THE INTERACTION AND RESONANCE STATES BETWEEN CHARMED BARYON AND NUCLEON

Saori Maeda

Makoto Oka

Tokyo Institute of technology

MIN16 - Meson in Nucleus 2016, YITP, 31th July 2016

CONTENTS

- Introduction
- $Y_c N$ Interaction & Binding energy
- Resonance states
- Summary

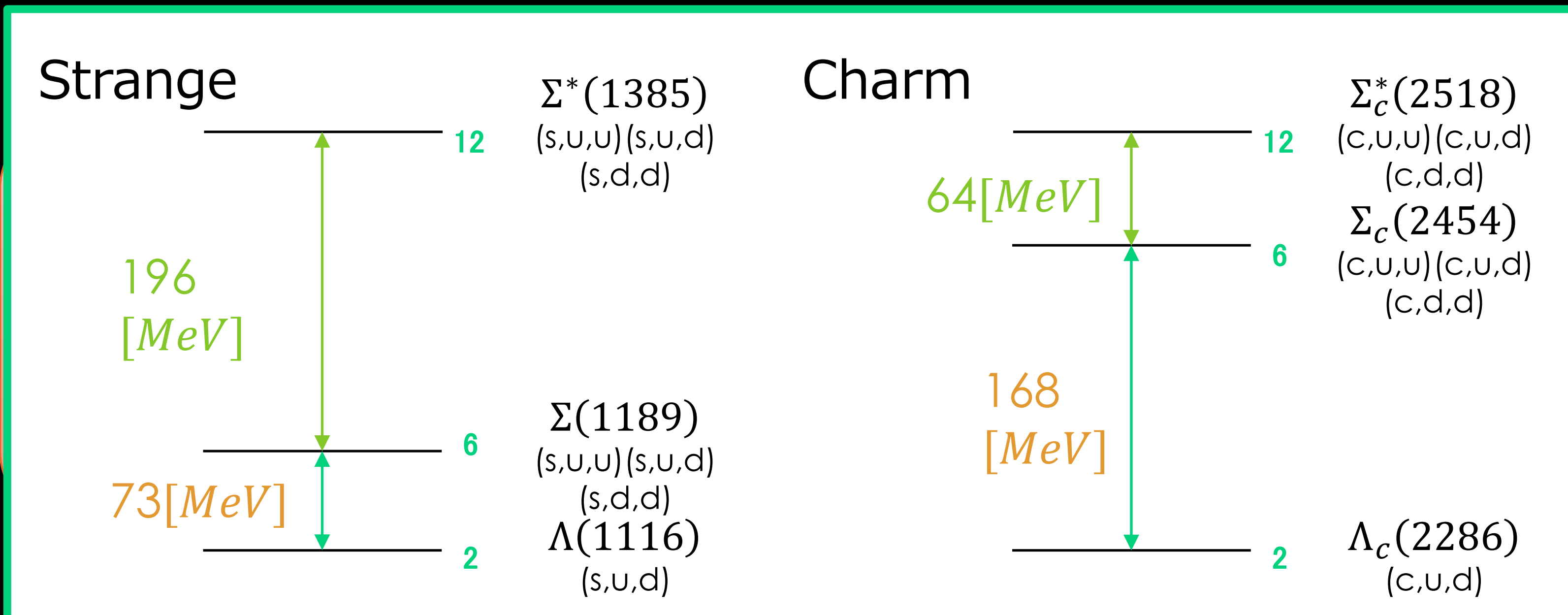
INTRODUCTION

- We have obtained many experimental data related to hypernuclei and hyperon-nucleon(YN) interactions.

the next stage → **Approaching to charm nuclei structure with theoretical knowledge**

- Interesting properties of charm nuclei
- Heavy quark symmetry
- Channel coupling including higher state than strange sector.

INTRODUCTION



- Interesting properties of charm nuclei

・Heavy quark symmetry

・Channel coupling including higher state than strange sector.

