Covariant Classification Scheme of Hadrons

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(Hadron 2001)

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I. Introduction

(Two contrasting view points of Level Classification)

	Non-Relativistic	Relativistic
Model	Non Relat. Q. M.	NJL model
approx. Symm.	LS-Symm.	Chiral Symm.
Evidence	Bases for PDG	π-nonet as NG Boson

σ-meson 2000

(Recent progress) It seems to be established !?

Existence of light $\sigma(600)$ in $\pi\pi$-prod. processes, as chiral partner of $\pi(140)$,

$\Rightarrow$ seemingly contradictory two view points

; Serious problem in Hadron Spectroscopy !

(Purpose of this talk)

to propose an attempt for unification of the contrasting two.

Non-Relativistic & Extremely Relativistic,

view points.

(overview of attempt)

(Light-q. hadrons)

	NRQM	COQM (old)	COQM (extended)
Confin. force	spin-indep.	"boosted"-spinindep.	Lorentz Scalar
Symmetry	$SU(6)_{SF}$	"boosted" $SU(6)_{SF}$	$\tilde{U}(12)_{SF}$
(WF)			
$(q\bar{q})$-meson	$f(x_1, x_2)\, \chi_q \bar{\chi}_{\bar{q}}$ Pauli Sp.	$f(x_1, x_2)\, U_q \bar{V}_{\bar{q}}$ $U_q = U_+(\mathbb{P})$, $\bar{V}_{\bar{q}} = \bar{V}_+(\mathbb{P})$, Boosted-Pauli Sp.	Dirac Sp. $U_-(-\mathbb{P})$ $\bar{V}_-(-\mathbb{P})$
(qqq)-baryon	$f(x_1, x_2, x_3)\, \chi_{q_1} \chi_{q_2} \chi_{q_3}$	$f(x_1, x_2, x_3)\, U_{q_1} U_{q_2} U_{q_3}$ $U_q = U_+(\mathbb{P})$,	 $U_-(-\mathbb{P})$
$(\bar{q}\bar{q}\bar{q})$-anti-baryon	$f(x_1, x_2, x_3)\, \bar{\chi}_{\bar{q}_1} \bar{\chi}_{\bar{q}_2} \bar{\chi}_{\bar{q}_3}$	$f(x_1\, x_2\, x_3)\, \bar{V}_{q_1} \bar{V}_{q_2} \bar{V}_{q_3}$ $\bar{V}_q = \bar{V}_+(\mathbb{P})$,	 $\bar{V}_-(-\mathbb{P})$
space(time)	$O(3) \otimes SU(2)_S \otimes SU(3)_F$	$O(3,1) \otimes \tilde{U}(4)_{D.S.} \otimes SU(3)_F$	
(spin-WF)	multi-Pauli spinor	multi-(boosted Pauli)	Dirac Spinor

freedom of Spin-Flavor WF

$q\bar{q}$-meson $\quad 6 \times \bar{6} = \underline{36}$

$= \underline{35} \oplus \underline{1}$

qqq-baryon $\quad (6 \times 6 \times 6)_S = \underline{56}$

$12 \times \bar{12} = 144$ (for M&$\bar{\text{M}}$

$(6 \times \bar{6}) = \underline{36}$ ¦ $(6 \times \bar{6}) \times 4 = 144$

$(12 \times 12 \times 12)_S = \underline{364}$ (for B+$\bar{\text{B}}$)

$\downarrow$

$\underline{182}$ (for B)

$\underline{182} = \underline{56} \times 2 + \underline{70} \times 1$

(general q and/or Q-hadrons)

WF : Tensors in $O(3,1) \otimes [\tilde{U}_q(4) \otimes SU(3)_q] \otimes [SU(2)_{Q,S} \otimes U(1)_Q]$

II. Covariant Framework for describing Composite Hadrons

(Wave function) $A = (\alpha, a)$, $B = (\beta, b)$ $\alpha = 1 \sim 4$

meson : $\Phi_A^B(x_1, x_2) = \langle 0 | \psi_A(x_1) \bar{\psi}^B(x_2) | M \rangle + \langle \bar{M} | \psi_A(x_1) \bar{\psi}^B(x_2) | 0 \rangle$

baryon : $\Phi_{A_1A_2A_3}(x_1, x_2, x_3) = \langle 0 | \psi_{A_1}(x_1) \psi_{A_2}(x_2) \psi_{A_3}(x_3) | B \rangle + \langle \bar{B} | \psi_{A_1}(x_1) \psi_{A_2}(x_2) \psi_{A_3}(x_3) | 0 \rangle$

(Basic Wave Eq.) Yukawa 1953

$$\left[\frac{\partial^2}{\partial X_\mu^2} - \mathcal{M}^2(r_\mu, \partial/r_\mu, \cdots) \right] \Phi(X, r, \cdots) = 0$$

$$\Phi(X, r \cdots) = \sum_{P_N, N} \left[e^{iP_N X} \underline{\psi_N^{(+)}(P_N, r, \cdots)} + e^{-iP_N X} \underline{\psi_N^{(-)}(P_N, r, \cdots)} \right]$$

$$P_{N, \mu=0} \equiv \sqrt{\mathbf{P}^2 + M_N^2} > 0$$

(mass operator)

$$\mathcal{M}^2(r, \partial/\partial r, \cdots) \Psi_N^{(\pm)} = M_N^2 \psi_N^{(\pm)}$$

$$\mathcal{M}^2 = \mathcal{M}^2_{conf.} + \delta \mathcal{M}^2_{pert.\, QCD}$$

$\mathcal{M}^2_{conf.}$ Lorentz scalar; A, B-indep., covariant oscillator

$\Rightarrow$ $\underline{\tilde{U}(12)\ \text{symm.}}$ ($\rightarrow$ $\underline{\text{chiral symm.}}$)

(Expansion on spinor freedom)

meson : $\underline{\Psi^{(\pm)B}_{N,A}(P_N, r)} = \sum_i \underline{W_\alpha^{(i)(\pm)\beta}(P_N)}\, M^{(i)(\pm)b}_{N,a}(r, P_N)$

baryon : $\underline{\Psi^{(\pm)}_{N, A_1A_2A_3}(P_N, r_1, r_2)} = \sum_i \underline{W^{(i)(\pm)}_{\alpha_1\alpha_2\alpha_3}(P_N)}\, B^{(i)}_{N, a_1a_2a_3}(r_1, r_2, P_N)$

