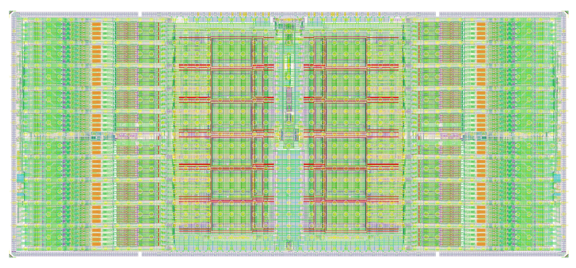
H2GCROC: Design and Performance of a Dedicated Very Front-End ASIC for SiPM readout of the CMS High Granularity Calorimeter.

J. D. González-Martínez & CMS Collaboration

OMEGA Microelectronics - Ecole Polytechnique - CNRS

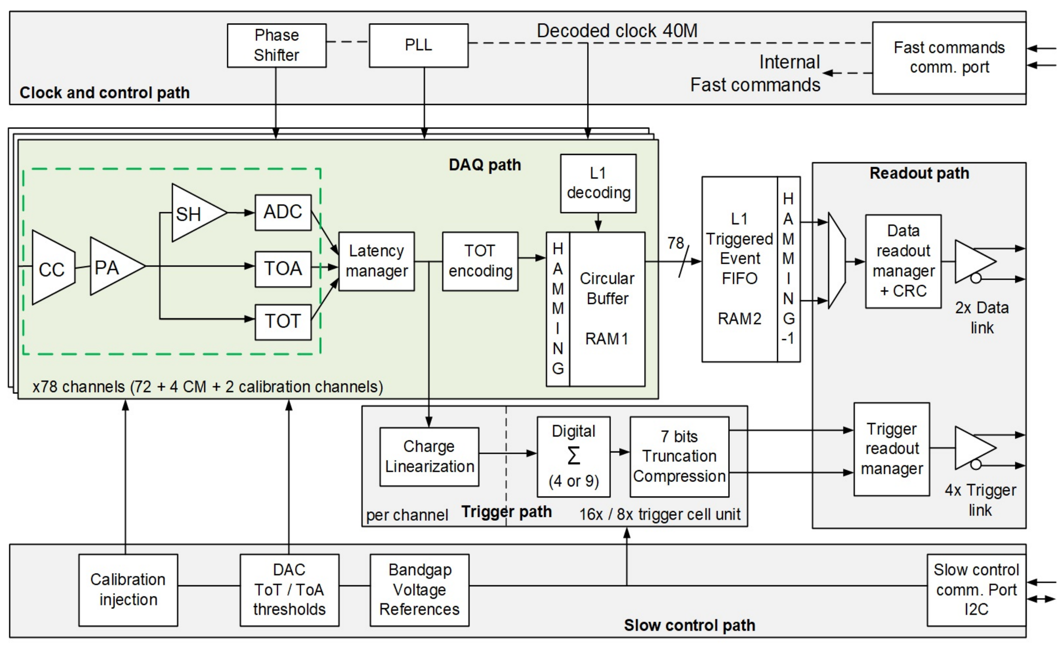
Abstract

The HGCROC ASICs are dedicated very front-end electronics designed to read out the High Granularity Calorimeter (HGCAL), which will replace the present end-cap calorimeters of the Large Hadron Collider (LHC) for the Compact Muon Solenoid collaboration (CMS). The H2GCROC ASIC was especially designed to readout the SiPMs coupled to the scintillating tiles of the back hadronic sections, where the radiation constraints are less severe. Inside the chip, the front-end preamplifier is adapted for the SiPM's higher signal level, expecting pC/MIP rather than fC/MIP ranges. The chip was received end of 2020 and extensively tested since then, in the lab and test beam. This work examines the very front-end design and performance, including timing performance with the sensor.



