Radiative decay into γ-baryon of dynamically generated resonances from the vector-baryon interaction

E.J. Garzón[1], Bao-Xi Sun[2], E. Oset[1]

[1]Departamento de Física Teórica and IFIC, Universitat de Valéncia-CSIC, Valencia, Spain

[2]Institute of Theoretical Physics, College of Applied Sciences Beijing University of Technology, Beijing, China

June 2, 2010
12th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon
College of William and Mary
Williamsburg, Virginia

Index

Formalism for VV interaction

We follow the formalisim[1] of the hidden gauge interaction of vector mesons

$$\mathcal{L}_{III} = -\frac{1}{4}\langle V_{\mu\nu}V^{\mu\nu}\rangle \tag{1}$$

where the symbol $\langle\rangle$ stands for the trace in the SU(3) space where

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig\,[V_\mu, V_\nu] \tag{2}$$

The lagrangian gives a contact term of four and three vector vertex

$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2}\langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu\rangle \tag{3}$$

$$\mathcal{L}_{III}^{(3V)} = ig\langle (V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu) V^\nu\rangle \tag{4}$$

[1] M. Bando, T. Kugo, and K. Yamawaki. Nonlinear Realization and Hidden Local Symmetries. Phys. Rept., 164:217314, 1988.

Formalism for VV interaction

Lagrangian for three vector vertex

$$\mathcal{L}_{III}^{(3V)} = ig\langle (V^{\mu}\partial_{\nu}V_{\mu} - \partial_{\nu}V_{\mu}V^{\mu})V^{\nu}\rangle \tag{5}$$

SU(3) matrix of the vectors of the octet of ρ

$$V_{\mu} = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_{\mu} \tag{6}$$

$$g = \frac{M_V}{2f}, \quad f = 93MeV, \quad M_v \approx 800MeV$$

Formalism for VV interaction

Lagrangian for coupling of vector mesons to the baryon octet

$$\mathcal{L}_{BBV} = g\left(\langle \bar{B}\gamma_\mu [V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle\right) \tag{7}$$

SU(3) matrix of the baryon octet

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix} \tag{8}$$

and similar for the baryon decuplet.

Dynamically generated resonances

Amplitude for $VB \to VB$

$$V_{ij} = -C_{ij}\,\frac{1}{4f^2}\,\left(k^0 + k'^0\right)\;\vec{\epsilon}\,\vec{\epsilon}\,'$$

Using the Bethe Salpeter equation

$$T = [1 - V\,G]^{-1}\,V$$

we construct the scattering matrix, which poles correspond to the resonances. G is the loop function of a vector meson and a baryon. The couplings of the resonances to the different channels g_i, are obtained from the residues at the poles.

