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THE SMALL-ANGLE VECTOR MESON PRODUCTION BY POLARIZED PROTONS AT SPRING-8

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Abstract

Arestov Yu.I. The Small-Angle Vector Meson Production by Polarized Photons at SPring-8: IHEP Preprint 2001-4. – Protvino, 2001. – p. 3.

The helicity amplitudes of the process $\gamma_\uparrow + p_\uparrow \to (1^- \to 0^- 0^-) + p$ with polarized photons and polarized target protons are analysed at small values of the production angle θ. Large polarization asymmetries are predicted under certain kinematic conditions.

Аннотация

Арестов Ю.И. Образование векторных мезонов под малыми углами поляризованными фотонами на поляризованной протонной мишени: Препринт ИФВЭ 2001-4. – Протвино, 2001. – 3 с.

Анализируются спиральные амплитуды процесса $\gamma_\uparrow + p_\uparrow \to (1^- \to 0^- 0^-) + p$ с поляризованными фотонами и поляризованными протонами мишени при малых углах рождения θ. Предсказываются большие поляризационные асимметрии при определенных кинематических условиях.

The helicity amplitude of the exclusive processes with three particles in the final state

$$\gamma_\uparrow + p_\uparrow \;\rightarrow\; (\phi \rightarrow K^+K^-) + p \;, \tag{1}$$
$$\gamma_\uparrow + p_\uparrow \;\rightarrow\; (\rho^0 \rightarrow \pi^+\pi^-) + p \;, \tag{2}$$
$$\gamma_\uparrow + p_\uparrow \;\rightarrow\; (K^{*+} \rightarrow K^+\pi^0) + \Lambda \;, \tag{3}$$

with both polarized initial photon beam and proton target is written as

$$A^n_{bd}(s,\theta,\phi) = \sum_m T^{nm}_{bd}(\theta,\phi)\, \overset{*}{D}{}^{1}_{m0}(\phi^*,\theta^*,-\phi^*)\, f_{00} = \sum_m T^{nm}_{bd}(\theta,\phi)\, \mathrm{e}^{im\phi^*}\, d^1_{m0} f_{00}, \tag{4}$$

where n, b, d are the helicities of the real photon and both initial and final nucleons, m counts the helicity states of the produced vector meson. The right-hand side of (4) contains the helicity amplitudes T^{nm}_{bd}, the Wigner rotation functions D and/or d and the decay factor f_{00}. The angles θ^*, ϕ^* are chosen in the helicity rest system. Formula (4) is valid only if the decay products are spinless.

There are 8 amplitudes A^n_{bd} describing the process. In terms of these amplitudes the differential cross section looks like

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} \sim \sum_{nbd} |A^n_{bd}|^2. \tag{5}$$

Below f_{00} will be dropped. The total number of the amplitudes T^{nm}_{bd} is equal to $2\cdot2\cdot3\cdot2 = 24$. This number reduces to 12 due to the parity conservation properties:

$$T^{-n-m}_{-b-d}(\theta,0) \;=\; \eta_a\eta_b\eta_c\eta_d\cdot(-1)^{s_c+s_d-s_a-s_b}\cdot(-1)^{\mu_i-\mu_f}\cdot T^{nm}_{bd}(\theta,0) =\; (-1)^{\mu_i-\mu_f}\cdot T^{nm}_{bd}(\theta,0), \tag{6}$$

where $\mu_i = n-b$ and $\mu_f = m-d$, so that $\mu_i-\mu_f = (n-m)-(b-d)$. At the small scattering angle θ the relation

$$T^{nm}_{bd}(\theta,0) \sim \left(\sin\frac{\theta}{2}\right)^{|\mu_i-\mu_f|}.$$

holds. The amplitudes A are decomposed as

$$A^+_{\pm\pm} \;=\; T^{11}_{\pm\pm}\,\mathrm{e}^{i\phi^*}\,d^1_{10} \;+\; T^{10}_{\pm\pm}\,d^1_{00} \;+\; T^{1-1}_{\pm\pm}\,\mathrm{e}^{-i\phi^*}\,d^1_{-10}\,, \qquad \left[\theta^0,\ \theta^1,\ \theta^2\right],$$
$$A^-_{\pm\pm} \;=\; T^{-11}_{\pm\pm}\,\mathrm{e}^{i\phi^*}\,d^1_{10} \;+\; T^{-10}_{\pm\pm}\,d^1_{00} \;+\; T^{-1-1}_{\pm\pm}\,\mathrm{e}^{-i\phi^*}\,d^1_{-10}\,, \quad \left[\theta^2,\ \theta^1,\ \theta^0\right],$$

