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Generalized Vector Dominance and the Low q^2 μp and μd Inelastic Scattering at 150 GeV[†*]

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Abstract: The generalized vector dominance model of Greco is used to relate recent electron and muon deep inelastic scattering measurements with the photoproduction cross-section. An accurate fit of the SLAC 4° ep and ed scattering data for $\omega > 9$ is obtained giving photoproduction cross-sections in good accord with the directly measured values. The same fit applied to our recent μp and μd inelastic scattering measurements for $q^2 < 1$, gives estimates of $\sigma_{\gamma d}$ and $\sigma_{\gamma p}$ up to 130 GeV.

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Generalized Vector Dominance and the Low q^2 μp and μd Inelastic Scattering at 150 GeV

We discuss here some new measurements of the inelastic scattering of muons on protons and deuterons at 150 GeV carried out at the Fermi National Accelerator Laboratory. We limit this report to a discussion of the muon-inclusive cross-sections. We measure the two Lorentz invariant quantities, $-q^2 = (p - p')^2$ and $q \cdot \underline{P} = M\nu$, where p (p') is the 4-momentum of the incident (scattered) muon and $\underline{P}$ is the 4-momentum of the nucleon target. In the laboratory system $\underline{P} = M$, the nucleon mass and $\nu = E - E'$ is the energy loss suffered by the muon in the collision.

It is conventional to summarize the scattering in terms of two structure functions, $2MW_1\ (\omega, q^2)$ and $\nu W_2\ (\omega, q^2)$; because of the way these show how the scattering differs from what may be expected from free and pointlike constituents. In the simple parton model, once a threshold value q_o^2 is exceeded, both functions depend only on a single variable, $\omega = \frac{2M\nu}{q^2}$, and remain constant in q^2. This is the scaling region for which it is usual to write

$$\begin{aligned} \nu W_2\ (\omega, q^2) &\to F_2(\omega) \\ 2MW_1\ (\omega, q^2) &\to F_1(\omega) \end{aligned} \tag{1}$$

to emphasize the dependence on the single scaling variable ω. The characteristic behavior exhibited by (1) found in the original SLAC experiments[(1)] is the cornerstone of the parton idea.

For $q^2 < q_o^2$, usually taken to be about 1 GeV^2, it is useful to emphasize the role of the virtual photon in the scattering by expressing the cross-section as a sum of contributions from its transverse and longitudinal polarization states. Thus, following Hand[(2)], the cross-section is written

$$\frac{d^2\sigma}{dq^2 d\nu} = \Gamma\left(\sigma_T\ (q^2,\nu) + \varepsilon\ \sigma_L\ (q^2,\nu)\right) \tag{2}$$

where Γ is a flux factor which depends on the kinematic variables of the scattering and ε is the fraction of longitudinal polarization of the virtual photon, also a function of the kinematics. The advantage of writing the cross-section in this form is the connection it provides with the cross-section found for real $q^2 = 0$ photons. Thus,

$$\lim_{q^2\to 0} \quad \sigma_T\ (q^2,\nu) = \sigma_\gamma(\nu) \tag{3}$$

$$\lim_{q^2\to 0} \quad \sigma_L\ (q^2,\nu) = 0 \cdot \tag{4}$$

The total photoproduction cross-section is generally parametrized as the sum of a diffractive and a Regge term[4]

$$\sigma_\gamma(\nu) = \sigma_\gamma^{\ D} + \sigma_\gamma^{\ R}\ (\nu) = A + B\ \nu^{-\frac{1}{2}}. \tag{5}$$

The connection with νW_2 is given by the formula[1]

$$\nu W_2\ (\nu,q^2) = \frac{1}{4\pi^2\alpha}\left(\frac{2M\nu + q^2}{2M}\right)\left(\frac{\nu q^2}{q^2 + \nu^2}\right)\left(1 + R\ \theta(q^2)\right)\sigma_T(\nu,q^2) \tag{6}$$

where $\alpha = 1/137$ is the fine structure constant. Here $R = \frac{\sigma_L}{\sigma_T}$ and $\theta(q^2)$ is a step function, with value 0 for $q^2 = 0$ and 1 for $q^2 > 0$. We take $R = 0.18$ from the SLAC determinations and use the step function to guarantee the vanishing of R at $q^2 = 0$.

