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WIDGET: A DATA ACQUISITION SYSTEM FOR A BALLOON BORNE SILICON PARTICLE CALORIMETER

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Abstract

We describe Widget; a complete data acquisition system (DAS) designed for a balloon-borne calorimeter using silicon strip detectors. The design includes a general purpose CPU as well as five to twenty Digital Signal Processors (DSP) in order to control the acquisition of the data. This local intelligence also allows the instrument to re-calibrate itself, to perform calculations on the data and to control the functionality of the instrumentation. The DSPs filter the data to avoid overflowing the radio link to ground. In principle the system could control the instruments, without direct intervention from the ground, on flights that last several days. Widget is also a prototype for future satellite borne Si calorimeter data acquisition systems.

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1. INTRODUCTION

Widget (Wizard Data Getter) is the data acquisition system for the balloon phase of the Wizard collaboration [1],[2]. The ultimate purpose of the collaboration is to launch a satellite borne instrument capable of extending our knowledge in cosmic ray physics and related disciplines. This includes the search for primordial antimatter, the determination of the energy spectra of antiprotons and positrons up to a few hundred Gev, and the measurement of energy and spectra of protons, electrons and nuclei up to Carbon.

The Wizard payload includes, in its various possible configurations, several other instruments besides the silicon calorimeter. The main concern of this paper is the data acquisition system of the silicon calorimeter.

The calorimeter provides discrimination of positrons from protons by measuring the energy deposited by the particles while passing through plates of tungsten. Positrons produce bremstrahlung photons, which in turn produce electron positron pairs, hence generating a particle shower. The slabs of high-Z material are alternated with planes of detectors to sample the development of the shower. The ability of the calorimeter to discriminate between positrons and protons resides in recognizing the different spatial development of both types of showers and in its energy resolution.

The collaboration chose silicon strip detectors as the detecting medium[3],[4],[5]. Silicon detectors are widely used in High Energy Physics (HEP) experiments. But, unlike its ground counterpart, air borne and space applications present additional requirements for the data acquisition system such as: low weight, low power consumption and high reliability.

Widget will be used for the already programmed balloon flights: two during 1993 and a third flight during 1994. Widget was designed and built using off-the-shelf components. The prototype system was designed to check the concept of massive computing power for balloon flights as well as to obtain relevant physics results.

For the satellite phase much of the electronics will be monolithic although the architecture will be the same. In particular, we will publish separately the details of the monolithic implementation of the front end electronics since it is an issue all by itself.

In an accelerator environment, the usual role of a data acquisition system is to wait for a trigger signal to enter into action. Some fast electronics generates the trigger signal every time that it recognizes, in one event, some predetermined sought after characteristic. At that moment the data acquisition system reads all the signals of each and every channel, it converts the analog values into digital form, it builds the event and stores the data into some magnetic media in order to analyze it off-line. If the operator wants to re calibrate the system or check its functionality, the data taking is stopped and it resumes only after the procedure has been carried out. If a system failure is detected there is ample time and easy access to the electronics.

A balloon borne data acquisition, instead, has to perform all the aforementioned tasks and more. Since a typical flight lasts for some 25 hours, time is at a premium and no physical access to the electronics is available. Some of these extra tasks are: to control the functionality of the whole instrument, to filter and compress the data since it has to be downloaded to ground through a narrow bandwidth radio link, to re calibrate the systems because of temperature variations or aging, to locally store the acquired data because the link is too slow or because the downloading is possible only at determined periods.

The fine details of the electronics and of the on-board software can be found in the technical literature written for the users of Widget [6],[7].

2. GENERAL ARCHITECTURE

Figure 1 shows the architecture of Widget. The main system architecture looks very much like a funnel, to have at all times and places, a data bandwidth and computing power coherent with the amount of data to be handled.