$$
\begin{aligned}
A^{+}_{+-} &= T^{11}_{+-}\, \mathrm{e}^{i\phi^*}\, d^1_{10} \;+\; T^{10}_{+-}\, d^1_{00} \;+\; T^{1-1}_{+-}\, \mathrm{e}^{-i\phi^*}\, d^1_{-10}\,, && \left[\theta^1,\ \theta^0,\ \theta^1\right], \\
A^{+}_{-+} &= T^{11}_{-+}\, \mathrm{e}^{i\phi^*}\, d^1_{10} \;+\; T^{10}_{-+}\, d^1_{00} \;+\; T^{1-1}_{-+}\, \mathrm{e}^{-i\phi^*}\, d^1_{-10}\,, && \left[\theta^3,\ \theta^2,\ \theta^1\right], \\
A^{-}_{+-} &= T^{-11}_{+-}\, \mathrm{e}^{i\phi^*}\, d^1_{10} \;+\; T^{-10}_{+-}\, d^1_{00} \;+\; T^{-1-1}_{+-}\, \mathrm{e}^{-i\phi^*}\, d^1_{-10}\,, && \left[\theta^1,\ \theta^2,\ \theta^3\right], \\
A^{-}_{-+} &= T^{-11}_{-+}\, \mathrm{e}^{i\phi^*}\, d^1_{10} \;+\; T^{-10}_{-+}\, d^1_{00} \;+\; T^{-1-1}_{-+}\, \mathrm{e}^{-i\phi^*}\, d^1_{-10} \\
&= -T^{1-1}_{+-}\, \mathrm{e}^{i\phi^*}\, d^1_{10} \;+\; T^{-10}_{-+}\, d^1_{00} \;-\; T^{11}_{+-}\, \mathrm{e}^{-i\phi^*}\, d^1_{-10}\,, && \left[\theta^1,\ \theta^0,\ \theta^1\right].
\end{aligned} \tag{7}
$$

To the leading order $(\theta/2)^0$, the differential cross section is proportional to

$$
\begin{aligned}
\frac{\mathrm{d}\sigma}{\mathrm{d}t\mathrm{d}\Omega^*} \;\sim\;& \left(d^1_{10}\right)^2 \cdot \left(|T^{11}_{++}|^2 + |T^{11}_{--}|^2 + |T^{-1-1}_{++}|^2 + |T^{-1-1}_{--}|^2\right) + \\
&+ \left(d^1_{00}\right)^2 \cdot \left(|T^{10}_{+-}|^2 + |T^{-10}_{-+}|^2\right) = \\
=\;& 2\ \left(d^1_{10}\right)^2 \cdot \left(|T^{11}_{++}|^2 + |T^{11}_{--}|^2\right) + 2\ \left(d^1_{00}\right)^2 \cdot |T^{10}_{+-}|^2 \equiv \\
\equiv\;& \sin^2\theta^*\, a(s,t) \;+\; \cos^2\theta^*\, b(s,t)\,.
\end{aligned} \tag{8}
$$

So, only 3 independent helicity amplitudes T describe the zero-angle limit of the vector meson photoproduction.

The first-order contributions to the differential cross section are derived as

$$
\begin{aligned}
|A^{+}_{\pm\pm}|^2 &= |T^{11}_{\pm\pm}|^2\ \left(d^1_{10}\right)^2 + 2\,\Re\left(T^{11}_{\pm\pm}\, \overset{*}{T}{}^{10}_{\pm\pm}\, \mathrm{e}^{i\phi^*}\right)\, d^1_{10}\, d^1_{00}\,, \\
|A^{-}_{\pm\pm}|^2 &= |T^{-1-1}_{\pm\pm}|^2\ \left(d^1_{-10}\right)^2 + 2\,\Re\left(T^{-10}_{\pm\pm}\, \overset{*}{T}{}^{-1-1}_{\pm\pm}\, \mathrm{e}^{i\phi^*}\right)\, d^1_{00}\, d^1_{-10}\,, \\
|A^{+}_{+-}|^2 &= |T^{10}_{+-}|^2\ \left(d^1_{00}\right)^2 + 2\,\Re\,\overset{*}{T}{}^{10}_{+-}\ \left(T^{11}_{+-}\,\mathrm{e}^{i\phi^*} \;-\; T^{1-1}_{+-}\,\mathrm{e}^{-i\phi^*}\right)\, d^1_{10}\, d^1_{00}\,, \\
|A^{+}_{-+}|^2 &= O\left(\theta^2\right), \\
|A^{-}_{+-}|^2 &= O\left(\theta^2\right), \\
|A^{-}_{-+}|^2 &= |T^{-10}_{-+}|^2\ \left(d^1_{00}\right)^2 - 2\,\Re\,\overset{*}{T}{}^{-10}_{-+}\ \left(T^{1-1}_{+-}\,\mathrm{e}^{i\phi^*} \;-\; T^{11}_{+-}\,\mathrm{e}^{-i\phi^*}\right)\, d^1_{10}\, d^1_{00}\,.
\end{aligned} \tag{9}
$$

