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Requirements/ideas/proposal for a future gas detector pixel readout device

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Abstract

The Timepix development is regarded as an important outcome of the EUDET project. This note explains the background to the development as well as its general context. The positive experience with Timpix leads to new ideas for future developments which might be better adapted to the requirements of the EUDET users and other particle physics applications. The options for such a development are outlined and the design choices and their implications briefly discussed.

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Background

Research into hybrid pixel detectors at CERN began in the late 1980's within the LAA project [1]. The RD19 project [2], which was formed in 1990/1, succeeded the LAA work and led soon to the creation of the Omega series of pixel readout chips which were used firstly in the form of a single chip telescope at the Omega experiment [3] then in the form of full pixel telescopes at WA97 (0.5M channels) [4] and NA57 (1M channels) [5]. A sub group of RD19 members modified one of the RD19 chips for use in the Delphi pixel detector [6]. RD19 was the first group to use sub-micron CMOS and radiation tolerant design techniques in a full pixel cell design in 0.5μm CMOS technology [7] and this work in turn led to the development of the Alice1 pixel detector readout chip [8] and the LHCb pixel-HPD readout chip [9], both of which were designed in 0.25μm CMOS. The Atlas and CMS pixel readout chips were developed independently of the CERN group, at first using the DMILL technology [10, 11] and then the same 0.25μm CMOS process [12, 13].

The Medipix1 chip [14] pioneered the use of hybrid pixel detector techniques in imaging applications and was directly derived from the RD19 Omega3/LHC1 chip. The Medipix2 chip [15] was quite separately funded from the LHC pixel chips but used much of the experience which had been accumulated during the development of the HEP chips at CERN. During this development the Medipix readout chips were bump bonded to widely available high resistivity Si and occasionally to more exotic sensor materials such as GaAs [16] and CdTe [17].

As a consequence of the success of the Medipix2 development a large number of systems became available in the collaborating institutes among which were CEA, Saclay and Nikhef. It was those institutes which pioneered the use of the Medipix2 pixel readout with gas gain grids [18]. A triple GEM foil was placed immediately above a bare Medipix2 die. The foil and die were placed in turn in a gas volume and first images were taken of single electron ionizations using cosmic rays and other particles. The Medipix2 chip counts the number of charge pulses which arrive at a pixel input while a shutter is opened and, since each ionized electron produces a large cluster of single hits at the output of the GEM foil, the image taken is composed of 'blobs' of 1's in a frame of mostly 0's. In the case of the micromegas foil the electrons produce more confined avalanches. However, again the single track images were composed of some 1's and many 0's.

It was the formation of the EUDET Collaboration in 2005 which permitted the work on Timepix [19] to begin. The Medipix2 chip was modified such that each hit pixel would count the number of clock ticks from the moment a pulse of charge hits the input bonding pad until the shutter closes. This development is a good example of a 'spin-off' activity such as Medipix 'spinning back' towards applications in physics.

In recent times the Medipix3 collaboration has been formed to develop a new imaging chip aimed at solving the issue of charge sharing in energy sensitive photon imaging. A successful prototype has been developed using a 0.13μm CMOS process and characterized [20]. This note suggests that a new 'spin back' possibility may be available and asks about the specifications for such a chip or chips.

Timepix

The Timepix chip is composed of a matrix of 256 x 256 identical pixels each of which has a preamplifier, comparator, synchronization logic and a counter with overflow logic. Each pixel has 4 threshold adjust bits which can be separately programmed to tune out the threshold dispersion. The minimum useable threshold is ~ 750 e^- and the threshold variation after tuning is around 35 e^- rms. The front-end noise is ~ 100 e^- rms. The counter counts up to 11180 at which point it stops to indicate overflow. The chip operates at a maximum frequency of 100MHz providing an arrival time resolution of 10ns. The synchronization logic permits individual pixels to be programmed into one of 3 useful modes: medipix mode where single incoming pulses are counted, Timepix mode where the number of clock ticks between the particle arrival and the shutter closing is counted and ToT mode where the number of clock ticks is counted as long as the comparator is above threshold. This latter mode provides a rough estimate of the energy deposited in a pixel. A full description of the chip is available in [19]

Although the chip performs to specifications it has a number of limitations when used in a physics experiment. Any charge which is shared between neighbouring pixels but falls below threshold is lost. In ToT mode the charge measurement is imprecise when the incoming charge is just above threshold. In ToT mode and especially in arrival time mode the counter depth effectively limits the useable dynamic range. There is no FAST-OR output and the chip is sensitive only after a shutter is opened preventing more conventional ways of triggered operation.

