Possible Existence of K^{bar}-Hyperon Resonances and the origin of K^{bar}-Hadron Attractions

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INTRODUCTION

Low-Energy Hadron-Hadron Interactions

A Long-standing problem since Yukawa Theory

Experimental Knowledge
- NN, πN, KN, ππ, Kπ : Phase Shift Analyses are available
- YN, YY : Cross sections, Hypernuclear Properties
- $K^{bar}N$: Cross sections, Scattering Lengths
- πY, $K^{bar}Y$, KK : Unknown(Not well known)

Theoretical Models:
- Hadron-Exchange Models : The SU(3) symmetry + Physical Hadron masses
- Quark Models (with Meson-Exchange) the SU(6) Symmetry + OGE
- Effective Field Theory : Chiral perturbation

First-Principle Calculations:

Hadron-Hadron potentials derived from Lattice QCD calculations

mB potential model

*p-space potential

Long-range part of potential: One Hadron Exchange

SU(3) symmetric Interaction Lagrangian
(**mBB** coupling constants are predetermined in BB potential model)
Gaussian Form factor with a common range
(Cutoff range is the same with the range of short-range potential.)

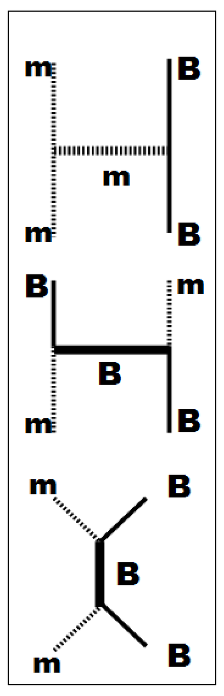
Short-range part of potential : Phenomenological

The SU(3)-symmteric Strengths
Common range for all mB pairs
We consider two cases of range

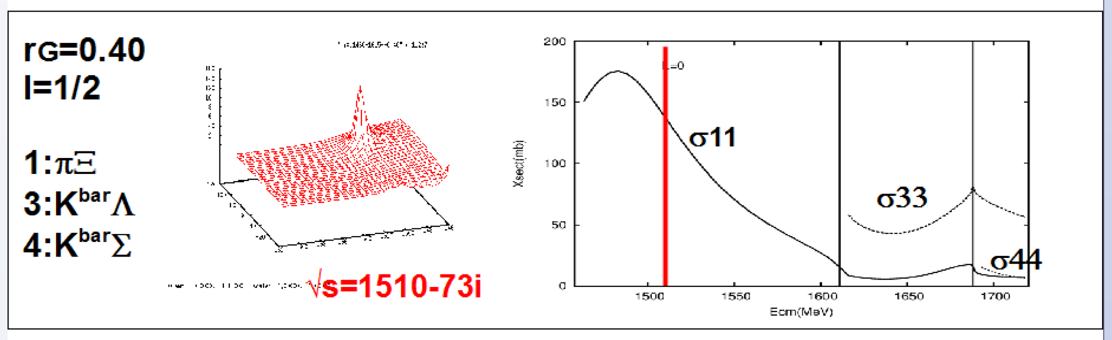
	pot I	pot II	
r_G	0.4	0.45	(fm)

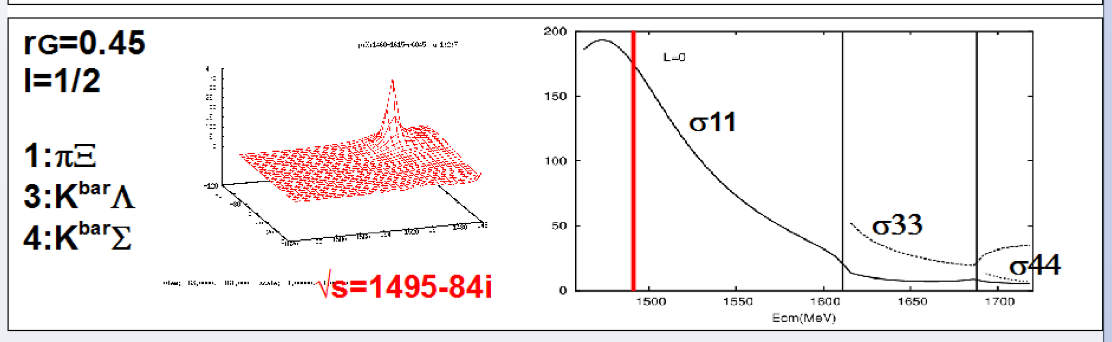
$$V = (\text{SU(3) symmteric strengths}) \times \exp(-q^2/L^2) + V(\text{one-hadron-exchange potential}) \times \exp(-q^2/L^2)$$

