Beam test of ATF2 Q-BPM electronics

Y.Honda

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Abstract

Resolution of the ATF2 cavity BPM was estimated by comparing two output ports of single cavity BPM. This study measures resolution determined by the electronics and the analysis procedure. It proved 100 nm position resolution in the linear range of the electronics. The resolution becomes worse in the case of signal saturation, but still it showed 1 μm resolution over 250 μm range. Overall, it satisfies the requirement.

1 Introduction

We have been developing cavity BPMs to be attached on quadrupole magnets in ATF2 beam line (Q-BPM). It requires 100 nm position resolution within ± 100 μm around the field center of the magnets.

One prototype ATF2 cavity BPM has been installed in the extraction line of ATF at present. More than three BPMs which are rigidly mounted are needed to measure the actual resolution. In the existing setup, we focused only on the study of the intrinsic resolution determined by the processing electronics and the analysis procedure. ATF2 BPM has two output ports for each direction. The two ports should give the same information since it sees the same dipole mode. (In the actual case in ATF2, signals from these two ports will be combined with an anti-phase hybrid to gain sensitivity.) In this study, the two ports were processed independently. Comparing the results of the two after all analysis procedure, we can estimate the resolution.

2 Setup and data taking

2.1 Setup

We used the ATF2 BPM prototype board (ver.2) developed in SLAC. It has four channels in one box. Two Y-ports, one X-port and a reference cavity were assigned. Another X-port which was not read out was terminated by 50 Ω load. BINP reference cavity which was placed $\sim$5 m upstream was used as a reference cavity. L.O. was supplied from a signal generator placed outside of the tunnel. The schematic figure and picture are shown in Figure 1 and 2. Couplers to input calibration tone were connected at the output of the BPM, but they were not used during this test.

2.2 Data taking

The data acquisition system developed by SLAC/LLNL/UK group was used for this test. A set of data which scanned the beam orbit around ATF2 BPM was used for this analysis. Table 1 summarizes the data set. Each run contains $\sim$30 beam pulse data. Beam charge was $\sim 0.6 \times 10^{10}$ e/bunch.

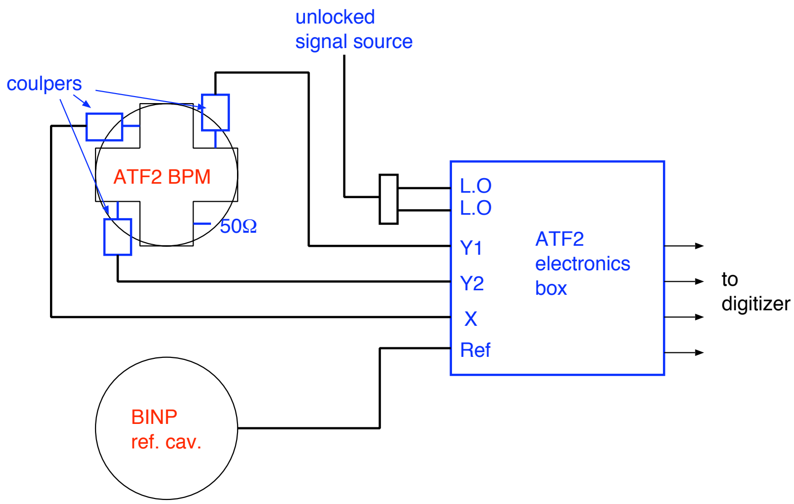

Figure 1: Setup of the electronics.

