First results of baryon interactions from lattice QCD with phyical masses (2)

--S=-3 and S=-4 sectors(ΞΞ, ΞΣ, ΞΛ-ΞΣ channels)—

Noriyoshi Ishii for HAL QCD Collaboration

Introduction

- Experimental determination of hyperon potentials is the one of the most important topics in J-PARC.

- They are mainly interested in S=-1 and -2 sectors.

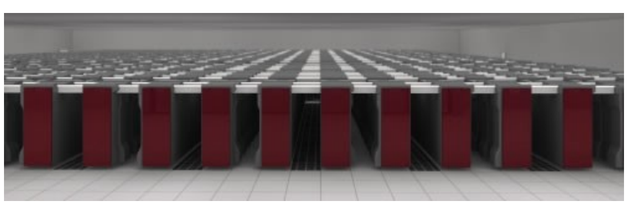
- Experimental determination of hyperon potentials become harder for increasing strange quarks.

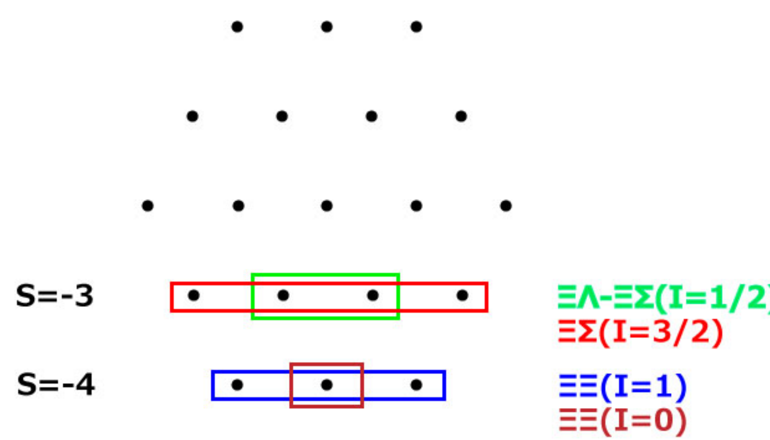
J-PARC

Exploration of multi-strangeness world

- On the lattice, determination of hyperon potentials become easier for increasing number of strange quarks.
(Statistical noise reduces)

- In this talk, we give our preliminary results of hyperon potentials in S=-3 and S=-4 sectors by using the physical point gauge confs. generated by K computer at AICS.

