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Estimates of Associated Charm Production Cross Sections

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ABSTRACT

We relate associated charm production to measured two-body reactions. Very generous estimates are unobservably small.

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If as has been widely speculated the narrow states $\psi(3105)$ and $\psi'(3695)$ recently discovered at SLAC and BNL are resonances with hidden charm (i.e., $c\bar{c}$ objects), it is of overriding interest to find particles with nonzero charm. In this note we shall assume the correctness of the charm interpretation and estimate the cross sections for associated charm production in quasi-two-body reactions. Our techniques involve the basic elements of charm spectroscopy as enunciated by Gaillard, Lee, and Rosner,[1] and conventional Regge theory with SU(4)-symmetric residue functions. We find that two-body quantum number exchange reactions are extremely unfavorable for charm searches.

The information needed to compute reaction cross sections in Regge theory includes the masses of the incident and produced particles, the trajectory function of the exchange Reggeon, and the coupling strengths. We proceed to estimate each of these ingredients in straightforward fashion.

1. <u>Masses of the Charmed Particles</u>[1,2]

The particle $\psi(3105)$ is identified as a 1^{--}, isoscalar $c\bar{c}$ state. Henceforth we refer to it as ϕ_c. With this identification, the mass scale of the charmed states is established. If we allow first-order SU(4) breaking for the masses, and use quadratic mass formulae for both mesons and baryons, we arrive at the estimates shown in Tables I and II. With a linear mass formula for baryons, the charmed baryon states would be considerably more massive.

2. Regge Trajectories

These may be computed in (at least) two ways. Assuming exchange degenerate vector and tensor trajectories, and using the masses listed in Table I, we obtain

$$\alpha_{D^*}(t) \simeq -0.61 + 0.32t \quad (1)$$

$$\alpha_{F^*}(t) \simeq -0.63 + 0.31t \quad (2)$$

$$\alpha_{\phi_c}(t) \simeq -0.79 + 0.19t \quad . \quad (3)$$

These trajectories are sketched together with the established ones in Fig. 1. The shallow slopes derive from the fact that the slopes of the ordinary trajectories, as deduced from the 1^- and 2^+ masses, satisfy

$$\alpha'_{\phi} < \alpha'_{K^*} < \alpha'_{\rho} \quad . \quad (4)$$

This regularity (which may be only illusory) is grossly magnified by the large charmed quark-strange quark mass difference. One could instead be more conventional, and assume that all trajectories have approximately unit slope. Then the intercepts of the charmed trajectories would be considerably lower. In our calculations we used the trajectories (1)-(3), to make very generous estimates.

3. Couplings

We assume that the couplings at Reggeon-particle-particle vertices satisfy SU(4) symmetry exactly, and relate the reactions of interest to known processes. A list of reactions, exchanges, and SU(4) analogs appears in Table III.

Results

We present our estimates for several typical charm-exchange reactions in Figs. 2-5. The cross sections are diminished from the values in the SU(4) analogs by strong $t_{minimum}$ effects and by the low intercept of the D^* trajectory. Even with our generous estimates, they are fantastically small.

Figure 6 shows an estimate of the inclusive cross section for $\pi^- p \to D^- +$ anything in the triple-Regge region. It is based on known[3] triple-Regge couplings and on the quark-model-inspired guess

$$\sigma_{total}(D^* N) = 13 \text{ mb} \quad , \tag{5}$$

which is probably not parsimonious.

If the charmed analog of the η meson, which we call η_c, contains some contamination of nonstrange quarks, it can be produced by ordinary A_2 exchange. Furthermore, since only one massive particle would be produced in the reaction $\pi N \to \eta_c N$, the effect of t_{min} is not as great as in the associated production reactions (but is is still a significant effect!). The quantity

$$\frac{\sigma(\pi N \to \eta_c N)}{\left| \langle \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} \mid \eta_c \rangle \right|^2}$$

can be estimated from the known cross section for $\pi N \to \eta N$. If we use the η_c mass quoted in Table I, we arrive at the results shown in

Fig. 7 and 8. These are not very encouraging, especially because the η_c wavefunction might be purely $c\bar{c}$. If the contamination were as large as

$$\left| \left< \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} \right| \eta_c \right> \right|^2 \approx \text{few per cent} \quad ,$$

at ZGS energies the cross section would be tens of nanobarns. The expected inclusive cross section in the pion fragmentation region is shown in Fig. 9, in terms of

$$\frac{d\sigma/dt\, d\mathcal{M}^2}{\left| \left< \frac{\bar{u}u+d\bar{d}}{\sqrt{2}} \right| \eta_c \right> \right|^2} \quad .$$

It also seems all but unobservable.

Conclusions

If charmed particles exist, it is unlikely that they will be discovered in two-body quantum number exchange reactions.

REFERENCES

[1] M. K. Gaillard, B. W. Lee, and J. L. Rosner, Fermilab preprint FERMILAB-Pub-74/86-THY, to appear in Rev. Mod. Phys.

[2] B. W. Lee and C. Quigg, Fermilab report FERMILAB-74/110-THY (unpublished), and notebooks.

[3] R. D. Field and G. C. Fox, Nucl. Phys. B80, 367 (1974).

TABLE I.

Charmed Meson Masses

J^P	Particle	Composition	Mass, GeV/c^2
0^-	D	$c\bar{u}, c\bar{d}$	2.24
	F	$c\bar{s}$	2.29
	η_c	$c\bar{c}$	3.07
1^-	D^*	$c\bar{u}, c\bar{d}$	2.26
	F^*	$c\bar{s}$	2.31
	ϕ_c	$c\bar{c}$	3.105
2^+	D^{**}	$c\bar{u}, c\bar{d}$	2.88
	F^{**}	$c\bar{s}$	2.93
	f_c	$c\bar{c}$	3.86

TABLE II.

