NAL PROPOSAL No. 18

Correspondent: G. K. O'Neill
Physics Department
Princeton University
Princeton, New Jersey
08540

FTS/Off-net 609-599-3511
452-4400

# PROPOSAL TO STUDY THE REACTIONS

$$p + p \rightarrow p + (p + \pi^+ + \pi^-)$$

$$p + (n + \pi^+)$$

At 200 And 500 GeV

W. W. Ash, D. C. Cheng, D. Coyne, G. K. O'Neill
Princeton University

G. Goggi, D. Scannicchio
Universita de Pavia

June 10, 1970

# PROPOSAL TO STUDY THE REACTIONS

$$p + p \rightarrow p + (p + \pi^+ + \pi^-)$$

$$p + (n + \pi^+)$$

# AT 200 AND 500 GeV.

(Princeton-Pavia Collaboration)

June 10, 1970

ABSTRACT: We would like to study isobar formation at 200-500 GeV in the moderate t-range (-0.1>t>-0.4), concentrating on the modes ($p\pi^+\pi^-$) and ($n\pi^+$). These isobar decay modes have such strong signatures that every event will be fully reconstructed with at least a 1C fit even without momentum analysis. Existing evidence is that these modes are either dominant or very strong in the cases of several known isobars.

Logistically, our experiment is designed to be suitable for the initial phase of operation of the NAL accelerator. We require only a diffraction-scattered proton beam. The apparatus required is small, simple, and compact enough to be located in the machine tunnel. We do not require a magnet or any rigging, and at least the first results can be obtained with a polyethylene target. The data rate should be very high, and the information gained should be very informative on possible microstructure in the baryon mass spectrum, on the interaction properties of the Pomeron, and on the possible utility of the double-Regge model and the Veneziano four-point function.

A 28.5 GeV run of this experiment has been approved as experiment #533 at the AGS, and will take place during October '70-May -71. That run will test <u>all</u> of the <u>same</u> apparatus needed for the N.A.L. experiment.

Members of the collaboration (including faculty and research staff only):

Princeton University:

W. W. Ash

D. C. Cheng

D. Coyne

G. K. O'Neill

Universita di Pavia:

G. Goggi

D. Scannicchio

Correspondent: G. K. O'Neill

(alt. D. C. Cheng)

I. The aims of our experiment are to study the reactions

$$p + p \rightarrow p + (p + \pi^+ + \pi^-)$$
$$p + (n + \pi^+)$$

where the brackets () mean a combination having a low-invariant-mass $M_I$. The experimental conditions are to include

a) Full reconstruction of every recorded event of these types, including the polar angle in the isobar rest frame, the Treiman-Yang angle, and the Toller angle.

b) Statistics equal to or better than those of missing-mass spectrometers: nominally $10^6$ resonance-peak events/50 hours.

c) A resolution better than ±20 MeV in isobar mass $M_I$ in kinematically favorable regions.

d) Simultaneous coverage of all isobar masses from 1200-5000 MeV/$c^2$.

e) Small overall size for the apparatus.

f) Compatability with the expected conditions for initial operation of the N.A.L. 200-500 GeV accelerator.

II. The reasons for doing this experiment are:

a) The processes listed are among the simplest pp reactions beyond elastic scattering.

b) At extreme s-values these processes should be very informative about production mechanisms. It is not known what roles are played by one-pion-exchange (OPE) and by Pomeron exchange at high s. The utility of the double-Regge model or the Veneziano four-point function can only be tested by high-resolution, high-statistics data.

c) With the exception of the experiment (AGS #533) which will shortly be carried out at 28.5 GeV(using the identical apparatus we would like then to take to N.A.L.), no full-reconstruction high-s experiment on these reactions will exist by 1971 other than two bubble-chamber experiments having only a few hundred events each.

d) Our technique happens to lend itself very well to the N.A.L. accelerator; we can use the machine's full energy, and we will not be handicapped by the minimal facilities which will exist when the accelerator first operates.

III. Our choice of t range, $-0.1<t<-0.4$, is optimal from the viewpoint of our experimental method. It happens also to cover a particularly interesting region including the isobar peaks and the breakover to less peripheral behavior.

