#580

A Search for Narrow and Broad Resonances Decaying into $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Lambda}\pi$, $K_s^0K_s^0$ and $K_s^0K_s^0\pi$ from π^-p Interactions at 300 GeV/c Using the Fermilab MPS

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One of the most effective ways to search for resonances in hadron interactions is to probe a definite quantum state such as e^+e^- or $\mu^+\mu^-$ (ρ, ω, ϕ, J/Ψ, Ψ', Υ). Due to the nature of dilepton resonances, these are restricted to the $J^P = 1^-$ system. Unexpected states such as the J/Ψ, Υ have been discovered using this technique.

We propose to expand this search to other quantum states such as 0^+, 0^-, and 2^+ with at least an order of magnitude greater sensitivity than all other previous measurements. The reactions we plan to study are

(1)	$\pi^- p \to \Lambda\bar{\Lambda} + X$	$I = 0$	only $J^P = 0^+, 0^- \ldots$
(2)	$\pi^- p \to \Lambda\bar{\Lambda}\pi^\pm + X$	$I = 1$	only $J^P = 1^+, 2^+ \ldots$
(3)	$\pi^- p \to K^0_s K^0_s + X$	$I = 0,1$	$J^P = 0^+, 2^+ \ldots$
(4)	$\pi^- p \to K^0_s K^0_s \pi^\pm + X$	$I = 1,2$	$J^P = 1^+, 1^- \ldots$

These reactions are good for high mass meson state searches. We believe that by probing these definite spin-parity states, new high-mass narrow resonances with these quantum numbers may be uncovered which cannot be produced directly in e^+e^- collisions. (See Fig. 1) Preliminary 15' bubble chamber data at 250 GeV/c show that K^* and Y^* resonance production can be observed, and therefore states which decay into K^*K^0 and $Y^*\Lambda$ can also be studied (see Fig. 11).

Our aim is to reach masses of up to 22 GeV and to reach high sensitivity in cross section (64 <u>visible</u> events per nb) with good mass resolution ($\sigma \sim 60$ MeV or less). This sensitivity is sufficient to give a signal of 8 standard deviations for a narrow 15 GeV resonance with a cross section times branching ratio, $\sigma.B$, of 1 nb. This represents a measurement at least one order of magnitude more sensitive than all the other previous measurements.[1] The planned trigger is a definite number (0, 1, 2) of charged tracks leaving the target and the appearance downstream of four additional tracks from the decays of the two V's. Similar triggers have already been used in the MPS.

The following sections detail our proposal:

a) Beam: 800 hour running time with 250 pulses per hour and 1.5×10^6 effective (corrected for dead time) π's per pulse at 300 GeV/c i.e., 3×10^{11} π^- for the experiment.

b) Target: A 30-cm liquid hydrogen target will be used. Cylindrical MWPC's will surround the target as discussed below in section c.

c) Setup: In order to detect K^o_s and Λ's with adequate efficiency, a decay region of the order of the particle's decay length is required. We have chosen 4 meters. The LH_2 target will be immediately followed by a rectangular MWPC. This chamber defines the upstream boundary of the 4-meter decay region (which will be vacuum) and also will serve as a veto for events where the number of prompt tracks is too large. MWPC's before and after the magnet will serve to reconstruct the V's. These chambers will also be used in the trigger to identify the appearance of four charged tracks after the decay region. Cylindrical MWPC's α, β surround the target and record other outgoing particles to aid in vertex location. Spark chambers follow the magnet to complete the measurement of the event. The only change we would make to the current setup is to increase the decay volume from 1.6 to 4 meters. The proposed configuration is shown in Fig. 2.

d) Sensitivity: In 800 hours of running, we expect to produce 160 events/nb for the $K^o_s K^o_s$ and $\Lambda\bar{\Lambda}$ decays into charged particles. The charged decay mode correction factor of 4/9 has already been applied. The geometrical acceptance of the spectrometer as a function of Feynman x for $K_s^oK_s^o$ and $\Lambda\bar{\Lambda}$ pairs of mass is shown in Fig. 3 and 4 the acceptance versus x_F for K^*K and $Y^*\Lambda$ is shown in Fig. 5 and 6. In this acceptance calculation, a decay length of 4 meters was used and events with prongs too close to be resolved as distinct tracks have been rejected.

Using a peak acceptance of 40%, our net sensitivity is about 64 detected events per nb for $K_s^oK_s^o$ and $\Lambda\bar{\Lambda}$, which is sufficient to give a signal of 8 standard deviations for a narrow 15 GeV resonance with a $\sigma.B$ of 1 nb.

e) Yield: The cross section for inclusive $\Lambda\bar{\Lambda}$ and $K_s^oK_s^o$ production as a function of the number of accompanying charged tracks has been measured in 250 GeV/c π^-p interactions.[2] The total inclusive $\Lambda\bar{\Lambda}$ and $K_s^oK_s^o$ cross sections are 0.15 mb and 0.60 mb respectively. Requiring that the accompanying number of charged tracks through the spectrometer be ≤ 2, these cross sections reduce to 0.02 mb and 0.045 mb respectively. We expect 1.2×10^6 $\Lambda\bar{\Lambda}$ event triggers and 2.5×10^6 $K_s^oK_s^o$ event triggers or roughly 18 event triggers/pulse. Actual trigger rates based on E110 data and backgrounds are discussed in the next section. But we point out that folding charge decay and acceptance into these ∿ 20 and ∿ 45 μb cross section gives us real trigger rate ∿ 12 μb.

f) Trigger and Trigger Rate: Telescope counters S_A, S_B, S_C, and MWPC module BB identify an incoming beam pion. MWPC module A, immediately followed by a dE/dx counter, restrict the trigger to events with a limited number of charged particles (≤ 2) entering the decay region. Cylindrical MPWC's α and β which surround the target aid in vertex location by detecting low-momentum, large-angle recoils. They also ensure that an interaction has taken place in the target. Following the decay region, MWPC modules B', B, C, and D detect the additional tracks produced by the decays of the two V's. These chambers, together with the spectrometer magnet and spark chamber modules E and F, analyze the momenta of the decay tracks.

In order to estimate trigger rates, we have looked at a sample of data from E110. These data were obtained with abnormally low spark chamber efficiency, with air rather than helium in the decay region, and with a shorter decay length than we have proposed. Helium bags have since been installed and their trigger rates have been observed to decrease by a factor of 3. Using this factor of 3 and the E110 data, we find trigger rates of 15 μb for the 1 to 5 trigger and 17 μb for the 2 to 6 trigger. The 0-4 data were taken along with eight other triggers and we cannot extract the trigger cross section for this topology, but it is small compared to either 1-5 or 2-6. (See section g.) The 250 GeV/c π^- FNAL-FSU 15 foot exposure has 10 events which had two vees and observed prongs which would have satisfied our 1-5 or 2-6 trigger. Using these ten events, we estimate a true $V^\circ V^\circ$ rate which is approximately half the observed trigger rates. Since this estimate is based on only 10 events (the current world sample), it is obviously consistent with as little as 20 or 25% true double vee events among the triggers. (See Fig. 9, 10)

In order to limit the data rate to a manageable level, we will restrict ourselves to 0-4, 1-5, and 2-6 triggers. With these triggers, the rate is 18 triggers per 10^6 π. With an incident flux of 2 x 10^6 π's per pulse and a 25% dead time, we obtain 27 triggers per pulse. Thus in 800 hours of running at 250 pulses/hour and at our peak spectrometer acceptance of 40% (see Fig. 3), we get a sensitivity of $\sim$64 visible events/nb.

