Hadron Spectroscopy, Chiral Symmetry and Relativistic Description of Bound Systems

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Nihon University Kaikan, Ichigaya, Tokyo

Experimental Search for Chiral Particles in $Q\bar{q}$ Systems

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Outline

1. Introduction
2. Analysis of $D^*\pi$ mass spectra in the seach for D_1^χ
3. Analysis of $B\pi$ mass spectra in the seach for B_0^χ
4. Conclusion

1. Introduction

Covariant Classification ⟹ Table

Light-light relativistic S-wave chiral states ⟹ σ -nonet

Heavy-light ⟹ $\begin{cases} \text{Scalar} \longrightarrow B_0^\chi \text{ (B Meson system)} \\ \text{Axial-vector} \longrightarrow D_1^\chi \text{ (D Meson system)} \end{cases}$

Approximate chiral symmetry

The purpose of this work is investigation of phenomenological possibility of existence for D_1^χ (the chiral axial-vector meson) and B_0^χ (the chiral scalar meson) by re-analyzing some experimental data.

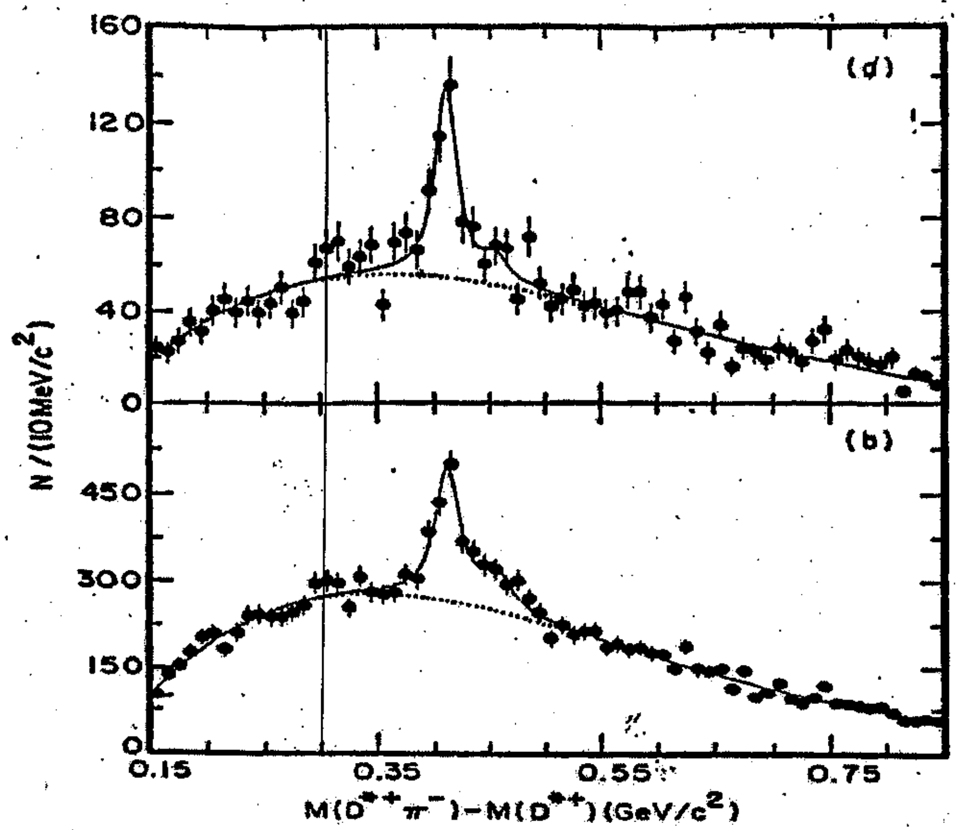
Covariant Classification

Prog. Theor. Phys. 104(2000) 785

$q\bar{q}$		J^{PC}	Experimental candidates
$P_s^{(N)} \otimes \{L\}$	$^1S_0$	0^{-+}	π, K, η, η'
$V_\mu^{(N)} \otimes \{L\}$	$^3S_1$	1^{--}	ρ, K^*, ω, ϕ
	$^1P_1$	1^{+-}	$h_1(1170)$, $b_1(1230)$
	$^3P_0$	0^{++}	$f_0(1370)$, $K_0^*(1430)$, $a_0(1450)$, $(f_0(1500))$
	$^3P_1$	1^{++}	$a_1(1230)$, $f_1(1285)$, $K_1(1270)$
	$^3P_2$	2^{++}	$a_2(1320)$, $f_2(1275)$, $K_2^*(1430)$, $f_2'(1525)$
$P_s^{(E)} \otimes \{L\}$	$^1S_0$	0^{-+}	(one out of $\eta(1275)$, $\eta(1420)$ and $\eta(1460)$)
$V_\mu^{(E)} \otimes \{L\}$	$^3S_1$	1^{--}	
	$^1P_1$	1^{+-}	
	$^3P_0$	0^{++}	
	$^3P_1$	1^{++}	
	$^3P_2$	2^{++}	
$S^{(N)} \otimes \{L\}$	$^1S_0$	0^{++}	σ, κ, $a_0(980)=\delta$, $f_0(980)=\sigma'$
	$^1P_1$	1^{--}	
$A_\mu^{(N)} \otimes \{L\}$	$^3S_1$	1^{++}	$a_1(900)$
	$^3P_0$	0^{--}	