$Y_c N$ INTERACTION

- $Y_c N$ potential ($Y_c = \Lambda_c, \Sigma_c, {\Sigma_c}^*$)

In this study, we construct a hybrid potential using a hadron model and a quark model

▪ One Boson Exchange potential [Y.R.Liu, M.Oka, Phys. Rev. D 85, 014015 (2012)]

▪ Quark Cluster Model [M.Oka, Nuclear Physics A 881 (2012) 6–13]

$$V_{(Y_c N)} = V_{OBEP} + V_{QCM}$$

- Channel coupling

Channels	1	2	3	4	5	6	7
$J^\pi = 0^+$	$\Lambda_c N(^1S_0)$	$\Sigma_c N(^1S_0)$	$\Sigma_c^* N(^5D_0)$				
$J^\pi = 1^+$	$\Lambda_c N(^3S_1)$	$\Sigma_c N(^3S_1)$	$\Sigma_c^* N(^3S_1)$	$\Lambda_c N(^3D_1)$	$\Sigma_c N(^3D_1)$	$\Sigma_c^* N(^3D_1)$	$\Sigma_c^* N(^5D_1)$

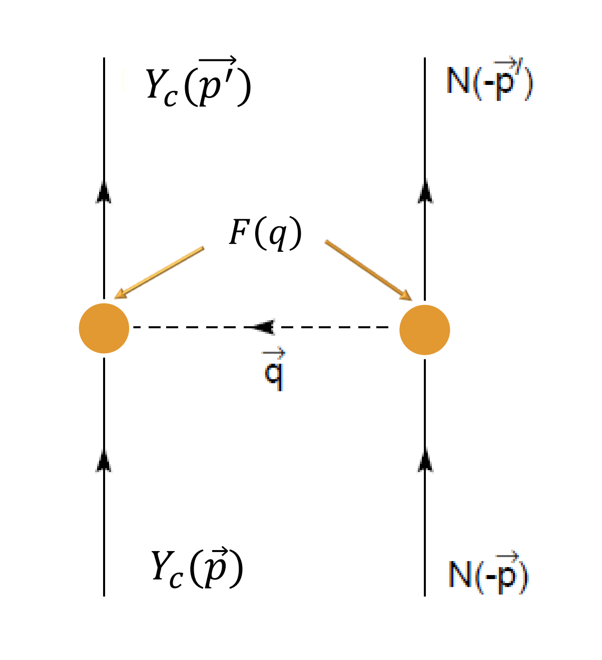
$Y_c N$ INTERACTION

- One Boson Exchange potential

We assume that the pion and the sigma meson exchange between the charm baryon and the nucleon.

At the vertices, we introduce the form factor $F(q)$ as follows

$$F(q) = \frac{\Lambda^2 - m^2}{\Lambda^2 - q^2}$$



$Y_c N$ INTERACTION

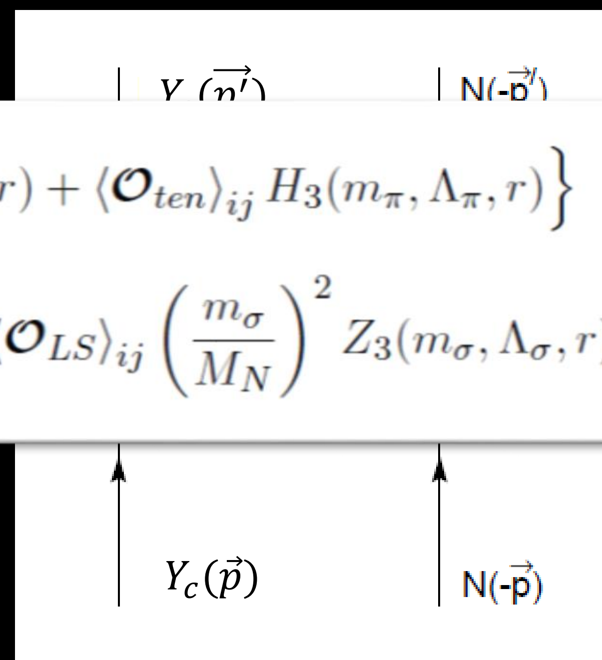
- One Boson Exchange potential

We assume that the pion and

$$V_\pi(i,j) = C_\pi(i,j)\frac{m_\pi^3}{24\pi f_\pi^2}\left\{\langle\mathcal{O}_{spin}\rangle_{ij} Y_1(m_\pi,\Lambda_\pi,r) + \langle\mathcal{O}_{ten}\rangle_{ij} H_3(m_\pi,\Lambda_\pi,r)\right\}$$

