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Comments on Generalized Vector Dominance

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As is well known, about ten years of photon hadron physics for $q^2 \approx 0$ (q^2 = photon four momentum squared) in the multi GeV energy range may be summarized by stating that photons behave hadronlike: Indeed, the total photoabsorption cross section from nucleons and complex nuclei, as well as inclusive and exclusive photon induced reactions may be qualitatively and semiquantitatively understood[1] on the basis of hadronlike behaviour as formulated within the framework of ρ^o, ω, ϕ dominance.

It seems thus a fundamental question whether the concepts of hadronlike behaviour and vector dominance remain relevant and useful in the region of large spacelike $q^2 \gtrsim 1$ GeV^2 explored in deep inelastic electron scattering. Some insight into the role of vector mesons in the scaling region may be obtained by quantitatively analysing the ρ^o induced part of the cross section for moderately large $q^2 \simeq 1$ GeV^2, where nevertheless scaling sets in precociously. The ρ^o induced part of the transverse photoabsorption cross section σ_T is given by

$$\sigma_T^{\rho^o \text{induced}}(W,q^2) = \frac{1}{\left(1 + \frac{q^2}{m_\rho^2}\right)^2} \frac{\alpha\pi}{\gamma_\rho^2} \sigma_{\rho^o p} \qquad (1)$$

$$= \frac{16\,\pi}{\sigma_{\rho^o p}} \frac{d\sigma}{dt}^{t=o} (\gamma_{\text{virt.}}\, p \to \rho^o p).$$

The fall-off with q^2 according to the ρ^o pole squared is supported by ρ^o electroproduction[2]. The role of ρ^o, ω, ϕ in deep inelastic scattering is best seen by looking[3] at $\nu W_2(\omega', q^2)$ at fixed $\omega' \equiv \frac{W^2}{q^2} + 1$ as a function of q^2 in the large ω' region, where vector dominance considerations are most likely to be relevant. The data on Fig. 1 nicely show the precocious onset of scaling, which goes away completely, however, as soon as the ρ^o, ω, ϕ induced parts are subtracted. The lesson learned from this simple exercise is that vector mesons form an integral part of the scaling phenomenon. This may suggest building up the virtual forward Compton amplitude in terms of vector state forward scattering including all 1^- states produced in e^+e^- annihilation, thus naturally leading to Generalized Vector Dominance (GVD). Moreover, if alternatively unobservable pointlike constituents are introduced to explain scaling, these should apparently be viewed as being dual to observable hadronic vector states.

Having thus hopefully convinced the audience of the relevance of vector mesons even in the scaling region, let me come to GVD. The q^2 dependence of the virtual photoabsorption cross section from nucleons is viewed as being due to the propagation of hadronic vector states, i. e. we have for the transverse part

$$\sigma_T(W,q^2) = \int \frac{m^2 \tilde{\rho}(W,m^2,m'^2)m'^2}{(q^2 + m^2)(q^2 + m'^2)} dm^2 dm'^2 . \tag{2}$$

The spectral weight function $\tilde{\rho}$ contains the vector state photon couplings from e^+e^- annihilation multiplied by vector meson forward scattering amplitudes. Quantitatively successful models[5,6] have been based on the diagonal approximation, $\tilde{\rho} = \rho(W,m^2)\delta(m^2 - m'^2)$, in which ρ is given by the product

$$\rho(W,m^2) = \frac{1}{4\pi^2\alpha} \sigma_{e^+e^-}(m^2) \sigma_{Vp}(W,m^2). \tag{3}$$

$\sigma_{e^+e^-}(m^2)$ denotes the $e^+e^- \rightarrow$hadrons cross section and σ_{Vp} the total absorption cross section for a hadronic vector state of mass m. The diagonal approximation became increasingly problematic, however, as progressively higher energy data on e^+e^- annihilation became available during the last two and a half years. Let me first discuss these problems and then briefly describe a recent attempt to formulate a model within the off-diagonal framework.

Indeed, with $\rho \sim 1/m^4$ as required for scaling of W_1 and the transverse part of νW_2, and with $\sigma_{e^+e^-}(m^2) \sim 1/m^2$ the vector state absorption cross section σ_{Vp} would have to fall as $1/m^2$ as with a mass independent σ_{Vp} logarithmic divergences and linear violations of scaling are encountered. (Things become even more problematic with $\sigma_{e^+e^-} \sim$ const as indicated by the CEA[7] and SPEAR[8] data beyond about 3.5 GeV c.m. energy.) $\sigma_{Vp} \sim 1/m^2$ may be intuitively unsatisfactory and more importantly makes the validity of the diagonal approximation doubtful. Validity of the diagonal approximation with decreasing diagonal terms would require[9] $d\sigma/dm^2 < 1/m^6$ for diffraction dissociation e. g. $\rho_o p \rightarrow \rho(m)p$, and it is hard to see how projecting out the spin conserving part should reduce the empirical diffraction dissociation cross section $d\sigma/dm^2 \sim 1/m^2$ as measured for $\pi p \rightarrow Xp$ to such a tiny fraction. Furthermore, with $\sigma_{Vp} \sim 1/m^2$ the $\rho''(1600)$ photoproduction cross section should be much smaller[9] than experimentally observed.

Thus it seems natural and almost compelling to give up the diagonal form and the $\sigma_{Vp} \sim 1/m^2$ law which it engenders and formulate GVD within an off-diagonal framework, although admittedly more freedom is thus introduced into the model. Off-diagonal terms in the Compton forward amplitude correspond to interference between different ingoing vector mesons in the total photoabsorption cross section σ_T, which interference may be destructive thus allowing for $\sigma_{e^+e^-} \sim 1/s$, while keeping σ_{Vp} = const. A quantitatively successful model along these lines has been constructed by Fraas, Read and myself[9]. I will briefly describe it next.

