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THE γ-ρ^o COUPLING CONSTANT, COMPTON SCATTERING, AND TOTAL HADRONIC γ-p CROSS SECTIONS*

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ABSTRACT

A Vector Dominance Model relation, free of interference terms, has been tested to discriminate for values of the γ_ρ coupling constant in favor of $\gamma_\rho^2/4\pi = 0.52$. The diffractive part of Compton scattering is examined under a ρ-dominance assumption and compared with ρ^o photoproduction, and the behavior of $\sigma_{total}(\gamma p)$ at high energies is shown.

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Recent experimental evaluations[1] of the γ-ρ coupling constant have clustered around two values: Values which are nearest[2] to $\gamma_\rho^2/4\pi = 0.52 \pm 0.03$ as determined[4] from from e^+e^- colliding beam experiments,[3,4] and one which is obtained from recent experiments of ρ^0 photoproduction on complex nuclei as $\gamma_\rho^2/4\pi = 1.10 \pm 0.15$(5) or $\gamma_\rho^2/4\pi = 1.2 \pm 0.3$.(6)

It has been conjectured that this apparent discrepancy can be due to the fact that the smaller γ_ρ value is obtained in experiments where an intermediate photon is on the ρ^0-mass-shell, whereas the recent larger γ_ρ value is obtained in experiments where the photon is on the photon-mass-shell; thus, the existence of a q^2 dependent form factor $F_{\gamma\rho}(q^2)$ is implied.

Measurements of the total hadronic γ-p cross sections provide an independent method of determining the γ_V coupling constants at $q^2 = 0$, through a Vector Dominance Model relation first obtained by Stodolsky[7] and Sakurai.[8] Using this relation, we show that existing photoproduction data favors the lower γ_ρ value, so that a form factor of $F_{\gamma\rho}(q^2)$ is not necessary.

The Compton scattering and vector meson photoproduction scattering amplitudes are related in the Vector Dominance Model (VDM) by:

$$A(\gamma p \rightarrow \gamma p) = \sum_{v} \frac{em_v^2}{2\gamma_v} \cdot \frac{1}{m_v^2 - q^2} \cdot A(\gamma p \rightarrow V_t p) \tag{1}$$

where γ_v is a universal vector meson coupling constant, and V_t is a transversely polarized vector meson, maintaining the physical photon polarization of $\lambda = \pm 1$. Equation (1) relates the diagrams in Figs. 1a and 1b. The subscript v applies for the ρ^0, ω^0 and ϕ^0 mesons, and the γ-(vector meson) transition is taken at the off-mass-shell value of $q^2 = 0$, with a strength of $em_v^2/2\gamma_v$.

Experimental observation shows,[9] that in photoproduction of vector mesons at $\theta_{cm} = 0$, the initial photon helicity is preserved by the vector mesons; that is, the

ρ^o and ω^o mesons are produced with a predominant $\sin^2 \theta_H$ distribution, where θ_H is the helicity angle, and $\rho^H_{00}(\theta_{cm} = 0) = 0$. Hence, in the forward direction, the transversality requirement V_t of Eq. (1), already is satisfied experimentally, and need not be imposed by a transversality projection.

The total hadronic γ-p cross section is related[7, 8] to forward vector meson photoproduction by:

$$\sigma_{tot}(\gamma p) = \sqrt{4\pi\alpha} \sum_V \left[\frac{1}{1+\beta_V^2} \cdot \frac{1}{\gamma_V^2/4\pi} \cdot \frac{d\sigma}{dt}(\gamma p \longrightarrow Vp)\Big|_{t=0}\right]^{1/2} \cdot \hbar c \qquad (2)$$

where $\alpha = e^2/4\pi = 1/137$, and β_V is the ratio of real over imaginary parts of the scattering amplitude $A(\gamma p \longrightarrow Vp)$, at the forward direction.

