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PHYSICS I
ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL FOR OMEGA
DOUBLE CHARGE EXCHANGE REACTIONS

(FORBIDDEN PEAKS)

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1. AIM OF THE EXPERIMENT

The experiment is sketched on fig. 1. A negative beam of momentum $p_\ominus$ hits the hydrogen target. The spark chambers are fired whenever a positive particle leaves the target whose momentum $p_\oplus$ is close to the beam momentum. The trigger is given by two large proportional chambers (2 m. wide, 1,2 m. high) placed at the downstream end of the magnet and equipped with an appropriate logics, which yield a fast measurement of the projected angle and momentum of the positive particle. The latter is identified by a large Cerenkov counter if it is a π^+, and by kinematic fitting if it is heavier (K^+, p or d).

The reactions which can be studied are those which lead to a negative recoiling system of mass $M_{Rec} \leq 1.5$ GeV, and in particular :

$$\pi^- p \rightarrow \pi^+ \Delta^- \quad (\hookrightarrow \pi^- n)$$
$$K^+ \Sigma^-$$
$$K^+ Y^{*-} \quad (\hookrightarrow \pi^- \Lambda^0)$$
$$p \pi^- \ (\rho^-, A_2^-)$$
$$d \bar{p}$$

$$K^- p \rightarrow \pi^+ \Sigma^- \ (Y^{*-})$$
$$K^+ \Xi^-$$
$$p K^- \ (K^{*-})$$

$$\bar{p} p \rightarrow \pi^+ \pi^- \ (\rho^-)$$
$$K^+ K^- \ (K^{*-})$$
$$p \bar{p}$$

The formula governing the kinematics at high energy reads :

$$W_\oplus (M_{Rec}, t) = W_\ominus - \frac{M^2_{Rec} - M^2_p + |t|}{2M_p} \qquad (1)$$

($W_\ominus$, $W_\oplus$ = total lab. energies of the incident and fast outgoing particle;

M_p = proton mass ;

t = squared 4-momentum transfer from the beam particle to the fast positive particle.)

For the reactions and energies anvisaged, $W_{\oplus}$ is very close to the projected momentum measured by the proportional chambers. By selecting appropriate combinations of wires of the first and second chambers, the triggering device is made to accept an angle-dependent momentum band about 2 GeV/c wide. It covers then the listed reactions with an efficiency which is nearly 100 % up to $|t| \approx 1$ and is still typically 20 % at $|t| = 2$ $(GeV/c)^2$.(see fig. 2).

The ability of the device to reject efficiently all lower momentum particles is essential in order to achieve a reasonable trigger rate, as fig. 3 shows (at 11 GeV/c, one trigger every 6.000 beam particles). Even so, the data taking rate will be limited by the camera dead time. We plan therefore to measure the first reaction, $\pi^- p \to \pi^+ \pi^- n$, responsible for maybe 90 % of the triggers, at the end of each burst only, and to exclude it otherwise by using the Cerenkov counter in anticoincidence, thereby reducing the trigger level by an order of magnitude. We expect to obtain, in two weeks of date taking time :

- a total of 1,5 10^6 triggers, at two momenta : 8 and 15 GeV/c ;
- statistical levels of 14 (80) fitted events per nanobarn at 8 (15) GeV/c for the pion induced reactions (except the first one) ; this gives a few hundred events at each momentum even for the forbidden two-body reactions if their cross sections are of several nanobarns at 15 GeV/c as suggested by the Regge cut models ;
- and statistics smaller by two orders of magnitude for the K^- and $\bar{p}$ induced reactions, which means that these are measurable only if their cross sections are not disastrously small.

If a film camera were used instead of the Plumbicon readout assumed here, these figures would be 30 % smaller.

The major advantages offered by the Ω apparatus for this experiment are the following :

- a selective trigger system efficient over a wide t range is made possible by its high analyzing power, and by its good accessibility which allows all high momentum particles emitted at angles of up to 10° to leave the magnet and reach the trigger system ;

- the momentum of the fast positive particle is measured with the same accuracy as the incoming particle, i.e. to ± 2,5 o/oo, so that an excellent missing mass resolution is achieved : e.g. for a recoiling Σ^- and at small t, ± 22 MeV at 8 GeV/c, and ± 45 MeV at 15 GeV/c ;

- the good acceptance (typically 75 %) for low momentum particles emitted all around the target, while only moderately helpful for two-body final states, is essential for the three particle final states, which cannot be interpreted if the measurement is not complete.

II. PHYSICS INTEREST

Those reactions in our list where a π^- is turned into a p, or a $\bar{p}$ into a π^+, are examples of baryon (Δ^{++}) exchange. Their interest is discussed in another proposal ; here, they are an inevitable and welcome byproduct, and will not be discussed further.

The main emphasis is on the forbidden reactions, which correspond to the exchange of a system with exotic quantum numbers, which may be an exotic particle, or a Regge cut.