where, $L=2/rG$



Resonance Poles $\Xi^*(I=1/2,Jp=1/2-)$ / Cross sections σ11, σ33, σ44





BB potential model

*r-space potential

Long-range part of potential : One Boson Exchange potential

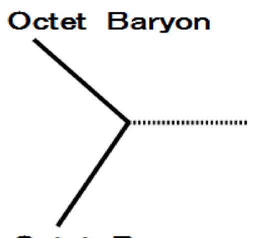
SU(3) symmetric Interaction Lagrangians
Physical masses, retardation effects
Smoothly cutoff by $[1-\exp(-(r/r_c)^2]^4$, r_c=0.4fm

Short-range part of potential : LQCD

SU(3) symmetric strengths and common range
Gaussian form : $\exp(-(r/r_Q)^2)$, r_Q=0.476fm
Relative strengths are determined by LQCD results (within ±10%)

Relative strengths:

	{27}	{10*}	{10}	{8a}	{8s}	{1}
LQCD	**1**	**0.8**	**1.1**	**0.2**	**4.1**	**-0.6**
	------NN-----		--------YN--------			---YY---



Scalar meson nonet
Pseudoscalar meson nonet
Vector mesons nonet

All pairs of Octet Baryons: p,n,Λ,Σ^+,Σ^-,Σ^0,Ξ^0,Ξ^-

Results for πN, KN scattering lengths

πN scattering lengths

rG	calc 0.40	calc 0.45	exp
S11	+0.2458	+0.2482	+0.2473±0.0043
S31	−0.1496	−0.1466	−0.1444±0.0057
P11	−0.2359	−0.2340	−0.2368±0.0058
P31	−0.1375	−0.1290	−0.1316±0.0058
P13	−0.0862	−0.0894	−0.0877±0.0058
P33	+0.6238	+0.6235	+0.6257±0.0058

fm**(2L+1)

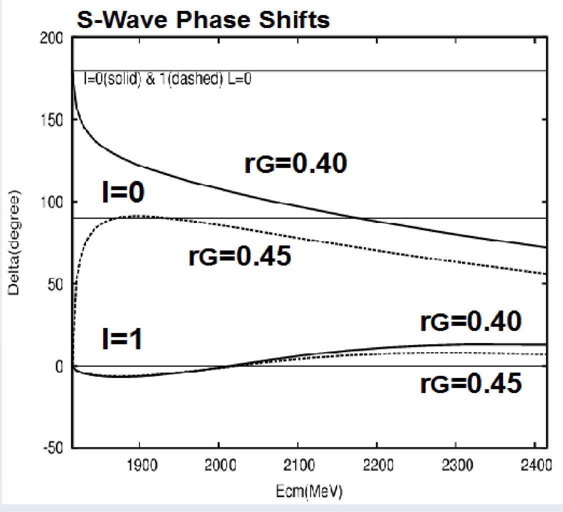
KN scattering lengths

rG	calc 0.40	calc 0.45	exp
S01	−0.008	−0.013	+0.00±0.02
S11	−0.365	−0.369	−0.33±0.02
P01	+0.166	+0.179	+0.08±0.02
P11	−0.106	−0.103	−0.16±0.02
P03	−0.058	−0.071	−0.13±0.02
P13	+0.047	+0.040	+0.07±0.02

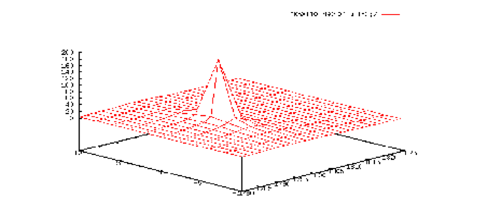
fm**(2L+1)

S=-3 and I=0	S=-3 and I=1
K^{bar} Ξ (1815)	K^{bar} Ξ (1815)

