UNIVERSITY OF STOCKHOLM

INSTITUTE OF PHYSICS

The NA27 Trigger

R. BIZZARRI, E. Di CAPUA, S. FALCIANO, M. IORI, G. MAREL,
G. PIREDDA, L. ZANELLO

and

L. HAUPT, S. HELLMAN, S.O. HOLMGREN, K.E. JOHANSSON

USIP Report 85 - 10 May 1985

The NA27 Trigger

R.Bizzarri, E.Di Capua, S.Falciano, M.Iori,
G.Marel†, G.Piredda, L.Zanello
Dipartimento di Fisica, Universita "La Sapienza", Roma, Italy
and
INFN - Sezione di Roma, Roma, Italy

L.Haupt, S.Hellman, S.O.Holmgren, K.E.Johansson
Institute of Physics, University of Stockholm, Sweden

Abstract

We have designed and implemented a minimum bias trigger together with a fiducial volume trigger for the experiment NA27, performed at the CERN SPS. A total of more than 3 million bubble chamber pictures have been taken with a triggered cross section > 75% of the total inelastic cross section. Events containing charm particles were triggered with an efficiency of 98^{+2}_{-3} %. With the fiducial volume trigger, the probability for a picture to contain an interaction in the visible hydrogen increased from 47.3% to 59.5%, reducing film cost and processing effort with ≈20%. The improvement in data taking rate is shown to be negligible.

* * * * *

† Now at Dept. des Particules Elementaires, CEN, Saclay, France

Contents

1. INTRODUCTION

In this report we describe the design and performance of the trigger for the experiment NA27 performed at the CERN SPS. In this experiment [1] the small rapid cycling hydrogen bubble chamber LEBC combined with the European Hybrid Spectrometer (EHS), described in reference [1c] and [2], was exposed to 360 GeV/c π^- and 400 GeV/c proton beams. For the π-data ≈850 000 pictures were collected during spring 1982 while ≈2.3 million pictures were collected for the proton part during two data taking periods, end of 1983 and spring 1984. The aim of the experiment is to study the production and weak decay of hadrons with open charm quantum number, by detecting their decay in the bubble chamber.

2. TRIGGER REQUIREMENTS

For this experiment the trigger was designed to meet four basic demands, imposed by the use of a small rapid cycling bubble chamber in a high energy fixed target environment and a priori known properties of charmed particles.

Definition of the beam; Since charm particles are known to have a lifetime a few times 10^{-13} s the resolution in the bubble chamber should be of the order of ≈20μm. With classical optics this resolution can be obtained only at the expense of the depth of field. In this experiment the depth of field was restricted to ≈2 mm. The beam used had a horizontal focus in the bubble chamber, roughly of this width. One of the trigger tasks was to ensure that the incoming beam particles were inside this limited band, and that they were not interacting upstream of the bubble chamber.

Precise timing information; For the analysis of the data the information from a bubble chamber picture will be combined with information from the electronic detectors in the spectrometer downstream of the bubble chamber. The detectors with drift time read-out need a precise timing information for the incoming beam particle to give maximum precision.

Selection of interactions; Only about 2.1 % (for the π run about 1.4 %) of the incoming beam particles give potentially interesting primary interactions. It is thus necessary to have an interaction trigger able to select these events. It is important that this selection is efficient to ensure that the data contain relevant information. Equally important is that the losses in this process are small and well understood not to introduce biases in the collected data.

Veto against interactions in the bubble chamber windows; A high resolution bubble chamber with the required bubble density along tracks has to be small, for two reasons: to achieve the necessary bubble density the chamber has to be run close to the foam limit (i.e. close to conditions where the liquid in the chamber boils). This requires a very smooth chamber body to avoid parasitic boiling. The technique used here to construct such a chamber [1c] is limited to small chamber bodies. Secondly, in order not to degrade the resolution when photographing the events the demagnification must be of the order of 1:1. Since the amount of film to be transported for each interaction scales as the size of the bubble chamber, an increased load on the film transport means increased camera dead-time. A larger bubble chamber would thus imply a reduced data taking rate and would be impractical also for this reason.

In a small hydrogen bubble chamber, the relative amount of material in beam windows and unseen hydrogen is large compared to the material in the visible region. For LEBC roughly 50% of the interactions take place in invisible material. The efficiency of the datataking can thus be considerably improved by eliminating these background triggers. We achieved this by introducing a Fiducial Volume Trigger, FVT,[3].

Finally one might note the desirability of a trigger which is capable of enriching the rather low fraction of events containing charm ($\approx 10^{-3}$). So far the only proposed methods to do so rely either on the identification of a lepton from a semi-leptonic decay of a charmed hadron, or the detection of tracks having an impact parameter at the primary vertex. Neither of these methods is applicable to this experiment since a lepton trigger would seriously reduce the sensitivity of the experiment. The spatial resolution of the existing detectors is not sufficient for an efficient on-line detection of an impact parameter due to a charm decay.

3. HARDWARE

For this trigger three types of detectors are used (fig 1); scintillators, silicon strip detectors and multiwire proportional chambers.

3.1 Scintillators

Six plastic scintillators were used to form the beam trigger. Their dimensions and the distance from the centre of LEBC are given in table 1 . The two scintillators T1 and T2 defined an incoming beam particle. The thin counter T3 ensured that the beam was horizontally contained inside the 2 mm depth of focus of the cameras. T4 was tilted to ensure that the triggered beam particles were vertically ("sideways" on the photograph) in the visible region 4 cm wide. This scintillator was read out in both ends to provide a timing signal with minimal jitter. The two counters V1 and V2 were positioned at the same distance from LEBC with a gap of ≈ 10 mm between them, centered on the ideal beam position. These counters were used in anticoincidence with the rest of the counters, in order to veto upstream interactions and beam halo.

Table 1

Scintillator dimensions and positions

Scintillator	h*w*t (cm^3)	Distance from Lebc (m)
T1	25*10*0.6	30.0
T2	25*10*0.6	5.1
T3	10*0.2*0.2	3.85
T4	5*10*0.5	5.4
V1	35*15*0.6	3.3
V2	35*15*0.6	3.3

3.2 Silicon Strip Detectors

The two silicons strip detectors SSD0 and SSD1 were positioned 6.0 and 3.4 m upstream of LEBC respectively. They both consist of 100 p-type, 300 mm length strips implanted on a 300 μm thick n-type silicon wafer. The pitch is 100 μm. More detailed information on the running conditions of these detectors can be found in reference [3]. The silicon strip detectors were used in the Fiducial Volume Trigger to give precise predictions for the horizontal impact coordinate at the bubble chamber windows for the incoming beam particles. We also took advantage of the small pitch of these detectors by using them during the beam-LEBC alignment procedure at the beginning of each run and by monitoring the stability of the alignment during datataking.

3.3 Multiwire Proportional Chambers

The MWPC:s W0 and W1 were used both to form an interaction trigger and as a part of the fiducial volume trigger (and to provide tracking information in the subsequent analysis of the data). Their dimensions and positions are given in table 2 below.

Table 2

MWPC parameters.

	W0	W1
Overall size; w*h*t (cm^3)	31.5*25.5*4.0	45.8*45.8*5.0
Sensitive area; w*h (cm^2)	8*10	32*32
Number of wires	160	320
Pitch (μm)	500	1000
Position relative LEBC (cm)	32.7	86.9

W0 is designed and constructed by a group at the Rutherford lab [4], and was originally used in the CERN experiment WA42. Detailed information on the construction and design is given in [4], but the main features are; the cathod planes consist of two graphite covered mylar windows, the anode plane consists of 160 goldplated tungsten wires with 10 μm diameter, flanked by four guard wires of progressively larger diameter at each end of the wireplane. The anod-cathod gap was 2.5 mm. The typical value of the high tension during running conditions of ≈3.75 kV corresponds to an electrical field of ≈15kV/cm.

