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ON-LINE EVENT SELECTION WITH THE FAMP MICROPROCESSOR SYSTEM

C. Daum, H. Dijkstra, D. Gosman, C. Hardwick, L. Hertzberger,
W. Hoogland, G. de Rijk, H. Tiecke and L. Wiggers

NIKHEF-H, Amsterdam, The Netherlands

Abstract: In the experiment NA11 at the CERN SPS the MC68000 based FAMP system has been succesfully implemented in a second stage trigger. It was used in a study of inclusive ϕ-meson production to select $\phi \rightarrow K^+K^-$ decays by determining the charged K-meson trajectories and calculating the K^+K^- invariant mass. A trigger rate reduction by a factor of 25 and an increase in the number of recorded ϕ-decays per unit time by a factor of 8 has been achieved.

NIKHEF SECTIE-H POSTBUS 41882, 1009 DB AMSTERDAM

1. Introduction

In an experiment with the NA11 spectrometer at the CERN-SPS data have been taken for a high statistics study of inclusive ϕ-meson production. A first use was made of a second-stage trigger, based on the FAMP (Fast Amsterdam Multi Processor)[1] system. A top view of the two-magnet spectrometer is shown in fig. 1. A fast trigger, using ECL-line logic, selects events with two oppositely charged K-meson candidates from the decay $\phi \rightarrow K^+K^-$. The K-mesons are identified by requiring the particles to give a signal in either the MA or MB scintillation counter arrays without giving light in the matching elements of the multicellular Cerenkov counters C2 and C3 respectively. Tracks satisfying the MB.$\bar{C}$3 coincidence have to give light in a corresponding C2 element. Two Cerenkovs are used to enlarge the momentum range in which kaons can be identified. The magnetic fields will bend the positive particles to positive x and the negative particles to negative x (fig. 1). In the trigger this feature is used by demanding at least one K-candidate at the left and one candidate at the right of the x=0 symmetry plane.

False triggers are for example due to π-mesons with momentum below the Cerenkov threshold and spurious hits in the scintillation counter array. Of the order of 10% of the triggers are due to good K^+K^- candidates, of which about 40% have an invariant mass of the K^+K^- pair within 50 MeV from the ϕ-meson mass (1019.6 MeV).

The trigger rate. for a beam flux of 10^6 particles / second incident on a Be target of 20 mm length, is typically of the order of 4000 / sec. This completely saturates the capacity of the data acquisition system, which, for an average event size of 4400 bytes and a 10 msec read-out time, has a maximum data recording rate of ~100 events / sec. In order to improve the sensitivity of the experiment, the second stage trigger has been implemented. The FAMP system is used in conjunction with a set of proportional chambers (P_{31}, P_{32} and P_{33}), downstream of the BBC magnet (fig. 1). From the coordinate information of the proportional chambers the FAMP microprocessor system calculates:

a. the momenta of the K-meson candidates, checking whether they fall within the momentum band set by the Cerenkov counter thresholds

b. the invariant mass of the K^+K^- pairs.

Events fulfilling the criteria of this second stage trigger are read out by the NORD-100 data taking computer and recorded onto tape.

2. Hardware

The additional hardware used for the second-stage trigger consists of

a. a set of proportional chambers
b. the associated read-out electronics
c. the interface to the FAMP-system
d. the FAMP-system

a. The experimental set-up has been extended with 5 proportional chamber planes. Two packs (P_{31ab} and P_{32ab}) each consist of two planes with inclined wires (±7°). The fifth plane P_{33}, about 1 meter downstream of P_{32ab} has vertical wires (0°). The planes have a wire pitch of 2 mm. In planes P_{32ab} and P_{33} the signals of two and four wires are combined on an intermediate printed circuit board, respectively. This procedure results in an effective pitch for P_{32ab} of 4 and for P_{33} of 8 mm. The modules P_{31ab} and P_{32ab} are located just before and after C_2, so that track information can be correlated easily with the data from the multicellular Cerenkov counter C2. This is also true for the Cerenkov counter C3, since its position relative to the Cerenkov counter C2 allows an almost one to one correlation between cells of C2 and C3, for particles identified by the Cerenkov counter C3. Hits in plane P_{33} provide a third point on a trajectory, so that ambiguous solutions from P_{31ab} and P_{32ab} can be rejected.

b. For the read-out of the proportional chambers RMH-compatible[2] D16/D32 Plessey modules[3] are used. The preamplifier/discriminators (D16) are mounted in special crates and connected to the wires with 70 cm long flat cables. The ECL level output pulses are transmitted over twisted pair cables (50 m) to line receiver modules (D32). Special features are a built-in acoustic wave delay and a fast-or output for every four channels. Fast-or signals are used in a coincidence cicuit added to the first level trigger to reject triggers caused by spurious hits in the scintillator array MA.

c. At the end of the RMH-chain a special module (Bypass Unit) gives control over the data stream either to the FAMP system or to the NORD computer (fig. 2).
When the FAMP system has control the purpose-built controller and concentrator (COCO) reads data, reformats it and transfers the reformatted data to intelligent data-memory modules (PRIME) connected to each processor.

