Development of a front-end electronics for an innovative monitor chamber for high-intensity charged particle beams

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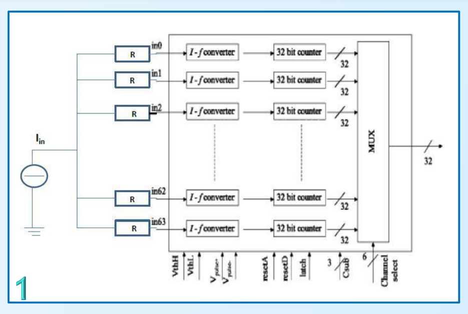
Introduction

A multi-gap ionization monitor chamber has been developed by INFN and Torino University, for monitoring of high intensity pulsed charged particle beams. The read-out of the chamber is based on a 64-channel ASIC, designed in CMOS 0.35µm technology which features for each channel an independent current-to-frequency converter followed by a synchronous counter. The chip was designed for connecting each channel to a different detector element. However, high beam intensities may lead to an input current above the saturation level of a single channel. A novel readout has been tested where all the input channels of the chip have been connected in parallel to the same detector element allowing to reach 64-times higher input current, with only a modest deterioration of the resolution.

Materials and Methods

The chip (TERA 08) to read-out the current is a 64-channel ASIC designed in CMOS 0.35µm and consists for each channel in a current-to-frequency converter followed by a counter (Fig 1, black part on the right), the maximum frequency of the converter being 20MHz. It can measure inputs of both polarities, having 32 bit synchronous counters with up/down counting capability [1]. The converter of each channel is based on the recycling integrator principle.

In order to measure high intensity beams the chip was set with a quantum charge Qc = 200fC. Considering the maximum acquisition frequency of ν_{max} = 20MHz, a single channel saturates at $I_{sat} = Q_c \times \nu_{max} = \pm 4\mu A$ and with this configuration it is expected that the maximum input current would increase up to 64-time before saturation occurs. Each channel is connected to the common input using a series resistance R = 10MΩ, to equalize the independence of all the channels (Fig 1, in blue).



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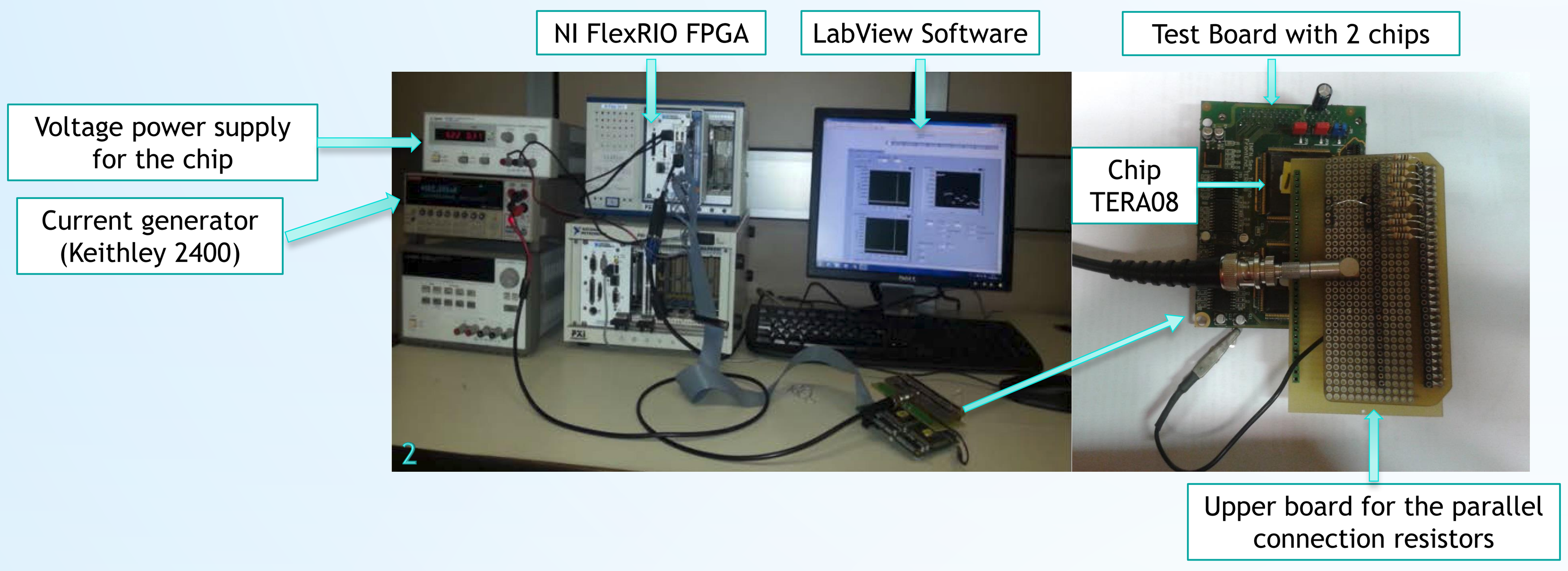

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The experimental setup which has been used to characterize the chip with this arrangement for the input is based on a NI FlexRIO FPGA module DAQ card [2] and on a LabView software [3].

