The fast Readout of HCAL1 and HCAL2 for the COMPASS Muon Trigger

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Abstract

In this paper the hardware concept of a part of the COMPASS muon trigger is described. It presently consists of a system of hodoscopes at about 30-50 m from the target which are used for muon tracking and a parallel readout of the hadron calorimeters HCAL1 and HCAL2 which provides information about the hadronic final state of a muon scattering event and which is the main topic of this note. A muon veto system 2-8 m upstream of the target is also part of the trigger system.

1 Introduction

The physics questions of the muon scattering part of the COMPASS experiment require a diversity of trigger concepts which make use of different pieces of hardware. The newest and most challenging part of the muon program is the measurement of the gluon polarisation. The experiment makes use of the high flux of circularly polarised quasi real photons in the scattering of muons of 100-200 GeV on a polarised proton or deuteron target. The hard scale in the processes observed is introduced by the selection of events with open charm or the requirement of the observation of two hadrons with transverse momenta in excess of 1-2 GeV/c.

Inelastic processes with a four momentum transfer close to the lower kinematical limit, which corresponds to forward scattering, can be described with the concept of quasi real photons. The use of two dipole spectrometers allows us to determine the energy of the quasi real photon by determination of the scattered muons deflection. This resembles the well known photon tagger concept. Allowing for finite scattering angles of a few mrad($\approx 5\,\mathrm{mrad}$) necessitates the introduction of a second measurement of the position in the magnetic deflection coordinate.

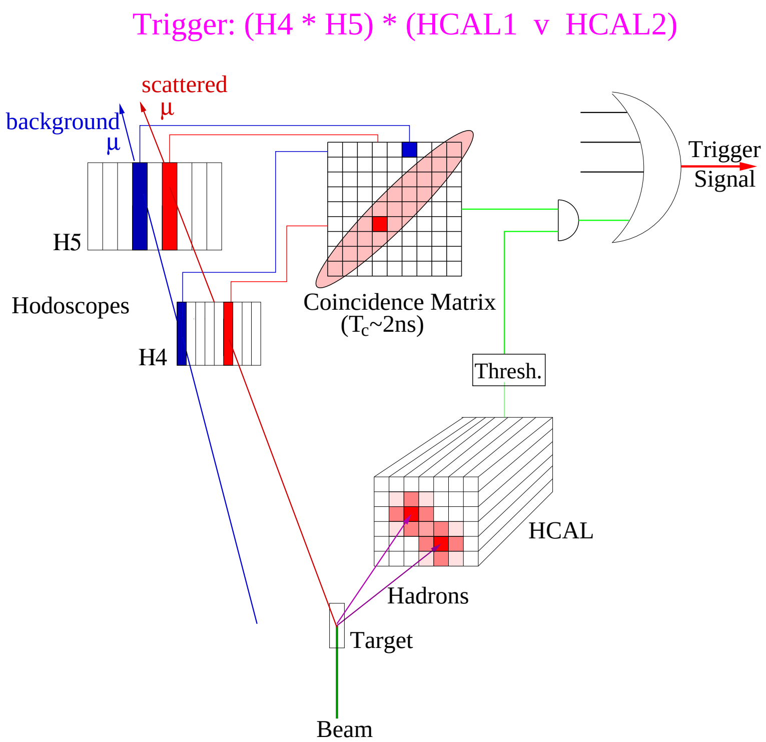


Figure 1: The trigger for quasi real photon events consists of the two hodoscopes H4 and H5 for muon tracking and the hadron calorimeters HCAL1 and HCAL2 for coincident hadron detection. The figure also shows the matrix for track selection and the logic for the formation of the quasi real trigger.

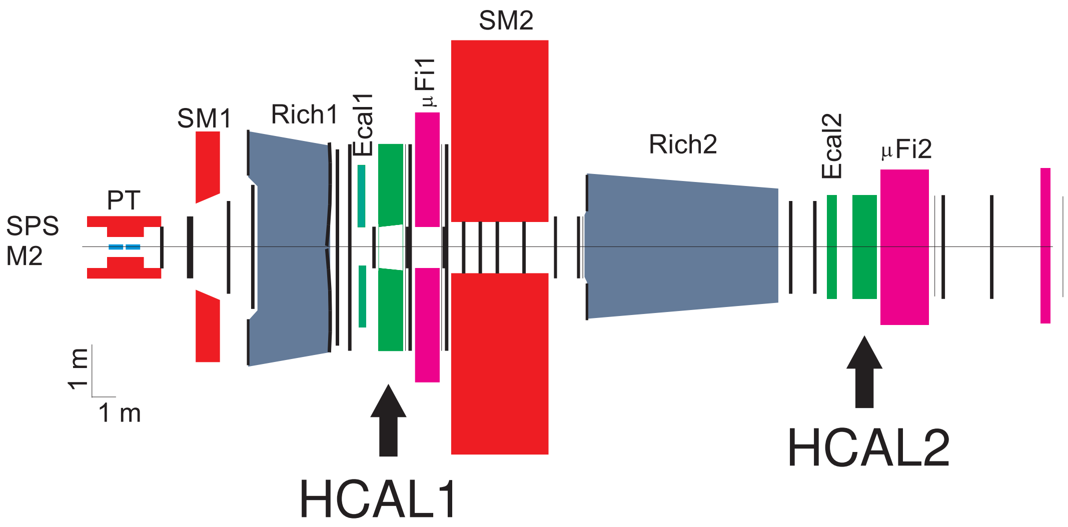


Figure 2: Top view of the COMPASS experiment. The positions of the hadron calorimeters HCAL1 and HCAL2 are indicated by arrows.

In fig.1 the correlated measurement of the scattered muons track coordinates is shown. This part of the muon trigger, called the geometrical trigger, is described in detail in M.Leberig's thesis. This trigger is supplemented by a veto system which suppresses halo tracks which is still under development (J. Pretz, C.Bernet) and the calorimetric trigger which is described in this note.

In addition to a muon track candidate with a minimum energy loss ν_{min} coming from the target, the calorimetric trigger asks for a minimum deposit of **hadronic energy** in at least one of the two hadron calorimeters HCAL1 and HCAL2. Fig.2 shows a top view of the COMPASS experiment. The positions of the two hadron calorimeters are indicated by arrows. In the final version of the COMPASS experiment both hadron calorimeters will have electromagnetic calorimeters (ECAL1 and ECAL2) in front of them. This protects them from electromagnetic showers initiated by photons or electrons. Alternatively for HCAL2 there exists a lead wall of 10 cm thickness which can be used to shield HCAL2 from electromagnetic showers in the absence of ECAL2.

The dual trigger system allows to reject inelastic muon scattering events with an energy loss below the threshold defined by the physics problem. The measurement may require a threshold energy loss as in $c\bar{c}$ production or a minimum photon polarisation. The main purpose, however, is the rejection of events with no hadrons in the final state like radiative events, Moeller scattering and halo muons. The largest single rate in the trigger hodoscope stems from beam tracks with large horizontal divergences which pass through the two hodoscopes and give rise to a ridge in the correlation matrix shown in fig.1. This ridge is excluded from the trigger acceptance and fully suppresses these events. In the case of multiple hits

