Decay of Roper Resonance in Hybrid Baryon Model

N. Supanam[1,2] <u>K. Khosonthongkee</u>[1,2] and Y. Yan[1,2]

[1] School of Physics, Institute of Science, Suranaree University of Technology,
Nakhon Ratchasima, 30000 Thailand
[2] Research Center in Computational and Theoretical Physics/ThEP Center
Nakhon Ratchasima, 30000 Thailand

Outline

- Introduction
- Hybrid baryon model
- Interaction operator
- Transition amplitude
- Results on decay widths
- Conclusion

Baryon excitation states ⇒ **understanding**

Nucleon internal structure

N, Nucleon(939) — J= 1/2, I = 1/2, P=+1

Δ(1232) — J= 3/2, I = 3/2, P=+1

N*(1440), Roper Resonance — J= 1/2, I = 1/2, P=+1

N*(1440) Intrinsic excitation of Nucleon at energy around 500 MeV

Simple Model for N*(1440)

N*(1440) is three-quark with the first radial excitation

N*(1440) ⇨ too low mass to be radial excitation

Various quarks models

Met difficulties to explain its mass and electromagnetic couplings

⇩

problems of the models

Hybrid Baryon Model

Bag Model N*(1440)

Hybrid

qqq G

TE (transverse electric)

TM (transverse magnetic)

low mass

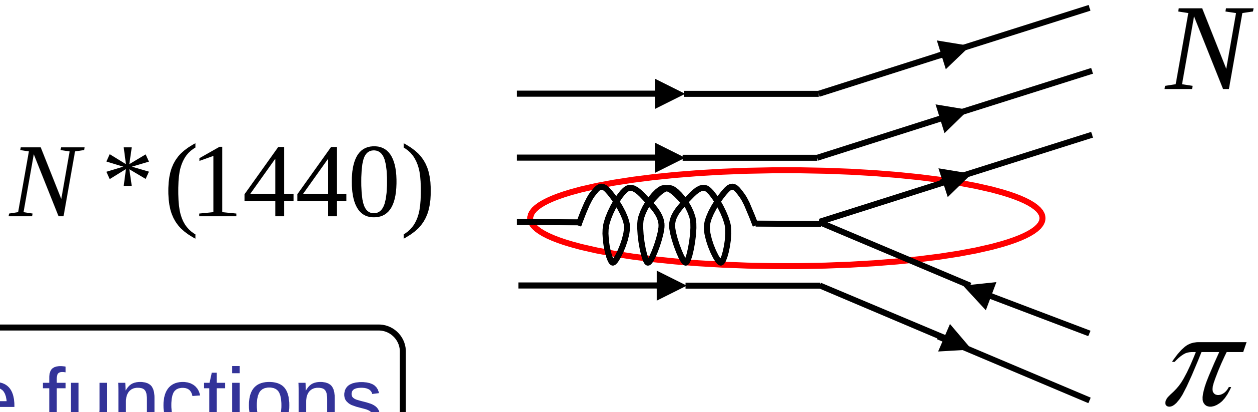
TE mode is the lowest eigenmode

N*(1440) ⇒ 3 quarks and a TE gluon

q^3G

 Hybrid Baryon Model

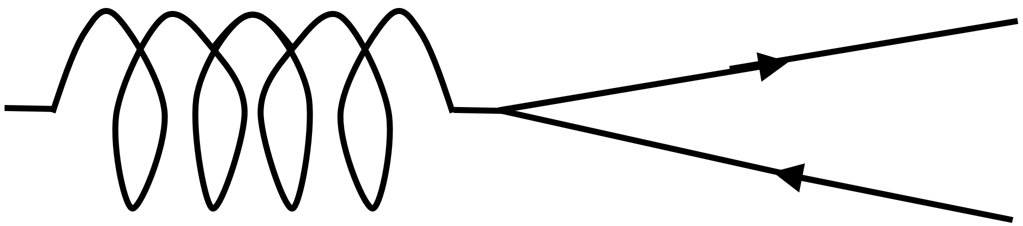
$N^*(1440) \rightarrow N\pi$



Wave functions

$$\psi_{N^*(1440)} \qquad \psi_N \qquad \psi_\pi$$

Interaction Operator



Nucleon wave function

$$\psi_{\mathrm{N}} = \psi_{\mathrm{N}}^{\text{spatial}} \psi_{\mathrm{N}}^{\text{spin-flavor}} \psi_{\mathrm{N}}^{\text{color}}$$

