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STUDIES OF RESOLUTION, EFFICIENCY AND NOISE FOR DIFFERENT FRONT END THRESHOLD ALGORITHMS USING ATLAS-A SILICON DETECTOR TEST BEAM DATA

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Data taken with an analogue read-out chain for an ATLAS prototype silicon detector[1] has been processed offline using several of the schemes proposed with binary pipelines. These schemes require either one or (at most) two bits of information from each hit channel following either a single or double threshold discriminator on the front-end amplifier. The resolutions, efficiencies and noise rates associated with various schemes are studied and compared with a full analogue treatment. Given the Lorentz angle to be expected in the 2T field of the experiment, the results presented here with a charge division design detector reflect some of the problems due to charge sharing to be anticipated in ATLAS. This study shows how enhancements to the single threshold binary scheme can substantially improve the robustness of the efficiency against signal loss whilst retaining low noise hit rates and adequate resolution.

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1 Introduction

A detector to the ATLAS n-strip in n-type design was designed and fabricated last year and tested in beam at CERN [2]. The main features of this detector were a 56.25μm diode pitch with 112.5μm pitch capacitively coupled read-out. The detector was equipped with FElix-128 LHC read-out electronics [3] which gives pulse height information for all channels in a trigger time bin and can be operated in both 'peak' mode and 'deconvoluted' mode. The chip uses a fast preamplifier on each of the 128 channels followed by a 75ns shaper, a 1.6μs analogue delay buffer and an analogue signal processor (APSP). The Analogue Pulse Shape Processor recovers the charge in a single trigger time slot by performing a weighted sum of the charge in 3 consecutive 25ns time slots giving a deconvolution of the shaper response but at the cost of some increase in the noise.

The detector was studied in the H8 beam line where a silicon hodoscope allows the position of tracks in the test detector to be determined to better than 2μm[2]. Using this information and the pulse height information recorded for each time bin with a track trigger it has proved possible to both study the optimal resolution, efficiency and noise hit rate with a full analogue treatment and to test the algorithms proposed for simplified read-out schemes with zero-suppression and only 1 or 2 bits of information per strip above threshold.

2 Full Analogue Results

Using the 'peak' and 'deconvoluted' operating modes of the chip gave two data sets with signal/noise of 17:1 and 11:1, respectively, as shown in figure 1. As can be seen, the total charge collected where tracks extrapolate to the intermediate strip is lower then for tracks extrapolating to the read out strips — an effect more pronounced in peak mode.

With the full analogue information available the hit position can be determined by interpolating the charge on neighbouring strips. This technique provides the optimal resolution and these values of signal/noise give the residual distributions shown in figure 2. These results are better than the $112.5\mu/\sqrt{48}$ that might be expected for diode pitch/$\sqrt{12}$ showing that some charge spreading is also contributing to enhance the resolution. This is borne out by the η distribution which shows the ratio of charge on on one strip to the total charge as a function of the interpolated position between the strips (see figure 3). These results were obtained with a cluster threshold of 6 times the average strip noise and a strip threshold, for inclusion in the cluster, of 1.5 times the individual strip noise.

Figures 4 and 5 show the efficiencies and noise hit rates for both data sets as the cluster significance cut is varied. Even at the lower signal/noise level, these plots show this read-out scheme would be fairly robust against moderate signal degradation in the detectors after irradiation. Note that the noise plot deviates from expectations for gaussian noise at a cluster significance of $\sim$3 times the average strip noise. This is also seen in subsequent noise hit plots, and is indicative of a low rate of real hits in the detector which are not reconstructed as tracks in the telescope. This is borne out by laboratory measurements (figure 6) for the same module which show no such effects.

