vertical plane and their decoherence patterns are more evident than the horizontal ones.
- The synchrotron tune has been also measured but with a lower precision. One of the effects of a non-zero chromaticity is to add sidebands to the spectral lines at distance $\pm qQ_s$, where Q_s is the synchrotron tune and q is an integer. From the spacing between the sidebands Q_s can be inferred. Such “satellite” lines have been observed during our measurement (one example is shown in the center plot of fig. 2.3), providing the following values:

  $$Q_s = 0.0038 \pm 0.0012$$

  to be compared with the nominal value [1]

  $$Q_s = \sqrt{\frac{|\eta| e h \hat{V} Z}{2\pi m_p \gamma \beta^2 c^2 A}} \simeq 0.0045$$

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[1] $\eta = 0.93696$,$h = 4$,$\hat{V} = 2$ kV,$Z = 47$,$A = 124$, $m_p = 1.67 \cdot 10^{-27}$kg,$\gamma = 1.0120$,$\beta = 0.15361$

The measured value is compatible with the predicted one but the uncertainty is rather large ($\approx 30\%$). Such an error is due to the fact that the tunes are known up to the third digit, with an uncertainty on the fourth. Since the distance between the tune lines and the sidebands is $\propto 10^{-3}$, an error on the fourth digit produces such a big relative error.

- As shown in tab. 1.4, the first satellites are not always detected. The reason is the following. The FFT routine provides only the position and the amplitude of the main spectral lines as they were delta functions. The routine performs the FFT of the data, detects the most prominent peak, subtracts this contribute from the data set (via the inverse FFT) and performs again the FFT of the new data. This is done recursively for ten times. Nevertheless the "physical" spectrum contains broad lines[2]. If two peaks overlap, one of the peaks could not be detected, since, when the inverse FFT is performed, also its contribution is removed. An example of this mechanism is shown in the bottom plot of fig. 2.3. At the step 1 (red), the tune peak is detected. Its contribution is removed and another FFT is performed in the step 2 (blue). The tune peak is not there anymore and the most prominent peak is the one corresponding to the first satellite $Q_y + Q_s$. This procedure is repeated and at the third step (green) the second satellite $Q_y - 2Q_s$ is detected. Removing its contribution, also the $Q_y - Q_s$ (expected) peak is deleted as shown by the orange line (step 4). To avoid such a mechanism, it is helpful to increase the decoherence time in order to have more than 256 data for the FFT and consequently a better resolution. It can be helpful also to increase the synchrotron tune applying a higher RF voltage (see the above formula): we applied 2 kV, whether applying 10 kV (the maximum available) we could about double Q_s, making sure that the bunch would still be matched to the bucket.

1.3 Technical considerations

- The data acquisition system didn't ensure the PCI card to sample always the kicked bunch. As shown in the sixth column of the tables in sec. 1.4 and the pairs of bunches sampled by the PCI card are different from one measurement to the other.

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[2] Actually also the FFT produce an intrinsic "spread". Since the samled data are limited in the time domain (in our case 256 turns), the FFT is in reality a convolution between the pure Fourier Transform of the data and the sinc(ν) function, which produces spread arround the peak and sidebands.

- A periodic BPM noise has been detected during the measurement. It produced the spectral line .410 in all the spectra, for both the Δ and the Σ signals. It corresponds to a frequency $f_n = .410 \cdot f_{rev} \simeq .410 \cdot 2.13 = 87.43$ kHz. For the present and future analysis such periodic noise can be neglected as long as the .410 line does not overlap with a resonance line.
- Part of the beam was lost after each kick, as suggested from the decrease of the Σ signals shown in the second plot of each measurement, no matter how we set the voltage of the Q-kicker.

beam	124Xe+47
energy	11.27 MeV/u
machine	speichermode_E*
RF-freq	853.009 KHz
rev-time	4.689282 μs
particles/μA	0.623E+06
cooling	MMI-kulzeit: 400.1 ms
	ku-dp/p-Inj: 0.0
	ku-glob. : 0
	rauf/run : 0.0
	kuhlerf.inj: 600.0 G
	kuhlerst. : 0.3 A
	wartenzeit : 0.0 ms

Table 1.1: Machine parameters

1.4 File tables and measured tunes

Tune table:

- first column: file name;
- second column: the plane analyzed;
- third column: the kick voltage set in the nodal program `MK`;
- fourth column: the kick phase set in the command # 23 of `TIMGEN` (for details about these two programs see the previous report on the chromaticity measurement);
- fifth column: if a kicked bunch has been sampled the file is flagged as “good”, if the kicked bunch has been rejected from the PCI card no oscillation are observable (“no osc.”);

- sixth column: indicates which of the two sampled bunch is kicked;
- seventh and eighth columns: measured fractional part of the tunes.

Qx = 4.29 Qy = 3.21

file #	plane	kick vol.	kick phase	result	kicked bunch	Q_x^m	Q_y^m
10	ver.	34 kV	48	no osc.			
11	ver.	34 kV	48	no osc.			
12	ver.	34 kV	48	good	third	.3186	.1969
13	ver.	34 kV	48	good	first	.3190	.1977
14	ver.	34 kV	48	good	first	.3190	.1979
15	hor.	34 kV	48	no osc.			
16	hor.	34 kV	48	no osc.			
17	hor.	34 kV	48	no osc.			
18	hor.	32 kV	48	no osc.			
19	hor.	32 kV	48	no osc.			
20	hor.	32 kV	48	good	third	.3190	
21	hor.	32 kV	68	no osc.			
22	hor.	32 kV	68	no osc.			
23	hor.	32 kV	68	good	third	.3188	
24	ver.	32 kV	68	good	third	.3190	.1968
25	ver.	34 kV	68	good	first	.3192	.1967
26	ver.	34 kV	68	good	third	.3187	.1967
27	ver.	34 kV	88	good	first	.3189	.1969

Table 1.2: Data files description and corresponding measured betatron tunes [first set].

Qx = 4.31 Qy = 3.20

file #	plane	kick vol.	kick phase	result	kicked bunch	Q_x^m	Q_y^m
28	ver.	34 kV	88	good	first	.3379	.1876
29	ver.	34 kV	88	good	third	.3380	.1876
30	hor.	34 kV	88	good	first	.3380	
31	hor.	NO KICK	88				
32	ver.	NO KICK	88				
33	ver.	34 kV	88	good	third	.3383	.1874
34	ver.	34 kV	88	good	third	.3377	.1875
35	ver.	34 kV	88	no osc.			
36	hor.	34 kV	88	good	first	.3378	
37	hor.	34 kV	88	good	first	.3378	

Table 1.3: Data files description and corresponding measured betatron tunes [second set].

file #	first satellite	second satelite	third satellite
	Q_s	$2Q_s$	$3Q_s$
12	0.00375	0.008052	
13		0.00570	
14		0.00607	
23	0.00378		
24	0.00403	0.00765	
25	0.00360	0.00722	
26	0.00371	0.00767	
27	0.00460	0.00737	
28	0.00389	0.00753	
29	0.00339	0.00844	
30*	0.00201	0.00574	
33	0.00368		
34	0.00400		0.011516
36	0.00360		
37	0.00448	0.00937	

Table 1.4: Measured synchrotron tune from the “satellite” sideband distance. * means that this file has been rejected.

Chapter 2

Plots and spectra

BPM noise

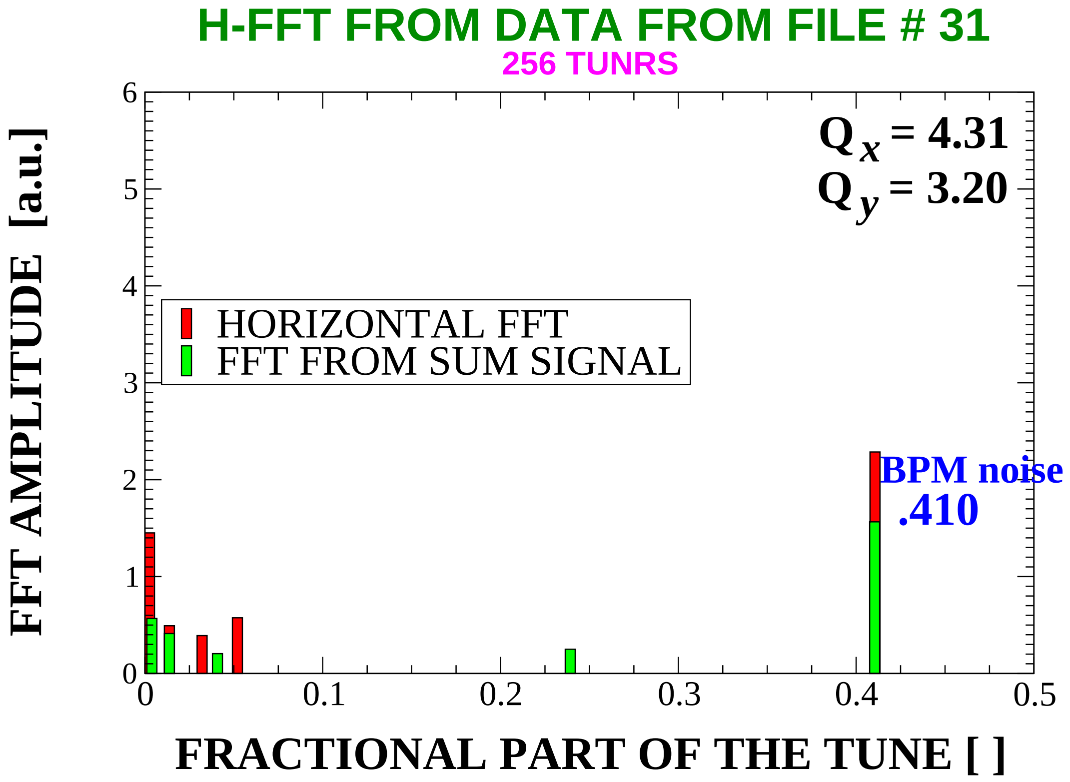

Figure 2.1: **The beam is not kicked: "fake" oscillations are observed anyway in both signals (SUM and DIFF): this suggests that these are produced by electric noise. The frequency corresponding to the .410 peak is $f_n = .410 \cdot f_{rev} \simeq .410 \cdot 2.13 = 87.43$ kHz. This peak was always present during our measurement.**

