Dirac orbital approach in the low-energy QCD

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Introduction

Whereas many baryon charateristics can be reasonably obtained in relativized quark models where all relativistic effects are treated via Salpeter equation (Isgur et al.) and spin corrections, some properties prove to be quite sensitive to the Dirac structure of quark wave functions, and in particular, as will be shown below, to the negative energy components. The most systematic treatment of a baryon as a relativistic quark system can be done in the three-body Bethe–Salpeter formalism, however in this approach a rigorous derivation ends up in the system of more than 20 integral equations, and therefore, a drastic simplification is needed to make realistic calculations. Also, one should note that the relativistic objects like negative energy component admixture are very sensitive to the form of interactions.

In our work we choose another and much simpler approach, which allows to treat all Dirac components properly including lower ones, and to work out the resulting wavefunctions, masses, charges etc. in a transparent way.

Three-quark system Hamiltonian

$$\hat{H} = \sum_{i=1}^{3} \hat{H}_i + \Delta H, \qquad \hat{H}_i = \boldsymbol{\alpha}_{(i)} \mathbf{p}_{(i)} + \beta_{(i)}(m_i + M(\mathbf{r}_i))$$

where $M(\mathbf{r}_i)$ in the limit of vanishing gluon correlation length is

$$M = \sigma |\mathbf{r}_i - \mathbf{r}_X|$$

σ is the string tension, and $\mathbf{r}_X$ is the string-junction coordinate.

Here ΔH contains perturbative gluon exchanges:

$$\Delta H \approx \sum_{i=1}^{3} \left(-\frac{\zeta}{r_i} \right), \qquad \zeta \approx 0.3 \Longleftrightarrow \alpha_s \approx 0.39$$

We expand the baryon wave function in a series of products of quark eigenfunctions $\psi_n^{(i)}$:

$$\Psi(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3) = \sum_{\{n_i\}} \prod_{i=1}^{3} \psi_{n_i}^{(i)}(\mathbf{r}_i) C_{n_1 n_2 n_3}$$

Equation for the quark wavefunction:

$$\left(\boldsymbol{\alpha}\mathbf{p} + \beta \cdot m_i + \hat{1} \cdot \left(-\frac{\zeta}{r} \right) + \beta \cdot \sigma r \right) \psi_i = E_i \psi_i$$

The orbital function can be expressed in terms of spherical spinors:

$$\psi_q^{jlm} = \begin{pmatrix} g(r)\Omega_{jlm} \\ (-1)^{\frac{1+l-l'}{2}} f(r)\Omega_{jl'm} \end{pmatrix}, \qquad \int\limits_0^\infty \left(f^2 + g^2\right) r^2 dr = 1$$

so for radial components we have the system of equations:

$$g' + \frac{1+\varkappa}{r} g - (E_q + m_q + \sigma r + \zeta/r)\, f = 0$$

$$f' + \frac{1-\varkappa}{r} f + (E_q - m_q - \sigma r + \zeta/r)\, g = 0$$

Introducing new dimensionless variables

$$x = r\sqrt{\sigma}, \quad \varepsilon_q = E_q/\sqrt{\sigma}, \quad \mu_q = m_q/\sqrt{\sigma}$$

and new dimensionless functions

$$g = \sigma^{3/4}\frac{G(x)}{x}, \quad f = \sigma^{3/4}\frac{F(x)}{x}, \quad \int_0^\infty \left(F^2 + G^2\right) dx = 1$$

we come to the following system of equations

$$G' + \frac{\varkappa}{x}G - \left(\varepsilon_q + \mu_q + x + \frac{\zeta}{x}\right) F = 0$$

$$F' - \frac{\varkappa}{x}F + \left(\varepsilon_q - \mu_q - x + \frac{\zeta}{x}\right) G = 0$$

which has been analysed further numerically.

Application for baryons

We start from a free polarized fermion with polarization vector a

$$a \cdot a = -1, \qquad a \cdot p = 0,$$

$$\rho = \frac{\gamma p + m}{4m}\left[1 - \gamma^5(\gamma a)\right],$$

$$\mathrm{Tr}\,\rho = 1$$

$$\widehat{W}^\mu = -\frac{1}{2m}\varepsilon^{\mu\nu\rho\sigma}\widehat{J}_{\nu\rho}\widehat{P}_\sigma,$$

$$\widehat{J}_{\mu\nu} = x_\mu \widehat{P}_\nu - x_\nu \widehat{P}_\mu + \frac{i}{4}\left[\gamma_\mu, \gamma_\nu\right],$$

$$\langle \widehat{W}^\mu \rangle = \frac{1}{2}a^\mu$$

Definition of axial and tensor currents

$$\widehat{j}^A_\mu = \widehat{\bar{\psi}}\gamma_\mu\gamma^5\widehat{\psi}, \qquad \widehat{j}^T_{\mu\nu} = \widehat{\bar{\psi}}\sigma_{\mu\nu}\gamma^5\widehat{\psi},$$

$$\left\langle \widehat{j}^A_\mu \right\rangle = -a_\mu, \qquad \left\langle \widehat{j}^T_{\mu\nu} \right\rangle = \frac{1}{m}(a_\mu p_\nu - a_\nu p_\mu)$$

Definition of charges

$$\left\langle p, a \left| \widehat{\bar{u}}\gamma_\mu\gamma^5\widehat{u} - \widehat{\bar{d}}\gamma_\mu\gamma^5\widehat{d} \right| p, a \right\rangle = -g_A a_\mu,$$

$$\left\langle p, a \left| \widehat{\bar{u}}\sigma_{\mu\nu}\gamma^5\widehat{u} - \widehat{\bar{d}}\sigma_{\mu\nu}\gamma^5\widehat{d} \right| p, a \right\rangle = \frac{g_T}{m}(a_\mu p_\nu - a_\nu p_\mu)$$

SU(4)–sym. octet wave functions

$$|p\uparrow\rangle = \sqrt{\frac{1}{18}}\Big[-2\big(|u\uparrow\rangle\otimes|u\uparrow\rangle\otimes|d\downarrow\rangle + \text{perm.}\big) + \big(|u\uparrow\rangle\otimes|u\downarrow\rangle\otimes|d\uparrow\rangle + \text{perm.}\big)\Big]$$

$$|n\uparrow\rangle = \sqrt{\frac{1}{18}}\Big[-2\big(|d\uparrow\rangle\otimes|d\uparrow\rangle\otimes|u\downarrow\rangle + \text{perm.}\big) + \big(|u\uparrow\rangle\otimes|d\downarrow\rangle\otimes|d\uparrow\rangle + \text{perm.}\big)\Big]$$

$$|\Lambda\uparrow\rangle = \frac{1}{2}\Big[\big(|u\uparrow\rangle\otimes|d\downarrow\rangle - |d\uparrow\rangle\otimes|u\downarrow\rangle + \text{perm.}\big)\otimes|s\uparrow\rangle\Big]$$

$$|\Sigma^-\uparrow\rangle = \sqrt{\frac{1}{6}}\Big[-2|u\uparrow\rangle\otimes|d\uparrow\rangle\otimes|s\downarrow\rangle + |d\uparrow\rangle\otimes|d\downarrow\rangle\otimes|s\uparrow\rangle + |d\downarrow\rangle\otimes|d\uparrow\rangle\otimes|s\uparrow\rangle\Big]$$