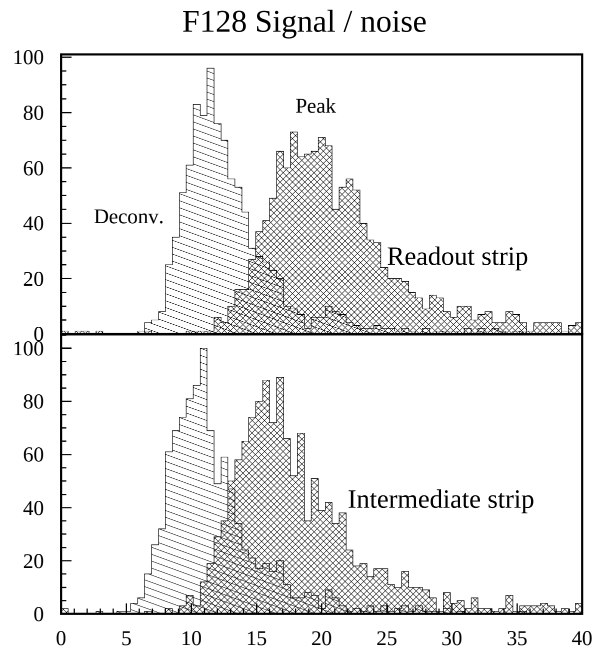

Fig. 1. *Pulse height for the ATLAS-A detector for tracks extrapolating to either the read-out (top) or intermediate strip (bottom) in units of the single strip noise using FElix-128 read-out. The dark hatched distributions show the results for the 'peak' mode of operation while the lighter hatched distributions are for the 'deconvoluted' mode.*

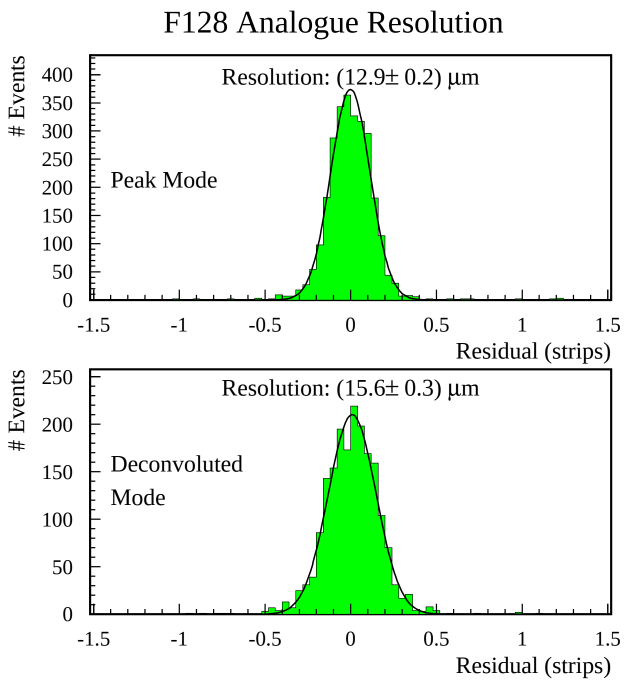

Fig. 2. *Spatial resolution for the ATLAS-A detector (112.5µm read-out pitch) in peak and deconvoluted modes with FElix-128 read-out.*

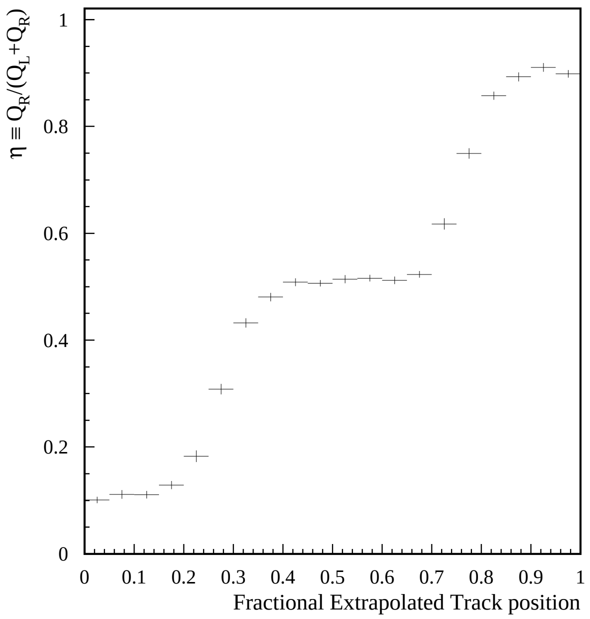

Fig. 3. *Charge interpolation function,* $\eta = \frac{Q_R}{Q_L+Q_R}$, *as a function of* x *modulo pitch.*

