Multiquark States and the Mixing of Scalar Meson

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Outline

1. Why mixing of scalar meson?
2. The chiral su(3) quark model
3. Results
4. Summary

1.Why mixing of scalar meson?

at quark level

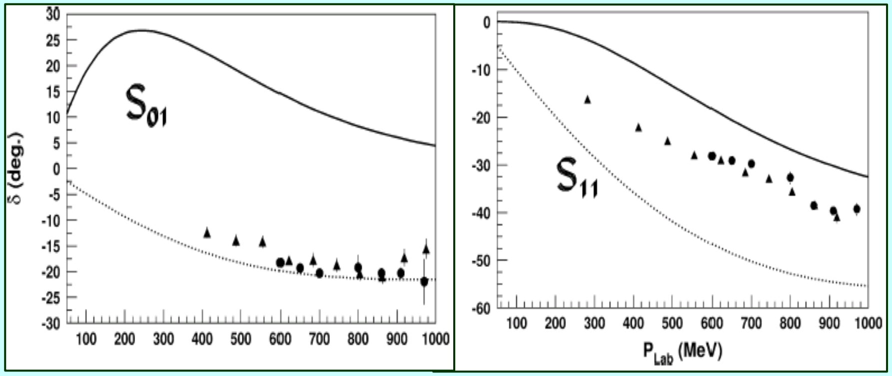
1) S. Lemaire, J. Labarsouque, B. Silvestre-Brac, Nucl. Phys. A 714 (2003) 265

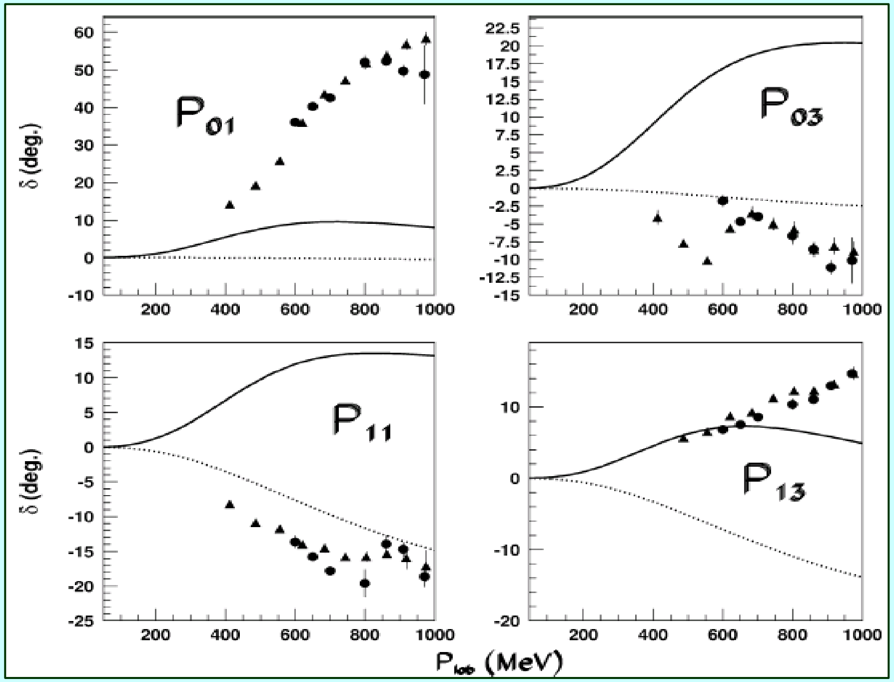
OGE + π + σ + confinement

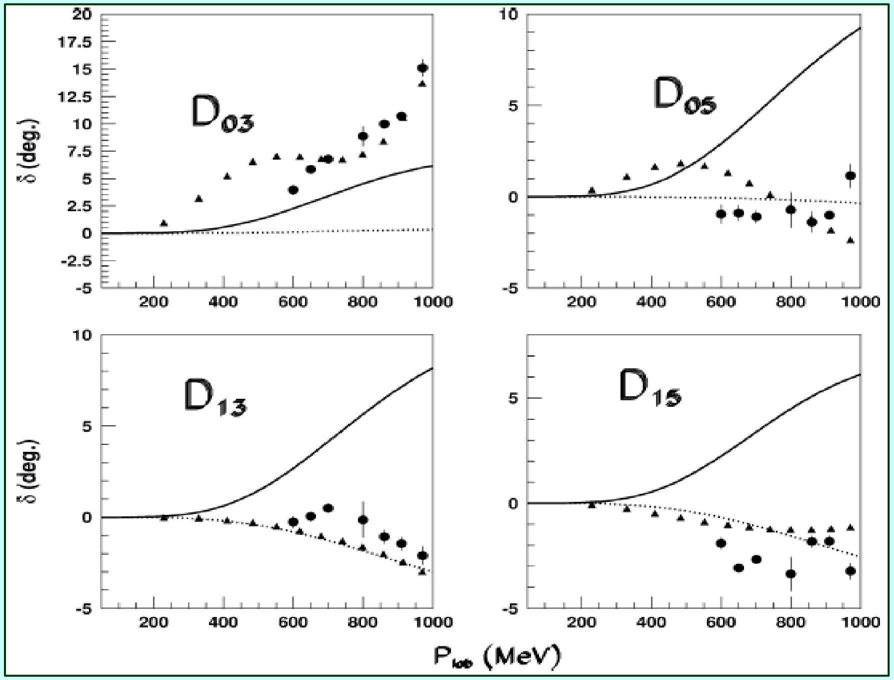
Resonating Group Method (RGM) calculation

