Draft Report	**Experimental test of "Libera Single Pass H" for beam phase and "time of flight" measurements.**	P. Forck M. Almalki
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Web-Link:		

➢ Introduction

For the P-linac at GSI, the "Libera Single Pass H" has been empirically tested for signal phase measurement and bunch dependence using a four plate BPM. After pre-amplification, the signals are processed by "Libera Single Pass H" and compared inphase in order to detect the plate signals of the BPM in respect to RF signal. Using digital down conversion technique, "Libera Single Pass H" achieves this task where the signals go throught a sophisticated signal processing algorithm. The processor in "Libera Single Pass H", consists of an analog front-end and digital signal processing modules for IQ demodulation and phase determination.

The aim of this study is to calculate the beam phase for the "time of flight" measurements. For this test a single BPM acts as a "Bunch arrival monitor". i.e the PBM signal is compared to the reference signal as the time reference. This experiment is done to test Libera capability to measure the phase with varying the signal amplitude and bunch shape. This report presents the results of this experiment.

➢ Beam Parameters and Macroplulse Structure

The " Libera Single Pass H" provides the measured phase which is calculated in respect to a Master Oscillator – RF accelerating frequency. The amplitude from Libera is given in steps of 1 µs (correspond to 108 bunches) for a train of 129 µs. Every data set corresponds to one macropulse. A second system was used where the signal of the pick-up was taken at a 5 GSa/s scope together with the master oscillator signal.

Bunch rep. rate	Macropulse length	Macropulse rep.rate	Beam Current	Beam Energy
108.408 MHz	200 µs	1 Hz	60 ~ 90 µA	Ne^{4+} @ 1.4MeV / u

Table 1. The Macropulse structure for the test measurement at 28thMarch 2012.

➢ The Results

This report is dedicated for studying the bunch shape sweep test. Therefore, the 22 shapes generated during the experiment using the buncher unit have been reproduced and studied for the data from the oscilloscope. The first step is that it was required to interpolate the sampled points for more precise analysis since the resolution of the samples points is 200 ps. The granularity can be short by the spline interpolation of the original curve.

Secondly, for 102 samples represent two cycles with 5 GSa/s sampling frequency, the points of interest have been determined and compared. These points are Zero-starting (Zs), Maximum (Max), Minimum (Min) and Zero-ending (Ze) with Zero-crossing (Zc) as the major point as it is shown in figure 1. The corresponding interpolated curve is used to determine these points. In order to calculate the phase difference, the shape (03) with an amplitude of 1.449 V has been chosen as the reference.

Thirdly, for the data stored on the "Libera Single Pass H" which present the measured phase, the standard deviation of the distribution (σ_dist) and the standard deviation of the mean σ_mean are calculated, where:

$$\sigma\_mean = \sigma\_dist / \sqrt{N} \qquad (1)$$

N= 129 of the measured data with a macropulse.

Table 2 shows the Zc – Zc (2), Zs - Zc and Zc – max in degree unit and Libera readout for different shapes. Only six bunch shapes with different amplitudes are shown in this report, a similar analysis was applied for all bunch shapes. So, the characterstics of each bunch shape and its measured phase by Libera is shown in the following plots:

1- Plot 1 shows the displayed signal on the oscilloscope with 102 samples whereas the interpolated signal is shown in plot 2.

2- Plot 3 illustrates in the uper part the measured phase by Libera H in steps of 1 μs for a train of 129 μs which represents a data set corresponds to one macropulse and the lower part shows its histogram distribution.

3- Plot 4 shows four rows of data collected by Libera H where each one represents the amplitude of one pick-up for one macropulse.

4- Plot 5 shows a comparison between the amplitudes of four pick-ups for one macropulse.

5- Plot 6 illustrate the persentage of the difference over sum of two opposite pick-ups for one macropulse.

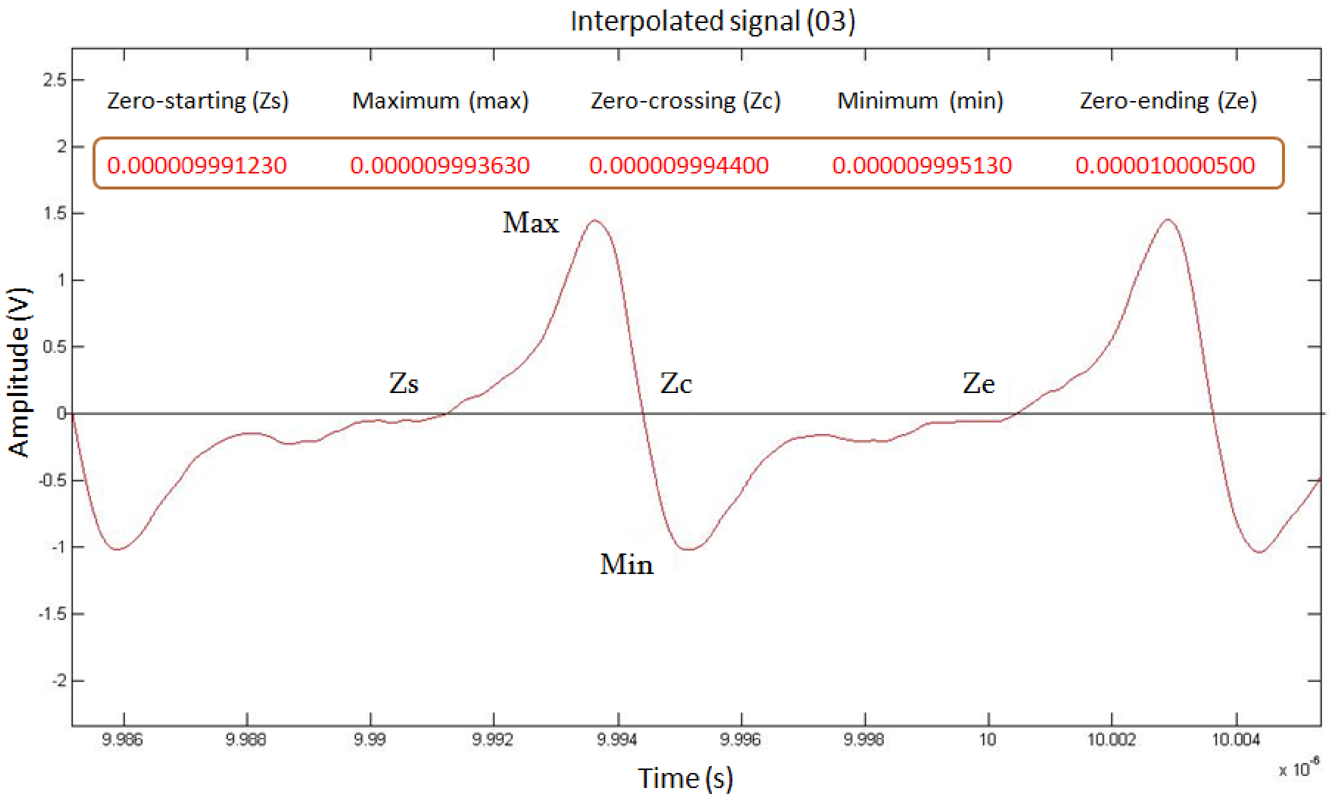


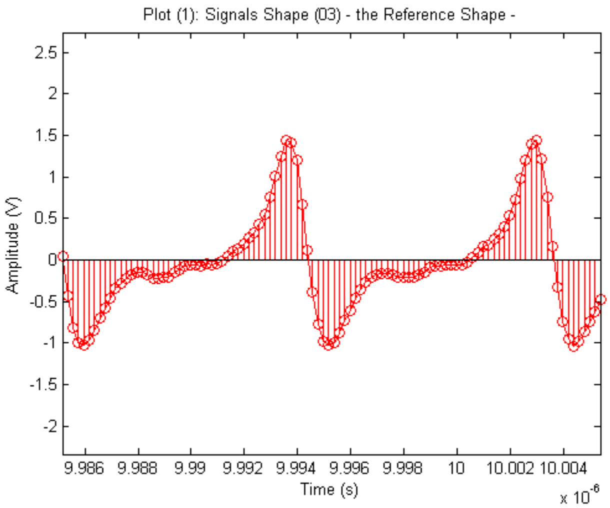
Figure 1, the reference bunch shape (data set (03) , table 2) with characteristic time & amplitude on the oscilloscope.