Charmed Baryon Masses

J^P	Particle	Composition	Mass, GeV/c^2
$1/2^+$	C_1	cuu, cud, cdd	3.40
	C_0	cud	2.98
	A	cus, cds	3.06
	S	cus, cds	3.65
	T	css	3.70
	$X_{u,d}$	ccu, ccd	4.44
	X_s	ccs	4.50
$3/2^+$	C_1^*	cuu, cud, cdd	3.16
	S^*	cus, cds	3.22
	T^*	css	3.28
	$X_{u,d}^*$	ccu, ccd	4.30
	X_s^*	ccs	4.34
	Θ^{++}	ccc	5.19

TABLE III.

Some Charm - Exchange Reactions

Reaction	Exchange	SU(4) Analog
$\pi^- p \to D^- C_1^+$	D^*	$\pi^- p \to K^0 \Sigma^0$
$\pi^- p \to D^- C_0^+$	D^*	$\pi^- p \to K^0 \Lambda$
$\pi^- p \to D^- C_1^{*+}$	D^*	$\pi^- p \to K^0 Y_1^{*0}$
$\pi^+ p \to \overline{D^0} C_1^{++}$	D^*	$\pi^+ p \to K^+ \Sigma^+$
$\pi^+ p \to \overline{D^0} C_1^{*++}$	D^*	$\pi^+ p \to K^+ Y_1^{*+}$
$K^- p \to F^- C_1^+$	D^*	$\pi^- p \to K^0 \Sigma^0$
$K^- p \to F^- C_0^+$	D^*	$\pi^- p \to K^0 \Lambda$
$K^- p \to F^- C_1^{*+}$	D^*	$\pi^- p \to K^0 Y_1^{*0}$