For $q^2 > 0$ we expect the virtual photon propagator to be dominated by vector meson effects. The idea of generalized vector meson dominance is to introduce a particular series of vector mesons so that

$$\lim_{\substack{q^2\to\infty \\ \omega \text{ fixed}}} \nu W_2(\omega,q^2) = \text{constant.} \tag{7}$$

An appropriate form has been given by Greco[4] whose functions we use to obtain an expression for $\sigma_T(\nu,q^2)$ which meets the conditions (3), (4), and (7):

$$\sigma_T(q^2,\nu) = \frac{G(1,q^2)}{G(1,0)}\sigma_\gamma^D + \frac{G(\frac{1}{2},q^2)}{G(\frac{1}{2},0)}\left(\frac{2M\nu}{2M\nu-q^2}\right)^{1/2}\sigma_\gamma^R(\nu) \tag{8}$$

$$G(\beta,q^2) = \sum_{n=0}^{\infty} \frac{(1+2n)^{1-\beta}}{\left(\frac{q^2}{m^2}+1+2n\right)^2}$$

Using this formula we have fitted the SLAC e-p and e-d data of Stein et al.[5] This is a very extensive set of data taken with high statistical accuracy. The measurements were taken at various energies from 7-20 GeV all at an angle of 4^o. We used the data with $W > 2.0$ GeV, excluding points in the resonance region. This left a set of 593 data points for hydrogen, 458 for deuterium, too many for economical computing and convenient plotting. Accordingly, we combined adjacent data points by statistical weighting into bins with $\Delta W = 0.1$ GeV. We limited our fit to values of $\omega > 9$. We deleted one point after finding that it deviated by more than 5 standard deviations from the fit. This reduced the number of points we had to fit to 56, in each case, mostly with $0.1 < q^2 < 1.0$. To avoid undue weighting of points with very small statistical errors we augmented all statistical errors by adding 2% in quadrature. This seems reasonable in view of the radiative corrections which constitute an uncertainty of this magnitude that varies appreciably over the range covered by the data.

In our analysis, we varied A, B, and m^2 for a best fit. Comparison of the photoproduction total cross-sections determined in this way with the direct measurements provides a check on the validity of the method.

The following results were obtained:

	Hydrogen	Deuterium
A	94.2 ± 2.0 μb	187.7 ± 0.8 μb
B	84.2 ± 2.7 μb $GeV^{1/2}$	121.2 ± 1.5 μb $GeV^{1/2}$
m^2	$0.766 \pm .006$ GeV^2	$0.797 \pm .003$ GeV^2
χ^2/f	0.94	0.63
RMS Deviation	2.6%	1.9%

We obtained an excellent fit to the data with χ^2/f less than 1 and an RMS deviation of the fit to the data of the same order as the experimental error. The values found for the total photo cross-section are in very good agreement with the direct measurements(6) as Figure 1 shows.

The fits are shown plotted in Figures 2 and 3 for various bands of the scaling variable ω. Since the SLAC 4° data are not necessarily given at the central value of the ω band represented, they are plotted to reflect correctly their fractional deviation from the fit. In Figure 2a and 3a for the band $9 < \omega < 14$ the points for $x = 0.1$ recently given in SLAC- MIT report of Riordan et al.(7) are also shown. All the plots show the preliminary data of our μp and μd Fermilab measurements at 150 GeV for comparison with the GVD predictions. The errors shown are statistical only and should be augmented by systematic errors of about 10% in general and more in some cases where the acceptance of our spectrometer is less well determined.

We defer to another paper the discussion of our data in the scaling region, $q^2 > 1$. Here we note that in the region $q^2 < 1$, where the vector meson dominated photon behavior is expected to prevail, our points fall close to the predicted curve. The agreement is particularly noteworthy in the band $240 < \omega < 600$ (Figures 2f and 3f) where the measurements reach q^2 values considerably less than 1. This suggests that the values of A and B obtained from our fit continue to give a good estimate of the total photoproduction cross-section up to the largest values of ν reached in our measurement, 130 GeV.

FIGURE CAPTIONS

Figure 1 - Direct measurements of $\sigma_T(\gamma d)$ and $\sigma_T(\gamma p)$ from the compilation of G. Giacomelli[6]. Solid lines are drawn to

$$\sigma_T(\gamma p) = 94.2 + 84.2\ E_\gamma^{-\frac{1}{2}}$$

$$\sigma_T(\gamma d) = 187.7 + 121.2\ E_\gamma^{-\frac{1}{2}}$$

from the fit to the SLAC[1] 4° ep and ed data.

Figures 2a-2f- The fit to the SLAC[5] 4° ep data (⧮) compared to μp at 150 GeV (✗). The larger angle SLAC data[7] is shown with (▲).

Figures 3a-3f- The fit to the SLAC 4° ed data compared to μd at 150 GeV. Same symbols as for Figure 2.