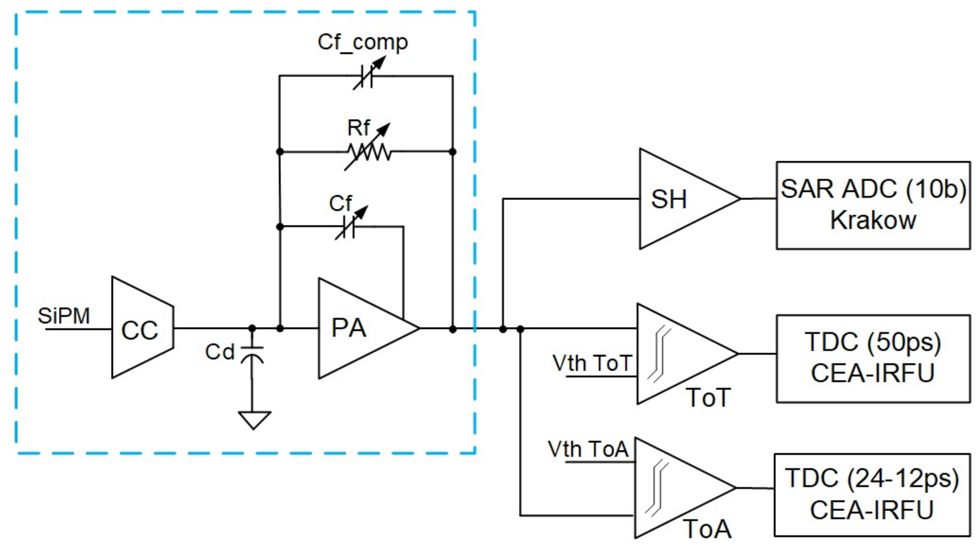
H2GCROCv3 layout design.

H2GCROC Architecture



- Radiation-hardened TSMC 130nm CMOS chip.
- 72 reading out standard cells, 2 channels for MIP calibration, and 4 channels not connected for common-mode noise estimation
- DAQ path: Circular buffer RAM, store ADC, ToT and ToA data.
- Trigger path. Sum of 4(9) channels, linearization, compression over 7 bits.
- I2C protocol for slow control.
- Fast commands. 320 MHz clock and 40 MHz extracted.

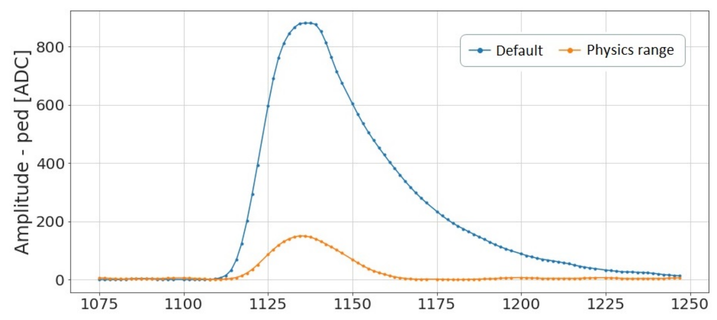
General Front-end architecture of one channel of H2GCROC