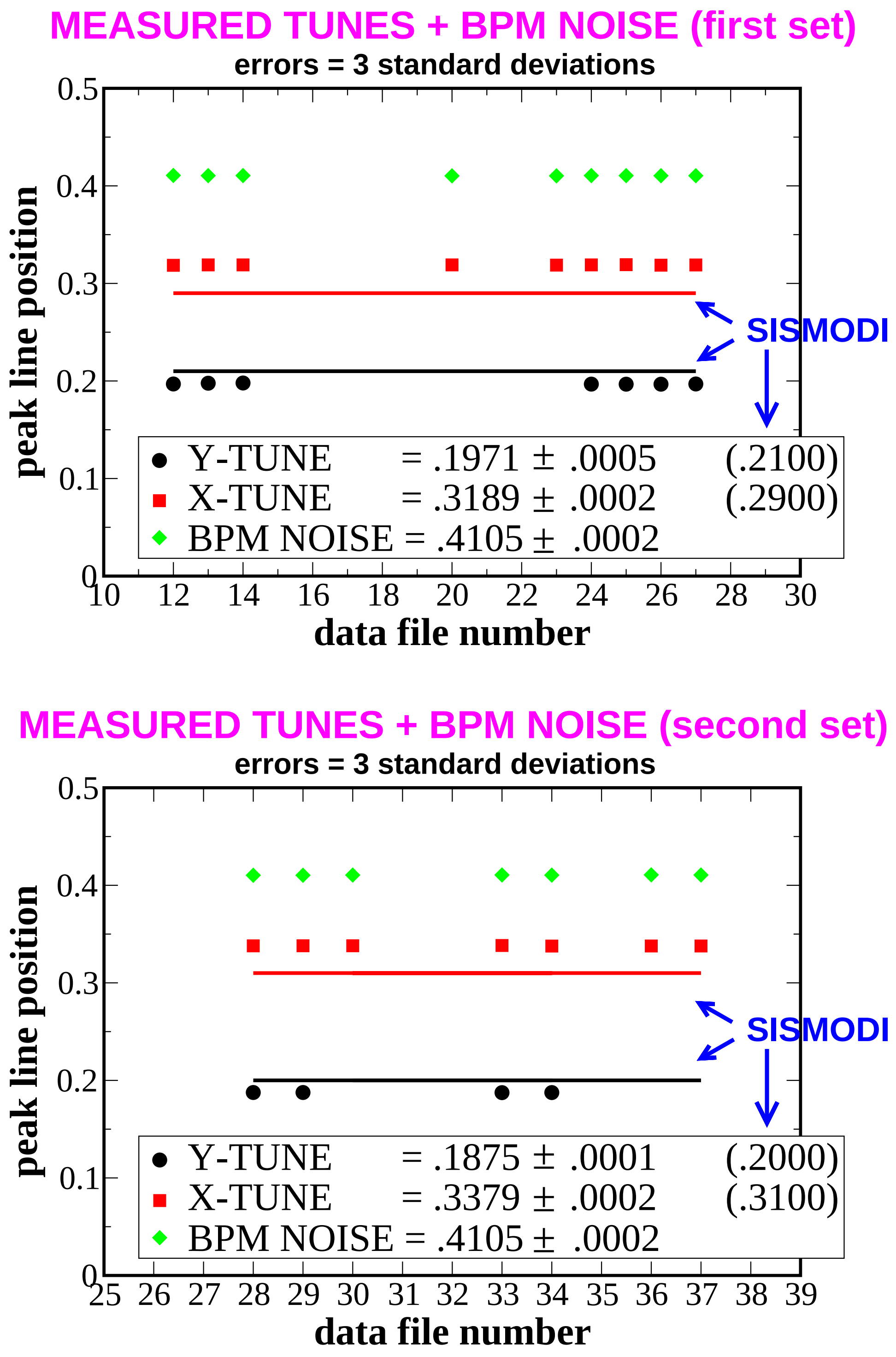

Figure 2.2: Measured betatron tunes for two different working points. In brackets the input values set in SISMODI. In the abscissa the numbers corresponding to the data file listed in the previous tabel are shown.

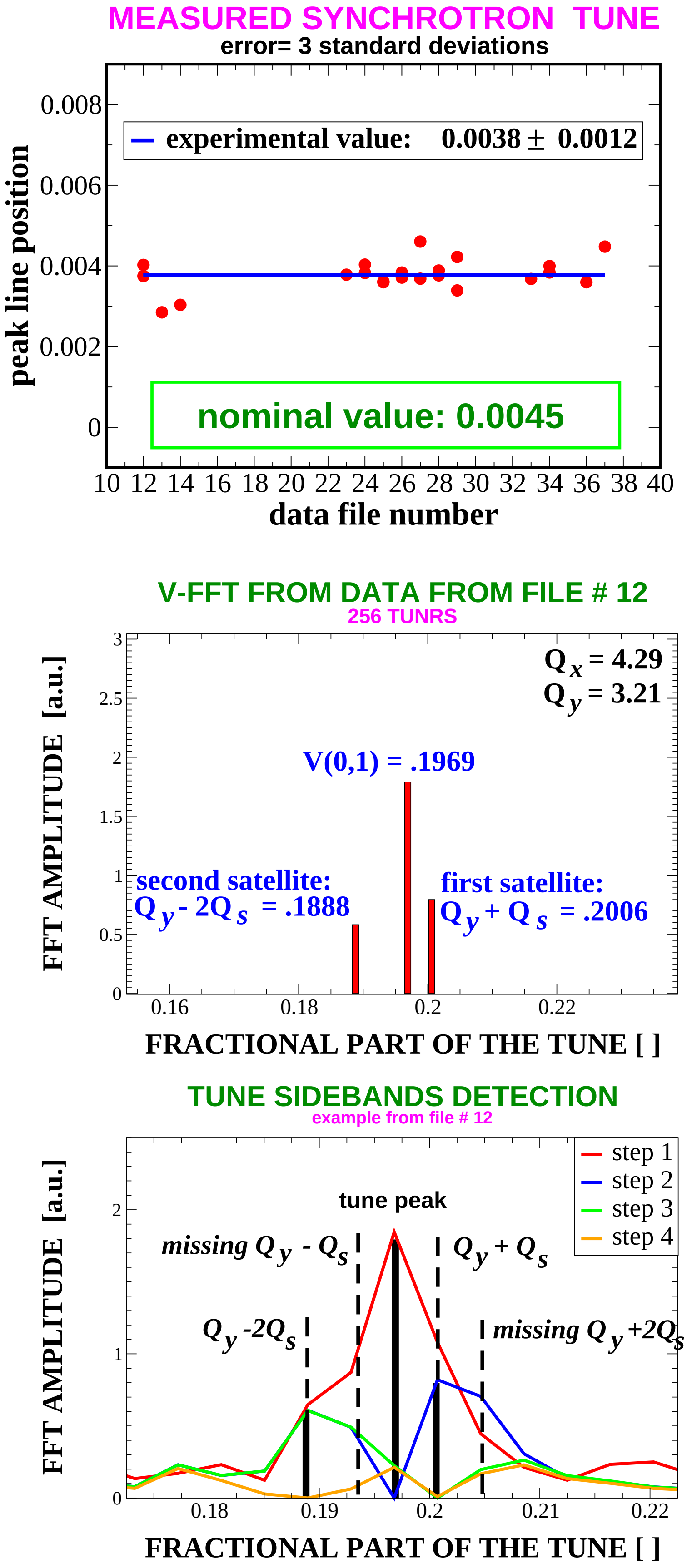

Figure 2.3: Measured synchrotron tune (*top*) and example of satellite lines close to the betatron tune due to chromaticity (*center*). The bottom picture is an example that shows how the satellite peak $Q_y - Q_s$ can not be detected: it has been hidden by the neighbor broad satellite line $Q_y - 2Q_s$.