This relation is independent of incident photon energy and should apply at all energies which are above γp s-channel resonance formation. Further, Eq. (2) has a unique property which is not easily found in VDM relations, in that it is independent of "$\rho - \omega$" type interference terms.

We apply Eq. (2) under three assumptions which are conservative in the sense that deviations from these assumptions tend toward requiring a smaller value for the γ_ρ coupling constant. These are: (a) the $\beta_V^2 = [\mathrm{Re}A(\gamma p \longrightarrow Vp)/\mathrm{Im}A(\gamma p \longrightarrow Vp)]^2$ terms are negligibly small in the forward direction, (b) the experimentally measured forward angular distributions, as given by a parametrization of $d\sigma/dt\ (\gamma p \longrightarrow Vp) = A \exp(-B|t| - Ct^2)$, are predominantly diffractive, and (c) the experimentally measured coupling constants $\gamma_V^2/4\pi$, whenever used in the scattering amplitude sum in Eq. (1), are taken to be in the relatively additive phase for all three vector mesons. We remark that in SU(3) symmetry, only the ϕ^o term would enter in the opposite[10] phase with respect to the ρ^o and ω^o terms. And with regard to assumption (b), the measured energy dependence of channel cross sections indicate that, for the case of $\gamma p \longrightarrow \rho^o p$ the assumption is well satisfied;

whereas, for the case of $\gamma p \rightarrow \omega^o p$, the nearby to forward region can have a non-diffractive part in the above parametrization which comes from a one-pion-exchange contribution. This contribution diminishes with incoming energy according to the observed cross-sectional behavior[9] of $\sigma(\gamma p \rightarrow \omega^o p) = (18.4 \pm 5.8)\ E_\gamma^{-1.6} + (1.9 \pm 0.9)\ E_\gamma^{-0.08}\ \mu b$. As it will be seen, in Eq. (2) the ω^o-term contribution is found to be at $\sim 15\%$ level and that of the ϕ^o-term at $\sim 5\%$, throughout the examined E_γ range. So that, deviations from our assumptions would require co-measurate compensation by a reduction of the γ_ρ value, to find agreement with the measured $\sigma_{tot}(\gamma p)$ cross sections.

We have used the available experimental data to evaluate the right-hand-side of Eq. (2) at 14 incident photon energy points in the range of $1.6 \leq E_\gamma \leq 17.8$ GeV. These are energy points where measurements of $d\sigma/dt(\gamma p \rightarrow \rho^o p)|_{t=0}$ exist.[12] Accordingly, we have matched to these points estimated values and errors for $d\sigma/dt(\gamma p \rightarrow \omega^o p)|_{t=0}$ and $d\sigma/dt(\gamma p \rightarrow \phi^o p)|_{t=0}$, by a smooth extrapolation of the available data[14, 15] for these channels. Here, in the absence of accurate experimental data at high energies, it may be that we have over-estimated the ω^o and ϕ^o forward photoproduction values. A recent theoretical investigation[16] of the energy dependence in the ratios of $\rho^o : \omega^o : \phi^o$ photoproduction indicates values smaller than what we have used.

The γ_ω and γ_ϕ coupling constants recently have been obtained by two independent methods: direct ω^o and ϕ^o formation in e^+e^- colliding beam experiments,[4] and by the measurement of their leptonic decay branching ratios.[1] The most recent values of $\gamma_\omega^2/4\pi = 3.70 \pm 0.7$ and $\gamma_\phi^2/4\pi = 2.75 \pm 0.4$ are obtained from the Orsay experiments.[4]

With the γ_ω and γ_ϕ coupling constants thus fixed, the VDM predictions for $\sigma_{tot}(\gamma p)$ has been obtained for the two γ_ρ values in question and the results compared with recent measurements[17,18] of the total hadronic γp cross section. Figure 2a shows this comparison.