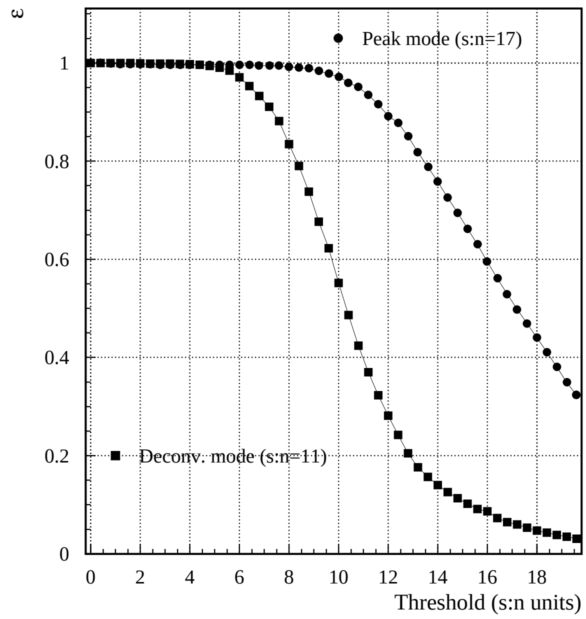

Fig. 4. *Analogue read-out efficiency as a function of the cluster significance cut in units of the single strip noise.*

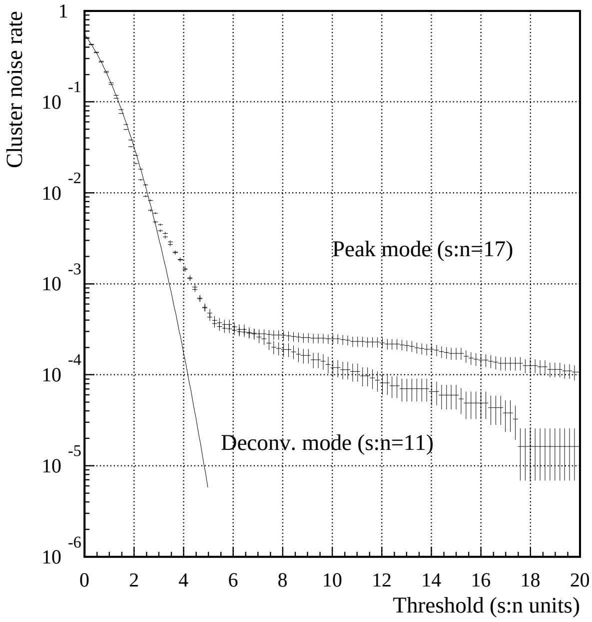

Fig. 5. *Analogue read-out noise hit rate for clusters as a function of the cluster significance cut in units of the single strip noise.*