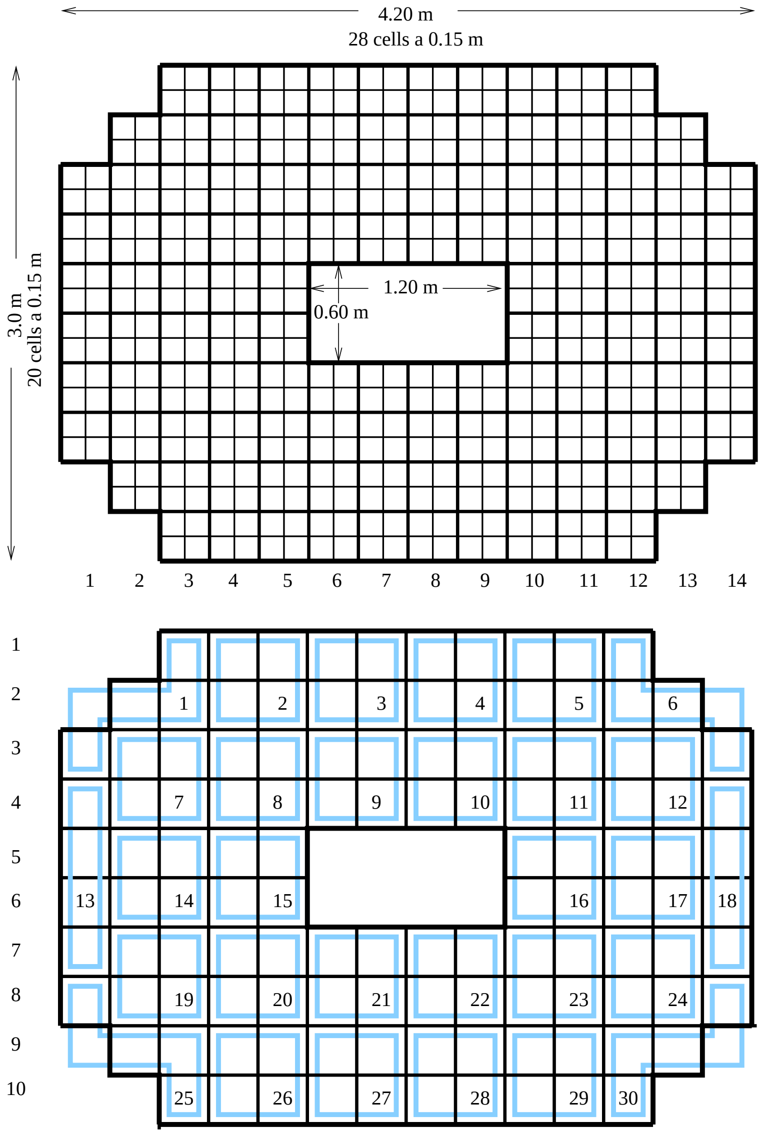


Figure 3: The shape and the distribution of the 480 cells of HCAL1 are shown in the upper part. In the lower part only modules of 2x2 cells are shown. The grouping of the modules into splitter boxes numbered from 1 through 32 each serving a maximum of four modules is indicated. The boxes which sit on the downstream side of the calorimeter are connected to the trigger barrack with a 25 m cable with four twisted pairs.

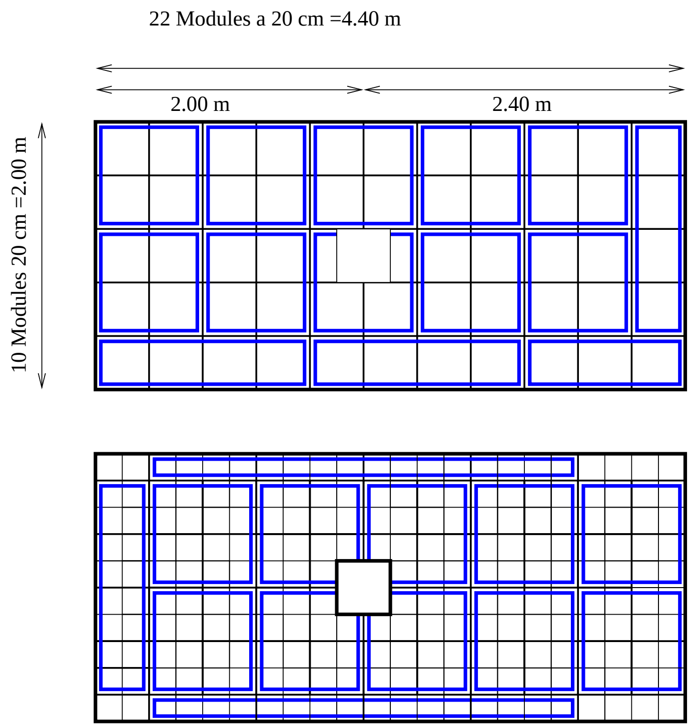


Figure 4: HCAL2 is 22 cells (20x20 cm^2) wide and 10 cells high. The beam hole which is **not** in the centre corresponds to 4 cells (40x40 cm^2). There are 216 elements grouped in 14 splitter boxes. The lower figure, in which all cells are shown, corresponds to an alternative, more symmetric grouping of cells into modules.

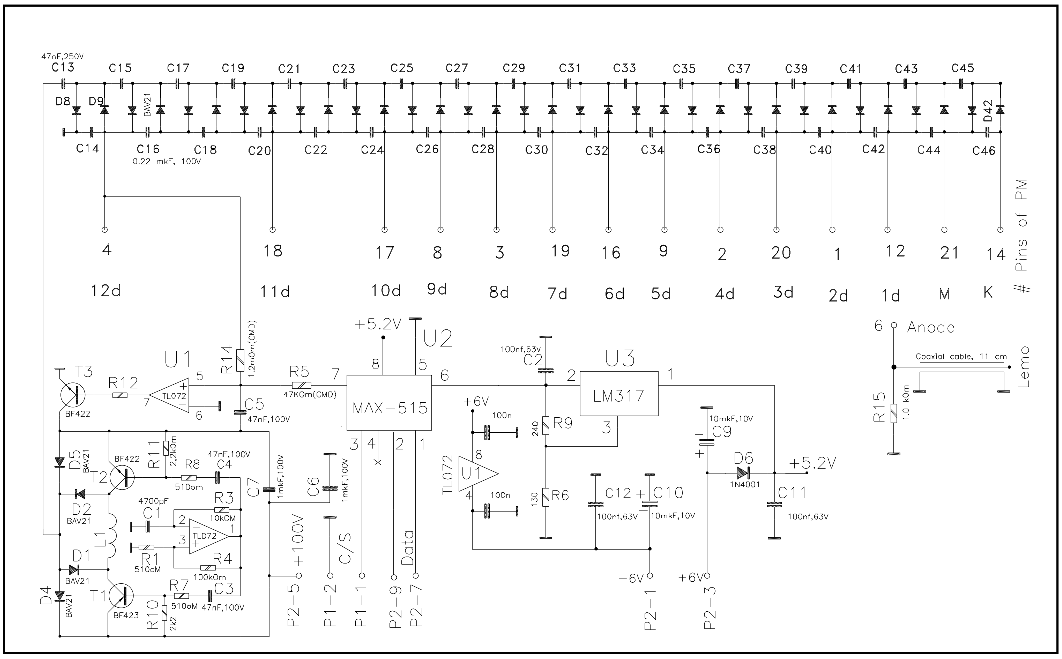
such a suppression is incomplete due to “ghosts” in the allowed matrix region. The calorimetric trigger, requiring the presence of a hadronic final state, removes this type of false triggers. A reduction of the trigger rate to values below 10-20 kHz is required due to the limited bandwidth of the data acquisition system.

The geometrical trigger has been studied in great detail and has been described elsewhere. In this note we summarise the properties and features of a system of parallel readout of the existing hadron calorimeters HCAL1 and HCAL2 for trigger purposes. Except for the split off of signals near the photo tubes there is no interference with the standard calorimeter readout.