	$^3P_1$	1^{--}	
	$^3P_2$	2^{--}	
$S^{(E)} \otimes \{L\}$	$^1S_0$	0^{+-}	
	$^1P_1$	1^{-+}	$\pi_1(1400)$
$A_\mu^{(E)} \otimes \{L\}$	$^3S_1$	1^{+-}	
	$^3P_0$	0^{-+}	
	$^3P_1$	1^{-+}	$\pi_1(1600)$
	$^3P_2$	2^{-+}	
$Q\bar{q}$, $q\bar{Q}$		J^P	
$P_s \otimes \{L\}$	$^1S_0$	0^-	D, B, D_s, B_s
$V_\mu \otimes \{L\}$	$^3S_1$	1^-	D^*, B^*, D_s^*, B_s^*
	$P_1^{j_q=1/2}$	1^+	D_1^*
	$P_1^{j_q=3/2}$	1^+	D_1
	$^3P_0$	0^+	D_0^*
	$^3P_2$	2^+	D_2^*
$S \otimes \{L\}$	$^1S_0$	0^+	$B_0^\chi(5520)$
$A_\mu \otimes \{L\}$	$^3S_1$	1^+	D_1^χ
	$P_1^{j_q=1/2}$	1^-	
	$P_1^{j_q=3/2}$	1^-	
	$^3P_0$	0^-	
	$^3P_2$	2^-	
$Q\bar{Q}$		J^P	
$P_s \otimes \{L\}$	$^1S_0$	0^-	η_c, B_c
$V_\mu \otimes \{L\}$	$^3S_1$	1^-	J/ψ, Υ, B_c^*
	$^1P_1$	1^+	h_c
	$^3P_0$	0^+	χ_{c0}, χ_{b0}
	$^3P_1$	1^+	χ_{c1}, χ_{b1}
	$^3P_2$	2^+	χ_{c2}, χ_{b2}

2. Analysis of $D^*\pi$ mass spectra in the search for D_1^χ

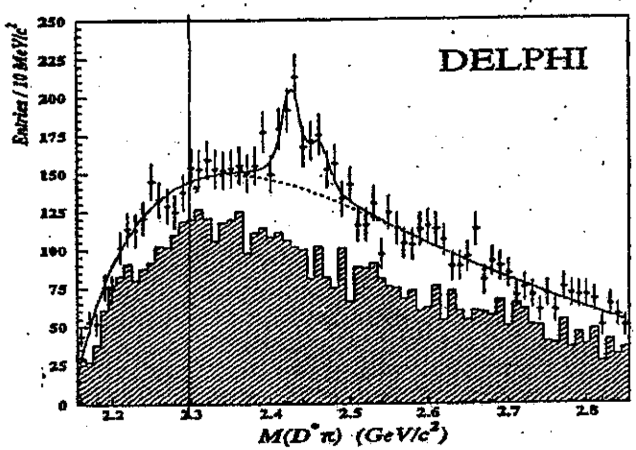
[Experimantal Data]



CLEO (a) , (b)

Phys. Lett. **B331** (1994)236. ,

$\Upsilon(4S)$ decay



DELPHI

Phys. Lett. **B426** (1998) 231.

Z^0 decay

[Relevant intermediate resonances]

The conventional three $(c\bar{q}) - P$ wave mesons may contribute, as intermediate states, to the final $D^{*+}\pi^-$ system with the respective angular momenta $l = 0, 1, 2$ as

$$D_1^* \to D^{*+} + \pi^- \quad (S-\text{wave}) ,$$
$$D_1 \to D^{*+} + \pi^- \quad (D-\text{wave}) ,$$
$$D_2^* \to D^{*+} + \pi^- \quad (D-\text{wave}) ,$$

large decay width ~ 300MeV

small decay width $\Gamma \propto p^{2\ell+1}$

where D_1^*, D_1 and D_2^* have, respectively, ${}^{j_q}L_J = {}^{1/2}P_1$, ${}^{3/2}P_1$ and ${}^{3/2}P_2$ ($\boldsymbol{j}_q = \boldsymbol{S}_q + \boldsymbol{L}$ is the total amgular momentum of the light quark), and the respective partial wave states in the above equations are deduced from the heavy quark symmetry (HQS).