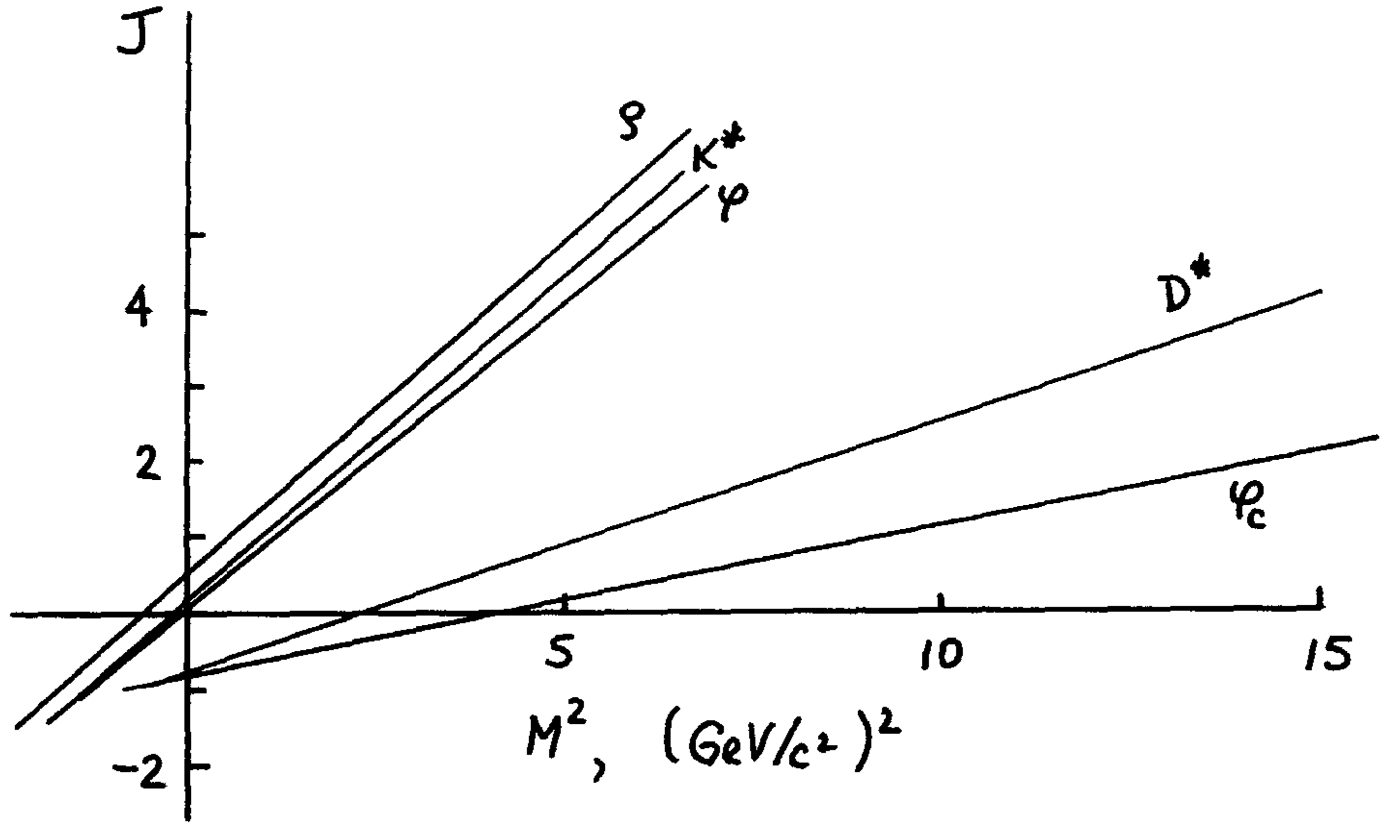
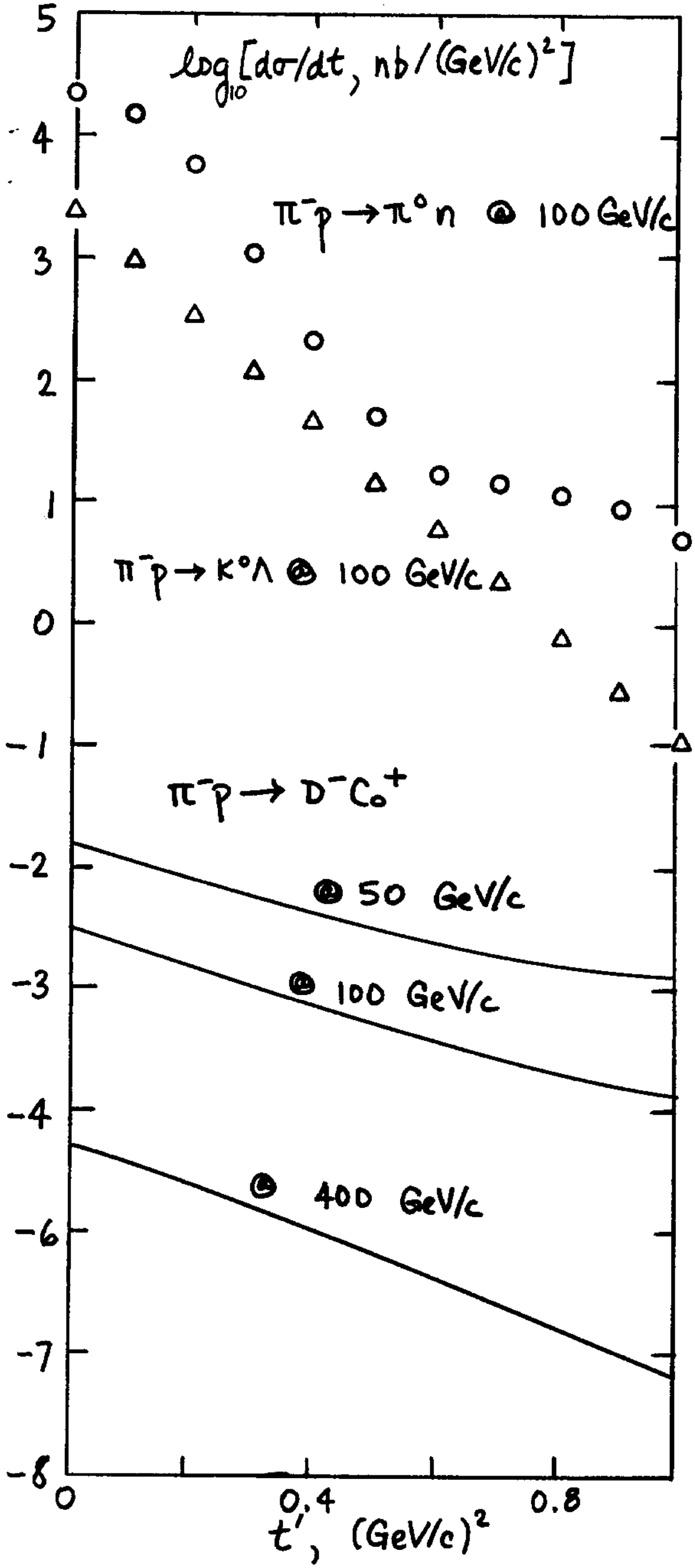
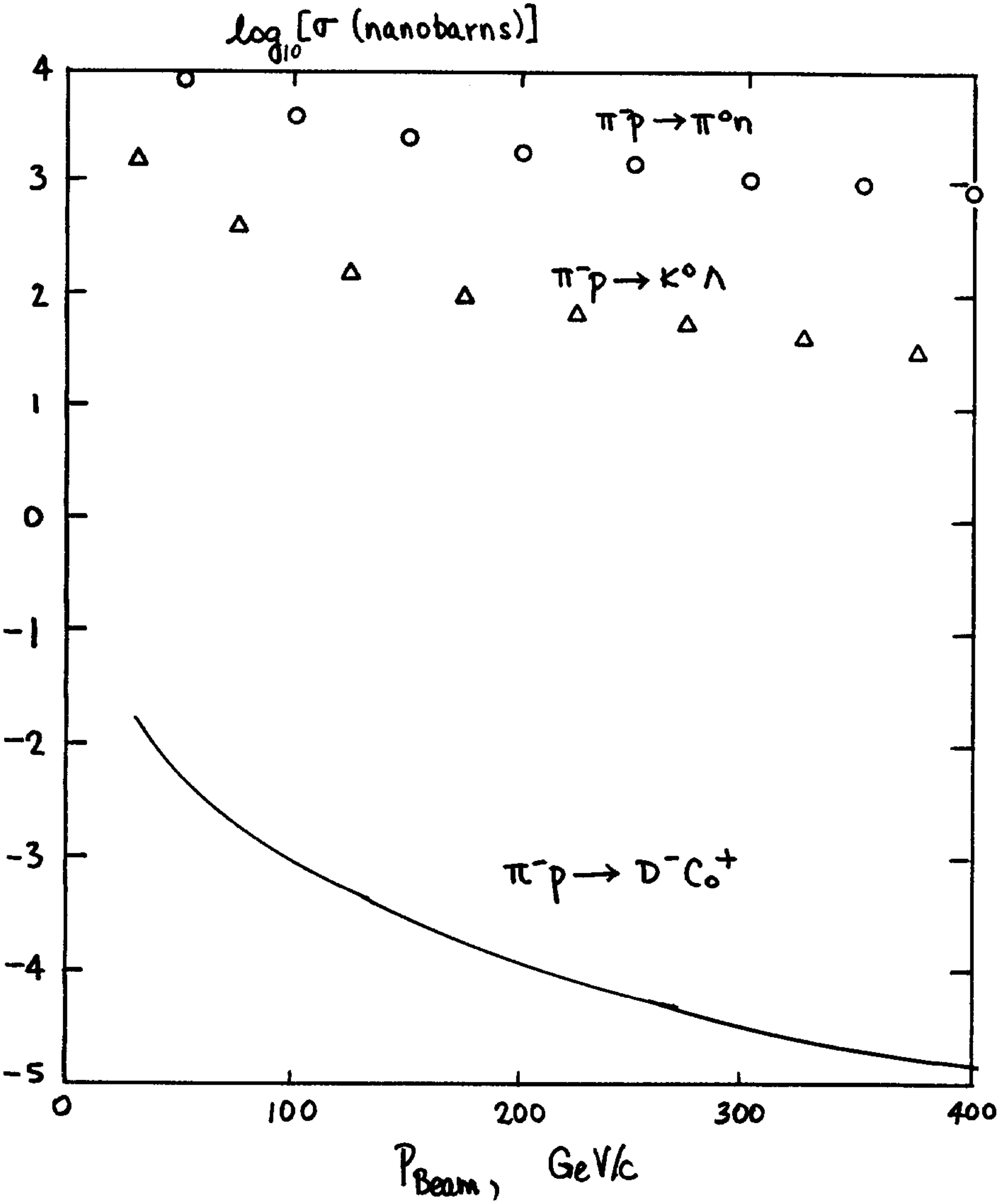


