ρB^* and ωB^* interaction and generation of states with spin $J = 0, 1$ and 2

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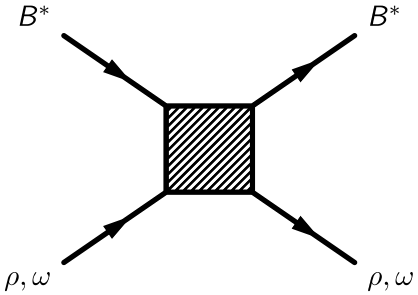
Statement of the problem



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- They reproduced states $D_2^*(2460)$ of $J = 2$ and $D^*(2640) \sim \frac{1}{2}(1^+)$ and predicted $\frac{1}{2}(0^+)$ state of 2592 MeV
- Lately the $D(2600)$ appeared

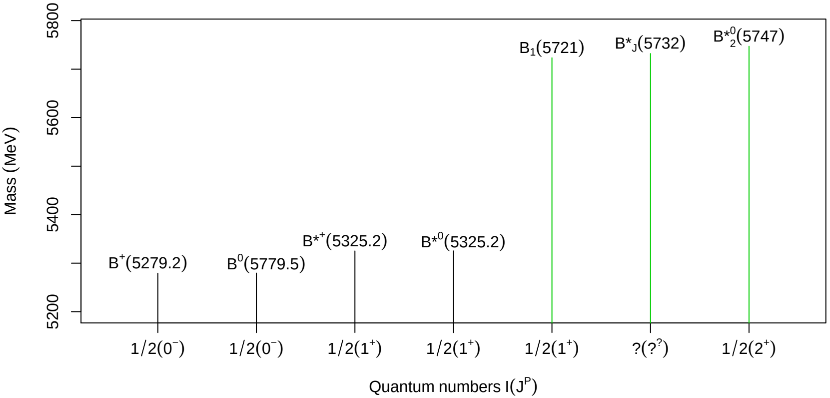
Statement of the problem

Quantum system of two particles.

$$
\begin{aligned}
|B^*, \rho\rangle &= |B^*\rangle \otimes |\rho\rangle \\
&= \left| i = \frac{1}{2}, j = 1 \right\rangle \otimes |i = 1, j = 1\rangle \\
&= \left| I = \left\{ \frac{1}{2}, \frac{3}{2} \right\}, J = \{0, 1, 2\} \right\rangle
\end{aligned}
$$

Statement of the problem

Spectrum of b mesons



Theoretical approach

We employ an effective Lagrangian based on the local hidden gauge approach

$$\mathcal{L}_{\mathcal{V}\mathcal{V}} = \frac{1}{4}\mathbf{Tr}\left\{\left(\partial_\mu V_\nu - \partial_\nu V_\mu - \mathrm{ig}\left[V_\mu, V_\nu\right]\right)\left(\partial^\mu V^\nu - \partial^\nu V^\mu - \mathrm{ig}\left[V^\mu, V^\nu\right]\right)\right\}$$

V_μ is a field matrix

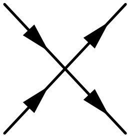
$$V_\mu = \begin{pmatrix} \left(\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}}\right) & \rho^+ & B^{*+} \\ \rho^- & \left(-\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}}\right) & B^{*0} \\ B^{*-} & \bar{B}^{*0} & \gamma \end{pmatrix}_\mu$$

Theoretical approach

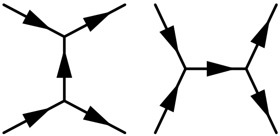
$$\mathcal{L}_{\mathcal{VV}} = \mathcal{L}_{\mathsf{c}} + \mathcal{L}_{\mathsf{ex}}$$

At tree level

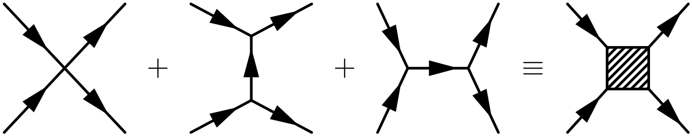
$$\mathcal{L}_{\mathsf{c}} \sim g^2 \mathbf{Tr}\left(V_\mu V_\nu V^\mu V^\nu - V_\mu V_\nu V^\nu V^\mu\right) \longleftrightarrow$$



$$\mathcal{L}_{\mathsf{ex}} \sim g\, \mathbf{Tr}\left((\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu\right) \longleftrightarrow$$