A possible contribution from, in addition to the above conventional resonances, the chiral axial-vector meson D_1^χ is taken into account as

$$D_1^\chi \to D^{*+} + \pi^- \ (S-\text{wave}) ,$$

where we inferred that the S-wave decay is dominant because of small Q-value.

[Method of analysis]

We shall apply the VMW method in our relevant case, where the absolute amplitude squared is given by

$$|M(s)|^2 = \sum_i |r_i \Delta_i(s)|^2 + \text{B. G.},$$

$$\Delta_i \equiv \frac{-m_i \Gamma_i}{s - m_i^2 + i m_i \Gamma_i}$$

r_i : production strength

Regions of the values of the masses and widths (MeV) considered.

i	D_1^X	D_1	D_2^*
m	2295–2320	2400–2450	2420–2480
Γ	10–60	10–35	10–100

Back Ground

$$B.G = \alpha (\Delta M)^\beta \exp\left(-\gamma_1 (\Delta M) - \gamma_2 (\Delta M)^2 - \gamma_3 (\Delta M)^3\right)$$

$$\Delta M = M(D^*\pi) - m_{D^*} - m_\pi$$

(*DELPHI* $\gamma_2 = \gamma_3 = 0$)

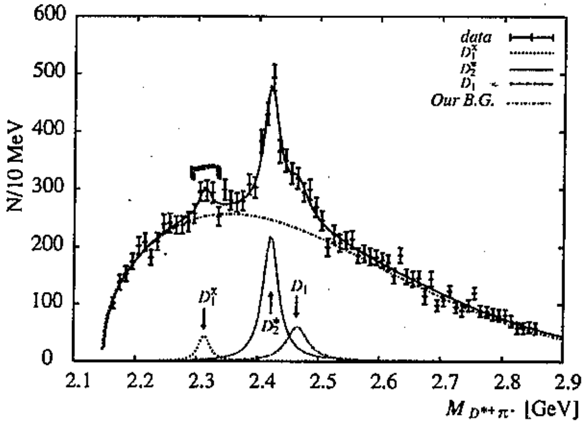
The relevant $D^*\pi$ mass spectrum is given by

$$\Gamma(s) = \frac{1}{2\sqrt{s}} \int \frac{d^3\boldsymbol{P}_{D^*} d^3\boldsymbol{P}_\pi}{(2\pi)^3 2E_{D^*} (2\pi)^3 2E_\pi} \times (2\pi)^4 \delta^{(4)}(P - P_{D^*} - p_\pi)|M(s)|^2$$

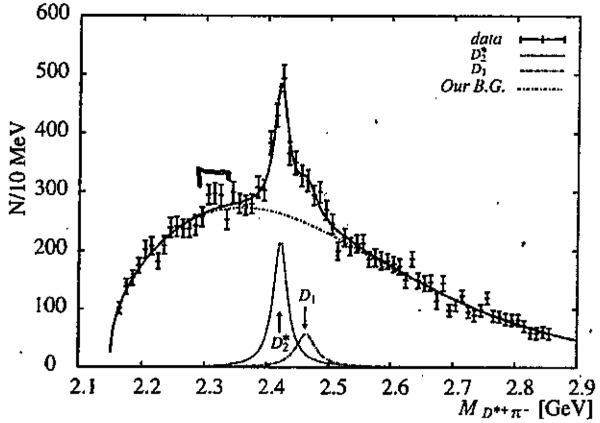
$s \equiv -(P_\mu)^2$; P_μ being the total 4-momentum of relevant system.

[Result of analysis]