$W^{(i)}$'s : $\underline{\text{complete set of spinor WF}}$ = relevant Bargmann-Wigner spinors

$$\left(\frac{\partial^2}{\partial X^2} - M^2 \right) W_{\alpha \cdots}^{\beta \cdots}(X) = 0 .$$

$$W_{\alpha\cdots}^{\beta\cdots}(X) = \sum_{\mathbf{P},\, P_0 = E} \left(e^{iPX} W_{\alpha\cdots}^{(+)\beta\cdots}(P) + e^{-iPX} W_{\alpha\cdots}^{(-)\beta\cdots}(P) \right)$$

meson : $\underline{W_\alpha^{(\pm)\beta}(P)}$; $\underline{\text{bi-Dirac spinors}}$

baryon : $\underline{W^{(\pm)}_{\alpha_1, \alpha_2, \alpha_3}(P)}$; $\underline{\text{tri-Dirac spinors}}$

(BW-Eq. and BW-spinors)

(Dirac Spinor)

$$\left(\frac{\partial^2}{\partial x_\mu^2} - M^2\right)\psi_\alpha(x) = 0 , \qquad P_\mu^2 + M^2 = 0, \quad P_0 = \pm E_{\mathbb{P}}, \; E_{\mathbb{P}} = \sqrt{\mathbb{P}^2+M^2}$$

quark: $$\psi_{q,\alpha}(x) \equiv \sum_{\substack{\mathbb{P}=(+\infty,-\infty)\\ \underset{\sim}{P_0=\pm E_P}}} e^{iP\cdot X} \underset{\uparrow}{u_{q,\alpha}(P_\mu)} = \sum_{\mathbb{P},\, \underset{\sim}{P_0=E_{\mathbb{P}}}} \left(u_+(\mathbb{P}) e^{iPX} + u_-(-\mathbb{P}) e^{-iPX} \right)$$

anti-quark: $$\psi_{\bar q,\alpha}(x) \equiv \sum_{\substack{\mathbb{P}=(-\infty,+\infty)\\ \underset{\sim}{P_0=\pm E_P}}} e^{-iP\cdot X} \underset{\uparrow}{v_{\bar q,\alpha}(P_\mu)} = \sum_{\mathbb{P},\, \underset{\sim}{P_0=E_{\mathbb{P}}}} \left(v_+(\mathbb{P}) e^{-iPX} + v_-(-\mathbb{P}) e^{iPX} \right)$$

all 4 spinors required <u>inside</u> of hadrons

(BW-Eq. & Spinors)

[Meson] $W^{(+)}(P)_\alpha^\beta$	$M^{(+)}(P)$	BW-Eq. ($\underset{\sim}{P_0 \equiv E_P > 0}$)
$U_\alpha^\beta(P) \equiv u(P)_\alpha \bar{v}^\beta(P)$;	P_s, V_μ.	$(iP\cdot\gamma^{(1)} + M)U = 0$, $U(-iP\cdot\gamma^{(2)} + M) = 0$
$C_\alpha^\beta(P) \equiv u_\alpha(P)\underset{\sim}{\bar{v}^\beta(-P)}$;	S, A_μ.	$(iP\cdot\gamma^{(1)} + M)C = 0$, $C(iP\cdot\gamma^{(2)} + M) = 0$
$D_\alpha^\beta(P) \equiv \underset{\sim}{u_\alpha(-P)}\, v^\beta(P)$;	S, A_μ.	$(-iP\cdot\gamma^{(1)} + M)D = 0$, $D(-iP\cdot\gamma^{(2)} + M) = 0$
$C_\alpha^\beta(P) \equiv \underset{\sim}{u_\alpha(-P)}\, \underset{\sim}{v^\beta(-P)}$;	$\bar{P}_s$, $\bar{V}_\mu$.	$(-iP\cdot\gamma^{(1)} + M)C = 0$, $\bar{V}(iP\cdot\gamma^{(2)} + M) = 0$

[Baryon] $W^{(+)}_{\alpha_1\alpha_2\alpha_3}(P)$	$B^{(+)}(P)$	BW-Eq. ($\underset{\sim}{P_0 \equiv E_P > 0}$)
$E_{\alpha_1\cdots\alpha_3}(P) \equiv u_{\alpha_1}(P)u_{\alpha_2}(P)u_{\alpha_3}(P)$;	$\psi(\frac{1}{2})$, $\psi_\mu(\frac{3}{2})$.	$(iP\cdot\gamma^{(1,2,3)} + M)E = 0$
$G_{\alpha_1\cdots\alpha_3}(P) \equiv u(P)\,u(P)\,\underset{\sim}{u(-P)}$;	$\psi(\frac{1}{2})$, $\psi_\mu(\frac{3}{2})$.	$(iP\cdot\gamma^{(1,2)} + M)G = 0$, $(-iP\cdot\gamma^{(3)} + M)G = 0$
$F_{\alpha_1\cdots\alpha_3}(P) \equiv u(P)\,\underset{\sim}{u(-P)}\,\underset{\sim}{u(-P)}$;	$\psi(\frac{1}{2})$, $\psi_\mu(\frac{3}{2})$.	$(iP\cdot\gamma^{(1)} + M)F = 0$, $(-iP\cdot\gamma^{(2,3)} + M)F = 0$

III. Transformation Rule for Hadrons and Chiral Symmetry

Any rule for Composite Hadrons $\xleftarrow{\text{Automatically}}$ from that for Constit. Quarks

(Chiral Transf.)

Meson $\quad \Psi_A{}^B(P,r) \rightarrow \left[e^{i\alpha\cdot\lambda/2\,\gamma_5}\, \Psi(P,r)\, e^{i\alpha\cdot\lambda/2\,\gamma_5} \right]_A^B$

Baryon $\quad \Psi_{A_1A_2A_3}(P,r_1,r_2) \rightarrow \prod_{i=1}^{3} \left[e^{i\alpha\cdot \overset{(i)}{\lambda}/2\, \overset{(i)}{\gamma_5}} \Psi(P,r_1,r_2) \right]_{A_1A_2A_3}$

(Physical meaning of chiral T.)

$\underline{u(P)} \xrightarrow{\gamma_5} u'(P) = \gamma_5 u(P) = \underline{u(-P)}\ ; \qquad u_\pm(P) \xleftrightarrow{\gamma_5} u_\mp(-P)$

$\underline{v(P)} \longrightarrow v'(P) = \gamma_5 v(P) = \underline{v(-P)}\ ; \qquad \bar{v}_\pm(P) \leftrightarrow \bar{v}_\mp(-P)$

Chiral T. transforms the members of BW-spinors with Each Other

If $\mathcal{M}^2$ operator is indep. from Dirac-γ matrices

$\rightarrow$ Hadron Mass Spetra have $\tilde{U}(4)$-symm. and Chiral Symm.

