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Δ^{++} SPECTROSCOPY STUDIES AT THE ISR

(proposal)

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1. INTRODUCTION

In the Letter of Intent ISRC/71-45 (19 October 1971) an experiment to study Δ^{++} production processes at the ISR was suggested and the status of Δ^{++} phenomenology briefly reviewed. Although the proposed program to measure

$$pp \rightarrow \Delta^{++} + \text{anything} \qquad (1)$$
$$\Delta^{++} \hookrightarrow p\pi^{+}$$

was to initially use the split-field-magnet facility (SFM), it was also stated that "a later generation higher resolution experiment might consist of two fairly large septum magnets positioned on either side of a vacuum pipe downstream of an interaction region to detect π^{+} and proton, respectively".

In view of the existence of the septum magnet spectrometer constructed for experiment R602, it now seems more appropriate that the Δ^{++} experiment be first performed with the septum magnet system.

We thus propose to perform an experiment to detect reaction (1) for a period of 500 hours using the apparatus of experiment R602 as shown in Fig. 1 (modifications discussed in Section 3). With the present program of R602, our experiment would start late summer 1972. We emphasize that the measurements we propose are to be made with the existing equipment; only two relatively small gas threshold Cerenkov counters (to be built and furnished by UCLA) are to be added to the system.

To illustrate the nature of the proton - π^{+} system detected by a forward particle spectrometer at PS energies, we show in Fig. 2a the uncorrected $P\,\pi^{+}$ mass spectrum obtained in the recent CERN-Munich-UCLA experiment[1] at 17 GeV/c. Although the data shown are for the $\Delta^{++}n$ final state, alone, similar spectra are also obtained when more complex final states are observed (bubble chamber data). A point of interest is the strong similarity between this spectrum and the $\pi^{+}p$ elastic cross-section shown in Fig. 2b (see discussion in ISRC/71-45 and Section 2 and 5 of this document).

We note that with the proposed time scale, the results from our experiment will be of direct and immediate interest to the development of the physics program of the SFM facility.

2. JUSTIFICATION OF THE EXPERIMENT AND PHYSICS GOALS

We plan to measure the differential cross-section and density matrix elements vs. t for Δ^{++} production for the entire range of missing mass to the Δ^{++} and over the full range of possible circulating beam energies in the ISR. Such data will be extremely useful in determining for the first time the characteristice of Δ^{++} production at very high energies.

More precisely, our direct aim is to obtain accurate measurements of the quantity

$$\frac{d^4\sigma}{dt\ dM_x\ d\Omega_\Delta} \tag{2}$$

for $pp \rightarrow \Delta^{++}$ + everything (we use the symbol Δ^{++} to mean the $p\pi^+$ system of any mass), t is the momentum transfer to the Δ^{++} system, M_x is the mass of "everything" (or the missing mass) and $d\Omega_\Delta \equiv d(\cos\theta)d\phi$ refers to the angular distribution of the outgoing proton in the Δ^{++} rest frame. This differential cross-section will be obtained for a range of Δ^{++} mass up to at least $m_{\pi^+p} = 2.5$ GeV, and includes therefore the prominent, resonant states $\Delta(1238)$ and $\Delta(1920)$.

The kinematic ranges of the variables t and M_x accessible to us, are shown in Fig. 3 in which the conventional Chew-Low boundaries (t_{min} vs. missing mass) are drawn for several values of assumed M_Δ and ISR circulating momenta p_{circ}. It is seen, for example, that with $M_\Delta = 1236$ and 25+25 ISR energies, $|t_{min}|$ is less than m_π^2 for $M_x \lesssim 9$ GeV and increases to only ~ 0.3 GeV^2 when $M_x \approx 25$ GeV. At lower ISR energies, say 20 on 20 GeV, values of $|t_{min}|$ of m_π^2 and ~ 0.3 GeV^2 occur for $M_x \sim 7$ and 20 GeV, respectively.

The nature of the distributions in t and M_x that we may expect to obtain if ISR physics bears any similarity to the situation at conventional accelerator energies is shown in Fig. 4; this figure [2] shows the Chew-Low plots obtained at $p_{lab} = 6.6$ GeV/c ($\sqrt{s} = 3.6$ GeV) for several specific missing mass states ($pp \rightarrow \Delta^{++}\pi^- p$, $\Delta^{++} n \pi^+ \pi^-$, $\Delta^{++} p \pi^- \pi^0$, respectively). An intense enhancement is always seen at the smallest momentum transfers possible. Furthermore, as discussed in ISRC/71-45, it has been observed [2),3),4)], at $p_{lab} = 6.6$ and 28.5 GeV/c, that cross-section ratios for these (and other related) reactions are simply related to cross-section ratios for $\pi^- p$ interactions going to the same states "anything" for small t, viz. :

$$\frac{\sigma(pp \rightarrow \Delta^{++} X_i)}{\sigma(pp \rightarrow \Delta^{++} X_j)} \simeq \frac{\sigma(\pi^- p \rightarrow X_i)}{\sigma(\pi^- p \rightarrow X_j)}$$

for any states X_i and X_j but providing $M_{x_i} = M_{x_j}$.