2 The general layout of the calorimeter trigger

The nature of a hadronic cascade in a modularised Fe-Sci sampling calorimeter needs some processing of the raw analog data before they are useable for a highly selective trigger decision. Generally the energy of a single hadron in a calorimeter wall of sufficient depth (5-6 λ) is spread over several neighbouring calorimeter cells which are usually chosen to have a square face of typically 20x20cm^2 or 15x15cm^2. More than 90% of the energy of a hadron cascade is deposited within a cylinder with the radius λ, which corresponds to 20 cm for a sampling calorimeter with a 2 cm Fe +.5 cm Sci. period. Consequently a signal corresponding to the total hadron energy can only be obtained by summing over an area of 60x60 to 80x80 cm^2 centred around the impact point. This operation has to be performed fast enough in order to derive a trigger signal to enter in the first level trigger decision i.e. within 300-400 ns. The timing information of the energy deposit has to be preserved as precisely as possible in order to relate the information to an event candidate derived from hodoscope information. Typically a RMS timing resolution of 1 ns can be achieved by utilising a CFD.

The hadron calorimeters in the COMPASS experiment are exposed to a muon halo. The halo distribution has been measured and simulated. The total rate in the hadron calorimeters is of order $10^6 - 10^7\,s^{-1}$, dominated by the cells near the beam holes. The pulse length of the calorimeter signals at the multiplier outputs is typically 50 ns wide so that the random pileup probability is of order 0.1-1. This forbids a summation of the cell signals over the full surface of the calorimeter. The energy deposit of a muon is highly localised, usually in a single cell. The energy response is described by the Landau distribution peaked at 1 Mips corresponding to a hadron energy of typically 2 GeV.



HCAL1 Cocroft–Walton PMT (FEU–84–3) base

Figure 5: The Cockroft-Walton base of the PM readout of HCAL1

2.1 Readout of HCAL1

The calorimeter HCAL1 comprises of 480 cells set up in a rectangular frame shown in fig.3 It is contained in a matrix of 28 x 20 cells. In the 4 corners 12 cells are removed and in the centre a rectangular window of 4x8 cells is left free to give access to the second stage of the spectrometer. The resulting number of cells is 560-4x12-4x8=480. Each cell has a front face of 15x15 cm^2 which results in an overall size of 3 m height and 4.20 m width. It was found that for trigger selection purposes a summation over an area corresponding to the typical size of a hadronic shower is needed. A module of 2x2 cells corresponds to 30 x 30 cm^2. As shown in fig.3 there are 120 such modules. The wavelength shifter panels are read out with a PM-84-A phototube. The PM-base which is shown in figure 5, is of the Cockroft-Walton type. Typical rise times measured at the anode are 12 ns. To preserve this rise time for later timing discrimination, the bandwidth amplification of this first summation stage has been chosen to 100 MHz with an amplification factor 2.

In order to preserve good baseline stability the grounding of the various circuits attention has to be given to grounding problems. The summation boxes are grounded statically to the body of the calorimeter over a 2 KΩ resistance which connets the ground of the board including the Lemo connectors to the metallic

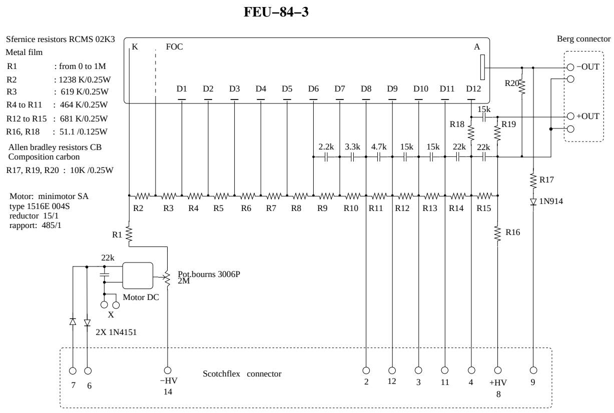


Figure 6: Diagram of the FEU-Base used for HCAL2

box. They are supplied with a DC-DC converter. The cable shields of the lemo cables and the 4x-twisted pair cable are connected to the box. The common grounding should be at the input of standard readout ADCs through the shield of the RC-50-3-31 cables.

2.2 Readout of HCAL2

The cells of HCAL2 shown in fig.4 are larger (20x20 cm^2) than in HCAL1. There are 216 cells in a matrix of 10 rows and 22 columns. There is a quadratic window of 2x2 (40x40 cm^2) cells foreseen with the centre moved 20 cm to the Jura side taking care of the beam deflection. Again modules of 2x2 cells corresponding to 80 x 80 cm^2 are formed and summed in the same type of boxes as for HCAL1. The situation in HCAL2 is different than that in HCAL1 since there is overlap of the active calorimeter surface and the trigger hodoscopes. A muon with an energy deposition of more than 3 Mips can be easily correlated with a track. This could not be studied up to now since the HCAL2 was not in perfect calibration state during the 2000 running.

2.3 The splitter boxes

The means to provide a signal for triggering purposes without compromising the quality of the analog signal are the splitter boxes. In fig7 a part of the rear view of a hadron calorimeter is shown. Four (2x2) cells are grouped into modules which are also indicated in fig.7. In the splitter boxes a summed signal corresponding to a module is formed. Four independent modules are formed in one physical box. This reduces the number of signals available for triggering purposes from 480 to 120 in HCAL1. The coarser subdivision of the calorimeter for triggering purposes is a compromise of cost and performance.

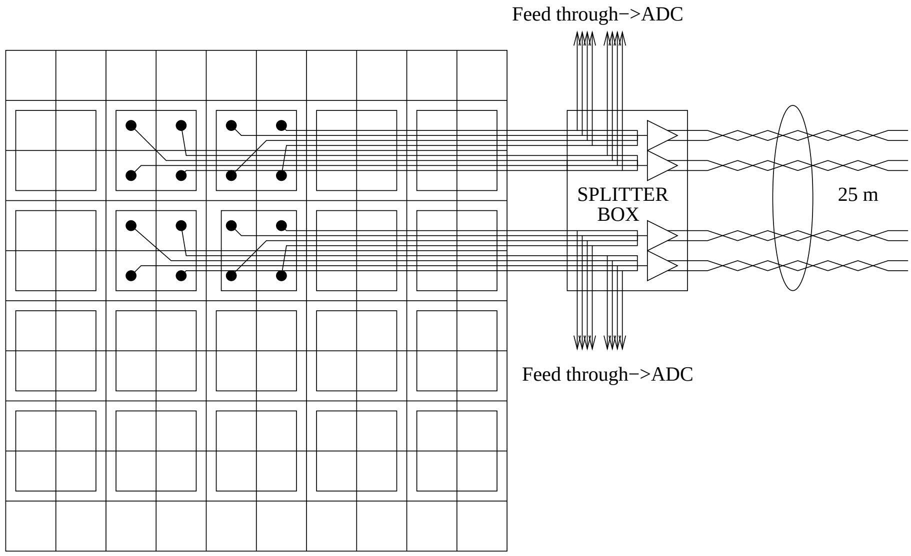


Figure 7: Readout of 16 cells and summation to 4 modules in the "Splitter-Box"

2.3.1 Description of the Splitter Box

The splitter box is designed to split an analog signal off the original PM output of the calorimeter with a minimum disturbance. The bandwidth is typically at 100 MHz and the amplification can be chosen between one and two. The splitter/summation circuit is shown in fig.8.As shown in fig.7 one box serves a total of 16 cells. Four groups called modules of 4 cells are formed. The original signals are fed through and the signals of 2x2 cells are summed to form module signals. The boxes are distributed over the downstream side of the calorimeter. The signal from the PM-output shown in fig.6 is fed into the box by a variable length standard lemo cable. The typical length of the lemo cable is 1-2 m. The length has to be sufficiently long to connect the box with the 16 elements corresponding to a square of $60 \times 60\,cm^2$ (HCAL1) or $80 \times 80\,cm^2$ (HCAL2). The cable length can be increased to compensate for individual signal delays before summing them to form a module. Such time spread is expected from different supply voltages of the photo tubes which in turn are necessary to obtain a common response in mV/GeV (hadrons) for all elements.