Mainly for technical reasons the model has been formulated with a discrete spectrum of vector mesons $V_N(N=0,1,\ldots)$ chosing vector meson photon couplings such that $\sigma_{e^+e^-} \sim 1/s$ is reproduced consistent with data up to 3.5 GeV c.m. energy (Fig. 2). Moreover, negative phases are introduced by assuming $1/\gamma_N \sim (-1)^N$ for the vector meson photon couplings, motivated from negative contributions needed for the nucleon form factors and also obtained in quark model calculations[10]. As for the hadron physics, $\sigma_{\rho_N p} = \sigma_{\rho_0 p}$ independent of N is assumed, and diffraction dissociation amplitudes are introduced by a power law taking into account effective transitions to next neighbors only. Convergence of $\sigma_T(W,q^2=0) \equiv \sigma_{\gamma p}(W)$ and normalization to the observed magnitude of $\sigma_{\gamma p}$ fixes the constants in the off-diagonal diffraction dissociation type terms. The q^2 dependence is then predicted to be $(\omega' \gtrsim 8)$

$$\sigma_T(W,q^2) = \frac{\bar{m}^2}{(q^2 + \bar{m}^2)} \sigma_{\gamma p}(W), \tag{4}$$

where $\bar{m}$ is obtained to be somewhat smaller than the ρ^0 mass, $\bar{m}^2 = 0.61\, m_\rho^2 = 0.36$ GeV^2. It is amusing to note that the same formula (4) motivated from a different reasoning had previously been shown[3] to fit the data with $\bar{m}^2$ fitted to be 0.37 GeV^2 in good agreement with the value now calculated. Thus we expect good agreement with the data as demonstrated for σ_T in Fig. 3 and for the precocious approach to scaling of the transverse part of νW_2 in Fig. 4. Formula (4) also implies[1] $\omega_W \equiv (2M\nu + b^2)/(q^2 + a^2)$ [11] to be a good scaling variable, provided $a^2 \equiv \bar{m}^2$, and a^2 had indeed been obtained from fits[12] to be $a^2 \doteq 0.38$ to 0.42 GeV^2.

Let me add two comments on these results. First of all, from $\sigma_{e^+e^-}$ approximately constant as recently observed beyond 3.5 GeV, one would expect positive violations of scaling in νW_2 for large ω' and sufficiently large q^2, where scaling has not been very well tested. Indications for positive violations of scaling for large ω' are indicated by the FNAL μ experiment as reported by Hand[13] to this conference. Secondly, concerning $R \equiv \sigma_L/\sigma_T$, let me remind you of the GVD prediction[5] $R \sim \xi \ln(q^2/m_\rho^2)$ (for q^2, W^2 large, $\omega' \gtrsim 10$) with $\xi \equiv \sigma_{\rho^o p}^{\text{long.}}/\sigma_{\rho^o p}^{\text{transv.}}$ which prediction is also valid in the off-diagonal framework. It is of great interest in this connection that larger values of R than the previously reported average of $R \cong 0.18$ seem not to be excluded by the data[14] anymore, especially for large values of $\omega' \gtrsim 10$.

The influence of off-diagonal transitions has also been investigated[15] for ρ^o electroproduction. Although changes for $t = 0$ relative to simple ρ^o dominance are small, off-diagonal terms may be responsible for possible changes of the ρ^o slope with increasing q^2. We conjecture that a possible flattening of the ρ^o slope with q^2 ("photon shrinkage") is related to observed differences in slope between elastic hadron hadron scattering and diffraction dissociation. For details I have to refer to ref. 15, but I would like to show a quantitative result on Fig. 5.

Finally let me add a remark on shadowing in complex nuclei. Fig. 6 shows the result of a recent DESY experiment[16] contributed to this conference, in which the existence of shadowing has been shown for the first time for forward Compton scattering. The situation is less clear for $q^2 > 0$ as investigated in inelastic electron scattering. As ρ^o meson electroproduction has been observed for $q^2 > 0$, we expect shadowing as quantitatively[17] shown on Fig. 7*. Unfortunately data with small errorbars are available at rather low energies only, where the effects to be expected are small. New data from NINA (Fig. 8) do not show shadowing for $q^2 > 0$. The theoretical expectations of Fig. 7 could be changed, if rapid phase changes occur with increasing q^2 or if ρ^o electroproduction would fall off considerably faster than expected from ρ^o dominance. Anyway, further data on inelastic electron scattering from complex nuclei for small q^2 but at high energies ($\gtrsim$ 15 GeV) would certainly help to clarify the situation.

*Note added in proof: G. Grammer pointed out at the Erice summerschool 1974 that recent as yet unpublished work by D. Yennie and by himself shows shadowing to emerge, if additional radiative corrections are taken into account.

In conclusion, let me collect some of the main points which have been made:

1. The low lying vector mesons ρ^o, ω, ϕ form an integral part of the scaling phenomenon. Without the ρ^o, ω, ϕ induced part of the photo-absorption cross section scaling is no longer precocious.

2. Off-diagonal GVD allows for $\sigma_{e^+e^-} \sim 1/s$ together with reasonable hadron physics. Precocity of scaling naturally follows from the smallness of the mass parameter, which sets the scale and is computed to be $\overline{m}^2 = 0.61\ m_\rho^2$. $\sigma_{e^+e^-} \sim \text{const}$ creates problems and may lead to positive scaling violations for large ω' for q^2 sufficiently large.

3. Off-diagonal transitions are able to explain possible "photon shrinkage" effects in vectormeson electroproduction.

4. Further search for higher mass vector mesons, comparison of $e^+e^- \rightarrow$ hadrons with diffractive photo- and electroproduction in the 100 GeV energy range and more data on large ω' deep inelastic scattering will be important to provide further tests of GVD in the near future.

References

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18) J. Bailey et al., Contribution to this conference.

Figure Captions

Fig. 1 The transverse part of the proton structure function as a function of q^2 for fixed ω' (from ref. 3). For the purpose of the discussion given here curves (a) and (b) only are important, (a) as a fit to the data[4] and (b) showing the result of the ρ^o, ω, ϕ subtraction from curve (a).