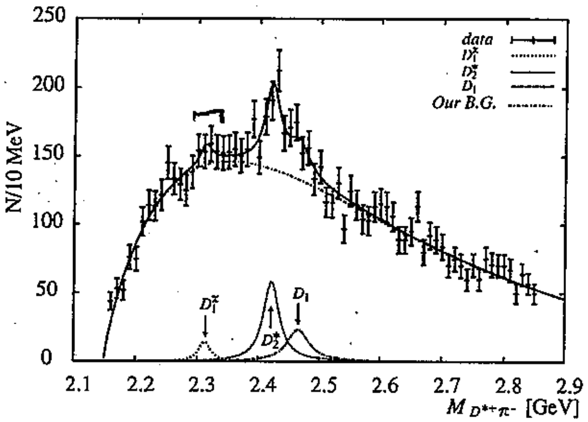
with D_1^{χ} without D_1^{χ}



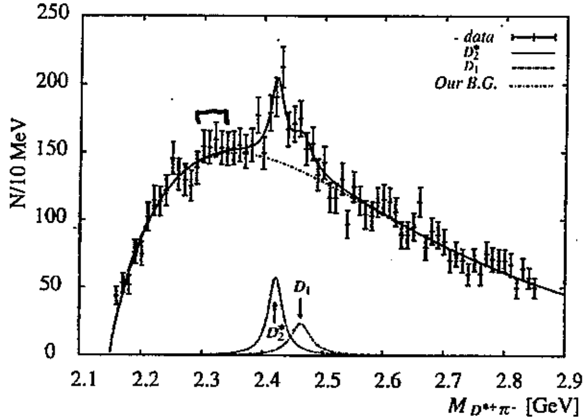
(a) CLEO(b) with D_1^{χ}



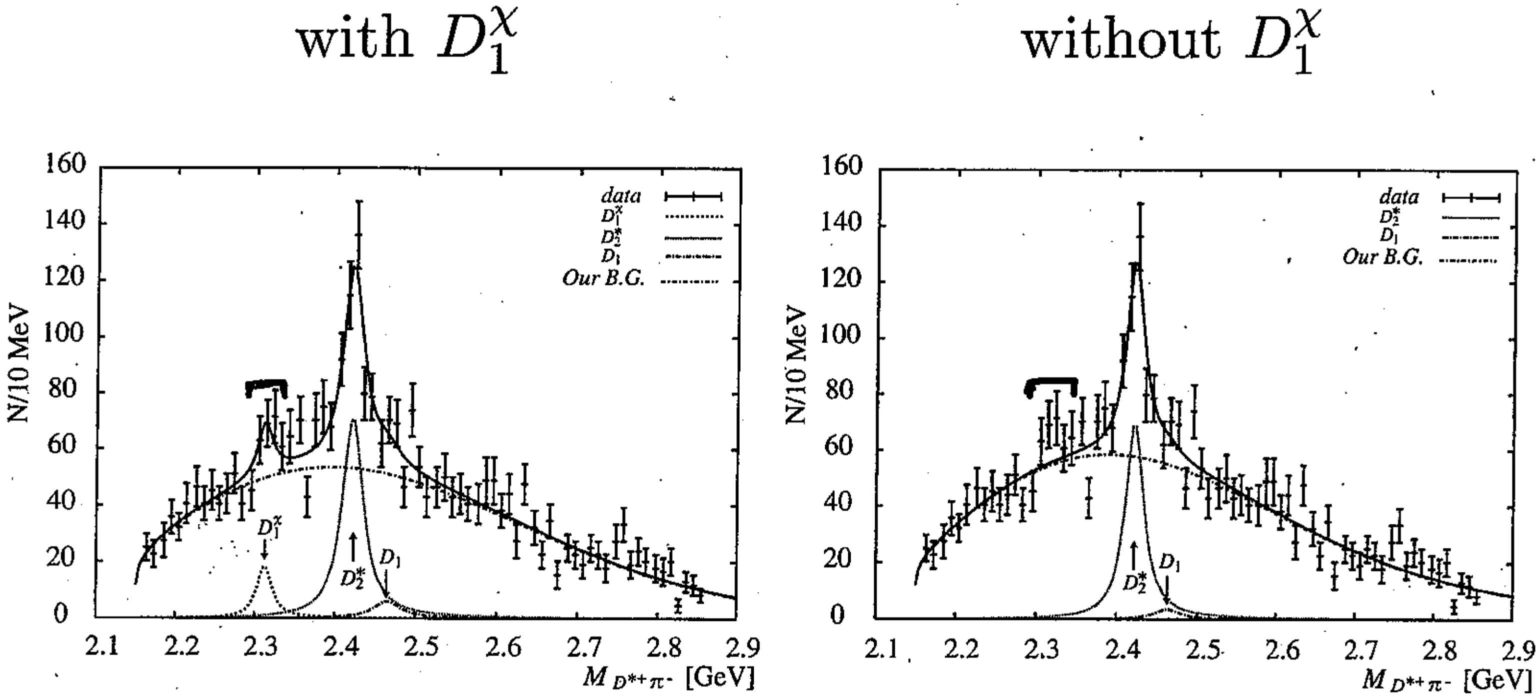
(b) CLEO(b) without D_1^{χ}



(c) DELPHI with D_1^{χ}



(d) DELPHI without D_1^{χ}



(a) CLEO(a) with D_1^χ (b) CLEO(a) without D_1^χ

Fig. 1. Fitted curves in the case with (without) D_1^χ are, for reference, given in comparison with experimental data, CLEO(a), where the values of mass and width of relevant resonances are determined in the analysis of CLEO(b) and DELPHI.