(meaning of BW-Eq. & "exciton"-quark mass)

BW-Spinors$(P_\mu, M) \approx \prod$ Dirac Spinor$(\overset{(i)}{p_\mu}, \overset{(i)}{m})$

meson $\boxed{\begin{array}{l} (iP\cdot\overset{(1)}{\gamma} + M)\,\bar{U}(P) = 0 \\ \bar{U}(P)(-iP\cdot\overset{(2)}{\gamma} + M) = 0 \end{array}} \begin{array}{c} \xrightarrow{\times \kappa_1} \\ \xrightarrow{\times \kappa_2} \end{array} \boxed{\begin{array}{l} (i\overset{(1)}{p}\cdot\overset{(1)}{\gamma} + \overset{(1)}{m})\,\bar{U}(P) = 0 \\ \bar{U}(P)(-i\overset{(2)}{p}\cdot\overset{(2)}{\gamma} + \overset{(2)}{m}) = 0 \end{array}}$

$\overset{(1)}{p_\mu} \equiv \kappa_1 P_\mu\,,\quad \overset{(2)}{p_\mu} \equiv \kappa_2 P_\mu\ ;\qquad \kappa_1 + \kappa_2 = 1$

$\boxed{\overset{(1)}{p_\mu} + \overset{(2)}{p_\mu} = P_\mu\ ;\quad \overset{(1)}{m} + \overset{(2)}{m} = M},\qquad \overset{(1,2)}{p_\mu}{}^2 = -\overset{(1,2)}{m}{}^2.$

Baryon $\quad \overset{(1,2,3)}{p_\mu} \equiv \kappa_{(1,2,3)} P_\mu\,,\quad \overset{(i)}{p_\mu}{}^2 = -\overset{(i)}{m}{}^2$ etc. ; $\quad \kappa_1 + \kappa_2 + \kappa_3 = 1$

$\boxed{\overset{(1)}{p_\mu} + \overset{(2)}{p_\mu} + \overset{(3)}{p_\mu} = P_\mu\ ;\quad \overset{(1)}{m} + \overset{(2)}{m} + \overset{(3)}{m} = M}.$

Excited Hadron

mass ; $\quad M_N = \overset{(1)}{m}_N + \overset{(2)}{m}_N + \cdots\cdots \qquad$ Sum of Excited-quark Mass

$\overset{(i)}{p}_N = \kappa_i P_N$ etc., $\quad \sum_i \kappa_i = 1$

IV. Level Structure of Mesons

(phenom. criteria for chiral symm.)

$$m_{q,N}^2 \ll \Lambda_{conf.}^2 \approx \Lambda_{\chi SB}^2 \approx 1\ GeV^2$$

(Estimate of $m_{q,N}$) Exciton picture

for ground-states: $m_0^{(1)} \equiv m_q$, $m_0^{(2)} \equiv m_{\bar{q}}$.

meson: $M_N^2 = M_0^2 + N\Omega$, $M_N = m_N^{(1)} + m_N^{(2)}$;

Bound-state picture

$$M_N^2 = \langle (\sqrt{m_q^2 + \mathbf{p}^2} + \sqrt{m_{\bar{q}}^2 + \mathbf{p}^2})^2 + V \rangle_N$$

$$\equiv (\underbrace{\sqrt{m_q^2 + \Lambda_N^2}}_{m_N^{(1)}} + \underbrace{\sqrt{m_{\bar{q}}^2 + \Lambda_N^2}}_{m_N^{(2)}})^2$$

$\mathbf{p}$; relative moment.

(Light(exciton) q. mass: m_N)

		$n\bar{n}$	$n\bar{c}$	$n\bar{b}$		
Ω/GeV		1.1	2.0	4.6		
$m_{n,N}$ (GeV)	N=0	0.38	0.38	0.38	○	chiral symm.
	N=1	0.64	0.70	0.74	△	
	N=2	0.83	0.95	1.07	X	
χiral symm.		$N \le 1$	$N \lesssim 0$ or 1	$N \lesssim 0$ or 1		

(Level structure of ground-state mesons)

	Mass	Approx. S.	Spin WF	SU(3)	Meson Type
$Q\bar{Q}$	$m_Q + m_{\bar{Q}}$	LS symm.	$U_Q(P)\bar{V}^{\bar{Q}}(P)$	$\underline{1}$	P_s, V_μ
$q\bar{Q}$	$m_q + m_{\bar{Q}}$	q-χiral S.	$U_q(P)\bar{V}^{\bar{Q}}(P)$	$\underline{3}$	P_s, V_μ
		Q-HQS	$U_q(-P)\bar{V}^{\bar{Q}}(P)$		$\boxed{S}$ $\boxed{A_\mu}$
$Q\bar{q}$	$m_Q + m_{\bar{q}}$	$\bar{q}$-χiral S.	$U_Q(P)\bar{V}_{\bar{q}}(P)$	$\underline{3}^*$	P_s, V_μ
		Q-HQS	$U_Q(P)\bar{V}_{\bar{q}}(-P)$		$\boxed{S}$ $\boxed{A_\mu}$
$q\bar{q}$	$m_q + m_{\bar{q}}$	chiral S.	$\frac{1}{\sqrt{2}}(U(P)\bar{V}(P) \pm U(-P)\bar{V}(-P))$		$P_s^{(N,E)}$ $V_\mu^{(N,E)}$
			$\frac{1}{\sqrt{2}}(U(P)\bar{V}(-P) \pm U(-P)\bar{V}(P))$		$S^{(N,E)}$ $A_\mu^{(N,E)}$

- There exists New multiplets of chiral particles, chiralons
- Spin W.F. of π & ρ are drastically diff. between in NRQM and COQM

(Level structure of Mesons in general)

mass : $M_N^2 = M_0^2 + N\Omega = m_N^{(1)} + m_N^{(2)}$

$(q\bar{q})$

$N = $ all	$P_s^{(N,E)} \otimes \{L, N\}$	$P = (-1)^{L+1}$, $C = (-1)^L$
	$V_\mu^{(N,E)} \otimes \{L, N\}$	$P = (-1)^{L+1}$, $C = (-1)^{L+1}$
$N = 0$ (and 1)	$\boxed{S^{(N,E)} \otimes \{L, N\}}$	$P = (-1)^L$, $C = \pm(-1)^L$
	$\boxed{A_\mu^{(N,E)} \otimes \{L, N\}}$	$P = (-1)^L$, $C = \pm(-1)^L$