Fig. 2 The e^+e^- annihilation cross section with the GVD curve used to predict deep inelastic ep scattering (ref. 9).

Fig. 3 Off-diagonal GVD prediction from (4) for $\sigma_T(W,q^2)$ as a function of q^2 (ref. 9) compared with SLAC-MIT data[4].

Fig. 4 The transverse part of the proton structure function νW_2 as a function of q^2 in the large ω' diffraction region showing the precocious approach to the scaling limit (compare ref. 9 for details.)

Fig. 5 The t dependence of the differential cross section for ρ electro- and photoproduction, showing how the inclusion of higher vector mesons can flatten the slope - especially for small $|t|$ and large q^2. (DESY-data[2] points and SBT photoproduction, see ref. 15 for details.)

Fig. 6 Shadowing in Compton scattering (ref. 16) as observed at DESY.

Fig. 7 Shadowing for photoproduction and inelastic electron scattering (from ref. 17).

Fig. 8 Photoproduction and inelastic electron scattering as measured at NINA (ref. 18).

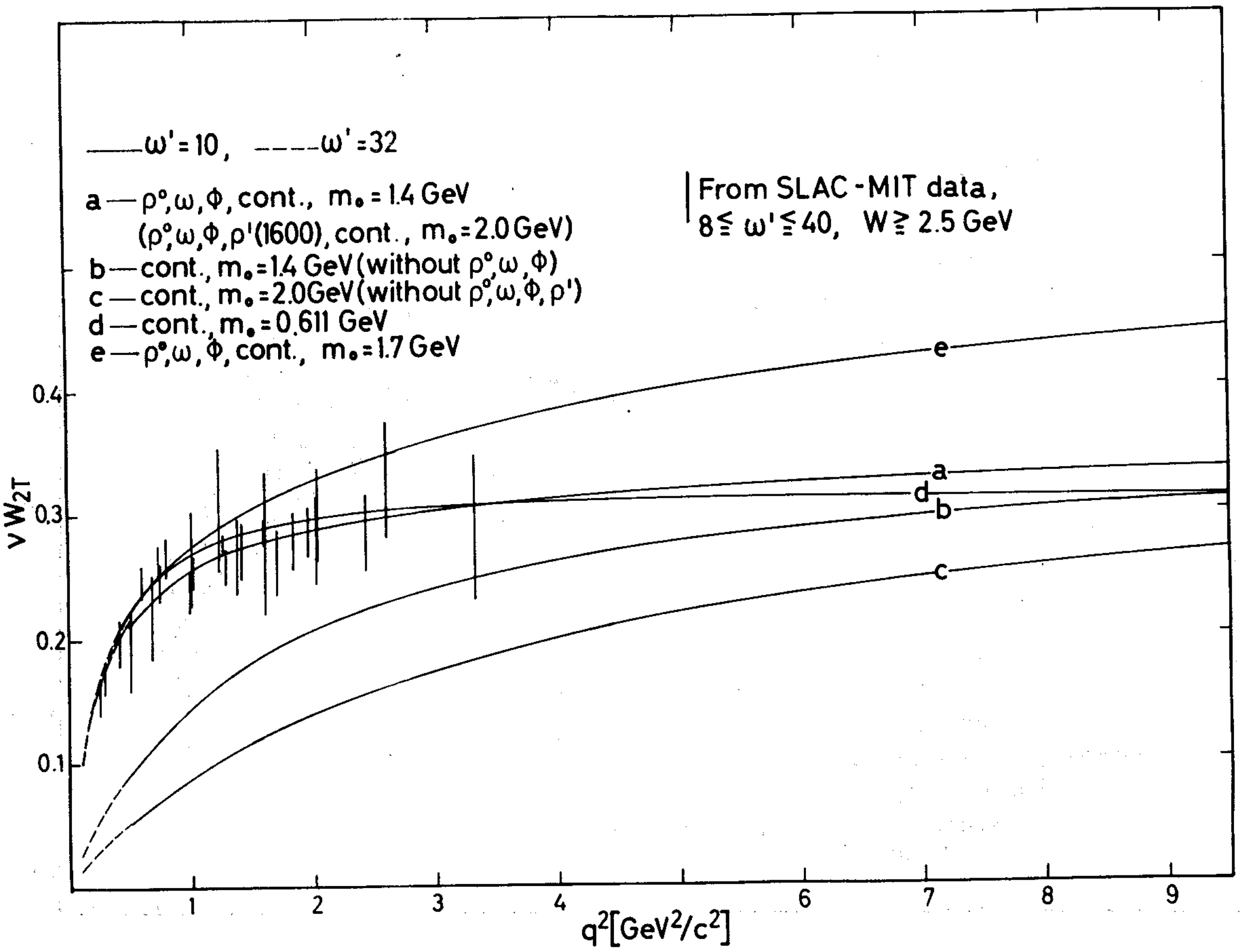

——ω' = 10, ----ω' = 32
a — ρ°, ω, Φ, cont., m₀ = 1.4 GeV
(ρ°, ω, Φ, ρ'(1600), cont., m₀ = 2.0 GeV)
b — cont., m₀ = 1.4 GeV (without ρ°, ω, Φ)
c — cont., m₀ = 2.0 GeV (without ρ°, ω, Φ, ρ')
d — cont., m₀ = 0.611 GeV
e — ρ°, ω, Φ, cont., m₀ = 1.7 GeV
From SLAC-MIT data,
8 ≦ ω' ≦ 40, W ≧ 2.5 GeV
a
b
c
d
e
ν W2T
0.1
0.2
0.3
0.4
1
2
3
4
6
7
8
9
q²[GeV²/c²]