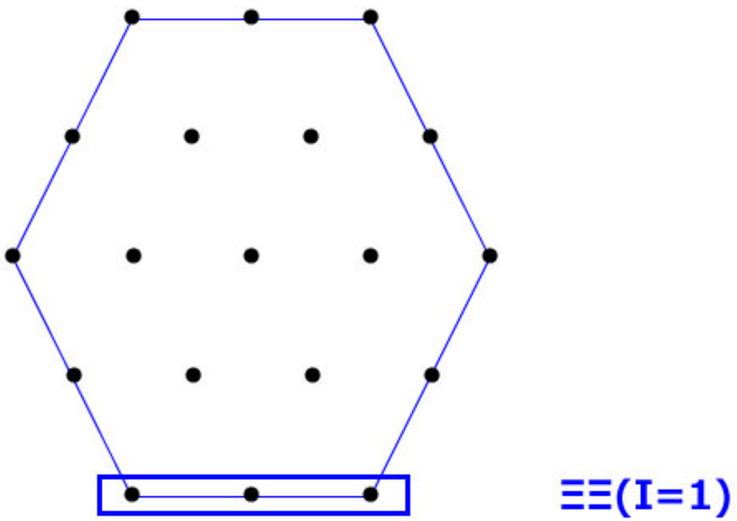




S=-4 sector: ΞΞ(I=0 and I=1) system

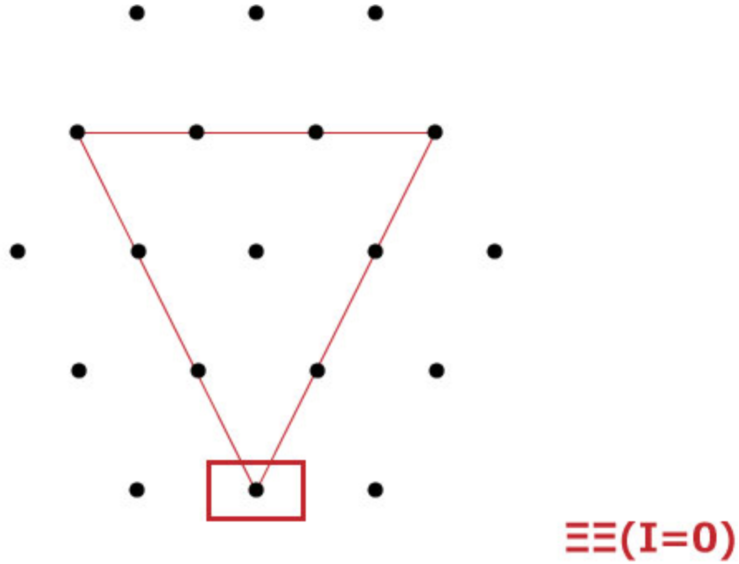
S=-4 sector : ΞΞ(I=0 and I=1)

I=1 sector



- Total spin is singlet
- In flavor SU(3) limit,
  it belongs to irrep. 27.
  (same irrep. as NN)

I=0 sector



- Total spin is triplet
- In flavor SU(3) limit,
  it belongs to irrep. 10.
  (same as ΣN(I=3/2)
  nothing to do with NN)

Time-dependent Schroedinger-like eq for equal-mass system

- We define R-correlator, which is expanded as

$$R(\vec{x}-\vec{y},t) \equiv e^{2mt} \left\langle 0 \middle| T\left[B(\vec{x},t)B(\vec{y},t)\cdot \overline{BB}(t=0) \right] \middle| 0 \right\rangle$$

$$= \sum_n \psi_{k_n}(\vec{x}-\vec{y}) \cdot \exp\left(-(E_n - 2m)t \right) \cdot a_n$$

where

$$\psi_{k_n}(\vec{x}-\vec{y}) \equiv \left\langle 0 \middle| B(\vec{x})B(\vec{y}) \middle| n \right\rangle$$

- Two-particle energy in CM frame satisfies

$$E \equiv 2\sqrt{m^2+k^2} \quad \Rightarrow \quad \frac{k^2}{m} = \frac{1}{4m}(E-2m)^2 + (E-2m)$$

- HAL QCD potential satisfies Schroedinger equation

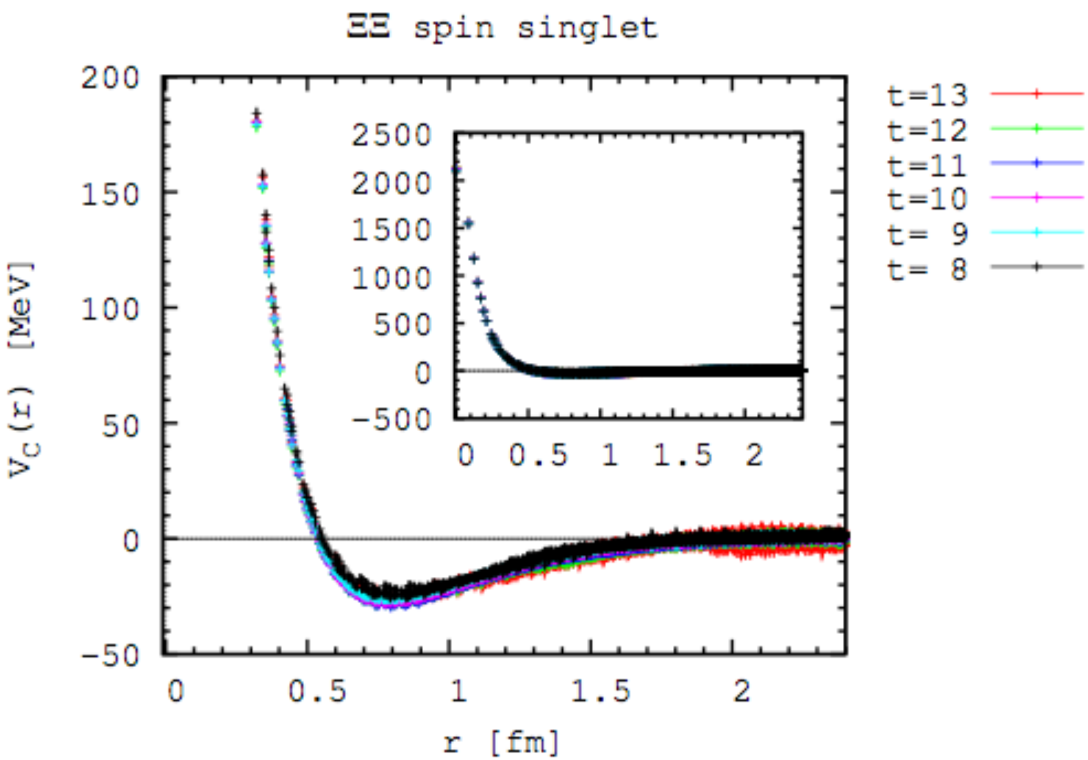
$$\left(\frac{\nabla^2}{m} + \frac{k_n^2}{m} \right) \psi_{k_n}(\vec{r}) = \int d^3r' V(\vec{r},\vec{r}')\, \psi_{k_n}(\vec{r})$$