To evaluate the continuum contribution to the 2-V° events, we have obtained data from M. Good, et al. for $pp \rightarrow K^+K^- + X$, $p\bar{p} + X$ which indicate that this background falls as $e^{-1.7m_{h\bar{h}}}$ h = K or p at $X_F = 0$. For $X_F > 0$ (not at $X_F = + 1$), we expect the background is overestimated. Combining this with the observed number of $K_s^0K_s^0$ events in the FSU/FNAL exposure, we find that a 10 nb signal in one 50 MeV bin represents an effect of 5.5 standard deviation - over background at a $K_s^0K_s^0$ mass of 4 GeV. At higher masses, the background becomes negligible and sensitivity correspondingly greater. For $(\Sigma\ (1385) \rightarrow \Lambda + \pi)^{-}\ \bar{\Lambda}\ (K^{*}(890) \rightarrow K_s^0 + \pi)^{-} K_s^0$ final states, we estimate that the acceptances are similar.

g) Study of Double Vee Events Based on E110 Data: We have studied the efficiency for the ratio of double-vee events to background using a sample of data from Experiment E110. The physicists associated with the Fermilab MPS, in particular, Carl Bromberg of Caltech, provided us with invaluable assistance in this study, though the data we used were of marginal quality. These data were obtained with abnormally low spark chamber efficiency, air rather than helium in the decay region, and with a shorter decay length than we have proposed. The following table summarizes the E110 data:

Run	Trigger topology	Triggers	Percent of triggers reconstructed	Percent of triggers with $K_s^0K_s^0$ (without He bag)	Expected Percent of triggers with $K_s^0K_s^0$ (with He bag)	$K_s^0K_s^0$ [#] Event
93-99	0-to-4	253	15%	5%	10%	5×10^3
105	1-to-5	996	4%	.1%	4%[+]	2×10^4
106	2-t-6	1404	3%	.1%	3%[+]	2×10^4
						$\sim 4.5 \times 10^4$

[#] Based on 3×10^{11} effective incident π^-'s, and triggers taken with He bag.

[+] Based on the assumption of improved chamber efficiency and improved reconstruction efficiency (see later test).

Of the reconstruction, the number of "$K_s^o K_s^o$ events" is 12, 1, and 1 respectively for the trigger topologies. In these triggers, the number of downstream tracks minus the number coming from the target is 4. The 0-to-4 trigger was in reality run with the following conditions: (a) no tracks in A chambers and (b) at least 3 but no more than 5 tracks in any 5 of 6 chambers immediately following the decay region. Two factors contribute to two-vee inefficiency; firstly, the spark chambers were having difficulty (gas problems, etc.), their efficiency varied from 70% to 95% and averaged perhaps at 85%; secondly, the reconstruction programs were not tuned especially well, as scrutiny of computer-generated event pictures revealed many instances of track-like spark configurations which were not reconstructed.

If we required that each "K_s^o" be in the decay region and that both "K_s^o" extrapolated back to a common vertex in the target region, the number of $K_s^o K_s^o$ events reduced to 6 or 3% of triggers. Figure 7 shows the mass of the reconstructed vee in the 0-to-4 trigger. A clean K_s^o signal, defined with mass between 0.44 and 0.54 GeV, can be observed in the plot. The invariant mass for these six $K_s^o K_s^o$ events are shown in Fig. 8. For the other two triggers, we did not observe a significant K_s^o signal in the mass of the reconstructed vee. This is due to the serious problem of secondary interactions from the primary tracks. With a helium bag installed (or with a vacuum pipe introduced), this problem should be reduced by a factor of 3 to 10. The data discussed here were unfortunately run before this installation.

In summary, we can say that the reconstruction efficiency of double vees is $\sim$ 3% in the 0-to-4 trigger. By improving the chamber performance (which has been accomplished in recent E110 runs) and by tuning the programs, we expect to increase the 0-to-4 trigger efficiency perhaps by a factor of two. There were inadequate data for the 1-to-5 and 2-to-6 triggers in our study. Their reconstruction efficiency was 25% of the 0-to-4 trigger efficiency because of deteriorating chamber conditions. Overall we expect to improve their efficiency by $\sim$ a factor of 10. With the vacuum pipe installed, the fraction of 2-to-6 triggers yielding good $K^o_sK^o_s$ may reach 4-to-10%.

Same argument can be applied to $\Lambda\bar{\Lambda}$ systems. We expect $1 \times 10^4 \sim$ events.

h) Comparison between P-548 and E-110: It is expected that E110 will detect zero-prong $2V^o$ events as one of their 9 triggers in the course of normal running. There will be no overlap between $2V^o$ + n charged (n = 1,2) physics in our experiment and that of E110. Our experiment concentrates exclusively on the $2V^o$ trigger and $2V^o$ + n charged (n - 1,2) as compared to E110. Their 9 triggers already saturate the readout. We propose to saturate the trigger with $2V^o$+ n charged (n = 0,1,2) and to gain a factor of $\sim$ 8 in zero-prong $2V^o$ events. The various enhancement factors are:

1) Decay region 4 meter vs. 2 meter. The calculated acceptances increase by a factor of $\sim$ 1.5.

2) Beam. 10^6/sec. vs 5×10^5/sec., giving a factor of $\sim$ 2.

   COMMENT: A 10^6/sec beam may prove conservative. From the operational view the M-6 beamline has higher flux capability. Similarly, the PWC memory time (100 ns) and the trigger logic times (200 ns) do not preclude higher fluxes.

3) Flat top. We plan to run the flat top at 2.0 sec.* yields a factor of $\sim$ 1.6, an improvement over the present 1 sec. flat top.

4) <u>Cross section.</u> $2V^{\circ}$ production at 300 GeV vs. 100 GeV, giving a factor of ~ 1.5.

Thus, the overall multiplicative improvement factor (R) in data rate per pulse is

$$R = \sim \ 7.$$

As a further comment, we note that E110 has data at several energies (one of them is 100 GeV/c) while this experiment concentrates at 300 GeV only. The higher available center-of-mass energy at 300 GeV allows us to explore the mass region up to 22 GeV, about 10 GeV higher than is available at the 100 GeV/c beam.

The new physics which can be obtained by running this experiment: a(an order of magnitude in the sensitivity for zero-prong double vee topologies, and c) the exploration of a higher mass region. At 15 GeV, we can reach $\sigma.\beta$ at a level of 20 visible events/nb.

i) <u>Commitments to This Experiment</u>: The groups involved in this proposal have expressed their <u>firm</u> and <u>enthusiastic</u> commitment. Letters of firm confirming for this experiment from <u>Arizona</u>, <u>Florida State</u>, <u>Tufts</u>, <u>Virginia Tech</u>., and <u>Vanderbilt</u> will each devote substantial manpower in the nature of either a research associate or graduate student who will be exclusively dedicated to this experiment. In particular, <u>E Jenkins</u> can spend a <u>six-month</u> leave of absence there if the experiment is approved. People with counter experience, such as <u>W. Morris</u>, <u>C. Spencer</u>, and <u>A. Segar</u>, will also be stationed at Fermilab. Florida State intends to seek to hire a research associate who will work full time at Fermilab, if the experiment is approved. <u>Kwan-Wu Lai</u> can be at Fermilab before, during and after the P-548 run. <u>Peter Yamin</u> can also devote a substantial fraction of his time to this experiment.

This proposal requires almost no hardware modifications of existing equipment.

