Report (6) 28th Oct 2013	**Time-domain Data Evaluation** **Experimental Data recorded 08. Nov. 2012**	P. Forck M. Almalki
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Web-Link:	http://www-bd.gsi.de/dokuwiki/doku.php?id=projects:bpm-linac	

For the purpose of investigating the jitter of zero-crossing within one macro-pulse, the processing steps are the following:

A) Signals periodicity determination

1- FFT was applied on a stream of bunches stored by a 10 GSa/s oscilloscope.

2- From the FFT, the resulted frequency and phase spectrum are shown in figure 1 for the first three harmonics, the amplitude spectrum shows the contribution of each harmonic (up) and its corresponding phase (down) as shifted by 180°.

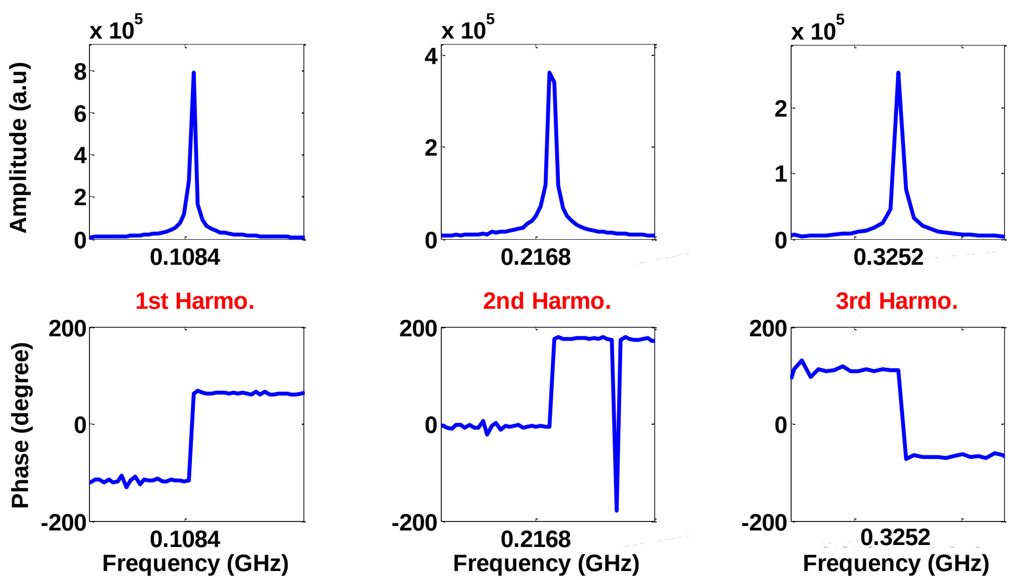


Figure 1. Fourier-spectra of 28985 bunches; the frequency span is 300 kHz.

3- The periodicity was determined using FFT phase at the acceleration frequency i.e. where the phase shift is 180 °.

For example, in this case the phase spectrum is shifted at -115.9066536636574 ° at frequency of 108.4 MHz and the periodicity is 9.224430929343646 ns.

B) Zero-crossing determination

1- Starting from the first stored sample at the beginning of the stream, ~ 92 successive samples have been extracted to represent the first bunch, figure 2.

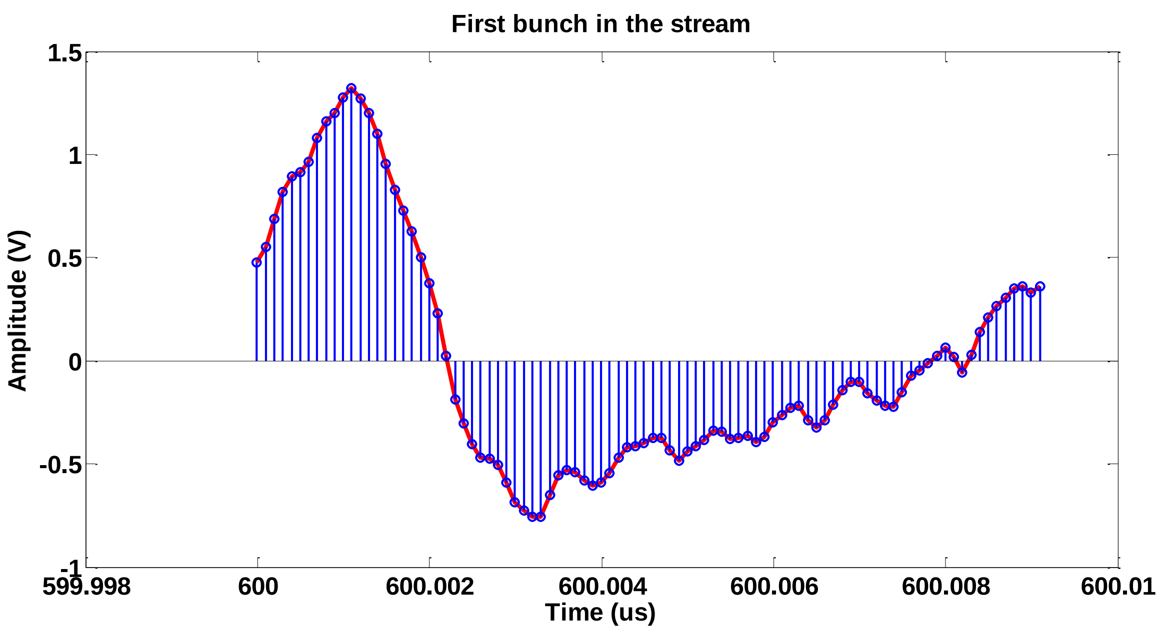


Figure 2.

2- Spline-interpolation was applied on the original curve to contain 2^{13} points, , corresponding to a discretization of 1.12 ps.

3- From the integration of the interpolated curve, the maximum point was determined which corresponds to the zero-crossing point.

C) Data processing for jitter evaluation

1- The steps in the previous section were applied on each successive bunch individually. So, the second bunch starts from ~ 92 to 180 sampling points. Likewise, the curve was spline-interpolated and the zero-crossing was determined. Similarly for the third bunch and so on.

2- The jitter deviation was calculated by subtracting zero-crossing value of the bunch from the bunch number * the periodicity (9.224430929343646 ns)

Jitter deviation for a single bunch = zero-crossing - N $\times$ 9.224430929343646

N the bunch number

3- The fluctuation will provide the jitter error as it shown in figures 3 & 4 in shape 1 for the first 3000 bunches and its histogram. Figure 5 & 6 show zero-crossing jitter for the first 500 bunches for shape 1 and figure 7 & 8 for shape 2. The other bunch shapes and RF signal can be seen in the appendix.

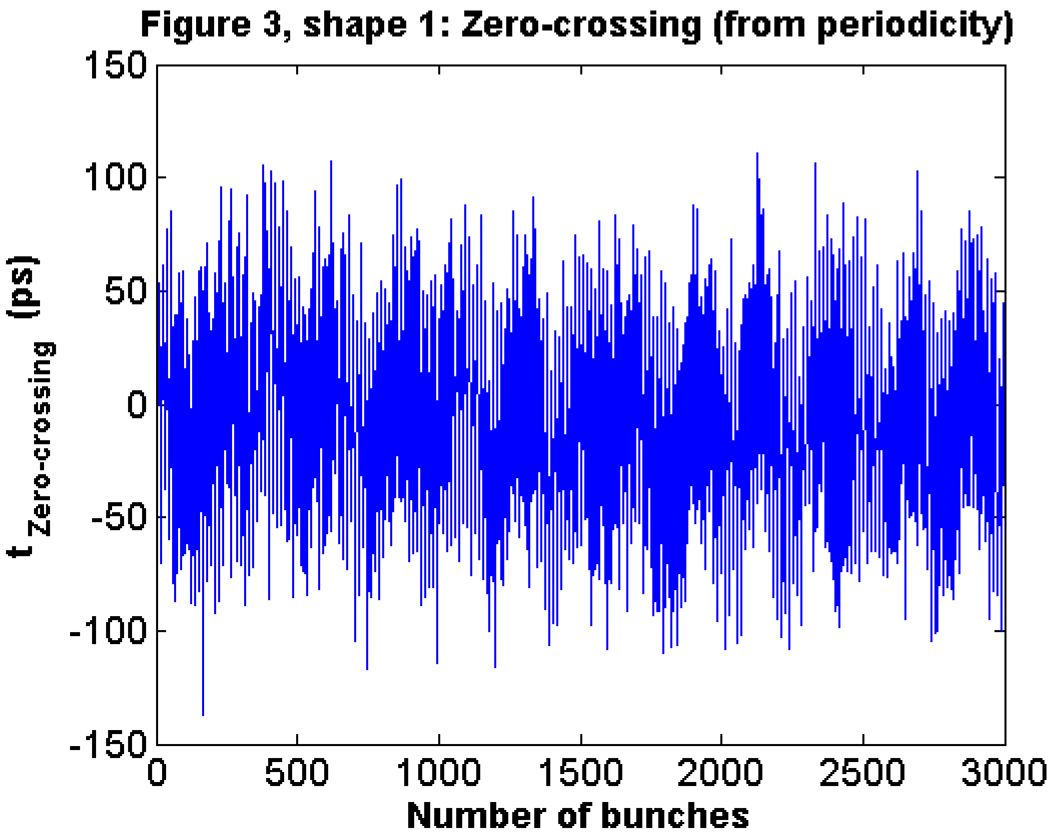


Figure 3, shape 1: Zero-crossing (from periodicity)
150
100
50
0
-50
-100
-150
t Zero-crossing (ps)
0
500
1000
1500
2000
2500
3000
Number of bunches

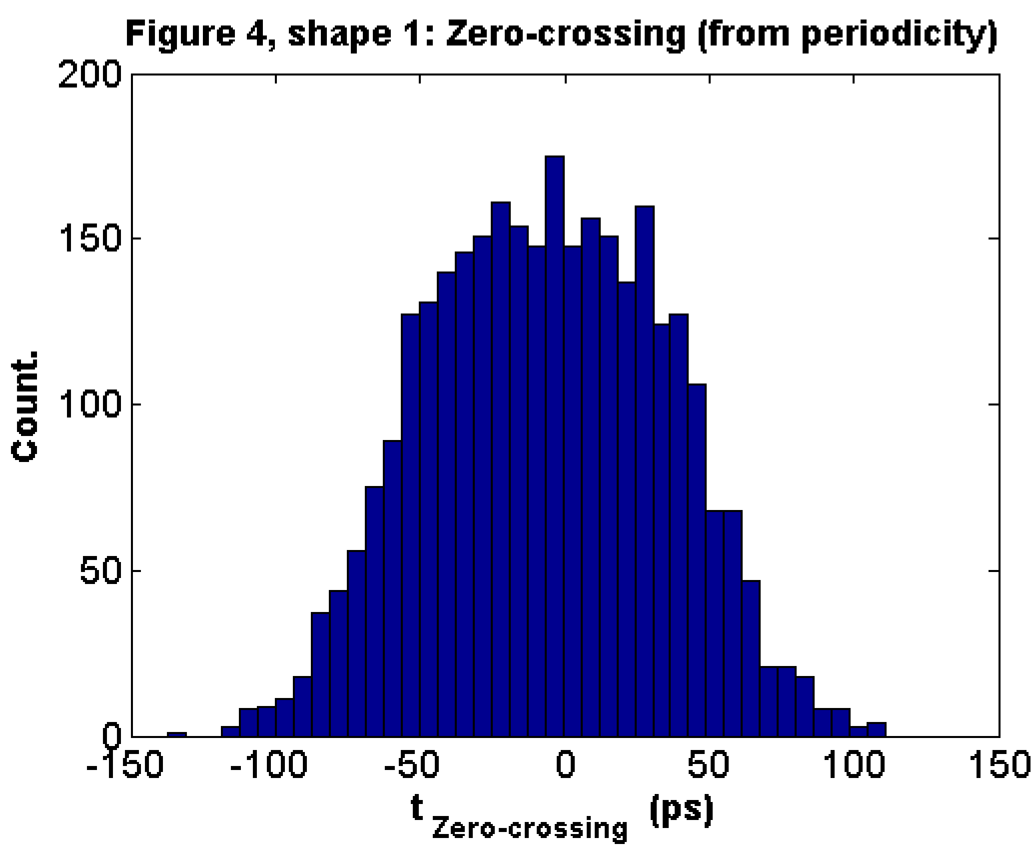


Figure 4, shape 1: Zero-crossing (from periodicity)
200
150
100
50
0
Count.
-150
-100
-50
0
50
100
150
t Zero-crossing (ps)

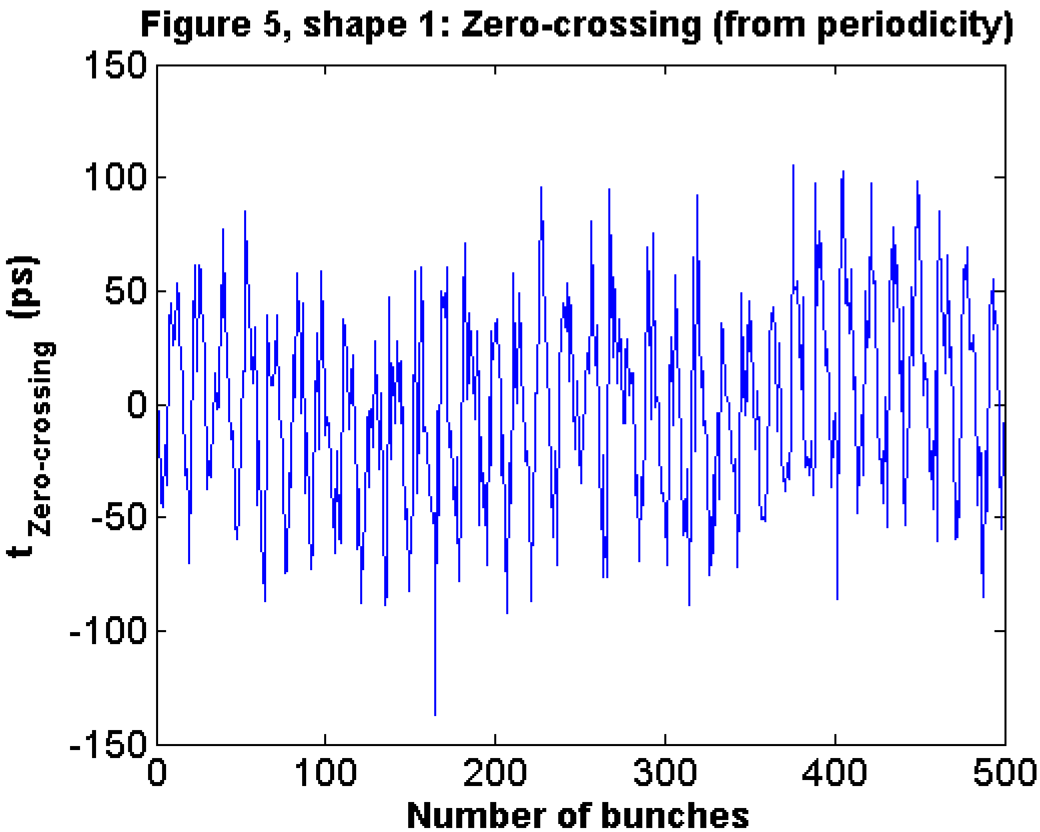


Figure 5, shape 1: Zero-crossing (from periodicity)
150
100
50
0
-50
-100
-150
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

