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PROPOSAL

STUDY OF HIGH ENERGY NUCLEUS-NUCLEUS INTERACTIONS USING THE Ω' SPECTROMETER EQUIPPED WITH A MULTIPARTICLE HIGH p_T DETECTOR

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ABSTRACT

We intend to perform an exploratory experiment to look for new physics in 225 GeV/c per nucleon O^{16} nucleus collisions in the Ω' spectrometer. In particular, we shall look for a quark gluon plasma signature in the increase of the strangeness production rate. In view of the large number of secondaries, we shall use a special detector arrangement, called a "butterfly system", which has a large acceptance for particles with $2.0 \leq y_{lab} \leq 4.5$ and $p_T > 0.6$ GeV/c and is insensitive to all the other particles. Most of the experimental equipment needed already exists at the Ω' spectrometer and the technique of the butterfly system has been used successfully by our collaboration.

1. PHYSICS CASE

1.1 Motivation

Numerous recent theoretical investigations are devoted to ultra relativistic nucleus-nucleus collisions. The results indicate that, at sufficiently high energy, the energy density produced during a central collision can be large enough to cause some of the hadronic matter to melt into a short lived plasma of quarks, anti-quarks and gluons [1]. This transition could already take place in a collision between a fairly light nucleus projectile, e.g. oxygen at 200 GeV/nucleon, and a heavy target nucleus [2,3].

The possibility of accelerating oxygen nuclei up to an energy of ~ 200 GeV/nucleon in the SPS [4], will allow experiments to look for this new state of matter called quark-gluon plasma.

The collisions in which a quark-gluon plasma has been formed, are expected to produce more particles containing strange quarks than normal collisions by at least a factor of two [5]. For example, plasma formation is predicted to manifest itself as a rise of the K^+/π^+ ratio as a function of the multiplicity, especially at transverse momenta above average [6].

We intend to search for such an increase of the strangeness production rate. For this purpose we will attempt to determine the yield of various particles and resonances, especially those containing strange quarks (kaons, ϕ-mesons, Λ and $\bar{\Lambda}$'s) in the central region of the rapidity interval where the highest energy densities are expected to be produced [7].

1.2 Method and measured quantities

We will use the Ω' spectrometer [8] in the "butterfly" mode (sect. 2.1) and its downstream Ring Imaging Cherenkov (RICH) detector [9] (sect. 2.2) to analyze the interactions of protons and oxygen nuclei at 225 GeV/c per nucleon with various nuclear targets. In addition to the strangeness enhancement, the expected properties of quark-gluon plasma production on which we base our proposal are briefly described as follows:

(a) The chances for producing a quark-gluon plasma are expected to be higher for heavy nuclei as target and as projectile.

(b) Central collisions give rise to the highest energy densities. They are favoured over peripheral collisions to look for the occurrence of a quark-gluon plasma.

(c) Higher energy densities result in higher multiplicities of emitted secondary particles.

(d) In the central collisions, all the nucleons in the incoming ion should participate in the interaction. It is thus expected that little energy will escape as spectator nuclear fragments in the forward direction.

These properties lead to the following method of event selection and analysis:

(a) The measurement of the charged particle multiplicity in the central rapidity region ($2 \leq Y_{lab} \leq 4.5$) will be used to separate central from peripheral collisions. For this purpose, it is not necessary (nor easy) to detect all the hundred of secondaries arising from central collisions. Instead, the measurement will be limited to the particles emitted in the rapidity interval defined above with a transverse momentum $P_T \geq 0.6$ GeV/c. This selection is provided by our butterfly system (sect. 2.1), and reduces the number of measured particles to ~ 2% of the total. The momenta of the selected charged particles will be measured in the Ω' spectrometer.

(b) A hadron calorimeter covering the dowstream region (sect. 2.5) will be used to tag the events with few spectator fragments from the incoming ions, i.e. with little energy in the forward direction.

(c) The RICH detector will be used to identify the kaons amongst the selected particles. In addition, the spectrometer allows the identification of ϕ, K^o, Λ and $\bar{\Lambda}$'s produced in the interaction. We will thus attempt to measure the spectrum of various species of particles:

$\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, K^{o}, ρ^{o}, ϕ, Λ and $\bar{\Lambda}$'s. Their relative abundances will be studied as functions of various parameters: incident and target nuclear numbers, observed charged multiplicities and transverse momentum.

(d) A large electromagnatic calorimeter [10] (sect. 2.6) will be used as an auxiliary. An attempt will be made to use the γ's (resulting mostly from π^{o} decay) to have an estimate of the total transverse energy flow in the central region of the rapidity interval.

2. EXPERIMENTAL SET-UP

2.1 Charged track spectrometer and butterfly system

The Ω' detector [8] will be equipped with 15 MWPC's (37 planes), 4 lever-arm MWPC planes (MY1-MY 4) and 2 lever-arm drift chambers (DC1, DC2) (fig. 1). Using a technique proposed and tested by our collaboration [11], the sensitive regions of all the multiwire proportional chambers will have the so-called butterfly shape (fig. 2).

As a consequence of this shape, all charged particles coming from the target and having a p_T less than 0.6 GeV/c are bent in the Ω' field so that they hit the multiwire proportional chambers in the region where they are not sensitive, as illustrated in fig. 2 using WA77 data [11]. In this way, the chambers, that we call a "butterfly system", will only detect particles having transverse momenta $p_T > 0.6$ GeV/c in the rapidity interval $2.0 < y_{lab} < 4.5$.

We have estimated (Appendix) that in a central collision between oxygen and uranium nuclei, there will be on average 7-8 tracks only in the butterfly system out of a total of ~ 320 charged particles. We are thus in conditions, as illustrated in fig. 3, where we do not expect particular difficulties in the pattern recognition and the geometric reconstruction of tracks.

As an example of the capability of the Ω' spectrometer in the "butterfly mode", we show some preliminary results of the WA77 experiment in which we used 4 MWPC with a butterfly shape with the same geometric acceptance as in this proposal. Fig. 4(a) shows the K^+K^- invariant mass for those pairs of tracks coming from a vertex inside the target and crossing the butterfly system, and fig. 4(b-c) show respectively the $\pi^+\pi^-$ and $p\pi^-$ invariant masses for those pairs having a vertex outside the target (V^o) and crossing the butterfly system. Clear signals are seen at the ϕ, K^o and Λ masses.

The single particle geometric acceptance of the butterfly system is shown in fig. 5. Above $p_T = 0.6$ GeV/c, the detection probability rapidly rises to ~ 50%. The apparatus has good geometric acceptances for the $K^o \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$ decays for $2.5 < Y_{lab} < 4.5$ and $p_T > 0.6$ GeV/c. Their values for various choices of Y_{lab} and p_T are given in table 1(a-b). In the same rapidity interval, we have good geometric acceptance for several resonances. As an example, table 2(a-b) gives the $\rho^o \to \pi^+\pi^-$ and $\phi \to K^+K^-$ acceptances for various Y_{lab} and p_T values.

2.2 RICH counter

A Ring Imaging Cherenkov (RICH) counter [9] has been built for the Ω' spectrometer. The Cherenkov light produced over the 5 m radiator length is focused by a set of mirrors onto an array of 16, 40 × 80 cm^2, TPC modules covering a 160 cm high and 320 cm wide area. The geometric acceptance of this RICH placed at x = 540 cm is shown in fig. 6. The RICH will be filled with C_2F_6 (*) giving thresholds for π, K and p, respectively at 3.5, 12.5 and 23.5 GeV. For particles having $\beta = 1$, the ring radius will be 20 cm and the average number of photoelectrons is expected to be ~ 30. In each TPC module, there are 200 sense wires separated by 4 mm which are read at time intervals corresponding to a drift length of 1.6 mm. These numbers correspond to an image definition of 4×10^5 pixels which will allow us to cope with events of high multiplicity.

(*) A recuperation system for this gas is being studied by the Rutherford Laboratory and the EF Division as a standard facility for the Ω' spectrometer.

Our experiment aims to detect the increase of the $K^{\pm}$ fraction predicted to be by at least a factor of two, amongst the particles detected in the butterfly system as a function of the observed multiplicity. In order to estimate the capability of the RICH to identify these kaons, we have undertaken a simulation study. For an average oxygen-uranium central collision (Appendix), 80 charged hadrons (73 pions and 7 kaons) and 32 electrons (from γ conversion) pass through the RICH. Fig. 7 shows how a typical event is seen by the TPC's under conditions of resolution, noise and background that are considered to be achievable.

