DEUTSCHES ELEKTRONEN – SYNCHROTRON DESY

DESY 87-102
August 1987

A COMPREHENSIVE DESCRIPTION OF PHOTON-PHOTON TOTAL CROSS-SECTION DATA

by

E. Gotsman, A. Levy, U. Maor

Deutsches Elektronen-Synchrotron DESY, Hamburg

and

School of Physics & Astronomy, Tel-Aviv Univ., Ramat-Aviv

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY
Bibliothek
Notkestrasse 85
2 Hamburg 52
Germany

DESY 87-102
August 1987

ISSN 0418-9833

A Comprehensive Description of Photon-Photon Total Cross Section Data

E. Gotsman, A. Levy and U. Maor
Deutsches Elektronen-Synchrotron, DESY, Hamburg, Germany
and
School of Physics and Astronomy,
Tel-Aviv University, Ramat-Aviv, Israel

Abstract:
In this note we fit the total cross section of photons on photons obtained from two photon experimental data. We show that a combination of QPM cross section and an hadronic cross section, given by a simple energy power expansion modified by a threshold factor, provides an excellent reproduction of all available data.

The photon has a special role in the theory of partons and their interactions due to its two component structure. As is well known, the photon interacts with quarks either directly through its point-like coupling, or collectively through its coupling to (vector) hadrons. In a naive picture, we may study the space-time properties of the probing photon and its coupling to a target photon through a quark-antiquark pair production. We anticipate that this coupling is dominated by the target photon hadronic component at low Q^2, and by its point-like component at high Q^2. The two contributions are added incoherently at any Q^2. This naive picture does not elucidate the intricate and complex relationship between the point-like and hadronic components, the understanding of which is crucial for QCD studies of the photon structure function and the determination of the QCD scale.

The ambiguity concerning the precise contributions of the two components to the photon-photon total cross sections (and thus the target photon structure function) is not clarified when using a more sophisticated approach utilizing either the operator product expansion (OPE)[1] or the evolution equations[2]. In either approach an arbitrary cutoff is needed in order to minimize the soft contributions. As a result, a realistic estimate of the hadronic (non-perturbative) component is essentially impossible. This is a major drawback for perturbative QCD studies, since the point-like contribution to photon-photon reactions cannot be isolated even for seemingly hard processes. From a practical point of view an overall description of photon-photon total cross sections, or the photon structure functions, including the limits of low Q^2 and low x, has not yet been attained.

In this note we attempt to quantitatively assess the full contributions of these two components to the photon-photon scattering cross section. We choose to discuss cross sections rather than structure functions, since this is a more natural description of the generally ill defined hadronic sector. This enables us to include in our analysis also the quasi real $Q^2 \simeq 0$ scattering data. Our goal is to provide, for the first time, a unified description of all photon-photon cross section data[3-5], covering the complete range of available Q^2 and energy W. This is not a QCD study, and as such the standard problems associated with soft processes are evaded. As we shall show, we are able to provide a comprehensive description of the photon-photon total cross section data. By doing so we hope to set realistic low Q^2 and low x limits on the photon's two components that will assist the more fundamental studies.

In the present analysis we utilize the complete set of available PETRA data[3] with no cuts on Q^2 or W supplemented by the Novosibirsk $Q^2 \approx 0$ data[4]. We do not include the TPC/2γ data[5] in the analysis because of apparent inconsistencies that we shall elaborate upon below. Whenever available we have used the reported γ-γ cross section data. However, most of the relevant data is given in the form of the photon structure function F_2^γ. This structure function data was transformed to cross sections:

$$(1) \qquad \sigma_T^{\gamma\gamma}(Q^2, W) = \frac{4\pi^2\alpha}{Q^2} F_2^\gamma(x, Q^2)$$

assuming the Callan-Gross relation $2xF_1^\gamma = F_2^\gamma$.