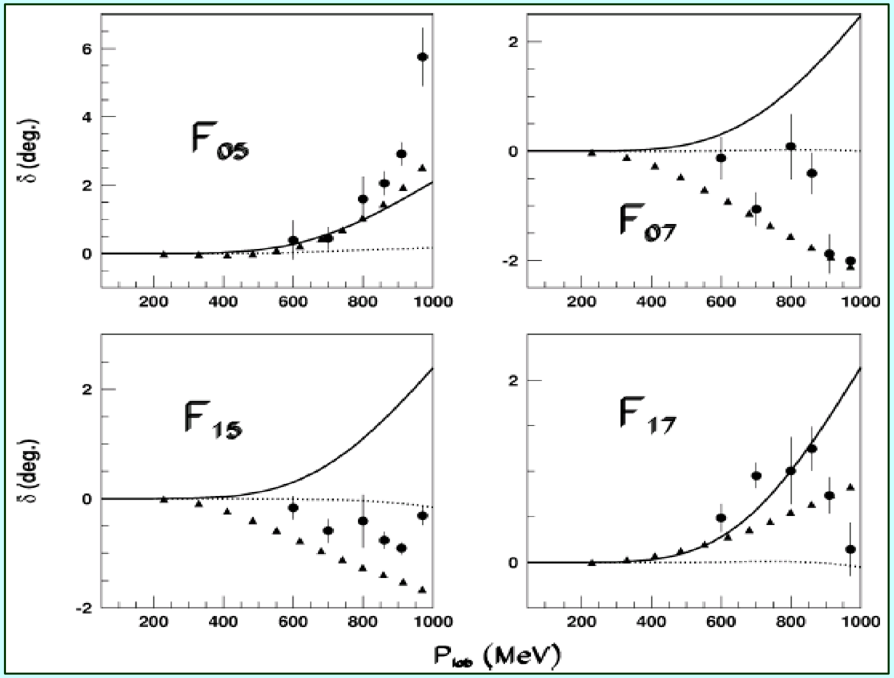
$\Rightarrow$ poor agreement with KN data

S. Lemaire et al, NPA 714 (2003) 265









2) F. Huang, Z. Y. Zhang, Y. W. Yu, Phys.Rev.C70 (2003) 044004

Chiral SU(3) quark model

RGM calculation

⇒ reasonable agreement

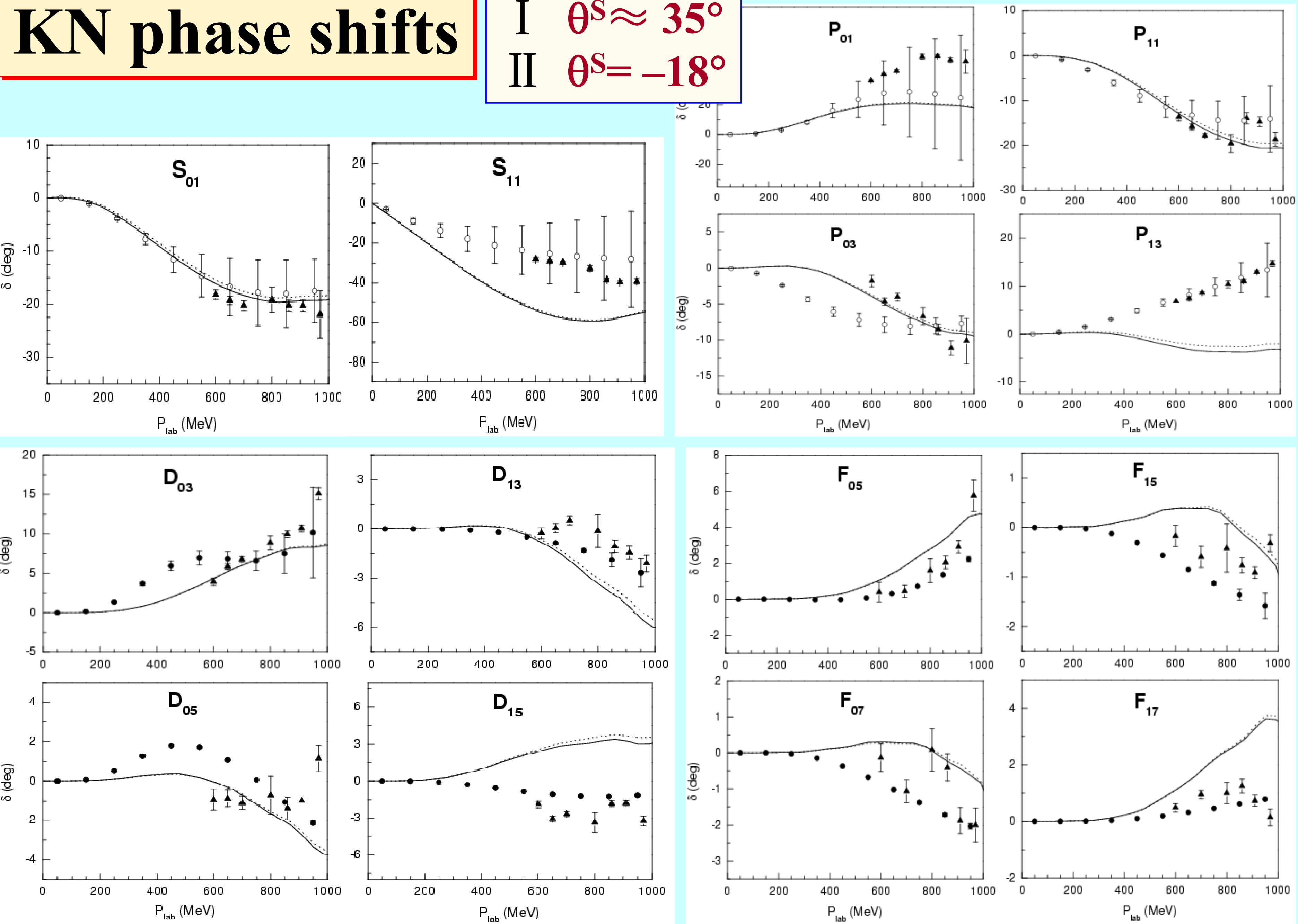
$$\begin{cases} \sigma = \sigma_8 \sin\theta^S + \sigma_0 \cos\theta^S \\ \epsilon = \sigma_8 \cos\theta^S - \sigma_0 \sin\theta^S \end{cases}$$