It has, in addition [5)], been observed that the Chew-Low distribution shown in Fig. 4a when extrapolated to the pion exchange pole (at $t = -m_\pi^2$) yields the correct cross-section for $\pi^- p \rightarrow \pi^- p$ over the range of $\pi^- p$ energy observed.

These facts, and others [5),6)] having to do with $p\pi^+$ angular correlations, argue rather convincingly that one pion exchange plays the dominant role in Δ^{++} production at conventional accelerator energies. It will be interesting to see if this situation persists up to ISR energies. We discuss the cross-section implications for us in Section 5. Our data with $|t| < m_\pi^2$ will permit us to study <u>for the first time</u> the low t structure of reaction (1) in a t region in which a strong coupling of one-pion-exchange to the $\Delta(1238)$ would produce a sharp forward spike in $d\sigma/dt$ due to the extreme proximity of the pion pole [7)] at $(t = +m_\pi^2)$. It should also be remarked that OPE dominance would also imply that the data on $d^2\sigma/dtdM_x$, when extrapolated to the pion pole in t (at fixed M_x), will permit us to measure the $\pi^- p$ total cross-section up to considerably higher energies than presently existing from direct measurements at Serpukhov.

More generally, data on $d\sigma/dt$ for any reaction $pp \rightarrow a+b$ over a large range of s permits one to determine the effective Regge trajectory for the process (as, for example, the ρ trajectory is determined by using data on $\pi^- p \rightarrow \pi^0 n$). Thus, we will be in a position to determine the effective trajectories which couple $\Delta(1238)$ and $\Delta(1920)$ (as well as the $\pi^+ p$ continuum lying between) to M_x for a very large range of M_x and over a range of s never before used in such analyses.

3. MODIFICATIONS TO EXISTING SPECTROMETER

The existing septum magnet spectrometer has one magnet underneath one outgoing arm in I-6 (call it the "down-magnet") and a second magnet (call it the "up-magnet") soon to be installed on top of the other outgoing arm at I-6. After the completion of experiment R602, we propose to move the "up-magnet" and reposition it on top of the "down-magnet", so that the two magnets sandwich the vacuum pipe between them, as shown in the side-view of this arm in Fig. 1. In order that the two magnets fit together as closely as possible, new magnet-end-shields will have to be made and a new septum plate fabricated. We estimate that this modification will take about one month and will cost about 50,000.- francs.(to be paid for by UCLA).

The only new equipment necessary will be two rather small ($\sim 0.6 \times 0.8 \times 2.0$ m^3) atmospheric pressure gas threshold Cerenkov counters, to be positioned in each magnet downstream of the wire chamber pack currently at the centre of each magnet. These Cerenkov counters will be constructed and supplied by the UCLA group.

With these modifications, we will have a large aperture (80×140 cm^2) forward particle magnetic spectrometer. The vacuum pipe and septum plate cause a "dead space" of dimension 80×7 cm^2 which, as shown below in the acceptance discussion (Section 4), causes no great difficulties.

4. ACCEPTANCE

Acceptance calculations have been completed for the spectrometer configuration shown in Fig. 1, as well as for a shorter configuration (distance from interaction to magnet centre of 450 cm).

For specific points in the Chew-Low plot of Fig. 3 and for specific ISR circulating momenta, Monte-Carlo Δ^{++} events have been generated with isotropic decay angular distributions in the Δ^{++} rest frame. Figure 5 shows the dependence of the efficiency on the cos of the t channel helicity (Gottfried-Jackson) angle Θ for several kinematic conditions.

The configuration of Fig. 1 is approximately optimized for Δ (1238) in that the loss of slow π^+ not entering the magnet aperture is comparable to the loss of fast small angle protons not leaving the vacuum pipe or striking the septum plate. For Δ (1940), an improved situation is achieved with a shorter configuration as illustrated by the dashed curves in Fig. 5.

Though a loss of $\cos\Theta \approx +1$ events (forward protons) is unavoidable near t_{min}, it is seen that this situation improves considerably away from the forward direction. In all cases, the over-all efficiency is quite acceptable (~50 %).

Experience with the CERN-Munich forward particle spectrometer [1,8,9] has shown that data obtained under such acceptance conditions can be reconstructed to give the actual physical distributions.