The chamber was tested with three different gas mixtures;

i) 75% argon bubbled through metylal at 5° C, 25% isobuthane.

ii) 75% argon bubbied through isopropylic alcohol at 5° C, 25% isobuthane.

iii) 75% argon bubbled through isopropylic alcohol at 5° C, 25% ethane

For all mixtures the argon used was premixed 99% argon, 1% freon.

The working conditions of the chamber depended on the gas mixture used, as shown in table 3 .

Table 3

Effect of different gas mixtures in WO

Gas mixture	i	ii	iii
High Voltage at beginning of plateau (kV)	3.9	3.8	3.6
High Voltage at break down (kV)	4.6	4.4	4.2
Average cluster size at beginning of plateau	≈1.05	≈1.05	≈1.09

Regardless of the gas-mixture the average cluster size, i.e. the average number of wires fired by a single particle, rises linearly with the high voltage with a common slope of about 0.03 per 100 V increase in the high voltage.

W1 is a scaled down version of a chamber designed by T.Modis [5], which was also originally used in the WA42 experiment at CERN. The original design had a sensitive area of 42*42 cm^2, whereas for our purposes a smaller chamber with sensitive area of 32*32 cm^2 was more suitable. Two such modules were constructed jointly by the Stockholm University group and CERN. The design resembles WO in the respect that the cathod planes are graphite covered mylar films. The anode plane consists of 320 goldplated tungsten wires with 20 μm diameter and 1 mm pitch. At each end of the wireplane the sense wires were flanked by grounded guard wires with progressively larger diameter. The anode-cathode distance was 6 mm, the normal operating high voltage, ≈5.4 kV, thus corresponds to an electric field of ≈9 kV/cm.

The chamber was tested with two different gas mixtures, ii and iii above (mixture i was excluded because of reasons explained in the endnote). Very much like for WO the chamber reached the plateau with a ≈250 V lower high voltage value with gas mixture iii than with mixture ii. We were not able to provoke a break down of the chamber during the tests. The chamber was well behaved up to 6.2 kV, the maximum otuput of the high voltage supply used. The difference in cluster size for the two gas mixtures observed in WO was not present in W1. The cluster size at the start of the plateau was ≈1.06 and rose with about 0.03 for each 100 V applied. During data taking both chambers were for practical reasons (not connected with the chambers themselves) run on gas mixture iii. Typical running parameteres for the chambers during NA27 data taking are shown in table 4 below.

Table 4

Running conditions for W0 and W1 during NA27 data taking

	W0	W1
High Voltage (kV)	3.75	5.40
Gas flow (l/h)	≈5	≈10
Efficiency	≈98.6%	≈99.5%
Average cluster size;		
beam trigger	1.10	1.10
interaction trigger	1.24	1.19

We used a preamplifier developed by J.C.Santiard [6] for both chambers. This is a charge amplifier which incorporates a discriminator and a line driver for twisted pairs in the ECL standard. When testing W0 using the same gas mixture as in [4] (75% argon (premixed argon/freon: 99/1), bubbled through methylal at +5° C and 25% isobuthane) we were able to reach the plateau of full sensitivity at about 200 V lower value of the high voltage than in [4] (fig 2). Since all other conditions were the same we ascribe this improvement to the more sensitive amplifiers.

3.4 Electronic modules

Most of the trigger logic was implemented using electronic modules in the CAMAC or NIM standard. The CAMAC standard [7] is developed for the interfacing between detectors and experiment computer, and specifies the logical, electrical and mechanical standards to allow interchangeability Table 5 lists the different logic modules used in the general trigger.

The subsystems for the proportional chambers,driftchambers and ISIS have microprocessors (the CERN developed type ESOP [8], in the case of the MWPC:s and ISIS) for datareduction and transfer of data to the CAMAC bus. The proportional chambers and driftchambers have in addition data buffers that can accomodate several events (multi time slot, MTS) which is used to collect beam triggers for calibration purposes.

The fiducial volume trigger [3], a modular CAMAC system with elements partly designed and built at INFN Rome, partly of the MBNIM system, consists of

- pattern units
- decoding processor unit (DPU)
- fast algorithm processor
- decision logic.

The pattern units are single width home built CAMAC modules with 2*16 bit (latch) registers. Each module has an analog output signal proportional to the number of hits (40 mV/hit) used for the interaction trigger, and two NIM output signals which are the logical OR of the 16 bits in each group, used to adress only those groups having at least one hit.

Table 5

Electronic modules used in the trigger

Type		Function	# in/out	Remark
428 A	LeCroy	Quad linear fan in/out	4/6	
428 F	LeCroy	Quad linear fan in/out	4/6	
429 A	LeCroy	Quad fan in/out	4/6	
430	LeCroy	Octal fan out	1/4	
465	LeCroy	Triple coincidence	4/5	Veto
621	LeCroy	Quad discriminator	1/6	Shape
623	LeCroy	Octal discriminator	1/3	Shape
4608	LeCroy	Octal discriminator		
U277	SEN	Dual timing unit	1/3	40ns - 10s
2251	CERN	Single timing unit	1/3	40ns - 10s
C85A	CAEN	Programmable logic unit	8/6	Shape
C85B	CAEN	Programmable logic unit	8/6	Shape
2551	LeCroy	12 channel scaler 24-bit		Clear/inhibit
2552	LeCroy	12 channel scaler 16-bit		Clear/inhibit
2088	SEN	16 channel output register		
2050	SEN	16 channel fan out		

3.5 The Magbox Facility.

NA27 used five magic boxes (six in the proton part). The inputs and logical functions are given in Table 6. With the aid of Magbox, a program package developed by B.Pylgroms [9], the logical contents of the magic boxes could be created, loaded and checked.

Normally a file containing the specifications for each magic box in a trigger set up is created with Magbox. Each of the six outputs (Y1-Y6) may be specified as a function of the eight inputs (X1-X8) and the other outputs, using the dummy variables Y1-Y6, X1-X8 and logical operators.
In this way a set of files for standard options were created and kept on disk, ready to be loaded. The magic boxes could be loaded in two ways :

- by the Data Acquisition System program. The MB1 was loaded each time the system was set up for datataking since the actual detector configuration determined the contents. MB2-5 were loaded from a file
- from a terminal running the Magbox program

Running Magbox from a terminal, the contents of any magic box in the system could be set, analysed or read back to the computer and saved. This possibility was useful when checking the trigger system. The program contained checks to prevent accidental changes of a running trigger set up.

Table 6

Magic box signals

MB#	Mode	Inputs		Outputs
1	Overlap	: 1 BC or Camera	busy	: Experiment ready
		: 2 Computer	busy	: Experiment ready
		: 3 ESOP	busy	: Experiment ready
		: 4 DC	busy	:
		: 5 ISIS	busy	:
		: 6 Event	seen	:
		: 7 Not BC window		:
2	Overlap	: 1 T1		: T1*T2
		: 2 T2		: T1*T2*V1
		: 3 T3		: T1*T2*V2
		: 4 T4		: $T1*T2*\overline{V1}*\overline{V2}$
		: 5 V1		: $T1*T2*T3*T4*\overline{V1}*\overline{V2}$
		: 6 V2		: $T1*T2*T3*\overline{V1}*\overline{V2}$
3	Strobe	: 1 T1		: Selected beam
		: 2 T2		: Selected beam
		: 3 T3		: Selected beam
		: 4 T4		:
		: 5 V1		:
		: 6 V2		:
		: 7 Artif. trigger		:
		: 8 Experiment ready		:
4	Strobe	: 1 Selected beam		: Event1 + MTS
		: 2 Mult SSD0 min		: Event1 + MTS
		: 3 max		: Event1
		: 4 Mult SSD1 min		: Event1
		: 5 max		:
		: 6 Mult W0 min		:
		: 7 Mult W1 min		:
		: 8 MTS mix from comp.		:
5	Strobe	: 1 Event1		: Event2
		: 2 FVT veto		: Event2
		: 3		: Level2 abort
		: 4		: Level2 abort

4. THE TRIGGER SYSTEM

The electronic detectors in EHS extended over a length of 50 m, (fig.3), and their information had to be read by the computer in the common counting room after decisions taken in the trigger system.