During reformatting wire-address clusters are encoded. Clusters are represented by their centre of gravity. Four bits in the 16 bit data-word give the width of the cluster, 11 bits encode the wire number in a plane and one bit indicates the presence of a single hole in the encoded cluster. Six planes are defined out of a potential number of 24 planes, each with a maximum of 127 encoded data-words per event. The total number of data-words per event cannot exceed the memory size in the PRIME, which is at present 896. The beginning of each plane is indicated by a flag switch at the respective Plessey read-out units. The data are stored into the PRIME according to increasing plane and wire number. In order to reduce the computing load of the microprocessors, special functions are implemented in the PRIME. They allow a sequential read-out of data in the planes and the searching of a hit on a given wire number with a certain tolerance.

The information from the scintillation-counter arrays MA, MB and the Cerenkov counters C2, C3 are transmitted via additional RMH read-out units. The data are grouped into a "plane", obviously without cluster encoding.

d. The microprocessor system is built up from three subsystems; one supervisor and two slaves. Each one consists of a FAMP module, two 32 Kbyte memory modules and a data buffer (fig. 2). An output-buffer in the supervisor crate takes care of the communication with the NORD 100 on-line computer. The FAMP system and its design philosophy are extensively described elsewhere[1]. Each module consists of a 16 bit 8 MHz MC68000 processor supported with 24 Kbyte RAM and 8 Kbyte ROM input and output facilities (2 input, 3 output and 2 interrupt lines). Processors are interconnected via Dual Port Memories (16 Kbyte) and can be grouped in several hierarchical levels. Communication with the experiment takes place through experiment-dependent interfaces, which for our application are the COCO and PRIME's, described in the previous section. In this experiment the three processors are grouped into two levels; first the two slave- then the supervisor-processor. The software is developed on the NORD computer, using assembler language, and is down-loaded via RS 232 lines to the processors.

Processing of an event is started when the busy signal of the COCO disappears. This indicates that the read-out has been finished. When either one of the three processors decides that the trigger criteria cannot be fulfilled, an interrupt is provoked. Subsequently all processors are stopped and the read-out electronics is cleared by a NIM fast-clear signal.

When the event is accepted the NORD computer is triggered to read out all experimental data. Intermediate results of the three processors are stored in the output buffer. This unit is read out by the NORD via an ROBD (Read Only Branch Driver). This is used for debugging and monitoring of the μP-system by displaying all intermediate results like the K^+K^- mass distribution by the NORD on-line computer.

The described mode of operation, i.e. holding the start of the read-out until the event is accepted by the second-stage trigger, is preferred because the alternative induces a long reset time (~500 μsec / event) of computer and electronics for the majority of rejected events. At the end of every SPS-burst the complete system is cleared and reinitialized. To check the performance of the second-stage trigger every tenth tape is recorded without the μP-interrupts enabled. The intermediate results and trigger decisions of all events are written onto tape.

3. Reconstruction procedure

Because of the good homogeneity of the magnetic field of the spectrometer magnets, the momentum of a particle can be determined with a simple algorithm from its trajectory behind the second magnet, assuming that its origin before the first magnet (x_0, y_0) is known. The momentum is given by

$$p = c_0 \cos\Theta \;/\; \left(c_1 u_1 - c_2 u_2 + y_0 \sin\Theta - x_0 \cos\Theta\right) \; ,$$

where $u_{1,2}$ are the coordinates of the trajectory at two different z-positions behind the second magnet, in a projection which makes an angle Θ with respect to the y-z plane. The quantities c_0, c_1 and c_2 are constants, depending on the geometry of the experimental set-up. For a particle originating in the target, placed at the origin (0,0), the contributions of the terms with x_0 and y_0 can be neglected, since the dimensions of the target are small. Accordingly, the calculated momentum is the same for two projections with oppositely signed Θ. Inversely, if the momenta calculated in those projections are found to be different, it indicates that a particle is not coming from the target and thus can be eliminated.

In our set-up the momenta of the particles are independently determined with the +7° and -7° wires (P_{31a}, P_{32a} and P_{31b}, P_{32b}). In this case different momentum values are found if y_0 is different from zero.

The data from the +7° and -7° planes are processed by the two slave processors in parallel. First it is checked roughly whether the proportional chamber hits are correlated with the hodoscope pattern which produces the fast trigger. When such a correlation exists, combinations of hits in the P_{32} and P_{31} planes are sought which yield momenta in the range imposed by the Cerenkov thresholds. If either of the slaves finds an insufficient number of track candidates a veto signal is produced. The coordinate and momentum information is stored by the slave processors in the Dual Port Memories. Subsequently the supervisor-processor scans the two sets of momenta corresponding with the two views for possible equal values. If such a momentum pair is found the processor searches with a hardware function in the data-buffer for a possible correlated hit in P_{33}. Also a more accurate check is made of the correlation with the MA.$\bar{C}$2 or MB.C2.$\bar{C}$3 coincidences. When all track candidates are dealt with in this way and a sufficient number of negative and positive particles have survived the second-stage trigger requirements a loop is performed over all combinations of oppositely charged particles to determine their invariant mass. For a K^+K^- invariant mass below 1.05 GeV/c^2 the ratio of the two K-meson momenta is in the range 0.5 to 2. If for a combination this condition is fulfilled the invariant mass $M_{K^+K^-}$ is calculated using the approximate relation:

$$M^2_{K^+K^-} = M^2_K(2 + p_1/p_2 + p_2/p_1) + ap_1p_2\left((x_1 - b/p_1 - x_2 + b/p_2)^2 + (y_2 - y_1)^2\right) .$$

where x_1, y_1, p_1 and x_2, y_2, p_2 are the coordinate and momentum values of the two kaons, respectively. Furthermore, a and b are constants, while M_K represents the kaon-mass. When no $M_{K^+K^-}$ is found to be smaller than 1.15 GeV/c^2 the event is rejected. In all processing steps extensive use is made of large look-up tables; 32 KByte for each of the slave-processors and 60 KByte for the master-processor. This takes advantage of the large addressing range of the MC68000. The procedure described above, applies to a search for phi-mesons. In an analogous way decay products from other resonances may be selected.