5. RATES

We have estimated the cross-sections for reaction (1) at ISR energies by assuming that Δ^{++} production has the same phenomenological behaviour as at PS energies. (Results from our experiment either confirming or disproving this assumption will be most interesting).

As has been demonstrated by Wolf [6] and Colton et al. [5], Δ^{++} differential cross-sections are rather well described in both absolute magnitude and shape by the Chew-Low equation for one-pion exchange. We have used the known π^+p elastic cross-sections at the Δ^{++} vertex and π^-p total cross-sections at the M_x vertex (assuming that $\sigma^{TOTAL}_{\pi^-p}$ remains equal to the Serpukhov value at even higher energies). The triple differential cross-section $d\sigma/dtdM_\Delta\, dM_x$, given by the Chew-Low equation, is integrated over a specified M_Δ range and up to a certain maximum momentum transfer t_{max} and over the entire accessible range of M_x.

For a $\Delta(1238)$ selection of 1.08–1.4 GeV, we find σ(reaction 1) $\approx$ 2 mbarn for $t_{max} = 0.3\ GeV^2$ and $p = 25\times25$ GeV/c (the same cross-section but for $t_{max} = 0.02\ GeV^2$ is 0.03 mbarn); these results are only very weakly dependent on ISR energies from 10×10 to 26×26 GeV.

With the present ISR luminosity ($\mathcal{L} \approx 10^{29}\ cm^{-2}\ sec^{-1}$) and taking into account our average acceptance and the fact that only $\frac{1}{2}$ of Δ^{++} production is along our spectrometer arm, we expect a total $\Delta^{++}(1238)$ event rate of ~20 events/sec (for $t < 0.02\ GeV^2$ we find ~3 events/sec).

For those readers who are surprised to find such large cross-sections for a one-pion exchange process, we note that the well-known P^{-2} behaviour holds only for fixed vertex masses. Summing the cross-section over all available final states and mass range at one vertex, introduces phase space factors which tend to cancel the P^{-2} drop-off [5].

We have calculated in a similar way the cross-section for production of reaction (1) in the $\Delta(1920)$ region (1.6–2.2 GeV) and find $\sigma \approx 0.8$ mb, which with our acceptance leads to an event rate perhaps a factor of 5 to 10 less than the $\Delta(1238)$ rate.

6. Missing Mass Resolution

Since the septum magnet spectrometer will measure the Δ^{++} momentum to ±0.5 %, the principal error in the missing mass M_x comes from the spread in circulating beam momentum. Before looking at the actual values of the resolution, we note, as in ISRC/71-45, that since we are not searching for structure in the M_x variable (there is not likely to be any for M_x > 2-3 Gev), we have no stringent requirements on this resolution. Thus, $\delta M_x \simeq$ 1-2 Gev would be adequate for our purposes.

The missing mass uncertainty is calculated to be ±2.6, ±1.3, and ±0.7 Gev at M_x = 5,10, and 20 Gev, respectively for $\delta p/p = \pm 1\%$ in the circulating beam. Thus, with the ISR design luminosity of $\mathcal{L} = 4 \times 10^{30}$ $cm^{-2}sec^{-1}$ and the corresponding momentum dispersion of ± 1 %, we would have acceptable resolution for, say, M_x > 8 Gev. To study smaller M_x, we would like to run under luminosity conditions approximating those currently existing at the ISR (10^{29}) where $\delta p/p \simeq \pm 0.3\%$.

7, Trigger

To protect against beam-gas collisions an inclusive detector will be installed on the other outgoing arm of I-6. This detector will also be useful to help identify specific reactions of type (1), especially for small missing masses M_x and low multiplicity. For instance, the complete dynamics of the reaction $pp \rightarrow p\pi^+ p\pi^-$ can thus be checked. Similarly a neutron detector in the same arm would allow to identify the channel $pp \rightarrow p\pi^+ n$.

This inclusive detector would be in coincidence with 2 large counters placed in front of the magnet-apertures. In a first stage, at least one particle would be required in each of these counters, a trigger which experience has shown to select about 1/4 of the total pp-cross section and which obviously does not add any bias, (for instance against particles from the M_X system which in some cases may go through the magnet). Thus about 1/20 of the triggers are expected to be due to reaction (1) yielding, with a data acquisition rate of $\sim$ 50 events/sec, a few Δ^{++} events per second. This situation could might be improved with a more selective trigger, after some experience is gained with the "loose" trigger described here.

Assuming total time of 500 hours of which 300 would be for data-taking and a rate of 1 useful event/sec, about 10^6 examples of reaction (1) could be collected. Such a high number is necessary in view of the large range of variables ($M_{p\pi^+}$, M_X, t) which is spanned by the experimental set-up.

