ELSEVIER

Nuclear Instruments and Methods in Physics Research A 419 (1998) 695–700

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

A 40 MHz-pipelined trigger for $K^0 \rightarrow 2\pi^0$ decays for the CERN NA48 experiment[1]

G. Fischer[a,*], C. Avanzini[b], G.D. Barr[a], P. Calafiura[b], M. Cirilli[b], F. Costantini[b], D. Cundy[a], H. Dibon[c], F. Formenti[a], B. Gorini[b], B. Hallgren[a], W. Iwanski[a,2], M. Jeitler[c], P. Kapusta[a,2], F. Laico[b], G. Laverrière[a], G. Magazzù[b], M. Markytan[c], I. Mikulec[c], F. Morsani[b], G. Neuhofer[c], M. Pernicka[c], G.M. Pierazzini[b], M. Porcu[d], D. Rizzi[b], F. Rossi[d], M. Sozzi[b], A. Taurok[c], R. Tripiccione[b], M. Velasco[a], O. Vossnack[a], H. Wahl[a], M. Ziolkowski[a,2]

[a] *CERN, CH-1211 Geneva 23, Switzerland*
[b] *INFN, sezione di PISA, via Livornese 1291, IT-56100 Pisa, Italy*
[c] *Institut für Hochenergiephysik, Nikolsdorfergasse 18, A-1050 Wien, Austria*
[d] *Università di Ferrara, via Paradiso 12, IT-44100 Ferrara, Italy*

Abstract

The "neutral" trigger system for the selection of $K^0 \rightarrow 2\pi^0 \rightarrow 4\gamma$ decays of the NA48 CP-violation experiment is described. The trigger system has been implemented in a 40 MHz "dead-time free" pipeline to allow large rate reduction and high-trigger efficiency. The trigger decision is based on the information from 13 340 cells of the electro-magnetic calorimeter. Every 25 ns the energy, the centre of gravity, the kaon lifetime and the number of peaks in calorimeter projections are calculated in the trigger. The pipeline system is described and the performance of the trigger during the 1997 data-taking period is discussed.

1. Introduction

NA48 is a high-precision experiment to measure direct CP-violation in the neutral kaon system (K_L^0, K_S^0) by determining the CP-violation parameter

$$\mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right) = \frac{1}{6}\left(1 - \frac{\Gamma(K_L^0 \rightarrow \pi^0\pi^0)\Gamma(K_S^0 \rightarrow \pi^+\pi^-)}{\Gamma(K_S^0 \rightarrow \pi^0\pi^0)\Gamma(K_L^0 \rightarrow \pi^+\pi^-)}\right). \quad (1)$$

with a precision of 2×10^{-4} [1].

The experiment uses two nearly collinear K_L^0 and K_S^0 beams produced concurrently and distinguished by tagging protons producing K_S^0. Since all four decay channels are measured concurrently, many of the systematic effects cancel. The number of

---

[*] Corresponding author. E-mail: gunther.fischer@cern.ch.

[1] The NA48 Collaboration is: Cagliari, Cambridge, CERN, Dubna, Edinbourgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Vienna, Warsaw.

[2] On leave from Institute of Nuclear Physics, Cracow, Poland.

0168-9002/98/$19.00 © 1998 Published by Elsevier Science B.V. All rights reserved.
PII: S0168-9002(98)00847-X

$K_L^0 \to 2\pi^0$ decays sets the limit on the statistical error. The high-intensity K_L^0-beam generates an instantaneous particle rate of ≈ 1 MHz in the detector.

The relevant neutral decays $K_{L,S} \to 2\pi^0 \to 4\gamma$ are detected by a 8 m^3 quasi-homogeneous electromagnetic Liquid-Krypton (LKr) calorimeter with a longitudinal readout structure. The detector readout geometry is a matrix of $20 \times 20 \times 1250$ mm^3 tower cells. The active volume length is equivalent to 27 radiation lengths.

In order to handle the high single rate a fast readout using the initial current method has been developed. The data is digitised and stored in ring-buffers with a length of 200 μs to allow a dead-time in the Data Acquisition (DAQ) system.

The neutral trigger has to produce a decision every 25 ns. The total latency has to be below 100 μs, otherwise the event might be lost. The trigger should select $2\pi^0$ events and suppress the high background from 3-body decays from K_L^0. The loss of events in which accidental activity from other particles is present in the detector should be low.