$(q\bar{Q}$ or $Q\bar{q})$

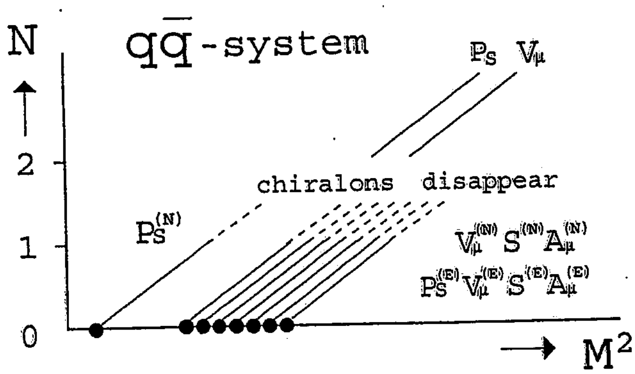
$N = $ all
- $P_s \otimes \{L, N\}$
- $V_\mu \otimes \{L, N\}$

$N = 0$ (and 1)
- $\boxed{S \otimes \{L, N\}}$
- $\boxed{A_\mu \otimes \{L, N\}}$

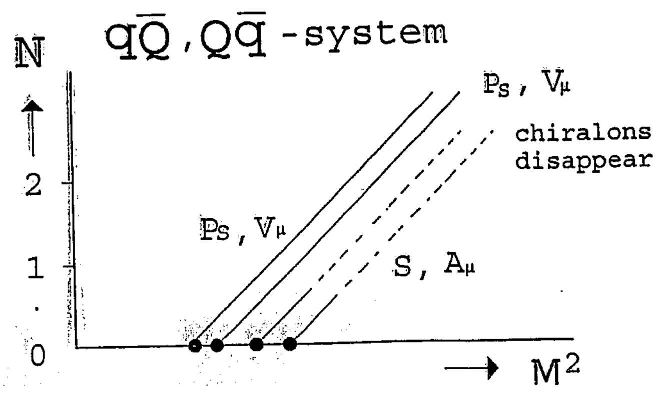
$(Q\bar{Q})$

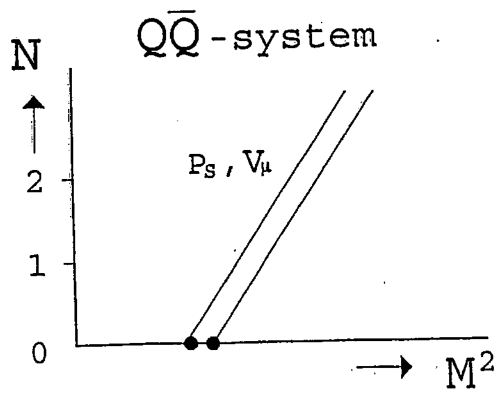
$N = $ all
- $P_s \otimes \{L, N\}$
- $V_\mu \otimes \{L, N\}$

Chiralons : Some with "exotic" Q. N.



Schematic Picture of Meson Spectroscopy





V. Level Structure of Baryons

(Baryon WF) S : full symm. on(1, 2, 3)

$$\Phi^{(S)}_{A_1A_2A_3}(x_1,x_2,x_3) = \sum_{\substack{N,\\ P_N(P_0=E_P)}} \left[e^{iP_N x}\, \Psi^{(+)}_{N,A_1A_2A_3}(P_N, r_1, r_2) + e^{-iP_N x}\, \Psi^{(-)}_{N,A_1A_2A_3}(P_N, r_1, r_2) \right]$$

$$\overline{\Phi}^{(S)A_1A_2A_3}(x_1,x_2,x_3) = \sum \left[e^{iP_N x}\, \overline{\Psi}_N^{(+)A_1A_2A_3} + e^{-iP_N x}\, \overline{\Psi}_N^{(-)A_1A_2A_3} \right]$$

$$\Psi^{(\pm)}_{N,A_1A_2A_3}(P_N, r_1, r_2) = \sum_i \left[\overset{(i)(\pm)}{W}_{\alpha_1\alpha_2\alpha_3}(P_N)\ \overset{(i)}{B}_{a_1a_2a_3}(r_1\, r_2 : P_N) \right]$$

$$\overline{\Psi}^{(\pm)A_1A_2A_3}(P_N, r_1, r_2) = \sum_i \left[\overline{W}^{(i)(\pm)\alpha_1\alpha_2\alpha_3}(P_N)\ \overline{B}^{(i)a_1a_2a_3}(r_1\, r_2 : P_N) \right]$$

$$\overline{\Phi}^{\alpha_1\alpha_2\alpha_3} \equiv \left[\Phi^{+} \overset{(1)}{\gamma_4}\, \overset{(2)}{\gamma_4}\, \overset{(3)}{\gamma_4} \right]^{\alpha_1\alpha_2\alpha_3} \quad \text{etc.}$$

[Ground states]

BW-Spinor	E(P)	G(P)	F(P)
$\overset{(i)(+)}{W}_{\alpha_1\alpha_2\alpha_3}(P)$	$U_{\alpha_1}(P)U_{\alpha_2}(P)U_{\alpha_3}(P)$,	$U(P)U(P)\underset{\sim}{U(-P)}$,	$U(P)\underset{\sim}{U(-P)}\,\underset{\sim}{U(-P)}$
$\overset{(i)(-)}{W}_{\alpha_1\alpha_2\alpha_3}(P)$	$V_{\alpha_1}(P)V_{\alpha_2}(P)V_{\alpha_3}(P)$,	$V(P)V(P)\underset{\sim}{V(-P)}$,	$V(P)\underset{\sim}{V(-P)}\,\underset{\sim}{V(-P)}$

(Freedom of Spin-Flavor WF) $\tilde{U}(12)$

light quark q_A $A = (\alpha, a)$ $4 \times 3 = \underline{12}$

Baryon $q_{A_1} q_{A_2} q_{A_3}\Big|_{\text{Symm.}}$ ${}_{12}H_3 = \underline{364}$

$$\underline{\underline{364}} = \underset{B}{\underline{182}} + \underset{\overline{B}}{\underline{182}}$$

[Static SU(6)

$2 \times 3 = \underline{6}$

$\underset{\underline{56}}{{}_6H_3(B)} + \underset{\underline{56}}{{}_6H_3(\overline{B})}$ $= \underline{\underline{112}}$]

(Symm Property of Spin-Flavor WF)

$$|\underset{\sim}{\rho} F \sigma\rangle_S = \begin{cases} |\rho\rangle_S\, |F\sigma\rangle_S \\ \frac{1}{\sqrt{2}}\left(|\rho\rangle_\alpha\, |F\sigma\rangle_\alpha + |\rho\rangle_\beta\, |F\sigma\rangle_\beta\right) \\ |F\rangle_A\, |\rho\sigma\rangle_A \end{cases}$$

New freed.