It is seen that the existing experimental measurements of $\sigma_{tot}(\gamma p)$ (dark points) can distinguish between the two indicated γ_ρ values, in favor of $\gamma_\rho^2/4\pi = 0.52$. We wish to remark that this separation is obtained with γ_ω and γ_ϕ values measured at $q^2 = m_\omega^2$ and m_ϕ^2, respectively. The implication that γ_ω and γ_ϕ would have higher values at $q^2 = 0$, in analogy to γ_ρ, makes this discrimination even more apparent. The VDM points (open circles) carry errors propagated by all of the quantities entering in the right-hand-side of Eq. (2).

To show the relative importance of the isoscalar vector mesons in this VDM relation, the "$\omega^o + \phi^o$" term has been presented separately. Although here, where interference terms are not present, these participate at a level of 15 - 20%; it is difficult from this to deduce their effective relative importance in other VDM relations where "$\rho - \omega$" type interference terms are present.[2]

In the range of 2 - 8 GeV, the VDM prediction shows excellent agreement with the measured $\sigma_{tot}(\gamma p)$ values using the indicated $\gamma_\rho^2/4\pi = 0.52$. Accordingly, we have extended this VDM calculation to higher energies, for the benefit of current experimental efforts of obtaining the total hadronic γp cross section at these energies.

Since Compton scattering plays a fundamental role in describing processes of the type $\gamma p \rightarrow Vp$ and $Vp \rightarrow V'p$ through VDM, we proceed to estimate the diffractive part of $\sigma_{e\ell}(\gamma p)$. To convert the scattering amplitude relationship of Eq. (1) into cross sections would require, not only a knowledge of the $\sigma^{diff}(\gamma p \rightarrow Vp)$, but in addition, that of the interference terms among the ρ^o, ω^o and ϕ^o photoproduction amplitudes. The lack of measurements of these terms guide us to invoke a ρ-dominance assumption here, accordingly, $\sigma^{diff}(\gamma p \rightarrow \gamma p) = (\alpha/4)\cdot(\gamma_\rho^2/4\pi)^{-1}\cdot \sigma^{diff}(\gamma p \rightarrow \rho^o p)$.

We have estimated the diffractive part of the $\gamma p \rightarrow \rho^o p$ cross section by integrating that part of the available angular distribution data[5,9,11] which has been parametrized as $d\sigma/dt(\gamma p \rightarrow \rho^o p) = A \exp(-B|t| - Ct^2)$. Within errors, the integrated cross sections agree well with the quoted channel cross sections of $\gamma p \rightarrow \rho^o p$, indicating the predominance of diffraction in this process. Figure 2b shows the expected behavior of the diffractive Compton scattering cross section, calculated with the $\gamma_\rho^2/4\pi = 0.52 \pm 0.03$ value.

For some time, the high energy behavior of both the diffractive part of Compton scattering and the total hadronic γp cross section have caused considerable interest in view of an apparent paradox,[19] independent of VDM. It has been expected that the diffractive part of forward Compton scattering should proceed via the exchange of a single Pomeranchuk particle Regge trajectory, $\alpha_P(t)$; where $\alpha_P(0) = 1$, behaves as a vector under three dimensional space rotations. But, when the diagram in Fig. 1a is viewed in the t-channel for the process of $\gamma\gamma' \rightarrow p\bar{p}$ at $t = 0$, the two incoming photons form a system of net helicity 2, which inhibits the exchange of a single P particle. In this case, the relation of $\sigma_{tot}(\gamma p) = (4\pi/k)\, \mathrm{Im}A(\gamma p \rightarrow \gamma p)|_{t=0}$ would imply a vanishing total hadronic photoproduction cross section at high energies — which is not consistent with the results shown in Fig. 2a.

Recent experiments[20] accommodate for a Pomeranchuk Regge trajectory with a slope of $\alpha'_P(t=0) \approx 1\ (\mathrm{GeV})^{-2}$. This value is theoretically understood[21] only if multiple P exchanges in high energy hadron-hadron scattering are considered. The above paradox in photoproduction can be resolved in a similar manner.