Only two forbidden reactions have been experimentally observed above 4 GeV/c so far : $\bar{p}\, p \to \bar{\Sigma}^-\, \Sigma^-$ at 5.7 GeV/c (H.W. Atherton et al., Phys.Letters 30B, 494 (1969)), with a cross section of 1.3 μb and 12 events found ; and $K^-\, p \to p\, K^-$ at 5 GeV/c (P. Lehmann, private communication) with 30 events found for a peak of integrated cross section ≃ 0.3 μb, and an exponential slope of roughly 1 $(\mathrm{GeV/c})^{-2}$.

Upper limits or single events have been measured for various other reactions, e.g. :

$$\frac{d\sigma}{dt}\ (\pi^-\, p \to K^+\, \Sigma^-) = 0.1 \pm 0.1\ \mu b/(\mathrm{GeV/c})^2 \text{ at } 5 \text{ GeV/c}$$

(C.W. Akerlof et al., Michigan report UM-HE-70-19)

$\frac{d\sigma}{dt}$ $(K^- p \to \pi^+ \Sigma^-) < 0.2\ \mu b/(GeV/c)^2$ at 8 GeV/c

(D. Birnbaum et al., Phys.Lett. 31 B, 36 (1969)).

Theoretical previsions based on Regge cuts foresee cross sections comparable or higher than these limits, decreasing with increasing energy like $p_e^{-(3\ to\ 4)}$, and depending rather weakly on t.

Precise measurements of a variety of forbidden reactions over a wide s and t region are clearly needed in order to reach a first insight into the reaction mechanism.

The reactions leading to three particle final states deserve special attention, as the discussion of the pseudo-forbidden peaks reported in 1969 has shown (see e.g. E.L. Berger, Phys,Rev. Letters 23, 1139 (1969); J. Kirz, in High Energy Collisions, Gordon and Breach, New York (1969), p.59). Let us take as an example the reaction $\pi^- p \to K^+ Y^{*-}$ and look at the $K^+ \pi^- \Lambda$ Dalitz plot for the events with small momentum transfer from the π^- to the K^+ (fig. 4) : one sees that the allowed processes $\pi^- p \to K^{*0}$ (890 or 1420) Λ^0 with the K^0 decaying backwards tend to simulate the forbidden peak as long as one looks at the projection of the Dalitz plot only. The simultaneous measurement of the π^- and/or the Λ will allow us to ascertain whether a given event is truly forbidden or not, i.e. whether the $K\pi$ mass is above the K^* resonance region. The interpretation should be facilitated by the narrowness of the Y^{*-}. But the most appealing feature is the possibility of observing the forbidden amplitude with much better sensitivity by interference with the allowed processes $\pi^- p \to K^* \Lambda$. The statistics being huge in the K^* region, the data can be cut in slices of given $K\pi$ mass whose width is limited only by the resolution. The K^* production phase is different for each slice, and we naively expect to observe, for some of them, a narrow peak or dip at the Y^{*-} mass, corresponding to constructive or destructive interference of the two amplitudes.

The situation of the reaction $\pi^- p \to \pi^+ \pi^- n$ is special in that as long as pion exchange is important, a Chew-Low extrapolation to the pion pole can be performed. It should thus be possible to measure the backward $\pi^- \pi^+ \to \pi^+ \pi^-$ cross section from 1 GeV up to over 3 GeV in the $\pi\pi$ rest system, and over a wide u range. Such results would be of great interest both as a search for massive dipions, and for Duality which predicts this process to be at least "in average", forbidden, while experimentally the ratio backward/forward is found to be of order 1 in the ρ, f^0 and even g^0 region.

III. THE EXPERIMENTAL SETUP

III. 1. Beam, Target, Interaction counter, Detector geometry.

The beam No. 4 (see "Possible Beams for Ω", Internal Report NP 70-29) is suitable. 1.3 % of the particles are K^- ; the $\bar{p}$ content drops from 0.4 % at 8 GeV/c to 0.07 % at 15 GeV/c. The standard beam equipment (counter telescope, hodoscopes measuring the incoming particle momentum to ± 0.25 %, and Cerenkov counters identifying its mass), hydrogen target (30 cm. long, located inside the second spark chamber module), and either one of the two proposed detector geometries are used. The magnetic field is 18 kgs at both momenta.

The only additional device introduced inside the useful magnetic volume is a counter of radius 1.5 cm located on the beam axis 1 m. downstream from the target (interaction counter). At such a distance, the wanted positive particles emitted at 0^0 pass at 3.6 cm. from its center, at 15 GeV/c ; therefore, little bias results for the good events, while the trigger rate with the target empty can be kept at a level of $\sim$ 10 % of the corresponding rate from hydrogen.

This experiment can therefore be run in while other experiments are taking data.