In order to reduce the background due to the unwanted particles (i.e. those which do not cross the butterfly system), we intend to mask the RICH's mirrors over a horizontal band centred on the median plane. This mask will intercept most of the Cherenkov light emitted by the unwanted particles. Fig. 8(a) shows how the same event would look like if we use such a mask (in this case an horizontal screen, 60 cm high). In fig. 8(b), we have indicated by heavier dots the points belonging to the rings of the wanted particles, i.e. those passing through the butterfly system, as well as their centres. Eight of these particles are pions (1-8), one is a kaon with momentum above threshold (9) and one is a kaon below threshold (10). The comparison between figs 7 and 8 shows that the use of the mask produces a drastic reduction in the background level and improves the visibility of the rings for the wanted particles.

The recognition of the ring signals for the wanted particles is made in a simple way by plotting the number of digitizings as a function of the distance to the ring centre predicted from the measured track direction "radial plot". The accumulation of digitizings at radii predicted from the measured track momenta identifies the particle. This is illustrated in fig. 9 which shows the radial plots for the tracks indicated in fig. 8(b).

Our ability to extract the ring signals is shown in the histograms of fig. 10 which represents the signal to noise (noise $\equiv$ square root of the number of background events) ratio for π's and K's on a sample of 90 events. The average value of the ratio is 6.5 for the pions and 3.0 for the kaons.

Above the kaon threshold (50% of the kaons) we estimate that we shall be able to identify more than 80% of the kaons with ~ 1% wrong decisions. This induces a systematic bias in the K/π ratio which can be taken into account. For instance, a 10% K/π ratio will be measured as ~ 9% and a 20% ratio as ~ 17%. However, we are particularly interested in the variation of this ratio between two samples of events having different characteristics. In this respect, our sensitivity is characterized by the difference in the kaon identification efficiencies between the two samples. For example, for oxygen-uranium interactions we estimate to be sensitive to an increase ≥ 20% in the K/π ratio as a function of the observed multiplicity (i.e. the number of particles which cross the butterfly system).

Below the kaon threshold, we can only measure the (K + p)/π ratio. In this sample, the percentage of misidentified pions is expected to be larger than above threshold since kaons are only identified by the absence of a signal. In the conditions of the above example we estimate to be still able to detect a 30% increase of the ratio as a function of the observed multiplicity.

2.3 Active target

The design of a target for nucleus-nucleus collisions encounters two opposite constraints. On the one hand, the target should be thick enough to allow for sufficient rates. On the other hand, it should be thin enough to minimize the interactions of the many secondaries and, most important, of the beam nuclear spectator fragments. In the latter case, one must be able to distinguish a single central collision from separate collisions of the beam fragments.

A good compromise is to use a segmented target composed of several thin subtargets separated sufficently well in order to distinguish possible secondary interactions. In our case, we plan to use 16 subtargets each of 0.1% interaction length in the form of a 3 x 40 mm^2 horizontal ribbon separated by 1.5 cm. This configuration, based on the possibility of getting a 3 x 8 mm^2 beam in the West Area, will reduce the secondary interactions especially for the high p_T tracks we are interested in.

This design is not sufficient however to recognize multiple collisions of nuclei from a single one. Following the proposal of the NA34 Collaboration [12] to make active such a multiple target, we intend to implement our target system inside a mini-drift chamber as shown in fig. 11. This drift chamber will have 2 X 40 mm drift space and sense wires equipped with FADC's every 7.5 mm. We are confident that enough information can be recorded with this detector to find the interaction vertex and to recognize possible reinteractions of nuclear fragments.

The 16 subtargets will be made out of three materials: aluminium, copper and uranium.

2.4 Butterfly hodoscopes

Two planes of hodoscopes (HZ0 and HZ1) with a butterfly shape are necessary for trigger purposes. They will be placed at x = 280 cm and x = 480 cm respectively. One of them (HZ1) already exists and has been used for a similar purpose by the WA77 Collaboration [11]. The other one will be built by the collaboration. They are composed of 4 quadrants with 15 horizontal slabs each. A coincidence in two corresponding elements of HZ0 and HZ1 will define, at the trigger level, a track with $p_T > 0.6$ GeV/c coming from the target. This will be useful to avoid triggering on interactions taking place downstream of the target. The coincidence logic will be implemented in the MBNIM standard [13] as is presently done in the first level trigger of the WA77 experiment.

2.5 Hadron calorimeter

In the central collisions where plasma production is most likely to be produced, all the nucleons of the incoming ion should participate to the interaction. For these collisions relatively little energy will escape in the a rapidity region close to the beam rapidity ($y_{beam} \sim 6$). In order to tag events where spectator fragments escape the collision, we will use a downstream hadron calorimeter. The dimensions of this calorimeter are such that it intercepts fragments with Z/A ranging from 0 (neutrons) to 1 (protons). However, since this calorimeter will sit far downstream (x = 1400 cm) and beam spectator fragments can interact e.g. in the RICH, it will be made large enough to intercept the most energetic secondaries of the spectator fragments interaction, i.e. those emitted within one rapidity unit from y_{beam} ($\theta \lesssim 10$ mrad). The size which satisfies these requirements is 80×60 cm^2. It will be designed to provide a resolution of $\sigma(E)/E \sim 1.0\ E^{-1/2}$ which corresponds to $\sigma(E) = 15$ GeV for an individual nucleon energy of E = 225 GeV.

2.6 Electromagnetic calorimeter

An electromagnetic calorimeter consisting of 4, 2×2 m^2, quadrants with a central hole of 0.4×0.4 m^2 has been built by the WA70 Collaboration [10] and is now operating at the Ω' spectrometer. Each quadrant is composed of six sections of a lead-liquid scintillator sandwich alternativily read in the horizontal and vertical directions. In addition, the first two layers are equipped with a time of flight system measuring the longitudinal position of a shower with a 2.5 cm precision. As measured in test beams and in real conditions as well, the energy resolution in $0.16\ E^{-1/2}$ and the two shower separation power is ~ 15 mm.

This detector covers the full rapidity range between 2.5 and 4.5 and may allow us to have an estimate of the transverse energy carried by γ rays in the same rapidity interval as for the charged particles.

3. TRIGGER

The triggering system we plan to use is designed to reject non-central collisions. Our strategy is based on the fact that the energy release in the central rapidity region should be higher in the collisions we want to study than in peripheral collisions. We will consequently require a high multiplicity in the butterfly system as measured by the number of coincidences between the HZ0 and HZ1 hodoscopes and the multiplicities recorded in the butterfly MWPC's 1 to 4. This multiplicity can be chosen so that it reduces the event rate to a value close to our acquisition rate (sect. 4). As an example, using our event generator (Appendix) we estimate that a rate reduction of ~ 200 can be obtained by asking ≥ 12 tracks through HZ0 and HZ1.

Peripheral interactions (which are the majority) may also give rise, in some cases to a high multiplicity in the butterfly system. However, as the nuclear spectator fragments go on almost undisturbed, the hadron calorimeter will tag those events. This information could be used as part of the trigger. We have estimated the contamination from those cases where the fragments reinteract downstream and miss the hadron calorimeter to be a few per cent of the good events.

4. ACQUISITION: READ OUT

The acquisition of the Ω' system is made by a VAX11/780 through the ROMULUS readout system. This system allows a readout at a rate of 1.5 μs per word. In an event with 12 butterfly tracks, we expect ~ 1500 words for the butterfly + drift chambers, 1500 words for the RICH, ~ 2000 words for the hadron calorimeter, the target and other user devices and ~ 2000 words for the electromagnetic calorimeter. In these conditions we can record ~ 100 events in a 2 s burst and still have a live time of 50%.

5. BEAM REQUEST

In order to achieve our physics goals, we wish to run this experiment at the highest ion beam energy.

We request 10 days of 225 GeV/c proton beam at 5×10^6 ppp for setting-up and data taking. We expect to take 2×10^6 triggers.

We then request a period of 17 days of 225 GeV/c per nucleon O^{16} beam, including 8 days in 1986. With a beam intensity of 10^6 ppp and an SPS efficiency of 50%, we expect to record 4×10^6 events.

In addition, we shall need as early as possible in 1986 some parasitic time in the Ω' in order to test the hadron calorimeter and the target drift chamber.

APPENDIX

EVENT GENERATORS

Two different event generators have been used. The first generator, HIJET, is a Monte-Carlo program which is known to reproduce fairly well the proton nucleus collisions [12], [14]. We have used this generator to determine the features of $O^{16}-U^{238}$ collisions. We have found that when all 16 nucleons interact, the mean charged multiplicity is ~ 320 out of which an average of 80 particles enter the RICH. For these collisions, the mean number of particles detected in the butterfly system is 7.5. These numbers only slightly increase if one select collisions with zero impact parameter.