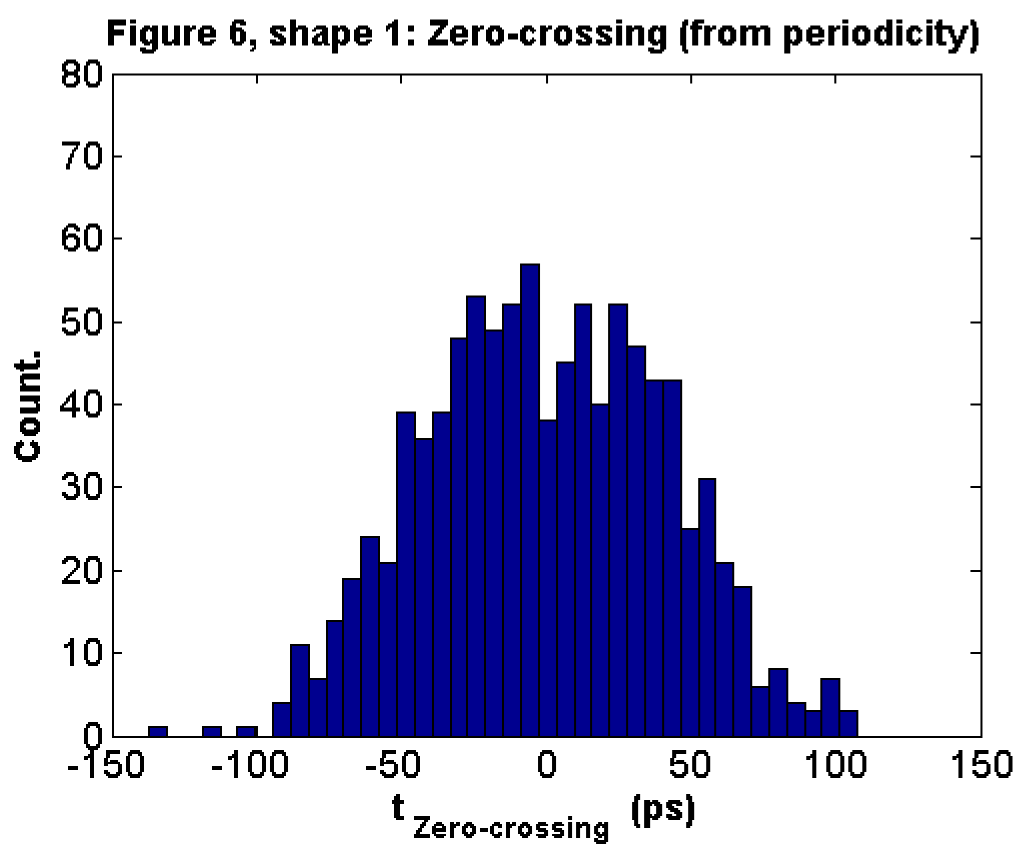


Figure 6, shape 1: Zero-crossing (from periodicity)
80
70
60
50
40
30
20
10
0
-150
-100
-50
0
50
100
150
Count.
t Zero-crossing (ps)

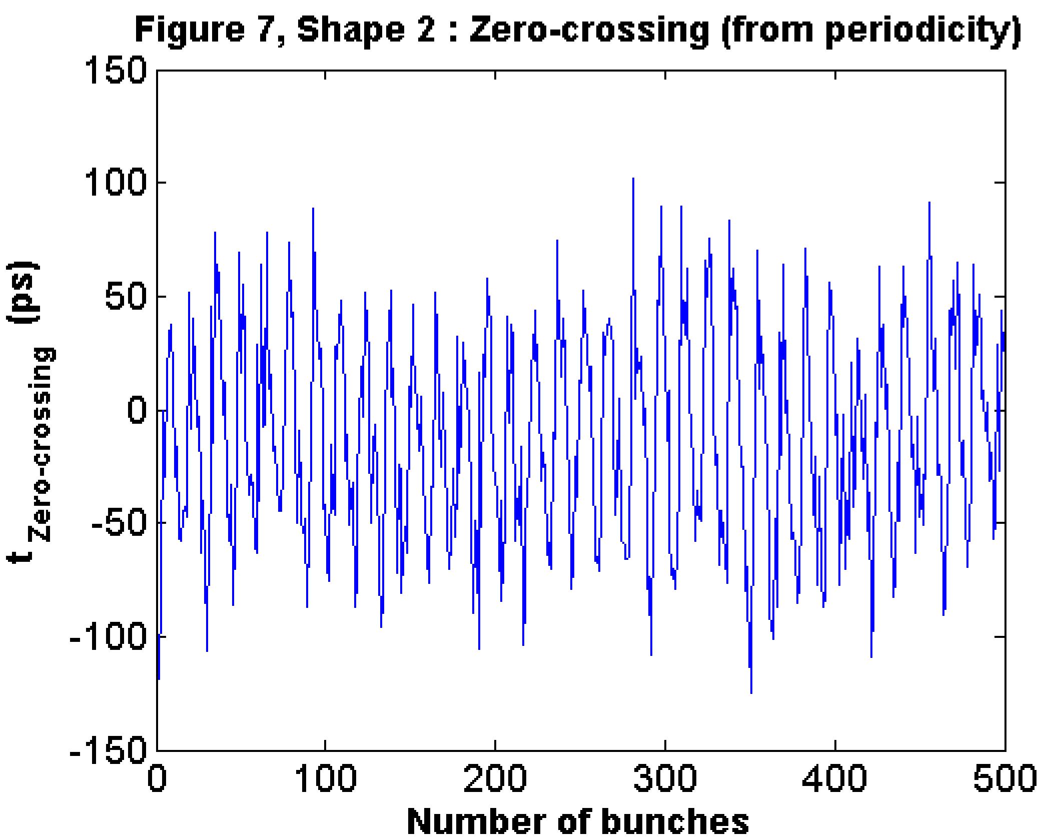


Figure 7, Shape 2 : Zero-crossing (from periodicity)
150
100
50
0
-50
-100
-150
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

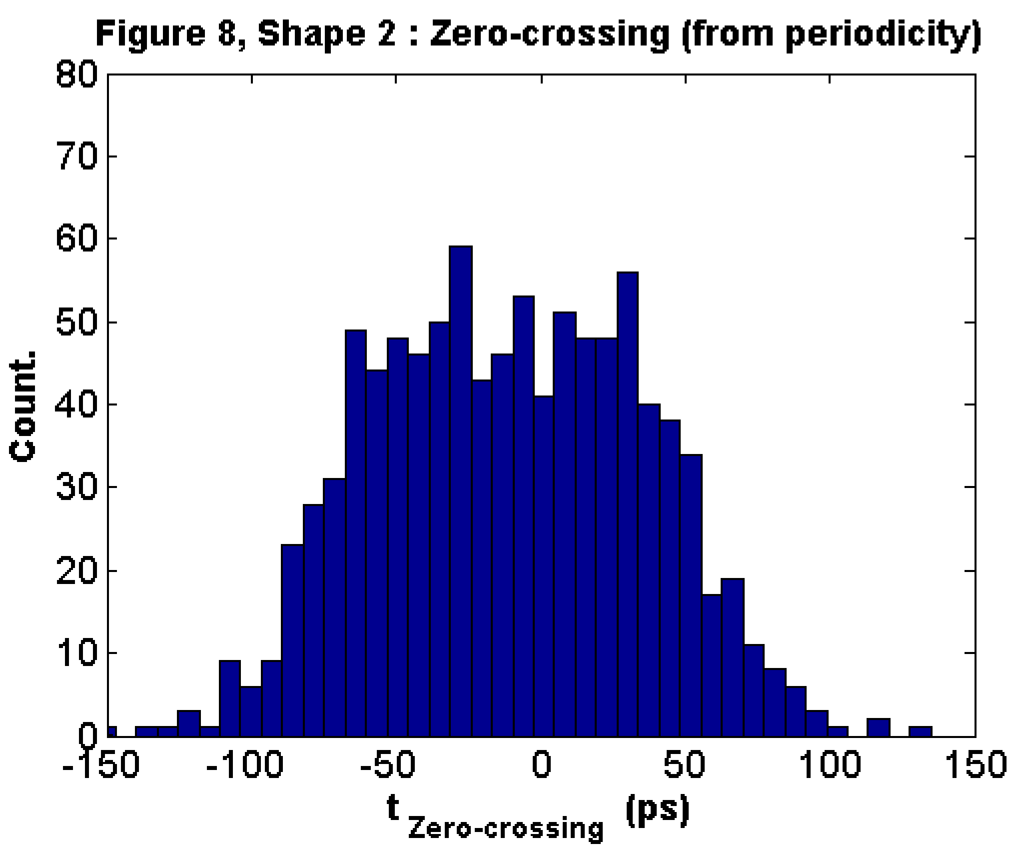


Figure 8, Shape 2 : Zero-crossing (from periodicity)
80
70
60
50
40
30
20
10
0
-150
-100
-50
0
50
100
150
t Zero-crossing (ps)
Count.

E) Zero-crossing jitter evaluation with another method,

Another method was introduced to calculate zero-crossing jitter regardless of the periodicity calculations. The method can be described as following:

1- A stream of bunches was extracted, 40 bunches.

2- Spline-interpolation was applied with steps of 0.2 ps.

3- The zero-crossing of each bunch was brought to zero (as vector beginning) to eliminate the jitter of this point. This point was taken as starting point of the next bunch. The similar process was applied for the next 40 bunches and so on.

4- The fluctuation will provide the jittter error as it shown in figures 9 & 10 in shape 1 for the first 3000 bunches and its histogram. Figure 11 & 12 show zero-crossing jitter for the first 500 bunches for shape 1 and figure 13 & 14 for shape 2. The other bunch shapes and RF signal can be seen in the appendix section F.

The standard deviations for the jitter from both methods are listed in table 1.

shape	Zc (ps) -from periodicity-	Zc (ps) -another method-
RF	16.19	24.77
1	40.99	37.81
2	46.41	41.95
3	55.61	55.89
4	68.92	70.35
5	87.24	94.49
6	101.49	112.43
7	315.65	336.72

Table 1

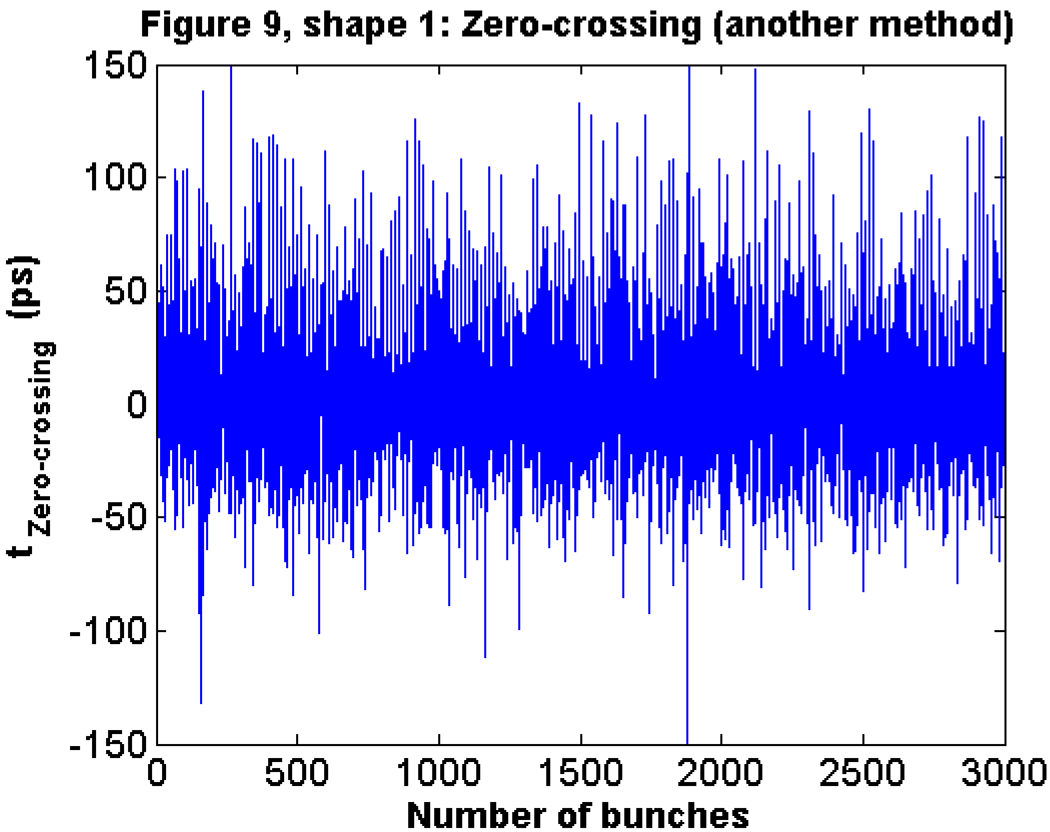


Figure 9, shape 1: Zero-crossing (another method)
150
100
50
0
-50
-100
-150
t Zero-crossing (ps)
0
500
1000
1500
2000
2500
3000
Number of bunches