4. Results

The system described in the previous sections has run succesfully from June till September 1982 for a total of 25 days. Various trigger conditions (K^+K^-, ϕ, $2K^+2K^-$, $\phi\phi$) have been set differing in the number of K^+K^- combinations required and in whether the low mass cut on the K^+K^- invariant mass was demanded. Data have been taken with different beam momenta, beam polarities and targets. In total, 7M events have been written onto tape. The largest statistics was collected with a single-phi trigger using a 100 GeV/c negative beam incident on a Be target. In the following, we present some results obtained in this run. The π-threshold of the C2 and C3 Cerenkovs were set at 3.7 GeV/c and 6.5 GeV/c respectively. The FAMP conditions for a K-meson were:

i. a MA.$\bar{C}$2 coincidence with a momentum in the range $3.5 < p < 13$ GeV/c,

ii. a MB.$\bar{C}$2.$\bar{C}$3 coincidence with $13 < p < 24$ GeV/c.

The mean multiplicity of tracks in arm 3 is 4.3 of which 31% were correlated with a MA.$\bar{C}$2 or MB.C2.$\bar{C}$3 signal. In fig. 3 an example is shown of the hit pattern in the MWPC's for a typical accepted event. The fast-or circuit in which signals from MA are correlated with hits of the proportional chamber plane P_{32a} rejects 28% of the triggers, i.e. most of the spurious triggers. In table 1 the fraction of events treated by the slave- or supervisor-processor is given together with the mean reconstruction time for that class of events. A large percentage (42%) is rejected in an early stage by the slave-processors. Only 5% of the events is eventually accepted.

The mean reconstruction time for an accepted event is 750 μsec, for all events it is 450 μsec. Time distributions for different event categories are shown in fig. 4. The distribution for events rejected after calculating the invariant mass is very similar in shape and magnitude to that for accepted events. Therefore, they are not shown separately in the figure. In order to get the dead-time of the microprocessor-system one has to add 50 μsec for resetting and initialization. An event with a simple configuration, i.e. two kaons from the ϕ and no additional hits in the MWPC's and hodoscopes takes 420 μsec before it is accepted by the μP-system. In that time 150 instructions in each slave and 250 instructions in the supervisor-processor have been carried out.

In fig. 5 the K^+K^- invariant mass spectrum is plotted as calculated by the FAMP and displayed on-line. In fig. 6 the relative difference between the values for the momentum of a particle as determined by the FAMP and the off-line reconstruction program is plotted. The RMS value of the distribution is about 3%. Using the more precise driftchamber data, the error in determining the momentum by the off-line reconstruction program is 0.7%. The difference between the invariant mass calculated by the FAMP and by the off-line reconstruction program is shown in fig. 7. The RMS value is 5 MeV/c^2 while the mass resolution in the off-line analysis is 1.5 MeV/c^2.

The second-stage trigger accepts about 20% more events than the off-line analysis program does, if similar selection criteria are applied. This is due to slightly relaxed trigger requirements by the FAMP and to ghost tracks found by the FAMP reconstruction programs. On the other hand the system does not find all good events. The hit efficiency in a proportional chamber plane is 98%. Demanding 5 hits for a track in the chamber causes a loss of 18% of good K^+K^- events. The track finding efficiency of the FAMP when a hit in every plane has been found amounts to 97%.

The dead-time without the FAMP system is fully determined by the CAMAC read-out time of the electronics. For a mean number of 4400 bytes / event 10 ms is needed. With a trigger rate of 3700/sec this gives a 2.4% sensitivity time of the spectrometer. Using the second-level trigger system, i.e. FAMP system and fast-or circuit, this improves to 25%. However, since it introduces an inefficiency of 23%, the effective gain in sensitivity is $0.77 \times 0.25/0.024 = 8.0$. This results in the recording of ten genuine phi-events per SPS-burst of 2.6 seconds.

5. Conclusion

The implementation of the FAMP system in the second-stage trigger makes it possible to impose in a flexible way complex trigger requirements. In the experiment described in this paper the system was used to trigger on low mass K^+K^- candidates. It has resulted in an increase of the density of good K^+K^- events on tape with a factor 25, at the same time decreasing the number of records written per burst onto tape by more than a factor two. The effect on the sensitivity has been an increase with a factor 8. As a result of that we expect to have gathered about 0.6 M phi-events during the runs in 1982.

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References

1. L.O. Hertzberger, Comput. Phys. Commun. 26 (1982) 79.
2. J. Lindsay et al., Nucl. Instr. and Meth. 156 (1978) 329.
3. Plessey product specifications: D16 and D32-02.