$|\ \rangle_{\alpha,\beta}$: partially symm. state

ρ-spin

$$U(P) = \begin{pmatrix} u_1 \\ u_2 \\ \hline u_3 \\ u_4 \end{pmatrix} \begin{matrix} \sigma \\ \sigma \end{matrix} \quad \rho\text{-spin}$$

$$U_+ \equiv U(P)\Big|_{P=0} = \begin{pmatrix} \chi \\ 0 \end{pmatrix}, \quad \rho_3 = +1$$

$$U_- \equiv U(P)\Big|_{P=0} = \begin{pmatrix} 0 \\ \chi \end{pmatrix}, \quad \rho_3 = -1$$

((Decomposition of Spin-Flavor WF))

intrinsic Parity of BW-Spinor $\quad \hat{P} = \prod_{i=1}^{3} \gamma_4^{(i)}$

$$E^{(+)} = u_+ u_+ u_+ \oplus, \quad G^{(+)} = u_+ u_+ u_- \ominus, \quad F^{(+)} = u_+ u_- u_- \oplus .$$

$$(E^{(-)} = v_+ v_+ v_+ \ominus), \ (G^{(-)} = v_+ v_+ v_- \oplus), \ (F^{(-)} = v_+ v_- v_- \ominus)$$

(Symm. of WF and Q-number)

			Static SU6	
$E^{(+)}$	$\lvert\rho\rangle_s \lvert F\sigma\rangle_s = \lvert\rho\rangle_s \lvert F\rangle_s \lvert\sigma\rangle_s$	$\Delta_{3/2}^{\oplus}$	$10\times4=40$	$\underline{56}$
	$\lvert\rho\rangle_s (\lvert F\rangle_\alpha \lvert\sigma\rangle_\alpha + \lvert F\rangle_\beta \lvert\sigma\rangle_\beta)$	$N_{1/2}^{\oplus}$	$8\times2=16$	
$G^{(+)}$	$\lvert\rho\rangle_\alpha \lvert F\sigma\rangle_\alpha + \lvert\rho\rangle_\beta \lvert F\sigma\rangle_\beta \ ; \ \lvert F\sigma\rangle_{\alpha(\beta)} = \lvert F\rangle_s \lvert\sigma\rangle_{\alpha(\beta)}$	$\Delta_{1/2}^{\ominus}$	$10\times2=20$	
	$\lvert F\rangle_{\alpha(\beta)} \lvert\sigma\rangle_s$	$N_{3/2}^{\ominus}$	$8\times4=32$	$\underline{70}$
	$\lvert F\rangle_A \lvert\rho\sigma\rangle_A = \lvert F\rangle_A (-\lvert\rho\rangle_\alpha \lvert\sigma\rangle_\beta + \lvert\rho\rangle_\beta \lvert\sigma\rangle_\alpha)$	$\Lambda_{1/2}^{\ominus}$	$1\times2=2$	
	$\lvert\rho\rangle_s \lvert F\sigma\rangle_s = \lvert\rho\rangle_s (\lvert F\rangle_\alpha \lvert\sigma\rangle_\beta + \lvert F\rangle_\beta \lvert\sigma\rangle_\alpha)$	$N_{1/2}^{\ominus}$	$8\times2=16$	
$F^{(+)}$	$\lvert\rho\rangle_s \lvert F\sigma\rangle_s = \lvert\rho\rangle_s \lvert F\rangle_s \lvert\sigma\rangle_s$	$\Delta_{3/2}^{\oplus}$	$10\times4=40$	$\underline{56}$
	$\lvert\rho\rangle_s (\lvert F\rangle_\alpha \lvert\sigma\rangle_\alpha + \lvert F\rangle_\beta \lvert S\rangle_\beta)$	$N_{1/2}^{\oplus}$	$8\times2=16$	

$$12\, H_3 = \underline{364} \xrightarrow{(\times \frac{1}{2})} \underline{182} = \underline{56}^{\oplus} \oplus \underline{56}^{\oplus} \oplus \underline{70}^{\ominus}$$

(Level Structure of ground-state qqq-baryons)

$\underline{56}^{\oplus} \times 2 \qquad N_{1/2}^{\oplus}, \ \Delta_{3/2}^{\oplus}, \ \boxed{N'^{\oplus}_{1/2}, \ \Delta'^{\oplus}_{3/2}}$ $\quad$ Chiralons.

$\underline{70}^{\ominus} \times 1 \qquad \boxed{N_{1/2}^{\ominus}, \ N_{3/2}^{\ominus}, \ \Delta_{1/2}^{\ominus}, \ \Lambda_{1/2}^{\ominus}}$

[[Level struct. of $(qqq)^*$-baryons, N = 1]]

1st Excited states also contain chiralons.

((Level struct. of $\underbrace{qqQ\text{-}, qQQ\text{-}}_{}$, $\underbrace{QQQ\text{-baryons}}_{}$))

Extension is easy $\qquad$ Chiralons exit ! $\qquad$ No chiralons

VI. Experimental Candidate for Chiral Particles

($q\bar{q}$-mesons)

- $\underline{\sigma(600) = S^{(N)}({}^1S_0)}$ σ-nonet [$\sigma(600), \kappa(900), a_0(980), f_0(980)$]

  Confirmed in ππ-production processes   Komada T.(A1), Ishida M(B4)

- 1 out of 3 η's ($\eta(1275), \eta(1440), \eta(1460)$) ; 0^{-+}

  $= P_S^{(E)}(L=0, N=0)$

- $\underline{\pi_1(1400),\ \pi_1(1600) = S^{(E)}({}^1P_1),\ A_\mu^{(E)}({}^3P_1)}$

  $1^{-+}(\eta\pi)$, $1^{-+}(\rho\pi, \eta'\pi)$: "exotic" states. S. U. Chung, Hadron '99

- $\underline{a_1^\chi(900)\text{ or }\pi^E(900)} = A_\mu^{(N)}({}^3S_1)$ or $P_S^{(E)}({}^1S_0)$

  1^{++} 0^{-+} $3\pi^0$-states in $\pi^- p \to n(3\pi^0)$. Takamatsu K (B4)

  → Fig.