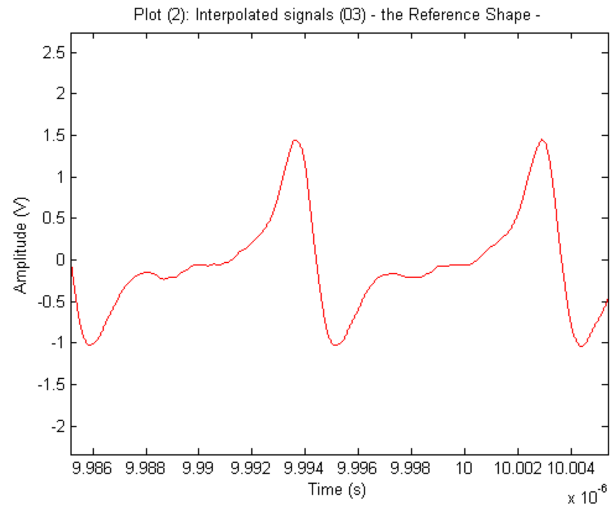
Table 2

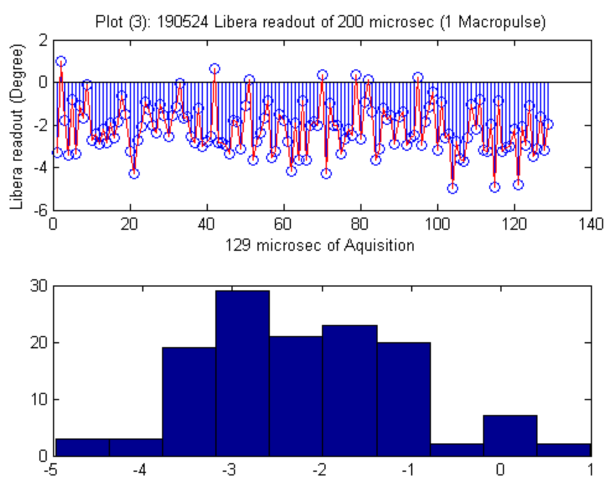
shape No.	Buncher phase	Buncher Amp	Libera read out (mean) degree	signal amp	Std_dist (σ) (degree)	σ_mean (degree)	Zc-Zc(3) (degree)	Zs - Zc (ns)	Zc - max (ns)
1	140	7	6.34	1.545	1.27	0.11	12.9	32.9	**0.79**
2	140	5	3.53	1.529	1.15	0.1	8.2	32.4	0.77
3	140	6	-2.18	1.449	1.17	0.1	0.0	31.7	0.77
4	140	4	0.43	1.34	1.02	0.09	12.9	33.3	0.84
5	140	8	8.43	1.33	1.50	0.13	16.4	33.4	1.00
6	140	3.5	-15.4	1.169	2.03	0.18	-9.4	33.4	0.78
7	140	8.6	8.13	1.124	1.40	0.12	15.2	33.5	1.17
8	140	3	4.82	1.109	2.16	0.19	11.2	34.6	0.929
9	140	2	9.05	0.912	3.32	0.29	11.6	36	1.06
10	140	1	18.31	0.755	5.34	0.47	9.4	38.2	1.29
11	0	0	21.89	0.557	12.16	1.07	2.0	38.7	1.12
12	320	5	37.41	0.433	14.63	1.29	12.9	40.1	2.63
13	320	1.6	98.95	0.423	17.25	1.52	24.6	44	1.86
14	320	2	-148.1	0.417	16.51	1.45	23.5	43.7	1.64
15	320	6	52	0.413	14.16	1.25	2.3	39	2.64
16	320	7	52.35	0.404	15.20	1.34	-5.9	36.4	2.35
17	320	1.5	42.8	0.399	25.54	2.25	14	44.1	1.87
18	320	8	66.54	0.397	12.93	1.14	14.1	36.5	2.59
19	320	8.6	65.9	0.389	11.52	1.01	32.8	37.2	2.53
20	320	4	-127.5	0.376	17.41	1.53	43.4	43.4	3.01
21	320	3	-147.4	0.382	16.87	1.49	7.0	42.4	2.25
22	320	3	17.25	0.338	31.35	2.76	7.9	43.5	1.98

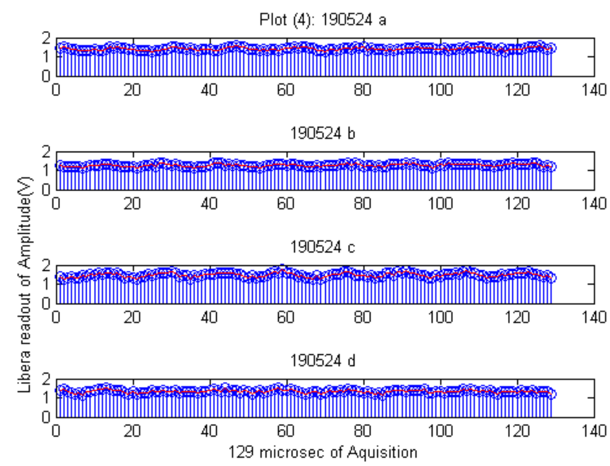
At 325 MHz → 360^o : 3.07 ns

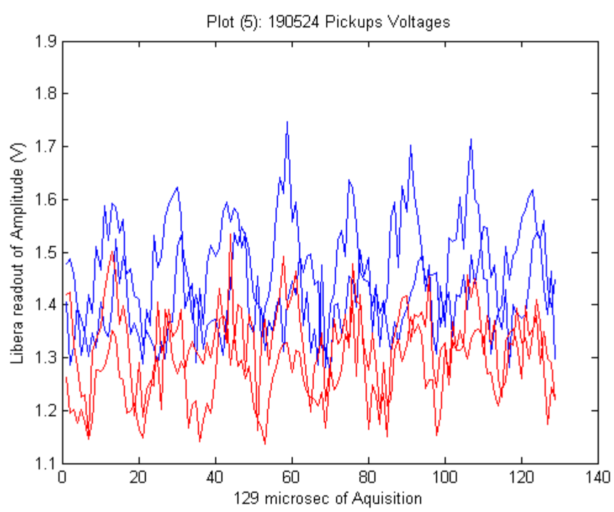
- Signal (03)

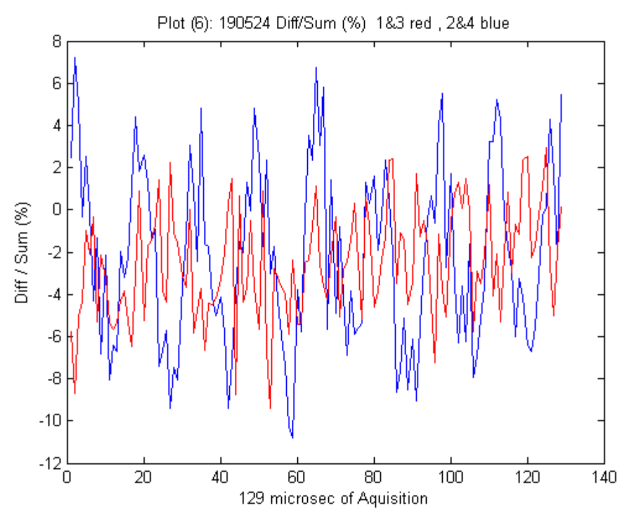

Plot (1): Signals Shape (03) - the Reference Shape -
Amplitude (V)
Time (s)
x 10^-6


Plot (2): Interpolated signals (03) - the Reference Shape -
Amplitude (V)
Time (s)
x 10^-6

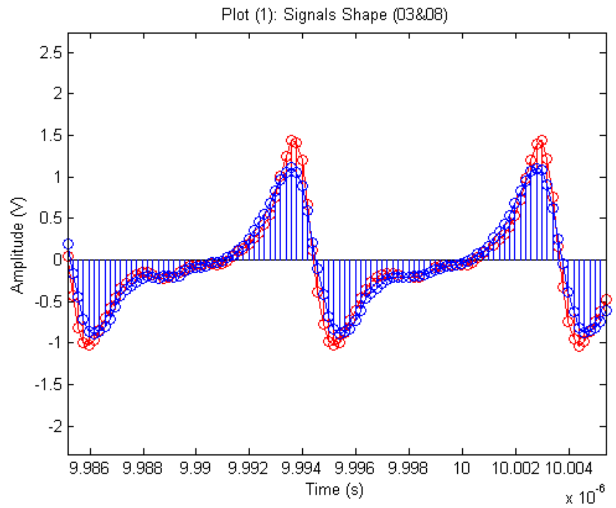

Plot (3): 190524 Libera readout of 200 microsec (1 Macropulse)
Libera readout (Degree)
129 microsec of Aquisition

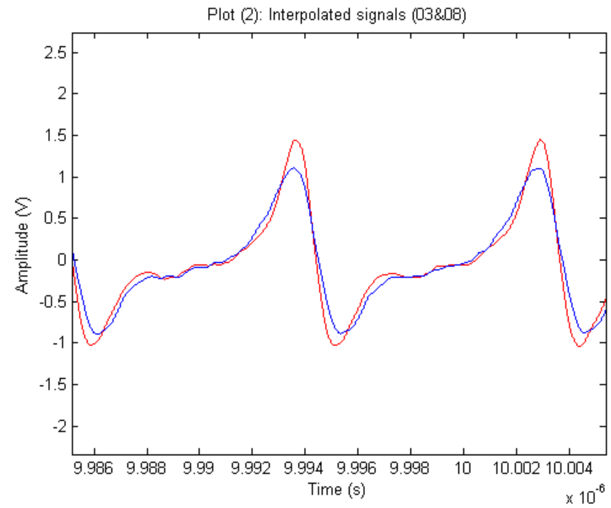

Plot (4): 190524 a
190524 b
190524 c
190524 d
Libera readout of Amplitude(V)
129 microsec of Aquisition