Table 1

Breakdown of the different event categories with their mean reconstruction time.

		fraction (%)	reconstr. time (μsec)
slaves:	no 2 track candidates	42	260
supervisor:	no K^+K^-	50	570
	no K^+K^- mass<1.15 GeV/c^2	3	730
	accepted	5	750
		100	

Figure captions

Fig. 1. Top view of the NA11 spectrometer. MNP33, BBC: magnets; DC2, DC3a, DC3b and DC3c: driftchambers; C1, C2 and C3: Cerenkov counter hodoscopes; MA and MB: scintillation counter hodoscopes; P_{31ab}, P_{32ab} and P_{33}: proportional chambers.

Fig. 2. Schematic diagram of the read-out electronics and the μP-system. The controller and data-buffer modules are denoted in the text by COCO and PRIME, respectively.

Fig. 3. Example of an accepted event. Indicated are the hit wires in the proportional chambers and the tracks reconstructed off-line. The shaded areas in MA represent the first-stage trigger logic. They are associated with track number 2 and 4 and satisfy the MA.$\bar{C}$2 and MB.C2.$\bar{C}$3 requirements, respectively.

Fig. 4. Distributions of the reconstruction times of the μP-system for the different event categories. Stage 1 stands for looking for K^+K^- candidates. Stage 2 represents the calculation of the invariant mass.

Fig. 5. K^+K^- mass distribution as calculated by the μP-system.

Fig. 6. Δp/p for tracks as determined by the μP-system and the off-line analysis program.

Fig. 7. Difference in invariant mass Δm for the K^+K^- pair as calculated by the μP-system and the off-line analysis program.