Calculation of charges

$$g_A = \left\langle p\uparrow \left| \hat{u}^+ \Sigma_3 \hat{u} - \hat{d}^+ \Sigma_3 \hat{d} \right| p\uparrow \right\rangle = +\frac{5}{3} \langle \chi_\uparrow | \Sigma_3 | \chi_\uparrow \rangle$$

$$g_T = \left\langle p\uparrow \left| \hat{u}^+ \beta\Sigma_3 \hat{u} - \hat{d}^+ \beta\Sigma_3 \hat{d} \right| p\uparrow \right\rangle = +\frac{5}{3} \langle \chi_\uparrow | \beta\Sigma_3 | \chi_\uparrow \rangle$$

$$g_A = \frac{5}{3} \int dx \left(G^2 - \frac{1}{3} F^2 \right) = \frac{5}{3} \left(1 - \frac{4}{3} \eta \right)$$

$$g_T = \frac{5}{3} \int dx \left(G^2 + \frac{1}{3} F^2 \right) = \frac{5}{3} \left(1 - \frac{2}{3} \eta \right)$$

$\eta = \int\limits_0^\infty F^2(r) dr$ — lower component bispinor contribution.

Decay constants:

For $n \to pl$ decay $\langle p\,|\bar{u}\gamma_\mu(1+\gamma_5)d|\,n\rangle \simeq \bar{p}\gamma_\mu(g_V + g_A\gamma_5)n$ and

$$\frac{g_A}{g_V} = -\int \left(G_q^2 - \frac{1}{3}F_q^2\right) dx$$

For $\Lambda \to pl$ decay $\langle p\,|\bar{u}\gamma_\mu(1+\gamma_5)s|\,\Lambda\rangle \simeq \bar{p}\gamma_\mu(g_V + g_A\gamma_5)\Lambda$ and

$$\frac{g_A}{g_V} = -\frac{\int \left(G_qG_s - \frac{1}{3}F_qF_s\right) dx}{\int (G_qG_s + F_qF_s)\, dx}$$

For $\Sigma \to nl$ decay $\langle n\,|\bar{u}\gamma_\mu(1+\gamma_5)s|\,\Sigma\rangle \simeq \bar{n}\gamma_\mu(g_V + g_A\gamma_5)\Sigma$ and

$$\frac{g_A}{g_V} = +\frac{1}{3}\cdot\frac{\int \left(G_qG_s - \frac{1}{3}F_qF_s\right) dx}{\int (G_qG_s + F_qF_s)\, dx}$$

Results for charges g_A, g_T, and η for various theoretical prescriptions in comparison with experimental data. Note that we have no firm experimental results for g_T; various theoretical estimations give disparate answers from 0.89 to 1.45 [Gamberg et al.,2001] and from lattice calculations it was obtained $g_T \sim 1.1 \div 1.2$ [Ali Khan et al.,2004]

	Exp.	NRQM	$\zeta = 0$	$\zeta = 0.3$
g_A	1.27	1.67	1.36	1.27
g_T	–	1.67	1.51	1.47
η	–	0	0.14	0.18

Results for g_A/g_V in comparison with experimental data

Decay	$n \to pl$	$\Lambda \to pl$	$\Sigma \to nl$
Theor.	-1.27	-0.78	+0.26
Exp.	-1.27	-0.74	+0.32

Results for hyperon decays should be corrected by taking into account the center-of-mass motion of the final baryon.

Baryon mass calculation

$$\mathbf{P} = \sum \mathbf{p}_i, \quad \langle \mathbf{P} \rangle = \mathbf{0}, \quad \langle \mathbf{P}^2 \rangle = \sum \langle \mathbf{p}_i^2 \rangle \neq 0; \qquad M_B = \sqrt{\left(\sum E_i\right)^2 - \sum \langle \mathbf{p}_i^2 \rangle}$$

$$\langle \mathbf{p}_i^2 \rangle = \langle \psi_i | \mathbf{p}^2 | \psi_i \rangle = \langle \psi_i | \boldsymbol{\alpha}\mathbf{p} | \boldsymbol{\alpha}\mathbf{p} | \psi_i \rangle =$$
$$= \int dr \left(G^2(r) + F^2(r)\right) \left(\left(\varepsilon_i + \frac{\zeta}{r}\right)^2 + (m_i + \sigma r)^2\right) -$$
$$- 2 \int dr \left(G^2(r) - F^2(r)\right) \left(\varepsilon_i + \frac{\zeta}{r}\right) (m_i + \sigma r)$$

Results for decuplet masses for $\sigma = 0.18$ GeV^2, $m_s = 210$ MeV:

Baryon	Δ	Σ^*	Ξ^*	Ω
Theor.	1233	1381	1527	1672
Exp.	1232	1383	1532	1672

Application for mesons

In most cases the quark model predicts meson states in good agreement with experiment. And we believe that we have a theory of bound states in QCD, working well in general. However, there are exclusions. Some states are shifted from the places prescribed by this theory. Some examples for mesons:

a) pions and kaons

b) some heavy-light mesons, like D_s

c) some light scalar mesons, like a_0, f_0.

In baryons, examples include $N(1440)(Roper), \Lambda(1405)$, etc. We expect that in some of these cases the Channel Coupling interaction is operating and explains the strong shift of masses. Moreover, we suggest a new mechanism, called the chiral coupling of channels, which works for a bound light quark and can explain the shift of $\gtrsim 100$ MeV in a mass. It is important, that this new mechanism does not contain any fitting parameters and its predictions are fixed in some sense. The usage of Dirac orbital approach is crucial here.

We start from the light quark + meson effective Lagrangian

$$L = i \int d^4x d^4y \psi^+(x) \widehat{M}(x,y) \psi(y)$$

which includes both effect of confinement and chiral symmetry breaking.
Here

$$\widehat{M}(x,y) = M_S(x,y) e^{i\gamma_5 \widehat{\phi}(x,y)}$$

and in the limit of small $T_g \to 0$

$$M_S(x,y) \approx \sigma |\mathbf{x}| \delta^{(4)}(x-y), |\mathbf{x}| \gg T_g$$

To lowest order in $\widehat{\phi}$

$$\Delta L^{(1)} = \int \overline{\psi}(x) \sigma |\mathbf{x}| \gamma_5 \frac{\pi^A \lambda^A}{F_\pi} \psi(x) dt d^3\mathbf{x}$$

$$\pi^A\lambda^A = \sqrt{2}\begin{pmatrix} \frac{\eta^0}{\sqrt{6}} + \frac{\pi^0}{\sqrt{2}}, & \pi^+, & K^+ \\ \pi^-, & \frac{\eta^0}{\sqrt{6}} - \frac{\pi^0}{\sqrt{2}}, & K^0 \\ K^-, & \bar{K}_0, & -\frac{2\eta^0}{\sqrt{6}} \end{pmatrix}$$