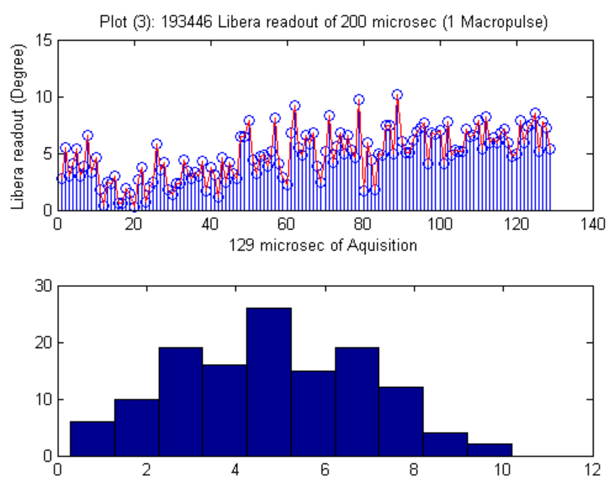

Plot (5): 190524 Pickups Voltages
Libera readout of Amplitude (V)
129 microsec of Aquisition

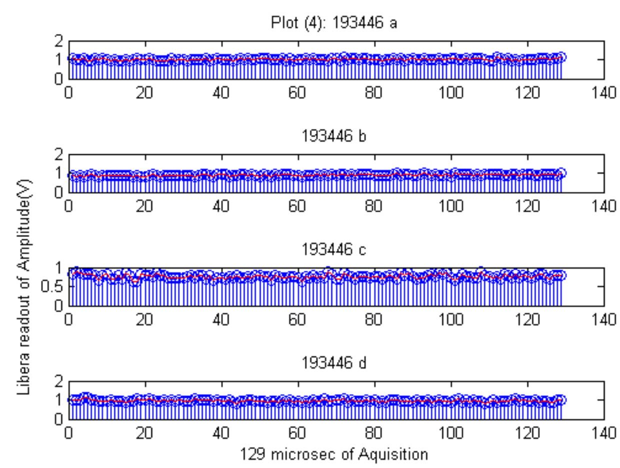

Plot (6): 190524 Diff/Sum (%) 1&3 red , 2&4 blue
Diff / Sum (%)
129 microsec of Aquisition

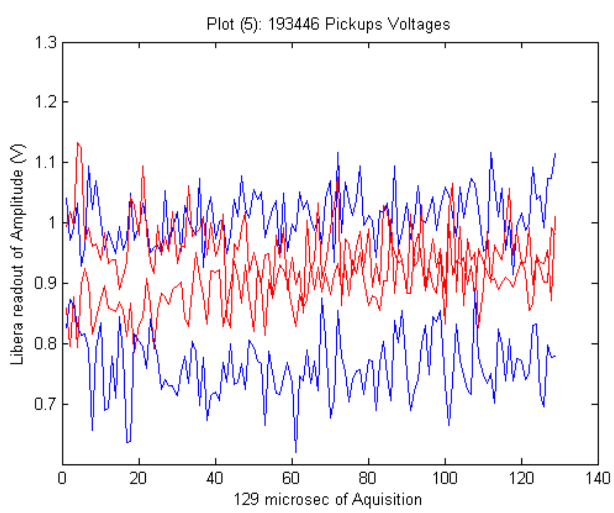
- Signals (03&08)