In the second event generator, we superimpose real events obtained in 300 GeV/c π Pb interactions at the Ω' spectrometer by the WA77 Collaboration. It has the advantage of allowing the simulation of events with any multiplicity, especially very high, by superimposing an adequate number of π Pb events. Comparing the two generators, we have found that the superimposition of 16 π Pb events give events with features comparable to HIJET events especially for the rapidity distribution in the central and forward regions i.e. for the multiplicities in the butterfly system and in the RICH.

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[14] This program was kindly made available to us by Dr. M. Heiden.

TABLE 1

(a) Geometric acceptance for $K^{\circ} \to \pi^{+}\pi^{-}$

p_T \ Y_{lab}	3.0	3.5	4.0
1.0 GeV/c	4.7%	10.4%	13.1%
1.5 GeV/c	15.6	20.1	18.4
2.0 GeV/c	26.8	27.9	21.8

(b) Geometric acceptance for $\Lambda \to p\pi^{-}$

p_T \ Y_{lab}	3.0	3.5	4.0
1.0 GeV/c	5.3%	9.3%	5.1%
1.5 GeV/c	9.9	12.8	11.2
2.0 GeV/c	15.6	17.7	13.6

TABLE 2

(a) Geometric acceptance for $\rho^{o} \to \pi^{+}\pi^{-}$

p_T \ Y_{lab}	3.0	3.5	4.0
1.5 GeV/c	2.9%	3.8%	3.0%
2.0 GeV/c	9.1	10.9	8.2
2.5 GeV/c	15.9	17.1	15.4

(b) Geometric acceptance for $\phi \to K^{+}K^{-}$

p_T \ Y_{lab}	3.0	3.5	4.0
1.5 GeV/c	4.8%	5.0%	4.9%
2.0 GeV/c	22.6	22.7	22.8
2.5 GeV/c	32.8	33.0	33.2

FIGURE CAPTIONS

Fig. 1 Layout of the experiment.

Fig. 2 Hits of charged particles with p_T < 600 MeV/c on the plane of the last chamber MY4. The shape of the sensitive region of MY4 is also shown. The data come from the WA77 experiment.

Fig. 3 Y-coordinates of the hits in the butterfly MWPC's system from a simulated oxygen-uranium central collision in which 350 charged particles were produced. The dotted lines indicate the detected tracks of which 7 cross the butterfly system and hit the RICH.

Fig. 4 Two particle invariant mass distributions from the WA77 experiment. Both particles are detected by the butterfly system which had the same acceptance than in this proposal.

(a) K^+K^- spectrum. Both particles come from the target and at least one is identified as a kaon.

(b) $\pi^+\pi^-$ mass spectrum. Both particles come from a secondary vertex (V^o).

(c) $p\pi^-$ mass spectrum. Both particles come from a V^o vertex.

Fig. 5 Single particle geometric acceptance of the butterfly system.

Fig. 6 Single particle geometric acceptance of the RICH. The solid lines are constant acceptance contours in the Y_{lab}, p_T plane. The dashed lines show the pion, kaon and proton thresholds.

Fig. 7 Plots of the hits in the TPC of RICH due to a simulated oxygen-uranium central collision in which 320 charged particle and 160 π^o were produced; 80 charged hadrons and 32 electrons from γ conversion pass through the RICH. The straight lines which cross some of the TPC simulate delta rays or nuclear fragments. Electron pairs from γ-conversion in the TPC's appear as a pair of overlapping rings.

FIGURE CAPTIONS (Cont'd)

Fig. 8 (a) As for fig. 7, but having placed a 60 cm high horizontal screen in front of the RICH's mirrors to intercept most of the Cherenkov light from the unwanted particles.

(b) As fig. 8(a). The numbers indicate the centre of the predicted ring for each of the 10 charged particles crossing the butterfly system and their photoelectrons are indicated by heavier dots.

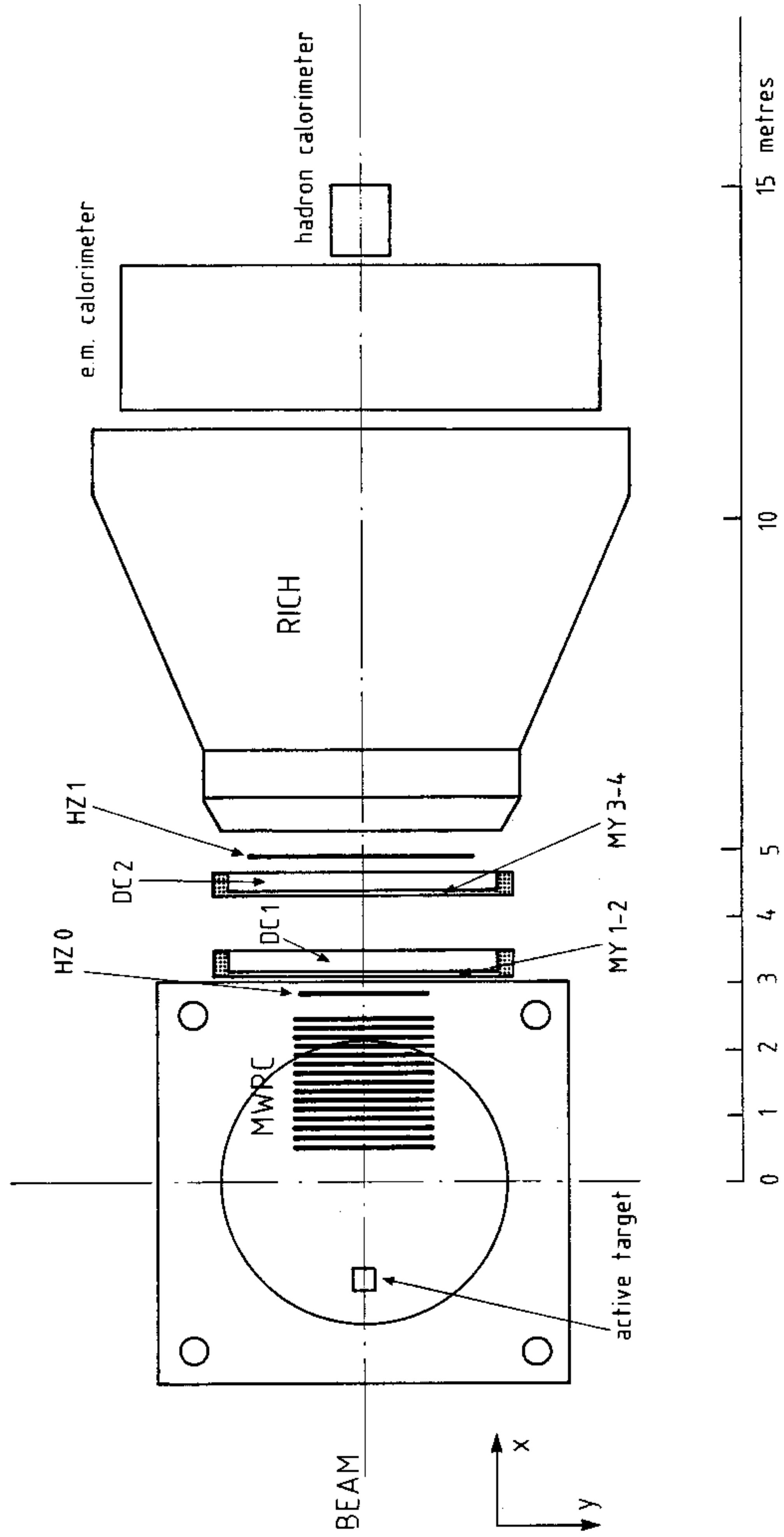
Fig. 9 Radial plot for the tracks detected by the butterfly system. The first eight particles are pions and the last two are kaons one above (No. 9) and one below (No. 10) threshold. The unlabelled arrows indicated the predicted ring radii if the particle were pions. The arrow labelled K indicates the predicted kaon ring radius.