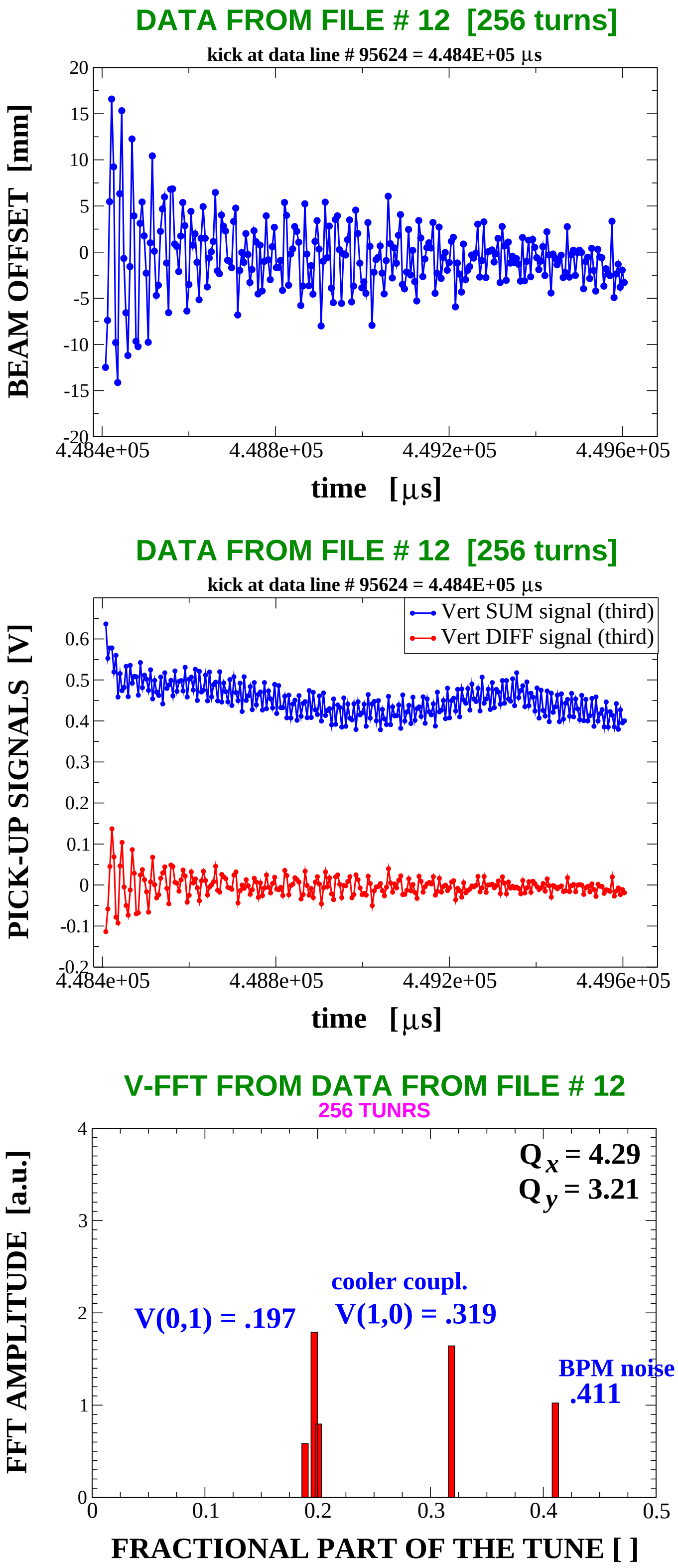

Figure 2.4: **Vertical data [kick voltage =34 kV ,kick start phase = 48, kicked bunch = third].**

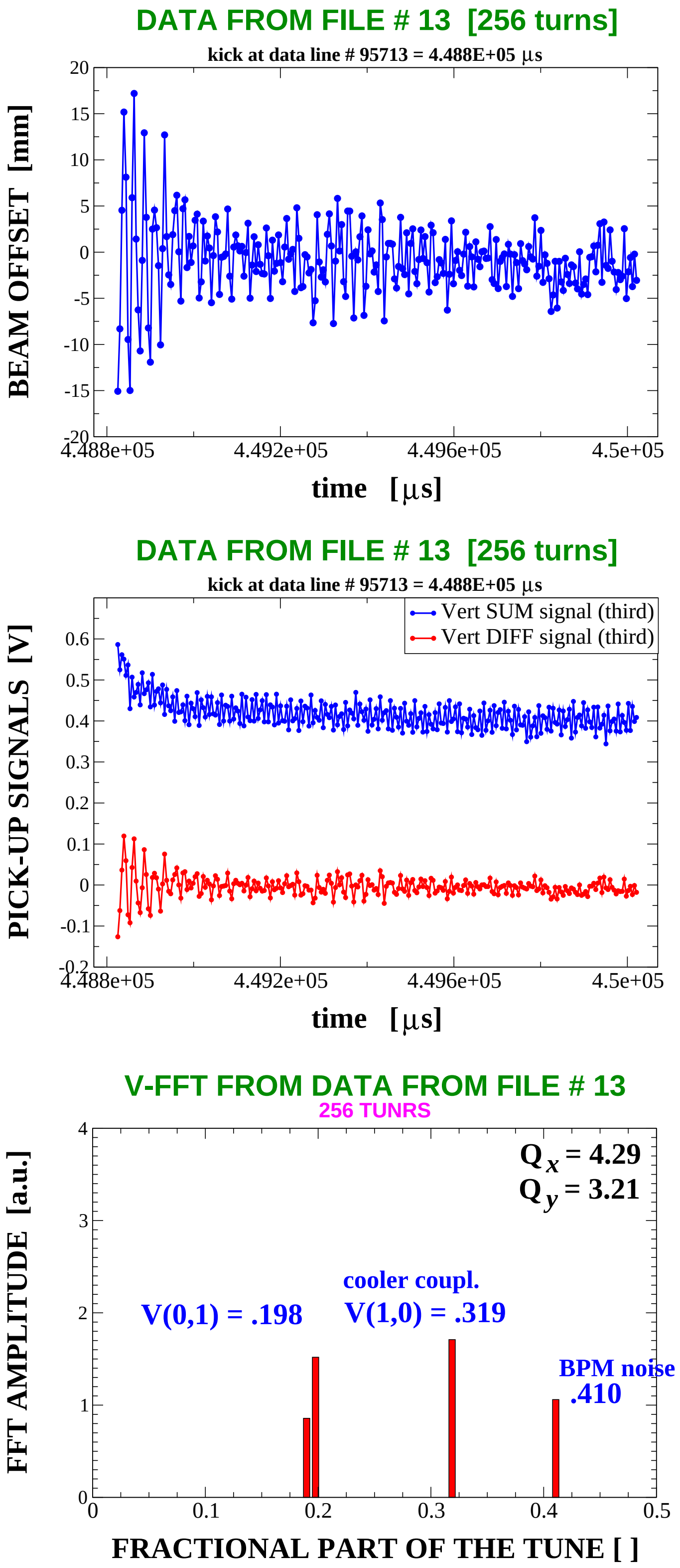

Figure 2.5: **Vertical data [kick voltage =34 kV ,kick start phase = 48, kicked bunch = first & third].**

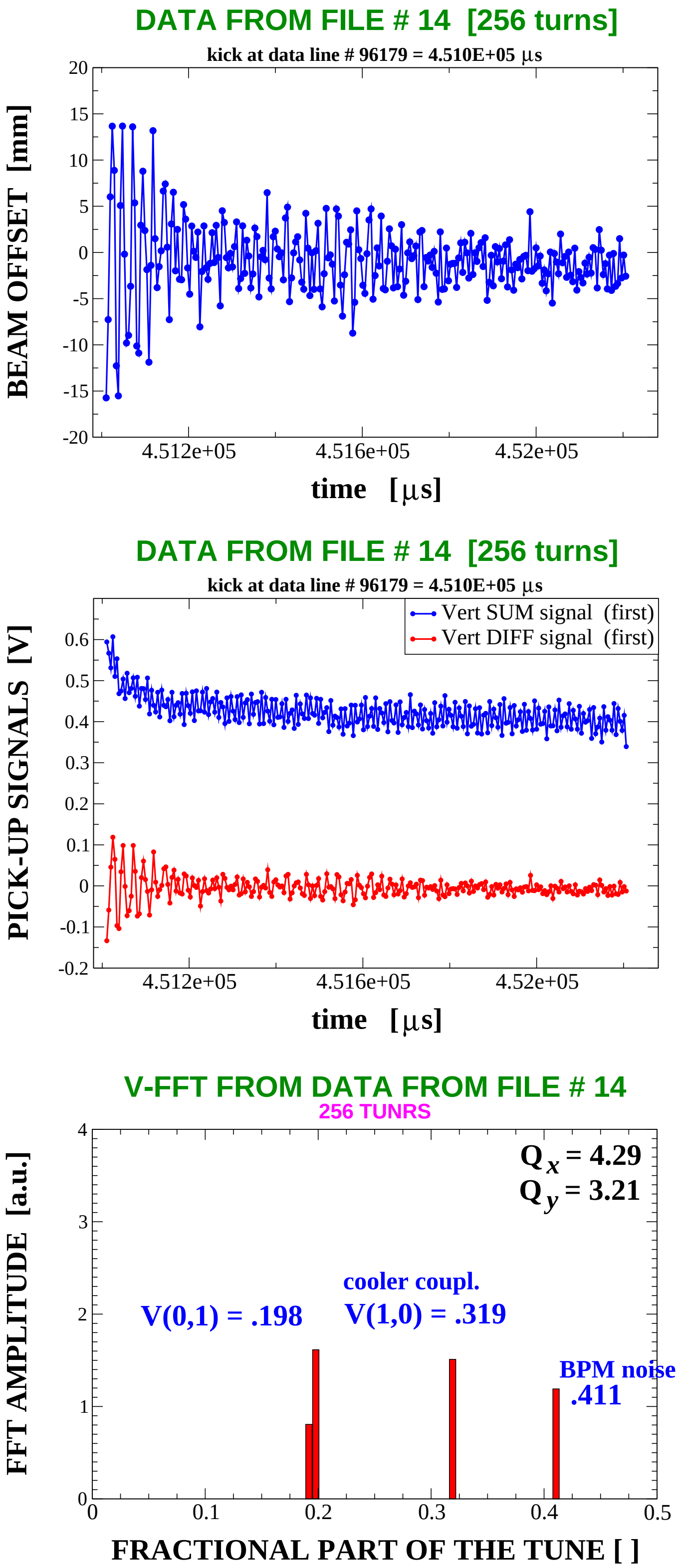

Figure 2.6: **Vertical data [kick voltage =34 kV ,kick start phase = 48, kicked bunch = first].**