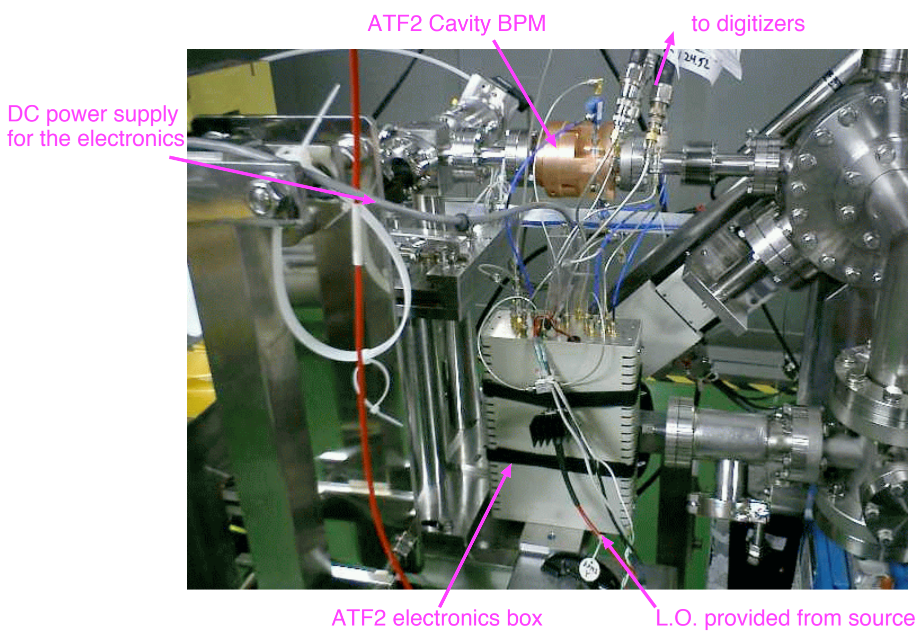

Figure 2: Setup

Table 1: Data set used for this analysis

Run number	beam offset
18-Apr-2006_14_55	0 μm
18-Apr-2006_14_57	-50 μm
18-Apr-2006_14_58	-100 μm
18-Apr-2006_15_0	-150 μm
18-Apr-2006_15_1	-200 μm
18-Apr-2006_15_2	-250 μm

3 Analysis

3.1 Waveform fitting

3.1.1 fitting function

The simplest model to describe BPM's signal should be a decaying sinusoidal function, $A\exp(-\frac{t}{\tau})\sin(\omega t+\phi)$. Adding terms for signal offset and time origin, I used the following function to fit the waveform

$$A\exp(-\frac{t-t_0}{\tau})\sin(\omega(t-t_0)+\phi)+B \quad . \tag{1}$$

Where, t is the sampling number (1~250), and t_0 means the beam timing (I used $t_0 = 30$). τ is the decaying time. ω means the frequency and ϕ is the phase at $t = t_0$. A is the amplitude at $t = t_0$. B is the DC offset. A, τ, ω, ϕ, B were left as free parameters in the fitting process.

Suffixes distinguish 4 kinds of signals (Reference, X, Y1, Y2), for example A_{Ref}, τ_X,... The most important outputs of the fitting are A and ϕ, these are used to extract IQ information.

3.1.2 fiducial of the fitting analysis

The very first part of the waveform should not be used in the fitting since it contains transient signal. Data points in $t < 50$ (first ~5 cycles of oscillation) were omitted.

In order to analyze a waveform that saturates in the first part, we needed to define the fiducial of the data. The ADC saturates at 4096 counts, and the non-linearity of the processor seems to appear around the saturation point of the ADC. The range that ADC counts was 500~3500 was defined to be the fiducial. Tail part of the waveform after it decays within this range was used for the fitting. It was extraporated to the time origin $t = t_0$ to extract the amplitude A. Figure 3 shows examples of the fitting.

3.1.3 fitting results

Distribution (mean (rms) of the ~30 pulses data) of fitting results of some important parameters are summarized in Table 2. The absolute values of ϕ have no meaning at this point because the L.O. is not locked to the beam in this study

3.2 Calibration of IQ phase

Signal of the reference cavity gives intensity and phase reference. Normalizing by intensity and taking relative phase with respect to the reference, I-Q information was defined as

$$I_{Yi} = \frac{A_{Yi}}{A_{Ref}}\sin(\phi_{Yi} - \phi_{Ref}) \tag{2}$$

$$Q_{Yi} = \frac{A_{Yi}}{A_{Ref}}\cos(\phi_{Yi} - \phi_{Ref}) \tag{3}$$

, where $i = 1, 2$.

Scatter plot of I_{Y1} vs Q_{Y1} and I_{Y2} vs Q_{Y2} of all corrector scan data are shown in Figure 4.