($q\bar{Q}$ or $Q\bar{q}$-mesons)

- $\underline{D_1^\chi = A_\mu({}^3S_1)}$, $J^P = 1^+$ Z^0-decay : $D_1^\chi \to D^* + \pi$,

- $\underline{B_0^\chi = S({}^1S_0)}$, $J^P = 0^+$ Z^0-decay : $B_0^\chi \to B + \pi$,

  } Ishida M (B4), Yamada K (B3)

  → Fig.

(qqq-baryons)

- Roper Res. $\underline{N(1440)^{\oplus}_{1/2}} = F(U_+U_-U_- : L=0)$ too light as $[N(940)]^*_{rad.}$
- $\underline{\Delta(1600)^{\oplus}_{3/2}} = F(U_+U_-U_- : L=0)$ lighter than $\Delta^{\ominus}_{\frac{1}{2}}(1620)$
- $\underline{\Lambda(1405)^{\ominus}_{1/2}} = G(U_+U_+U_- : L=0)$ too light as $[\Lambda(1116)]^*_{L=1}$

[Possible chiral baryons]

SU(6)	SU(3), J^P		SU(3) J^P	
$\underline{56}$	$\underline{8}$ $\frac{1}{2}^+$	N(939), Λ(1116), Σ(1192), Ξ	$\underline{10}$ $\frac{3}{2}^+$	Δ(1232) Σ(1385), ...
$\underline{56'}$	$\underline{8}$ $\frac{1}{2}^+$	$\boxed{N(1440)}$, $\boxed{\Sigma(1660)}$,	$\underline{10}$ $\frac{3}{2}^+$	$\boxed{\Delta(1600)}$,
70	$\underline{8}$ $\frac{1}{2}^-$	N(1535),	$\underline{10}$ $\frac{1}{2}^-$	Δ(1620),
	$\underline{1}$ $\frac{1}{2}^-$	—— $\boxed{\Lambda(1405)}$ ——		

VII. Concluding Remarks

- I have presented an attempt for Level-Classification
  Unifying the seemingly contradictory two view points;
  Non-Relativistic one with LS-Symmetry
  Relativistic one with chiral symmetry.

- As results, I have predicted the existence of
  New chiral particles in the Lower Mass Regions,
  "Chiralons", which had never been appeared in NRQM

- We have several good candidates for chiralons

  for example,

  σ-nonet $\{\sigma(600),\ K(900),\ a_0(980),\ f_0(980)\}$;
  as "Relativistic" S-wave states of $(q\bar{q})$.

  $\pi_1(1400),\ \pi_1(1600)\ (1^{-+})$;
  as "Relativistic" P-wave states of $(q\bar{q})$.

  Roper reson. $N(1440)(\frac{1}{2}^+)$
  SU(3) siglet $\Lambda(1405)(\frac{1}{2}^-)$;
  as Relativistic S-wave states of (qqq)

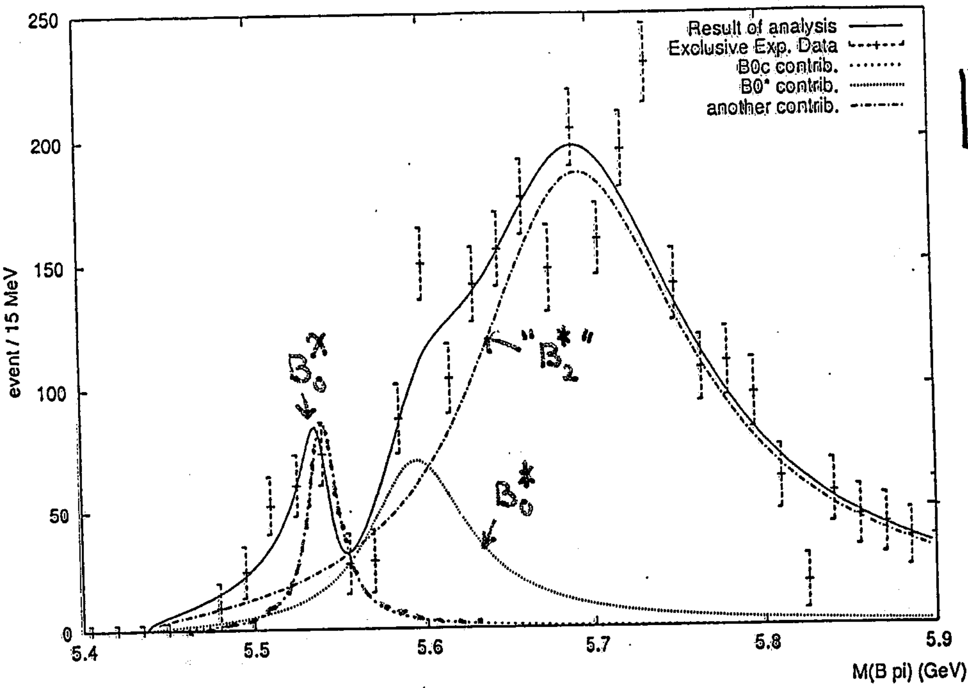
- Further Search, both experimental & theoretical, for Chiralons is necessary and important.

◎. Evidences from the contributions to this conferences:

Donachie A.; $\rho(1450)$, $\omega(1420)$; as rel. S-wave of $(q\bar{q})$: $V_\mu^{(N)}(^3S_1)$

Gobel C. E791: $K(797)$; as Rel. S-wave of $(q\bar{q})$; $S^{(N)}(^1S_0)$.