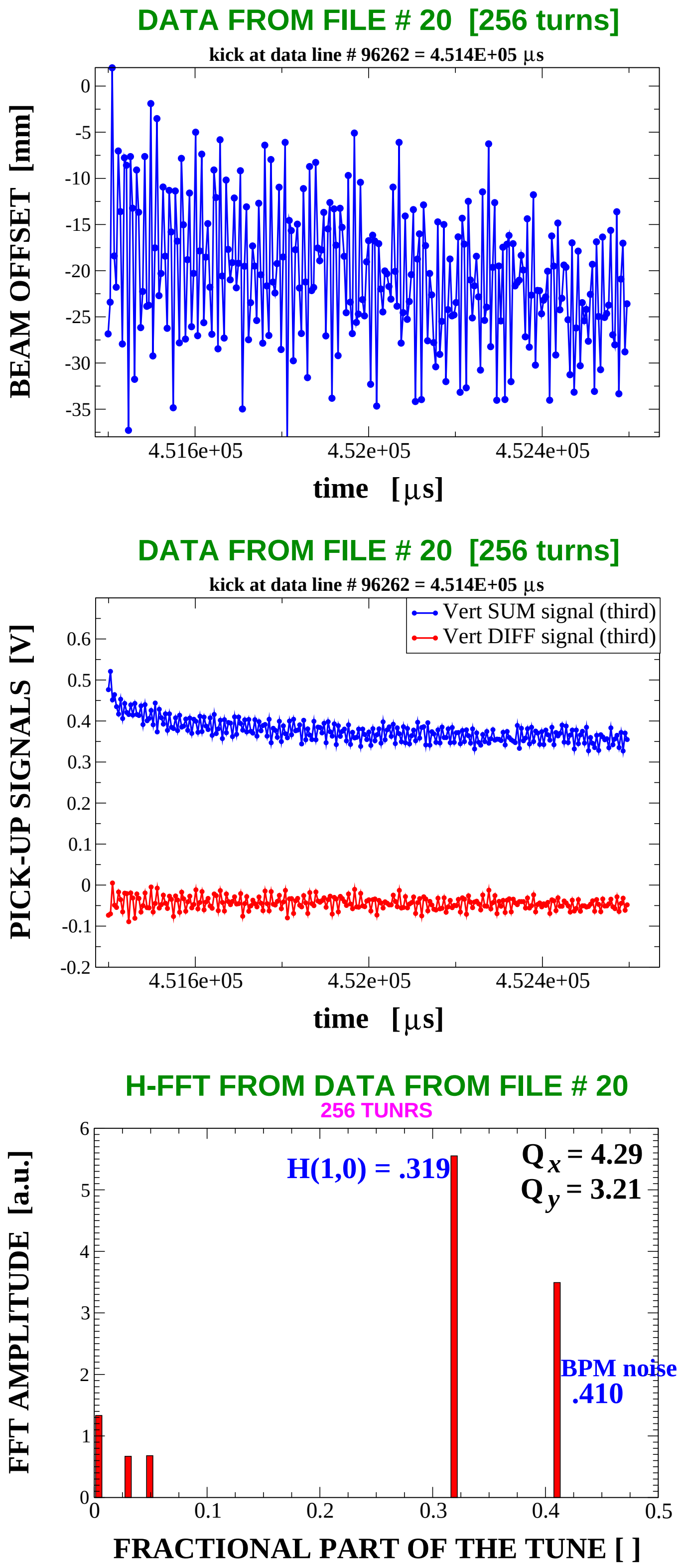

Figure 2.7: **Horizontal data [kick voltage =32 kV ,kick start phase = 48, kicked bunch = third].**

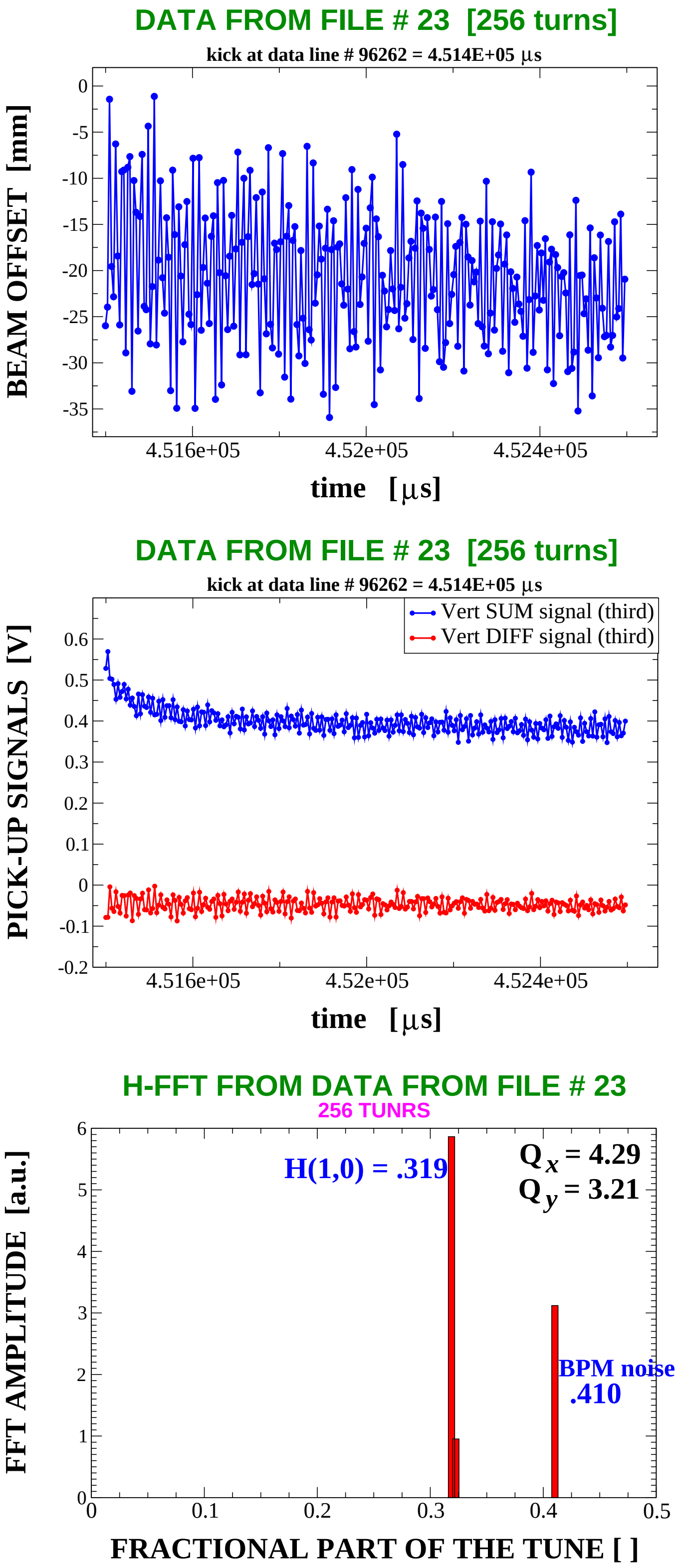

Figure 2.8: **Horizontal data [kick voltage =32 kV ,kick start phase = 68, kicked bunch = third].**

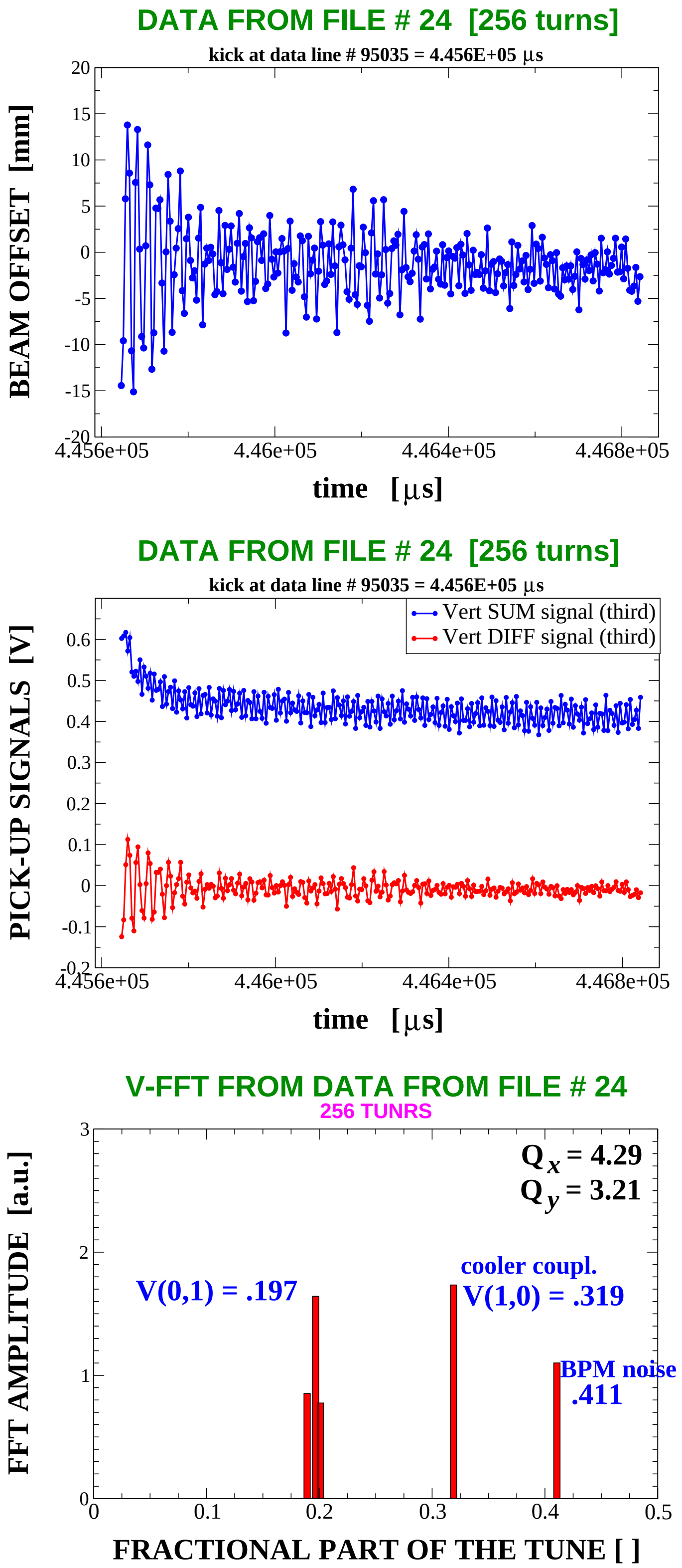

Figure 2.9: **Vertical data [kick voltage =32 kV ,kick start phase = 68, kicked bunch = third].**