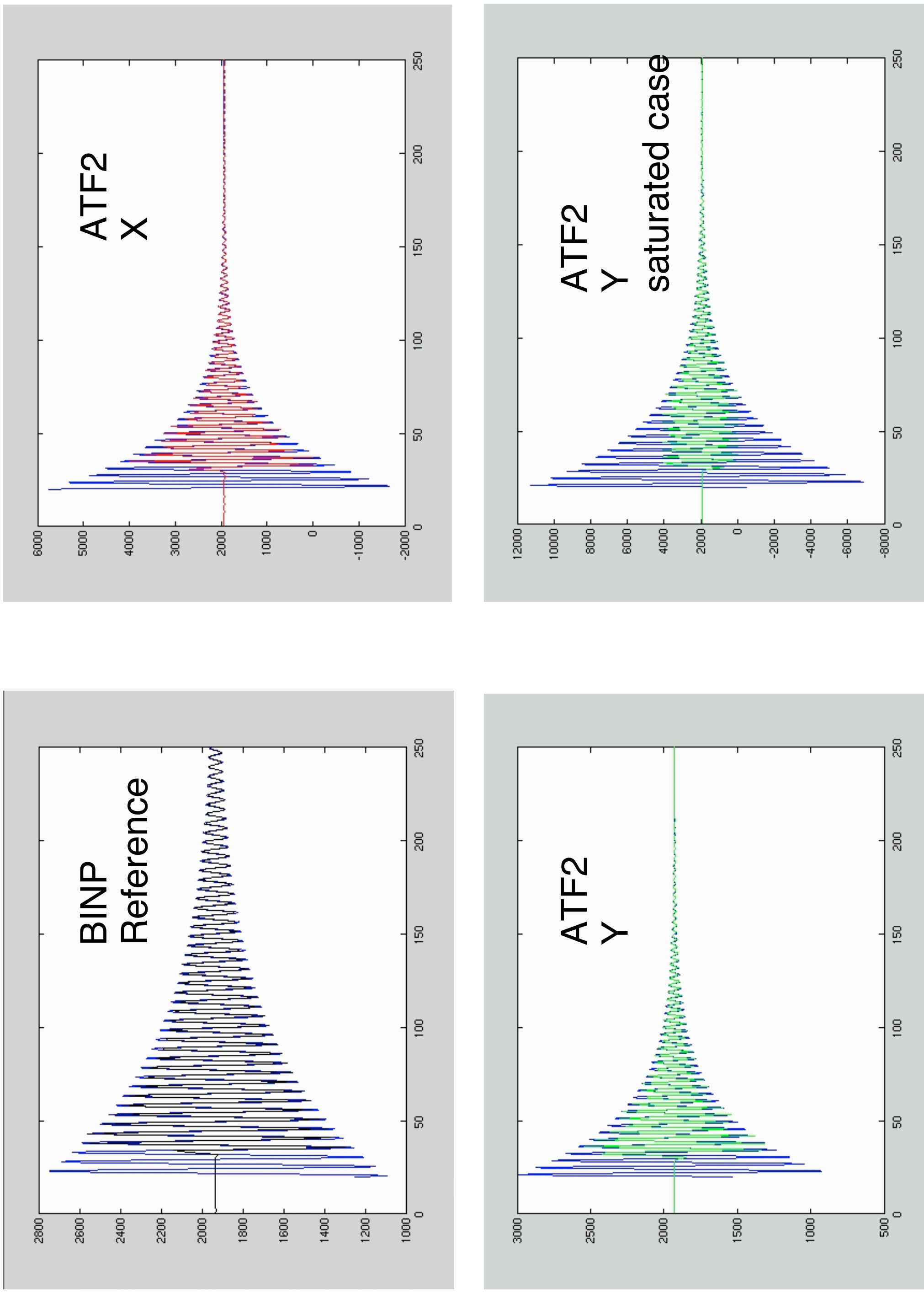

Figure 3: Examples of the waveform and fitting.