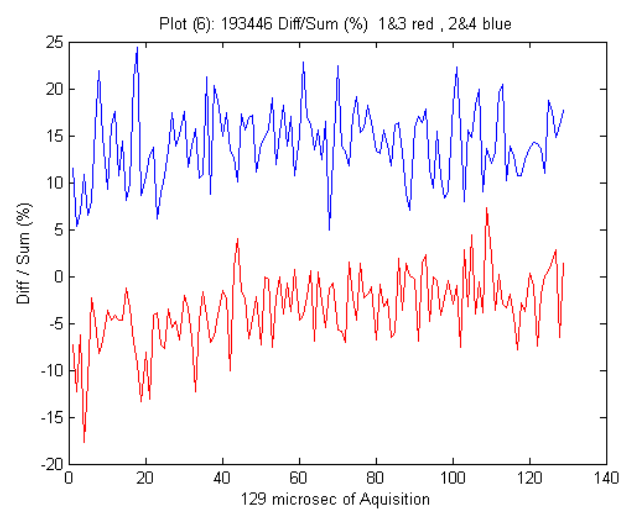




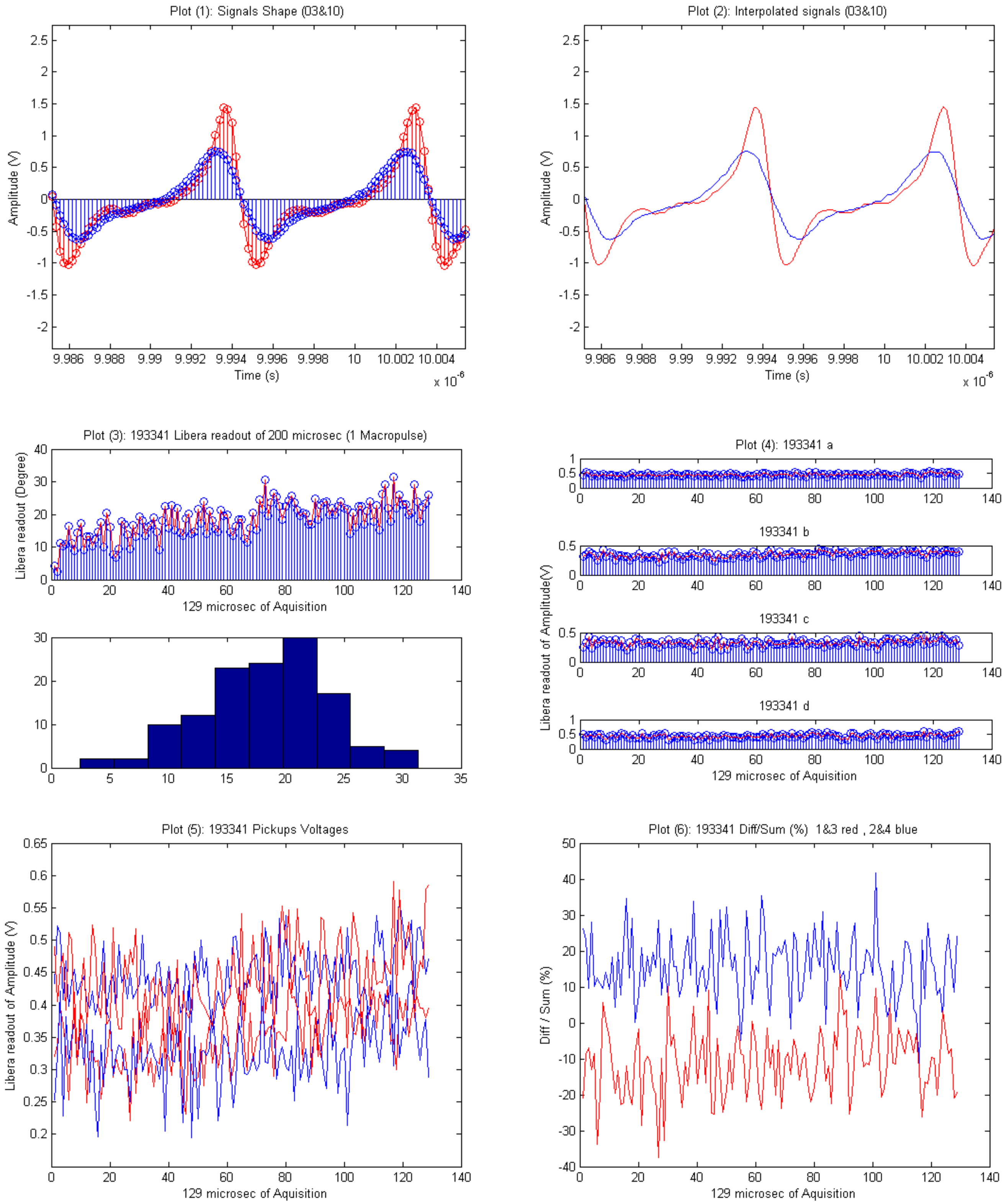




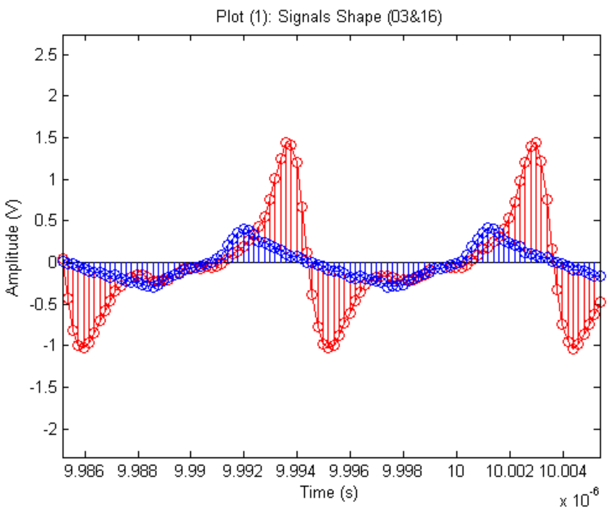


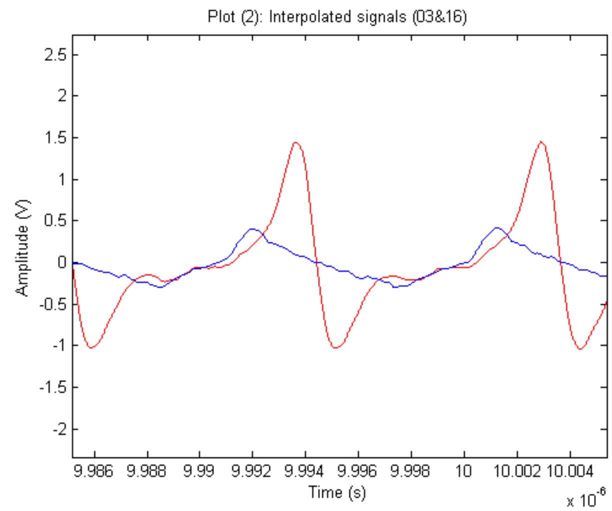


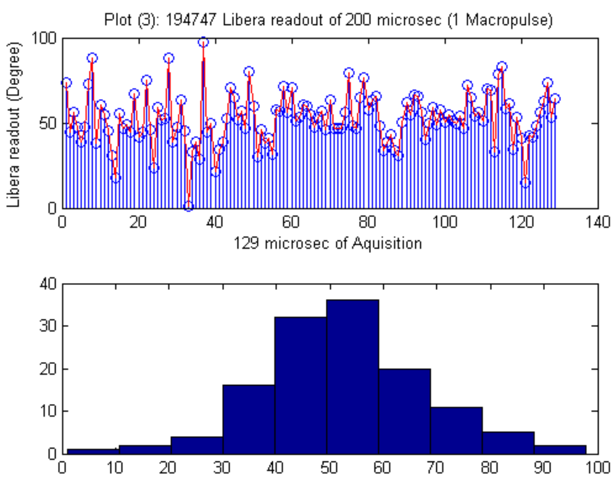
- Signals (03&10)

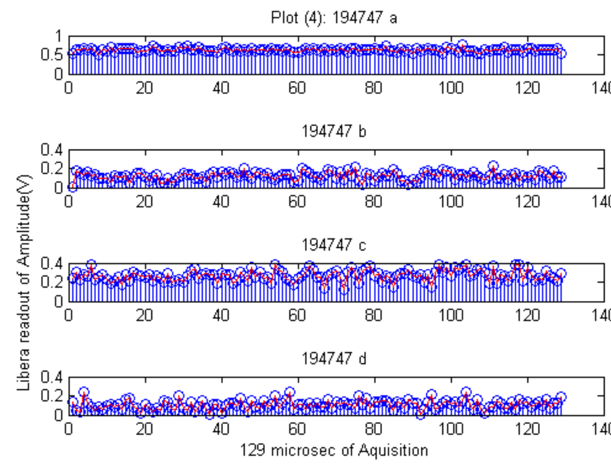


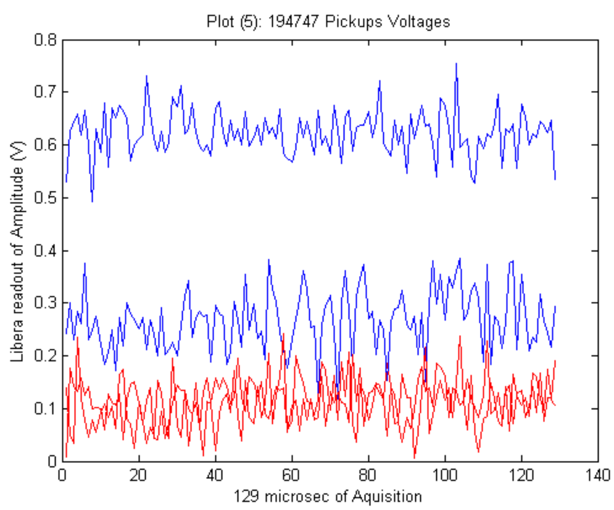
- Signals (03&16)

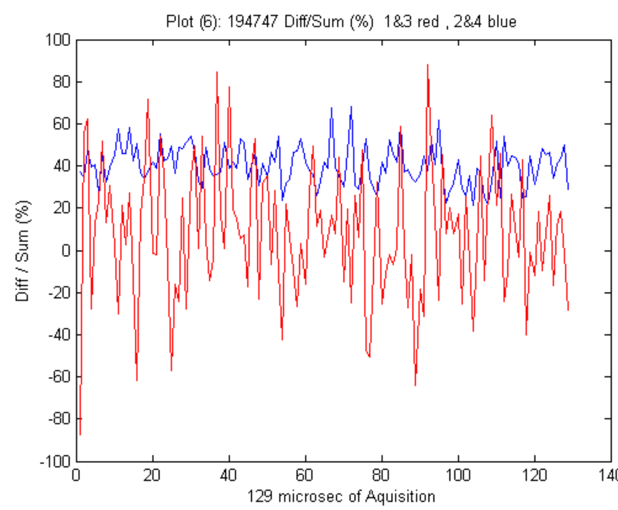

Plot (1): Signals Shape (03&16)
Amplitude (V)
Time (s)
x 10^-6


Plot (2): Interpolated signals (03&16)
Amplitude (V)
Time (s)
x 10^-6

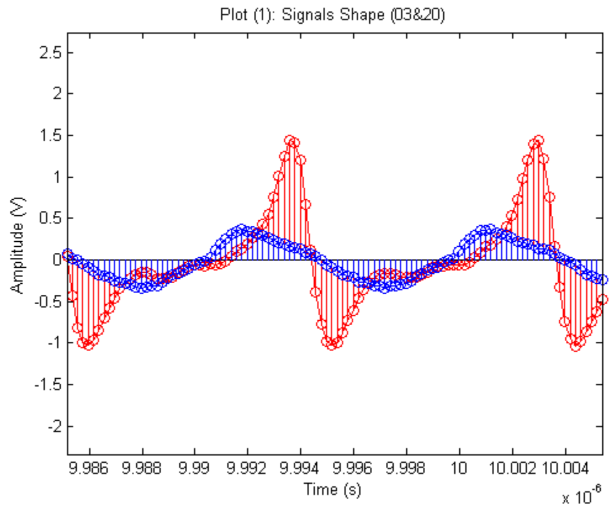

Plot (3): 194747 Libera readout of 200 microsec (1 Macropulse)
Libera readout (Degree)
129 microsec of Aquisition

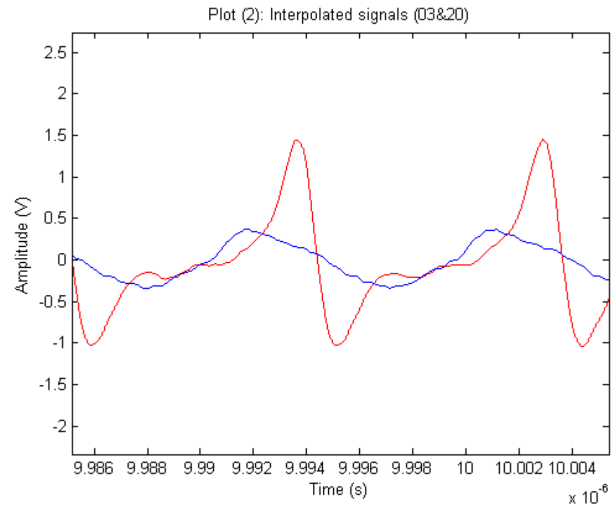

Plot (4): 194747 a
194747 b
194747 c
194747 d
Libera readout of Amplitude(V)
129 microsec of Aquisition

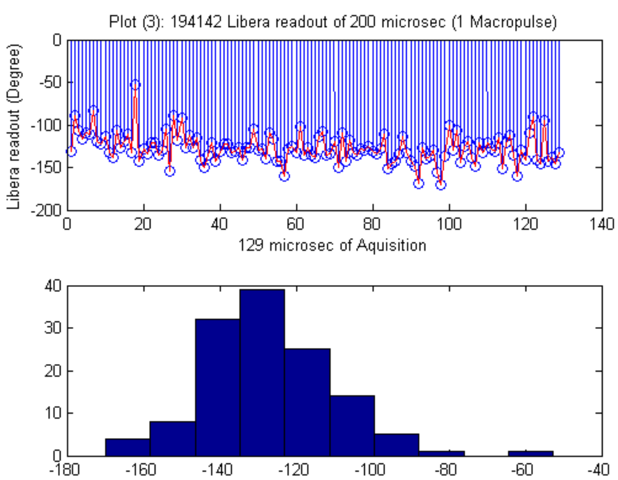

Plot (5): 194747 Pickups Voltages
Libera readout of Amplitude (V)
129 microsec of Aquisition