The first version of the calorimeter will fly with only five silicon detector planes, the second with seven and the last with thirteen planes. Hence, we designed a modular hardware architecture admitting up to 32 detector planes and capable of processing 50-100 events per second regardless of the number of planes.

This flexible data acquisition system requires the following modules: a) the GMX a general purpose commercial single board CPU[8] capable of running OS-9, a real-time operating system; b) the PiggyBoard ,a module that provides general services; c) the RomeModule, a board capable of generating test signals for the maintenance and in-flight calibration of the system; d) the FlashDisk, an ultra low power consumption solid state disk using a bank of FlashCards; e) the VoodooBoards -one for each plane- they embody a digital signal processor (DSP), 16 A/D converters and a 4 kword double port memory (DPM). With the exception of the GMX all the other boards were custom designed. We will refrain from describing here the FlashDisk since it is only needed when flying with more than five planes.

For the sake of completeness we will also briefly describe a detector plane and the Laben preamplifier.

2.1 The Detector plane

Figure 3 shows a schematic view of a plane assembly. A complete detector plane consists of a plate of tungsten and, beneath it, two planes of silicon strips, at right angles. The silicon planes detect the x and y coordinates of the point struck by the particle. Each coordinate has 128 x-channels and 128 y-channels. All of the channels are read to identify the point struck by the particle.

2.2 The Front End Preamplifier

Eight diode outputs are connected to a low noise preamplifier board, shown in figure 1 and 2 as Laben preamps[9]. Each data channel is treated individually until the outputs are fed into an analog multiplexer. The 10 nsec duration charge pulses generated by the passing particle are first integrated and then shaped into a semi-gaussian form[10]. The shaping time of 7 microseconds has been chosen in order to maximize the signal to noise ratio. After we sample and hold the signal, the signal is connected to a multiplexer that can be activated by the DSP. The multiplexer lets through none or one out of the eight input signals. The output signal is fed to a 12 bit ADC through either a x1 or x16 amplifier. The sample and hold signal, the choice of the amplification and the activation of the multiplexer are all controlled by the DSP.

2.3 The VoodooBoard

Each plane has 16 programmable 12 bit ADC[11], a DPM and one DSP[12] acting sometimes as a sequencer and sometimes as a CPU[13]. The 4 kword memory is divided into two 2 kword regions. The upper 2 kwords are addressable by both the DSP and the GMX while the lower part, only by the DSP. In this memory area the DSP keeps thresholds and other necessary variables. After commanding the sample and hold of the signal the DSP instructs the ADCs to start the conversion of 16 channels out off the 256 channels of the plane. Once the conversion of a set of 16 channels is finished the DSP gathers the digitized values and compares them with the noise thresholds held in a table of the DPM. If the value is above the threshold, the value is written into the DPM together with the channel number and amplification. This procedure is repeated until the 256 channels have been processed for the two available amplifications. At that moment the

DSP writes in the first memory position of the DPM the word count of the block of data that the GMX has to read. At this point one of the VoodooBoards will interrupt the GMX flagging the end of the conversion and comparison phase. This phase is performed in 2.2 msec and, since the operations are performed in parallel in all the planes, this time is independent of the number of planes and barely sensitive to the number of hits per planes.

While the GMX read the several DPMs the DSPs are free to perform several housekeeping chores such as ordering the re,calibration of the ADCs and the calculation of new means and RMS deviation for the pedestals with the arrival of each new event. After this tasks have been performed, the DSPs wait for the arrival of the trigger or an interrupt from the GMX.

The full computing power of the DSPs is not yet fully utilized by the present software since the DSPs are idle a large percentage of the time.

One of the inputs of the ADCs is connected to a reference voltage, hence the DSPs can also control the functionality of the ADCs with a signal that is independent of the preamplifier signal.