Most of the logical decisions had to be taken in fast hardware electronics rather than in the computer because of time constraints.

Fig 4 shows a scheme of the trigger system as of the end of the pion run in 1982. During a running period, several modes of operation were selected;

- artificial triggers generated by the computer were used while setting up the experiments
- calibration runs for the spectrometer without the bubble chamber using beam trigger

- normal datataking with all operational detectors in use

These modes, for which the exact configuration varied between the experiments using EHS, required different logic in the trigger. Programmable logic modules (magic boxes) were used to achieve the necessary changes in a reliable and transparent manner. During normal datataking in NA27 the typical sequence of actions was:

time	action
0	The scintillator signals arrive in the counting room
30 ns	The Beam trigger is formed and strobes the trigger detectors
130 ns	The Level1 trigger is formed, and the spectrometer detectors are strobed. For an interaction trigger the Fiducial Volume Trigger processor starts its operations.
6 μs	Transfer of Multi Timeslot Events to the buffers is completed
8 μs	The Fiducial Volume Trigger decision is taken. If a veto is formed the detector registrers are cleared and in 100 μs the experiment is ready to accept new beam triggers. If there is no veto the read out of the spectrometer detectors proceeds, the kicker magnet and the camera flashes are triggered.
70 μs	The photograph is taken
60 ms	The read out is completed and the experiment is ready to accept new triggers.

4.1 Experiment ready.

In magic box 1 the Experiment ready signal was set when new triggers could be accepted. It was used in overlap mode so new triggers were prevented whenever a subsystem became busy.

Particles arrived at the experiment every 12 seconds, typically 50.000 during the two seconds spill. During the spill the bubble chamber expands at a rate of 30 Hz with a sensitive time of 500 μs at the pressure minimum, the BC window. The film advance set an upper limit for the instantaneous data taking rate of 15 Hz.

Each trigger level introduced a dead time via the Event seen signal; 6 μs for an MTS trigger and 100 μs for an interaction trigger. The computer needed up to 60 ms to read out a complete event (this means that the expansion after a level2 trigger is lost).

With an interaction probability of 2 % and these dead times the Event2 rate is about 12 per spill.

4.2 The Beam Trigger.

The beam condition was $T1*T2*T3*T4*\bar{V1}*\bar{V2}$. The signals were transmitted to the counting room in high speed cables and transformed to standard size and length in discriminators ; 30 ns for T1-T4 and 44 ns for V1-V2. In the Beam selection magic box, strobed by T1 and used in overlap mode, the coincidence between the beam and the Experiment ready signal was formed. The selected beam signal appeared 30 ns after the arrival of the scintillator signal to the counting room.

4.3 The Interaction Trigger, Level1.

The trigger chambers SSD0, SSD1, W0 and W1 are connected to the latch units. The analog outputs are summed in linear fan-in units, giving one signal proportional to the number of hits for each chamber. Discriminators, set to 120 mV, give an output signal when there are more than two hits in W0 and W1.

The Selected beam signal strobed the latch units, the actual hit pattern was conserved and further signals were prevented from entering the units. With a delay of 8 ns the Event1 magic box was strobed, and if the multiplicity condition was met, the first level trigger was obtained about 130 ns after the Selected beam signal appeared. The level1 trigger must be formed within the duration of the pulses from the preamplifiers for the trigger chambers. These signals were 200 ns long, with a jitter of ≈30-40 ns. To initiate readout of the detectors the Level1 signal is used to:

- strobe the wire chambers
- open a gate for the AD-converters for the gamma detectors, the neutral calorimeters, SAD and the transition radiation detector.
- enable the stop signal -time reference- from T4 to the drift chambers

The event seen signal was formed, the duration depending on the trigger being a multi timeslot or an Interaction one.

4.4 The Interaction Trigger, Level 2.

It was possible to reject an event without loosing the rest of the useful bubble chamber expansion cycle, provided the decision was taken within 8 μs from Event1. This time limit was set by the gamma detector subsystem. The Fiducial Volume Trigger (FVT, summarized below) determined if the interaction had occurred inside or close to one of the windows of the bubble chamber, and if so created a veto signal which entered the Event2 magic box. If there was no veto, the trigger level2 was formed on the strobe from Event1 and the following actions initiated:

- a signal was sent to the computer, delayed by 2 ms in order that all detectors be ready for readout
- the event seen signal was extended to 2.5 ms.
- a stop signal was sent to the large driftchamber ISIS
- a trigger was sent to the MWPC micro processor to enable readout
- the databox, which prints roll and frame number on the film after the film advance, was triggerd after 20 ms
- a trigger for picture taking was sent to the bubble chamber control system.

- the event time counter was stopped
- the kicker magnet got a trigger to avoid further beam tracks in the picture.

4.5 Aborts.

Abort signals were produced in two situations: an expansion ends without an interaction, or the FVT rejects the event (in the proton set up, too many incoming beam tracks in an expansion would also cause an abort). At the end of expansion the MTS buffers had to be cleared, since there would be no computer initiated clearing of registers. In the case of a FVT veto also the gamma detectors, SAD, the transition radiation detector and the neutral calorimeters had to be cleared. In a few μs after an abort, all detectors were ready to accept new triggers.

4.6 The Fiducial Volume Trigger.

The Fiducial Volume Trigger was used to create a veto against interactions taking place in the beam windows of the bubble chamber or in the unilluminated part of the hydrogen close to the ends of the bubble chamber. Below we give a summary of its principles of operation. The Fiducial Volume Trigger has been described in detail in [3].

4.6.1 The algorithm

Knowing the (horizontal) z-coordinate for the incoming beam in SSD0, z_1, and SSD1, z_2, the coordinates for tracks in W1, z_4, could be predicted from the coordinates in W0, z_3, under the assumption that the interaction had taken place in one of the bubble chamber windows. If the separation between the silicon detectors is D (cf. fig 1) and the distance from SSD0 to the exit window is d_1, the z-coordinate in the exit window, z_w, is:

$$z_w = z_1 + d_1(z_2 - z_1)/D$$

With d_2 the distance between the exit window and W0 and d_3 the distance between the exit window and W1, each hit in W0 at coordinate z_3 then extrapolates to:

$$z_4 = z_3d_3/d_2 - z_2d1(d_3-d_2)/(d_2D) + d_1(d_1-D)(d_3-d_2)/(d_2D)$$

If a hit corresponding to the prediction exists in W1 this is called a "match", if not the prediction is registred as a "mismatch". If the number of matches is ≥2 and the number of matches ≥ the number of mismatches, a veto is formed for the exit window. The equivalent procedure is followed for the entrance window, and the exclusive OR of the two vetoes was used to form a veto against window interactions.

4.6.2 Realisation

Each latch unit receiving the output signals from 2*16 channels in SSD0, SSD1, W0 or W1 produced two output signals which were the logical OR of the incoming 16 signals. Each group was adressable from the Decoding Processor Unit, DPU. For the silicon detectors the DPU decoded the adress for the single hit in the single non empty group and ouptut it during the whole processing time. The DPU connected to W0 looped over all non-empty groups. The adress of each hit in W0 was output twice, once for each window. The Fast Algorithm Processor then computed the predicted coordinate in W1 using the algorithm above. The predicted hit pattern in W1 was compared bit by bit with the actual one. The number of matches and mismatches were counted in four-bit scalers. For each window these were combined to form an eight bit word used to adress a look-up table. To each input adress corresponds two outputs, veto or non-veto, which were used to decide whether to veto the event or not.

4.7 Data Taking Monitoring.

The beam conditions and event rates were continously checked, both on-line by scalers displayed on TV monitors, and recorded on tape. The magic box 2 was used to give the following quantities:

- T1*T2 — the total number of beam particles
- T1*T2*V1 and T1*T2*V2 — give the left-right assymetry of the beam
- T1*T2*$\overline{V1}$*$\overline{V2}$ — compared to T1*T2 gives a measure of the horizontal focussing
- T1*T2*T3*$\overline{V1}$*$\overline{V2}$ — gives a measure of the vertical focussing
- T1*T2*T3*T4*$\overline{V1}$*$\overline{V2}$ — is the number of beam trigger candidates

In addition the number of Selected beam, Event1, Event2 and Aborts were counted. To record these one 24-bit and two 16-bit scalers were used as shown in Table 7.