- R-correlator satisfies **time-dependent Schroedinger-like equation**

$$\left(\frac{\nabla^2}{m} + \frac{1}{4m}\frac{\partial^2}{\partial t^2} - \frac{\partial}{\partial t} \right) R(\vec{r},t) = \int d^3r' V(\vec{r},\vec{r}') R(\vec{r}',t)$$

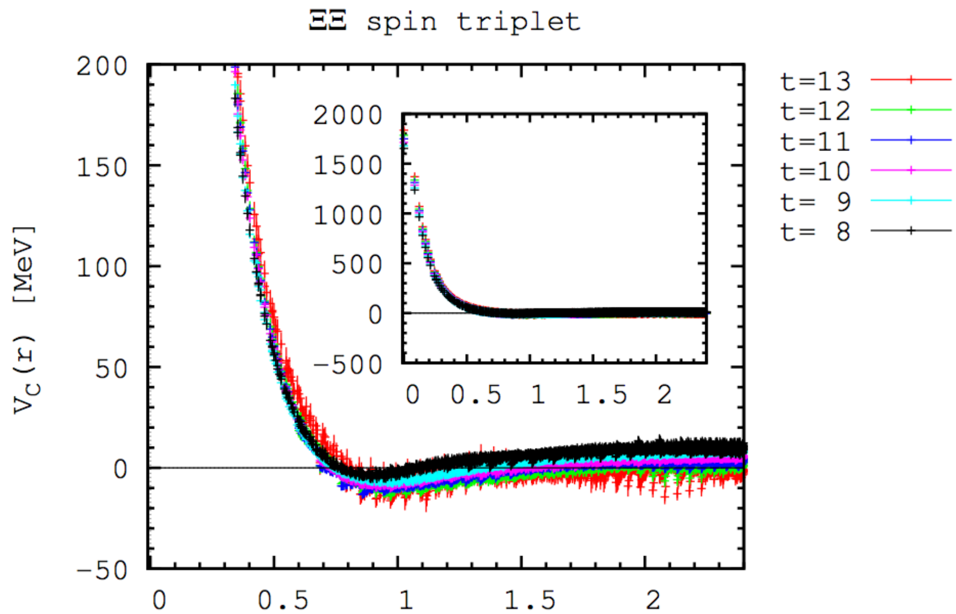
Preliminary results

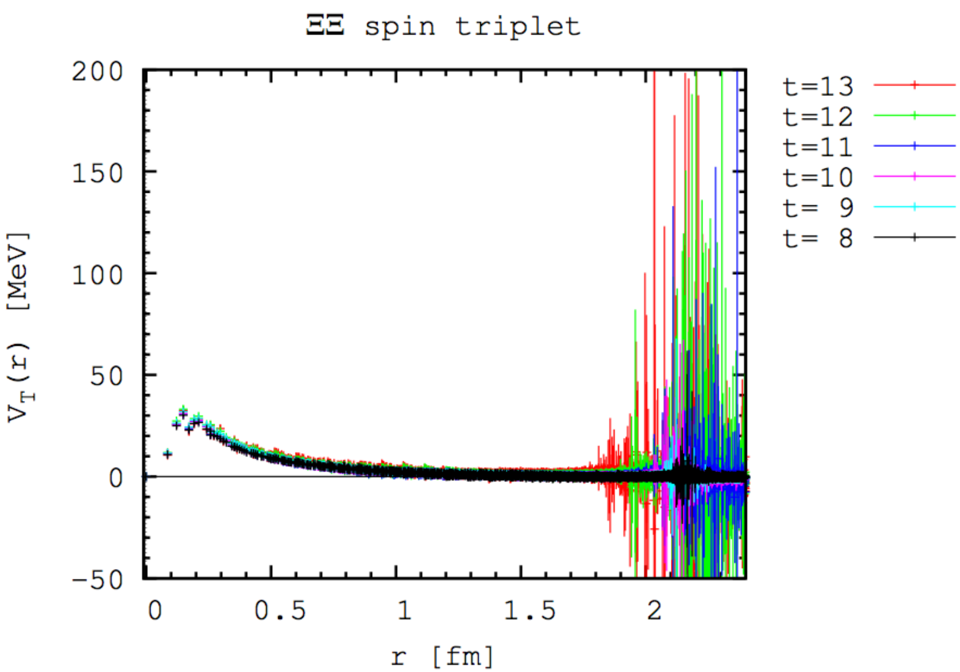
- 1/a ～2300 MeV, L ～8.2 fm
- 200 gauge confs. are used.
- Binsize = 10
- 12 source points * 4 rotations
- Point sink and wall source



