DEVELOPMENT OF A HIGH DYNAMIC RANGE BEAM POSITION MEASUREMENT SYSTEM USING LOGARITHMIC AMPLIFIERS FOR THE SPS AT CERN

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Abstract

A new Front-End electronics, based on Logarithmic Amplifiers, is currently being developed for the CERN SPS Multi Orbit POsition System (MOPOS). The aim is to resolve the multi-batch structure of the beams and cope with their large intensity range (> 70 dB). Position and intensity signals are digitized in the Front-End electronics installed in the tunnel. The data are then transmitted over a serial fibre-optic link to a VME Digital Acquisition board located in surface buildings. A first prototype, equipped with a calibration system, has been successfully tested on the SPS under different beam conditions, including single bunch, 25 ns and 50 ns bunch trains. The system architecture and the first beam measurements are shown in this poster.

Position Measurement Principle for New MOPOS System

Logarithmic derivation of normalized position

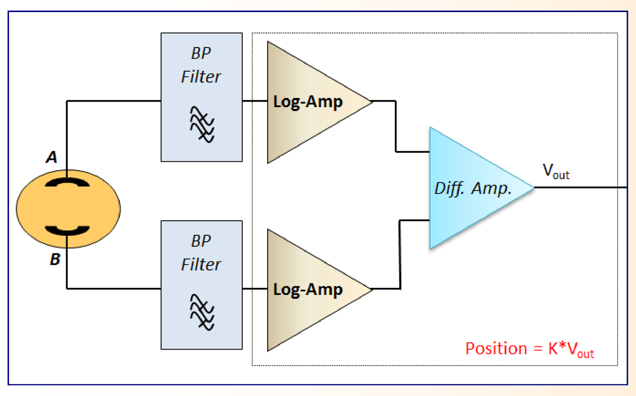
$$x = \frac{A-B}{A+B} \quad \Rightarrow \quad \frac{A}{B} = \frac{1+x}{1-x}$$

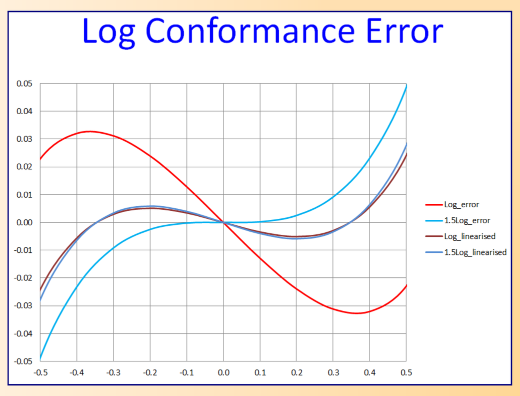
$$\ln\frac{1+x}{1-x} = 2\left(x + \frac{x^3}{3} + \frac{x^5}{5} + \dots\right)$$