Povov A. E852
Dorofeev V. VES exp. } $\pi_1(1400)$, $\pi_1(1600)$ 1^{-+}; $S^{(E)}(^1P_1)$ and $A_\mu^{(E)}(^3P_1)$



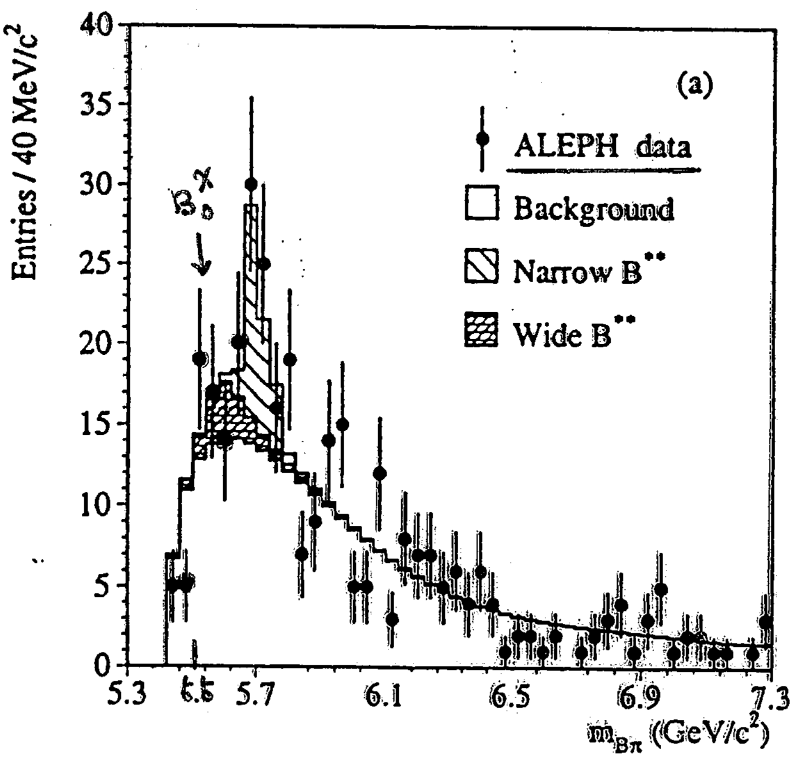
$\lfloor Z^0$ decay : $B\pi$ chann

B_0^χ (5540)

Γ = 21 MeV

1999

L3 Collab. at LEP:



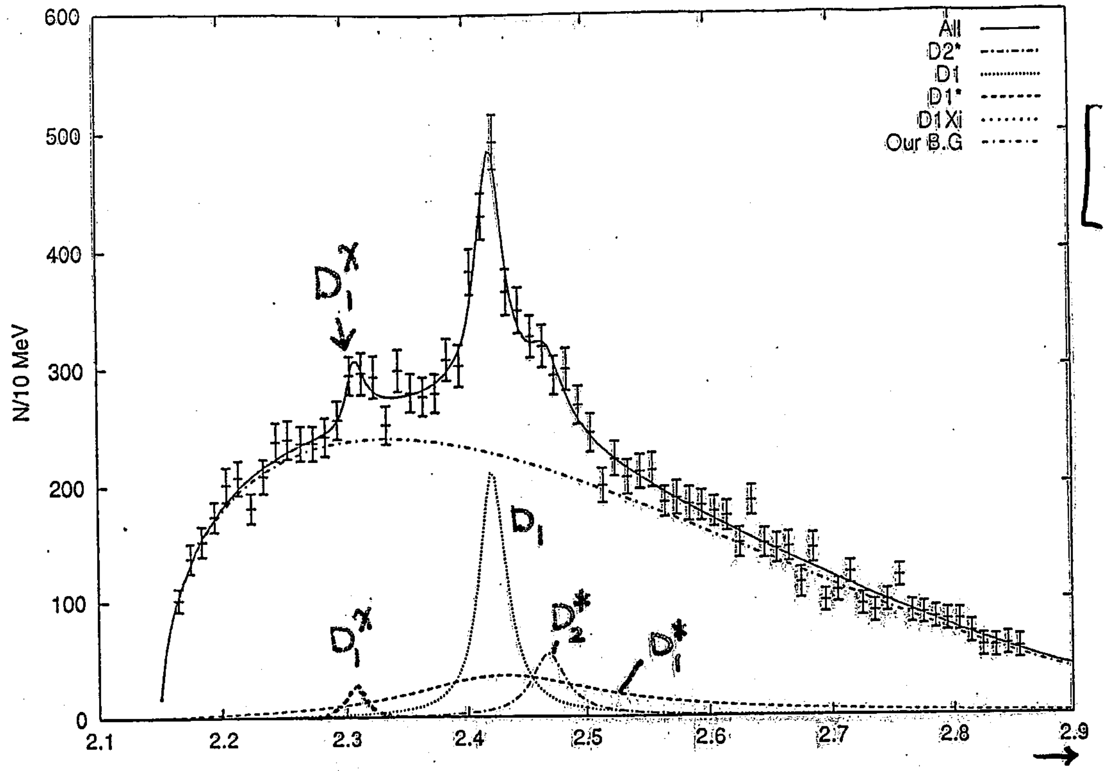
ALEPH Collab.

$$|\mathcal{M}(s)|^2 = |r_1 e^{i\theta_1}\Delta_{B_0^\chi}(s) + r_2 e^{i\theta_2}\Delta_{B_0^*}(s)|^2 + |r_3 e^{i\theta_3}\Delta_{B-another}(s)|^2$$

$$\left(\Delta_R(s) = \frac{-m_R\Gamma_R}{s - m_R^2 + i m_R\Gamma_R}\right)$$

$$B.G = P_1(M_{B\pi} - P_2)^{P_3} exp(\ P_4(M_{B\pi} - P_2) + P_5(M_{B\pi} - P_2)^2 + P_6(M_{B\pi} - P_2)^3\ )$$

