STRONG COUPLING CONSTANTS OF HEAVY BARYONS WITH LIGHT MESONS IN QCD

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Outline

- Introduction
- Interpolating Currents
- Why LCSR?
- Sum Rules for Strong Coupling Constants of Heavy Baryons with Light Mesons
- Results & Conclusion

Introduction

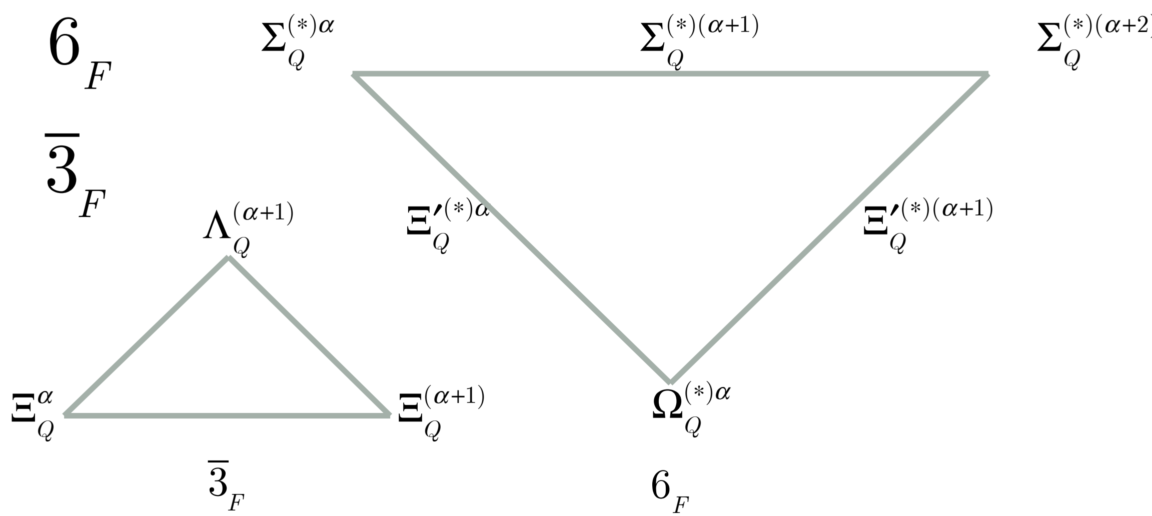
- $SU(3)$ classifications of heavy baryons

$3 \times 3 = 6 + \overline{3}$

- Ground states: 1 for 6_F (two light
- Total spin 0 for $\overline{3}_F$ quarks)

- • $J^P = \frac{1}{2}^+$ or $\frac{3}{2}^+$ $\quad 6_F$

  $J^P = \frac{1}{2}^+$ $\quad \overline{3}_F$



$\alpha, \alpha+1, \alpha+2$

$(\alpha = -1$ or $0)$(Charges of baryons, $*$ – denote $J^P = \dfrac{3}{2}^+$ states

Introduction

Exciting experimental results:

- $\frac{1}{2}^+$ and $\frac{1}{2}^-$ $\overline{3}_F$ states $\Lambda_c^+, \Xi_c^+, \Xi_c^0$
  $\Lambda_c^+(2593), \Xi_c^+(2790), \Xi_c^0(2790)$
- $\frac{1}{2}^+$ and $\frac{3}{2}^+$ $\overline{6}_F$ states $\Omega_c^*, \Sigma_c^*, \Xi_c^*$ are observed
- $\Lambda_b, \Sigma_b, \Sigma_b^*, \Xi_b^0$ and Ω_b are observed.
- LHC - New window for Heavy Baryon Physics.

Introduction

- A detailed theoretical study of experimental results and various weak & strong decays can provide us useful information about the quark structure of new hadrons at $\Lambda_{had} (\rightarrow$ non-perturbative sector).

- Nonperturbative methods

- SUM RULES (STANDART OR LIGHT CONE VERSION)

Interpolating Currents

$$\eta^{(s)} = -\frac{1}{\sqrt{2}}\varepsilon^{abc}\Big\{(q_1^{aT} c Q^b)\gamma_5 q_2^c - (Q^{aT} c q_2^b)\gamma_5 q_1^c + \beta\Big[(q_1^{aT} c\gamma_5 Q^b) q_2^c - (Q^{aT} c\gamma_5 q_2^b) q_1^c\Big]\Big\}$$

$$\eta^{(a)} = \frac{1}{\sqrt{6}}\varepsilon^{abc}\Big\{2(q_1^{aT} c q_2^b)\gamma_5 Q^c + (q_1^{aT} c Q^b)\gamma_5 q_2^c + (Q^{aT} c q_2^b)\gamma_5 q_1^c + \beta\Big[2(q_1^{aT} c\gamma_5 q_2^b) Q^c + (q_1^{aT} c\gamma_5 Q^b) q_2^c + (Q^{aT} c\gamma_5 q_2^b) q_1^c\Big]\Big\}$$