Our parametrization of the point-like cross section is essentially parameter free. We utilize the observation[6] that for presently available data, the corrections imposed by QCD on the zero order QPM cross section are rather small. Our point-like cross section is given thus by:[7]

$$(2) \qquad \sigma_{QPM}^{\gamma\gamma}(Q^2, W) = \frac{8\pi\alpha^2}{(W^2+Q^2)^3}\, 3\sum \Big\{ L\Big[\frac{(W^2+Q^2)^2}{2} + 2m_i^2 W^2 - 4m_i^4 - Q^2W^2\Big] - \frac{2\Delta t}{W^2+Q^2}\Big[\frac{(W^2+Q^2)^2}{4} + m_i^2 W^2 - Q^2 W^2\Big]\Big\}$$

where

$$L = 2\ln\Big[\frac{1}{2m_i}\left(W + \sqrt{W^2 - 4m_i^2}\right)\Big]$$

$$\Delta t = \frac{W^2+Q^2}{W}\sqrt{W^2 - 4m_i^2}$$

Eq. (2) also contains the non leading QPM terms. For the quark constituent masses we use the standard values of $m_u = m_d = 300$ MeV, $m_s = 500$ MeV and $m_c = 1500$ MeV. We neglect the contributions from heavier quarks.

Our description of the hadronic cross section is motivated by our earlier success[8] in providing an economical parametrization of virtual photon-proton cross sections over a wide range of energy and Q^2. We write a cross section given by an energy power expansion, compatible with Bjorken scaling in the high Q^2 limit and with the finiteness of real γ-γ cross section in the $Q^2 \to 0$ limit. This cross section is modified by a threshold factor $\left(\frac{2q}{W}\right)^a$, which in our case reduces to $(1-x)^a$. The importance of the threshold factor for high Q^2 scattering was elaborated upon in ref. 8. Since we are dealing with relatively low energy data (W<25 GeV), we omit the high energy scale breaking term proportional to $\ln^2(s/so)$. Our parametrization of the hadronic cross section depends on four parameters and has the form

$$(3) \qquad \sigma_{HAD}^{\gamma\gamma} = (1-x)^a \left[\frac{A_1}{Q^2 + b} + \frac{A_2}{W\sqrt{Q^2+b}} \right]$$

where the two terms in Eq. (3) are associated with Pomeron and Regge t-channel exchanges. Our fits suggest that there is no need for a third term corresponding to the secondary exchanges, i.e. $\frac{A_3}{W^2} \simeq 0$. This is not surprising as the QPM cross section is dominated by a $\frac{1}{W^2}$ term, which is apparently sufficient to describe the data.

For comparison we have also examined the GVDM and VDM cross sections. These are alternative hadron sector parametrizations which are frequently used. For GVDM[9] we must introduce an energy dependence, which is not included in the model. We take:

$$(4) \qquad \sigma_{GVDM}^{\gamma\gamma} = \left(A + \frac{B}{W}\right) F_{GVDM}(Q^2)$$

where $F_{GVDM}(Q^2)$ is given in ref. 9 and A,B are fitted parameters. The fitted A and B provide an excellent reproduction of real γ-γ scattering cross section. For VDM[10] we take

(5) $F_2^{VDM} = C\ 0.2\ \alpha(1-x)$

where C is a fitted parameter. Clearly this is not a suitable parametrization for $Q^2=0$.

As stated, we shall present fits corresponding only to the PETRA data[3] taken by the CELLO, JADE, PLUTO and TASSO groups and the $Q^2\simeq0$ data from Novosibirsk[4]. We have also tried to incorporate the TPC/2γ data[5] but have consistently obtained unacceptable fits with $\frac{\chi^2}{df} \simeq 3$. Not only have we failed to establish the compatibility of TPC/2γ with PETRA data, we have been unable to obtain satisfactory fits for TPC/2γ data on its own. TPC has published an extensive set of low $Q^2<1$ GeV^2 data[5]. We were unable to achieve compatibility of this data set, with or without their $Q^2\simeq0$ data, with any of the three hadronic models considered here. The point-like background, Eq. 2, was included in one attempt and excluded in the other. Based on these extensive checks we conclude that we are unable to find a systematic allover description of TPC/2γ data on its own. As such this data is incompatible with the data obtained from the various PETRA detectors which show a remarkable systematic behaviour.