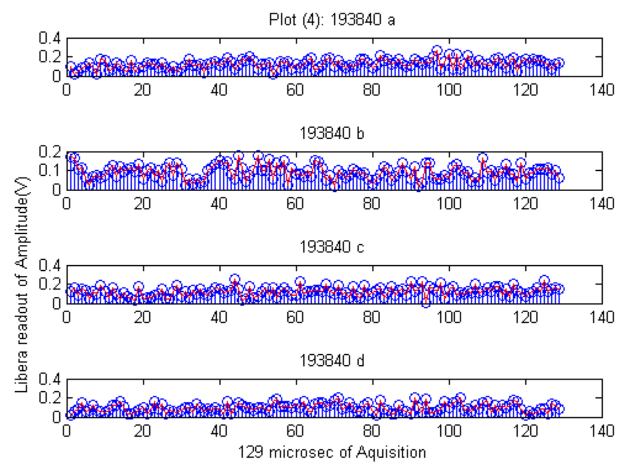

Plot (6): 194747 Diff/Sum (%) 1&3 red , 2&4 blue
Diff / Sum (%)
129 microsec of Aquisition

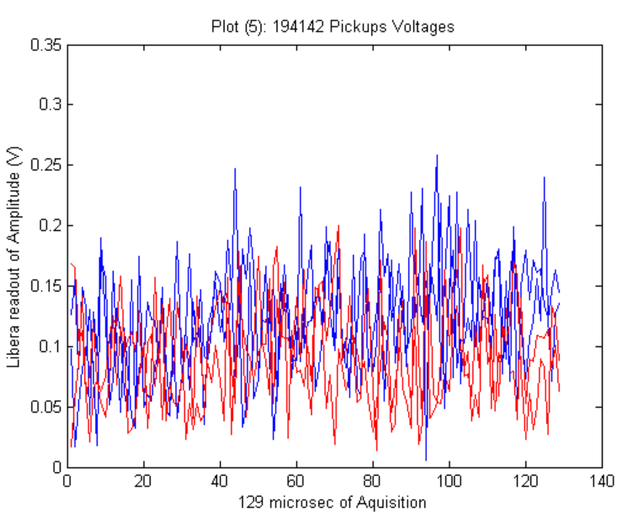
- Signal (03&20)

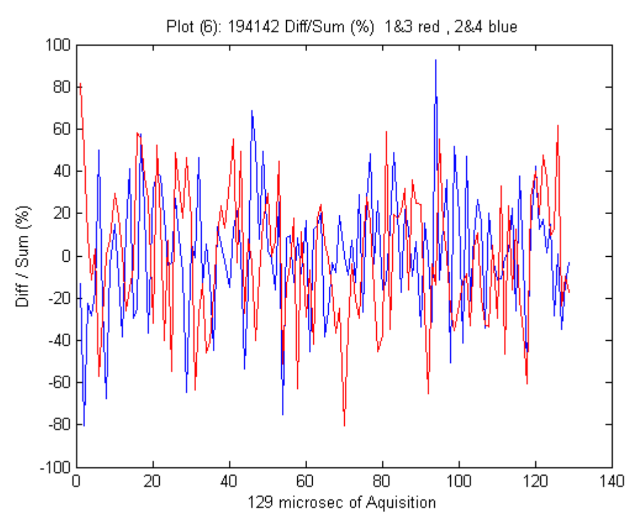

Plot (1): Signals Shape (03&20)
Amplitude (V)
Time (s)
x 10^-6


Plot (2): Interpolated signals (03&20)
Amplitude (V)
Time (s)
x 10^-6

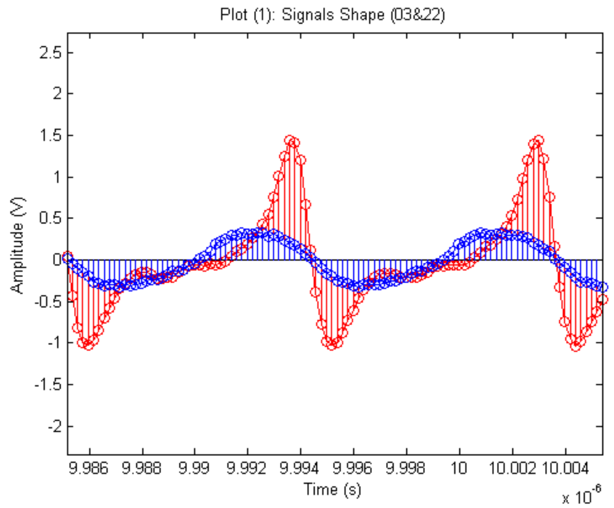

Plot (3): 194142 Libera readout of 200 microsec (1 Macropulse)
Libera readout (Degree)
129 microsec of Aquisition

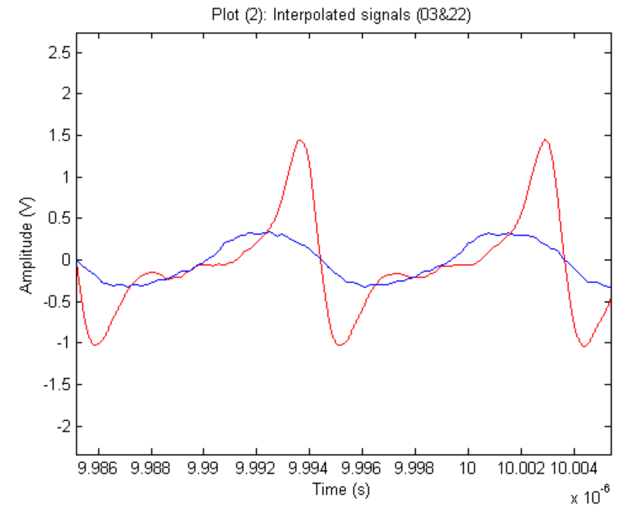

Plot (4): 193840 a
193840 b
193840 c
193840 d
Libera readout of Amplitude(V)
129 microsec of Aquisition

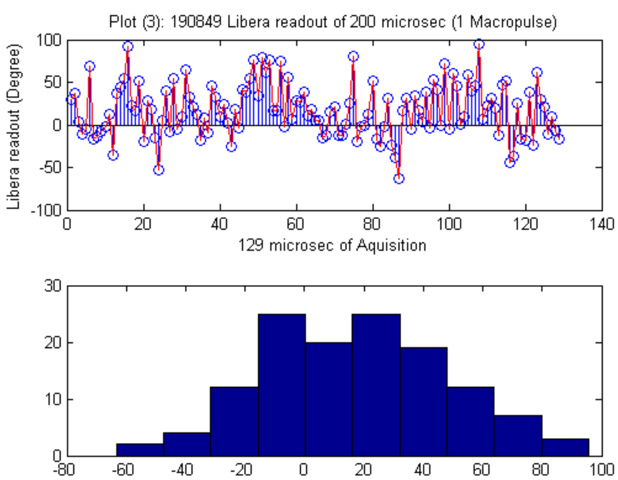

Plot (5): 194142 Pickups Voltages
Libera readout of Amplitude (V)
129 microsec of Aquisition

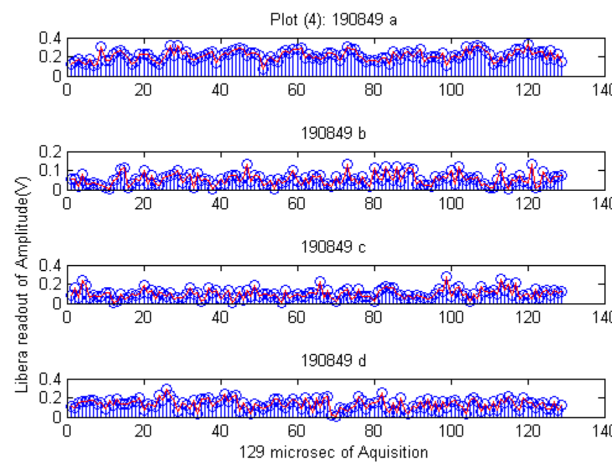

Plot (6): 194142 Diff/Sum (%) 1&3 red , 2&4 blue
Diff / Sum (%)
129 microsec of Aquisition

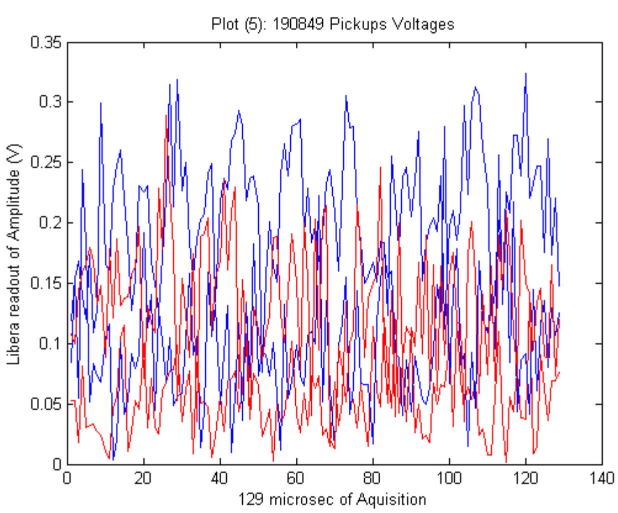
- Signal (03&22)