REFERENCES

1. G. Grayer, B. Hyams, C. Jones, W. Blum, H. Dietl, W. Koch, E. Lorenz, G. Lütjens, W. Männer, J. Meissburger, W. Ochs, U. Stierlin, P. Weilhammer, W. Hoogland and P. Schlein (to be published)
2. Eugene Colton, Peter E. Schlein, Eugene Gellert and Gerald A. Smith, Phys. Rev. Letters 21, 1548 (1968)
3. Eugene Colton, Peter E. Schlein, Z. Ming Ma, R. Sprafka and Gerald A. Smith, Phys. Rev D2, 2108 (1970)
4. W. E. Ellis et al., Phys. Rev. Letters 32B, 140 (1970)
5. Eugene Colton, Peter E. Schlein, Eugene Gellert and Gerald A. Smith, Phys. Rev. D3, 1063 (1971) and Proceedings of the XIV International Conference on High Energy Physics, Vienna (July 1968), pp. 157, 159.
6. G. Wolf, Phys. Rev. Letters 19, 925 (1967) and Phys. Rev. 182, 1538 (1969)
7. Geoffry Fox, Proceedings of Caltech Phenomenology Conference, (March 1971) and notes on one-pion-exchange for symposium at Argonne National Laboratory (1971). Fox stresses the importance of studying Δ^{++} production processes at very high energies in order that t_{min} is close to zero and hence to the pion pole and thus that non-pion exchange processes can be neglected.
8. G. Grayer et al., Phys. Letters 34B, 333 (1971)
9. G. Grayer et al., Phys. Letters 35B, 610 (1971)

FIGURE CAPTIONS

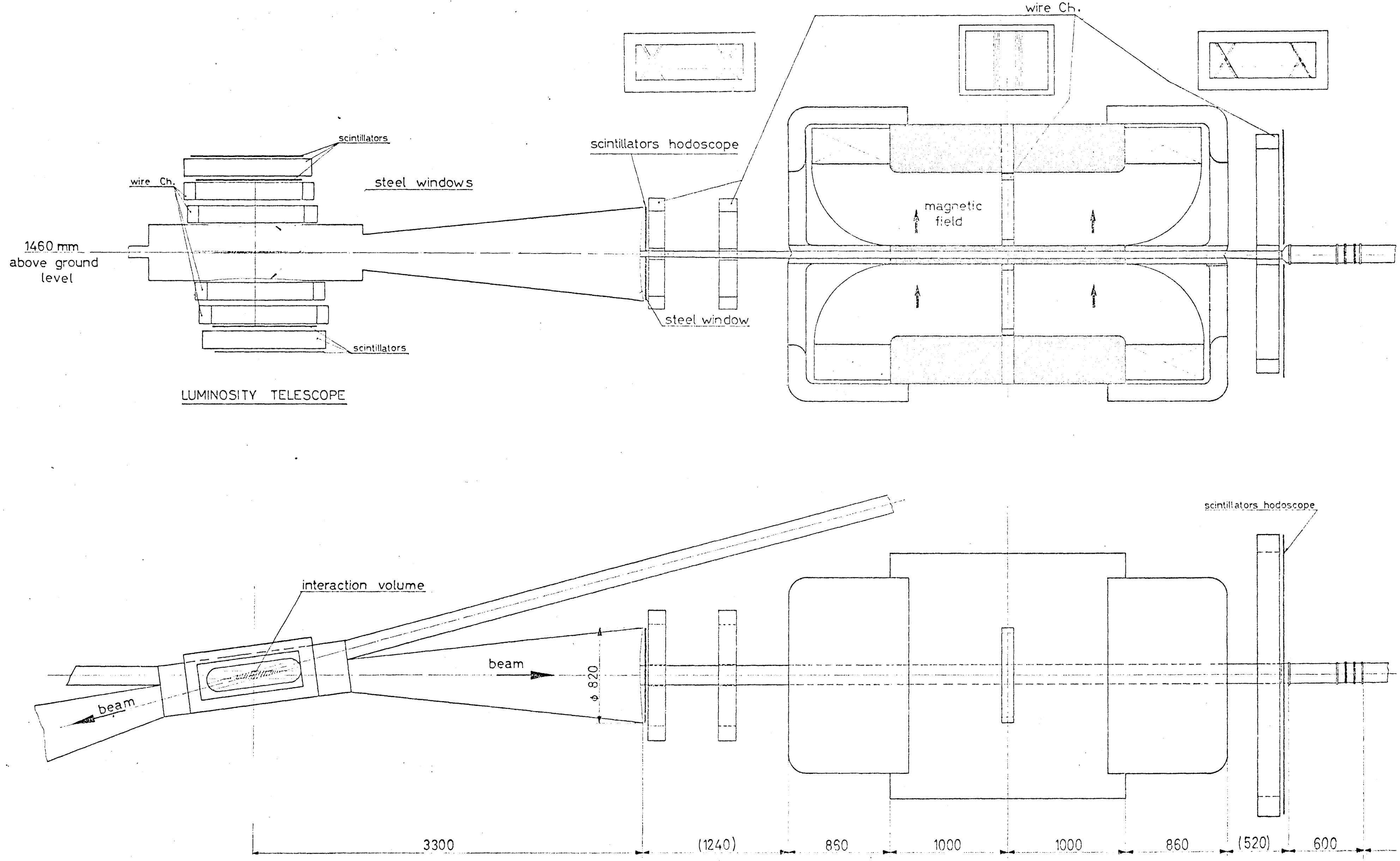
Fig. 1. Side and top view of spectrometer layout proposed for this experiment. Neither the Cerenkov counters in the downstream end of each magnet nor the telescope in the other arm are shown.

