Omega photoproduction. *

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Photoproduction of $\omega$ is analyzed within meson exchange model and Regge model and compared to $\rho$ photoproduction. An interplay between two models and uncertainties in data reproduction are discussed.

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The vector meson photoproduction at small momentum transfers $|t|$ or $|u|$ is traditionally discussed in terms of the Regge model. Recent CLAS data on $\rho$ photoproduction [1] at low $|t|$ indicate that at low energies the dominant contribution comes from $f_2$ exchanges, while at high energies [2] it is due to Pomeron exchange. ZEUS data [3] on $\rho$ photoproduction require an additional contribution from hard Pomeron exchange [2]. The $\phi$ photoproduction [4] even at low energies at small $|t|$ is dominated by Pomeron exchange because of the $s\bar{s}$ structure of the $\phi$-meson. At backward angles, where $|u|$ is small, the $\rho$-meson photoproduction is given by the exchange of nucleon and $\Delta$ Regge trajectories in the $u$ channel. The backward $\phi$-meson photoproduction is due to the $u$-channel nucleon exchange.

While $\rho$ and $\phi$ photoproduction were studied systematically, the $\omega$ photoproduction has been analyzed very selectively. It was found [5, 6] that Regge model calculation by $\simeq 26\%$ underestimate experimental data on total $\gamma+p\rightarrow\omega+p$ cross section at $E_{\gamma}\geq 20$ GeV. This discrepancy is disturbing since it is strongly believed that at high energies the Pomeron exchange should be able to describe the $\omega$ photoproduction as well as available data on $\rho$ and $\phi$ photoproduction.
Fig. 1. Figures a) and b) show total $\gamma+p\rightarrow\rho+p$ and $\gamma+p\rightarrow\omega+p$ cross section as a function of photon energy $E_\gamma$ (lower axis) or invariant collision energy $\sqrt{s}$ (upper axis). The solid line in a) shows the meson exchange calculation. The solid lines in c) indicate the Pomeron exchange calculations with cut-off parameter $\mu_0=1.1$ GeV and coupling $\beta_0=2.35$ GeV$^{-1}$, while the dashed lines are the results for $\beta_0=2.0$ GeV$^{-1}$. Figure b) shows the ratio of the total $\omega$ and $\rho$ photoproduction cross sections, the solid line is the ratio of $\omega\gamma$ to $\rho\gamma$ couplings determined by their $e^+e^-$ decay widths, while the dashed line indicates the expected SU(3) ratio.

The Pomeron exchange amplitude $T_P$ for vector meson photoproduction is explicitly given \cite{2, 5} as

$$T_P = 3F_1(t) \left( \frac{\sqrt{6}\, m_q e_q f_{\gamma V} \beta_0^2}{4m_q^2 - t} \right) (\varepsilon \cdot \varepsilon_V) s \left( \frac{s}{s_0} \right)^{\alpha_P(t)-1} \frac{\mu_0^2}{2\mu_0^2 + 4m_q^2 - t}, \quad (1)$$

where $F_1(t)$ is proton isoscalar EM form factor, $e_q$ and $m_q$ are the quark charge and mass, while $\varepsilon$ and $\varepsilon_V$ are the polarization vectors of the photon and vector meson, respectively and $f_{\gamma V}$ is the coupling constant given by $V\rightarrow l^+l^-$ decay width. Furthermore, $s$ is the squared invariant collision energy, $\alpha_P=1.08 + 0.25t$ is the Pomeron trajectory, $s_0=4$ GeV$^2$ and $\beta_0$ determines the strength of the effective Pomeron coupling to the quark, while $\mu_0$ accounts that the coupling to off-shell quark is not pointlike but dressed with the form factor given by the last term of Eq.(1).

It is clear that within the Pomeron exchange model\footnote{As well as for all models accounting for the $\gamma\omega$ and $\gamma\rho$ couplings given by their experimental dileptonic decay widths.} the ratio of $\gamma+p\rightarrow\omega+p$ to $\gamma+p\rightarrow\rho+p$ cross sections is driven by the ratio of $f_{\gamma\omega}^2/f_{\gamma\rho}^2$ coupling constants squared, which are determined by relevant dileptonic decay
widths. The experimental ratio given by $V \to e^+e^-$ decay is $0.088\pm0.005$ and it is different from the SU(3) ratio given by $1/9$.

Fig.1a) shows the total $\rho$ and $\omega$ photoproduction cross sections, while Fig.1b) illustrates the ratio $R$ of the total $\gamma + p \to \omega + p$ to $\gamma + p \to \rho + p$ cross sections. Obviously at $E_\gamma \geq 6$ GeV experimental data are consistent with $R=1/9$, but they are underestimated by 26% as compared with ratio given by experimental $V \to e^+e^-$ decay width. This discrepancy can not be addressed to the finite $\rho$ width correction [7] (factor $\simeq 1.1$) or to the standard $\rho$ vector dominance model correction [8] ($\simeq 1.25$) and still remains an open problem. One of the possible explanation is the $\rho-\omega$ mixing or $\rho N \to \omega N$ transition due to final state interaction. In that case the photoproduced $\rho$-mesons can be converted to detected $\omega$-mesons, which might account for an additional $\simeq 26\%$ for $\omega$ production rate.