For chiral transitions between heavy-light mesons we obtain the matrix element

$$U_{21} = \int \overline{\psi}_2(\mathbf{x})\frac{\sigma|\mathbf{x}|}{F_\pi}\gamma_5\frac{\lambda^A e^{i\mathbf{kx}}}{\sqrt{2\omega_\pi(\mathbf{k})V}}\psi_1(\mathbf{x})d^3\mathbf{x}$$

and the corresponding perturbation width

$$w = 2\pi|U_{21}|^2\delta(E_1 - E_2 - \omega)\frac{Vd^3\mathbf{k}}{(2\pi)^3}$$

Let $\hat{U}$ be any (local or nonlocal) operator, which causes a transition from channel i to channel j by the matrix element U_{ij}. Then the multichannel relativistic Green's function G_{ik} satisfies Hamiltonian-like equations (N – number of channels):

$$[(H_i - M)\delta_{ik} + U_{il}]G_{lk} = 1, \quad i, k, l = 1, ..., N$$

For two channels one can reduce the problem to an effective one-channel equation

$$(H_1 - E)G_{11} - U_{12}\frac{1}{H_2 - E}U_{21}G_{11} = 1$$

Consider an unperturbed set of states $|n\rangle$ in channel 1 and $|m\rangle$ in channel 2. Then a nonlinear equation for the energy eigenvalue M is

$$M = M_1^{(n)} - \sum_m \langle n|U_{12}|m\rangle \frac{1}{M_2^{(m)} - M}\langle m|U_{21}|n\rangle$$

Equation for the mass shift of the i^{th} state:

$$m[i] = m^{(0)}[i] - \sum_f \frac{|<i|\widehat{V}|f>|^2}{E_f - m[i]}$$

We consider the following thresholds:

i	$D_s(0^+)$	$D_s(1^+)$	$D_s(2^+)$
f	$D(0^-) + K(0^-)$	$D^*(1^-) + K(0^-)$	$D^*(1^-) + K(0^-)$

i	$B_s(0^+)$	$B_s(1^+)$	$B_s(2^+)$
f	$B(0^-) + K(0^-)$	$B^*(1^-) + K(0^-)$	$B^*(1^-) + K(0^-)$

Masses of meson states used for calculation (MeV):

$$m_D = 1869, \quad m_D + m_K = 2363$$

$$m_{D^*} = 2010, \quad m_{D^*} + m_K = 2504$$

$$m_B = 5279, \quad m_B + m_K = 5773$$

$$m_{B^*} = 5325, \quad m_{B^*} + m_K = 5819$$

In what follows all equations are given for D, D_s mesons; changes for B, B_s mesons are obvious.

Notations:

$$E_f = \omega_D + \omega_K, \quad T_f = E_f - m_D - m_K,$$

$$\omega_K(\mathbf{p}) = \sqrt{\mathbf{p}^2 + m_K^2}, \quad \omega_D(\mathbf{p}) = \sqrt{\mathbf{p}^2 + m_D^2},$$

$$E_0 = m^{(0)}[D_s] - m_D - m_K, \quad \delta m = m[D_s] - m^{(0)}[D_s],$$

$$\Delta = E_0 + \delta m = m[D_s] - m_D - m_K$$

We neglect the DK interacting and the D-meson moving in the f-state, so

$$|f> = \Psi_K(\mathbf{p}) \otimes \Psi_D(M_f), \quad |i> = \Psi_{D_s}(M_i),$$

$$\Psi_K(\mathbf{p}) = \frac{e^{i\mathbf{p}\mathbf{r}}}{\sqrt{2\omega_K(\mathbf{p})}}, \quad \sum_f \to \int \frac{d^3\mathbf{p}}{(2\pi)^3} \sum_{M_f}$$

One may write the equation for the mass shift as

$$E_0 - \Delta = \mathcal{F}(\Delta)$$

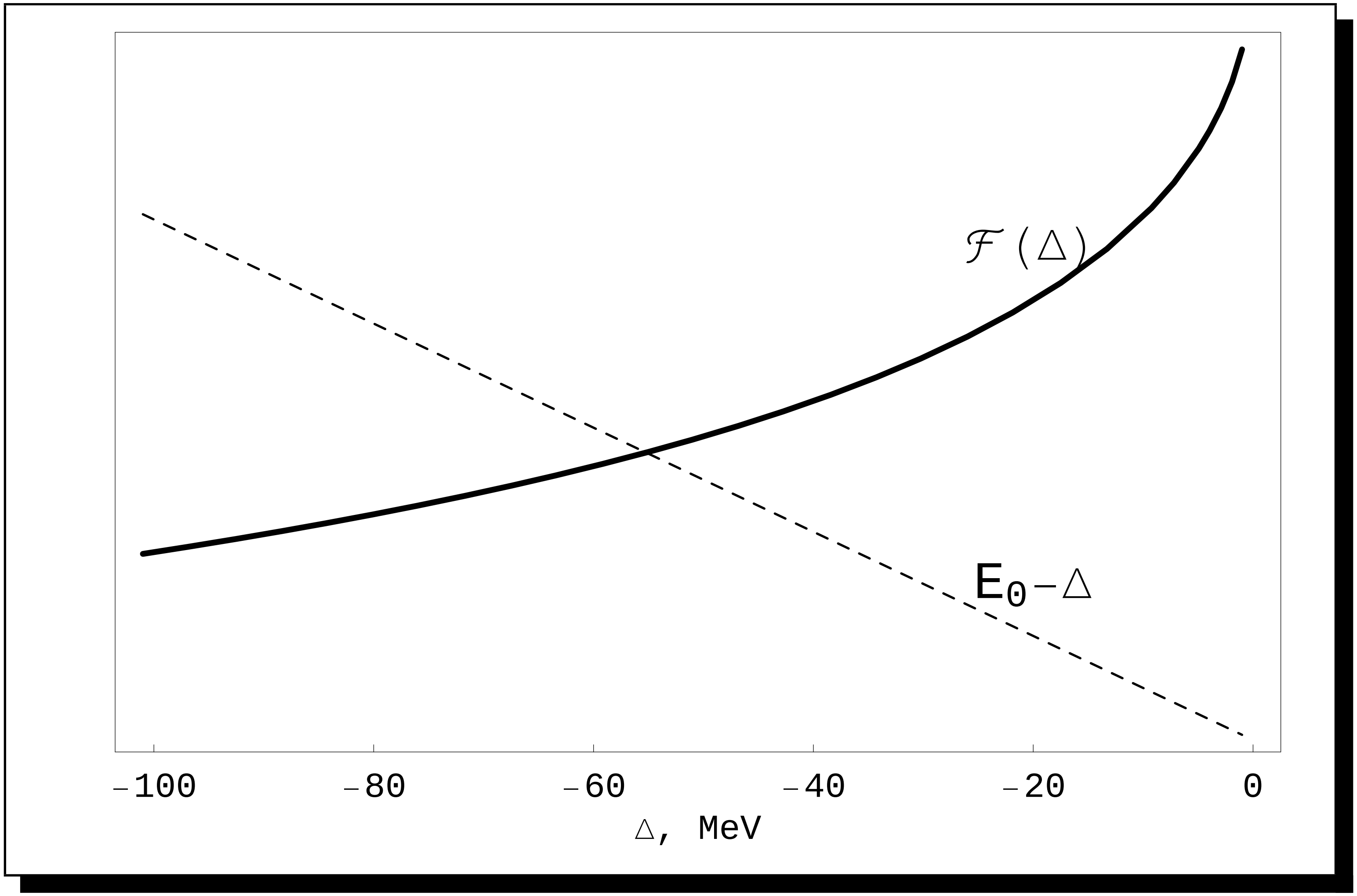
where

$$\mathcal{F}(\Delta) \stackrel{\text{def}}{=} \int \frac{d^3\mathbf{p}}{(2\pi)^3} \sum_{M_f} \frac{\left|\left\langle M_i \middle| \hat{V} \middle| \mathbf{p}, M_f \right\rangle\right|^2}{T_f(\mathbf{p}) - \Delta}$$