For most of the tests, to inject a constant current I_{in}, into a given channel, a Keithley 2400 in current generator configuration was used. The current generator was connected with a coaxial cable to an upper board mounted above the test board. This upper board allows to connect in parallel the channels of the chip, each with its own input resistor. A small ripple was observed in the current produced by the Keithley 2400; for the determination of the uncertainty of the measurements, a more stable current provided by a battery was used.

Results

Linearity

The linearity of the pulse frequency as a function of the input current for different number of channels connected in parallel is shown in Fig 3. The input current saturation limit increases as the number of channel N. The full range of ±256µA is reached for N = 64.

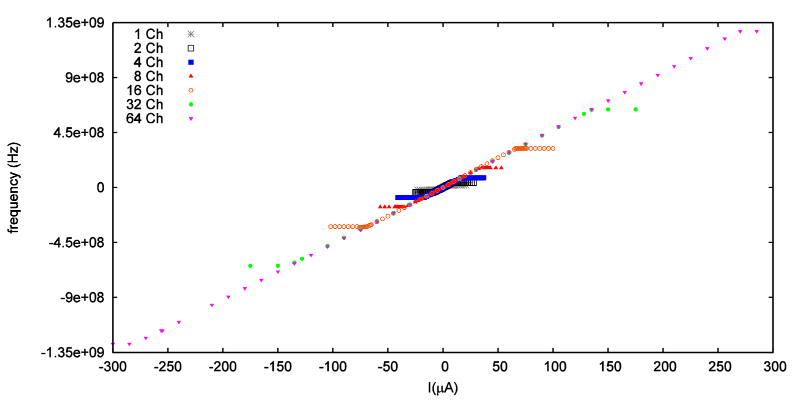

Fig 3. Linearity of the pulse frequency as a function of the input current for different number of channels connected in parallel.

The relative deviation from linearity as a function of the input current is shown Fig 4. The deviation is limited to ±0.6% in the range between 15µA to 256µA and to ± 1% in the range between 5nA to 256µA, which is considered quite acceptable for the application in radiotherapy.

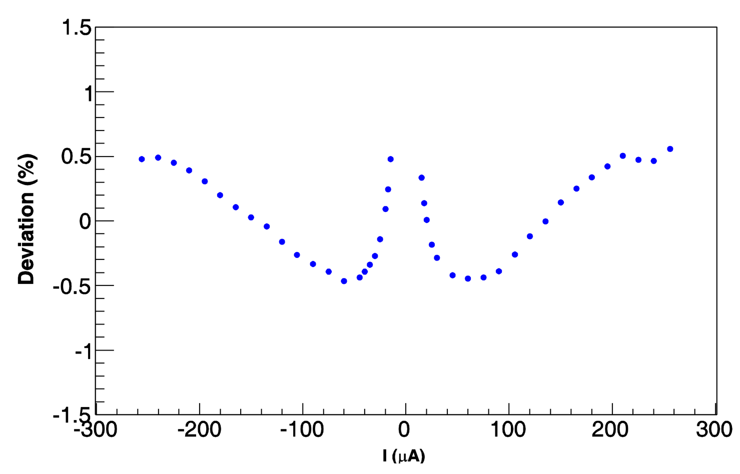

Fig 4. Relative deviation form linearity as a function of the input current.

Resolution

To study the resolution, we determined the average value of the input current and its standard deviation for a time interval acquisition of 1ms. The measurements were performed as a function of the number of the channels connected in parallel.

Assuming that the counting rate of one channel, at a fixed input current, is not statistically correlated with the counting rate of the other channels, it is expected that the dependence of the standard deviation of the total number of counts on the number of channels equals to $\sigma = \sigma_{1ch} \times \sqrt{N_{ch}}$, where σ_{1ch} it is expected to be about half a count. In order to test this assumption, a simple simulation of the behavior of the readout was developed to predict the statistical fluctuation in the number of counts for a given time interval as a function of the number of channels bounded together.

Then we verified this predicted behavior by measuring the standard deviation with the test setup.

The comparison between the simulation and the measurement is shown below:

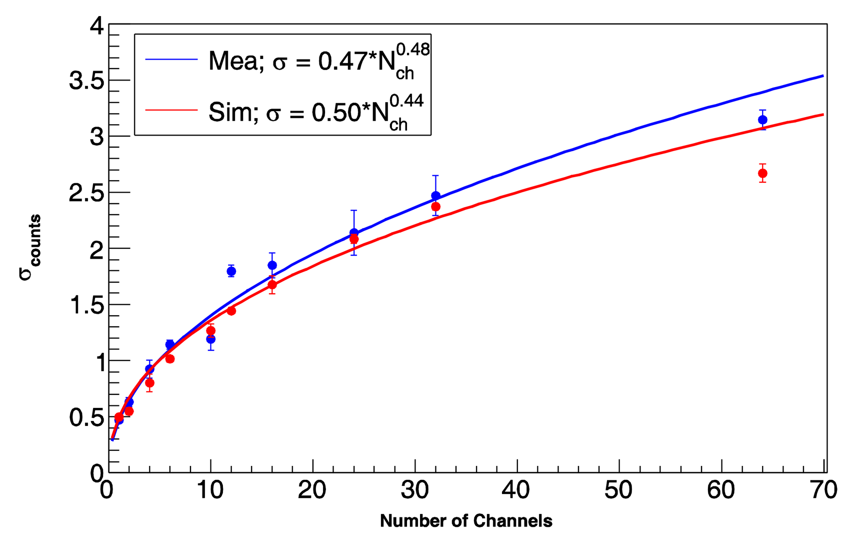

Fig 5. Simulation (red) and measurement (blue) of the standard deviation of the total counts depending on the number of channels.