Since the individual delays are not known before a calibration procedure is defined, we will use cables of 1-2 m length initially. The splitter circuit is shown in fig.8. The original signal is fed through a lemo connector to go into the regular readout cables. The signal picked off with a 1 kΩ resistance is amplified and summed with three additional signals to form the module signal. This signal is symmetrised to drive a twisted pair cable of 25 m length which connects the module signals formed near the calorimeter with the trigger hut. Each cable bundles four such twisted pairs. They use 9-pin D-connectors on both sides.

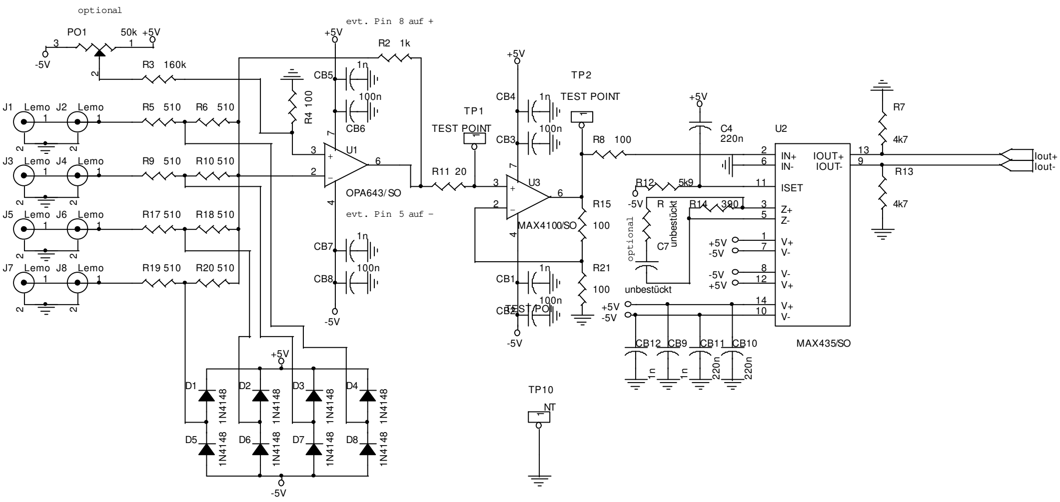


Figure 8: The scheme represents 1/4 of a summation box. The 4 input signals and the feed through signals are visible on the left side. The inputs to the summation stage are diode protected. The MAX amplifier on the right drives the twisted pair cable with a symmetrical line signal.

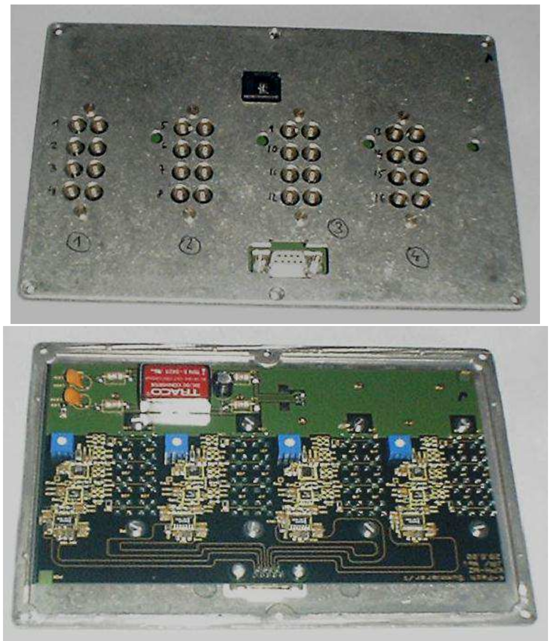


Figure 9: Photos of the splitter box. The top side (left) has 32 input-feed through lemo connectors for four groups of 4 cell signals. The 9pin D-connector is used for the 4 twisted pair output signals. The RG8 connector is used for the low voltage supply. The right side shows the printed cicuit board connected with the cover of the box.

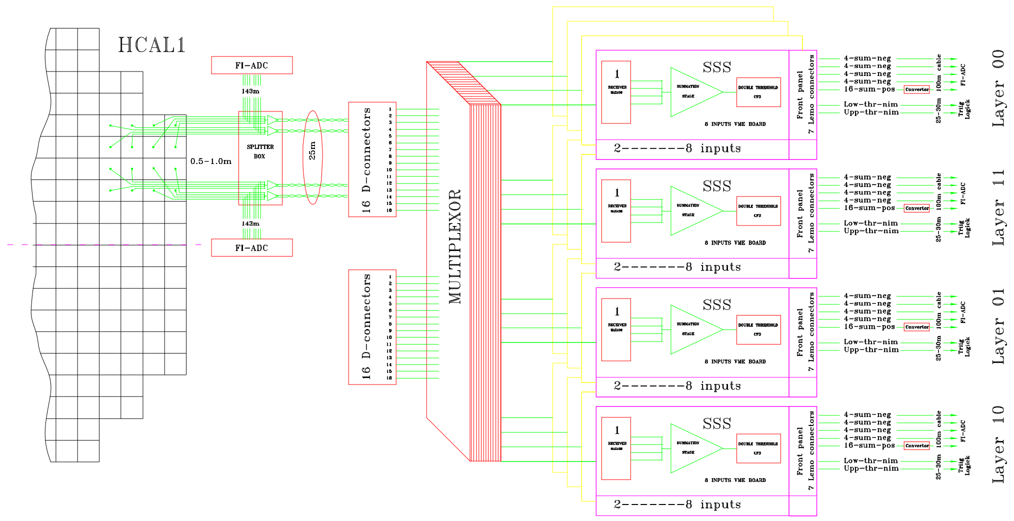


Figure 10: The complete readout chain comprising of the splitter/summation boxes (left) the multiplexer network forming the four layers and the second summation stage with the 4x4 sums and discriminators (from O. Gavrichtchouk)

2.4 Second Summation Stage and Pulse height Discrimination

The complete readout chain is shown in figure 10. The electronics in the trigger barrack receives the signals from the splitter boxes. Each of the signals is passively split into 4 identical signals. This is performed on a backplane which receives the cables from the calorimeter and regroups the module signals into different combinations. This stage allows the formation of 4 different pattern covering the calorimeter surface. The programming of the 4 layers is made by patch cables which regroup the incoming signals in sets of 4.

Unused outputs are properly terminated into 2x50 Ω. The second layer is formed by grouping the module signals according to fig.11. Using this layer obviously improves the signal to noise ratio by a factor two since it takes care of hadrons impinging near to the corners of the 4x4 groups of layer 1. In this layer these events would be central.

The groups of signals to be summed are formed on a back plane which receives the cables representing the subdivision shown in fig.3. The incoming signals enter in a top row and a bottom row of 16 D-connectors each. The space in between is used to "program" the various combinations which make up the layers 1-4. The programming is done by connecting the output D-connectors with the appropriate set of the multiplexed (4x) input signals with twisted pair patch

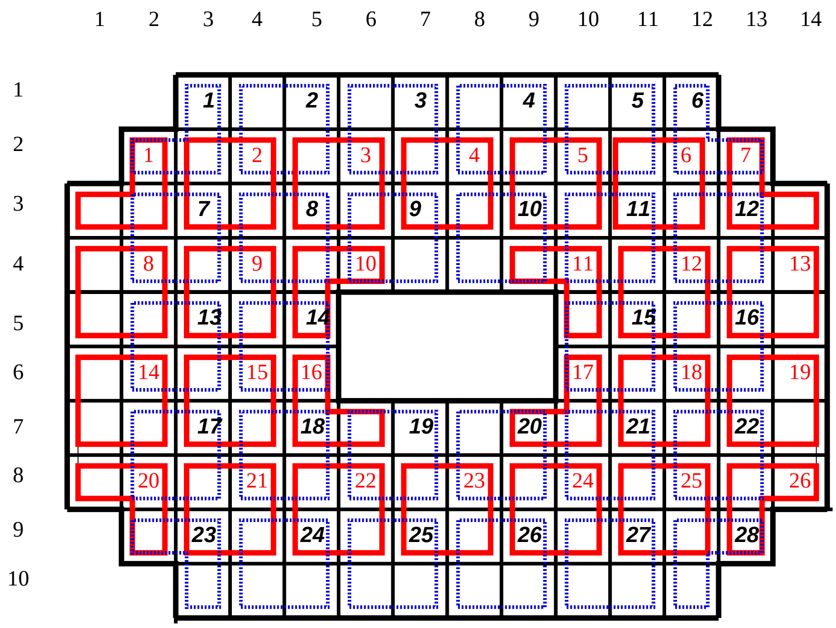


Figure 11: This figure shows two different subdivisions of HCAL1. In addition to the layer 1 which is organised almost exactly as the distribution of the splitter boxes as shown in fig.3 (dashed) a new layer 2 with boundaries shifted diagonally by one module size is shown. Sums which correspond to only two modules are left out since they would reoccur in layers 3 and 4. Layer 1 needs 28 and layer 2 26 summation channels.

cables. The width of the backplane is 32 cm. The patch cables are 20 cm long.