III. 2. The Cerenkov counter.

Use is made of the large Cerenkov counter described in the Ω proposal on baryon exchange processes, of useful cross section 2 x 1.5 m^2, and radiator length 1.5 m. The radiator gases are chosen such that at both momenta the counter works at atmospheric pressure, and with refractive indices below the K^+ threshold. Thin windows will be used. At 15 GeV/c, the counter will have to be increased in length, to $\sim$ 4 m., by mounting in place of the front window a structure which extends into the coils of the magnet. The optics will remain unchanged.

The following table shows the working conditions :

p_{LAB} GeV/c	gas	$(n-1) \cdot 10^6$	$(1-\beta)_K \cdot 10^6$	$(1-\beta)_\pi \cdot 10^6$	Θ_C mrad	Length of radiator	Photons produced (1000 . Θ^2/ cm)	Photo-electrons in P.M.
8	Isobutane	1300	1900	152	47	150	330	16 - 33
15	CO_2	450	540	43	28	420	330	16 - 33

III. <u>3. The Proportional Chambers, Geometry, Logics.</u>

The second chamber, which limits the acceptance should have useful dimensions of 2m. in width, carrying 1000 vertical wires with 2 mm. spacing, and 1.20 m. in height. The first chamber may have the same dimensions, but only 700 wires need to be equipped. Its overall height should not exceed 1.50 m., as it will be located in between the coils of the magnet. One may note that the dimensions of these chambers are such that they can also be used inside the magnet, for other experiments, provided the supports and electronics can be made small enough.

Here, the chambers serve two purposes : to measure the particle's trajectory, by recording the individual wires hit, and to decide whether the optical chambers are to be fired.

In both cases, the "event gate" is opened when a coincidence in the beam telescope is accompanied by no signal in the interaction counter.

The readout of the chambers, helpful during setting up and useful at the analysis stage to improve the momentum resolution, is done by standard technique ; care must be taken to avoid troubles with pickup from the spark chambers.

A triggering signal must result whenever there is a coincidence between a signal from any wire x_1 of the first chamber, and one of a number of conjugate wires $x_{2min}(x_1) \leq x_2 \leq x_{2max}(x_1)$ of the second chamber. Care must be taken that the function $x_{2max}(x_1)$, which delimits the acceptance region on the low momentum side, closely obeys the law imposed by kinematics, which is of the form

$$x_{2max}(x_1) = a + b \cdot x_1 + c \cdot x_1^2$$

The coefficient c is required to lower the accepted momentum band for large t, according to formula (1), in order to cover a t- independent missing mass range.

For a fixed geometry, all three coefficients would depend on energy, each one in its own way, leading to an inextricably complicate logics.

The geometries shown on fig. 1, are designed mainly to simplify the electronic logics, according to several criteria :

- The chambers are adjusted laterally with respect to each other, in order to have a = 0.

- The distance from the target to the second chamber, PC2, is proportional to P_{LAB}, in order to achieve a constant t range.

- The distance between the two chambers is proportional to P_{LAB}^2, granting that the coincidence between a wire of PC1 and a set of wires of PC2 covers a fixed momentum bite independent of P_{LAB}. (In fact, a momentum dependence slightly slower than P_{LAB}^2 is chosen, in order to cover a somewhat wider momentum bite at 15 GeV/c, required by the worsening on-line resolution - see III.5.) With the latter two conditions, b <u>and</u> c are energy-independent.

- Finally, it is useful to set b = 1 by treating the wires not individually, but by packets whose width is proportional to the distance from the target.

The quadratic term is treated as a correction varying in steps.

The parameters of the resulting choice are given in the following table :

Beam momentum	8	15
Distance target - PC1	3,6 m.	5 m.
Distance target - PC2	5,4 m.	10 m.
Number of logical elements (each chamber)	168	168
Wires per element - PC1	4	3
Wires per element - PC2	6	6
Number of elements of PC2 in coincidence with any one element of PC1	5	5
Useful momentum interval covered (not including an extra 0.4 GeV/c manoeuvring margin above the highest physical momentum)	2 GeV/c	2,5 GeV/c
Missing mass range covered without bias	0,14-1,45 GeV	0,14-1,5GeV
t - range covered (average)	0 - 2	0 - 2 $(GeV/c)^2$

The electronic logics itself can be realized either as a straight forward coincidence matrix ($\sim$ 800 coincidences), or more elegantly by digital computation using binary coded wire (element) numbers. This alternative is based on MSI circuits : a cascade of encoders, and units which perform the necessary arithmetic operations (add, subtract, compare). The process might take 200 nsec. Half of this time could be gained by encoding the wire element numbers at once, on the chamber frames, and imposing the event gate later on, once the interaction signal becomes available. The system, which treats only one signal per chamber at a time, may get a wrong answer if spurious signals appear simultaneously with a particle. With the geometry chosen, the most favorable location of the Cerenkov counter is between the two chambers ; still, at 8 GeV/c, a too strong stray field or a too big overall length might force it to follow PC2.