$\eta^{(s)}$ is symmetric $q_1 \leftrightarrow q_2$

$\eta^{(a)}$ is asymmetric $q_1 \leftrightarrow q_2$

Interpolating Currents

	q_1	q_2
$\Sigma_{b(c)}^{+(++)}$	u	u
$\Sigma_{b(c)}^{0(+)}$	u	d
$\Sigma_{b(c)}^{-(0)}$	d	d
$\Xi_{b(c)}^{\prime -(0)}$	d	s
$\Xi_{b(c)}^{\prime 0(+)}$	u	s
$\Omega_{b(c)}^{-(0)}$	s	s
$\Lambda_{b(c)}^{0(+)}$	u	d
$\Xi_{b(c)}^{-(0)}$	d	s
$\Xi_{b(c)}^{0(+)}$	u	s

Interpolating Currents

$$\eta_\mu = A\varepsilon^{abc}\left\{(q_1^{aT} c\gamma_\mu q_2^b)Q^c + (q_2^{aT} c\gamma_\mu Q^b)q_2^c + (Q^{aT} c\gamma_\mu q_1^b)q_2^c\right\}$$

	q_1	q_2	A
$\Sigma_{b(c)}^{*+(++)}$	u	u	$1/\sqrt{3}$
$\Sigma_{b(c)}^{*0(+)}$	u	d	$\sqrt{2}/\sqrt{3}$
$\Sigma_{b(c)}^{*-(0)}$	d	d	$1/\sqrt{3}$
$\Xi_{b(c)}^{*0(+)}$	u	s	$\sqrt{2}/\sqrt{3}$
$\Xi_{b(c)}^{*-(0)}$	d	s	$\sqrt{2}/\sqrt{3}$
$\Omega_{b(c)}^{*-(0)}$	s	s	$1/\sqrt{3}$

Why LCSR?

- We use LCSR, why?

Example: $D^{*}D\pi$ coupling

$$\Pi_{\mu}(p,q) = i\int d^{4}x\, e^{ipx}\left\langle \pi(q)\middle|\bar{d}\gamma_{\mu}c(x)c(0)i\gamma_{5}u(0)\middle|0\right\rangle$$

$$\Rightarrow \left\langle \pi(q)\middle|\bar{d}\gamma_{\mu}\gamma_{5}u(0)\middle|0\right\rangle$$

SDE expansion

$$\bar{d}\gamma_{\mu}\gamma_{5}u(0) = \sum_{n}\frac{1}{n!}\bar{d}(0)(\overleftarrow{D}x)^{n}\gamma_{\mu}\gamma_{5}u(0)$$

$$\Pi_{\mu} \approx i\frac{m_{c}}{m_{c}^{2}-p^{2}}\sum\frac{(2pq)^{n}}{(m_{c}^{2}-p^{2})^{n}}M_{n}q_{\mu}$$

where $\left\langle \pi(q)\middle|\bar{d}\overleftarrow{D}_{\alpha_1}\overleftarrow{D}_{\alpha_2}\ldots\overleftarrow{D}_{\alpha_n}\gamma_{\mu}\gamma_{5}u(0)\middle|0\right\rangle = (i)^{n}q_{\mu}q_{\alpha_1},\ldots,q_{\alpha_n}M_{n}$

Why LCSR?

$\tilde{\xi} = \dfrac{2pq}{m^2 - p_c^2} = \dfrac{(p+q)^2 - p^2}{m^2 - p_c^2}$ $\Rightarrow$ SDE is useful only if $\xi \to 0$

i.e. $p^2 \cong (p+q)^2 \quad (q \cong 0)$. The series can truncated!!!

In general: $p^2 \neq (p+q)^2$

Infinite numbers of local operators are needed!!!

Why LCSR?

This problem can be solved by using techniques developed for hard exclusive processes in QCD.