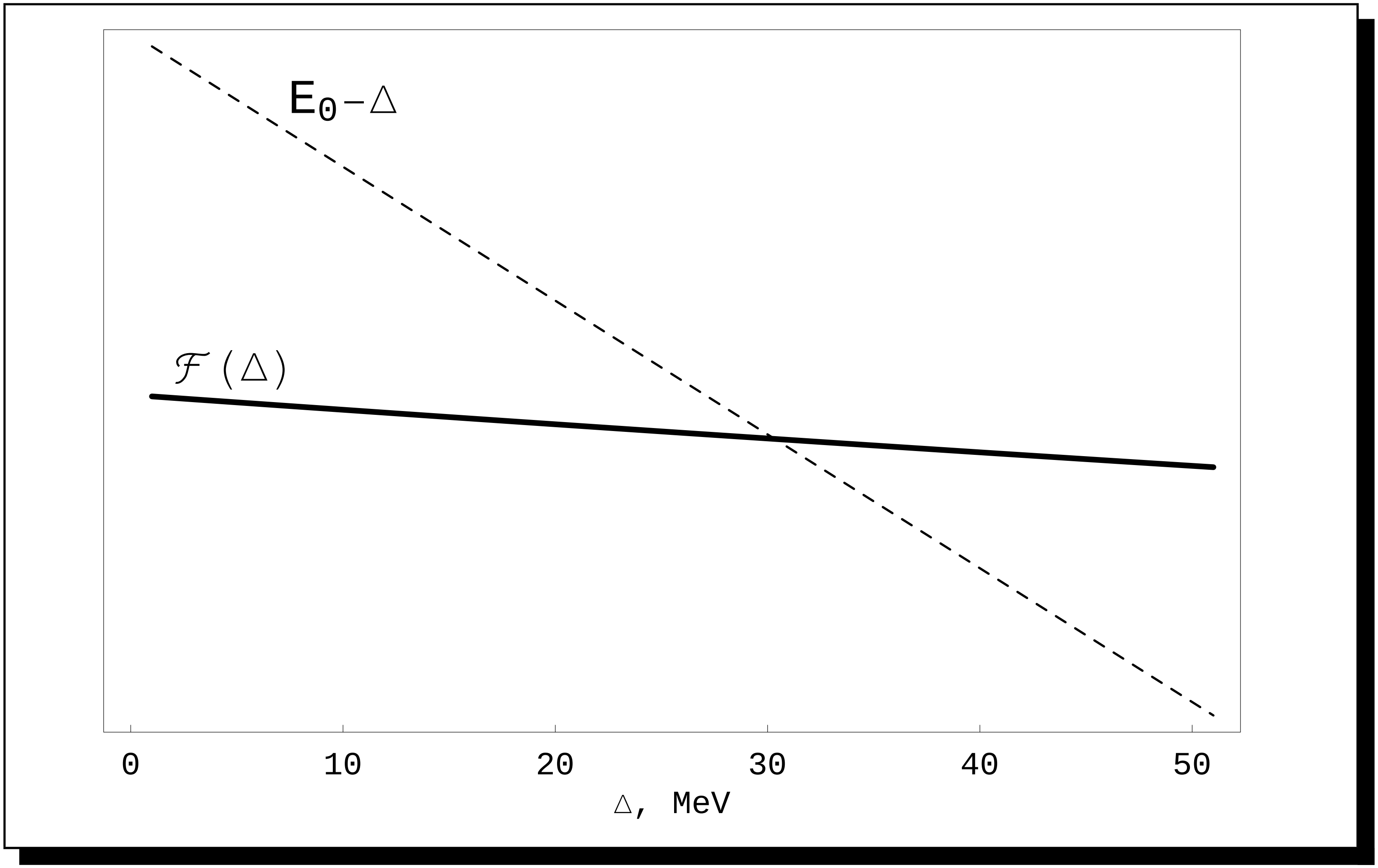
and

$$\left\langle M_i \middle| \hat{V} \middle| \mathbf{p}, M_f \right\rangle = -\int \Psi^{\dagger}_{D_s}(M_i)\, \sigma|\mathbf{r}|\gamma_5 \frac{\sqrt{2}}{f_K}\, \Psi_D(M_f)\, \frac{e^{i\mathbf{pr}}}{\sqrt{2\omega_K(\mathbf{p})}}\, d^3\mathbf{r}$$

While solving this equation we have two possible situations: $E_0 < E_0^{\rm crit}$ and $E_0 > E_0^{\rm crit}$, where $E_0^{\rm crit} = \mathcal{F}(-0)$.



If $E_0 < E_0^{\rm crit}$, the equation has a negative real root $\boldsymbol{\Delta} < 0$ and the resulting mass of the D_s meson proves to be under the threshold.



If $E_0 > E_0^{\text{crit}}$, the equation has a complex root $\Delta = \Delta' + i\Delta''$ with positive real part $\Delta' > 0$ and negative imaginary part $\Delta'' < 0$, so the resulting mass of the D_s meson proves to be over the threshold, the meson having a finite width $\Gamma = 2|\Delta''|$. But an analytic continuation of the $\mathcal{F}(\Delta)$ from the upper half-plane is required here.

In D and D_s mesons considered here we treat c-quark as heavy and static so the mesons are described by the following wave functions:

$$\Psi_D\left(J^-, M_f\right) = C^{J,M_f}_{\frac{1}{2},M_f-\frac{1}{2};\frac{1}{2},+\frac{1}{2}} \psi_q^{\frac{1}{2},0,M_f-\frac{1}{2}} \otimes \left|\bar{c}\uparrow\right\rangle + \\ + C^{J,M_f}_{\frac{1}{2},M_f+\frac{1}{2};\frac{1}{2},-\frac{1}{2}} \psi_q^{\frac{1}{2},0,M_f+\frac{1}{2}} \otimes \left|\bar{c}\downarrow\right\rangle$$

$$\Psi_{D_s}\left(J_j^+, M_i\right) = C^{J,M_i}_{j,M_i-\frac{1}{2};\frac{1}{2},+\frac{1}{2}} \psi_s^{j,1,M_i-\frac{1}{2}} \otimes \left|\bar{c}\uparrow\right\rangle + \\ + C^{J,M_i}_{j,M_i+\frac{1}{2};\frac{1}{2},-\frac{1}{2}} \psi_s^{j,1,M_i+\frac{1}{2}} \otimes \left|\bar{c}\downarrow\right\rangle$$

where $\psi_{q,s}^{jlm}$ is the light quark wave function – Dirac bispinor.