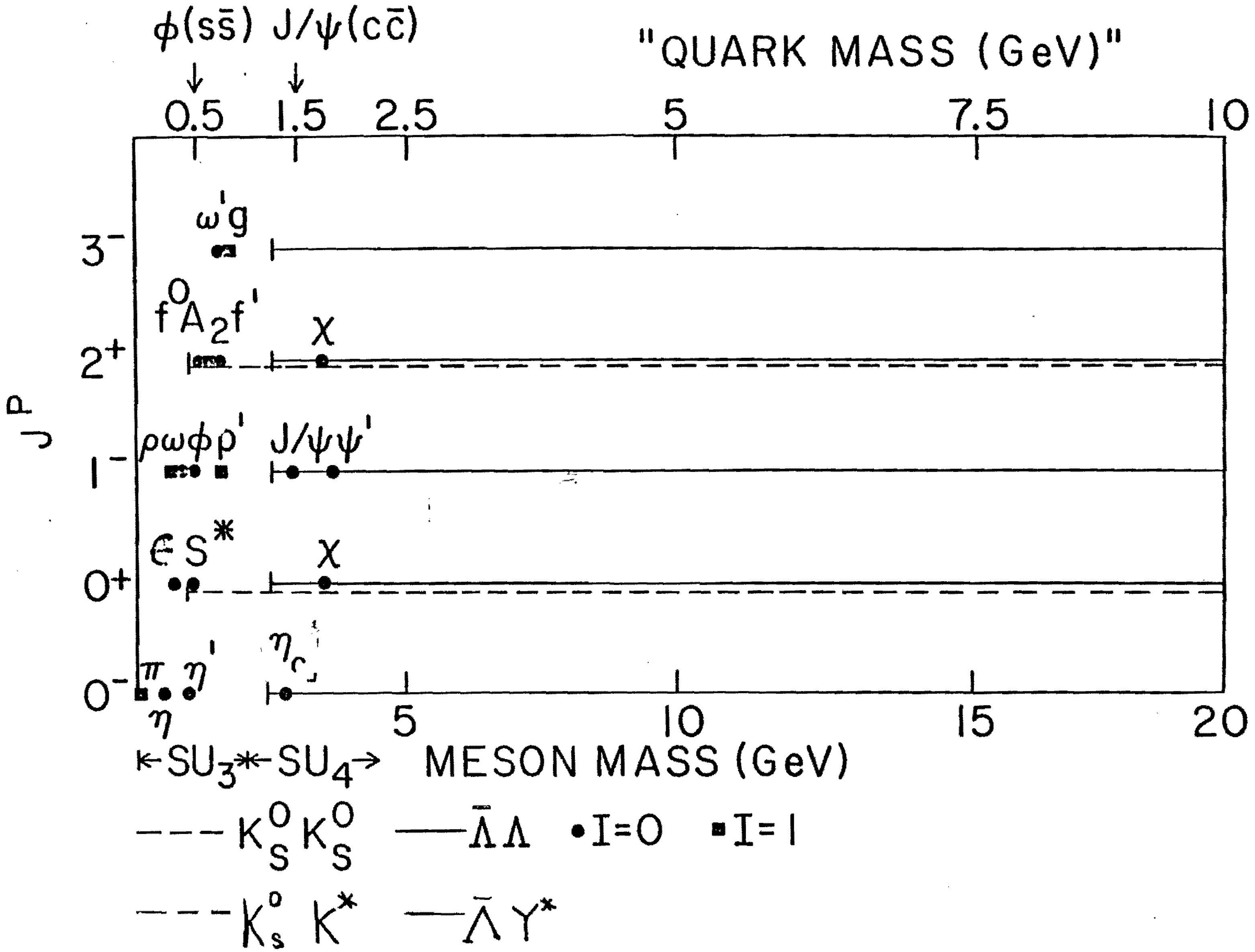
j) Operation of the Fermilab MPS: With the presently assigned Fermilab staff, two physicists and two technicians, we forsee no difficulty in operating the MPS for our experiment. Members of this collaboration with counter/track chamber experience are E. Jenkins, K. W. Lai, P. Yamin, J. A. Poirier, A. J. Segar, J. Marraffinno, C. Roos, M. S. Webster and J. Ficenec.

We plan to have enough individuals become "expert" in the operation of the MPS so that three such"experts" are available during all running periods of the experiment. Another three "partial experts" will also be available during all running periods. The remaining members of the collaboration will also participate in the data collection as required. Thos individuals responsible for the operation of the MPS plan to be trained by participating in the running of E110.

k) Software & Data Analysis. This collaboration possesses substantial software and data analysis expertise. We analyzed the tapes, wo we believe the analysis of data from this proposal will proced smoothly.

References

1. W. Beusch et al., Physics Letters 25B, 357 (1967); Physics Letters 28B, 211 (1968).
2. D. Bogert, et al., to be published in Phys. Rev. D (1977).



ϕ(ss̄) J/ψ(cc̄)
"QUARK MASS (GeV)"
0.5
1.5
2.5
5
7.5
10
J^P
3⁻
ω'g
2⁺
f^0 A_2 f'
χ
1⁻
ρωϕρ'
J/ψψ'
0⁺
ϵ S*
χ
0⁻
π η'
η
η_c
5
10
15
20
←SU_3→←SU_4→
MESON MASS (GeV)
--- K⁰_S K⁰_S
— Λ̄Λ
• I=0
▪ I=1
--- K⁰_s K*
— Λ̄Y*