⇒The mixing of scalar meson σ_0 and σ_8 is needed to describe KN

KN phase shifts

I $\theta^S \approx 35°$

II $\theta^S = -18°$



Already **Prediction of Dibaryons**

in chiral su(3) quark model

1. **Phys . Rev. C60 (1999) 045203** $(\Delta\Delta)_{ST=30}$ (CC)
2. Phys . Rev. C61 (2000) 065204 $(\Omega\Omega)_{ST=00}$
3. **Phys . Rev. C62 (2000) 028202** $(\Xi^*\Omega)_{ST=0\frac{1}{2}}$,
4. Eur. Phys. J. A8(2000)417;

   Nucl. Phys . A683 (2001) 487

$(\Sigma^*\Delta)_{ST=3\frac{1}{2}}$ $(\Sigma^*\Delta)_{ST=0\frac{5}{2}}$, $(\Delta\Delta)_{ST=03}$ $(N\Omega)_{ST=2\frac{1}{2}}$, $(\Delta\Omega)_{ST=3\frac{3}{2}}$,

However, the mixing of scalar meson still not discussed !

2.The chiral SU(3) quark model

The NPQCD effect is very important for the light quark system. But up to now, there is no effective approach to solve the NPQCD problem seriously. We still need QCD inspired model to help.

In the framework of the constituent quark model, to understand the source of the constituent quark mass, the spontaneous vacuum breaking has to be considered, and as a consequence, the coupling between quark field and goldstone boson is introduced to restore the chiral symmetry.

The chiral SU(3) quark model can be regarded as a quite reasonable and useful model to describe the medium range NPQCD effect.

In the chiral SU(3) quark model, the coupling between chiral field and quark is introduced to describe low momentum medium range NPQCD effect. The interacting Lagrangian L_I can be written as:

$$L_I = -g_{ch}\bar{\psi}\left(\sum_{a=0}^{8}\sigma_a\lambda_a + i\sum_{a=0}^{8}\pi_a\lambda_a\gamma_5\right)\psi \, .$$

$\sigma, \sigma', \chi, \varepsilon$ $\qquad$ π, K, η, η'

scalar nonet fields $\qquad$ **pseudo-scalar nonet fields**

It is easy to prove that L_I is invariant $SU(3)_L \times SU(3)_R$ under the infinitesimal chiral transformation.

In chiral SU(3) quark model, we still employ an effective OGE interaction to govern the short range behavior, and a confinement potential to provide the NPQCD effect in the long distance.

Hamiltonian of the system:

$$H = \sum_i t_i - T_G + \sum_{i<j} V_{ij} \quad ,$$

$$V_{ij} = V_{ij}^{conf} + V_{ij}^{oge} + V_{ij}^{ch} \quad ,$$

$$V_{ij}^{ch} = \sum_a (V_{ij}^{s(a)} + V_{ij}^{ps(a)}) \quad .$$

The expressions of $\mathbf{V_{ij}^{s}}$ and $\mathbf{V_{ij}^{ps}}$:

$$\mathbf{V_{ij}^{s(a)}} = -\frac{\mathbf{g_{ch}^2}}{\mathbf{4\pi}} C(g_{ch}, m_{ps(a)}, \Lambda) X_1(m_{s(a)}, \Lambda, r_{ij}) \lambda_a(i) \lambda_a(j)$$

$$+\vec{l}\cdot\vec{s} \quad \text{term},$$

$$\mathbf{V_{ij}^{ps(a)}} = \frac{\mathbf{g_{ch}^2}}{\mathbf{4\pi}} C(g_{ch}, m_{ps(a)}, \Lambda) \frac{m_{ps(a)}^2}{12 m_{qi} m_{qj}} X_2(m_{ps(a)}, \Lambda, r_{ij})$$

$$(\vec{\sigma}_i \cdot \vec{\sigma}_j) \lambda_a(i) \lambda_a(j) + \text{tensor term}$$

