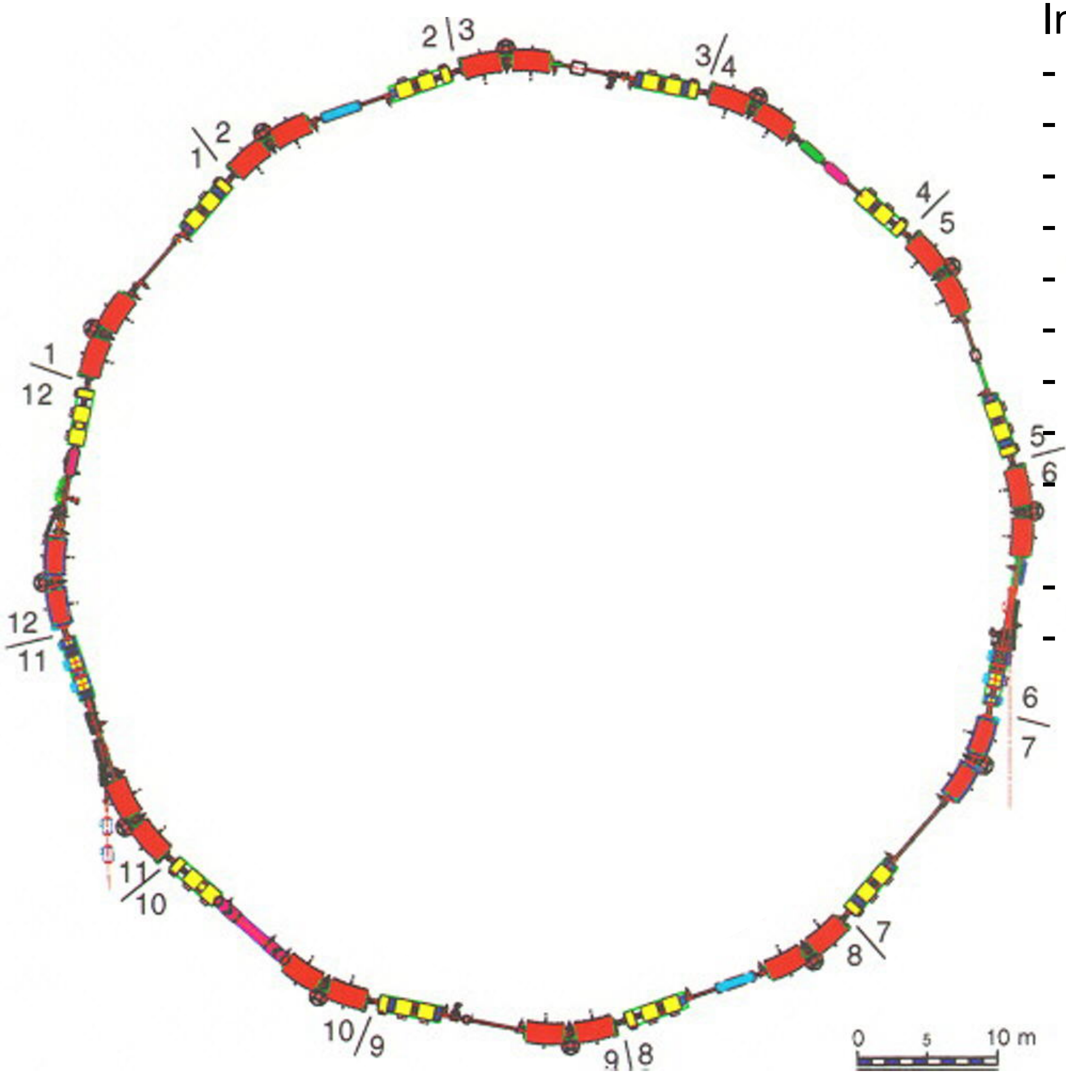
Position and tune out of digitized BPM data

Udo Rauch

Outline

- ⇒ Brief review to accelerator SIS-18 at GSI and motivation
- Direct digitized data: Position calculation and results
- Tune: Beam excitation and baseband measurements
- Summary and outlook.

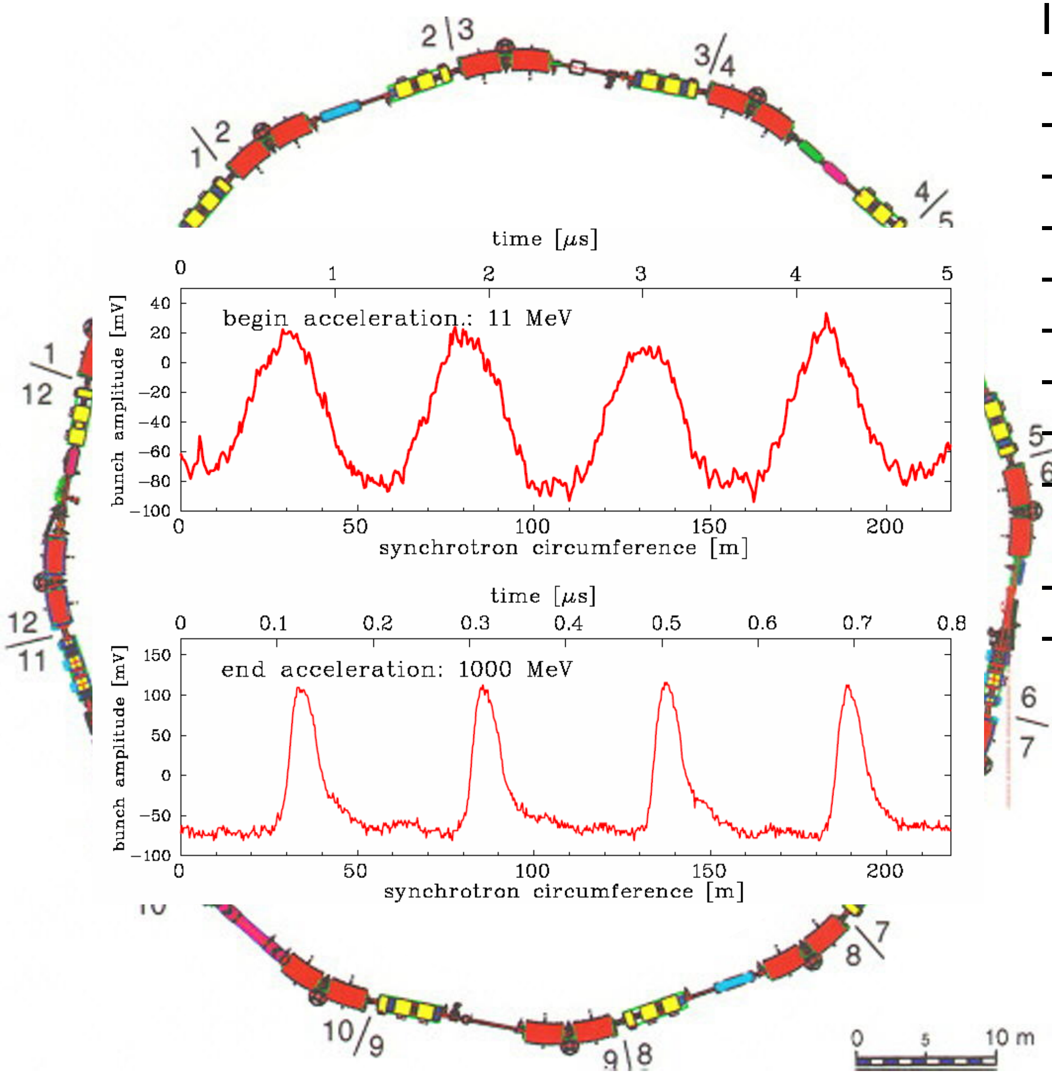
SIS-18 synchrotron at GSI



Important parameters of SIS-18:

- Circumference	216 m
- Inj. type	Multiturn
- Energy range	11 MeV → 2 GeV
- Acc.RF	0.8 → 5 MHz
- Acc. harmonic	4 (no. of bunches)
- Bunching factor	0.6 → 0.2
- Ramp duration	0.3 → 1.5 s
- Typical tune h/v	4.319 3.29
- Tune meas. sys.	Exciter + BPM Schottky
- Ion range (Z)	1 → 92 (p to U)
- Design beams	2 x 10^{11} U 28+ 1 x 10^{13} p

SIS-18 synchrotron at GSI



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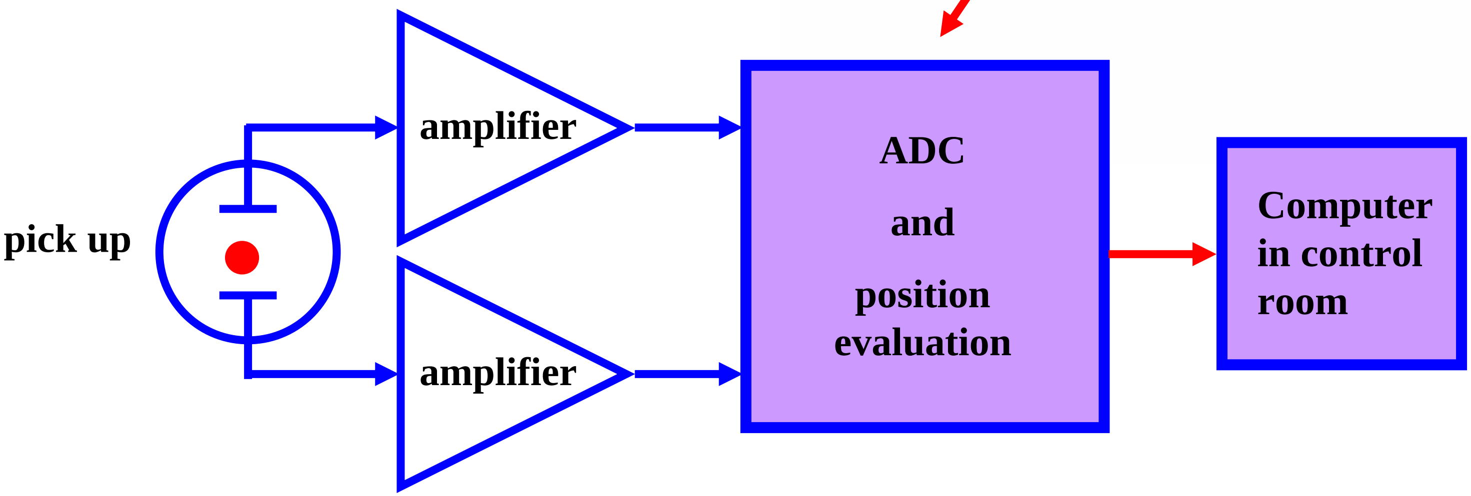
Motivation

- Up to now no tune tracking system yet available at GSI
- Necessity arises due to upgrade of existing accelerator for higher beam intensities and/for future accelerator(s) in FAIR project
- Target
  - (PLL) tune tracking
  - BaseBand – q
  - Single bunch separation
- Two platforms possible for baseband: 3D (by M.Gasior et al, CERN) and direct digitization
- Starting point: Position determination

What is Libera

- Instrumentation Technology (I-Tech) – Libera is an integrated setup using a high resolution ADC for onboard data processing on a FPGA
- Input actually is one BPM per Libera: 2 channels horizontally and 2 channels vertically
- It is targeted to process data online delivering beam position data with delay of about 3 turns, repetition rate of tune spectra of about 100 Hz (presently only offline)

4 channel ADC
125 MSa / s per channel
14 bit resolution
256 Mb onboard memory



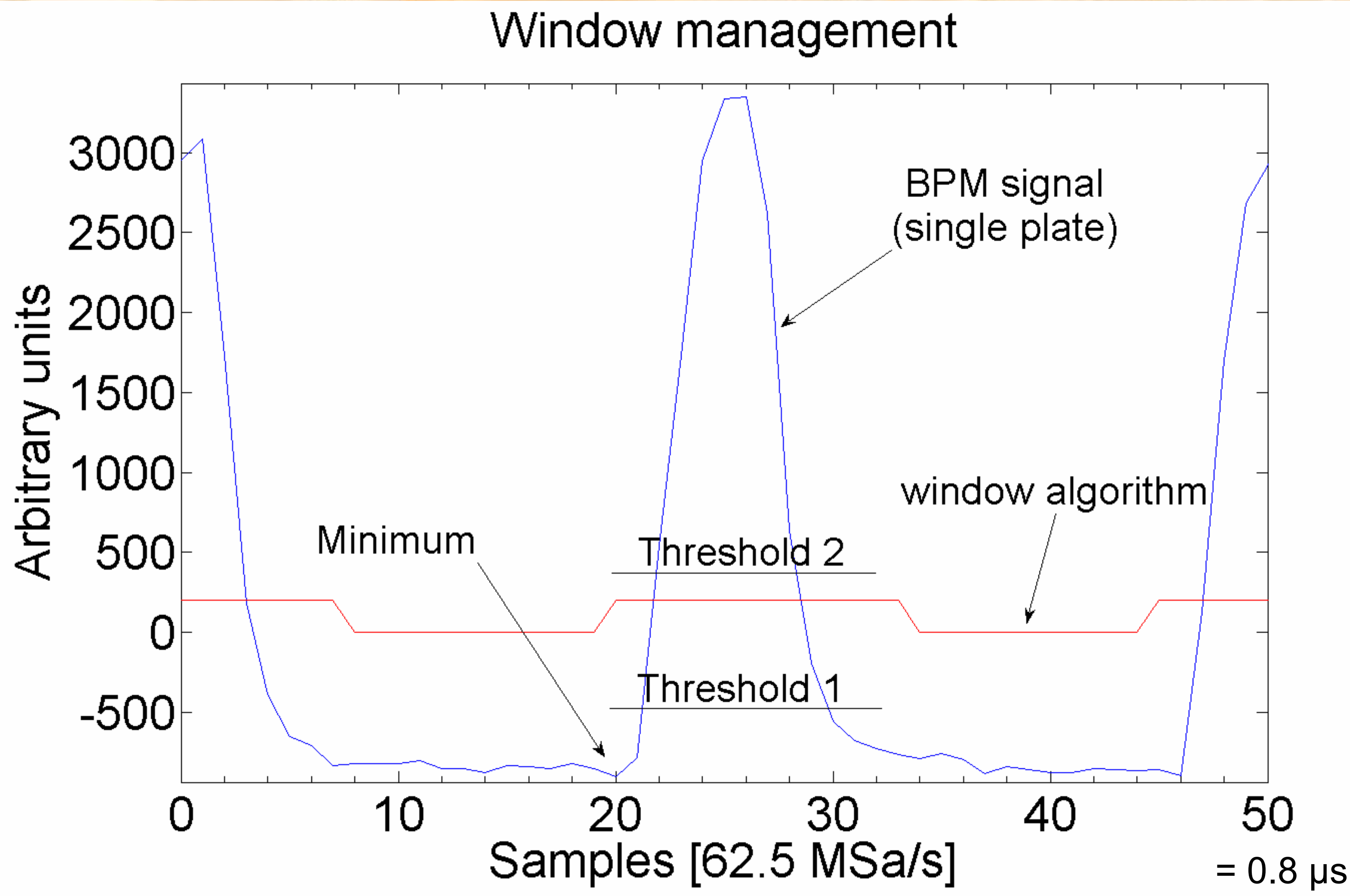
Motivation for digital measuring method

- One point per integrated bunch (frequency variation eliminated) -> shift to tune baseband when applying FFT
- For digital method bunching factor, baseline shift and frequency range is no problem
- Noise averaging thanks to integration of bunch data
- Bunch by bunch tune separation by software

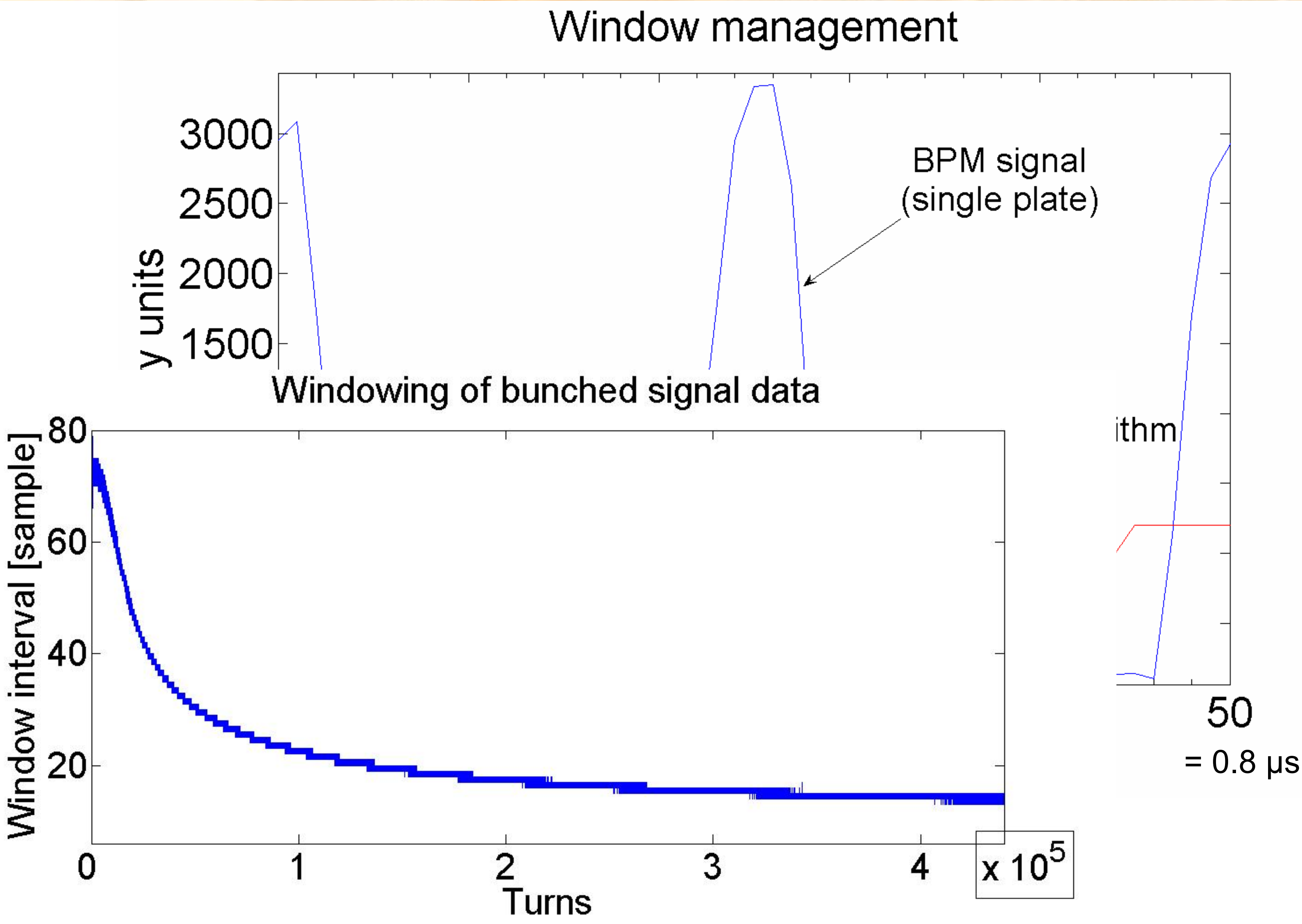
What is needed for position calculation:

- Windowing data stream for bunch integration
- Baseline restoring (due to AC coupling)