Table 7

CAMAC scaler contents

Input	Scaler1	Scaler2	Scaler3
0	T1*T2		Event time
1	T1*T2*V1	0-3 same as	Sel.beam
2	T1*T2*V2	scaler 1	T1*T2
3	T1*T2*$\overline{V1}$*$\overline{V2}$	Restr.beam	
4	T1*T2*T3*T4*$\overline{V1}$*$\overline{V2}$		
5	Restricted beam †		
6	T1*T2*T3*$\overline{V1}$*$\overline{V2}$		
7	Event1		
8	Event2		
9	Selected beam		
10			
11	T1*T2*BC Window		
Inhibit	$\overline{\text{Spill}}$	$\overline{\text{Exp. ready}}$	$\overline{\text{BC Window}}$
Clear			Start BC W

† = 4 with the additional condition one and only one hit in the SSD:s

Scaler 1 counted during spills, scaler 2 during experiment ready and scaler 3 during the bubble chamber window. Eight numbers related to beam rates, trigger rates and abort rates were computed from the scalers. These numbers indicated immediately if there was something wrong with the data taking. They were continously printed and could also be displayed on-line. Typical values of these quantites are shown in table 8.

Table 8

Trigger monitoring scalers (pion run)

Slot	Definition	Mean (10 spills)
1	T1*T2/spill	49002
2	Beam/T1*T2 †	0.72
3	(V1-V2)/(V1+V2)	0.29
4	Beam/High beam ††	0.99
5	Time exp.ready/Time spill	0.017
6	Not used	
7	Event1/Beam*exp.ready	0.014
8	Event2/Beam*exp.ready	0.014

† Beam = $T1*T2*T3*T4*\bar{V1}*\bar{V2}$ †† High beam = $T1*T2*T3*\bar{V1}*\bar{V2}$

Another important tool for monitoring and verification of the trigger was a multichannel logic analyser. Up to 16 different signals could be collected and displayed on a screen for different time ranges, giving detailed information on their length and mutual relations. One feature that made this analyser especially useful for verification of the signal flow in the trigger set up, was the possibility to trigger the collection of signals into the analyser memory by a preset sequence of the input signals.

4.8 Clocks, Beam Kicking

The event time was obtained with a 10 MHz clock started at the beginning of the BC window and stopped by Level2 or the end of BC window. The spill time was counted with a 10 kHz clock in a scaler gated by a spill signal from the SPS.

At a level2 trigger a signal was sent to the kicker magnet to prevent particles from entering the bubble chamber after the interaction but before the cameras were flashed. If no event took place the signal to the kicker was sent at the end of expansion.

4.9 Changes in the Trigger.

In the 1982 run,the FVT was not introduced in the trigger, but data from this level were recorded for offline analysis of the veto function. The main changes for the proton runs in 1983 and 1984 were :

- introduction of the FVT in the trigger
- introduction of a third trigger level between the earlier level one and level two. The main reason was to allow a rejection based on the beam cerenkov counters in experiment NA22. In NA27 events with too many incoming beam tracks in one expansion were rejected at this new level two, since they could obscure the interesting interactions. No bias is expected for such a veto.

5. PERFORMANCE OF THE INTERACTION TRIGGER

One of the aims of the interaction trigger is to trigger on the largest possible fraction of the total inelastic cross section and to increase the data taking rate while minimizing the biasses. An important measure of the quality of the interaction trigger is the ratio between the triggered cross section and the total inelastic cross section for the process in question. The triggered cross section can be determined from:

$$\sigma_{tri} = P_{tri} * A/(l \rho N) \quad (1)$$

where P_{tri} is the probability for an incoming beam to give a triggered interaction, A is the atomic number, 1 in our case, l is the length of the fiducial volume, ρ is the density of the target, which under picture taking conditions in the bubble chamber is $\rho = 0.05713$ g/cm^3, and N is Avogadros number, $6.023*10^{23}$. The inelastic cross section for 360 GeV/c $\pi^- p$ interactions is 21.6 mb and for 400 GeV/c pp interactions 33 mb [10].

5.1 The Pion Exposure.

For the part of the experiment using a π^- beam, 865 000 triggers were collected. For technical reasons only 775 000 of the pictures were classified as good for physics. Of these 264 000 contained a primary interaction in the fiducial volume of the bubble chamber, giving a trigger efficiency of 34.2 %. The trigger rate, defined as the number of triggers per incoming beam, was 1.40±.03 %. The probability for a beam to give a triggered interaction in the fiducial volume is thus $4.79 \pm 0.10 * 10^{-3}$.

Using the actual position distribution of primary events, the fiducial length of LEBC was determined as 8.5±0.5 cm. Using (1) these numbers determine the triggered cross section as 16.4±1.0 mb i.e. 75.9±4.6 % of the total inelastic cross section.

The multiplicity distribution of primary events can be seen in fig. 5, together with the multiplicity distribution as measured by Firestone et al. [10] (note that the statistical errors are smaller in this experiment). The data points are normalised for $n_{charged} \geq 10$. Clearly there are some losses up to $n_{charged} \approx 8$. Assuming that the efficiency is 1 for $n_{charged} \geq 10$, it is possible to compute the efficiency for the low multiplicity topologies shown in table 9 below.

Table 9

Trigger efficiency for low multiplicities

Multiplicity	Efficiency (%)
2 (inelastic)	19±2
4	43±2
6	68±3
8	87±3

The efficiencies given in table 9 are the hardware efficiency folded with the geometrical acceptancies. The component of 2 prong, which by construction should be 0 is explained by secondary interactions, knock on electrons and particles firing more than one wire in W0 and W1. Also the use of an analogue threshold for the multiplicity condition leaves some room for accidental triggers.

Using the efficiencies in the various topologies given in table 9 and the cross sections for these topologies from [10] we obtain the triggered cross section as 17.0±0.4 mb. The agreement between this determination and the one given in 5.1 justifies the assumption that the efficiency is ≈1 for charged multiplicities larger than eight.

5.2 The Proton Exposure.

For the part of the experiment using proton beam 2.3 million triggers were collected. The analysis of these data is still in progress so this section is based on a study of a small subsample of the data. For the proton part the fiducial volume trigger was implemented. There exists some data taken without using the veto produced by FVT, which was used for off-line checks of the performance of FVT. These data are used for a comparison and consistency check with the data collected without FVT during the π^- exposure.

In a study of 1451 triggered events **not** using the veto from FVT we found 686 primary interactions in the fiducial volume, giving a trigger efficiency of 47.3±1.8 %. The increase from 34.2 is explained by the increased lenght of the fiducial volume from 8.5±0.5 to 11.0±0.5 cm (caused by changing the optical demagnification). The trigger rate defined as above was 2.12±0.02 %, which is again consistent with the increase in cross section from 21.6 mb for πp interactions to 33 mb for pp interactions. The probability for a beam to give a triggered interaction in hydrogen was thus $1.00 \pm 0.04 * 10^{-2}$. Again using (1) we obtain the triggered cross section as 26.5±1.5 mb, i.e. 80.3±4.5 % of the total inelastic cross section, in perfect agreement with the value for the π^- exposure.

6. PERFORMANCE OF THE FIDUCIAL VOLUME TRIGGER

6.1 Theoretical expectations

The process of taking a picture and reading out the spectrometer information introduced a dead time during which the experiment was insensitive. Because of this dead time, the bubble chamber expansion following an expansion during which an event was registered was "lost" in the sence that no interactions could be registered. Calling the probability for a beam to cause a triggered interaction P, the number of particles per expansion M and the number of expansions per spill N, the average number of pictures taken per spill is:

$$Pix = NPM/(1+PM) \qquad (2)$$

The ratio of number of useful pictures per spill with and without the FVT is then

$$R = \{\varepsilon_{FVT}P_{FVT}(1+PM)\}/\{\varepsilon P(1+P_{FVT}M)\} \quad (3)$$

where ε is the probability for a triggered event to contain a primary interaction in the fiducial volume.