- Repulsive core is surrounded by attractive well.
  This is similar to NN potential in spin singlet sector.

Preliminary results





- 1/a ～2300 MeV, L ～8.2 fm
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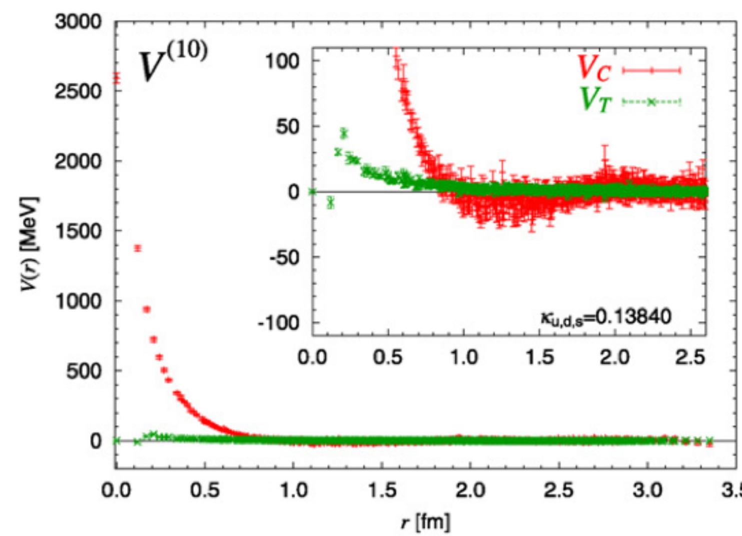
- Qualitative behaviors are similar to irrep. 10 potentials in flavor SU(3) limit.



(T.Inoue et al., NPA881,28(2012))

<u>S=-3 sector: ΞΣ(I=3/2)</u>

S=-3 sector: ΞΣ (I=3/2)

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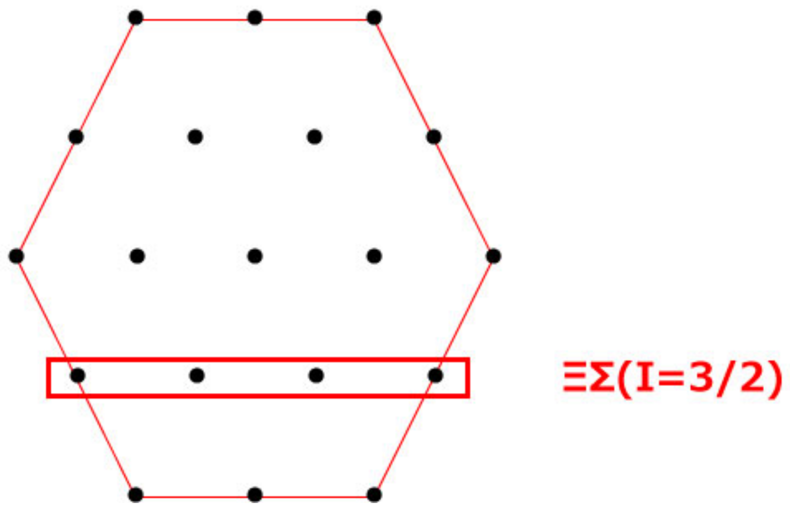
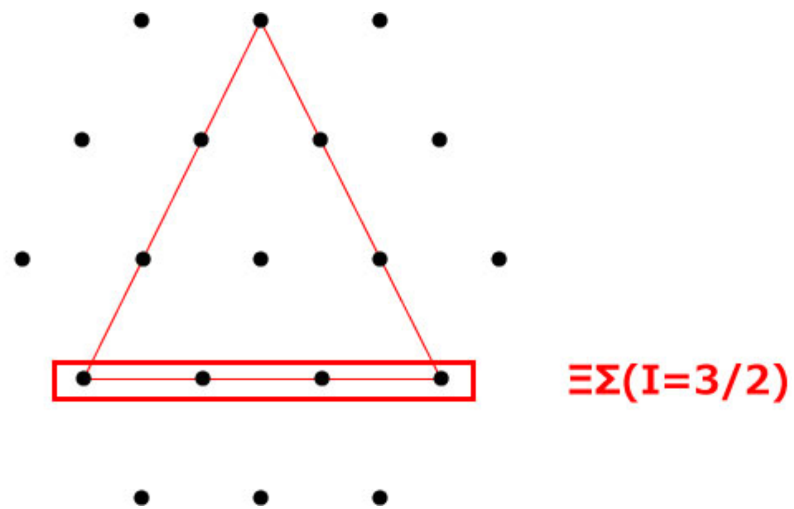