See $\longrightarrow$ Yamada K, B3



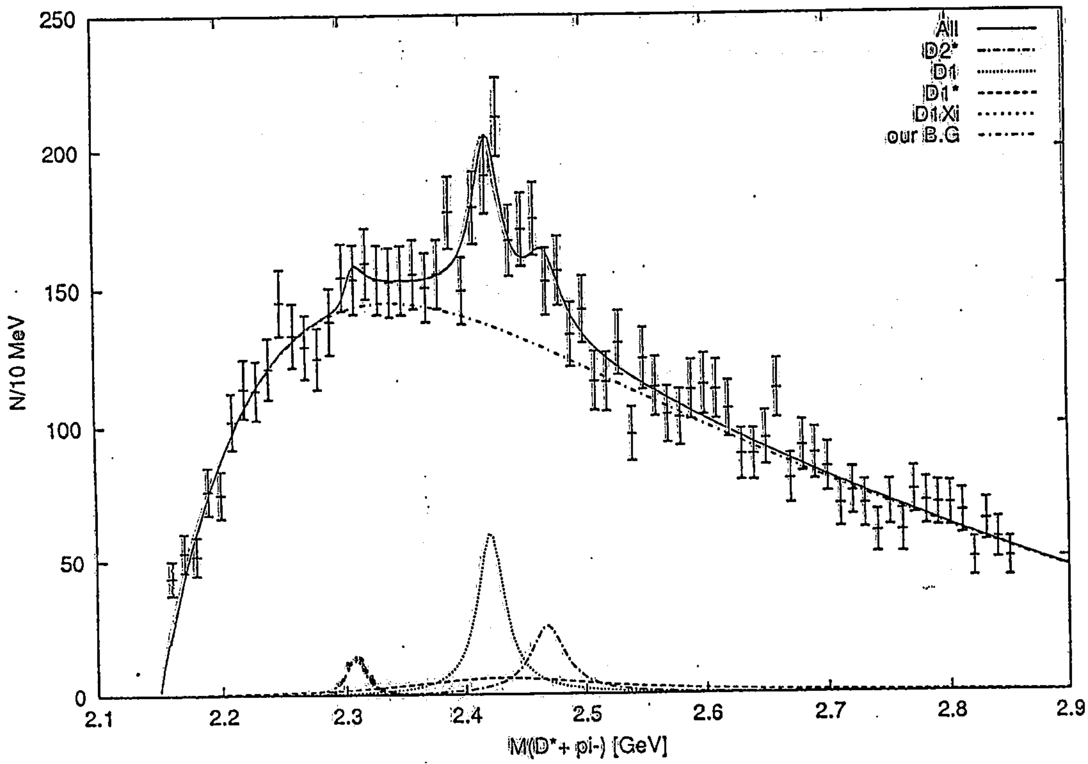
[Z^0 decay : in $D^*\pi$ chann

$D_1^\chi(2307)$

Γ = 17 MeV

1994
CLEO

$m(D^*\pi)$



1998
DELPHI

$$|\mathcal{M}(s)|^2 = \left|r_1 e^{i\theta_1}\Delta_{D_1^\chi}(s) + r_2 e^{i\theta_2}\Delta_{D_1^{*0}}(s)\right|^2 + \left|r_3 e^{i\theta_3}\Delta_{D_1^0}(s)\right|^2 + \left|r_4 e^{i\theta_4}\Delta_{D_2^{*0}}(s)\right|^2$$

$$\left(\Delta_R(s) = \frac{-m_R\Gamma_R}{s - m_R^2 + i m_R \Gamma_R}\right)$$

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

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

Covariant Classification Scheme of Hadrons

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Abstract. Starting from the multi-local Klein-Gordon equations with Lorentz-scalar squared-mass operator we give a covariant quark representation of the general composite mesons and baryons with definite Lorentz transformation property. The mass spectra satisfy the approximate symmetry under the $\tilde{U}(4)$ transformation group, including the chiral transformation as a subgroup, concerning the spinor freedom of light constituent quarks, and this symmetry predicts the existence of new type of chiral mesons and baryons out of the conventional framework in non-relativistic quark model: For example, for light $q\bar{q}$ systems, the scalar σ- and axial-vector a_1-nonets, and for heavy-light $Q\bar{q}$ and $q\bar{Q}$ systems the scalar and axial-vector mesons are predicted to exist as relativistic S-wave states besides the ordinary P-wave state mesons. The existence of two "exotic" 1^{-+} meson nonets is predicted as the relativistic P-wave states in $q\bar{q}$ systems. For light quark baryons the extra <u>**56**</u> with positive parity and the extra <u>**70**</u> with negative parity of the static $SU(6)$ are predicted to exist as the ground state chiral particles.

The σ-Meson Production in Excited ϒ Decay Processes

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Abstract. We analyze the $\pi\pi$ production amplitudes in the excited Υ decay processes, $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(3S) \to \Upsilon(2S)\pi^+\pi^-$, and the $\pi\pi$ and $K\bar{K}$ production amplitudes in the charmonium decay processes, $\psi(2S) \to J/\psi\pi^+\pi^-$ and $J/\psi \to \phi\pi^+\pi^-$, ϕK^+K^-, including the possible effect of light σ production. The amplitudes are parametrized by the sum of Breit-Wigner amplitudes for the σ and the other relevant particles and of the direct 2π-production amplitude, following the VMW method. All the $\pi\pi$ (and $K\bar{K}$) mass spectra are reproduced well with the obtained values of σ-parameters, $m_\sigma = 526^{+48}_{-37}$MeV and $\Gamma_\sigma = 301^{+145}_{-100}$MeV, which is almost consistent with the values in our previous phase shift analyses.

Confirmation of σ(450–600)-Meson in $\Upsilon' \to \Upsilon\pi\pi$ & Other ππ-Production Processes

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Abstract. Applying the effective amplitude, which is evidently consistent with general constraints from chiral symmetry, the $\pi\pi$ spectra in the relevant processes are analyzed, leading to a strong evidence for existence of the light σ meson. It is also pointed out that the $\pi\pi$ scattering process, which had been one of the main sources for PDG table for these many years, is, in principle, exceptionally difficult to investigate the property of σ-meson.

Property of Chiral Scalar and Axial-Vector Mesons in Heavy-Light Quark Systems

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Abstract. Recently we have proposed a new level-classification scheme of hadrons with a manifestly covariant framework. In this scheme the requirement of chiral symmetry on the light quark leads to a prediction of existence of new type of scalars X_B, X_D and axial-vectors X_{B^*}, X_{D^*} as the chiral partners of ground state pseudoscalar B, D and vector B^*, D^* mesons, respectively. They belong to "relativistic S-wave states," and are discriminated from the conventional P-wave mesons with $j_q = 1/2$ appearing in the heavy quark effective theory. In this talk we examine the properties of these chiral mesons: The mass-splittings between the respective chiral partners are predicted to be equal, and the decay widths of one pion emission of X_B, X_D, X_{B^*} and X_{D^*} are to take the same value due to both chiral and heavy quark symmetries. Some experimental indications for existence of X_B and X_{D^*} are also given, which are consistent with the above prediction.

Possible Evidence for a Chiral Axial-Vector State in the *D* Meson System

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Abstract. We reanalyze the $D^{*+}\pi^-$ mass spectrum from CLEO II by the VMW method in order to examine the existence of a chiral axial-vector state, which is predicted in a covariant level-classification scheme recently proposed, other than normal orbitally-excited P-wave states in the D meson system. A result of the present analysis seems to suggest that there exists an extra axial-vector meson, in addition to the two normal ones, in a similar mass region.