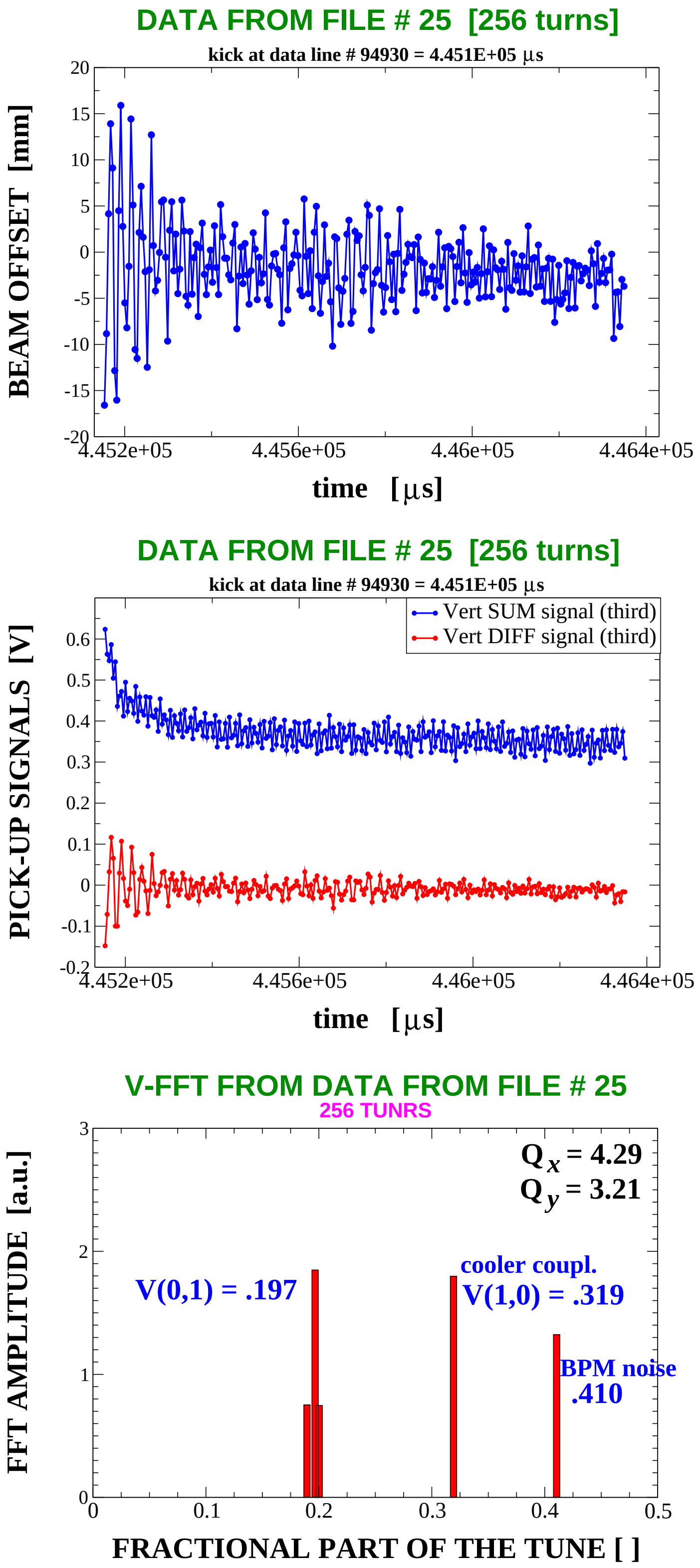

Figure 2.10: **Vertical data [kick voltage =34 kV ,kick start phase = 68, kicked bunch = first].**

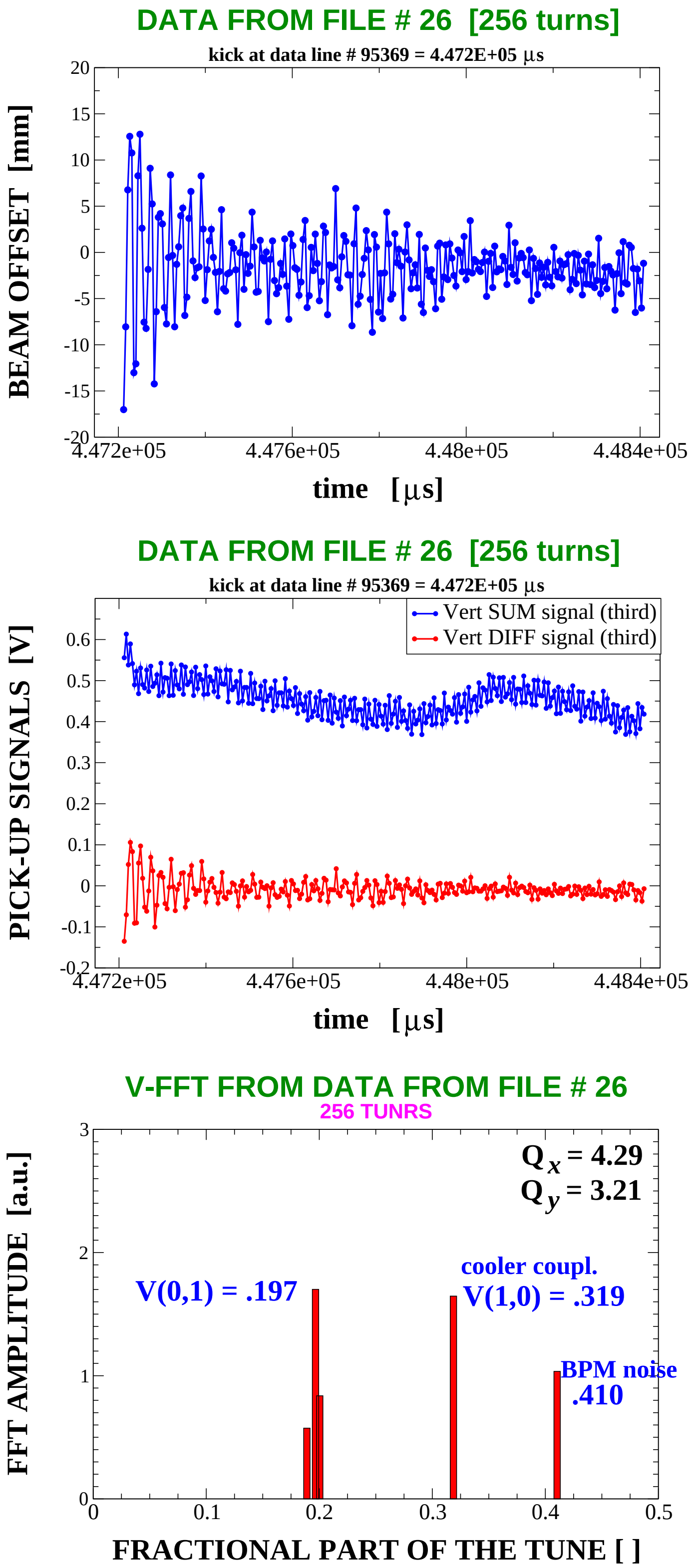

Figure 2.11: **Vertical data [kick voltage =34 kV ,kick start phase = 68, kicked bunch = third].**

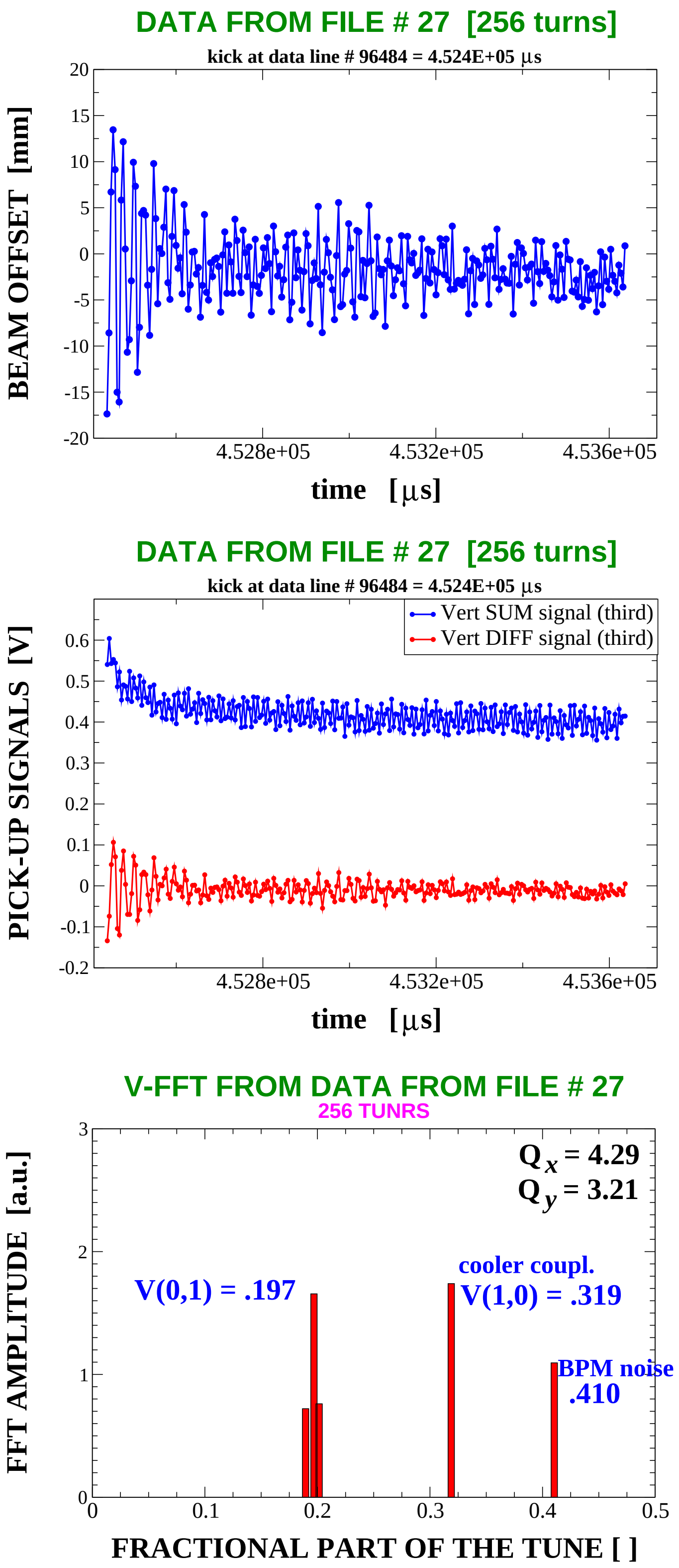

Figure 2.12: **Vertical data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = first].**