Fig. 10 Signal to noise ratio: $S/\sqrt{B}$. $S \equiv$ signal: number of hits above background in the signal region. $B \equiv$ background: number of background hits under the signal:

(a) $S/\sqrt{B}$ for 660 pion tracks,

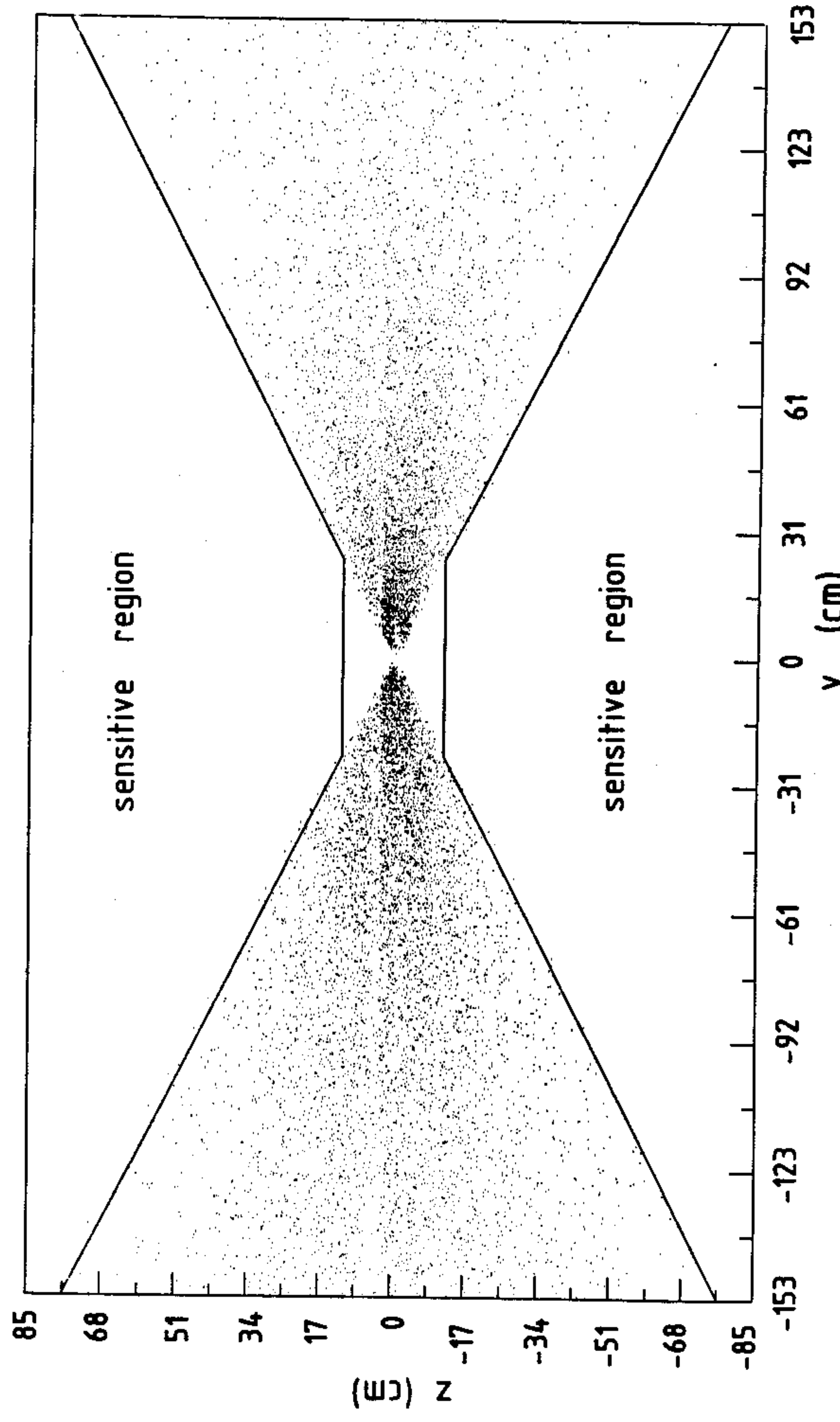
(b) $S/\sqrt{B}$ for 26 kaon tracks.

Fig. 11 Sketch of the active target system. 16 subtargets are placed in between 5 μm thick foils constituting the cathode plane of two small drift chambers.



hadron calorimeter
e.m. calorimeter
RICH
HZ1
MY 3-4
DC 2
DC 1
HZ 0
MY 1-2
MWPC
active target
BEAM
x
y
0
1
2
3
4
5
10
15
metres

Fig. 1


sensitive region
sensitive region
y (cm)
z (cm)
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-123
-92
-61
-31
0
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68
51
34
17
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-68
-85