For D, D_s mesons with given parity several quantum sets are possible:

D			
J^P	j	l	$\varkappa$
0^-	$\frac{1}{2}$	0	-1
1^-	$\frac{1}{2}$	0	-1
1^-	$\frac{3}{2}$	2	+2

D_s			
J^P	j	l	$\varkappa$
0^+	$\frac{1}{2}$	1	+1
1^+	$\frac{1}{2}$	1	+1
1^+	$\frac{3}{2}$	1	-2
2^+	$\frac{3}{2}$	1	-2
2^+	$\frac{5}{2}$	3	+3

Physical $D_s(1^+)$ states are mixed:

$$\Psi_{D_s}\left(1^+_L, M_i\right) = -\sin\phi\cdot\Psi_{D_s}\left(1^+_{1/2}, M_i\right) + \cos\phi\cdot\Psi_{D_s}\left(1^+_{3/2}, M_i\right),$$

$$\Psi_{D_s}\left(1^+_H, M_i\right) = \cos\phi\cdot\Psi_{D_s}\left(1^+_{1/2}, M_i\right) + \sin\phi\cdot\Psi_{D_s}\left(1^+_{3/2}, M_i\right)$$

Note: we neglect possible mixing between $D(1^-_{1/2})$, $D(1^-_{3/2})$ states and also between $D_s(2^+_{3/2})$, $D_s(2^+_{5/2})$ states.

In what follows short notations for quark bispinors are used:

$$\psi_1(m_1) \stackrel{\text{def}}{=} \psi_s^{\frac{1}{2},1,m_1}, \quad \psi_2(m_2) \stackrel{\text{def}}{=} \psi_q^{\frac{1}{2},0,m_2}, \quad \psi_3(m_3) \stackrel{\text{def}}{=} \psi_s^{\frac{3}{2},1,m_3}$$

We used the following parameters, as usual

$$\sigma = 0.18\ \text{GeV}^2, \quad \alpha_s = 0.39,$$

$$m_s = 210\ \text{MeV}, \quad m_q = 4\ \text{MeV}$$

and obtained Dirac eigenvalues ε

$\varkappa$	$\bar{Q}q,\ \mu_q = 0.01$	$\bar{Q}s,\ \mu_s = 0.5$
-1	1.0026	1.28944
+1	1.7829	2.08607
-2	1.7545	2.08475

and eigenfunctions G, F.

Using explicit expressions for spherical spinors

$$\Omega_{l+1/2,l,m} = \begin{bmatrix} \sqrt{\frac{j+m}{2j}}\, Y_{l,m-1/2} \\ \sqrt{\frac{j-m}{2j}}\, Y_{l,m+1/2} \end{bmatrix}, \quad \Omega_{l-1/2,l,m} = \begin{bmatrix} -\sqrt{\frac{j-m+1}{2j+2}}\, Y_{l,m-1/2} \\ \sqrt{\frac{j+m+1}{2j+2}}\, Y_{l,m+1/2} \end{bmatrix},$$

and expansion of a plane wave on spherical functions

$$e^{i\mathbf{pr}} = 4\pi \sum_{l,m} i^l j_l(pr) Y^*_{l,m}\left(\frac{\mathbf{p}}{p}\right) Y_{l,m}\left(\frac{\mathbf{r}}{r}\right)$$

after long cumbersome transformations . . .

we obtain

$$\left\|\mathcal{V}_{12}\right\|_{m1,m2} = -\int \psi_1^\dagger(m_1)\,\sigma|\mathbf{r}|\gamma_5\frac{\sqrt{2}}{f_K}\,\psi_2(m_2)\,\frac{e^{i\mathbf{pr}}}{\sqrt{2\omega_K(\mathbf{p})}}\,d^3\mathbf{r} =$$

$$= \frac{\sqrt{\sigma}}{f_K\sqrt{\omega_K(p)}}\Phi_0\left(\frac{p}{\sqrt{\sigma}}\right)\sqrt{4\pi}Y^*_{0,m_1-m_2}\left(\frac{\mathbf{p}}{p}\right)$$

$$\left\|\mathcal{V}_{32}\right\|_{m3,m2} = -\int \psi_3^\dagger(m_3)\,\sigma|\mathbf{r}|\gamma_5\frac{\sqrt{2}}{f_K}\,\psi_2(m_2)\,\frac{e^{i\mathbf{pr}}}{\sqrt{2\omega_K(\mathbf{p})}}\,d^3\mathbf{r} =$$

$$= -\frac{\sqrt{\sigma}}{f_K\sqrt{\omega_K(p)}}\Phi_2\left(\frac{p}{\sqrt{\sigma}}\right)\sqrt{\frac{4\pi}{5}}Y^*_{2,m_3-m_2}\left(\frac{\mathbf{p}}{p}\right)\cdot\begin{bmatrix} -1 & +2 \\ -\sqrt{2} & +\sqrt{3} \\ -\sqrt{3} & +\sqrt{2} \\ -2 & +1 \end{bmatrix}$$

where

$$\Phi_0(q) = \int\limits_0^\infty j_0(qx)xdx\Big[G_1(x)F_2(x) - F_1(x)G_2(x)\Big],$$

$$\Phi_2(q) = \int\limits_0^\infty j_2(qx)xdx\Big[G_3(x)F_2(x) - F_3(x)G_2(x)\Big]$$