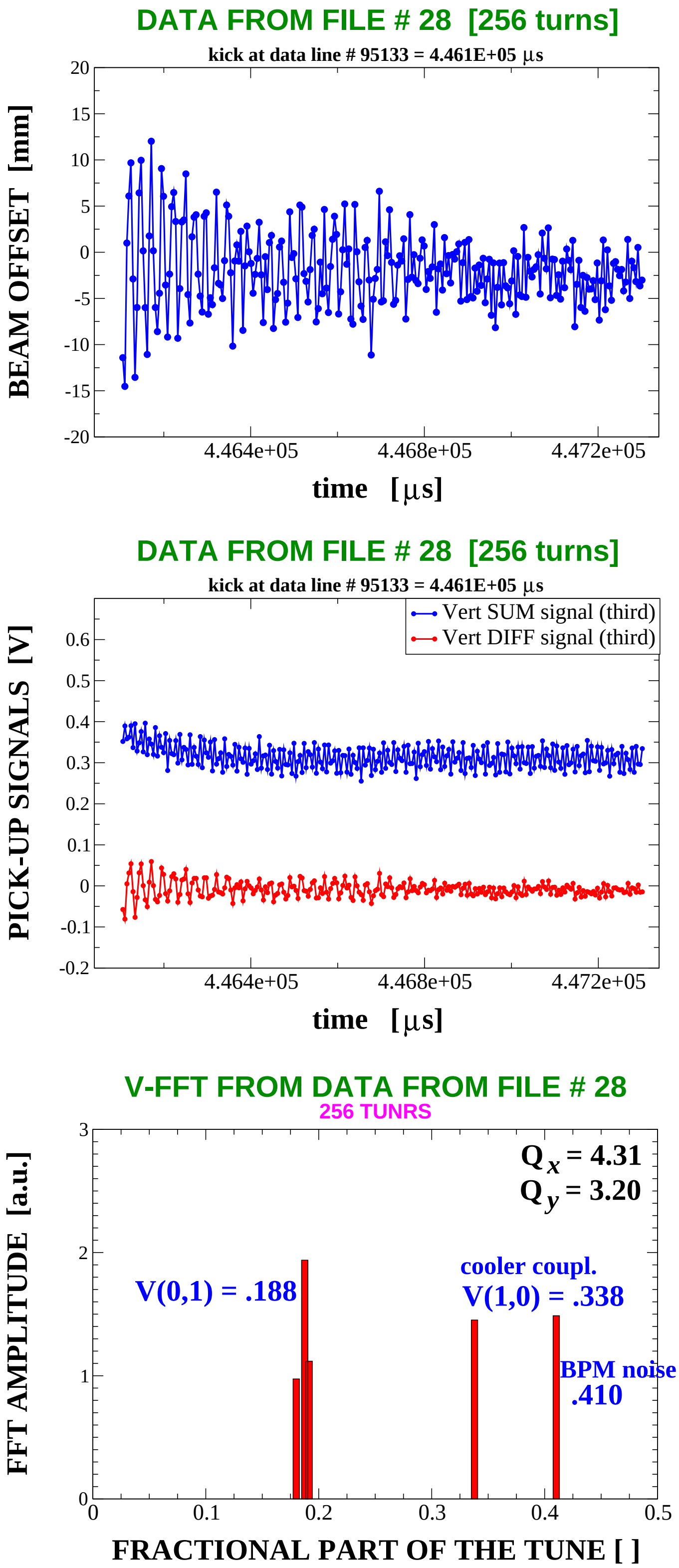

Figure 2.13: **Vertical data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = first].**

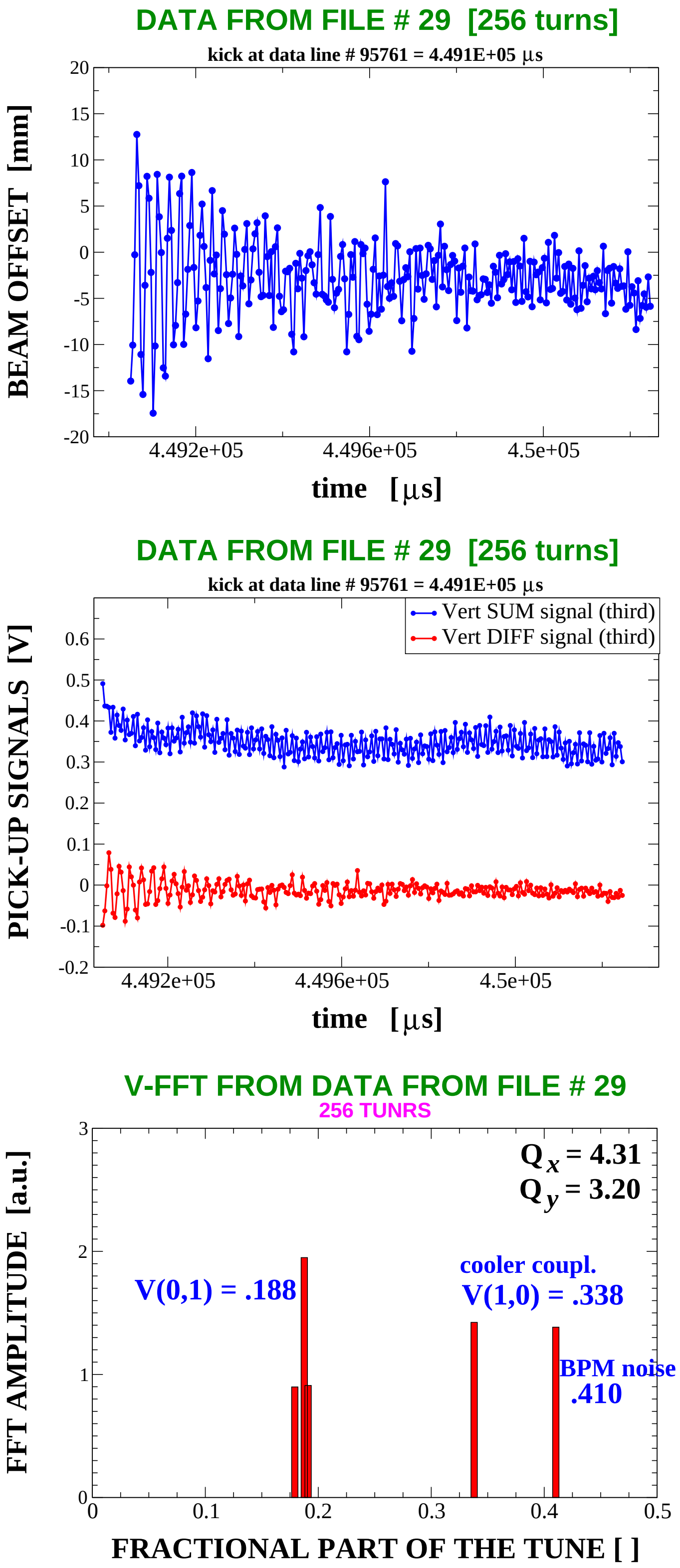

Figure 2.14: **Vertical data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = third].**