Theoretical approach



S-wave amplitudes for the $\mathbf{1} \equiv \rho B^*$ and $\mathbf{2} \equiv \omega B^*$ channels interaction

$$t^{I,J}_{\alpha,\beta}, \qquad \alpha, \beta = \mathbf{1}, \mathbf{2}$$

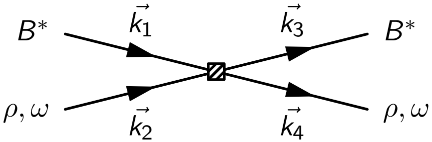
Theoretical approach

We will look at energies from $m_B + m_\pi \approx 5{,}5$ GeV up to $m_{B^*} + m_\rho \approx 6{,}4$ GeV

We will neglect the three-momenta of external vector mesons

$$\frac{\vec{k}_\rho^2}{M_\rho^2}, \frac{\vec{k}_{B^*}^2}{M_{B^*}^2} \to 0$$

Theoretical approach



$$\mathbf{P^0} = \frac{1}{3}\epsilon_\mu(\vec{k}_1)\epsilon^\mu(\vec{k}_2)\epsilon_\nu(\vec{k}_3)\epsilon^\nu(\vec{k}_4) \equiv \frac{1}{3}\epsilon_\mu\epsilon^\mu\epsilon_\nu\epsilon^\nu$$

$$\mathbf{P^1} \equiv \frac{1}{2}\left(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu - \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu\right)$$

$$\mathbf{P^2} \equiv \frac{1}{2}\left(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu + \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu\right) - \frac{1}{3}\epsilon_\mu\epsilon^\mu\epsilon_\nu\epsilon^\nu$$

Theoretical approach

Solve the interaction by the unitarization of the amplitudes:
on shell factorized Bethe-Salpeter equation

$$\hat{T}^{I,J} = \frac{\hat{V}^{I,J}}{1 - \hat{V}^{I,J}\hat{G}}, J = 0, 1, 2 \quad I = \frac{1}{2}, \frac{3}{2}$$

Theoretical approach

on shell factorized Bethe-Salpeter equation

$$\hat{T}^{I,J} = \frac{\hat{V}^{I,J}}{1 - \hat{V}^{I,J}\hat{G}}, J = 0, 1, 2 \quad I = \frac{1}{2}, \frac{3}{2}$$

$$\left(\hat{V}^{I,J}\right)_{\alpha,\beta} \sim t^{I,J}_{\alpha,\beta}, \quad \alpha, \beta = \mathbf{1}, \mathbf{2}$$

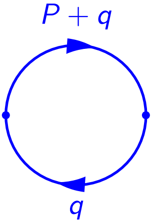
Theoretical approach

on shell factorized Bethe-Salpeter equation

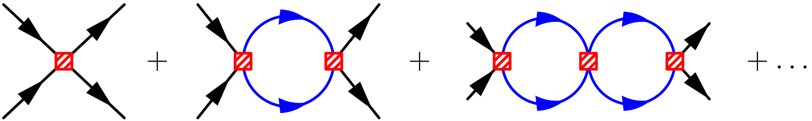
$$\hat{T}^{I,J} = \frac{\hat{V}^{I,J}}{1 - \hat{V}^{I,J}\hat{G}}, J = 0, 1, 2 \quad I = \frac{1}{2}, \frac{3}{2}$$

$$\left(\hat{V}^{I,J}\right)_{\alpha,\beta} \sim t^{I,J}_{\alpha,\beta}$$

$$(\hat{G})_{\alpha,\alpha} = \int \mathrm{d}^4 q \frac{1}{(P+q)^2 - M^2_{\alpha,1} + \mathrm{i}\epsilon} \frac{1}{q^2 - M^2_{\alpha,2} + \mathrm{i}\epsilon} \longleftrightarrow$$