Here we have only one coupling constant $\mathbf{g_{ch}}$

more detail in Nucl. Phys. A625 (1997) 59

• Parameters:

(1). Input part: **taken to be the usual values.**

$$\mathbf{b_u = 0.5fm, \quad m_u = 313MeV, \quad m_s = 470MeV.}$$

(2). Chiral field part:

$$\frac{g_{ch}^2}{4\pi} = \frac{9}{25}\frac{m_u^2}{M_N^2}\frac{g_{NN\pi}^2}{4\pi}, \qquad g_{ch} = 2.63$$

m_σ **and** θ^s **are adjustable.**

$m_\pi, m_\eta, m_{\eta'}, m_K$ **are taken to be experimental values,**

$m_{\sigma'} = m_\varepsilon = 980$ MeV, $m_\kappa = 1430$ MeV

(3). OGE and confinement part:

g_u **and** g_s **are fixed by** $M_\Delta - M_N$ **and** $M_\Sigma - M_\Lambda$.

$a_{cuu}, \cdots$ **are determined by the stability condition of** N, Λ, Ξ.

About the mixing of σ_0 and σ_8

$$\begin{cases} \sigma = \sigma_8 \sin\theta^S + \sigma_0 \cos\theta^S \\ \epsilon = \sigma_8 \cos\theta^S - \sigma_0 \sin\theta^S \end{cases}$$

The mass of σ meson m_σ is decided by fitting the deuteron experimental data

Model parameters

	θ^S	m_σ
set I	$0°$	595 MeV
set II	$35°$	560 MeV

Binding energy of deuteron:

	$B_{deuteon}$
set I	2.13 MeV
set II	2.10 MeV

3.Results

- **RGM calculation**

- The antisymmetrization operator:

$$A = (1 - \sum_{i \in A, j \in B} P_{ij})(1 - P_{AB})$$

$P_{ij} = P_{ij}^{r} P_{ij}^{\sigma f c}$ **is the permutation operator of quark i and j, and** P_{AB} **of baryon A and B. When two cluster is closed together and L=0,** $< P_{ij}^{r} > \approx 1$.

Thus $< P_{ij}^{\sigma f c} >$ **is very important to measure the quark exchange effect for various spin-flavor states.**

$$\left(1-\sum_{i\in A,j\in B}\langle P_{ij}^{\sigma fc}\rangle\right)\approx 1,$$

the quark exchange effect is not important,

$$\left(1-\sum_{i\in A,j\in B}\langle P_{ij}^{\sigma fc}\rangle\right)\approx 0,$$

the Pauli Block Effect is very serious,

$$\left(1-\sum_{i\in A,j\in B}\langle P_{ij}^{\sigma fc}\rangle\right)\approx 2,$$

the quark exchange effect makes two baryon cluster closer

In all of two baryon systems, only 6 of them belong to this interesting case, they are:

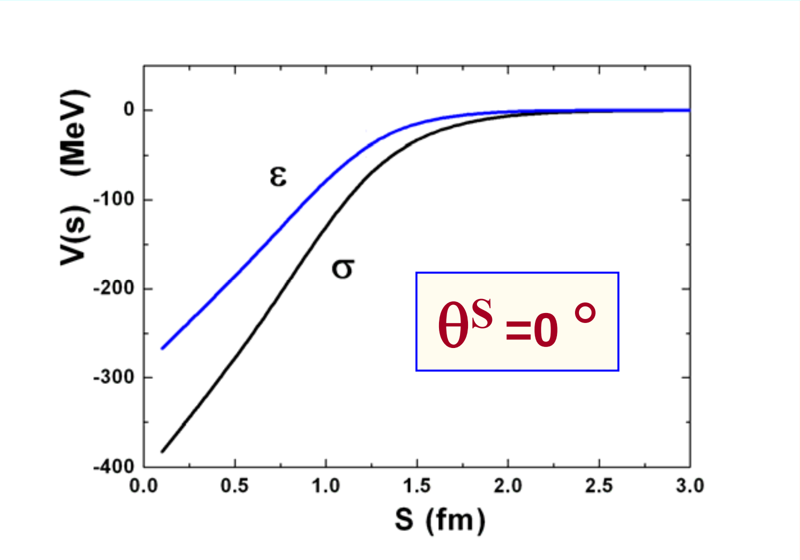
$$(\Omega\Omega)_{ST=00} \quad (\Xi^*\Omega)_{ST=0\frac{1}{2}}, \quad (\Delta\Delta)_{ST=30}, \quad (\Delta\Delta)_{ST=03},$$