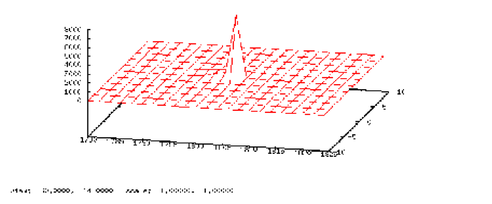
S-Wave Phase Shifts



Isospin=0 state

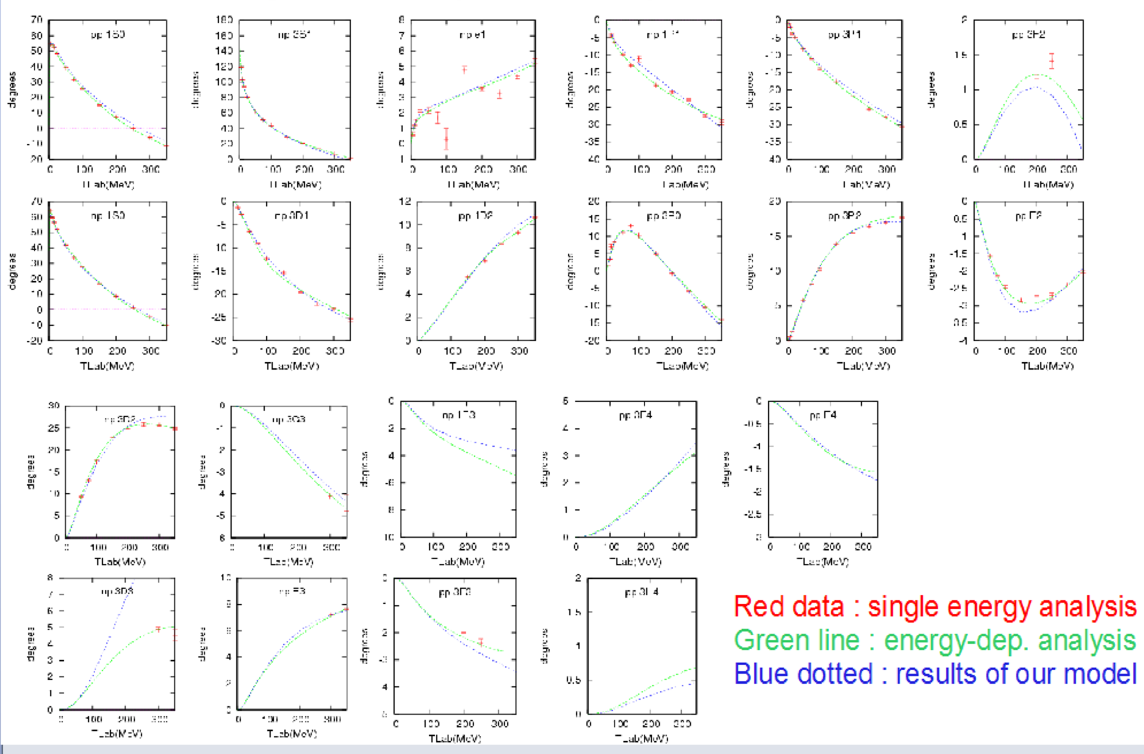


Bound state pole(Im(q)>0) for rG=0.40 at **E=1796MeV(BE=19MeV)**



Virtual state pole(Im(q)<0) for rG=0.45 at **E=1802MeV("BE"=13MeV)**

We obtain a good description of NN phase shifts



Red data : single energy analysis
Green line : energy-dep. analysis
Blue dotted : results of our model

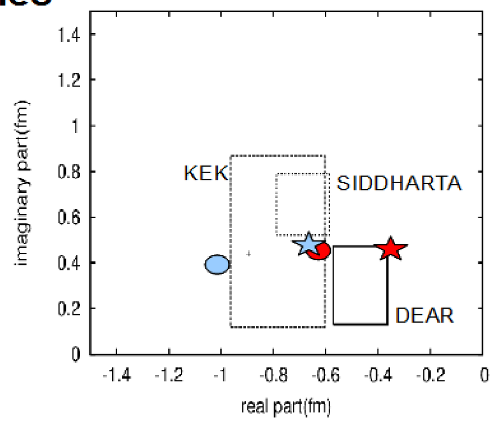
Results for K^{bar} N scattering quantities

K^-p threshold data:

rG	calc 0.40	calc 0.45	exp
γ	2.35	2.36	2.36±0.04
R_C	0.660	0.700	0.664±0.011
R_n	0.189	0.172	0.189±0.015
Re(a)	-0.666	-1.019	figure
Im(a)	0.462	0.398	figure
	☆	○ (blue)	(fm)

If Isospin-symmetric masses are used

Re(a)	-0.354	-0.639
Im(a)	0.453	0.440
	★ (red)	● (red)



a(K-p) ≠ (a(I=0) + a(I=1))/2 (not so simple!)

