TURN-BY-TURN POSITION MEASUREMENTS AT CNAO WITH THE LIBERA SPARK HR PROTOTYPE

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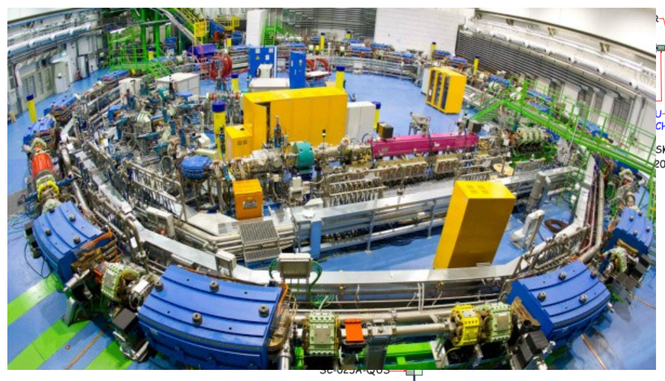
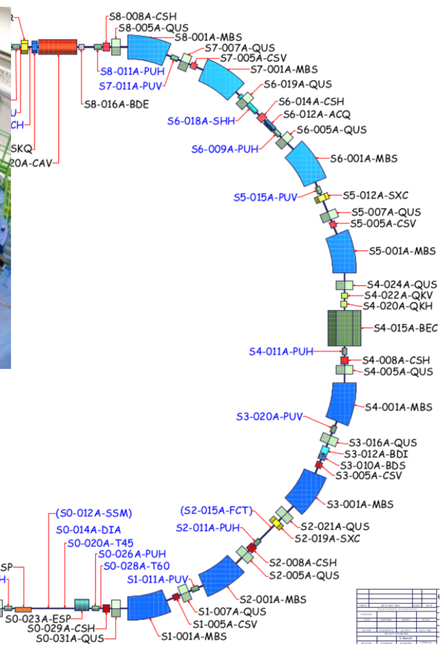




CNAO in Pavia is one of the first centers for hadron therapy in Europe, treating patients since 2011. The center is an international reference for a whole new concept of machines being constructed for this purpose. The existing synchrotron BPM electronics is based on analog boards that compute the ratio between difference and sum signals from the shoebox pickup, later acquired by digital cards. Although the system operates reliably, it just calculates the position with 1 kHz rate.

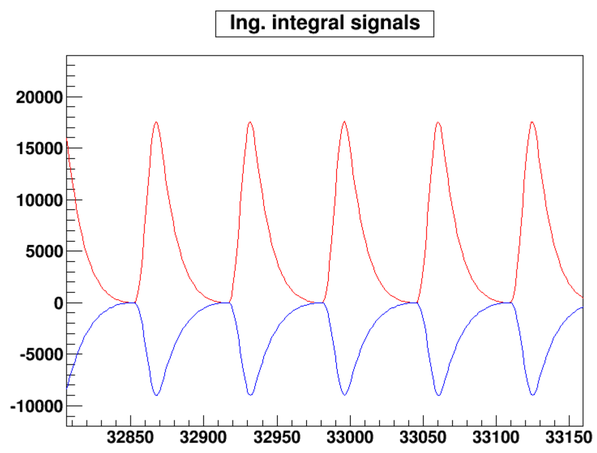
	Spark
Dimensions (H x W x D) mm	44 x 210 x 210
A/D conversion	125 MHz /14 bit
FPGA / CPU	Zynq-7020, ARM Cortex-A9
Cooling	Passive
Power supply	PoE
Input gain / attenuation	Programmable, 31 dB
Temperature stability	0.3 micrometer / °C
Long term stability [8 h]	< 2 micrometer (kx = ky = 100 mm)
Data processing	bunch-by-bunch

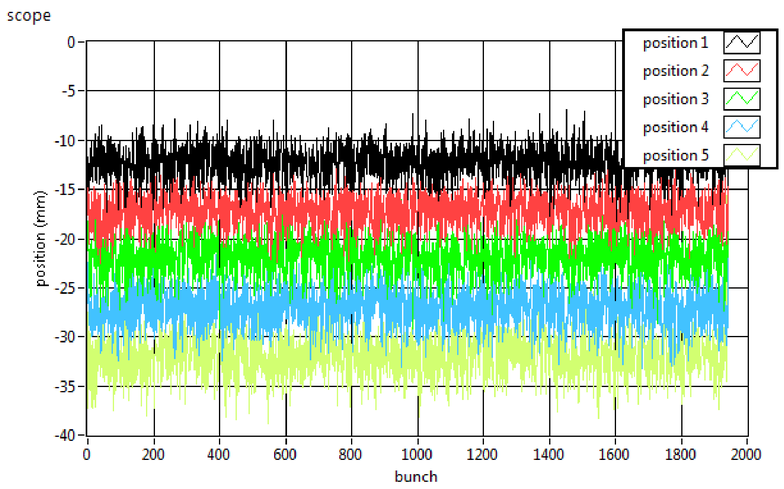
The goal of the Libera Spark HR prototype is to provide position and charge information from the circular hadron machines with bunch-by-bunch rate. The specific characteristics of the hadron synchrotrons such as variable RF frequency, bunch length and signal intensity, require the RF front-end to offer a linear frequency response. This is achieved with a carefully designed low pass filter with 35 MHz bandwidth, based on the solution developed for Libera Hadron and implemented in the prototype.