qqq ⇨ harmonic oscillator potential

$$\psi_{\mathrm{N}} = N_N \exp\left[-\frac{1}{4}a^2\left(\vec{p}_1 - \vec{p}_2\right)^2\right]\exp\left[-\frac{1}{12}a^2\left(\vec{p}_1 + \vec{p}_2 - 2\vec{p}_3\right)^2\right]$$

$$\frac{1}{\sqrt{2}}\sum_{J=0,1}\left|\left(\frac{1}{2}^{(1)} \otimes \frac{1}{2}^{(2)}\right)_J \otimes \frac{1}{2}^{(3)}\right\rangle_{\frac{1}{2},S_Z}^{\text{Spin}} \left|\left(\frac{1}{2}^{(1)} \otimes \frac{1}{2}^{(2)}\right)_J \otimes \frac{1}{2}^{(3)}\right\rangle_{\frac{1}{2},T_Z}^{\text{Flavor}}$$

$$\frac{1}{\sqrt{6}}\sum_{i,j,k}\varepsilon_{ijk}\left|q_1\right\rangle_i \left|q_2\right\rangle_j \left|q_3\right\rangle_k$$

Pion wave function

$$\psi_\pi = \psi_\pi^{\text{spatial}} \psi_\pi^{\text{spin-flavor}} \psi_\pi^{\text{color}}$$

$q\bar{q}$ ⇨ harmonic oscillator potential

$$\psi_\pi = N_\pi \exp\left[-\frac{1}{8} b^2 (\vec{p}_1 - \vec{p}_2)^2\right] \left| \left(\frac{1}{2}^{(1)} \otimes \frac{1}{2}^{(2)} \right) \right\rangle_{0,0}^{\text{Spin}}$$

$$\left| \left(\frac{1}{2}^{(1)} \otimes \frac{1}{2}^{(2)} \right) \right\rangle_{1,t_z}^{\text{Flavor}} \frac{1}{\sqrt{3}} \sum_{l=1}^{3} |\bar{q}_1\rangle_l |q_2\rangle_l$$

N*(1440) wave function

$$\psi_{\mathrm{N^*(1440)}} = \psi_{\mathrm{N^*(1440)}}^{\mathrm{spatial}} \psi_{\mathrm{N^*(1440)}}^{\mathrm{spin\text{-}flavor\text{-}color}}$$

$\psi_{\mathrm{N^*(1440)}}^{\mathrm{spatial}}$ q^3G ⇨ harmonic oscillator potential

$$\psi_{\mathrm{N^*}}^{\mathrm{Spatial}} = N_{N^*} \exp\left[-\frac{1}{4}a^2\left(\vec{p}_1 - \vec{p}_2\right)^2\right] \exp\left[-\frac{1}{12}a^2\left(\vec{p}_1 + \vec{p}_2 - 2\vec{p}_3\right)^2\right]$$

$$\exp\left[-\frac{2}{3}\frac{a^2}{(3R+1)^2}\left(\vec{p}_1 + \vec{p}_2 + \vec{p}_3 - 3R\,\vec{p}_4\right)^2\right]$$

where $R = \dfrac{m_q}{m_g}$

$$\psi^{\text{spin-flavor-color}}_{N^*(1440)} = A\left|{}^{2}N_g\right\rangle + B\left|{}^{4}N_g\right\rangle$$

$2S+1$ S :total spin of 3 quarks

$$\left|{}^{2}N_g\right\rangle = \frac{1}{2}\left[\left(\phi^\rho\chi^\rho - \phi^\lambda\chi^\lambda\right)\varphi^\rho - \left(\phi^\rho\chi^\lambda - \phi^\lambda\chi^\rho\right)\varphi^\lambda\right]\otimes\left|G\right\rangle$$

$$\left|{}^{4}N_g\right\rangle = \frac{1}{\sqrt{2}}\left[\left(\phi^\lambda\varphi^\rho - \phi^\rho\varphi^\lambda\right)\chi^S\right]\otimes\left|G\right\rangle$$