FIG. 1

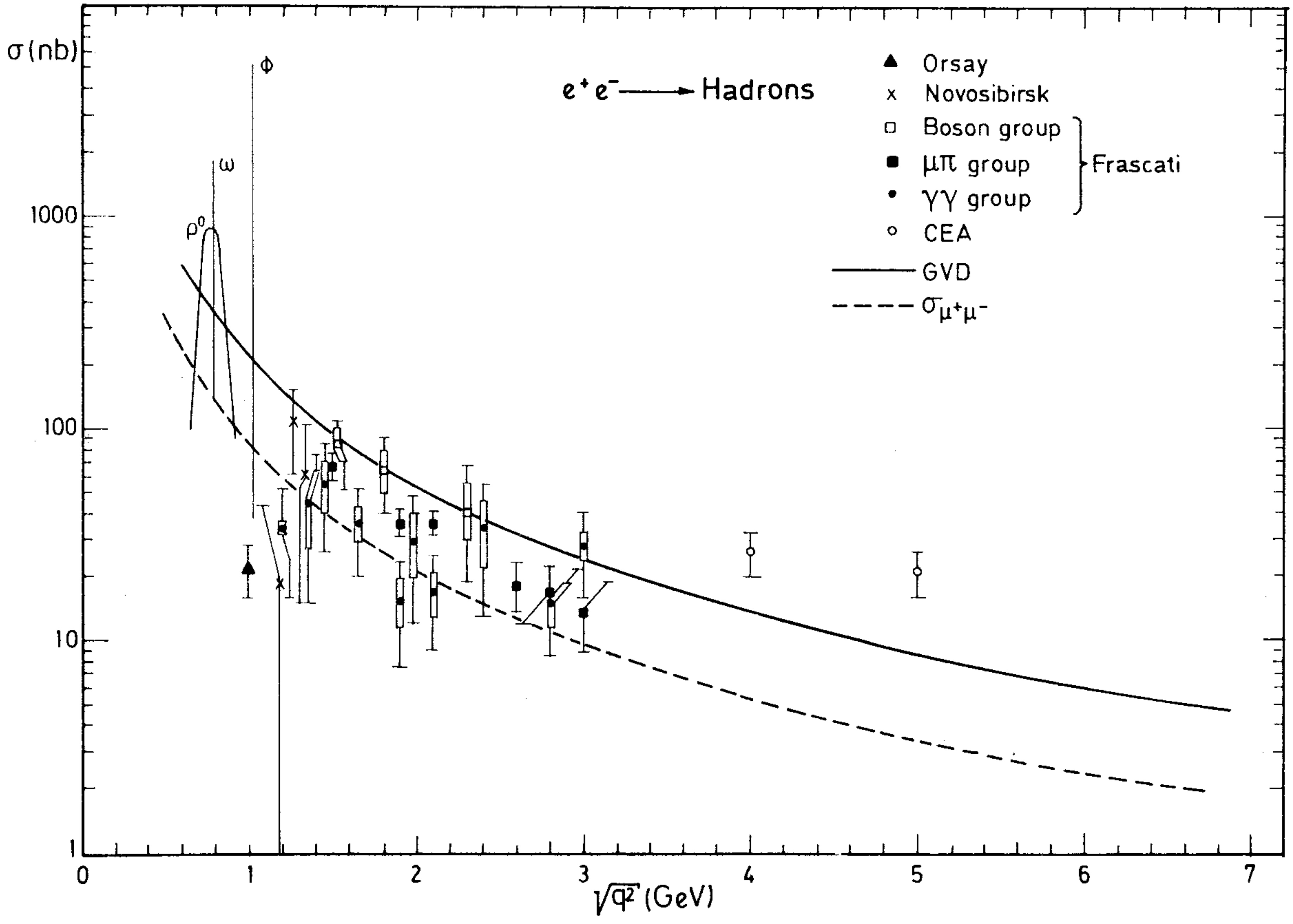

σ (nb)
e⁺e⁻ ⟶ Hadrons
Orsay
Novosibirsk
Boson group
μπ group
γγ group
Frascati
CEA
GVD
$\sigma_{\mu^+\mu^-}$
ρ⁰
ω
Φ
1000
100
10
1
0
1
2
3
4
5
6
7
$\sqrt{q^2}$ (GeV)