2. The neutral trigger pipeline

The NA48 neutral trigger is implemented in a 40 MHz "dead-time free" pipeline using the information of the LKr-calorimeter. The total latency of the trigger pipeline is 128 clock cycles corresponding to 3.2 μs.

The trigger reconstructs the total energy, the Centre Of Gravity (COG), the kaon lifetime and the number of peaks in the horizontal and vertical calorimeter projection online every 25 ns and performs a cut on this physical quantities.

In order to calculate these quantities, the calorimeter single-cell information is reduced to two orthogonal views of projective calorimeter information. The data flow in the neutral trigger is shown in Fig. 1.

The first step in making the granularity of the calorimeter coarser is to add the calorimeter signals from 16 (2×8) single cells with analogue-sum circuits to form super-cells. The information from a single calorimeter cell is used twice to get two orientations (x- and y-view). This is done in the Calorimeter Pipeline Digitiser (CPD) system [3].

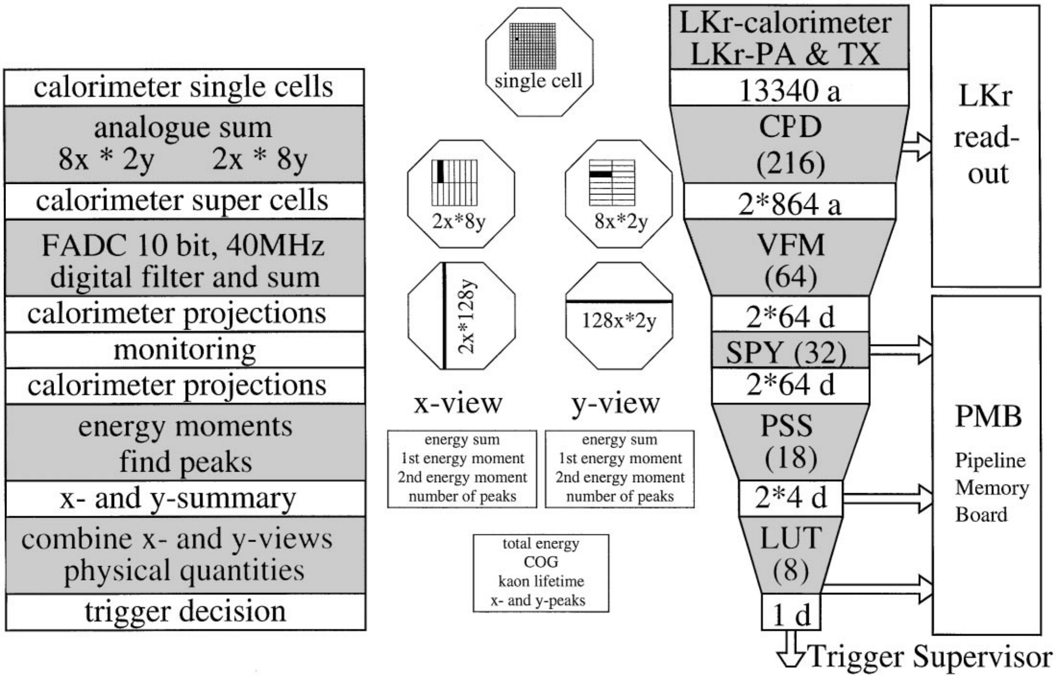

Fig. 1. The signal flow in the neutral trigger.

The signal of the super-cell is digitised by a 10-bit 40 MHz FADC. This digital signal is filtered to remove super-cells with an energy below a certain threshold. In this way the noise in the system is reduced. The digital super-cell signals are summed up into 64 vertical and 64 horizontal projections to gain coarser granularity (4 cm wide strips). This digitisation and summing into strips is done in the Vienna Filter Module (VFM) system.

The SPY system fans out the vertical and horizontal projections to the Pipeline Memory Board (PMB) system [2] and the Peak Sum System (PSS) [4].

In the PSS the total energy deposited in the LKr-calorimeter, the first and second energy moments and the number of peaks seen in the two views are calculated. The peaks are counted in bins of 3.125 ns to identify accidental hits in the calorimeter.

In the Look-Up Table (LUT) system [5] these quantities are merged from both views, the physical quantities are calculated and the trigger cuts are applied.