ϕ flavor wave function

φ color wave function

χ spin wave function

$\left|G\right\rangle$ Gluon wave function

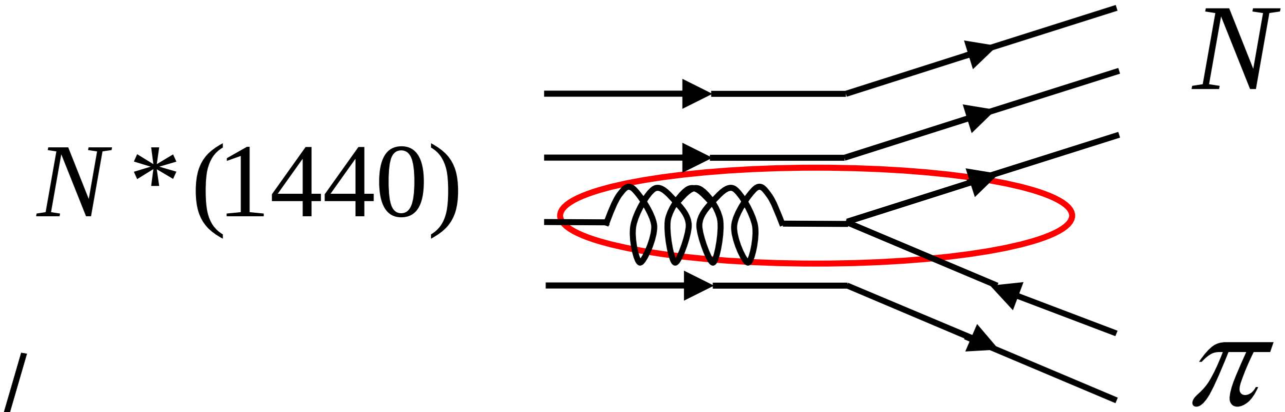
S totally symmetric

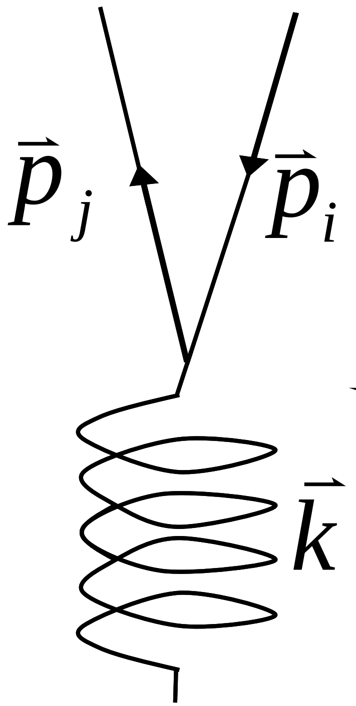
λ mix symmetric

ρ mix antisymmetric

Interaction Operator

$$N^*(1440) \to N\pi$$





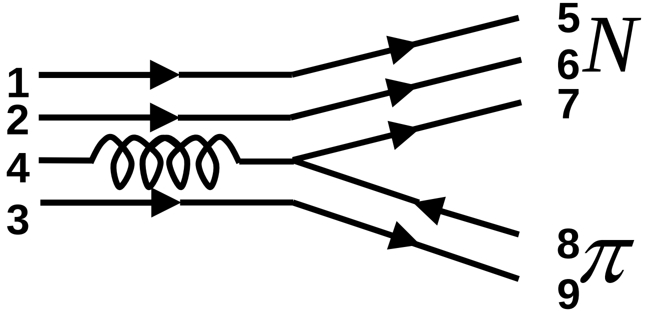
$$L_{\text{int}} = \bar{\psi} g \gamma^{\mu} A^{\alpha}_{\mu} \frac{\lambda^{\alpha}}{2} \psi$$

Nonreletivistic approximation $^{3}S_{1}$

$$V_{ij} = g \sum_{\mu} (-1)^{\mu+1} \sigma^{\mu}_{ij} \mathbf{1}^{F}_{ij} \varepsilon_{-\mu} A^{\alpha} \tfrac{\lambda^{\alpha}}{2} \delta\left(\vec{p}_i + \vec{p}_j - \vec{k}\right)$$