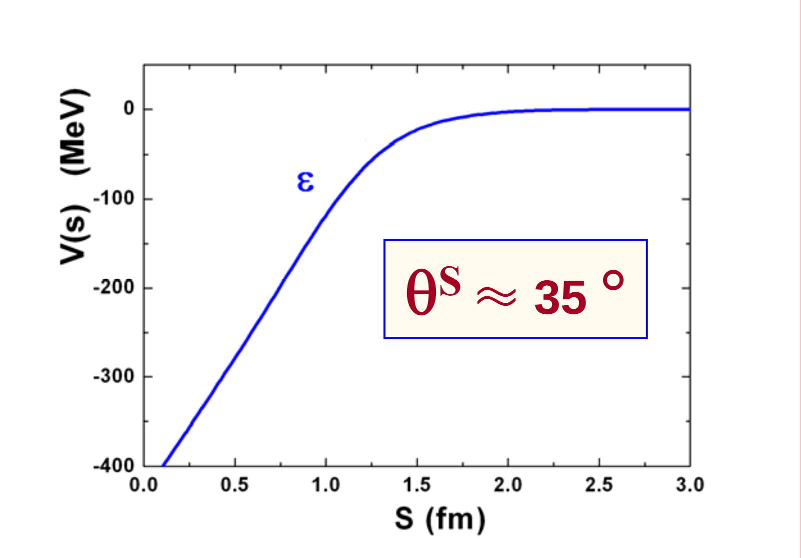
.

$$(\Sigma^*\Delta)_{ST=0\frac{5}{2}}, \quad (\Sigma^*\Delta)_{ST=3\frac{1}{2}},$$

Results - ΩΩ (ST=00)

Strangeness -6





GCM matrix elements

Binding energy:

$$B_{\Omega\Omega} = 2M_{\Omega} - M_{\Omega\Omega}$$

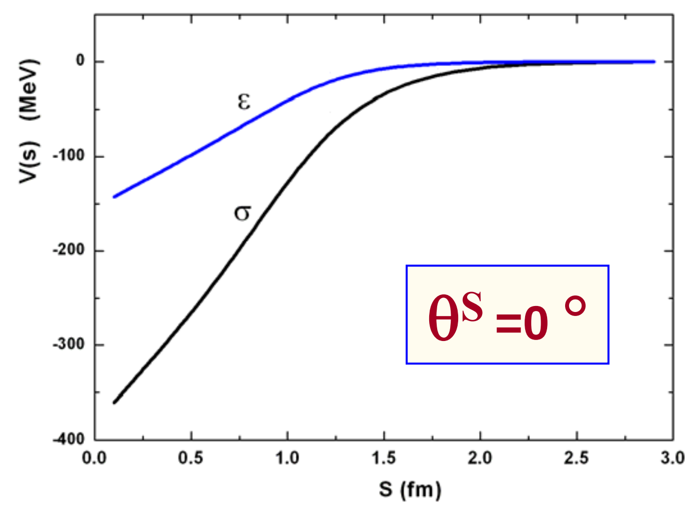
	θ^S	$B_{\Omega\Omega}$ (MeV)	contribution
I	0	171	$\sigma + \epsilon$
II	35.3	61	ϵ

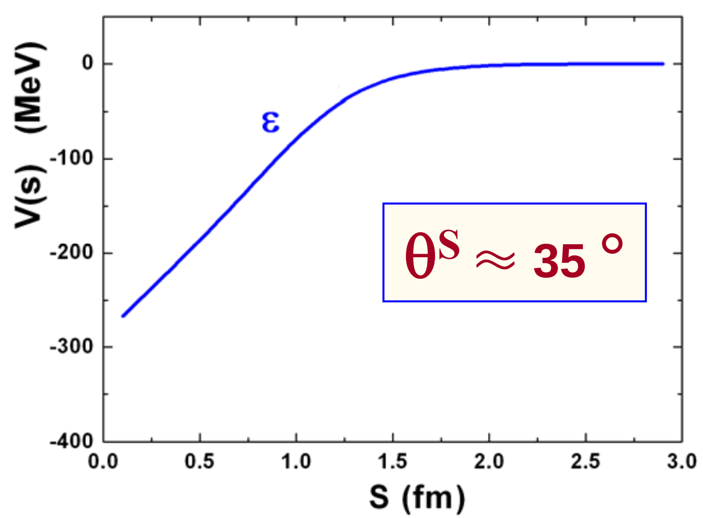
Why a bound state?

- **the quark exchange effect makes two baryon cluster closer**
- **when no mixing, it is a deeply bound state.**
- **ideally mixing, i.e. there is no σ meson exchange between s quarks, the binding energy is still large.**

Results - $\Xi^*\Omega \quad (ST = 0\frac{1}{2})$

Strangeness -5





Binding energy:

$$B_{\Xi^*\Omega} = M_{\Xi^*} + M_\Omega - M_{\Xi^*\Omega}$$

	θ^S	$B_{\Xi^*\Omega}$ (MeV)	contribution
I	0	117	$\sigma + \epsilon$
II	35.3	31	ϵ

Why a bound state?