Fig. 2

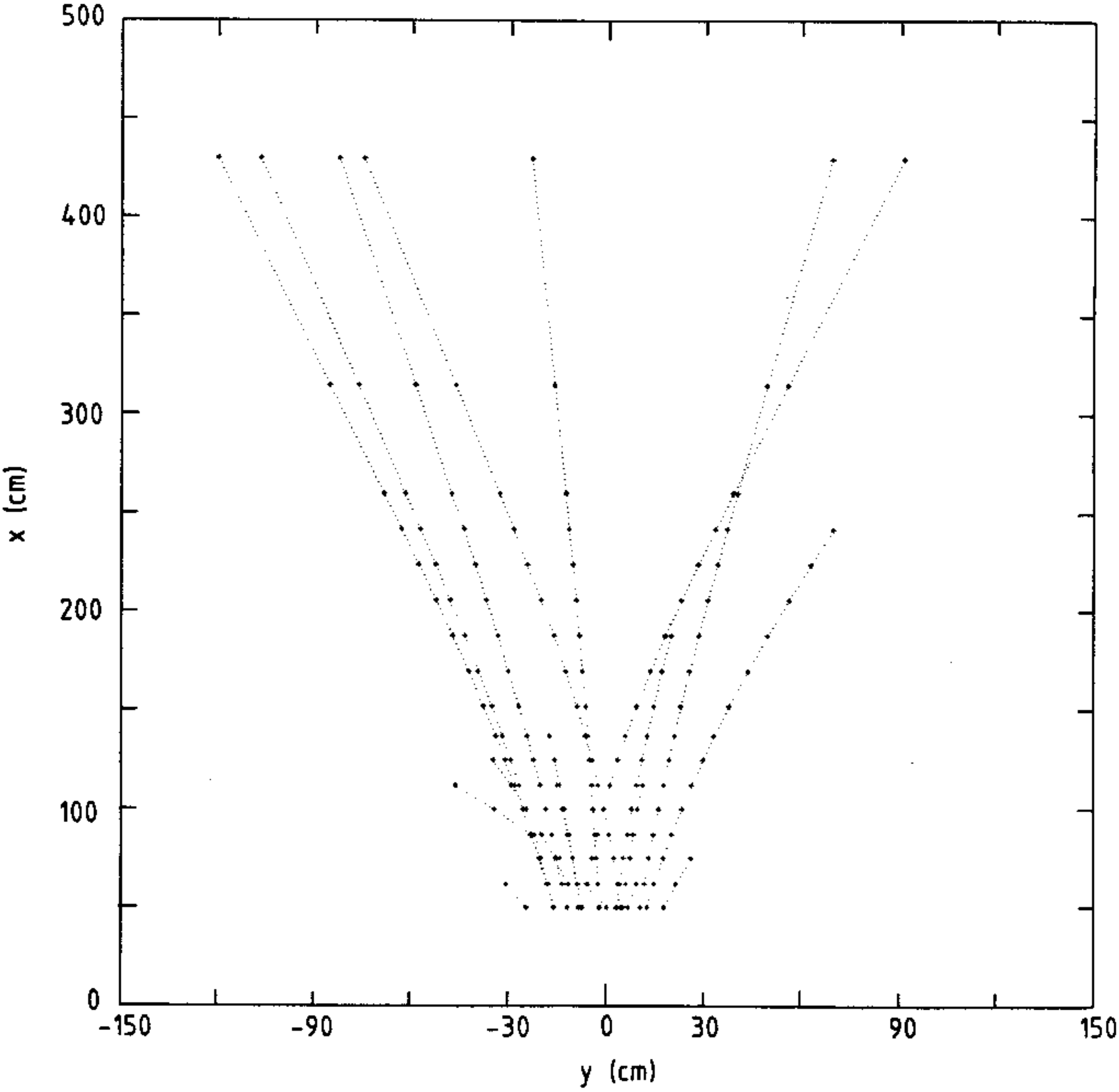


Fig. 3

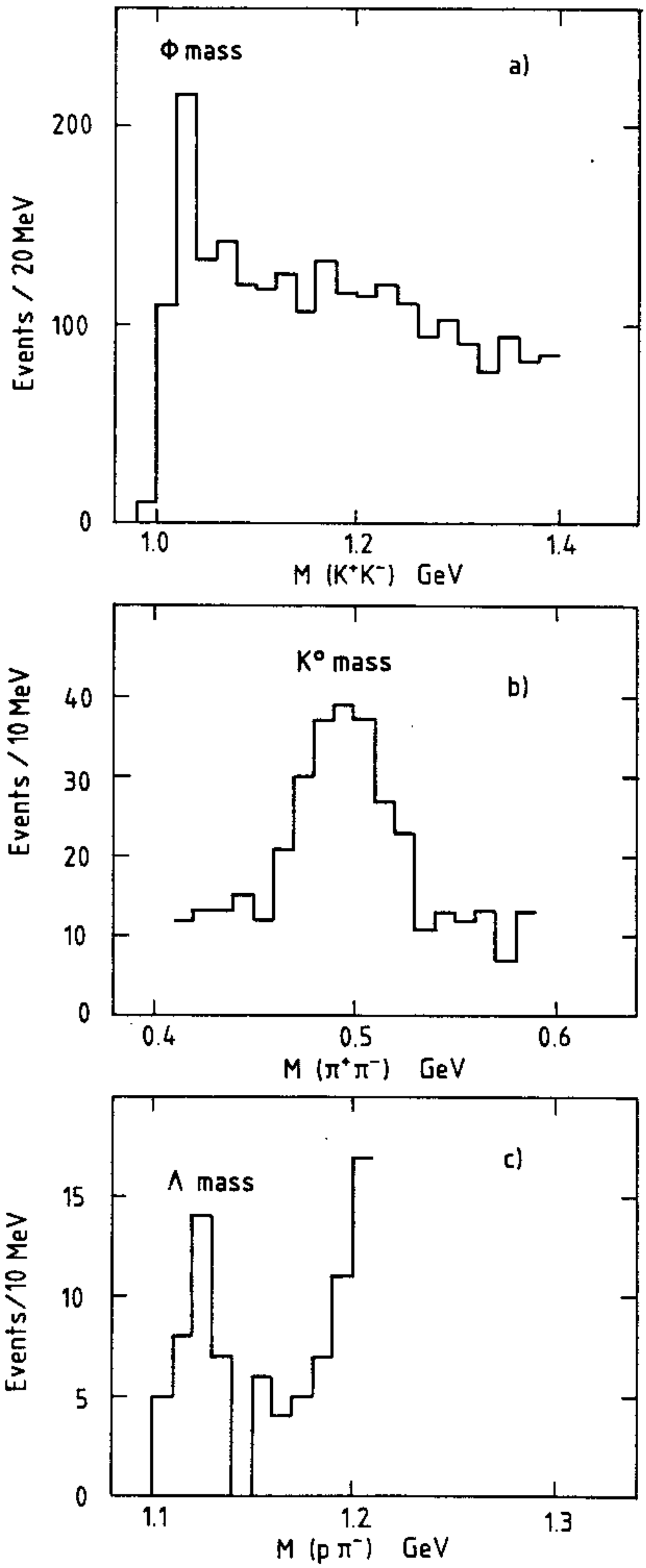

Φ mass
a)
Events / 20 MeV
200
100
0
1.0
1.2
1.4
M (K⁺K⁻) GeV
K° mass
b)
Events / 10 MeV
40
30
20
10
0
0.4
0.5
0.6
M (π⁺π⁻) GeV
c)
Λ mass
Events/10 MeV
15
10
5
0
1.1
1.2
1.3
M (p π⁻) GeV