For all steps the digital information is stored in the PMB system and recorded with an accepted event. This allows the online monitoring of the neutral trigger and an off-line comparison between the information of the calorimeter readout and the information in the neutral trigger.

2.1. The Calorimeter Pipeline Digitiser (CPD)

The initial current induced in the LKr-calorimeter electrodes is amplified and shaped with a charge-sensitive pre-amplifier working at a temperature of 120 K. The signal is then reshaped by a transceiver at the warm end of the feed-through and converted to a differential signal.

This signal is handled by the CPD [3], which shapes, digitises and stores the signal for the main DAQ. The Bessel filter shapes the signal to generate pulses with 70 ns FWHM and a flat undershoot of 3% of the maximum pulsehight.

For the trigger the pulses are summed by analogue electronics into super-cells in two steps. At first, two signals are summed together on the CPDAS card and in a second step these signals are added on the CPDTR card. One CPD produces eight trigger super-cell sums, four in x and four in y. All signals are handled as differential-current signals with both sides driven. (see Fig. 2).

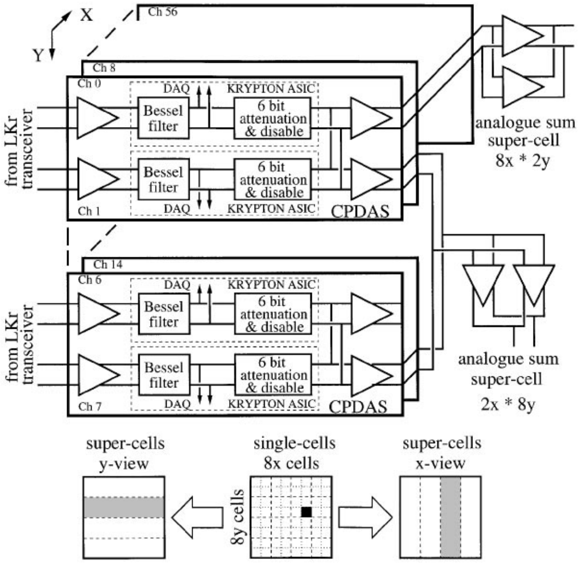

Fig. 2. Scheme of the neutral trigger signal flow in the CPD.

With a 6-bit programmable attenuator the channel-to-channel gain differences can be adjusted within 50% before the analogue sum is built. These calibration is done using a calibration pulser system. In addition, each channel can be disabled individually to allow the elimination of noisy channels in the trigger. The analogue functions described above are implemented in a fully custom-made ASIC (the KRYPTON ASIC).

An auxiliary FASTBUS backplane is used to group the super-cell signals to allow the summing of projections in the VFM system .

2.2. The Vienna Filter Module (VFM)

The analogue super-cell signals coming from the CPDs are not reshaped but filtered with a band-pass to reduce noise. These signals are digitised with the pipeline frequency of 40 MHz by 10-bit FADCs (Philips TDA8760).

The gain of each super-cell channel can be adjusted within 12% by changing the reference voltage on the FADC using a DAC. The shift of the baseline is compensated using a resistive network.

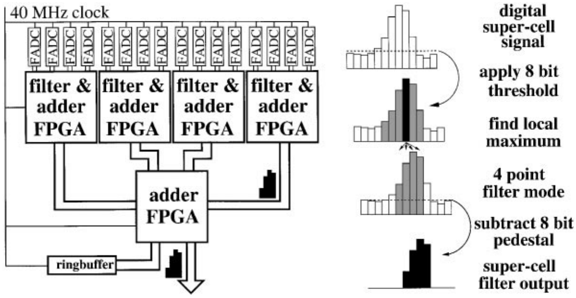

Fig. 3. Block scheme of the VFM and the flow in the digital filter.

Analogue and digital parts are strictly separated on the VFM. The analogue filter and the FADC are mounted on a daughter card which is plugged on to the mother board housing the digital parts.

The digital filtering and summing is done in FPGAs on the mother board in 25 pipeline steps. The block diagram of one side of the double-sided 9U-VME module and the operations of the filter pipeline are shown in Fig. 3.

First, the filter applies an individually adjustable threshold (which is about 3 ADC-counts above the pedestal) on the digitised signal. If two consecutive time-slices are above this value, a maximum is identified. Two samples before the maximum, the maximum and one sample after the maximum are passed through the filter after subtracting the pedestal.