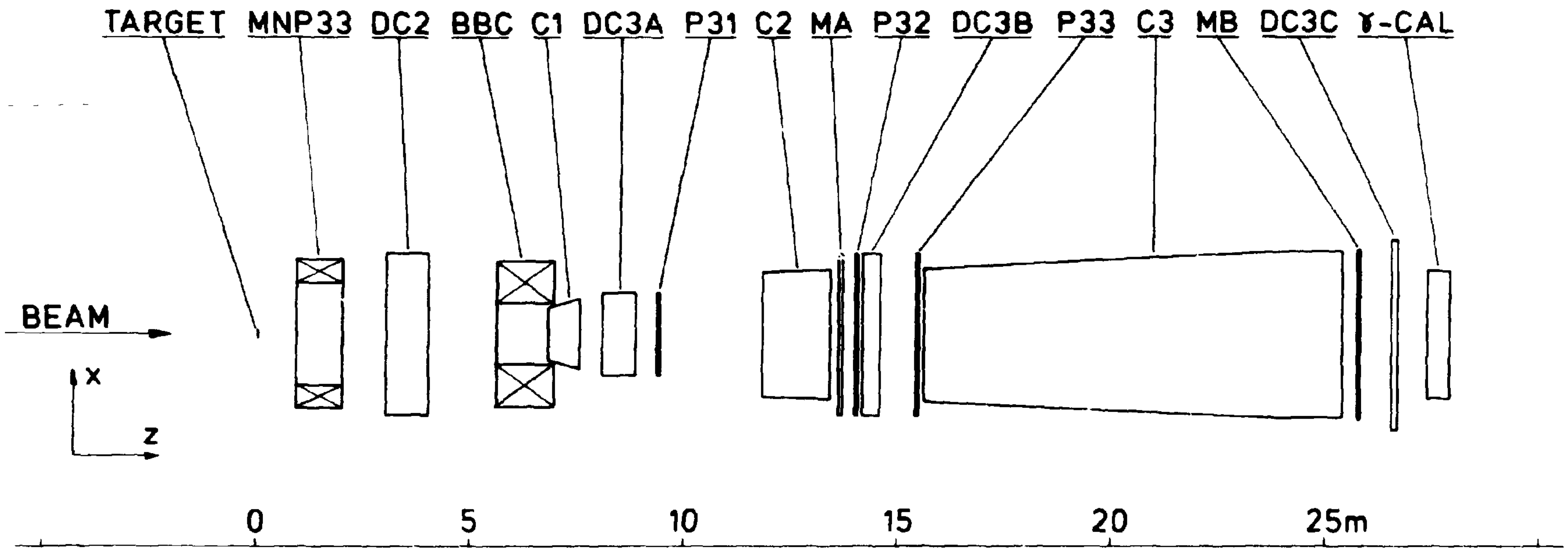

TARGET
MNP33
DC2
BBC
C1
DC3A
P31
C2
MA
P32
DC3B
P33
C3
MB
DC3C
γ-CAL
BEAM
x
z
0
5
10
15
20
25m

Fig. 1

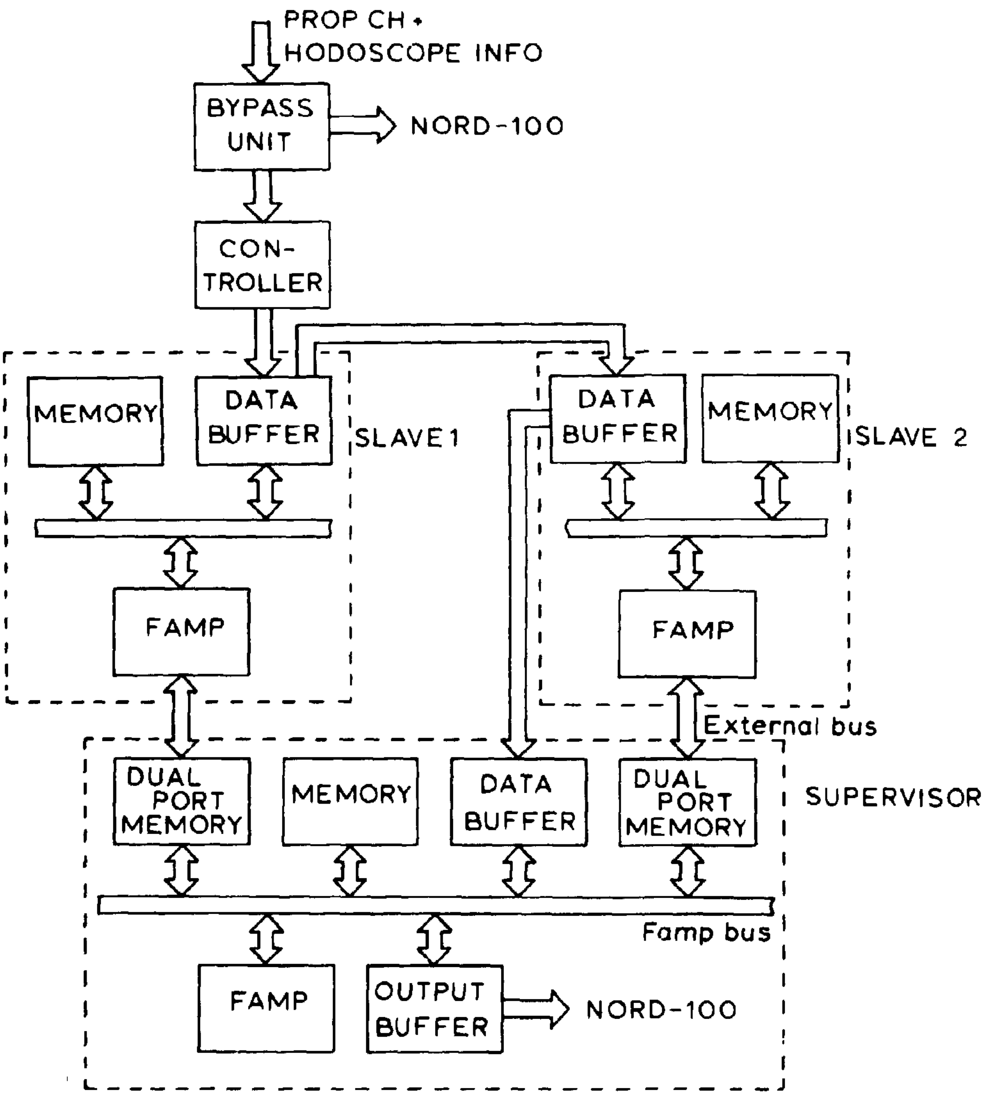

PROP CH +
HODOSCOPE INFO
BYPASS UNIT
NORD-100
CON-TROLLER
MEMORY
DATA BUFFER
SLAVE 1
FAMP
DATA BUFFER
MEMORY
SLAVE 2
FAMP
External bus
DUAL PORT MEMORY
MEMORY
DATA BUFFER
DUAL PORT MEMORY
SUPERVISOR
Famp bus
FAMP
OUTPUT BUFFER
NORD-100

