CERN/SPSC/81-71
SPSC/P 167
21.09.1981

PROPOSAL

MEASUREMENT OF THE LIFETIME OF THE BEAUTY IN THE Ω' SPECTROMETER BY A HIGH PRECISION VERTEX DETECTOR AND EMULSION TARGET.

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The main difficulties to observe beauty decay are a very short expected decay path and a very low signal to background ratio. The use of nuclear emulsion allows to solve the first problem, while the second one asks for a very selective trigger and for a very high precision in the interaction vertex reconstruction inside the emulsion.

We present here a proposal for an experiment to measure the lifetime of the beauties.

The experiment has been projected under the following hypothesis:

i) cross section for BB production: $\sigma_{B\bar{B}} = 50$ nb

ii) average charged kaon number per BB decay: 2.2 (1).

The scheme of the proposed experiment foresees the use of the upgraded Ω' spectrometer. A 350 GeV/c π^- beam hits a nuclear emulsion target, 1.5 cm thick along the beam direction (Fig. 1). This target is followed by a high spatial resolution telescope which gives an accurate vertex reconstruction. The expected precisions are 10 μm across the beam direction and 100 μm along the beam. Target and telescope coupled to the Ω' spectrometer will give a very good kinematical reconstruction of the primary interaction and of the decay. The set-up for particle identification will be used to enrich the beauty sample.

The focal points of the experiment are:

a) the high resolution telescope

b) the trigger system

Apart from these two points the experiment is a conventional one.

The high resolution telescope

Many tests have been done to check the possibility of using solid state area image sensors as particle detectors.

These devices are made up by planes of photodiodes with a pitch ranging from 60 to 16 μm. The photodiode arrays are serially read by a sequential line-by-line read-out through a CCD mechanism.

It has to be pointed out here advantages and disadvantages of this apparatus in comparison with other ones (stripped silicon detectors).

The advantages are:

a) very high precision (up to 16 μm or better) by determining the weighted center of the collected charge;

b) very simple associated electronics: only one output channel for a very high number ($2\div3\ 10^5$) of pixels;

c) no ambiguity for any multiplicity;

d) resolution as good as about 80 μm;

e) commercial availability.

The disadvantages are:

a') rather long read-out time (10^{-2} s)

b') sensitivity lasting even during the read-out time.

a') precludes the use of this device for on-line triggers. b') bounds the beam intensity to the ability of taking the interesting data out of all those collected during the read-out time.

Many tests have been performed to check several points:

a) flatness of the base line in the dark (fixed pattern);

b) measurement of the standard deviation of the signal in one pixel as a function of the temperature, due to the fluctuation of the collected charge from the dark current;

c) sensitivity of the device to the minimum ionizing particles;

d) measurement of the signal to fixed pattern ratio under different work conditions;

e) measurement of the width (in pixels) of the signal due to the minimum ionizing particles.

The tests a) and b) have been done in our laboratories, the tests c), d) and e) have been done using 22 MeV/c electrons from the Linac of the Radiology Institute of Florence University.and exposing also the device to cosmic rays.

Among several tested devices the MA357 GEC from the GEC Hirst Research Center has fulfilled our needs.

The main features of these arrays are: 22 μm x 22 μm single pixel dimensions, 8.5x12.5 mm^2 overall dimension, 385 columns and 576 rows corresponding to 221,760 pixels, 10 MHz operating frequence, 20 ms read-out time.

The operating temperature was fixed at -25°C. In this condition, when a minimum ionizing particle crosses the device the pixel collecting the most of the charge gives a signal (6000 electrons) about 3 times the fixed pattern background, while the whole charge is distributed at the most over 3x3 contiguous pixels. The charge due to the dark current is 6000 electrons too, with a statistical fluctuation of 80 electrons. It is then easy to localize the crossing of a minimum ionizing particle inside one pixel or even a fraction of it.
By lowering the temperature it can be probably reduced the fixed pattern background and this is important to obtain good information on the particle trajectory.

The results of the tests are shown in Fig. 2. By exposing the array to cosmic rays with suitable electronics a number of pulses corresponding to the expected number of cosmic rays has been counted. The height of these pulses is comparable with that given from the electrons.

In any case, during this year, we like to do some tests mainly to check the efficiency of the array to the minimum ionizing particles, efficiency that now seems very close to 1. Our electron beam is however not suitable for these measurements so we will ask for a test run with a hadronic beam.

The best compromise between cost and performances of the telescope is given by 7 planes, 1 cm. spaced.

Many computer tests have been done on this configuration to determine the ability of reconstructing verteces of events produced by 350 GeV/c pions. The events have been generated by the Monte Carlo FOWL program with the geometry of Fig. 1, taking into account a 18 kgauss magnetic field and including the multiple scattering effect in the emulsion.

The transverse precision on the vertex reconstruction turns out to be about 10 μm, the longitudinal one about 100 μm.

The reconstruction program, written by us, is able to solve, without loosing information, several contemporary events spread over the target volume and with multiplicity up to 15. These results have been obtained with a background of 400 out-of-time points (Figg. 3 and 4). Only 2 over 1000 events are lost and the extra-track percentage is less than 1%. A track is classified as extra when its distance from the reconstructed vertex is more than 50 μm.

The telescope seems then able to determine the position of a vertex in the emulsion with a precision of 20 μm x 100 μm, i.e. inside one microscope field of view.

The main features of the telescope read-out, that allow to discriminate out-of-time tracks, are illustrated in the Appendix.

The read-out time of a single row is about 40 μs. Furthermore it is easy to eliminate a priori a great amount of spurious information due to non interacting primary particles.

Tests to increase the read-out frequency up to 20 MHz are in progress in order to double the beam intensity without increasing the background.

The trigger system

The trigger selection is based on the result, quoted above, that the average number of charged K per $B\bar{B}$ is 2.2. Therefore we think to ask for a trigger with 3 charged K detected by the Ω' Cerenkov system.

Using the CLEO data(1) about the momentum distribution of the K° from B decay and assuming for the pion-nucleon interactions a B central production of the type $(1-|X_F|)^2$, we have estimated by a Monte Carlo program that the detection efficiency for each of the charged kaons coming from the B decay is about 0.5 with the present Ω' Cerenkov system. It turns then out that the 3 charged K trigger will select about 10% of the produced $B\bar{B}$ pairs.

It is difficult to evaluate the number of background hadronic interactions detected by this multikaonic trigger because at these energies there is a lack of information about the production of more than 2 charged kaons. Assuming the central production of charged K with X_F and P_T distributions as those of the K° at 40 GeV(2) and 250 GeV(3), it is possible to estimate a detection efficiency of about 10% for each of the charged K. In this case about 0.1% of the background events with 3 charged K would be detected by the Cerenkov.

Under the hypothesis that the production cross-section for the events with more than 2 charged K is lower or equal to 1/100 of the total inelastic cross-section, one can foresee few hundred background events per each $B\bar{B}$ pair detected by a 3 charged K trigger, taking also into account the eventual wrong identification of a π as a K.

We are anyhow studying the possibility of using a less selective trigger with 2 charged K: the advantage of having a larger number of detected $B\bar{B}$ events could however be made void by a prohibitive number of background events.

It could be crucial for taking a final decision a test run to study the background event rates with different kinds of multiadronic triggers.

Experimental yield and time request

The emulsion target will be made up of 16 layers, 600 μm thick, so as to have a stack of 1 cm. Each target will be 1.5 cm wide and 15 cm long, as shown in Fig.1b. A stack will be exposed to a beam of $1_{(z)} \times 2_{(y)}$ cm^2 five times, moving it 3 cm at a time in the y direction and leaving 1 cm between one exposition and the other one. Each part of the stack will so have a volume 1.5x3 = 4.5 cm^3.