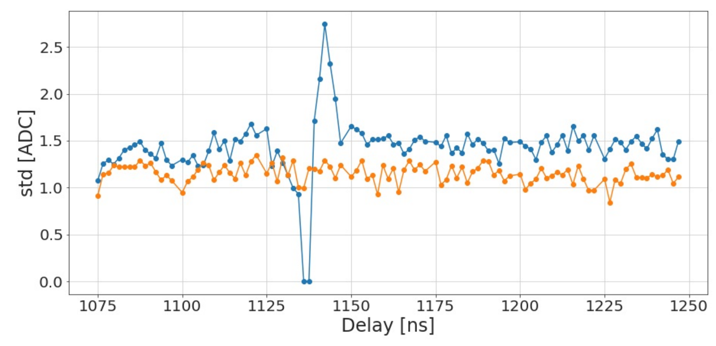


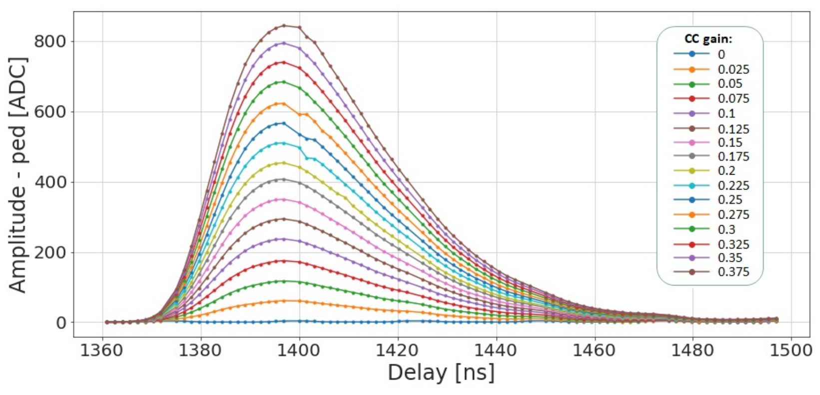
- Current conveyor (CC) attenuation from 0.025 to 0.325.
- Preamplifier (PA) gain configurable with R_f (11kΩ to 100kΩ) and C_f, C_{comp} (50fF to 750fF).
- Feedback capacitor split into C_f and Cf_{comp} to improve preamplifier stability.
- Charge information with time over threshold (ToT) over 200 ns and 50 ps resolution.
- Charge measurement range from 160fC to 320 pC.
- Time of Arrival (ToA) measurement with 25 ps resolution.

Amplification

- The preamplifier gain and output duration can be adapted to the MIP signal.
- The default configuration is good for single-photon measurement and for calibration.
- **Default configuration:** 6.8 fC per ADC count with around 1.5 ADC counts (10.2 fC) of noise.
- **Physics range:** 38 fC per ADC count with around 1.3 ADC counts (49.4 fC) of noise.

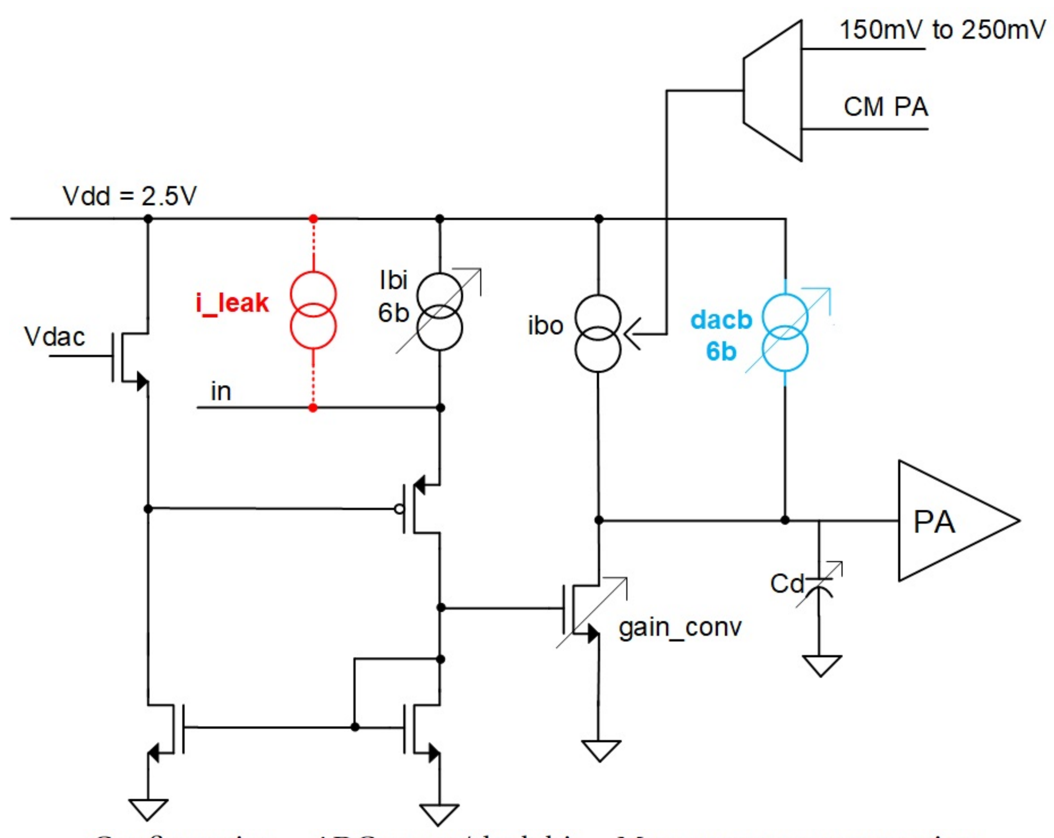






- The **Current Conveyor** applies a reduction in the current before the input preamplifier; its design is based on the input stage of the KLauS chip from Heidelberg University.
- The CC shows good linearity over the full range of attenuation.