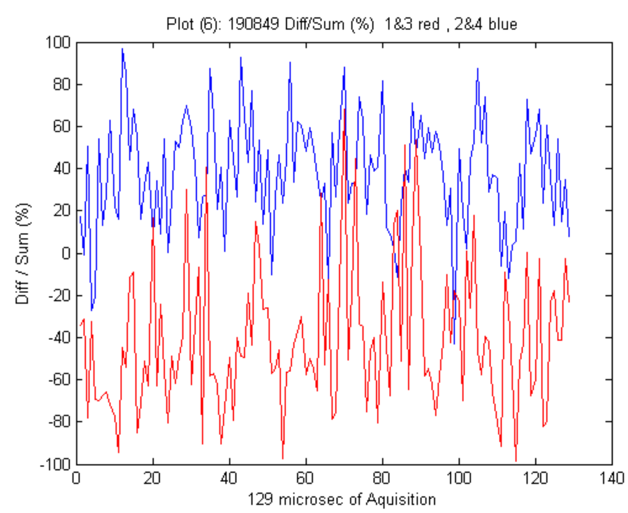

Plot (1): Signals Shape (03&22)
Amplitude (V)
Time (s)
x 10-6


Plot (2): Interpolated signals (03&22)
Amplitude (V)
Time (s)
x 10-6


Plot (3): 190849 Libera readout of 200 microsec (1 Macropulse)
Libera readout (Degree)
129 microsec of Aquisition


Plot (4): 190849 a
190849 b
190849 c
190849 d
Libera readout of Amplitude(V)
129 microsec of Aquisition


Plot (5): 190849 Pickups Voltages
Libera readout of Amplitude (V)
129 microsec of Aquisition


Plot (6): 190849 Diff/Sum (%) 1&3 red , 2&4 blue
Diff / Sum (%)
129 microsec of Aquisition

➢ Phase and bunch amplitude

Figure 4 illustrates the measured phase using Libera Single Pass H versus the bunch amplitude. It shows that for the input signal amplitude of higher than 0.9 V, the standard deviation gives a range of $1^{o} – 3.3^{o}$ and increases dramatically as the input level is below 0.7 V. The points of the range higher than 0.9 V are highlighted and shown in figure 5. The phase value per the macropulse is represented by the center of the distribution where the shown error bars are the width of the distribution. The resolution can be characterised by the displayed width of the distribution divided by the number of samples, as it shown in eq(1).

The standard deviation of the distribution for Libera readout phase versus the input signal is depicted in figure 6. Figure 7 shows the phase resolution with an amplitude of the values higher than 0.9 V.

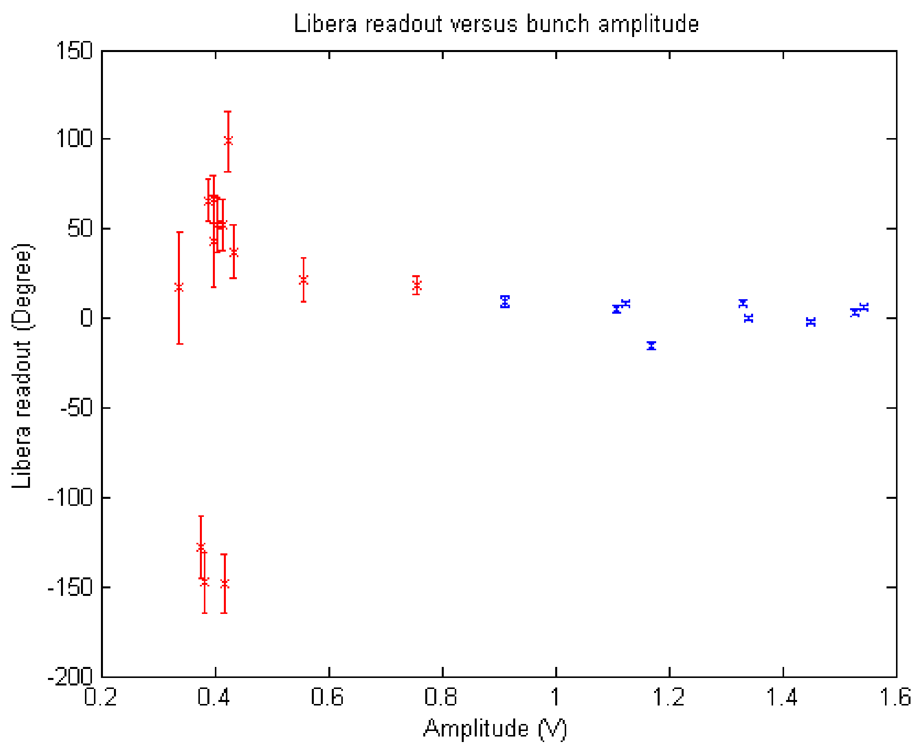


Figure 4, Libera phase readout versus bunch amplitude.

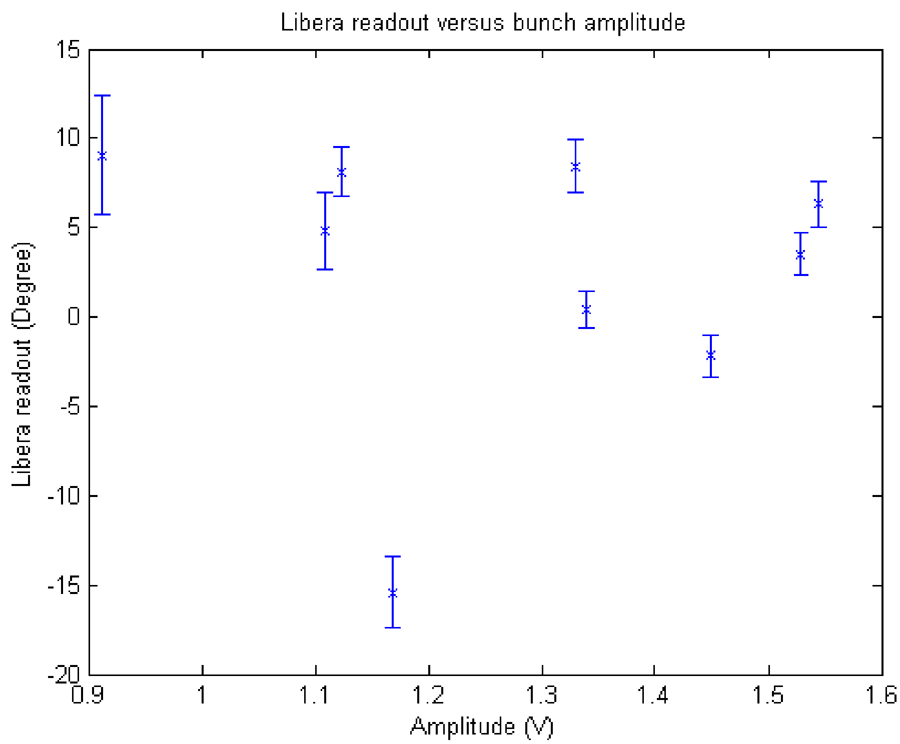


Figure 5, Libera phase readout versus the bunch amplitude of higher than 0.9 V

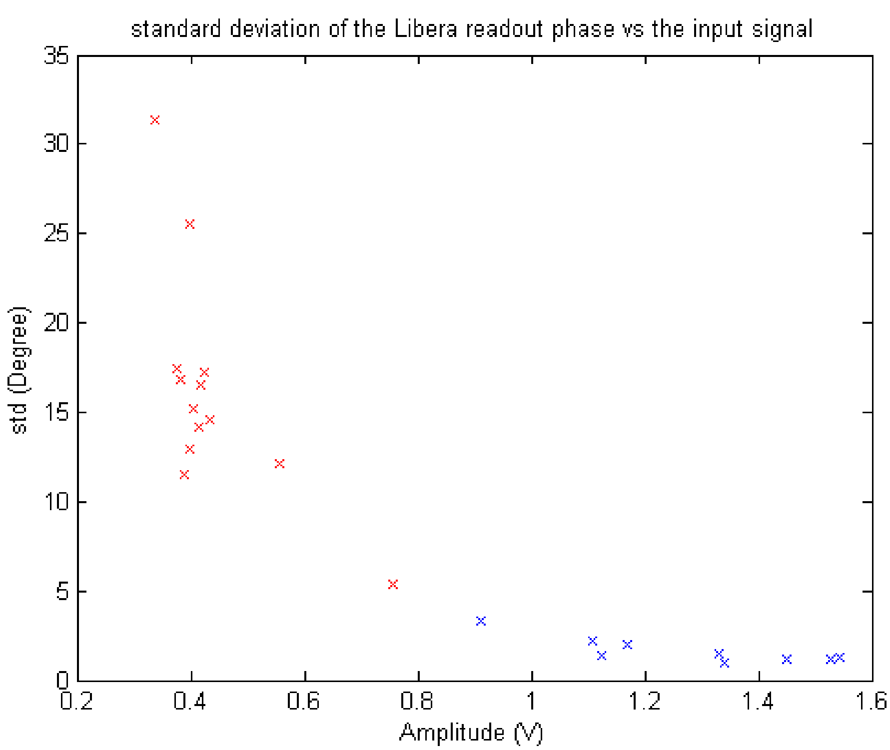


Figure 4. the phase resolution.