By the Monte Carlo program it is possible to determine the maximum particle background supported by the photodiode arrays of the telescope (as already said, the photodiodes are sensitive also during the read-out time). This background is of 400 tracks per each array. Each telescope plane is made up of 4 arrays covering an area of 17x25 mm^2 to give a minimum angular acceptance of 10 degrees with respect to the target of 10x20 mm^2. Therefore the maximum acceptable background will be of about 1600 spurious tracks per plane.

For this reason the maximum beam intensity has to be of about 10^3 primary tracks in 20 ms (read-out time of the arrays), i.e. $5\ 10^4\ \pi$ /burst. In fact 10^3 primary tracks crossing 1.5 cm of emulsion during the read out time give about 35 interactions. Assuming an average multiplicity of 8 tracks entering the telescope, 300 tracks will be added.

The number of produced $B\bar{B}$ pairs is given by

$$N_{B\bar{B}} = \frac{L_T}{l_\pi} \cdot \frac{\sigma_B}{\sigma_t^{(in)}} \cdot \frac{A}{A^{2/3}}$$

where L_T = total track length

l_π = π mean free path in emulsion

σ_B = $B\bar{B}$ production cross section on nucleon

$\sigma_t^{(in)}$ = total inelastic cross section

A = average mass number in emulsion

With the quoted beam intensity it will be

$$N_{B\bar{B}} = \frac{5\,10^4\,1.5}{40} \cdot \frac{50\,10^{-6}}{20} \cdot 3.75 = 0.02\ B\bar{B}/\text{burst}$$

Because of the 3 charged K trigger the number of selected $B\bar{B}$ pairs per burst will go to 0.002.

To collect at least 100 $B\bar{B}$ pairs $5\ 10^4$ bursts are necessary. With a 70% SPS efficiency and including the set-up time the requested number of bursts corresponds to 9 days of run, i.e. 1 shift.

Our experience indicates that the maximum accettable track density in emulsion is about $2\ 10^3$ tracks/mm^2. Therefore for each part (4,5 cm^3) of one stack 8 bursts will be necessary.

The total requested amount of nuclear emulsion is then $\frac{5\ 10^4}{8}\ 4.5 = 28\ 10^3\ \text{cm}^3$, i.e. 28 liters.

Under the hypothesis done in the "Trigger system" paragraph less than $3\ 10^4$ hadronic interactions will be detected by the 3 charged K trigger.

During the emulsion scanning it is possible to select the events with two

9 physicists
1 expert in programming
5 electronic technicians
2 mechanical technicians
6 nuclear emulsion scanners

The number of people available for the experiment seems adeguate to the work to be done. At the initial stage the work consists mainly in making ready the electronics associated to the telescope (see Appendix). Also the number of people available for scanning emulsion plates and performing data analysis seems well proportionate.

The software for the one vertex reconstruction has already been done and it has given particularly good results in simulation; for the multivertex reconstruction the work is still in progress.

The software for matching the telescope to Ω' , which we believe would improve TRIDENT, has still to be done.

The mechanical parts will be built entirely in our shops. The electronic part prototypes will be made in our laboratories and then given to commercial houses for mass-production.

Computations will be done on the CYBER 76 at CINECA laboratories and on the VAX of Bologna CNAF.

The list of the expected expenses is enclosed.

Conclusions

The proposed experiment foresees the detection of 100 $B\bar{B}$ pairs out of about 1000 pairs produced in 28 litres of nuclear emulsion with a particularly reduced scanning time.

This result will be achieved by using the detecting particle device described above. This kind of detector may have several different uses in all the cases where vertex reconstruction accuracy is very important and it is not essential to have the relative information in real time. A feature to be underlined is the cost particularly low respect to detection methods (stripped silicon detectors) with comparable performances and an almost comparable precision.

From the point of view of this experiment it has to be pointed out that the longitudinal development of interaction and decay allows a resolution between interaction and decay verteces in emulsion of 30 μ m or better. Therefore it is possible to observe beauties with momenta greater or equal to 50 GeV/c, if the lifetime is $\tau_B = 10^{-14}$ s, and beauties with momenta greater or equal to 5 GeV/c, if it is $\tau_B = 10^{-13}$s.

The available path in emulsion, long enough to allow the observation of the whole chain B→C→X, will make easier the topological identification of the event.

As far as the 3 charged K trigger is concerned, its efficiency could be considerably improved by using the identification particle system described in P140 of the Omega-Photon Collaboration. This system increases the momentum range useful for identifying charged kaons. Identification efficiency can reach 0.75 for the charged K coming from the B decays. Therefore the number of detected $\bar{B}B$ pairs may increase.

Finally for the high multiplicity events the kinematical reconstruction efficiency of the spectrometer and the associated TRIDENT program ought to be much improved since the data for the tracks in the central cone, as given by the telescope, can allow a very accurate geometrical reconstruction by TRIDENT. For this reason it is possible to forese a relatively low fraction of incomplete or unsuccessful kinematical reconstructions.

Time estimate.

We think to be ready for the test run in the second half of 1982. A more precise date depends on the delivery time of the materials and on the time needed for building the apparatus. To complete the analysis of the test run data about 5 months will be needed.

Therefore we think to be ready for the main run about at the end of 1983 or at the beginning of 1984.

TABLES

	I	II
	MAIN RUN	TEST RUN
BB produced	1000	
BB observed	70	
Total number π^- 350 GeV/c	2.5 10^9	1.6 10^8
π/burst	5 10^4	2 10^4
Beam dimension	$20_y \mathrm{x} 10_z$ mm^2	$7.6_y \mathrm{x} 3.6_z$ mm^2
Bursts/target	8	3
π^-/mm^2 in emulsion	2 10^3	2 10^3
Number of targets	6.2 10^3	2.9 10^3
Number of hadronic interactions	9.4 10^7	6 10^6
Number of triggers	3 10^4	2 10^3
Run time (70% S.P.S. efficiency)	1 shift	1.5 days
Emulsions	28 l	2 l
Scanning time	2000 hours	700 hours

LIST OF EXPENSES

Cost of a single array and related electronics

Array MA 357	10000 SF
Buffers, ADC,drivers, ampliphier	5500 SF
Derandomizer (FIFO)	900 SF
Buffer memory (8KW, 32 bits)	1800 SF
Other materials	1800 SF
	20000 SF

Cost of other parts

Control logic	5400 SF
Crate CAMAC and controller	10000 SF
Refrigerating system	6300 SF
Mechanical driver	7000 SF
Device to cut emulsion	7000 SF

Evaluation of the cost of the test run

7 arrays and electronics	140000 SF
Control logic	5400 SF
Crate CAMAC and controller	10000 SF
Refrigerating system	6300 SF
Mechanical driver	7000 SF
Device to cut emulsion	7000 SF
2 l emulsion	25400 SF
	201100 SF

Evaluation of the cost of the main run

21 arrays and electronics (to be added to the ones of the test run)	420000 SF
3 more Crates CAMAC and controllers	30000 SF
28 l emulsion	356000 SF
	806000 SF
Total (test run + main run)	1007100 SF

The whole expenses of the test run (including transfers, emulsion developing and computing) are supported by I.N.F.N. and M.P.I. (Ministero Pubblica Istruzione)

FIGURE CAPTIONS

1a) General layout of the experiment

1b) Enlarged view of the target and vertex detector

2) Oscilloscope picture of the signals from the array. The first three rows are the outputs of one row of pixels when a 22 MeV/c electron beam hits the array. The last three rows are without the beam. a) and b) differs only for the time scale on the oscilloscope.

3) Sketch of a tipical configuration of points collected by seven planes of arrays and projected on the Y-Z plane: the points have been generated simulating 2 on time events, 8 out of time events and 300 not interacting primary tracks. The lines are the reconstructed traks of the on time events. The arrangement of the target and the planes is the same of that of the test run.

4) Differences between generated and reconstructed coordinates of interaction vertices.

5) Beauty momentum distribution in the lab system.

6) Momentum of the Kaons from Beauty decay.

7) Momentum of the Kaons from hadronic interactions.

