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Implementation of a Configurable FE-I4 Trigger Plane for the AIDA Telescope

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Abstract

To evaluate the performance of detector prototypes belonging to different sensor technologies, a fast read-out reference device (AIDA telescope) with excellent resolution and modular configuration is required. The successful development of a telescope with these characteristics was part of the EUDET project [1], currently continued within the framework of the AIDA activity [2]. The addition of a FE-I4-based reference plane to the existing telescope configuration allows the implementation of a user-defined region-of-interest trigger window, tunable to match the area defined by the device under test (DUT). Such a flexible setup is implemented and the proof of principle is demonstrated while operating a DEPFET pixel sensor as DUT in between the two telescope arms. The data acquisition for this small area DUT is shown to be improved in terms of trigger efficiency by more than a factor three with respect to the standard telescope configuration.

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1 Introduction

The implementation and commissioning of a FE-I4-based trigger scheme for the AIDA telescope is the topic of this note, for a detailed description see [3]. The telescope used for these studies is the final version of the EUDET telescope, which by convention is referenced AIDA telescope. At present, the trigger signal is generated by a coincidence circuit of two crossed scintillators in front and two behind the whole telescope assembly. This telescope setup however is not very efficient in terms of data acquisition if the dimensions of the DUT are much smaller than those of the trigger scintillators. If this is the case, many tracks seen by the telescope and triggered by the scintillators are not passing through the smaller DUT, which just reads an empty frame. An elegant option to overcome this efficiency issue is the implementation of a size-configurable region-of-interest (ROI) trigger by using an additional telescope reference plane instead of the scintillator pair at the very end of the downstream telescope arm. This ROI trigger plane is made of a ATLAS hybrid pixel detector using the FE-I4 [4] front end ASIC with a planar silicon sensor attached to it. Compared to a scintillator, which has a fixed sensitive area, the FE-I4 based pixel detector has the advantage that the sensitive region can be configured by including (or excluding) pixels individually. By having such a programmable ROI, the area on which the telescope is triggered can be remotely chosen in a way that it matches just the area covered by the DUT. Such a configuration makes a beam test campaign much more efficient in terms of data taking.

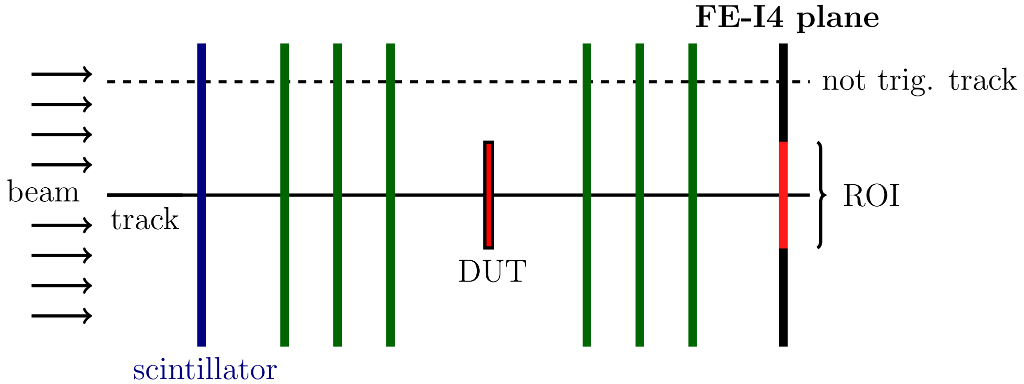


Figure 1: Setup of the AIDA telescope with a DUT and one ROI trigger plane replacing the scintillator pair behind the reference planes.

The trigger efficiency is defined as number of tracks including a hit in the DUT divided by overall number of collected tracks in the telescope. The setup of a beam telescope including the ROI trigger plane is depicted in figure 1. Through a proper ROI window selection only tracks that pass through the DUT trigger the system and the events are recorded. The commissioning of this new telescope arrangement performed with a DEPFET pixel sensor showed a trigger efficiency of 80%, while using the standard telescope configuration the efficiency was typically a factor three lower.

2 Implementation of ROI trigger plane

The ROI trigger plane is based on a hybrid pixel detector using FE-I4 readout. The FE-I4 chip, that was designed for the new innermost pixel detector system in the upgrade of the ATLAS experiment, the Insertable B-layer (IBL [5]), can amplify and discriminate the signal of the charge generated in the sensor. The pixel matrix of the FE-I4 consists of rectangular pixels arranged in 80 columns with $250\,\mu$m pitch and 336 rows with $50\,\mu$m pitch, resulting in a total sensitive size of $18.6 \times 20\,\text{mm}^2$. The ASIC is built in CMOS technology with a feature size of 130 nm.
Each pixel has embedded the same analog circuitry, see figure 2, which outputs a rectangular pulse that is high as long as the signal is above an adjustable threshold. This pulse is further processed digitally by the standard readout but it can also act as an input to a wired OR - the HitOR feature of all pixels. The connection of each pixel to the HitOR is configurable through the Enable HitOR local pixel register.