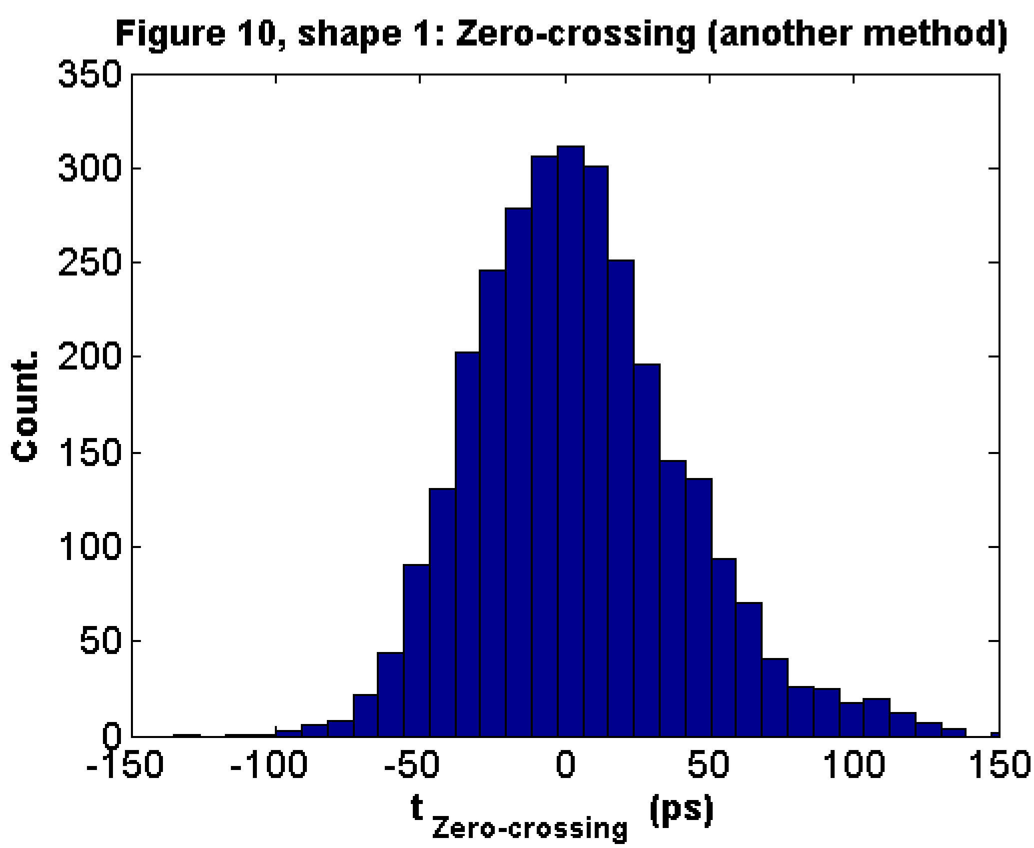


Figure 10, shape 1: Zero-crossing (another method)
350
300
250
200
150
100
50
0
Count.
-150
-100
-50
0
50
100
150
t Zero-crossing (ps)

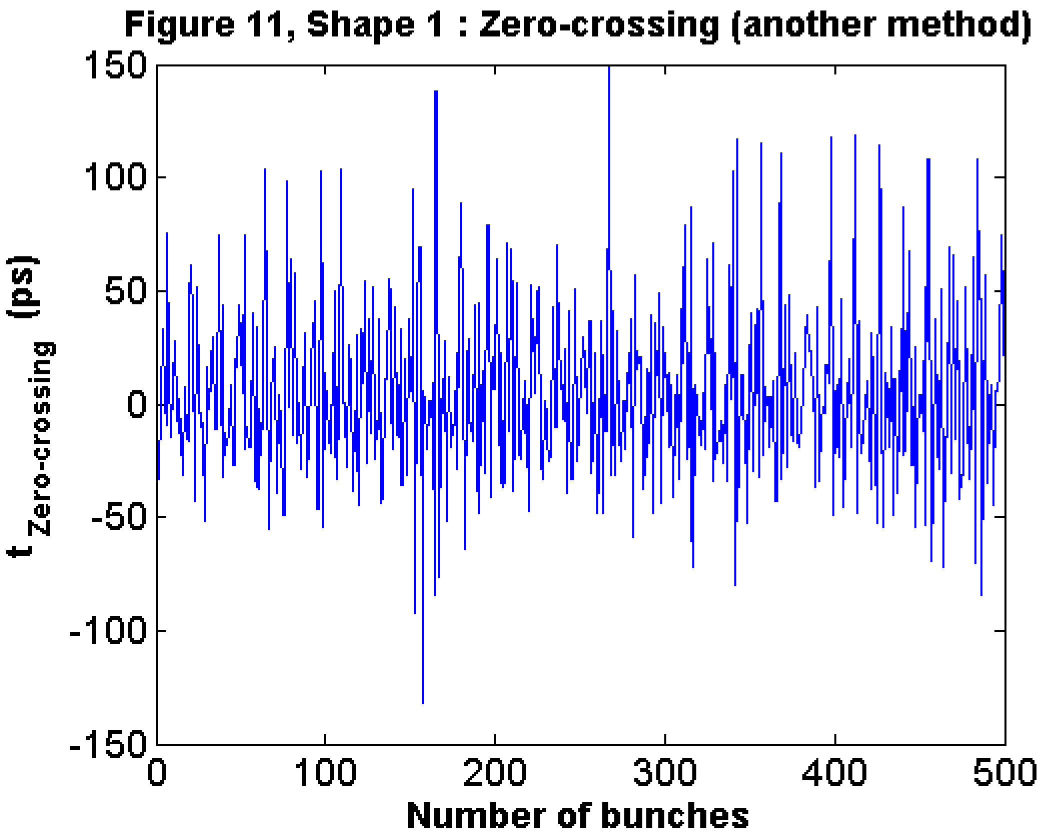


Figure 11, Shape 1 : Zero-crossing (another method)
150
100
50
0
-50
-100
-150
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

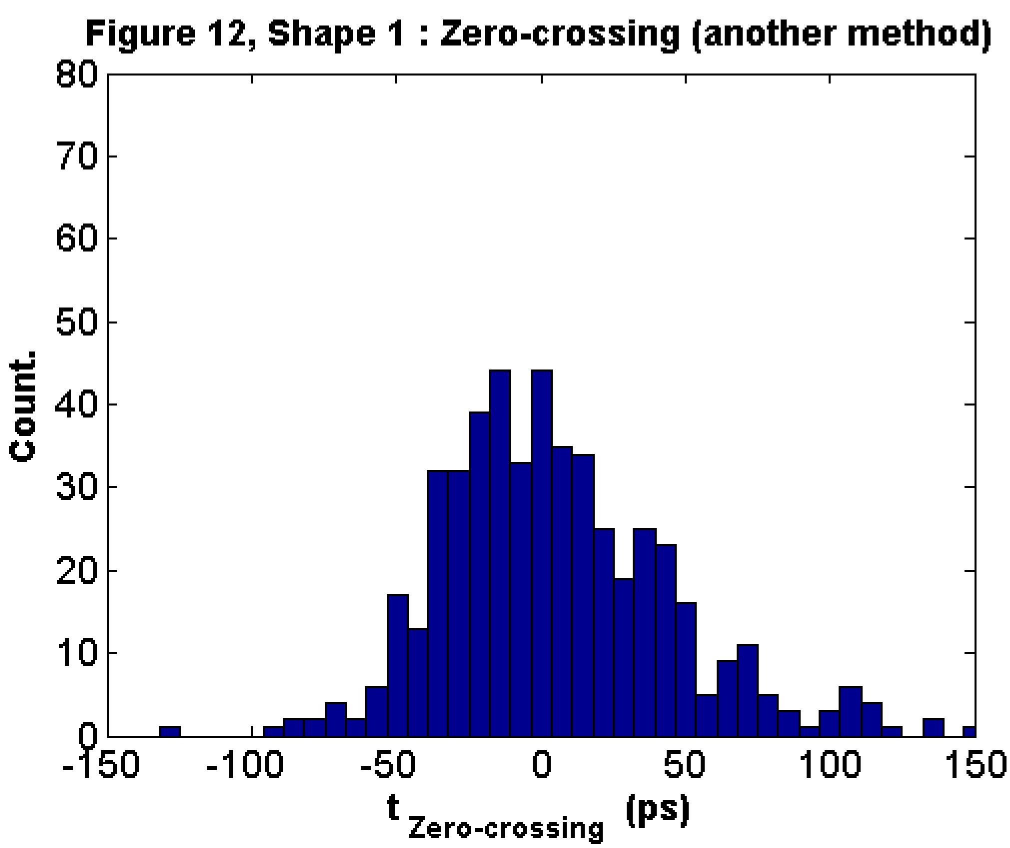


Figure 12, Shape 1 : Zero-crossing (another method)
80
70
60
50
40
30
20
10
0
-150
-100
-50
0
50
100
150
Count.
t Zero-crossing (ps)

Figure 13, Shape 2 :Zero-crossing (another method)

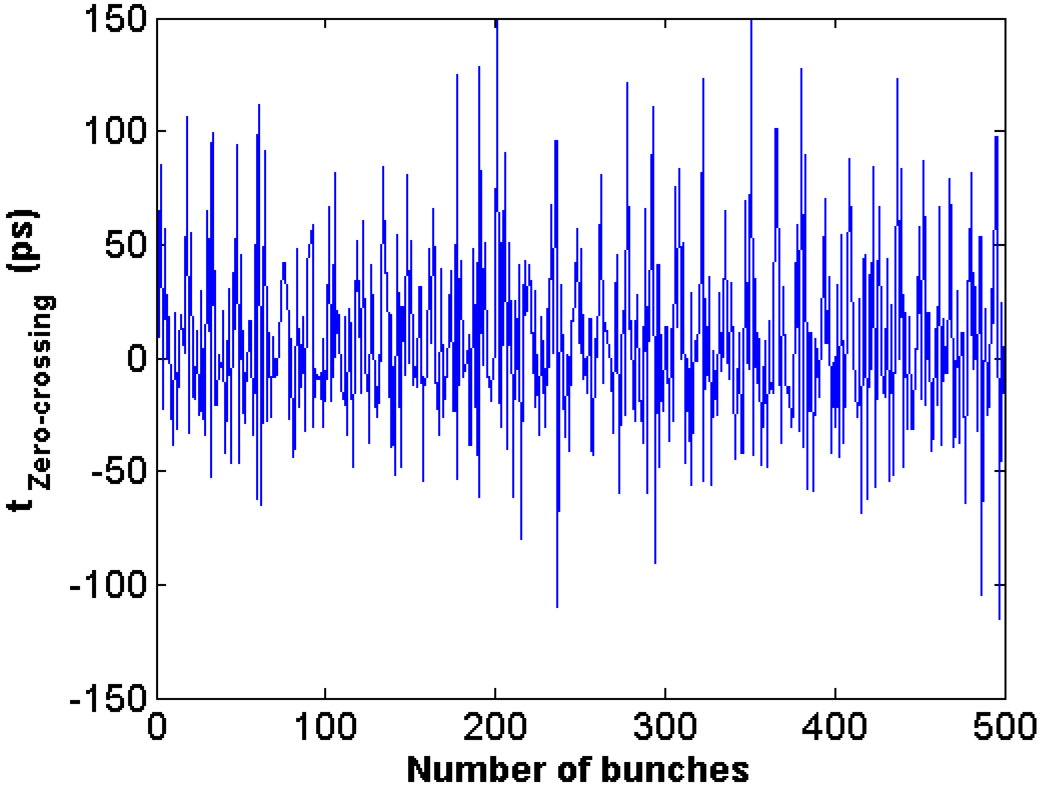
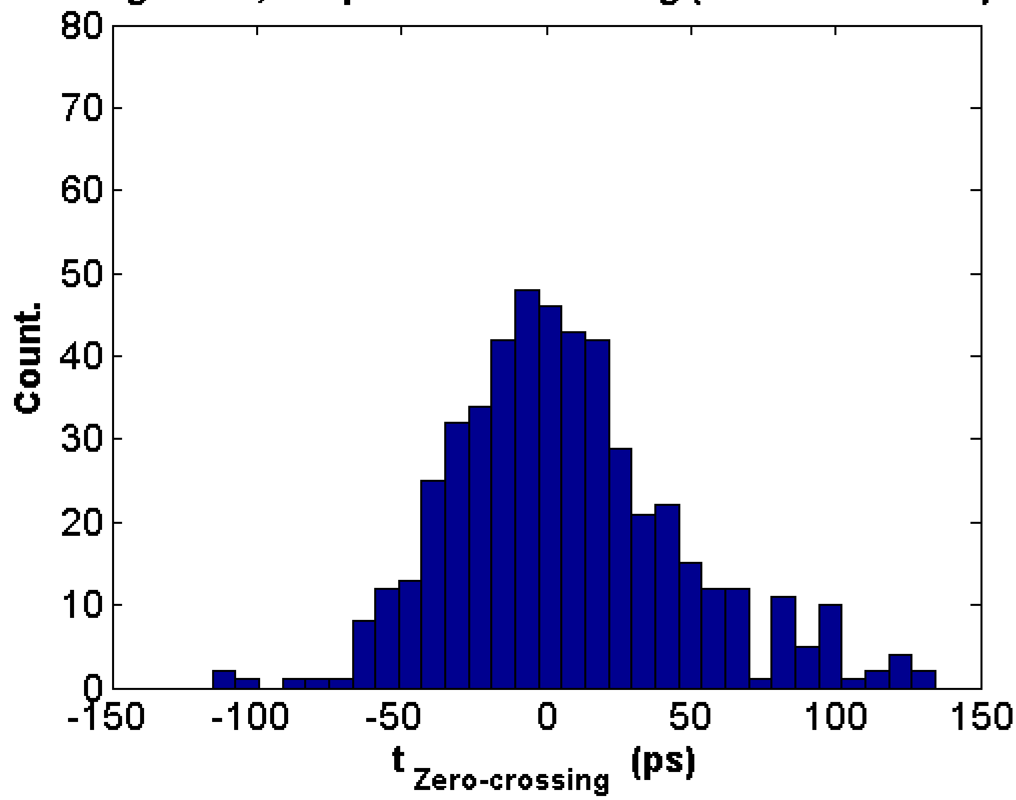