Fig. 2

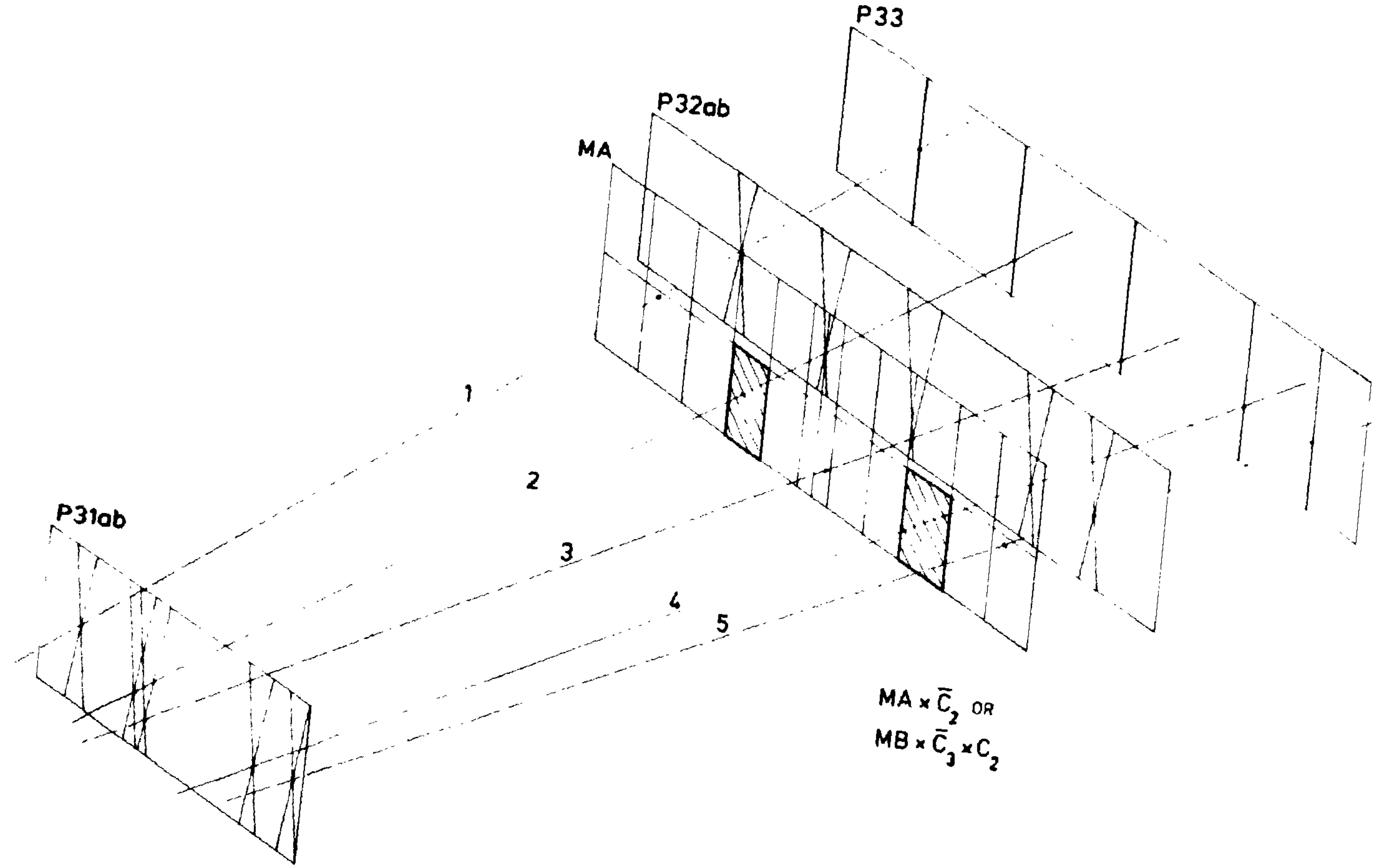
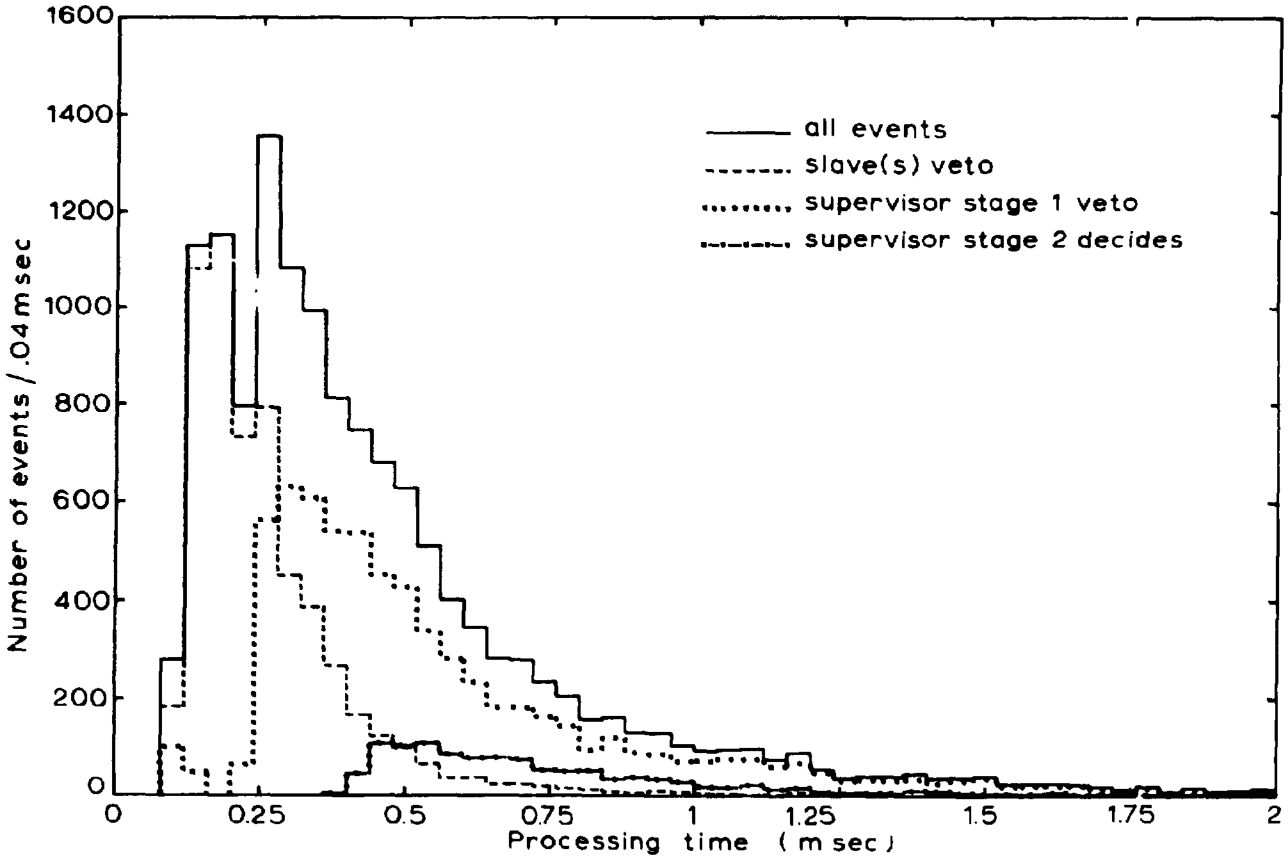
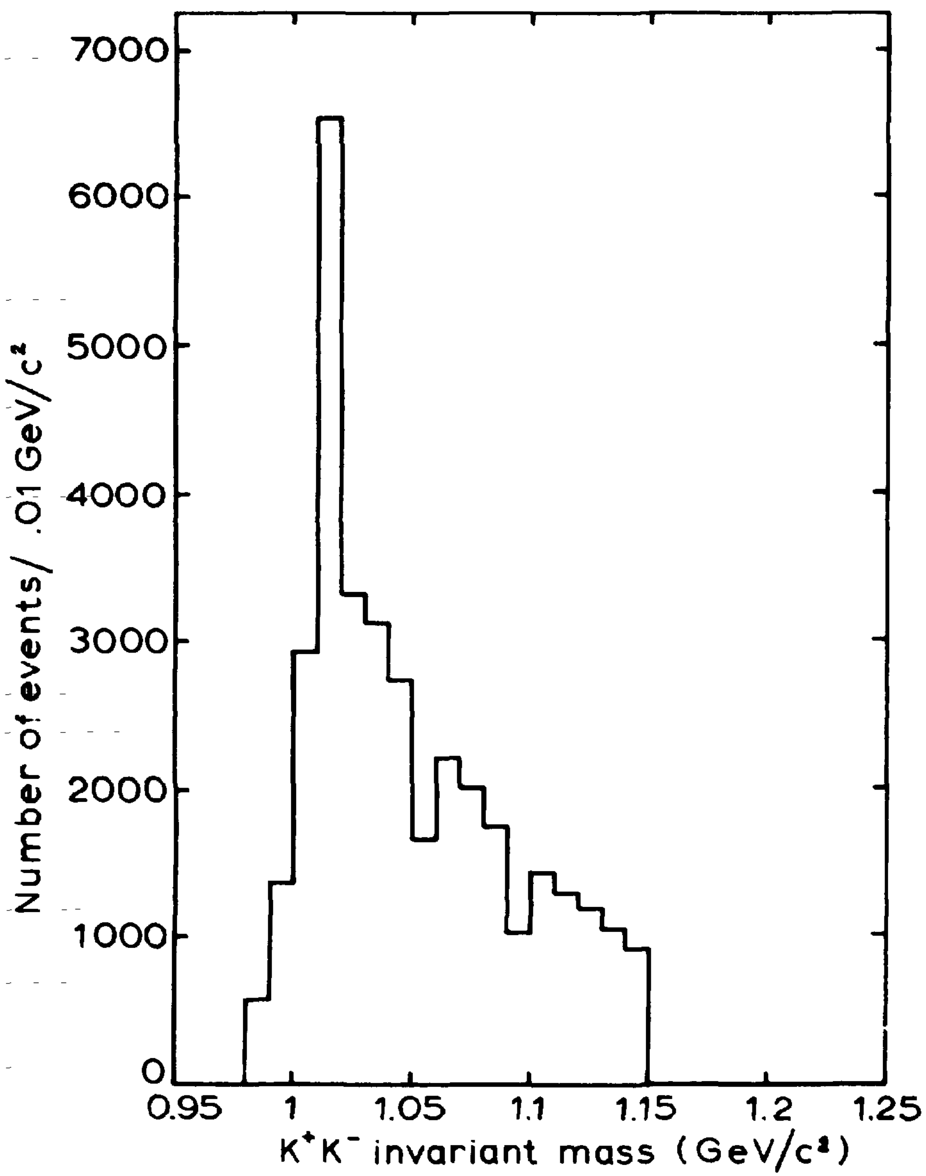