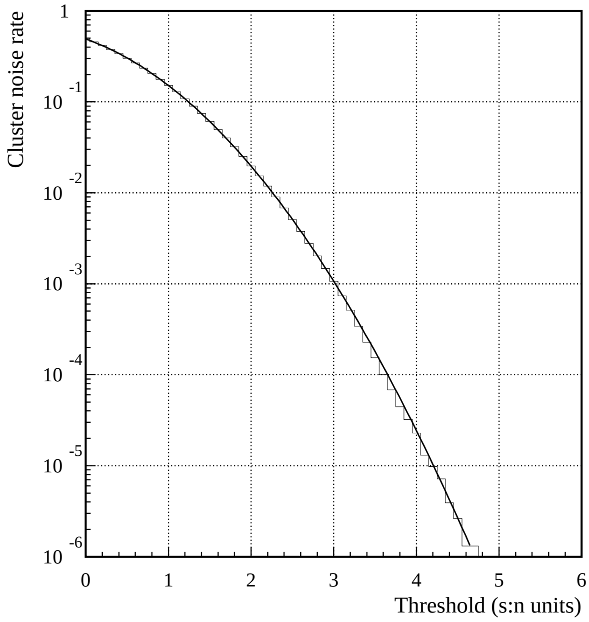

Fig. 6. *Analogue noise hit rate for clusters as a function of cluster significance cut for source tests in the laboratory.*

3 Single Threshold Binary Style Read-out

The proposed 'binary' solution for the experiment assumes detectors with no intermediate strip and smaller pitch (80μm) than that employed here. Nevertheless, the presence of the intermediate strip simulates, to some extent, the effect of the anticipated charge spread coming from the Lorentz angle in the barrel region. In addition, the use of a larger pitch with charge division delivering the desired resolution could prove financially attractive. For the simple binary case, a single channel threshold is used and a bit is set in the binary pipeline for channels above the threshold. The read-out just gives the channel numbers for each hit strip in the corresponding trigger time slot. This solution benefits from simplicity (and therefore cost) but does suffer from a reduced efficiency where charge is spread over 2 or more channels. There have also been concerns expressed about the monitoring of such a solution which would probably require occasional threshold scans to check the pulse-height and noise in the system as it deteriorates under irradiation.

With the data collected here it is possible to implement this scheme offline for the 2 cases (signal/noise=11 & signal/noise=17) to see how it performs for resolution, efficiency and noise. In the experiment the target noise with 18pF of load capacitance on the electronics is $1500e$ so the proposed 1fC threshold will correspond to roughly 4 times the single channel noise. Our 17:1 data corresponds to a noise of $1300e$ whilst the 11:1 corresponds to $2000e$.

The results are shown in figures 7, 8 & 9. It is seen from figure 8 that with the poorer signal to noise value, the efficiency for tracks where the charge is recorded on two strips is becoming marginal. However, the indications are that if the desired noise is achievable in ATLAS and good charge collection efficiency is retained in the detectors, this study does not exclude the use of this scheme. It can be seen in figure 7 that the resolution deteriorates as the threshold is increased due to tracks between two strips being reconstructed as only on one strip. As the threshold increases still further, these hits are not registered at all, and the resolution improves as the efficiency falls off.

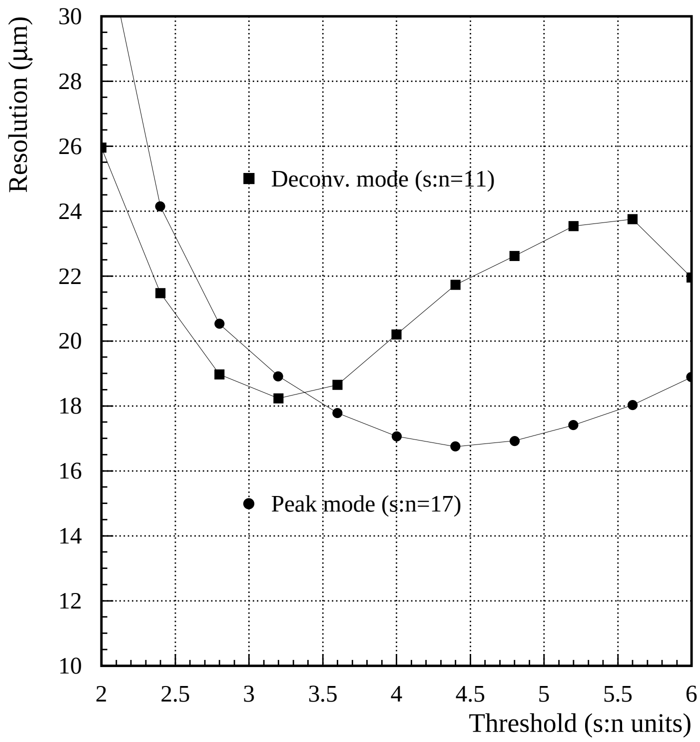

Fig. 7. *Spatial resolution of the ATLAS-A detector (112.5μm read-out pitch) for single threshold binary read-out as a function of strip significance and with no pulse height information.*

