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Appendix A

UCAL Readout

A.1 Introduction

The \textit{ZEUS UCAL} readout system is described extensively in [45, 46]. In this chapter modifications to this system are detailed.

A.2 Transmission Errors

\textit{INMOS} Transputers of Type T2x, T4x, T8x communicate via four serial channels with each other. The hardware transmission protocol does however not foresee any kind of check of the transmission. Tests at \textit{NIKHEF} have shown that the transmission between transputers is very reliable [46] and so it was considered unnecessary to protect against transmission errors.

A.2.1 Transmission Error Detection

During comparisons of data produced by the calorimeter second level trigger system and its offline simulation in \textit{ZGANA} [47] differences were found in the energy sums reported by both sources: The data was transported by different transputer networks to the offline database where the comparison was performed: The second level trigger network sent its results to the global second level trigger system while the readout network sent the data to the event builder. The differences coincided with the event being processed by a particular sub-farm of the \textit{ZEUS} third level trigger system. This meant that the data had been sent over the same transputer link by the event builder system to the third level trigger. Intensive tests showed that indeed the link was faulty and was replaced.

This error triggered the implementation of test procedures and built awareness of the problem.

Transmission errors were then also found to be the cause of various crashes of the transputer network during data-taking.

A.2.2 Transmission Error Cause and Cure

The transputer transmission errors observed by \textit{ZEUS} were caused by a bug on the 2-TP-Transputer modules developed for \textit{ZEUS} [48]. The problem was traced to the transputer clock signal being outside of the specifications and all boards were modified.
A.2.3 Transmission Checks

Since transmission errors can systematically affect data, transmission error checks are put in place to detect such errors early enough.

A.2.4 Dedicated Link Tests

Programs are available to test transputer links in situ. Through these tests, errors can be verified.

Checksums in Offline Data, Offline DQM Tests

Calorimeter data are checked with data banks CxXOR which contain checksums on an event by event basis. The checksums are calculated using a simple XOR of all the data words. Through this checksum, single bit failures can be detected. The calorimeter data quality monitoring also includes a check for transmission errors. Moreover, the calorimeter reconstruction program CCRECON [49, 36] checks prior to reconstructing an event whether a transmission error occurred. If that is the case, the event is not reconstructed.

The calculation of the checksums is done through transputer assembler routines which are highly optimized and perform about 30% better than the OCCAM equivalent.

Checksums in Online Data

Transmission errors can, apart from corrupting data, cause the transputer network to crash, for example if the length of a data array is transmitted and the receiver receives an incorrect number, the receiving transputer can crash because it will find its buffers too small or will wait for the rest of the data forever. For this reason, a number of control messages have been protected via checksums and the transmission will be retried if an error is detected.

Checksums of Calibration Constants

Transmission errors can have much more serious consequences if they occur with calibration constants. In such a case, the calorimeter data would be systematically wrong for all events and such errors might not be detected. For this reason, calibration data are checksum-protected from the time they are generated on the transputer. Also when the constants are modified on the equipment computer, the checksums are tested and recalculated. Finally, when they are downloaded to the DSP before the beginning of a new run, they are checked again by the DSP.

Online Checks of Digital Card Output

Transmission errors can also occur when data are transported through VME from the digital card memory to the transputers. These errors are detected through a data consistency check which is performed on a regular basis while the system is taking data. This consistency check is possible because the DSP code running on the digital cards outputs both the data for each channel to be shipped by the CAL-DAQ to the TLT and also the sum of left and right channel and timing sums to be used by the CALSLT (see [50, 51]). The transputer simply recalculates on a subset of the events the CALSLT data from the CAL-DAQ data and compares it to the digital card output. The test is typically performed every 100 triggers on one of the digital cards.
Transmission Errors in UCAL SLT Network

The calorimeter second level trigger network consists of a large network of transputers. Also here transmission errors were observed which caused the network to crash. In order to avoid these crashes checks were implemented which ensured the synchronization between transputers. It is however not possible to calculate a checksum for all data because then the throughput of the network would be compromised.

A.3 Exclusion from Readout by Event Builder

Transputers allow processes to be executed at two different priorities, the high priority processes can always interrupt low priority processes. Interrupts can be generated through the arrival of data through a link or through the EVT pin of the transputer or through the high priority timer.

It is however possible that a high priority process is descheduled by a low priority process. This was the case for a problem that caused the UCAL transputer readout network to be excluded from the run by the event builder: The event builder system distributes the GSLT message to all components. Those have to accept the message within a certain timeout, a few milliseconds only. Should the component not accept the data within the timeout it will be excluded from the run. This behavior of the event builder is necessary to ensure a high rate of GSLT decisions to be broadcast (design rate 1 kHz). In the UCAL case the data are broadcast through the control and switch box (CSB) to all READOUT transputers. The data are not buffered but each byte is transmitted to all transputers and only if all transputers have acknowledged the receipt an acknowledgement is sent back to the event builder. In order to ensure that the data can be received a high priority process was set up who’s only task it was to buffer the data and send it to a low priority process. The high priority process sent the data through a transputer channel. This was the problem though, the low priority process, if it was not capable of receiving the message, caused the high priority process to be descheduled. The problem was only diagnosed when the GSLT simulator (see section B.7) was installed and then fixed by enabling a simple round-robin buffer between the high priority and low priority process.