Fig. 1

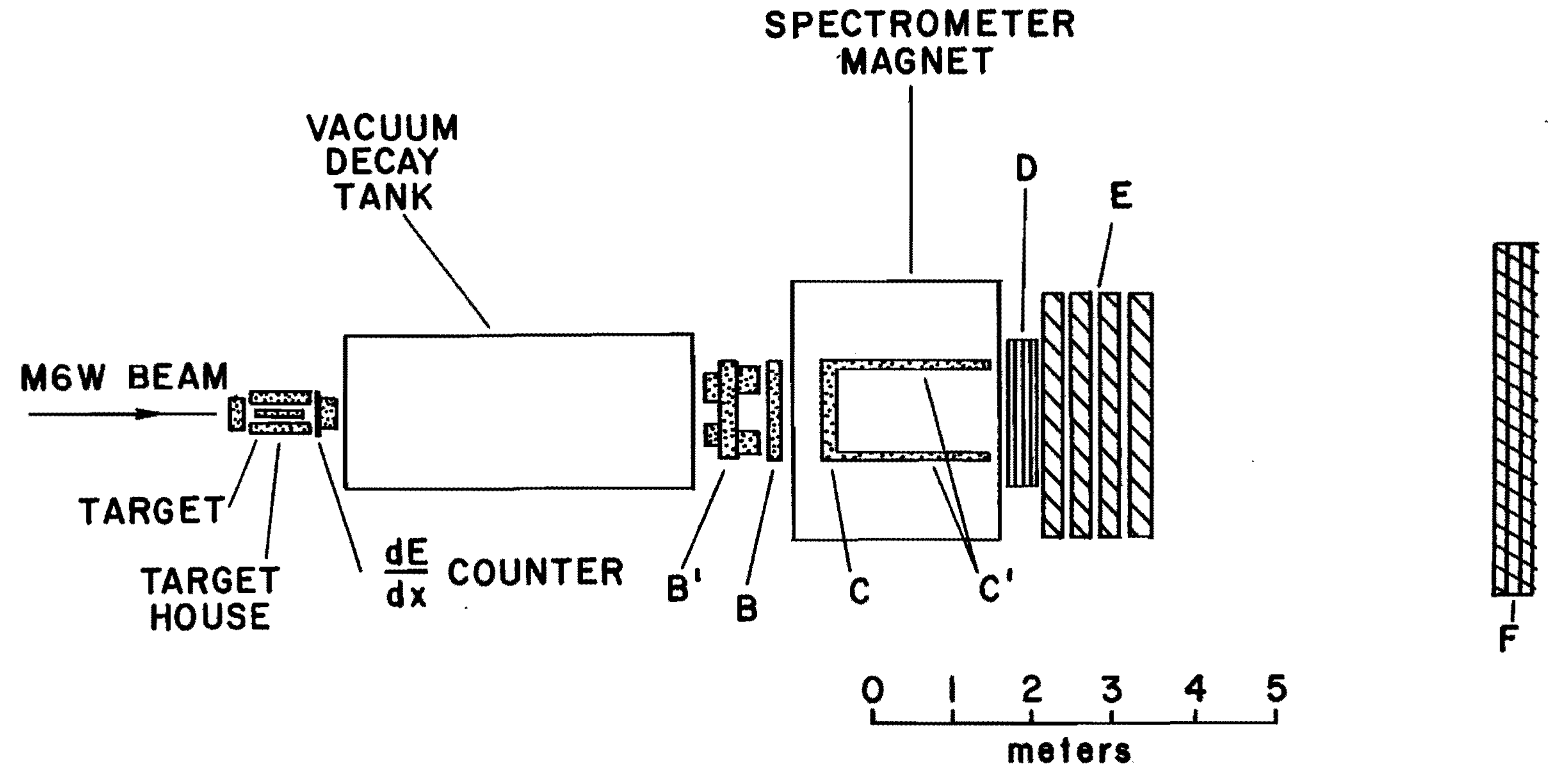
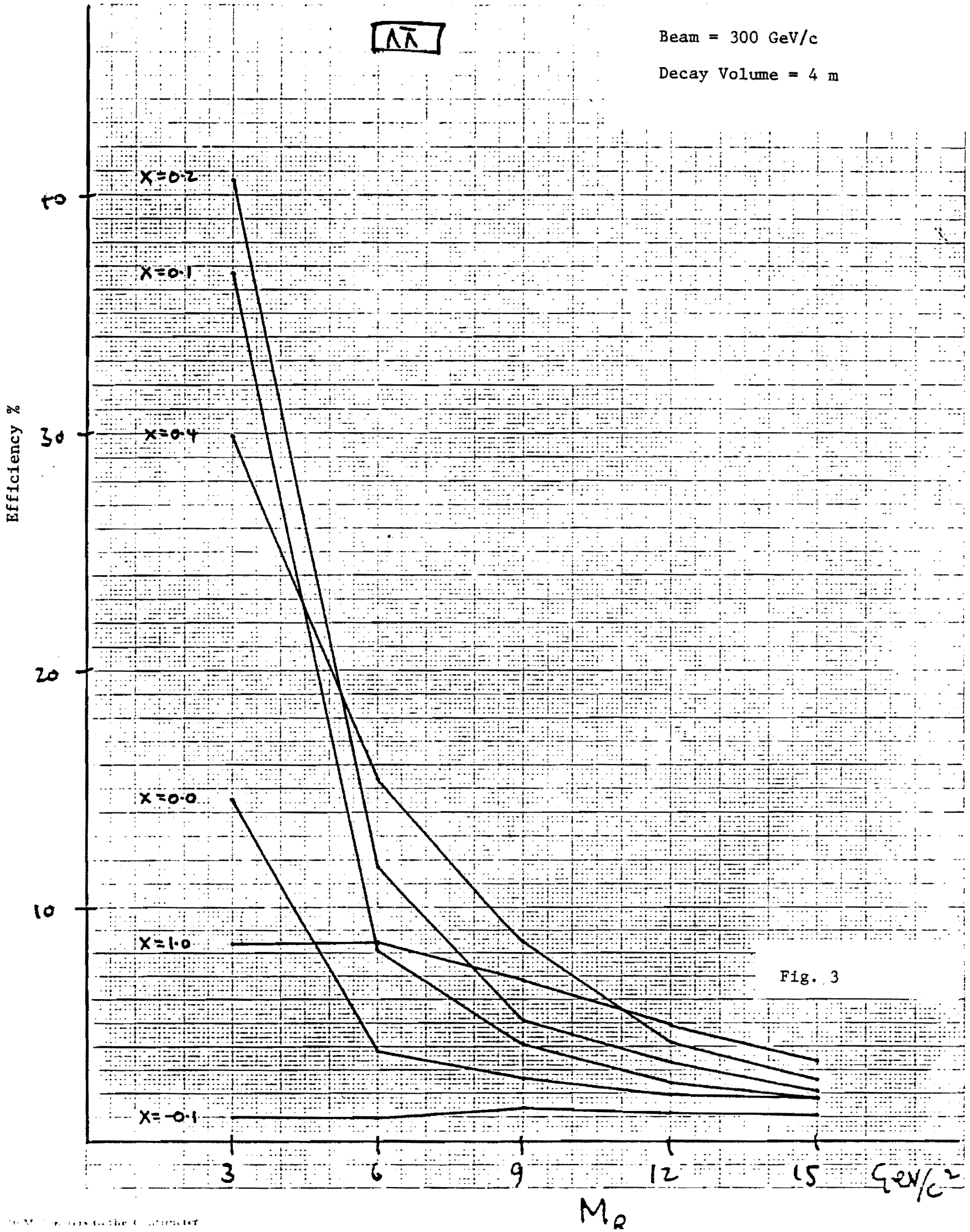

SPECTROMETER MAGNET
VACUUM DECAY TANK
D
E
M6W BEAM
TARGET
TARGET HOUSE
$\frac{dE}{dx}$ COUNTER
B'
B
C
C'
F
0
1
2
3
4
5
meters