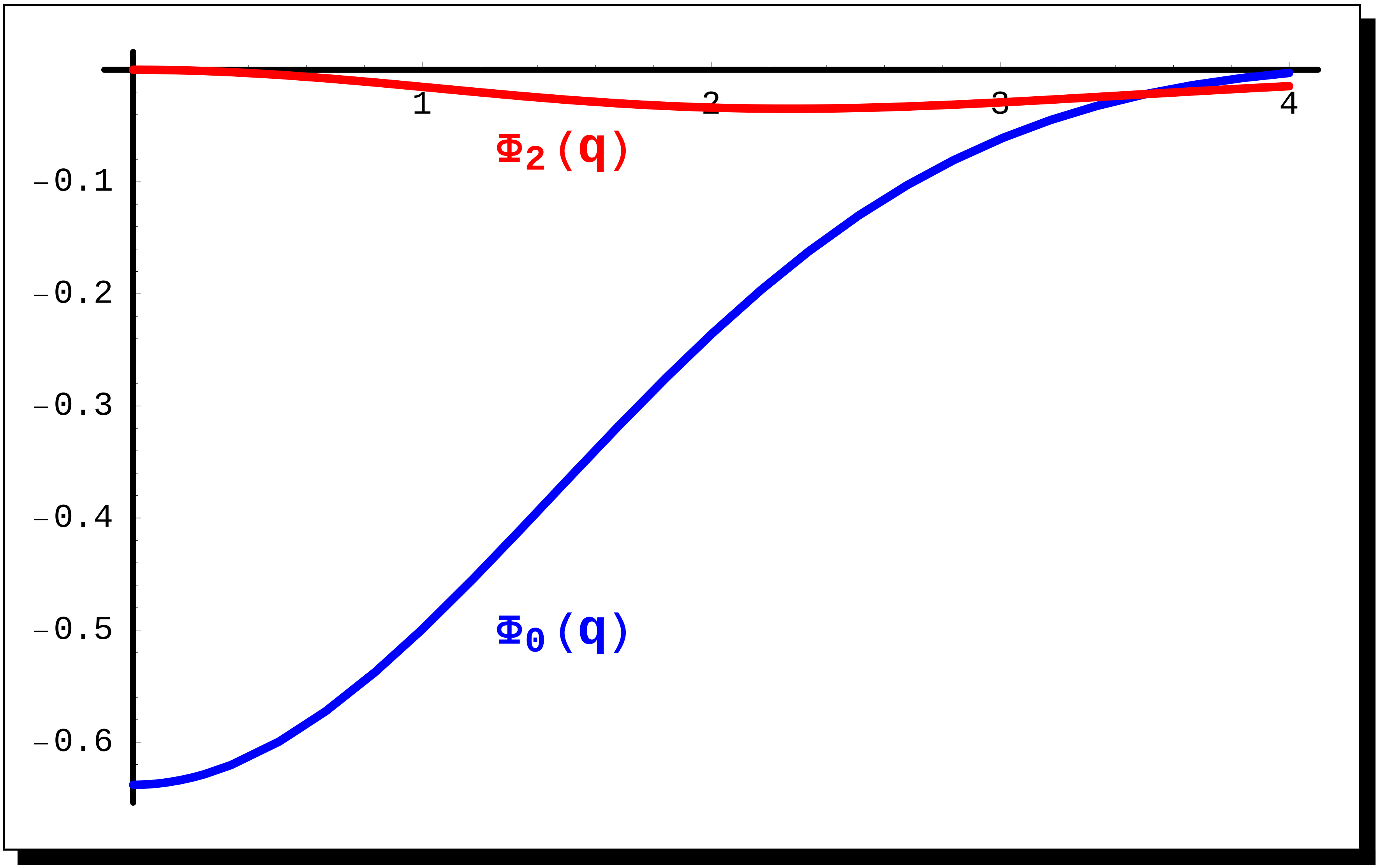
Finally, introducing functions

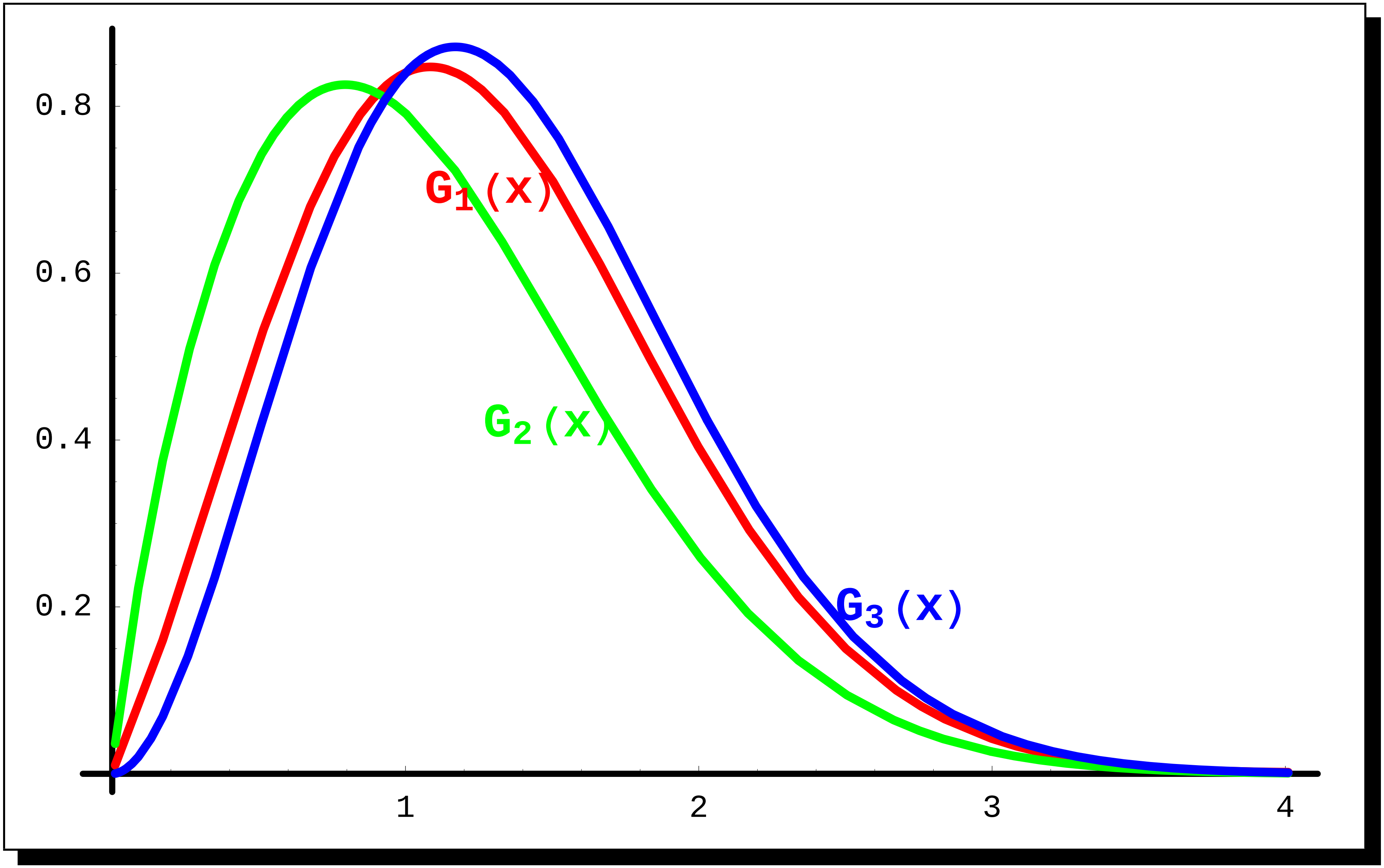
$$\tilde{\mathcal{F}}_{0,2}(\Delta) = \frac{\sigma}{2\pi^2 f_K^2}\int\limits_0^\infty \frac{p(T_f)\omega_D(T_f)dT_f}{T_f + m_D + m_K} \cdot \frac{\Phi_{0,2}^2\left(\frac{p(T_f)}{\sqrt{\sigma}}\right)}{T_f - \Delta}$$