2.4 The PiggyBoard

Besides driving signals and controlling the interrupts through the long cables, this board essentially provides services to the system. It has a watchdog circuit that once activated Resets the system every few seconds if not itself Reset by the GMX. The watchdog guards the DAS from going dead for more that a few seconds. It also has 16 kwords of EEPROM where the initial parameters necessary for the system to start working are stored. Values such as threshold values for each amplification and channel are kept here as well as programming modes and S/H times for each plane. Every number needed in the system is kept safely in this memory.

The Rome Module (see fig. 2) is controlled through this board. During data taking this module receives the payload event trigger and delivers it to the DAS. Occasionally, the system needs to calibrate itself. For calibration purposes the module generates triggers at 15 Hz rate to the DAS, providing at the same time test-in signals to the preamplifiers. The GMX programs one of the 16 possible strengths of the test-in signals. If the signal is zero the DAS measures its own noise (pedestal) else it can check the linearity and functionality of the pre-amplifiers.

2.5 The GMX

The GMX is a general purpose single board computer [8]. It has a MC68020 microprocessor running at 25 Mhz, 2 Mb of memory and an I/O connector to control peripherals. During ground testing we connect an Ethernet and a large SCSI disk in order to perform calibrations and acquire muons with test purposes and independently from the services of the payload. It is also through the I/O connector that this computer is connected to the rest of the system.

The GMX is the master of the system with all other boards acting as a hierarchy of coprocessors. The coprocessors are programmed and activated by it. The GMX uses the OS-9 real-time operating system. The use of an operating system is consistent with the philosophy of programming time critical tasks in assembly language. Assembly language programming was used for the DSP and also for drivers at operating system level. The rest of the programs were written in "C". This allows users not involved in the original development of the system or not conversant in assembly language to program new tasks different from the originally contemplated for WIDGET.

After a Reset is received by the system the GMX boots OS-9, and then sends the necessary parameters for its operation to each plane. These numbers are stored in the EEPROM. Once all parts of the system are ready to handle data, the GMX enables the necessary interrupt lines and waits to receive an interrupt from one of the Voodoos. When the interrupt is acknowledged it reads the DPMs of each plane, and compresses the data adding the address of the plane from which it came. Then, it writes the information into the CamacBoard DPM. The first word of the DPM contains the word count of the block, and the second a word that describes if the data was generated by: an event, a test-in run, etc.

Through the CamacBoard the GMX can be interrupted in order to perform tasks under ground request. The whole system can also be Reset from ground from this board.

2.6 The CamacBoard

From an electronic point of view, this is the less complicated of all the boards. Its function is to allow the transfer of data and commands between WIDGET and the service on-board Micro VAX, and it consists of a large PAL, line drivers and a DPM. From the GMX side this DPM is seen as a regular DPM, but from the CAMAC bus side it is seen as registers. The PAL performs this trick. The PAL also decodes the instructions coming from the GMX and the Camac, and generates the standard Camac signals and answers.

Also, through this board the ground operators can send data and instructions to the system. For example, if some anomaly is noticed in the data coming from the payload, the flight control could ask for re calibrations or other available activities.

During long flights the on-board computer could determine by itself and without ground intervention that some re calibration or control of the hardware is in order to avoid corruption of the data. Such a test could determine the variation of parameters or deactivation of some software or hardware modules.

3. SYSTEM PERFORMANCE

The first phase of the data acquisition of an event at the plane level precludes a fixed time of approximately 2.2 msec. This time is independent of the number of planes since it is an activity that takes place in all planes in parallel. This initial phase is followed by the GMX gathering, compressing and writing the significant data into the Camac DPM. The time needed to complete this second phase depends linearly on the number of hits per plane, the processing of each hit taking approximately 15 microseconds/hit.

Figure 4 shows a typical muon trace. It leaves roughly 10 hits/plane above the thresholds for both coordinates and both amplifications . Hence, the time t to deliver the data to the Camac crate is given by

$$\mathbf{t = 2.2 + .015 x 10 x N}$$

where t is given in milliseconds, and N is the number of planes. Figure 5 shows the total time required by WIDGET to process one event as a function of the number of planes.