What is data looking like

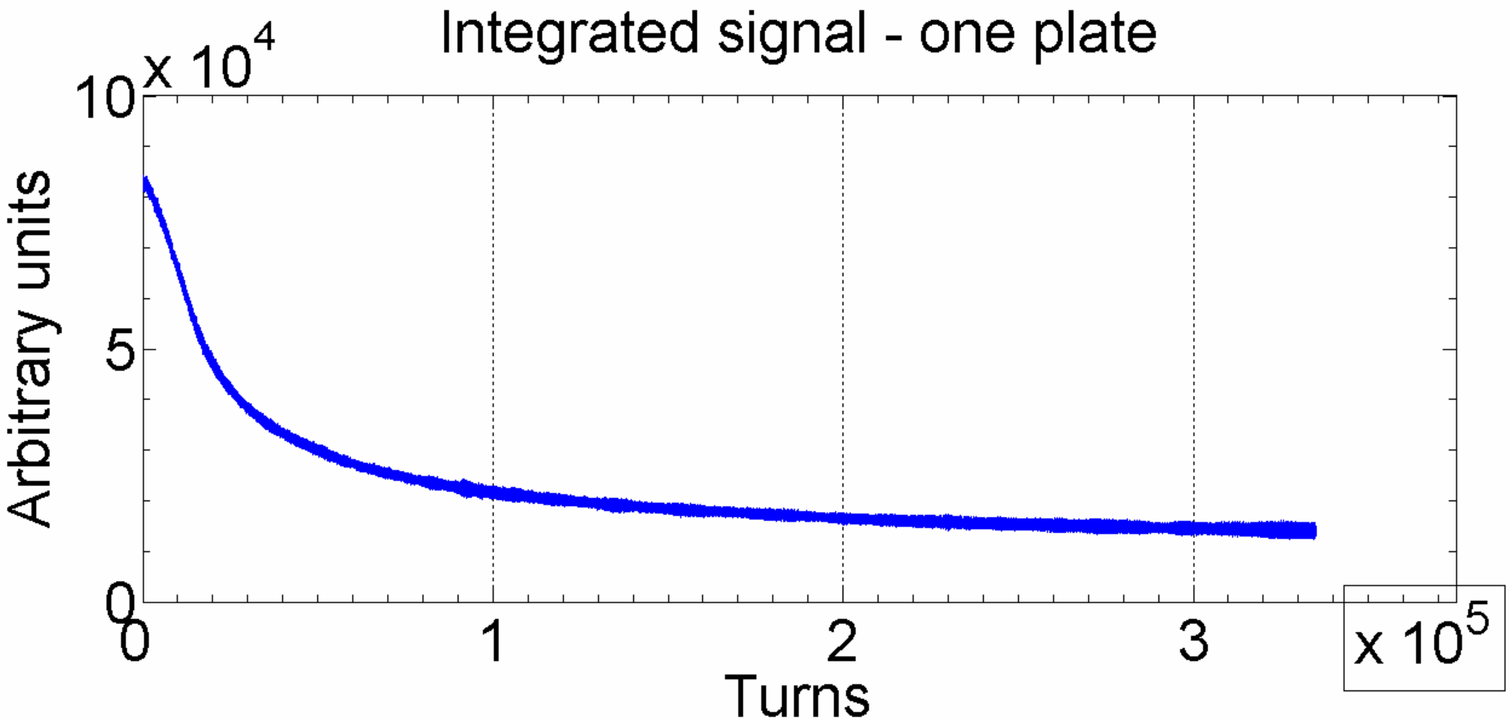


Whole ramp

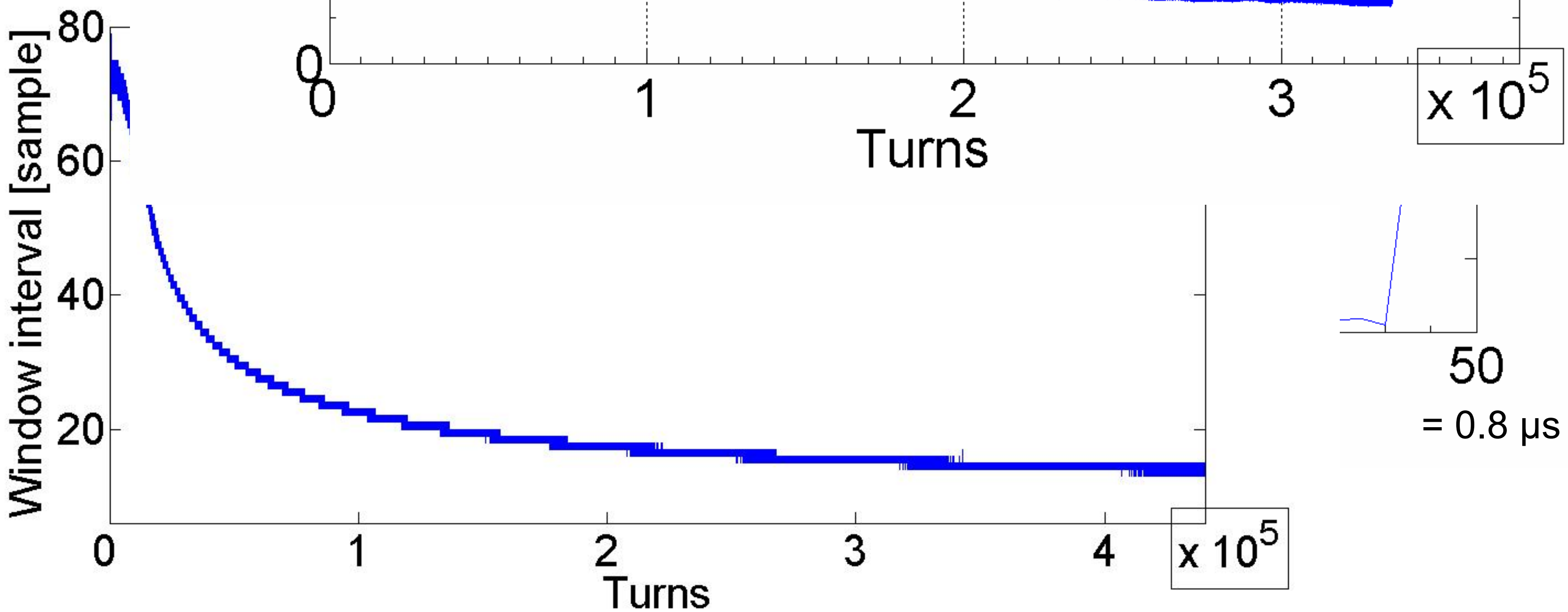


Window management
3000
2500
2000
1500
y units
BPM signal
(single plate)
Windowing of bunched signal data
ithm
50
= 0.8 µs
Window interval [sample]
80
60
40
20
0
1
2
3
4
x 10^5
Turns

Whole ramp

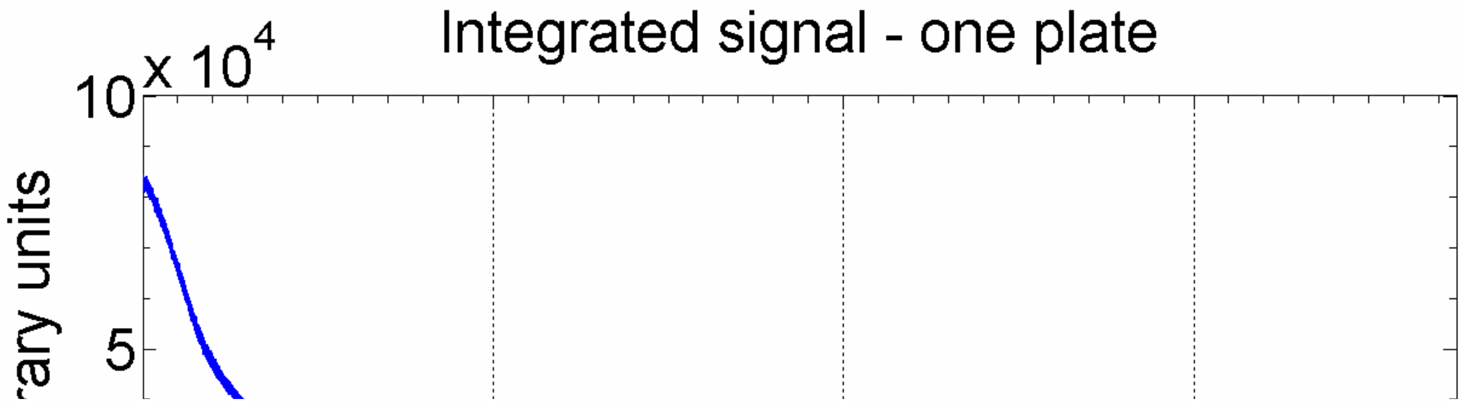


Integrated signal - one plate
x 10^4
10
5
0
Arbitrary units
0
1
2
3
x 10^5
Turns

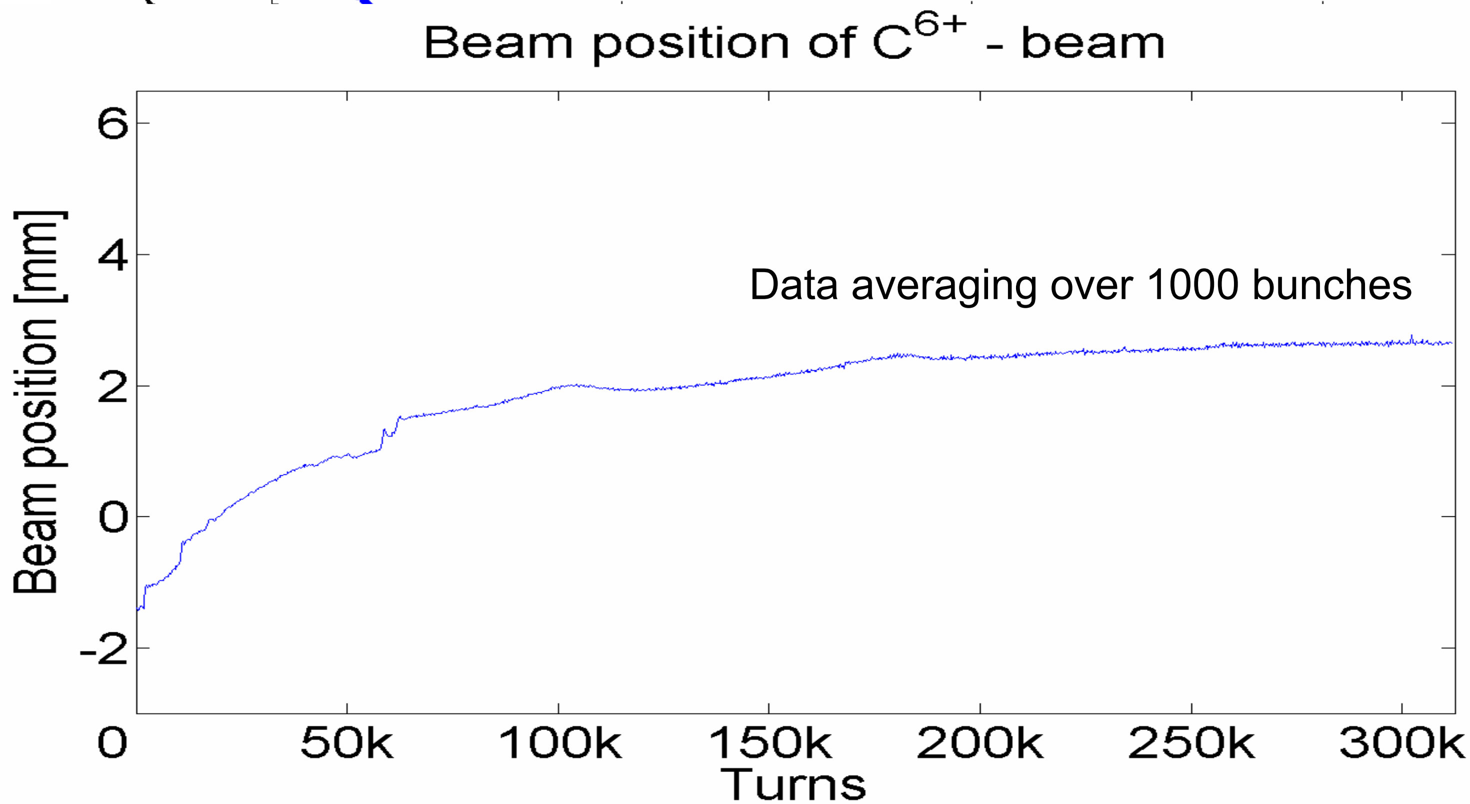


80
60
40
20
Window interval [sample]
0
1
2
3
4
x 10^5
Turns
50
= 0.8 µs

Whole ramp

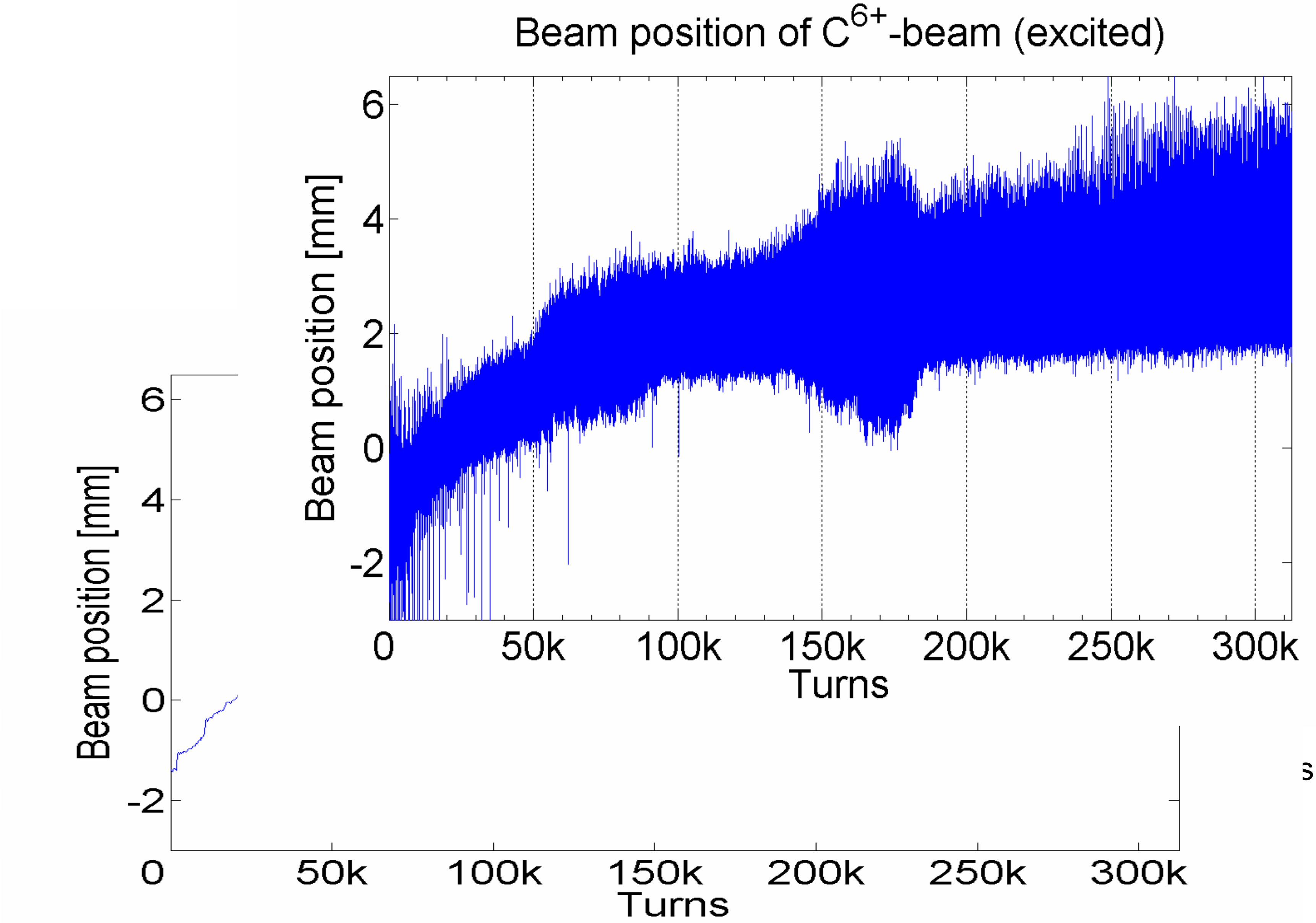


Integrated signal - one plate
x 10^4
10
5
ary units



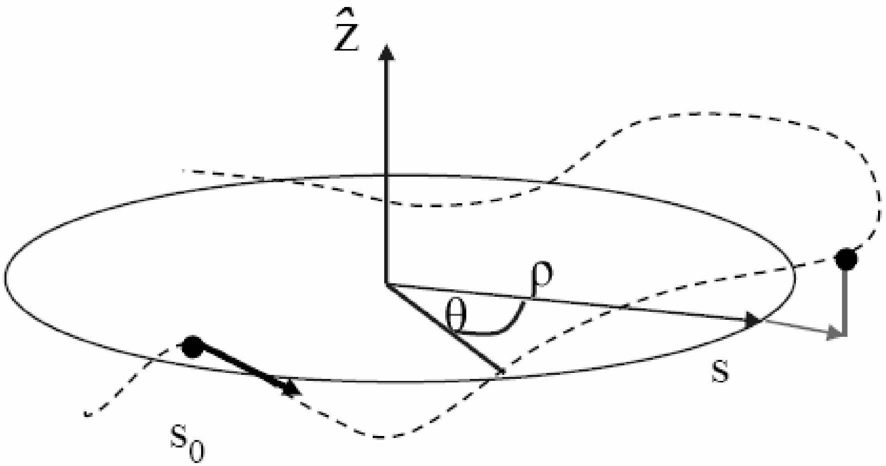
Beam position of C6+ - beam
Data averaging over 1000 bunches
Beam position [mm]
6
4
2
0
-2
0
50k
100k
150k
200k
250k
300k
Turns

Whole ramp

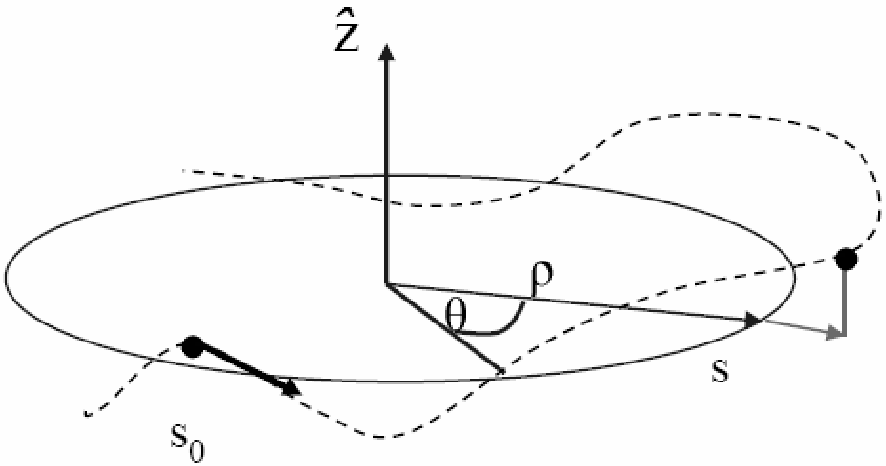


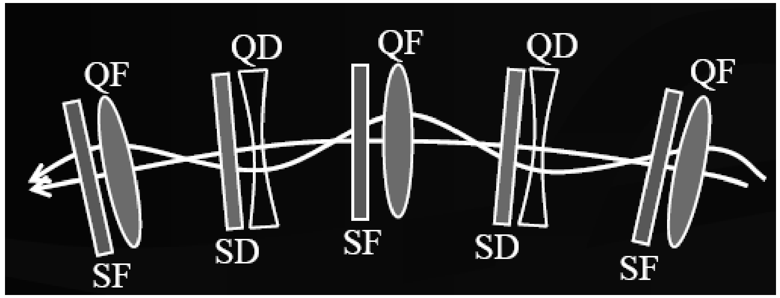
Beam position of C^{6+}-beam (excited)
Beam position [mm]
6
4
2
0
-2
0
50k
100k
150k
200k
250k
300k
Turns