$$V_\sigma(i,j) = C_\sigma(i,j)\frac{m_\sigma}{16\pi}\left\{\langle 1\rangle_{ij} 4Y_1(m_\sigma,\Lambda_\sigma,r) + \langle\mathcal{O}_{LS}\rangle_{ij}\left(\frac{m_\sigma}{M_N}\right)^2 Z_3(m_\sigma,\Lambda_\sigma,r)\right\}$$

$$F(q) = \frac{\Lambda^2 - m^2}{\Lambda^2 - q^2}$$



$Y_c N$ INTERACTION

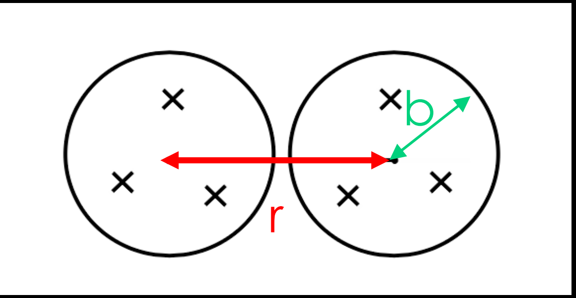
- Quark Cluster Model (QCM)

The QCM considers **two baryon clusters** each made of **three quarks**.

When two baryons overlap completely, r=0, all the six quarks occupy the lowest energy orbit with a single center.

Potential equation

$$V_{QCM} = V_0 e^{-\frac{r^2}{b^2}}$$



$Y_c N$ INTERACTION

- Quark Cluster Model (QCM)

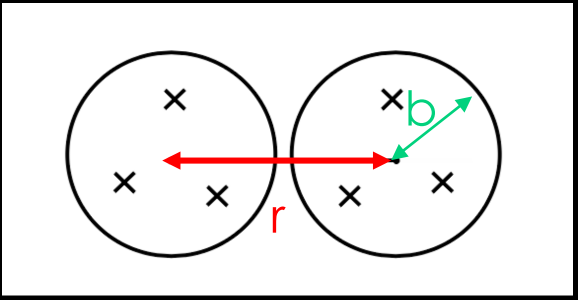
The QCM considers **two baryon clusters** each made of **three quarks**.

When two baryons overlap completely, r=0, all the six quark … gle center.

$$V(r=0) \approx < 6q|H|6q > -2 < 3q|H|3q >$$

Potential equation

$$V_{QCM} = V_0 e^{-\frac{r^2}{b^2}}$$



$Y_c N$ INTERACTION

- Parameter fix

we determine the parameters of the potential so as to reproduce the NN interaction data using the same model.

▪Fixed parameter

Pi-baryon coupling constants, Range parameter of QCM

▪Determined parameter

Cutoff parameter (Λ_π, Λ_σ), sigma-baryon coupling constants

Y_cN INTERACTION

- Parameter

Y_cN-Corresponding To NN

we determine the parameters of the potential so as to reproduce th ame model.