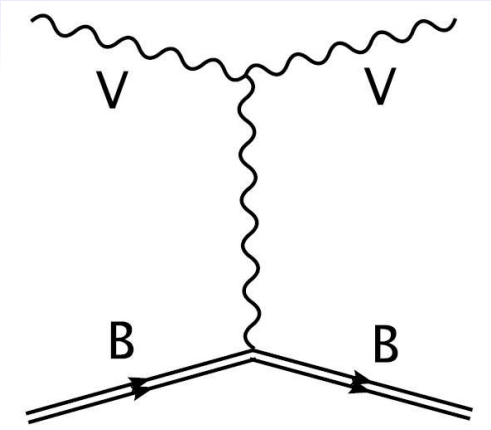

Figure: VB diagram

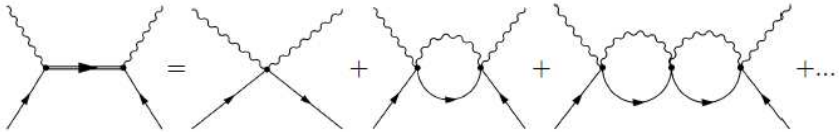

Figure: Diagrams involved in Bethe-Salpeter equation

Dynamically generated resonances

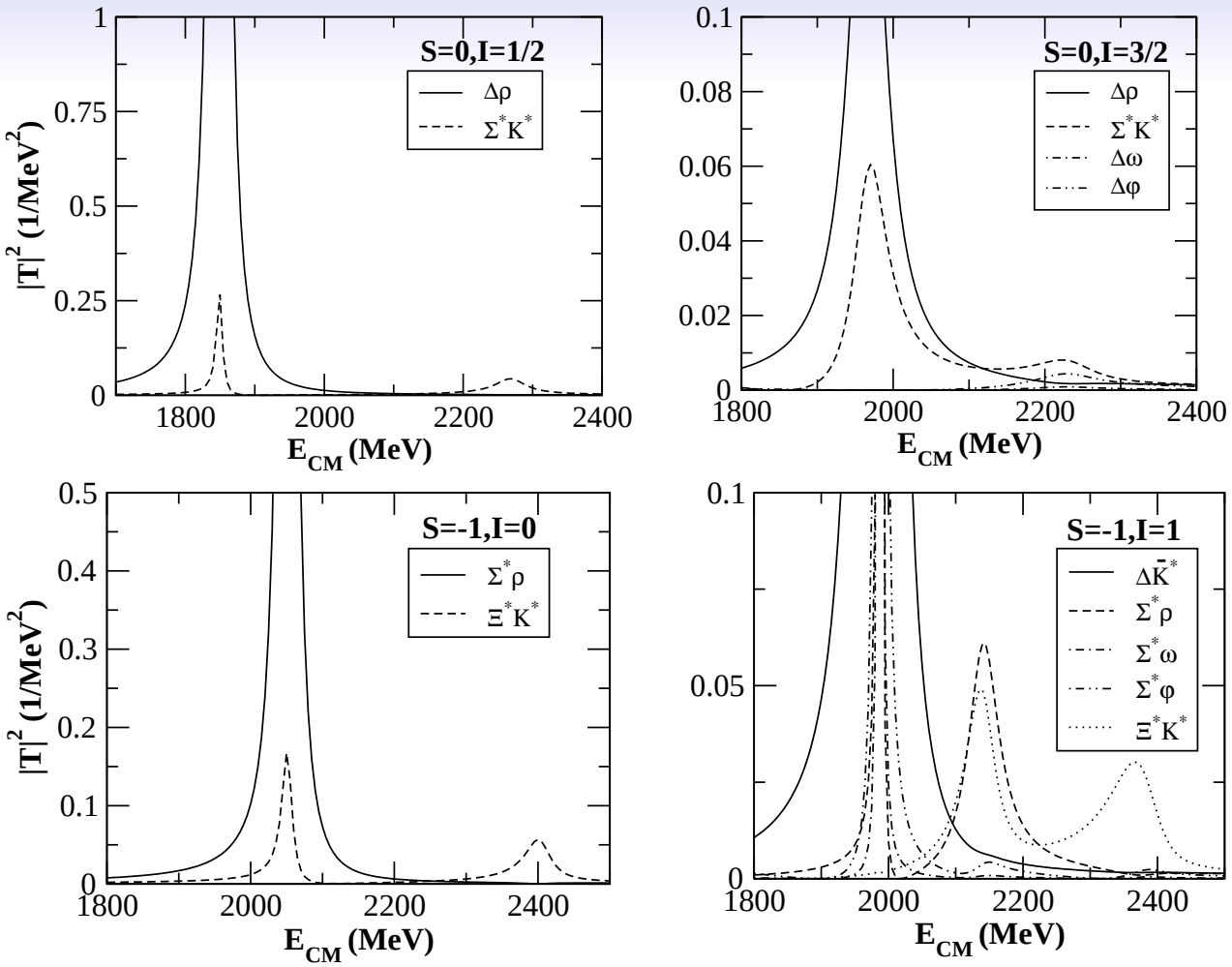

Figure: $|T|^2$ with different channels for resonances of vector-baryon interaction

Resonances found with vector meson-baryon decuplet[2] [3]

