QUARK FRAGMENTATION AND OFF-DIAGONAL HELICITY DENSITY MATRIX ELEMENTS FOR VECTOR MESON PRODUCTION

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As confirmed by some recent LEP data on ϕ, K^* and D^* production, final state interactions in quark fragmentation may give origin to non-zero values of the off-diagonal element $\rho_{1,-1}$ of the helicity density matrix of vector mesons produced in e^+e^- annihilations: we give estimates for $\rho_{1,-1}$ of vector mesons with a large x_E and collinear with the parent jet, relating its size and sign to the associated hard constituent dynamics. We mention possible non-zero values of $\rho_{1,-1}$ in several other processes.

Due to final state interactions and a coherent $q\bar{q}$ fragmentation process, the off-diagonal matrix element $\rho_{1,-1}$ of vector mesons inclusively produced in e^+e^- annihilation may be sizeably different from zero [1,2]. On the contrary, the commonly adopted incoherent fragmentation scheme of a single, independent quark leads to zero values for such off-diagonal elements. These coherent fragmentation effects have recently received some confirmation from experimental results at LEP [3]. Numerical estimates of $\rho_{1,-1}(V)$ in the coherent fragmentation of $q\bar{q}$ pairs in $e^+e^- \to q\bar{q} \to VX$ processes have been given [4] for several vector mesons produced in two jet events, provided they have a large energy fraction $x_E = E_V/E_{beam}$, and a small transverse momentum p_T inside the jet.

The polarization state of V is described by its helicity density matrix $\rho(V)$, whose general expression is:

$$\rho_{\lambda_V \lambda'_V}(V) = \frac{1}{N_V} \sum_{q,X,\lambda' s} \mathcal{D}_{\lambda_V \lambda_X ; \lambda_q \lambda_{\bar{q}}} \, \mathcal{D}^*_{\lambda'_V \lambda_X ; \lambda'_q \lambda'_{\bar{q}}} \, \rho_{\lambda_q \lambda_{\bar{q}} ; \lambda'_q \lambda'_{\bar{q}}}(q\bar{q}) \tag{1}$$

where N_V is such that $\mathrm{Tr}(\rho) = 1$, and the $\mathcal{D}$'s are unknown, non perturbative helicity amplitudes for the process, $q\bar{q} \to VX$. The $q\bar{q}$ density matrix is in turn given by

$$\rho_{\lambda_q \lambda_{\bar{q}} ; \lambda'_q \lambda'_{\bar{q}}}(q\bar{q}) = \frac{1}{N_q} \sum_{\lambda_{e^-} \lambda_{e^+}} M_{\lambda_q \lambda_{\bar{q}} ; \lambda_{e^-} \lambda_{e^+}} M^*_{\lambda'_q \lambda'_{\bar{q}} ; \lambda_{e^-} \lambda_{e^+}} \tag{2}$$

where the M's are the helicity amplitudes for the process $e^- e^+ \to q\bar{q}$. It is easy to show that in case of a single, independent, collinear quark fragmentation all off-diagonal elements of $\rho_{\lambda_V \lambda'_V}(V)$ vanish.

Although the amplitudes $\mathcal{D}_{\lambda_V \lambda_X; \lambda_q \lambda_{\bar{q}}}$ are unknown, it is possible[4], at least in some kinematical regimes, to express $\rho_{\lambda_V \lambda'_V}(V)$ by means of essentially only one unknown, non perturbative, quantity. In details, the procedure is the following: *i)* Consider only vector mesons collinear with the parent jet $(p_T/(x_E\sqrt{s}) \to 0)$. This implies that the diagonal matrix elements are the same (up to corrections of the order $[p_T/(x_E\sqrt{s})^2]$ as in the incoherent fragmentation picture; moreover, the only non-vanishing, off-diagonal matrix elements are, to the same order, $\rho_{\pm 1, \mp 1}(V)$. The surviving combinations of $\mathcal{D}$ amplitudes in Eq. (1) are: $\sum_X |\mathcal{D}_{1,0;+,-}|^2 = D^{V,+1}_{q,+}$; $\sum_X |\mathcal{D}_{0,-1;+,-}|^2 = D^{V,0}_{q,+}$; $\sum_X |\mathcal{D}_{-1,-2;+,-}|^2 = D^{V,-1}_{q,+}$; $\sum_X \mathcal{D}_{1,0;+,-} \mathcal{D}^*_{-1,0;-,+} \simeq D^{V,+1}_{q,+}$, where parity conservation and dominance of the $S_X = 0$ contribution have been used. *ii)* By limiting ourself to the region $x_E \geq 0.5$, we may reasonably assume that the $q\bar{q}$ pair fragments into a meson V only if q is a valence quark for V itself. In first approximation, we can also set $D^{V,-1}_{q,+} = 0$, $D^{V,0}_{q,+} \simeq \alpha^V_q D^{V,+1}_{q,+}$, as for $SU(6)$ vector meson wavefunctions with no orbital angular momentum. *iii)* Finally, we assume that $\alpha^V_q \simeq \alpha^V$ independently of the valence quark flavour. This condition is well satisfied for vector mesons with valence quarks all of the same flavour (*e.g.*, for ϕ meson), for vector mesons where one valence quark dominates (*e.g.* D^{*+}, B^{*+}), or with only u, $\bar{u}$,d, $\bar{d}$,valence quarks (*e.g.* ρ). It may be weaker for mesons like K^{*+}; in this case the results can be similar to those for ρ^+ (if u and $\bar{s}$ contribute almost equally) or to those for B^{*+} (if $\bar{s}$ contribution dominates).