What is tune

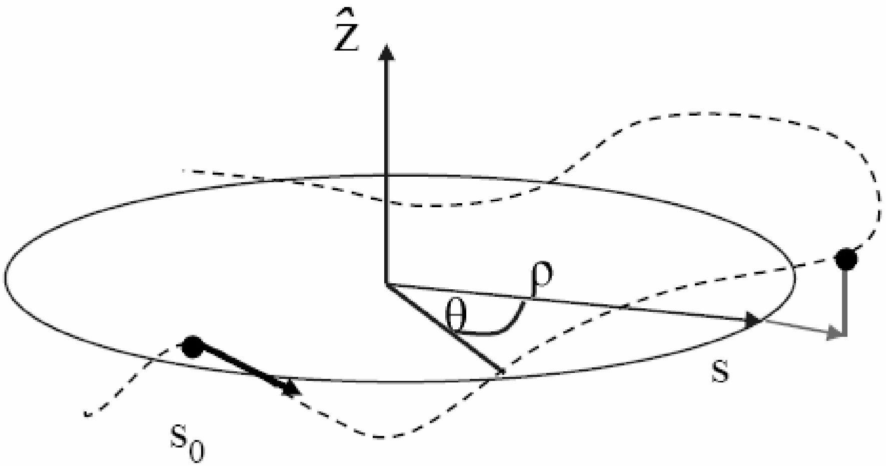


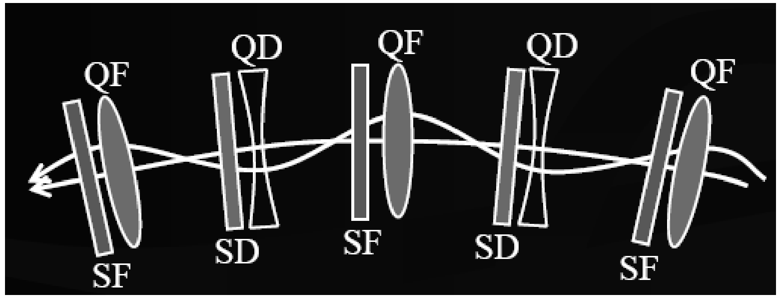
What is tune





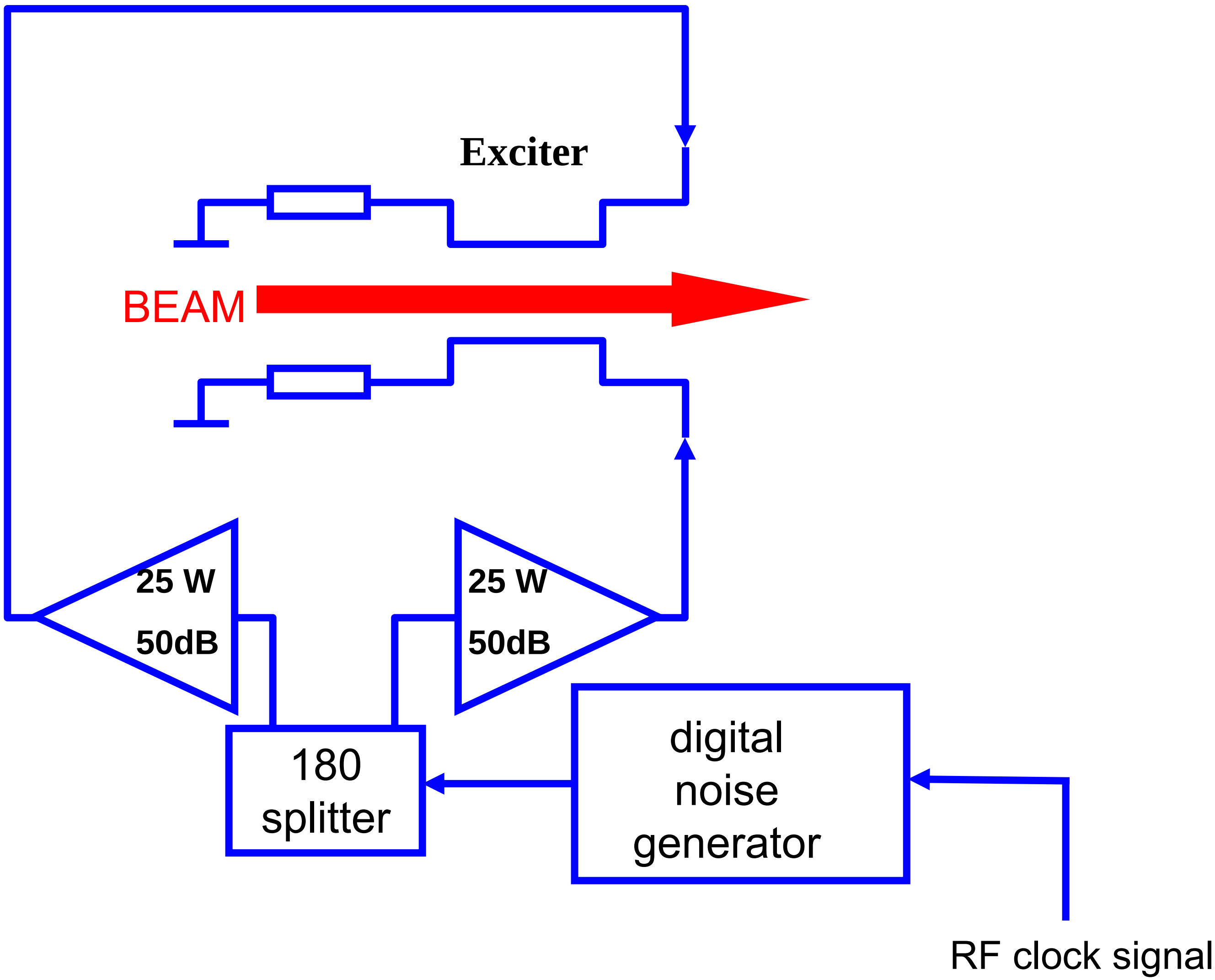
What is tune



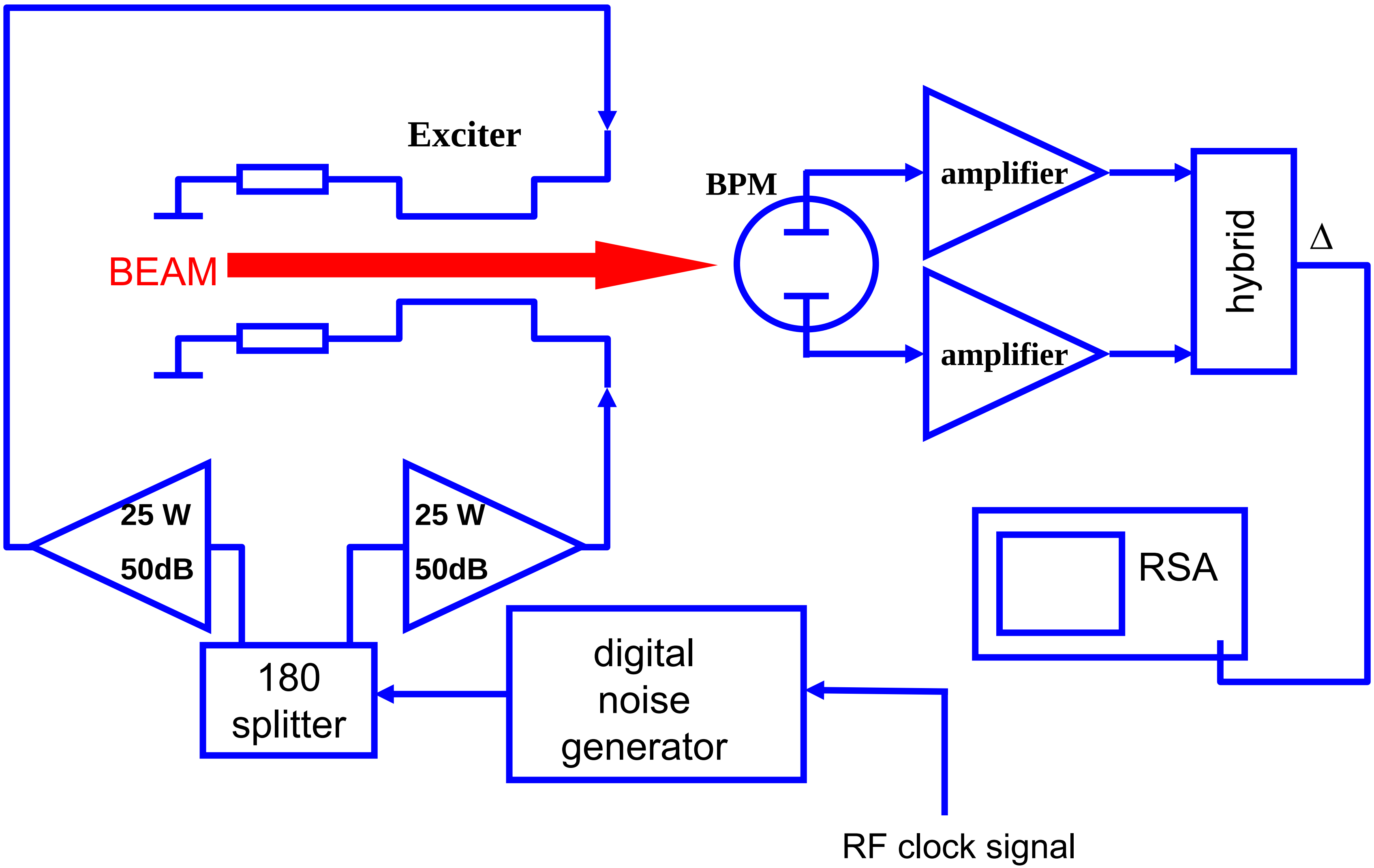


-Machine intrinsic value: characteristic frequency of the Magnet Lattice (given by the strength of the quadrupole magnets)
-Tune should always have a fractional part because of resonances
-This fractional part can be measured only! (due to undersampling)
-Can be excited directly for measuring purpose

Digital Random Noise Generator



Digital Random Noise Generator



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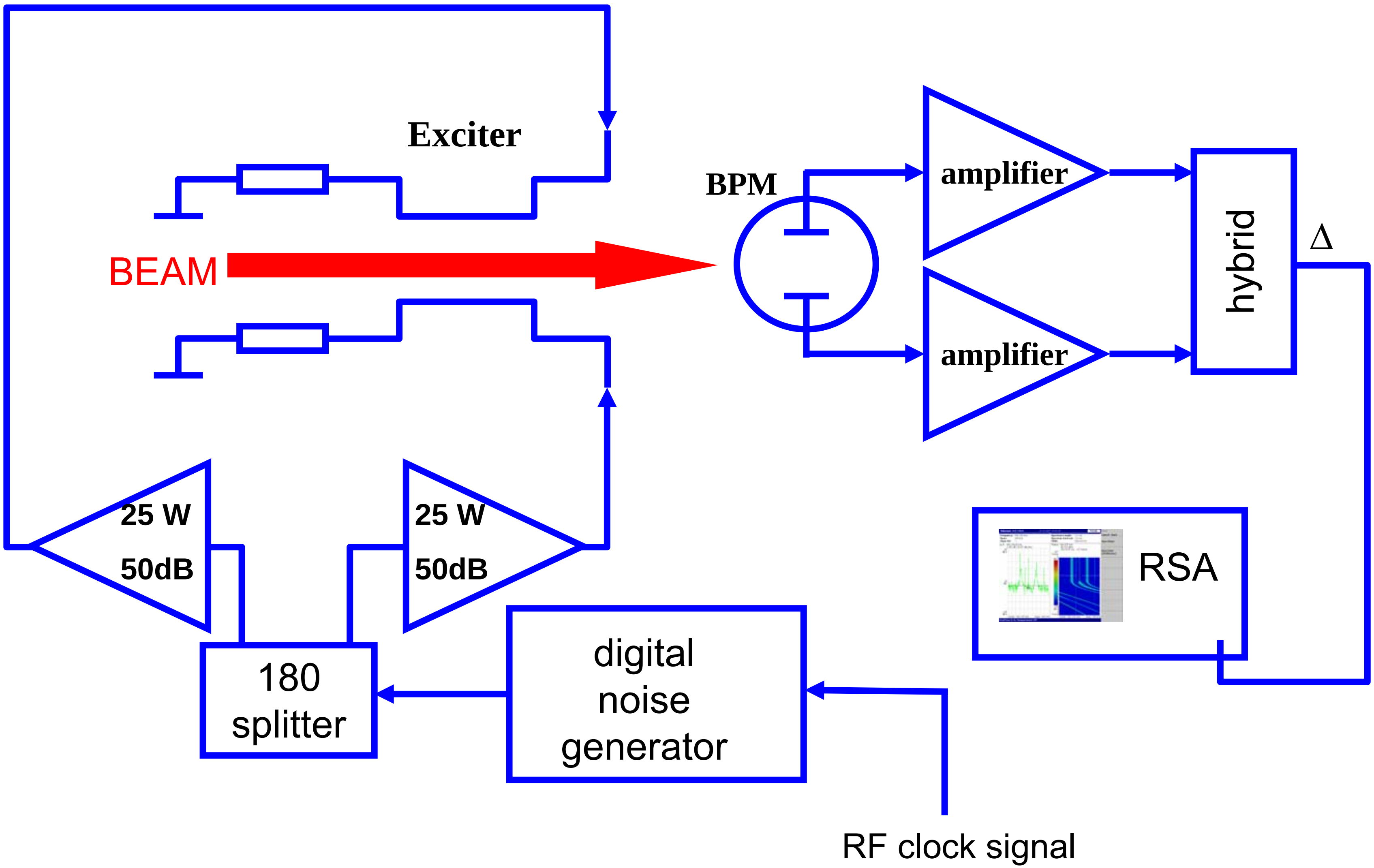

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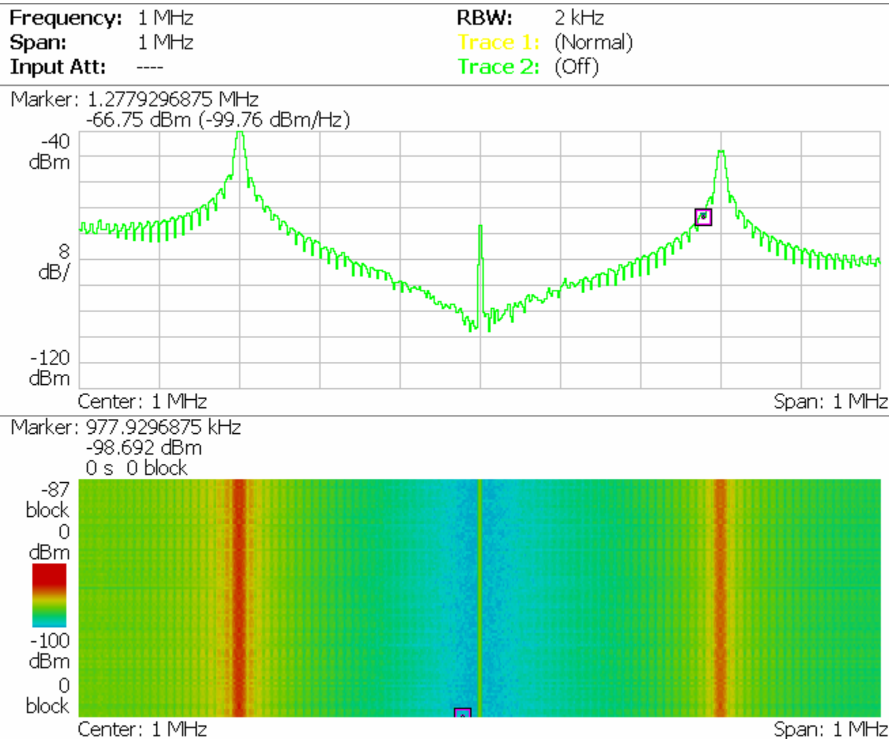
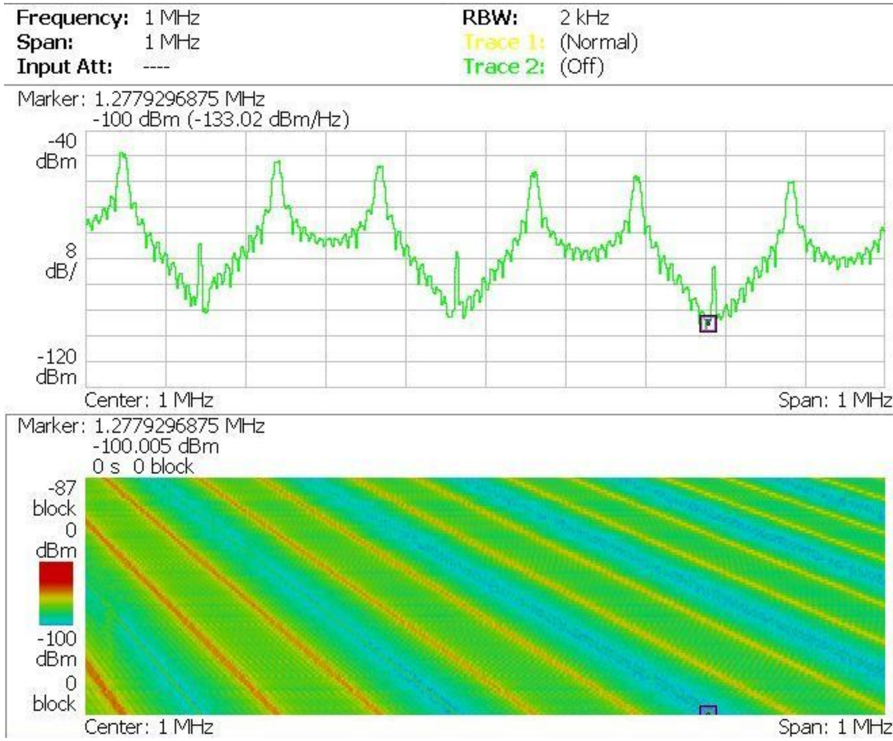


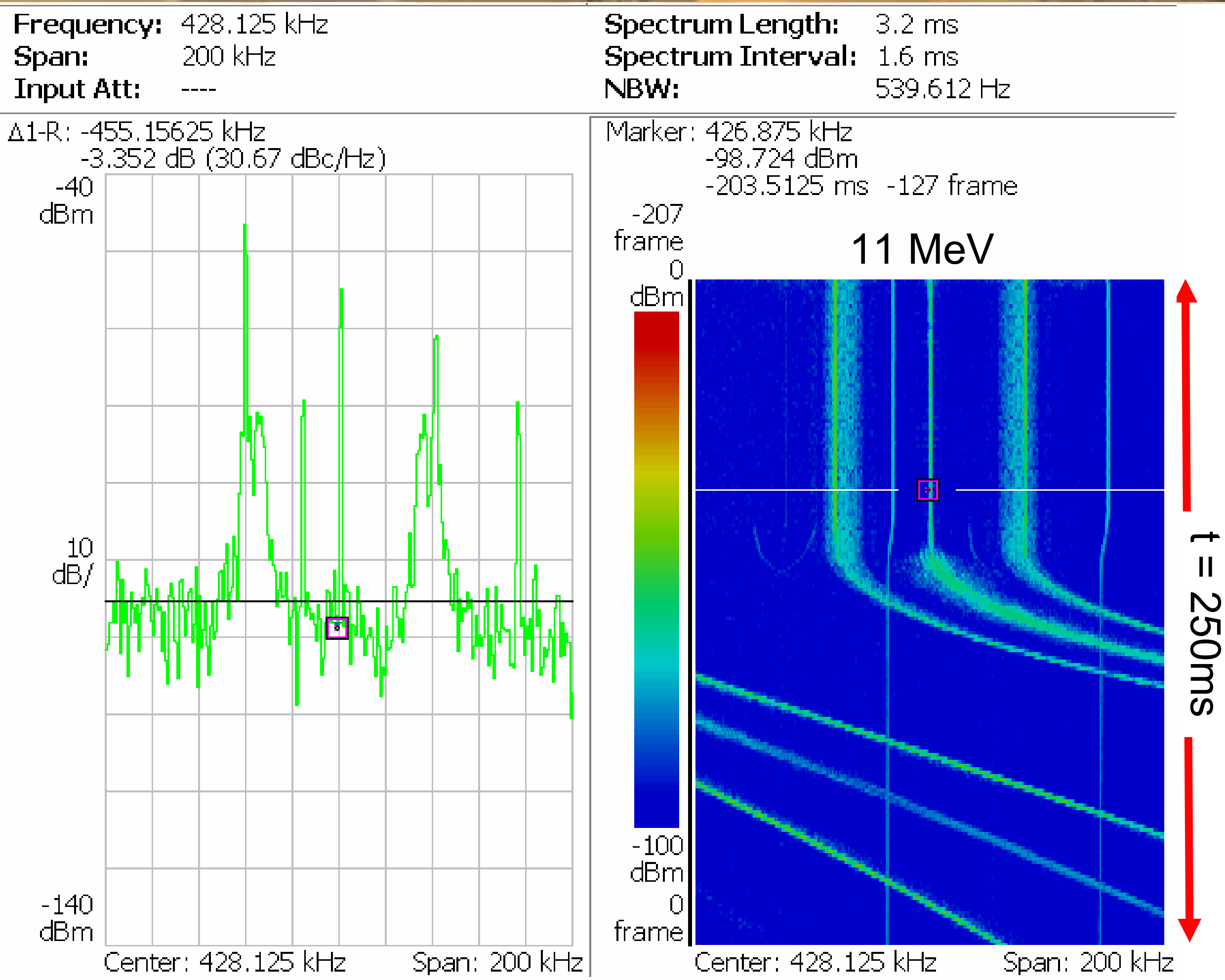


1 MHz carrier frequency
Number of harmonics : 1
q is set to 0.3 with a dq of 0.01

Frequency sweep (pseudo-RF as input)
Number of harmonics : 4
q is set to 0.3 with a dq of 0.03

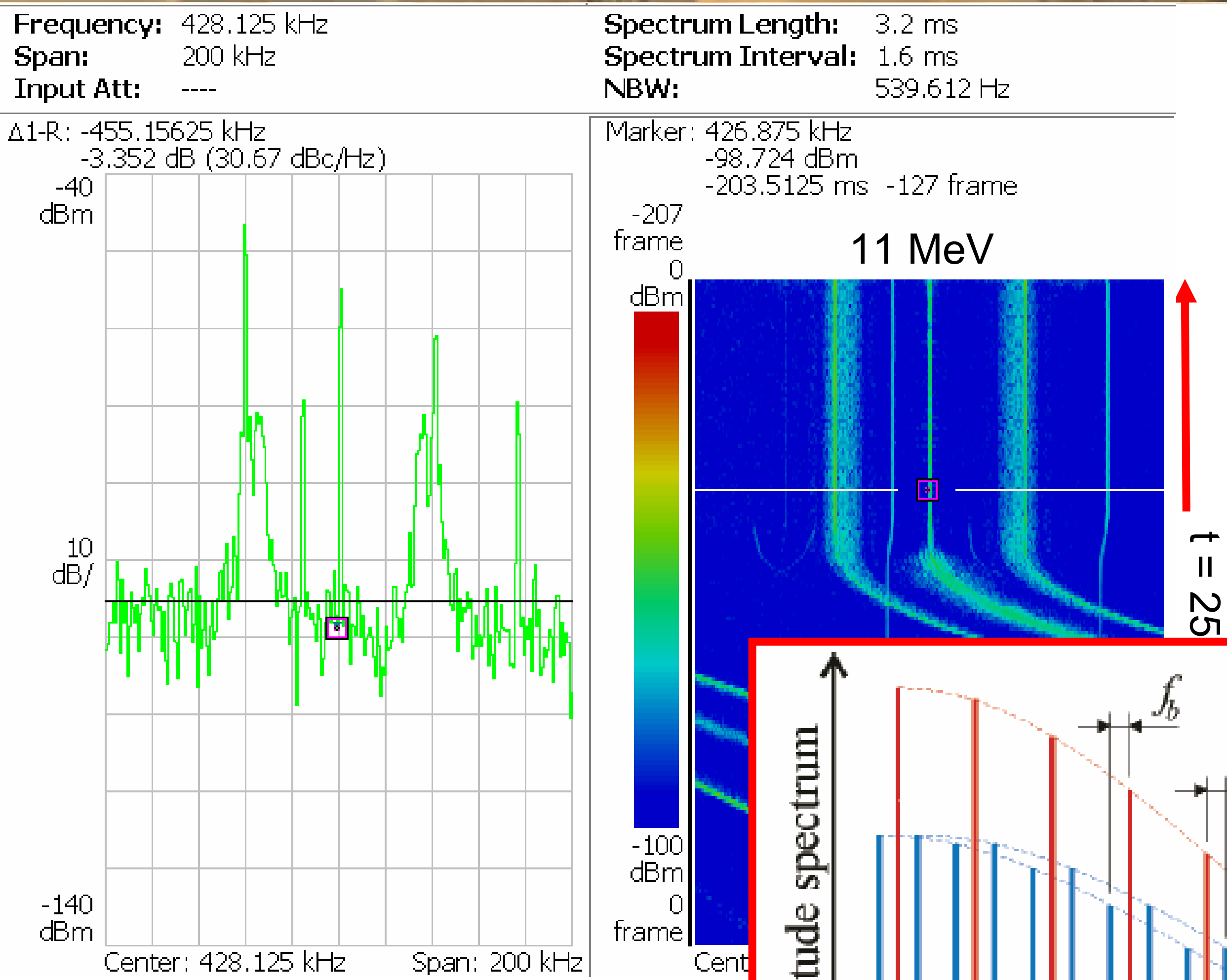
Amplitude and width of excitation can be modified also remote controlled