Fitted values of mass and width of resonances (in MeV)

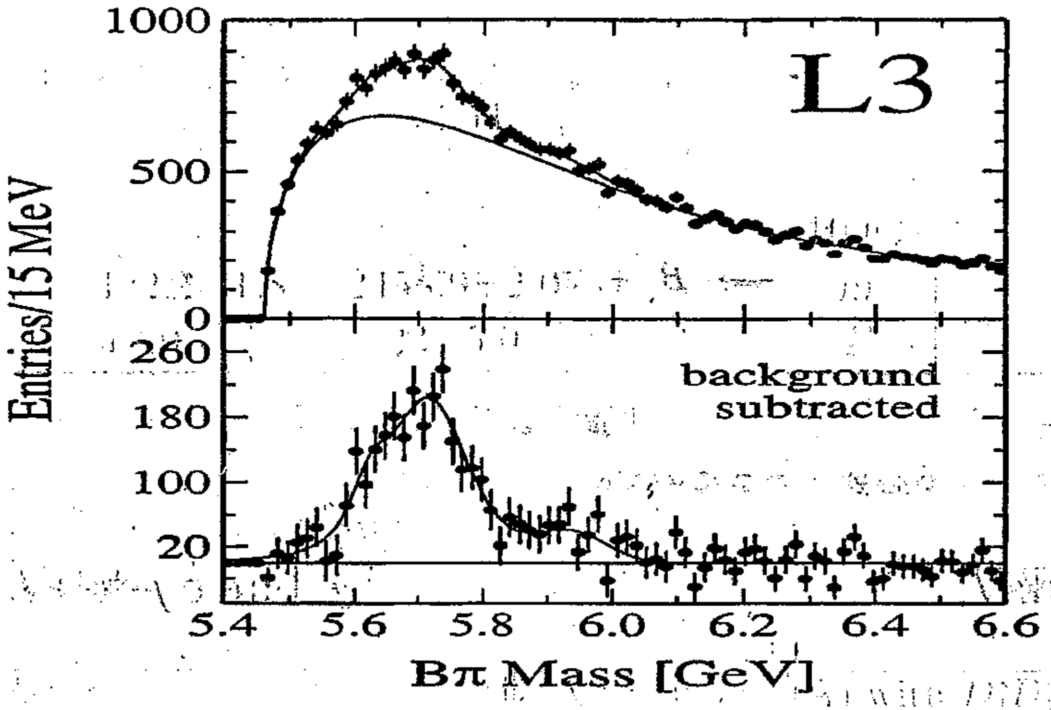
	D_1^χ	D_1	D_2^*
m	2312	2421	2465
Γ	23.03	30.73	42.54
PDG			
m		2422.2±1.8	2458.9±2.0
Γ		$18.9^{+4.6}_{-3.5}$	23±5.0

Values of χ^2 and $\tilde{\chi}^2$

	(A) with D_1^χ			(B) without D_1^χ		
	CLEO (b)	DELPHI	CLEO (a)	CLEO (b)	DELPHI	CLEO (a)
$\tilde{\chi}^2$	$\frac{110}{(140-20)} = 0.923$		$\frac{80.6}{(70-8)} = 1.30$	$\frac{119}{(140-16)} = 0.957$		$\frac{85.5}{(70-7)} = 1.36$
χ^2	59.51	51.28		66.41	52.25	

3. Analysis of $B\pi$ mass spectra in the search for B_o^χ

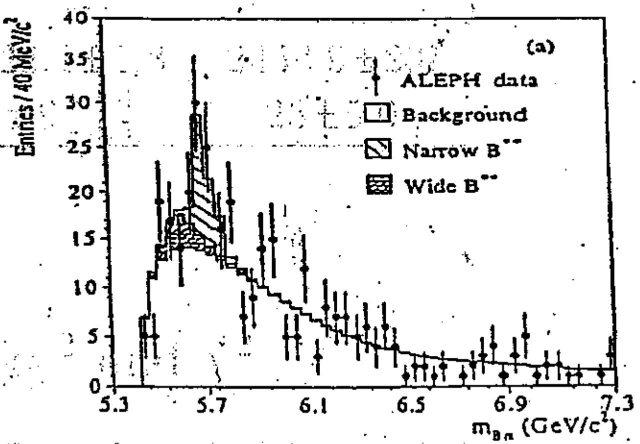
[Experimantal Data]



L3 exclusive and inclusive data

Phys. Lett. **B465** (1999) 331.