Fig. 2. (a) Uncorrected π^+p mass spectrum obtained at 17.2 Gev/c by a CERN-Munich-UCLA collaboration[1)] in the reaction $\pi^+p \rightarrow \Delta^{++}n$. (b) The π^+p elastic cross section from the compilation by Giacomelli et al.

Fig. 3. Minimum momentum transfer vs. missing mass M_X (Chew-Low boundary) for the reaction $pp \rightarrow \Delta^{++} + M_X$ at ISR circulating proton momenta of 25 + 25 and 15 + 15, respectively.

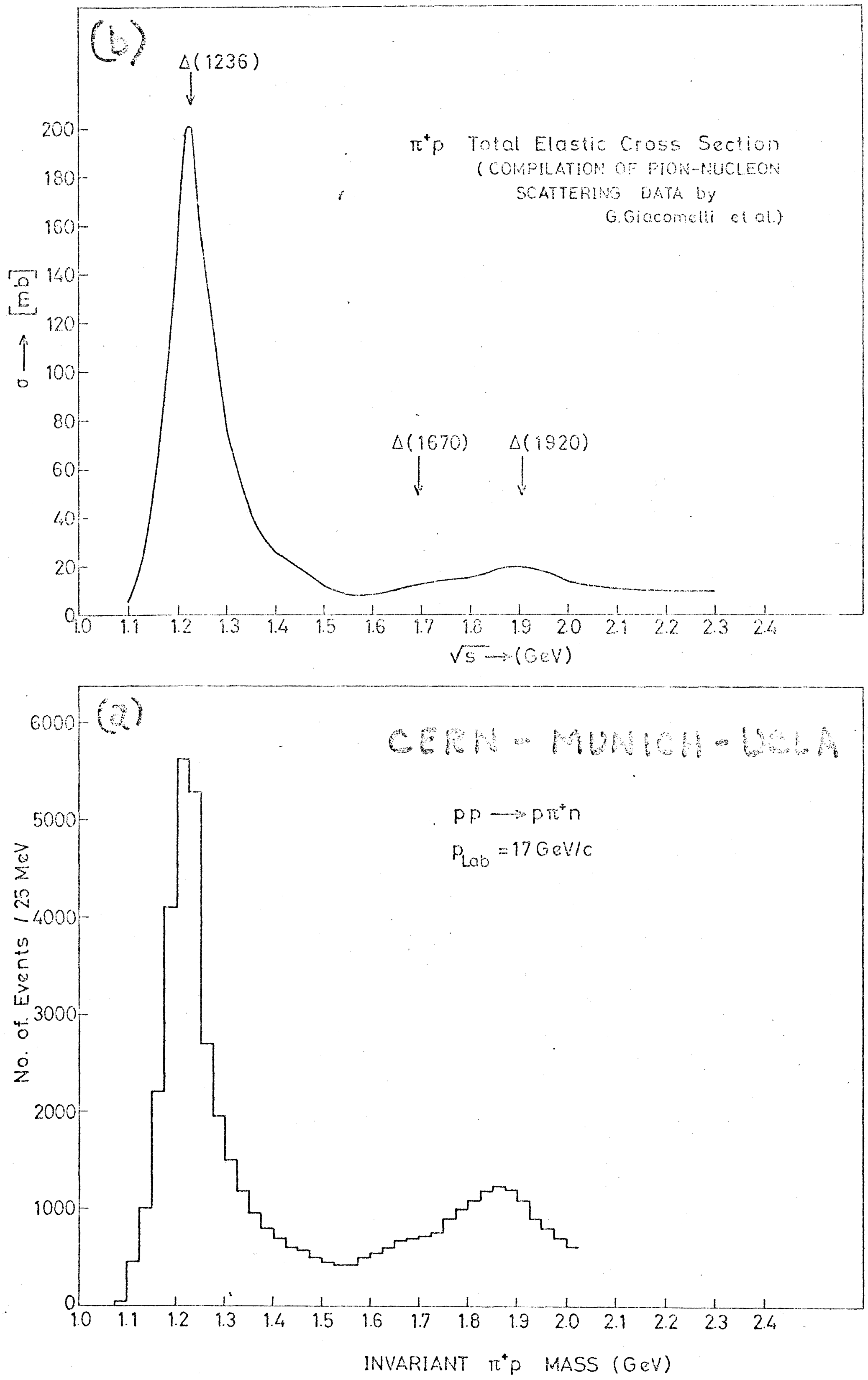
Fig. 4. Chew-Low distributions obtained at 6.6 Gev/c by Colton et al.[2)]. for the indicated reactions of the type $pp \rightarrow \Delta^{++}M_X$.