Classical approach: one harmonic only



Argon 18+
100 ms cooling
Ramp to 2 GeV in 700 ms

Classical approach: one harmonic only



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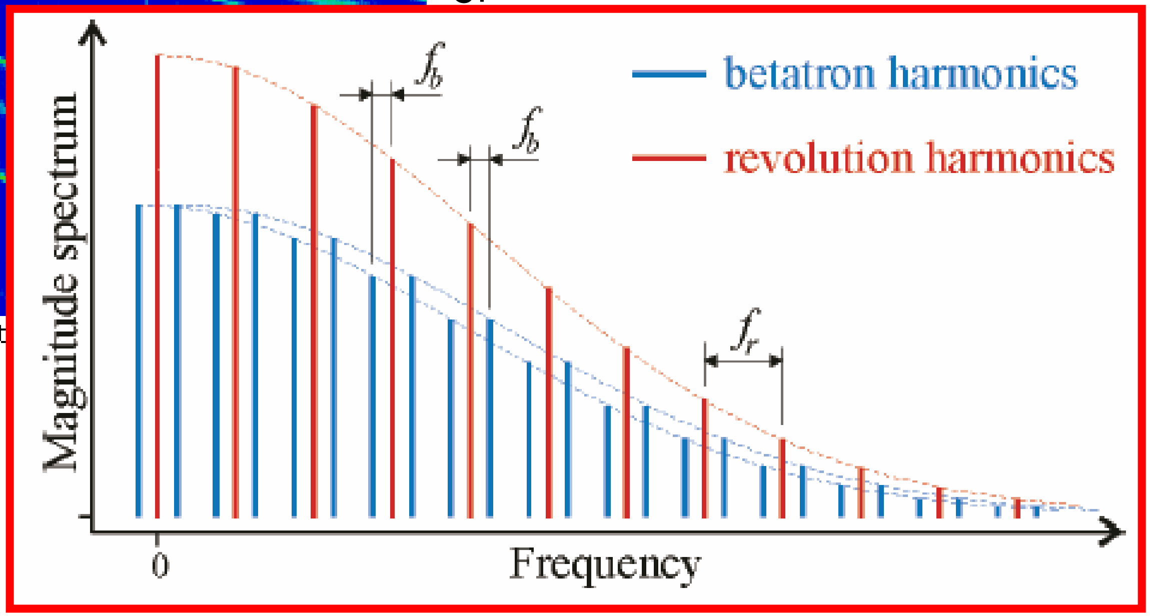
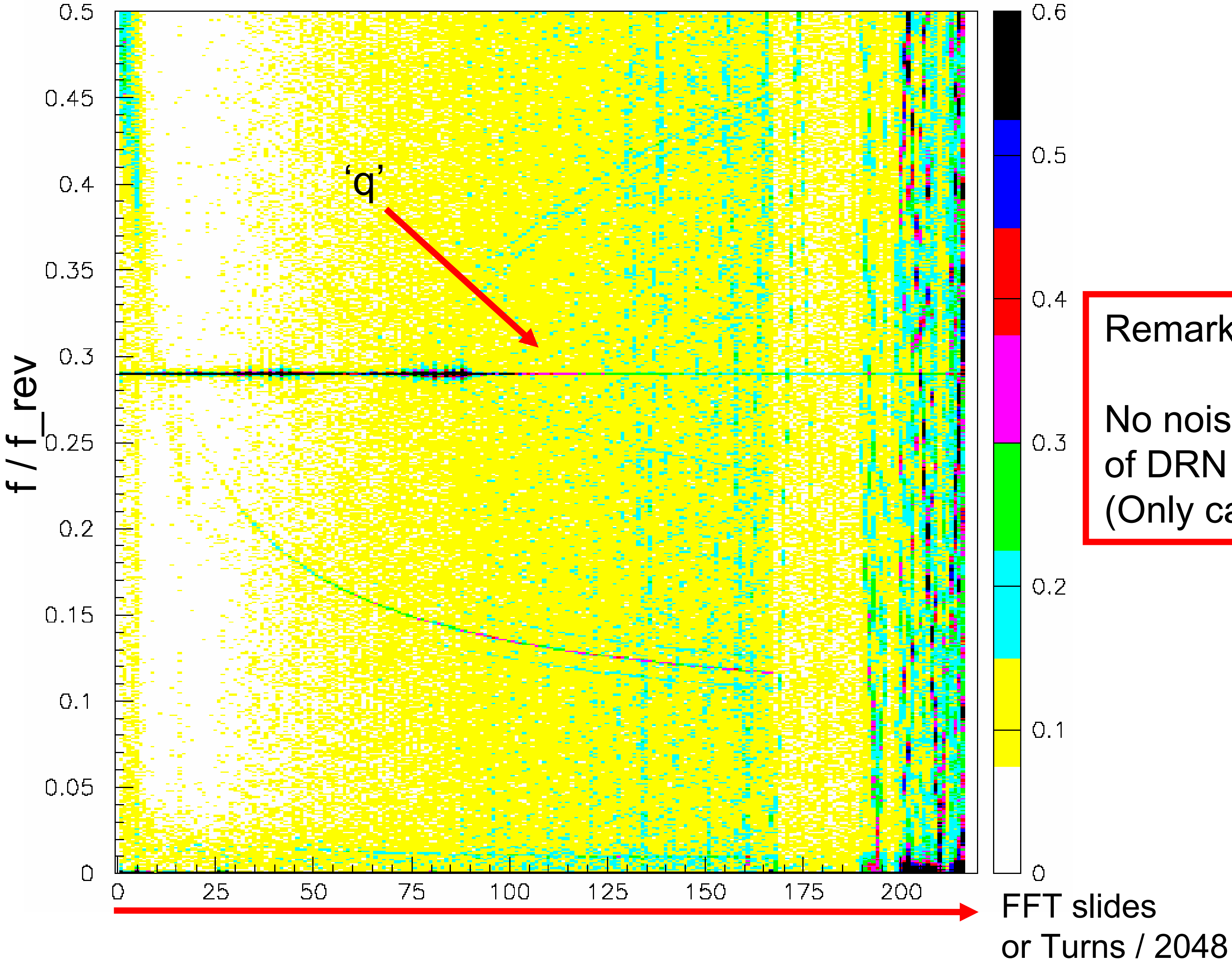


- Only one harmonic
- Signal to noise improvable

Spectrum



Remark error:

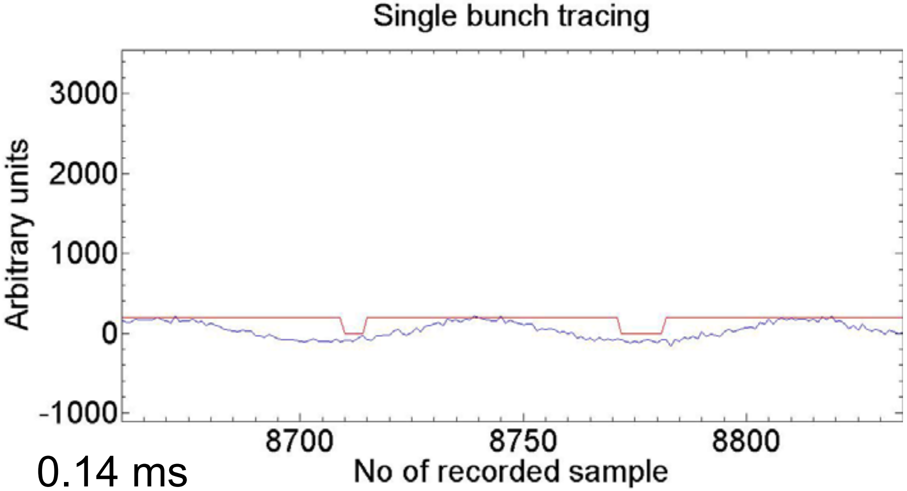
No noise sideband of DRN generator! (Only carrier freq.)

Summary and outlook

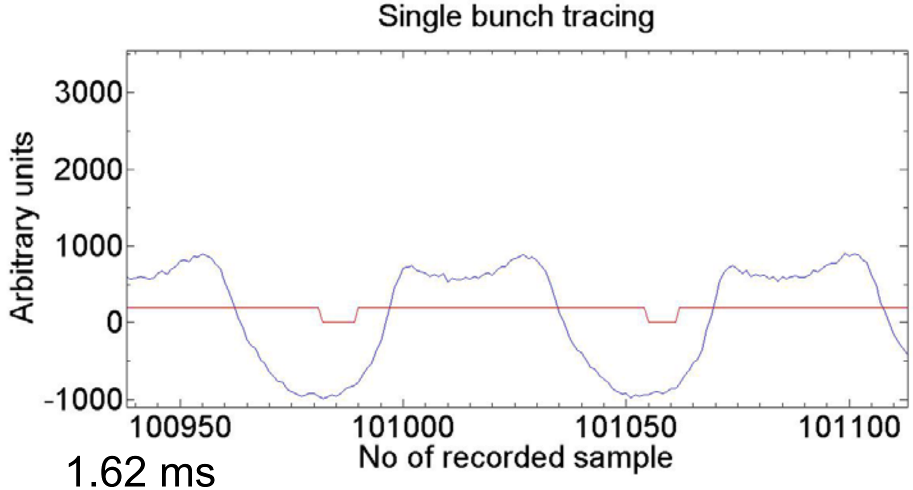
- First approach to establish tune measurement system at GSI
- Beam position out of direct digitized data working properly
- FFT to tune baseband through bunch – synchronous position data possible
- First measurements promising
- Further measurements and theoretical evaluations foreseen
- First measurements with real electronics for 3d (by M.Gasior et al) foreseen in spring 2008

- Now let‘s have a look at the single bunch behaviour:

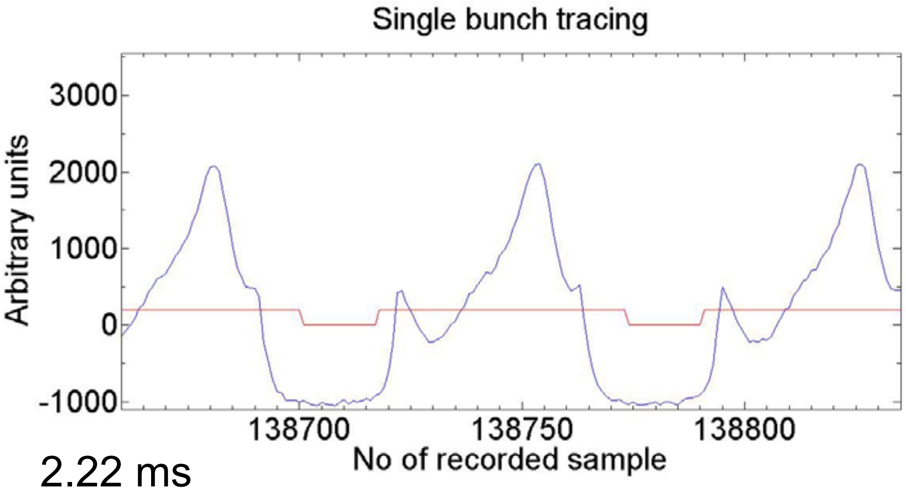
Single bunch behaviour



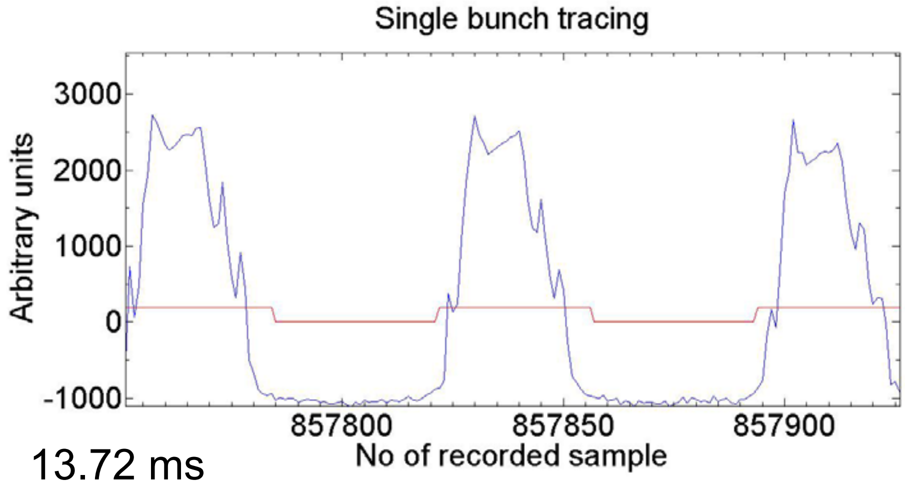
0.14 ms
22 Turns



1.62 ms
340 Turns



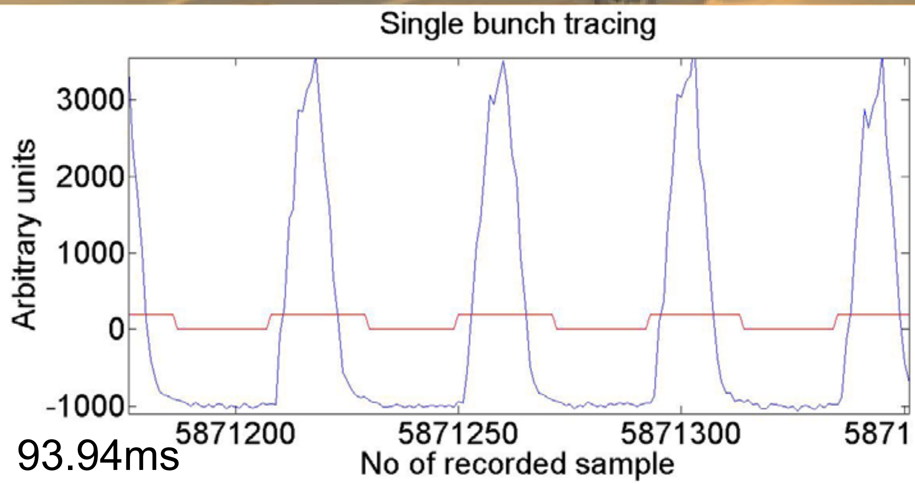
2.22 ms
470 Turns



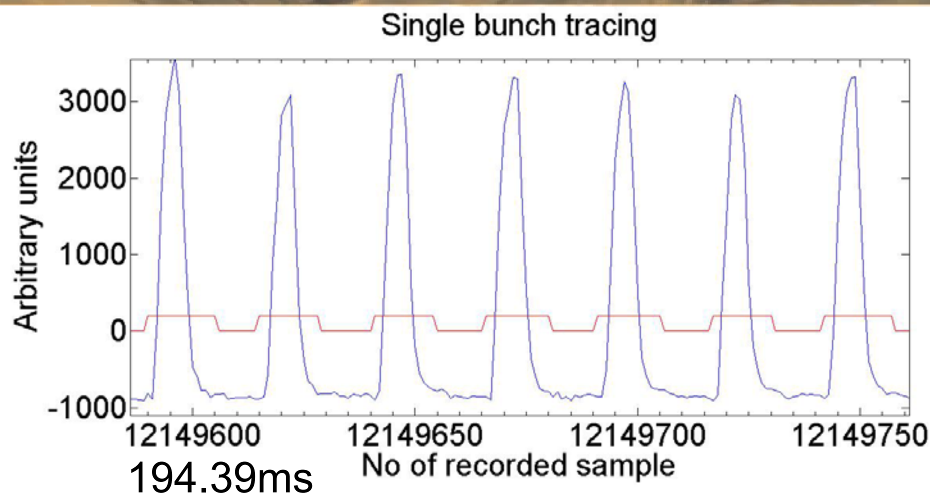
13.72 ms
2950 Turns

Timespan of every figure: 2.6 µs
Note bunch spacing

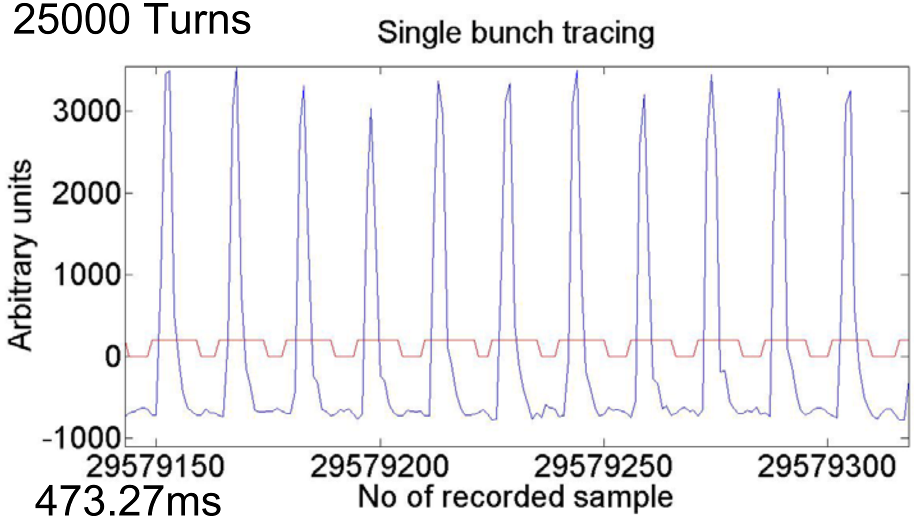
Time and turns after start of bunch forming



93.94ms
25000 Turns



194.39ms
75000 Turns



473.27ms
300000 Turns

All for now…

Timespan of every figure: 2.6 μs
Note window widths!

Time and turns after start of bunch forming

Thank you for your attention!

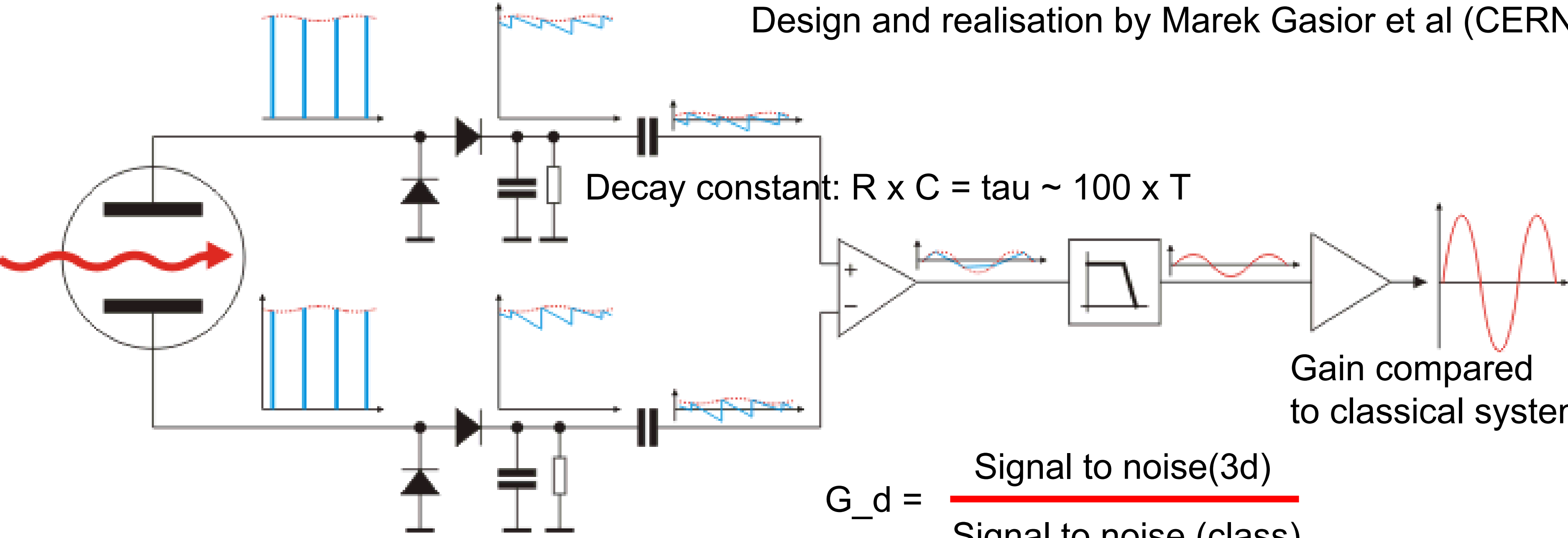
- Earlier recorded data (FFTransformed) show rich amount of not understood frequency spikes in spectra also in region of baseband (without any beam excitation). Thus: starting with an easy and safe method => noise excitation of sidebands

<u>To do:</u>

- Gain factor not yet evaluated (about same range as 3D)
- Total time for real time signal processing not yet estimated
  - Presently only offline analysis
  - Feedback?
- Usage of differential signal instead of single plates
  - Used for "optimization process"

The direct diode detection (principles)

Design and realisation by Marek Gasior et al (CERN)



Decay constant: R x C = tau ~ 100 x T

Gain compared
to classical system

$$G\_d = \frac{\text{Signal to noise(3d)}}{\text{Signal to noise (class)}}$$

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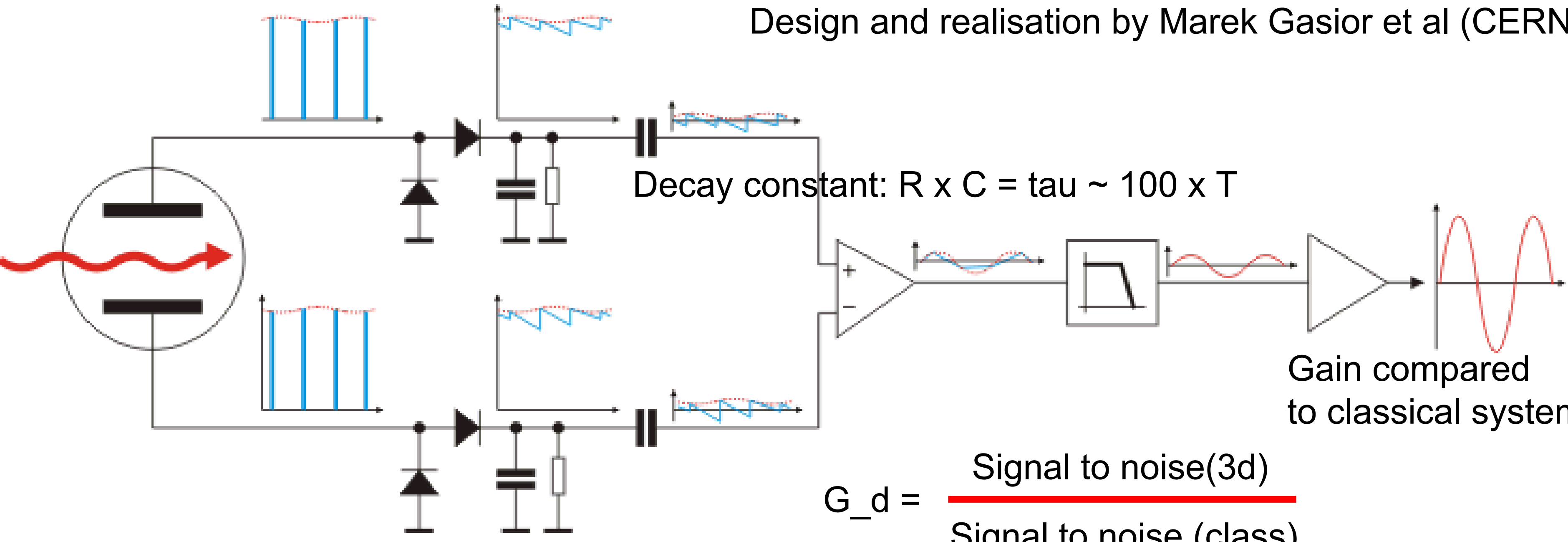