8) Distribution of the distances between the primary vertex and the farthest charm decay. The dotted line refers to $\tau_B = 10^{-14}$ s. The full line to $\tau_B = 10^{-13}$ s.

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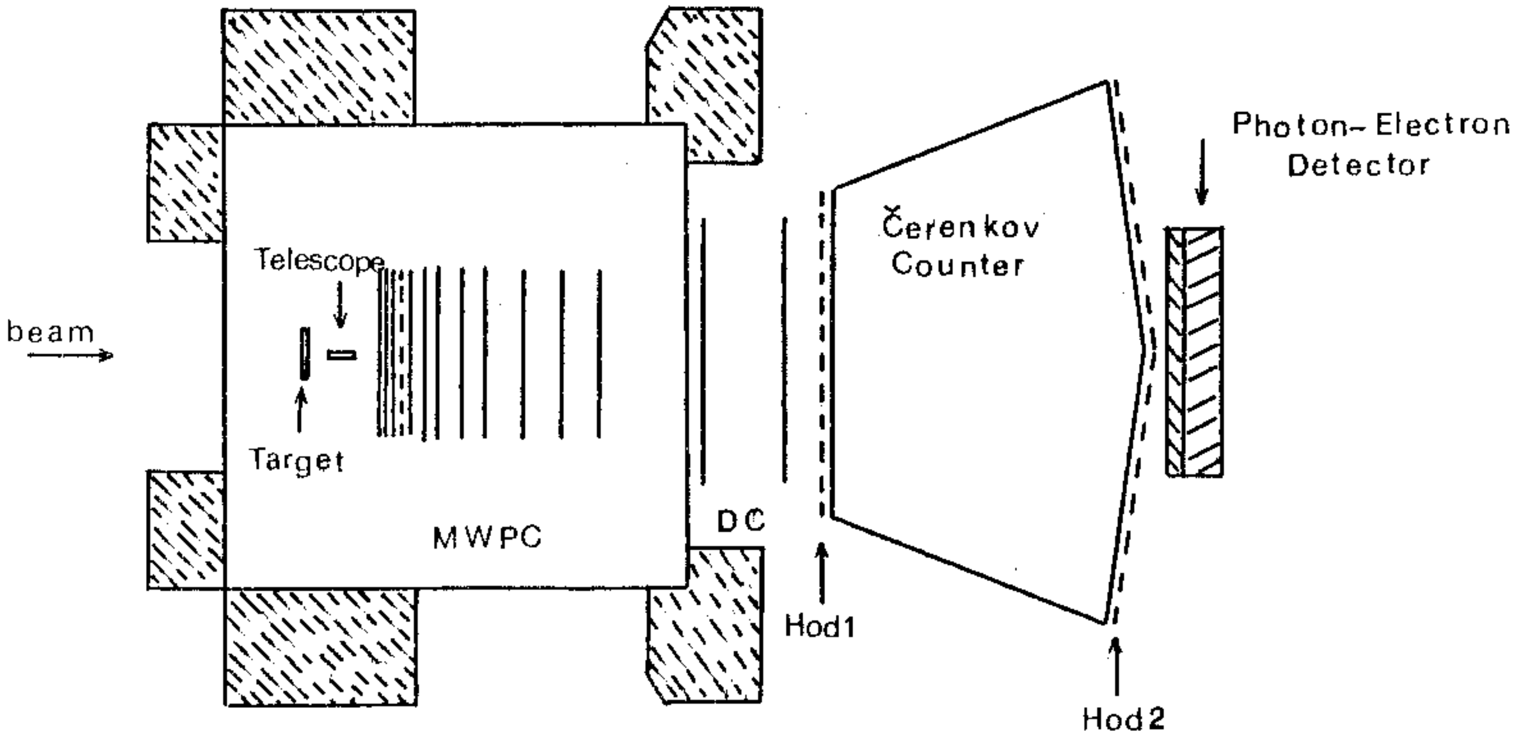

Photon-Electron
Detector
Čerenkov
Counter
beam
Telescope
Target
MWPC
DC
Hod1
Hod2

Fig 1a

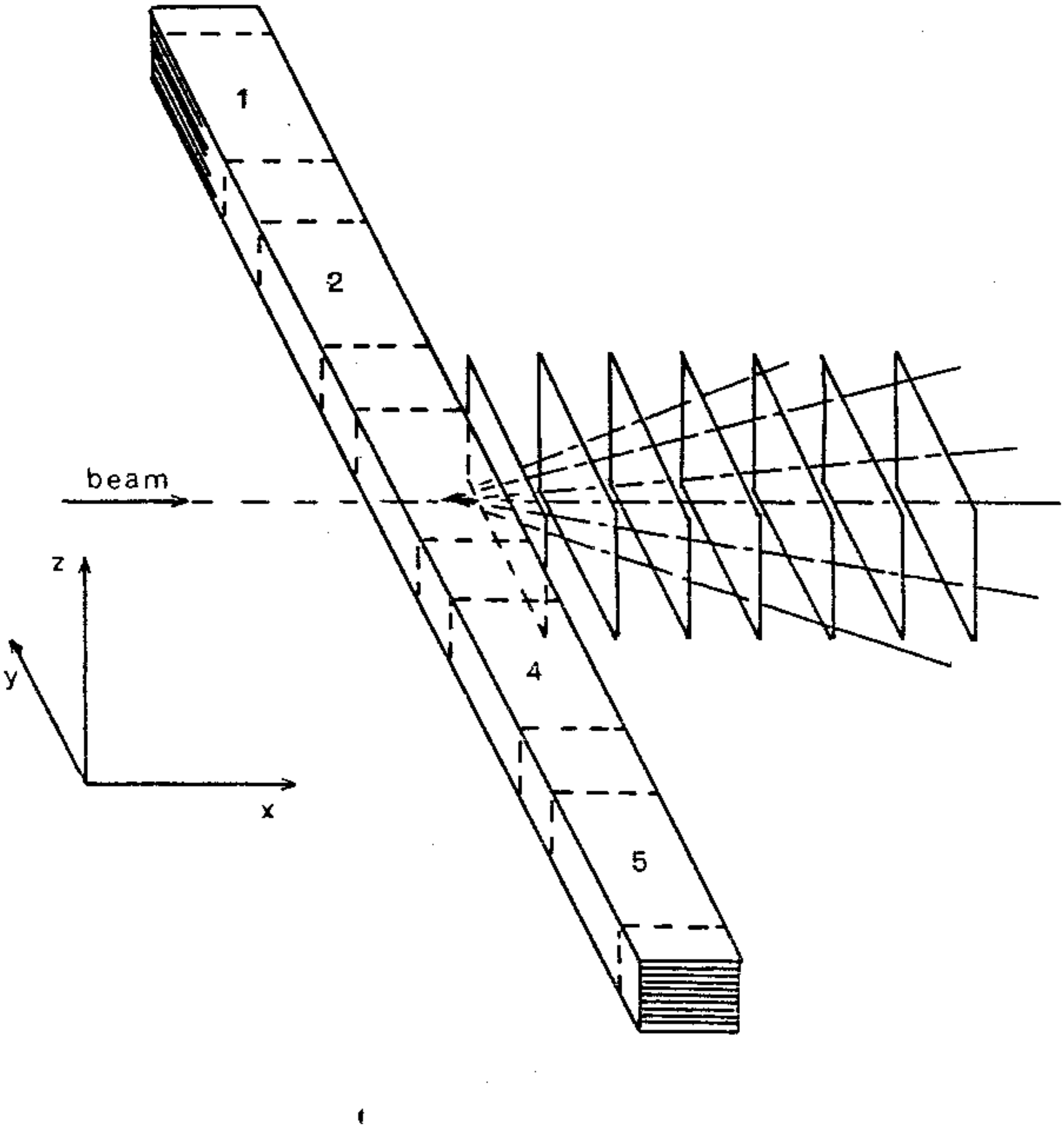
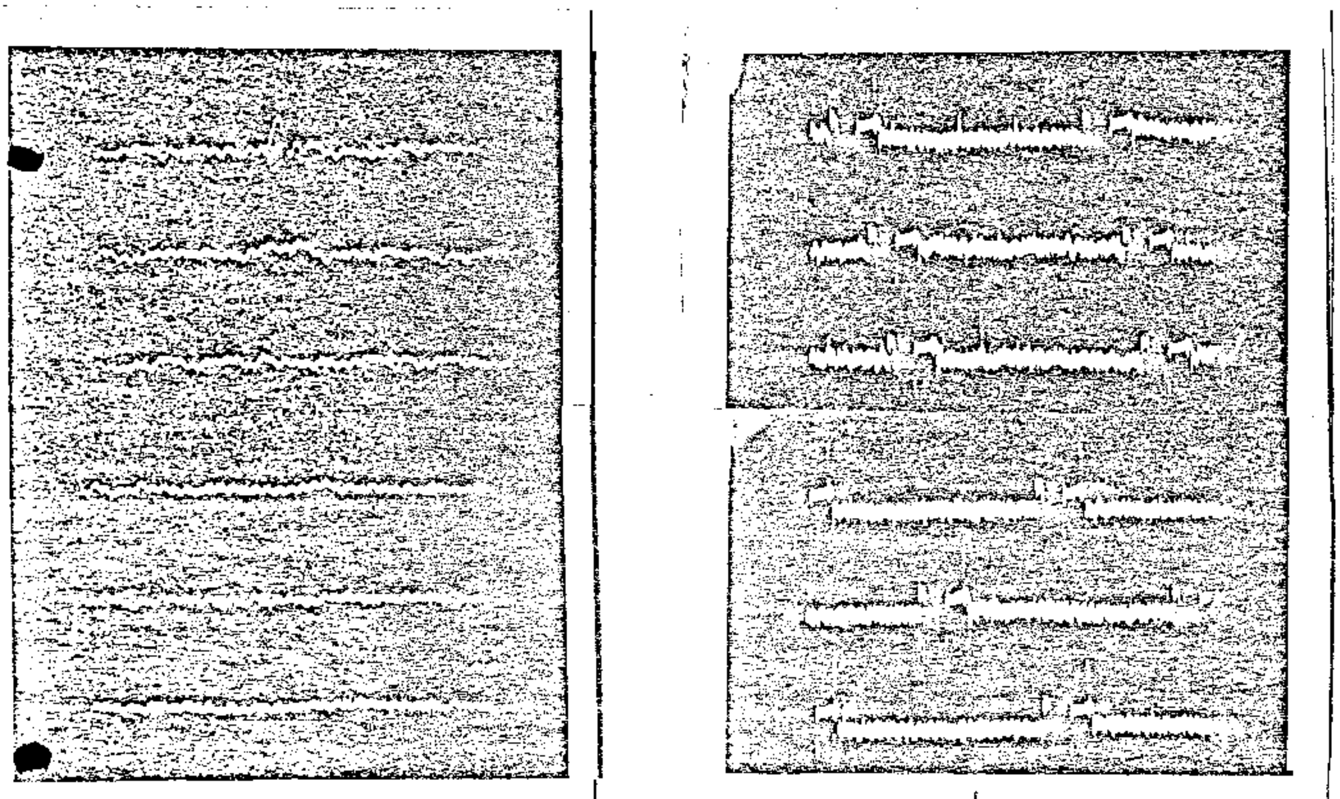