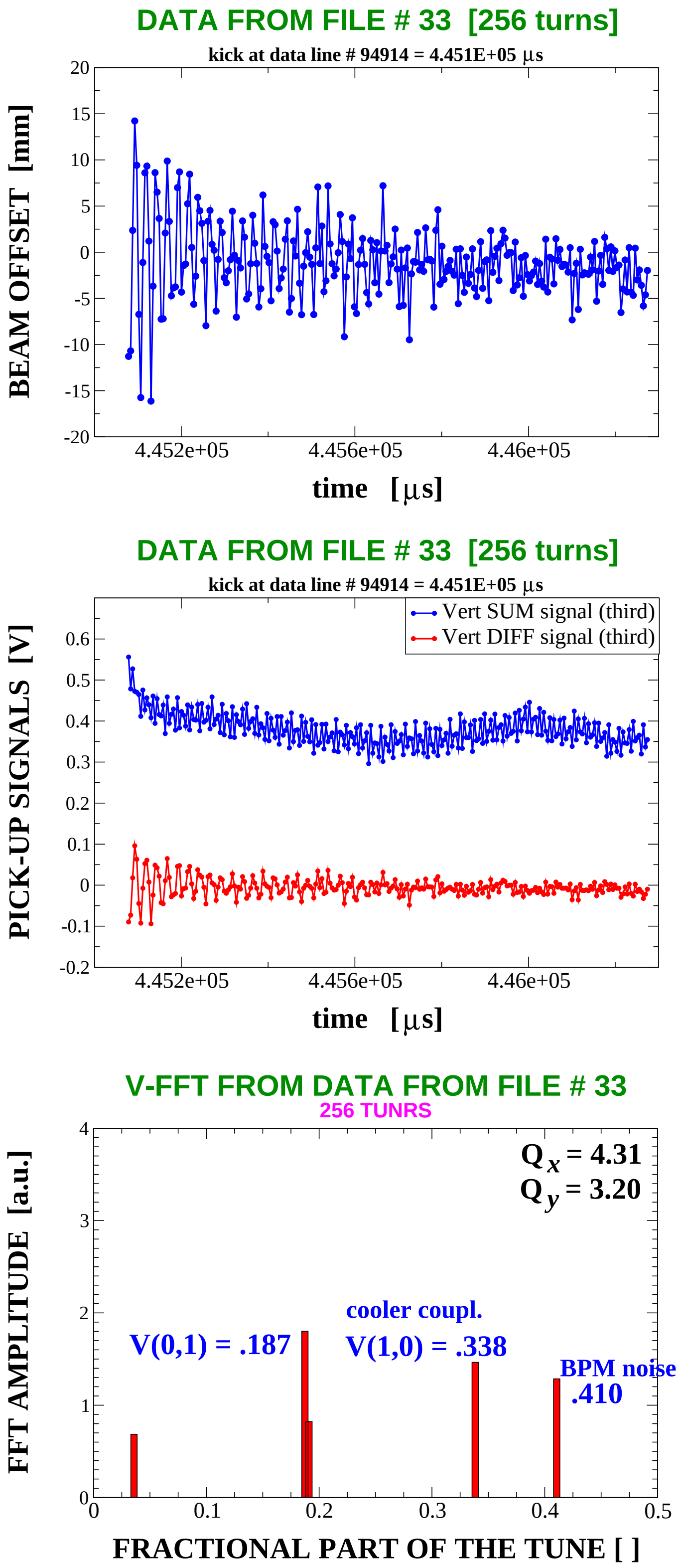

Figure 2.15: **Vertical data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = third].**

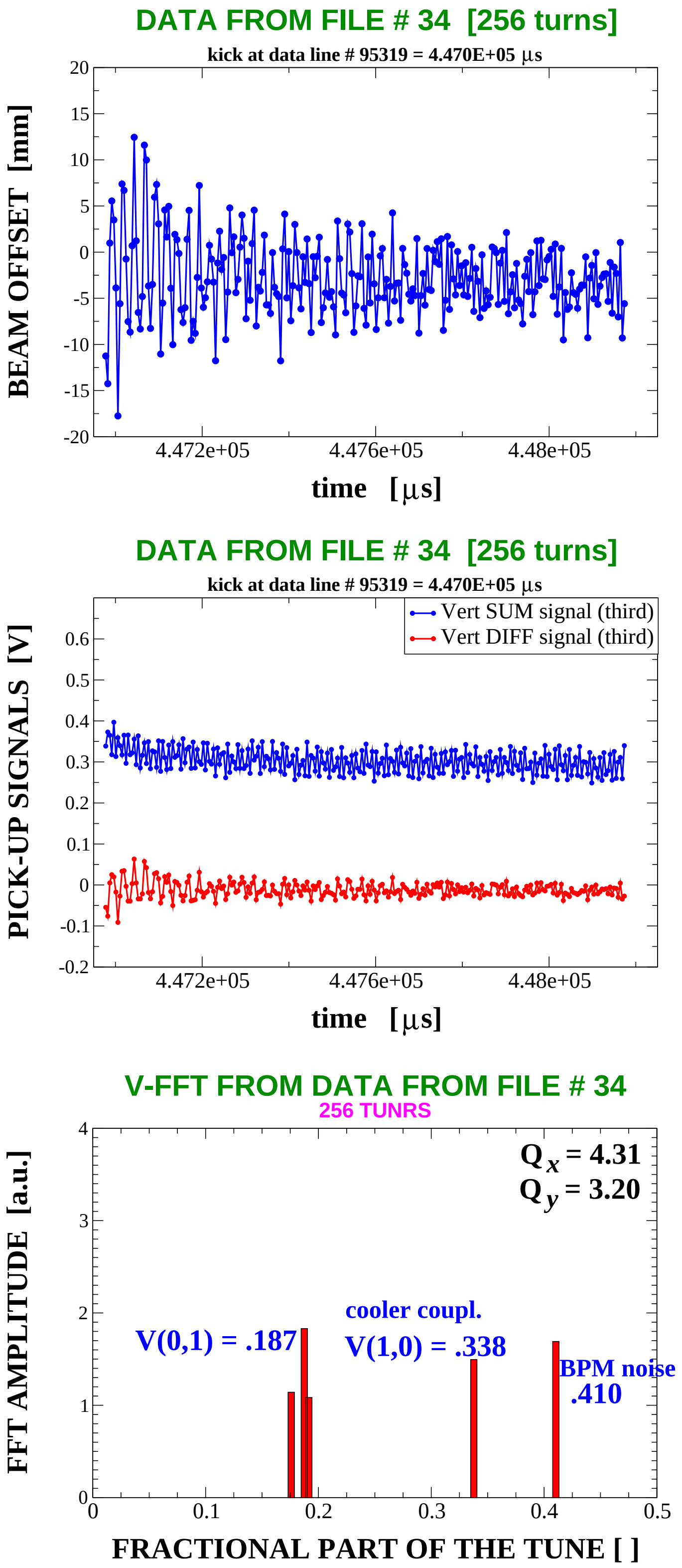

Figure 2.16: **Vertical data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = third].**

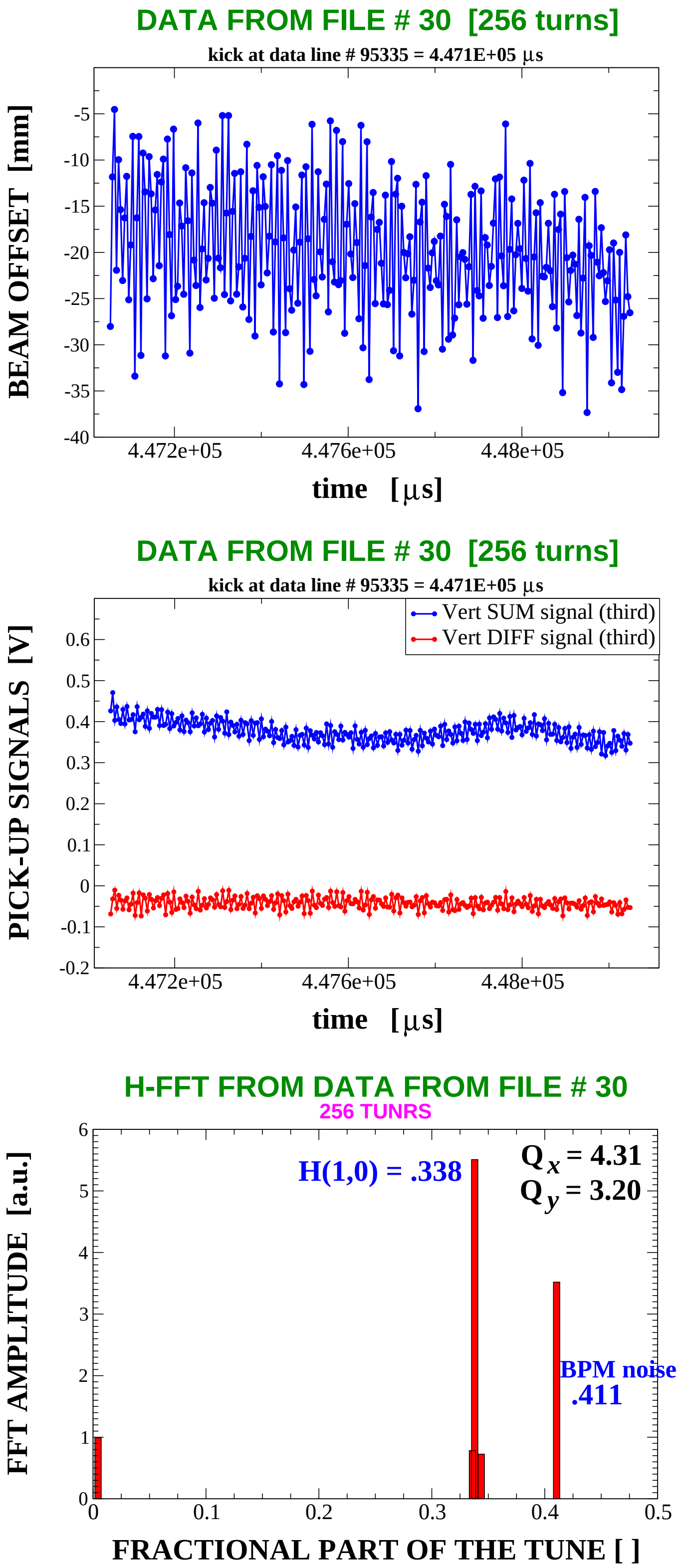

Figure 2.17: **Horizontal data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = first].**