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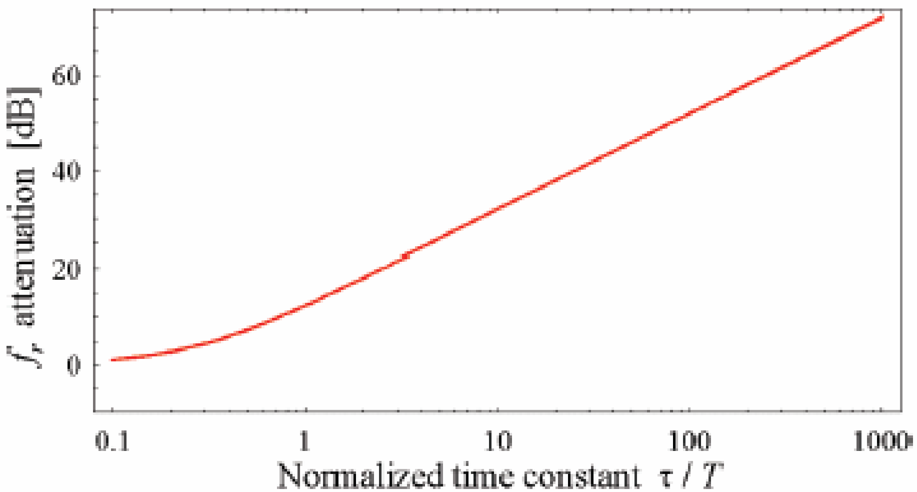
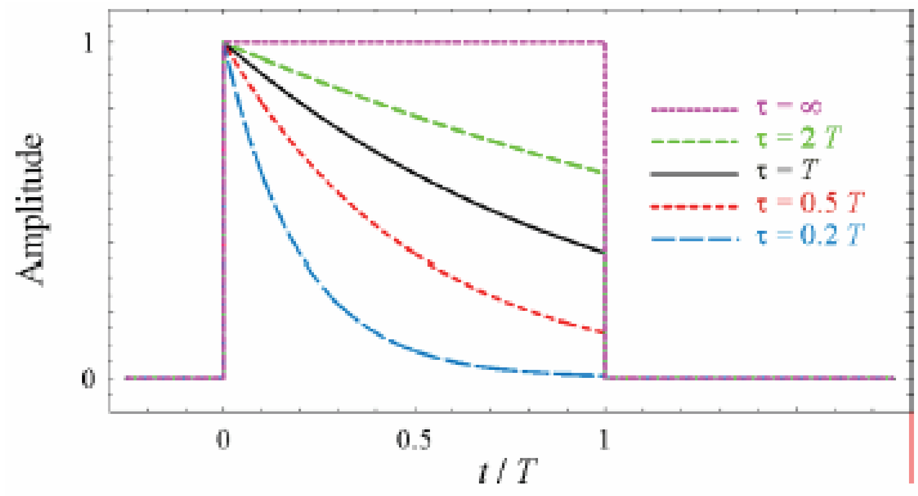
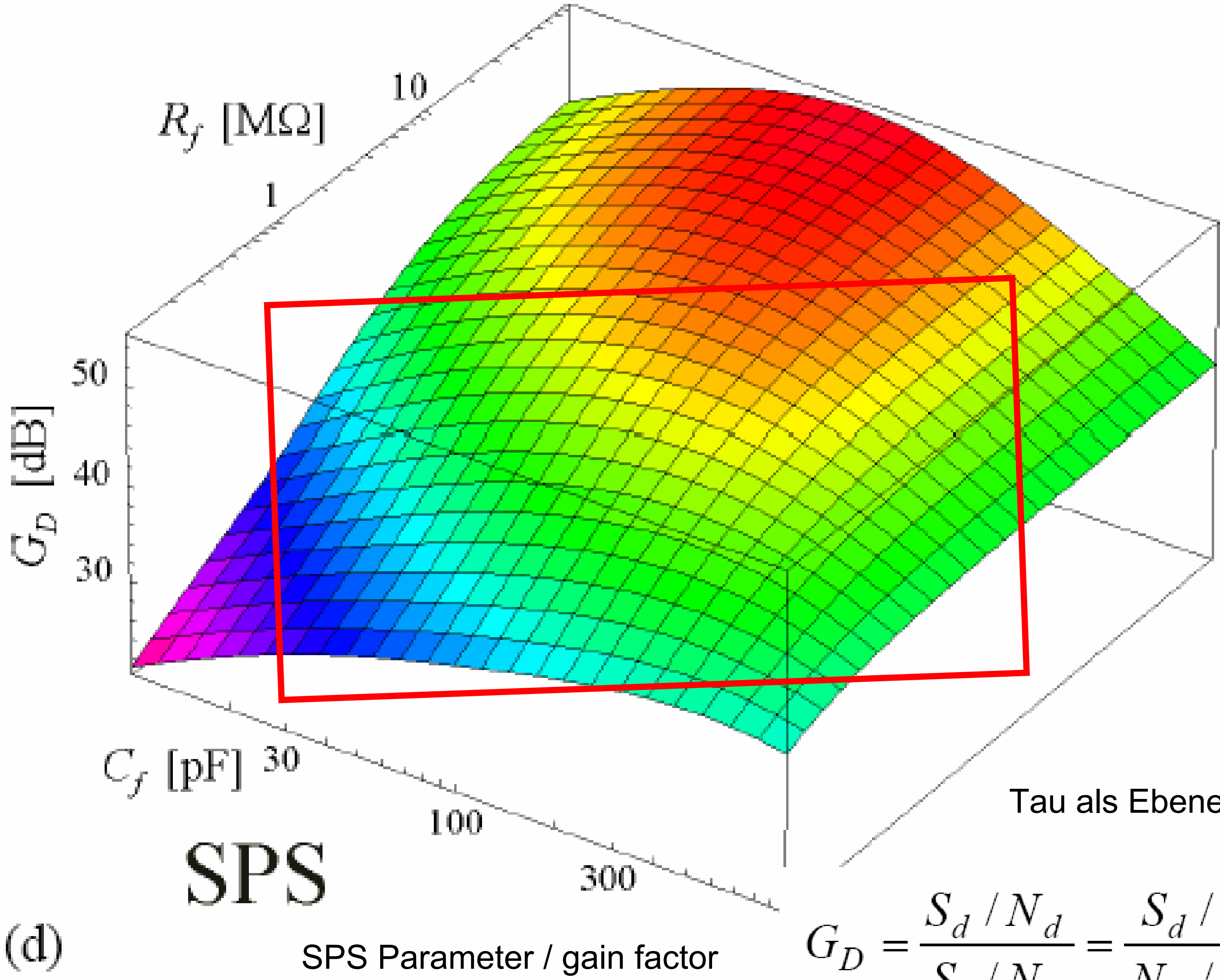




Open questions

- Due to our frequency range (0.8-5.5MHz) and the varying bunching factor (0.6…0.2) usability of 3d-method not yet sure
- Beam intensities on pickup of SIS-18 vary even within 3s from one cycle to the next by order of up to 5 magnitudes (100dB)
  - Pre-amplifier between pickup and diode required?
  - one peak detector might not be sufficient (discussion ongoing)
- Gain factor significantly lower compared to CERN accelerators because of much longer bunches and the higher revolution frequency
- BPM signal has large baseline shift which may introduce additional uncertainties
- Test and comparison to ‘direct digital processing’

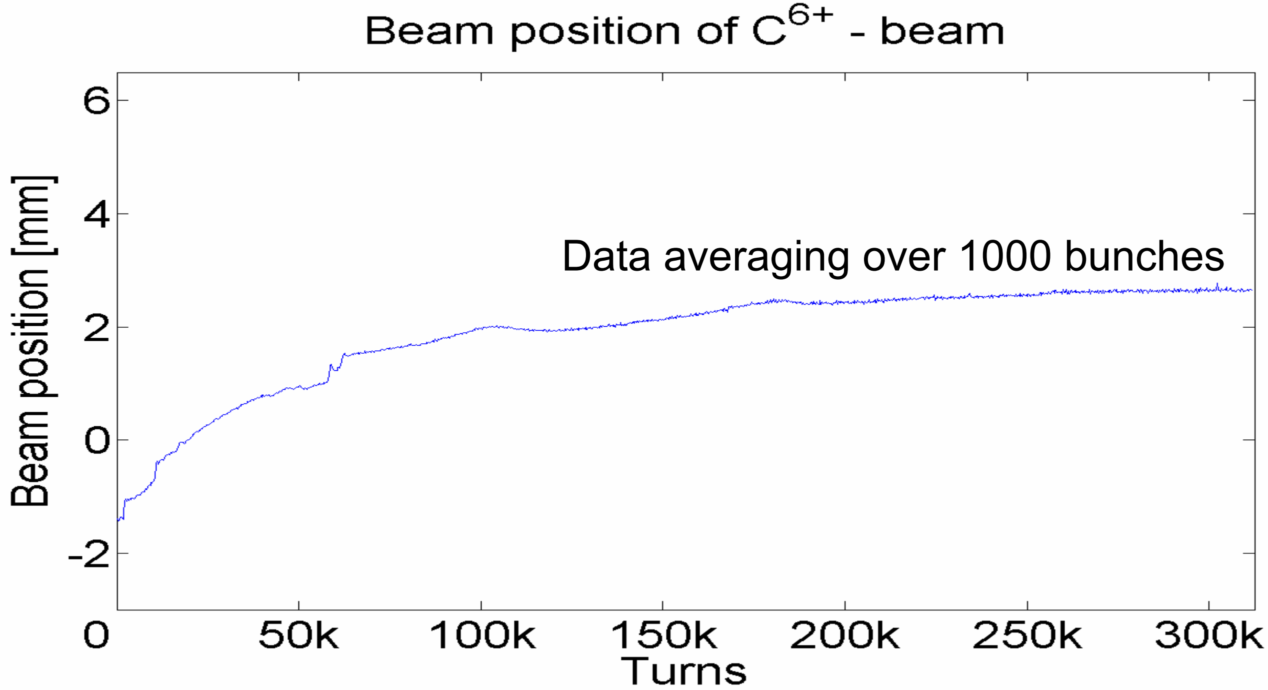
The direct diode detection

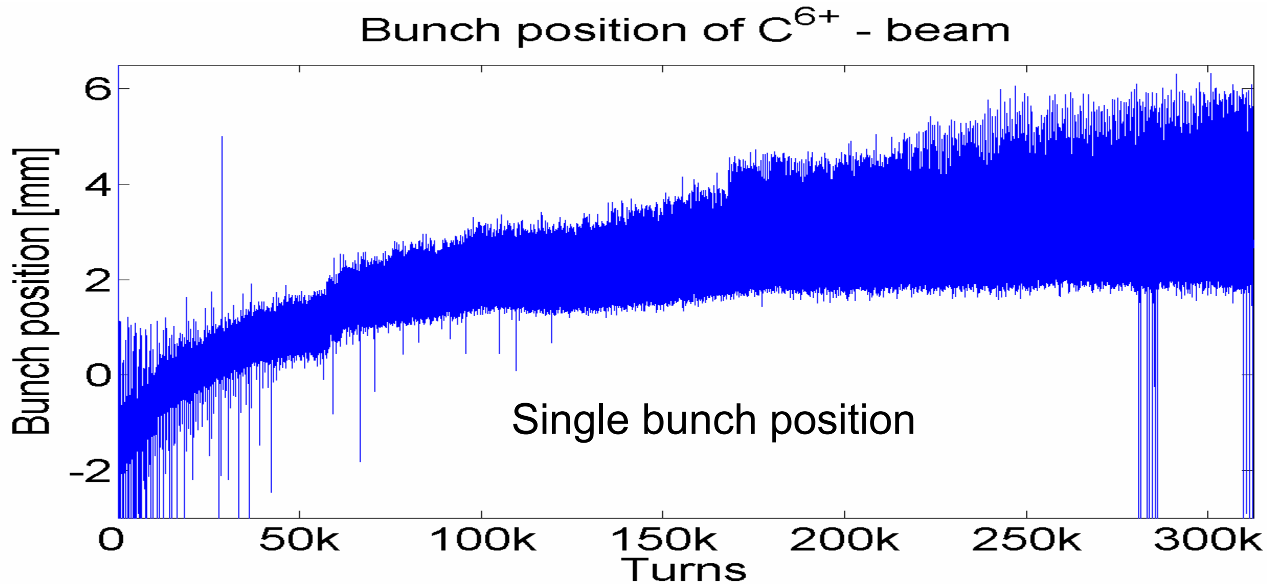


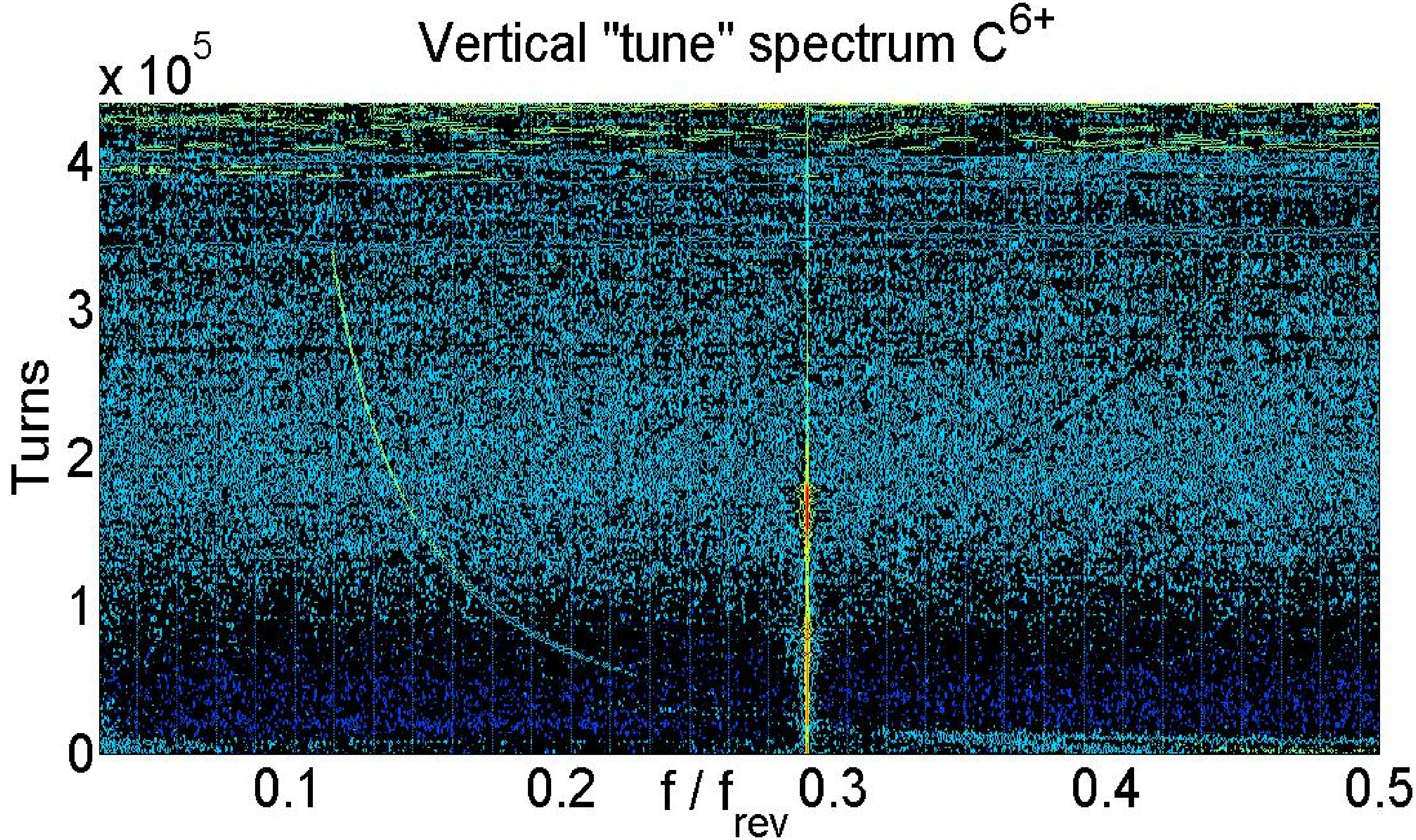
Tau als Ebene = RC = 100

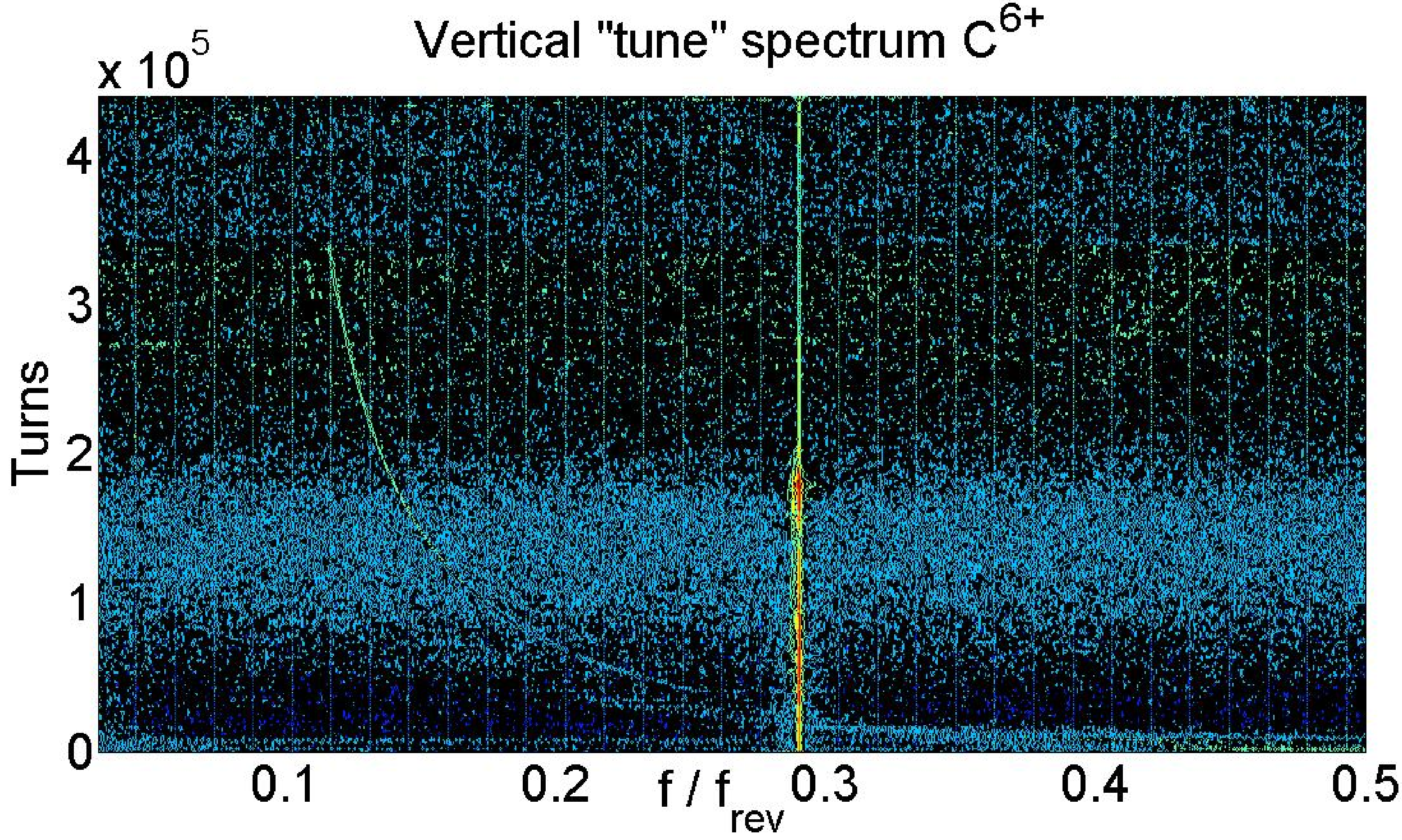
SPS Parameter / gain factor

$$G_D = \frac{S_d / N_d}{S_c / N_c} = \frac{S_d / S_c}{N_d / N_c} = \frac{G_S}{G_N}$$


Beam position of C6+ - beam
Beam position [mm]
Data averaging over 1000 bunches
Turns
6
4
2
0
-2
0
50k
100k
150k
200k
250k
300k