Figure 14, Shape 2 :Zero-crossing (another method)

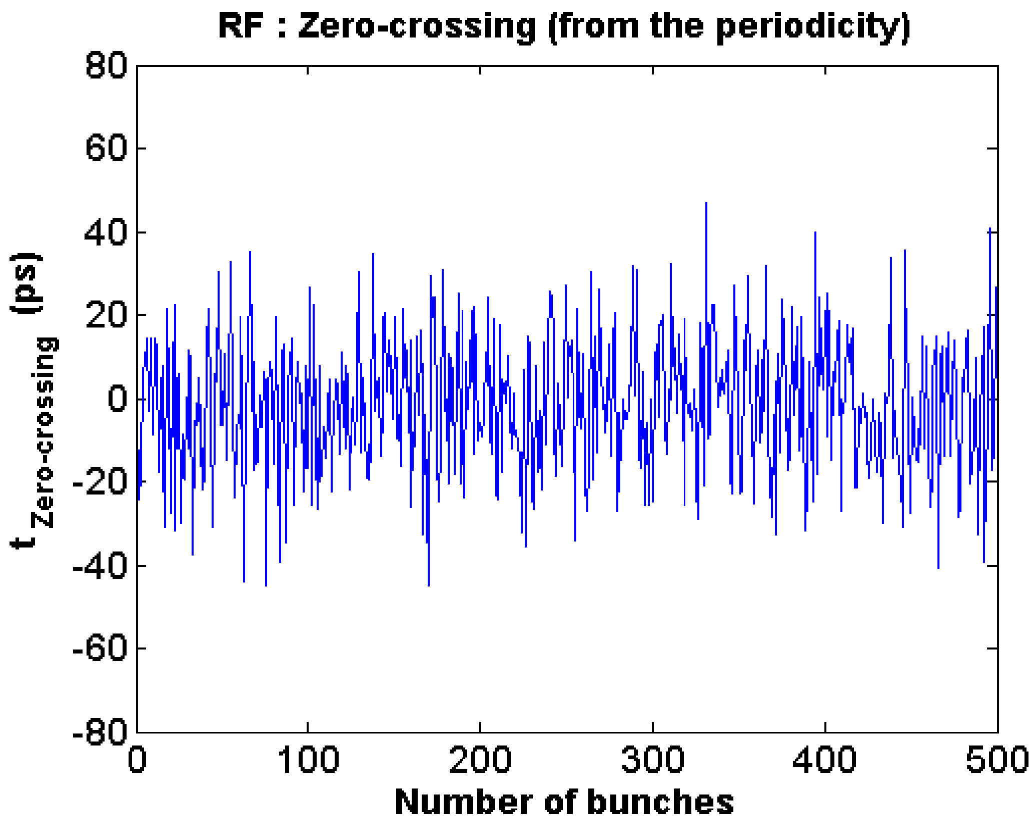


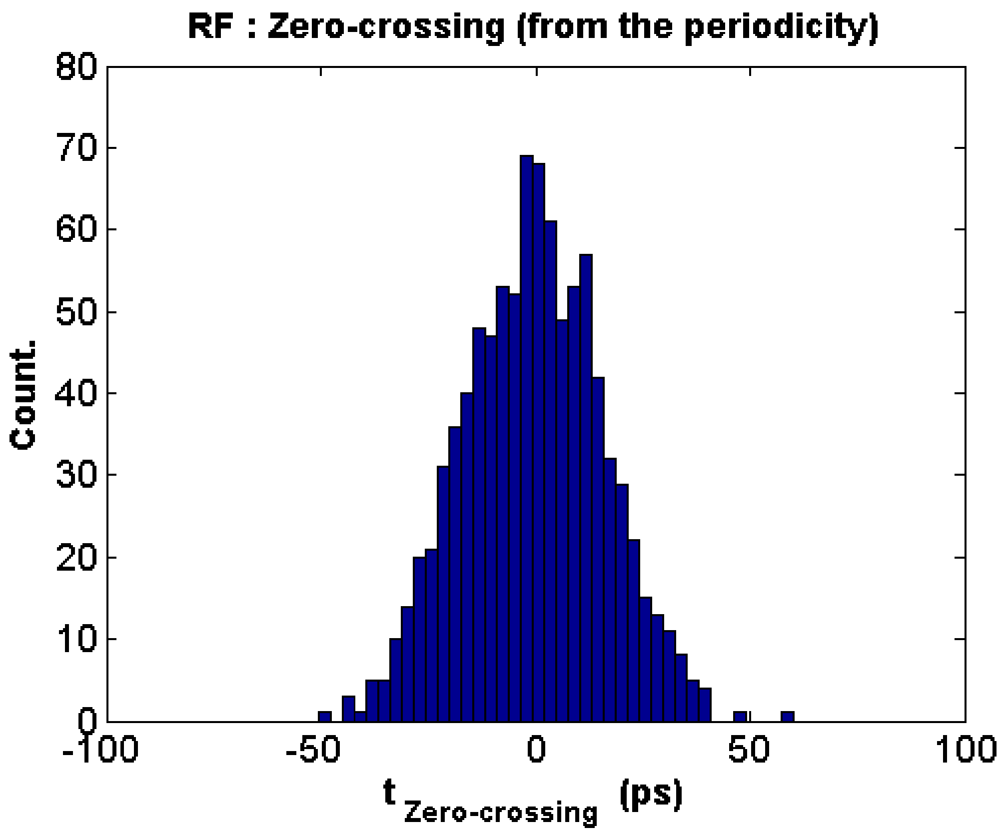
E) Conclusion

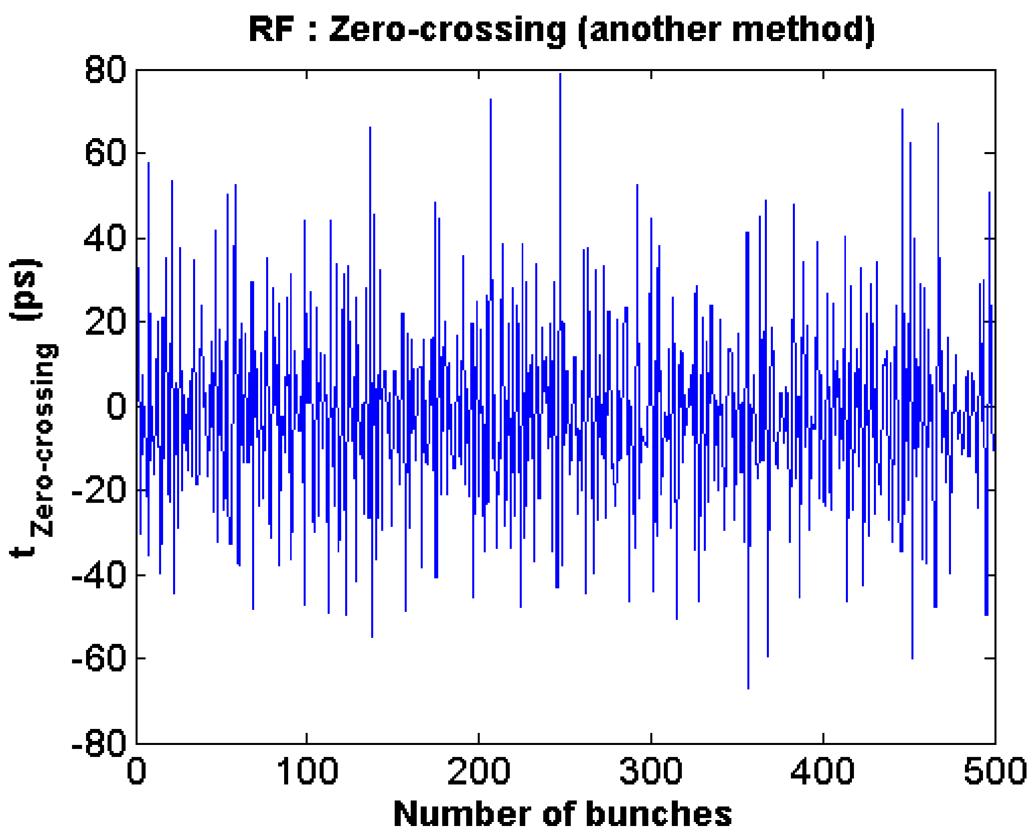
This investigation shows that the r.m.s of the zero-crossing jitter depends on the bunch shape. For the seven different shapes, it was observed that the zero-crossing jitter inside one macro-pulse is between ~ 40 ps (corresponds to 1.56 ° @ 108.4 MHz) for the first bunch to 315 ps (corresponds to 12.3 ° @ 108.4 MHz) for bunch 7. For the RF accelerating signal the zero-crossing jitter is 16.2 ps (corresponds to 0.63 ° @ 108.4 MHz).

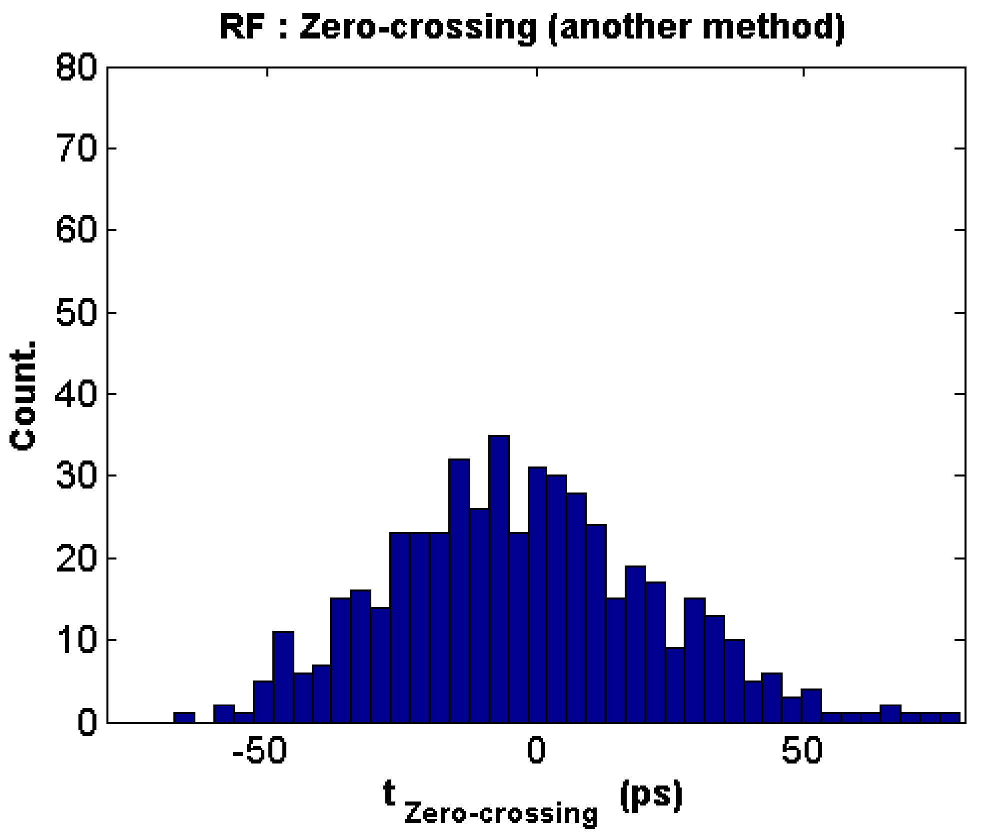
The calculated jitter can be called ‘time resolved jitter’ because the zero-crossing variation has been calculated for each individual bunch. It has systematic reason acting with a repetition of ≈ 7.5 MHz common for all bunch shapes. The origin of the systematic fluctuations is given by the acceleration process and is presently not understood. Due to the readout repetition for the LSPH of 1 µs (corresponding to 108.48 bunches) these systematic fluctuations of 133 ns (133 ns = $(7.5\ \mathrm{MHz})^{-1}$) should be averaged out and therefore the **LSPH data must show a significantly lower jitter**. The action on this averaging depends on the used algorithm running on the LSPH FPGA; this algorithm is not known to us and we ask I-Tech to perform a related calculation.