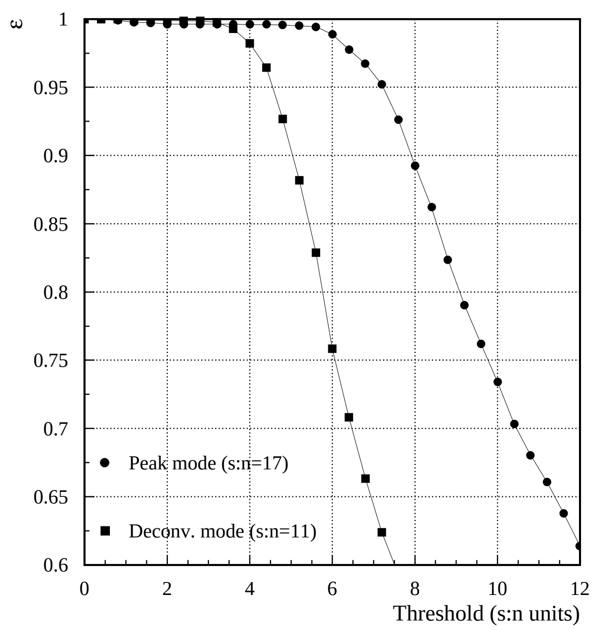

Fig. 8. *Single threshold binary read-out efficiency as a function of the strip significance cut in units of the single strip noise.*

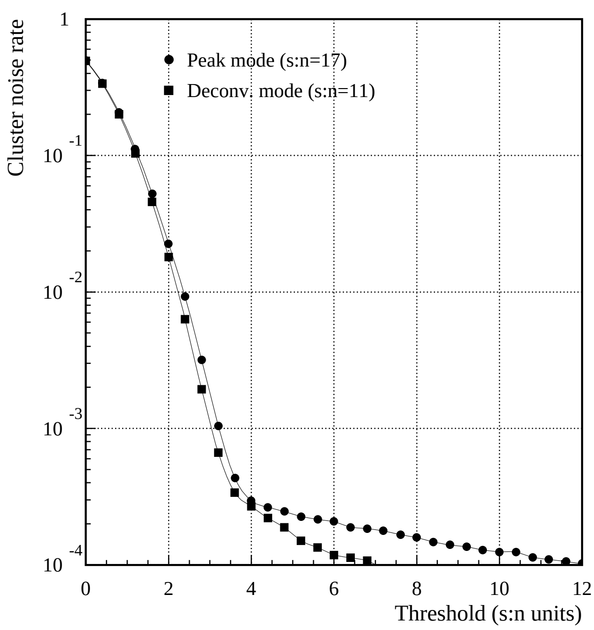

Fig. 9. *Single threshold binary read-out noise hit rate as a function of the cluster significance cut in units of the single strip noise.*

4 Dual Threshold Binary Style Read-out

In the experiment the bulk of fast tracks are expected to either give 1 or 2 strip clusters with the latter, on average, having $\leq \frac{1}{2}$ the charge per strip of the former. To be equally efficient for both cases requires the use of at least two thresholds or some means of adding the charge on adjacent channels prior to comparison with a threshold level. The simplest scheme to model is one where two thresholds are employed and two binary pipelines are required, one for channels passing the low threshold and the other for the high threshold . Given that the 2 strip clusters are expected to have ~half the charge per strip of one hit clusters it is assumed in the following that the high threshold is simply 2 times the low. The resolutions, efficiencies and noise rates per strip for such a scheme are shown in figures 10, 11 & 12 as a function of the high threshold cut in units of the single strip noise. The expected improvement in the 2 strip cluster efficiency is clearly seen.

