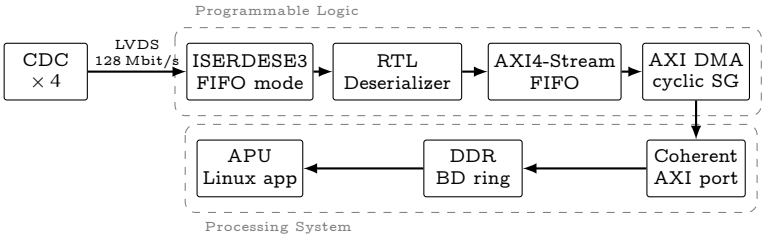
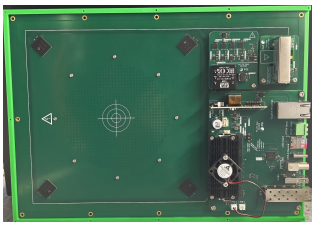
Pixelated Ionization Chamber for PIF

At the Proton Irradiation Facility (PIF) at PSI, the proton beam is characterized with a pixelated ionization chamber of 933 pixels. This work implements the FPGA readout of its four 256-channel current-to-digital converters, the transfer of the data into the processor, and validates the detector in the beam.



Readout chain from the converter to the processor



Assembled detector with the four converters

FPGA Readout

Each of the four 256-channel current-to-digital converters (CDC) sends its samples over a source-synchronous LVDS link at 128 Mbit/s with a phase-shifted copy of the clock. The deserializer uses the ISERDESE3 primitive in FIFO mode and captures each converter on the clock it forwards with its data, so that no clock inside the FPGA has to be phase-aligned. Its built-in FIFO crosses into a common 128 MHz readout clock, which also makes the four converters synchronous. As this clocking lies outside the characterized configuration, it was verified in simulation, in timing analysis and on hardware. For validation, the converters can send a known ramp pattern that tests the whole chain.

FPGA to Processor

The frames must reach the processor without occupying it. Each readout block therefore carries its own AXI4-Stream FIFO and AXI DMA, so that a further converter only means another instance. The DMA runs in cyclic scatter-gather mode over a ring of four descriptors and writes the frames without per-frame software interaction. It writes over a high-performance cache-coherent port, so that the driver needs no cache maintenance. The processor time left free carries the digital integration of up to 10 s and the website with the live pixel map, the beam analysis and the detector configuration.

Readout Results

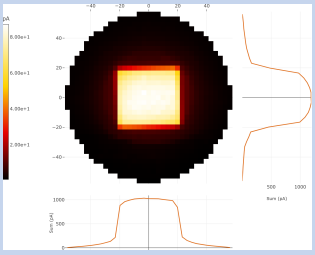
The application loads one processor core by 3.26 %, whereas the same readout with a polled stream FIFO saturated a full core. The design occupies 36 % of the LUTs of the xczu2cg device and closes timing with 1.165 ns of positive slack. Under 10 krad of proton irradiation at 200 MeV, with the converters driven by the ramp pattern, no wrong bit was received in 38 Mbit of transmitted data, no packet was lost and three redundant deserializers never disagreed.

Detector Results

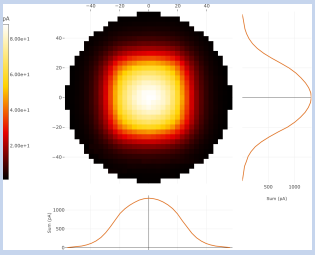
The response is proportional to the beam current from 0.1 nA to 10 nA, with fitted power-law exponents between 0.988 and 1.003, and the crosstalk to neighboring pixels stays below 2 ppm. Seven acquisitions of the same beam reproduce the fitted profile width to 0.07 % and the centroid to 0.05 mm, 1.5 % of the 3.175 mm pixel pitch. The detector is validated in the proton beam and ready for operation at the PIF.

Measured Beam Profiles

Behind a 4 × 4 cm collimator the aperture is imaged as a top-hat at 200 MeV, while at 50 MeV multiple Coulomb scattering blurs it into a Gaussian:



200 MeV



50 MeV

Project Team:
Melvin Deubelbeiss

Client:
Paul Scherrer Institut, Villigen

Coach:
Prof. Dr. Mathieu Coustans

Repository:
`https://gitea.psi.ch/deubelbeiss_m/PIC_PIF`