$$\log\left(\frac{A}{B}\right) \cong \frac{2x}{\ln 10}$$

$$x = K(\log A - \log B)$$

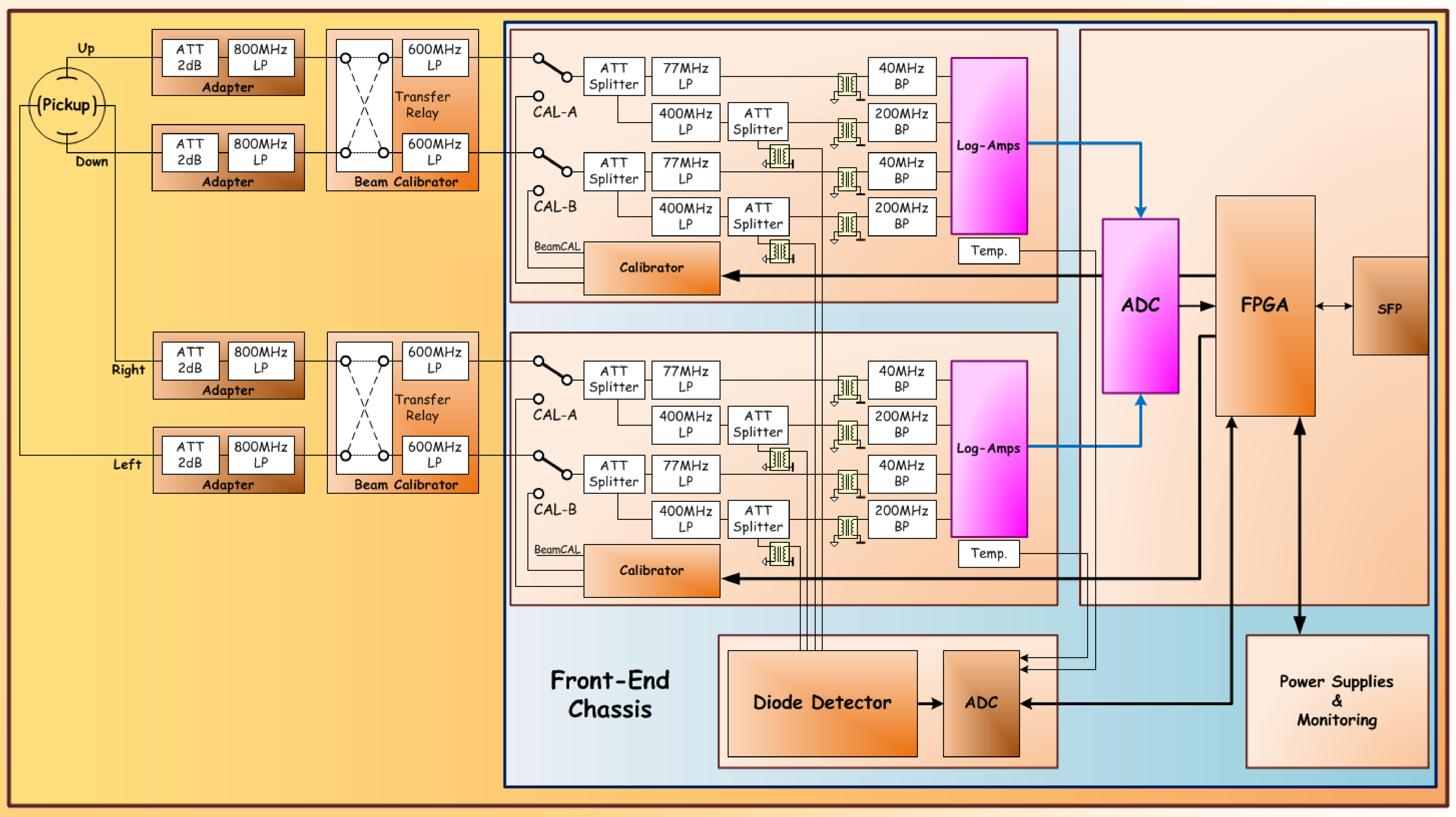
$$K = \frac{\ln 10}{2}$$





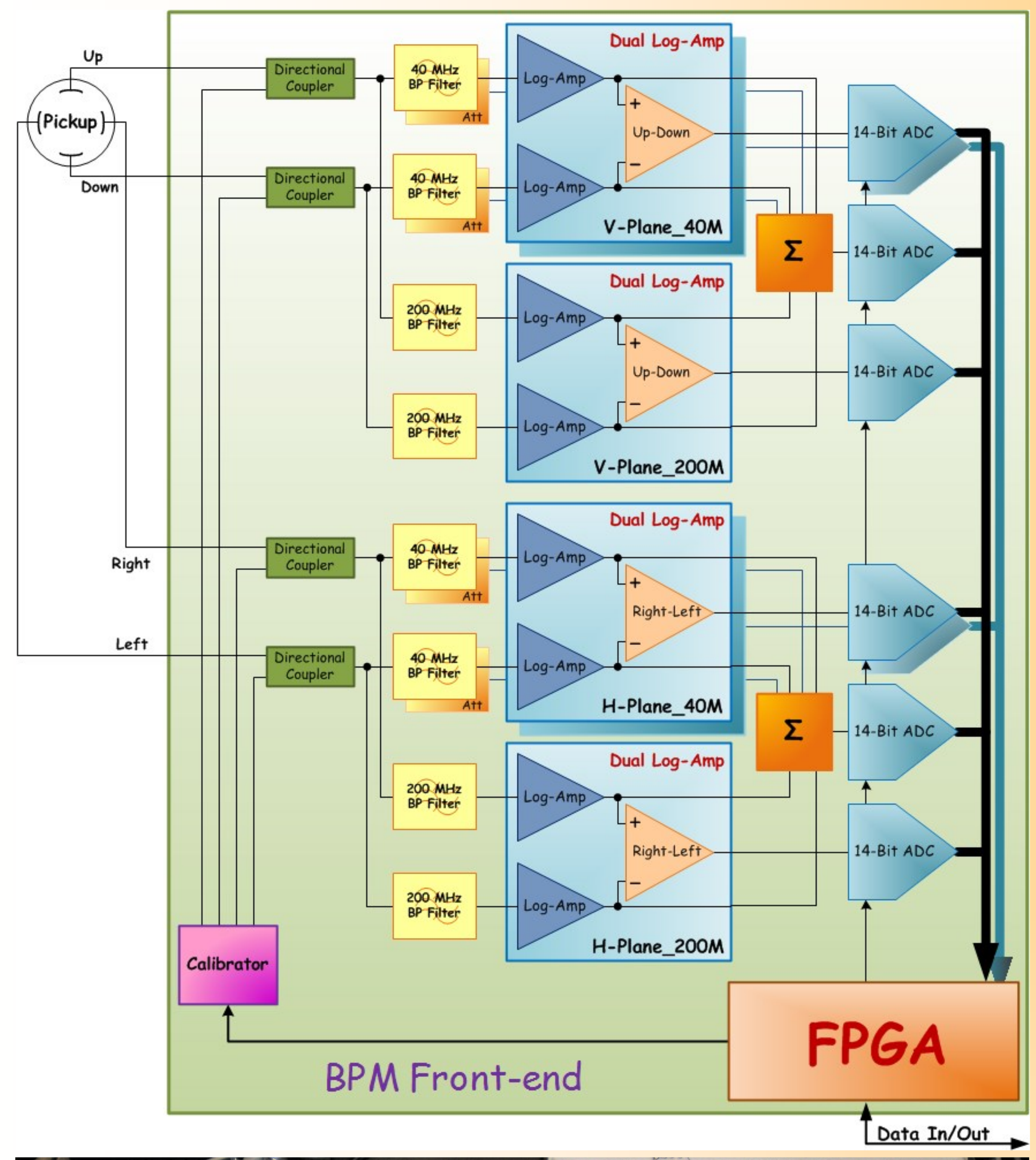
The MOPOS comprises 216 Beam Position Monitors (BPM) installed in the beam pipe of the SPS accelerator. They are mostly single-plane shoe-box electrostatic pick-ups, but some of them are two-plane strip-line monitors. The signals, which are induced on the electrodes by single-bunch and multi-bunch proton and lead-ion beams, are processed by Logarithmic-Amplifier (Log-Amp) modules to measure the position of the beam.