FIG. 1: CHEW-FRAUTSCHI PLOT FOR THE NATURAL-PARITY MESONS.



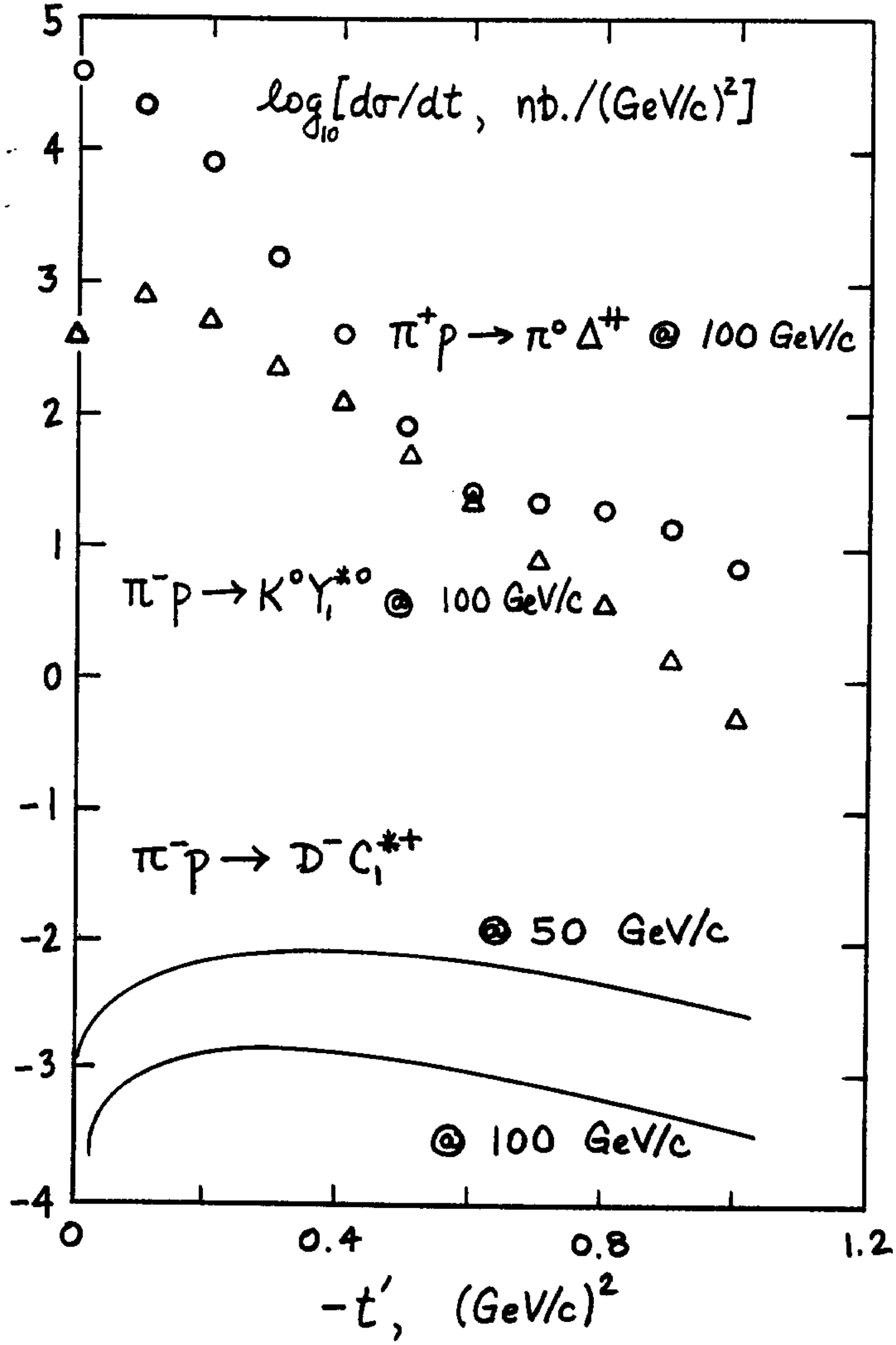
$\log_{10}[d\sigma/dt, nb/(GeV/c)^2]$
$\pi^- p \to \pi^0 n$ @ 100 GeV/c
$\pi^- p \to K^0 \Lambda$ @ 100 GeV/c
$\pi^- p \to D^- C_0^+$
@ 50 GeV/c
@ 100 GeV/c
@ 400 GeV/c
5
4
3
2
1
0
-1
-2
-3
-4
-6
-7
-8
0
0.4
0.8
t', $(GeV/c)^2$