S, I	Theory			PDG data				
	pole position	real axis mass	width	name	J^P	status	mass	width
$0, 1/2$	$1850 + i5$	1850	11	$N(2090)$	$1/2^-$	$\star$	1880-2180	95-414
				$N(2080)$	$3/2^-$	$\star\star$	1804-2081	180-450
		2270(*bump*)		$N(2200)$	$5/2^-$	$\star\star$	1900-2228	130-400
$0, 3/2$	$1972 + i49$	1971	52	$\Delta(1900)$	$1/2^-$	$\star\star$	1850-1950	140-240
				$\Delta(1940)$	$3/2^-$	$\star$	1940-2057	198-460
				$\Delta(1930)$	$5/2^-$	$\star\star\star$	1900-2020	220-500
		2200(*bump*)		$\Delta(2150)$	$1/2^-$	$\star$	2050-2200	120-200
$-1, 0$	$2052 + i10$	2050	19	$\Lambda(2000)$	$?^?$	$\star$	1935-2030	73-180
$-1, 1$	$1987 + i1$	1985	10	$\Sigma(1940)$	$3/2^-$	$\star\star\star$	1900-1950	150-300
	$2145 + i58$	2144	57	$\Sigma(2000)$	$1/2^-$	$\star$	1944-2004	116-413
	$2383 + i73$	2370	99	$\Sigma(2250)$	$?^?$	$\star\star\star$	2210-2280	60-150
				$\Sigma(2455)$	$?^?$	$\star\star$	2455 ± 10	100-140
$-2, 1/2$	$2214 + i4$	2215	9	$\Xi(2250)$	$?^?$	$\star\star$	2189-2295	30-130
	$2305 + i66$	2308	66	$\Xi(2370)$	$?^?$	$\star\star$	2356-2392	75-80
	$2522 + i38$	2512	60	$\Xi(2500)$	$?^?$	$\star$	2430-2505	59-150
$-3, 0$	$2449 + i7$	2445	13	$\Omega(2470)$	$?^?$	$\star\star$	2474 ± 12	72 ± 33

Table: The properties of the ten dynamically generated resonances and their possible PDG counterparts. We also include the N^* bump around 2270 MeV and the Δ^* bump around 2200 MeV.

[2] Sourav Sarkar, Bao-Xi Sun, E. Oset, and M. J. Vicente Vacas. Dynamically generated resonances from the vector octet- baryon decuplet interaction. *Eur. Phys. J.*, A44: 431, 2010.

[3] P. Gonzalez, E. Oset and J. Vijande, Phys. Rev. C **79** (2009) 025209

Resonances found with vector meson-baryon octet[4]

I, S	Theory			PDG data				
	pole position	real axis						
		mass	width	name	J^P	status	mass	width
$1/2, 0$	—	1696	92	$N(1650)$	$1/2^-$	⋆ ⋆ ⋆⋆	1645-1670	145-185
				$N(1700)$	$3/2^-$	⋆ ⋆ ⋆	1650-1750	50-150
	$1977 + i53$	1972	64	$N(2080)$	$3/2^-$	⋆⋆	≈ 2080	180-450
				$N(2090)$	$1/2^-$	⋆	≈ 2090	100-400
$0, -1$	$1784 + i4$	1783	9	$\Lambda(1690)$	$3/2^-$	⋆ ⋆ ⋆⋆	1685-1695	50-70
				$\Lambda(1800)$	$1/2^-$	⋆ ⋆ ⋆	1720-1850	200-400
	$1907 + i70$	1900	54	$\Lambda(2000)$	$?^?$	⋆	≈ 2000	73-240
	$2158 + i13$	2158	23					
$1, -1$	—	1830	42	$\Sigma(1750)$	$1/2^-$	⋆ ⋆ ⋆	1730-1800	60-160
	—	1987	240	$\Sigma(1940)$	$3/2^-$	⋆ ⋆ ⋆	1900-1950	150-300
				$\Sigma(2000)$	$1/2^-$	⋆	≈ 2000	100-450
$1/2, -2$	$2039 + i67$	2039	64	$\Xi(1950)$	$?^?$	⋆ ⋆ ⋆	1950 ± 15	60 ± 20
	$2083 + i31$	2077	29	$\Xi(2120)$	$?^?$	⋆	≈ 2120	25

Table: The properties of the nine dynamically generated with vector and baryon octet resonances and their possible PDG counterparts.