Z^0 decay



ALEPH

Frascati Physics series **Vol. XV** (1999) P311.

Z^0 decay

Relevant intermediate resonances

The conventional two $(b\bar{q}) - P$ wave mesons may contribute directly, as intermediate states, to the final $B\pi$ system with the respective angular momenta $l = 0, 2$ as

$$\text{Direct Resonant Process} \qquad B_0^* \rightarrow B + \pi \quad (S - \text{wave}) \ ,$$
$$B_2^* \rightarrow B + \pi \quad (D - \text{wave}) \ ,$$

where B_0^* and B_2^* have, respectively, ${}^{j_q}L_J = {}^{1/2}P_0$ and ${}^{3/2}P_2$ ($\boldsymbol{j}_q = \boldsymbol{S}_q + \boldsymbol{L}$ is the total amgular momentum of the light quark).

In this work, a possible direct contribution from, in addition to the above conventional resonances, the chiral scalar meson B_0^χ is taken into account as

$$\text{Direct Resonant Process} \qquad B_0^\chi \ \rightarrow \ B + \pi \ (S - \text{wave}) \ ,$$

Regarding the chiral particle B_0^χ, structure that cannot be accounted for by the background around the mass $m \sim 5550$ MeV, which is seen in both the data of L3 and ALEPH, is identified as being due to production of B_0^χ.

In the relevant experiment the low energy γ was unable to be observed. Accordingly we must take into account the background process from the intermediate resonances, decaying into $B^* + \pi$ (successively B^* decays into B and missing γ).

Backgd. Resonant Process
$$\begin{aligned} B_1^* &\to B^* + \pi \ (S - \text{wave}) \ , \\ B_1 &\to B^* + \pi \ (D - \text{wave}) \ , \\ B_2^* &\to B^* + \pi \ (D - \text{wave}) \ , \\ B^* &\to B + \gamma \ (\text{missing}). \end{aligned}$$

[Method of analysis]

We shall apply the VMW method in our relevant case, where the absolute amplitude squared is given by

$$|M(s)|^2 = \{|r_1\Delta_{B_0^\chi}(s) + r_2 e^{i\theta}\Delta_{B_0^*}(s)|^2 + |r_3\Delta_{B_2^*}(s)|^2\}$$
$$+\{|r_4\Delta_{B_1^*}(s)|^2 + |r_5\Delta_{B_2^*}(s)|^2 + |r_6\Delta_{B_1}(s)|^2\} \ + B.G.$$
$$\Delta_i(s) \equiv \frac{-m_i\Gamma_i}{s - m_i^2 + im_i\Gamma_i} \qquad (i \text{ denoting respective resonances}) \, .$$

Here the first (second) term represents the contributions from the direct (background) resonance processes , the $m_i(\Gamma_i)$ are the mass(width) of relevant resonances, and r_i represent their production strength. In the above equtaion a possible interference effect between the two direct decay processes of the B_0^* and of the B_0^χ are taken into account, while no interference effects among any background process are expected.

The relevant $B\pi$ mass spectrum is given by

$$\Gamma(s) = \frac{1}{2\sqrt{s}} \int \frac{d^3\mathbf{P_B}}{(2\pi)^3 2E_B} \frac{d^3\mathbf{P}_\pi}{(2\pi)^3 2E_\pi} \times (2\pi)^4 \delta^4(P - P_B - P_\pi) \, |\mathcal{M}(s)|^2$$

$s \equiv -(P_\mu)^2$; P_μ being the total 4-momentum of relevant system.

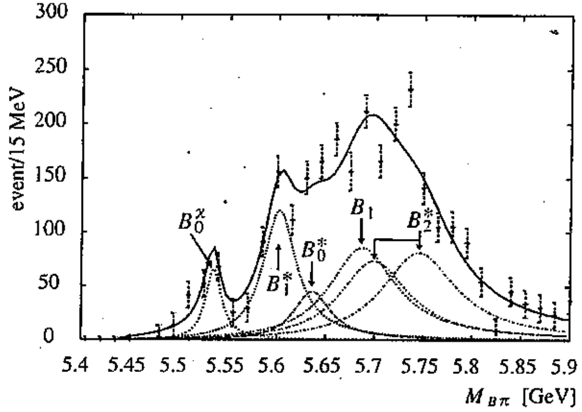
The original data are inclusive and the relevant exclusive mass spectra of $B\pi$ system are obtained by subtracting from the original ones the backgrounds of the form

$$\begin{aligned} B.\,G. &= P_1(\Delta M)^{P_3} \exp\left[P_4(\Delta M) + P_5(\Delta M)^2 + P_6(\Delta M)^3\right] \\ \Delta M &\equiv M_{B\pi} - P_2, \end{aligned}$$