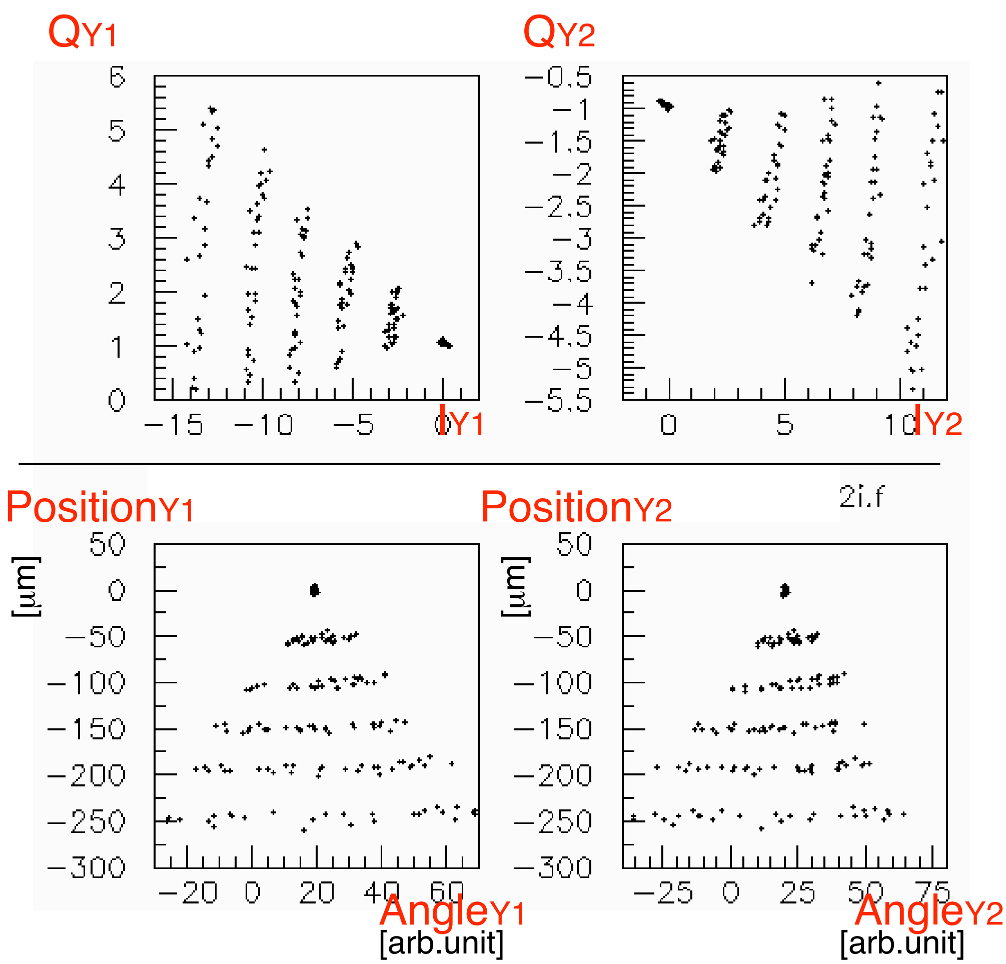

Figure 4: Plot on I-Q plane

Table 2: Results of the fitting. Mean (RMS) of parameters for each run were summarized.