An alternative proposal, the Dabrowski algorithm [4], retains the single binary pipeline per channel but combines the dual threshold information to determine whether or not a strip is set as above threshold. This loses some of the monitoring advantage of a true dual threshold scheme where rates above the different thresholds could be recorded but saves a factor of 2 in the number of binary pipeline channels. Any channel above the high threshold is automatically read out in this scheme as is any channel above the lower threshold adjacent to another over-threshold channel. No single strip clusters below the lower threshold are read out reducing the noise occupancy coming from the lower threshold setting. The performance of this scheme, for which a detailed electronics implementation is now under investigation, are shown in figures 13, 14 & 15. These plots show comparable performance to the previous results suggesting this represents a significant saving if the logic and 2 threshold discriminator can be implemented at the front of the binary pipeline. Concerns about loss of information for monitoring are difficult to quantify and represent the main disadvantage of this scheme with respect to the 2 pipeline solution.

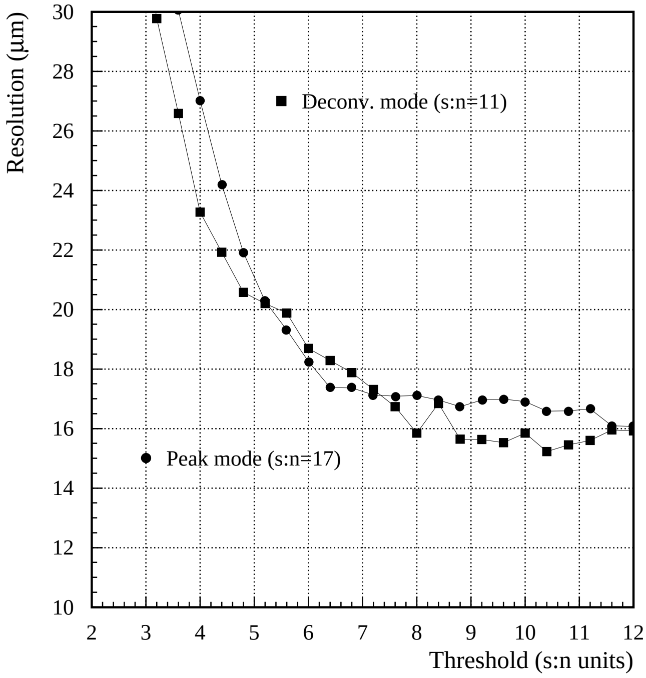

Fig. 10. *Spatial resolution of the ATLAS-A detector (112.5μm read-out pitch) with dual threshold binary read-out as a function of the high threshold and with no pulse height information.*

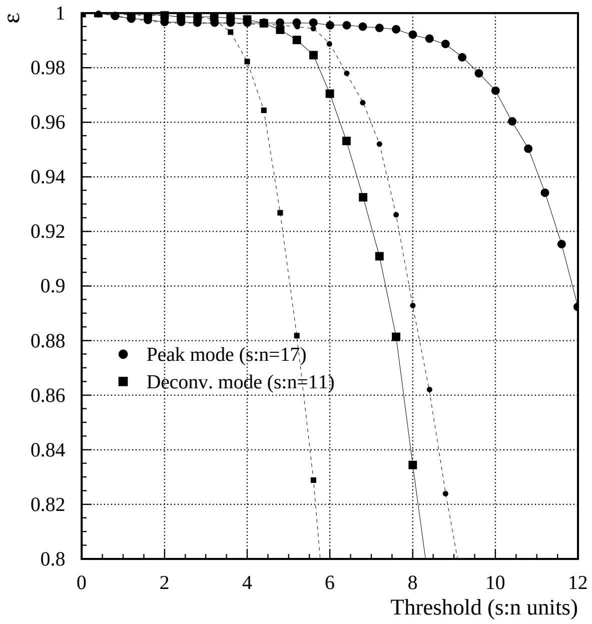

Fig. 11. *Dual threshold binary read-out efficiency as a function of the high threshold (=2×low threshold) cut in units of the single strip noise. The dotted lines show the single threshold results of figure 8.*