Example:

$$i\int d^4x e^{ipx}\left\langle \pi(q)\middle| T\left\{J^{el}(x), J^{el}(0)\right\}\middle|0\right\rangle$$

$$= \varepsilon_{\mu\nu\alpha\beta} p^\alpha q^\beta F^*\left(p^2, (p+q)^2\right)$$

$$-p^2 \to \infty, -(p+q)^2 \to \infty$$

$$F = F_0 \int_0^1 \frac{du\, \varphi_\pi(u)}{(p+uq)^2} \qquad F_0 = \frac{4\pi\alpha\sqrt{2} f_\pi}{3}$$

Pion DA. with definite twist

Why LCSR?

$$\left\langle \pi(q) \middle| \bar{d}\gamma_\mu\gamma_5 u(0) \middle| 0 \right\rangle = -iq_\mu f_\pi \int_0^1 du\, e^{iuqx} \varphi_\pi(u)$$

Physically: Distribution

In fraction of the light- cone momentum $q_0 + q_3$ of the pion carried by a constituent quark!!!

Let's consider almost equal virtualities

i.e. $\xi = 2pq/(-p^2) << 1$; Expanding

$$\frac{1}{(p+uq)^2} = \frac{1}{p^2 + 2pqu} = -\frac{1}{-p^2}\left[1 + \frac{2pqu}{-p^2} + \dots\right]$$

$$= \frac{1}{p^2}\left[1 + \xi u + \dots\right]$$

Why LCSR?

$$F = \frac{F_0}{p^2} \sum^{n} \xi \int_0^1 du\, u^n \varphi_\pi(u)$$

when $p^2 = (p+q)^2$ only lowest $n = 0$ give $F = F_0 / p^2$

Relations Between Invariant Functions

SSP:

$$\Pi^{\Sigma_b^0 \to \Sigma_b^0 \pi^0} = g_{\pi uu} \Pi_1^{(1)}(u,d,b) + g_{\pi dd} \Pi_1'^{(1)}(u,d,b) + g_{\pi bb} \Pi_2^{(1)}(u,d,b)$$

$$J_{\pi^0} = \sum g_{\pi qq} \bar{q} \gamma_5 q$$

$$\Rightarrow g_{\pi uu} = -g_{\pi dd} = \tfrac{1}{\sqrt{2}},\ g_{\pi bb} = 0$$

$$\Pi_1'^{(1)}(u,d,b) = \Pi_1^{(1)}(d,u,b)$$

$$\Pi^{\Sigma_b^0 \to \Sigma_b^0 \pi^0} = \tfrac{1}{\sqrt{2}} \left[\Pi_1^{(1)}(u,d,b) - \Pi_1^{(1)}(d,u,b) \right]$$

In $SU(2)$ limit $\Pi^{\Sigma_b^0 \to \Sigma_b^0 \pi^0} = 0$

Relations Between Invariant Functions

- For $\Sigma_b^+ \to \Sigma_b^+ \pi^0$ can be obtained from

$\Sigma_b^0 \to \Sigma_b^0 \pi^0 : d \to u$ and $\Sigma_b^0 = -\sqrt{2}\Sigma_b^+$

$$\underset{\downarrow}{4}\,\Pi_1^{(1)}(u,d,b) = -2\left\langle uu \middle| \Sigma^+ \Sigma^+ \middle| 0 \right\rangle$$

Σ^+ cont. $2u \to 4$ ways for rad. π^0 from u

$$\Pi^{\Sigma_b^+ \to \Sigma_b^+ \pi^0} = \sqrt{2}\Pi_1^{(1)}(u,u,b)$$

- $\Xi_b'^{-(0)} \to \Xi_b'^{-(0)} \pi^0$

From $\Sigma_b^0 \to \Sigma_b^0 \pi^0 : \Xi_b'^0 = \Sigma_b^0 (d \to s),\ \Xi_b'^- = \Sigma_b^0 (u \to s)$

$$\Pi^{\Xi_b'^0 \to \Xi_b'^0 \pi^0} = \tfrac{1}{\sqrt{2}}\Pi_1^{(1)}(u,s,b)$$

$$\Pi^{\Xi_b'^- \to \Xi_b'^- \pi^0} = -\tfrac{1}{\sqrt{2}}\Pi_1^{(1)}(d,s,b)$$

Relations Between Invariant Functions

- For charged pion

$$\left\langle \bar{d}d \left| \Sigma_b^0 \bar{\Sigma}_b^0 \right| 0 \right\rangle$$

d from Σ_b, $\bar{d}$ from $\bar{\Sigma}_b^0$ form $\bar{d}d$ final state u, b, spectators

$$\left\langle \bar{u}d \left| \Sigma_b^+ \bar{\Sigma}_b^0 \right| 0 \right\rangle \approx \left\langle dd \left| \Sigma_b^0 \bar{\Sigma}_b \right| 0 \right\rangle$$