FIG. 2



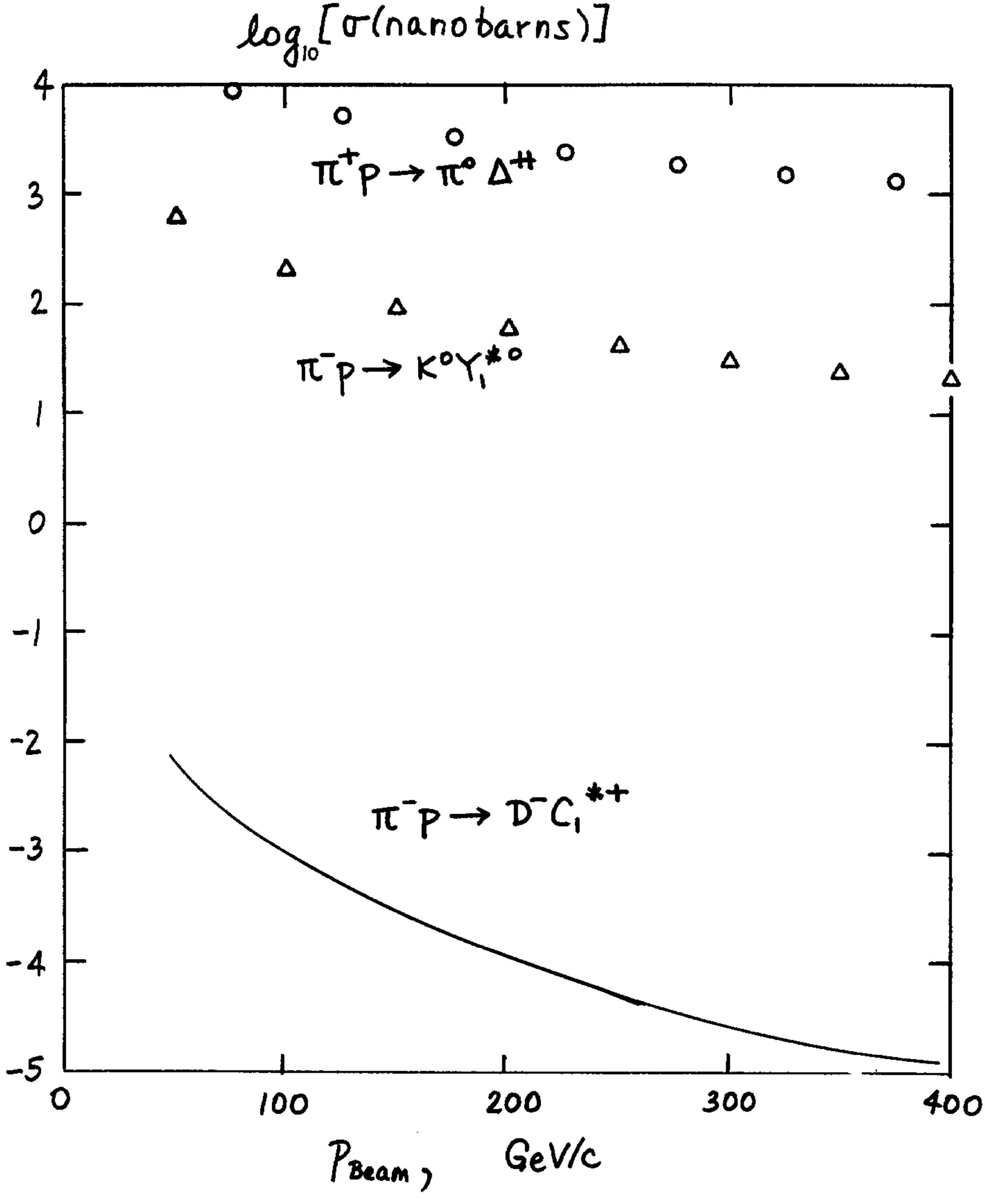
log10[σ (nanobarns)]
4
3
2
1
0
-1
-2
-3
-4
-5
0
100
200
300
400
π⁻p → π°n
π⁻p → K°Λ
π⁻p → D⁻C₀⁺
P_Beam, GeV/c