Transition amplitude

$N^*(1440)$



$$T = \left\langle N\pi \middle| V_{78} \middle| N^* \right\rangle$$

$$V_{78} = g \sum_{\mu} (-1)^{\mu+1} \sigma_{78}^{\mu} \mathbf{1}_{78}^{F} \varepsilon_{-\mu} A^{\alpha} \tfrac{\lambda^{\alpha}}{2} \delta\left(\vec{p}_7 + \vec{p}_8 - \vec{p}_4\right)$$

Properties

$$\left\langle 0,0 \middle| \sigma_{i,j}^{\mu} \middle| \left[\bar{\chi}_i \otimes \chi_j\right]_{JM} \right\rangle = (-1)^{M} \sqrt{2}\, \delta_{J,1} \delta_{M,-\mu}$$

$$\left\langle 0,0 \middle| \mathbf{1}_{78}^{F} \middle| T, T_Z \right\rangle = \sqrt{2}\, \delta_{T,0} \delta_{T_z,0}$$

$$\left\langle 0,0 \middle| \varepsilon_{-\mu} \middle| \mathrm{e}_{sm_s} \right\rangle = \delta_{-\mu,m_s}$$

Decay width

$$N^*(1440) \to N\pi$$

$$\Gamma_{N^*(1440)\to N\pi} \propto \frac{E_N E_\pi}{M_{N^*}} g^2 p^3 \beta \exp\left(-2\alpha p^2\right)$$

depend on a, b

$$\times \sum_{S_Z} \sum_{m_l} \left| (-1)^{m_l} \left(\frac{A}{2} Q_1 + \frac{B}{\sqrt{2}} Q_2 \right) \right|^2$$

depend on a, b, R

$$\psi^{\text{spin-flavor-color}}_{N^*(1440)} = A\left|{}^2N_g\right\rangle + B\left|{}^4N_g\right\rangle$$

$$Q_1 = \left\langle \psi^{\text{spin-flavor-color}}_{N\pi} \middle| O_{\text{spin-flavor-color}} \middle| {}^2N_g \right\rangle \qquad Q_2 = \left\langle \psi^{\text{spin-flavor-color}}_{N\pi} \middle| O_{\text{spin-flavor-color}} \middle| {}^4N_g \right\rangle$$

Where a and b are determined by the nucleon and meson sizes, $NN, N\bar{N}, \pi N$ interactions

$$a = 3.1\text{GeV}^{-1} \qquad b = 4.1\text{GeV}^{-1}$$

Decay channels

Interested channels

$$N^*(1440) \to N\pi$$

$$N^*(1440) \to \Delta\pi$$

$$N^*(1440) \to N\rho$$

$$N^*(1440) \to N\eta$$

Results on decay widths

PRD 46 (1992) p70-74

	Hybrid Baryon Model				Experimental Data (PDG)
	A=0 B=1	A=1 B=0	A/B=1 $A=\sqrt{\frac{1}{2}}$	A/B= -1 $A=-\sqrt{\frac{1}{2}}$	
$\frac{\Gamma_{N^*(1440)\to N\rho}}{\Gamma_{N^*(1440)\to N\pi}}$	0.027	0.018	0.016	0.021	< 0.15
$\frac{\Gamma_{N^*(1440)\to N\eta}}{\Gamma_{N^*(1440)\to N\pi}}$	0.784	0.196	0.577	0.124	-
$\frac{\Gamma_{N^*(1440)\to \Delta\pi}}{\Gamma_{N^*(1440)\to N\pi}}$	1.812	0.065	0.179	0.392	0.27 - 0.55

Conclusions

- $N^*(1440)$ is treated as a hybrid baryon, q^3G, in nonrelativistic regime.
- The vertex where a gluon is destroyed and form a pair of quark-antiquark is described in the effective $^3S_1$
- The decay width ratios of $N^*(1440)$ have been shown. It is found that our theoretical results are fairly consistent with experimental data.