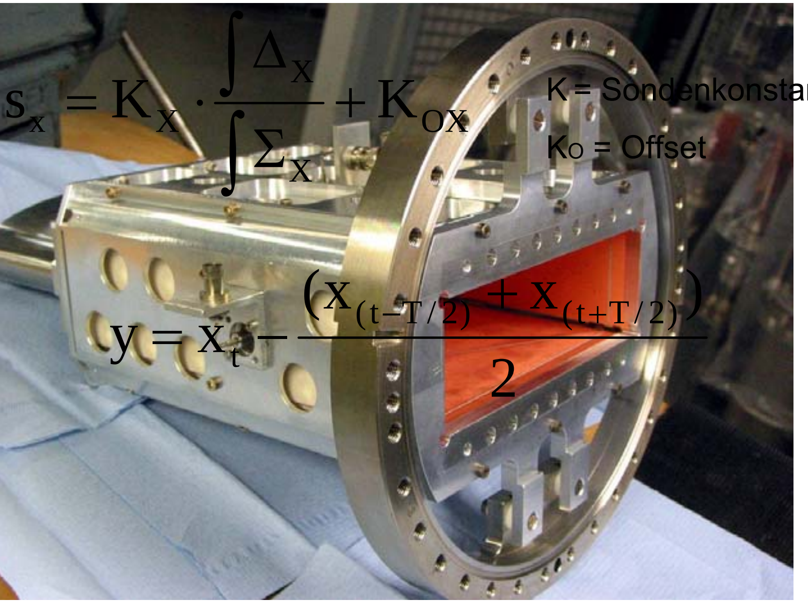

Bunch position of C6+ - beam
Bunch position [mm]
Single bunch position
Turns
6
4
2
0
-2
0
50k
100k
150k
200k
250k
300k


Vertical "tune" spectrum C6+
x 10^5
Turns
0
1
2
3
4
0.1
0.2
f / f rev
0.3
0.4
0.5


Vertical "tune" spectrum C^{6+}
x 10^5
Turns
0
1
2
3
4
0.1
0.2
f / f_{rev}
0.3
0.4
0.5

Data acquisition

pick up → **amplifier** → **position evaluation** → **Shift to frequency domain** → **tune?**



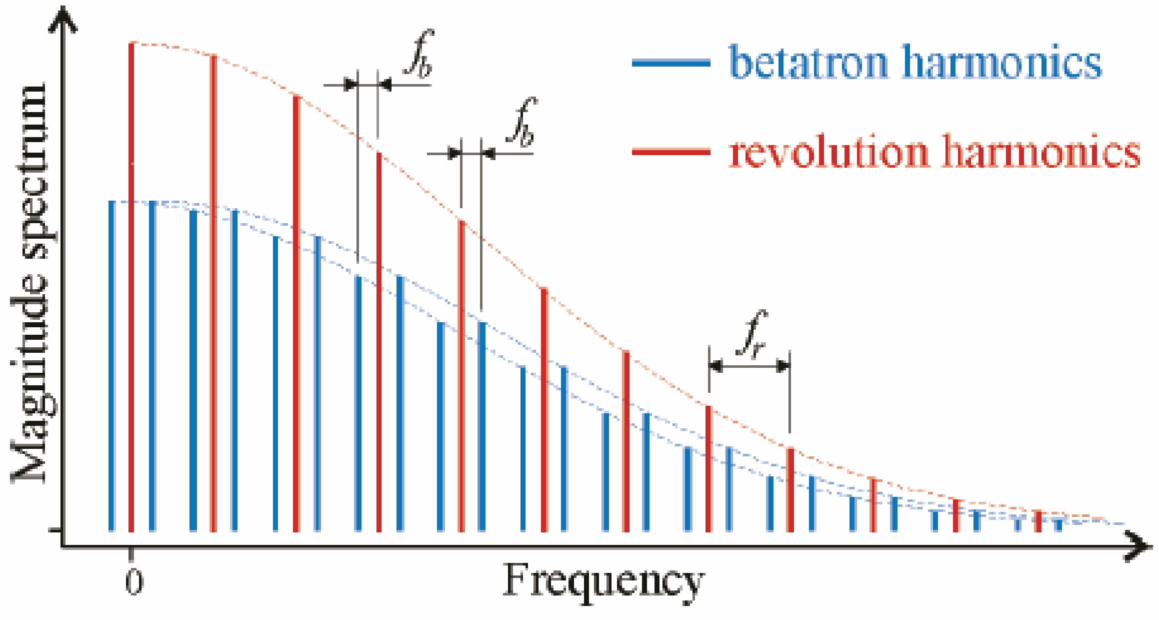
$$s_x = K_X \cdot \frac{\int \Delta_X}{\int \Sigma_X} + K_{OX}$$

K = Sondenkonstante

Ko = Offset

$$y = x_t - \frac{(x_{(t-T/2)} + x_{(t+T/2)})}{2}$$

Comparison to Classical Approach:

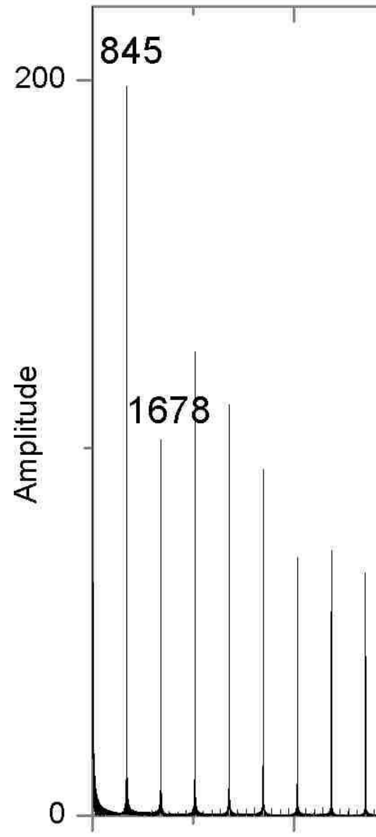


„one betatron harmonic filtering“

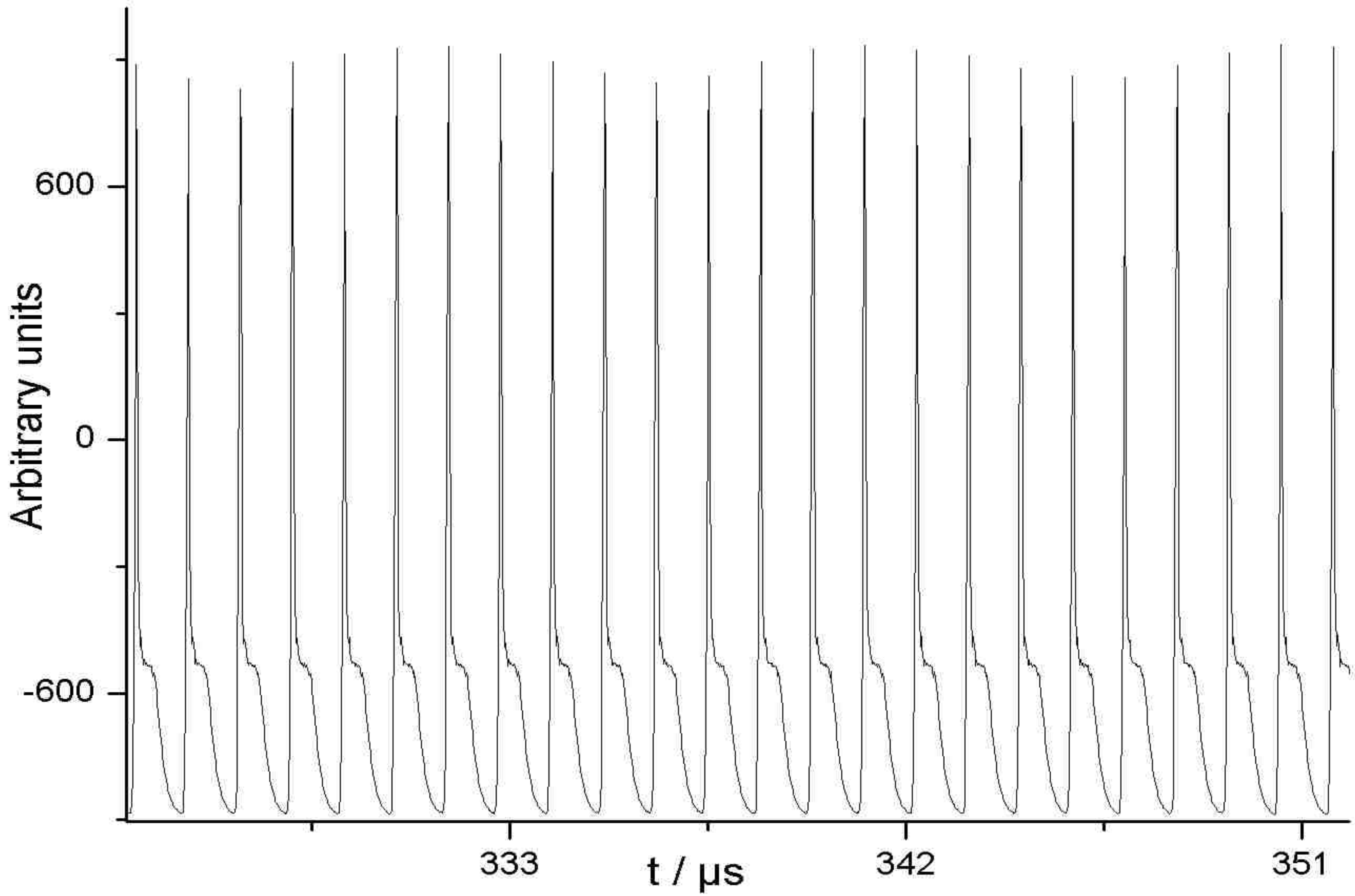
$$S_c(f) = \frac{1}{\sqrt{2}\,T}\left|S_{b1}(f-f_b)\sum_{n=-\infty}^{\infty}\delta\left(f-f_b-\frac{n}{T}\right)+S_{b1}(f+f_b)\sum_{n=-\infty}^{\infty}\delta\left(f+f_b-\frac{n}{T}\right)\right|+$$

$$+\frac{1}{T}\left|S_{o1}(f)\sum_{n=-\infty}^{\infty}\delta\left(f-\frac{n}{T}\right)\right|$$

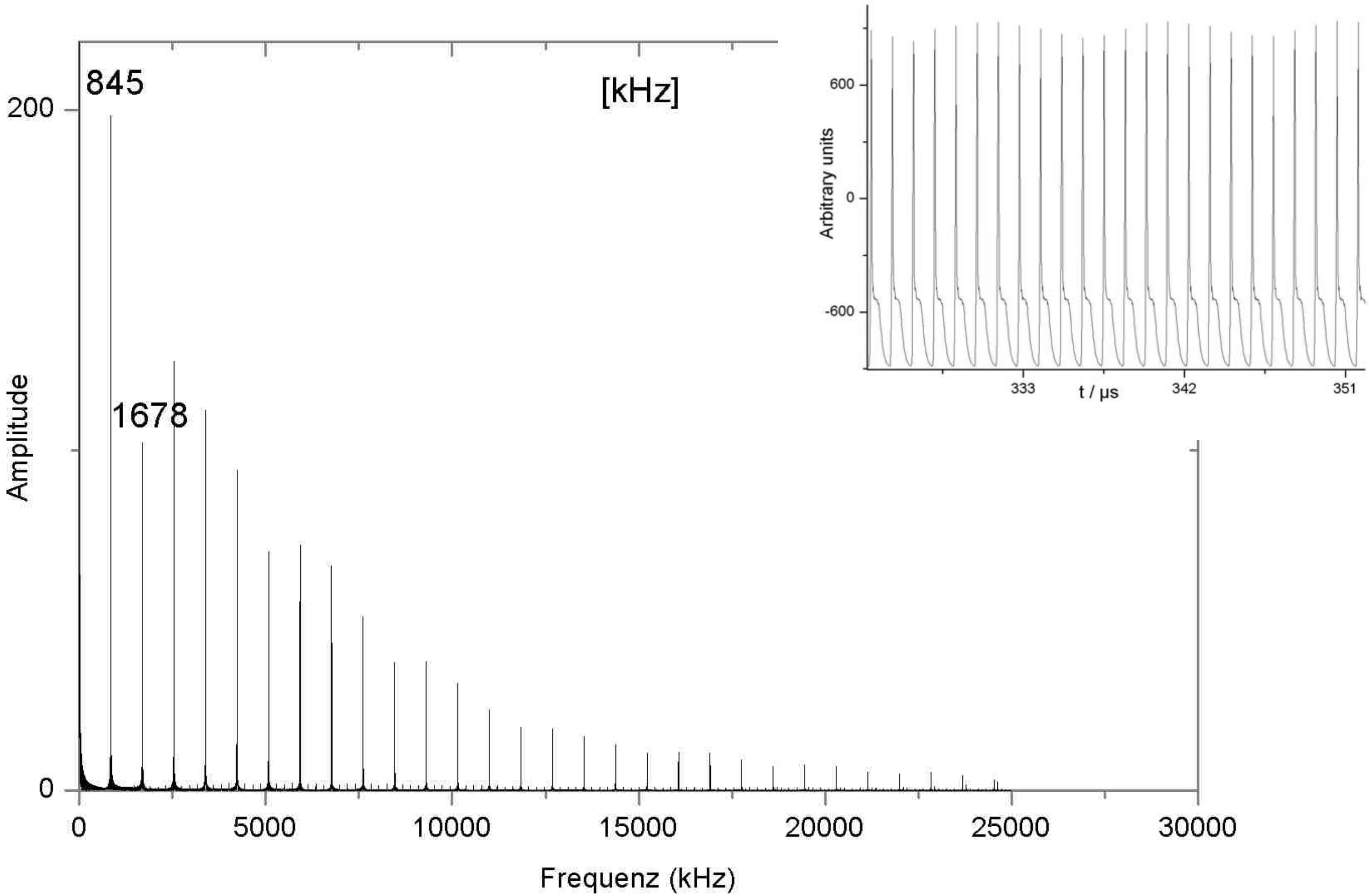
- Considered 4-Sigma bunch lengt
- One obtains a cut-off of about 13
- Thus low noise amps required be
- Saturation during ramp has to be



Some results

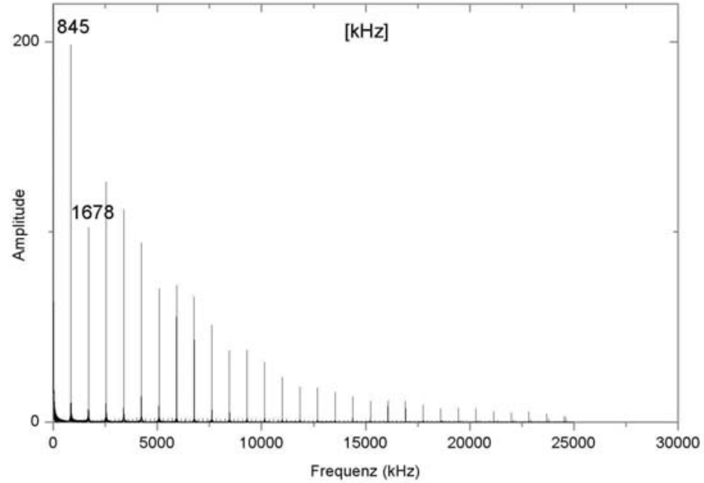


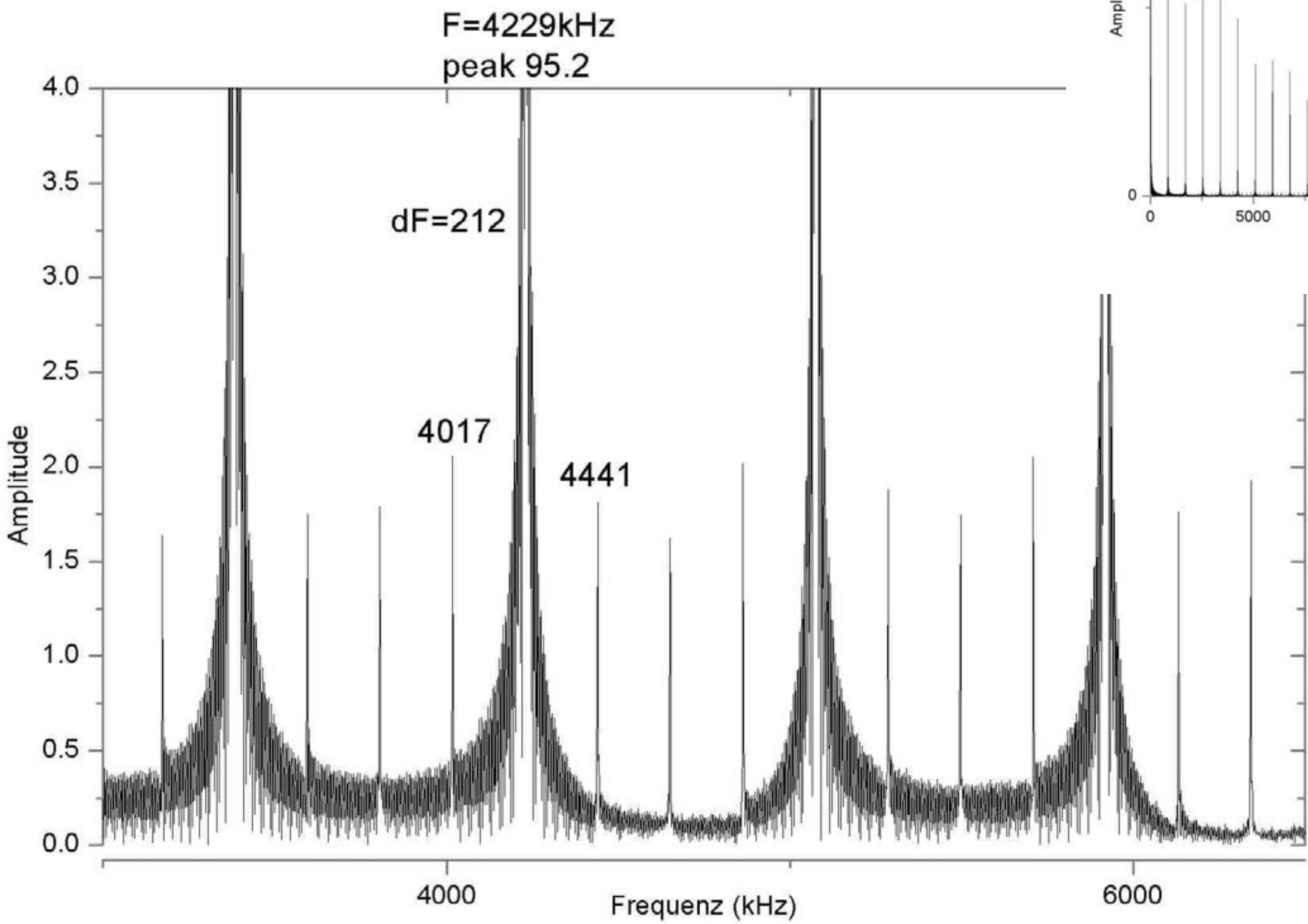
Some results



Time span for every actual done Fourier Transformation is 0.5 ms (25000 data points/channel)