IV. The setup of the experiment is shown as fig. 1. The essential points of the design are

a) We concern ourselves with isobar-events which are made by excitation of the fast proton. With that choice, it is easy to build a magnetless missing-mass-spectrometer of small size and cost, large solid angle, and high resolution for the slow recoil proton. The corresponding isobar decays forward and is therefore easy to catch.

b) We use Charpak proportional-wire-chambers so that we can make measurements in the beam to high angular precision with apparatus of small size.

c) We choose decay modes which have very strong signatures. By angle measurements alone, without any magnet, we obtain a 1C fit on every $p\pi^+\pi^-$ event and 2C on $n\pi^+$. The 1C can be thought of as a comparison of two independent isobar-mass measurements on each event.

## V. Measurement outline.

The line of each incoming beam proton is measured by chambers C1, C2 and C3. All chambers have 2mm wire spacing, but C3 is offset by 1mm from C2. The recoil proton is measured in C4 and C5. The interaction point within the hydrogen target is measured by the intersection of the beam proton line (known as $\pm 1\text{mm}/\sqrt{12}$) with the plane of the recoil proton. That plane is defined by the wires in C4 and C5, perpendicular to the plane of fig. 1, near which the recoil proton passes.

With no further measurements, the apparatus so far described constitutes a missing-mass spectrometer with respectable resolution (see fig. 3). That resolution is wholly dominated by scattering of the 50-200 MeV recoil proton in the hydrogen target.

The direction of the outcoming isobar is obtained from the sum of the beam track vector (200 GeV/c) and the recoil proton track vector (maximum 0.6 GeV.c, and measured to ±0.5% by a ±1% measurement of recoil proton energy in the total-absorption scintillation counter S2).

Given the isobar direction and low-precision knowledge of the synchrotron energy (±0.5% is adequate) the six polar angles of the particles $p\pi^+\pi^-$ from the isobar decay yield a second, nearly independent, measurement of isobar mass. These six angles are measured from the interaction point to C6. The second mass-measurement is of considerably higher precision than the first (see fig. 4). At high masses, $M_I \sim 3000-5000$ MeV/$c^2$, that measurement is better than ±10 MeV both for 200 and 500 GeV beam energy. This is an order of magnitude better than the resolution of existing bubble chamber isobar experiments, and good enough for a meaningful search for microstructure in the isobar mass continuum.

The two mass measurements taken together yield a 1C fit for each $p\pi^+\pi^-$ event. For each such event, three possibilities for identification of the proton among the three tracks are tried. Over most of the mass range, the constraint yields an unambiguous identification for over 80% of the events.

## VI. Events of the type $(n\pi^+)$.

The interaction of a neutron in the chambers C7-C10 yields a 2C fit, but of relatively low precision, for about 50% of the $n\pi^+$ events. These constraints give some discrimination against the $(n\pi^+\pi^\circ)$ mode, and provide positive identification of $n\pi^+$ vs. $p\pi^\circ$, because the chance of a $\pi^\circ$ decay gamma hitting the correct $4cm^2$ of the neutron chambers is small.

## VII. Branching ratios.

The decay modes of high-mass isobars are essentially unknown, because bubble chamber experiments have inadequate statistics in that region and none but missing-mass electronic experiments have been carried out there. Even for low masses, however, the $p\pi^+\pi^-$ mode is a popular one:

| $M_I$ | B.R. ($M_I \to N\pi\pi$) |
|---|---|
| N'(1470) | 40% |
| N'(1520) | 50% |
| N(1670) | 58% |
| N(1688) | 40% |

The $N\pi$ mode is dominant for certain low-mass isobars, and comparable to the $N\pi\pi$ for others.