A.4 Features added to the Readout System

A.4.1 Readout of other Subdetectors

The calorimeter readout system was extended to readout more components, SRTD (Small Angle Rear Tracking Detector), PRES (Forward and Rear Presampler), FNC (Forward Neutron Calorimeter), PRT (Proton Remnant Tagger), BPC (Beam Pipe Calorimeter), SRTDFLT (First Level Trigger of the Small Angle Rear Tracking Detector) and BRES (Barrel Presampler). All these components are based on the readout of photomultipliers and use the same or only slightly modified front-end electronics as the UCAL. As a result of the use of one readout system for these components the cost as well as number of people necessary for maintenance is greatly reduced.

A.4.2 Testtrigger processing

The calorimeter readout code is capable of calculating the mean and r.m.s. of the readout values for testtriggers. Since most of the detector monitoring is based on these values the monitoring
task could be speeded up dramatically by calculating these values online and only transmitting the result at the end of the run.

A.4.3 Startup Procedures

The startup of the transputer network is significantly improved over older versions because the calibration constants, about 3.8 MByte of data, do not have to be downloaded. Instead the calibration constants are loaded once and stored in the READOUT transputer memory. Even when the transputer is rebooted at SETUP the data are still present and can thus be downloaded immediately. The data are checked with a CRC checksums. The calorimeter network setup time could be reduced from several minutes to only a few seconds.

A.4.4 UCAL Electronics Calibration

The calorimeter electronics calibration consists of a number of runs with different settings of the electronics. This way the pedestals and gains of each pipeline chip as well as the gain of each buffer chip can be measured. This process took up to several hours because all the data had to be written to disk and then calibration constants had to be generated. This process was significantly improved by generating the electronics calibration constants directly on the transputers. In order to do that the data had to be stored locally. On the READOUT transputer however with its 4 MByte of RAM there is not enough space. To solve this problem a system by which the memory of the adjacent “layer-1” trigger transputer could be used had to be developed. Both transputers communicate via the triple ported memory to exchange the data which is then stored in a simple way on the layer-1 trigger transputers’ memory.

A.4.5 CAL-DAQ Monitoring Task

Some errors in the transputer programs are very difficult to debug. This is due to the fact that the communication is not reliable (see section A.2) and due to the complexity of the task to be performed. Sometimes the system stops without any indication of a reason. To improve this situation, counters were introduced at many processing steps in the system. These counters are written into TPM, together with counters produced by the CALSLT transputers. A process on the main control transputer of the network monitors the data acquisition. If no events are sent to the EVB for several seconds, the process asks all READOUT transputers to send the counters and it then analyses the counters to determine if the problem is inside the CAL-DAQ or somewhere else and generates appropriate warning messages.

A.4.6 Speedups

Loop Unrolling while Re-Ordering

UCAL second level trigger processing is based on the same data that are used for readout. The LAYER-1 processing algorithm requires the data to be ordered in a certain way, but the front-end channels are not connected in the same order to the digital cards. The original algorithm foresaw the trigger processors using a double-indexed list to access the data. Since the “READOUT transputer” only had to process events at a rate of 100 Hz while the “trigger transputer” has to operate a 1 kHz the job was split into a reordering step performed on the “READOUT transputer” while the “trigger transputer” accessed the list through a single indexed list. The
reordering step however was still done using a double-indexed list. By loop-unrolling this step could be speeded up significantly.

A.5. "EVENT PLAYER"

Achieved Speed

The calorimeter readout system can send events to the event builder at a rate of 102 Hz which is more than the design rate of 100 Hz. During normal data taking this rate is not achieved however because other ZEUS subdetector readout systems and the third level trigger system can not keep up with that rate.

A.4.7 Data Compression

The ZEUS calorimeter readout data are compressed to reduce the amount of storage space used offline but also in order to improve the throughput of the higher level trigger systems. The compression leads to a reduction of a factor 5 in size without any loss of data.

A.4.8 Reverse Polish Notation Processor

For the readout of the LED and LASER components the calculation of the data required the implementation of a reverse polish notation processor. It allows the modification of the online reconstruction algorithm through downloading a parameter file which contains the formulas. These formulas are programmed using reverse polish notation.

A.4.9 Standalone Run-Control

Standalone tests of the calorimeter readout and second level trigger system require a flexible runcontrol system. This was implemented and is now part of the host transputer program. An environmental variable selects whether the host transputer uses the standard runcontrol system or the standalone system.

A.4.10 Multiple DSP Code Types

The DSP code which calculates energy and time from the samples taken by the front end system is dependent on the component read out. In order to allow several components to be read out, different versions of DSP code can be downloaded.

A.4.11 Begin-Of-Run Data Banks

Startup of the calorimeter readout system was delayed by downloading begin-of-run data banks from the equipment computer to the transputer network which were subsequently forwarded into the data stream. The data downloaded included a list of bad channels. This list is available though on each READOUT transputer through the calibration constants. So at the beginning of a run each readout transputer generates the bad channel list and enters it into the data stream.

A.5 "Event Player"

A special version of the DSP code was developed which uses the memory of the digital cards to be used as event store. Upon a signal the DSP starts to act as if it was receiving first level trigger decisions. This feature is used to do performance tests of the readout and second level trigger
network. Before starting event data can be downloaded together with the rate at which the
digital cards should “play back” the data. Together with the GSLT simulator (see section B.7)
this provides the possibility to test the UCAL data acquisition and second level trigger system
independently of the rest of the ZEUS data acquisition system. The only difference is that
the digital cards are running asynchronously while for normal ZEUS operation all digital cards
receive the first level trigger at the same time. As a result during “event player” simulation, if
the event player rate is higher than the rate that can be handled by the CALSLT some of the
digital cards report a “buffer full” condition while others don’t. This however does not affect the
operation of the CALSLT or CAL-DAQ algorithms as they have large enough buffers to allow
for the event processing on different processing elements of the same level to be out of synch.