FIG. 3



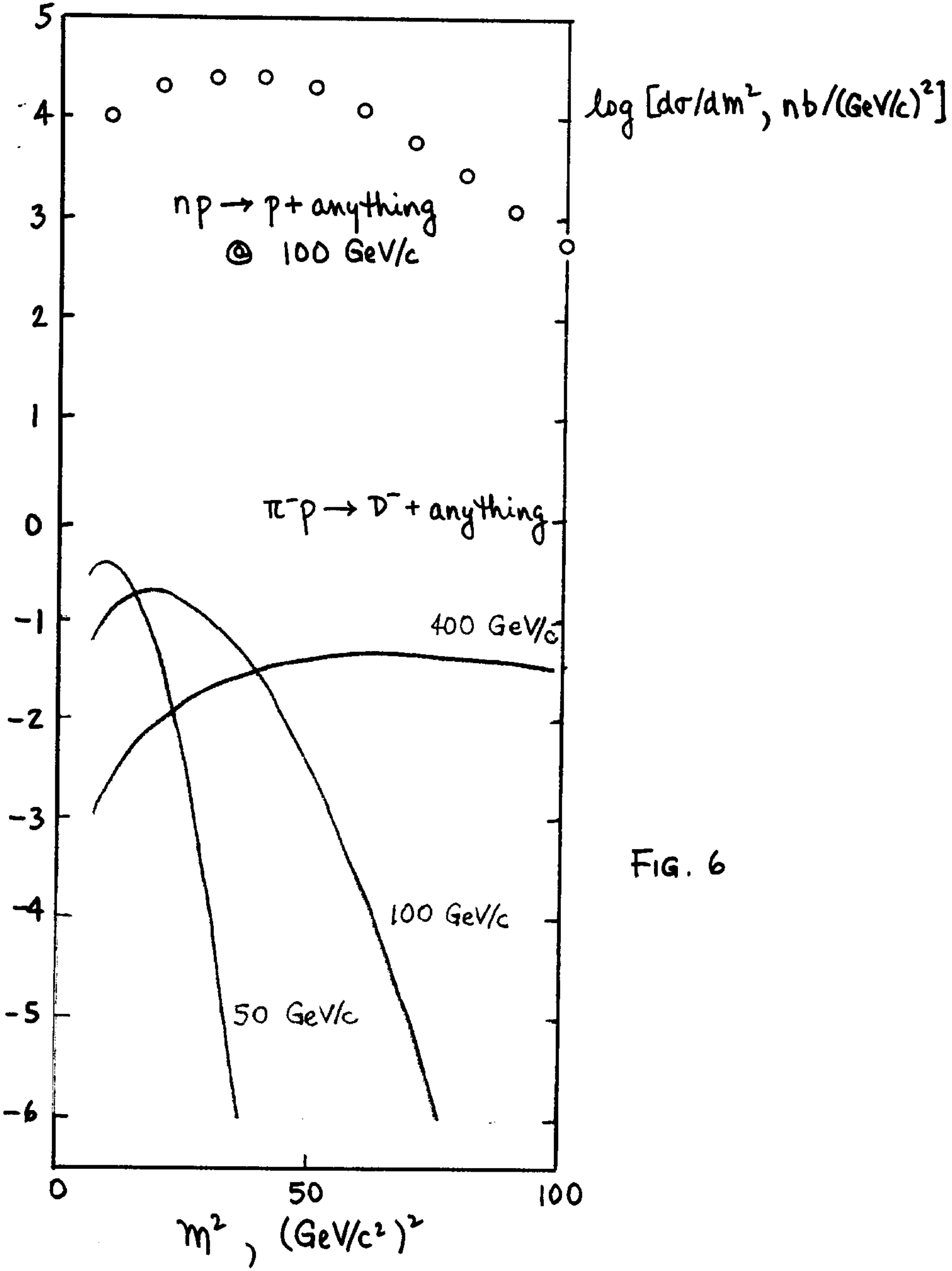
5
4
3
2
1
0
-1
-2
-3
-4
0
0.4
0.8
1.2
log10[dσ/dt, nb./(GeV/c)²]
π⁺p → π°Δ⁺⁺ @ 100 GeV/c
π⁻p → K°Y₁*° @ 100 GeV/c
π⁻p → D⁻C₁*⁺
@ 50 GeV/c
@ 100 GeV/c
−t′, (GeV/c)²

FIG. 4



log10[σ(nanobarns)]
4
3
2
1
0
-1
-2
-3
-4
-5
0
100
200
300
400
π+p → π0 Δ++
π−p → K0Y1*0
π−p → D−C1*+
PBeam, GeV/c

FIG. 5



5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
50
100
log [dσ/dm², nb/(GeV/c)²]
np → p + anything
@ 100 GeV/c
π⁻p → D⁻ + anything
400 GeV/c
100 GeV/c
50 GeV/c
m², (GeV/c²)²