III. 4. Trigger Rates and Acceptance

The trigger rates corresponding to the conditions just described have been estimated in two ways : at 11 GeV/c, by processing 2-, 4- and 6-prong events from a HBC π^- exposure of the Genova - Hamburg - Milano Saclay Collaboration *) ; and at several momenta, by summing up the known cross sections for neutral meson production reactions ($\pi^- p \to \rho^0 n$, $f^0 n$, $K^{0*}\Lambda$, $K^{**0}\Lambda$) multiplied by the probability that the meson decays at backward angles such that its positive decay product (π^+ or K^+) meets the above requirements. The trigger cross section decreases roughly with the third inverse power of energy (two powers from the production mechanism, plus one from the fraction of accepted decays). The results roughly agree, and we find for a π^- beam :

$$\sigma_{trigger} \cong 150 \times (11/P_{LAB})^3 \ \mu b$$

that is 380 (60) μb at 8 (15) GeV/c. Values 10-15 times smaller are expected if the Cerenkov counter is used to exclude π^+'s. The contributions of e^+ from γ conversion, and of double scattering (e.g. $\pi^- p \to K^0\Lambda$, $K^0 p \to K^+ n$) are found to be negligible.

Preliminary typical acceptance curves for the positive particle are shown in fig. 4.

The probability of detecting and measuring the slow recoil particle(s) in the optical spark chambers has also been estimated. For elastic backscattering, where a π^- of 800 MeV/c can be emitted at $\theta_{Lab} = 90^0$ it is quite bad as long as all chamber plates are perpendicular to the beam (but the measurement of the proton suffices to identify the reaction anyway). For all other reactions, it turns out to be of the order of 75 % per particle to be detected (100 % for the $\bar{p}$ in $\pi^- p \to d \bar{p}$),

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*) The precious help of Dr. H. Grote, CERN, is gratefully acknowledged.

energy - independent, and almost independent of t.

III. 5. Resolution

We discuss first the resolution on the missing mass at the triggering stage, and secondly the resolution after complete kinematical analysis of the events.

The resolution in the trigger determines essentially the ratio between wanted and unwanted triggers. At small t, the error on $p_{\oplus}$ is mainly due to the target width, and is $\frac{\Delta p_{+}}{p_{+}} = \pm 2$ (4) %, at 8 (15) GeV/c. The effect of the target length becomes dominant at large t', and is ± 6 (6) % at t' = -2. The corresponding resolution on the missing mass is given by

$$\Delta M^2_{Rec} = 2 M_p \Delta p_{\oplus} + \Delta t$$

and contains a contribution $\Delta t = \pm 0.4$ from the t range seen by the individual wire. Mixing several wires together as suggested above does not significantly alter the resolution.

The precision on the missing mass after full measurement of the incident and fast positive particles depends mainly on the errors on their momenta :

$$\Delta M^2_{Rec} = 2 M_p \sqrt{(\Delta p_{\ominus})^2 + (\Delta p_{\oplus})^2}$$

The following table gives $\Delta p_{\oplus}/p_{\oplus}$ and ΔM_{Rec} for the readout systems that are being discussed; $\Delta p_{\ominus}/p_{\ominus}$ is ± 2.5 o/oo ; ΔM_{Rec} is given at the Σ mass, and is inversely proportional to M_{Rec}.

	Film		Plumbicon		Plumbicon + Trigger chambers	
Momentum	8	15	8	15	8	15
$\Delta p_{\oplus} / p_{\oplus}$ (o/oo)	± 2.1	2.5	2.7	3.7	2.4	2.8
ΔM_{Rec} (MeV)	± 21	42	24	52	22	45
at $M_{Rec} = M_{\Sigma}$						

The spatial accuracy of the Plumbicon system, which is assumed to be a factor of two worse than that of a film camera (σ = ± 0.4 mm. instead of ±0,2mm.), affects the momentum resolution especially at high momenta. Nevertheless, the use of the informations from the proportional chambers brings us back to an overall performance quite comparable to that of the film camera. It should be good enough to clearly identify the two-body final states, allowing to check the efficiency of the detector for the associated slow particle.

At least one more particle must be well measured for the three-particle channels. The fitted invariant masses of pairs of produced particles should be accurate to ± 5 - 10 MeV in most cases, allowing to search for the fine structure effects on the Dalitz plot mentioned in Chapter II.

IV. BEAM, MACHINE TIME AND TIMETABLE.

The Beam No 4 (see "Possible Beams for Ω", Int. Report CERN-NP-70-29), with 500.000 π^- and $\frac{\Delta p}{p}$ = ± 1 %, is suitable. To reach this intensity at 8 (15) GeV/c, 10^{11} (4×10^{11}) protons have to be ejected into the West Area.