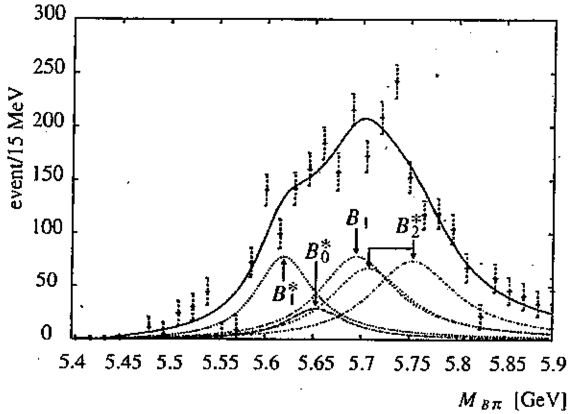
with fitting parameters P_i $(i = 1, 2, \cdots, 6)$. We shall apply the same formula to the above equation for the backgrounds, taking into account the possible effects of intermediate B_0^χ production.

Result of Analysis

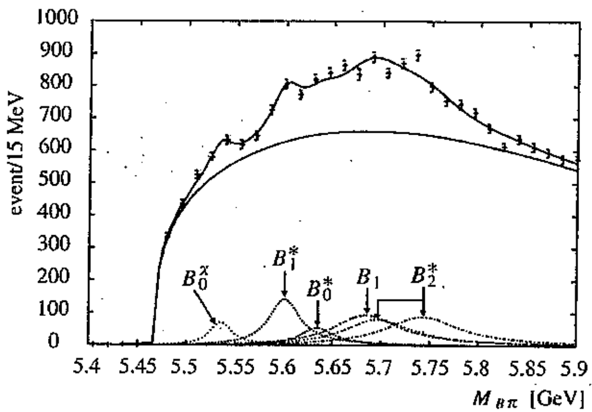
with B_0^χ without B_0^χ



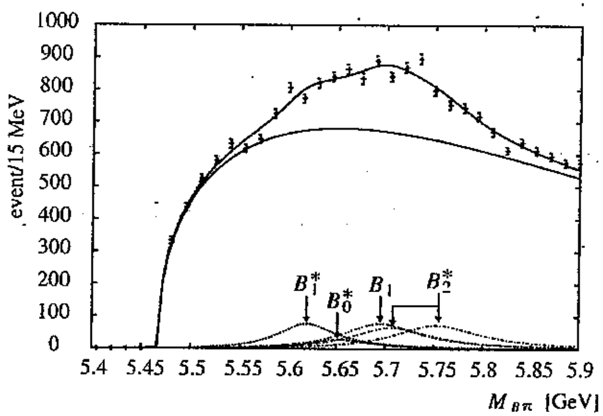
(a) L3(exclusive) with B_0^χ



(b) L3(exclusive) without B_0^χ

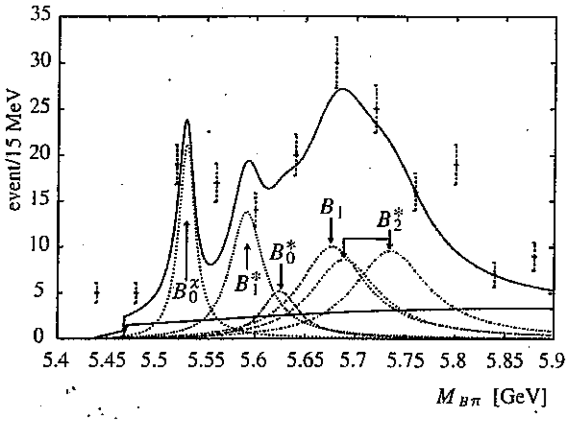


(c) L3(inclusive) with B_0^χ

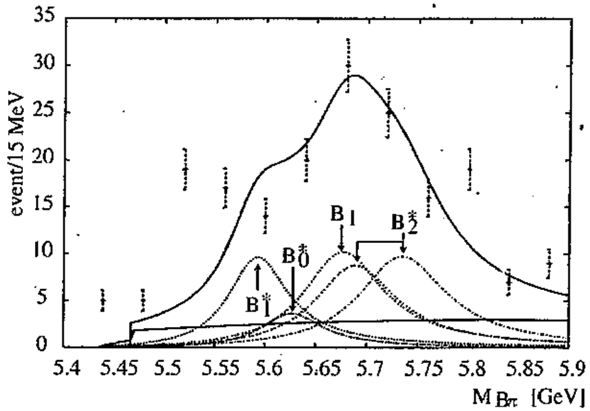


(d) L3(inclusive) without B_0^χ

with B_0^χ | without B_0^χ



(e) ALEPH with B_0^χ



(f) ALEPH without B_0^χ

Fitted values of mass and width (in MeV)