From (3) one can also see under what conditions the data taking rate is affected by the implementation of a Fiducial volume Trigger. For very low rates for the incoming beam the ratio goes towards:

$$R_{low} = (\varepsilon_{FVT}P_{FVT})/(\varepsilon P) \quad (4)$$

Ideally this goes towards 1, in reality the term ε_{FVT} also includes losses due to events in hydrogen vetoed by FVT, giving a R_{low} below 1. At low beam rates the introduction of a fiducial volume trigger normally implies a reduction of the data taking rate. This is intuitively easy to understand: if the incoming beam particle rate is so low that the dead time of read out becomes negligible compared to the time between interactions no good events are lost in either case, and the ratio should be exactly one, except for the case where events actually are lost. For high rates on the other hand the ratio approaches:

$$R_{high} = \varepsilon_{FVT}/\varepsilon \quad (5)$$

This situation is also intuitively clear: for very high beam rates, the data taking rate is saturated (the product PM is always ≤ 1) and the number of pictures per spill instead becomes N/2 since the expansion following a triggered interaction is lost. In this situation the ratio between rates of good pictures is simply the ratio between the probabilities that a photograph contains an interaction in the fiducial volume.

The introduction of a Fiducial Volume Trigger thus introduces a real gain in data taking rate only in situations where the trigger efficiency without FVT is low, the FVT efficiency is high and the beam rate is high enough. The advantage with lowered film cost and processing effort is of course present as soon as the gain in efficiency balances the loss of signal.

6.2 Performance

To investigate the performance of the FVT we study the sample of 1451 triggers collected with the FVT veto not implemented on line, but registered for an off line analysis. For 385 (26.5%) of these triggers the FVT would have vetoed the interaction.

The interactions can be classified as: "window", i.e. an interaction taking place in the entrance window, or the first, not illuminated, region of the hydrogen; "hydrogen", i.e. an interaction in the fiducial volume of the bubble chamber, and; "beam", i.e. a frame where no interaction is visible on the photograph, which could be either due to an interaction in the exit window or the last 5 mm of not illuminated hydrogen (not visible on the photograph), or trigger malfunction. The distribution of the triggers among these categories is shown in table 10 below.

Table 10

Classification of triggers

	Not vetoed	Vetoed	Total
"Window"	99 (9.3%)	88 (22.9%)	187 (12.9%)
"Hydrogen"	634 (59.5%)	52 (13.5%)	686 (47.3%)
"Beam"	333 (31.2%)	245 (63.6%)	578 (39.8%)
Sum	1066	385	1451

The percentages given are normalised to the sum given in the bottom line.

These numbers show, as mentioned above, that by implementing the FVT the trigger efficicency was increased, from 47.4±1.8% to 59.5±2.4%. The losses of hydrogen interactions is 7.6±1.1% of the total number of triggered hydrogen interactions (not using the FVT veto). The position distribution of these events are, as expected, peaked close to the ends of the bubble chamber, cf. fig 6.

The expected number of interactions for the three cathegories can be derived from known interaction lengths and the geometry. Making the assumption that all "beam" events, i.e. events where no interaction is visible in the photograph, are exit window interactions we would expect that for the total sample in table 10 the ratio window:hydrogen:beam would be 0.33:1:0.52, whereas the measured ratio is 0.27:1:0.84. There is thus an excess of "beam" events corresponding to about 15% (≈220 events) of the total number of triggered events (not using the FVT information).

To investigate the nature of this excess we used data collected demanding only beam trigger. The multiplicity distribution for the cases when one of the chambers fulfilled the trigger condition of $n_{charged} \geq 3$, while the other chamber was "quiet", i.e. having $n_{charged} \leq 2$, was compared to the distributions for normally triggered events. This comparison showed that for the events where only one chamber had $n_{charged} \geq 3$ there was an excess at both low and high multiplicities as compared to normal events. The excess at low multiplicities is roughly compatible with what could be expected from the cluster size being $\vec{1}$ in the chambers [table 4] and corresponds to 2.6% of the total number of triggered events. There is also a small fraction of the events with an excess at high multiplicities, for which the most probable interpretation is electronics noise.

All in all there remains a fraction of triggered events for which there is no interaction visible in the fiducial volume, nor in the entrance window, corresponding to about 10% of the triggered events. In the subsample of rejected events the ratio window:beam is 1:2.8, compared to 1:3.1 measured for the total sample and the theoretically expected ratio 1:1.6. This disagreement is not fully understood, but if the excess of "beam" is due to some random process we would expect the vetoed sample to be depleted on this type of events as compared to the full sample. This effect can be explained by some additional material immediately downstream of the fiducial volume (for example the equivalent of 1 mm of LEXAN would be sufficient to explain the effect).

6.3 Over all Performance with the FVT.

For the sample presented in table 10, the information from the FVT is present. One can then define the subset for which there is no veto from the FVT to investigate the effect of the FVT veto. This subset contains 1066 events. In 634 of these events there was a primary interaction in the fiducial volume. The introduction of the FVT thus increases the trigger efficiency to 59.5±2.4 %. On the other hand the trigger rate decreases, since the probability for an incoming beam to give a triggered interaction goes down.

The exact trigger rate depends on the efficiency of the silicon strip detectors; if for a beam trigger there was no hit in one of the silicon strip detectors, no veto could be created. In this situation, which could be caused either by inefficiencies of the silicon detectors, or for purely geometrical reasons, the interaction trigger was for all practical purposes the Level1 trigger. This means that during data taking the trigger was in some respects a mix of Level1 and Level2 triggers. Depending on the eficicency of the silicon detectors, which varied but normally was ≈90% for each detector, the trigger rate varied in the interval 1.65 to 1.75%. The lowered trigger rate cancel to some extent the effect of the increased efficiency. The probability for an incoming beam to give a triggered interaction in hydrogen (not vetoed by FVT) is $0.98-1.04\pm.04*10^{-2}$. This corresponds to a triggered cross section of 25.9-27.5±1.5 mb which is 78.5-83.3±4.5 % of the total inelastic cross section (the errors indicated are the statistical errors).

The change in datataking rate can be computed from (3). Using P=2.12%, ε=47.3%, P_{FVT}=1.70, ε_{FVT}=57% and M=12.5 (taken as average of the trigger rates and efficiencies over the data taking period) we obtain R=1.01. The datataking rate is thus only marginally higher when running with the FVT implemented as compared to running without FVT. The gain using the FVT during these conditions is the 20% reduction of pictures taken to obtain a given sensitivity. This is of course important because it reduces film costs and both cost and effort when analysing the film to find secondary interactions. It also reduces the load on camera flash system, resulting in fewer interrupts in the datataking.

7. CONCLUSIONS

We have designed and implemented a minimum bias trigger for the experiment NA27 performed at the CERN SPS. The multiplicity dependent trigger efficiency folded with the multiplicity distribution of events containing charmed particles observed in the experiment gives an efficiency of 98^{+2}_{-3}% for events containing charm. The triggered cross section was >75% of the total inelastic cross section.

The Fiducial Volume Trigger raised the probability for a picture to contain an interaction in the fiducial volume from 47.3% to 59.5%, thus reducing film costs and film processing effort with 20%.

8. ACKNOWLEDGEMENTS

Several people have contributed in making the EHS trigger system work. In particular we would like to mention J.Hrubec and G.Neuhofer who worked with the trigger and B.Pylgroms who designed and documented the software for the programmable logic units.

We also thank P.Gervasoni for his assistance with assembling and maintaining the wire chambers, E.Heijne and P.Jarron for help with the silicon detectors, T.Modis and J.C.Santiard who gave us a lot of technical advice, and R.J.Gray for lending us a WO module and giving advice on how to handle it.