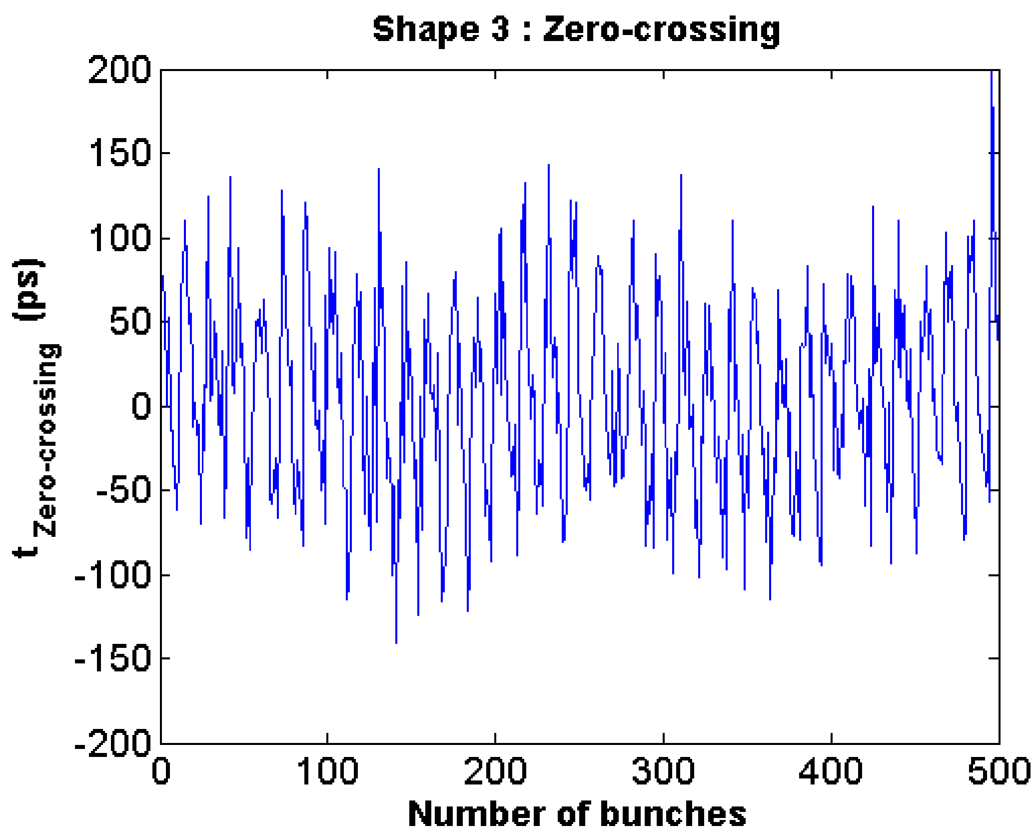
F) Appendix

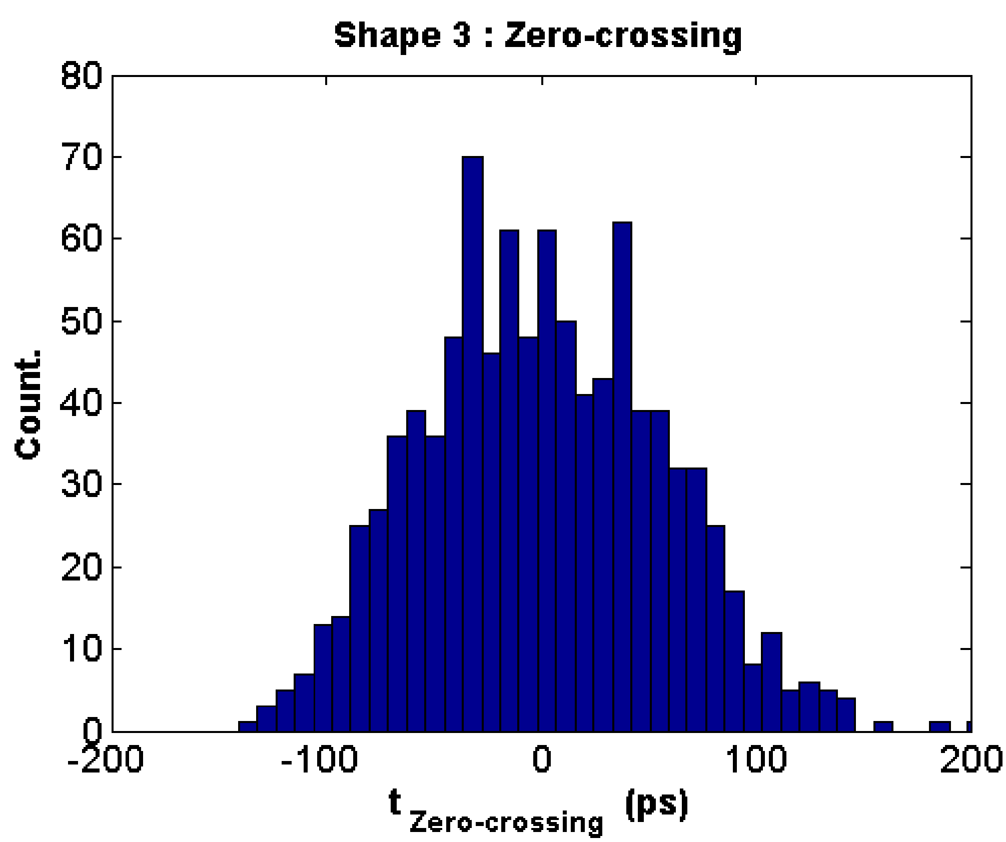

RF : Zero-crossing (from the periodicity)
80
60
40
20
0
-20
-40
-60
-80
$t_{Zero\text{-}crossing}$ (ps)
0
100
200
300
400
500
Number of bunches

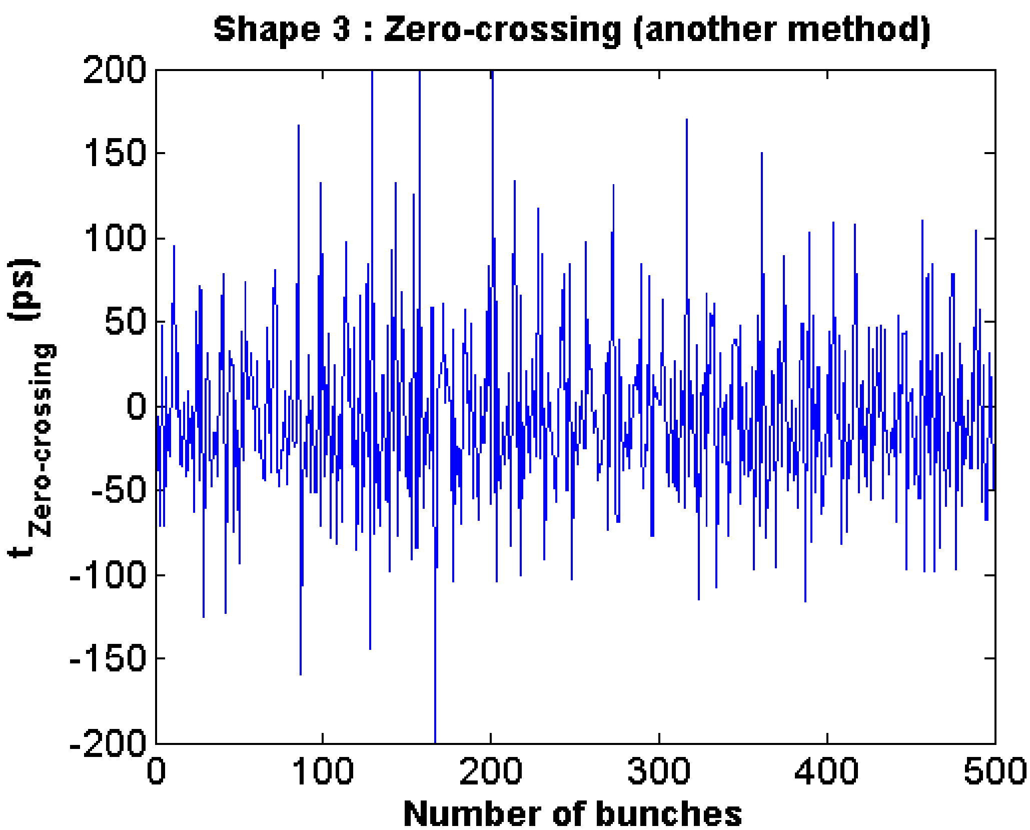

RF : Zero-crossing (from the periodicity)
80
70
60
50
40
30
20
10
0
Count.
-100
-50
0
50
100
$t_{Zero\text{-}crossing}$ (ps)

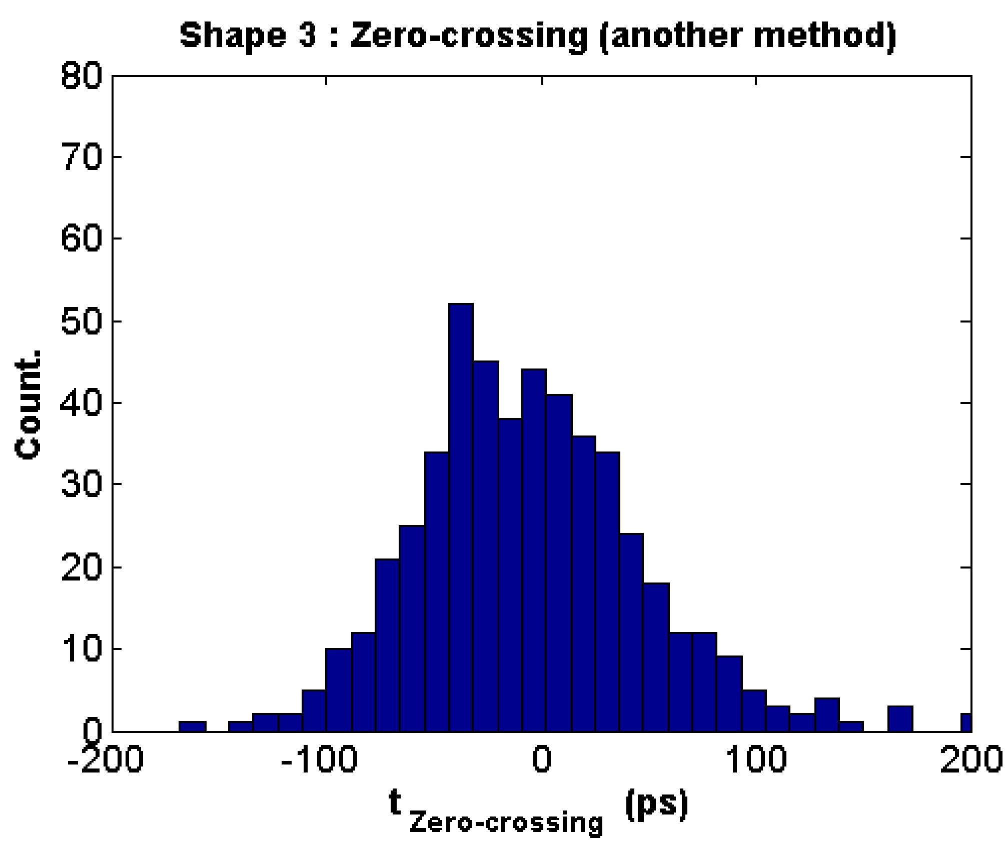

RF : Zero-crossing (another method)
$t_{Zero\text{-}crossing}$ (ps)
Number of bunches
80
60
40
20
0
-20
-40
-60
-80
0
100
200
300
400
500

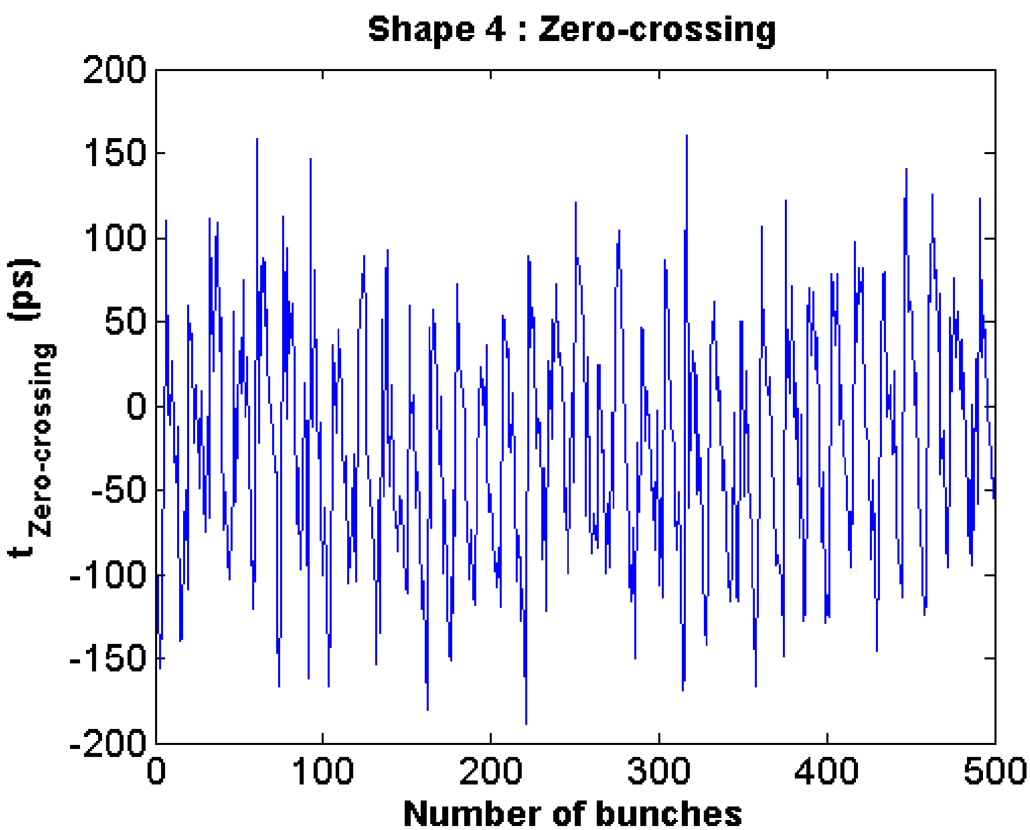

RF : Zero-crossing (another method)
Count.
$t_{Zero\text{-}crossing}$ (ps)
80
70
60
50
40
30
20
10
0
-50
0
50