Fig. 3



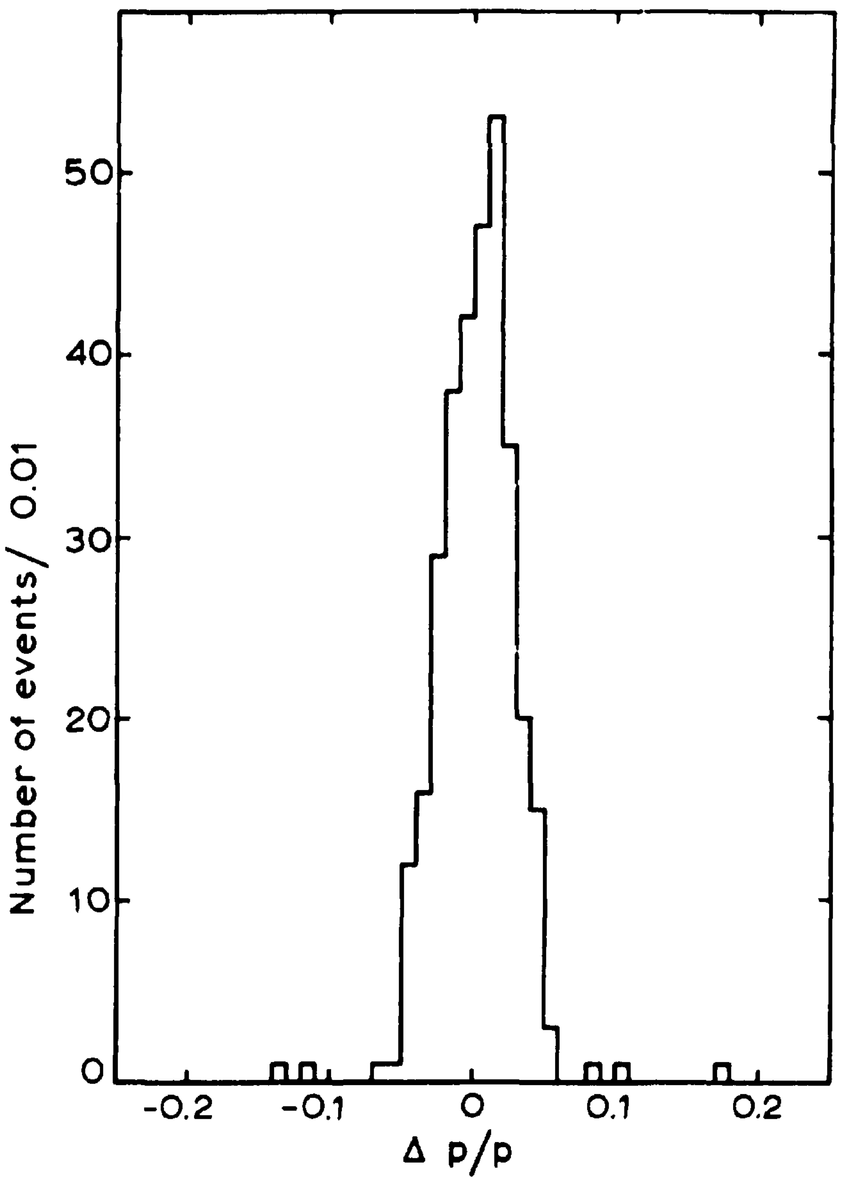
all events
slave(s) veto
supervisor stage 1 veto
supervisor stage 2 decides
Number of events / .04 m sec
Processing time (m sec)
0
200
400
600
800
1000
1200
1400
1600
0.25
0.5
0.75
1
1.25
1.5
1.75
2