- Total spin triplet
- In flavor SU(3) limit,
  it belongs to irrep. 10*.
  (same as NN)



Time-dependent Schroedinger-like eq for unequal-mass system

- We define R-correlator, which is expanded as

$$R(\vec{x}-\vec{y},t) \equiv e^{(m_1+m_2)t} \left\langle 0 \middle| T\left[B_1(\vec{x},t) B_2(\vec{y},t) \cdot \overline{BB}(t=0) \right] \middle| 0 \right\rangle$$

$$= \sum_n \psi_{k_n}(\vec{x}-\vec{y}) \cdot \exp\left(-(E_n - m_1 - m_2)t\right) \cdot a_n$$

where

$$\psi_{k_n}(\vec{x}-\vec{y}) \equiv \left\langle 0 \middle| B_1(\vec{x}) B_2(\vec{y}) \middle| n \right\rangle$$

- Two-particle energy in CM frame satisfies

$$E \equiv \sqrt{m_1^2 + k^2} + \sqrt{m_2^2 + k^2} \quad \Rightarrow \quad k^2 E^2 = \frac{1}{4}\left(E^2 - (m_1+m_2)^2\right)\left(E^2 - (m_1-m_2)^2\right)$$

- HAL QCD potential satisfies Schroedinger equation

$$\left(\frac{\nabla^2}{2\mu} + \frac{k_n^2}{2\mu} \right) \psi_{k_n}(\vec{r}) = \int d^3r' \, V(\vec{r},\vec{r}') \, \psi_{k_n}(\vec{r}) \qquad \text{where} \qquad \mu \equiv \frac{m_1 m_2}{m_1 + m_2}$$

- R-correlator satisfies **time-dependent Schroedinger-like equation**

$$\left(\frac{\nabla}{2\mu} D_t^2 + \frac{1}{8\mu}\left(D_t^2 - (m_1+m_2)^2\right)\left(D_t^2 - (m_1-m_2)^2\right) \right) R(\vec{r},t) = \int d^3r' V(\vec{r},\vec{r}') D_t^2 R(\vec{r}',t)$$