Fig. 2

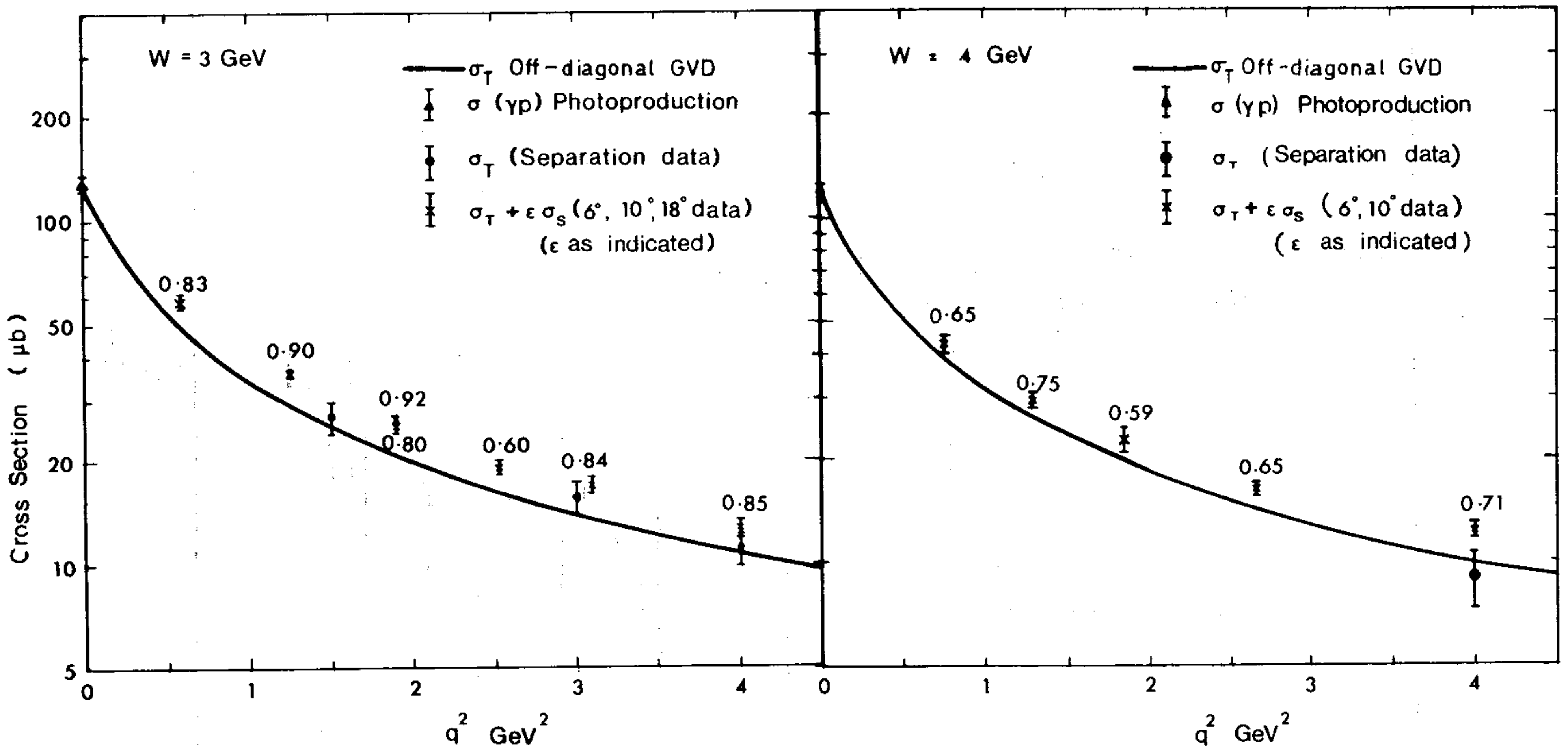

W = 3 GeV
σ_T Off-diagonal GVD
σ (γp) Photoproduction
σ_T (Separation data)
$\sigma_T + \varepsilon\sigma_S$ (6°, 10°, 18° data)
(ε as indicated)
0·83
0·90
0·92
0·80
0·60
0·84
0·85
W = 4 GeV
σ_T Off-diagonal GVD
σ (γp) Photoproduction
σ_T (Separation data)
$\sigma_T + \varepsilon\sigma_S$ (6°, 10° data)
(ε as indicated)
0·65
0·75
0·59
0·65
0·71
Cross Section (μb)
200
100
50
20
10
5
0
1
2
3
4
q^2 GeV^2

Fig. 3

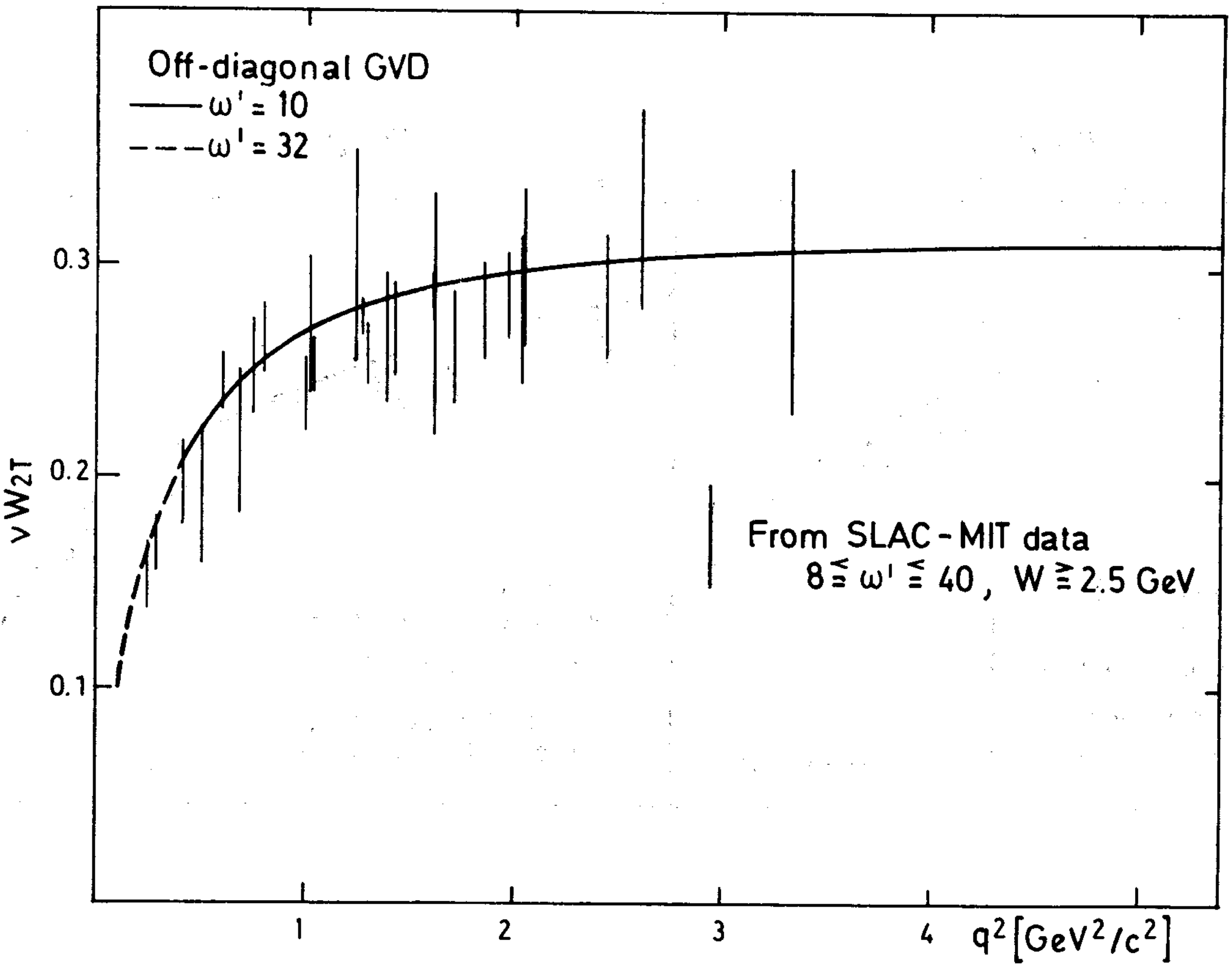

Off-diagonal GVD
$\omega' = 10$
$\omega' = 32$
From SLAC-MIT data
$8 \leqq \omega' \leqq 40$, $W \geqq 2.5$ GeV
νW_{2T}
0.3
0.2
0.1
1
2
3
4
$q^2\,[\mathrm{GeV}^2/c^2]$