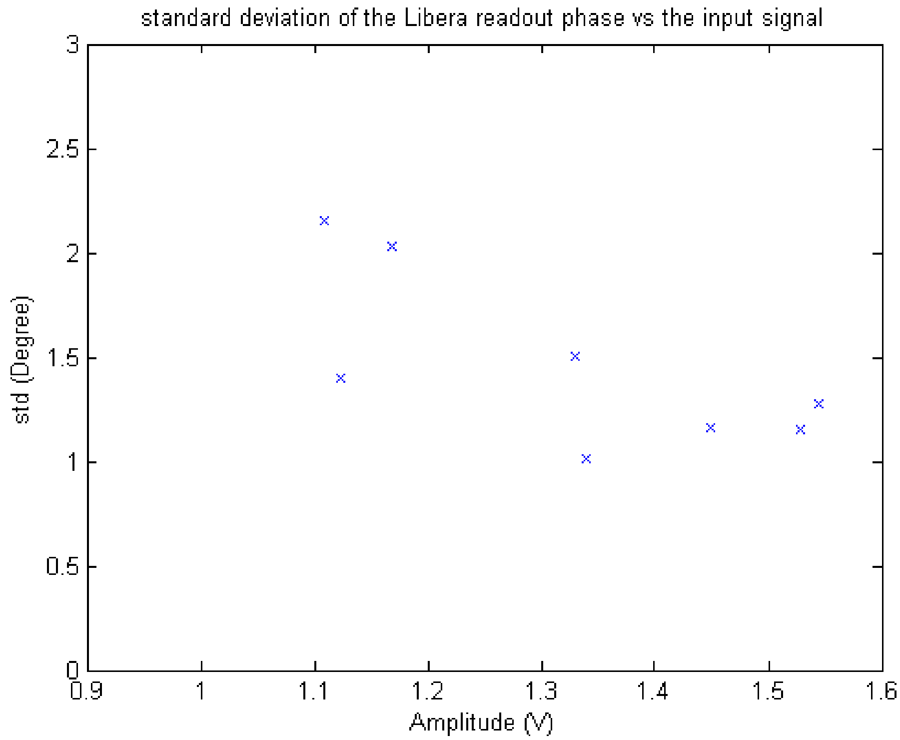


Figure 6. the phase resolution with an amplitude of higher than 0.9 V.

- Phase and phase difference.

The measured phase by Libera Single Pass H has been compared to the phase of the interpolated curves shown on the oscilloscope with 5 GSa/s sampling frequency. Figure 2 shows the phase difference in respect to shape (03). figure 3 illustrates Libera readout phase versus phase difference for the bunch amplitude higher than 0.9 V.

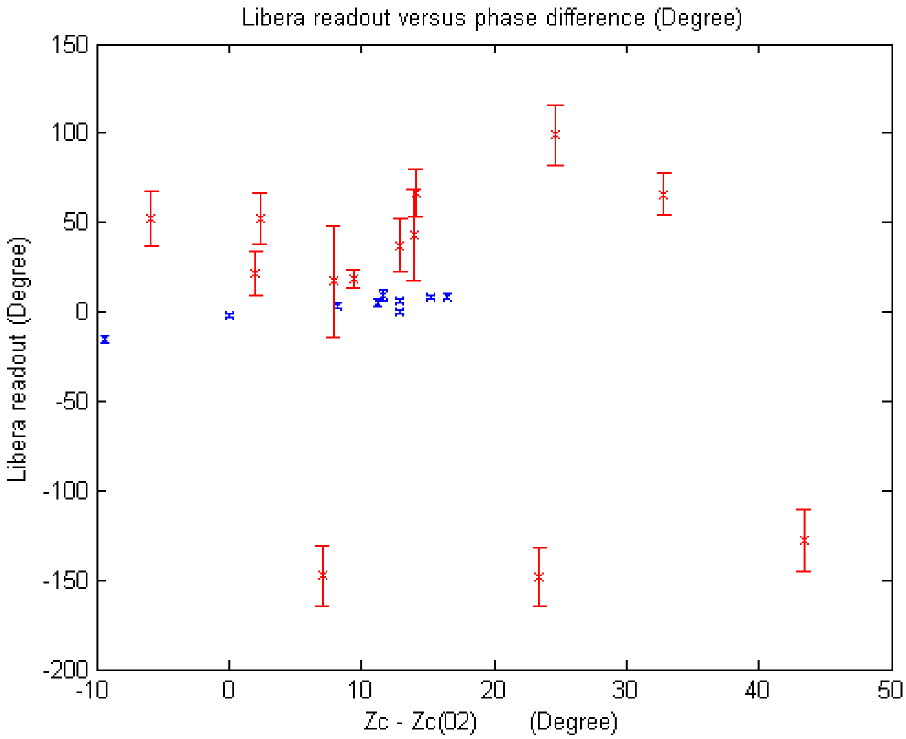


Figure 2 Libera readout phase versus phase difference in respect to the reference shape.

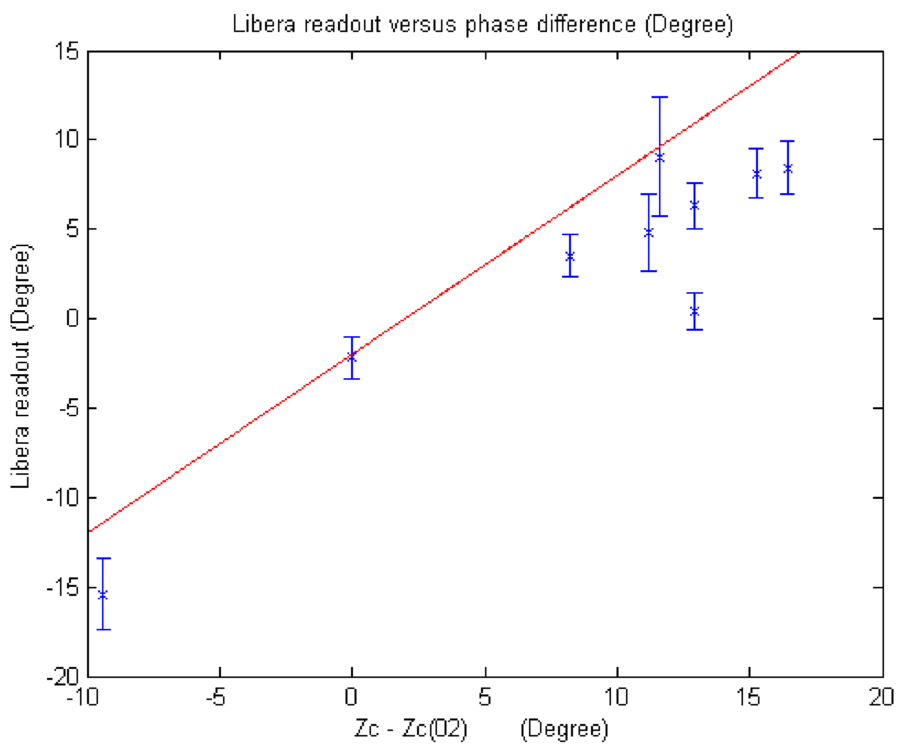


Figure 3 Libera readout phase versus phase difference of the bunch amplitude of higher than 0.9 V.

➢ Phase and bunch width

The limitation of Libera performance regarding the bunch shape – stretched bunch – have been investigated. By comparing Libera response with the signal width, two characteristics for the width of the signal are considered which are Zs - Zc and Zc – Max, see figure 1. For (Zs – Zc) the distance between the zero starting and the zero crossing points, figures 8 and 9, show that for length of more than ~ 3.6 ns, Libera readout gives large fluctuation. In the second signal width parameter (Zc – Max) the distance between the zero crossing and the maximum points figures 10 and 11 show for a maximum width of some correlation is 1.3 ns.