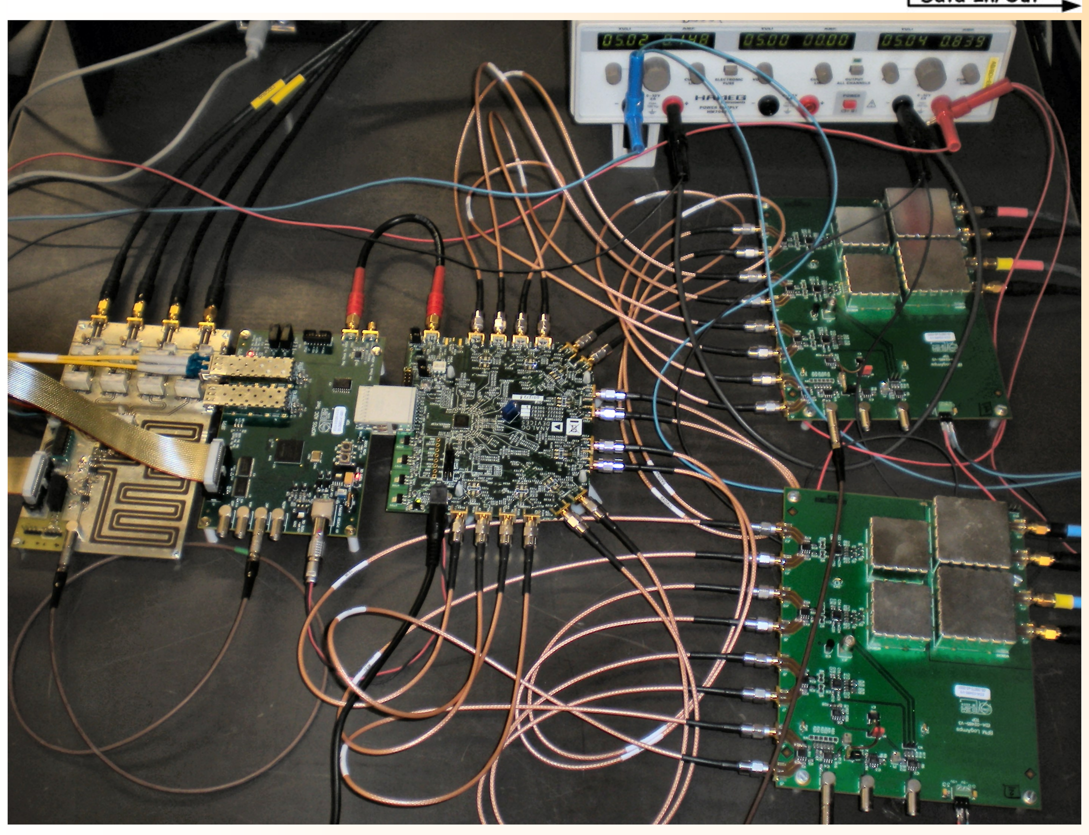
MOPOS Front-End Architecture



An impedance matching adapter with low-pass filtering is connected directly to each pick-up electrode to limit the bandwidth of the BPM signal. A beam-based calibrator with further low-pass filtering is then used to deliver suitable signals to the Front-End chassis for centred-beam calibration. The Front-End chassis, which sits in the tunnel, contains two Log-Amp boards, a Diode Detector for even more accurate orbit measurements and the acquisition board that serializes the data prior to transmitting the optical signals to a VME acquisition system located in surface buildings.