We have examined several fits to the data: A 4 parameter fit based on the sum of Eq. 2 and Eq. 3, i.e. a parameter free QPM to which we add our hadronic parametrization. The best fit has $\frac{\chi^2}{df} = 1.15$ for 68 data points, with $a = 1.25\pm0.24$, $b = 0.23\pm0.04$ GeV^2, $A_1 = 34.4\pm10.2$ nb GeV^{-2}, $A_2 = 234\pm36$ nb GeV^{-2}. The results of this fit are compared with the experimental data points in Figs. 1 and 2 and the corresponding structure function data in Fig. 3. A similar 2 parameter fit with GVDM describing the hadronic cross section (Eq. 4) gives an acceptable fit with inferior $\frac{\chi^2}{df} = 1.34$. The fitted parameters are $A = 162\pm17$ nb, $B = 323\pm59$ nb GeV^{-1}. If the hadronic sector is described by VDM (Eq. 5) we get a much poorer fit of $\frac{\chi^2}{df} = 4.6$, with a fitted $C = 0.4\pm0.1$. The VDM fit does not include the $Q^2\simeq0$ data.

Following are some comments concerning the data and the fits:

1) We have used the published data with charm contributions included. However, the CELLO published data are VDM and charm subtracted. We thus have added these contributions according to the procedure with which they were subtracted. An alternative approach, to fit the subtracted data with our model, with hadronic and charm production removed, yields equivalent results.

2) TASSO data has a bigger charm production than anticipated: Indeed, these 5 data points contribute a sizeable $\chi^2 \simeq 11$ to our overall fit. If we choose instead to examine the charm subtracted data, we obtain a much smaller $\chi^2 \simeq 0.5$, resulting in an overall improvement of our best fit to $\frac{\chi^2}{df} = 1.0$ with the same parameters.

3) When examining the TPC/2γ data, we note that their high Q^2 data with W>2 GeV are compatible with our fit. Our problems with this set of data are thus associated with low Q^2

4) We have examined the relative importance of the two photon components as a function of Q^2 and W. Our results are summarized in Table 1. Evidently, our fit interpolates well between Q^2=0 and 100 GeV^2 for all W (see also Fig. 2). However, we note that the low Q^2<1 GeV^2 data can be fitted, as well, without any QPM contribution utilizing only Eq. 3 or Eq. 4. The resulting parameters are different and such a parametrization lacks the ability to reproduce higher Q^2 data. Such fits as well as the overall fit containing QPM do not show precocious scaling as suggested by TPC[5].

5) The hadronic cross section (Eq. 3) translates into a structure function:

$$(6) \quad F_2^{HAD}(x,Q^2)/\alpha = \frac{(1-x)^a}{4\pi^2\alpha}\left[\frac{A_1}{1+\frac{b}{Q^2}} + \frac{A_2}{\sqrt{1+\frac{b}{Q^2}}}\sqrt{\frac{x}{1-x}}\right]$$

which scales in the high Q^2 limit. This structure function should be compared with the standard VDM structure function (Eq. 5) and the GVDM structure function inferred from Eq. 4.

The comparison is shown in Fig. 4. Actually, the displayed difference between the various structure functions is slightly misleading. Our fitted C = 0.4 rescales VDM down. As a result the three models do not differ much at small x, which is the only experimentally interesting x interval for small Q^2. It is the difference at medium and high x which makes the fit with Eq. 3 superior to the alternatives.

6) As is evident from Table 1, any choice of Q^2 and W (or Q^2 and x) relevant to QCD studies necessitates the inclusion of both photon components. This should be taken into account in any QCD analysis which may suppress the hadronic contributions by appropriate cuts but cannot eliminate it so as to be hadron insensitive.

To conclude: We have shown that a sum of a simple hadronic model and QPM can provide an excellent overall reproduction of photon-photon cross section over the entire experimentally available Q^2 and W range.

Acknowledgements

We wish to thank the DESY directorate for their kind hospitality and support and the Minerva Foundation for financial support which made our visit to DESY possible. Helpful discussions with Dr. J.H. Field are appreciated.