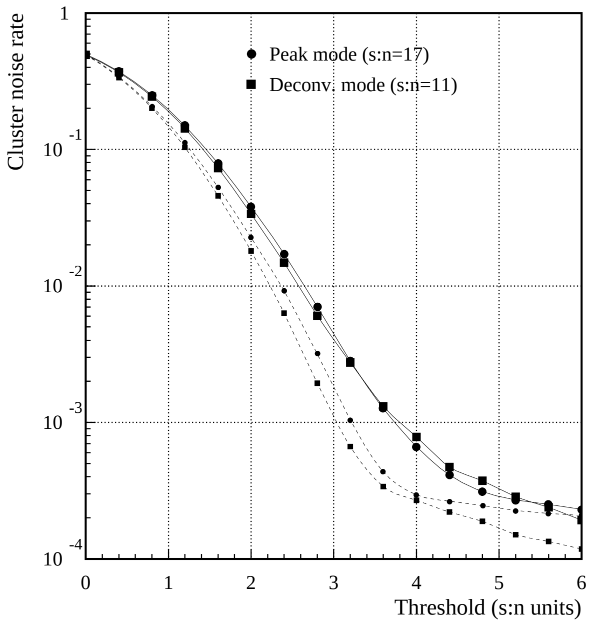

Fig. 12. *Dual threshold binary read-out noise hit rate as a function of the high threshold (=2×low threshold) cut in units of the single strip noise. The dotted lines show the single threshold results of figure 9.*

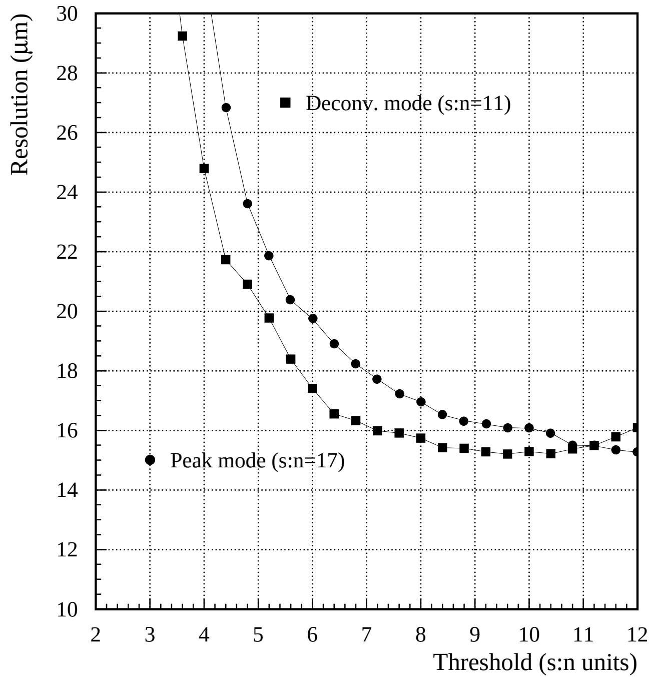

Fig. 13. *Spatial resolution of the ATLAS-A detector (112.5µm read-out pitch) using the Dabrowski algorithm as a function of the high threshold and with no pulse height information.*