Data analysis with CNAO offline algorithm

Data from Libera and CNAO front end was analyzed with this algorithm.

- The integral signals (corresponding to the bunch charges) are calculated integrating the Sigma and Delta signals separately.
- The data from each bunch is isolated
- The offset subtraction is applied to the signals.
- For each bunch the integral of Sigma and Delta, proportional to the beam charge, are computed using a fixed threshold
- The ratio between Delta and Sigma is multiplied by the mechanical sensitivity in to calculate the beam position





Results

Position measurement

Set beam position [mm]	CNAO front end CNAO DSP [mm]	Libera Spark HR CNAO DSP [mm]	Libera Spark HR Libera DSP [mm]
- 35	-32.91	-31.66	-29.06
- 30	-27.79	-26.81	-24.68
- 25	-22.52	-22.02	-20.31
- 20	-17.63	-17.49	-16.37
- 15	-12.5	-12.62	-11.67

Standard deviation

Set beam position [mm]	CNAO front end CNAO DSP [mm]	Libera Spark HR CNAO DSP [mm]	Libera Spark HR Libera DSP [mm]
- 35	2.21	0.24	0.14
- 30	2.18	0.23	0.10
- 25	1.99	0.21	0.12
- 20	1.79	0.22	0.11
- 15	1.79	0.19	0.08

** Positions achieved with Spark HR and CNAO front end are slightly different. This could be due to the signal splitting and not equal cables used for connecting both devices. The reconstructed position after rescaling is equal.

** Standard deviation of the Libera reconstructed position is better than the CNAO one. This can be explained with the fact that Libera is “all in one” low noise system, avoiding the long cables between the front end and the back end electronics what is the case of CNAO front end.

** Signal level provided to the Spark HR instrument was very low (1/10 of full scale).

** Minor discrepancies in slope linearity were found when comparing CNAO algorithm and Libera algorithm results. Further studies will be needed in order to understand these phenomena.

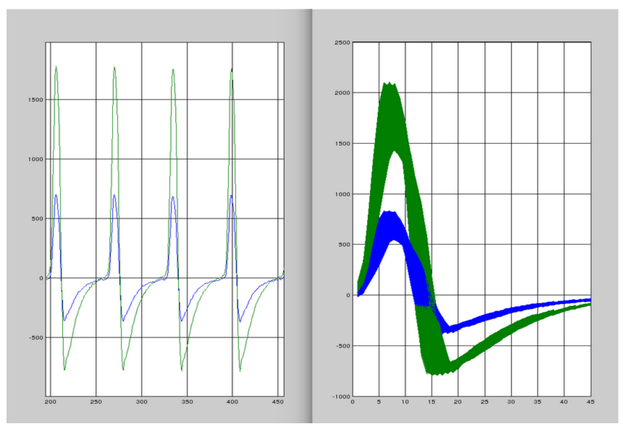
Data analysis with Libera bunch-by-bunch online algorithm

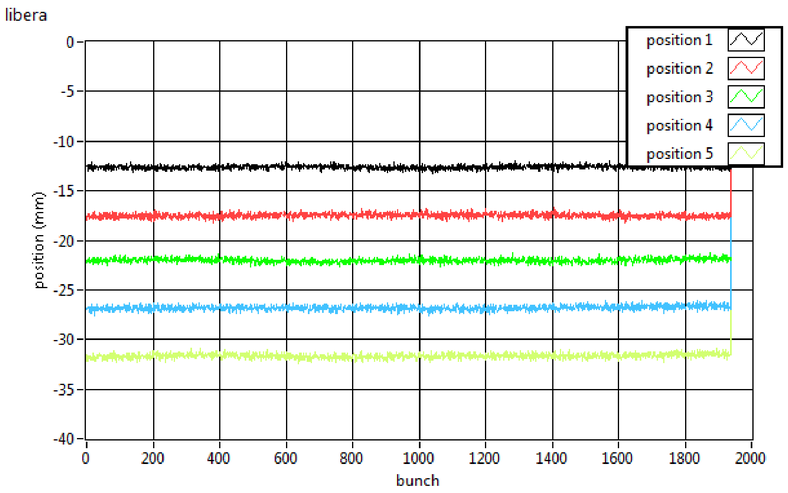
The output of the CNAO front end is delta and sigma signals, while Libera Spark processes directly signals from the pickups. Only data from Libera was analyzed here

- From the ADC data from individual channels, the samples belonging to individual bunches are identified.
- For each channel and for each bunch, the amplitude is calculated with sum-of-squares formula

$$V_A = \sqrt{\sum_{PROC\ WIN.\ START}^{PROC\ WIN.\ END} A^2} \qquad V_C = \sqrt{\sum_{PROC\ WIN.\ START}^{PROC\ WIN.\ END} C^2}$$

$$X = K_X \frac{(V_A' - V_C')}{(V_A' + V_C')} + X_{OFFSET}$$





The idea of using Libera Spark as a BPM readout system for hadron therapy machines has been confirmed. The tests at CNAO provided clean results with a turn-by-turn beam position resolution of hundred micrometers, with still some margin for improvement.

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