Fig. 4

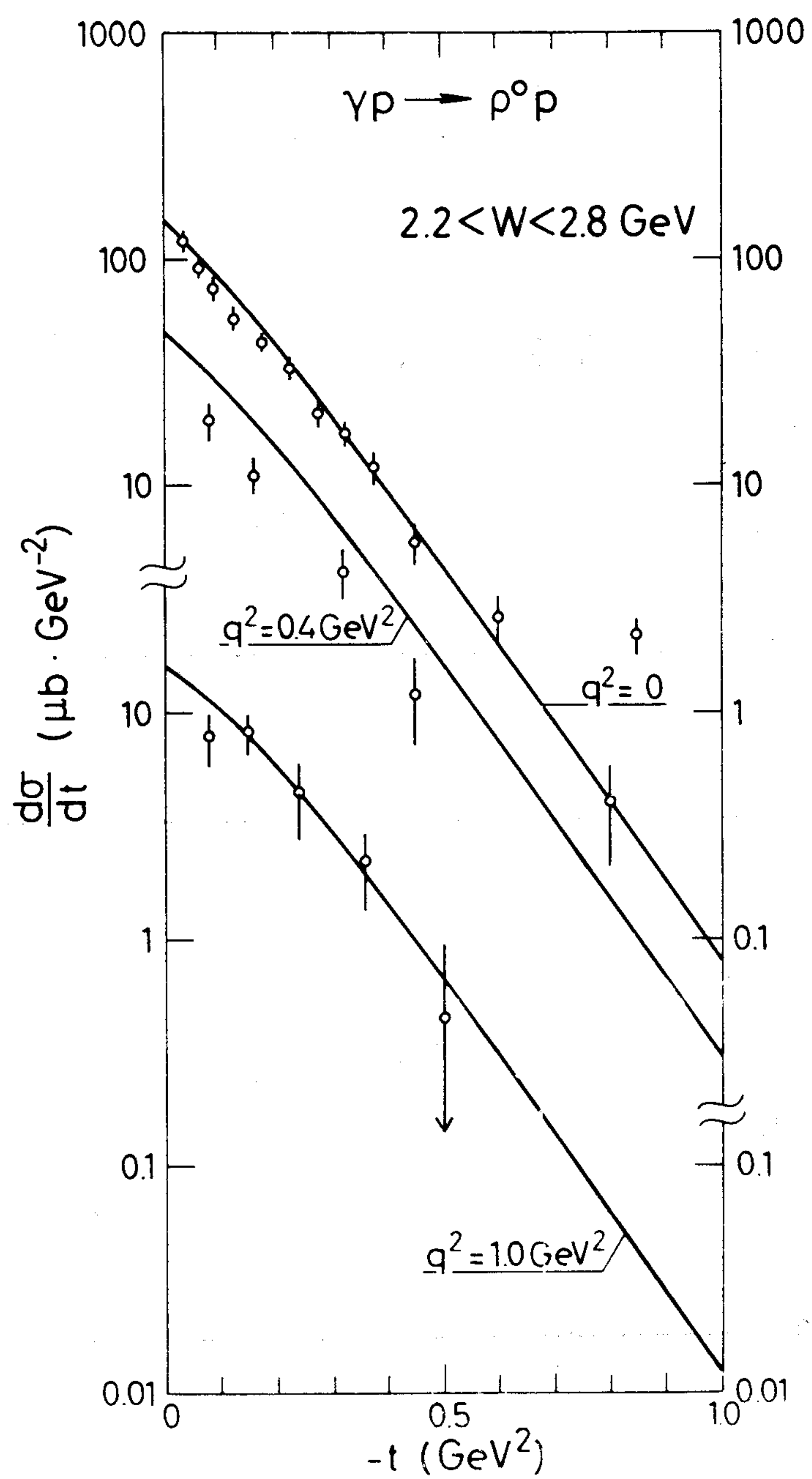

$\gamma p \longrightarrow \rho^0 p$
$2.2 < W < 2.8$ GeV
$\frac{d\sigma}{dt}$ (μb · GeV^{-2})
$q^2 = 0$
$q^2 = 0.4$ GeV^2
$q^2 = 1.0$ GeV^2
1000
100
10
10
1
0.1
0.01
1000
100
10
1
0.1
0.1
0.01
0
0.5
1.0
$-t$ (GeV^2)