Fig. 4



Number of events/ .01 GeV/c²
7000
6000
5000
4000
3000
2000
1000
0
0.95
1
1.05
1.1
1.15
1.2
1.25
K⁺K⁻ invariant mass (GeV/c²)

Fig. 5



Number of events/ 0.01
50
40
30
20
10
0
-0.2
-0.1
0
0.1
0.2
Δ p/p

Fig. 6

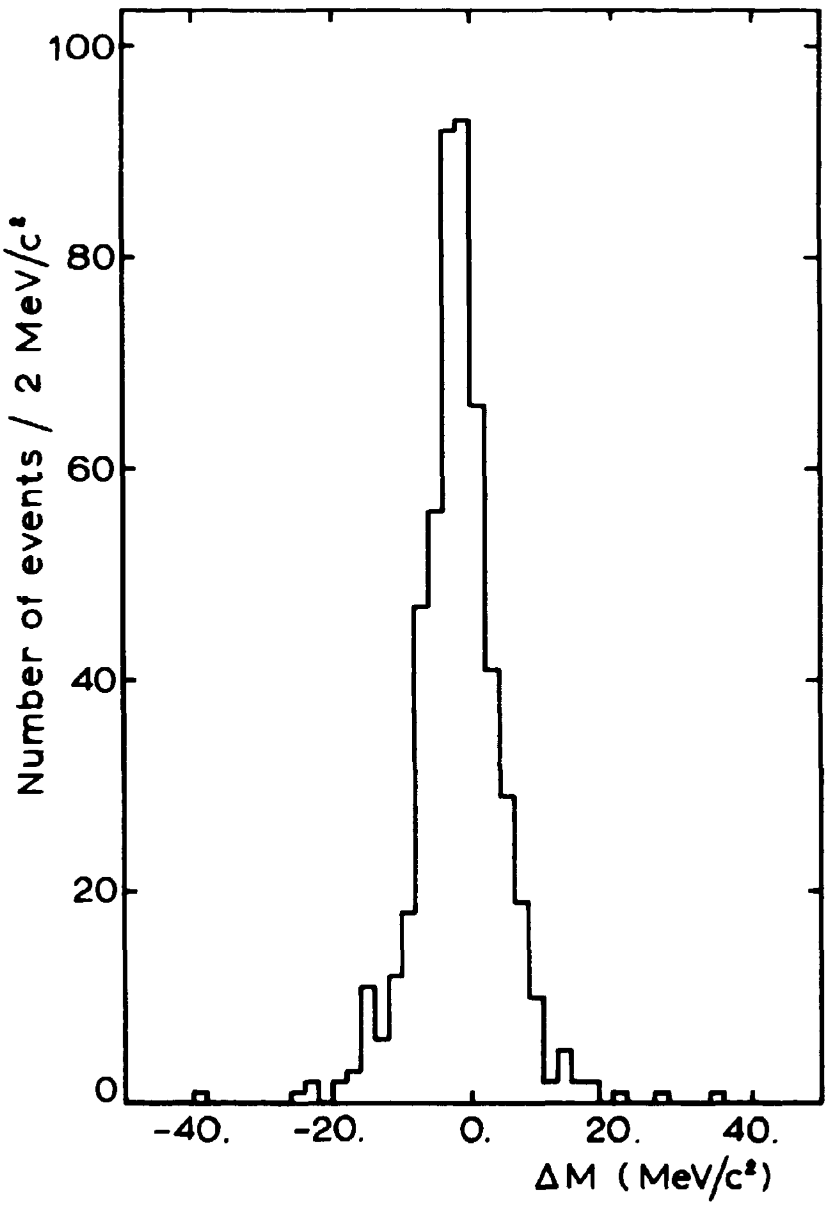


Fig. 7