Theoretical approach



$$\left(1 - \hat{V}\hat{G}\right)^{-1}\hat{V} = \hat{V} + \hat{V}\hat{G}\hat{V} + \hat{V}\hat{G}\hat{V}\hat{G}\hat{V} + \ldots$$

Results

- Cut-off regularization: $q_{\text{max}} = 1{,}3$ GeV
- $g = \frac{M_\rho}{2f_\pi}$
- Convolution due to the ρ mass distribution:

$$\left[\hat{G}^{(c)}\right]_{\mathbf{1,1}} = \int_{(m_\rho - 2\Gamma_\rho)^2}^{(m_\rho + 2\Gamma_\rho)^2} dm^2 f(m^2) G(s, m^2, M_{B^*}^2)$$

$$f(m^2) = \frac{1}{N}\left(\frac{-1}{\pi}\right) \text{Im} \frac{1}{m^2 - m_\rho^2 + i\Gamma(m^2)m}$$

$$N = \int_{(m_\rho - 2\Gamma_\rho)^2}^{(m_\rho + 2\Gamma_\rho)^2} \left(\frac{-1}{\pi}\right) \text{Im} \frac{1}{m^2 - m_\rho^2 + i\Gamma(m^2)m}$$

$$\Gamma(m) = \Gamma_\rho \left(\frac{m^2 - 4m_\pi^2}{m_\rho^2 - 4m_\pi^2}\right)^{3/2} \Theta(m - 2m_\pi)$$

Results

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$$\left[\hat{G}^{(c)}\right]_{\mathbf{1,1}} = \int dm_\rho^2 f(m_\rho^2) G(s, m_\rho^2, M_{B^*}^2)$$

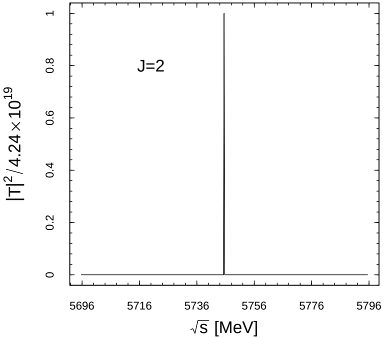
We find 3 states

$$M\left(\frac{1}{2}(0^+)\right) = 5812 \text{ MeV}$$

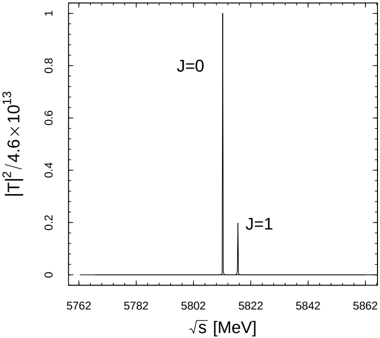
$$M\left(\frac{1}{2}(1^+)\right) = 5817 \text{ MeV}$$

$$M\left(\frac{1}{2}(2^+)\right) = 5745 \text{ MeV}$$

Results



J=2
$|T|^2/4.24\times10^{19}$
0
0.2
0.4
0.6
0.8
1
5696
5716
5736
5756
5776
5796
$\sqrt{s}$ [MeV]



J=0
J=1
$|T|^2/4.6\times10^{13}$
0
0.2
0.4
0.6
0.8
1
5762
5782
5802
5822
5842
5862
$\sqrt{s}$ [MeV]

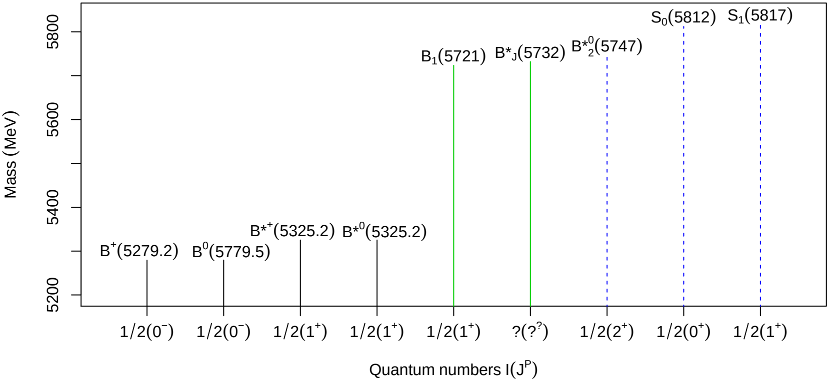
Results

Couplings to the channels

$$\left[\hat{T}(z)\right]_{i,j} \approx \frac{g_i g_j}{z - z_R}, \; z_R = M_R - \mathrm{i}\frac{\Gamma_R}{2}$$