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10. In SU(3) symmetry, the electromagnetic interactions conserve U-spin, where the photon is accepted as a singlet U-spin zero particle. Hence, a direct photon-(vector meson) transition can occur only with the U-spin singlet state of $1/2 \cdot \left[\sqrt{3}\,|\rho^o\rangle - |\phi_{(0)}\rangle\right]$, where $|\phi_{(0)}\rangle = |\phi^o\rangle \cos\lambda - |\omega^o\rangle \sin\lambda$, and λ is the mixing angle between the physical ω^o and ϕ^o isoscalar vector mesons. Taking a value of $\sin\lambda = 1/\sqrt{3}$, $\cos\lambda = \sqrt{2/3}$, from the Gell-Mann-Okubo mass formula, the photon in SU(3) is represented by $|\gamma\rangle = \sqrt{3}/2 \cdot \left[|\rho^o\rangle + 1/3|\omega^o\rangle - \sqrt{2}/3\,|\phi^o\rangle\right]$, which implies the relative phases and strengths among the $(\gamma - V^o)$ coupling constants. The phases enter directly in Eq. (2), because $\sigma_{tot}(\gamma p) = (4\pi/k)\,\mathrm{Im}A(\gamma p \rightarrow \gamma p)|_{t=0} = (4\pi/k)\sum_V (e/2\gamma_V)\,\mathrm{Im}A(\gamma p \rightarrow Vp)|_{t=0}$; where the last term is obtained from $d\sigma/dt$ by: $d\sigma/dt(\gamma p \rightarrow Vp)|_{t=0} = (\pi/k^2)\left[A(\gamma p \rightarrow Vp)\right]^2|_{t=0} = (\pi/k^2)\left[\mathrm{Im}A(\gamma p \rightarrow Vp)\right]^2 \cdot (1 + \beta_V^2)|_{t=0}$.

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FIGURE CAPTIONS

1. Diagrams for, (a) Compton scattering; (b) Vector meson photoproduction, and (c) Vector meson formation in e^+e^- colliding beams, through the Vector Dominance Model.

2. (a) Comparison of the Vector Dominance Model test (open circles) from Eq. (2), with measured $\sigma_{tot}(\gamma p)$ data, Refs. 17 and 18 (dark points); for the values of $\gamma_\rho^2/4\pi = 0.52 \pm 0.03$ (band on $\sigma_{tot}(\gamma p)$ measurements), and $\gamma_\rho^2/4\pi = 1.10 \pm 0.15$ (lower band). The "$\omega^o + \phi^o$" contribution is shown separately (lowest band).

   (b) The diffractive part of Compton scattering cross section, estimated from ρ-dominance and the $\sigma^{diff}(\gamma p \longrightarrow \rho^o p)$ values.