Fig 1b



a b

Fig 2

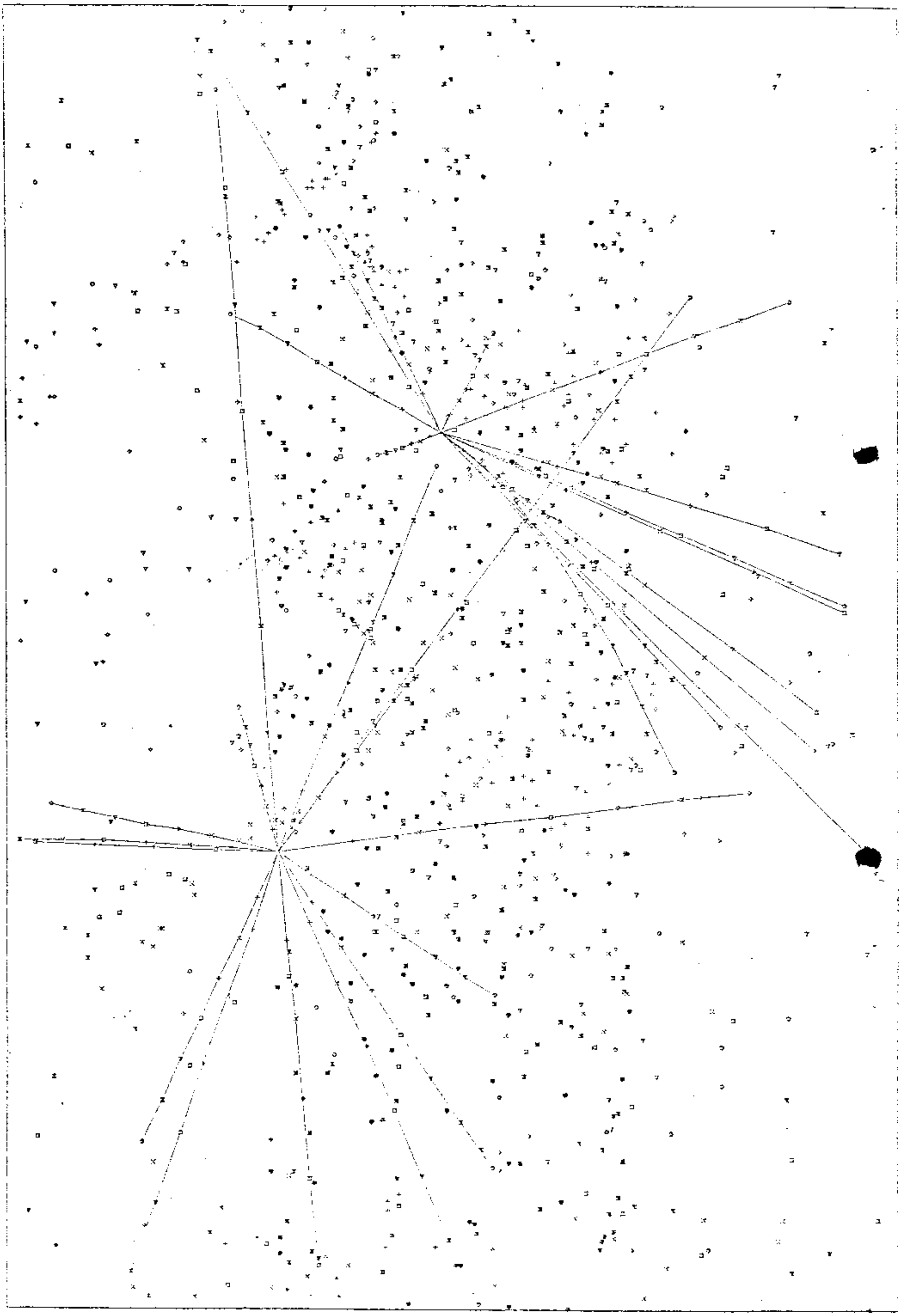
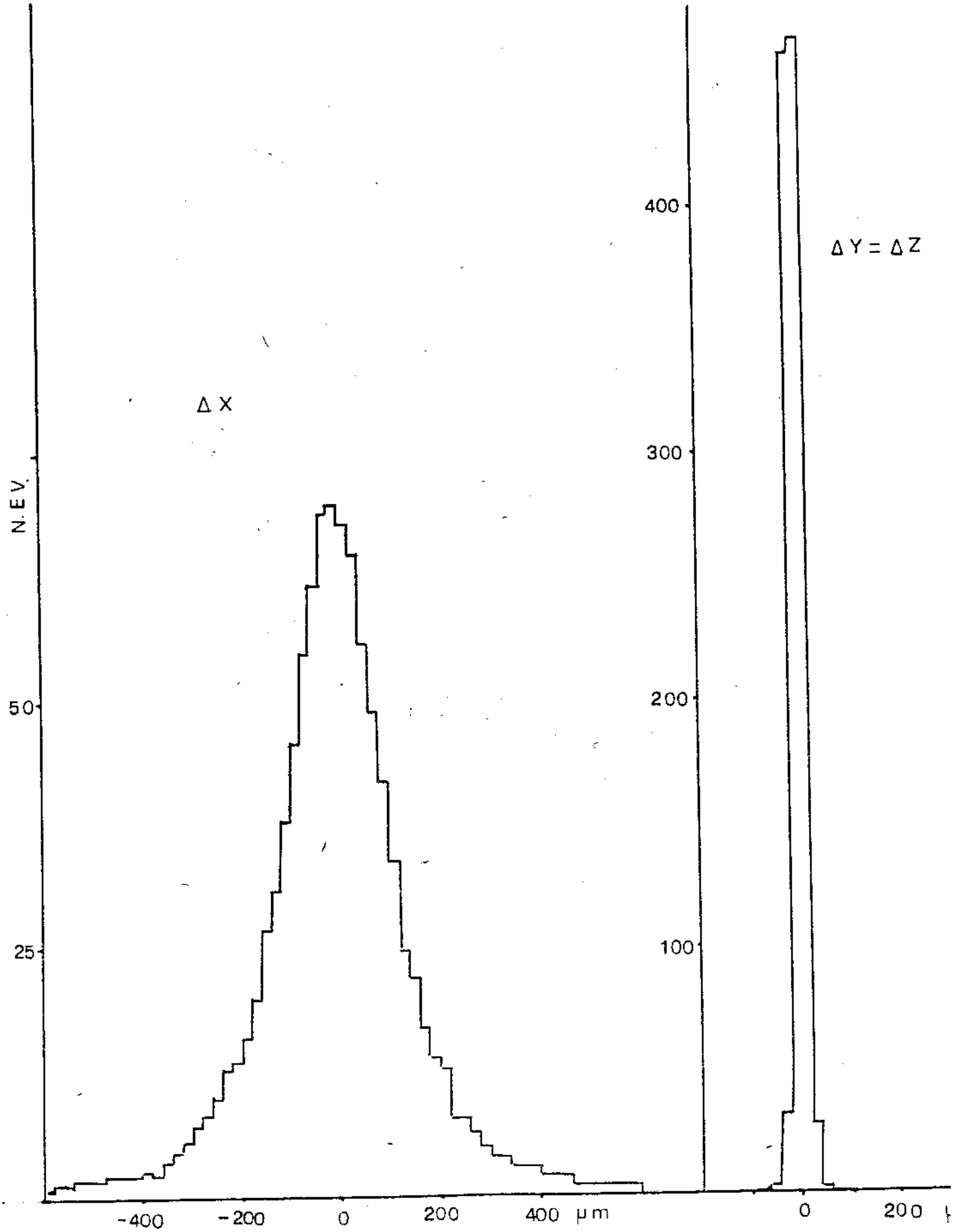