Free parameters of Pomeron exchange are the Pomeron-quark coupling $\beta_0$ and form factor cut-off $\mu_0$. The coupling $\beta_0=2.0$ GeV$^{-1}$ was deduced [2] from $pp$ scattering, while $\beta_0=2.35$ GeV$^{-1}$ was obtained [9] from an analysis of $\pi p$ elastic scattering at high energies. The cut-off $\mu_0$ can be fitted to photoproduction data. The calculations by the Pomeron exchange model with experimental values $\beta_0=2.0$ GeV$^{-1}$ and $\mu_0=1.1$ GeV [2] are shown by the dashed lines in Fig.1c) and substantially underestimate experimental data both for $\rho$ and $\omega$ photoproduction. Here we used the $\gamma\omega$ and $\gamma\rho$ couplings from SU(3). The solid line show our results obtained with the coupling constant $\beta_0=2.35$ GeV$^{-1}$. Data can be as well fixed by adjusting the cut-off parameter $\mu_0=2.5$ GeV, as is illustrated by Fig.2a)-d). Here the data on differential $\gamma p \to \omega p$ cross section are compared to calculations. Obviously, the data can be well reproduced by varying both $\beta_0$ and $\mu_0$ and for this reason it is impossible to fix the Pomeron-quark coupling by photoproduction data alone.

Moreover, Fig.1b) indicates strong differences between $\rho$ and $\omega$ photoproduction at $E_\gamma \leq 6$ GeV. Substantial enhancement of $\omega$ photoproduction at $E_\gamma \leq 6$ GeV comes from the strong pion exchange contribution because the ratio of $\omega\gamma\pi$ to $\rho\gamma\pi$ coupling constants squared accounts for $\simeq 5.8$. The solid lines in Fig.1a) and Fig.2e) show the calculation [6] with meson exchange model, which as well includes $\pi$, $\eta$, $\sigma$ and $N$ exchanges. Our calculations well reproduce the data at $E_\gamma \leq 5$ GeV and indicate that this energy range can be entirely addressed by the standard meson exchange approach. Apparently, low energy data can be well fitted by Regge model with inclusion of $\pi$ and $f_2$ exchanges as is shown by the dashed line in Fig.2e).

Finally, the data on $\omega$ photoproduction at high energies can be well reproduced by Regge model when readjusting the Pomeron exchange amplitude parameters. However within the same set of parameters and with experimental $\gamma\omega$ and $\gamma\rho$ couplings it is not possible to describe simultaneously
Fig. 2. Figures a)-d) show differential $\gamma+p\to\omega+p$ cross section as a function of four momentum transfer squared at different photon energies. The lines show the calculations by Pomeron exchange with parameters: $\beta_0=2.0$ GeV$^{-1}$, $\mu_0=1.1$ GeV -dotted, $\beta_0=2.35$ GeV$^{-1}$, $\mu_0=1.1$ GeV -dashed and $\beta_0=2.0$ GeV$^{-1}$, $\mu_0=2.5$ GeV -solid. Figure e) shows the energy dependence of the total $\omega$ photoproduction cross section. Solid line is the meson exchange calculation, while the dashed line shows the Regge model result obtained with $\pi$, $f_2$ and soft and hard Pomeron exchanges.

$\omega$ and $\rho$ photoproduction data. Data on $\omega$ photoproduction at $E_{\gamma}\leq 5$ GeV indicate a substantial contribution from meson exchange reactions and can be well reproduced by calculations with $\pi$, $\eta$, $\sigma$ and $N$ exchanges [6].

REFERENCES

[1] M. Battaglieri et al., Phys. Rev. Lett. 87, 172002 (2001).
[2] A. Donnachie and P.V. Landshoff, Phys. Lett. B 348, 213 (1995); Nucl. Phys. B 311, 509 (1988); Phys. Lett. B 470, 243 (1999).
[3] J. Breitweg et al., Eur. Phys. J. C 1, 81 (1998).
[4] E. Anciant et al., Phys. Rev. Lett. 85, 4682 (2000).
[5] J.M. Laget, Phys. Lett. B 489, 313 (2000).
[6] A. Sibirtsev, K. Tsushima and S. Krewald, nucl-th/0202083, in preparation.
[7] F.M. Renard, Nucl. Phys. B 15, 267 (1970).
[8] G. Gounaris and J.J. Sakurai, Phys. Rev. Lett. 21, 244 (1968); F. Klingl, N. Kaiser and W. Weise, Z. Phys. A 356, 193 (1996).
[9] M.A. Pichowsky and T.S.H. Lee, Phys. Rev. D 56, 1644 (1997).