$$D_t \equiv \partial_t - m_1 - m_2$$

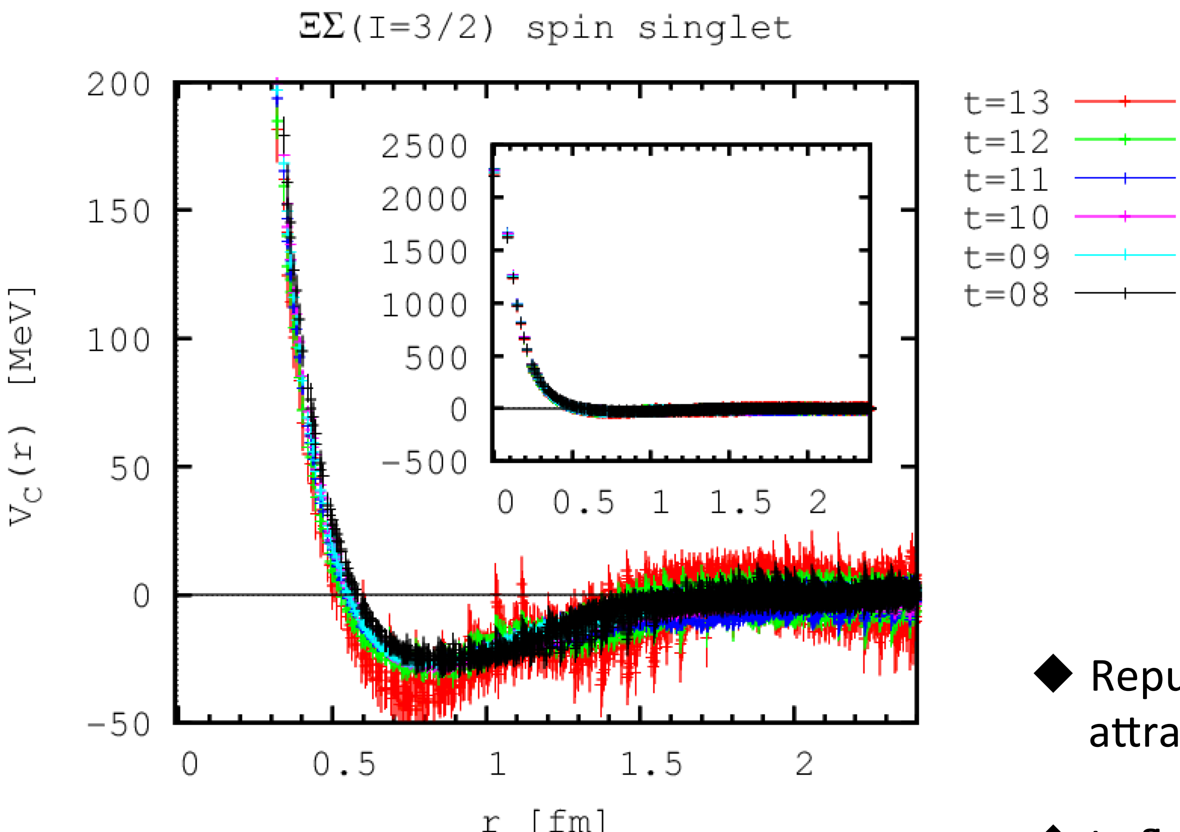
However

In this talk,
due to time limit,
we use a non-relativistically approximated version:

$$\left(\frac{\nabla^2}{2\mu} - \frac{\partial}{\partial t} \right) R(\vec{r}, t) \simeq \int d^3 r' V(\vec{r}, \vec{r}') R(\vec{r}', t)$$