9. REFERENCES

1a CERN/SPSC 81-86 SPSC/P 169 (1981)
NA27 proposal

b M.Aguilar-Benitez et al.
Physics Letters **146B** (1984) 246

c M.Aguilar-Benitez et al.
Charmed Hadron Properties in 360 GeV/c $\pi^- p$ interactions
to be submitted to Zeitschrift fur Physik

2 M.Aguilar-Benitez et al.
Nuclear Instruments and Methods **205** (1983) 79

3 R.Bizarri et al.
Nuclear Instruments and Methods **222** (1984) 441

4 R.J.Gray
Nuclear Instruments and Methods **176** (1980) 133

5 T.Modis
Nuclear Instruments and Methods **176** (1980) 129

6 J.C.Santiard CERN/EP 80-84 (1980)
"Low Threshold Amplifier-Discriminator"

7a IEEE trans. on Nuclear Science NS-20 no.2 (1973)

b J.O.Petersen (1982)
"An introduction to CAMAC, notes for CERN summer students"

8 D.A.Jacobs
Computer Physics Communications **22** (1981) 285

9 B.Pylgroms CERN/EP/EHS/ON-LINE 82-1 (1982)
"Maglog, a utility package for programmable logic units"

10 A.Firestone et al.
Physical Review **D14** (1976) 2902

10. ENDNOTE

The use of methylal had serious side-effects when using chambers with graphite anodes. After a few hours of running the graphite covered mylar film slackens, an effect which for W0 is less serious than for W1, with its larger cathode planes. For W1 the slackening of the mylar made the cathode plane bulge towards the anode plane enough to cause break-down before the plateau could be reached. Remarkably enough the mechanical tension of the cathode planes could be restored by dismounting the chambers and evaporate the methylal with a hot air hair dryer.

11. FIGURE CAPTIONS

1. Trigger detectors in NA27. T1-T4, V1 and V2 are scintillators SSD0 and SSD1 are silicon strip detectors and W0 and W1 are multi

wire proportional chambers. The distances indicated are used in the algorithm for the fiducial volume trigger.

2. WO efficiency for two different amplifiers as a function of the high voltage on the cathode. Full circles represent the amplifiers used in this experiment.

3. European Hybrid Spectrometer. Charged particle momentum determination is obtained with the driftchambers D1-D6 and the magnets M1 and M2. and particle identification with the Cerenkov counters SAD and FC, and the ionisation sampling drift chamber ISIS2. Neutral particle detection is done in the gamma detectors IGD and FGD.

4.a Scheme of the trigger logic. The main signal flow is indicated by a thick line. MB1-MB5 are programmable logic units whose functions are indicated by the names above each box.

4.b Symbols used in the scheme

5. Multiplicity distribution of primary interactions. The circles are from this experiment and the crosses from an experiment performed at the same energy by Firestone et al [10]. The experimental points are normalised to Firestone et al. for multiplicities ≥10.

6. Distribution of the interaction point for events in the visible hydrogen vetoed by the Fiducial Volume Trigger

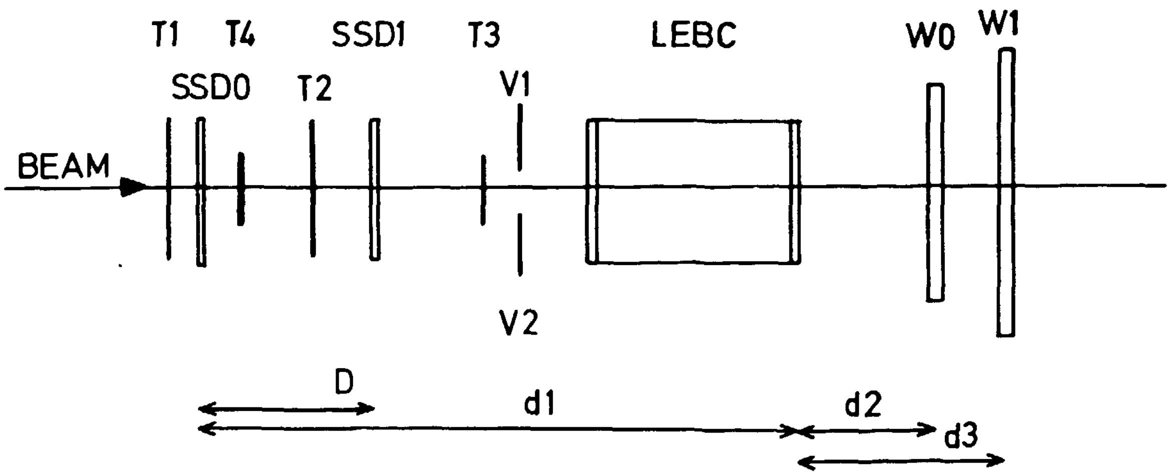
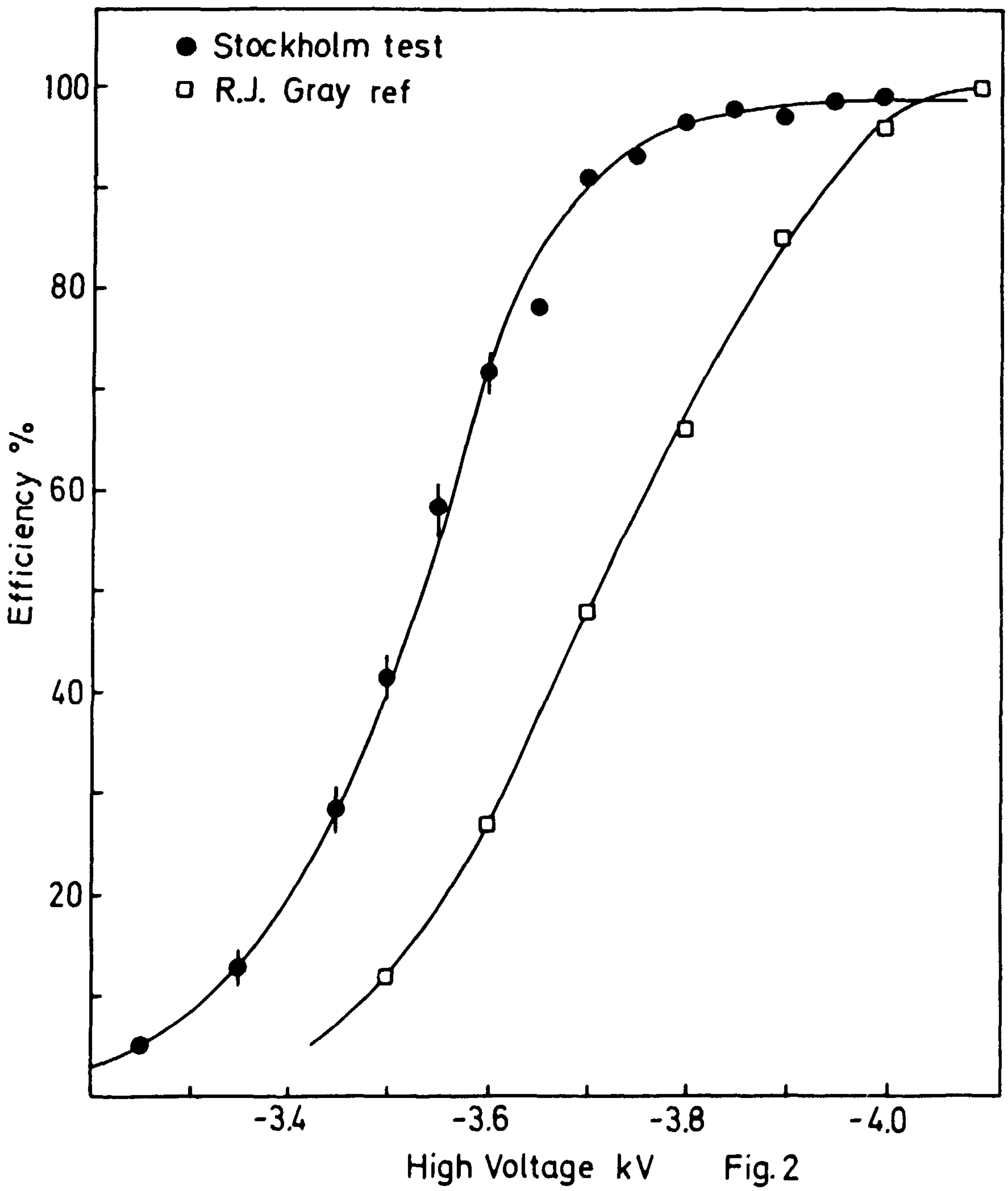


