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Cross-Section for the Charge Exchange Reaction $\pi^+ + n \rightarrow p + \pi^0$ at 6 GeV/c Pion Momentum

F. Bruyant, M. Goldberg*), G. Vegni**), and H. Winzeler,
CERN, Geneva,

P. Fleury, J. Huc, R. Lestienne, G. de Rosny and R. Vanderhaghen,
Ecole Polytechnique, Paris.

Recently (Reference 1) we published a study of two-prong stars from interactions of 6 GeV/c π^+ mesons in deuterium. The analysis was based on 388 events of the type $\pi^+ + d \rightarrow p + p$ + neutrals, observed in the 81 cm Saclay bubble chamber at the CERN proton synchrotron. Protons were identified by ionisation up to a momentum of 1.3 GeV/c.

The frequency distribution of the events as function of the square of the missing (neutral) masses displays two clear accumulations, certainly not due to phase space (Figure 1, see also reference 1): One is at the very beginning of the spectrum, the second one is centered at about 1.55 GeV^2. The latter has been discussed in detail in Reference 1 and was interpreted as mainly due to f^0 production with the f^0 decaying into neutral pions. In the present letter we want to comment on the first peak and derive from it an estimate for the cross-section of the charge exchange process

$$\pi^+ + n \rightarrow p + \pi^0 .$$

The individual identification of single π^0-events is not feasible at our energy in the 80 cm chamber (i.e. one cannot rely on the answer of programs of fits). The proof that we deal with single π^0-emission will be a statistical one. For this one needs careful error considerations.

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*) On leave of absence from Institut de Radium, Laboratoire Curie, Paris

**) On leave of absence from the University and Section of INFN of Milan

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From the analysis of four-prong events fitting the reaction

$$\pi^+ + d \rightarrow p + p + \omega^0$$
$$\hookrightarrow \pi^+ + \pi^- + \pi^0$$

the errors of the squares of the p-p missing masses were estimated to be 0.1 GeV^2. Furthermore, in order to improve the resolution we retained a limited sample of 'best measured' events, i.e. of events with a calculated individual error < 0.1 GeV^2. This cut-off, while improving the resolution between mass peaks, does not introduce a distortion of the missing mass spectrum, since no significant correlation between ΔM_0^2 and M_0^2 was observed all over the spectrum of M_0^2.

The ideogram as function of M_0^2 for the restricted sample, is shown in Figure 2. The figure also shows the 'expected ideogram' for a zero-width accumulation at M_{π^o} (feeding into the calculation the experimental distribution of errors). Agreement between both curves is very good. A best fit of the experimental distribution gives $M_0^2 = 0.03 \pm 0.01$ GeV^2. This result leads to the conclusion that we deal here essentially with charge exchange events. In addition, from the observation of a bump in the η^0-mass region, we can derive an estimation for the production of the η^0.

Further proof for this conclusion comes from the analysis of a sample of 800 four-prong events*) of the type $\pi^+ + d \rightarrow p + p + \pi^+ + \pi^- + n\pi^0$, $n \geq 0$, from a similar total path scanned. No accumulation at low p-p (missing mass)^2 was found, only 5 events had a (missing mass)^2 < 0.2 GeV^2. Furthermore, among the fitted five-body reactions $\pi^+ + d \rightarrow p + p + \pi^+ + \pi^- + \pi^0$, one single event was in the η^0-mass region. Thus, only an (unknown) particle of mass < 0.3 GeV with the majority of its decays via neutral electromagnetical channels might mislead us (and could still simulate a 'π^0-peak'). We are thus led to conclude that the events in the 'zero mass peak' are due to π^0-production via the mechanism

$$\pi^+ + d \rightarrow p + p + \pi^0.$$

One can assume that practically all of these events were due to interactions with the (loosely) bound neutrons (i.e. we assume the validity of the impulse approximation, and neglect possible final-state interactions between the two protons. More detailed investigation of this point performed in the present experiment

*) To be published elsewhere

confirmed this assumption). The observed process is therefore reducible to the elementary charge exchange interaction

$$\pi^+ + n \rightarrow p + \pi^0$$

with a CM energy spread (due to the 'Fermi-motion' of the neutron) as shown in Figure 3.