Fig. 4

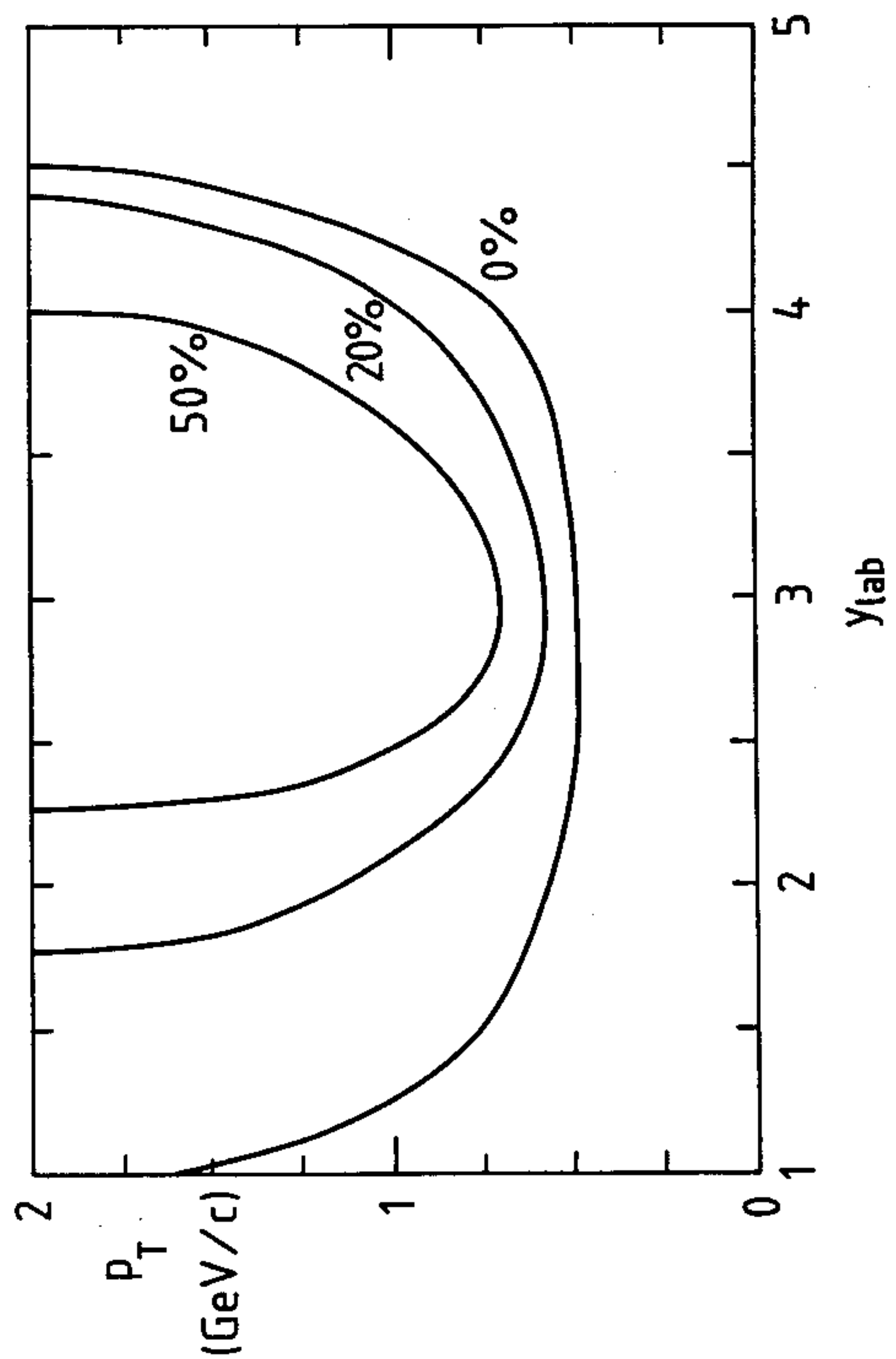


Fig. 5

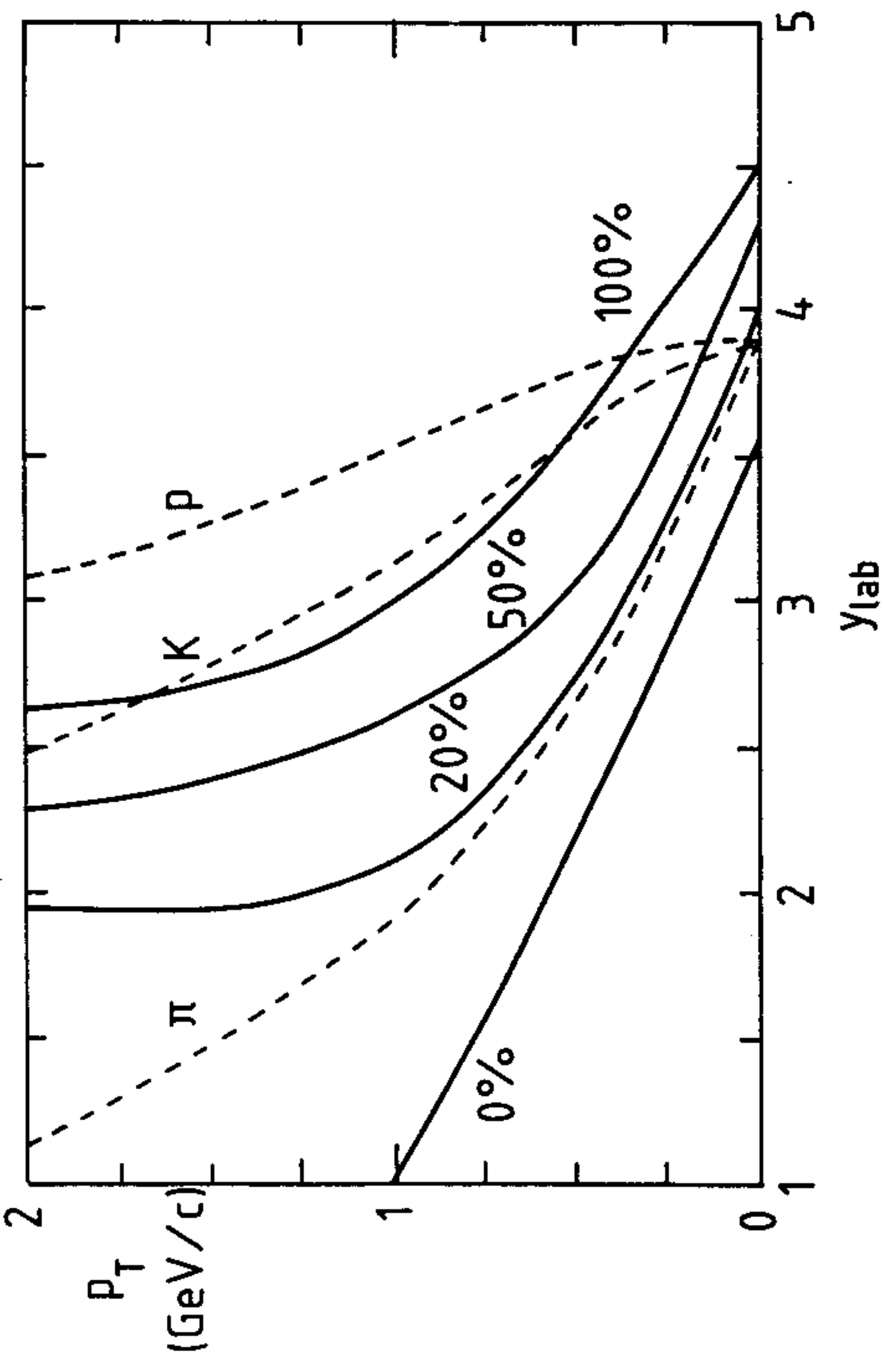


Fig. 6

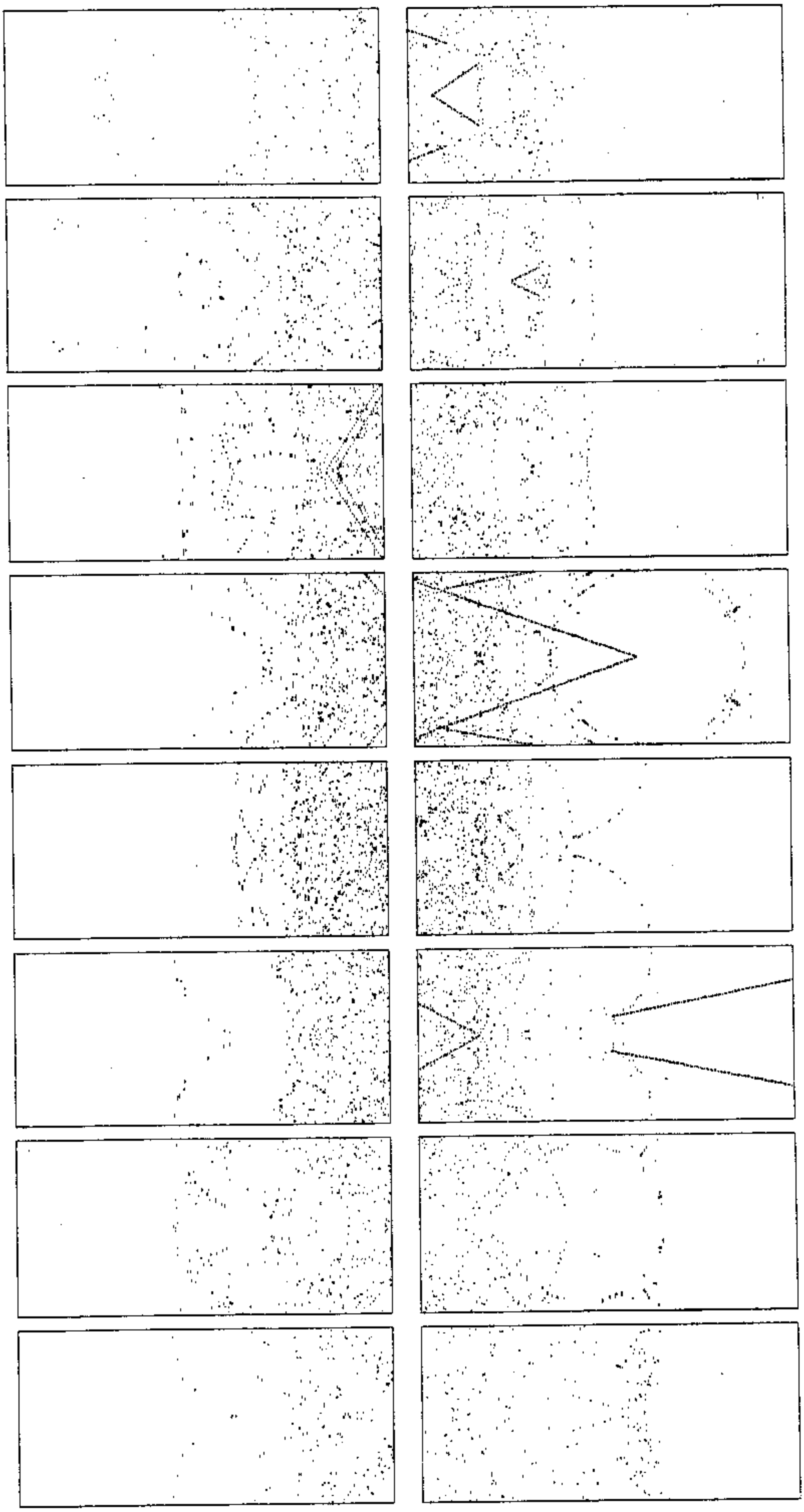