References

1) I. Antoniadis and G. Grunberg, Nucl.Phys. B213 (1983), 445;
I. Antoniadis and L. Marleau, Phys.Lett. 161B (1985), 163

2) J.H. Field, F. Kapusta and L. Poggioli, DESY 86-073 (1986)

3) CELLO Collaboration, presented by L. Poggioli at the 22nd Rencontre de Moriond, to be published (1987)
JADE Collaboration, W. Bartel et al., Z.Phys. C24 (1984), 231; Phys.Lett. 121B (1983), 203
PLUTO Collaboration, Ch. Berger et al., Z.Phys. C26 (1984), 353; Phys.Lett. 142B (1984), 111; Phys.Lett. 149B (1984), 421; Nucl.Phys. B281 (1987), 365
TASSO Collaboration, H. Althoff et al., Z.Phys. C31 (1986), 527

4) A.E. Blinov et al., Novosibirsk preprint 85-95, unpublished (1985)

5) TPC/2γ Collaboration, H. Aihara et al., Phys.Rev.Lett. 58 (1987), 97; Z.Phys. C34 (1987), 1;
D. Bintiger et al., Phys.Rev.Lett. 54 (1985), 763

6) J.H. Field, F. Kapusta and L. Poggioli, Phys.Lett. 181B (1986), 362

7) V.M. Budnev, I.F. Ginzburg, G.V. Meledin and V.G. Serbo, Phys.Rep. C15 (1975), 181

8) A. Levy and U. Maor, Phys.Lett. 182B (1986), 108

9) I.F. Ginzburg and V.G. Serbo, Phys.Lett. 109B (1982), 231

10) C. Peterson, T.F. Walsh and P.M. Zerwas, Nucl.Phys. B174 (1980), 424

Figure Captions

Fig. 1: Cross section data points (Ref. 3, 4) compared with our best fit

Fig. 2: Cross sections for different W bands against Q^2, compared with our best fit