	B_0^χ	B_0^*	B_2^*
m	5534	5635	5743
Γ	19.7	40.3	73.1

Values of χ^2 and $\tilde{\chi}^2$

	with B_0^χ	without B_0^χ
χ^2	18.5	22.4
$\tilde{\chi}^2$	$\frac{18.5}{34-9} = 0.74$	$\frac{22.4}{34-5} = 0.77$

Conclusion

About D1 χ

We have made reanalysis of the $(D^{*+}\pi^-)$ mass spectra obtained through the processes Eqs. (??) and (??), by applying the formulas Eqs. (??) and (??). As the intermediate resonant particles we have taken into account the D_1^χ, a new chiral axial-vector meson outside of the conventional level classification scheme. As a result we have obtained a possible evidence for D_1^χ with $m = 2312$ MeV and $\Gamma = 23.0$ MeV. The obtained values of reduced χ square, $\tilde{\chi}^2 \equiv \chi^2/(\text{No. of data points} - \text{No. of param.})$, are

$\tilde{\chi}^2 = 110/(140-20) = 0.923$ for the case with D_1^χ and $119/(140-16) = 0.957$ for the case without D_1^χ, respectively. However, the statistical accuracy of the relevant data is very poor. It is required to have the more accurate data in order to get a definite conclusion.

About B0 χ

We have made reanalysis of the $(B\pi)$ mass spectra obtained through the process Eq. (??), by applying the formulas (??) and (??). As the intermediate direct resonance we have taken into account the B_0^χ, a new chiral scalar meson outside of the conventional level-classification scheme. As a result we have obtained a possible evidence of B_0^χ with $m = 5530$ MeV and $\Gamma = 19.7$ MeV. The obtained values of reduced χ square, $\tilde{\chi}^2 = 18.5/(34-9) = 0.74$ for the case with B_0^χ and $22.4/(34-5) = 0.77$ for the case without B_0^χ, respectively. However, the statistical accuracy of the relevant data is very poor, and the more accurate data are required in order to get a definite conclusion.

(*Universal property of chiral particles*) In the previous works the universal relations*) of chiral particles through the D- and B-meson systems are predicted from the chiral symmetry on the light-quark and the heavy quark symmetry: The mass splittings between the respective chiral partners are equal, and the decay widths for the one-pion emission of the chiral particles, scalar and axial vector mesons are also equal.

We can check some of these universal relations experimentally, using the results of the analyses given in this letter and the previous one, as follows:

$$\begin{array}{ll} \Delta m_D(\equiv m(D_1^\chi) - m(D^*)) = & \Delta m_B(\equiv m(B_0^\chi) - m(B)) \\ 302(\underline{2312} - 2010)\ \text{MeV} & 238(= \underline{5535} - 5297)\ \text{MeV}. \end{array}$$

$$\begin{array}{ll} \Gamma(D_1^\chi \to D^*\pi) = & \Gamma(B_0^\chi \to B\pi) \\ 23\ \text{MeV} & 20\ \text{MeV}. \end{array}$$

From the above we may conclude that the theoretical predictions on the universal properties of chiral particles are consistent with the present experiment.

*)
M. Ishida and S. Ishida, PTP **106** (2001), 373.
W. A. Bardeen and C. T. Hill, RPD**49** (1994), 409.
D. Ebert, T. Feldmann, R. Friedrich and H. Reinhardt, NPB **434** (1995), 619.

(Chiral particles D0 χ and B1 χ)

In the covariant level-classi fication scheme,the existence of other chiral particles,the scalar D χ 0 in the D-meson system and the axial-vector B χ 1 in the B -meson system,is also predicted.Applying the universalit relations 10) Eqs.(4 .1)and (4 .2) they are predicted to have the masses

$$m(D_0^{\chi}) = m(D) + \Delta m_D \approx 2170\text{MeV}$$
$$m(B_1^{\chi}) = m(B^*) + \Delta m_B \approx 5560\text{MeV}$$

and the widths

$$\Gamma(D_0^{\chi} \to D\pi) = \Gamma(B_1^{\chi} \to B^*\pi) \approx 20 \sim 25\text{MeV}$$

Presently,to our regret,there are no experimental data whose statistics are sufficiently good to allow for analysis.However,it maybe worthwhile to note the possibilitythat the peak structure denoted as B χ 0 in Fig.3(a) actually represents the sum of the direct B χ 0 contribution and the background B χ 1 contribution (B χ 1 →B *+ π ;B *→B +missing γ).