After correction for cut-off in the spectator protons range (see Reference 1) and account for scanning loss, the cross-section becomes*)

$$\sigma_{Ch.Exch.} = 138 \pm 20 \ \mu \text{ barn.}$$

Furthermore, we can give an estimate for η^0-production (decaying via neutrals)

$$\sigma_{\eta^0} \approx 35 \ \mu \text{ barn.}$$

For the derivation of the angular distribution (Figure 4) all events in the zero-mass peak of Figure 1 defined by $M_0^2 < 0.2 \text{ GeV}^2$ were taken. The average value of the square of the four-momentum transfer is $\langle t \rangle = -0.16 \text{ GeV}^2$.

In order to obtain an estimate of a forward scattering amplitude, we extrapolated to $t = 0$ with an exponential shape for the $(-t)$ interval $< 0.4 \ (\text{GeV}/c)^2$. This gives $\left.\frac{d\sigma}{dt}\right|_0 = 660 \pm 100 \ \mu \text{ barn} /(\text{GeV}/c)^2$, a value which is larger than that obtained by Wahlig et al[2], $\left.\frac{d\sigma}{dt}\right|_0 = 360 \ \mu \text{ barn} /(\text{GeV}/c)^2$.

Pion-nucleon charge exchange and elastic scattering amplitudes are related by $T_{Ch.ex.}(t) = \frac{1}{\sqrt{2}} (T_{el.\pi^+p}(t) - T_{el.\pi^-p}(t))$. The values of $\left.\frac{d\sigma}{dt}\right|_0$ extrapolated from measurements at finite t are much larger than the 'optical value' **), ($I^2 = 145 \ \mu \text{ barn}/(\text{GeV}/c)^2$), which would hold if the real part were vanishing at $t=0$. Höhler et al[3] made use of the dispersion relations to extrapolate from low energy values the real parts of the scattering amplitudes. They obtained for the forward charge-exchange at 6 GeV/c $\left.\frac{d\sigma}{dt}\right|_0 = 215 \ \mu \text{ barn}/(\text{GeV}/c)^2$ which is more than four standard deviations different from our extrapolated value. A possible interpretation of this observation could be that $\frac{d\sigma}{dt}(t)$ has a sudden decrease when t approaches

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*) The error is the statistical one. Due to uncertainties in the estimate of background a further systematical error of $\pm$ 20 μ barn is possible.

**) This value is obtained by the relation above when one replaces $T_{el.\pi p}(t=0)$ by the optical theorem value.

zero ($-t < 0.05$ $(GeV/c)^2$). For lack of statistics such an effect would have escaped detection in our experiment[*)]. Besides, it could account for the difference between our results and those of Wahlig et al, since their value corresponds to integration over the t interval : $-t < 0.05$ $(GeV/c)^2$.

Acknowledgments

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References

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2) M.A. Wahlig, I. Mannelli, L. Sodickson, O. Fackler, C. Ward, T. Kan and E. Shibita, Phys.Rev.Letters 13, 103 (1964).

3) G. Höhler, G. Ebel and J. Giesecke, "The Pion-Nucleon Forward Scattering Amplitude", preprint Karlsruhe (1st June 1964), to be published in Zeitschrift für Physik.

*) In contrast to measurement of elastic scattering in hydrogen, there is in this case no detection cut-off for small -t.