If the technical problems with large proportional counters can be solved, the equipment should be ready by June 1972. Setting up and testing can be done parasitically and may take 4 - 6 months. A two weeks production run is required near the end of 1972. The following table shows the expected performances:

	8 GeV/c		15 GeV/c	
Momentum	8 GeV/c		15 GeV/c	
PS Bursts (Security factor $\frac{1}{2}$)	50.000		200.000	
Trigger	K^+, p	π^{+*}	K^+, p	π^{+*}
Trigger rate (μb)	$\sim$30	400	$\sim$5	60
Total number of triggers	$\sim$600.000	100.000	$\sim$550.000	300.000
Good events per nanobarn (2 final particles measured)	14	0,2	80	3,5
$\pi^- p \to K^+ \Sigma^-$ assumed σ	50 nb		5 nb	
expected events	700		400	
Main 3-particle channel	$K^+ \pi^- \Lambda$	$\pi^+ \pi^- n$	$K^+ \pi^- \Lambda$	$\pi^+ \pi^- n$
Expected events	250.000** 80.000***	50.000	250.000** 80.000***	150.000

If a film camera were used instead of a Plumbicon readout, the numbers of events would be decreased by $\sim$30 %.

The analysis of the data will rely mostly on the Saclay computing facilities, and will require at least one year.

V. COMPARISON WITH OTHER EXPERIMENTS, POSSIBLE EXTENSIONS, CONCLUSIONS.

Two other PS proposals can be compared with our proposal.

The Ω proposal by Orsay - E.P. Paris - CdF - CERN suggests a study

*) The Cerenkov counter is used in coincidence during the last 20 msec of each burst.

**) not required.

***) K^+, π^- and (- $p\pi^-$) measured.

of baryon exchange by triggering on fast forward going protons. While several reactions are covered by both proposals, the trigger is clearly and necessarily different : they accept a much wider range of momenta (and angles) and have to reject K^+ particles by a high pressure Cerenkov counter in order to achieve a reasonable trigger rate ; our main interest are K^+'s (and partly π^+'s) ; in turn, we have to restrict the momentum range.

The IPN-Orsay proposal on Forbidden Peaks is more closely related to ours. Only two-body reactions are studied, counters around the target eliminate the three-body channels right away, thus achieving a very favorable triggering rate. The smaller magnet restricts the scope to small t and lower energies, but the exclusive use of proportional counters allows to obtain higher statistics. While information from their experiment, if done before ours, will be valuable to us, we stress the importance of reaching higher energies and momentum transfers, and studying the 3-body channels, as foreseen in our proposal.

As a possible later extension of this experiment, the use of a polarized target might be envisaged at least for lower energies and small t. A search for I = 5/2 nucleon isobars might be done by looking for fast negative pions produced by a positive beam.

In conclusion, two kinds of results are expected from this experiment : A thousand two-body events per million triggers, in the most optimistic hypothesis, will give us a first insight into the mechanism of forbidden reactions for which the available data are extremely scanty at low energy, and in existing above 5 GeV/c. The bulk of the expected data will be well measured three-body events, in a narrow slice of the Dalitz plot ; their interpretation is not straightforward, but a new appealing possibility of measuring the forbidden amplitude by interference with allowed amplitudes is open.