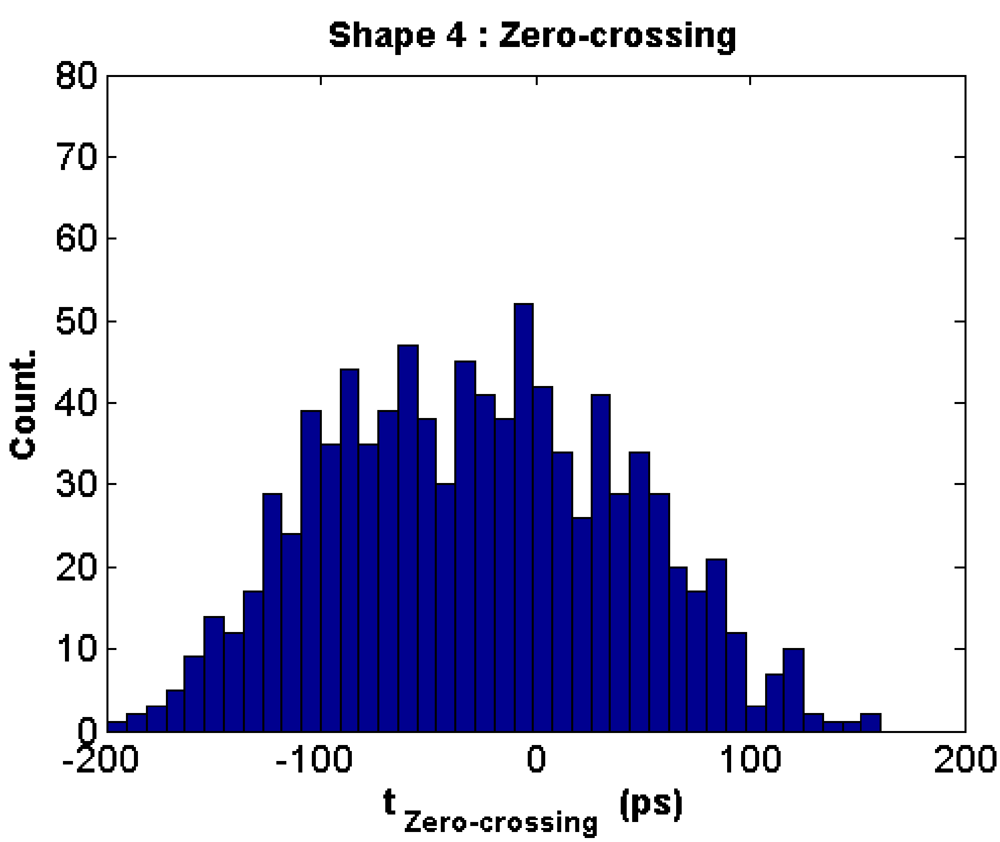

Shape 3 : Zero-crossing
200
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

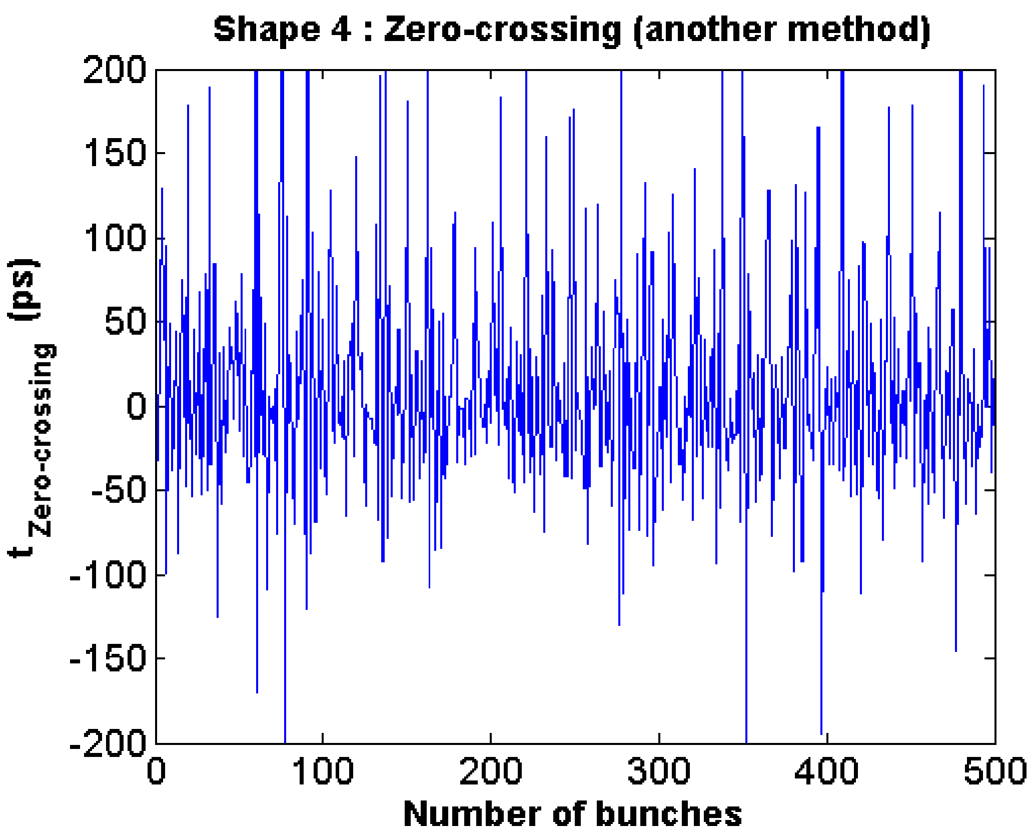

Shape 3 : Zero-crossing
80
70
60
50
40
30
20
10
0
-200
-100
0
100
200
t Zero-crossing (ps)
Count.

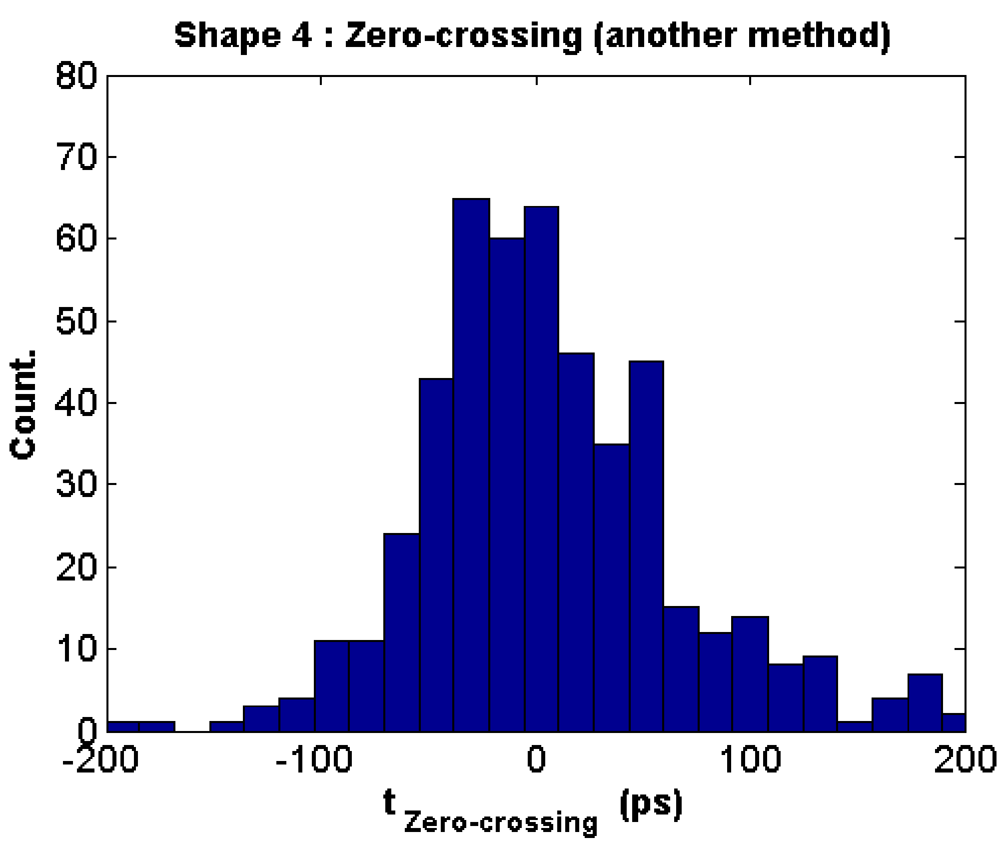

Shape 3 : Zero-crossing (another method)
200
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

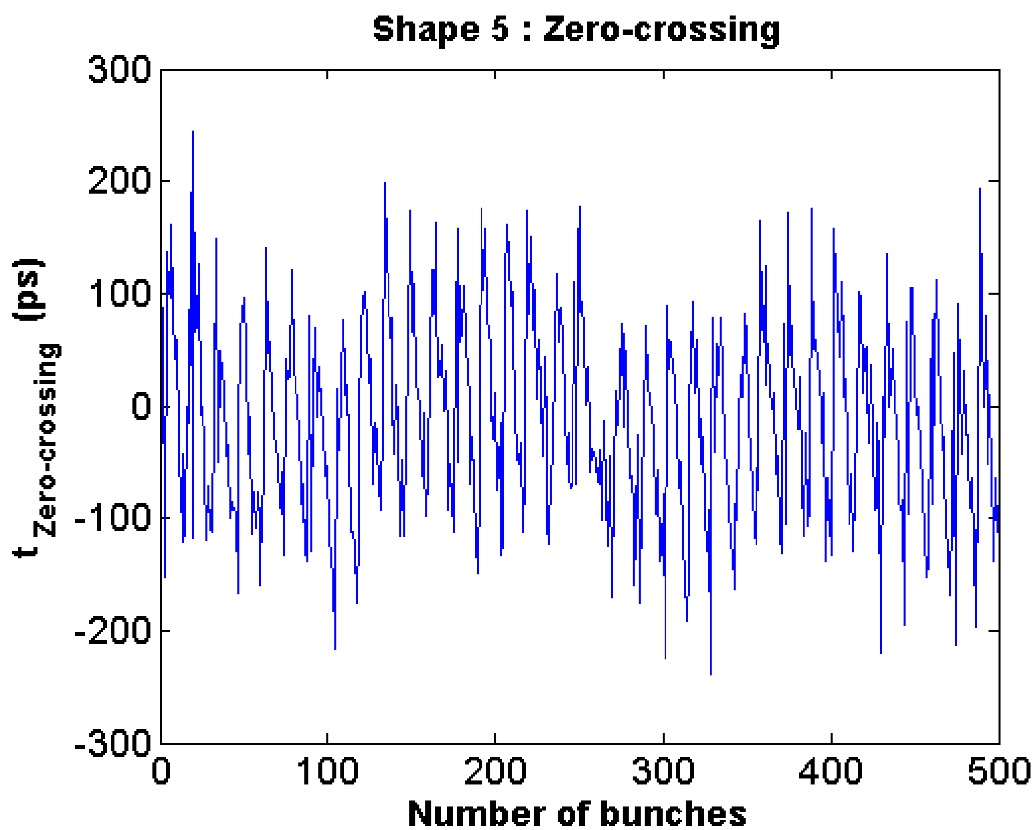

Shape 3 : Zero-crossing (another method)
80
70
60
50
40
30
20
10
0
-200
-100
0
100
200
Count.
t Zero-crossing (ps)

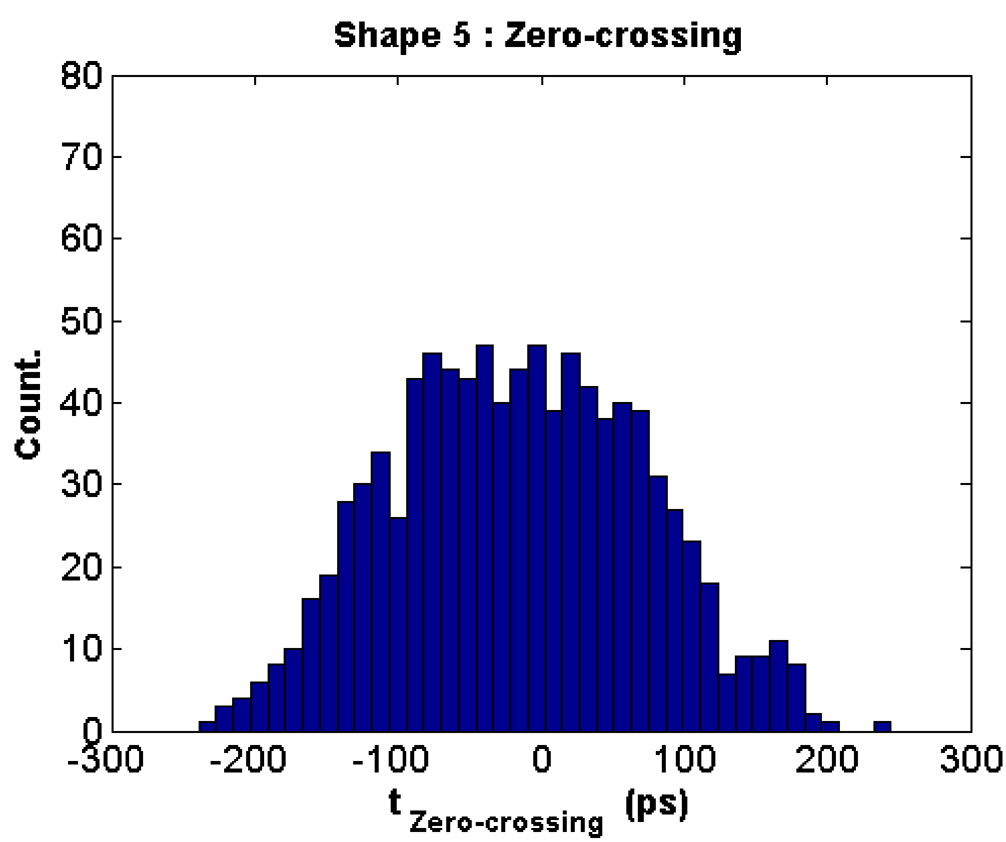

Shape 4 : Zero-crossing
200
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