Rest Distribution

The distribution of the rest of the ratio between the total number of counts and an integer number allows to verify that the contribution of each channel to the total number counts is uncorrelated with the contribution of the other channels. If each channel counts independently, the rest of the division by N of the number of counts, obtained after any given data acquisition time, will be an integer number between 0 and N-1 with a uniform probability distribution. On the other hand, if there are some recurring structures in the rest distribution, it means that some channels are correlated.

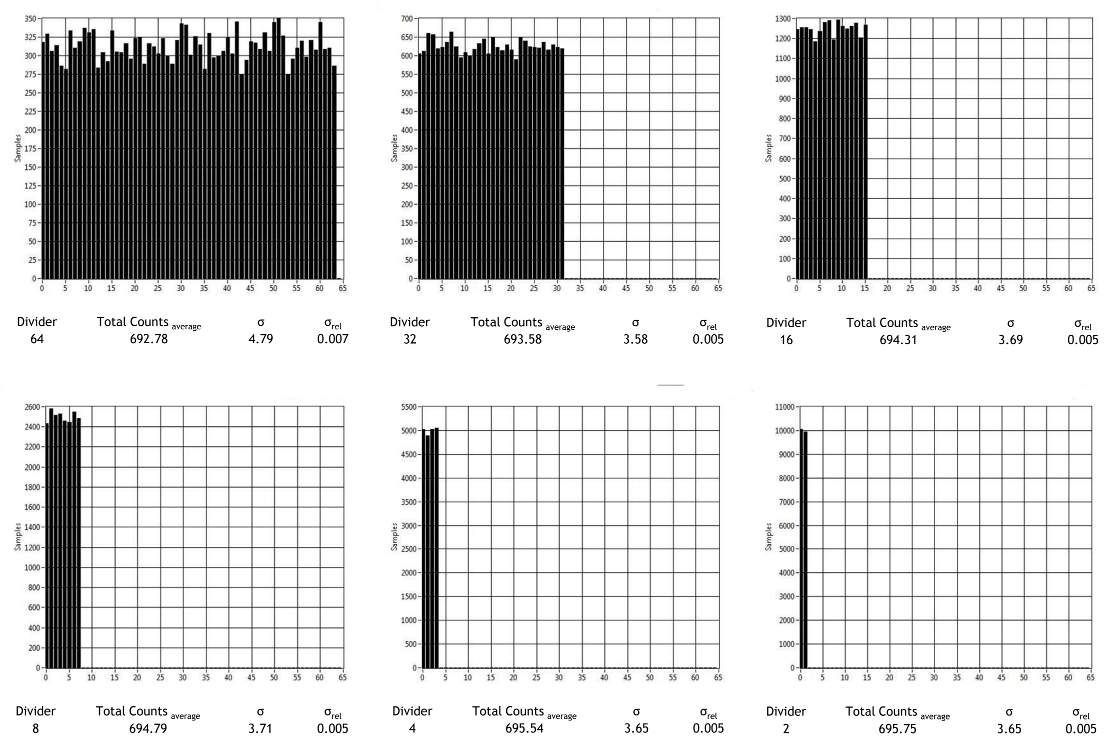

Fig 6. Rest distribution of the number of counts divided by 64,32,16,8,4,and 2.

It can be seen from the histograms that the rest distribution does not indicate structures with higher probabilities than others, suggesting that no correlation occurs in the readout between channels.

Conclusions

Evolvements of the accelerators for radiotherapeutic treatments with charged particles call for an increase of the accepted input current of the front-end electronics.

The behavior of an integrated 64-channel device in CMOS 0.35µm technology developed by INFN and Torino University was characterized with the parallel connection of the channels in order to overcome the problem of current saturation in high intensity regime.

The measurements of the linearity of current-to-frequency of counts conversion shows a good linearity in range up to ±250µA, when all 64 channels are connected to the same input.

The resolution of the readout was compared to the results of a Monte Carlo model that assumes that all the channels are behaving independently; a very good agreement was found.

The increase of the uncertainty is however limited and the linearity over the increased range is found to be within 1%, that is considered acceptable for the application in radiotherapy.

References

[1] A. La Rosa, et al., Nuclear Instruments and Methods in Physics Research. A 583 (2007) 461-468.

[2]http://www.ni.com/pdf/manuals/373047b.pdf.

[3]http://www.ni.com/labview/.