Fig. 2



Beam = 300 GeV/c

Decay Volume = 4 m

Fig. 3

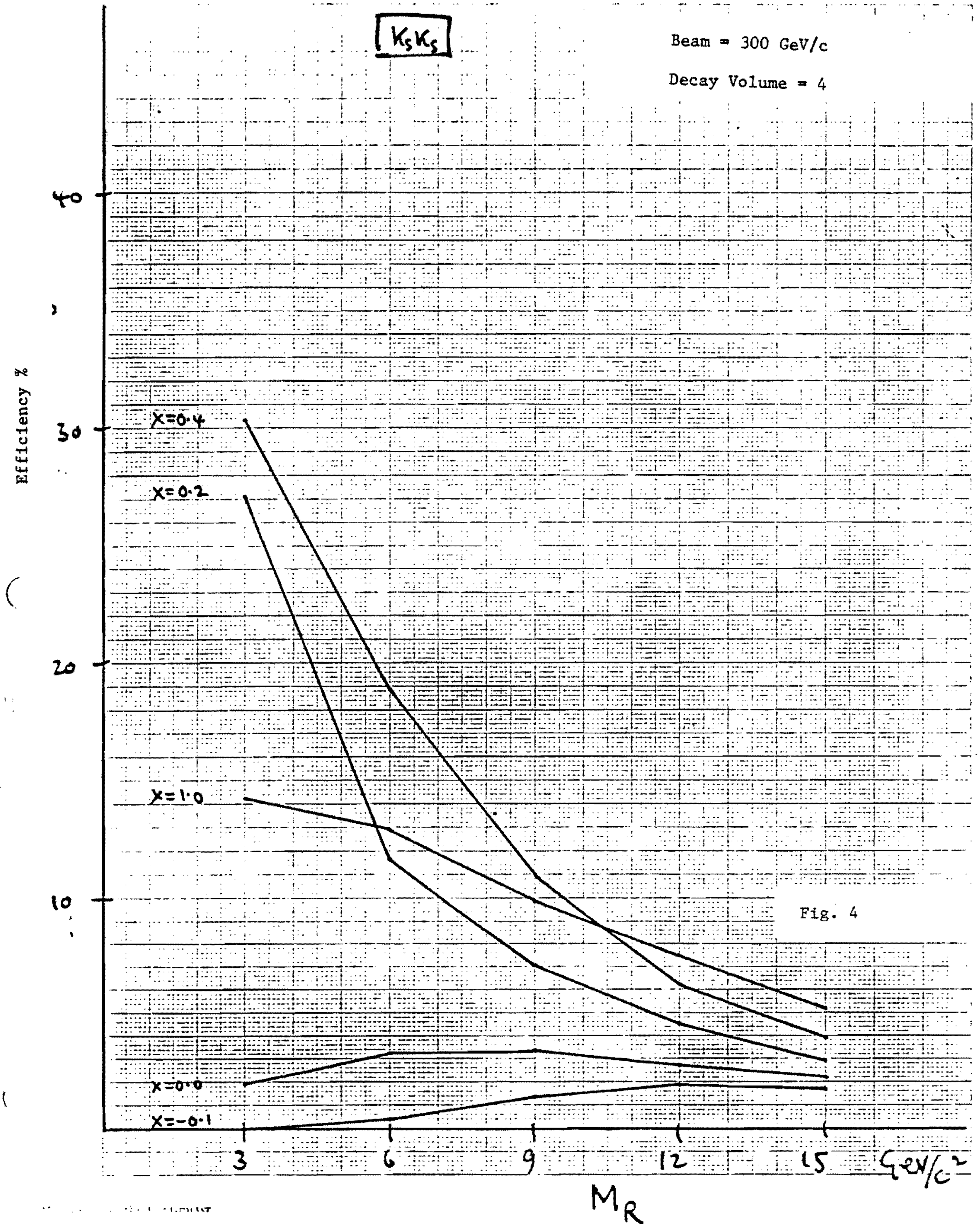
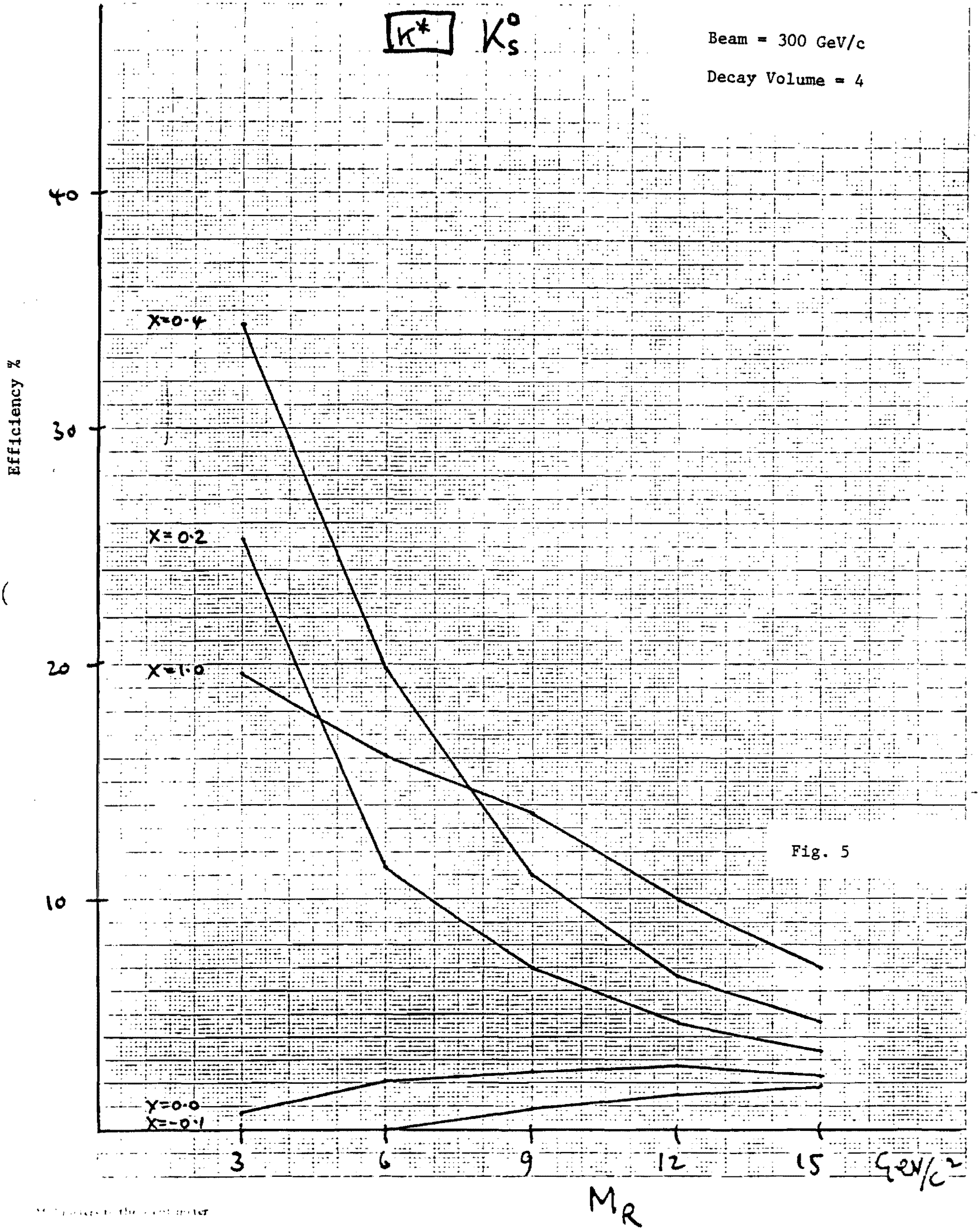

KsKs
Beam = 300 GeV/c
Decay Volume = 4
Efficiency %
40
30
20
10
X=0.4
X=0.2
X=1.0
X=0.0
X=-0.1
3
6
9
12
15
GeV/c²
M_R