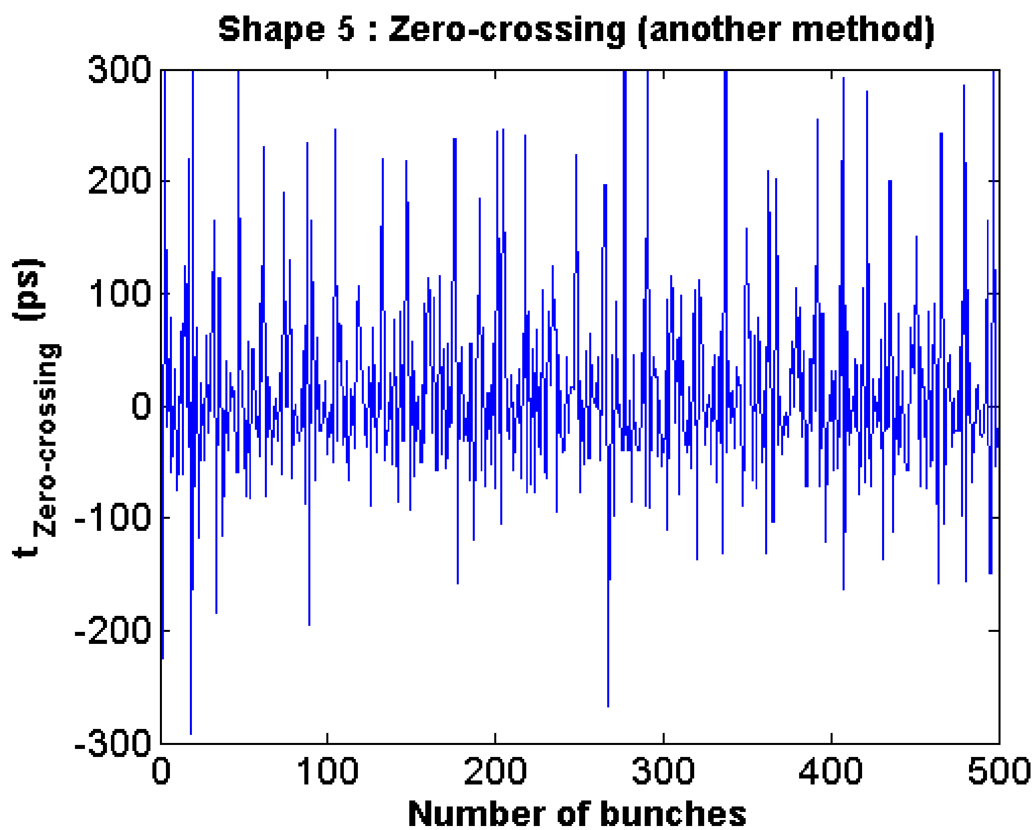

Shape 4 : Zero-crossing
80
70
60
50
40
30
20
10
0
-200
-100
0
100
200
Count.
t Zero-crossing (ps)


Shape 4 : Zero-crossing (another method)
200
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)

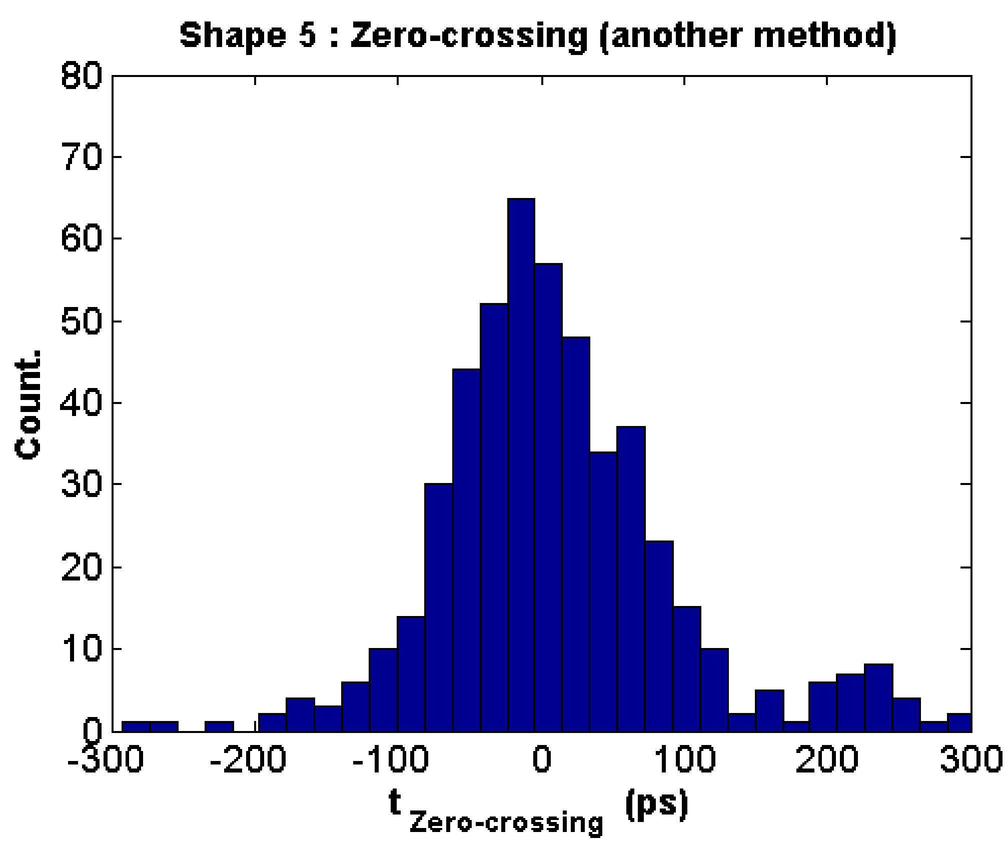

Shape 4 : Zero-crossing (another method)
80
70
60
50
40
30
20
10
0
-200
-100
0
100
200
t Zero-crossing (ps)
Count.


Shape 5 : Zero-crossing
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
Number of bunches
$t_{Zero\text{-}crossing}$ (ps)

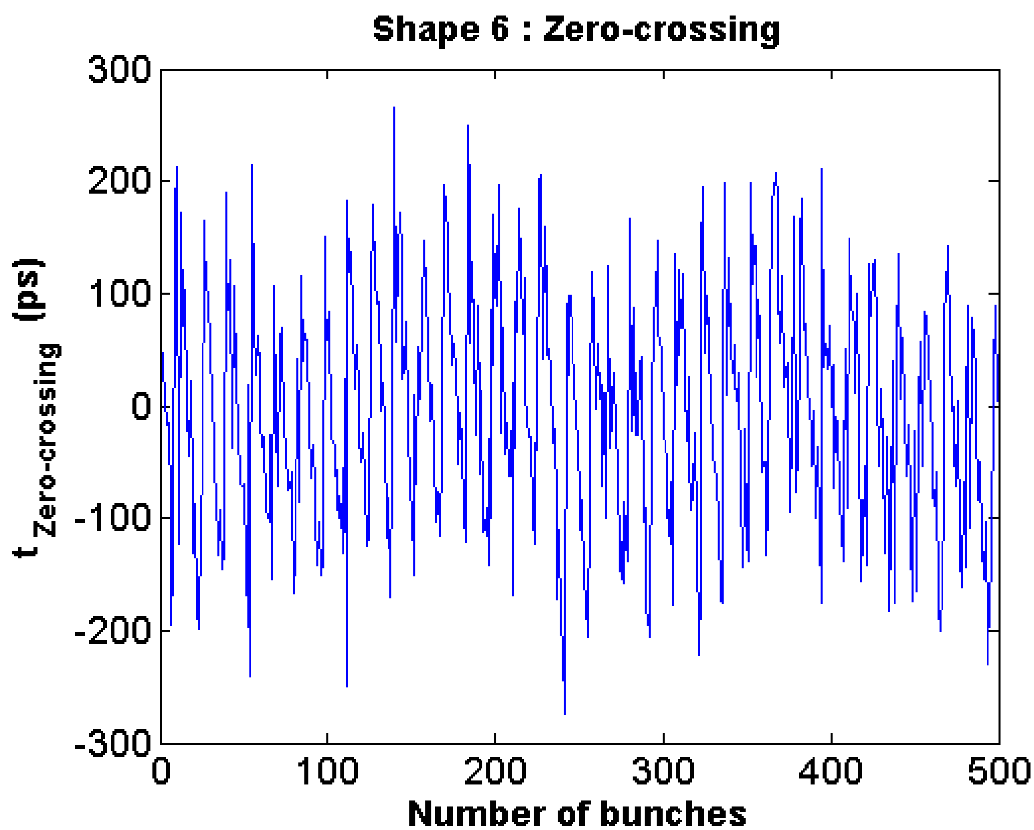

Shape 5 : Zero-crossing
80
70
60
50
40
30
20
10
0
-300
-200
-100
0
100
200
300
$t_{Zero\text{-}crossing}$ (ps)
Count.

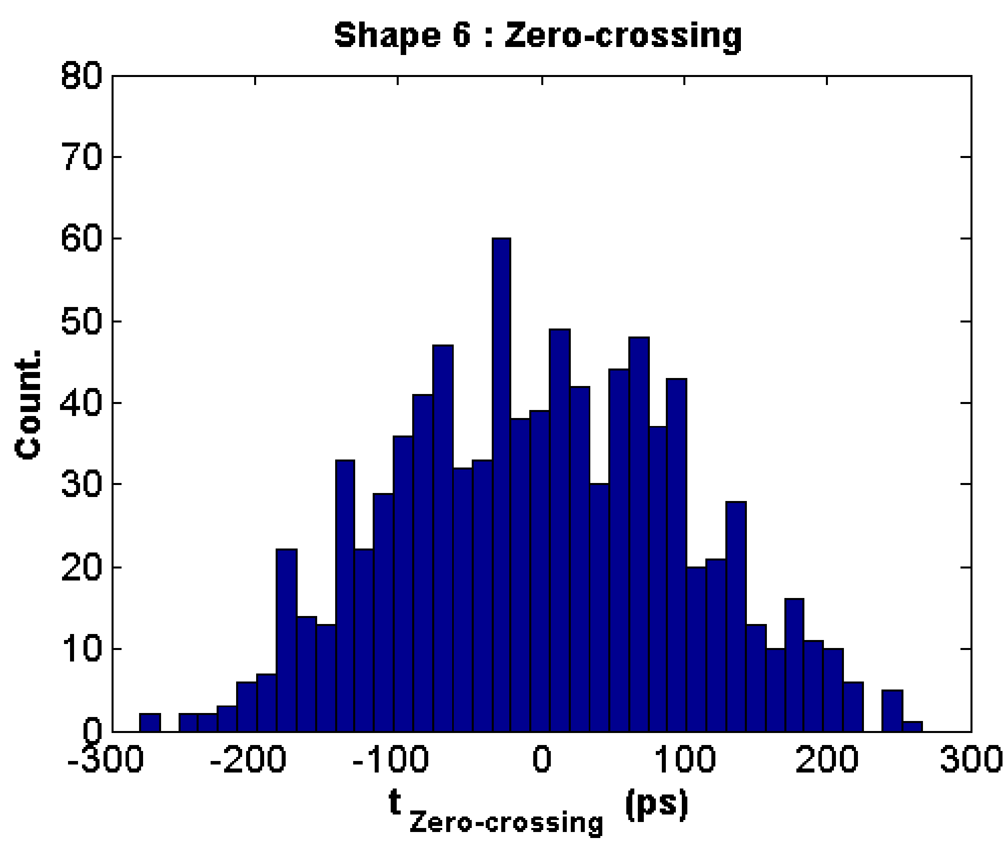


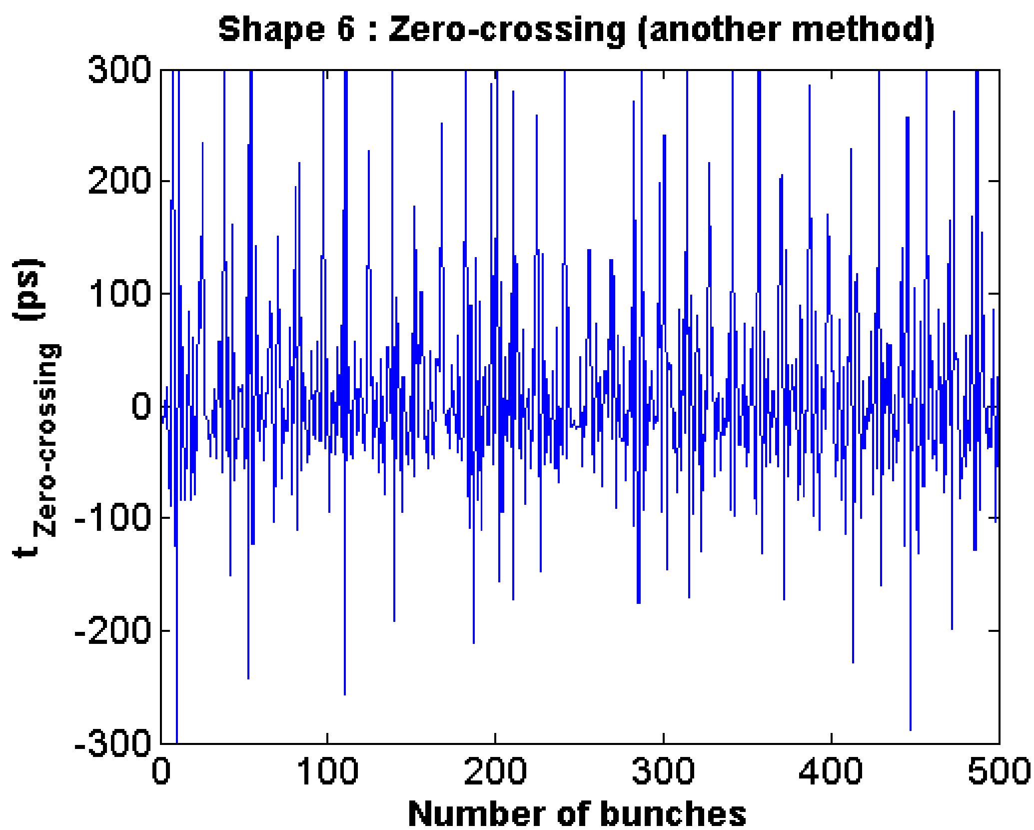
Shape 5 : Zero-crossing (another method)
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)