Calculations:

$$\Pi^{\Sigma_b^0 \to \Sigma_b^+ \pi^-} = \left\langle \bar{u}d \left| \Sigma_b^+ \bar{\Sigma}_b^0 \right| 0 \right\rangle = -\sqrt{2} \left\langle \bar{d}d \left| \Sigma_b^0 \Sigma_b^0 \right| 0 \right\rangle$$

$$= -\sqrt{2} \Pi_1^{(1)}(d,u,b)$$

$$u \leftrightarrow d$$

$$\Pi^{\Sigma_b^0 \to \Sigma_b^- \pi^+} = \sqrt{2} \left\langle u\bar{u} \left| \Sigma_b^0 \bar{\Sigma}_b^0 \right| 0 \right\rangle = \Pi_1^{(1)}(u,d,b)$$

Relations Between Invariant Functions

Similar arguments holds for all
SSP, SAP, AAP, SSV, SAV, AAV
transitions:

- Main results: All these transitions (with P, V) can be represented in terms of only one invariant function for each class.
- • Relations among the invariant functions are structure independent, but their explicit forms are structure dependent.

$B_Q\, B_Q\, M$ Coupling Constants in QCD

$$\Pi^{ij}_{(\mu),(\nu)} = i\int d^4x\, e^{ipx} \left\langle M(q) \left| \left\{ \eta^{(i)}_{(\mu)} \eta^{(i)}_{(\nu)} \right\} \right| 0 \right\rangle$$

$i = 1,\ j = 1$ Sextet- sextet

$i = 1,\ j = 2$ Sextet- antitriplet

$i = 2,\ j = 2$ Antitriplet-antitriplet

- Π – two different representations

Hadrons

Quark Gluons

Sum Rules
(via disper. relation)

$B_Q\, B_Q\, M$ Coupling Constants in QCD

$$\Pi^{ij}_{(\mu),(\nu)} = \frac{\left\langle 0 \left| \eta^{(i)}_{(\mu)} \right| B_2(p) \right\rangle \left\langle B_2(q) M(1) \left| B_1(p+q) \right\rangle \right. \left\langle B_1(p+q) \left| \bar{\eta}^{j}_{\nu} \right| 0 \right\rangle}{\left(p^2 - m_2^2\right)\left[(p+q)^2 - m_1^2\right]}$$

$$+ \ldots$$

Matrix Elements

$$\left\langle 0 \left| \eta^{(i)}_{(\mu)} \right| B_2(p) \right\rangle = \lambda^i u_{(\mu)}(p)$$

$$\left\langle B_1(p+q) \left| \bar{\eta}^{j}_{\nu} \right| 0 \right\rangle = \lambda^j \bar{u}(p+q)$$

$$\left\langle B_2(q) M(1) \left| B_1(p+q) \right\rangle \right. =$$

$B_Q\, B_Q\, M$ Coupling Constants in QCD

$= g\bar{u}(p) i\gamma_5 u(p+q)$ spin $1/2$ spin $1/2$ P

$$\bar{u}(p)\left[f_1\gamma_\mu - i\frac{\sigma_{\mu\nu}q^\nu}{m_1+m_2} f_2 \right] u(p+q)\varepsilon^\mu \qquad 1/2 \to 1/2\ V$$

charge — magnetic formfactors

$$g^*\bar{u}(p)u_\alpha(p+q)q^\alpha \qquad 3/2 \to 1/2\ P$$

$$\bar{u}(p)\Big\{ g_1\left(q_\alpha \not{\varepsilon} - \varepsilon_\alpha \not{q}\right)\gamma_5 + g_2\left(\left(p\varepsilon\right)q_\alpha - Pq\varepsilon_\alpha\right)\gamma_5 +$$

$$g_3\left(\left(p\varepsilon\right)q_\alpha - q^2\varepsilon_\alpha\right)\gamma_5 \Big\} \qquad 3/2 \to 1/2\ V$$

(For on shell vector mesons last term $\to 0$)

$B_Q B_Q M$ Coupling Constants in QCD

Two problems (in participation of spin $3/2$ baryons)

• The spin $1/2$ states also contribute to the matrix element

$$\langle 0 | \eta_\mu | B(1/2) \rangle = A \left(\gamma_\mu - \frac{4}{m} p_\mu \right) u(p)$$

i.e. η_μ – couples to both spin $3/2$ and spin $1/2$

• • Not all structures are independent.

$B_Q B_Q M$ Coupling Constants in QCD

Solution: Ordering Dirac Matrices!