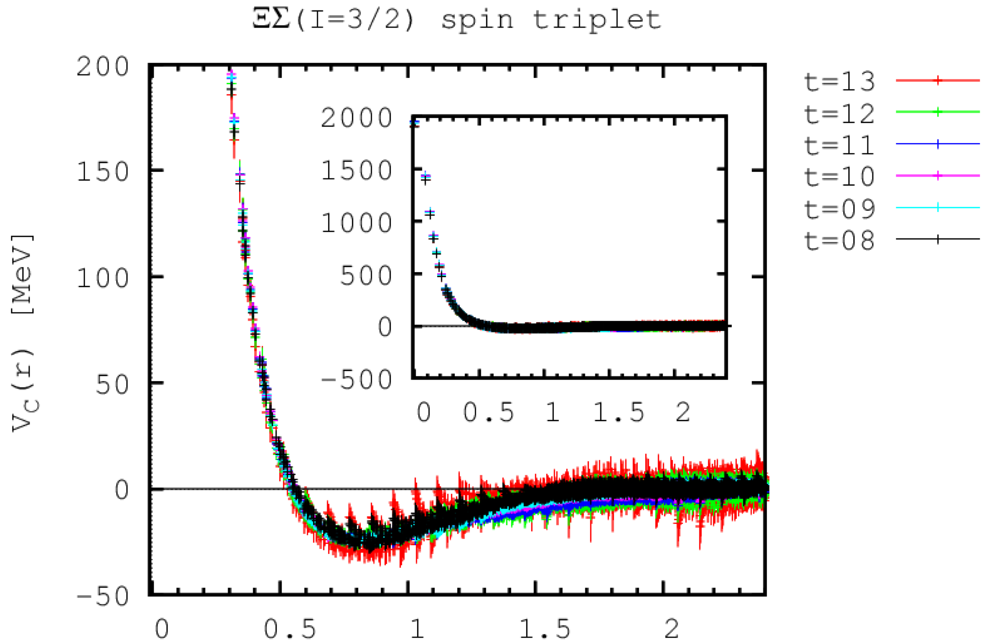
Preliminary results

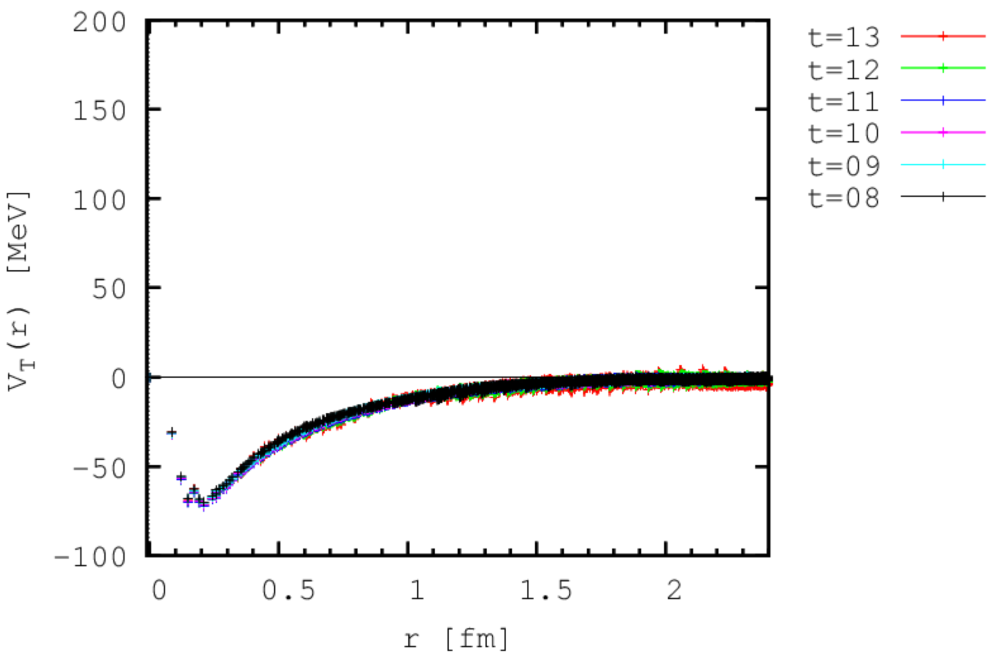
- 1/a ∼2300 MeV, L ∼8.2 fm
- 200 gauge confs. are used.
- Binsize = 10
- 12 source points * 4 rotations
- Point sink and wall source



- Repulsive core is surrounded by attractive well like NN(spin singlet).
- In flavor SU(3) limit, this channel belongs to irrep. 27. (same as NN)

Preliminary results





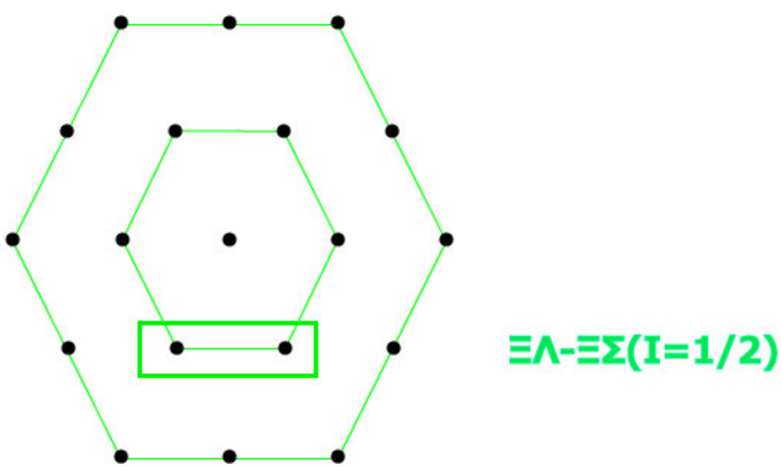
- 1/a ∼2300 MeV, L ∼8.2 fm
- 200 gauge confs. are used.
- Binsize = 10
- 12 source points * 4 rotations
- Point sink and wall source

- Qualitative behaviors are similar to NN (spin triplet sector).
- In flavor SU(3) limit, this channel belongs to the irrep. 10*. (same as NN)