Some results





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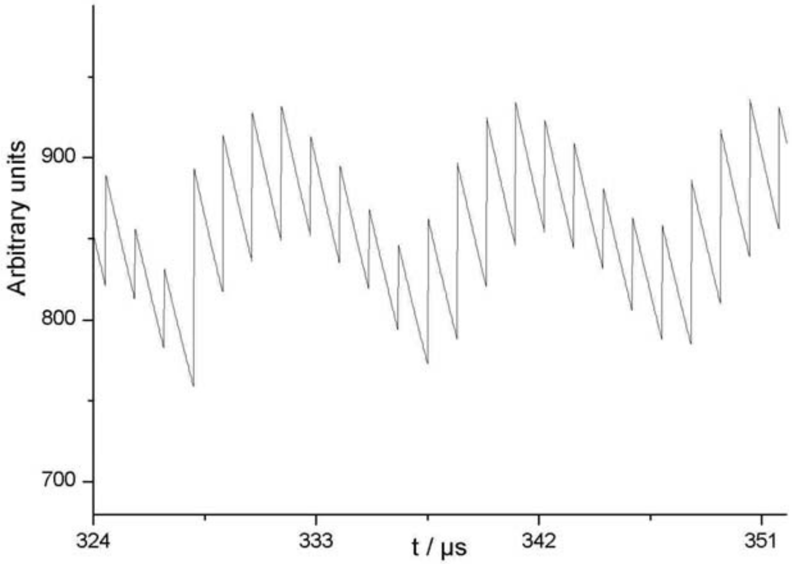
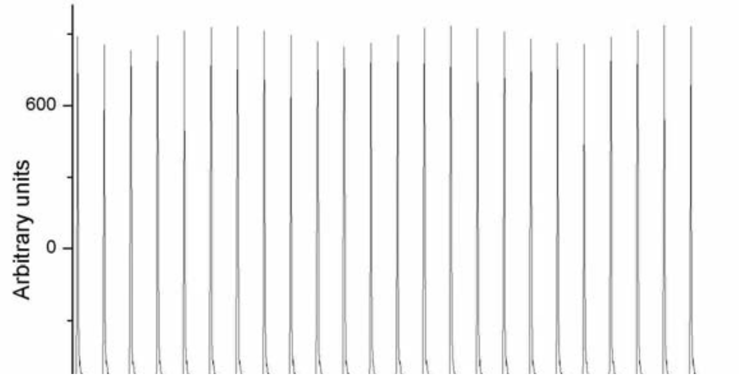
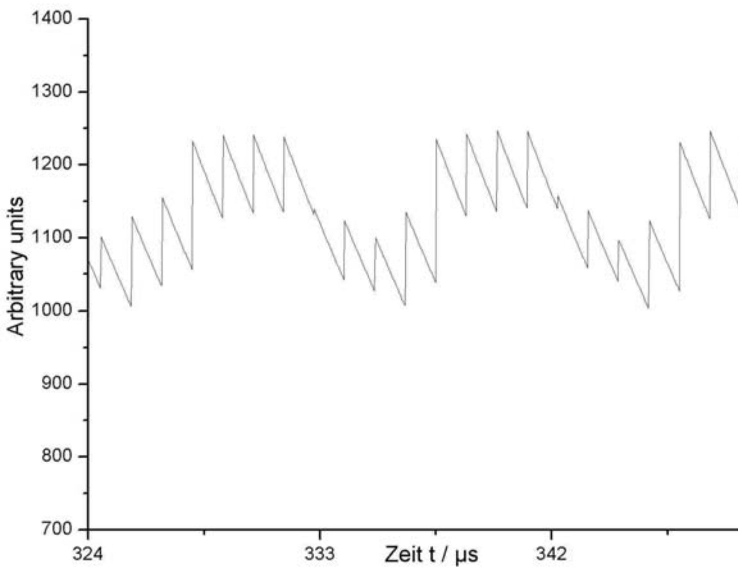
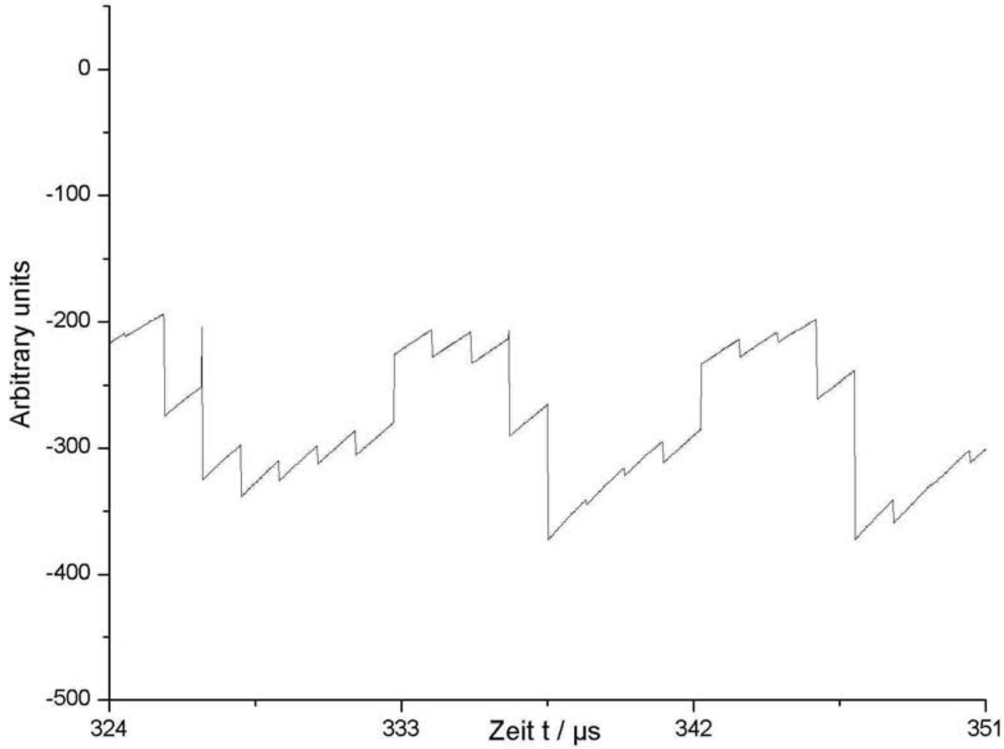
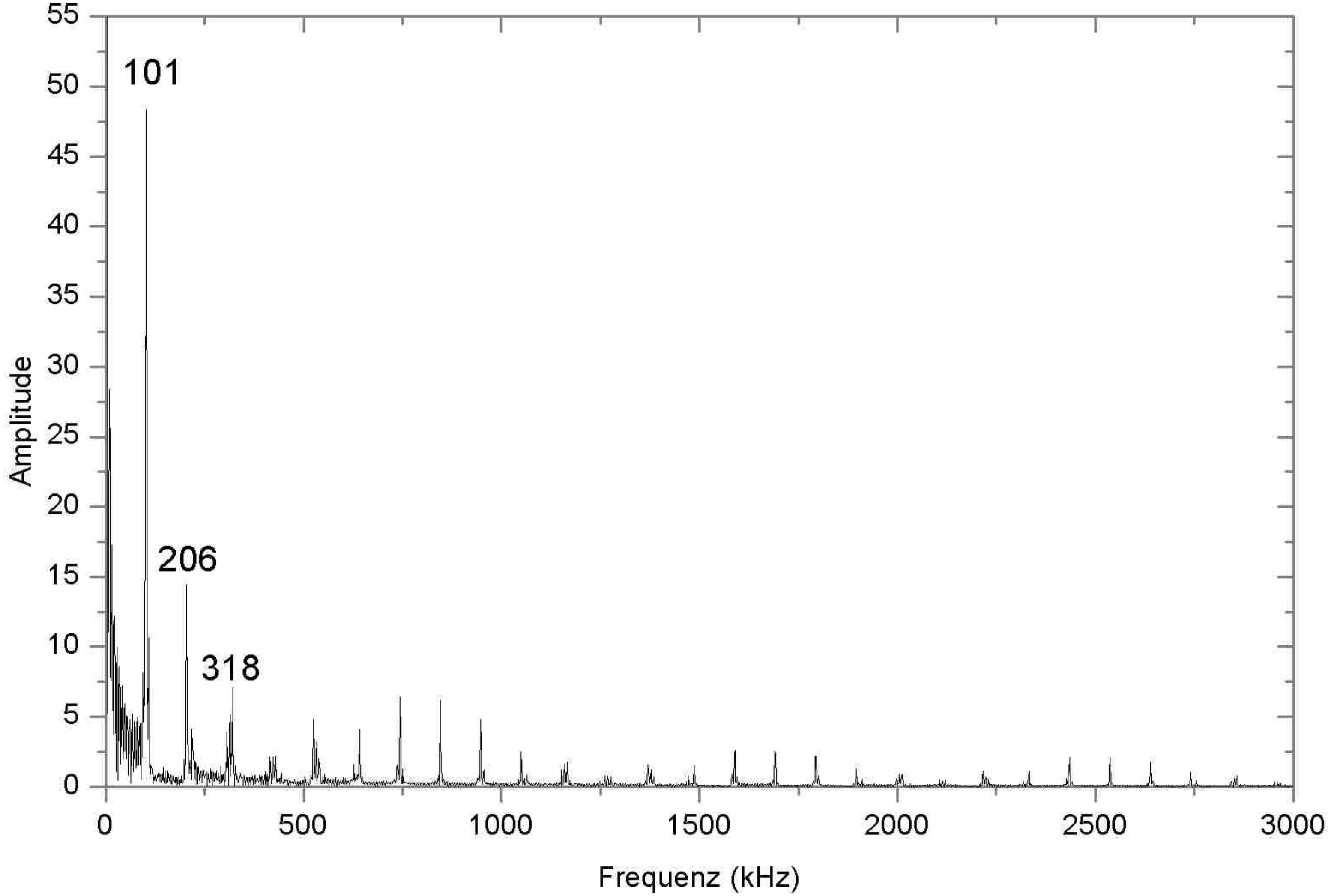