We can compare our approach to the time required by a pipeline that reads every channel at x1 and x16 amplifications, feeds the signal to a Flash ADC, compares the result with a threshold, and stores without compressing the result in a Camac register. The time employed by the pipeline is bounded by the time it takes to open the multiplexer and to wait for the output signal to stabilize. For the Laben preamplifiers this time is longer than 2 microseconds. Even assuming, that the conversion is performed instantly, we find that a lower bound for the total time t for processing one event, is given by

$$\mathbf{t = .002 x 256 x 2 x N}$$

Fig. 5 also shows the total time for processing an event for the pipeline as a function of the number of planes. It is evident that already for three planes Widget is faster than a pipeline. This result moved us to decide the present architecture for WIDGET without even considering the advantage of flexibility and fault tolerance offered by our parallel processing system.

Widget itself is fast enough to process events at a higher rate than the natural cosmic ray arrival rate of about 110 events/sec. However, within the balloon there are elements that influence the payload data rate: other instruments, the on-board Micro VAX and a narrow bandwidth radio link that slows down the total data that can be transmitted to ground. Approximately 80-100 events/sec can be processesed for a five plane calorimeter. For a calorimeter with more than five planes the link becomes the real bottleneck, and as a consequence on-board recording is mandatory.

Fig. 4 shows the noise filtering performance of the system. In a) the trace left by a passing muon cannot be distinguished clearly from the background. The noise is highly variable and there are strips with pathologically important levels. We therefore cannot define one threshold level for an entire plane, but we require to characterize a threshold for each strip and amplification. In b) the above procedure distinctively separates the trace left by the muon from the background noise. Only the data in b) is transmitted through the data link to ground where it will be adjusted according to the sensitivity and linearity of each channel.

4. CONCLUSIONS

The flexibility and modularity of the system allow us to accommodate from 1 to 20 Si strip detector planes with almost no degradation of the 50-100 events/sec acquisition data rate. The high system programmability permits to execute novel tasks with a simple change of software, such as a complete autonomous control of all the functions of the instruments.

Also, the presence of a general purpose computer allows the system to control the hardware faults minimizing their influence on the overall performance. The flexibility and spare computing power are needed for long flights with duration of several days.

This flying Si calorimeter is the first of a series of similar forthcoming instruments, among them satellite instruments for particle and gamma ray detection, for which WIDGET is their working prototype.