MOPOS Front-End Prototype



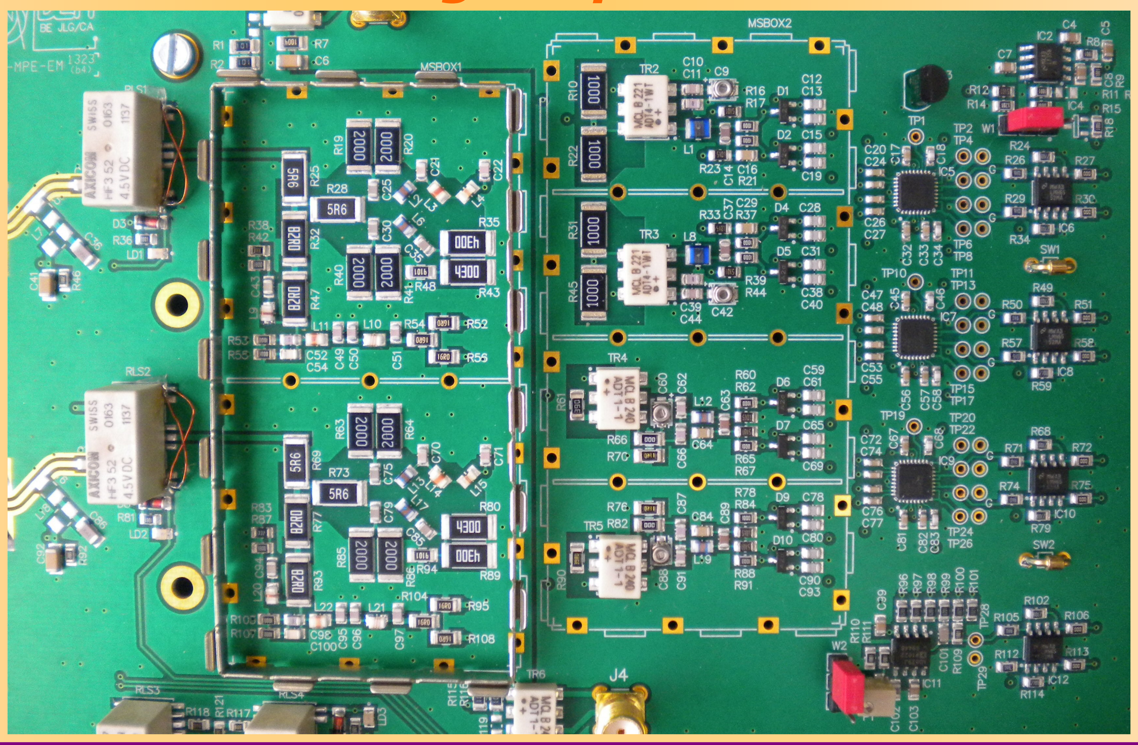


The Front-End test setup consists of two Log-Amp boards, a commercial octal 14-bit-ADC evaluation board, an FPGA-based acquisition board equipped with Small Form-Factor (SFP) optical transceivers, and a calibrator circuit. The calibrator is used to generate beam-like patterns that simulate known position values.

During the tests in the CERN-SPS, the Log-Amps are connected to both a stripline and a shoe-box BPM to measure the horizontal and vertical beam positions respectively.

The analogue signals are then digitized at 10 MSa/s and the resulting data are packed into a frame that is sent to a VME acquisition system via the optical link.

Log-Amp Board



SPS Beams

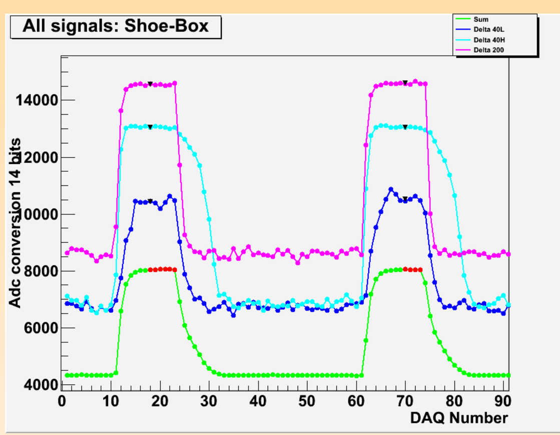
Beam Type	Bunch spacing	Bunch number	Bunch charge $[10^{10}]$	Bunch length $[4\sigma$, ns]
FT / CNGS	5 ns	400-4000	0.1-2	1-4
LHC25NS	24.96 ns	$N_{bat} \times 72$	1-50	1-4
LHC50NS	49.92 ns	$N_{bat} \times 36$	1-50	1-4
LHC75NS	74.88 ns	$N_{bat} \times 24$	1-50	1-4
LHC single bunch	524.4-2022.6 ns	1-16	0.2-50	1-4
LHC ion / Pb82+	100 ns	$N_{bat} \times 4$	0.01-2	1-4

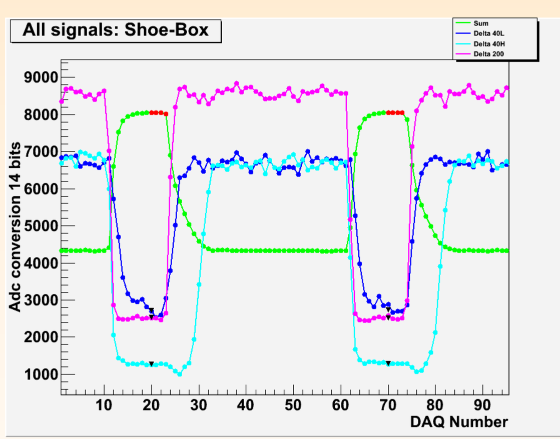
The new MOPOS system needs to measure the multi-batch structure of the SPS beams with a resolution of 0.1 mm in orbit mode and 0.4 mm in trajectory mode. Bunch intensities range from 1×10^{9} to 5×10^{11} for proton beams and from 1×10^{8} to 2×10^{10} for lead-ion beams. Bunch spacing can extend from 5 ns up to 23 µs. The nominal number of batches N_{bat} can vary between 1 and 4 for protons and up to 13 for ion-beams.