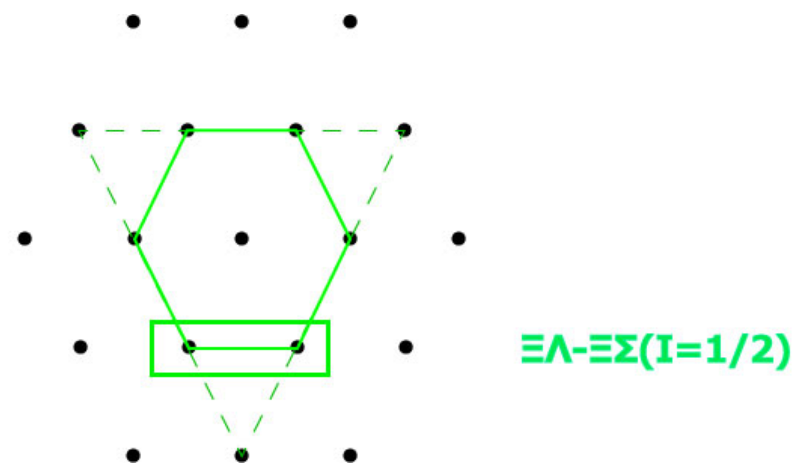
S=-4 sector: ΞΛ-ΞΣ(I=1/2)

S=-4 sector: ΞΛ-ΞΣ(I=1/2)

- Total spin singlet
- In flavor SU(3) limit,
  it is a linear combination
  of two irreps: 27 and 8s.
  (cf. NN belongs to irrep. 27)



- Total spin triplet
- In flavor SU(3) limit,
  it is a linear combination
  of two irreps: 10 and 8a.
  (Nothing to do with NN)



Results are not ready now.

Comments

$$C_B(t) \equiv \frac{1}{V}\sum_{\vec{x}} \left\langle 0 \middle| T\left[B(\vec{x},t)\cdot \overline{B}(t=0) \right] \middle| 0 \right\rangle$$

- To reduce the statistical noise, we used

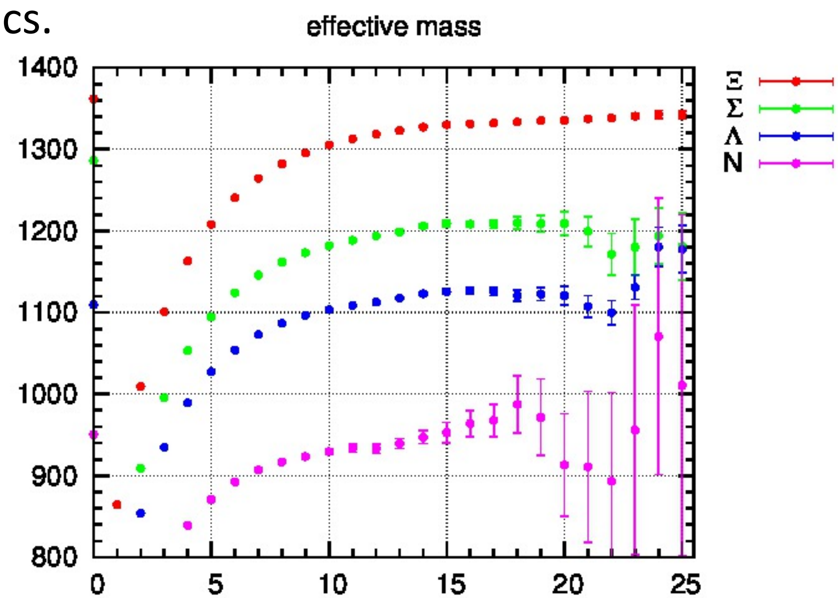
$$R(\vec{x}-\vec{y},t) \equiv C_B(t)^{-2} \left\langle 0 \middle| T\left[B(\vec{x},t)B(\vec{y},t)\cdot \overline{BB}(t=0) \right] \middle| 0 \right\rangle$$

instead of

$$R(\vec{x}-\vec{y},t) \equiv e^{2mt} \left\langle 0 \middle| T\left[B(\vec{x},t)B(\vec{y},t)\cdot \overline{BB}(t=0) \right] \middle| 0 \right\rangle$$

➔ We have to go to the single-baryon plateau region.

- However, before achieving single baryon plateaux, the potential becomes rather stable. (We will go to larger t region by increasing statistics. Statistics are going to be improve 8 times more.)



Summary

- We have presented preliminary results of baryon-baryon potentials in S=-3 and -4 sectors using the physical point gauge configs generated by K computer at AICS.
  - S=-4 sector:
    ΞΞ (I=0)
    ΞΞ (I=1)
  - S=-3 sector:
    ΞΣ(I=3/2)
    ΞΛ-ΞΣ(I=1/2): [This is not ready yet]
  - These potentials show qualitatively similar behaviors as those in flavor SU(3) limit.
- To do
  - ΞΛ-ΞΣ(I=1/2) system
  - Statistics should be increased
  - Scattering phase shifts
  - Other applications
  - LS forces and parity-odd sectors