VIII. Rates, acceptance and data-recording.

The acceptance of the C6 chamber for $p\pi^+\pi^-$ events, as calculated from an invariant-phase-space Monte-Carlo program, is about 80% at $M_I$ = 3500 MeV. The data rate (calculated in detail in the Appendix) is computer-limited. We write 4000 16-bit words onto tape during each NAL pulse, using our (existing) HP2114A computer as a buffer. Our coding and word-addressing scheme has been worked out in detail, and requires only 16 words per event. About 250 events are therefore recorded per pulse. Assuming s-independence for certain isobar peaks seen over the 15-28 GeV range, about one event in 12 should be in such a peak. A conservative estimate is therefore about 20 interesting events per NAL pulse, or $1.2 \times 10^6$ in 50 hours of operation. Current theoretical fashions suggest that the continuum may be of comparable interest to, and perhaps physically identical to, the peaks. At least 10% of our total events will be processed on line by the 2114A.

IX. Logistics and growth.

If successful, this experiment could naturally develope by the addition of a downstream magnet for the identification of $p\pi^\circ$ with 1C, and $n\pi^+$ with 3C, fits. We would require only a relatively small magnet, (8" x 20" aperture, 14' length at 15Kg) and the resolution would be ±35 MeV at 200 GeV.

We feel, however, that it is premature to propose such an experiment, because the magnetless version presented here seems much more appropriate to the initial phase of NAL operation. It should be emphasized that all the apparatus we require is, with the exception of the target, literally small enough to be put in a station wagon, and that every individual piece can be picked up by two men. The computer, complete with 8K memory, digital scope, storage scope, and read/write tape unit, fits in a single relay rack and the remaining electronics does not even fill a second rack. The diffraction-scattered proton beam should be one of the easiest to obtain from the NAL, and the flight path from our target to C6 could, if it cannot be accommodated in the synchrotron tunnel, occupy a simple 3' diameter concrete pipe into the surrounding hill. It should also be noted that the lengths $\ell_1$ and $\ell_2$ of fig. 1 can be reduced simply at the expense of mass resolution.

## Appendix -- Rate

In a diffraction-scattered proton beam the available intensity is normally as high as $10^8$ protons per pulse. We calculate for $10^7$ protons/pulse, a figure which approaches simultaneously the computer word-storage limit and the instantaneous rate-limit of the Charpak counter electronics.

The total production cross-section in this t-range is obtained by integration over the $\theta_{lab}$ = 40 milliradian missing-mass spectrometer data of Allaby et al,[1] extrapolating over the upper half of the $M_I$ range. That integral is 8.2 mb. Assuming conservatively that the fraction of three-charged-particle production in continuum regions is the same as the branching ratio to $p\pi^+\pi^-$ in known peaks, from section (6) we take 0.45(2/3) for that fraction, and so estimate 2.5 mb as the cross-section for production of events with the correct three-track signature in C6. The trigger rate $R_1$ (deadtimeless) is then

$$R_1 = \frac{30\text{cm}}{374\text{cm}} \times \frac{2.5\text{mb}}{63\text{mb}} \times .045 \times 0.8 \times 10^7 = 1150/\text{sec}$$

- $\frac{30\text{cm}}{374\text{cm}}$: target length
- $\frac{2.5\text{mb}}{63\text{mb}}$: $\sigma/\sigma_T$
- .045: recoil spectrometer angular acceptance
- 0.8: minimum geometrical acceptance of C6 at $M_I$ = 3500 MeV
- $10^7$: instant. beam rate

For our Charpak counters we use a very simple circuit which is DC coupled except for hard clipping at the input; the circuit's recovery time is about 200 ns, the same as its output square-pulse length.

We therefore assume, conservatively, an 0.5 μsec dead time for each wire. The beam is spread over 14 wires, so $10^7$ instantaneous means 7 x $10^5$/wire. The trigger rate with deadtime is therefore

$$R_2 = 1150 \times \frac{7\text{x}10^5}{1+7\text{x}10^5\text{x}.5\text{x}10^{-6}} = 850 \text{ triggers/sec.}$$

Storing 8 words/event, we require 20 μsec/word + 80 μsec of overhead on entry of each event into the computer. The computer deadtime is therefore 240 μsec/event. The final rate with both Charpak wire and computer deadtimes included is therefore

$$R_3 = \frac{850}{1+850(.24\text{x}10^{-3})} = 700/\text{sec.}$$

Our 4000-word capacity will therefore permit us to fill memory with 250 events in 350 milliseconds. Integrating over known peaks, taking account on Nππ branching ratios, the Clebsch-Gordon coefficient for the all-charged mode, and the $e^{bt}$ dependences of known isobars, we find 0.23 mb for the production cross-section in the peaks (above continuum). This is about 1/12 of the total. A conservative estimate is therefore 20 interesting events/pulse, or 1.1 x $10^6$/50 hours.