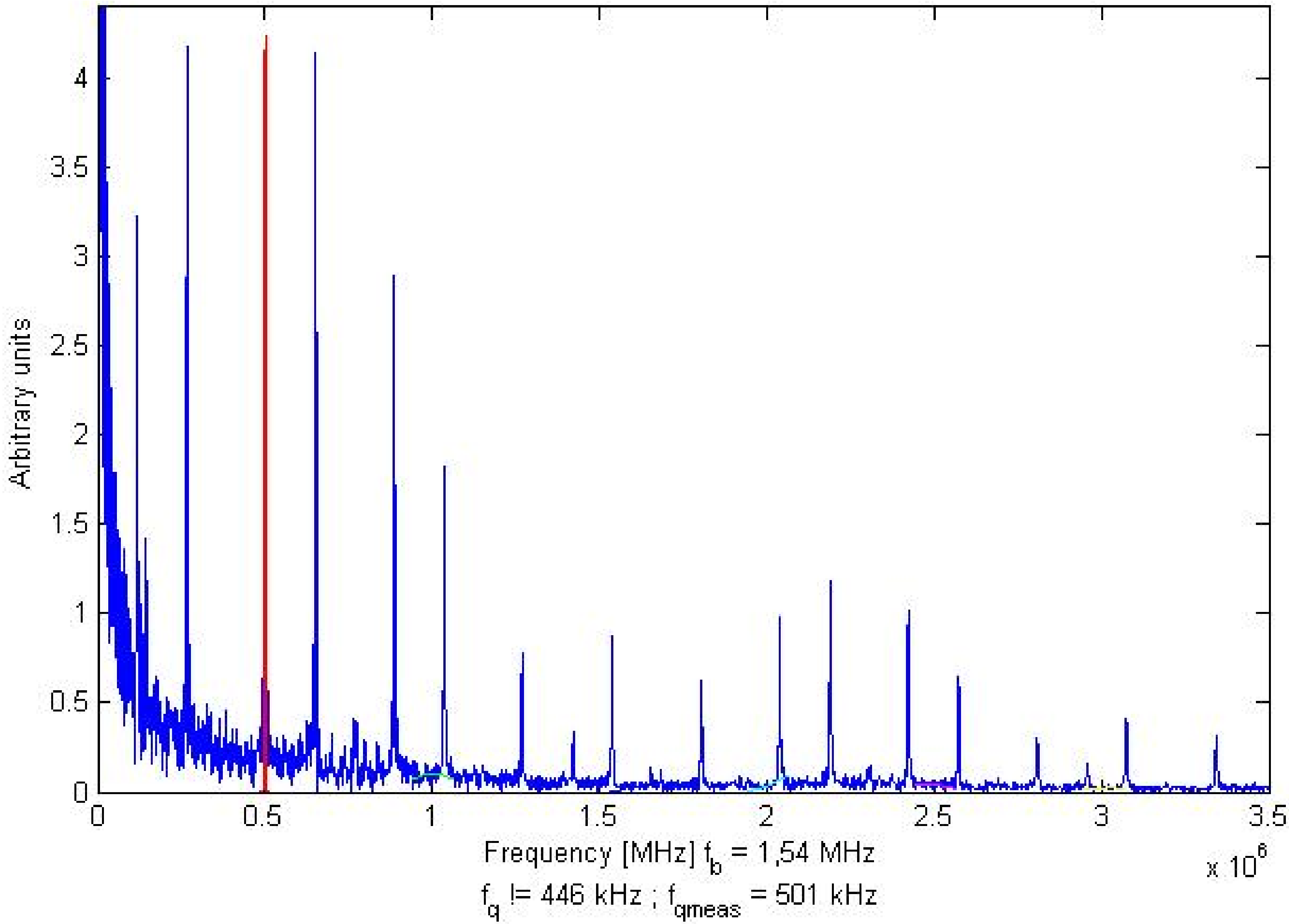




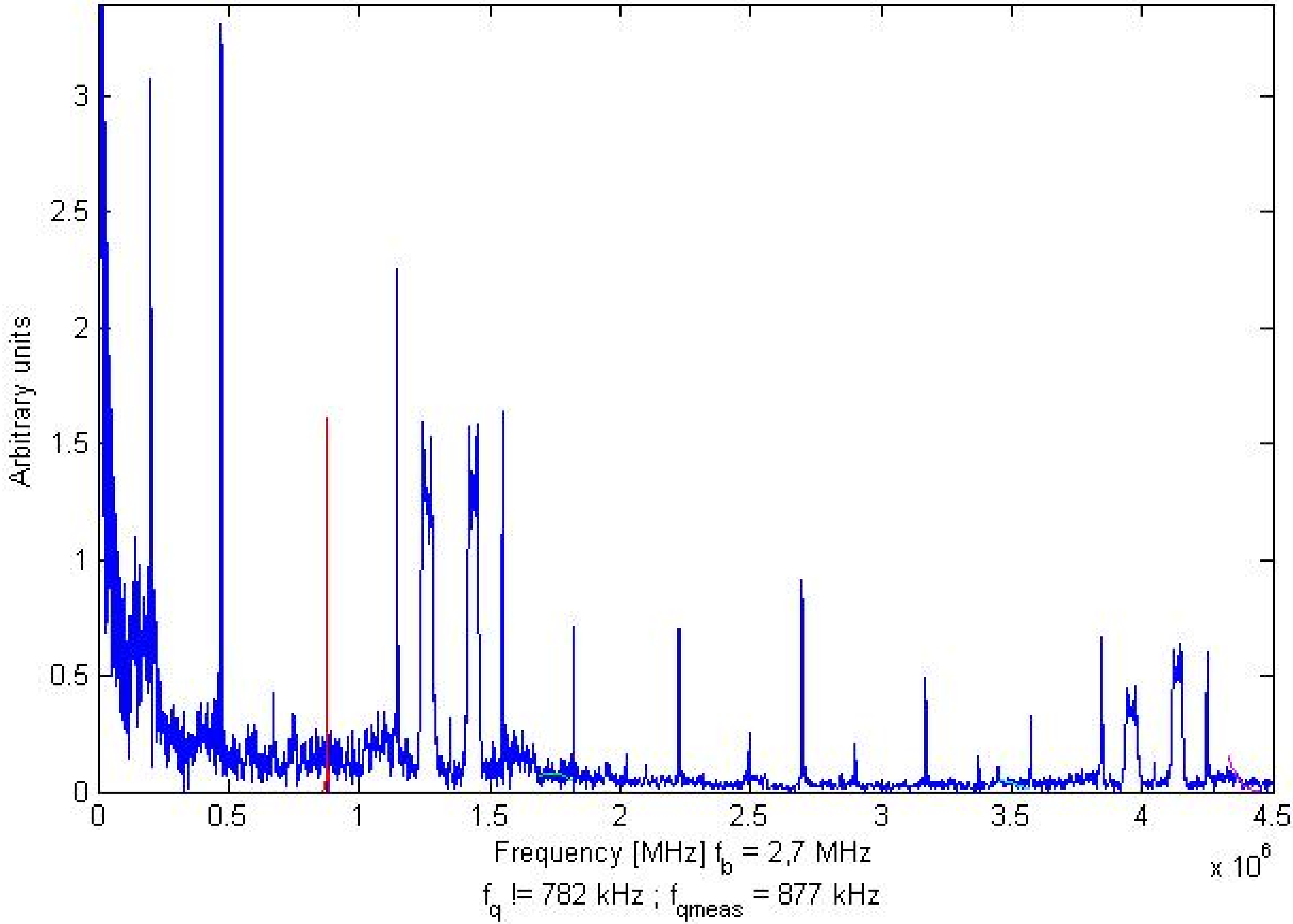
Some results



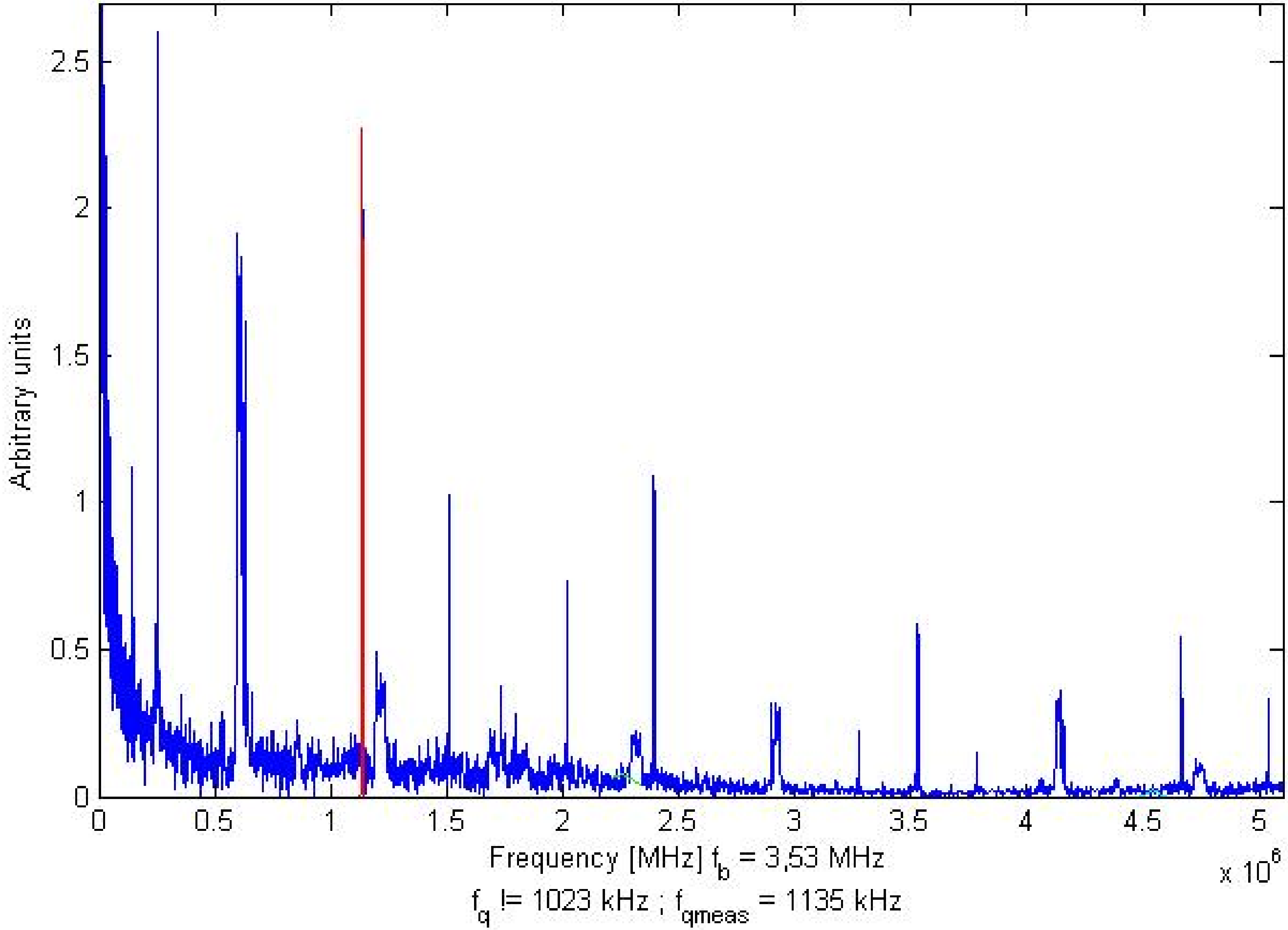
Results of one ramp cycle



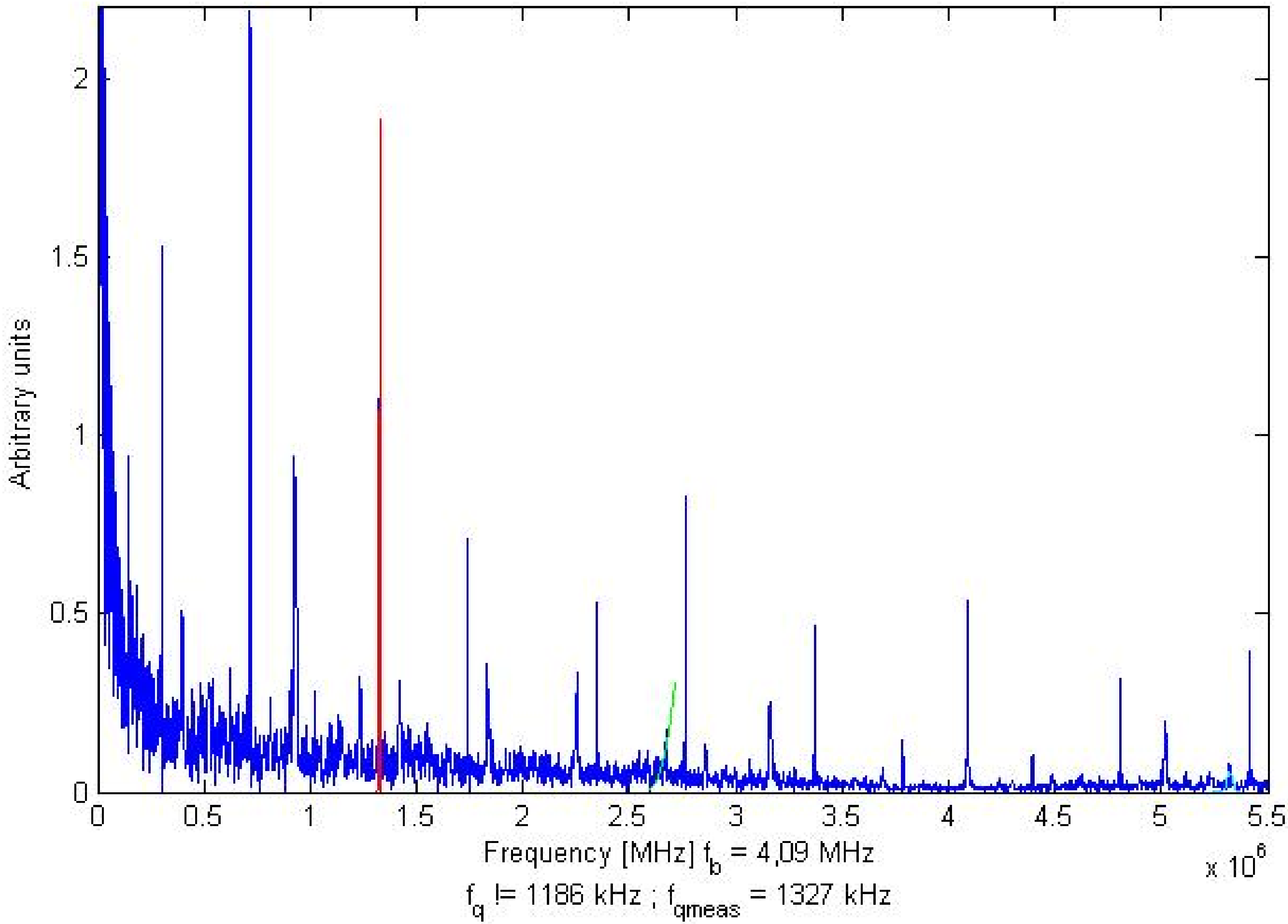
Results of one ramp cycle



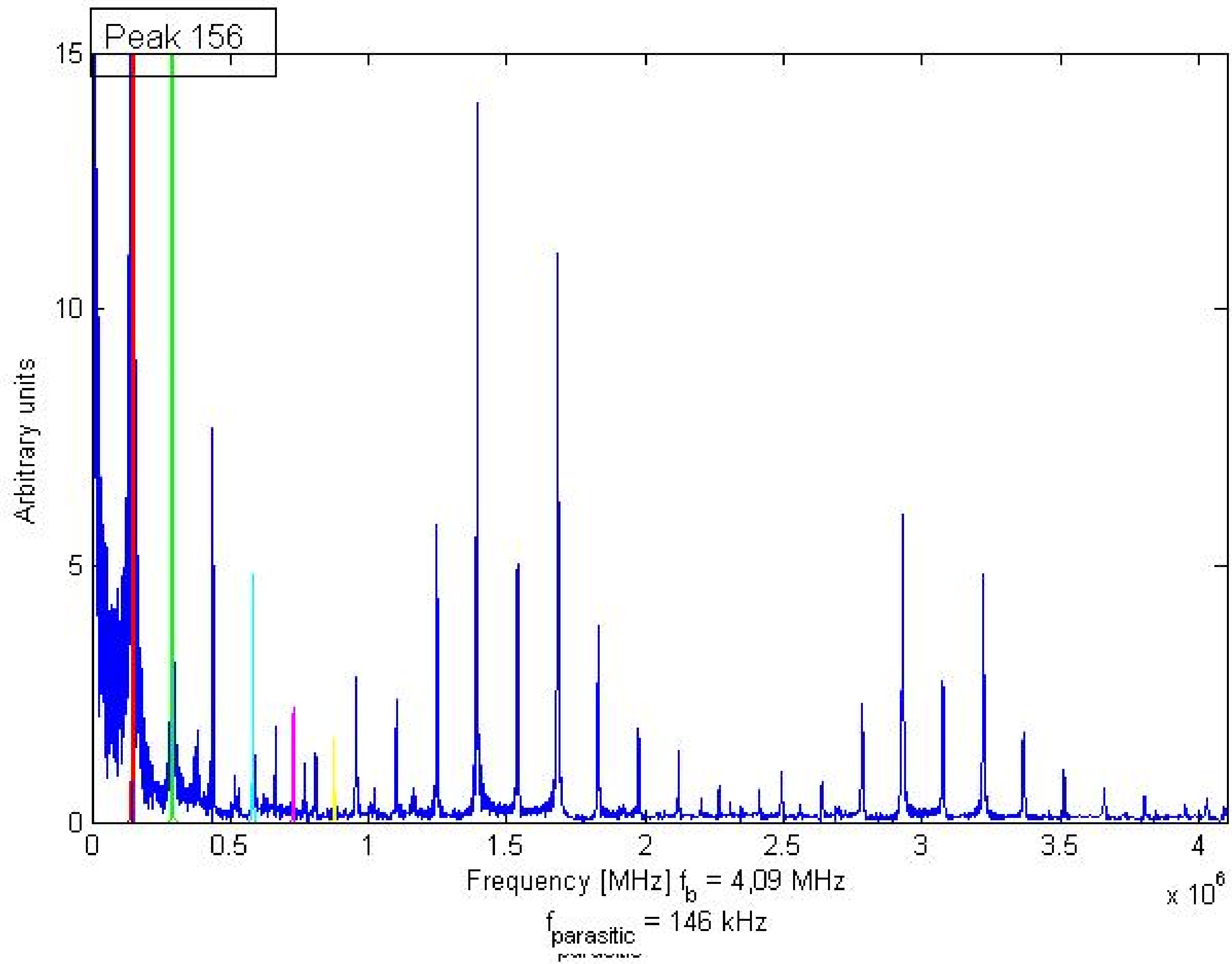
Results of one ramp cycle



Results of one ramp cycle



Curiosities (PosSon6)



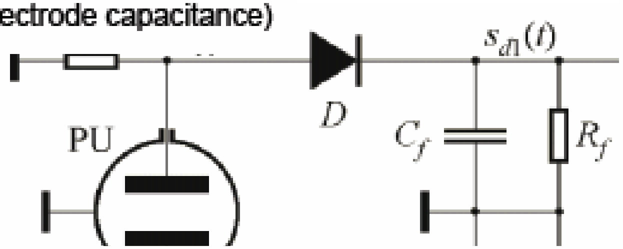
What‘s missing

- Programming, programming, programming. (matlab, mathematica,...)
- Calculations
- Identifying obtained frequencies (tune? Half tune? Amplifier? Power Plant?)
- Statistics on when tune is identifiable. More data needed for statistics, because most of recent collected data is corrupted mostly due to the parasitic frequency on BPM 6

The direct diode detection (principles)

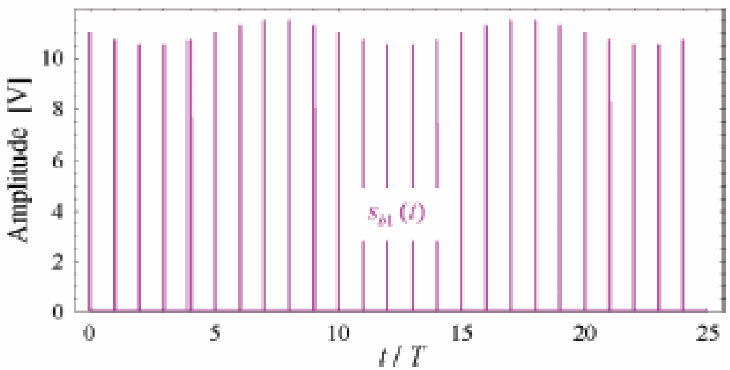
beam relative offset $\alpha = 0.1$
betatron oscillation relative amplitude $\beta = 0.05$
simulated tune value $q = 0.1$
filter time constant $\tau = 10T$ ($T-$ revolution period)
storage capacitor $C_f = C_{pu}$ (PU electrode capacitance)

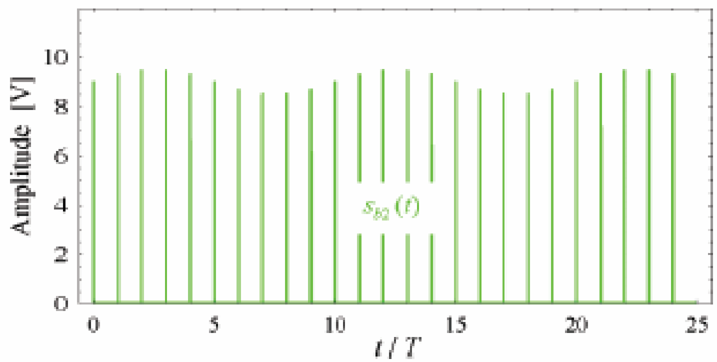
$$s_{b1}(t) = s_b(t)(1+\alpha)(1+\beta\cos(2\pi f_b t))$$
$$s_{b2}(t) = s_b(t)(1-\alpha)(1-\beta\cos(2\pi f_b t))$$



beam relative offset $\alpha = 0.1$
betatron oscillation relative amplitude $\beta = 0.05$
simulated tune value $q = 0.1$
filter time constant $\tau = 10T$ ($T-$ revolution period)
storage capacitor $C_f = C_{pu}$ (PU electrode capacitance)

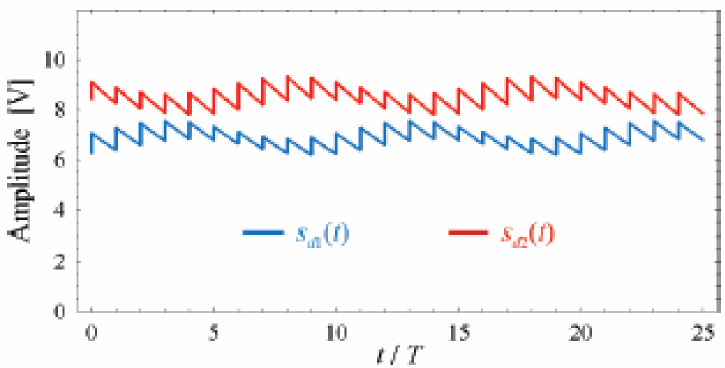
Electrode 1 signal

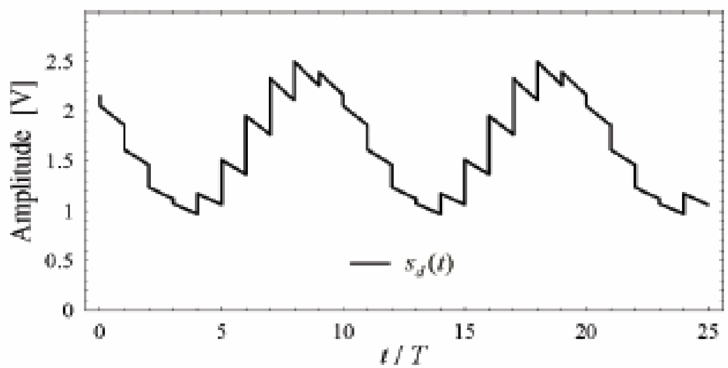




Electrode 2 signal

Signals of both peak detectors

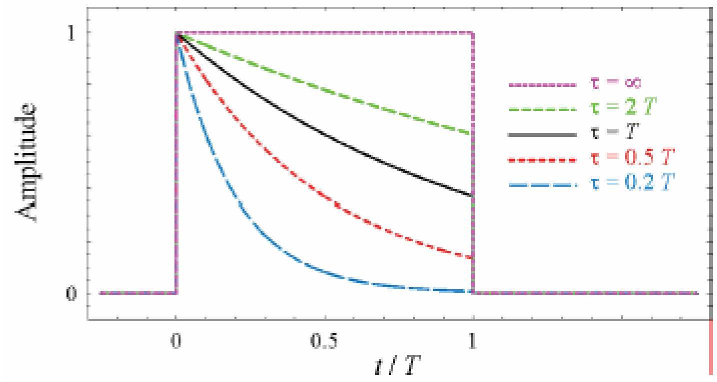


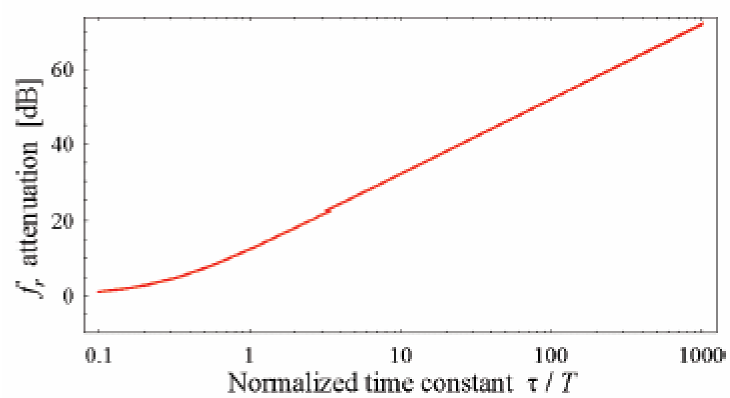


Detector signal difference

Scheme, mathematics and plots by Marek Gasior, CERN

The direct diode detection (principles)



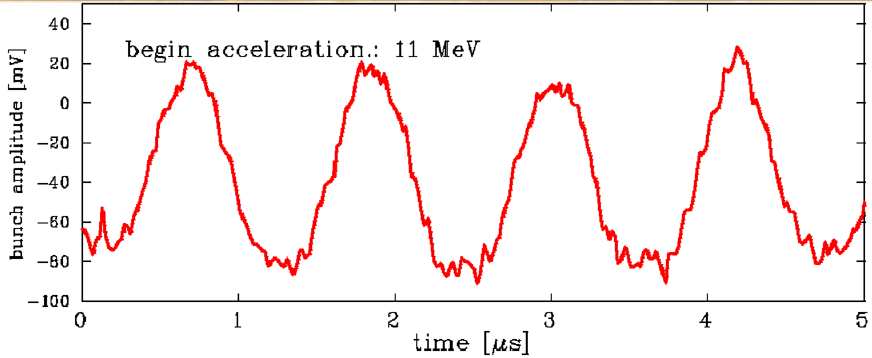


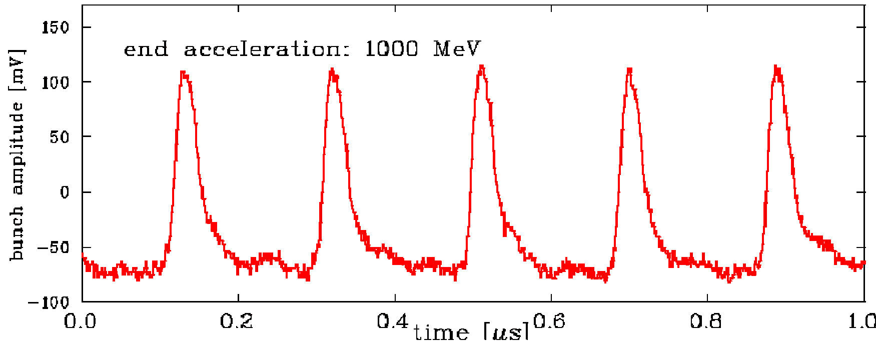
$$\begin{array}{c}\text{bunch spectrum}\\ \text{3 dB cut-off}\end{array} \cong \frac{0.133}{\text{bunch length}}$$

The direct diode detection (analytics / results)

Calculation of R and C (and gain factor G)

Dependent on:
- Pickup capacity
- Accelerator cycle
- Bunch length
- Temperature
- Diode leakage current
- Spectral noise density and current of Detector Amplifier
- Expected tune value



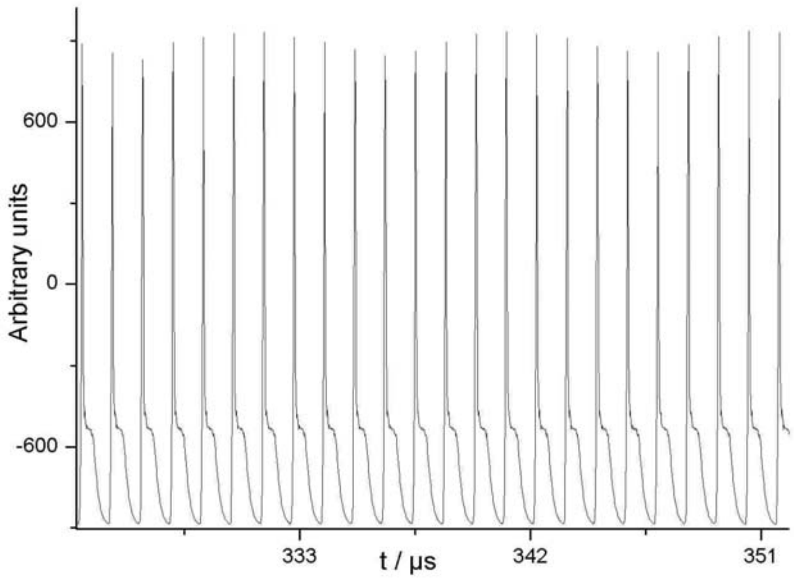


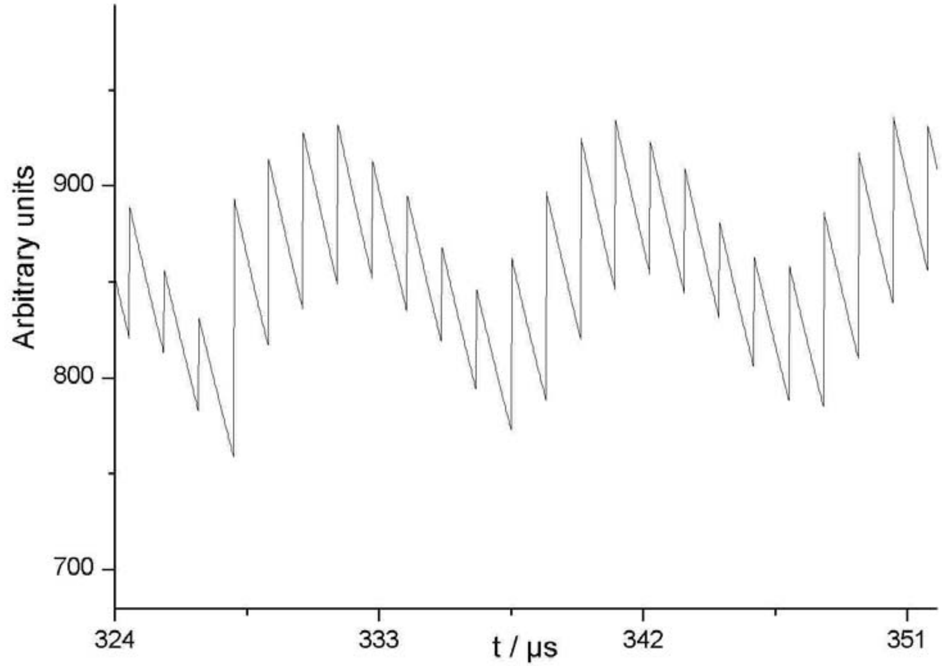
$$G_D = \frac{S_d / N_d}{S_c / N_c} = \frac{S_d / S_c}{N_d / N_c} = \frac{G_S}{G_N}$$

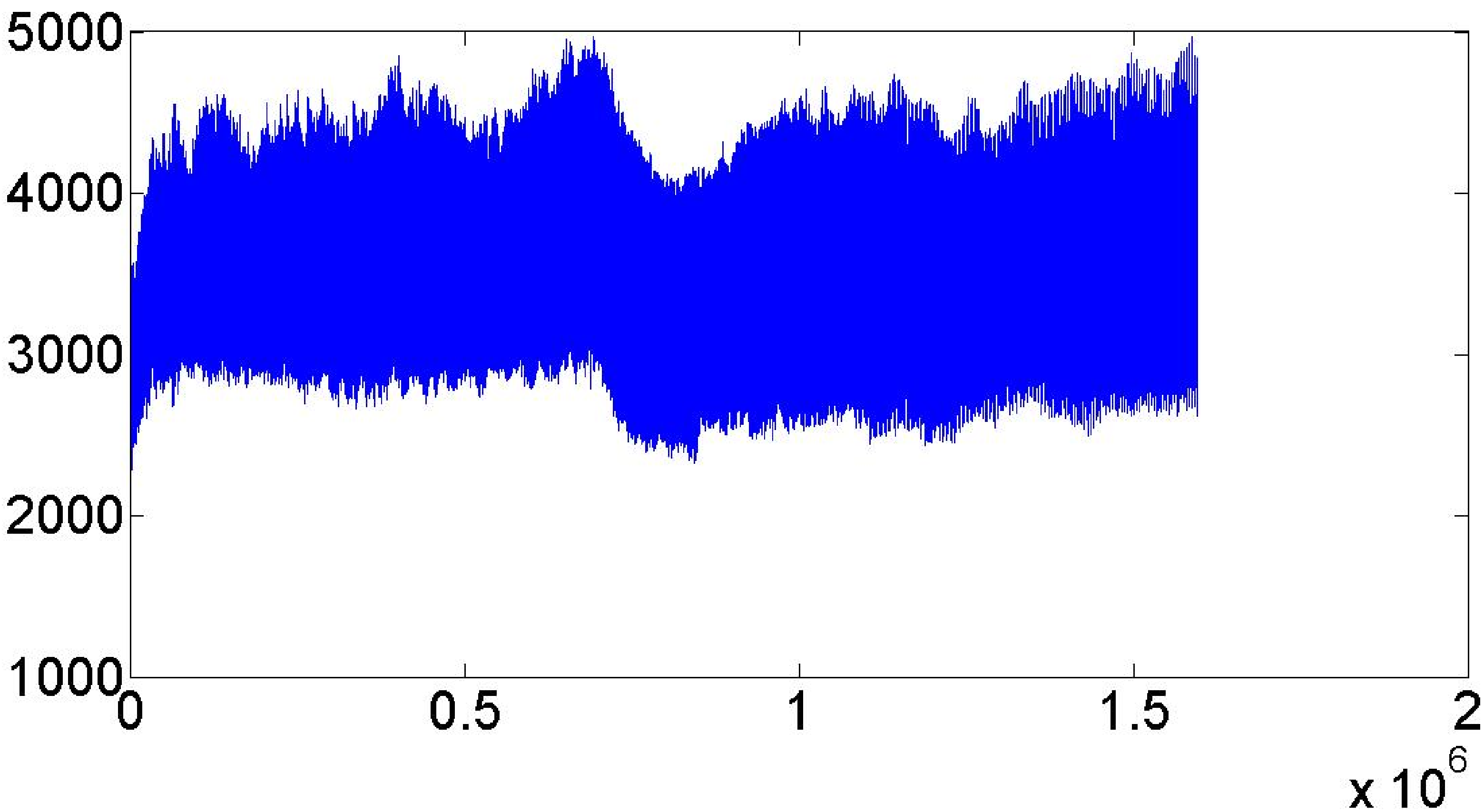
Beschleuniger	C_{fo} [pF]	R_{fo} [MΩ]	G_{Do} [dB]	G_{Do}(Faktor)
SIS - 18in	177,24	2,26	9,4	2,95
SIS 18ex	84,73	1,18	15,31	5,83
SIS 100in	89,246	6,05	27,72	24,31
SIS 100ex	70,70	5,09	27,9	24,83

	SIS18in			SIS18ex			SIS100in			SIS100ex		
	$C_{fo}[pF]$	$R_{fo}[M\Omega]$	$G_D[dB]$	$C_{fo}[pF]$	$R_{fo}[M\Omega]$	$G_D[dB]$	$C_{fo}[pF]$	$R_{fo}[M\Omega]$	$G_D[dB]$	$C_{fo}[pF]$	$R_{fo}[M\Omega]$	$G_D[dB]$
Optimal	177,24	2,26	9,4	84,73	1,18	15,31	89,246	6,05	27,72	70,7	5,09	29,04
Mittelwert	130,99	1,72	8,24	130,99	1,72	15,21	79,97	5,57	27,09	79,97	5,57	28,545
Schlecht	84,73	1,18	5,44	177,24	2,26	14,22	70,7	5,09	26,32	89,246	6,05	27,9

Some results






5000
4000
3000
2000
1000
0
0.5
1
1.5
2
x 10^6