$\Lambda(1405)$ and $\Lambda(1520)$ decay in non-relativistic quark model

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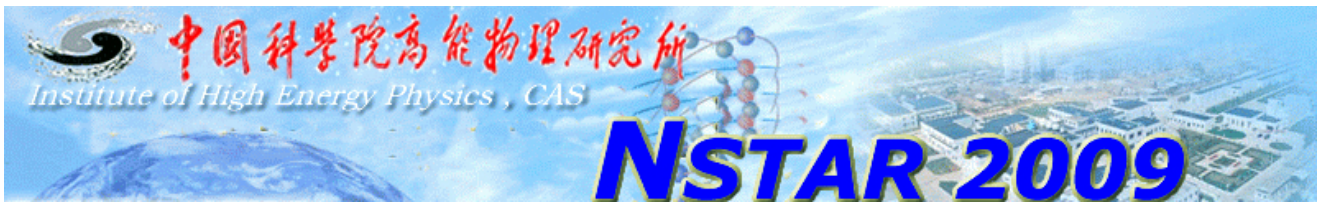


Outline

- Introduction
- Non-relativistic quark model
- Results of decay widths
- Conclusion

$\Lambda(1405)$ and $\Lambda(1520)$

PDG

	$I(J^P)$	m (MeV)	Γ (MeV)
$\Lambda(1405)$	$0(\frac{1}{2}^-)$	1406±4	50±2
$\Lambda(1520)$	$0(\frac{3}{2}^-)$	1519.5±1	15.6±1

They have been investigated for decades but their internal structures are still unclear.

Possibilities :

- $\bar{K}$N (PRL 2, 425; Ann. Phys. 10, 307; ...)
- pentaquark $(q^4\bar{q})$ (NPA 790, 530; arXiv:0708.2339; ...)
- q^3 baryon (PRD 18, 4187; ...)

Decay channels

Interested reactions:

- $\Lambda(1405) \rightarrow \Sigma\pi$ (100%)
- $\Lambda(1520) \rightarrow \Sigma\pi$ (42%)

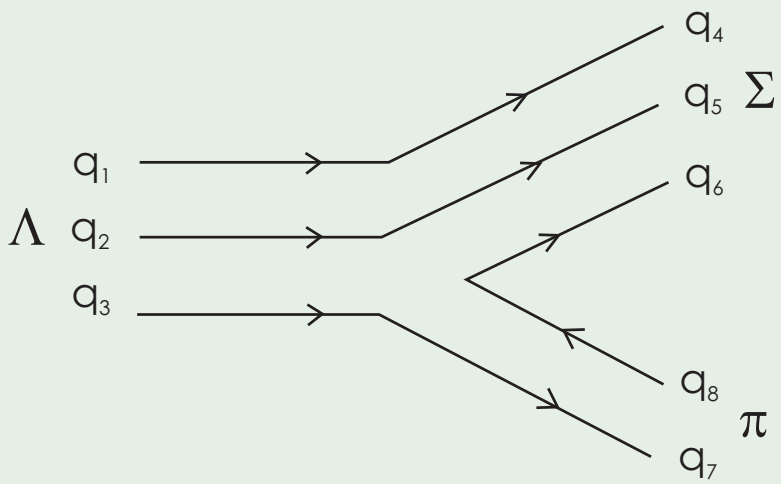
Decay width

$$\Gamma = \frac{2\pi E_\Sigma E_\pi k}{M_\Lambda} \frac{1}{2S+1} \sum |T_{\Lambda\rightarrow\Sigma\pi}|^2$$

In this work we calculate the decay width in the $^3P_0$ non-relativistic quark dynamics.

The $^3P_0$ quark pair creation

$^3P_0$ vertex for the $q\bar{q}$ dynamics:



- the $q\bar{q}$ pair is created with vacuum quantum numbers $I^G(J^{PC}) = 0^+(0^{++})$
- $q\bar{q}$ pair must be in an odd relative orbital angular momentum
- $q\bar{q}$ pair has to be coupled to spin S=1 which together with orbital angular momentum L=1 couples to J=0

Transition amplitude

According to the $^3P_0$ quark model

$$T = \langle \Sigma\pi | V_{68} | \Lambda \rangle$$

$$V_{68} = \lambda \vec{\sigma}_{68} \cdot (\vec{p}_6 - \vec{p}_8) \hat{F}_{68} \hat{C}_{68} \delta(\vec{p}_6 + \vec{p}_8)$$

- $\vec{p}_6$ and $\vec{p}_8$ are the momenta of q and $\bar{q}$ created out of vacuum
- $\vec{\sigma}_{68} = (\vec{\sigma}_6 + \vec{\sigma}_8)/2$ is spin operator
- $\hat{F}_{68}$ and $\hat{C}_{68}$ are flavor and color operators, projecting a $q\bar{q}$ pair to the respective vacuum quantum numbers

Properties of the operators

$$\langle 0,0|\,\hat{F}_{68}\,|T,T_z\rangle = \sqrt{2}\delta_{T,0}\delta_{T_z,0}$$

$$\langle 0,0|\,\sigma^{\mu}_{68}\,\left|[\bar{\chi}_6\otimes\chi_8]_{J,M}\right\rangle = (-1)^M\sqrt{2}\delta_{J,1}\delta_{M,-\mu}$$

$$\langle 0,0|\,\hat{C}_{68}\,\left|q^6_\alpha\bar{q}^8_\beta\right\rangle = \delta_{\alpha\beta}$$

Then the total transition amplitude can be expanded into flavor, color, spatial and spin parts.