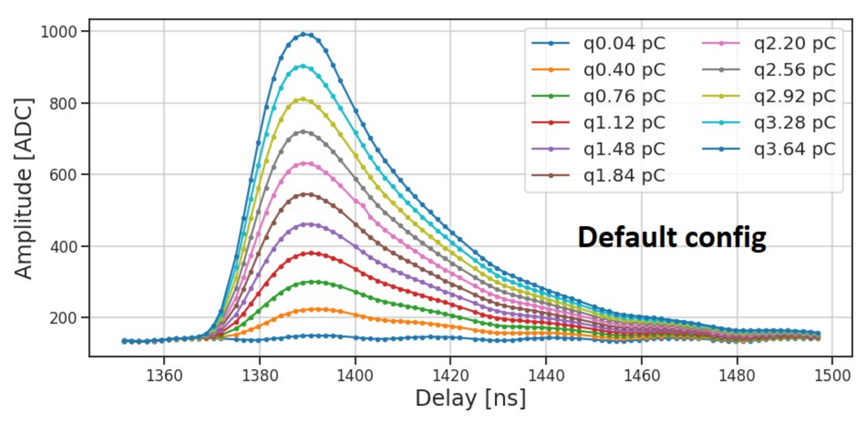
Leakage compensation and calibration

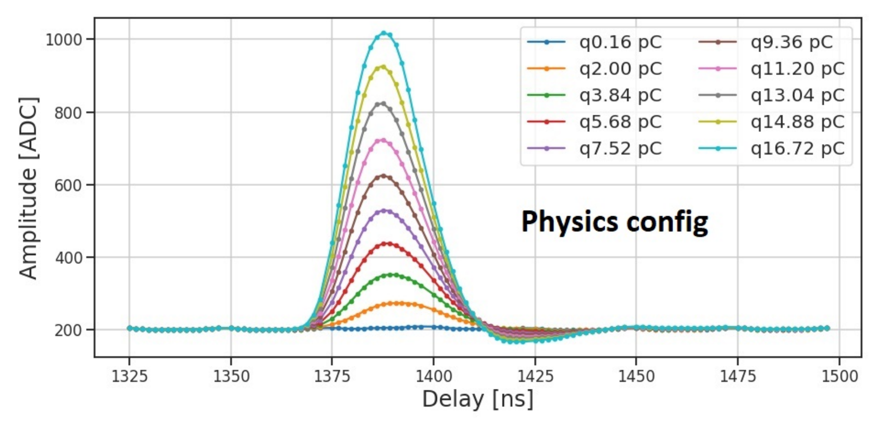


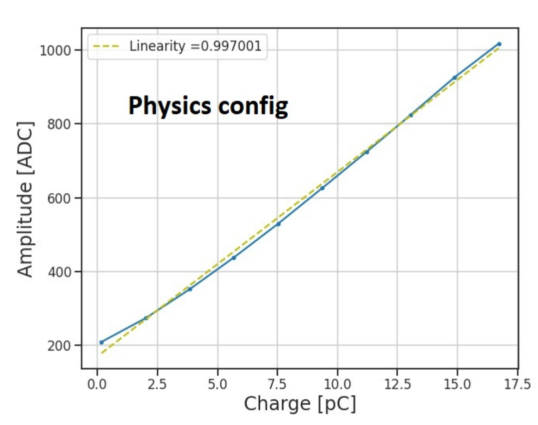
Configuration	ADC count/dacb bit	Max current compensation
3	17	290μA
2	43	700μA
1	72	1mA
0	87	1.2mA

- The CC has a tuning DC voltage at the input to compensate for breakdown voltage fluctuations on SiPMs due to temperature changes and production tolerances.
- The V_{dac} can be tuned in a small range to adjust the sensor gain and compensate between the channels.
- At the CC input, a calibration circuit can be used for internal or external injection on the ASIC.
- The internal injection uses a 12bit DAC going from 0 to 2.5 V and converting the signal into charge with two selectable capacitors (3 pF for low range and 120 pF for high range).
- C_d can be configured with 3 bits from 0 to 35 pC to add a capacitance that improves the linearity of ToT.
- The current injected by I_{bi} is automatically compensated by I_{bo}.
- Leakage currents (I_{leak}), produced by radiation, are expected to be up to 1mA.
- A 6bit DAC ($dacb$) can inject a current with a configuration variable of 2 bits to adapt the dynamic range to compensate I_{leak} as on the table.