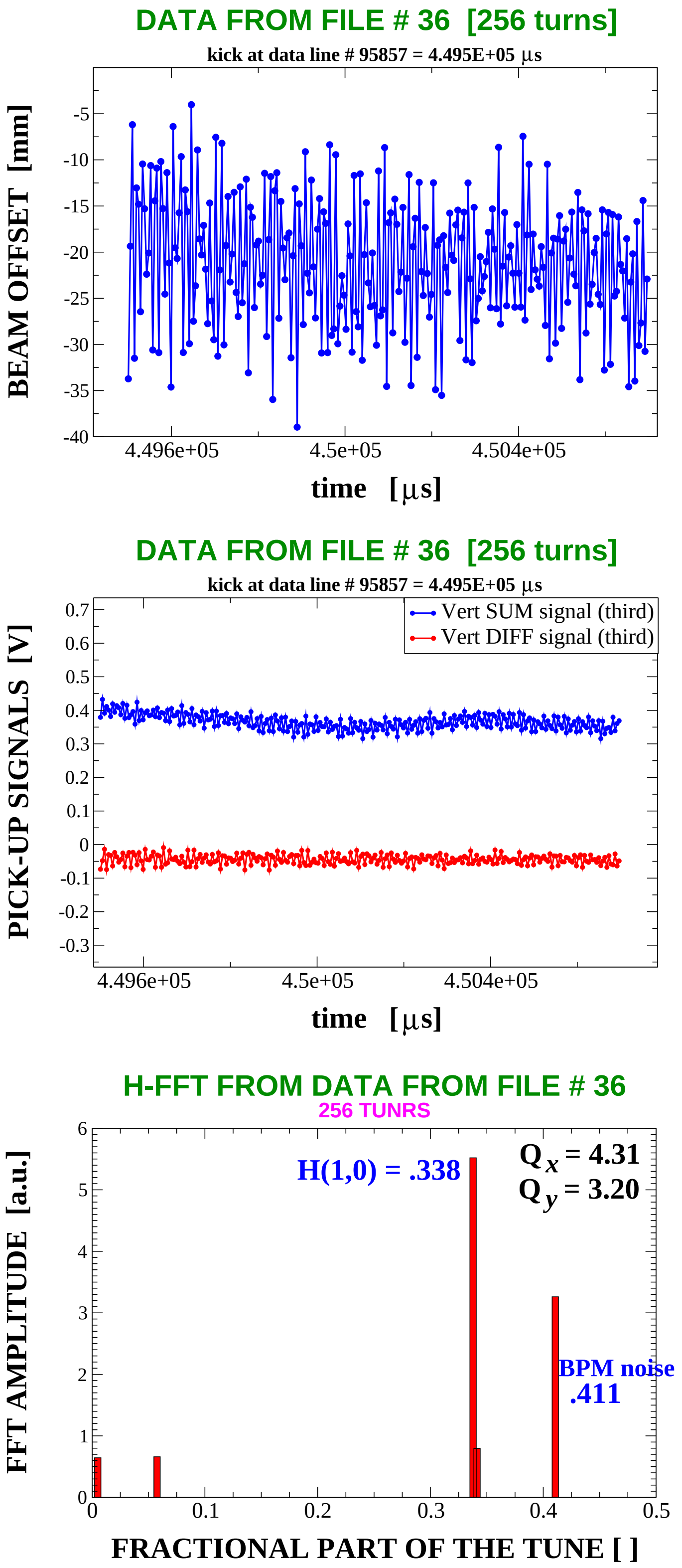

Figure 2.18: **Horizontal data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = first].**

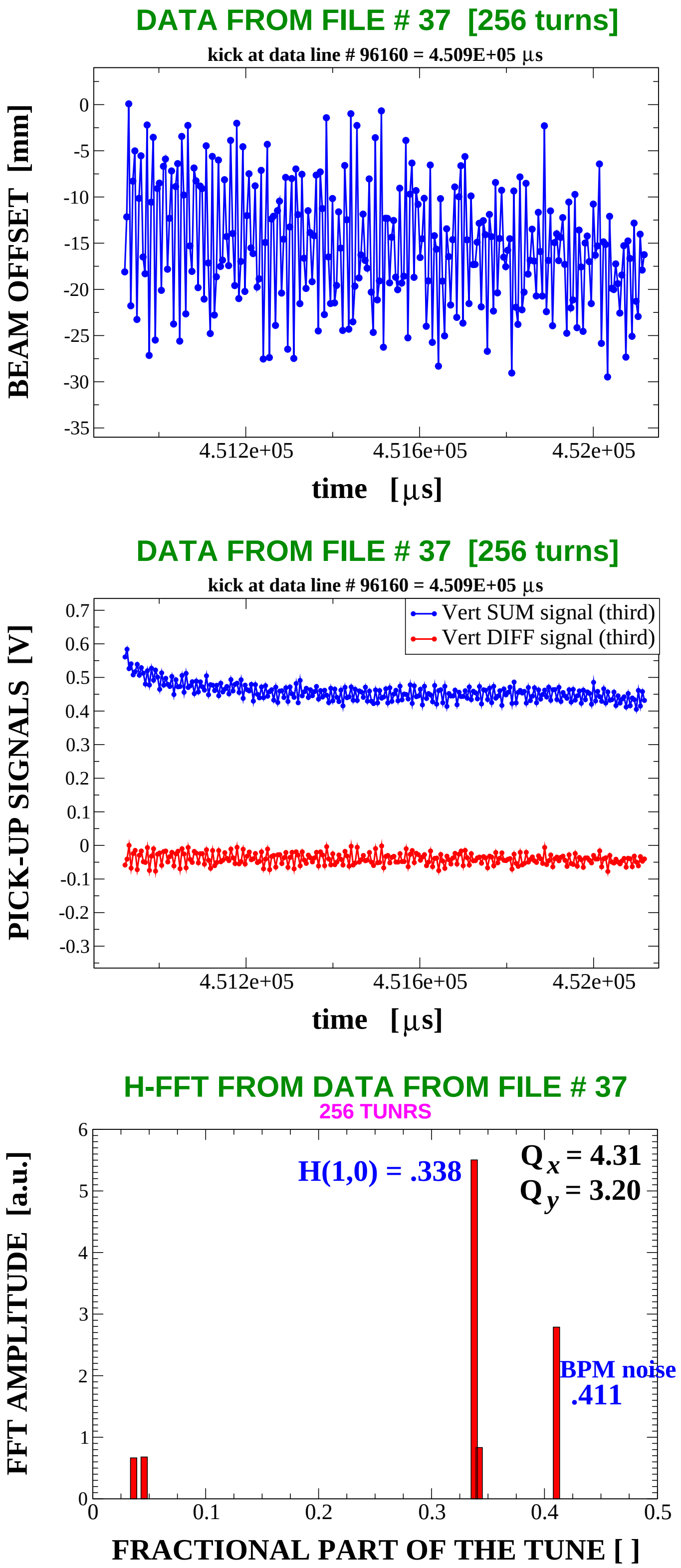

Figure 2.19: **Horizontal data [kick voltage =34 kV ,kick start phase = 88, kicked bunch = first].**

APPENDIX: the post-processing code

The program is written in Fortran77 and uses the FFT routine with the Hanning filter written by Bazzani and Todesco[1]. The code reads the Σ and Δ signals from Peter Moritz' software output file `XXX.bin`[2] and converts them in Volt[3] (the range is [-1, 1] V). Next it detects automatically the betatron oscillations due to the kicking and converts them in millimeter using the following relations

$$x = C_x \frac{\Delta_x}{\Sigma_x} \qquad y = C_y \frac{\Delta_y}{\Sigma_y}$$

where $C_{x,y}$ are the BPM calibration constant: $C_x = 174$ mm, $C_y = 70$ mm. The Σ and Δ signals in Volt and the oscillation pattern in millimeter relative to the isolated betatron oscillations only are written on the file `XXX_oscillat.dat`. The FFT of both the Σ and the oscillation pattern is now performed and, for each one of them, the ten most prominent spectrum peaks are inferred: their positions, amplitudes and phases are written on the file `XXX_spectrum.dat`. In the same file the distances between the sidebands (if they appear) and the tune line are printed. The FFT of the Σ signal is calculated to check whether one of more lines in the beam centroid oscillation spectrum comes from the BPM noise. If one line is present in both spectra, we can attribute this to the pick-up noise and reject it (this occurred in our measurement with the line .410). Since the FFT is performed on a real signal x or y, the spectrum is symmetric with respect to 0.5. This is the reason why in the plot only the range [0, 0.5] is shown instead of the natural [0, 1]. When the setup with two BPMs will be ready, we will extend the Fourier analysis to the complex signal $x + ip_x$ and $y + ip_y$, providing the full spectrum.

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[1] R. Bartolini *et al.* "Tune evaluation in simulation and experiments", Part. Acc. 52, 1996.

[2] This file is binary and the corresponding data are written in ASCII format on the file `XXX.dat` .

[3] Since the PCI card works at 12 bits, the conversion is the following

$$\Sigma, \Delta(V) = \left[\Sigma, \Delta(\text{INTEGER}) \cdot \frac{2}{4095}\right] - 1$$

.

How to use the program

As shown below, the program need some parameters:

```
********************************************
TYPE INPUT FILE NAME      :
WHICH  PLANE?  X=1   Y=2  :
TYPE # OF TURNS FOR FFT   :
TYPE REV TIME [micro sec] :
TYPE DELAY    [micro sec] :
TYPE JUMP FACTOR [IN %]   :
********************************************
```

- The input file is the path of the `XXX.bin` file provided by Moritz' software.
- The user must select the plane whom the data belong to: this flag will select which BPM coefficient C must be used.
- The user must introduce the number N^{FFT} of turns used for the FFT (a power of 2).
- The revolution time (in our case was 4.689282 μs) is used to have a time scale of the sampled data, i.e. the first 1000 data (turns) correspond to 46.89282 μs.
- The delay time is introduced to facilitate the recognition of the coherent oscillations from the noise/random data fluctuations. Since the sampling started at the beginning of the UNILAC cycle, the kick occurred approximately after 0.45 s. The coherent oscillations are detected looking at the difference between two neighbor data: if this is bigger than a threshold given in input (generally 10% in y, 6% in x) the following N^{FFT} data are interpreted as coherent betatron oscillations. In this way, especially in x where these are rather small and the threshold must be kept low, some random fluctuations can make the detection technique fail. The delay is introduced to shift the pattern recognition start point close to the expected point where the kick occurs (usually for this particular set of measurements a delay of 0.44 s was good)
- The jump factor is the threshold described above.