Spatial wave function

Initial

$$\Psi^{\Lambda}_{spatial} = N_B \exp\left[-\frac{a^2}{2}\left(\frac{\vec{q}_1-\vec{q}_2}{\sqrt{2}}\right)^2 - \frac{a^2 d^2}{2}\left(\frac{\vec{q}_1+\vec{q}_2-2m_r\vec{q}_3}{\sqrt{6}}\right)^2\right]$$

Final

$$\Psi^{\Sigma}_{spatial} = N_B \exp\left[-\frac{a^2}{2}\left(\frac{\vec{q}_6-\vec{q}_5}{\sqrt{2}}\right)^2 - \frac{a^2 d^2}{2}\left(\frac{\vec{q}_6+\vec{q}_5-2m_r\vec{q}_4}{\sqrt{6}}\right)^2\right]$$

$$\Psi^{\pi}_{spatial} = N_\pi \exp\left[-b^2\left(\frac{\vec{q}_7-\vec{q}_8}{\sqrt{8}}\right)^2\right]$$

$$m_r = \frac{m_{u(d)}}{m_s}, \quad d = \frac{3}{(1+2m_r)}$$

a is baryon size parameter and b is meson size parameter

In this work the $\Lambda(1405)$ and $\Lambda(1520)$ are studied by assuming that both of them are q^3 states with a P-wave s-quark.

Parameters

Baryon and meson size parameters (a, b)

- a varying from 2 to 4 GeV^{-1} (according to baryon radius: 0.4 - 0.8 fm)
- $b = 3.85$ GeV^{-1} , fixed from the $\rho \longrightarrow e^+e^-$ reaction (PRC 71,025204)

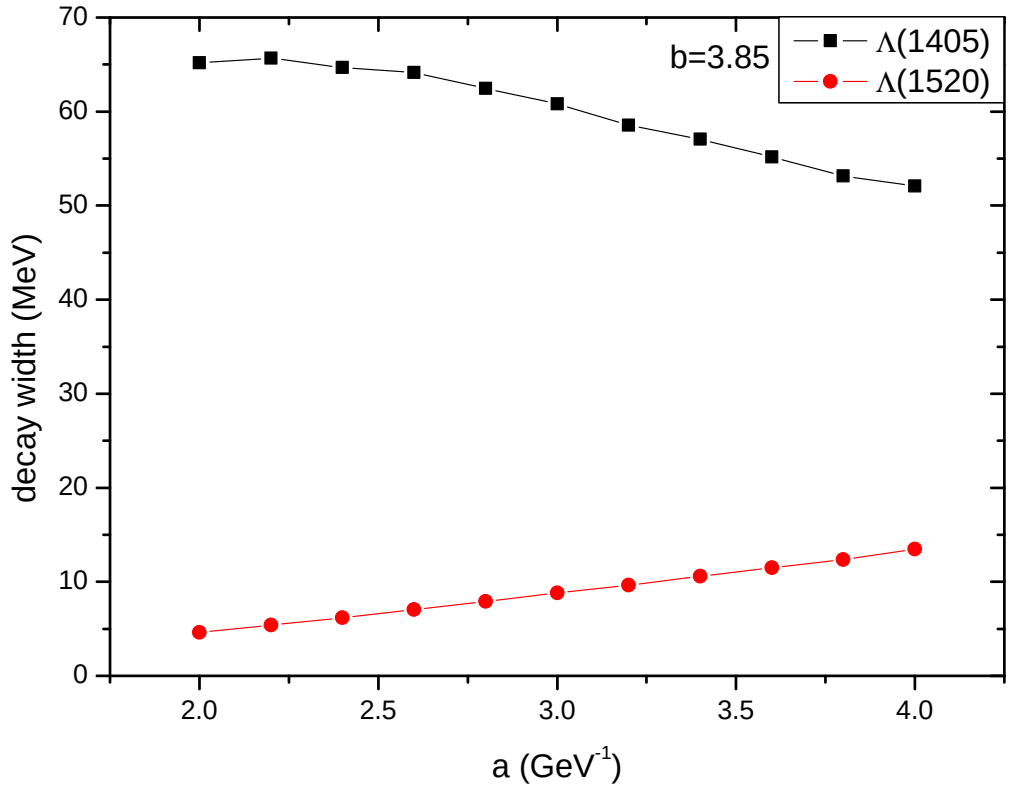
Masses are taken from PDG

- $M_{\Lambda(1405)} = 1406$ MeV
- $M_{\Lambda(1520)} = 1519.5$ MeV
- $M_{\Sigma} = 1189$ MeV
- $M_{\pi} = 139.5$ MeV

The strength parameter λ is fixed from the reaction:

- $\Sigma(1385) \longrightarrow \Lambda\pi$

Our result



The experimental data (PDG):

- $\Gamma(\Lambda(1405) \rightarrow \Sigma\pi) = 50$ MeV
- $\Gamma(\Lambda(1520) \rightarrow \Sigma\pi) = 6.55$ MeV

Conclusion

The partial decay widths of the processes $\Lambda(1405) \to \Sigma\pi$ and $\Lambda(1520) \to \Sigma\pi$ are evaluated in the $^3P_0$ non-relativistic quark model with all model parameters fixed by other hadron processes.

It is found that our theoretical results are fairly consistent with experimental data.

The work indicates that both the $\Lambda(1405)$ and $\Lambda(1520)$ may have a large three-quark component, which is not in line with that the $\Lambda(1405)$ has been interpreted as a $\overline{K}N$ resonance since it was discovered.

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