Outputs of the filter stage are then summed in two steps and the full projection data is produced. In this way only channels which are above the threshold contribute to the signal and the noise of one projection.

2.3. The Peak Sum System (PSS)

This PSS [4] computes the energy sum (m_0) the first and second moments of the energy (m_1 and m_2) and the number of peaks for each projection every 25 ns.

A peak is defined as a maximum in space and time which are above an adjustable threshold. The reference time of the detected peak are reconstructed by interpolating the rising edge of the pulse to a programmable fraction (f) of the maximum time sample (see Fig. 4). f can be adjusted between 0.5 and 0.6875.

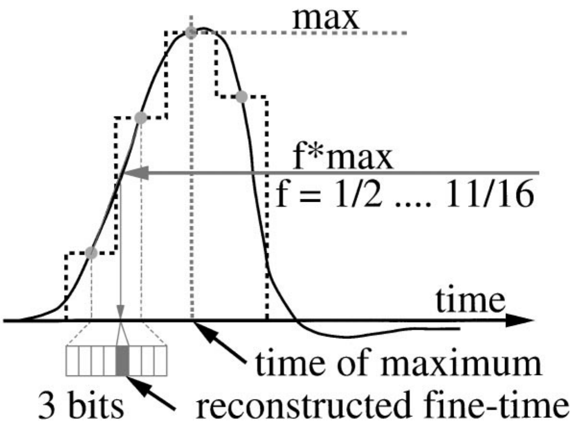

Fig. 4. The fine-time reconstruction of the peak.

The system counts the number of peaks for each projection in bins of 3.125 ns to avoid discarding good events in case of accidental particles in the calorimeter.

Numerical calculations of the energy moments and the peak finding are performed by a semi-custom VLSI chip. The information is passed on by a double daisy chain in a floating point data format and is merged at the Final Recombinator. After 31 clock cycles, the full information from the projection is available.

2.4. The Look-Up Table (LUT)

The LUT system [5] combines the results of the two views to reconstruct the relevant physical quantities and to take the final trigger decision.

The system is highly flexible to allow changes in the trigger algorithm. It uses identical boards with different contents of the memories. Mathematical functions are pre-calculated and loaded into the memories to allow fast and fully synchronous calculations. The memories have an 18-bit address and a 12-bit data field. One LUT module contains 6 memories and 4 FPGAs to route the signals. The latency of the calculations is 24 clock cycles.

The LUT system is shown in Fig. 5. It uses 8 LUT modules connected together. The LKr energy E_{LKr} is computed from three time-slices

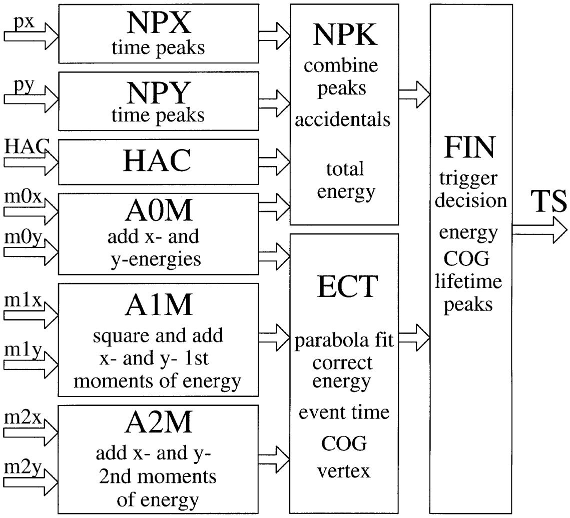

Fig. 5. Block diagram of the LUT system.

around the maximum in time, using a parabolic interpolation and averaging the energies from both views.

The centre of gravity

$$\mathrm{COG} = \frac{\sqrt{m_{1,x}^2 + m_{1,y}^2}}{E_{\mathrm{LKr}}}$$

and the decay vertex

$$z_v = \frac{\sqrt{E_{\mathrm{LKr}}(m_{2,x} + m_{2,y})(m_{1,x}^2 + m_{1,y}^2)}}{m_{\mathrm{K}}}$$

are computed. The decay length in units of K_S^0 decay length is then calculated assuming calibration and geometrical constants. If an accidental is identified, the number-of-peaks cut is not applied.