Eight such quartets are then connected to the rear side of a single 9 unit VME board by 8 D-type 9 pin connectors. The VME board called the second summation stage (SSS) shown in fig.13 performs the summation of each quartet shown in fig.14 and the triggering of the summed signal shown in fig.15. The quartet of signals and their sum is available as lemo connectors on the front panel of the board.

The discriminator is a constant fraction discriminator with a fraction of 0.5 optimised for signals with rise times of 5-10 ns. Two different output signals are generated corresponding to two different threshold values. Threshold values can be set through a programmable interface.

The coverage of the HCAL1 surface with 4 different subdivisions (L00,L11,L01,L10) is depicted in fig.11and fig.12.

Each board of the second summation stage can form 8 sums of 4 modules and apply two different thresholds to it. Four boards can handle 32 summation channels which is sufficient for one layer.

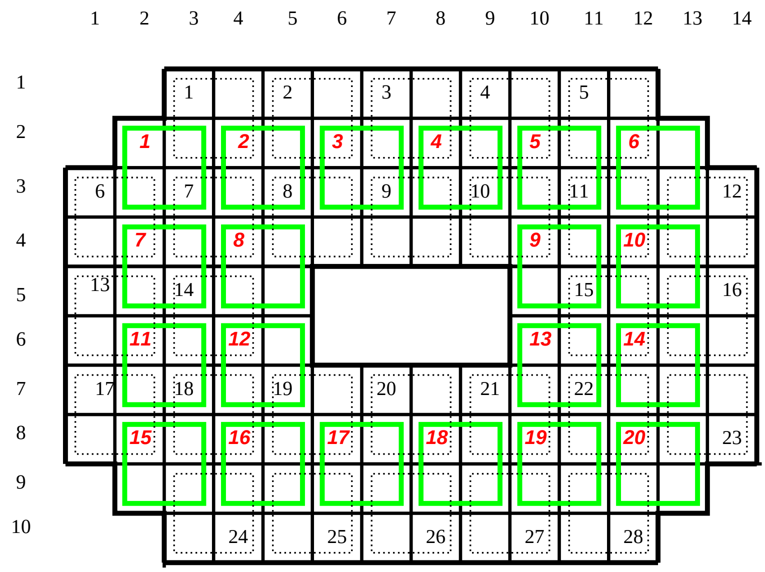


Figure 12: The 20 sums corresponding to layer L01 (full/green, one module down relative to L00) and the 28 summation channels corresponding to layer10 (dotted/black, one module to the right relative to L00).

HCAL1	# of 4x4 sums	Thr. 1+2	analog (4x4)	analog (2x2)
Layer 00	28	56	28	
Layer 11	26	52	26	
Layer 01	20	40	20	
Layer 10	28	56	28	
1-4	102	204	102	120

A total of 16 boards in one VME crate is needed to handle all four layers of HCAL1. It would be possible in principle to use only 13 boards to form all sums. But a topological grouping of the multiplicity units in 4-quadrants requires 4 boards per layer. There is a maximum of 128(120) module signals and 128(102) different combinations to sum 4 or 3 modules. Two discriminator outputs are available for each of the 128(102) combinations which leads to 256(204) logical timing signals.

HCAL2	# of 4x4 sums	Thr. 1+2	analog (4x4)	analog (2x2)
Layer 00	10	20	10	
Layer 11	10	20	10	
Layer 01	10	20	10	
Layer 10	10	20	10	
1-4	40	80	40	55

In fig.17 the four layers of HCAL2 are shown. Each layer requires 10 summation channels which can in principle be handled by 5 boards. Again a reasonable

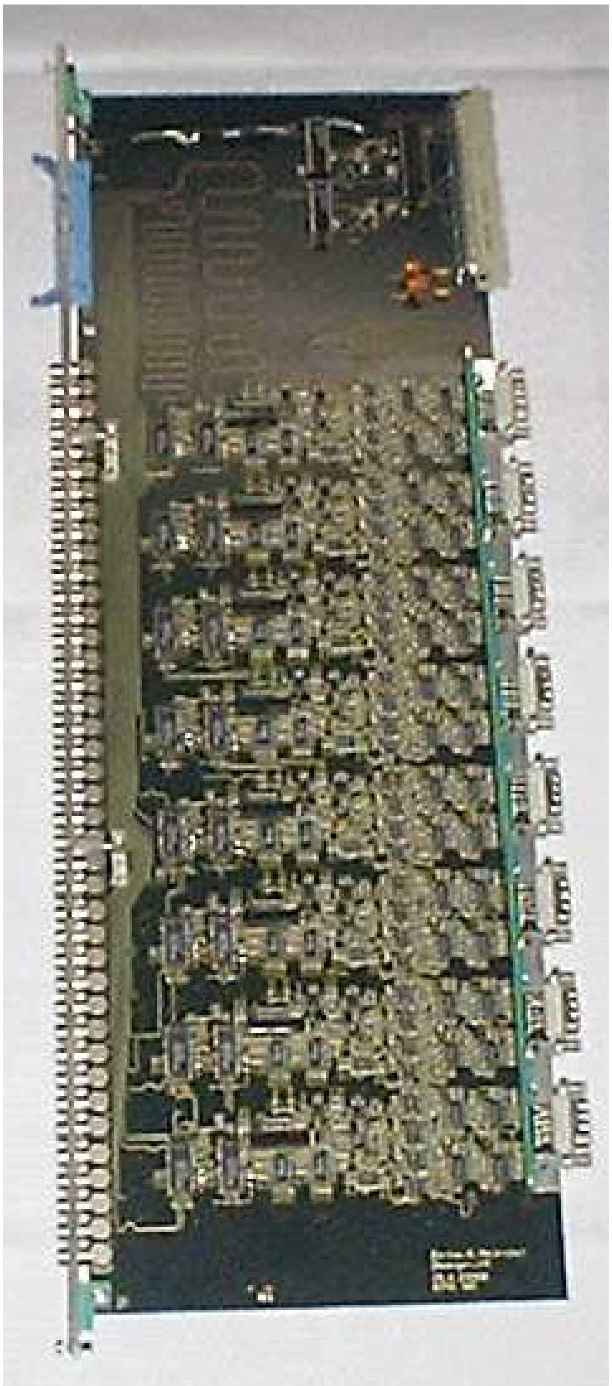


Figure 13: Photo of the Y2000 version of the second summation stage (SSS) 9-unit VME board. The twisted pair signal cables enter from the right. The incoming signals and the sums are available on the front panel lemo connectors (left). The trigger outputs for the two different thresholds are available as ECL-signals on a 32 pin connector near the top of the front panel. The Y2001 version will have the multiplicity logic of fig.16 on the free area near the top of the board.