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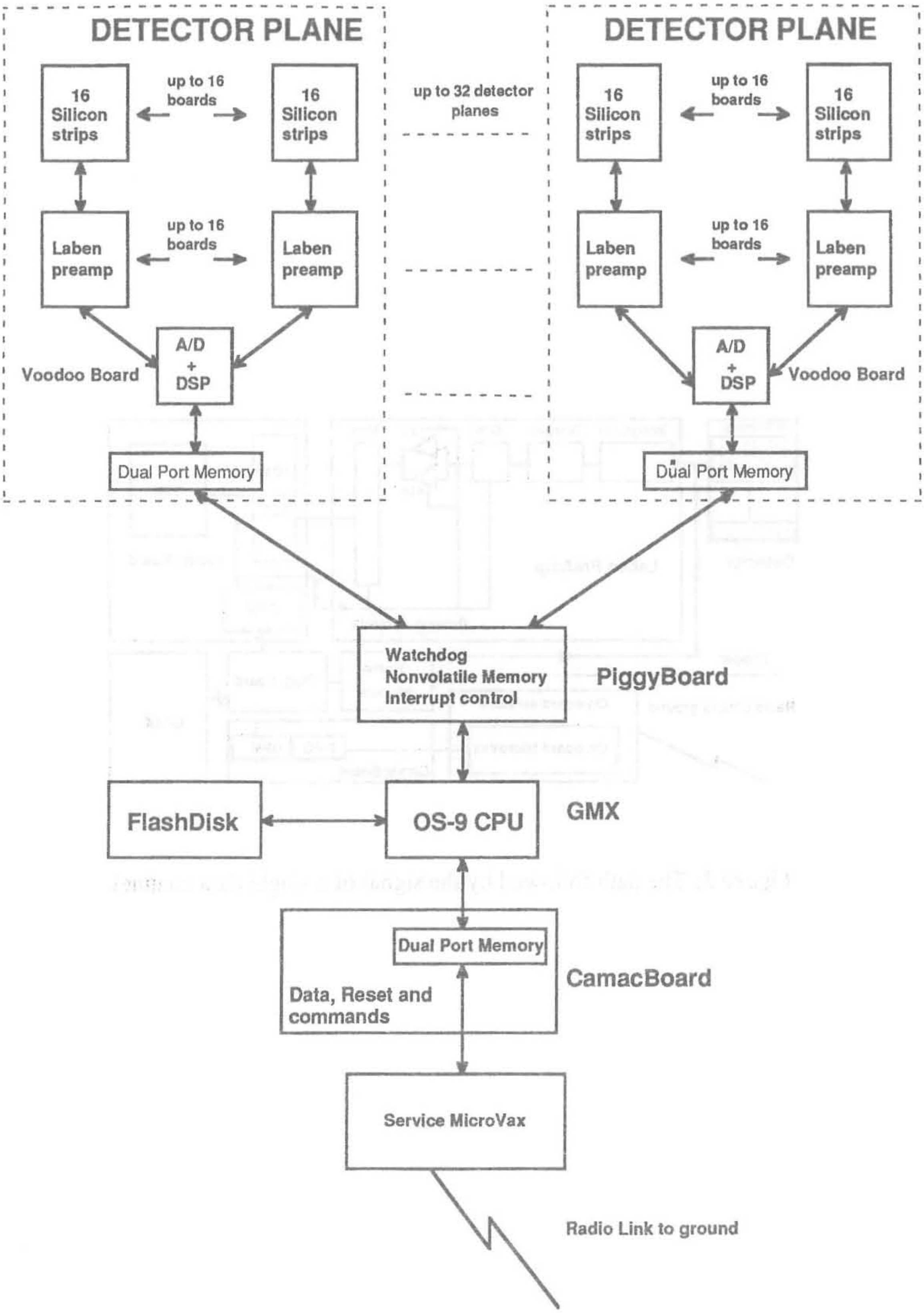

Figure 1: Schematic view of the Widget data acquisition system.

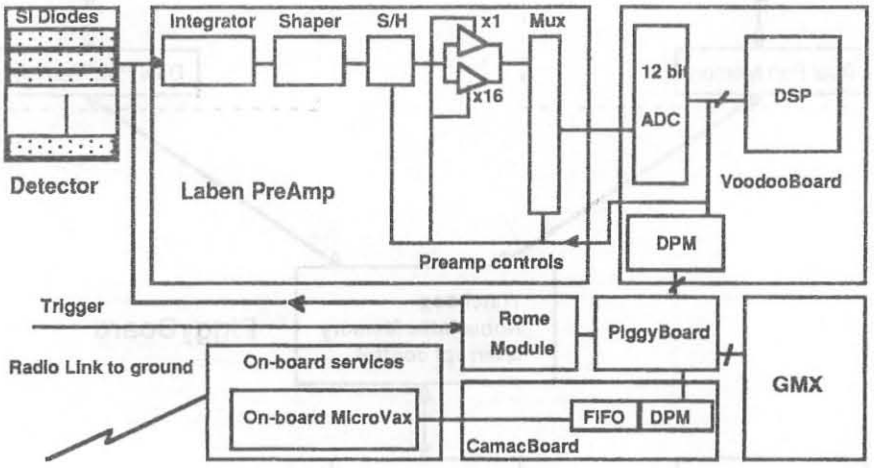

Figure 2: The path followed by the signal of a single data channel.

