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A Reconfigurable Monolithic Active Pixel Sensor for Digital Electromagnetic Calorimetry

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Here we describe the DECAL Monolithic Active Pixel Sensor (MAPS) for digital electromagnetic calorimetry. The sensor consists of a matrix of 64x64 55um pixels, and provides a readout at 40MHz of the number of particles which have struck the matrix in the preceding 25ns. It can be configured to report this as a total sum across the sensor (equivalent to the pad of an analogue calorimeter) or the sum per strip (equivalent to a traditional strip detector). Design and operation of the sensor is described, and the results of chip characterisation are reported and compared to simulations.

Summary

Calorimetry is an important technique for the determination of the energy of incident particles in a detector. A small fraction of electromagnetic calorimeters are silicon-based devices, with the largest example under construction [1], and use layers of a dense absorber material (such as iron or tungsten) interleaved with silicon as the detecting material. Particles incident on the absorber initiate showers of lower energy particles, which deposit energy in the detecting layers. The total charge deposited in each detector layer is then summed and read out. By performing this operation for each detector layer, the energy of the initial particle can be determined.

However, it has been suggested that a digital approach can lead to higher energy resolution [2]. In contrast to an analogue calorimeter, which counts the total deposited energy in a given volume, a digital electromagnetic calorimeter is segmented and counts the total number of particles passing through said volume.

Monolithic Active Pixel Sensors (MAPS) are well placed to be the technology of choice for such a detector, since they have the potential to offer good integration of the complex circuitry required for counting, good radiation tolerance, and low cost (thanks to the rapid commercial development of this technology).

In this talk, we will report details and results of the DECAL sensor –a MAPS device for digital electromagnetic calorimetry. DECAL was designed and fabricated in a 180nm commercial CMOS process. It has a matrix of 64x64 pixels with 55um resolution and can be read out at a rate of 40MHz using 16 LVDS channels. Each pixel contains a pre-amplifier, shaper and comparator, as well as trimming logic for individual threshold calibration of the pixels. To perform the digital calorimetry function, each column contains logic to calculate the total number of hits in a column, and the chip sums the hits from each column to provide the total number of hits across the chip. As a further feature, the chip can be reconfigured between "pad mode"in which it behaves as just described, and "strip mode". In "strip mode", the chip reports number of hits on a per column basis, behaving more like a traditional strip detector. This could allow standardisation of components between the calorimeter and tracker in a future detector, by using the same reconfigurable chip. To allow operation at the required 40MHz rate (equivalent to the bunch crossing time of the LHC), the operation of the chip is pipelined. Particle detection, column summation and chip summation each require 25ns and occur simultaneously for consecutive bunch crossings.

We will also report the results of chip characterisation, (functionality of the digital logic, analogue pixel performance and operation of the trimming circuitry). Digital operation is shown to be as expected, and measurements of the analogue performance are compared to SPICE simulations.

[1] M. Valentan, The CMS high granularity calorimeter for the high luminosity LHC, Nuclear Inst. and Methods in Physics Research, A (2019),https://doi.org/10.1016/j.nima.2018.10.131
[2] Dauncey, Paul. (2011). Performance of CMOS sensors for a digital electromagnetic calorimeter. 502. 10.22323/1.120.0502.

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