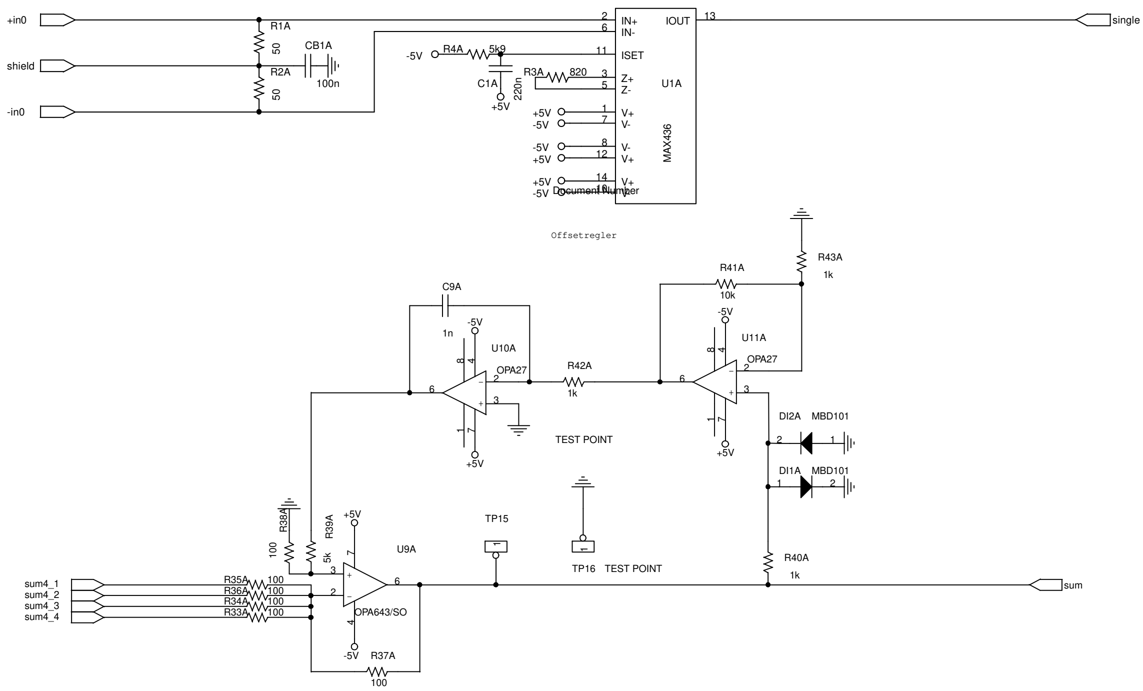


Figure 14: The upper part shows the receiver circuit for the twisted pair signal. The lower part shows the second summation stage. Signals from four modules are summed. A special circuit shown in the lower part of the figure fixes the baseline.

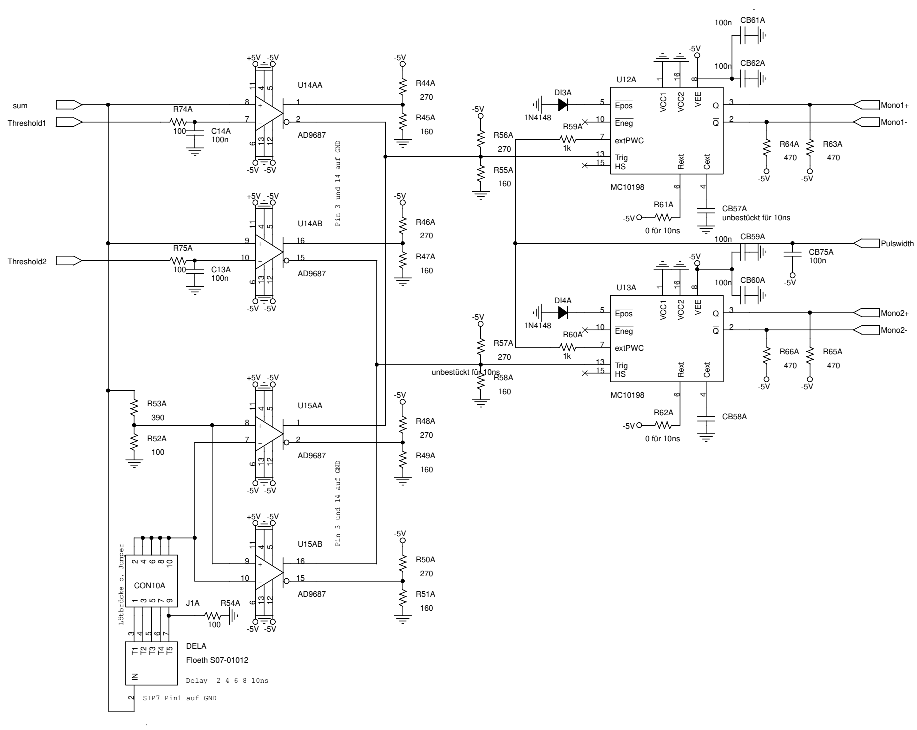


Figure 15: The summed signal is fed into the double threshold+constant fraction discriminator. Two different thresholds can be applied to the same signal. The discriminator outputs are formed by a mono stable to provide an updating discriminator. The dead time can be varied from 10-50 ns