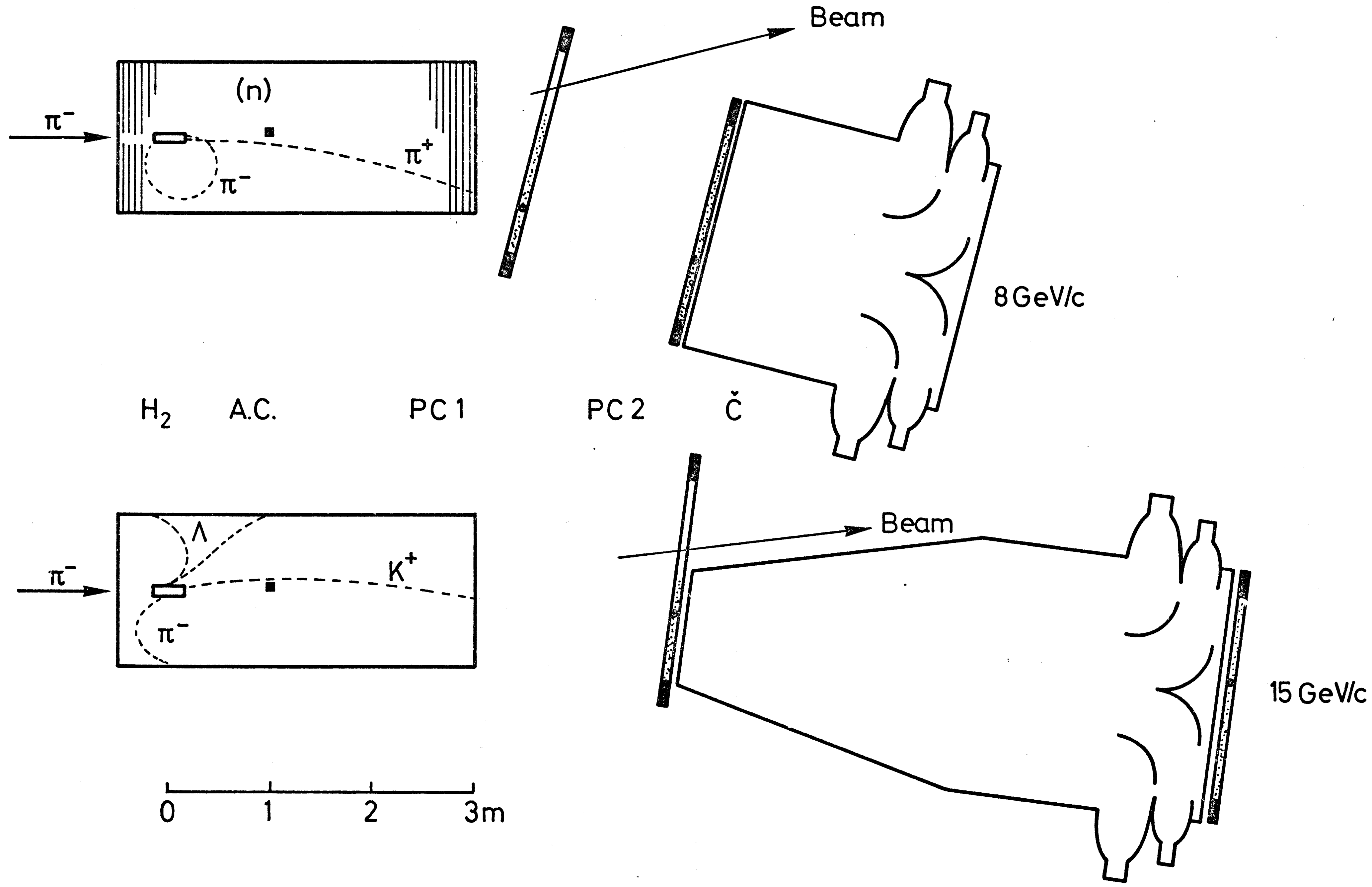

Fig. 1 : Experimental layout at 8 and 15 GeV/c.