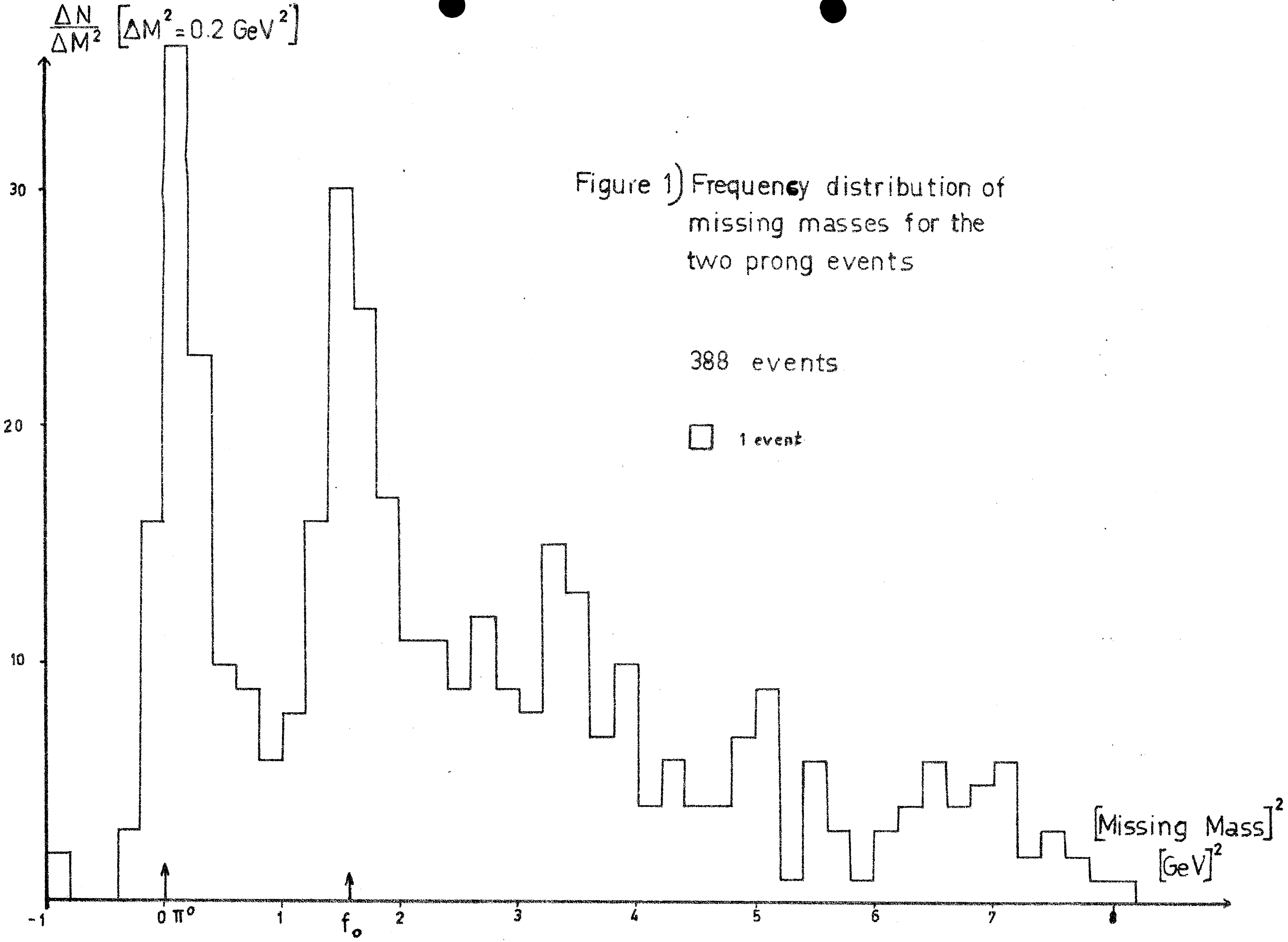

Figure 1) Frequency distribution of missing masses for the two prong events

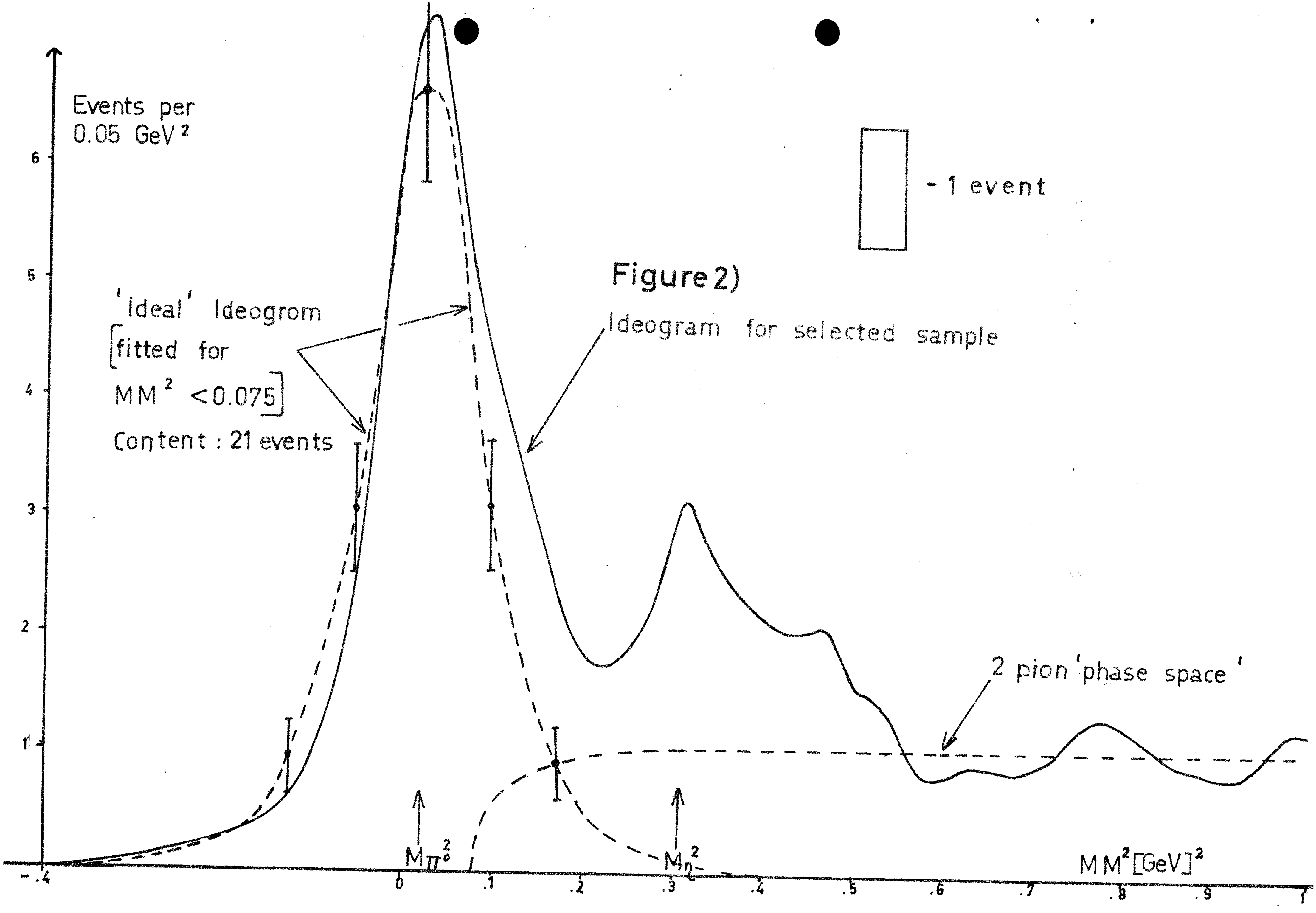
Events per
0.05 GeV²
'Ideal' Ideogrom
[fitted for
MM² <0.075]
Content : 21 events
Ideogram for selected sample
- 1 event
2 pion 'phase space'
M$_{\pi^0}^2$
M$_{\eta}^2$
MM²[GeV]²
6
5
4
3
2
1
-.4
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1

Figure 2)