[4] E. Oset and A. Ramos. Dynamically generated resonances from the vector octet-baryon octet interaction. *Eur. Phys. J.*, A44:445, 2010.

Lagrangian of the Vγ coupling

The peculiarity of this theory concerning photons is that they couple to hadrons by converting first into a vector meson, ρ^0, ω, ϕ.

$$\mathcal{L}_{V\gamma} = -M_V^2 \frac{e}{\tilde{g}} A_\mu \langle V^\mu Q \rangle \quad (9)$$

where Q is the charge matrix

$$Q \equiv \begin{pmatrix} 2/3 & 0 & 0 \\ 0 & -1/3 & 0 \\ 0 & 0 & -1/3 \end{pmatrix} \quad (10)$$

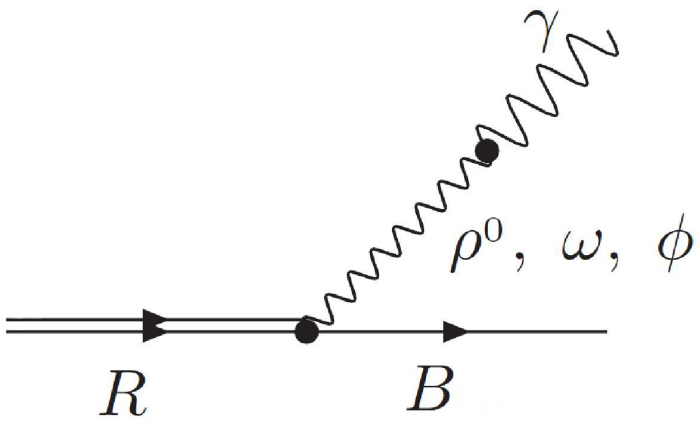

Figure: Coupling of a γ to a baryon thought a vector meson

Previous work in radiative decay of mesons

Decay of the $f_0(1370)$ and $f_2(1270)$ into $\gamma\gamma$[5]

$$S = 2 \;\; \Gamma = \frac{1}{5}\frac{1}{16\pi}\frac{1}{M_R} g_T^2 \frac{7}{3}\frac{1}{12} e^4 \left(\frac{2f}{M_\rho}\right)^2$$

$$S = 0 \;\; \Gamma = \frac{1}{16\pi}\frac{1}{M_R} g_S^2 \frac{2}{3}\frac{1}{12} e^4 \left(\frac{2f}{M_\rho}\right)^2$$

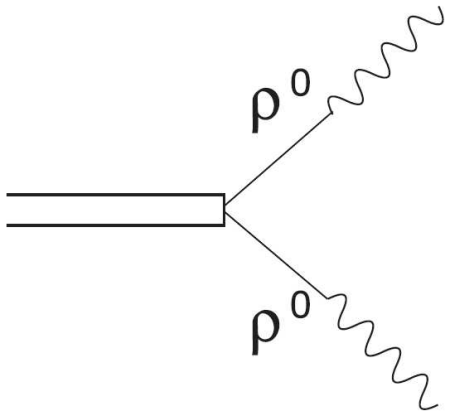

Figure: R$\rightarrow \gamma\gamma$ diagram

$$\Gamma\left(f_0(1370) \rightarrow \gamma\gamma\right) = 1.62 KeV$$

$$\Gamma\left(f_2(1270) \rightarrow \gamma\gamma\right) = 2.6 KeV$$

In a good agreement with experiment.

[5] H. Nagahiro, J. Yamagata-Sekihara, E. Oset, and S. Hirenzaki. The $\gamma\gamma$ decay of the $f_0(1370)$ and $f_2(1270)$ resonances in the hidden gauge formalism. *Phys. Rev.*, D79:114023, 2009.