Fig 3

Fig.4



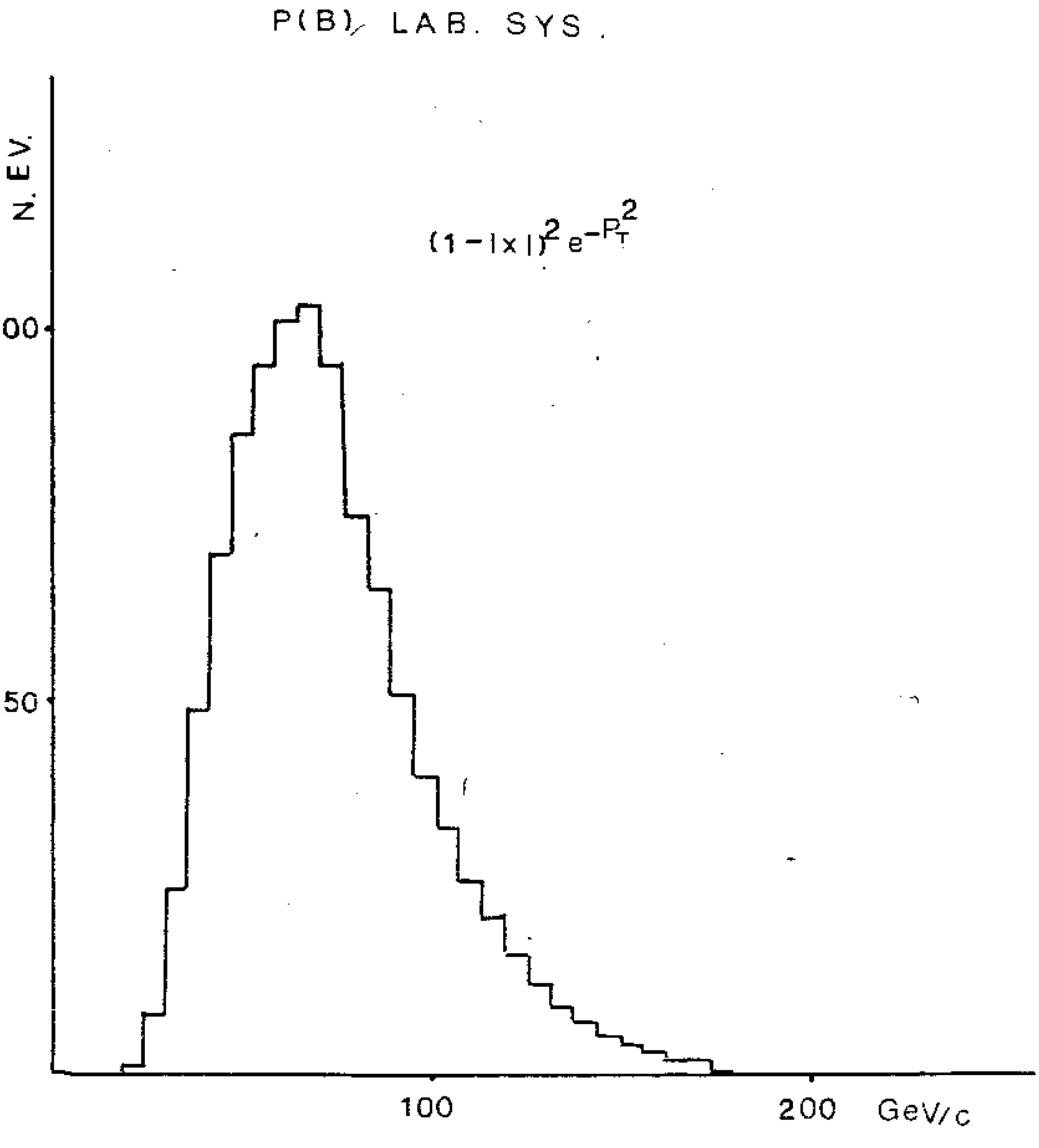


Fig. 5

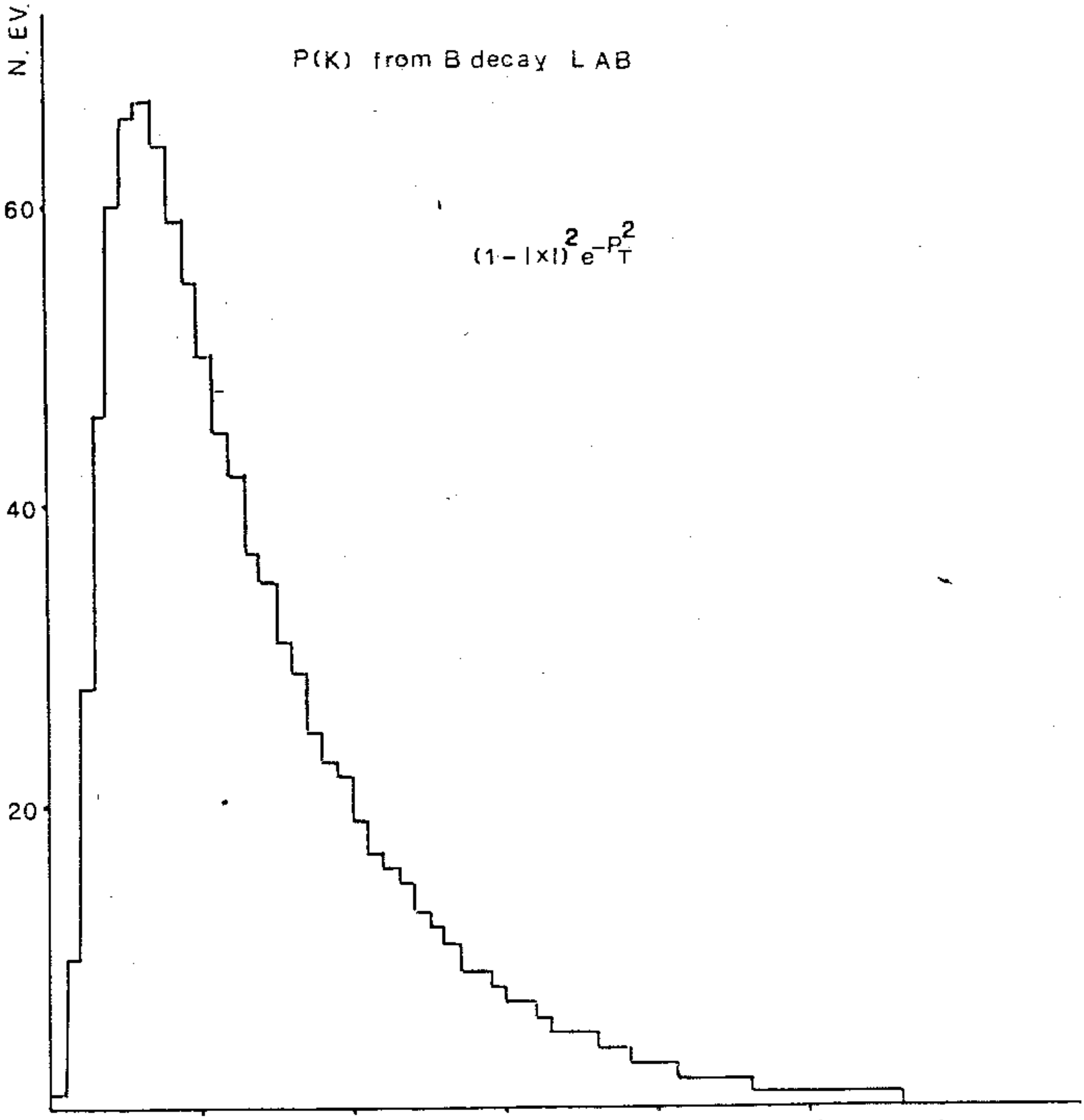


Fig. 6