Fig. 7

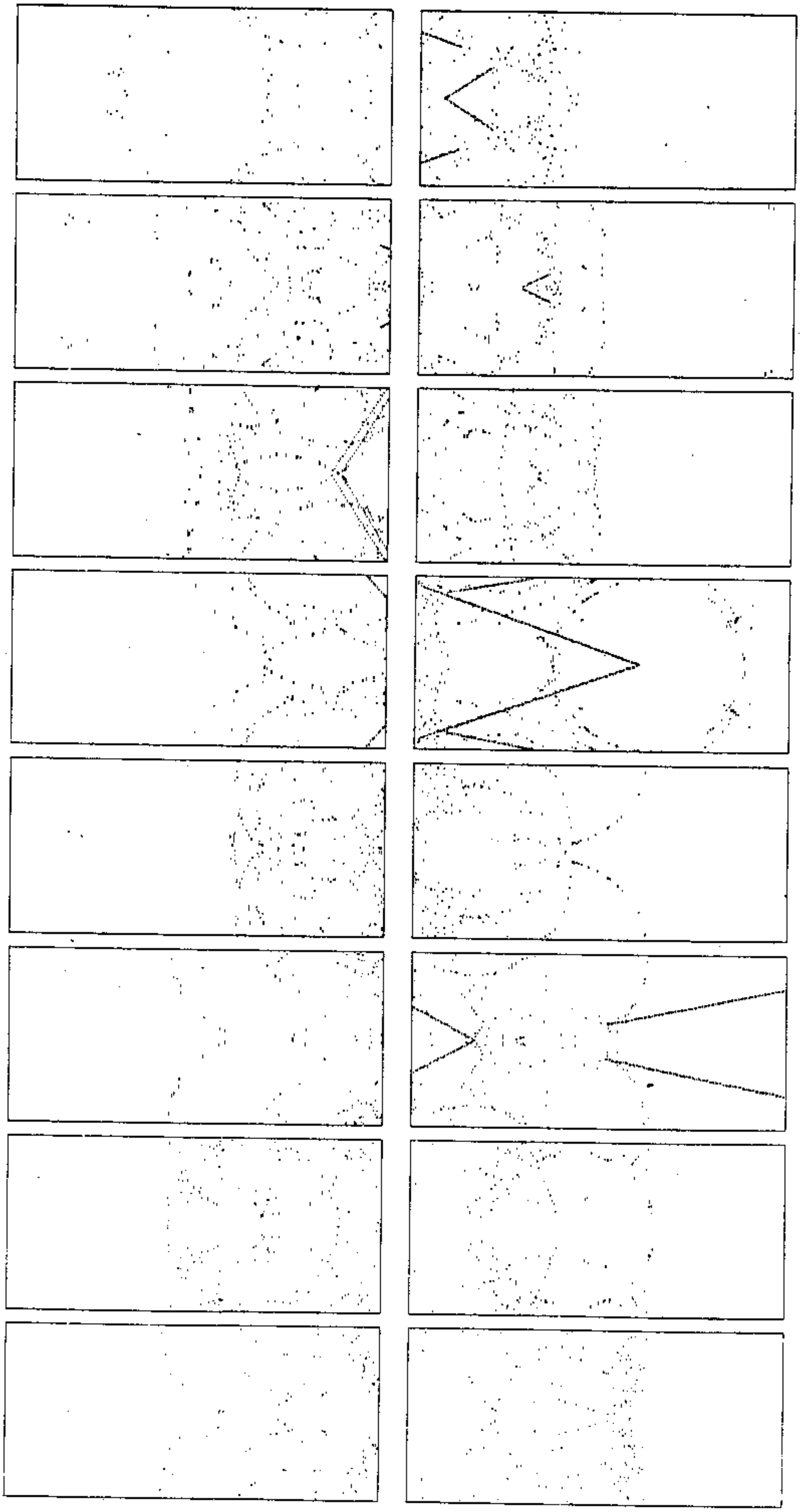


Fig. 8a

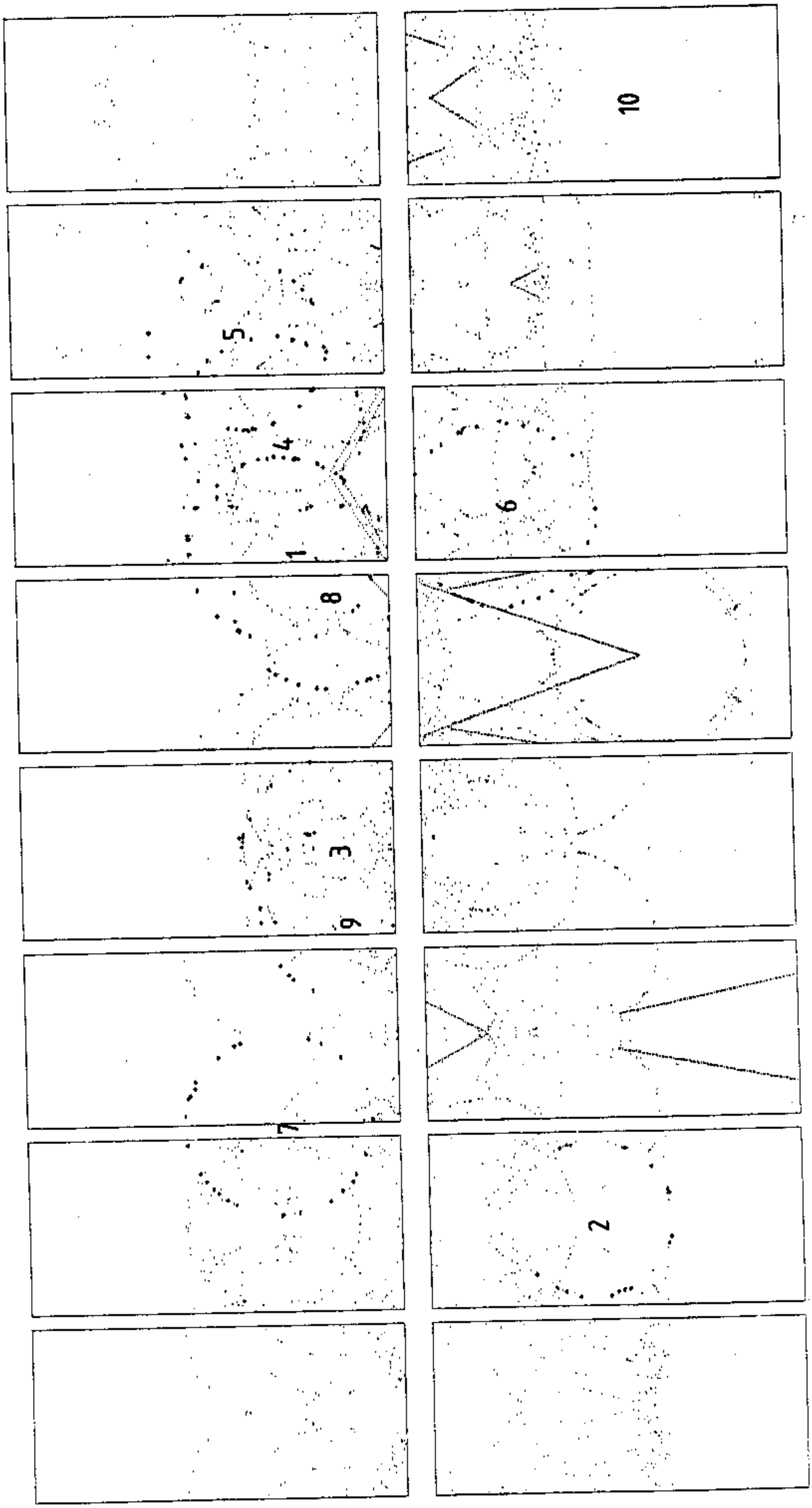
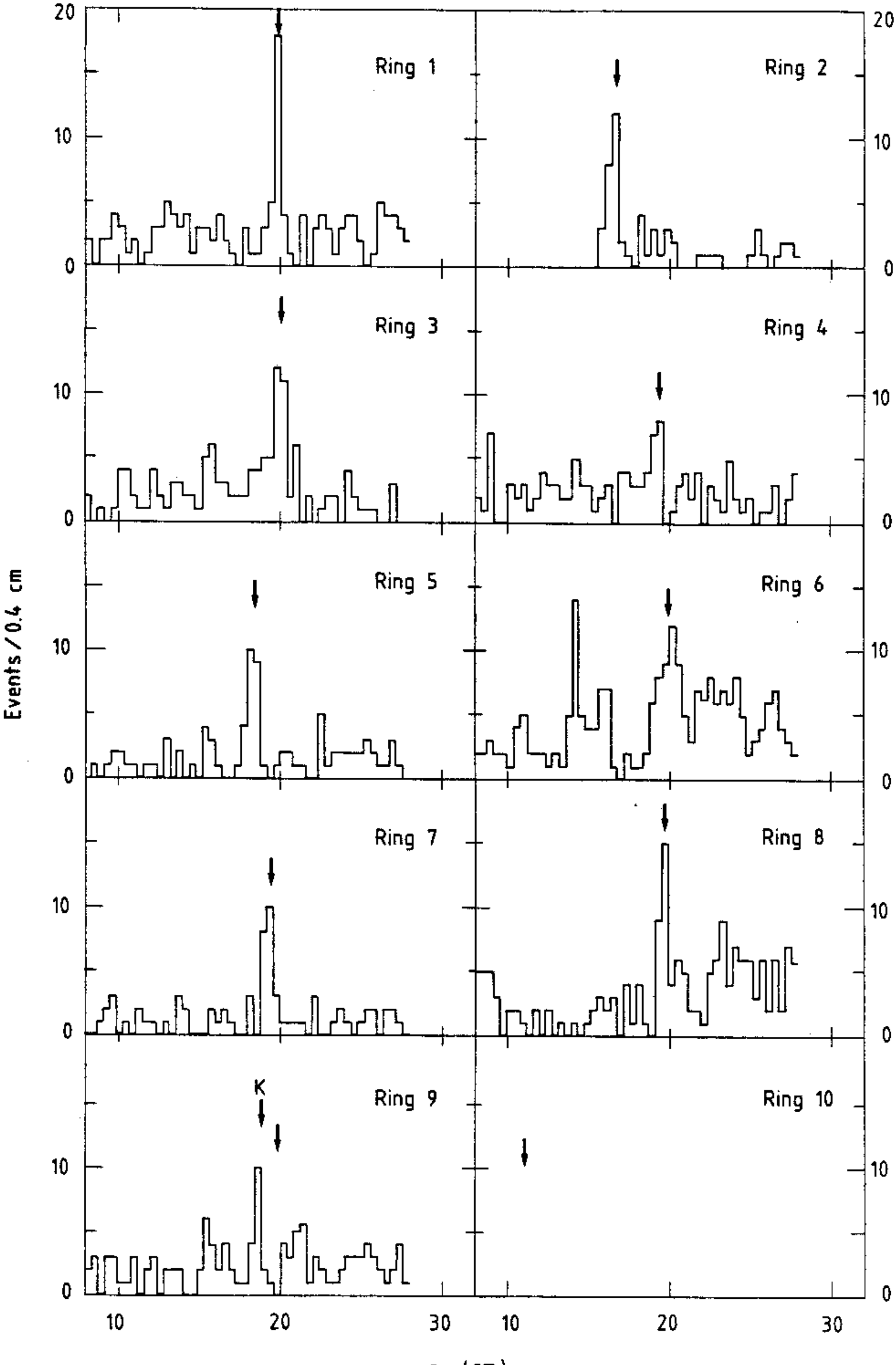