Fig. 5. Monte-Carlo calculated spectrometer acceptance for the indicated conditions vs. cosine of the Gottfried-Jackson angle in the Δ^{++} rest frame. See discussion in the text.

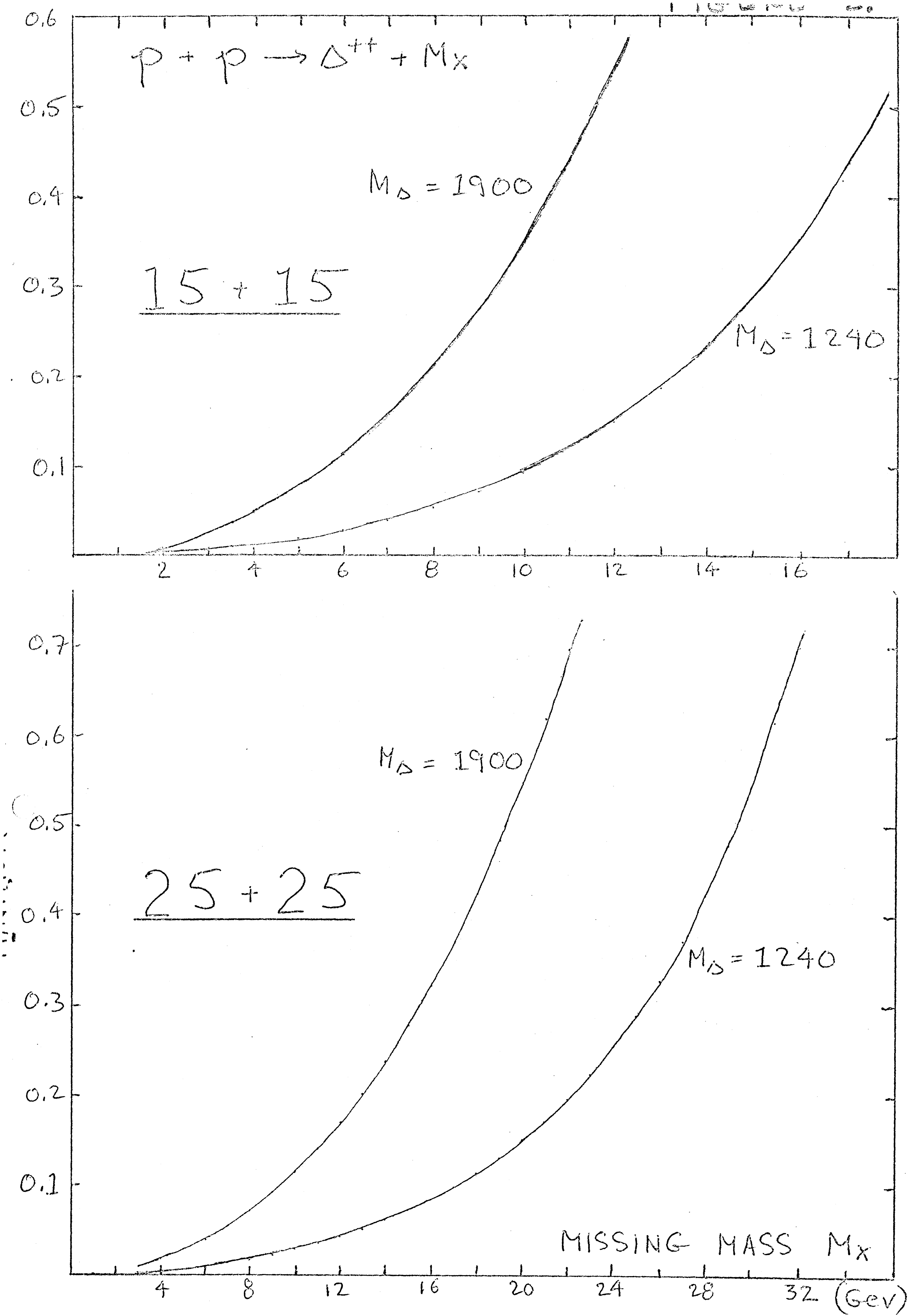


wire Ch.
scintillators
wire Ch.
steel windows
scintillators hodoscope
magnetic field
1460 mm above ground level
steel window
scintillators
LUMINOSITY TELESCOPE
scintillators hodoscope
interaction volume
beam
φ 820
beam
3300
(1240)
860
1000
1000
860
(520)
600

FIGURE 2.



(b)
Δ(1236)
π⁺p Total Elastic Cross Section
(COMPILATION OF PION-NUCLEON SCATTERING DATA by G. Giacomelli et al.)
Δ(1670)
Δ(1920)
σ ⟶ [mb]
0
20
40
60
80
100
120
140
160
180
200
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4
√s ⟶ (GeV)
(a)
CERN - MUNICH - UCLA
pp ⟶ pπ⁺n
P_Lab = 17 GeV/c
No. of Events / 25 MeV
0
1000
2000
3000
4000
5000
6000
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4
INVARIANT π⁺p MASS (GeV)



$p + p \to \Delta^{++} + M_x$
15 + 15
$M_\Delta = 1900$
$M_\Delta = 1240$
0.1
0.2
0.3
0.4
0.5
0.6
2
4
6
8
10
12
14
16
25 + 25
$M_\Delta = 1900$
$M_\Delta = 1240$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
MISSING MASS M_x
4
8
12
16
20
24
28
32
(Gev)

FIGURE 4.

P_{LAB} = 6.6 GeV/c Colton et al.