FIG. 6

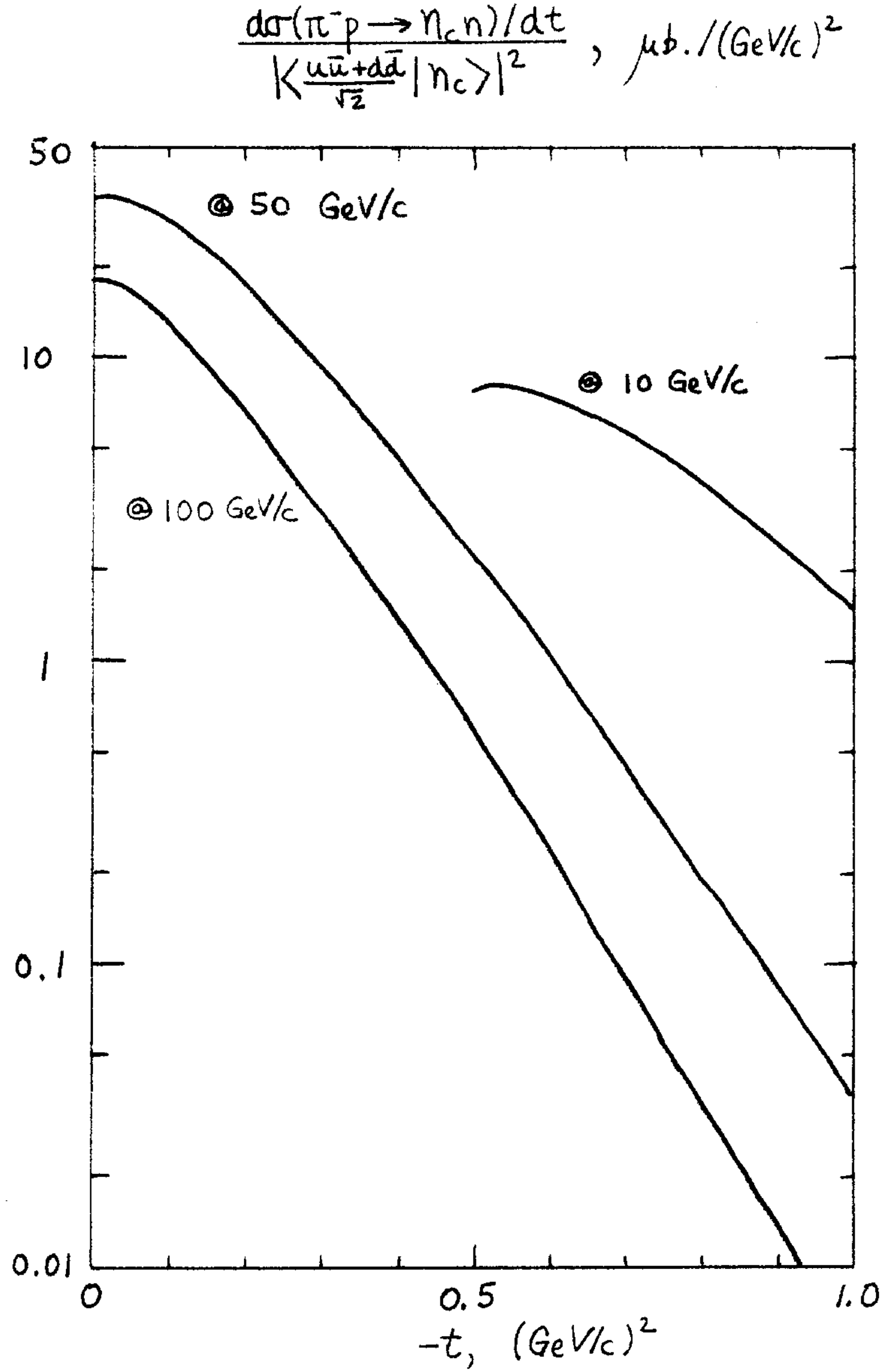
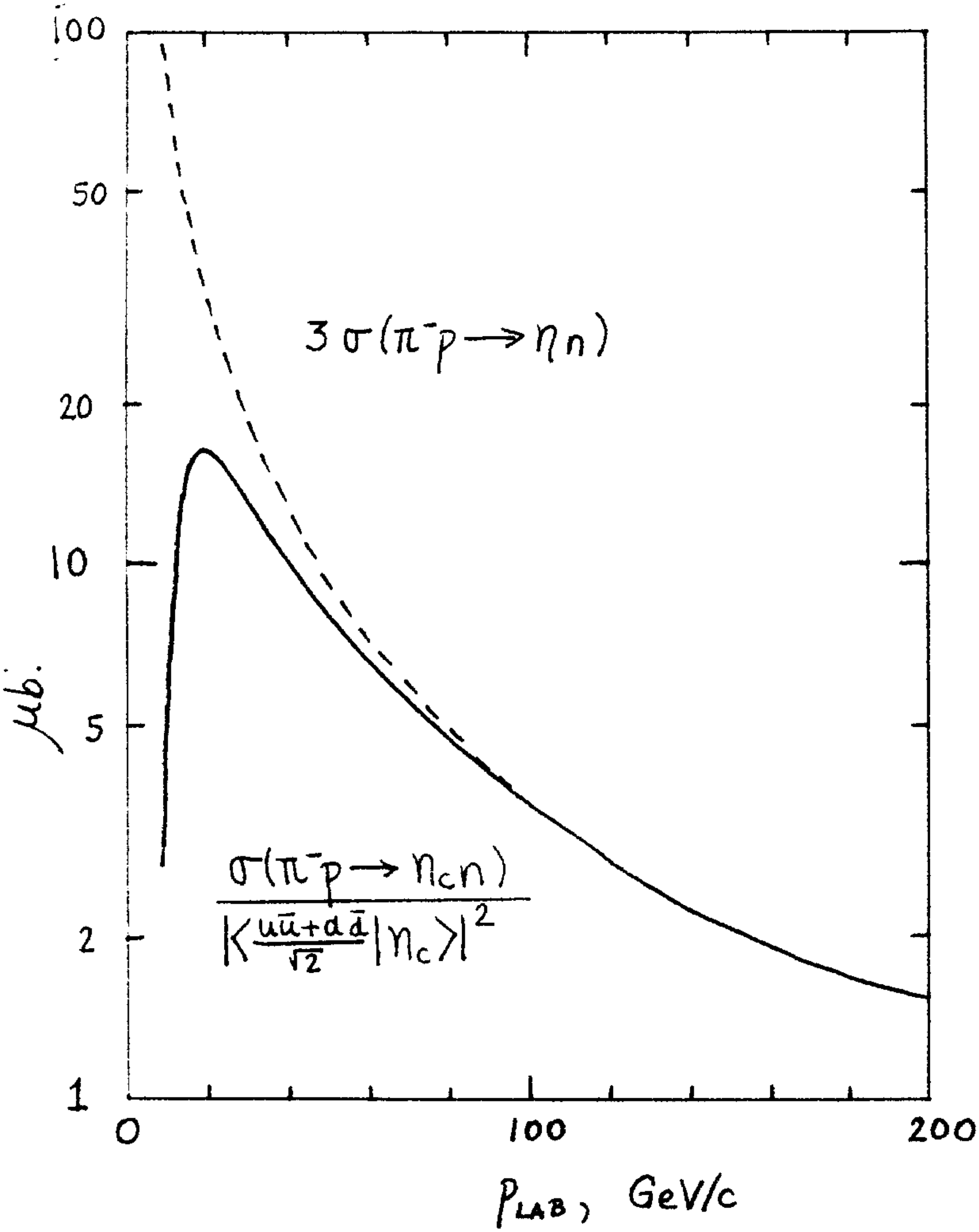
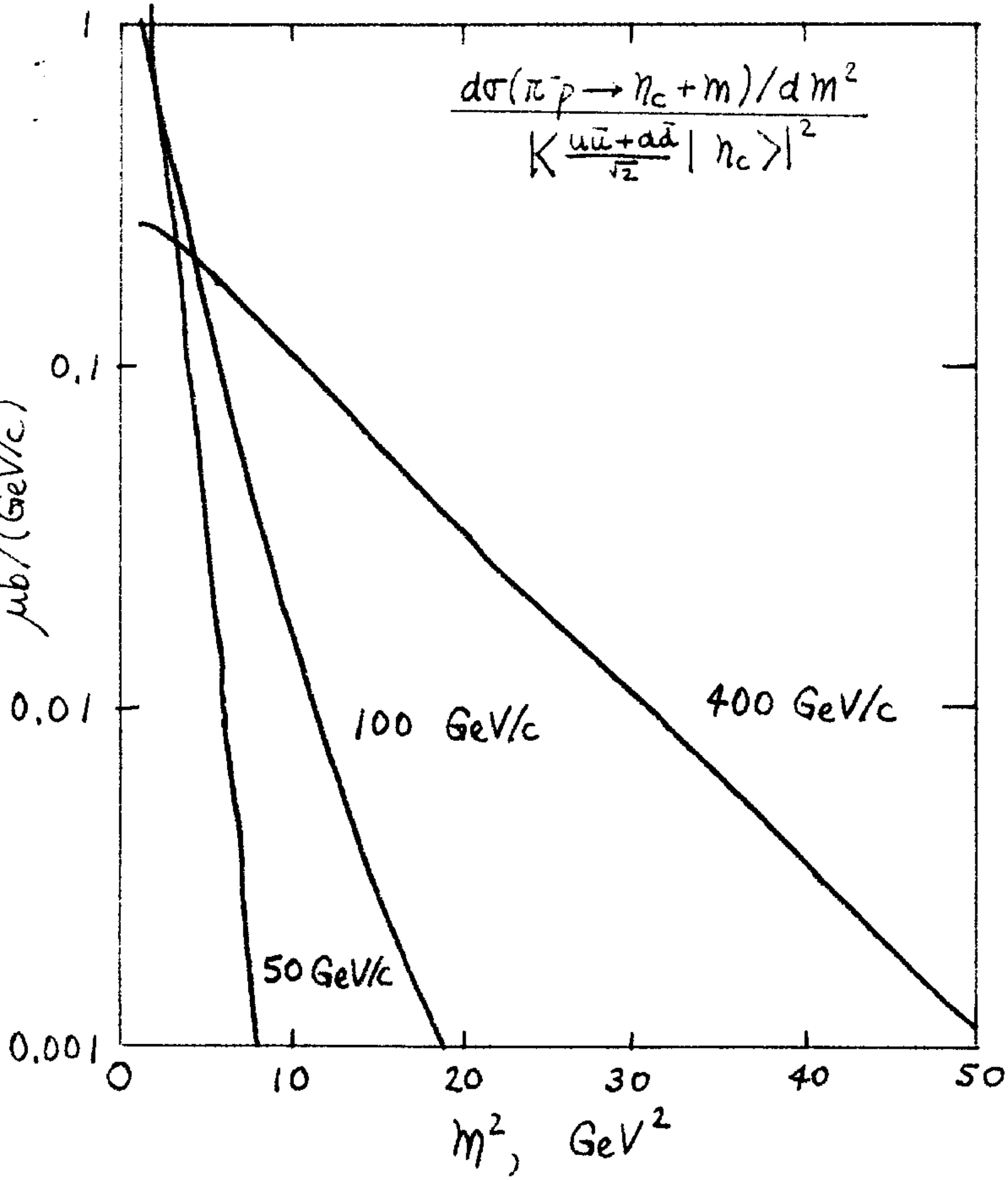

$\frac{d\sigma(\pi^- p \rightarrow \eta_c n)/dt}{|\langle \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} | \eta_c \rangle|^2}$, μb./(GeV/c)²
50
10
1
0.1
0.01
@ 50 GeV/c
@ 10 GeV/c
@ 100 GeV/c
0
0.5
1.0
$-t$, (GeV/c)²

FIG. 7



100
50
20
10
5
2
1
μb.
$3\sigma(\pi^- p \to \eta n)$
$\dfrac{\sigma(\pi^- p \to \eta_c n)}{\left|\langle \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} | \eta_c \rangle\right|^2}$
0
100
200
p_{LAB}, GeV/c

FIG. 8



$d\sigma(\pi^- p \to \eta_c + m)/dm^2$ / $|\langle \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} | \eta_c \rangle|^2$
$\mu b/(GeV/c)^2$
1
0.1
0.01
0.001
0
10
20
30
40
50
m^2, GeV^2
50 GeV/c
100 GeV/c
400 GeV/c

FIG. 9