## REFERENCES

EXPERIMENTAL:

1. Allaby et al, Phys. Letters 28B, 3, 229 (1968).
2. L. Lyons, Production Characteristics of $pp \to pn\pi^+$ at 7 GeV/c, Rehovoth preprint (1969).
3. W. E. Ellis, D. J. Miller, T. W. Morris, R. S. Panvini and A. M. Thorndike, Phys. Rev. Letters 21, 697 (1968) and 1969 Lund Conference Proceedings; see also BNL 13671.

THEORETICAL:

One-pion exchange:

4. See G. Wolf, SLAC preprint SLAC-PUB-544 (1969) for recent references.

Pomeron-exchange:

5. H. Satz, CERN preprint TH-1044.
6. L. Resnick, Phys. Rev. 175, 2185 (1968).
7. J. G. Rushbrooke, Phys. Rev. 177, 2357 (1969).
8. A. B. Clegg, Nucl. Phys. B13, 222 (1969).

Use of isospin amplitudes:

9. H. Bøggild et al, Phys. Letters 30B, 364 (1969).

Double-Regge model:

10. Chan Hong-Mo, K. Kajantie and G. Ranft, Nuovo Cimento 49A, 157 (1967).
11. N. F. Bali, G. F. Chew and A. Pignotti, Phys. Rev. 163, 1572 (1967).
12. E. L. Berger, Phys. Rev. Letters 21, 701 (1968).

(See also ref. [2].)

Veneziano four-point function:

13. H. Satz and S. Pokorski, CERN preprint TH-1088 (1969).

Pomeron-scattering:

14. E. Byckling and K. Kajantie, CERN preprint TH-1099 (1969).

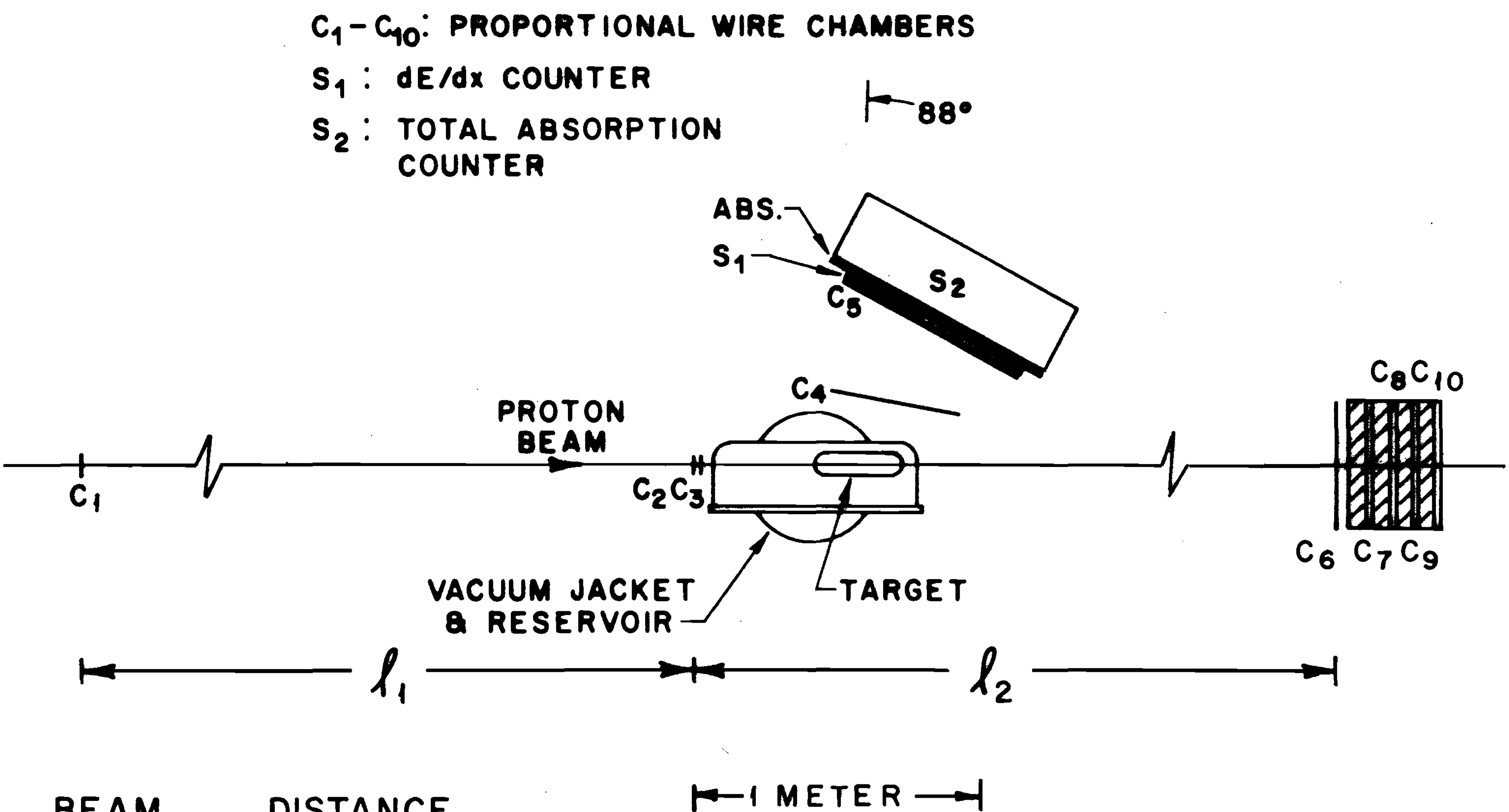
# FIGURE CAPTIONS

Fig. 1. Plan view of isobar experiment. Note lengths for 200 and 500 GeV, and the absence of a magnet.

Fig. 2. Recoil-proton angle vs. energy, for 200 GeV incident protons, as a function of isobar mass.

Fig. 3. Mass resolution for the missing-mass spectrometer (recoil-proton detector). The solid lines show the contributions from angular errors, dominated by scattering in the target. The dashed lines show the contribution from errors (±1%) in recoil-proton energy measurement. Note that $p\pi^+\pi^-$ reconstruction, shown in fig. 4, provides the better of the two isobar mass measurements.

Fig. 4. Mass resolution $\Delta M_I$ and identification efficiency as a function of isobar mass $M_I$, for 200 and 500 Gev. The identification efficiency is defined as the ratio of unambiguously identified $p\pi^+\pi^-$ events (in which the proton is identified by more than two standard deviations) to the total number of events. The mass resolution, ±5 to ±50 MeV, compares with typical values of ±100 MeV for present-day bubble-chamber experiments. On all curves, the scatter of points is due to the finite sample of events used in the computer calculation.




| BEAM ENERGY (GeV) | DISTANCE (METERS) $\ell_1$ | $\ell_2$ |
|---|---|---|
| 200 | 10 | 9 |
| 500 | 25 | 23 |