First Beam Measurements

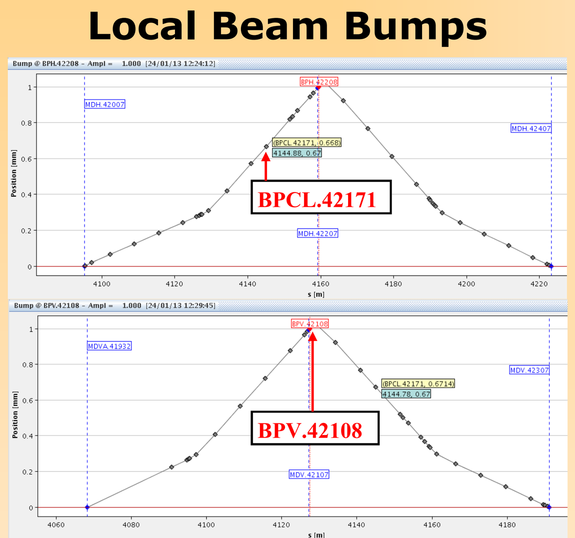
Calibration

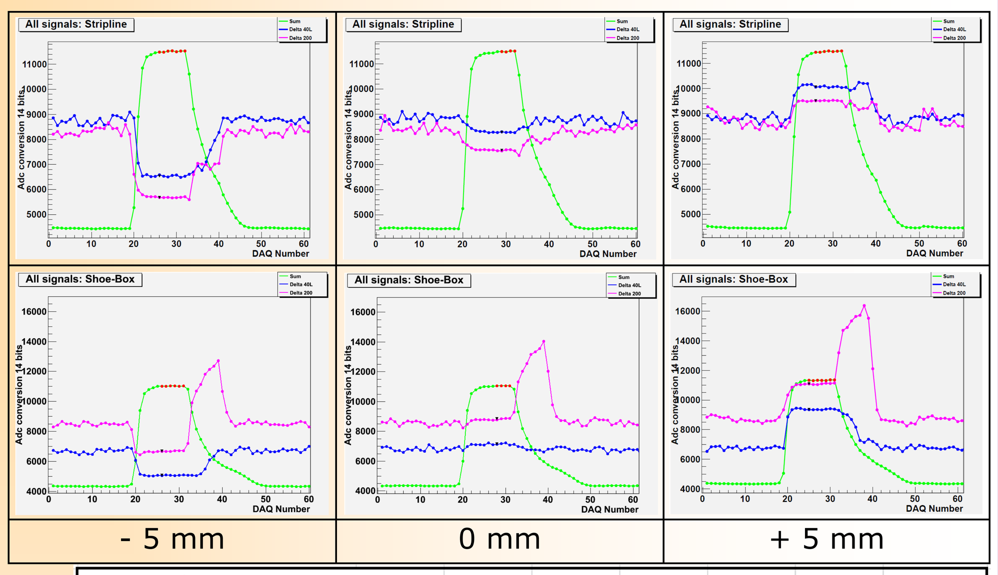
Log-Amps are calibrated using beam-like pulse patterns (36 pulses with 25 ns spacing) and accurate attenuators (±6 dB, on these acquisitions).