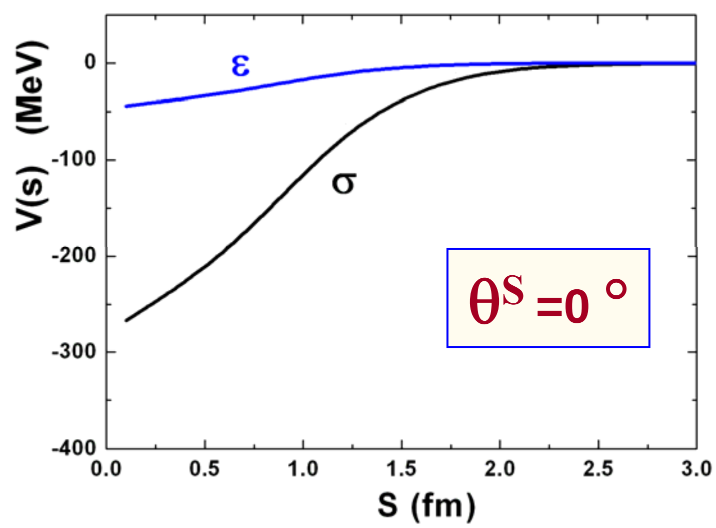
similar results as $\Omega\Omega$ dibaryon

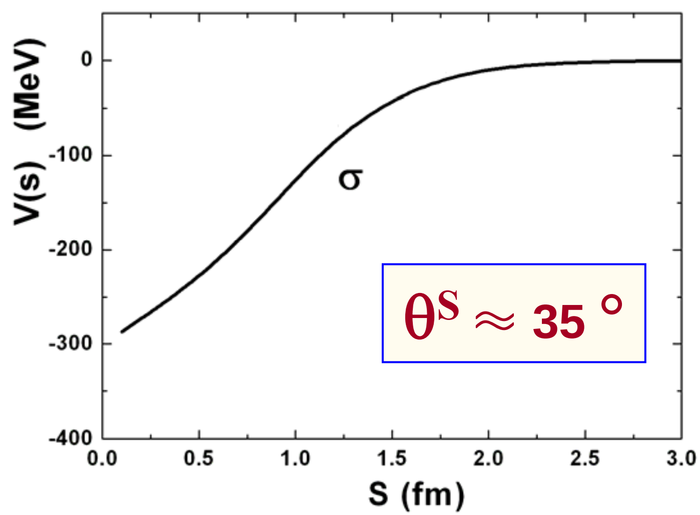
- the quark exchange effect makes two baryon cluster closer
- when no mixing, it is a deeply bound state.
- ideally mixing, still bound state.

GCM matrix elements

Results - $\Delta\Delta$ (ST=03)

nonstrangeness





Binding energy:

$$B_{\Delta\Delta} = 2M_{\Delta} - M_{\Delta\Delta}$$

	θ^S	$B_{\Delta\Delta}$ (MeV)	contribution
I	0	22.3	σ, ϵ
II	35.3	21.7	σ

binding energy is stable !

- **the quark exchange effect is important**
- **σ meson exchange dominately provide attractive force**
- **no matter what kind of mixing, it is a bound state.**

GCM matrix elements

Results - $\Delta\Delta$ (ST=30)

nonstrangeness

$$B_{\Delta\Delta} = 2M_{\Delta} - M_{\Delta\Delta}$$

Binding energy $B_{\Delta\Delta}$(MeV)

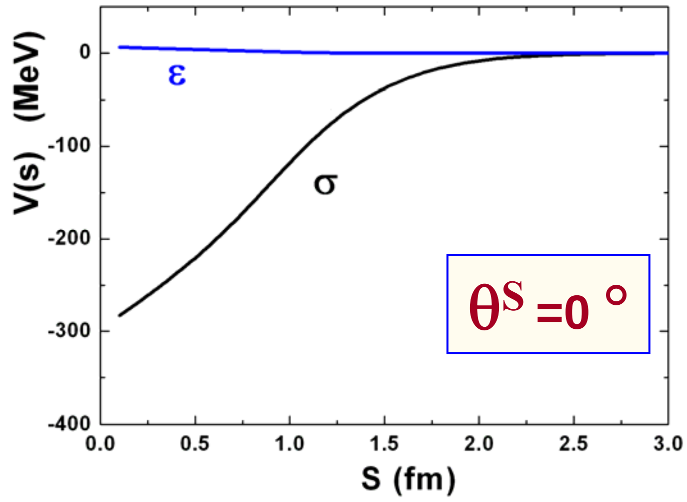
	$\Delta\Delta(L=0)$	$\Delta\Delta\begin{pmatrix} L=0 \\ +2 \end{pmatrix}$	$\begin{matrix}\Delta\Delta \\ CC\end{matrix}(L=0)$	$\begin{matrix}\Delta\Delta \\ CC\end{matrix}\begin{pmatrix} L=0 \\ +2 \end{pmatrix}$
set I	23	29	40	48
set II	21	27	37	45

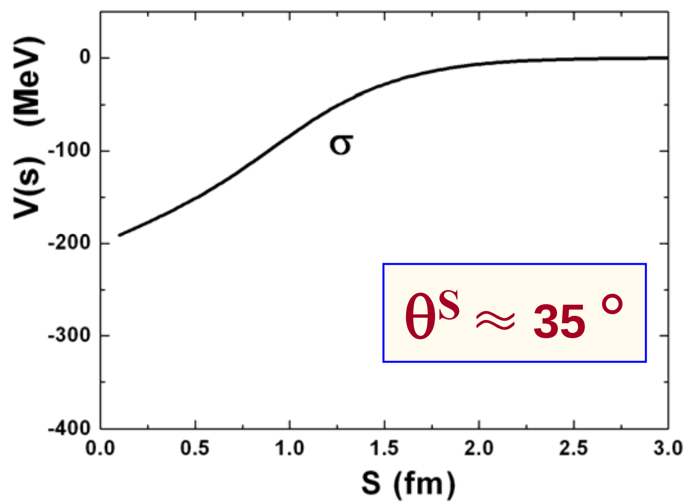
binding energy is stable !