Medipix3

A fundamental limitation of energy resolving single photon counting results from several different physical processes that cause charge sharing between neighbouring pixels in the semiconductor detector. The most frequent case occurs when electron-hole pairs generated by photons which interact near to the boundaries of a pixel are diffused as they drift towards the collection electrodes. Hence the spectrum detected by a single pixel under uniform exposure is distorted by a long tail towards lower energies [20]. In the Medipix3 architecture each pixel preamplifier is connected to a shaper which generates 4 copies a current proportional to the incoming charge. Each current is sent to one corner of the pixel where it is added to the currents of its neighbours. The summed currents are fed to a comparator and neighbouring comparator outputs are connected to arbitration logic. The arbitration logic works such that every incoming charge is counted only once by the summing circuit with the highest total charge. Thus the pixel corners provide an output spectrum which does not have the charge sharing tail. A prototype chip consisting of 8 x 8 pixels has been designed and characterized extensively [20]. A full 256 x 256 chip is being designed at present.

GasSiPix or Timepix2

The Timepix development is recognised as an important achievement of the EUDET project. It has also attracted quite some interest outside of the project in the wider gas detector community. Also as experience is being accumulated in 0.13µm CMOS it seems reasonable to ask if a new development can be proposed aimed, like Timepix, more towards single event imaging (or detection) than Medipix3 which is aimed more towards imaging applications. The Timepix development was relatively fast and cheap because it reused almost all of the

Medipix2 building blocks. However, it has a rather limited number of uses in high energy physics because of the limitations mentioned above. The Timepix2, or GasSiPix chip could go further towards the needs of the physics users but at the expense of a longer development lead time. Below is a list of points for discussion with the eventual users.

ToT and arrival time in a pixel. The Timepix chip can measure one variable per pixel: number of hits, arrival time or ToT. It seems evident that the new chip should take advantage of the possibility of having both arrival time and energy measurements within the same pixel. It is not expected that the new chip will have a counting mode as the aim is to readout individual hits and/or tracks. It may, however, be interesting to have the possibility of recording a number of hits in a pixel.

Time precision and range. The depth of the arrival time counter should be determined as a function of the precision required and the expected readout time. The GOSSIPO 2 development from Nikhef [21] demonstrated that a kind of Vernier time measurement could be made by implementing a local oscillator in each pixel which is active only during the clock period when a pixel is hit. The performance of such a circuit in a large system and under widely varying fluxes remains to be studied however. The precision of the time measurement will be determined by the performance of this circuit as well as by the possibility of correcting timewalk with the energy information. Moreover the Medipix3 front-end has a rise time to 25ns and a shaping time of 100ns. A Timepix2 chip would have a continuous return to zero to enable a good ToT measurement. The required precision of the ToT is to be determined.

Semiconductor and gas compatibility. Like Timepix the new chip should be compatible with the readout of semiconductor detectors and gas detectors. There is a small penalty to pay in the complexity of the front-end in order to mitigate the effect of semiconductor detector leakage. However, this penalty is likely to be large offset by an increased user community with its attendant synergy debugging effort and readout hardware and software. It is proposed to include an extra device to reduce the sensitivity of the chip to spark induced breakdown for gas detector use.

Front-end performance. A trade-off has to be found between speed, power consumption and noise. In Medipix3 the preamp consumes 5µW for a rise time of 25ns and a noise of 72 e- rms.

Triggered readout. The new chip should have the possibility to be externally triggered or self triggered. A FAST-OR may be generated from the chip itself.

Readout architecture. The most flexible system is probably a data driven readout whereby hit pixels automatically initiate readout. However the exact choice of scheme remains to be determined.

Readout type/speed. The Medipix3 chip will be read out using between 1 and 8 fast LVDS lines. The 0.13µm process should allow > 250 MHz readout clock speed. It is proposed to use a similar scheme.

Tiling in 2 dimensions. The chip, like Medipix3, should be designed to be compatible with through wafer via technology to provide for minimum dead space in a large tiled array.

ILC compatibility. The JRA2 team are planning to study power pulsing of the Timepix chip. It would be reasonable to include any extra logic necessary to allow such an operating mode at ILC.

Conclusions

The Timepix chip is a clear example of the synergies which can be achieved between imaging applications and particle physics oriented developments. The EUDET community was able to benefit from the considerable investments made earlier by the Medipix2 collaboration in gaining the necessary design experience and providing readout hardware and software. The Medipix3 project is in full development. If another design such as Timepix is to evolve from Medipix3 it would seem prudent to start thinking now about answering the various questions about requirements raised in this note. The larger the number of groups who are able to share such a common development the greater is likely to be the benefit of pooling the very limited resources.

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