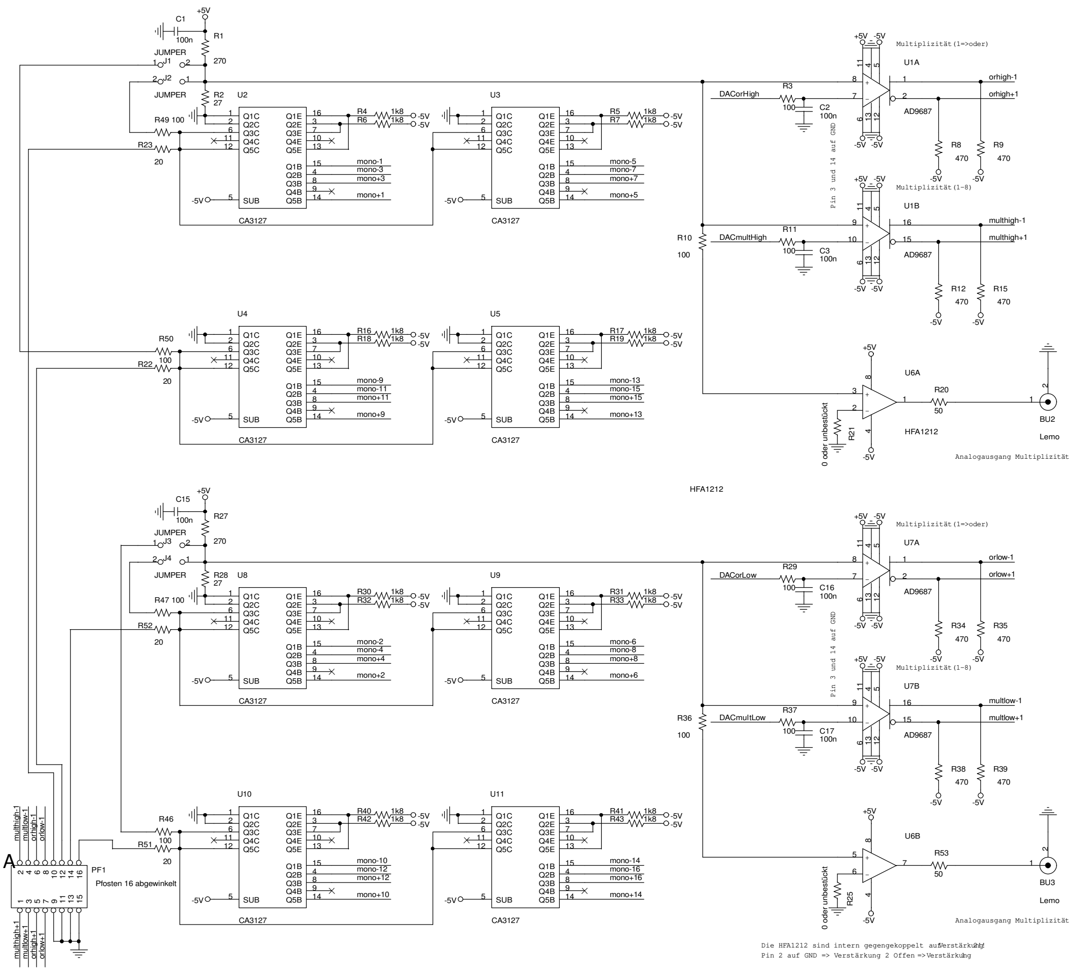


Figure 16: Multiplicity unit for the discriminator outputs of threshold 1 and 2. The outputs of 8 discriminators are wired together to produce a signal proportional to the number of discriminators above threshold. This sum is formed for the lower and upper 4 channels independently. The two groups can be jumpered together. The sums are made available on a front panel connector.
Additional sums from neighbouring boards can be fed into the same connectors to form a multiplicity signal for a larger group of channels.
Two variable thresholds can be set on this multiplicity signal to provide an "or" output and a multiplicity-n output.

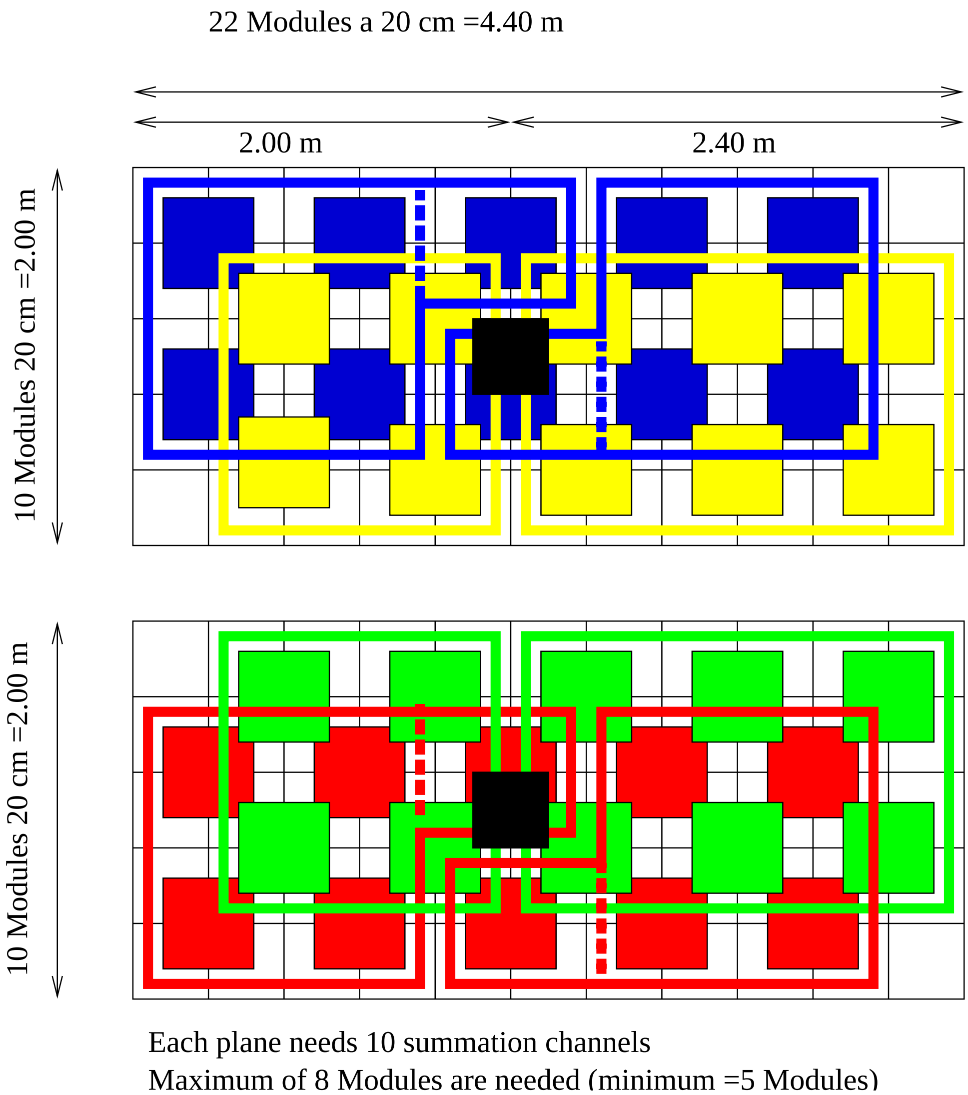


Figure 17: Readout of the 4 layers of HCAL2

subdivision in two halves (R-L) requires 8 boards. If instead of a 5+5 a 4+6 subdivision of the layers is used we can reduce the number of boards to 6.

The number of boxes for the summation stage 1 of HCAL2 is 14. For the readout of the HCAL2 signals of the secons summation stage 80 timing channels are required. One catch with 128 is sufficient for that purpose. There are 55 analog module signals and 40 different sums of 4.

In addition to the 2x8 discriminator signals each board has 2 independent multiplicity units handling the discriminator outputs of threshold 1 and 2. The multiplicity unit is shown in fig.16. It produces the analog sum of the upper and lower 4 channels which can be combined by an appropriate setting of jumpers. The analog sum is discriminated in a system of two threshold discriminators which can provide an "OR" by setting the multiplicity threshold to 1.

Programming of thresholds

The two trigger thresholds of the individual channels and the threshold for the multiplicity circuits shown in fig.16 can be set by a programmable interface. The interface is driven by an Ethernet terminal adapter. Digital values can be set for all discriminators of the second summation stage with values ranging from 0-255 corresponding to 0-512 mV or 1024 mV.

Two different multiplicity thresholds can be set for each summed logical output. One additional hit corresponds to 30 mV.

Calibration Procedures

Two conditions have to be fulfilled in the summation stage:

1. The relative timing of the four original signals has to be equalised by cable insertion to within 1 ns to preserve the timing of the summed signal.
2. The relative calibration (mV/GeV) has to be equal within 5% to allow optimum muon rejection and sensitivity.

The procedure for calibration and compensation has still to be defined. The energy calibration has been done partially by the Dubna group (Oleg Gavrichtchouk and collaborators) in a test beam to determine the settings of the high voltage to obtain a standard response in units of mV or pC per GeV. The transit time of the signals roughly reduces by 1.5 ± 0.05 ns per 100 V increase of the HV.

The procedure to determine the appropriate delays for the insert between the PM-output and the splitter/summation box could go as follows:

By switching off the HV of 15 out of 16 cells the timing of one individual cell relative to an external trigger can be determined, since there are discriminators and TDC channels available for the summed response of 16 cells.