REFERENCES

1. G. Miller, et al., Phys. Rev. D5, 528(1972).
2. L.M. Hand, Phys. Rev. 129, 1834(1963).
3. E. Gabathuler, International Symposium on Electron and Photon Interactions, (1973) Bonn; North Holland, Amsterdam, (1974).
4. M. Greco, Nucl. Phys. B63, 398(1973). Fits similar to ours have been given by G.J. Gounaris, E.K. Manesis and A. Verganelakis, Phys. Letters, 59B 391(1975) and by R. Devenish and D. Shildknecht, contribution to 1975 Lepton-Photon Symposium, Stanford, California, U.S.A. To be published in Phys. Rev. D, July 1, 1976.
5. Stein et al. Phys. Rev. D12, 1884(1975) and SLAC Pub. 1528 (1975)
6. G. Giacomelli, Physics Reports 23C, 125(1976).
7. F.M. Riordan, et al., SLAC-PUB-1634, August (1975).

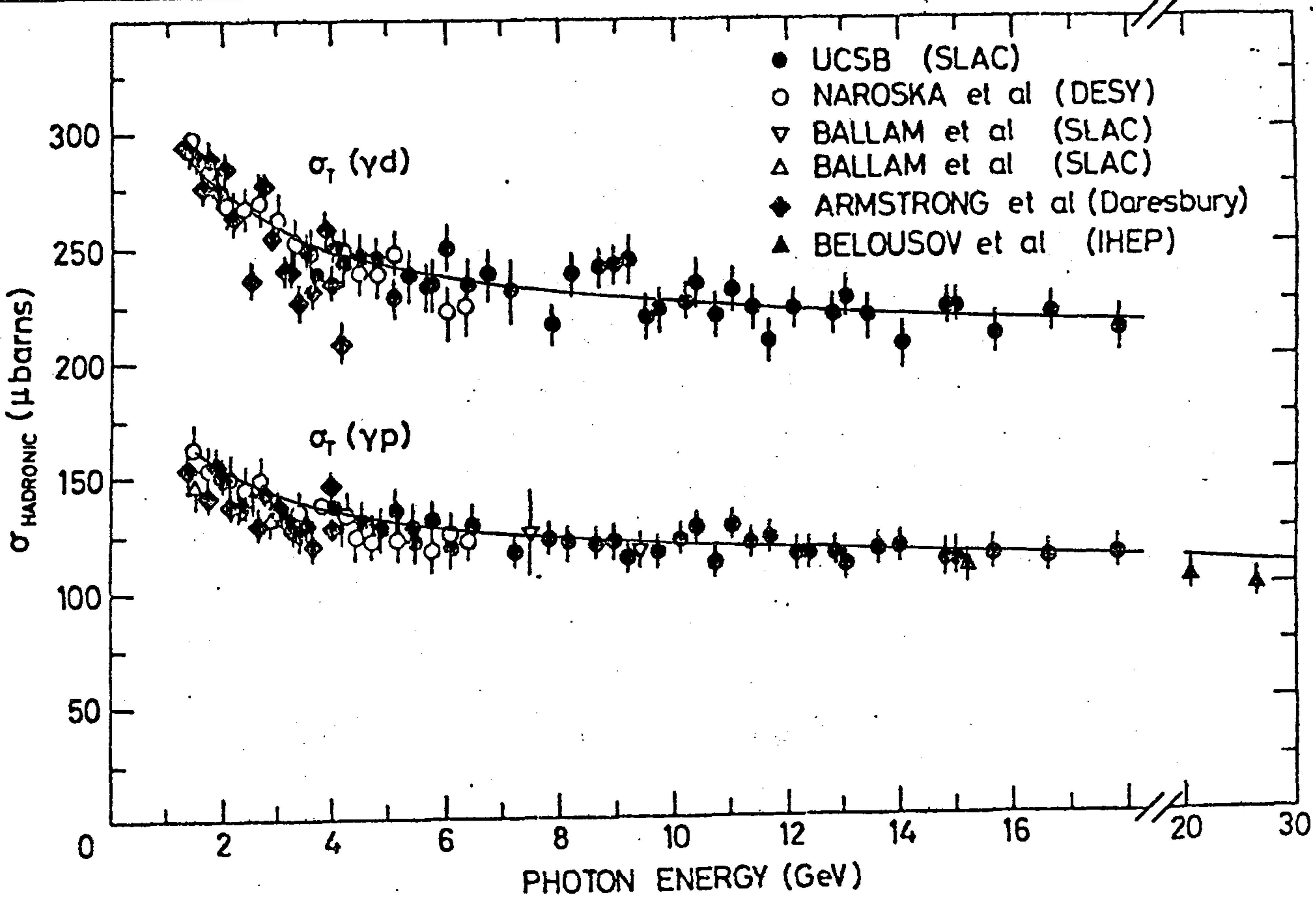
UCSB (SLAC)
NAROSKA et al (DESY)
BALLAM et al (SLAC)
BALLAM et al (SLAC)
ARMSTRONG et al (Daresbury)
BELOUSOV et al (IHEP)
σ_T (γd)
σ_T (γp)
$\sigma_{HADRONIC}$ (μbarns)
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
20
30
PHOTON ENERGY (GeV)