Local Beam Bumps





- 5 mm | 0 mm | + 5 mm

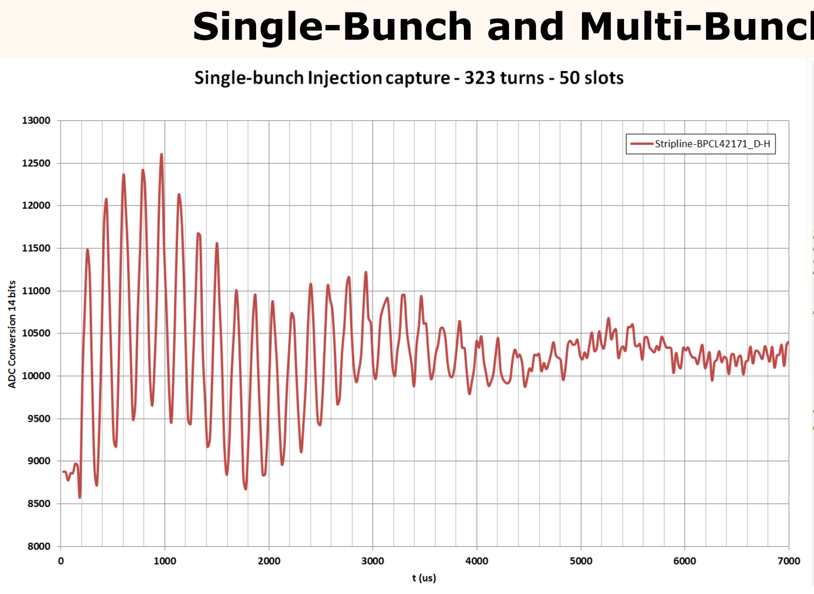
To characterize the sensitivity of the system, magnetic correctors are used to generate local beam displacements of ±1 mm up to ±5 mm in the vicinity of selected BPMs. These results show that the sensitivity is about 1.7µm/bin for the stripline BPM and 2.5µm/bin for the shoe-box BPM.

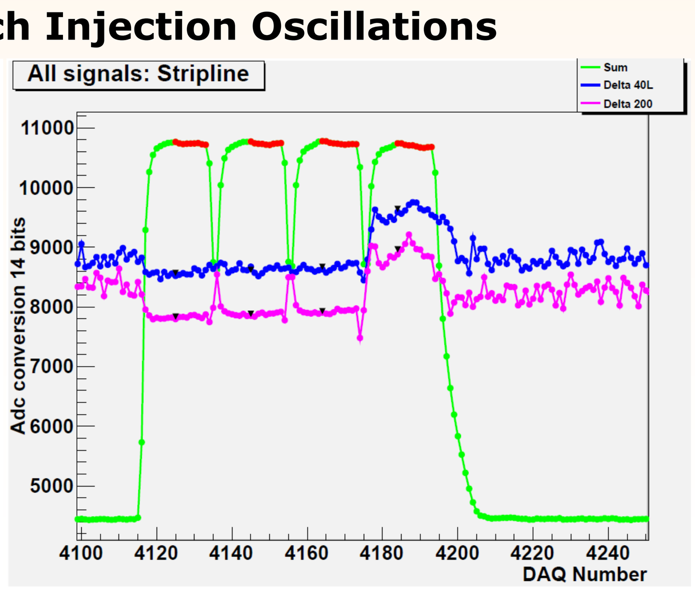
TestHCA4/LogBumpProtonSb.csv							
H [Stripline]; V [Shoe-box]							
	-5mm	-2.5mm	-1mm	+1mm	+2.5mm	+5mm	AVG
Sensitivity um/bin H	1.8	1.7	1.8	2.0	1.7	1.8	1.8
Sensitivity um/bin V	2.3	2.5	2.6	2.6	2.4	2.4	2.5

TestHCA4/LogBumpProtonMb48_25_selected.csv							
H [Stripline]; V [Shoe-box]							
	-5mm	-2.5mm	-1mm	+1mm	+2.5mm	+5mm	AVG
Sensitivity um/bin H 40L	1.9	1.9	1.5	1.7	2.1	1.8	1.8
Sensitivity um/bin H 200	1.8	1.7	1.4	1.6	1.9	1.7	1.7
Sensitivity um/bin V 40L	2.3	2.4	2.6	2.6	2.2	2.3	2.4
Sensitivity um/bin V 200	2.2	2.3	2.6	2.4	2.1	2.2	2.3

The estimated resolution (limited by noise and beam position jitter) is about 375 µm in trajectory mode and 80 µm in orbit mode, which agrees with the specifications. Some optimization is still needed to improve the sensitivity on the 40MHz High-Sensitivity channel for low charge beams.

Single-Bunch and Multi-Bunch Injection Oscillations





Proton beam injections were measured during consecutive turns on a single bunch (left) and during the injection of the fourth batch (right), which is off-centre. The LHC multi-bunch beam consisted of 36 bunches per batch with 50 ns bunch-spacing and 1.4×10^{11} protons/bunch.

A pre-series needs to be installed in 2014.

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