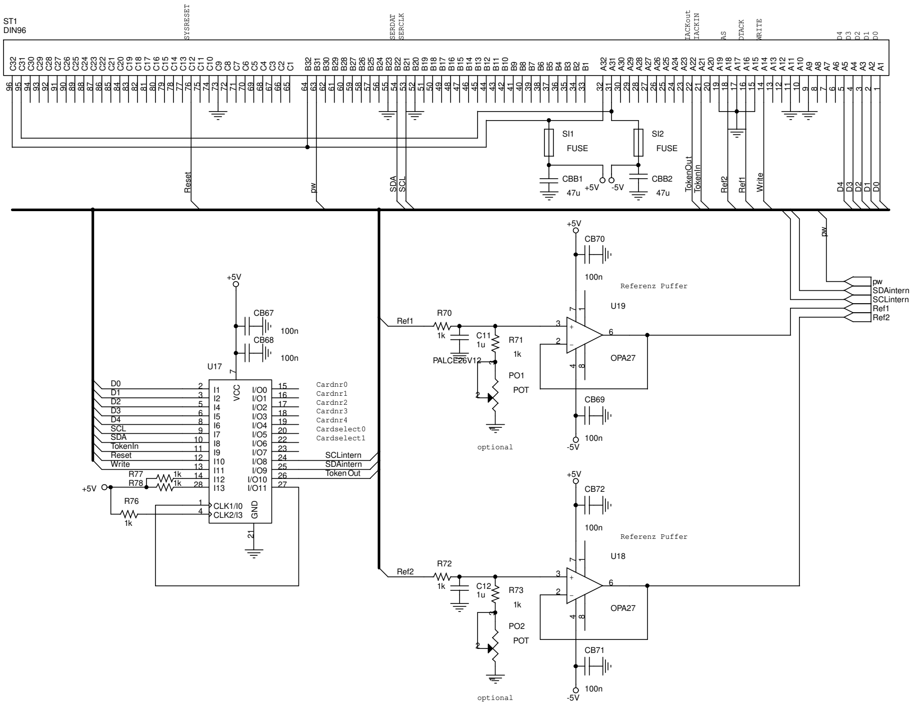


Figure 18: J1 bus on the Discriminator boards

Alternatively a dedicated movable hodoscope system allowing to select particles hitting a given cell can be used. Switching off a part of the other cells may be still necessary.

The terminal adapter needs a standard Internet address. While addressed each board has an indicator light on.

Appendix A

A possible distribution of the summation channels to different boards is given in figs.

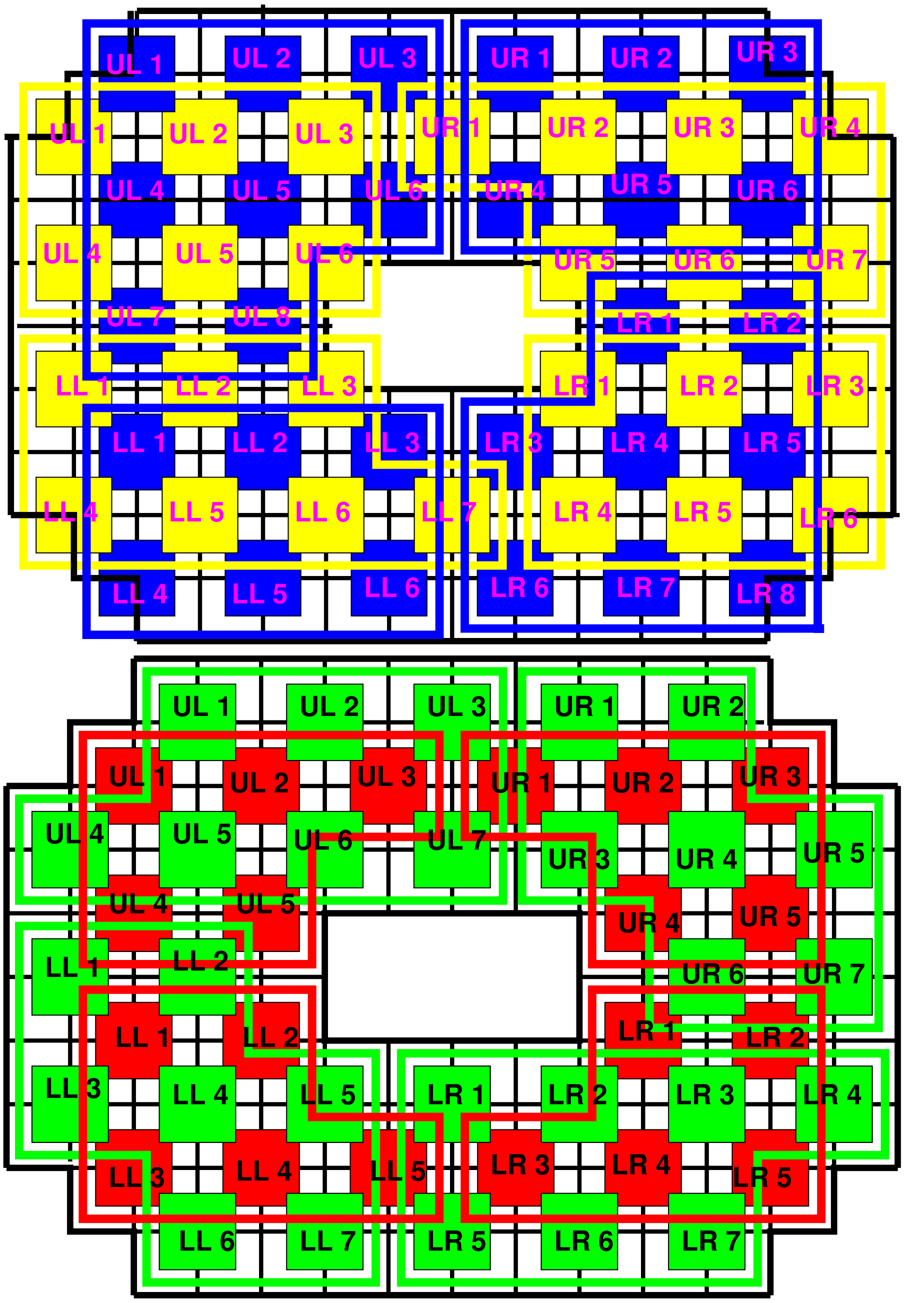


Figure 19: In the upper part a subdivision of layers L00 into 4 boards UL,UR,LL and LR with 8,6,6,8 channels and of L11 into 6,7,7,6 channels is shown. The lower part shows L01 with 5,5,5,5 channels and L10 with 7,7,7,7 channels is shown. The coding of layers is LΔx Δy.

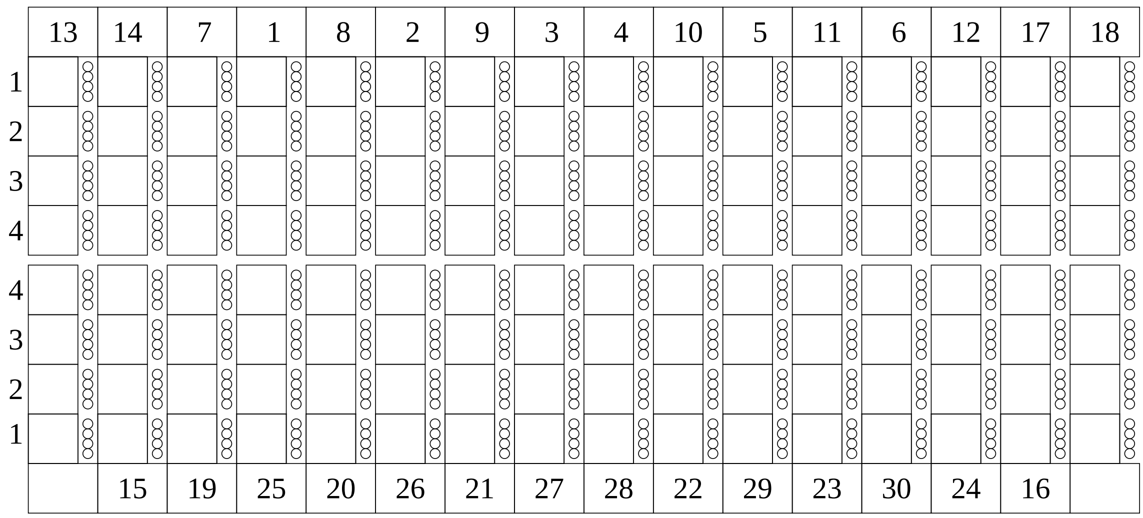


Figure 20: Connector panel for the 2x2 signals. The incoming signals are split into 4 and are regrouped to form the 4 layers of the readoud system.