Radiative decay of baryons into γ-Baryon

Amplitude of R-Bγ transition

$$t_\gamma = -\frac{e}{\tilde{g}} \sum_{j=\rho^0,\ \omega,\ \phi} g_j F_j \quad (11)$$

$$F_j = \begin{cases} \frac{1}{\sqrt{2}} & for \quad \rho^0 \\ \frac{1}{3\sqrt{2}} & for \quad \omega \\ -\frac{1}{3} & for \quad \phi \end{cases} \quad (12)$$

$\tilde{g} = \frac{M_V}{2f}; \qquad f = 93 MeV$
$e^2 = 4\pi\alpha$

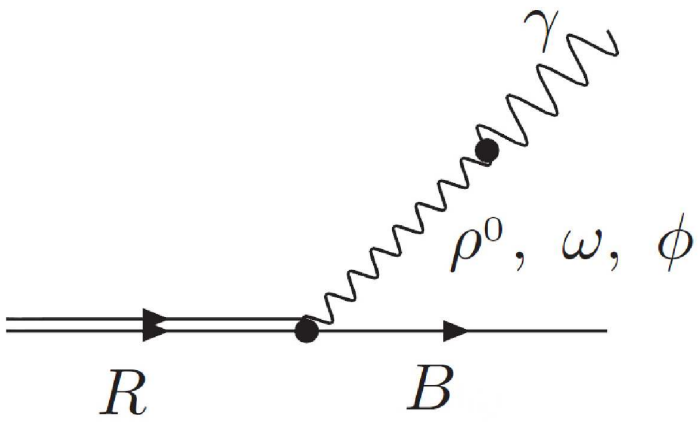

Figure: R$\rightarrow$Bγ diagram

Width of the R-Bγ

$$\Gamma_\gamma = \frac{1}{2\pi}\,\frac{2}{3}\,\frac{M_B}{M_R}\,q\,|t_\gamma|^2 \quad (13)$$

A short example

$$m_R = 1696 \quad I = 1/2,\ S = 0, \quad \rho N,\ \omega N,\ \phi N$$

$$|\rho N, \frac{1}{2}, \frac{1}{2}\rangle \ = \ -\sqrt{\frac{1}{3}}|\rho^0 p\rangle \ - \ \sqrt{\frac{2}{3}}|\rho^+ n\rangle \tag{14}$$

$$|\rho N, \frac{1}{2}, -\frac{1}{2}\rangle \ = \ \sqrt{\frac{1}{3}}|\rho^0 n\rangle \ - \ \sqrt{\frac{2}{3}}|\rho^- p\rangle \tag{15}$$

Amplitude of R-Bγ transition for $I_3 = 1/2$

$$t_\gamma = -\frac{e}{\tilde{g}} \sum_{j=\rho^0,\ \omega,\ \phi} g_j F_j = -\frac{e}{\tilde{g}} \left(-\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} 3.2 + \frac{1}{3\sqrt{2}} 0.1 - \frac{1}{3}(-0.2) \right) = -\frac{e}{\tilde{g}} 1.4$$

$$|t_\gamma|^2 = \frac{4\pi\alpha}{4.3^2} 1.4^2 = 9.68 \cdot 10^{-3} \qquad q = q_\gamma = \frac{M_R^2 - M_B^2}{2M_R} = 588.6\ MeV$$

$$\Gamma = \frac{1}{2\pi} \frac{2}{3} \frac{M_B}{M_R} q |t_\gamma|^2 = 334\ KeV$$

Decay width of γ-baryon decuplet[6]

S, I	Theory	PDG data		Predicted width (KeV) for I_3						
	pole position (MeV)	name	J^P	$-3/2$	-1	$-1/2$	0	$1/2$	1	$3/2$
$0, 1/2$	$1850 + i5$	$N(2090)$	$1/2^-$			722		722		
		$N(2080)$	$3/2^-$							
$0, 3/2$	$1972 + i49$	$\Delta(1900)$	$1/2^-$	1582		203		143		1402
		$\Delta(1940)$	$3/2^-$							
		$\Delta(1930)$	$5/2^-$							
$-1, 0$	$2052 + i10$	$\Lambda(2000)$	$?^?$				583			
$-1, 1$	$1987 + i1$	$\Sigma(1940)$	$3/2^-$		20		199		561	
		$\Sigma(2000)$	$1/2^-$							
	$2145 + i58$	$\Sigma(2250)$	$?^?$		2029		206		399	
	$2383 + i73$	$\Sigma(2455)$	$?^?$		537		277		182	
$-2, 1/2$	$2214 + i4$	$\Xi(2250)$	$?^?$			54		815		
	$2305 + i66$	$\Xi(2370)$	$?^?$			1902		320		
	$2522 + i38$	$\Xi(2500)$	$?^?$			165		44		
$-3, 1$	$2449 + i7$	$\Omega(2470)$	$?^?$				330			