Reference Run number	beam offset	A_{Ref}	τ_{Ref}	ω_{Ref}
18-Apr-2006_14_55	0 μm	739 (21)	68.65 (0.07)	1.25 (0.3×10^{-4})
18-Apr-2006_14_57	-50 μm	720 (15)	68.55 (0.07)	1.25 (0.2×10^{-4})
18-Apr-2006_14_58	-100 μm	690 (29)	68.61 (0.07)	1.25 (0.3×10^{-4})
18-Apr-2006_15_0	-150 μm	690 (30)	68.65 (0.11)	1.25 (0.3×10^{-4})
18-Apr-2006_15_1	-200 μm	682 (40)	68.47 (0.12)	1.25 (0.4×10^{-4})
18-Apr-2006_15_2	-250 μm	677 (35)	68.45 (0.16)	1.25 (0.3×10^{-4})
X Run number	beam offset	A_X	τ_X	ω_X
18-Apr-2006_14_55	0 μm	2711 (222)	28.07 (0.03)	1.67 (0.6×10^{-4})
18-Apr-2006_14_57	-50 μm	1752 (179)	28.15 (0.04)	1.67 (0.7×10^{-4})
18-Apr-2006_14_58	-100 μm	4312 (294)	28.38 (0.02)	1.67 (3.8×10^{-4})
18-Apr-2006_15_0	-150 μm	4599 (198)	28.54 (0.02)	1.67 (4.2×10^{-4})
18-Apr-2006_15_1	-200 μm	1777 (240)	28.33 (0.06)	1.67 (0.6×10^{-4})
18-Apr-2006_15_2	-250 μm	1991 (297)	28.32 (0.08)	1.67 (2.1×10^{-4})
Y1 Run number	beam offset	A_{Y1}	τ_{Y1}	ω_{Y1}
18-Apr-2006_14_55	0 μm	796 (26)	31.1 (0.06)	1.67 (0.7×10^{-4})
18-Apr-2006_14_57	-50 μm	2288 (143)	31.0(0.05)	1.67 (0.5×10^{-4})
18-Apr-2006_14_58	-100 μm	4009 (236)	31.3(0.18)	1.67 (2.7×10^{-4})
18-Apr-2006_15_0	-150 μm	5777 (293)	31.6(0.10)	1.67 (1.2×10^{-4})
18-Apr-2006_15_1	-200 μm	7383 (446)	31.6(0.09)	1.67 (0.8×10^{-4})
18-Apr-2006_15_2	-250 μm	9339 (575)	31.6(0.07)	1.67 (0.8×10^{-4})
Y2 Run number	beam offset	A_{Y2}	τ_{Y2}	ω_{Y2}
18-Apr-2006_14_55	0 μm	709 (22)	30.9 (0.06)	1.67 (0.9×10^{-4})
18-Apr-2006_14_57	-50 μm	1966 (121)	30.9 (0.05)	1.67 (0.7×10^{-4})
18-Apr-2006_14_58	-100 μm	3416 (210)	31.1 (0.06)	1.67 (2.6×10^{-4})
18-Apr-2006_15_0	-150 μm	4897 (250)	31.5 (0.11)	1.67 (2.3×10^{-4})
18-Apr-2006_15_1	-200 μm	6234 (367)	31.6 (0.07)	1.67 (1.4×10^{-4})
18-Apr-2006_15_2	-250 μm	7866 (471)	31.6 (0.06)	1.67 (1.3×10^{-4})

Clusters of points correspond to the 6 corrector settings. Supposing that the corrector scan produces pure beam offset, the direction of position signal was determined. To align the position information on the y-axis of the plot, the data points were rotated in the I-Q plane. At the same time, scale of the position (k) was calibrated to μm unit beleaving the corrector setting (1 step = 50 μm).

$$\begin{pmatrix} \text{position} \\ \text{angle} \end{pmatrix} = k \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \text{I} \\ \text{Q} \end{pmatrix} \quad . \tag{4}$$

Plots after applying the rotation and the scale calibration are also shown in Figure 4.

3.3 Resolution

3.3.1 all range

After the analysis above, position measured by Y1 and Y2 are plotted in Figure 5. The resolution can be estimated from the disagreement between two Y channels. Rms of Y1-Y2 distribution was measured to be 1.38 μm for all data over 250 μm range of corrector scan. The resolution was estimated to be $1.38/\sqrt{2} = 0.98$ μm.