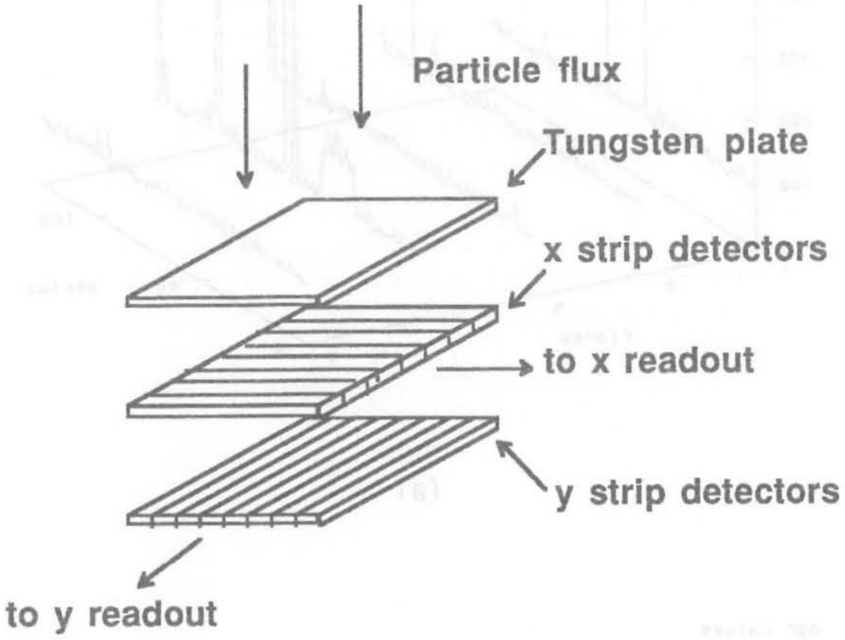

Figure 3: A schematic mechanical assembly for a calorimeter plane showing the position of the silicon strip diodes.