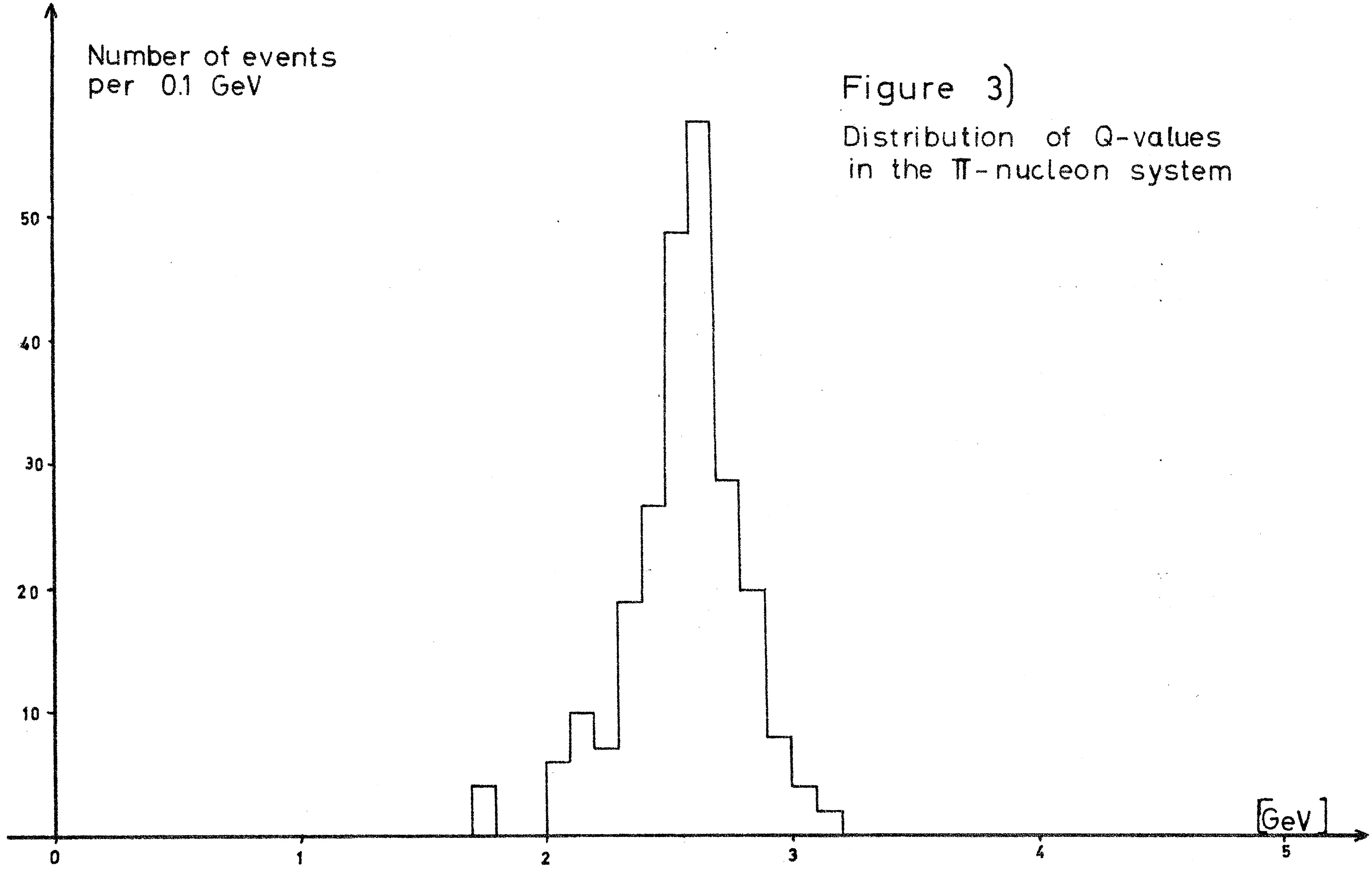

Figure 3)