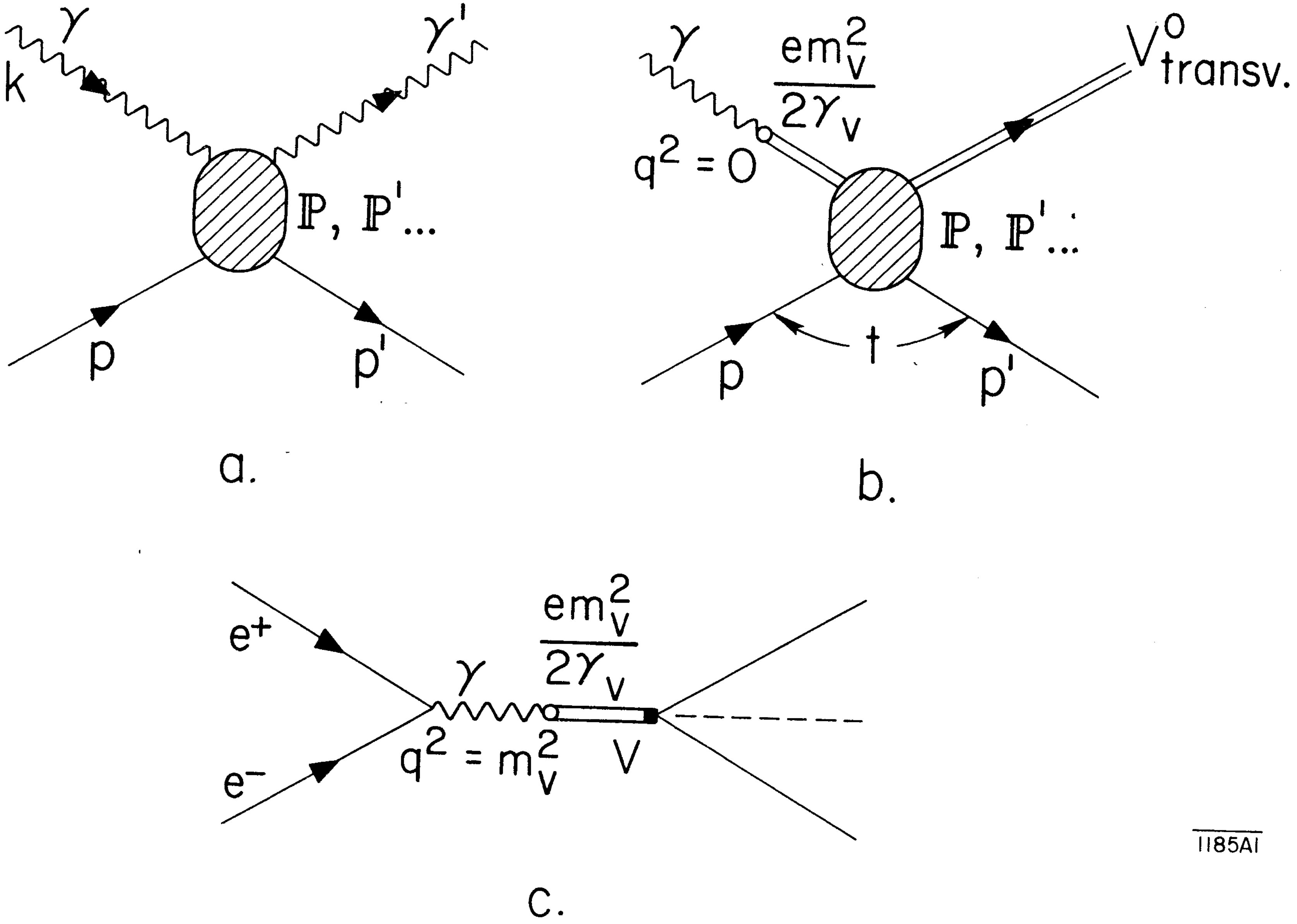
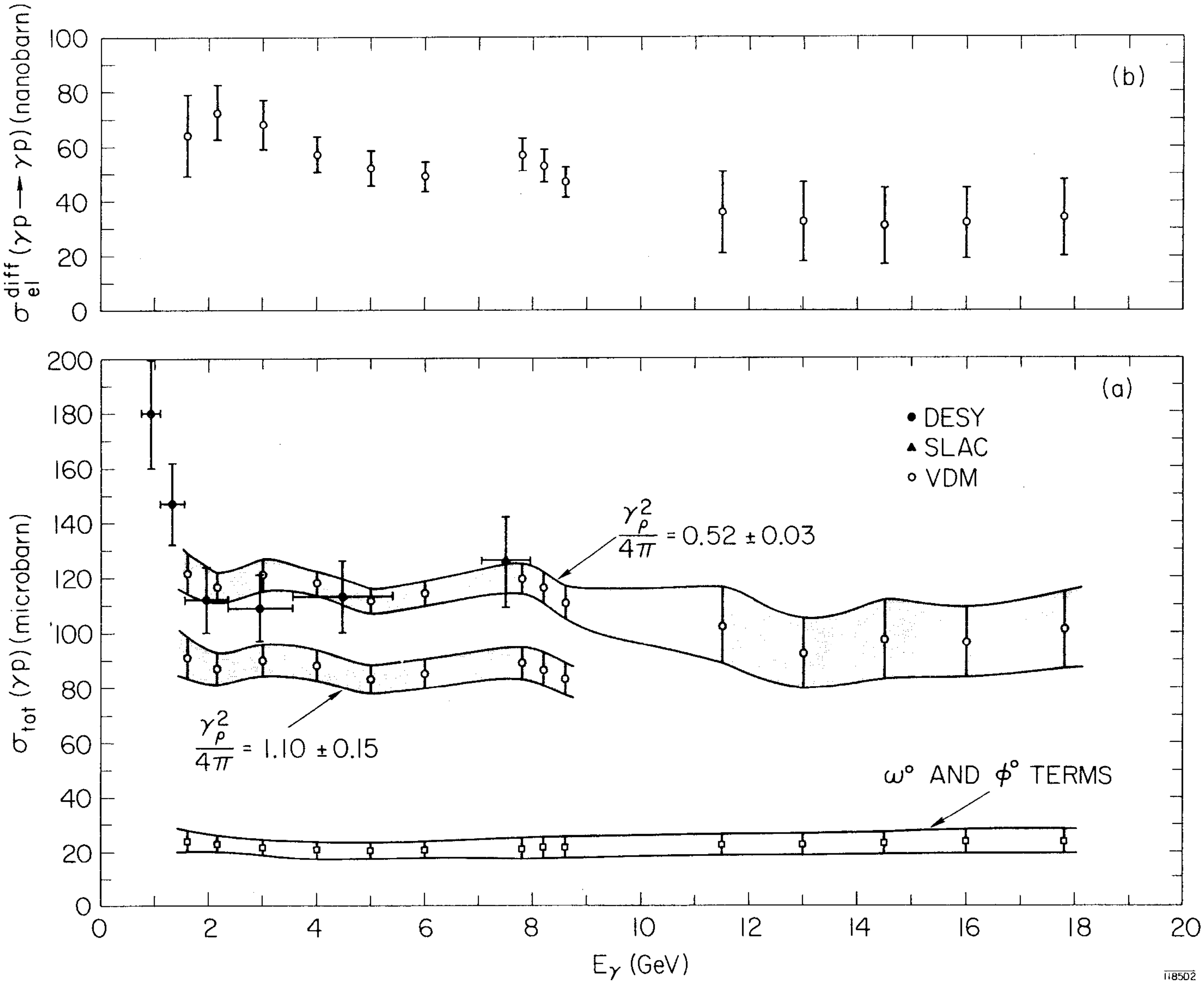

γ
γ'
k
ℙ, ℙ'...
p
p'
a.
γ
$\frac{em_V^2}{2\gamma_V}$
$V^0_{transv.}$
$q^2 = 0$
ℙ, ℙ'...
p
t
p'
b.
e^+
γ
$\frac{em_V^2}{2\gamma_V}$
e^-
$q^2 = m_V^2$
V
1185A1
c.

Fig. 1



$\sigma_{el}^{diff}(\gamma p \rightarrow \gamma p)$ (nanobarn)
100
80
60
40
20
0
(b)
$\sigma_{tot}(\gamma p)$ (microbarn)
200
180
160
140
120
100
80
60
40
20
0
(a)
● DESY
▲ SLAC
○ VDM
$\frac{\gamma_\rho^2}{4\pi} = 0.52 \pm 0.03$
$\frac{\gamma_\rho^2}{4\pi} = 1.10 \pm 0.15$
ω° AND ϕ° TERMS
0
2
4
6
8
10
12
14
16
18
20
E_γ (GeV)
118502

Fig. 2