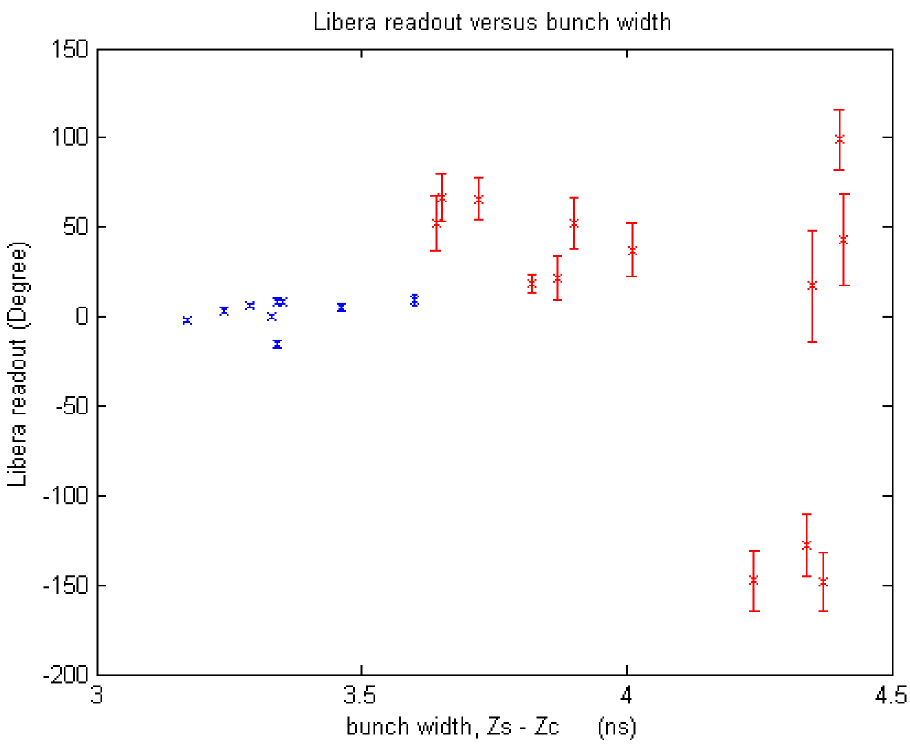


Figure 8, phase vs width Zs - Zc.

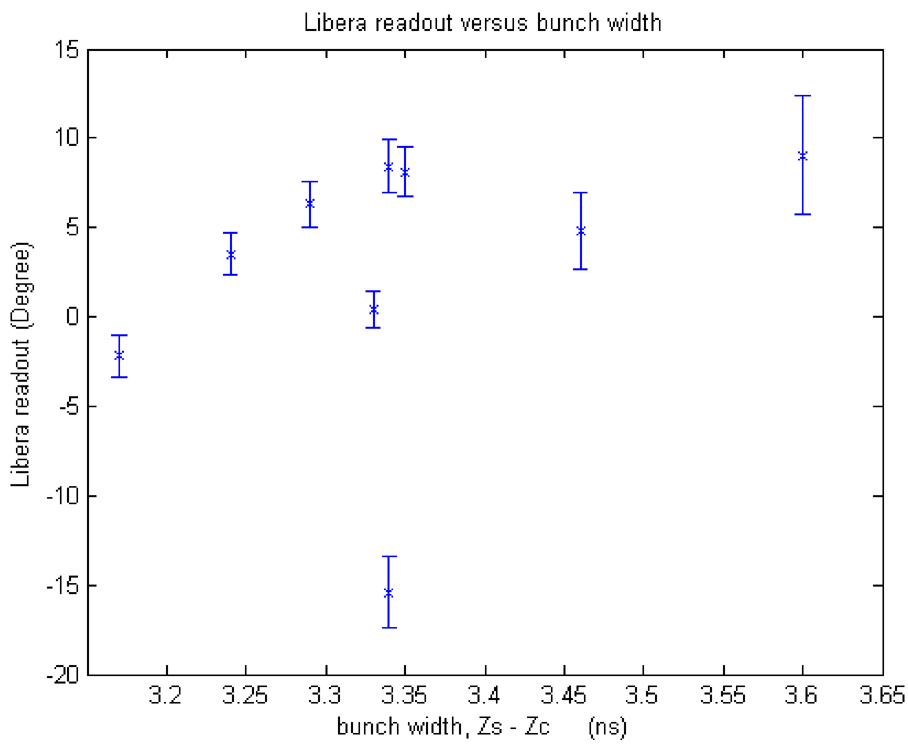


Figure 9, phase vs width Zs – Zc of the bunch amplitude of higher than 0.9 V .

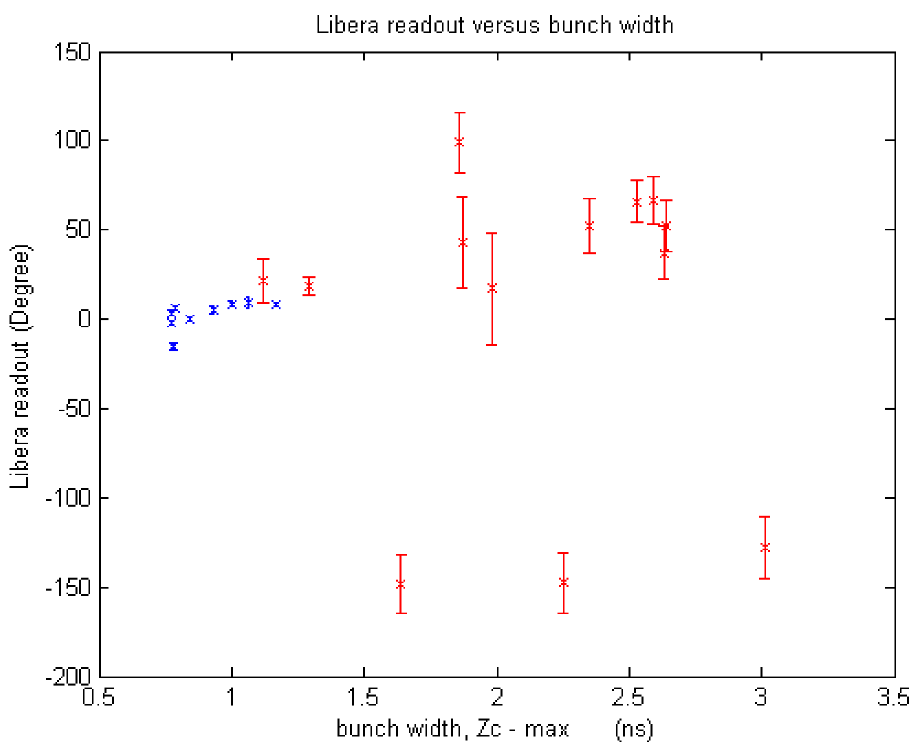


Figure 10, phase vs width Zc - Max.

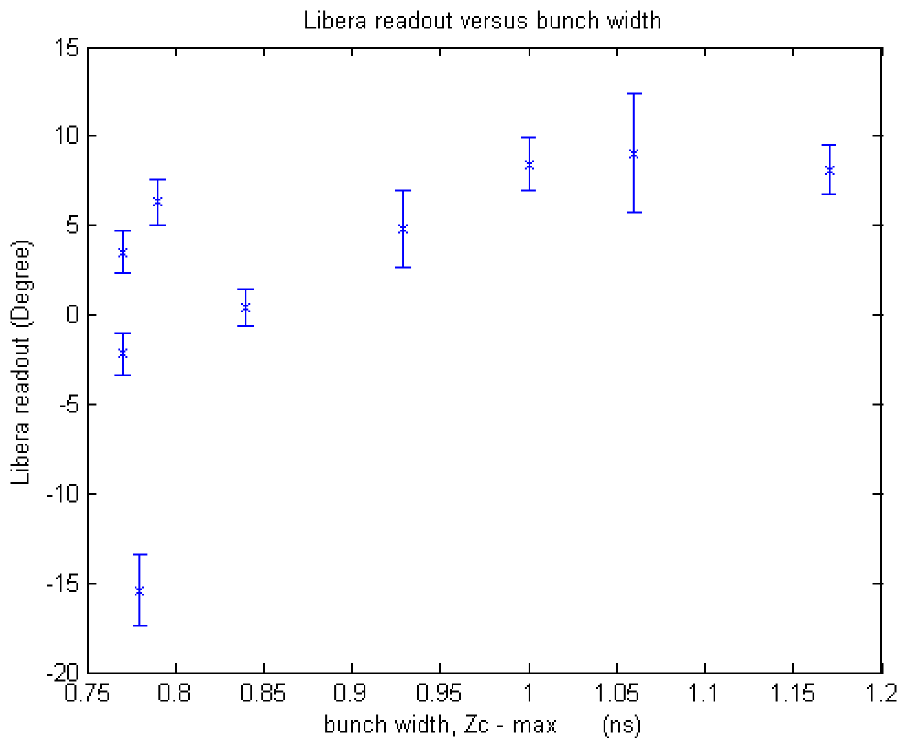


Figure 11, phase vs width Zc – Max of the bunch amplitude of higher than 0.9 V.

➢ Conclusion

For the given beam parameters and a varying bunch shape, the results of the first measurements show typically phase response achieved over the input amplitude of range 0.9 to 1.5 V with standard deviation of $1^o – 3.3^o$. In this range a correlation of the Libera phase reading and the time domain measurements by the oscilloscope is visible, but a linear function can not be fitted to data with the anticipated accuracy.

The fluctuation of the phase readout increases drastically with increasing the bunch width (Zs - Zc) and (Zc - max) more than 3.6 ns and 1.3 ns respectivily. Even though there is some correlation between (Zs - Zc) and (Zc - max) read by the oscilloscope and Libera Single Pass H readout, a linear dependence can not be observed. Therefore, it can be concluded that " Libera Single Pass H" serves for phase measurement of bunchs with only at an amplitude over than 0.9 V. The time domain processing leads to a different arrival time compared to the phase evaluation for various bunch shapes.