Every 25 ns a trigger decision is passed on to the trigger supervisor (TS).

3. The neutral trigger performance

After the channel-to-channel inter-calibration, a special run was performed to measure the absolute energy calibration using electrons from $\mathrm{K}_{\mathrm{e}3}$ decays ($\mathrm{K}_\mathrm{L}^0 \to \pi^{\pm}\mathrm{e}^{\mp}\nu$). The energy equivalent for one ADC-count is 160 MeV.

The overall coherent and random noise in the system is very low except for the cells on the boundary of the LKr-calorimeter. These cells were disabled in the trigger. The RMS of the pedestal is about 0.7 ADC-counts for the majority of the channels. The threshold in the digital filter for each channel is set individually to 3 sigmas above the pedestal. The threshold for the peak finder was set to zero.

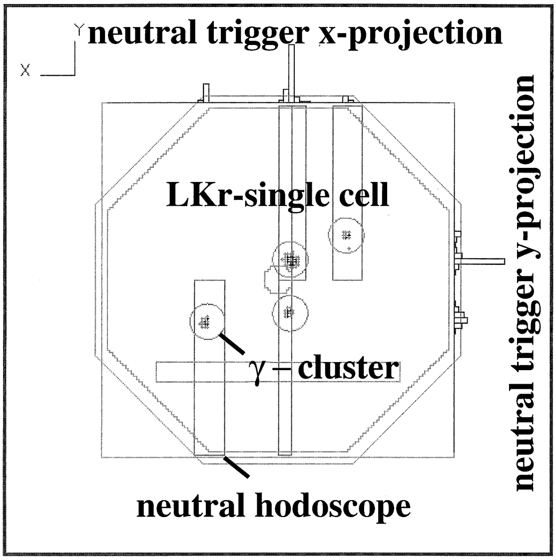

Fig. 6. $\mathrm{K}_{\mathrm{L,S}}^0 \to 2\pi^0 \to 4\gamma$ event in the LKr calorimeter.

In Fig. 6 the event display of a $\mathrm{K}_{\mathrm{L,S}}^0 \to 2\pi^0 \to 4\gamma$ event in the LKr-calorimeter is shown. The neutral hodoscope is a scintillating-fiber detector installed in the LKr-calorimeter at the shower maximum.

The energy resolution of the trigger has been determined to be 2.7% over the full energy range. The value was measured comparing the energy seen online in the trigger with the energy reconstructed off-line from the calorimeter readout.

The trigger rate for the minimum-bias trigger ($E_{\mathrm{LKr}} >$ 30 GeV) was $\approx$ 110 kHz. After the energy cut has been set to 50 GeV and the COG cut has been applied, the trigger rate was $\approx$ 16 kHz. The final trigger rate after all cuts, including the lifetime and number-of-peaks cut was $\approx$ 1.8 kHz.

The efficiency of the trigger has been measured using independent triggers from the neutral hodoscope. For a pure K_S^0 beam the efficiency is $\varepsilon_{\mathrm{K^0_S} \to 2\pi^0} = (99.91 \pm 0.02)\%$ and for a combined

$K_S^0 + K_L^0$ beam the efficiency is $\varepsilon_{K^0_{L,S} \to 2\pi^0} = (99.79 \pm 0.06)\%$. Since the efficiency is very high and the error on the measured efficiency is small, no systematic effect from the neutral trigger efficiency on the measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$ is expected.

The trigger fulfilled perfectly all requirements and performed very well during the two month of data-taking in 1997.

Acknowledgements

We are greatly indebted to the Austrian Federal Ministry for Science and Transport for the financial support of this project (GZ 616.360/2-IV/6/95).

References

[1] G.D. Barr et al., Proposal for a precision measurement of ε'/ε in CP violating $K^0 \to 2\pi$ decays, CERN/SPSC/90-22/P253.
[2] A. Lai, L. Musa, IEEE Trans. Nucl. Sci. 42 (1995) 812.
[3] B. Hallgren et al., IEEE Trans. Nucl. Sci. 43 (1996) 1605.
[4] C. Avanzini et al., IEEE Trans. Nucl. Sci. 43 (1996) 1789.
[5] G.D. Barr et al., IEEE Trans. Nucl. Sci. 43 (1996) 1689.