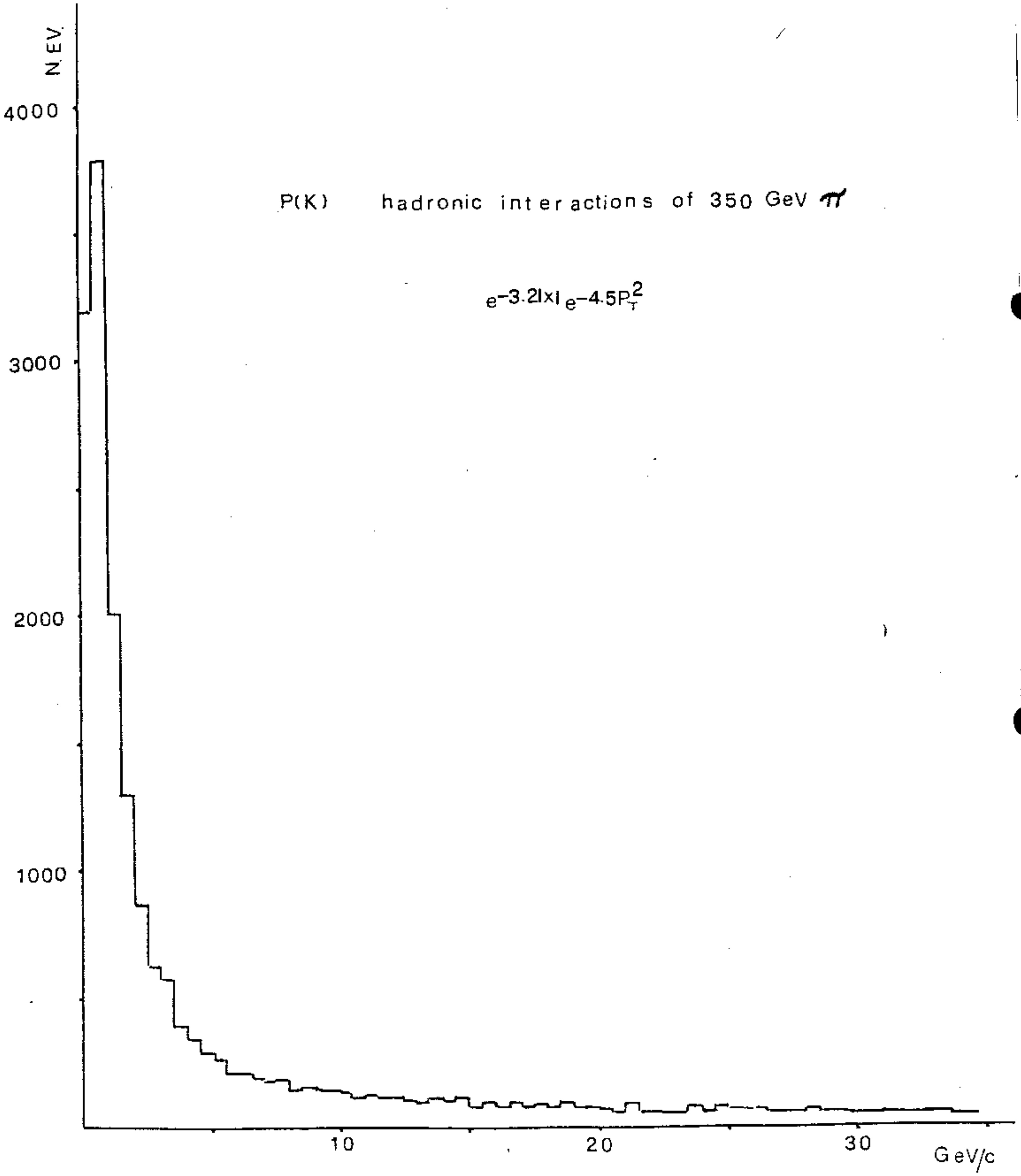

N.EV.
4000
3000
2000
1000
P(K) hadronic interactions of 350 GeV π
$e^{-3.2|x|} e^{-4.5P_T^2}$
10
20
30
GeV/c