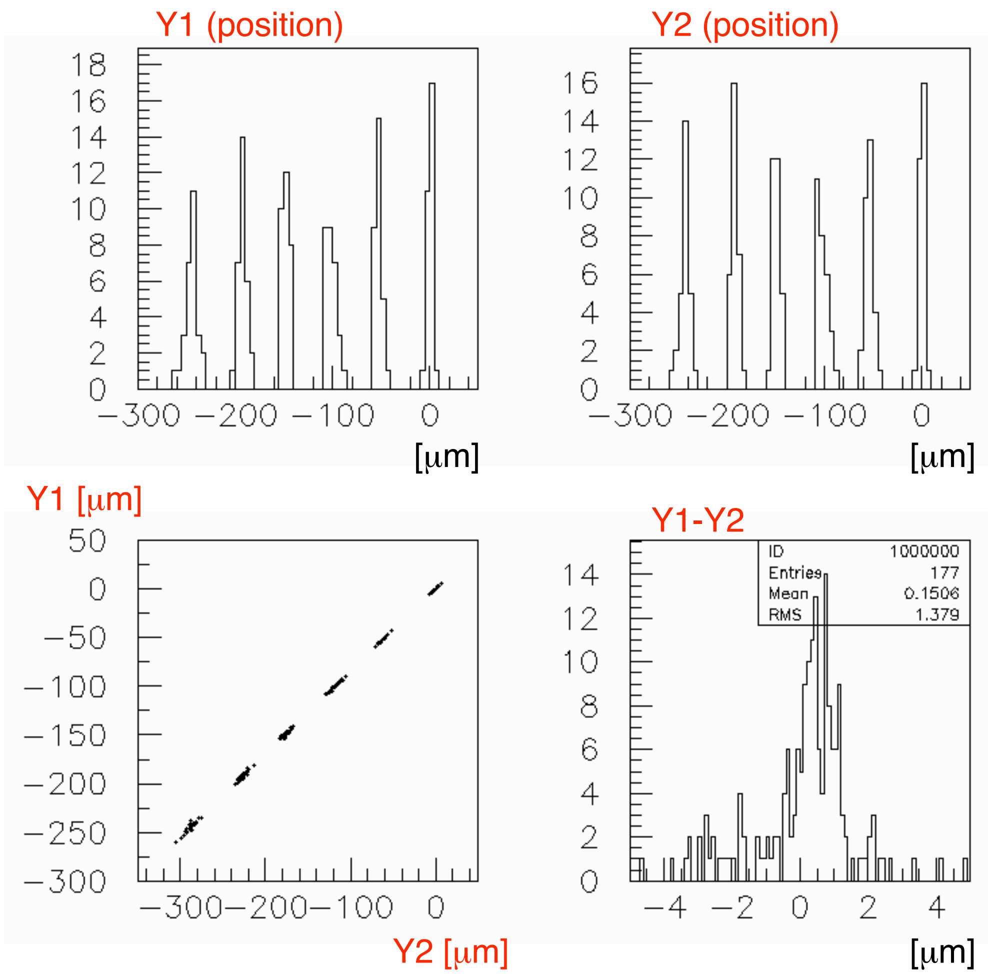

Figure 5: Correlation between Y1 and Y2 for all corrector scan data.

3.3.2 offset dependence

Separate analysis of 6 sets of corrector setting data gives offset dependence of resolution. Figure 6 shows examples of Y1-Y2 plot for unsaturated and saturated signal case. Resolution becomes worse in the case of saturated signal. The resolution as a function of beam offset is shown in Figure 7. In the cases of unsaturated signal, the resolution looks good and it gradually becomes worse depending on the amount of extraporation needed in the fitting. Note that the beam intensity was a little lower than the specification, and a hybrid combiner was not used in the BPM. Taking the loss of sensitivity due to these condition into account, still about factor 2 improvement of resolution can be assumed.