Fig. 4



Beam = 300 GeV/c

Decay Volume = 4

Fig. 5

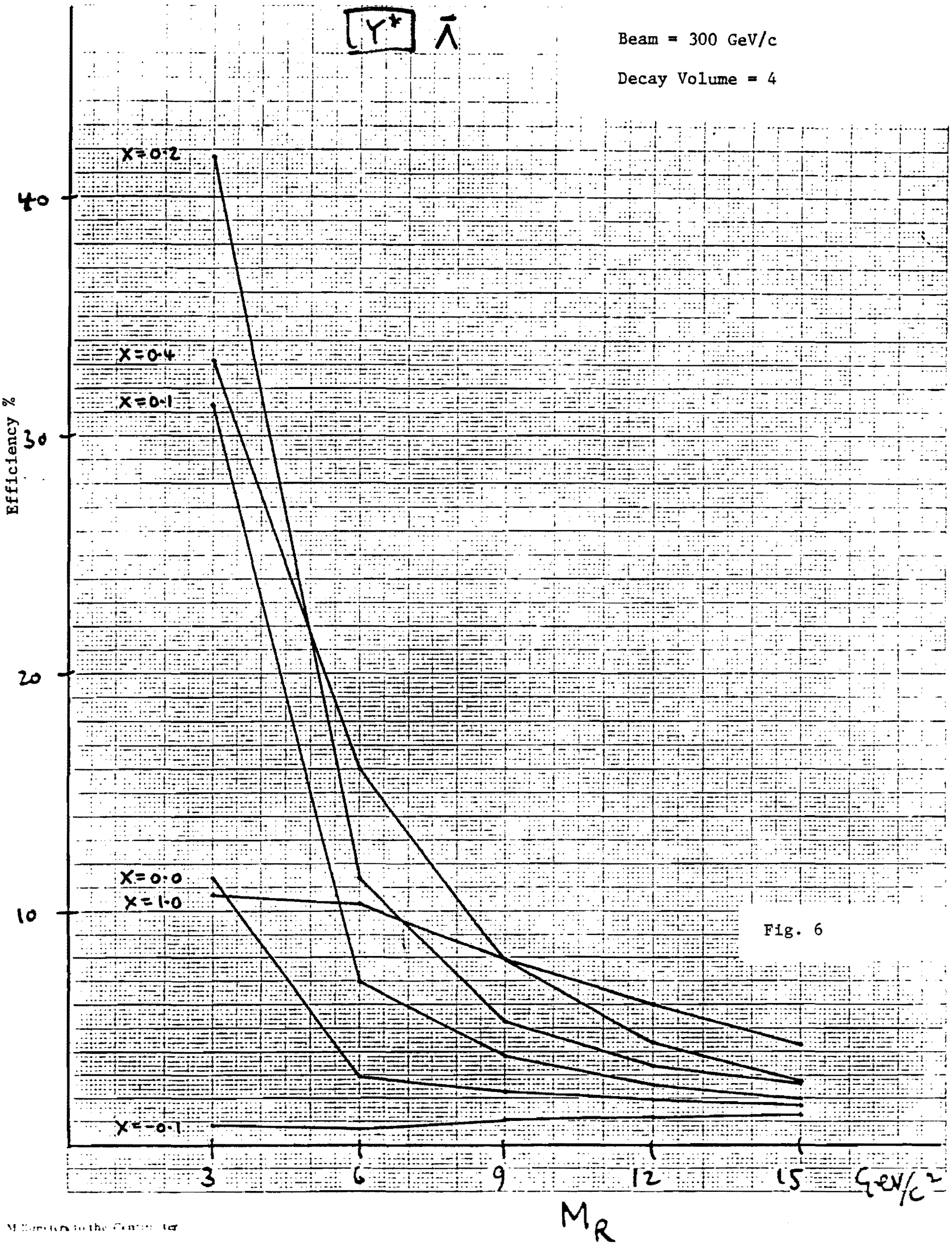

Y* Λ̄
Beam = 300 GeV/c
Decay Volume = 4
Efficiency %
40
30
20
10
X=0·2
X=0·4
X=0·1
X=0·0
X=1·0
X=-0·1
3
6
9
12
15
GeV/c²
M_R