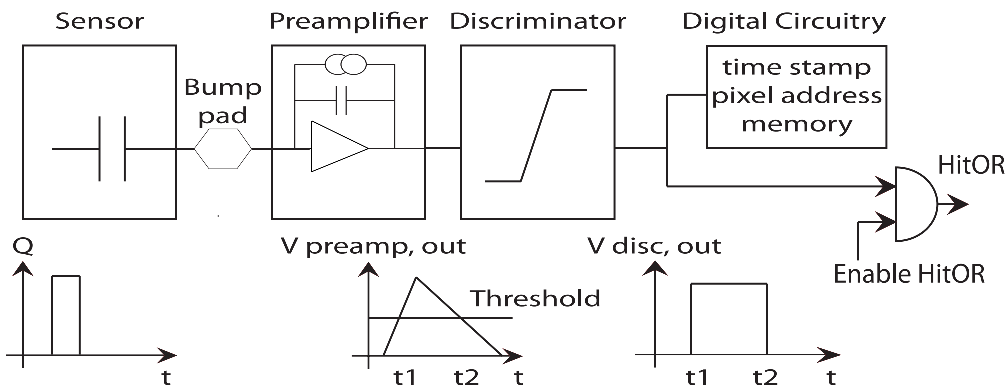


Figure 2: Simplified analog circuitry of the FE-I4 chip present on each pixel. The HitOR signal used as trigger is taken at the output of the discriminator.

As an adjustable ROI trigger signal, the HitOR capability is used. The HitOR pulse is in a high state if at least one enabled pixel sees a hit and in a low state otherwise. The length of the HitOR pulse is determined by the

time that the signal is above the threshold, which for a standard setting is $\mathcal{O}(100\,\text{ns})$.
In a standard telescope configuration a trigger logic unit (TLU) [6] is used to create a trigger signal and distribute it to all the attached planes. In order to use the HitOR signal as a trigger it has to be inverted and then connected to the TLU in the same manner as a scintillator. The TLU discriminates the signal with a tunable threshold of a comparator ranging from -800 mV to +800 mV. A schematic of the whole signal path is shown in figure 3. Once the signal at the input becomes smaller than the threshold, a trigger signal will be processed by the TLU and the read out of the telescope starts.
The definition of the ROI mask can be easily accomplished by using a dedicated software tool (STControl), that is part of the test system USBpix, see [7] for a detailed description. In order to activate the ROI trigger signal the FE-I4 only needs to be configured. No direct communication between the FE-I4 and the AIDA telescope software is needed, yet this feature is implemented and tested, see [8, 9].

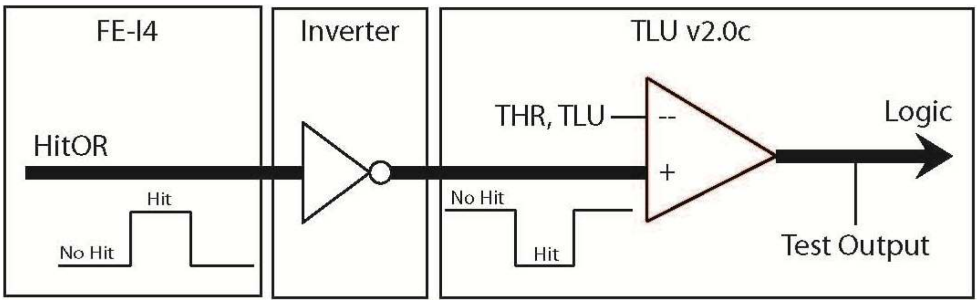


Figure 3: The HitOR signal of the FE-I4 gets inverted and then acts as an input to the TLU.

3 ROI trigger commissioning with a DEPFET as device under test

A measurement to test the complete functionality of the ROI trigger in a test beam environment together with an external DUT was carried out at CERN. The experiment is done in the North Hall H6B area, where a pion beam of 120 GeV energy is available. The actual setup, shown in real in figure 4, reflects a typical configuration of a future AIDA telescope as proposed in figure 1. It consists of the AIDA telescope with six planes in a double arm configuration, a DEPFET pixel detector [10] in between the two arms as DUT and a ROI trigger plane at the end. The AIDA reference planes use MAPS sensors (MIMOSA26 flavour [11]), thinned down to 50 μm for minimum material budget.