In $\frac{3}{2} \to \frac{1}{2} P$ Ordering $\not{q}\not{p}\gamma_\mu$ ($\not{q}q_\mu$ structure is chosen)

$\frac{3}{2} \to \frac{1}{2} V$ Ordering $\gamma_\mu \not{\varepsilon}\not{q}\not{p}\gamma_5$

$\not{\varepsilon}\not{p}\gamma_5 q_\mu$ for g_1

$\not{q}\not{p}(p\varepsilon)$ g_2

$q^2 \not{q}\not{p}\varepsilon_\mu \gamma_5$ g_3

$B_Q B_Q M$ Coupling Constants in QCD

$\frac{3}{2} \to \frac{3}{2} P$

$$\gamma_\mu \not{p} \not{q} \gamma_\nu \gamma_5$$

$$g_{\mu\nu} \not{p} \not{q} \gamma_5$$

$\frac{3}{2} \to \frac{3}{2} V$

$$\gamma_\mu \not{\varepsilon} \not{q} \not{p} \gamma_\nu$$

$$g_{\mu\nu} \not{q} \varepsilon p \qquad g_1 + \frac{g_2 m_2}{m_1 + m_2}$$

$$q_\mu q_\nu \varepsilon \not{q} \not{p} \qquad \frac{g_2}{m_1 + m_2}$$

$$2\varepsilon p q_\mu q_\nu \not{\varepsilon} \not{q} \not{p} \qquad \frac{g_3}{(m_1 + m_2)^2}$$

$B_Q\, B_Q\, M$ Coupling Constants in QCD

$$g^{**}\overline{u}(p) i\gamma_5 u_\alpha(p+q)$$

$3/2 \to 3/2\ P$

$$\overline{u}(p)\left\{ g^{\alpha\beta}\left[\not{\varepsilon} g_1 + 2p\varepsilon \frac{g_2}{m_1+m_2} \right] + \frac{q^\alpha q^\beta}{(m_1+m_2)^2}\left[\not{\varepsilon} g_3 + 2p\varepsilon \frac{g_4}{m_1+m_2} \right]\right\} u^\beta(p+q)$$

$3/2 \to 3/2\ V$

Results

SSP	Bottom Baryons	Charmed Baryons
$g^{\Xi_Q^{10(+)} \to \Xi_Q^{10(+)} \pi^0}$	9 ± 3	4 ± 1.4
$g^{\Sigma_Q^{0(+)} \to \Sigma_Q^{-(0)} \pi^+}$	17 ± 6	8 ± 2.8
$g^{\Xi_Q^{10(+)} \to \Sigma_Q^{+(++)} K^-}$	19 ± 6.7	9 ± 3.4
$g^{\Omega_Q^{-(0)} \to \Xi_Q^{10(+)} K^-}$	21 ± 6.8	9 ± 3.4
SAP		
$g^{\Xi_Q^{10(+)} \to \Xi_Q^{10(+)} \pi^0}$	7.5 ± 2.6	3.1 ± 1.1
$g^{\Sigma_Q^{-(0)} \to \Lambda_Q^{0(+)} \pi^-}$	15 ± 4.9	6.5 ± 2.4
$g^{\Sigma_Q^{0(+)} \to \Xi_Q^{0(+)} \bar{K}^0}$	11.5 ± 3.9	5.0 ± 1.7
$g^{\Xi_Q^{10(+)} \to \Xi_Q^{-(+)} K^+}$	12 ± 4.3	4.5 ± 1.6
AAP		
$g^{\Xi_Q^{0(+)} \to \Xi_Q^{0(+)} \pi^0}$	1 ± 0.3	0.7 ± 0.22
$g^{\Xi_Q^{-(0)} \to \Lambda_Q^{0(+)} K^-}$	1.5 ± 0.5	0.9 ± 0.3
$g^{\Xi_Q^{0(+)} \to \Xi_Q^{0(+)} \eta_1}$	0.6 ± 0.2	0.07 ± 0.02
$g^{\Lambda_Q^{0(+)} \to \Lambda_Q^{0(+)} \eta_1}$	1 ± 0.3	0.75 ± 0.24

Conclusion

- Using the symmetry arguments it is shown that all SSM, SAM, and AAM transitions are described by only one universal function for each class of transition for any Lorentz structure.

- Violation of $SU(3)_F$ does not produce any new structure in addition than that one existing in $SU(3)_F$ symmetry case.

- Relations between invariant functions are structure independent, while their explicit expressions are structure dependent.