Table: The predicted radiative decay widths of the ten dynamically generated resonances for different isospin projection I_3. Their possible PDG counterparts are also listed. Note that the $\Sigma(2000)$ could be the spin parter of the $\Sigma(1940)$, in which case the radiative decay widths would be those of the $\Sigma(1940)$.

[6] B. X. Sun, E. J. Garzon and E. Oset, "Radiative decay into gamma-baryon of dynamically generated resonances from the vector-baryon interaction," arXiv:1003.4664 [hep-ph].

Decay width of γ-baryon octet[7]

S, I	Theory	PDG data		Predicted width (KeV) for I_3				
	pole position (MeV)	name	J^P	-1	$-1/2$	0	$1/2$	1
$0, 1/2$	1696	$N(1650)$	$1/2^-$		334		253	
		$N(1700)$	$3/2^-$					
	$1977 + i53$	$N(2080)$	$3/2^-$		196		79	
		$N(2090)$	$1/2^-$					
$-1, 0$	$1784 + i4$	$\Lambda(1690)$	$3/2^-$			65 (166)		
		$\Lambda(1800)$	$1/2^-$					
	$1907 + i70$	$\Lambda(2000)$	$?^?$			321 (21)		
	$2158 + i13$					0 (17)		
$-1, 1$	$1830 + i40$	$\Sigma(1750)$	$1/2^-$	363		69 (240)		7
	$1987 + i240$	$\Sigma(1940)$	$3/2^-$	307		27 (90)		426
		$\Sigma(2000)$	$1/2^-$					
$-2, 1/2$	$2039 + i67$	$\Xi(1950)$	$?^?$		400		89	
	$2082 + i31$	$\Xi(2120)$	$?^?$		212		84	

Table: The predicted radiative decay widths of the nine dynamically generated resonances for different isospin projection I_3. Their possible PDG counterparts are also listed. The values in the bracket for $I_3 = 0$ denote widths for the radiative decay into $\Lambda\gamma$, while the values outside the bracket denote widths for $\Sigma\gamma$.

[7] B. X. Sun, E. J. Garzon and E. Oset, "Radiative decay into gamma-baryon of dynamically generated resonances from the vector-baryon interaction," arXiv:1003.4664 [hep-ph].

Definition for the helicity amplitudes

$$A_{1/2}^{N^*} = \sqrt{\frac{2\pi\alpha}{k}}\frac{1}{e}\left\langle N^*, J_z = 1/2|\epsilon_\mu^{(+)}J^\mu|N, J_z = -1/2\right\rangle \quad (16)$$

$$A_{3/2}^{N^*} = \sqrt{\frac{2\pi\alpha}{k}}\frac{1}{e}\left\langle N^*, J_z = 3/2|\epsilon_\mu^{(+)}J^\mu|N, J_z = 1/2\right\rangle \quad (17)$$

$$A_{1/2}^{J=1/2} = -t_\gamma\frac{1}{\sqrt{2k}}C(1/2,1,1/2;-1/2,1,1/2) = \frac{1}{\sqrt{2k}}\sqrt{\frac{2}{3}}t_\gamma \quad (18)$$

$$A_{1/2}^{J=3/2} = -t_\gamma\frac{1}{\sqrt{2k}}C(1/2,1,3/2;-1/2,1,1/2) = -\frac{1}{\sqrt{2k}}\sqrt{\frac{1}{3}}t_\gamma \quad (19)$$

$$A_{3/2}^{J=3/2} = -t_\gamma\frac{1}{\sqrt{2k}}C(1/2,1,3/2;1/2,1,1/2) = -\frac{1}{\sqrt{2k}}t_\gamma \quad (20)$$

