Heavy Flavour $Q\overline{Q}$ Admixture in the Proton and its Test in Exclusive Hadronic Processes

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At the interface of effective meson-baryon and fundamental quark-gluon degrees of freedom, the investigation of the microscopic structure of mesons and baryons is a major goal for modern electron and hadron factories in the GeV region.

As an example, particularly the proton has been under intensive studies with respect to its spin content ("spin crisis"). One major source of the proton spin is the contribution from $Q\overline{Q}$ sea quarks to the qqq light quark proton ground state. In this work we investigate the admixture of heavy $s\overline{s}$ (together with $c\overline{c}$ and $b\overline{b}$) sea quark pairs to the proton. In a Fock space decomposition of the proton ground state,

$$\begin{aligned} H\,|\psi\rangle &= M\,|\psi\rangle \\ |\psi\rangle &= (P+Q+R)\,|\psi\rangle = \alpha\,|qqq\rangle + \beta\,|qqq\,Q\overline{Q}\rangle + \gamma\,|qqq\,\mathrm{rest}\rangle \end{aligned} \tag{1}$$

where M is the proton mass and P, Q and R are standard projection operators, the $Q\overline{Q}$ admixture is given in the lowest order impulse approximation schematically as

$$|qqq\,Q\overline{Q}\rangle = \frac{V_{q\to qQ\overline{Q}}}{H_{qqqQ\overline{Q}} - M}\,|qqq\rangle \tag{2}$$

To estimate the $Q\overline{Q}$ probability we employ different approximations. We compare the $Q\overline{Q}$ excitation for a non-relativistic qqq and a quark-scalar diquark model for the proton with a corresponding calculation in the infinite momentum frame (on the light-cone). In the simplest approximation the full Hamiltonian in the $qqqQ\overline{Q}$ channel is just the sum of the masses and kinetic energies, whereas the $Q\overline{Q}$ creation potential for a one-gluon exchange with an effective mass m_G and light and heavy quarks with masses m_q and m_Q is given as

$$V^{ij}_{q\to qQ\overline{Q}} = 4\,\pi\,\alpha_s\,\frac{\lambda_i\,\lambda_j}{4}\,\frac{1}{2\,m_q\,m_Q}\,\frac{1}{\vec{k}^{\,2}+m_G^2}\left[(\vec{\sigma}_i\times\vec{\sigma}_j)\cdot\vec{k} - i\,\frac{m_Q-m_q}{m_Q}\,\vec{\sigma}_j\cdot\vec{k} - i\,\frac{m_q}{m_Q}\,\vec{\sigma}_j\cdot\vec{p}\right] F(\vec{k}^{\,2}) \tag{3}$$

Above an effective quark-gluon form factor $F(\vec{k}^{\,2})$ is introduced for bounded resonating group model calculations of the qqq proton wave function; due to the presence of form factors the resulting $Q\overline{Q}$ admixture probability is finite. In practice it is calculated analytically by expanding the full amplitude in Gaussians and Hermite polynomials [1].

For the $Q\overline{Q}$ admixture on the light-cone the q-(qq) proton wave function is derived from a covariant harmonic confining kernel [2] (schematically)

$$\phi(x,\vec{p}_\perp) = [a\,f(x)\,F(a,b,x) + b\,g(x)\,F(a',b',x)]\,H_m(p_x)\,H_n(p_y) \tag{4}$$

with the confluent hypergeometric functions $F(a,b,x)$ and the Hermite polynomials $H_n(p_i)$, with the energy spectrum in the longitudinal component fixed by the boundary conditions $\phi(0,\vec{p}_\perp) = \phi(1,\vec{p}_\perp) = 0$. In the limit of heavy $Q\overline{Q}$ quarks the gluon propagator is derived as

$$G_{\mathrm{gluon}}\big((p-k)^2\big) = -\left[M^2_{Q\overline{Q}}\,(x-y)^2 + (\vec{p}_\perp - \vec{k}_\perp)^2 + m_G^2\right]\theta(\Lambda^2 - |\vec{p}_\perp|^2)\,\theta(\Lambda^2 - |\vec{k}_\perp|^2) \tag{5}$$

with a transversal cut-off of $\Lambda \approx 1$GeV.

We present and compare various scenarios from the different models both for the $Q\overline{Q}$ momentum distributions and admixture probability, provide a through discussion of the parameter sensitivities and approximations in the calculation (such as the heavy quark mass limit or the influence of multi-gluon exchange) and discuss the possibility to test particularly the $s\overline{s}$ admixture in near-threshold production of K^+ and ϕ mesons in pp collisions [3].

[1] H.M. Hofmann et al., Few Body Syst. Suppl. 5 (1992) 471.

[2] F.G. Pilotto, PhD Thesis, Univ. Erlangen-Nürnberg (in preparation).

[3] P. Moskal et al., AIP Conf. Proc. 512 (2000) 65.