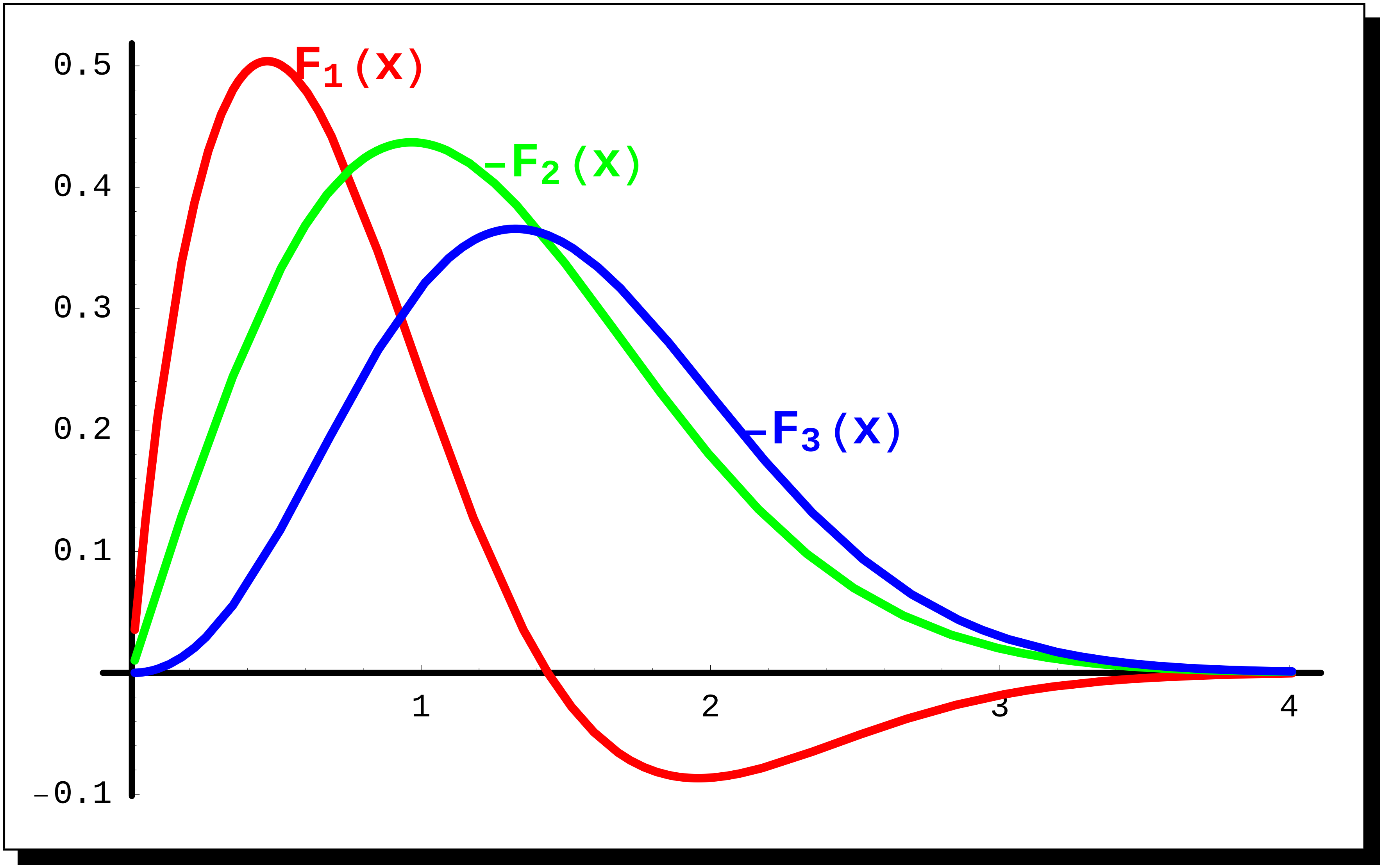
$$\tilde{\Gamma}_{0,2}(T_f) = \frac{\sigma}{\pi f_K^2} \cdot \frac{p(T_f)\omega_D(T_f)}{T_f + m_D + m_K} \cdot \Phi_{0,2}^2\left(\frac{p(T_f)}{\sqrt{\sigma}}\right)$$

we obtain the following equations to determine meson masses and widths:

$D_s(0^+)$	$E_0[0^+] - \Delta = \tilde{\mathcal{F}}_0(\Delta)$
$D_s(1^+_H)$	$E_0[1^+_H] - \Delta = \cos^2\phi \cdot \tilde{\mathcal{F}}_0(\Delta) + \sin^2\phi \cdot \tilde{\mathcal{F}}_2(\Delta)$
$D_s(1^+_L)$	$E_0[1^+_L] - \Delta' = \sin^2\phi \cdot \tilde{\mathcal{F}}_0(\Delta') + \cos^2\phi \cdot \tilde{\mathcal{F}}_2(\Delta')$
	$\Gamma[1^+_L] = \sin^2\phi \cdot \tilde{\Gamma}_0(\Delta') + \cos^2\phi \cdot \tilde{\Gamma}_2(\Delta')$
$D_s(2^+_{3/2})$	$E_0[2^+_{3/2}] - \Delta' = \frac{3}{5} \cdot \tilde{\mathcal{F}}_2(\Delta')$
	$\Gamma[2^+_{3/2}] = \frac{3}{5} \cdot \tilde{\Gamma}_2(\Delta')$


1
2
3
4
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Φ2(q)
Φ0(q)


0.8
0.6
0.4
0.2
1
2
3
4
G1(x)
G2(x)
G3(x)


0.5
0.4
0.3
0.2
0.1
-0.1
1
2
3
4
F1(x)
-F2(x)
-F3(x)

$D_s(0^+)$-meson mass shift due to DK channel and $B_s(0^+)$-meson mass shift due to BK channel. Thresholds: $m_D + m_K = 2363$ MeV, $m_B + m_K = 5772$ MeV.

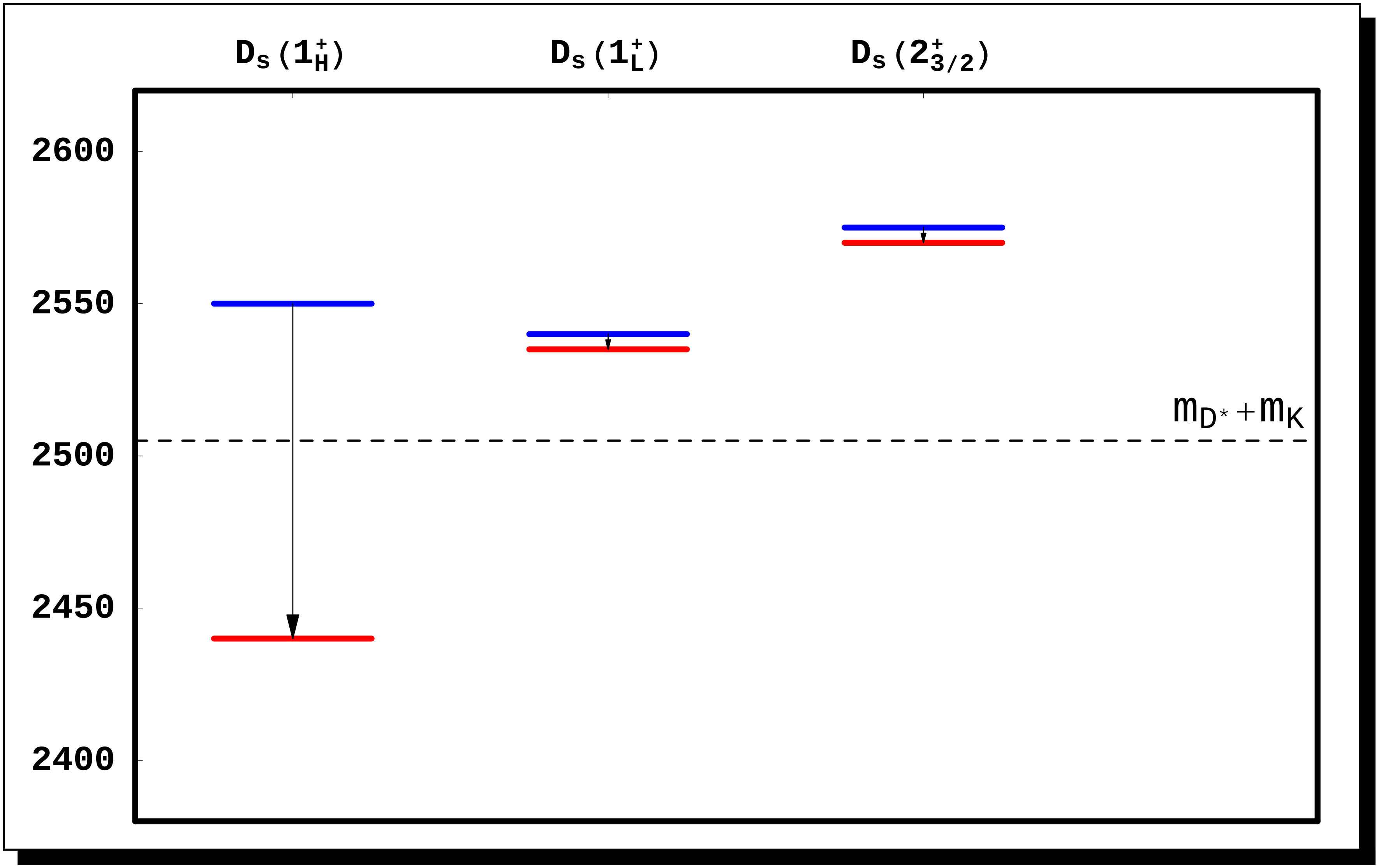
state	$m^{(0)}$	$m^{(\text{theor})}$	$m^{(\text{exp})}$	δm
$D_s(0^+)$	2475(20)	2330(20)	2317	-145
$B_s(0^+)$	5814(15)	5709(15)	not seen	-105