Fig. 3: Structure function data points and our corresponding curves

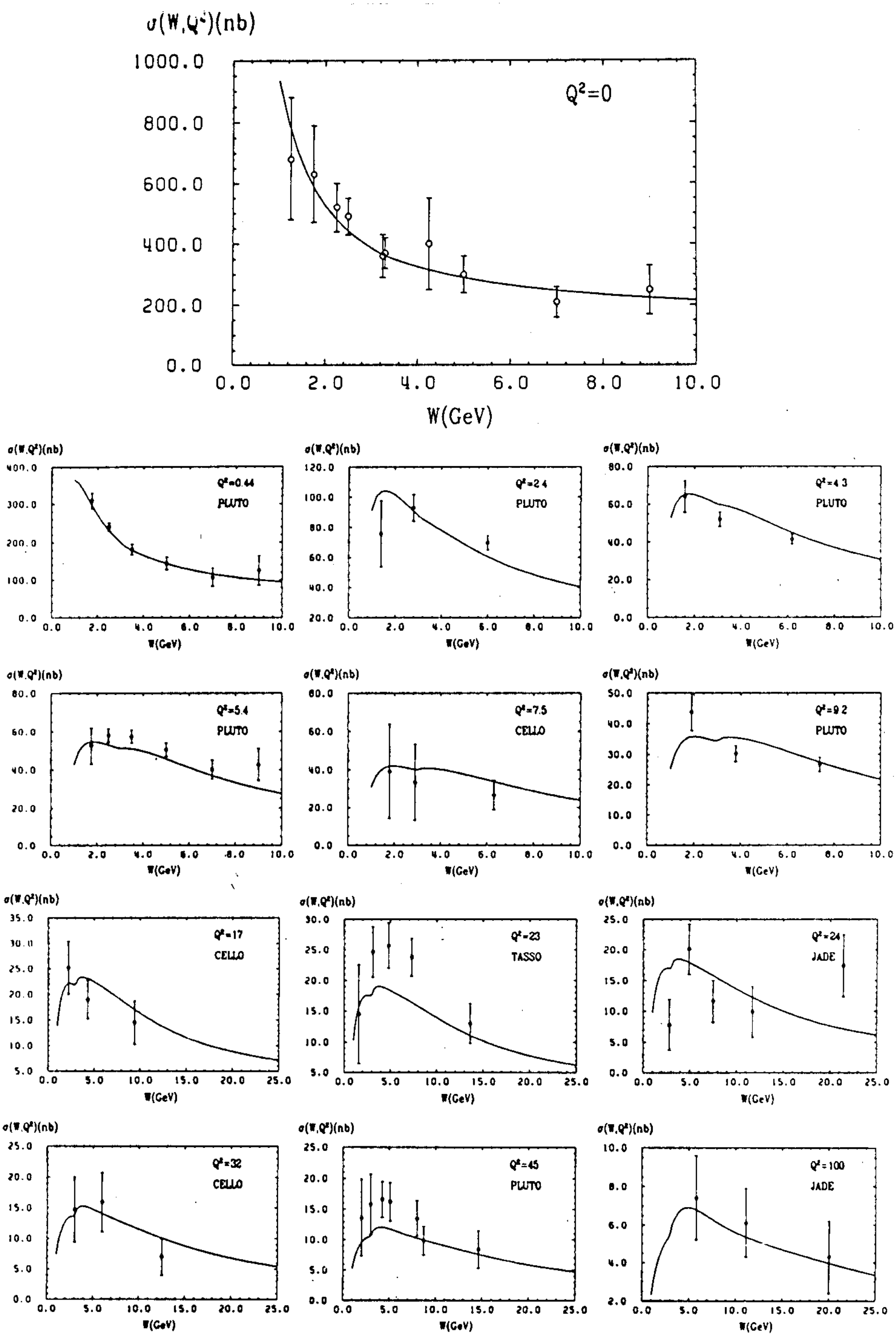
Fig. 4: Hadronic structure functions

a) Our model, Eq. 6, $Q^2 = 50\ GeV^2$ (full line);
$Q^2 = 5\ GeV^2$ (dotted line);
$Q^2 = 0.5\ GeV^2$ (dashed line),
VDM (dashed-dotted line).

b) GVDM: $Q^2 = 50\ GeV^2$ (full line);
$Q^2 = 5\ GeV^2$ (dotted line);
$Q^2 = 0.5\ GeV^2$ (dashed line).

Table 1: QPM and hadronic cross sections (in nb) for various Q^2 and W values

$Q^2(GeV^2)$	W(GeV)	2.5	7.5	30
	QPM	93.6	23.7	2.4
0	HAD	350.2	218.7	169.3
	TOT	443.8	242.4	171.7
	QPM	85.0	23.3	2.4
0.05	HAD	143.0	83.2	56.6
	TOT	228.0	106.5	59.0
	QPM	67.1	22.4	2.4
2	HAD	55.4	34.8	20.6
	TOT	122.5	57.2	23.0
	QPM	47.9	20.8	2.4
5	HAD	22.9	18.2	9.9
	TOT	70.8	39.0	12.3
	QPM	32.9	18.6	2.4
10	HAD	9.9	10.7	5.7
	TOT	42.8	29.3	8.1
	QPM	5.2	7.2	2.0
100	HAD	0.3	1.0	1.0
	TOT	5.5	8.2	3.0
	QPM	1.1	2.2	1.2
500	HAD	0.02	0.08	0.24
	TOT	1.12	2.28	1.44



σ(W,Q²)(nb)
Q²=0
W(GeV)
Q²=0.44
PLUTO
Q²=2.4
PLUTO
Q²=4.3
PLUTO
Q²=5.4
PLUTO
Q²=7.5
CELLO
Q²=9.2
PLUTO
Q²=17
CELLO
Q²=23
TASSO
Q²=24
JADE
Q²=32
CELLO
Q²=45
PLUTO
Q²=100
JADE