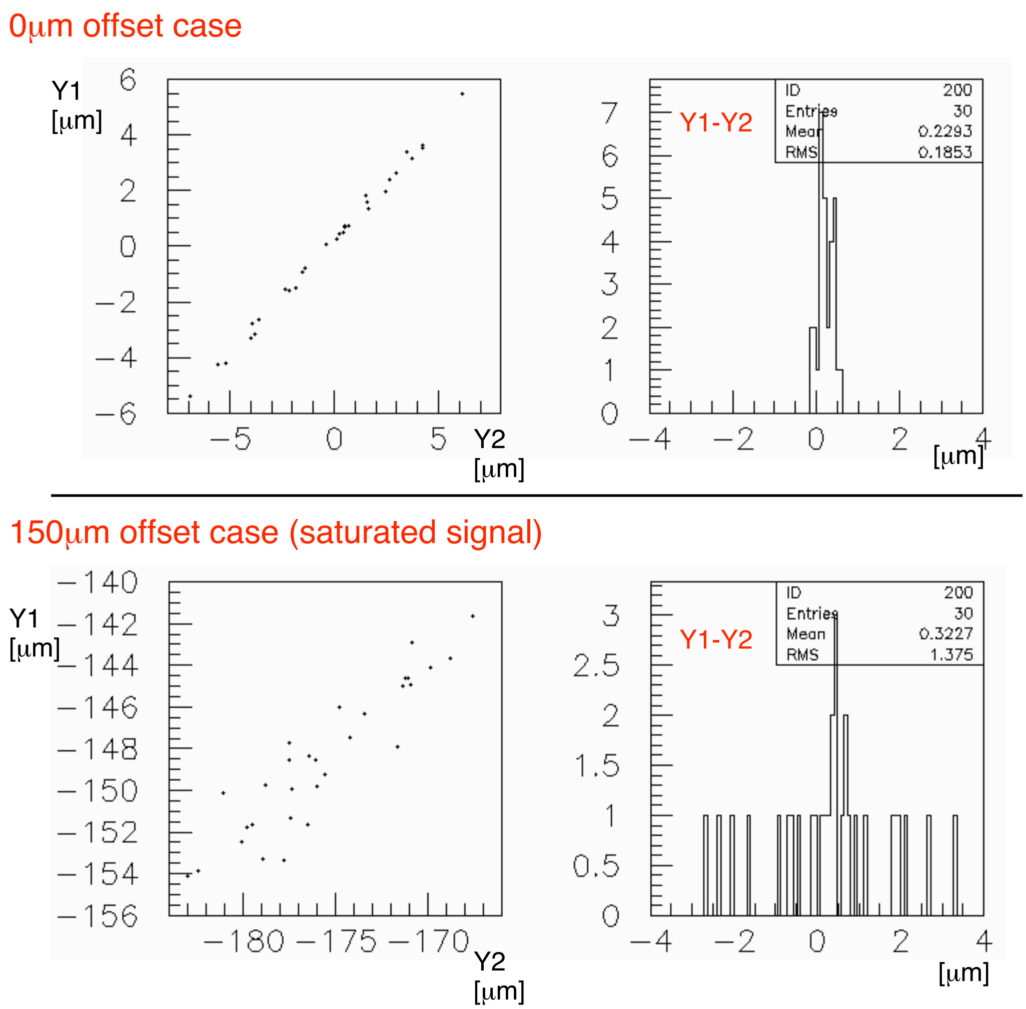

Figure 6: Resolution analysis for different offset data

4 Summary

Resolution of the ATF2 cavity BPM was estimated comparing two output ports of single cavity BPM. This study measures resolution determined by the electronics and the analysis procedure. It proved 100 nm position resolution in the linear range of the electronics. The resolution becomes worse in the case of signal saturation, but still it showed 1 μm resolution over 250 μm range. Overall, it satisfies the specification.

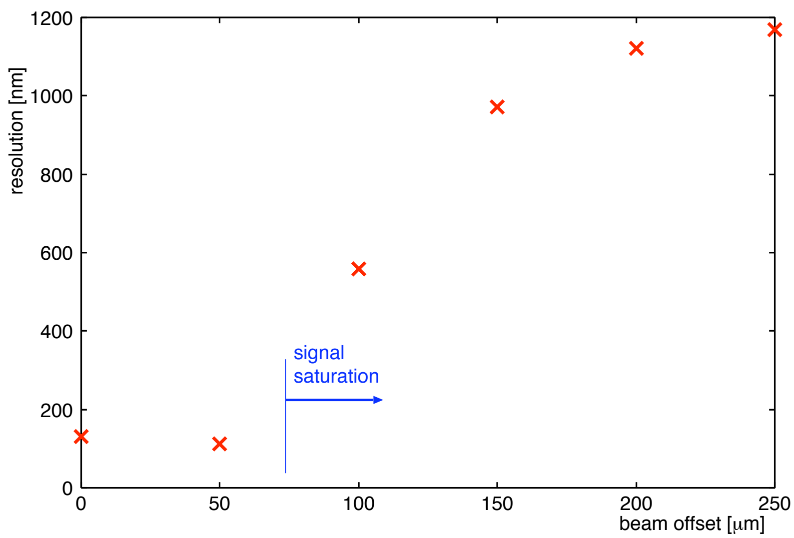

Figure 7: Resolution vs beam offset