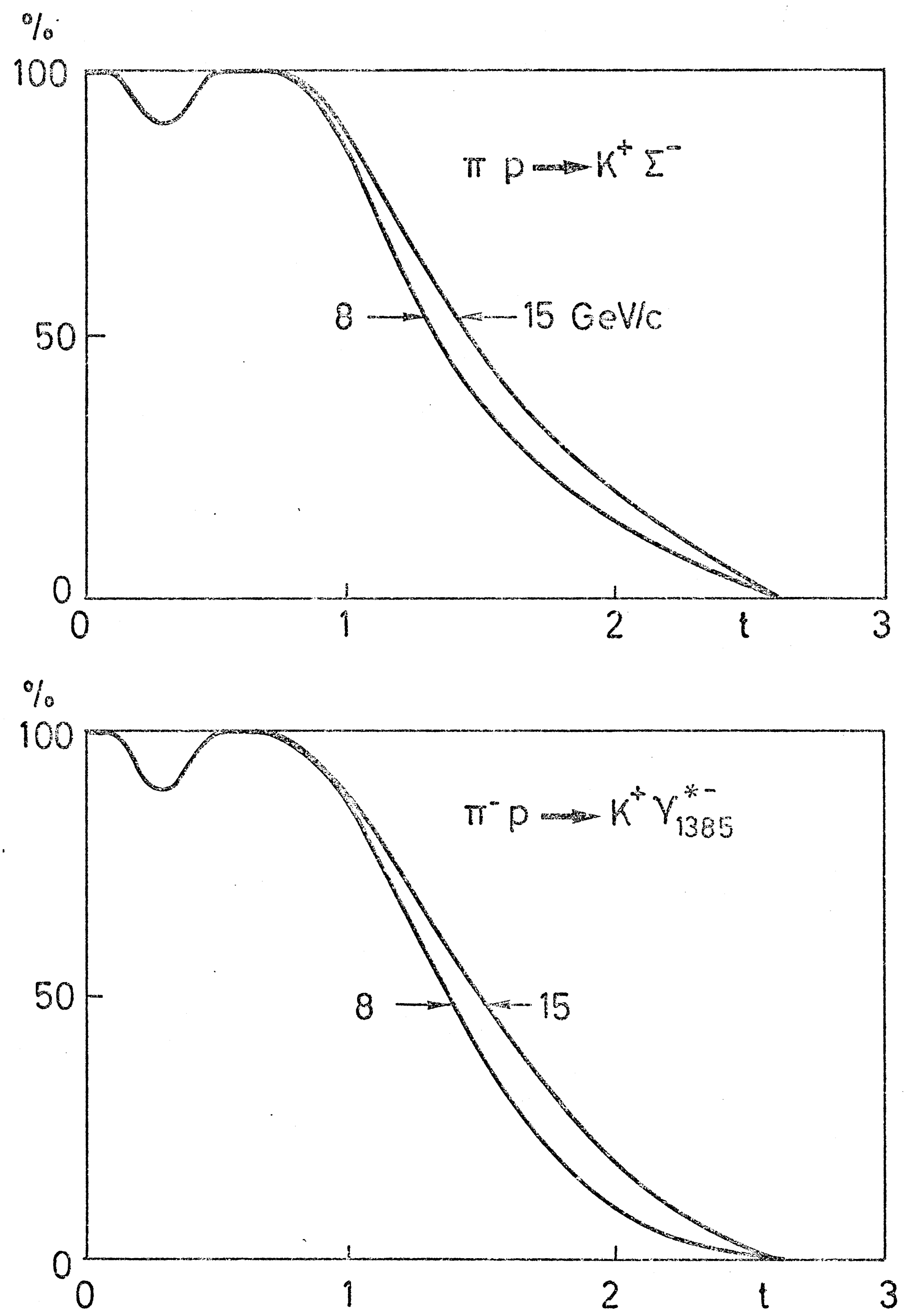

Fig. 2 : Efficiency for detecting the K^+, as a function of $t \simeq t'$, for reactions $\pi^- p \to K^+ \Sigma^-$ (above) and $\pi^- p \to K^+ Y^{*-}$ (below).

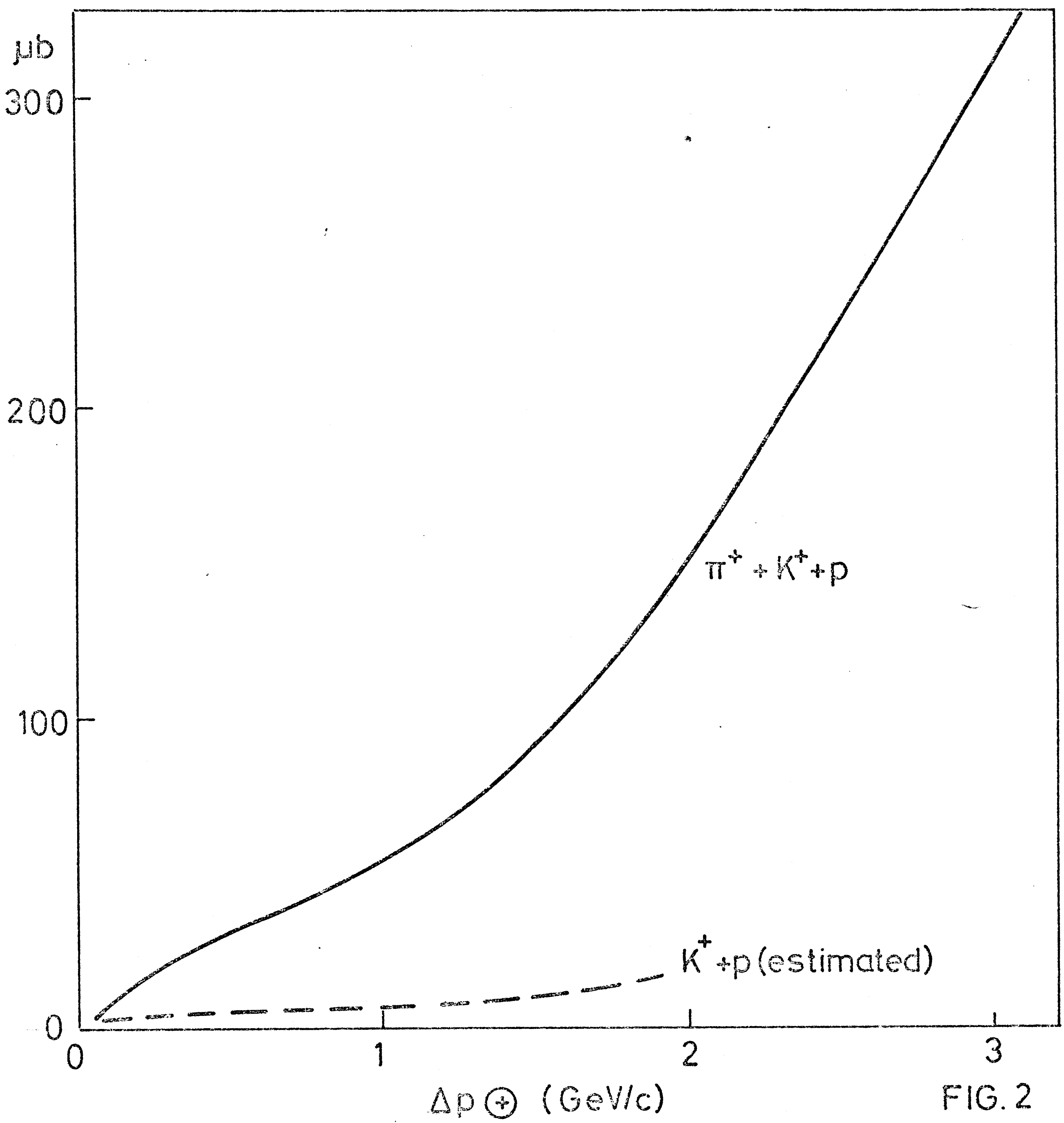

FIG. 2

Fig. 3 : Triggering cross section at 11 GeV/c vs. the accepted momentum band $\Delta p_{\ominus}$, estimated from the data of a $\pi^- p$ HBC experiment. $\Delta p_{\oplus}$ is measured from the momentum of elastically scattered protons downwards, and is angle-dependent.