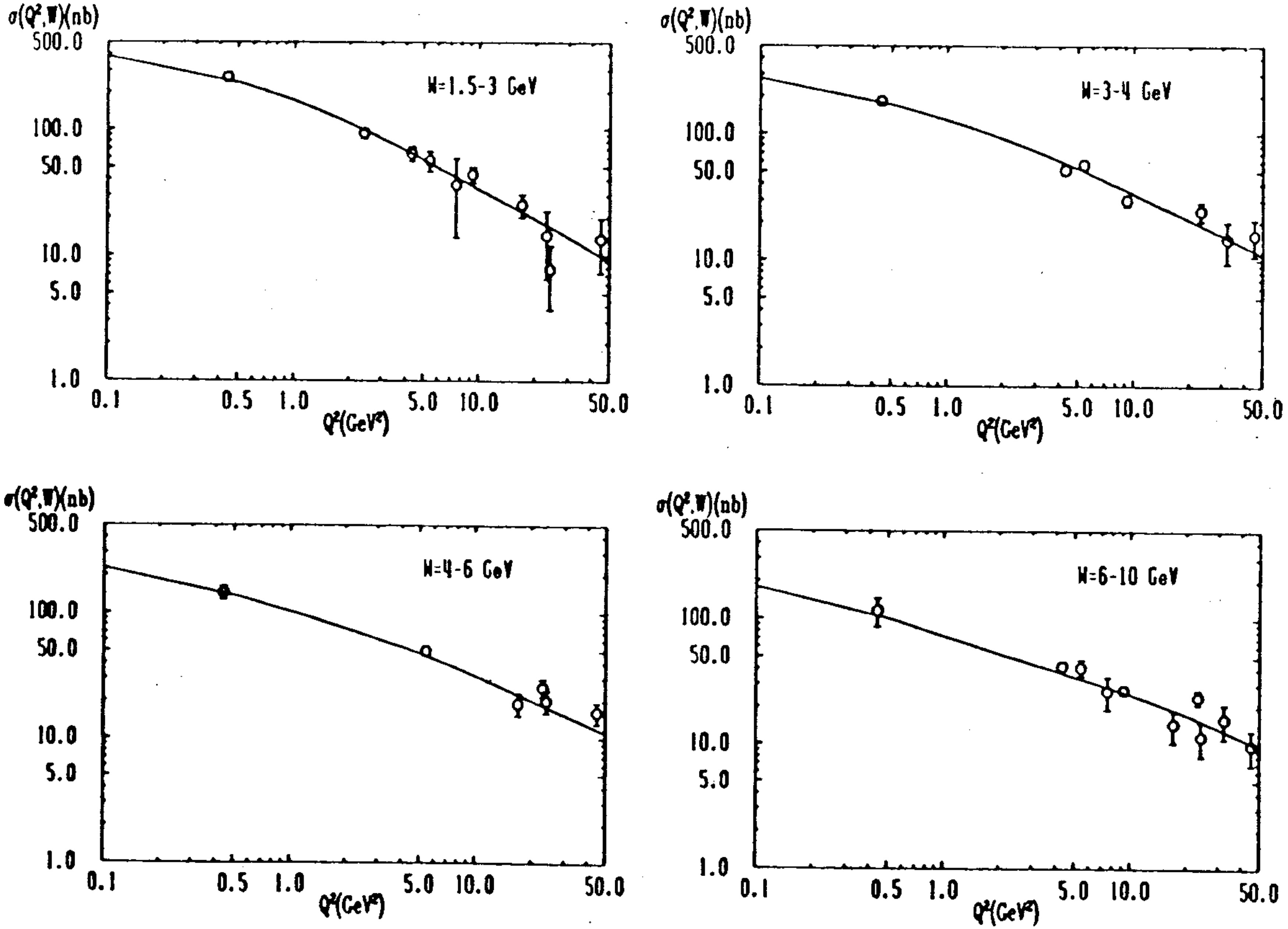
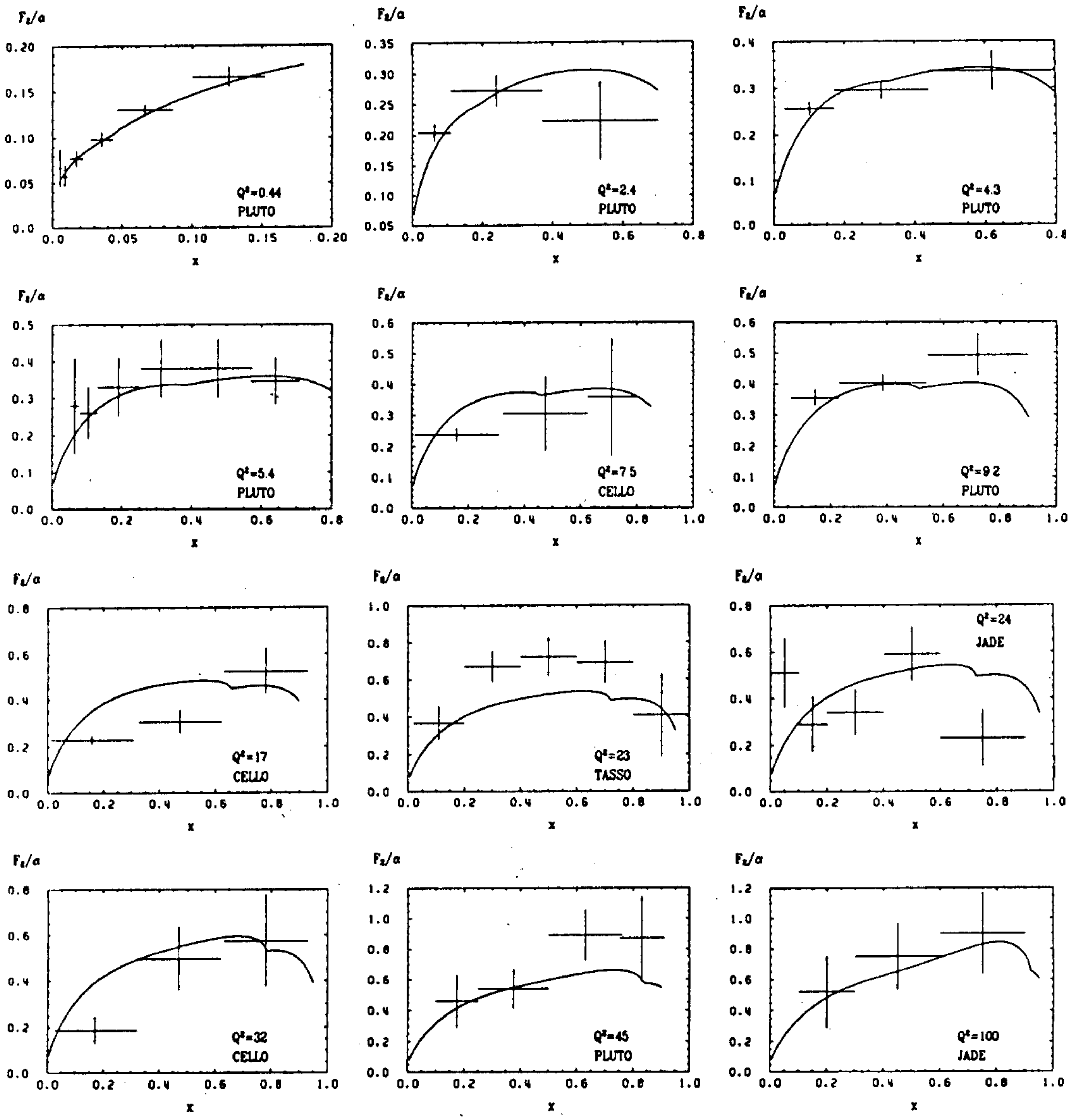
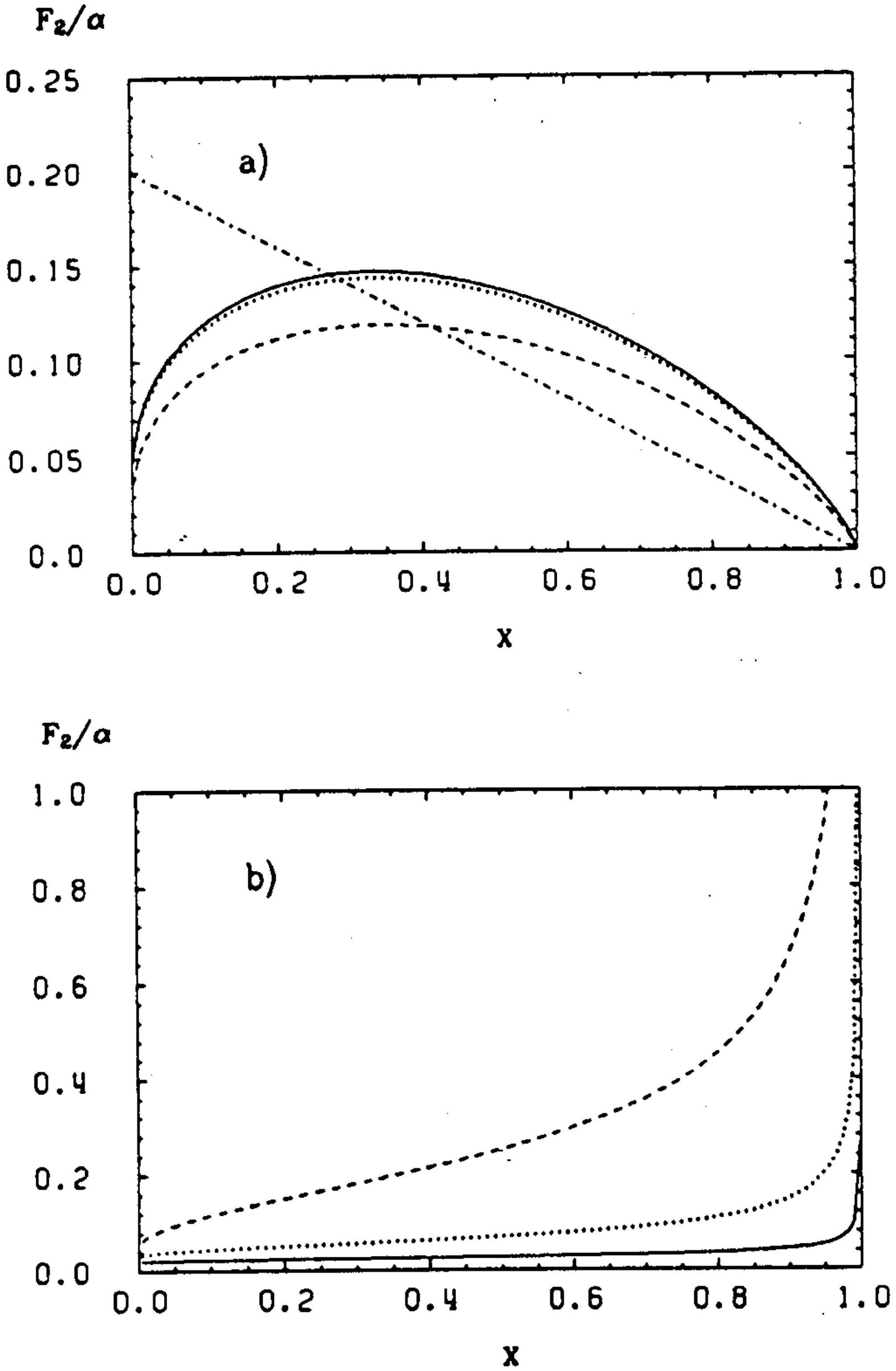

σ(Q²,W)(nb)
500.0
100.0
50.0
10.0
5.0
1.0
0.1
0.5
1.0
5.0
10.0
50.0
Q²(GeV²)
W=1.5-3 GeV
W=3-4 GeV
W=4-6 GeV
W=6-10 GeV

Fig. 2



F₂/α
Q²=0.44
PLUTO
Q²=2.4
PLUTO
Q²=4.3
PLUTO
Q²=5.4
PLUTO
Q²=7.5
CELLO
Q²=9.2
PLUTO
Q²=17
CELLO
Q²=23
TASSO
Q²=24
JADE
Q²=32
CELLO
Q²=45
PLUTO
Q²=100
JADE
x

Fig. 3



F2/α
0.25
0.20
0.15
0.10
0.05
0.0
a)
0.0
0.2
0.4
0.6
0.8
1.0
X
F2/α
1.0
0.8
0.6
0.4
0.2
0.0
b)
0.0
0.2
0.4
0.6
0.8
1.0
X

Fig. 4