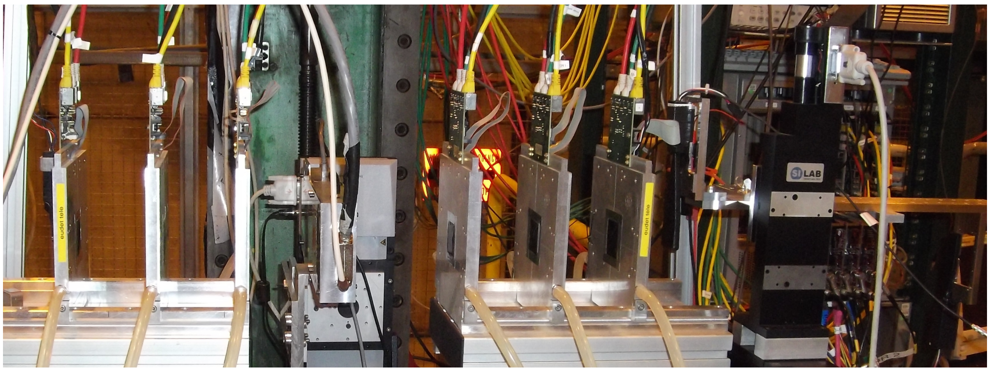


Figure 4: Setup of AIDA-telescope with a DEPFET DUT and a ROI trigger plane, at H6B line in the North Area at CERN.

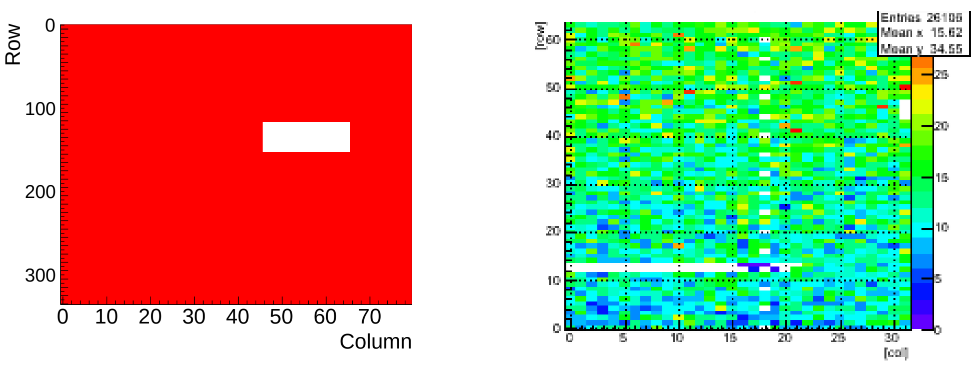
The DEPFET sensor is a small DUT as it is less than 5 % in area compared to the AIDA telescope reference planes, see table 1. As a consequence the usual trigger scheme as tested in previous test beams leads to a data taking where 75% of the events triggered and stored do not show a hit on the DEPFET. This number is achieved using a small scintillator of $4 \times 4\,\text{mm}^2$ area which is not optimal considering that the DEPFET in that measurement has an area of $3 \times 1.5\,\text{mm}^2$ [12, 13].

	columns	rows	pitch [μm^2]	thickness [μm]	size [mm^2]
DEPFET	32	64	50 × 75	50	1.6 x 4.8
FEI4	336	80	50 × 250	470	16.8 x 20.0
MIMOSA26	576	1152	18.4 × 18.4	50	10.6 x 21.2

Table 1: Description of pixel detectors used here.

To be more efficient in terms of data acquisition (i.e. nearly all the read out frames contain at least one hit in the DUT) the trigger for the whole system is generated through a coincidence between one big scintillator in front and the FE-I4 plane behind the telescope, with the ROI conveniently chosen to cover just the area defined by the DEPFET. The mechanical setup and alignment of this trigger device is much more flexible compared to having a second scintillator of the correct DUT size. The HitOR signal from the FE-I4 plane is integrated as described before and its configuration is defined as described in the following.

In order to find the position of the ROI that matches to the DUT a correlation plot between those is useful. In a correlation plot the x-coordinates of hits of the one plane are plotted against the same coordinate of hits in the other plane. For perfectly aligned planes this results in a diagonal through the origin. Offsets to this diagonal indicate shifts in the corresponding direction. The same can be done for the y-direction and like this the relative positions can be found automatically and the ROI set accordingly. Since this feature is not yet implemented for FE-I4 and DEPFET another method is used to identify the best ROI position.
Both the DEPFET and the ROI trigger plane are mounted such that they are coarsly aligned to the AIDA reference planes. Correlation plots between the ROI trigger plane and the AIDA reference planes are available in an online data monitor as soon as the beam is switched on. This makes a more precise alignment of the ROI trigger plane possible and is done remotely through the usage of an x-y-table.
An iterative selection of the optimal ROI based on the trigger efficiency of the DEPFET is done, while this number is obtained from the DEPFET online data monitor. After a few number of iterations, the final configuration of the ROI is found, see figure 5a for the ROI setting and the DEPFET hitmap in figure 5b. The DEPFET hitmap shows a roughly homogeneous hit distribu-



(a) ROI of FE-I4 plane.