Figure 1

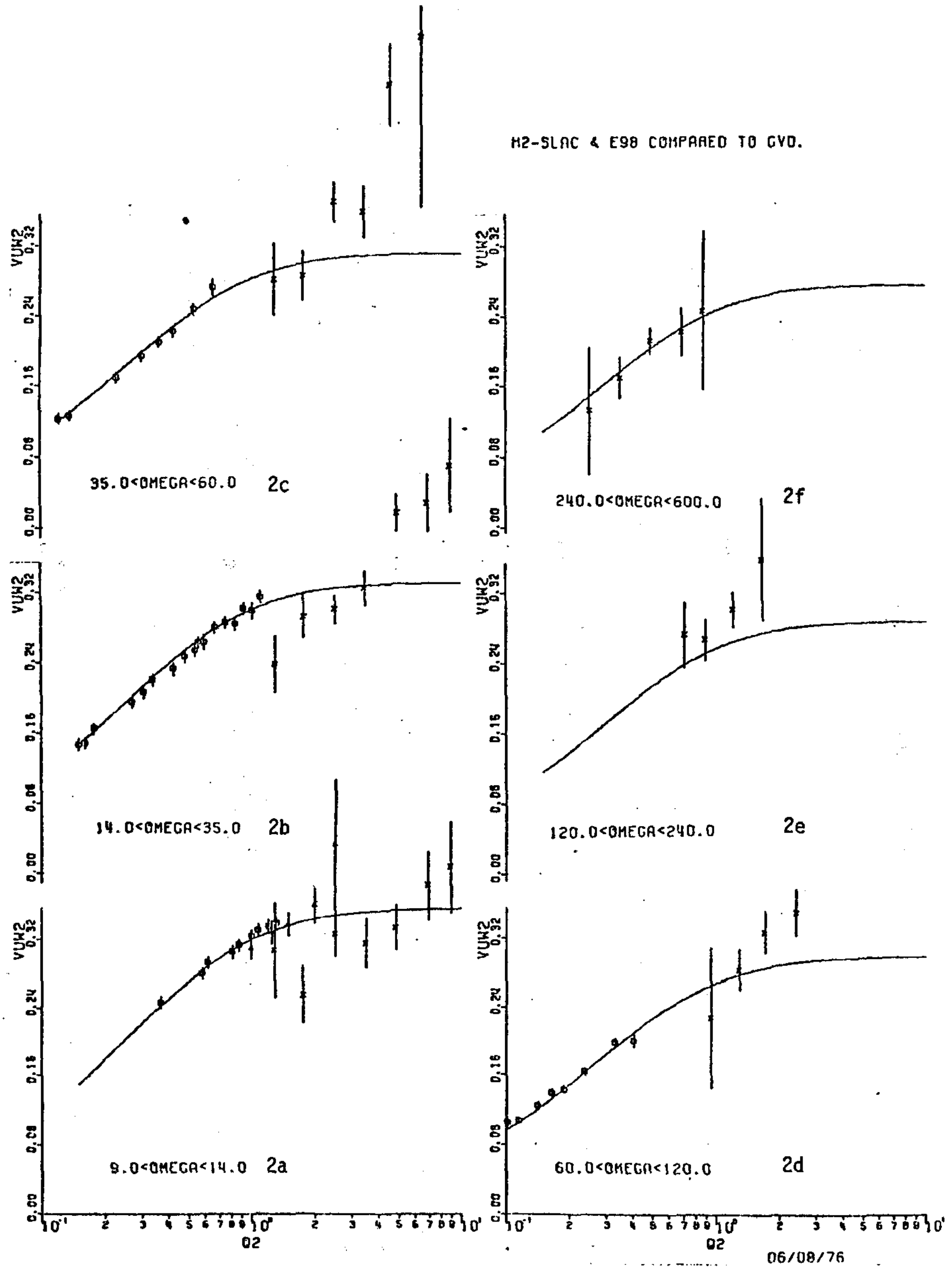
H2-SLAC & E98 COMPARED TO GVD.
VWW2
35.0<OMEGA<60.0 2c
240.0<OMEGA<600.0 2f
14.0<OMEGA<35.0 2b
120.0<OMEGA<240.0 2e
9.0<OMEGA<14.0 2a
60.0<OMEGA<120.0 2d
Q2
06/08/76