Distribution of Q-values in the π-nucleon system

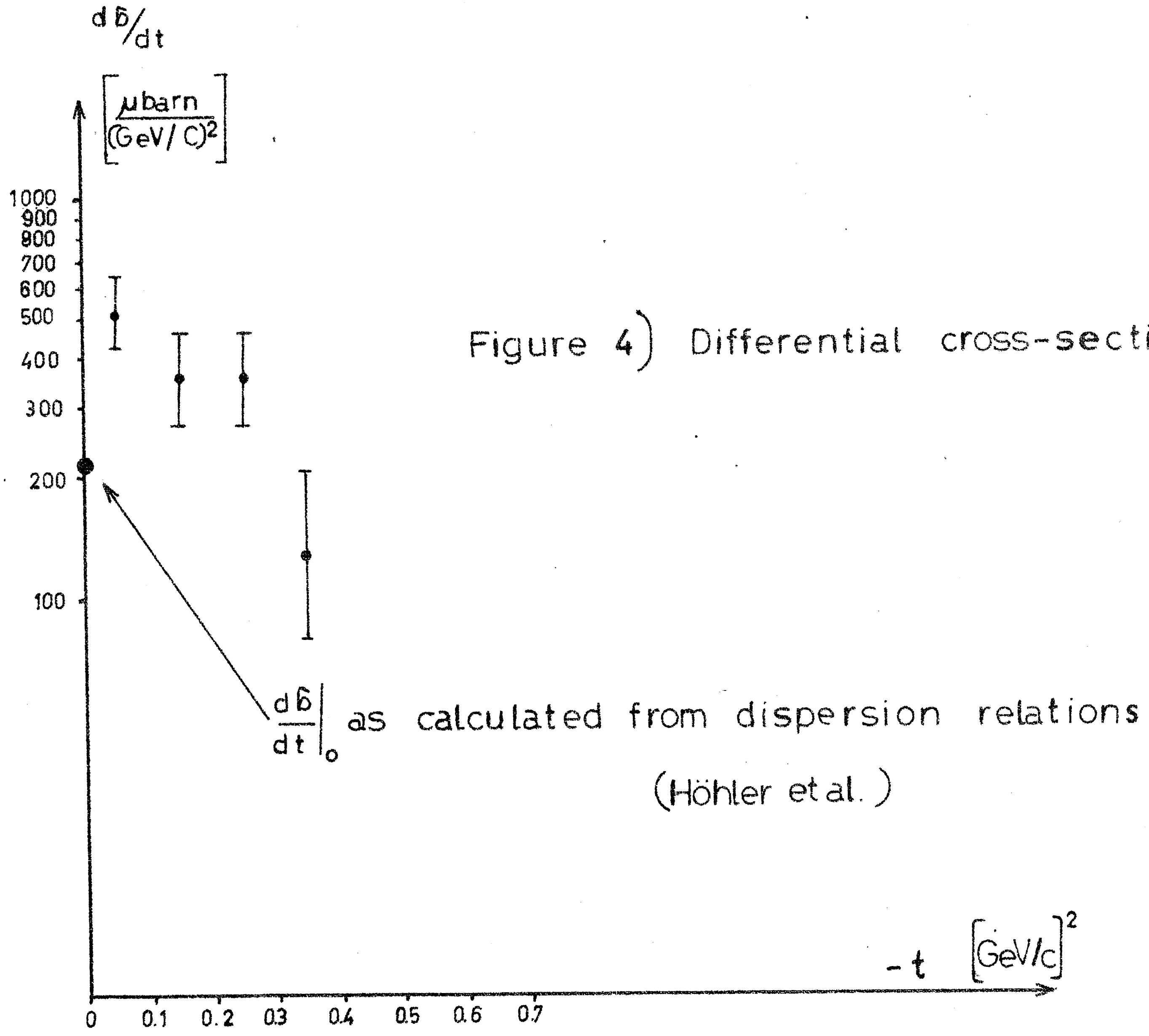

Figure 4) Differential cross-section