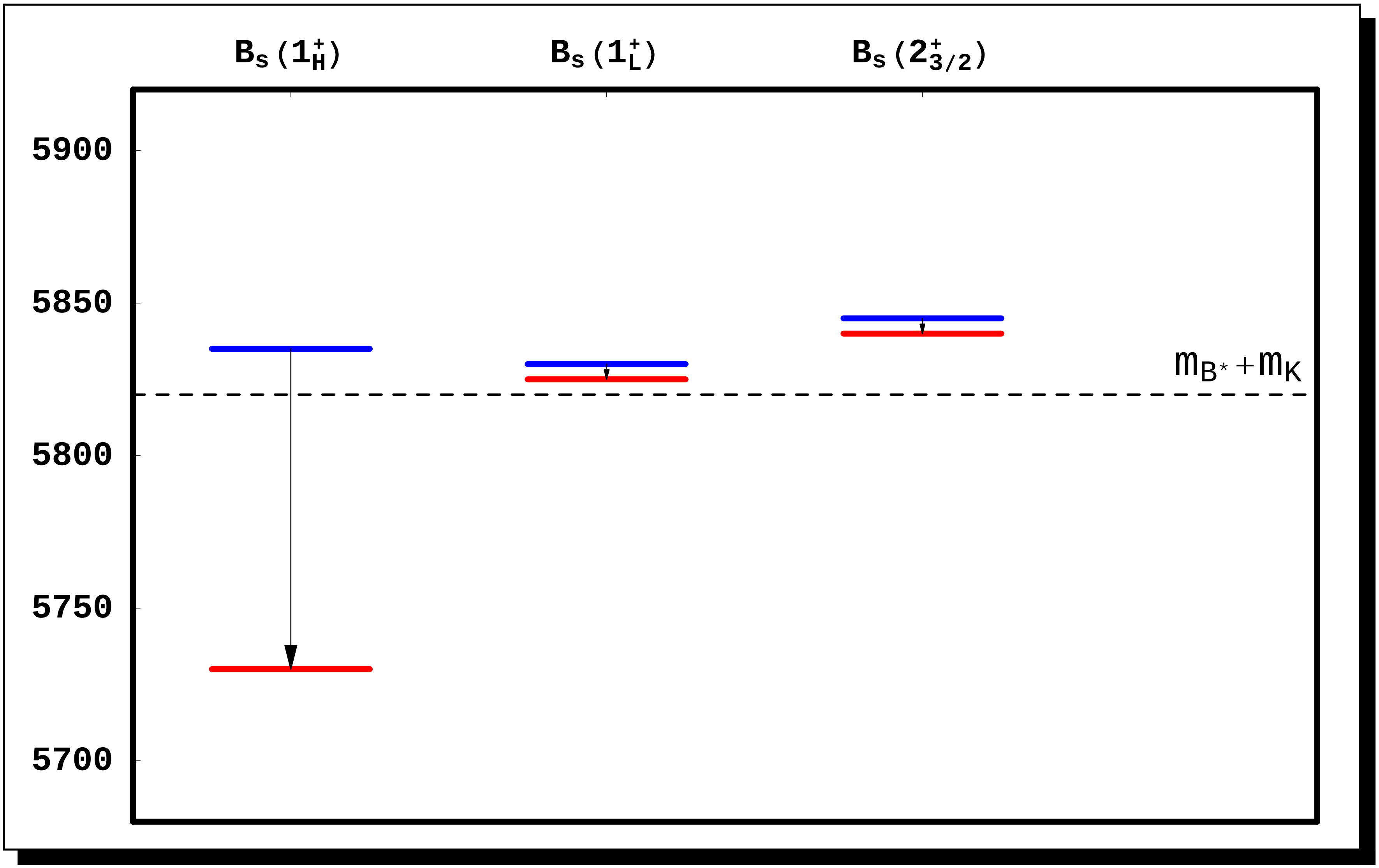
Results on D_s meson mass shift and partial width due to D^*K channel.
Threshold $m_{D^*} + m_K = 2504$ MeV, mixing angle $\sim 4^\circ$.

state	$m^{(0)}$	$m^{(\text{theor})}$	$m^{(\text{exp})}$	δm	$\Gamma^{(\text{theor})}_{(D^*K)}$	$\Gamma^{(\text{exp})}_{(D^*K)}$
$D_s(1^+_H)$	2568(15)	2458(15)	2460	-110	$\times$	$\times$
$D_s(1^+_L)$	2537	2535	2535	-2	1.1	< 2.3
$D_s(2^+_{3/2})$	2575	2573	2573	-2	0.03	not seen

Results on B_s meson mass shift and partial width due to B^*K channel.
Threshold $m_{B^*} + m_K = 5819$ MeV, mixing angle $\sim 4^\circ$.

state	$m^{(0)}$	$m^{(\text{theor})}$	$m^{(\text{exp})}$	δm	$\Gamma^{(\text{theor})}_{(B^*K)}$	$\Gamma^{(\text{exp})}_{(B^*K)}$
$B_s(1^+_H)$	5835(15)	5727(15)	not seen	-108	$\times$	$\times$
$B_s(1^+_L)$	5830	5828	5829	-2	0.8	< 1.3 ?
$B_s(2^+_{3/2})$	5840	5838	5839	-2	$< 10^{-3}$	not seen


$D_s(1^+_H)$
$D_s(1^+_L)$
$D_s(2^+_{3/2})$
2600
2550
2500
2450
2400
$m_{D^*}+m_K$



$B_s(1^+_H)$
$B_s(1^+_L)$
$B_s(2^+_{3/2})$
5900
5850
5800
5750
5700
$m_{B^*}+m_K$

Summary I

- Our method yields a good description of baryon properties and demonstrates clearly the importance of the lower bispinor component contribution.
- The nucleon charges, semileptonic decay constants and decuplet masses have been calculated in a fine agreement with experiment.

Summary II

- Our method yields final masses and widths of D_s and B_s mesons in good agreement with experimental data (better than 20 MeV). The interaction is deduced from QCD and is almost parameter free.

- The suggested mechanism ensures strong shifts $\gtrsim$ 100 MeV for $j = 1/2$ levels, while $j = 3/2$ levels remain almost *in situ*. Also the mechanism may lead to reordering of the initial levels due to chiral coupling.

- We believe that the chiral coupling might be the universal mechanism also responsible for baryon mass shifts.