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## An innovative detection module concept for PET

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The design of a positron emission tomography (PET) detection module capable of working inside a magnetic resonant imaging (MRI) system is the main objective of the INFN 4D-MPET project. Simultaneous PET/MRI technology offers better soft tissue contrast and lower radiation doses by providing both functional and morphological information at the same time. The detector will be based on Silicon Photomultipliers (SiPM), which are magnetic field compatible, coupled to a single LYSO scintillator crystal in order to determine the x and y coordinates on the detector with high precision. An improved performance will be accomplished by measuring the Depth of Interaction (DOI) and evaluating the Time of Flight (TOF): the former information is used for decreasing the uncertainty of the z coordinate while the latter reduces the image background noise.

The SiPM detectors will be laid out on both the top and bottom large scintillator faces with respect to the incoming radiation. The two faces will feature identical and independent readout electronics for time and energy measurement. Each readout system will include four identical front-end (FE) mixed-mode ASIC's connected to the SiPM matrices, a cluster processor (CP) ASIC for data reduction and a laser driver/photodiode receiver/clock reconstruction (LD) ASIC for communication with the external data acquisition system through fibre-optics. All ASIC's will be mounted and wire-bonded without package and communicate each other through low voltage differential signalling (LVDS) pads for MRI interference reduction.

The front-end ASIC's will have multiple-channels each of them reading one SiPM output. Every channel will be made up of a preamplifier, a shaper, two discriminators for self-triggering and a time to digital converter (TDC) with a time over threshold (TOT) feature for energy evaluation. The first discriminator will have a fast response so as to trigger efficiently on single photo-electrons; it will provide the starting time information to the TDC/TOT block so as to measure a time which is very close to the interaction time in the scintillator. The second discriminator will provide event validation and TOT start/stop signals with a threshold which must be programmable between 3 and 10 photo-electrons. Such a double threshold technique is necessary to get a high resolution ( $\sigma_{LSB} = 100\text{ps}$ ) if the SiPM intrinsic background rate of around  $2\text{MHz/mm}^2$  is considered. If the event is valid then the conversion can be completed and the event is transmitted to the cluster processor. If, on the other hand, the high threshold is not reached within a given time window then the TDC must reset itself and wait for the next low threshold event. Moreover, simulations have shown that a better time resolution can be accomplished if the timing information from both crystal faces is used. Shaping is necessary to avoid challenging constraints on the stability and uniformity of the signal shape which must be used for the TOT measurement. Moreover, the tail-linearising filter implies a lower precision requirement on the trailing edge thus reducing the readout complexity.

The cluster processor task will consist in reducing the amount of data to be sent to the external acquisition system based on a clustering technique. Three different clustering levels with increasing complexity are under investigation: the first is the time-stamp clustering, where the cluster comprises all the channels with the same time-stamp. If the cluster energy is higher than a given threshold, all its data is transmitted. The second clustering level is based on both time-stamp and spatial distribution: in this case only one time value per cluster is transmitted; time-stamp and spatial clustering with centroid is the third clustering option where the data transmission is reduced to the cluster position coordinates (x, y, time and amplitude). Moreover, clustering will be used in the evaluation of the DOI by considering the asymmetry in the cluster size on the two crystal faces.

Finally, the LD ASIC will be used in order to minimize the number of communication devices to one optical input plus one optical output.

An active temperature control is required for the system so as to reduce the SiPM dark count and keep its heat dissipation as low as possible in order to avoid degradations in the electronics performance.  
Furthermore, two modes of operation will be implemented both for pre-clinical and clinical applications.

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