State $I(J^P)$	$\frac{1}{2}(0^+)$	$\frac{1}{2}(1^+)$	$\frac{1}{2}(2^+)$
$\lvert g\rvert$ to ρB^* in GeV	39,58	39,32	43,58
$\lvert g\rvert$ to ωB^* in GeV	0,97	2,05	2,40

Results

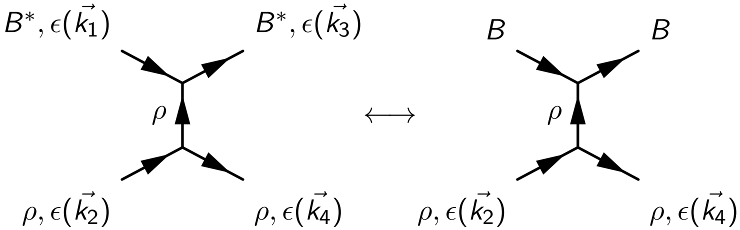

B+(5279.2)
B0(5779.5)
B*+(5325.2)
B*0(5325.2)
B1(5721)
B*J(5732)
B*02(5747)
S0(5812)
S1(5817)
1/2(0-)
1/2(0-)
1/2(1+)
1/2(1+)
1/2(1+)
?(??)
1/2(2+)
1/2(0+)
1/2(1+)
Quantum numbers I(JP)
Mass (MeV)
5200
5400
5600
5800

Results

ρB interaction

$$\mathcal{L}_{\mathcal{PPV}} = -ig\,\mathbf{Tr}\left\{[\phi, \partial_\mu \phi]\, V^\mu\right\}$$

$$\vec{k}_i \longrightarrow \vec{0}$$



$$t_{i,j}\epsilon_\alpha(\vec{k_1})\epsilon^\alpha(\vec{k_3})\epsilon_\beta(\vec{k_2})\epsilon^\beta(\vec{k_4}) \longleftrightarrow t_{i,j}(-\epsilon_\beta(\vec{k_2})\epsilon^\beta(\vec{k_4}))$$

Results

Consider the exchange term of the Lagrangian

$$\mathcal{L}_{\text{ex}} = \text{i}g\,\textbf{Tr}\left((\partial_\mu V_\nu - \partial_\nu V_\mu)V^\mu V^\nu\right) = \text{i}g\,\textbf{Tr}\left\{\left(V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu\right) V^\nu\right\}$$

$$\mathcal{L}_{\text{ex}} = \text{i}g\,\textbf{Tr}\left\{\left(V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu\right) V^\nu\right\} \quad \text{external meson}$$

$$\vec{k} \to 0 \;\; \text{for external mesons!} \Rightarrow \nu = 1, 2, 3 \text{ is spatial}$$

$$\partial_\nu V_\mu \propto k_\nu \to 0$$

So V^ν correspond to an interchanged ρ

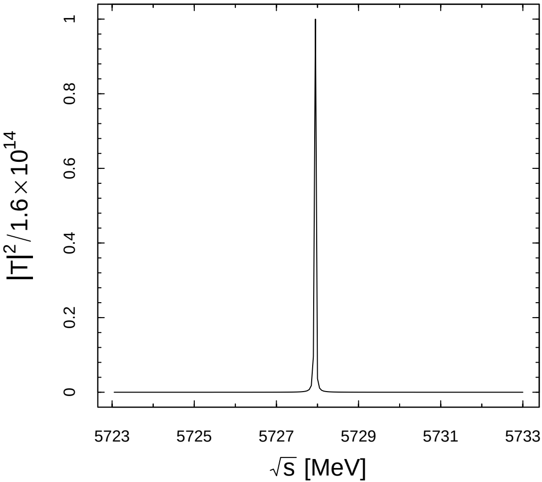
Results

$$\mathcal{L}_{\mathcal{PPV}} = -ig\,\mathbf{Tr}\left\{\left[\phi, \partial_\mu \phi\right] V^\mu\right\}$$

$$\mathcal{L}_{\text{ex}} = ig\,\mathbf{Tr}\left\{\left(V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu\right) V^\nu\right\} \quad \text{exchanged } \rho$$