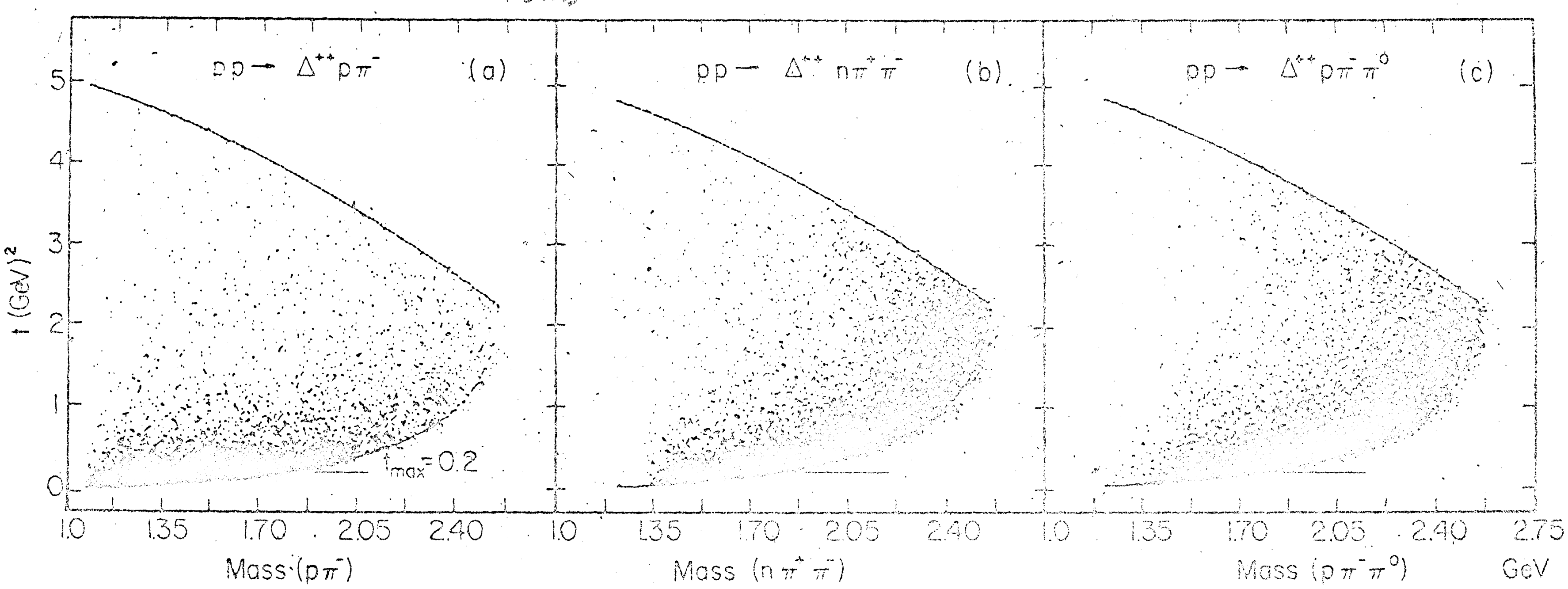
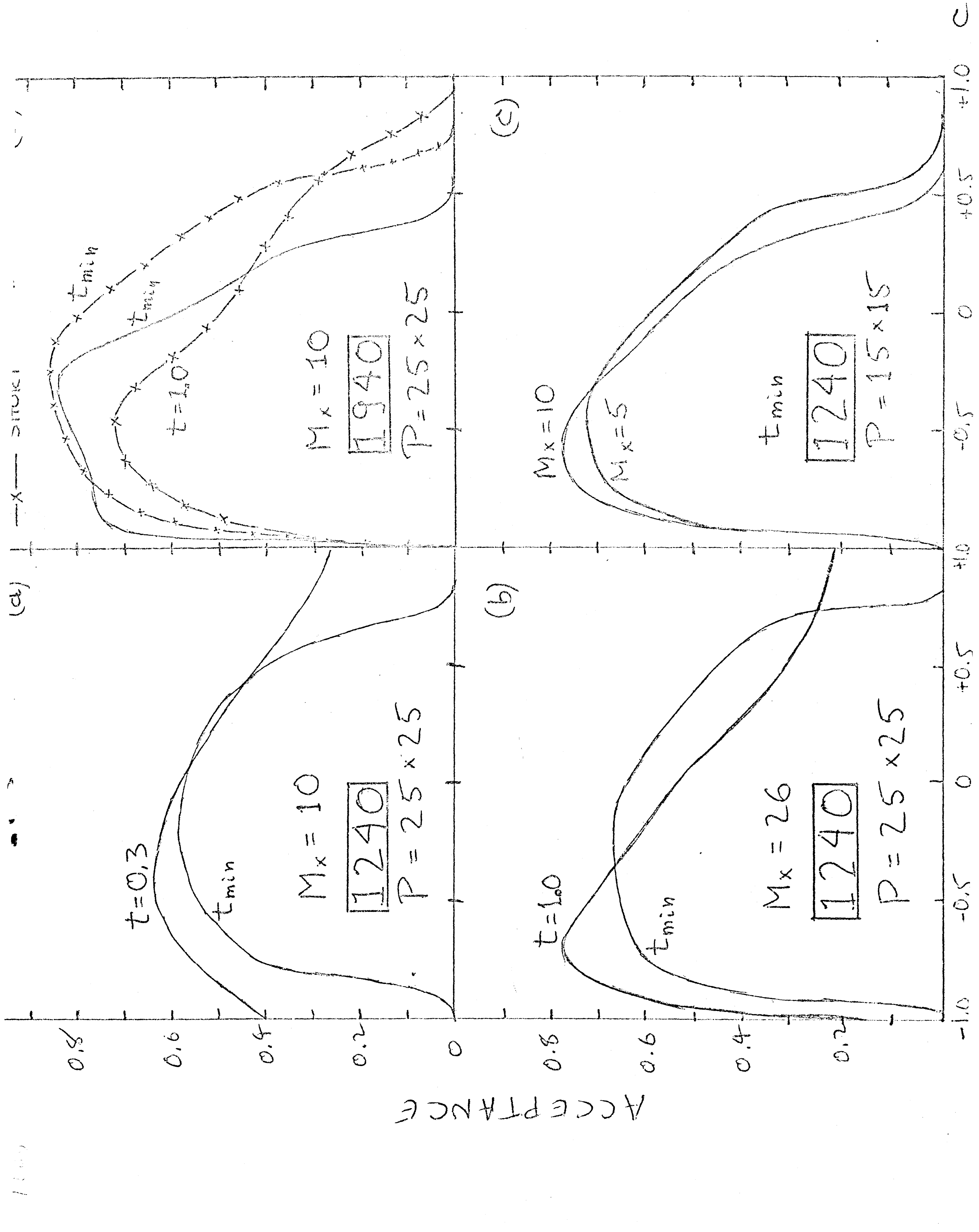


FIGURE 5.



(a)
(b)
(c)
t=0.3
t_{min}
$M_x = 10$
1240
P = 25×25
t=1.0
$M_x = 26$
1940
$M_x = 5$
P = 15×15
ACCEPTANCE
cos $\theta_{t\text{-}chan}$
0.8
0.6
0.4
0.2
0
-1.0
-0.5
+0.5
+1.0