Fig. 6

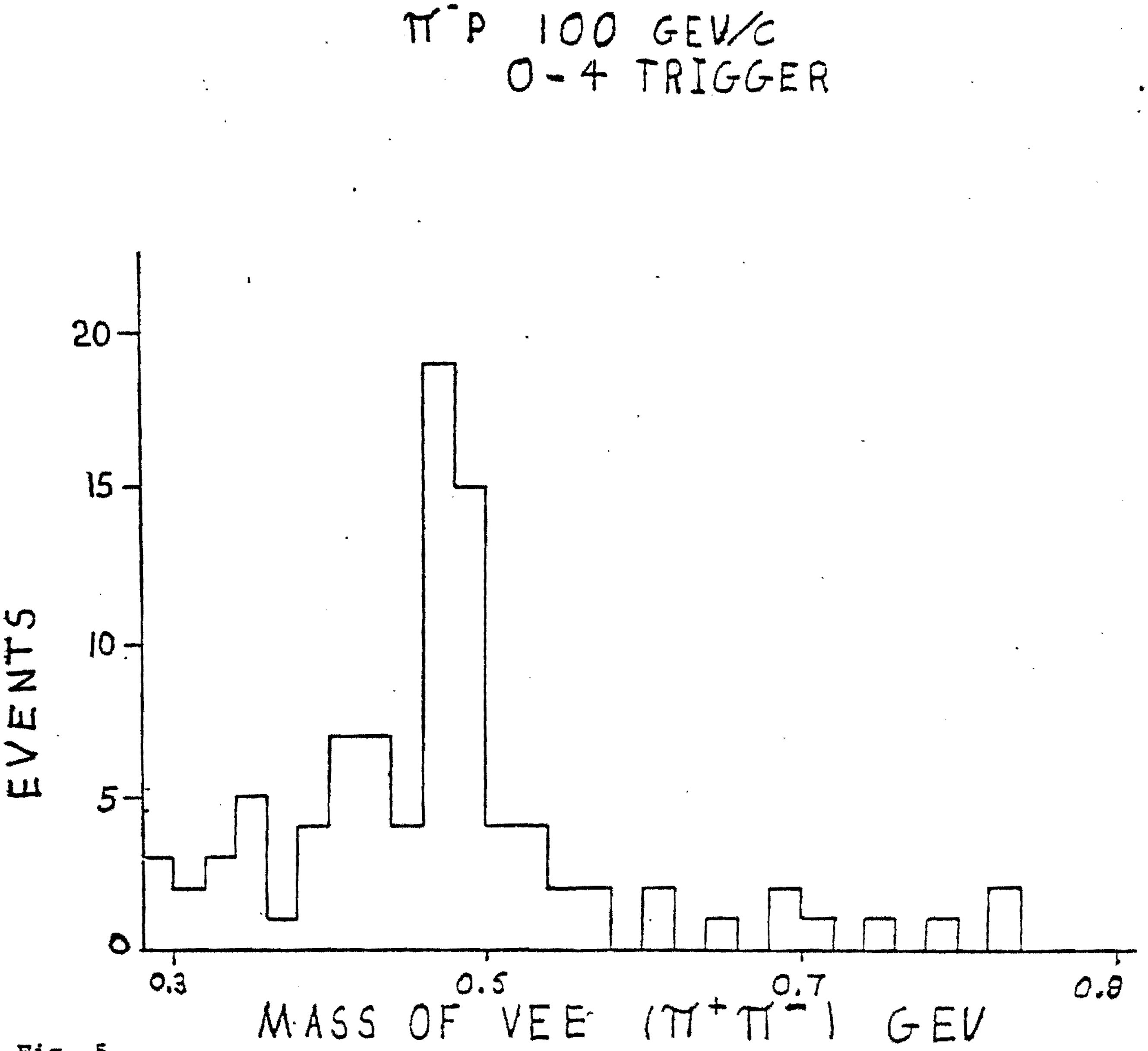

π⁻P 100 GEV/C
O-4 TRIGGER
EVENTS
20
15
10
5
0
0.3
0.5
0.7
0.8
MASS OF VEE (π⁺π⁻) GEV

Fig. 5

Fig. 7

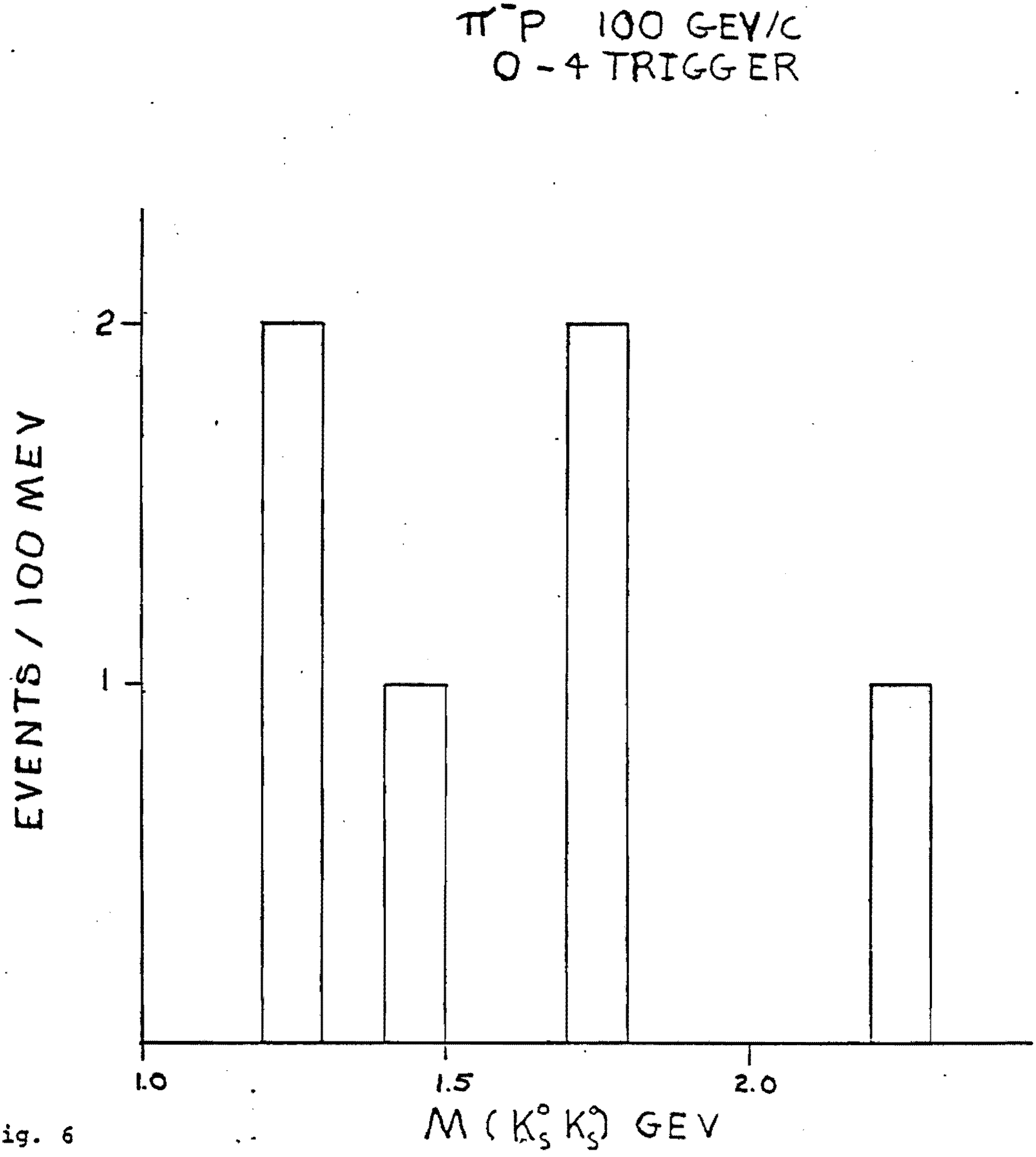
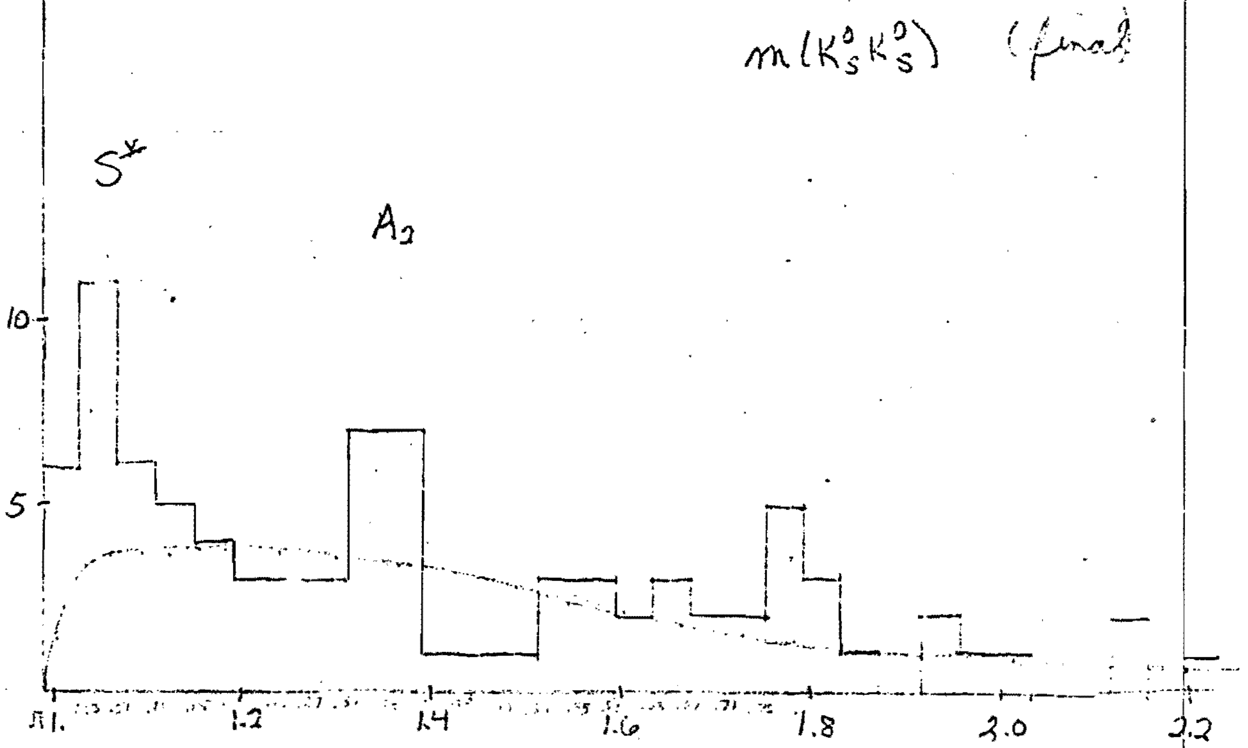


Fig. 6

Fig. 8



Mass (K°K°)