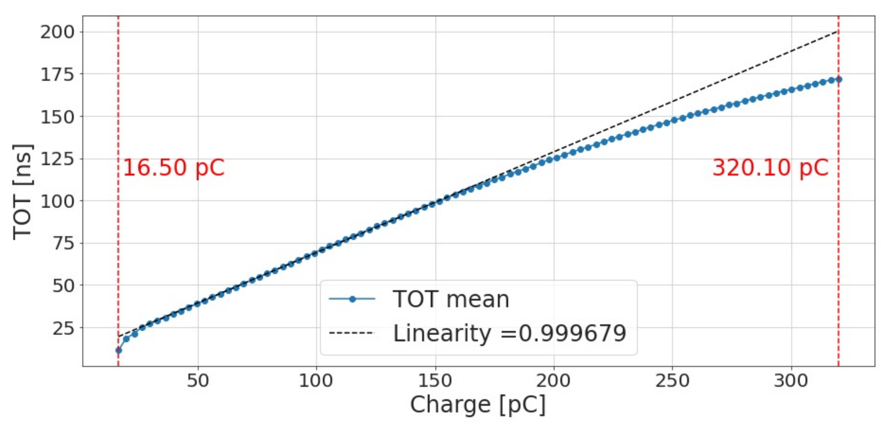
Charge Measurement





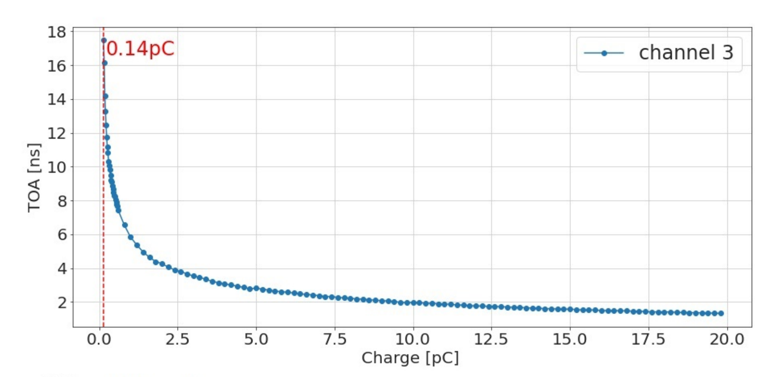


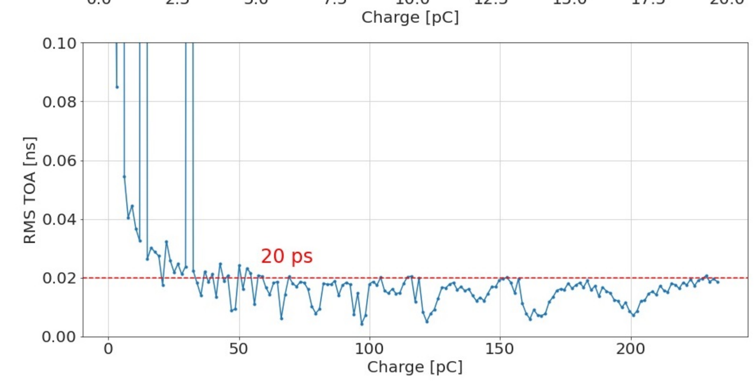
- The **ADC** measure the charge in the linear part of the PA.
- While ToT triggers, ADCm has the full data of the charge (next bunch crossing).
- ADC Linearity of 99.7 % from 160 fC to 20 pC range with Physics configuration.



- The **ToT** measure the charge from the saturation of the PA.
- The ToT value is proportional to the charge injected into the SiPM.
- ToT is measured by subtracting the ToT signal's falling edge minus the ToA signal's rising edge.
- ToT linearity of 99.9 % up to 200 pC and 99 % for the full range with Physics configuration.