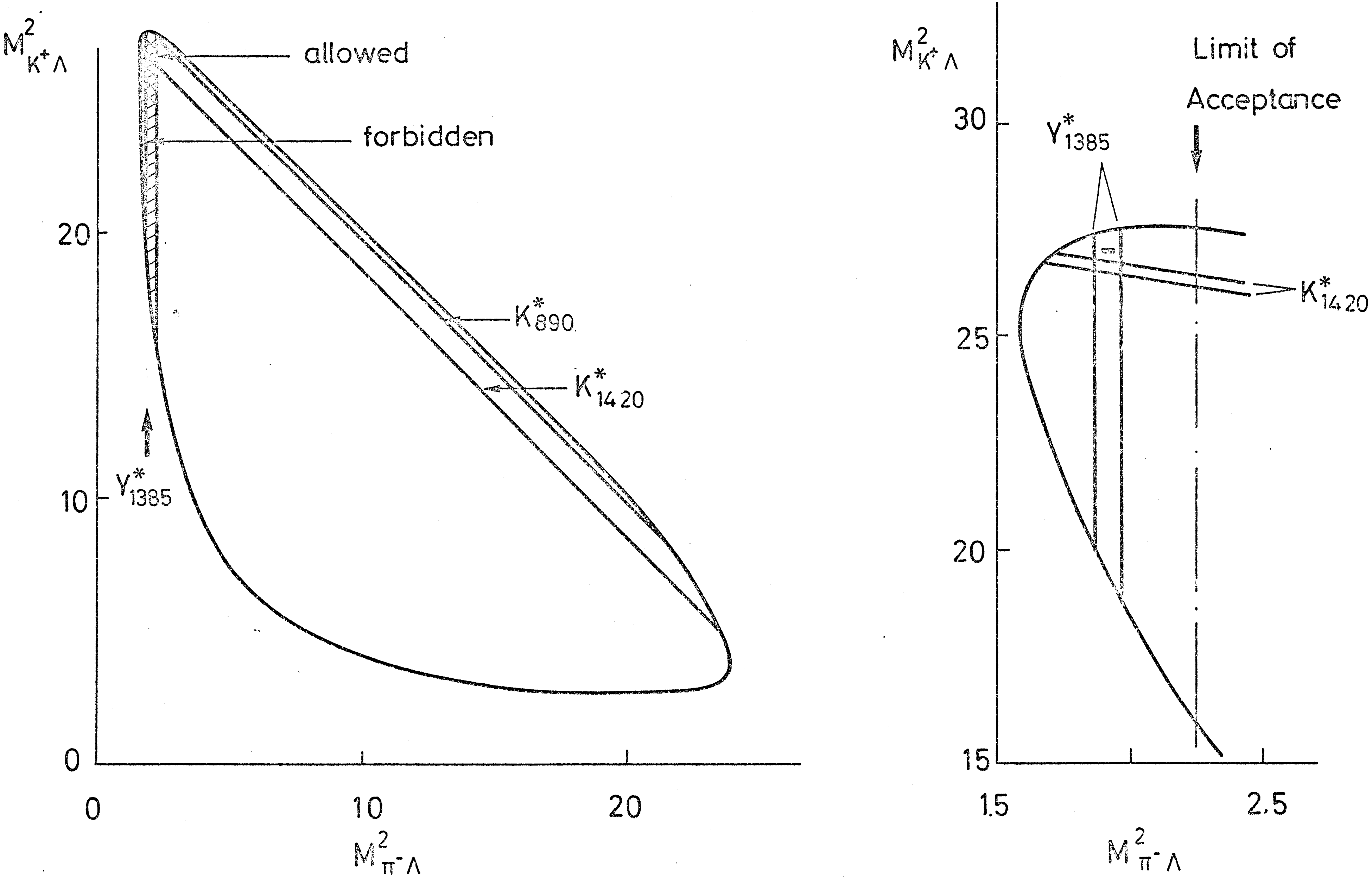

Fig. 4 : (a) Dalitz plot for the reaction $\pi^- p \rightarrow K^+ \pi^- \Lambda$ at 15 GeV/c. The hatched region (which is shown enlarged in b) is accepted by the trigger logic ; most events are expected to lie in the cross-hatched K* region. The small rectangle is an estimate of the errors for fitted events.