YcN-CTNN	C_σ	b[fm]
parameter a	-67.58	0.6
parameter b	-77.5	0.6
parameter c	-60.76	0.5
parameter d	-70.68	0.5

[Prog. Theor. Exp. Phys. (2016) 023D02]

▪Fixed paran

Pi-baryon co er of QCM

▪Determined parameter

Cutoff parameter (Λ_π, Λ_σ), sigma baryon coupling constants

$Y_c N$ INTERACTION

- Result of binding energy and scattering length

$J^\pi = 0^+$	CTNN-a	CTNN-b	CTNN-c	CTNN-d
B.E. [MeV]	-	-	1.72×10^{-3}	1.37
(+ Coulomb)				(0.56)
scattering length [fm]	-3.64	-65.15	130.93	5.31

$J^\pi = 1^+$	CTNN-a	CTNN-b	CTNN-c	CTNN-d
B.E. [MeV]	-	2.62×10^{-4}	1.97×10^{-2}	1.57
(+ Coulomb)				(0.72)
scattering length [fm]	-4.11	337.53	39.27	5.01

$Y_c N$ INTERACTION

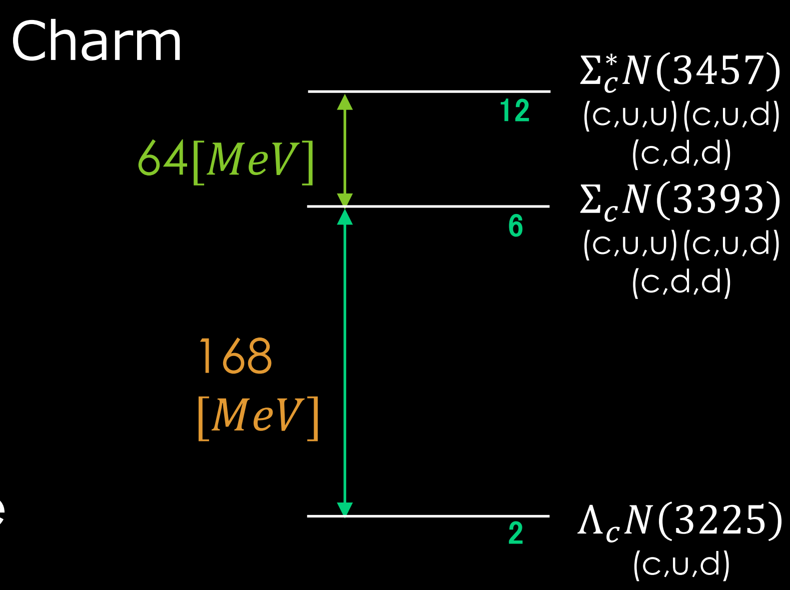
- Resonance

In the previous calculation, we consider only the state under the $\Lambda_c N$ threshold.

So, we calculate with the Complex scaling method

[J. Aguilar, J.M. Combes, Commun. Math. Phys. 22 (1971) 269.]

to search the state above the $\Lambda_c N$ threshold with $Y_c N$-CTNN d-potential.



$Y_c N$ INTERACTION

- Resonance

▪ $J^P = 2^+$

$\Lambda_c N$ and $\Sigma_c N$ channel have no S-wave because of the rule of total angular momentum.

The S-wave and G-wave are the characteristic behavior of Σ_c^* having the spin = $\frac{3}{2}$

Channels	1	2	3	4	5	6	7	8
$J^\pi = 2^+$	$\Lambda_c N(^1D_2)$	$\Sigma_c N(^1D_2)$	$\Lambda_c N(^3D_2)$	$\Sigma_c N(^3D_2)$	$\Sigma_c^* N(^3D_2)$	$\Sigma_c^* N(^5S_2)$	$\Sigma_c^* N(^5D_2)$	$\Sigma_c^* N(^5G_2)$