Figure 2

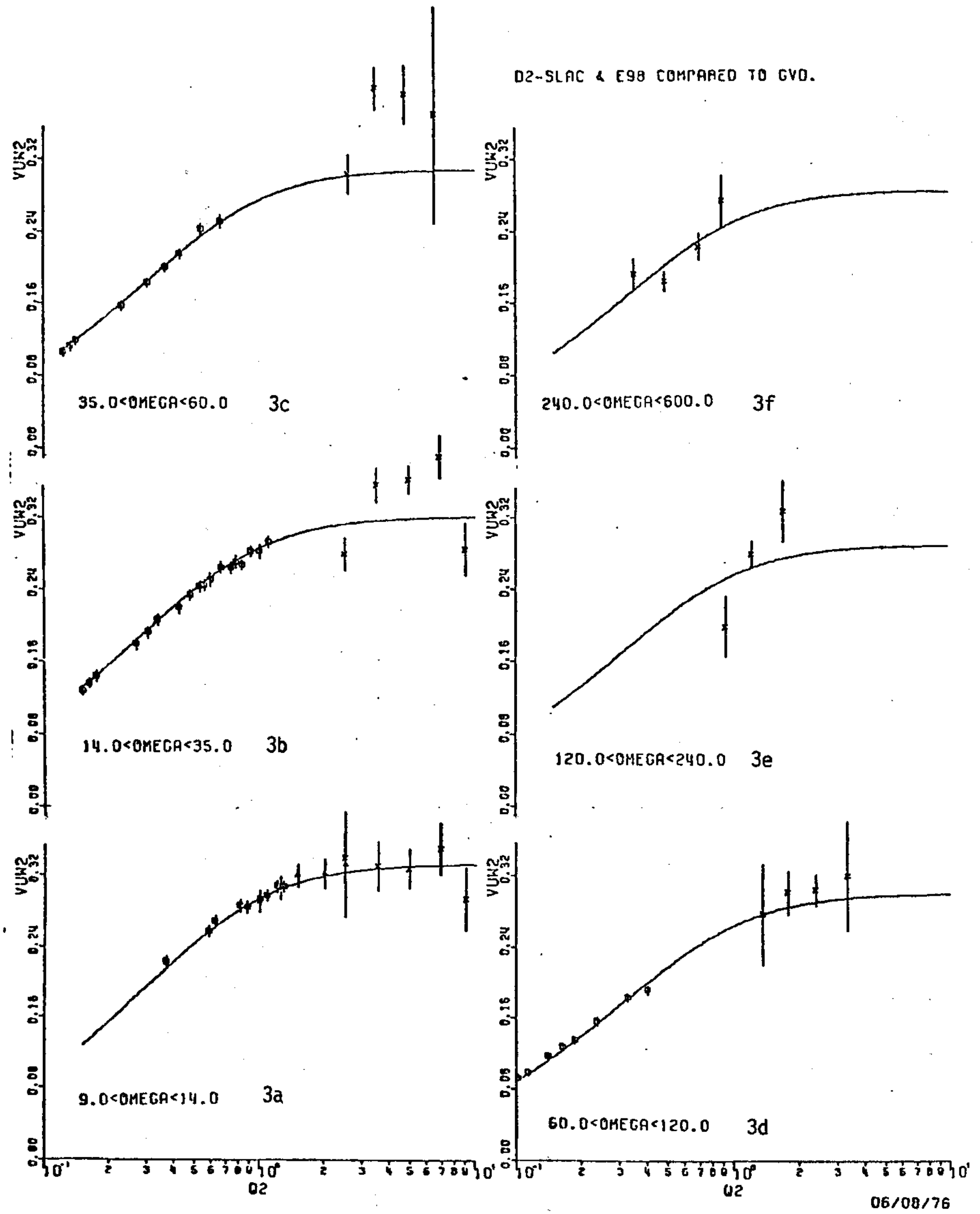
D2-SLAC & E98 COMPARED TO GVD.
VUW2
35.0<OMEGA<60.0
3c
240.0<OMEGA<600.0
3f
14.0<OMEGA<35.0
3b
120.0<OMEGA<240.0
3e
9.0<OMEGA<14.0
3a
60.0<OMEGA<120.0
3d
Q2
06/08/76

Figure 3