Results

Another state $\frac{1}{2}(1^+)$ 5728 MeV $\approx M[B_1(5721)^0] = 5723{,}5 \pm 5$ MeV



Results

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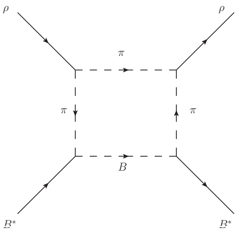
- We consider $\rho \to \pi\pi$ and $B^* \to \pi B$



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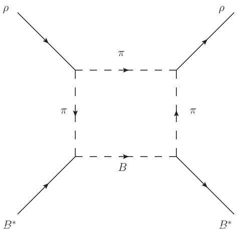

- Only allowed for $J = 0, 2$

Results

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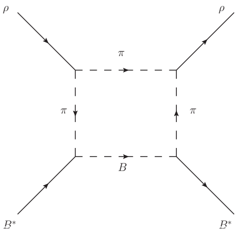

- Only allowed for $J = 0, 2$
- Parametrize off-shell pions $F(q^2) = e^{-\vec{q}^2/\Lambda^2}$, $\Lambda \approx 1$ GeV

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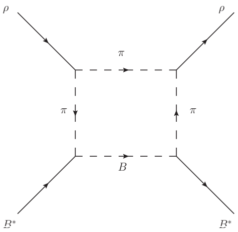
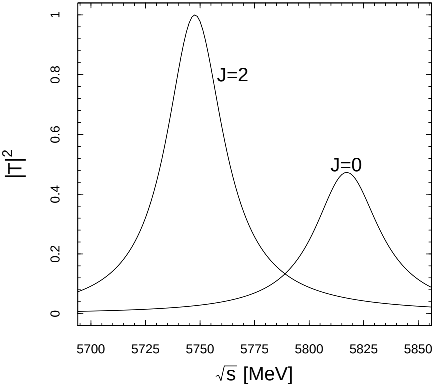


- Only allowed for $J = 0, 2$
- Parametrize off-shell pions $F(q^2) = e^{-\vec{q}^2/\Lambda^2}$, $\Lambda \approx 1$ GeV
- $g_{B^* B\pi} = g\frac{M_{B^*}}{M_{K^*}}$

Results

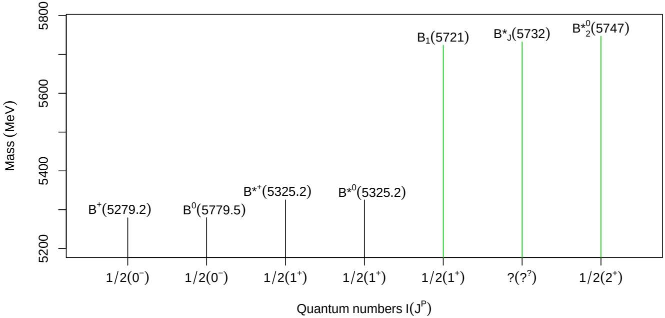


We find with $\Lambda \approx 0{,}7$ GeV $\Gamma_{J=2} = 30$ MeV and $\Gamma_{J=0} = 36$ MeV. From the PDG $\Gamma_{B_2(5745)} = 25^{+5}_{-7}$

Results

State $I(J^P)$	$\frac{1}{2}(0^+)_{\rho B^*}$	$\frac{1}{2}(1^+)_{\rho B^*}$	$\frac{1}{2}(2^+)_{\rho B^*}$	$\frac{1}{2}(1^+)_{\rho B}$
Mass in MeV	5812	5817	5745	5727

$$\frac{1}{2}(2^+)_{\rho B^*} \leftrightarrow B_2^{*0}(5747) \qquad \frac{1}{2}(1^+)_{\rho B} \leftrightarrow B_1(5721)$$



Thank you for your attention