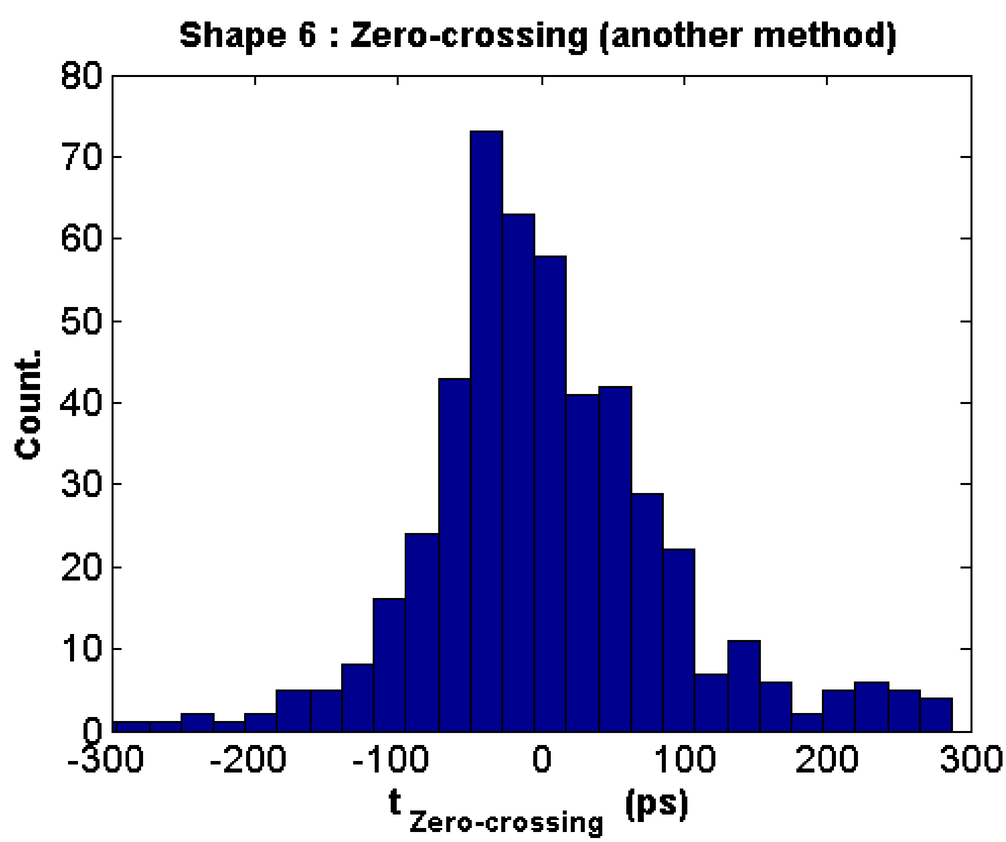
Shape 5 : Zero-crossing (another method)
80
70
60
50
40
30
20
10
0
-300
-200
-100
0
100
200
300
Count.
t Zero-crossing (ps)


Shape 6 : Zero-crossing
300
200
100
0
-100
-200
-300
t Zero-crossing (ps)
0
100
200
300
400
500
Number of bunches

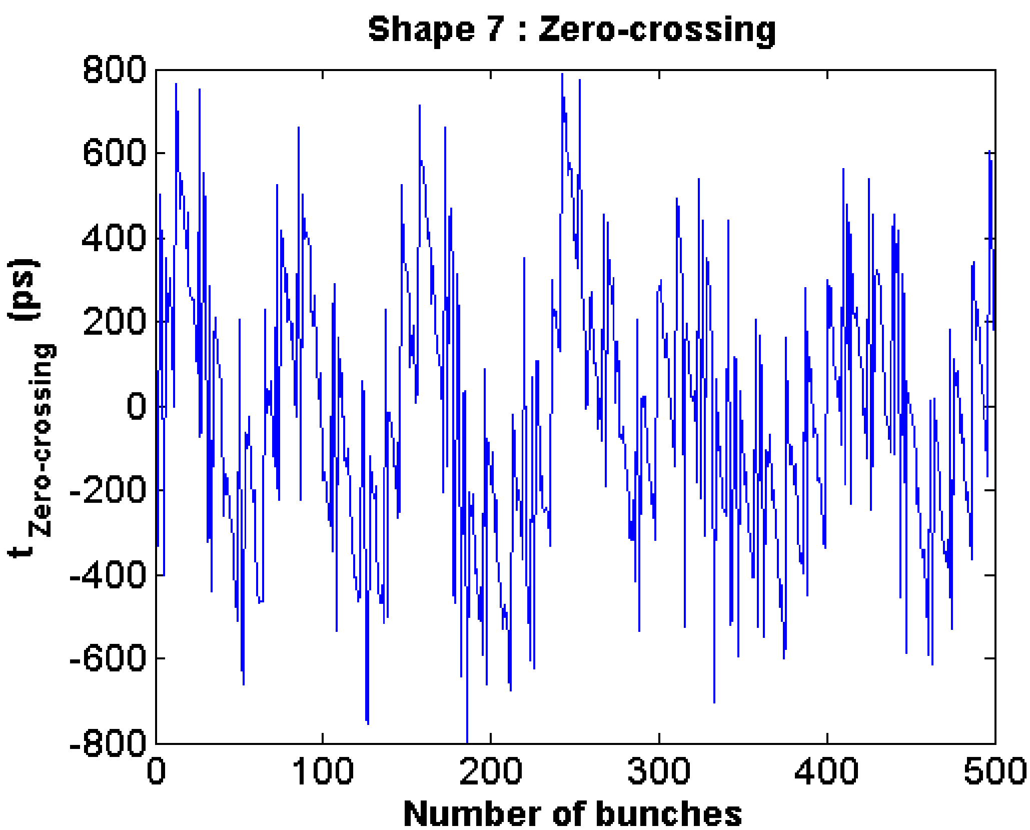

Shape 6 : Zero-crossing
80
70
60
50
40
30
20
10
0
Count.
-300
-200
-100
0
100
200
300
t Zero-crossing (ps)



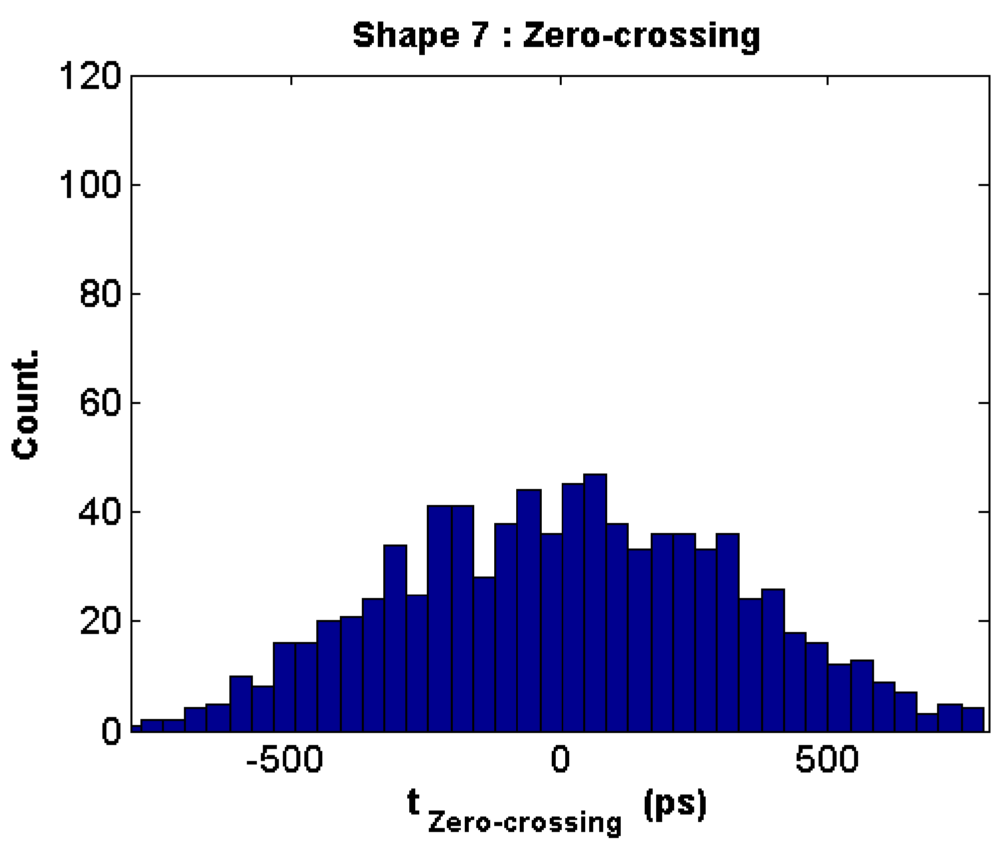
Shape 6 : Zero-crossing (another method)
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)



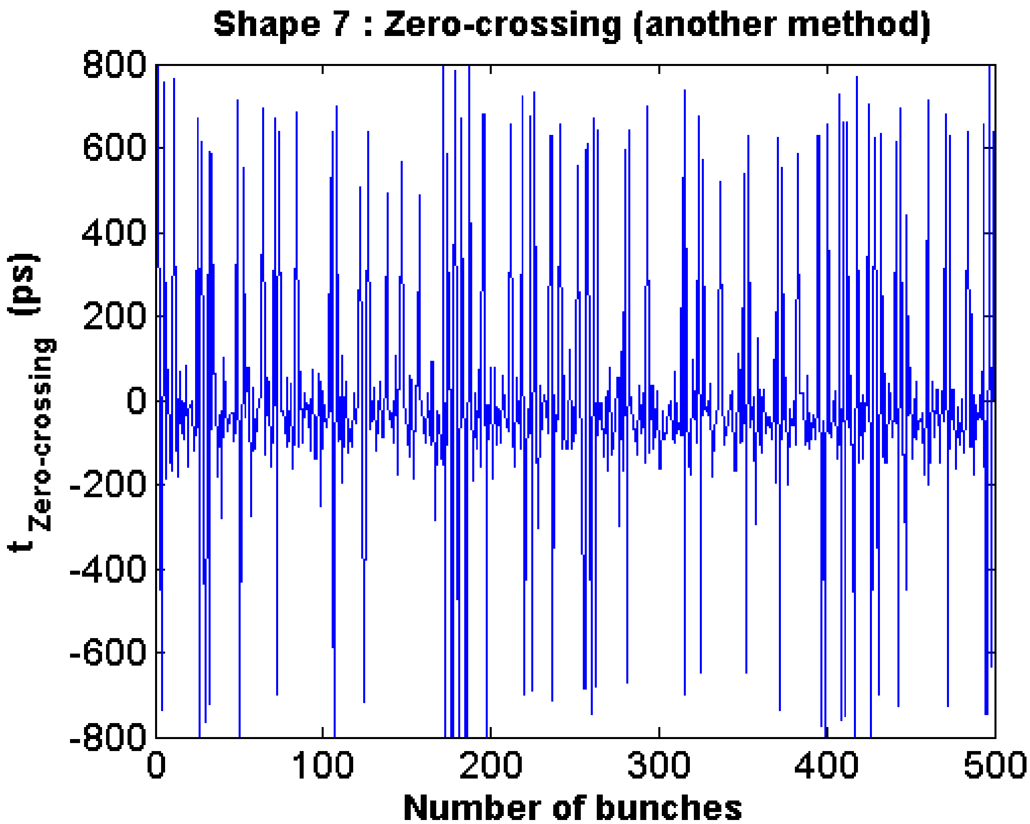
Shape 6 : Zero-crossing (another method)
80
70
60
50
40
30
20
10
0
-300
-200
-100
0
100
200
300
Count.
t Zero-crossing (ps)

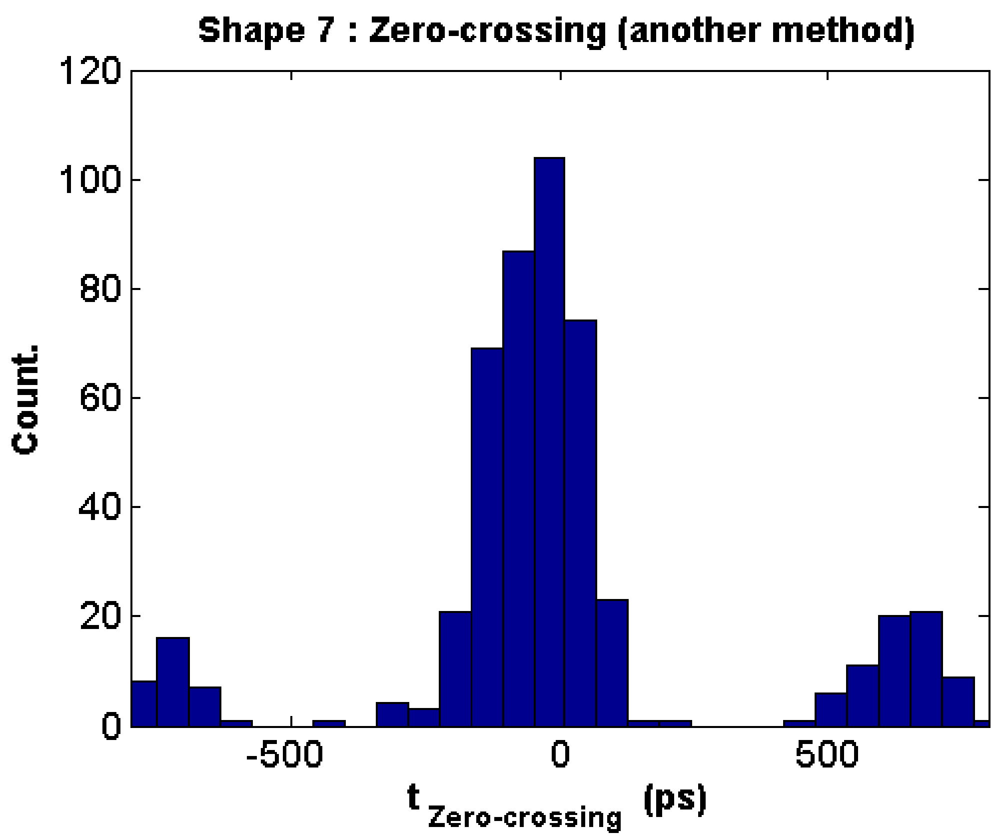


Shape 7 : Zero-crossing
800
600
400
200
0
-200
-400
-600
-800
$t_{Zero\text{-}crossing}$ (ps)
0
100
200
300
400
500
Number of bunches



Shape 7 : Zero-crossing
120
100
80
60
40
20
0
Count.
-500
0
500
$t_{Zero\text{-}crossing}$ (ps)


Shape 7 : Zero-crossing (another method)
800
600
400
200
0
-200
-400
-600
-800
0
100
200
300
400
500
Number of bunches
t Zero-crossing (ps)


Shape 7 : Zero-crossing (another method)
120
100
80
60
40
20
0
-500
0
500
t Zero-crossing (ps)
Count.