Decay width with helicity amplitudes

γ-decay width using helicity amplitudes (PDG 2008 pag 1076)

$$\Gamma_\gamma = \frac{k^2}{\pi}\frac{2M_B}{(2J_R+1)M_R}\left[(A_{1/2})^2+(A_{3/2})^2\right] \tag{21}$$

We reproduce the radiative decay width of Eq. (13) using the helicity amplitudes definition

$$J^P = 1/2^- \quad \Gamma_\gamma = \frac{k^2}{\pi}\frac{2M_B}{2M_R}\left[\frac{2}{3}|t_\gamma|^2\frac{1}{2k}\right] = \frac{1}{2\pi}\frac{2}{3}\frac{M_B}{M_R}k|t_\gamma|^2$$

$$J^P = 3/2^- \quad \Gamma_\gamma = \frac{k^2}{\pi}\frac{2M_B}{4M_R}\left[\frac{1}{3}|t_\gamma|^2+|t_\gamma|^2\right]\frac{1}{2k} = \frac{1}{2\pi}\frac{2}{3}\frac{M_B}{M_R}k|t_\gamma|^2$$

Helicity amplitudes for the N* dynamically generated resonances with the baryon octet

PDG data		Helicity amplitudes $10^{-3}(GeV^{-1/2})$							
name	J^P	Decay	Our Theory	Exp.[8] PDG	Exp.[9] Barbour	Exp.[10] Devenish	Th.[11]	Th.[12]	Th.[13]
$N(1650)$	$1/2^-$	$A^p_{1/2}$	64 ± 7	53 ± 16			5	46	54
		$A^n_{1/2}$	-74 ± 7	-15 ± 4			-16	-58	-35
$N(1700)$	$3/2^-$	$A^p_{1/2}$	-46 ± 5	-18 ± 13	-33 ± 21		-13	-3	-33
		$A^p_{3/2}$	-79 ± 9	-2 ± 24	-14 ± 25		-10	15	18
		$A^n_{1/2}$	52 ± 5	0 ± 50	50 ± 42		16	14	-3
		$A^n_{3/2}$	91 ± 9	-3 ± 44	35 ± 30		-42	-23	-30
$N(2080)$	$3/2^-$	$A^p_{1/2}$	-21 ± 5	-20 ± 8		26 ± 52			
		$A^p_{3/2}$	-36 ± 8	17 ± 11		128 ± 57			
		$A^n_{1/2}$	-29 ± 5	7 ± 13		53 ± 83			
		$A^n_{3/2}$	-50 ± 8	-53 ± 34		100 ± 141			
$N(2090)$	$1/2^-$	$A^p_{1/2}$	30 ± 6						
		$A^n_{1/2}$	41 ± 6						

[8] Claude Amsler et al. Review of particle physics. *Phys. Lett.*, B667:1, 2008.

[9] I. M. Barbour, R. L. Crawford, and N. H. Parsons. *Nucl. Phys.*, B141:253, 1978.

[10] R. C. E. Devenish, D. H. Lyth, and W. A. Rankin. *Phys.Lett.*, B52:227, 1974.

[11] D. Merten, U. Loring, K. Kretzschmar, B. Metsch, and H. R. Petry. *Eur. Phys. J.*, A14:477489, 2002.

[12] C. E. Carlson and C. D. Carone. *Phys. Rev.*, D58:053005, 1998.

[13] S. Capstick. *Phys. Rev.*, D46:28642881, 1992.

Conclusions

- In some resonances (e.g. N(1940) or $\Sigma(1750)$), the radiative decay width varies an order of magnitude for different third component of isospin, this should be a good test for the theory.
- Data of the decay width could be used to determine the nature of some resonances like N(2080), N(2090) or $\Sigma(2000)$.
- Some discrepancies in the helicity amplitudes could be due to the fact that the PDG average are probably done over different resonances.
- Despite some disagreements, this theory provides a general agreement of better quality than other theories.
- The theory predicts a ratio of $\frac{1}{\sqrt{3}}$ between $A^{3/2}_{3/2}$ and $A^{3/2}_{1/2}$ that should be tested and could be used to correctly identify the resonances.
- More data on helicity amplitudes are needed and the separation of different states would be useful to further learn about the nature of baryon resonances.

Thank you for your attention