Fig. 8b



Ring 1
Ring 2
Ring 3
Ring 4
Ring 5
Ring 6
Ring 7
Ring 8
Ring 9
Ring 10
K
Events / 0.4 cm
0
10
20
30
r (cm)

Fig. 9

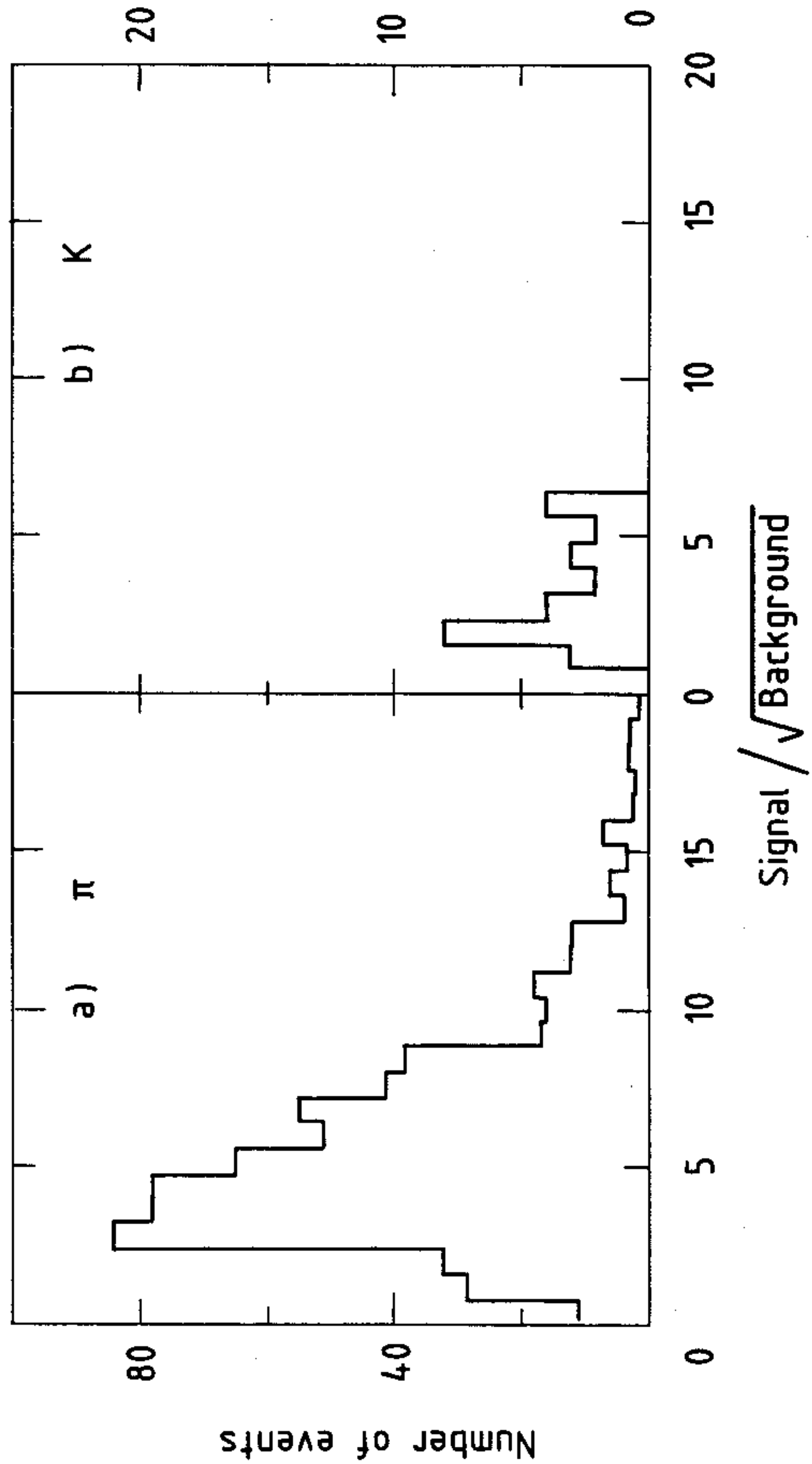

a) π
b) K
Signal / √Background
Number of events
0
5
10
15
20
0
40
80
0
10
20

Fig. 10

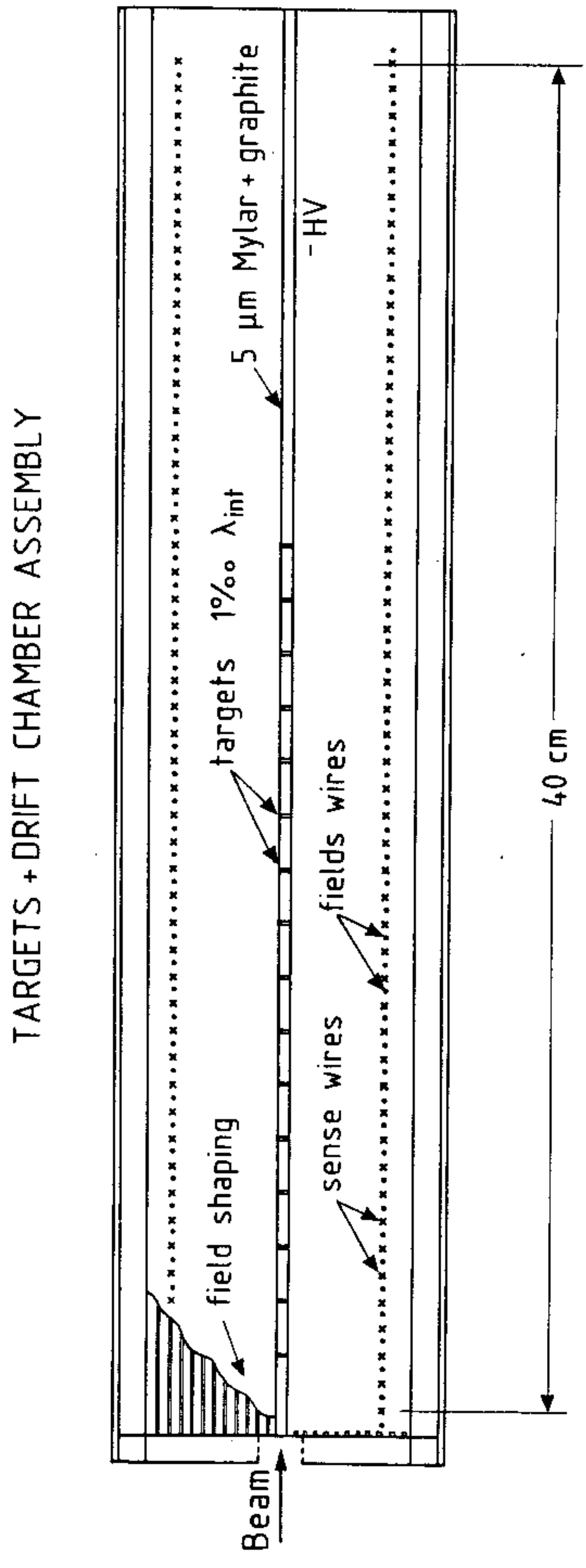

TARGETS + DRIFT CHAMBER ASSEMBLY
5 µm Mylar + graphite
-HV
targets 1‰ λint
fields wires
sense wires
field shaping
40 cm
Beam

Fig. 11