$Y_c N$ INTERACTION

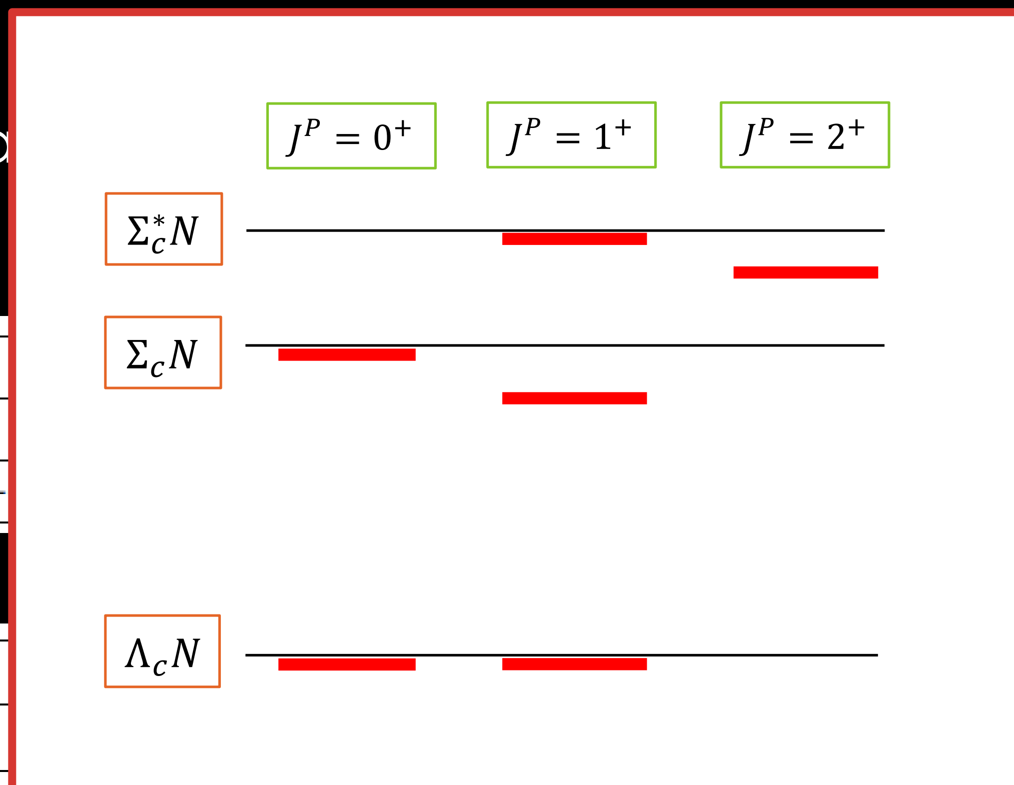
- Resonance
  - Result

	$J^\pi = 0^+$ near $\Sigma_c N$		$J^\pi = 1^+$ near $\Sigma_c^* N$	
	resonance	width	resonance	width
CTNN-d	163.09 (-4.01)	1.09	225.00 (-6.51)	1.54

	$J^\pi = 1^+$ near $\Sigma_c N$		$J^\pi = 2^+$ near $\Sigma_c^* N$	
	resonance	width	resonance	width
CTNN-d	144.28 (-22.82)	11.92	206.34 (-25.17)	14.01

$Y_c N$ INTERACTION

- Resona
- Result



	ar $\Sigma_c^* N$	
		width
CTNN-	)	1.54

				ear $\Sigma_c^* N$		
						width
CTNN-d	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.01

$Y_c N$ INTERACTION

- Resonance
  - Result with partial channel coupling

$\Sigma_c N$ threshold: 167.10 MeV
$\Sigma_c^* N$threshold: 231.51 MeV

potential	$J^P = 0^+(\Sigma_c N)$	$J^P = 1^+(\Sigma_c N)$	$J^P = 1^+(\Sigma_c^* N)$	$J^P = 2^+(\Sigma_c^* N)$
CTNN-d	2.22[MeV]	14.28[MeV]	7.67[MeV]	17.68[MeV]

$Y_c N$ INTERACTION

- Resonance

▪Heavy quark limit

We assume $\Sigma_c N$ and $\Sigma_c^* N$ are doublet, so we set the $Y_c N$ threshold in substitute for $\Sigma_c N$ and $\Sigma_c^* N$ threshold.