(b) Hitmap of DEPFET DUT.

Figure 5: Selected ROI trigger and corresponding Hitmap of DEPFET.

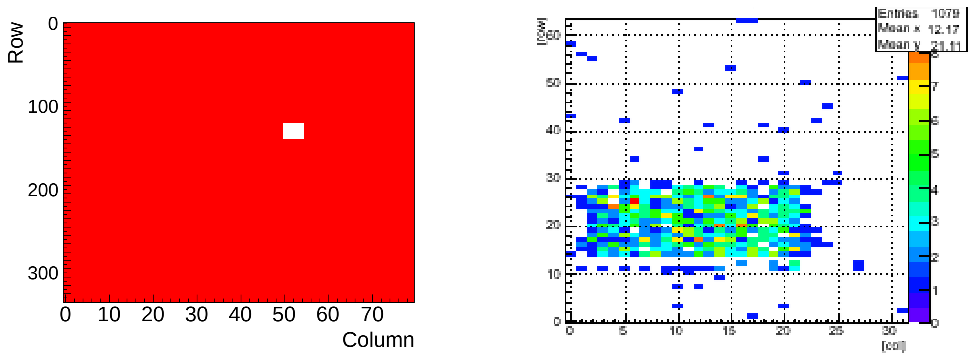
tion. More entries are found at higher row values which is expected because of the beam profile. From this inspection it can be deduced that the ROI fully overlaps the DEPFET and that the full chain is working. With a size of 20 FE-I4-columns and 36 FE-I4-rows, which is equivalent to $5 \times 1.8\,\mathrm{mm}^2$, the ROI is chosen to extend over the edges of the DEPFET in order to avoid a possible data loss through movements of the order of $100\,\mu$m.

The trigger efficiency of this measurement with a fully overlapping ROI is 80% as compared to 25% which is reached when triggering only on the scintillators in front and behind the telescope.

- In the case of 25% trigger efficiency, that was found with a scintillator of $4 \times 4\,\mathrm{mm}^2$ area and a DUT of $3 \times 1.5\,\mathrm{mm}^2$ area [12], the ratio of the area of the DUT to the sensitive trigger area is $f_1 = 28\%$.

- With the ROI scheme a trigger efficiency of 80% is reached by having a trigger sensitive area of $5 \times 1.8\,\mathrm{mm}^2$ and a DUT area of $4.8 \times 1.6\,\mathrm{mm}^2$. That gives a ratio of DUT area to trigger sensitive area of $f_2 = 98\%$.

From this an improvement in trigger efficiency of a factor of $f_2/f_1 \approx 3.5$ is expected. The measured value of this factor is roughly 3.2 and agrees with the estimated factor of 3.5 on percent level. With an improvement in trigger efficiency of roughly a factor three the proof of principle of the new telescope configuration is demonstrated.
If the position of the DEPFET is changed the opening of the trigger window can be adjusted remotely. The minimum step size of the ROI in both directions is the pixel pitch, so $250\,\mu$m column and $50\,\mu$m row wise. As the ROI is fully flexible in size even small areas can be switched on or off just by acting on individual pixels.
The ROI can be chosen to be even smaller than the DEPFET if certain areas of the sensor are of special interest. The ROI mask configuration as well as the DEPFET hitmap of such a configuration are shown in figure 6. In the



(a) ROI of FE-I4 plane. (b) Hitmap of DEPFET DUT.

Figure 6: Selected ROI, which is smaller than the DEPFET and corresponding hitmap of DEPFET.

hitmap of the DEPFET the ROI is clearly visible and only a small number of hits lie outside of the ROI. Those hits can be due to two tracks that are in the same trigger window and are expected at the given beam conditions.

4 Conclusions and outlook

The modular ROI trigger has been successfully implemented into the AIDA telescope and a flexible and time efficient usage is possible. Compared to the conventional trigger generation the advantage of the ROI is that no dedicated scintillators matching the DUT size are needed as through the ROI sensitive areas of sizes between one FE-I4 pixel and the whole area, that means from $50 \times 250\,\mu\text{m}^2$ to $16.8 \times 20\,\text{mm}^2$, can be configured. Even while the data acquisition is running the ROI can be chosen or changed and no time consuming mechanical re-alignment is needed.
In addition, the FE-I4 readout is implemented into the DAQ and therefore the ROI trigger plane can contribute to the telescope as a reference plane that delivers hit information.

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