 Acknowledgement

Acknowledgement

This work is supported by

- The Commission on Higher Education of Thailand, CHE-RES-RG Theoretical Physics
- Thailand Center of Excellence in Physics (ThEP)
- Thailand Research Fund

Expand the total transition amplitude in partial wave

$$T_{N*(1440)\to N\pi} = \sum_{l,m_l} T_{lm_l} Y^*_{lm_l}(\hat{p})$$

$$T_{lm_l} = g\delta_{S_Z,S''_Z}\delta_{T_Z,T''_Z} P_{1m_l}\left[\frac{A}{2}Q_1 + \frac{B}{\sqrt{2}}Q_2\right]$$

depend on m_l, a, b, c, R

$$Q_1 = \left\langle \psi_{N\pi}^{\text{spin}-\text{flavor}-\text{color}} \middle| O_{\text{spin}-\text{flavor}-\text{color}} \middle| {}^2N'_g \right\rangle$$

$$Q_2 = \left\langle \psi_{N\pi}^{\text{spin}-\text{flavor}-\text{color}} \middle| O_{\text{spin}-\text{flavor}-\text{color}} \middle| {}^4N'_g \right\rangle$$

$$N^*(1440) \rightarrow N\pi$$

m_l	S_z	Q_1	Q_2
-1	-1/2	-0.148	0.131
	1/2	-0.444	0.079
0	-1/2	-0.296	-0.052
	1/2	0.296	0.052
1	-1/2	0.444	-0.079
	1/2	0.148	-0.131

Values of Q_1 and Q_2 for different initial and final states

$$\left|{}^4N_g\right\rangle = \frac{1}{\sqrt{2}}\left[\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_1\otimes\frac{1}{2}^{(3)}\right\rangle_{\frac{3}{2},m_{123}}\otimes\left(Y_{1m_l}(\vec{p}_1+\vec{p}_2+\vec{p}_3-3R\vec{p}_4)\otimes e_{1,m_s}\right)_{1,m_2'}\right]^{\text{Spin}}_{\frac{1}{2},S_Z''}$$

$$\left\{\left[\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_1\otimes\frac{1}{2}^{(3)}\right\rangle^{\text{Flavor}}_{\frac{1}{2},T_Z''}\frac{1}{\sqrt{8}}\sum_\alpha \psi^\rho_\alpha\left|g\right\rangle^{\text{color}}_\alpha\right]\right.$$

$$\left.-\left[\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_0\otimes\frac{1}{2}^{(3)}\right\rangle^{\text{Flavor}}_{\frac{1}{2},T_Z''}\frac{1}{\sqrt{8}}\sum_\alpha \psi^\lambda_\alpha\left|g\right\rangle^{\text{color}}_\alpha\right]\right\}$$

$$\left|{}^{2}N_{g}\right\rangle=\frac{1}{2}\sum_{J_{12}}\Bigg\{\Bigg((-1)^{J_{12}}\left[\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_{J_{12}}\otimes\frac{1}{2}^{(3)}\right\rangle_{\frac{1}{2},m_{123}}\otimes\left(Y_{1,m_l}(\vec{p}_1+\vec{p}_2+\vec{p}_3-3R\vec{p}_4)\otimes e_{1,m_s}\right)_{1,m_2'}\right]^{\mathrm{Spin}}_{\frac{1}{2},S_Z''}$$

$$\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_{J_{12}}\otimes\frac{1}{2}^{(3)}\right\rangle^{\mathrm{Flavor}}_{\frac{1}{2},T_Z''}\frac{1}{\sqrt{8}}\sum_{\alpha}\psi^{\rho}_{\alpha}\left|g\right\rangle^{\mathrm{color}}_{\alpha}$$

$$-\Bigg(\left[\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_{1-J_{12}}\otimes\frac{1}{2}^{(3)}\right\rangle_{\frac{1}{2},m_{123}}\otimes\left(Y_{1,m_l}(\vec{p}_1+\vec{p}_2+\vec{p}_3-3R\vec{p}_4)\otimes e_{1,m_s}\right)_{1,m_2'}\right]^{\mathrm{Spin}}_{\frac{1}{2},S_Z''}$$

$$\left|\left(\frac{1}{2}^{(1)}\otimes\frac{1}{2}^{(2)}\right)_{J_{12}}\otimes\frac{1}{2}^{(3)}\right\rangle^{\mathrm{Flavor}}_{\frac{1}{2},T_Z''}\frac{1}{\sqrt{8}}\sum_{\alpha}\psi^{\lambda}_{\alpha}\left|g\right\rangle^{\mathrm{color}}_{\alpha}\Bigg)\Bigg\}$$