$\Sigma_c^* N(3457)$
(c,u,u)(c,u,d)
(c,d,d)

$\Sigma_c N(3393)$
(c,u,u)(c,u,d)
(c,d,d)

$\Lambda_c N(3225)$
(c,u,d)

$Y_c N(3414)$
(c,u,u)(c,u,d)
(c,d,d)

$\Lambda_c N(3225)$
(c,u,d)

$Y_c N$ INTERACTION

- Resonance
  - Result

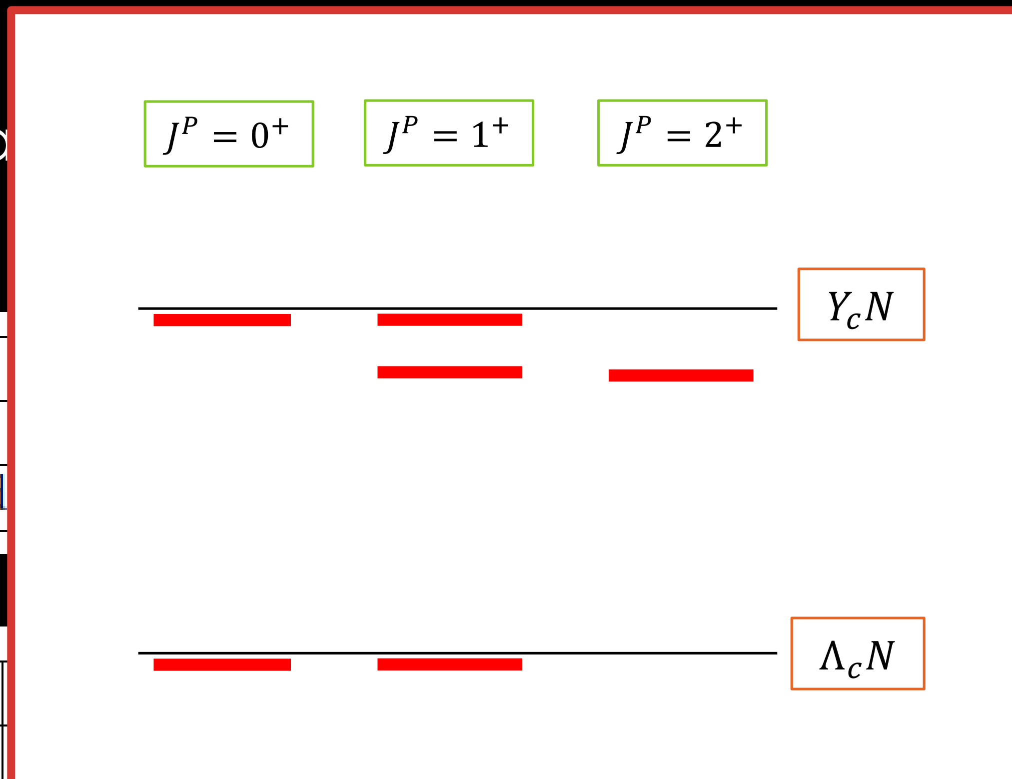
	$J^\pi = 0^+$ near $\Sigma_c N$		$J^\pi = 1^+$ near $\Sigma_c^* N$	
	resonance	width	resonance	width
CTNN-d	183.79 (-4.78)	0.91	183.72 (-4.85)	0.89

	$J^\pi = 1^+$ near $\Sigma_c N$		$J^\pi = 2^+$ near $\Sigma_c^* N$	
	resonance	width	resonance	width
CTNN-d	163.88 (-24.69)	13.16	163.84 (-24.73)	12.46

$Y_c N$ INTERACTION

- Resona
  - Result

		ar $\Sigma_c^* N$	
			width
CTNN-d		5)	0.89



				ar $\Sigma_c^* N$	
					width
CTNN-d	163.88	(-24.69)	13.16	163.84 (-24.73)	12.46

SUMMARY

- We propose the $Y_c N$ potential model based on the hadron model and the quark model, and find four parameter set to reproduce experimental data of NN system.
- Calculating the $Y_c N$ 2-body system, we get not only the shallow bound state but also resonance states for several potential models.