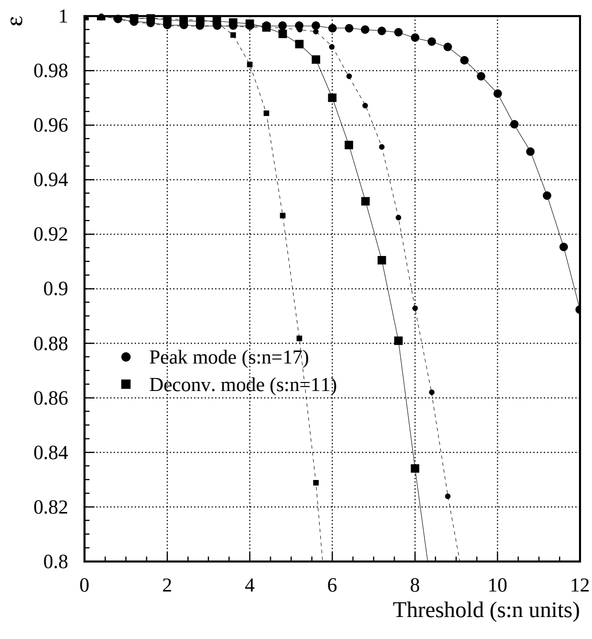

Fig. 14. *Dabrowski algorithm binary read-out efficiency as a function of the high threshold (=2×low threshold) cut in units of the single strip noise. The dotted lines show the single threshold results of figure 8.*

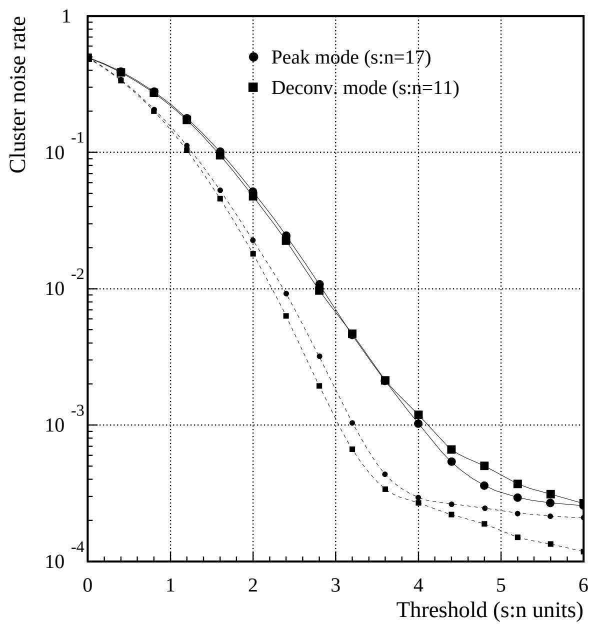

Fig. 15. *Dabrowski algorithm binary read-out noise hit rate as a function of the high threshold (=2×low threshold) cut in units of the single strip noise. The dotted lines show the single threshold results of figure 9.*

5 Conclusions

Test beam data has been analysed using both full analogue information and the reduced information that would be available in the various binary schemes under consideration within ATLAS. Resolution, efficiency and noise rates are presented as a function of the threshold cuts used showing performance to the ATLAS specifications (allowing for the 112.5μm pitch used here) should be attainable with all the proposed schemes given detectors and electronics to the nominal performance. However, at a given pitch the analogue read-out clearly gives better spatial resolution even at moderate signal/noise whilst the single threshold binary could be marginal for 2 strip clusters if the electronics noise or charge collection efficiencies are poorer than expected. The schemes with dual threshold circumvent this latter problem but at the cost of extra complexity in the read-out chips. However, if a binary solution is to be adopted in ATLAS it is suggested that the extra safety offered by either implementation of the dual threshold proposal makes this a very attractive route to pursue.

References

[1] ATLAS Technical Proposal. CERN/LHCC/94-43

[2] P.P. Allport et al. ATLAS Beam Test Results. INDET-NO-117

[3] RD20 Status Report to the DRDC. CERN/DRDC-94-39

[4] W. Dabrowski, Study of Spatial Resolution and Efficiency of Silicon Strip Detectors using Charge Division Readout. *Proceedings 2nd International Symposium on Development and Application of Semiconductor Tracking Detectors, Hiroshima (1995)* to be published *Nucl. Instrum. Methods* A