ISOBAR EXPERIMENT

PLAN VIEW

$\ell_1 \equiv$ DISTANCE C1 TO C2

$\ell_2 \equiv$ DISTANCE C2 TO C6

FIG. 1

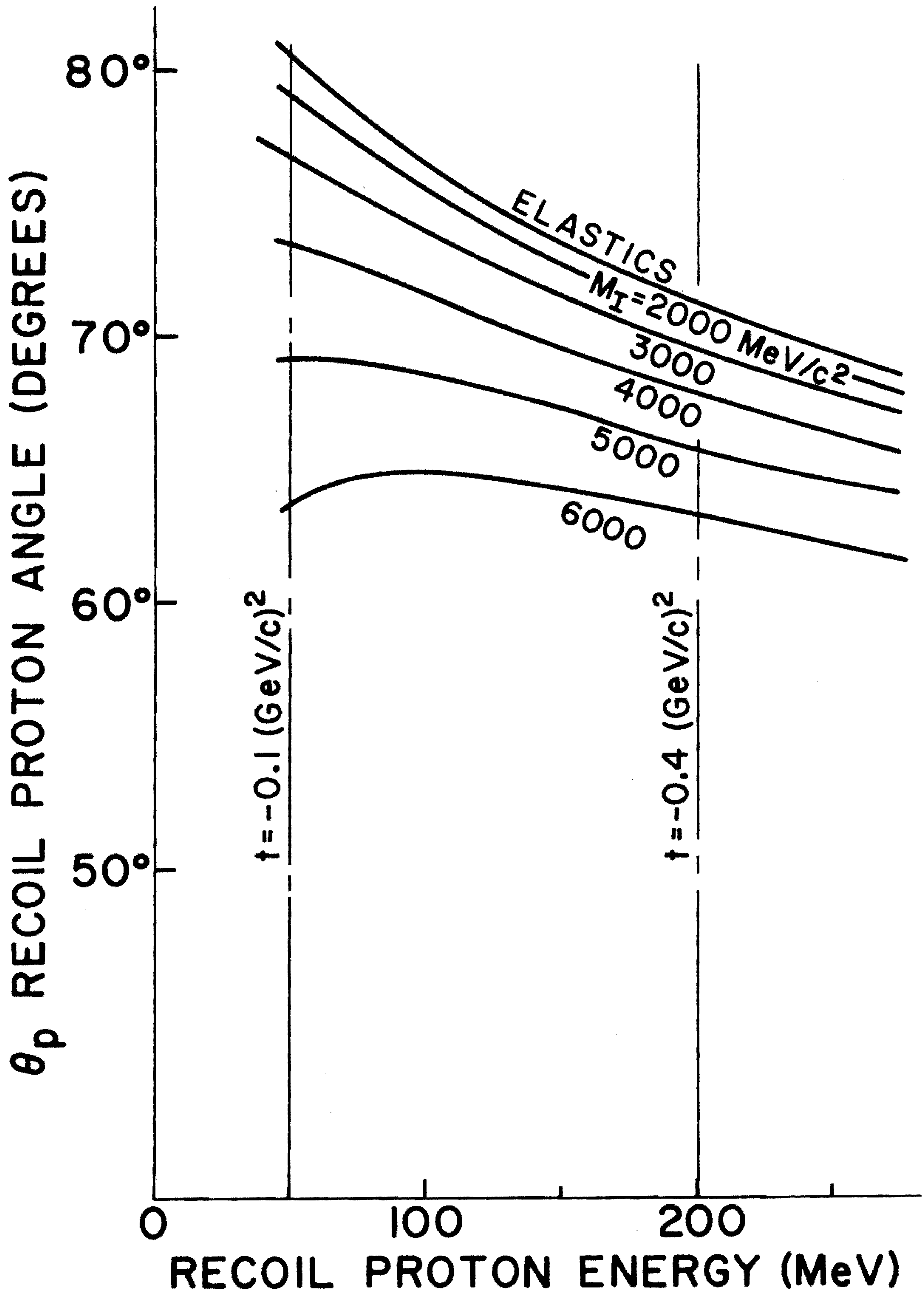
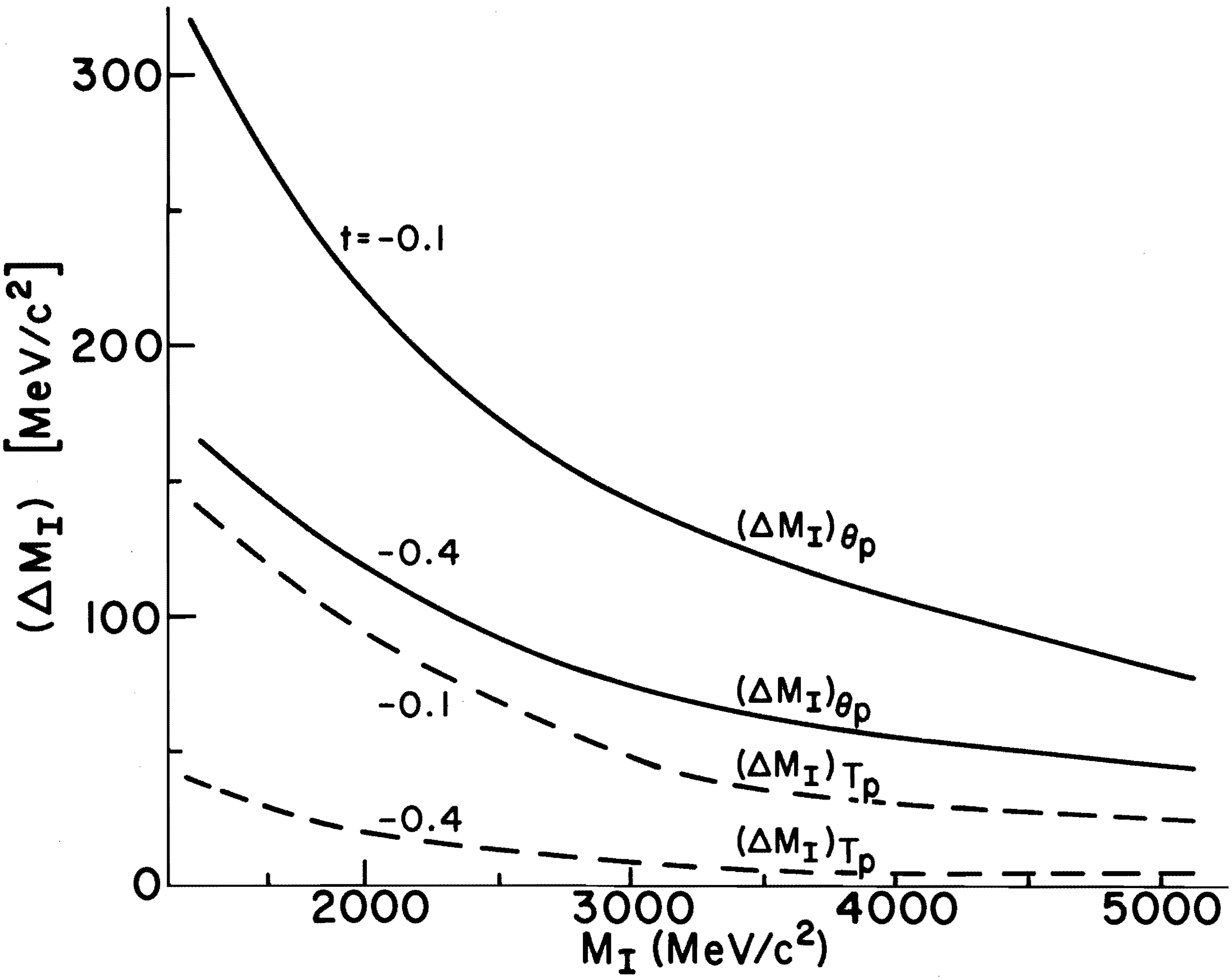