New parameters are only two!

	{27}	{10*}	{10}	{8-1}+5/9 {8-2}	{8-2}	{1}
πN	○	○	○	○	—	—
KN	○	○	—	—	—	—
$K^{bar}N$	○	○	○	○	●	●

The origin of the K^{bar}-Baryon Attractions in S-states

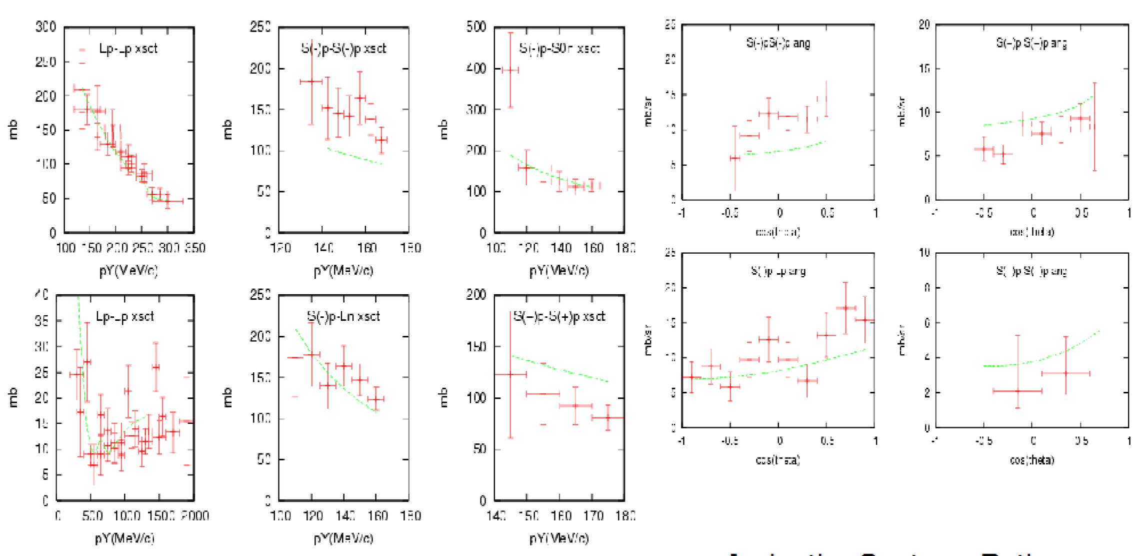
= Isospin-dependent ρ-contribution + large attractive ω contribution

On-shell Potential Values(V/4pi) at 50MeV above each K^{bar}-Baryon threshold

K^{bar}-B	Isospin	ρ	ω	φ	scalar	Baryon	Short	Total	
$K^{bar}N$	0	-42.4	-91.7	20	-25.0	22.4	-44.9	-161.5	Λ*(1405)
$K^{bar}N$	1	14.1	-91.7	20	-25.3	156.5	11.5	85.2	
$K^{bar}Λ$	1/2	0	-84.7	49.6	-28.7	6.5	-12.1	-69.4	} Ξ*(1510)
$K^{bar}Σ$	1/2	-78.4	-87.5	55.9	-27.1	30.7	18.5	-87.9	
$K^{bar}Σ$	3/2	39.2	-87.5	55.9	-30.0	0	-2.2	-24.6	
$K^{bar}Ξ$	0	-69.4	-70.3	90.7	-28.7	14.2	7.1	-56.4	Ω*(1796)
$K^{bar}Ξ$	1	23.1	-70.3	90.7	-32.7	5.2	14.2	30.4	

Scalar mesons provide almost constant attraction (~-30MeV)