Fig. 7

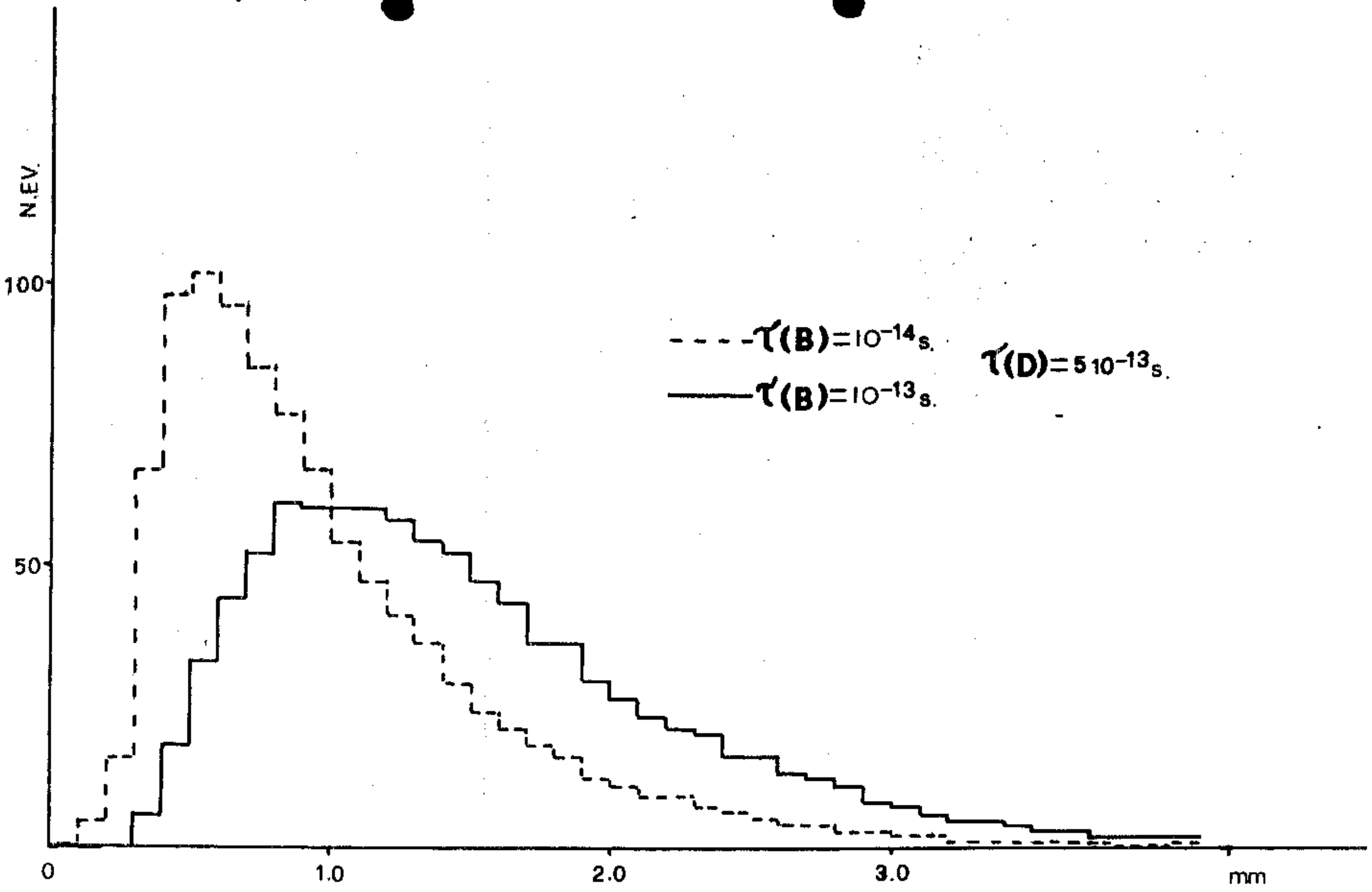


Fig 8

APPENDIX

1. Photodiode arrays and telescope structure

a) The photodiode arrays. The GEC AIS MA357 photodiode arrays have been chosen. They consist of 576 rows with 385 photodiodes each. The read-out sequence, free running in our experiment, implies the shift of the collected electrons from one row to the next one until they reach the output register (Fig. 1A). The output register then transfers serially the collected charges to an output channel with a frequency of about 10 MHz. This means a frequency of 10/385 MHz to read a row, i.e. an exposition time of about 40 μs. per row.
To carry out all these operations, 7 phase signals are necessary, 3($S\,\Phi_1$, $S\,\Phi_2$, $S\,\Phi_3$) for the shift from one row to the next one, 3($R\,\Phi_1$, $R\,\Phi_2$, $R\,\Phi_3$) for the serial transfer from the output register to the output channel and 1 (Φ_R) to reset the base line. Two signals are received at the exit: one, V_S, proportional to the number of electrons collected on the photodiodes and the other, V_D (dummy output), carrying only the noise, so as to obtain a clean signal $V_C = V_S - V_D$.

b) Set up of the telescope. As shown in Fig. 2A, a telescope built by 7 planes, 4 photodiode arrays each, will be used. The arrows in Fig. 2A indicate that the shift of charges from one row to the next one is done in opposite directions for the contiguous planes. In this way, besides the geometrical correlation, it is also possible to obtain a time correlation. The tracks of a "triggered event" will be separated from the background tracks with a resolution time equal to the shift time of a row, i.e. about 40 μs. because they will be no longer aligned.

c) Read-out. The read-out is dimensioned on the basis of about 2.10^3 minimum ionizing particles crossing the telescope planes during the 20 ms exposition time (corresponding to the reading of the photodiode arrays).

2. Block scheme of electronics and read-out

The arrays are handled in parallel and the output data are memorized in the same way. Therefore 28 identical and not interactive chains are used to send the data to a computer via CAMAC.

The scheme of the system is shown in Fig. 3A, where

M	is the photodiode array
MD	matches the signal to the array. It consists of few chips to be mounted near the arrays.
AFD	amplifies the V_S-V_D signal and send it to a "Flash Converter". The "Flash-Converter" converts the signal, if it is greater than a fixed threshold, at the "leading edge" of the signal CONV. At the end the signal CP_i makes valid the result coding it in a 8 bit word. This circuit is mounted near the corresponding array.
FIFO	is a fast memory of "First in - First out" type consisting of 16 words, 26 bit each. In input one has the conversion code (8 bits) and the serial number of the pixel which has given the converted signal. This unity, when the level RS (read-out signal) is present, derandomizes the data flux and gives a couple of words of 16 bits for each input.
WS	is a RAM memory of 8 K words, 32 bits in CAMAC standard units. It memorizes addresses and serial numbers of the pixels which have given an accepted signal. It is dimensioned in order to memorize several triggers in each bursts.
DU	is an unity to manage asynchronously the arrays. When a "trigger-signal" (T) reaches a "scaler", it begins a counting starting from the first row "shift". The contents of the scaler, sent to FIFO, identifies the serial numbers of the pixels which give a signal above the background. This unity gives then a signal (CONV), synchronous with each output (therefore at 10 MHz) and with a scale of time adequate to choose the more convenient time of conversion. Finally, always starting from the signal T, it generates the signal RS which lasts the whole read-out time of the photodiode arrays.

3. Notes on structure and feasibility

The mechanical lodging of the arrays must allow their refrigeration by means of a gas flux. It is then convenient to have passing-by connectors so as to link two cards contiguous to each plane of the telescope. One card acts as a support for 4 MD units and the other one as a support for 4 AFD units.

When the prototypes are available, one person for 30 days per plane will be necessary to do this work.

In view of their function the FIFO units have to be built on the basis of a specific project. They will be located in CAMAC or NIM containers. The use of NIM modules may be advantageous because they are less expensive and convenient, because they do not involve data or control exchanges by a CAMAC "data-way".

For each of these devices (28 in total) it will be necessary a building time of less than 15 days of a man.

The DU unit is a unique exemplar which will manage the photodiode arrays, codify the addresses, etc. In this unit one has to reproduce the circuits used for the GEC MA357 telecameras. The time necessary to do the work is estimated to be of about 30 days of a man.

APPENDIX FIGURE CAPTIONS

1A) Layout of one array.

2A) Layout of the telescope. The arrows indicate the sense of read-out for each plane.

3A) Block diagram of the electronics.