80°
70°
60°
50°
$\theta_p$ RECOIL PROTON ANGLE (DEGREES)
ELASTICS
$M_I$=2000 MeV/c$^2$
3000
4000
5000
6000
t=-0.1 (GeV/c)$^2$
t=-0.4 (GeV/c)$^2$
0
100
200
RECOIL PROTON ENERGY (MeV)

FIG. 2



300
200
100
0
$(\Delta M_I)$ [MeV/c²]
t=-0.1
-0.4
-0.1
-0.4
$(\Delta M_I)_{\theta_p}$
$(\Delta M_I)_{\theta_p}$
$(\Delta M_I)_{T_p}$
$(\Delta M_I)_{T_p}$
2000
3000
4000
5000
$M_I$ (MeV/c²)


FIG. 3

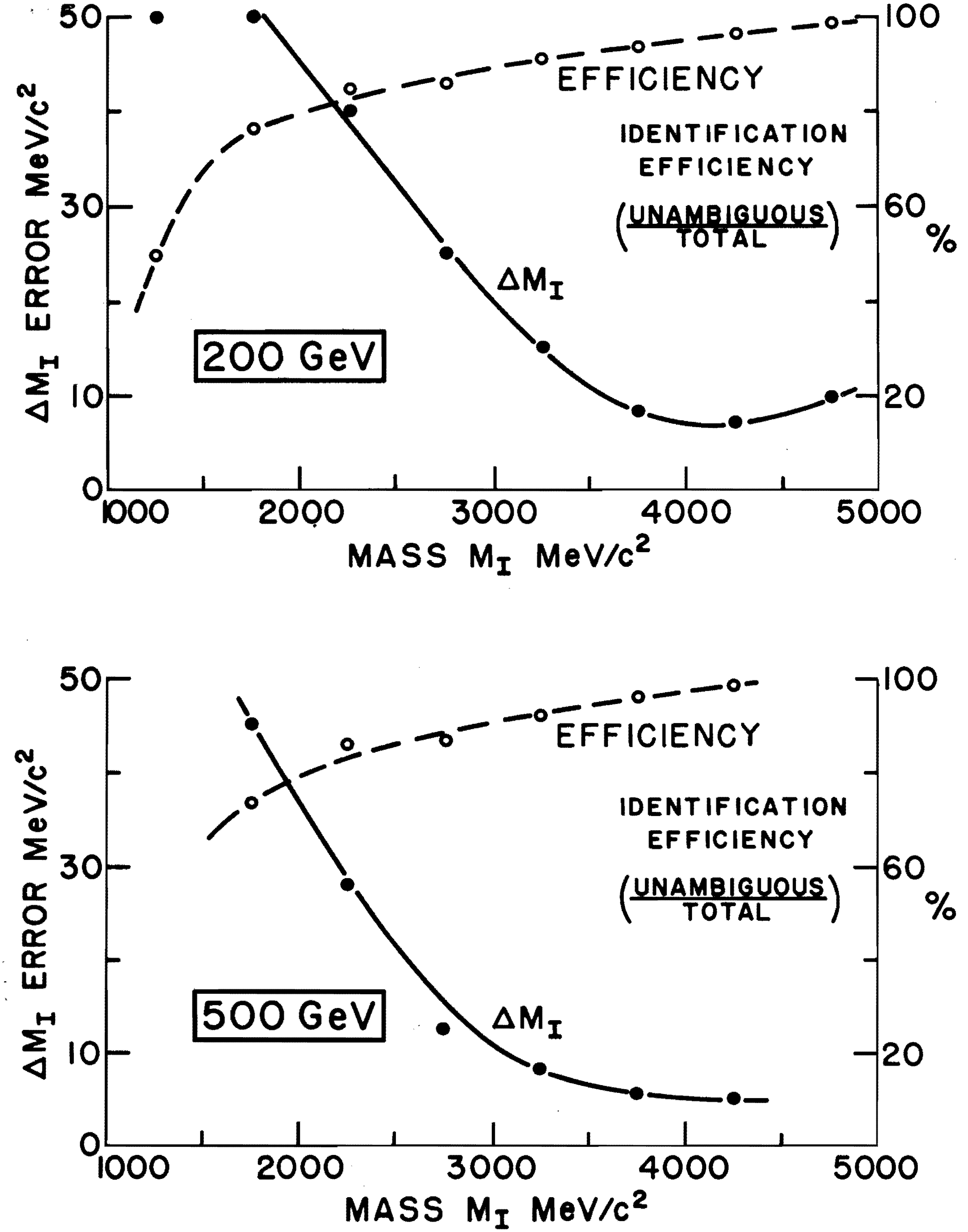

50
30
10
0
100
60
20
%
ΔM_I ERROR MeV/c²
EFFICIENCY
IDENTIFICATION
EFFICIENCY
(UNAMBIGUOUS / TOTAL)
ΔM_I
200 GeV
1000
2000
3000
4000
5000
MASS M_I MeV/c²
50
30
10
0
100
60
20
%
ΔM_I ERROR MeV/c²
EFFICIENCY
IDENTIFICATION
EFFICIENCY
(UNAMBIGUOUS / TOTAL)
ΔM_I
500 GeV
1000
2000
3000
4000
5000
MASS M_I MeV/c²

FIG. 4