Fig. 9

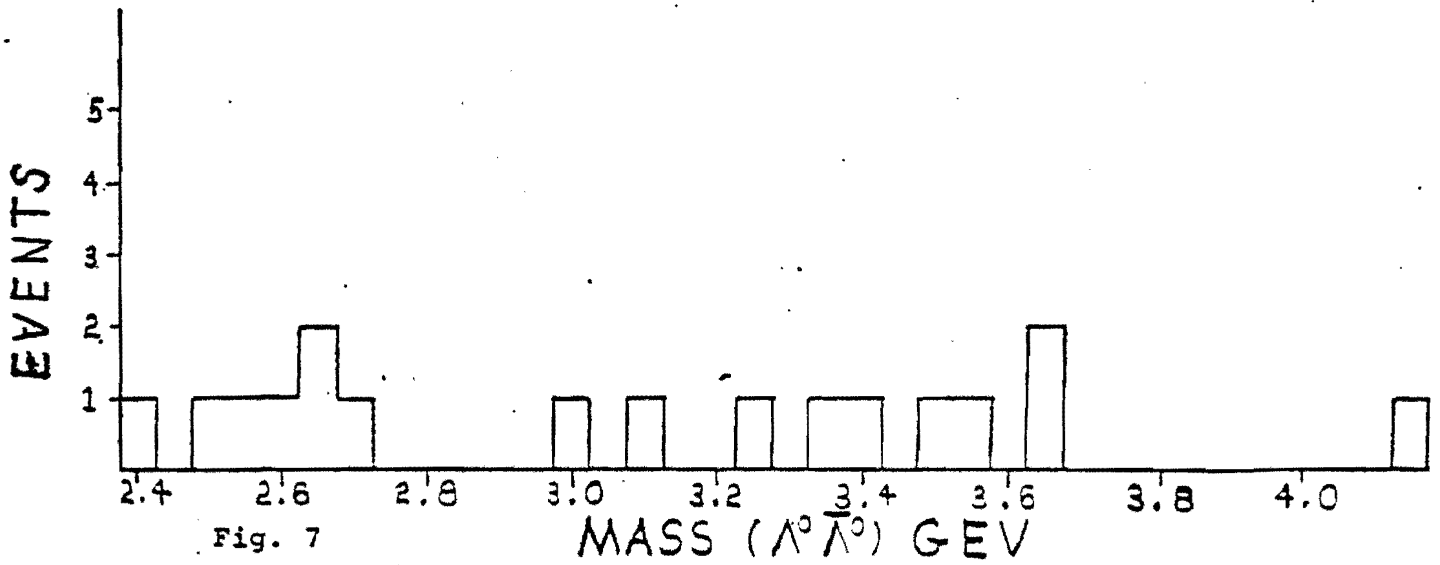
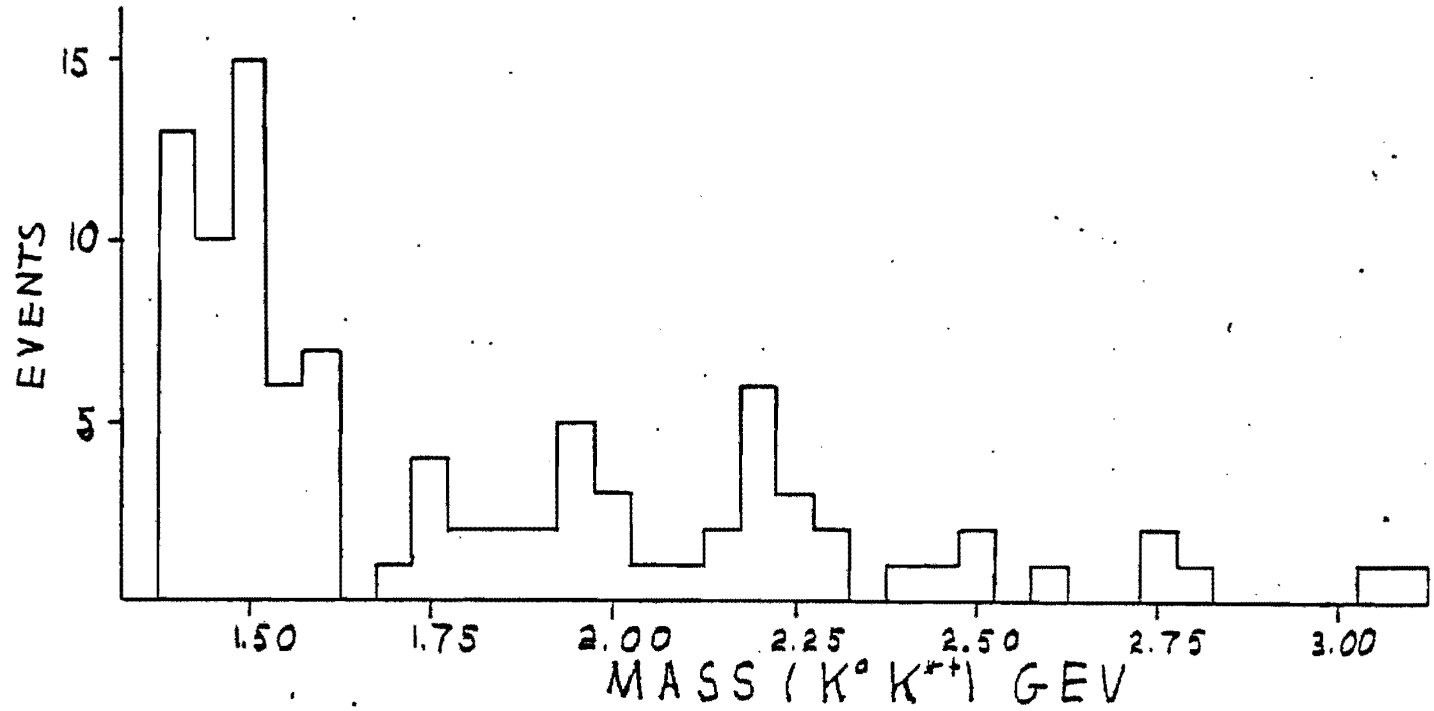

EVENTS
5
4
3
2
1
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
MASS ($\Lambda^0\bar{\Lambda}^0$) GEV

Fig. 7

Fig. 10

$\pi^- P$ 250 GEV/C



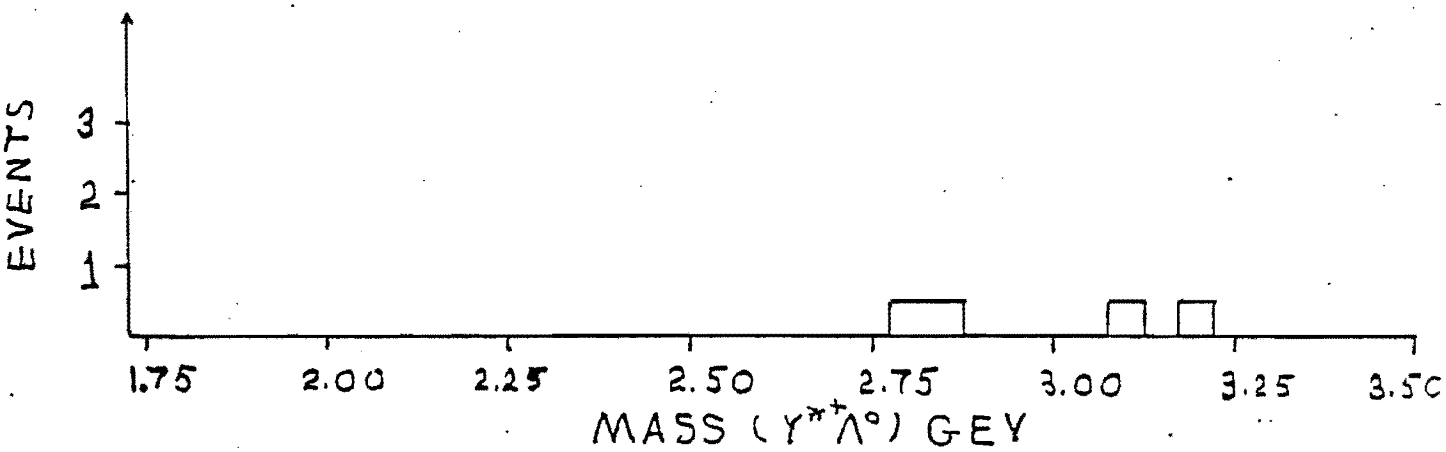


Fig. 9

Fig. 11