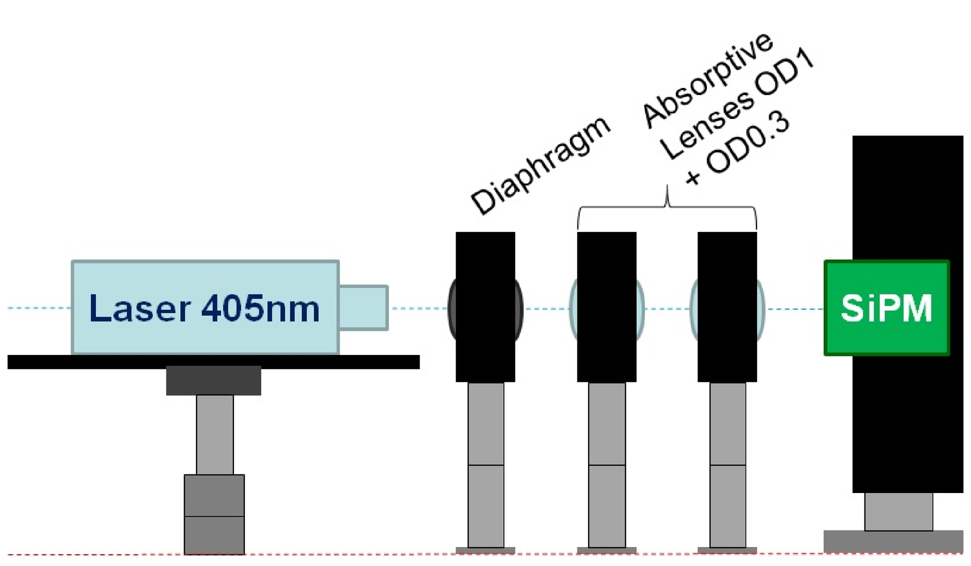
Time Measurement

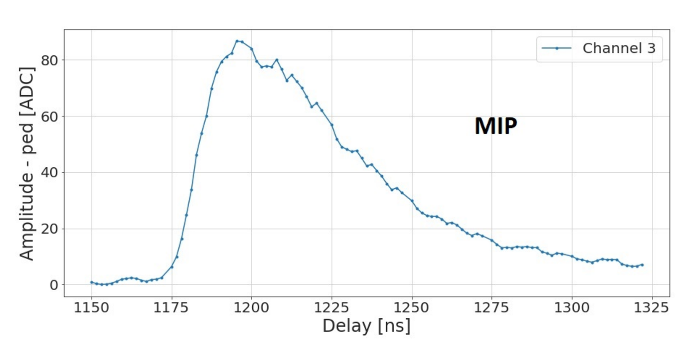


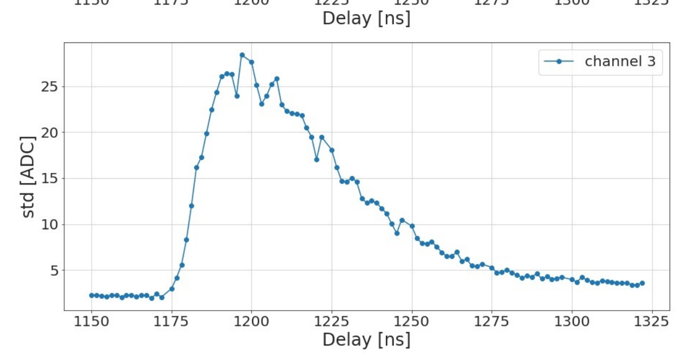


- **ToA** time walk of 16 ns from 0 to 20 pC charge injection.
- Noise of 40 ps measured for small charge injection.
- Noise of 20 ps arrives at 40 pC charge injection and up to 320 pC (full range).
- The two discriminators can be calibrated with two external trigger inputs available.
- Two global 10b-DACs adjust the discriminators' thresholds.
- Two local trimming 5b-DACs reduce the dispersion per channel.

Laser Measurements







- Laser PILAS Picosecond Pulsed diode PiL040-FS configured with a wavelength of 405 nm.
- Diaphragm and absorptive lenses to reduce the light injection to the SiPM.
- SiPM S14160-1315PS with an effective photosensitive area of 1.3x1.3 mm, a pixel pitch of 15 μm, and HV = 41.78 V (OV = 4 V).
- MIP signal injected equal to 15 p.e. (555 fC) using the default configuration of PA gain and minimum attenuation of CC gain.
- Single-photon pixels measured with default configuration and phase 13 selected.