Fig.1



● Stockholm test
□ R.J. Gray ref
100
80
60
40
20
Efficiency %
-3.4
-3.6
-3.8
-4.0
High Voltage kV

Fig. 2

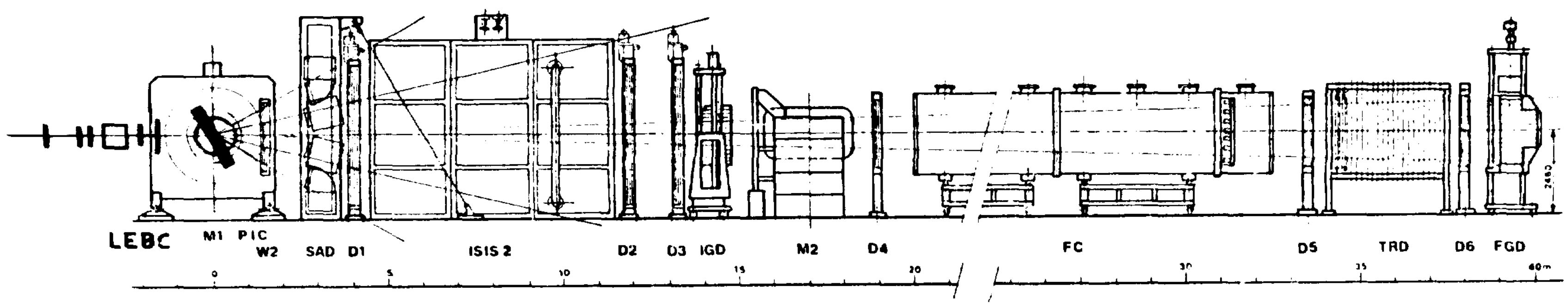

LEBC
M1
PIC
W2
SAD
D1
ISIS 2
D2
D3
IGD
M2
D4
FC
D5
TRD
D6
FGD
2460
0
5
10
15
20
30
35
40m

FIG. 3

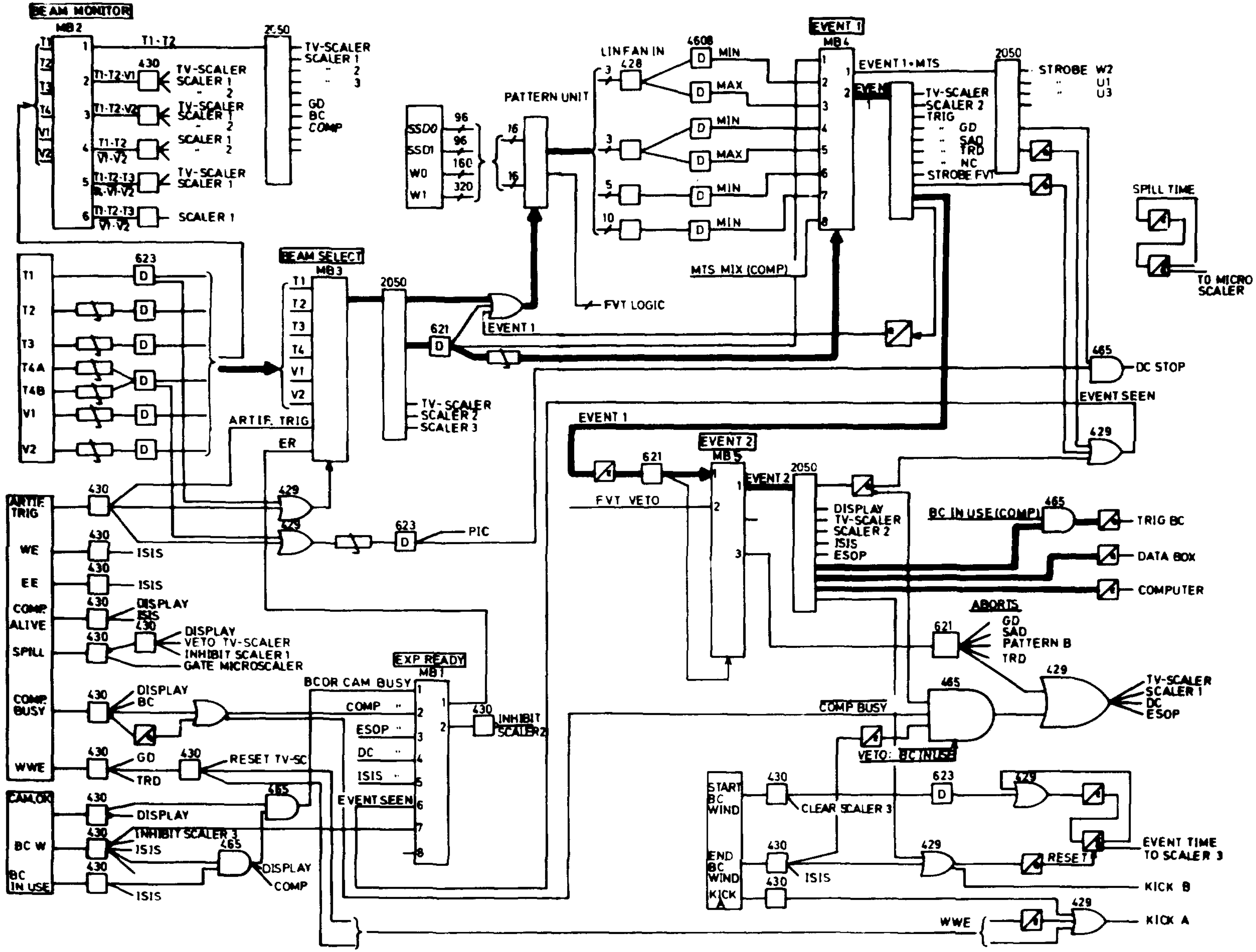

BEAM MONITOR
MB2
T1-T2
2050
TV-SCALER
SCALER 1
GD
BC
COMP
430
T1-T2-V1
T1-T2-V2
T1-T2 V1-V2
T1-T2-T3 T4-V1-V2
T1-T2-T3 V1-V2
PATTERN UNIT
SSD0
SSD1
W0
W1
96
160
320
16
LINFAN IN
428
4608
MIN
MAX
EVENT 1
MB4
EVENT 1+MTS
STROBE W2
U1
U3
TRIG
SAD
TRD
NC
STROBE FVT
SPILL TIME
TO MICRO SCALER
MTS MIX (COMP)
FVT LOGIC
BEAM SELECT
MB3
623
621
T1
T2
T3
T4A
T4B
V1
V2
ARTIF. TRIG
ER
SCALER 2
SCALER 3
465
DC STOP
EVENT SEEN
429
EVENT 2
MB5
FVT VETO
DISPLAY
JSIS
ESOP
BC IN USE (COMP)
TRIG BC
DATA BOX
COMPUTER
ABORTS
PATTERN B
PIC
WE
ISIS
EE
COMP. ALIVE
SPILL
VETO TV-SCALER
INHIBIT SCALER 1
GATE MICROSCALER
COMP. BUSY
EXP READY
MB1
BCOR CAM BUSY
INHIBIT SCALER 2
ESOP
DC
WWE
RESET TV-SC
CAM.OK
BC W
INHIBIT SCALER 3
BC IN USE
COMP BUSY
VETO: BC IN USE
START BC WIND
CLEAR SCALER 3
END BC WIND
KICK
RESET
EVENT TIME TO SCALER 3
KICK B
KICK A