Fig. 5

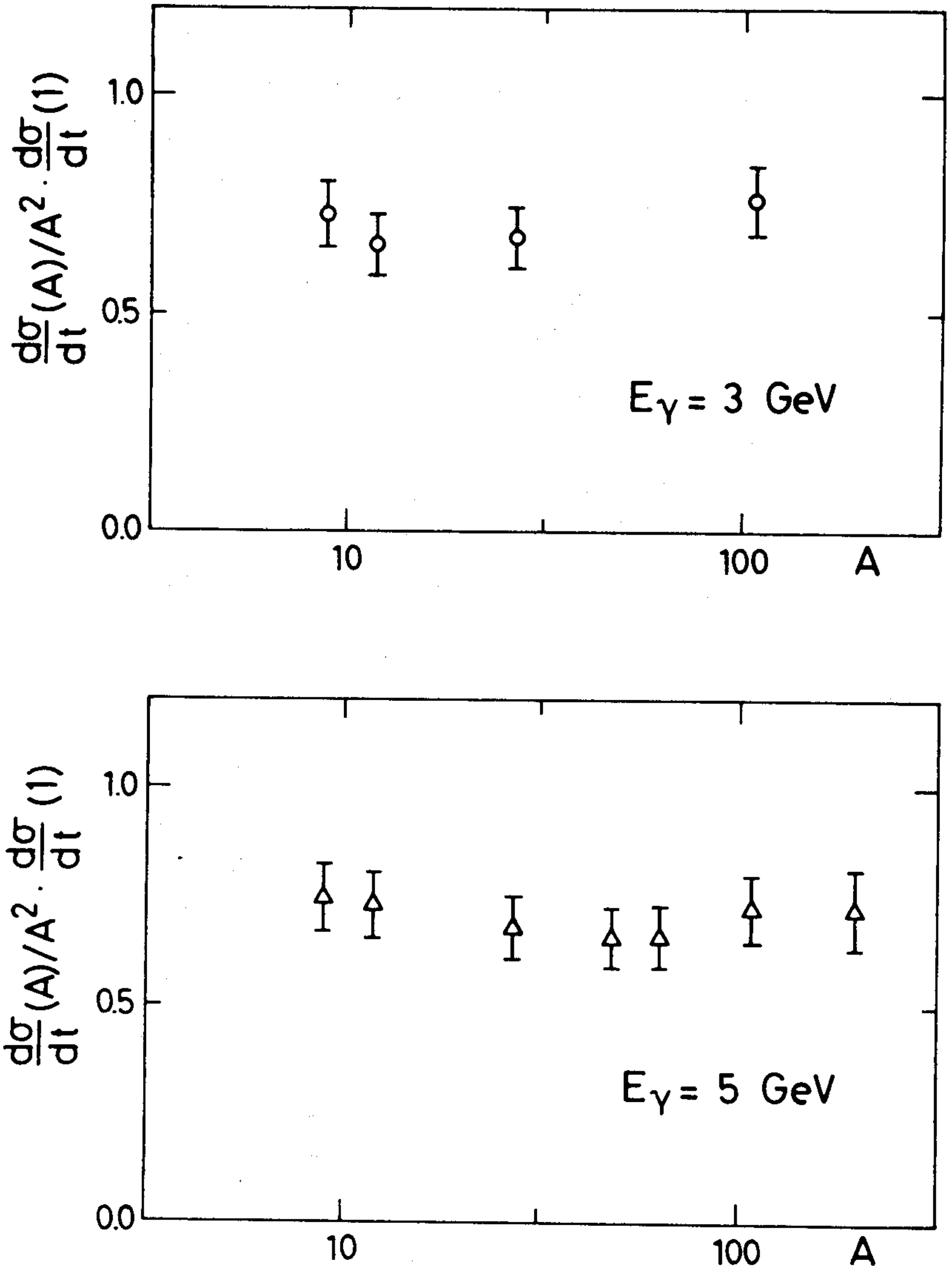

dσ/dt (A)/A² · dσ/dt (1)
1.0
0.5
0.0
10
100
A
Eγ = 3 GeV
dσ/dt (A)/A² · dσ/dt (1)
1.0
0.5
0.0
10
100
A
Eγ = 5 GeV