We obtain a reasonable description of YN scattering data

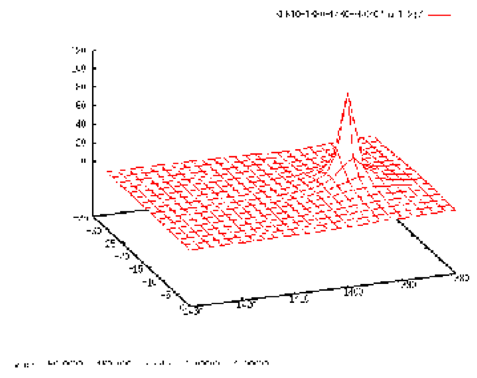


Inelastic Capture Ratio rc

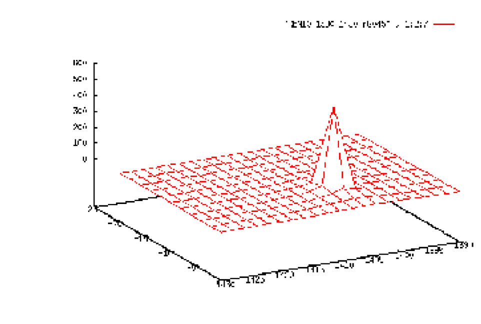
$$rc = \frac{\sigma(\Sigma^-p \to \Sigma^0 n)}{\sigma(\Sigma^-p \to \Sigma^0 n) + \sigma(\Sigma^-p \to \Lambda n)}$$

calc	exp
0.465	0.33±0.05(1958)
	0.474±0.016(1968),
	0.465±0.011(1970)

Our potentials provide Λ(1405) resonance as a single resonance



√s=1393-16i (M=1393MeV, Γ=32MeV) for potential I (rG=0.40 fm)



√s=1406-6i (M=1406MeV, Γ=12MeV) for potential II (rG=0.45 fm)

Attractive Kπ, K^{bar}K interactions and resonances

Our model of Meson-meson Interaction → Parallel Session :
Friday 08 Hadron Interaction(09:00-10:30)
A Talk by Ngo Thi Hong Xiem

Kπ-Kη(I=1/2,Jp=0+)		two poles
	κ	√s=650-200i
		√s=(1410-1420)-(17-23)i
Kπ-Kη(I=1/2,jp=1-)		one pole
	K*	√s=(905-910)-(18-20)i
ππ-K^{bar}K-ηη(I=0,Jp=0+)		two poles
	σ	√s=(360-410)-(510-540)i
	f_0	√s=(925-975)-(36-60)i

The origin of attractions
* vector-meson- (ρ−, ω−, K*−, φ−) exchange

Property of our BB potential : Single particle potentials in symmetric nuclear matter at normal density (kF=1.36 (1/fm))

Baryon	proton-part	neutron-part	total	0.8×
p	-24.7	-44.8	-69.4	-55.5
n	-44.8	-24.7	-69.4	-55.5
Λ	-18.3	-17.9	-36.3	-29.0
Σ+	33.7	4.5	38.3	30.6
Σ-	3.4	31.8	35.1	28.1
Σ0	18.7	19.1	37.9	30.3
Ξ0	18.2	3.4	21.5	17.2
Ξ-	2.8	17.8	20.5	16.4

(MeV)

For all of Σ+,Σ-,Σ0,Ξ0,Ξ-,
Repulsive interaction with nuclear matter (both proton part and neutron part)
(Especially, Σ-, Ξ- interact very repulsively with neutron matter)

We constructed a potential model describing simultaneously Baryon-Baryon and Meson-BaryonScattering.
Based on SU(3)-symmetry and
One-hadron-exchange mechanism

NN, YN, YY, πN, KN, $K^{bar}N$ interactions at low energies,

We extend the potential to

S=-2 $\pi\Xi$–$K^{bar}\Lambda$–$K^{bar}\Sigma$–$\eta\Xi$
S=-3 $K^{bar}\Xi$

and discuss **existence of S-wave resonances**

Summary

(1) We constructed **a potential model which describes consistently NN, YN, YY, πN, KN $K^{bar}N$ scattering.**
One-hadron-exchange mechanisms with
the SU(3) symmetric coupling constants,
physical hadron masses and
short-range cutoff.
The SU(3)-symmetric short-range potential with
We tried two ranges rG=0.4 and 0.45 fm for mB potentials,
SU(3)-symmetric strengths
(BB:relative strengths by LQCD calculations HAL-QCD)

(2) Using our potentials, we calculated
S=-2 $\pi\Xi$–$K^{bar}\Lambda$–$K^{bar}\Sigma$–$\eta\Xi$ and **S=-3** $K^{bar}\Xi$

(3) We found **an S-wave resonance and a bound or virtual state.**
$\Xi^*(I=1/2, J^\pi=1/2^-)$ at √s=1495-1510MeV with width Γ~150MeV
$\Omega^*(I=0,J^\pi=1/2^-)$ at √s=1789MeV (BE=19MeV) or 1802("BE"=13MeV)

The resuts are still model-dependent. We need a careful refinement:
Full inclusion of Decouplet baryons : Ξ*, Ω^-
Better fit to K^-p cross sections, etc