- the quark exchange effect is important.
- σ meson exchange dominantly provide attractive force.
- tensor force provide some attraction.
- hidden color channel provide relatively larger attraction.
- no matter what kind of mixing, it is a stable bound state.

Results - $\Sigma^*\Delta \quad (ST = 0\frac{5}{2})$

Strangeness -1





GCM matrix elements

Binding energy:

$$B_{\Sigma^*\Delta} = M_{\Sigma^*} + M_{\Delta} - M_{\Sigma^*\Delta}$$

	θ^S	$B_{\Sigma^*\Delta}$ (MeV)	contribution
I	0	27.3	σ, ϵ
II	35.3	15.7	σ

It is a bound state

- **the quark exchange effect is important**
- **σ meson exchange dominantly provide attractive force**
- **no matter what kind of mixing, it is a bound state.**

Results - $\Sigma^*\Delta$ $(ST = 3\frac{1}{2})$

Strangeness -1

$$B_{\Sigma^*\Delta} = M_{\Sigma^*} + M_{\Delta} - M_{\Sigma^*\Delta}$$

Binding energy $B_{\Sigma^*\Delta}$(MeV)

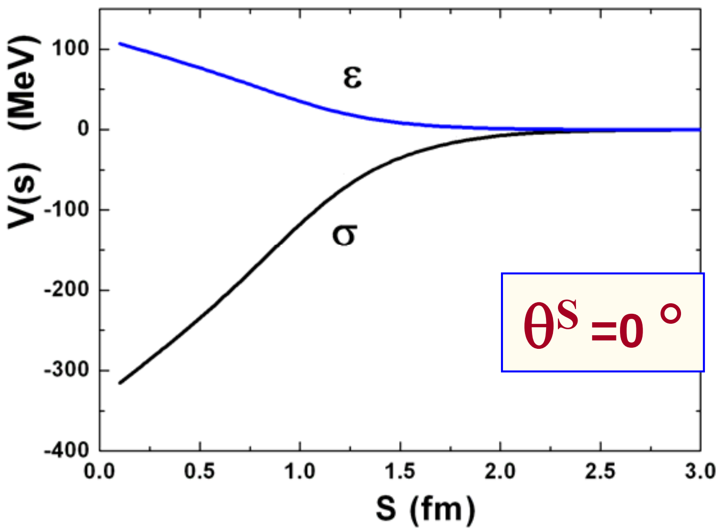
	θ^S	L=0	L=0+2
I	0	34.2	37.8
II	35.3	16.5	20.0

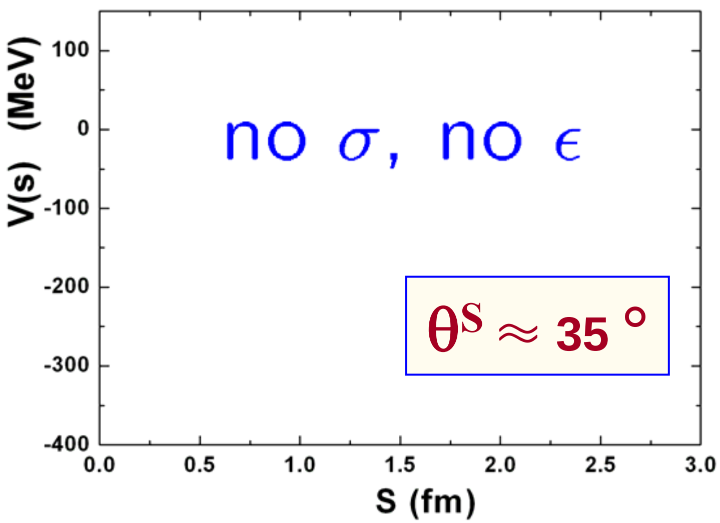
It is a bound state

- **the quark exchange effect is important**
- **σ meson exchange dominantly provide attractive force**
- **tensor interaction provides some attraction**
- **no matter what kind of mixing, it is a bound state.**