Fig. 6

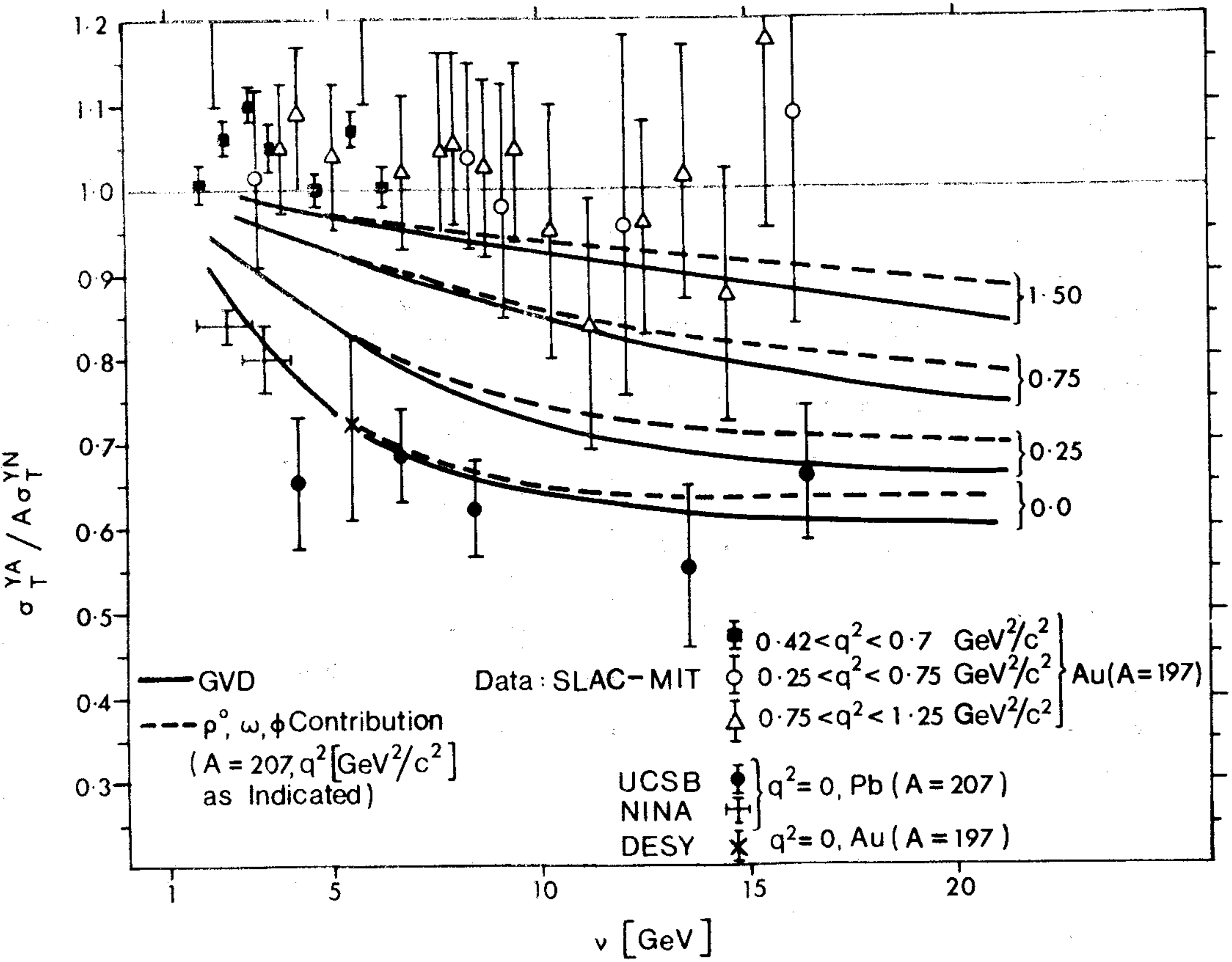
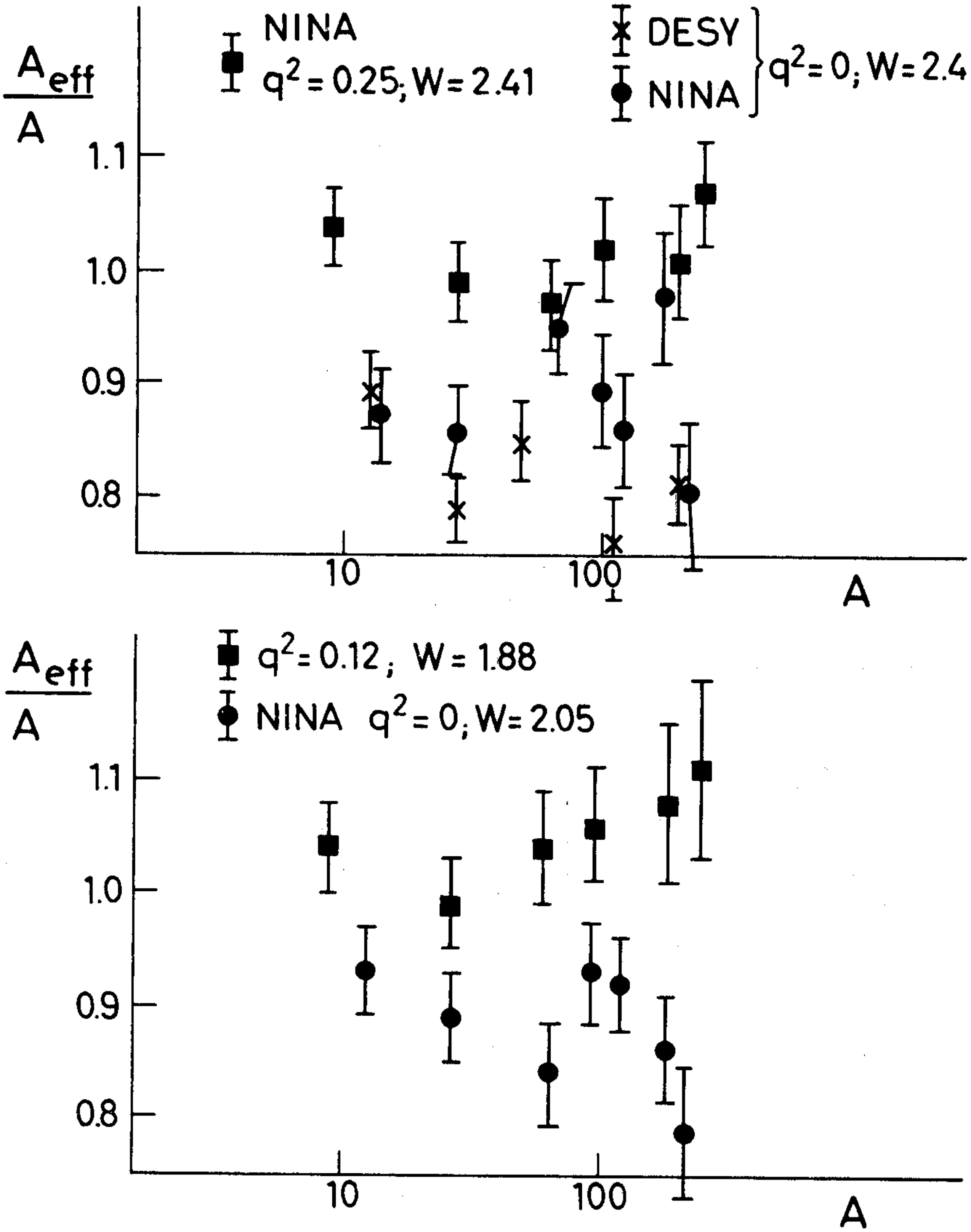

1·2
1·1
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
$\sigma_T^{\gamma A} / A\sigma_T^{\gamma N}$
1
5
10
15
20
ν [GeV]
1·50
0·75
0·25
0·0
GVD
ρ°, ω, ϕ Contribution
($A = 207, q^2$ [GeV^2/c^2] as Indicated)
Data : SLAC-MIT
$0·42 < q^2 < 0·7$ GeV^2/c^2
$0·25 < q^2 < 0·75$ GeV^2/c^2
$0·75 < q^2 < 1·25$ GeV^2/c^2
Au(A=197)
UCSB
NINA
DESY
$q^2 = 0$, Pb (A = 207)
$q^2 = 0$, Au (A = 197)

Fig. 7



NINA
$q^2 = 0.25$; $W = 2.41$
DESY
NINA
$q^2 = 0$; $W = 2.4$
$\frac{A_{eff}}{A}$
1.1
1.0
0.9
0.8
10
100
A
$q^2 = 0.12$; $W = 1.88$
NINA $q^2 = 0$; $W = 2.05$
$\frac{A_{eff}}{A}$
1.1
1.0
0.9
0.8
10
100
A

Fig. 8