After a tedious algebra, one gets partial sums of the differential cross section:

$$
\begin{aligned}
|A^{+}_{++}|^2 \;+\; |A^{-}_{--}|^2 &= 2\,|T^{11}_{++}|^2\ \left(d^1_{10}\right)^2 + \ 4\, d^1_{10}\, d^1_{00} \cos\phi^*\, \Re\left(T^{11}_{++}\, \overset{*}{T}{}^{10}_{++}\right)\,, \\
|A^{+}_{--}|^2 \;+\; |A^{-}_{++}|^2 &= 2\,|T^{-1-1}_{++}|^2\ \left(d^1_{-10}\right)^2 - \ 4\, d^1_{10}\, d^1_{00} \cos\phi^*\, \Re\left(T^{-1-1}_{++}\, \overset{*}{T}{}^{-10}_{++}\right)\,, \\
|A^{+}_{+-}|^2 \;+\; |A^{-}_{-+}|^2 &= 2\,,|T^{10}_{+-}|^2\ \left(d^1_{00}\right)^2 + \ 4\, d^1_{10}\, d^1_{00} \cos\phi^*\, \Re\left(\left(T^{11}_{+-} \;-\; T^{1-1}_{+-}\right) \overset{*}{T}{}^{10}_{+-}\right)\,.
\end{aligned}
$$

Simple relations are obtained for the non-flip amplitudes:

$$
\begin{aligned}
\theta^* \;=\; 0 \text{ or } \pi\ :\quad & \frac{\mathrm{d}\sigma}{\mathrm{d}t\mathrm{d}\Omega^*} \;\sim\; 2\,\cos^2\theta^* \cdot |T^{10}_{+-}|^2\,, \\
\theta^* \;=\; \pi/2\ :\quad & \frac{\mathrm{d}\sigma}{\mathrm{d}t\mathrm{d}\Omega^*} \;\sim\; \sin^2\theta^* \cdot \left(|T^{11}_{++}|^2 \;+\; |T^{-1-1}_{++}|^2\right)\,.
\end{aligned} \tag{10}
$$

The spin correlations between photon and vector meson are described by the interference terms proportional to $\cos\phi^*$.

The polarization asymmetries are obtained from the amplitudes summed over the scattered proton helicities:

$$\frac{\mathrm{d}\sigma(n,b)}{\mathrm{d}t\mathrm{d}\Omega^*} = \sum_d |A^n_{bd}|^2 \,. \tag{11}$$

The small-angle behavior of the double-spin asymmetries can be tracked in the same manner through the relations

$$A_{\gamma\uparrow} = \frac{\mathrm{d}\sigma(+,+) - \mathrm{d}\sigma(-,+)}{\mathrm{d}\sigma(+,+) + \mathrm{d}\sigma(-,+)}\,, \tag{12}$$

$$A_{p\uparrow} = \frac{\mathrm{d}\sigma(+,+) - \mathrm{d}\sigma(+,-)}{\mathrm{d}\sigma(+,+) + \mathrm{d}\sigma(+,-)}\,. \tag{13}$$

For example, for the K^+ and K^- selected in the cones which are transverse to the vector meson momentum in its rest frame ($\theta^* \sim \pi/2$), the two-spin asymmetries are expressed as

$$A_{\gamma\uparrow} = A_{p\uparrow} = \frac{|T^{11}_{++}|^2 - |T^{-1-1}_{++}|^2}{|T^{11}_{++}|^2 + |T^{-1-1}_{++}|^2} \quad \text{at } \theta^* = \pi/2\,. \tag{14}$$

And for the selection in the cones collinear with the z^* axis, one obtains

$$A_{\gamma\uparrow} = +1\,, \quad A_{p\uparrow} = 0 \quad \text{at } \theta^* = 0 \text{ or } \pi\,. \tag{15}$$

Thus, big asymmetries can be expected in the kinematic region where the resonance products are collinear with the vector-meson momentum, in its rest frame.

Of course, some asymmetries can be suppressed by the dynamic reasons. Nevertheless, the indications given above are model-independent and they can form a specific field in the experimental studies at Spring-8.

The above formulae are not given exhaustingly and one can easily give more sophisticated relations.

The experimental study of the spin correlations allows one to extract the helicity amplitudes. Being interpreted in terms of intermediated exchanges, they allow one to judge the nucleon couplings and, in the model way, the nucleon structure.

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