Results - $N\Omega \quad (ST = 2\frac{1}{2})$

Strangeness -3





GCM matrix elements

Binding energy:

$$B_{N\Omega} = M_N + M_\Omega - M_{N\Omega}$$

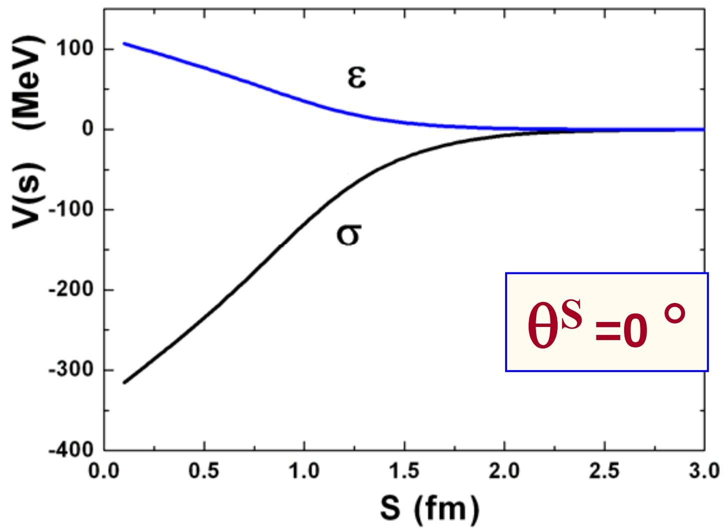
	θ^S	$B_{N\Omega}$ (MeV)	contribution
I	0	4.7	σ, ϵ
II	35.3	unbound	no ϵ, no σ

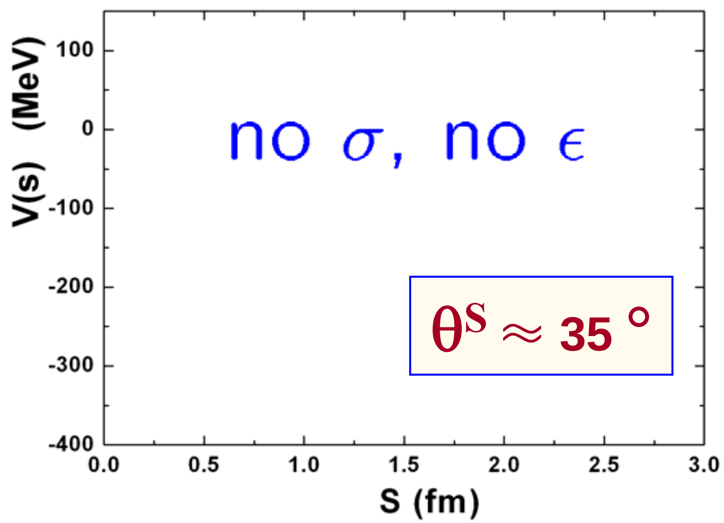
Why becomes unbound ?

- **the quark exchange effect is not important**
- **when no mixing, it is a weakly bound state.**
- **ideally mixing, it becomes unbound..**

Results - $\Delta\Omega$ $(ST = 3\frac{3}{2})$

Strangeness -3





GCM matrix elements

Binding energy:

$$B_{\Delta\Omega} = M_\Delta + M_\Omega - M_{\Delta\Omega}$$

	θ^S	$B_{\Delta\Omega}$ (MeV)	contribution
I	0	3.1	$\sigma + \epsilon$
II	35.3	unbound	no ϵ, no σ

Why becomes unbound ?

- **the quark exchange effect is not important**
- **when no mixing, it is a weakly bound state.**
- **ideally mixing, it becomes unbound..**

State	$(1-\sum_{ij}<P_{ij}^{\sigma fc}>)$	B(MeV) $\theta^S=0°$	B(MeV) $\theta^S \approx 35°$
$(\Omega\Omega)_{ST=00}$	2	171	61
$(\Xi^*\Omega)_{ST=0\frac{1}{2}}$	2	117	31
$(\Sigma^*\Delta)_{ST=3\frac{1}{2}}$	2	27	16
$(\Sigma^*\Delta)_{ST=0\frac{5}{2}}$	2	38	20
$(\Delta\Delta)_{ST=03}$	2	22	22
$(\Delta\Delta)_{ST=30}$	2	48	45
$(N\Omega)_{ST=2\frac{1}{2}}$	1	4.7	unbound
$(\Delta\Omega)_{ST=3\frac{3}{2}}$	1	3.1	unbound

For $\theta^S=-18°$, we have **PRELIMINARY** results! not shown here!

Summary:

1. The binding energy of deuteron can be produced very well with and without mixing of scalar meson.

2. using the same parameters, we studied some interesting dibaryons:

1) For strangeness -6 $(\Omega\Omega)_{ST=00}$, the quark exchange effect is very important make it deeply bound state. For ideally mixing, i.e. there is no σ_0 meson exchange between two s quarks, the binding energy is still relatively larger. Similar result for strangeness -5 $(\Xi^*\Omega)_{ST=0\frac{1}{2}}$ dibaryon.

2) For nonstrangeness $(\Delta\Delta)_{ST=03}$ and $(\Delta\Delta)_{ST=30}$ dibaryon, no matter what kind of mixing is taken, they are bound states and the binding energy is very stable.

3) For strangeness -1 $(\Sigma^{*}\Delta)_{ST=0\frac{5}{2}}$ and $(\Sigma^{*}\Delta)_{ST=3\frac{1}{2}}$ dibaryons, no matter what kind of mixing is taken, they are still bound states .

4) For strangeness -3 $(N\Omega)_{ST=2\frac{1}{2}}$ and $(\Delta\Omega)_{ST=3\frac{3}{2}}$ dibaryon , the quark exchange effect is not very important. With no mixing, they are weakly bound states, however, for ideally mixing, they become unbound states.

THANK YOU!