These approximations lead to very simple results for $\rho(V)$:

$$\rho_{00}(V) \simeq \frac{\alpha^V}{1+\alpha^V} \quad \Longrightarrow \quad \alpha^V \simeq \frac{\rho_{00}(V)}{1-\rho_{00}(V)} \tag{3}$$

$$\rho_{1,-1}(V) \simeq \Big[1 - \rho_{00}(V)\Big] \frac{1}{n_V} \sum_q \rho_{+-;-+}(q\bar{q}) \tag{4}$$

where n_V is the number of leading quarks contributing.

The unknown parameter α^V can thus be estimated from experimental data on $\rho_{00}(V)$. Notice that, in $SU(6)$, $\alpha^V = 1/2$, corresponding to $\rho_{00}(V) = 1/3$, *i.e.* no spin alignment, $A = (3\rho_{00} - 1)/2 = 0$.

Both ρ_{00} and $\rho_{1,-1}$ can be measured via the angular distribution of the vector meson decays into two pseudoscalar particles. At LEP energies ($\sqrt{s} = M_Z$), computing $\rho_{+-;-+}(q\bar{q})$ as given by $q\bar{q}$ annihilation into Z_0, one gets[4]

$$\rho_{1,-1}(V) \simeq K^Z_V \Big[1 - \rho_{00}(V)\Big] \frac{\sin^2\theta}{1+\cos^2\theta} \tag{5}$$

with $K^Z_{\rho,K^{*\pm}} = -0.265$, $K^Z_{K^{*0},\phi,B^*} = -0.170$, $K^Z_{D^*} = -0.360$. We want to stress that at low energies, where the e.m. contribution dominates, one gets $K^\gamma_V = 1/2$ for all mesons.

The following table compares our results with recent experimental data from LEP [3] (after averaging the $\rho_{1,-1}(V)$ values over the production angle of the vector meson).

Exp (OPAL Collab. [3])		Theory
ϕ ($x_E > 0.7$)	-0.11 ± 0.07	-0.042
D^* ($x_E > 0.5$)	-0.039 ± 0.016	-0.116
K^{*0} ($0.5 < x_E < 0.7$)	-0.05 ± 0.04	-0.043
K^{*0} ($0.7 < x_E < 1.0$)	-0.08 ± 0.07	-0.031

Our results compare well with data from OPAL Collaboration. We notice however that DELPHI Collaboration [5] measured $\rho_{1,-1}$ for ρ, K^{*0}, ϕ mesons over different x_E ranges, finding values compatible with zero, although error bars are comparable with our estimated theoretical values. We clearly need more experimental, dedicated investigations, possibly with an accurate selection of the kinematical range where our predictions are supposed to be most reliable. If the OPAL results will be confirmed, this should be a strong indication for the relevance of coherent fragmentation processes.

Let us finally stress that our model and its simple prediction, Eq. (5), can be further tested in present or near-future experiments. For example, in e^+e^- annihilation at low energies, we predict $K^\gamma_V = 1/2$, that is $\rho_{1,-1}$ positive for all vector mesons. A detailed account for inclusive vector meson production in NN, γN, ℓN collisions has also been given [6], while the case of $\gamma\gamma$ collisions is under study [7].

References

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