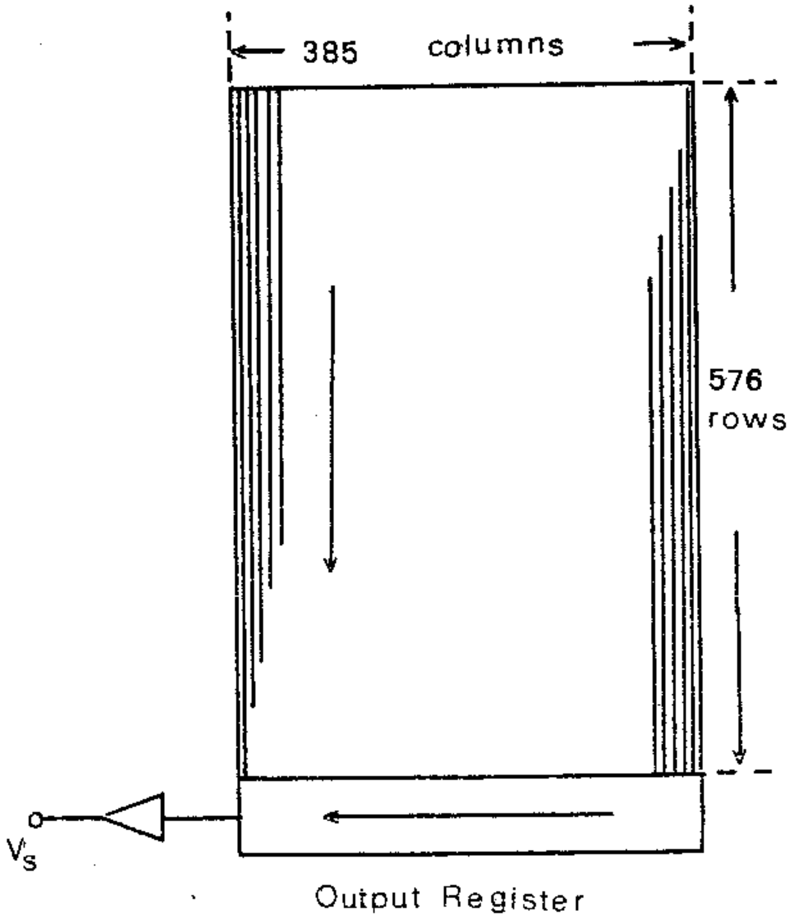


Fig 1 A

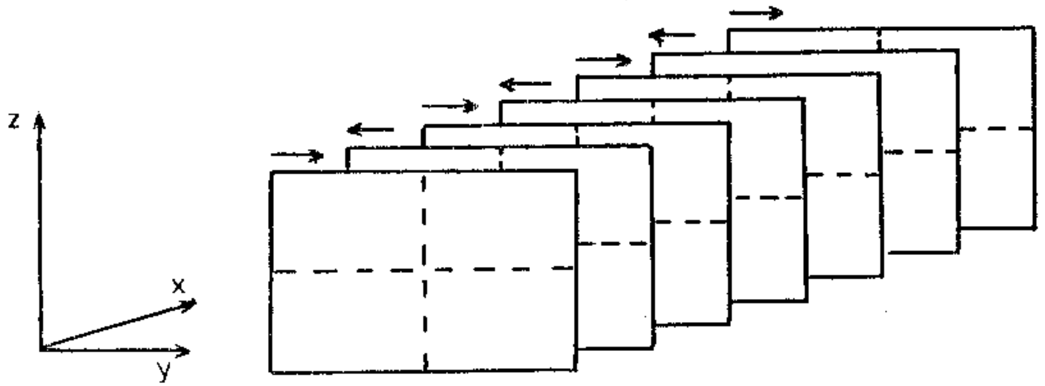


Fig 2A

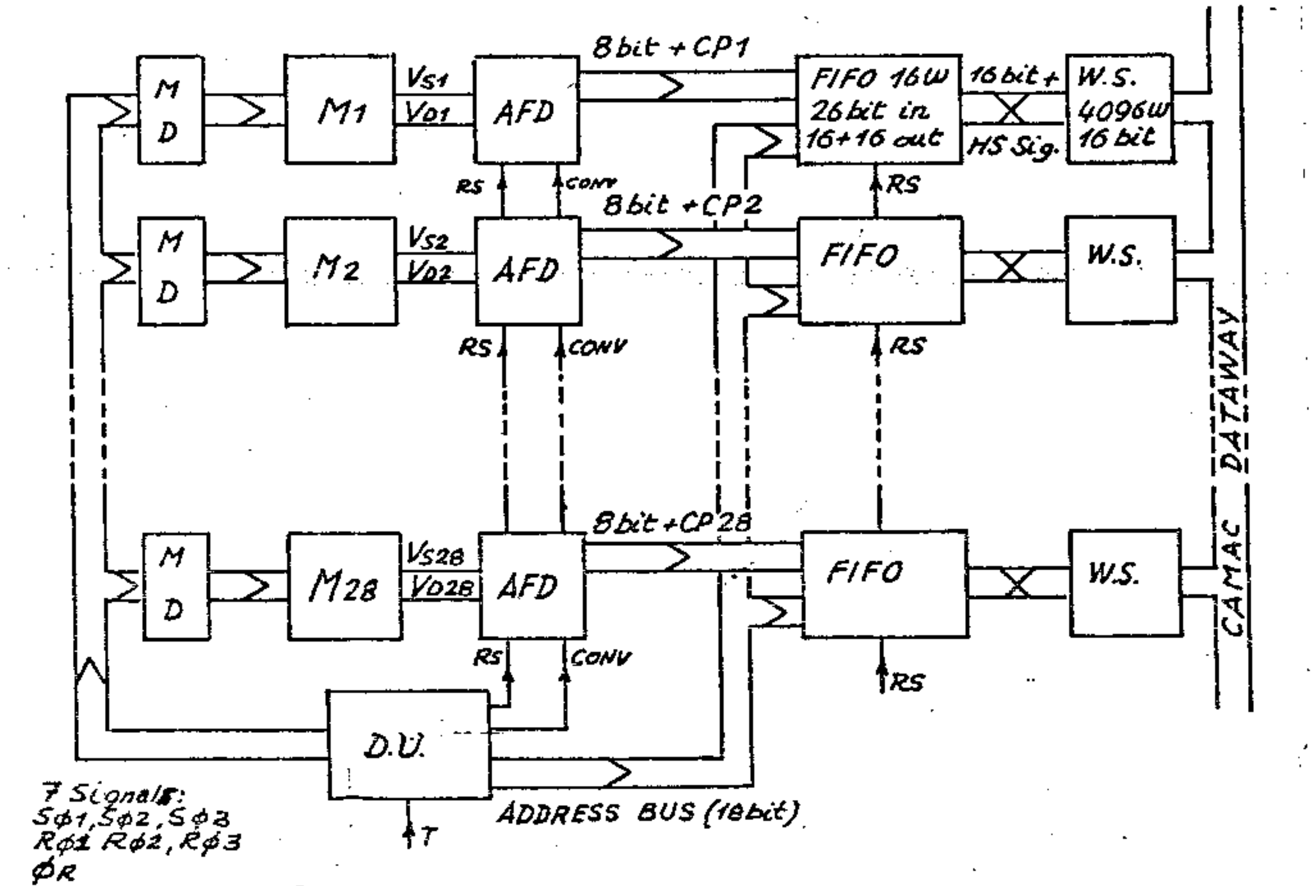

M
D
M1
Vs1
VD1
AFD
8bit + CP1
FIFO 16W
26bit in
16+16 out
16 bit +
HS Sig.
W.S.
4096W
16 bit
RS
CONV
RS
M
D
M2
Vs2
VD2
AFD
8bit + CP2
FIFO
W.S.
RS
CONV
RS
CAMAC DATAWAY
M
D
M28
Vs28
VD28
AFD
8bit + CP28
FIFO
W.S.
RS
CONV
RS
D.U.
T
ADDRESS BUS (18bit)
7 Signals:
Sφ1, Sφ2, Sφ3
Rφ1 Rφ2, Rφ3
φR

Fig 3 A