Fig. 4a

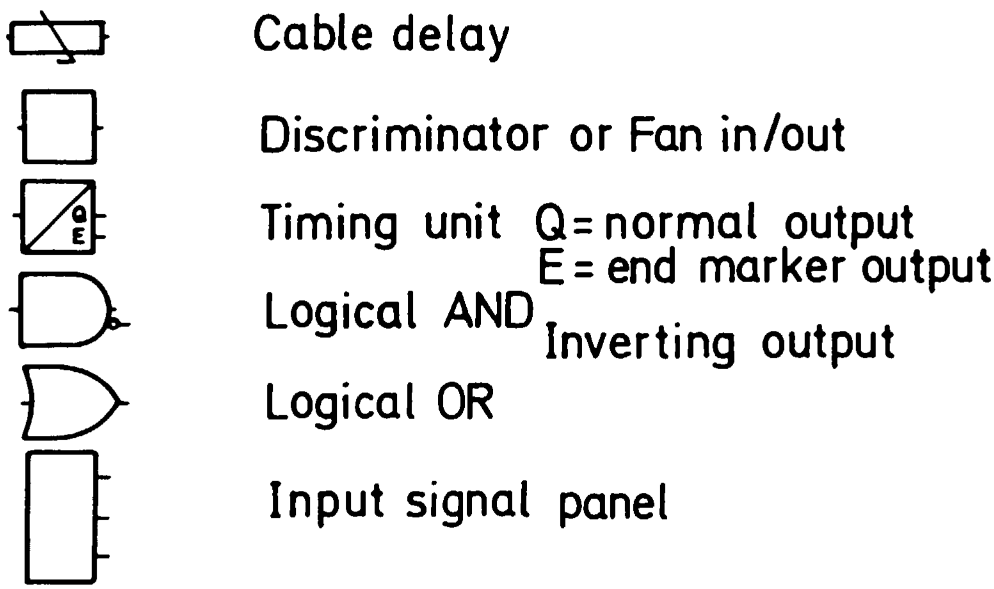
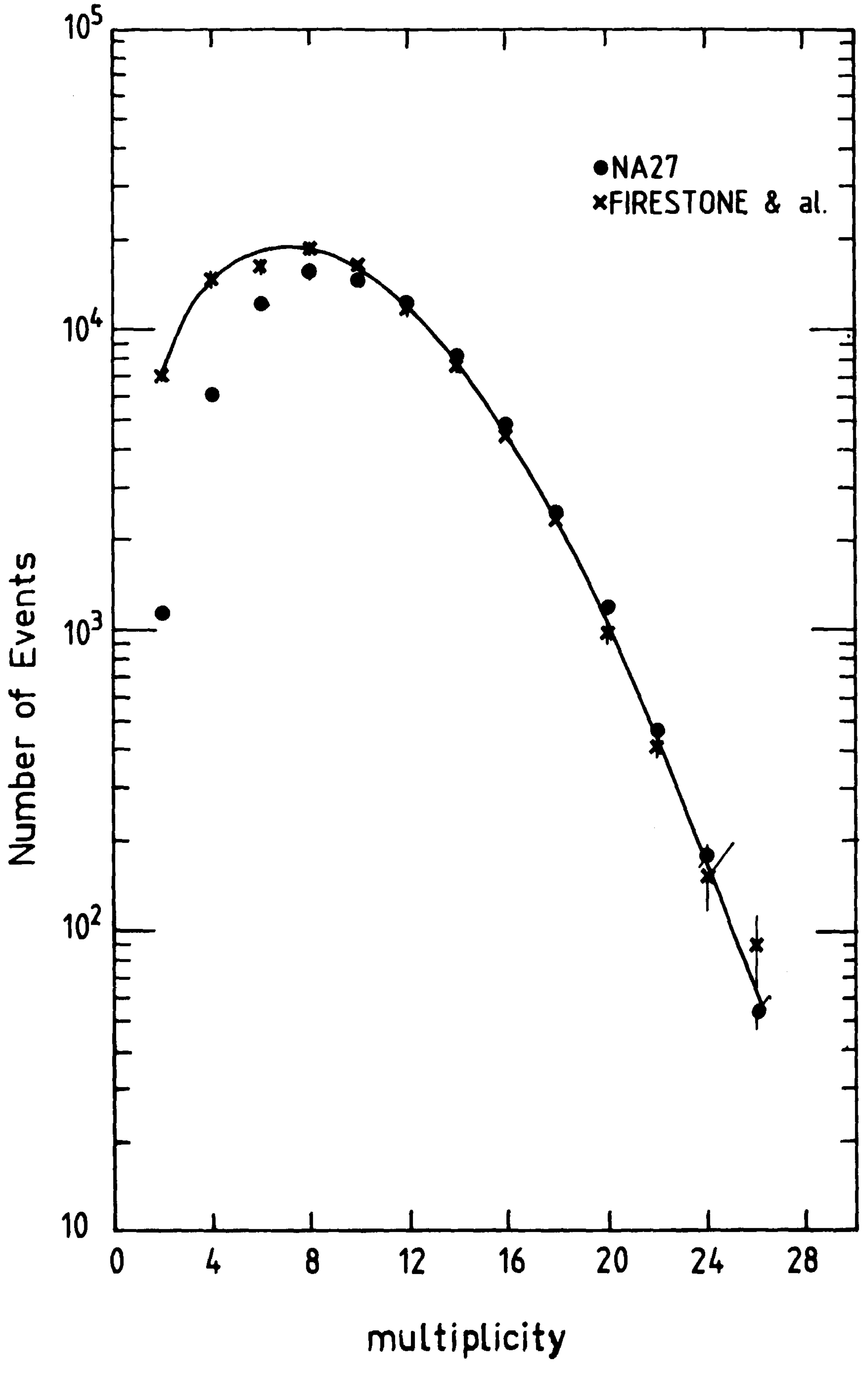

Cable delay
Discriminator or Fan in/out
Timing unit Q = normal output
E = end marker output
Q
E
Logical AND
Inverting output
Logical OR
Input signal panel

Fig. 4b



10^5
10^4
10^3
10^2
10
Number of Events
●NA27
×FIRESTONE & al.
0
4
8
12
16
20
24
28
multiplicity

Fig. 5

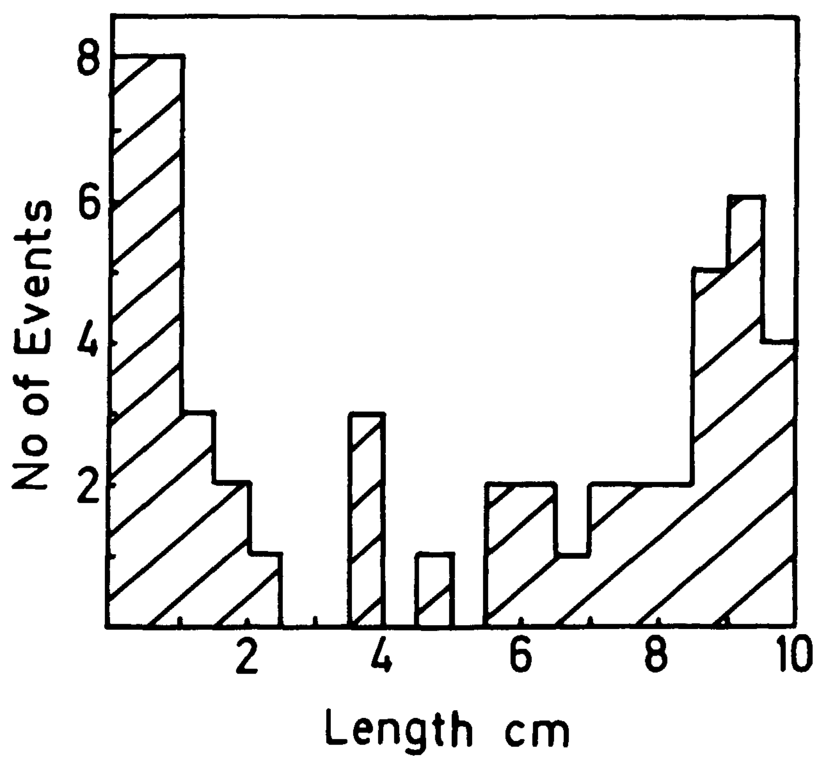


Fig. 6