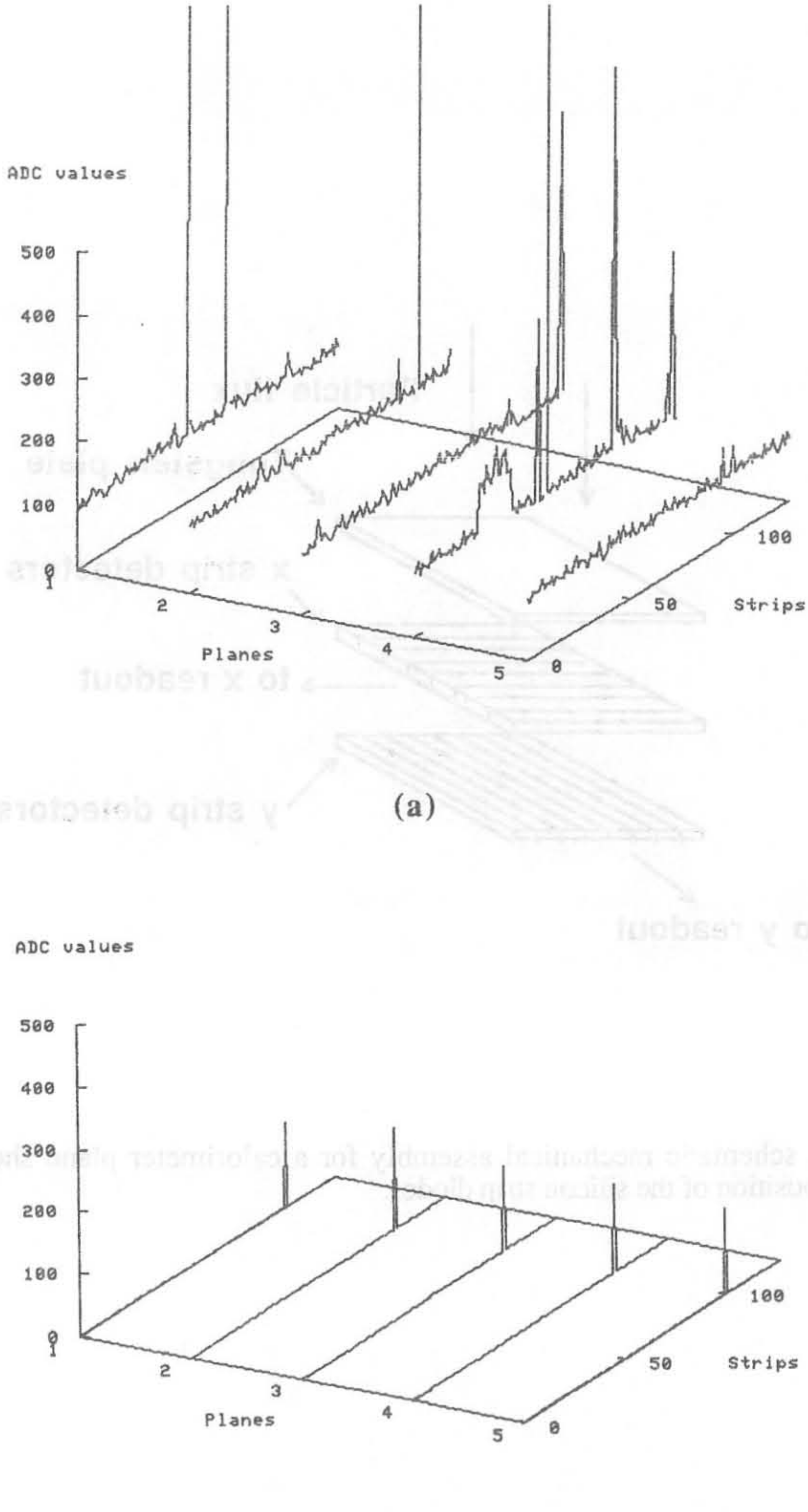

Figure 4: Signals, in ADC divisions, for the x-coordinate strips for an actual muon event. a) shows the raw signal while b) shows only values above 2.5 rms deviations from the noise. It is clearly seen that, even if there are very noisy strips, the individual threshold values for each strip are capable of cleaning the trace from unwanted features.

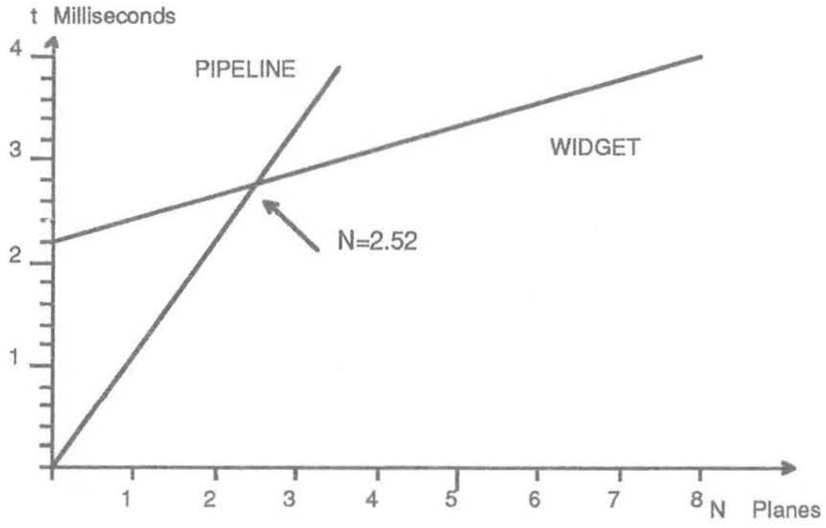

Figure 5: Total time t employed to process one event, for Widget versus a pipelined single ADC system, as a function of the number of planes.